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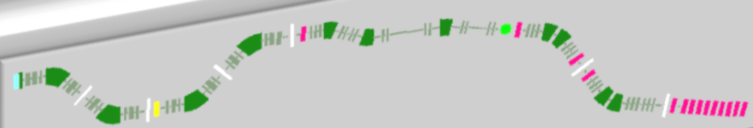
Production of Fast Rare Ion Beams

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

26-31 / 08 / 2013

LISE++



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

NSCL

2. Production

1. **Choice of place for the experiment**
   - ✓ Intensities
   - ✓ Primary beam lists
2. **Planning of Fast RIB Experiment**
   - ✓ Ion yields after target
3. **Settings**
   - ✓ Beam
   - ✓ Target
   - ✓ Fragment of interest
   - ✓ Charge state model
   - ✓ Energy loss model
   - ✓ Secondary reactions in target
   - ✓ Reaction mechanism
4. **Reaction mechanisms**
   - ✓ Evaporation cascade
     - Fission barrier
   - ✓ Projectile fragmentation
   - ✓ Fission fragment production model
   - ✓ Coulomb fission
   - ✓ Abrasion-Fission
   - ✓ Fusion-Fission
   - ✓ Fusion-Residual
   - ✓ Two body reactions
   - ✓ others
5. **Efficiency transmission at target**

Some definitions will be used in the lectures

- **for whom this information**
- **who is responsible**


User


Advanced


Beam physicist

Choice of place for the experiment with RIBs

- What is priority?
  - Energy & Intensity combination
  - Energy
  - Intensity
  - Purity

- Technical devices (Detector arrays, specific targets)
- Beam Inclination on target (LISE@GANIL, A1900@NSCL)
- Specific separation devices (Wien-filter, RF-kicker)
- Reliability of accelerator complex

- Out of discussion
  - Your proposal: how difficult to pass through a PAC
  - How expensive travelling and lodging
  - Visa troubles, local food, and so on

- Accelerator type is not criteria

Information:
- Primary beam list
- Technical devices availability
- Call for proposal

Intensity: Factors for production of new isotopes

$$Y = I \; t \; N_t \; \sigma \; \varepsilon_t \; \varepsilon_s \; \varepsilon_i$$

Laboratory	Separator	Energy, Mev/u	target thickness	atoms/cm^2	Intensity, pnA	Experiment time	published measured cross section [barn]		dose, beam particles	reduced* CS, barn
GSI	FRS	500-1000	Be:1-10g	8.00E+22	3.00E-03	1 week	1E-10	M.Bernas et al., PL B 415 (1997) 111	1E+13	1E-12
GANIL	LISE	75	Ta:1g	3.60E+21	10-100	1 week	2E-13	O.Tarasov et al., PL B409 (1997)64	2E+17	1E-15
RIKEN	RIPS	90	Ta:0.7g	2.30E+21	10-100	1 week	2E-14	H.Sakurai et al., PL B448 (1999) 180	2E+17	3E-15
GANIL	LISE	60	Ta:0.3g	8.80E+20	10-100	1 week	6E-14	S.Lukyanov et al., J Phys G 28 (2002) L41	4E+17	3E-15
RIKEN	BigRIPS	340	Be:1g	6.20E+22	0.1-10	1 week	1E-13	T.Ohnishi et al., JPSJ 79 (2010) 073201	9E+14	2E-14
Dubna	GFS	6-10	Bk: 3e-4 g	7.30E+17	1000	half year	1E-13	Yu.Oganessian et al., PRL 104 (2010) 142502	1E+20	1E-14
NSCL	A1900	140	W:1.9g	6.30E+21	8.00E+01	11 days	*9.4E-15*	T.Baumann et al., Nature 449 (2007) 1022	5E+17	3.3E-16
NSCL	A1900	130	Be:0.7g	4.70E+22	2.50E+01	1 week	8E-15	O.Tarasov et al., PRL 102 (2009) 142501	9E+16	2.3E-16
NSCL	A1900	140	Be:0.8g	5.35E+22	3.50E+01	1 week	3E-15	O.T. et al., PRC 87 (2013) 054612	1E+17	1.4E-16
	FUTURE									
GSI	SuperFRS	1.50E+03	Be:15g	1.00E+24	1.60E+02	1 week			6E+17	1.7E-18
FRIB	A2400	200	Be:1g	6.20E+22	1.00E+04	1 week			4E+19	4.3E-19

* *reduced*, Y=1 , assuming ε_t ε_s ε_I equal to 100%, 100% time just for one production run

** RIKEN : ^{48}Ca 345 MeV/u 150 pnA

Primary beam lists

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
^{96}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

RIKEN NISHINA CENTER

http://www.nishina.riken.jp/RIBF/accelerator/tecinfo.html

Beam particle	E/A(MeV)	Beam current (pnA)		Injector
		Maximum (instantaneous) achieved so far	Expected ¶ (for exp. planning in your proposal)	
d	250	1000	200	AVF
d(pol.)	250	120	30	AVF
^{4}He	320	1000	1000	AVF
^{14}N	250	400	400	RILAC
^{18}O	345	1000	500	RILAC
^{48}Ca	345	415	150	RILAC
^{70}Zn	345	100	75	RILAC
^{76}Ge	345	not tested	N/A	RILAC
^{78}Kr	345	under development	50	RILAC
^{86}Kr	345	30	50	RILAC
^{136}Xe	345	not tested	20	RILAC2
^{124}Xe	345	27	20	RILAC2
^{238}U	345	15.1	10	RILAC2

¶ Some intensities are limited by shielding requirements

Stable beams

Grand Accélérateur National d'Ions Lourds GANIL Laboratoire commun CEA/DSM - CNRS IN2P3

http://pro.ganil-spiral2.eu/users-guide/accelerators/available-stable-ion-beams-at-ganil/view/

SPIRAL beams http://pro.ganil-spiral2.eu/users-guide/accelerators/spiral-beams/

Planning of Fast Rare Ion Beam Experiment

- Select correct configuration file
- Choose reaction for desired product
- Choose of primary beam and production target based on the reaction choice
- Settings
  - Set desired fragment
  - Multi-step fragmentation in very thick targets?
  - Set options (energy loss, charge state and so on) corresponding to these energies, reaction and so on
  - Define momentum acceptance
  - Set wedge slits
- Define detector system in beam-line
- Optimize target thickness
  - Compromise between target yield and energy loss
  - Use optimum target calculator
- Choose wedge thickness
  - Compromise between intensity and purity
  - Also depends on the type of experiment
  - Can use target-wedge optimizer, but slow…
- Forecast of yields and purity
- Define detector system in the focal plane
- Test of experiment feasibility

Note for "Planning of Fast Rare Ion Beam Experiment "

- Select correct configuration file

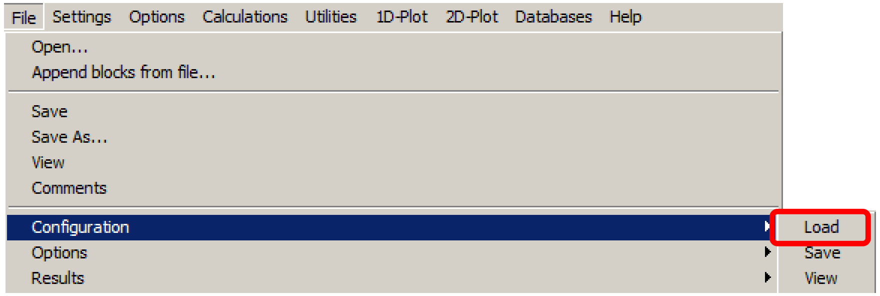
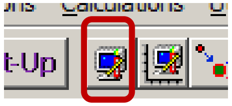


Table 1. *File extensions used by LISE++.*

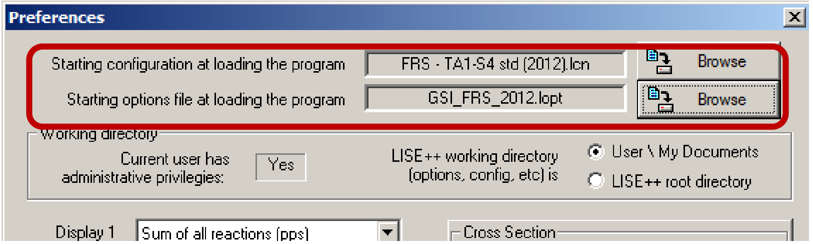
Type of file	LISE++	Default directory
Regular	lpp	/files
Configuration (set-up)	lcn	/config
Option	lopt	/options
Degrader	degra	/degrader
Calibration	cal	/calibrations
Matrix	mat	/files
Cross section	cs	/CrossSections
….	…	…

LPP = LCN +
LOPT +
Experiment settings +
Calculation results +
User Cross sections

After installation of the LISE^{++} package



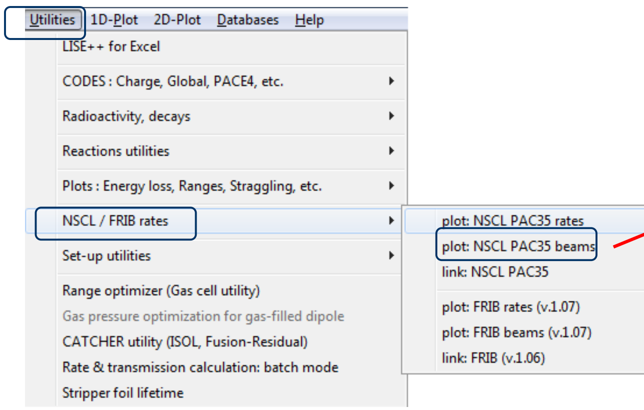
Default configuration: A1900_2013.lcn
Default option file: A1900_2013.lopt
which are set for projectile fragmentation (~80-200 MeV/u)

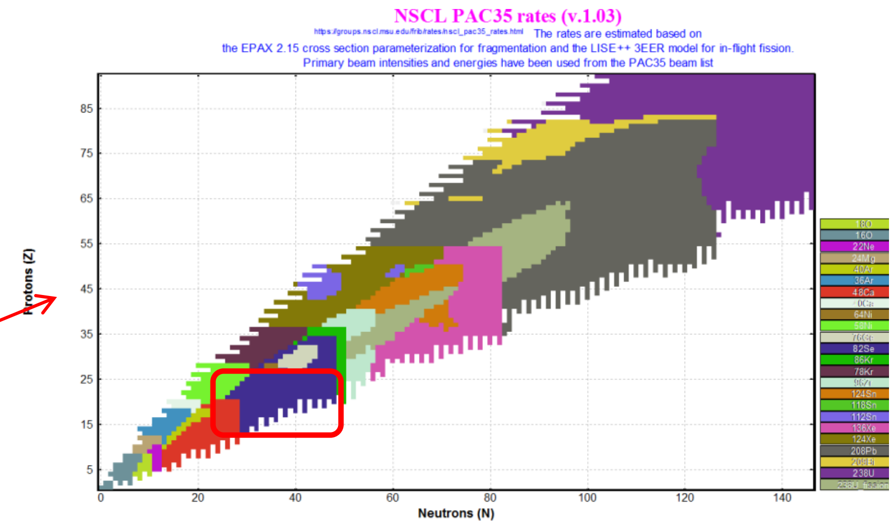


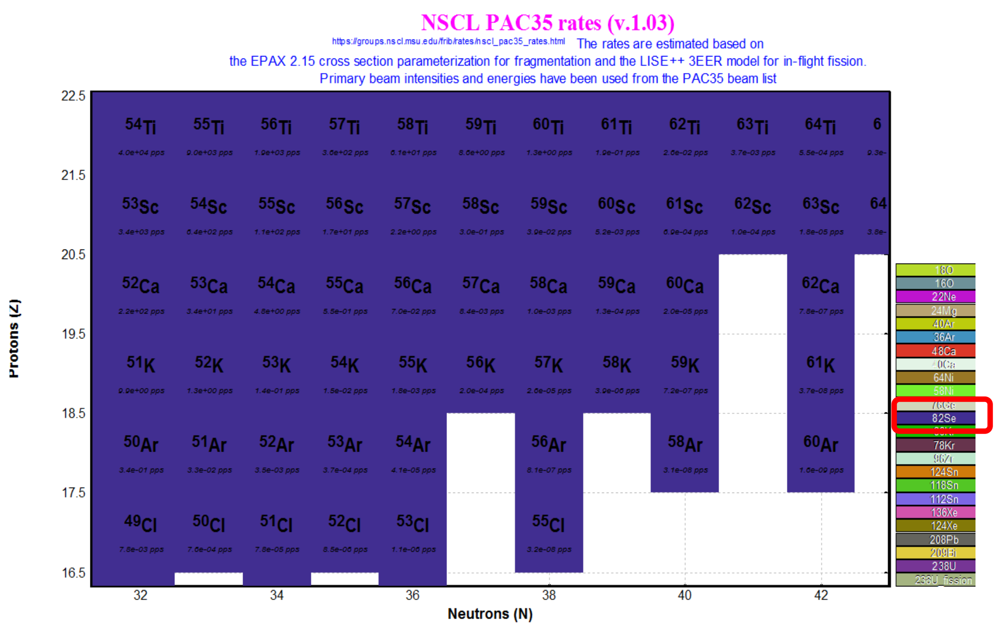
Choose reaction for desired product

Question:

What reaction and beam for production of neutron rich calcium isotopes?







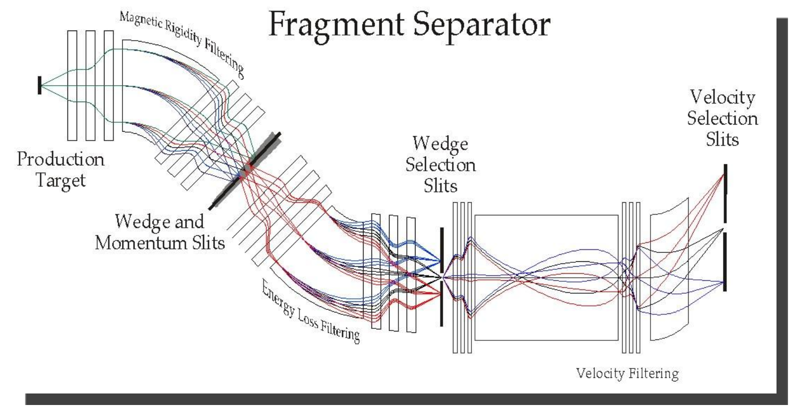
Answer:

Projectile fragmentation of ^{82}Se

Ion yields after target

$$Y = I \; t \; N_t \; \sigma \; \varepsilon_t \; \varepsilon_s \; \varepsilon_i$$

1. Production Area



3. Identification

2. Separation

Y number of registered events

σ production cross section — **Reaction**

N_t number of target atoms — **Target**

$N_t = d_t M_t / N_A$

where

- d_t target thickness
- N_A Avogadro number
- M_t atomic mass number

I beam intensity — **Beam**

t duration of measurement

ε_t efficiency transmission at target — **Settings, Options**

ε_s efficiency transmission through sep[arator]

ε_i identification efficiency

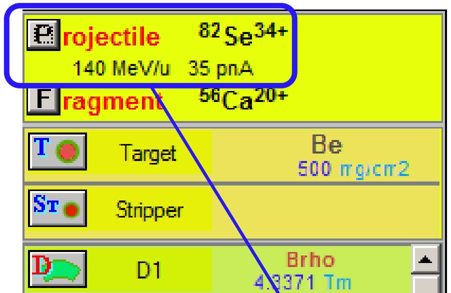
ε_t efficiency transmission at target
- lost of primary beam and fragments of interest due to reaction in target and stripper
- Charge state factor after target (stripper)
- Gain due to secondary reactions

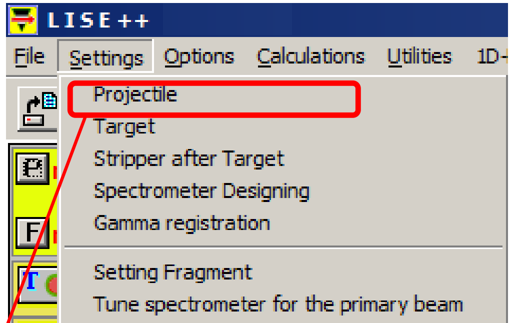
ε_s efficiency transmission through separator
- lost of fragments of interest due to reaction in materials located in the separator
- charge state factor after materials
- Angular acceptance
- Momentum selection
- Wedge selection
- Other selections

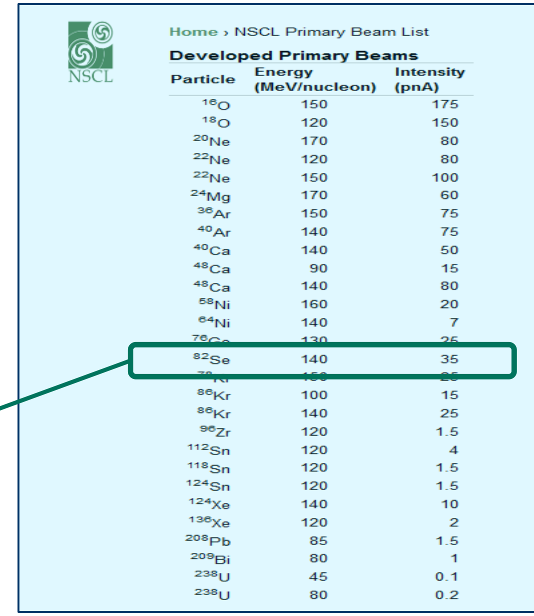
ε_i identification efficiency
- lost of fragments of interest due to reaction in detectors
- Live time (as well pile-ups)

Setting the Beam

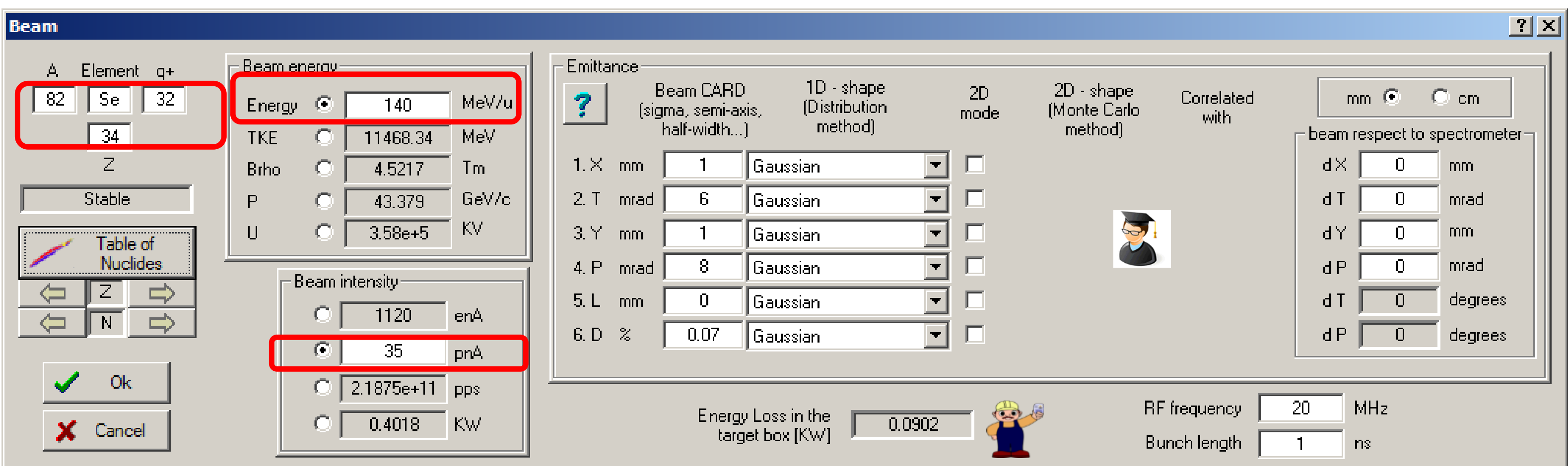
for all icons in the toolbar and in the production panel there are corresponding commands in the menu







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
^{96}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



Target

projectile fragmentation

- Heavy target : larger cross sections
- Light targets have more nuclei per electron, hence larger nuclear interaction probability at fixed electronic slowing down than heavy target
- Overall case for projectile fragmentation: $(\sigma\ N_t)_{light} > (\sigma\ N_t)_{heavy}$
- Chemical and physical properties of material as melting point, thermal conductivity etc,

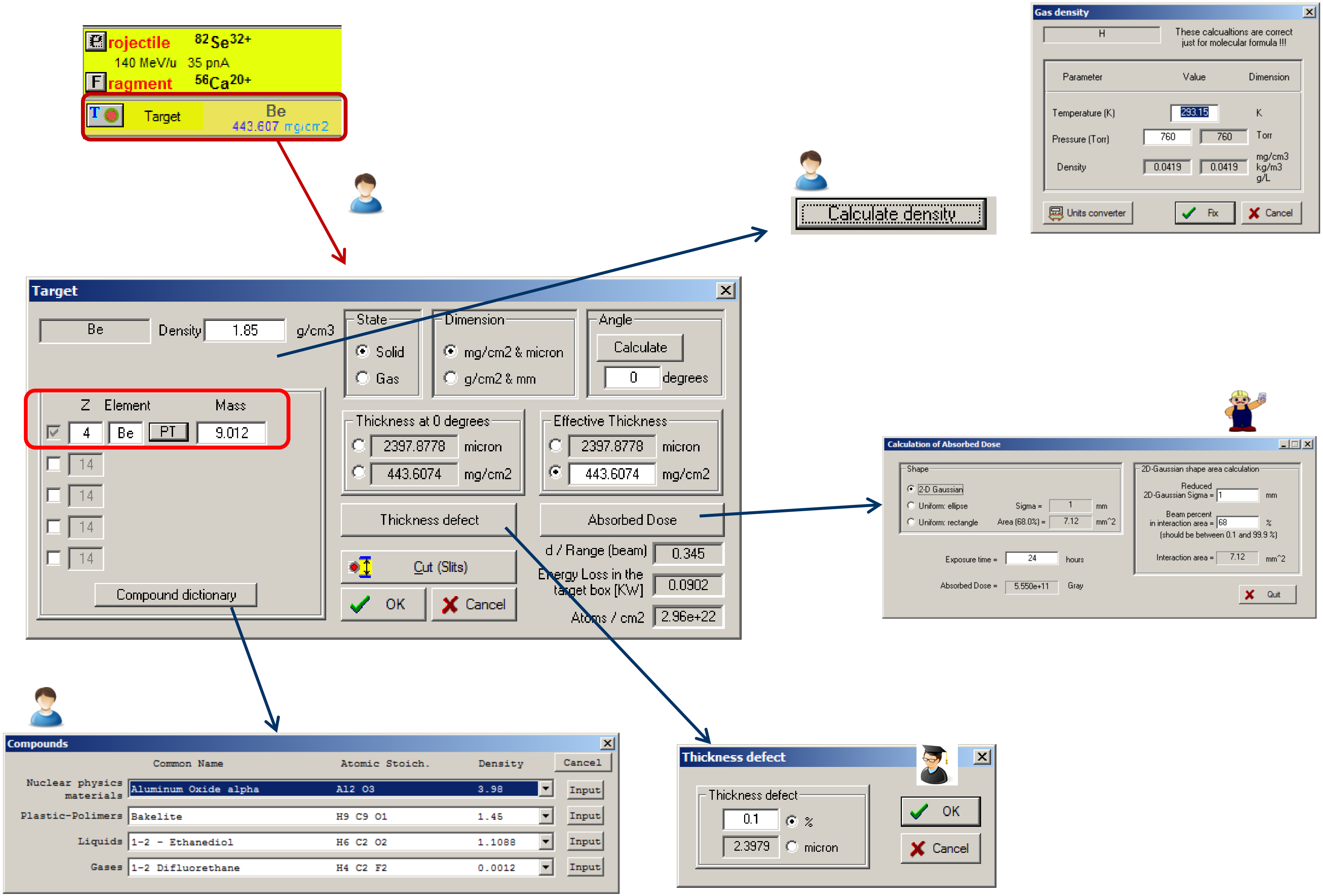
  so lifetime of Be target >> lifetime of equivalent Ta target
- Charge state distribution after target: light targets provide higher average *q* of ions

  ** using strippers after heavy targets*
- Dissipation process larger with heavy targets

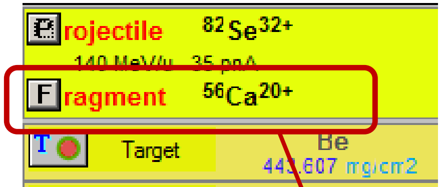
  so ^{40}Mg and ^{44}Si been have observed in ^{48}Ca+W

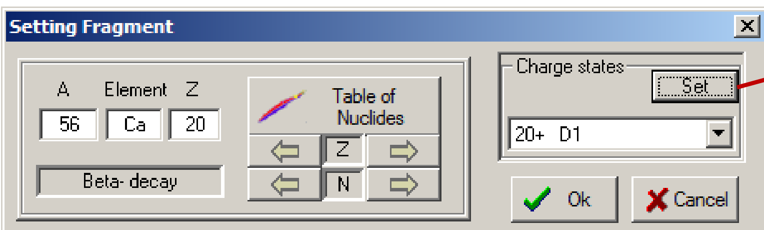
This favors light targets (NSCL uses Be)

Setting the target

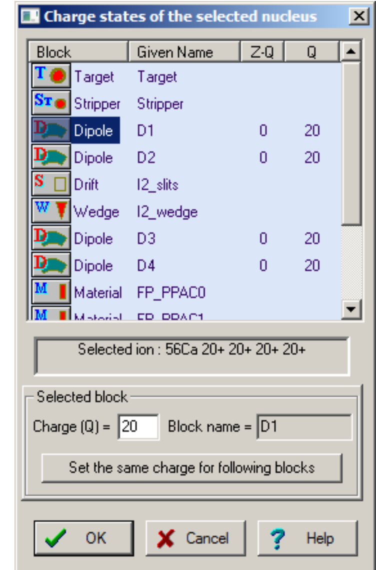


Setting fragment





If Charge state option is ON



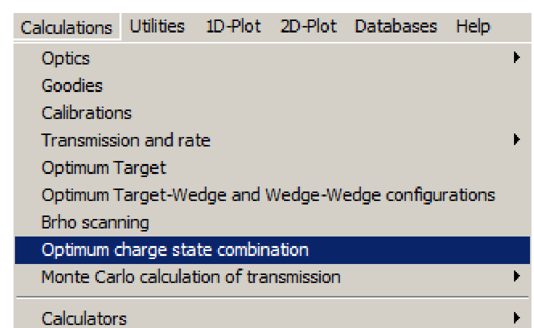
It is used to tune the fragment separator on setting ions

Use "Charge state" for
- **Low energy**
- **Heavy fragments**

For example in the reaction ^{82}Se(140MeV/u) + Be no charge states expected.

It is recommended to turn off charge states to provide fast calculation.

Alternative:
LISE++ can find the optimum charge state combination



Charge state fraction

Should pay attention for charge state distribution after target and each time passing material.

Then more materials
(at low energies or with heavy elements experiment),
then less setting ion transmission

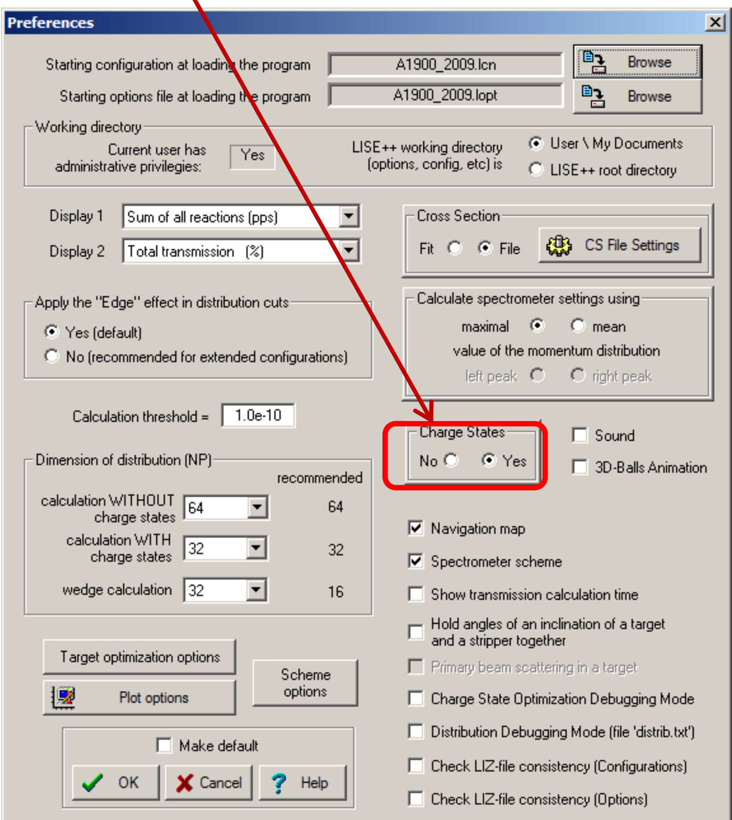
Depends on:

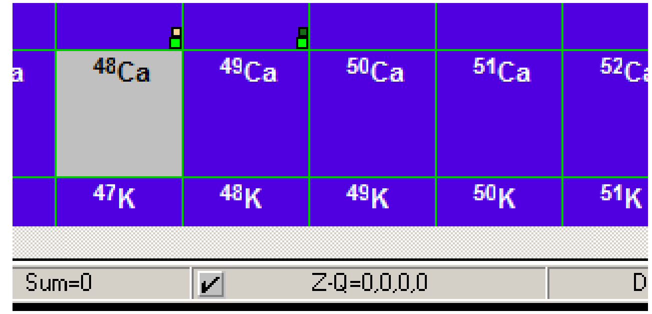
- **Primary beam atomic number**
- **Primary beam energy**
- **Target atomic number**
- **Initial ionic charge before passing material (for non-equilibrium process)**

Complicates particle identification of radioactive beam

- Isotopes of different masses and charges become mixed up during Bρ selection

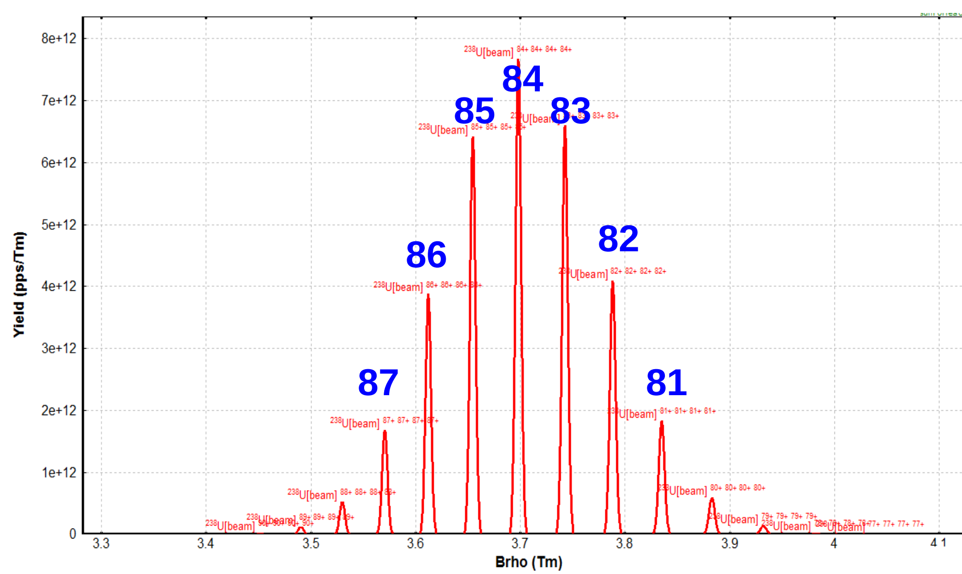
Setting the Charge state option





New Alternative way

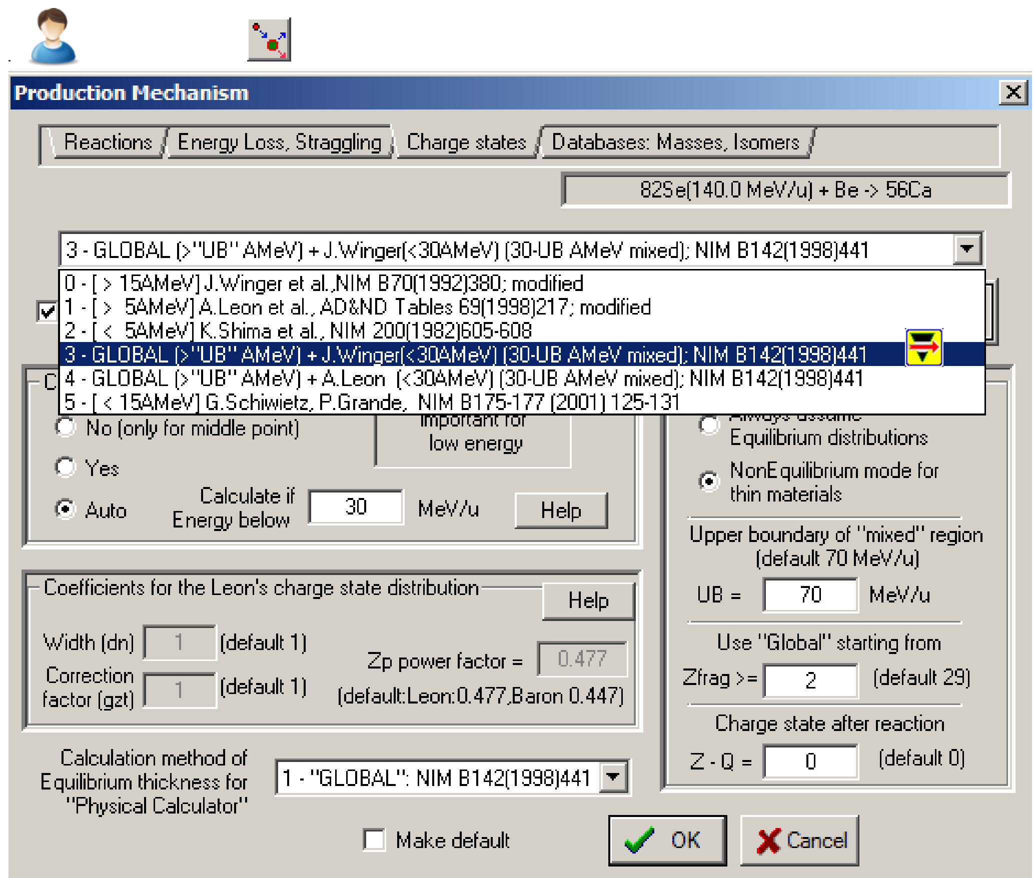
Bρ distribution of ^{238}U(80MeV/u) after Au(10 mg/cm^2)



	Model	Ref.	Region (AMeV)
1	J. Winger	[10]	>15
2	A. Leon	[11]	>5
3	K. Shima	[12]	<5
4	Global	[13]	>30
5	G. Schiwietz	[14]	<15

[10] J. Winger et al., Nucl. Instr. and Meth. B 70 (1992) 380.
[11] A. Leon et al., Atom. Data Nucl. Data Tabl. 69 (1998) 217.
[12] K. Shima et al., Nucl. Instr. and Meth. 200 (1982) 605.
[13] C. Scheidenberger et al., Nucl. Instr. and Meth. B 142 (1998) 441.
[14] G. Schwietz et al., Nucl. Instr. and Meth. B 175 (2001) 125.

