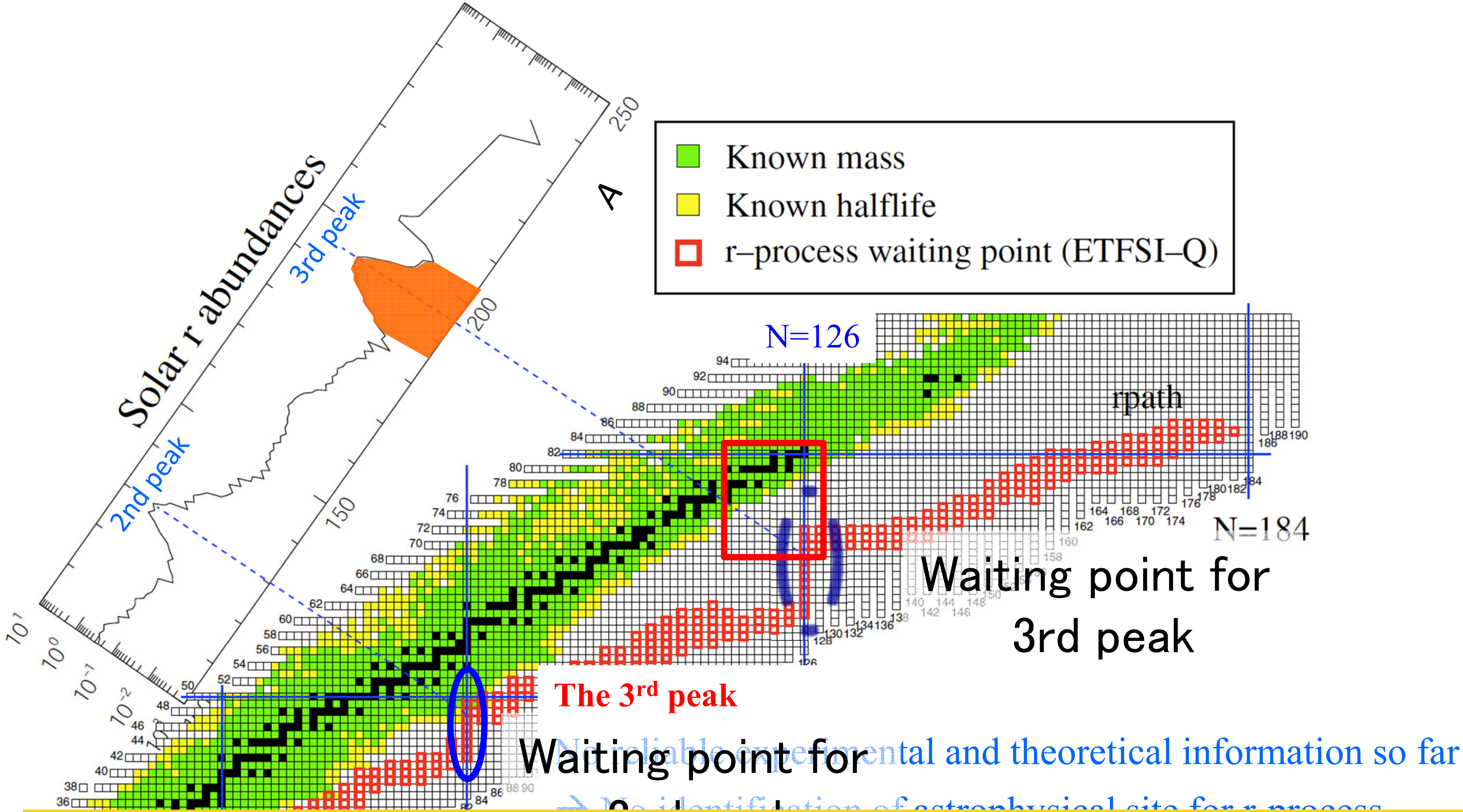
Present status of KEK isotope separation system (KISS)

Y.X. Watanabe (IPNS, KEK)

Contents

Identification of astrophysical site for r-process
~ How are the elements of Gold and Platinum synthesized ~

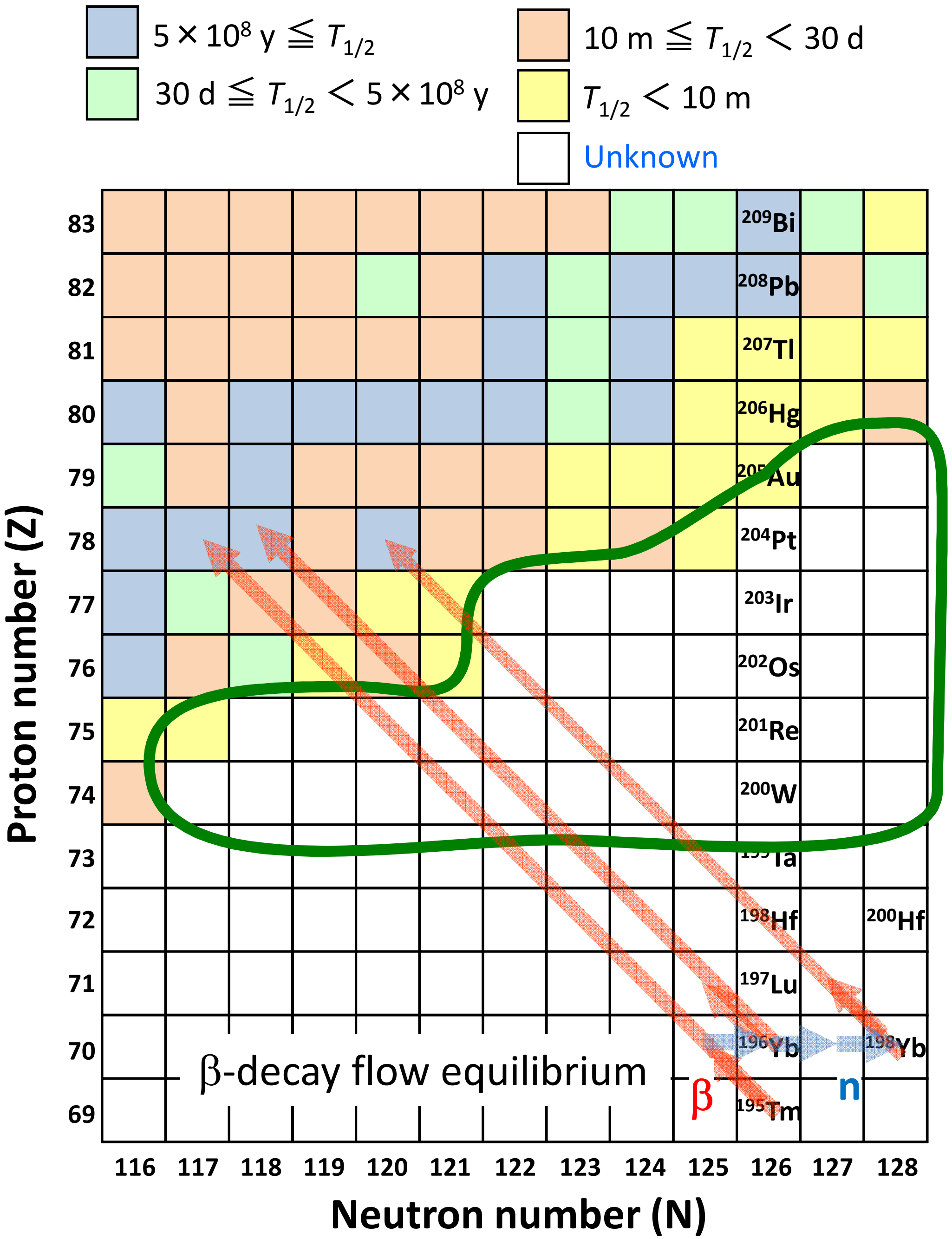


Ultimate goal of physics motivation

- Actual r-process path
- Astrophysical N_n – T condition
- Duration time passing through waiting point
- Sensitive test for actinide element production rate

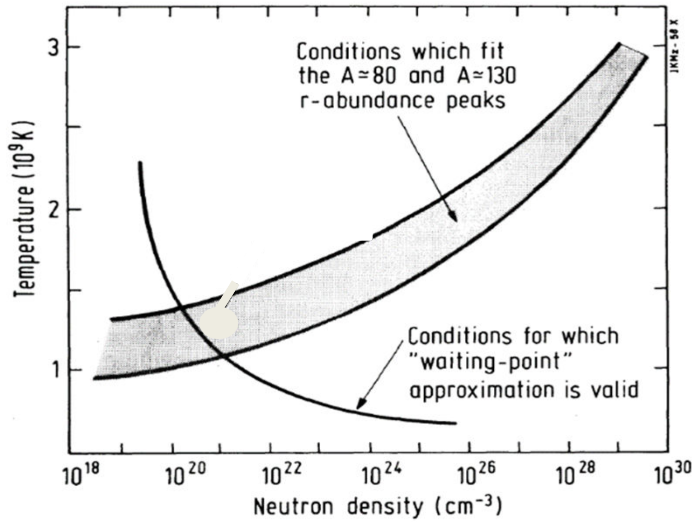
H. Grawe et al., Rep. Prog. Phys. 70 (2007), 1525-1582

Identification of astrophysical site for r-process



- Lifetime measurement of N = 126 nuclei
  - → Actual r-process path (β-decay flow equilibrium)
- Mass measurement
  - → Temperature and neutron density condition for the 3rd peak formation ((n,γ)-(γ,n) equilibrium)

1st stage: Lifetime of nuclei from ^{204}Pt to ^{200}W



Experimental issues

How to access?

Efficient production of nuclei of interest

→ MNT reaction

How to collect and separate?

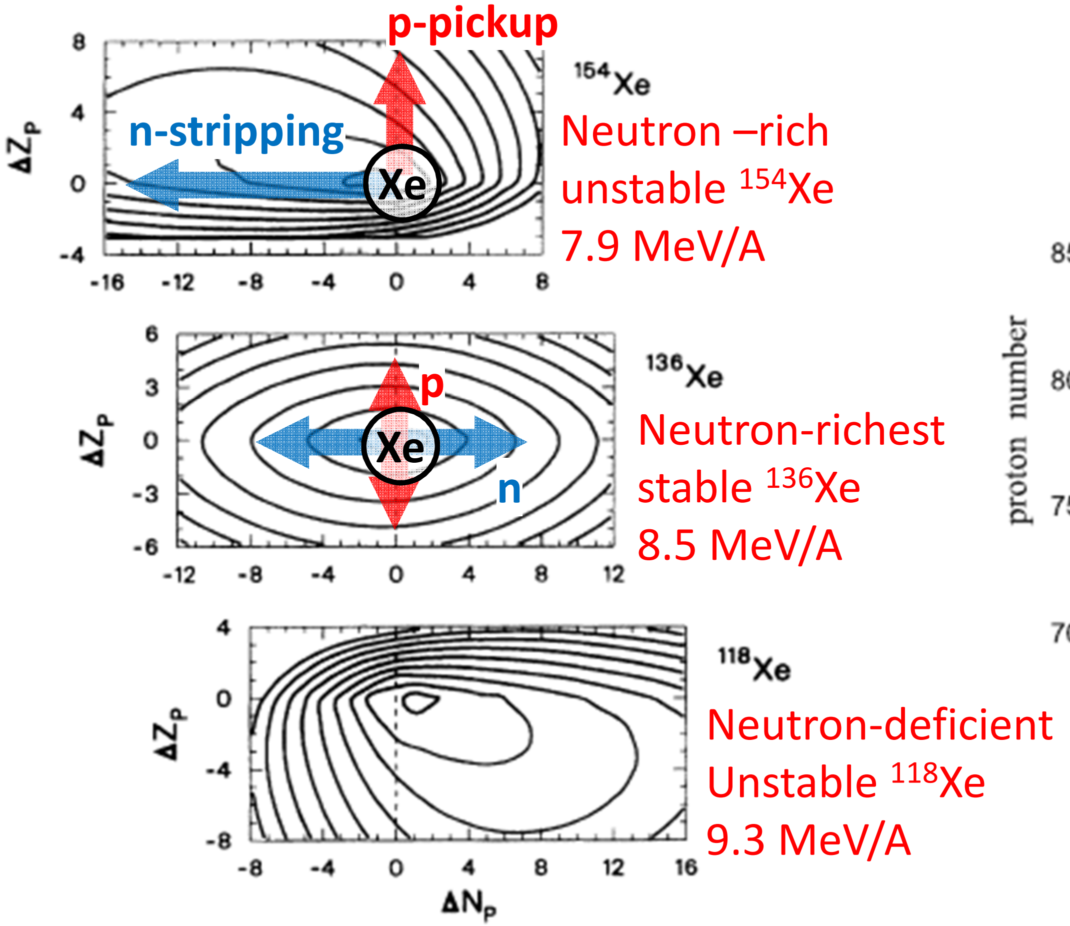
High efficiency and purity

→ KISS

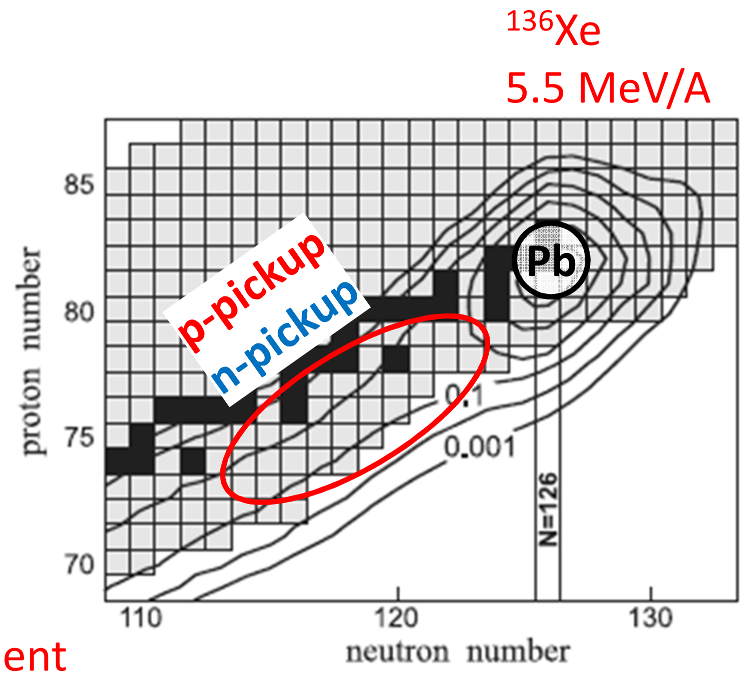
Nuclear production by MNT reactions

Proposed by C.H. Dasso et al., Phys. Rev. Lett. 73 (1994), 1907.
Recently revised by V. Zagrebaev and W. Greiner, Phys. Rev. Lett. 101 (2008), 122701

Xe + ^{208}Pb (E_{cm} = 700 MeV)



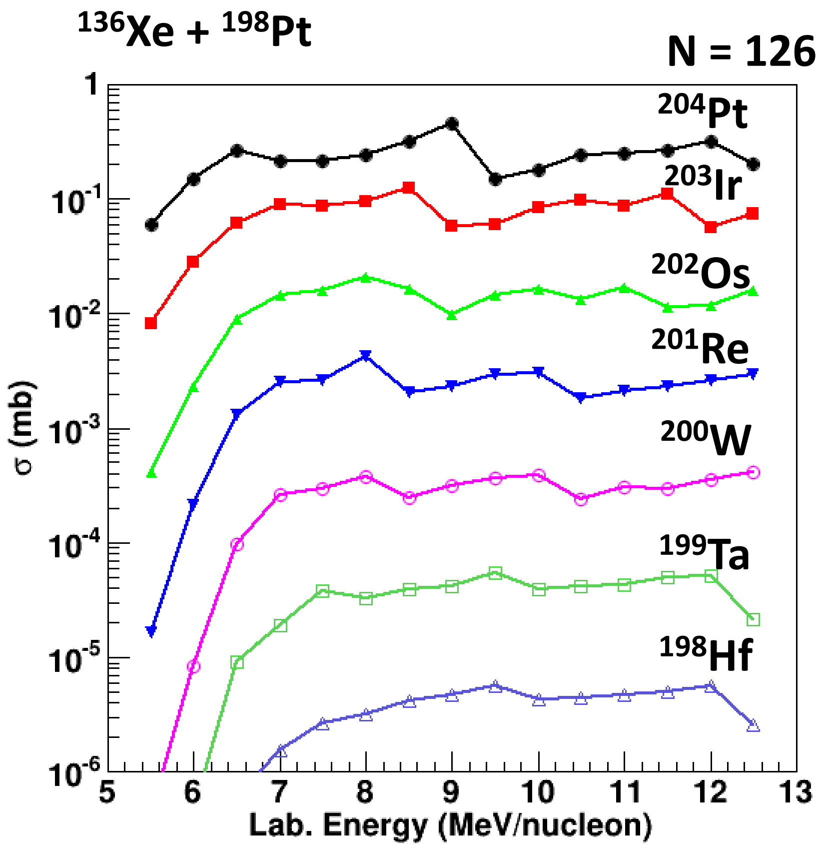
^{136}Xe + ^{208}Pb (E_{cm} = 450 MeV)

