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NCSL / MSU, USA

26-31 / 08 / 2013

Production of Fast Rare Ion Beams

Euroschool on Exotic Beams 2013, Dubna
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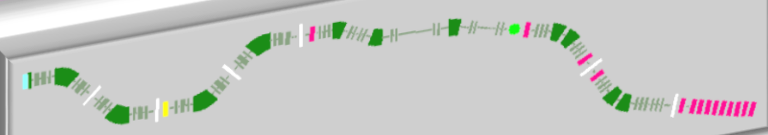
LISE++



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

4. Identification

- What is PID?
- Detector setup
- Obtaining A, Z, q
- Momentum acceptance
- Particle identification assignments

What is Particle IDentification?

What do we want to know?

1. A
2. Z
3. Q
4. Energy (property of incoming ion in detectors)

What do we measure?

1. Total kinetic energy
2. Magnetic (electric) rigidity
3. Energy loss in detector
4. velocity (time of flight)

Detector setup

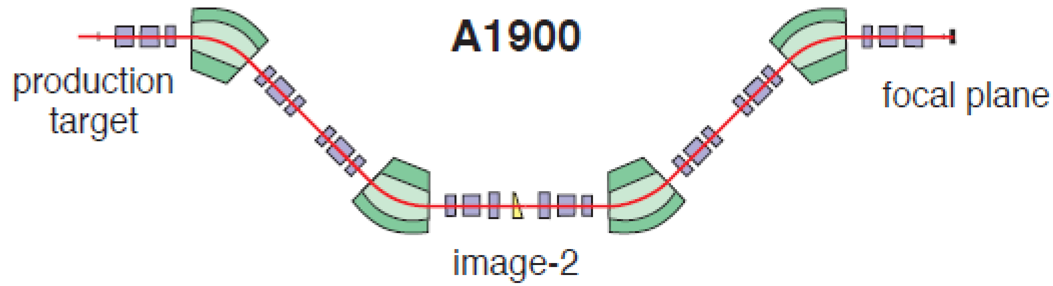


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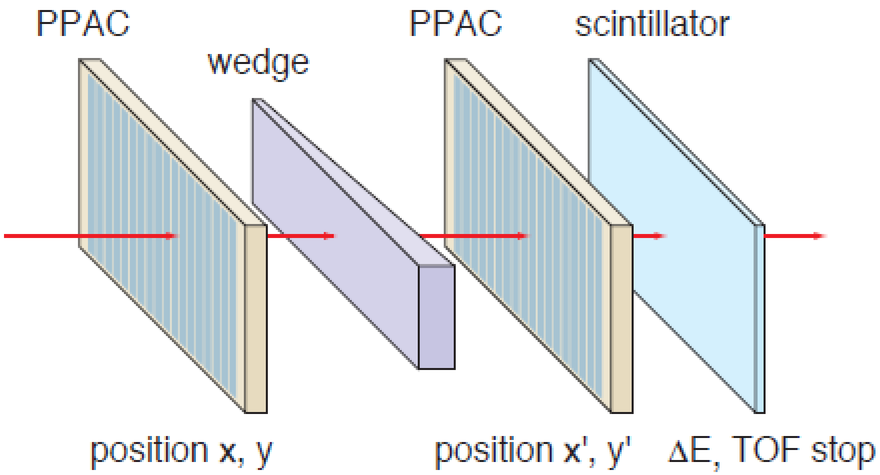
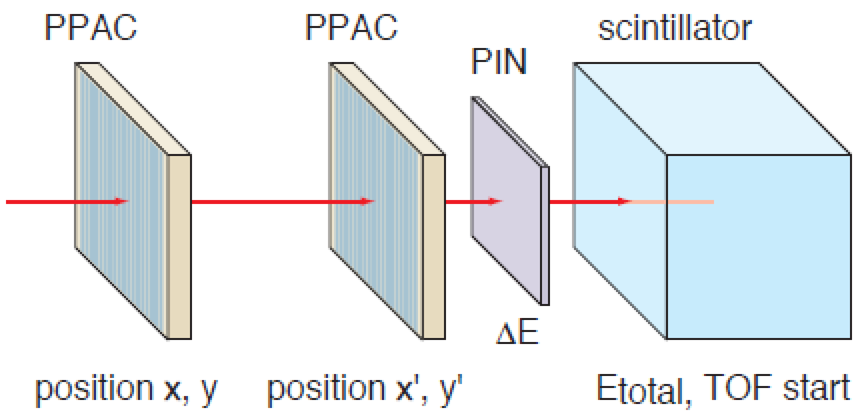
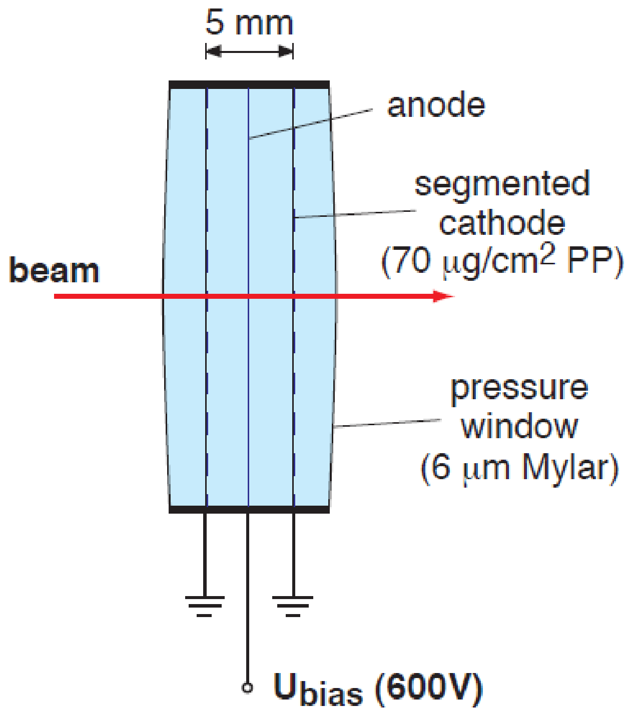
Image-2



Focal Plane



PPAC detector



- active area 100 mm x 100 mm
- streched PP foils with Al strips
- 80 horizontal and vertical cathode strips
- strip pitch 1.27 mm
- isobutane, pressure 5 Torr
- mass thickness 2.2 mg/cm^2 Al equiv.

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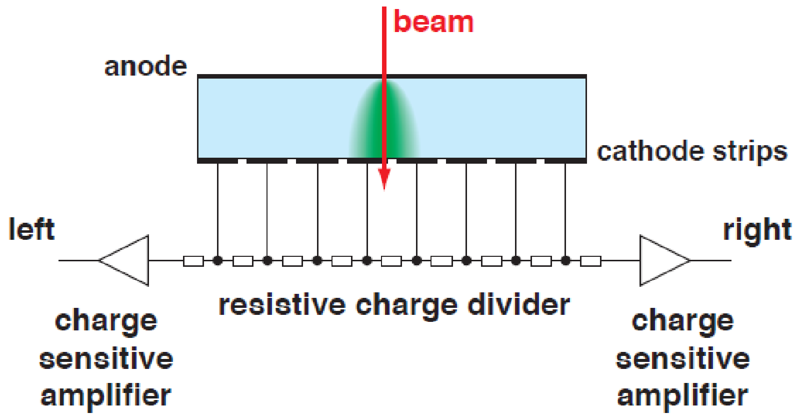
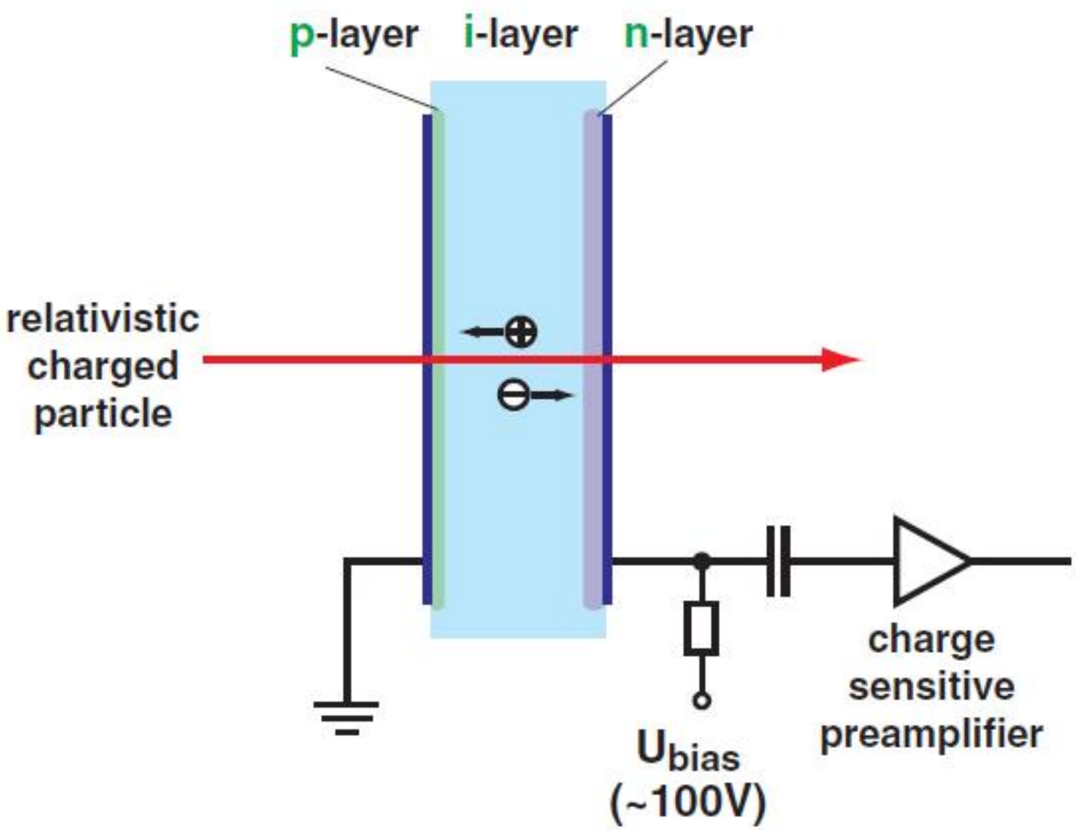
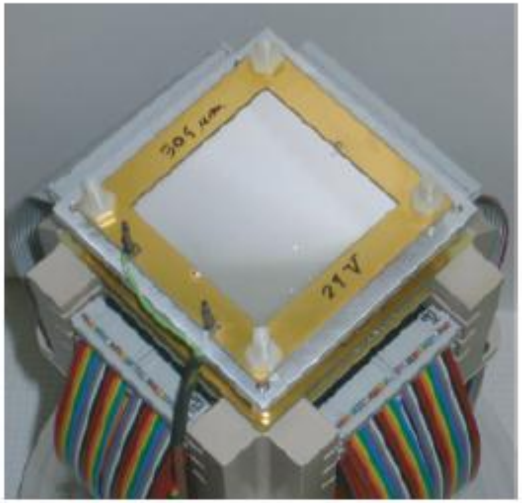


