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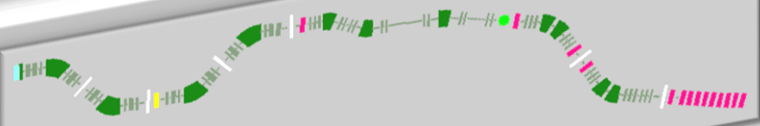
December 16, 2020

Rare Isotope Beams
Particle Identification

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

Workshop on Techniques and Detectors for Heavy-ion Charge-

LISE++



LISE++

Table of Contents

1. PID introduction

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

http://lise.nscl.msu.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"

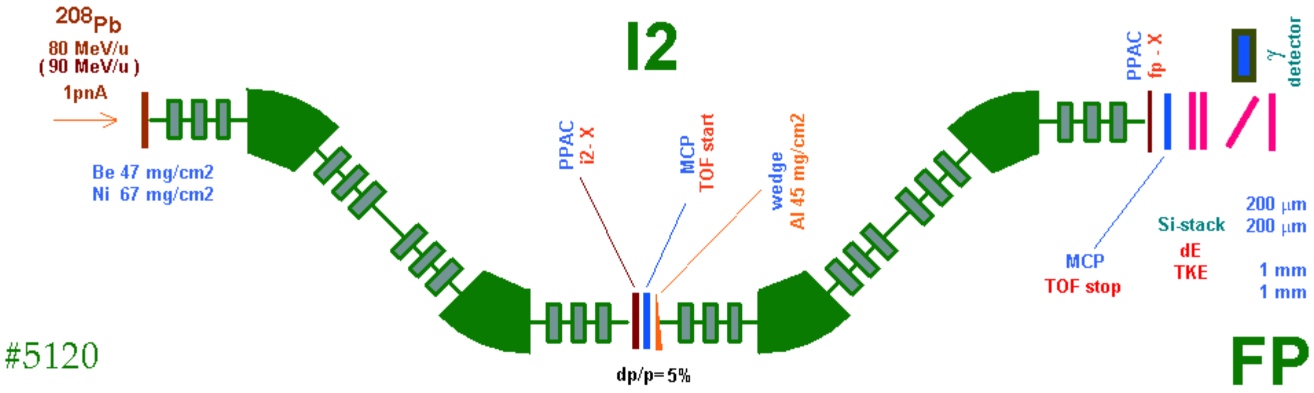
1. Bρ: Magnetic (electric) rigidity
2. dE: Energy loss in detector (material)
3. ToF: Velocity (time of flight)
4. TKE: Total kinetic energy

1–3: "fast"

1–4: "stopped"

Obtaining A, Z, q

	stopped beams		fast beams
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, Bρ* $A/q = \frac{B\rho}{\beta\gamma} \frac{c}{m_u}$
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, Bρ*	$q = 3.33 \times 10^{-3} \frac{TKE \times \beta\gamma}{B\rho \, (\gamma - 1)}$	



PID assignment

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 (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

See for details http://lise.nscl.msu.edu/paper/Euroschool2013/4_Identification.pdf

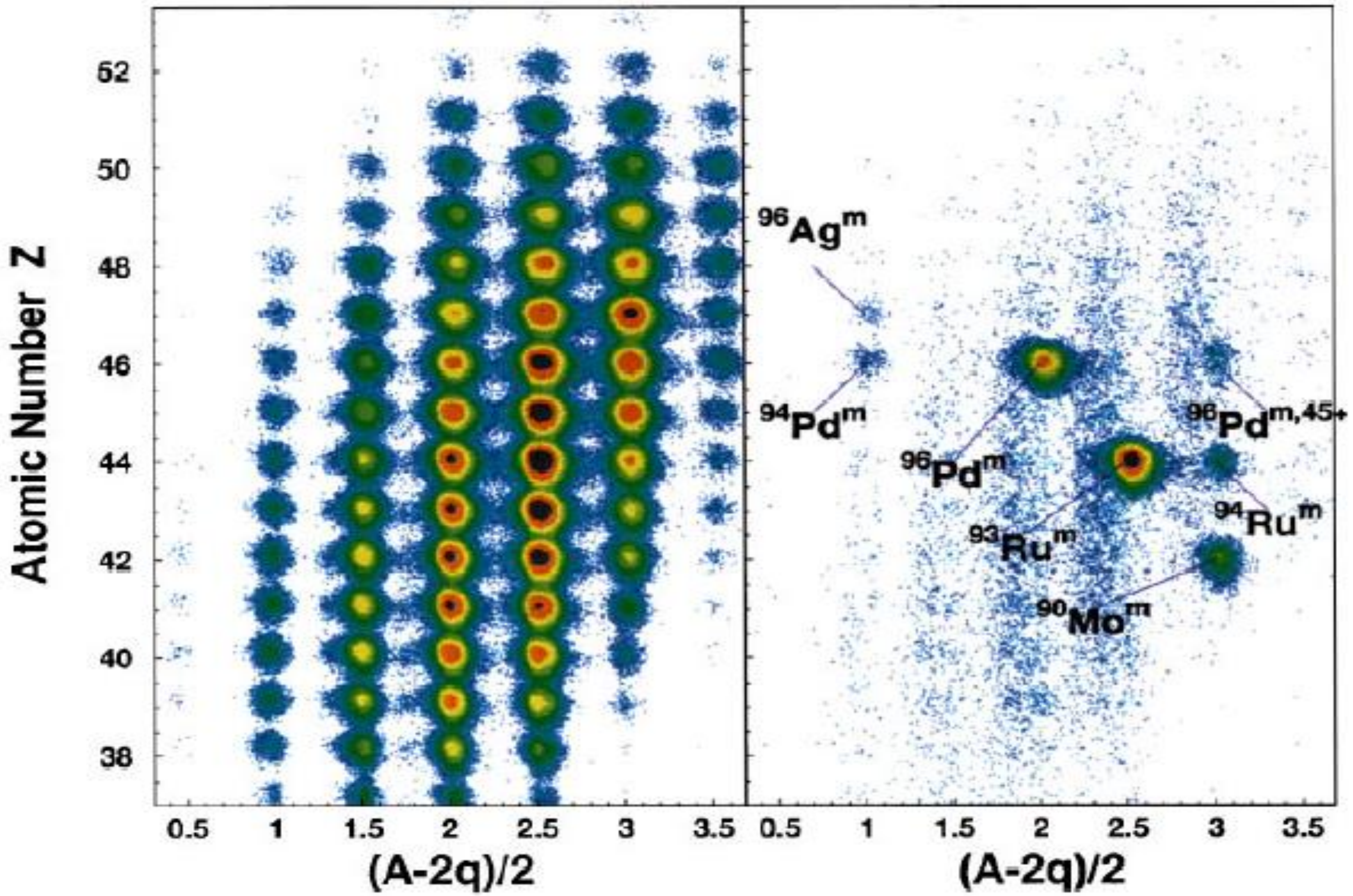
Identification with μs-isomers

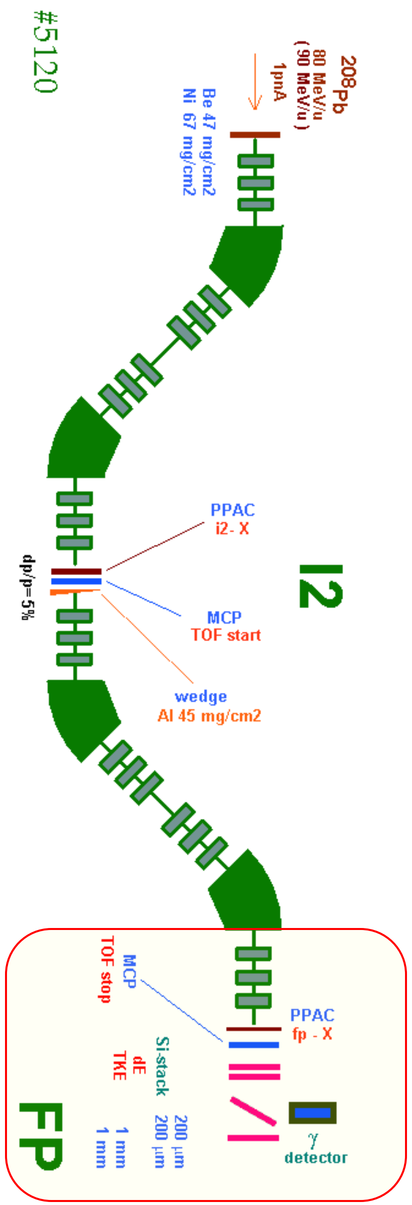
Stopped fragment tagging with isomeric gamma-rays

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

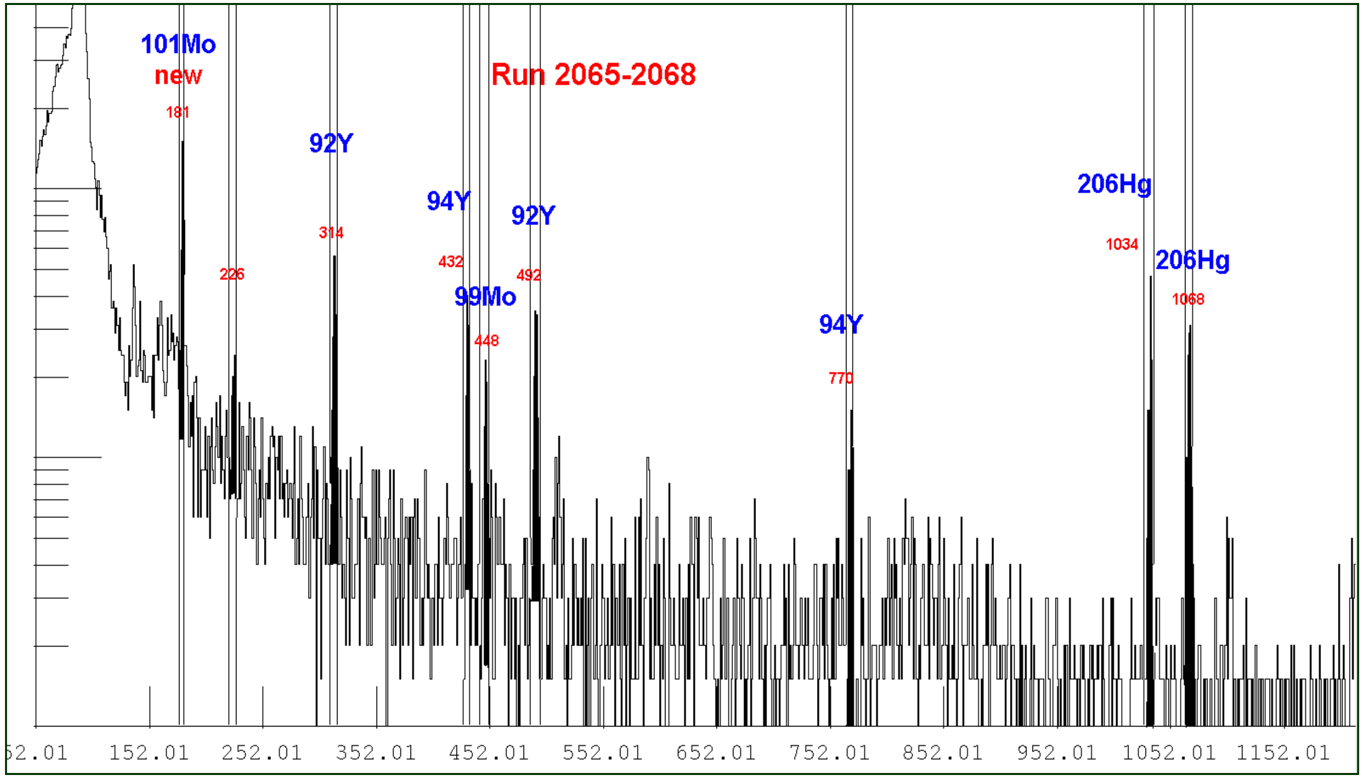
R. Grzywacz,[1,2] R. Anne,[2] G. Auger,[2] C. Borcea,[3] J. M. Corre,[2] T. Dörfler,[4] A. Fomichov,[5] S. Grevy,[6] H. Grawe,[7] D. Guillemaud-Mueller,[6] M. Huyse,[8] Z. Janas,[7] H. Keller,[7] M. Lewitowicz,[2] S. Lukyanov,[5,2] A. C. Mueller,[6] N. Orr,[9] A. Ostrowski,[2] Yu. Penionzhkevich,[5] 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]

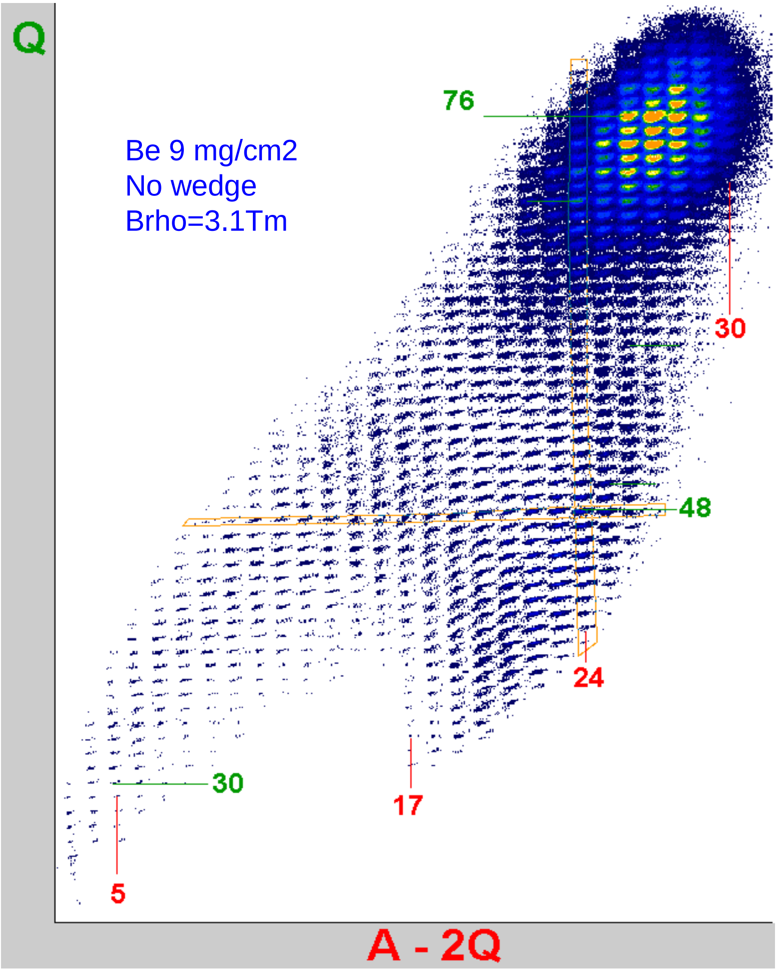




Example of Stopped fragment tagging with isomeric gamma-rays

NSCL #05120
^{208}Pb (86 MeV/u) + Be

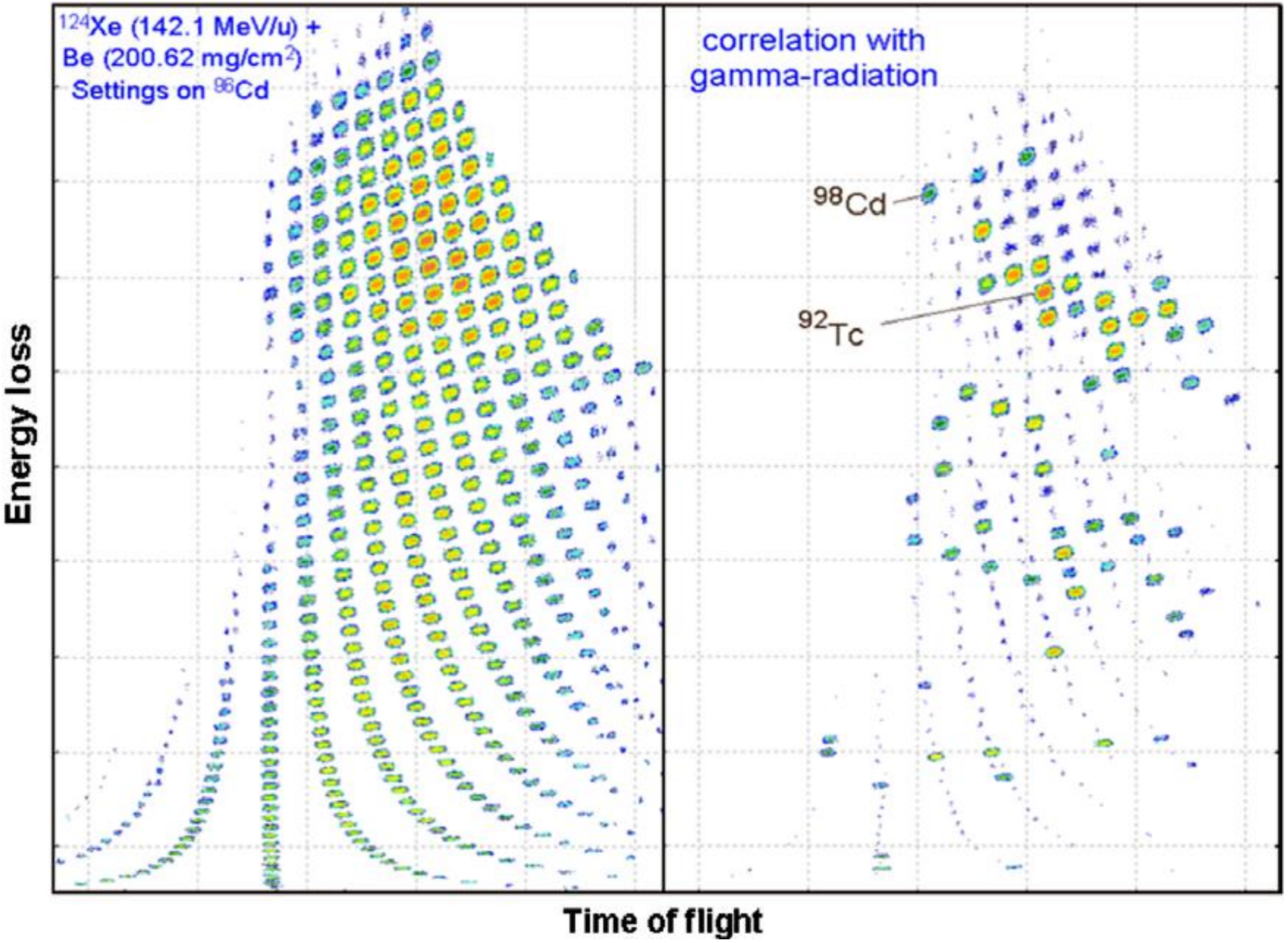




Gamma Information

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^{++}



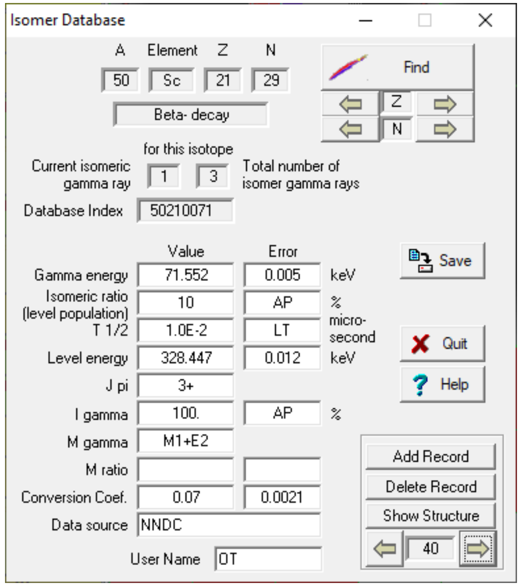
LISE^{++} identification plot of all nuclei produced in the reaction ^{124}Xe + Be (left panel) and those in coincidence with gamma-radiation (right panel)

http://lise.nscl.msu.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^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).



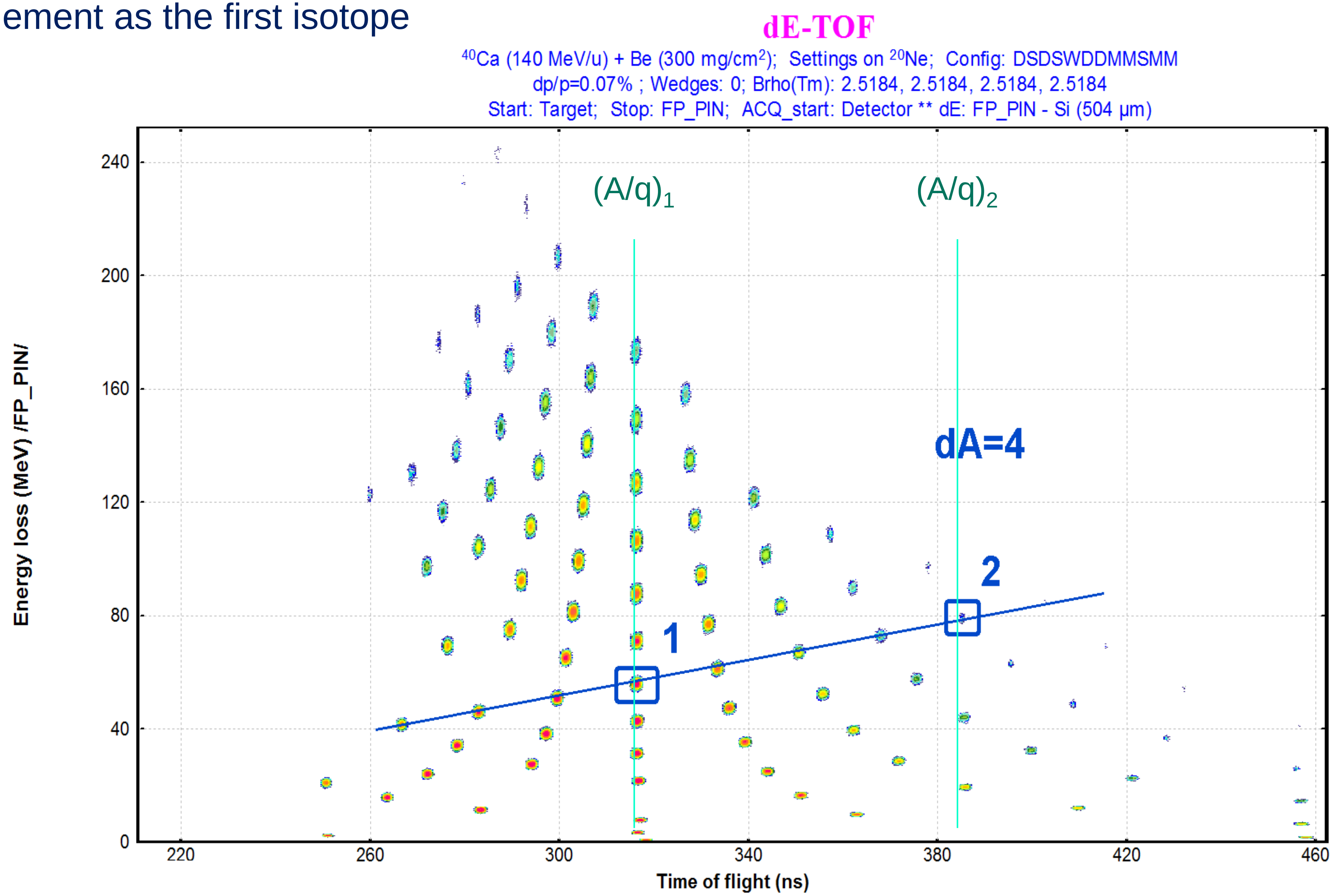
A,*Z* -identification based on *A*/*q*-lines

A,Z -identification based on *A/q*-lines (Elaine's formula)

$(A/q)_1$ isotope – should be 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

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

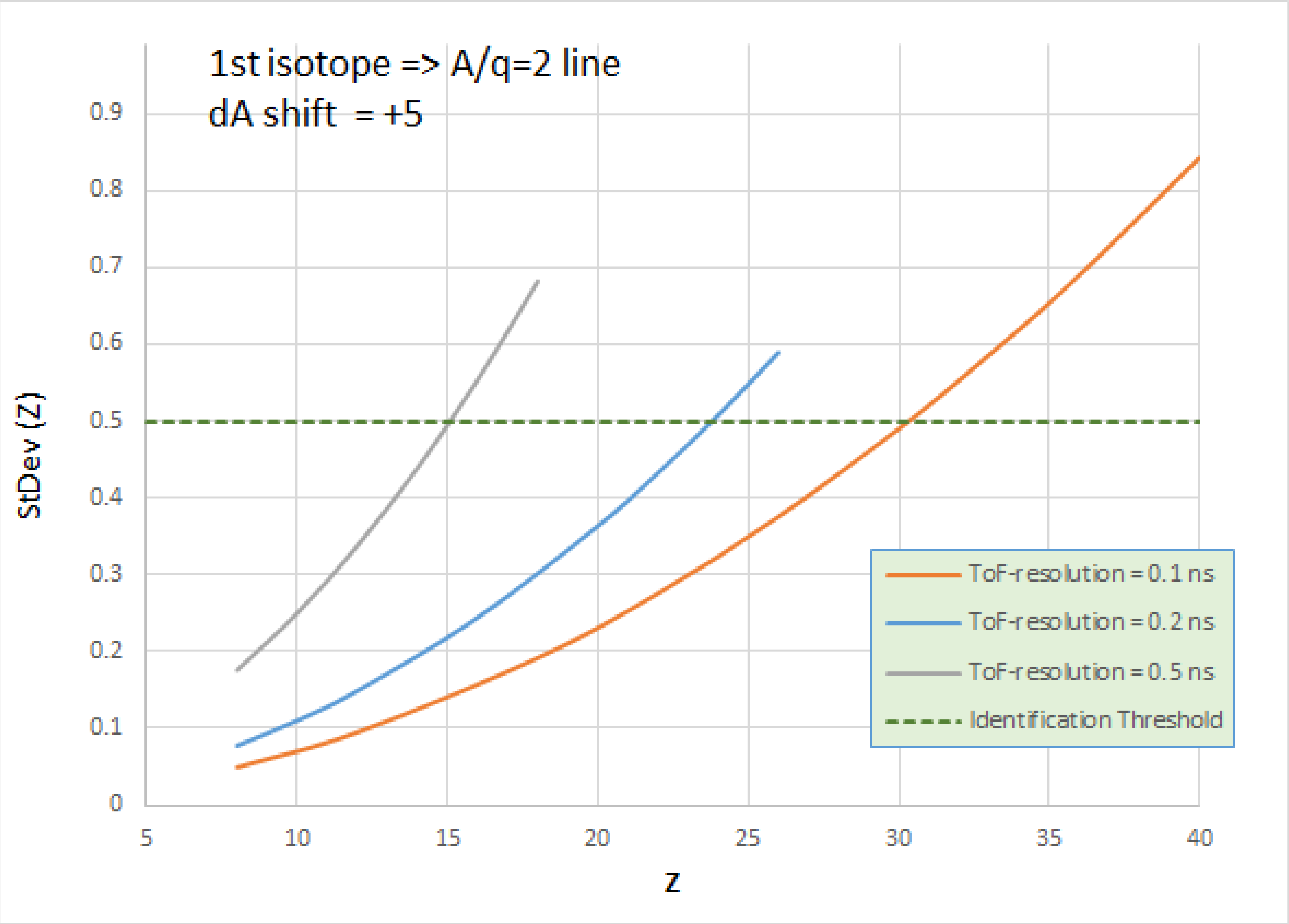
- For Light Z
- Non-wedge settings
- ToF-calibration should be done to have A/q



New PID capabilities and features : timing resolution

All calculations were done for
- A1900 separator
- No wedge
- E(1st fragment)=120 MeV/u
- I1_slits = ± 1mm

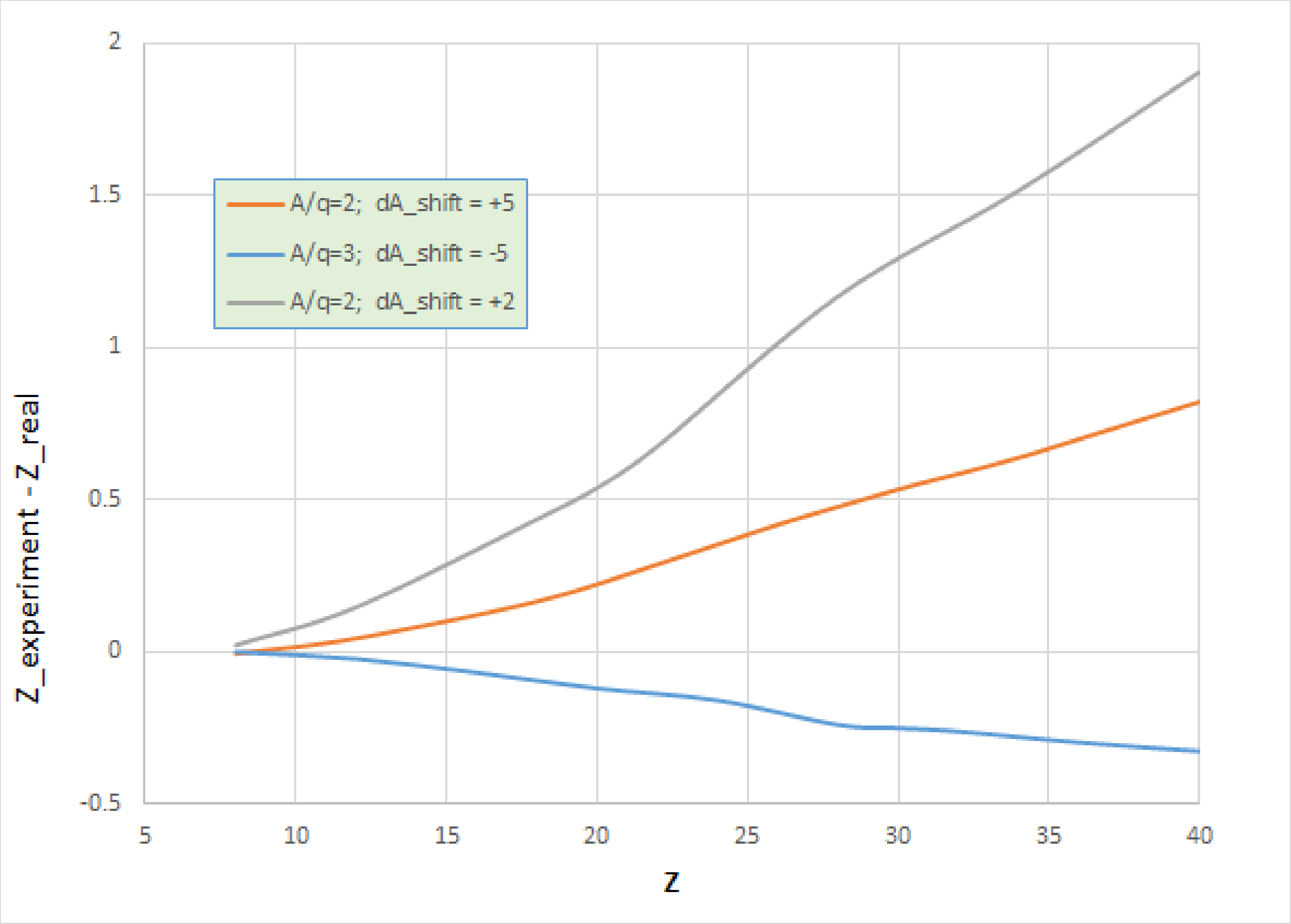
Under current conditions, the identification above Calcium is possible