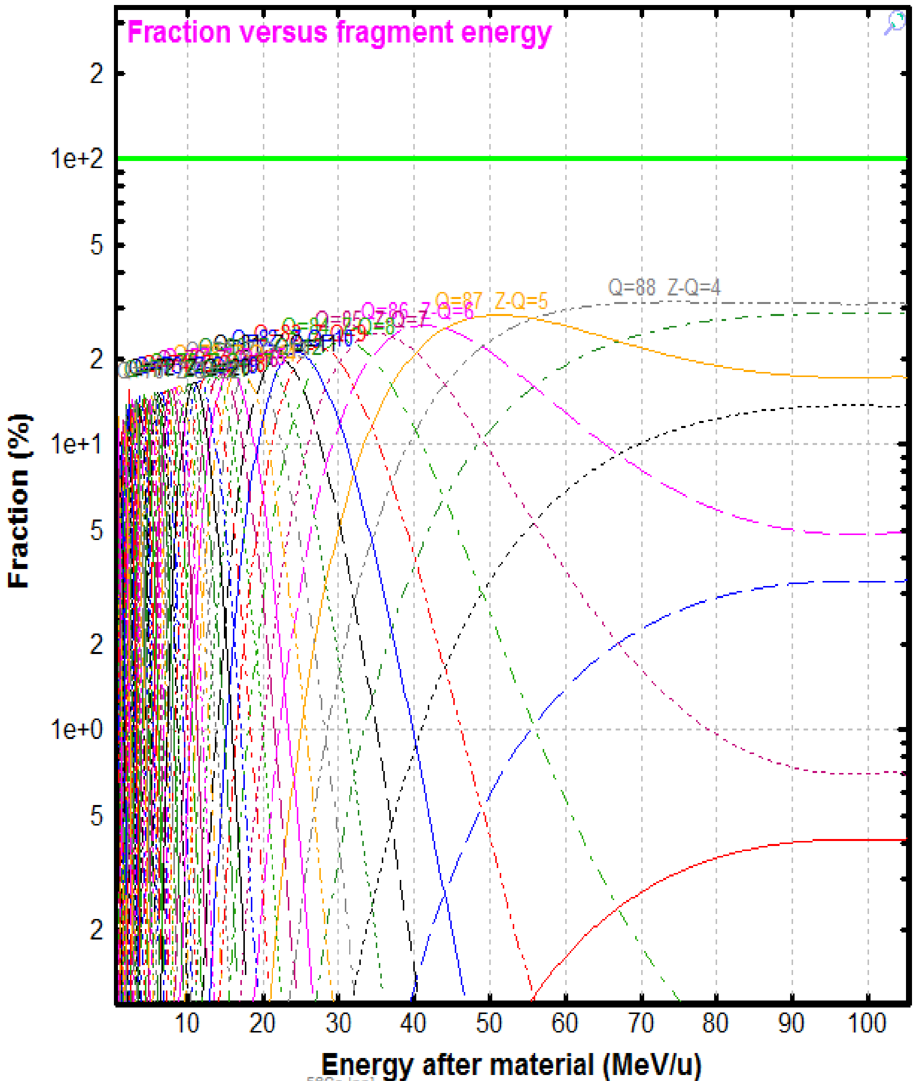
- The model used in Global allows to calculate non-equilibrium charge states distributions
- The programs Global and Charge [13] have been incorporated into the LISE++ package
- These programs developed in GSI are intended to calculate atomic charge-changing cross-sections, charge state evolution

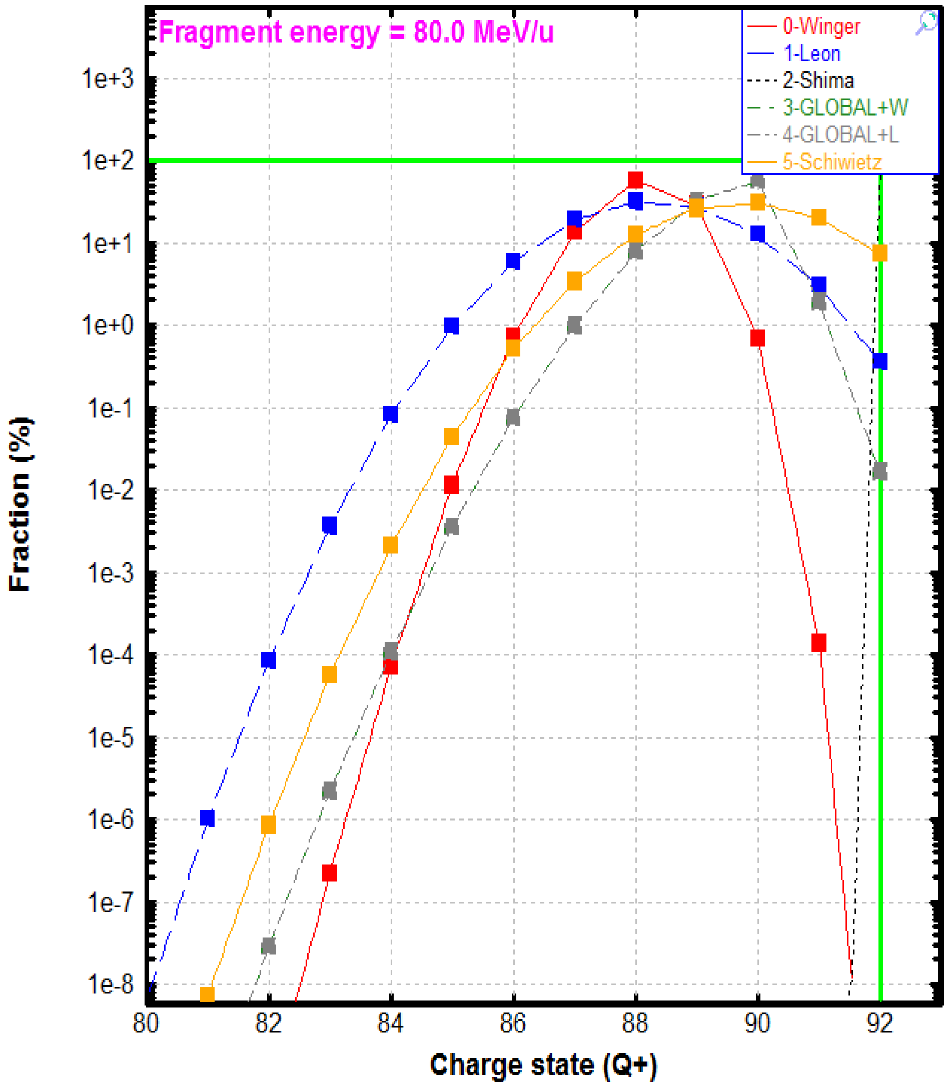


Menu
"1D-plot" ⇒
"Charge distributions"

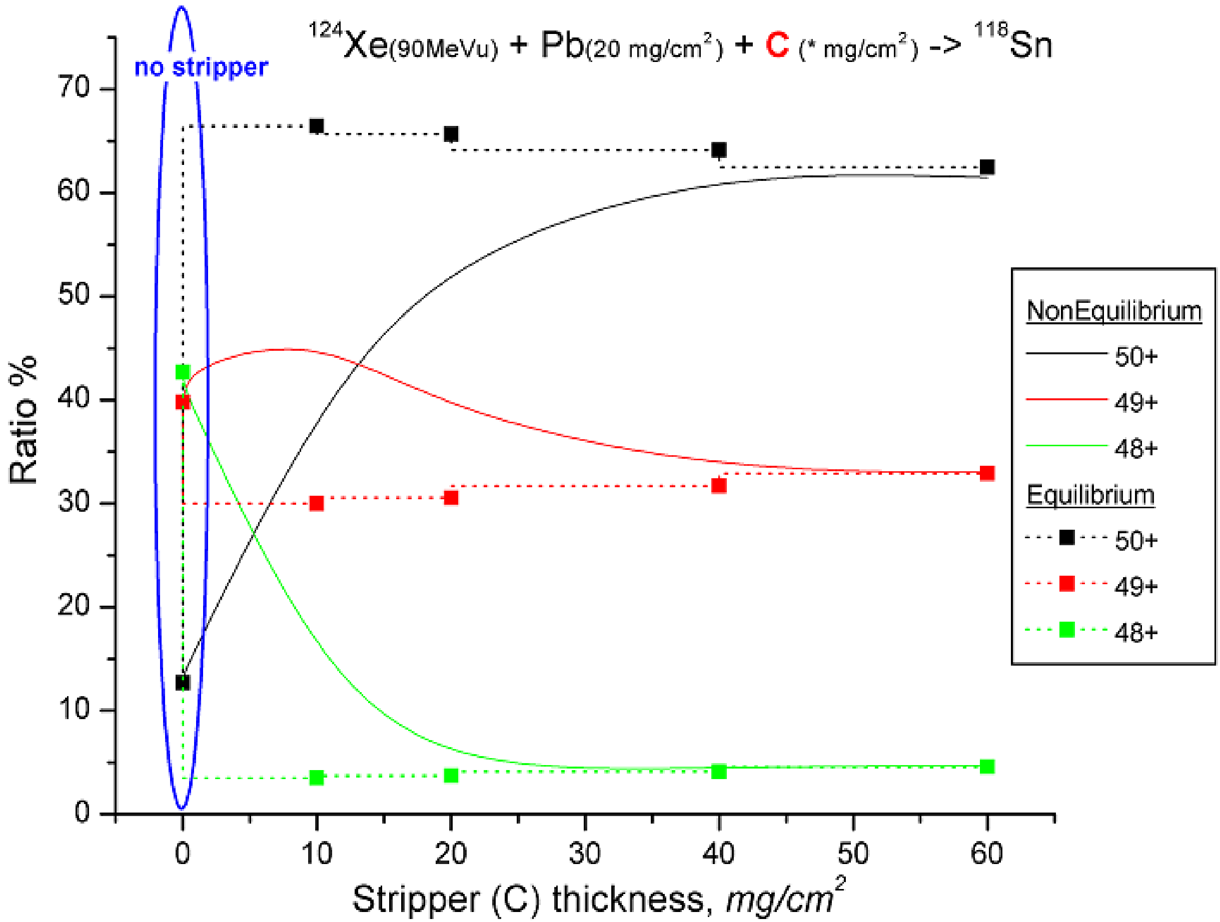
^{238}U equilibrium charge distribution after Target (Be)

^{238}U (80.0 MeV/u) + Be (443.61 mg/cm^2)
Calculations for ^{238}U ; Material Be
Charge Distribution Method is 1; Coefficient Width=1.00





Non-equilibrium charge state calculations



Charge state evolution* of the fragment ^{118}Sn after a C-stripper as a function of its thickness for equilibrium and non-equilibrium cases in the reaction ^{124}Xe (90 MeV/u)+Pb(20mg/cm^2)+C(x mg/cm^2).

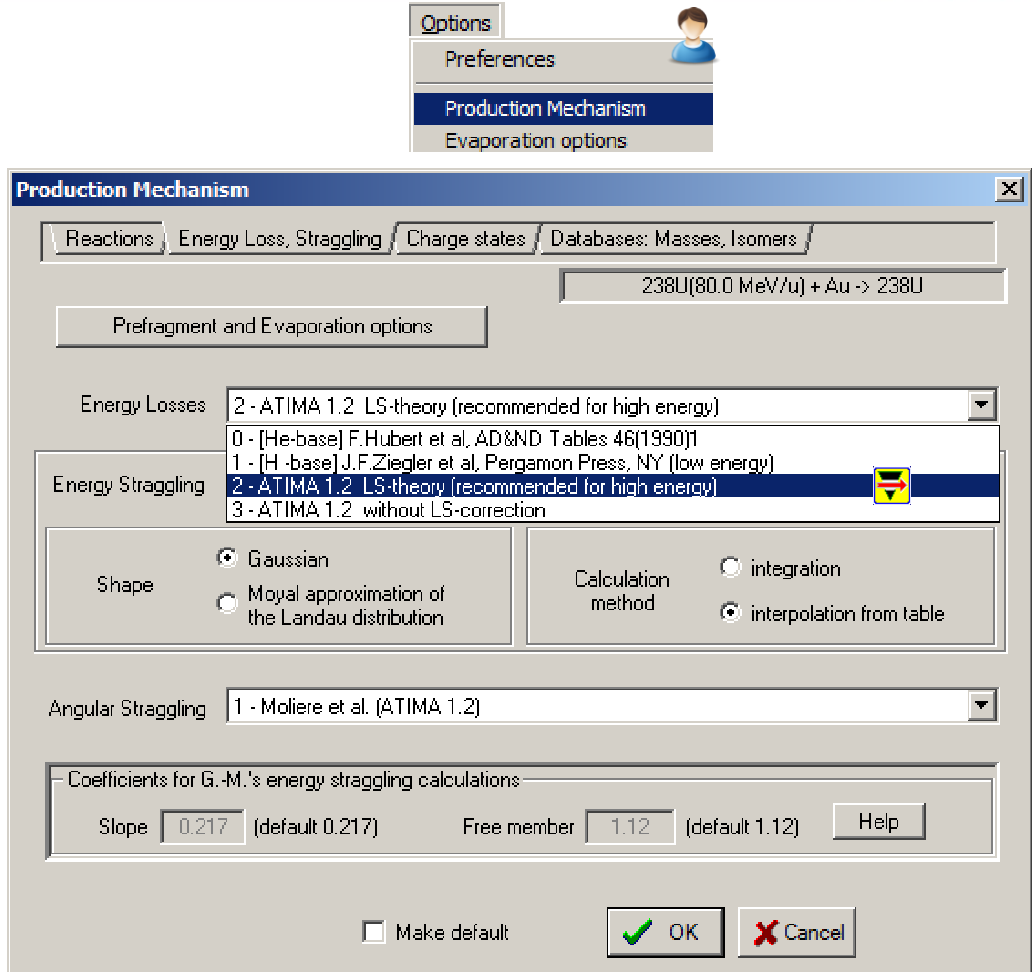
* C.Scheidenberger et al, NIM **B142** (1998) 441-462;
web-docs.gsi.de/~weick/charge_states/

http://lise.nscl.msu.edu/6_3/lise++_6_3.pdf

Energy loss models

The following energy loss calculation methods are available in LISE++ :

1. **He-parameterization [1]; the starting point at 2.5 AMeV is given by range tables [2]**
2. **H-parameterization: TRIM code [3]**
3. **ATIMA 1.2: LS-theory [4]**
4. **ATIMA 1.2: without LS-corrections**



References:

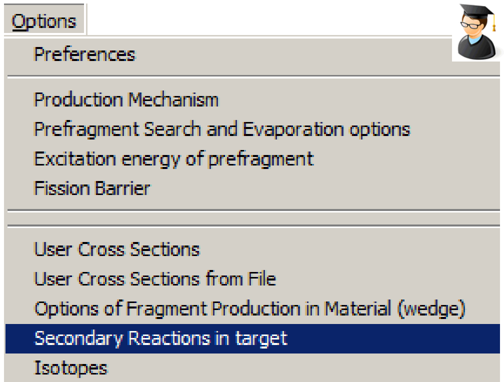
[1] F. Hubert et al., Atom. Data Nucl. Data Tabl. 46 (1990) 1.

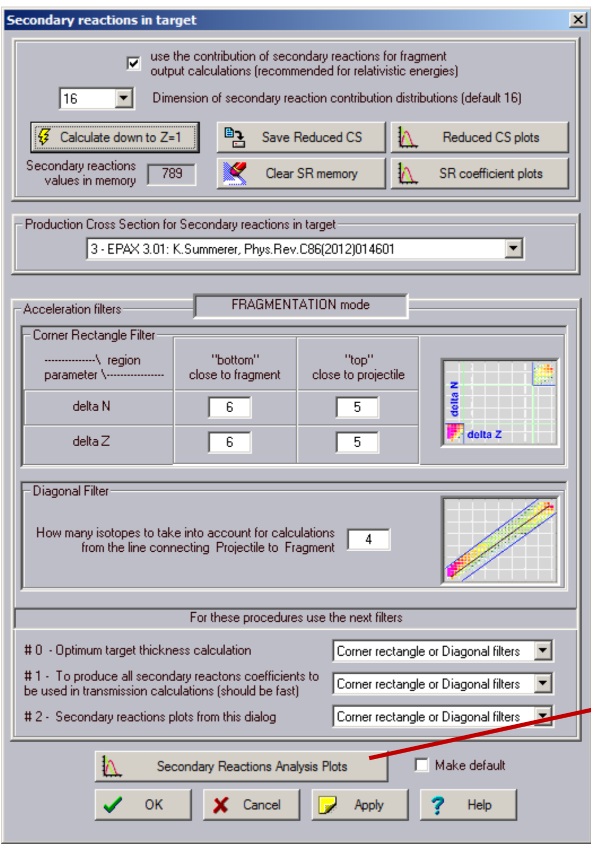
[2] L.C. Northcliffe et al., Nucl. Dat. Tabl. A 7 (1970) 233.

[3] J.F. Ziegler et al., The Stopping and Range of Ions in Solids, Pergamon Press, New York, 1985.

[4] J. Lindhard, A.H. Soerensen, Phys. Rev. A 53 (1996) 2443; ATIMA site: http://web-docs.gsi.de/~weick/atima/

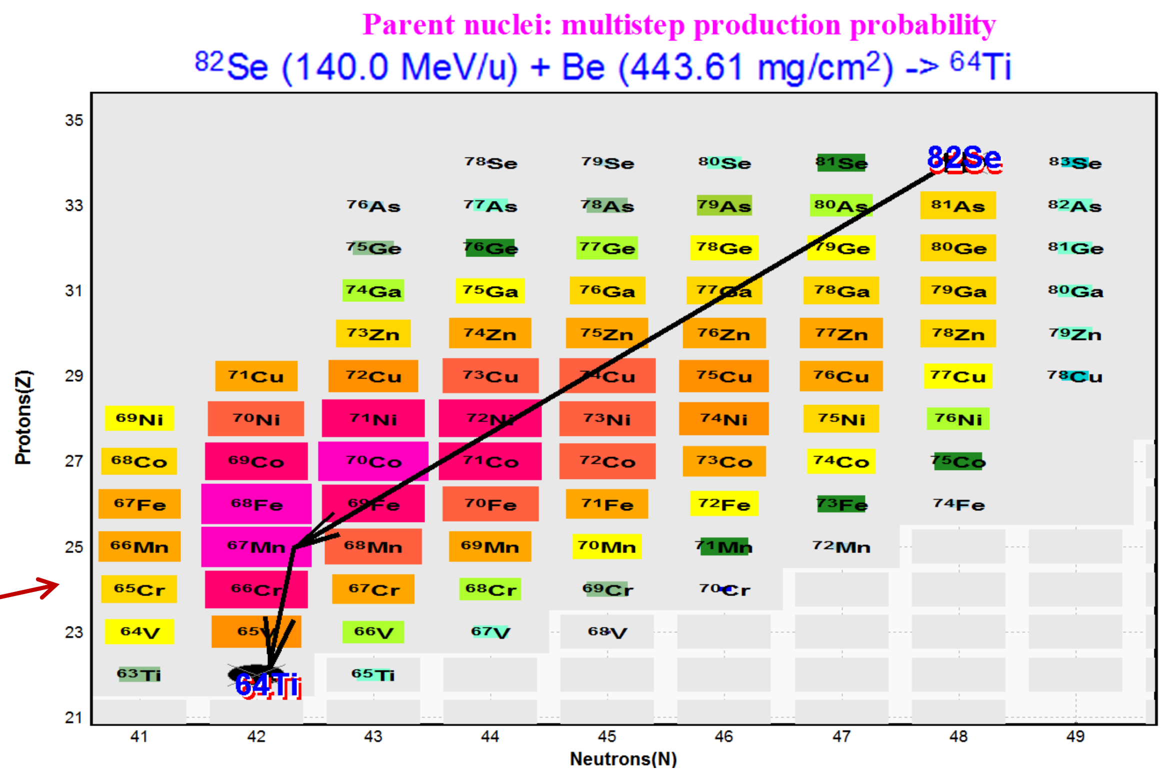
Secondary (multi-step) reactions in target





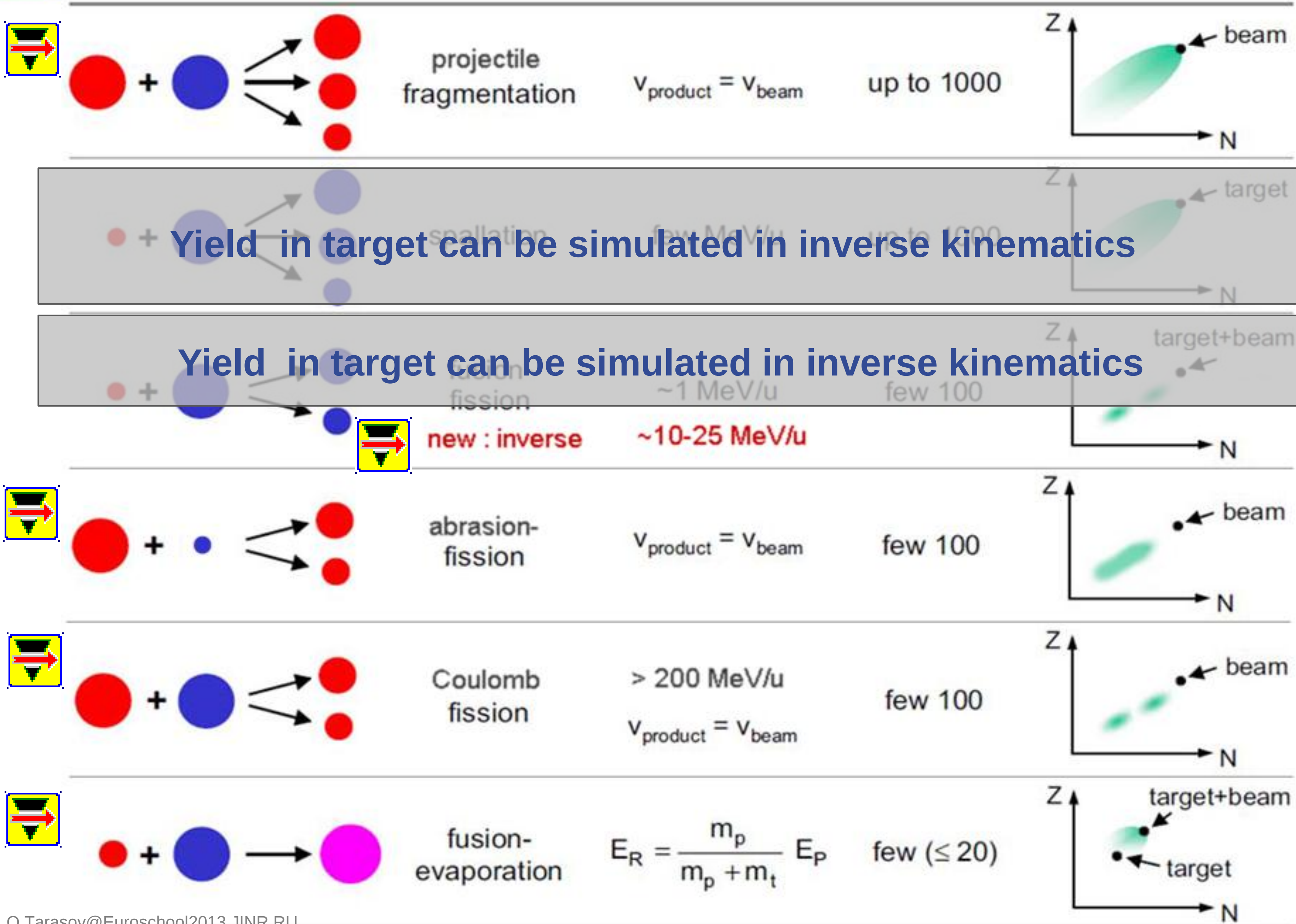
Applied for thick targets

- In this process, the projectile undergoes a series of successive reactions until the fragment of interest is produced
- For the second and next reactions LISE++ always assumes a projectile fragmentation and uses the EPAX parameterizations to speed up calculations



O.Tarasov@Euroschool2013.JINR.RU

Sketch of main production mechanisms for RIB



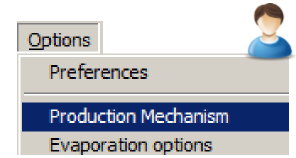
Yield in target can be simulated in inverse kinematics

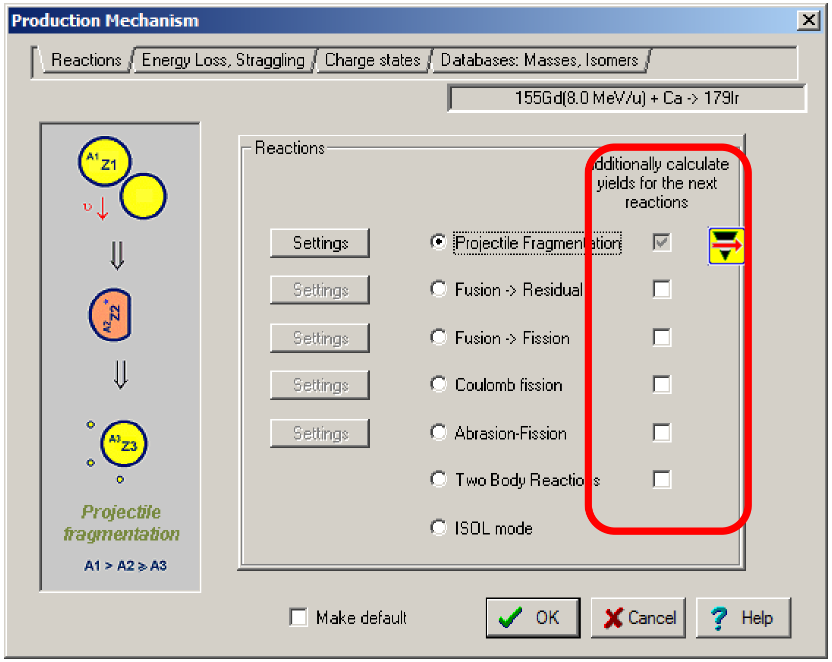
Yield in target can be simulated in inverse kinematics

Reactions in LISE++

Table
Reactions and production models implemented in LISE++

Reaction	Production cross-section model	Ref.
Projectile fragmentation	EPAX 2.15, 3.1	[17]
	LISE++ abrasion–ablation	[27]
Fusion-residues	LisFus model	[27]
	PACE4 (manually)	[28]
Fusion–fission	LISE++ package	[29]
Coulomb fission	LISE++ package	[30]
Abrasion–fission	LISE++ 3EER model	[31]
Two body kinematics	EPAX 2.15 (temporary)	





References:

[17] K. Summerer, B. Blank, Phys. Rev. C 61 (2000) 034607; K. Summerer, Phys. Rev. C 86 (2012) 014601

[27] O. Tarasov, D. Bazin, Nucl. Instr. and Meth. B 204 (2003) 74.

[28] A. Gavron, Phys. Rev. C 21 (1980) 230.

[29] O.B. Tarasov, A.C.C. Villari, , Nucl. Instr. and Meth. B 266 (2008) 4670-4673.

[30] O.B. Tarasov, Eur. Phys. J. A 25 (2005) 751; Tech. Rep. MSUCL1299, NSCL, Michigan State University, 2005.

[31] O.B. Tarasov, Tech. Rep. MSUCL1300, NSCL, Michigan State University, 2005.

Reaction mechanism : Evaporation Cascade

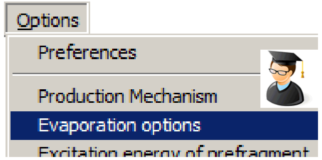
- ❑ The evaporation cascade is used in Abrasion-Ablation (Projectile Fragmentation), All fission reactions, Fusion-Residue

- ❑ It is treated in a macroscopic way on the basis of a master equation which leads to a diffusion equations

  X. Campi, J. HuË fner, Phys. Rev. C 24 (1981) 2199; J.-J. Gaimard, K.-H. Schmidt, Nucl. Phys. A 531 (1991) 709

- ❑ The LISE^{++} evaporation model works with **probability distributions** as a function of excitation energy, taking into account possible parent and daughter channels (n, 2n, p, 2p, d, t, 3He,a), as well as fission and breakup de-excitation channels

- ❑ The influence of dissipation on the fission process is taken into account B. Jurado et al., Phys. Lett. B 553 (2003) 186



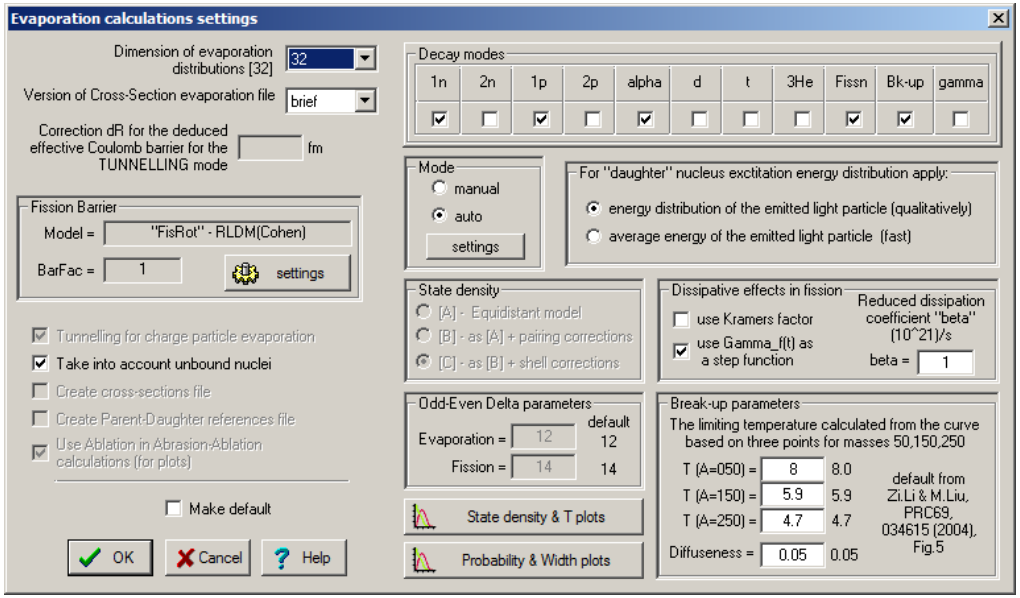
- ❑ The **analytical solution** of the evaporation cascade is performed using the transport integral

  D. Bazin, B. Sherrill, Phys. Rev. E 50 (1994) 4017

- ❑ The main advantage is speed. Only such a type of fast calculations is suitable for calculating the production of nuclei with very low cross-sections

- ❑ Disadvantages are …

- ❑ Monte Carlo version will be done soon



Evaporation Example : ^{216}Fr, E*=50 MeV, σ=1 barn

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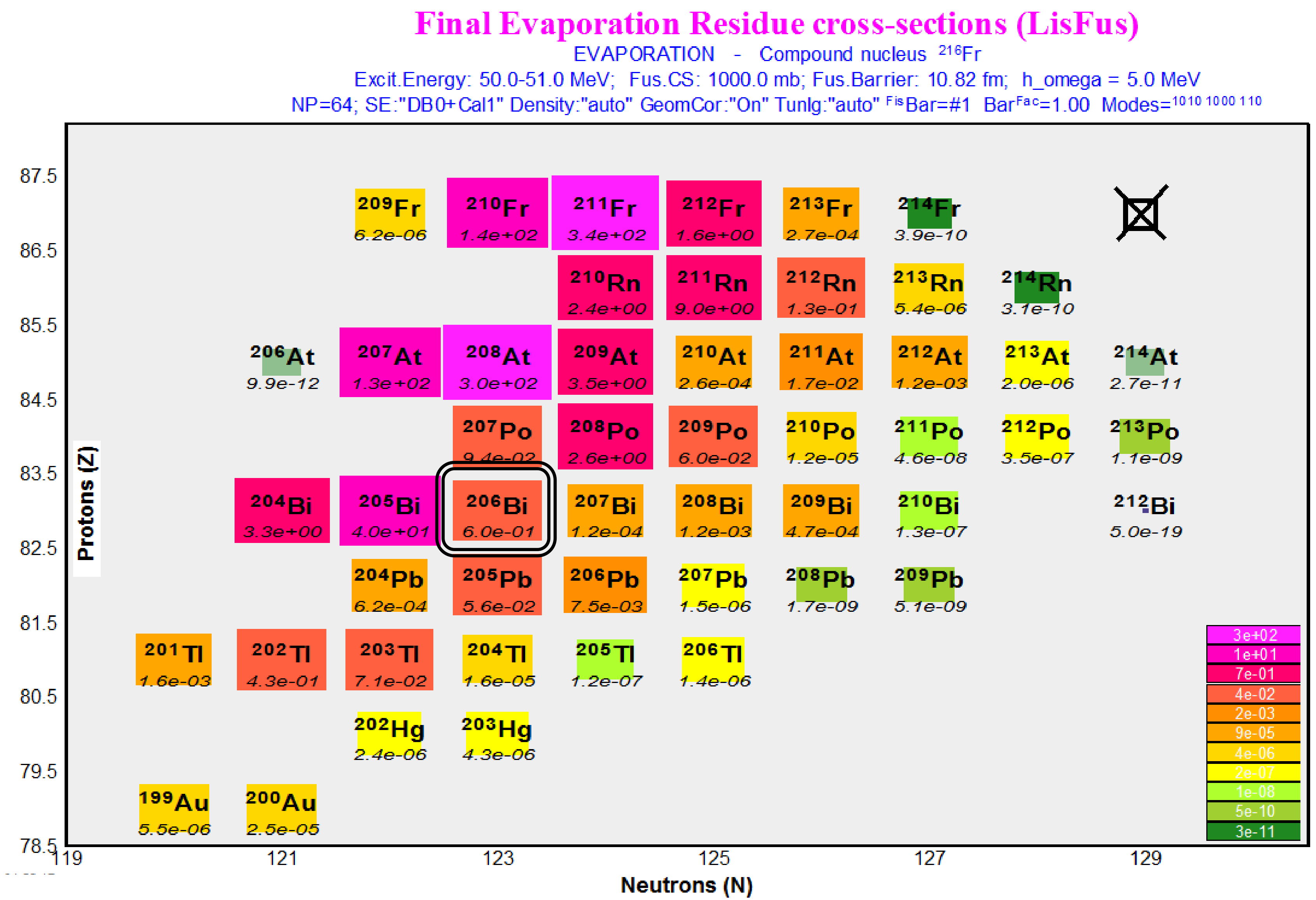
LISE++

