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Production of Fast Rare Ion Beams

Euroschool on Exotic Beams 2013, Dubna
Euroschool on Exotic Beams 2013, Dubna

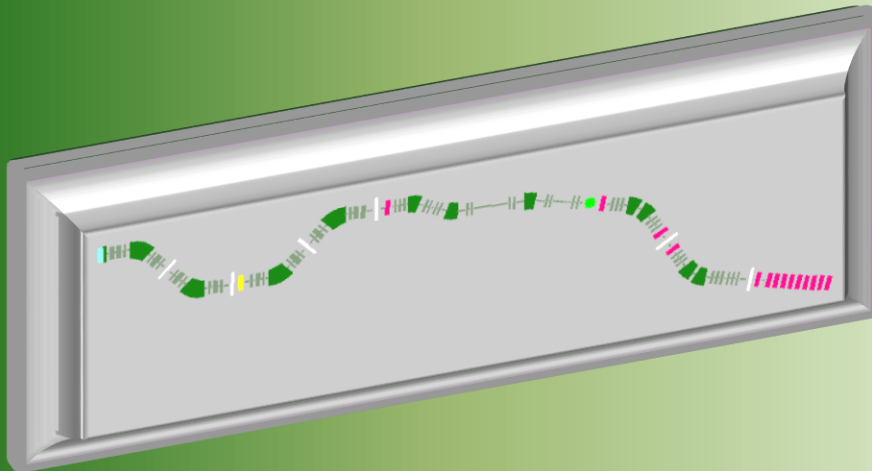
26-31 / 08 / 2013

LISE++

1. Introduction to production of Fast Rare Ion Beams
2. Production Area
3. **Separation**
4. Identification
5. Production of new isotopes
6. LISE++: Utilities
7. Radioactive beam physicist task



LISE++



1. Beam optics

- ✓ Coordinate system
- ✓ Transport matrix
- ✓ Definitions
- ✓ Focusing conditions
- ✓ Separation and beam optics
- ✓ Achromatic fragment separator
- ✓ High order optics

2. Separator features

- ✓ Ion transport codes
- ✓ Fragment separator design
- ✓ LISE⁺⁺ block classification
- ✓ Block properties
- ✓ LISE⁺⁺ configuration types
- ✓ Angular acceptances

3. Types of transmission calculations

4. Selections with EM devices

- ✓ Magnetic rigidity ($B\rho$) – selection
 - *Gas-filled separator*
- ✓ Electrostatic rigidity ($E\rho$) – selection
 - *E & B bends combination : m & q dispersions*
- ✓ Velocity selection
 - *Wien & B-bend combination : A/q dispersion*
- ✓ Time selection
- ✓ Selection with bunching
- ✓ Selection with focusing

5. “Wedge” selection

- ✓ Types of wedge
- ✓ Fragment production in material
- ✓ Two stage separation

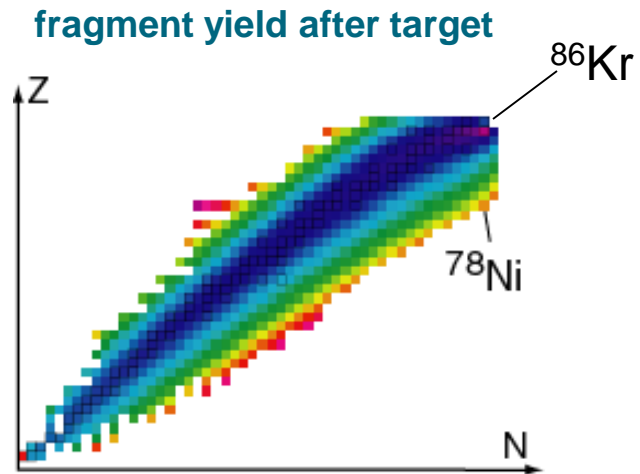
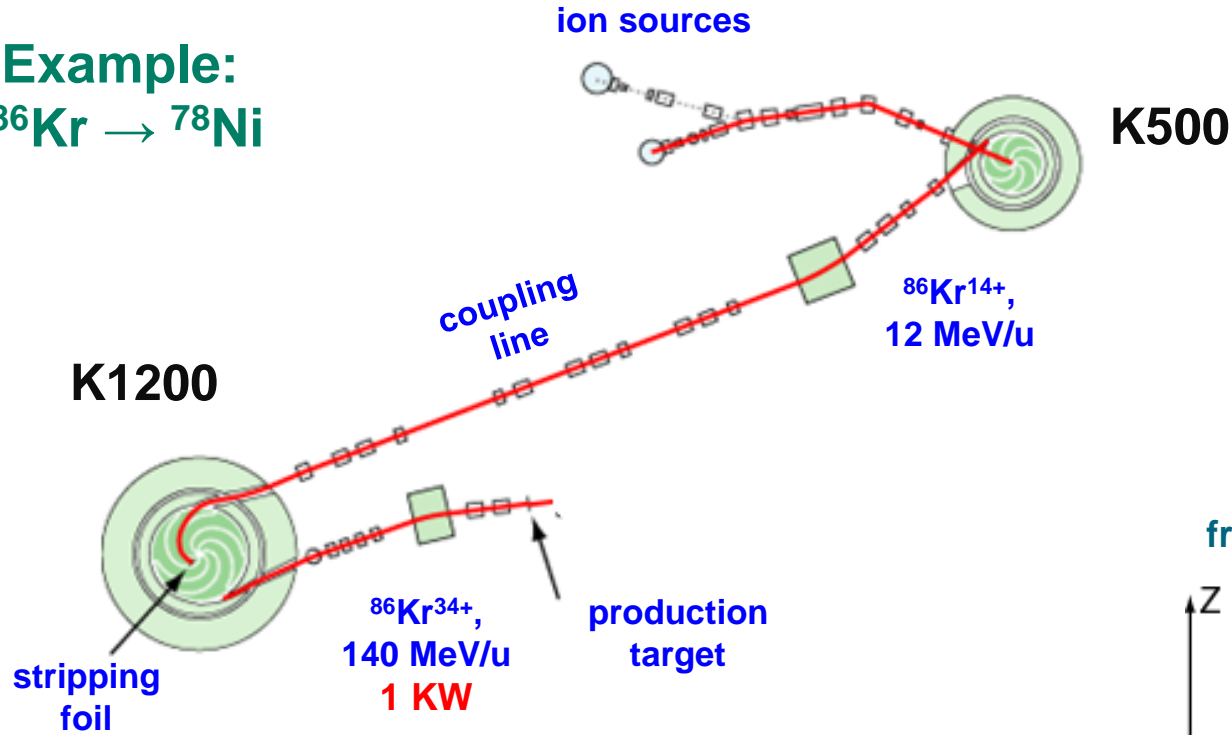
6. Transmission

7. Optimization utilities

8. New generation of fragment separators

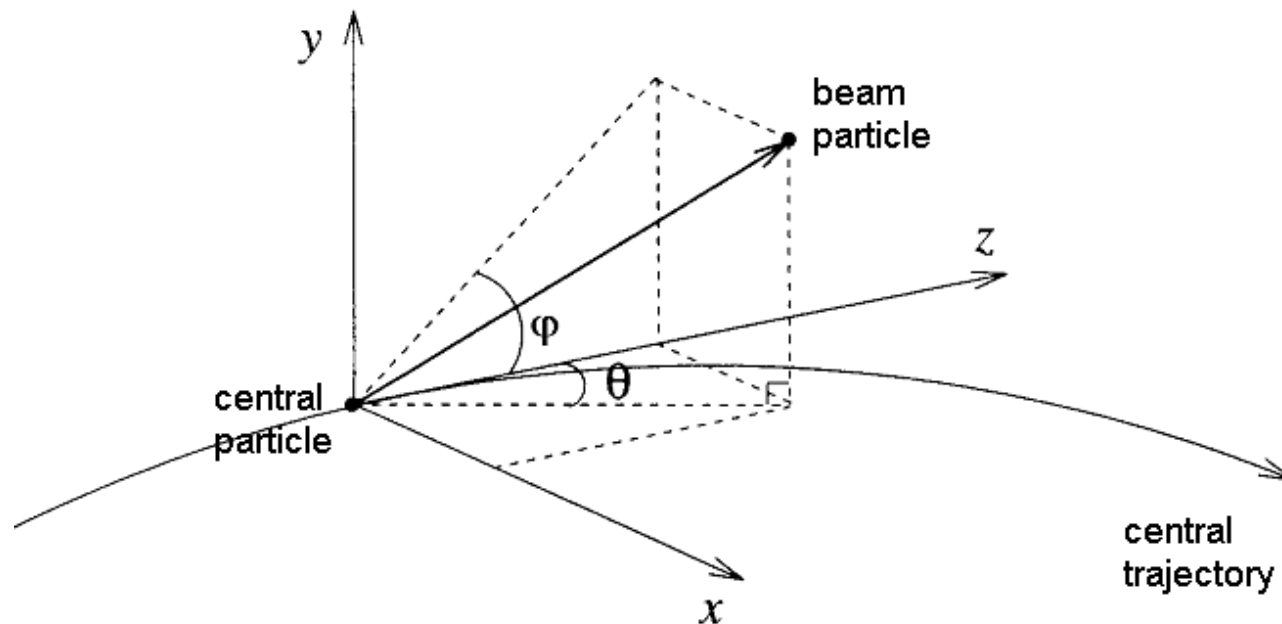
9. Example of secondary beam production

Example:
 $^{86}\text{Kr} \rightarrow ^{78}\text{Ni}$



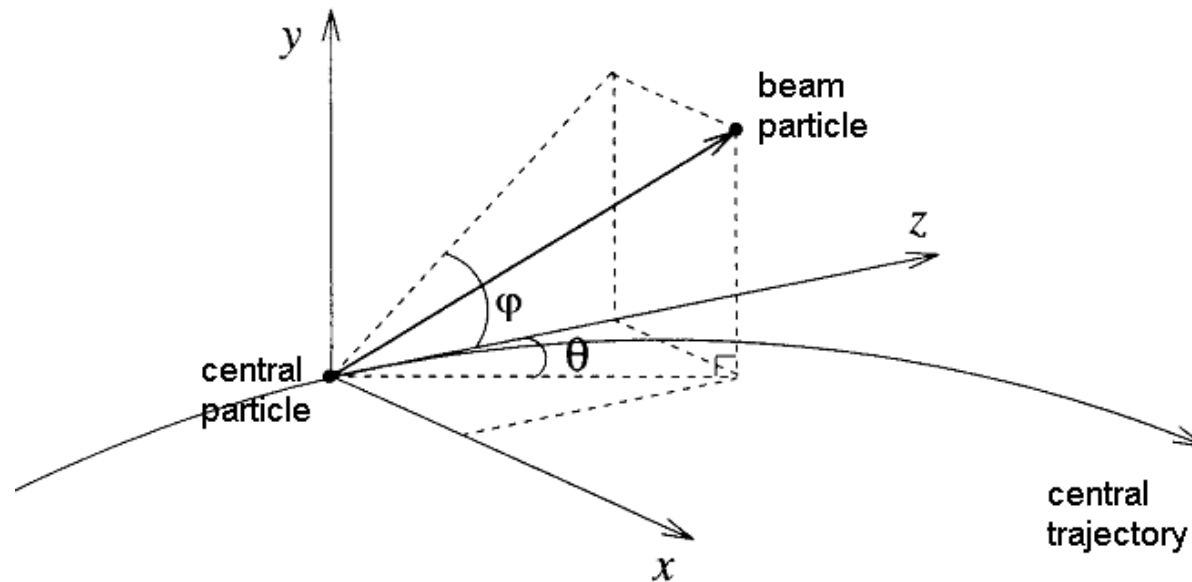
How we are doing this selection?

- Electromagnetic devices (dipoles, quadrupoles etc) are used for transportation and selection of ion beams
- Transport (optical) matrices are used to describe ion trajectories through these devices
- It serves for estimation of first order deviations for each particle trajectory from the central axis



The beam particle motion can be described by 6 dimensional vector
(*“Transport” code formalism*)

- x – distance from the central axis in the horizontal plane
- θ (or x' or a) – angle between projection on the horizontal plane and the central axis
- y – distance from the central axis in the vertical plane
- φ (or y' or b) – angle between projection on the vertical plane and the central axis
- l – length difference between the central and projectile trajectories
- δ - relative difference of projectile and central particles $\delta = (p-p_c) / p_c$



- Let's consider a charge particle passing through magnet elements between Z_i and Z_f , then final coordinates are defined as:
- where the functions f_x f_θ f_y f_φ f_l f_δ are motion equations of charge particle in electromagnetic field

$$\begin{cases} x_f = f_x(x_i, \theta_i, y_i, \varphi_i, l_i, \delta_i) \\ \theta_f = f_\theta(x_i, \theta_i, y_i, \varphi_i, l_i, \delta_i) \\ y_f = f_y(x_i, \theta_i, y_i, \varphi_i, l_i, \delta_i) \\ \varphi_f = f_\varphi(x_i, \theta_i, y_i, \varphi_i, l_i, \delta_i) \\ l_f = f_l(x_i, \theta_i, y_i, \varphi_i, l_i, \delta_i) \\ \delta_f = f_\delta(x_i, \theta_i, y_i, \varphi_i, l_i, \delta_i) \end{cases}$$

- Assuming small deviations the Taylor expansion can be used:

$$x_f = \left(\frac{\partial f_x}{\partial x}\right)_{z_f} x_i + \left(\frac{\partial f_x}{\partial \theta}\right)_{z_f} \theta_i + \left(\frac{\partial f_x}{\partial y}\right)_{z_f} y_i + \left(\frac{\partial f_x}{\partial \varphi}\right)_{z_f} \varphi_i + \left(\frac{\partial f_x}{\partial l}\right)_{z_f} l_i + \left(\frac{\partial f_x}{\partial \delta}\right)_{z_f} \delta_i$$

- Obtained first order values can be compiled as 6x6 matrix, which describes action on the charged particle from electromagnetic devices located between on Z_i and Z_f

$$\begin{pmatrix} x_f \\ \theta_f \\ y_f \\ \varphi_f \\ l_f \\ \delta_f \end{pmatrix} = \begin{pmatrix} \frac{\partial f_x}{\partial x} & \frac{\partial f_x}{\partial \theta} & \frac{\partial f_x}{\partial y} & \frac{\partial f_x}{\partial \varphi} & \frac{\partial f_x}{\partial l} & \frac{\partial f_x}{\partial \delta} \\ \frac{\partial f_\theta}{\partial x} & \frac{\partial f_\theta}{\partial \theta} & \frac{\partial f_\theta}{\partial y} & \frac{\partial f_\theta}{\partial \varphi} & \frac{\partial f_\theta}{\partial l} & \frac{\partial f_\theta}{\partial \delta} \\ \frac{\partial f_y}{\partial x} & \frac{\partial f_y}{\partial \theta} & \frac{\partial f_y}{\partial y} & \frac{\partial f_y}{\partial \varphi} & \frac{\partial f_y}{\partial l} & \frac{\partial f_y}{\partial \delta} \\ \frac{\partial f_\varphi}{\partial x} & \frac{\partial f_\varphi}{\partial \theta} & \frac{\partial f_\varphi}{\partial y} & \frac{\partial f_\varphi}{\partial \varphi} & \frac{\partial f_\varphi}{\partial l} & \frac{\partial f_\varphi}{\partial \delta} \\ \frac{\partial f_l}{\partial x} & \frac{\partial f_l}{\partial \theta} & \frac{\partial f_l}{\partial y} & \frac{\partial f_l}{\partial \varphi} & \frac{\partial f_l}{\partial l} & \frac{\partial f_l}{\partial \delta} \\ \frac{\partial f_\delta}{\partial x} & \frac{\partial f_\delta}{\partial \theta} & \frac{\partial f_\delta}{\partial y} & \frac{\partial f_\delta}{\partial \varphi} & \frac{\partial f_\delta}{\partial l} & \frac{\partial f_\delta}{\partial \delta} \end{pmatrix} \begin{pmatrix} x_i \\ \theta_i \\ y_i \\ \varphi_i \\ l_i \\ \delta_i \end{pmatrix}$$

- The matrix also reflects upon many of the symmetries of the motion.

The most notable of them is referred to as horizontal midplane symmetry and it is a result of having only electromagnetic fields that are symmetric about the $y=0$ plane.

$$\mathbf{A} = \begin{bmatrix} (x,x) & (x,a) & 0 & 0 & (x,l) & (x,\delta) \\ (a,x) & (a,a) & 0 & 0 & (a,l) & (a,\delta) \\ 0 & 0 & (y,y) & (y,b) & 0 & 0 \\ 0 & 0 & (b,y) & (b,b) & 0 & 0 \\ (l,x) & (l,a) & 0 & 0 & (l,l) & (l,\delta) \\ (\delta,x) & (\delta,a) & 0 & 0 & (\delta,l) & (\delta,\delta) \end{bmatrix}$$

As a consequence, all cross terms between the horizontal and vertical plane will vanish

- If midplane symmetry about $y=0$ is imposed, along with explicit time-independence and energy constancy, then the resulting form of the transfer matrix is

$$\mathbf{A} = \begin{bmatrix} (x,x) & (x,a) & 0 & 0 & 0 & (x,\delta) \\ (a,x) & (a,a) & 0 & 0 & 0 & (a,\delta) \\ 0 & 0 & (y,y) & (y,b) & 0 & 0 \\ 0 & 0 & (b,y) & (b,b) & 0 & 0 \\ (l,x) & (l,a) & 0 & 0 & (l,l) & (l,\delta) \\ 0 & 0 & 0 & 0 & 0 & (\delta,\delta) \end{bmatrix}$$

- ❖ The transport matrix R of system from n blocks is the result of production of n transport matrices:

- ❖ In practice the next designation are used:

- ❖ The σ - matrix describes phase space widths

- ❖ Transmission will be done by cuts in distribution, defined by the σ -matrix and transport matrices

- ❖ σ - vector

$$R = R_n \times R_{n-1} \times \dots \times R_1$$

$$\frac{\partial f_x}{\partial x} = \left(\frac{x}{x} \right)$$

$$\frac{\partial f_\theta}{\partial x} = \left(\frac{\theta}{x} \right)$$

$$\vdots$$

$$\sigma = \begin{pmatrix} \sigma_{xx} & \sigma_{x\theta} & \sigma_{xy} & \sigma_{x\varphi} & \sigma_{x\delta} \\ \sigma_{\theta x} & \sigma_{\theta\theta} & \sigma_{\theta y} & \sigma_{\theta\varphi} & \sigma_{\theta\delta} \\ \sigma_{yx} & \sigma_{y\theta} & \sigma_{yy} & \sigma_{y\varphi} & \sigma_{y\delta} \\ \sigma_{\varphi x} & \sigma_{\varphi\theta} & \sigma_{\varphi y} & \sigma_{\varphi\varphi} & \sigma_{\varphi\delta} \\ \sigma_{\delta x} & \sigma_{\delta\theta} & \sigma_{\delta y} & \sigma_{\delta\varphi} & \sigma_{\delta\delta} \end{pmatrix}$$

$$\sigma' = R \cdot \sigma \cdot R^T$$

Emittance		
	Beam CARD (sigma, semi-axis, half-width...)	1D - shape (Distribution method)
1. X mm	1	Gaussian
2. T mrad	6	Gaussian
3. Y mm	1	Gaussian
4. P mrad	8	Gaussian
5. L mm	0	Gaussian
6. D %	0.07	Gaussian

❖ Meanings of some coefficients:

- (x/x) – horizontal spatial magnification
 - (θ/θ) – horizontal angular magnification
 - (y/y) – vertical spatial magnification
 - (φ/φ) – vertical angular magnification
 - (x/θ) – horizontal **focus (if equal to 0)**
 - (y/φ) – vertical **focus (if equal to 0)**
 - (x/δ) – horizontal spatial dispersion
 - (θ/δ) – horizontal angular dispersion
 - (y/δ) – vertical spatial dispersion
 - (φ/δ) – vertical angular dispersion
-
- the system is **achromatic** in the horizontal space
 - betatron isochronism
 - isochronous chromatism

Emittance

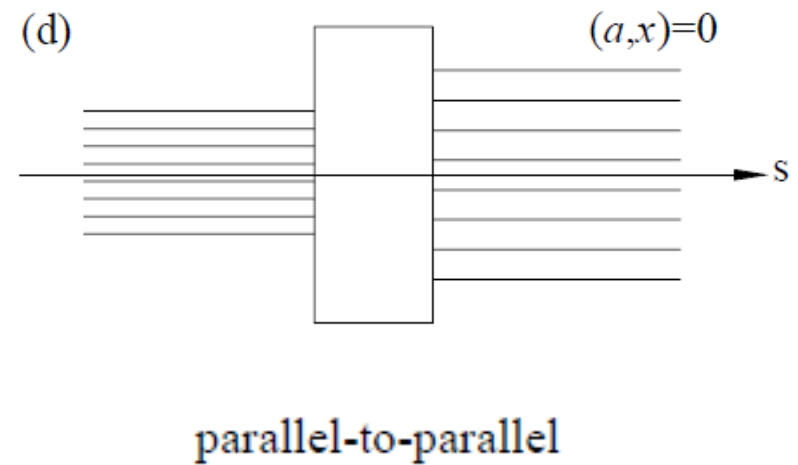
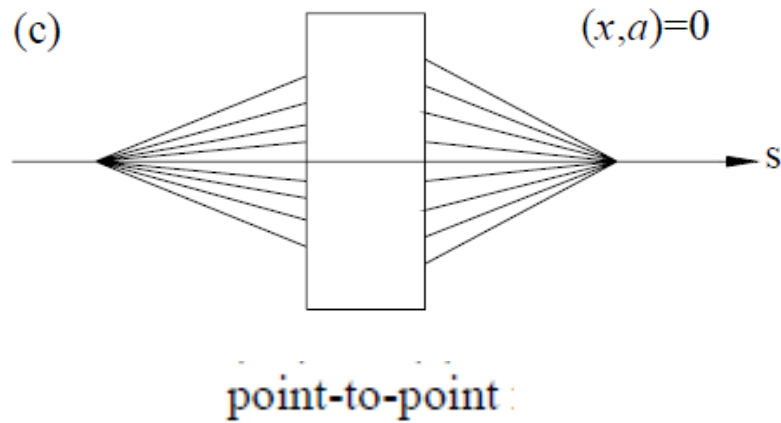
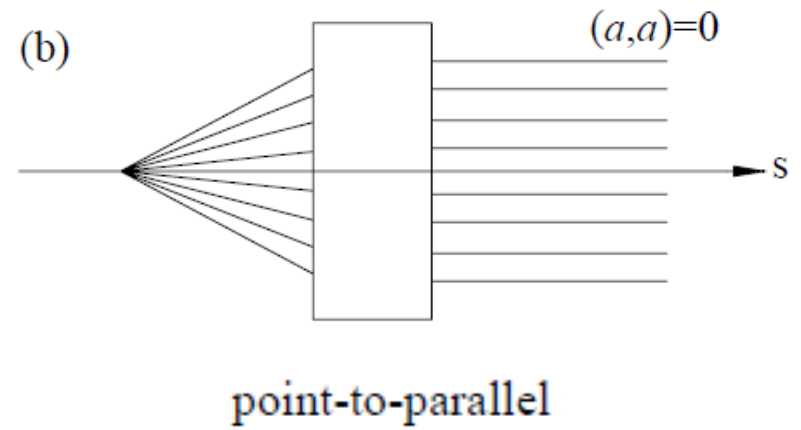
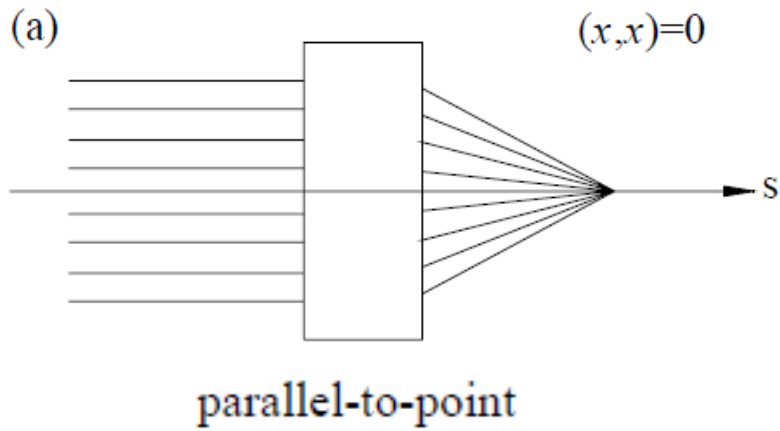
$\epsilon_h = \pi \Delta x \Delta \theta$

Δx – initial beam size
in the object point,
 $\Delta \theta$ - angular spread

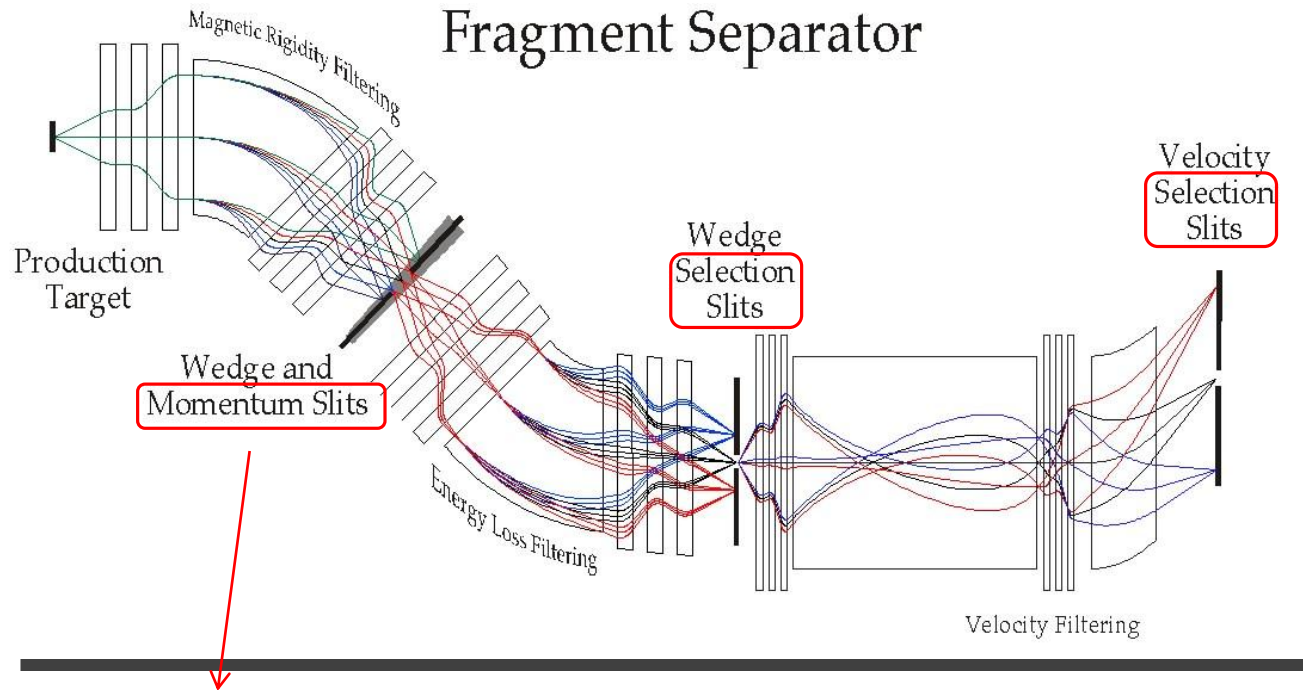
$$\left(\frac{x}{\delta}\right) = \left(\frac{\theta}{\delta}\right) = 0$$

$$\left(\frac{l}{x}\right) = \left(\frac{l}{\theta}\right) = \left(\frac{l}{y}\right) = \left(\frac{l}{\varphi}\right) = 0$$

$$\left(\frac{l}{\delta}\right) = 0$$



What is “Separation”, where and when it takes place?



Magnetic rigidity selection

Global matrix						
1. X	2.19739	0.04483	0	0	0	-59.12102 [mm]
2. T	-1.05083	0.43363	0	0	0	0 [mrad]
3. Y	0	0	0.83626	-0.00008	0	0 [mm]
4. F	0	0	6.30069	1.19541	0	0 [mrad]
5. L	6.21266	-2.56373	0	0	1	12.20843 [mm]
6. D	0	0	0	0	0	1 [%]
	/[mm]	/[mrad]	/[mm]	/[mrad]	/[mm]	/[%]

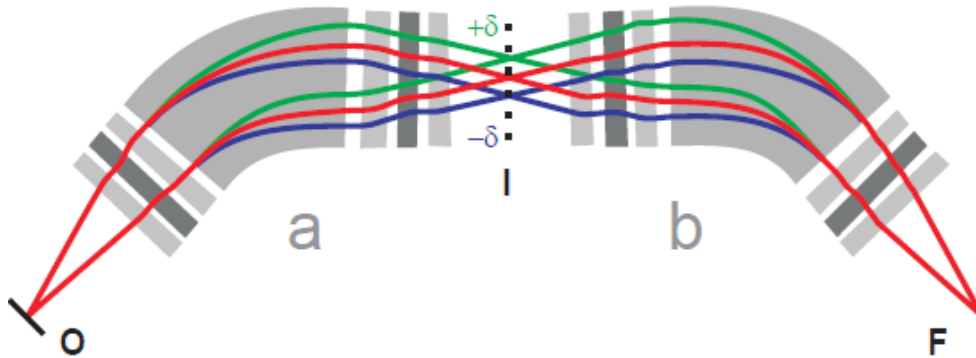
1. Selection is cuts by slits
2. There is some kind of dispersion
3. In Focal planes



achromatic in the horizontal space

$$\begin{pmatrix} x \\ \delta \end{pmatrix} = \begin{pmatrix} \theta \\ \delta \end{pmatrix} = 0$$

No wedge

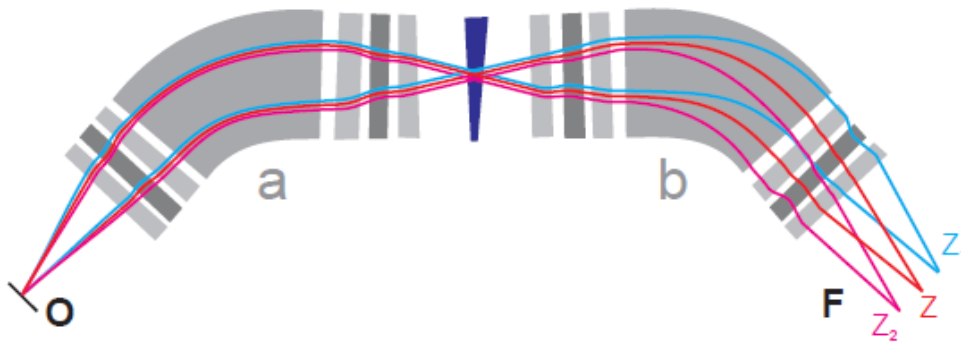


A1900 matrix

1. X	2.52039	-0.00767	0	0	0	-0.06177	[mm]
2. T	-1.05985	0.39998	0	0	0	0.00317	[mrad]
3. Y	0	0	2.39004	0.01879	0	0.00003	[mm]
4. F	0	0	6.43696	0.46906	0	0.00005	[mrad]
5. L	0.00578	-0.00251	0	0	1	30.1454	[mm]
6. D	0	0	0	0	0	1	[%]
	/[mm]	/[mrad]	/[mm]	/[mrad]	/[mm]	/[%]	

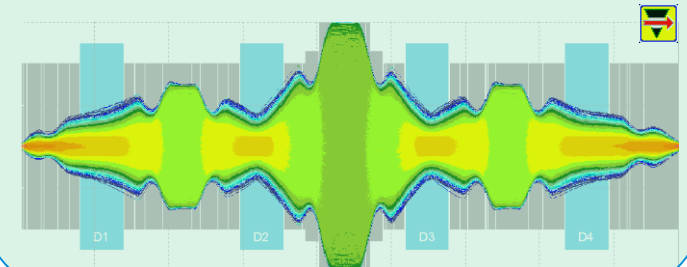
Figures by courtesy of Th.Baumann (MSU)

With achromatic wedge



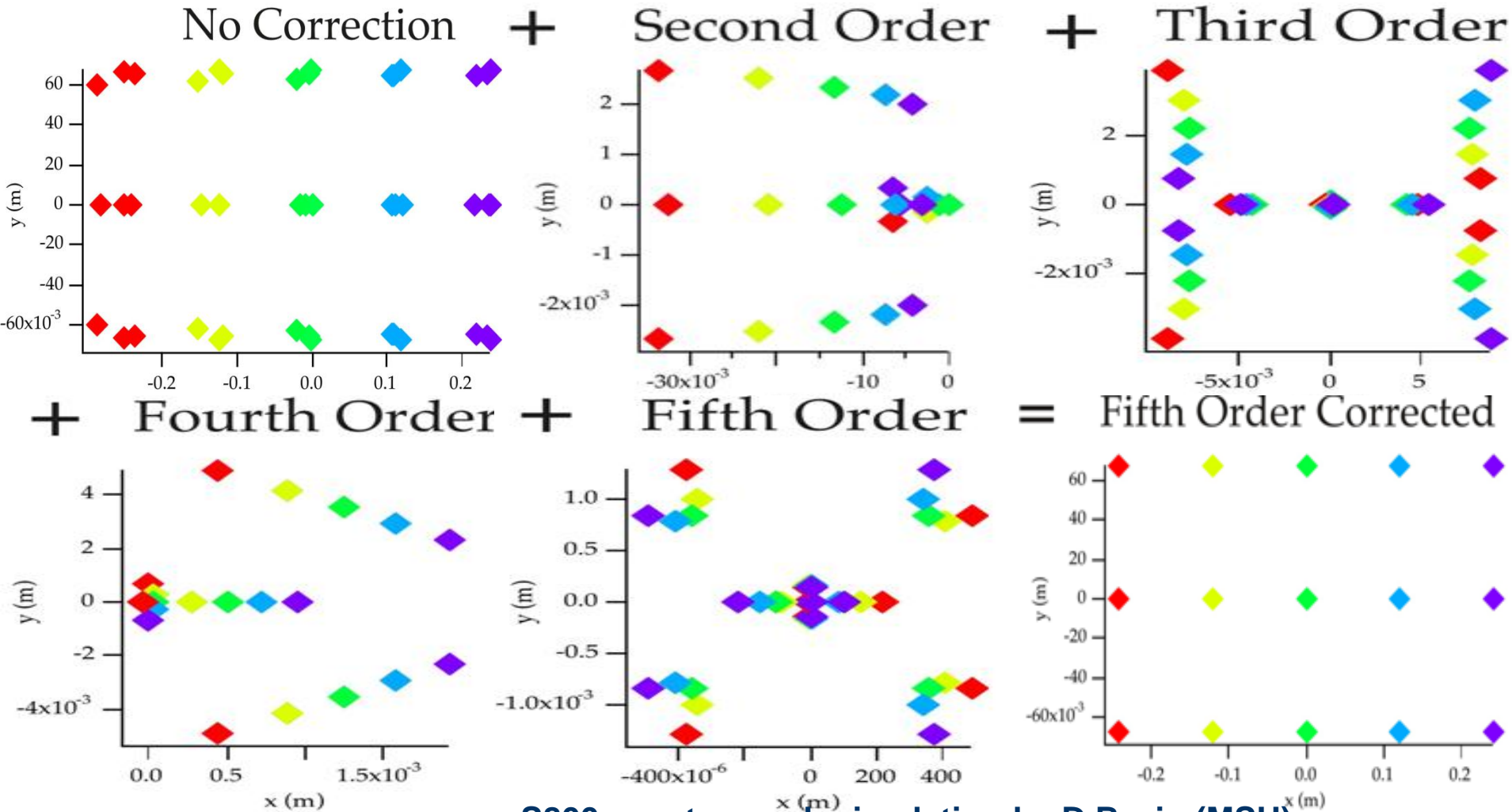
Be a researcher!

Play with LISE++ in Monte Carlo mode changing optical matrices parameters





- In order to create the Transport matrix we used the first order coefficients of the Taylor expansion assuming small deviation
- In reality the life is more complicated.....
Nowadays we are using devices with large angular and momentum acceptances

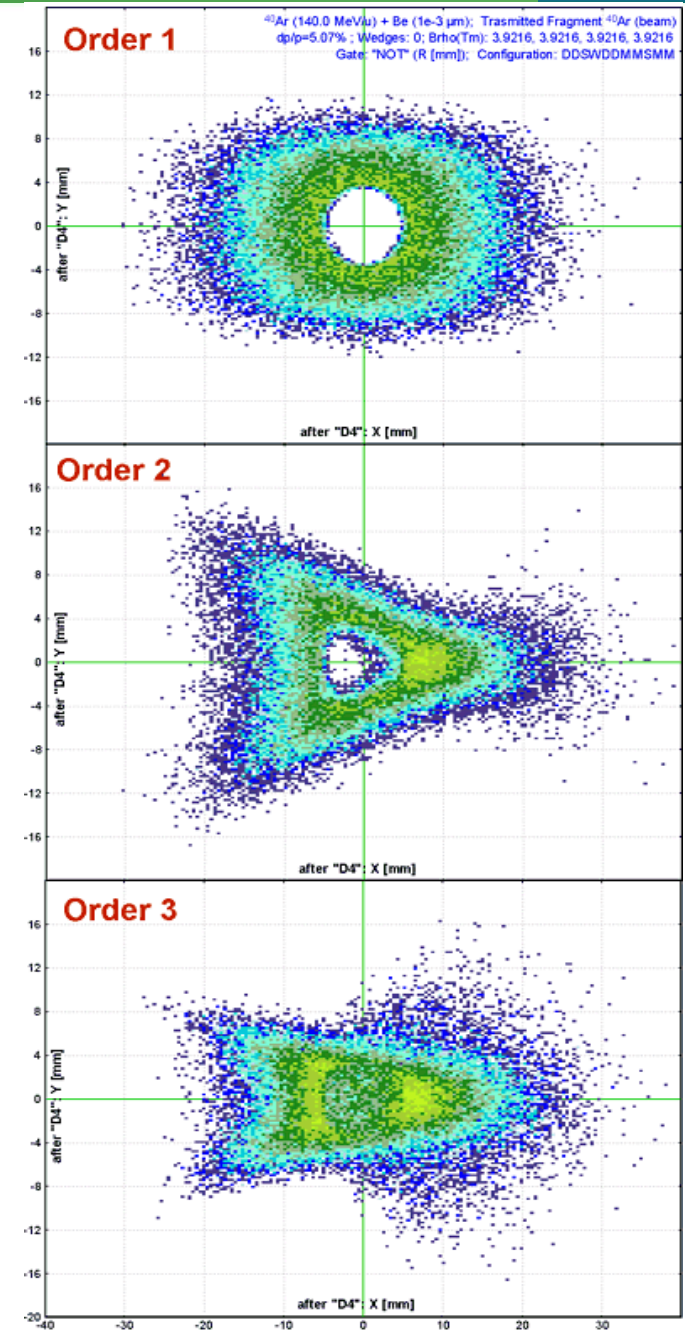
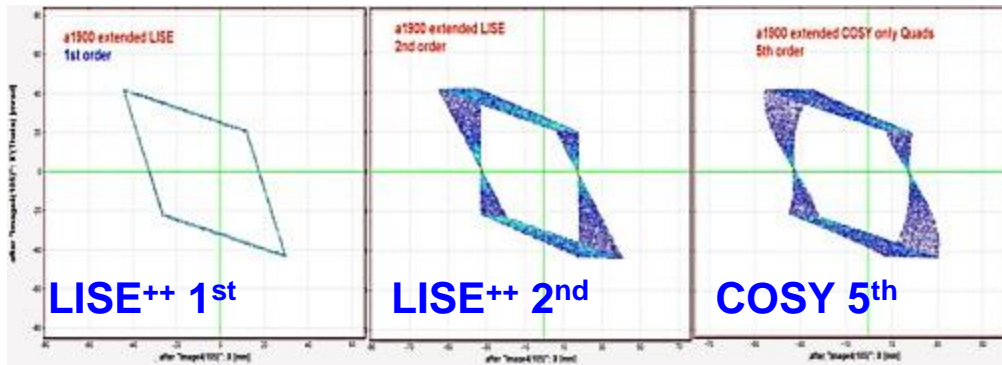


S800 spectrograph simulation by D.Bazin (MSU)

- LISE++ is able to operate with 5th order matrices
- High order optics can be used only in Monte Carlo mode
- LISE++ can calculate 1st and 2nd order matrices based on the Transport formalism
- Higher matrices can be loaded (or linked) from files prepared by the COSY code

http://lise.nsl.msu.edu/8_3/HighOrder_v8_3_158.pdf

http://lise.nsl.msu.edu/9_2/9_2_33/9_2_33.pdf



- ❑ **Linear Algebra (Matrix calculations)**
 - first and second order ion-optics calculations (e.g. TRANSPORT, LISE++)
 - use up to 5th order (e.g. LISE++, MOCADI)

- ❑ **Higher order ion-optics code to solve equation of motion**
 - Code COSY Infinity uses Differential Algebraic techniques to arbitrary orders using matrix representation for fast calculations.
 - Code RAYTRACE slices the system in small sections along the z-axis and integrates numerically the particle ray through the system
 - MOTER – RAYTRACE version with optimizer.
The new update has not been finished.. Anybody?

- ❑ **Electro-magnetic field program (solution of Maxwell's Equations)**
 - (e.g. finite element (FE) codes, 2d & 3d: POISSON, MagNet et al.)

TRANSPORT K. L. Brown, The ion optical program TRANSPORT. Technical Report 91, SLAC, 1979;
Graphic Transport Framework by Urs Rohrer http://aea.web.psi.ch/Urs_Rohrer/MyWeb/trans.htm

LISE++ <http://lise.nsl.msui.edu/>

MOCADI <http://web-docs.gsi.de/~weick/mocadi/>

COSY 10.0 http://www.bt.pa.msui.edu/index_cosy.htm

GIOS H. Wollnik, J. Brezina and M. Berz, NIM, A258, (1987) 408

GICOSY <http://web-docs.gsi.de/~weick/gicosy/> (based on COSY 5.0)

RAYTRACE

MOTER <http://lise.nsl.msui.edu/moter.html>

Configuration: A1900_S800BL_extended_LISE 2012 2nd order

Spectrometer designing

Block	Given Name	Z-Q	Length,m	Enable
T	Target			+
St	Stripper			+
D	Dipole	tuning	0	+
S	Drift	z015	0.396	+
Q	Drift	Q017-1TA	0.748	+
S	Drift	z018	0.176	+
Q	Drift	Q019-1TB	0.748	+
S	Drift	z020	0.172	+
Q	Drift	Q021-1TC	0.43	+
S	Drift	z022	0.526	+
D	Dipole	D1	2.43	+
S	Drift	z030	0.564	+
Q	Drift	Q031-2TA	0.43	+
S	Drift	z032	0.136	+
Q	Drift	Q033-2TB	0.812	+
S	Drift	z034	0.136	+
Q	Drift	Q035-2TC	0.43	+
S	Drift	z036	0.586	+
S	Drift	Imane1(037)	0	+

Insert Mode

before
 after

Move element

Up
Down

Edit
Delete

OK
Help

Insert block

- Target
- Stripper after Target
- Wedge
- Material(Detector)
- Faraday cup
- Dispersive (Dipole)
- Wien velocity filter
- Drift (multipole,slits)
- Beam Rotation
- Shift of Optical Axis
- Electrostatic dipole
- Gas-filled separator
- Compensating Dipole
- RF separator
- RF buncher
- Solenoid
- Delay (efficiency) block

Selected block

Enable Dispersive (Dipole)

Let call automatically Block Length [m] 0.0001

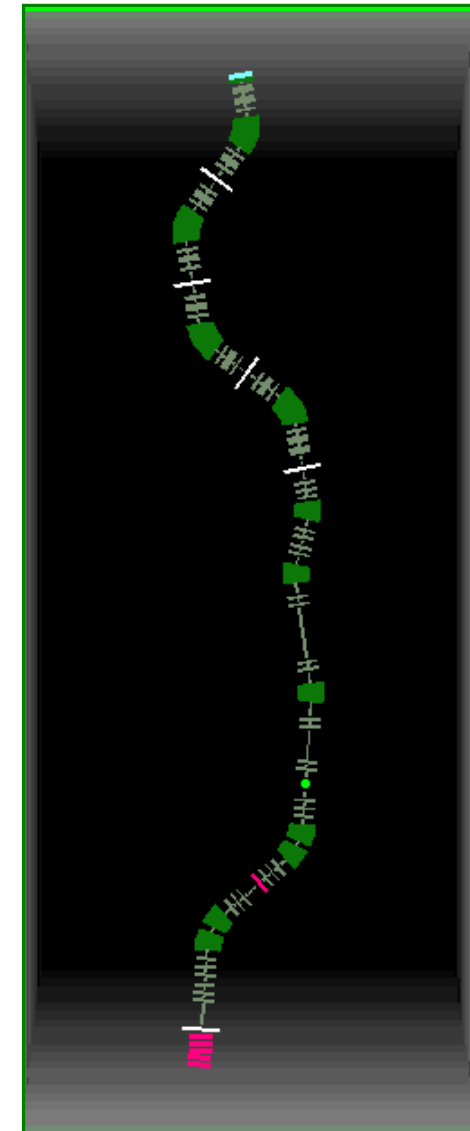
Block name = tuning Length after this block [m] 0

Charge State [Z-Q] = 0 Sequence number 3

Total

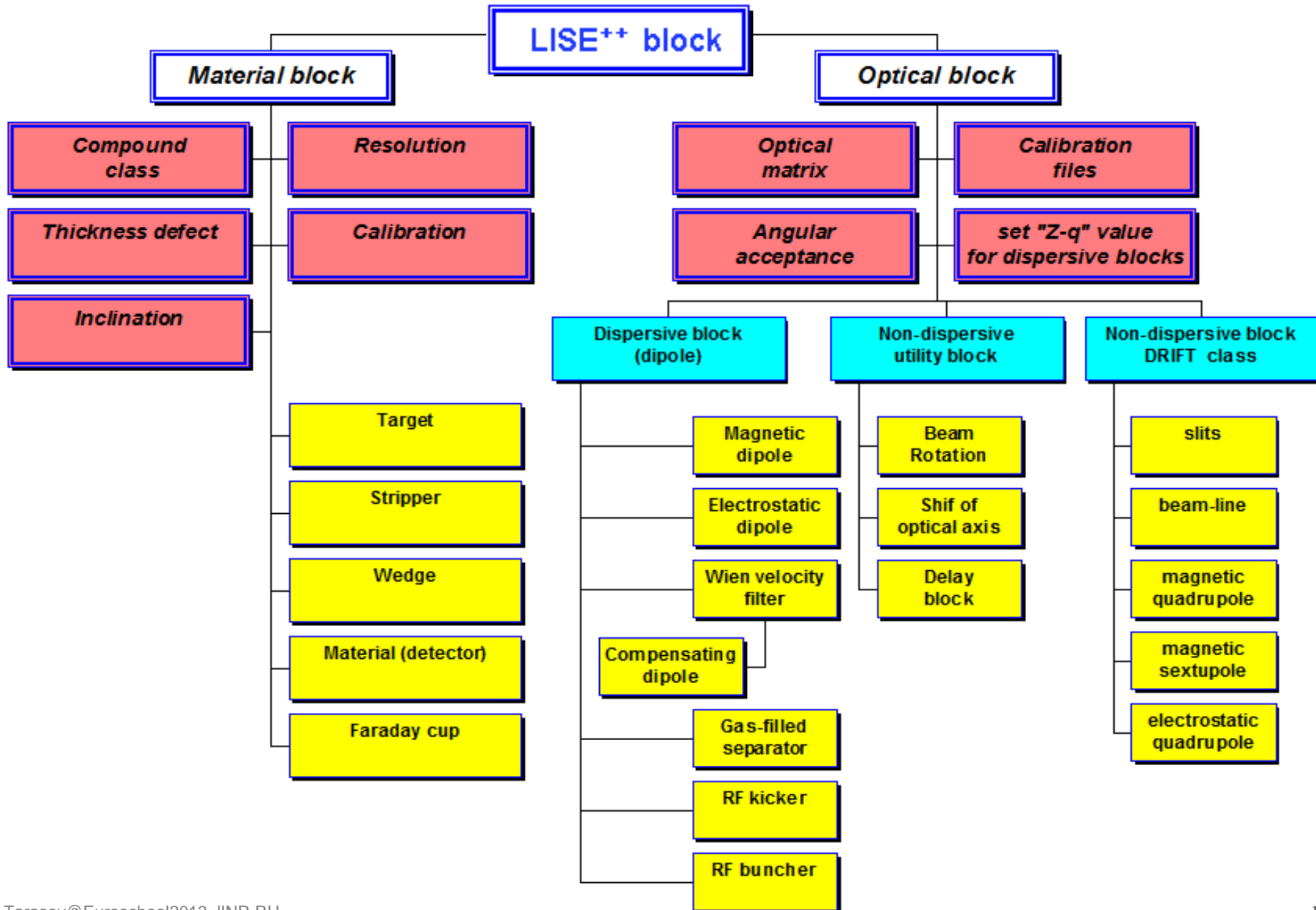
Number of Blocks: 164

Length [m]: 82.898



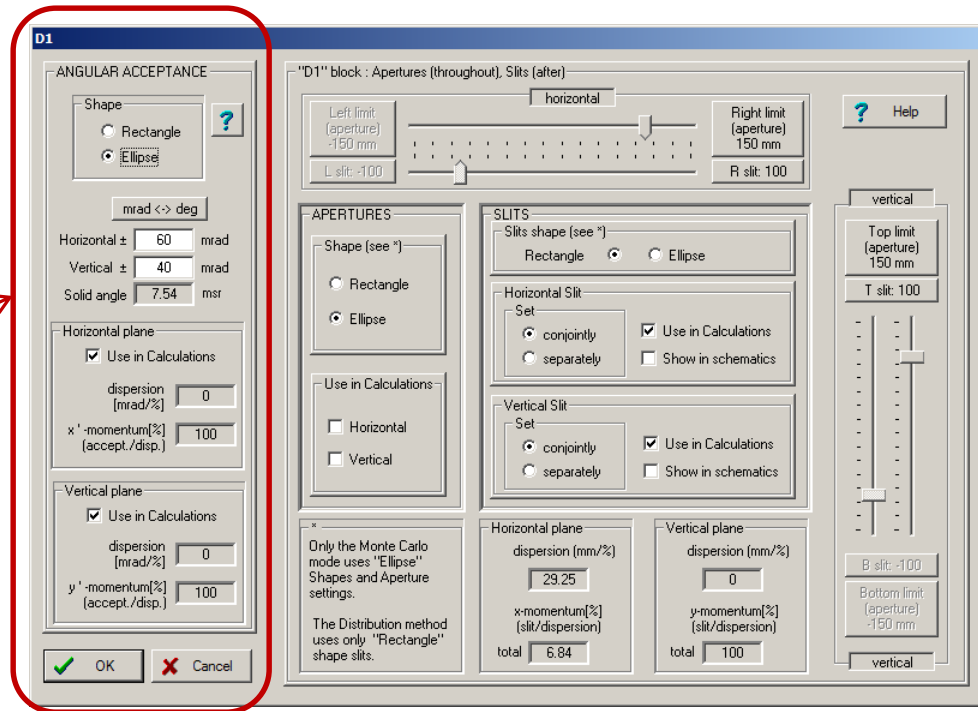
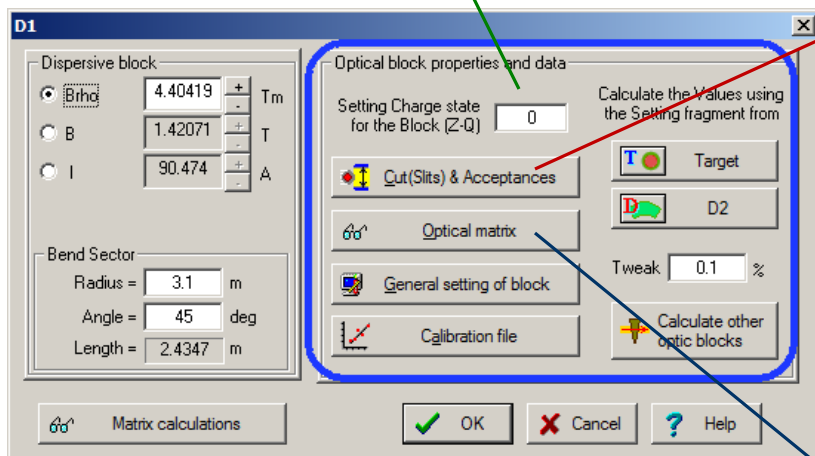
- **Setup of fragment separator**
 - “Blocks” are individual elements with their own characteristics
 - Optics blocks describe beam line components with optical matrix, acceptances, length and slits
 - Material blocks describe things in the way of the beam such as targets, wedges, detectors

- **Up to 300 blocks**



Charge State (Z-Q): property of **dispersive optical block** -- you can edit the charge state value for the setting fragment.

