Production yields and cross sections at the BigRIPS separator

Y. Shimizu
BigRIPS team

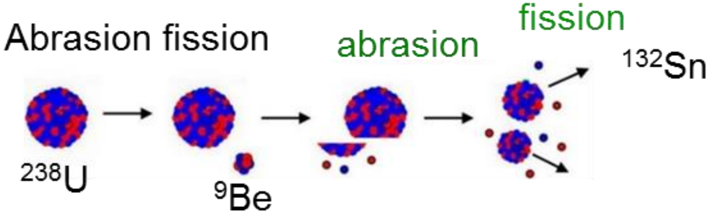
N. Fukuda, H. Takeda, H. Suzuki, D.S. Ahn,
T. Sumikama, D. Murai, Y. Yanagisawa, K. Kusaka,
M. Ohtake, N. Ianbe, K. Yoshida, T. Kubo

Outline

- Introduction
  - Production mechanism of RI beams
  - Particle identification (PID) scheme
  - RI beams at the BigRIPS separator
- Measured production yields and cross sections
  - Neutron-rich nuclei by in-flight fission of ^{238}U beam
  - Proton-rich nuclei by projectile fragmentation of ^{124}Xe and ^{78}Kr beams
  - Neutron-rich nuclei by projectile fragmentation of ^{70}Zn and ^{48}Ca beams
- Database of RI beams produced at BigRIPS
- Summary

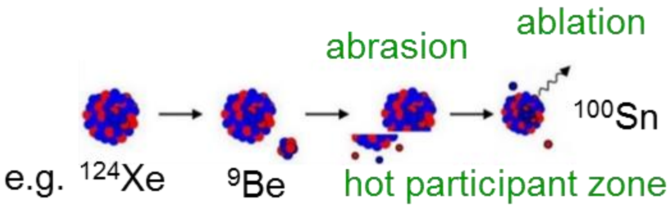
Production reactions at BigRIPS

- **In-flight fission of ^{238}U beam**



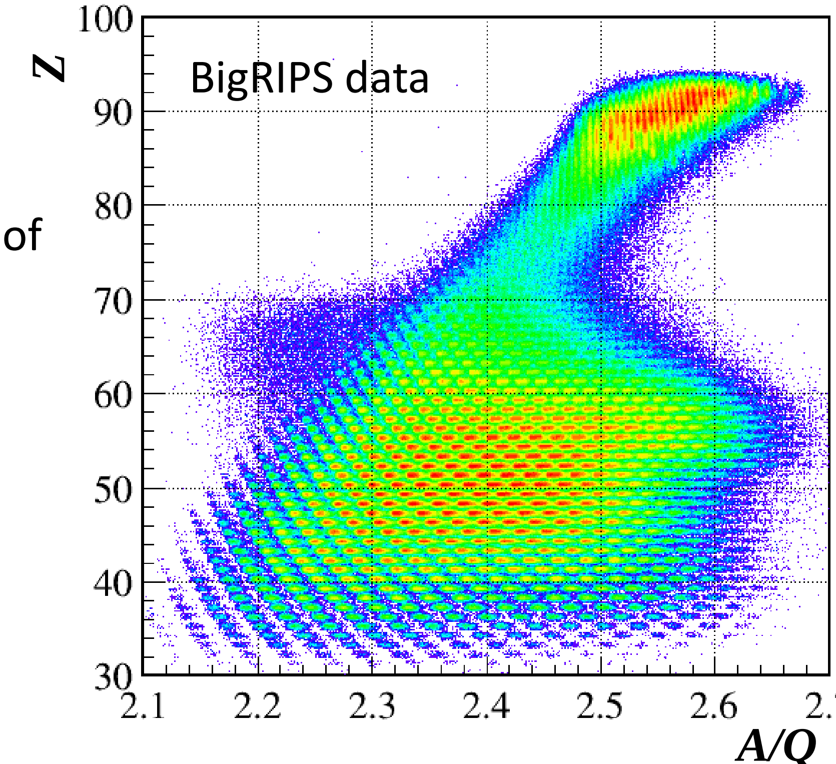
  - very powerful for producing a wide range of medium-heavy neutron-rich isotopes
  - large production cross section

- **Projectile fragmentation**



  - all kinds of fragments (RI beams) lighter than projectile can be produced

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



Some cartoons are based on those from GSI.

Particle identification (PID) scheme at BigRIPS: *Z* vs *A*/*Q*

- TOF-$B\rho$-ΔE method with trajectory reconstruction

$$\frac{A}{Q} = \frac{B\rho}{\gamma\beta}\frac{c}{m_u}$$

$$Z \leftarrow \Delta E = f(Z, \beta)$$

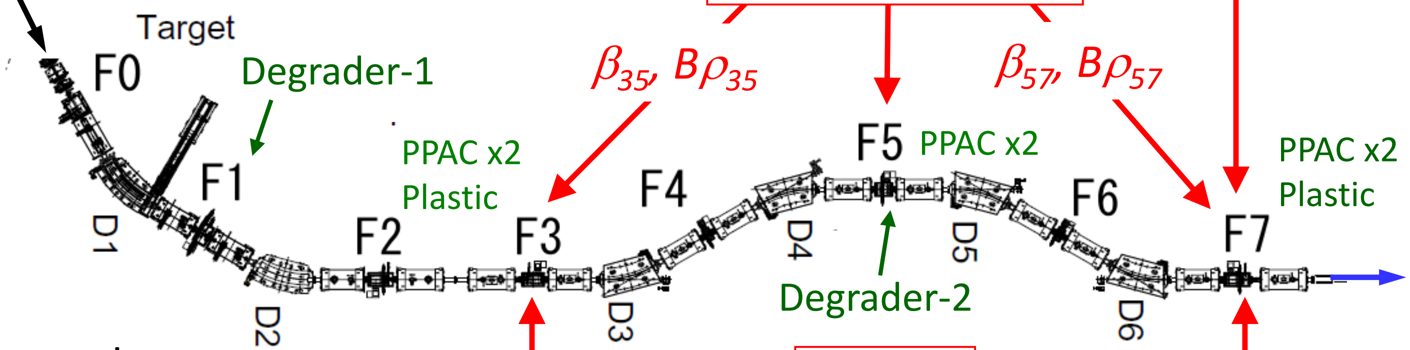
Bethe-Bloch formula

2nd stage

$B\rho$ with track reconstruction

ΔE: MUSIC, Si
Isomer tagging: Ge

1st stage



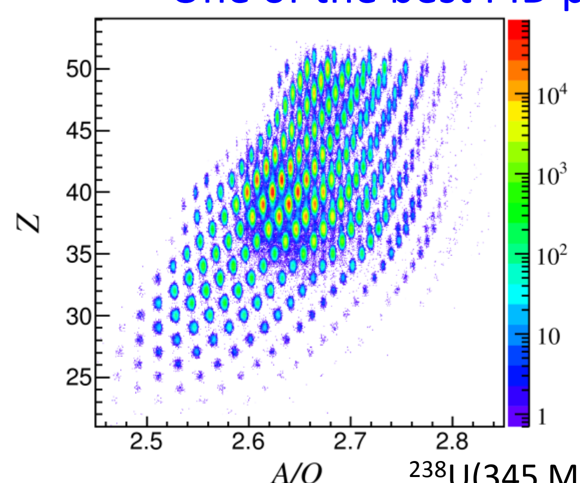
TOF: β

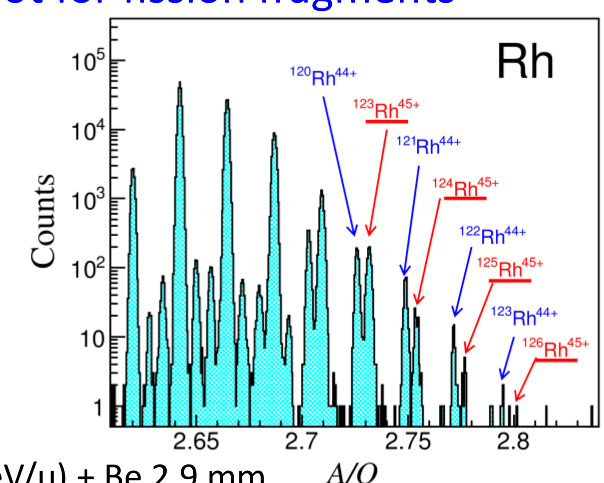
- Trajectories are measured at the focuses for trajectory reconstruction which allows improvement of *A*/*Q* resolution.

r.m.s. *A*/*Q* resolution: 0.034 %

6.1σ peak separation between the fully stripped peak and H-like peak

One of the best PID plot for fission fragments





^{238}U(345 MeV/u) + Be 2.9 mm
$B\rho$01 = 7.990 Tm, F1 deg Al 2.18mm
G2 setting in J. Phys. Soc. Jpn. 79 (2010) 073201.

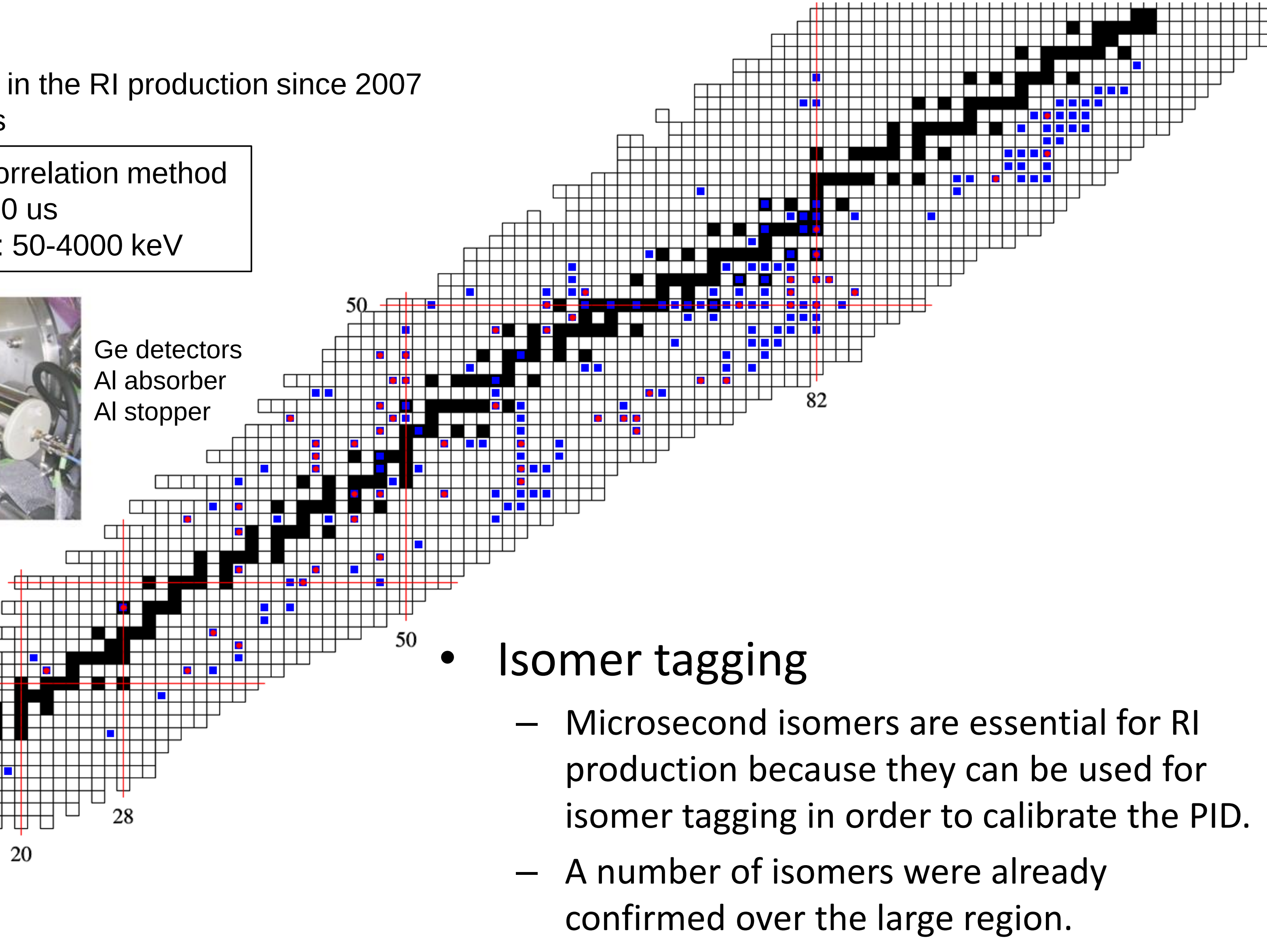
PID at BigRIPS:
N. Fukuda *et al.*, Nucl. Instr. Meth. B 317 (2013) 323.

Observed isomers

Isomers observed in the RI production since 2007
$T_{1/2}$ = 0.1 – 100 us

Particle-γ slow correlation method
- Time window: 30 us
- Dynamic range: 50-4000 keV

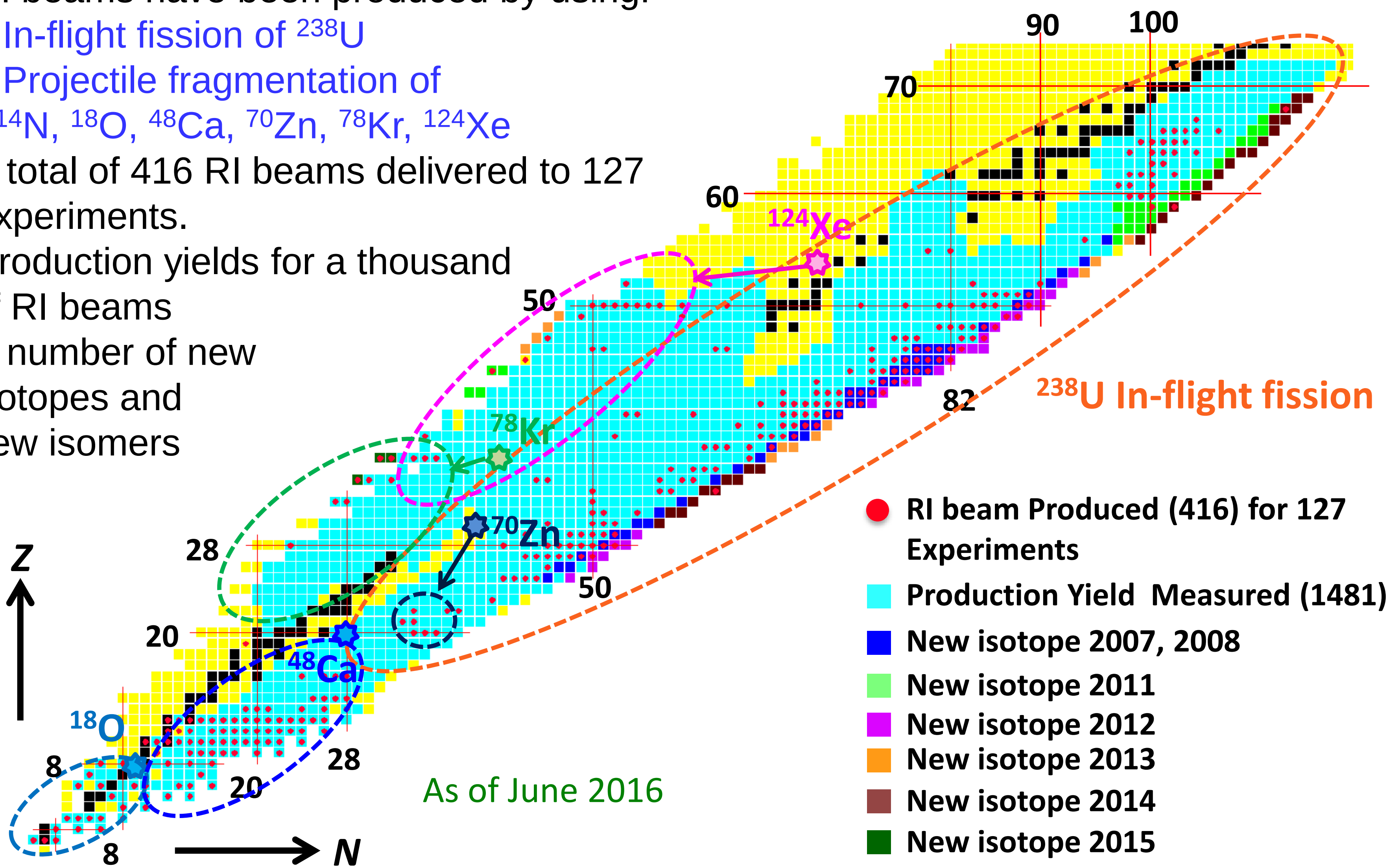
Ge detectors
Al absorber
Al stopper



- Isomer tagging
  - Microsecond isomers are essential for RI production because they can be used for isomer tagging in order to calibrate the PID.
  - A number of isomers were already confirmed over the large region.