Parallel Plate Avalanche Chamber : X,Y

position calculation: $x = \frac{\text{right} - \text{left}}{\text{right} + \text{left}}$

Silicon PIN Detector





output signal proportional to collected charge
=
proportional to energy loss in detector

energy to generate electron-ion pair: 3.6 eV

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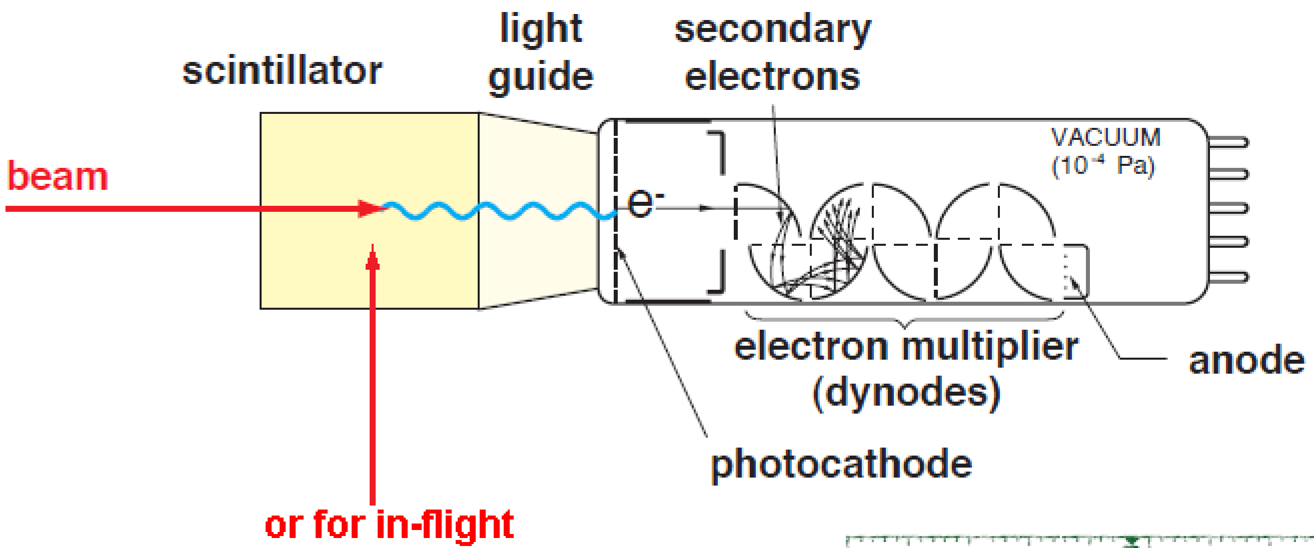
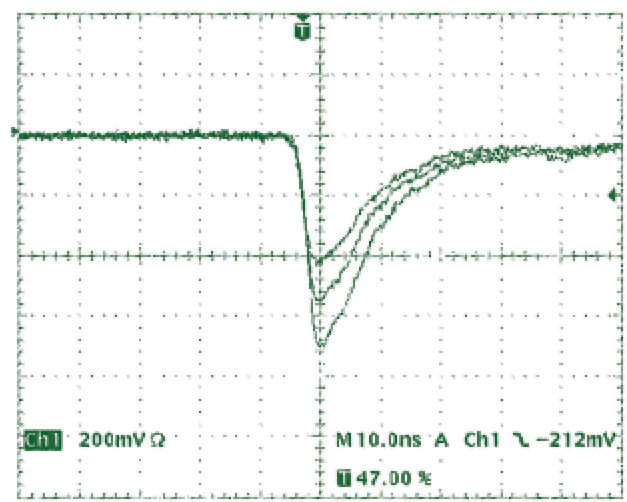
Plastic Scintillator Detector



photomultiplier output:

- fast rise time (5ns) → time
- pulse integral → energy



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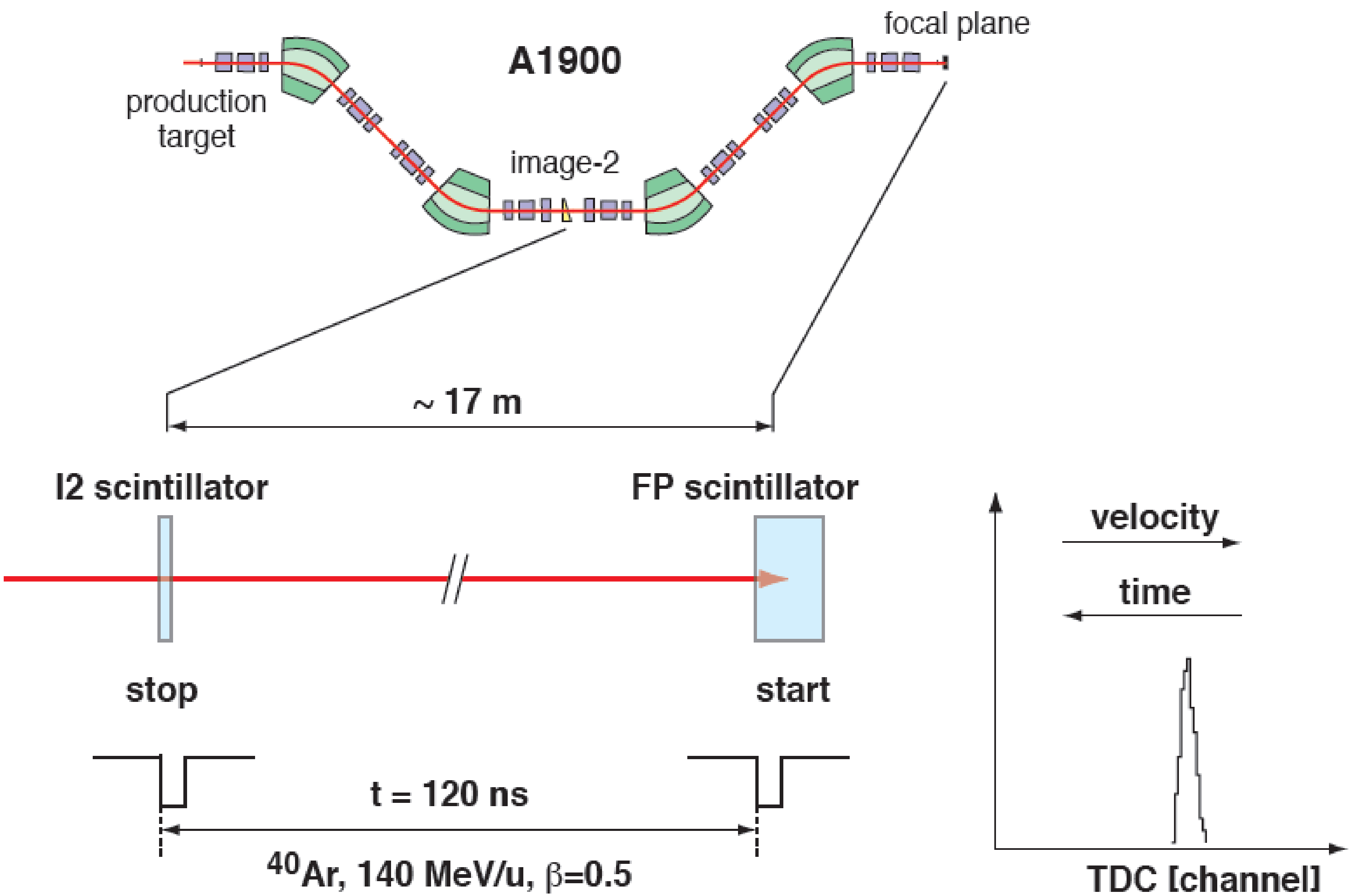
Time-of-flight measurement



TDC = Time to Digital Converter

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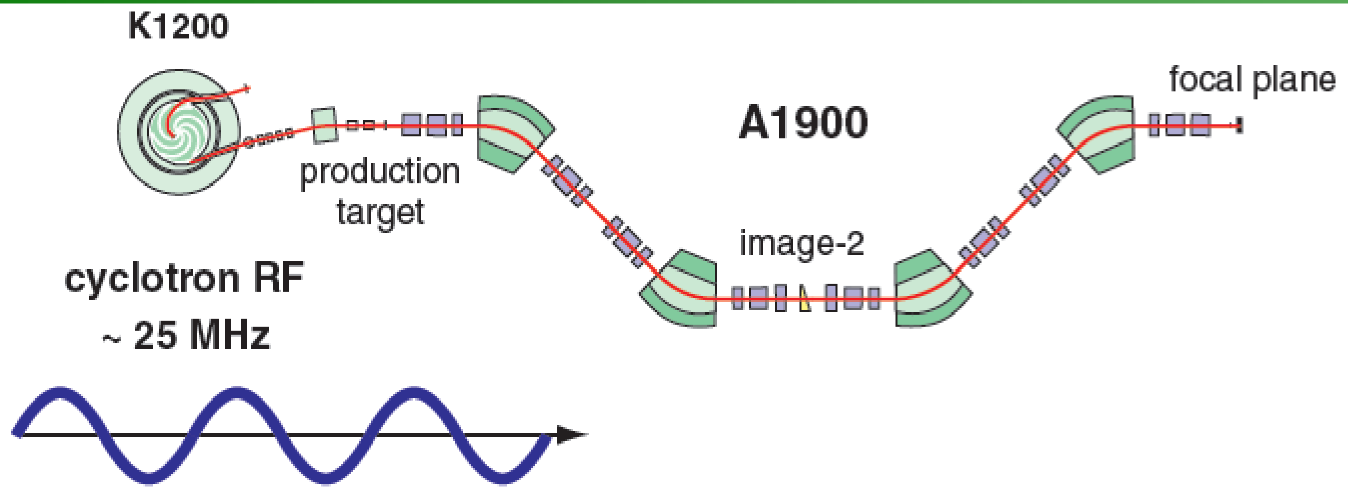
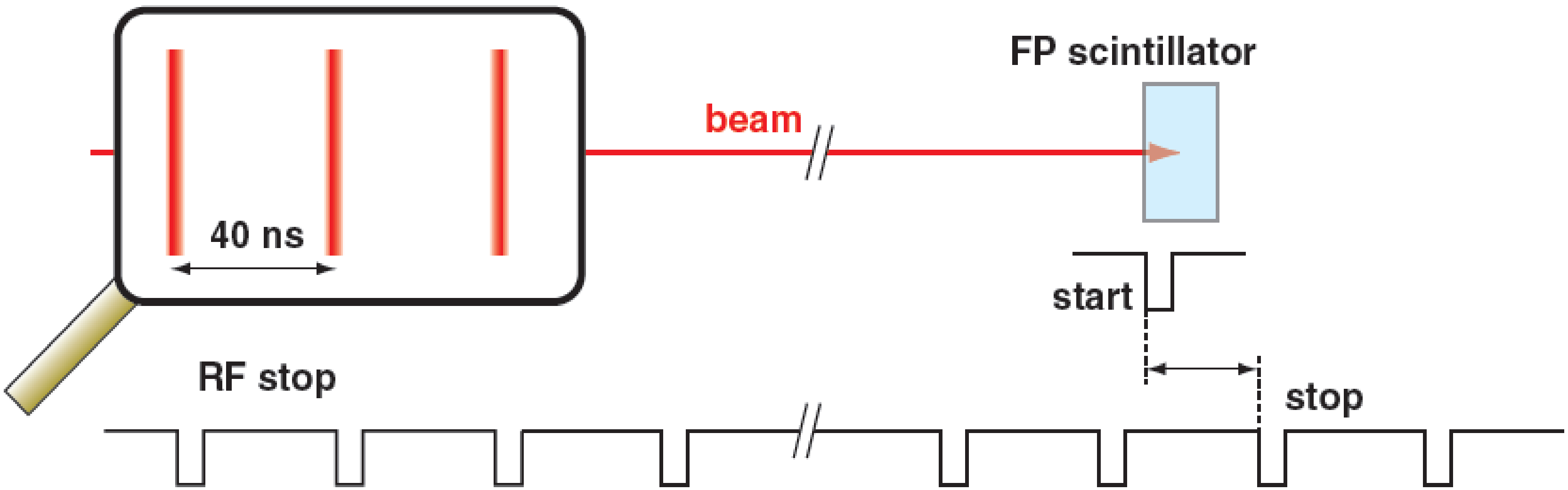
Time-of-flight measurement (RF timing)