Couple seconds and… Fission = 18.6 mb, Residues 981 mb



Evaporation calculator will be discussed on Friday

Example : ^{216}Fr, E*=50 MeV, σ=1 barn ⇒ ^{206}Bi

NSCL

MICHIGAN STATE UNIVERSITY

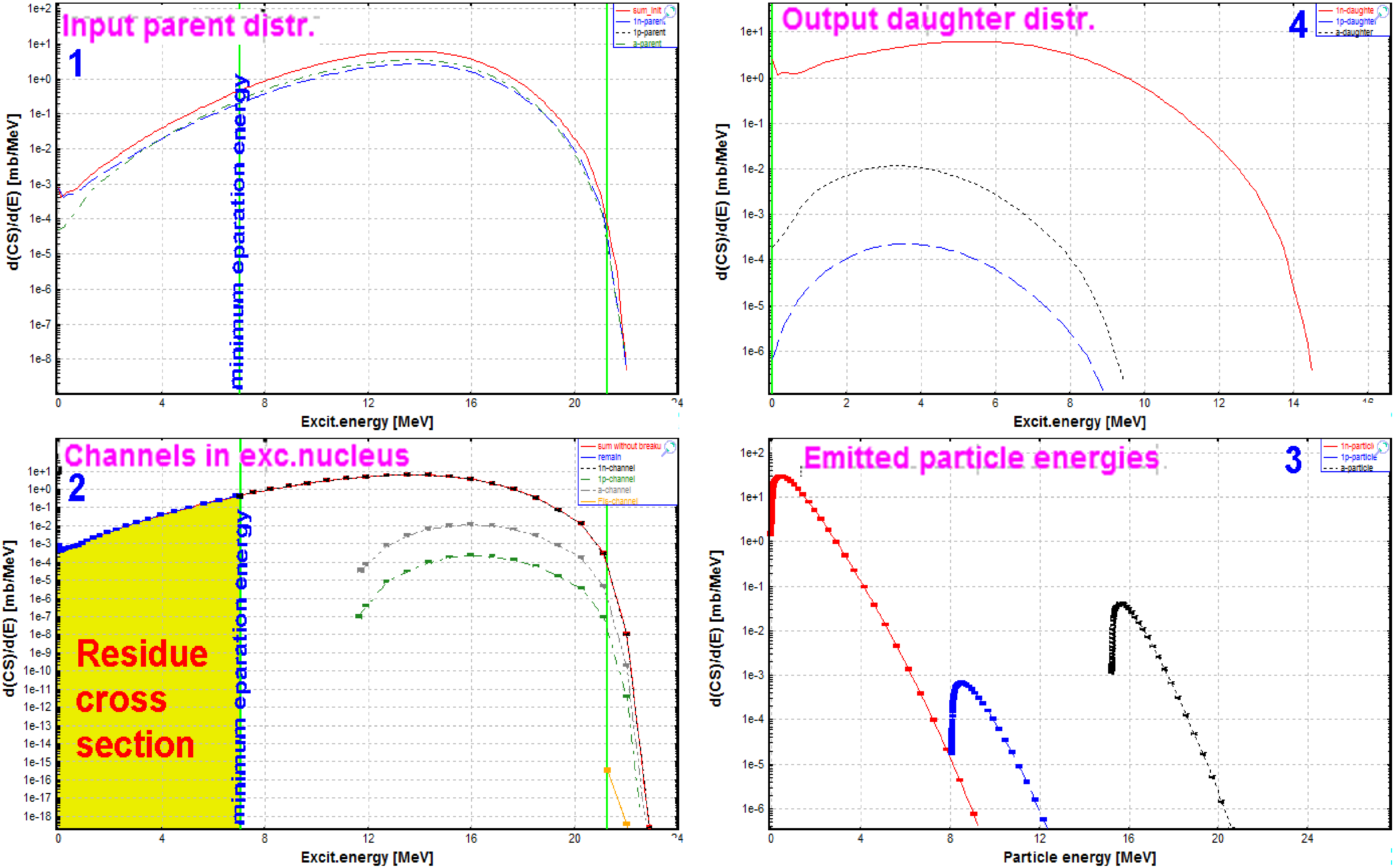
LISE++

^{206}Bi excitation distributions

EVAPORATION - Compound nucleus ^{216}Fr

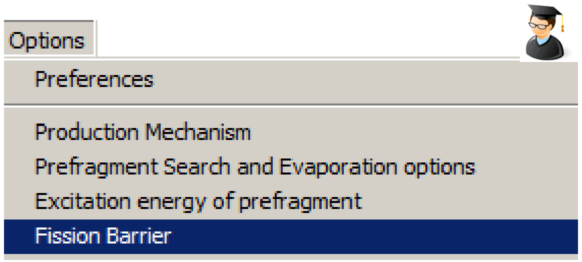
Excit.Energy: 50.0-51.0 MeV; Fus.CS: 1000.0 mb; Fus.Barrier: 10.82 fm; h_omega = 5.0 MeV

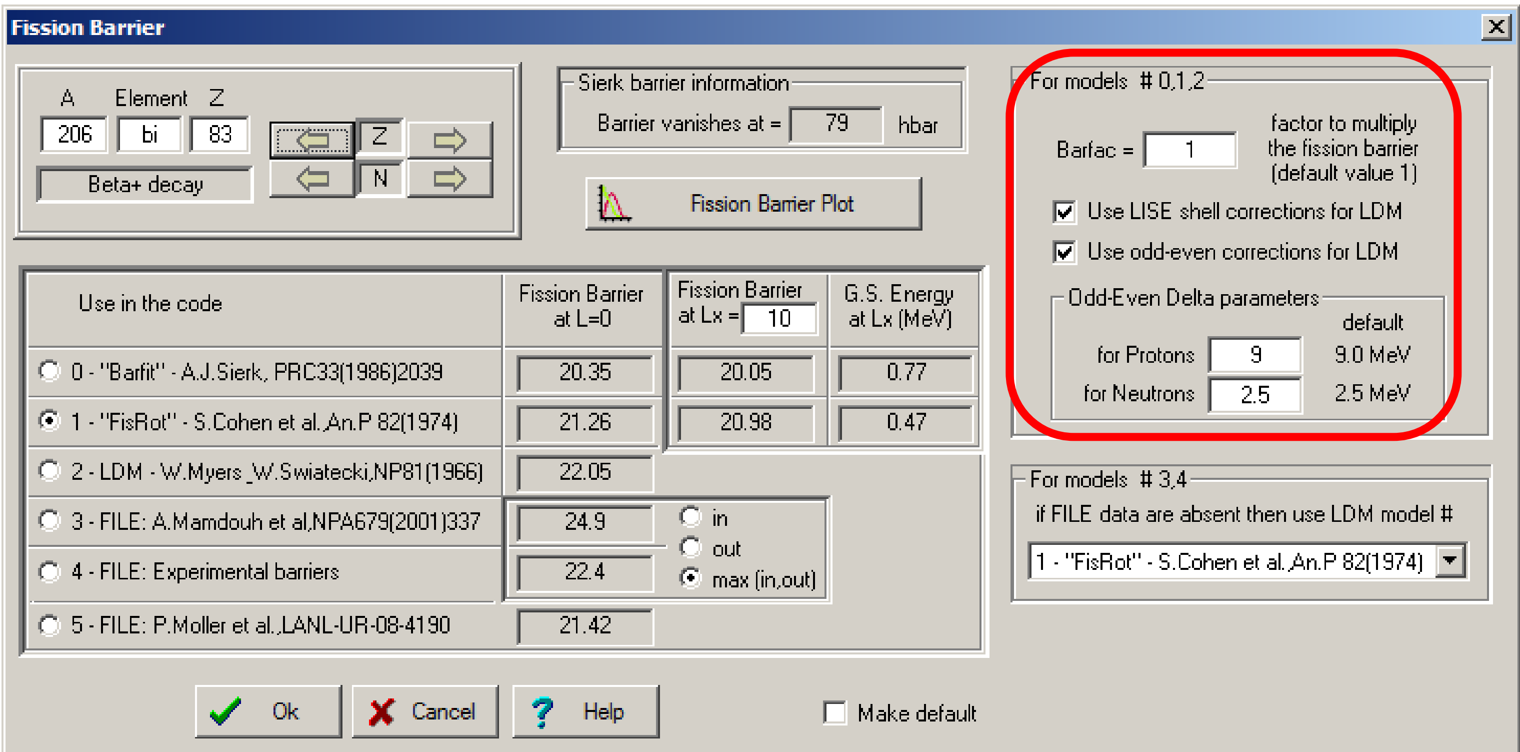
NP=64; SE:"DB0+Cal1" Density:"auto" GeomCor:"On" Tunlg:"auto" ^{Fis}Bar=#1 Bar^{Fac}=1.00 Modes=$^{1010\ 1000\ 110}$



Fission barriers are necessary to calculate fission de-excitation channels and estimate

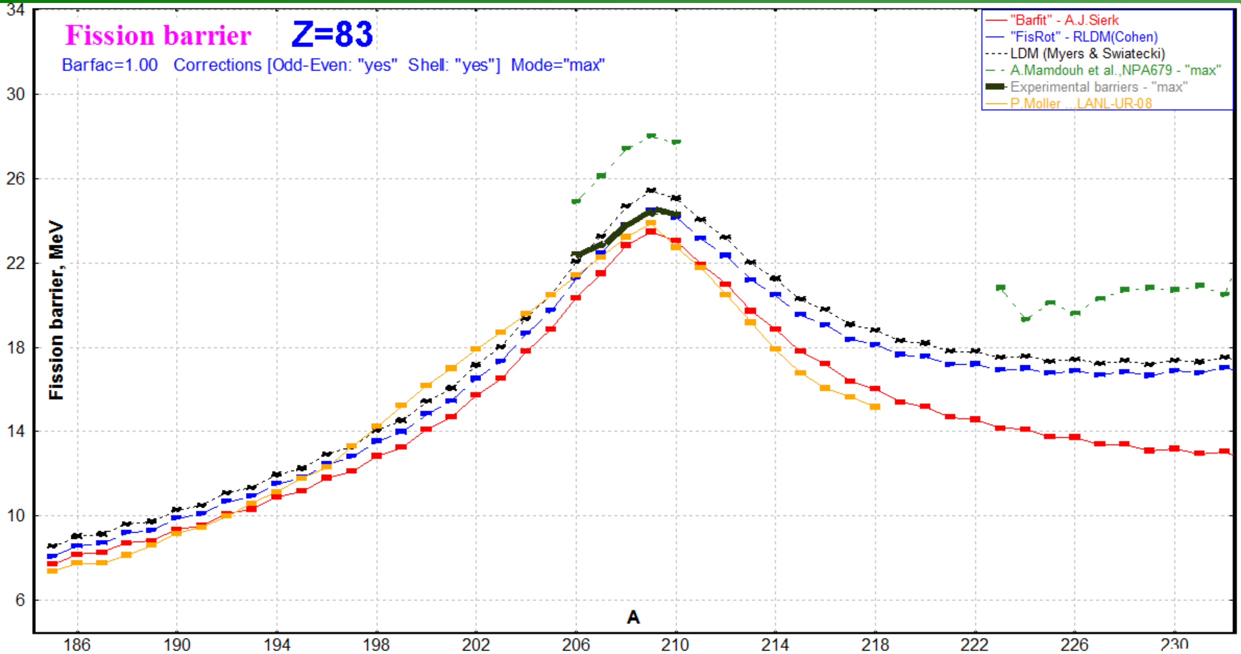
- **total cross-sections of fission reactions**
- **evaporation residue cross-sections**
- **decay widths in the post-scission nucleon emission process**



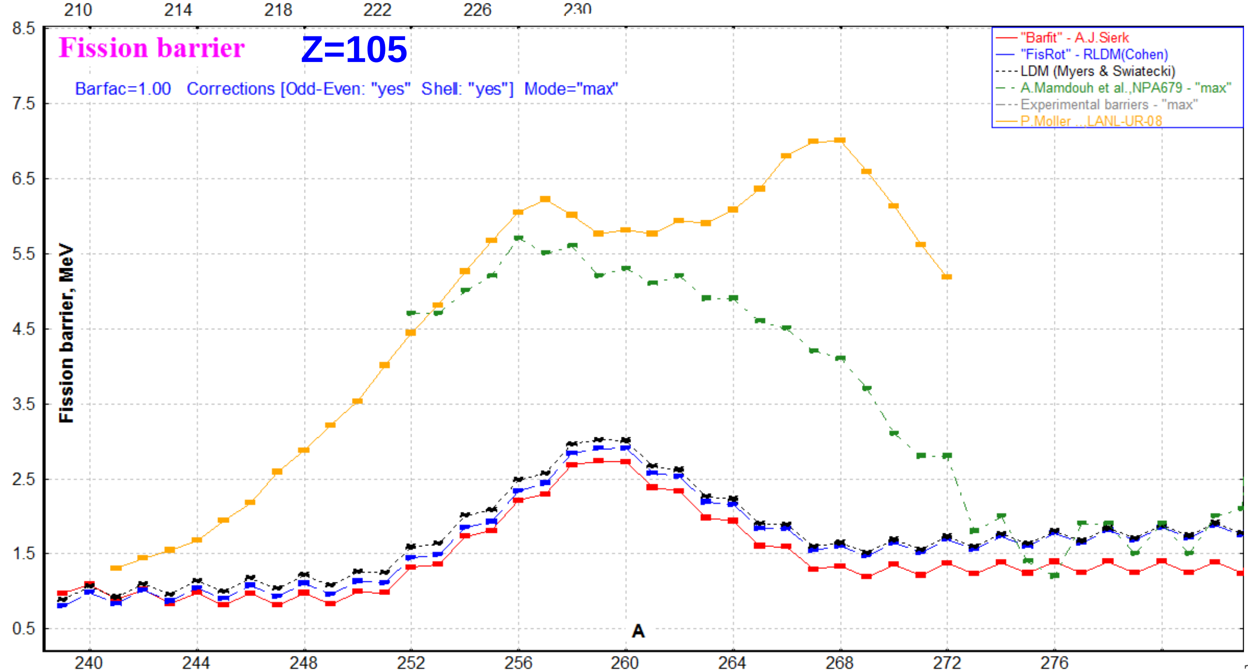


$$B_f^{\text{final}} = B_f^{\text{init}} \cdot b + \varepsilon_{\text{shell}} + \varepsilon_{\text{odd-even}} \qquad \text{default value of } b = 1$$

Fission Barrier Models

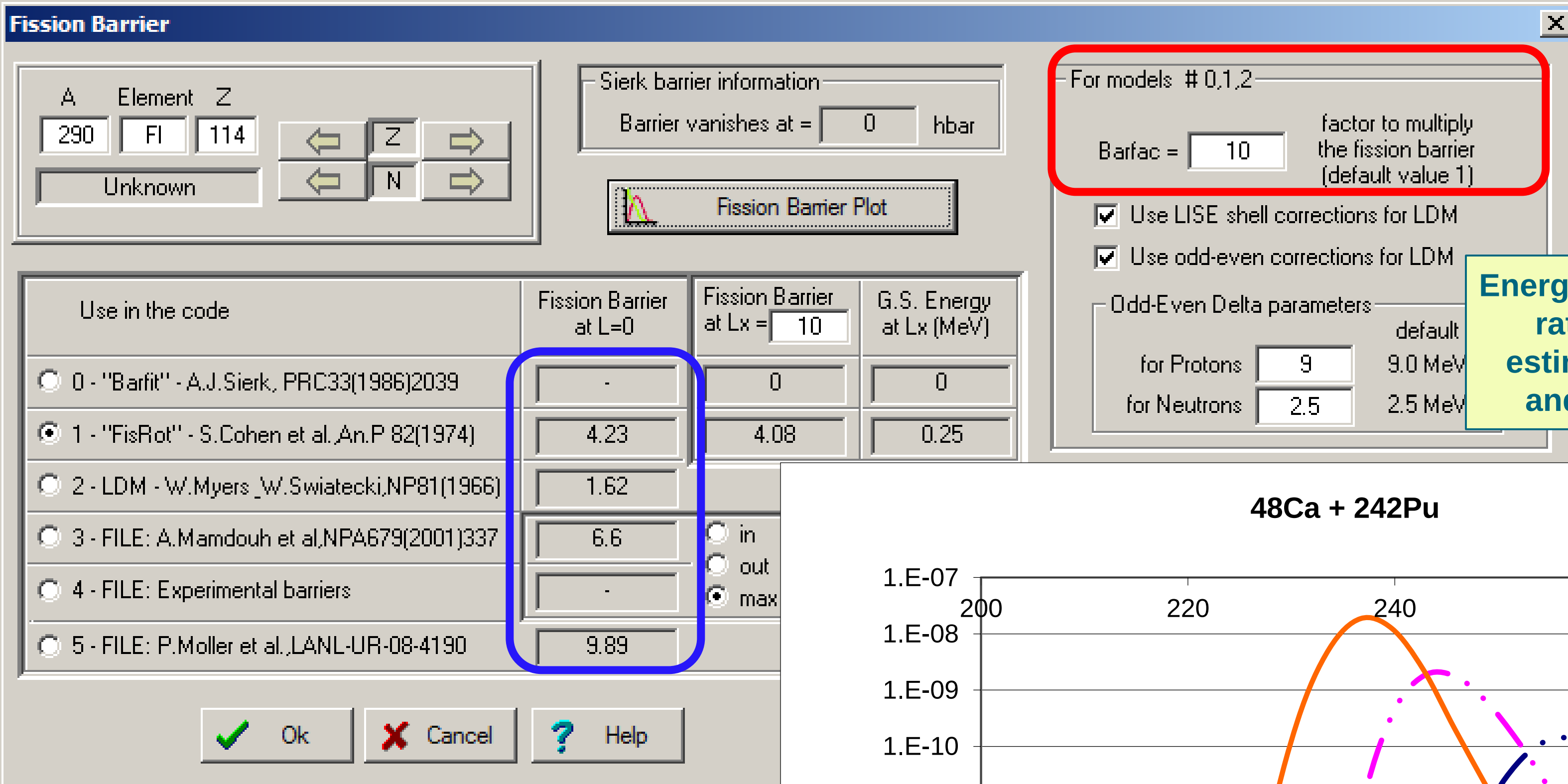


Below Uranium general agreement

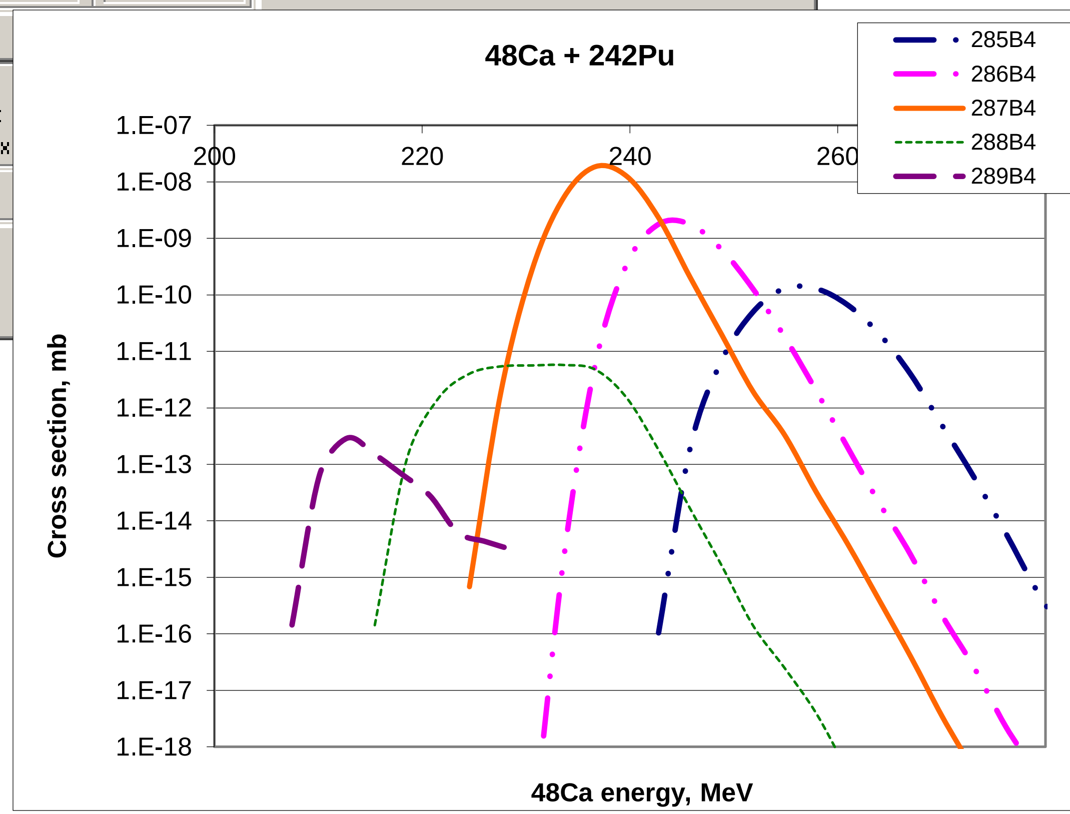


In SHE region first three models significantly underpredict

Fission Barrier for High Z

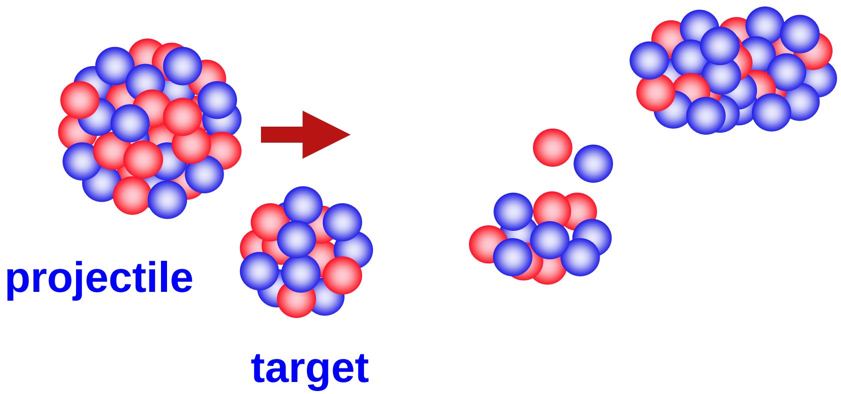


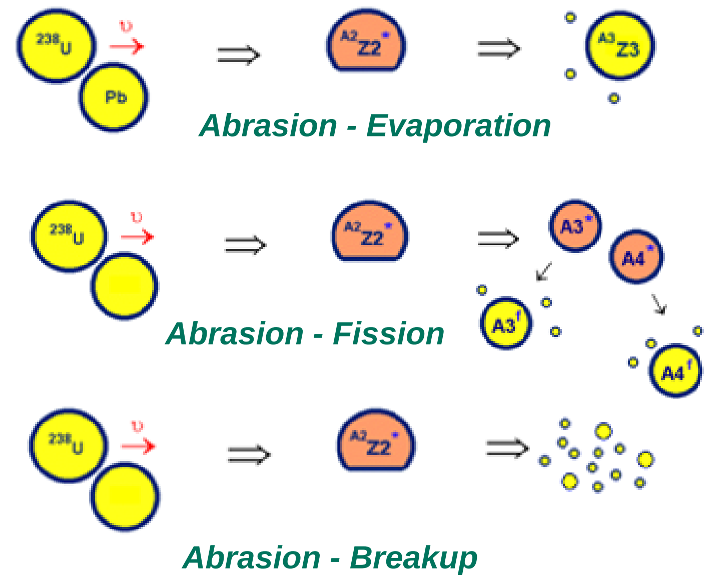
Energies and channels ratio, In order to estimate kinematics and transmission



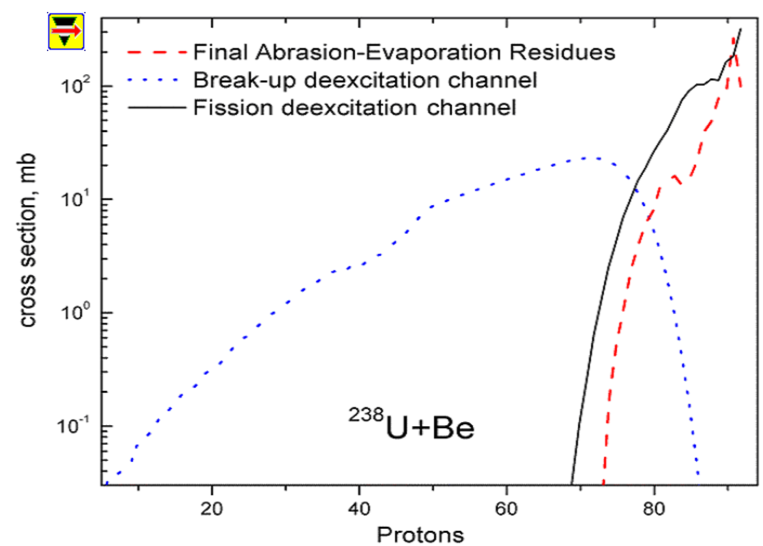
For estimation it is possible to take experimental data (if they exist) or calculations from Prof.V.I.Zagrebaev in order to normalize Fusion-Residue cross sections playing with the Barfac value

http://lise.nscl.msu.edu/8_5/2009_catcher.pdf

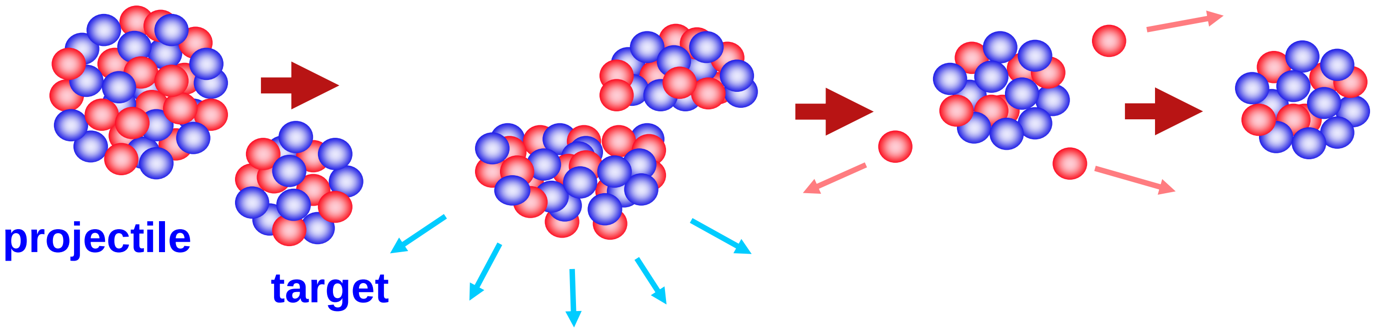


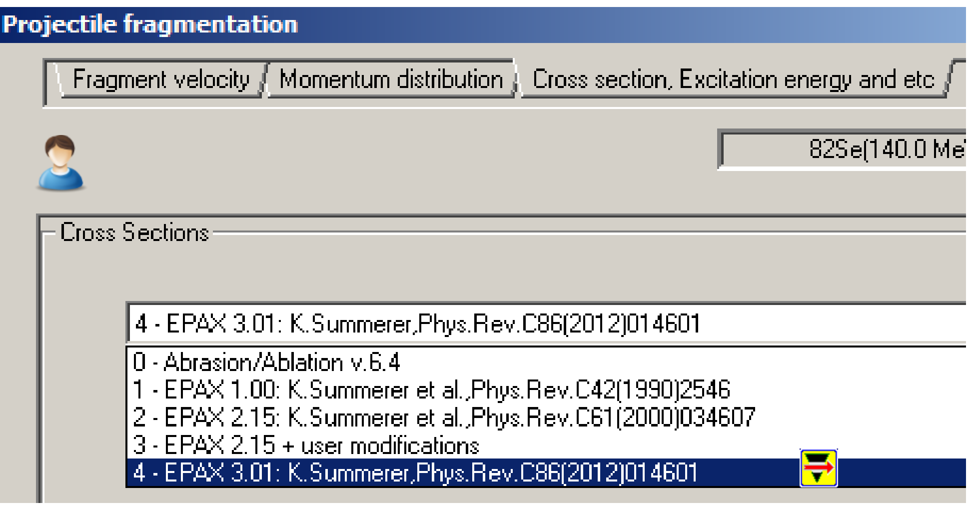


De-excitation channel	Collisions	Reaction
Abrasion – Evaporation Abrasion – Ablation	peripheral	Projectile fragmentation
Abrasion – Fission	peripheral	In-flight fission ~~*Projectile fission*~~
Abrasion – Breakup	central	Multi-fragmentation



Nuclear charge yields for different de-excitation channels after ^{238}U(1AGeV) abrasion on a Be-target.





- **Cross sections for projectile fragmentation**
  - EPAX parametrizations [1] based on fragmentation data
  - LISE++ Abrasion-Ablation model (analytical) [2]
  - Possibility to input cross sections manually via file
- **ABRABLA : Abrasion-Ablation Monte Carlo [3]**
- **COFRA : a simplified, analytical version of ABRABLA**, which only considers neutron evaporation from the pre-fragments formed in the abrasion stage **[4].**
- **Intra-nuclear Cascade Models, e.g. ISABEL [5]**

References:

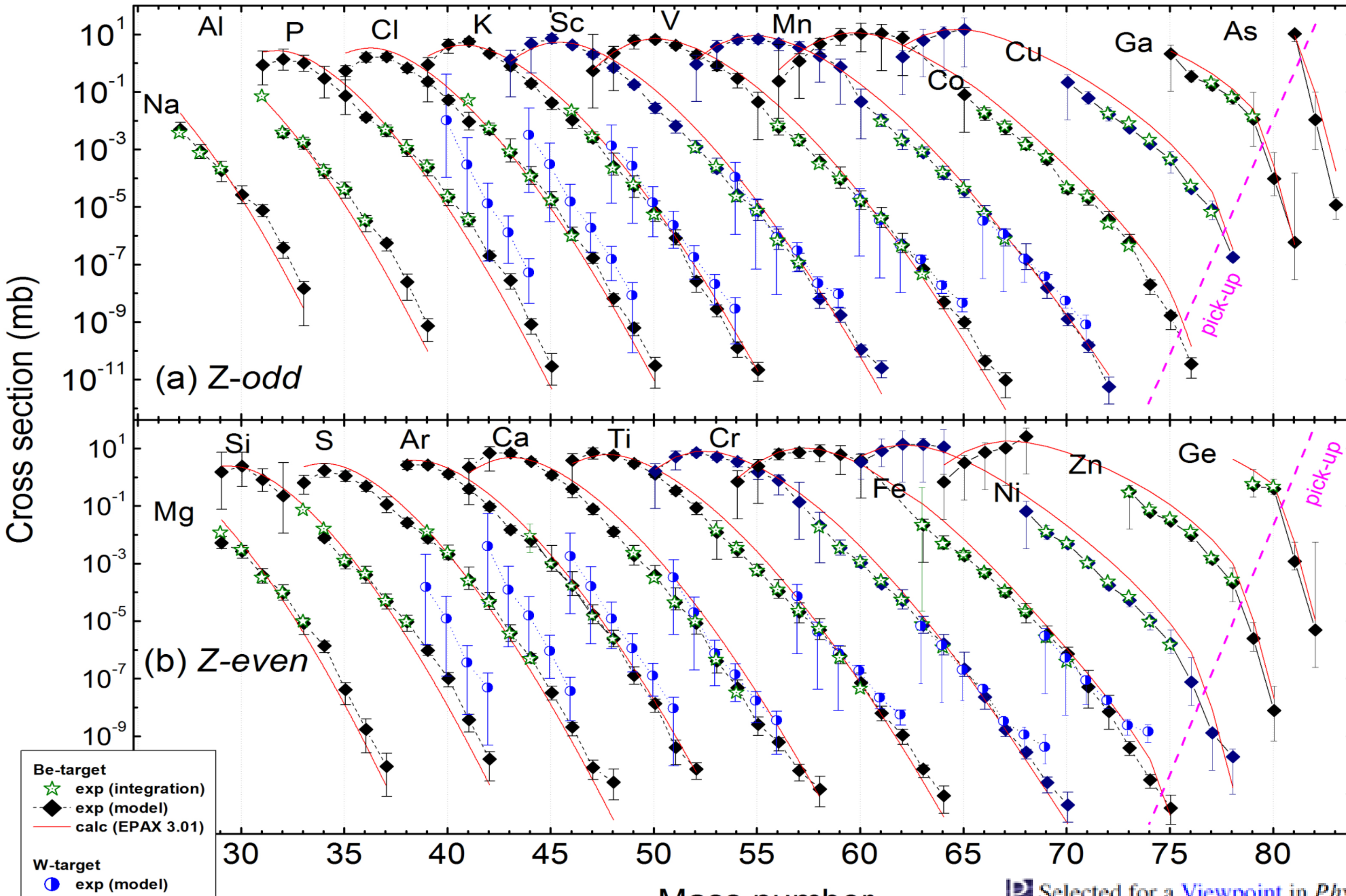
[1] K. Summerer, B. Blank, Phys. Rev. C 61 (2000) 034607;
K. Summerer, Phys. Rev. C 86 (2012) 014601
[2] O. Tarasov, D. Bazin, Nucl. Instr. and Meth. B 204 (2003) 74.
[3] J.-J. Gaimard, K.-H. Schmidt, Nucl. Phys. A 531 (1991) 709.
[4] J. Benlliure , et al. Nucl. Phys. A 660 (1999) 87.
[5] Yariv and Fraenkel,Phys. Rev. C20 (1979) 2227.