New PID capabilities and features : extracted Z-value

All calculations were done for

- A1900 separator
- No wedge
- E(1st fragment)=120 MeV/u
- I1_slits = ± 1mm



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

PID resolution calculator

Based on analysis of derivatives

MICHIGAN STATE UNIVERSITY

LISE for Excel

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

Resolution	sigma		systematical (calibration)	
TOF =	0.100	ns	0.01	%
Eloss =	0.60	%	0.33	% *(straggling)*
TKE =	0.40	%	0.10	%
Z =			0.2	%
Momentum (Brho) =	0.0745	%	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			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)	%		Brho	Beta	TKE	E1_loss	Zsyst	A/q	Z
						contribution in error						
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		0.075%	0.026%					
A/q(2)=	2.48728		0.002236	0.090	A/q2	0.076%	0.047%					
PID values			**error (σ)**	**%**								
Z (Eloss) =	50		0.198	0.40			0.020%		0.34%	0.20%		
q =	49.000		0.206	0.42		0.075%	0.024%	0.412%				
A (from TKE) =	119.8753		0.498	0.42			0.050%	0.412%				
A (from [A/q]*q_integer) =	119.8753		0.095	0.08								
A (from [A/q]*q_measur) =	119.8753		0.512	0.43		0.075%	0.026%	0.420%				
A-2q =	21.88		0.122			0.07	0.04	0.09				
A-3q =	-27.12		0.159			0.11	0.02	0.11				
A-2Z * =	22.32		0.131								0.10	0.09

http://lise.nscl.msu.edu/excel.html

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

Resolution criteria for “integer” distributions

PID values	
Z =	50
q =	75.000
A (from TKE) =	119.8747
A (from [A/q]*q_integer) =	119.8748
A (from [A/q]*q_measur) =	119.8747
A-2q =	-30.13
A-3q =	-105.13
A-2Z * =	-20.08

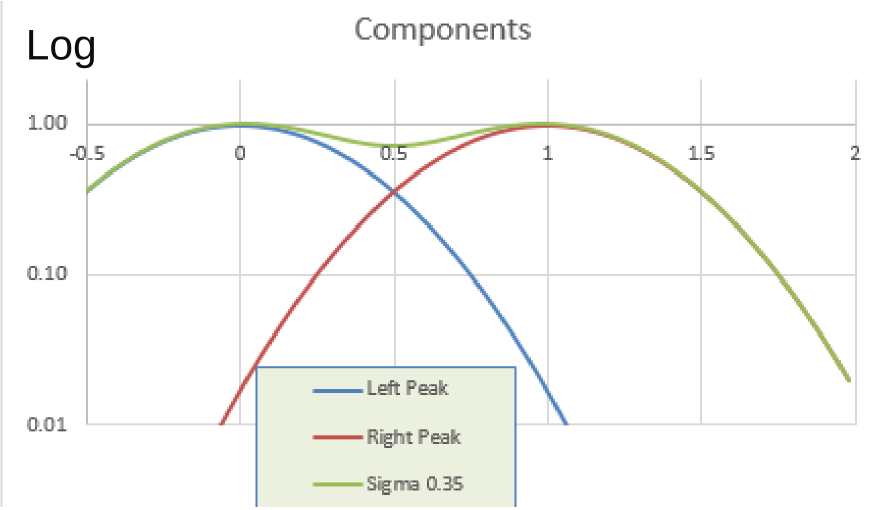
error (σ)
0.185
0.269
0.514
0.175
0.464
0.174
0.361
0.138

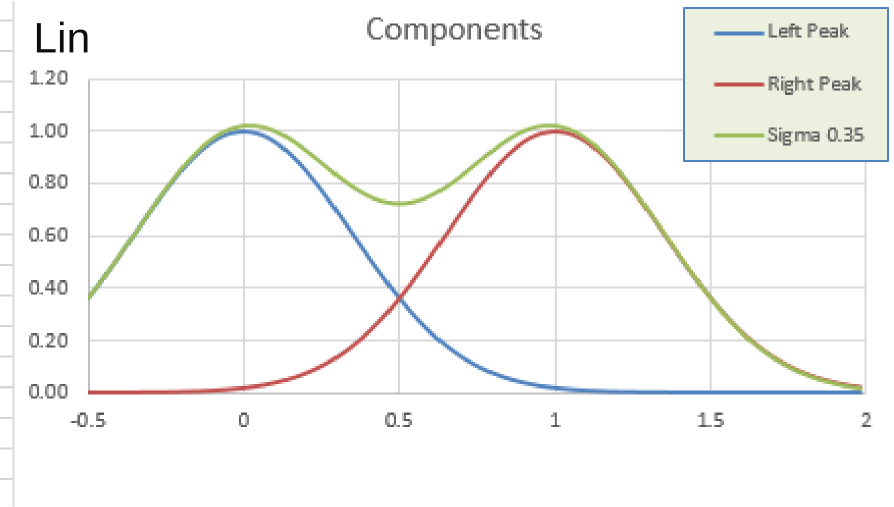
Let’s assume

$\sigma = 0.35$

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 (<x>=0) peak with sigma = 0.35 goes to gate [-0.5, +0.5].
0.14 are coming from neighbors

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

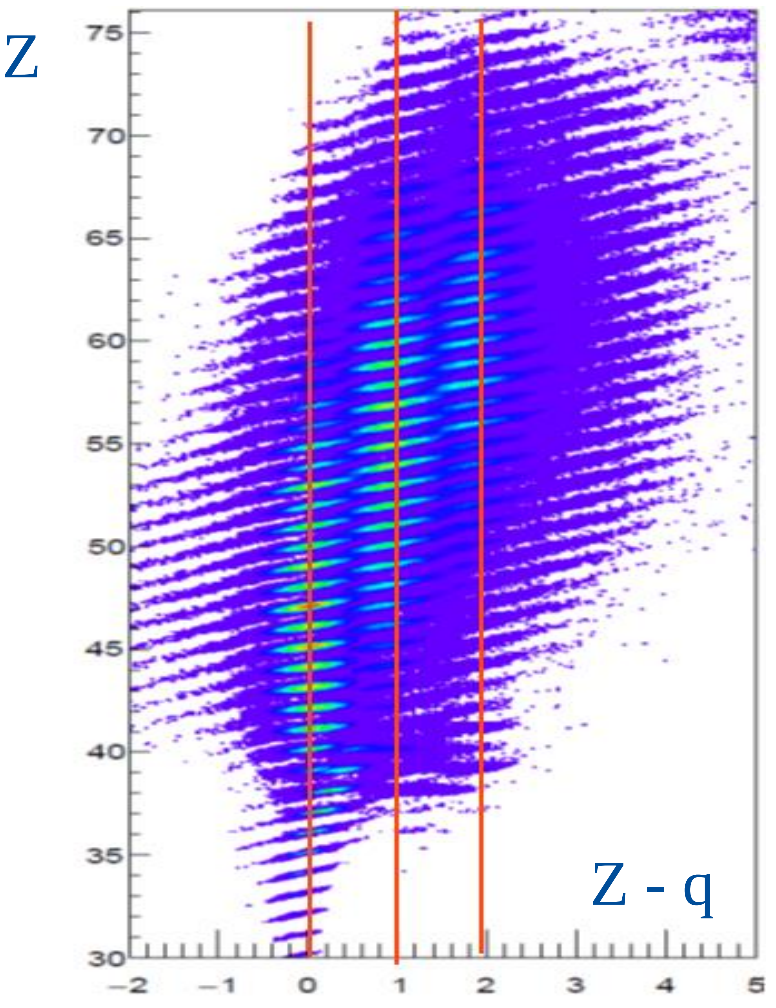
Systematics

A – n · q

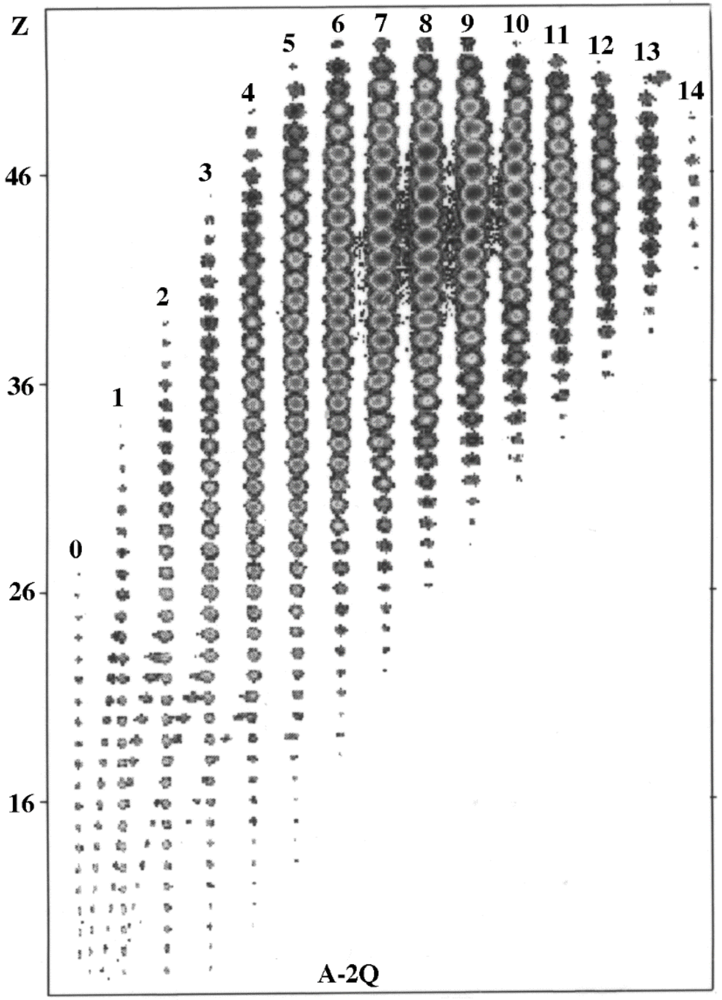
Z – q

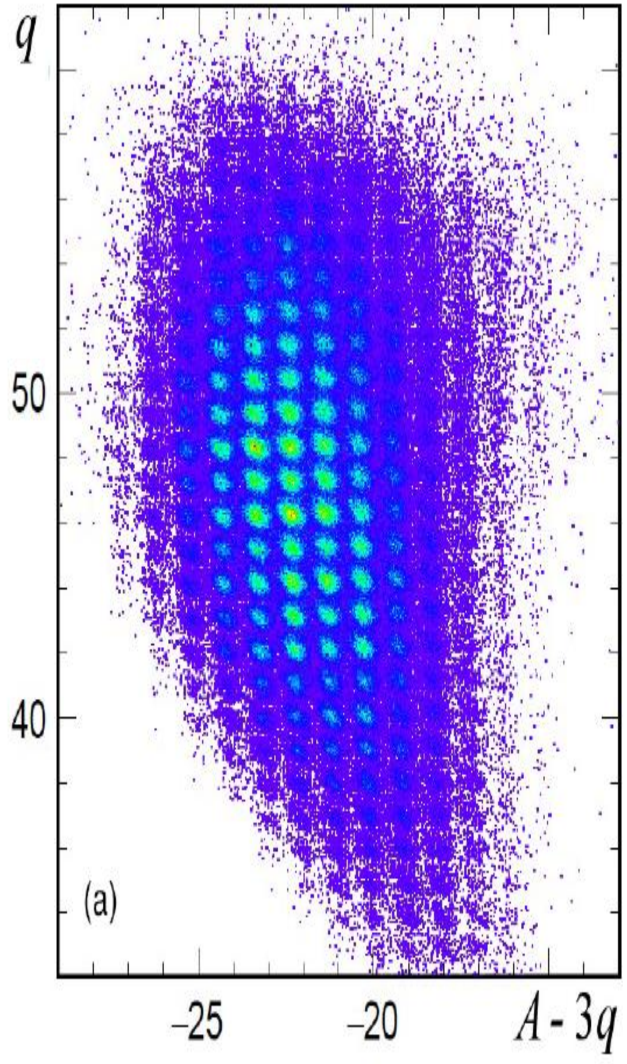
Systematics "A – n · q" & "Z – q"

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





$A - n \cdot q$: mass resolution

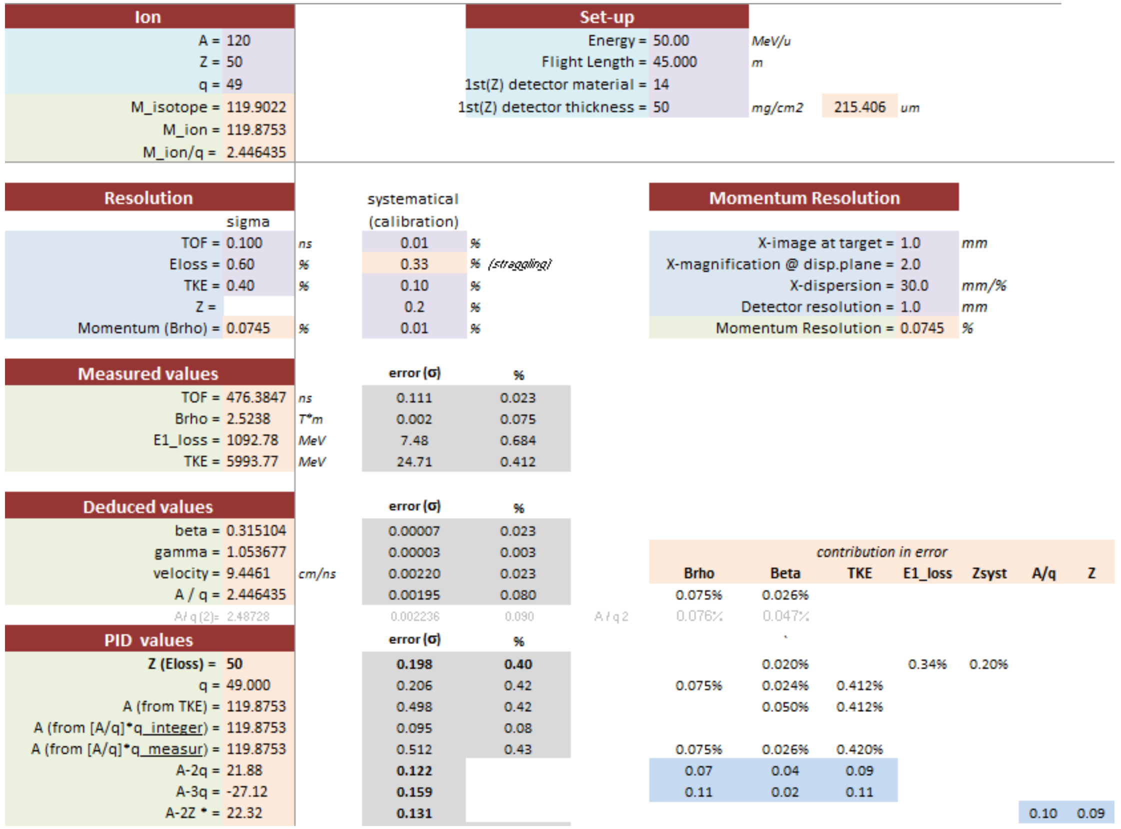
ion				resolution					
A	Z	q	A/q	A/q	A	A	A-2q	A-2.5q	A-3q
					TKE	*(A/q) * q*			
100	50	50	**2.00**	0.00159	0.415	0.427	0.079		0.236
120	50	49	**2.45**	1.95E-03	0.498	0.512	0.122	< 0.1	0.159
136	50	45	**3.02**	2.40E-03	0.565	0.581	0.206		0.107

- 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 $A/Q = 3$.)



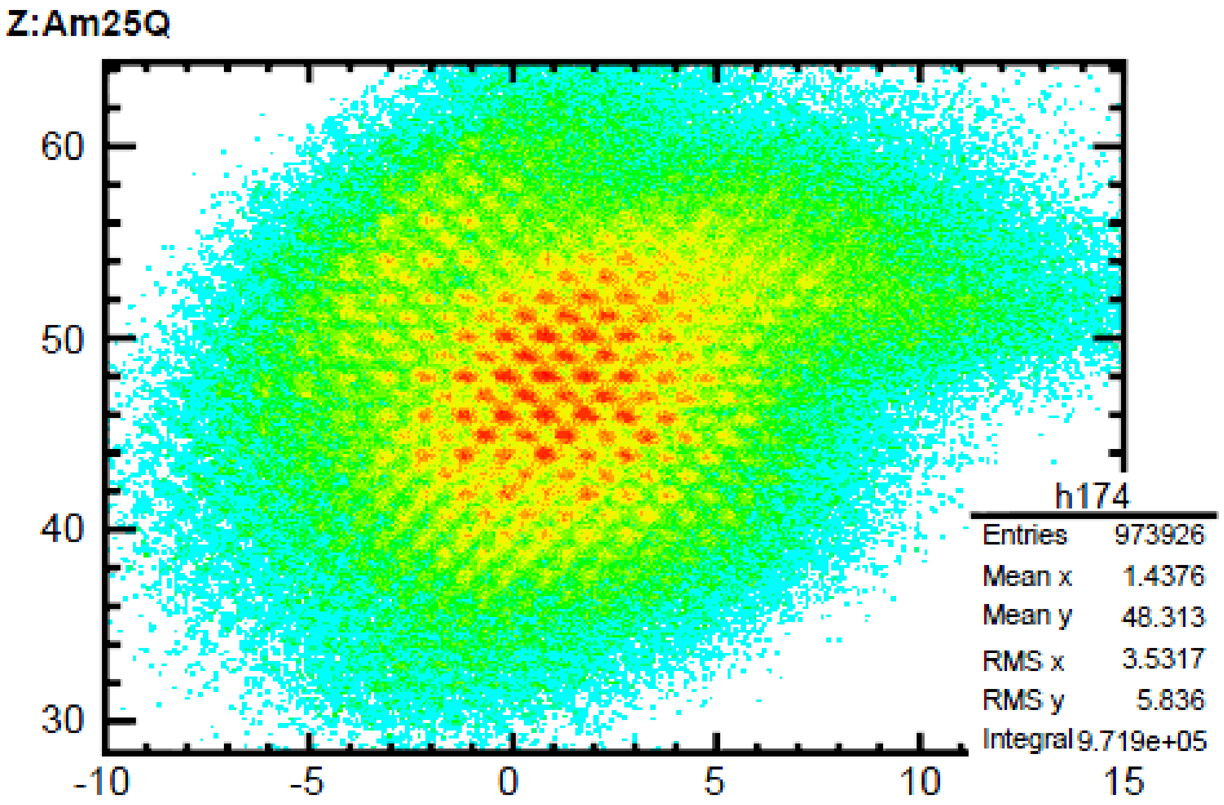
PHYSICAL REVIEW C **96**, 034604 (2017)

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

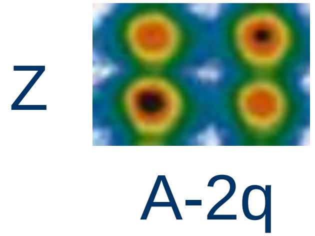
H. Suzuki,[1,*] T. Kubo,[1] N. Fukuda,[1] N. Inabe,[1] D. Kameda,[1] H. Takeda,[1] K. Yoshida,[1] K. Kusaka,[1] Y. Yanagisawa,[1] M. Ohtake,[1] H. Sato,[1] Y. Shimizu,[1] H. Baba,[1] M. Kurokawa,[1] K. Tanaka,[1] O. B. Tarasov,[2] D. Bazin,[2] D. J. Morrissey,[2] B. M. Sherrill,[2] K. Ieki,[3] D. Murai,[3] 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. Steiger[10]

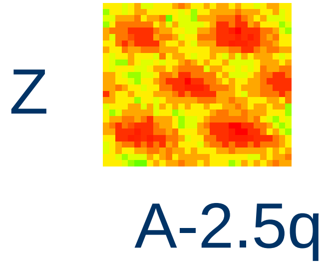
A – 2.5 q : "improving "Z-separation"

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



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



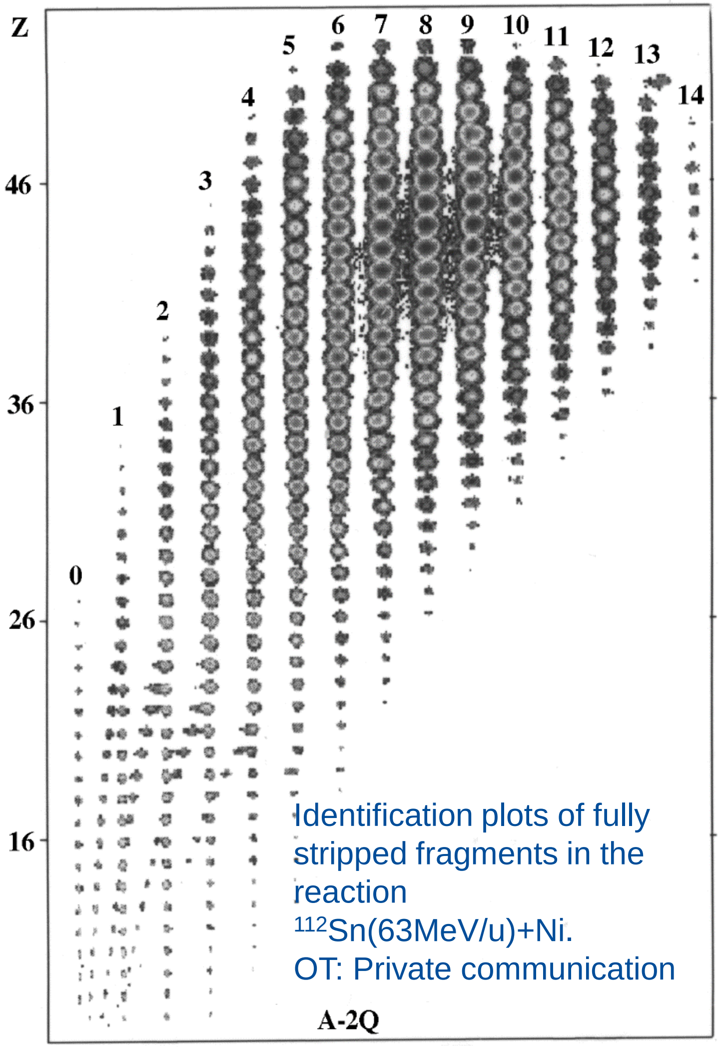


2. “Stopped” beam experiments

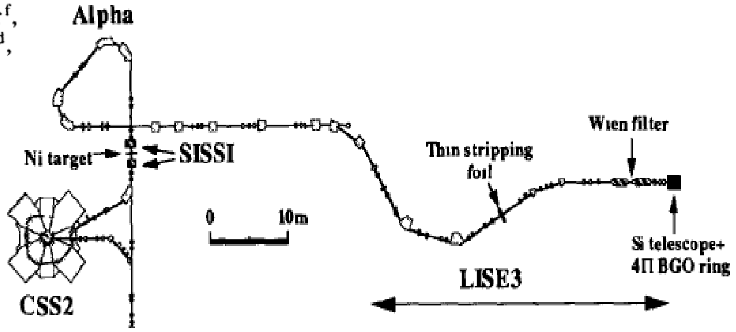
Physics Letters B 332 (1994) 20–24

Identification of the doubly-magic nucleus ^{100}Sn in the reaction ^{112}Sn + ^{nat}Ni at 63 MeV/nucleon

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. Fomichov [e], R. Grzywacz [f], D. Guillemaud-Mueller [c], 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]



Identification plots of fully stripped fragments in the reaction
^{112}Sn(63MeV/u)+Ni.
OT: Private communication



^{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

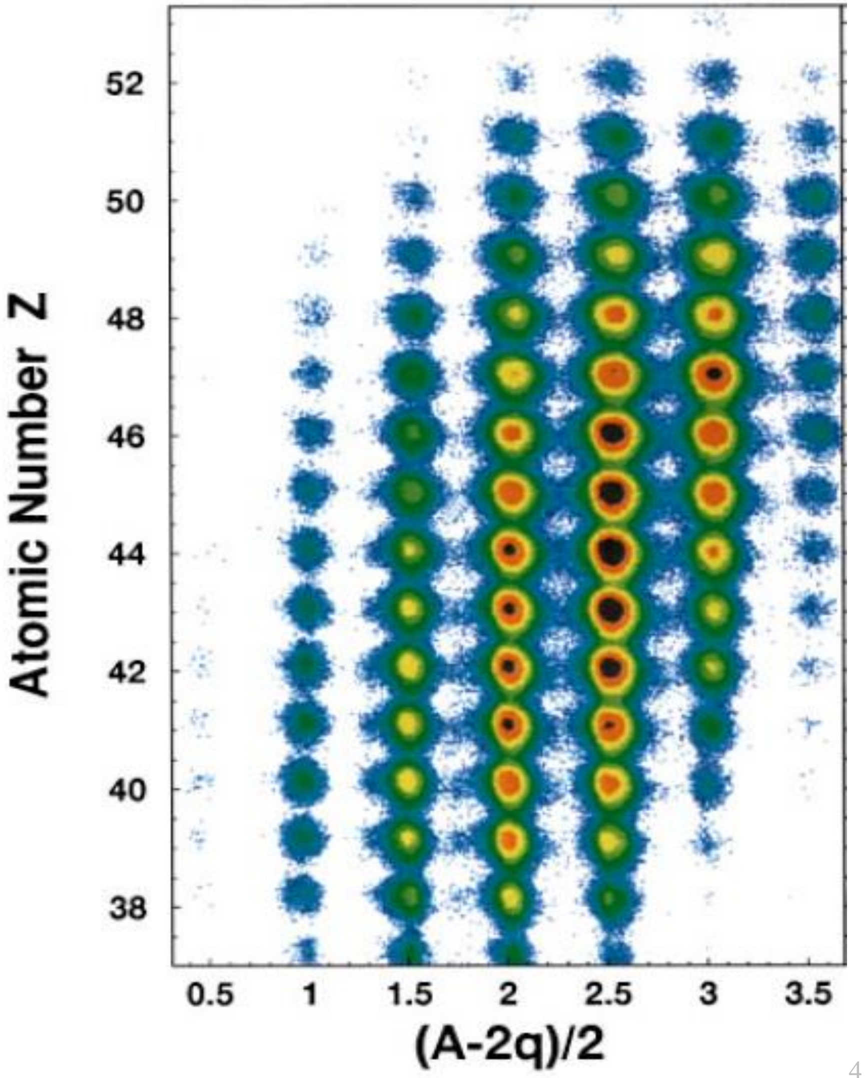
"Isomers" experiment

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

PHYSICAL REVIEW C VOLUME 55, NUMBER 3 MARCH 1997

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

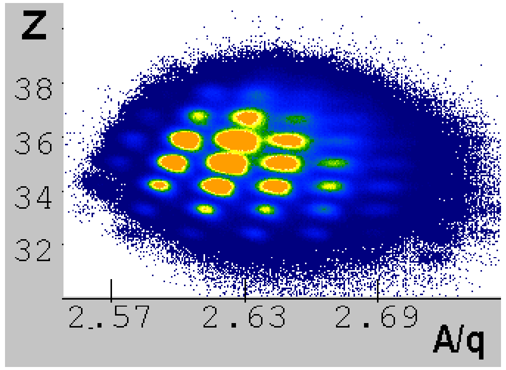
…ywacz, [1,2] R. Anne, [2] G. Auger, [2] C. Borcea, [3] J. M. Corre, [2] T. Dörfler, [4] A. Fomichov, [5] S. Grevy, [6] H. Grawe, [7] …maud-Mueller, [6] M. Huyse, [8] Z. Janas, [7] H. Keller, [7] M. Lewitowicz, [2] S. Lukyanov, [5,2] A. C. Mueller, [6] N. Orr, [9] …strowski, [2] Yu. Penionzhkevich, [5] 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. Zylicz [1]



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}U + 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].

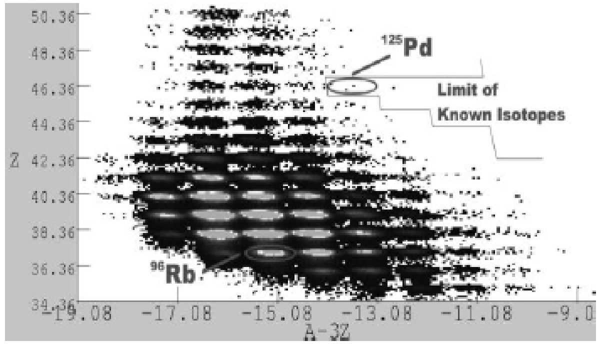


FIGURE 5. Partial identification plot [15] showing measured atomic number Z vs. the calculation function A-$3Z$ for fully stripped ions obtained during a search for new isotopes.

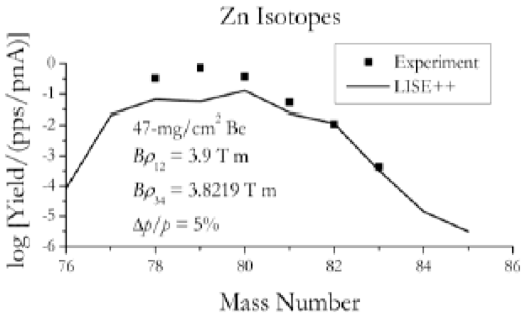
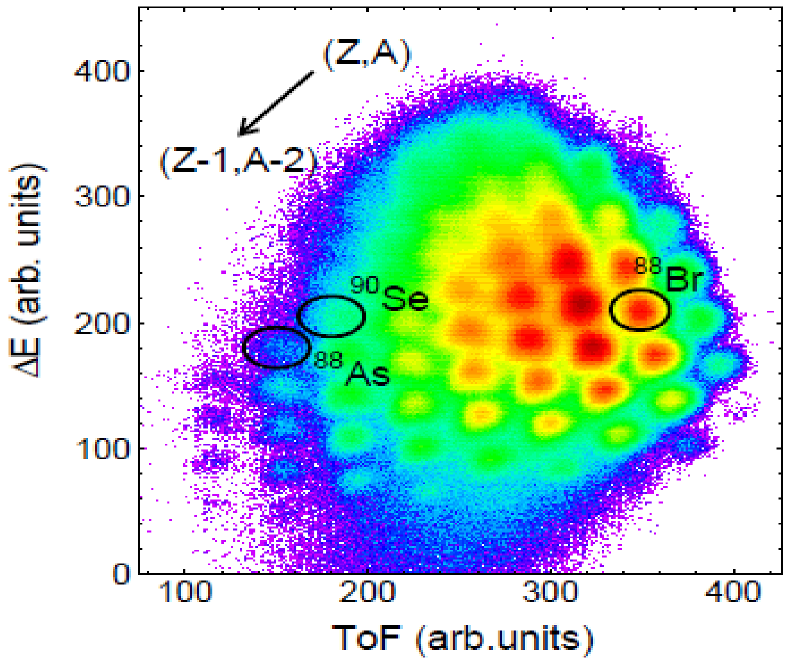


FIGURE 6. Comparison [15] of the observed yield of Zn isotopes produced by in-flight fission of ^{238}U (80MeV/u) to calculations by the LISE^{++} program [18].



Courtesy by J.Pereira

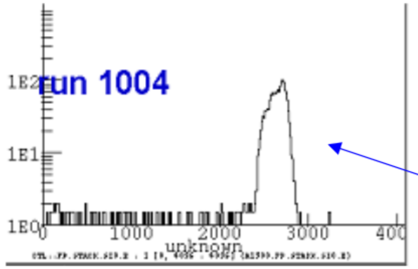
FIG. 1: (Color online) Particle-identification (PID) spectrum with the nuclei transmitted into the experimental area ($^{76-80}$Zn, $^{77-83}$Ga, $^{79-86}$Ge, $^{83-89}$As, $^{84-90}$Se, $^{87-93}$Br, $^{90-96}$Kr, $^{93-98}$Rb, and $^{97-100}$Sr). (See text for details.)

