

December 16, 2020

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NCSL / MSU, USA

Rare Isotope Beams Particle Identification

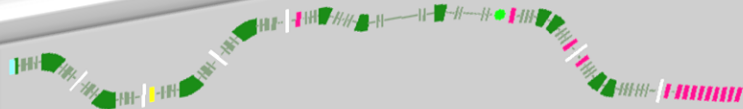
Workshop on Techniques and Detectors for Heavy-ion Charge-
State Identification in High-acceptance Spectrometers

LISE++

LISE++



1. Introduction
2. Stopped beams
3. Fast beams
4. PID features
5. Detector system requirements
6. Irreplaceable helper for PID: LISE++
7. Summary



1. PID introduction

1.1. "Mathematics"

1.2. PID assignment

1.2.1. Identification with us-isomers

1.2.2. A,Z -identification based on A/q-lines

1.3. PID resolution calculator

1.4. A - n*q , Z-q systematics

2. PID with stopped beams

2.1. GANIL 90s

2.2. MSU ^{238}U @ A1900

2.3. MSU ^{208}Pb @ A1900

2.4. MSU ^{238}U @ A1900+S800BL

2.5. MSU ^{238}U @ S800

2.6. GANIL ^{238}U @ LISE3

2.7. RIKEN 2007

2.8. RIKEN 2017

2.8.1 Advanced technique (wedge for Z, range detector, A/q resolution)

2.9. Filtering with TKE

2.10. Spectrometers

2.10.1. VAMOS, Prism, Samurai, MSP144, S800

3. PID with fast beams

3.1. A/q resolution

3.2. RIKEN

4. PID features

4.1. Cleaning from charge states

4.1.1. FLNR

4.2. Reconstruction

4.3. "Global" (net) Calibration

5. Detector system requirements

5.1. Pb-experiment

5.3. Requirement Sketch

6. Irreplaceable helper for PID: LISE⁺⁺

6.1. Pseudo-MC and MC plots

6.2. $LISE_{cute}^{++}$

6.3. LISE for Excel

7. Summary

1. PID introduction

Lectures at the Euroschool on Exotic Beams 2013
August 26-31, 2013, Dubna, Russia

http://lise.nsl.msui.edu/paper/Euroschool2013/4_Identification.pdf

What do we want to know?

RIB case

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

What do we measure?

“Classical”

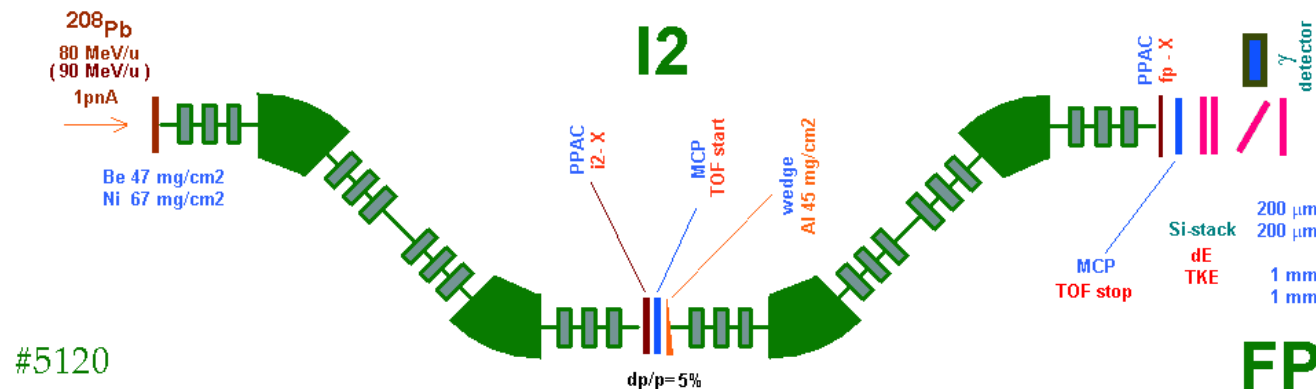
1. $B\rho$: Magnetic (electric) rigidity
2. dE : Energy loss in detector (material)
3. ToF: Velocity (time of flight)
4. TKE: Total kinetic energy

“fast”

“stopped”

Obtaining A, Z, q

	<i>stopped beams</i>		<i>fast beams</i>
The atomic number is determined from the combination of energy loss (ΔE) and time of flights (ToF) values according to the Bethe formula:	dE, ToF	$Z \approx \sqrt{\Delta E / \left(\frac{1}{\beta^2} \ln \left(\frac{5930}{1/\beta^2 - 1} \right) - 1 \right)}$	
The fragment mass can be extracted in atomic units from the relativistic formula:	TKE, ToF	$A = \frac{TKE}{m_u c^2 (\gamma - 1)}$	$ToF, B\rho$ $A/q = \frac{B\rho}{\beta\gamma} \frac{c}{m_u}$
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:	$TKE, B\rho$	$q = 3.33 \times 10^{-3} \frac{TKE \times \beta\gamma}{B\rho (\gamma - 1)}$	



PID assignment

- 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 (more common)
- A, Z -identification based on known A/q -lines (new)
- X-ray from ions passing material
- Laser induced fluorescence
- Precise isobar selection with known masses

Identification with
 μ S-isomers

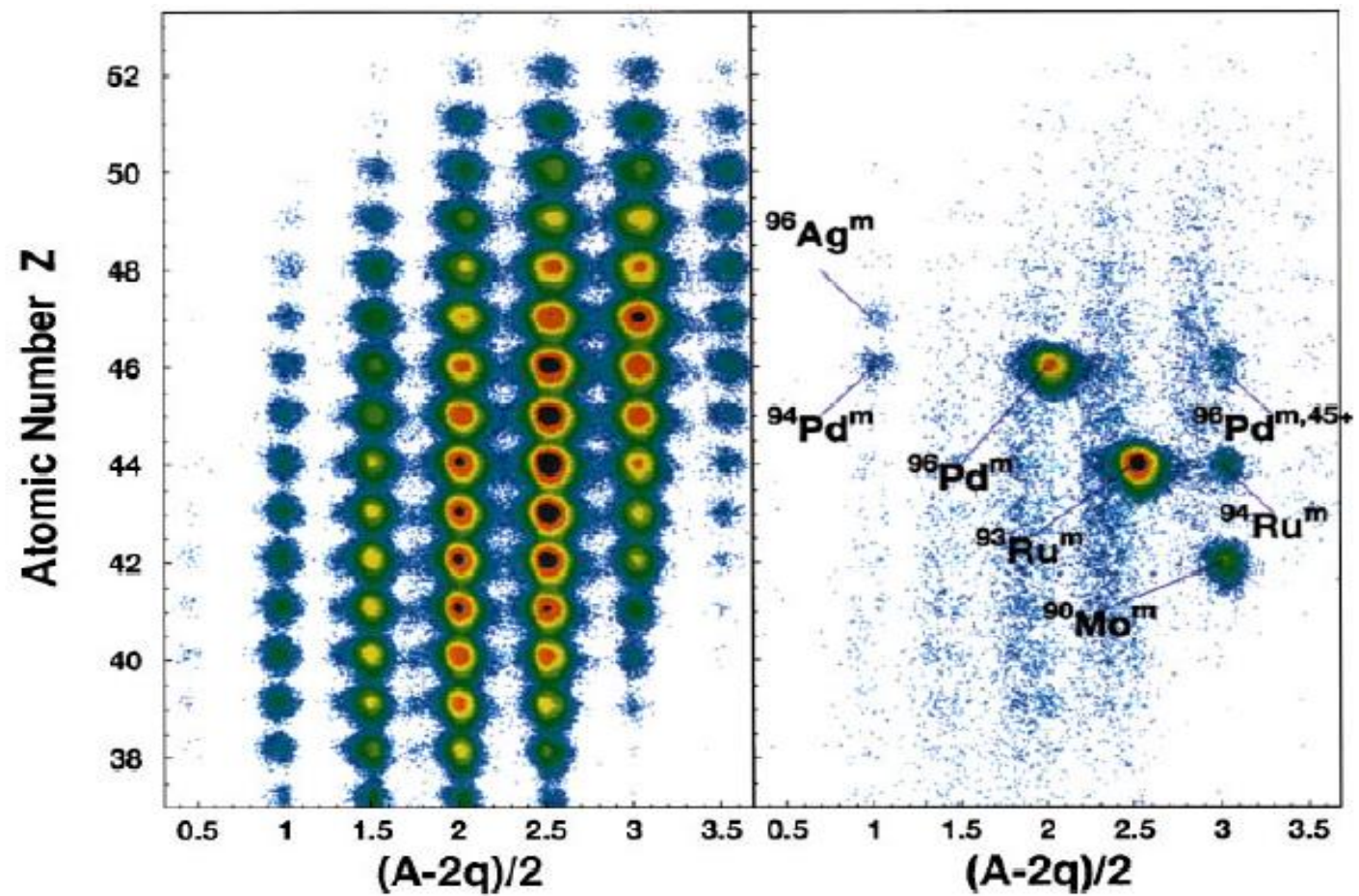
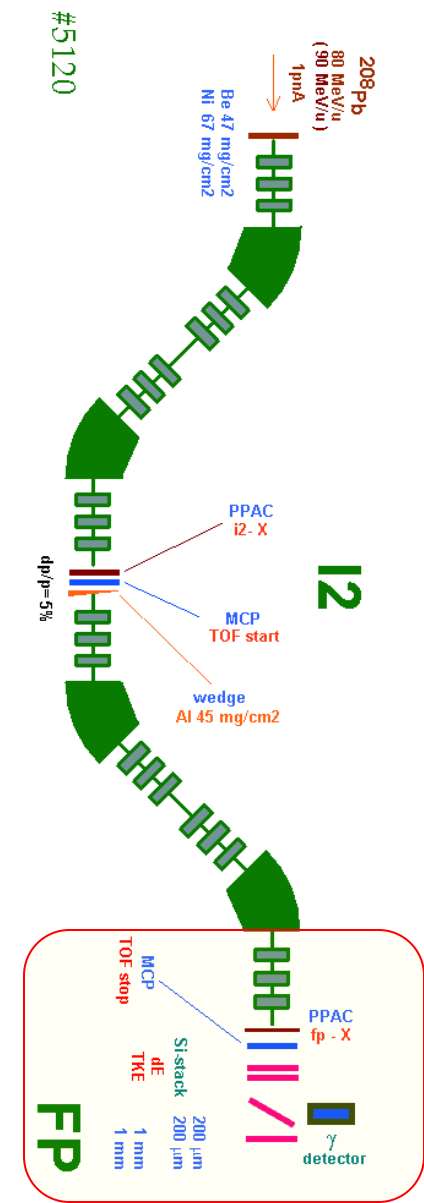
PHYSICAL REVIEW C

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MARCH 1997

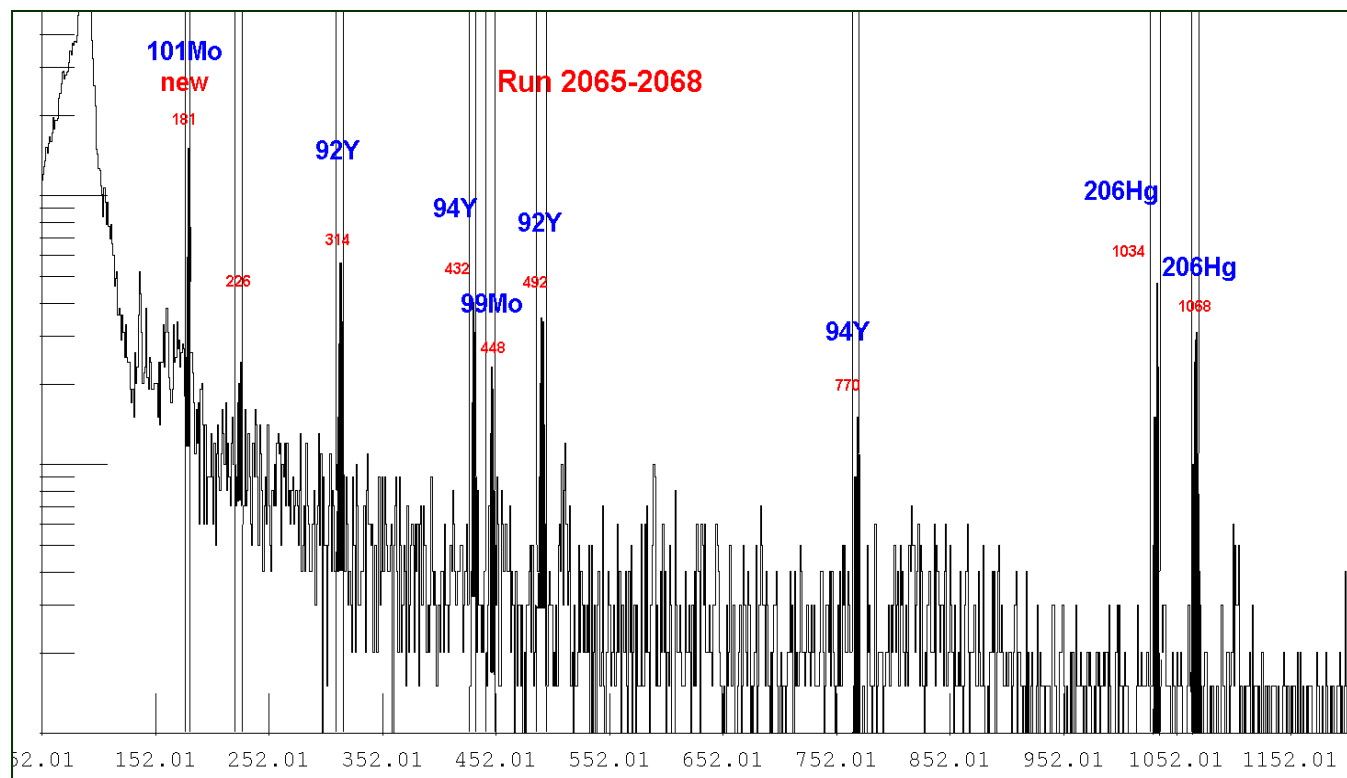
New μs isomers in $T_z=1$ nuclei produced in the $^{112}\text{Sn}(63A \text{ MeV}) + ^{\text{nat}}\text{Ni}$ reaction

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. Żylicz¹



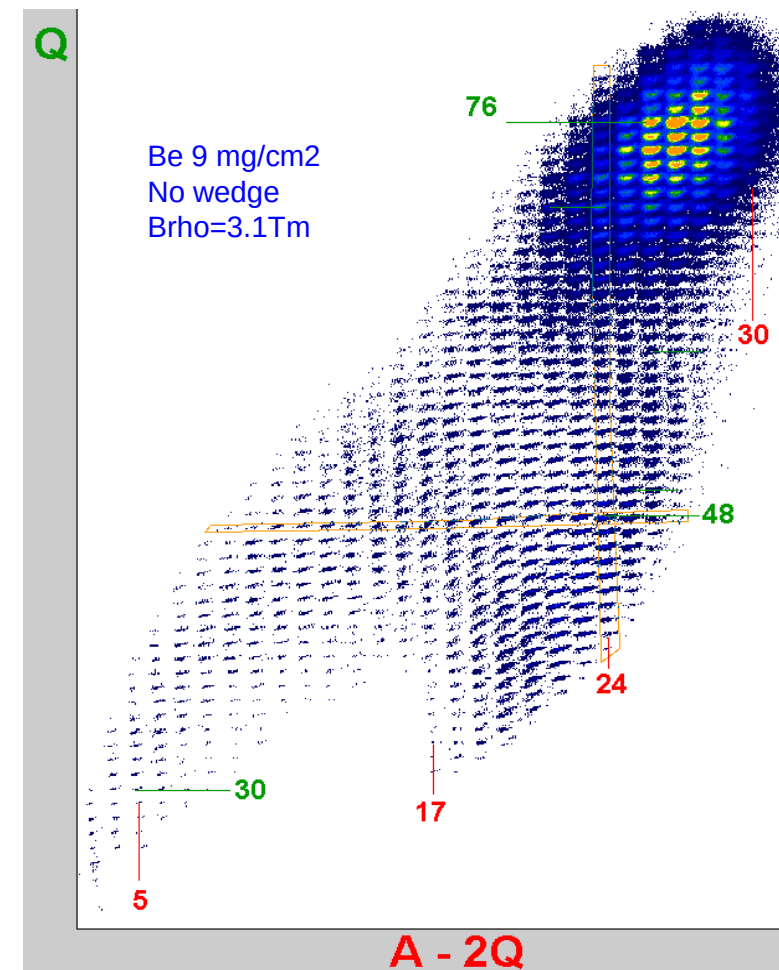
NSCL #05120

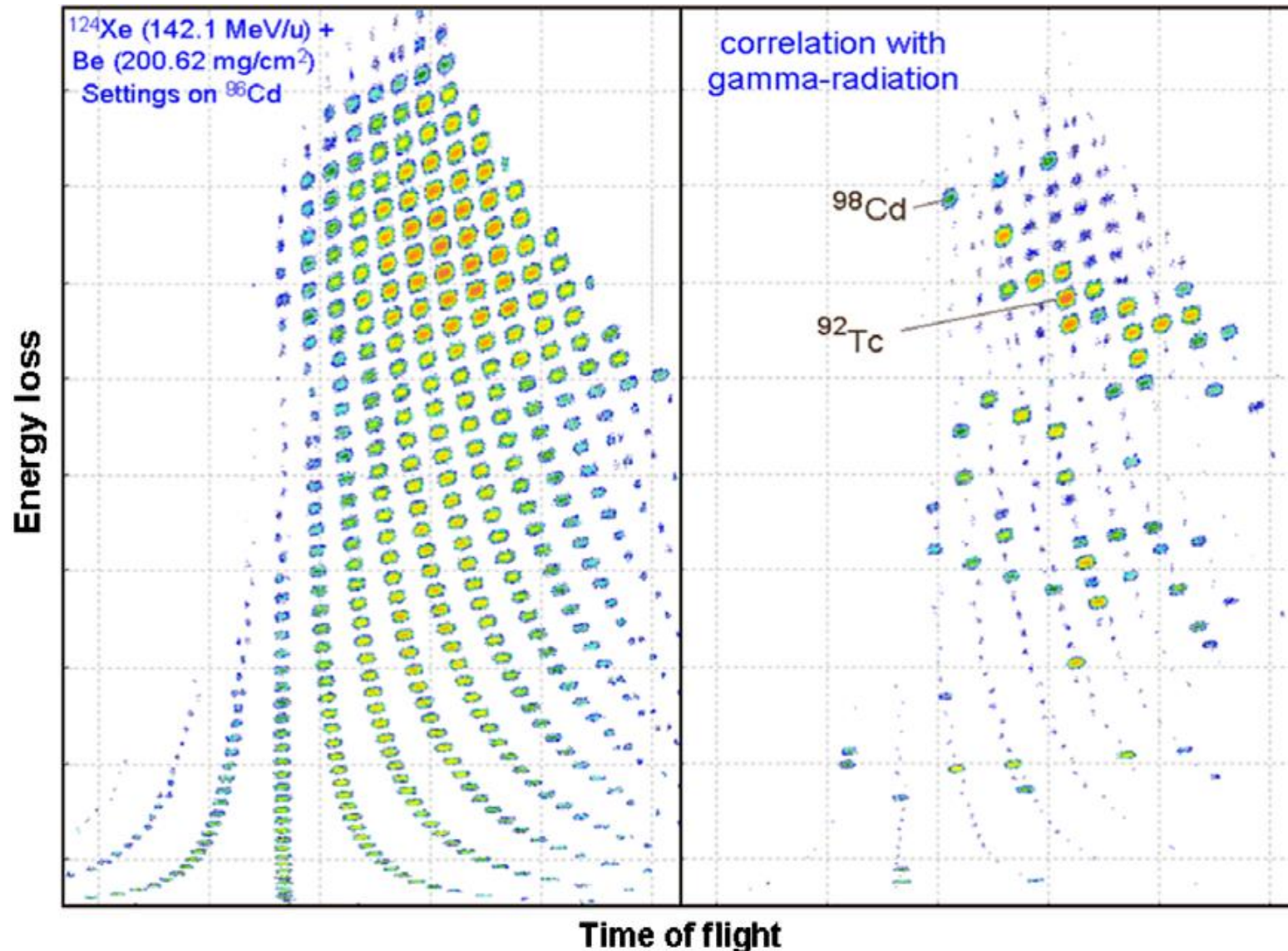
^{208}Pb (86 MeV/u) + Be



Gamma Information

Nucleus	$E_{\text{level}}(\text{keV})$	J^π	$T_{1/2}$	$E_\gamma(\text{keV})$	I_γ	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		





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

<http://lise.nsl.msui.edu/paper/isomers.pdf>

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_γ^m , $T_{1/2}$, 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: $Y_\gamma^m = I_\gamma^m \cdot Y_{\text{frag}} \cdot \epsilon_{\text{gate}} \cdot \epsilon_{\text{det}}$, where Y_{frag} is the rate of implanted fragments, I_γ^m 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).

Isomer Database			
A	Element	Z	N
50	Sc	21	29
Beta-decay			
for this isotope			
Current isomeric gamma ray	1	3	Total number of isomer gamma rays
Database Index	50210071		
Gamma energy	Value	Error	keV
Isomeric ratio (level population)	10	AP	%
T 1/2	1.0E-2	LT	micro-second
Level energy	328.447	0.012	keV
J pi	3+		
I gamma	100.	AP	%
M gamma	M1+E2		
M ratio			
Conversion Coef.	0.07	0.0021	
Data source	NNDC		
User Name	DT		

A, Z -identification based
on A/q -lines

$(A/q)_1$ isotope – should belong to A/q line as 2, 2.5 or 3

$(A/q)_2$ isotope – should be the element as the first isotope

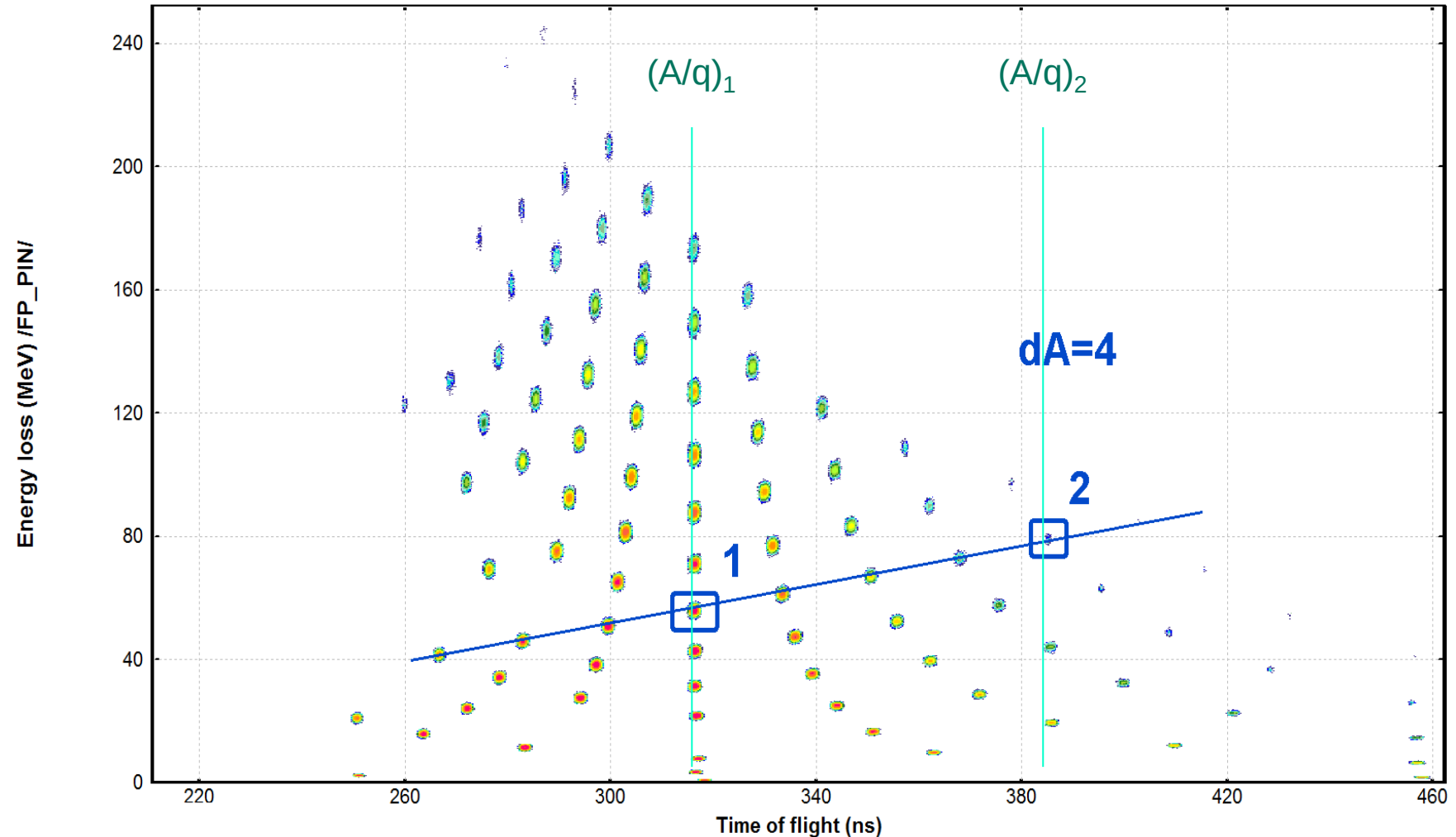
ΔA – isotope mass difference

$$Z = \frac{\Delta A}{(A/q)_1 - (A/q)_2}$$

- For Light Z
- Non-wedge settings
- ToF-calibration should be done to have A/q

dE-TOF

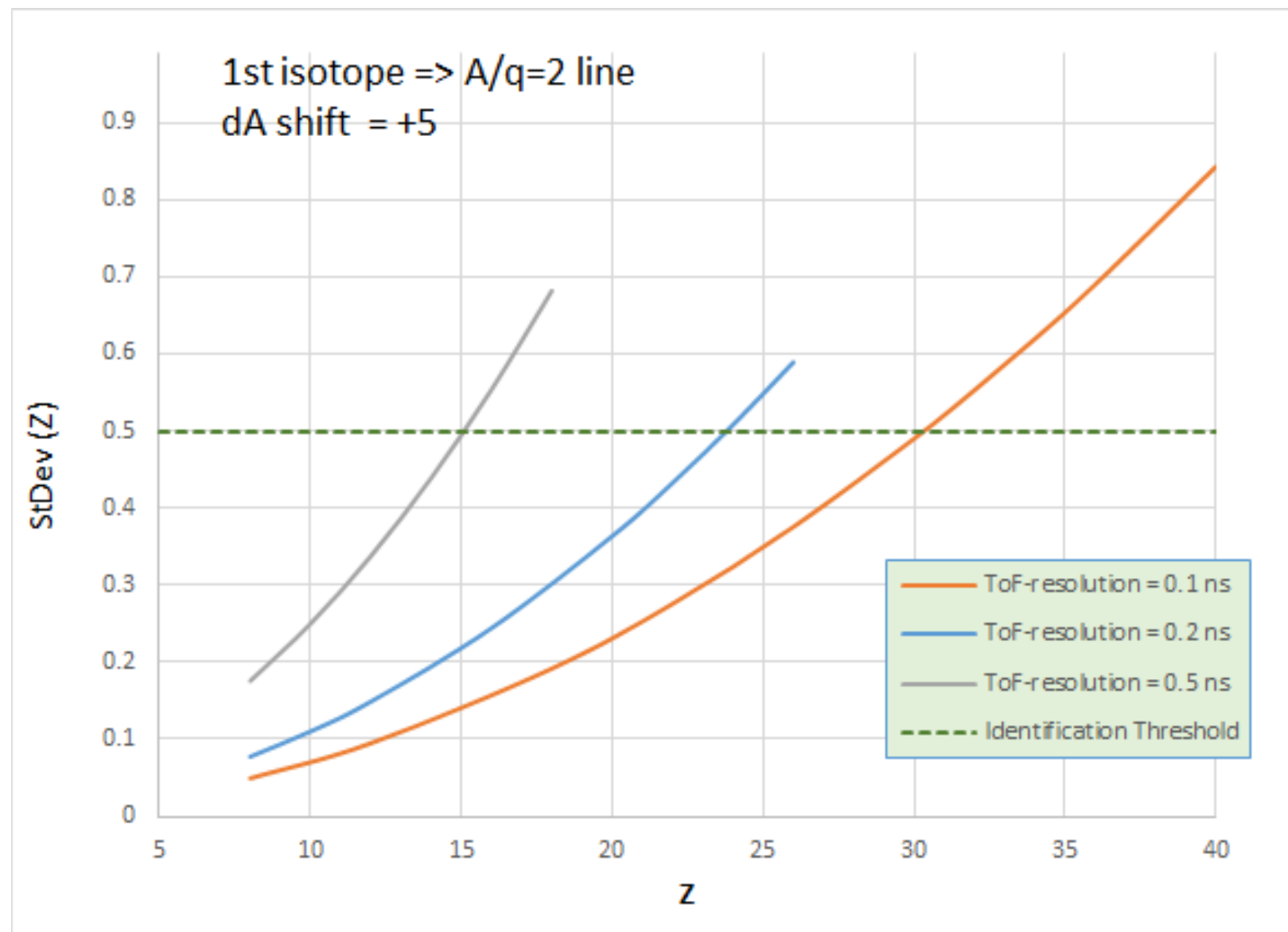
^{40}Ca (140 MeV/u) + Be (300 mg/cm²); Settings on ^{20}Ne ; Config: DSDSWDDMMMSMM
 dp/p=0.07% ; Wedges: 0; Brho(Tm): 2.5184, 2.5184, 2.5184, 2.5184
 Start: Target; Stop: FP_PIN; ACQ_start: Detector ** dE: FP_PIN - Si (504 μm)



All calculations were done for

- A1900 separator
- No wedge
- $E(1^{\text{st}} \text{ fragment}) = 120 \text{ MeV/u}$
- $l1_slits = \pm 1 \text{ mm}$

Under current conditions,
the identification above
Calcium is possible

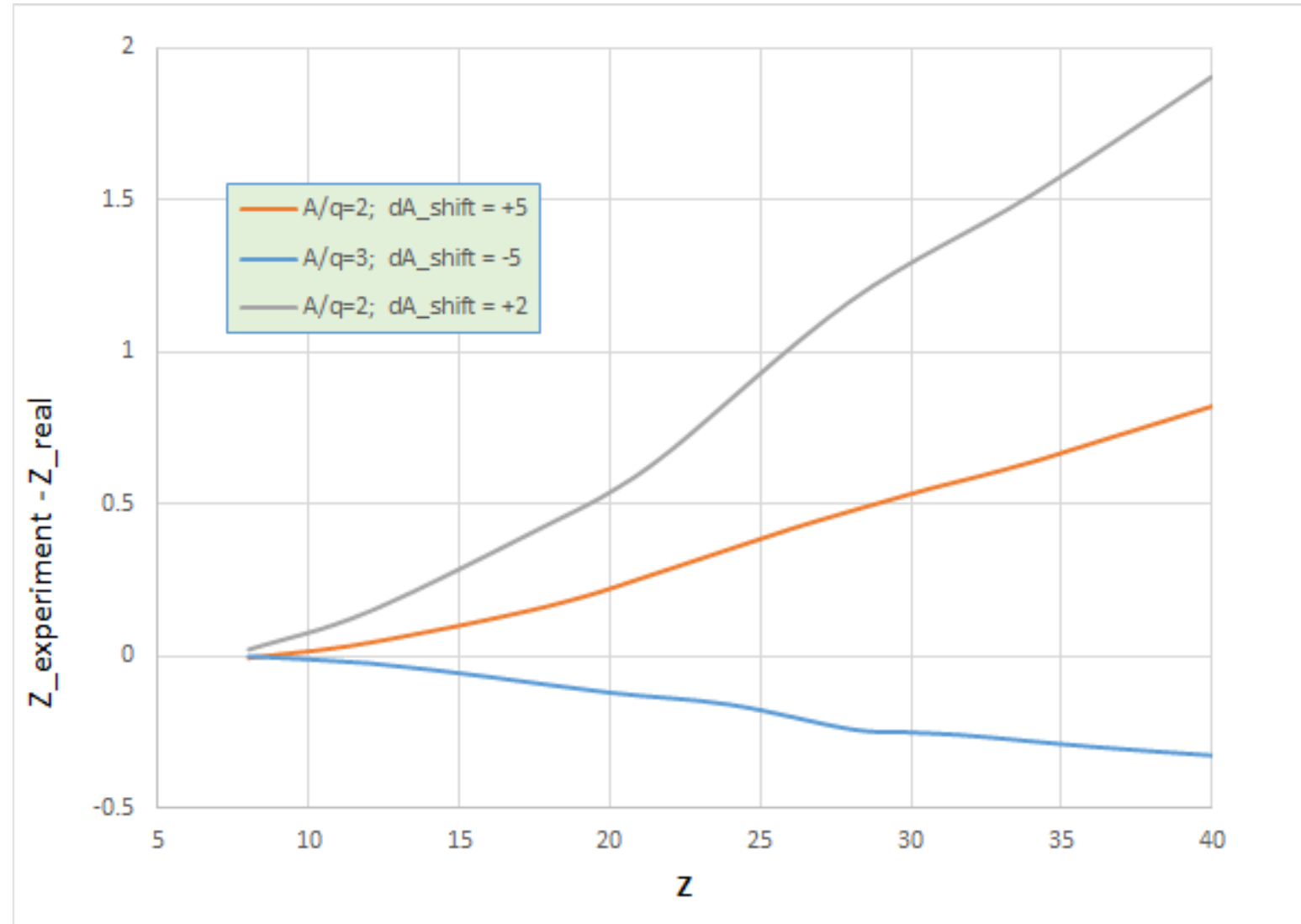


All calculations were done for

- A1900 separator
- No wedge
- $E(1^{\text{st}} \text{ fragment}) = 120 \text{ MeV/u}$
- $l1_slits = \pm 1 \text{ mm}$

Pay attention:

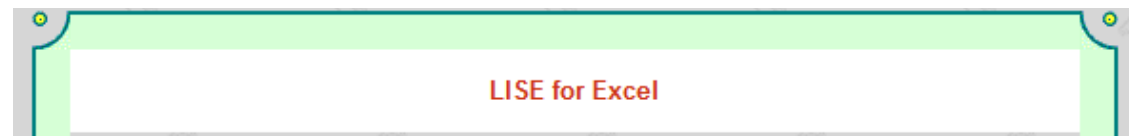
An extracted Z value won't be integer cause we are using in calculation an integer shift between the isotopes, but the second experimental “A/q” value is in reality equal to “ M_{ion}/q ”, where M_{ion} is not integer value



PID resolution calculator

Ion	
A =	120
Z =	50
q =	49
M_isotope =	119.9022
M_ion =	119.8753
M_ion/q =	2.446435

Set-up	
Energy =	50.00 MeV/u
Flight Length =	45.000 m
1st(Z) detector material =	14
1st(Z) detector thickness =	50 mg/cm2
	215.406 um



<http://lise.nsl.msui.edu/excel.html>

Resolution	
sigma	
TOF =	0.100 ns
Eloss =	0.60 %
TKE =	0.40 %
Z =	
Momentum (Brho) =	0.0745 %

systematical (calibration)	
0.01	%
0.33	% (straggling)
0.10	%
0.2	%
0.01	%

Momentum Resolution	
X-image at target =	1.0 mm
X-magnification @ disp.plane =	2.0
X-dispersion =	30.0 mm/%
Detector resolution =	1.0 mm
Momentum Resolution =	0.0745 %

Measured values	
TOF =	476.3847 ns
Brho =	2.5238 T*m
E1_loss =	1092.78 MeV
TKE =	5993.77 MeV

error (σ)	
0.111	0.023 %
0.002	0.075 %
7.48	0.684 %
24.71	0.412 %

Deduced values	
beta =	0.315104
gamma =	1.053677
velocity =	9.4461 cm/ns
A / q =	2.446435
A / q (2) =	2.48728

error (σ)	
0.00007	0.023 %
0.00003	0.003 %
0.00220	0.023 %
0.00195	0.080 %
0.002236	0.090 %

contribution in error						
Brho	Beta	TKE	E1_loss	Zsyst	A/q	Z
0.075%	0.026%					
0.076%	0.047%					
	0.020%		0.34%	0.20%		
0.075%	0.024%	0.412%				
	0.050%	0.412%				
0.075%	0.026%	0.420%				
0.07	0.04	0.09				
0.11	0.02	0.11				

PID values	
Z (Eloss) =	50
q =	49.000
A (from TKE) =	119.8753
A (from [A/q]*q_integer) =	119.8753
A (from [A/q]*q_measur) =	119.8753
A-2q =	21.88
A-3q =	-27.12
A-2Z *	22.32

error (σ)	
0.198	0.40 %
0.206	0.42 %
0.498	0.42 %
0.095	0.08 %
0.512	0.43 %
0.122	
0.159	
0.131	

0.10 0.09

The new sheet "PID resolution calculator" allows to estimate resolution of ion identification values as $Z, q, A, A/q$ and others in the case of regular in-flight separation technique with magnetic rigidity measurement. The user should provide resolutions of timing, position, energy detectors, input ion properties (Z, q, A, E), length of flight, and optical properties of dispersive plane where Brho-measurements take place. The PID resolution utility calculates final ID values and their errors, and provide information for partial contributions of measured components (time, energy loss, total kinetic energy, magnetic rigidity).

