

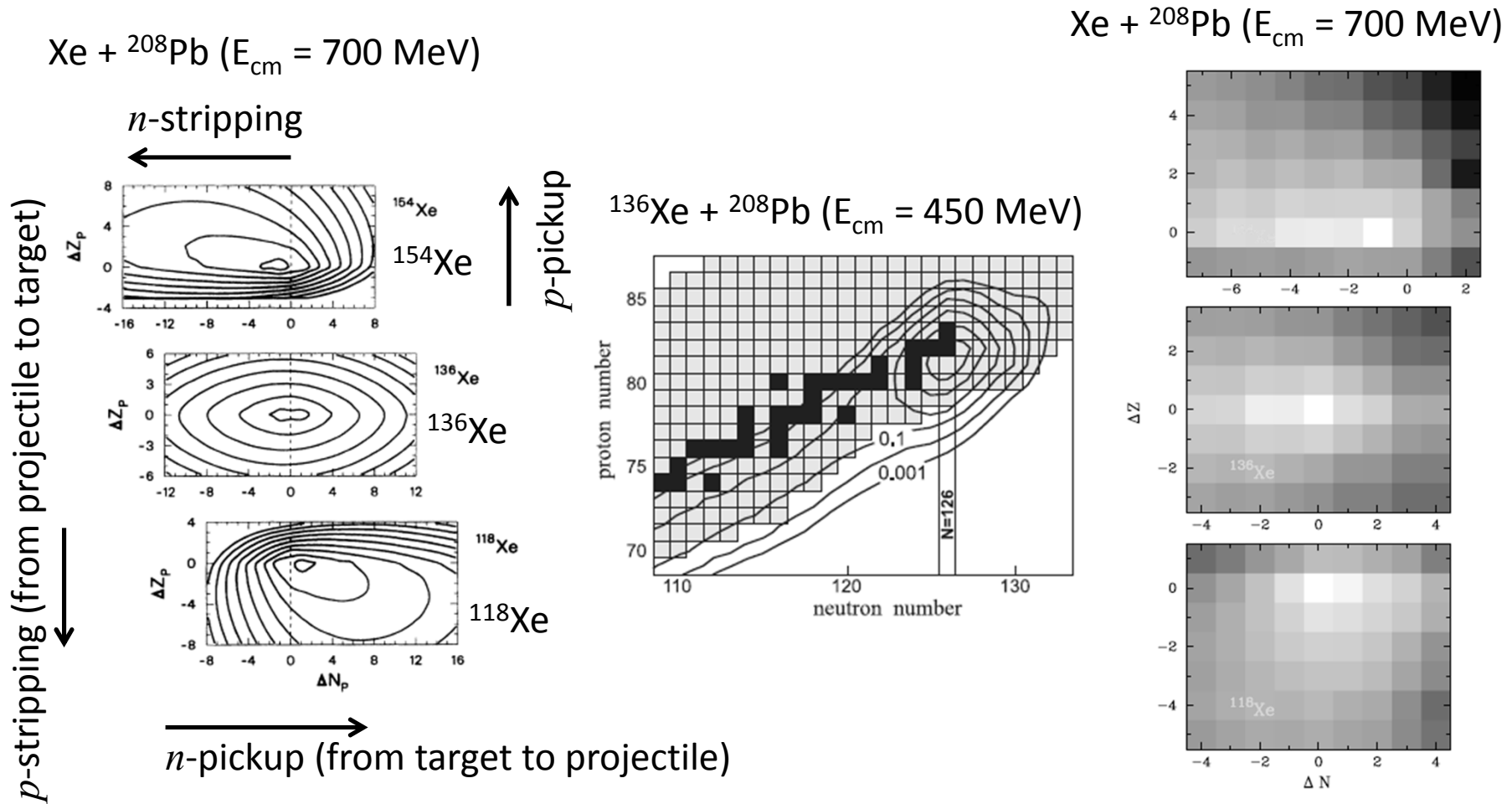
# Study of multinucleon transfer (MNT) reactions of $^{136}\text{Xe} + ^{198}\text{Pt}$ for production of exotic nuclei

Y.X. Watanabe (KEK)

## Contents

1. Introduction (MNT reactions for nuclear production)
2. KEK isotope separation system (KISS)
3. MNT measurements of  $^{136}\text{Xe} + ^{198}\text{Pt}$
4. Summary

# Nuclear production by MNT reactions

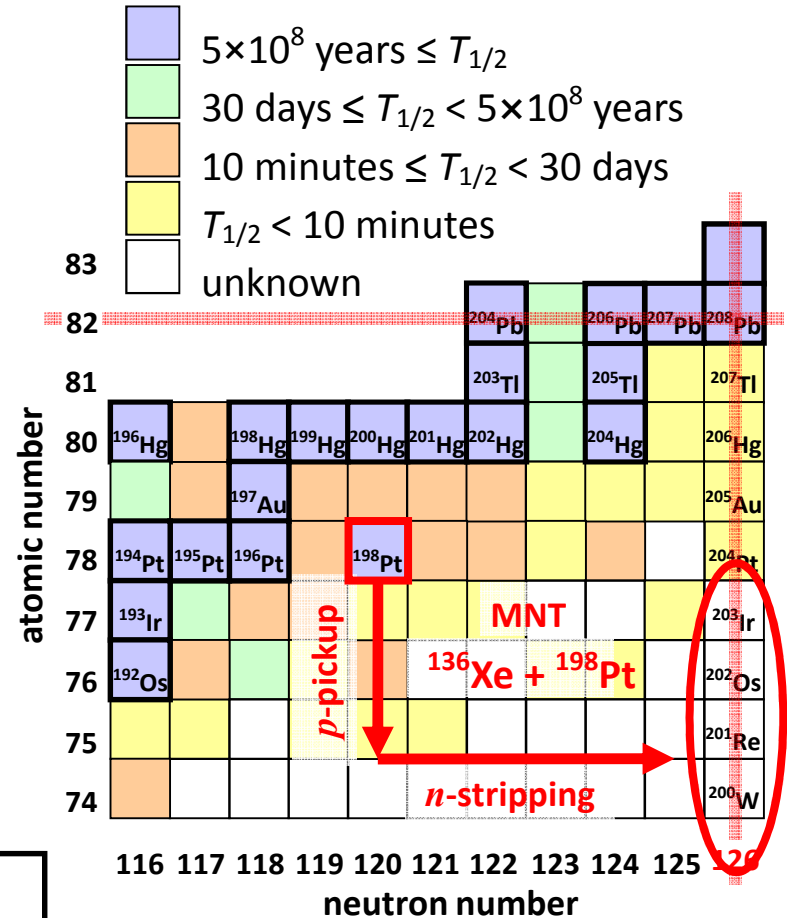
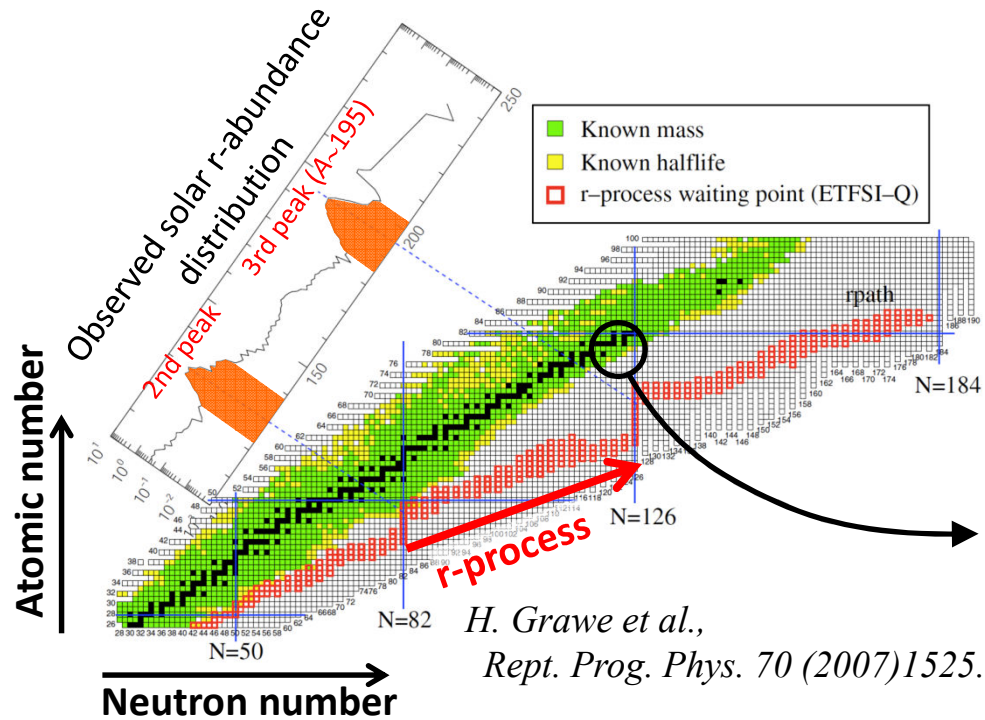


C.H. Dasso et al., Phys. Rev. Lett. 73, 1907 (1994).