Projectile Fragmentation Cross Section Models

Model	Plus		Minus
EPAX 1-step calculation	fast		no primary beam energy dependence
	reference line	wide distributed no parameters to modify EPAX modifications are very rare	does not take nuclide masses: predicts yield for unbound isotopes, no shell and even-even effects
LISE^{++} Abrasion-Ablation (analytical) 2 steps	Takes nuclide masses for evaporation cascade		no beam energy dependence (yet)
	Using experimental results, it can be applied to deduce excitation energy parameters in order to predict an yield of more exotic nucleus		difficult choice of excitation energy initial parameters
	User-friendly results analysis and visualization		large set of parameters to play
HIPSE D.Lacroix et al., PRC69, 054604 (2004) 3 steps	More physics involved	Building partition Reaggregation phase evaporation stage	developed for multifragmentation and multi-nucleon transfers: significant overprediction for stripping of several nucleons
	Excitation energy of prefragment and fragment kinetic energy can be extracted		slow, difficulties to predict exotic yield (Monte Carlo)
			Fixed parameters just for 25,50,80 MeV/u

AMD, Isabel and so on..

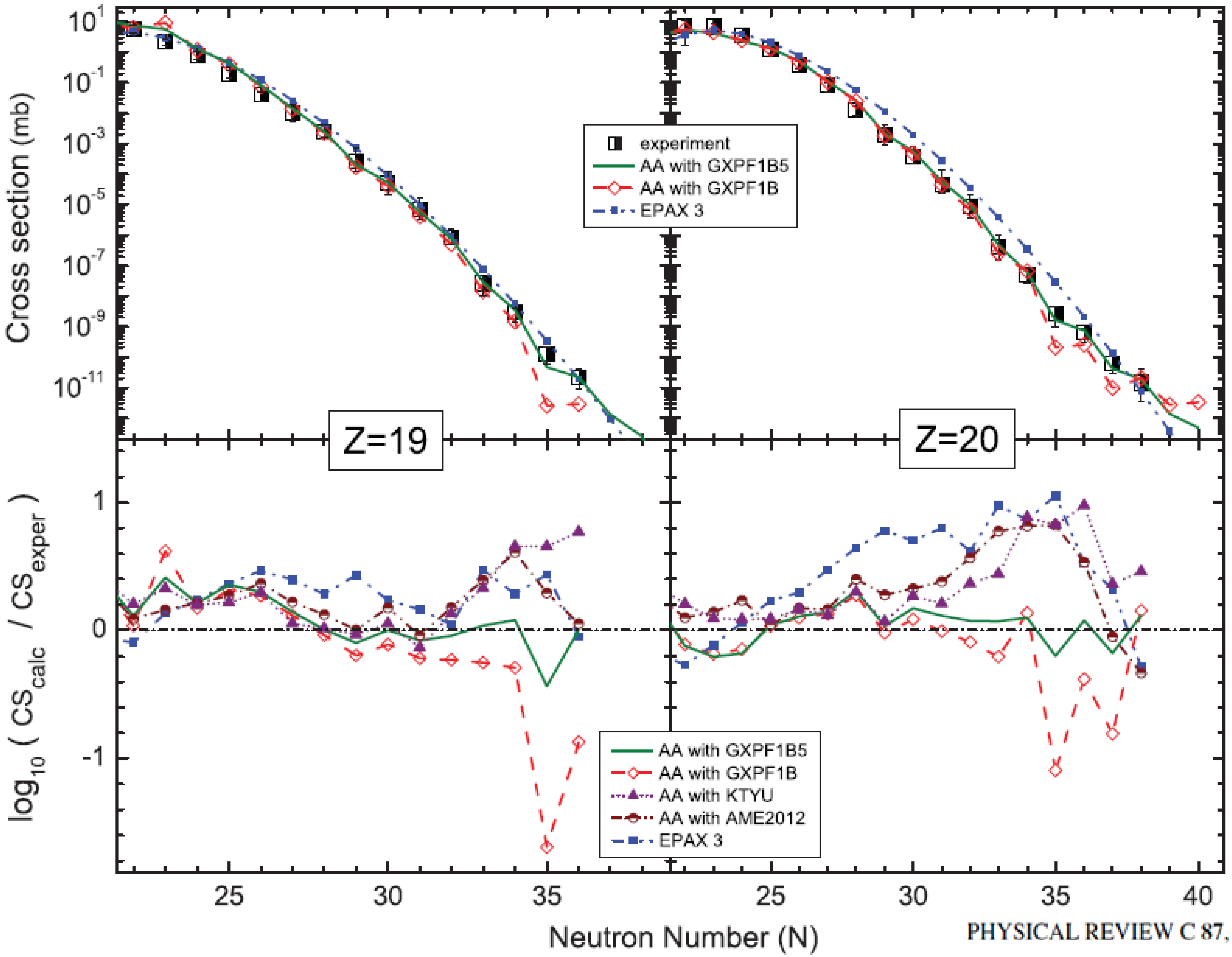
^{82}Se (139 MeV/u) + Be, W : exp. cross sections vs. EPAX3



Selected for a Viewpoint in *Physics*

PHYSICAL REVIEW C 87, 054612 (2013)

^{82}Se (139 MeV/u) + Be, W : exp. cross sections vs. AA



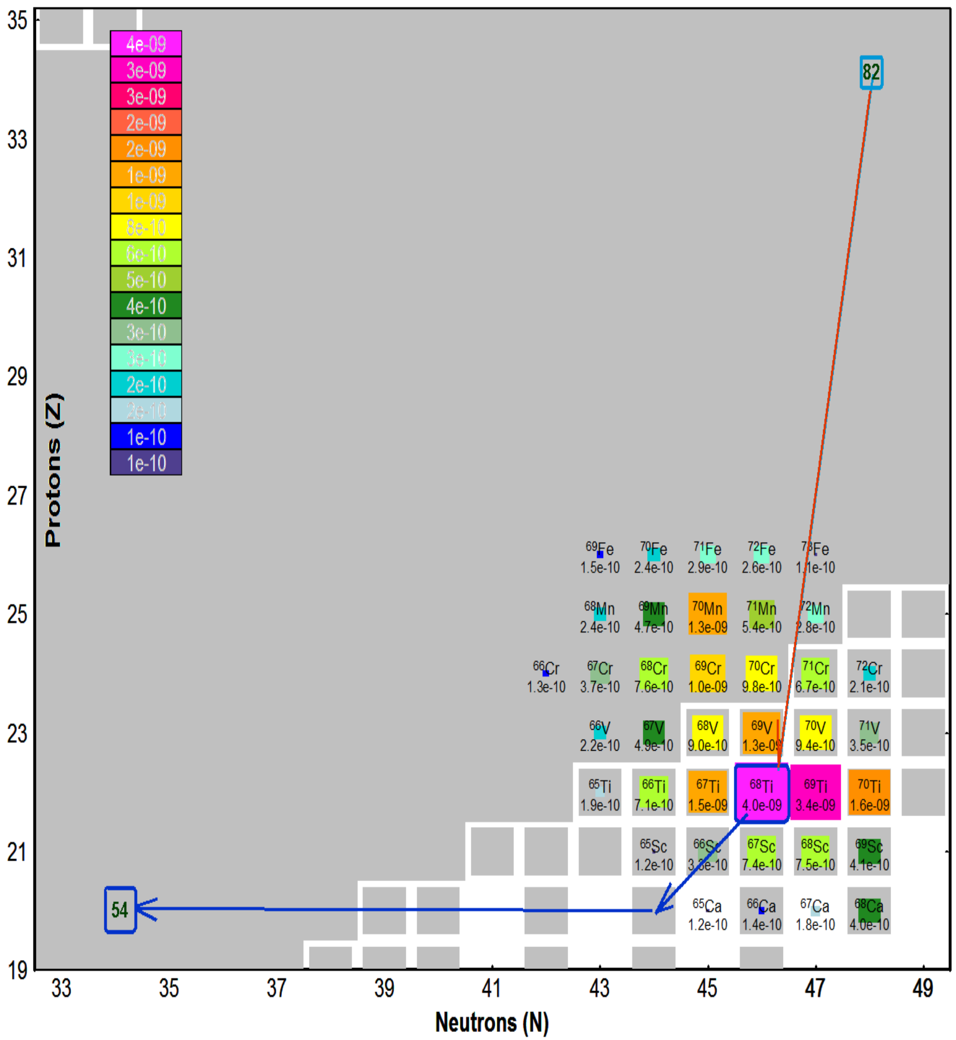
PHYSICAL REVIEW C 87, 054612 (2013)

Initial Prefragments Plot for ^{54}Ca (2.78e-08 mb)

ABRASION-ABLATION - ^{82}Se + Be: more probable ^{68}Ti(4.02e-09 mb); <-dZ>=2.88 <-dN>=11.78

Excit.Energy Method:< 2 >; <E*>:15.0*dA MeV sigma:9.20; Thermal.Intr.Coef. = 5.00e-22 MeV*s

NP=64; SE:"DB1+Cal0" Density:"auto" Geom.Corr:"On" TunIg:"auto" FisBar=#1 BarFac=1.00 Modes=1010 1010 01(

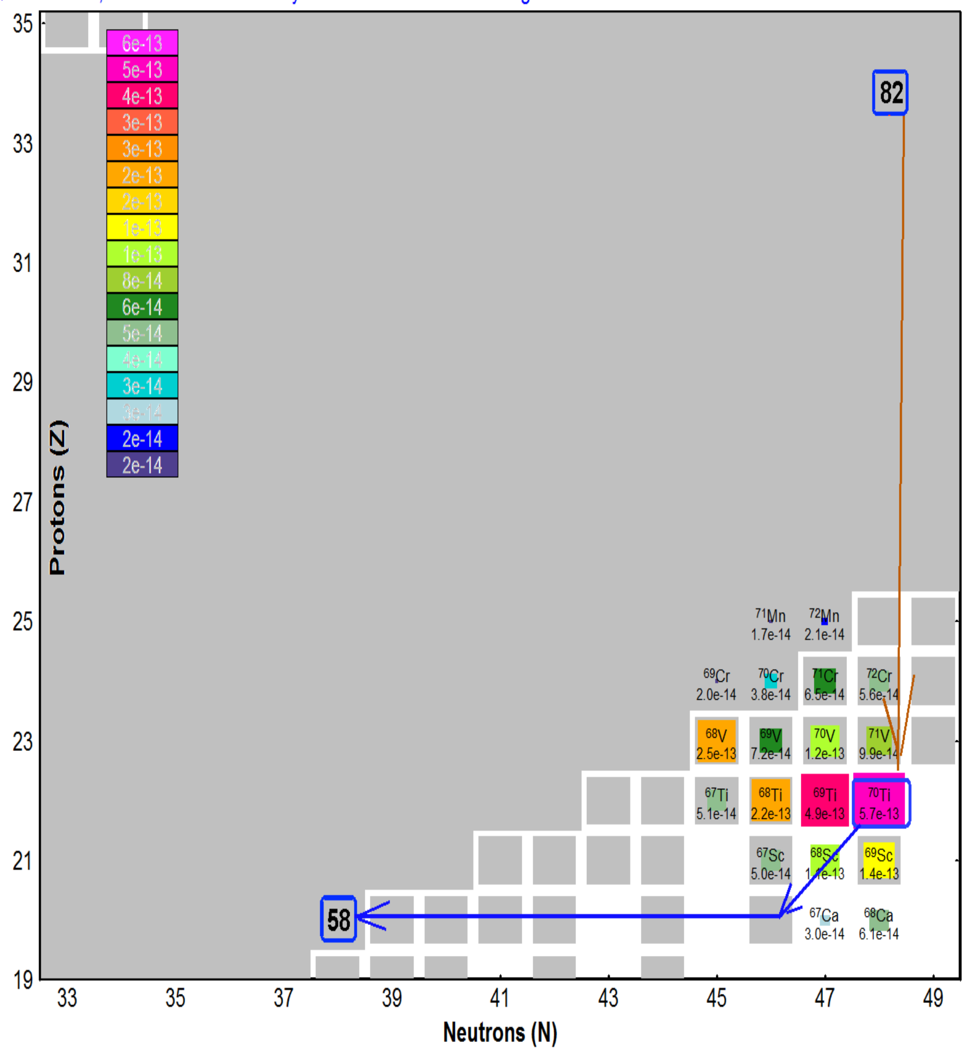


Initial Prefragments Plot for ^{58}Ca (2.57e-12 mb)

EVAPORATION - Compound nucleus ^{68}Ti: more probable ^{70}Ti(5.73e-13 mb); <-dZ>=2.27 <-dN>=8.89

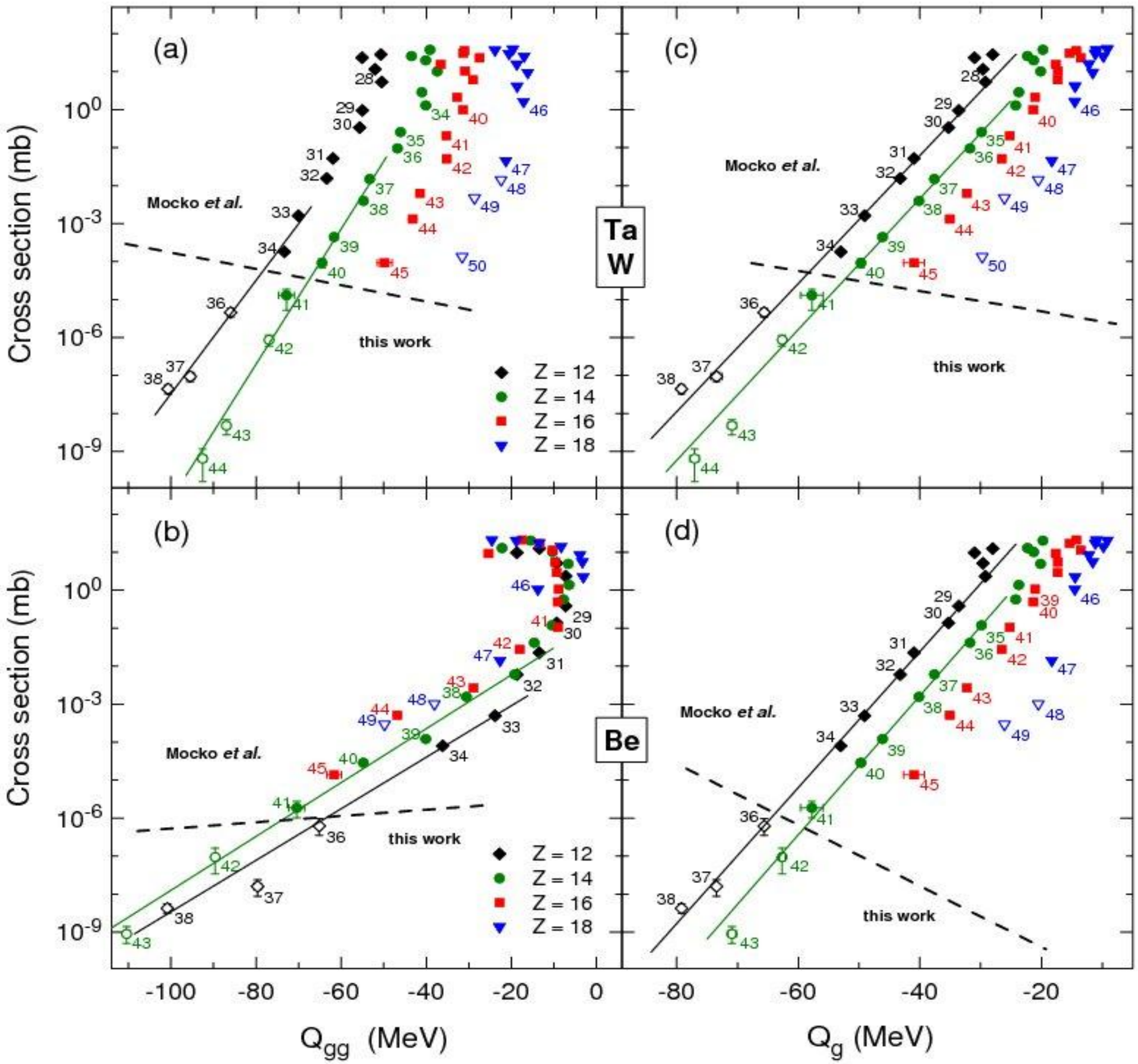
Excit.Energy: 149.0-207.0 MeV; Fus.CS: 0.0 mb; Fus.Barrier: 10.82 fm; h_omega = 2.0 MeV

NP=64; SE:"DB1+Cal0" Density:"auto" GeomCor:"On" TunIg:"auto" FisBar=#1 BarFac=1.00 Modes=1010 1010 010



More probable prefragments are Ti-isotopes (dZ=2)

Q_g- systematics



^{48}Ca(140MeV/u) + W,Be

A simple systematic framework was found to describe the production cross sections based on thermal evaporation from excited prefragments that allows extrapolation to other weak reaction products.

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

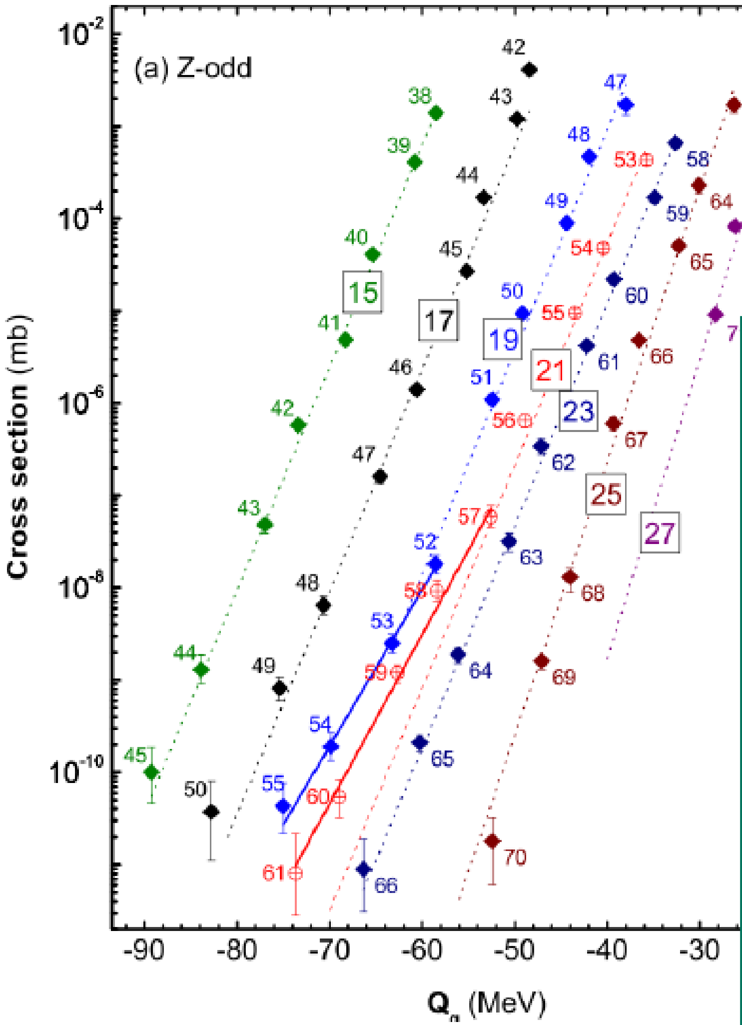
Compilation with data from M. Mocko et al., Phys. Rev. C 74, 054612 (2006)

Figure. The variation of the cross sections for the production of neutron rich nuclei as a function of the two-body *Q* values [Q_{gg}, left panels (a), (b)] and as a function of the one-body *Q* value [Q_g, right panels (c), (d)]. Upper panels (a), (c) show data for W (Ta), lower panels (b), (d) for Be targets.

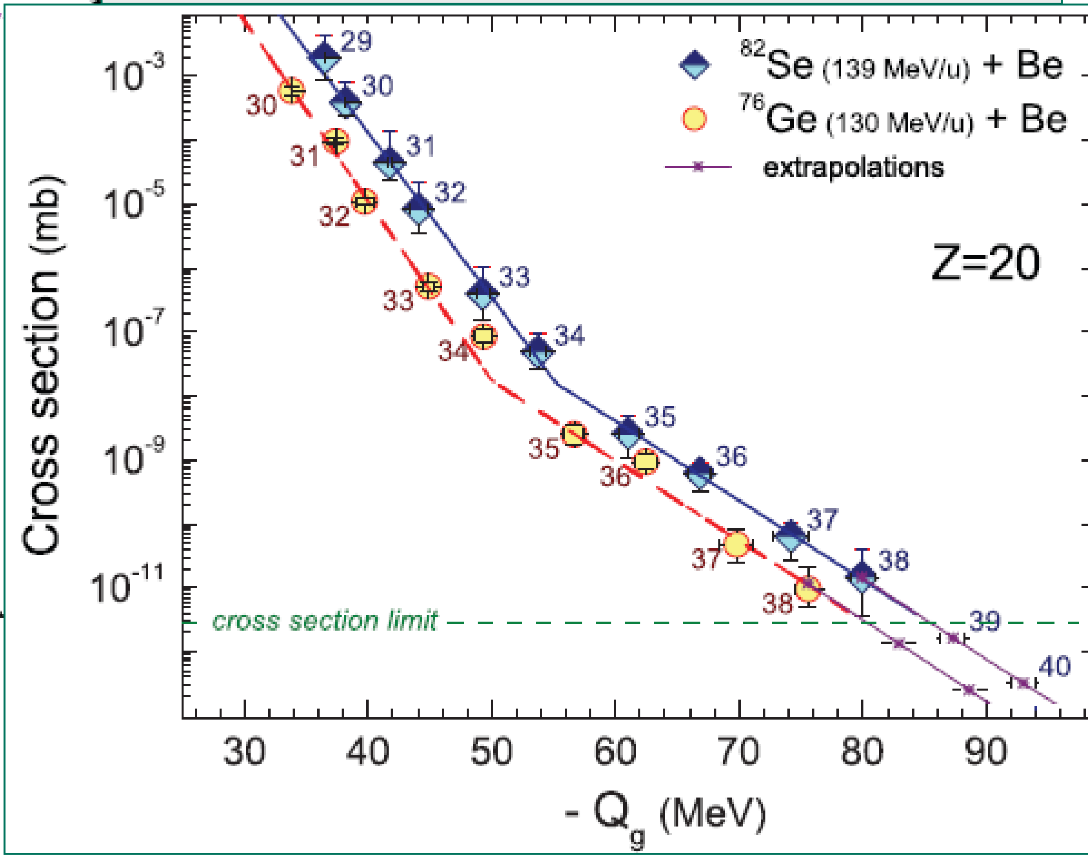
$$Q_g = ME(Z=20, A=48) - ME(Z,A)$$

^{76}Ge (130 MeV/u) + Be

O.T. et al., Phys. Rev. Lett. 102, 142501 (2009)



Production cross sections from ^{82}Se fragmentation as indications of shell effects in neutron-rich isotopes close to the drip-line



O.T. et al., Phys. Rev. C 87, 054612 (2013)

Production cross sections as indications of shell effects in neutron-rich isotopes close to the drip-line

O.T. et al., Phys. Rev. C 87, 054612 (2013)

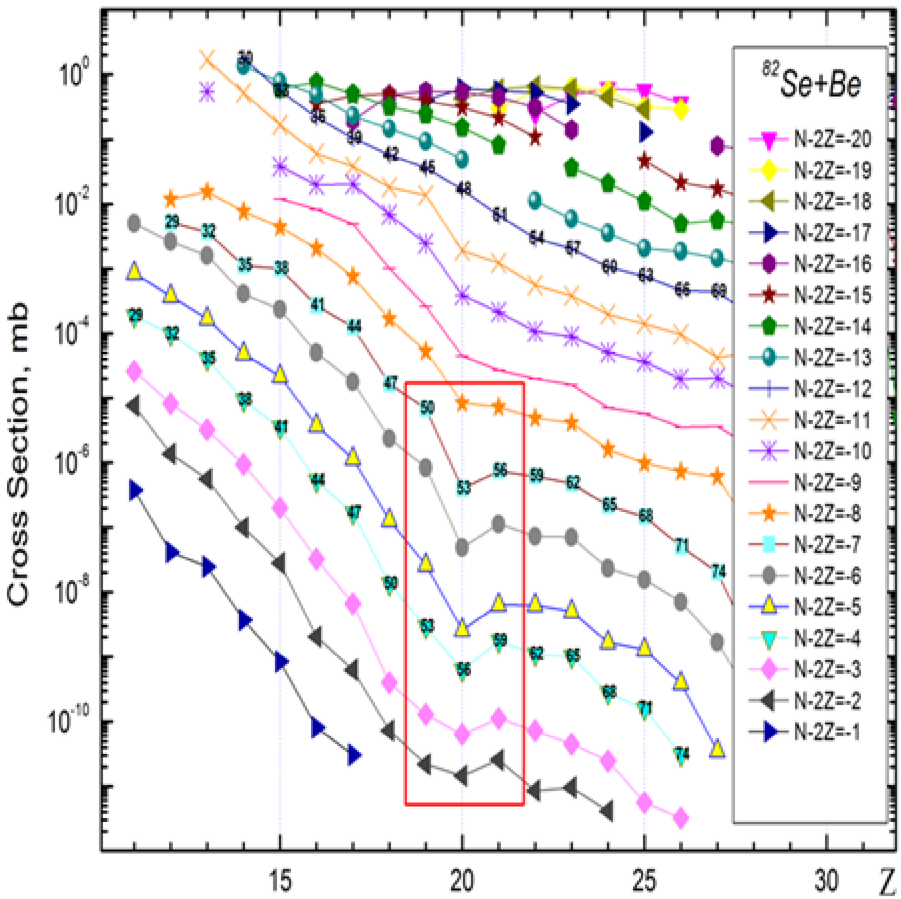


Figure . Production cross sections for fragments from the reaction of ^{82}Se with beryllium targets vs. the atomic number of the fragment. The cross sections are connected by lines of constant N-2Z.

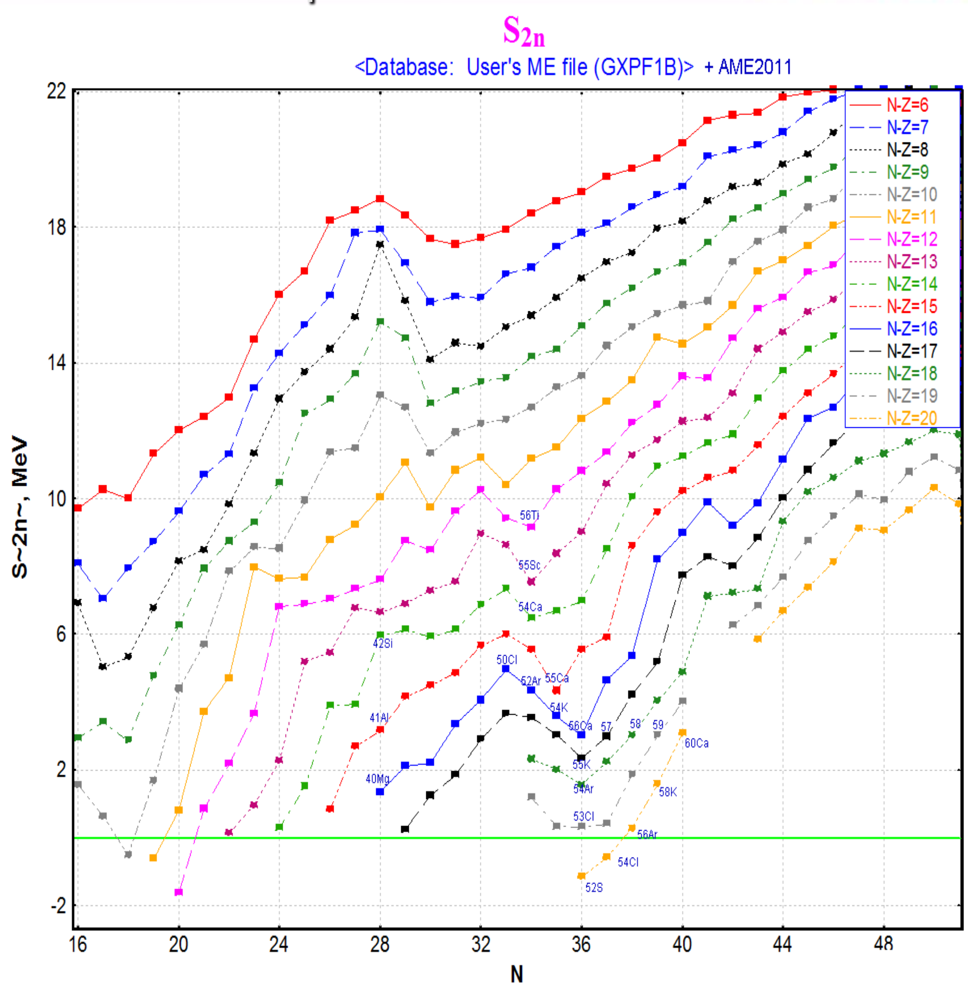
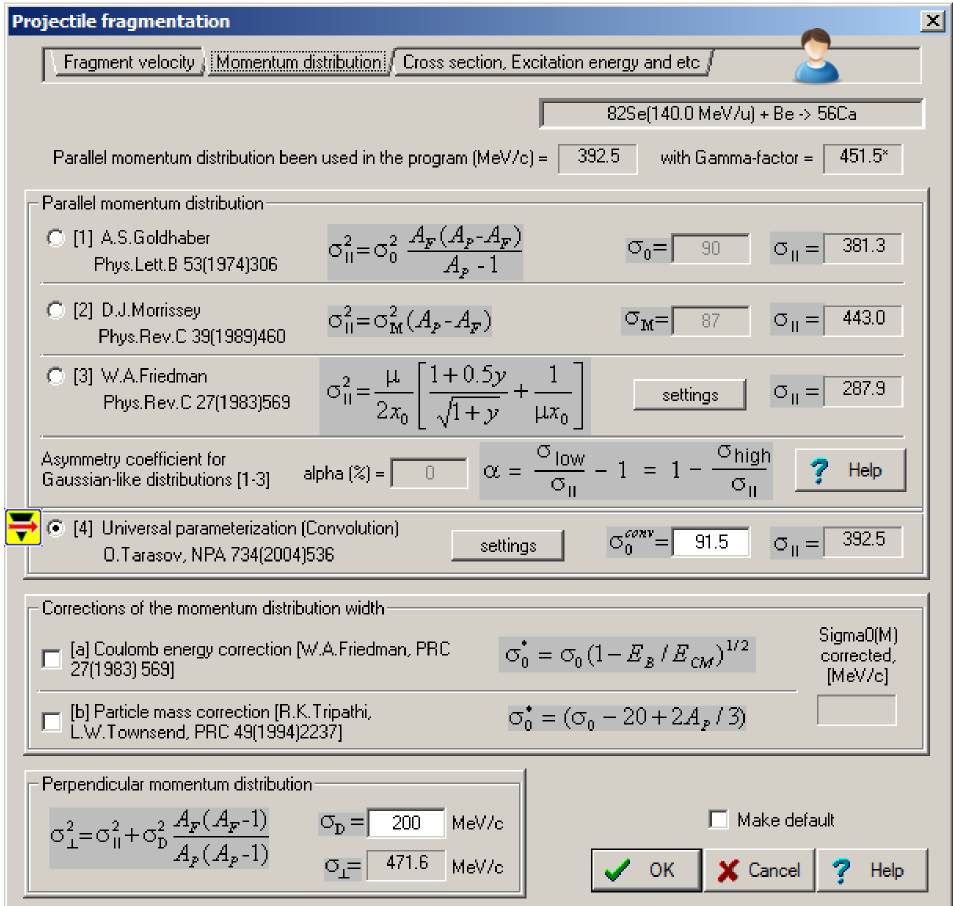
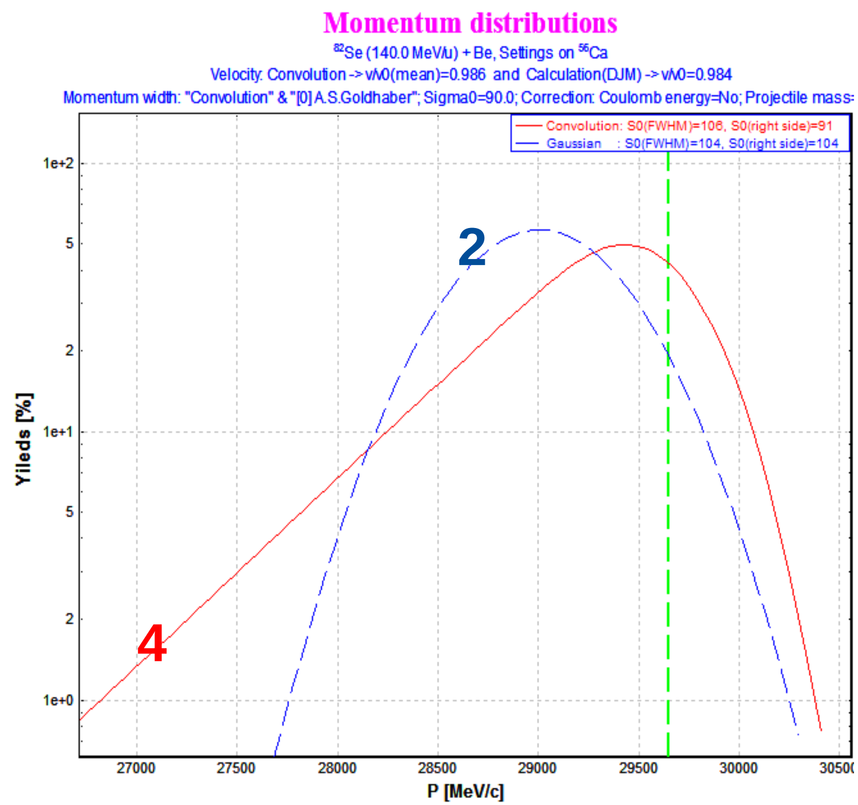


Figure. Two-neutron separation energy (S_{2n}) versus neutron number (N), *and connected by lines of constant N-Z. Values are* calculated using results from the GXPF1B5* model.

* Y. Utsuno, T. Otsuka, B. A. Brown, M. Honma, T. Mizusaki, and N. Shimizu, Phys. Rev. C 86, 051301(R) (2012).

