

RIBFでの核破砕データ測定：生成断面積

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- ◆ BigRIPSでのRビーム生成
- ◆ Rビーム生成率・生成断面積(^{238}U , ^{124}Xe , ^{48}Ca ビーム)

BigRIPS における RI ビーム生成

- 2007年のコミッショニング以降、多種のRIビームを生成・供給
- RIビーム生成に用いる反応:
 - 入射核破碎反応
 - ^{238}U の飛行核分裂

Parameters:

$$\Delta\theta = \pm 40 \text{ mr}$$

$$\Delta\phi = \pm 50 \text{ mr}$$

$$\Delta p/p = \pm 3 \%$$

$$B\rho = 9 \text{ Tm}$$

$$L = 78.2 \text{ m}$$

BigRIPS の主な特徴

➤ 超電導磁石

14台の超電導三連四重極磁石

大口径: $\phi 240 \text{ mm}$, ポール端磁場: 2.4-2.5 T

➤ 大アクセプタンス

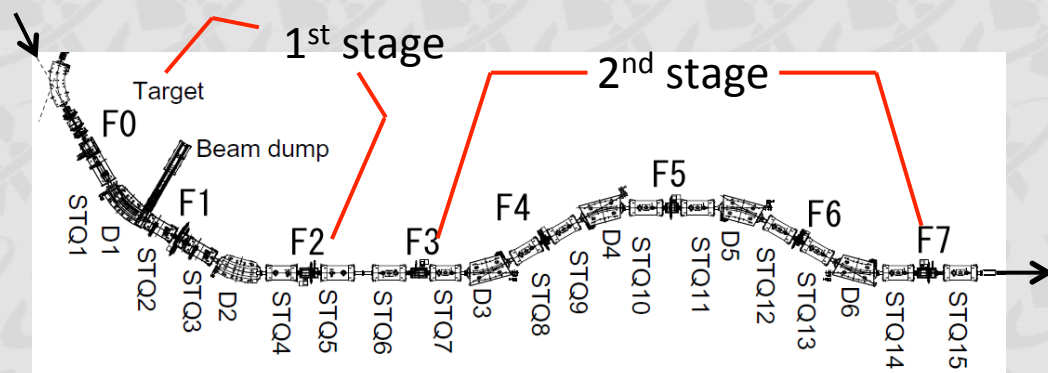
RIBFエネルギー領域での飛行核分裂片の運動学的広がりには匹敵

➤ Two-stage separation scheme

1st stage: 生成と分離

2nd stage: 粒子識別

2段階分離



BigRIPS での粒子識別

軌道再構成を使った ΔE -TOF- $B\rho$ 法

$\Delta E, \text{TOF}, B\rho$ 測定 @ 2nd stage

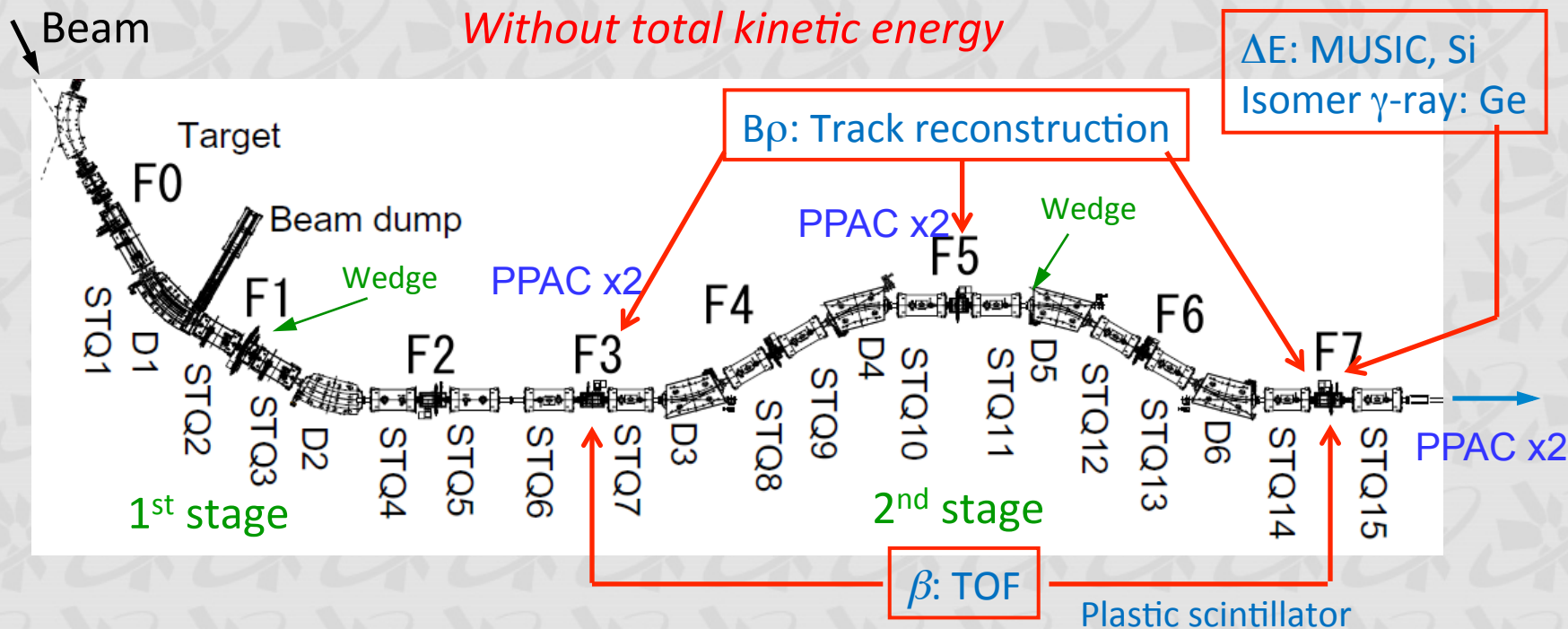
↓ + isomeric γ -ray

$Z, A/Q$

$$Z \leftarrow -dE / dx = f(Z, \beta)$$

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

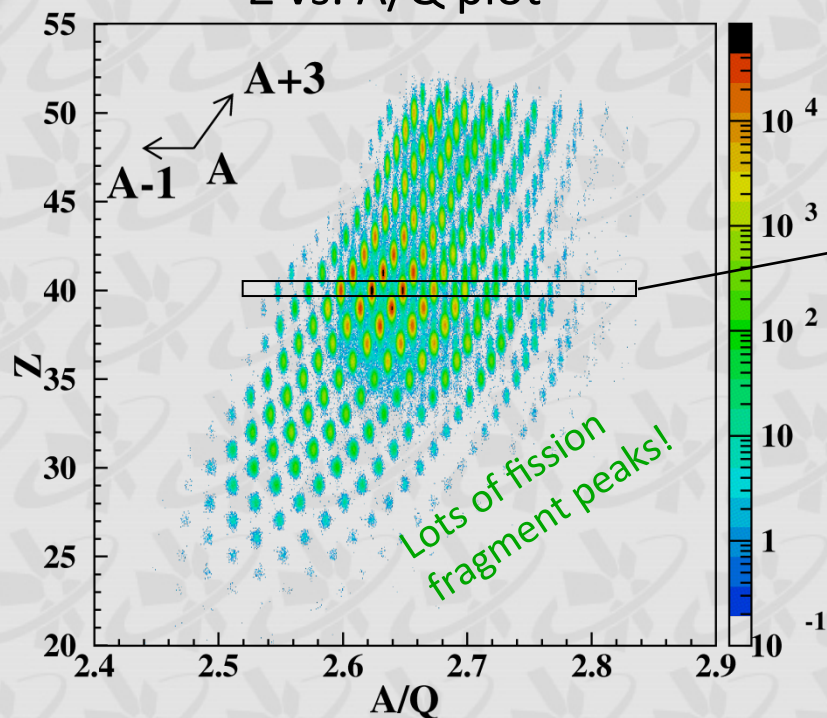
Without total kinetic energy



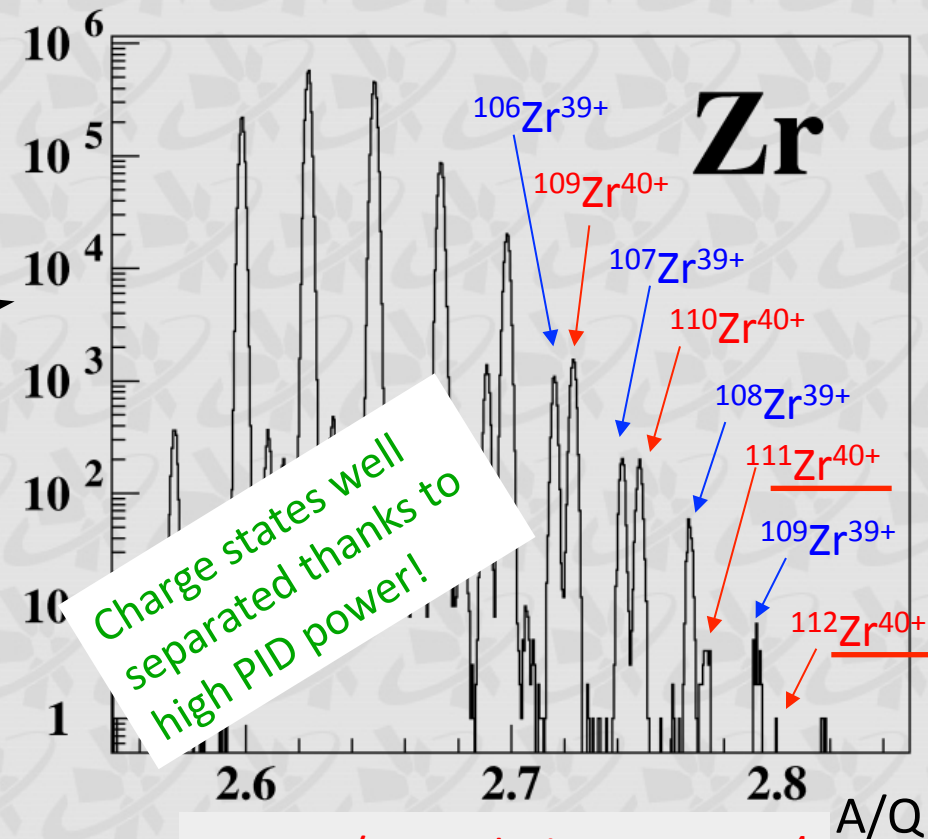
BigRIPS の粒子識別性能

High enough to well identify charge states thanks to the track reconstruction!

$^{238}\text{U} + \text{Be}$ at 345 MeV/u
Z vs. A/Q plot



A/Q spectrum for Zr isotopes (Z=40)