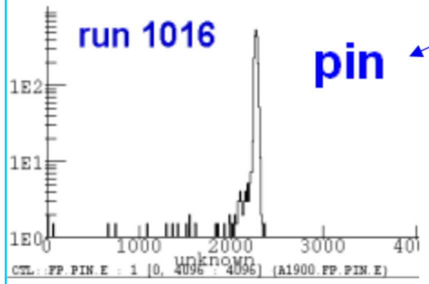
Good Z, short length of flight (moderate A)

Experiment #5120 : ^{208}Pb @ A1900

NSCL research discussion
http://lise.nscl.msu.edu/paper/208pb/2009_208Pb_RD.pdf

AIP Conference Proceedings Volume 1224, ISBN: 978-0-7354-0768-8
Preprint MSUCL1409, NSCL/MSU 2009; http://groups.nscl.msu.edu/nscl_library/nscl_preprint/MSUCL1409.pdf



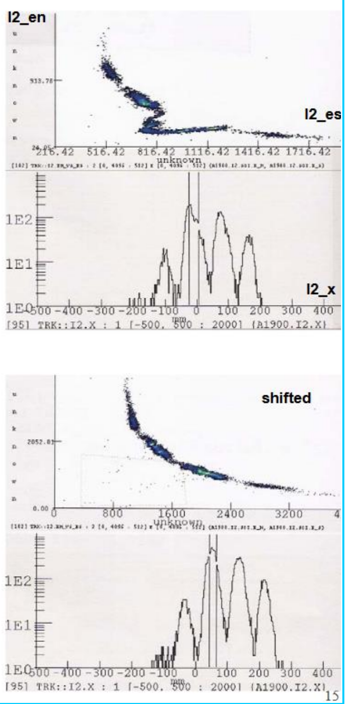


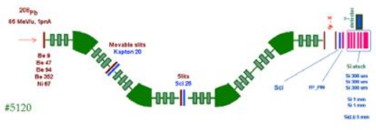
New ORTEC SBD detectors* (D~20mm) have been substituted during the experiment for PIN diodes 500 um (50x50mm),

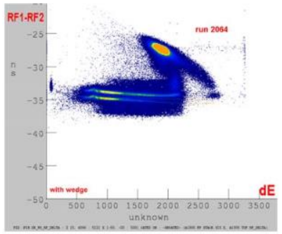
** - though measured own resolution before and after the experiment for α-particles was about 20-22 KeV*

- No explanation. Double peak structure. Position dependance. 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)

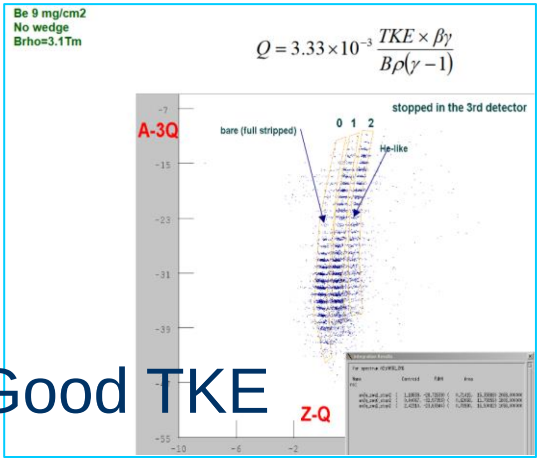
- I2-Sci X-position problem during the experiment ☹
- No Kapton in I1 (no reference lines, difficult analysis : set of charge states, different velocities) ☹
- I2-wedge 26 mg/cm² (Sci) is too thick for heavy ions Z~70-80 ☹
- TOF I2&FP resolution is not good enough (short path) ☹
- TOF RF-Pin - unstable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



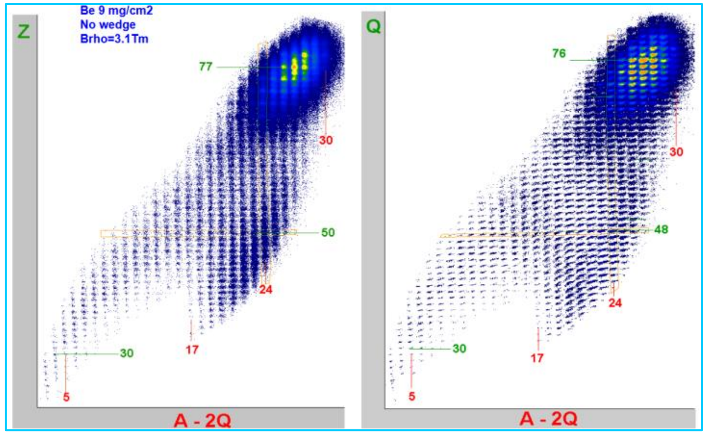




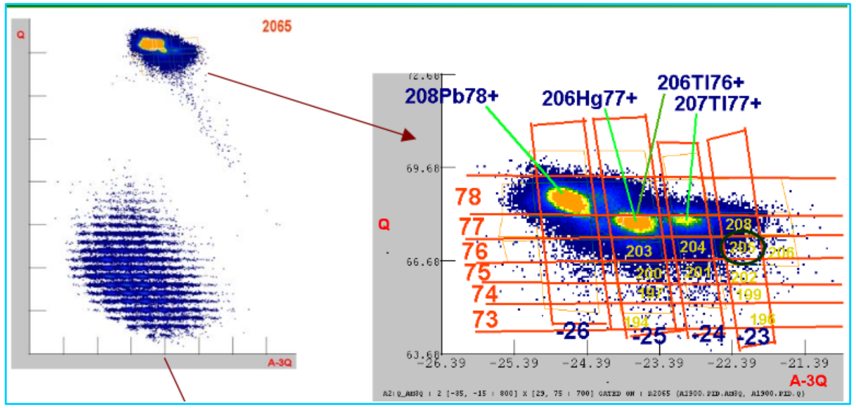
02/12/09. Research Discussion



Good TKE



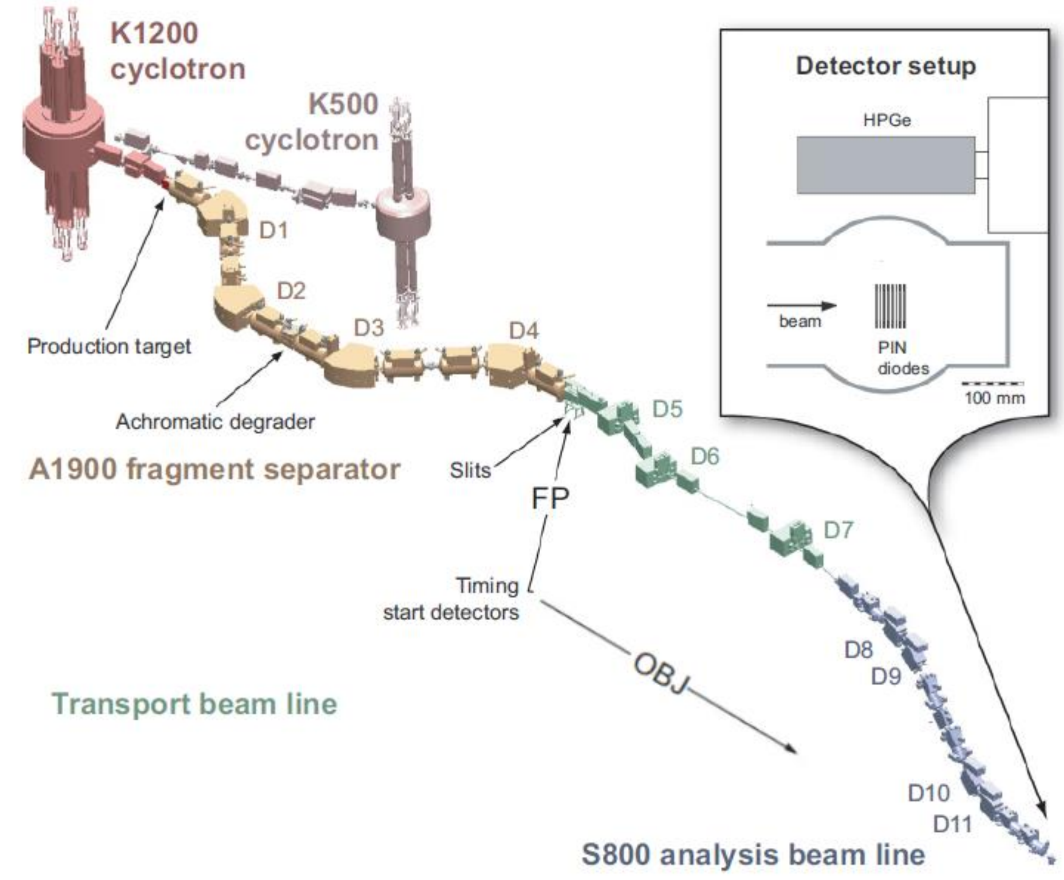
No wedge, small dp/p, RFstop

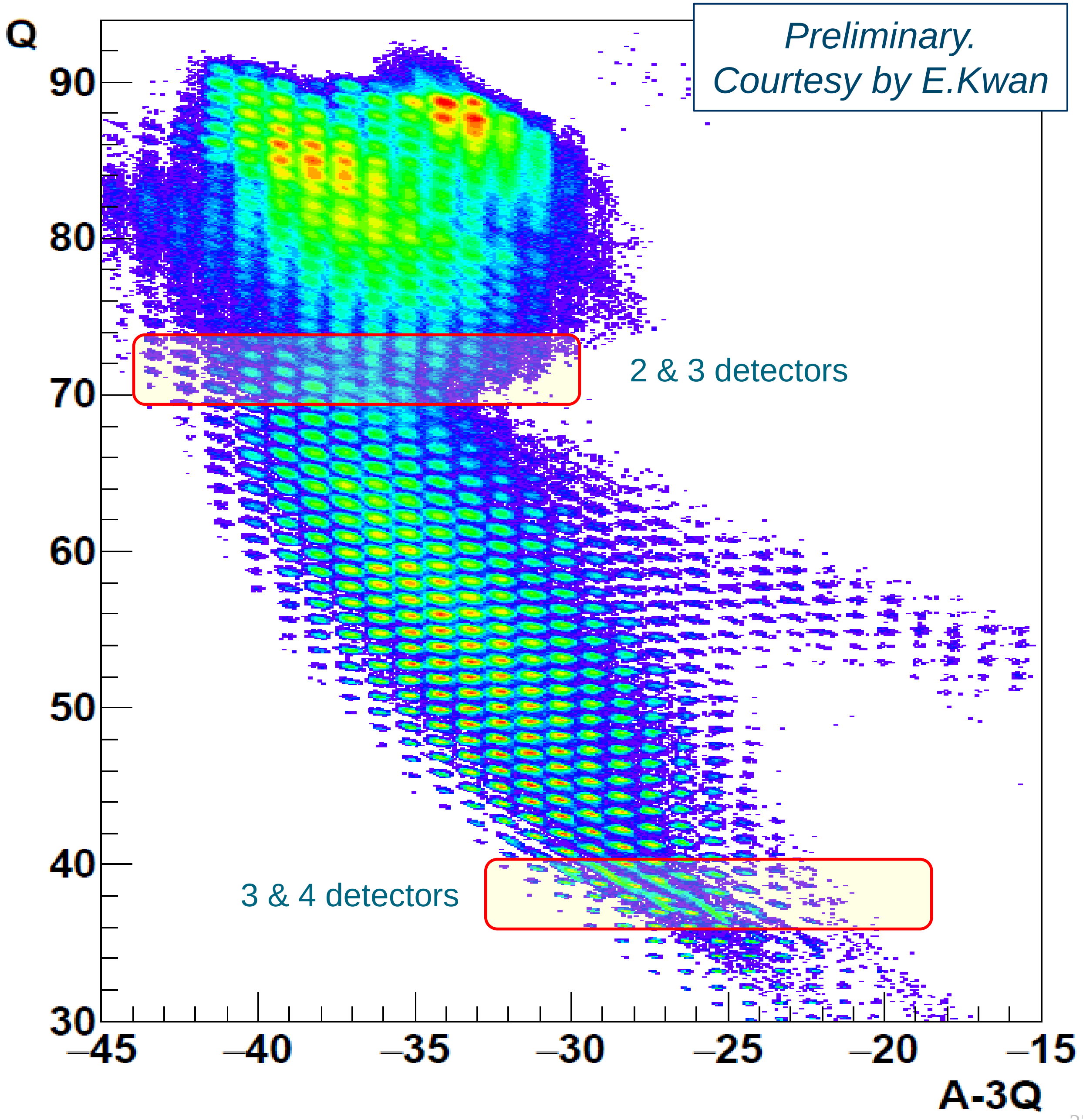


With I2-Sci as wedge, short length

e09063 : Projectile fragmentation of ^{238}U

2016: E.Kwan – spokesperson



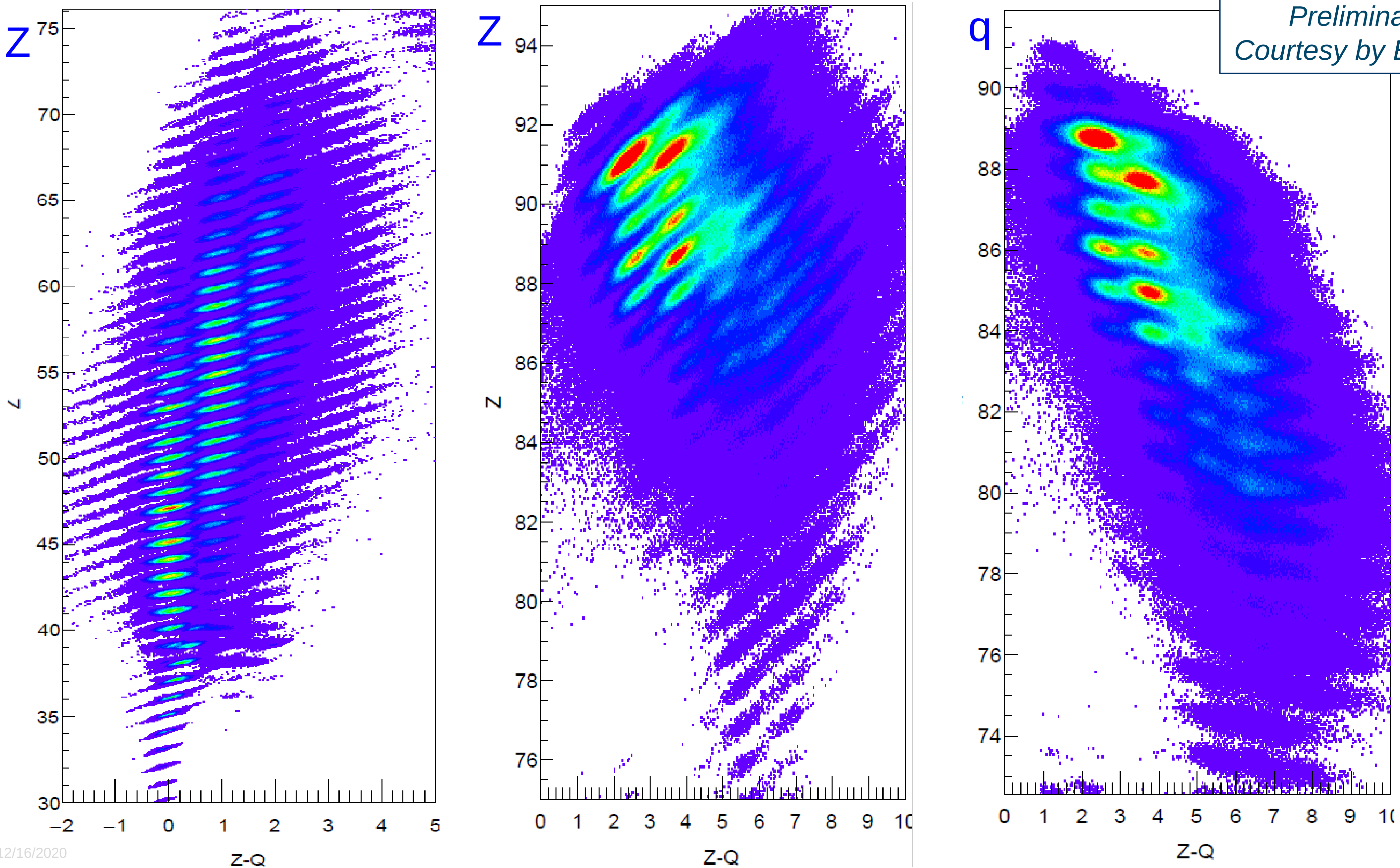


- Small Momentum acceptance
- Non-cooled PIN-diodes (50x50 mm^2 0.5mm)

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

e09063 : Projectile fragmentation of ^{238}U

Preliminary.
Courtesy by E.Kwan

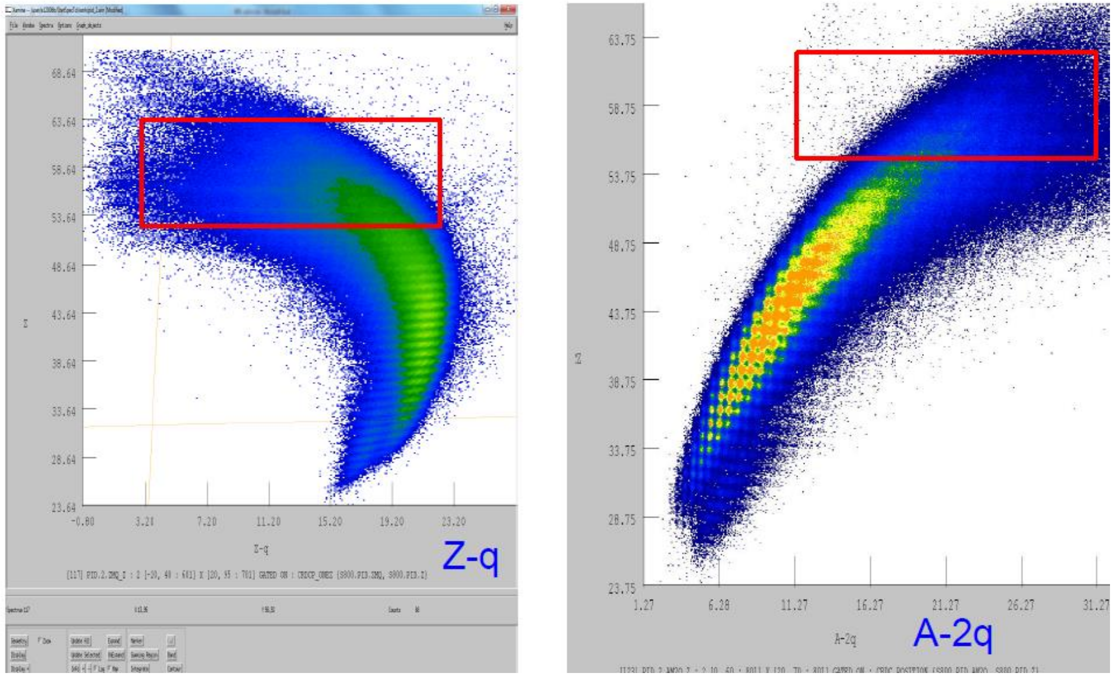


Experiment #12006 : ^{238}U @ S800

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

e12006 - Z resolution

Z resolution up to 60 can be reached



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

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

Resolution	sigma		systematical (calibration)	
TOF =	0.175	ns	0.07	%
Eloss =	0.25	%	0.30	% (straggling)
TKE =	0.30	%	0.20	%
Z =			0.2	%
Momentum (Brho) =	0.0261	%	0.01	%

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	%

Measured values			error (σ)	%
TOF =	117.8505	ns	0.193	0.164
Brho =	3.3365	T*m	0.001	0.028
E1_loss =	1833.34	MeV	7.09	0.387
TKE =	7730.18	MeV	27.87	0.361

main component

Deduced values			error (σ)	%	contribution in error: Brho	Beta	TKE	E1_loss	Zsyst	A/q	Z
beta =	0.410426		0.00067	0.164							
gamma =	1.096619		0.00067	0.164							
velocity =	12.3037	cm/ns	0.02020	0.164							
A / q =	2.385857		0.00541	0.227	0.028%	0.225%					

answer

PID values		error (σ)	%	Brho	Beta	TKE	E1_loss	Zsyst	A/q	Z
Z =	36	0.112	0.31		0.140%		0.19%	0.20%		
q =	36.000	0.213	0.59	0.028%	0.468%	0.361%				
A (from TKE) =	85.8908	0.671	0.78		0.693%	0.361%				
A (from [A/q]*q_integer) =	85.8909	0.195	0.23						0.227%	
A (from [A/q]*q_measur) =	85.8908	0.544	0.63	0.028%	0.225%	0.592%				
A-2q =	13.89	0.263		0.02	0.26	0.05				
A-3q =	-22.11	0.123		0.03	0.09	0.08				
A-2Z * =	13.89	0.200							0.19	0.04

Diamond target – T signal

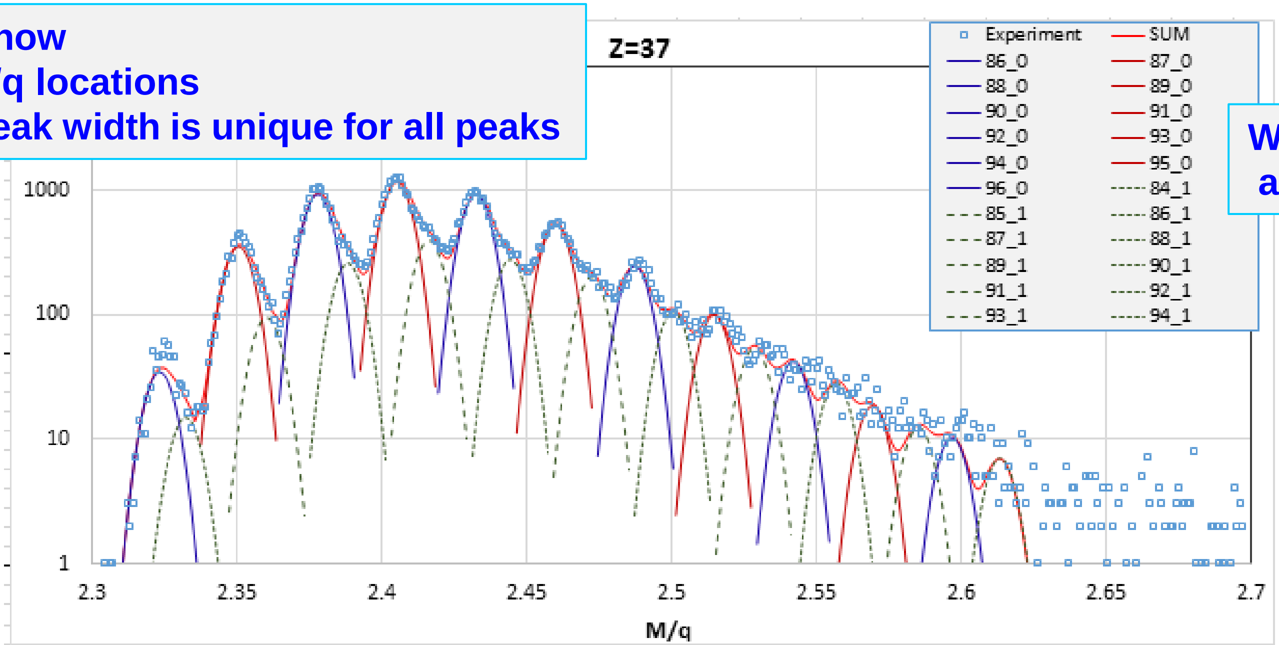
No TKE for fission fragments,
Short length
dE with IC, moderate

No q, poor A/q

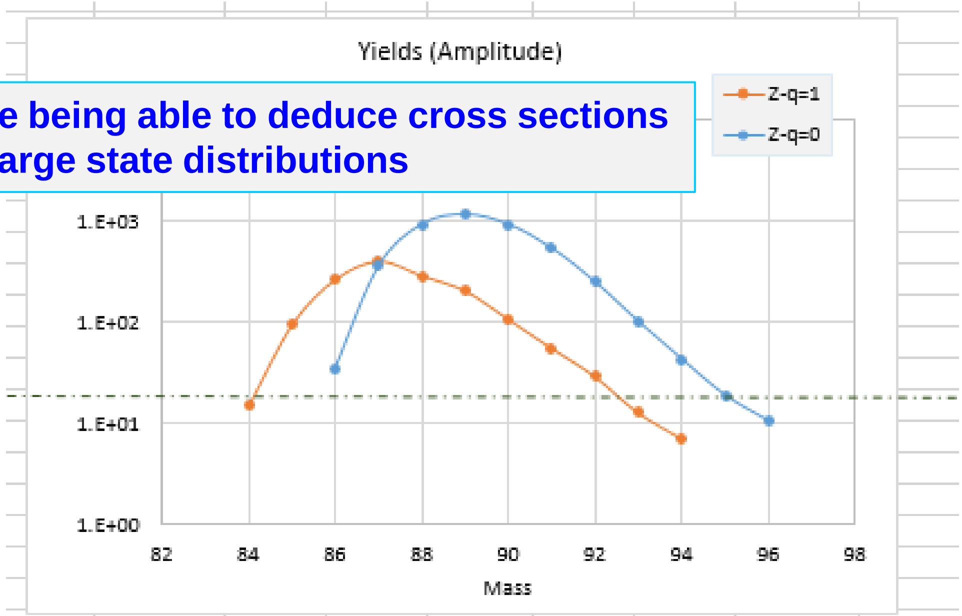
To reproduce results I used sig(ToF) = 175 ps, that according to A.S. is reasonable in the case of ToF configuration of e12006 experiment due to mostly Sci-scintillator resolution.

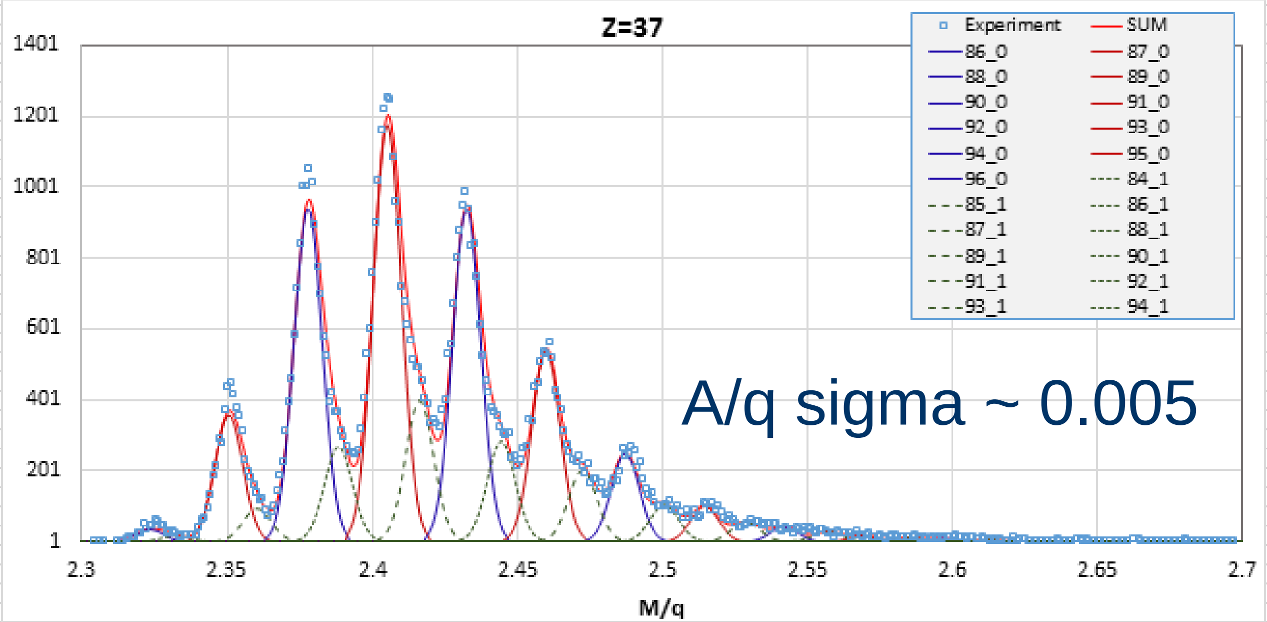
E12006 : Cross section and charge state distributions

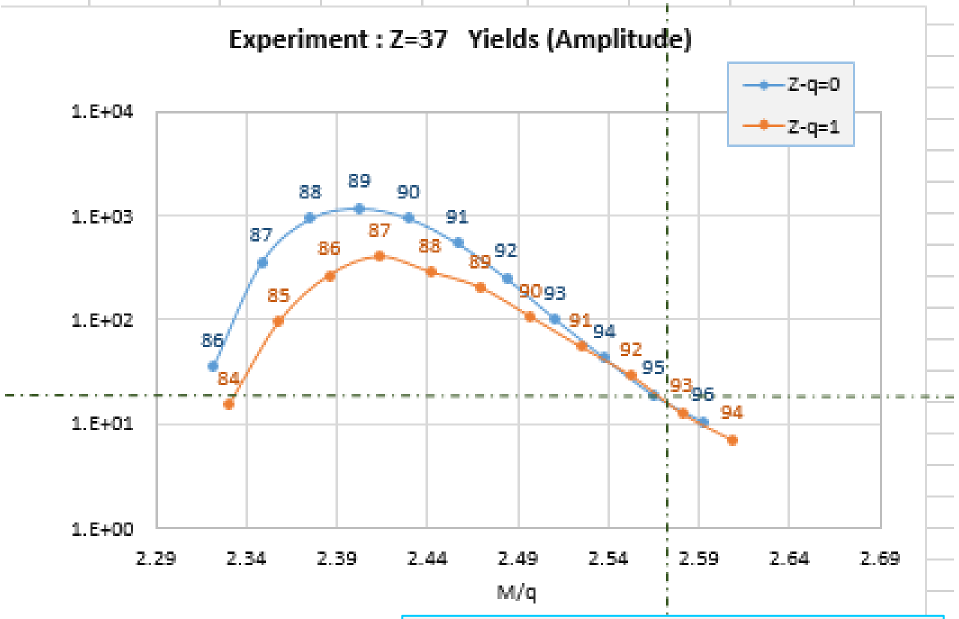
We know
- **A/q locations**
- **Peak width is unique for all peaks**



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





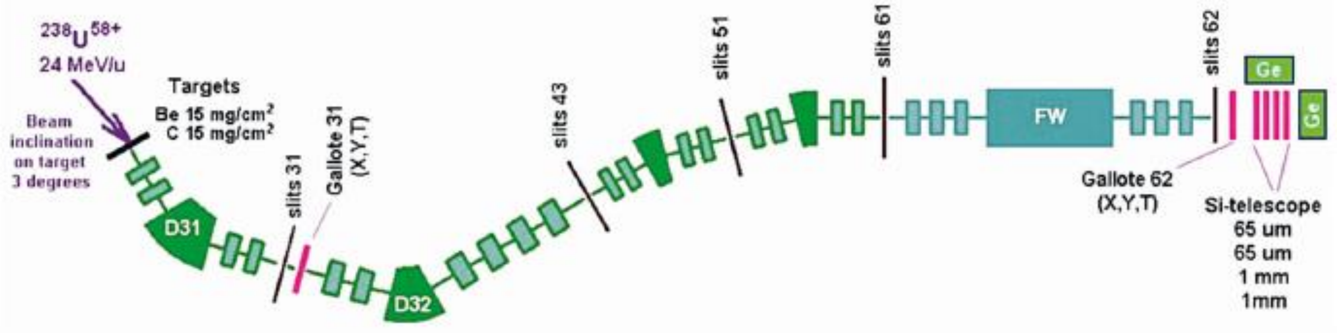


Will be finally published in 2021? ☺

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

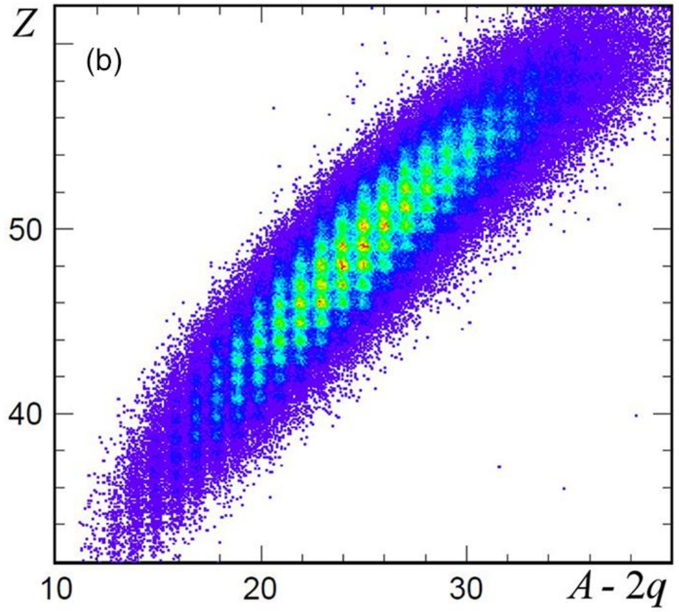
Fission fragment yields from heavy-ion–induced reactions measured with a fragment separator