V. Zagrebaev and W. Greiner, Phys. Rev. Lett. 101, 122701 (2008).

L. Corradi et al., J. Phys. G: Nucl. Part. Phys. 36, 113101 (2009).

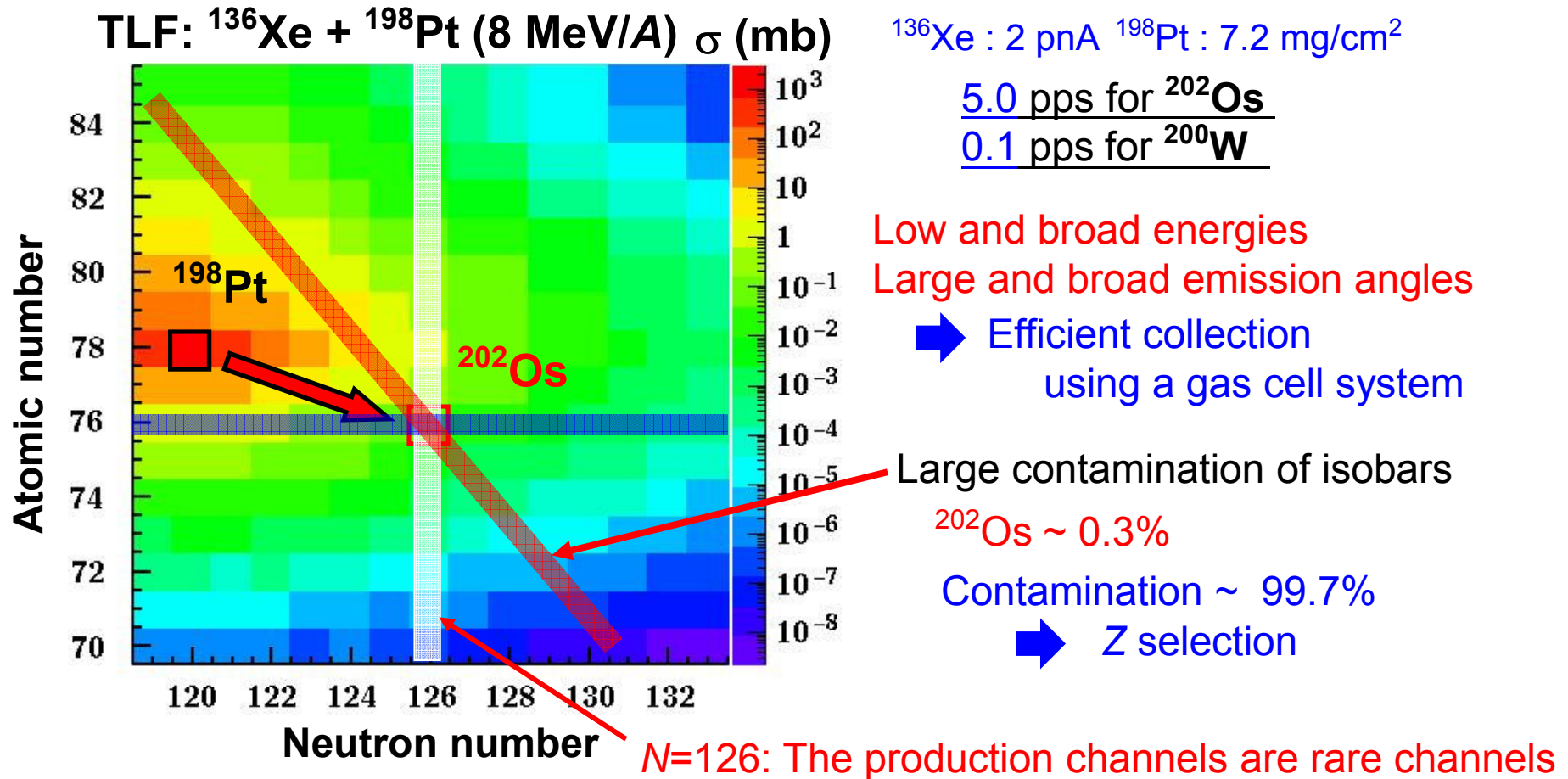
# Neutron-rich nuclei around $N=126$



Lifetime measurements around  $N=126$   
 → Astrophysical environments for r-process

# MNT reactions of $^{136}\text{Xe} + ^{198}\text{Pt}$

GRAZING calculation *A. Winther, Nuclear Physics A572, 191 (1994);  
A. Winther, Nuclear Physics A594, 203 (1995).*



The separation of A and Z is essential for the measurement of rare channel products.

Laser Ion-source with argon gas-cell

# KEK isotope separation system (KISS)

## Detection system

- 3 detection stations
  - Tape-transport system
  - Multi-layered plastic scintillators
  - Ge detectors
- $\beta$ -decay measurements

E2 & E3 experimental halls  
in RIKEN Nishina Research Center

Mass separator  
(**A selection**)

## Gas catcher system

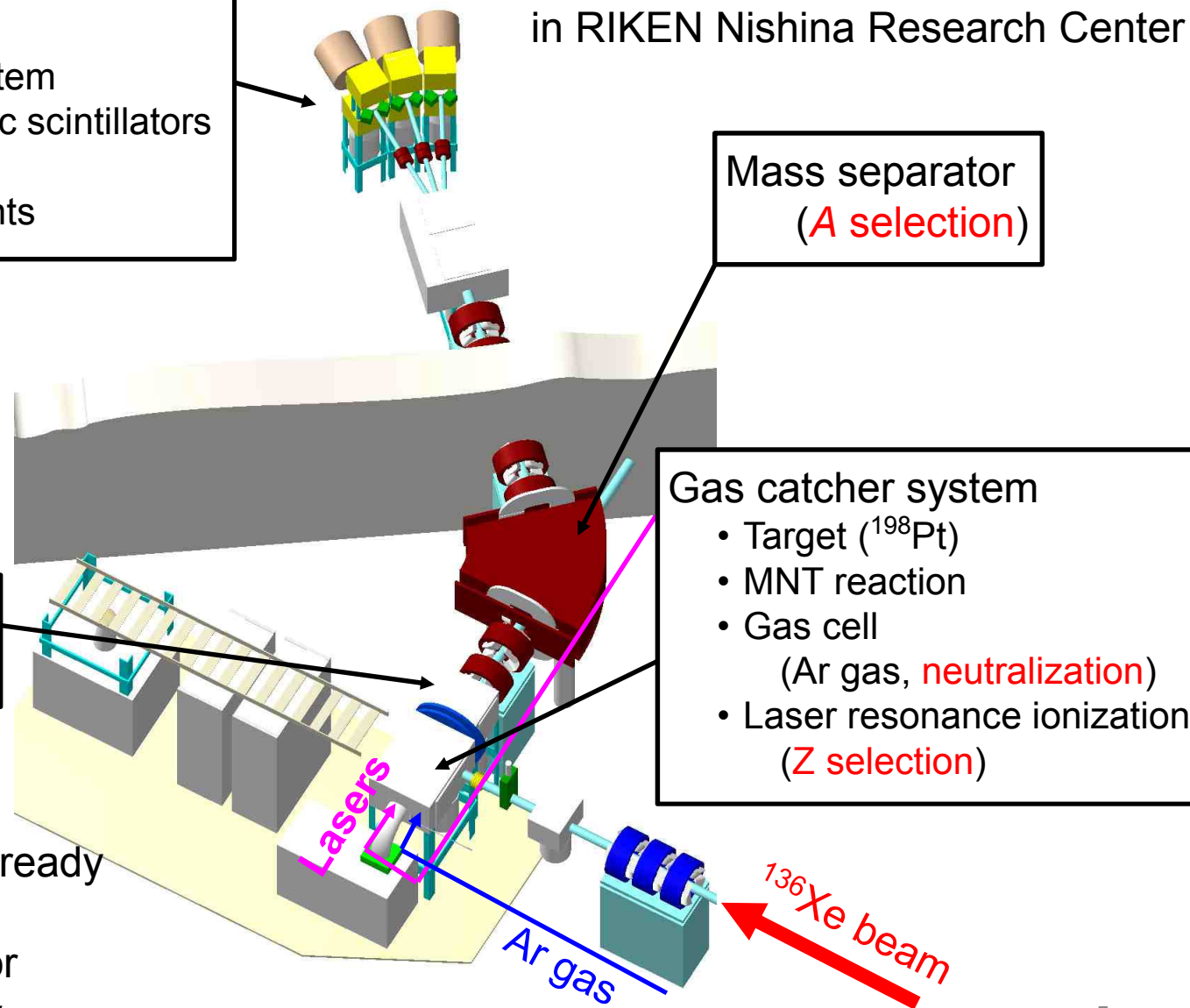
- Target ( $^{198}\text{Pt}$ )
- MNT reaction
- Gas cell  
(Ar gas, **neutralization**)
- Laser resonance ionization  
(**Z selection**)

## Extraction chamber

- High voltage (30 kV)

All apparatus except for  
detection system was already  
installed.