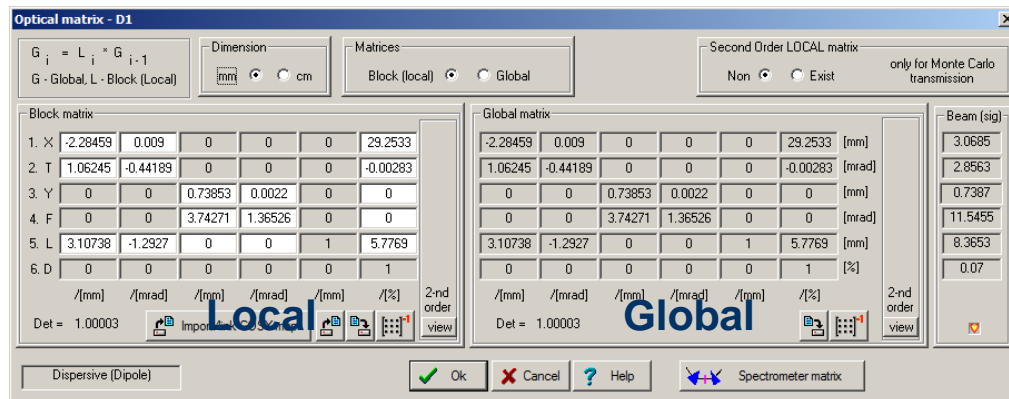
Angular acceptance



Optical matrices

$$G_i = L_i \times G_{i-1}$$

where G is the global matrix, and L is the local matrix



Depending from material thickness or necessity you can set this material being used for charge state calculations

I2_PPA/CO

Al Density [g/cm³] 2.702

calculate reactions in this material

Use in Q-state calculations

Z	Element	Mass
<input checked="" type="checkbox"/>	13 Al PT 26.982	
<input type="checkbox"/>	14	
<input type="checkbox"/>	14	
<input type="checkbox"/>	14	
<input type="checkbox"/>	14	

Compound dictionary

State: Solid Gas

Dimension: mg/cm² & micron g/cm² & mm

Angle: Calculate 0 degrees

Thickness at 0 degrees: 8.142117 micron 2.2 mg/cm²

Effective Thickness: 8.142117 micron 2.2 mg/cm²

Atoms / cm²: 4.91e+19

Buttons: Set the spectrometer after this block using changes, Cut (Slits), General setting of block, OK, Cancel

inclination

Calculation of Angle

Thickness at 0 degrees: 2.2 mg/cm²

Thickness Effective: 2.2 mg/cm²

Angle: 0.00 degrees

Buttons: OK, Cancel

Resolution, Calibration, Thickness defect

Parameter	Calibration	Resolution (sigma)	Dimension
Energy Loss	dE	2	<input checked="" type="radio"/> % <input type="radio"/> MeV
Time of flight	TOF	1	ns
Horizontal space	X	2.54	mm
Vertical space	Y	3.125	mm

Thickness defect: 0.3 % 0.024 micron

Buttons: OK, Cancel



- **Classical (segmented) configuration:**
dispersive block contains quads, drifts, dipole and so on



- **Extended (elemental) configuration:**
like in TRANSPORT all elements are separated, and their matrices can be calculated inside LISE⁺⁺

So, let's take the first dispersive block of A1900

segmented

1 block after stripper

Taken from
TRANSPORT

Block matrix

1. X	-2.28459	0.009	0	0	0	29.2533
2. T	1.06245	-0.44189	0	0	0	-0.00283
3. Y	0	0	0.73853	0.0022	0	0
4. F	0	0	3.74271	1.36526	0	0
5. L	3.10738	-1.2927	0	0	1	5.7769
6. D	0	0	0	0	0	1

extended

17 blocks after stripper

Calculated by
LISE⁺⁺
including 2nd
order

Global matrix

-2.30361	0.00906	0	0	0	28.88518	[mm]
1.07573	-0.43836	0	0	0	-0.00018	[mrad]
0	0	0.73839	0.00259	0	0	[mm]
0	0	3.731	1.36722	0	0	[mrad]
3.10724	-1.26623	0	0	1	-2.42226	[mm]
0	0	0	0	0	1	[%]
/[mm]	/[mrad]	/[mm]	/[mrad]	/[mm]	/[%]	

Calculations	
Optics	Tune spectrometer for setting fragment on beam axis
Goodies	Tune spectrometer for setting fragment at middle of slit
Calibrations	
Transmission and rate	Update matrices linked with COSY files
Optimum Target	Envelope plot
Optimum Target-Wedge and Wedge-Wedge configurations	First order matrix elements : PLOT
Brho scanning	First order matrix elements : View & Print
Optimum charge state combination	
Monte Carlo calculation of transmission	Quad & Dipole settings : EDIT
	Quad & Dipole settings : View & Print
Calculators	Brho(Erho) Analyzer
	The First- and Second-Order Matrix Elements for an Ideal Magnet

segmented

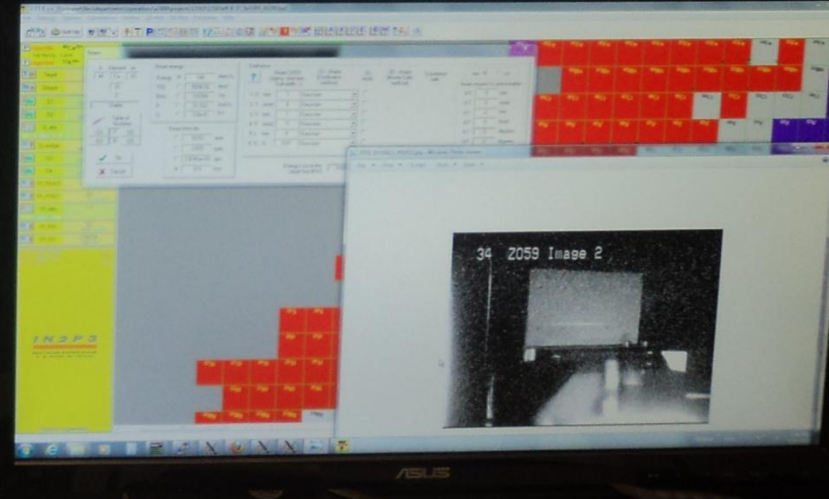
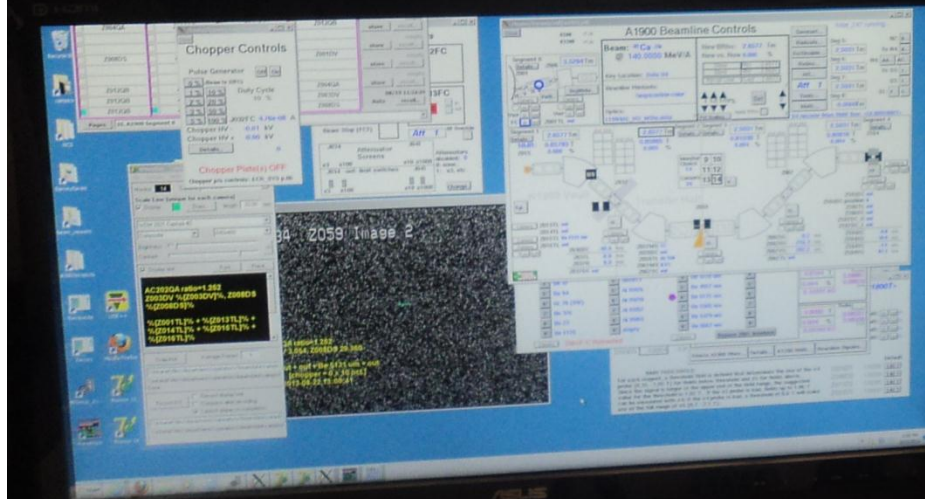
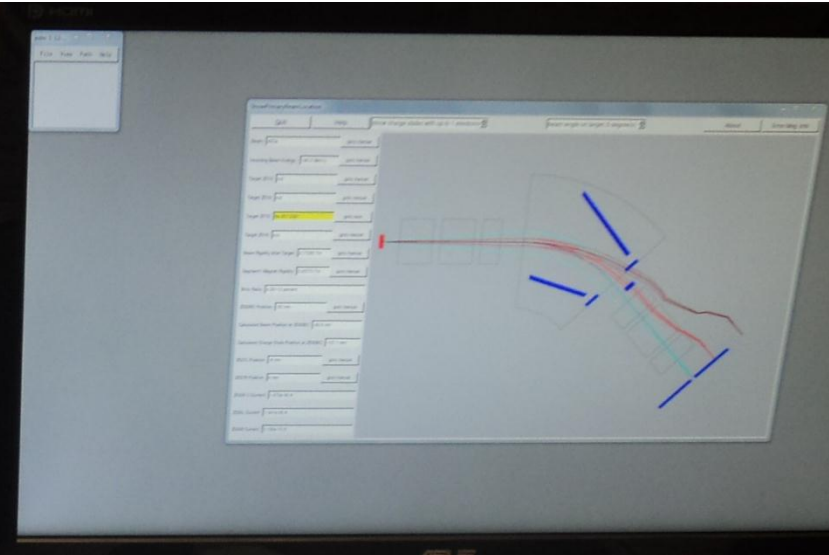
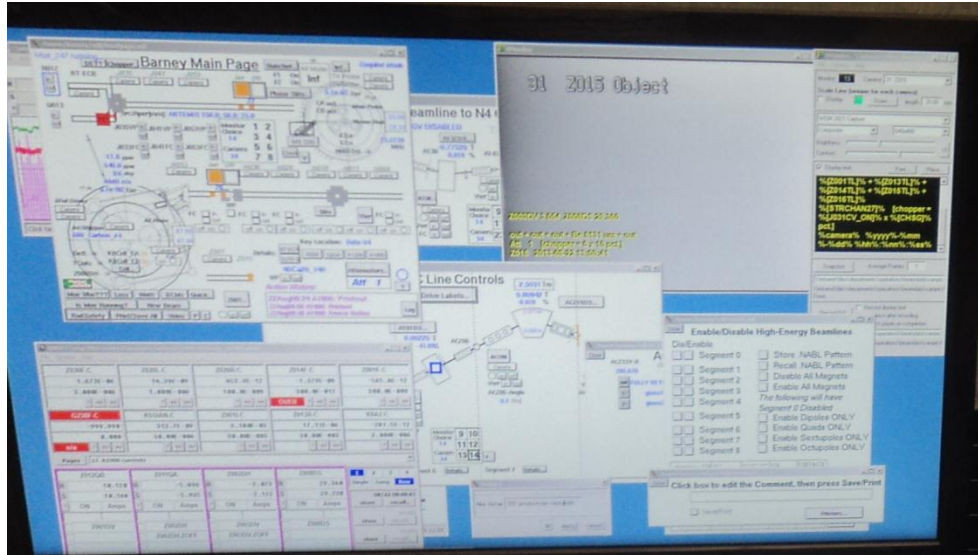
Block	Given Name	Start(m)	Length(m)	B0(kG)	Br(Tm)corr/*real	DriftM/*Angle	Rapp(cm)/*R(m)	L_eff(m)/*L_dip(m)	2 nd order	CalcMatr/*Z-Q	AngAcc.Apps.Slits
Dipole	D1	0.000	8.7190	+14.2116	* 4.4056	* 45.0	* 3.1000	* 2.4347	no	* 0	HV -- HV

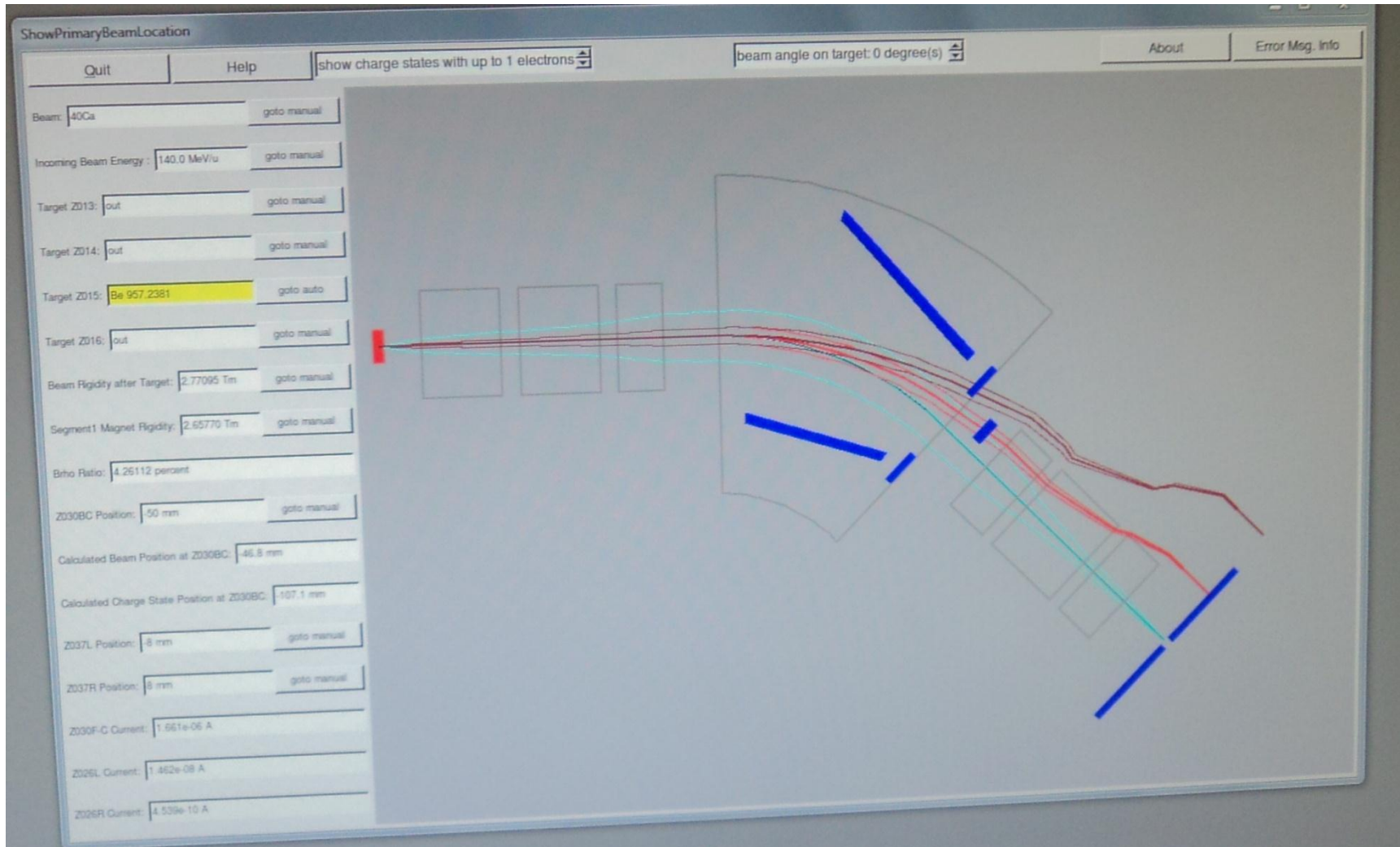
Brho → ← **Slits, acceptance**

extended

Block	Given Name	Start(m)	Length(m)	B0(kG)	Br(Tm)corr/*real	DriftM/*Angle	Rapp(cm)/*R(m)	L_eff(m)/*L_dip(m)	2 nd order	CalcMatr/*Z-Q	AngAcc.Apps.Slits
Dipole	tuning	0.000	0.0001	+14.6853	* 4.4056	* 0.0	* 3.0000	* 0.0000	no	* 0	-- -- --
Drift	z015	0.000	0.3960			standard					-- HV --
Drift	Q017-1TA	0.396	0.7480	+15.4196	4.4056	quadrupole	13.3000	0.7480	yes	1	-- HV --
Drift	z018	1.144	0.1756			standard					-- HV --
Drift	Q019-1TB	1.320	0.7480	-14.3295	4.4056	quadrupole	13.3000	0.7480	yes	1	-- HV --
Drift	z020	2.068	0.1720			standard					-- HV --
Drift	Q021-1TC	2.240	0.4300	+10.3091	4.4056	quadrupole	15.0000	0.4300	yes	1	-- HV --
Drift	z022	2.670	0.5260			standard					-- HV --
Dipole	D1	3.196	2.4300	+14.2396	* 4.4056	* 45.0	* 3.0939	* 2.4299	yes	* 0	-- HV --
Drift	z030	5.626	0.5640			standard					-- HV --
Drift	Q031-2TA	6.190	0.4300	+12.6140	4.4056	quadrupole	15.0000	0.4300	yes	1	-- HV --
Drift	z032	6.620	0.1358			standard					-- HV --
Drift	Q033-2TB	6.755	0.8120	-15.5591	4.4056	quadrupole	15.0000	0.8120	yes	1	-- HV --
Drift	z034	7.567	0.1358			standard					-- HV --
Drift	Q035-2TC	7.703	0.4300	+13.6724	4.4056	quadrupole				1	-- HV --
Drift	z036	8.133	0.5860			standard					-- HV --
Drift	Image1(037)	8.719	0.0000			SLITS					-- -- HV

Beam dump location





Close K500 rf ok K1200 rf ok

A1900 Beamline Controls

13:00:43 2013-08-22

Beam: $^{40}\text{Ca}^{20+}$ @ 140.0000 MeV/A

New BRho: 2.6577 Tm
New vs. Now 0.000 %

Store	Rcl	2.6577
Store	Rcl	2.5031
Recall Line	Last	2.6577

Key Location: Data U4

Beamline Printouts:
`\exp\control-color`

Optics:
L19N4AC HO MStc.data

↑ 1/2 1/10% ↓ Set

Apply BRho

Saveset...

Radsafe... Seg 5: N2: B...

En/Disable... 2.5031 Tm To N4: A...

Ratios... Seg 6: N4: AA... AC...

Att... 2.5031 Tm To S3: I...

Att 1 Seg 7: S3: I...

Tools... 2.5031 Tm S1: F... G...

NMR... Seg 8: -0.0000 m

D1 Answer from NMR Box: <L0.8579059T>

Segment 0 3.5294 Tm

Segment 1 2.6577 Tm NMR: 0.85793 T 2015 0.008 %

Segment 2 2.6577 Tm 0.85865 T -0.005 %

Segment 3 2.5031 Tm 0.81039 T 0.004 %

Segment 4 2.5031 Tm 0.80918 T 0.004 %

Monitor Choice: 9 10 14 11 12

Camera: 34 13 14 v

K1200 Vault Transfer Hall

Z037 Z059 Z082

Z030DC -89.9 mm Z057MS 15 Z082XC 0.2 mm

Z037L -8.0 mm Z059DC out Z082XG 216.3 mm

Z037R 8.0 mm Z059TL Al 158 Z082YG 202.2 mm

Z037DC out Z061MS 6.55 Z082TL wet

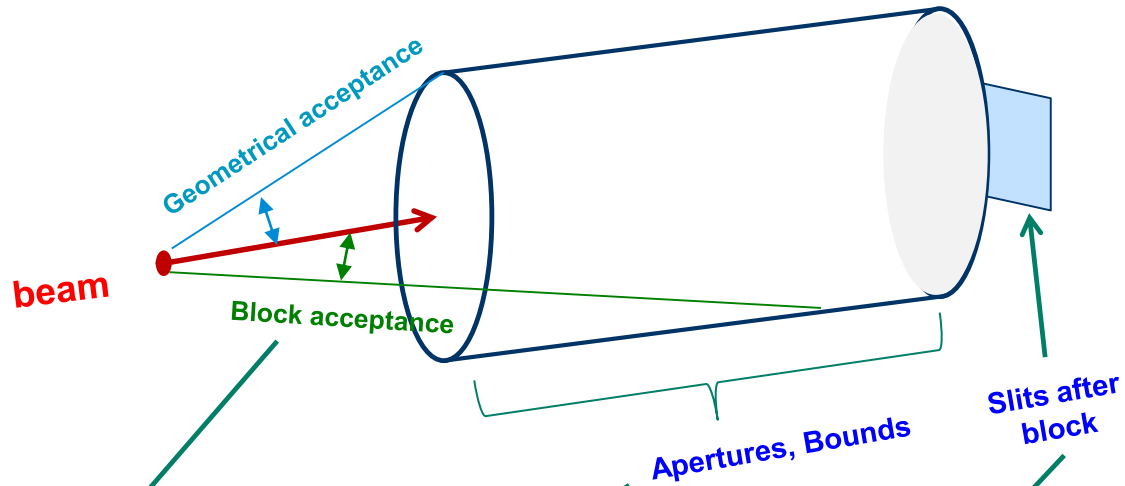
Z103DC out Z104DC position 0 Z104XC 0.0 mm

Z104TL out Z105TL out Z104XG 10.6 mm

Z106DC out Z107DC U out Z104YC -1.5 mm

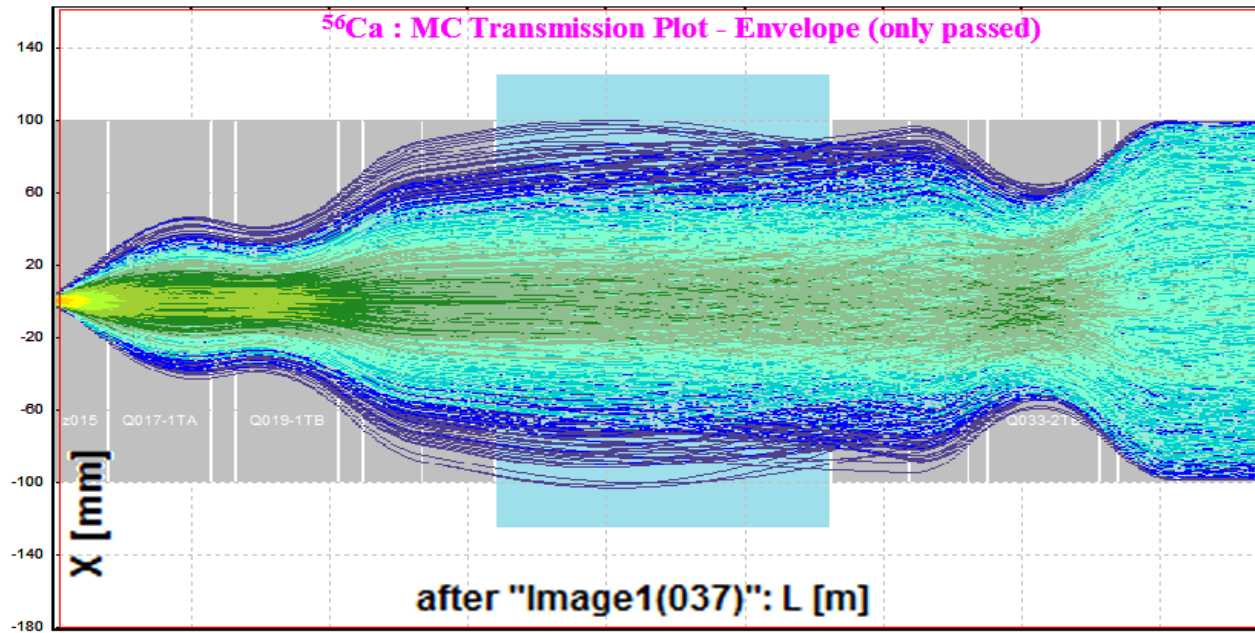
Z107DC L out Z104YG 87.3 mm

Block angular acceptance < Geometrical acceptance

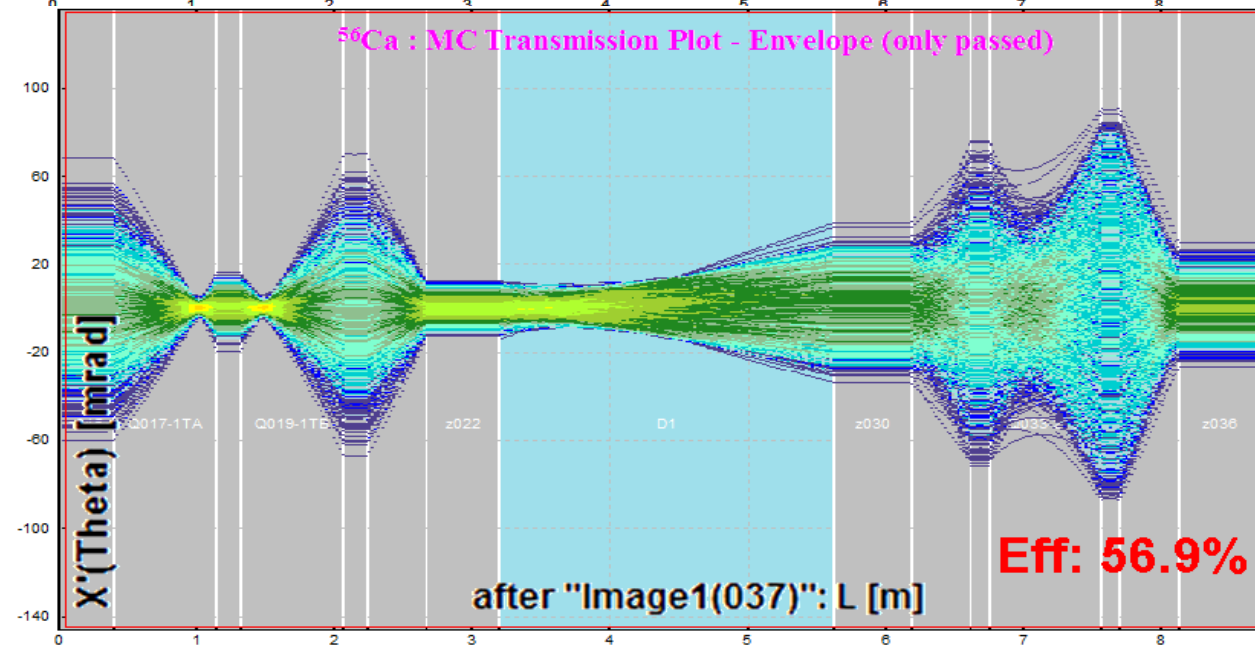


Configuration	Angular Acceptance	Aperture	Slits after block
Classical ("segment")	Yes	No	Yes
Extended ("element")	No	Yes*	please use only for "slits" element

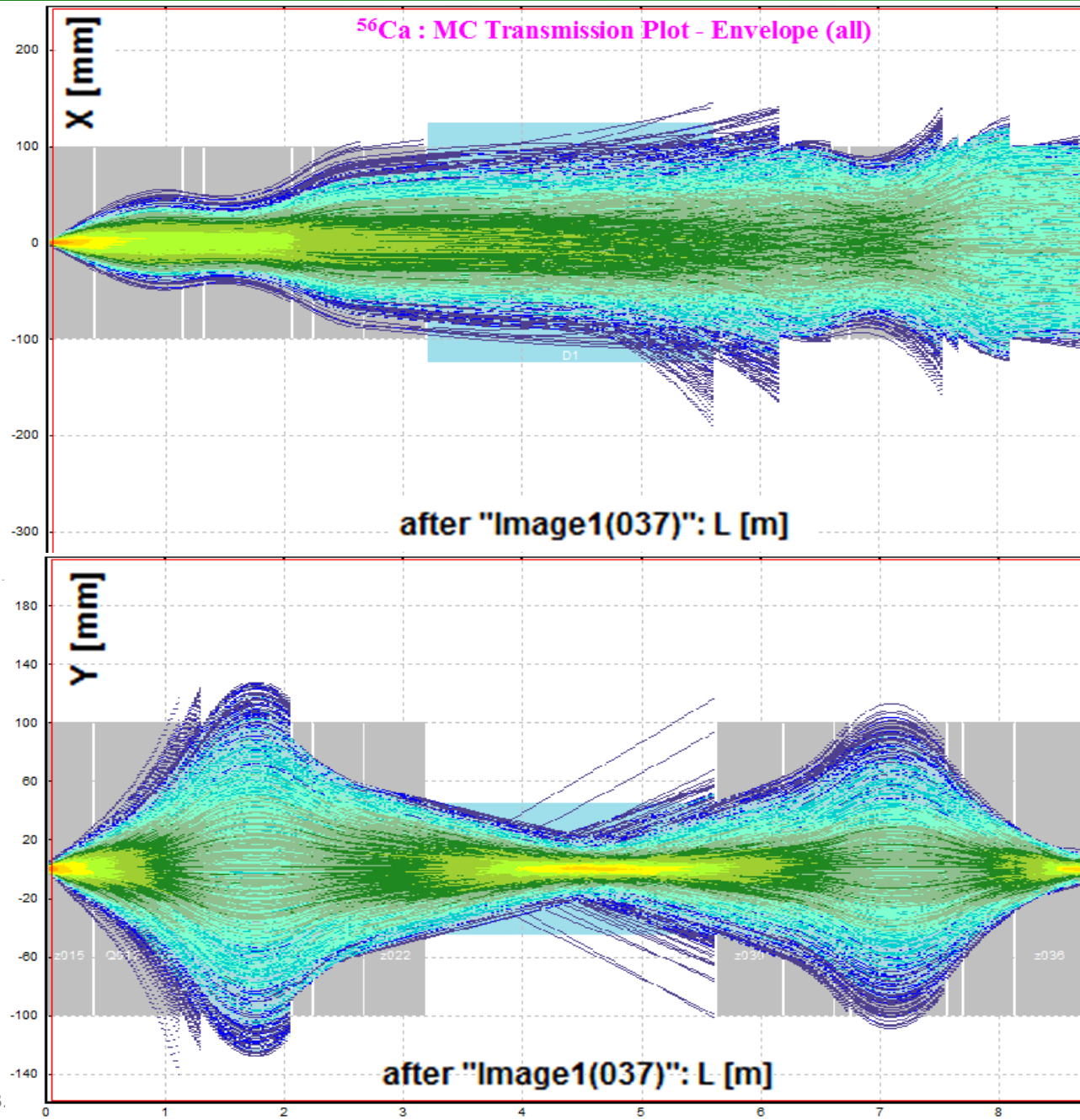
* - Apertures are used only in Monte Carlo calculations

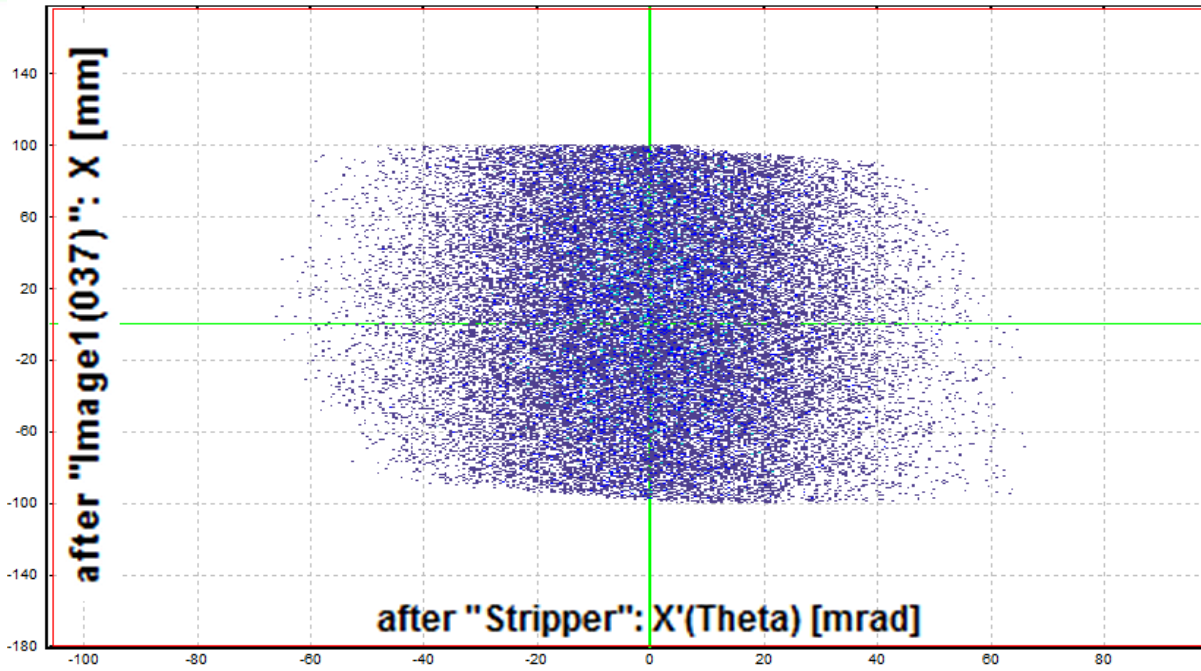


SUM
2.838e+03
CPU speed
0 pps
Eff: 56.8%

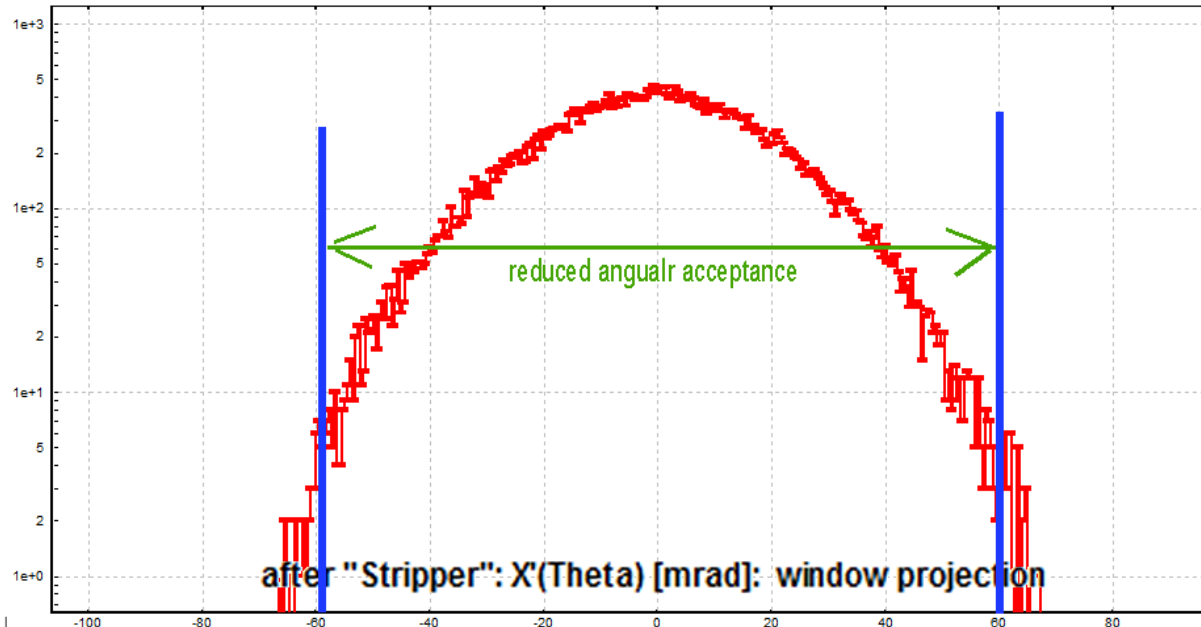


extended configurations





These Fragments passed through the system





➤ **Classical (segmented) configuration:**

- Fast transmission calculations
- Simple structure
- Effective with analytical calculations for experiment planning



➤ **Extended (elemental) configuration:**

- Detailed analysis of transmission
- Optical matrices can be calculated in the code, and used in segmented configurations
- Tools to obtain angular acceptances, which can be used in segmented configurations
- Good tools for understanding (learning) ion-beam optics issues
- Effective with Monte Carlo calculations for fragment separator design

➤ **“Distribution” (analytical) method**



- Fast calculations
- All Optimization procedures in the code based on this method
- Effective with segmented configurations for experiment planning
- Calculation of low transmission (important for primary beams)

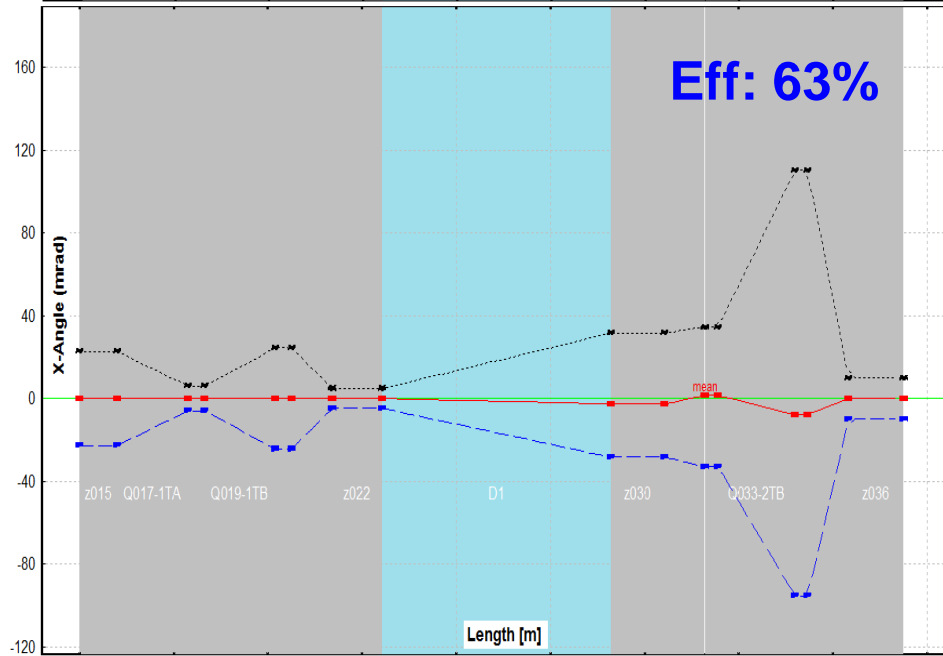
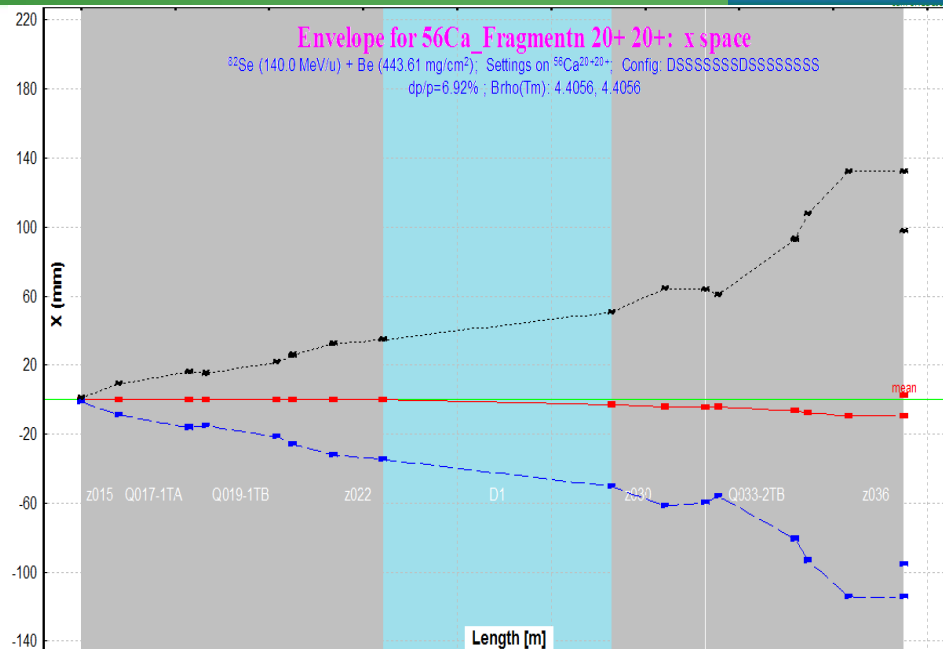
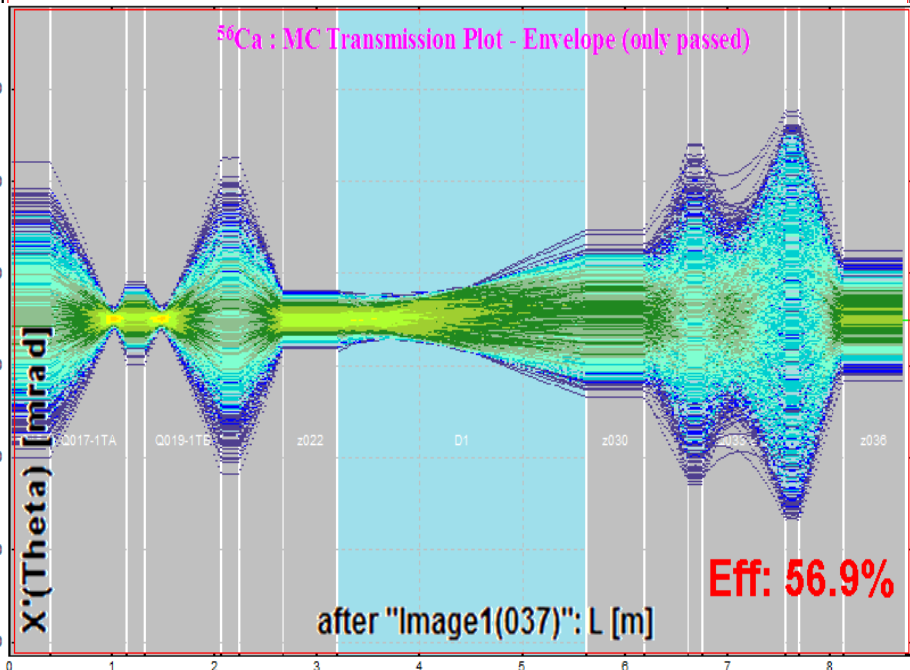
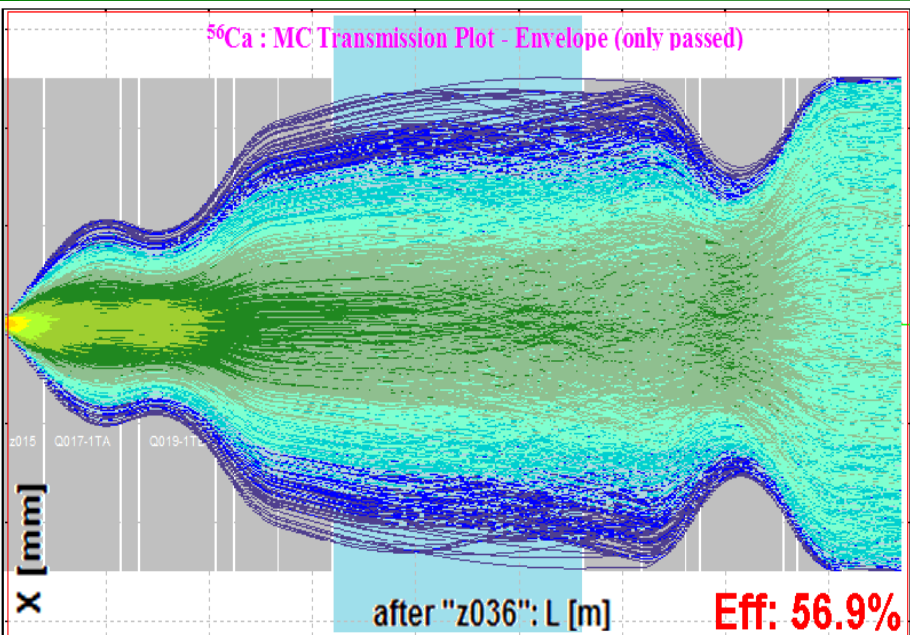
LISE class “Distribution” : D. Bazin, B. Sherrill, Phys. Rev. E 50 (1994) 4017
 LISE class “Distribution2” : 2000
 LISE++ class “Distribution4” : 2003

➤ **Monte Carlo method:** (from 2007)



- Benchmark for the “Distribution” method
- Detailed analysis of transmission with extended configurations
- Possibility to use High Order Optics
- Observation of correlations between different parameters of different blocks
- Possible gates on different parameters
- Good tools for understanding (learning) ion-beam optics issues
- Effective for fragment separator design
- Some optical blocks (Solenoid, RF buncher) are effective only in MC mode

Envelope calculations by different methods



Monte Carlo calculation of fragment transmission

Monte Carlo calculation of fragment transmission

What isotope transmission to calculate?

- One fragment of interest. Chose manually here
- Group of Isotopes already calculated by the Distribution method (Ncalc = 6)
- List of isotopes from file to produce inside target -- no file --
- Input ions rays from file emitted from target -- no file --

Chose fragment of interest

A	Element	Z
56	Ca	20

Beta-decay

Charge states: 20+ D1 Set

Reaction mechanism: Projectile Fragmentation

MC transmission options

Add in the previous MC plot window

"Distribution" calculation

MC calculation to file

Monte Carlo calculation 2D-plot

Quit

X-coordinate

Into block: FP_PIN as Y

- X mm
- X' (T) mrad
- Y mm
- Y' (P) mrad
- dP/P %
- Radial [f(X,Y) mm
- Angle [f(X',Y'') mrad
- Energy MeV/u
- TKE MeV
- Momentum MeV/c
- Brho T*m
- Erho MJ/C
- Energy Loss MeV
- Range mm
- Envelope m
- Energy Deposition MeV/mm /particle
- Time of flight ns
- Length m

Y-coordinate

Into block: FP_PIN as X

- X mm
- X' (T) mrad
- Y mm
- Y' (P) mrad
- dP/P %
- Radial [f(X,Y) mm
- Angle [f(X',Y'') mrad
- Energy MeV/u
- TKE MeV
- Momentum MeV/c
- Brho T*m
- Erho MJ/C
- Energy Loss MeV
- Range mm
- Envelope m
- Energy Deposition MeV/mm /particle
- Time of flight ns
- Length m

Stripper < Start --> Stripper

FP_PIN < Stop --> FP_PIN

Cyclotron RF-signal

Velocity

Velocity_Z [cm/ns]

Ion parameters (M,Z,q...)