RI beams produced at BigRIPS (May 2007 – June 2016)

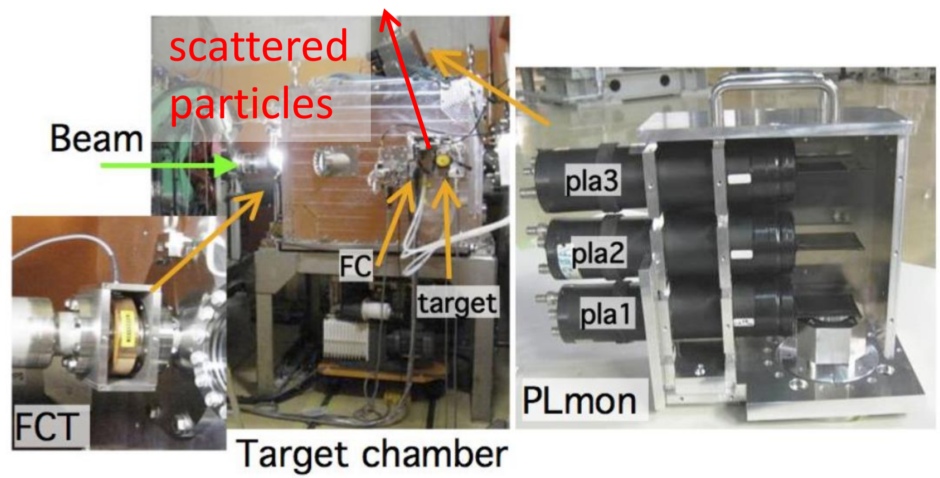
- RI beams have been produced by using:
  - In-flight fission of ^{238}U
  - Projectile fragmentation of ^{14}N, ^{18}O, ^{48}Ca, ^{70}Zn, ^{78}Kr, ^{124}Xe
- A total of 416 RI beams delivered to 127 experiments.
- Production yields for a thousand of RI beams
- A number of new isotopes and new isomers



Measurement of production cross sections

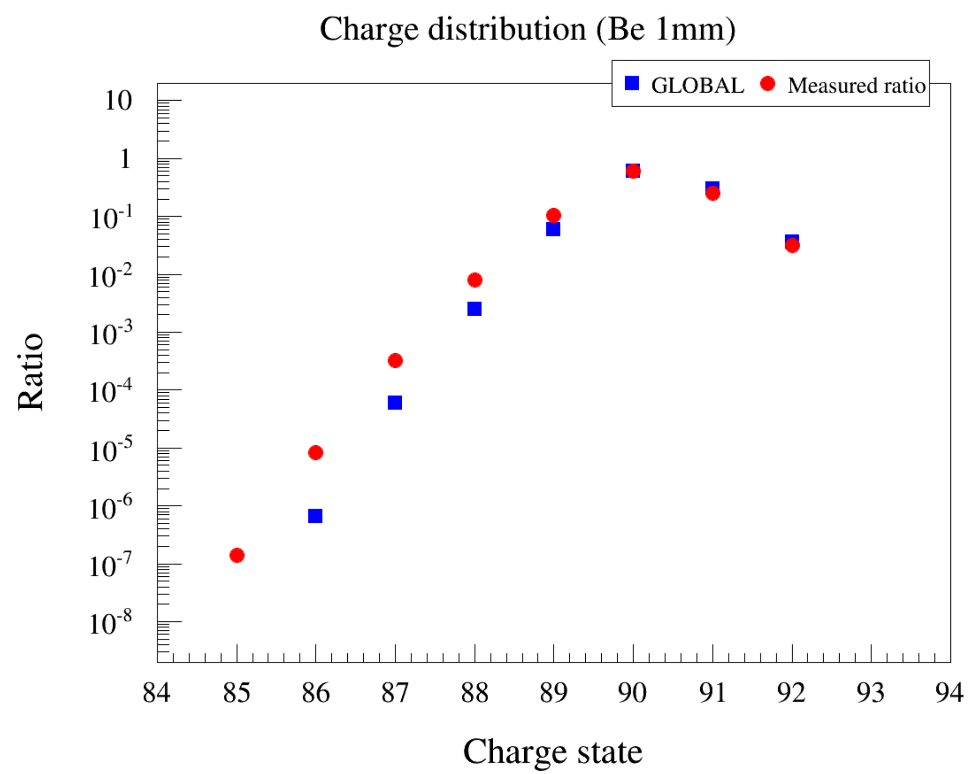
Measurement of production cross section is important.
→ Allowing accurate estimation of RI beams.

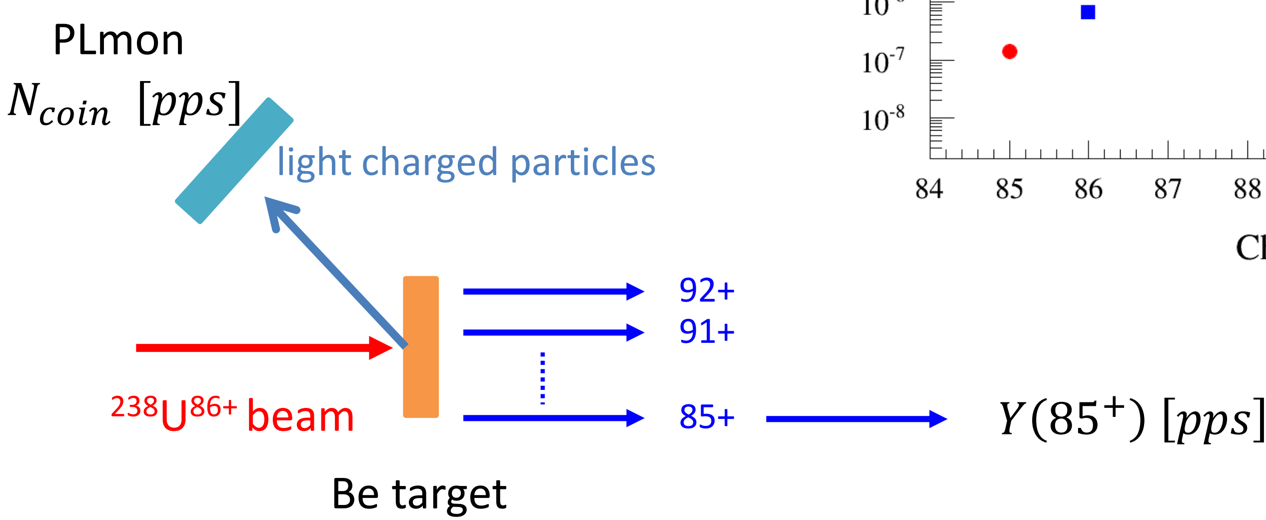
- Production cross section is deduced from
  - Yield:
    - High resolution PID analysis
  - Transmission:
    - LISE^{++} simulation (Monte Carlo mode)
  - Beam intensity:
    - monitored by detecting light charged particles recoiling out of the target



Beam intensity

- Calibration of Beam monitor
  - Charge distribution of U beam through the Be target
  - yield measurement of 85+ @ F2





Beam intensity: $I\ [pnA] = \dfrac{Y(85^+)}{P(85^+)} \times e = C \times N_{coin}$

e: elementary charge

Measurement with ^{238}U beam
Neutron-rich isotopes by in-flight fission

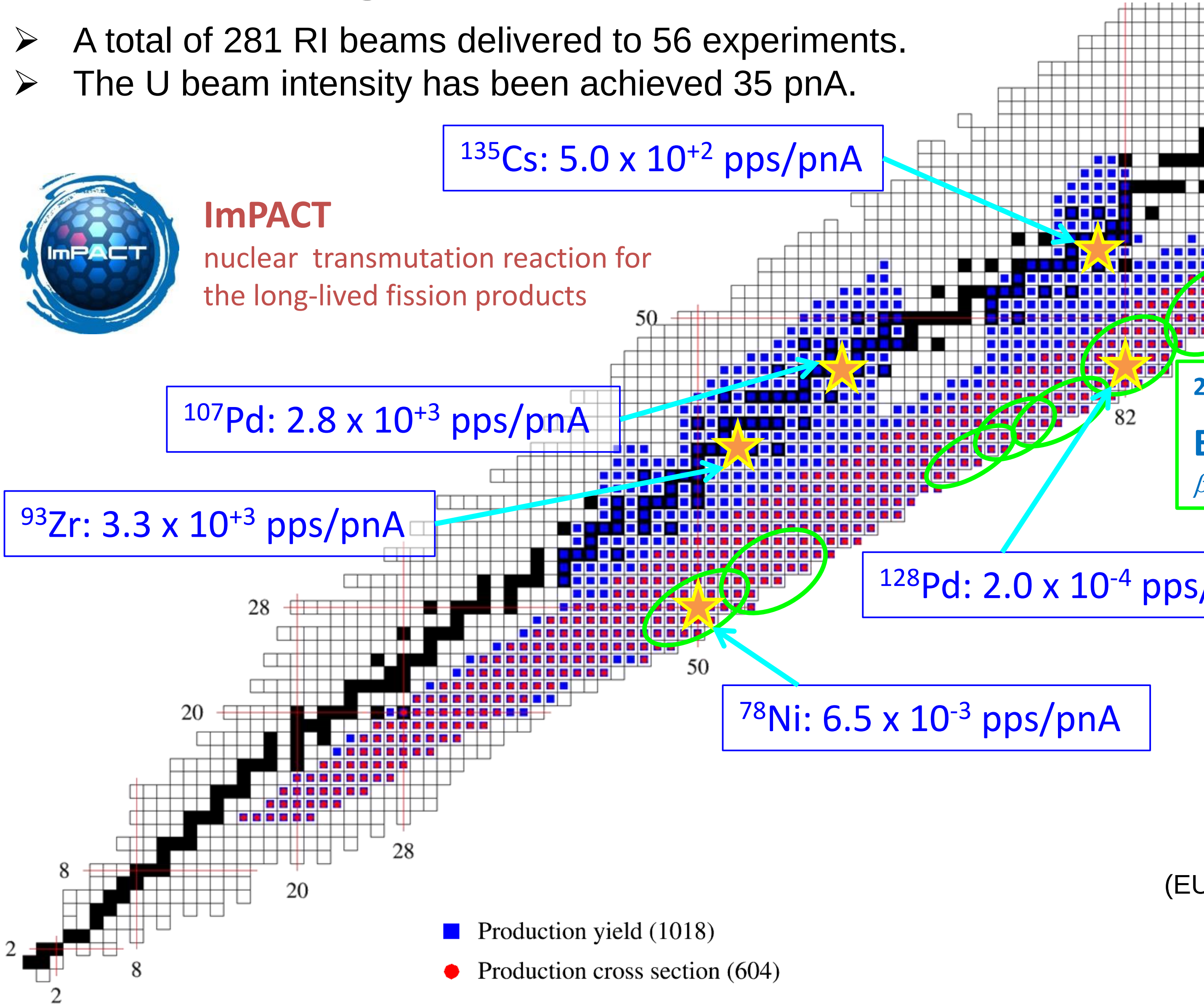
- Measured production yields
- Measured production cross sections
  - comparison with LISE++ prediction
- Example of Z ~ 64

Measured production cross sections for in-flight fission of ^{238}U

- A total of 281 RI beams delivered to 56 experiments.
- The U beam intensity has been achieved 35 pnA.