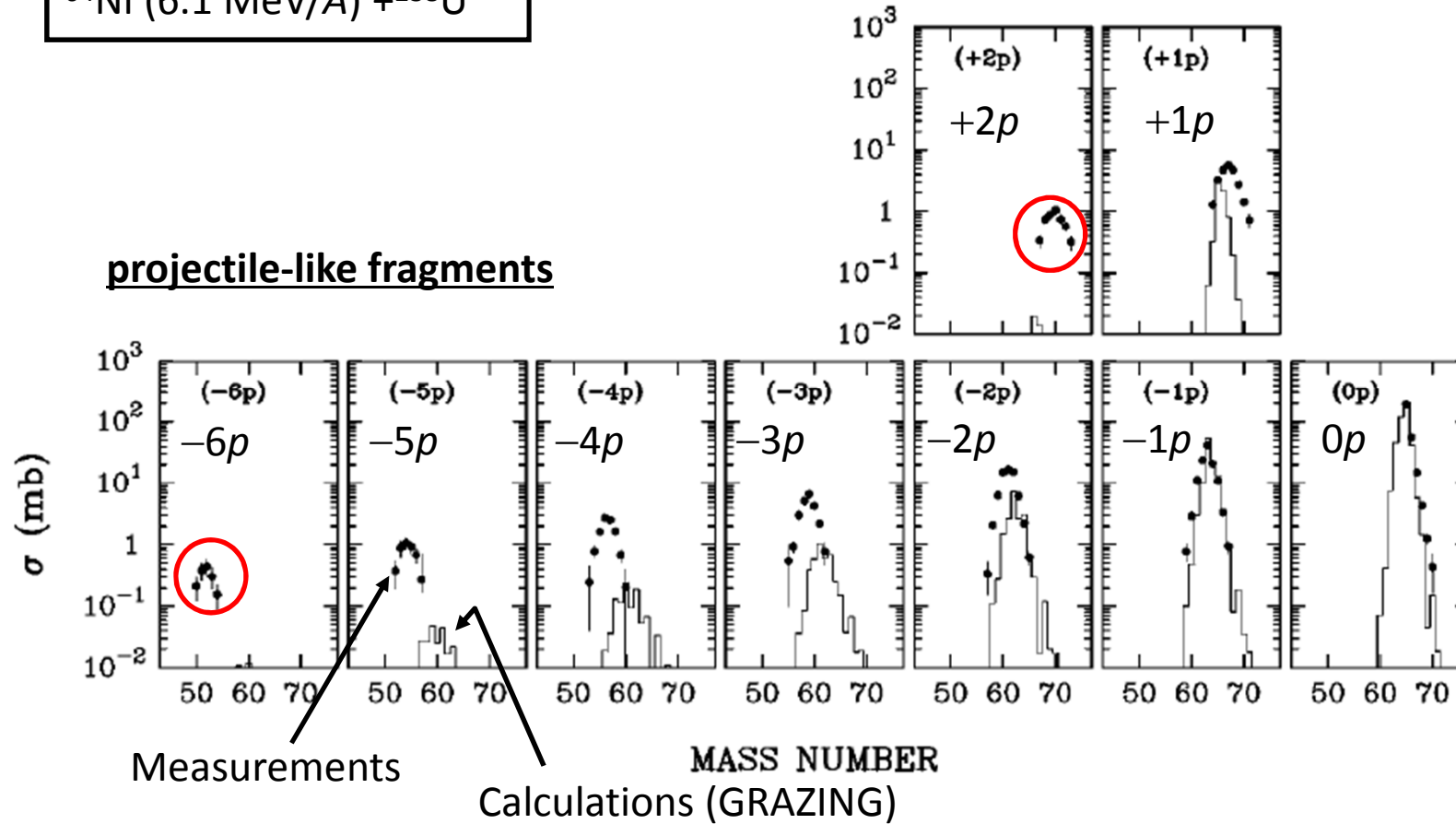
Under commissioning for  
efficiency and selectivity.



# MNT reactions

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

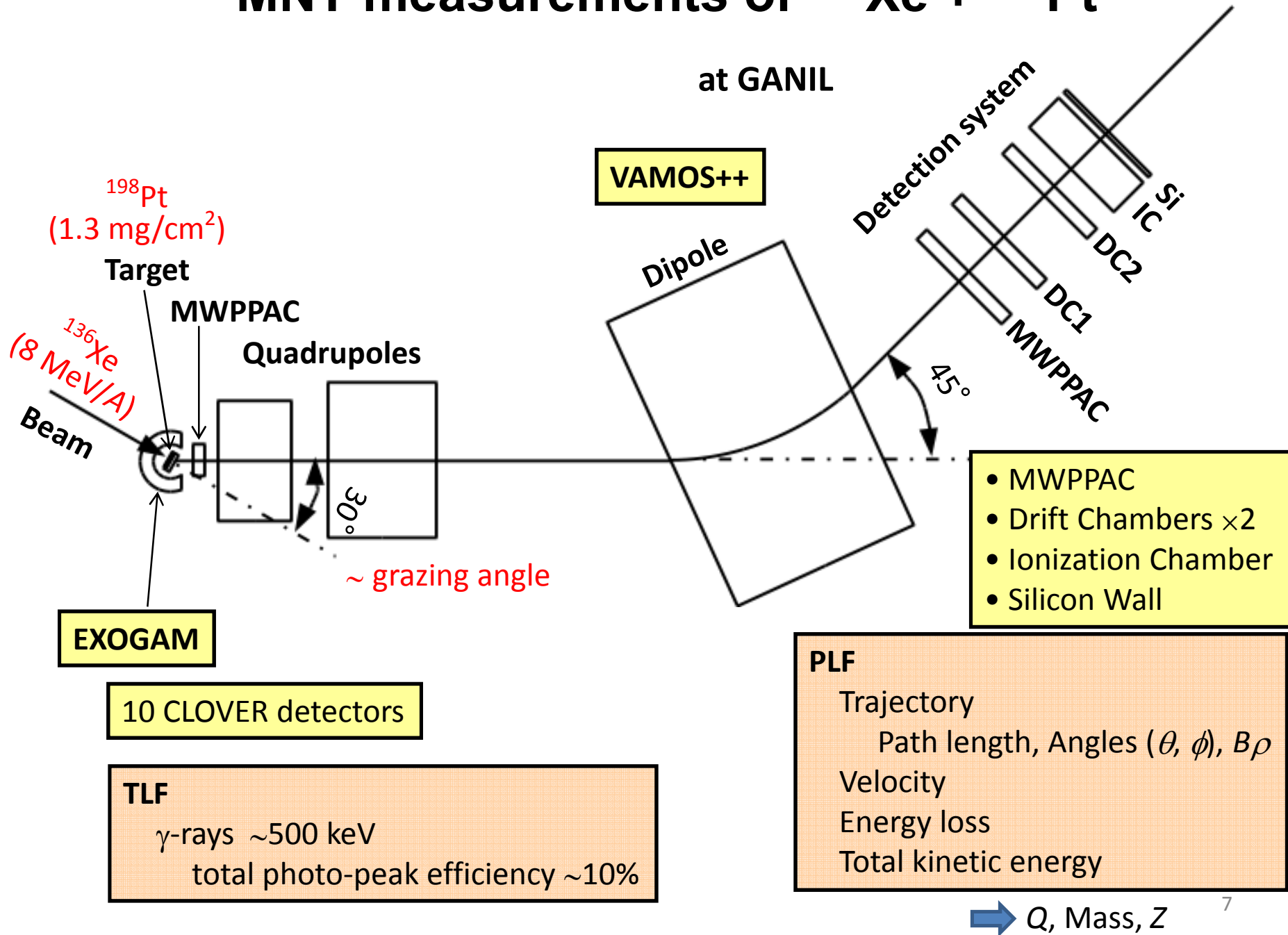
*L. Corradi et al., Physical Review C59 (1999) 261.*



