PIAVE-ALPI ACCELERATOR

Production yields of neutron-rich heavy nuclei in the $^{238}U+^{124}Sn$ multinucleon transfer reaction

PRISMA + NOSE + AGATA experiment

Spokespersons: L. Corradi, F.Galtarossa, T.Mijatovic

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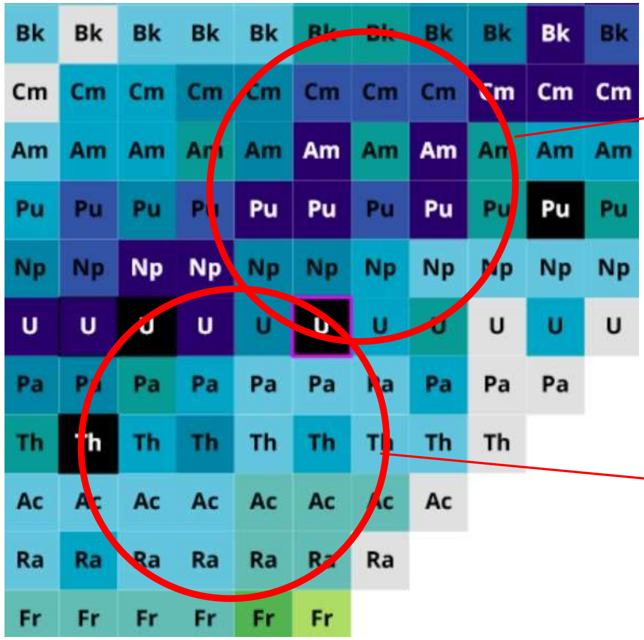
Physics goal

study the A,Z,Q-value distributions and associated σ for the population of nuclei around Z=92 → comparison with state-of-art theories

Exploiting the multinucleon transfer mechanism to get access to neutron-rich regions above and below Z=92



Z > 92 interesting for

- spectroscopy of neutron-rich transactinides
- fission properties (barriers, mass partitions)

Z < 92 interesting for

- octupole deformation
- Electric Dipole Moments (Ra)
- Parity non conservation (Fr)

Exp: big interest in developing advanced techniques for high detection efficiency and high A,Z,Q resolution to get σ and associated nuclear structure information