r.m.s. A/Q resolution: 3.5×10^{-4}

U+Be 2.9 mm Bp 01 = 7.990 Tm
F1 deg Al 2.18mm
 $\Delta P/P = \pm 3\%$

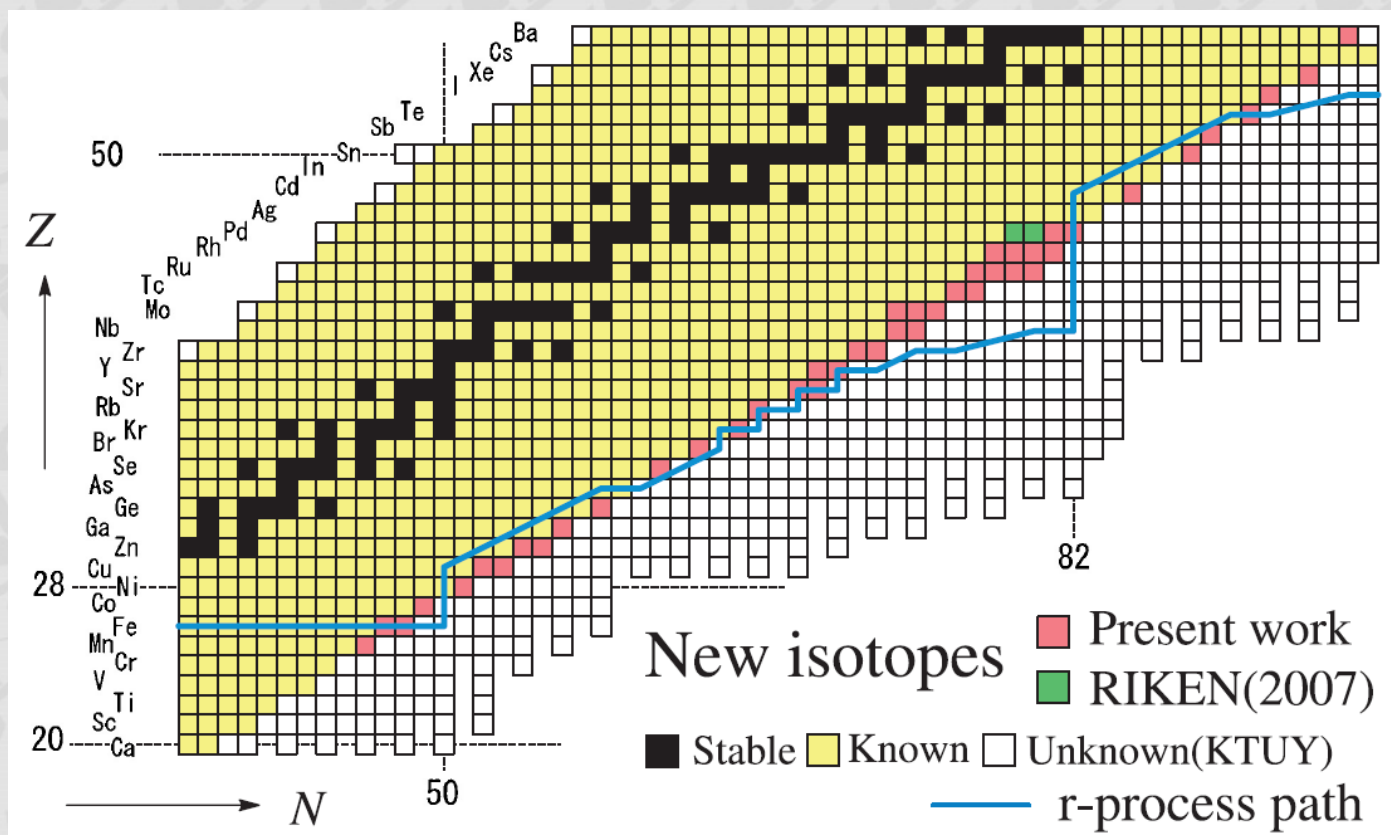
BigRIPS での生成断面積測定

- 新同位元素探索・生成断面積測定 (^{238}U , ^{124}Xe)
- ユーザーへのビーム供給前に生成断面積測定を実施

⇒ 生成断面積データを蓄積

- ^{238}U 345 MeV/u
- ^{124}Xe 345 MeV/u
- ^{48}Ca 345 MeV/u

^{238}U ビーム 345 MeV/u, ~ 0.22 p nA



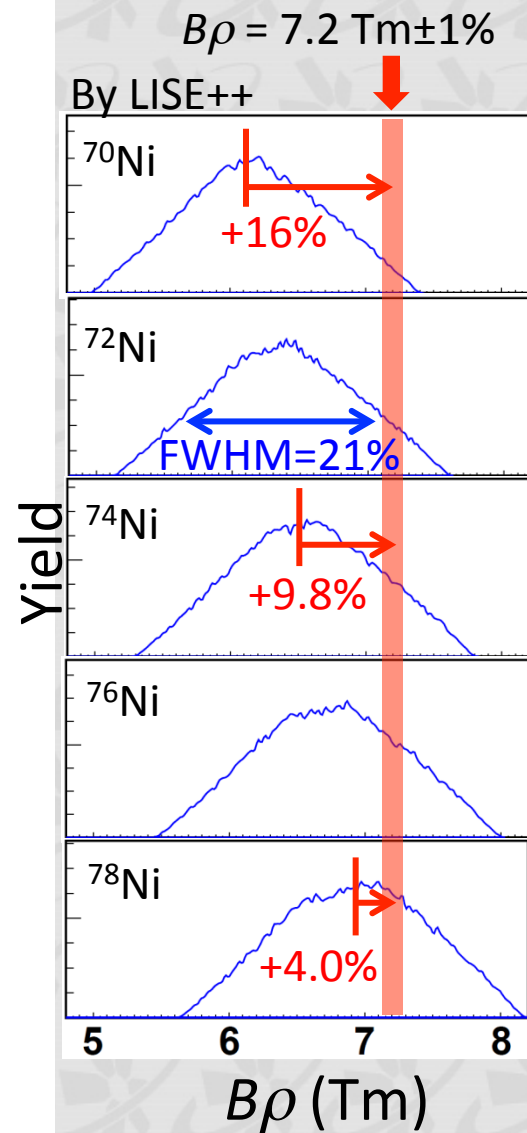
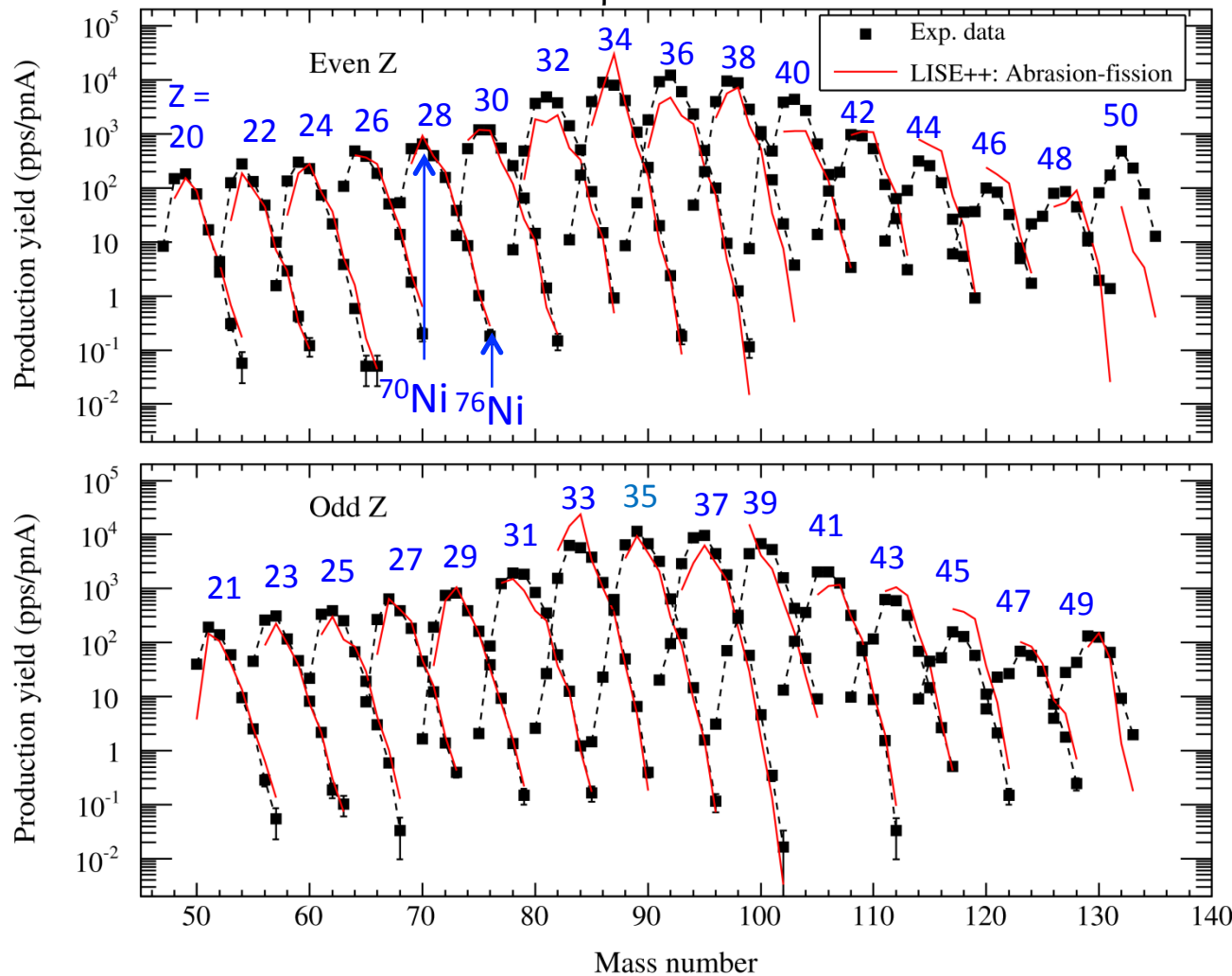
^{238}U ビーム飛行核分裂片の生成断面積測定

Target		Be 7 mm		Pb 1.5 mm	Be 5.1 mm	Be 2.9 mm	Pb 0.95 mm + Al 0.3 mm
$B\rho$ (Tm)	7.2	7.4	7.6	7.0	7.902	7.990	7.706
$\Delta p/p$	$\pm 1\%$	$\pm 1\%$	$\pm 2\%$	$\pm 0.1\%$	$\pm 3\%$	$\pm 3\%$	$\pm 3\%$
Degrader	None	None	None	None	F1: 1.29 mm	F1: 2.18 mm	F1: 2.56 mm F5: 1.8 mm
F2 slit (mm)	± 30	± 30	± 30	± 50	± 13.5	± 15.5	± 15

Target	Be 4.00 mm	Be 4.93 mm*	W 0.7 mm*	Be 4.93 mm		W 0.7 mm	
$B\rho$ (Tm)	7.306	6.950	6.950	6.950	7.300	6.950	7.300
$\Delta p/p$	$-2\%/+3\%$	$-2\%/+3\%$	$-2\%/+3\%$	$\pm 0.1\%$	$\pm 0.1\%$	$\pm 0.1\%$	$\pm 0.1\%$
Degrader	F1: 1.27 mm F5: 1.40 mm	F1: 1.27 mm F5: 1.40 mm	F1: 1.27 mm F5: 1.40 mm	None	None	None	None
F2 slit (mm)	$-3/+15$	$-4/+15$	$-4/+15$	± 120	± 120	± 120	± 120
F7 slit (mm)	$-5/+25$	± 15	± 15	± 120	± 120	± 120	± 120