A (mass number)

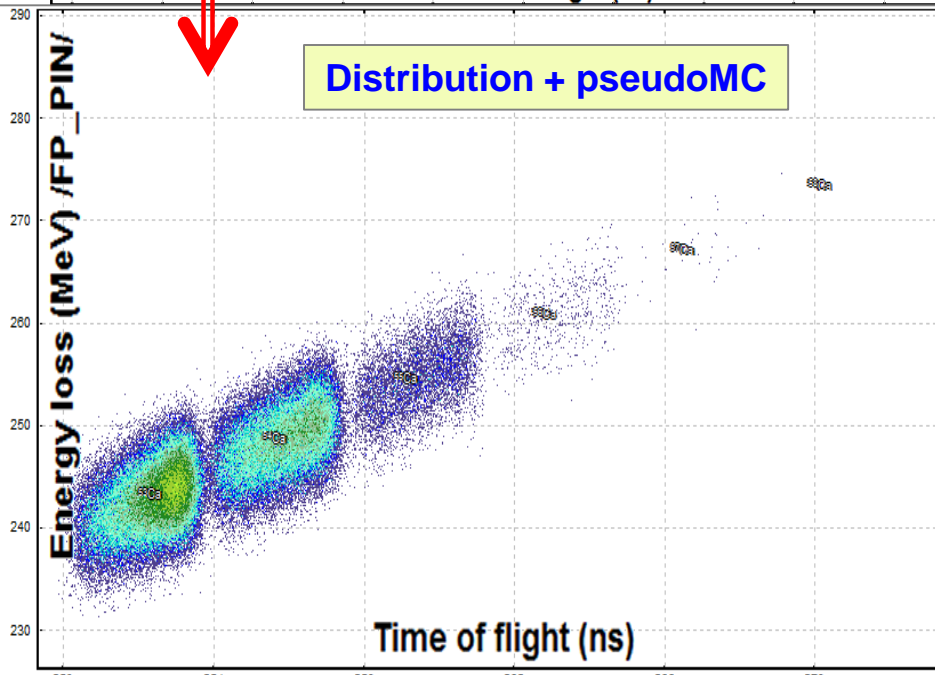
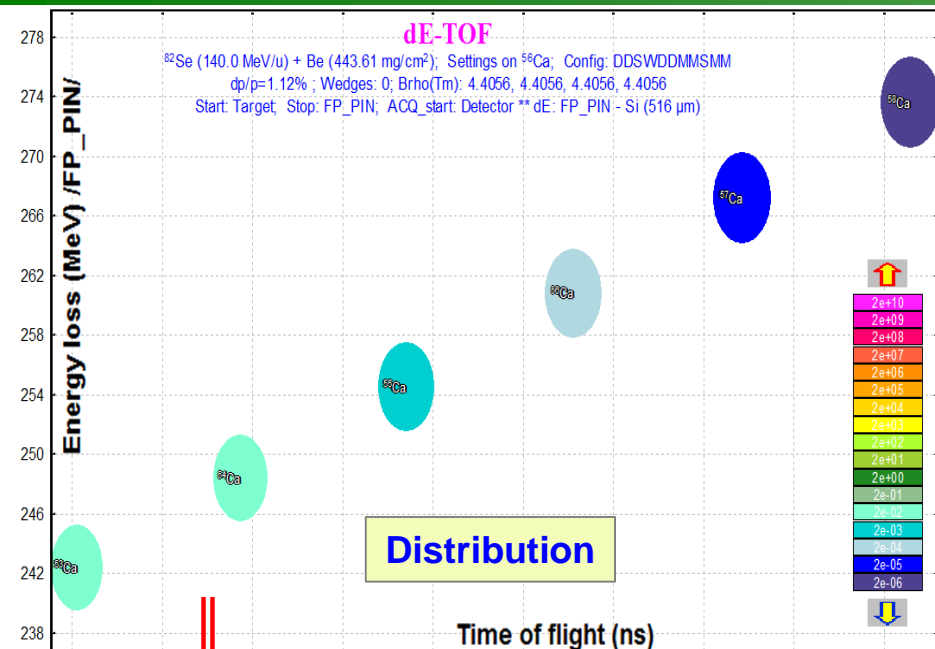
Z-q

Gate 1: no gate

Gate 2: no gate

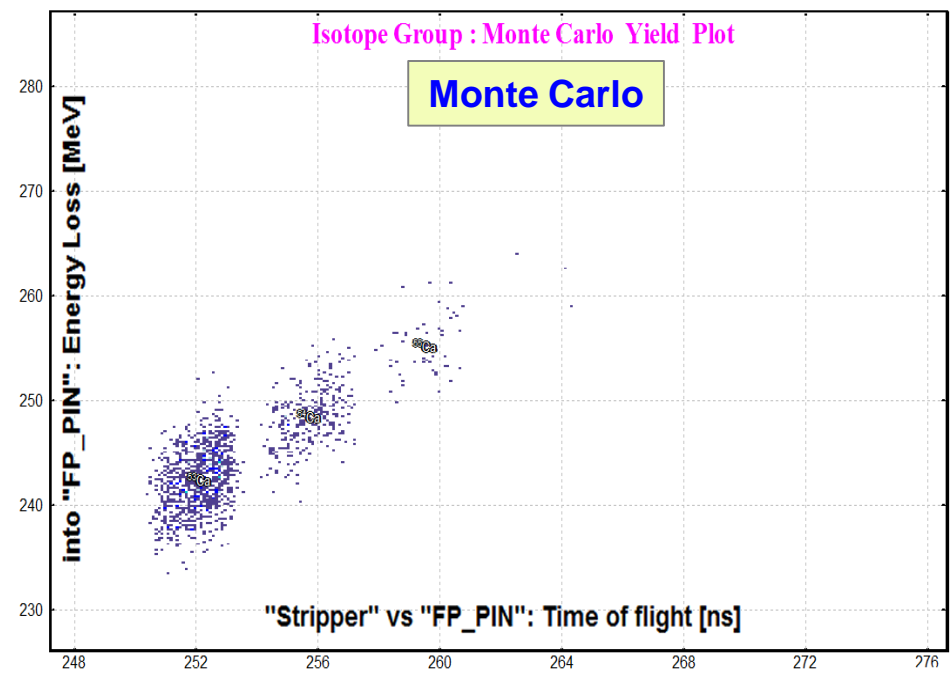
Gate 3: no gate

Gate 4: no gate

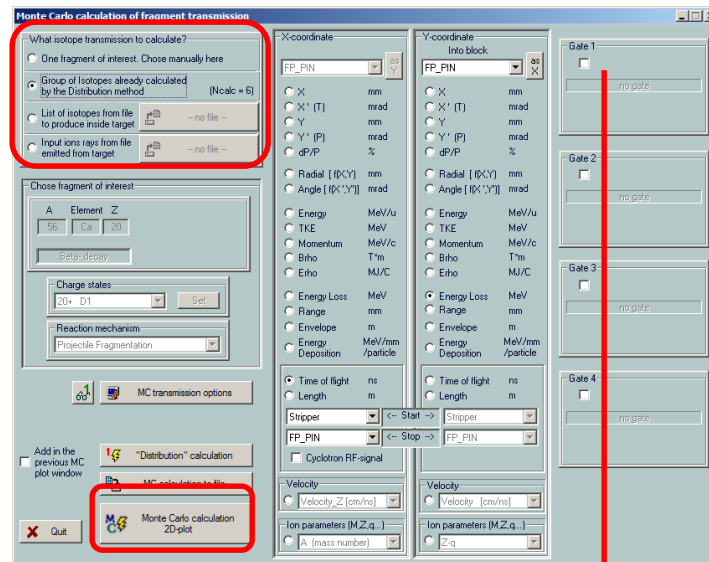
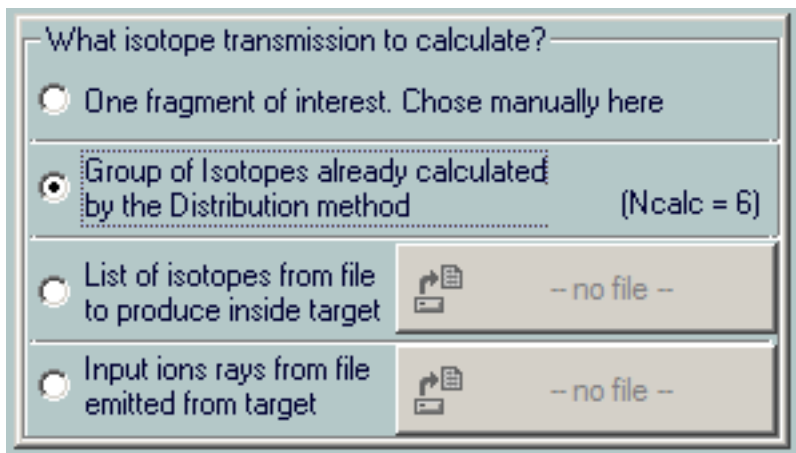


pseudoMC method for plots :

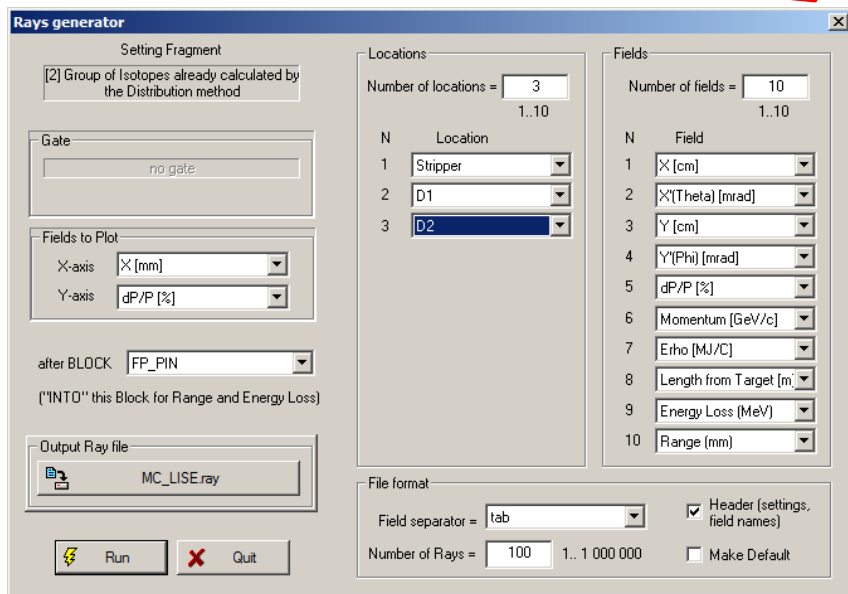
Monte Carlo method is applied to analytically calculated Final Distributions



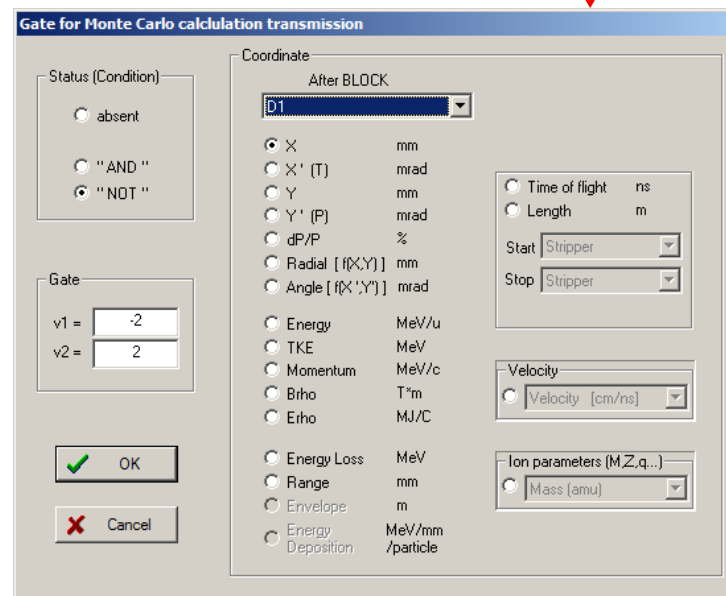
Different input sources



Output in file : Rays generator



Up to 4 Gates



Gate for Monte Carlo calculation transmission

Status (Condition)

absent

"AND "

"NOT "

Gate

v1 =

v2 =

Coordinate

After BLOCK

Q017-1TA

X mm

X' (T) mrad

Y mm

Y' (P) mrad

dP/P %

Radial [f(X,Y)] mm

Angle [f(X',Y')] mrad

Energy MeV/u

TKE MeV

Momentum MeV/c

Brho T*m

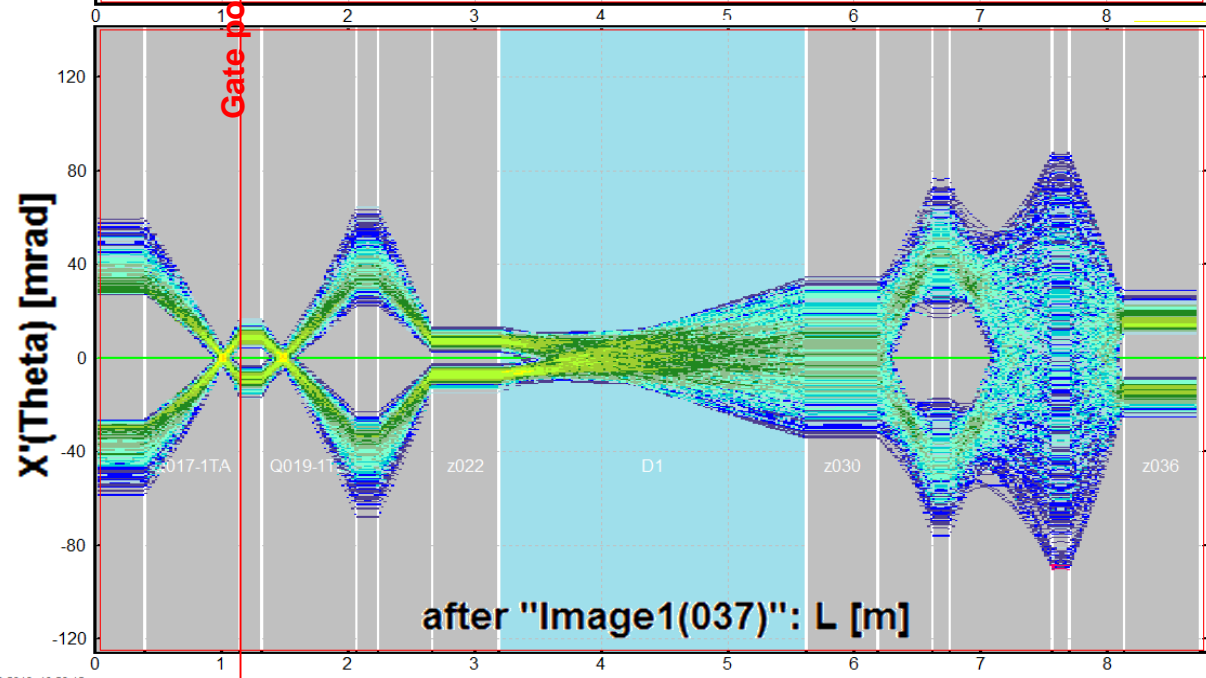
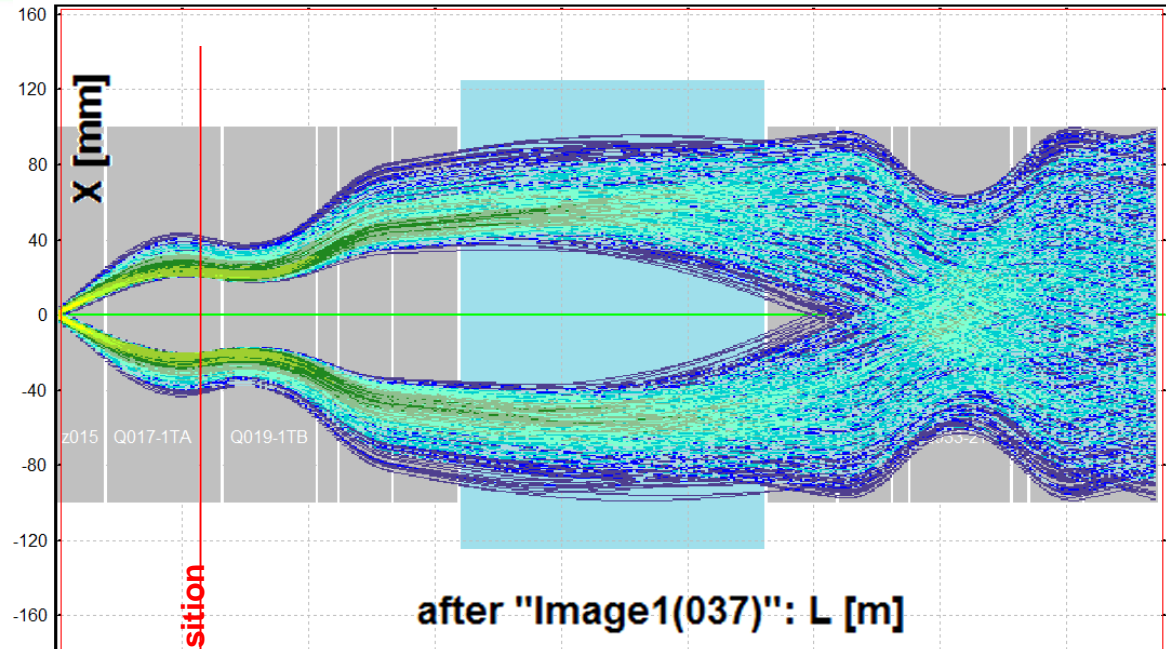
Erho MJ/C

Energy Loss MeV

Range mm

Envelope m

Energy Deposition MeV/mm /particle

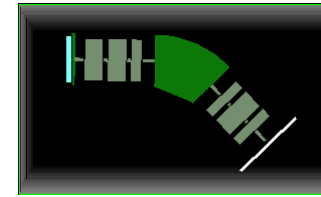


Exclude $x=[-20,20]$ after the first quadrupole

Electromagnetic separation devices in LISE⁺⁺

Separation device	Changeable field	Strength	Selection by
Magnetic dipole	Magnetic (B[T])	$\vec{F}_B = q\vec{v} \times \vec{B}$	Magnetic rigidity $B\rho = \frac{mv}{q}$ [T·m]
Gas-filled separator	Magnetic (B[T])	\vec{F}_B	Magnetic rigidity
Solenoid	Magnetic (B[T])	\vec{F}_B	Focusing (combination A, q, v)
Electrostatic dipole	Electric (E [kV/m])	$\vec{F}_E = q\vec{E}$	Electric rigidity $E\rho = \frac{mv^2}{q}$ [J/C]
RF kicker	Electric (E [kV/m])	\vec{F}_E	Time
RF buncher	Electric (E [kV/m])	\vec{F}_E	Bunching
Wien-filter <i>E-cross-B filter</i>	Magnetic (B[T]) Electric (E [kV/m])	$\vec{F} = \vec{F}_B + \vec{F}_E$	Velocity

Separation device	Changeable field	Strength	Selection by
Magnetic dipole	Magnetic (B[T])	$\vec{F}_B = q\vec{v} \times \vec{B}$	Magnetic rigidity $B\rho = \frac{mv}{q}$ [T·m]



D1

Dispersive block

- Brho 4.4056 Tm
- B 1.42396 T
- I 90.737 A

Bend Sector

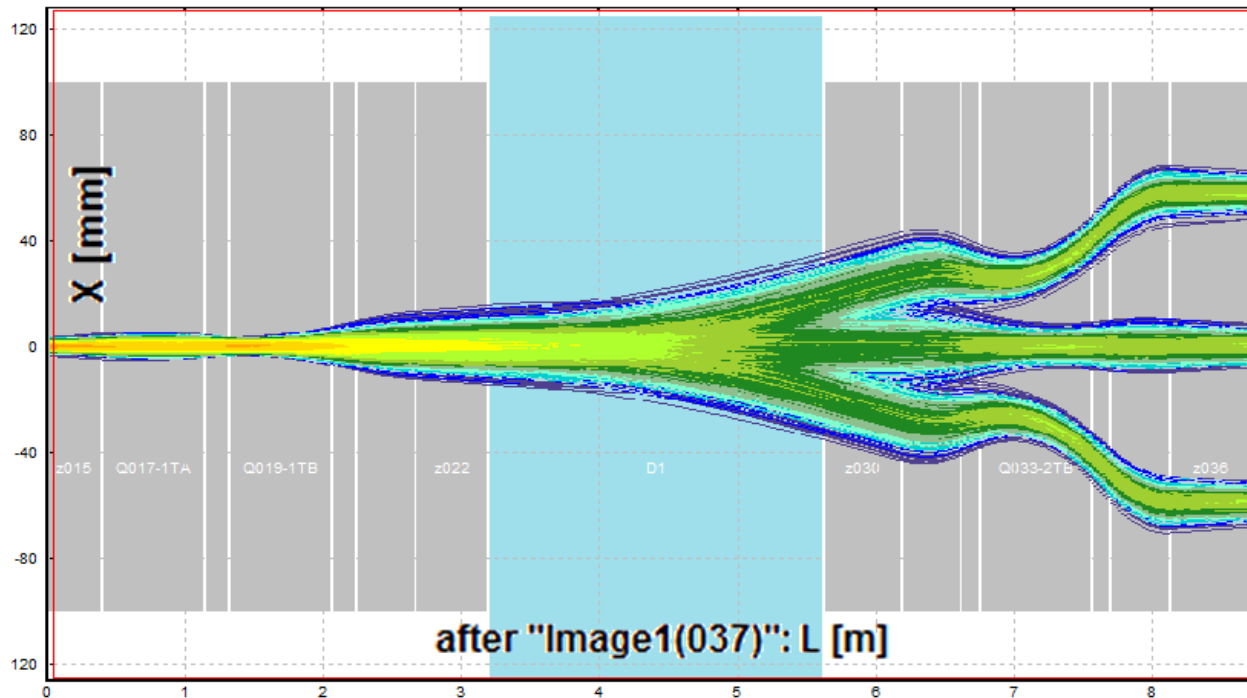
- Radius = 3.0939 m
- Angle = 45 deg
- Length = 2.4299 m

Matrix calculations

Ions rays after target : MC Yield Plot - Envelope (only passed)

Input rays file: "beam_2procents"; Number of rays: 9; Optics Order: 1
 dp/p=6.92% ; Brho(Tm): 4.4056, 4.4056

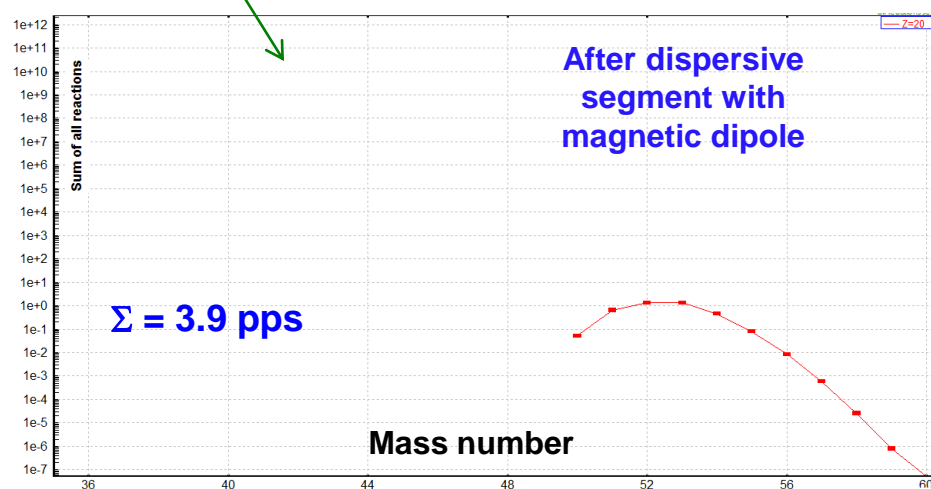
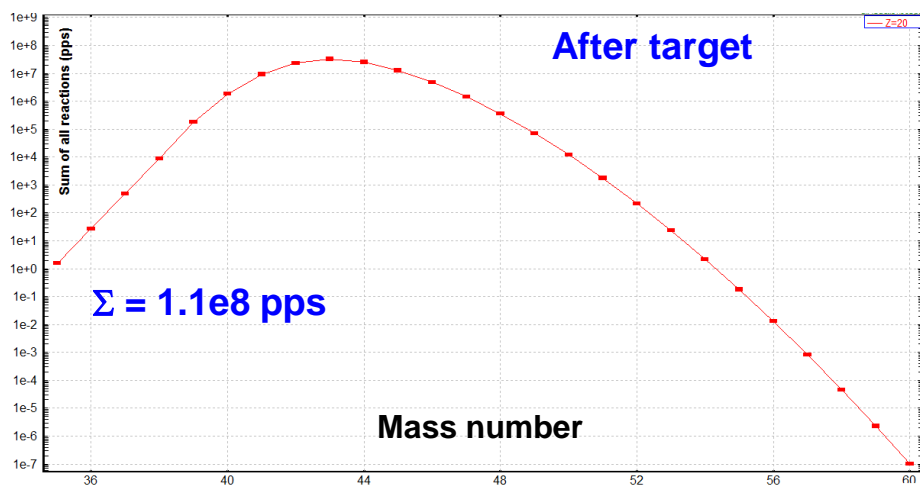
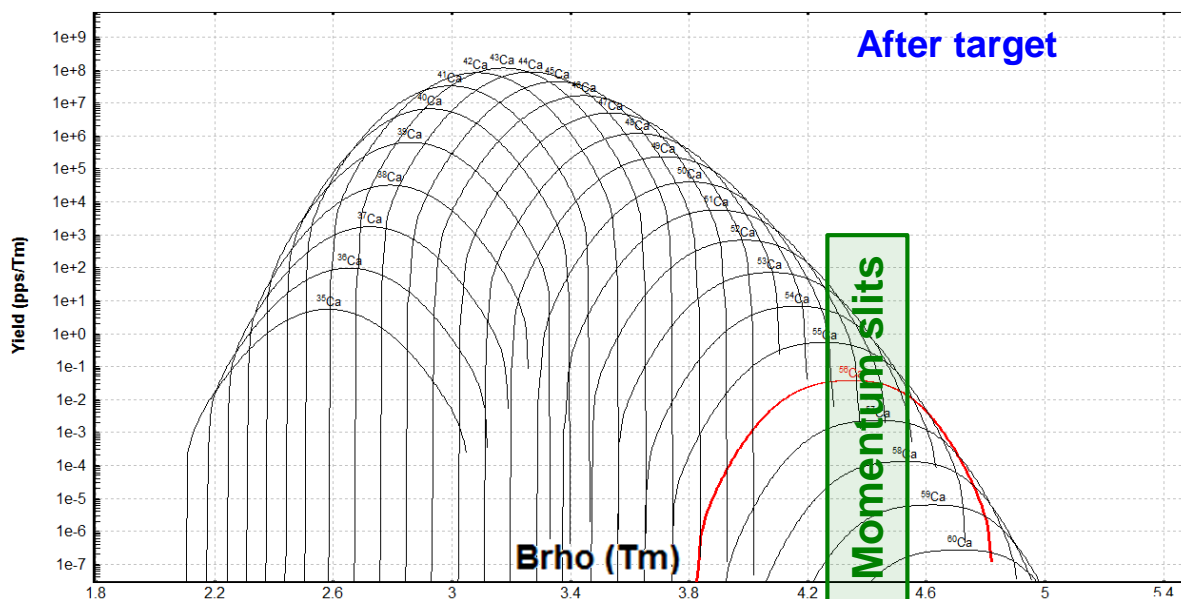
Bounds: Off; "Image1(037)" - last block for MC calc; Gate 1: "AND" (X(Theta) [mrad]); Config: DSSSSSSSSSSSSSSSS



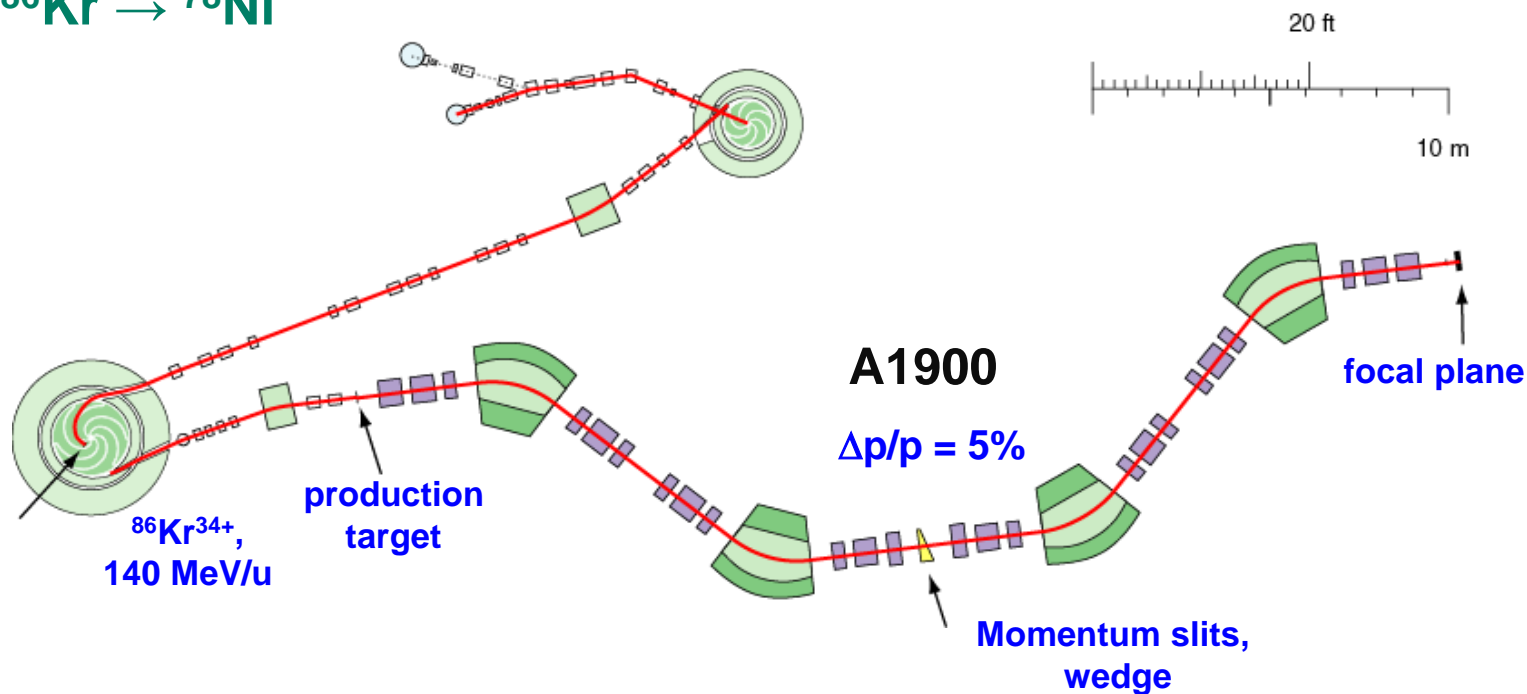
$\Delta p/p = +2\%$

$\Delta p/p = 0\%$

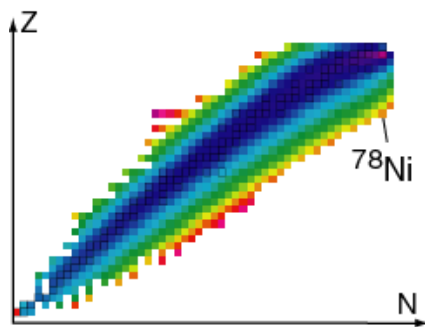
$\Delta p/p = -2\%$



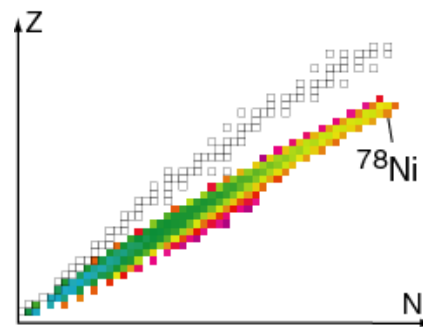
Example: $^{86}\text{Kr} \rightarrow ^{78}\text{Ni}$



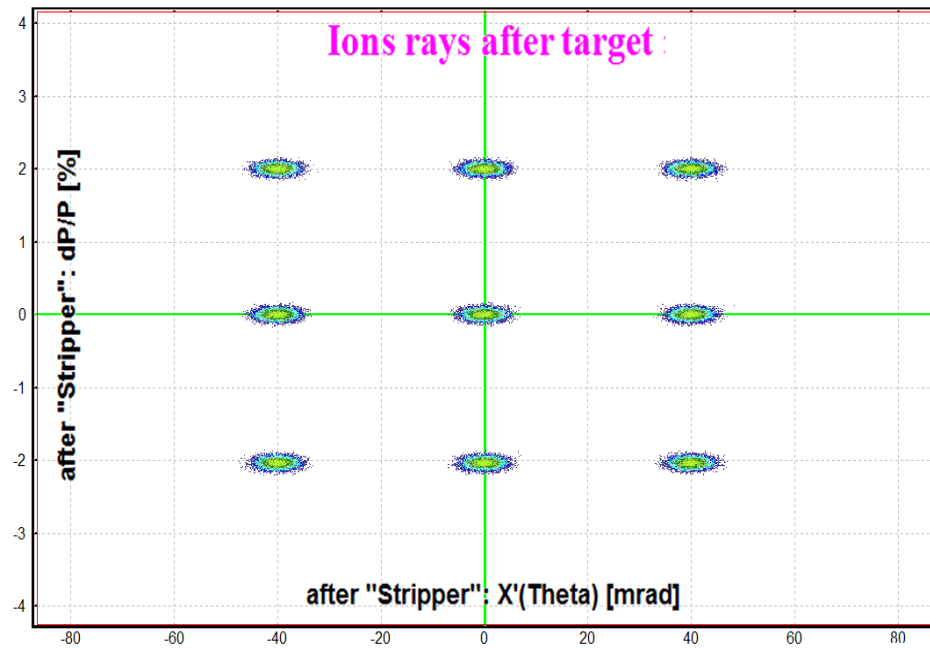
fragment yield after target



fragment yield after momentum slits

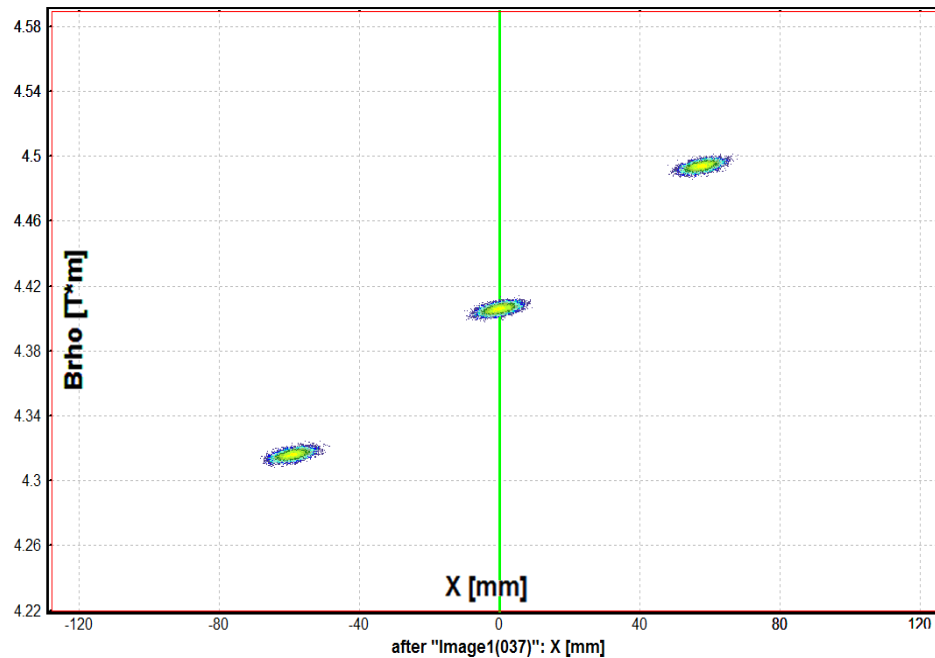
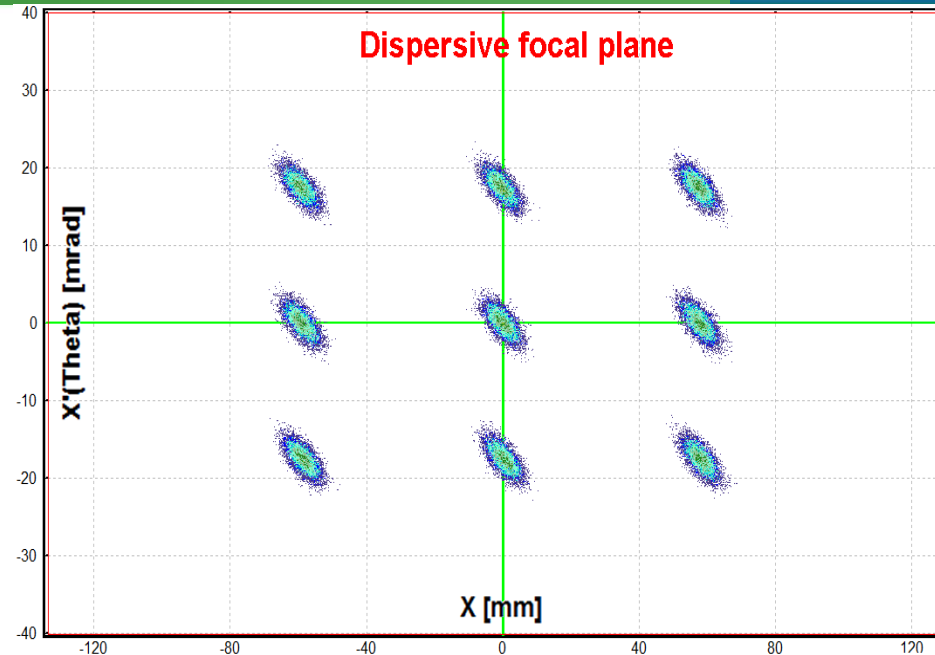


Initial conditions

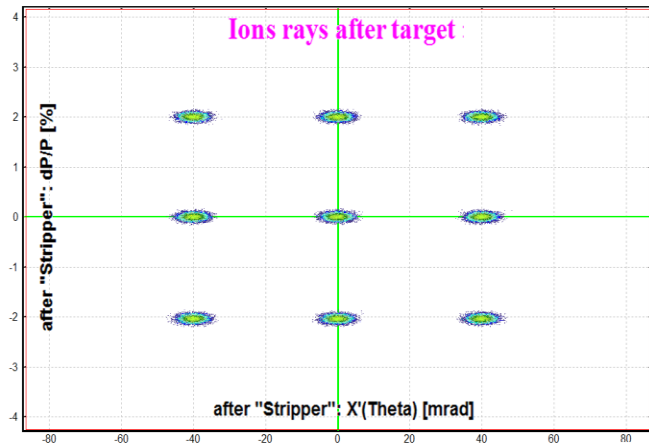


- Small object size
- Good focus in the dispersive plane

Good resolution !

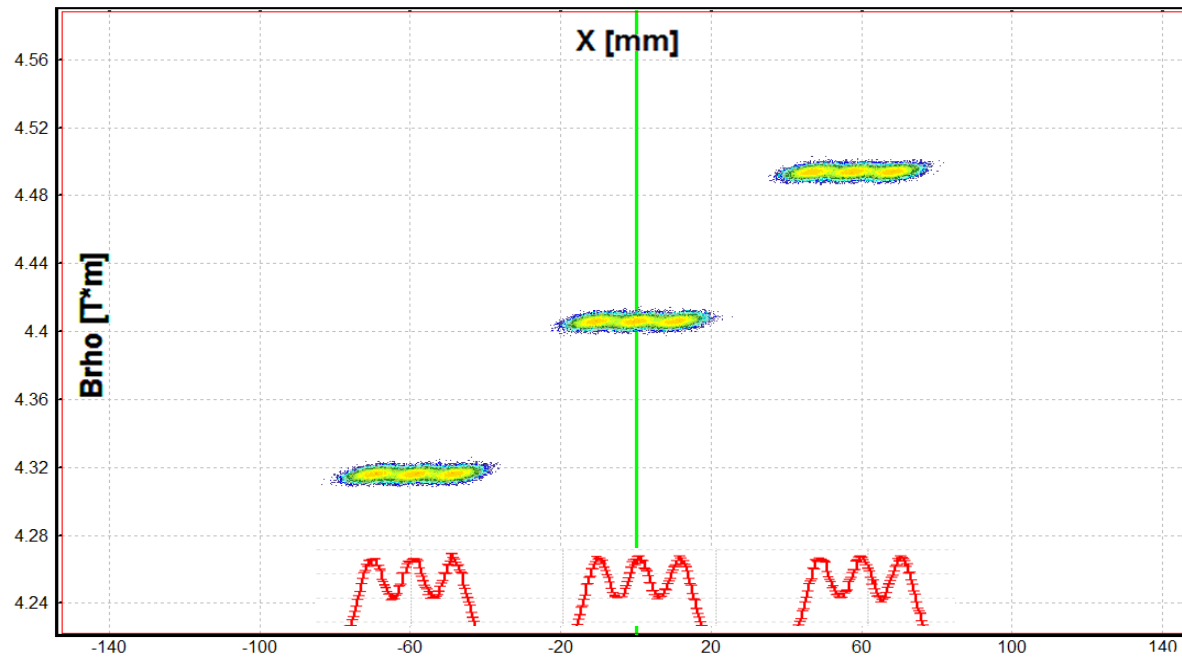
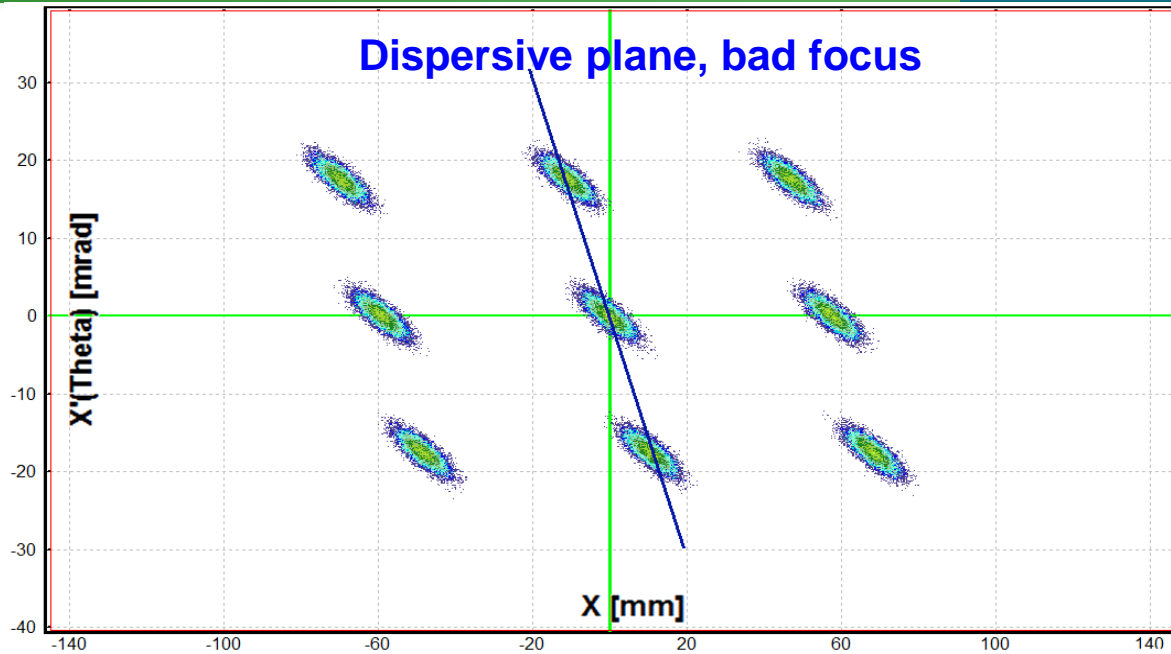


Initial conditions

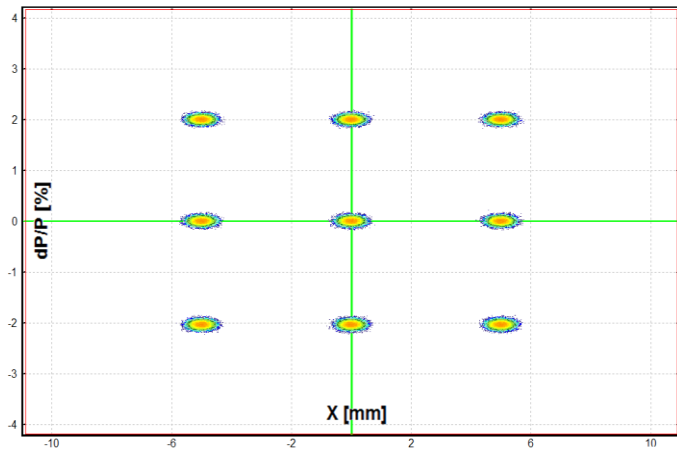


- Small object size
- Bad focus in the dispersive plane

BAD resolution !

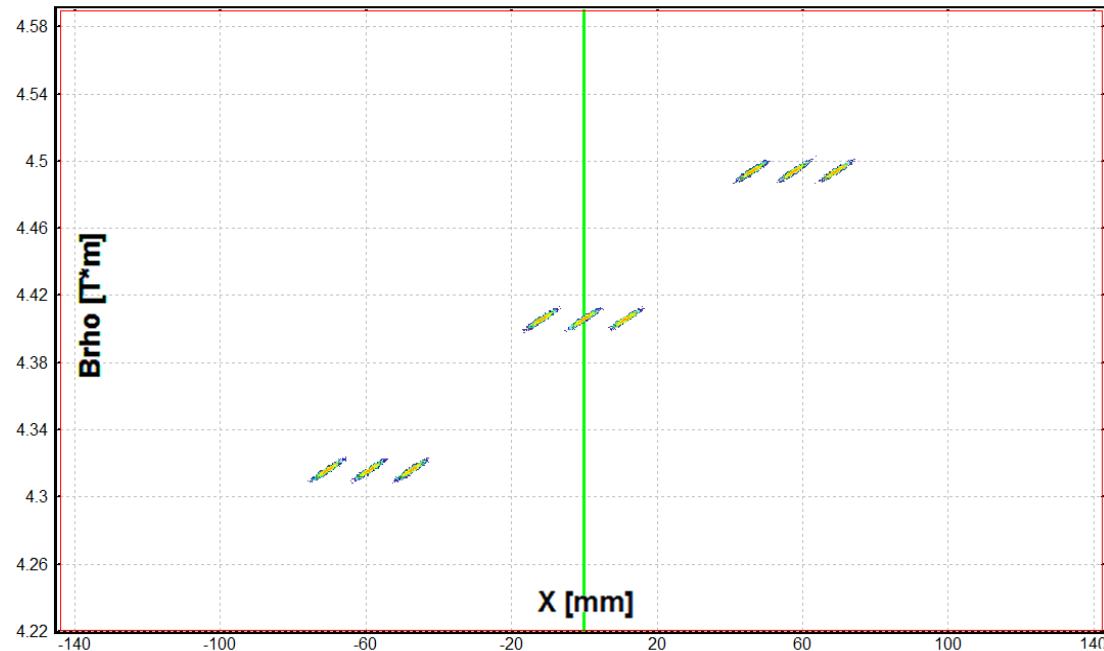
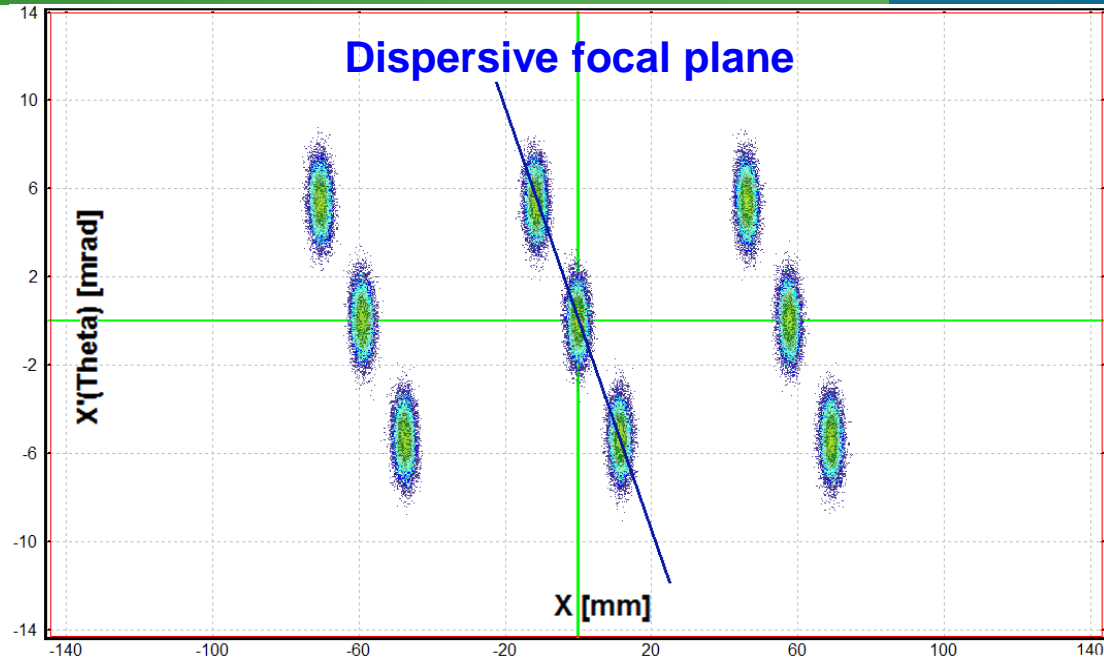


Initial conditions

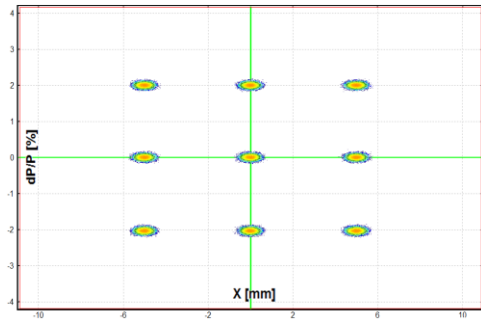


- Large object size
- Good focus in the dispersive plane

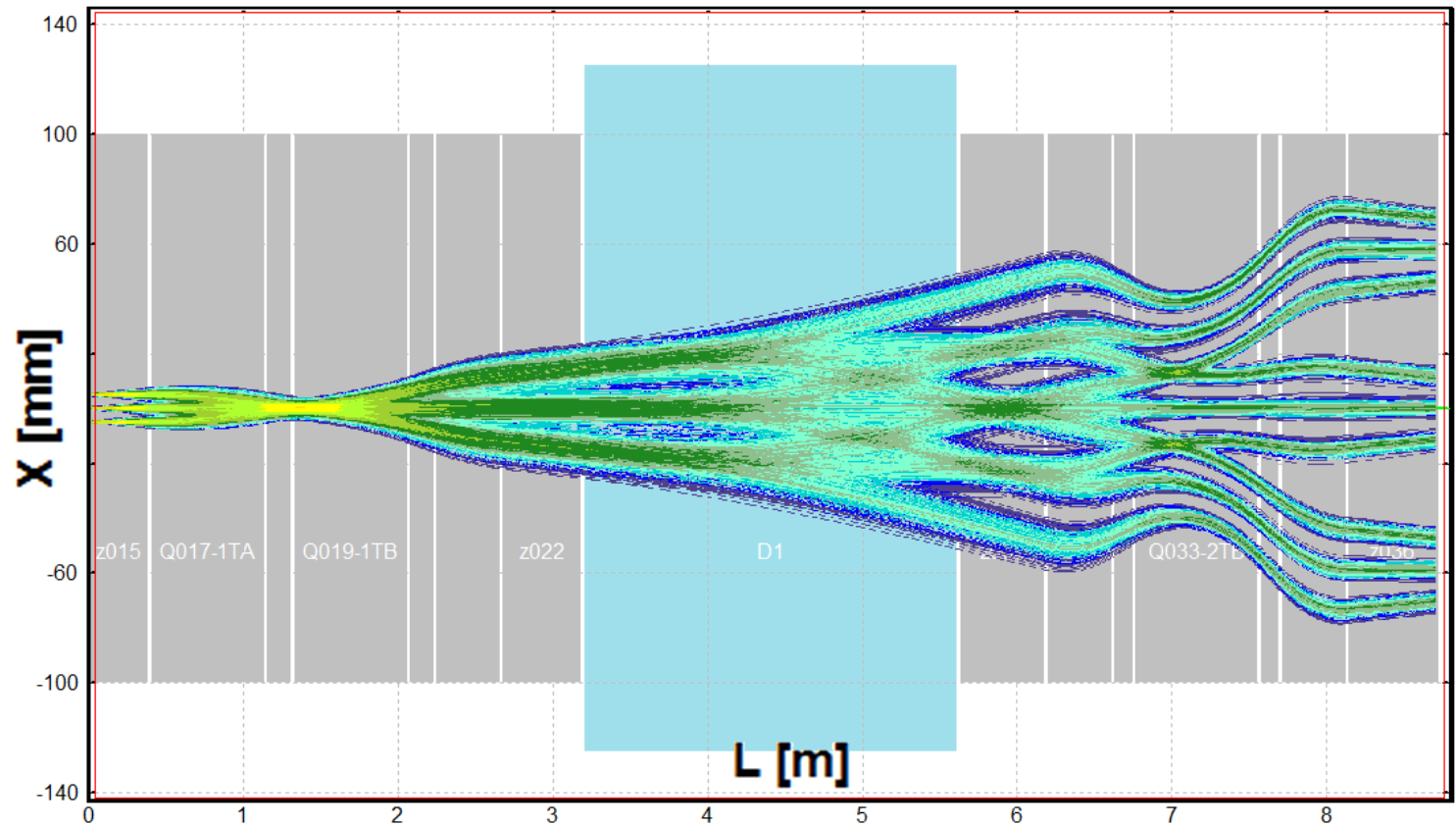
BAD resolution !



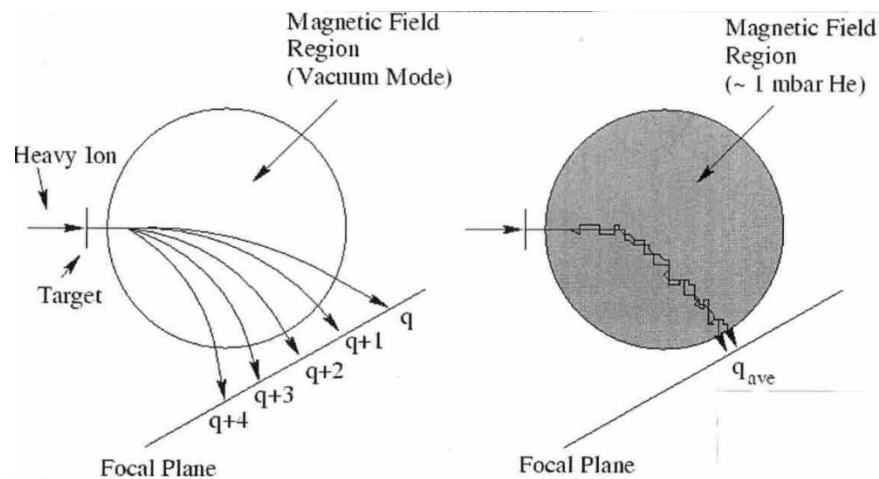
Initial conditions



Large object

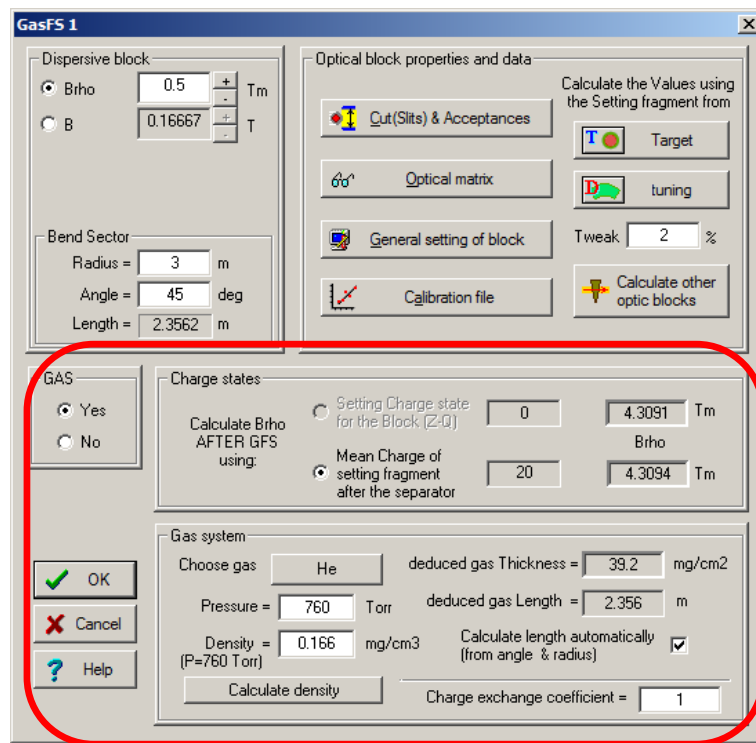


- ❖ It is used at low energy for heavy recoils
- ❖ Gas is used to increase transmission efficiency cause of broad ionic charge distribution after target
- ❖ Gas-filled separators make use of magnetic field elements only
- ❖ Electric fields of needed strength cannot be maintained in gas atmosphere when the pressure is in the order of 1 mbar
- ❖ This block should be optimized in LISE++
Implementation of RayTracing solution?