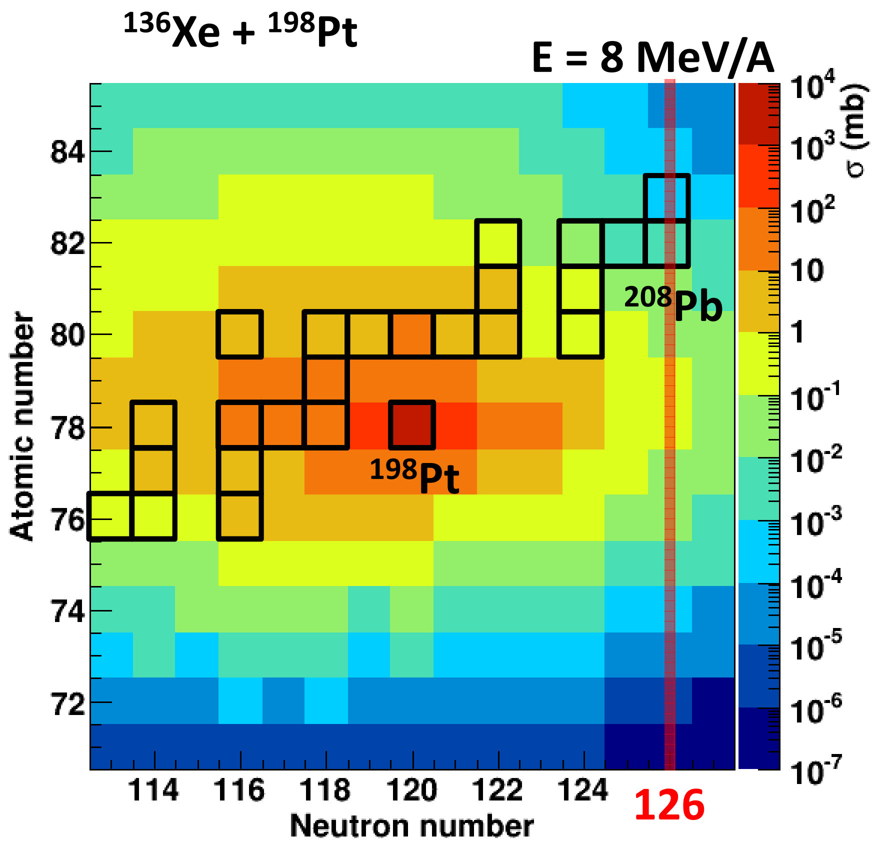


MNT reaction of $^{136}Xe + ^{198}Pt$

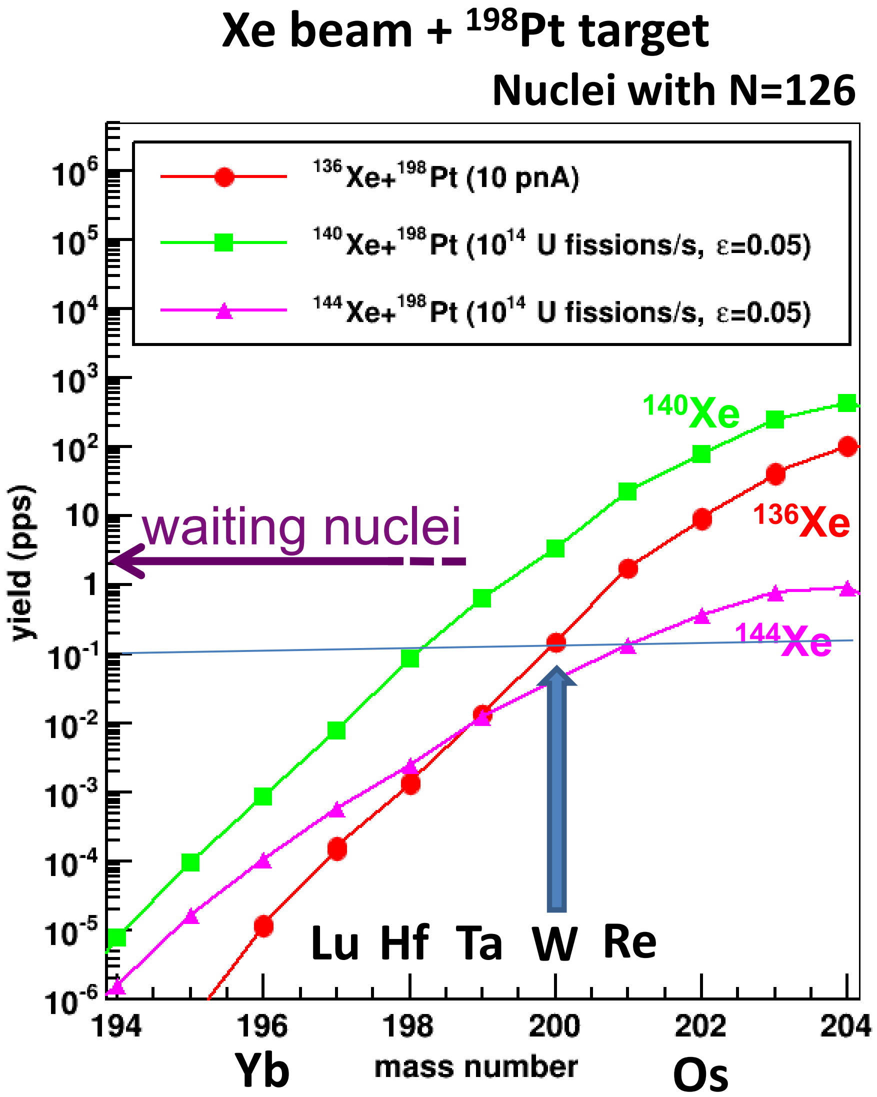
GRAZING calculation

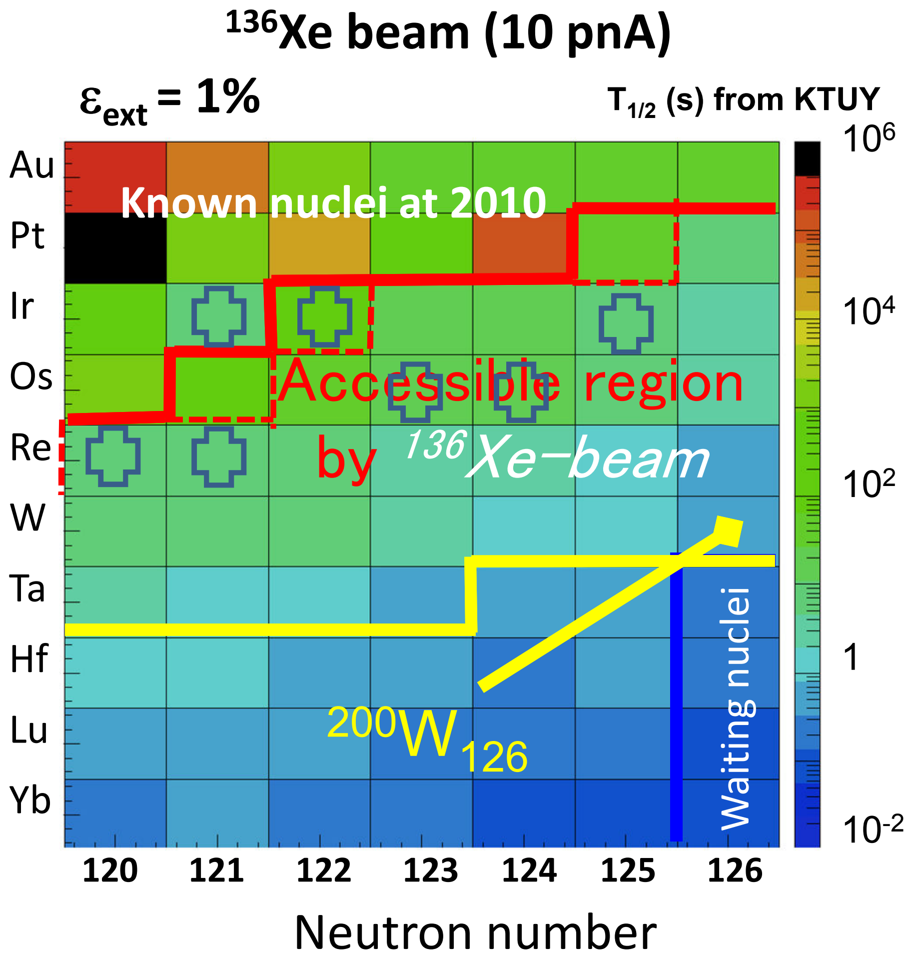
A. Winther, Nuclear Physics A572 (1994), 191-235;
A. Winther, Nuclear Physics A594 (1995), 203-245.





Estimation of production yields





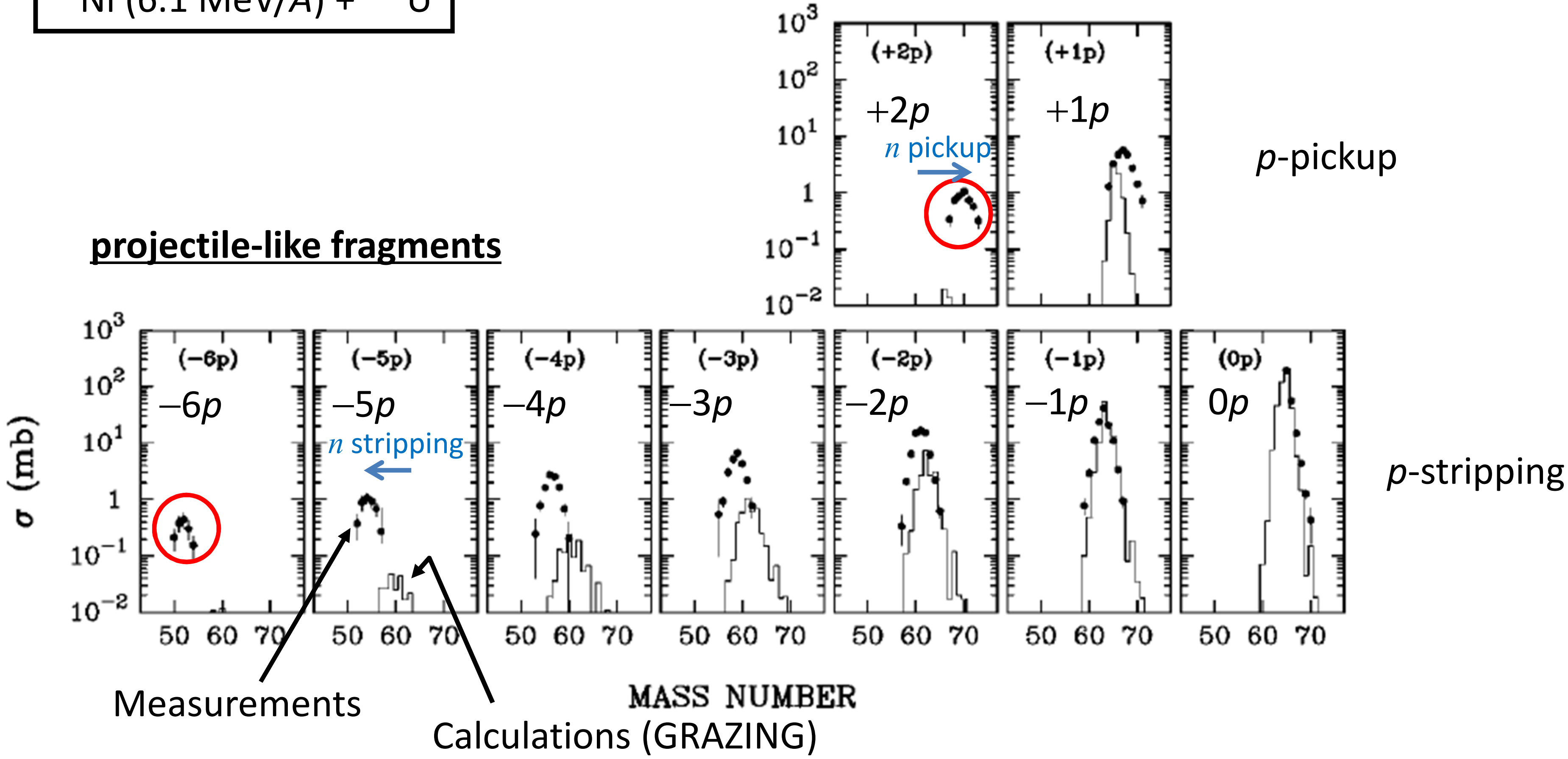
T. Kurtukian-Nieto et al.,
Eur. Phys. J. A 50 (2014), 135

Comparison with measurements

^{64}Ni (6.1 MeV/A) + ^{238}U

L. Corradi et al., Physical Review C59 (1999) 261.

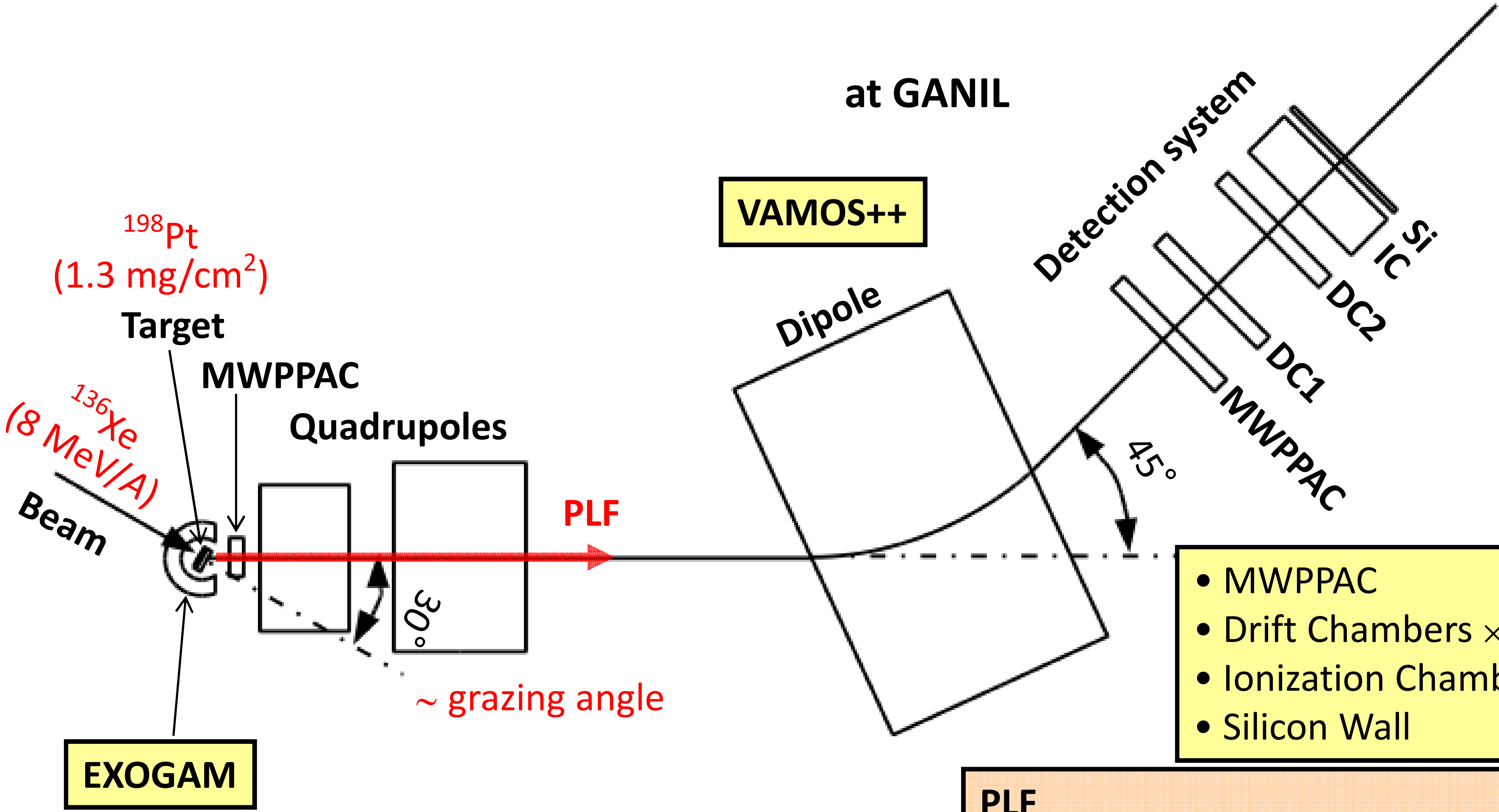
<u>**projectile-like fragments**</u>



Discrepancy of **centroids of the isotopic distributions** and **absolute cross sections** of them becomes larger as number of transferred protons increase