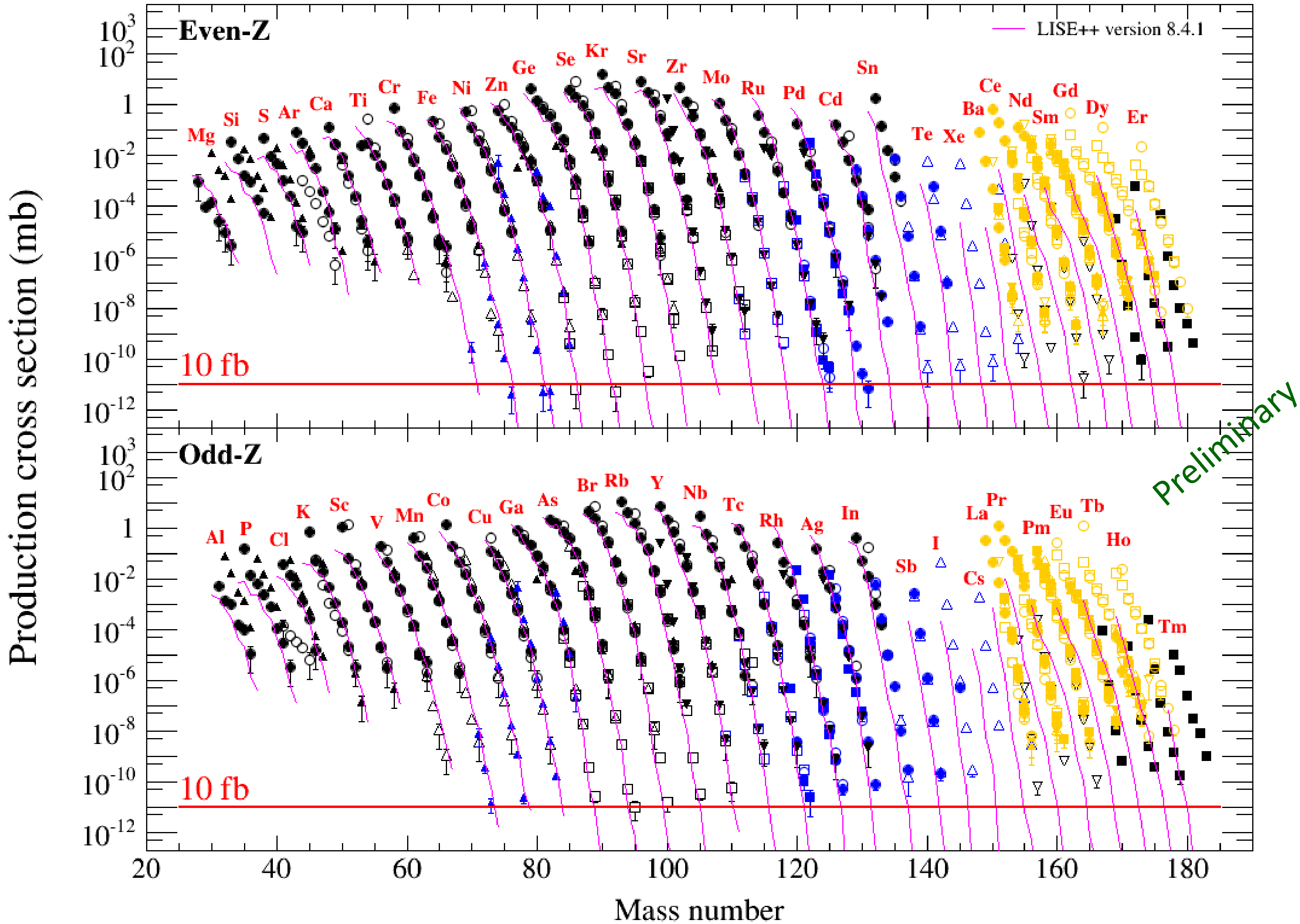
ImPACT

nuclear transmutation reaction for the long-lived fission products



EURICA Ge array
(EUROBALL RIKEN Cluster Array)

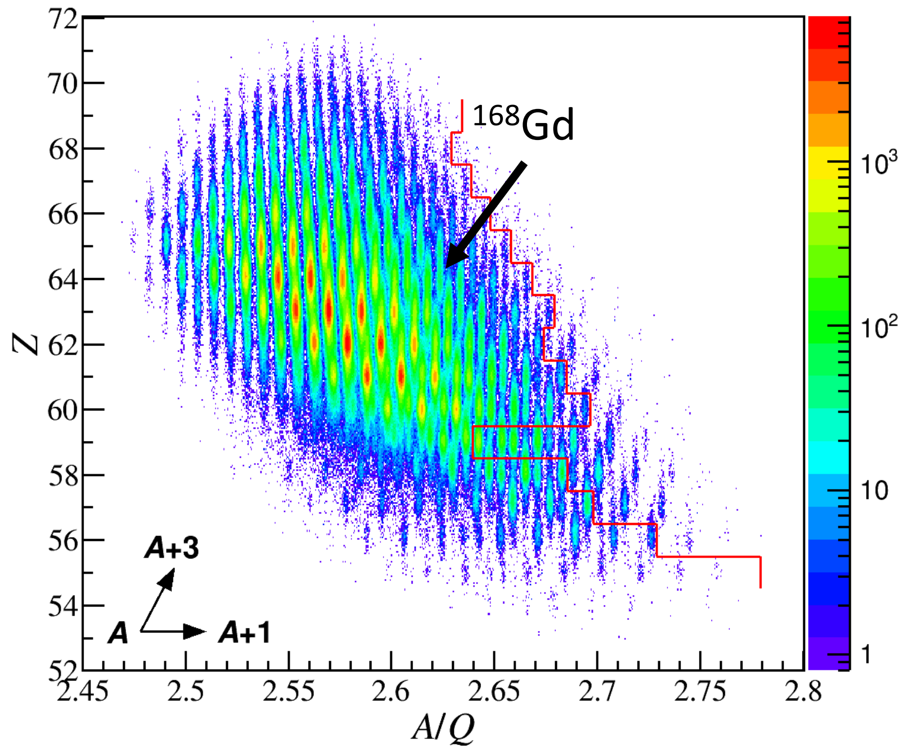
Measured production cross sections for in-flight fission of ^{238}U (Be target)



New isotope search around Z ~ 64

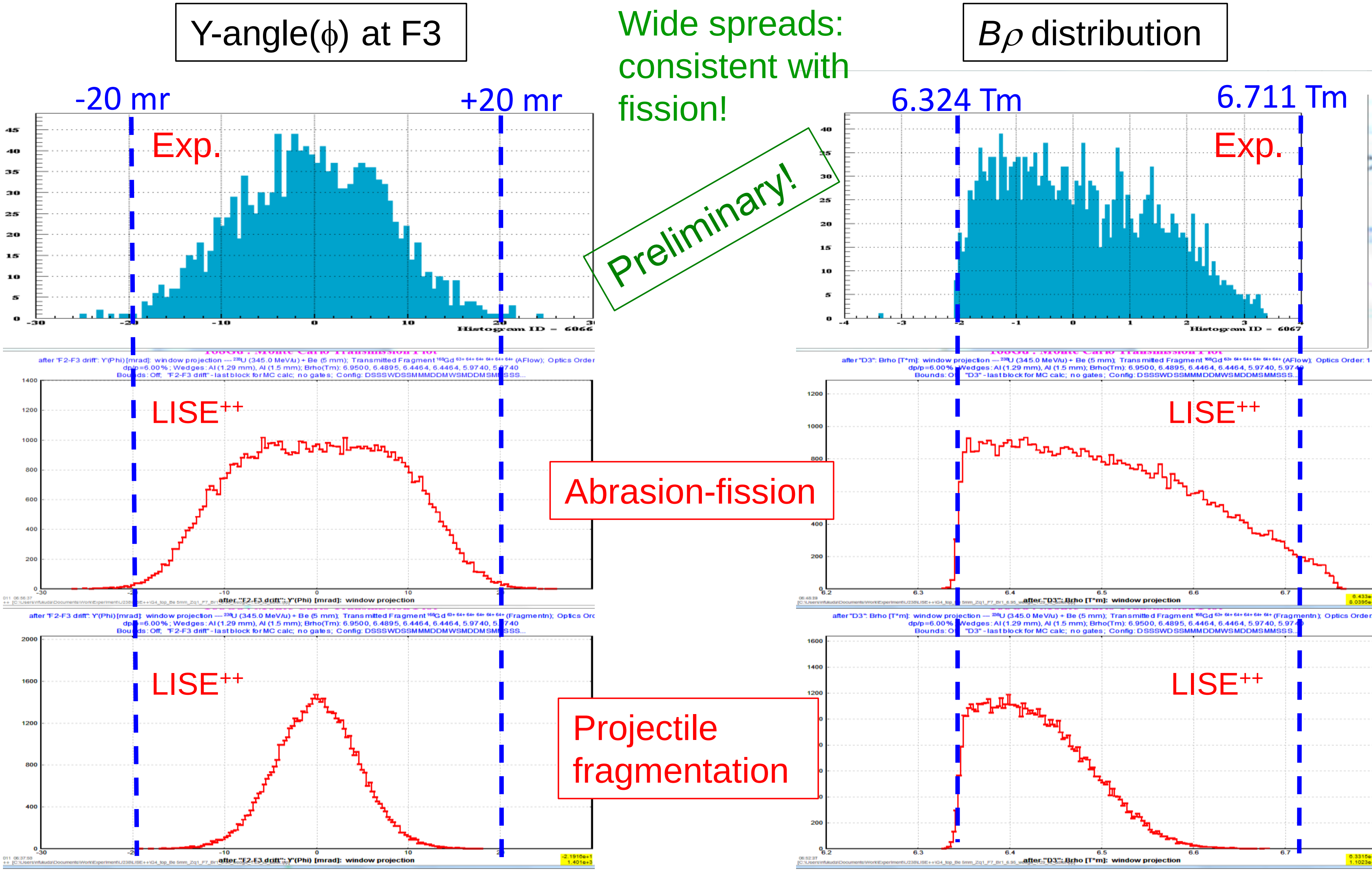
Experimental condition

Setting	1	2
Target	Be 4.9 mm	
D1 Bρ	6.950 Tm	
Tuned for	^{168}Gd	
F1 degrader	Al 1.27 mm	
F5 degrader	Al 1.40 mm	
F1 slit ($\Delta p/p$)	+3/-2%	+/- 3%
F2 slit (mm)	+15 / -4	+15 / -5
F5 slit (mm)	+/- 120	
F7 slit (mm)	+/- 15	



- ***A/Q*** resolution: 0.036 % (σ)
- ***A/Q*** accuracy: +/- 0.1 %
- ***Z*** resolution: 0.50 % (σ)

Kinematics of fragments: angular and momentum distribution for ^{168}Gd

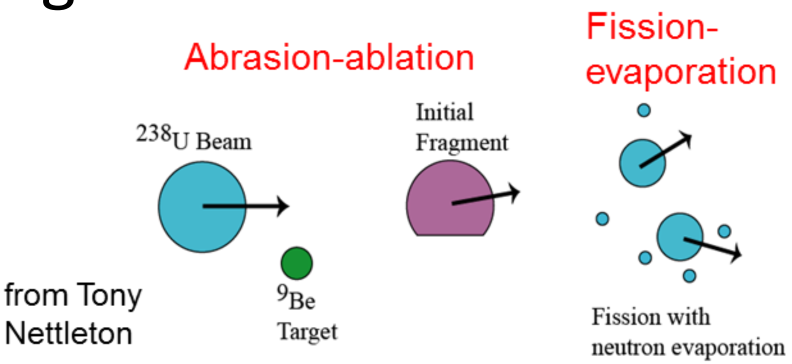


Abrasion Fission model

- LISE^{++} (next talk by T. Oleg)
  - Three excitation energy regions method

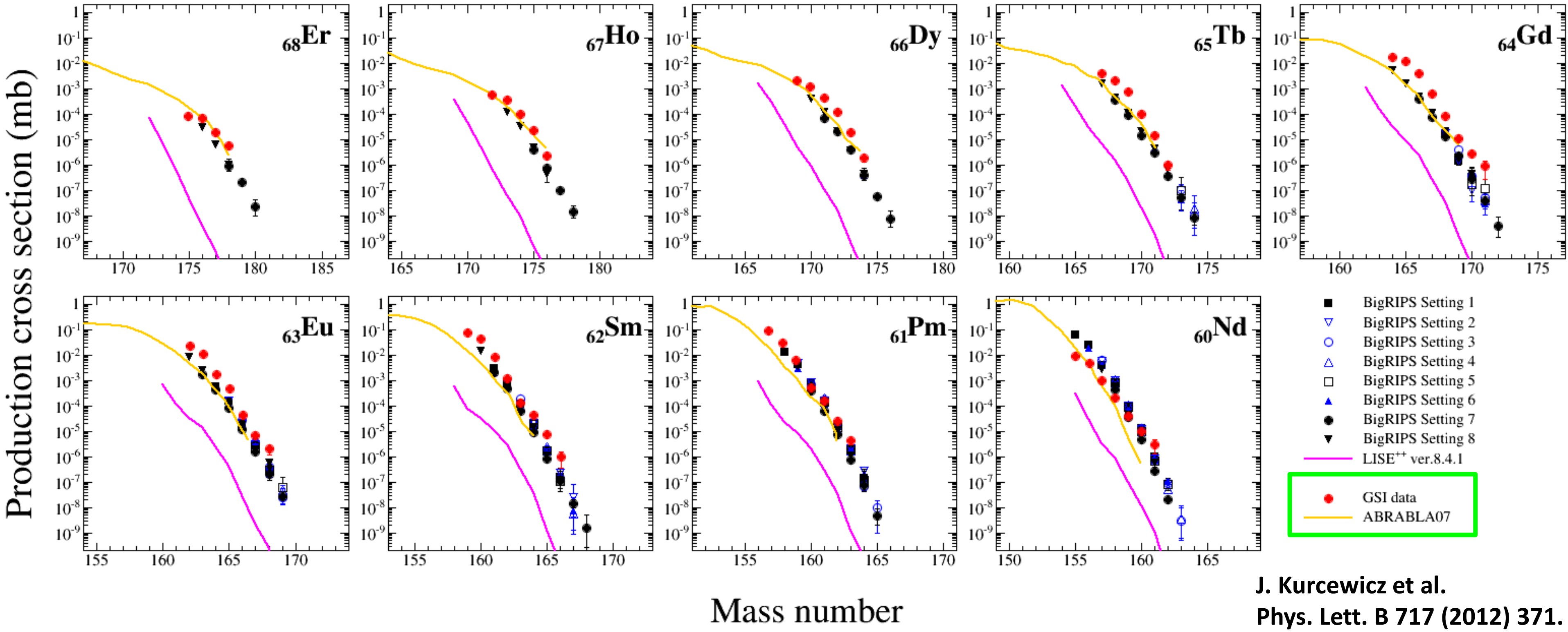
Parameters for ^{238}U + Be

	Low	Middle	High
fissile	$^{236}_{92}$U	$^{226}_{90}$Th	$^{220}_{84}$Ra
*E** MeV	23.5	100	250
σ mb	200	500	350



- ABRABLA07
  - three-stage nuclear-reaction model developed for description of peripheral and semi-peripheral collisions at relativistic energies

Measured production cross sections for in-flight fission of ^{238}U (Be target)



J. Kurcewicz et al.
Phys. Lett. B 717 (2012) 371.

- the LISE predictions are three orders of magnitude smaller than the measured cross sections.
- BigRIPS data were consistent with GSI-FRS data.
  - GSI-FRS: ^{238}U(1 GeV/u) + Be
- The ABRABLA07 predictions are in good agreement with measured cross sections.