See for details

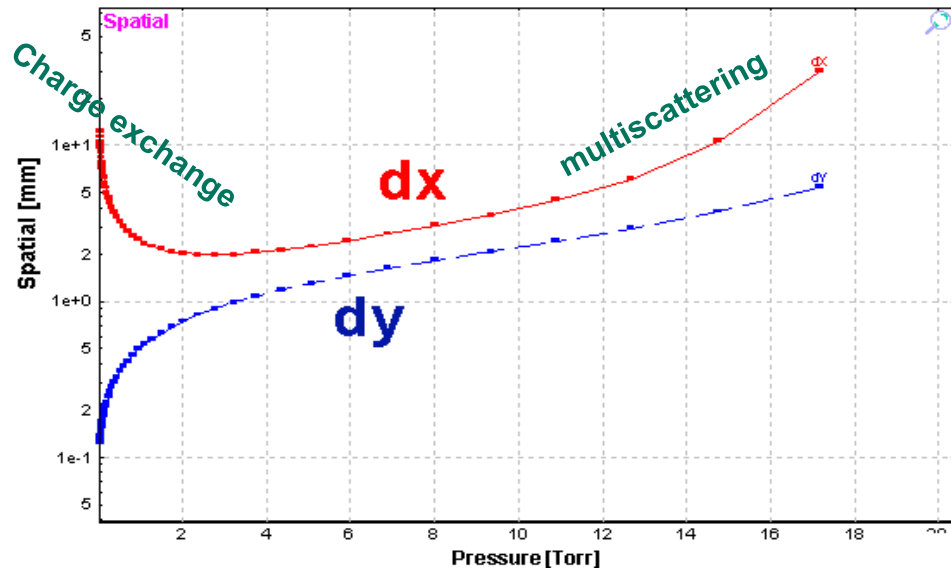
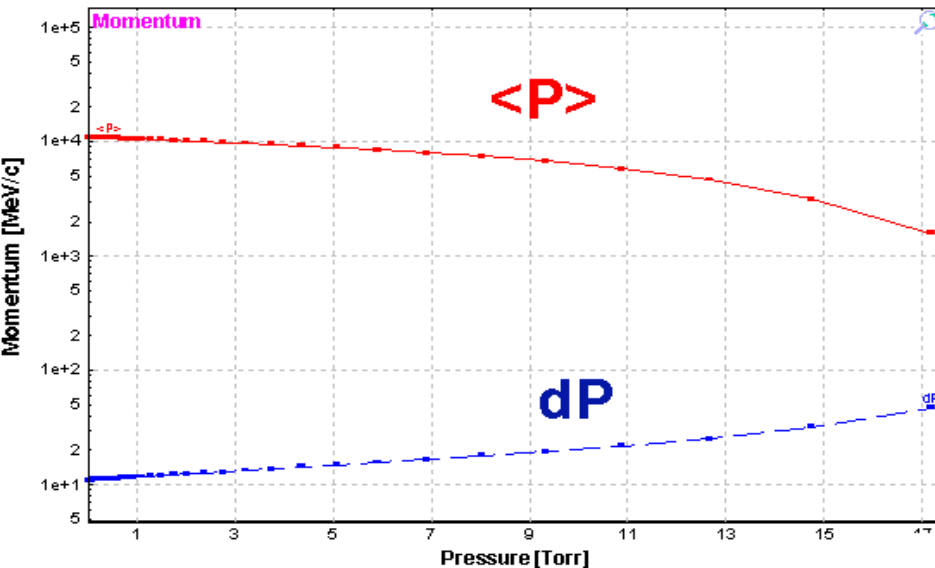
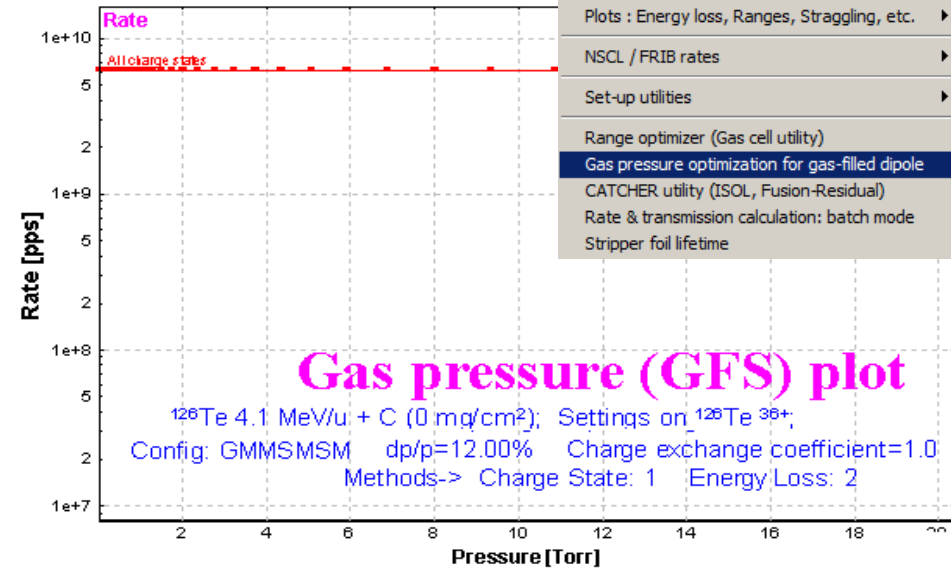
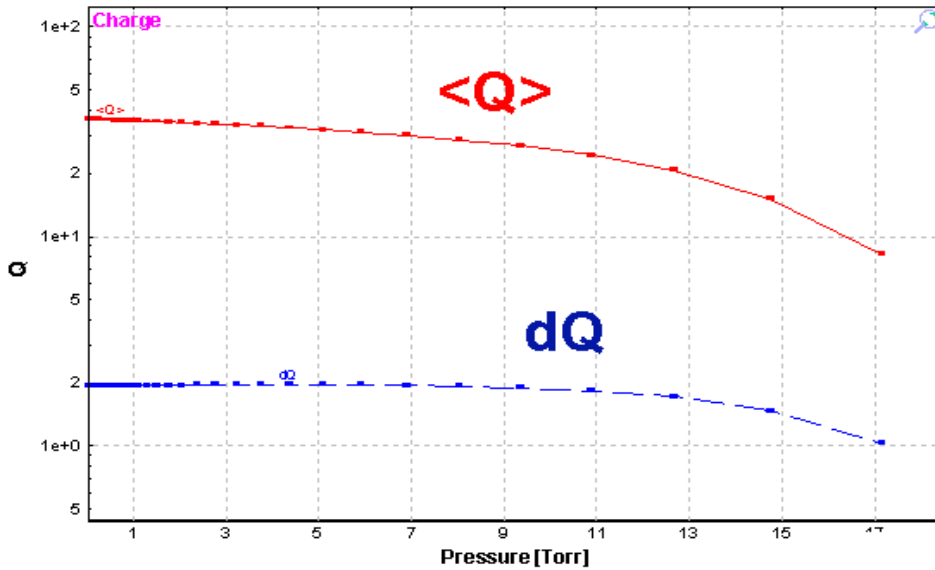
M. Paul et al. NIM A 277 (1989) 418



The choice of the gas pressure in a gas-filled separator plays a crucial role for the spatial resolution in the final focal plane of separator.

The utility to optimize the gas pressure has been developed in LISE++

Utilities	
LISE++ for Excel	
CODES : Charge, Global, PACE4, etc.	▶
Radioactivity, decays	▶
Reactions utilities	▶
Plots : Energy loss, Ranges, Stragglings, etc.	▶
NSCL / FRIB rates	▶
Set-up utilities	▶
Range optimizer (Gas cell utility)	
Gas pressure optimization for gas-filled dipole	
CATCHER utility (ISOL, Fusion-Residual)	
Rate & transmission calculation: batch mode	
Stripper foil lifetime	



Separation device	Changeable field	Strength	Selection by
Electrostatic dipole	Electric (E [kV/m])	$\vec{F}_E = q\vec{E}$	Electric rigidity $E\rho = \frac{mv^2}{q}$ [J/C]

* This block is used at low energy

- Electric rigidity corresponds to TKE selection
- Therefore instead J/C (MJ/C) we can use eV (MeV)

Last Changes

Version	Description
9.6.117 06-08-13	Optical blocks in the code: E-quad, E-bender, Shift

http://lise.nsci.msu.edu/9_6/Edipole/9_6_117.pdf

ElecDip 1

Electrostatic Dipole Settings

Separation plane
 Horizontal Vertical

E (electric field) 133.51 KV/m
 U (voltage) 13.351 KV
 Electric rigidity 0.40053 MJ/C
 Magnetic rigidity 0.09106 Tm
 (corresponds to the setting fragment)

Electrostatic Dipole Constants

Distance between plates (gap) = 0.1 m

Bend Sector

Radius (r0) = 3 m
 Angle = 45 deg
 Length = 2.3562 m

Optical block properties and data

Setting Charge state for the Block (Z-Q) 0

Calculate the Values using the Setting fragment from
 Target
 D1

Tweak 0.1 %

Cut (Slits) & Acceptances
 Optical matrix
 General setting of block

Advanced Elec Dipole settings for extened configurations

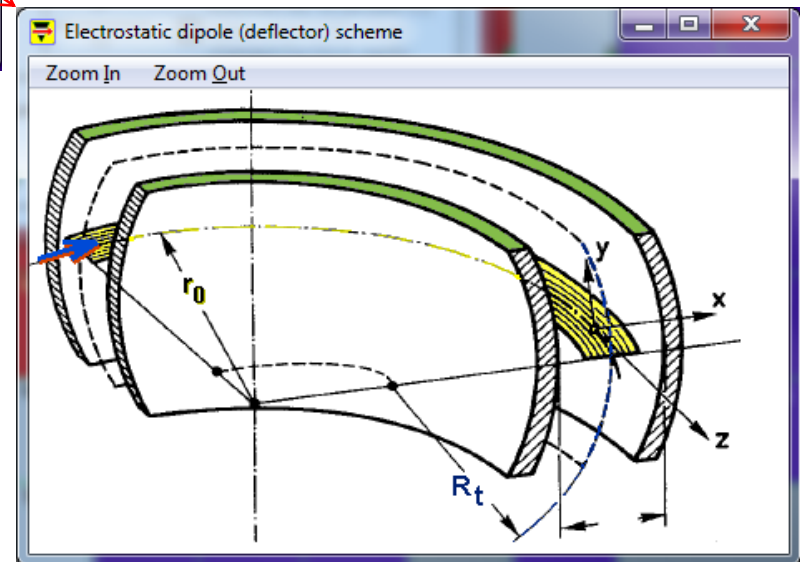
Bend type: Rt (m)

Cylindrical INF
 Spherical 3
 Toroidal 10

Automatically recalculate the matrix, when LISE++ has changed the block rigidity

Important: Selection [X/D] in this block by Electric rigidity, where $D = d(Erho)/Erho$

OK Cancel Help



Matrix calculations

```

Utility: Electrostatic deflector

Electrostatic dipole
mode = Cylindrical

direct = X
radius = 1 m
angle = 45 deg
length = 0.7854 m
  n = 0
  beta = 0.02674
  e_xi = 1.414
  n_eta = 0
  Nk = 0.99982
  Nm = 0.00017876
  k2x = 2 m^(-2)
  k2y = 0 m^(-2)
    
```

```

transport format [cm-mrad]

* TRANSFORM 1 *

[D] -- Momentum transfer matrix (Important!)  it is used for calculation of the Global matrix

1 [X]:      +4.4419e-01 +6.3363e-02  0          0          0          +5.5581e-01
2 [T]:      -1.2668e+01 +4.4419e-01  0          0          0          +1.2668e+01
3 [Y]:      0          0          1          +7.8540e-02  0          0
4 [F]:      0          0          0          1          0          0
5 [L]:      -1.2668e+00 -5.5581e-02  0          0          1          -3.0342e-01
6 [D]:      0          0          0          0          0          1
    
```

```

transport format [cm-mrad]

* TRANSFORM 1 *

[D] -- Electrostatic rigidity selection (Important!)  it is used for transmission calculations,
                                                       which are based on ERHO selection for
                                                       E-static benders

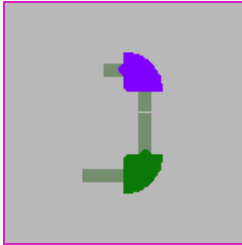
1 [X]:      +4.4419e-01 +6.3363e-02  0          0          0          +2.7800e-01
2 [T]:      -1.2668e+01 +4.4419e-01  0          0          0          +6.3363e+00
3 [Y]:      0          0          1          +7.8540e-02  0          0
4 [F]:      0          0          0          1          0          0
5 [L]:      -6.3363e-01 -2.7800e-02  0          0          1          -7.5910e-02
6 [D]:      0          0          0          0          0          1
    
```

http://lise.nsci.msu.edu/9_6/Edipole/EB_case.lpp

Purpose

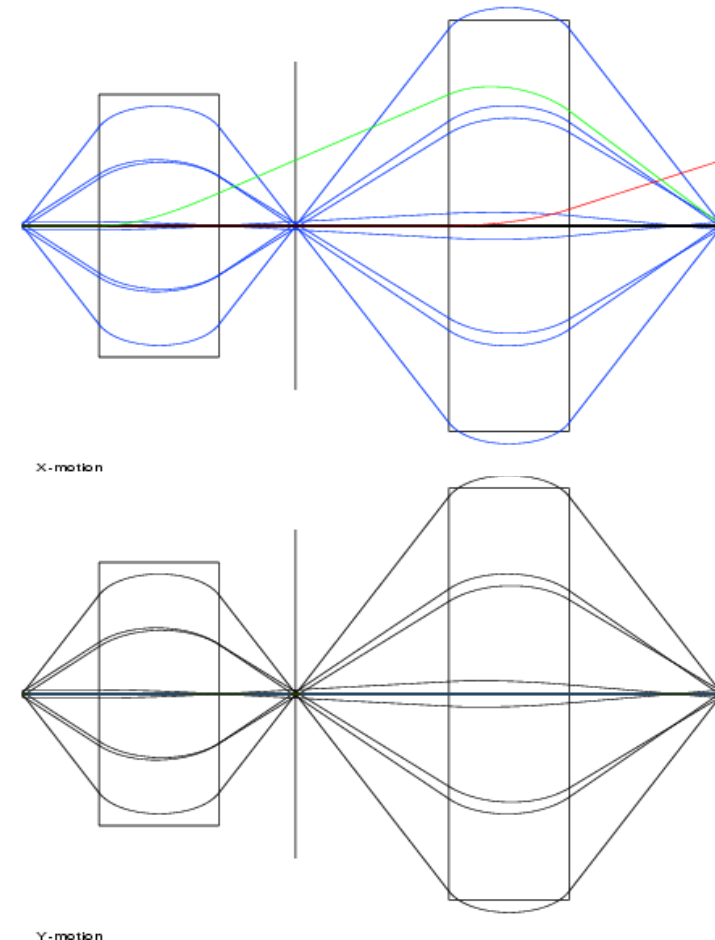
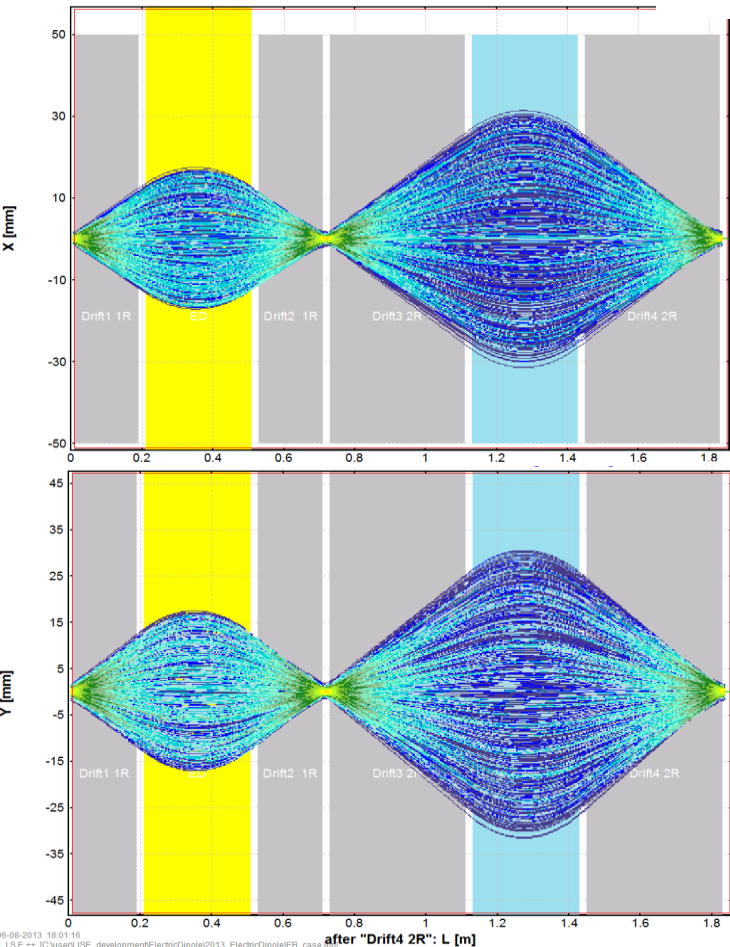
MM.Portillo's example, and COSY calculations

LISE++



- Create an energy achromat system
 - Using double focusing
 - E-dipole
 - » Bend of 90deg at $R=0.2$ m
 - » spherical electrodes for equal x- and y-focus strength
 - » Drift before and after bend = R
 - B-dipole
 - » Bend of 90deg at $R=0.2$ m
 - » 26.56deg entranc & exit edge angles for equal x- and y-focus strength
 - » Drift before and after bend = $2R$

COSY



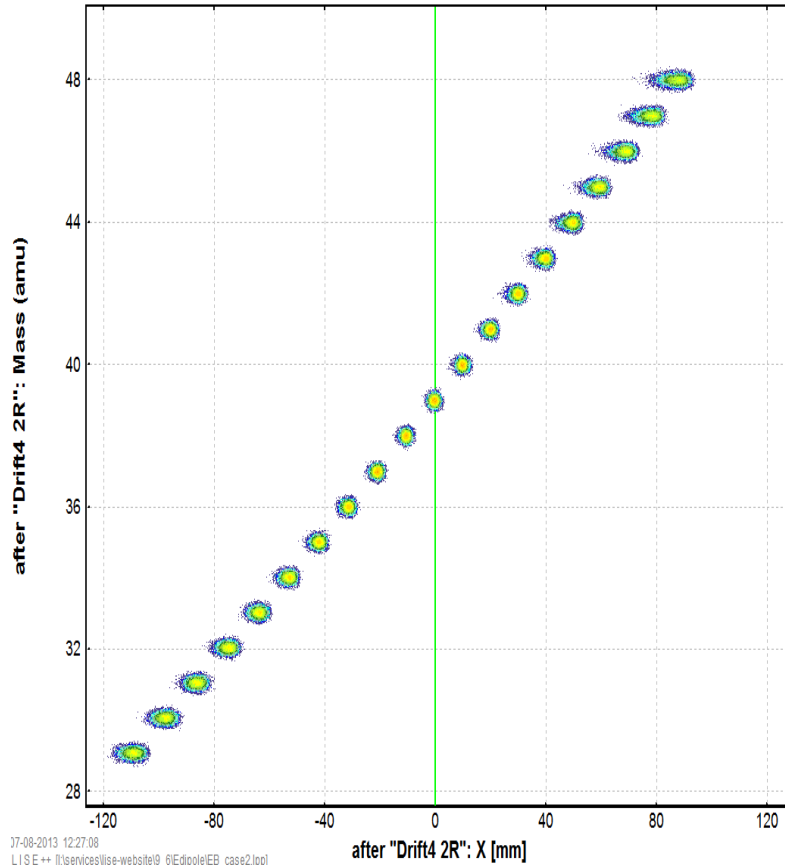
http://lise.nsci.msu.edu/9_6/Edipole/EB_case2.lpp

Ions rays after target : Monte Carlo Yield Plot

Input rays file: "K_isotopes"; Number of rays: 20; Optics Order: 1

dp/p=100.00% ; Brho(Tm): 0.6229

Bounds: Off; "Drift4 2R" - last block for MC calc; no gates; Config: SESSDS



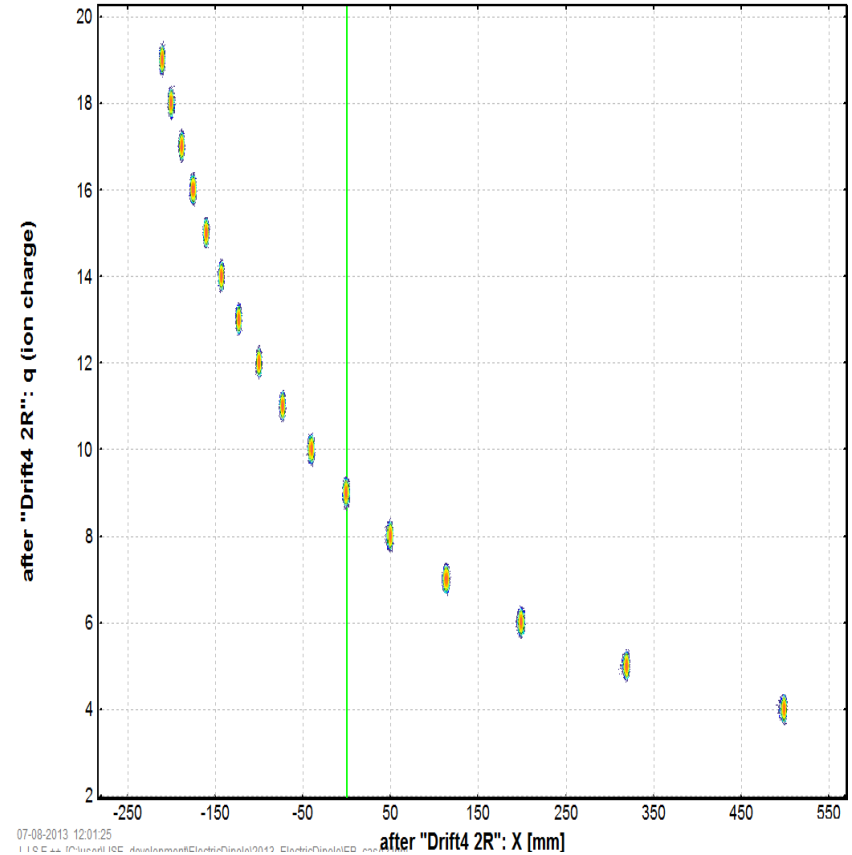
The same q , TKE
Different $Masses$

Ions rays after target : Monte Carlo Yield Plot

Input rays file: "39K_charge_states"; Number of rays: 19; Optics Order: 1

dp/p=100.00% ; Brho(Tm): 0.6229

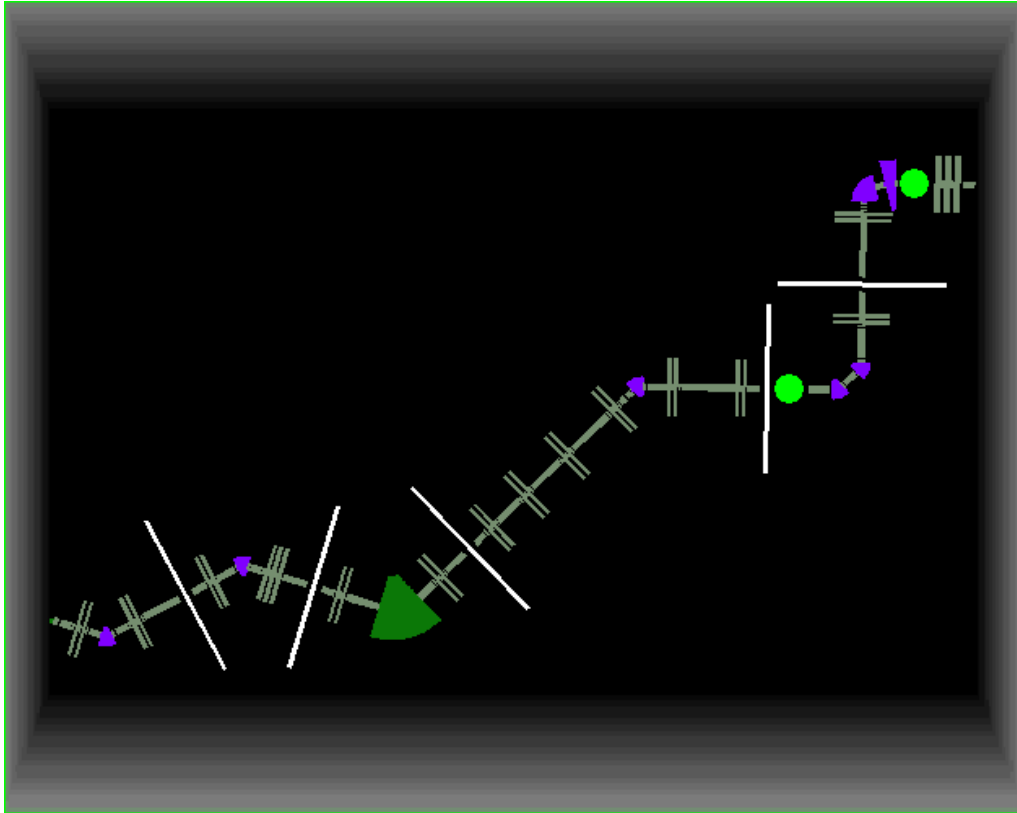
Bounds: Off; "Drift4 2R" - last block for MC calc; no gates; Config: SESSDS



The same $Masses$, E
Different q

LISE++ file:

http://lise.nsci.msu.edu/9_6/Edipole/D-line_BTS01-12%20with%20rotation.lpp

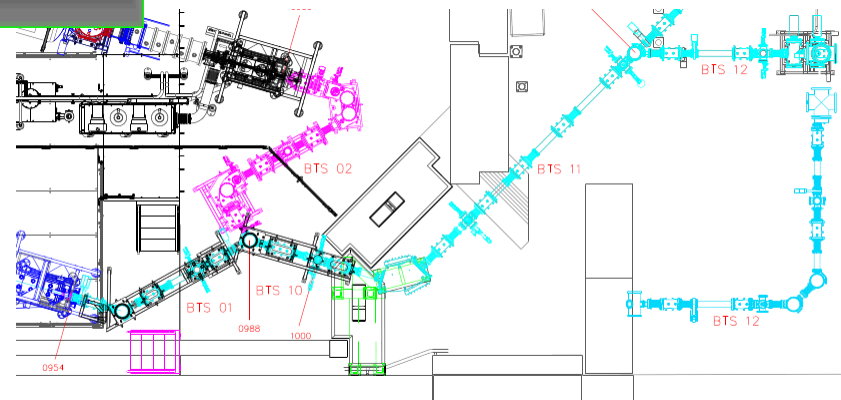


Almost 137 blocks,
where

M-dipole : 1

E-dipole : 7

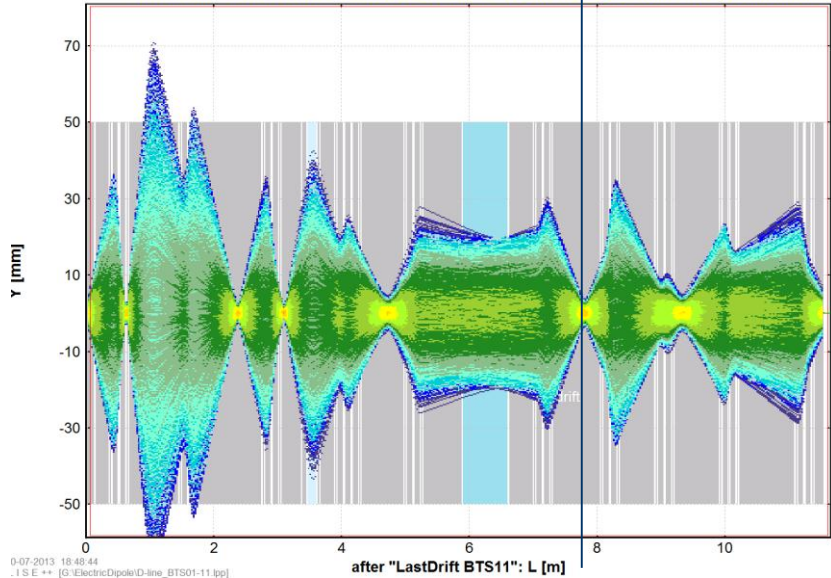
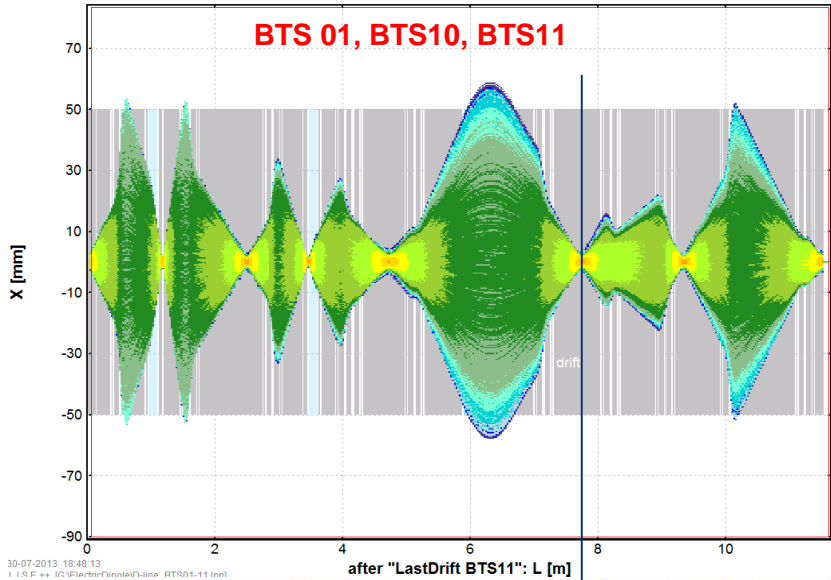
E-quad : 32



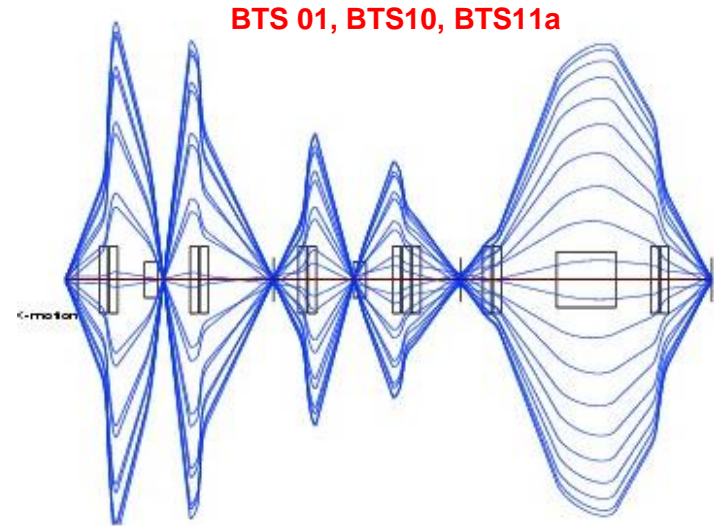
LISE++ file: http://lise.nsl.msu.edu/9_6/Edipole/D-line_BTS01-12%20with%20rotation.lpp

From "Report on recalculation of Low-E beam lines" by M.Portillo

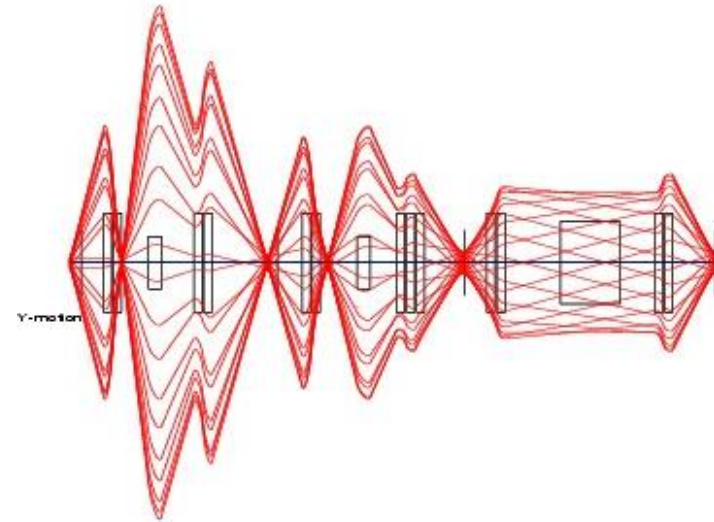
¹⁰⁰Ru (0.0 MeV/u) + ; Transmitted Fragment ¹⁰⁰Ru^{1+,-1+} (beam); Optics Order: 1
 dp/p=0.76% ; Brho(Tm): 0.3523, 0.3523
 Bounds: Off; "LastDrift BTS11" - last block for MC calc; no gates; Config: DSSSSSSSSSESSSSSSSSSS



X



Y



Velocity selection

Separation device	Changeable field	Strength	Selection by
Wien-filter <i>E-cross-B filter</i>	Magnetic (B[T]) Electric (E [kV/m])	$\vec{F} = \vec{F}_B + \vec{F}_E$	Velocity

* This block is used for energies below 40-50 MeV/u

* It is an unique block with floating dispersion in an optical matrix. It is recalculated for each ion

http://lise.nsci.msu.edu/8_5/8_5_040_Wien.pdf

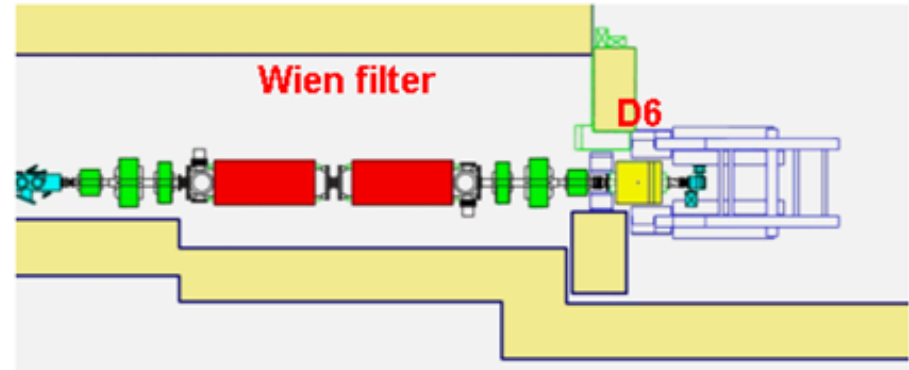
See more for Wien-filter

LISE 3: a magnetic spectrometer—Wien filter combination for secondary radioactive beam production by Remy Anne, Alex C. Mueller

Nuclear Instruments and Methods in Physics Research Section B
Volume 70, Issues 1-4, 1 August 1992, Pages 276-285
[http://dx.doi.org/10.1016/0168-583X\(92\)95943-L](http://dx.doi.org/10.1016/0168-583X(92)95943-L)

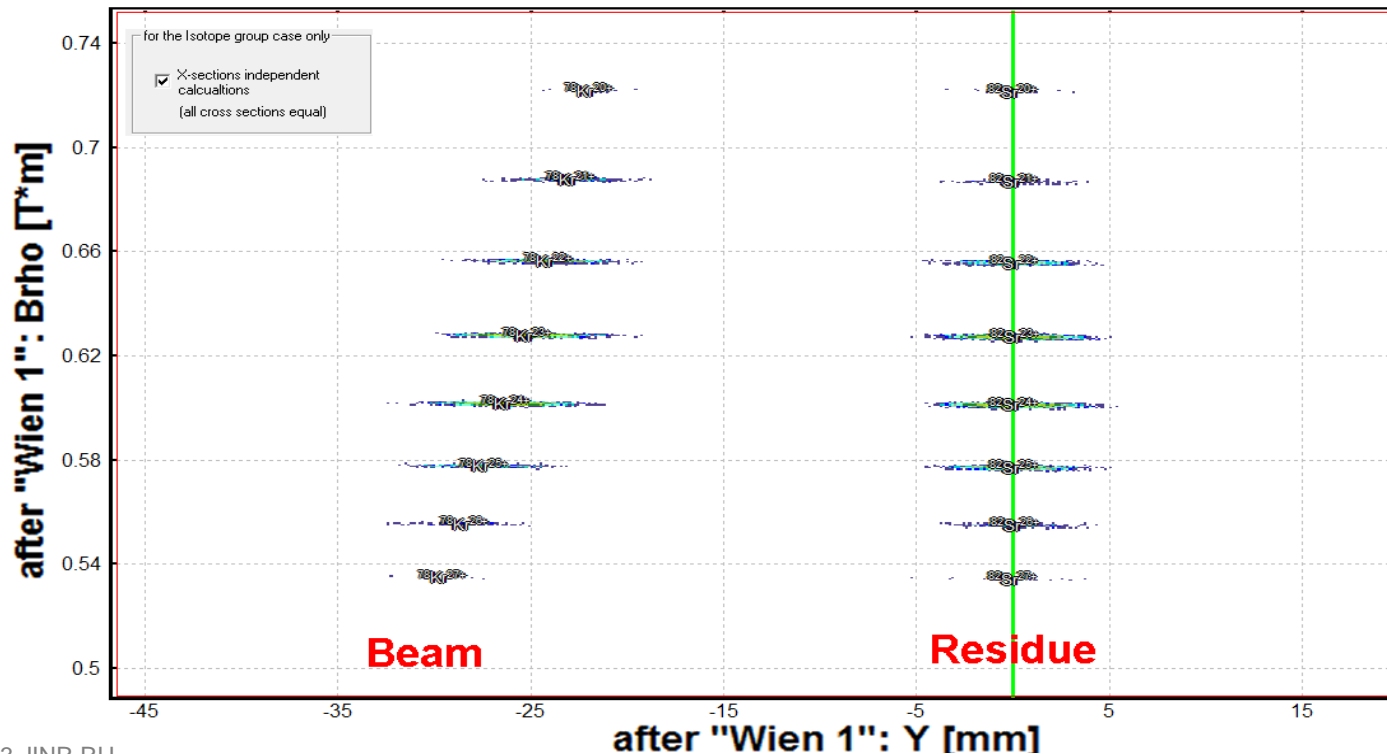
$$E = \beta \cdot v_c \cdot B / R_{L_E/L_B}$$

- E** electric field [in KV/m]
- β** setting fragment velocity
- v_c** speed of light
- B** magnetic field [in Gauss]
- R_{L_E/L_B}** effective electric & magnetic lengths ratio



Isotope Group : Monte Carlo Transmission Plot

^{78}Kr (1.7 MeV/u) + He (5e-2 mg/cm²); Transmitted Fragment $^{82}\text{Sr}^{24+}$ (FusRes)





- ❑ Wien filter provides velocity selection : v
- ❑ Magnetic Dipole provides $B\rho$ selection (momentum)
 $B\rho = mv / q$
- ❑ If Dipole Dispersion (% / mm) = - Wien Dispersion (% / mm) then A/q selection
- ❑ Realized with VAMOS & LISE3 (GANIL), MARS (TAMU)

Compensating dipole properties

<p>Direction to compensate the dispersion</p> <p><input type="radio"/> X (horizontal) <input checked="" type="radio"/> Y (vertical)</p> <p><input checked="" type="checkbox"/> Change dispersion automatically on the basis of the previous block</p> <p><input checked="" type="checkbox"/> Calculate Angle and Radius using dispersion, Lm & Lf</p>	<p>Local block Dispersion <input type="text" value="-18.104"/> mm/%</p> <p>Lm - dipole <input type="text" value="0.7788"/> m</p> <p>Lf - dipole <input type="text" value="0.7983"/> m</p> <p>Global Block Dispersion <input type="text" value="0"/> mm/%</p>
--	--

http://lise.nsci.msu.edu/3_4/lise_3_4.html#Dipole%20D6

Image shift

The image shift of nuclei in the final focus plane can be roughly determined

$$shift_{FD} = shift_{filter} + shift_{D6},$$

where

$$shift_{filter} = D_{filter} \cdot \frac{v - v_0}{v_0},$$

$$shift_{D6} = D_{D6} \cdot \frac{\Delta B\rho}{B\rho},$$

D_{filter} is the filter dispersion [mm/%] and D_{D6} is the dipole dispersion [mm/%].

Using equation

$$B\rho = c \frac{A}{Q} \frac{\beta}{\sqrt{1-\beta^2}},$$

we find that

$$\frac{\Delta B\rho(A/Q, \beta)}{B\rho} = \frac{\frac{\partial B\rho}{\partial(A/Q)} \cdot \Delta(A/Q)}{B\rho} + \frac{\frac{\partial B\rho}{\partial \beta} \cdot \Delta \beta}{B\rho}$$

and then

$$\frac{\Delta B\rho(A/Q, \beta)}{B\rho} = \frac{\Delta(A/Q)}{A/Q} + \frac{\Delta \beta}{\beta \cdot (1-\beta^2)}.$$

Taking into account that the sum

$$\frac{\Delta \beta_{D6}}{\beta_{D6} \cdot (1-\beta_{D6}^2)} \cdot D_{D6} + \frac{\Delta \beta_{filter}}{\beta_{filter}} \cdot D_{filter}$$

is close to 0 (in the case of combined work must be $\beta_{D6} = \beta_{filter}$),

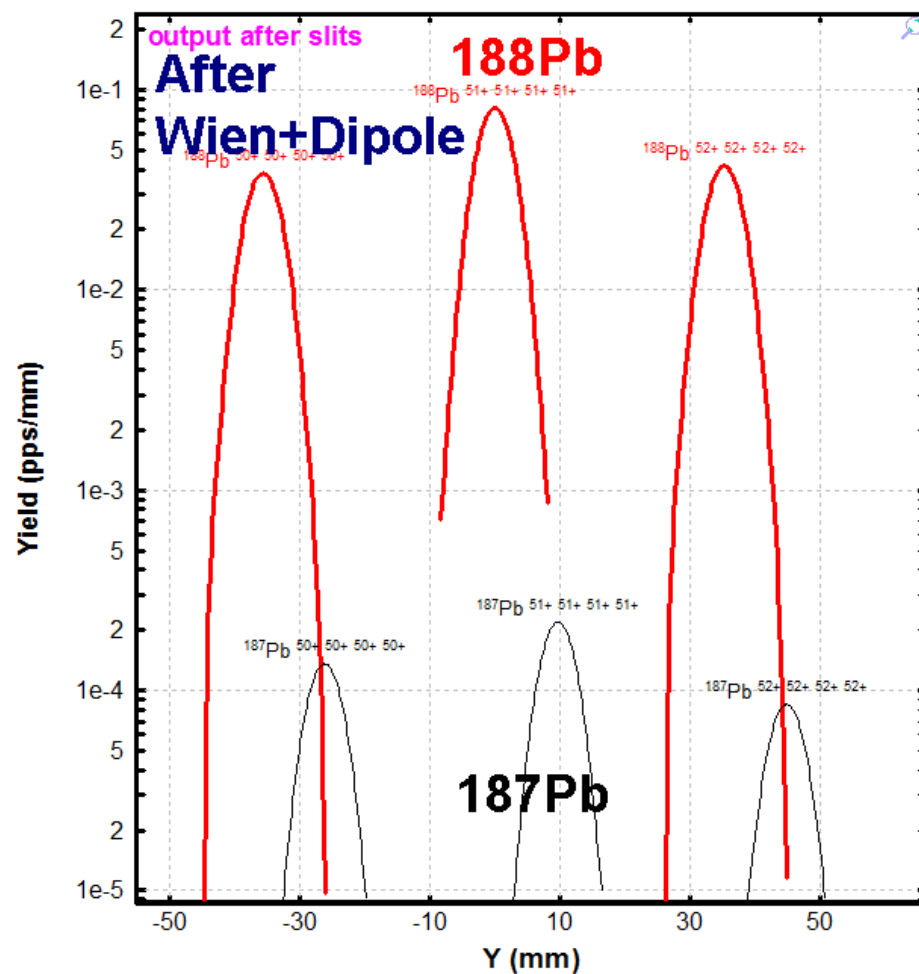
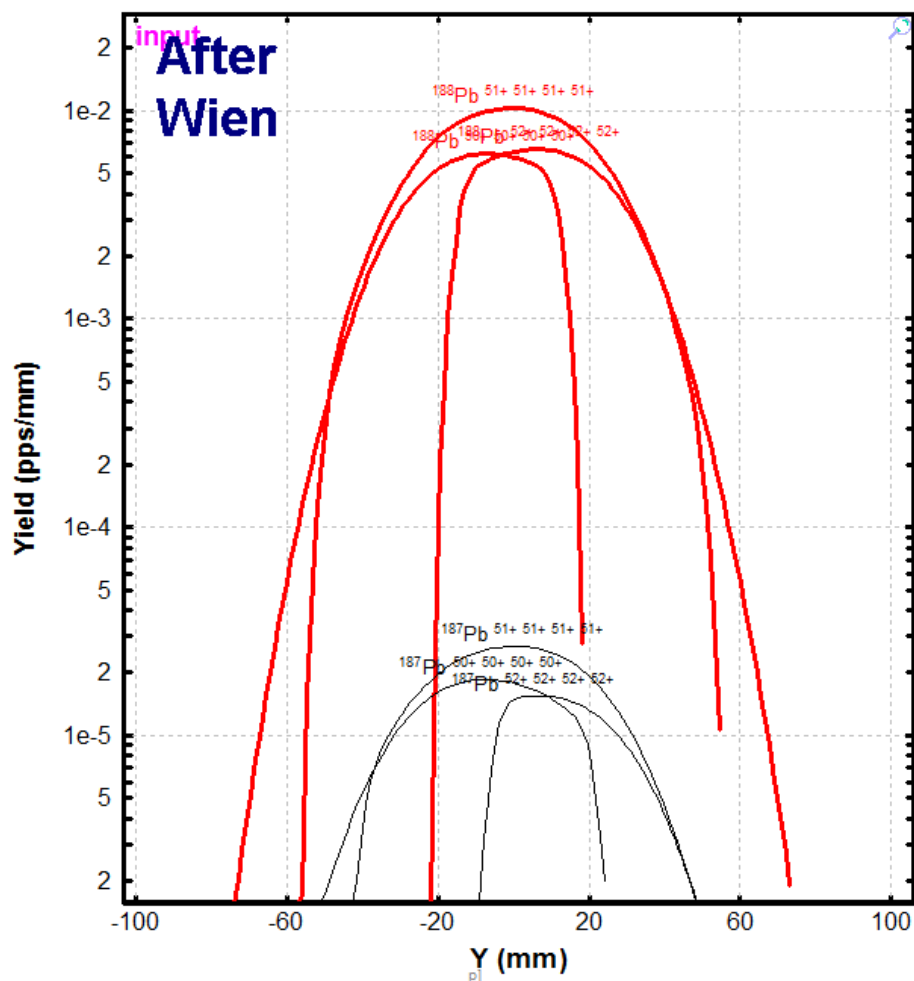
$$shift_{FD} \cong \frac{\Delta(A/Q)}{A/Q} \cdot D_{D6}$$

or, in other words, only the A/Q selection takes place.