MNT measurement of $^{136}Xe + ^{198}Pt$

at GANIL



- MWPPAC
- Drift Chambers ×2
- Ionization Chamber
- Silicon Wall

11 CLOVER detectors

TLF

γ-rays ~500 keV

total photo-peak efficiency ~10%

PLF

Trajectory

Path length, Angles (θ, ϕ), $B\rho$

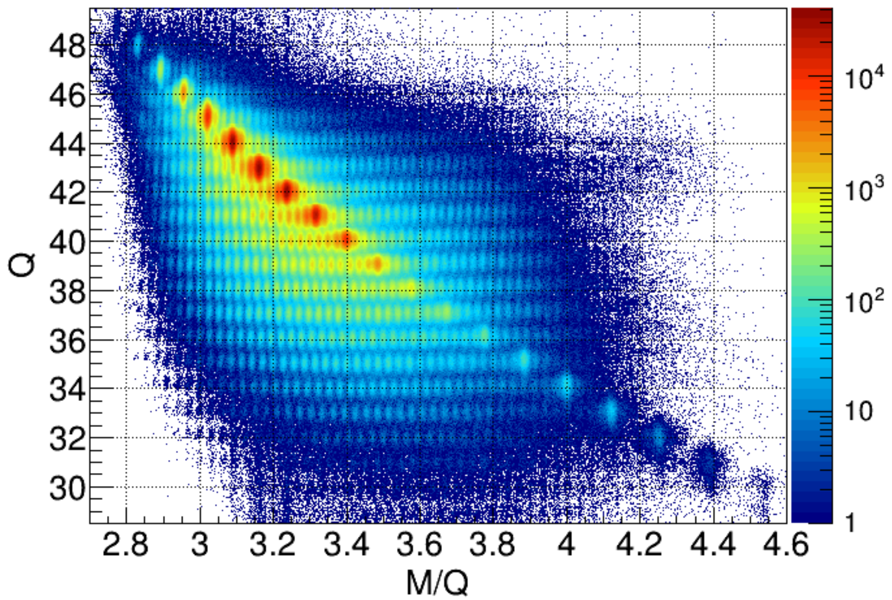
Velocity

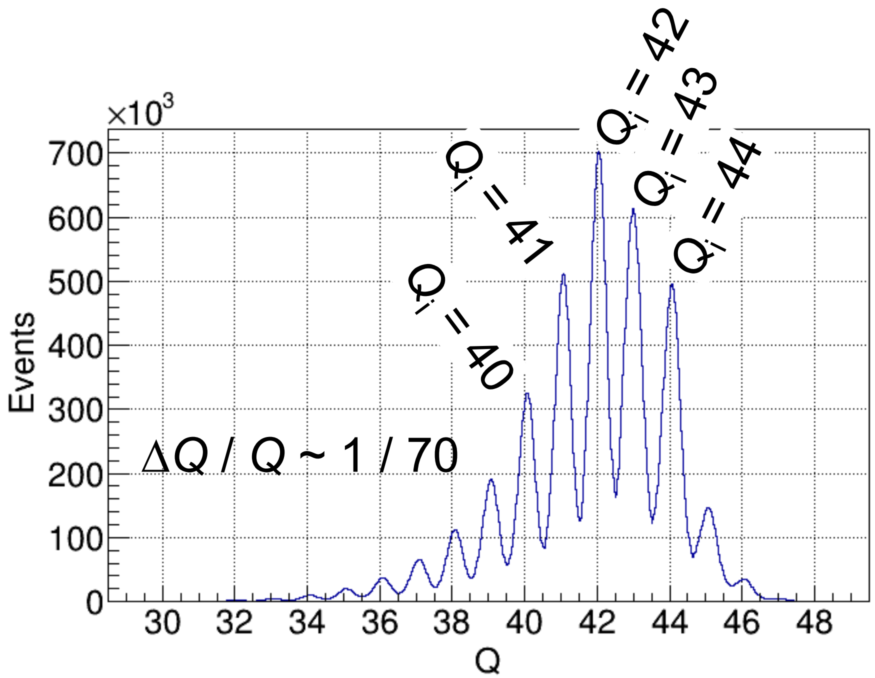
Energy loss

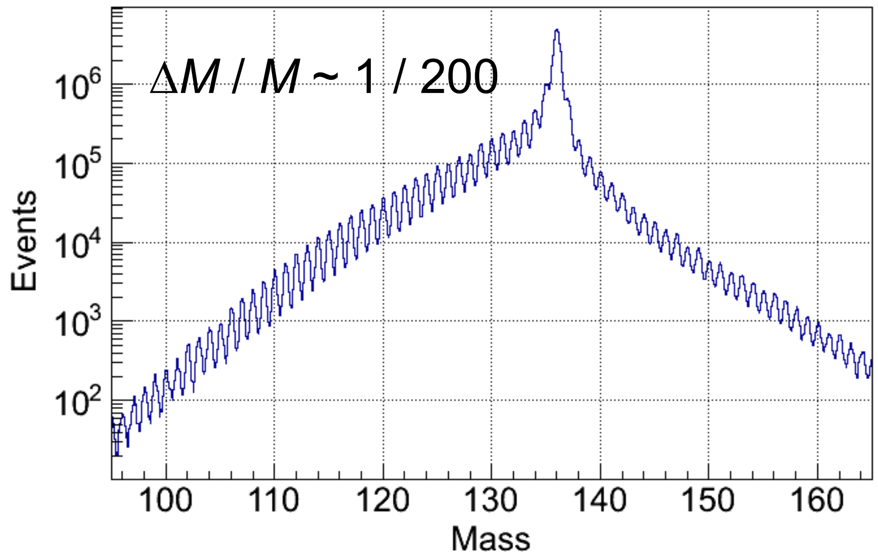
Total kinetic energy

⇨ Q, Mass, Z

Charge and mass distributions of PLF





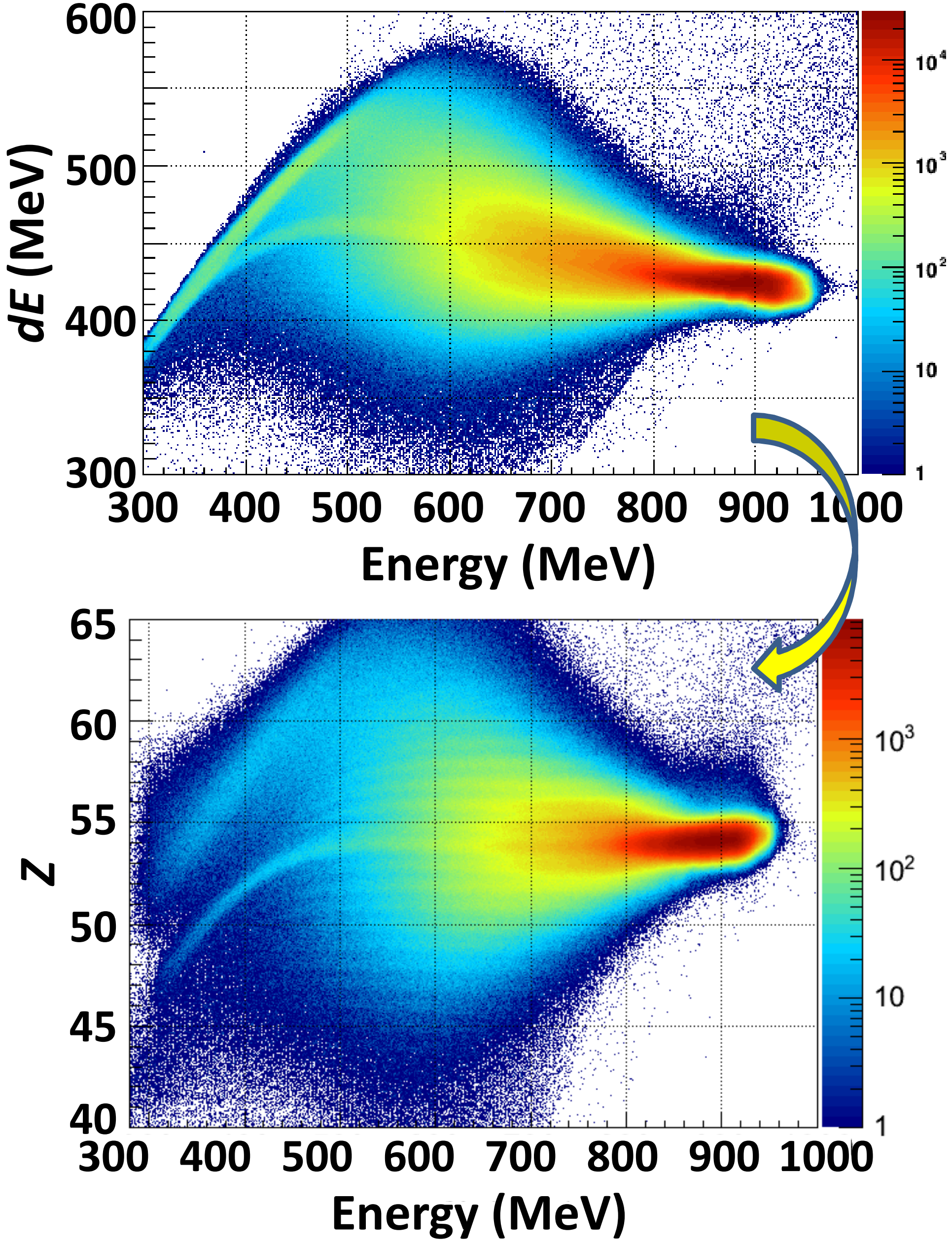


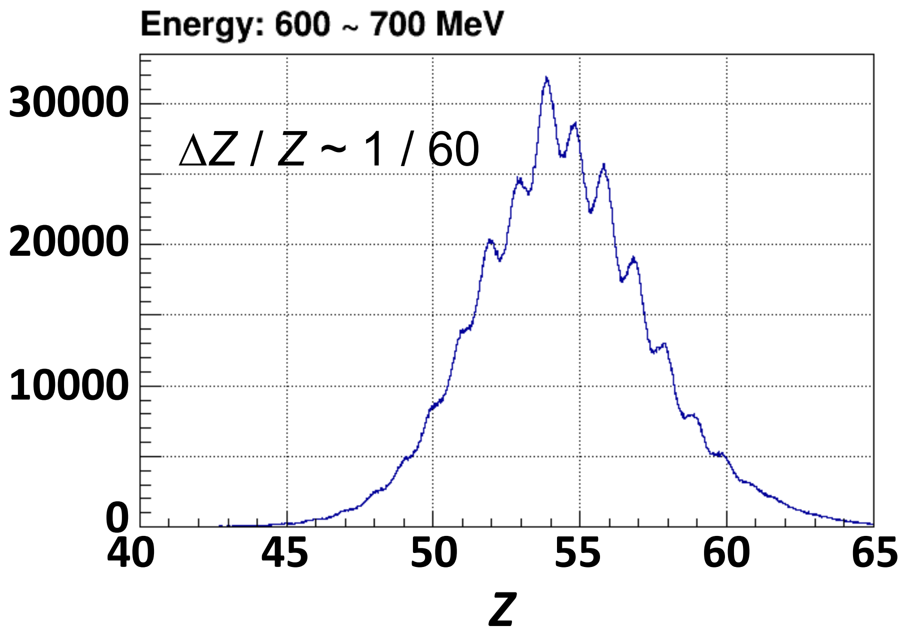
$$M / Q = B\rho / v$$

$$Q = 2\,E / B\rho\, v$$

$$M = Q_i \,\mathrm{M} / \mathrm{Q}$$

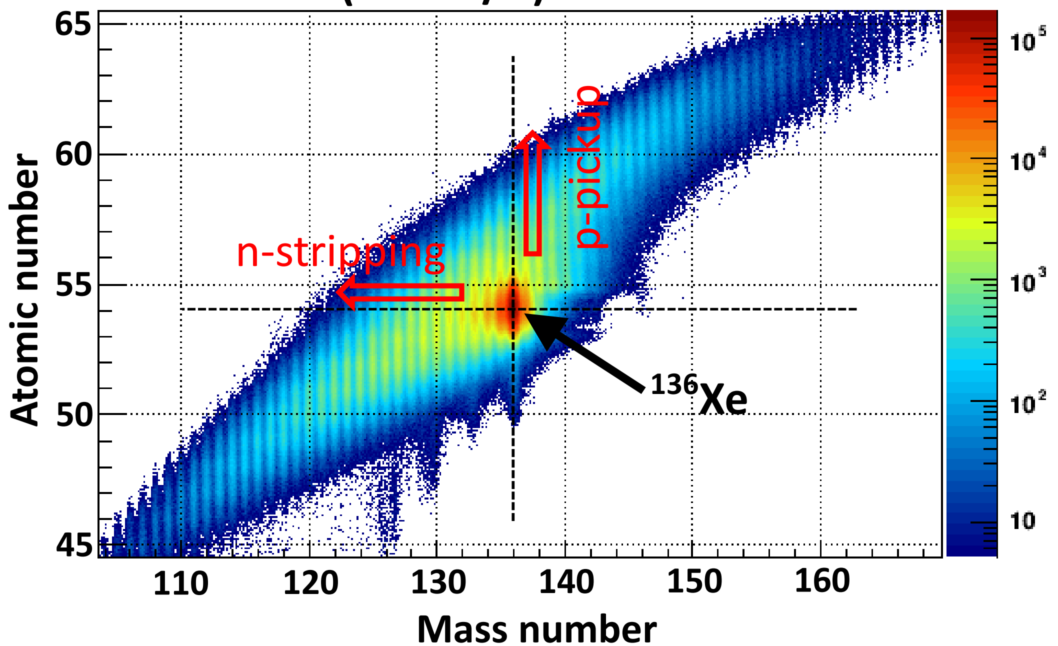
Z identification of PLF

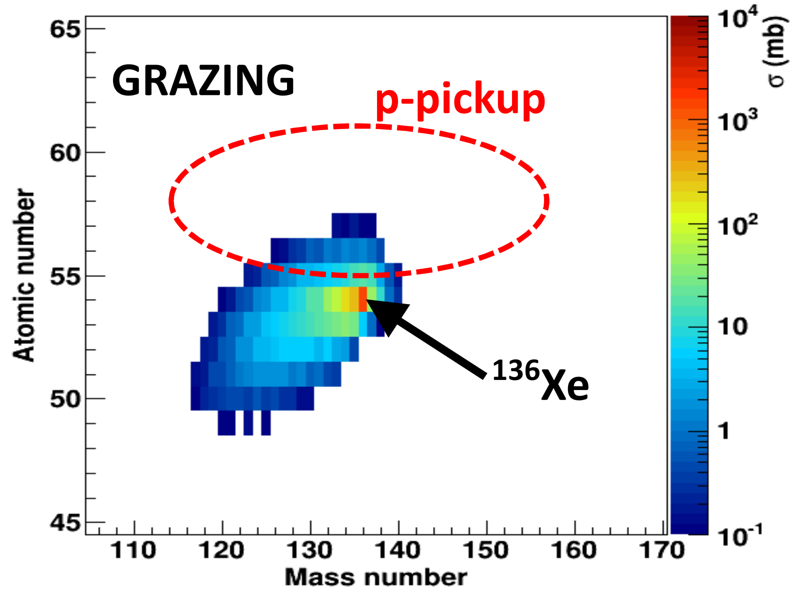




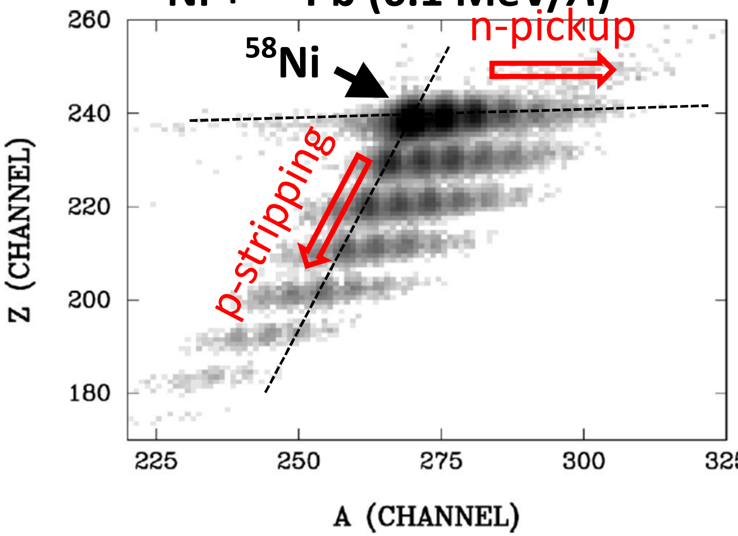
Z-A distribution of PLF

^{136}Xe + ^{198}Pt (8 MeV/*A*)





^{58}Ni + ^{208}Pb (6.1 MeV/*A*)

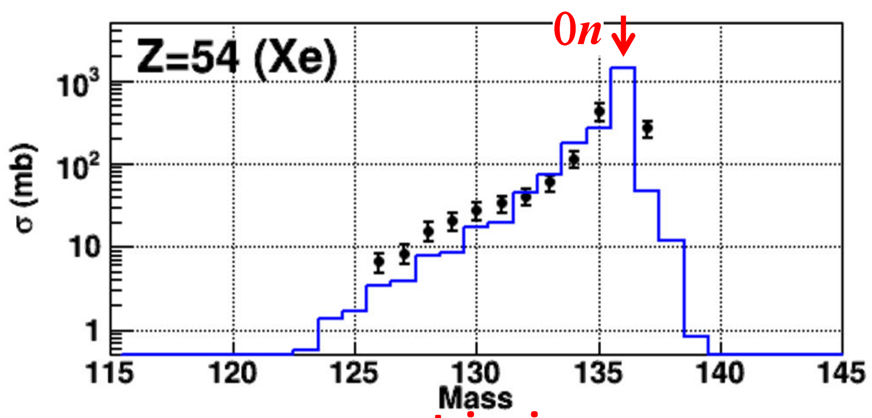


L. Corradi et al., Phys. Rev. C66 (2002), 024606

Contribution of p-pickup and n-stripping channels was observed.

c.f. n-pickup and p-stripping channels dominate in ^{58}Ni + ^{208}Pb.