'wrap around' after 40 nsec

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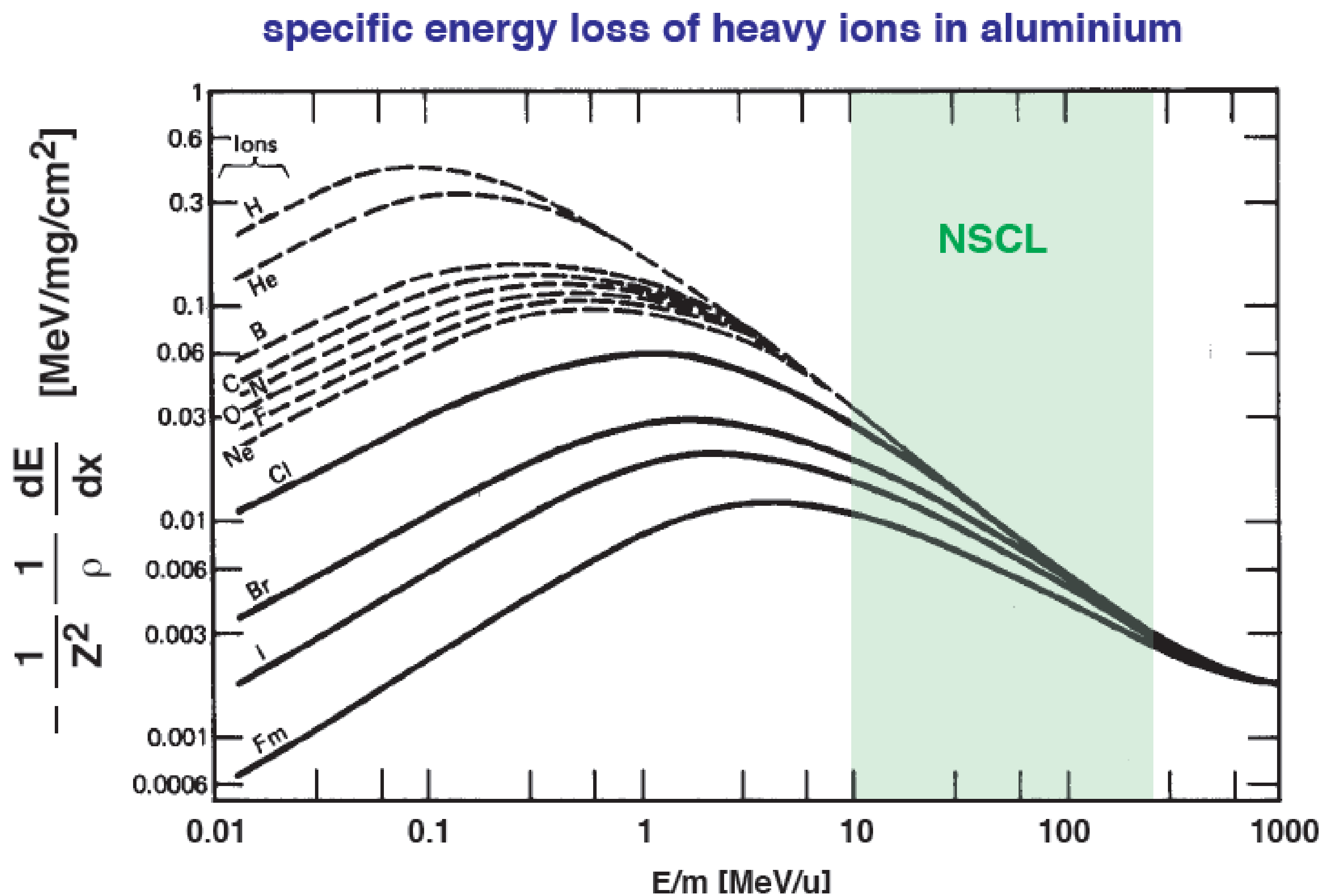
Energy loss in matter



$$\frac{dE}{dx} \sim \frac{Z^2}{E}$$

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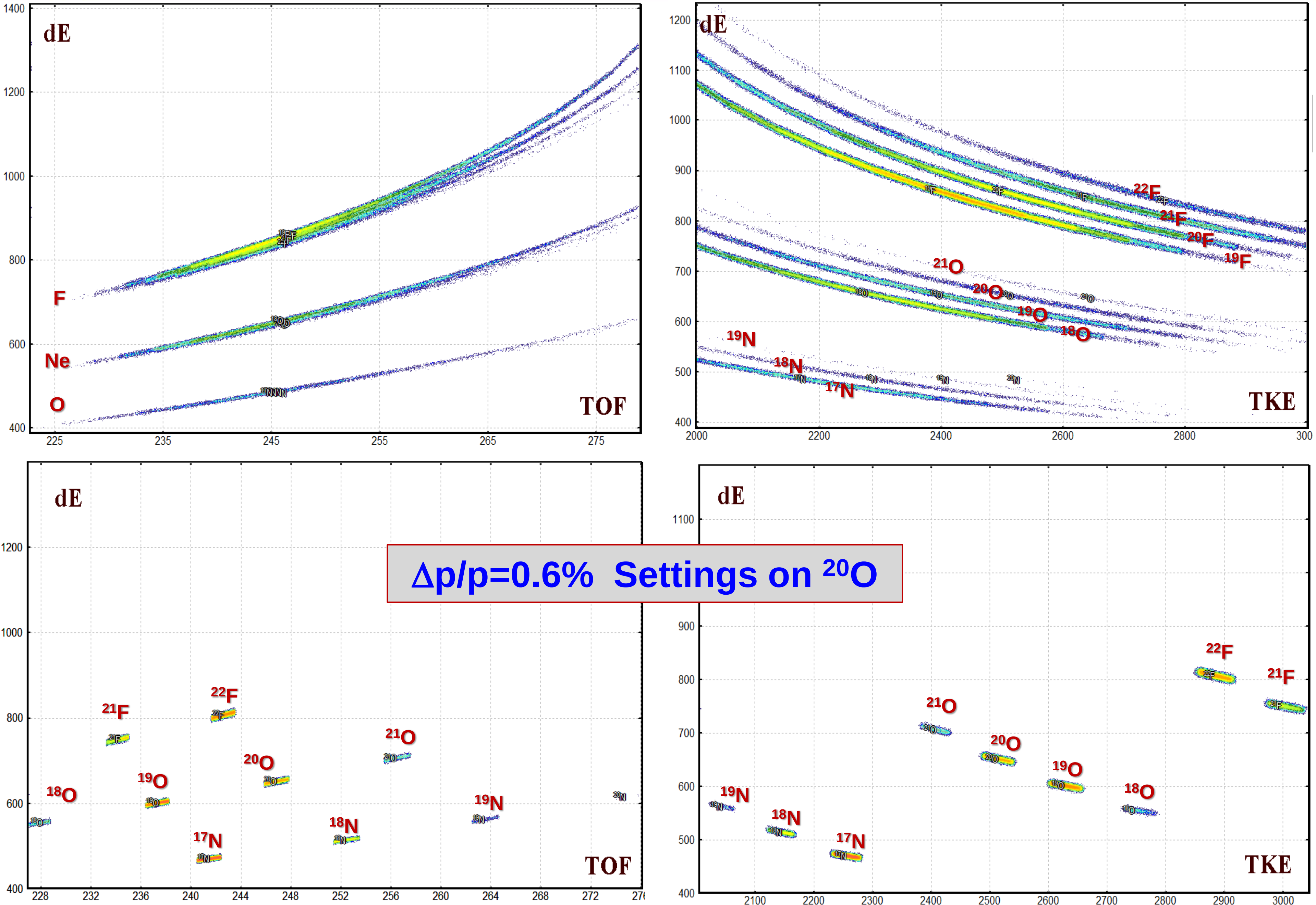
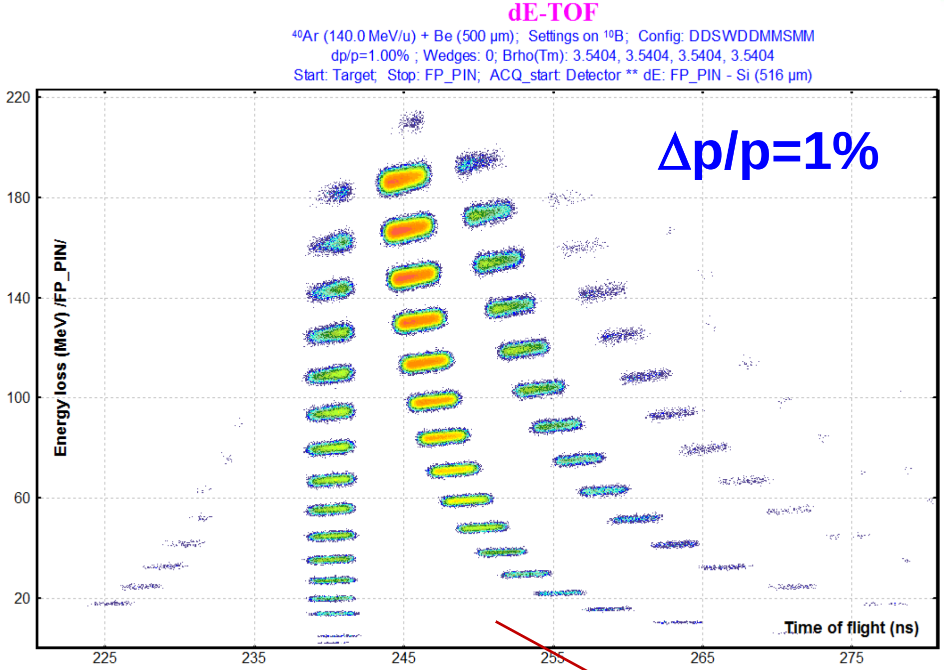
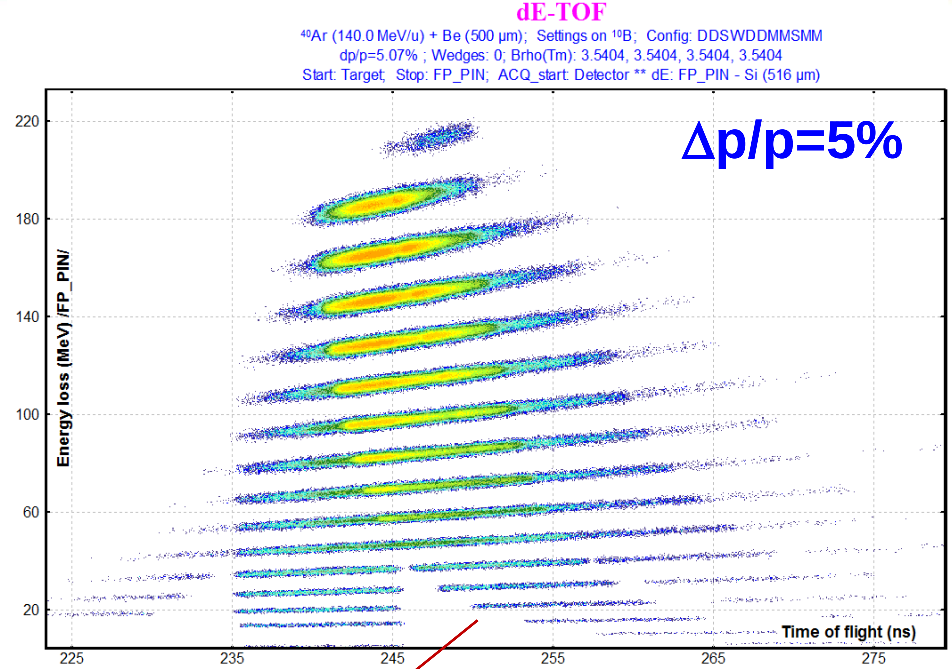
Correlation plots and Bρ-selection