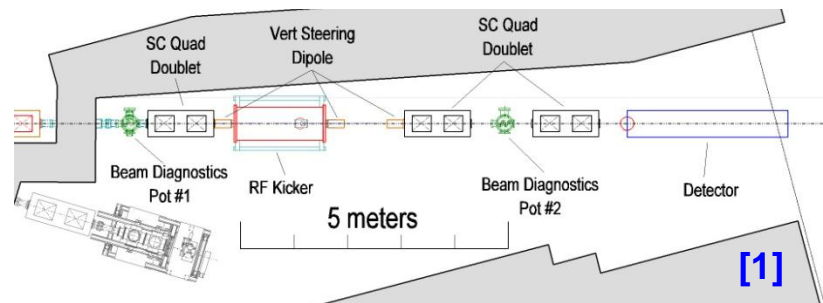
Some possible combinations are considered in the program :

D6-Yspace

^{155}Gd (6.0 MeV/u) + Ca (1 mg/cm²); Settings on $^{188}\text{Pb}^{51+..51+}$

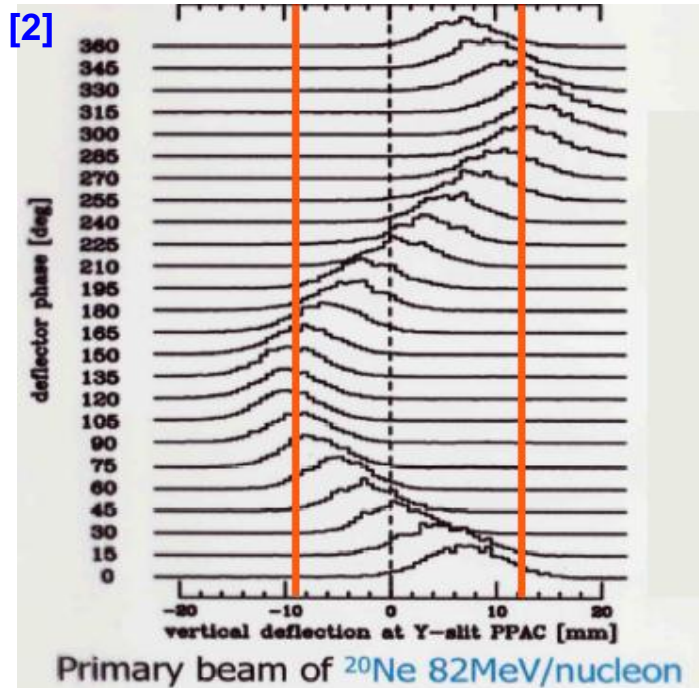


**RF
kicker**



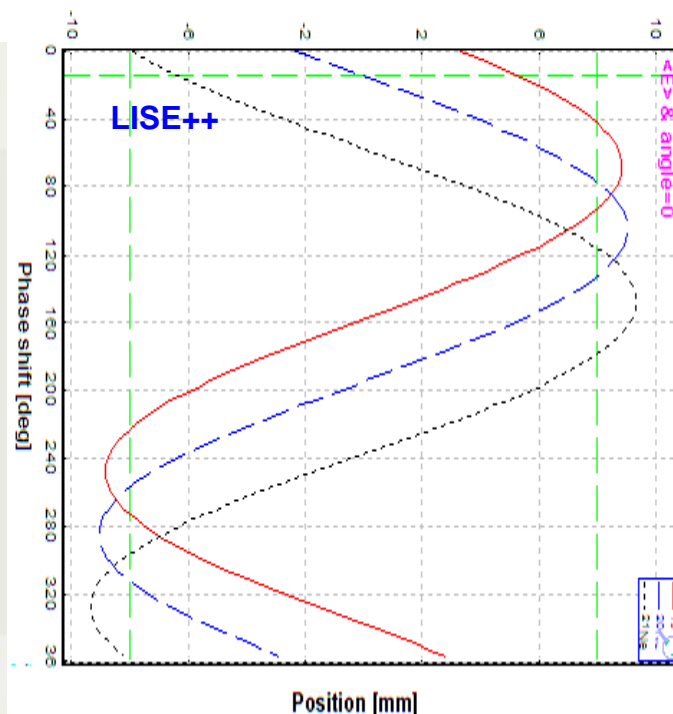
RF Kicker provides vertical (RIKEN, NSCL[3]) beam separations for different secondary beam species due to their different time of flight values

RF Separation System (RFSS)



Spatial distribution after the RF separator

^{20}Ne (135.0 MeV/u) + Be (10 mm); Settings on ^{20}Ne ; Config: DSWMDSMMSKSM
 $dp/p=2.00\%$; Wedges: 0; Brho(Tm): 2.6880, 2.6817
 RFseparator U=100.0kV Gap=40.0mm RF=16.3MHz LLb=0.70,1.80m



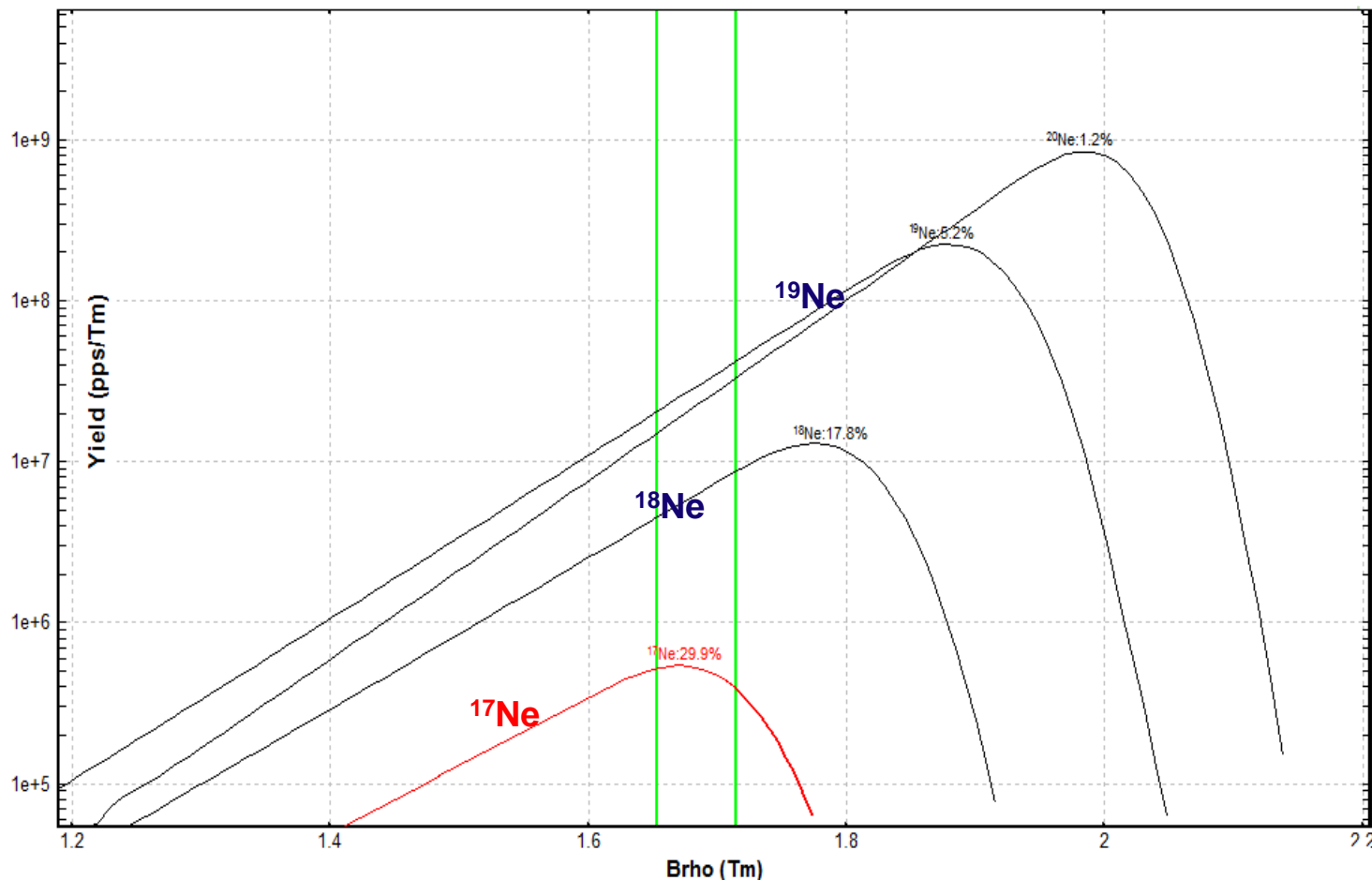
- 1) RF kicker proposal, V. Andreev, D. Bazin, M. Doleans, D. Gorelov, F. Marti, X. Wu; RF-KICKER SYSTEM FOR SECONDARY BEAMS AT THE NSCL”, D. Gorelov, V. Andreev, D. Bazin, M. Doleans, T. Grimm, F. Marti, J. Vincent, X. Wu, Proceedings of 2005 Particle Accelerator Conference, Knoxville,
- 2) K. Yamada et al., Nuclear Physics A746 (2004) 156c-160c.
- 3) J. Stoker et al., “Commissioning Report on the NSCL RF Fragment Separator,” future presentation at the 234th ACS National Meeting, Boston, MA, 19th–23rd, August 2007

- Low energy exponential tails create difficulties to separate proton-rich nuclei
- Wien filter is not effective for energies above 50 MeV/u

The main aim of RF deflector system is to increase the fraction of proton-rich nuclei of interest in RI beams

D1-BrhoPlot

^{24}Mg (53.0 MeV/u) + Be (100 mg/cm²); Settings on ^{17}Ne ; Config: DWDMSMM
 $dp/p=3.66\%$; Wedges: 0; Brho(Tm): 1.6838, 1.6837



RFsepar 1

RF separator settings

Select method

Electric field E = 5000 KV/m

Voltage U = 200 KV

Gap = 40 mm

Separation plane

Horizontal

Vertical

Beam profile for different phase shifts

Geometry

La = 0 m

L = 0.7 m

Lb = 1.5 m

RF settings

use Beam settings RF (MHz) = 20 Phase shift = 126 [deg]

manually RF (MHz) = 19

Separator Tuning

Mode

find the POSITION value using the phase shift

find the PHASE SHIFT using the position value

Tuning on Position

0 (+/-)

0 (-/+) Set slits automatically after tuning

Minimum

Maximum

manually (+/-)

manually (-/+)

Optical block properties and data

Setting Charge state for the Block (Z-Q) = 0

Calculate the RF separator using the Setting fragment

Cut (Slits) & Acceptances

Optical matrix

General setting of block

Tweak = 0.1 %

Calculations for the setting fragment

Before the RF separator	<E>-dE	<E>	<E>+dE
Energy [MeV/u]	128.88	133.58	138.28
Values corresponding to Energy			
Time of flight [ns]	15.04	14.82	14.61
Phase [deg]	342.27	340.73	339.20

After the RF separat

Position [m]

Reduced val

Dispersion (0.152

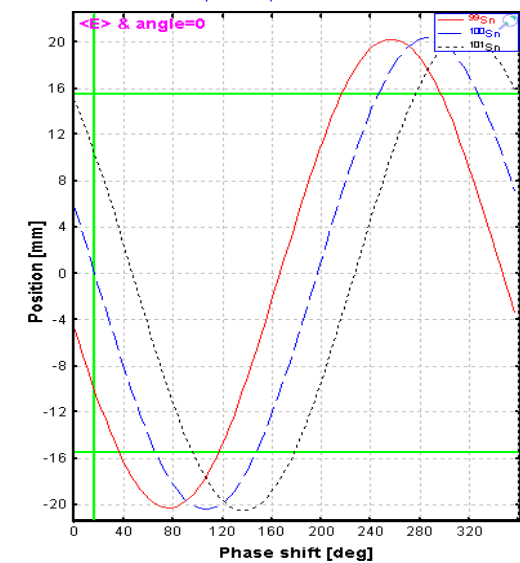
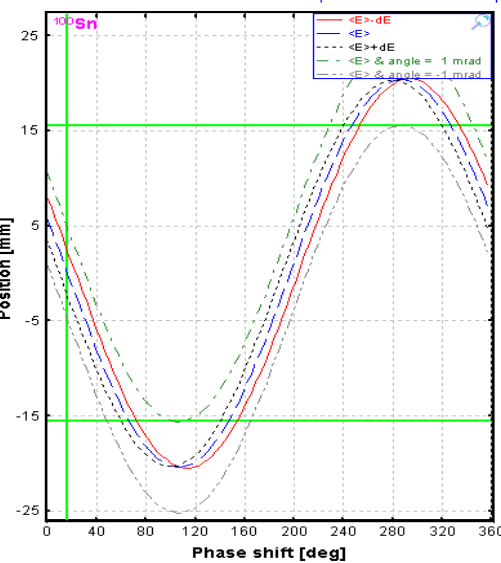
0

Car

H

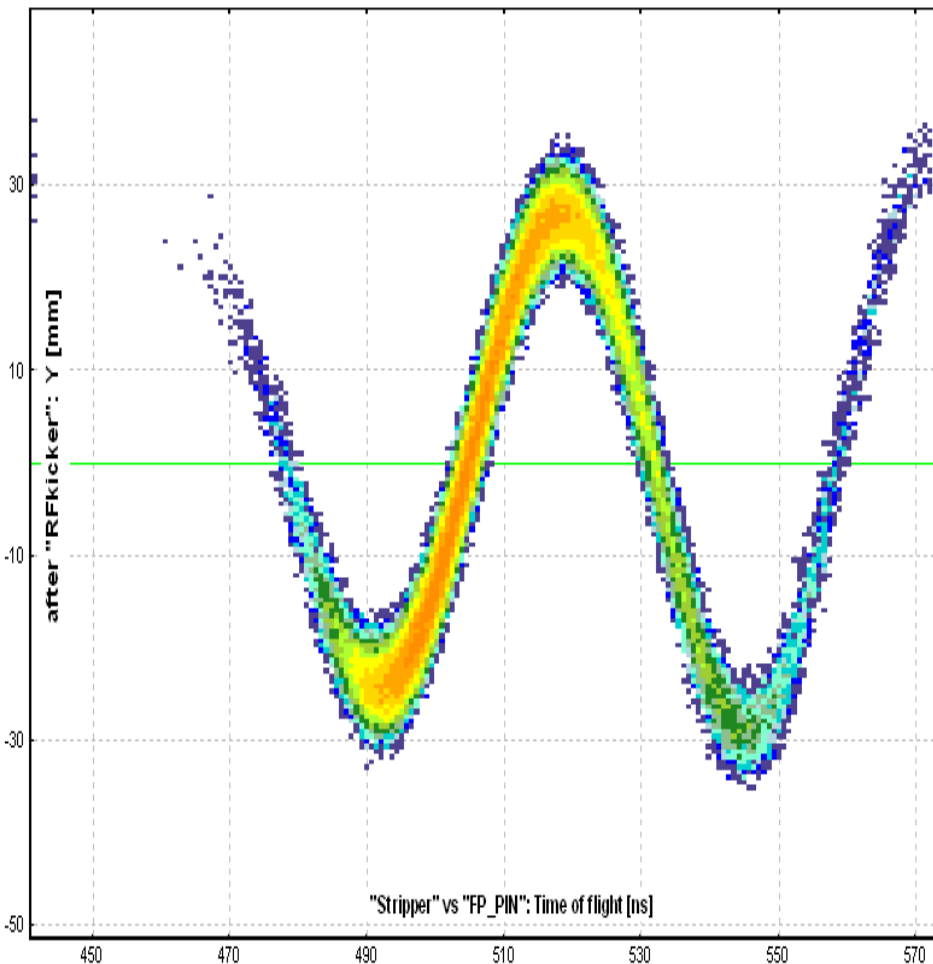
Spatial distribution after the RF separator

¹¹²Sn (140.0 MeV/u) + Be (250 mg/cm²); Settings on ¹⁰⁰Sn 50+ 50+ 50+ 50+; Config: DDMSWDDSSSKMM
 dp/p=1.01%; Wedges: Be (100 mg/cm²); Brho(Tm): 3.1072, 3.1072, 2.8917, 2.8917
 RF separator: U=100.0kV Gap=50.0mm RF=23.1MHz L,Lb=1.50,3.30m



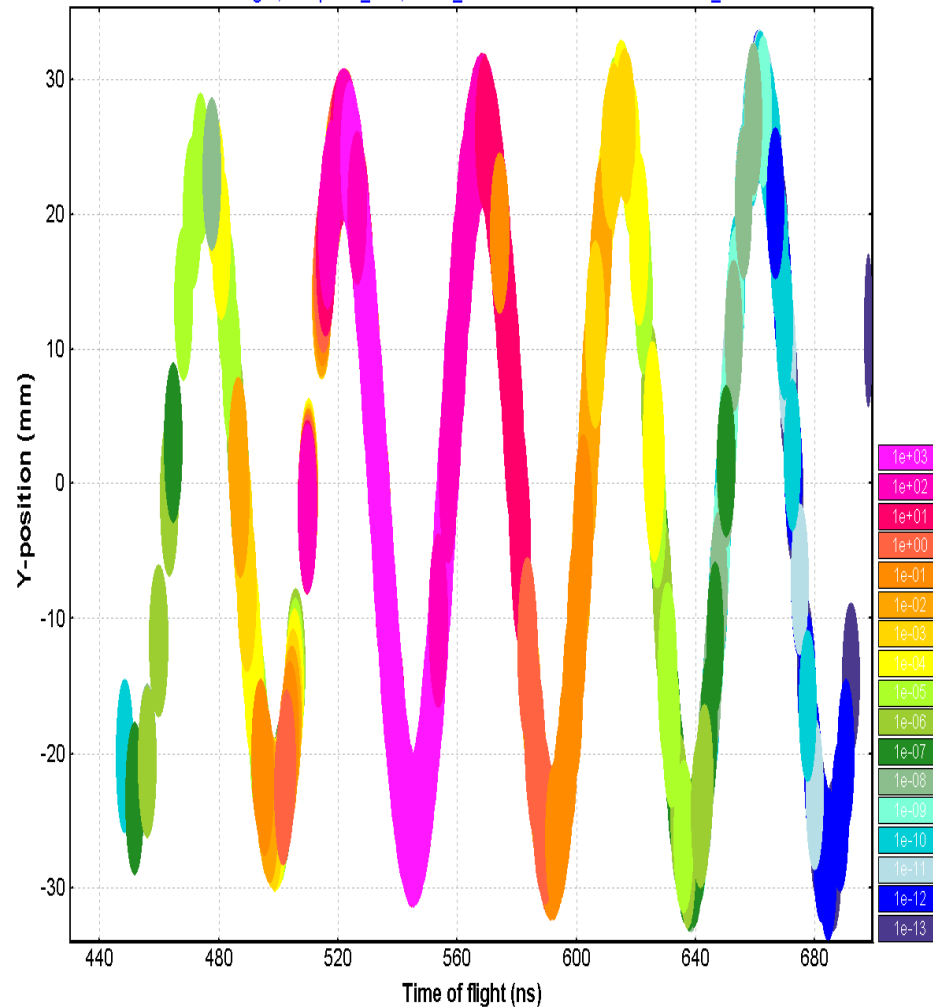
^{100}Sn : Monte Carlo Transmission Plot

^{124}Xe (140.0 MeV/u) + Be (500 mg/cm²); Transmitted Fragment $^{100}\text{Sn}^{50+50+50+50+}$ (Fragmentn)
 dp/p=100.00% ; Wedges: 0; Brho(Tm): 2.5425, 2.5425, 2.5425, 2.5425
 "FP_PIN" - last block for MC calculation; no gate; Configuration: DDSWDDMSSSKMMMM



TOF-Y

^{124}Xe (140.0 MeV/u) + Be (500 mg/cm²); Settings on ^{100}Sn ; Config: DDMSWDDSSSKMM
 dp/p=1.01% ; Wedges: 0; Brho(Tm): 2.5101, 2.5101, 2.5038, 2.5038
 Start: Target; Stop: FP_PIN; ACQ_start: Detector **Y-detector: FP_PIN



RF buncher

Note: RF-buncher block is more effective in MC mode

RESOLUT (FSU) configuration

http://lise.nsci.msu.edu/9_4/buncher/9_4_87_buncher.pdf

RFbuncher 1

RF buncher settings

Select method

Electric field E = 2500 KV/m

Voltage U = 500 KV

RF buncher plots:
E = f(phase,x), V = f(x), dE = f(phase)

Geometry

La = 0 m

L (gap) = 0.2 m

Lb = 0 m

RF settings

use Beam settings RF (MHz) = 20 Phase shift = 185.6 [deg]

manually RF (MHz) = 97

tff (transit time factor)

$V(t) = V_0 * tff * \sin(\omega t + \text{phase_shift})$

parameterization -0.032

manually 1

tuning

chose d-mode: d5

Optical block properties and data

Setting Charge state for the Block (Z-Q) = 0

Calculate the RF buncher using the Setting fragment

Tweak = 0.1 %

Calculations for the setting fragment

Before the buncher gap

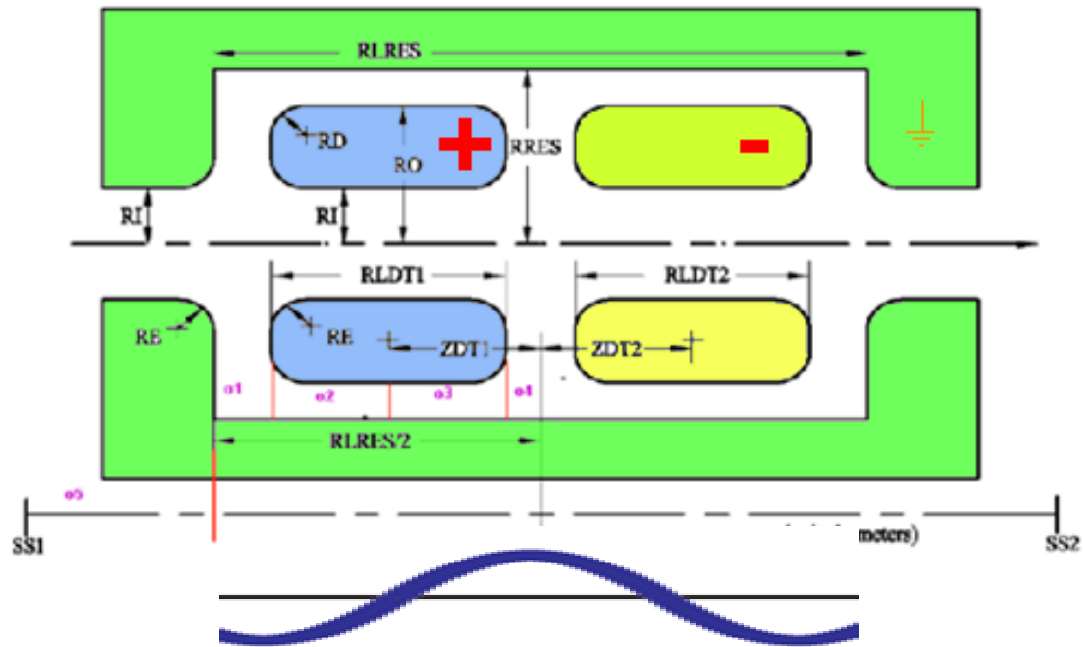
	<E>-dE	<E>	<E>+dE
Energy [MeV/u]	1.49	1.49	1.50

Values corresponding to Energy in middle of the gap

Time of flight [ns]	-1548.1	-771.1	5.9
Phase [deg]	-160.7	-326.3	228.0

After the RF buncher

Energy [MeV/u]	1.40	1.40	1.40
----------------	------	------	------



Gap	Gap Size	Bias
1	D	+V
2	2D	-2V
3	D	+V

Multi-gaps bunchers are constructed for specified speed

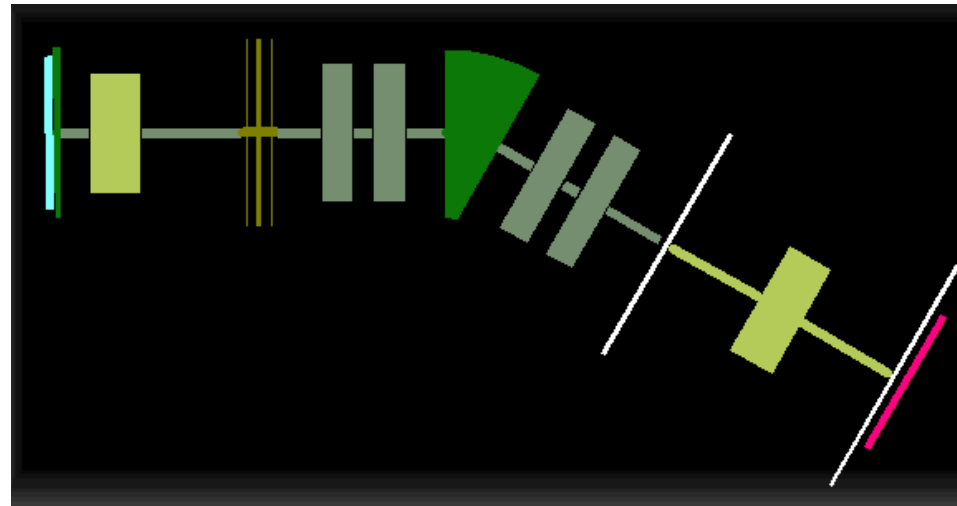
D	Tuning Dipole	Brho 0.6197 Tm
S	Drift 1	standard 0.35 m
L	Solenoid 1	B 2.6844 T
S	Drift 2	standard 1.21 m
B	RFbuncher 1	U 119 kV Ph 35 deg
B	RFbuncher 2	U 238 kV Ph 215 deg
B	RFbuncher 3	U 119 kV Ph 35 deg
S	Drift 3	standard 0.54 m
Q	MQ1	quadrupole 0.38 m
S	Drift 4	standard 0.22 m
Q	MQ2	quadrupole 0.41 m
S	Drift 5	standard 0.47 m
D	Dipole	Brho 0.6197 Tm
S	Drift 6	standard 0.48 m
Q	MQ3	quadrupole 0.41 m
S	Drift 7	standard 0.22 m
Q	MQ4	quadrupole 0.38 m
S	Drift 8	standard 0.74 m
S	slits1	s ls
		-200 X +200 -50 Y +50
L	Solenoid 2	B 2.2688 T
S	slits2	s ls
		-200 X +200

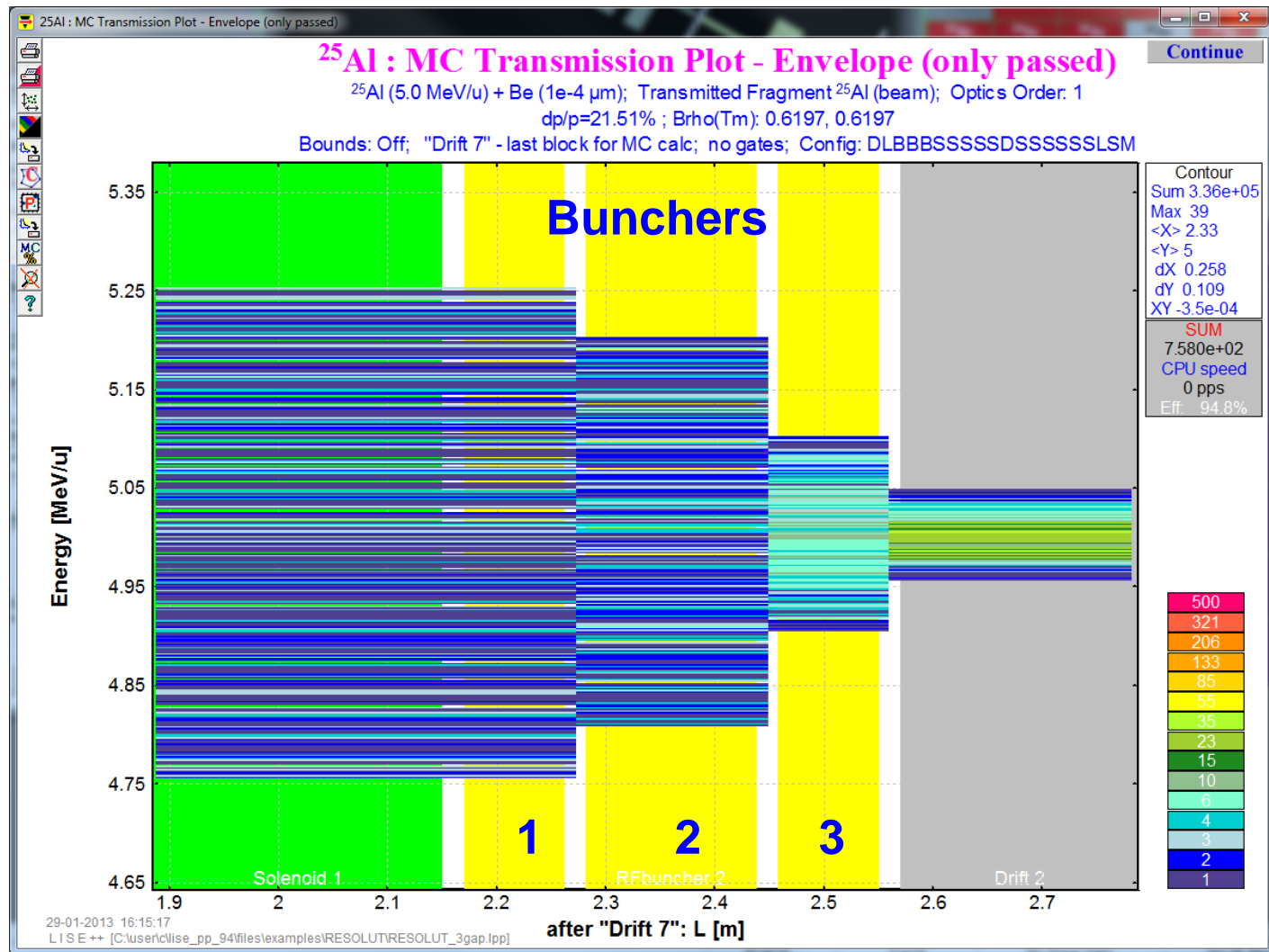
← Tuning dipole to define magnetic rigidity of the separator,
Unitary matrix, no slits, zero length

← Initial drift+solenoid+drift
configuration to define angular acceptance

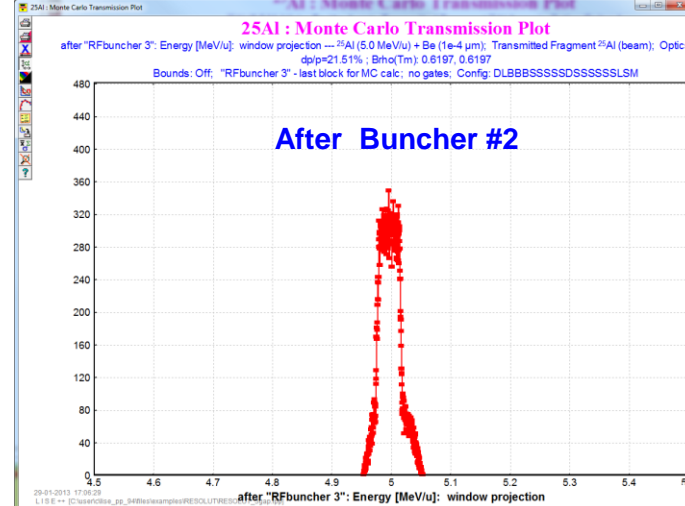
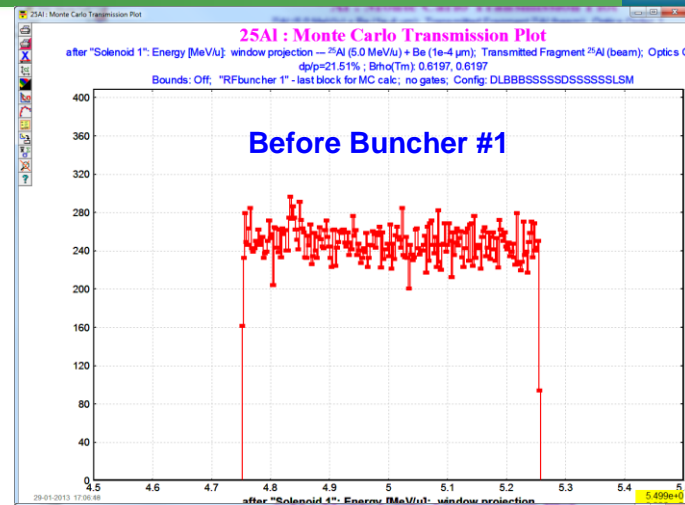
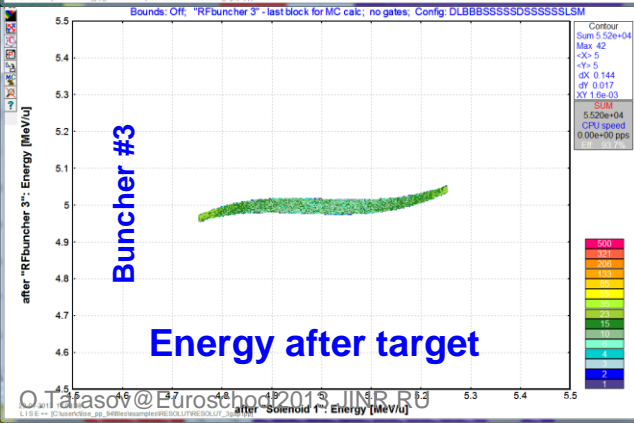
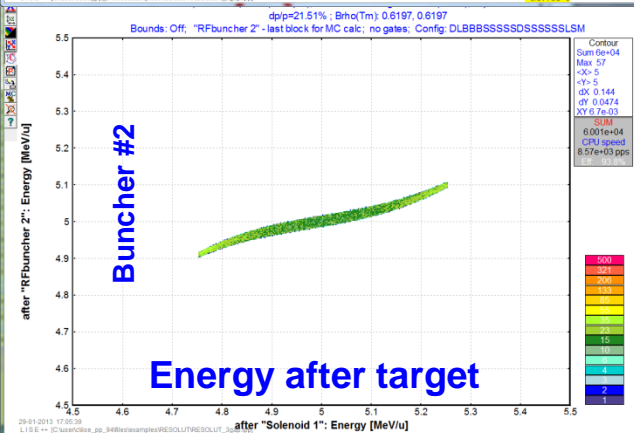
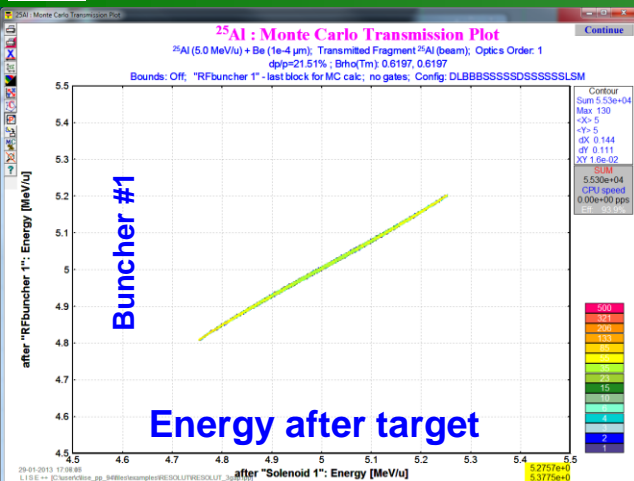
← 3 gap Rf-buncher was realized as 3 RF bunchers

← QQDQQ spectrometer



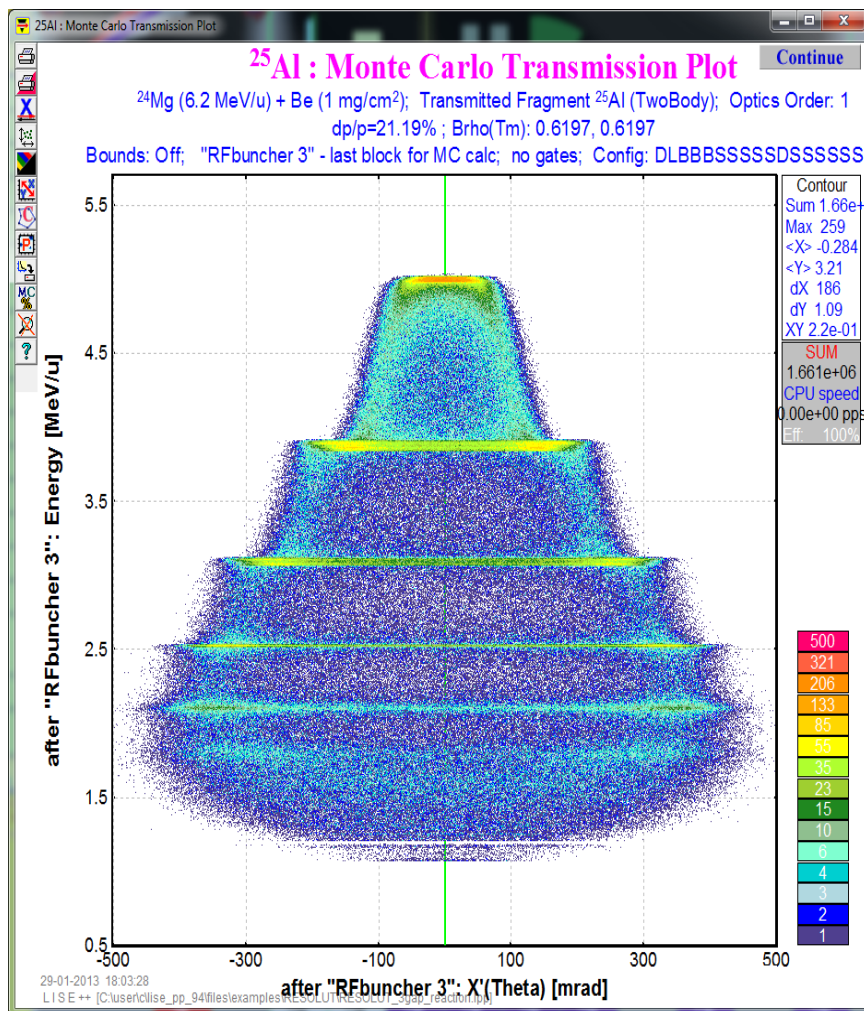


File: RESOLUT_3gap.lpp

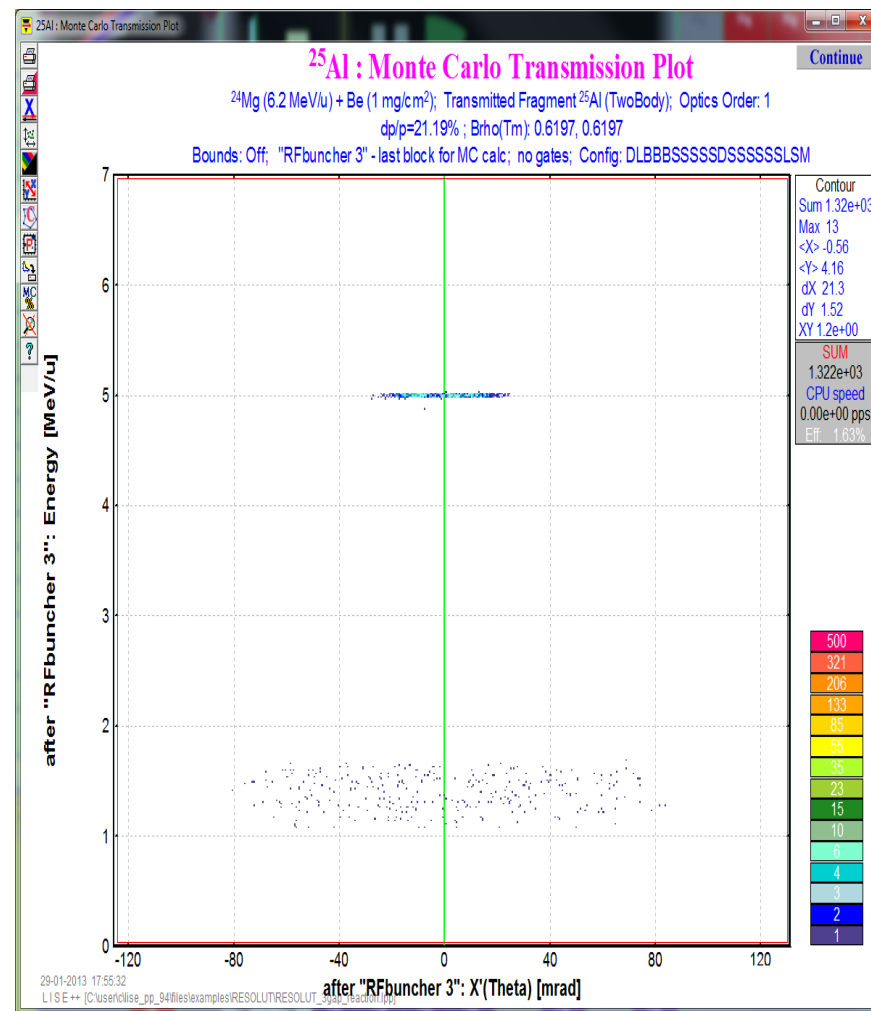


	StDev
Before Buncher#1	0.144
After Buncher #1	0.111
After Buncher #2	0.0474
After Buncher #3	0.017

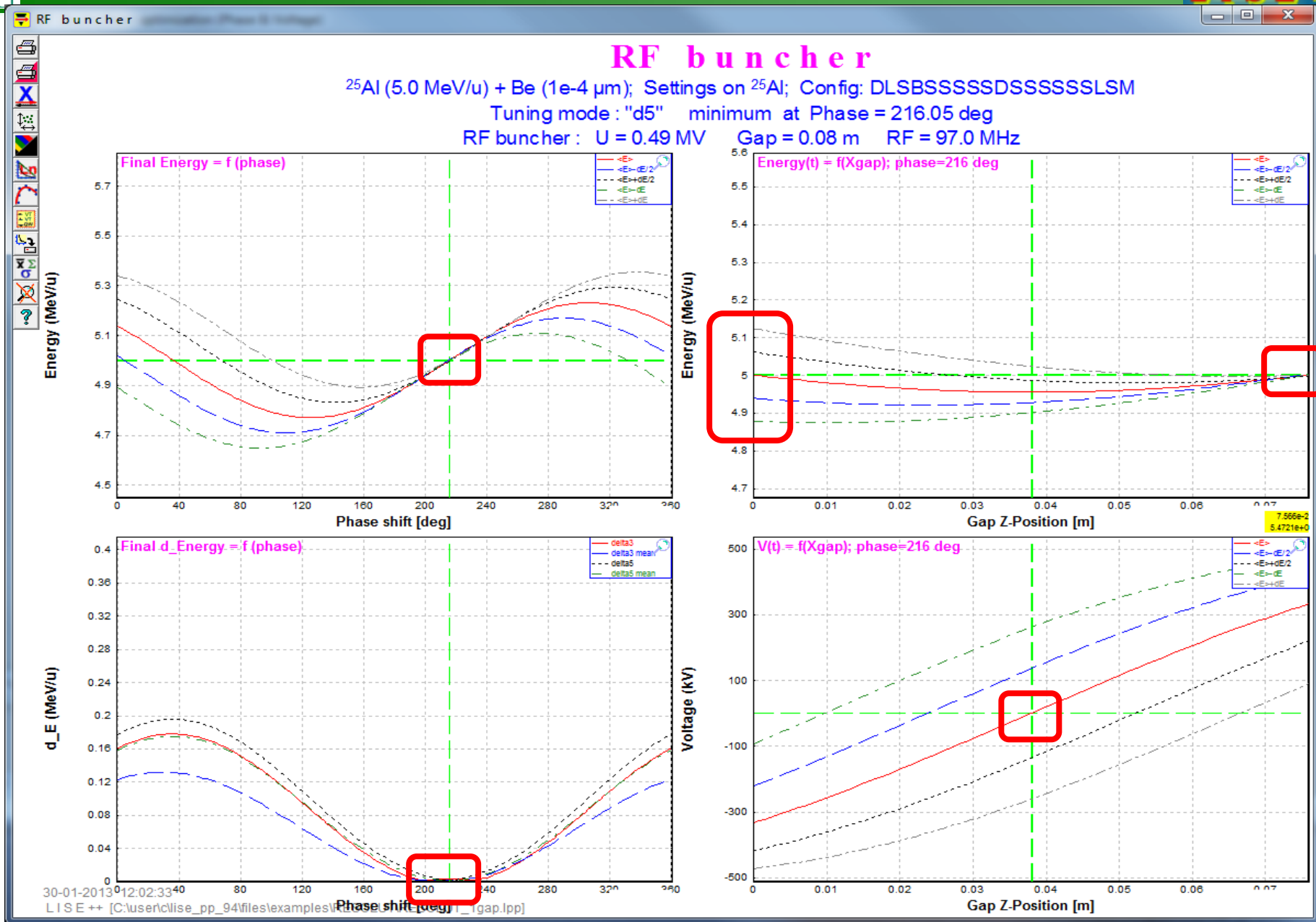
After the 3 gap buncher **without** angular acceptance



After the 3 gap buncher **with** angular acceptance



**+/- 47 mrad acceptance,
 Transmission 1.6%**



Solenoid

Solenoid settings

B, max field T

I, current A

Use the "soft-edge" corrections for solenoid matrix calculations

V (L * B / PI) = Tm

V / Brho =

Field Direction

"+" positive

"-" negative

Solenoid Block Scheme

TwinSol Utility

Optical block properties and data

Setting Charge state for the Block (Z-Q)

Cut(Slits) & Acceptances

Optical matrix

General setting of block

Tweak %

Block Tuning

Tune Solenoid using the Setting fragment

Take into account the GLOBAL matrix of the previous block.

Tuning is minimisation of

13. matrix: X/X

Plot v=f(B)

Geometry

1-st half = m

2-nd half = m

Coil length = m

Effective radius = m

Block Length = m

optional (estimation of Ang.Accept.)

Solenoid length = m

Bore = m

Ang.Accept. ± mrad

MA = MAconst * I

MAconst = T/A

MA = T

$B(0) = MA * CoilLength / \sqrt{(EffRadius^2 + CoilLength^2 / 4)}$

Setting fragment parameters

	Mean	StDev	Method
1. X	0.00	29.00	"Distribution"
2. T	0.00	41.42	
3. Y	0.00	29.00	
4. F	0.00	41.42	
5. E	1.4	0.1	

Setting fragment distribution parameters before Solenoid

OK Cancel Help

The diagram shows a cross-section of a solenoid block. The total length is 2.6 m, divided into a 0.6 m first half and a 2.0 m second half. The coil length is 1.0 m. The bore (inner diameter) is 0.2 m. The effective radius is 0.2123 m. The diagram also shows the positions of various parameters: x0 at the start, x1L and x1R at the coil boundaries, x2L and x2R at the coil ends, and xF at the end of the block.

LISE++ attention!!

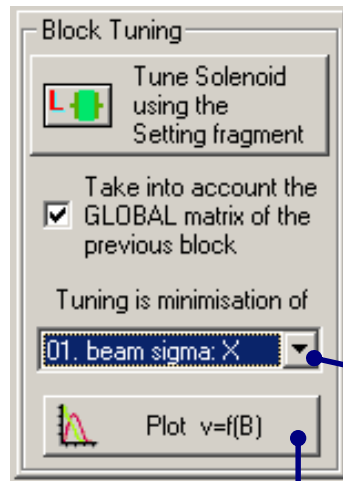
Memo: The Solenoid block is effective for the Monte Carlo transmission mode

OK

Calculation of setting fragment parameters in front of the solenoid and solenoid tuning are done by the "Distribution" method.

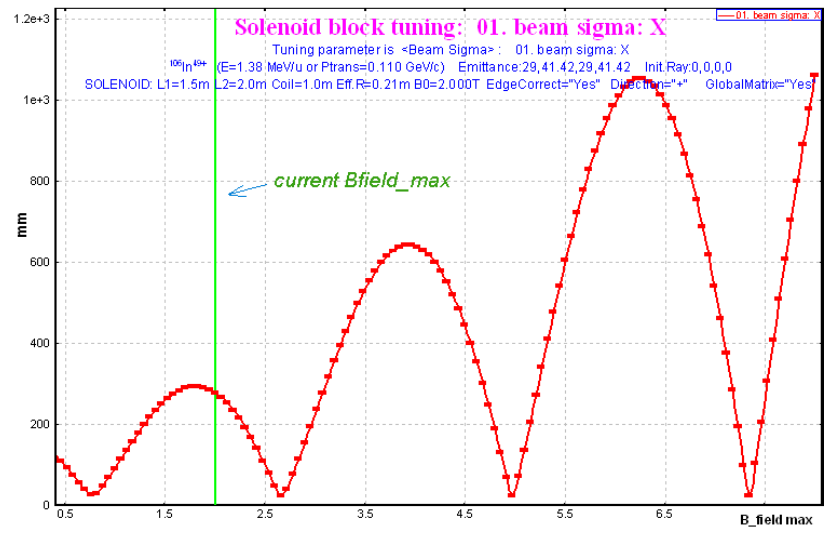
Phase space distributions and transmission with the Solenoid block are recommended with the Monte Carlo transmission method.

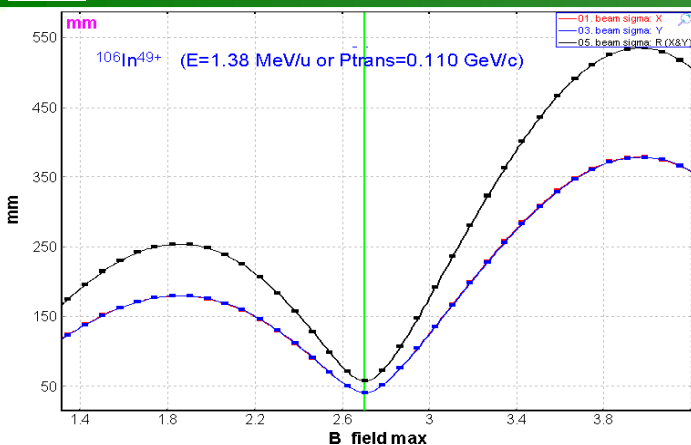
http://lise.nsl.msui.edu/8_3/SolenoidBlock_v8_3_58.pdf



Tuning is minimisation of

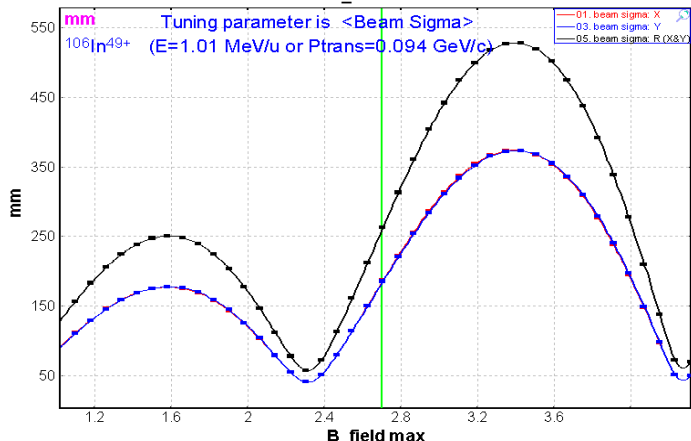
- 01. beam sigma: X
- 02. beam sigma: T (X')
- 03. beam sigma: Y
- 04. beam sigma: P (Y')
- 05. beam sigma: R (X&Y)
- 06. beam sigma: A (P&T)
- 07. beam ray: X
- 08. beam ray: T (X')
- 09. beam ray: Y
- 10. beam ray: P (Y')
- 11. beam ray: R (X&Y)
- 12. beam ray: A (P&T)
- 13. matrix: X/X
- 14. matrix: X/T
- 15. matrix: X/Y
- 16. matrix: X/P
- 17. matrix: T/X
- 18. matrix: T/T
- 19. matrix: T/Y
- 20. matrix: T/P
- 21. matrix: Y/X
- 22. matrix: Y/T
- 23. matrix: Y/Y
- 24. matrix: Y/P
- 25. matrix: P/X
- 26. matrix: P/T
- 27. matrix: P/Y
- 28. matrix: P/P





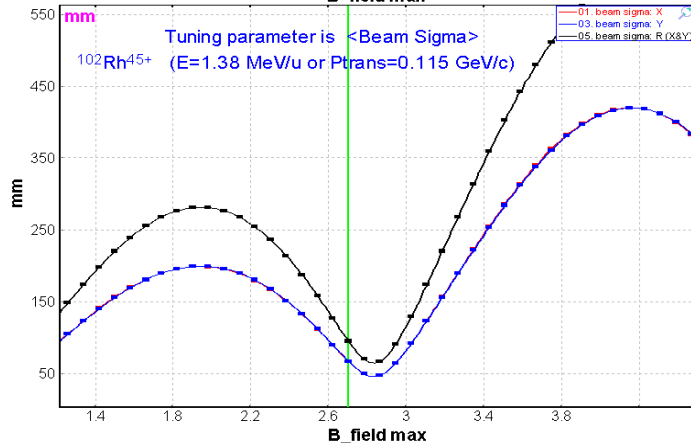
106In at 1.4 MeV/u

Block matrix							Global matrix							Beam	
1. X	-0.9105	1.1786	-0.5655	0.7319	0	0	-0.9105	0.5413	-0.5655	0.3361	0	0	[mm]	12.654	
2. T	-1.1175	0.6539	-0.694	0.4061	0	0	-1.1175	-0.1283	-0.694	-0.0797	0	0	[mrad]	3.292	
3. Y	0.5655	-0.7319	-0.9105	1.1786	0	0	0.5655	-0.3361	-0.9105	0.5413	0	0	[mm]	12.927	
4. F	0.694	-0.4061	-1.1175	0.6539	0	0	0.694	0.0797	-1.1175	-0.1283	0	0	[mrad]	3.306	
5. L	0	0	0	0	1	0	0	0	0	0	1	0	[mm]	0	
6. D	0	0	0	0	0	1	0	0	0	0	0	1	[%]	0.07	
	/[mm]	/[mrad]	/[mm]	/[mrad]	/[mm]	/[%]	/[mm]	/[mrad]	/[mm]	/[mrad]	/[mm]	/[%]			



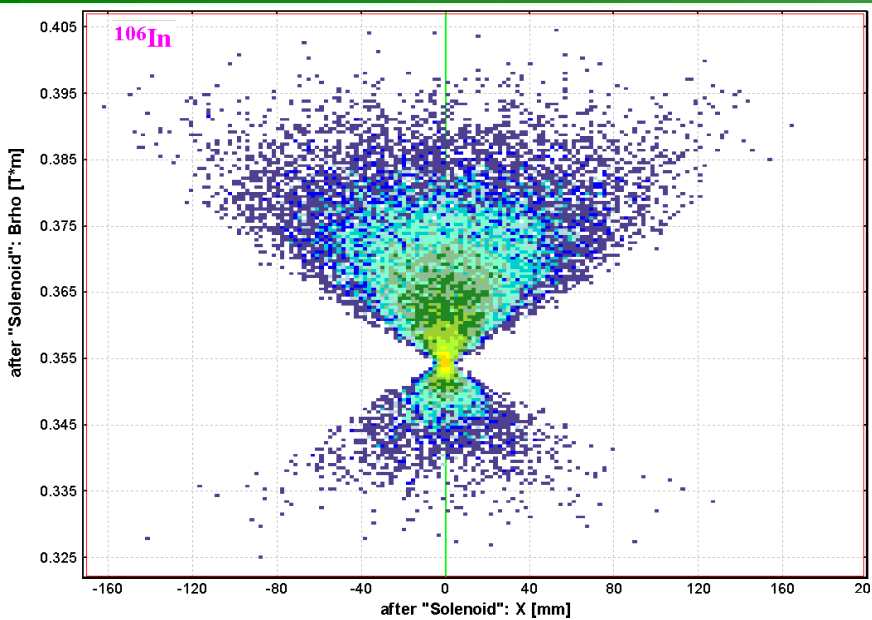
106In at 1.0 MeV/u

Block matrix							Global matrix							Beam	
1. X	-1.8574	0.1773	-4.4777	0.4273	0	0	-1.8574	-1.1229	-4.4777	-2.7071	0	0	[mm]	59.83	
2. T	-1.3632	0.0511	-3.2863	0.1231	0	0	-1.3632	-0.9031	-3.2863	-2.1773	0	0	[mrad]	48.098	
3. Y	4.4777	-0.4273	-1.8574	0.1773	0	0	4.4777	2.7071	-1.8574	-1.1229	0	0	[mm]	57.823	
4. F	3.2863	-0.1231	-1.3632	0.0511	0	0	3.2863	2.1773	-1.3632	-0.9031	0	0	[mrad]	46.476	
5. L	0	0	0	0	1	0	0	0	0	0	1	0	[mm]	0	
6. D	0	0	0	0	0	1	0	0	0	0	0	1	[%]	0.07	
	/[mm]	/[mrad]	/[mm]	/[mrad]	/[mm]	/[%]	/[mm]	/[mrad]	/[mm]	/[mrad]	/[mm]	/[%]			