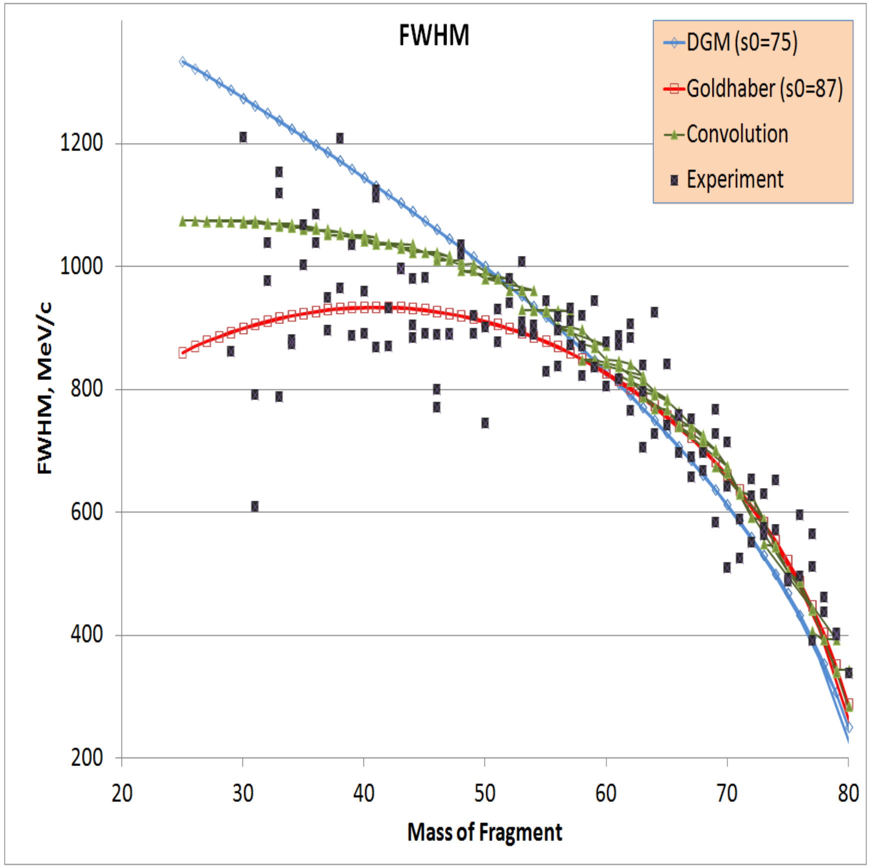
Projectile Fragmentation: Momentum Distributions

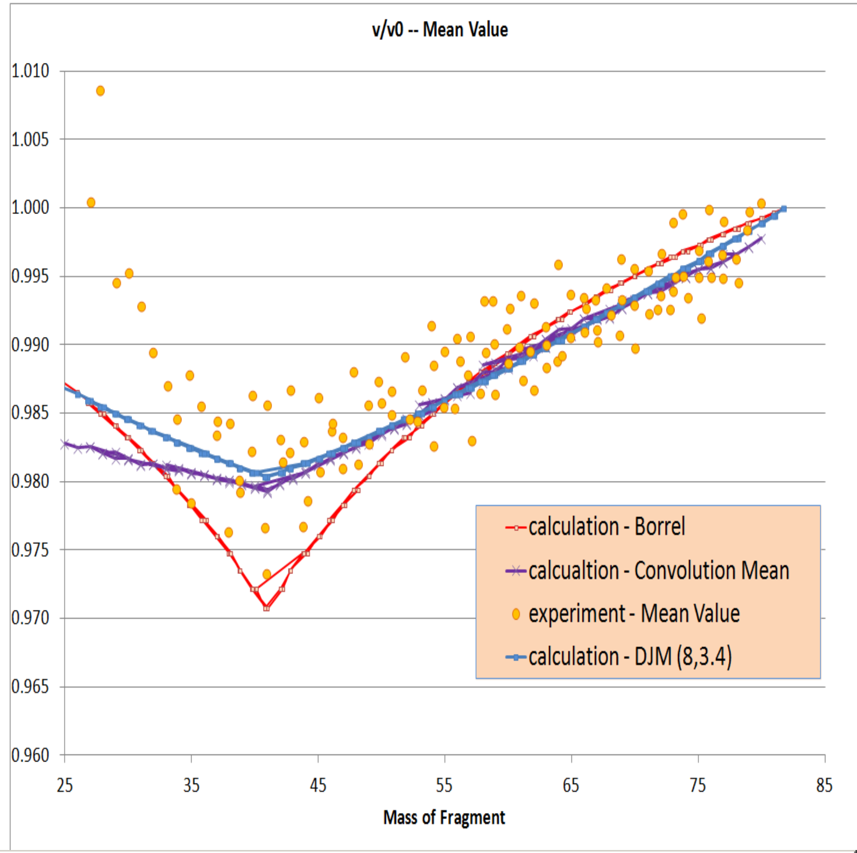




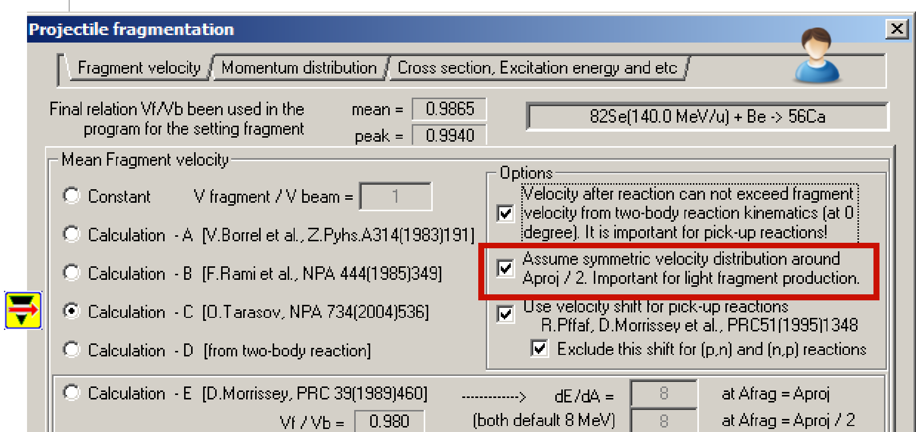
- **Models [1-3] : Gaussian distributions**
- **Model [4] : Convolution**
- **Proton rich side : low-exponential energy tails create difficulties with purity of RIBs**

^{82}Se (139 MeV/u) + Be : Momentum Distributions



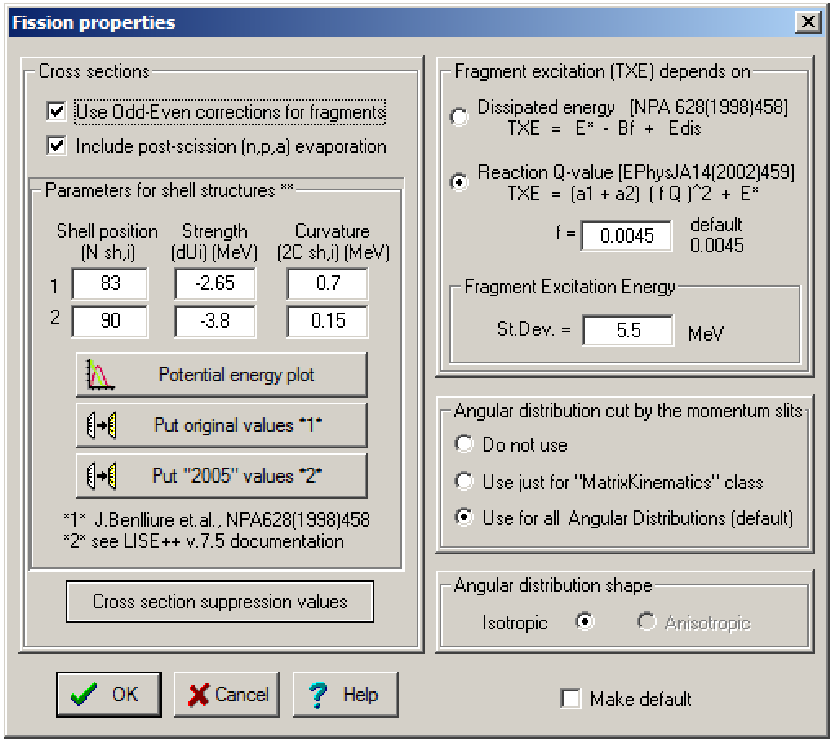


O.T. et al., will be submitted to NIMA



Fission fragment production model in LISE++

- The fission fragment production model is at the basis of all fission reactions implemented in LISE++
- The fissile nucleus (A,Z), fission channel cross section (σ_{fis}), and excitation energy (E*) are the input parameters
- The kinetic energy of the fissile nucleus is used for kinematics calculations in order to estimate the transmission through the separator.



1-st step: Calculation of an initial fission cross-section matrix of excited fragments using the semi-empirical model of Benllliure [1]. This model has some similarities with previously published approaches [2,3] with the added advantage of describing fission properties of a large number of fissile nuclei over a wide range of excitation energies.

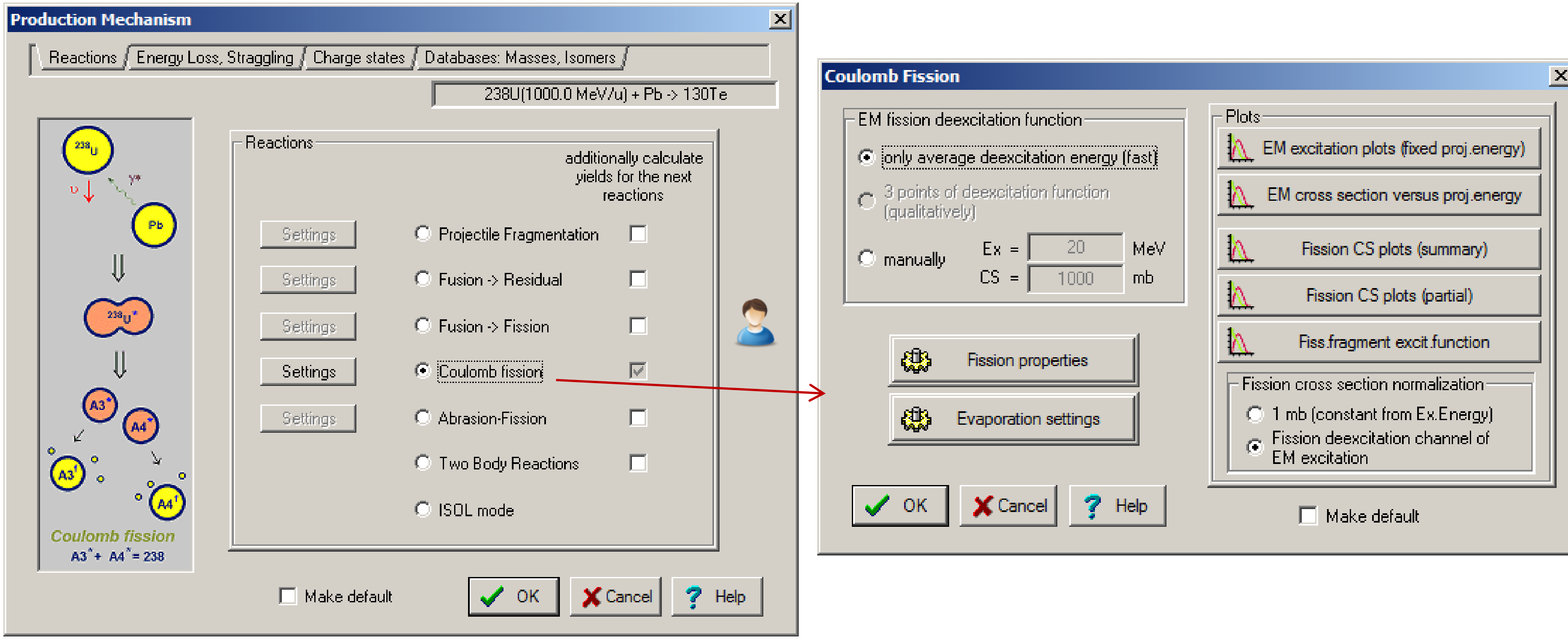
2-nd step: Post-scission nucleon emission. The code calculates the number of post-scission nucleons with LISE evaporation cascade, which enables the user to make <u>rapid</u> and <u>qualitative</u> calculations.

Less than 5 seconds for low-energy fission!

References

1. J.Benlliure et al., Nuclear Physics A 628 (1998) 458-478.
2. M.G.Itkis et al., Yad.Fiz. 43 (1986) 1125.
3. M.G.Itkis et al., Fiz.Elem.Chastits At.Yadra 19 (1988) 701.
4. O.Tarasov and D.Bazin, NIM B204 (2003) 174-178.

Coulomb Fission



1. The program assumes that the reaction takes place in middle of the target. Therefore the first step is the **calculation of the primary beam energy in the middle of the target.**
2. **Total fission cross-section and average excitation energy**:
   a. Calculation of differential electromagnetic cross-section.
   b. Deexcitation fission function $d\sigma^f/d(E^*)$.
   c. Calculation of statistical parameters of the deexcitation fission function: mean value $<E^*>$, and area σ^f.
3. **Calculation of an initial fission cross-section matrix**
4. **Post-scission nucleon emission**

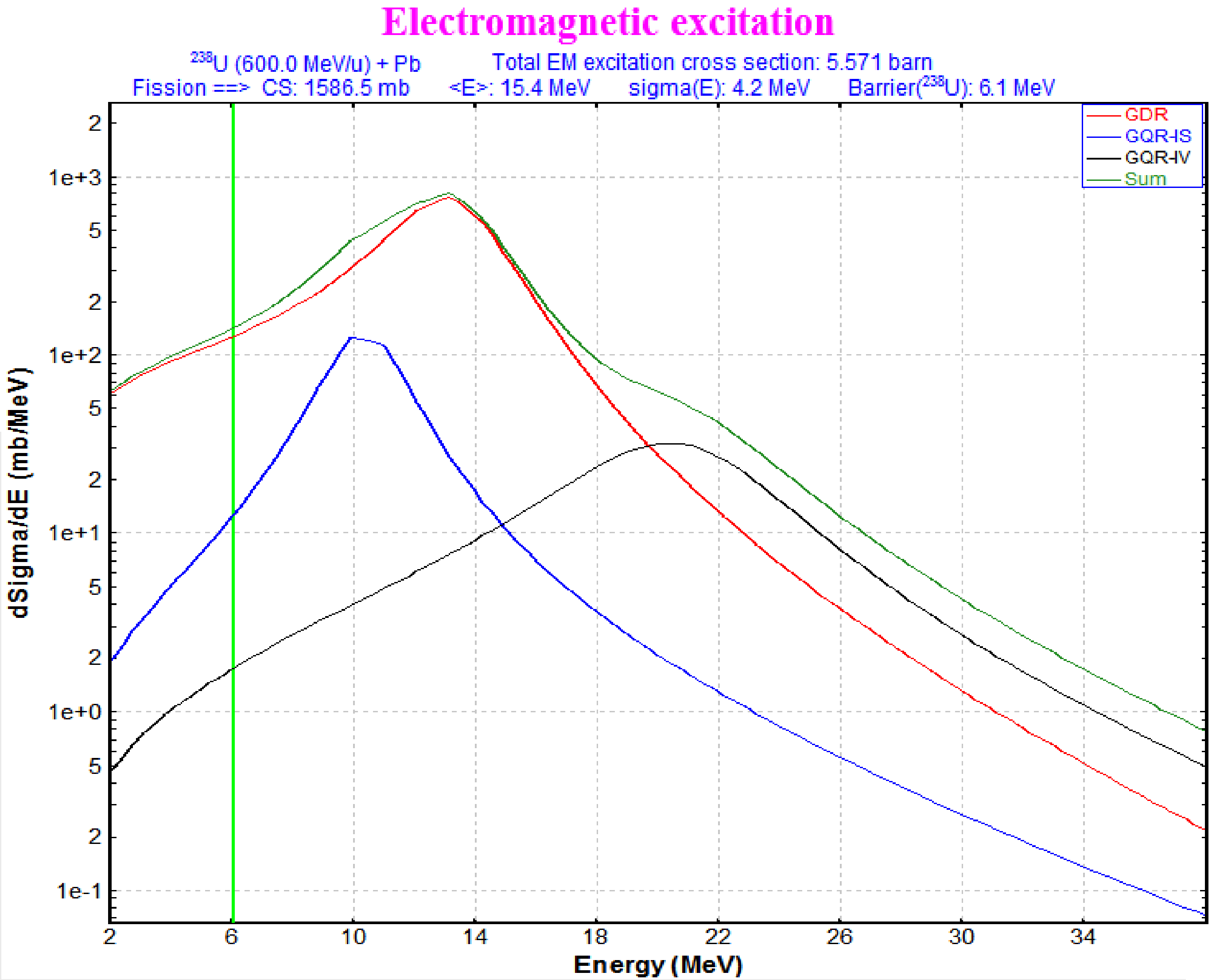
Electromagnetic excitation

A well-known review of the processes generated by the electromagnetic interaction in relativistic nuclear, and atomic collisions, by C.Bertulani and G.Baur [Physics Report 163 (1988) 299-408] has been used to obtain the excitation energy function for fission.

The differential cross-section for electromagnetic excitation is given by:

$$\frac{d\sigma_{em}}{dE_\gamma} = \frac{n_{E1}}{E_\gamma}\cdot\sigma_\gamma^{E1} + \frac{n_{E2}}{E_\gamma}\cdot\left(\sigma_{\gamma,1}^{E2} + \sigma_{\gamma,2}^{E2}\right)$$

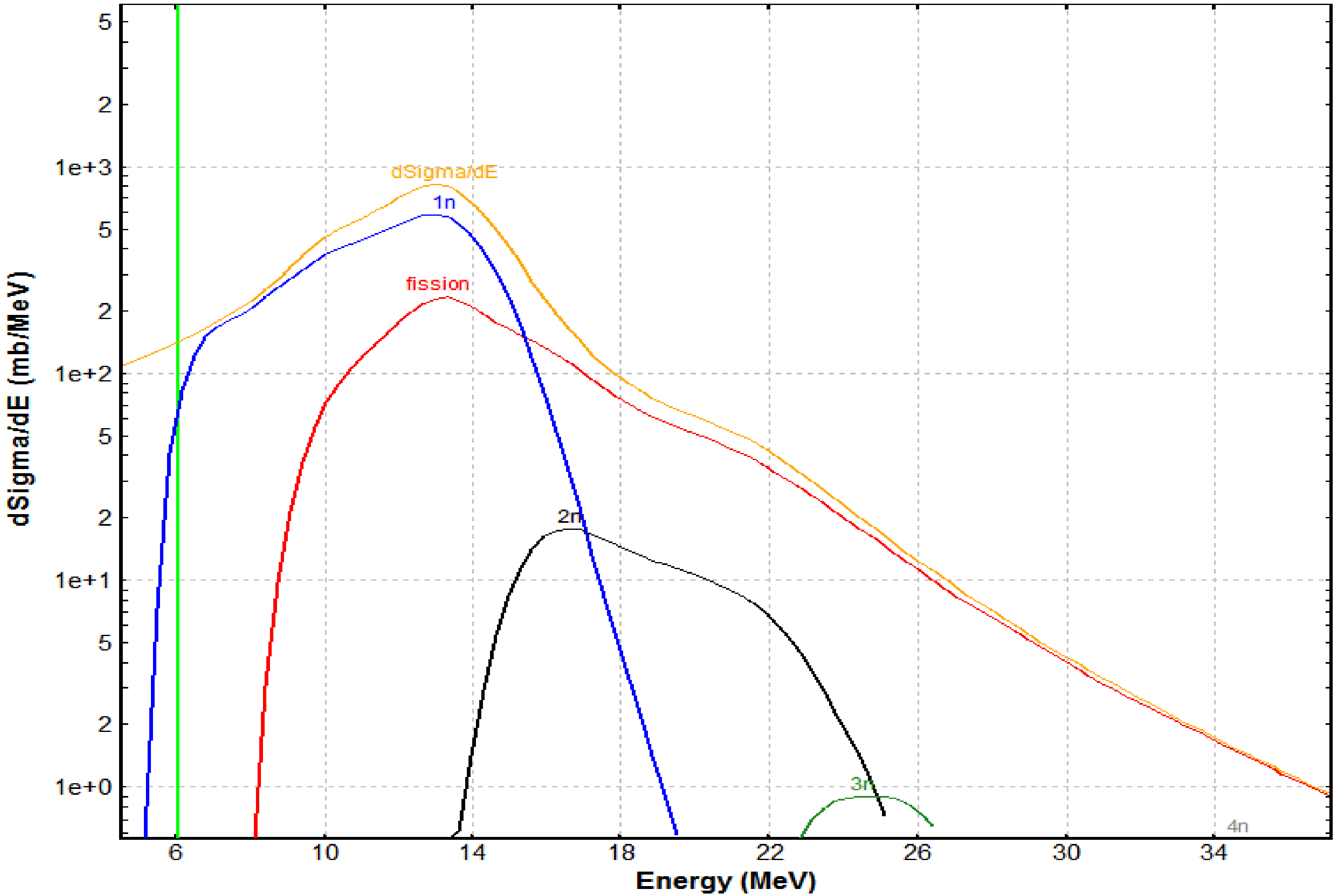
with n_{E1}, n_{E2} being the number of equivalent photons for electric dipole and quadrupole excitations respectively. $\sigma_\gamma^{E1}, \sigma_{\gamma,i}^{E2}$ are the photon absorption cross-sections for giant E1 and E2 excitations, where for E2 excitations i=1 denotes isoscalar and i=2 denotes isovector giant quadrupole resonances. Multiple excitations of the quadrupole resonances are neglected.



Differential cross-sections of GDR (red solid curve), GQR(IS) (blue dashed curve), and GQR(IV) (black dot curve) excitations in ^{238}U as calculated from the equivalent photon spectrum representing a ^{208}Pb projectile nucleus at 600 MeV/u.

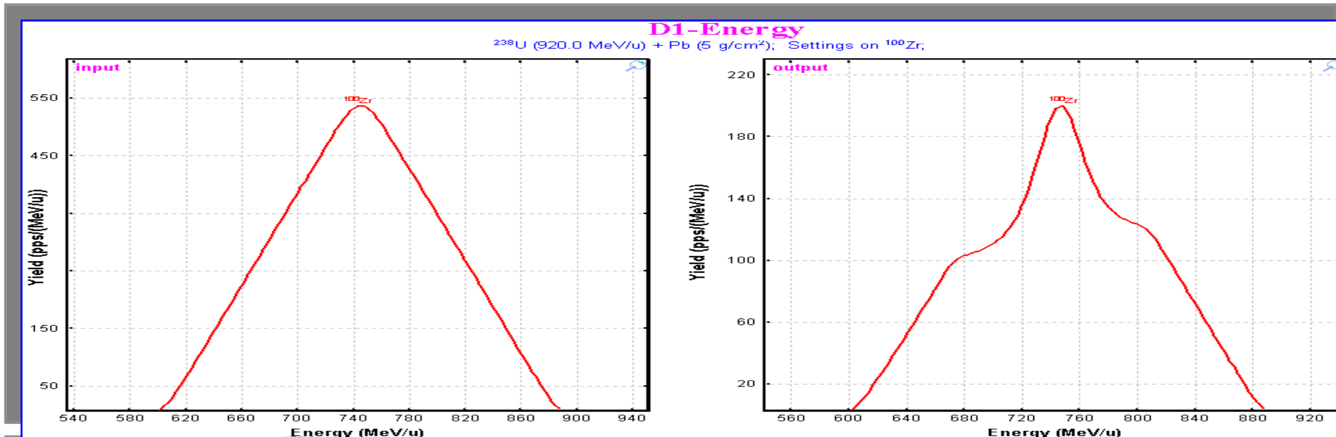
Deexcitation channels

Deexcitation channels for ^{238}U nuclei at 600 MeV/u excited by a lead target. The solid red curve represents fission decay. The blue dashed line represents 1n-decay channel, black dotted and green dot-dashed curves respectively 2n- and 3n-decay channels.



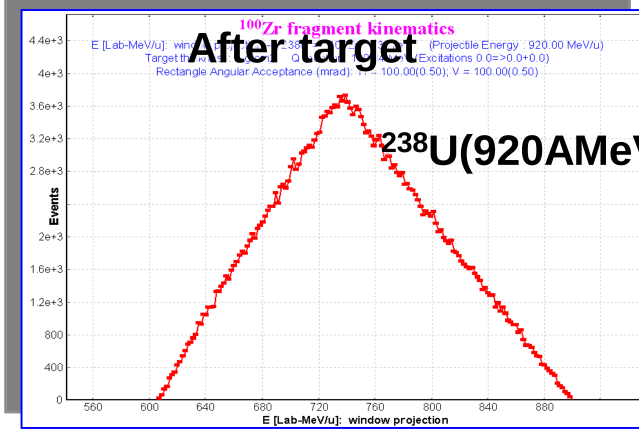
Comparison of different calculation methods

LISE++ Distribution Method



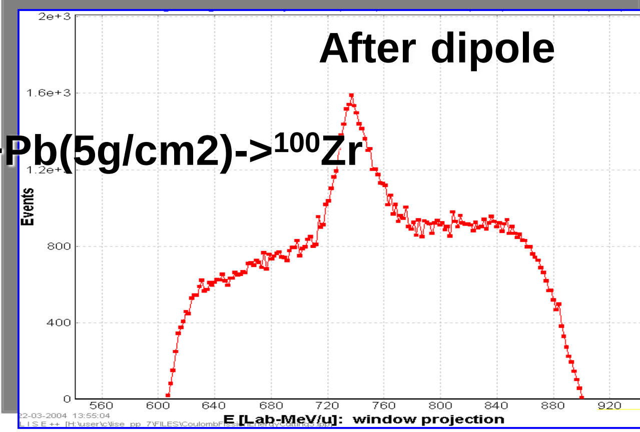
LISE++ MC method

After target

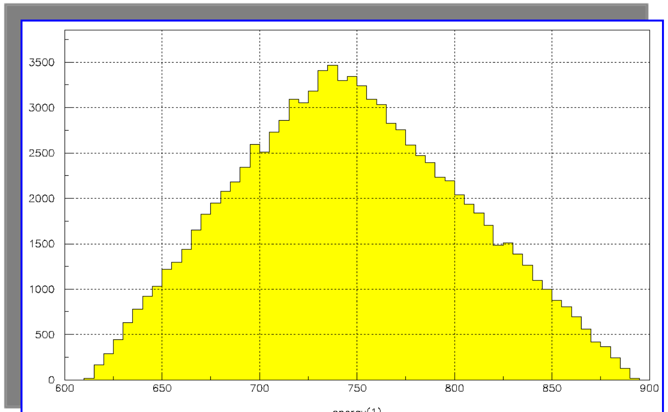


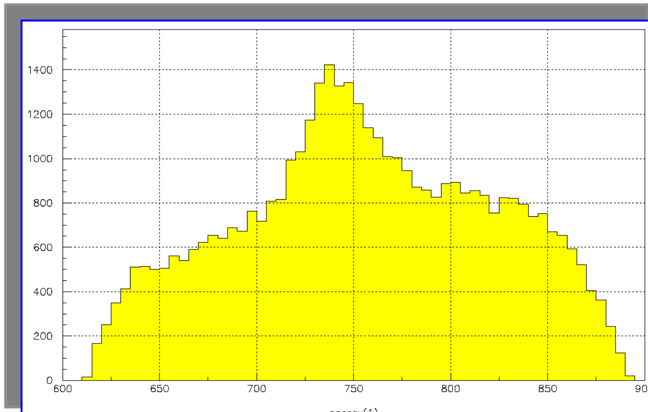
$^{238}U(920AMeV)+Pb(5g/cm2)\rightarrow{}^{100}Zr$

After dipole

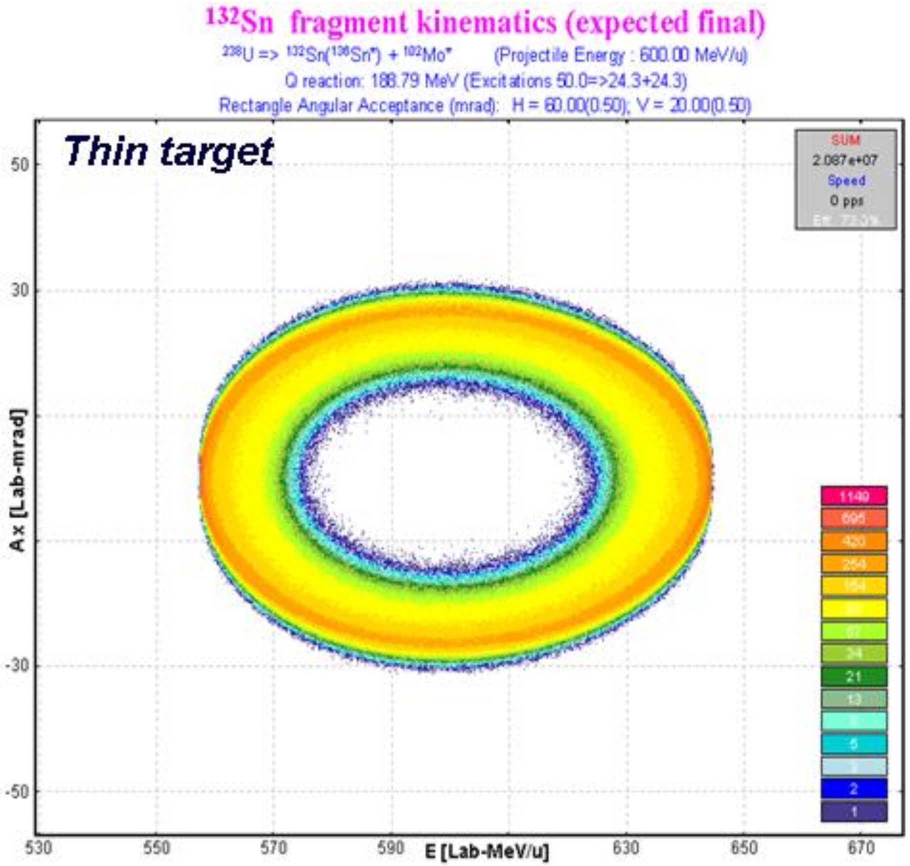


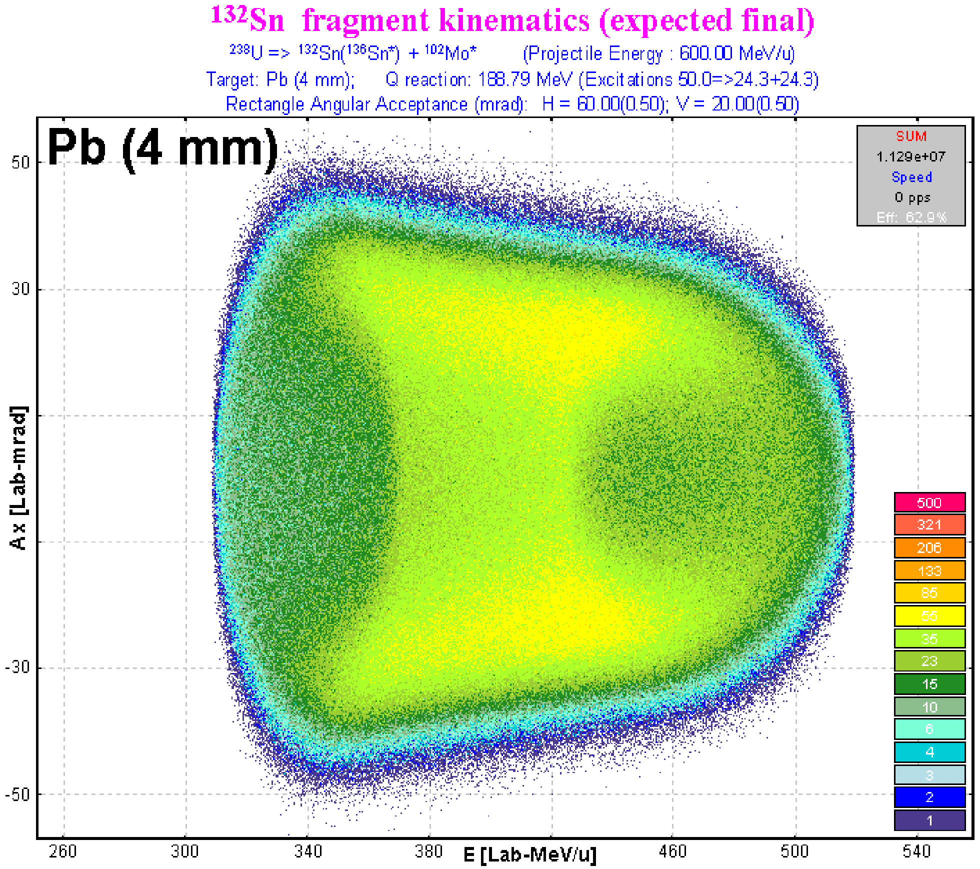
MOCADI





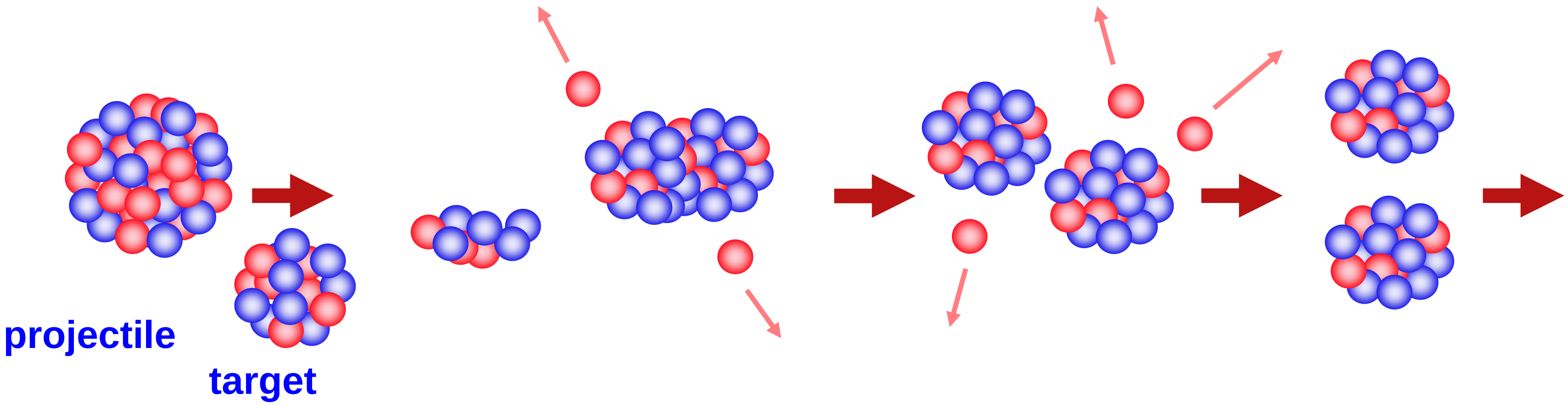
Fission kinematics by Monte Carlo method





2D-plots Ax(horizontal component of the angle in the laboratory frame) versus Energy per nucleon of ^{132}Sn final fragment after ^{238}U(600MeV/u, Ex=50MeV) fission. Angular acceptances H=60mrad and V=20mrad. The left plot has been produced with very thin target, the right picture represents the case of thick target (Pb 4mm).