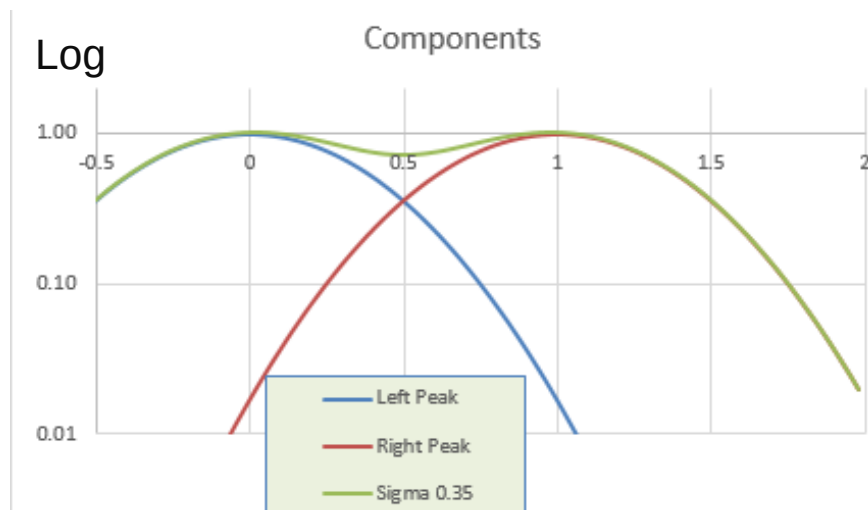
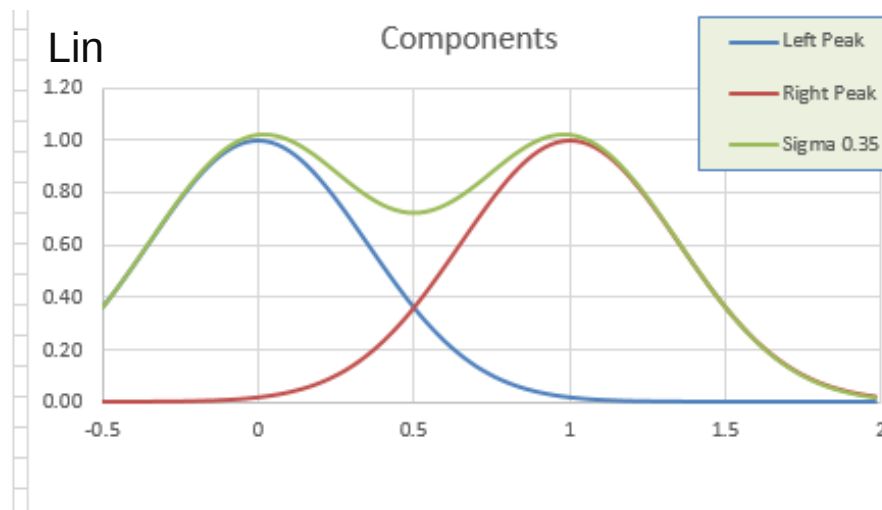
Only 32-bits MS Office

PID values	
Z =	50
q =	75.000
A (from TKE) =	119.8747
A (from $[A/q] \cdot q_{\text{integer}}$) =	119.8748
A (from $[A/q] \cdot q_{\text{measur}}$) =	119.8747
A-2q =	-30.13
A-3q =	-105.13
A-2Z =	-20.08

error (σ)
0.185
0.269
0.514
0.175
0.464
0.174
0.361
0.138

Let's assume
 $\sigma = 0.35$
 for integer values A, Z, q

Two neighbor peaks with the same Amplitude (=1) and Sigma (=0.35)



If original peak area is equal to 1, then

0.86 of ($\langle x \rangle = 0$) peak with sigma = 0.35 goes to gate $[-0.5, +0.5]$.
 0.14 are coming from neighbors

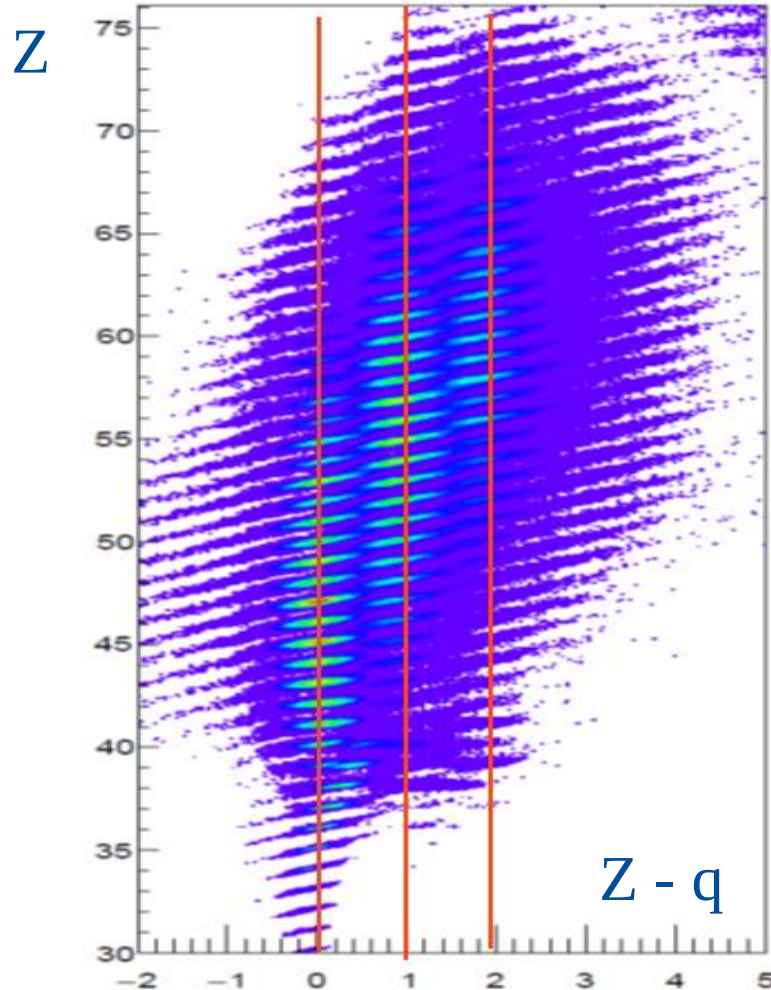
0.76 of ($\langle x \rangle = 0$) peak with sigma = 0.35 goes to gate $[-0.4, +0.4]$.
 0.08 are coming from neighbors

Systematics

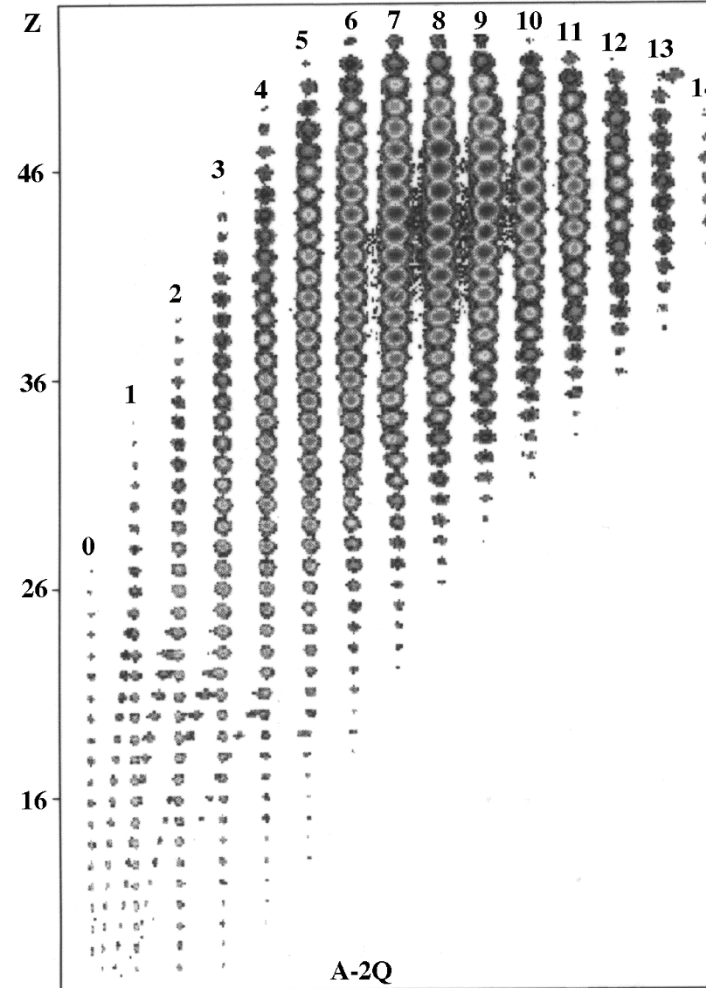
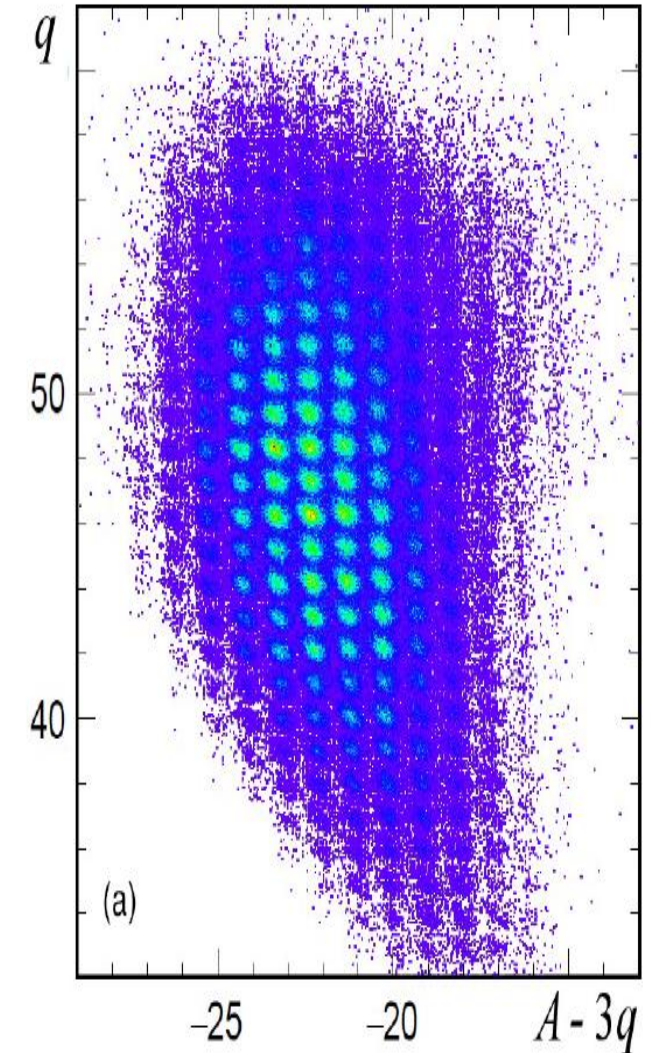
$$A = n \cdot q$$

$$Z = q$$

Z vs. Z-q plot allows to select a charge state



Z vs. A-nq plots represent deduced mass values, and allow to improve mass resolution for isotopes close to corresponding isospin lines



ion				resolution					
A	Z	q	A/q	A/q	A	A	A-2q	A-2.5q	A-3q
					TKE	(A/q) * q			
100	50	50	2.00	0.00159	0.415	0.427	0.079		0.236
120	50	49	2.45	1.95E-03	0.498	0.512	0.122	< 0.1	0.159
136	50	45	3.02	2.40E-03	0.565	0.581	0.206		0.107

- LISE PID resolution calculator
- ^{208}Pb experiment preparation analysis (discussed here later)
- A-nq analysis in work of H.Suzuki et al., PRC96, 034604 (2017)

The use of $A - 2Q$ allows significantly better resolution than A due to the nature of its error propagation. The error of $A - 2Q$ is given by Eq.

$$\Delta_{A-2Q} = A \sqrt{\left(1 - \frac{2}{A/Q}\right)^2 \left(\frac{\Delta_A}{A}\right)^2 + \left(\frac{2}{A/Q}\right)^2 \left(\frac{\Delta_{A/Q}}{A/Q}\right)^2}$$

Here, Δ_{A-2Q} , Δ_A , and $\Delta_{A/Q}$ represent the errors of $A - 2Q$, A , and A/Q , respectively. It is found from the equation that the contribution from Δ_A is canceled in the vicinity of $A/Q = 2$ so that the resolution of $A - 2Q$ can be almost as good as that of A/Q . (Such a cancellation also happens in the case of using $A - 3Q$ for the region of $A/Q = 3$.)

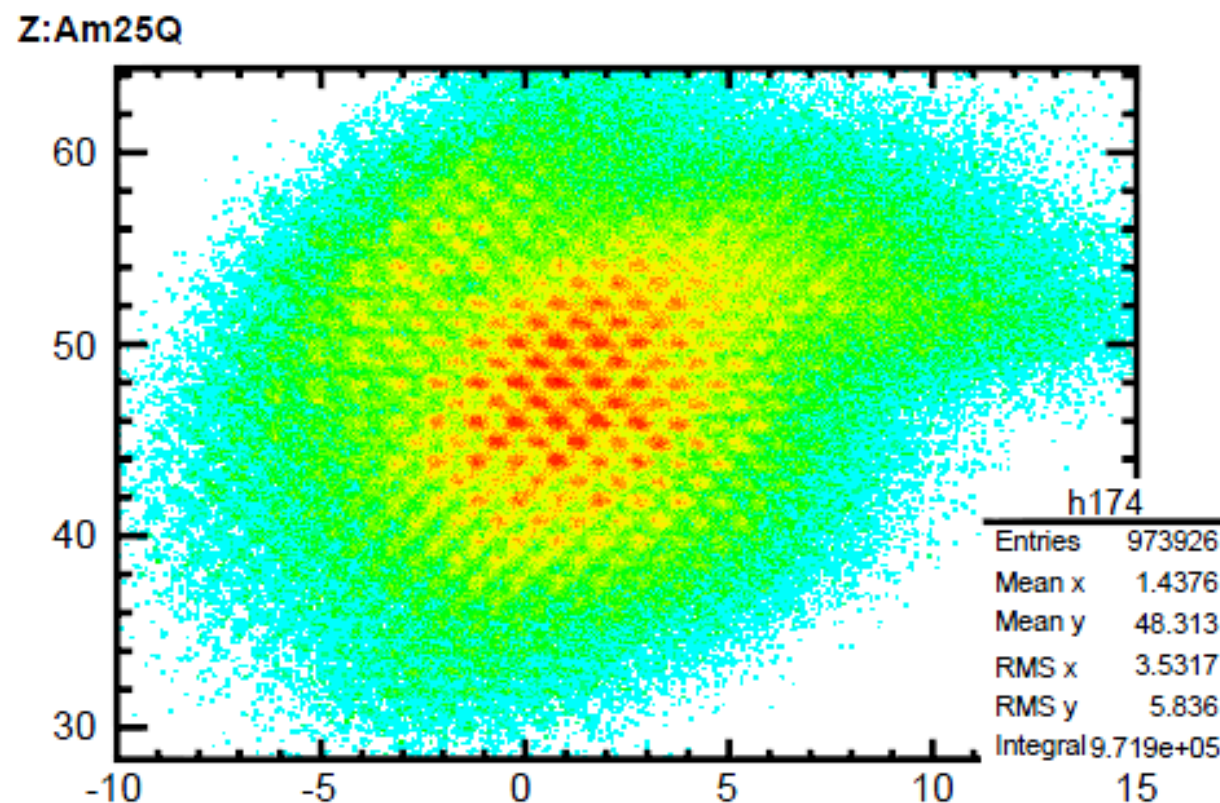
Ion		Set-up	
A = 120		Energy = 50.00	MeV/u
Z = 50		Flight Length = 45.000	m
q = 49		1st(Z) detector material = 14	
M_isotope = 119.9022		1st(Z) detector thickness = 50	mg/cm ²
M_ion = 119.8753			215.406 um
M_ion/q = 2.446435			
Resolution		Momentum Resolution	
sigma		X-image at target = 1.0	mm
TOF = 0.100	ns	X-magnification @ disp.plane = 2.0	
Eloss = 0.60	%	X-dispersion = 30.0	mm/%
TKE = 0.40	%	Detector resolution = 1.0	mm
Z =		Momentum Resolution = 0.0745	%
Momentum (Brho) = 0.0745	%		
Measured values		error (σ)	
TOF = 476.3847	ns	0.111	0.023
Brho = 2.5238	T*m	0.002	0.075
E1_loss = 1092.78	MeV	7.48	0.684
TKE = 5993.77	MeV	24.71	0.412
Deduced values		error (σ)	
beta = 0.315104		0.00007	0.023
gamma = 1.053677		0.00003	0.003
velocity = 9.4461	cm/ns	0.00220	0.023
A / q = 2.446435		0.00195	0.080
A/q (2) = 2.48728		0.002236	0.090
PID values		error (σ)	
Z (Eloss) = 50		0.198	0.40
q = 49.000		0.206	0.42
A (from TKE) = 119.8753		0.498	0.42
A (from [A/q]*q_integer) = 119.8753		0.095	0.08
A (from [A/q]*q_measur) = 119.8753		0.512	0.43
A-2q = 21.88		0.122	
A-3q = -27.12		0.159	
A-2Z = 22.32		0.131	

PHYSICAL REVIEW C 96, 034604 (2017)

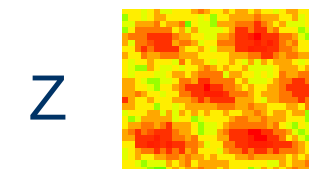
Discovery of new isotopes $^{81,82}\text{Mo}$ and $^{85,86}\text{Ru}$ and a determination of the particle instability of ^{103}Sb

H. Suzuki,^{1,*} T. Kubo,¹ N. Fukuda,¹ N. Inabe,¹ D. Kameda,¹ H. Takeda,¹ K. Yoshida,¹ K. Kusaka,¹ Y. Yanagisawa,¹ M. Ohtake,¹ H. Sato,¹ Y. Shimizu,¹ H. Baba,¹ M. Kurokawa,¹ K. Tanaka,¹ O. B. Tarasov,² D. Bazin,² D. J. Morrissey,² B. M. Sherrill,² K. Ieki,³ D. Murai,³ N. Iwasa,⁴ A. Chiba,⁴ Y. Ohkoda,⁴ E. Ideguchi,⁵ S. Go,⁵ R. Yokoyama,⁵ T. Fujii,⁵ D. Nishimura,⁶ H. Nishibata,⁷ S. Momota,⁸ M. Lewitowicz,⁹ G. DeFrance,⁹ I. Celikovic,⁹ and K. Steiger¹⁰

The best representation for Z-separation,
and the best mass resolution for ions around $A/q=2.5$



A-2q

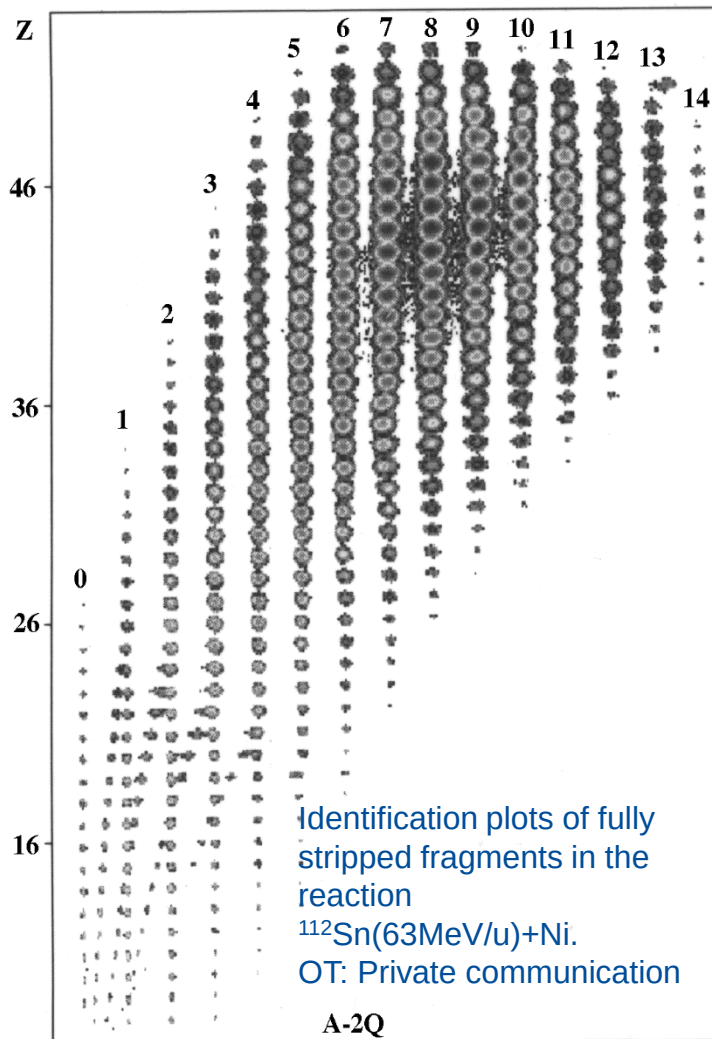
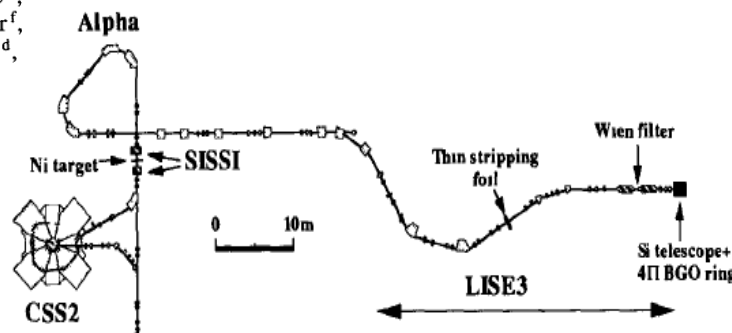


A-2.5q

OT private communications from Eur. Phys. J. A (2018) 54: 66

2. “Stopped” beam experiments

M. Lewitowicz^a, R. Anne^a, G. Auger^a, D. Bazin^a, C. Borcea^b, V. Borrel^c, J.M. Corre^a, T. Dörfler^d, A. Fomichev^e, R. Grzywacz^f, D. Guillemaud-Mueller^e, R. Hue^a, M. Huyse^g, Z. Janas^{h,1}, H. Keller^h, S. Lukyanov^e, A.C. Mueller^c, Yu. Penionzhkevich^e, M. Pfützner^f, F. Pougheon^c, K. Rykaczewski^f, M.G. Saint-Laurent^a, K. Schmidt^h, W.D. Schmidt-Ott^d, O. Sorlin^c, J. Szerypo^{g,1}, O. Tarasov^e, J. Wauters^g, J. Żylicz^f



^{100}Sn experiment

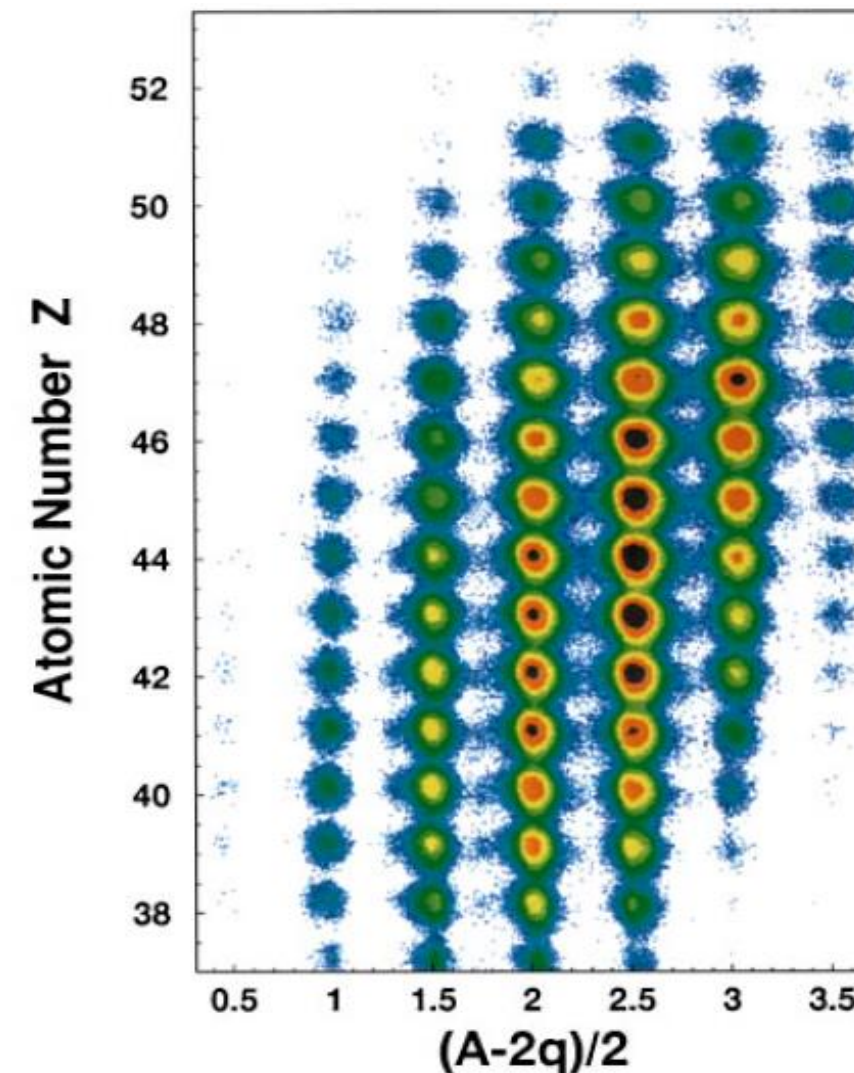
- Length 118 m
- Timing : Si - RF
- Si-telescope (4 detectors)
- No wedge
- Ni-target
- Stripping foil against light-Z background
- Small momentum acceptance (0.29%)
- Large angular acceptance

“Isomers” experiment

- Momentum acceptance (1%)
- MCP at Disperse FP for T and Bp

New μs isomers in $T_z=1$ nuclei produced in the $^{112}\text{Sn}(63.4 \text{ MeV}) + ^{nat}\text{Ni}$ reaction

Grzywacz,^{1,2} R. Anne,² G. Auger,² C. Borcea,³ J. M. Corre,² T. Dörfler,⁴ A. Fomichev,⁵ S. Grevy,⁶ H. Grawe,⁷ 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 Rykaczewski,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. Żylicz¹



PHYSICAL REVIEW C 79, 064318 (2009)

New neutron-rich microsecond isomers observed among fission products of ^{238}U at 80 MeV/nucleon

C. M. Folden III,^{1,*} A. S. Nettleton,^{1,2} A. M. Amthor,^{1,2} T. N. Ginter,¹ M. Hausmann,¹ T. Kubo,³
W. Loveland,⁴ S. L. Manikonda,⁵ D. J. Morrissey,^{1,6} T. Nakao,^{3,7} M. Portillo,¹ B. M. Sherrill,^{1,2}
G. A. Souliotis,⁸ B. F. Strong,⁶ H. Takeda,³ and O. B. Tarasov^{1,9}

$^{238}\text{U} + \text{Be}$

Fission of an 81-MeV/u ^{238}U beam following abrasion by a Be target has been studied at the NSCL [15]. Recoiling fragments were spatially separated from the primary beam and identified using the A1900 fragment separator with magnetic rigidity varied in steps from 2.5–3.9 T m. A search for new neutron-rich nuclides was performed and has shown evidence for production of ^{125}Pd (see Fig. 5). It is necessary to note, that at the same time this isotope has been also observed in RIKEN [16] and GSI [17].

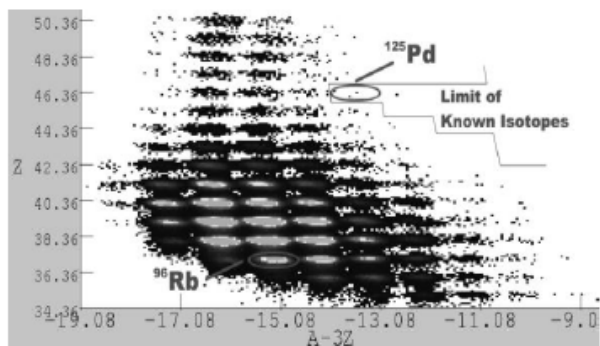


FIGURE 5. Partial identification plot [15] showing measured atomic number Z vs. the calculation function $A-3Z$ for fully stripped ions obtained during a search for new isotopes.