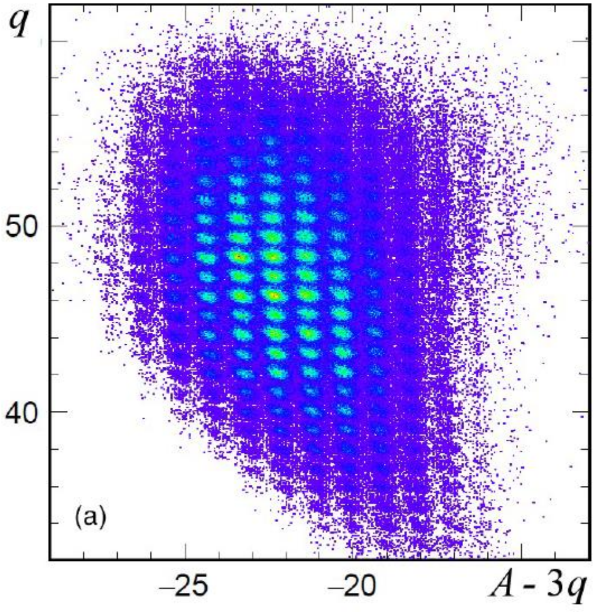
O.B. Tarasov[1,a,b], O. Delaune[2,c], F. Farget[2], D.J. Morrissey[1,3], A.M. Amthor[4], B. Bastin[2], D. Bazin[1], B. Blank[5], L. Caceres[2], A. Chbihi[2], B. Fernández-Dominguez[6], S. Grévy[5], O. Kamalou[2], S.M. Lukyanov[7], W. Mittig[1,8], J. Pereira[1], L. Perrot[9], M.-G. Saint-Laurent[2], H. Savajols[2], B.M. Sherrill[1,8], C. Stodel[2], J.C. Thomas[2], and A.C. Villari[10]

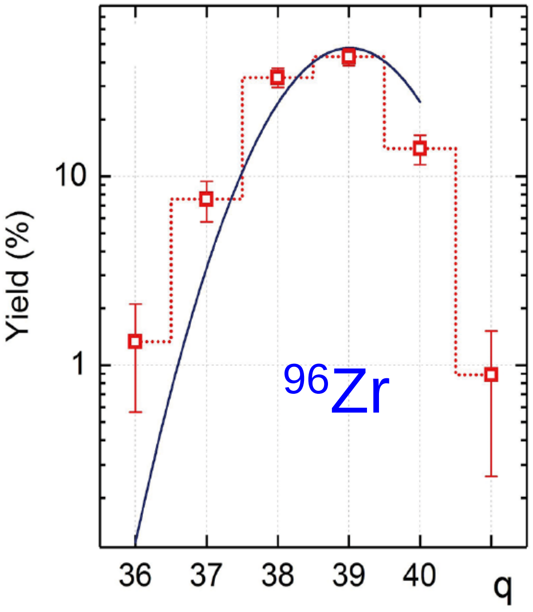


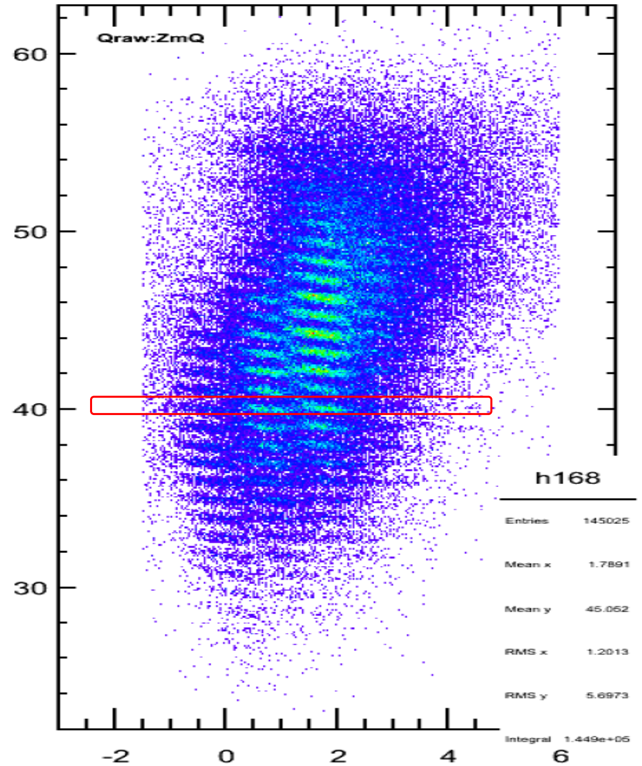
- Beam was inclined 3 deg. on target

- ToF: Good
- TKE: Good
- Bρ: moderate [dispersion 19 mm/%, FP-X corrections]
- dE : moderate [thin dE detectors, middle Z]









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

Working in High-Z region at intermediate energies

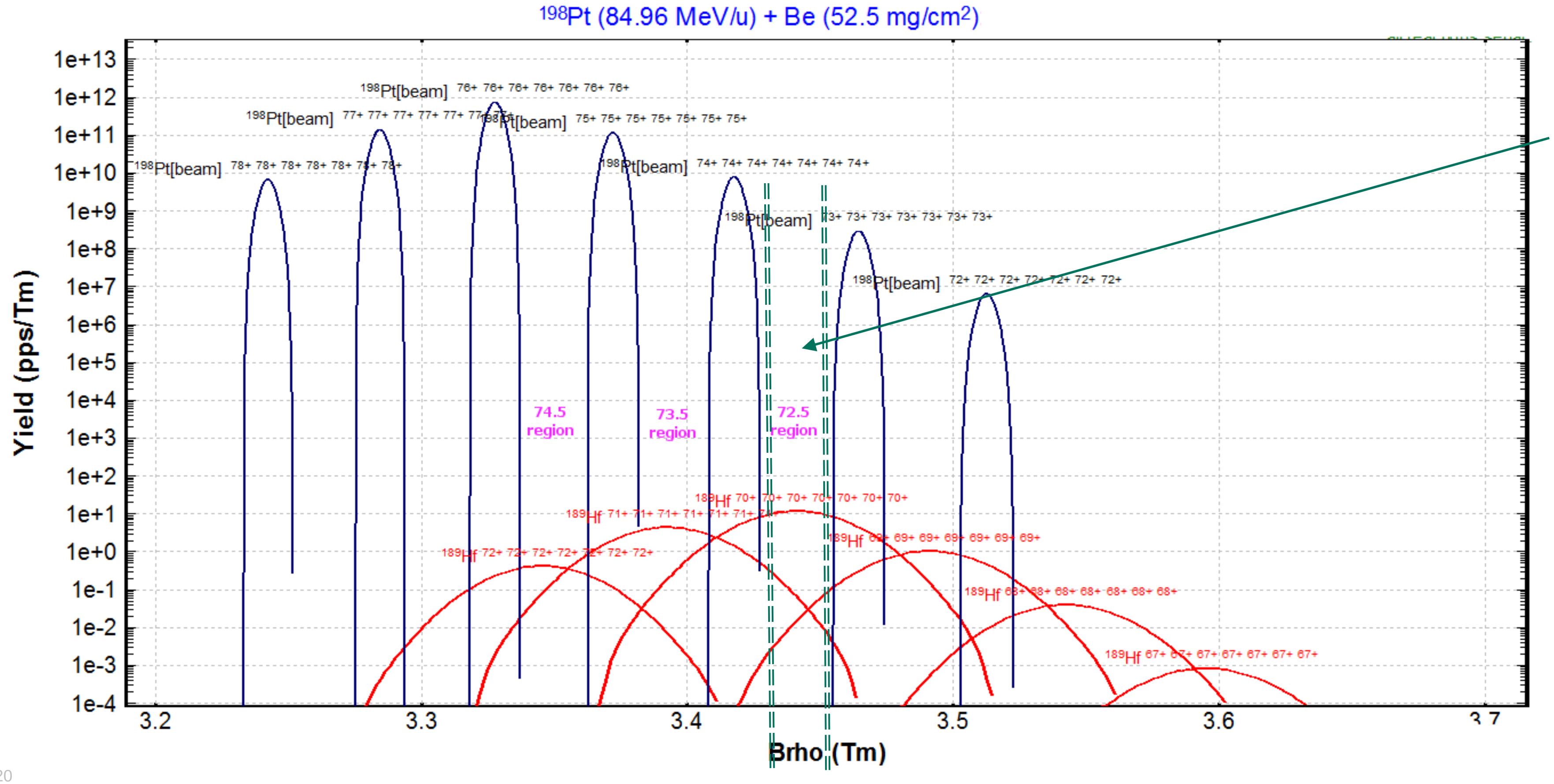
NSCL E15130

"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



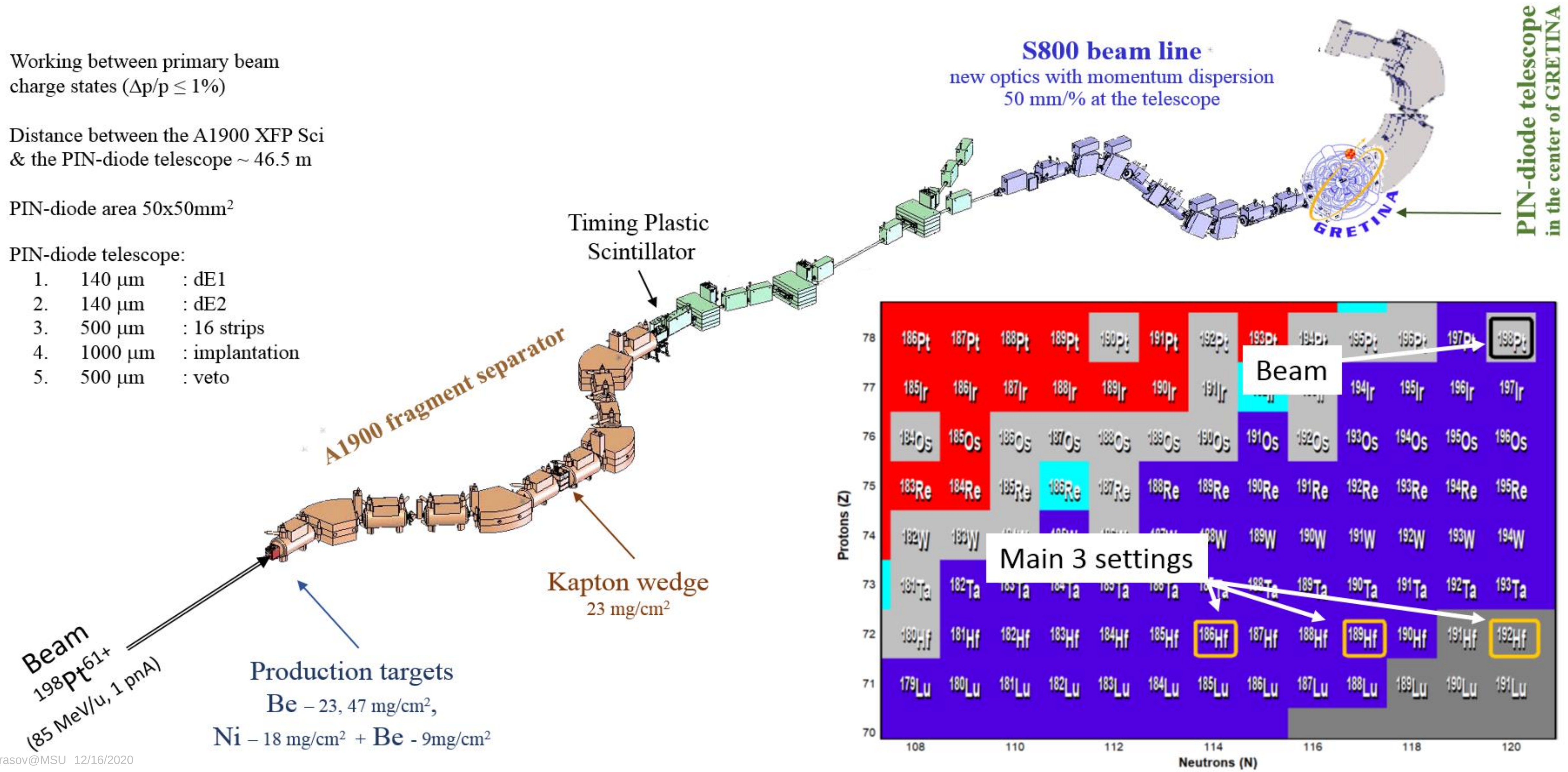
Working region
dP/P ~ 0.8-1.0%

07 / 2019

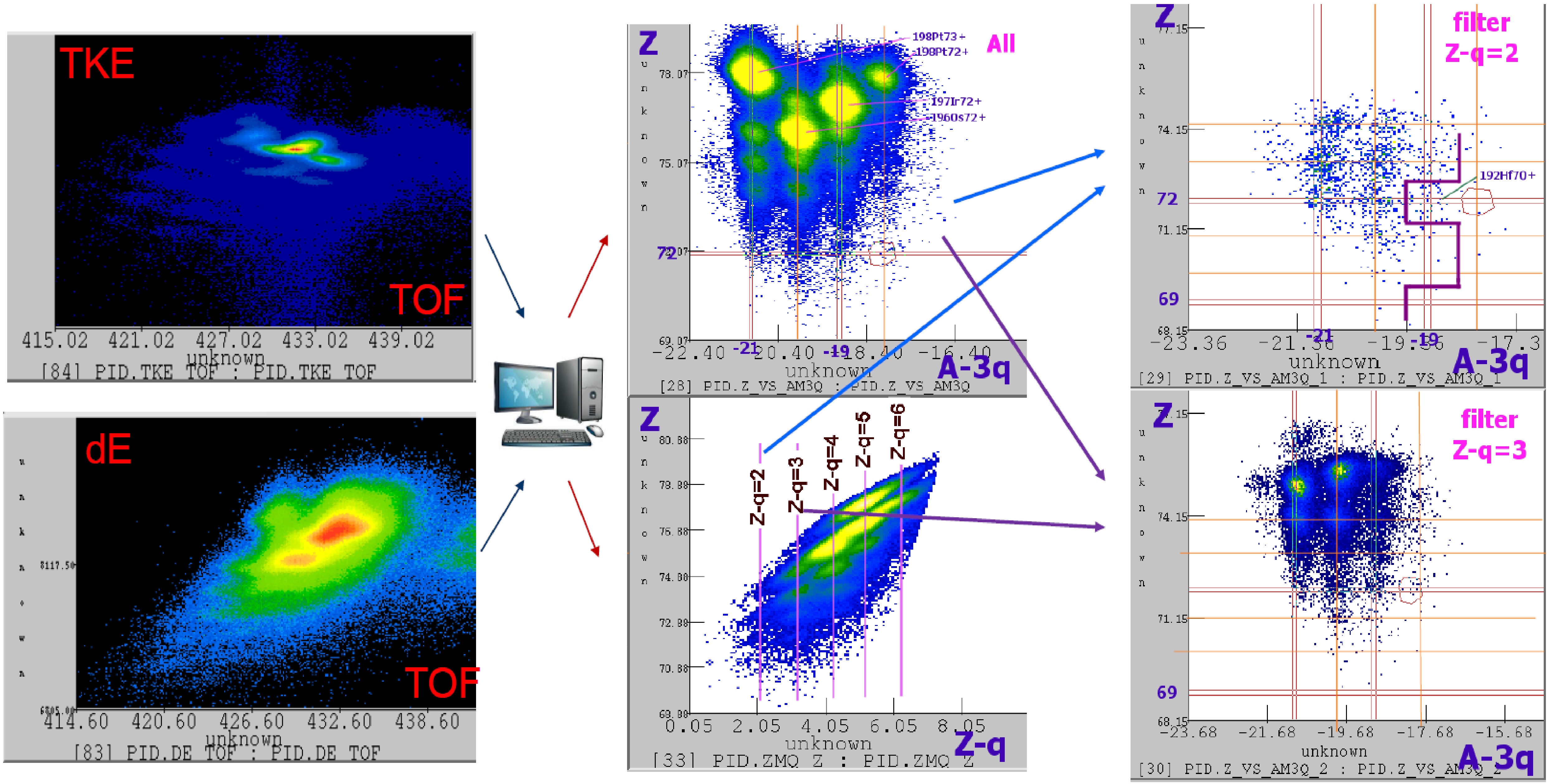
Layout of the e15130 experiment at NSCL / MSU (07/2019):

"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 50x50mm^2
- PIN-diode telescope:
  1. 140 μm : dE1
  2. 140 μm : dE2
  3. 500 μm : 16 strips
  4. 1000 μm : implantation
  5. 500 μm : veto



e15130 experiment : from dE, ToF, TKE, Bρ to A, Z, q

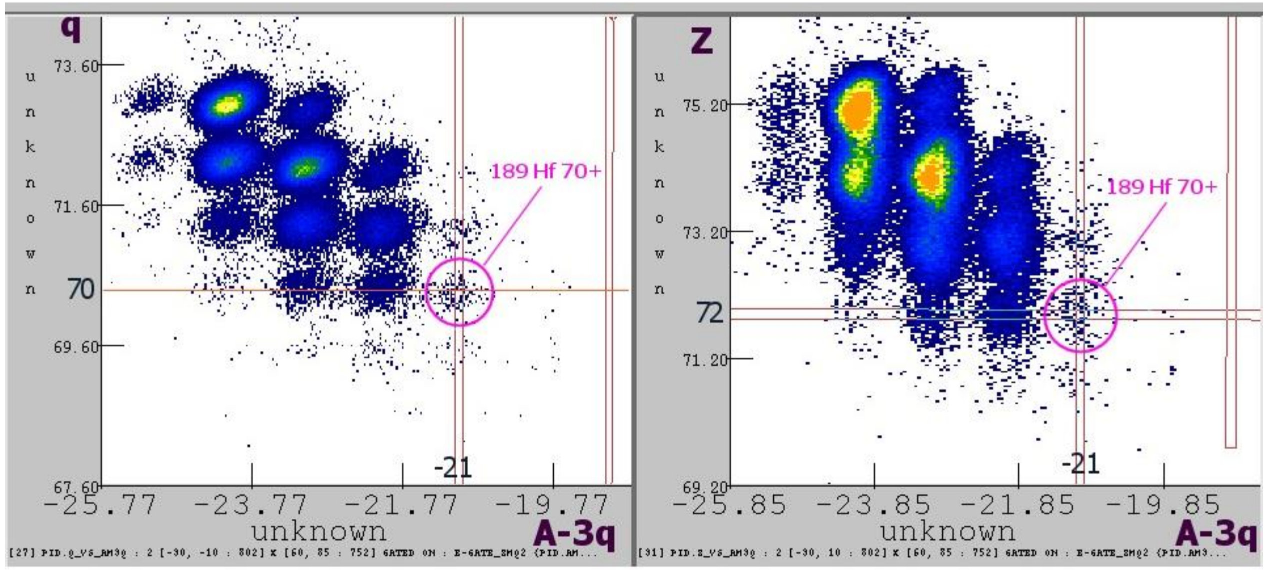


It is possible to suggest about ten isotopes from dE-ToF-TKE plots. No.. More than hundred (5*6*4)!

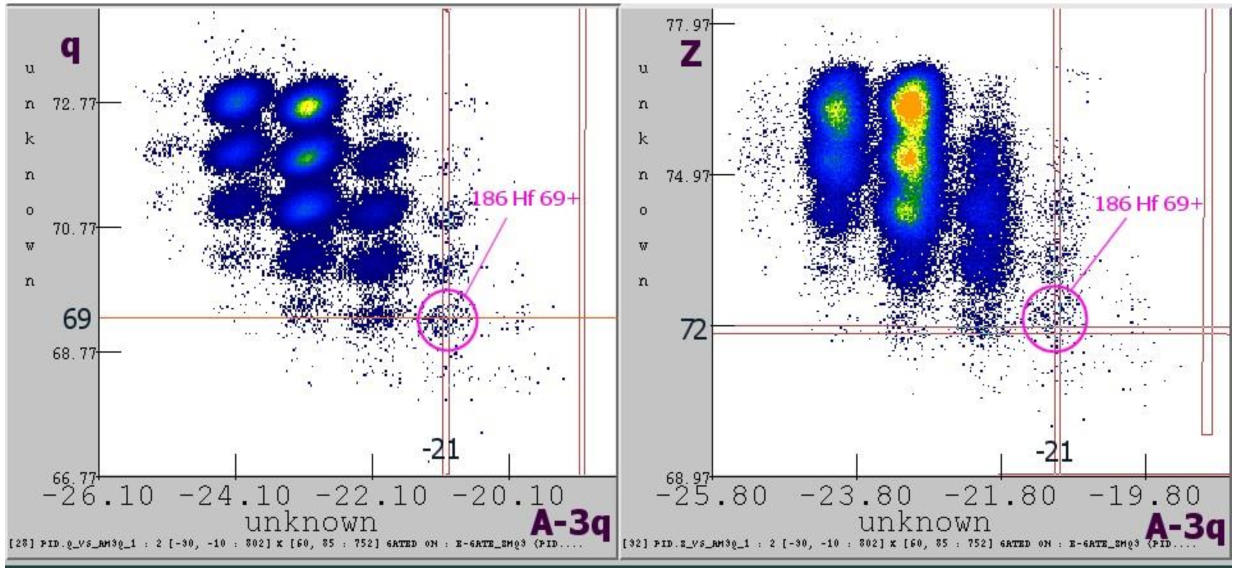
Experiment #e15130; July 2019 @ NSCL/MSU

^{198}Pt (85 MeV/u) + Be (47 mg/cm^{2}) -> Wedge -> ^{189}Hf^{70+}

selection Z-q=2



selection Z-q=3



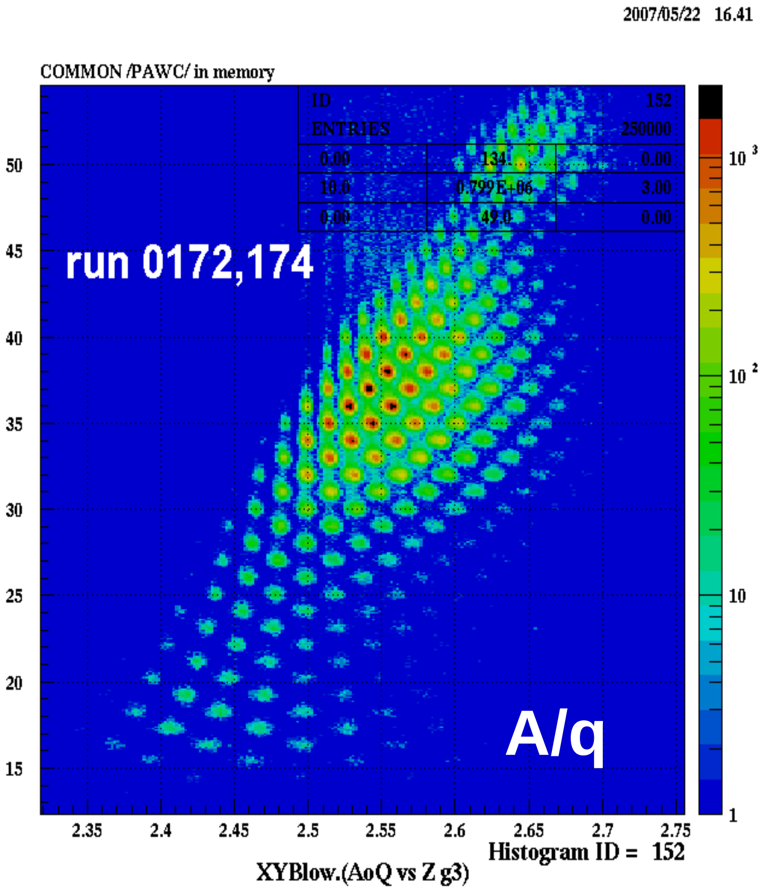
- ToF: Excellent
- TKE: Good
- Bρ: moderate [strip detector (3 mm), dispersion 50 mm/%]
- dE : moderate [thin dE detectors, high Z]

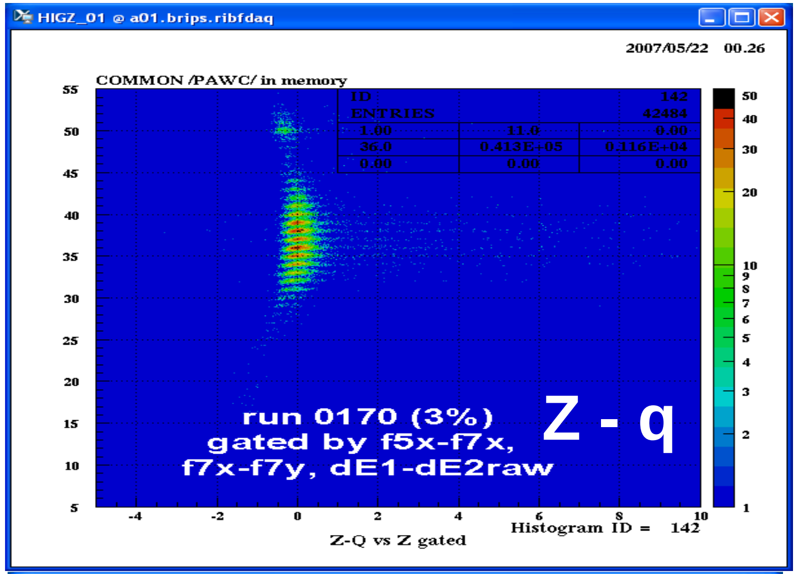
- q: good
- A: good
- Z: moderate - poor

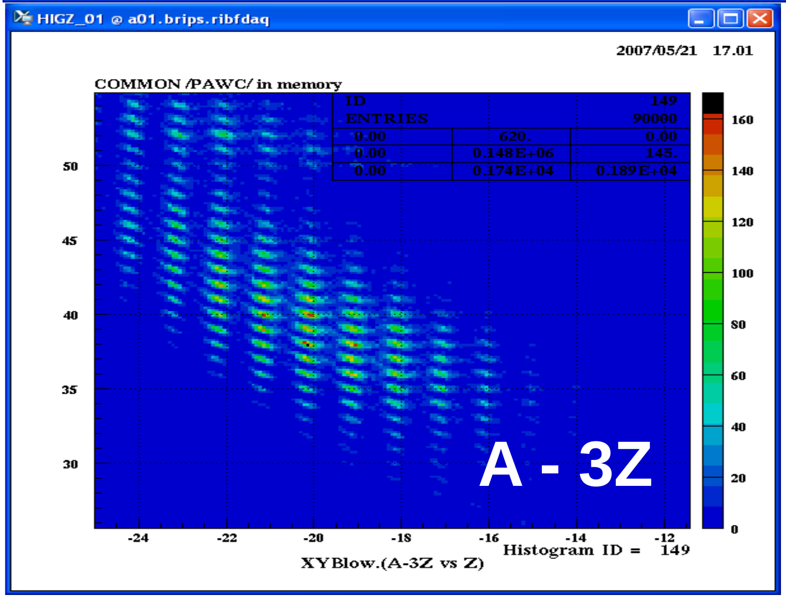
RIKEN

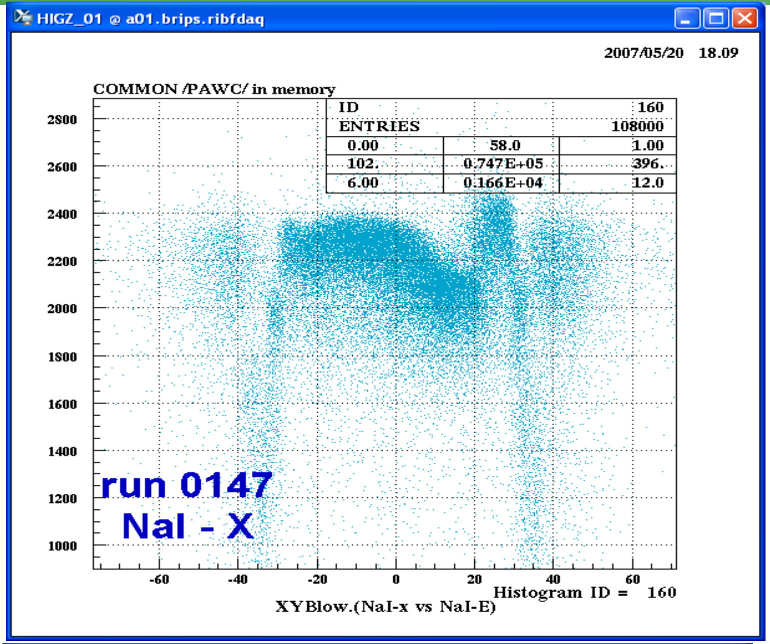
RIKEN 2007

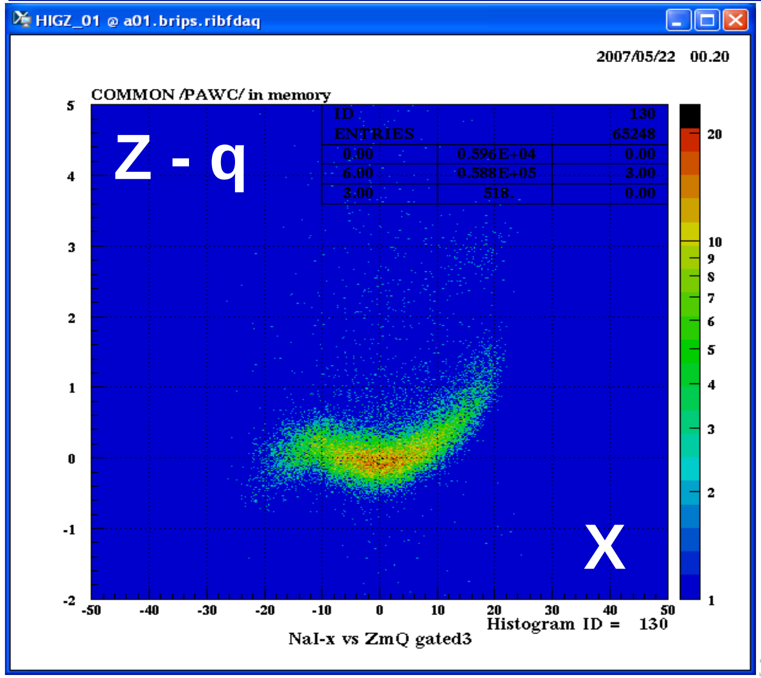
1. We brought the PID subroutines to implement into BigRIPS acquisition software
2. Si-detectors for dE and NaI for TKE
3. Good PID at first, then NaI detector has been destroyed (not due to high rate)











RIKEN 2017

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

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

- Advanced detector development
- Optics & detectors :
  - Bρ & 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