Isotopic distributions of PLF (0, ±1p, ± 2p transfer)

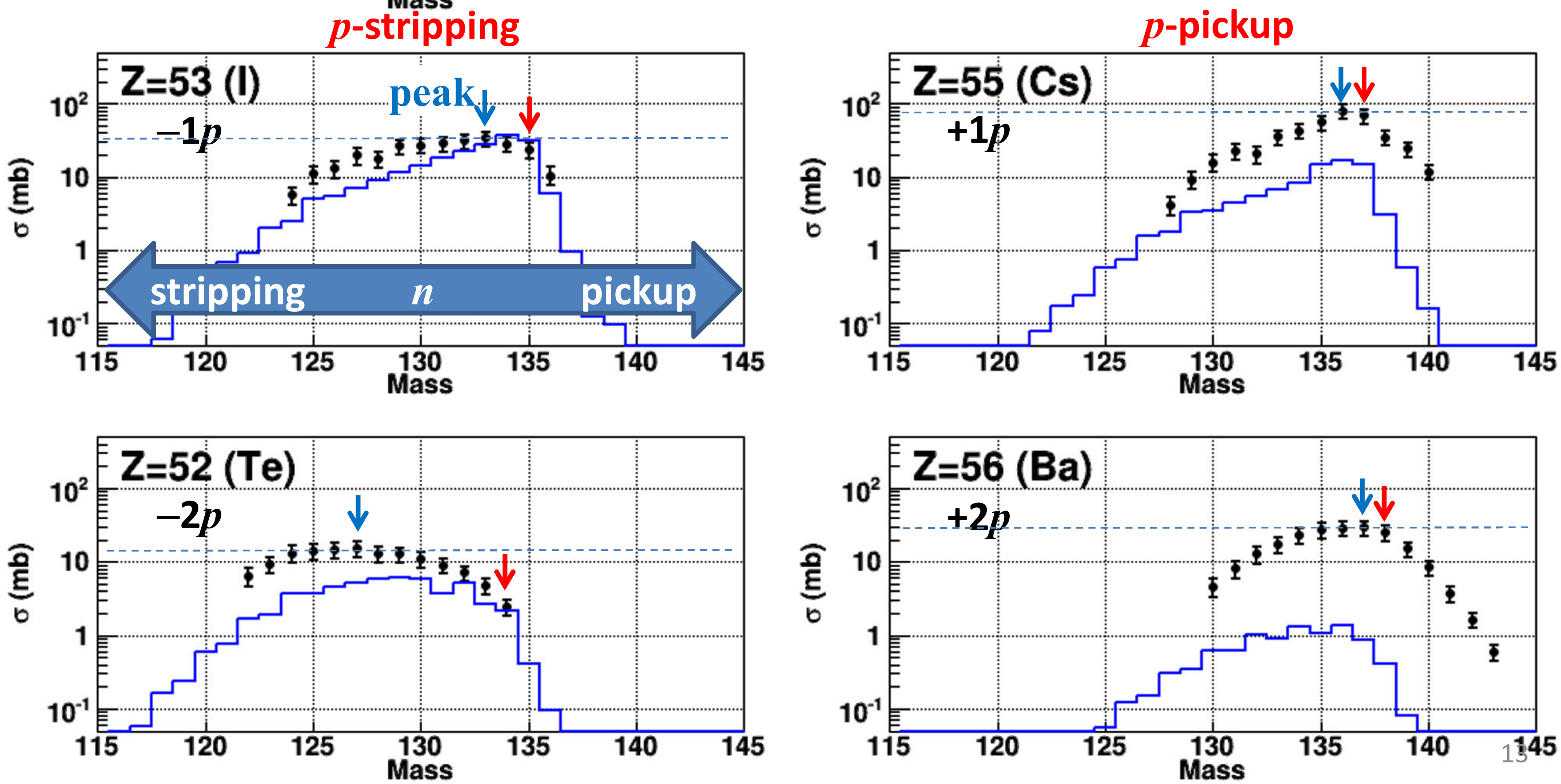


● Measurements

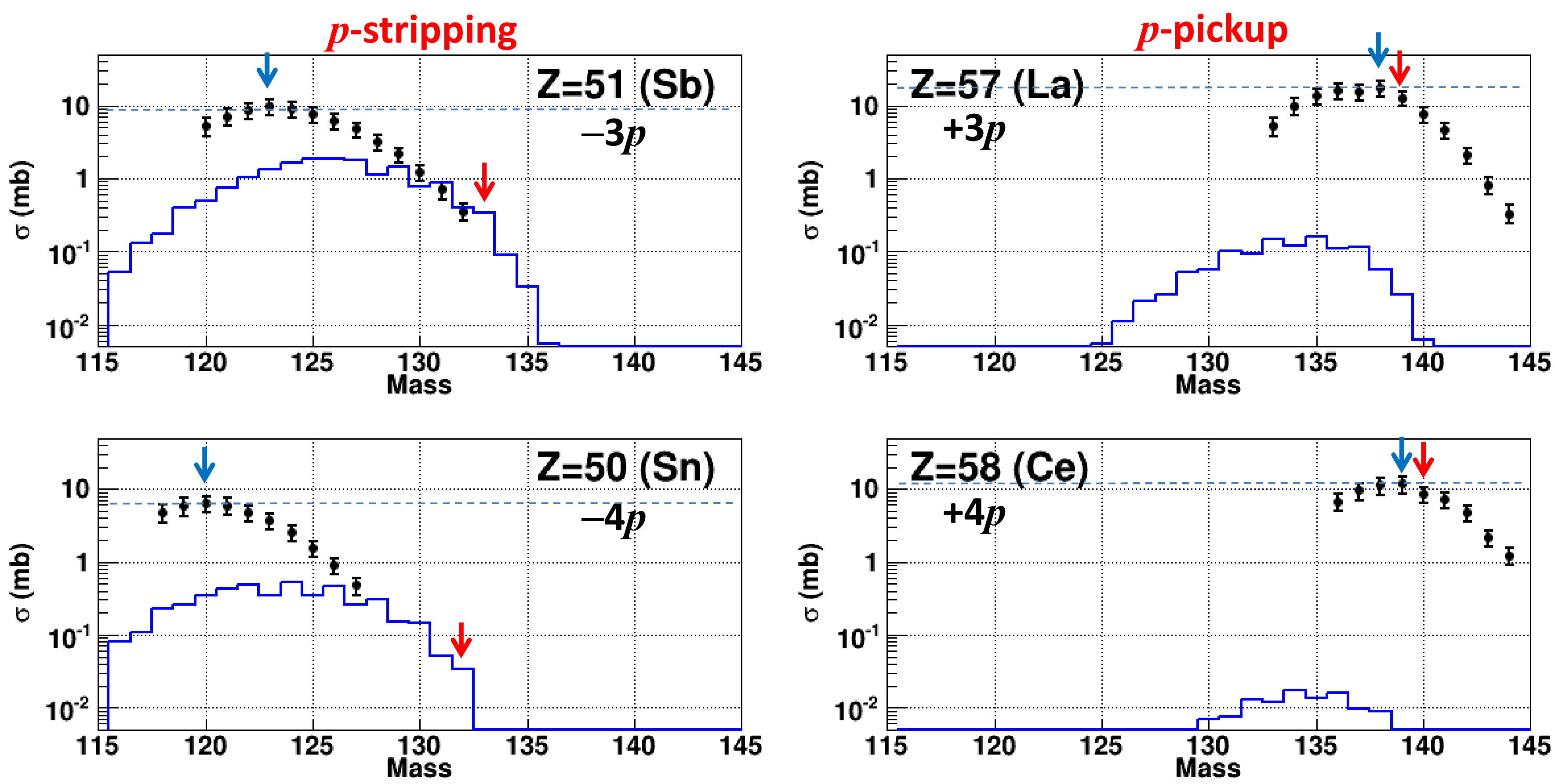
— GRAZING after evaporation

p-pickup: Larger cross section

p-stripping: Lighter distribution



Isotopic distributions of PLF (±3p, ± 4p transfer)



● Measurements

GRAZING after evaporation

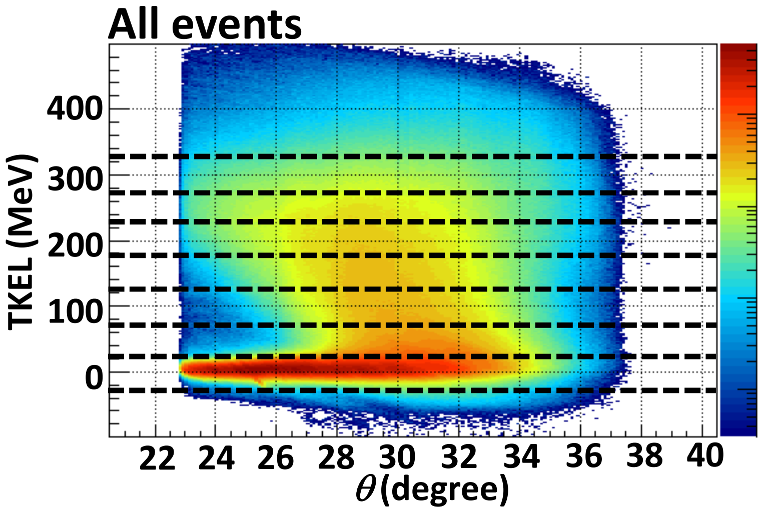
E_{lab} = 8 MeV/A

(55% higher than the Coulomb barrier)

Deep-inelastic components

Equilibrium of mass-to-charge ratio

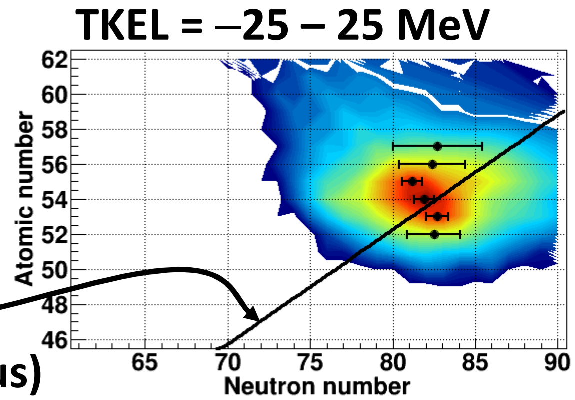
Z – N distribution of PLF for different TKEL

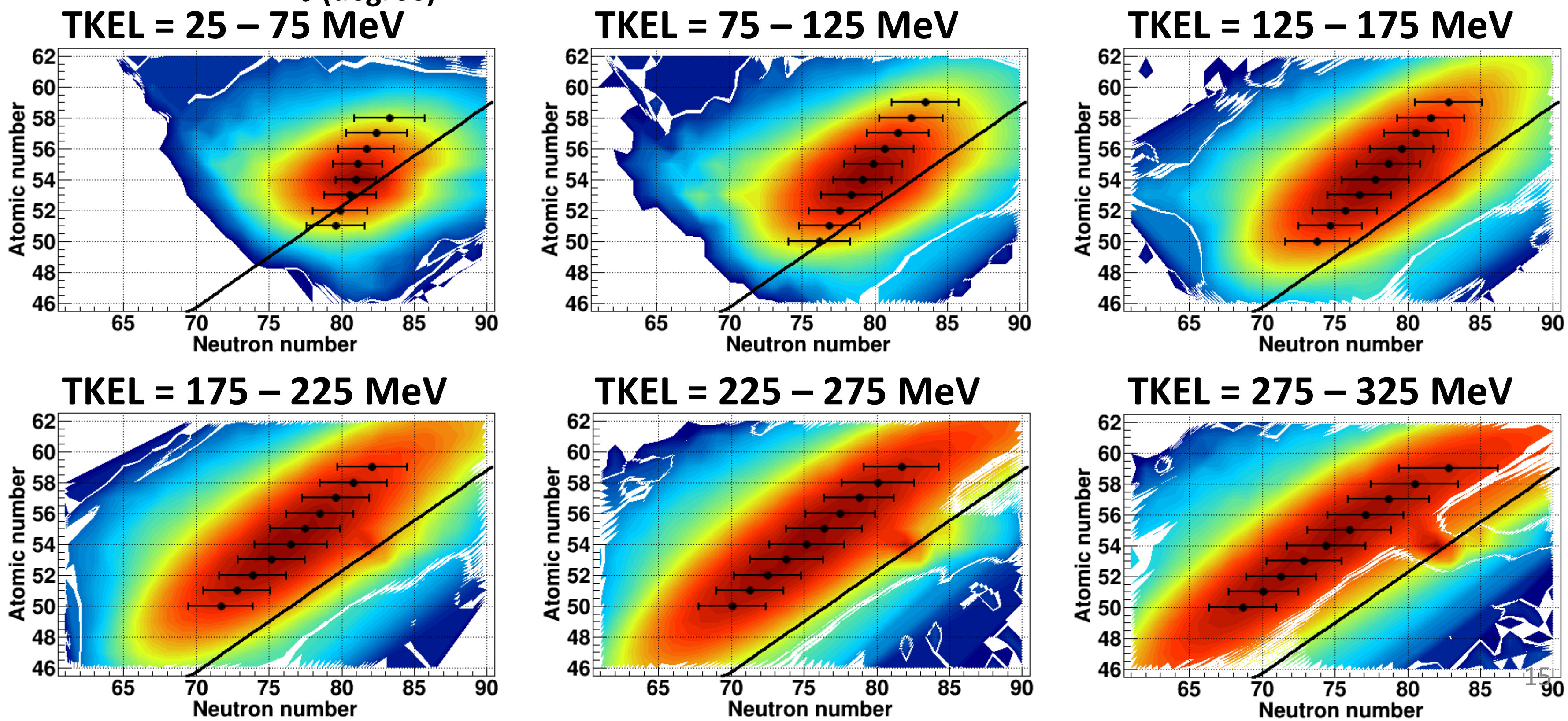


Pure binary kinematics was assumed

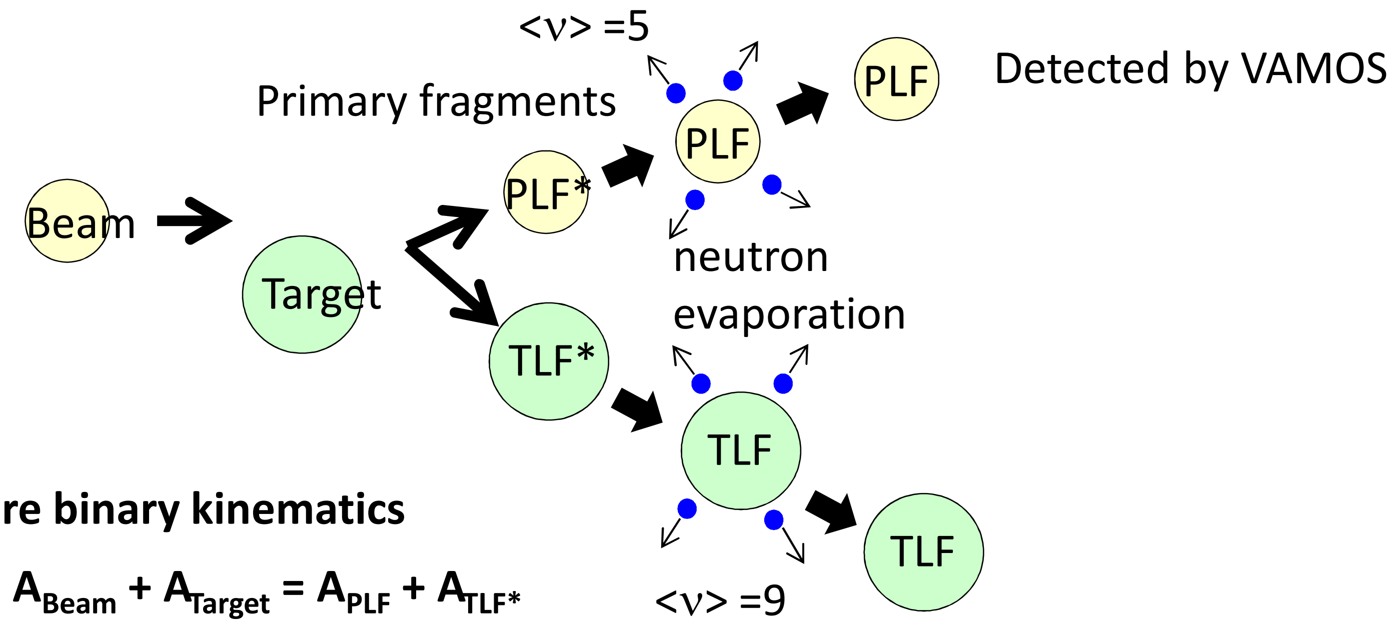
Evolution of Z-N distribution (50 MeV window)

***Z/N* equilibrium (compound nucleus)**





Evaluation of TLF distribution



Pure binary kinematics

$$A_{Beam} + A_{Target} = A_{PLF} + A_{TLF*}$$

$$Z_{Beam} + Z_{Target} = Z_{PLF} + Z_{TLF*}$$

Excitation energy sharing in mass ratio

$$TKEL = E^*_{TOT} - Q$$

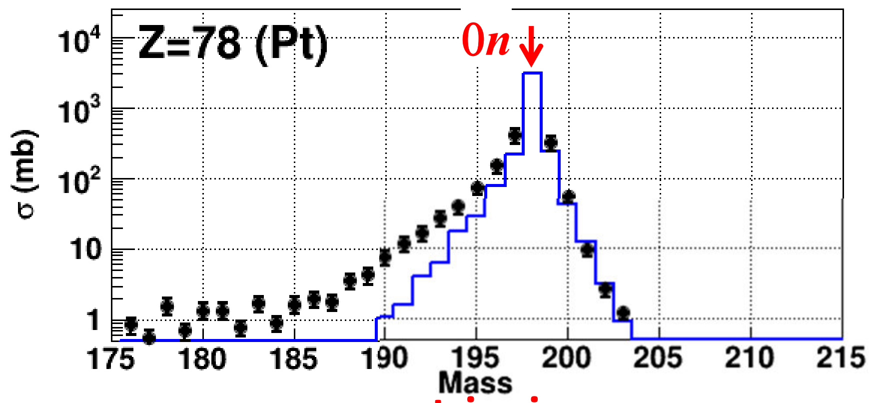
$$E^*_{PLF} = E^*_{TOT} \times M_{PLF} / (M_{PLF} + M_{TLF}^*)$$

⇨ ν_{PLF} ⇨ Primary PLF A ⇨ Primary TLF A

$$E^*_{TLF*} = E^*_{TOT} \times M_{TLF*} / (M_{PLF} + M_{TLF*})$$

⇨ ν_{TLF} ⇨ TLF A

Isotopic distributions of TLF (0, ±1p, ± 2p transfer)