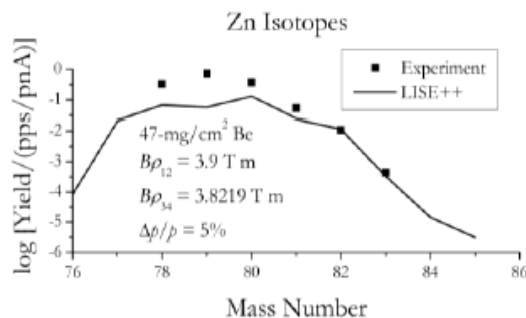
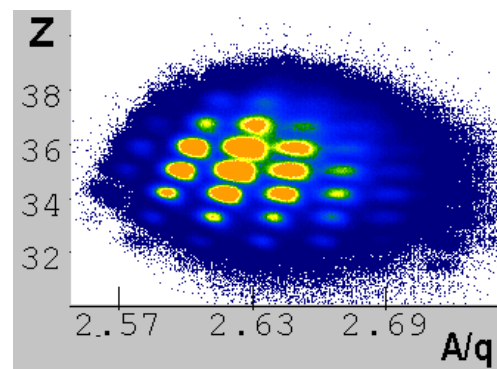
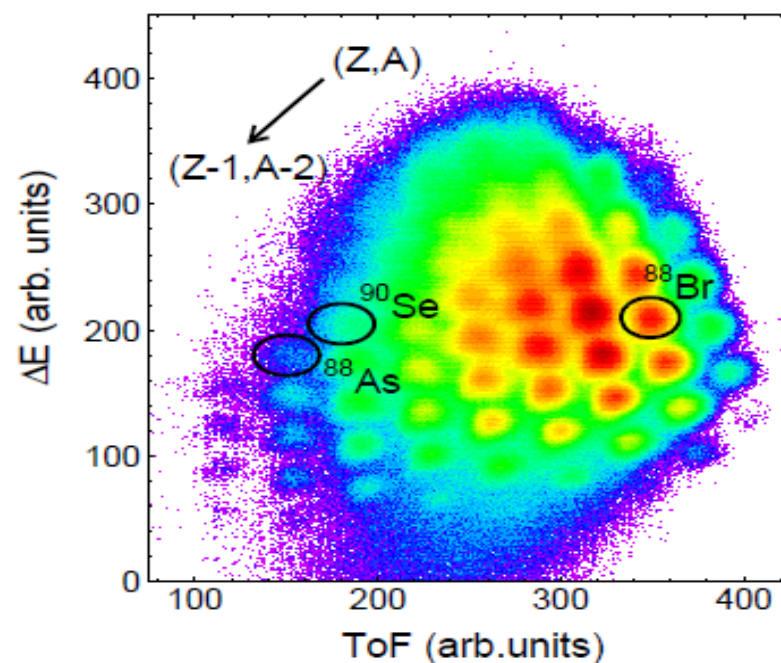


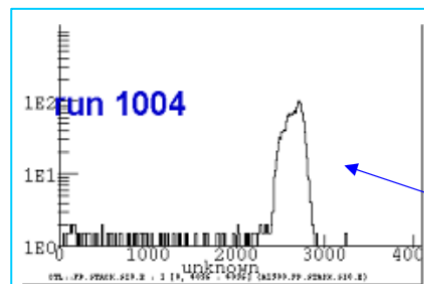
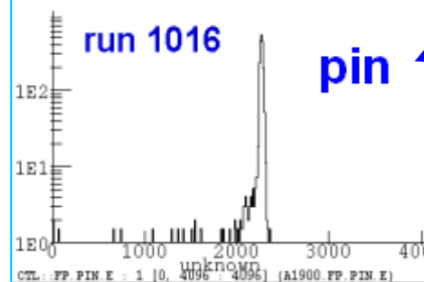
FIGURE 6. Comparison [15] of the observed yield of Zn isotopes produced by in-flight fission of ^{238}U (80MeV/u) to calculations by the LISE++ program [18].



Courtesy by J.Pereira

FIG. 1: (Color online) Particle-identification (PID) spectrum with the nuclei transmitted into the experimental area ($^{76-80}\text{Zn}$, $^{77-83}\text{Ga}$, $^{79-86}\text{Ge}$, $^{83-89}\text{As}$, $^{84-90}\text{Se}$, $^{87-93}\text{Br}$, $^{90-96}\text{Kr}$, $^{93-98}\text{Rb}$, and $^{97-100}\text{Sr}$). (See text for details.)

Good Z , short length of flight (moderate A)

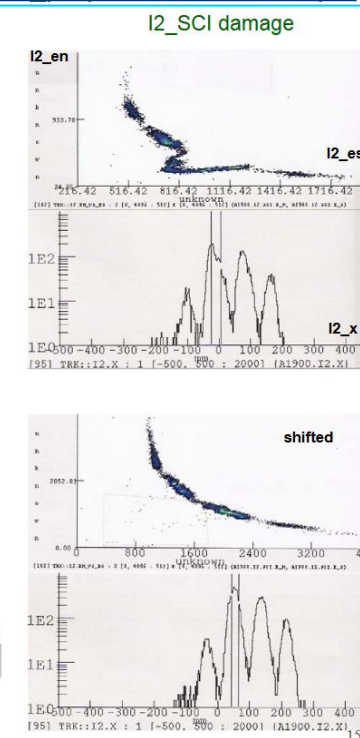
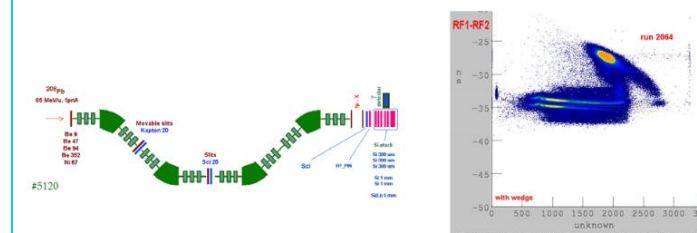


New ORTEC SBD detectors* (D~20mm) have been substituted during the experiment for PIN diodes 500 um (50x50mm),

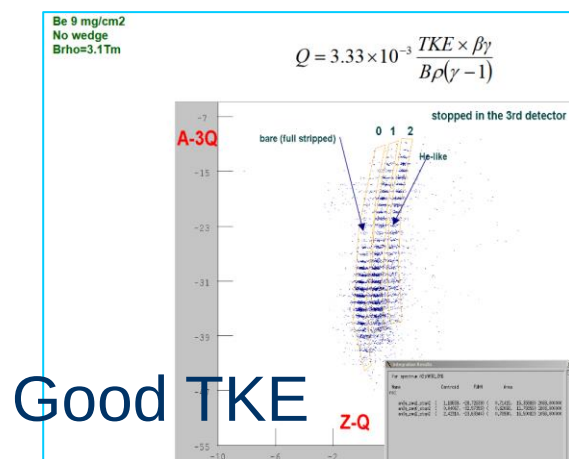
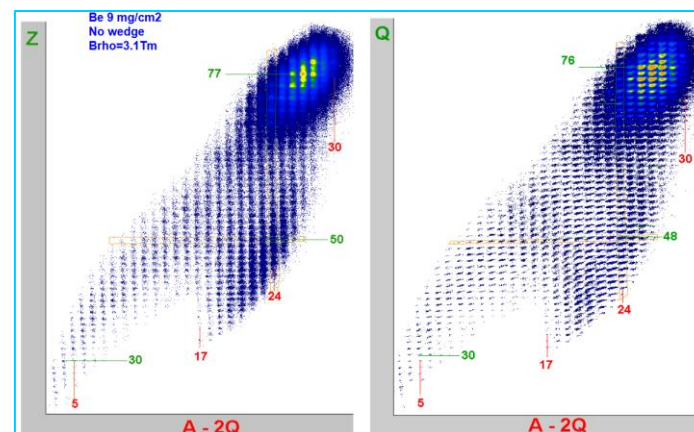
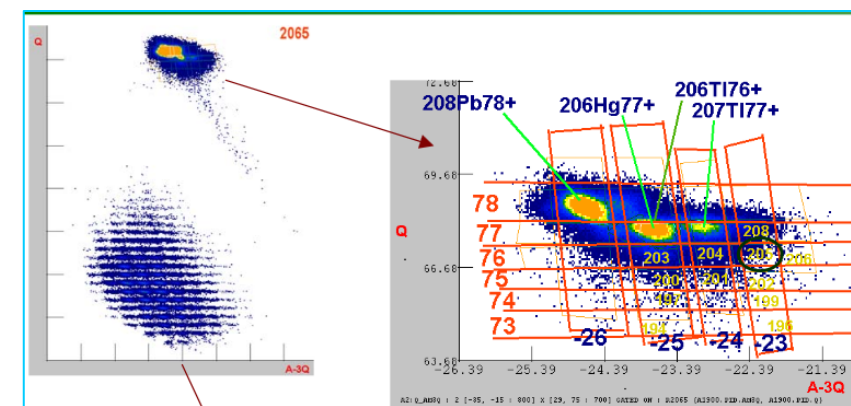
* - though measured own resolution before and after the experiment for α -particles was about 20-22 KeV

- No explanation. Double peak structure. Position dependence. Channeling?
- Similar effect has been observed at the GANIL experiment with the U-beam
- It is necessary to test them with other beams (Kr,Xe)

- I2-Sci X-position problem during the experiment ☹
- No Kapton in I1 (no reference lines, difficult analysis : set of charge states, different velocities) ☹
- I2-wedge 26 mg/cm² (Sci) is too thick for heavy ions Z~70-80 ☹
- TOF I2&FP resolution is not good enough (short path) ☹
- TOF RF-Pin - unstable ☹
- It is possible to work at dp/p = 0.5% with Ni-target (67mg/cm²) between beam charge states ☺



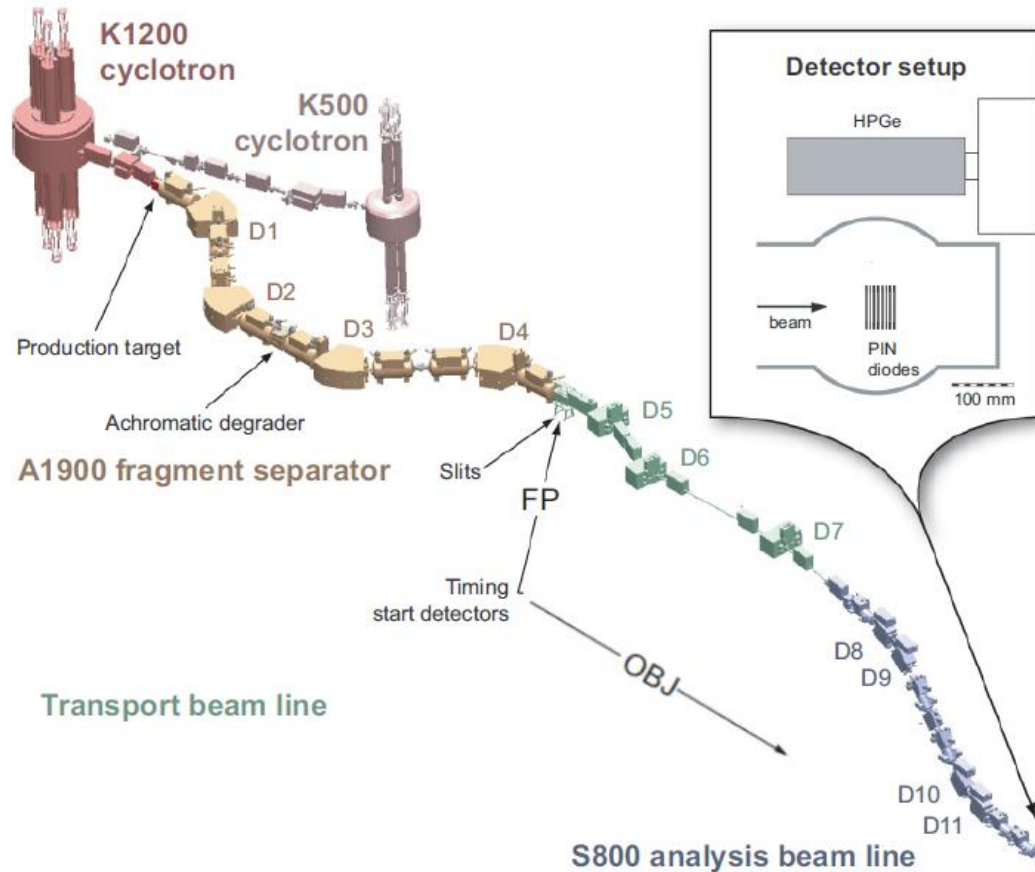
02/12/09, Research Discussion



No wedge, small dp/p, RFstop

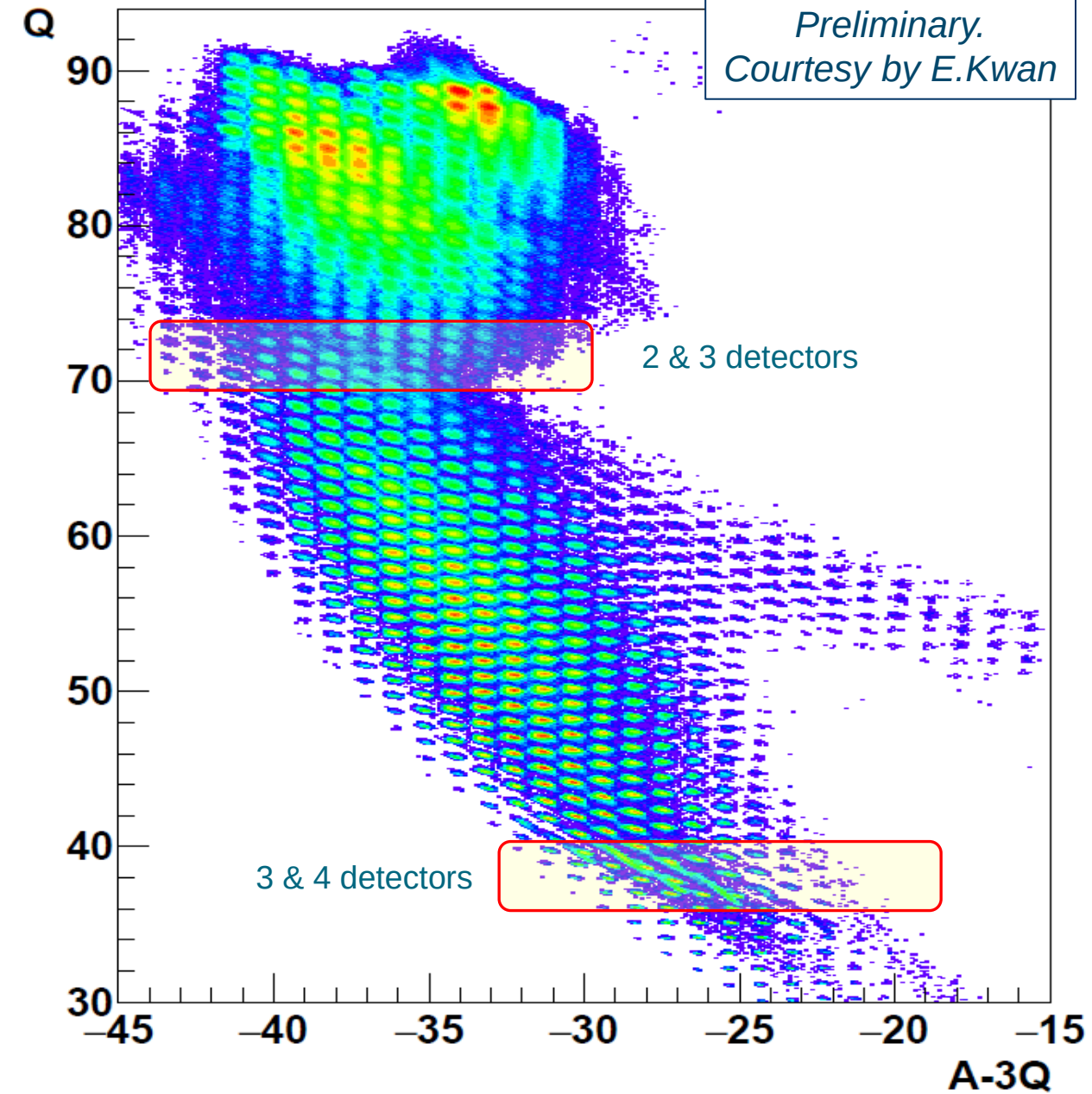
With I2-Sci as wedge, short length

2016: E.Kwan – spokesperson

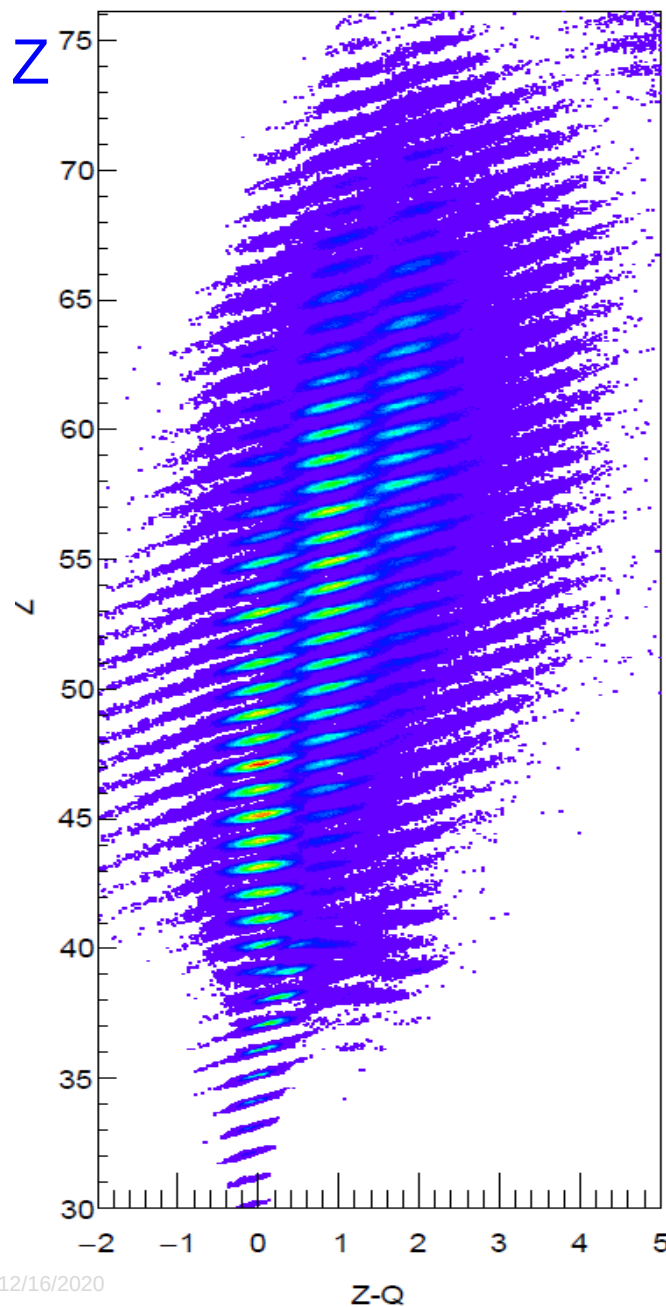
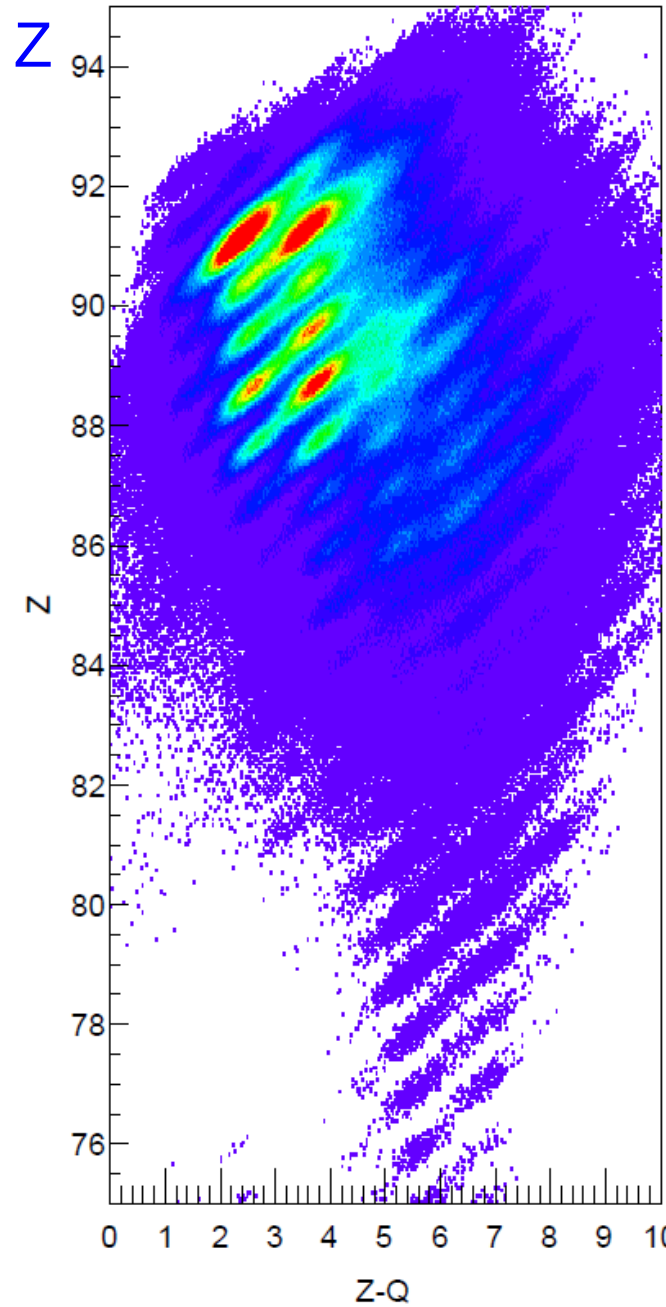
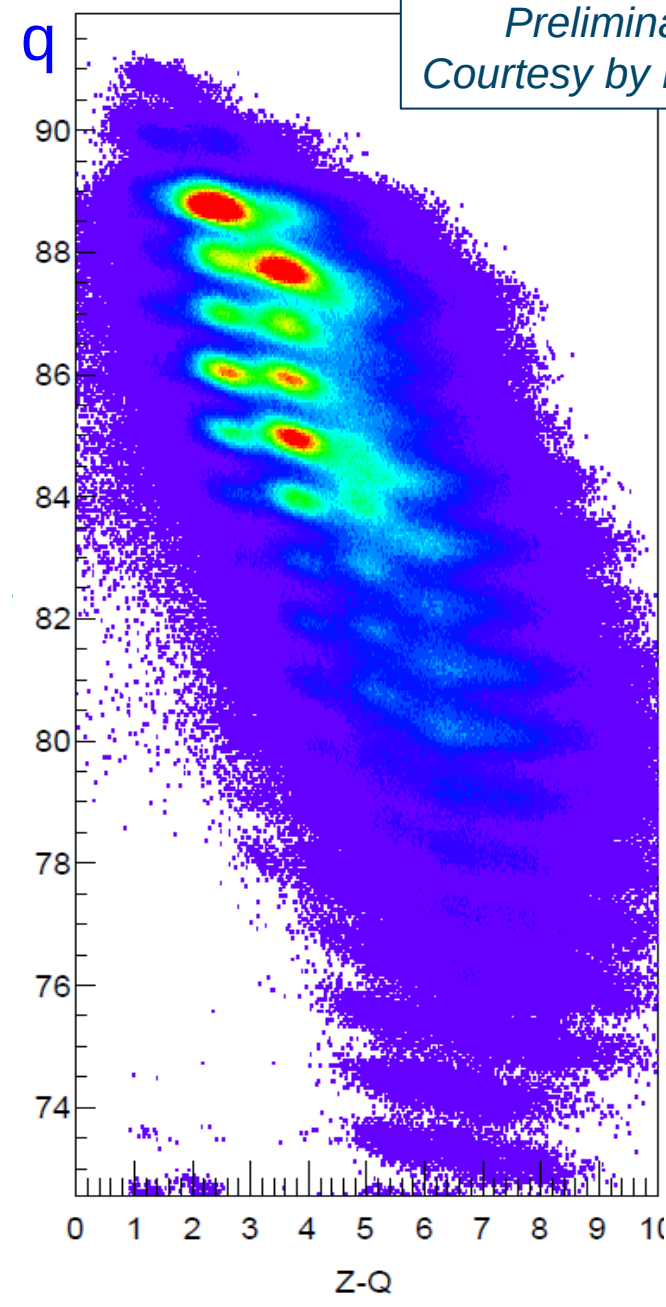


- Small Momentum acceptance
- Non-cooled PIN-diodes (50x50 mm² 0.5mm)

B_p measurement is still a huge issue:
Location, detectors, charge states



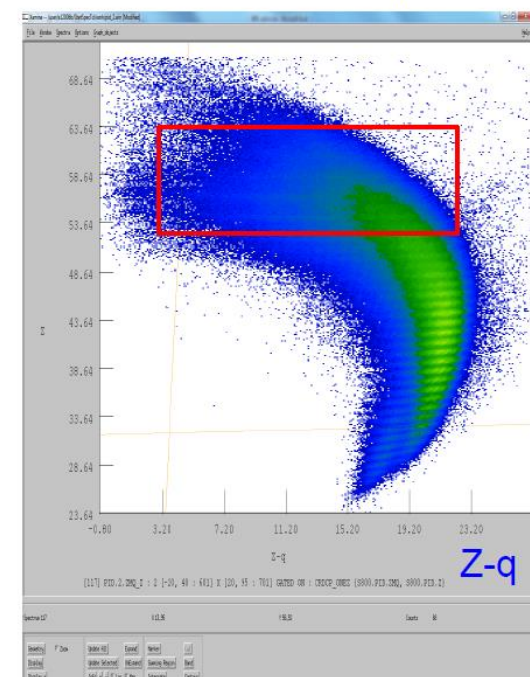
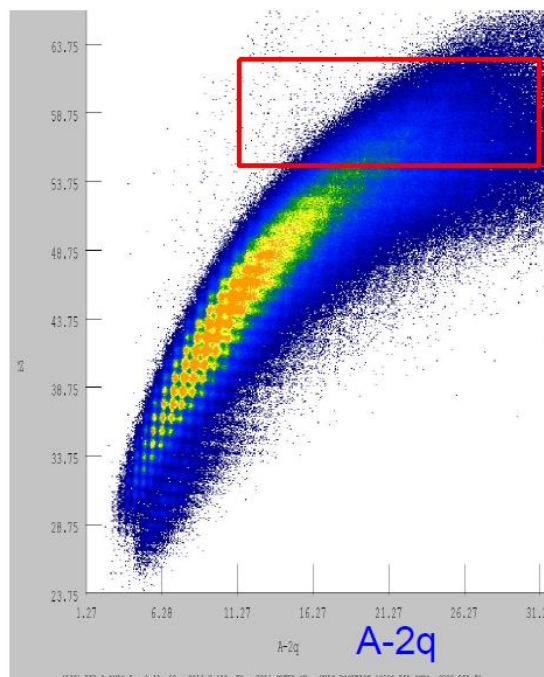
*Preliminary.
Courtesy by E.Kwan*



M.Bowry, J.Berryman, A.Gade et al.

e12006 - Z resolution

Z resolution up to 60 can be reached



Diamond target – T signal
No TKE for fission fragments,
Short length
dE with IC, moderate

No q, poor A/q

Ion	
A = 86	
Z = 36	
q = 36	
M_isotope = 85.91061	
M_ion = 85.89086	
M_ion/q = 2.385857	

Resolution	
sigma	
TOF = 0.175	ns
Eloss = 0.25	%
TKE = 0.30	%
Z =	
Momentum (Brho) = 0.0261	%

Measured values	
TOF = 117.8505	ns
Brho = 3.3365	T*m
E1_loss = 1833.34	MeV
TKE = 7730.18	MeV

Deduced values	
beta = 0.410426	
gamma = 1.096619	
velocity = 12.3037	cm/ns
A / q = 2.385857	

PID values	
Z = 36	
q = 36.000	
A (from TKE) = 85.8908	
A (from [A/q]*q_integer) = 85.8909	
A (from [A/q]*q_measur) = 85.8908	
A-2q = 13.89	
A-3q = -22.11	
A-2Z = 13.89	

Set-up	
Energy = 90.00	MeV/u
Flight Length = 14.500	m
1st(Z) detector material = 6	
1st(Z) detector thickness = 190	mg/cm2
	843.320 um

systematical (calibration)	
0.07	%
0.30	% (straggling)
0.20	%
0.2	%
0.01	%

error (σ)	%
0.193	0.164
0.001	0.028
7.09	0.387
27.87	0.361

error (σ)	%
0.00067	0.164
0.00067	0.164
0.02020	0.164
0.00541	0.227

error (σ)	%
0.112	0.31
0.213	0.59
0.671	0.78
0.195	0.23
0.544	0.63
0.263	
0.123	
0.200	

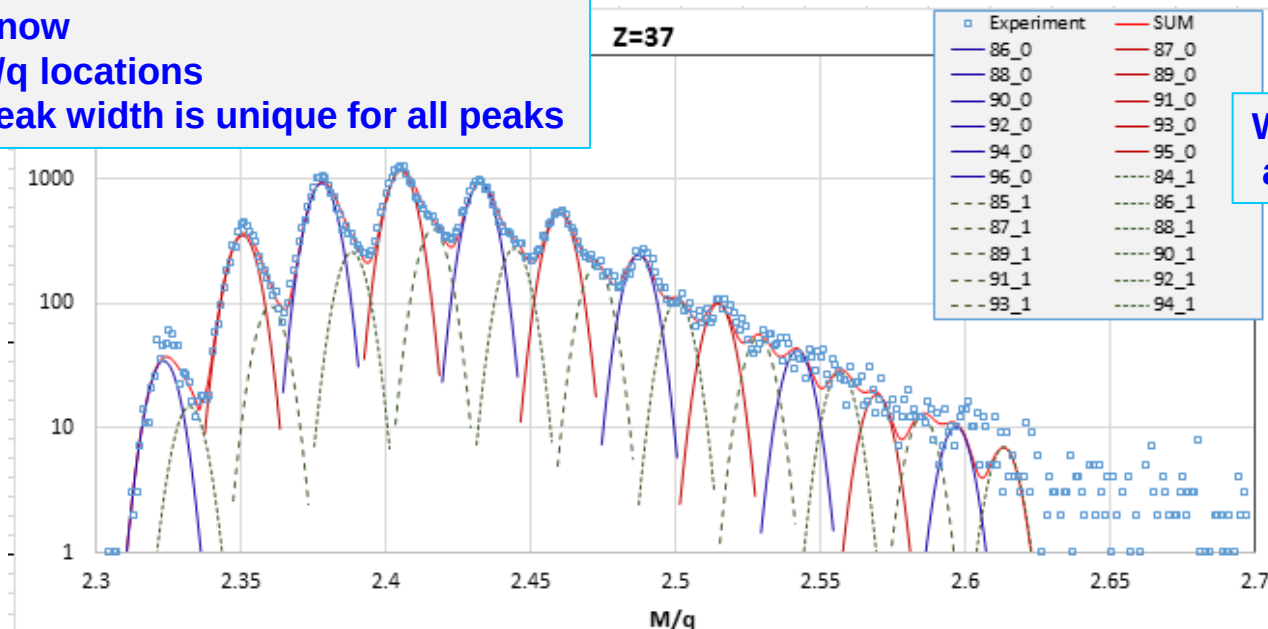
Momentum Resolution	
X-image at target = 1.5	mm
X-magnification @ disp.plane = 1.7	
X-dispersion = 97.0	mm/%
Detector resolution = 0.2	mm
Momentum Resolution = 0.0261	%

contribution in error						
Brho	Beta	TKE	E1_loss	Zsyst	A/q	Z
0.028%	0.225%					
	0.140%		0.19%	0.20%		
0.028%	0.468%	0.361%				
	0.693%	0.361%				
0.028%	0.225%	0.592%				0.227%
0.02	0.26	0.05				
0.03	0.09	0.08				
					0.19	0.04

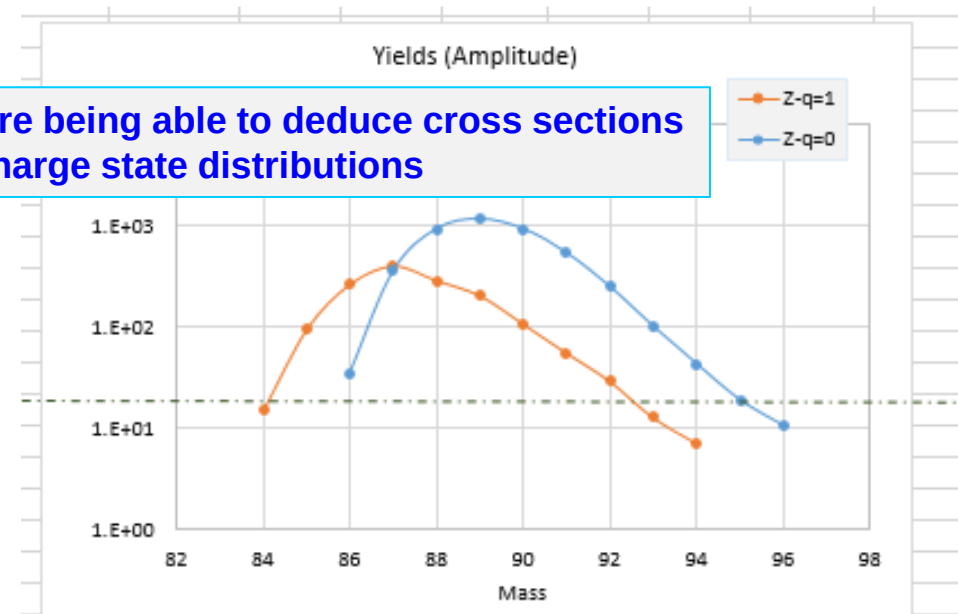
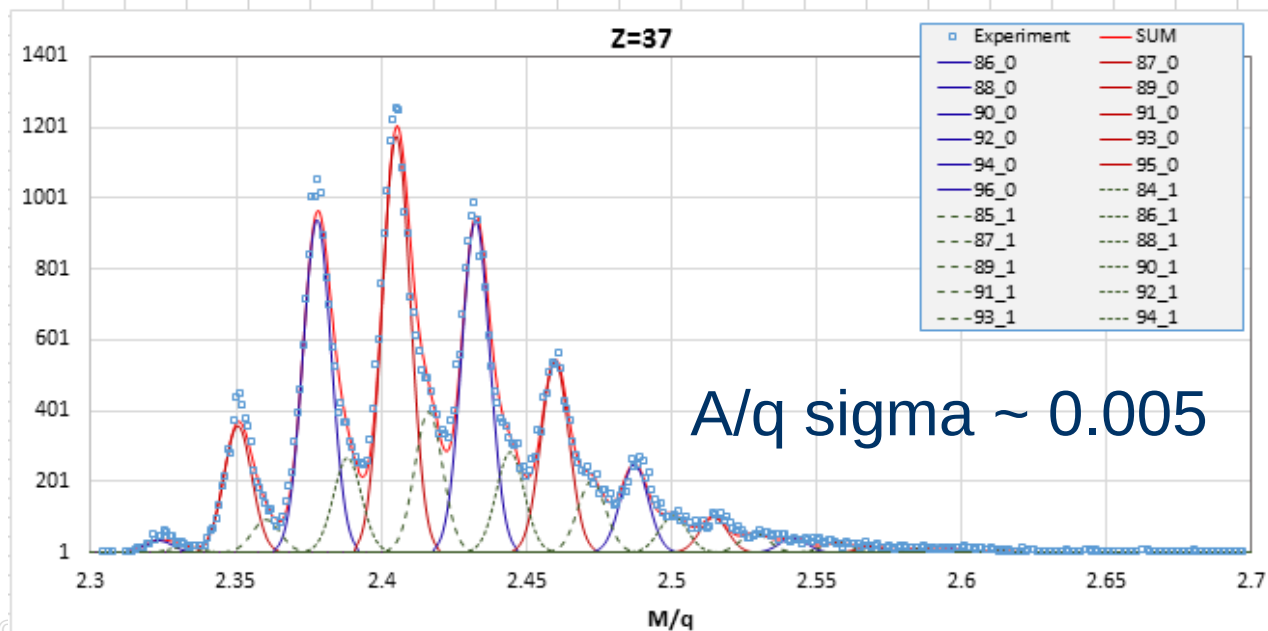
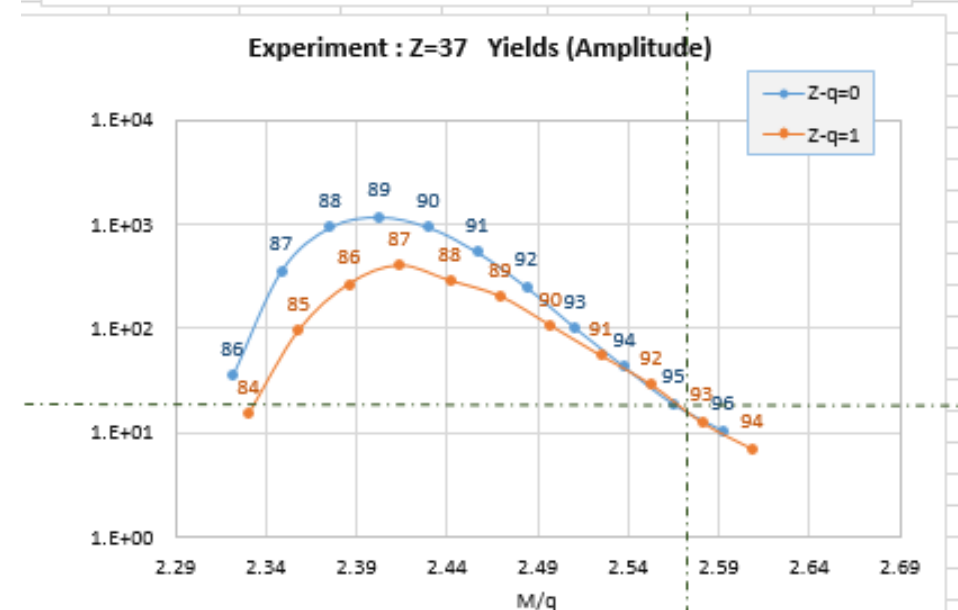
To reproduce results I used $\text{sig}(\text{ToF}) = 175$ ps, that according to A.S. is reasonable in the case of ToF configuration of e12006 experiment due to mostly Sci-scintillator resolution.