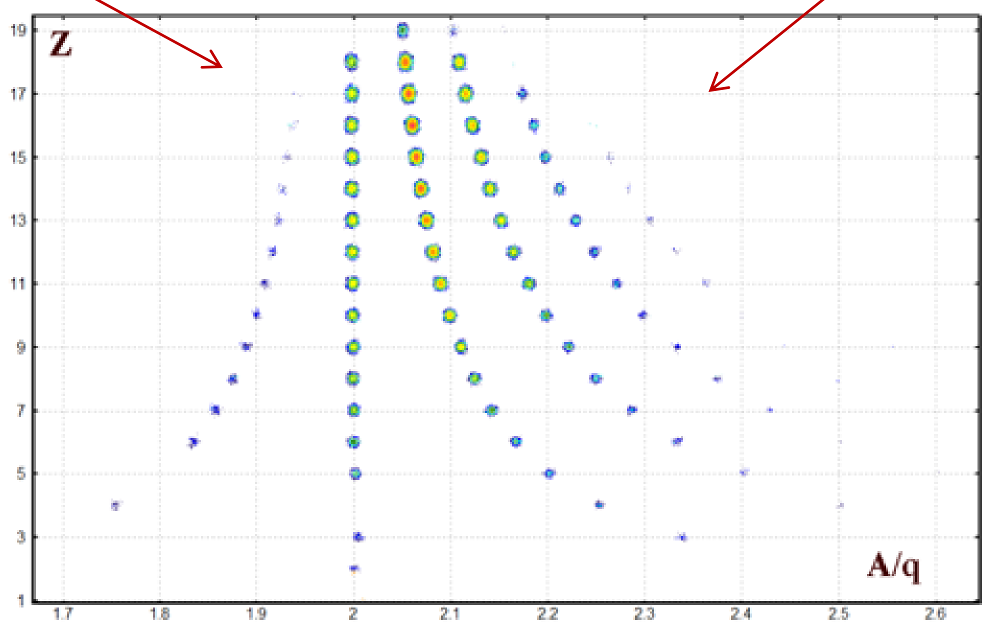


Δp/p=0.6% Settings on ^{20}O

Momentum acceptance







Obtaining *A*, *Z*, *q*

The atomic number is determined from the combination of energy loss (ΔE) and time of flights (TOF) values according to the Bethe formula:

$$Z \approx \sqrt{\Delta E \Big/ \left(\frac{1}{\beta^2} \ln\left(\frac{5930}{1/\beta^2 - 1} \right) - 1 \right)}$$

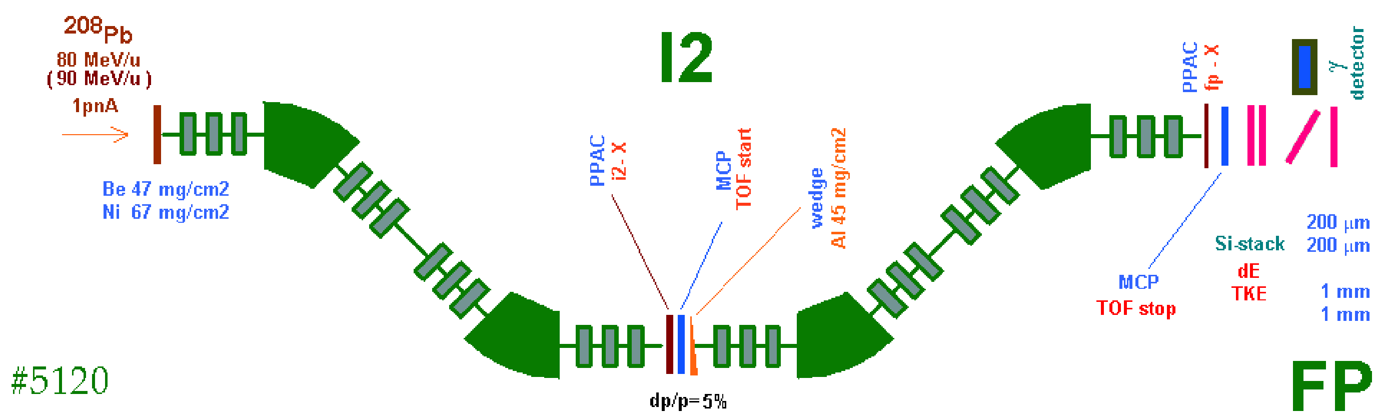
The fragment mass can be extracted in atomic units from the relativistic formula:

$$A = \frac{TKE}{931.5 \times (\gamma - 1)}$$

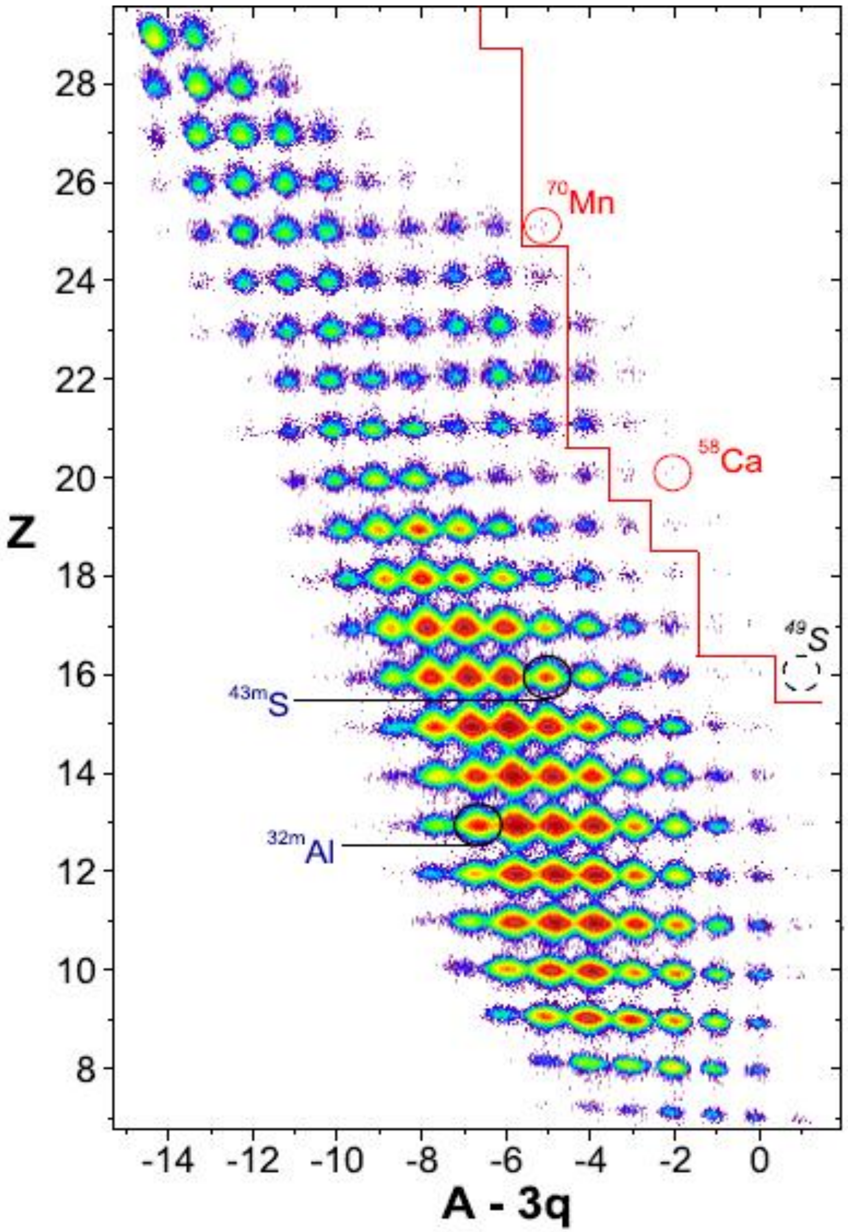
where TKE is calculated as a sum of the energy loss values in each of the detectors in a multilayer telescope stopping the products. The charge state (Q) of the ion evaluated from a relation based on the TKE, velocity and magnetic rigidity values:

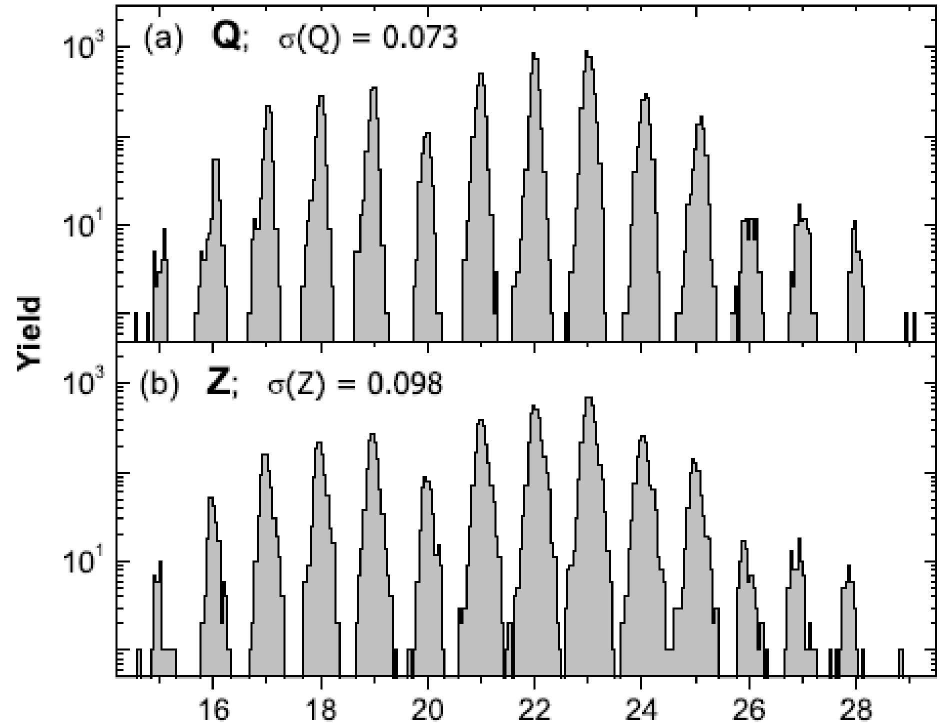
$$Q = 3.33 \times 10^{-3} \frac{TKE \times \beta\gamma}{B\rho(\gamma - 1)}$$

- **Beam monitoring**
- **Gamma detector**
- **I2-X, FP-X,**
- **Several TOFs**



^{76}Ge(130MeV/u) + W,Be : PID, resolution





For all particles stopped in the Si-telescope in the production runs

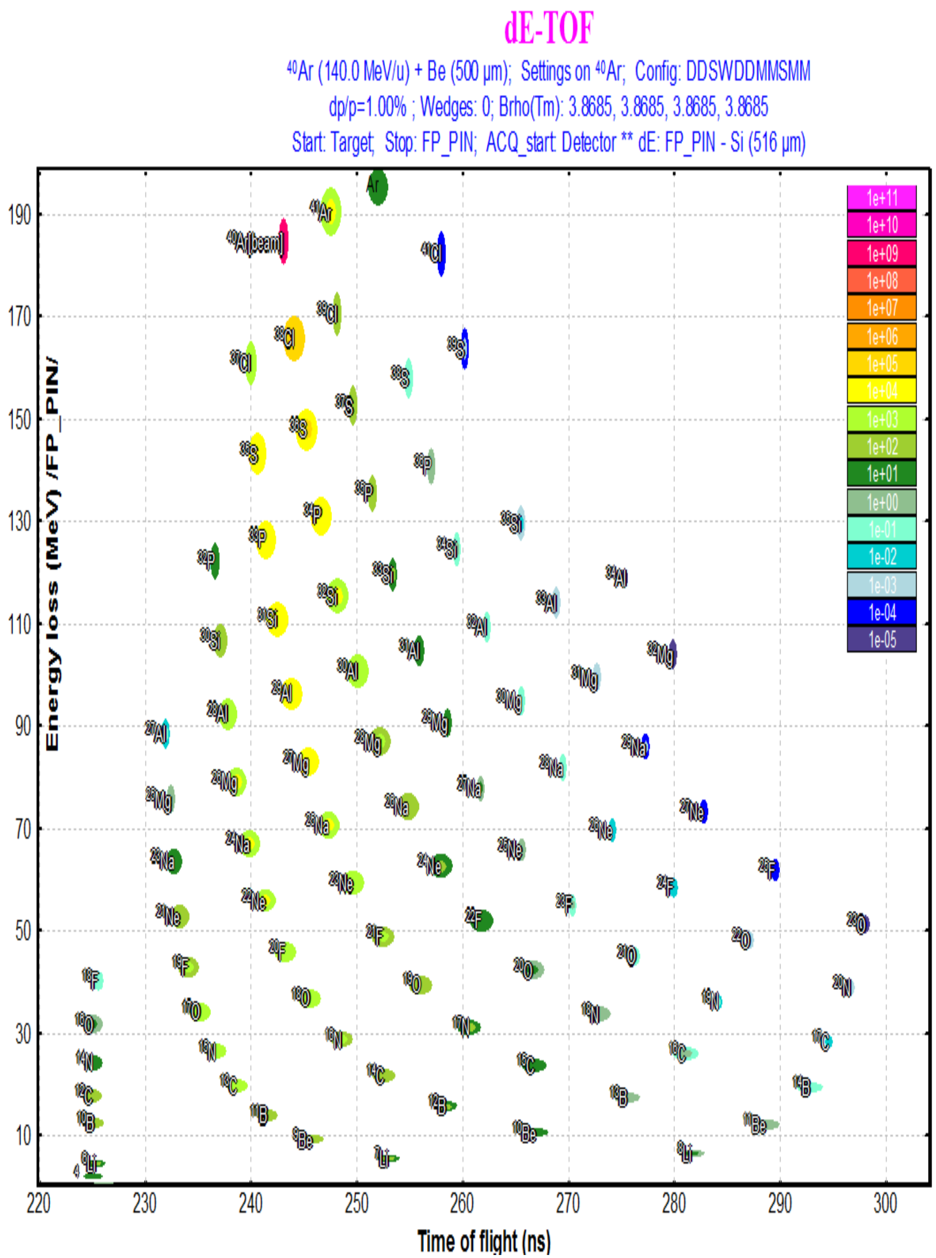
This means, the probabilities of one event misidentified as a neighboring charge state or element are equal to $\Phi_q(0.5) = 3.7\ 10^{-12}$ and $\Phi_Z(0.5) = 1.7\ 10^{-7}$, respectively.

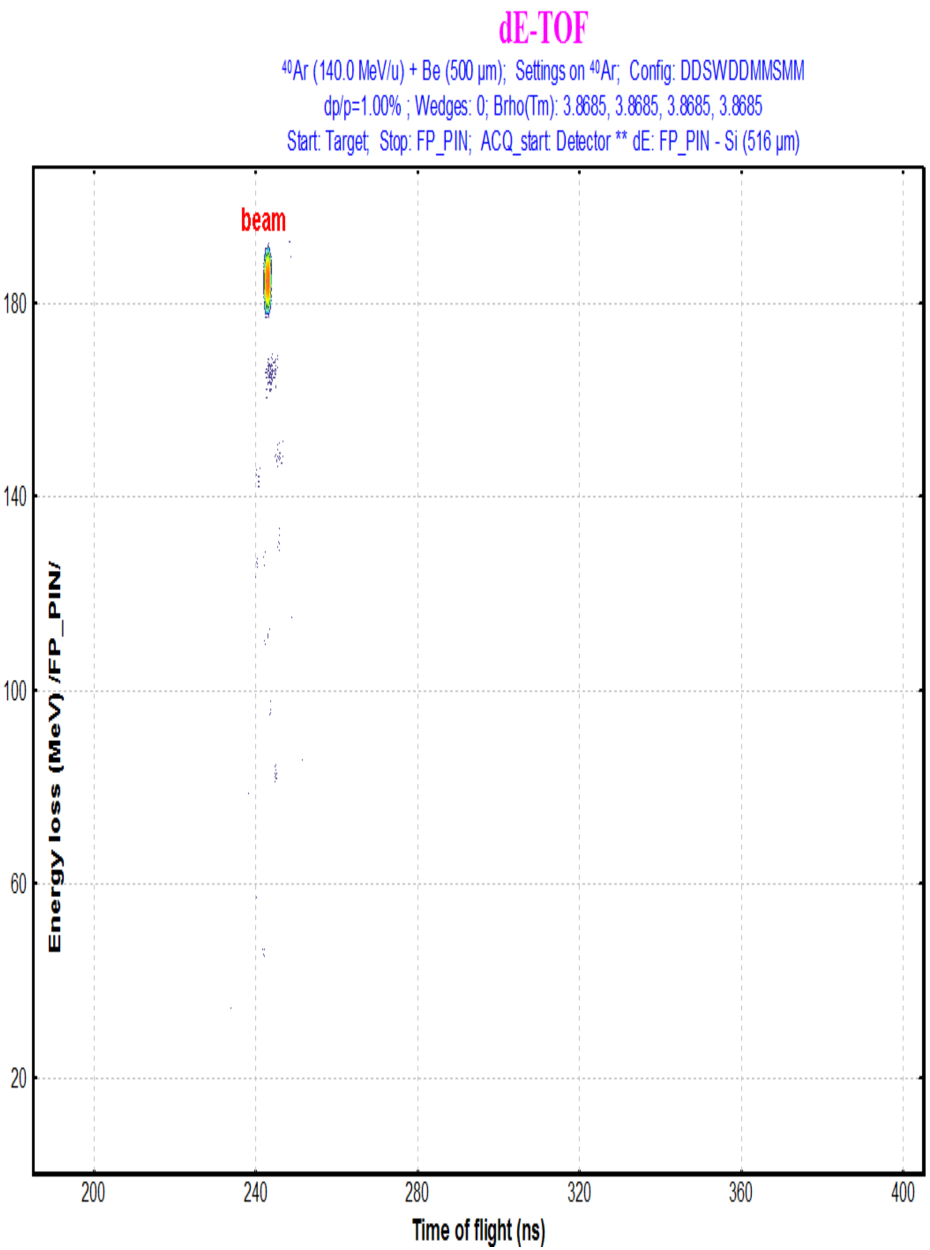
OT et al. Phys.Rev.Lett. 102, 142501 (2009)
OT et al. Phys.Rev.C. 80, 034609 (2009)