1 setting, no energy degraders used

— LISE++ abrasion fission Fairly good reproduction
 $B\rho = 7.2 \text{ Tm}$

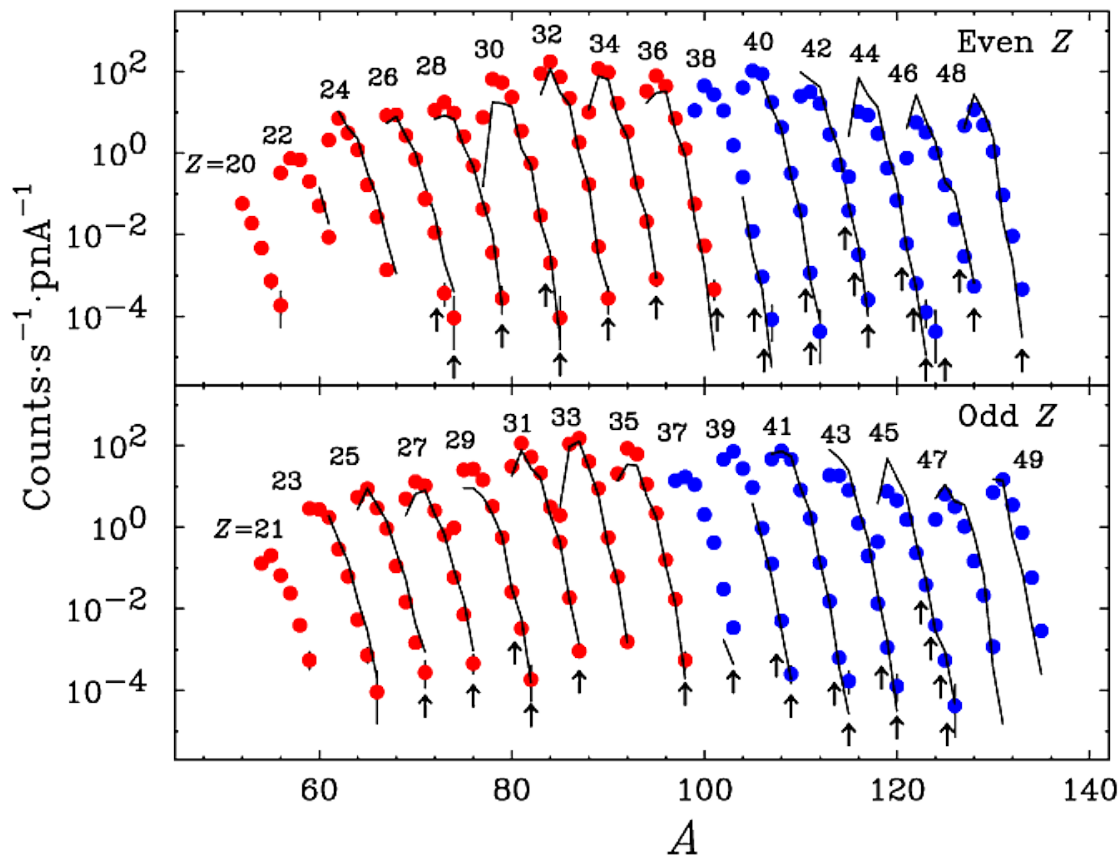


Fairly well reproduced by LISE++ simulations

— LISE++(ver. 8.4.1)