We know

- A/q locations
- Peak width is unique for all peaks



We were being able to deduce cross sections and charge state distributions



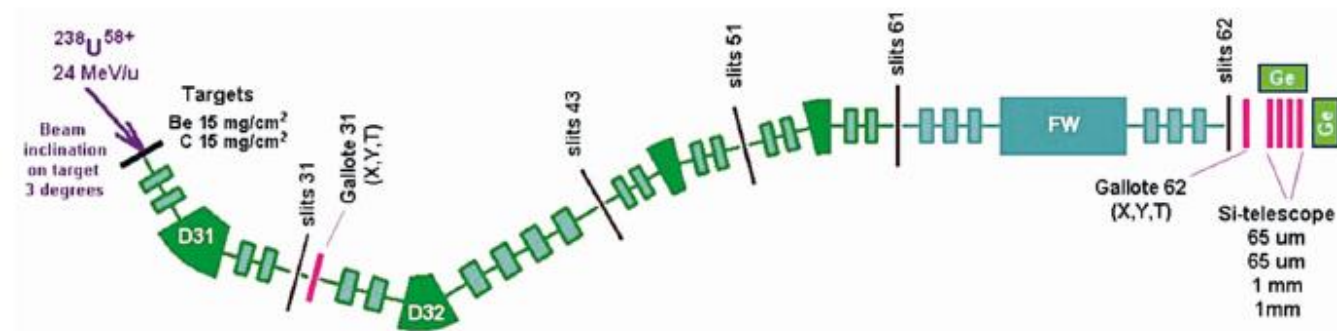
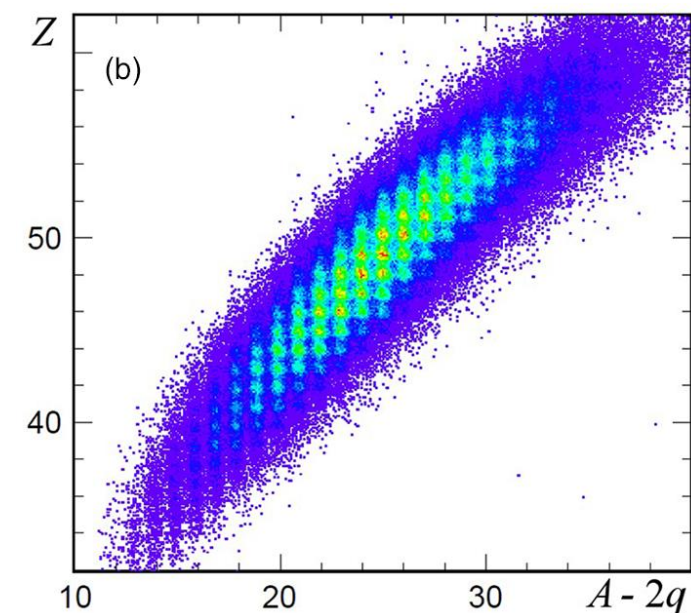
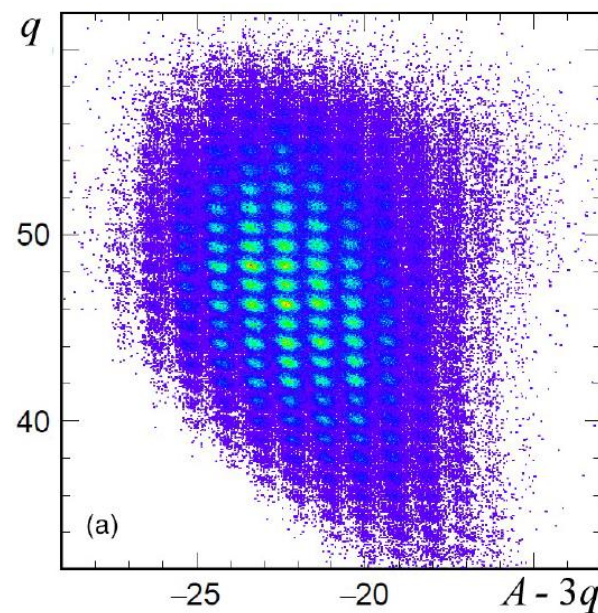
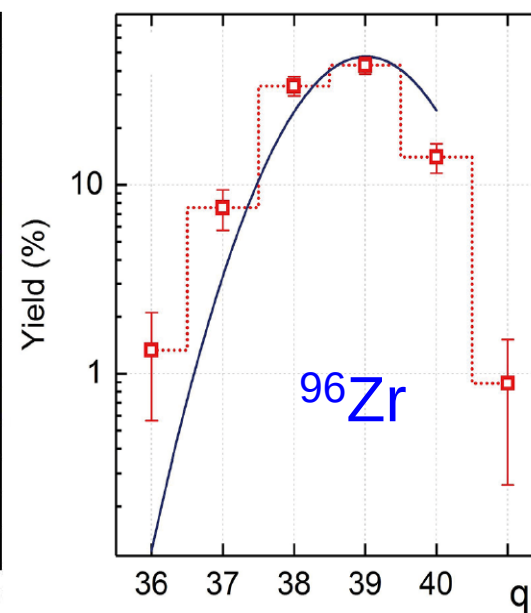
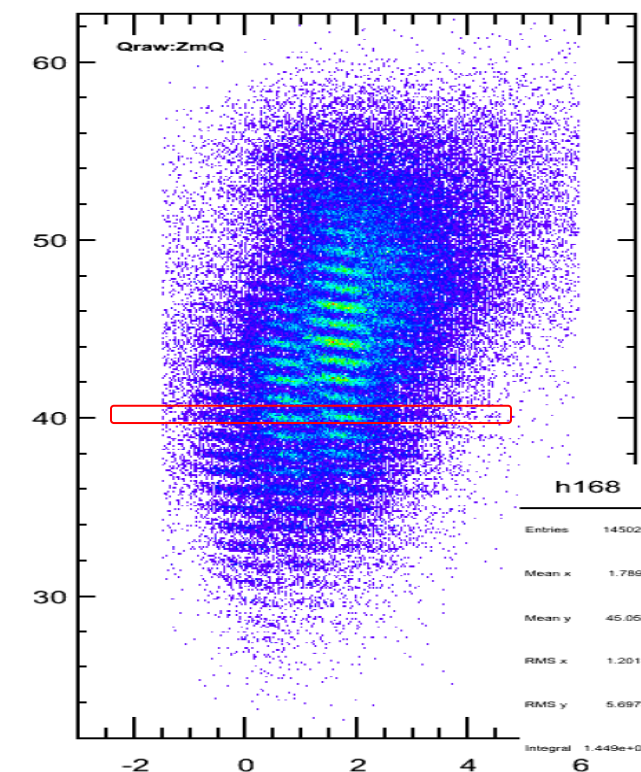
Will be finally published in 2021? ☺

Eur. Phys. J. A (2018) **54**: 66

Fission fragment yields from heavy-ion-induced reactions measured with a fragment separator

O.B. Tarasov^{1,a,b}, O. Delaune^{2,c}, F. Farget², D.J. Morrissey^{1,3}, A.M. Amthor⁴, B. Bastin², D. Bazin¹, B. Blank⁵, L. Cacères², A. Chbihi², B. Fernández-Domínguez⁶, S. Grévy⁵, O. Kamalou², S.M. Lukyanov⁷, W. Mittig^{1,8}, J. Pereira¹, L. Perrot⁹, M.-G. Saint-Laurent², H. Savajols², B.M. Sherrill^{1,8}, C. Stodel², J.C. Thomas², and A.C. Villari¹⁰

- Beam was inclined 3 deg. on target
- ToF: Good
- TKE: Good
- Bp: moderate [dispersion 19 mm/%, FP-X corrections]
- dE : moderate [thin dE detectors, middle Z]



^{198}Pt experiment : fragment-separator & spectrometer

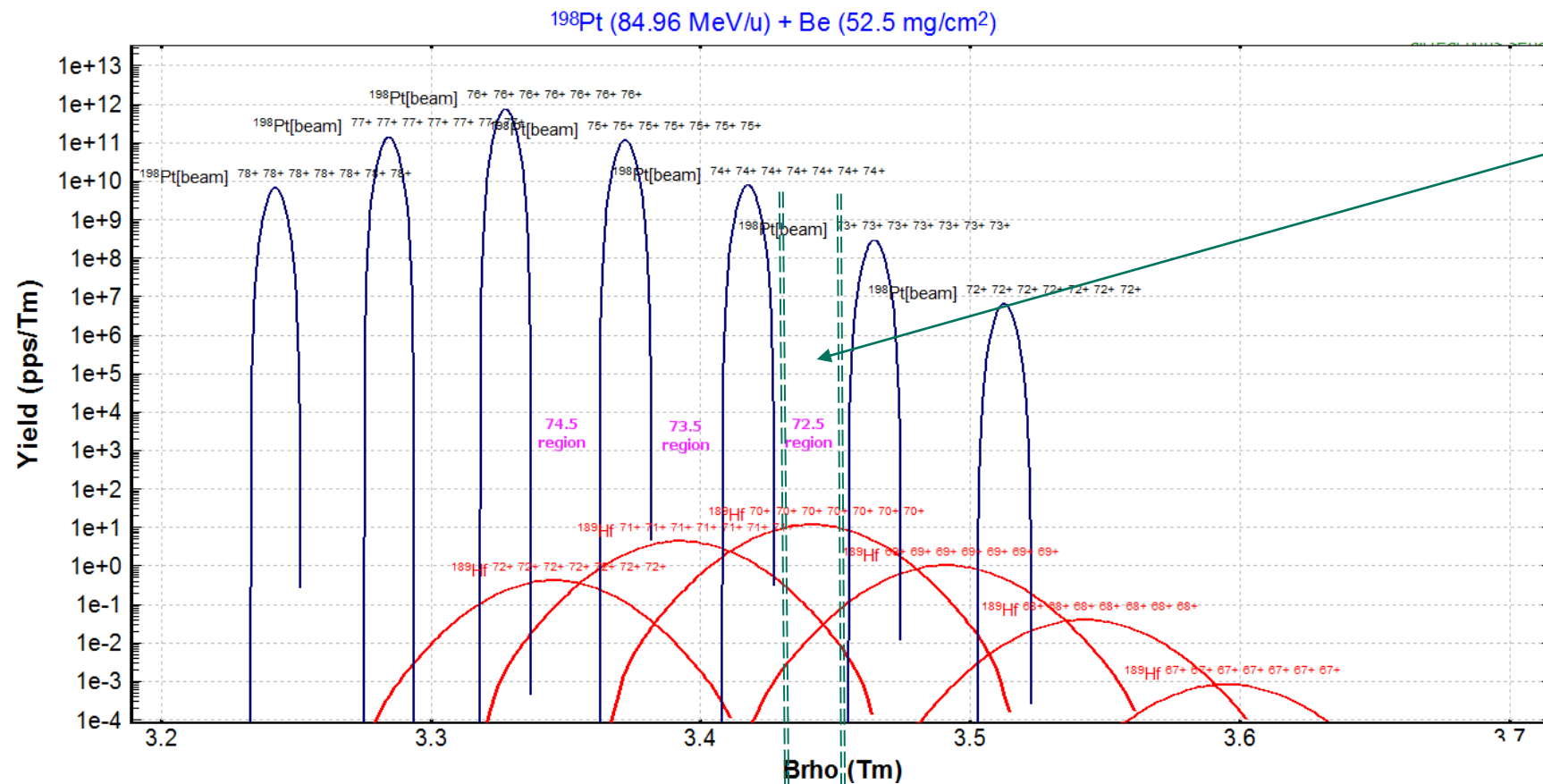
NSCL E15130

“Search for isotopes and isomers in the Hf region”

PIs:

- Partha Chowdhury (UML)
- Oleg Tarasov (MSU)
- Andrew Rogers (UML)

- Working between primary beam charge states
- Try to avoid in-flight detectors (charge state production)
- **No in-flight detectors in Dispersive plane (“wedge” property)**
- “Separator + Long Spectrometer” method

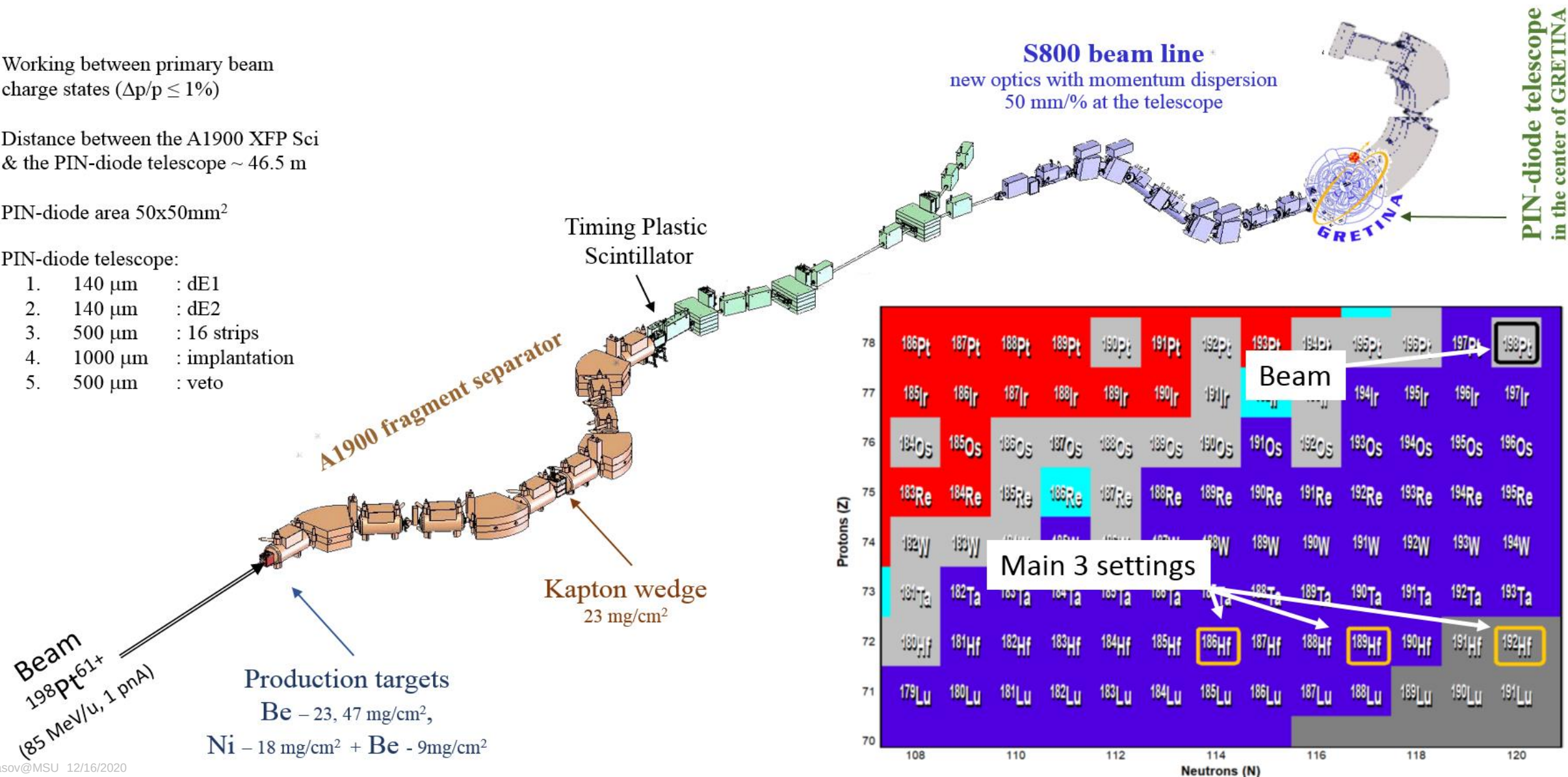


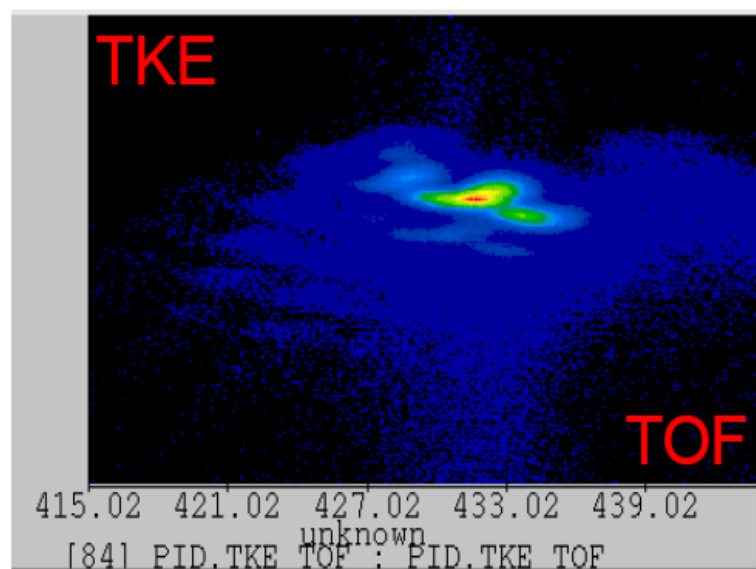
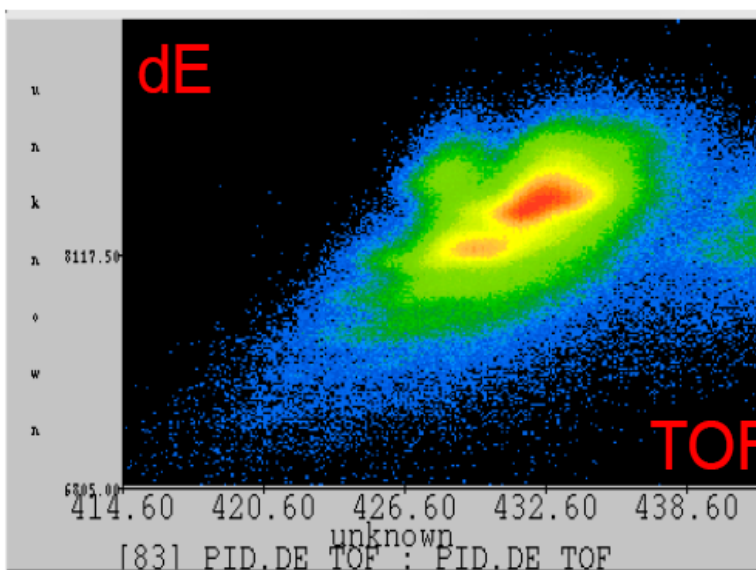
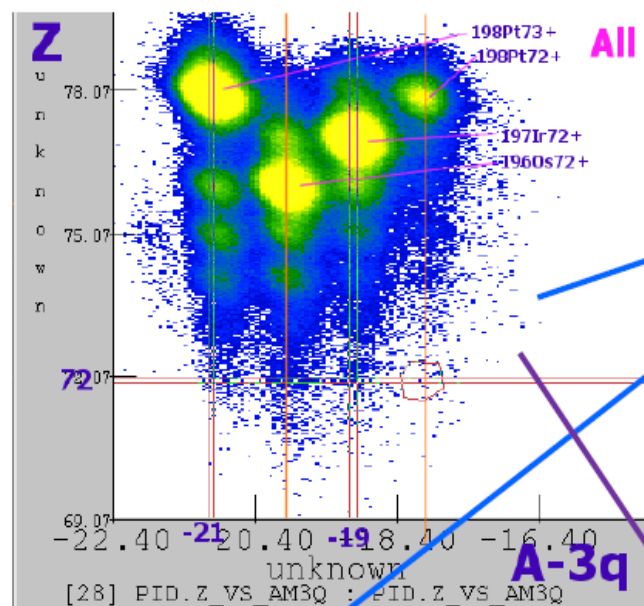
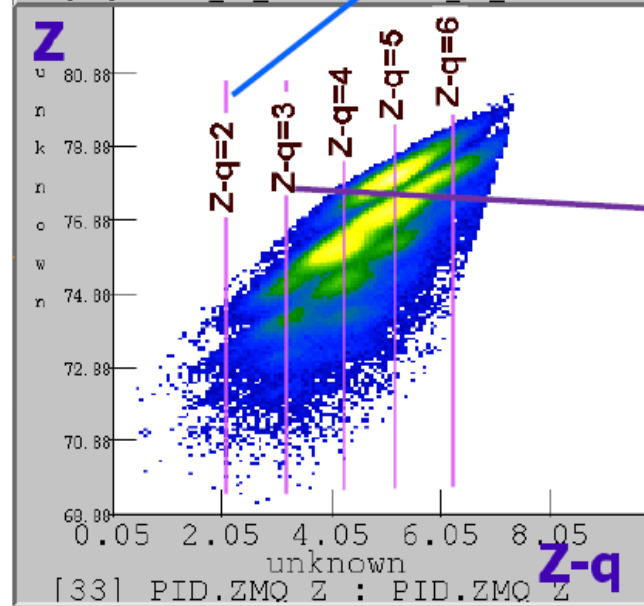
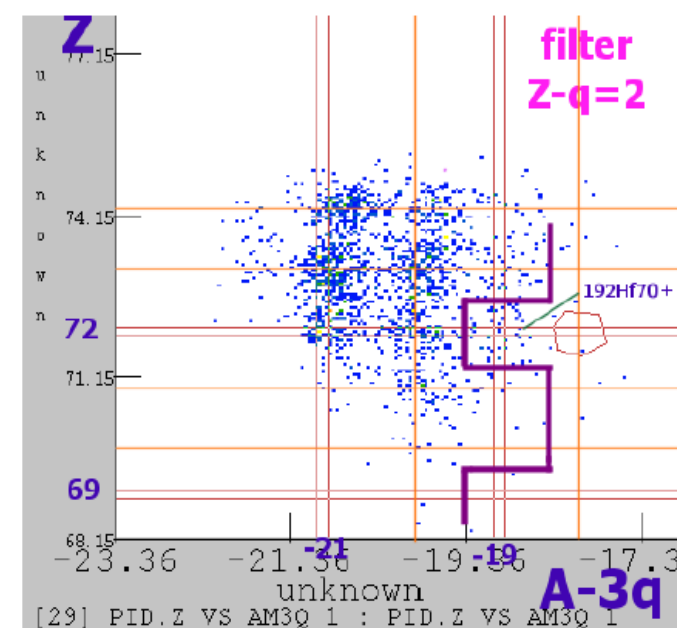
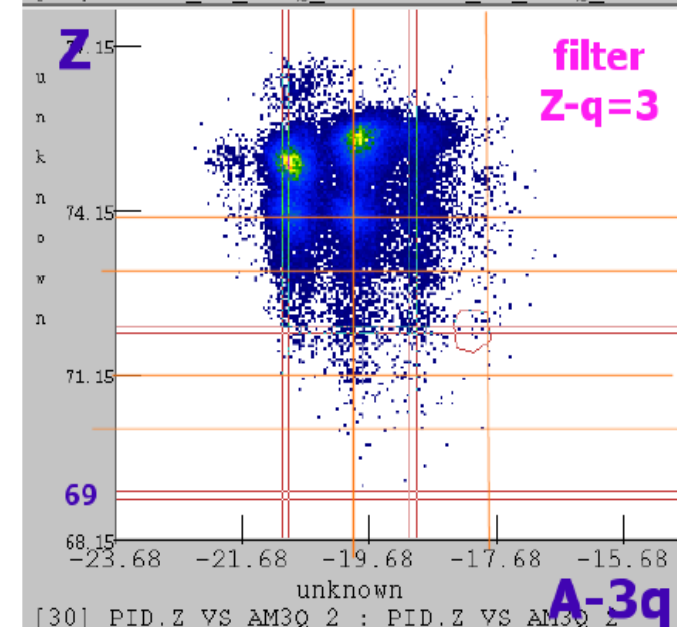
Working region
dP/P ~ 0.8-1.0%

07 / 2019

"Search for isotopes and isomers in the Hf region"

- Working between primary beam charge states ($\Delta p/p \leq 1\%$)
- Distance between the A1900 XFP Sci & the PIN-diode telescope ~ 46.5 m
- PIN-diode area $50 \times 50 \text{ mm}^2$
- PIN-diode telescope:
 - 140 μm : dE1
 - 140 μm : dE2
 - 500 μm : 16 strips
 - 1000 μm : implantation
 - 500 μm : veto



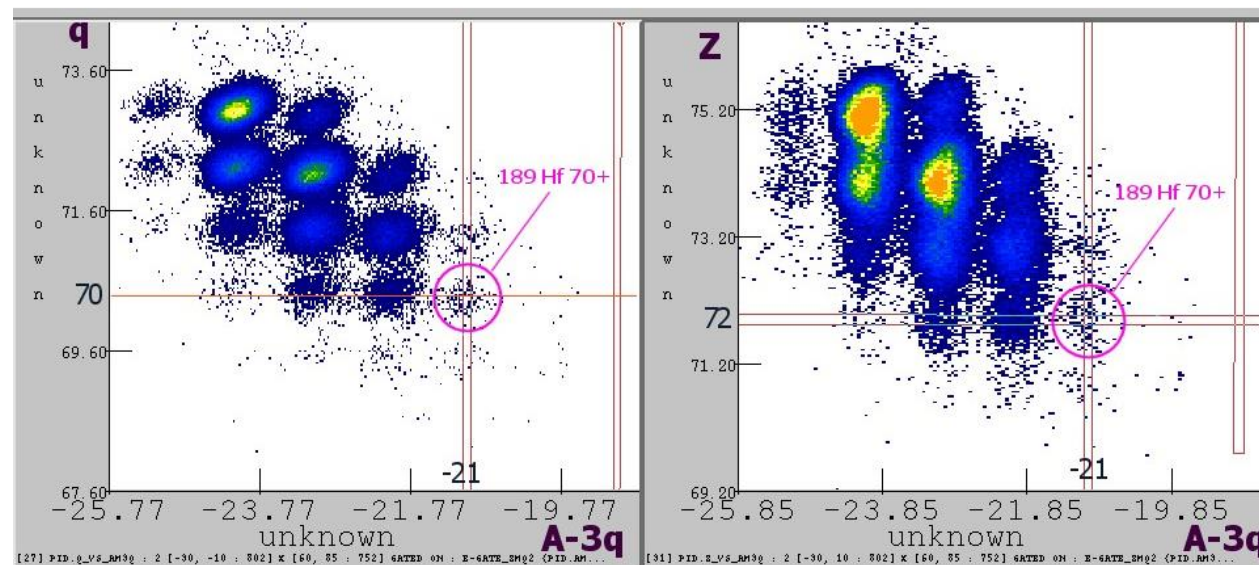


It is possible to suggest about ten isotopes from dE-ToF-TKE plots. No.. More than hundred (5*6*4)!