● Measurements

— GRAZING after evaporation

p-pickup: Larger cross section

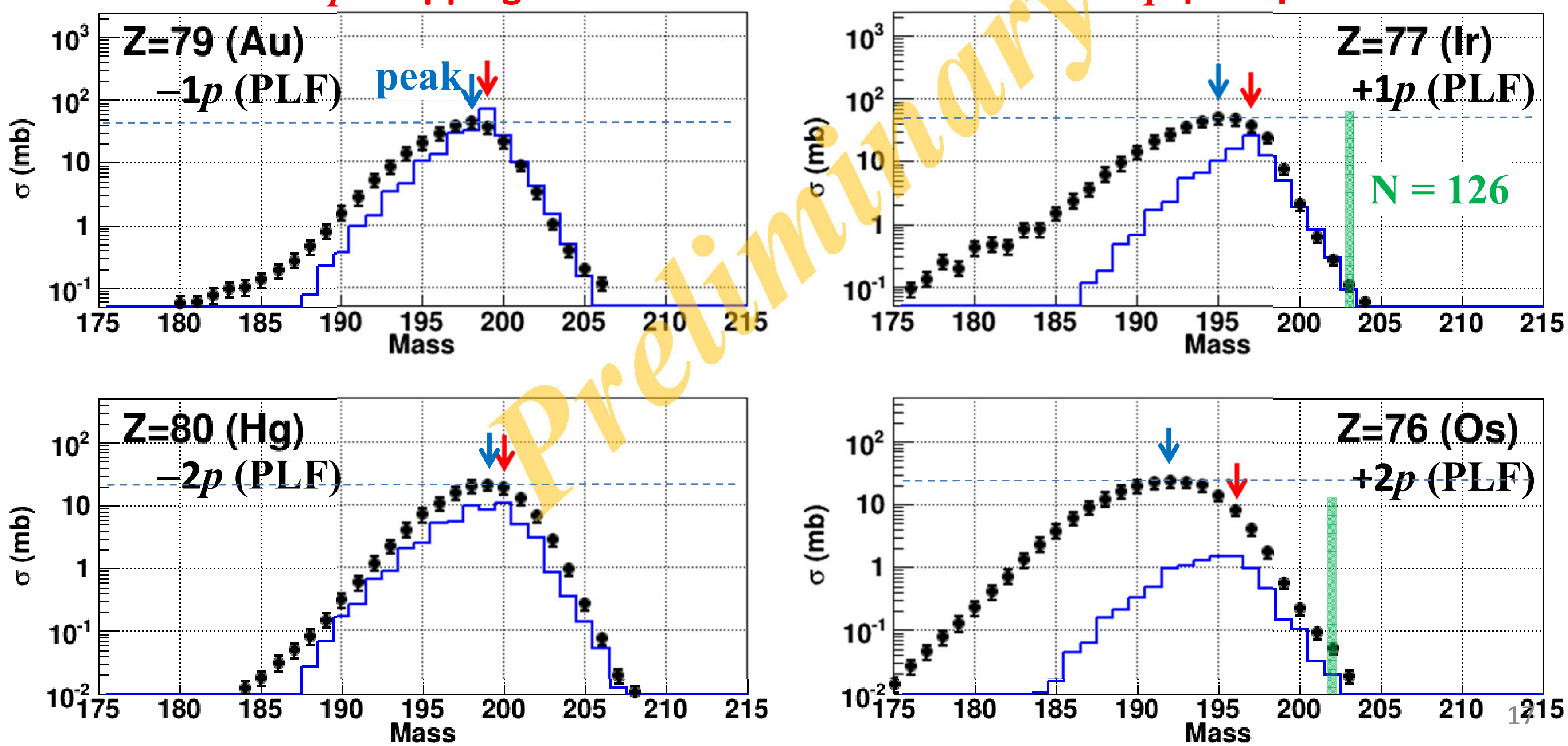
Lighter distribution

A/Z equilibrium & evaporation

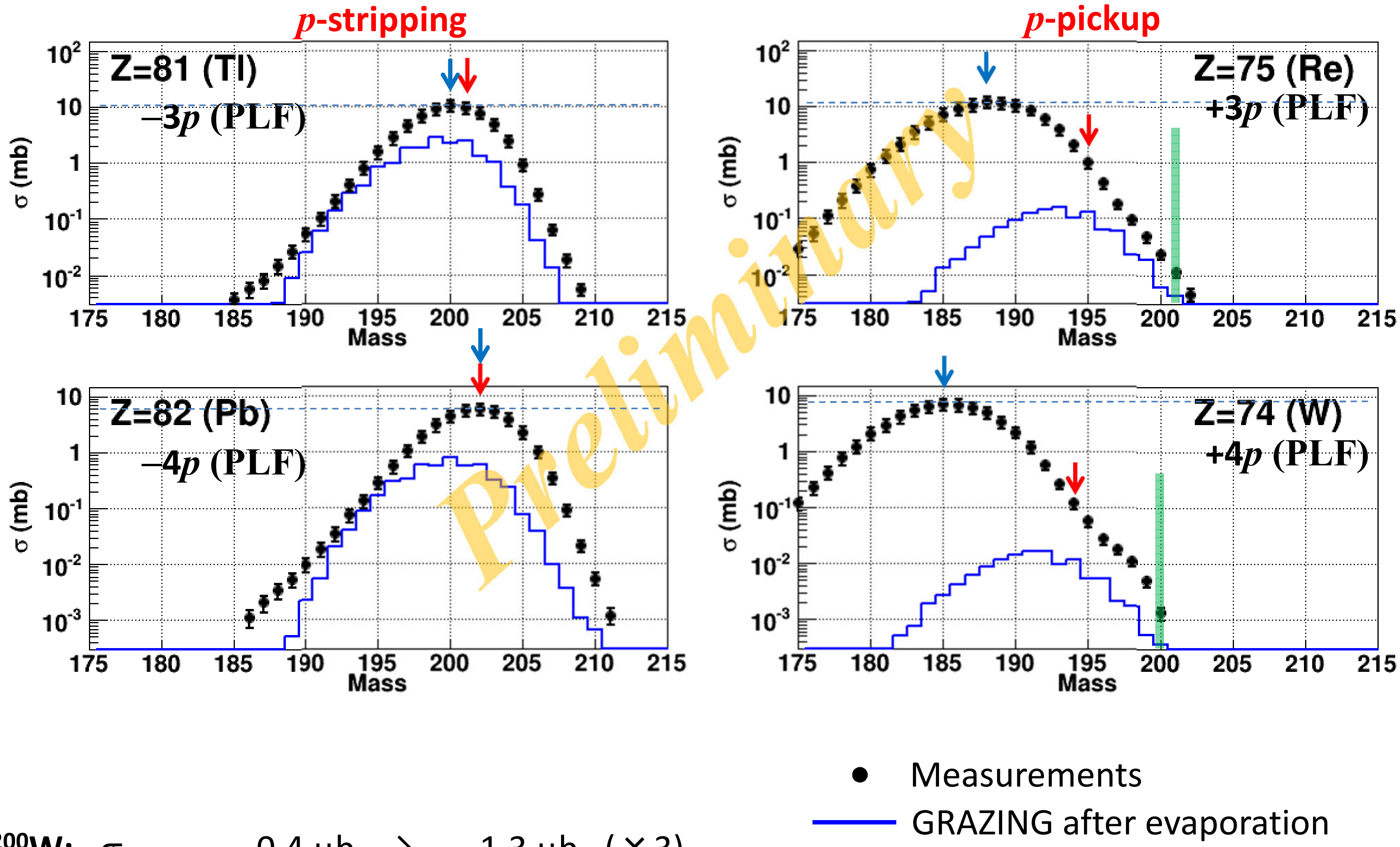
^{202}Os: $\sigma_{GRAZING} \sim 20\ \mu b \rightarrow \sim 50\ \mu b$ (×2.5)

p-stripping

p-pickup

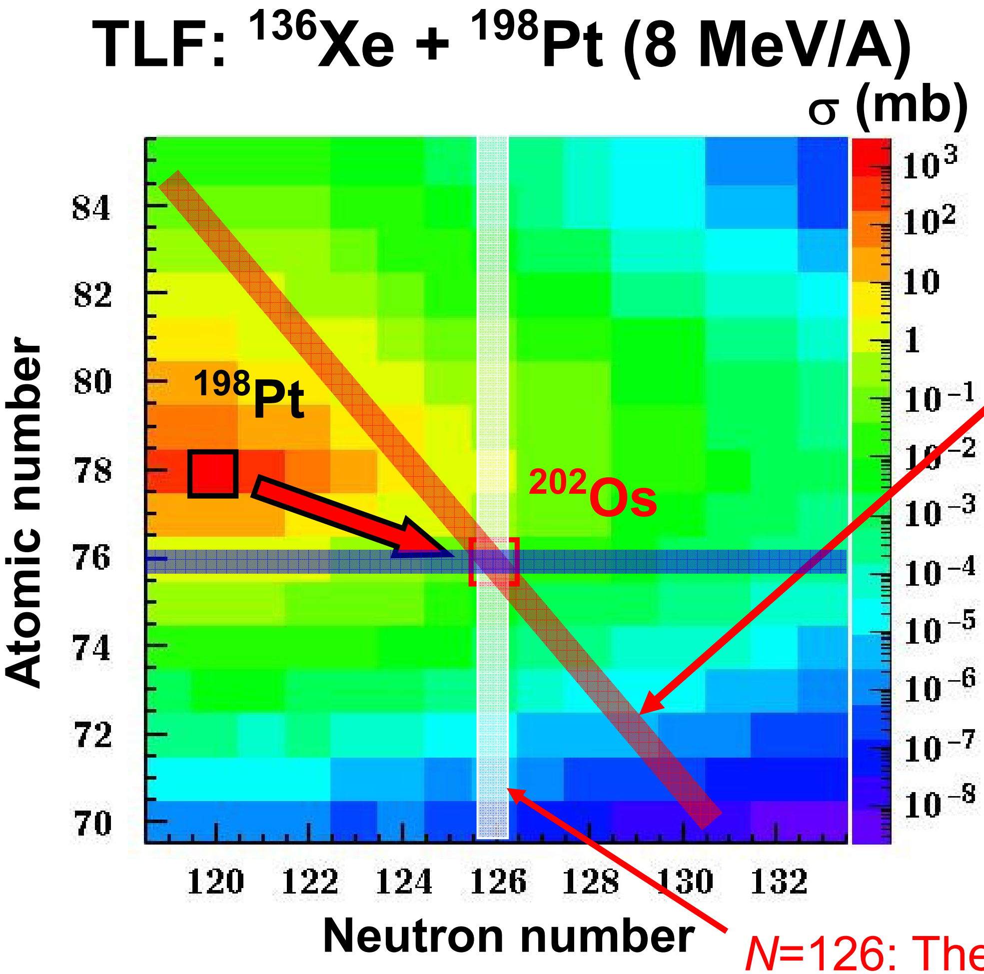


Isotopic distributions of TLF (±3p, ± 4p transfer)



^{200}**W:** $\sigma_{GRAZING} \sim 0.4\ \mu b \rightarrow \sim 1.3\ \mu b\ \ (\times 3)$

How to collect and separate MNT products?



^{136}Xe : 8 MeV/A, 10 pnA

^{198}Pt : 7.1 mg/cm^2

7.8 pps for ^{202}**Os**

0.11 pps for ^{200}**W**

Large contamination of isobars

^{202}Os ~ 0.2%

Contamination ~ 99.8%

➡ *Z* selection

Low and broad energies (< 1.5 MeV/A)

Large and broad emission angles (~60°)

➡ Efficient collection

N=126: The production channels are rare channels

- Efficient collection
- Separation of Z and A

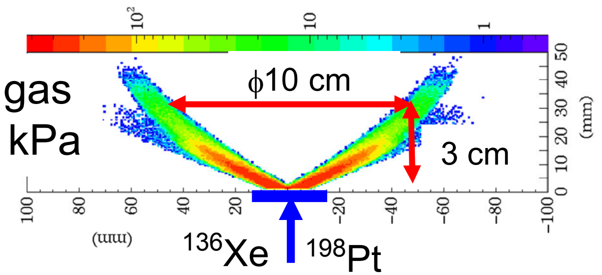
➡ Laser ion-source with argon gas-cell

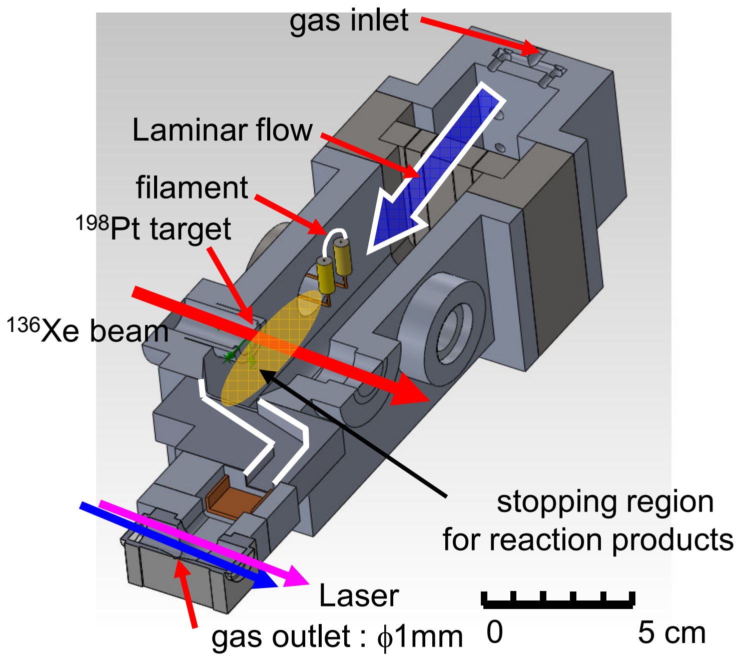
What is KISS

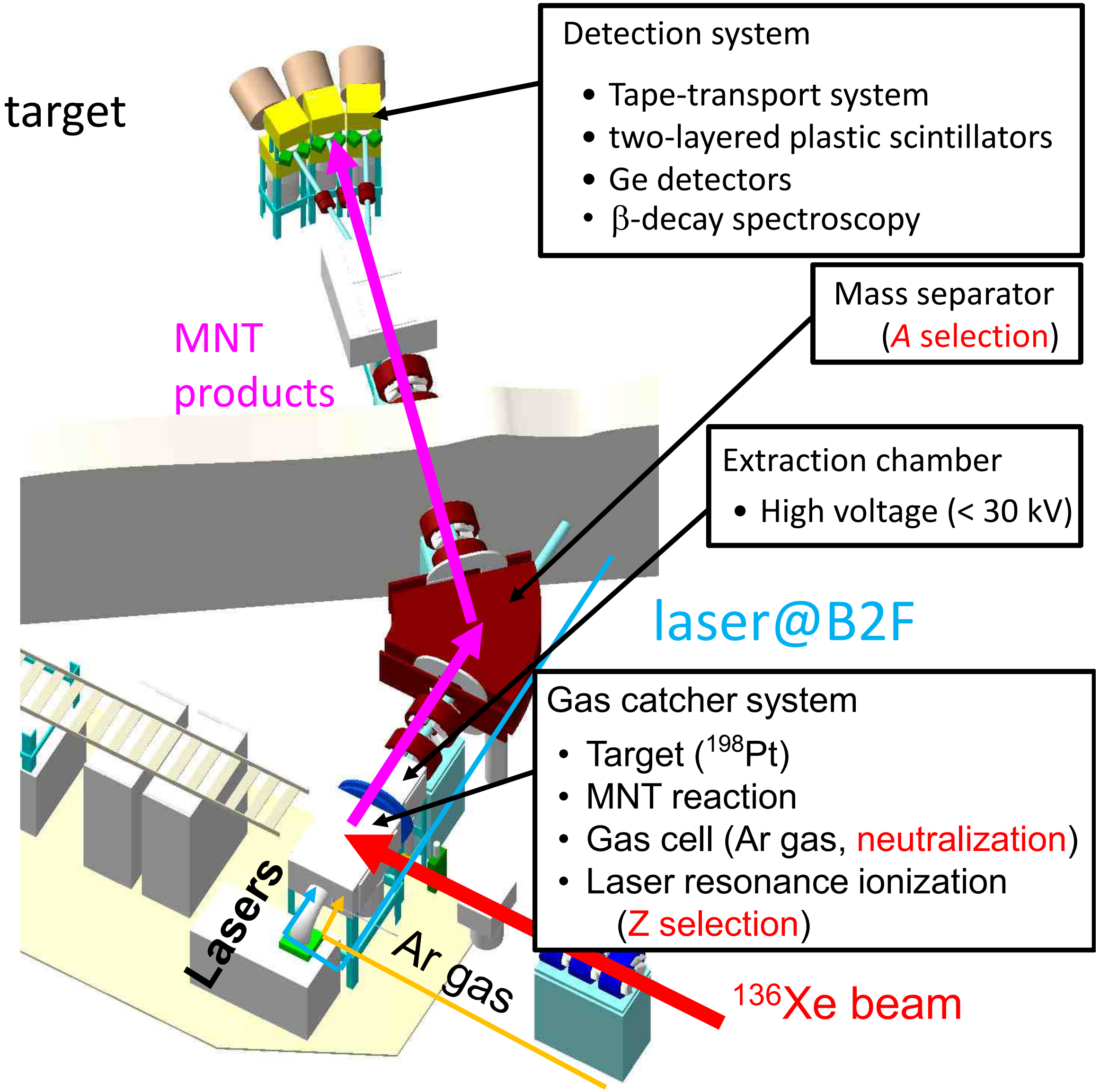
The KISS is designed for **simultaneous separation of mass (A) and element (Z)** of products by MNT reactions in heavy nuclear system with **a high collective efficiency**.