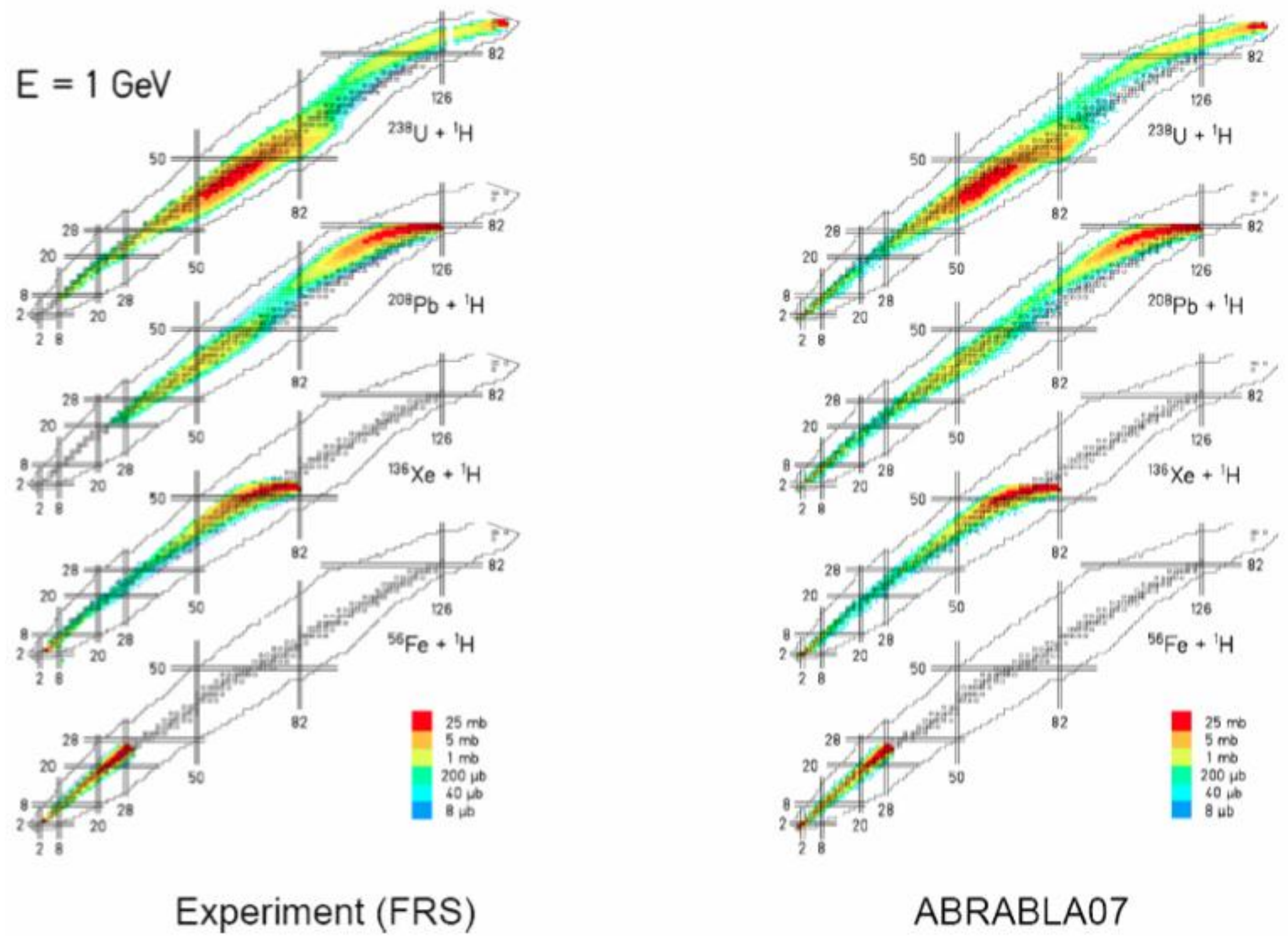
Abrasion-Fission



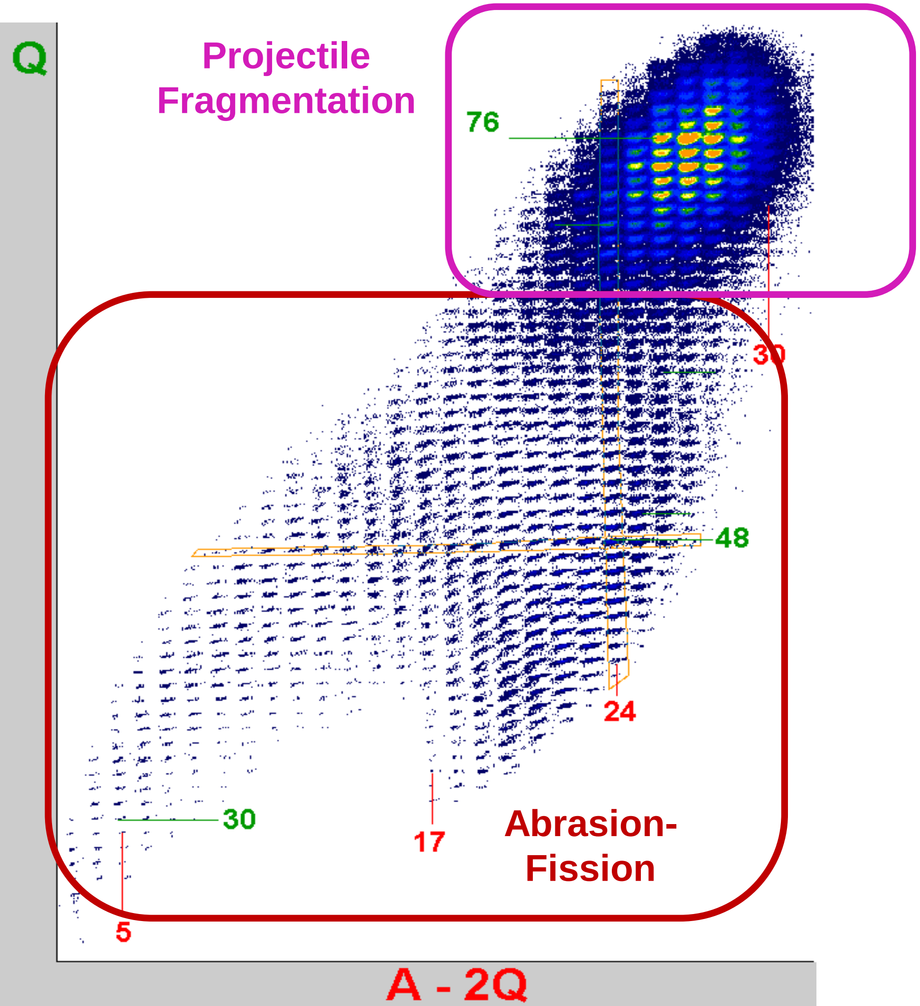
- **ABRABLA : Abrasion-Ablation Monte Carlo**
  J.-J. Gaimard, K.-H. Schmidt, Nucl. Phys. A 531 (1991) 709.
- **PROFI : semi-empirical fission Monte-Carlo code**
  J. Benlliure, A. Grewe, M. de Jong, K.-H. Schmidt, S. Zhdanov, Nucl. Phys. A 628 (1998) 458
- **LISE^{++} 3EER Abrasion-Fission model (analytical)**
  O.T., Tech. Rep. MSUCL1300, NSCL, Michigan State University, 2005
  http://lise.nscl.msu.edu/7_5/lise++_7_5.pdf

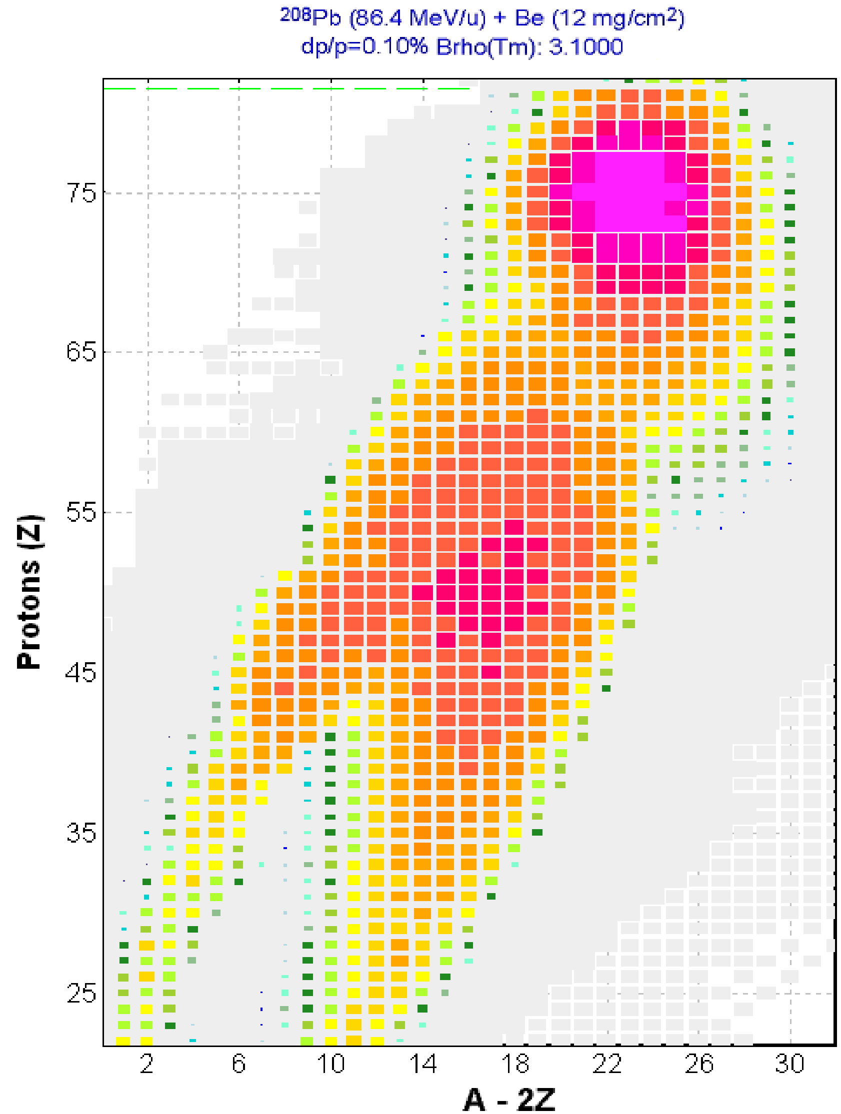
http/www.gsi.de/charms

A. Kelić, S. Lukić, M. V. Ricciardi, K.-H. Schmidt



Contribution of different reaction mechanisms : ^{208}Pb (86 MeV/u) + Be data vs. LISE++





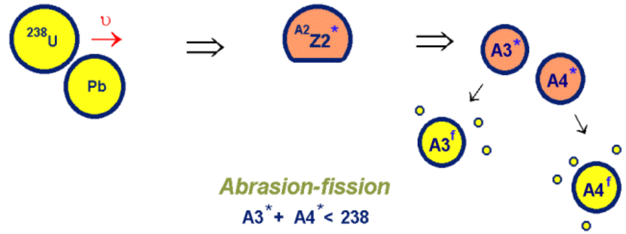
Experiment #05120 @ NSCL

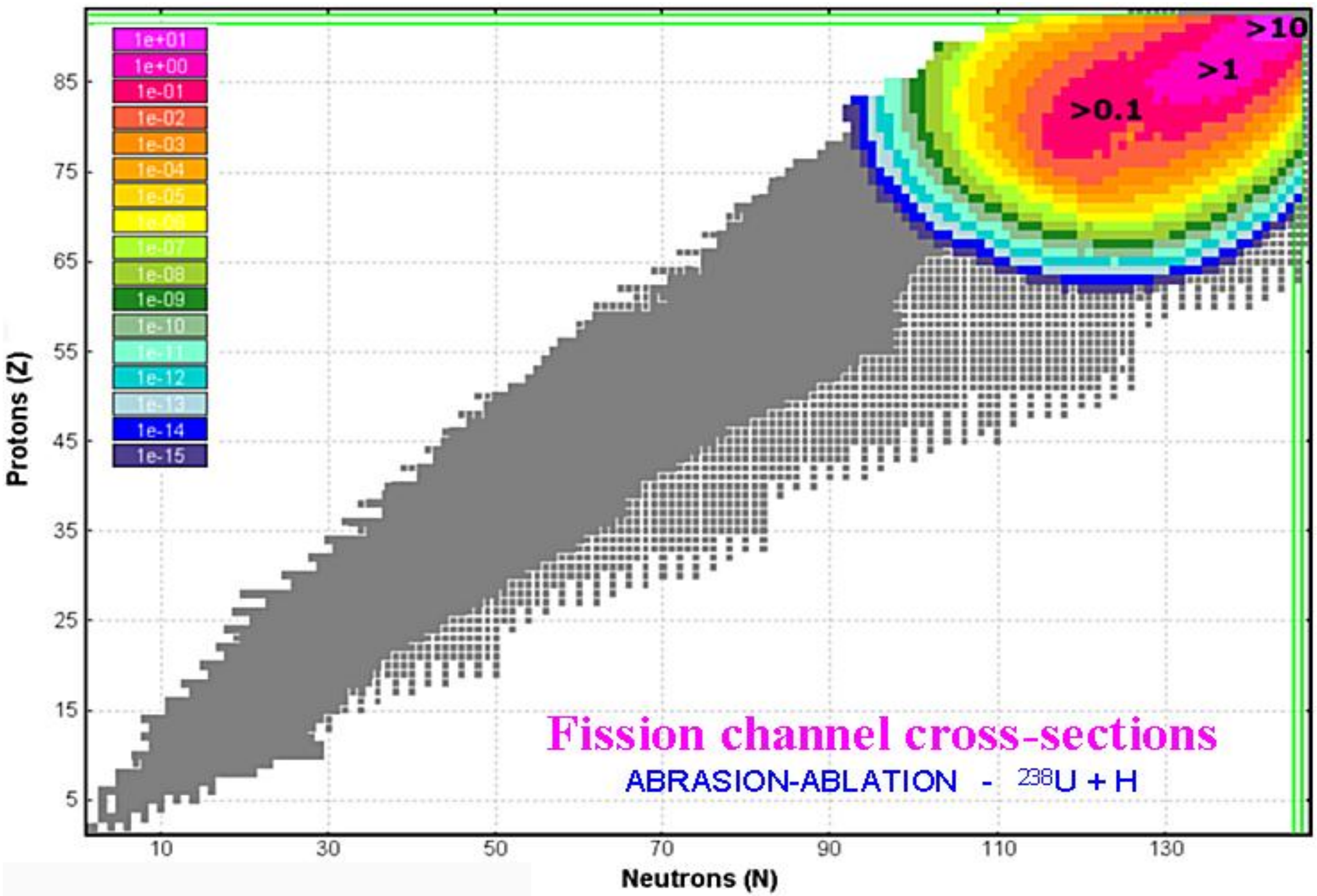
O.T. AIP Conference Proceedings Volume 1224, ISBN: 978-0-7354-0768-8 ; Preprint MSUCL1409, NSCL/MSU 2009

Good qualitative agreement between experimental data & LISE^{++} AA & AF

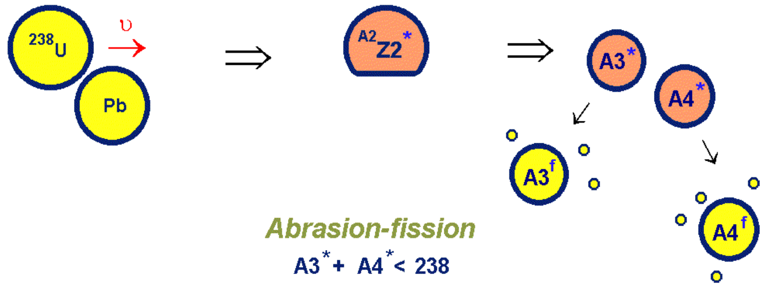
How do we calculate?

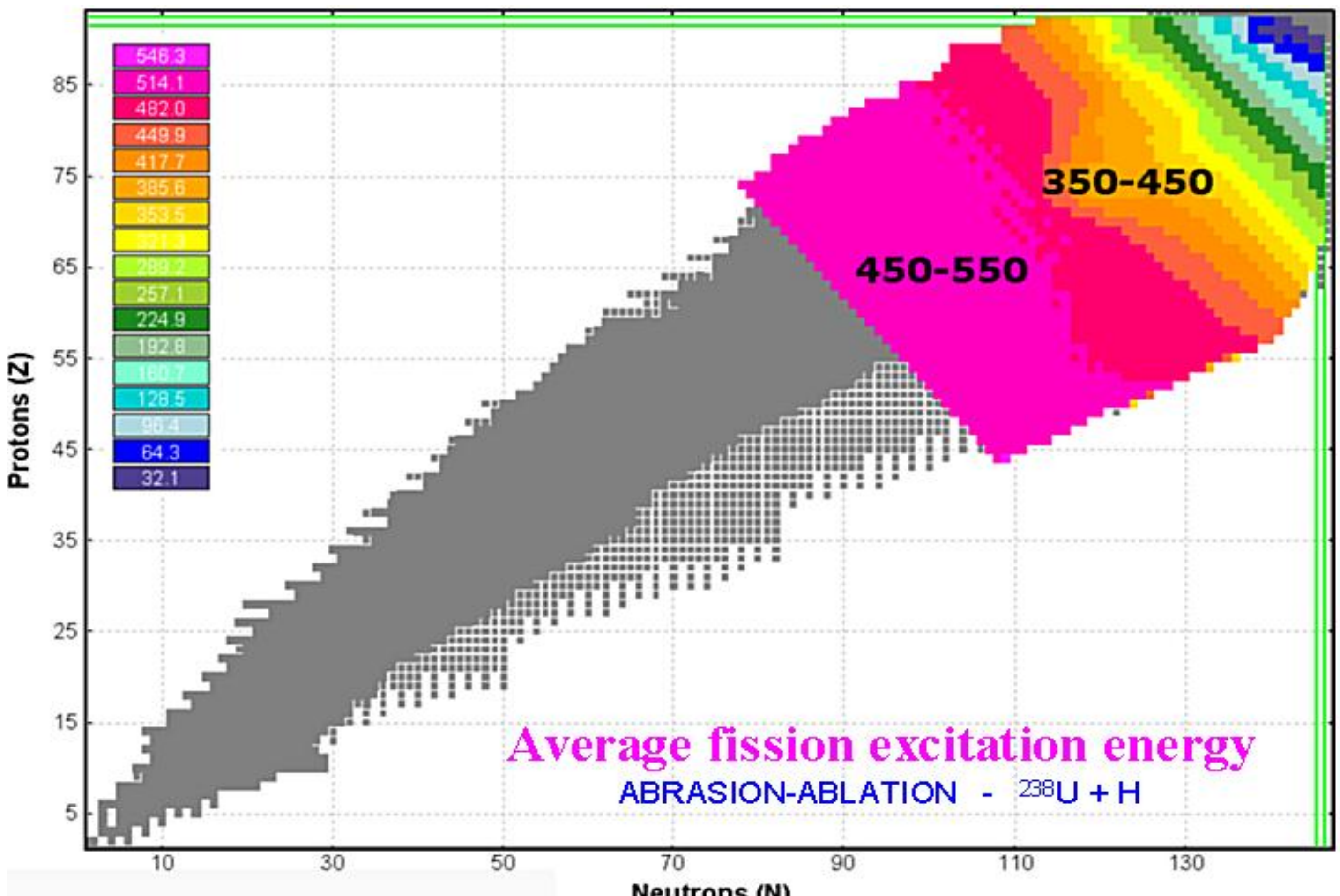
Abrasion-Fission : ocean of fissile nuclei



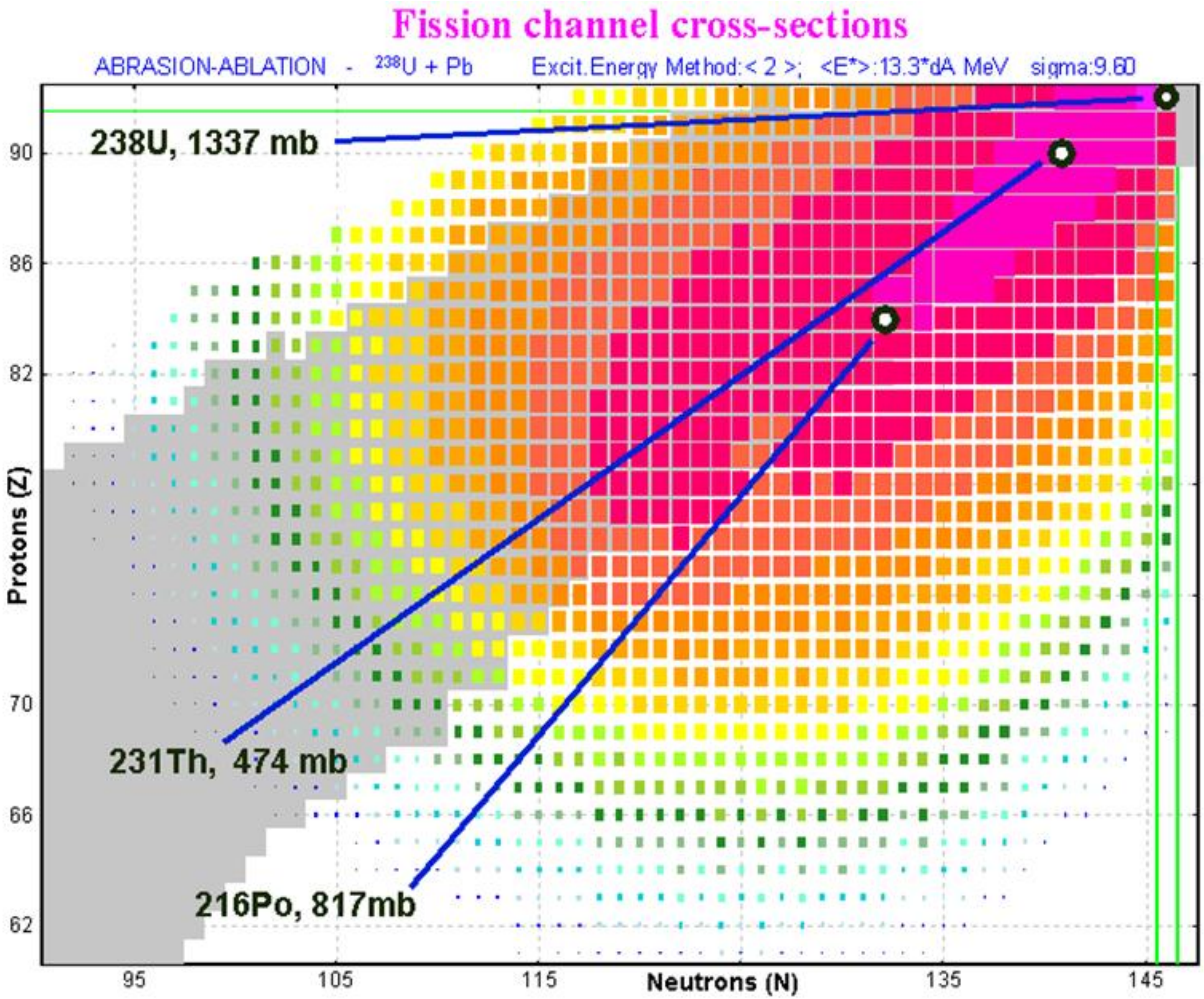


Abrasion-Fission : ocean of hot fissile nuclei

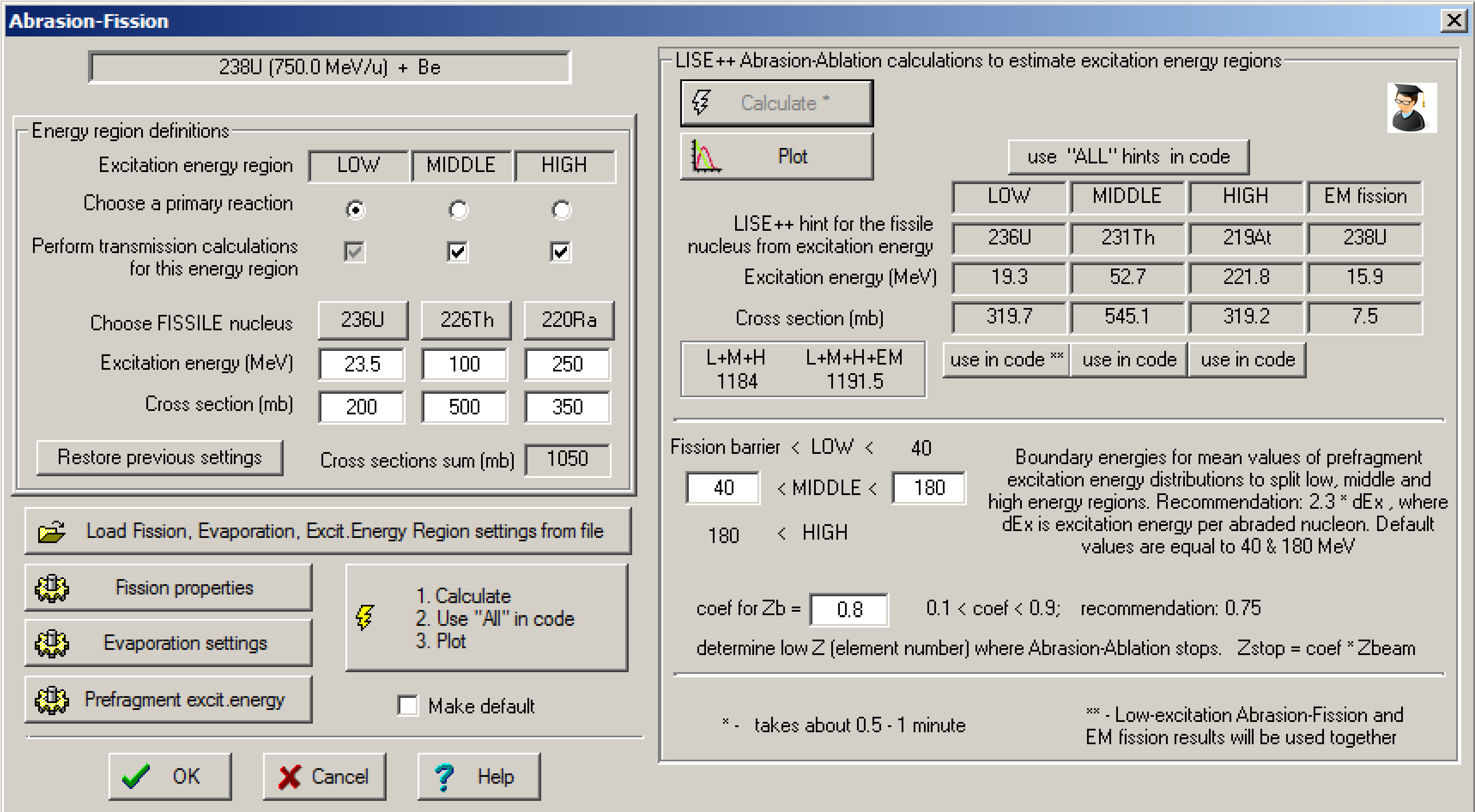




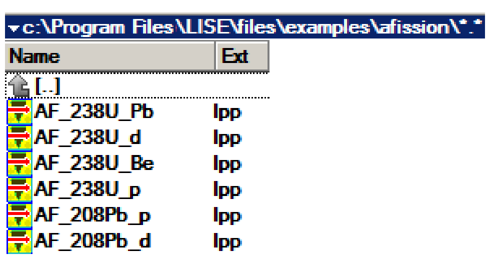
Abrasion-Fission : 3 EER model

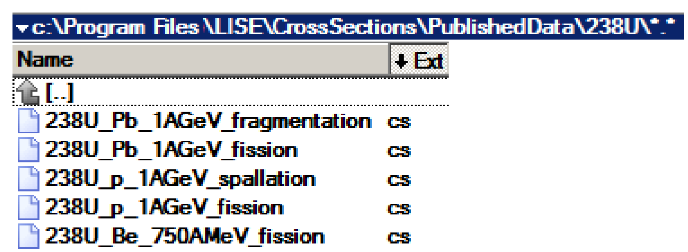


Three-excitation-energy-region model

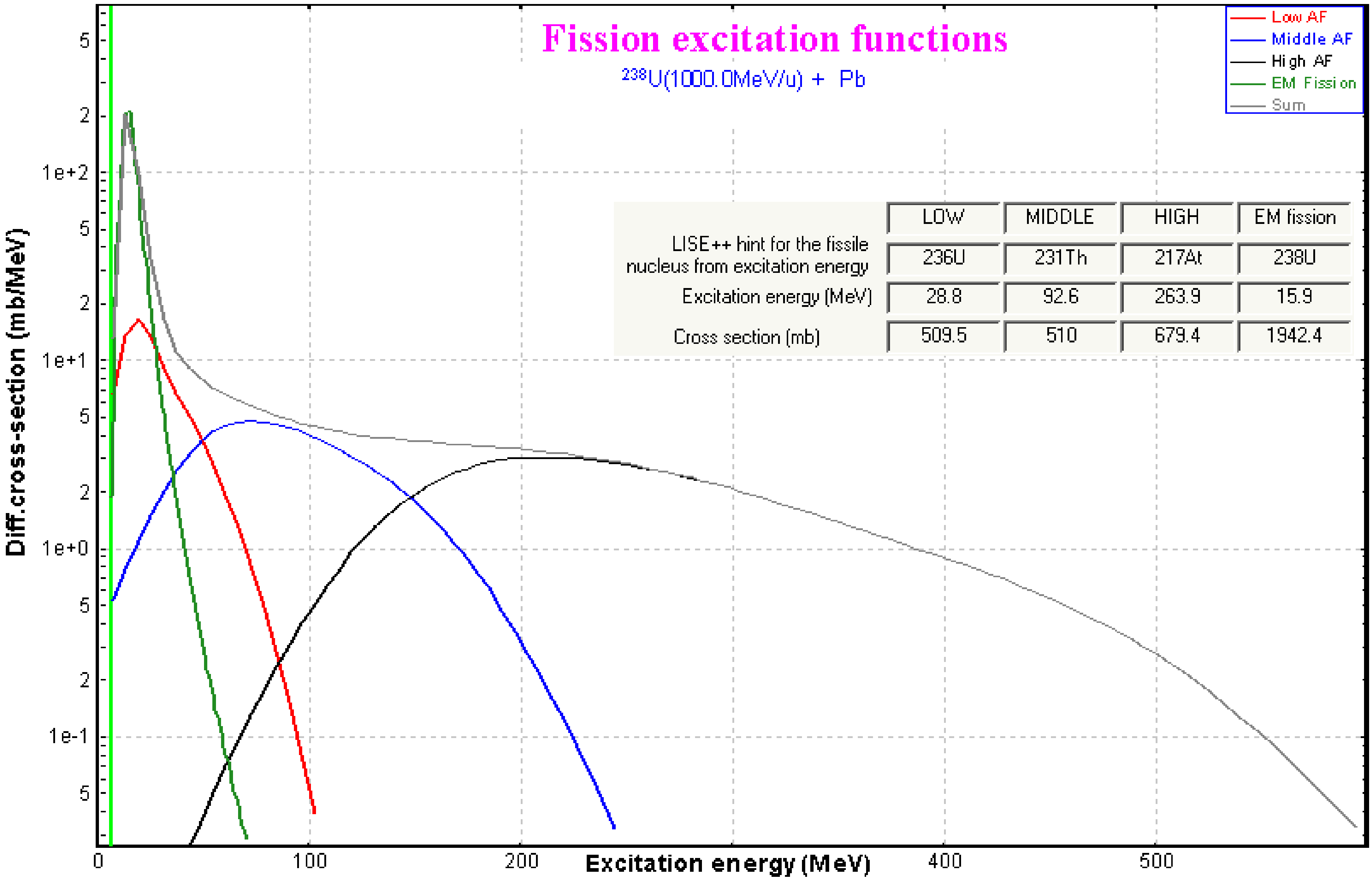


LISE^{++} package:



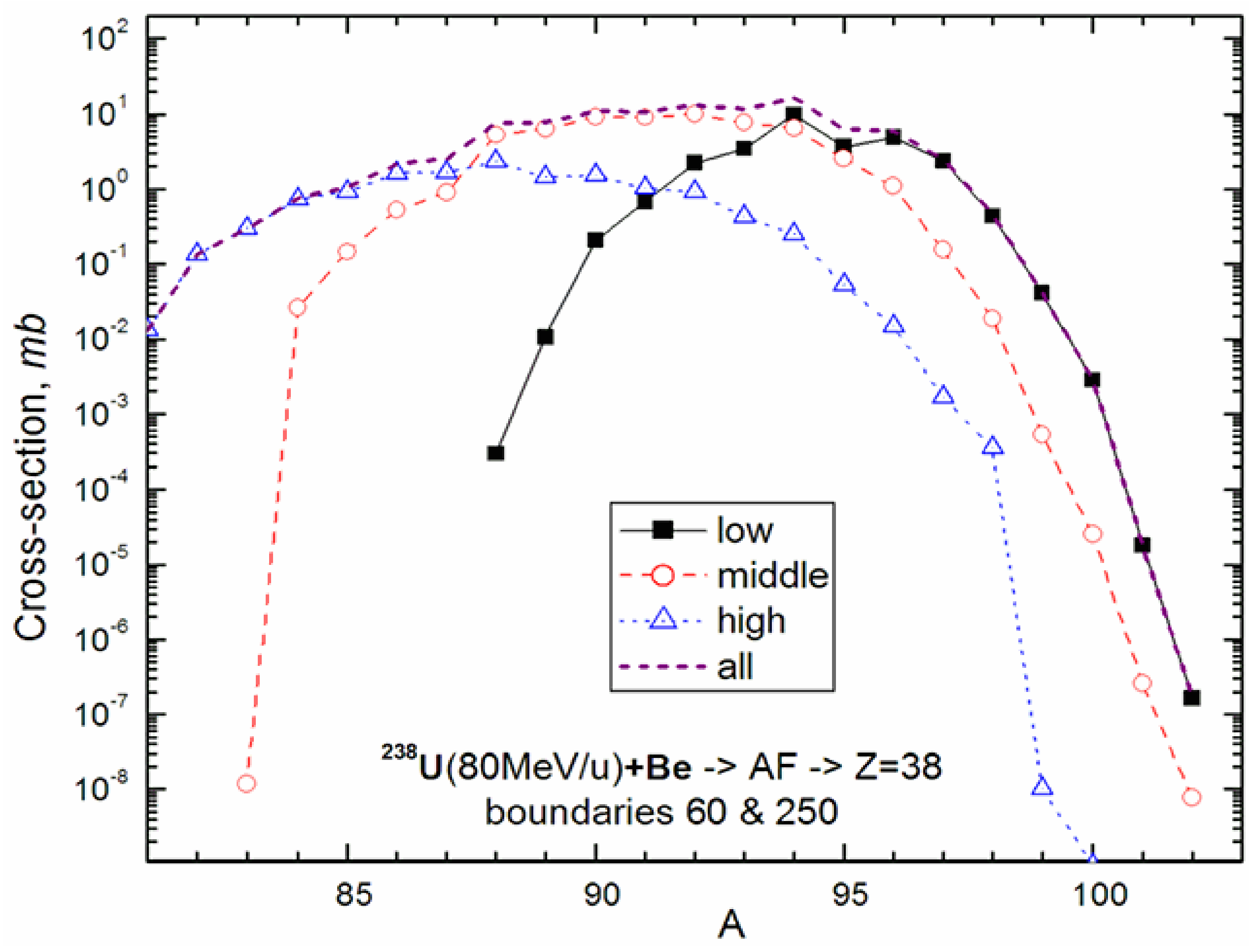


Fission excitation functions



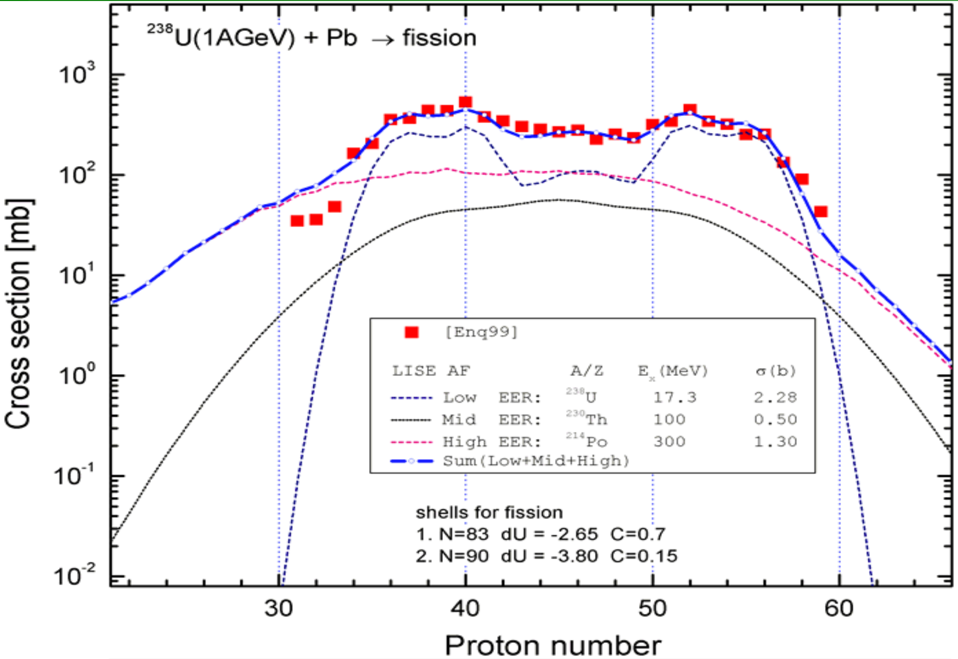
	LOW	MIDDLE	HIGH	EM fission
LISE++ hint for the fissile nucleus from excitation energy	236U	231Th	217At	238U
Excitation energy (MeV)	28.8	92.6	263.9	15.9
Cross section (mb)	509.5	510	679.4	1942.4

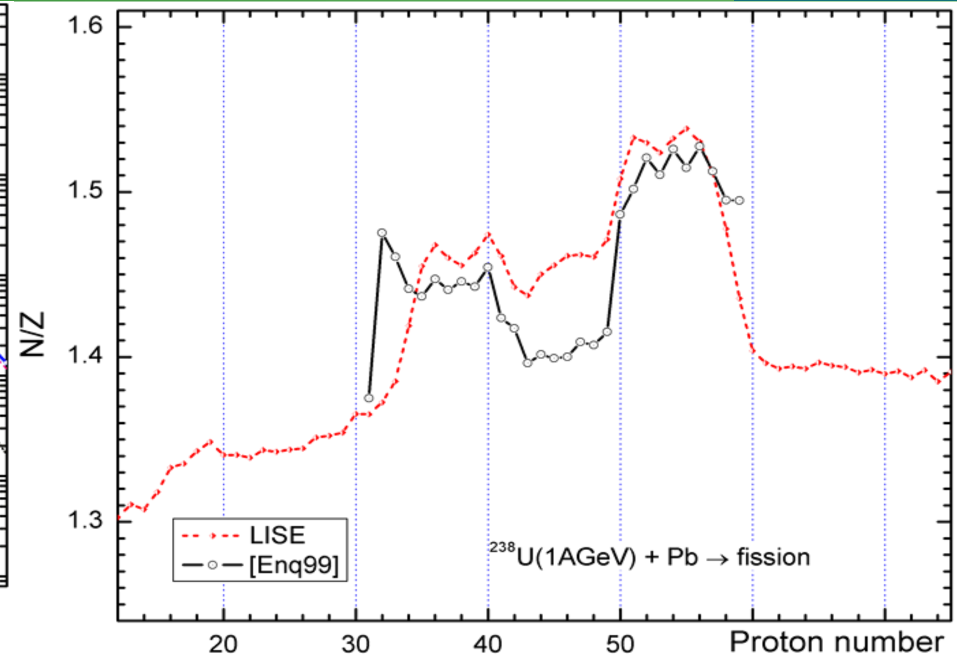
Three-excitation-energy-region model

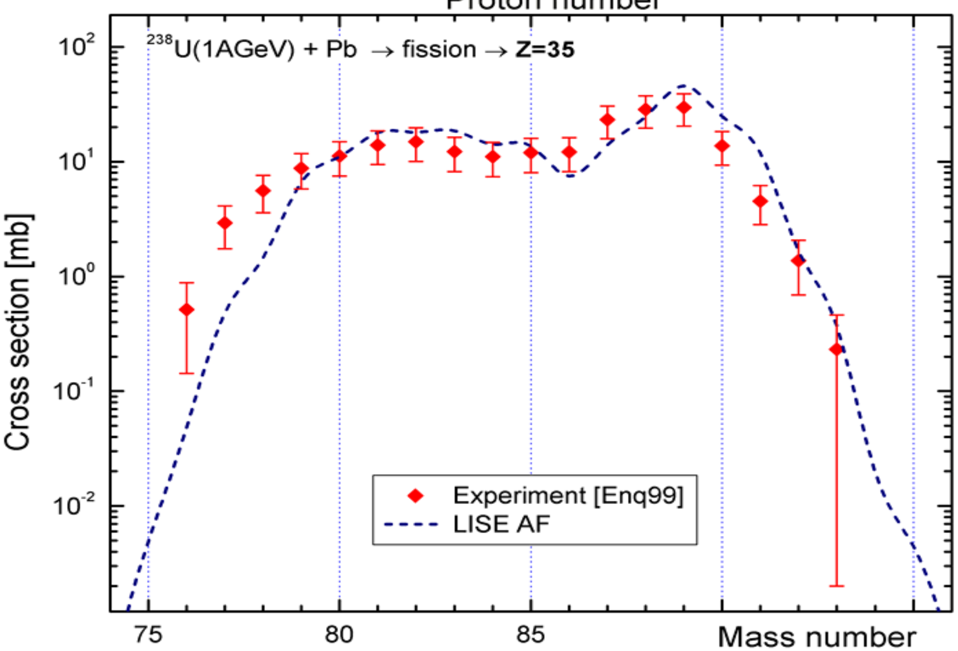


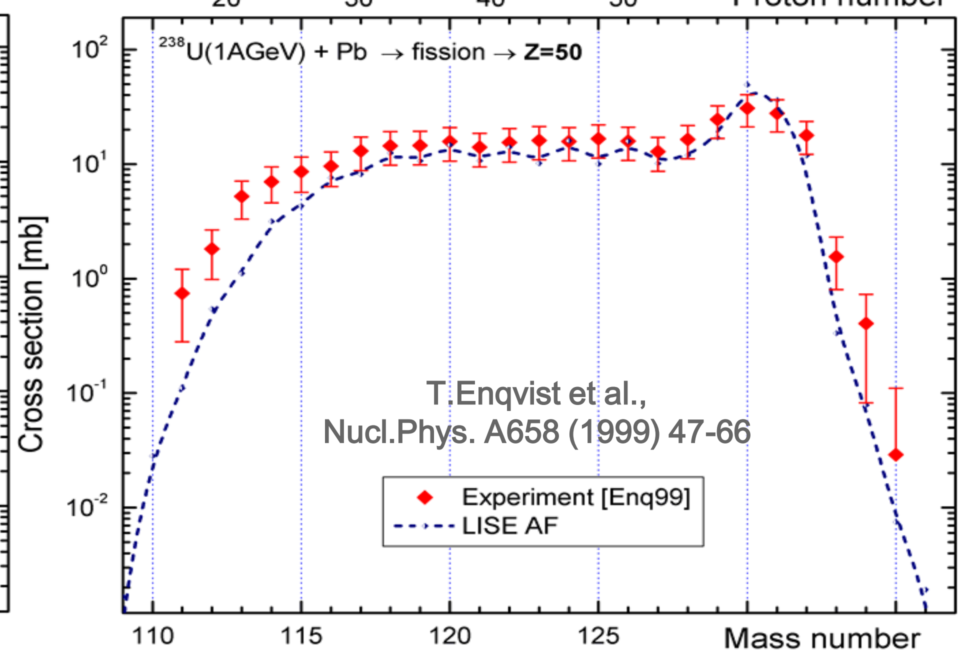
Partial and total mass distributions of Strontium fission fragments in the reaction ^{238}U(80MeV/u)+Be.

^{238}U(1AGeV) + Pb









In-flight fission of ^{238}U with Be and Pb targets

Abrasion fission

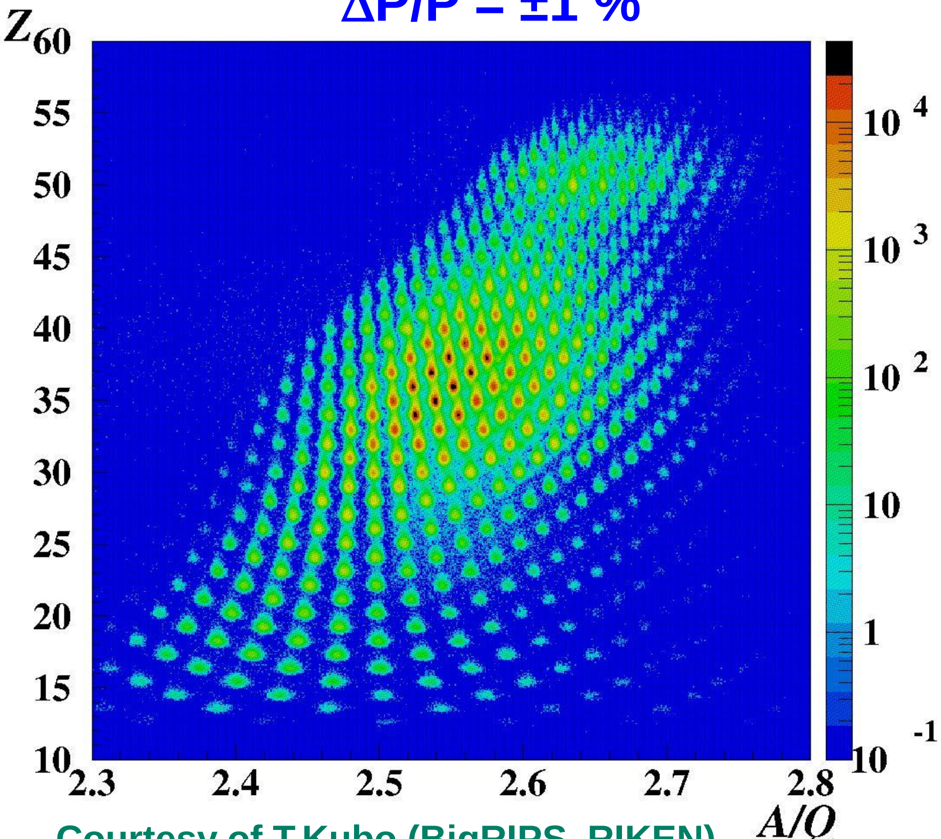
^{238}U + Be (7mm) at 345 MeV/u

Be target

Bρ = 7.249 Tm

F1 slit: ±21 mm

ΔP/P = ±1 %



Courtesy of T.Kubo (BigRIPS, RIKEN)

Coulomb fission

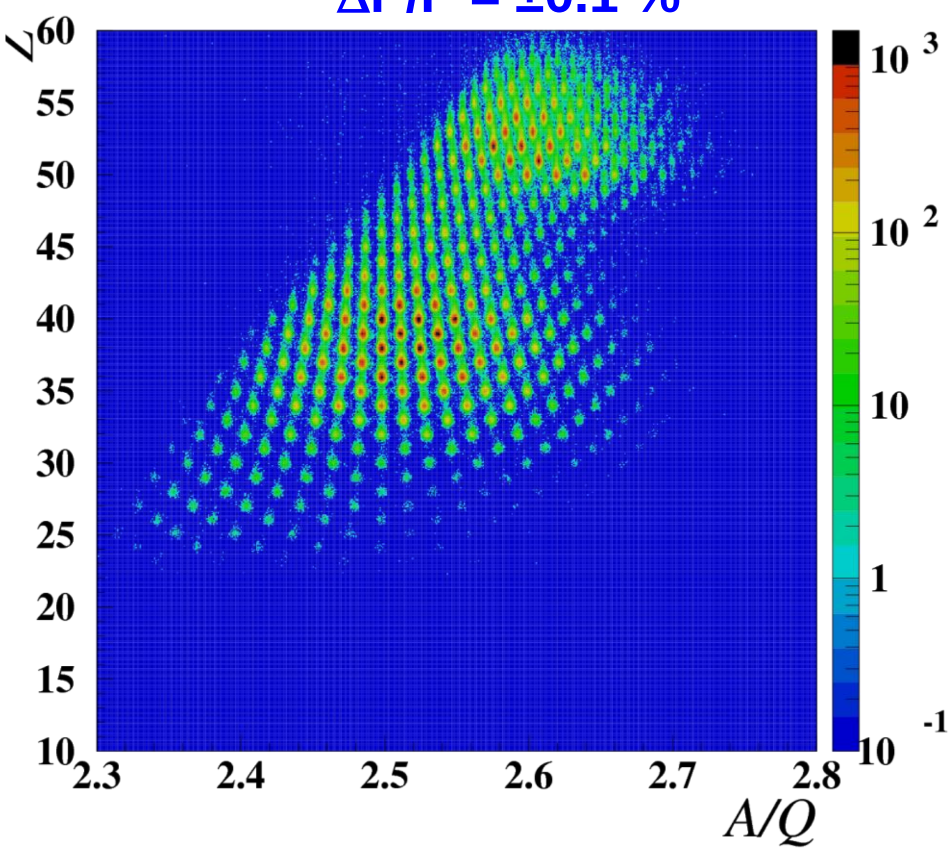
^{238}U + Pb (1.5 mm) at 345 MeV/u

Pb target

Bρ = 6.992 Tm

F1 slit: ±2 mm

ΔP/P = ±0.1 %

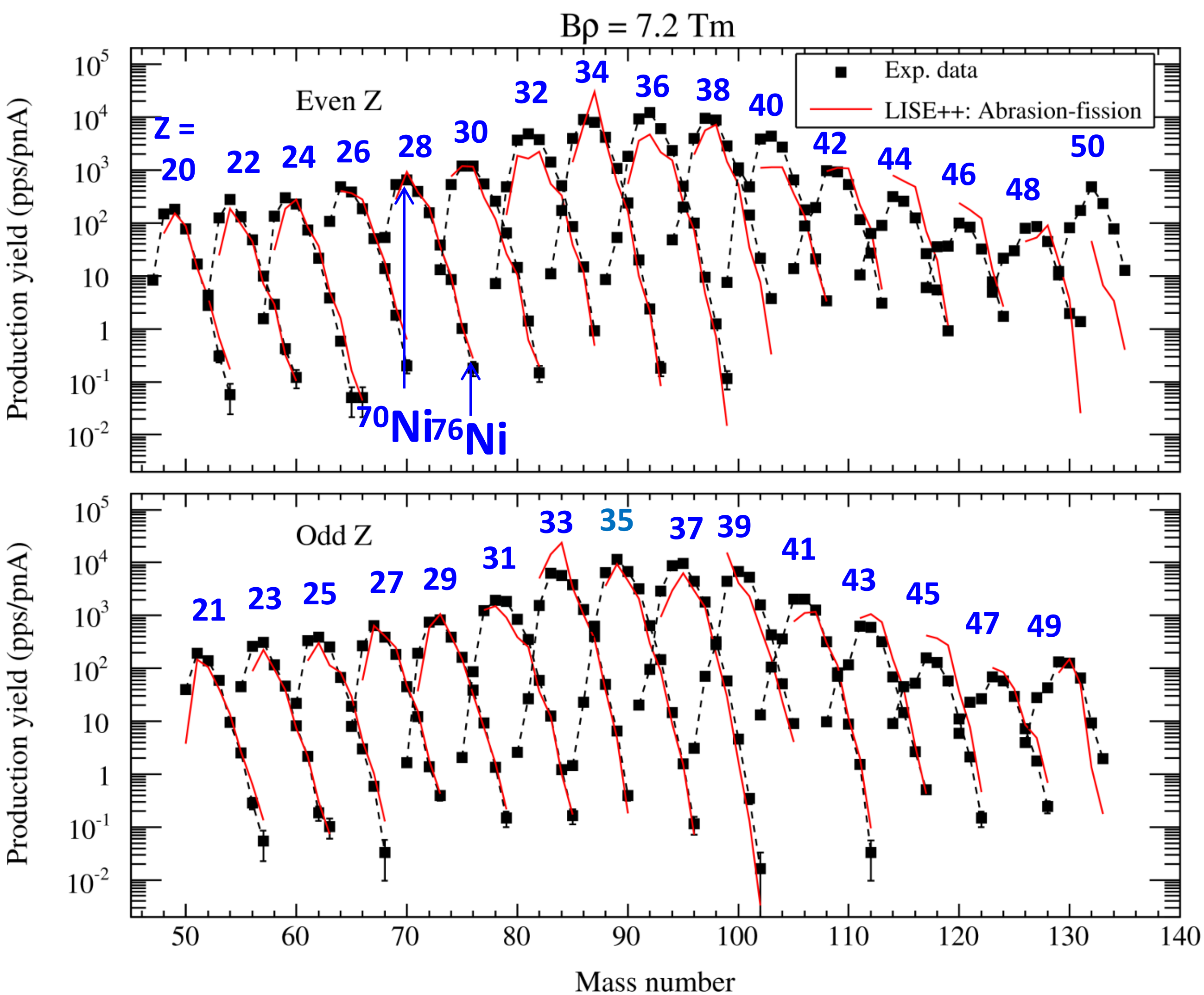


Production rates by ^{238}U + Be(7mm) at $B\rho = 7.249$ Tm

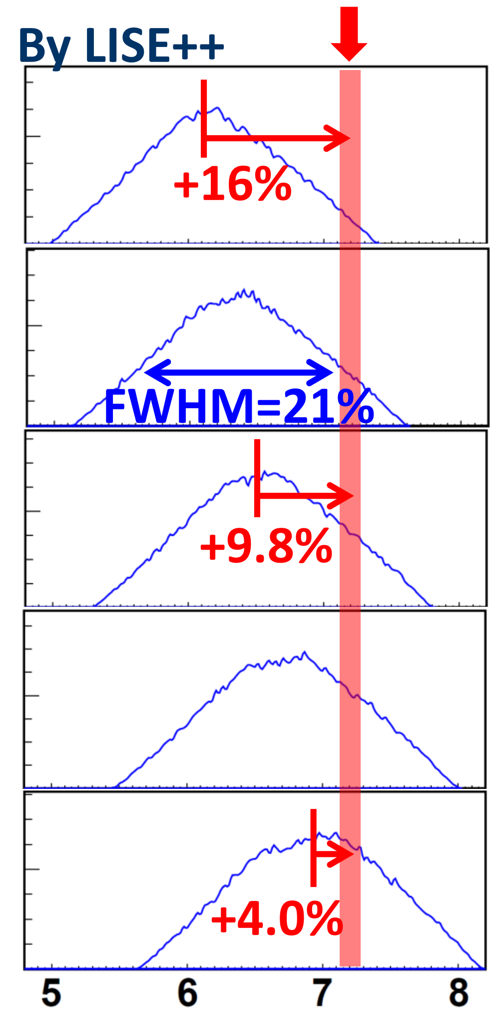
1 setting, no energy degraders used

$B\rho = 7.2$ Tm ± 1%

LISE++ Abrasion-Fission Fairly good reproduction

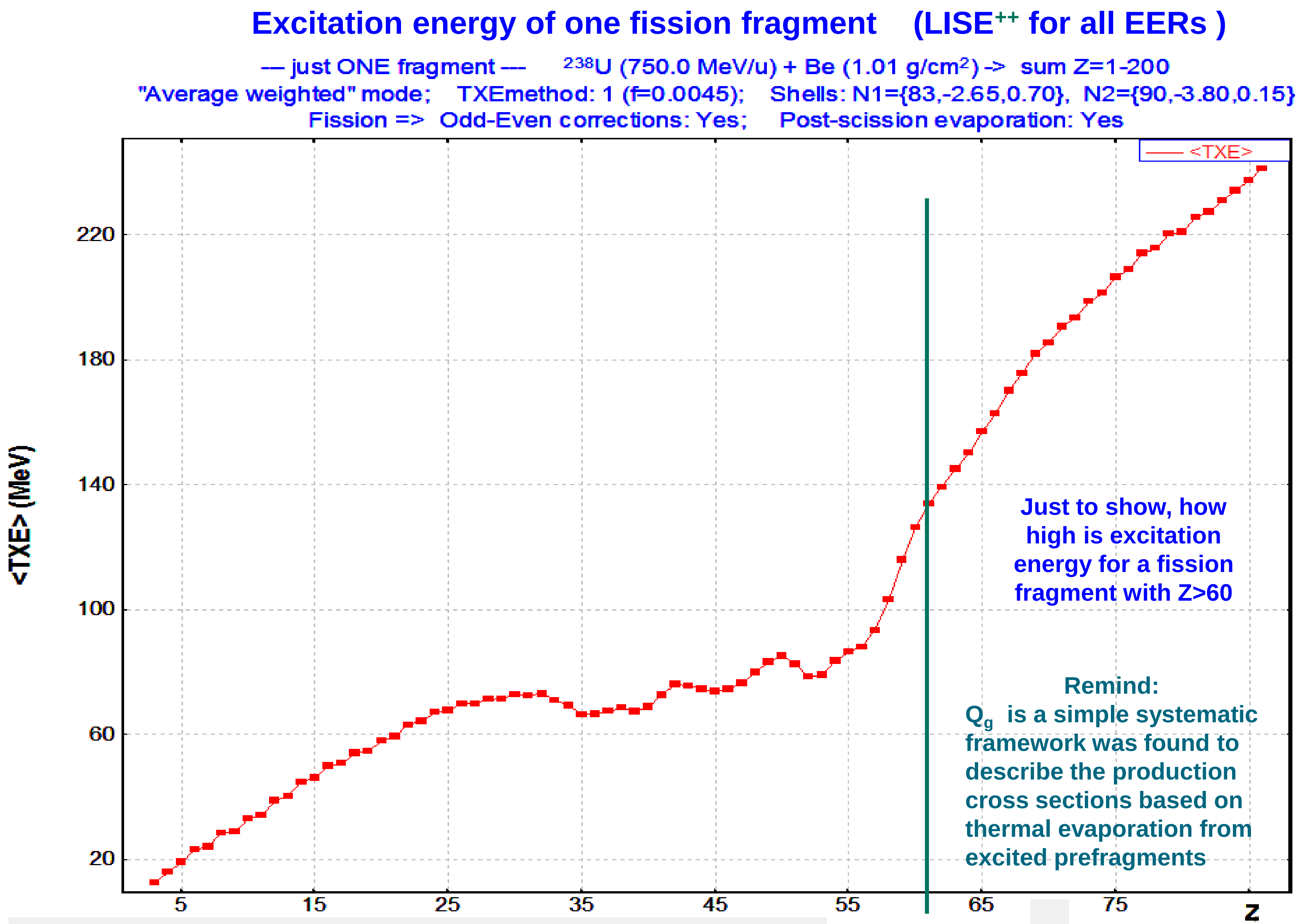


By LISE++



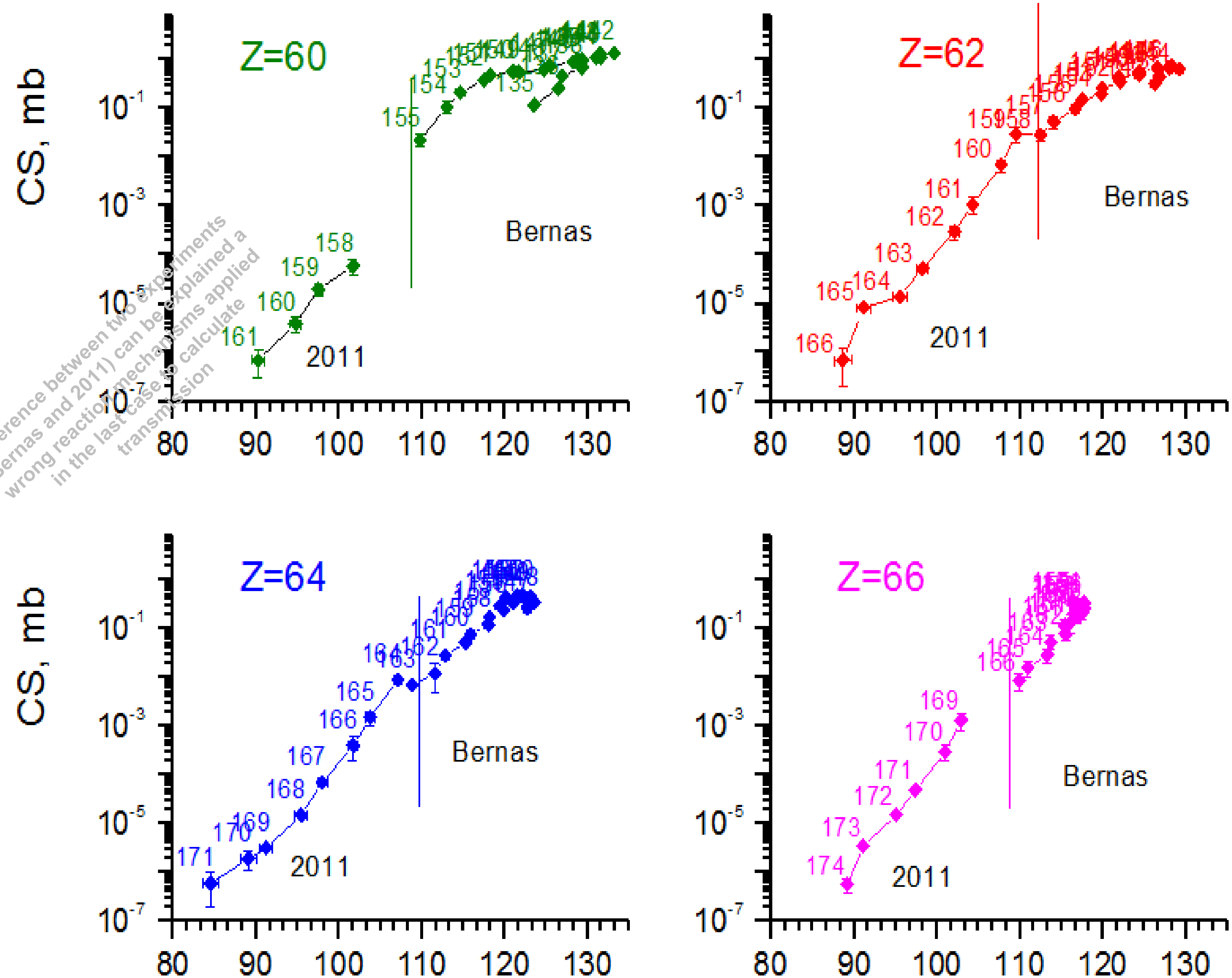
Courtesy of T.Kubo (BigRIPS, RIKEN)

Q_g- systematics for Abrasion-Fission products (^{238}U+Be)



Remind:
Q_g is a simple systematic framework was found to describe the production cross sections based on thermal evaporation from excited prefragments

Q_g- systematics for in-flight fission products



M.Bernas et al., NPA A765 (2006) 197

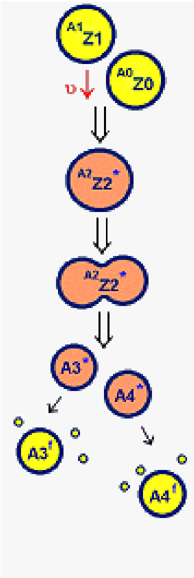
238U +*p at 1A GeV*

http://arxiv.org/PS_cache/arxiv/pdf/1112/1112.0521v1.pdf

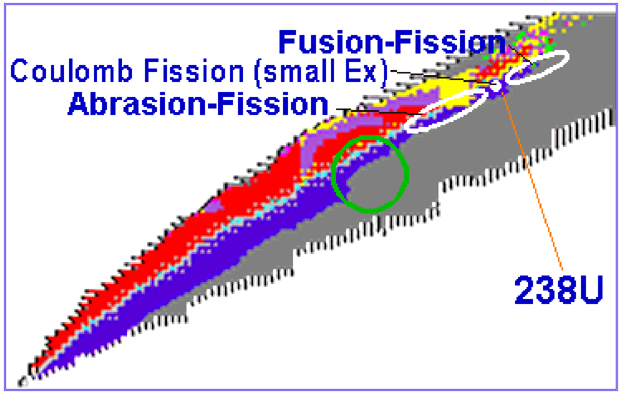
238U +*Be at 1A GeV*

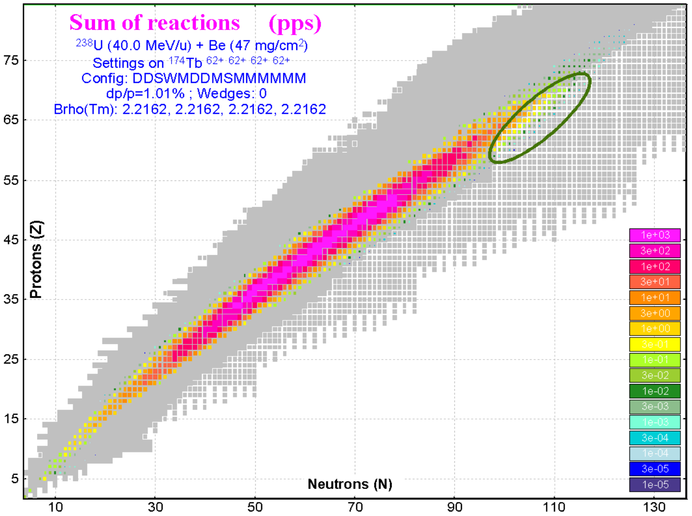
J.Kurcewicz et al., Published in PLB

Fusion-Fission is a new reaction mechanism to produce exotic radioactive beams



O.T. and A. C. C. Villari, NIM B 266 (2008) 4670





2010: E547 @ LISE3.GANIL

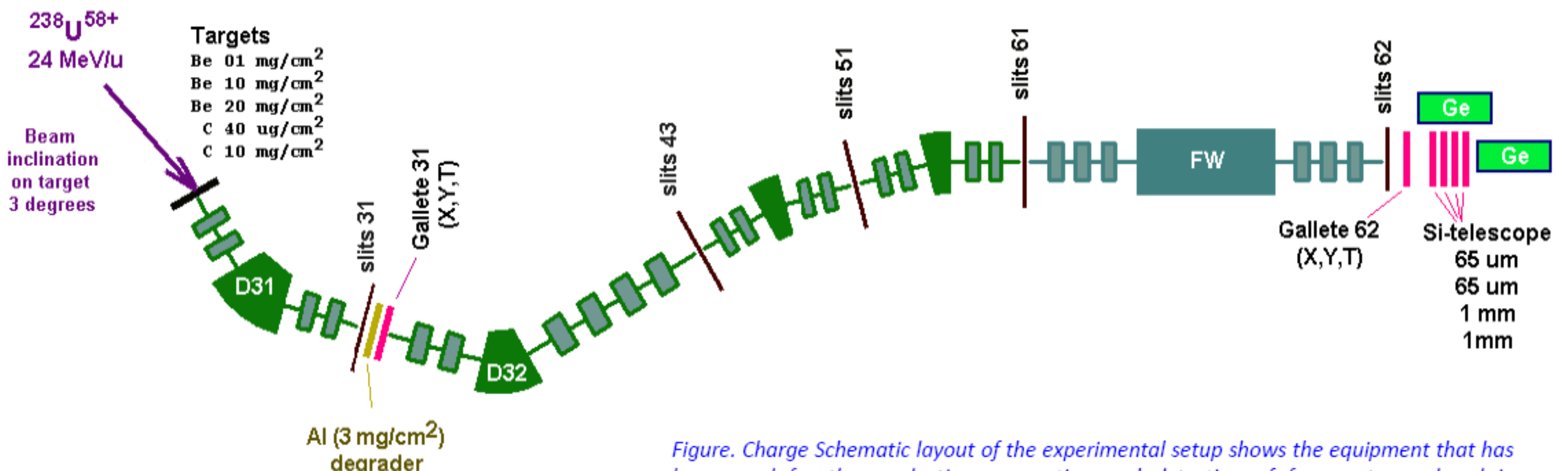
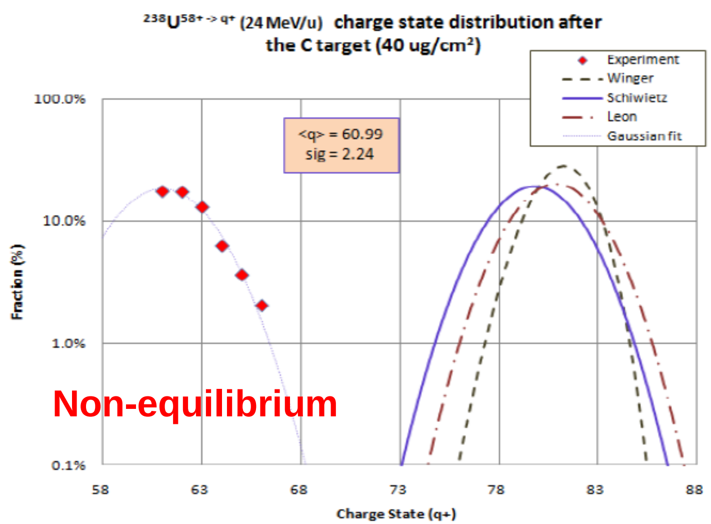
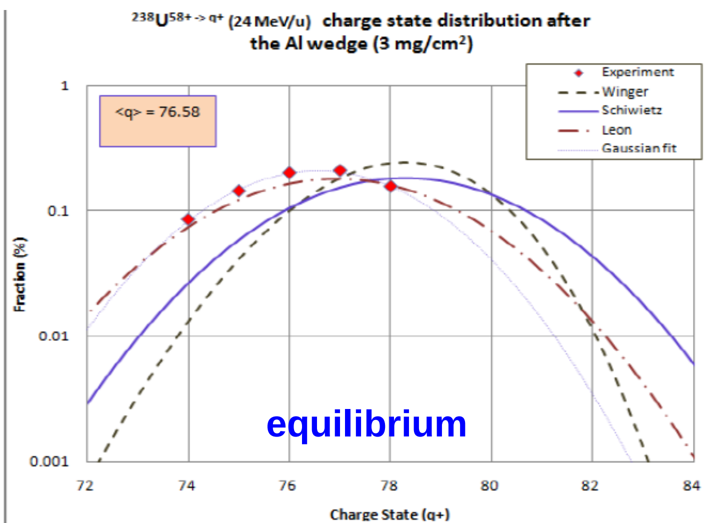


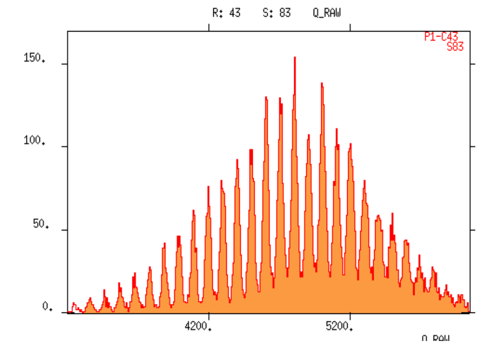
Figure. Charge Schematic layout of the experimental setup shows the equipment that has been used for the production, separation and detection of fragments produced in reactions with the ^{238}U beam.