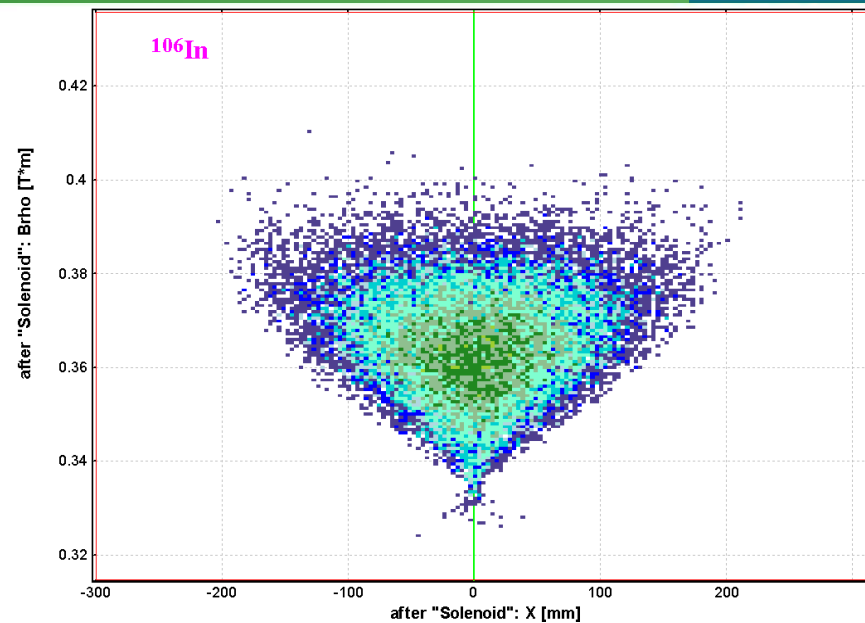


102Rh at 1.4 MeV/u

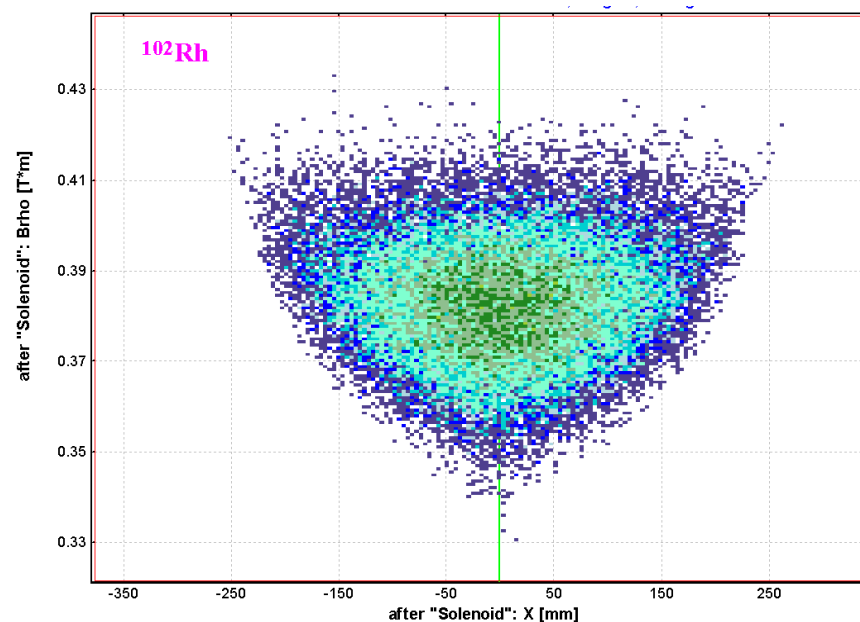
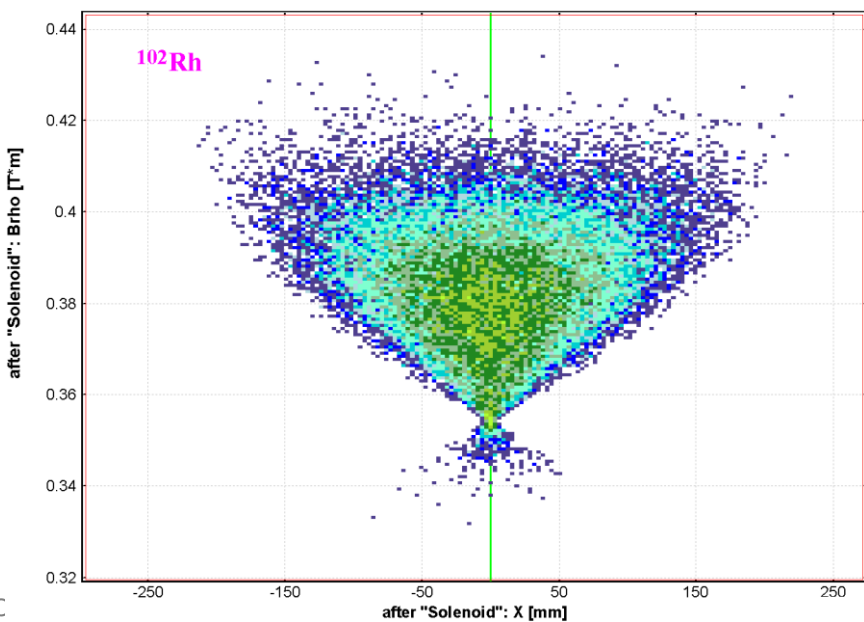
Block matrix							Global matrix							Beam	
1. X	-0.0842	1.4274	-0.0341	0.5788	0	0	-0.0842	1.3685	-0.0341	0.5549	0	0	[mm]	29.009	
2. T	-0.6504	0.8264	-0.2637	0.3351	0	0	-0.6504	0.3711	-0.2637	0.1505	0	0	[mrad]	7.903	
3. Y	0.0341	-0.5788	-0.0842	1.4274	0	0	0.0341	-0.5549	-0.0842	1.3685	0	0	[mm]	30.068	
4. F	0.2637	-0.3351	-0.6504	0.8264	0	0	0.2637	-0.1505	-0.6504	0.3711	0	0	[mrad]	8.181	
5. L	0	0	0	0	1	0	0	0	0	0	1	0	[mm]	0	
6. D	0	0	0	0	0	1	0	0	0	0	0	1	[%]	0.07	
	/[mm]	/[mrad]	/[mm]	/[mrad]	/[mm]	/[%]	/[mm]	/[mrad]	/[mm]	/[mrad]	/[mm]	/[%]			

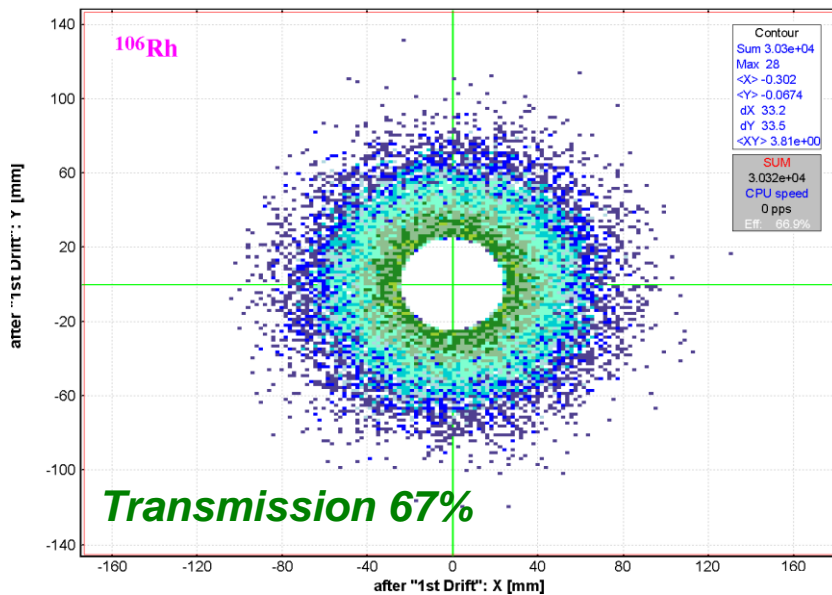
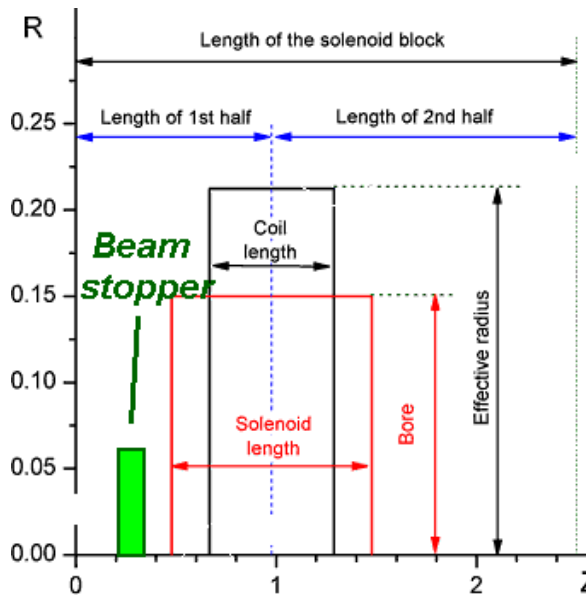
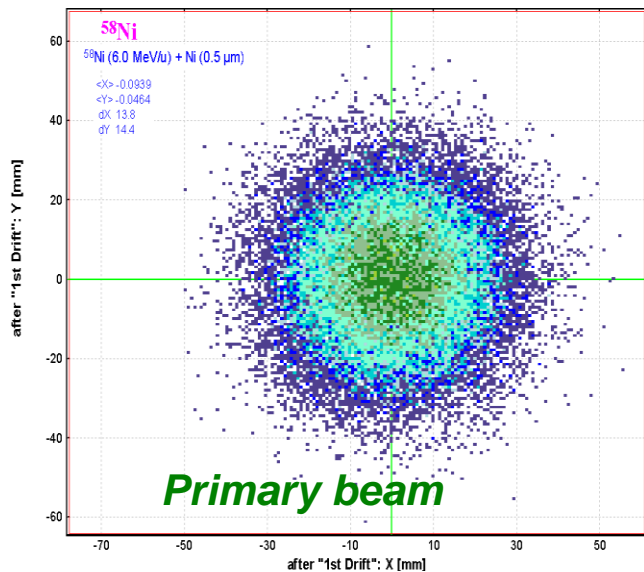


$B_{\text{solenoid}} = 2.7 \text{ T}$



$B_{\text{solenoid}} = 2.55 \text{ T}$





Gate for Monte Carlo calculation transmission

Coordinate

Alter BLOCK

1st Drift

X mm
 X' (T) mrad
 Y mm
 Y' (P) mrad
 dP/P %
 R [f(X;Y)] mm
 A [f(X;Y)] mrad

Energy MeV/u
 TKE MeV
 Momentum MeV/c
 Biho T-m
 Velocity cm/ns

Energy Loss MeV
 Range mm
 Energy Deposition MeV/mm /particle

Time of flight ns
 Length m

Status (Condition)

absent
 "AND"
 "NOT"

Gate

v1 = -25

v2 = 25

OK

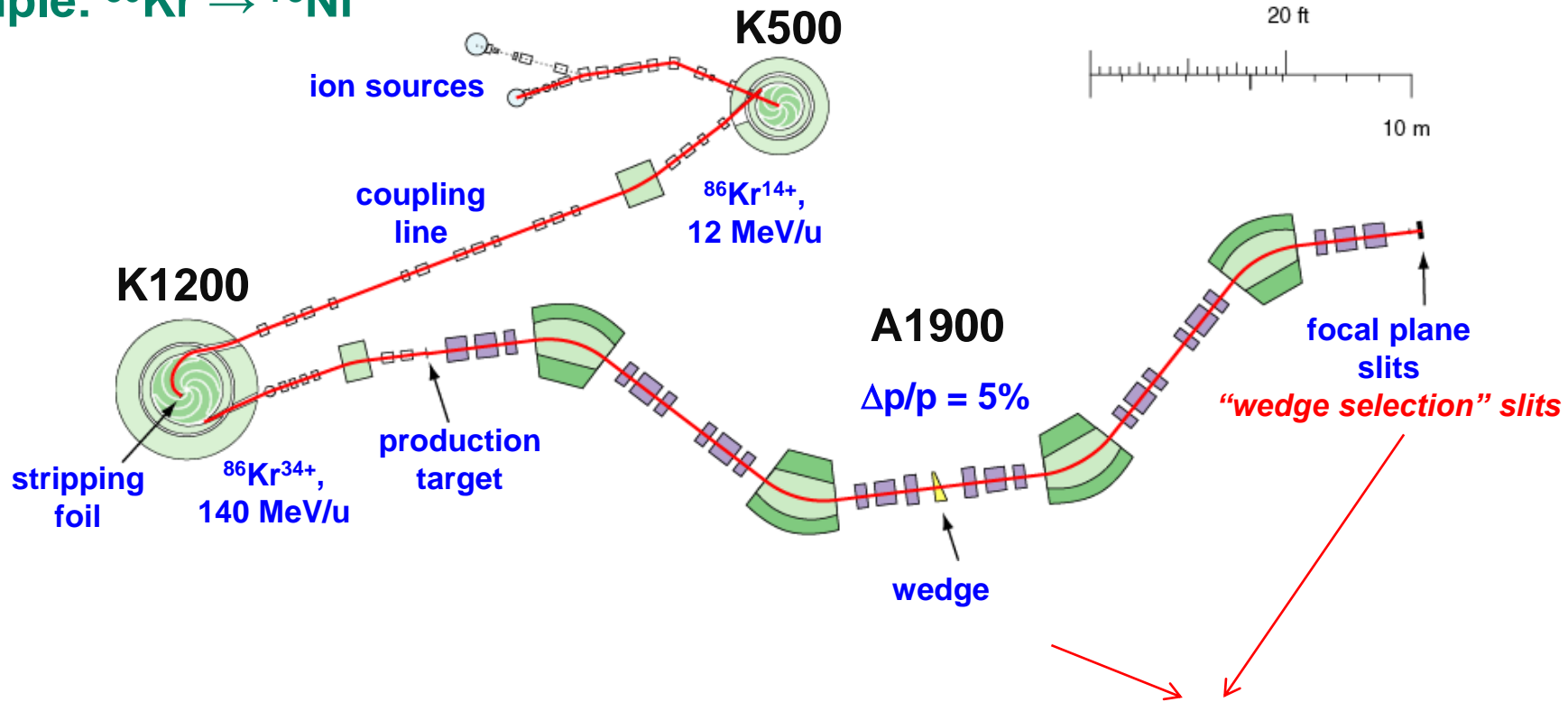
Cancel

Start Stripper

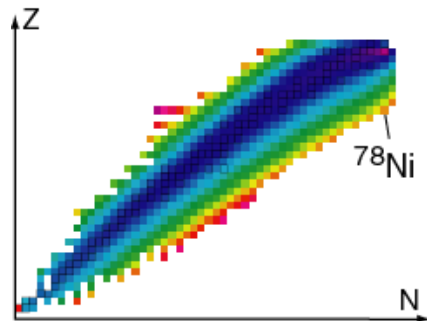
Stop Stripper

5. Selection with WEDGE

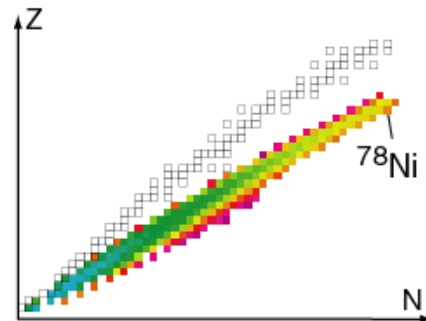
Example: $^{86}\text{Kr} \rightarrow ^{78}\text{Ni}$



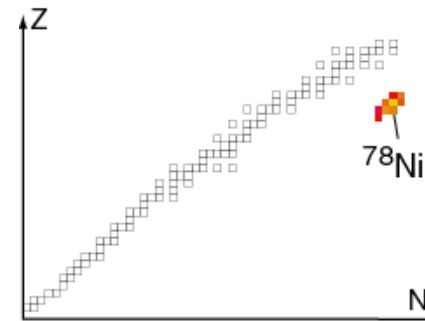
fragment yield after target



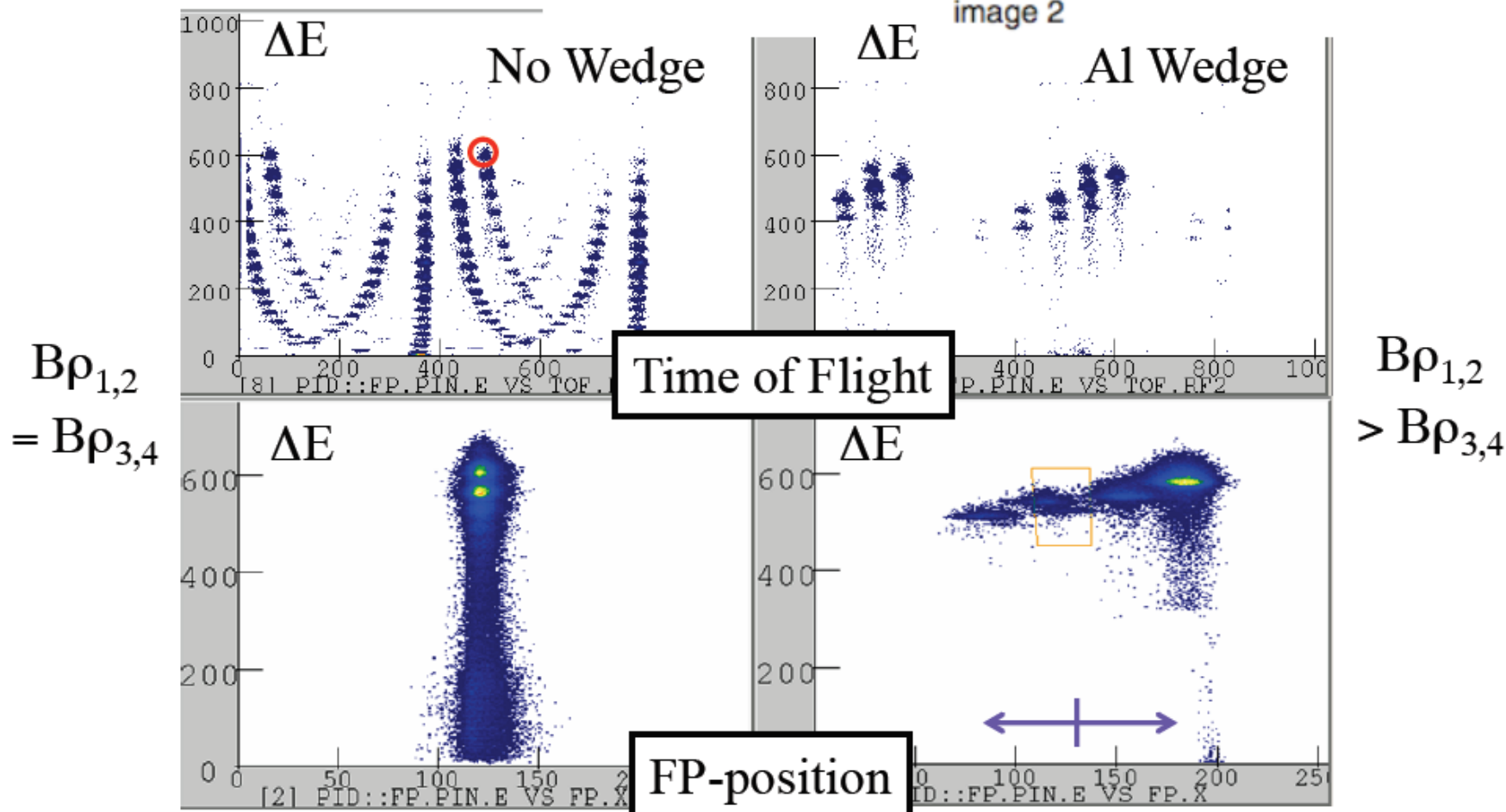
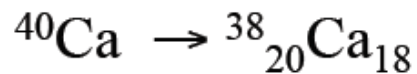
fragment yield after wedge



fragment yield at focal plane



Example:



Wedge

Be Density [g/cm3] 1.848

calculate reactions in this material

State: Solid Gas

Dimension: mg/cm2 & micron g/cm2 & mm

Thickness defect (!!): % 0.1 micron 1.1364

Calculate the Wedge thickness from Previous & Next optical blocks for the setting fragment

Set the spectrometer after this block using changes

Z	Element	Mass
<input checked="" type="checkbox"/>	4 Be PT	9.012
<input type="checkbox"/>	14	
<input type="checkbox"/>	14	
<input type="checkbox"/>	14	
<input type="checkbox"/>	14	

Compound dictionary

General setting of block

OK Cancel

Thickness at 0 degrees: 1136.3636 micron 210 mg/cm2

Position - thickness: -11 coordinate, mm +11 d / R = 0.516
197.29 thickness, mg/cm2 222.71 Atoms/cm2 = 1.40e+22

Degrader profile: Wedge profile Homogeneous Curved profile Custom shape

Angle (mrad) 6.2538

Calculate angle

Wedge degrader in dispersive focal plane

Dispersion Plane: X (horizontal) Y (vertical)

Mode: Choose the block: to calculate an angle for the setting mode after it

Drift

mode	Wedge angle (mrad)	
<input checked="" type="radio"/> Achromatic	0.16	Fix
<input type="radio"/> Monochromatic	12.21	Fix
<input type="radio"/> Fixed in the code	6.2538	

To plot a dependence from angle

Block: WEDGE

Degrader Profile: Wedge degrader

Setting fragment: 17Ne10+

-11 <- slits(mm) -> +11
-92.71 <-angle (mrad) -> +92.71
min max

For the central trajectory

Thickness: Be (1136.36 micron)

Energy before the degrader: 46.09 MeV/u

Energy after the degrader: 30.69 MeV/u

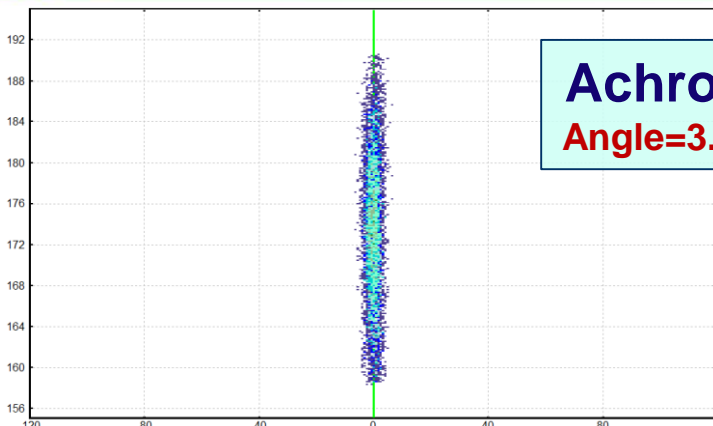
Dimension of wedge angle distributions (default 16): 32

Wedge angle calculations from formulae (mrad)

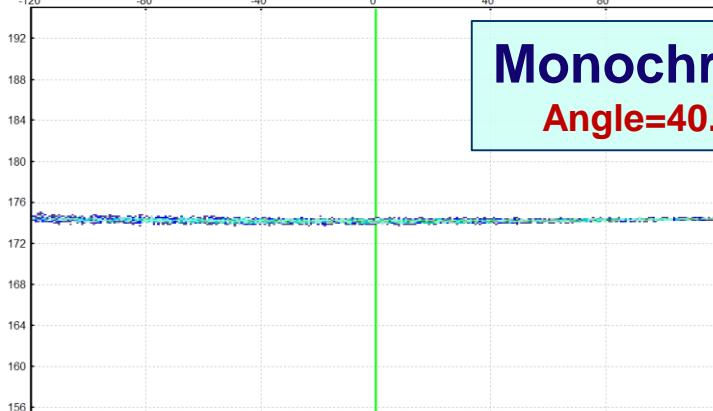
Achromatic: 6.25 Fix Monochromatic: 12.79 Fix

Ok Quit Help

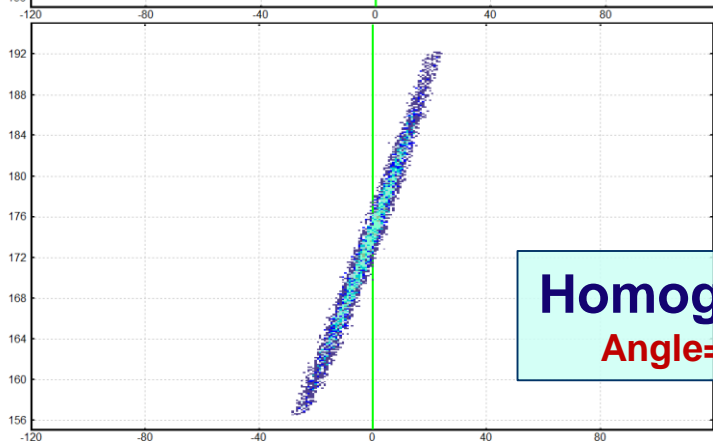
Energy in focal plane, MeV/u



Achromatic
Angle=3.94 mrad



Monochromatic
Angle=40.8 mrad



Homogeneous
Angle=0 mrad

X-position in focal plane, mm

Universal:
Any number of blocks including material

Wedge degrader in dispersive focal plane

Dispersion Plane
 X (horizontal)
 Y (vertical)

Mode
 Choose the block: to calculate an angle for the setting mode after it
 D2

mode	Wedge angle (mrad)	
<input checked="" type="radio"/> Achromatic	3.94	Fix
<input type="radio"/> Monochromatic	38.02	Fix
<input type="radio"/> Fixed in the code	40.824	

To plot a dependence from angle

Block: WEDGE
 Degradar Profile: Wedge degrader
 Setting fragment: 17Ne10+
 -60 <- slits(mm) -> +60
 -40.56 <- angle (mrad) -> +40.56
 min max

For the central trajectory
 Thickness: Be (2705.63 micron)
 Energy before the degrader: 185.67 MeV/u
 Energy after the degrader: 174.15 MeV/u

Dimension of wedge angle distributions (default 16): 32

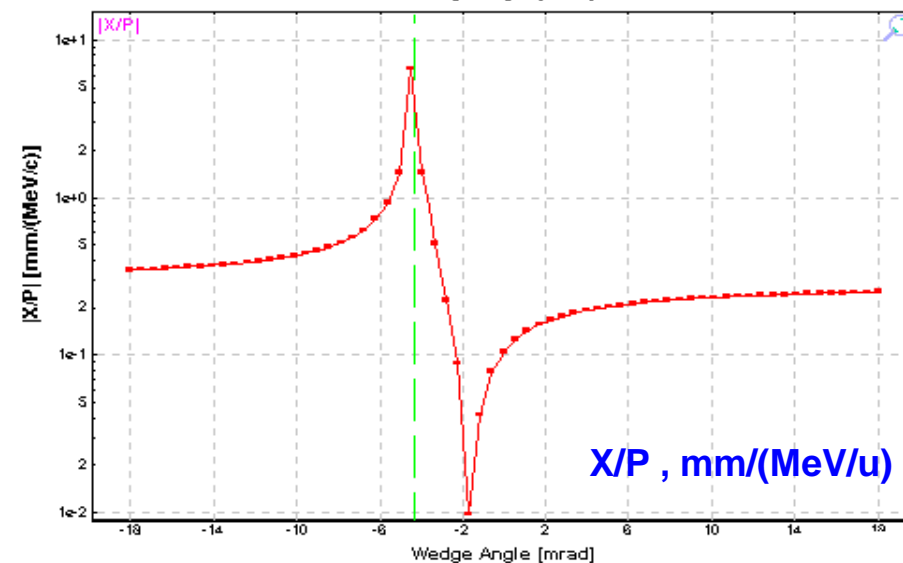
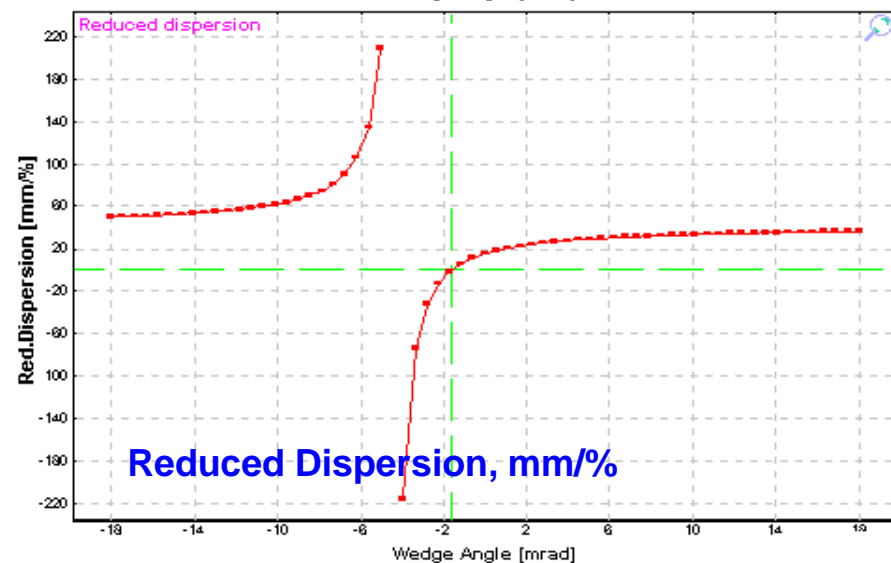
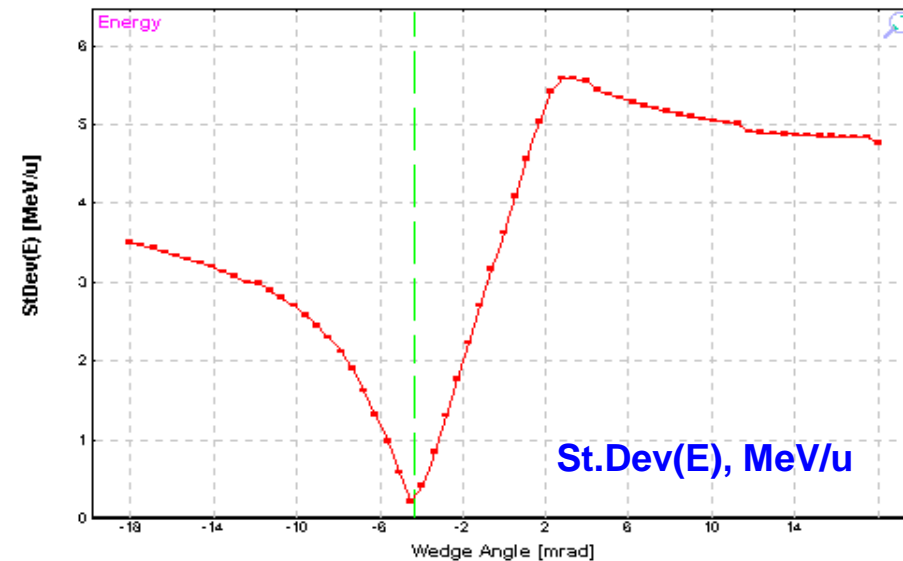
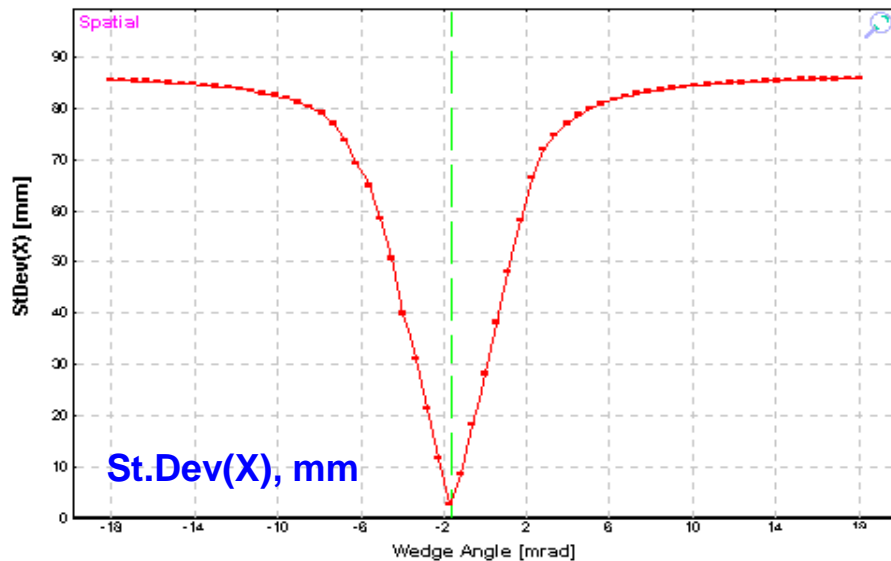
Wedge angle calculations from formulae (mrad)
 Achromatic: 3.95 Fix Monochromatic: 40.82 Fix

Assuming wedge & 1 dipole combination

Wedge_Im2 calculations for D4

⁴⁰Ar 140.0 MeV/u + Be (500 μ m); Settings on ³²S; Config: DDMSWMDSDMMMMMMMMMM
 dp/p=5.07% ; Wedges: Al (3000 μ m); Brho(Tm): 3.4821, 3.4821, 3.0101, 3.0101

Horizontal direction



Profile dergader in dispersive focal plane

Dispersion Plane

X (horizontal)

Y (vertical)

Mode

Choose the block: to calculate an angle for the setting mode after it

D4

Corresponding Wedge angle (mrad)

Achromatic -1.6191

Monochromatic -3.9438

User-defined -1.619

From profile file -1.6191

To plot a dependence from angle

Curved Degrader

Chose mode

Profile from file

X0 150 mm

L 300 mm

h 121.74 mm

e0 2757.14 micron

Calculate

Calculate & Plot

Block Wedge_lm2

Degrader Profile Curved

Setting fragment 32516+

-150 <- slits (mm) -> +150

-18 <-angle (mrad) -> +18

min max

For the central trajectory

Thickness Al (3000 micron)

Energy before the degrader 136.33 MeV/u

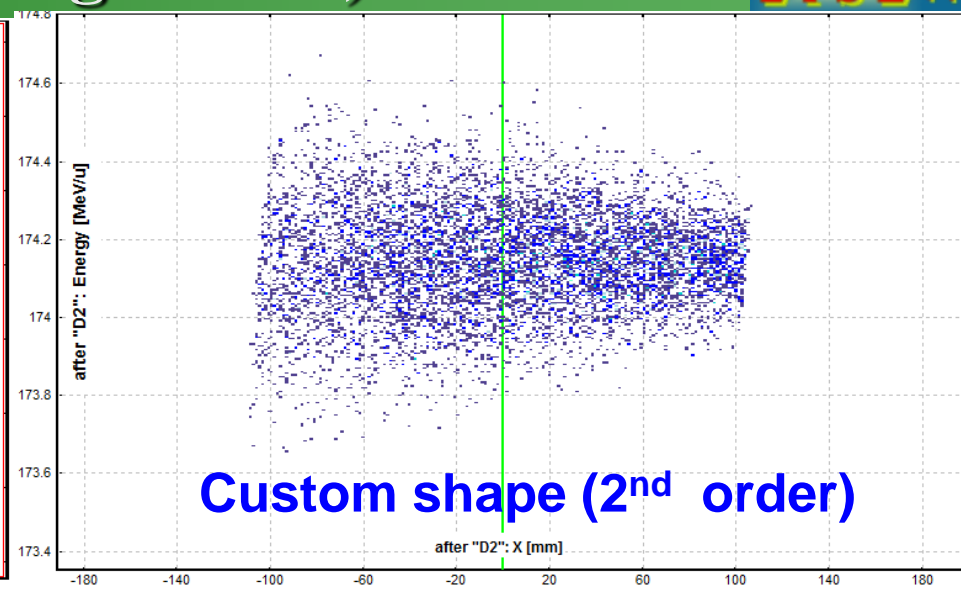
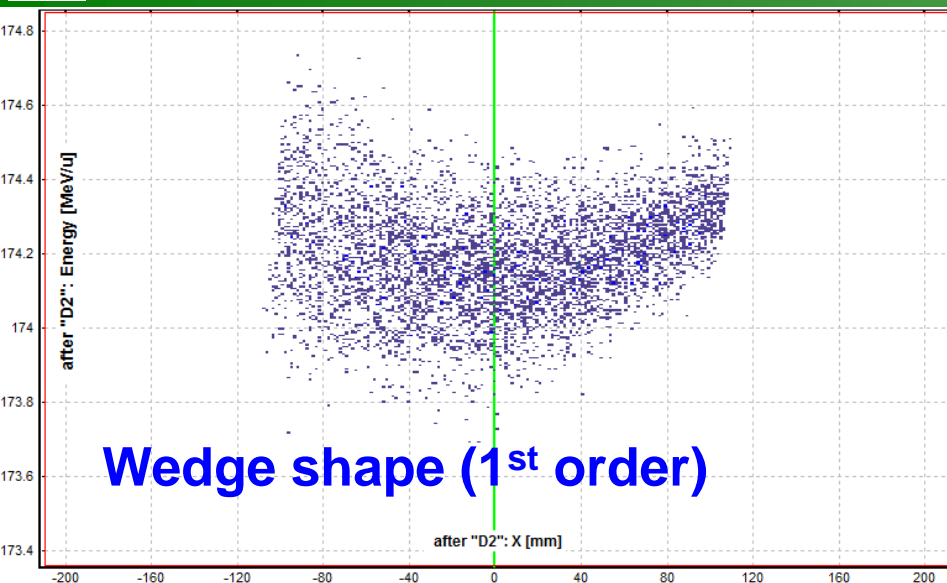
Energy after the degrader 103.89 MeV/u

Dimension of wedge angle distributions (default 16)

Beam

Ok
Quit
Help

Custom profile (High order)



Custom Shape degrader in dispersive focal plane

Dispersion Plane

X (horizontal) Y (vertical)

Mode

Choose the block: to calculate an angle for the setting mode after it

D2

Corresponding Wedge angle (mrad)

Achromatic

Monochromatic

Current profile 40.7824

To plot a dependence from angle

Custom Shape Degrader

Chose mode

Current profile

X0 150 mm

L 300 mm

e0 2705.63 micron

Calculate

Plot

Make it as Current

Polynomial mode

Polynom order: 2

Coefficients:

a0 = 2.7056e+0 mm

a1 = 4.0806e-2 mm⁻¹

a2 = 1.9277e-5 mm⁻²

Polynomial fit of the CURRENT custom shape

Boundaries for fit (mm)

x-left -38.4

x-right 38.4

Fit by a polynomial

Block: Wedge

Degrader Profile: Custom shape

Setting fragment: 17Ne10+

min max

-48 <- slits (mm) -> +48

-50.69 <-angle (mrad) -> +50.69

For the central trajectory:

Thickness: Be (2705.63 micron)

Energy (MeV/u) before the degrader 185.67

after the degrader 174.15

Dimension of distributions (default 32): 32

Wedge angle calculations from formulae (mrad)

Achromatic

Monochromatic

Ok Quit Help

Current profile

= internal profile =

Method to keep the profile

Inside LISE++ file

Load profile from file

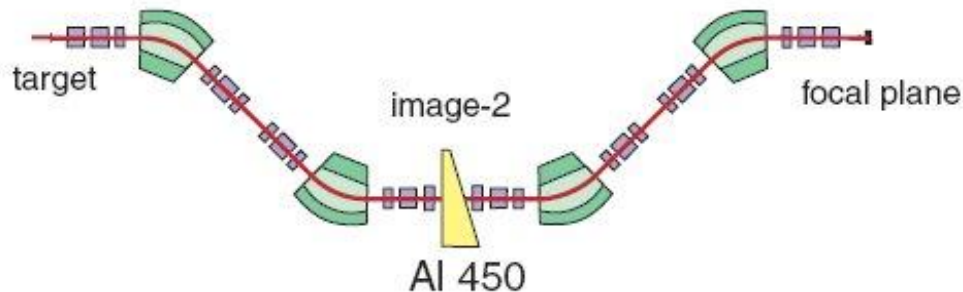
Save current profile

Attached profile file

Browse

See current profile Comments Erase current profile

^{58}Ni , 160 MeV/u + natNi, 811 mg/cm² → ^{46}Fe



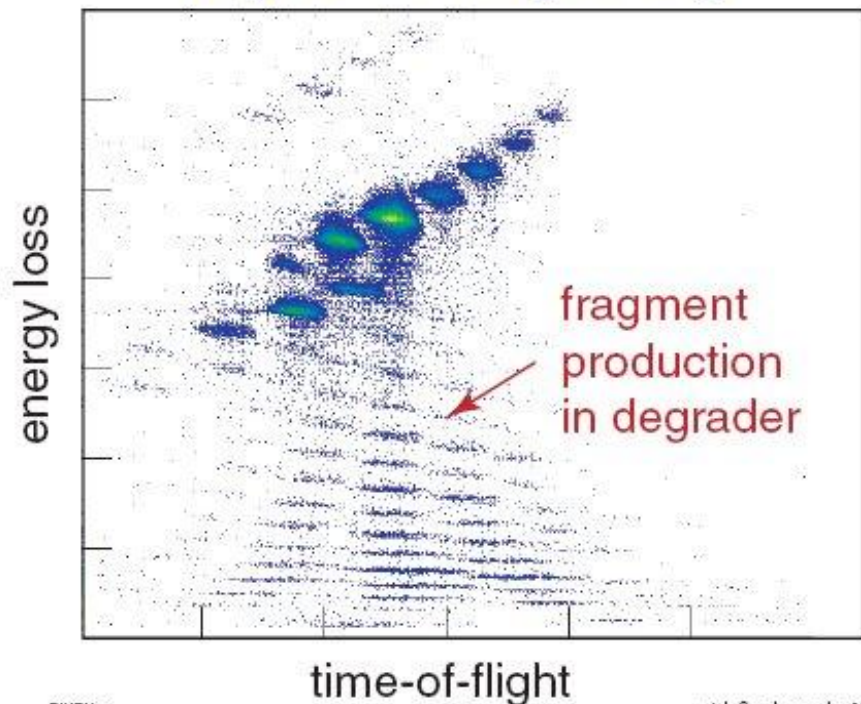
Comparasion with experimental data



dE-TOF

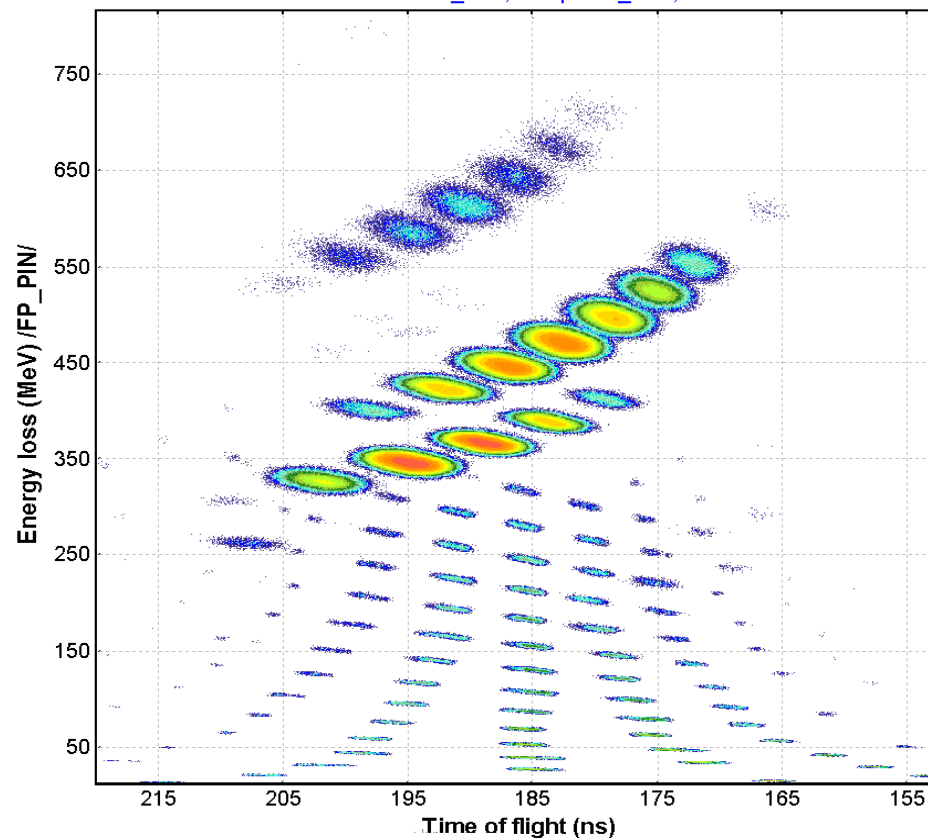
^{58}Ni (160.0 MeV/u) + Ni (811 mg/cm²); Settings on ^{46}Fe 26+ 26+ 26+ 26+
 dp/p=1.66% ; Wedges: Al (450 mg/cm²); Brho(Tm): 2.7596, 2.1165
 Start: I2_SCI; Stop: FP_PIN;

degrader @ image-2 only



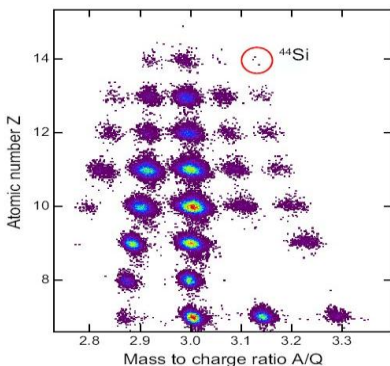
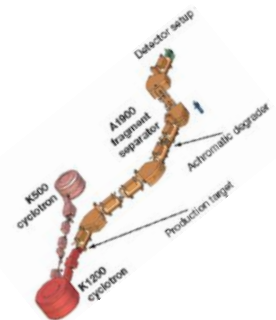
RIKEN06

stolz@nscl.msu.edu 2006-05



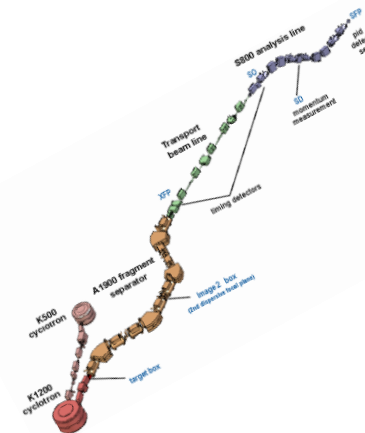
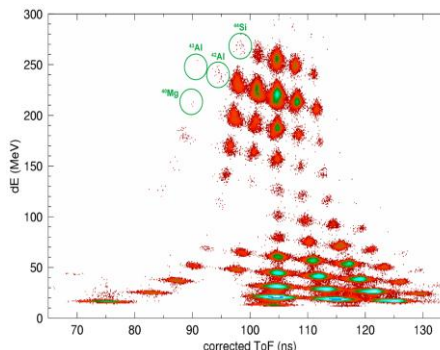
O.T. et al., Phys.Rev. C 75, 064613 (2007)

⁴⁴Si



⁴⁰Mg, ⁴²Al, ⁴³Al

T.Baumann et al., Nature (London) 449, 1022 (2007)

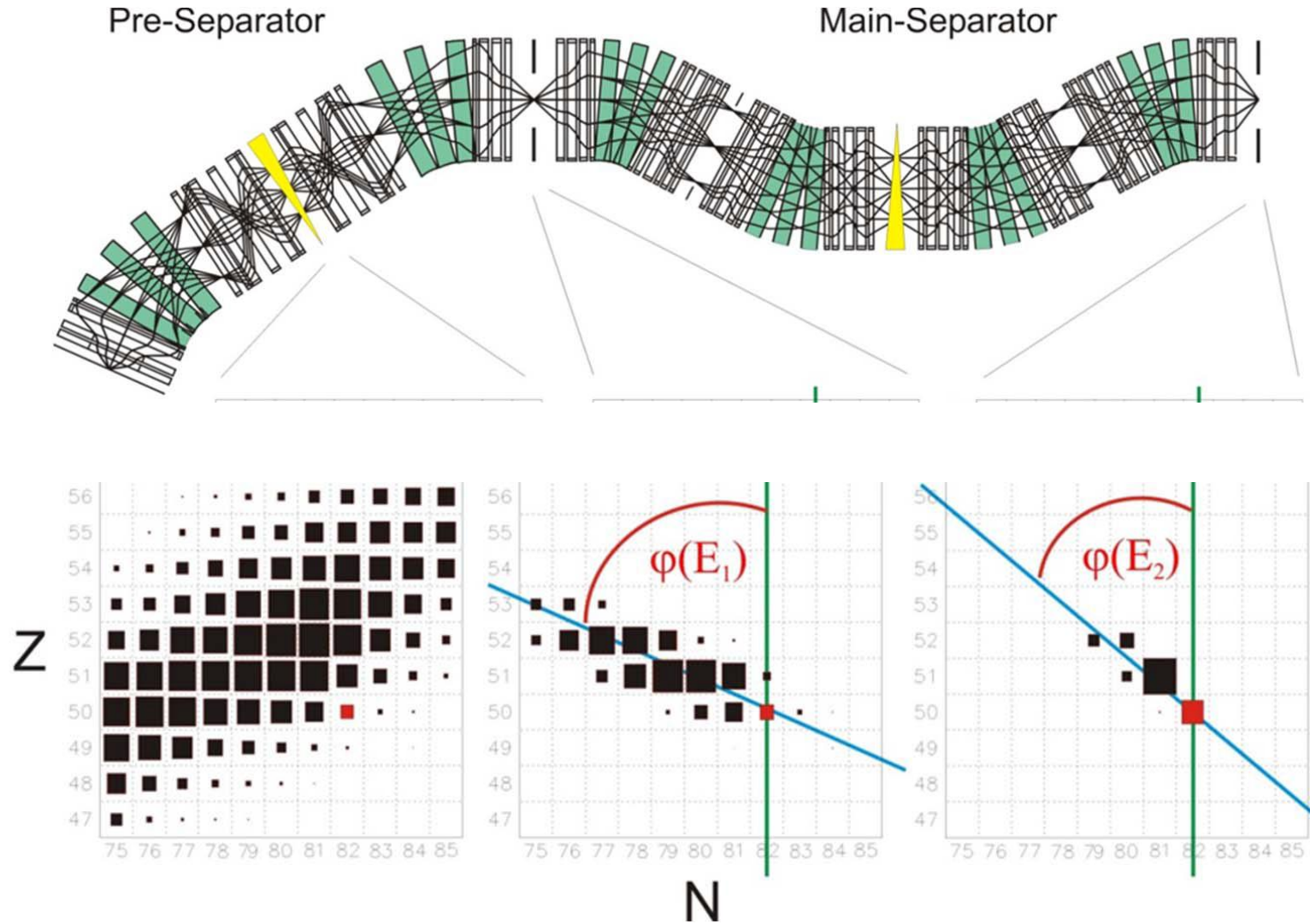


³⁶ Ca	³⁷ Ca	³⁸ Ca	³⁹ Ca	⁴⁰ Ca	⁴¹ Ca	⁴² Ca	⁴³ Ca	⁴⁴ Ca	⁴⁵ Ca	⁴⁶ Ca	⁴⁷ Ca	⁴⁸ Ca	⁴⁹ Ca	⁵⁰ Ca	⁵¹ Ca	⁵² Ca
³⁵ K	³⁶ K	³⁷ K	³⁸ K	³⁹ K	⁴⁰ K	⁴¹ K	⁴² K	⁴³ K	⁴⁴ K	⁴⁵ K	⁴⁶ K	⁴⁷ K	⁴⁸ K	⁴⁹ K	⁵⁰ K	⁵¹ K
³⁴ Ar	³⁵ Ar	³⁶ Ar	³⁷ Ar	³⁸ Ar	³⁹ Ar	⁴⁰ Ar	⁴¹ Ar	⁴² Ar	⁴³ Ar	⁴⁴ Ar	⁴⁵ Ar	⁴⁶ Ar	⁴⁷ Ar	⁴⁸ Ar	⁴⁹ Ar	⁵⁰ Ar
³³ Cl	³⁴ Cl	³⁵ Cl	³⁶ Cl	³⁷ Cl	³⁸ Cl	³⁹ Cl	⁴⁰ Cl	⁴¹ Cl	⁴² Cl	⁴³ Cl	⁴⁴ Cl	⁴⁵ Cl	⁴⁶ Cl	⁴⁷ Cl	⁴⁸ Cl	⁴⁹ Cl
³² S	³³ S	³⁴ S	³⁵ S	³⁶ S	³⁷ S	³⁸ S	³⁹ S	⁴⁰ S	⁴¹ S	⁴² S	⁴³ S	⁴⁴ S	⁴⁵ S	⁴⁶ S	⁴⁷ S	⁴⁸ S
³¹ P	³² P	³³ P	³⁴ P	³⁵ P	³⁶ P	³⁷ P	³⁸ P	³⁹ P	⁴⁰ P	⁴¹ P	⁴² P	⁴³ P	⁴⁴ P	⁴⁵ P	⁴⁶ P	
³⁰ Si	³¹ Si	³² Si	³³ Si	³⁴ Si	³⁵ Si	³⁶ Si	³⁷ Si	³⁸ Si	³⁹ Si	⁴⁰ Si	⁴¹ Si	⁴² Si	⁴³ Si	⁴⁴ Si		2007
²⁹ Al	³⁰ Al	³¹ Al	³² Al	³³ Al	³⁴ Al	³⁵ Al	³⁶ Al	³⁷ Al	³⁸ Al	³⁹ Al	⁴⁰ Al	⁴¹ Al	⁴² Al	⁴³ Al		
²⁸ Mg	²⁹ Mg	³⁰ Mg	³¹ Mg	³² Mg	³³ Mg	³⁴ Mg	³⁵ Mg	³⁶ Mg	³⁷ Mg	³⁸ Mg		⁴⁰ Mg				2007
²⁷ Na	²⁸ Na	²⁹ Na	³⁰ Na	³¹ Na	³² Na	³³ Na	³⁴ Na	³⁵ Na		³⁷ Na						2002
²⁶ Ne	²⁷ Ne	²⁸ Ne	²⁹ Ne	³⁰ Ne	³¹ Ne	³² Ne		³⁴ Ne								2002
²⁵ F	²⁶ F	²⁷ F		²⁹ F		³¹ F										1999
²⁴ O	²⁶ O	²⁸ O														1990 1997

Two-stage separation

- No detectors in beam line down to wedge selection slits (A1900 FP).
- Position (B_p) measurement in the dispersive focal plane in the second stage (S800BL)
- The first stage (A1900) of the system serves as a selector whereas the second stage (transfer hall line + S800BL) contains detectors and functions as analyzer
- All new fragment separators BigRIPS, SuperFRS, A2400 are multi-stage separators.