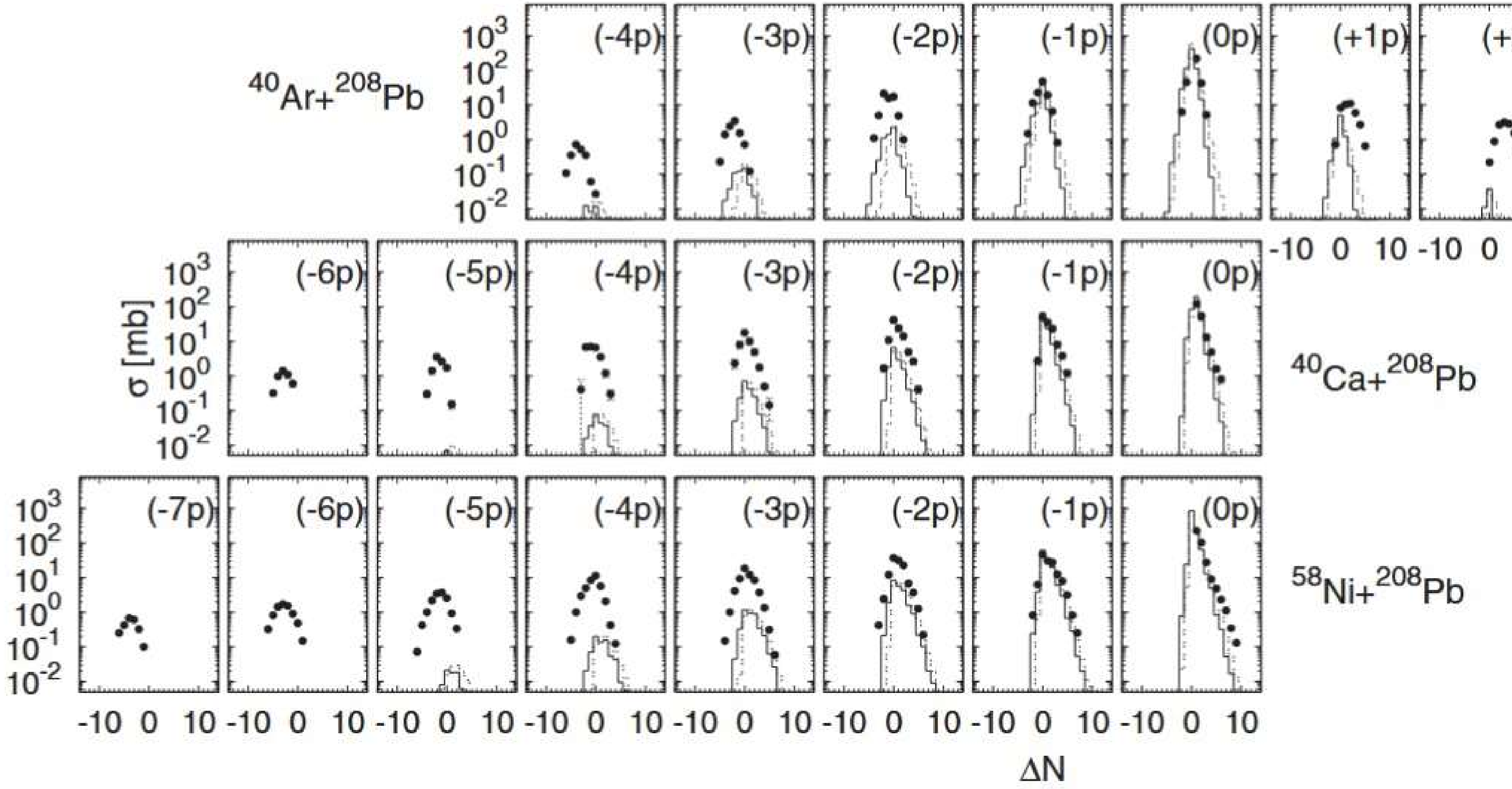
Theory: big interest in developing theories able to predict cross sections and effects of secondary processes (Coupled channel, Semiclassical, TDHF, Langevin, QMD, DNS, EDF)

opening of proton pick-up channels: one textbook example

PHYSICAL REVIEW C **94**, 064616 (2016)