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

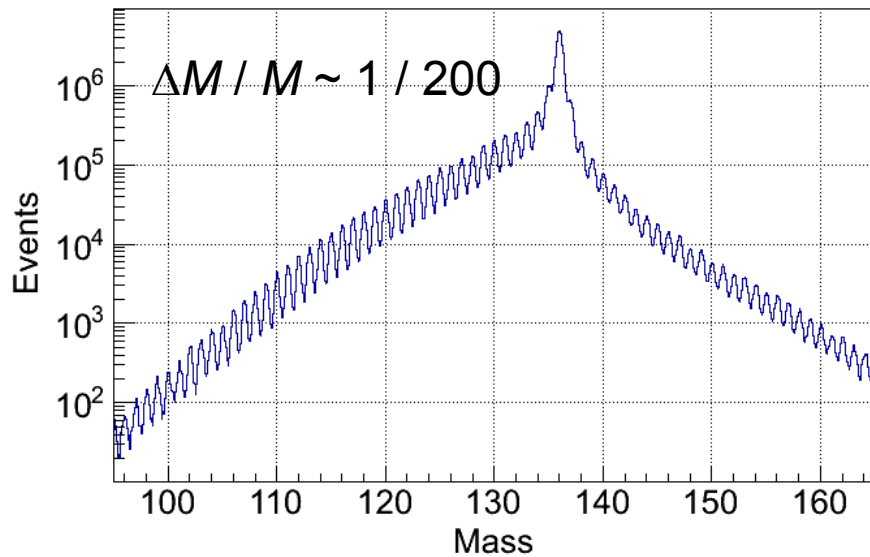
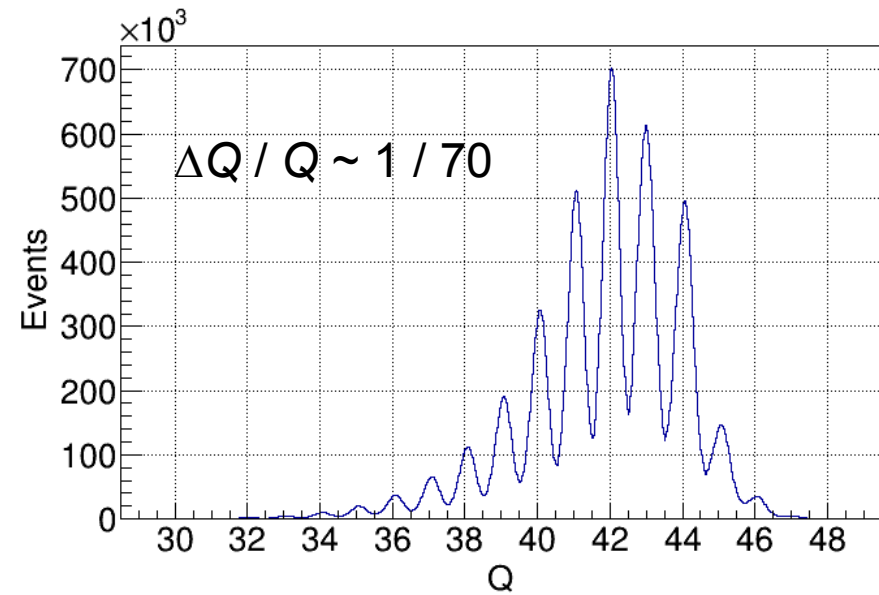
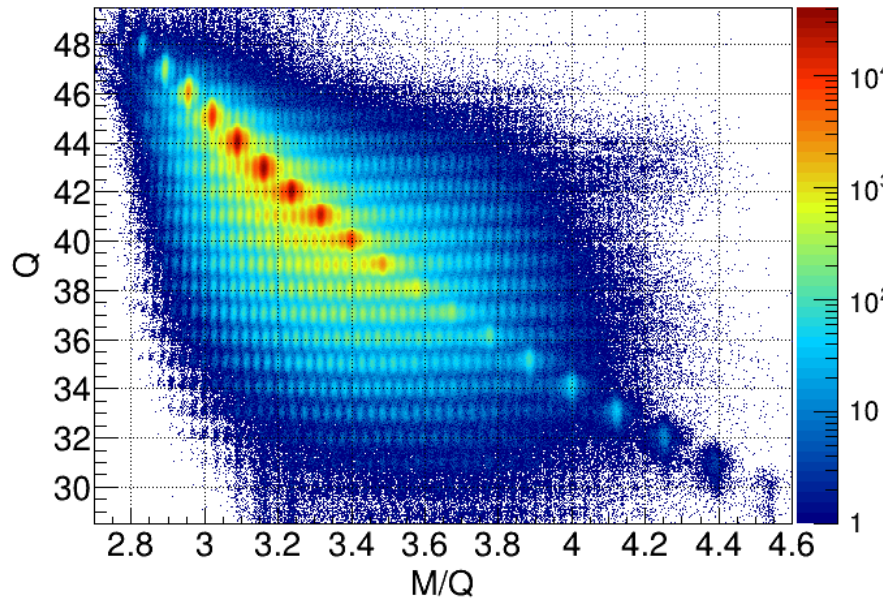
# MNT measurements of $^{136}\text{Xe} + ^{198}\text{Pt}$

at GANIL





# Charge and mass distributions of PLF



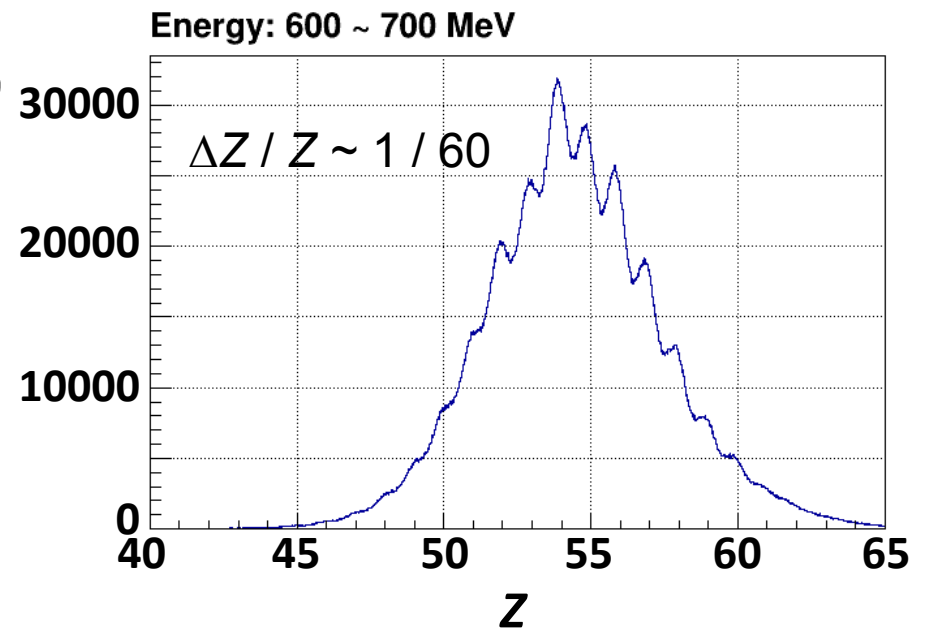
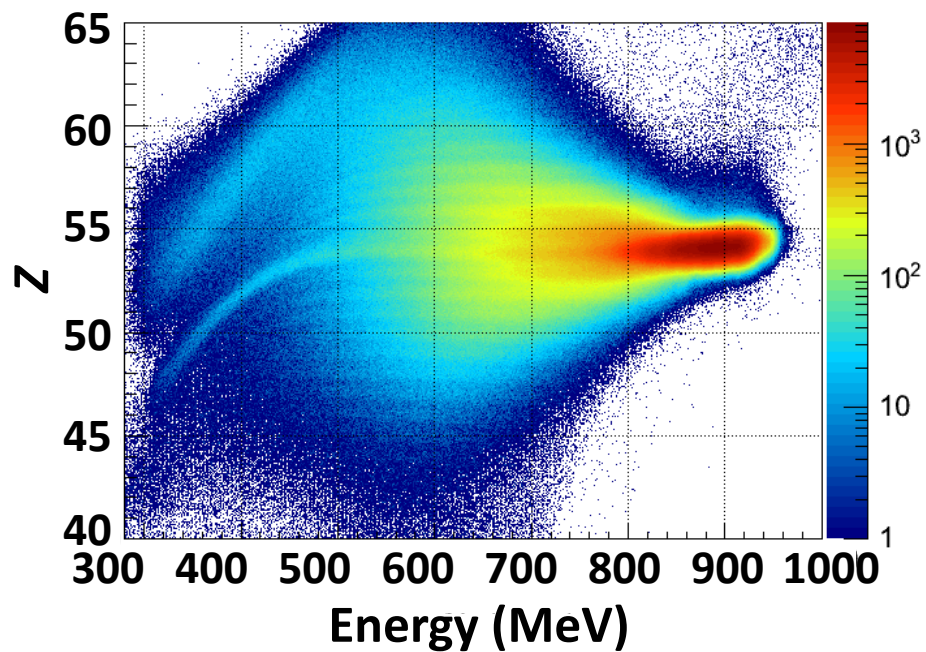
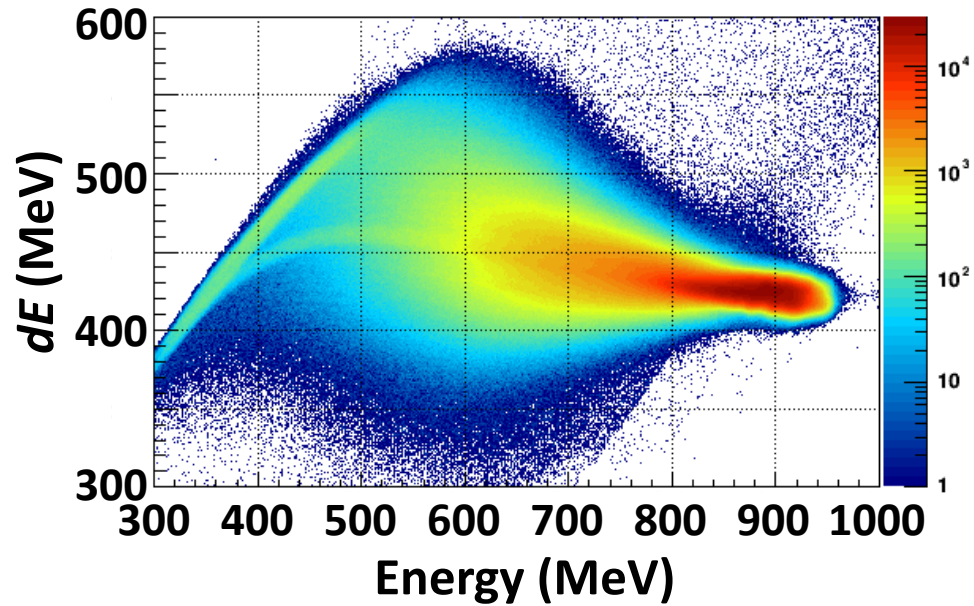
$$M / Q = B \rho / v$$