$^{238}\text{U}^{86+}$ 345MeV/u + Be

Abrasion fission

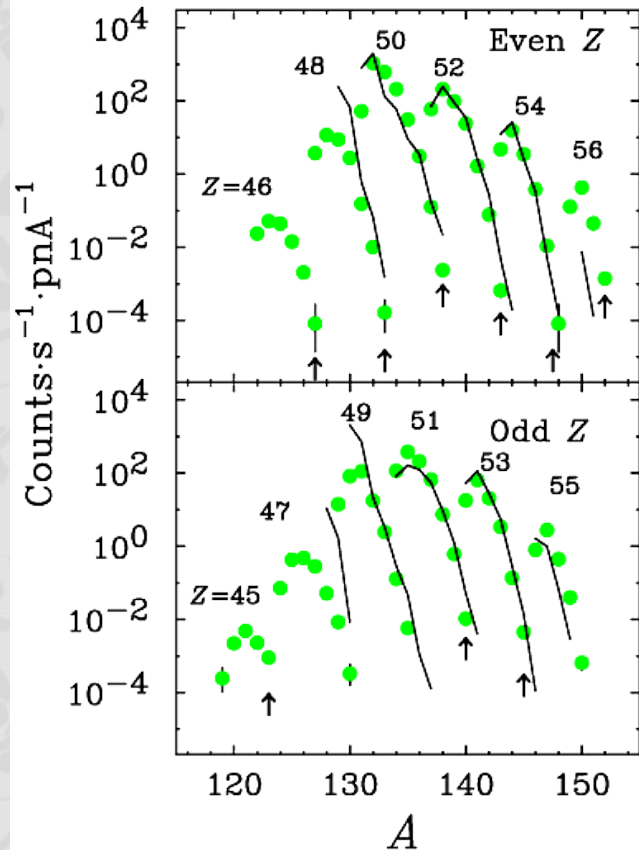


● Setting1: Z~30

● Setting2: Z~40

$^{238}\text{U}^{86+}$ 345MeV/u + Pb

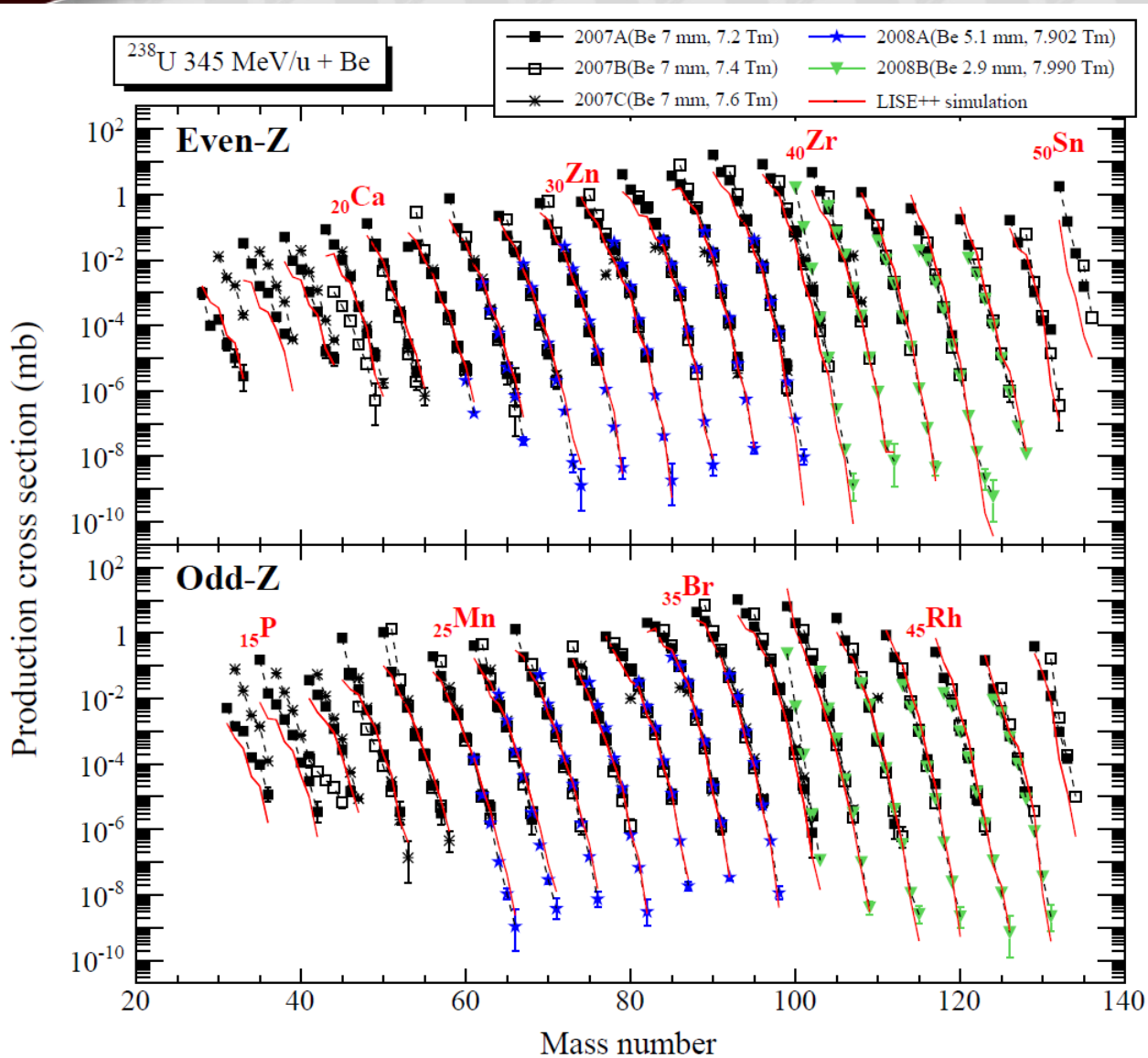
Coulomb fission



● Setting3: Z~50

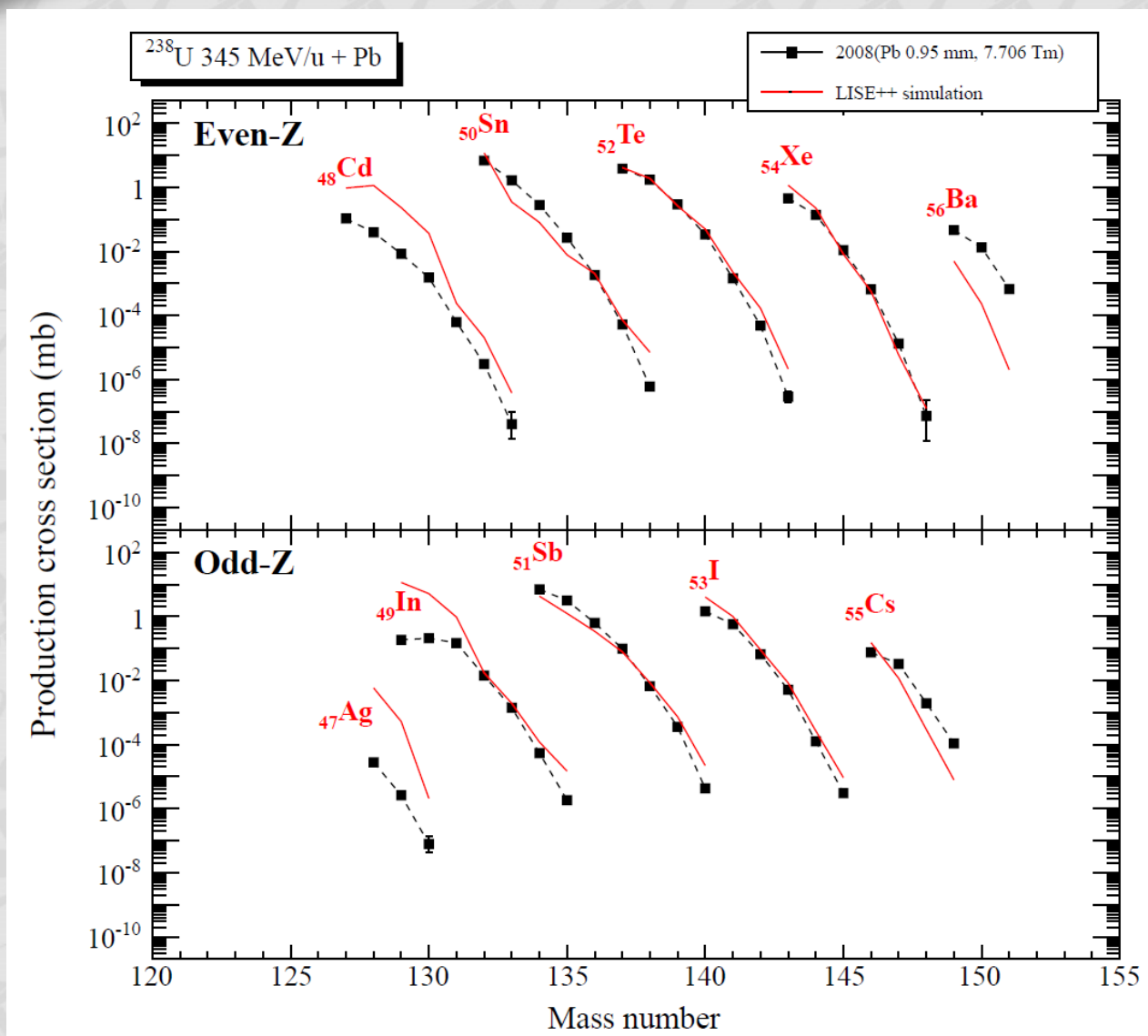
生成断面積: $^{238}\text{U} + \text{Be}$

Transmission は LISE++ を用いて見積もった。



生成断面積: $^{238}\text{U} + \text{Pb}$

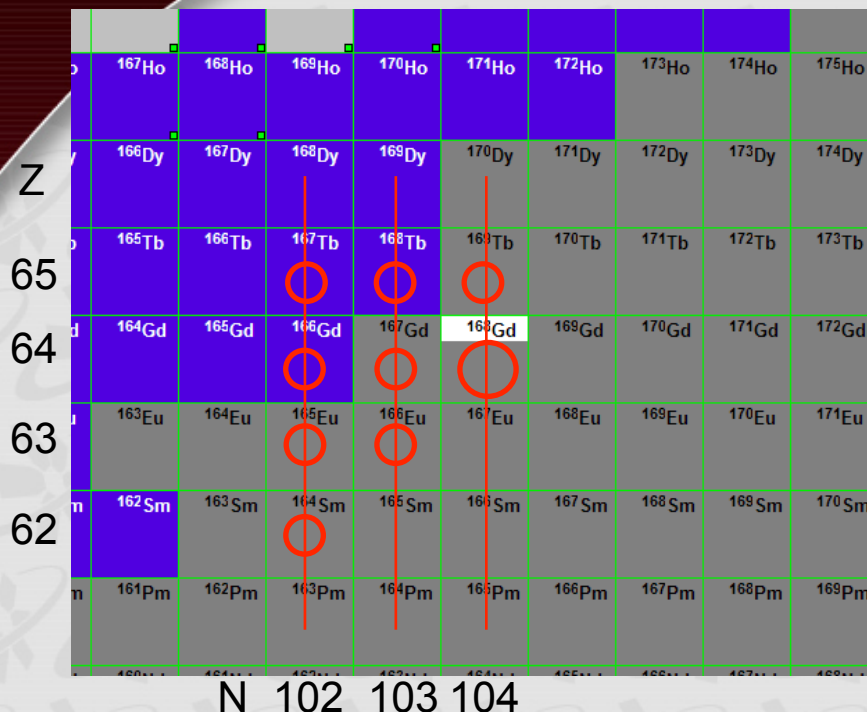
Transmission は LISE++ を用いて見積もった。



Production of higher-Z neutron-rich isotopes using in-flight fission of ^{238}U at 345 MeV/u

Oct. 2011

Z ~ 60 - 65



Comparison of production rates

Isotope	Exp rate (pps/pnA)	LISE++ rate (pps/pnA)
Tb-167	3.1.E+00	2.6.E-01
Tb-168	1.4.E+00	1.1.E-01
Tb-169	5.4.E-01	2.5.E-02
Gd-166	2.1.E+00	2.5.E-01
Gd-167	5.3.E-01	4.2.E-02
Gd-168	1.3.E-01	6.5.E-03
Eu-165	7.6.E-01	7.4.E-02
Eu-166	1.3.E-01	6.2.E-03
Sm-164	1.4.E-01	9.9.E-03

Preliminary

Exp./LISE++ ~10 !



Abrasion fission model

BigRIPS setting : Tuned for ^{168}Gd (63+, 64+, 64+, 64+) at (D1, D2, D3-D4, D5-D6)

- Target: Be 4.926 mm
- Bp01: 6.950 Tm, Bp12: 6.496 Tm
- F1 deg.: Al 1.27 mm, F5 deg.: Al 1.40 mm
- F1 slit: -64.2/+42.8 mm, F2 slit: -4/+15 mm
- F7 slit: -15/+15 mm

Experimental data:

- Particle identification is made with Z vs A/Q plot.