Particle identification assignments

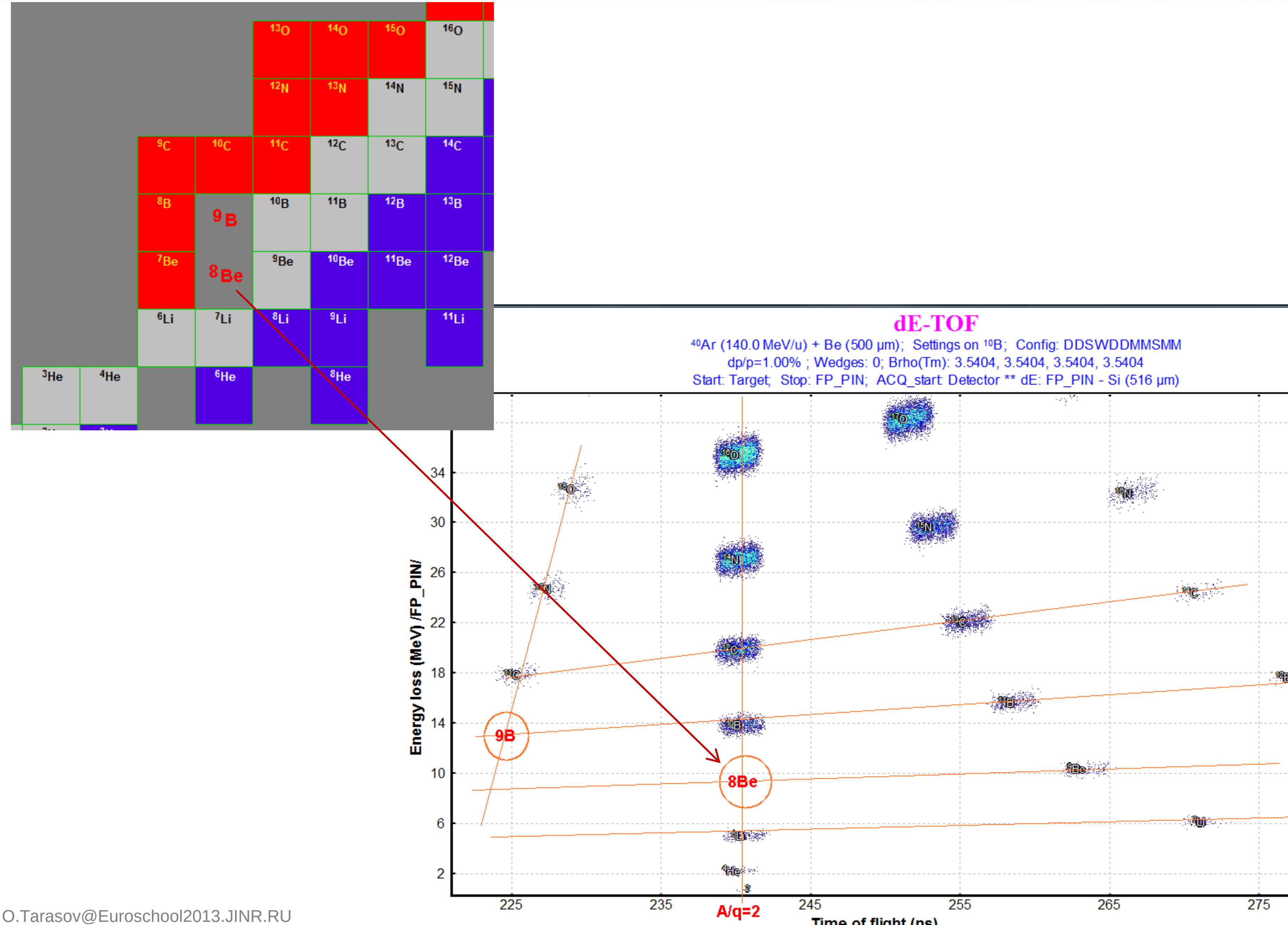
- **Calibration with the primary beam (or other reference line as sources)**
- **Unbound nuclei in the table of nuclides**
- **In-flight fragment tagging with prompt gamma**
- **Stopped fragment tagging with isomeric gamma-rays**
- **X-ray from ions passing material**
- **Laser induced fluorescence**
- **Precise isobar selection with known masses**

Calibration with the primary beam





Unbound nuclei in the table of nuclides

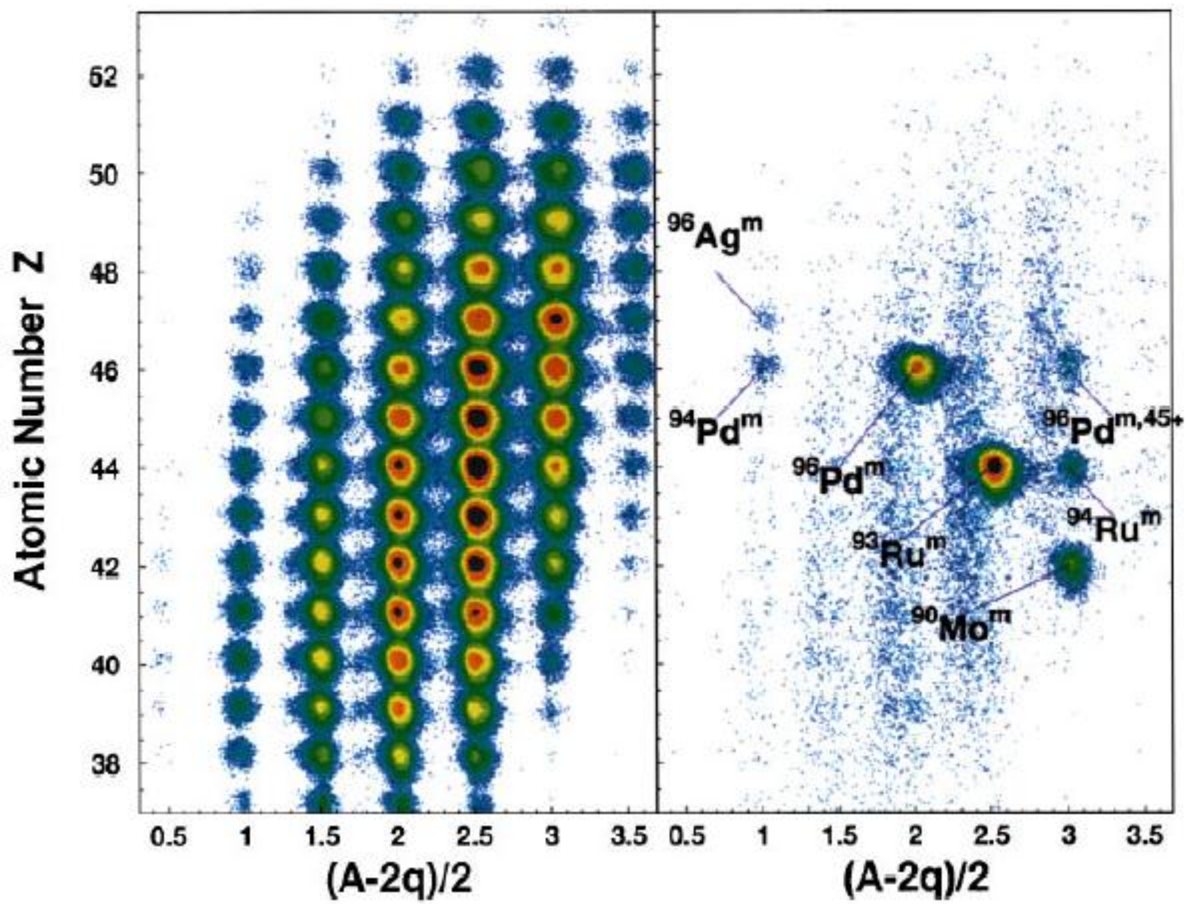


Stopped fragment tagging with isomeric gamma-rays

PHYSICAL REVIEW C VOLUME 55, NUMBER 3 MARCH 1997

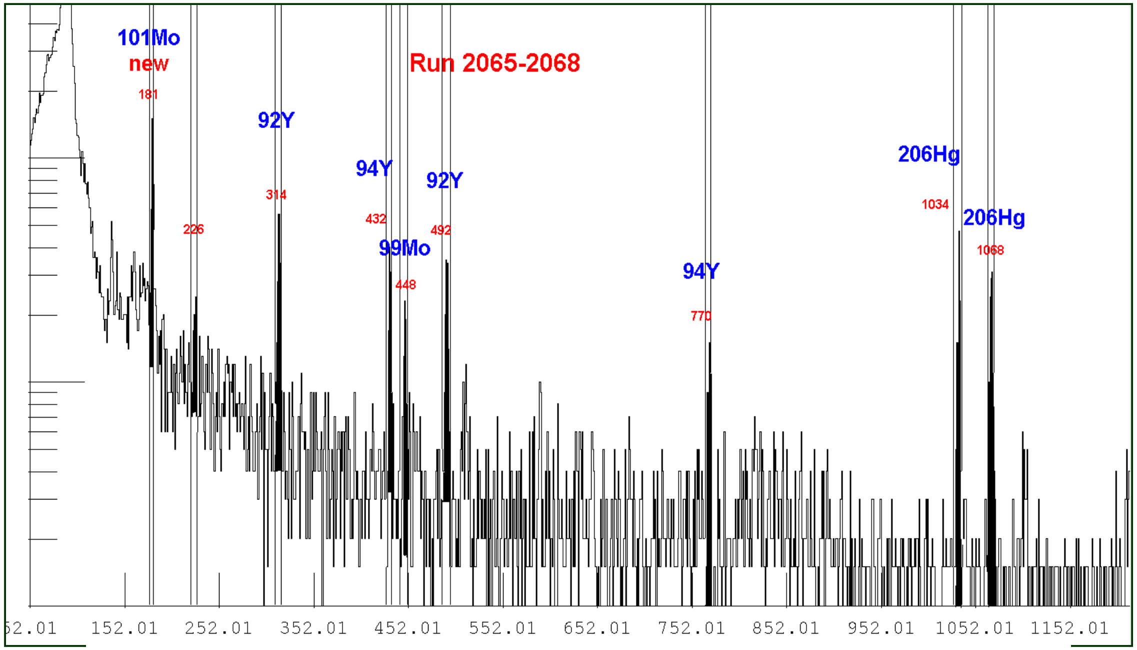
New μs isomers in $T_z=1$ nuclei produced in the ^{112}Sn(63A MeV) + ^{nat}Ni reaction