Measurements by projectile fragmentation

- Proton rich nuclei:
  - ^{124}Xe beam
  - ^{78}Kr beam
- Neutron rich nuclei:
  - ^{70}Zn beam
  - ^{48}Ca beam

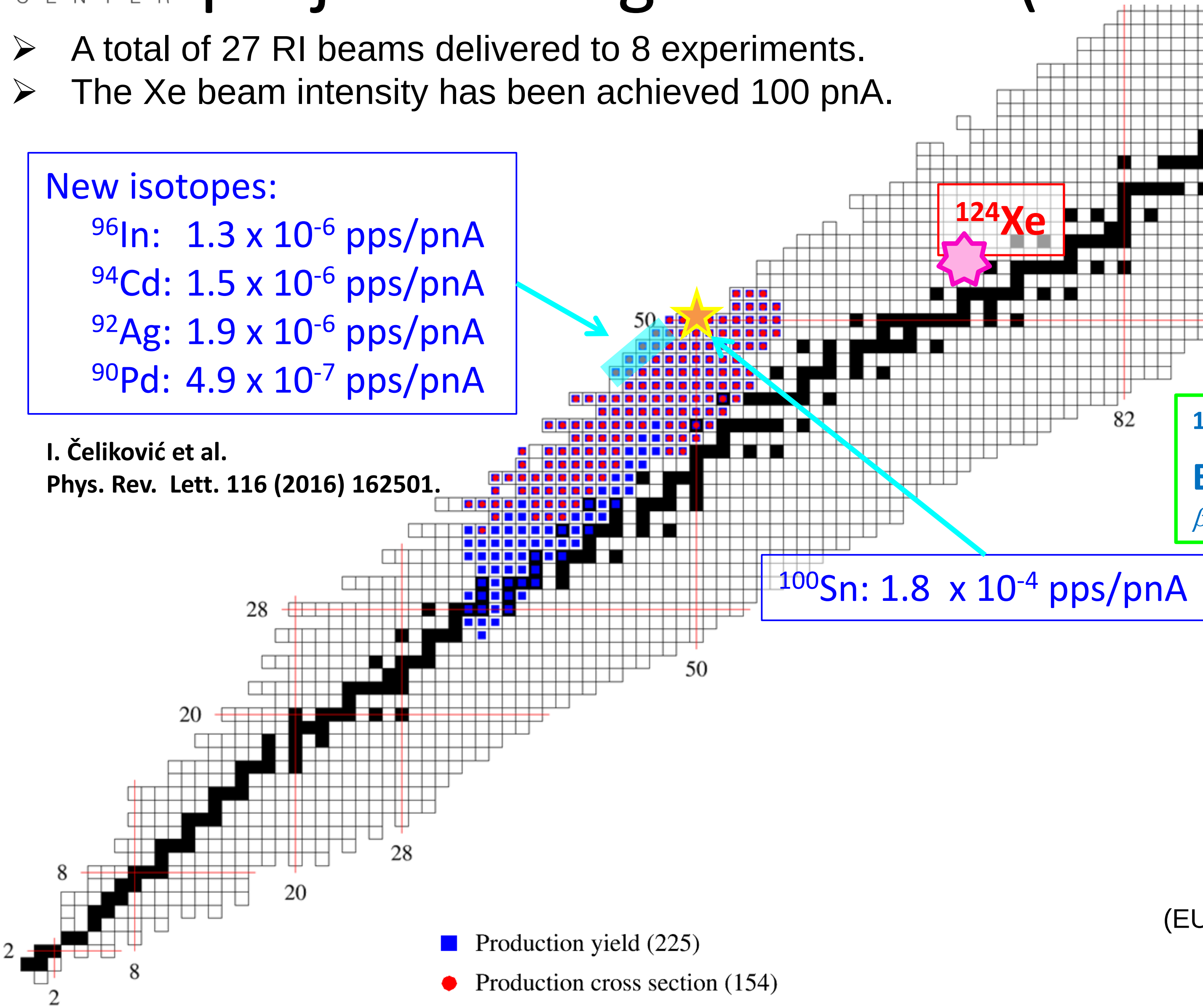
Measured production cross sections for projectile fragmentation (^{124}Xe beam)

- A total of 27 RI beams delivered to 8 experiments.
- The Xe beam intensity has been achieved 100 pnA.

New isotopes:

^{96}In: 1.3 x 10^{-6} pps/pnA
^{94}Cd: 1.5 x 10^{-6} pps/pnA
^{92}Ag: 1.9 x 10^{-6} pps/pnA
^{90}Pd: 4.9 x 10^{-7} pps/pnA

I. Čeliković et al.
Phys. Rev. Lett. 116 (2016) 162501.

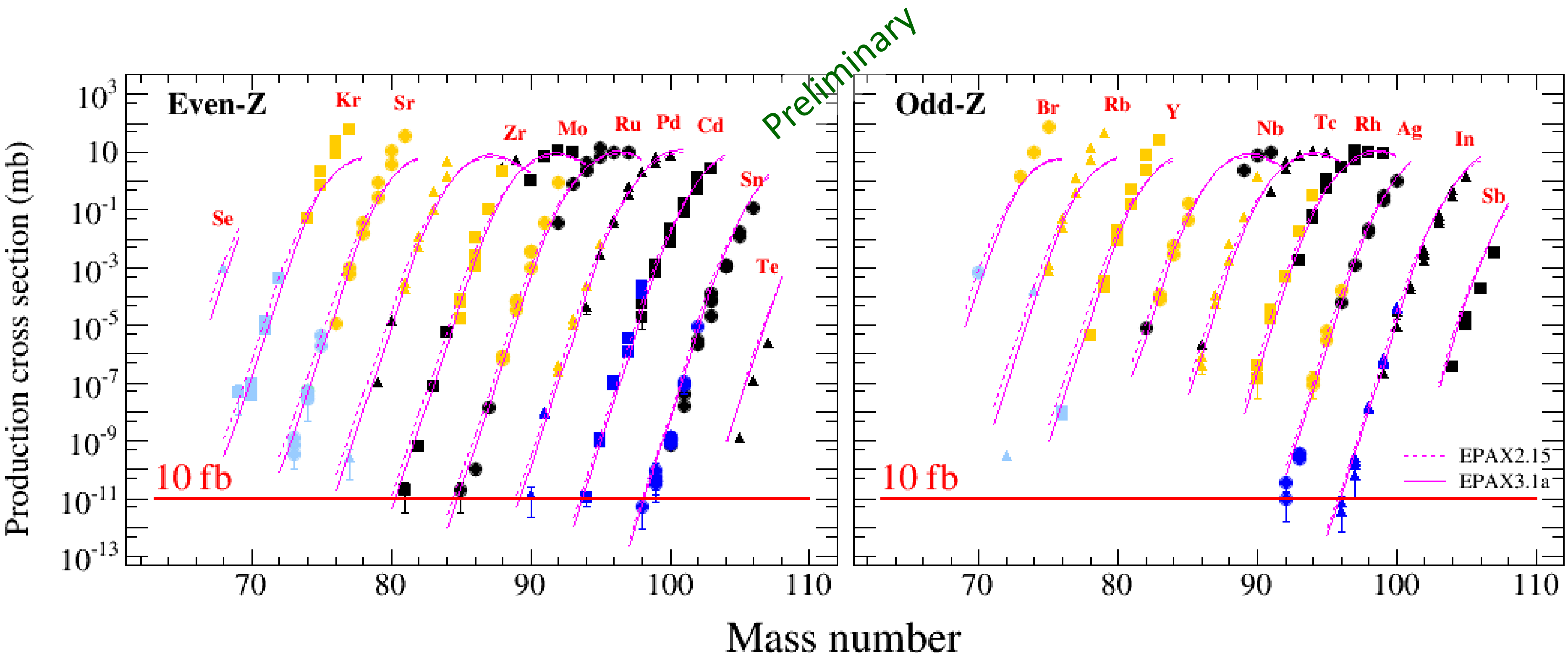


^{100}Sn: 1.8 x 10^{-4} pps/pnA

^{124}Xe beam
EURICA campaign
β-and isomer-decay measurements

EURICA Ge array
(EUROBALL RIKEN Cluster Array)

Measured production cross sections for projectile fragmentation (^{124}Xe beam)



- The measured cross sections are fairly well reproduced by EPAX3.1a.
- In very proton-rich region and higher *Z* region, our measured cross sections are almost one order of magnitude smaller than the calculated values with the EPAX3.1a.
  cf) ^{100}Sn ~ 1/6, ^{73}Sr ~1/3

Measured production cross sections for projectile fragmentation (^{78}Kr beam)

- A total of 12 RI beams delivered to 6 experiments.
- The Kr beam intensity has been achieved 450 pnA.

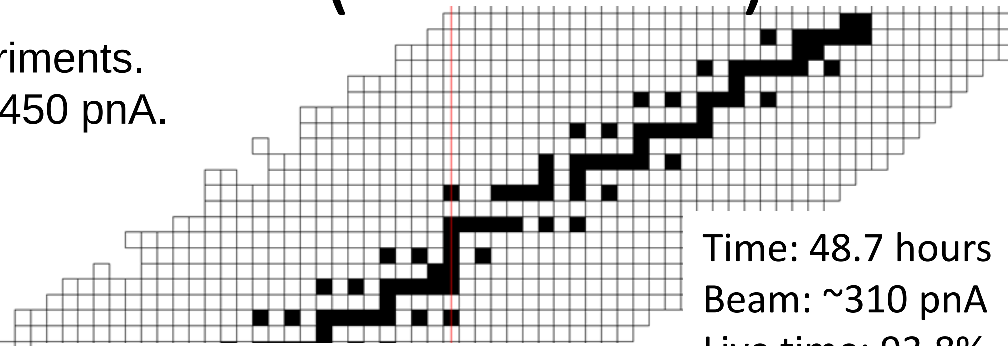
New isotopes:

^{68}Kr: 3.1×10^{-6} pps/pnA

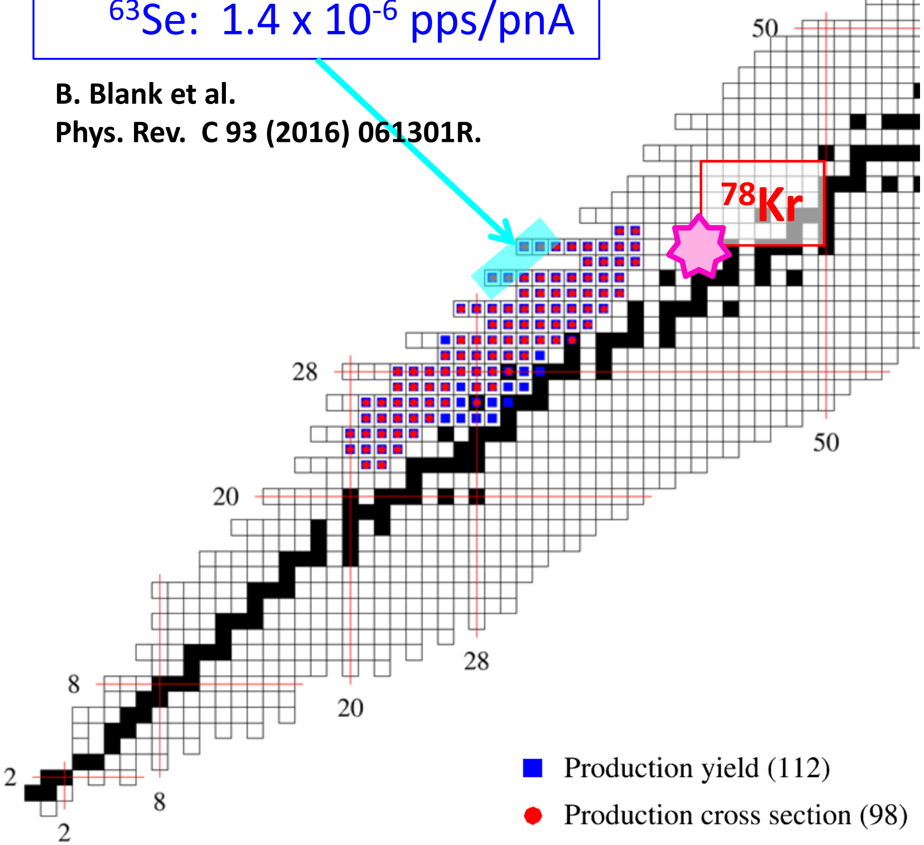
^{67}Kr: 5.1×10^{-7} pps/pnA

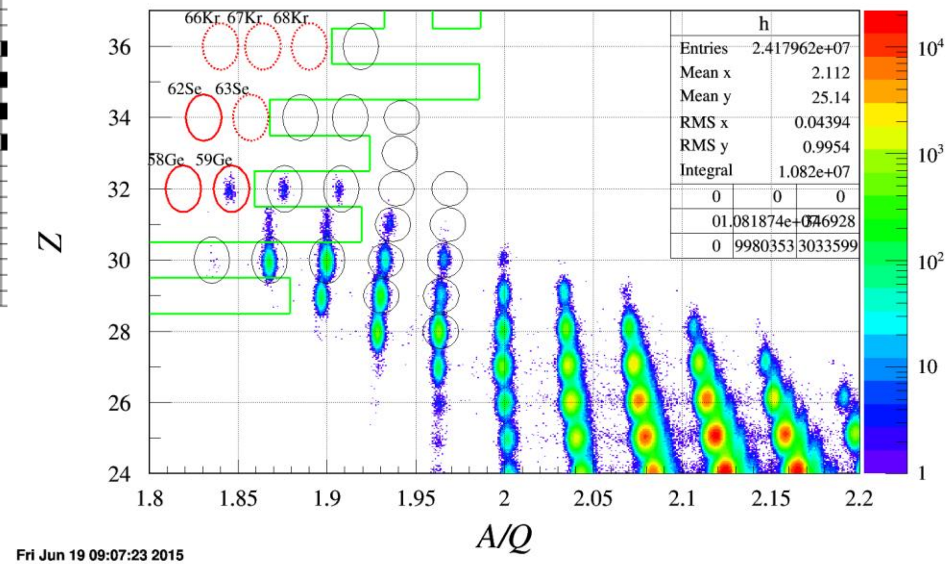
^{63}Se: 1.4×10^{-6} pps/pnA

B. Blank et al.
Phys. Rev. C 93 (2016) 061301R.



Time: 48.7 hours
Beam: ~310 pnA
Live time: 93.8%



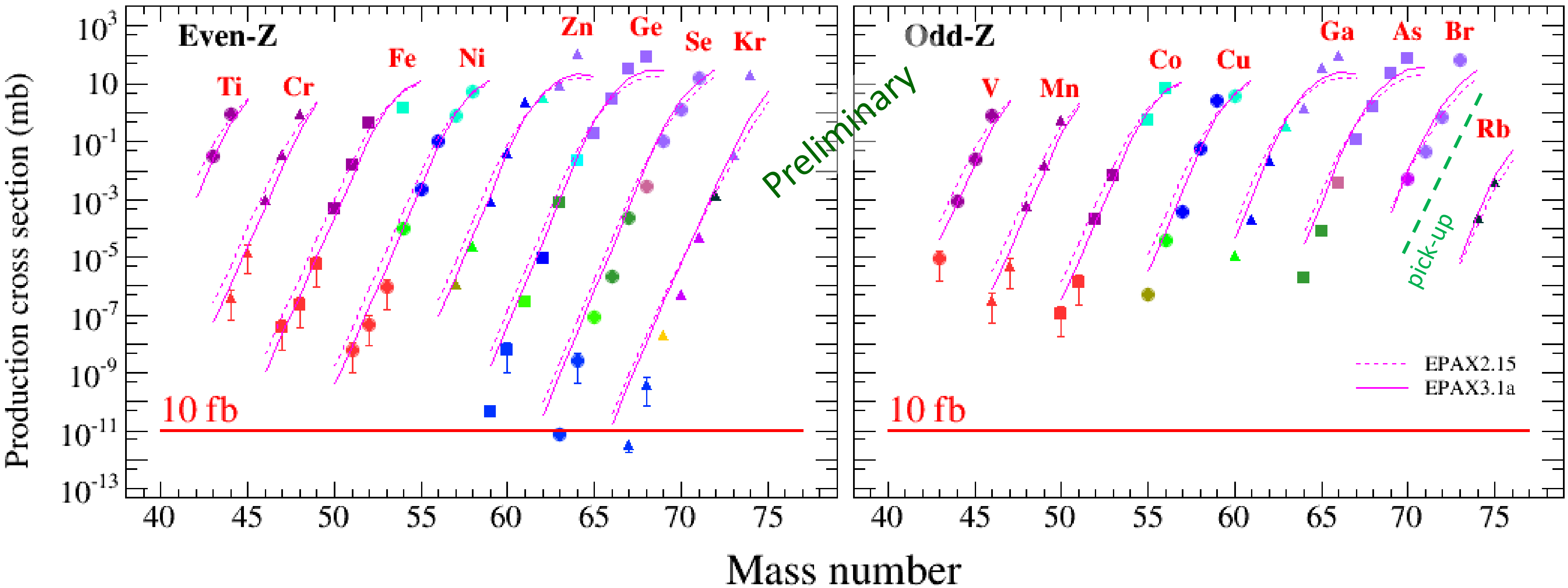


New isotope search: ^{58}Ge and ^{62}Se

-- ^{58}Ge and ^{62}Se could not be found.