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

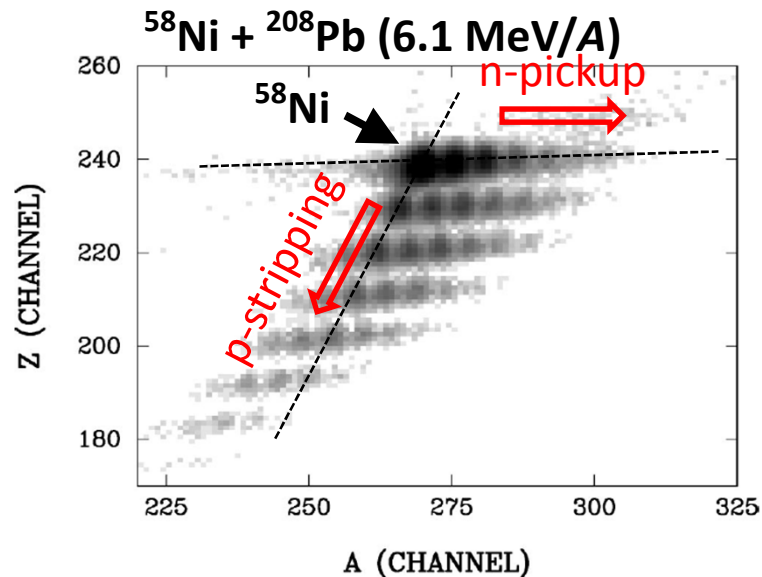
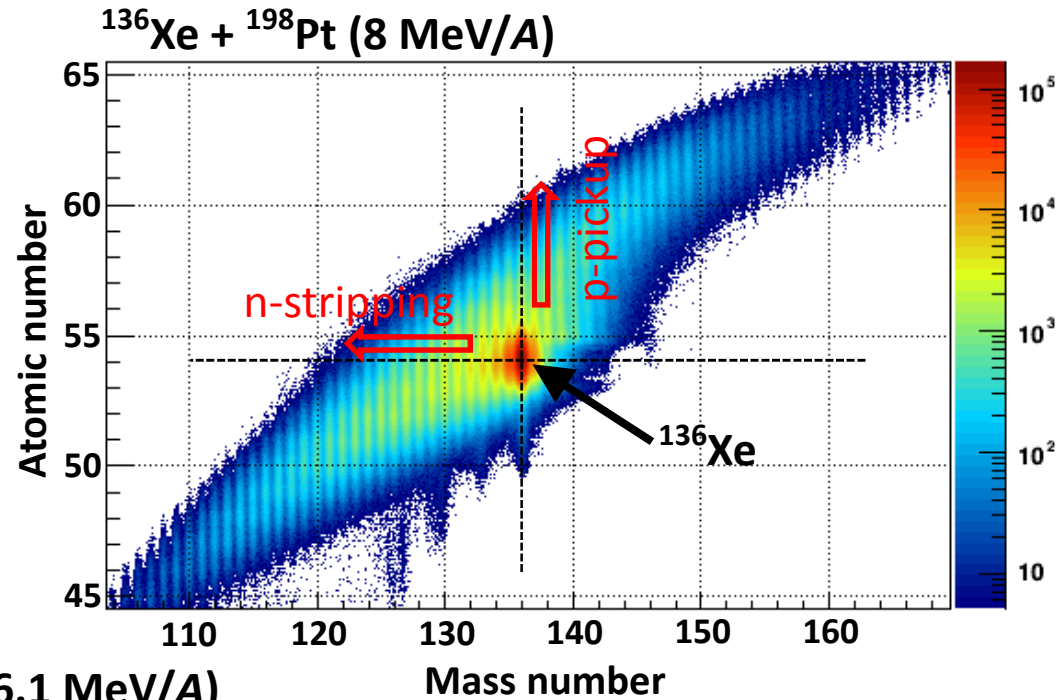
$$M = Q_i M / Q$$



# Z identification of PLF



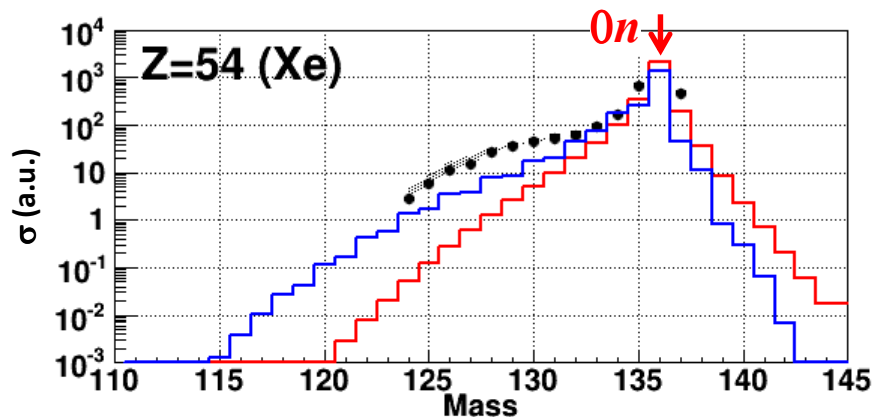
# Z - A distribution of PLF



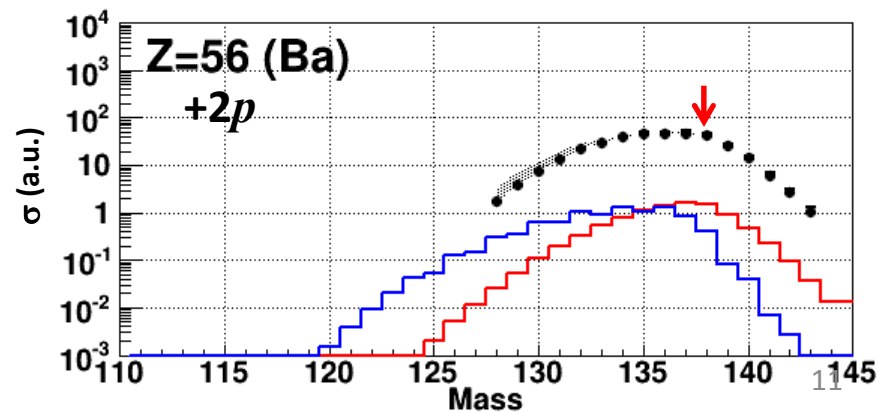
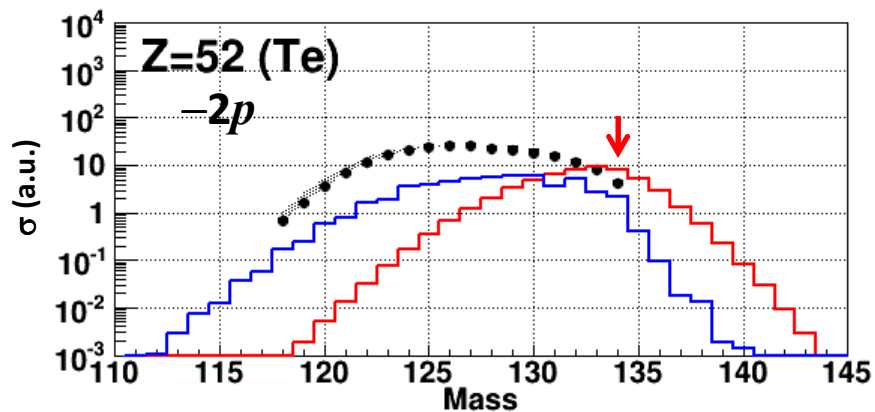
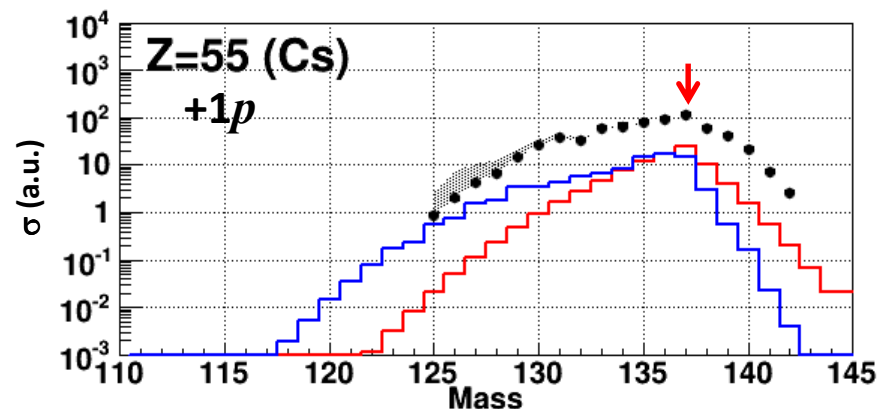
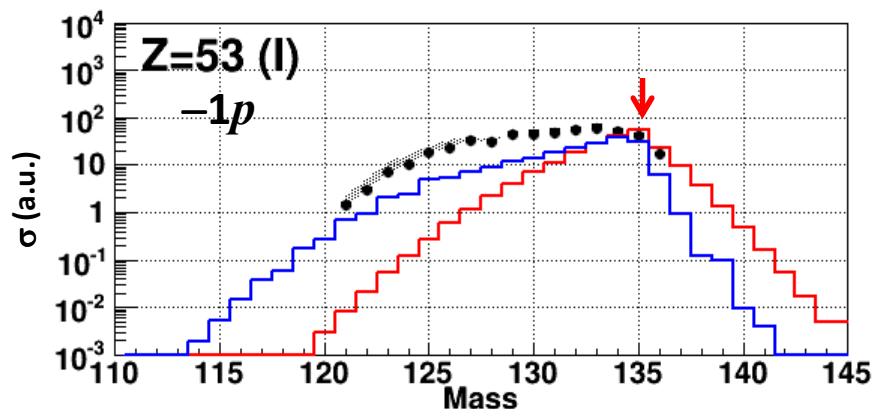
Contribution of  $p$ -pickup and  $n$ -stripping channels was observed.