Multinucleon transfer reactions in the $^{40}Ar + ^{208}Pb$ system

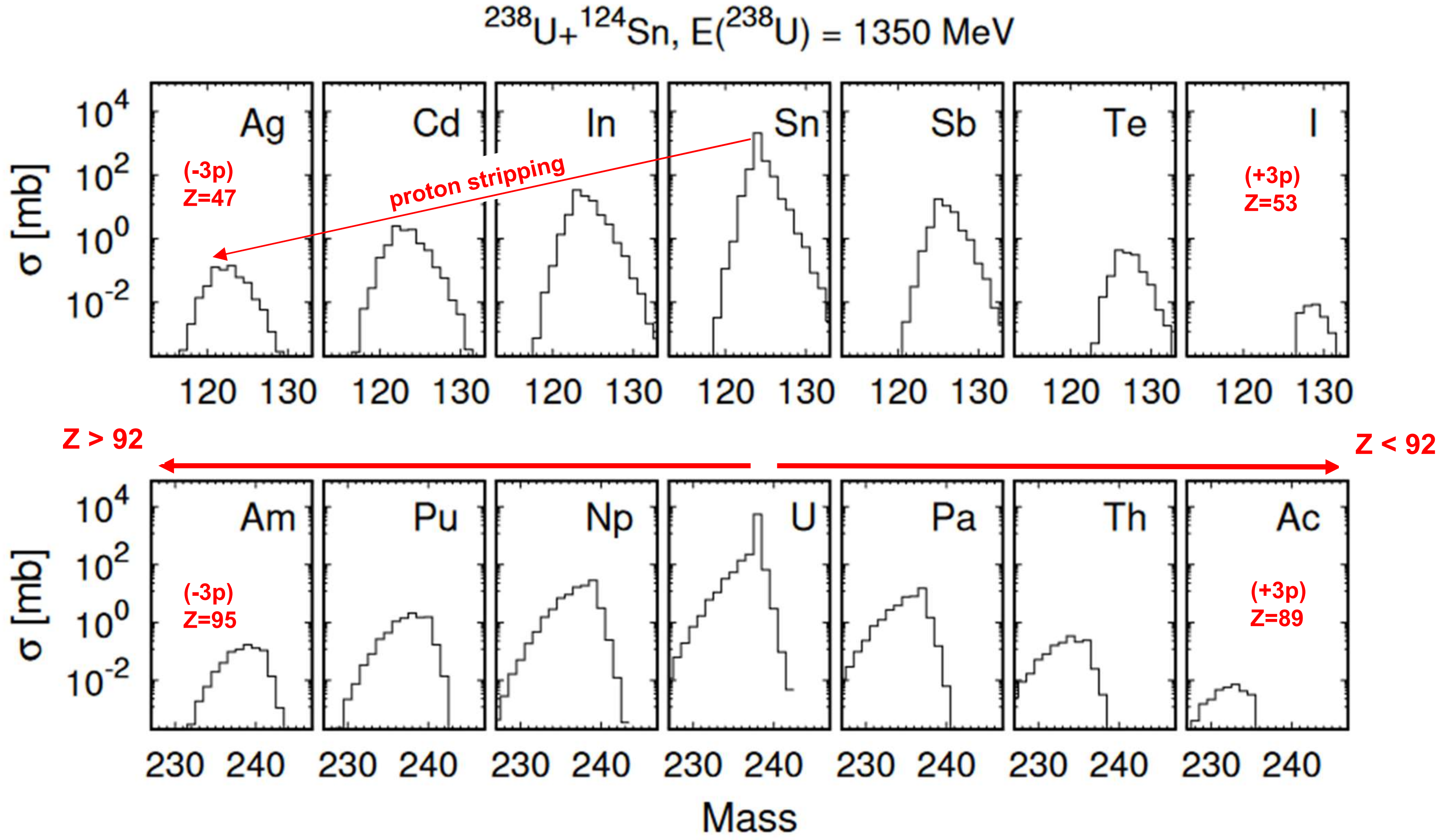
T. Mijatović,[1,*] S. Szilner,[1] L. Corradi,[2] D. Montanari,[3,4] G. Pollarolo,[5] E. Fioretto,[2] A. Gadea,[6] A. Goasduff,[2] D. Jelavić Malenica,[1] N. Mărginean,[7] M. Milin,[8] G. Montagnoli,[3] F. Scarlassara,[3] N. Soić,[1] A. M. Stefanini,[2] C. A. Ur,[7] and J. J. Valiente-Dobón[2]