-- upper limit of **0.07 fb**

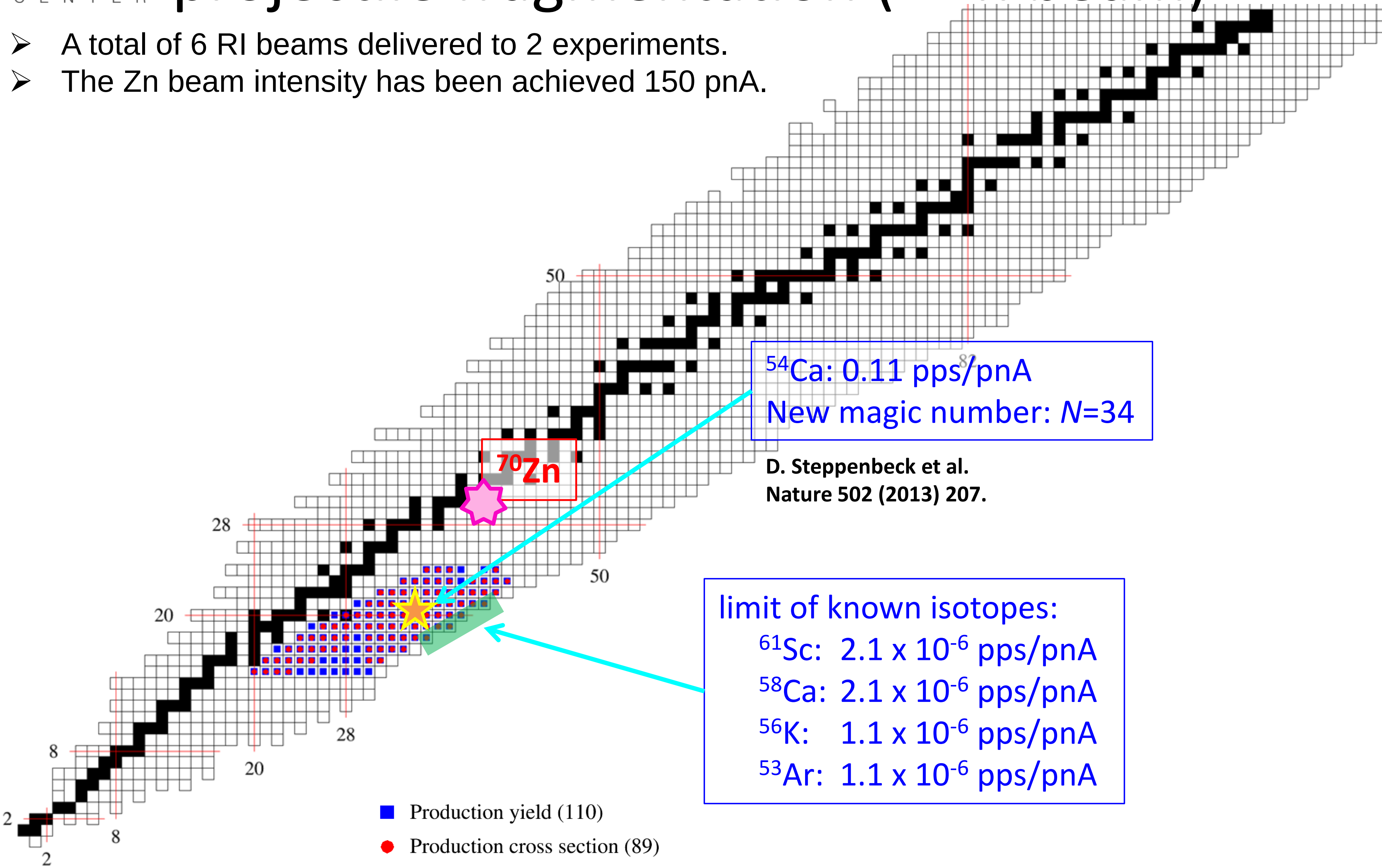
Measured production cross sections for projectile fragmentation (^{78}Kr beam)



- The measured cross sections are fairly well reproduced by EPAX3.1a.
- In very proton-rich region, our measured cross sections are almost one order of magnitude smaller than the calculated values with the EPAX3.1a.
  cf) ^{69}Kr ~ 1/14, ^{64}Sr ~1/9, ^{60}Ge ~ 1/7
- It is surprising that measured cross sections for Rb are well reproduced.

Measured production cross sections for projectile fragmentation (^{70}Zn beam)

- A total of 6 RI beams delivered to 2 experiments.
- The Zn beam intensity has been achieved 150 pnA.



^{54}Ca: 0.11 pps/pnA

New magic number: N=34

D. Steppenbeck et al.
Nature 502 (2013) 207.

limit of known isotopes:

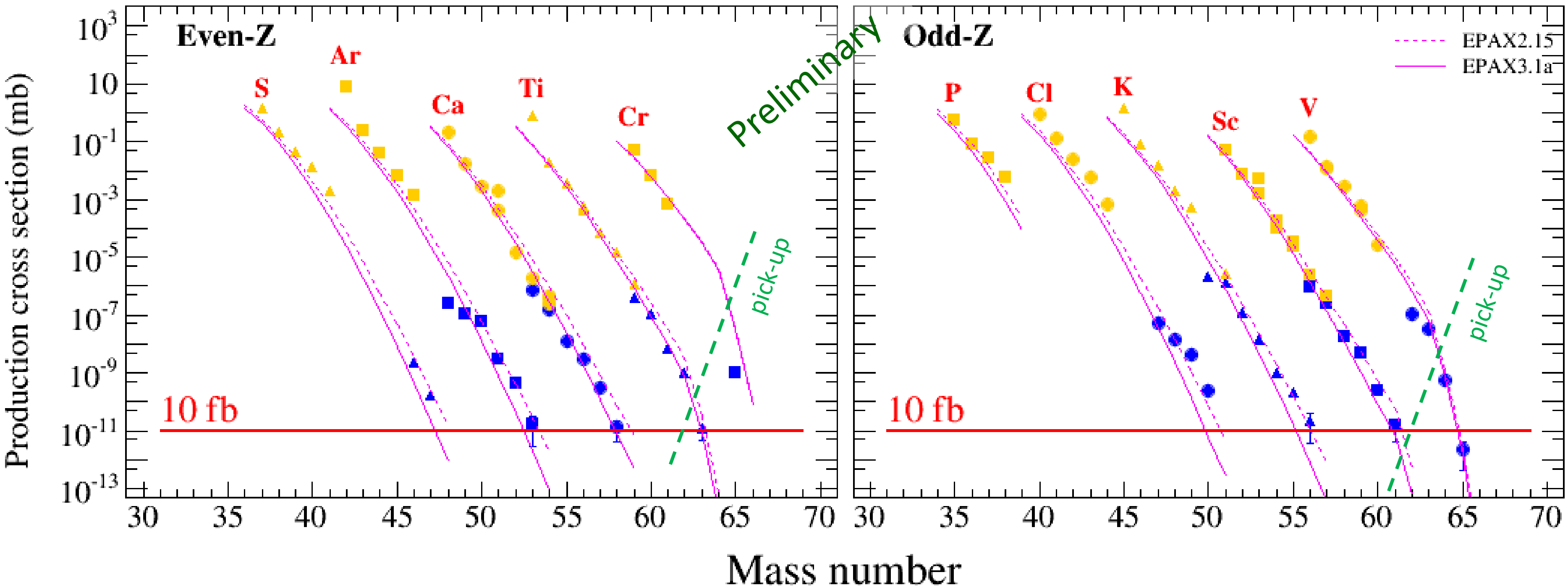
^{61}Sc: 2.1 x 10^{-6} pps/pnA

^{58}Ca: 2.1 x 10^{-6} pps/pnA

^{56}K: 1.1 x 10^{-6} pps/pnA

^{53}Ar: 1.1 x 10^{-6} pps/pnA

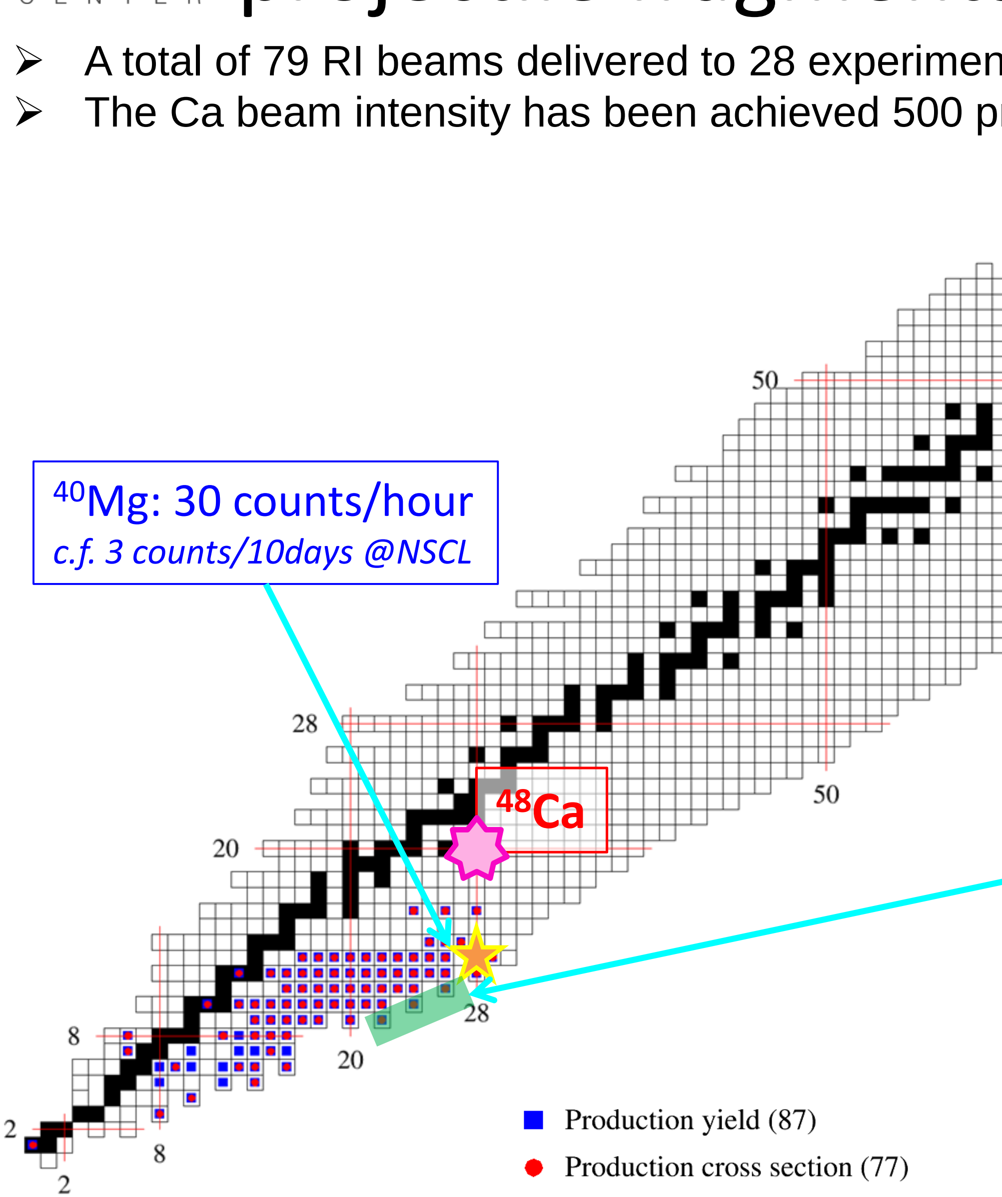
Measured production cross sections for projectile fragmentation (^{70}Zn beam)



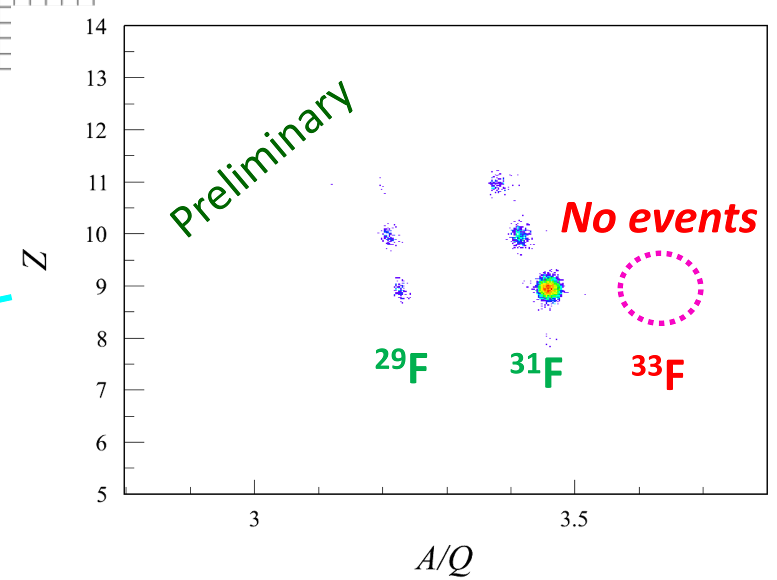
- Overall, the calculated cross sections with both EPAXs are in good agreement with the experimental cross sections.
- For $Z < 20$, EPAX2.15 estimates the cross section better than EPAX3.1a.
- For $Z > 20$, EPAX3.1a estimates them better than EPAX2.15.