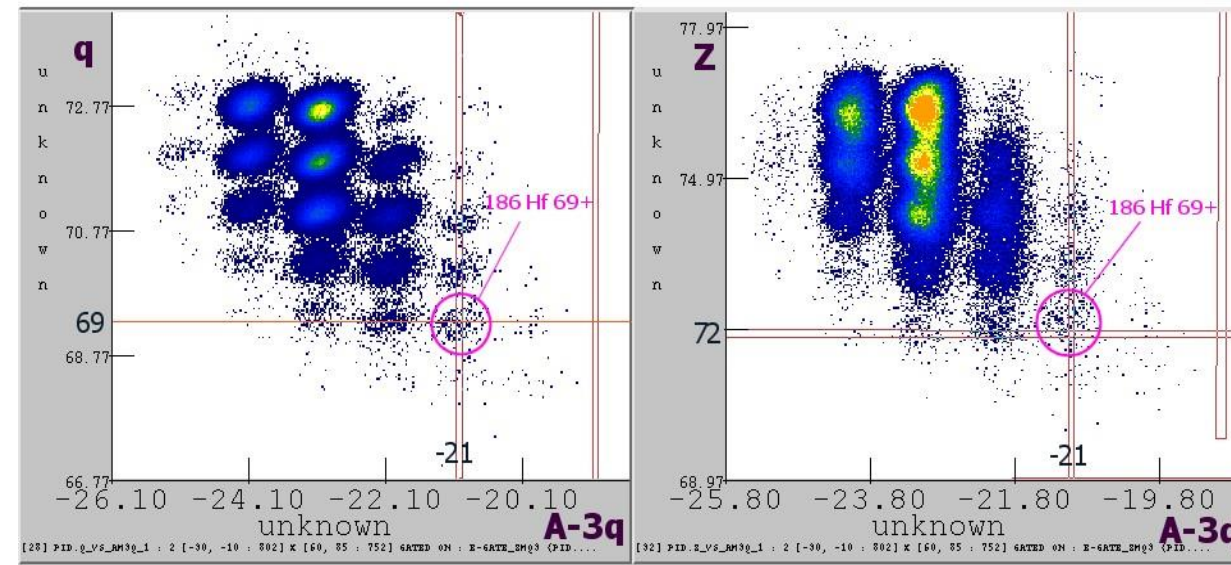
Experiment #e15130; July 2019 @ NSCL/MSU

^{198}Pt (85 MeV/u) + Be (47 mg/cm²) -> Wedge -> $^{189}\text{Hf}^{70+}$

selection Z-q=2



selection Z-q=3



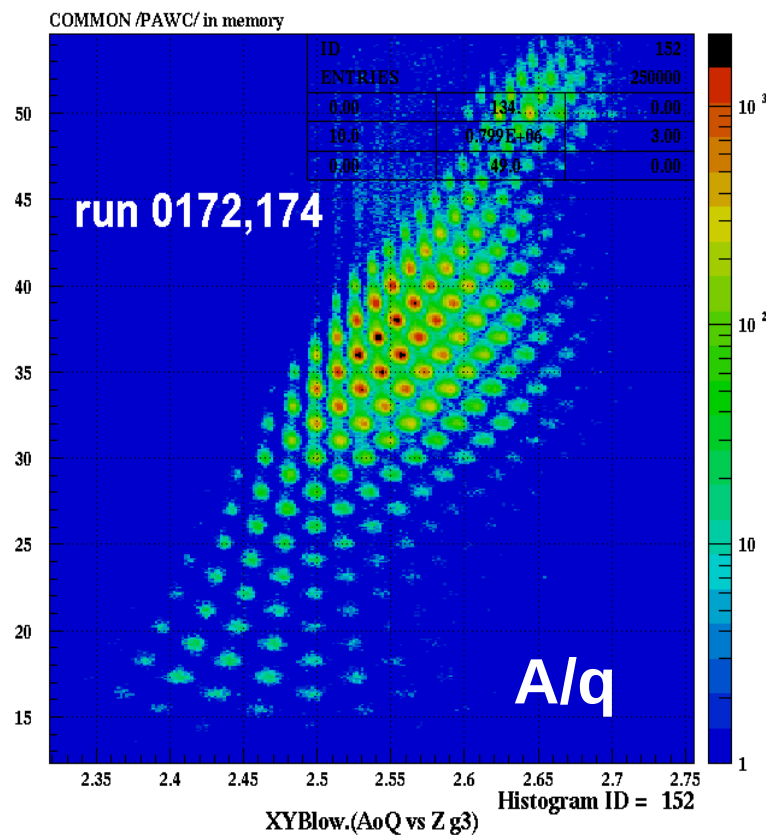
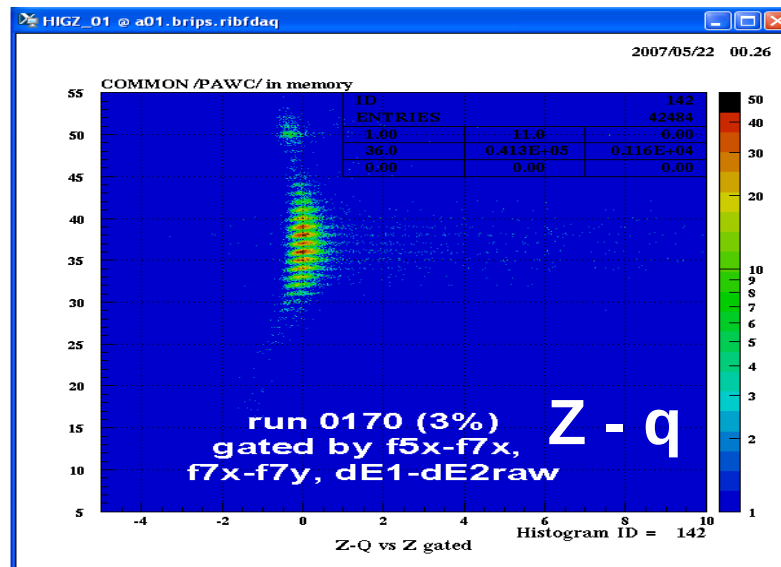
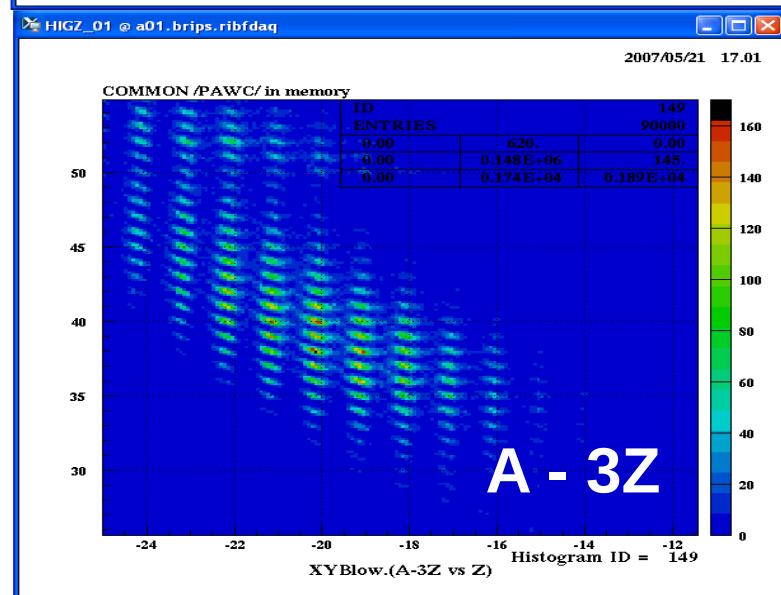
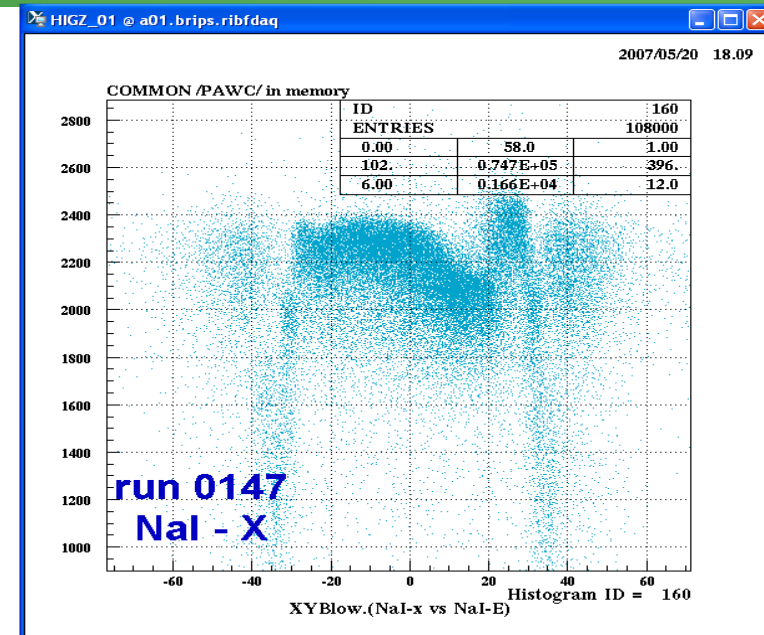
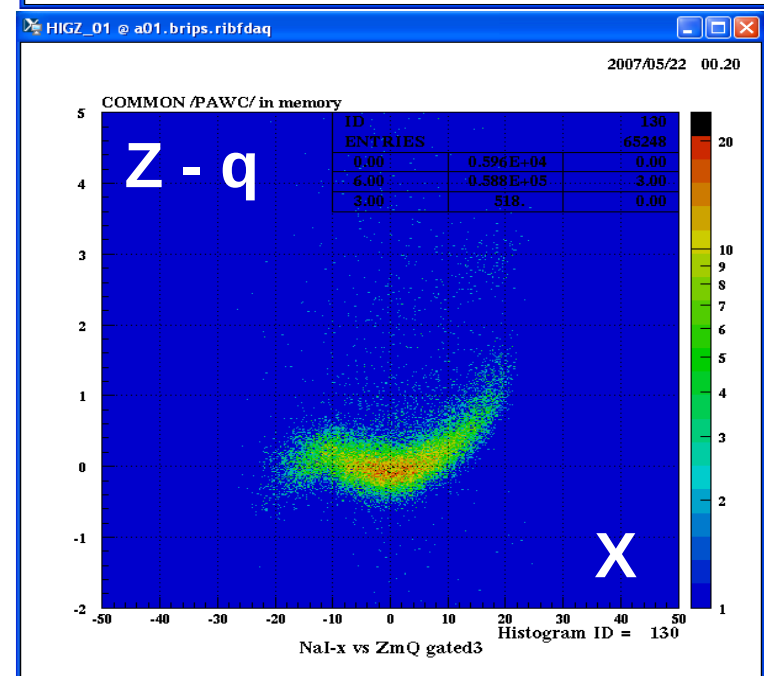
- ToF: Excellent
- TKE: Good
- B_p: moderate [strip detector (3 mm), dispersion 50 mm/%]
- dE : moderate [thin dE detectors, high Z]

- q: good
- A: good
- Z: moderate - poor

RIKEN

1. We brought the PID subroutines to implement into BigRIPS acquisition software
2. Si-detectors for dE and NaI for TKE
3. Good PID at first, then NaI detector has been destroyed (not due to high rate)

2007/05/22 16.41



1. Mostly performing PID with Z vs. A/q plots without TKE measurements
2. Attempts with TKE-PID in 2010-2011 failed
3. 2017 : using TKE for PID

B_p: outstanding TKE: good
β: excellent dE: moderate

- Advanced detector development
- Optics & detectors :
 - B_p & trajectory reconstruction
- A/q-value : separator record
- New PID techniques:
 - Identification Z based on E-loss in wedge
 - Using “range” technique for PID

Thursday 17 December 2020

6.00 am – 6.45 am: Fukuda Naoki

Particle identification at BigRIPS Separator

Nuclear Instruments and Methods in Physics Research B 317 (2013) 323–332

Identification and separation of radioactive isotope beams by the BigRIPS separator at the RIKEN RI Beam Factory

N. Fukuda*, T. Kubo, T. Ohnishi, N. Inabe, H. Takeda, D. Kameda, H. Suzuki

PHYSICAL REVIEW C 96, 034604 (2017)

Discovery of new isotopes ^{81,82}Mo and ^{85,86}Ru and a determination of the particle instability of ¹⁰³Sb

H. Suzuki,^{1,*} T. Kubo,¹ N. Fukuda,¹ N. Inabe,¹ D. Kameda,¹ H. Takeda,¹ K. Yoshida,¹ K. Kusaka,¹ Y. Yanagisawa,¹ M. Ohtake,¹ H. Sato,¹ Y. Shimizu,¹ H. Baba,¹ M. Kurokawa,¹ K. Tanaka,¹ O. B. Tarasov,² D. Bazin,² D. J. Morrissey,² B. M. Sherrill,² K. Ieki,³ D. Murai,³ N. Iwasa,⁴ A. Chiba,⁴ Y. Ohkoda,⁴ E. Ideguchi,⁵ S. Go,⁵ R. Yokoyama,⁵ T. Fujii,⁵ D. Nishimura,⁶ H. Nishibata,⁷ S. Momota,⁸ M. Lewitowicz,⁹ G. DeFrance,⁹ I. Celikovic,⁹ and K. Steiger¹⁰

DISCOVERY OF NEW ISOTOPES ^{81,82}Mo AND ...

PHYSICAL REVIEW C 96, 034604 (2017)

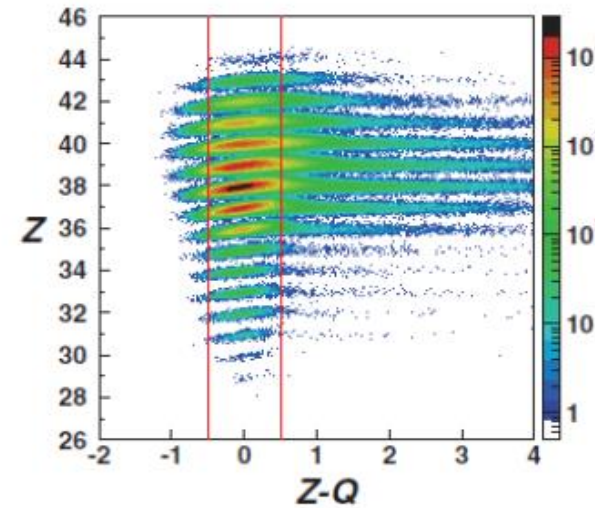
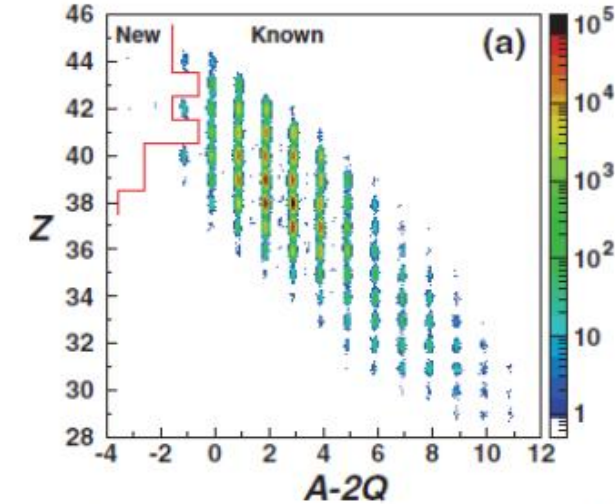
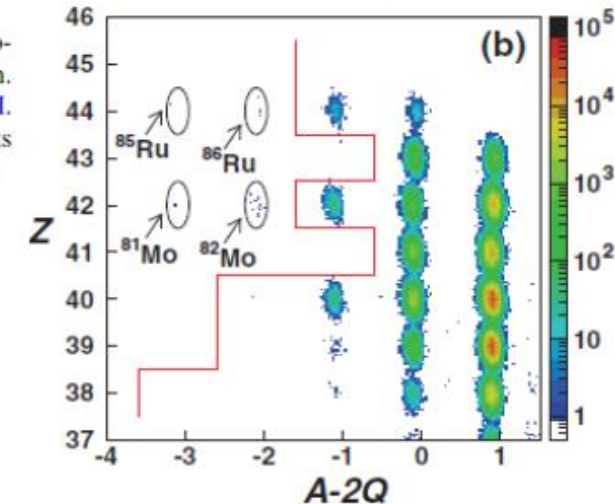


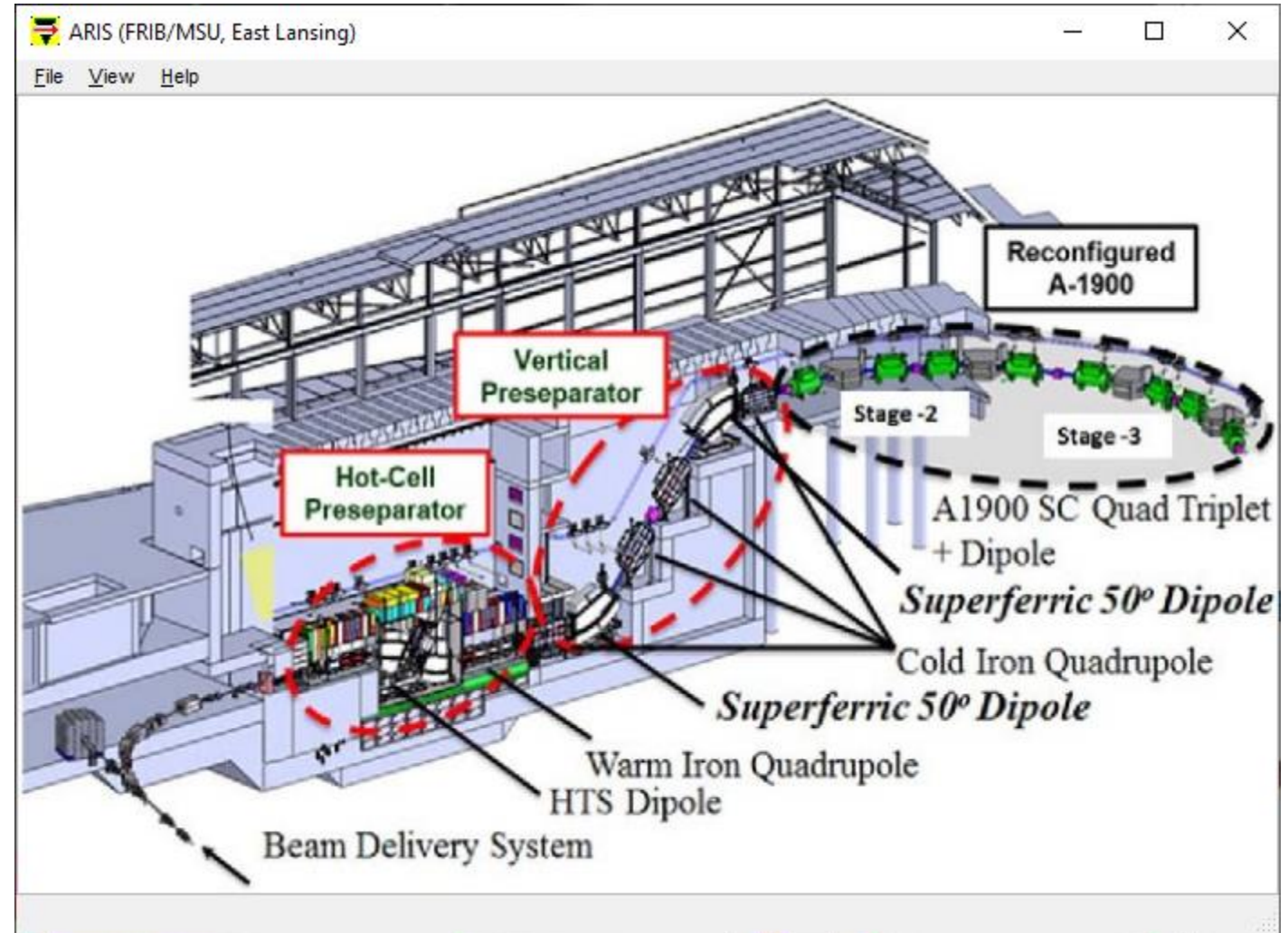
FIG. 3. The Z versus $Z - Q$ plot for projectile fragments produced in the reaction of $^{124}\text{Xe} + \text{Be}$ (4.03 mm) at 345 MeV/nucleon. The experimental conditions are given as the ^{85}Ru setting in Table I. The red solid lines indicate the gate used to select fully stripped events of which the gate width is taken to be $|Z - Q| \leq 0.5$. See the text.



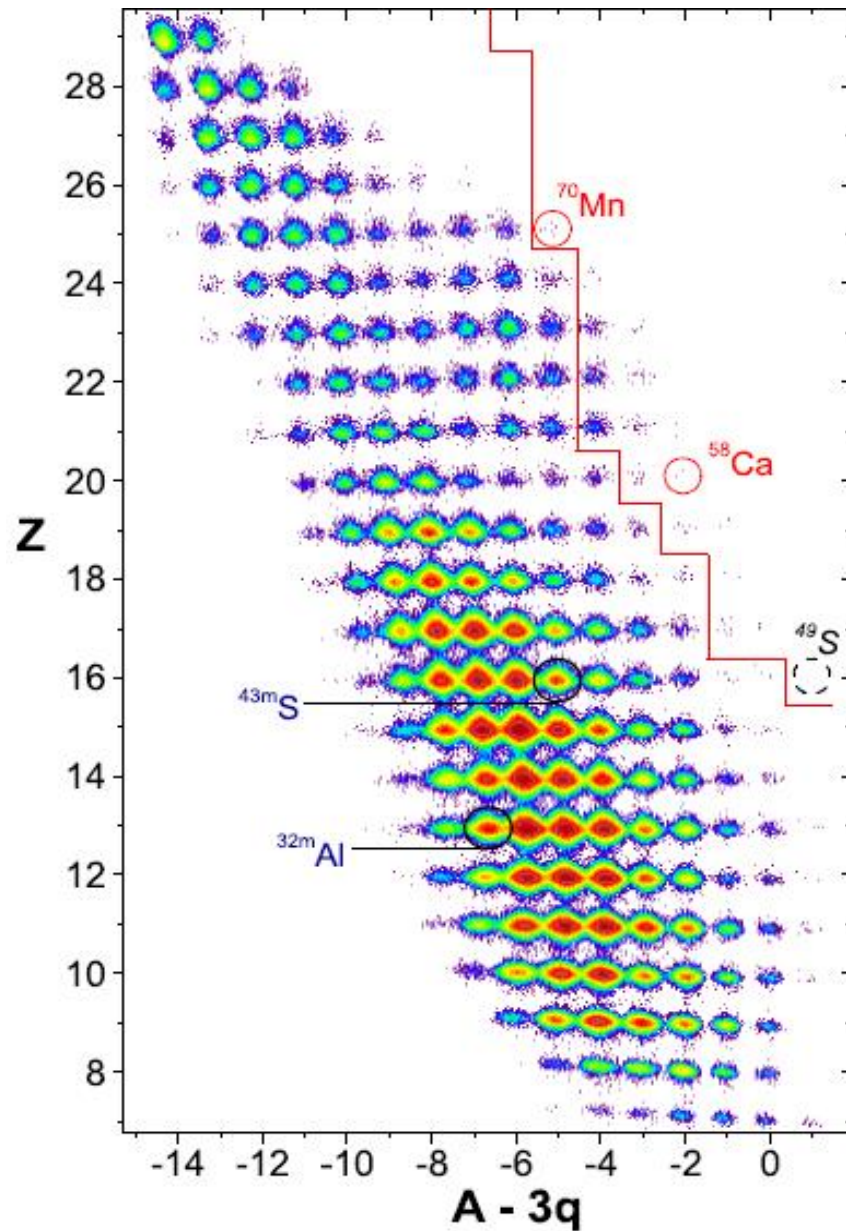
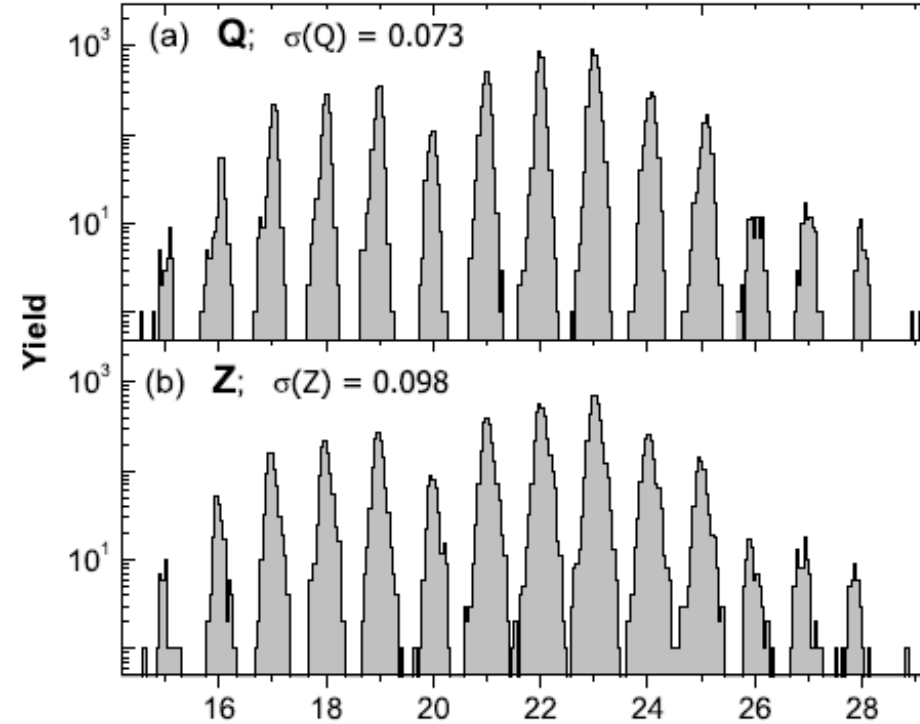
Wednesday 16 December 2020

10:10 am –10:55 am: Marc Hausmann

FRIB Fragment Separator Overview and
Opportunities for Advanced Detector Systems



“Stopped” beam experiments:
filtering with TKE

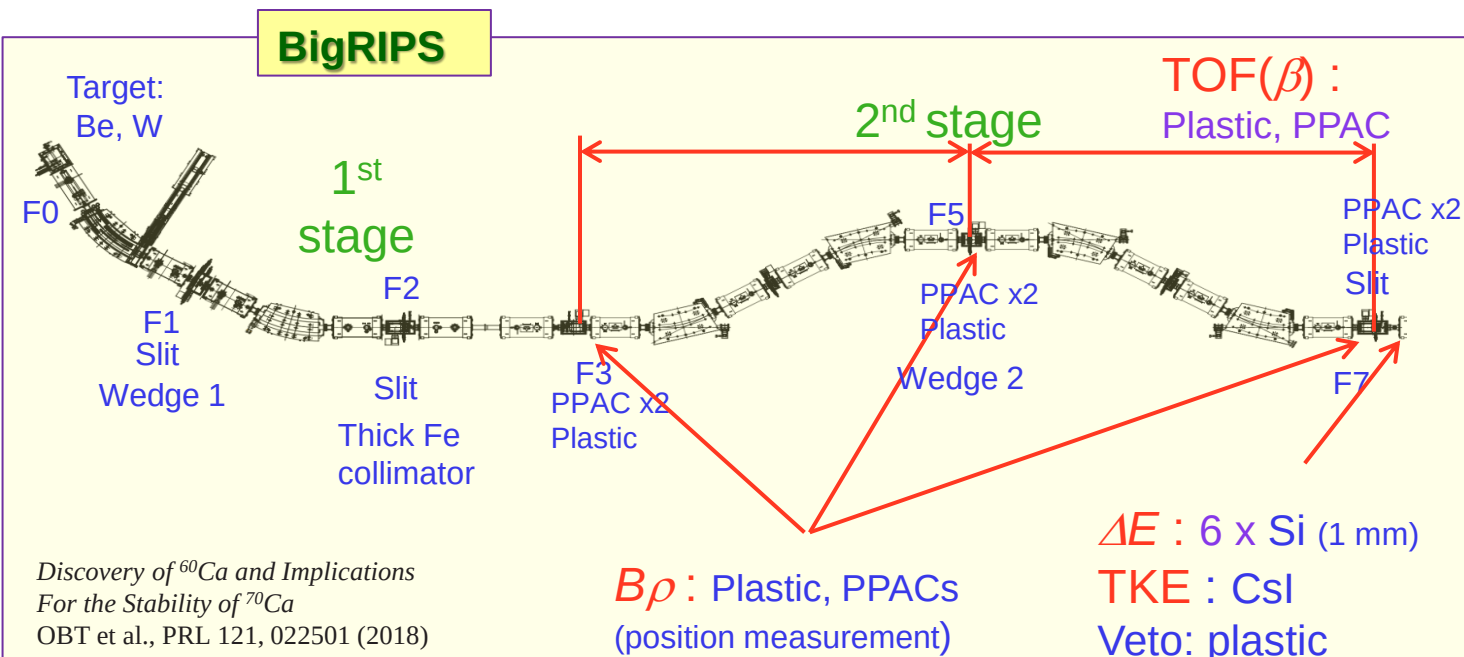


For all particles stopped in the Si-telescope in the production runs

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

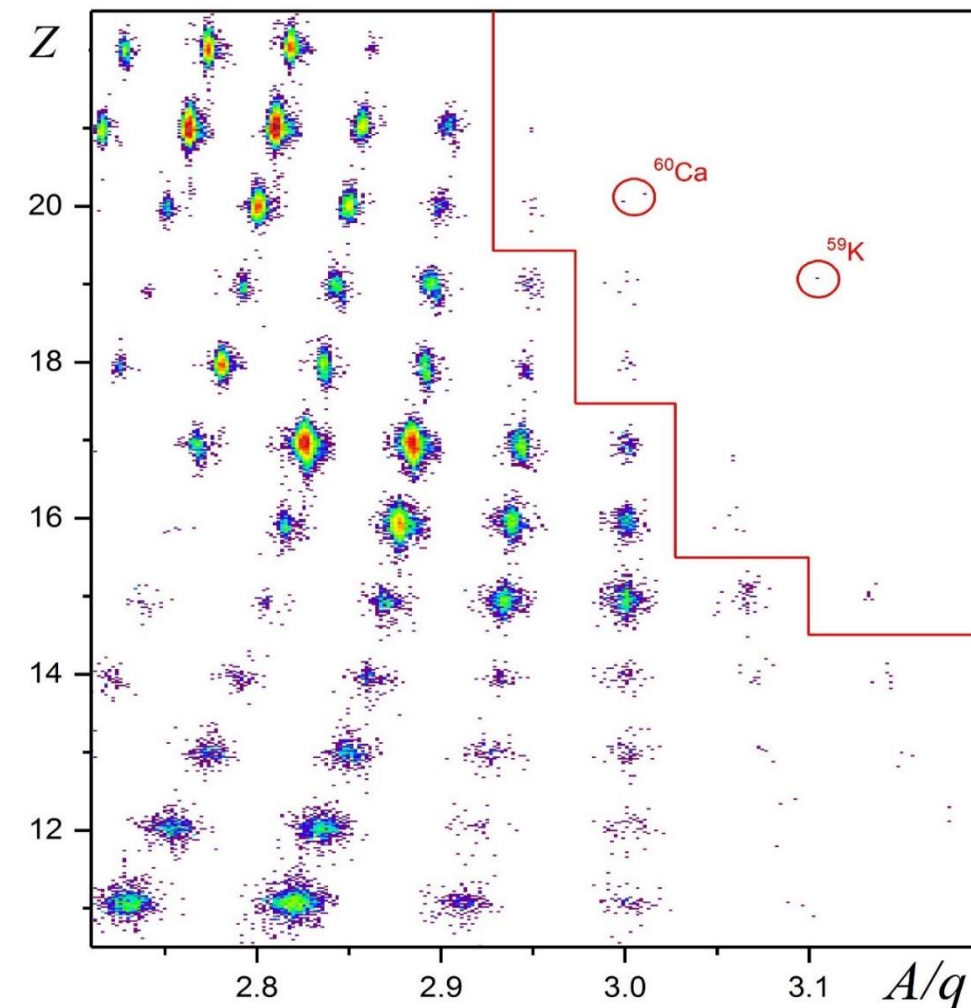
q-resolution is used to be
always better than Z-
resolution

Good filter for new
isotopes search,
because in this region at
these energies $Z=q$



Filtering

- Double position (Sci, PPAC) @ F3, F5, F7
- Double timing signals (Sci, PPAC) @ F3, F5, F7,
- Advanced techniques against pile-ups at PPACs & Sci,
- Six PIN diodes (6 cross checking Z-identification),
- TKE measurement (Csl)
- Additional veto detector after Csl



Spectrometers

VAMOS, SAMURAI, PRISM,
MAGNEX, S800, HRS, MSP144, ...

Wednesday 16 December 2020

^{238}U @ S800 experiment example was shown

6.55 am – 7.40am: Masaki Sasano

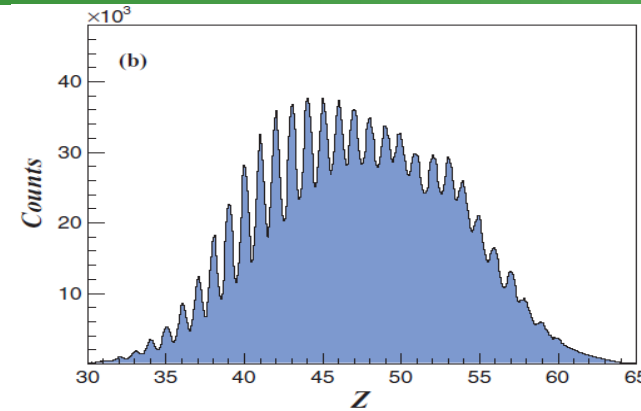
“Particle identification of RI beam in Sn region with
the SAMURAI spectrometer

7.40 – 7.55 am: Salvatore Calabrese

The MAGNEX spectrometer at INFN/LNS and its
challenges within the NUMEN project

9.25 am – 10.10 am: Jorge Pereira

Particle identification with the S800 Spectrograph –
Current status and future plans



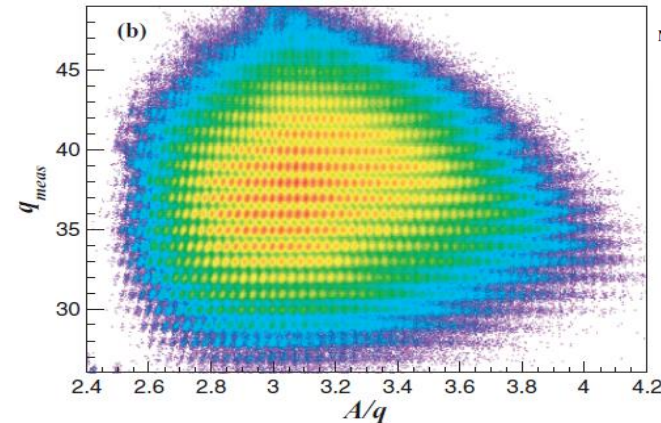
^{238}U (6.1MeV/u) + C @ VAMOS

A,q – good
Z - moderate

PHYSICAL REVIEW C 88, 024605 (2013)

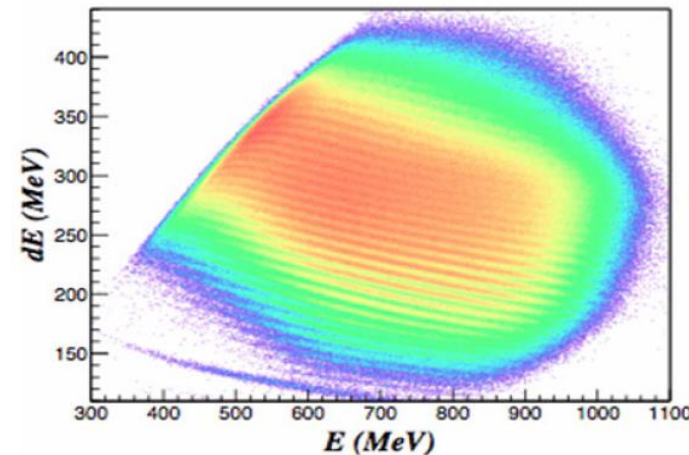
Isotopic yield distributions of transfer- and fusion-induced fission from $^{238}\text{U} + ^{12}\text{C}$ reactions in inverse kinematics

M. Caamaño,^{1,2,*} O. Delaune,^{1,†} F. Farget,^{1,‡} X. Derckx,^{1,§} K.-H. Schmidt,¹ L. Audouin,³ C.-O. Bacri,³ G. Barreau,⁴
J. Benlliure,² E. Casarejos,⁵ A. Chbihi,¹ B. Fernández-Domínguez,⁶ L. Gaudet,⁷ C. Golabek,¹ B. Jurado,⁴
A. Lemasson,¹ A. Navin,¹ M. Rejmund,¹ T. Roger,¹ A. Shrivastava,¹ and C. Schmitt¹



Identified fission fragments.