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 ^{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. Steiger[10]

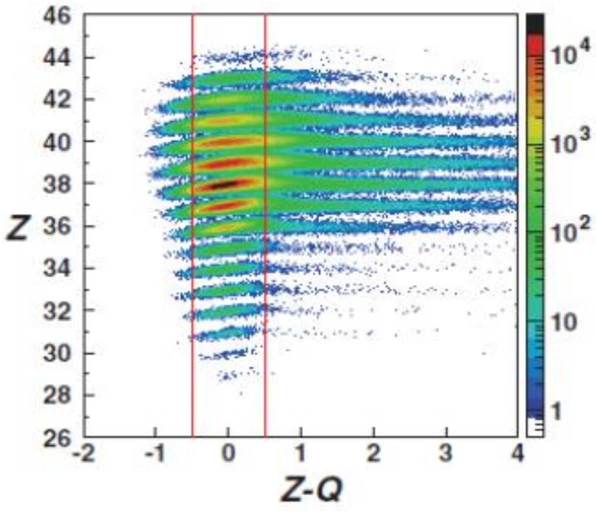
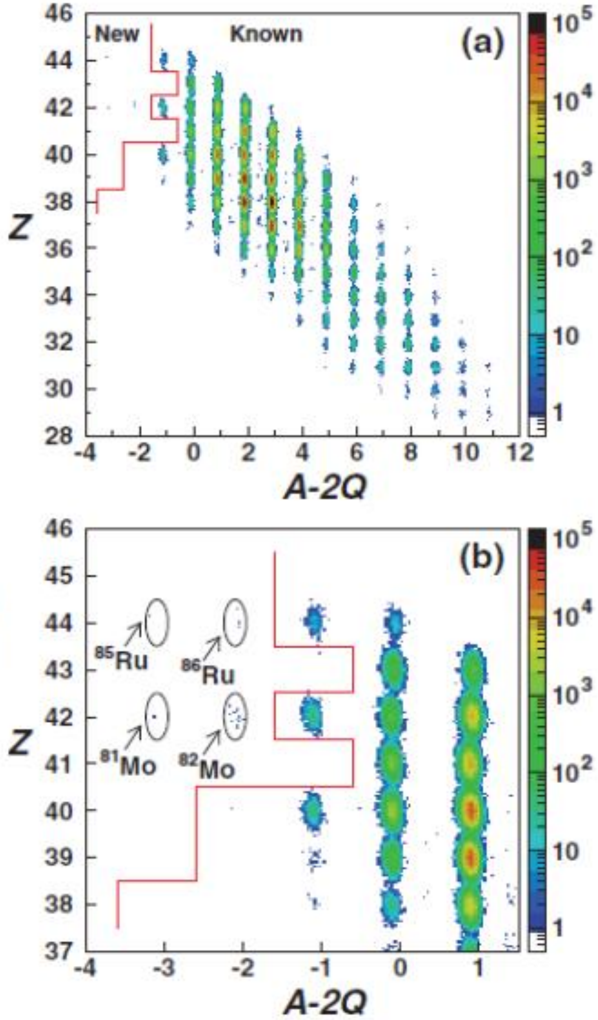


FIG. 3. The Z versus $Z-Q$ plot for projectile fragments produced in the reaction of ^{124}Xe + Be (4.03 mm) at 345 MeV/nucleon. The experimental conditions are given as the ^{85}Ru setting in Table I. The red solid lines indicate the gate used to select fully stripped events of which the gate width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



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

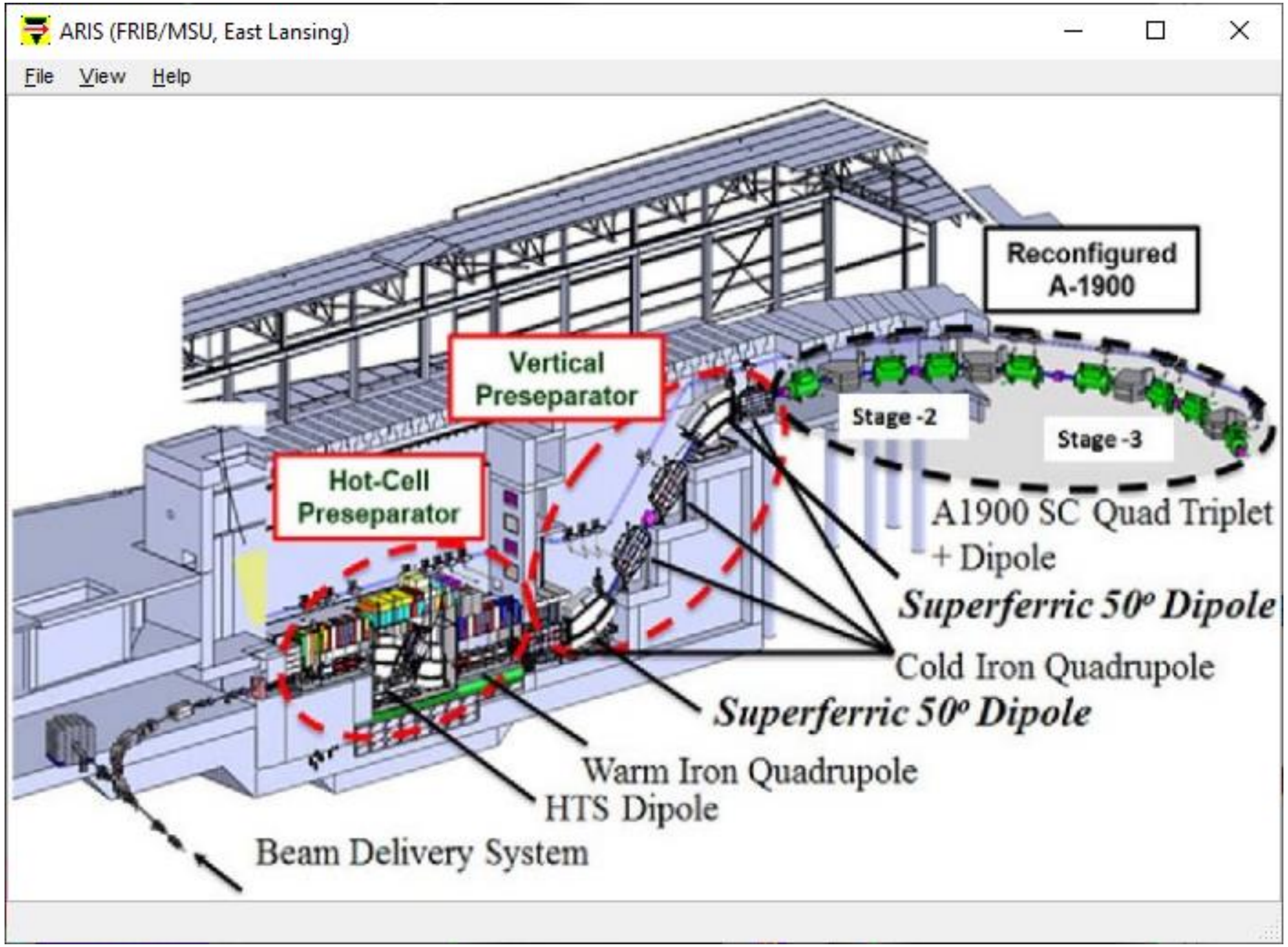
ARIS @ FRIB

Wednesday 16 December 2020

10:10 am –10:55 am: Marc Hausmann

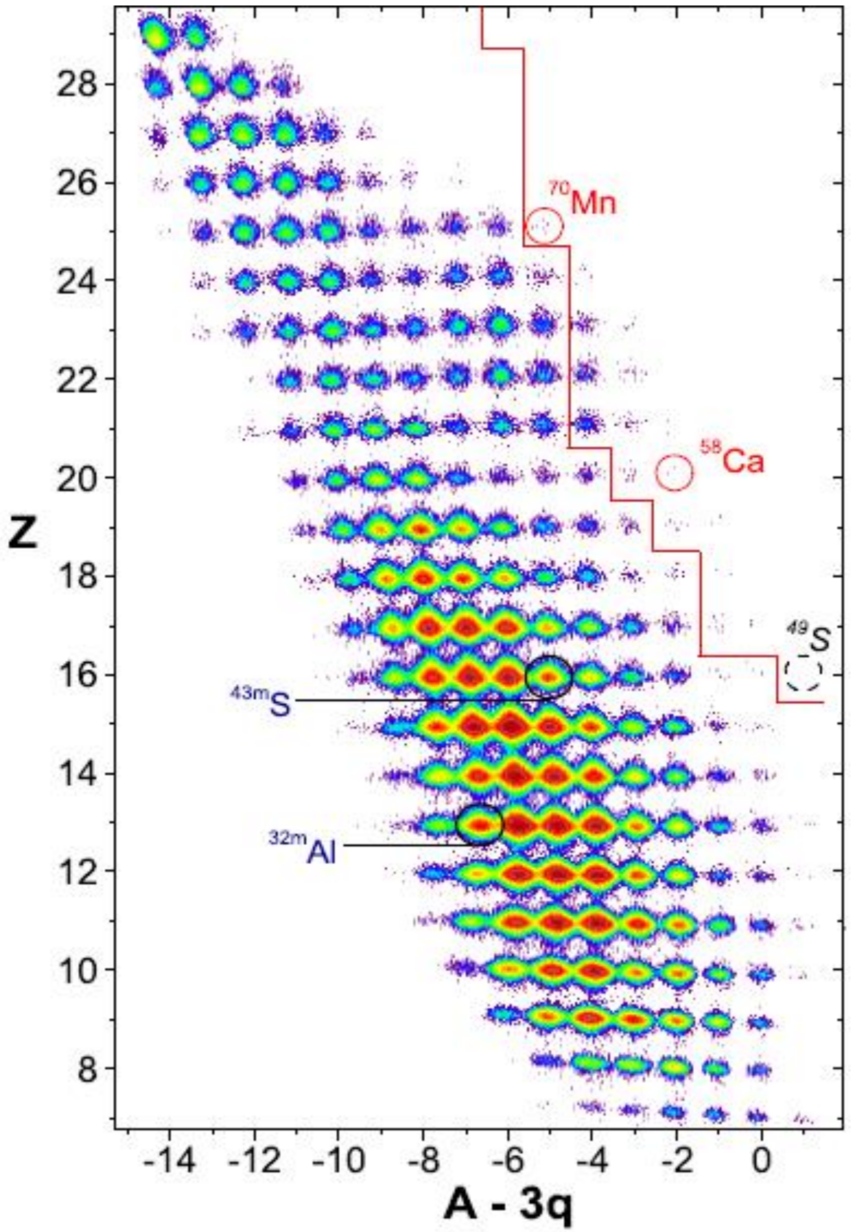
FRIB Fragment Separator Overview and

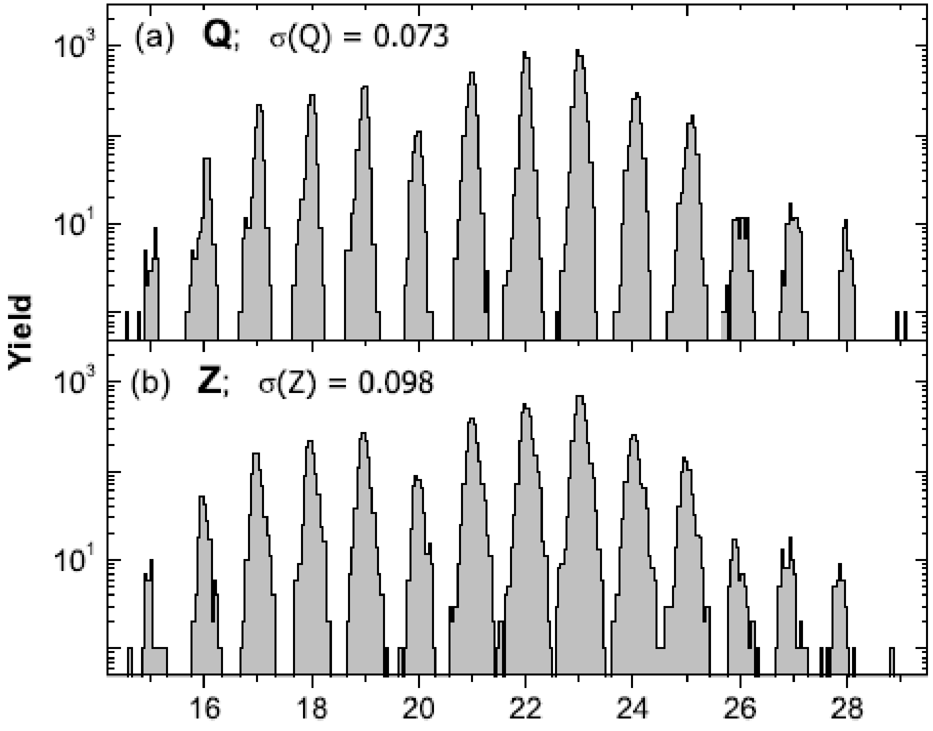
Opportunities for Advanced Detector Systems



“Stopped” beam experiments: filtering with TKE

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





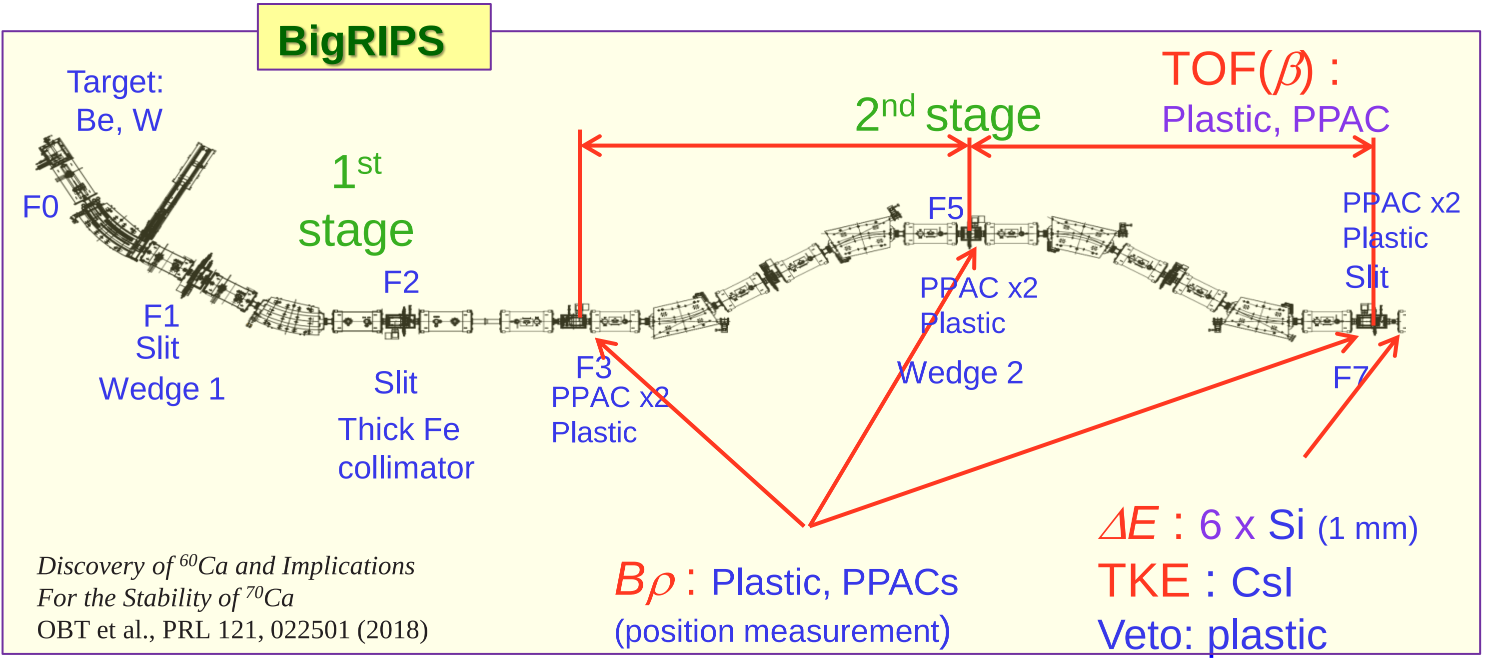
For all particles stopped in the Si-telescope in the production runs

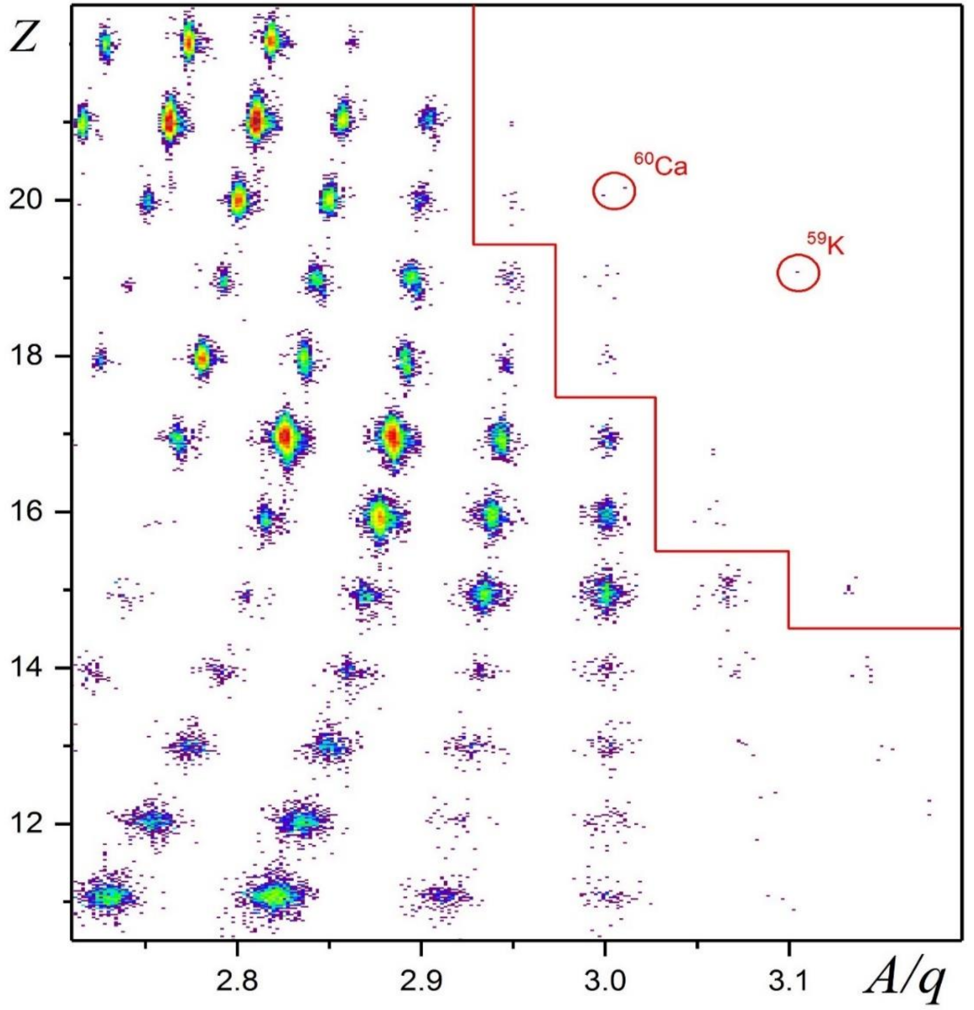
q-resolution is used to be always better than Z-resolution

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

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

^{60}Ca: Experimental setup and particle identification at BigRIPS





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 (CsI)
- Additional veto detector after CsI

Spectrometers

Spectrometers

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

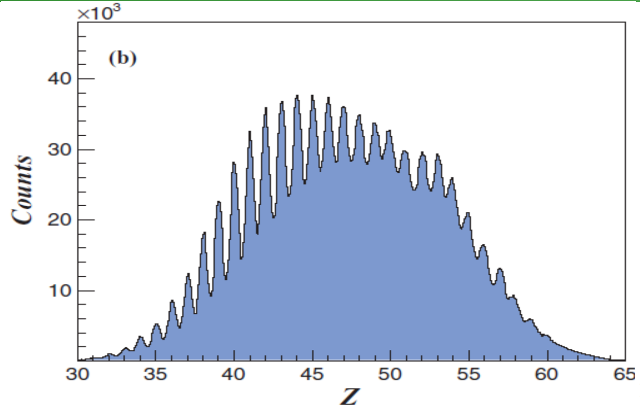
Wednesday 16 December 2020

^{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



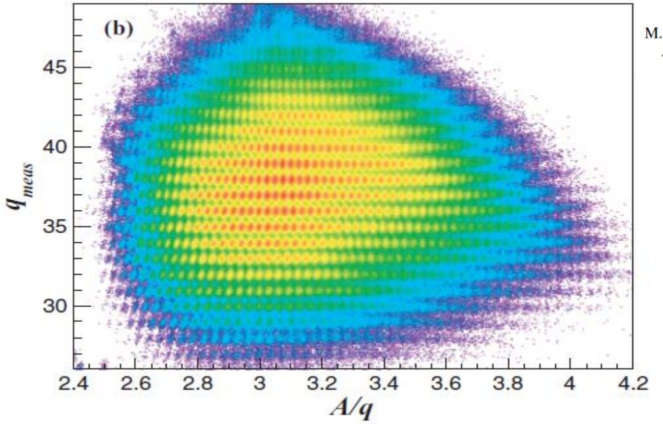
^{238}U (6.1MeV/u) + C @ VAMOS

A,q – good
Z - moderate

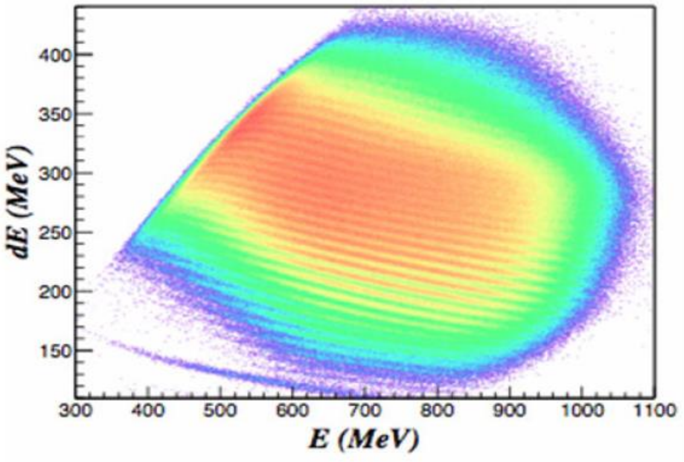
PHYSICAL REVIEW C 88, 024605 (2013)

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

M. Caamaño,[1,2,*] O. Delaune,[1,†] F. Farget,[1,‡] X. Derkx,[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. Gaudefroy,[7] C. Golabek,[1] B. Jurado,[4] A. Lemasson,[1] A. Navin,[1] M. Rejmund,[1] T. Roger,[1] A. Shrivastava,[1] and C. Schmitt[1]



Identified fission fragments.
Charge state $q_{\rm meas} = A/(A/q)$ as a function of A/q.

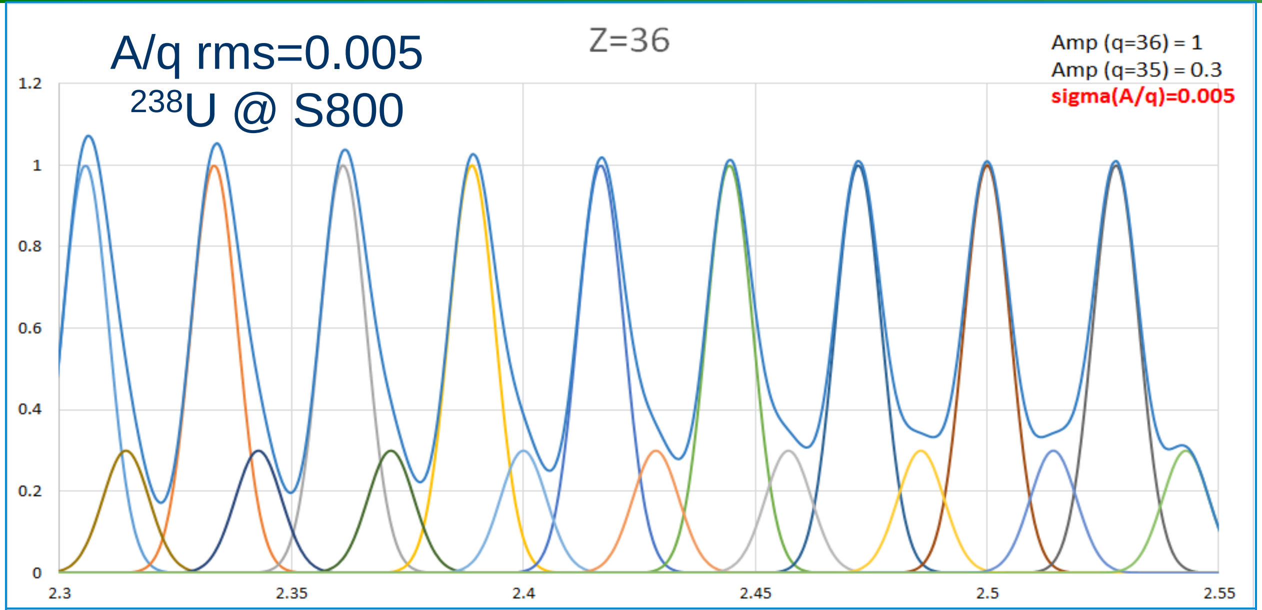


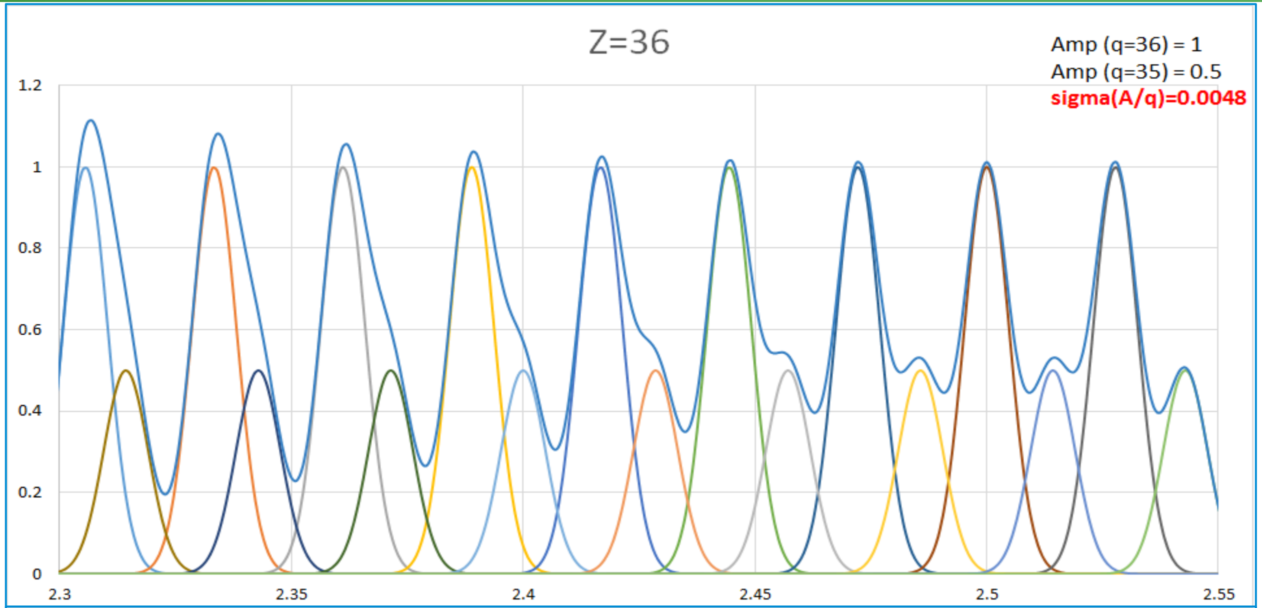
F.Farget et. al,Eur. Phys. J. A (2015) **51**: 175

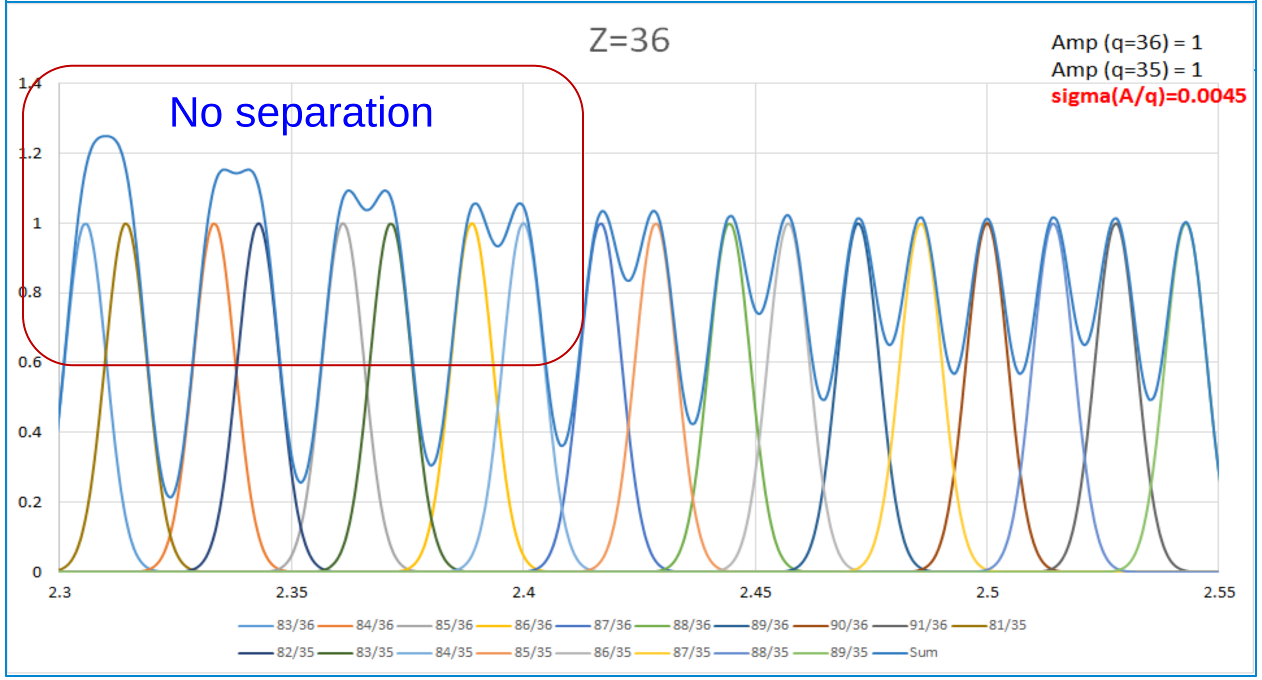
Fig. 2. Energy loss of fission fragments in the ionisation chamber of the focal plane, plotted as function of their energy. Each line is produced by isotopes of the same element, produced in the fusion-fission reaction of ^{238}U on ^{12}C at 6.1 MeV/u.