Measured production cross sections for projectile fragmentation (^{48}Ca beam)

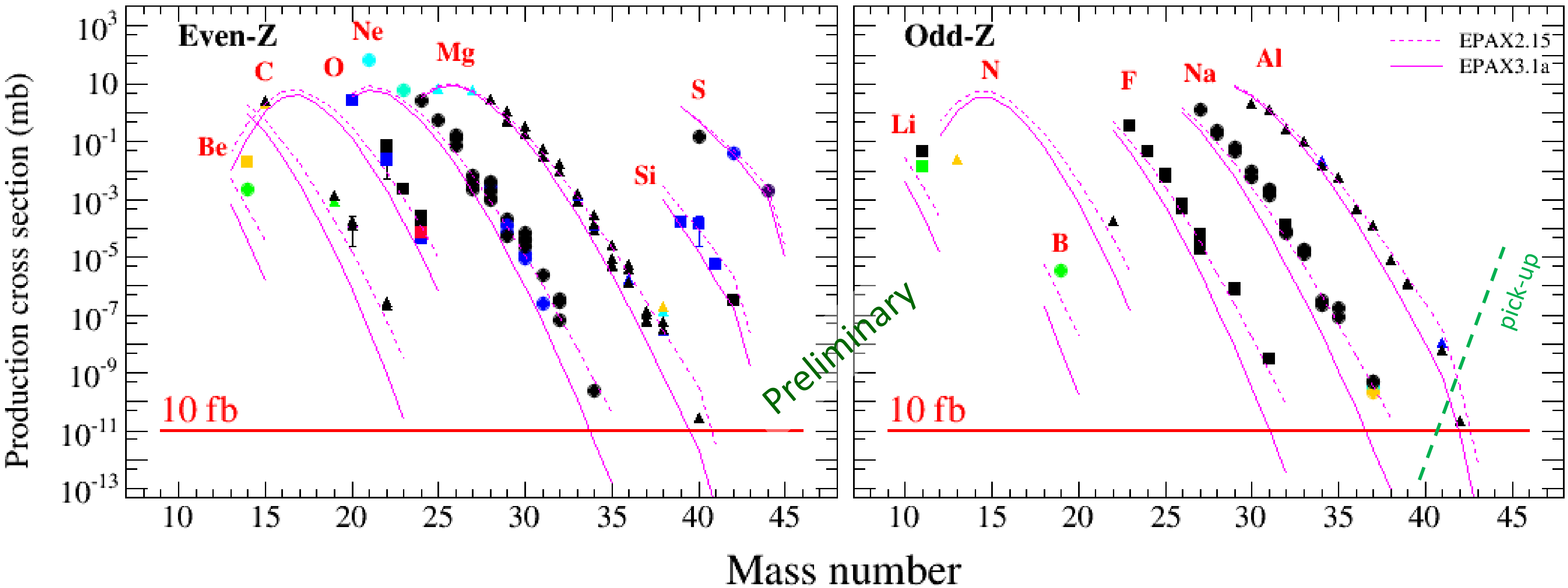
- A total of 79 RI beams delivered to 28 experiments.
- The Ca beam intensity has been achieved 500 pnA.



Drip line search: F, Ne, Na
^{48}Ca beam: 415 pnA



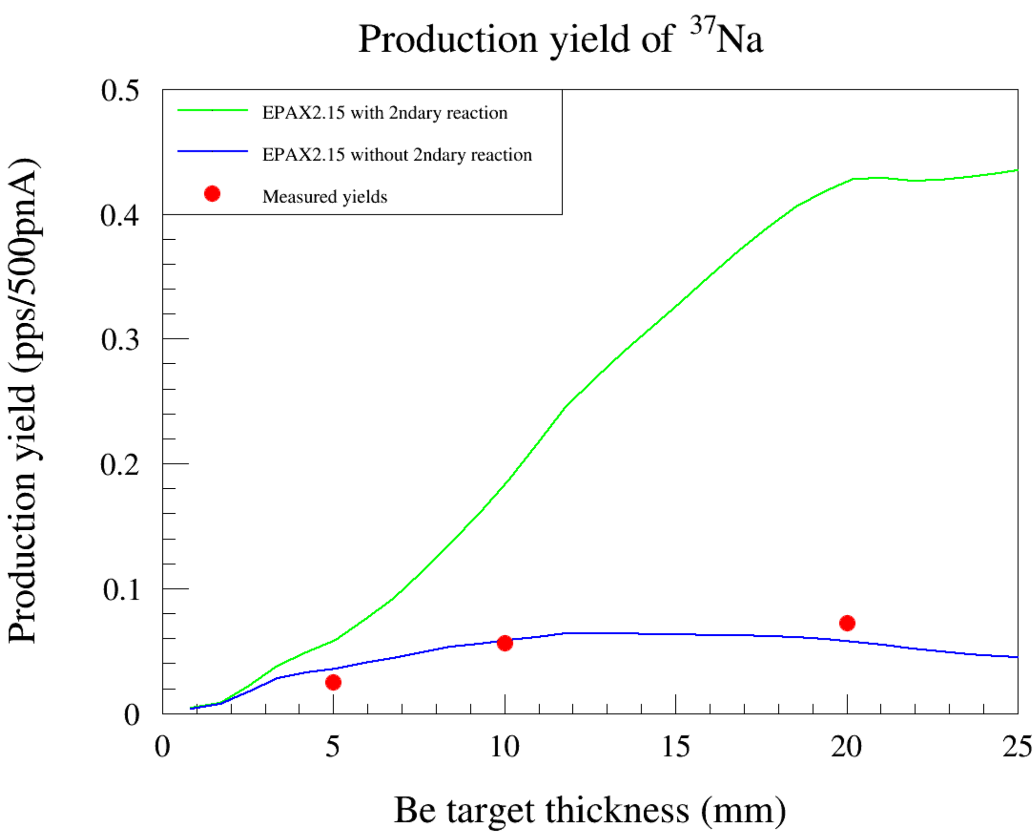
Measured production cross sections for projectile fragmentation (^{48}Ca beam)



- Overall, the calculated cross sections with EPAX2.15 are in good agreement with the experimental cross sections.
- The EPAX3.1a underestimates the cross sections.
- In the LISE^{++} simulation, secondary reaction in the target is NOT included.

Secondary reaction in the target

- ^{37}Na were produced with different target thicknesses to study the effect of secondary reaction in the target material.



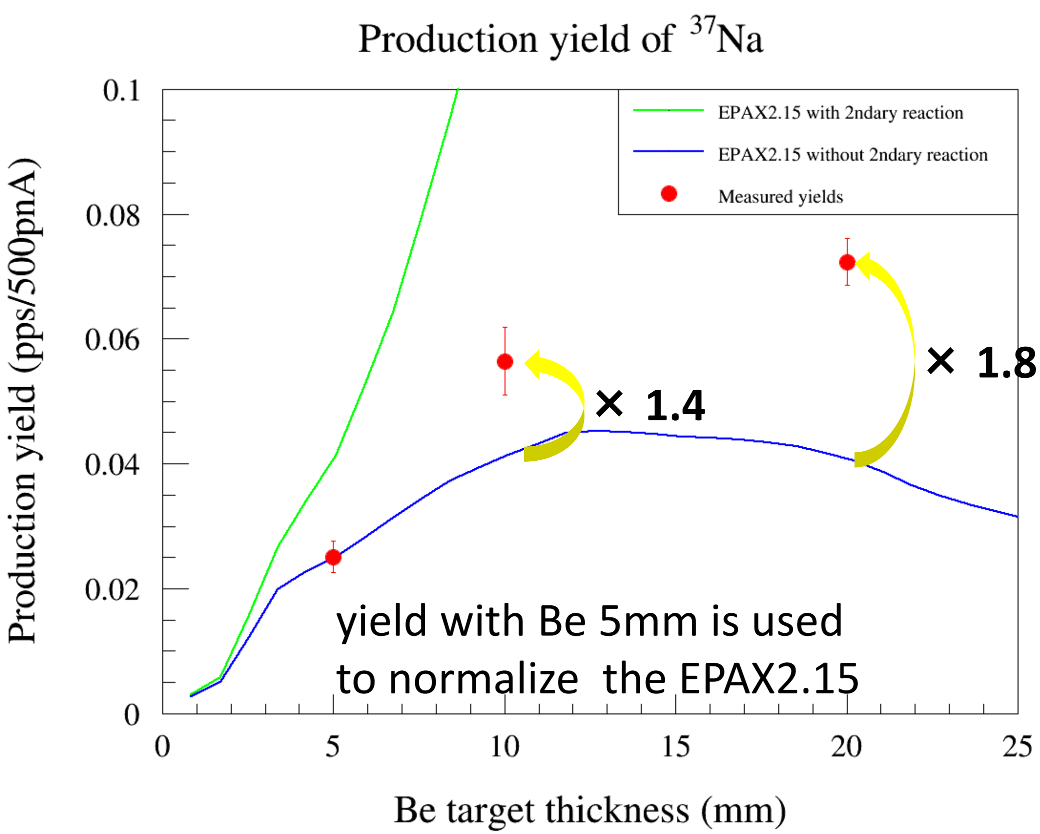
Experimental condition

Target	Be 5mm	Be 10mm	Be 20 mm
D1 Bρ	9.433 Tm	9.259 Tm	8.838 Tm
F1 slit	+/- 120 mm		
F1 deg	15 mm		
F5 deg	7 mm		

- Overall, the calculated yields without secondary reaction are in good agreement with the measured yields.

Secondary reaction in the target

- ^{37}Na were produced with different target thicknesses to study the effect of secondary reaction in the target material.



Effect of secondary reaction

Target	Be 5mm	Be 10mm	Be 20 mm
Exp	x 1.0	x 1.4	x 1.8
LISE^{++}	x 1.6	x 3.2	x 7.4

- Effect of secondary reaction:
  - smaller than LISE predictions
  - not be ignored
- More data…
  - thin target
  - dependence of RI beams

Database of RI beams produced at BigRIPS

- Analyzed data of RI beams (as of august 2016)
  - number of settings: 227
  - number of yields: 4692
  - number of c.s. : 2579
- Database of RI beams
  - Production cross sections and yields
    - Experimental conditions
  - Isomeric nucleus
    - Gamma ray energy
    - Half life
    - Sample of gamma ray energy spectrum
  - Y. Shimizu *et al.*, APR **47**, 166 (2014).

Table of Nuclides (Login)

Database of RI beams produced at BigRIPS

Web Interface (*Access restriction!*)

																73Sr	74Sr	75Sr	76Sr	77Sr	78Sr	79Sr	80Sr
																		74Rb	75Rb	76Rb	77Rb	78Rb	79Rb
														69Kr	70Kr	71Kr	72Kr	73Kr	74Kr	75Kr	76Kr	77Kr	78Kr
																70Br	71Br	72Br	73Br	74Br	75Br	76Br	77Br
											64Se	65Se	66Se	67Se	68Se	69Se	70Se	71Se	72Se	73Se	74Se	75Se	76Se
												64As	65As	66As	67As	68As	69As	70As	71As	72As	73As	74As	75As
										60Ge	61Ge	62Ge	63Ge	64Ge	65Ge	66Ge	67Ge	68Ge	69Ge	70Ge	71Ge	72Ge	73Ge	74Ge
											60Ga	61Ga	62Ga	63Ga	64Ga	65Ga	66Ga	67Ga	68Ga	69Ga	70Ga	71Ga	72Ga	73Ga
						54Zn	55Zn	56Zn	57Zn	58Zn	59Zn	60Zn	61Zn	62Zn	63Zn	64Zn	65Zn	66Zn	67Zn	68Zn	69Zn	70Zn	71Zn	72Zn
								55Cu	56Cu	57Cu	58Cu	59Cu	60Cu	61Cu	62Cu	63Cu	64Cu	65Cu	66Cu	67Cu	68Cu	69Cu	70Cu	71Cu
		48Ni	49Ni	50Ni	51Ni	52Ni	53Ni	54Ni	55Ni	56Ni	57Ni	58Ni	59Ni	60Ni	61Ni	62Ni	63Ni	64Ni	65Ni	66Ni	67Ni	68Ni	69Ni	70Ni
					50Co	51Co	52Co	53Co	54Co	55Co	56Co	57Co	58Co	59Co	60Co	61Co	62Co	63Co	64Co	65Co	66Co	67Co	68Co	69Co
	45Fe	46Fe	47Fe	48Fe	49Fe	50Fe	51Fe	52Fe	53Fe	54Fe	55Fe	56Fe	57Fe	58Fe	59Fe	60Fe	61Fe	62Fe	63Fe	64Fe	65Fe	66Fe	67Fe	68Fe
			46Mn	47Mn	48Mn	49Mn	50Mn	51Mn	52Mn	53Mn	54Mn	55Mn	56Mn	57Mn	58Mn	59Mn	60Mn	61Mn	62Mn	63Mn	64Mn	65Mn	66Mn	67Mn

Table of Nuclides

14N Beam   18O Beam   48Ca Beam   70Zn Beam   78Kr Beam   124Xe Beam   238U Beam

Isotope Search   Isomer Search   List of Publications   List of Experiments

Database of RI beams produced at BigRIPS

Web Interface (*Access restriction!*)

^{66}As Arsenic Z: « »

Z = 33 N = 33 N: « »

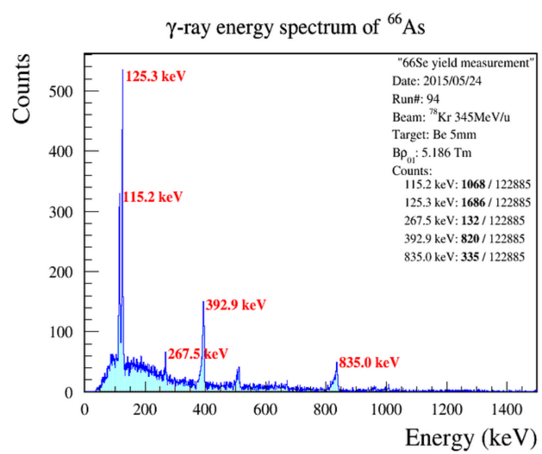
Cross section & yield

ID[1]	Yield [pps/pnA]	Cross section (exp) [mb]	Error[2] [mb]	LISE++ [mb]	Measurement date	Beam	Target	Brho01[3] [Tm]	F1 slit L [mm]	F1 slit R [mm]
8	2.09e-5	---	---	---	2015-06-02	78Kr 345MeV	Be 5mm	4.9668	60.0	2.0
11	9.41e+2	3.62e-3	8.78e-4	2.54e-2	2015-05-24	78Kr 345MeV	Be 5mm	5.4550	64.2	64.2
48	2.94e-1	---	---	---	2013-06-28	124Xe 345MeV	Be 4mm	5.1100	64.2	40.0

Isomer information **Isomer information**

Gamma ray energy (keV)	Intensity (%)	Error[4] (%)	Half life (us)	Error (us)
115.2	0	---	8.2	0
125.4	0	---	1.1	0
267.3	0	---	8.2	0
394.2	0	---	8.2	0
837.1	0	---	8.2	0
963.3	0	---	8.2	0
1552	0	---	8.2	0