Charge state $q_{\text{meas}} = A/(A/q)$ as a function of A/q .



F.Farget et. al, Eur. Phys. J. A (2015) 51: 175

Fig. 2. Energy loss of fission fragments in the ionisation chamber of the focal plane, plotted as function of their energy. Each line is produced by isotopes of the same element, produced in the fusion-fission reaction of ^{238}U on ^{12}C at 6.1 MeV/u.

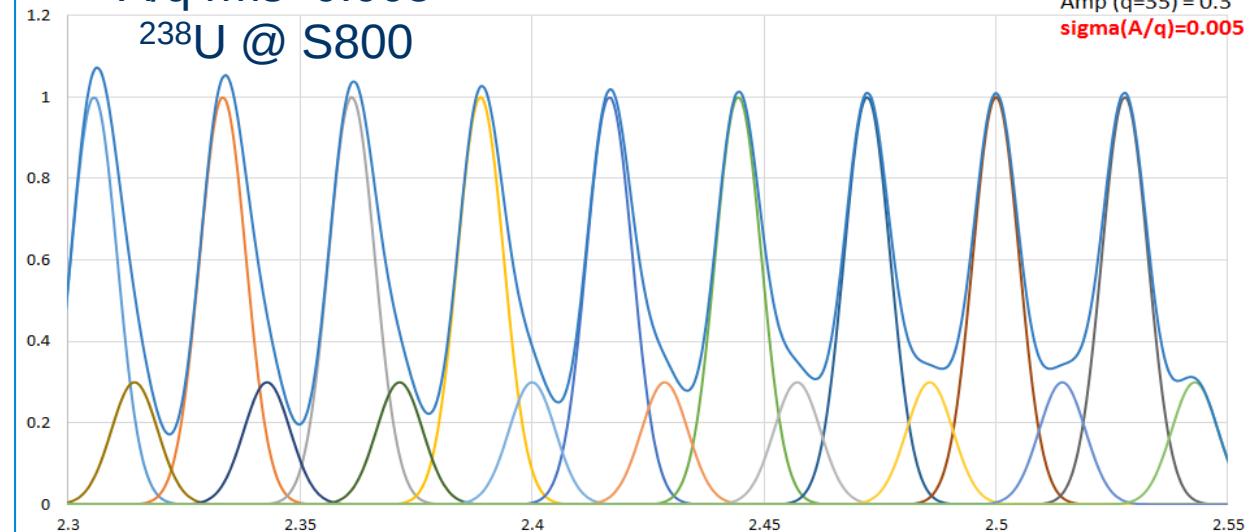
3. “Fast” beams experiments

When and where we can separate charge states?

$A/q_{rms}=0.005$
 ^{238}U @ S800

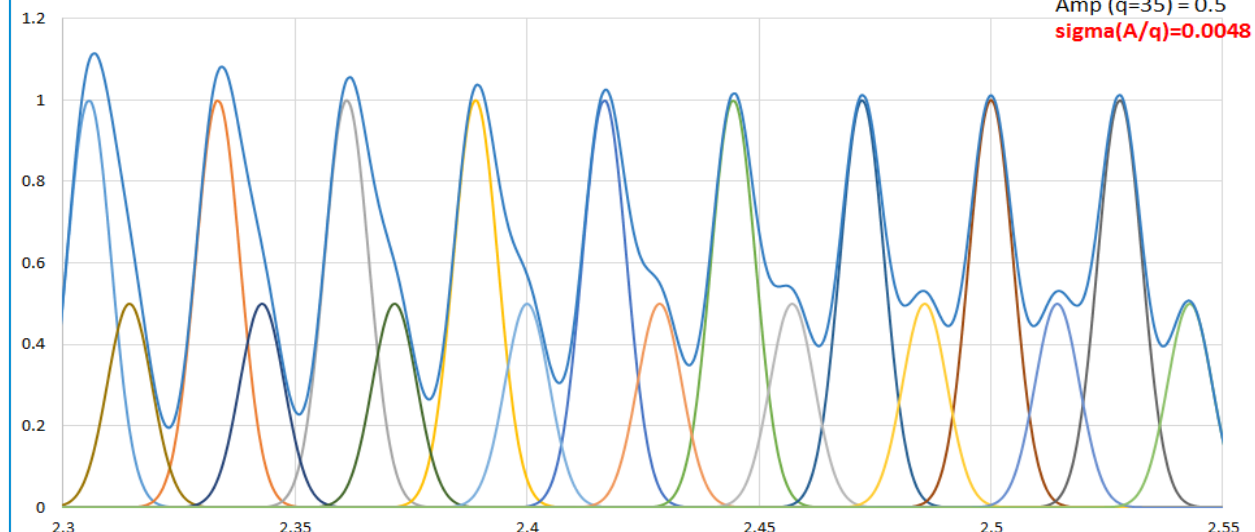
$Z=36$

Amp (q=36) = 1
Amp (q=35) = 0.3
 $\sigma(A/q)=0.005$



$Z=36$

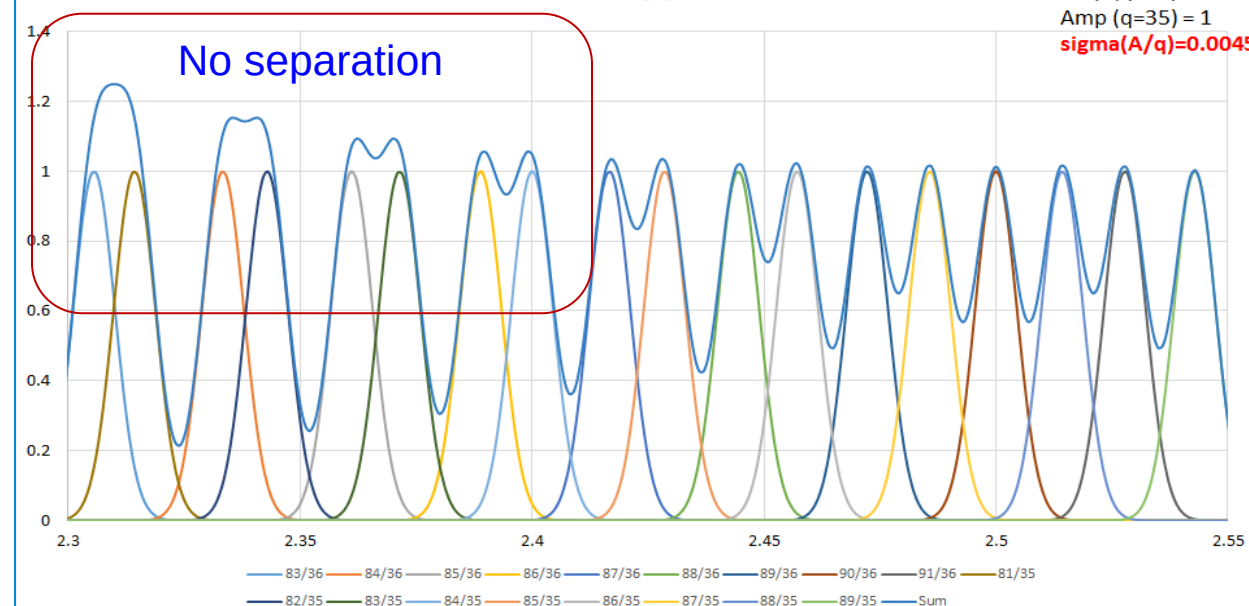
Amp (q=36) = 1
Amp (q=35) = 0.5
 $\sigma(A/q)=0.0048$



$Z=36$

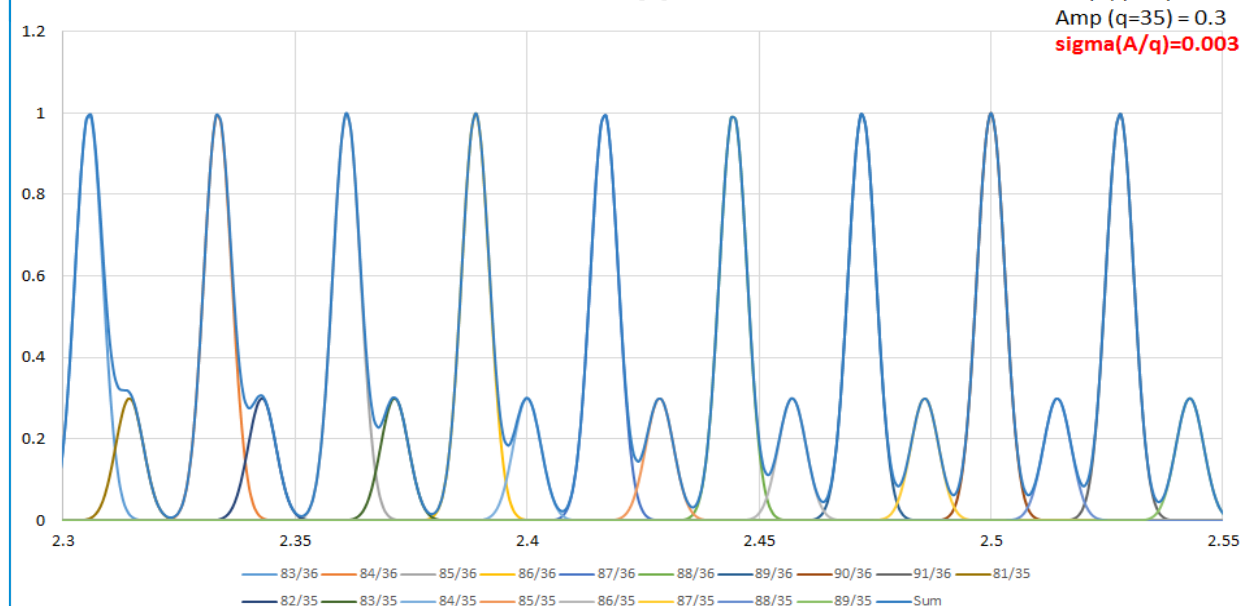
Amp (q=36) = 1
Amp (q=35) = 1
 $\sigma(A/q)=0.0045$

No separation



$Z=36$

Amp (q=36) = 1
Amp (q=35) = 0.3
 $\sigma(A/q)=0.003$



Resolution

sigma

TOF = 0.180

ns

Momentum (Brho) = 0.0865

Set-up

Energy = 70.00

MeV/u

Flight Length = 32.000

m

Momentum Resolution

X-image at target = 1.0

mm

X-magnification @ disp.plane = 2.3

X-dispersion = 29.0

mm/%

Detector resolution = 1.0

mm

Momentum Resolution = 0.0865

%

Resolution 3.1E-03

Brho

Beta

0.0871%

0.0841%

Hg-isotopes around A/q=2.6 : $d(A/q)=0.00314$

70

60

50

40

30

20

10

0

2.58

2.59

2.6

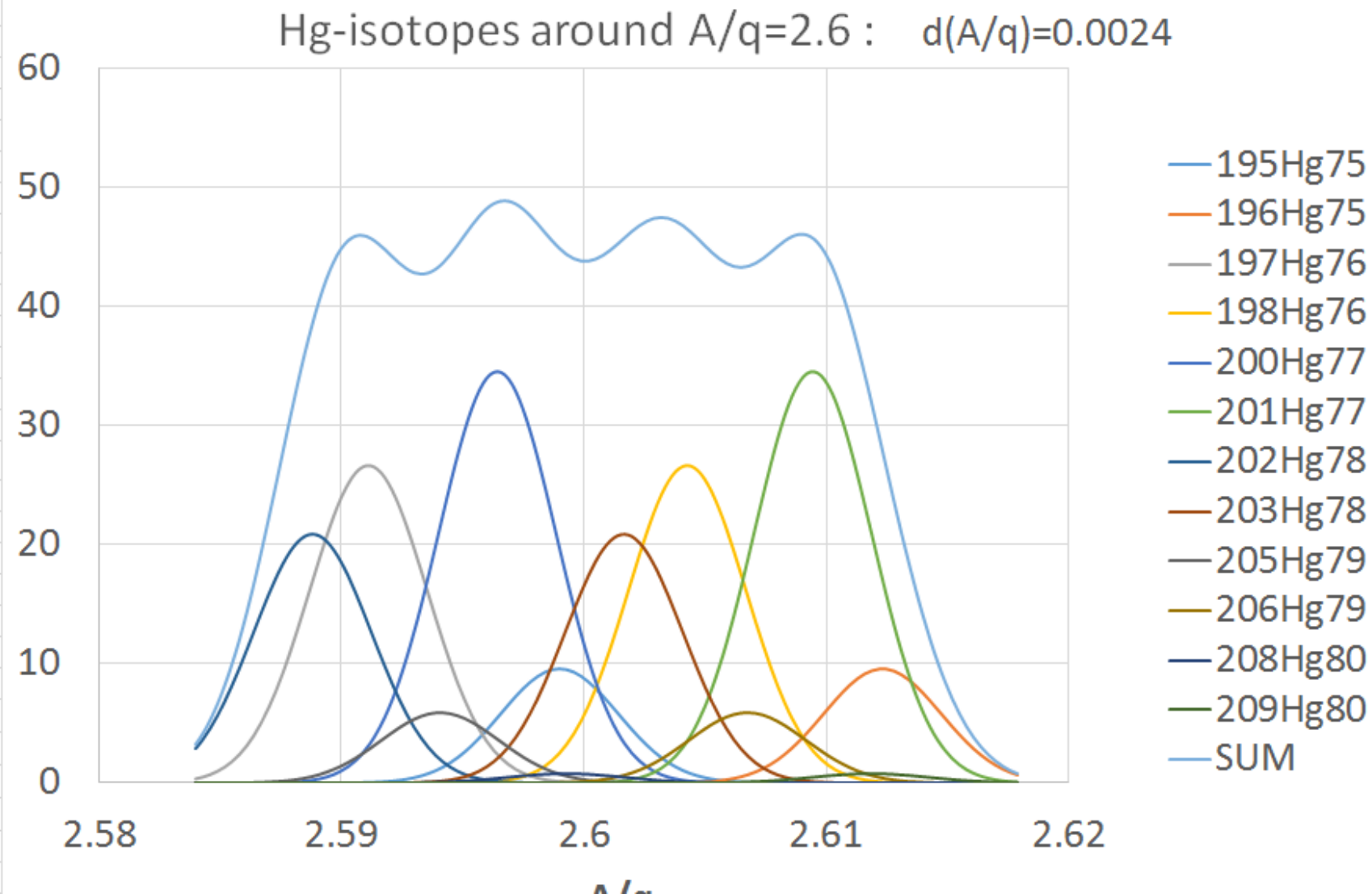
2.61

2.62

A/q

— 195Hg75
 — 196Hg75
 — 197Hg76
 — 198Hg76
 — 200Hg77
 — 201Hg77
 — 202Hg78
 — 203Hg78
 — 205Hg79
 — 206Hg79
 — 208Hg80
 — 209Hg80
 — SUM

Resolution			
	sigma		
TOF = 0.100	ns		
Momentum (Brho) = 0.0479			
Set-up			
Energy = 70.00	MeV/u		
Flight Length = 19.000	m		
Momentum Resolution			
X-image at target = 1.0	mm		
X-magnification @ disp.plane = 2.0			
X-dispersion = 59.0	mm/%		
Detector resolution = 2.0	mm		
Momentum Resolution = 0.0479	%		
	Resolution	2.4E-03	
	Brho	Beta	
	0.049%	0.079%	



Resolution

sigma

TOF = 0.050

ns

Momentum (Brho) = 0.0479

Set-up

Energy = 70.00

MeV/u

Flight Length = 19.000

m

Momentum Resolution

X-image at target = 1.0

mm

X-magnification @ disp.plane = 1.5

X-dispersion = 59.0

mm/%

Detector resolution = 1.0

mm

Momentum Resolution = 0.0306

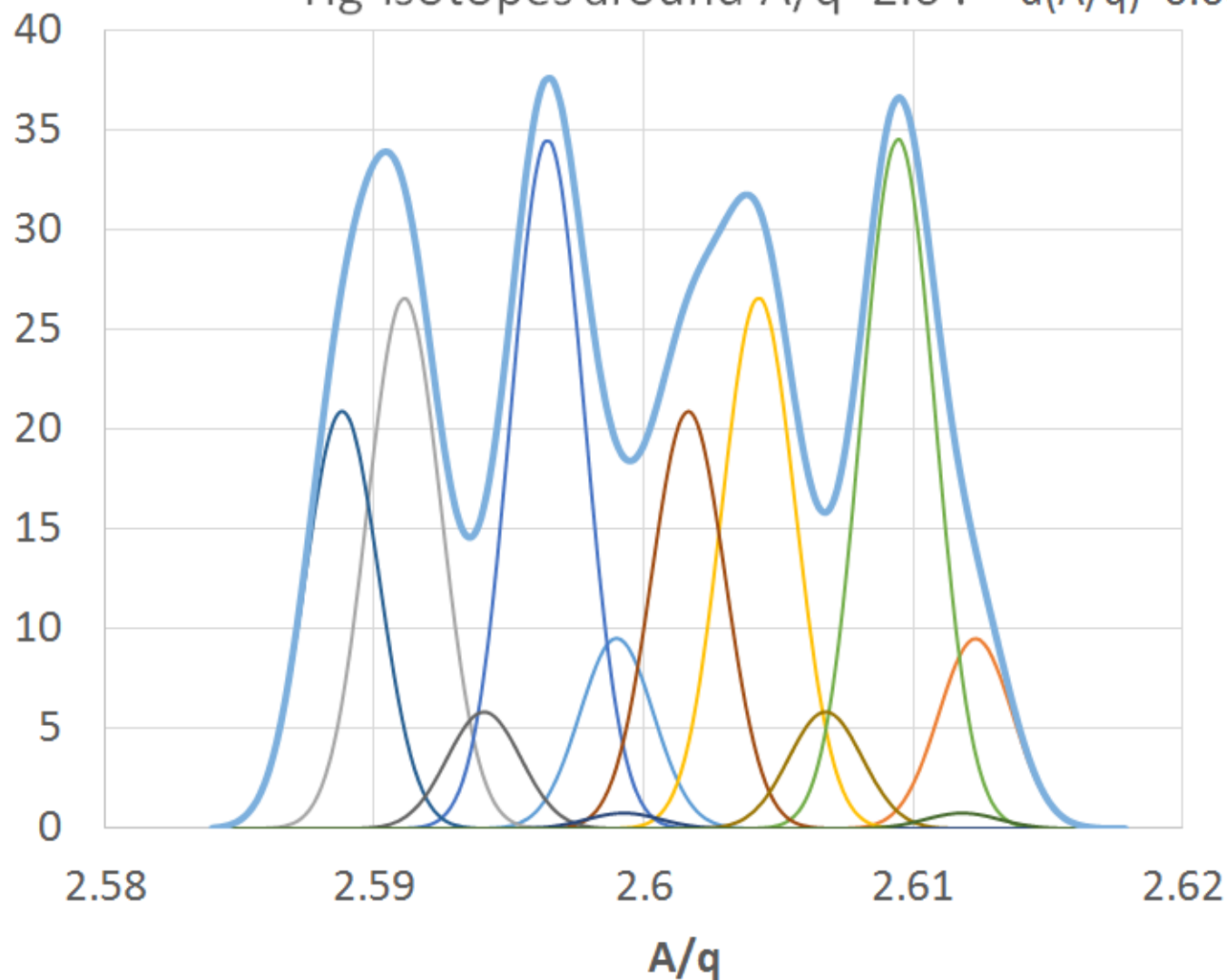
%

Resolution 1.4E-03**Brho****Beta**

0.039%

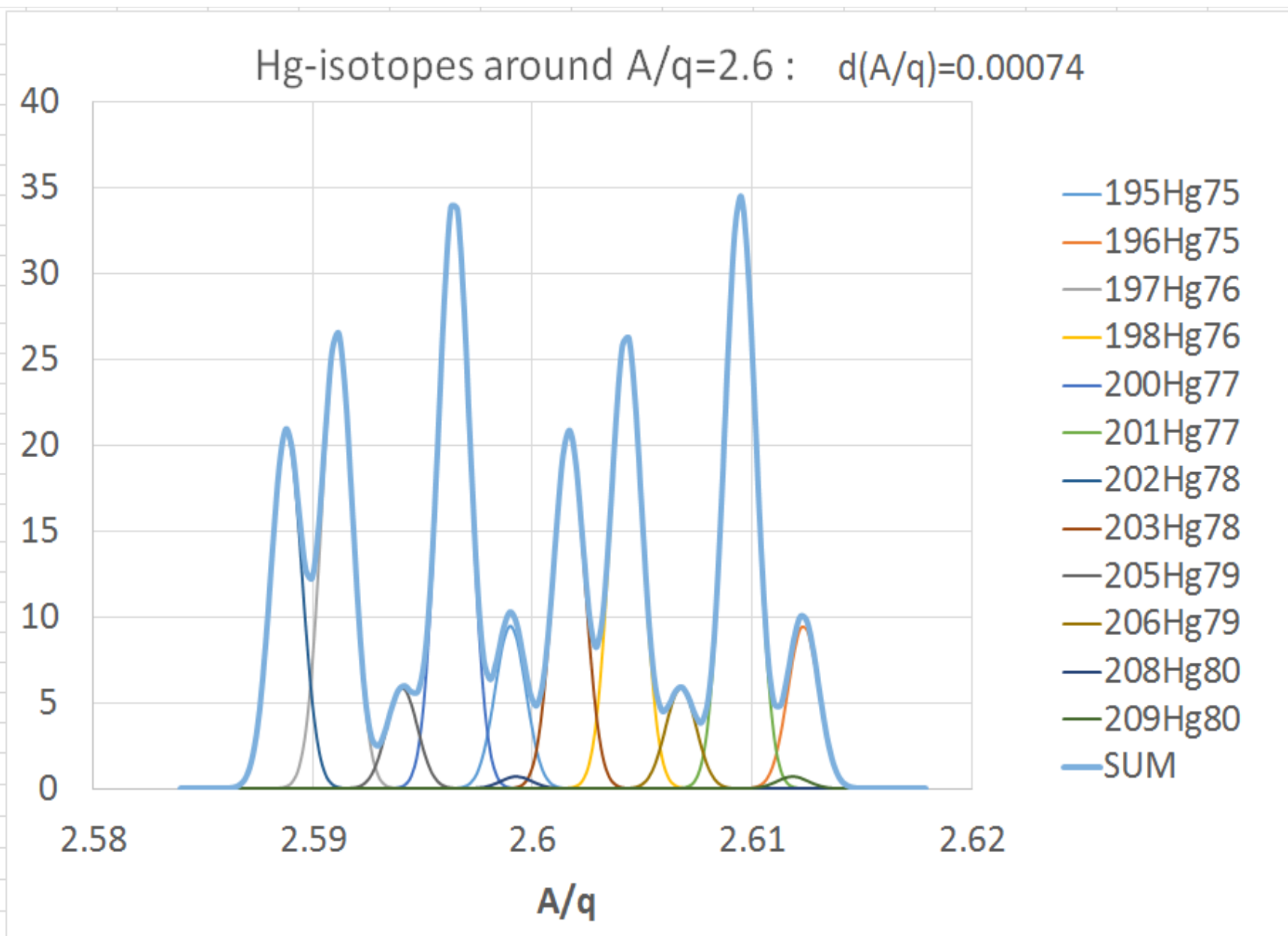
0.041%

Hg-isotopes around A/q=2.6 : d(A/q)=0.0014



SUM

Resolution			
	sigma		
TOF = 0.050	ns		
Momentum (Brho) = 0.0479			
Set-up			
Energy = 70.00	MeV/u		
Flight Length = 70.000	m		
Momentum Resolution			
X-image at target = 1.0	mm		
X-magnification @ disp.plane = 1.5			
X-dispersion = 100.0	mm/%		
Detector resolution = 1.0	mm		
Momentum Resolution = 0.0180	%		
	Resolution	7.0E-04	
	Beta	Brho	
	0.017%	0.021%	



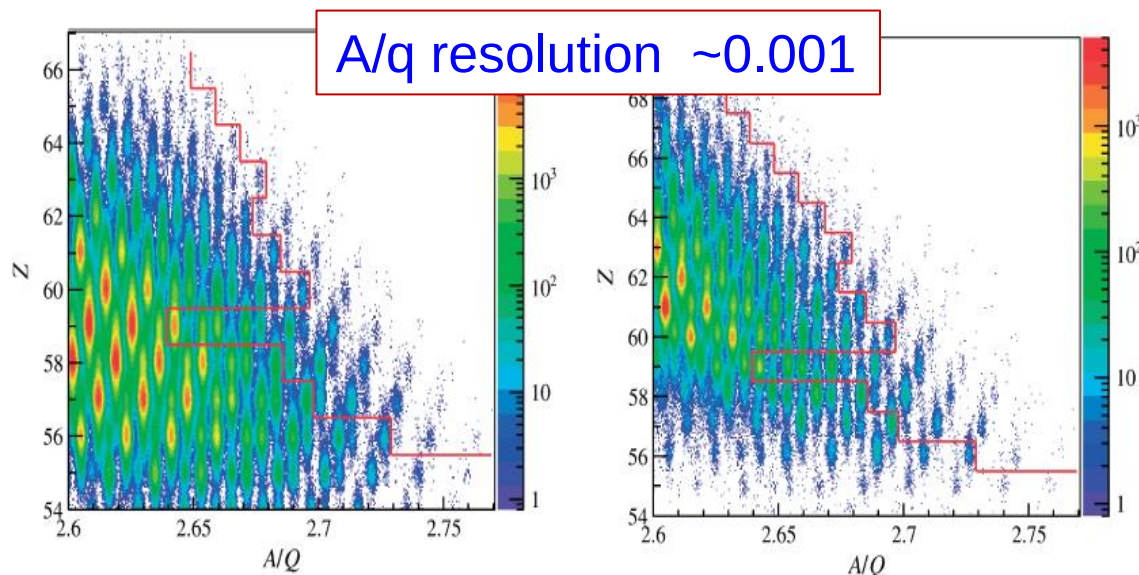
Journal of the Physical Society of Japan 87, 014202 (2018)

<https://doi.org/10.7566/JPSJ.87.014202>

Identification of New Neutron-Rich Isotopes in the Rare-Earth Region

Produced by 345 MeV/nucleon ^{238}U

Naoki Fukuda^{1*}, Toshiyuki Kubo^{1†}, Daisuke Kameda¹, Naohito Inabe¹, Hiroshi Suzuki¹, Yohei Shimizu¹, Hiroyuki Takeda¹, Kensuke Kusaka¹, Yoshiyuki Yanagisawa¹, Masao Ohtake¹, Kanenobu Tanaka¹, Koichi Yoshida¹, Hiromi Sato¹, Hidetada Baba¹, Meiko Kurokawa¹, Tetsuya Ohnishi¹, Naohito Iwasa², Ayuko Chiba², Taku Yamada², Eiji Ideguchi³, Shintaro Go³, Rin Yokoyama³, Toshihiko Fujii³, Hiroki Nishibata⁴, Kazuo Ieki⁵, Daichi Murai⁵, Sadao Momota⁶, Daiki Nishimura⁷, Yoshiteru Sato⁸, Jongwon Hwang⁸, Sunji Kim⁸, Oleg B. Tarasov⁹, David J. Morrissey⁹, and Gary Simpson¹⁰



Thursday 17 December 2020
6.00 am – 6.45 am: Fukuda Naoki
Particle identification at BigRIPS Separator

Ion	
A = 200	
Z = 74	
q = 73	
M_isotope = 199.9936	
M_ion = 199.9535	
M_ion/q = 2.739089	

Resolution	
sigma	
TOF = 0.050	ns
Eloss = 0.75	%
TKE = 0.45	%
Z =	
Momentum (Brho) = 0.0142	%

Measured values	
TOF = 252.1534	ns
Brho = 6.6405	T*m
E1_loss = 3556.97	MeV
TKE = 49988.38	MeV

Deduced values	
beta = 0.615158	
gamma = 1.268386	
velocity = 18.4412	cm/ns
A / q = 2.739089	
A/q(2) = 2.76662	

PID values	
Z (Eloss) = 74	
q = 73.000	
A (from TKE) = 199.9535	
A (from [A/q]*q_integer) = 199.9535	
A (from [A/q]*q_measur) = 199.9535	
A-2q = 53.95	
A-3q = -19.05	
A-2Z* = 54.69	

Set-up	
Energy = 250.00	MeV/u
Flight Length = 46.500	m
1st(Z) detector material = 14	
1st(Z) detector thickness = 200	mg/cm ²
	861.623 um

systematical (calibration)	
0.005	%
0.40	% (straggling)
0.05	%
0.2	%
0.01	%

error (σ)	
0.052	0.020
0.001	0.017
30.22	0.850
226.33	0.453

error (σ)	
0.00013	0.020
0.00016	0.012
0.00377	0.020
0.00102	0.037
0.001241	0.045

error (σ)	
0.347	0.47
0.331	0.45
0.913	0.46
0.074	0.04
0.911	0.46
0.258	
0.112	
0.267	

Momentum Resolution reconstruction	
X-image at target = 0.1	mm
X-magnification @ disp.plane = 1.0	
X-dispersion = 36.0	mm/%
Detector resolution = 0.5	mm
Momentum Resolution = 0.0142	%

Probably, it's not enough.
On the limit.
Increase flight length,
Decrease energy

contribution in error				
Brho	Beta	TKE	E1_loss	Zsyst
0.017%	0.033%			
0.018%	0.041%			
0.017%	0.026%	0.453%		0.42%
0.017%	0.033%	0.454%		0.20%
0.03	0.08	0.24		
0.04	0.06	0.09		

On the limit

Good!