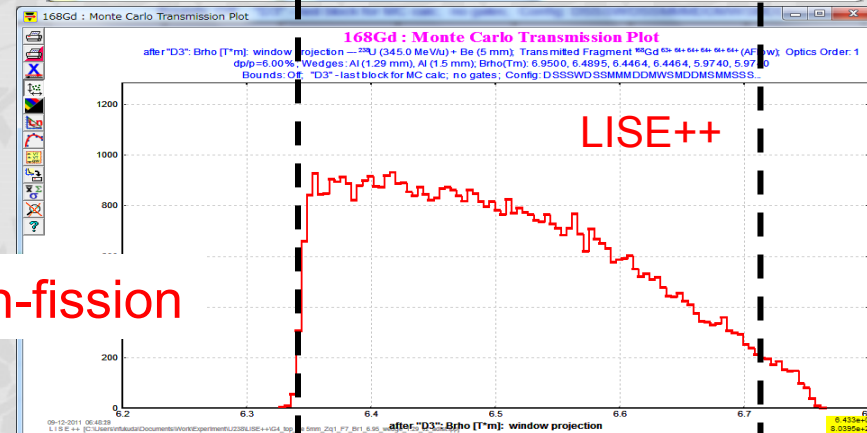
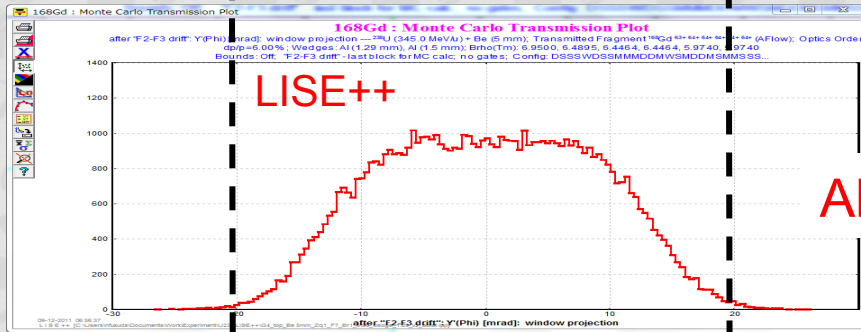
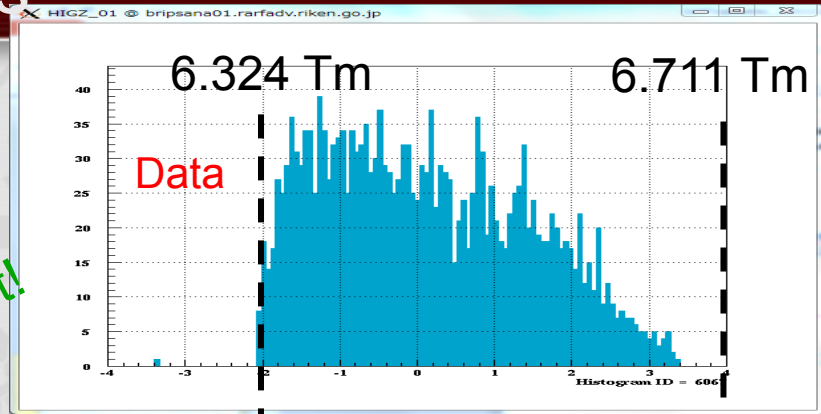
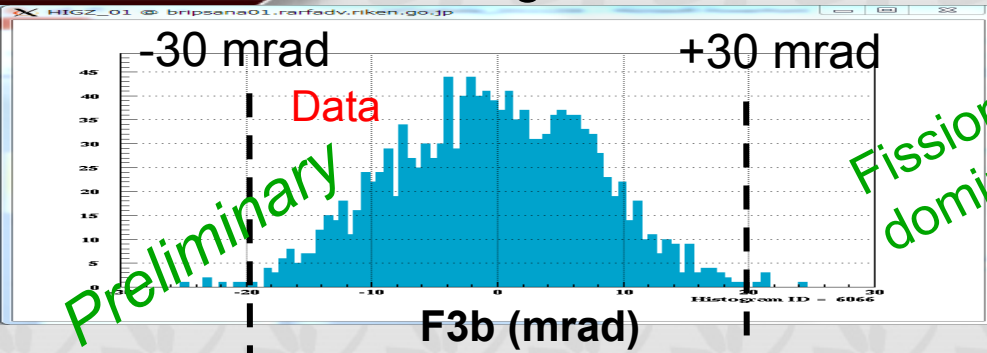
LISE++ simulation:

- Version 9.2.126
- Abrasion-Fission model is used.
- Contribution from the projectile fragmentation is not included.
- Transmission is obtained with "distribution-mode".

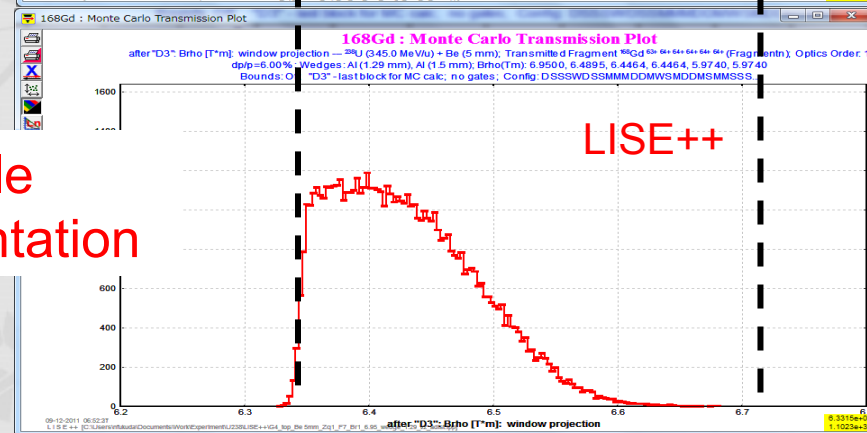
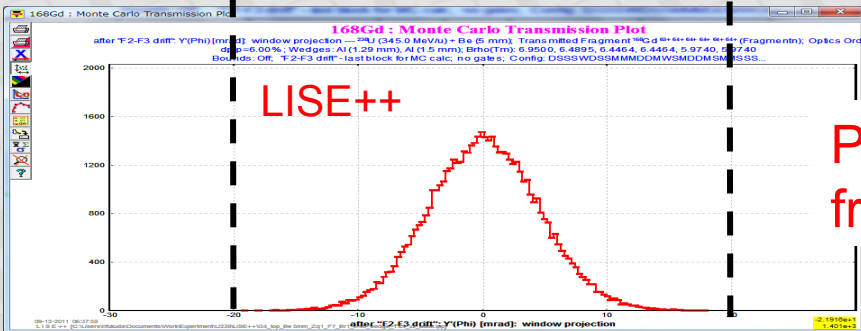