***γ* ray energy spectrum**



			73Sr	74Sr	75Sr	76Sr	77Sr	78Sr	79Sr	80Sr
					74Rb	75Rb	76Rb	77Rb	78Rb	79Rb
	69Kr	70Kr	71Kr	72Kr	73Kr	74Kr	75Kr	76Kr	77Kr	78Kr
			70Br	71Br	72Br	73Br	74Br	75Br	76Br	77Br
66Se	67Se	68Se	69Se	70Se	71Se	72Se	73Se	74Se	75Se	76Se
65As	66As	67As	68As	69As	70As	71As	72As	73As	74As	75As
64Ge	65Ge	66Ge	67Ge	68Ge	69Ge	70Ge	71Ge	72Ge	73Ge	74Ge
63Ga	64Ga	65Ga	66Ga	67Ga	68Ga	69Ga	70Ga	71Ga	72Ga	73Ga
62Zn	63Zn	64Zn	65Zn	66Zn	67Zn	68Zn	69Zn	70Zn	71Zn	72Zn
61Cu	62Cu	63Cu	64Cu	65Cu	66Cu	67Cu	68Cu	69Cu	70Cu	71Cu
60Ni	61Ni	62Ni	63Ni	64Ni	65Ni	66Ni	67Ni	68Ni	69Ni	70Ni
59Co	60Co	61Co	62Co	63Co	64Co	65Co	66Co	67Co	68Co	69Co
58Fe	59Fe	60Fe	61Fe	62Fe	63Fe	64Fe	65Fe	66Fe	67Fe	68Fe
57Mn	58Mn	59Mn	60Mn	61Mn	62Mn	63Mn	64Mn	65Mn	66Mn	67Mn

Table of Nuclides

14N Beam 18O Beam 48Ca Beam 70Zn Beam 78Kr Beam 124Xe Beam 238U Beam

Isotope Search Isomer Search List of Publications List of Experiments

Database of RI beams produced at BigRIPS

Web Interface (*Access restriction!*)

73Sr 74Sr 75Sr 76Sr 77Sr 78Sr 79Sr 80Sr

66As

Arsenic

Z = 33 N = 33

Z: « »

N: « »

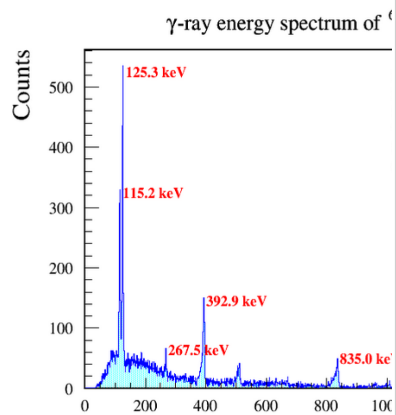
Cross section & yield

ID[1]	Yield [pps/pnA]	Cross section (exp) [mb]	Error[2] [mb]	LISE++ [mb]	Measurement date	Beam	Target	Brho01[3] [Tm]
8	2.09e-5	---	---	---	2015-06-02	78Kr 345MeV	Be 5mm	4.9668
11	9.41e+2	3.62e-3	8.78e-4	2.54e-2	2015-05-24	78Kr 345MeV	Be 5mm	5.4550
48	2.94e-1	---	---	---	2013-06-28	124Xe 345MeV	Be 4mm	5.1100

Isomer information

Isomer information

Gamma ray energy (keV)	Intensity (%)	Error[4] (%)	Half life (us)	Error (us)
115.2	0	---	8.2	0
125.4	0	---	1.1	0
267.3	0	---	8.2	0
394.2	0	---	8.2	0
837.1	0	---	8.2	0
963.3	0	---	8.2	0
1552	0	---	8.2	0



BigRIPS setting

Memo			
Run	83	Measurement date	2015-05-24
Target	Be 5mm	Beam	78Kr 345MeV
Trigger	F7		
Log Book Vol.	---	Log Book Page	---
Device setting			
Exit Beam Dump L [mm]	124.8	Exit Beam Dump R [mm]	40.1
F1 Detector	Not used	F1 Degrader	Al 4.5mm
F1 slit L [mm]	64.2	F1 slit R [mm]	64.2
F2 Detector	Not used		
F2 slit L [mm]	25	F2 slit R [mm]	25
F3 Detector	Pla 0.2mm,PPAC1,PPAC2	F4 Detector	Not used
F5 Detector	Pla 0.1mm,PPAC1,PPAC2	F5 Degrader	Not used
F5 slit L [mm]	120	F5 slit R [mm]	120
F6 Detector	Not used	F7 Detector	IC,Pla 0.2mm,PPAC1,PPAC2
F7 slit L [mm]	50	F7 slit R [mm]	50
Magnetic rigidity			
Brho01 [Tm]	5.455	Brho12 [Tm]	4.811
Brho23 [Tm]	4.8115		
Brho34 [Tm]	4.787	Brho45 [Tm]	4.787
Brho56 [Tm]	4.770	Brho67 [Tm]	4.770

Table of Nuclides

14N Beam 18O Beam 48Ca Beam 70Zn Beam 78Kr Beam 124Xe Beam 238U Beam

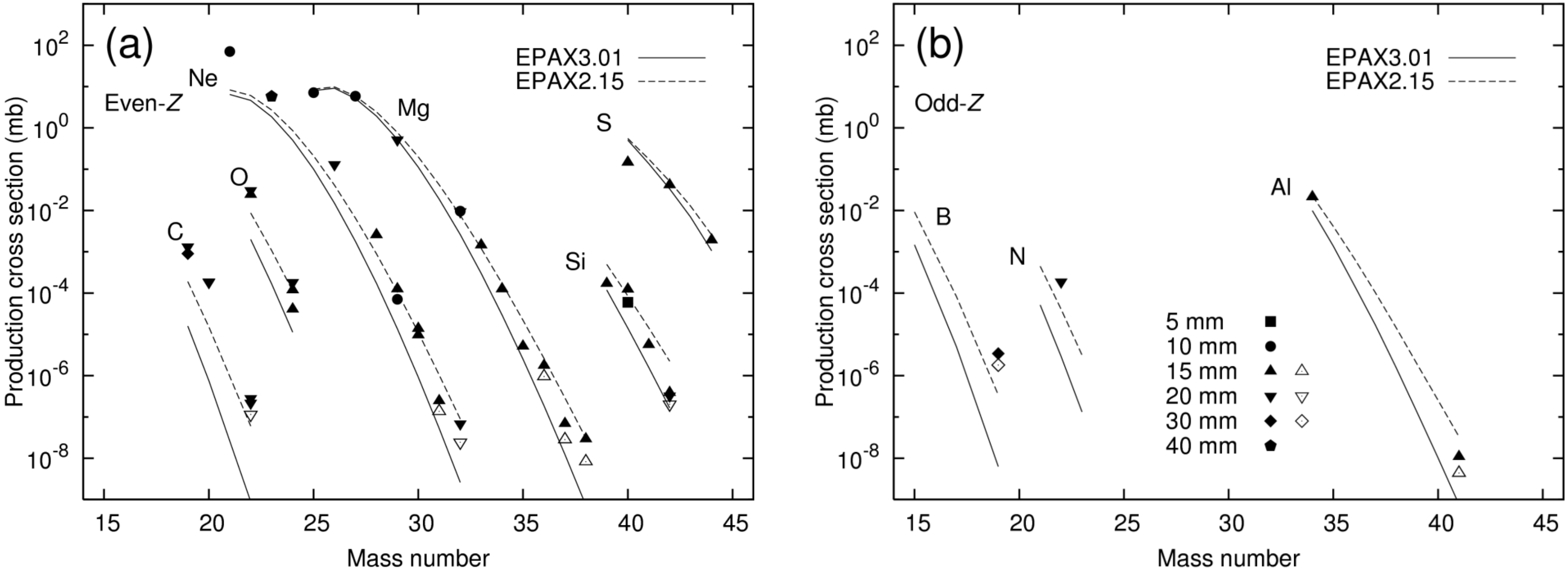
Isotope Search Isomer Search List of Publications List of Experim

The RI database system helps us not only to manage lots of data but also to operate the BigRIPS separator.

Summary

- Production yields and cross sections of various radioactive isotopes were measured using the BigRIPS separator at RIBF
- Neutron-rich isotopes from ^{238}U beam
  - For the region of $Z < 50$, measured yields are well reproduced by LISE predictions
  - For the region of $Z > 50$, LISE predictions are three orders of magnitude smaller than the measured yields.
  - The ABRABLA predictions are good agreements with measured cross sections for the region of $Z > 60$
- Proton-rich isotopes from ^{124}Xe and ^{78}Kr beams
  - EPAX3.1a reproduces the measured cross sections except for very proton-rich region and high Z region (near projectile).
- Neutron-rich isotopes from ^{70}Zn and ^{48}Ca beams
  - For the region of $Z < 20$, measured cross sections are well reproduced by EPAX2.15.
  - For the region of $Z > 20$, measured cross sections are well reproduced by EPAX3.1a.
- Work on the RI database system is currently operating.

Measured production cross sections compared with EPAX 3.01 & 2.15 (^{48}Ca 345 MeV/u + Be)



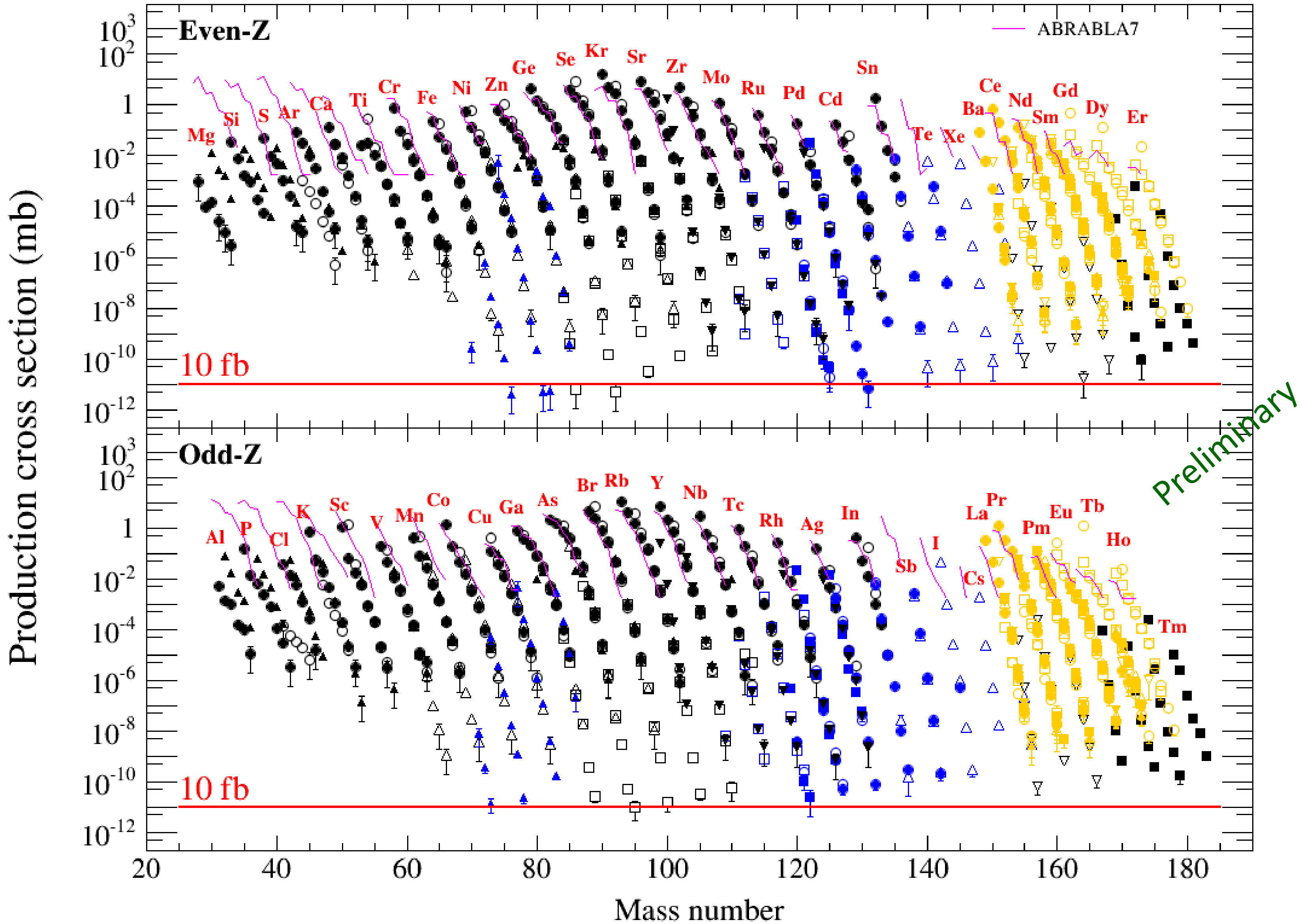
Open symbols: cross sections with the correction for the secondary reaction effect in the target (only for the nuclides whose augmentation factors are more than 1.6.)

- Fairly good agreement between the experimental cross sections and EPAX 2.15.
- EPAX 3.01 underestimates the cross sections.

Modification of EPAX3 from EPAX2

The c.s. of very neutron-rich fragments from medium-mass and heavy projectile were modified, which were overestimated by EPAX2. At the same time, the good agreement of EPAX2 for the neutron-deficient side is maintained.