KISS (KEK Isotope Separation System) @ RIKEN

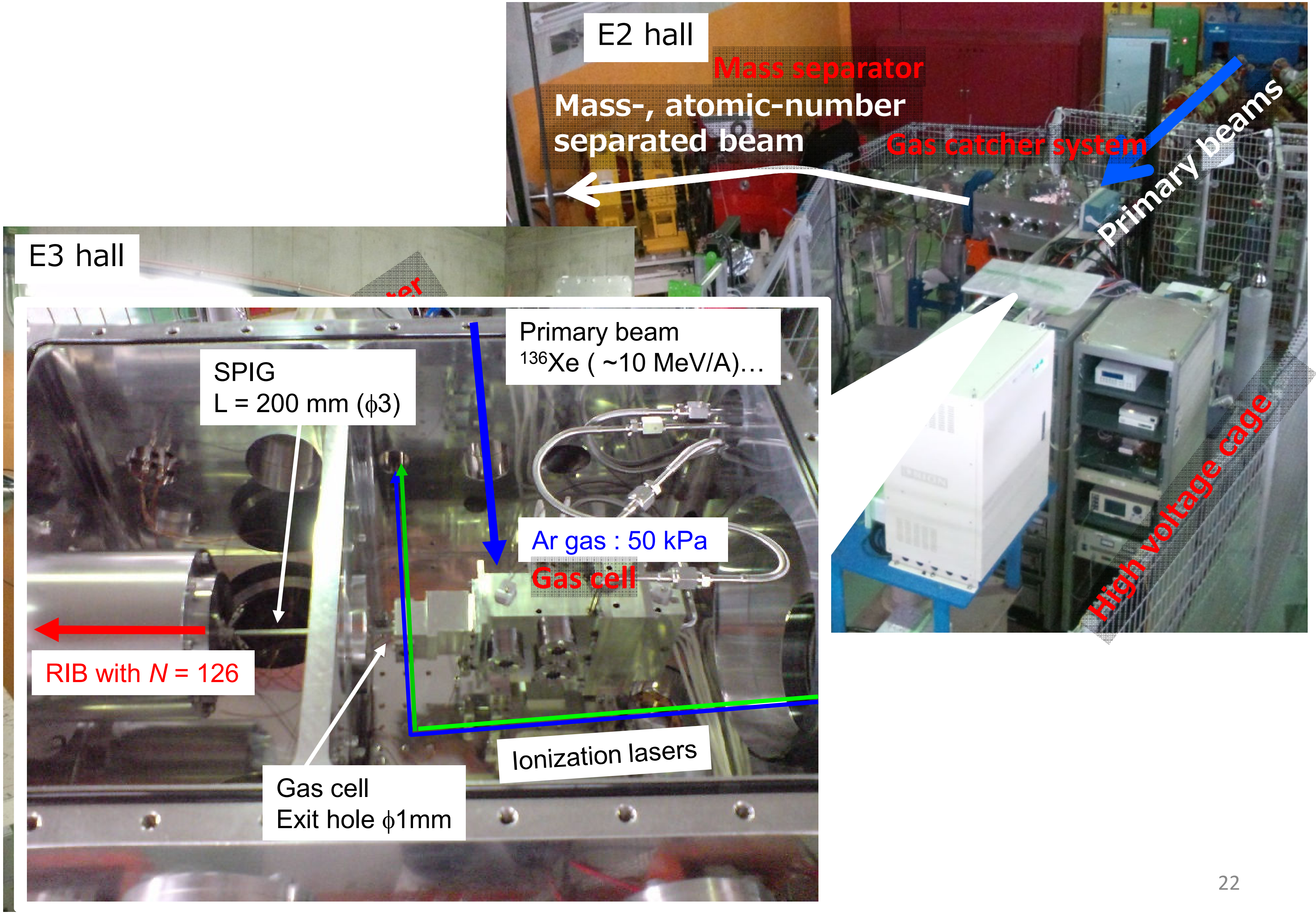
MNT reaction: ^{136}Xe beam + ^{198}Pt target



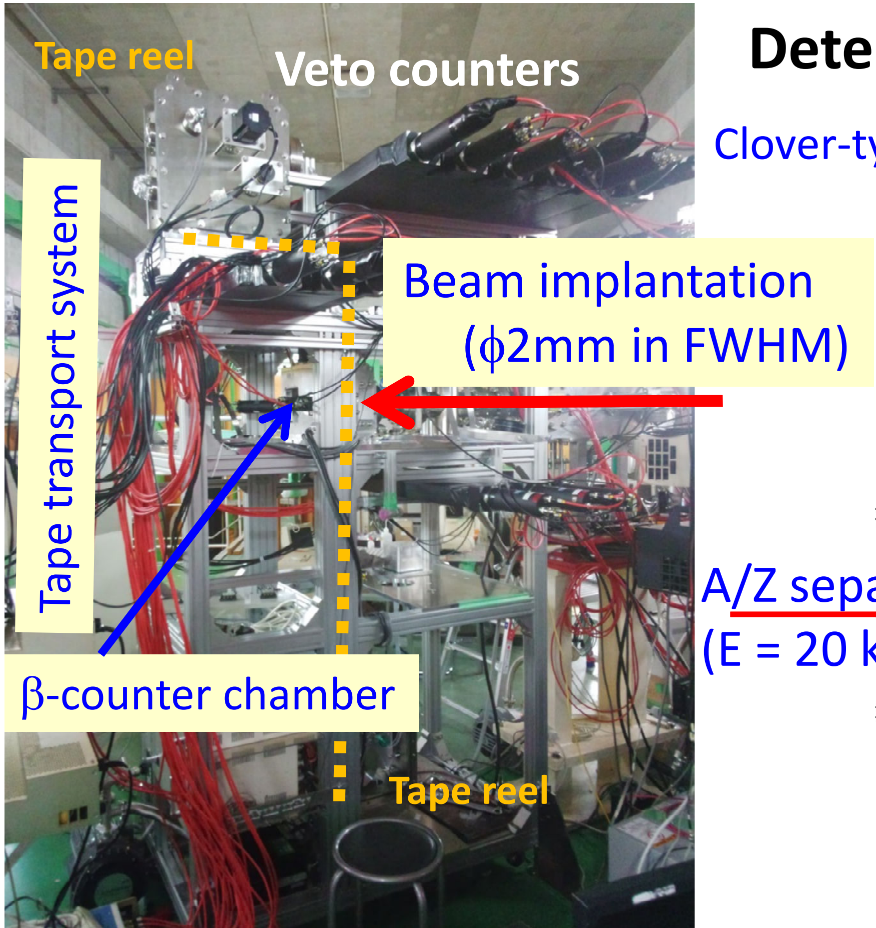


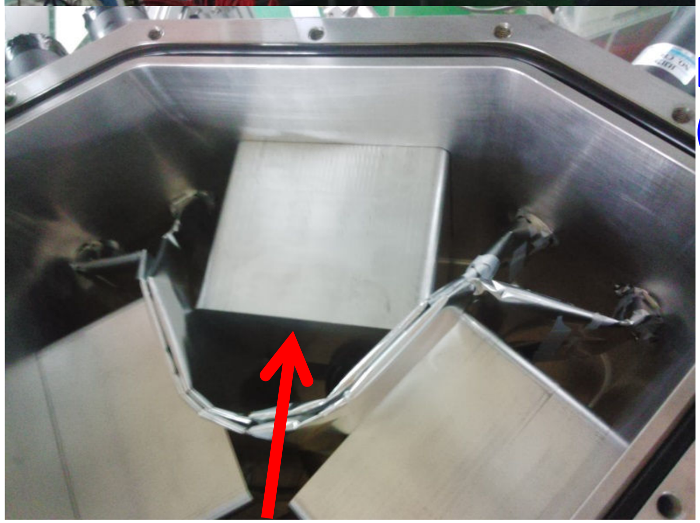


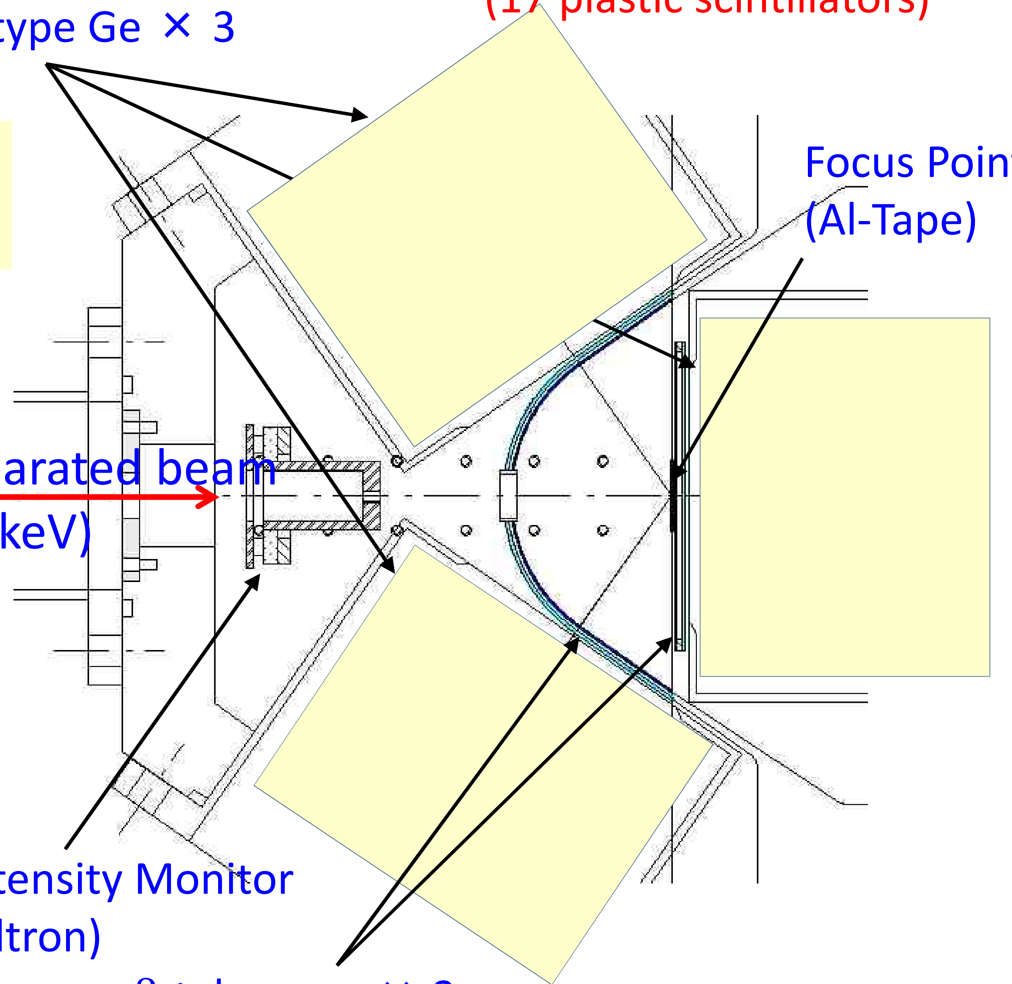
KISS setup


E2 hall
Mass separator
Mass-, atomic-number
separated beam
Gas catcher system
Primary beams
High voltage cage
E3 hall
SPIG
L = 200 mm (ϕ3)
Primary beam
^{136}Xe (~10 MeV/A)…
Ar gas : 50 kPa
Gas cell
RIB with N = 126
Gas cell
Exit hole ϕ1mm
Ionization lasers

Detector system







β-telescope × 3

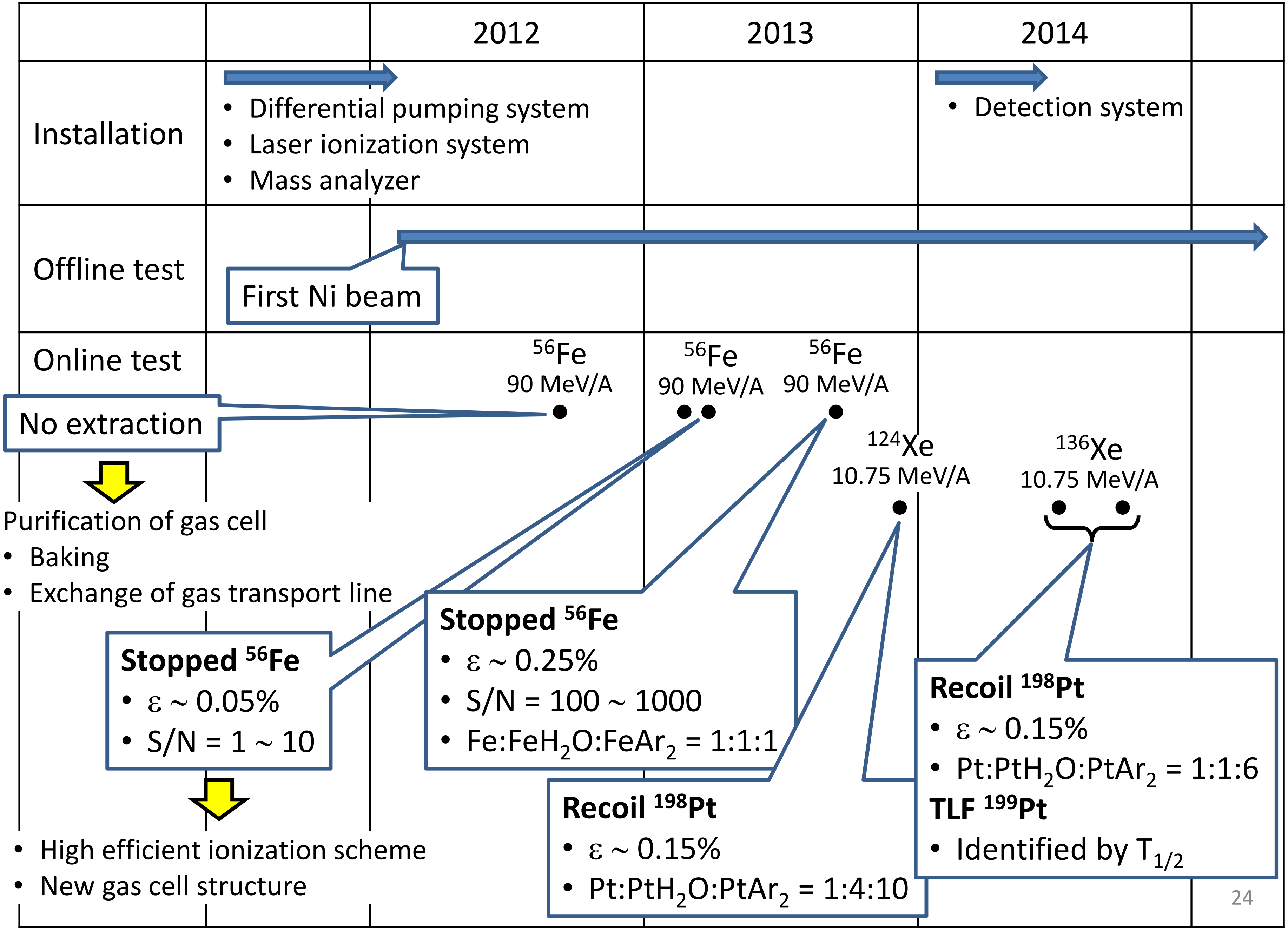
ΔE (0.5 mm^t) – E (1 mm^t) Plastic scintilltor

(ΔΩ ~ 90%, ΔE_{th} ~ 20 keVee, E_{th} ~ 70 keVee)

ε_β ~ 46% (Q_β ~ 2 MeV)