4. PID features

Charge states
“cleaning”

DispersionI2= 112.00000

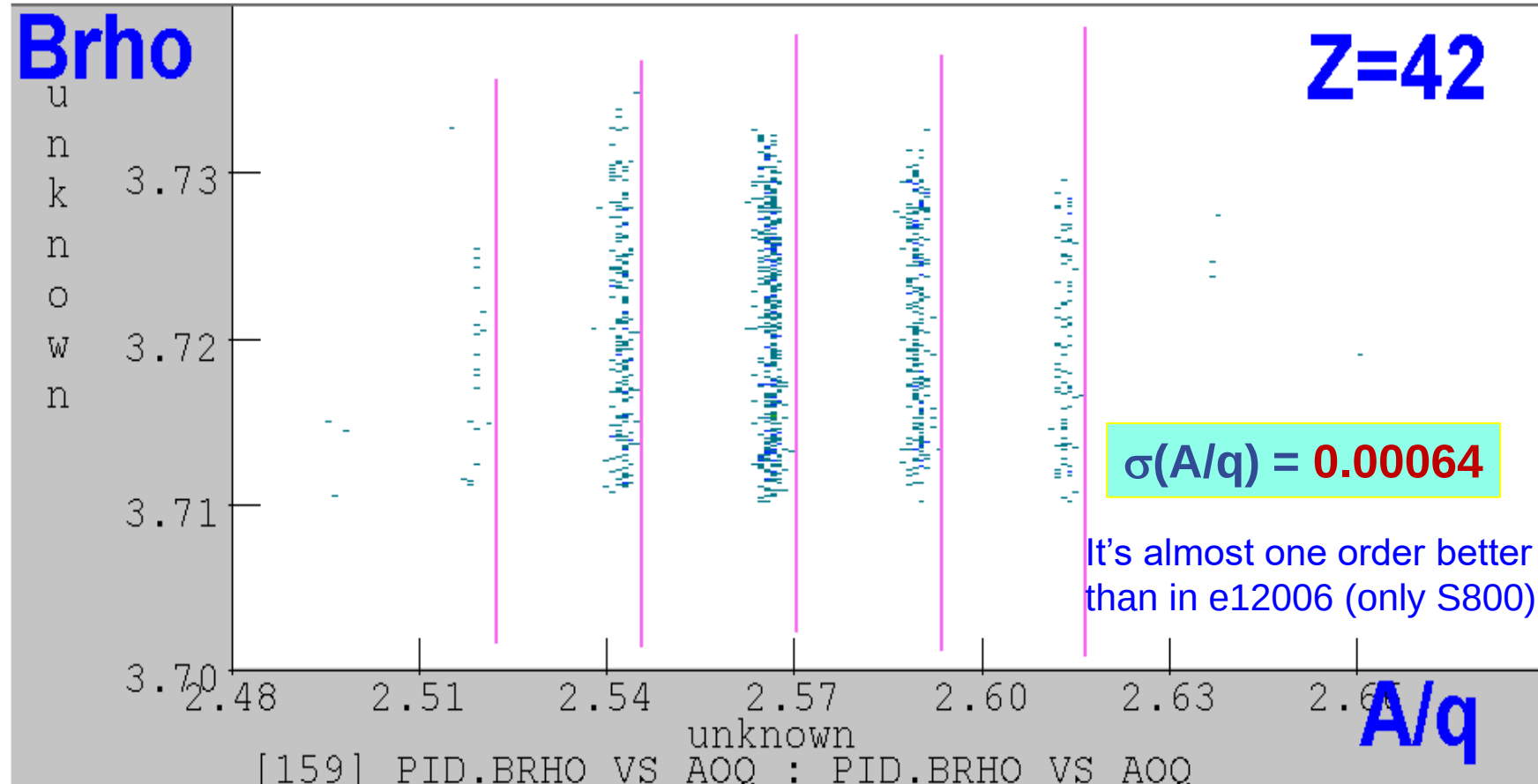
mm/%

user.mcpm_x1_a3	-19.399
user.mcpm_x1_a2	-3.38656
user.mcpm_x1_a1	-26.62532
user.mcpm_x1_a0	-4.11869

Excellent

PI: M.Famiano

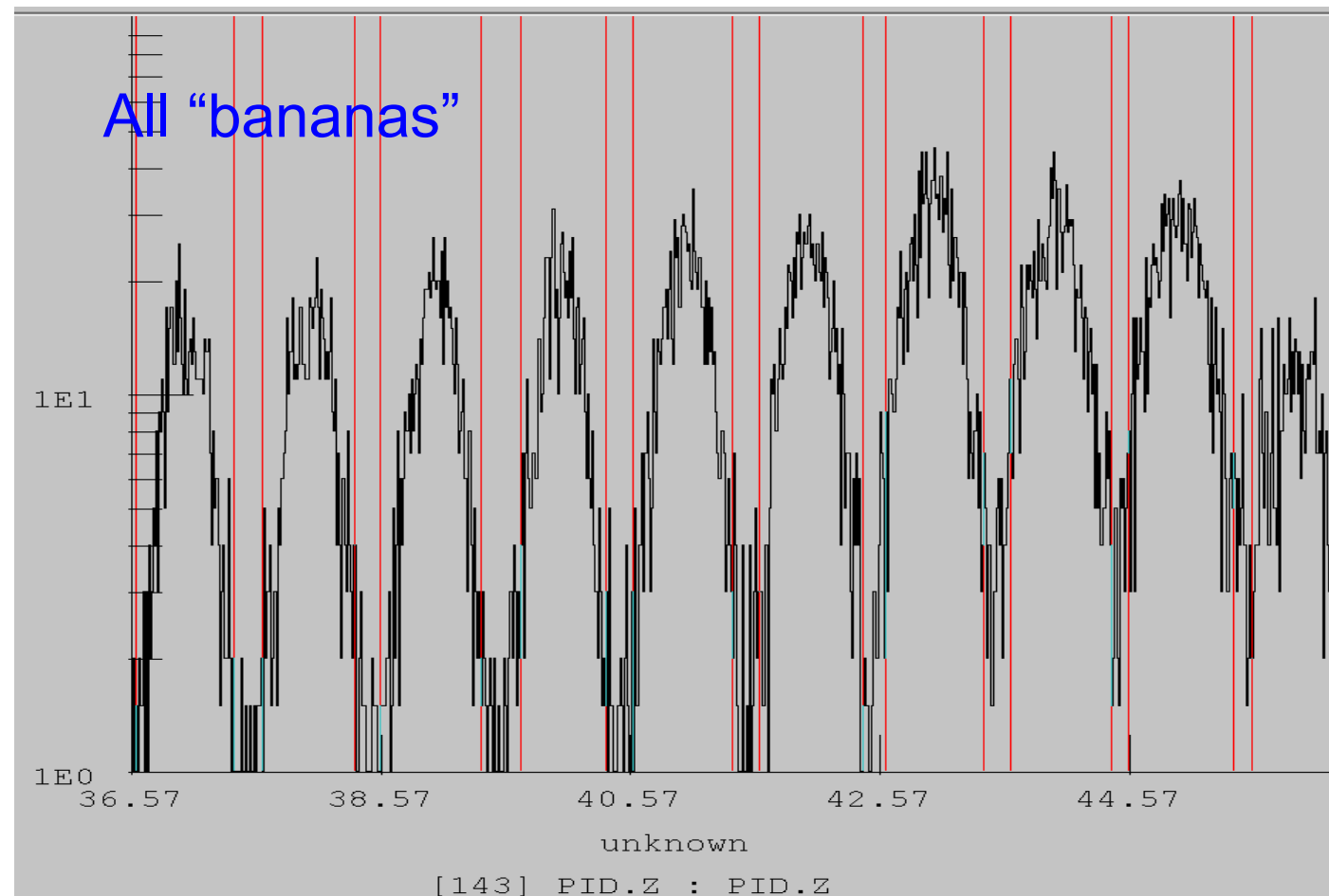
- Mass measurement
- Disperse mode
- PIN-telescope at the S800 FP
- $B\rho$ measurement at the S800 TP by MCP
- Intermediate energy, Long flight length, very high dispersion



Good!

Average of $|Z_{\text{calc}} - Z_{\text{peak}}| = 0.057$ in $Z=32-50$ region

$\sigma(Z) = 0.157$ for all $Z=42$ isotopes, $\sigma(Z) = 0.153$ for ^{108}Mo

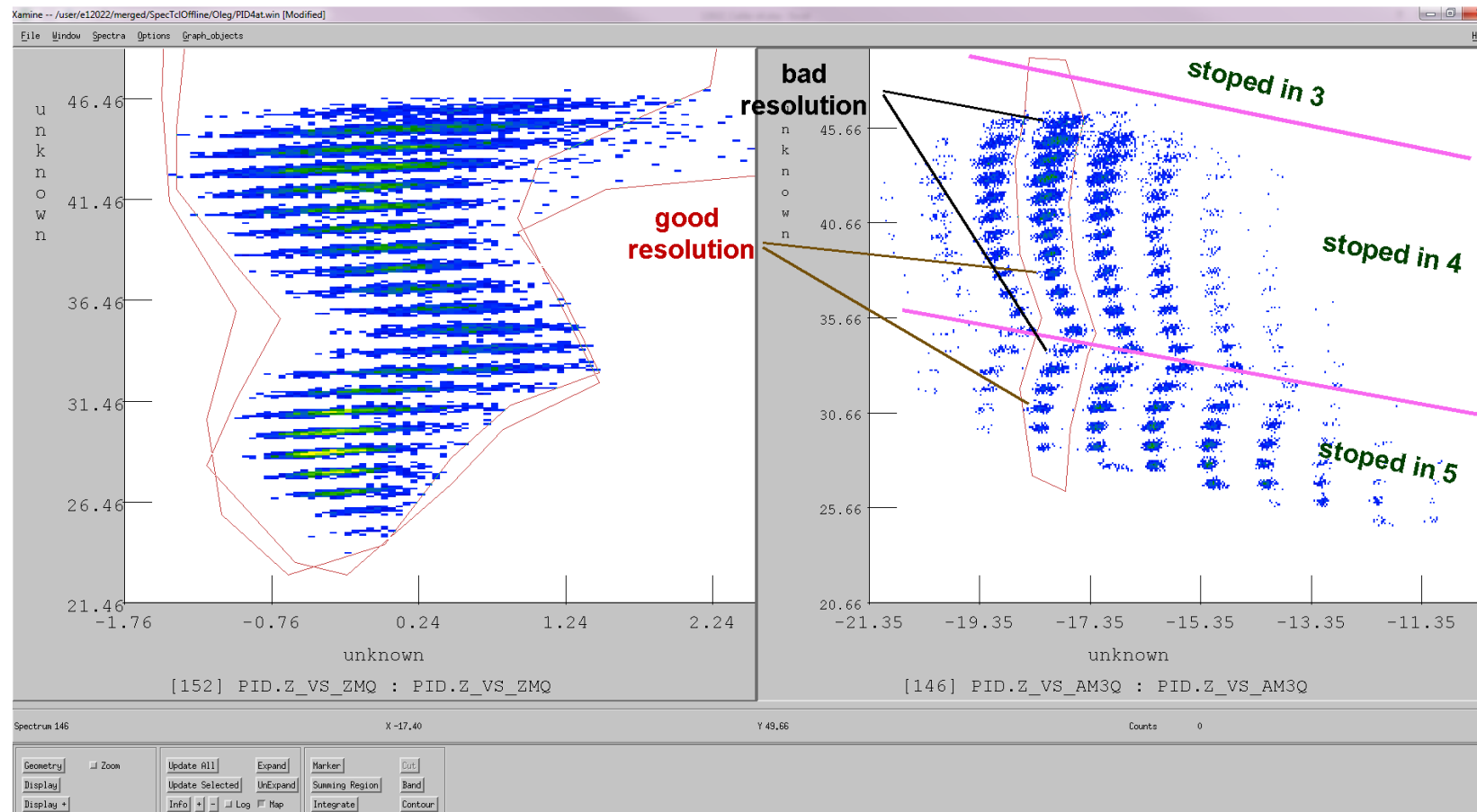


3rd and 4th PIN-diodes **not well** depleted

BAD !

Average of $|q_{\text{calc}} - q_{\text{peak}}| = 0.29$ (!) in Z=32-50 region

$q_{\text{measured}} = 42.24$ with $\sigma(q) = 0.27$ for $^{108}\text{Mo}^{42+}$, for all Z=42 full-stripped isotopes $\sigma(q) = 0.274^*$

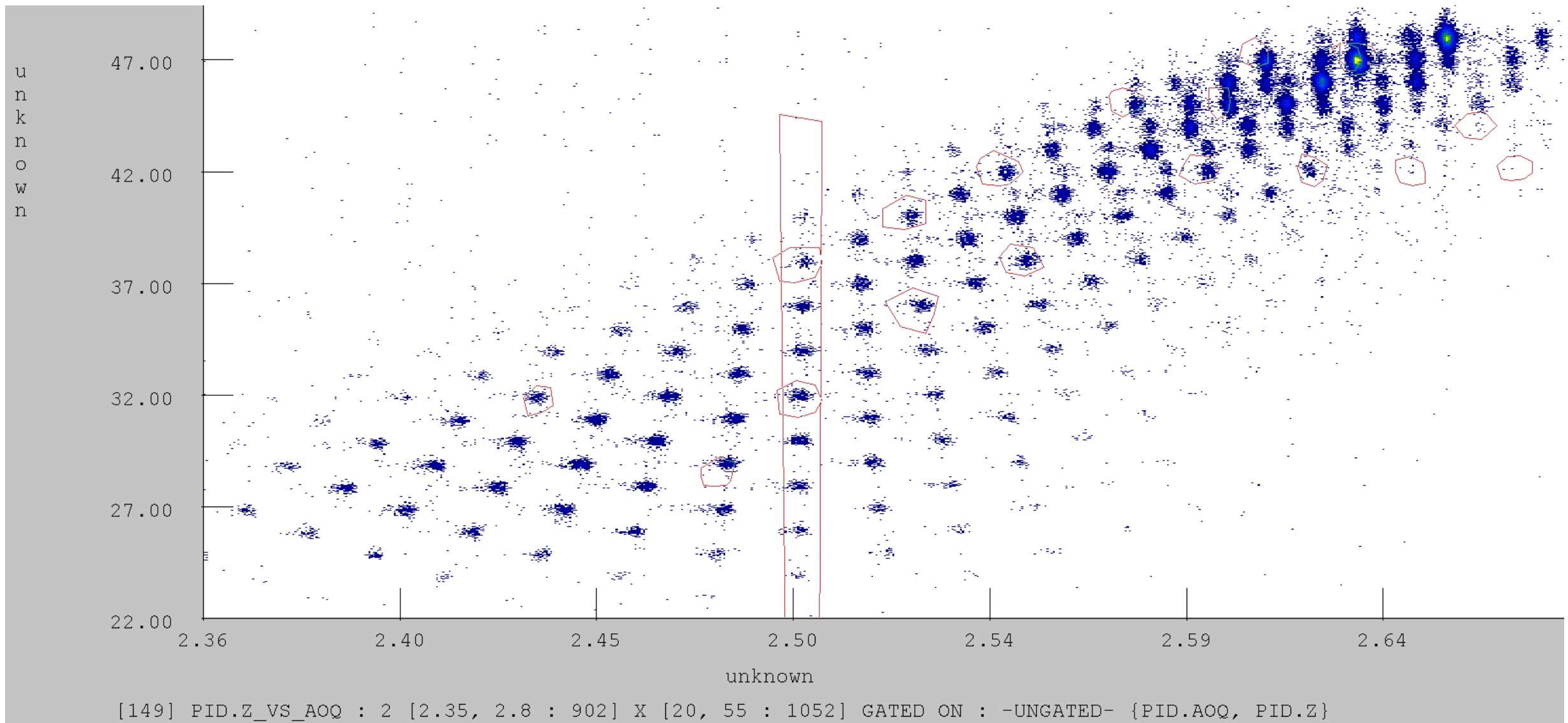


Actually $\sigma(q)$ is not so bad, but charge state overlapping was observed in the Z-q plot. So, the “banana” selection method can help. See next slides

F11

PID plot without filtering

Z



A/q

Charge state separation with “A-3Z” integer values

This method can be used only in the case of

- perfect Z and A/q resolution
- far from integer values of A/Z (2,3)
- Only to separate Z-q=0 and Z-q=1.

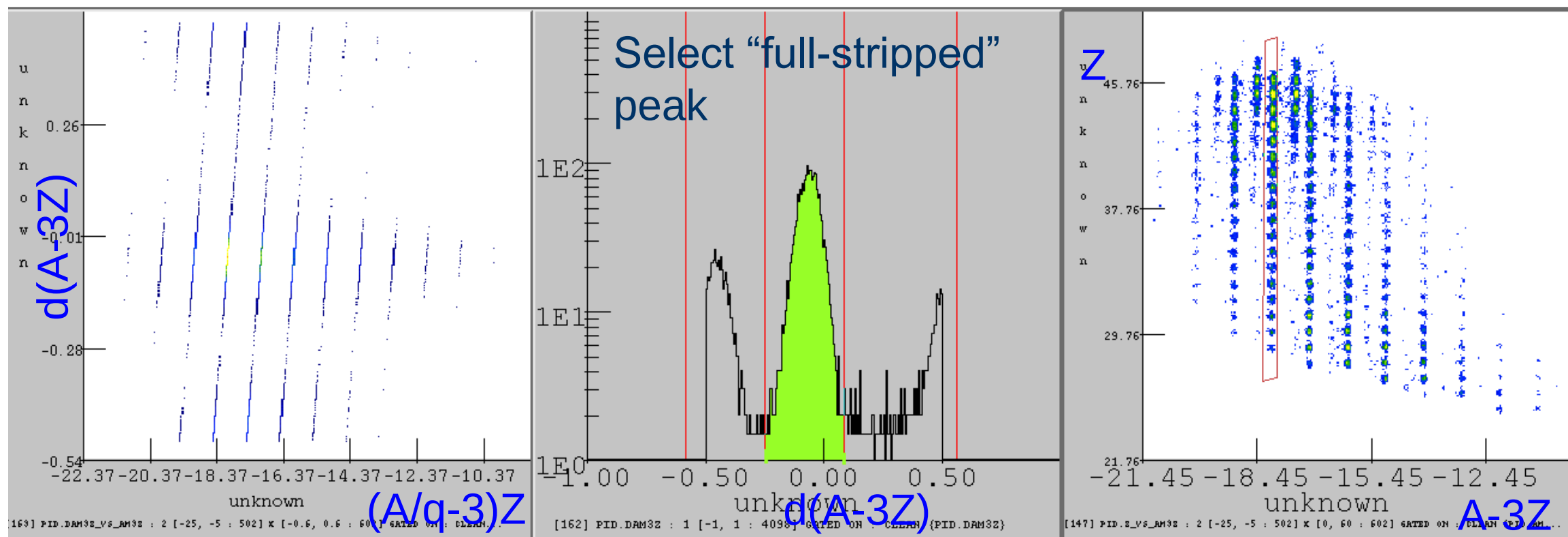
So, in our case we are working around 2.5, and no helium-like products

$$Z_i = \text{int}(Z+0.5)$$

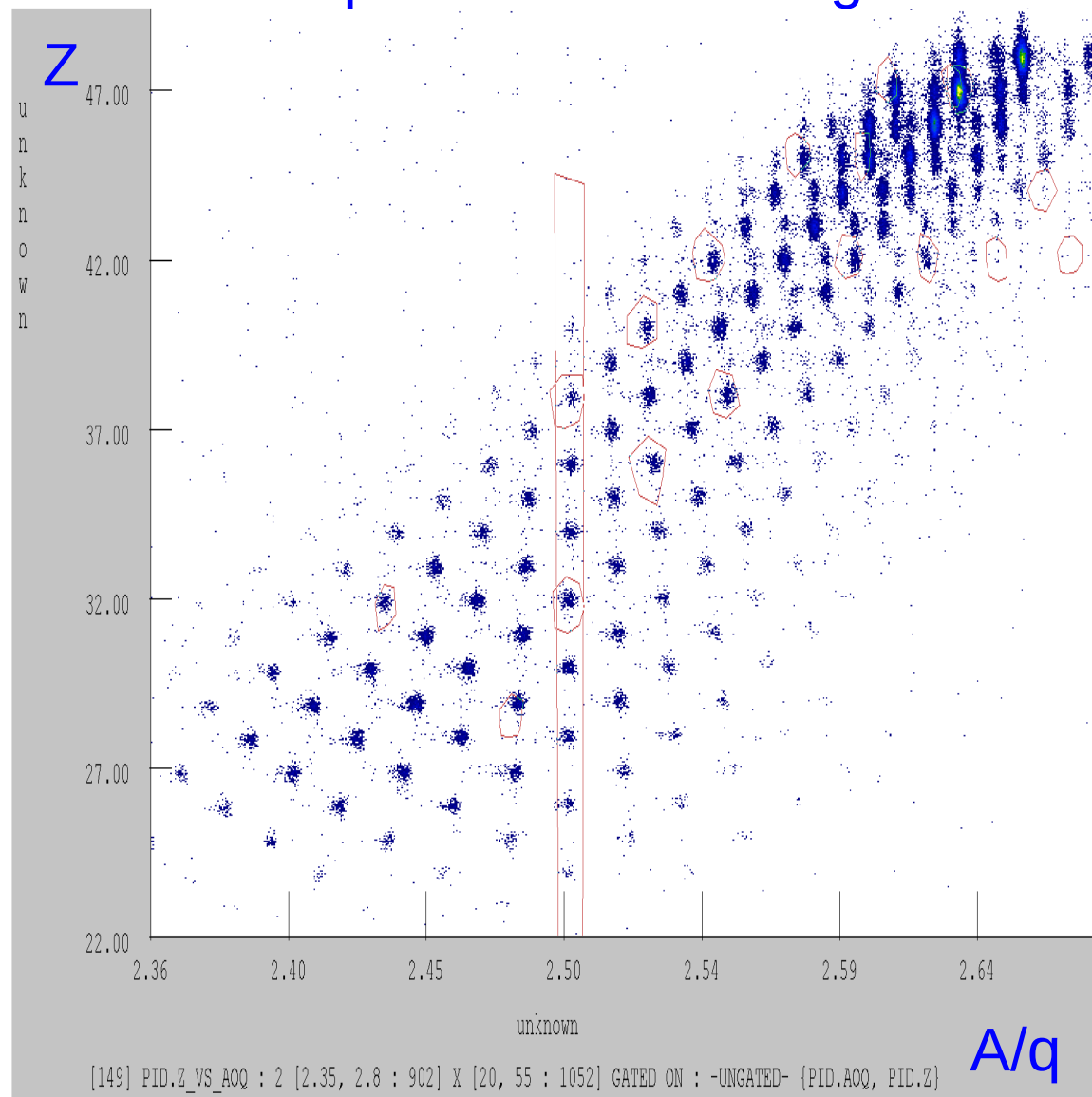
$$\text{Am}3Z = (A/q - 3) * Z_i$$

$$\text{Am}3Z_i = \text{int}(\text{Am}3Z + 1.5)$$

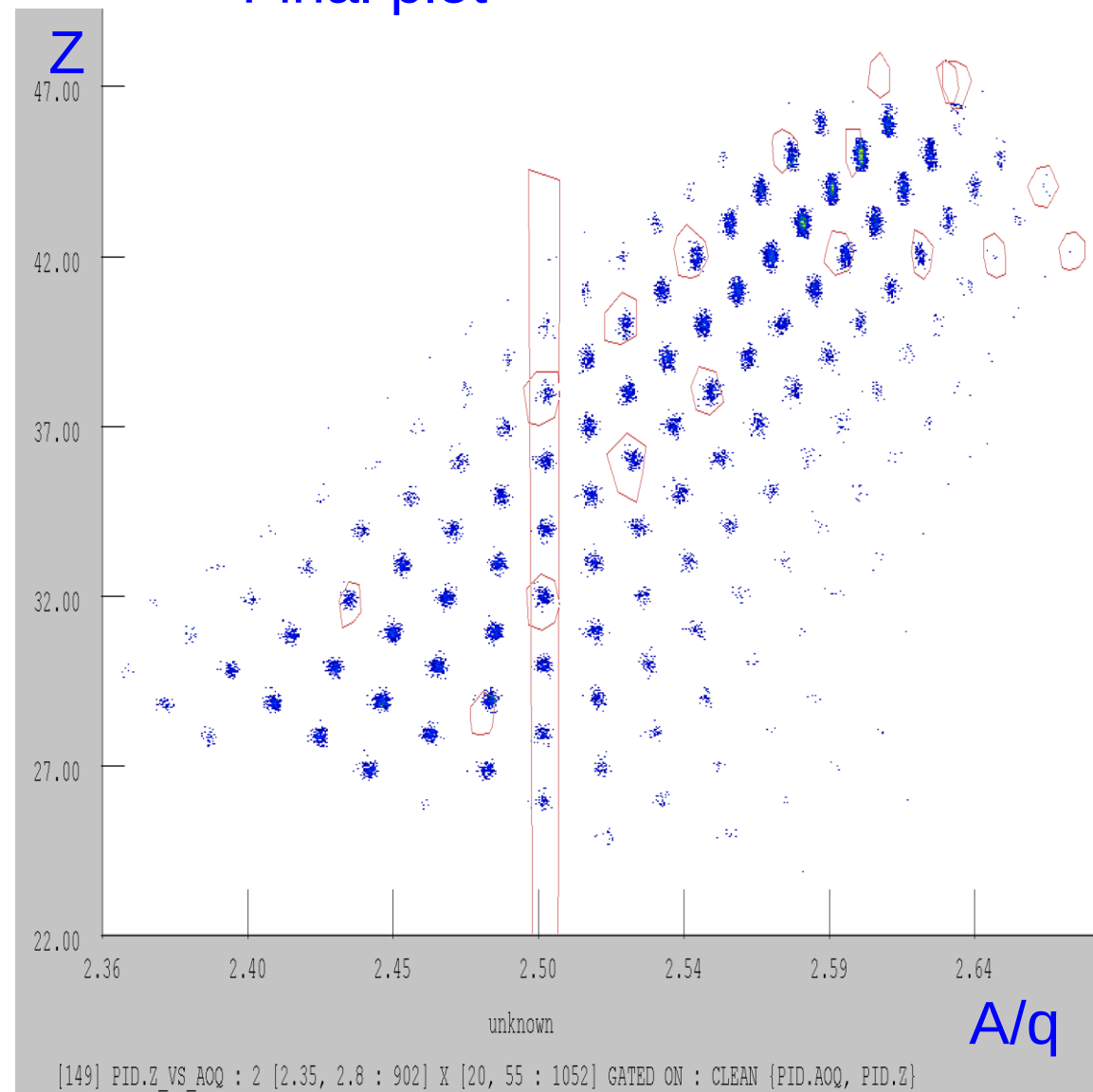
$$\text{dA}3\text{m}Z = \text{Am}3Z - \text{Am}3Z_i$$



Initial plot without filtering



Final plot

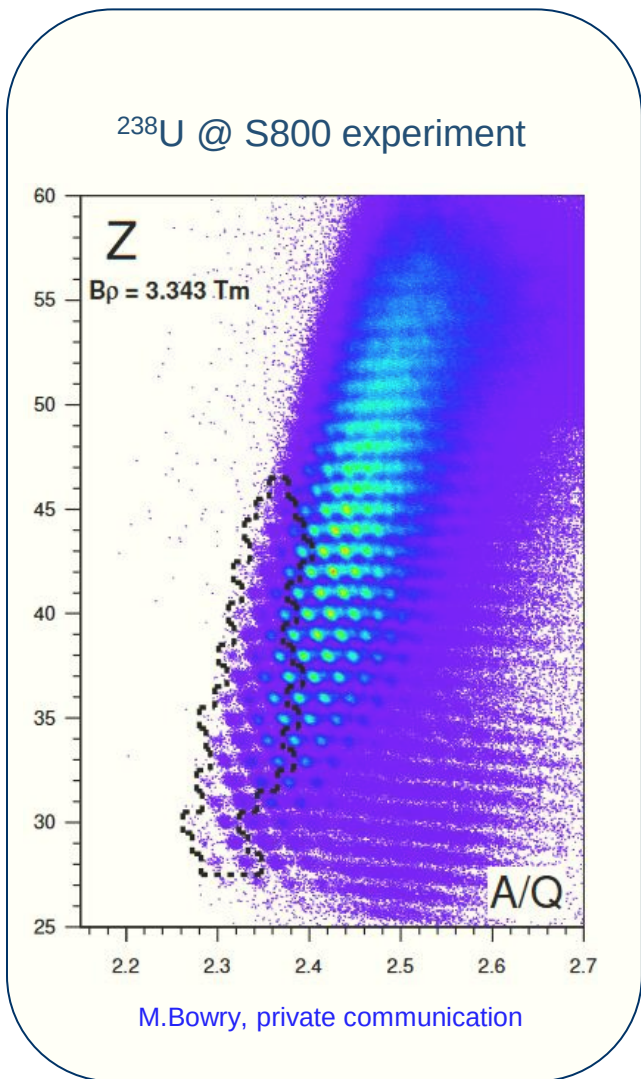
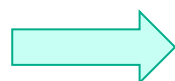
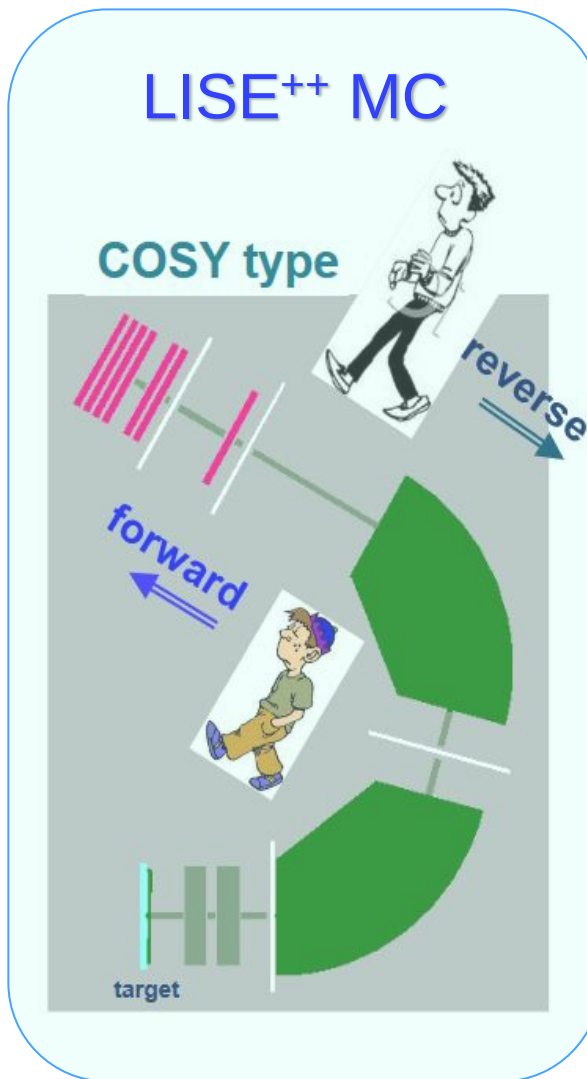
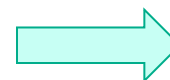
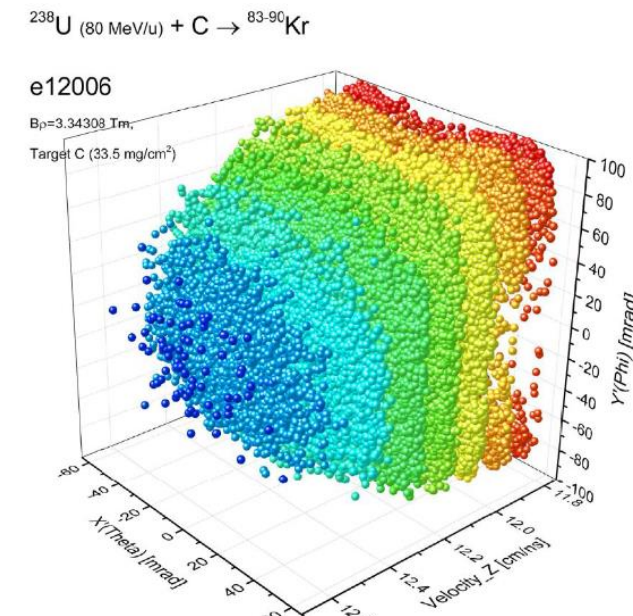


The **red** color shows that charge states will be cut for specific isotope of $Z=42$

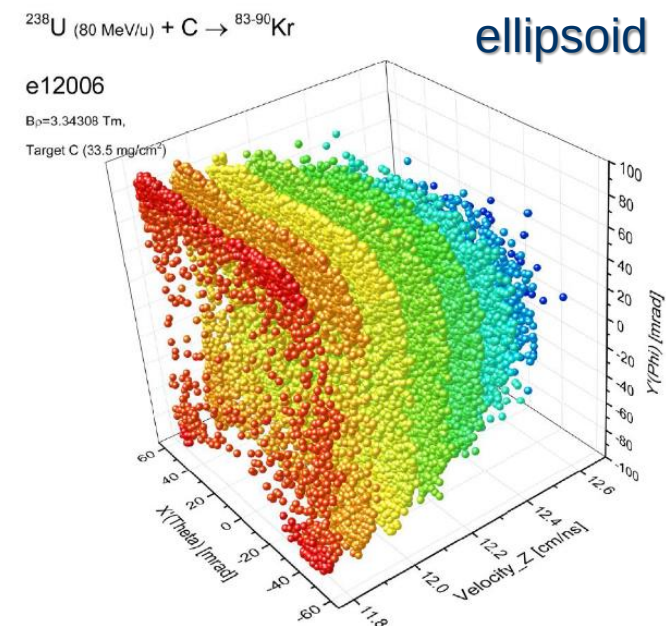
For “fast” beams
In RIKEN and MSU
to get clean A-xn plots,
which are more convenient to
use for counting and gating

Z	42									
A	Z-q					A	Z-q			
	1	2	3	4			1	2	3	4
80	0.049	0.000	0.154	0.421		100	0.439	0.000	0.308	0.474
81	0.024	0.050	0.231	0.474		101	0.463	0.050	0.231	0.368
82	0.000	0.100	0.308	0.368		102	0.488	0.100	0.154	0.263
83	0.024	0.150	0.385	0.263		103	0.488	0.150	0.077	0.158
84	0.049	0.200	0.462	0.158		104	0.463	0.200	0.000	0.053
85	0.073	0.250	0.462	0.053		105	0.439	0.250	0.077	0.053
86	0.098	0.300	0.385	0.053		106	0.415	0.300	0.154	0.158
87	0.122	0.350	0.308	0.158		107	0.390	0.350	0.231	0.263
88	0.146	0.400	0.231	0.263		108	0.366	0.400	0.308	0.368
89	0.171	0.450	0.154	0.368		109	0.341	0.450	0.385	0.474
90	0.195	0.500	0.077	0.474		110	0.317	0.500	0.462	0.421
91	0.220	0.450	0.000	0.421		111	0.293	0.450	0.462	0.316
92	0.244	0.400	0.077	0.316		112	0.268	0.400	0.385	0.211
93	0.268	0.350	0.154	0.211		113	0.244	0.350	0.308	0.105
94	0.293	0.300	0.231	0.105		114	0.220	0.300	0.231	0.000
95	0.317	0.250	0.308	0.000		115	0.195	0.250	0.154	0.105
96	0.341	0.200	0.385	0.105		116	0.171	0.200	0.077	0.211
97	0.366	0.150	0.462	0.211		117	0.146	0.150	0.000	0.316
98	0.390	0.100	0.462	0.316		118	0.122	0.100	0.077	0.421
99	0.415	0.050	0.385	0.421		119	0.098	0.050	0.154	0.474

http://lise.nslc.msu.edu/paper/2016/Reconstruction_with_LISE.pdf



Fission
ellipsoid



Will be finally published in 2021? ☺

“Global” (net)
calibration

Why global?