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

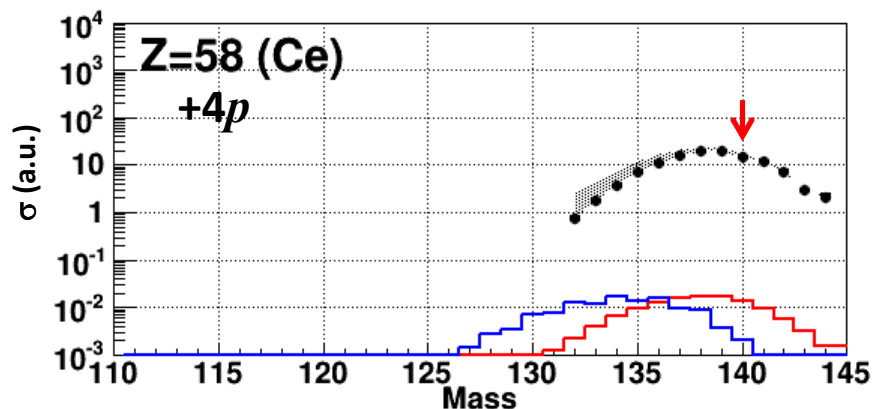
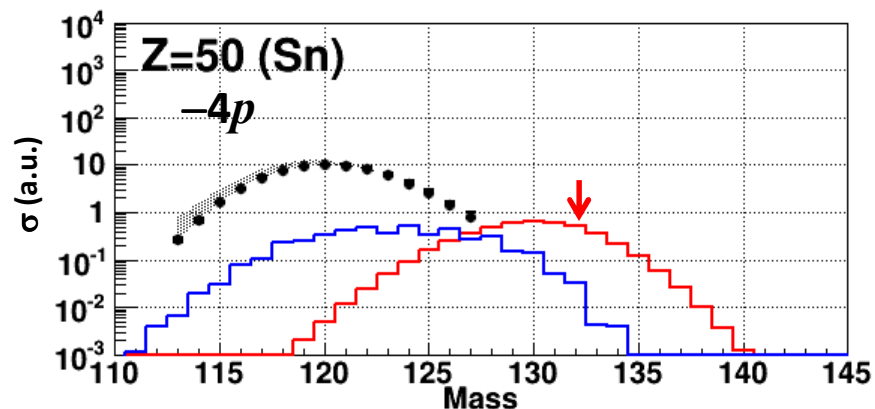
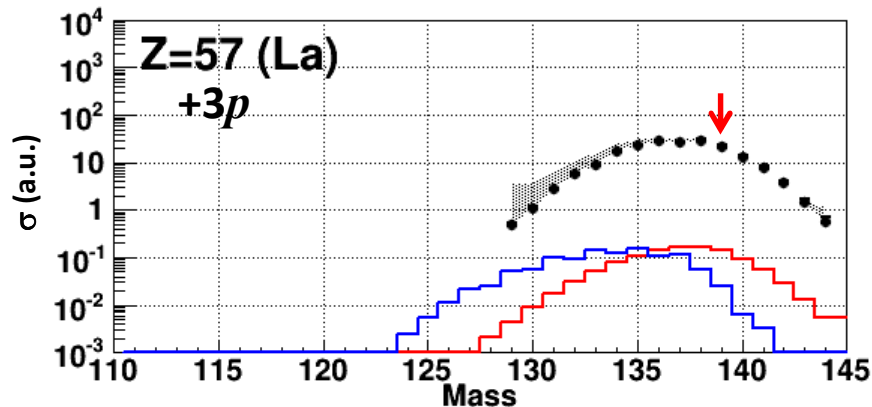
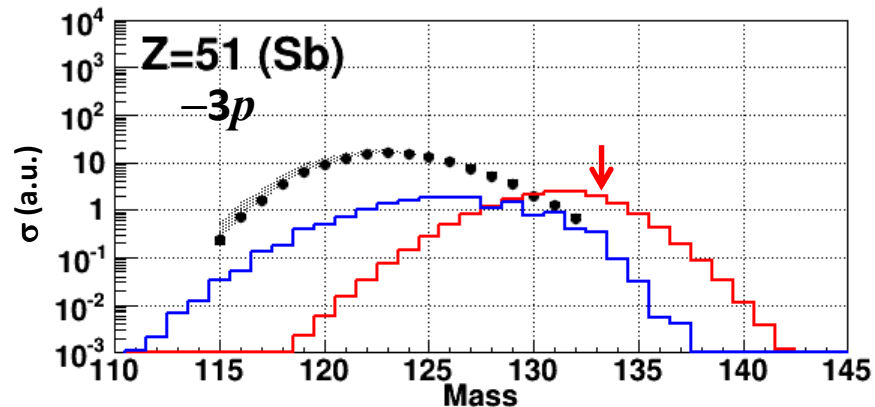
# Isotopic distributions of PLF ( $0, \pm 1p, \pm 2p$ transfer)



- Measurements
  - ▨ Correction for missing events
  - GRAZING before evaporation
  - GRAZING after evaporation
- $p$ -pickup: Larger cross section  
 Heavier distribution



# Isotopic distributions of PLF ( $\pm 3p, \pm 4p$ transfer)



$E_{\text{lab}} = 8 \text{ MeV/A}$

(55% higher than the Coulomb barrier)

Highly damped collision

Large contribution of neutron evaporation

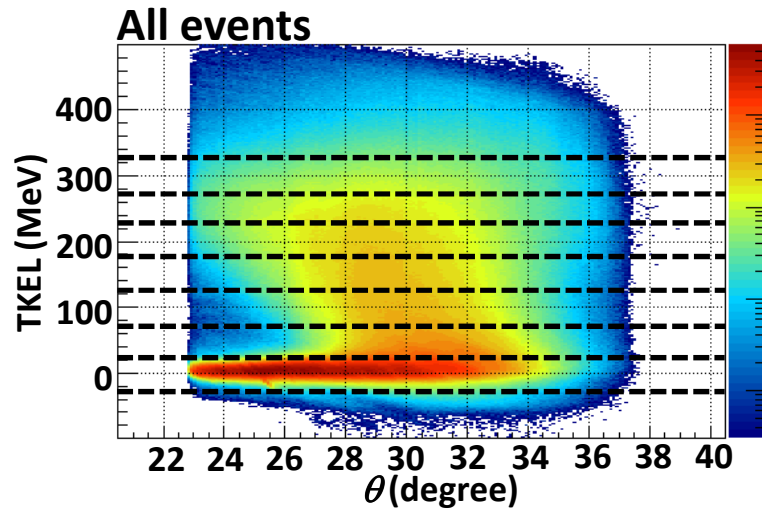
● Measurements

▨ Correction for missing events

— GRAZING before evaporation

— GRAZING after evaporation

# Z - N distribution of PLF for different TKEL

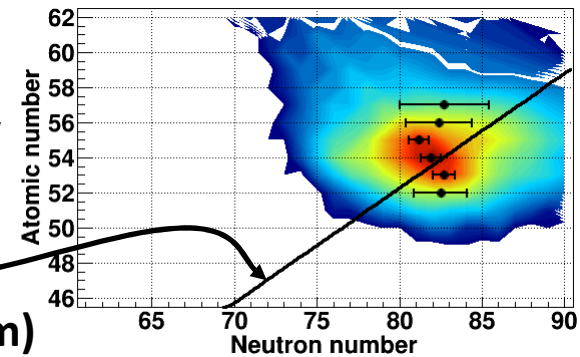


Pure binary kinematics  
was assumed

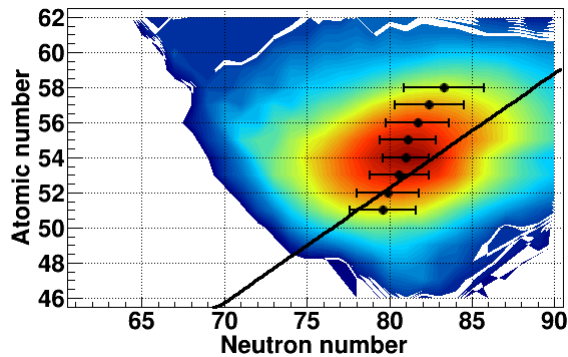
Evolution of Z-N  
distribution (50 MeV  
window)

Z/N equilibrium  
(compound system)