Background Rate (telescope) ~ 1.1 cps

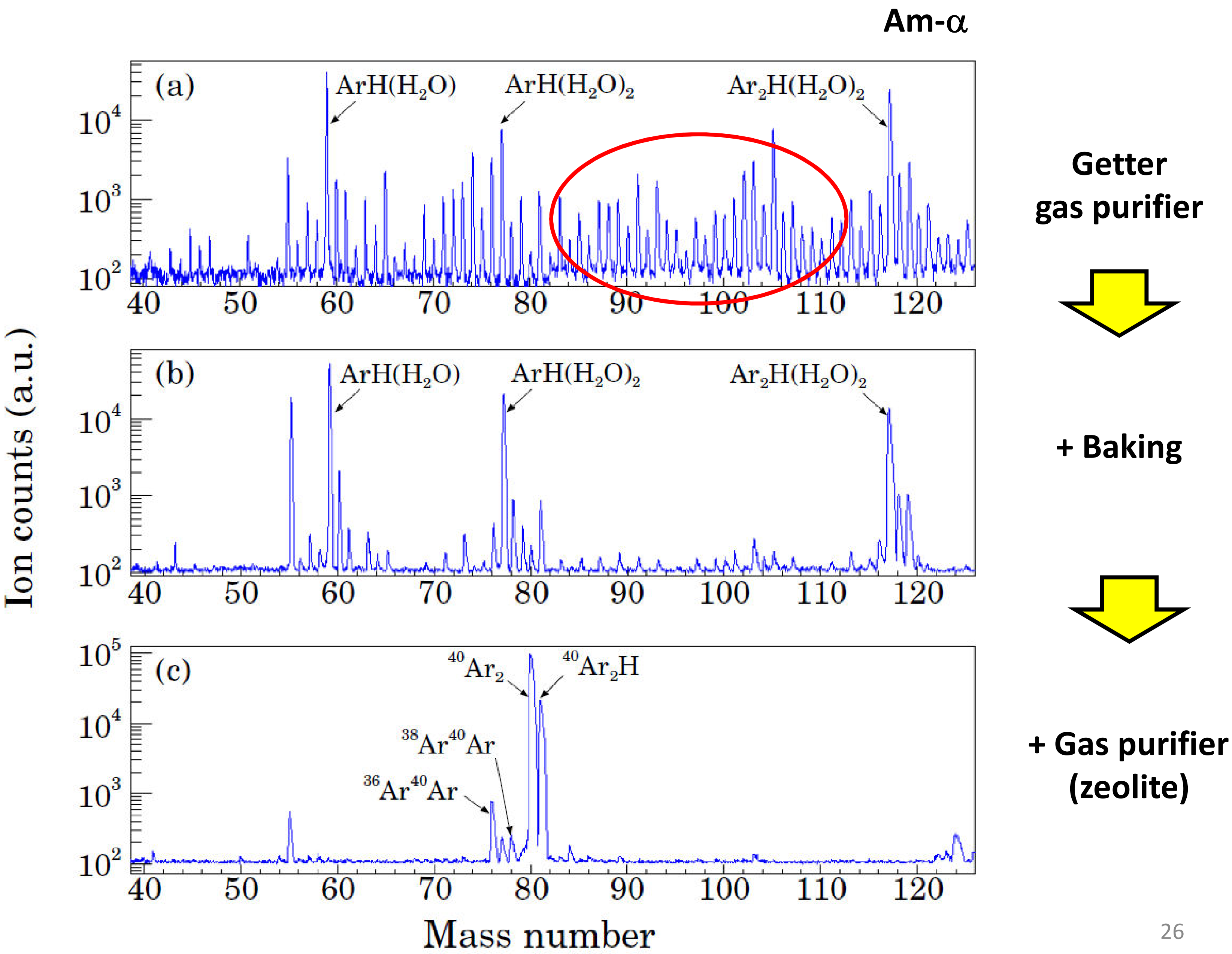
R&D History


2012
2013
2014
Installation
Differential pumping system
Laser ionization system
Mass analyzer
Detection system
Offline test
First Ni beam
Online test
56Fe 90 MeV/A
56Fe 90 MeV/A
56Fe 90 MeV/A
124Xe 10.75 MeV/A
136Xe 10.75 MeV/A
No extraction
Purification of gas cell
• Baking
• Exchange of gas transport line
Stopped 56Fe
• ε ~ 0.05%
• S/N = 1 ~ 10
• High efficient ionization scheme
• New gas cell structure
Stopped 56Fe
• ε ~ 0.25%
• S/N = 100 ~ 1000
• Fe:FeH2O:FeAr2 = 1:1:1
Recoil 198Pt
• ε ~ 0.15%
• Pt:PtH2O:PtAr2 = 1:4:10
Recoil 198Pt
• ε ~ 0.15%
• Pt:PtH2O:PtAr2 = 1:1:6
TLF 199Pt
• Identified by T1/2

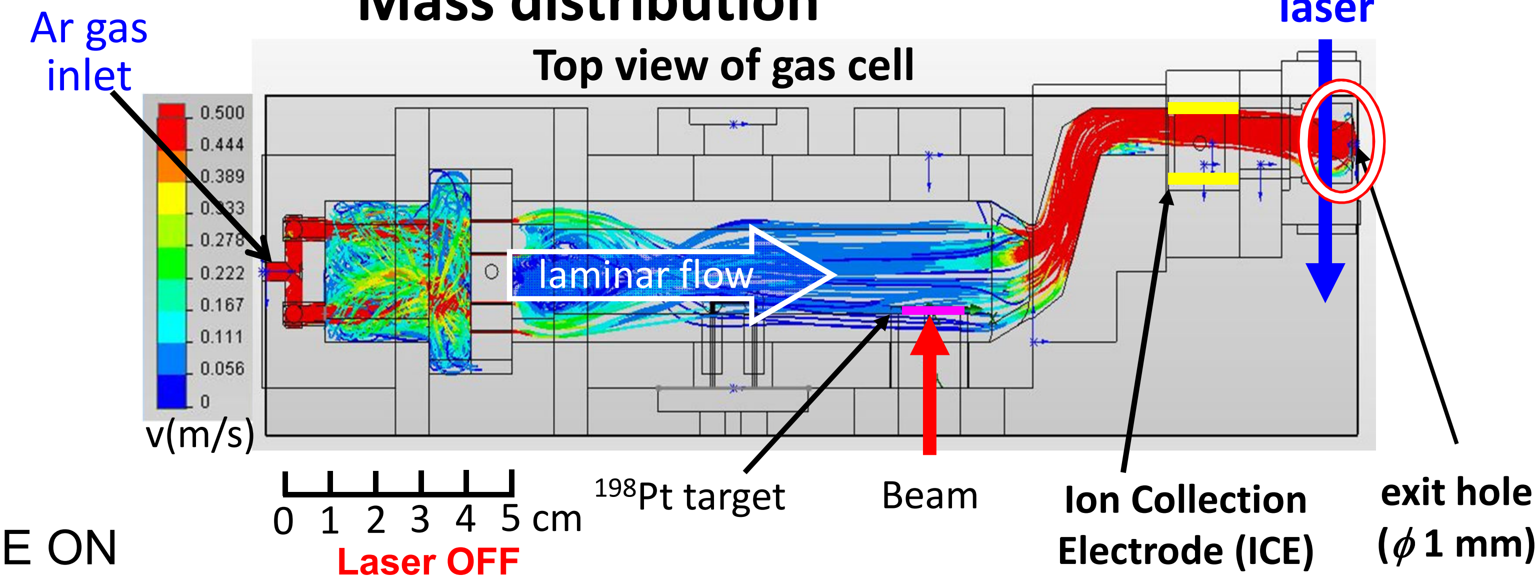
Off- and on-line test results

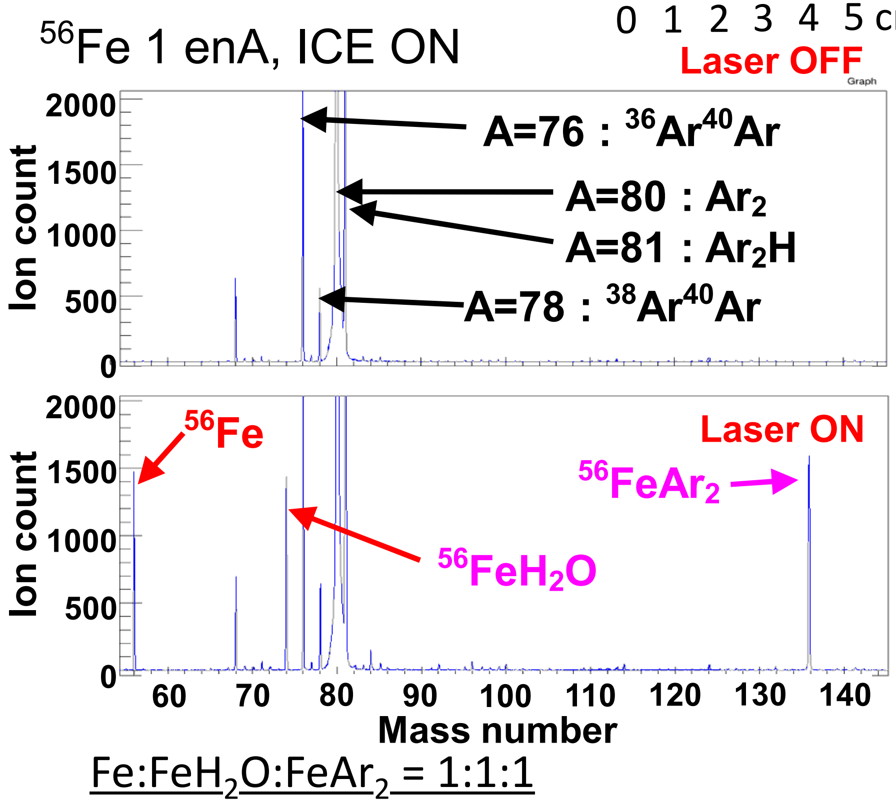
- Gas cell purity
- Extraction time
- Extraction efficiency
- Signal-to-noise ratio (Beam purity)

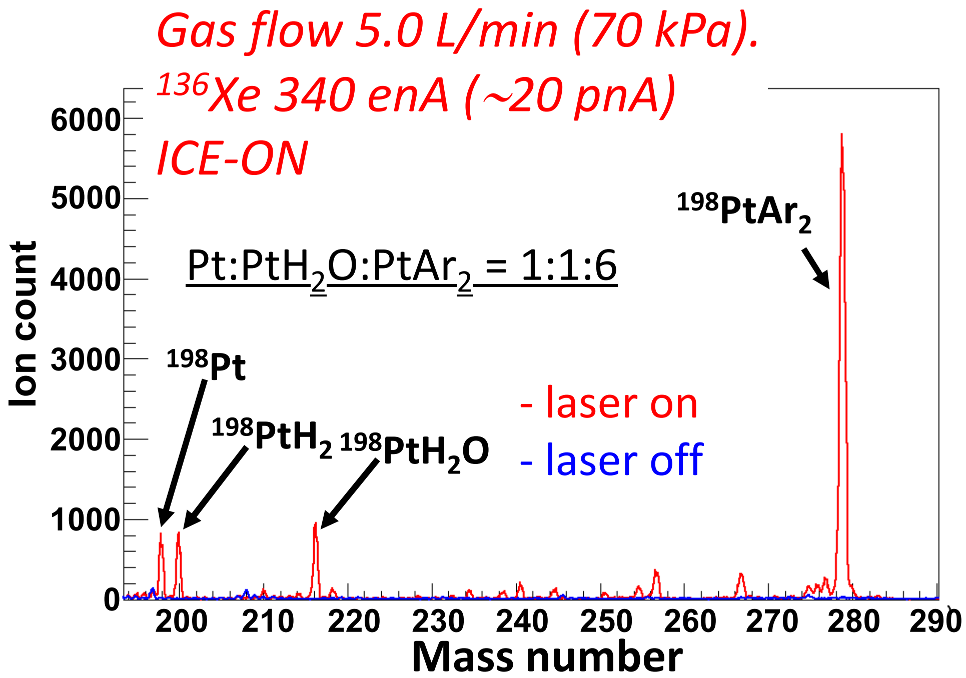
Gas cell purity



Mass distribution

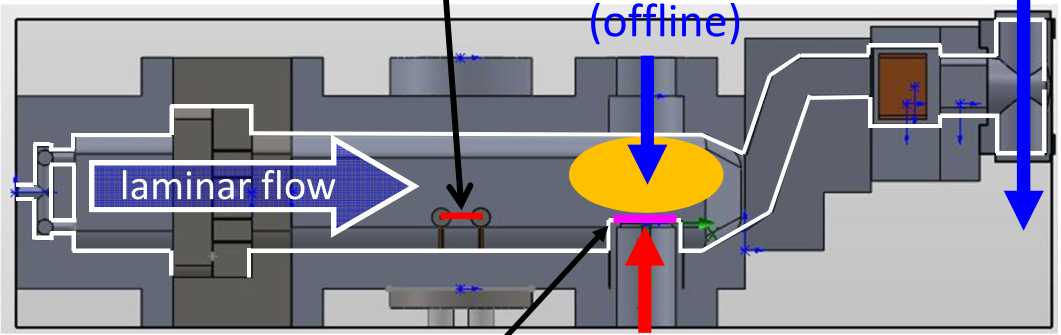






Stating from single Fe^{1+}, Pt^{1+} ions (laser ionized), molecules are formed in ~10 ms !!!

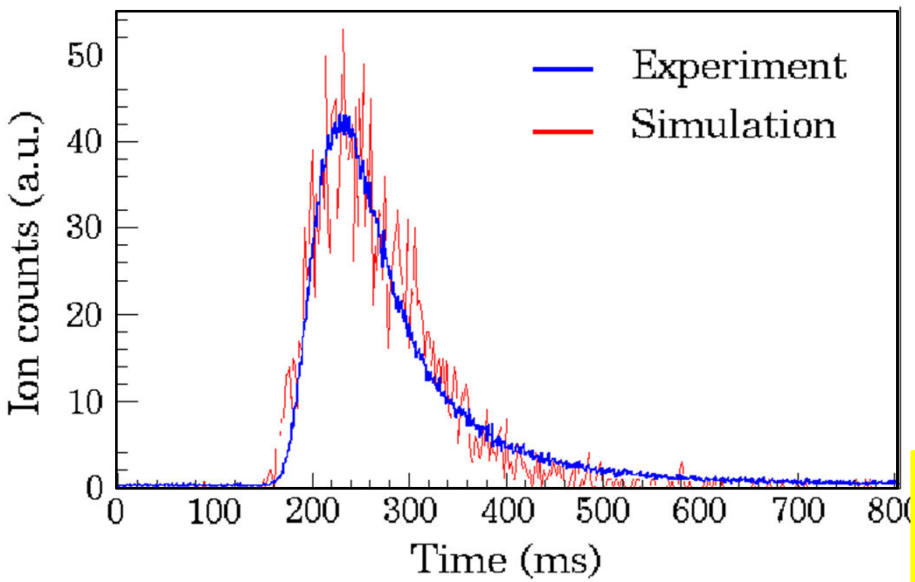
Extraction time profile

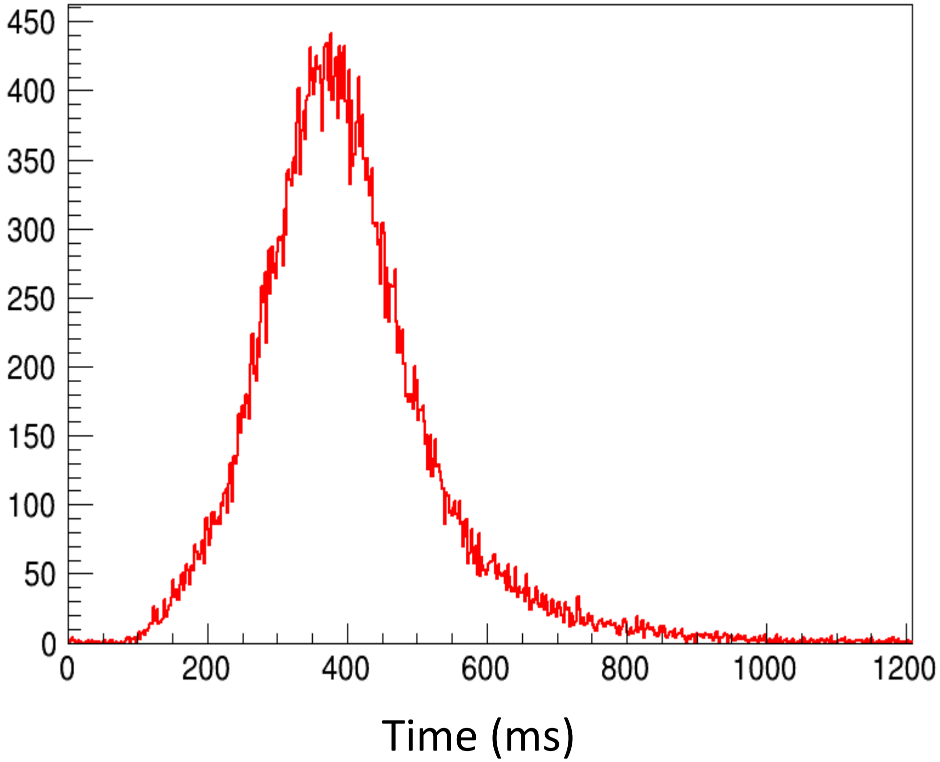


$^{193}IrAr_2{}^{1+}$: 300 ms (off-line)
$^{198}PtAr_2{}^{1+}$: 370 ms (on-line)

Time profile of ^{56}Fe beam :
230 ms (off-line)
270 ms (on-line)