1.1 A GeV ^{238}U on 4 g/cm² C target, two Al degraders $d/R=0.3$, $d/R=0.7$



6. Transmission

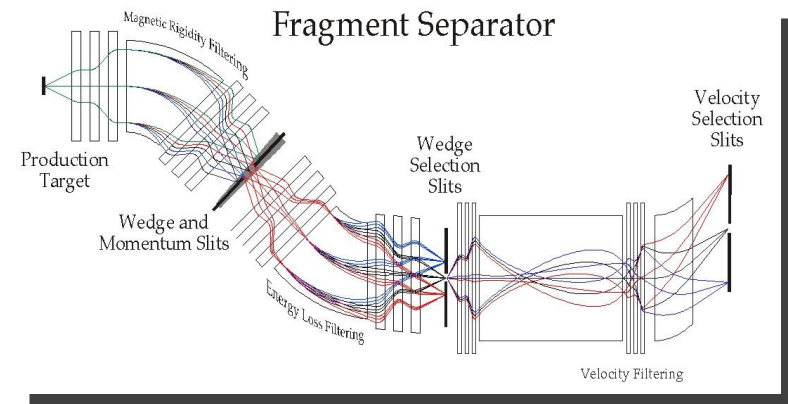
$$Y = I \cdot t \cdot N_t \cdot \sigma \cdot \epsilon_t \cdot \epsilon_s \cdot \epsilon_i$$

- Y** number of registered events
- σ** production cross section
- N_t** number of target atoms
- I** beam intensity
- t** duration of measurement
- ϵ_t** efficiency transmission at target
- ϵ_s** efficiency transmission through separator
- ϵ_i** identification efficiency

Depends on:

- ❑ Fragment separator characteristics
- ❑ Optics mode
- ❑ Production mechanism of fragments
 - Fragment velocity
 - Momentum width
- ❑ Energy loss straggling in materials

1. Production Area



3. Identification

2. Separation

- ϵ_t** efficiency transmission at target
 - lost of primary beam and fragments of interest due to reaction in target and stripper
 - charge state factor after target (stripper)
 - Gain due to secondary reactions
- ϵ_s** efficiency transmission through separator
 - lost of fragments of interest due to reaction in materials located in the separator
 - charge state factor after materials
 - Angular acceptance
 - Momentum selection
 - Wedge selection
 - Other selections
- ϵ_i** identification efficiency
 - lost of fragments of interest due to reaction in detectors
 - Live time (as well pile-ups)

statistics: 188Pb

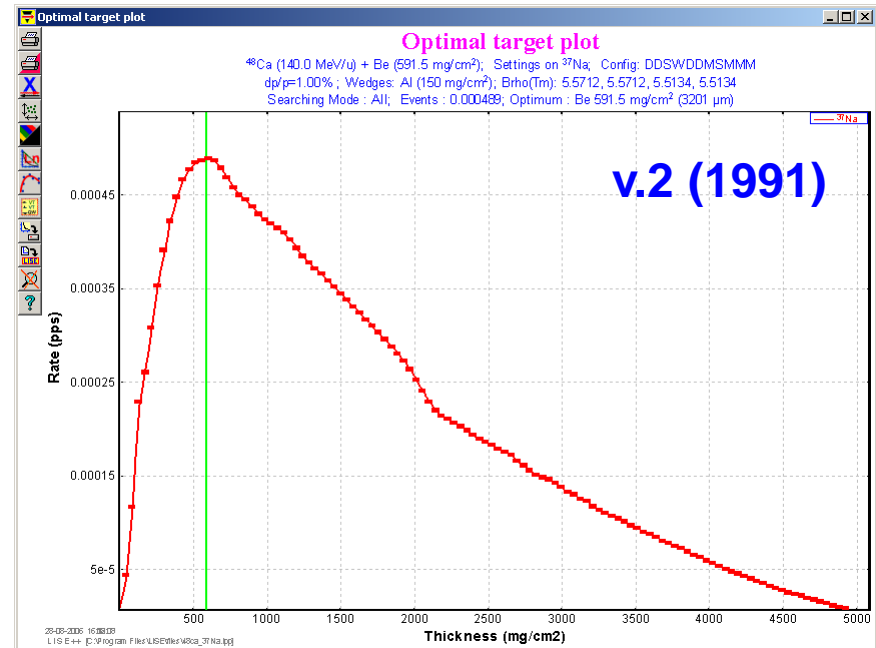
188Pb **Alpha and Beta+ decay (Z=82, N=106)**

Q1 (Dipole 1)		51
Q2 (Dipole 2)		51
Q3 (Wien)		51
Q4 (D6)		51
<hr/>		
Production Rate	(pps)	4.44e-1
Sum of charge states	(pps)	4.44e-1
Reaction		FusRes
Sum of all reactions	(pps)	4.44e-1
CS in the target	(mb)	1.67e-1
Total transmission	(%)	2.834
<hr/>		
Target	(%)	25.14
Unreacted in mater.	(%)	100
Q (Charge) ratio	(%)	25.14
Unstopped in mater.	(%)	100
<hr/>		
Dipole 1	(%)	68.01
X space transmission	(%)	97.64
Y space transmission	(%)	100
X angular transmissn.	(%)	83.46
Y angular transmissn.	(%)	83.46
<hr/>		
PPAC	(%)	25.11
Unreacted in mater.	(%)	100
Q (Charge) ratio	(%)	25.11
Unstopped in mater.	(%)	100
<hr/>		
Dipole 2	(%)	70.35
X space transmission	(%)	85.24
Y space transmission	(%)	100
X angular transmissn.	(%)	90.8
Y angular transmissn.	(%)	90.89
<hr/>		
Wien	(%)	100
D6	(%)	100
Final_Slits	(%)	93.84
X space transmission	(%)	100
Y space transmission	(%)	93.84
<hr/>		
Material 2	(%)	0
Unreacted in mater.	(%)	100
Unstopped in mater.	(%)	0

7. Optimization utilities

- ❖ Target thickness (v.2.0)
- ❖ Range optimizer (v.6.1)
Gas cell utility
- ❖ Gas pressure optimization (v.6.2)
Gas-filled separator utility
- ❖ Charge states combination (v.7.5)
- ❖ Target thickness (v.7.5)
charge states optimization + secondary reactions
- ❖ Brho scanning (v.7.5)
background rate calculation

to produce an intense and pure secondary beam using different reaction mechanisms

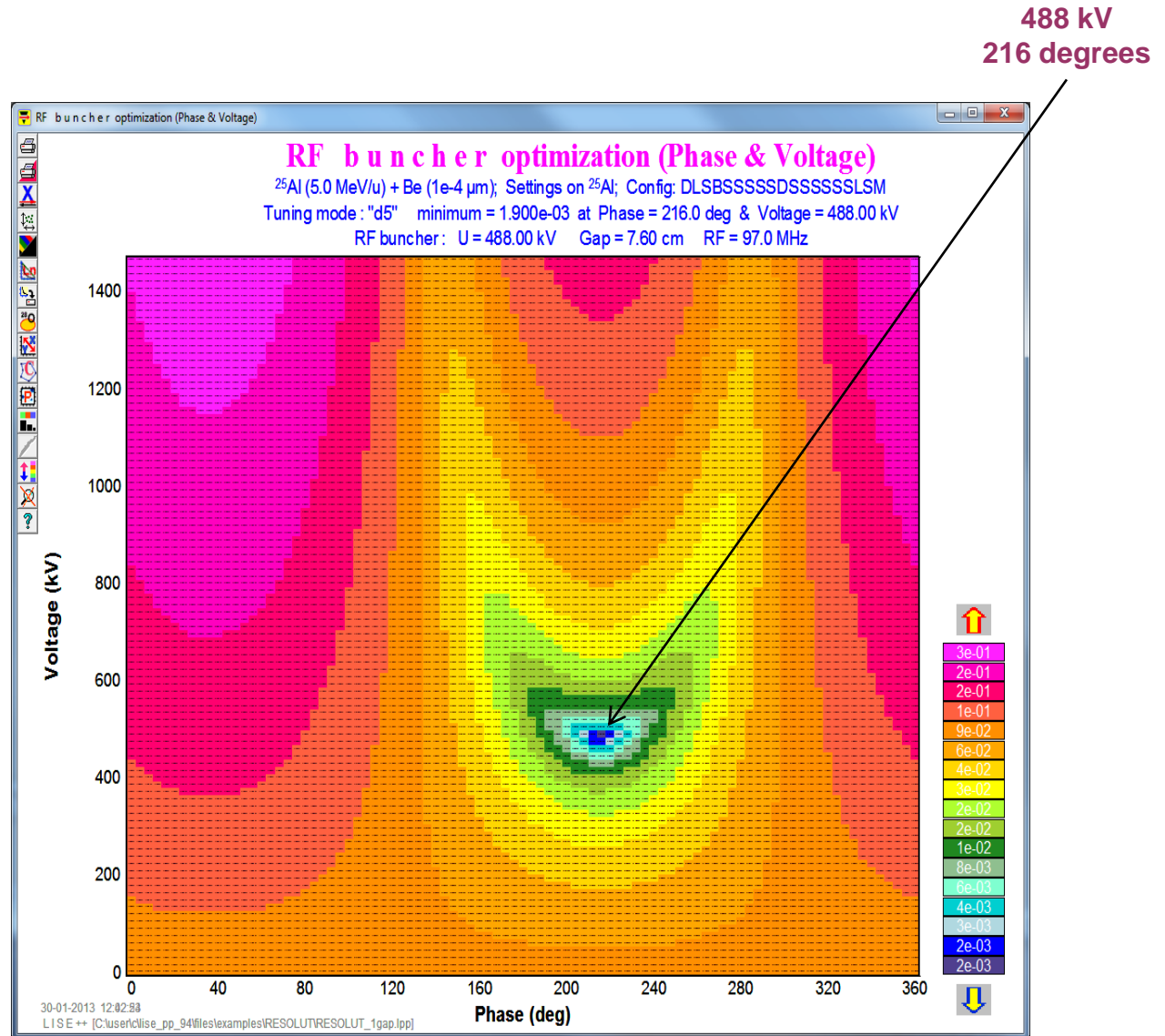


❖ **Target – Wedge (v7.5)**
yield vs purity

❖ **RF kicker (v.7.6)**
position, slits size,
phase: yield vs purity

❖ **Wedge – Wedge (v.7.8)**
yield vs purity

❖ **RF buncher optimization (v.9.5)**
voltage, phase:
energy
compression



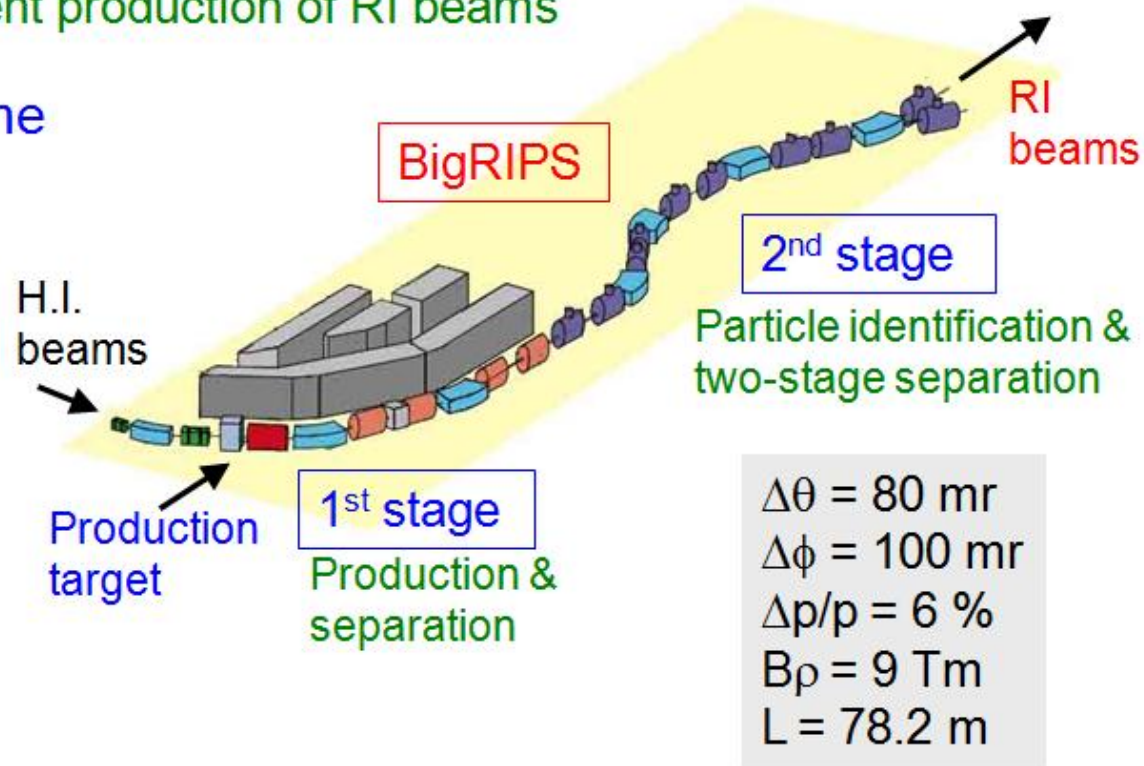
8. New generation of fragment separators

BigRIPS (March 2007)

- Large acceptances
 - Comparable with spreads of in-flight fission of U beam at RIBF energies, allowing efficient production of RI beams
- Two-stage separator scheme



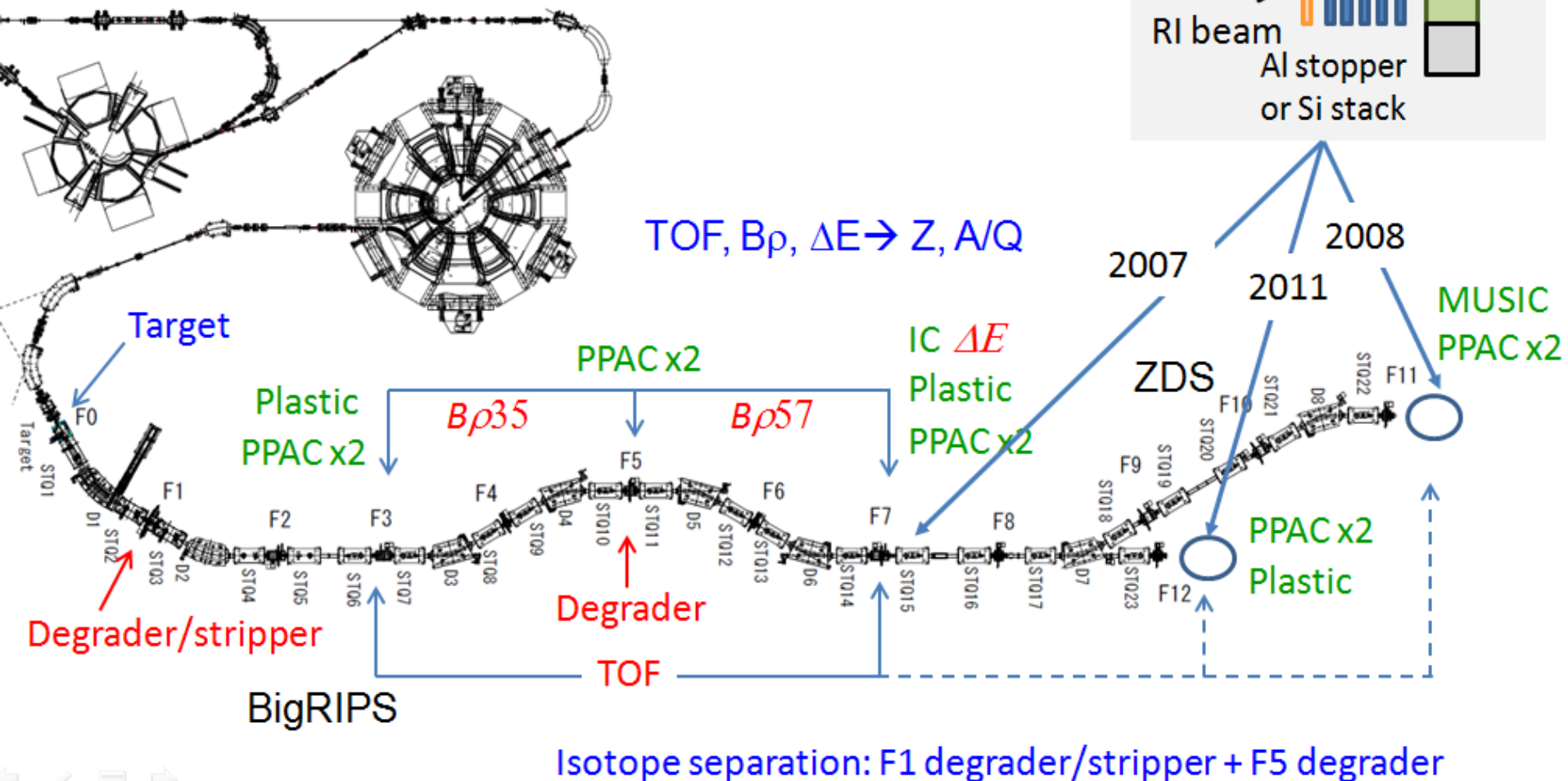
BigRIPS 2nd stage



- 2nd stage with high resolution
 - Allows excellent particle identification (PID) including charge states of RI beams
 - Charge states are a crucial issue at our energies

Experimental setups

- Standard beam-line detectors at BigRIPS for TOF, $B\rho$, ΔE measurement for PID
- Clover-type Ge detectors for isomer measurement

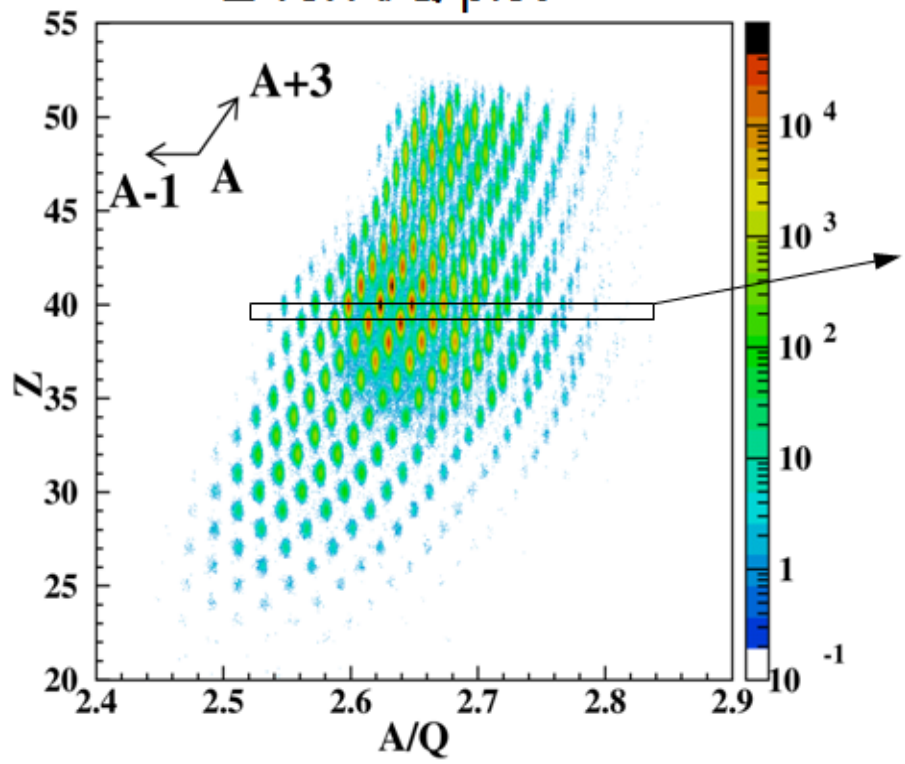


Excellent particle identification (PID) power for fission fragments

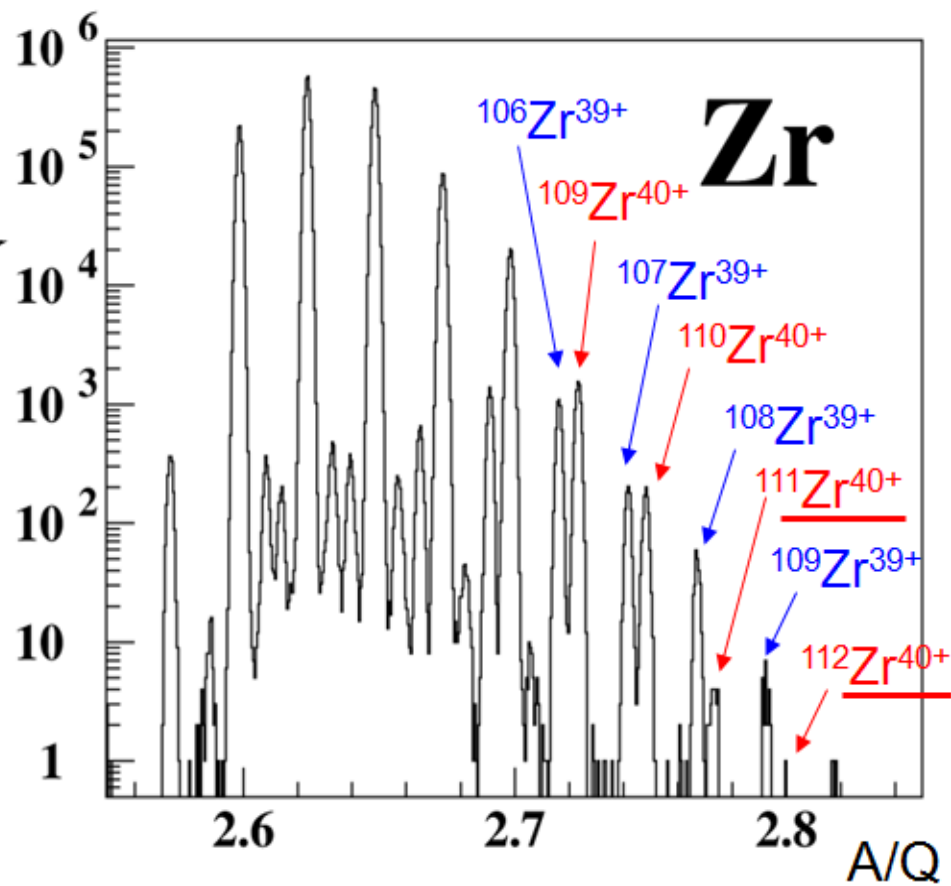
TOF-B ρ - ΔE method with track reconstruction

High enough to well identify charge states of fragments

Z vs. A/Q plot



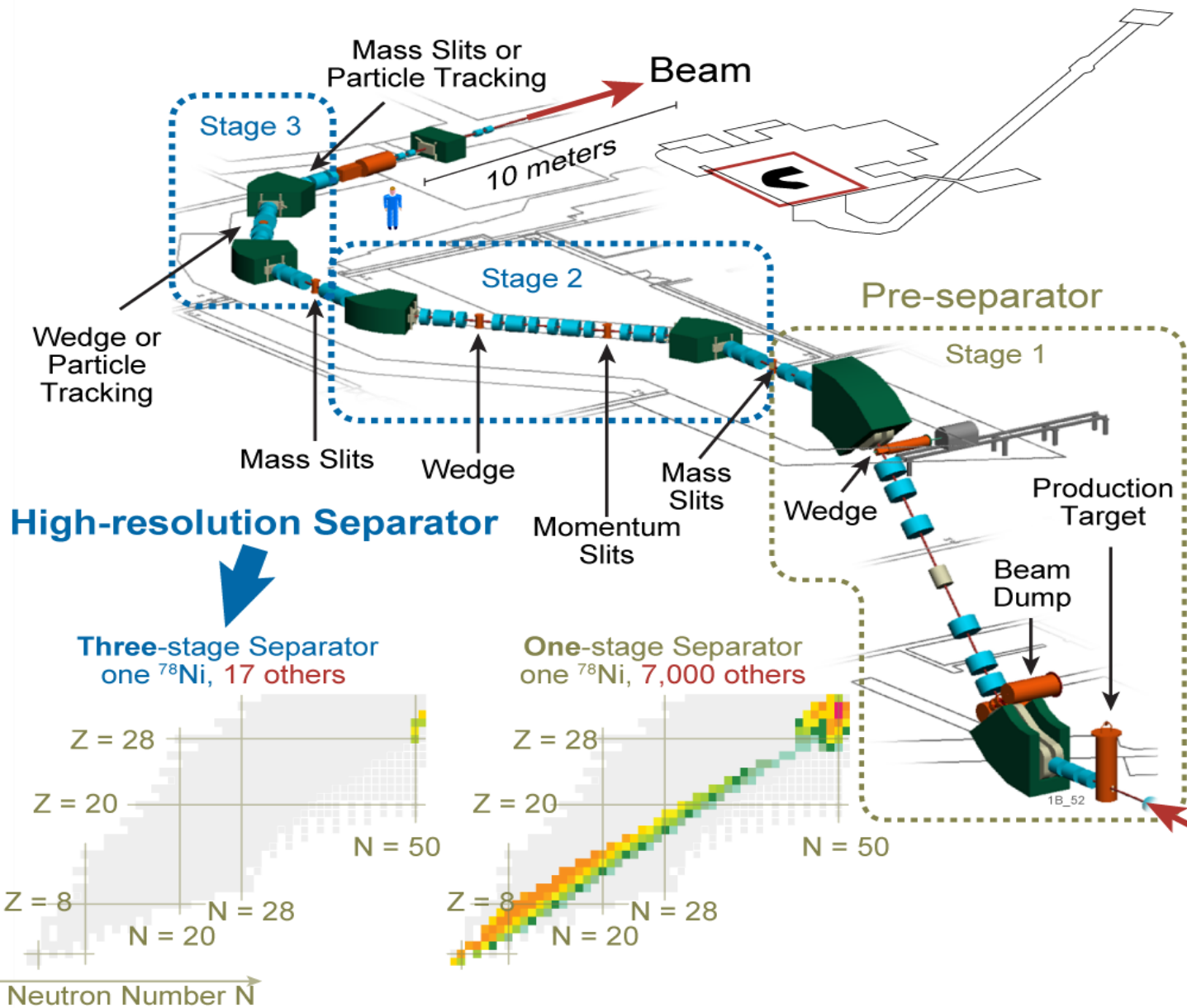
A/Q spectrum for Zr isotopes (Z=40)



U+Be 2.9 mm B ρ 01 = 7.990 Tm
F1 deg Al 2.18mm $\Delta P/P = \pm 3\%$
G3 setting in J. Phys. Soc. Jpn. 79 (2010) 073201.

Courtesy of T.Kubo (RIKEN)

r.m.s. A/Q resolution: 0.035 %



Layout of the Super-FRS

Design Parameters:

$$\epsilon_x = \epsilon_y = 40 \pi \text{ mm mrad}$$

$$\varphi_x = \pm 40 \text{ mrad}$$

$$\varphi_y = \pm 20 \text{ mrad}$$

$$\Delta P/P = 2.5\%$$

$$B_p = 2 - 20 \text{ Tm}$$

$$R_{\text{sep}} = 750 / 1500$$

(first / second stage)

Spot size on target

$$\sigma_x = 1.0 \text{ mm}$$

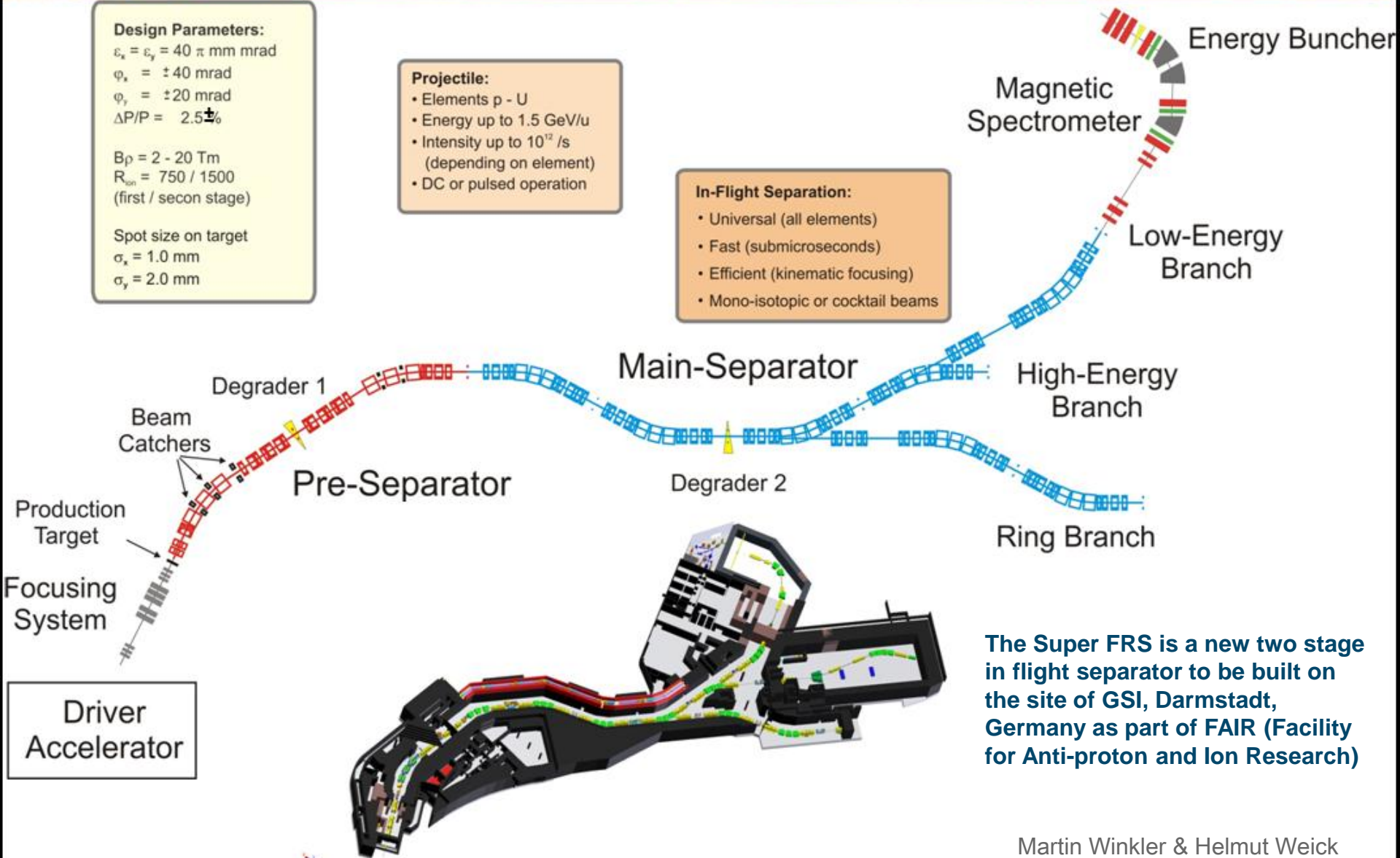
$$\sigma_y = 2.0 \text{ mm}$$

Projectile:

- Elements p - U
- Energy up to 1.5 GeV/u
- Intensity up to 10^{12} /s (depending on element)
- DC or pulsed operation

In-Flight Separation:

- Universal (all elements)
- Fast (submicroseconds)
- Efficient (kinematic focusing)
- Mono-isotopic or cocktail beams



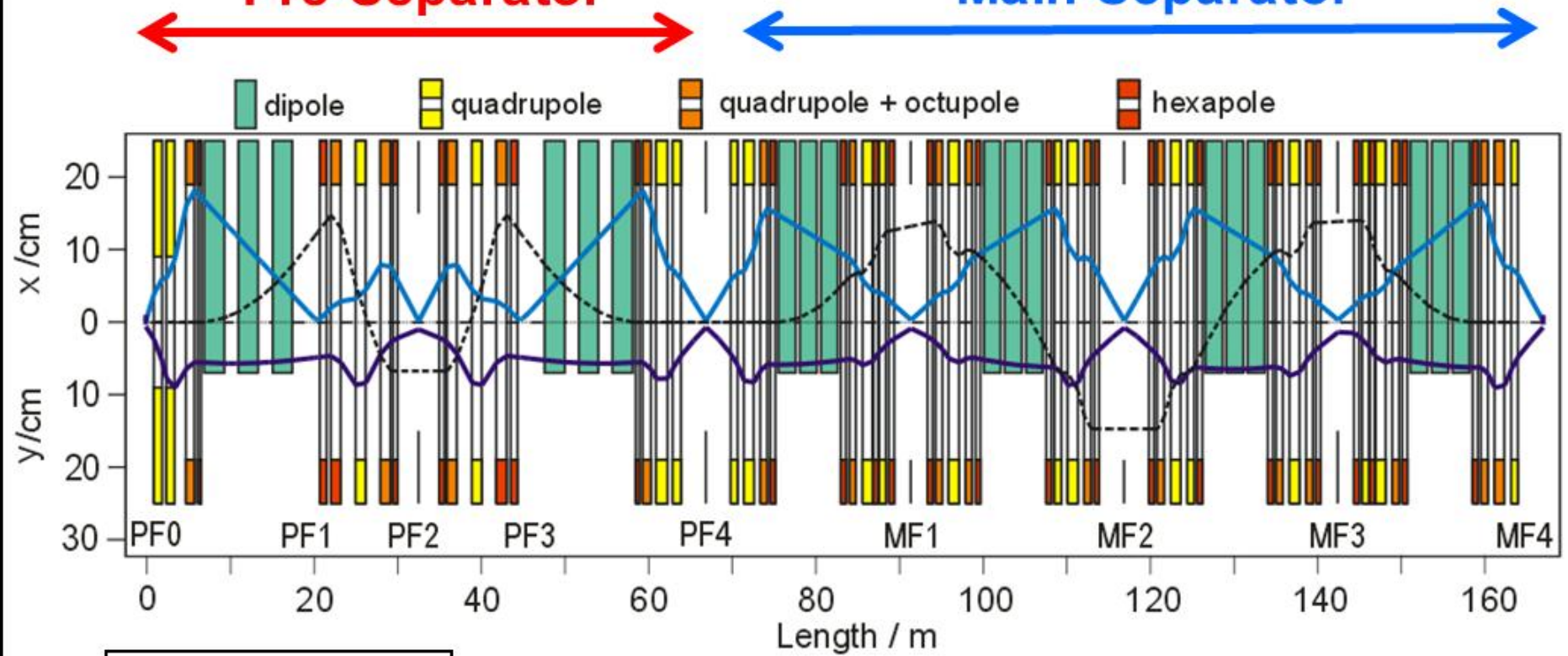
The Super FRS is a new two stage in flight separator to be built on the site of GSI, Darmstadt, Germany as part of FAIR (Facility for Anti-proton and Ion Research)

Ion-optical design of the Super-FRS High-Energy Branch (HEB)



Pre-Separator

Main-Separator



$\epsilon_x = 40 \pi \text{ mm mrad}$
 $\phi_x = \pm 40 \text{ mrad}$
 $\epsilon_y = 40 \pi \text{ mm mrad}$
 $\phi_y = \pm 20 \text{ mrad}$
 $\Delta p/p = \pm 2.5 \%$

Main magnet requirements:

Dipole (unit): $\rho = 12.5 \text{ m}$, $\phi = 9,75^\circ$, $G = \pm 85 \text{ mm}$, $B = 1.6 \text{ T}$

Quadrupole: $L = 0.8/1.2 \text{ m}$, $G = \pm 190 \text{ mm}$, $g_{\text{Max}} = 10 \text{ T/m}$

+ Sextupole Magnets and Octupole correction coil

9. Example of secondary beam production

Let's start from ISOL using HRIBF



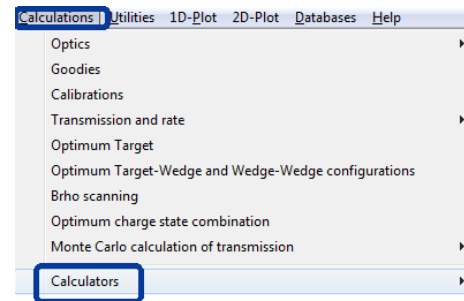
1. Calculate a range of protons, define number of atoms
2. Applying inverse kinematics, set p- target thickness (using the same number of atoms)
3. Applying inverse kinematics, set Beam characteristics. No charge states
4. Set Abrasion-Fission as production mechanism
5. Load settings for ${}^{238}\text{U}+p$ abrasion-Fission
6. Insert "Delay" and "Faraday cup" blocks after the stripper
7. Set values in the "Delay" block *
8. Calculate calcium isotopes production
9. Plot calcium isotopes yields, Save yields in file
10. Set "Delay" block disable
11. Repeat 8 and 9
12. Include additional production mechanism?

* do not forget to save sometimes all your changes in a LISE⁺⁺ file

Calculations Utilities 1D-Plot 2D-Plot



for all icons in the toolbar there are corresponding commands in the menu



Physical calculator

A Element Z Q

Energy MeV/u

Brho Tm

Erho MJ/C

P MeV/c

p_trnspt GeV/c

Energy Remain. AMeV

TKE MeV

Velocity cm/ns

Beta

Gamma

Block	Z \ Thickness	MeV/u	MeV	MeV	<Q>
M FP_PIN	Si 518 micron	38.587	38.889	1.4242	1.00
M FP_SCI	C9H10 100 mm	0	0	38.889	0.00

Range and Energy Loss to

Range 3773.1 1981.36

dRange (sigma) 57.942 mg/cm2 30.427 micron

Energy Remain. MeV/u

Material thickness for energy rest mg/cm2 micron

Calculation method of

Energy Losses Energy straggling

Charge States Angular straggling

Range to

Density g/cm3

State Solid Gas

Dimension mg/cm2 & micron g/cm2 & mm

Angle degrees

Z	Element	Mass
<input checked="" type="checkbox"/>	92 U	PT 238.03
<input type="checkbox"/>	14	
<input type="checkbox"/>	14	
<input type="checkbox"/>	14	
<input type="checkbox"/>	14	

Thickness at 0 degrees 1981.359 micron 3773.1019 mg/cm2

Effective Thickness 1981.359 micron 3773.1019 mg/cm2

Atoms quantity / cm2

Range p(40 MeV) in ^{238}U ~ 2 mm, 9.55×10^{21} atoms/cm 2 ,
 that corresponds to number of atoms in 16 mg/cm 2 of H-target

Projectile	$^{238}\text{U}^{92+}$
	1000 MeV/u 5000 pnA
LowEx:	23 MeV $^{237}\text{U}^*$
MidEx:	75 MeV $^{226}\text{Th}^*$
HighEx:	180 MeV $^{220}\text{Ac}^*$
Fragment	$^{54}\text{Ca}^{20+}$
T	Target H 16 mg/cm ²
St	Stripper

$p(40\text{MeV}, 5\mu\text{A}) + ^{238}\text{U}$

inverse

^{238}U (high energy, 5uA) + p (16 mg/cm²)

Target

H Density: 0.0715 g/cm³

State: Solid Gas

Dimension: mg/cm² & micron g/cm² & mm

Angle: Calculate 0 degrees

Z	Element	Mass
<input checked="" type="checkbox"/>	1 H PT	1.008
<input type="checkbox"/>	14	
<input type="checkbox"/>	14	
<input type="checkbox"/>	14	
<input type="checkbox"/>	14	

Compound dictionary

Thickness at 0 degrees: 2237.7622 micron 16 mg/cm²

Effective Thickness: 2237.7622 micron 16 mg/cm²

Thickness defect Absorbed Dose

Cut (Slits)

OK Cancel

d / Range (beam) 0.004

Energy Loss in the target box [KW] 3.31

Atoms / cm² 9.56e+21

Range p(40 MeV) in ^{238}U ~ 2 mm, 9.55e²¹ atoms/cm²,
that corresponds to number of atoms in 16 mg/cm² of H-target

P rojectile	$^{238}\text{U}^{92+}$	1000 MeV/u	5000 pA
LowEx:	23 MeV	$^{237}\text{U}^+$	
MidEx:	75 MeV	$^{226}\text{Th}^+$	
HighEx:	180 MeV	$^{220}\text{Ac}^+$	
F ragment	$^{54}\text{Ca}^{20+}$		
T arget	H	16 mg/cm ²	
St ripper			

$p(40\text{MeV}, 5\mu\text{A}) + ^{238}\text{U}$

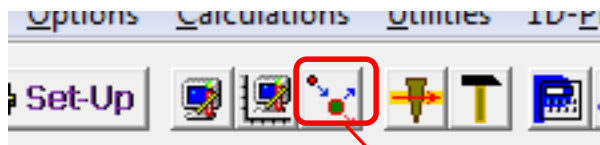
inverse

^{238}U (high energy, 5uA) + p (16 mg/cm²)

The screenshot shows the 'Beam' configuration window with the following settings:

- Projectile:** Element: U, Charge: 92+, Mass: 238
- Beam energy:** Energy: 1000 MeV/u
- Beam intensity:** 5000 pA
- Emittance:** Beam CARD (sigma, semi-axis, half-width...), 1D - shape (Distribution method), 2D mode, 2D - shape (Monte Carlo method), Correlated with
- beam respect to spectrometer:** dX, dT, dY, dP (mm, mrad, degrees)
- Energy Loss in the target box [KW]:** 3.31
- RF frequency:** 20 MHz
- Bunch length:** 1 ns

Range $p(40\text{ MeV})$ in $^{238}\text{U} \sim 2\text{ mm}$, 9.55e^{21} atoms/cm², that corresponds to number of atoms in 16 mg/cm² of H-target



Production Mechanism

Reactions / Energy Loss, Straggling / Charge states / Databases: Masses, Isomers

238U(1000.0 MeV/u) + H -> 54Ca

Abrasion-Fission
A3⁺ + A4⁺ < 238

Reactions

Settings Projectile Fragmentation

Settings Fusion -> Residual

Settings Fusion -> Fission

Settings Coulomb fission

Settings **Abrasion-Fission**

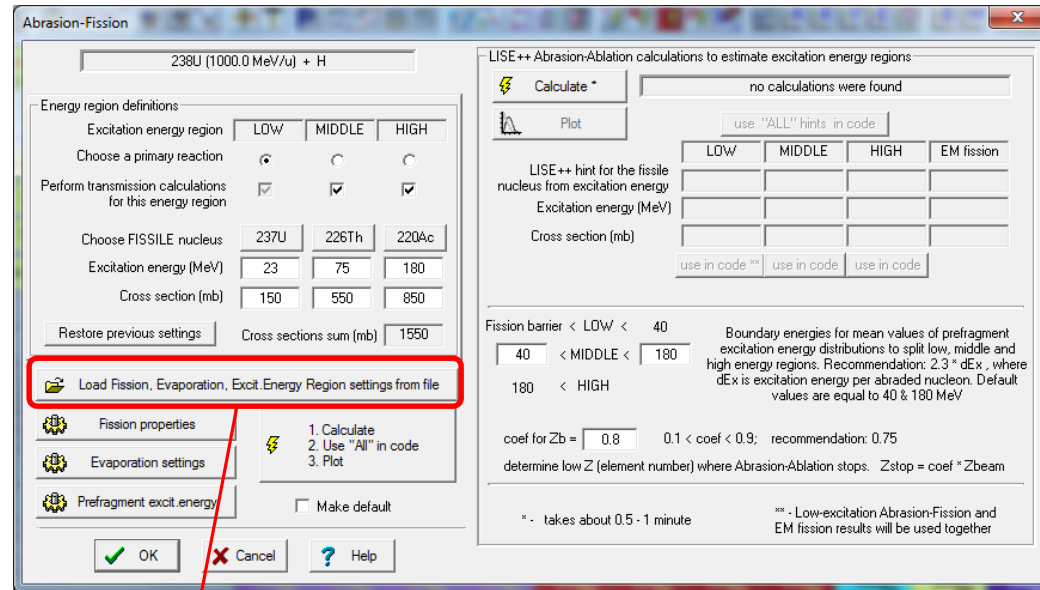
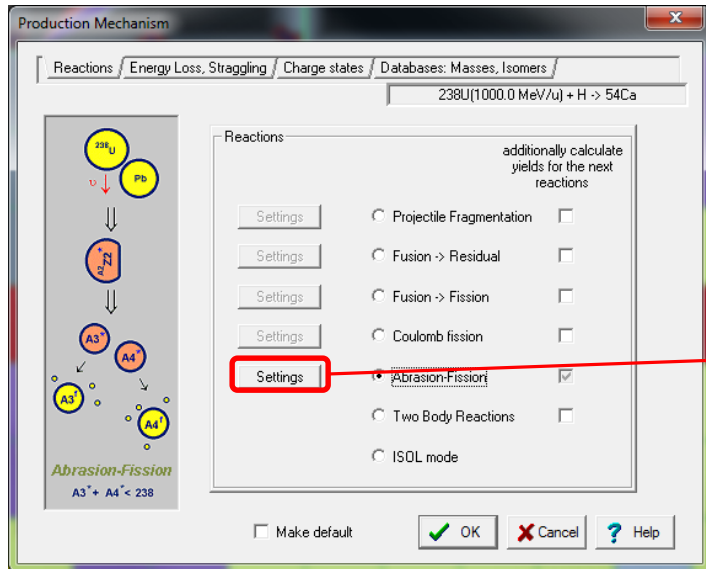
Settings Two Body Reactions

Settings ISOL mode

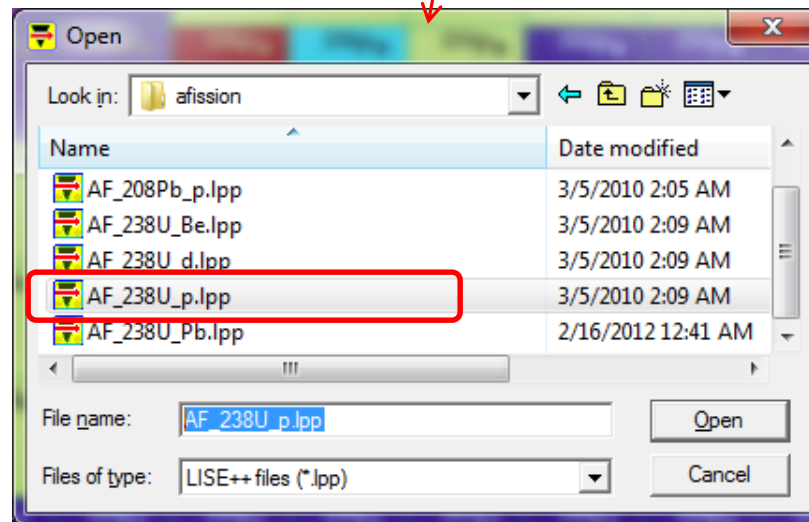
additionally calculate yields for the next reactions

Make default

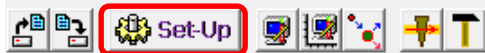
OK Cancel Help



Documents\LISE\files\examples\afission\AF_238U_p.lpp



File Settings Options Calculations Utilities



Spectrometer designing

Block	Given Name	Z-Q	Length.m	Enable
Target	Target			+
Stripper	Stripper			+
Delay	Delay 1		0	+
FaradayCup	FaradayCup 1			+
Dipole	D1	0	8.719	+
Drift	I1_slits		0	NO
Wedge	I1_wedge			NO
Dipole	D2	0	8.767	+
Material	I2_PPAC0			NO
Drift	I2_slits		0	+
Wedge	I2_wedge			+
Material	I2_PPAC1			NO
Material	I2_SCI			NO
Dipole	D3	0	8.767	+
Drift	I3_slits		0	NO
Wedge	I3_wedge			NO
Dipole	D4	0	9.39	+
Material	FP_PPAC0			+
Material	FP_PPAC1			+

Selected block: Enable Delay (efficiency) block

Let call automatically Block Length [m] 0

Block name = Delay 1 Length after this block [m] 0

Sequence number 3

Total Number of Blocks: 28

Total Length [m]: 35.643

Insert Mode: before after

Move element:

Insert block:

- Target
- Stripper after Target
- Wedge
- Material(Detector)
- Faraday cup
- Dispersive (Dipole)
- Wien velocity filter
- Drift (multipole,slits)
- Beam Rotation
- Shift of Optical Axis
- Electrostatic dipole
- Gas-filled separator
- Compensating Dipole
- RF separator
- RF buncher
- Solenoid
- Delay (efficiency) block

Projectile $^{238}\text{U}^{92+}$
 1000 MeV/u 5000 pA
 LowEx: 23 MeV $^{237}\text{U}^*$
 MidEx: 75 MeV $^{226}\text{Th}^*$
 HighEx: 180 MeV $^{220}\text{Ac}^*$

Fragment $^{54}\text{Ca}^{20+}$

Target H
 ^{16}O ^{12}C ^{20}Ne

Stripper

Z Delay 1

A FaradayCup 1
 enat e

Delay 1

Time (drift, extraction or breeding)

Use

Mass	Time, sec
Light <= 50	0.05
50 < Medium < 150	0.05
150 <= Heavy	0.05

Efficiency

Use

Mass	Efficiency, %
Light <= 50	10
50 < Medium < 150	10
150 <= Heavy	10

Efficiency as function of RATE

Use

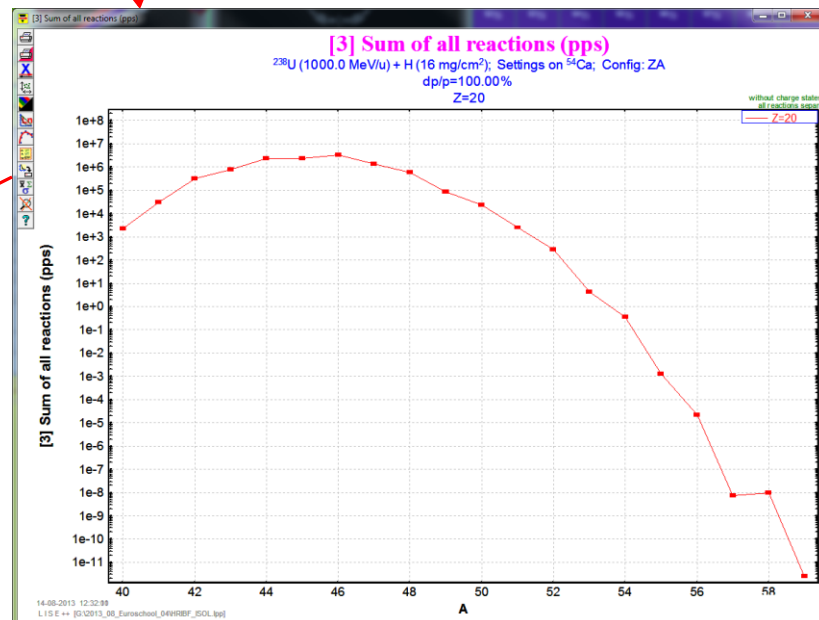
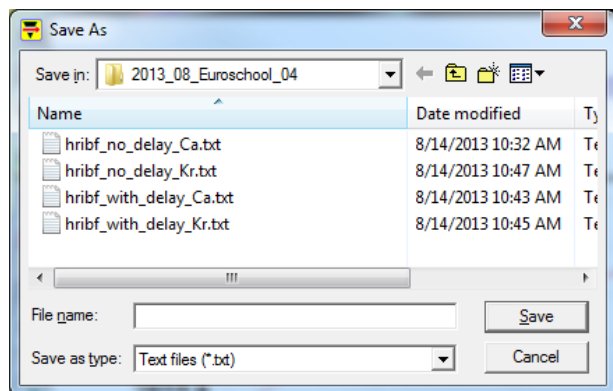
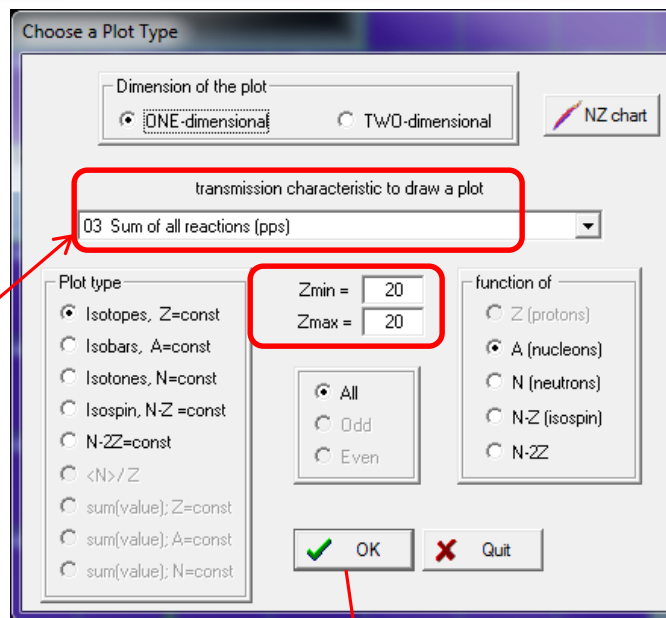
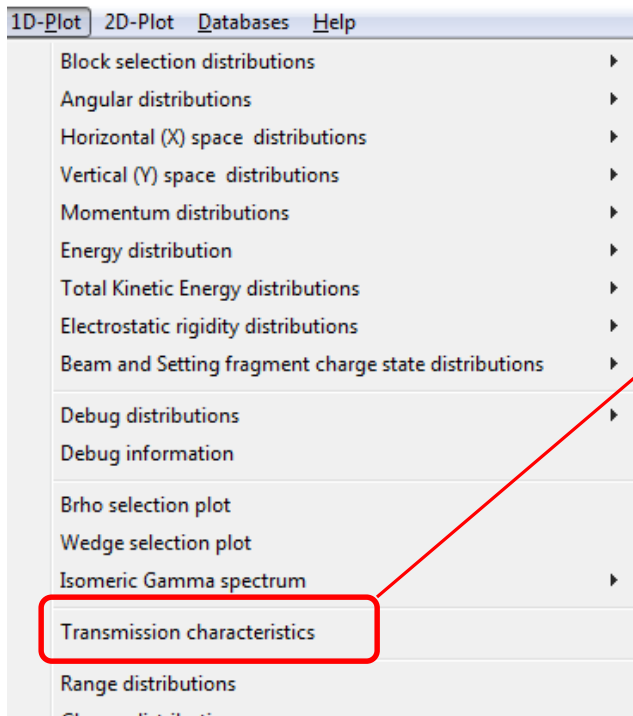
Mass	Efficiency file
Light <= 50	
50 < Medium < 150	
150 <= Heavy	

Buttons: Cut (Slits) & Acceptances, Optical matrix, General setting of block, OK, Cancel, Help

The screenshot shows a software interface for calculating calcium isotope production. A red box highlights a specific icon in the toolbar. A dialog box titled "Choose First corner of rectangle" is open, showing fields for A (60), Element (Ca), and Z (20). The periodic table below shows the calcium row (Z=20) highlighted in red, with a red box around it. The calcium row data is as follows:

Isotope	40Ca	41Ca	42Ca	43Ca	44Ca	45Ca	46Ca	47Ca	48Ca	49Ca	50Ca	51Ca	52Ca	53Ca	54Ca	55Ca	56Ca	57Ca	58Ca
Abundance	2.24e+3	3.1e+4	3.11e+5	7.75e+5	2.27e+6	2.38e+6	3.3e+6	1.01e+6	6.03e+5	8.78e+4	2.24e+4	2.47e+3	2.75e+2	4.12e+0	3.47e-1	1.26e-3	2.21e-5	7.37e-9	9.63e-9
Percentage	9.851%	9.851%	9.85%	9.85%	9.849%	9.846%	9.848%	9.847%	9.846%	9.822%	9.812%	9.771%	9.132%	6.699%	2.038%	0.422%	0.075%	0.459%	

Plot calcium isotopes yields, Save yields in file



Production Mechanism

Reactions / Energy Loss, Straggling / Charge states / Databases: Masses, Isomers

238U(1000.0 MeV/u) + H -> 54Ca

Reactions

Settings Projectile Fragmentation *additionally calculate yields for the next reactions*

Settings Fusion -> Residual

Settings Fusion -> Fission

Settings Coulomb fission

Settings **Abrasion-Fission**

Settings Two Body Reactions

Settings ISOL mode

Make default

OK Cancel Help

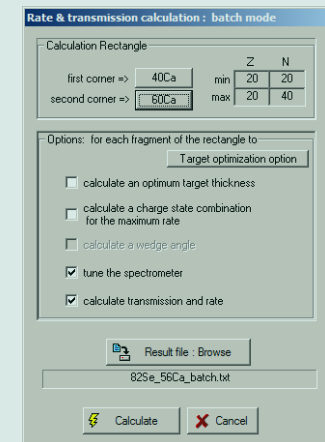
In-Flight : NSCL

For neutron-rich Ca-isotopes

⁸²Se (140 MeV/u) + Be

1. Why ⁸²Se for neutron rich calcium isotopes?
2. Load the A1900 configuration
3. Set beam characteristics using the NSCL primary beam list
4. Set target - Be
5. Set Projectile fragmentation as production mechanism
6. Set fragment of interest (assume ⁵⁶Ca).
7. Set No charge states option
8. Set maximum momentum acceptance
9. Calculate the Optimum thickness target
10. Estimate wedge thickness
11. Set the fragment separator for ⁵⁶Ca
12. Calculate ⁵⁶Ca ion transmission*
13. Insert “Delay” and “Faraday cup” blocks after the stripper
14. Set values* in the “Delay” block
15. Calculate calcium isotopes production
16. Plot calcium isotopes yields, Save yields in file

Instead 11-15 it is possible to use “Rate& transmission calculation: batch mode” in the “Utilities” menu



Why ^{82}Se for neutron rich calcium isotopes?