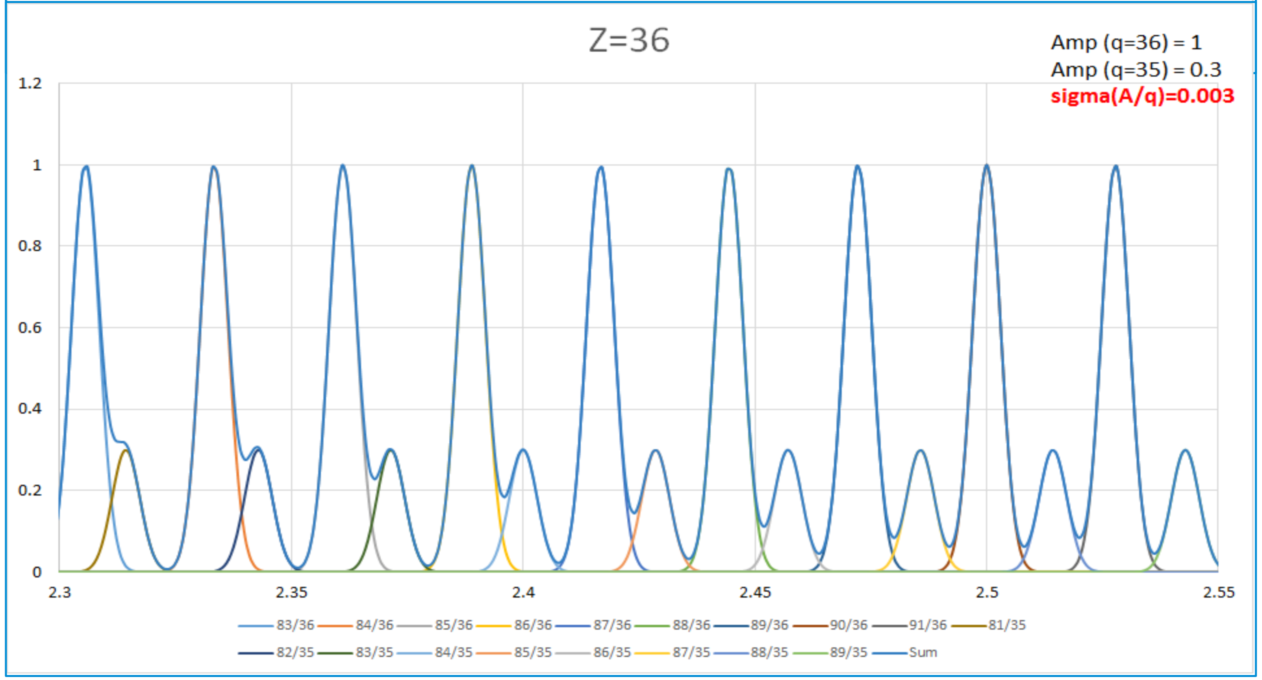
3. “Fast” beams experiments

When and where we can separate charge states?









A/q resolution 0.00314 : Hg (Z=80) isotopes

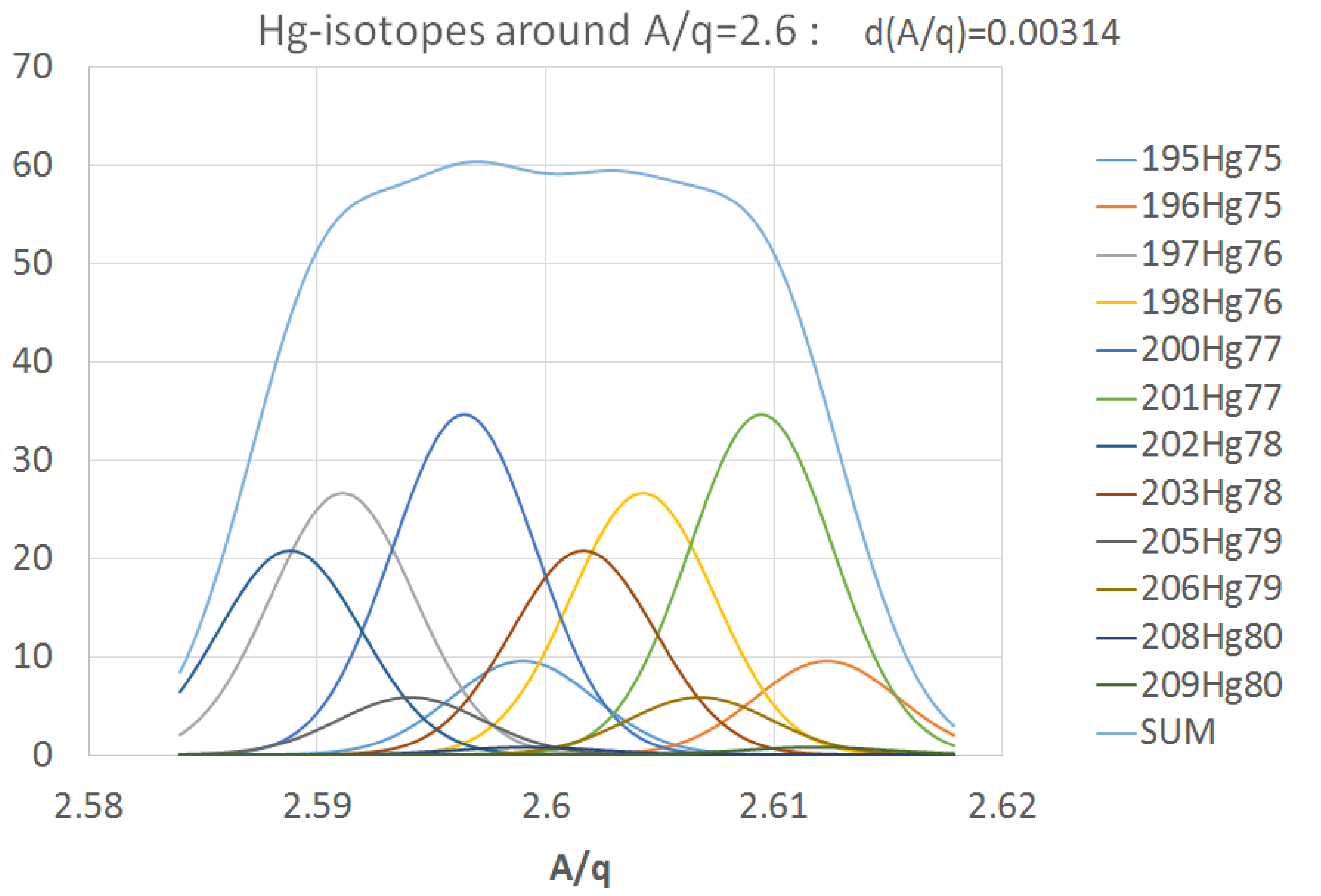
Resolution		
	sigma	
TOF =	0.180	*ns*
Momentum (Brho) =	0.0865	

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%



A/q resolution 0.0024 : Hg (Z=80) isotopes

Resolution

	sigma	
TOF =	0.100	*ns*
Momentum (Brho) =	0.0479	

Set-up

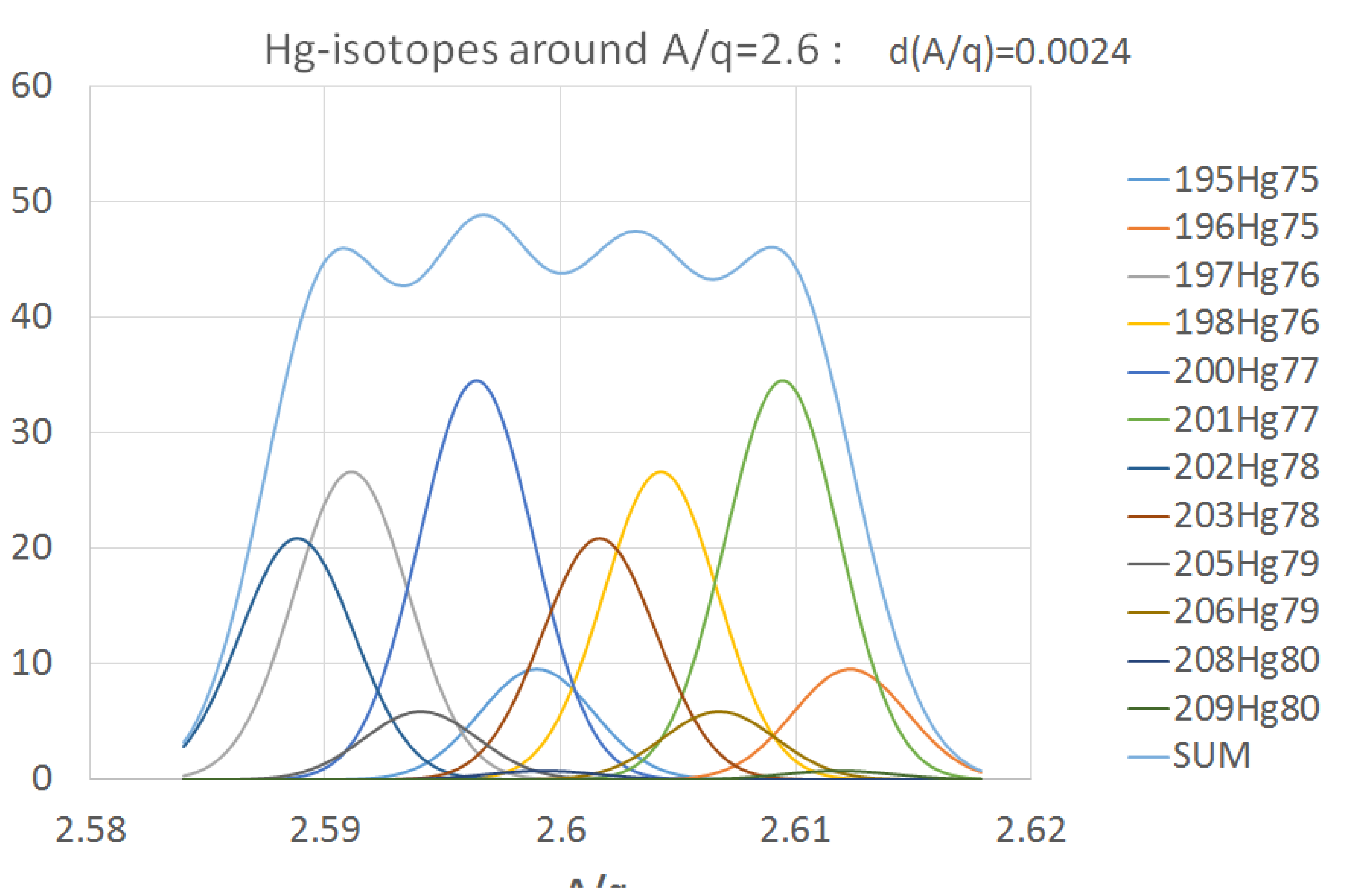
Energy =	70.00	*MeV/u*
Flight Length =	19.000	*m*

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%



A/q resolution 0.0014 : Hg (Z=80) isotopes

Resolution

	sigma	
TOF =	0.050	*ns*
Momentum (Brho) =	0.0479	

Set-up

Energy =	70.00	*MeV/u*
Flight Length =	19.000	*m*

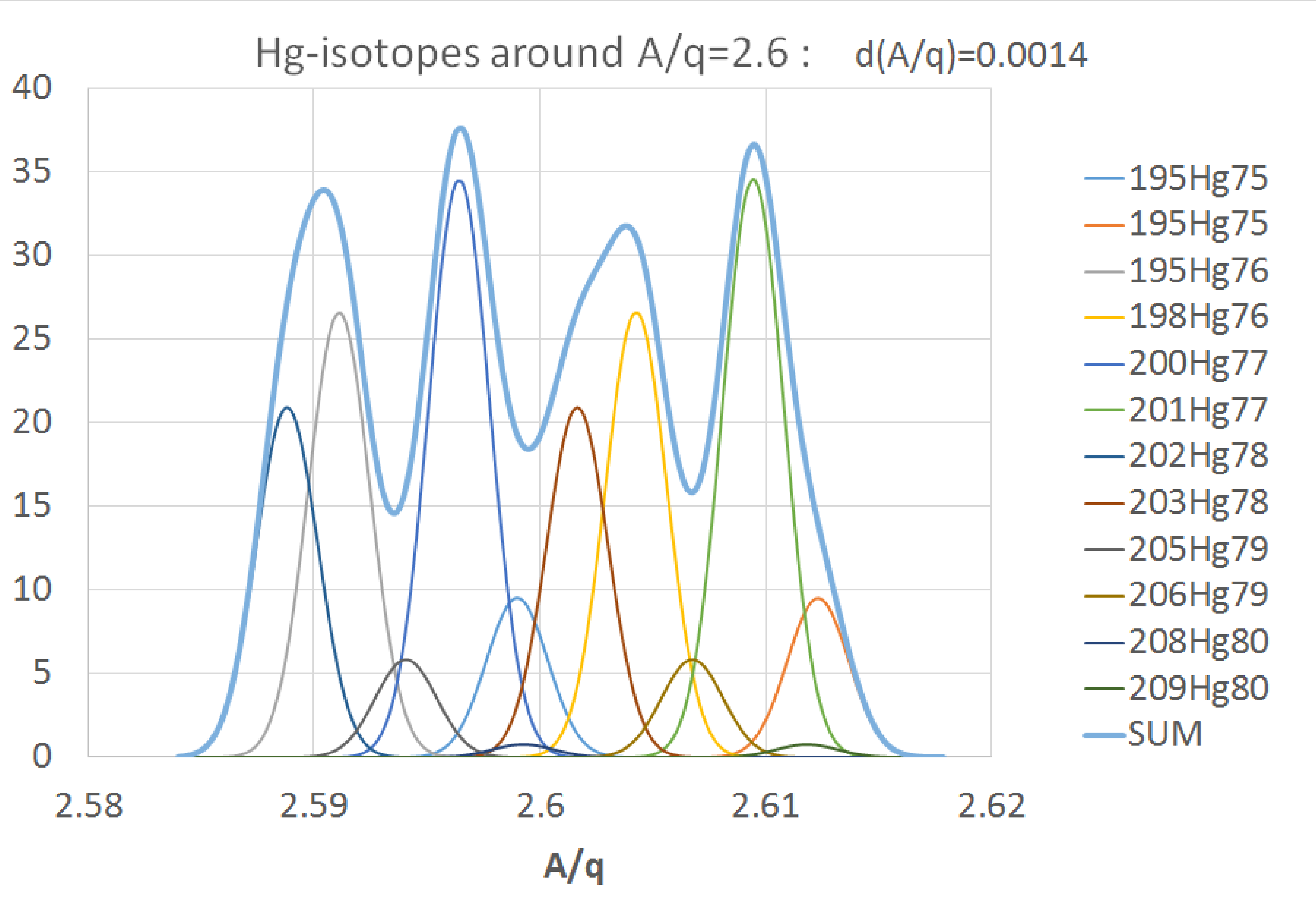
Momentum Resolution

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%

SUM



A/q resolution 0.0074 : Hg (Z=80) isotopes

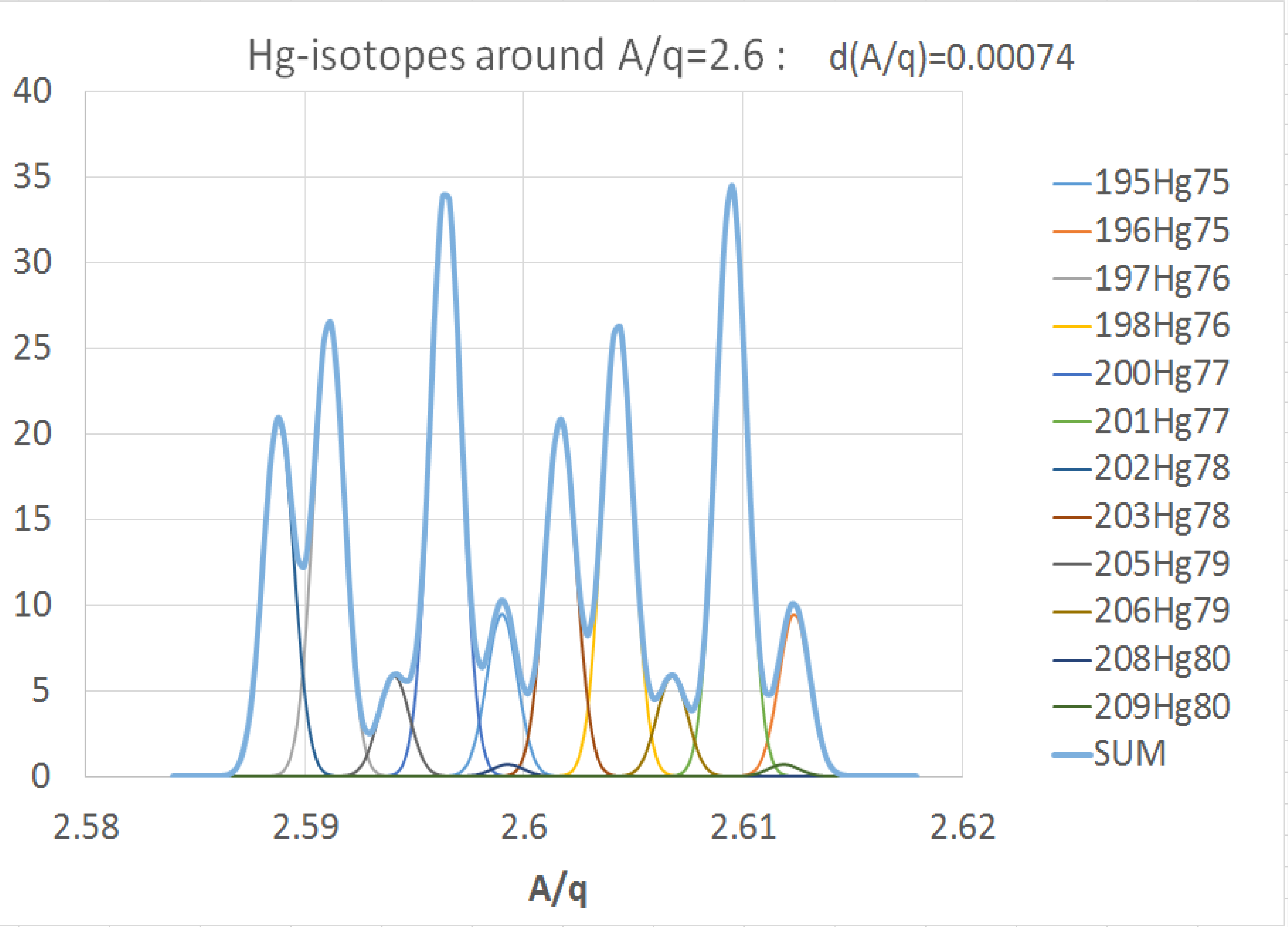
Resolution			
	sigma		
TOF =	**0.050**	*ns*	
Momentum (Brho) =	0.0479		

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%



RIKEN

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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

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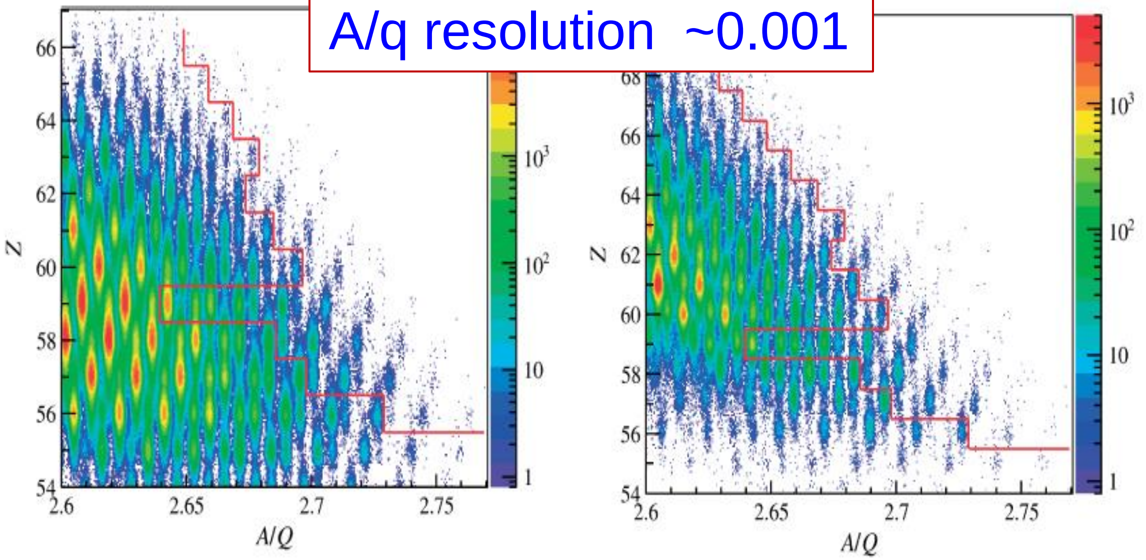
A/q resolution ~0.001



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

Set-up				
Energy =	250.00	MeV/u		
Flight Length =	46.500	m	F3-F7	
1st(Z) detector material =	14			
1st(Z) detector thickness =	200	mg/cm2	861.623	um

Resolution	sigma		systematical (calibration)		
TOF =	0.050	ns	0.005	%	
Eloss =	0.75	%	0.40	%	(straggling)
TKE =	0.45	%	0.05	%	
Z =			0.2	%	
Momentum (Brho) =	0.0142	%	0.01	%	

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	%

Measured values			error (σ)	%
TOF =	252.1534	ns	0.052	0.020
Brho =	6.6405	T*m	0.001	0.017
E1_loss =	3556.97	MeV	30.22	0.850
TKE =	49988.38	MeV	226.33	0.453

Deduced values			error (σ)	%
beta =	0.615158		0.00013	0.020
gamma =	1.268386		0.00016	0.012
velocity =	18.4412	cm/ns	0.00377	0.020
A / q =	2.739089		0.00102	0.037
A/q (2)=	2.76662		0.001241	0.045

PID values		error (σ)	%
Z (Eloss) =	74	0.347	0.47
q =	73.000	0.331	0.45
A (from TKE) =	199.9535	0.913	0.46
A (from [A/q]*q_integer) =	199.9535	0.074	0.04
A (from [A/q]*q_measur) =	199.9535	0.911	0.46
A-2q =	53.95	0.258	
A-3q =	-19.05	0.112	
A-2Z * =	54.69	0.267	

contribution in error					
	Brho	Beta	TKE	E1_loss	Zsyst
A / q	0.017%	0.033%			
A / q 2	0.018%	0.041%			
Z (Eloss)		0.017%		0.42%	0.20%
q	0.017%	0.026%	0.453%		
A (from TKE)		0.059%	0.453%		
A (from [A/q]*q_measur)	0.017%	0.033%	0.454%		
A-2q	0.03	0.08	0.24		
A-3q	0.04	0.06	0.09		

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

On the limit

Good!

4. PID features

Charge states “cleaning”

E12022 : PID

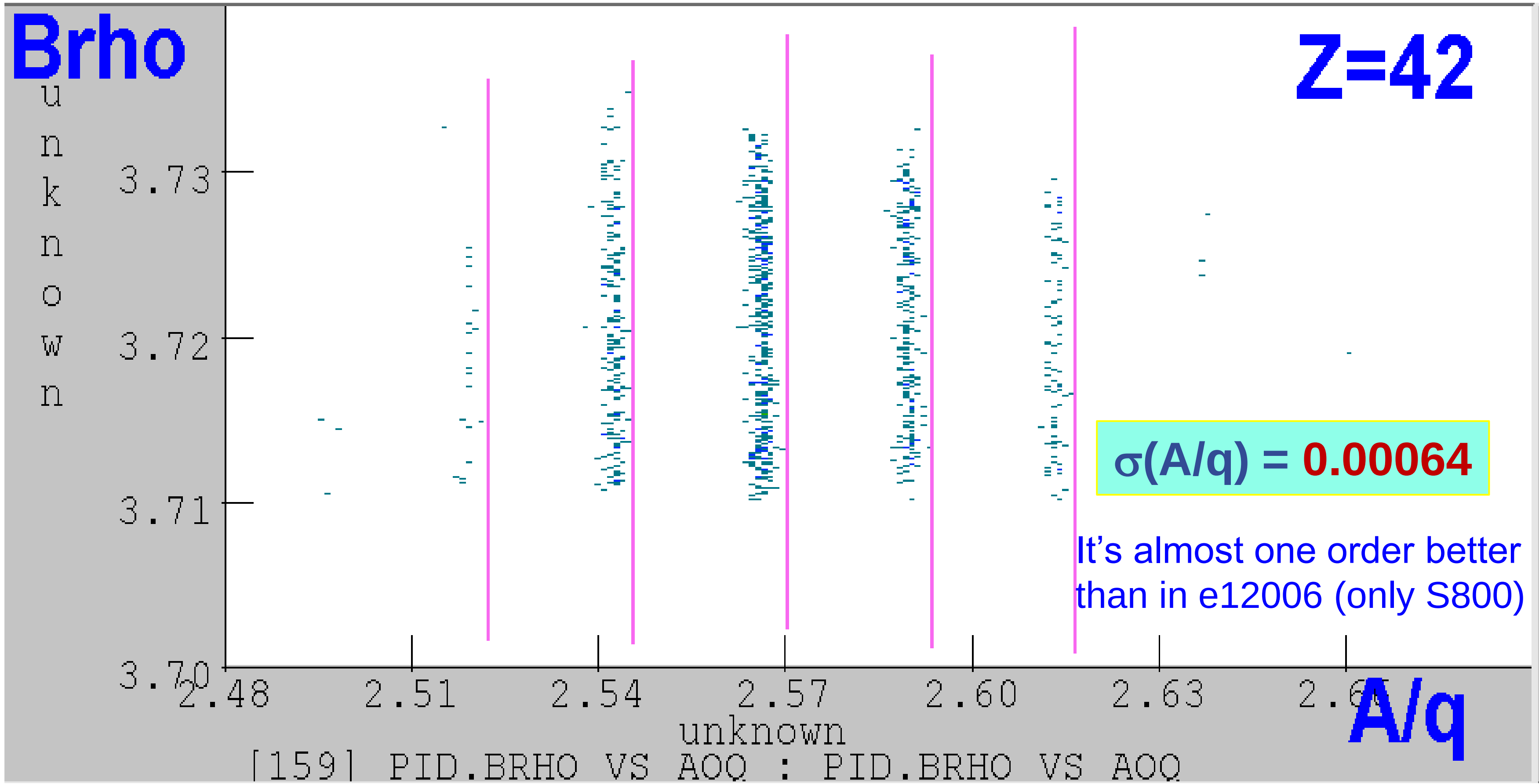
PI: M.Famiano

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

Dispersionl2= 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

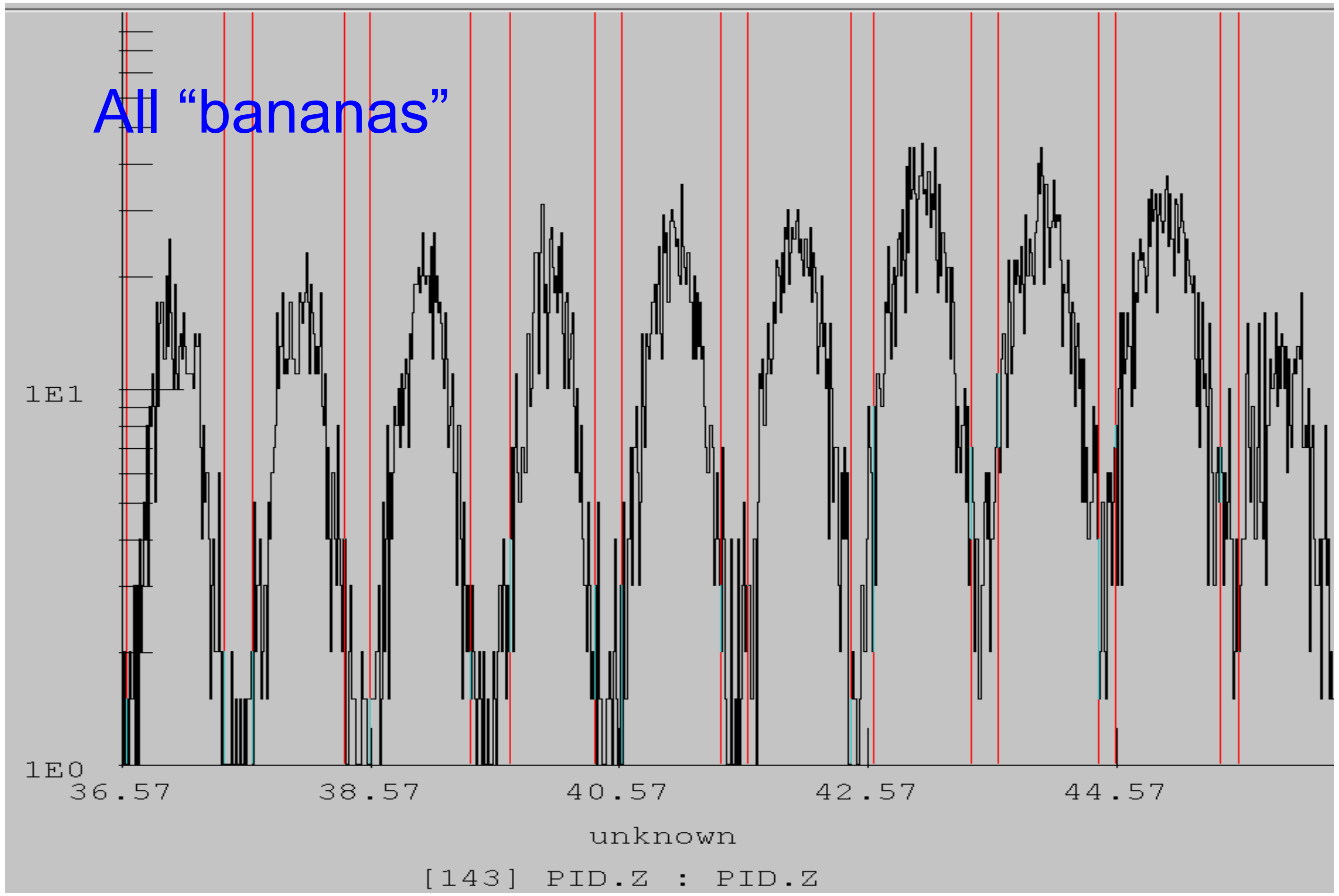


Resolution : Z

Good!

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

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



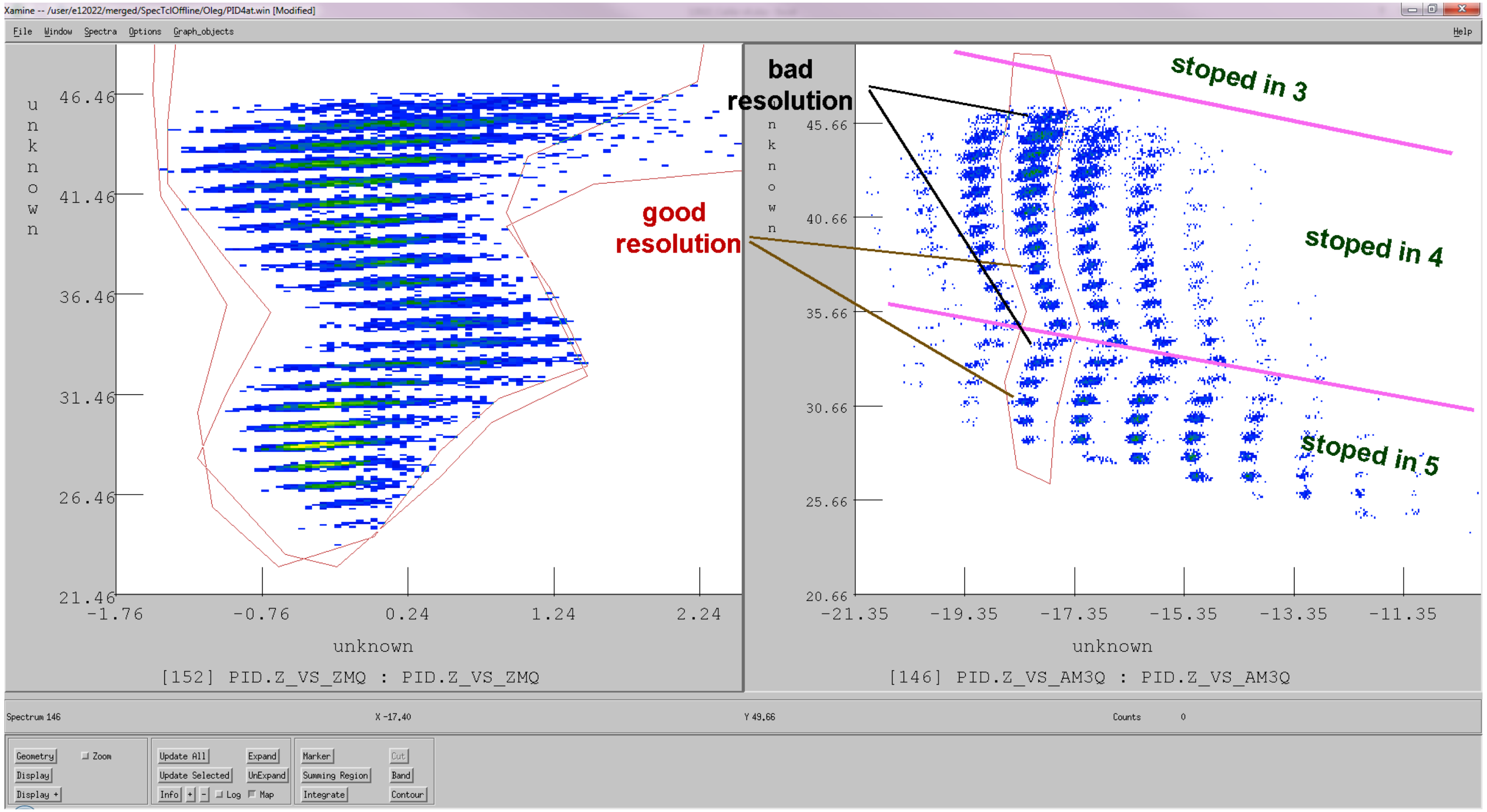
Resolution : TKE & q

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

BAD !