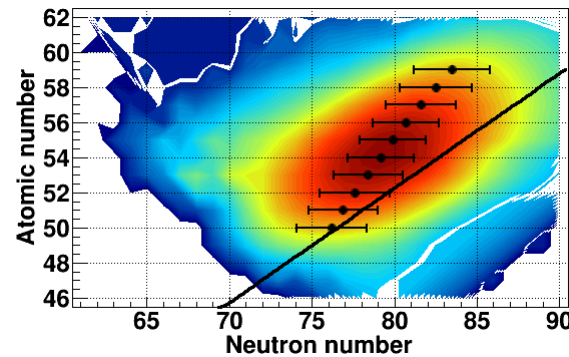
TKEL = -25 - 25 MeV



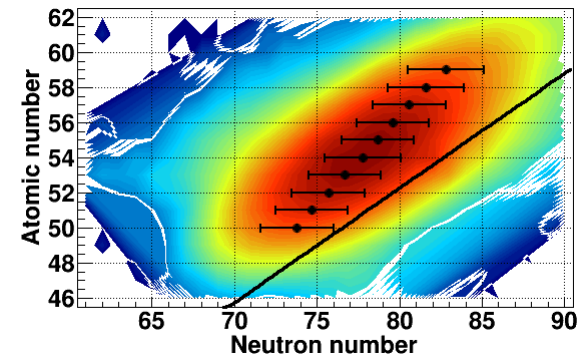
TKEL = 25 - 75 MeV



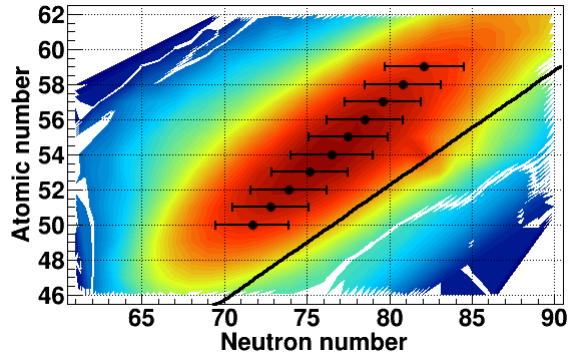
TKEL = 75 - 125 MeV



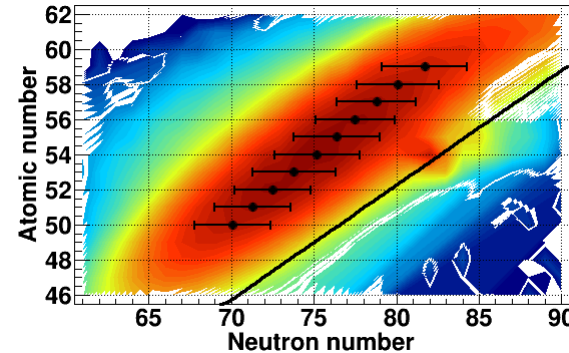
TKEL = 125 - 175 MeV



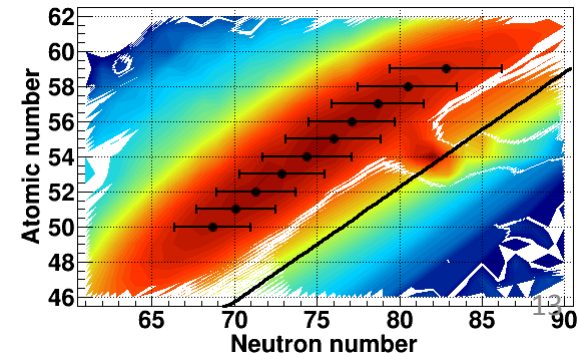
TKEL = 175 - 225 MeV



TKEL = 225 - 275 MeV

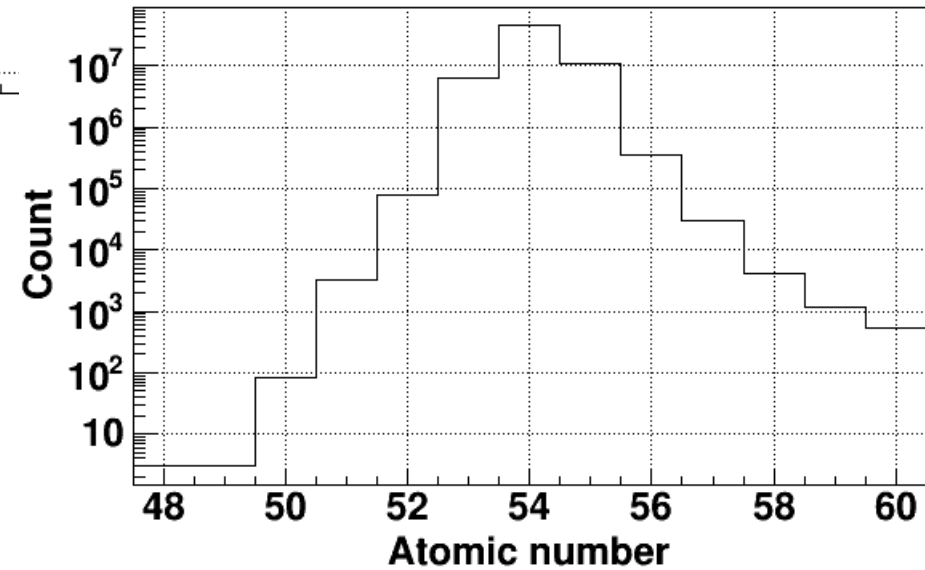
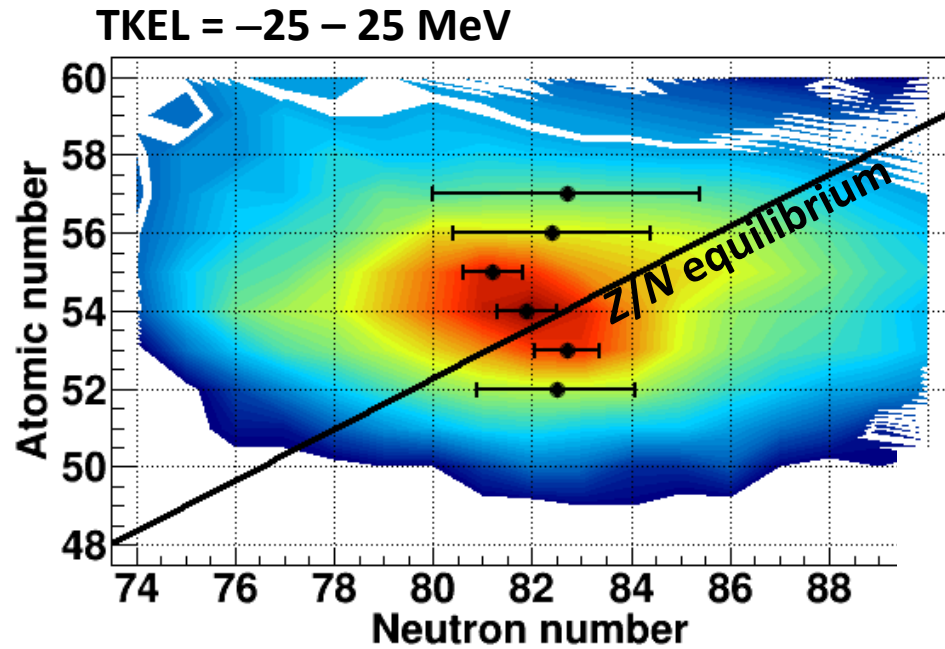


TKEL = 275 - 325 MeV



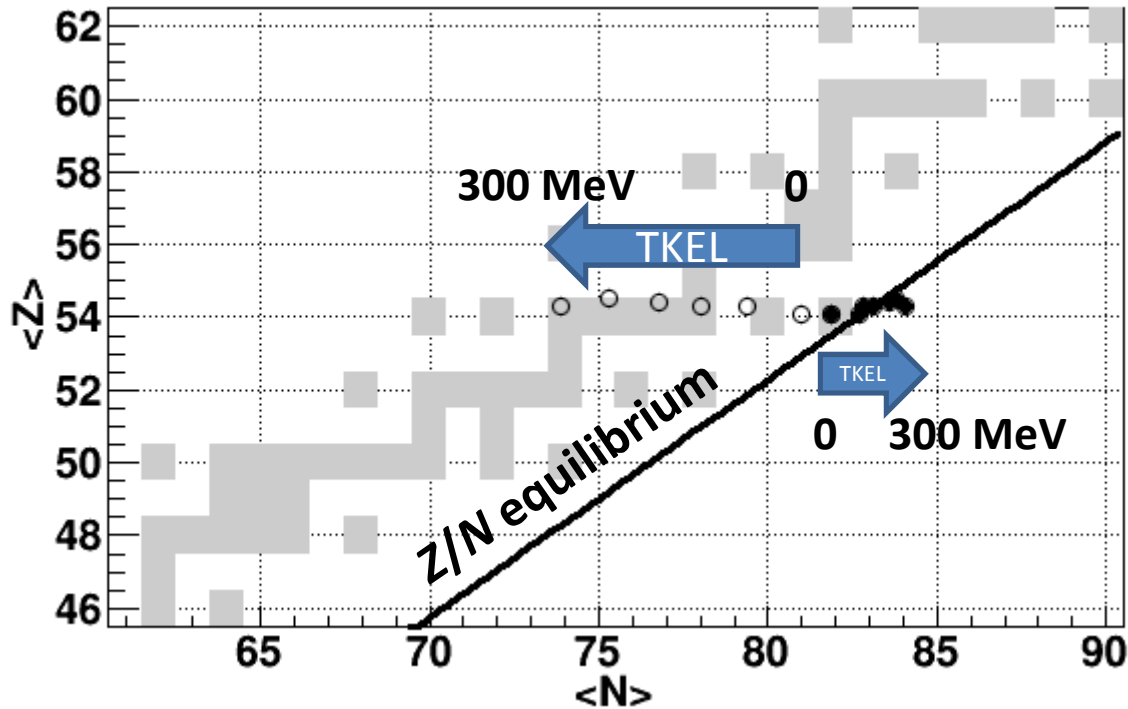


# Z - N distribution of PLF at low TKEL



Almost no neutron transfer is favored on average.  
Proton pickup is a little bit favored.