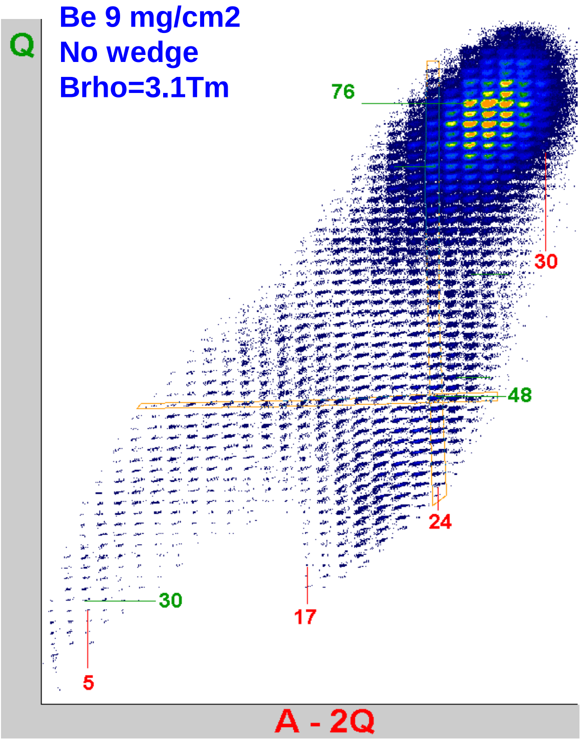
R. Grzywacz,[1,2] R. Anne,[2] G. Auger,[2] C. Borcea,[3] J. M. Corre,[2] T. Dörfler,[4] A. Fomichov,[5] S. Grevy,[6] H. Grawe,[7] D. Guillemaud-Mueller,[6] M. Huyse,[8] Z. Janas,[7] H. Keller,[7] M. Lewitowicz,[2] S. Lukyanov,[5,2] A. C. Mueller,[6] N. Orr,[9] A. Ostrowski,[2] Yu. Penionzhkevich,[5] A. Piechaczek,[8] F. Pougheon,[6] K. Rykaczewski,[1,10] M.G. Saint-Laurent,[2] W. D. Schmidt-Ott,[4] O. Sorlin,[6] J. Szerypo,[1] O. Tarasov,[5,2] J. Wauters,[8] J. Żylicz[1]



NSCL #05120

^{208}Pb (86 MeV/u) + Be



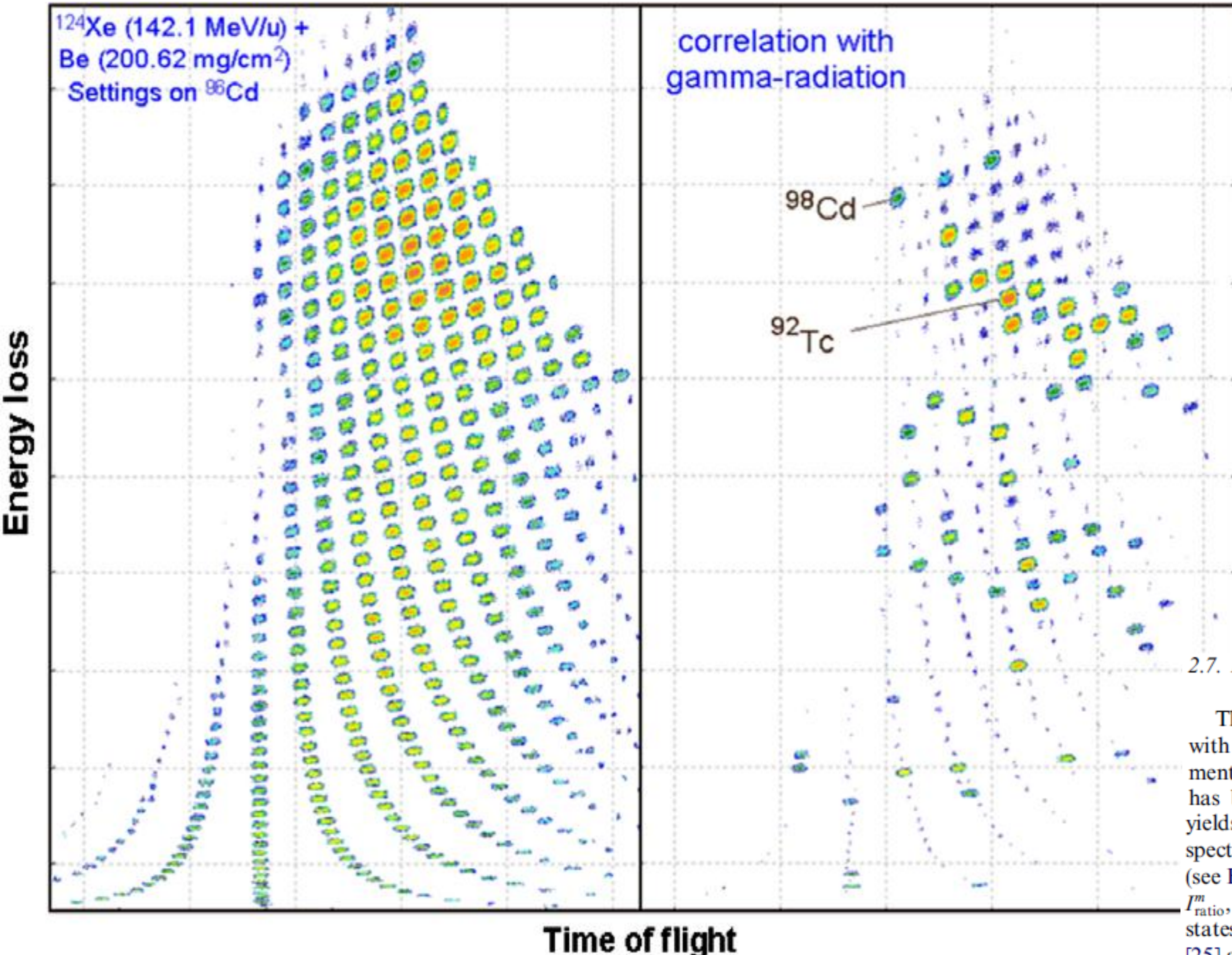


Gamma Information

Nucleus	Elevel(keV)	Jπ	T1/2	Eγ(keV)	Iγ	γ mult.	γ mix. ratio	γ conv. coeff.
206HG	1068.54 10	2+	< 21 ns	1068.54 10	100	E2		
206HG	2102.6 2	5-	2.15 μS 21	1034.01 10	100	E3		

Stopped fragment tagging with isomeric gamma-rays : LISE++

http://lise.nscl.msu.edu/paper/isomers.pdf



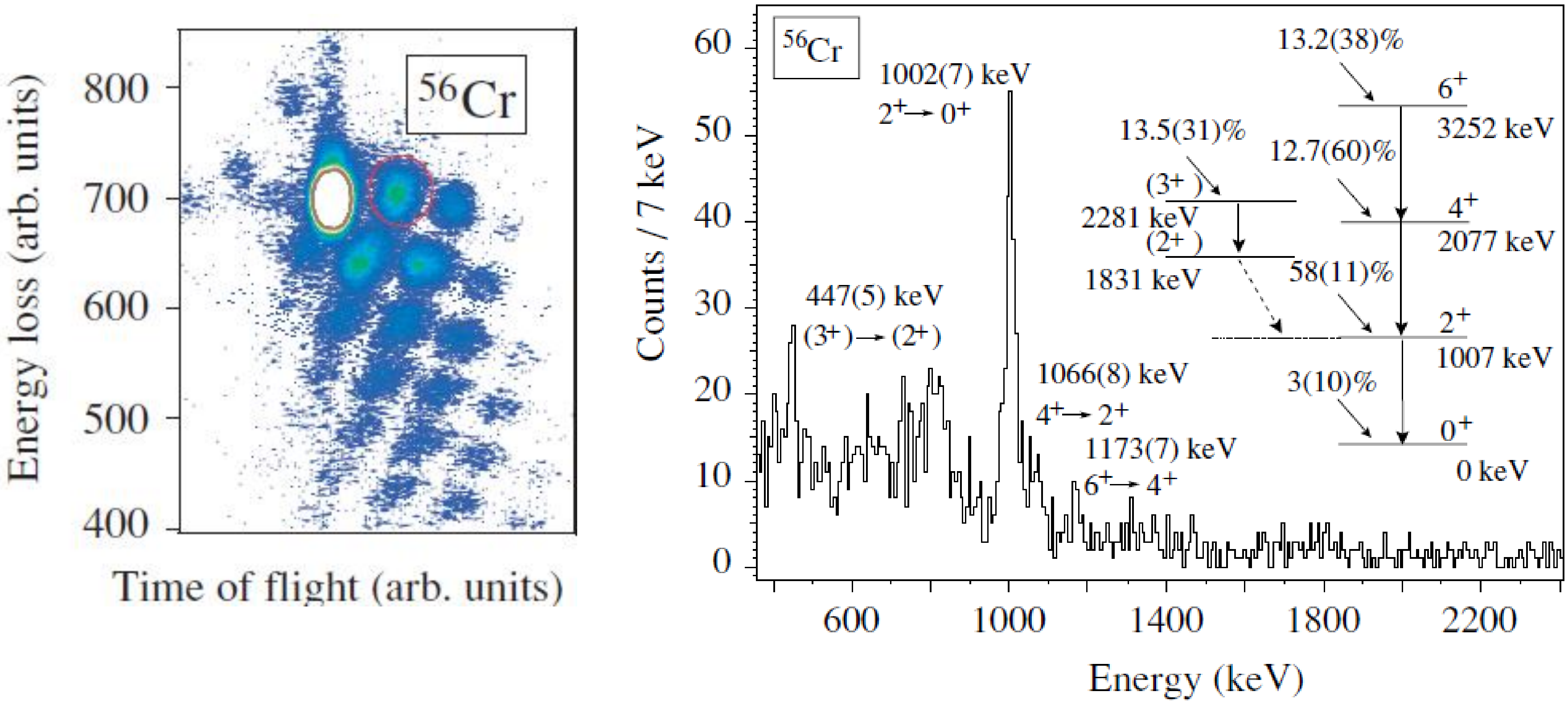
LISE++ identification plot of all nuclei produced in the reaction ^{124}Xe + Be (left panel) and those in coincidence with gamma-radiation (right panel)

Nuclear Instruments and Methods in Physics Research B 266 (2008) 4657–4664

2.7. Isomers in LISE++

The fragment identification method using correlation with μs isomer states is a powerful tool in modern experiments based on in-flight separation. An isomer database has been implemented in LISE++ to simulate fragment yields in coincidence with γ-ray and create an isomeric γ-spectrum and identification plot in coincidence with γ-rays (see Fig. 2). The isomer database contains information (E_γ, I^m_{ratio}, $T_{1/2}$, E_{level}, I_γ, M_γ) about 2000 short-lived isomeric states extracted from NNDC, the GANIL isomer database [25] and other sources. Using this database the program is able to estimate the γ-rays yield: $Y^m_\gamma = I^m_{ratio} Y_{frag} \varepsilon_{gate} \varepsilon_{det}$, where Y_{frag} is the rate of implanted fragments, I^m_{ratio} is an isomeric transition ratio, ε_{det} is the detector efficiency, ε_{gate} is the probability to be in the γ-acquisition gate defined by $T_{1/2}$, the fragment velocity, the length of flight and the γ-acquisition gate parameters (delay and width).