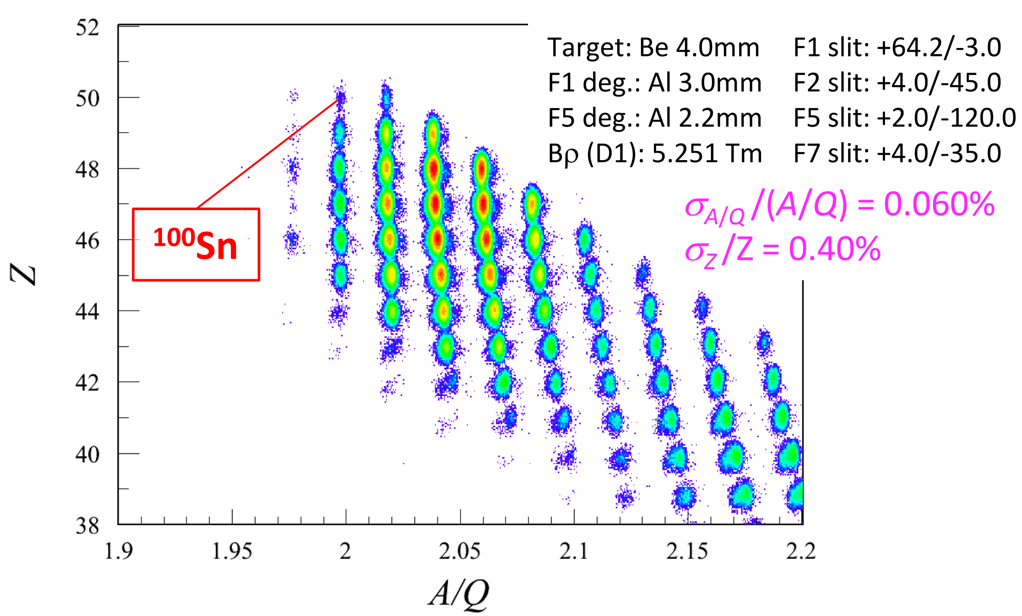
Measured production cross sections for in-flight fission of ^{238}U (Be target)

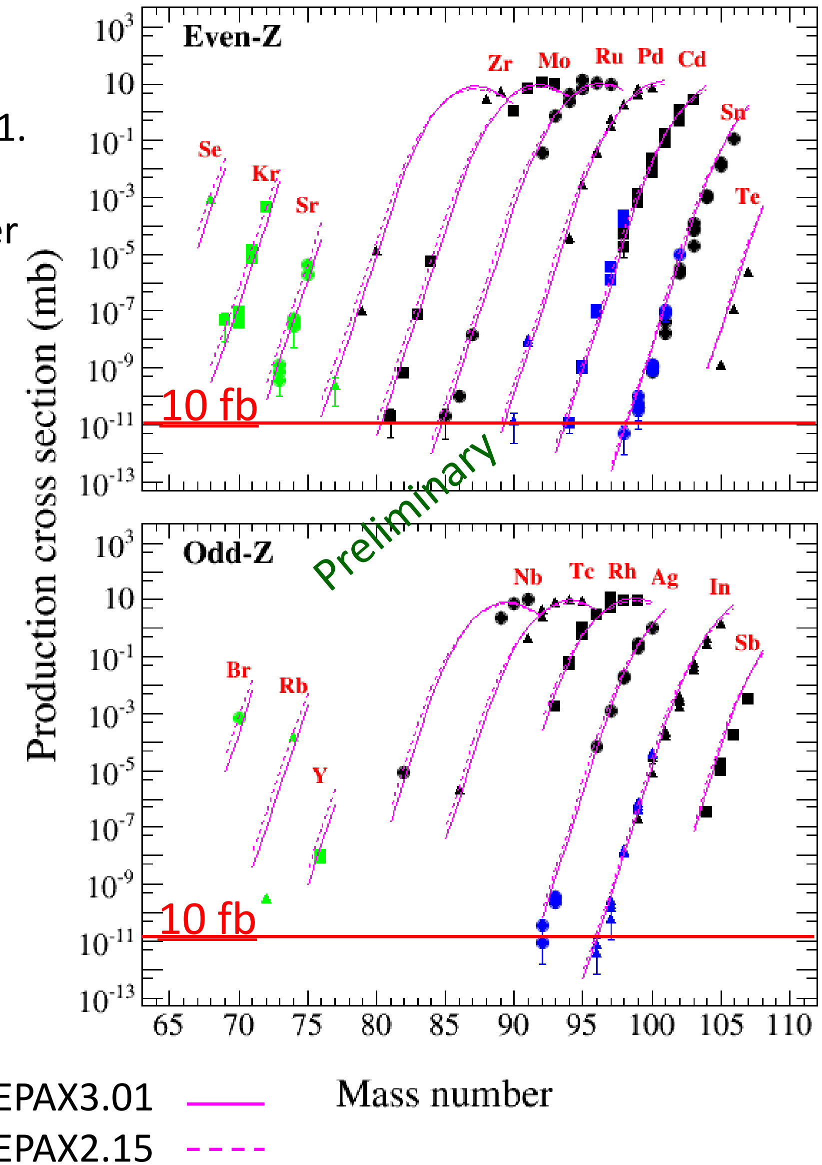


Measured production cross sections for projectile fragmentation (^{124}Xe beam)

^{124}Xe+Be at 345 MeV/u

- The measured c.s. are fairly well reproduced by EPAX3.01.
- In very proton-rich region and higher *Z* region, our measured c.s. are almost one order of magnitude smaller than the calculated values with the EPAX.
  e.g. ^{100}Sn ~ 1/6, ^{73}Sr ~1/3
- Example: ^{100}Sn setting for EURICA 2013
  - ✓ Beam current: 35 pnA
  - ✓ ^{100}Sn: 4.0 x 10^{-3} pps at 35 pnA

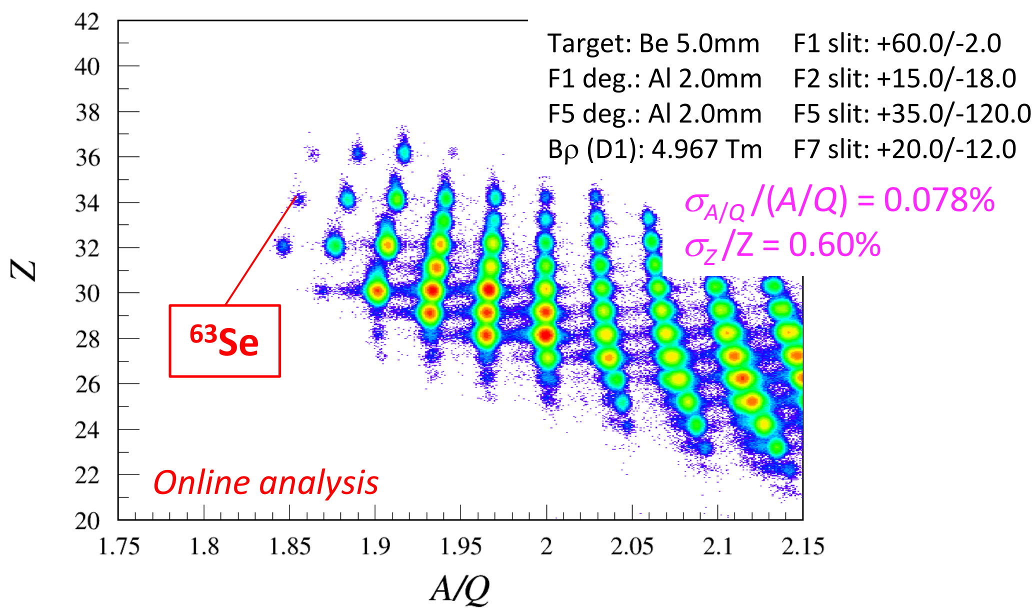


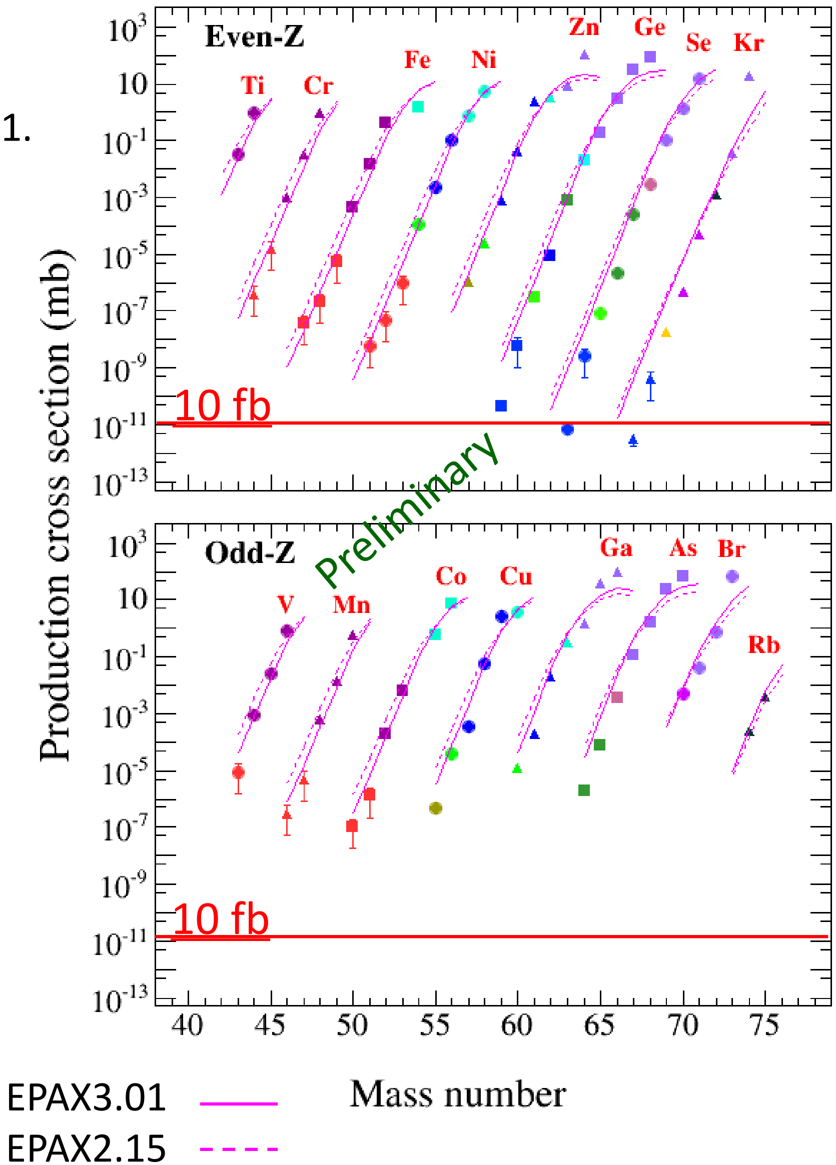


Measured production cross sections for projectile fragmentation (^{78}Kr beam)

^{78}Kr+Be at 345 MeV/u

- The measured c.s. are fairly well reproduced by EPAX3.01.
- In very proton-rich region, our measured c.s. are almost one order of magnitude smaller than the calculated values with the EPAX.
  e.g. ^{69}Kr ~ 1/14, ^{64}Sr ~1/9, ^{60}Ge ~ 1/7
- Example: ^{67}Kr setting for EURICA 2015
  - ✓ Beam current: 400 pnA
  - ✓ ^{63}Se: 5.6 x 10^{-4} pps at 400 pnA

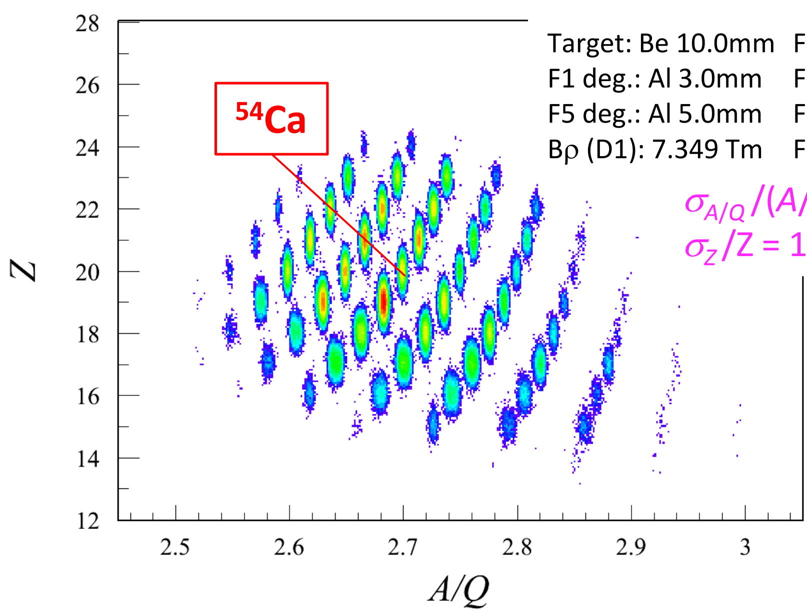




Measured production cross sections for projectile fragmentation (^{70}Zn beam)

^{70}Zn+Be at 345 MeV/u

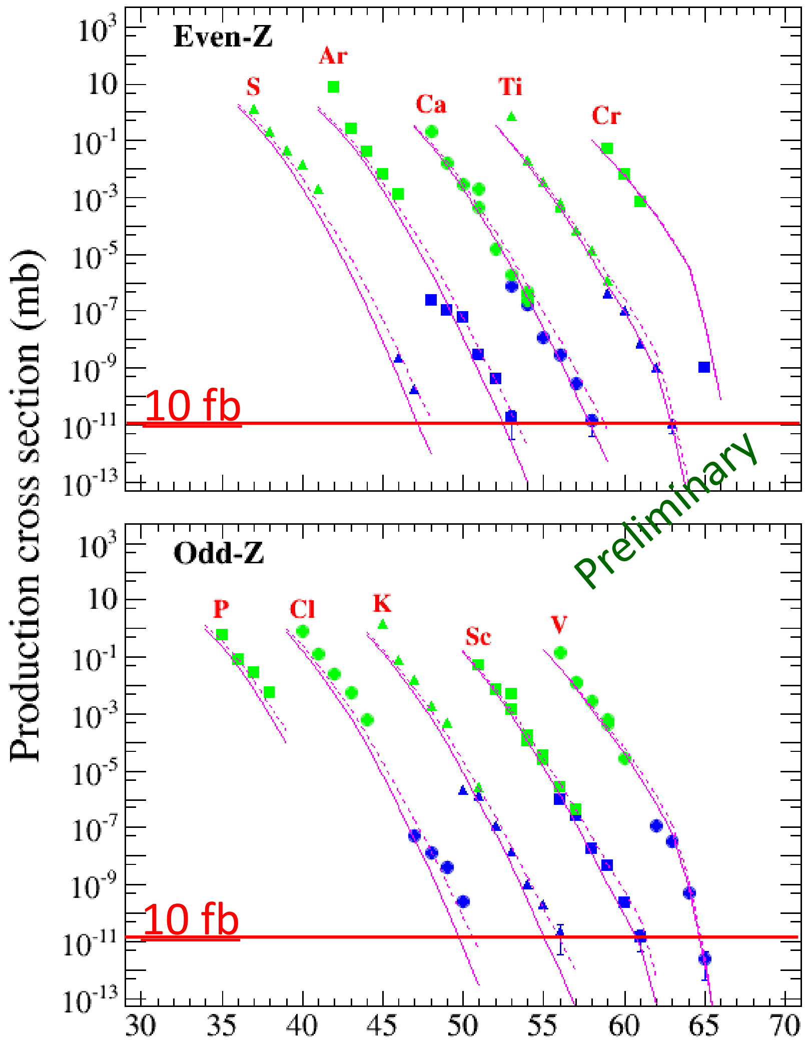
- For the region of $Z < 20$, measured cross sections are well reproduced by EPAX2.15.
- For the region of $Z > 20$, measured cross sections are well reproduced by EPAX3.01.
- Example: ^{54}Ca setting for SHARAQ 2014
  - Beam current: 150 pnA
  - ^{54}Ca: 5.6 pps at 150 pnA



Target: Be 10.0mm	F1 slit: +64.2/-64.2
F1 deg.: Al 3.0mm	F2 slit: +50.0/-15.0
F5 deg.: Al 5.0mm	F5 slit: +120.0/-120.0
Bρ (D1): 7.349 Tm	F7 slit: +50.0/-50.0

$\sigma_{A/Q}/(A/Q) = 0.065\%$

$\sigma_Z/Z = 1.41\%$



EPAX3.01

EPAX2.15

Measured production cross sections for projectile fragmentation (^{48}Ca beam)

^{48}Ca+Be at 345 MeV/u

- The predictions from the EPAX2.15 formula are in better agreement with the measured cross sections than those from the EPAX3.01 formula.
- Example: ^{33}F setting for Drip line search 2014
  - ✓ Beam current: 340 pnA
  - ✓ ^{31}F: 3.6 x 10^{-1} pps at 340 pnA