# Evolution of centroids of distributions

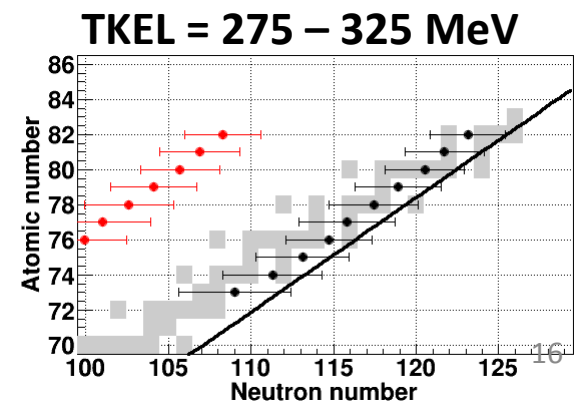
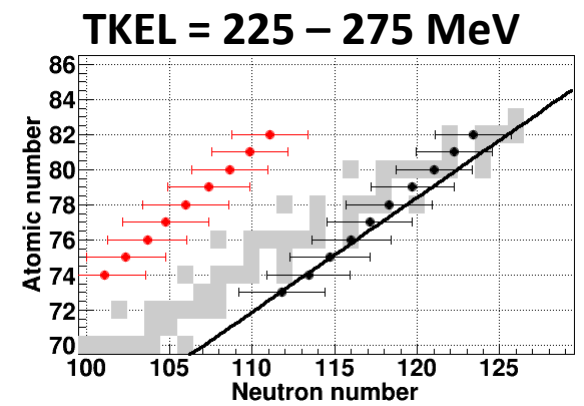
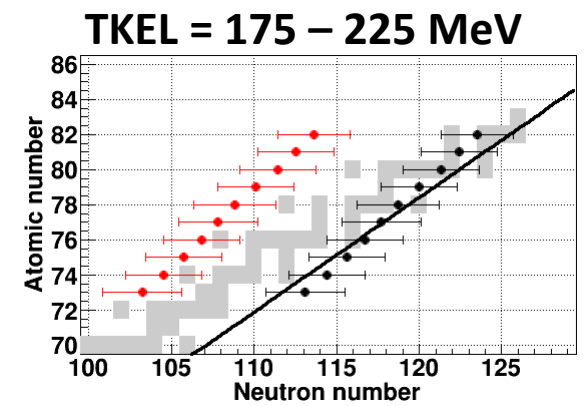
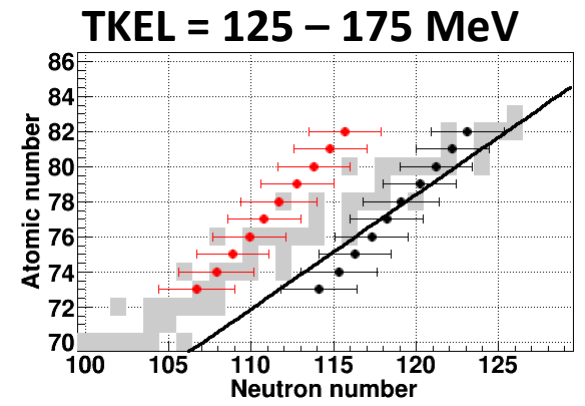
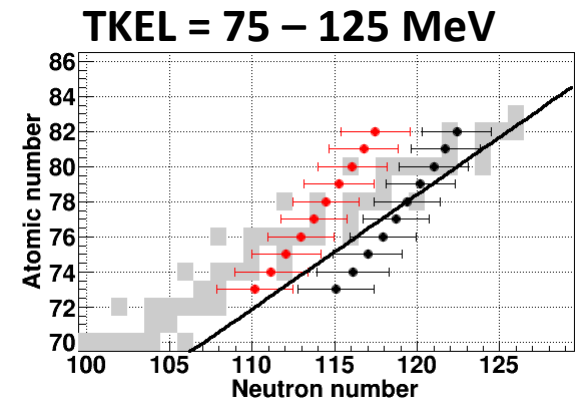
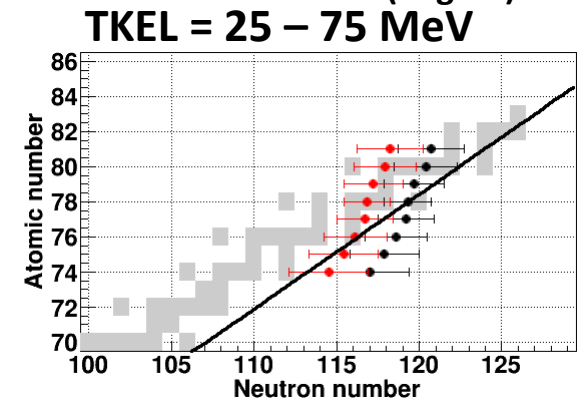
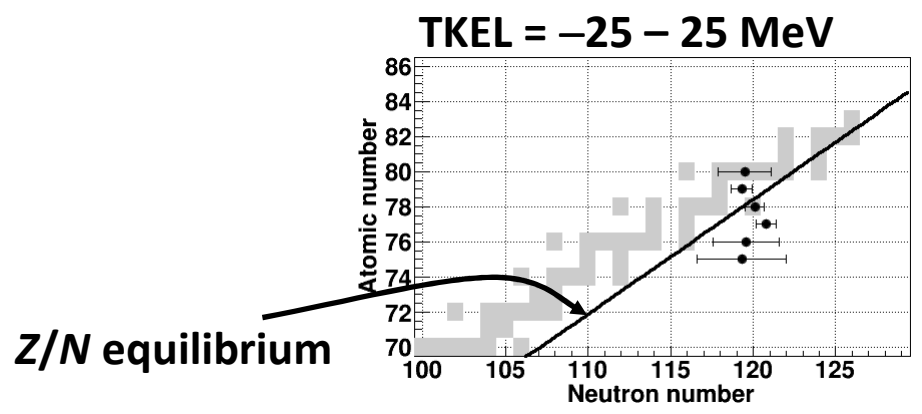
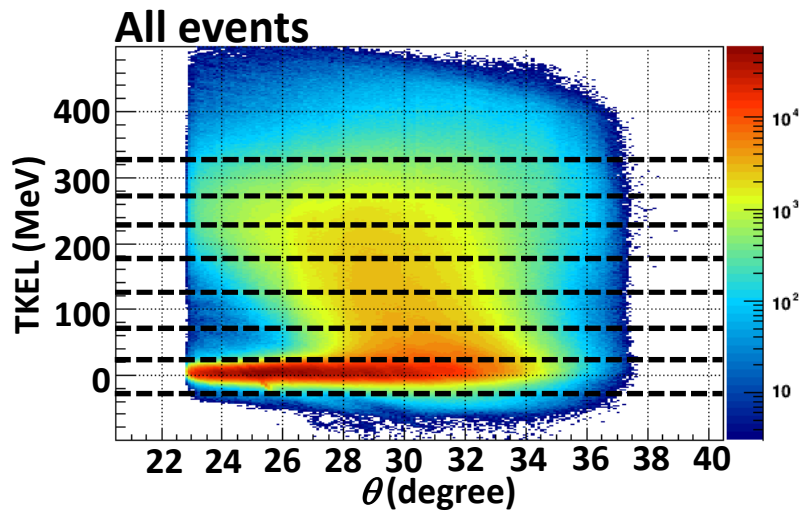


- Measurements
- Derived primary centroids  
(Evaporation energy: 12 MeV/neutron)

TKEL = 300 MeV : PLF's are populated along the  $Z / N$  equilibrium line  
Neutron stripping (pickup) accompanies proton stripping (pickup)



# Derived Z - N distribution of TLF for different TKEL



# Summary

- **MNT reactions have been proposed for production of exotic nuclei**
- **We are advancing the KISS project**
  - Lifetime measurements around  $N=126$  nuclei from astrophysical interest
  - Nuclear production by the MNT reaction between  $^{136}\text{Xe}$  and  $^{198}\text{Pt}$
- **MNT measurements were performed at GANIL for  $^{136}\text{Xe} + ^{198}\text{Pt}$  reaction**
  - PLF's were detected by VAMOS :  $\Delta Q / Q = 1 / 70$ ,  $\Delta M / M = 1 / 200$ ,  $\Delta Z / Z = 1 / 60$
- **Z-A distribution**
  - Contribution of  $p$ -pickup and  $n$ -stripping channels was observed
- **Isotopic distributions were deduced for each proton transfer channel**
  - $p$ -pickup channels larger than  $p$ -stripping channels were observed
  - Neutron stripping (pickup) seems to accompany proton stripping (pickup) on average
- **Evolution of isotopic distributions as increasing TKEL were studied**
  - Distribution gradually evolves from quasi-elastic regime to deep-inelastic regime
  - Lower TKEL ( $\sim 0$ ) : Proton pickup is a little bit favored
    - Almost no correlation between neutron transfer and proton transfer
  - High TKEL ( $\sim 300$  MeV): In parallel to Z-N equilibrium of compound system
    - Large effect of neutron evaporation
    - Neutron stripping (pickup) accompanies proton stripping (pickup) according to Z-N ratio of the compound system
  - Low TKEL reaction would contribute to the production of neutron-rich TLF's

# Collaboration

## KISS project

<b>KEK</b>	Y. Hirayama, N. Imai, H. Ishiyama, S.C. Jeong, H. Miyatake, M. Oyaizu, Y.X. Watanabe
<b>Seoul National University</b>	Y.H.Kim
<b>Tsukuba University</b>	M. Mukai, S. Kimura
<b>RIKEN</b>	M. Wada, T. Sonoda
<b>K.U. Leuven</b>	P. Van Duppen , Yu. Kudryavtsev, M. Huyse

## MNT measurements at GANIL

<b>KEK</b>	Y. Hirayama, N. Imai, H. Ishiyama, S.C. Jeong, H. Miyatake, Y.X. Watanabe
<b>Seoul National University</b>	S.H. Choi, Y.H. Kim, J.S. Song
<b>GANIL</b>	M. Rejmund, C. Schmitt, A. Navin, G. de France, E. Clement
<b>Torino University</b>	G. Pollarolo
<b>LNL</b>	L. Corradi, E. Fioretto
<b>Padova University</b>	D. Montanari
<b>IPN</b>	M. Niikura, D. Suzuki
<b>Osaka University</b>	H. Nishibata, J. Takatsu