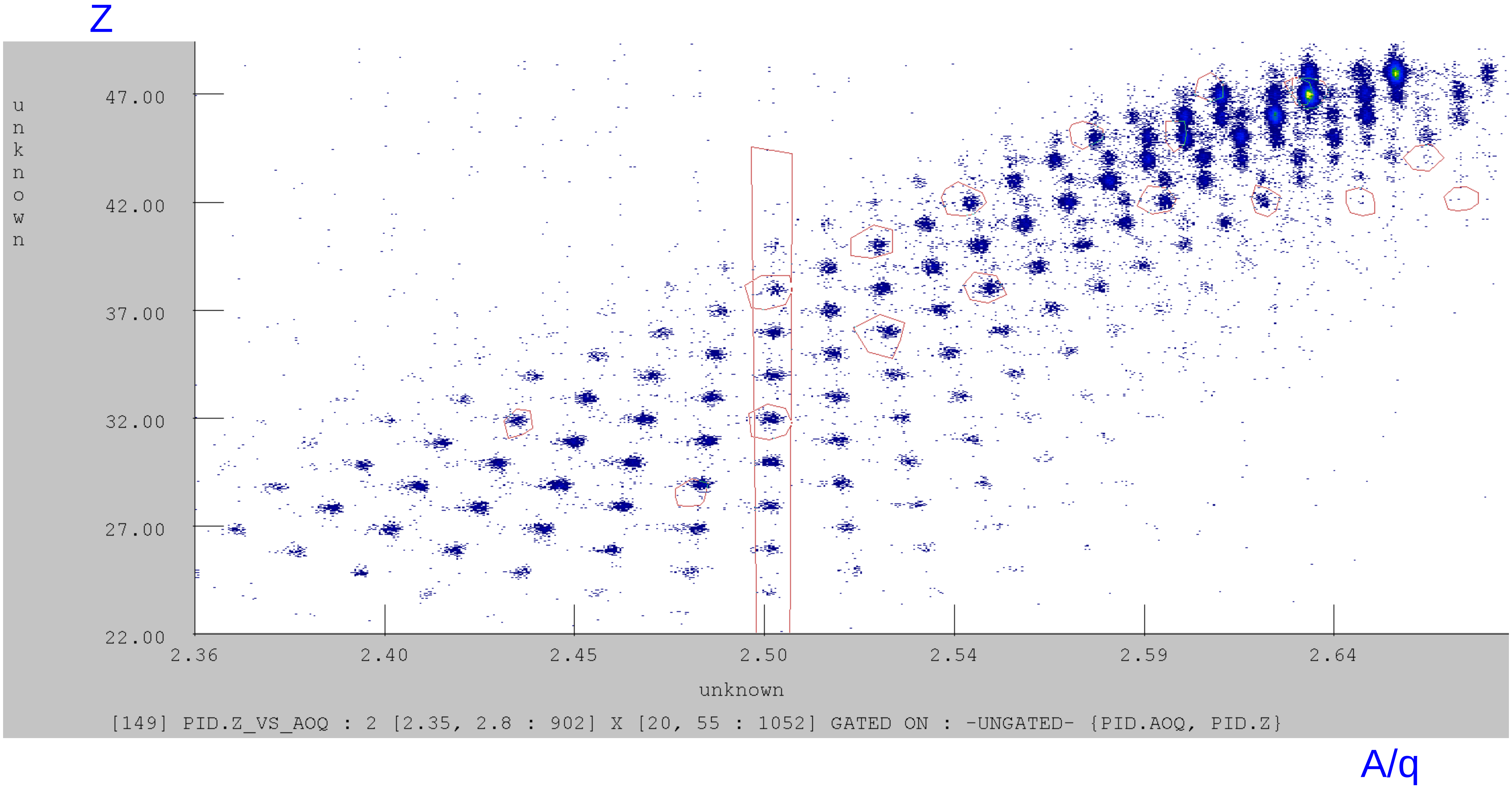
Average of $|q_{calc} - q_{peak}|$ = **0.29 (!)** in Z=32-50 region

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



Actually σ(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

PID plot without filtering



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.

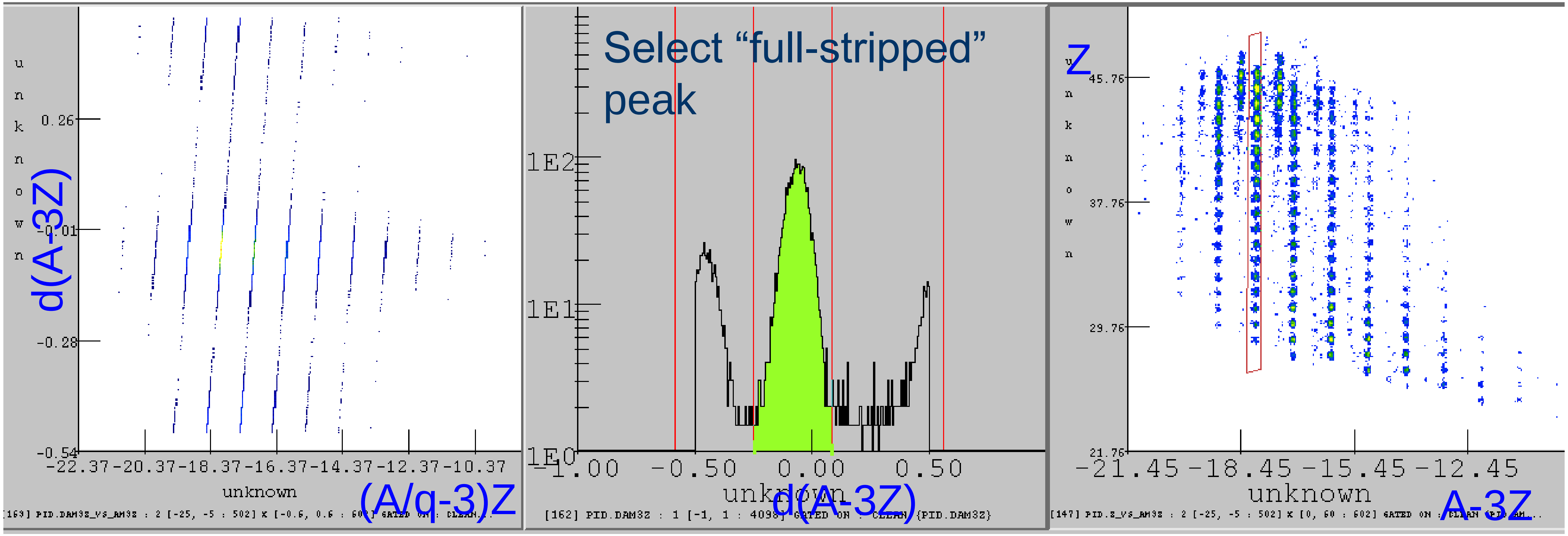
So, in our case we are working around 2.5, and no helium-like products

Zi = int(Z+0.5)

Am3Z = (A/q – 3) * Zi

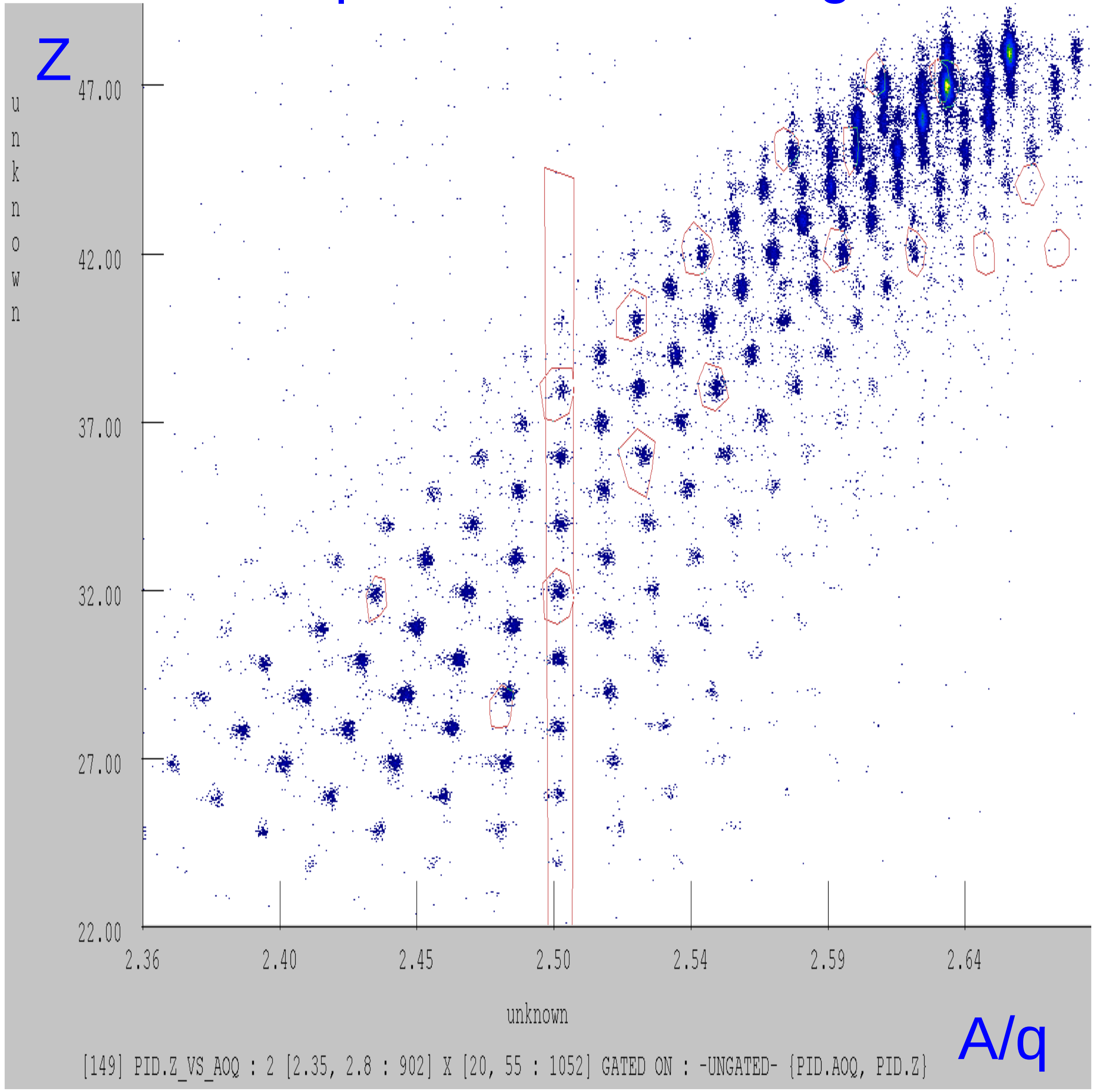
Am3Zi = int(Am3Z + 1.5)

dA3mZ = Am3Z - Am3Zi

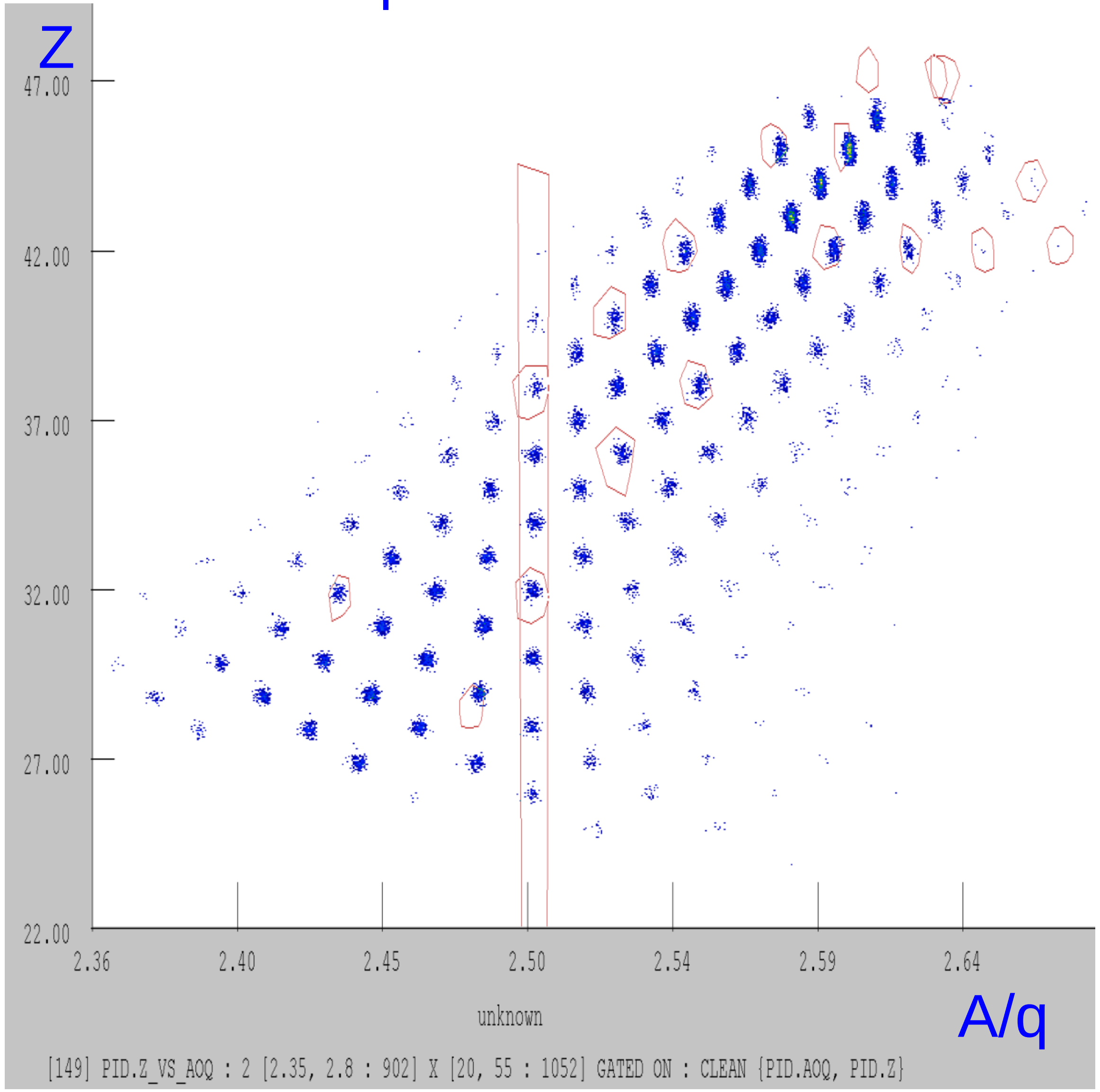


Final PID plot of full-stripped ions passed to the 4th detector

Initial plot without filtering



Final plot



Region to cut charge states using the "integer" method

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

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

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

MICHIGAN STATE UNIVERSITY

MSP-144 magnetic spectrometer with
dE-E ionization chamber
@ FLNR (Dubna)

$$dE \approx \frac{AZ^2}{E},$$

$$E = k(Bx)^2\frac{q^2}{A},$$

Assuming *q=Z*
for the identification matrix

O.B. Tarasov et al. / Nuclear Physics A 629 (1998) 605–620 607

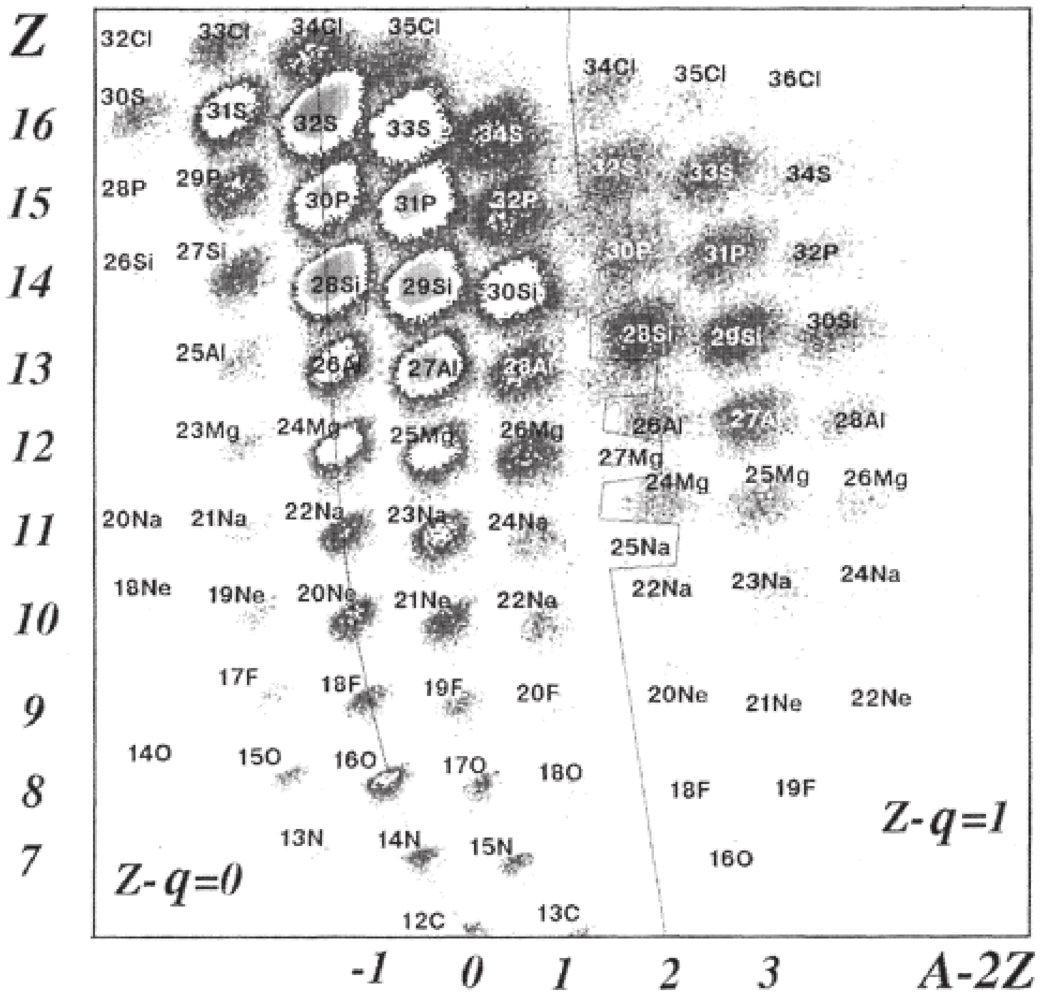
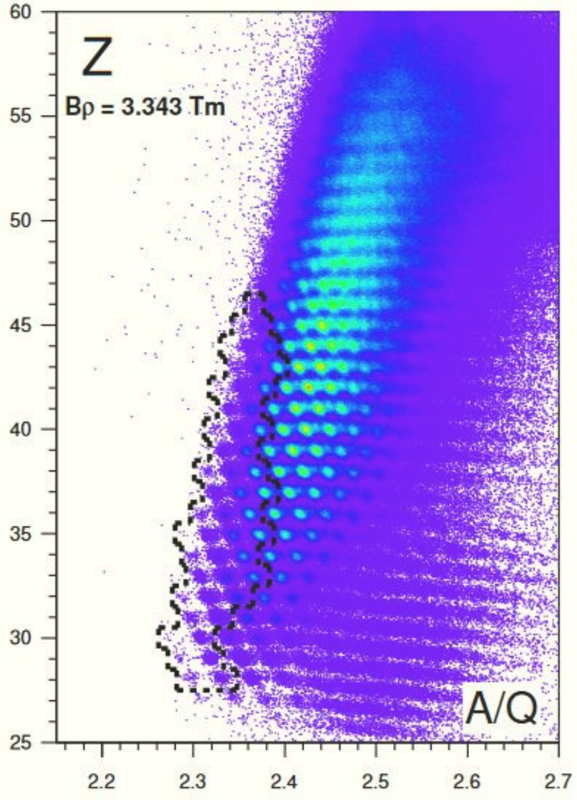


Fig. 1. Identification matrix $(A-2Z, Z)$ of the products of the ^{32}S(14.5 MeV/A)+C reaction obtained at a magnetic field B = 0.7975 T. The left solid line passes through the completely stripped nuclei with zero isotopic spin. The right curve discriminates between regions of nuclei with charge $q = Z$ and $q = Z - 1$.

Inverse technique. Reconstruction (e12006)

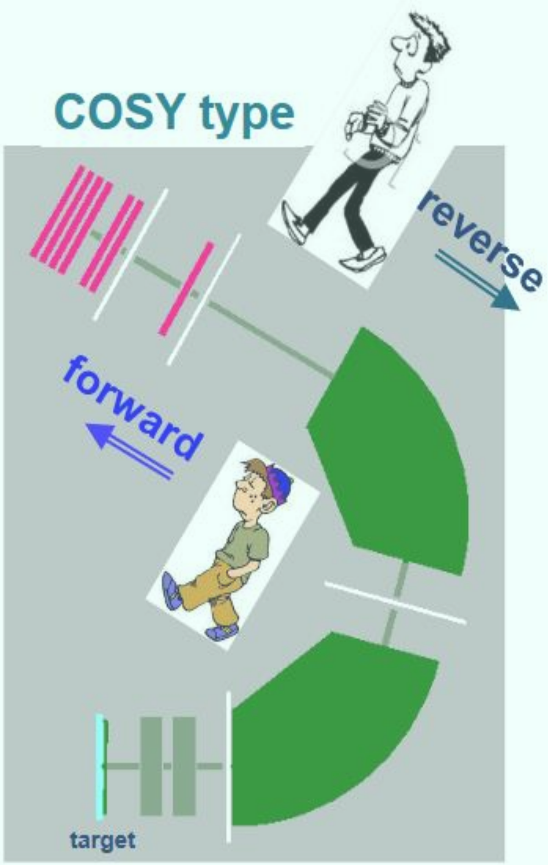
http://lise.nscl.msu.edu/paper/2016/Reconstruction_with_LISE.pdf

^{238}U @ S800 experiment

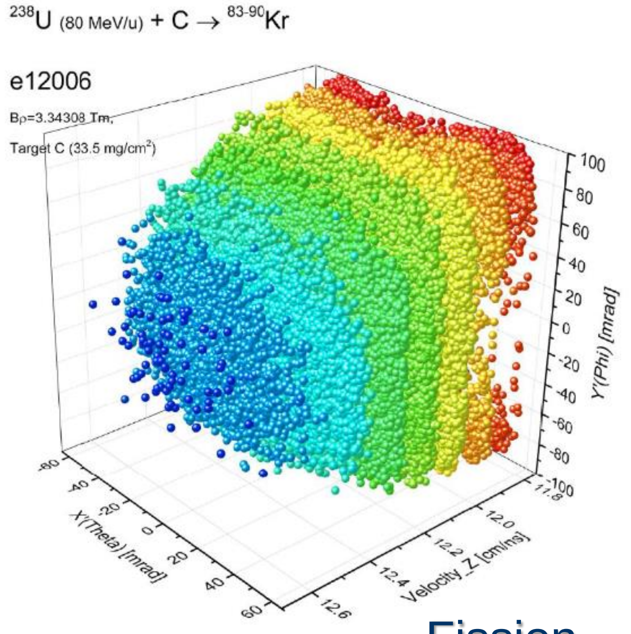


M.Bowry, private communication

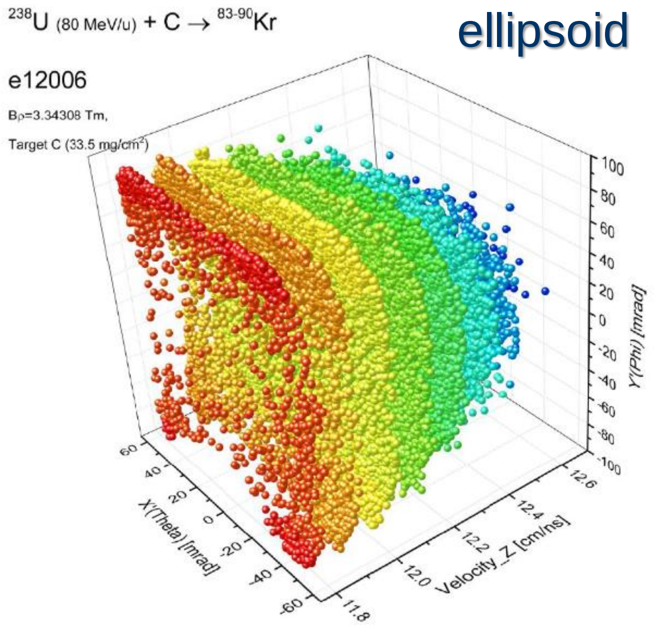
LISE^{++} MC



Will be finally published in 2021? ☺



Fission ellipsoid



“Global” (net) calibration

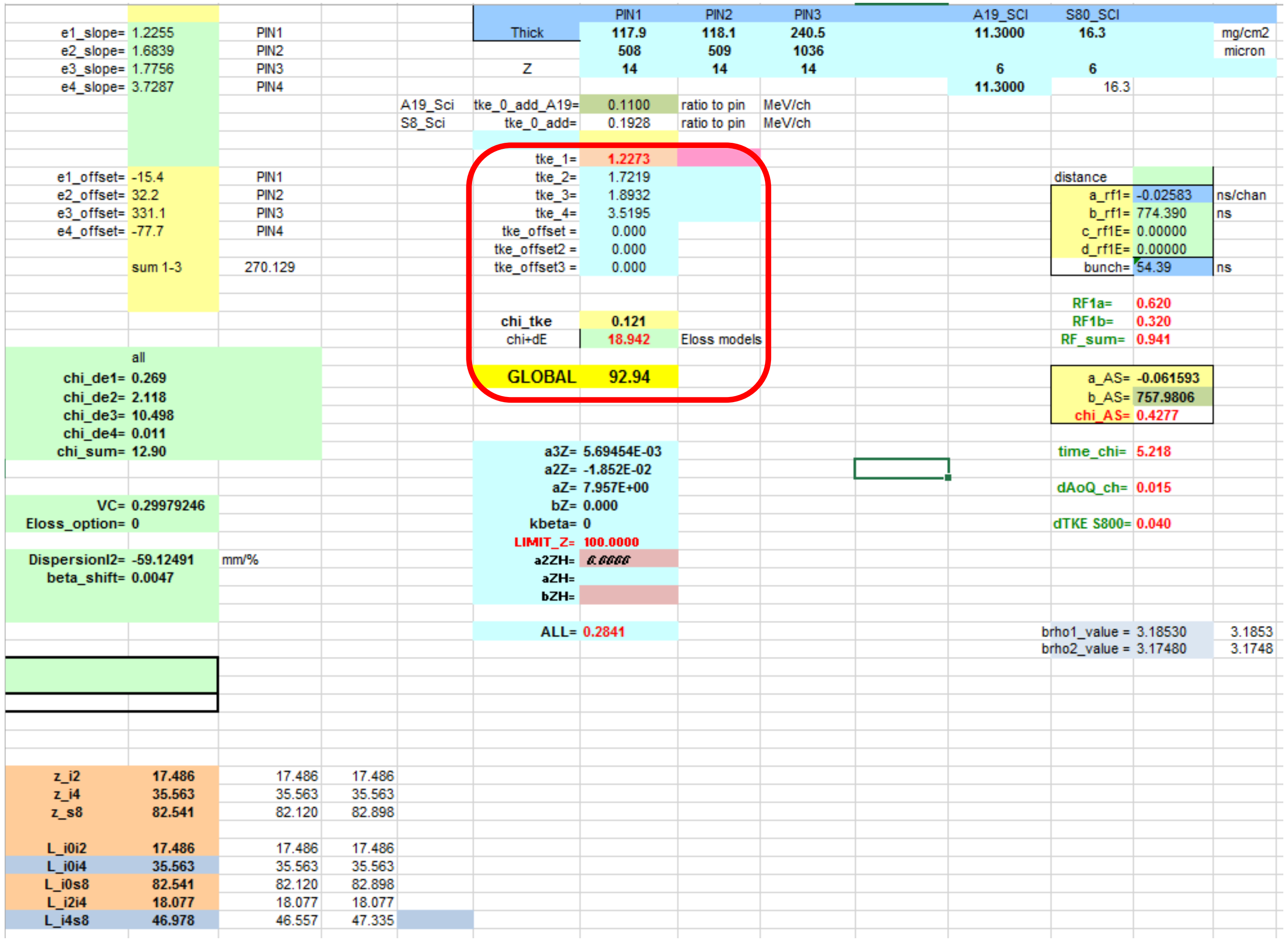
"Global" (net) calibration

Finally, it has to be published….
Or at least documented

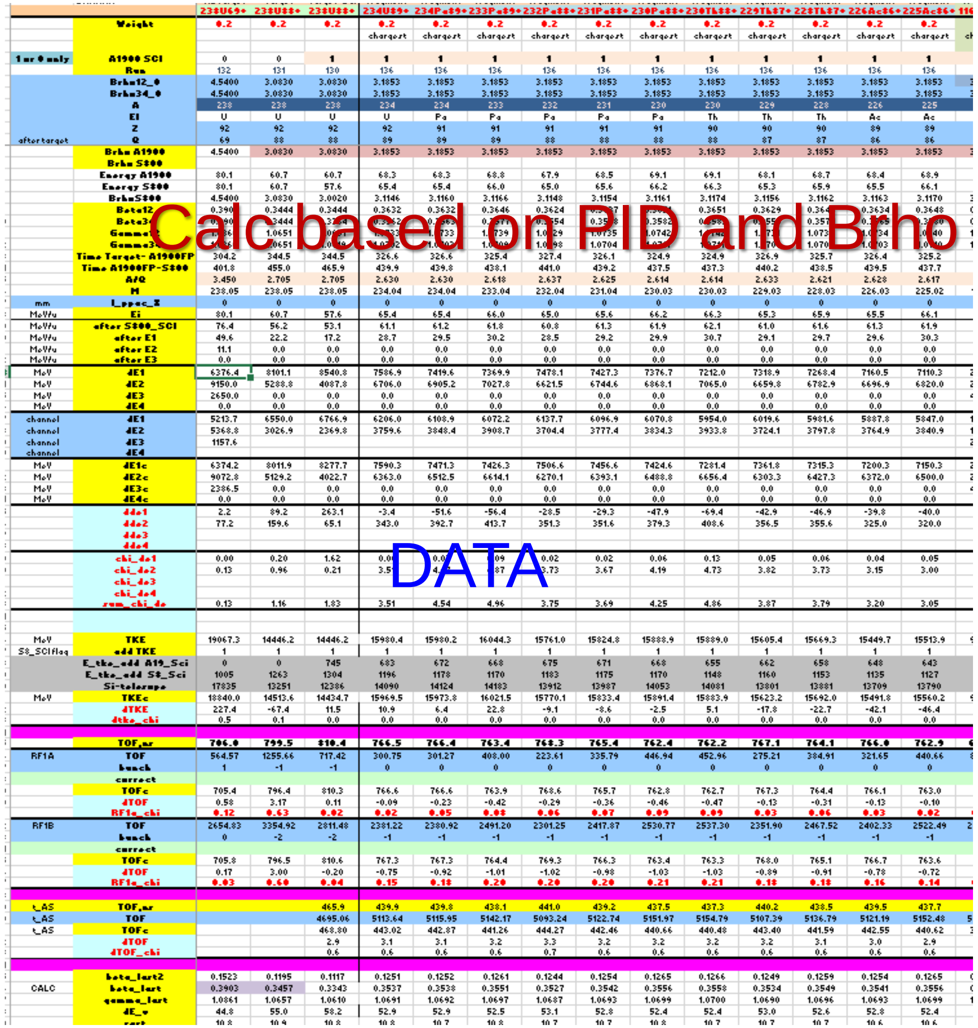
It is necessary to use LISE for Excel

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

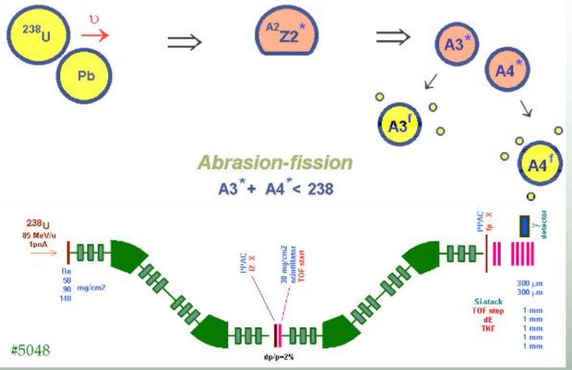


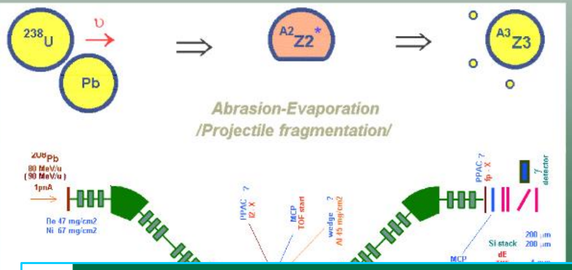
Z ToFs dE & TKE



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

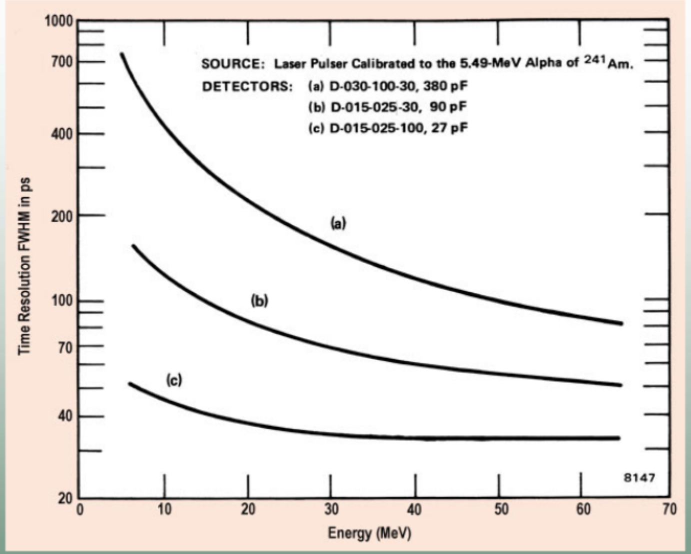
I2	*FP*
MCP (t)	Si-stack (dE,TKE)
MCP (x)	Si-stack (t)
Sci (t)	PPAC (t)
Sci (x)	PPAC (x)
PPAC (t)	MCP (t)
PPAC (x)	MCP (x)
Diamond (t)	Diamond (t)