Angular and momentum distribution for ^{168}Gd ($Z=64$) fragments

Angle



Abrasion-fission

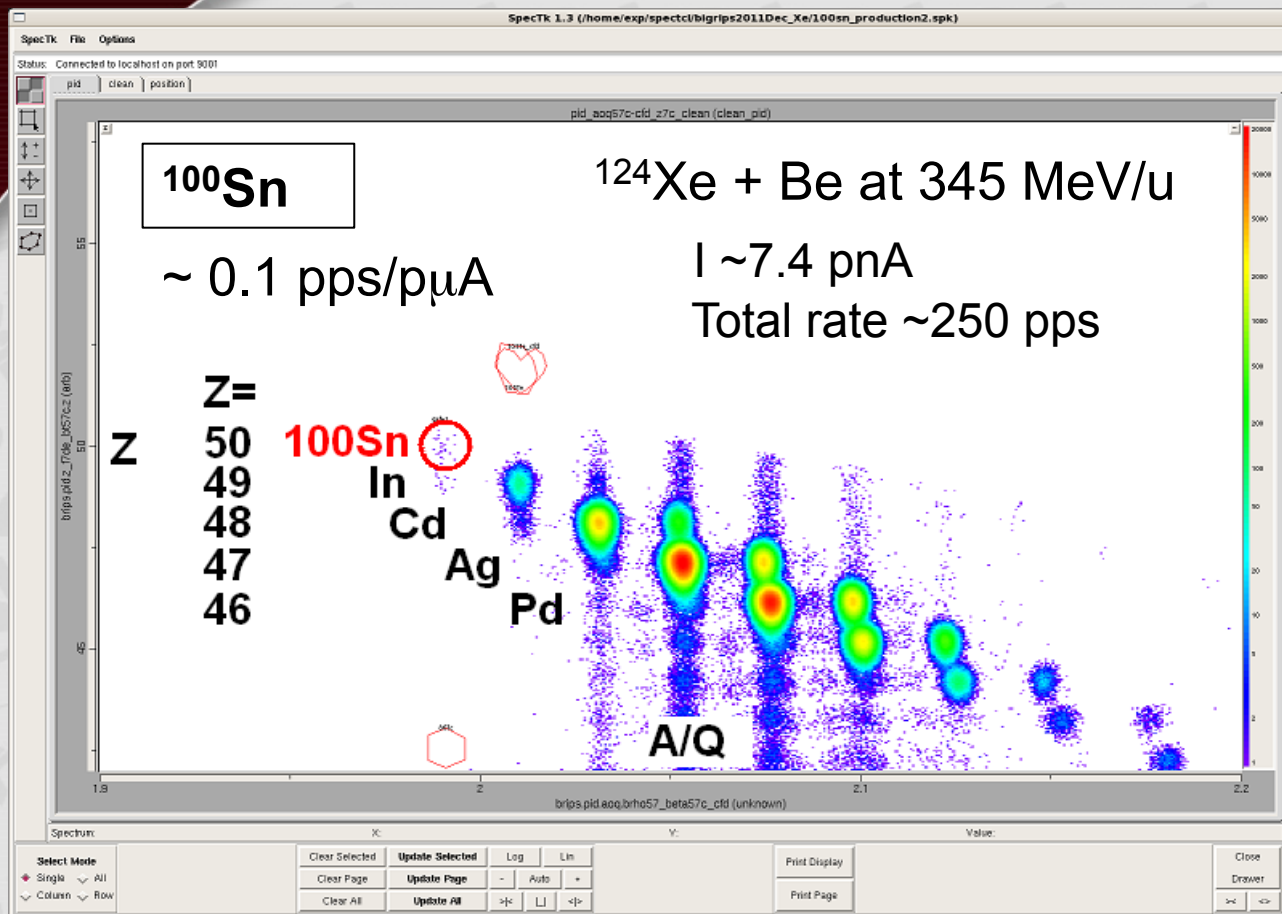


Projectile fragmentation

^{100}Sn 生成

^{124}Xe 345 MeV/u ビーム 入射核破碎反応

Dec. 2011



- Target: 4-mm Be, F1-deg: 3-mm Al, F5-deg: 3-mm Al
- Br01: 5.255, Br12,Br23: 4.622, Br35: 4.585, Br57: 3.667 (Tm)
- F1 slits: +/-42.8, F2: +/-3.0, F5: +/-65.0, F7: +8/-15 (mm)

Analyzed by H.Suzuki

100Sn の生成率

Preliminary

¹⁰⁰ Sn	Exp.	LISE++ (EPAX2.15)
Yield (pps/pnA)	(1.1 +/-0.2)E-4	9.4E-4
Purity	(3.9 +/-0.8)E-6	3.1E-6

Exp./
Cal.:
0.12
~1

The purity can be improved by a factor of ~4 by adjustment of slit settings or charge state separation.

Production rates (pps/pnA) of other Sn isotopes

Nuclei	Experiment	LISE++
¹⁰⁰ Sn	$(1.1 \pm 0.2) \times 10^{-4}$	9.4×10^{-4}
¹⁰¹ Sn	$(7.0 \pm 0.8) \times 10^{-3}$	5.0×10^{-2}
¹⁰² Sn	$(4.6 \pm 1.2) \times 10^{-1}$	2.2×10^0

Exp./Cal.(EPAX2.15)

~0.12

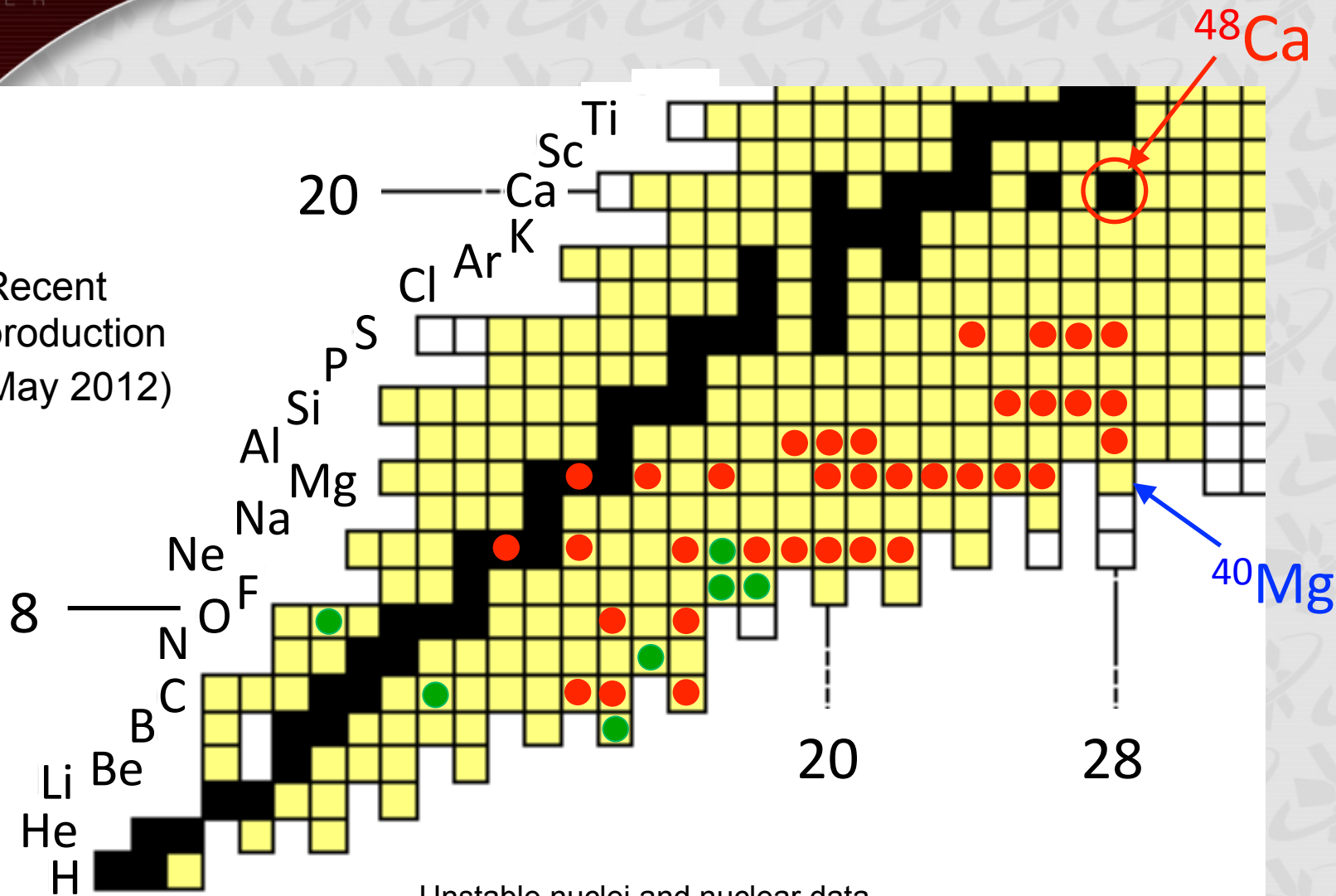
~0.14

~0.21

Preliminary

Production of neutron-rich RI beams using a ^{48}Ca beam at 345 MeV/u

● Recent production (May 2012)



Production rates of very neutron-rich exotic nuclei

Yields (pps/200pnA)