1. For all energies
2. For all particles
3. No energy loss models
4. Dead layers are taken into account
5. Help to find discrepancies in data, calibration

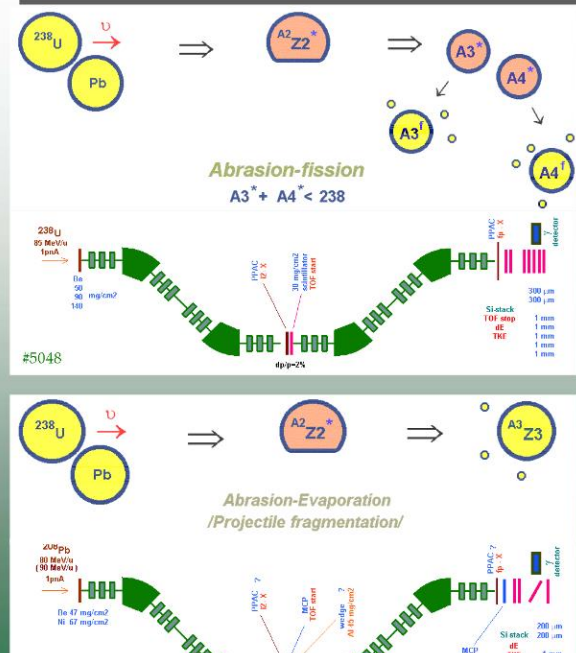
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		23A0660			23A0661			23A0662			23A0663			23A0664			23A0665			23A0666			23A0667			23A0668			23A0669			23A0670			23A0671			23A0672			23A0673			23A0674			23A0675			23A0676			23A0677			23A0678			23A0679			23A0680			23A0681			23A0682			23A0683			23A0684			23A0685			23A0686			23A0687			23A0688			23A0689			23A0690			23A0691			23A0692			23A0693			23A0694			23A0695			23A0696			23A0697			23A0698			23A0699			23A0700			23A0701			23A0702			23A0703			23A0704			23A0705			23A0706			23A0707			23A0708			23A0709			23A0710			23A0711			23A0712			23A0713			23A0714			23A0715			23A0716			23A0717			23A0718			23A0719			23A0720			23A0721			23A0722			23A0723			23A0724			23A0725			23A0726			23A0727			23A0728			23A0729			23A0730			23A0731			23A0732			23A0733			23A0734			23A0735			23A0736			23A0737			23A0738			23A0739			23A0740			23A0741			23A0742			23A0743			23A0744			23A0745			23A0746			23A0747			23A0748			23A0749			23A0750			23A0751			23A0752			23A0753			23A0754			23A0755			23A0756			23A0757			23A0758			23A0759			23A0760			23A0761			23A0762			23A0763			23A0764			23A0765			23A0766			23A0767			23A0768			23A0769			23A0770			23A0771			23A0772			23A0773			23A0774			23A0775			23A0776			23A0777			23A0778			23A0779			23A0780			23A0781			23A0782			23A0783			23A0784			23A0785			23A0786			23A0787			23A0788			23A0789			23A0790			23A0791			23A0792			23A0793			23A0794			23A0795			23A0796			23A0797			23A0798			23A0799			23A0800			23A0801			23A0802			23A0803			23A0804			23A0805			23A0806			23A0807			23A0808			23A0809			23A0810			23A0811			23A0812			23A0813			23A0814			23A0815			23A0816			23A0817			23A0818			23A0819			23A0820			23A0821			23A0822			23A0823			23A0824			23A0825			23A0826			23A0827			23A0828			23A0829			23A0830			23A0831			23A0832			23A0833			23A0834			23A0835			23A0836			23A0837			23A0838			23A0839			23A0840			23A0841			23A0842			23A0843			23A0844			23A0845			23A0846			23A0847			23A0848			23A0849			23A0850			23A0851			23A0852			23A0853			23A0854			23A0855			23A0856			23A0857			23A0858			23A0859			23A0860			23A0861			23A0862			23A0863			23A0864			23A0865			23A0866			23A0867			23A0868			23A0869			23A0870			23A0871			23A0872			23A0873			23A0874			23A0875			23A0876			23A0877			23A0878			23A0879			23A0880			23A0881			23A0882			23A0883			23A0884			23A0885			23A0886			23A0887			23A0888			23A0889			23A0890			23A0891			23A0892			23A0893			23A0894			23A0895			23A0896			23A0897			23A0898			23A0899			23A0900			23A0901			23A0902			23A0903			23A0904			23A0905			23A0906			23A0907			23A0908			23A0909			23A0910			23A0911			23A0912			23A0913			23A0914			23A0915			23A0916			23A0917			23A0918			23A0919			23A0920			23A0921			23A0922			23A0923			23A0924			23A0925			23A0926			23A0927			23A0928			23A0929			23A0930			23A0931			23A0932			23A0933			23A0934			23A0935			23A0936			23A0937			23A0938			23A0939			23A0940			23A0941			23A0942			23A0943			23A0944			23A0945			23A0946			23A0947			23A0948			23A0949			23A0950			23A0951			23A0952			23A0953			23A0954			23A0955			23A0956			23A0957			23A0958			23A0959			23A0960			23A0961			23A0962			23A0963			23A0964			23A0965			23A0966			23A0967			23A0968			23A0969			23A0970			23A0971			23A0972			23A0973			23A0974			23A0975			23A0976			23A0977			23A0978			23A0979			23A0980			23A0981			23A0982			23A0983			23A0984</		
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Z ToFS dE & TKE

DATA

5. Detector system requirements

Detector systems for incoming experiments (#5048 & #5120)



Questions

- Si-detector stack : thickness & size
 In-flight ^{238}U -fission experiment
 ^{208}Pb fragmentation experiment
- ^{208}Pb fragmentation experiment detector system: identification & intensity.

Possible components

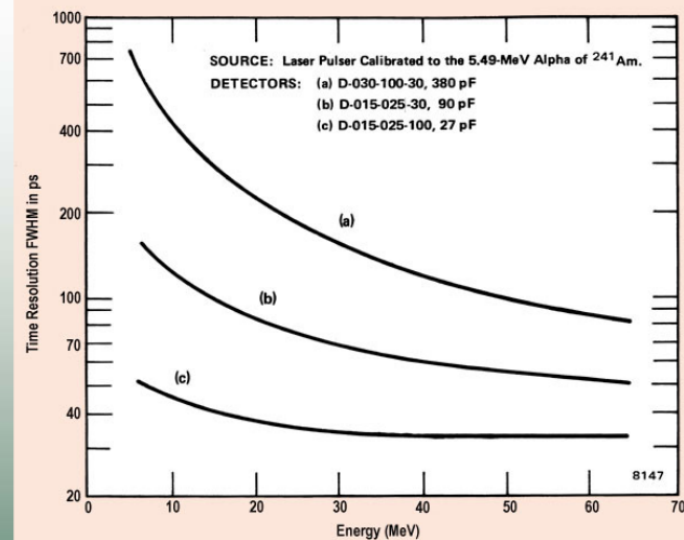
I2	FP
MCP (t)	Si-stack (dE, TKE)
MCP (x)	Si-stack (t)
Sci (t)	PPAC (t)
Sci (x)	PPAC (x)
PPAC (t)	MCP (t)
PPAC (x)	MCP (x)
Diamond (t)	Diamond (t)

Time resolution

It is planning to use for TOF-measurement the MCP detector (or Scintillator) in the intermediate focal plane (I2) and the **Si-detector** in the final focal plane.

$E(^{123}\text{Ag}) = 90.93 \pm 0.165 \text{ MeV/u}$
 TOF-detectors: Scintillator (20 mg/cm^2) and Si ($501 \mu\text{m}$)

Component	$\sigma(\text{TOF})$ ns	FWHM(TOF) ns
Fragment Energy	0.115	0.271
Experiment	0.271	0.444
detectors	0.149	0.352
		0.24%



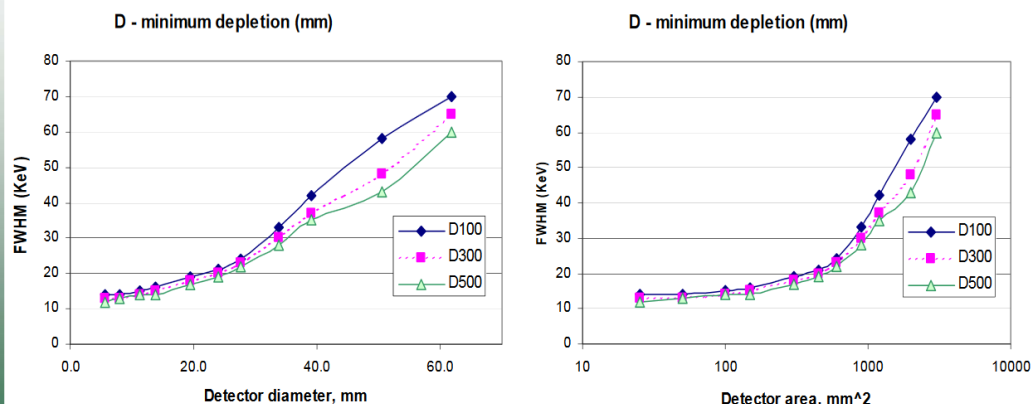
Resolution_{time} $\sim$ Thickness $\times$ / Area $\sqrt{}$

Typical Time Resolution vs. Energy for

Energy resolution of semiconductor detectors

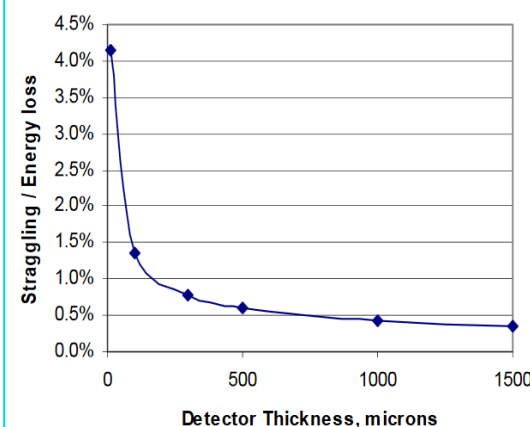
Guaranteed Maximum Resolution (ORTEC)

For 5.486-MeV alphas
 (FWHM/E are equal to 1.06%, 0.87%, 0.78% for diameter=50mm)

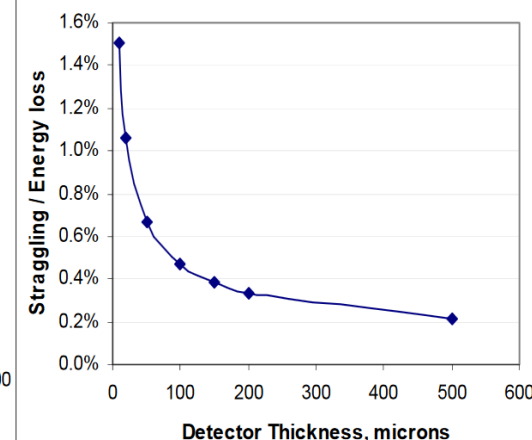


Energy straggling

Straggling (^{64}Zn 118MeV in Si-detector)



Straggling (^{202}Os 70MeV in Si-detector)



http://lise.nsl.mscl.msu.edu/paper/2006_february_detectors.pdf

Z resolution at large acceptance

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

$\sigma(Z)$: $^{202}\text{Os}^{74+}$, straggling coefficient=1

Energy = 70 MeV/u
Length = 18 m
dp/p=1.0%

Energy Loss detector
Si (t=300 μm , $\Delta t=0.5 \mu\text{m}$)

Main contribution in the $\sigma(Z)$ value
the large acceptance (dp/p=1.0%)
the Si dE-detector resolution
($\sigma(\text{dE})/\text{dE}=0.43\%$)

$\sigma(Z)$: Configuration MCP

	$\sigma_{\text{Acc}}(Z)$	1
^{208}Pb	0.11	0.29
^{202}Os	0.10	0.27
^{184}Yb	0.08	0.25
^{124}Sn	0.03	0.22

$\sigma_{\text{Acc}}(Z)$ – St.Dev of Z due to the acceptance value
suggesting all other contributions equal to zero

Z_{formula} validity ($\sigma_v(Z)=0.02$) was taken into account for $\sigma(Z)$.

"Banana" (A-3Q) resolution

Configurations			$\sigma(A)$:				^{202}Os	
I2	FP(TOF)	mode	$\sigma(\beta)/\beta$	$\sigma(\pi)/\pi$	$\sigma(\text{TKE})/\text{TKE}^*$	$\sigma(A-3Q)^*$		
			%	%	%			
MCP	Si	A	0.127	1.00	0.58 / 0.38	0.30 / 0.28		
MCP	Si		0.094	0.74	0.55 / 0.35	0.24 / 0.21		
MCP	MCP	A	0.113	0.89	0.58 / 0.38	0.28 / 0.25		
MCP	MCP		0.073	0.58	0.55 / 0.35	0.21 / 0.18		
Sci	Si	A,S	0.123	0.97	0.58 / 0.38	0.29 / 0.27		
Sci	PPAC	A,S	0.123	0.97	0.58 / 0.38	0.29 / 0.27		
Sci	PPAC		0.088	0.70	0.55 / 0.35	0.23 / 0.20		
Dia	Si	A,S	0.117	0.92	0.58 / 0.38	0.28 / 0.26		
PPAC	Si	A	0.140	1.11	0.58 / 0.38	0.32 / 0.30		
PPAC	PPAC	A	0.127	1.00	0.58 / 0.38	0.30 / 0.28		
PPAC	PPAC		0.111	0.88	0.55 / 0.35	0.27 / 0.25		
PPAC	RF+Si		0.438	3.44	0.55 / 0.35	0.91 / 0.90		

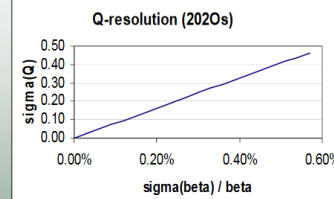
* $\sigma(\text{TKE})/\text{TKE}$ are taken for two different TKE configurations

It is Possible to separate isotopes using this method!
The time resolution is crucial factor

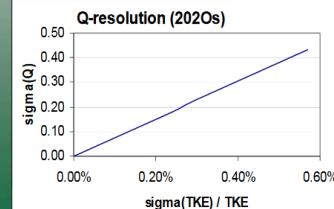
Q resolution

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

$$\sigma(Q) = f(A, Z, \sigma(\beta))$$



$$\sigma(Z) = f(A, Z, \sigma(\text{TKE}))$$



Configurations			$\sigma(Q)$:			^{202}Os	
I2	FP(TOF)	mode	$\sigma(\beta)/\beta$	$\sigma(\text{TKE})/\text{TKE}^*$	$\sigma(Q)^*$		
			%	%			
MCP	Si	A	0.127	0.58 / 0.38	0.45 / 0.30		
MCP	Si		0.094	0.55 / 0.35	0.42 / 0.28		
MCP	MCP	A	0.113	0.58 / 0.38	0.45 / 0.30		
MCP	MCP		0.073	0.55 / 0.35	0.42 / 0.27		
Sci	Si	A,S	0.123	0.58 / 0.38	0.45 / 0.30		
Sci	PPAC	A,S	0.123	0.58 / 0.38	0.45 / 0.30		
Sci	PPAC		0.088	0.55 / 0.35	0.42 / 0.27		
Dia	Si	A,S	0.117	0.58 / 0.38	0.45 / 0.30		
PPAC	Si	A	0.140	0.58 / 0.38	0.45 / 0.31		
PPAC	PPAC	A	0.127	0.58 / 0.38	0.45 / 0.30		
PPAC	PPAC		0.111	0.55 / 0.35	0.43 / 0.28		
PPAC	RF+Si		0.438	0.55 / 0.35	0.53 / 0.43		

* $\sigma(\text{TKE})/\text{TKE}$ are taken for two different TKE configurations

Two main $\sigma(\text{TKE})/\text{TKE}$ components are Si-resolution and "dead" layer.

TKE configurations			$\sigma(Q)$: Configuration MCP+Si+A	
	1	2		
Resolution of Si	0.43%	0.34%	Configuration	
Dead layer	0.34%	0.10%	1	2
			^{208}Pb	0.49 0.33
			^{202}Os	0.45 0.30
			^{184}Yb	0.42 0.28
			^{124}Sn	0.30 0.20

http://lise.nsl.mscl.msu.edu/paper/2006_february_detectors.pdf

Si-detector stack

Factor	Thickness		Size		Comments
Energy Detector Resolution	Increasing	☹☹			Increasing Energy loss value
Energy Resolution noise	Increasing	☹	Decreasing	☹☹	Increasing Energy loss value
Energy Straggling, Charge state fluctuations	Increasing	☹☹☹☹			
A,Z,Q identification formulas validity	Increasing	☹			100-500 microns
Time Resolution	Increasing	☹	Decreasing	☹☹	
Thickness "defect"	Increasing	☹	Decreasing	☹	
Spectra Cleaning	Decreasing	☹			should be 2-4 dE detectors
Detector cost	Increasing	☹	Decreasing	☹☹	
Detector size (horizontal)			25-30 mm for fragmentation		circle or rectangle shapes.
			40-60 mm for fission		we do not need large vertical size

Proposed configuration: 3 X 300 * 3 X 1000 Scintillator

- * Fission H.Size = 50 mm (30?)
- * Fragmentation H.Size = 30 mm

Final table of resolution values for ^{202}Os

Configurations			$\sigma(Z)^*$	$\sigma(A)^*$	$\sigma(Ai)$	$\sigma(Q)^*$	$\sigma(A-3Q)^*$
I2	FP(TOF)	FP(X)					
MCP	Si		.26/.36	1.30/0.96	0.30	.45/.30	.30/.28
MCP	MCP		.26/.35	1.28/0.92	0.26	.45/.30	.28/.25
Sci	Si		.26/.36	1.30/0.95	0.29	.45/.30	.29/.27
Sci	PPAC		.26/.36	1.30/0.95	0.29	.45/.30	.29/.27
Dia	Si		.27/.35	1.29/0.93	0.27	.45/.30	.28/.26
PPAC	Si		.27/.36	1.33/0.99	0.33	.45/.30	.32/.30
	RF+Si		.41/.48	2.27/2.11	1.02	.53/.43	.91/.90
With B _p -corrections							
MCP	Si		0.27		0.23	.45/.31	.26/.23
MCP	Si	PPAC	0.27		0.25	.45/.31	.28/.25
MCP	MCP	MCP	0.27		0.21	.45/.30	.25/.22
MCP	PPAC	PPAC	0.27		0.25	.45/.31	.28/.25
Sci	Si		0.27		0.26	.45/.31	.30/.28
Sci	PPAC		0.27		0.26	.45/.31	.30/.28
Sci	PPAC	PPAC	0.27		0.28	.45/.31	.31/.29
PPAC	Si		0.27		0.29	.46/.33	.30/.28
PPAC	PPAC		0.27		0.29	.46/.33	.30/.28
PPAC	PPAC	PPAC	0.27		0.29	.46/.33	.30/.28
PPAC	RF+Si		0.41		0.29	.85/.79	.92/.91

* Straggling coefficient equal to 1 (left) and 2 (right) accordingly

* Different TKE-configurations

TKE configurations	1	2
Resolution of Si	0.43%	0.34%
Dead layer	0.34%	0.10%

Main contribution

Calculated Value	from
$\sigma(Z)$	dE
$\sigma(A)$	TKE
$\sigma(Ai)$	β
$\sigma(Q)$	TKE
$\sigma(A-3Q)$	β , B _p

Main contribution

Calculated Value	from
dE	E _{det-resol.} , stragg.
β	Accept, T _{det-resol.}
TKE	TKE _{det-resol}
B _p	X-object, X _{det-resol.}

More difficult case is $\sigma(Q)$,
or by another words TKE

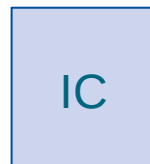
Assume the ^{238}U beam $\rightarrow$ fission ($Z=25-75$) and fragmentation ($Z=75-92$)

different ranges: where and how to get qualitative dE & TKE measurement for both reaction product types?

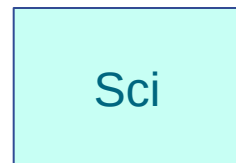
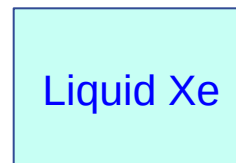
1. PIN-diode telescope : good resolution, but large numbers for high energy, radiation durability, dead (non-depletion, windows) layers
2. Scintillators : moderate E-resolution, but thick
3. IC : relatively thin, E-resolution?

2-4 PIN diodes

It's good for a fragment-separator, but for HRS we need detectors with larger area



dE



TKE

Sci (Veto) :
Multifragmentation,
reactions in detectors



Spectrometers

1. ToF detectors (spectrometer case) : start(where?) & stop
2. X, X', Y, Y' detectors in the Dispersive focal plane
($B\rho$ -resolution, inverse reconstruction)
3. dE, ToF, TKE for full identification (A, Z, q, E)
4. Wide Z-range of products
5. Radiation resistance
6. PID confirmation (isomers) – Gamma detectors vs. Large size PID detectors
7. Multi-particles registration

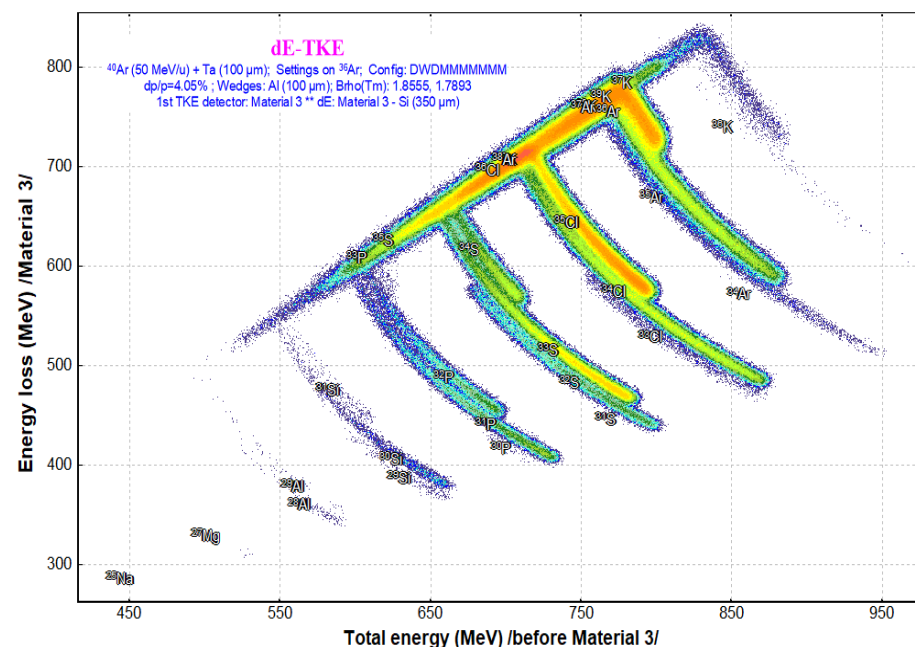
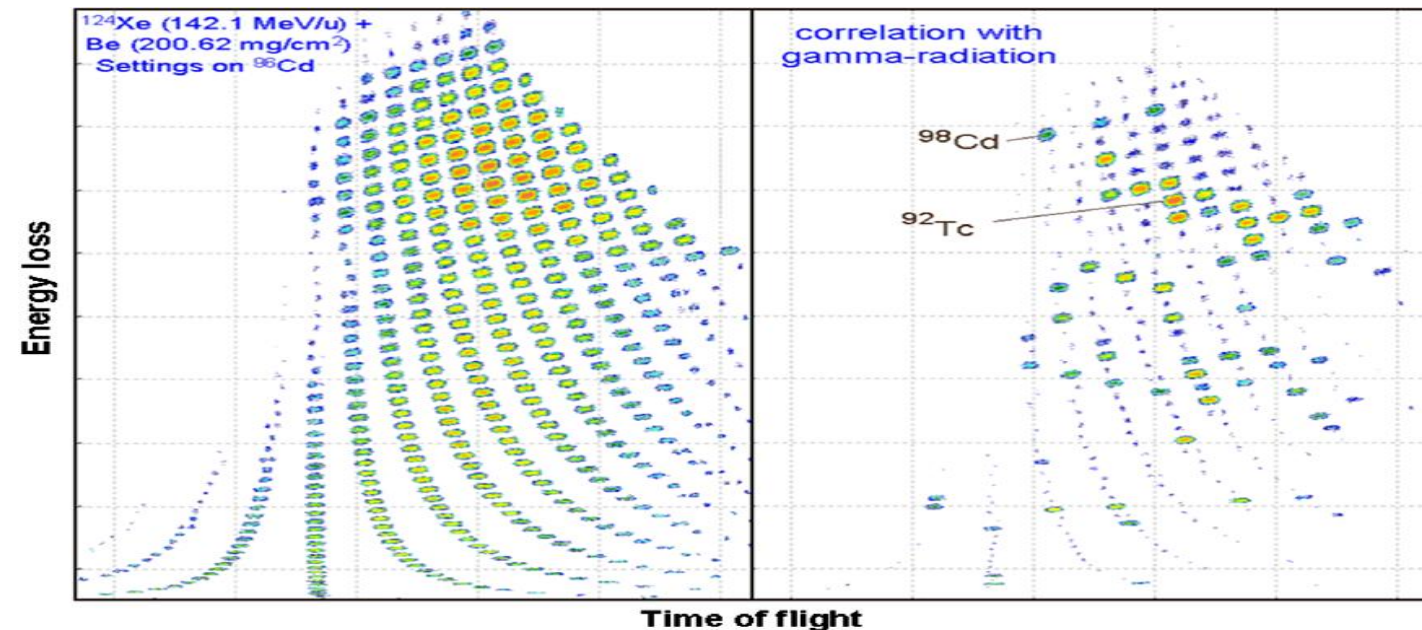
Separators

1. Signals Doubling (filtering)
2. Si-detectors: Depletion issue
3. Optical trajectory reconstruction (Isochronous term (L/δ))

6. Irreplaceable helper for PID

LISE⁺⁺

LISE⁺⁺_{*cute*}



Comfort
Speed
Quality
Large Variety of destinations

Would like to thank
colleagues
for Inspiring, discussions,
feedbacks, requests, advices,
collaborations



Thank you for
choosing our
company!

We appreciate your
business

Nuclear Instruments and Methods in Physics Research B 376 (2016) 168–170

Plans for performance and model improvements in the LISE⁺⁺ software
M.P. Kuchera, O.B. Tarasov, D. Bazin, B.M. Sherrill, K.V. Tarasova

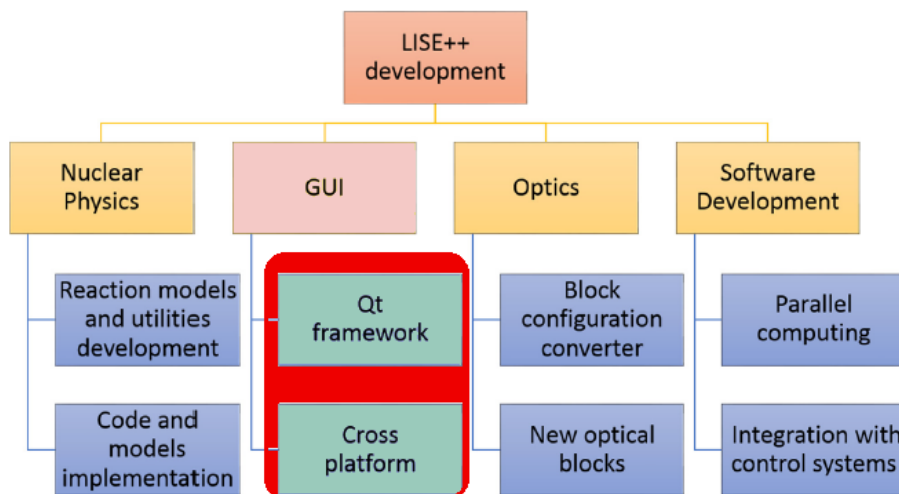
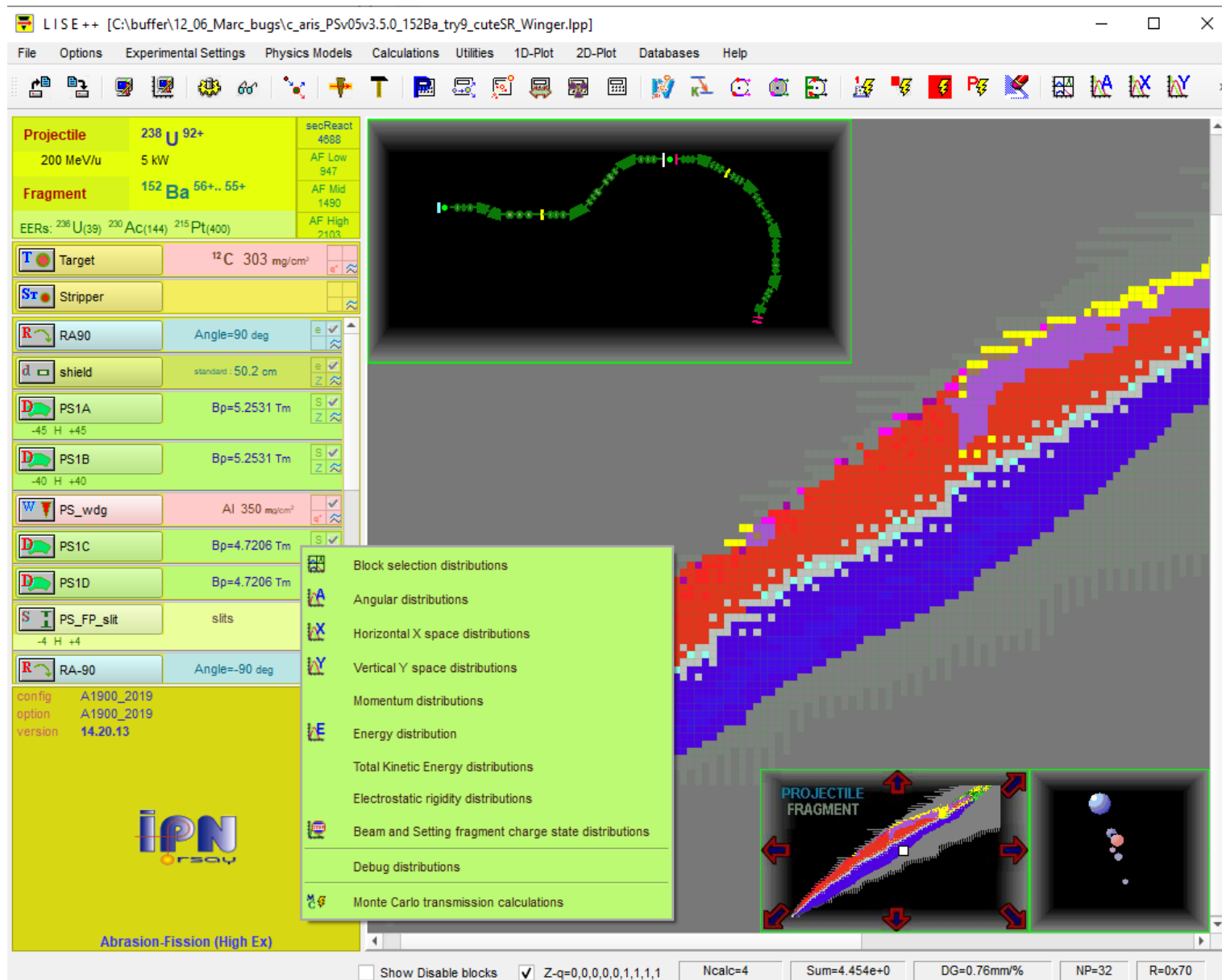


Fig. 1. A schematic diagram of the LISE⁺⁺ development plans.

The LISE⁺⁺ software suite is undergoing a major transportation to a new graphics framework in order to support modern compilers and computing methods.

Qt framework. For compatibility with future operating systems, the graphics framework is being transported to Qt. Benefits include provisions for 64-bit operation, cross-platform compatibility, and the ability to take advantage of computational advances. Qt was chosen as the graphics framework based on its cross-platform capabilities, large feature set, and widespread use in cross-platform C++ applications. Qt is a package of C++ graphics libraries that has great benefits for developing applications for nearly all operating systems and devices. The code remains essentially identical for all platforms, which allows for easy compilation of executable programs for any operating system or device. We will release Windows, Mac, and Linux versions of the software.



1. Next week : announce to experts about the new version to benchmark and update their configurations
2. LISE⁺⁺_{cute} version can be downloaded free from the LISE site next week
3. The official version will be released at the end of January
4. A lot of new features. Some old bugs were solved. Hope, that new bugs number is small 😊 and they will be fixed during the next month with your help.



Index of/download

Name	Last modified	Size	Description
Parent Directory	-	-	-
LISE++ 12 1 2.exe	2020-02-10 12:07	20M	
LISE++ 13 4 5 beta.exe	2020-05-04 12:56	20M	
Linux/	2020-12-12 03:48	-	
MS open versions/	2020-12-12 04:21	-	
macOS/	2020-12-11 13:55	-	
other/	2019-09-16 12:41	-	

Help	
Documentaton	
Production of Fast Rare Ion Beams (lectures)	
Check for new version	
Contact to us (e-mail)	General questions, Reaction mechanism
Register now	Operations in MS Windows
Our web-sites	Operations in Mac OS
Partner sites	Operations in Linux(UNIX)
Update My Documents\LISE with last installation	
View of spectrometer	
Periodic Table of Elements	
About ...	

		Porting schedule			
		37	38	39	40
		49	50	51	52
		11-Dec	18-Dec	25-Dec	1-Jan
SetupPanel	Layout, Timer	0.1	done		
	StatusBar		done		
Plots	Graphics	0.1	done		
	Connection		done		
	Benchmarks		done		
Dynamical menu		done	done		
Monte Carlo calculations	Graphics	done	done		
	Benchamrk	0.1	done		
Read/Write	Files	done	done		
Options Results configuraton Append		done	done		
Restore/Document LISE structure	initialization/closing	0.1	0.1		
	rerdraw, cleaning	0.1	done		
Tune separator	middle brho	done	done		
d_CN -- table of isotopes	benchamrks	done	done		
Table of Nuclides	sizes	done	done		
Application size (adaptation to HDPI)		0.1	0.1		
correction and updates list		0.1	done		
remake WinHelp links		0.1	done		
HighOrderOptics & ReactionInMaterial		done	done		
ATIMA 1.4		done	done		
LIBRARIES, Codes (Charge ...)		0.1			
New version - html access		done	done		
dialog About		0.1	done		
Creation of multiplatform versions				0.3	
installation of multiplatform versions					
benchmarks & corrections			0.2	0.7	1
benchmarks & corrections		1	1	1	1
char * -->QString					
Profile					
OT@MSU 12/11/2020		2	1.5	2	2.10

Thank you
for your attention!

Be healthy!

Do not forget to download **LISE⁺⁺_{cute}**