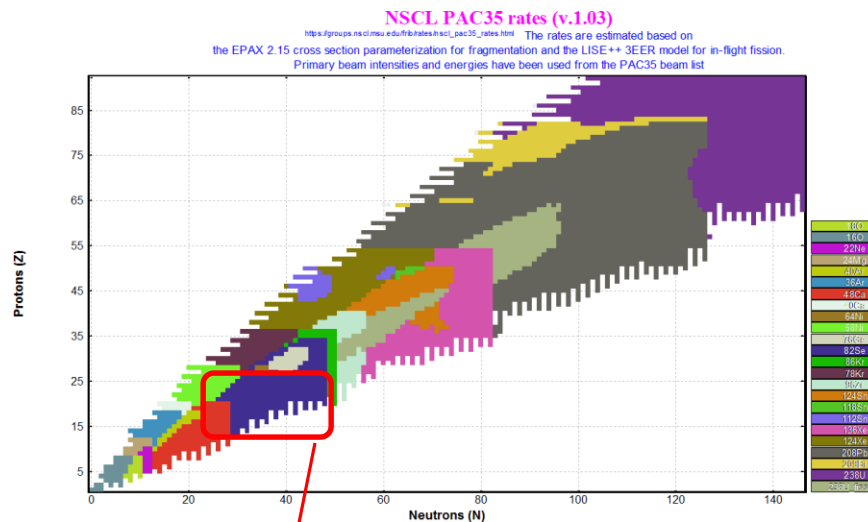
Utilities 1D-Plot 2D-Plot Databases Help

- LISe++ for Excel
- CODES: Charge, Global, PACE4, etc.
- Radioactivity, decays
- Reactions utilities
- Plots: Energy loss, Ranges, Stragglings, etc.
- NSCL / FRIB rates**
- Set-up utilities
- Range optimizer (Gas cell utility)
- Gas pressure optimization for gas-filled dipole
- CATCHER utility (ISOL, Fusion-Residual)
- Rate & transmission calculation: batch mode
- Stripper foil lifetime

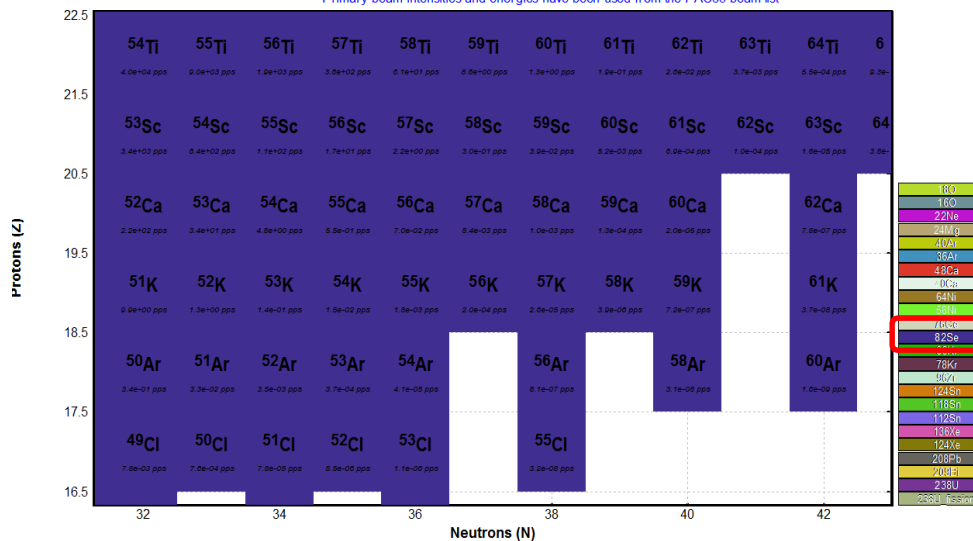


plot: NSCL PAC35 rates
 plot: NSCL PAC35 beams
 link: NSCL PAC35

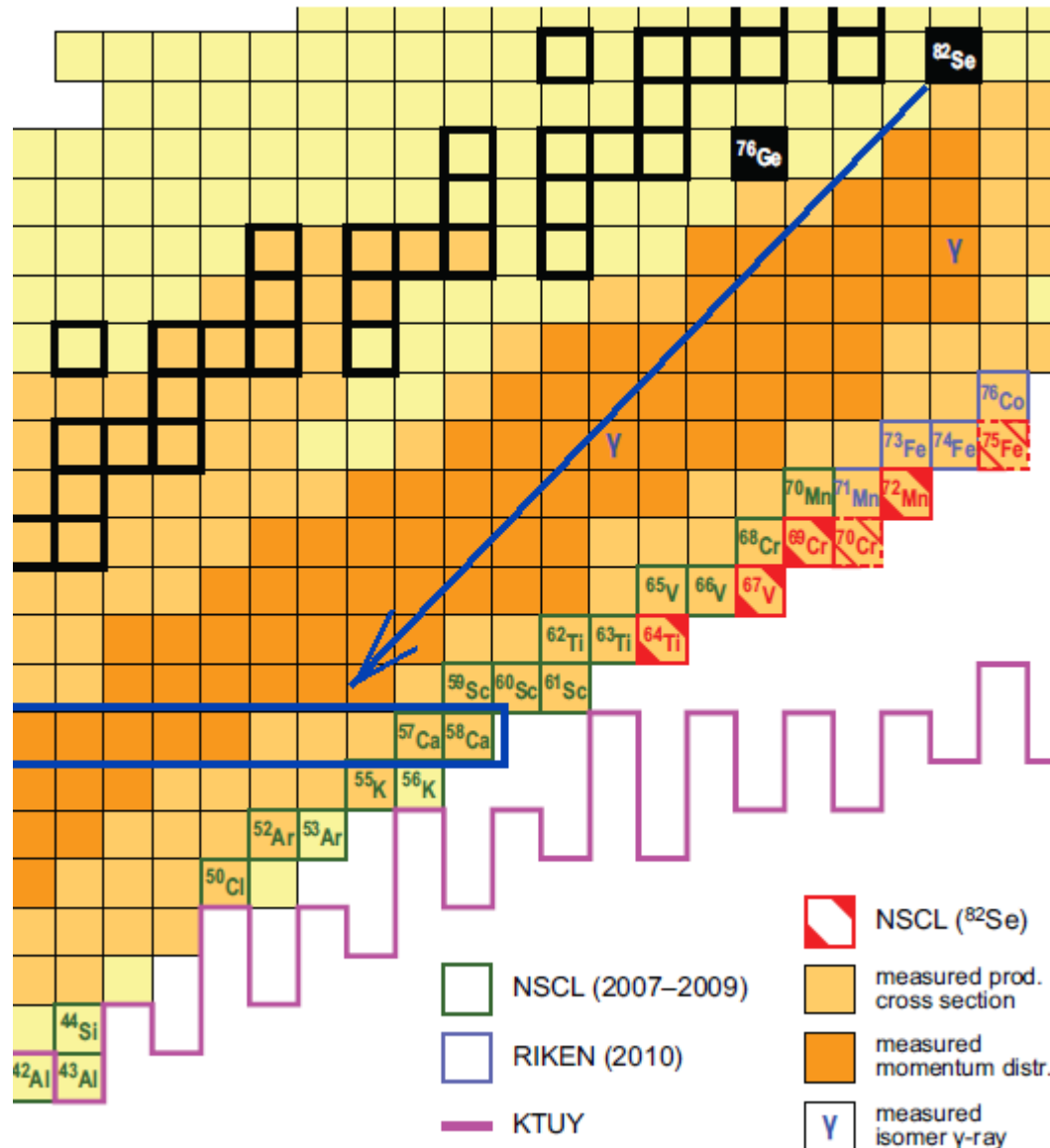
plot: FRIB rates (v.1.07)
 plot: FRIB beams (v.1.07)
 link: FRIB (v.1.06)

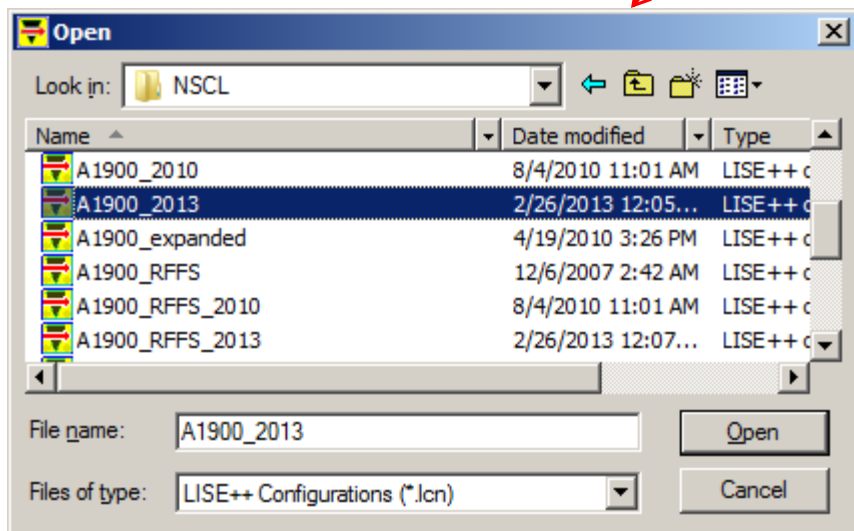
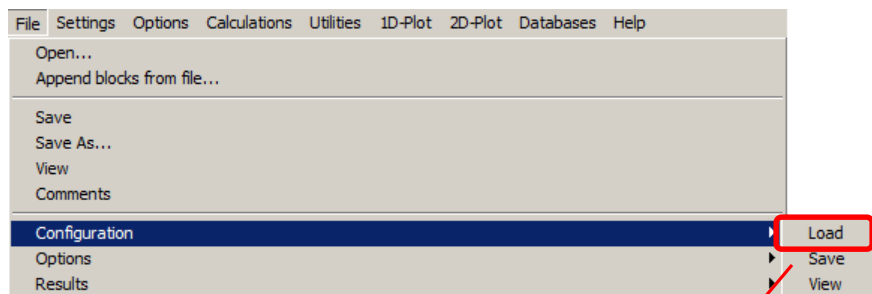


NSCL PAC35 rates (v.1.03)
https://groups.nsl.msu.edu/frib/rates/nscl_pac35_rates.html The rates are estimated based on the EPAX 2.15 cross section parameterization for fragmentation and the LISe++ 3EER model for in-flight fission. Primary beam intensities and energies have been used from the PAC35 beam list



O.T. et al, PRC 87, 054612 (2013)





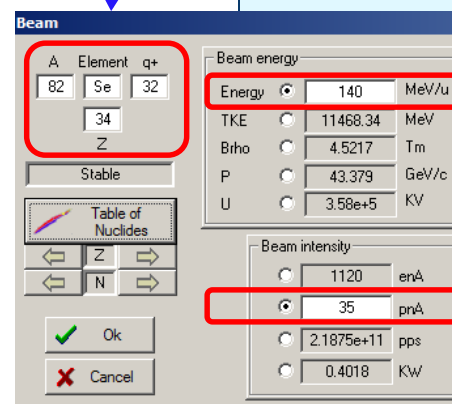
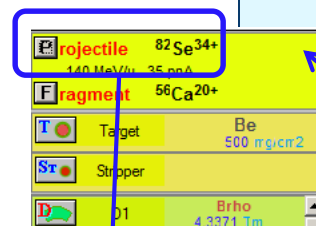
<http://www.nscl.msu.edu/exp/propexp/beamlist>



Home > NSCL Primary Beam List

Developed Primary Beams

Particle	Energy (MeV/nucleon)	Intensity (pnA)
¹⁶ O	150	175
¹⁸ O	120	150
²⁰ Ne	170	80
²² Ne	120	80
²² Ne	150	100
²⁴ Mg	170	60
³⁶ Ar	150	75
⁴⁰ Ar	140	75
⁴⁰ Ca	140	50
⁴⁸ Ca	90	15
⁴⁸ Ca	140	80
⁵⁸ Ni	160	20
⁶⁴ Ni	140	7
⁷⁶ Ge	130	25
⁸² Se	140	35
⁷⁸ Kr	150	25
⁸⁶ Kr	100	15
⁸⁶ Kr	140	25
⁹⁸ Zr	120	1.5
¹¹² Sn	120	4
¹¹⁸ Sn	120	1.5
¹²⁴ Sn	120	1.5
¹²⁴ Xe	140	10
¹³⁶ Xe	120	2
²⁰⁸ Pb	85	1.5
²⁰⁹ Bi	80	1
²³⁸ U	45	0.1
²³⁸ U	80	0.2



Set target - Be

Target

Be Density: 1.85 g/cm³

Z	Element	Mass
<input checked="" type="checkbox"/>	4 Be	PT 9.012
<input type="checkbox"/>	14	
<input type="checkbox"/>	14	
<input type="checkbox"/>	14	
<input type="checkbox"/>	14	

Compound dictionary

Set Projectile fragmentation as production mechanism

Production Mechanism

Reactions / Energy Loss, Straggling / Charge states / Databases: Masses, Isomers /

82Se(140.0 MeV/u) + Be -> 56Ca

Reactions:

- Projectile Fragmentation
- Fusion -> Residual
- Fusion -> Fission
- Coulomb fission
- Abrasion-Fission
- Two Body Reactions
- ISDL mode

OK Cancel Help

Set fragment of interest (assume ⁵⁶Ca)

Setting Fragment

A: 56 Element: Ca Z: 20

Charge states: 20+ D1

Ok Cancel

Set "No charge states" option

53K	54K	55K	56K	57K
52Ar	53Ar	54Ar	56Ar	
14	<input checked="" type="checkbox"/> No charge states			DG=-0.0

S	I2_slits	slits
	-150	+150
W	I2_wedge	AI 50 mg/cm ²
D	D3	Brho 4.2969 Tm
D	D4	Brho 4.2969 Tm
M	FP_PPAC0	AI 2 mg/cm ²
M	FP_PPAC1	AI 2 mg/cm ²
S	FP_slits	slits
	-25	+25
M	FP_PIN	Si 516 micron
M	FP_SCI	C9H10 100 mm
config: A1900_2013		
option: A1900_2013		
version: 9.6.119		
	dpp	5.07% total

"I2_slits" block : Apertures (throughout), Slits (after)

horizontal

Left limit (aperture) -150 mm

Right limit (aperture) 150 mm

L slit: -150

R slit: 150

APERTURES

Shape (see *)

Rectangle

Ellipse

Use in Calculations

Horizontal

Vertical

SLITS

Slits shape (see *)

Rectangle Ellipse

Horizontal Slit

Set

conjointly

separately

Use in Calculations

Show in schematics

Vertical Slit

Set

conjointly

separately

Use in Calculations

Show in schematics

Horizontal plane

dispersion (mm/%)

-59.12

x-momentum[%] (slit/dispersion)

total 5.07

Vertical plane

dispersion (mm/%)

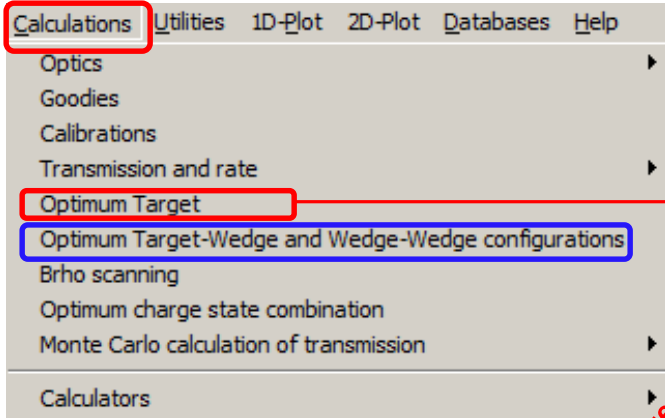
0

y-momentum[%] (slit/dispersion)

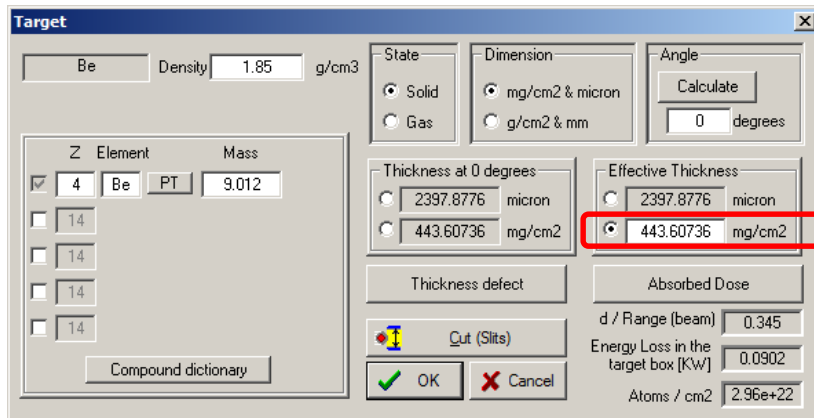
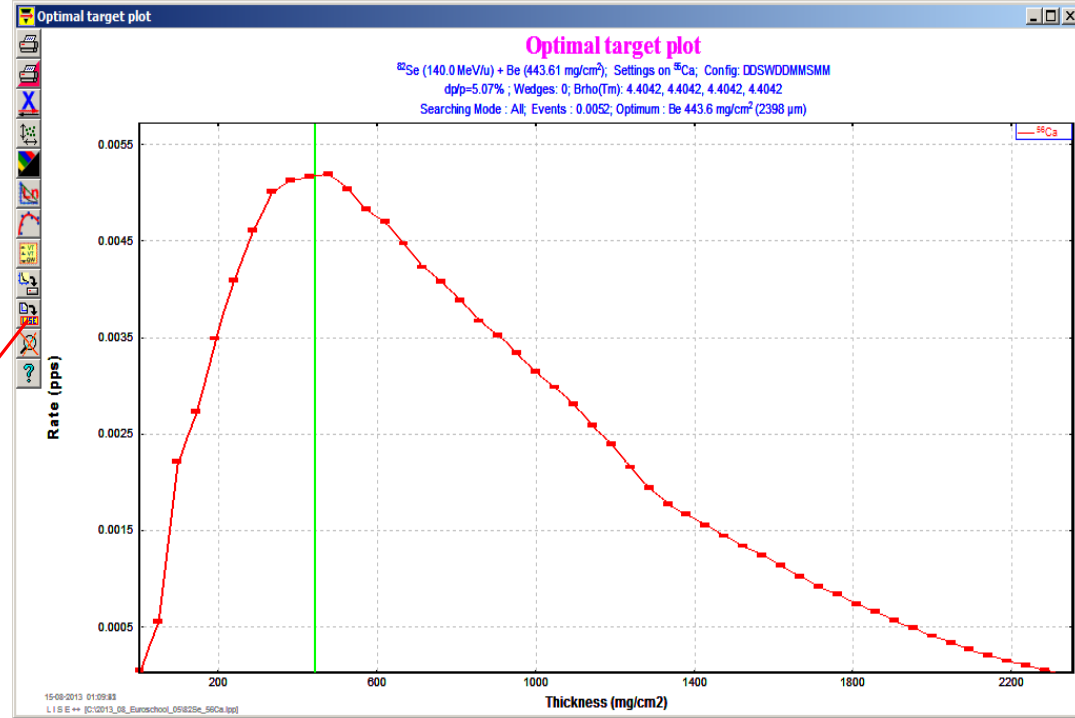
total 100

* Only the Monte Carlo mode uses "Ellipse" Shapes and Aperture settings.

The Distribution method uses only "Rectangle" shape slits.



Assign the calculated value to the target thickness



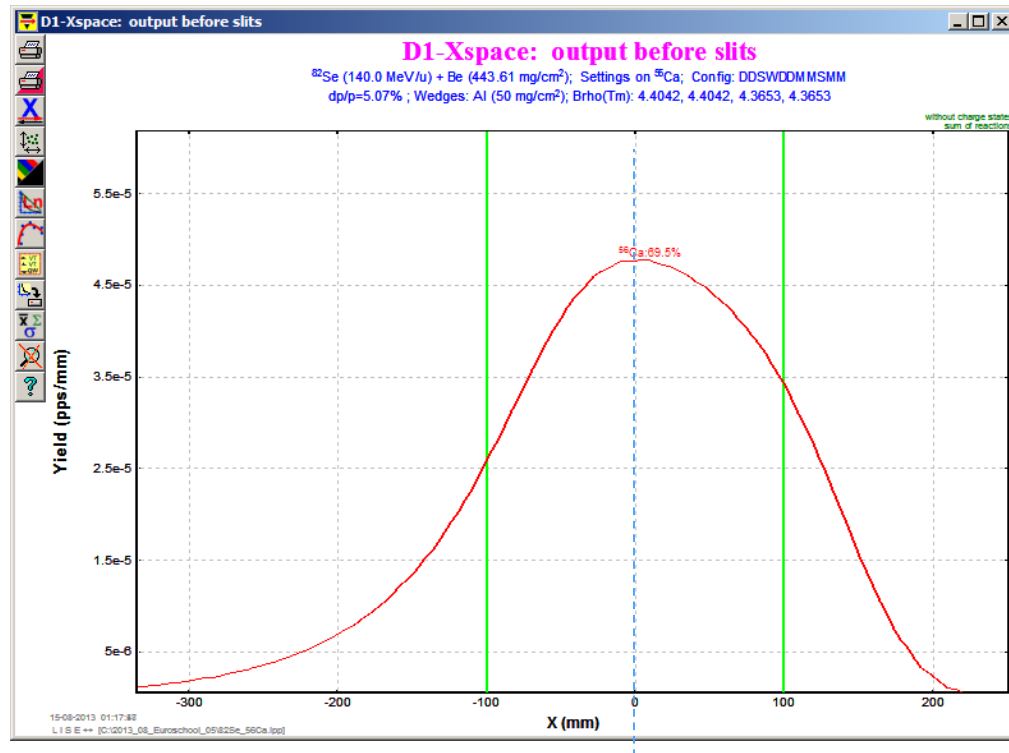
!!! Remember you should also enter a wedge thickness

Several iterations, or use the Optimum target-wedge optimization

Estimate wedge thickness



D1	Brho 4.4042 Tm
D2	Brho 4.4042 Tm
I2_slits	S IS
I2_wedge	Al 50 mg/cm ²
D3	Brho 4.3653 Tm
D4	Brho 4.3653 Tm
FP_PPAC0	Al 2 mg/cm ²



LISE++ tunes the fragment separator to be maximum* of spatial distributions (in dispersive direction) at the central optical axis

* - tuning options can be modified at the Preference dialog



Calculate spectrometer settings using

maximal mean

value of the momentum distribution

left peak right peak

Click by a right button of mouse on the ^{56}Ca cell

^{55}Sc	^{56}Sc	^{57}Sc	^{58}Sc	^{59}Sc
^{54}Ca	^{55}Ca	^{56}Ca 5.1e-3 37.456%	^{57}Ca	^{58}Ca
^{53}K	^{54}K	^{55}K	^{56}K	^{57}K
^{52}Ar	^{53}Ar	^{54}Ar	^{55}Ar	^{56}Ar

statistics: ^{56}Ca

^{56}Ca	Beta- decay (Z=20, N=36)	Calcium
Q1 (D1)	20	
Q2 (D2)	20	
Q3 (D3)	20	
Q4 (D4)	20	
Production Rate (pps)	5.1e-3	
Reaction	Fragmentn	
Sum of all reactions (pps)	5.1e-3	
CS in the target (mb)	2.1e-9	
Total transmission (%)	37.456	
Target (%)	94.59	
X space transmission (%)	100	
Y space transmission (%)	100	
Unreacted in mater. (%)	94.59	
Unstopped in mater. (%)	100	
D1 (%)	64.61	
X space transmission (%)	69.51	
Y space transmission (%)	100	
X angular transmision. (%)	99.66	
Y angular transmision. (%)	93.25	
D2 (%)	72.86	
X space transmission (%)	72.92	
Y space transmission (%)	100	
X angular transmision. (%)	100	
Y angular transmision. (%)	100	
I2_slits (%)	91.15	

Assume, that this value is nearby the same for other neutron rich calcium isotopes at their tunings

1. Calculate calcium isotopes production
2. Plot Calcium isotopes transmission →

Choose a Plot Type

Dimension of the plot
 ONE-dimensional TWO-dimensional NZ chart

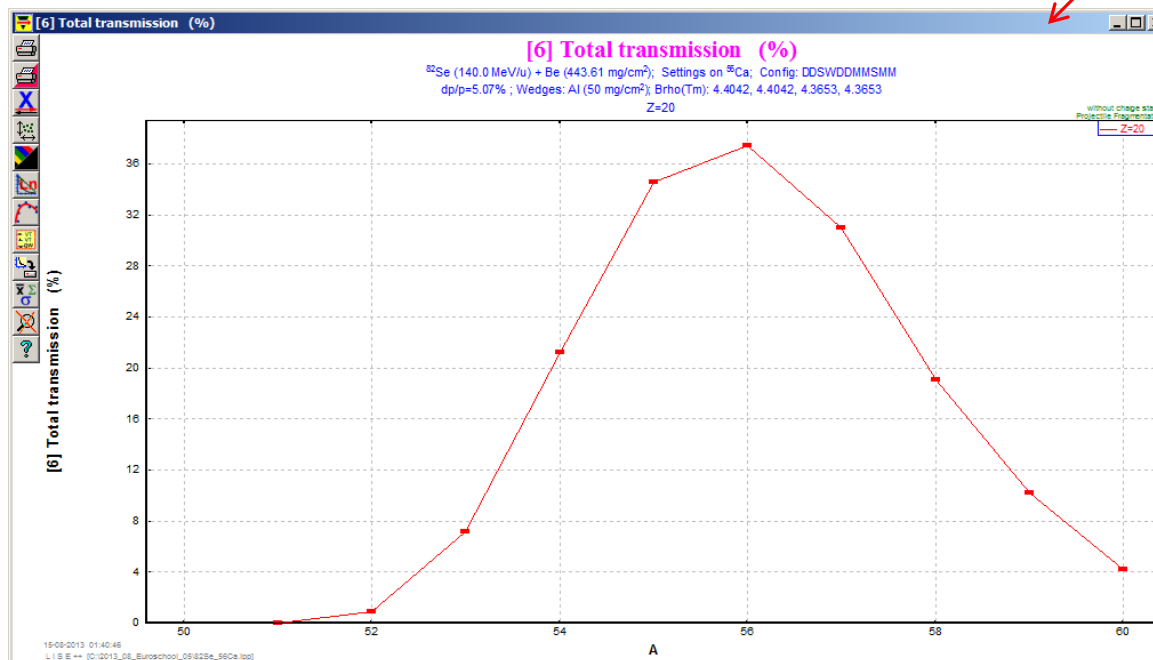
transmission characteristic to draw a plot
 06 Total transmission [%]

Plot type
 Isotopes, Z=const
 Isobars, A=const
 Isotones, N=const
 Isospin, N-Z=const
 N-ZZ=const
 <N>/Z
 sum(value); Z=const
 sum(value); A=const
 sum(value); N=const

Zmin = 20
 Zmax = 20

function of
 Z (protons)
 A (nucleons)
 N (neutrons)
 N-Z (isospin)
 N-ZZ

All
 Odd
 Even



1. Insert “Delay” and “Faraday cup” blocks after the stripper
2. Set values* in the “Delay” block \longrightarrow
3. Calculate calcium isotopes production
4. Plot calcium isotopes yields, Save yields in file \longrightarrow

Delay 1

Time (drift, extraction or breeding)

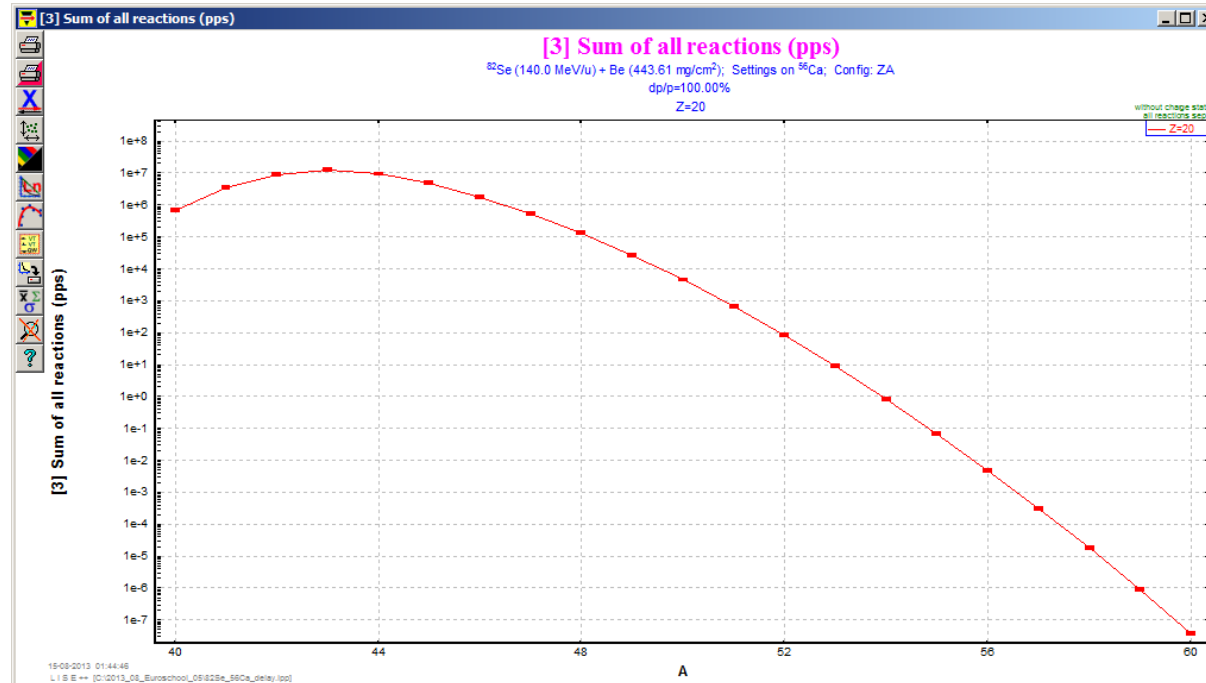
Use

Mass	Time, sec
Light <= 50	
50 < Medium < 150	
150 <= Heavy	

Efficiency

Use

Mass	Efficiency, %
Light <= 50	37
50 < Medium < 150	37
150 <= Heavy	37



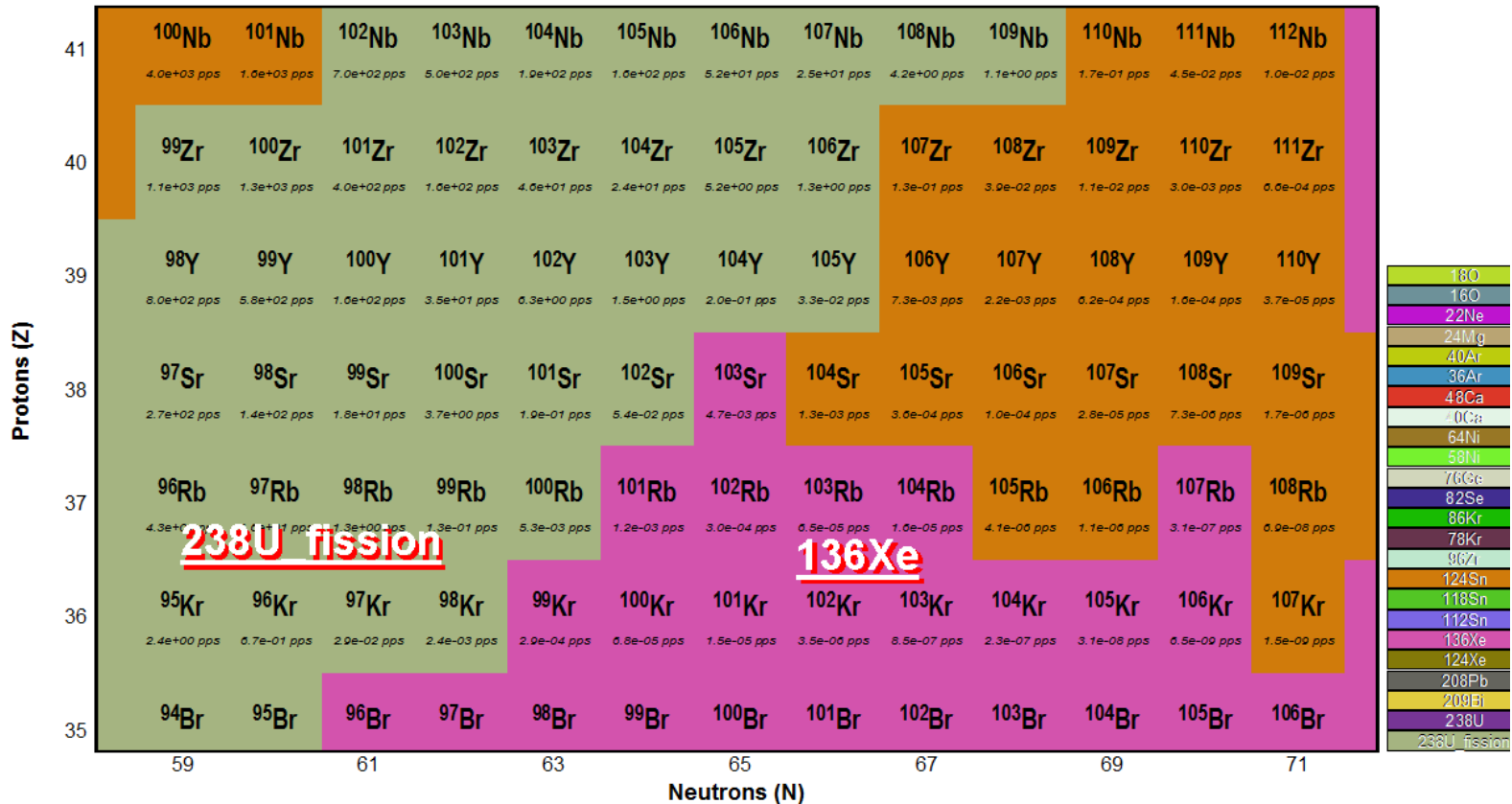
ISOL : the same steps as for Calcium isotopes

In-flight:

1. Projectile fragmentation of ^{136}Xe
2. Abrasion-fission of ^{238}U (turn on the “charge state” option !!)

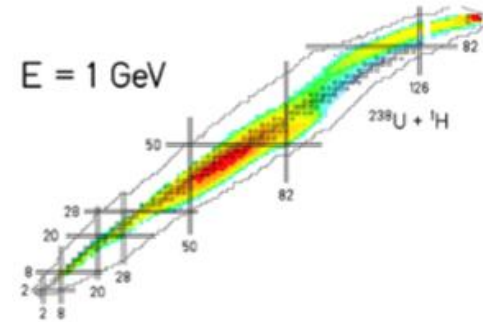
NSCL PAC35 rates (v.1.03)

https://groups.nsl.msu.edu/frab/rates/nsl_pac35_rates.html The rates are estimated based on the EPAX 2.15 cross section parameterization for fragmentation and the LISE++ 3EER model for in-flight fission. Primary beam intensities and energies have been used from the PAC35 beam list



HRIBF : p(40MeV, 5uA) + ^{238}U

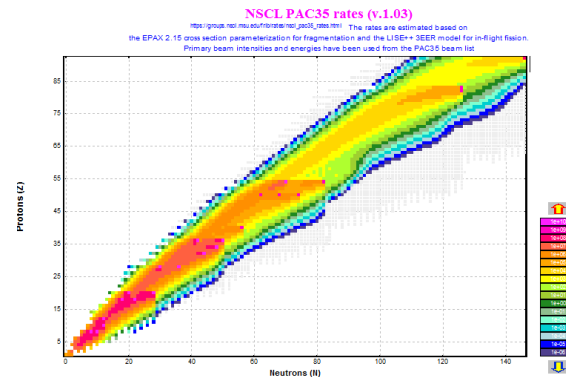
Assumptions for ISOL method:
 Total efficiency: 10%
 Extraction time: 50 ms

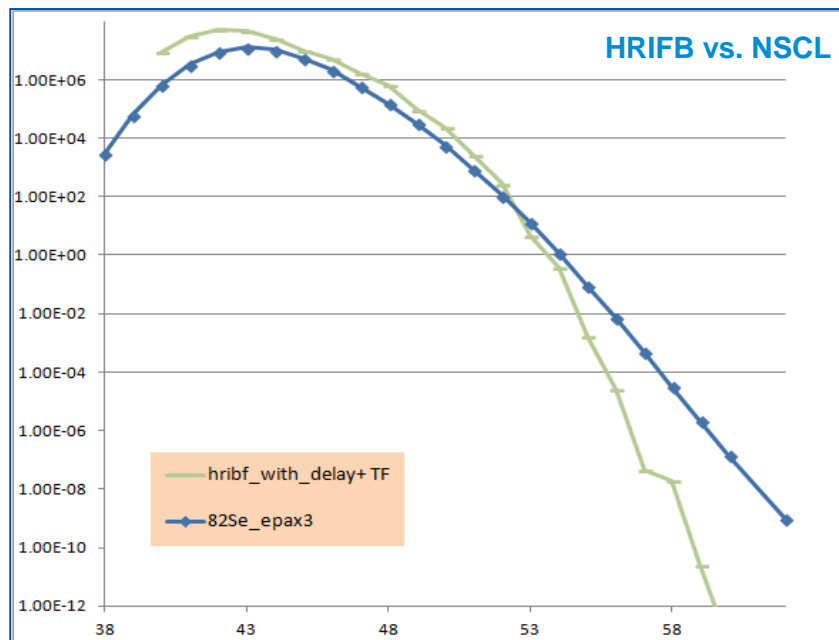
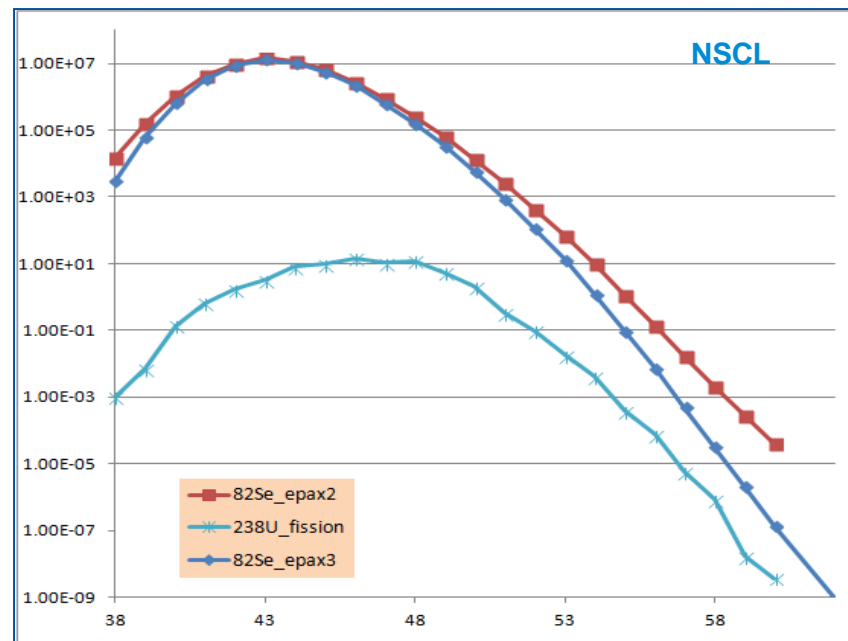
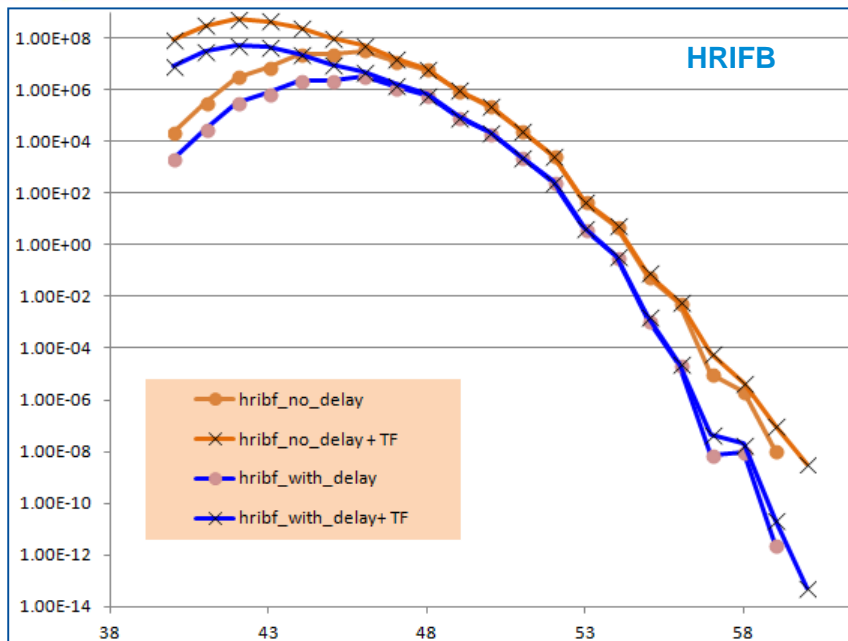


NSCL : from the beam list

for Ca isotopes ^{82}Se (140MeV/u, 35 pna)
 ^{238}U (80MeV/u, 0.2 pna)

for Kr isotopes ^{136}Xe (120MeV/u, 2 pna)
 ^{238}U (80MeV/u, 0.2 pna)





“Delay” block

Total efficiency: 10%

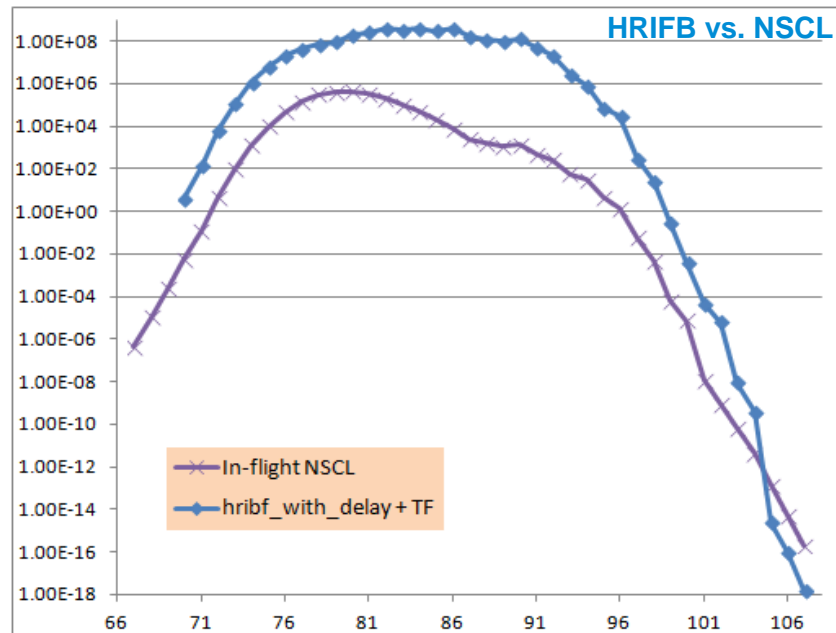
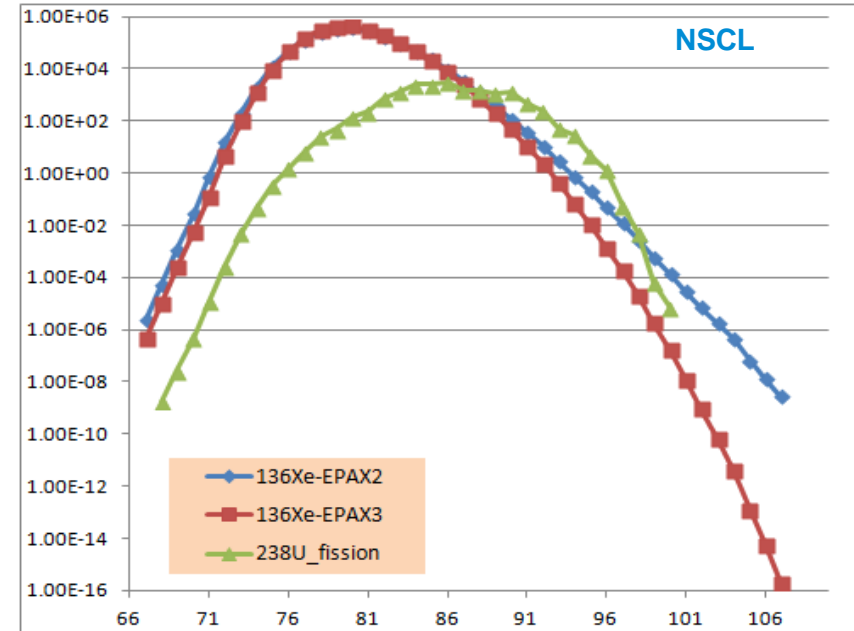
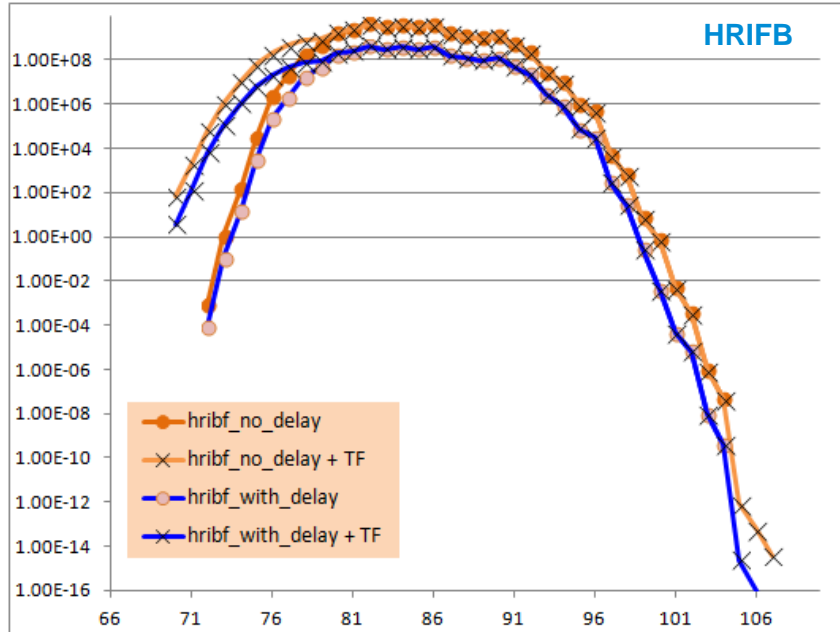
Extraction time: 50 ms

X-axis : Mass number

Y-axis : rate (pps)

TF – target fragmentation
calculated with EPAX3

Last neutron-rich Calcium isotopes $^{57,58}\text{Ca}$ have been observed @ NSCL in projectile fragmentation of ^{76}Ge and ^{82}Se



“Delay” block
 Total efficiency: 10%
 Extraction time: 50 ms

X-axis : Mass number
 Y-axis : rate (pps)

TF – target fragmentation
 calculated with EPAX3

Last neutron-rich Krypton isotopes $^{98-101}\text{Kr}$ have been observed @ GSI & RIKEN in in-flight fission of ^{238}U

Future for Two-step process?

1. ISOL fission
2. In-flight PF

Questions ?

Haben Sie Fragen?

Вопросы ?

有問題嗎？

¿Preguntas?

Demandoj?

質問？

Pytania?

Domande?

Sorular?