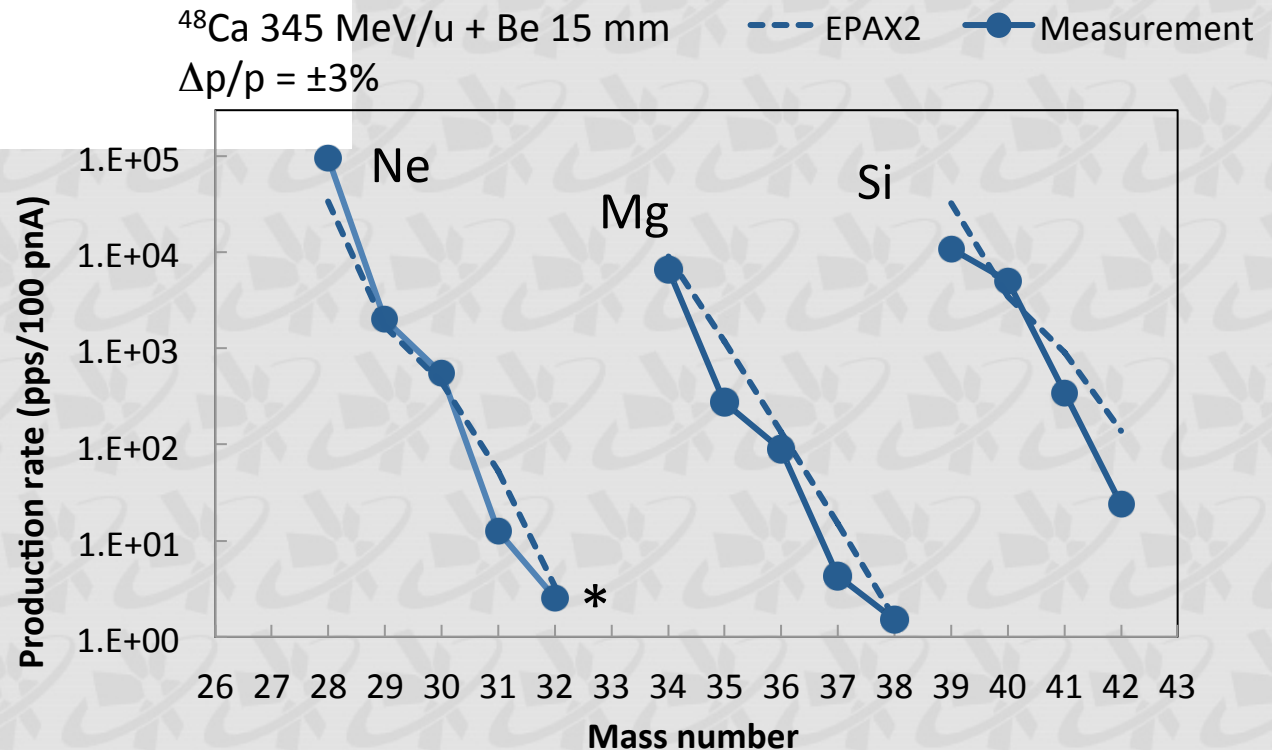
	BigRIPS	RIPS (old facility)
^{22}C	10 cps	0.006 cps
^{30}Ne	1100 cps	0.2 cps
^{31}Ne	26 cps	20 counts/4days
^{32}Ne	7 cps	
^{38}Mg	3 cps	
^{41}Al	1 cps	
^{42}Si	48 cps	

Recent ^{48}Ca -beam
intensity: ~ 400 pnA

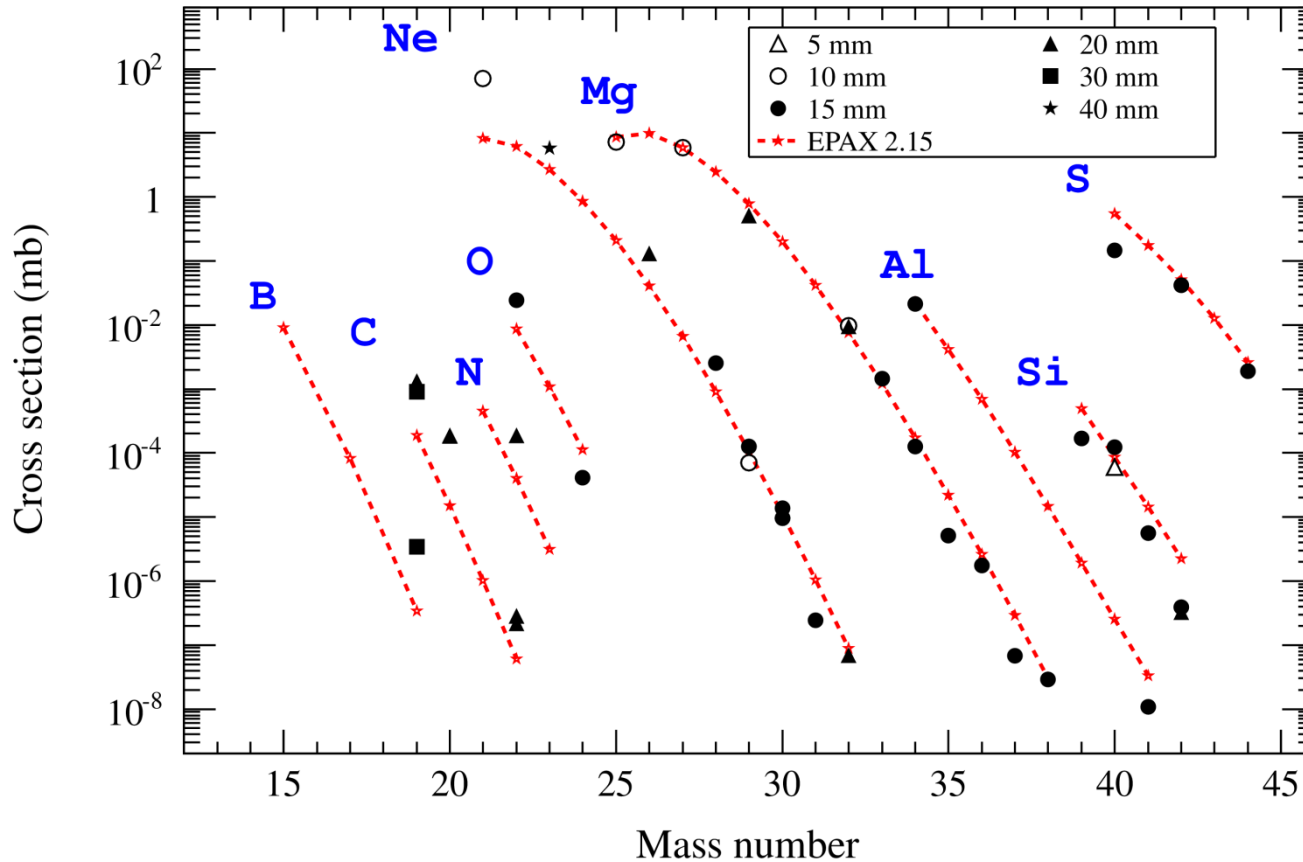
(May 2012)

New data

^{19}B	110 cps/200pnA
^{22}N	8000 cps/200pnA



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



Be target thickness

^{19}C	20 mm, 30 mm
^{29}Ne	10 mm, 15 mm
^{32}Mg	10 mm, 20 mm
^{40}Si	5 mm, 15 mm
^{42}Si	15 mm, 20 mm

Fairly good agreement has been obtained.

生成断面積データ:

RIBF Users' Information

<http://www.nishina.riken.jp/RIBF/BigRIPS/intensity.html>

* 現時点では 2010年までに実施した 48Ca, 238U ビームのデータを掲載

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大竹政雄, 柳澤善行, 田中鐘信, 稲辺尚人,
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- 2007.03 BigRIPS コミッショニング (^{86}Kr , ^{238}U)
- 2007.05 新同位元素探索 (^{238}U) – $^{125,126}\text{Pd}$
- 2008.11 ZeroDegree コミッショニング (^{238}U)
新同位元素探索 (^{238}U) – 45 new isotopes
- 2008.12 DayOne 実験 (^{48}Ca)
- 2009.03 SHARAQ コミッショニング (^{14}N)
- 2009.12 DayTwo 実験 (^{238}U , ^{48}Ca)
- 2010.05 MUST2 実験 (^{48}Ca)
- 2010.11-12 ^{48}Ca campaign 実験
- 2011.10 新同位元素探索 (^{238}U)
- 2011.12 ^{100}Sn 生成・新同位元素探索 (^{124}Xe)
- 2012.03 SAMURAI コミッショニング
- 2012.04 EURICA コミッショニング
- 2012.05-06 ^{48}Ca campaign 実験
- 2012.06 ^{124}Xe campaign 実験
- 2012.07 ^{70}Zn ビーム 実験