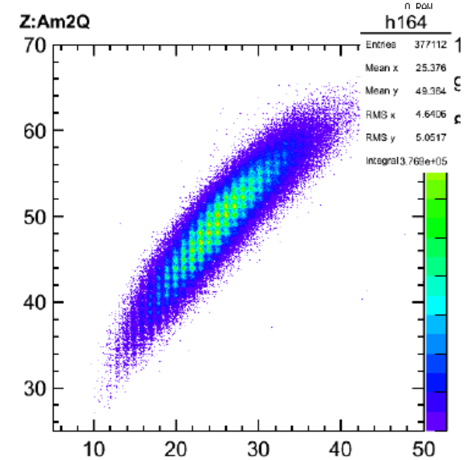
Fusion-Fission : experiment E547

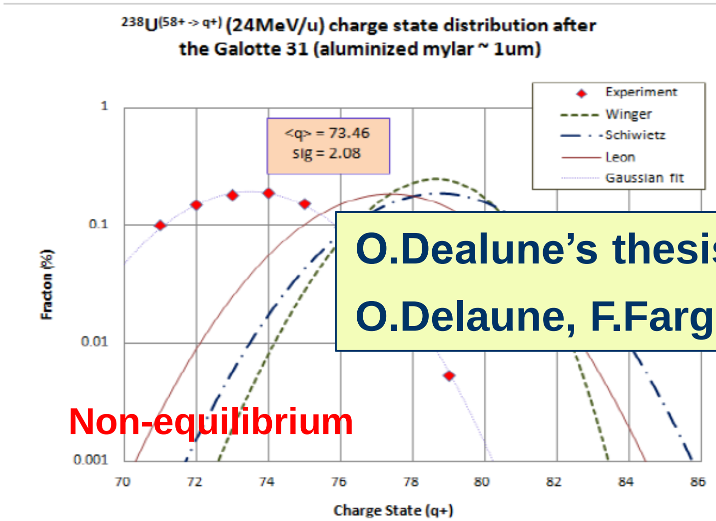
- **Handle with charge states**
- **Identify fragments *(A,Z,q)***

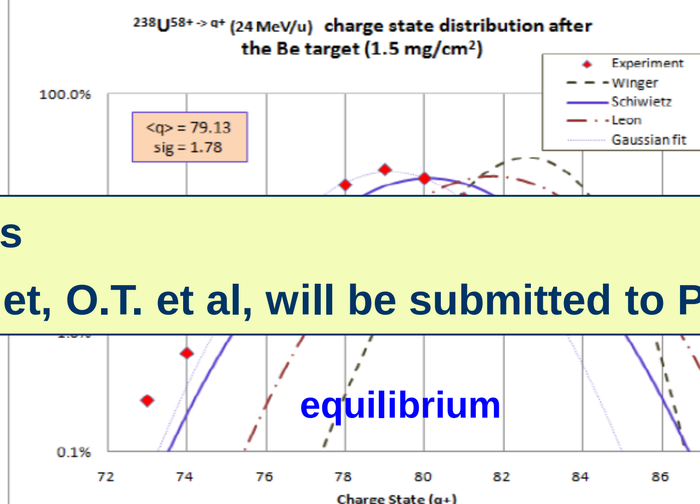


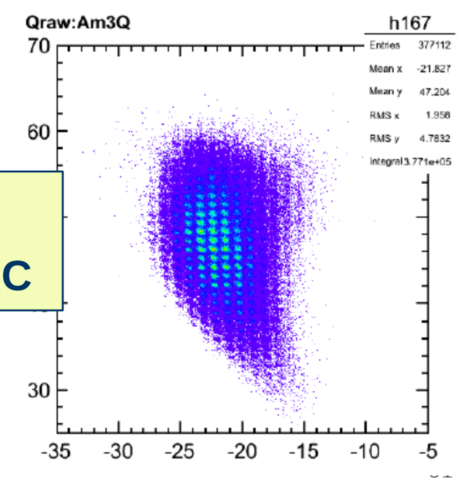










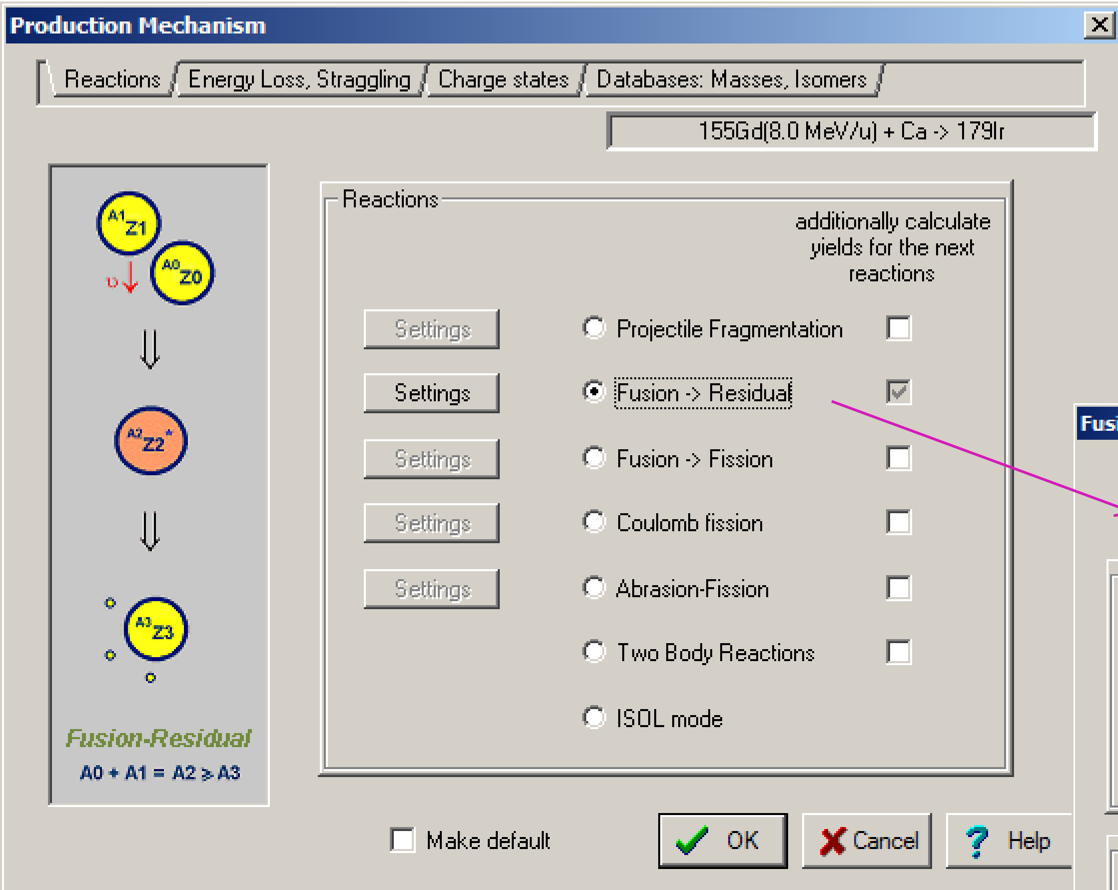


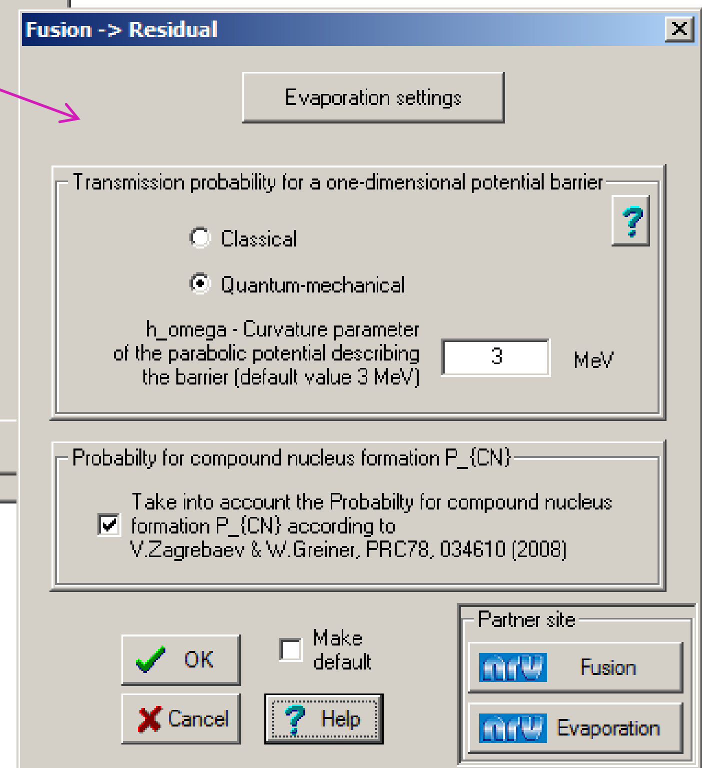
O.Dealune's thesis

O.Delaune, F.Farget, O.T. et al, will be submitted to PRC

Fusion – Residue (Fusion-Evaporation)

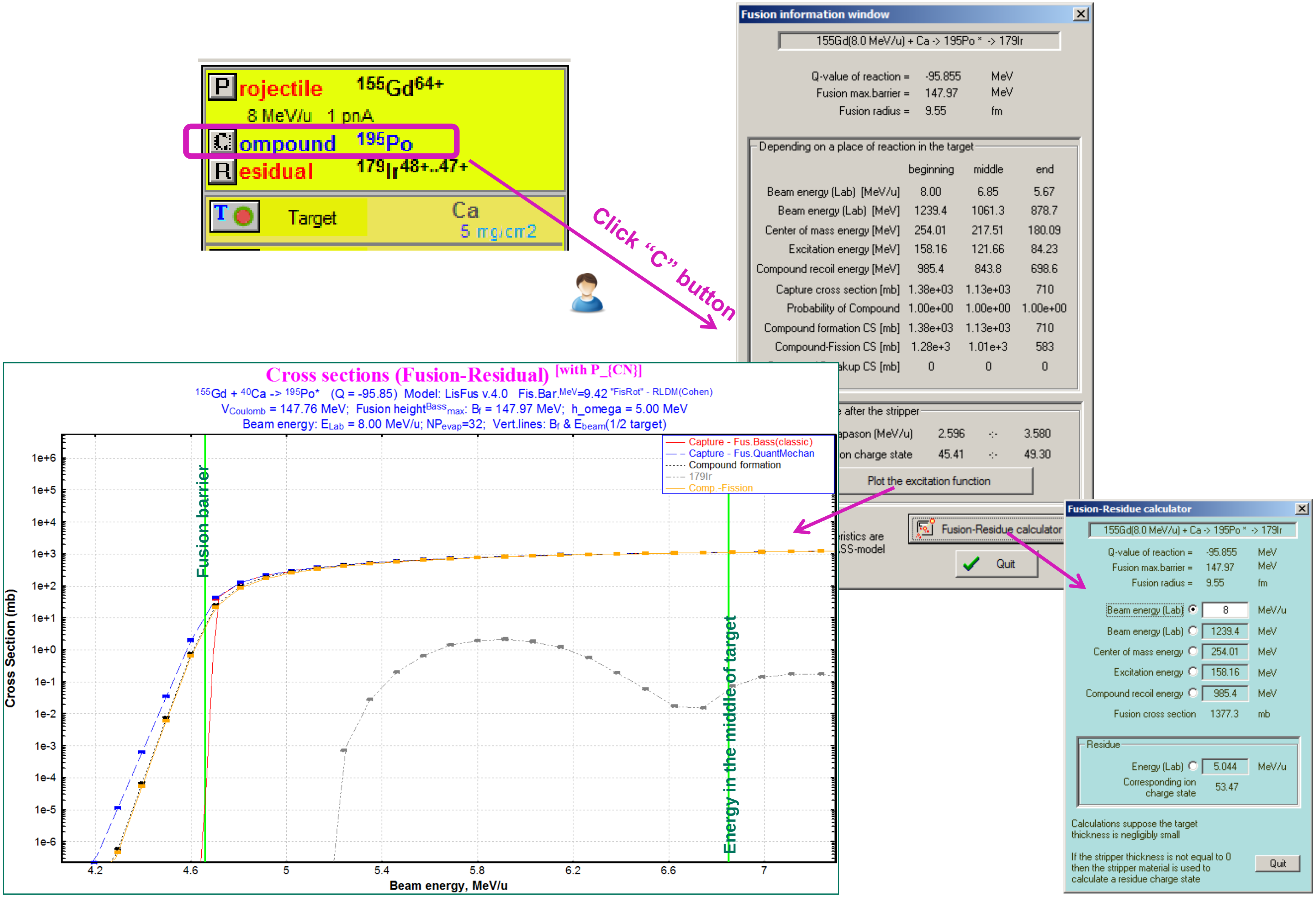
See talks this topic
V.I. Zagrebaev
A.G. Popeko



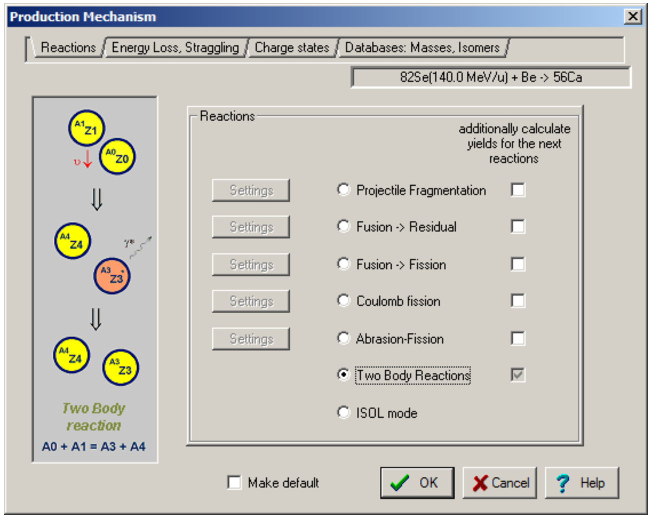


- **Pay attention for the Fission Barrier model !**
- **Fusion –Evaporation code PACE 4 in the LISE++ package**
- **Partner site : NRV**

Fusion Information Window

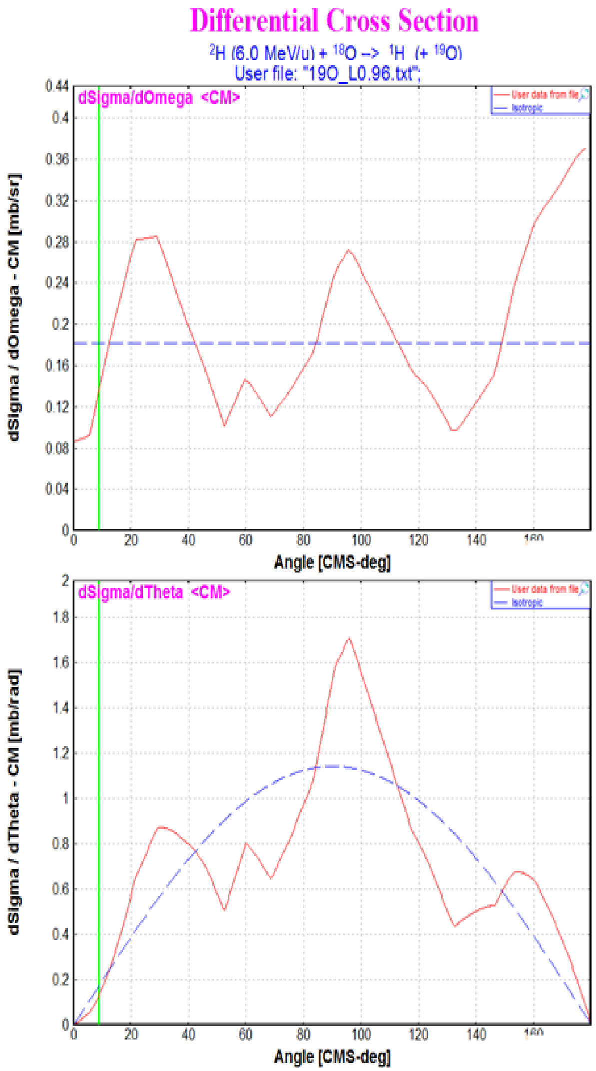


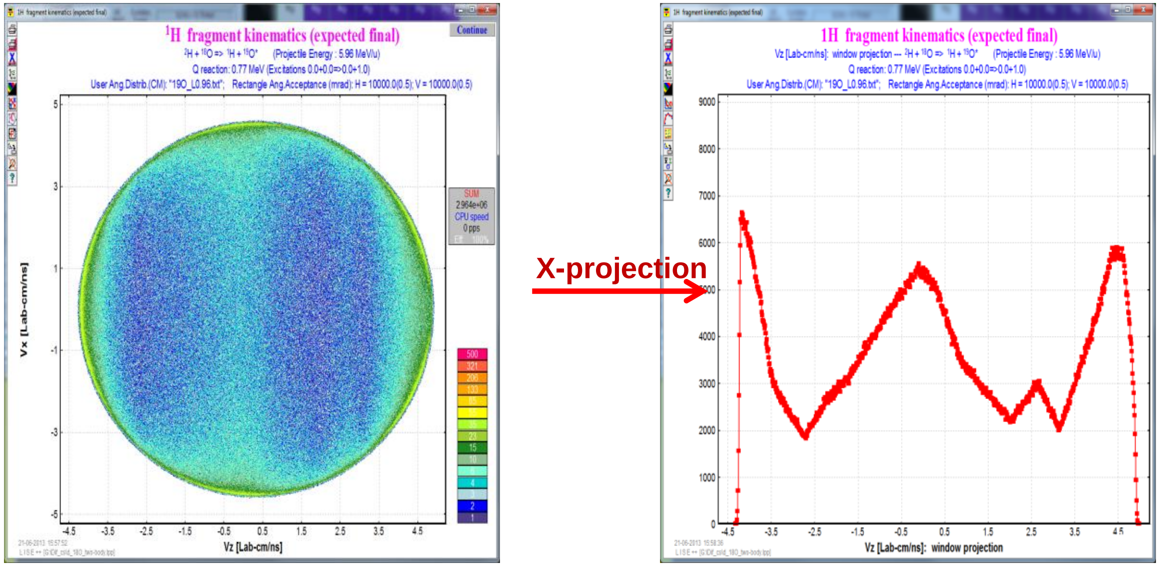
Two-body reactions



9.6.46 Differential Cross Sections
24-06-13

http://lise.nscl.msu.edu/9_6/DifCS/9_6_44_DifCS.pdf





Reaction's Characteristics
Differential Cross Sections ; LAB <-> CM converter
Electromagnetic excitation plots
Create an initial file for nucleon pick-up (beta)
User cross-sections analysis using Abrasion-Ablation model

Kinematics

O.T., D. Bazin,
Nucl. Instr. and Meth. in Phys. Res. B 266 (2008) 4657–4664

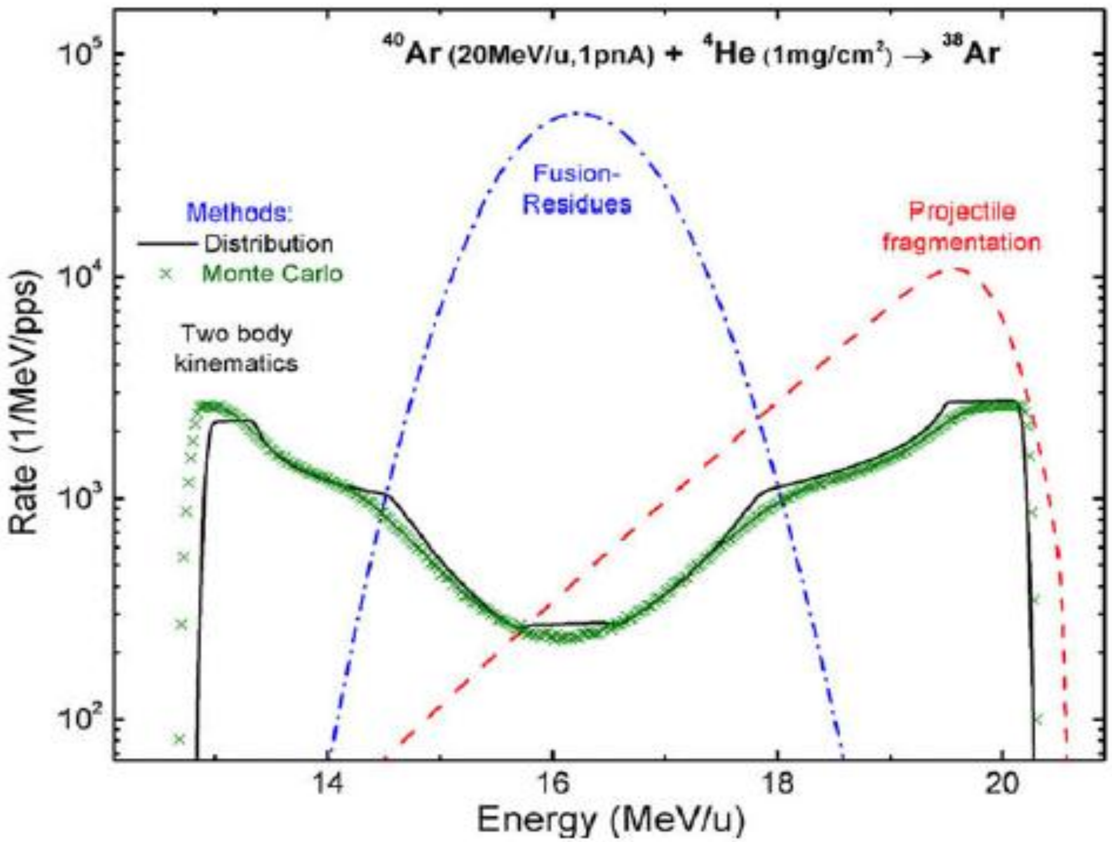


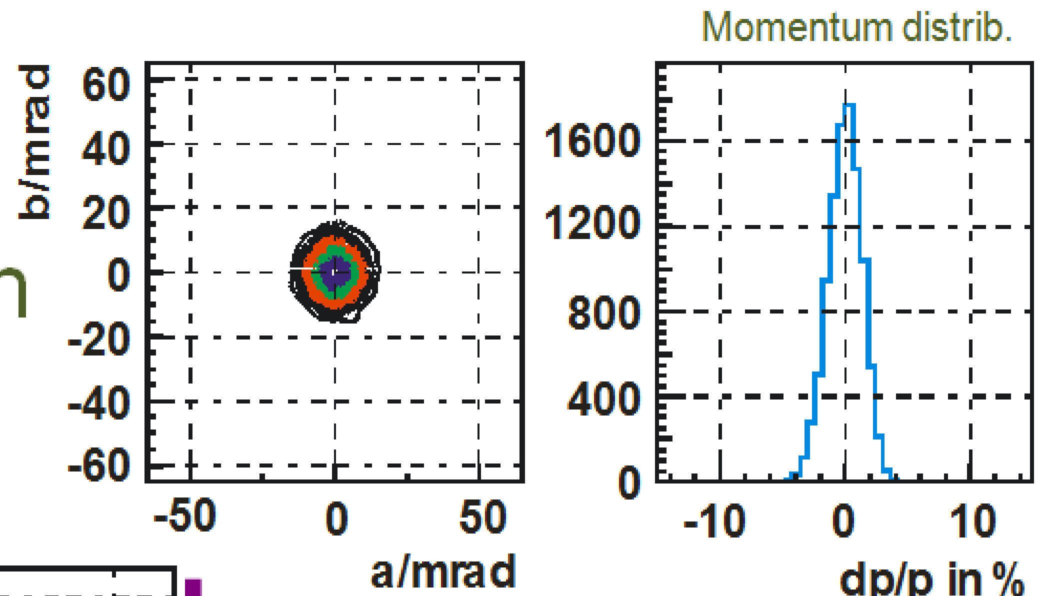
Fig. 6. Energy spectra calculated by the "Distribution" method of ^{38}Ar fragments produced by different reaction mechanisms, using an ^{40}Ar beam at 20 MeV/u on a ^{4}He target (1 mg/cm^2) and gated by a rectangular angular acceptance $X' = \pm 100$ mrad, $Y' = \pm 60$ mrad. The Monte-Carlo calculation of the energy spectrum of ^{38}Ar fragment produced in two body reaction is also shown. The default LISE++ production cross-sections EPAX 2.15 and LisFus model were used to estimate the rates.

Fragmentation at 400MeV/u

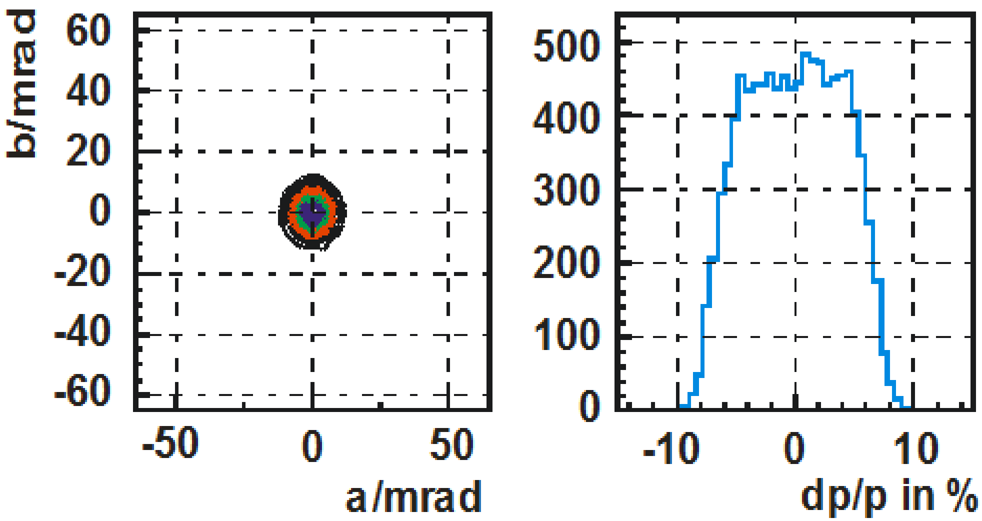
- LISE++ Simulation for ^{124}Xe and ^{208}Pb fragmentation

Relatively 'easy' to collect due to small phase space

^{100}Sn



^{200}W



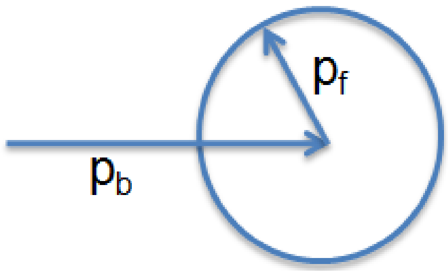
- Angles ≤ ± 20 mrad
- Momentum ± 3 - 8 %

M. Hausmann, T. Nettleton

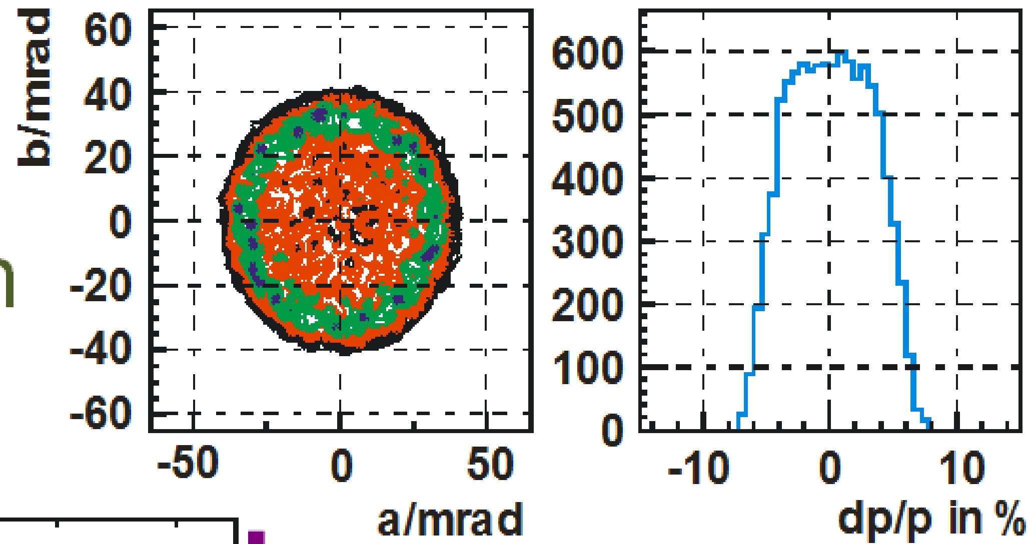
Courtesy of B.Sherrill

In-Flight Fission at 400 MeV/u

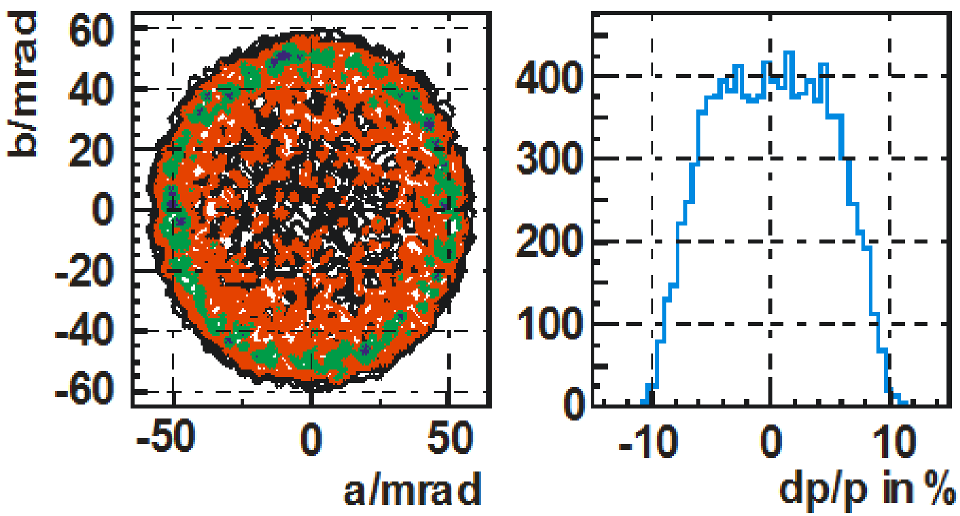
- LISE++ Fission model for ^{238}U



^{132}Sn



^{76}Ni



- Angles ± 40 - 60 mrad
- Rigidity ± 6 - 10 %
- Plus correlations due to fission kinematics

M. Hausmann, T. Nettleton

Courtesy of B.Sherrill

Efficiency transmission at target

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**

Let's consider the following case :

^{136}Xe (345 MeV/u) + Be (2g/cm^2) $\Rightarrow$ ^{125}Ag^{47+}

Clicking the right button of mouse on the ^{125}Ag cell in the table of nuclides

statistics: 125Ag

125Ag Beta- decay (Z=47, N=78) Silver

Q1(Dipole 1)		47	46	45
Q2(Dipole 2)		47	46	45
Q3(Wien)		47	46	45
Q4(D6)		47	46	45
Production Rate	(pps)	7.73e+0	6.71e-1	1.4e-2
Sum of charge states	(pps)	8.41e+0	8.41e+0	8.41e+0
Reaction		Fragmentn	Fragmentn	Fragmentn
Sum of all reactions	(pps)	8.41e+0	8.41e+0	8.41e+0
CS in the target	(mb)	1.35e-5	1.35e-5	1.35e-5
Total transmission	(%)	68.521	5.954	0.124
Target	(%)	68.52	5.95	0.124
Unreacted in mater.	(%)	71.17	71.17	71.17
Q (Charge) ratio	(%)	91.85	7.98	0.166
Unstopped in mater.	(%)	100	100	100
Secondary Reactions	(coef)	1.05	1.05	1.05
FaradayCup 1				

Total transmission includes blocks from Target up to FaradayCup 1

End of Lecture 2

Questions ?

Haben Sie Fragen?

Вопросы ?

有問題嗎？

¿Preguntas?

Demandoj?

質問？

Pytania?

Domande?

Sorular?