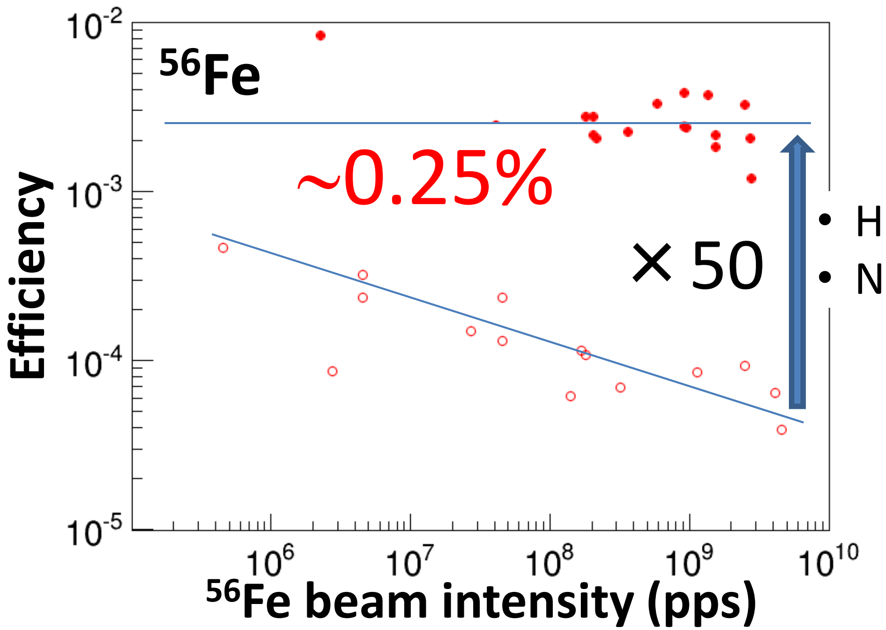
t=0, Single
laser shot



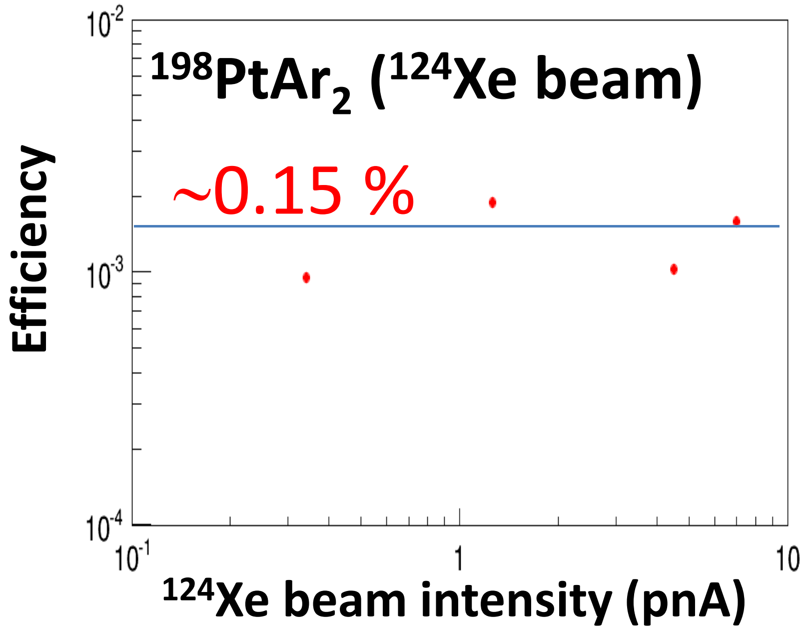


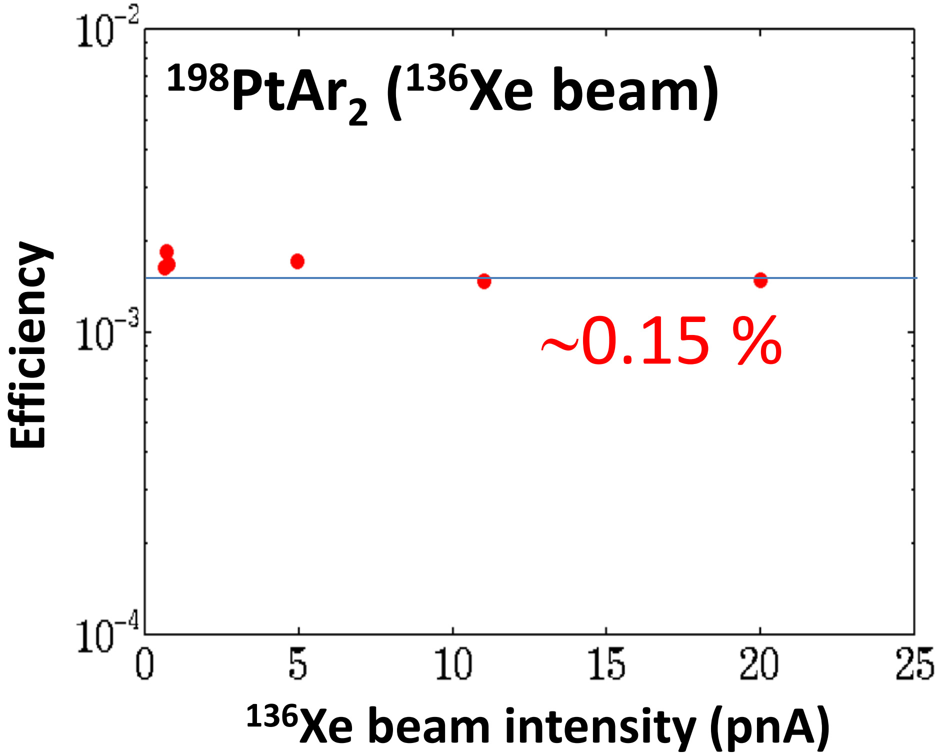
Factor ~1.5 slower than the flow simulation
However, possible to extract ^{200}W ($T_{1/2}$~500 ms)

Extraction efficiency



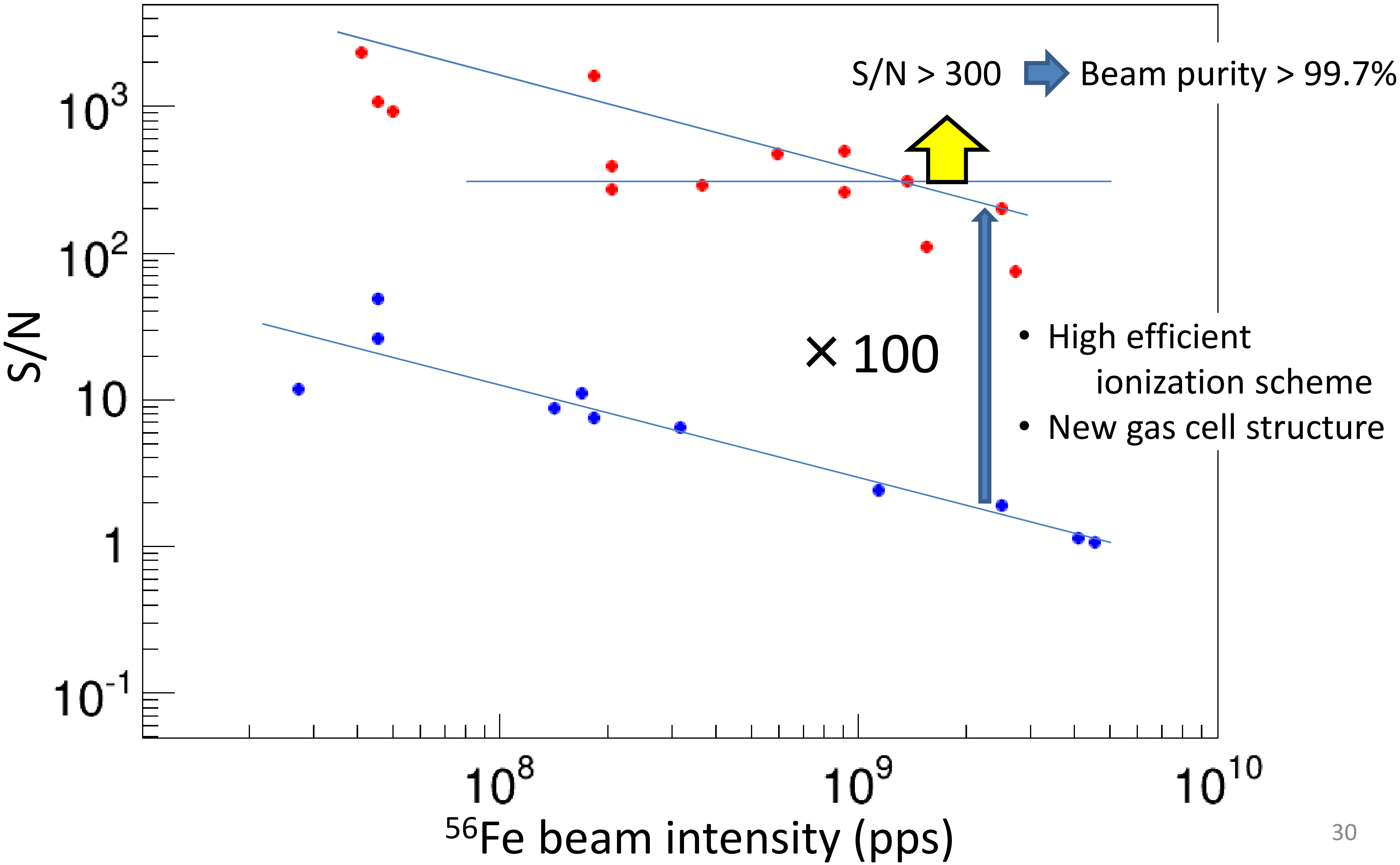
- High efficient ionization scheme
- New gas cell structure





Signal-to-noise ratio (Beam purity)

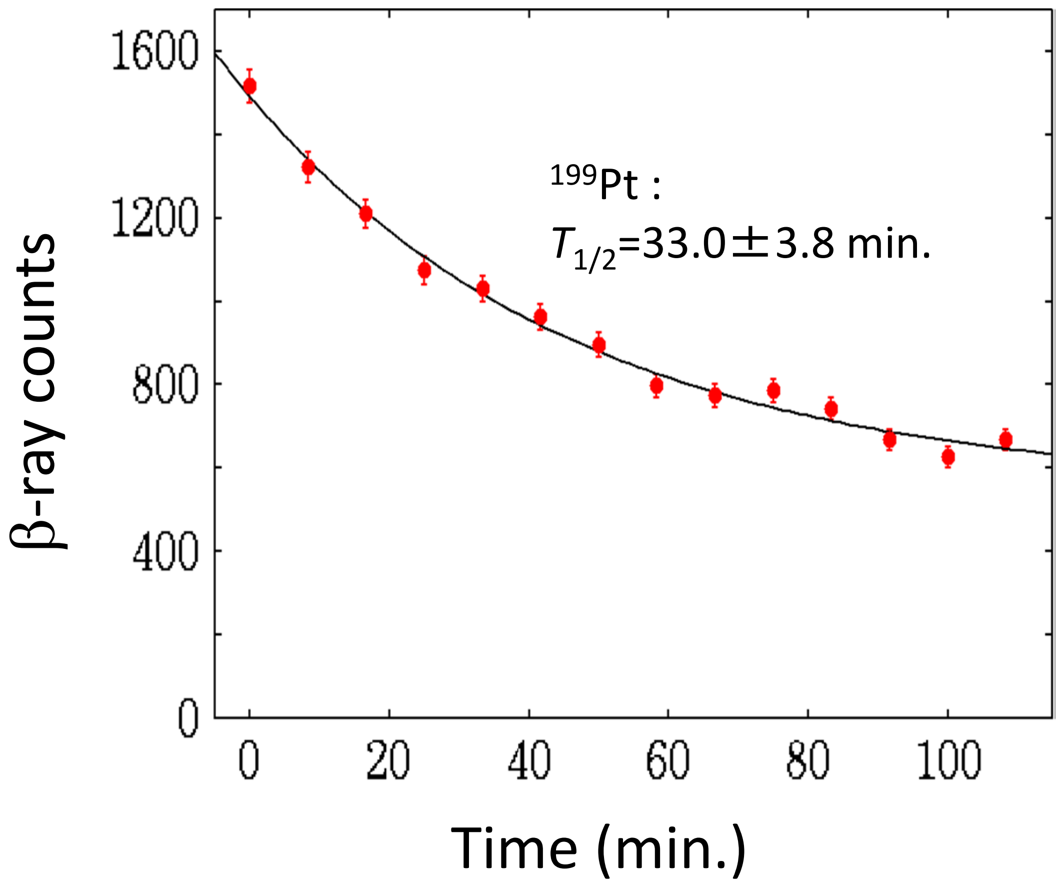
$$\frac{S}{N} = \frac{I_{\text{Laser-on}}}{I_{\text{Laser-off}}}$$



Extraction of unstable nucleus

Detection system was installed in 2014

Extracting unstable ^{199}Pt (30.8 min.) (1n stripping)
Measuring lifetime successfully

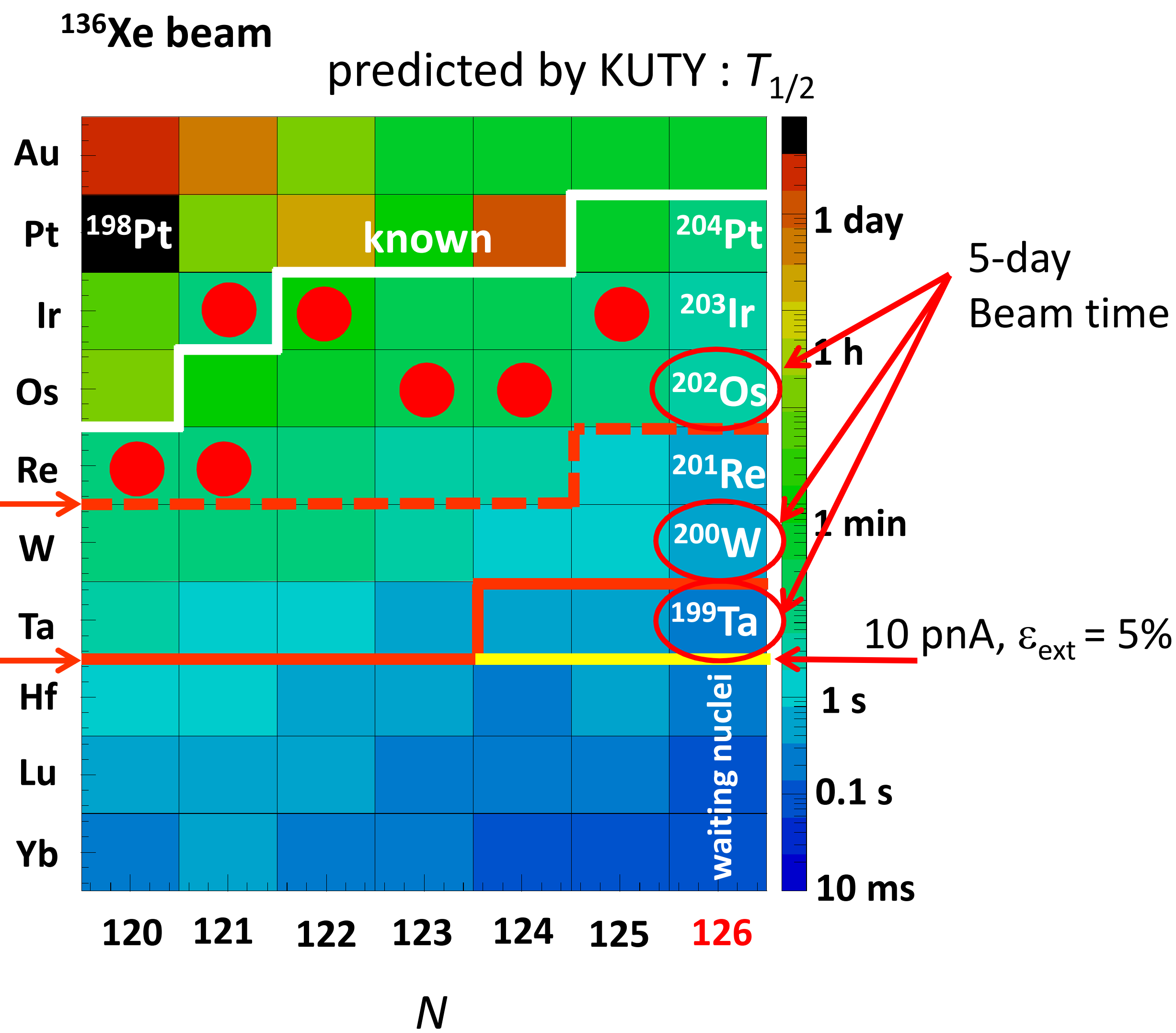


Accessible region for lifetime measurements

Lifetime measurement
<30% error
Purity > 90%
(S/N > 10)

10 pnA, ε_{ext} = 0.1%

10 pnA, ε_{ext} = 1%



● T. Kurtukian-Nieto et al., Eur. Phys. J. A 50 (2014), 135

KUTY : T.Tachibana, M. Yamada, Proc. Inc. Conf. on exotic nuclei and atomic masses, Arles, 1995, p763.

Comparison between MNT and fragmentation

	MNT	U-fragmentation
Production σ (^{202}Os) Ratio	20 μb (GRAZING code) 1	~4.4 pb (J. Kurcewicz et al., PLB 717 (2012), 371) 10^{-7}
Target thickness Ratio	2 mg/cm^2 (^{198}Pt) 1	1.7 g/cm^2 (^9Be 9 mm) 10^4
Beam intensity Ratio	~100 pnA (20 pnA practically) 1	~1 pμA (?) (10 pnA practically?) 1
Efficiency Ratio	$>10^{-3}$ 1	10^{-1} 10^2
S/N (Beam purity)	300 (99.7%)	?
Total ratio	1	10^{-1} ?

Further R&D issues

- **Improvement of extraction efficiency : ~0.1% → ~1% → more**
  - Investigation for molecular ion formation in gas
    Time measurement of molecular ion formation (Colinear laser)
  - Further purification of gas (Suppression of contaminants H_2O, H)
    Low-outgassing material (Ti) for gas cell
    Cooling of gas cell
  - Investigation of neutralization efficiency
    New gas cell structure to suppress plasma induced by beam
  - Improvement of transportation efficiency and dissociation of molecular ion
    Multistage SPIG
- **Modification/optimization of the detection system**
  - β-telescope structure
    Improvement of detection efficiency : ε_β = 46% → >80%
    Background rate : 1.1 cps → ~ 0.1 cps
  - Low background β-telescope
    Gas counter + plastic scintillator : ~ 10 cph
- **More favorable production**
  - ^{238}U beam + ^{198}Pt target : ~10 times larger cross section (GRAZING)
    Optimization of gas cell design

KISS will be open for external user program in 2016,
start call-for-proposal at the end of 2015 from RIKEN NP-PAC2015

Summary

Characterize *3rd peak of* abundance pattern in terms of nuclear physics points of view through lifetime measurements of the waiting point nuclei as an ultimate goal of the physics motivation of the project

1st stage : Lifetime measurements ^{204}Pt ~ ^{200}W (*N*=126) ← MNT of ^{136}Xe + ^{198}Pt

- Installation of KISS was completed

  Detection system is under modification for higher detection efficiency and lower background

- Results of PLF measurements support N = 126 TLF production
- Under on-line test for extracting MNT TLFs as R&D exp.

  ε_{ext} ~ 0.15%, S/N ~ 300

  → Reducing the formation of molecular ions, especially H_2O- and H-attachments

  → Looking for the missing 999 parts among 1000

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Collaboration

KISS project

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