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}Ag) = 90.93±0.165 MeV/u
TOF-detectors: Scintillator (20 mg/cm^2) and Si (501 μm)

Component	σ(TOF) ns	FWHM(TOF) ns
Fragment Energy	0.115	0.271
Experiment	0.271	0.444
detectors	**0.149**	0.352
		0.24%

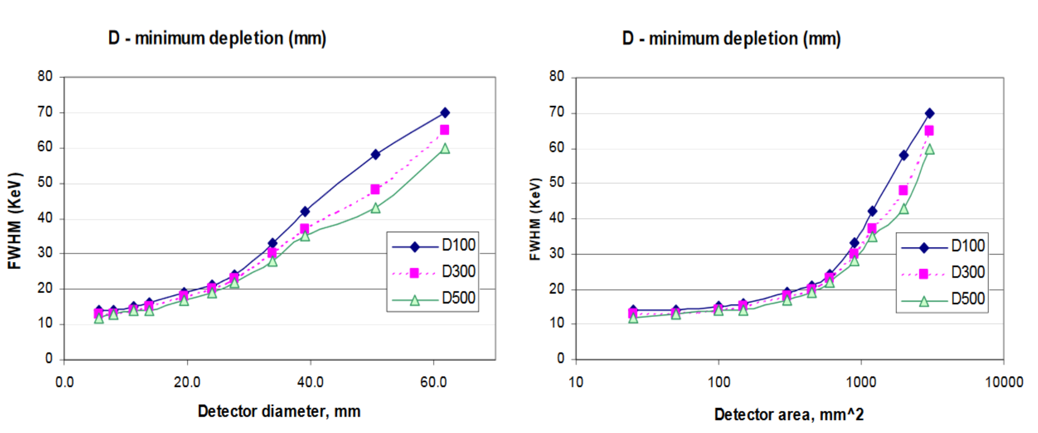


Resolution$_{time}$ ~ Thickness^x / Area^y,

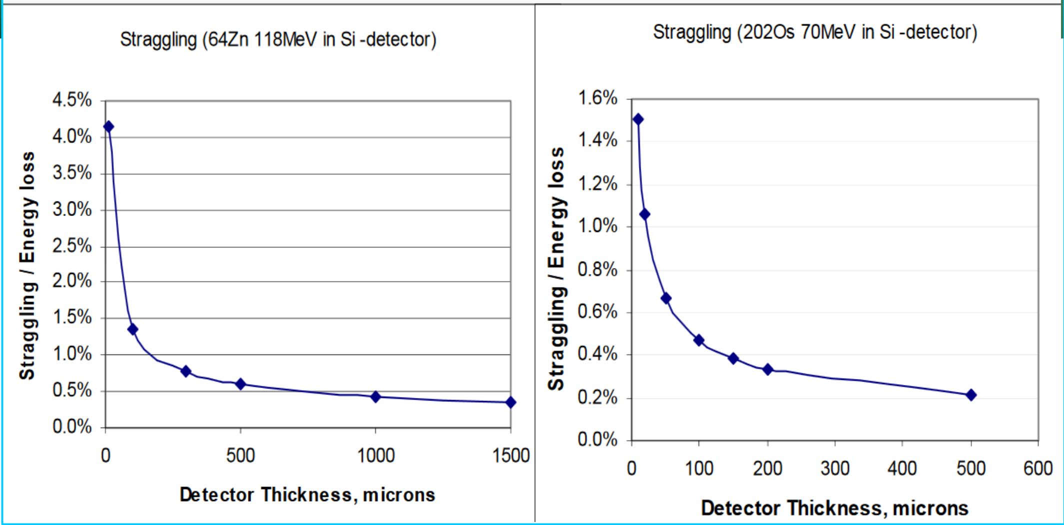
Typical Time Resolution vs. Energy for

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



http://lise.nscl.msu.edu/paper/2006_february_detectors.pdf

Z resolution at large acceptance

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

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

Energy Loss detector
Si (t=300 μm, Δt=0.5 μm)

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

Configurations		σ(β) / β	σ(dE)/dE	$σ_{Acc}$(Z)	σ (Z)
I2	*FP(TOF)*	%	%		
MCP	Si	0.094	0.53	0.1	0.271
MCP	MCP	0.073	0.53	0.1	0.268
MCP	PPAC	0.094	0.53	0.1	0.271
Sci	PPAC	0.088	0.54	0.1	0.274
PPAC	PPAC	0.111	0.53	0.1	0.275

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

$Z_{formula}$ validity ($σ_v$(Z)=0.02) was taken into account for σ(Z).

Main contribution in the σ(Z) val
the large acceptance (dp/p=1.0
the Si dE-detector resolu
(σ(dE)/dE=0.43%)

σ(Z): Configuration MCP

Strag.co

	$σ_{Acc}$(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

"Banana" (A-3Q) resolution

σ(A): ^{202}Os

Configurations			σ(β) / β	σ(ϖ)/ϖ	σ(TKE)/TKE*	σ(A-3Q)*
I2	*FP(TOF)*	*mode*	%	%	%	
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
	RF+Si		0.438	3.44	0.55 / 0.35	0.91 / 0.90

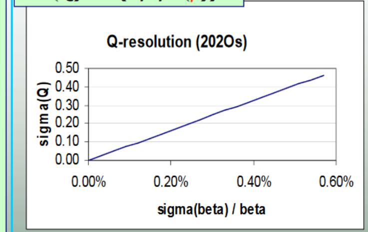
* σ(TKE)/TKE are taken for two different TKE configurations

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

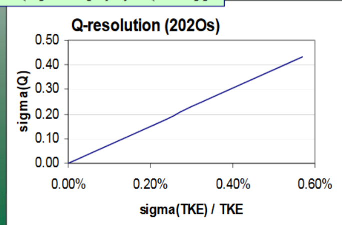
Q resolution

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

σ(Q) = f(A,Z, σ(β))



σ(Z) = f(A,Z, σ(TKE))



σ(Q): ^{202}Os

Configurations			σ(β) / β	σ(TKE)/TKE*	σ(Q)*
I2	*FP(TOF)*	*mode*	%	%	
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
	RF+Si		0.438	0.55 / 0.35	0.53 / 0.43

* σ(TKE)/TKE are taken for two different TKE configurations

Two main σ(TKE)/TKE components are Si-resolution and "dead" layer.

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

σ(Q): Configuration MCP+Si+A

Configuration	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.nscl.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
dp/p = 0.2%

I2	*FP(TOF)*	*FP(X)*	σ (Z) ♣	σ(A) ♦	σ(Ai)	σ(Q) ♦	σ(A-3Q) ♦
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 Bρ–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%

Calculated Value	Main contribution from
σ(Z)	dE
σ(A)	TKE
σ(Ai)	β
σ(Q)	TKE
σ(A-3Q)	β, Bρ

Calculated Value	Main contribution from
dE	E_det-resol., stragg.
β	Accept, T_det-resol.
TKE	TKE_det-resol
Bρ	X-object, X_det-resol.

More difficult case is σ(Q), or by another words TKE

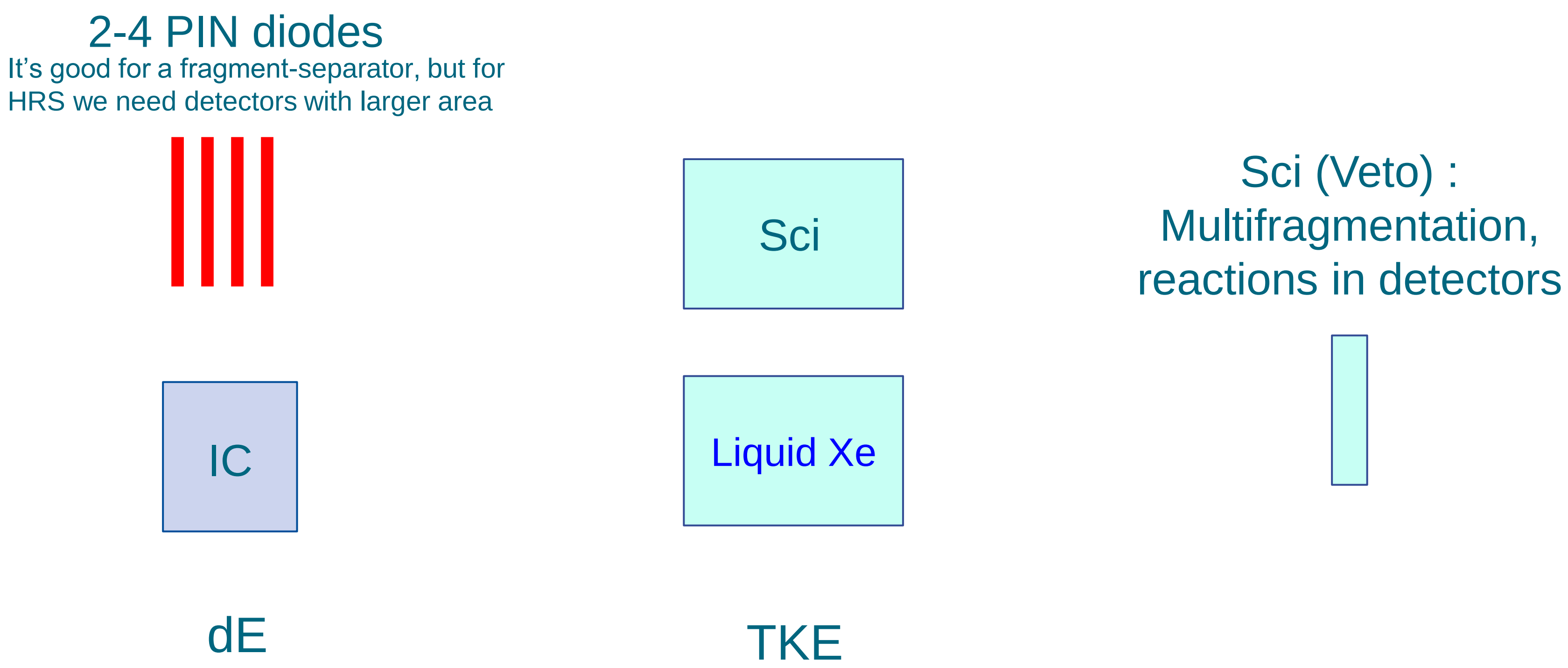
IGAN STATE VERSITY The NSCL is funded in part by the National Science Foundation and Michigan State University.

Universal dE-TKE system for HI beams

Assume the ^{238}U beam → 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?



Pay attention for

Spectrometers

1. ToF detectors (spectrometer case) : start(where?) & stop
2. *X, X', Y, Y'* detectors in the Dispersive focal plane
   (Bρ-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

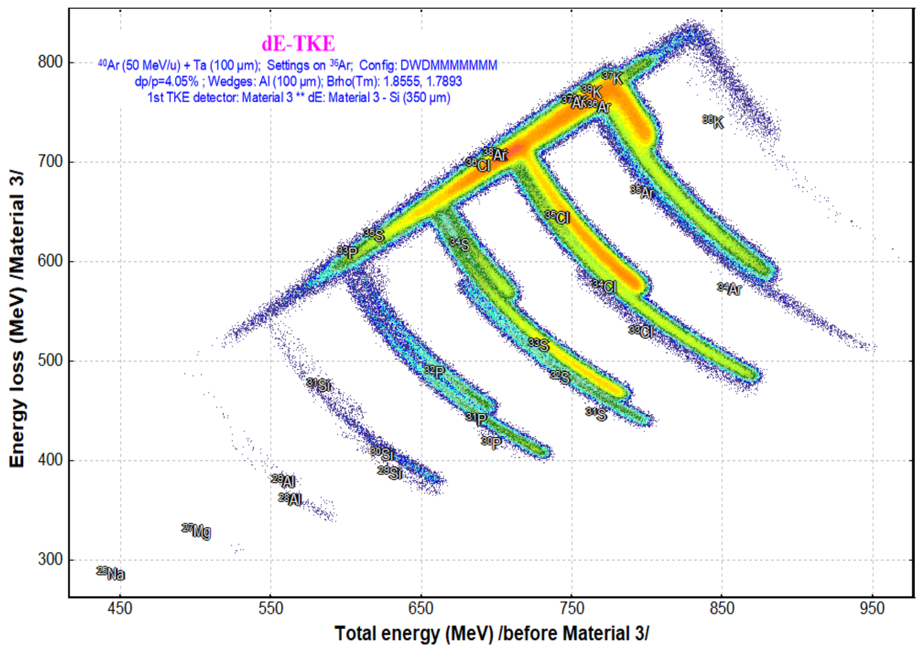
1. Signals Doubling (filtering)
2. Si-detectors: Depletion issue
3. Optical trajectory reconstruction (Isochronous term (L/δ)

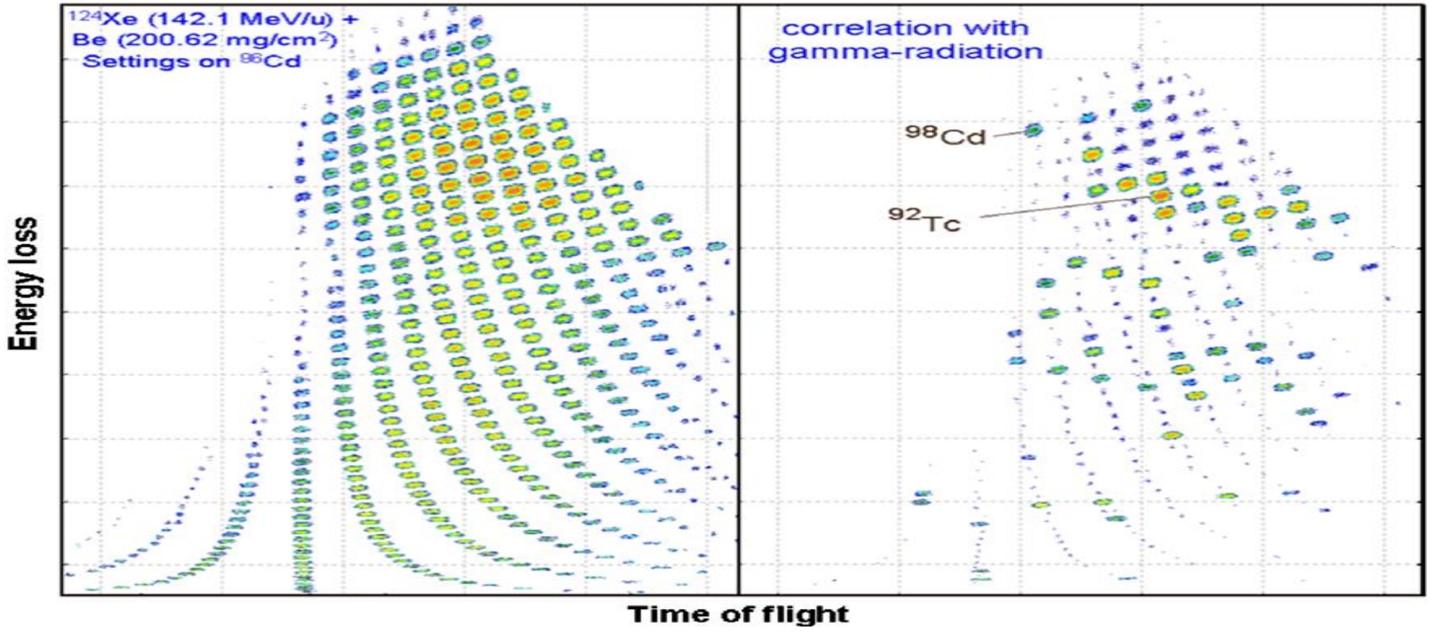
6. Irreplaceable helper for PID

$LISE^{++}$

$LISE^{++}_{cute}$

LISE++ : Irreplaceable helper for PID





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

LISE++ cute : DONE!

MICHIGAN STATE UNIVERSITY

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

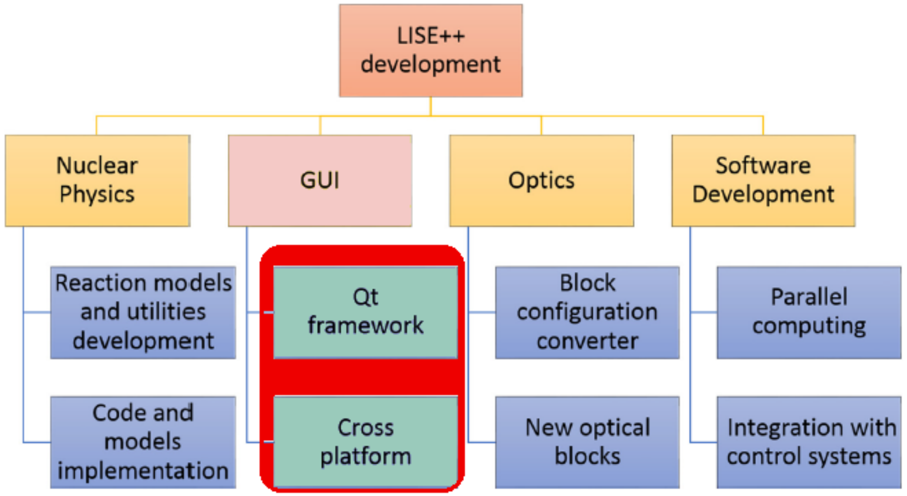
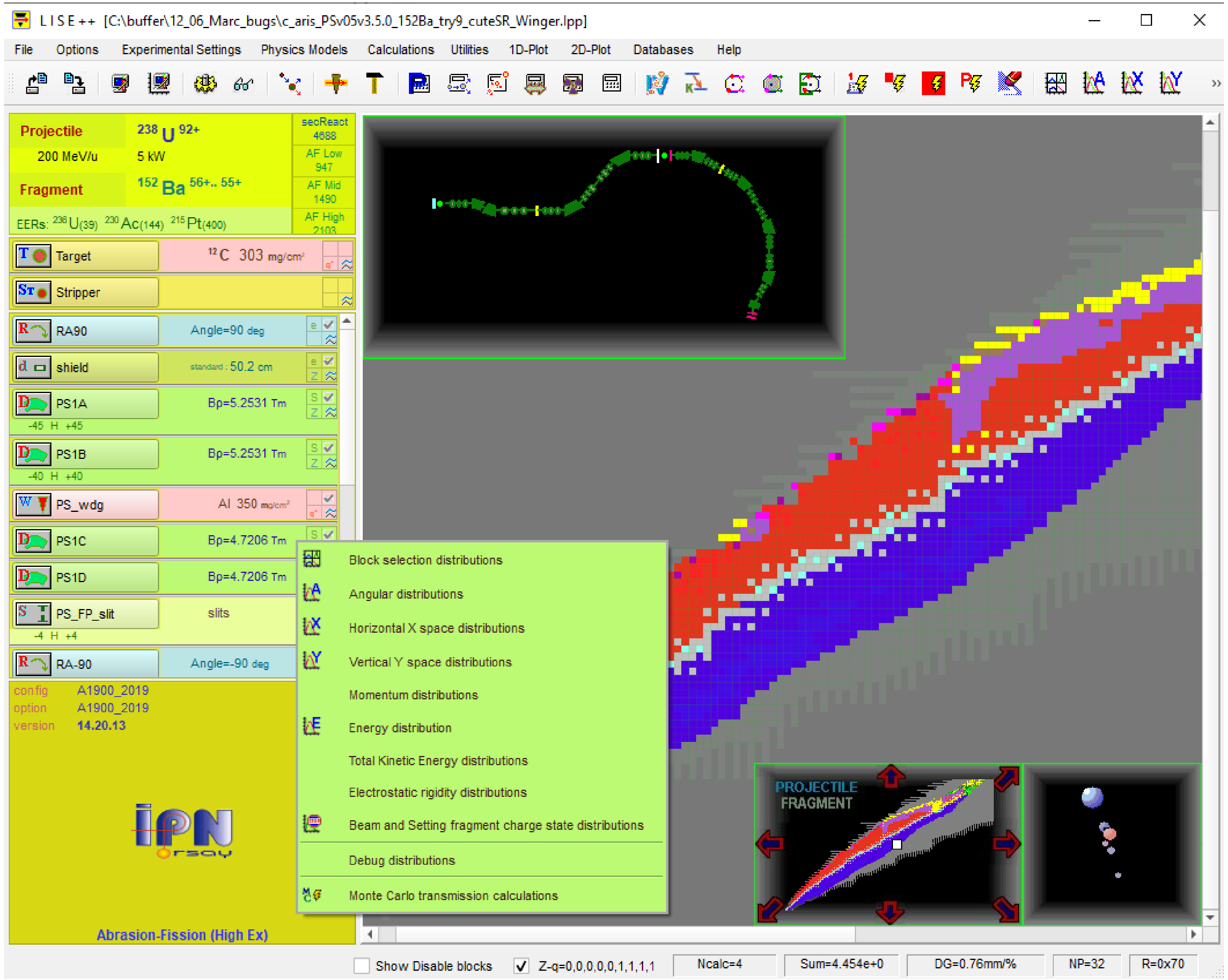


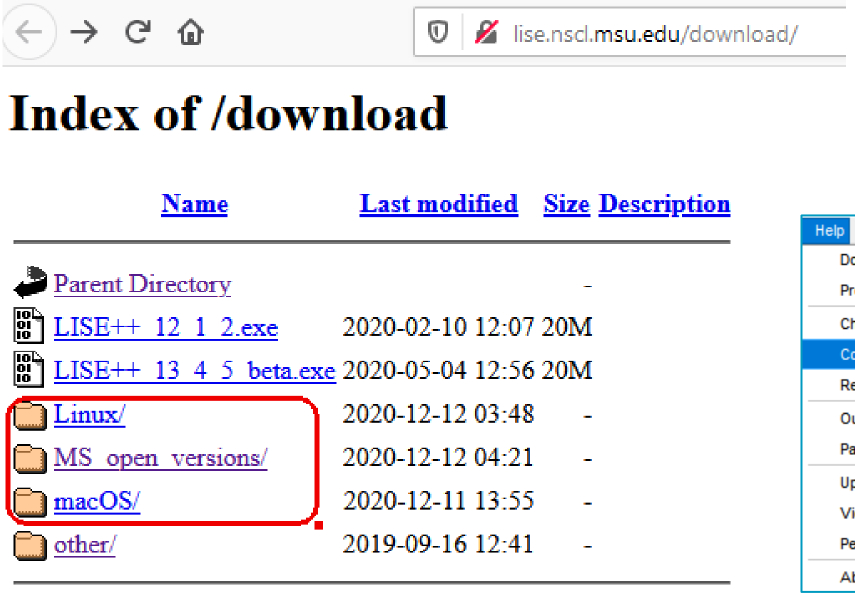
Fig. 1. A schematic diagram of the LISE++ development plans.

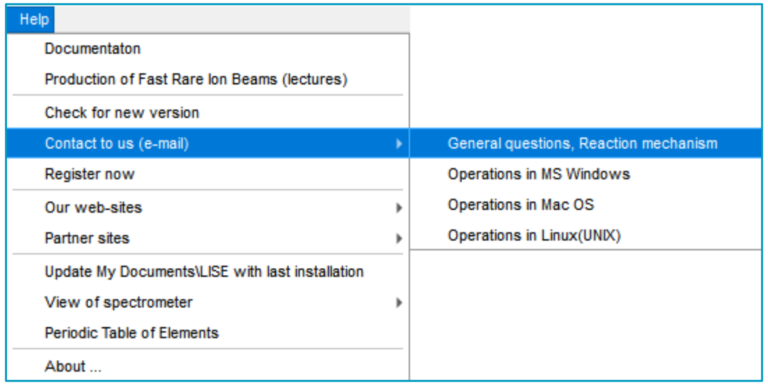
The LISE++ software suite is undergoing a major transportation to a new graphics framework in order to support modern compilers and computing methods.

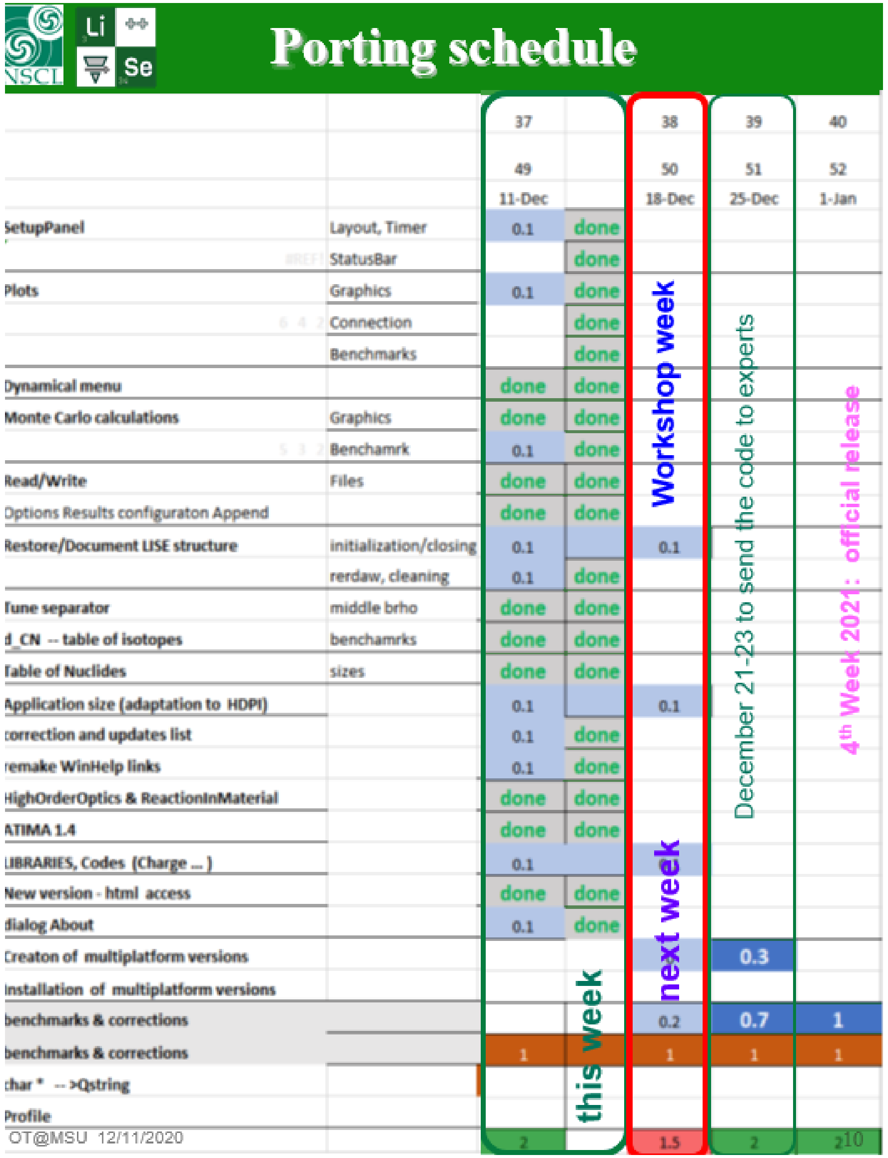
Qt *framework*. For compatibility with future operating systems, the graphics framework is being transported to Qt. Benefits include provisions for 64-bit operation, cross-platform compatibility, and the ability to take advantage of computational advances. Qt was chosen as the graphics framework based 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.







		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		
	rerdaw, 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			
Creaton 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						
		2		1.5	2	2

Thank you
for your attention!

Be healthy!

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