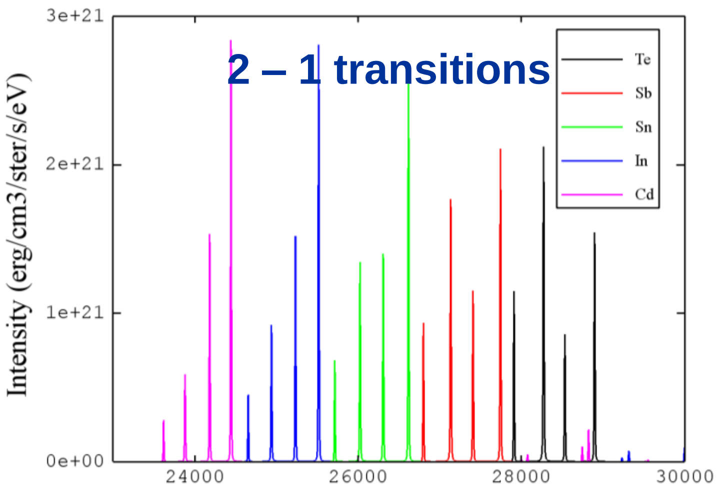
- **Large yield around target → you have to know "location"**
- **Fragments can be used downstream**

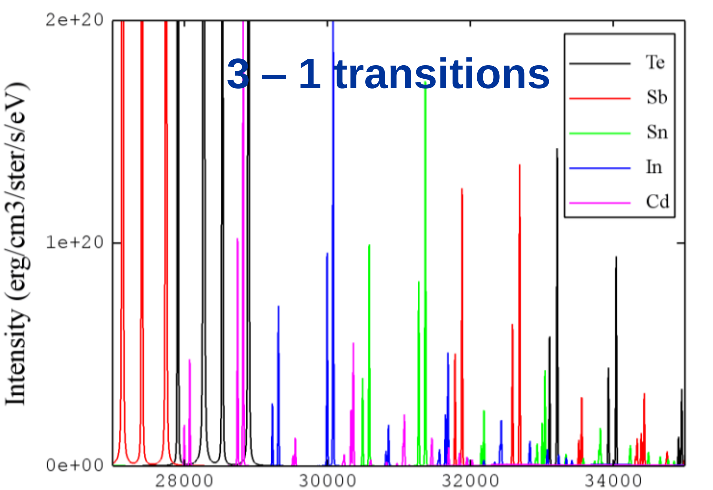


A.Gade et al., PRC 74, 047302 (2006)

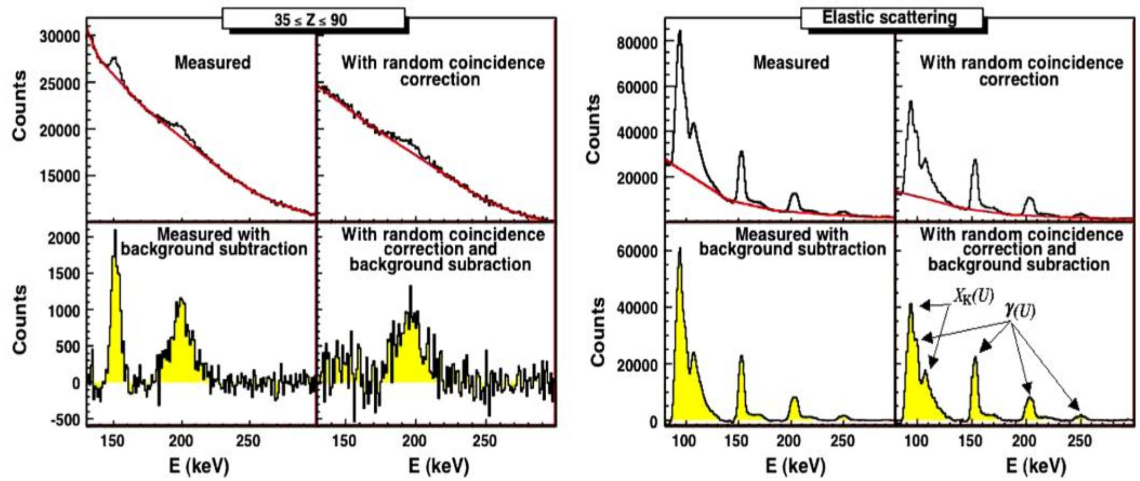
X-ray from ions passing material

Material Identification: Cd, In, Sn, Sb, Te





I. E. Golovkin (Prism CS)



M. O. Fregeau, *et al.*, PRL 108, 122701 (2012)

x-rays give → ***Z*, *q***
With tof and Bρ measurements → ***A*/*q***

***A* can be obtained**

Laser induced fluorescence

Etienne Rollin (thesis)

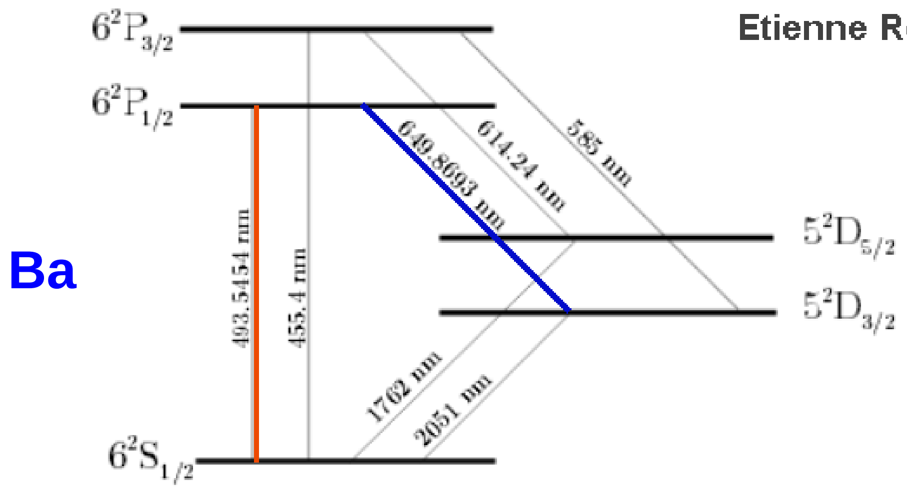


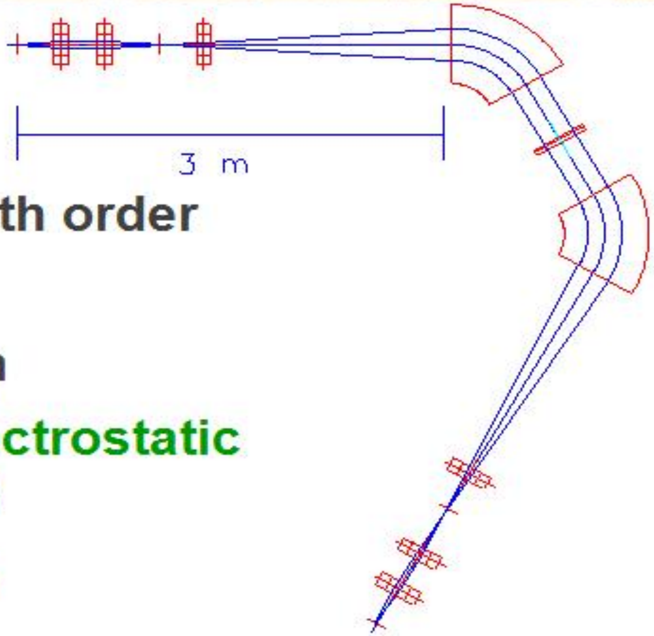
Figure 4.1: Energy levels of the barium ion and the wavelength in vacuum for the different transitions. Values taken from Curry et al. [47].

Most of the spectroscopic measurements of Ba^+ were done in vacuum with helium as buffer gas at a level around 10^{-5} Torr. In that case the procedure is simple. A 493 nm laser is used to excite the ground state to the first excited state $(6^2S_{1/2} - 6^2P_{1/2})$. Then, the decay back to the ground state takes 7.74 ± 0.4 ns [48] and the fluorescence photon can be detected. By saturating this transition, about 10^8 photons per second can be produced. Unfortunately, $26.5 \pm 2\%$ of the time [48] the excited state decays into the metastable state $(6^2P_{1/2} - 5^2D_{3/2})$, which stops the fluorescence. Therefore, a second laser at 650 nm is used to unshelve the ion from the D state back to the P state. Both lasers are run continuously. This procedure maximizes the number of photons produced and is very simple to implement.

"Compact" isobar separator

- Need to select specific activity
- Take advantage of low emittance and energy spread of extracted beams:

Beam Properties from gas catcher:
$\varepsilon \approx 3\ \pi$ mm•mr $\delta E \approx 1$eV



- Matching sections at entrance and exit transform beam to a ribbon beam.
- 2 x 60 degree bends, R = 50 cm
- 3 electrostatic multipoles correct through 5th order
- First order mass resolution: 1/20,000
- Small enough footprint to fit on HV platform
- All optics, except for bending magnet, is electrostatic so that tune is essentially mass independent

i.e: changing isotope with one knob

End of Lecture 4

Questions ?

Haben Sie Fragen?

Вопросы ?

有問題嗎？

¿Preguntas?

Demandoj?

質問？

Pytania?

Domande?

Sorular?