S.Szilner et al., PRC71(2005)044610

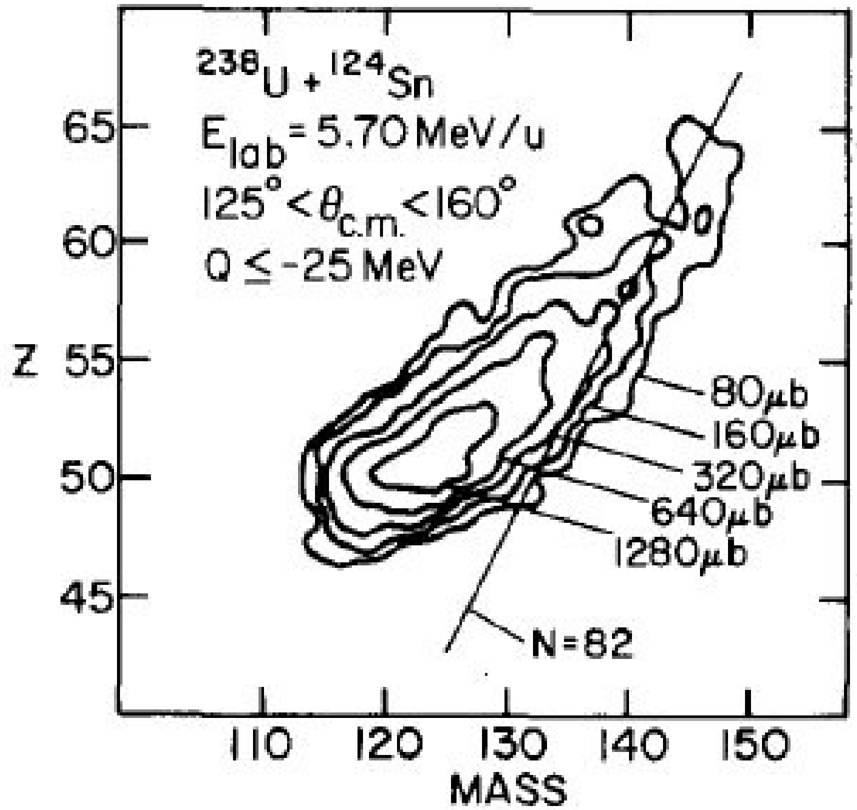
L.Corradi et al., PRC66(2002)024606

GRAZING cross section predictions for $^{238}U+^{124}Sn$

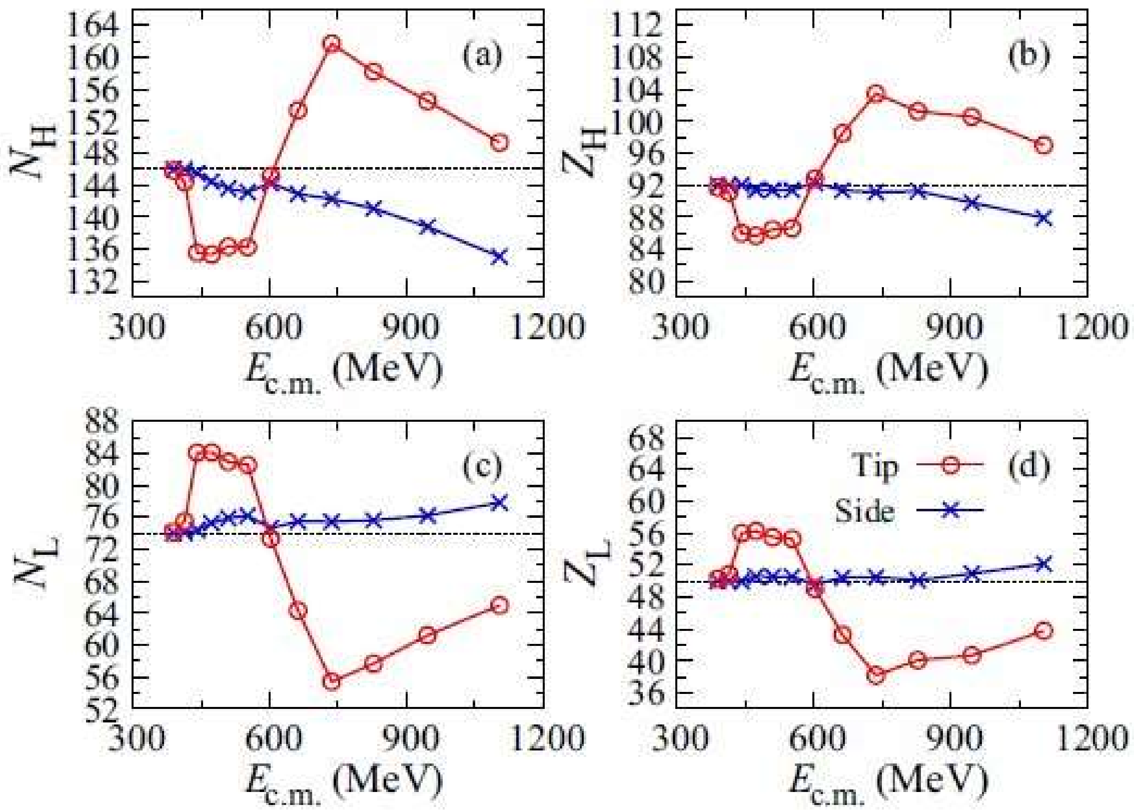


for multiproton transfer GRAZING predicts larger cross sections along the stripping direction and thus Z > 92 for the heavy partner

Light and heavy transfer products in $^{238}U + ^{124}Sn$



W.Mayer et al., Phy. Lett. B 152, 162 (1985)

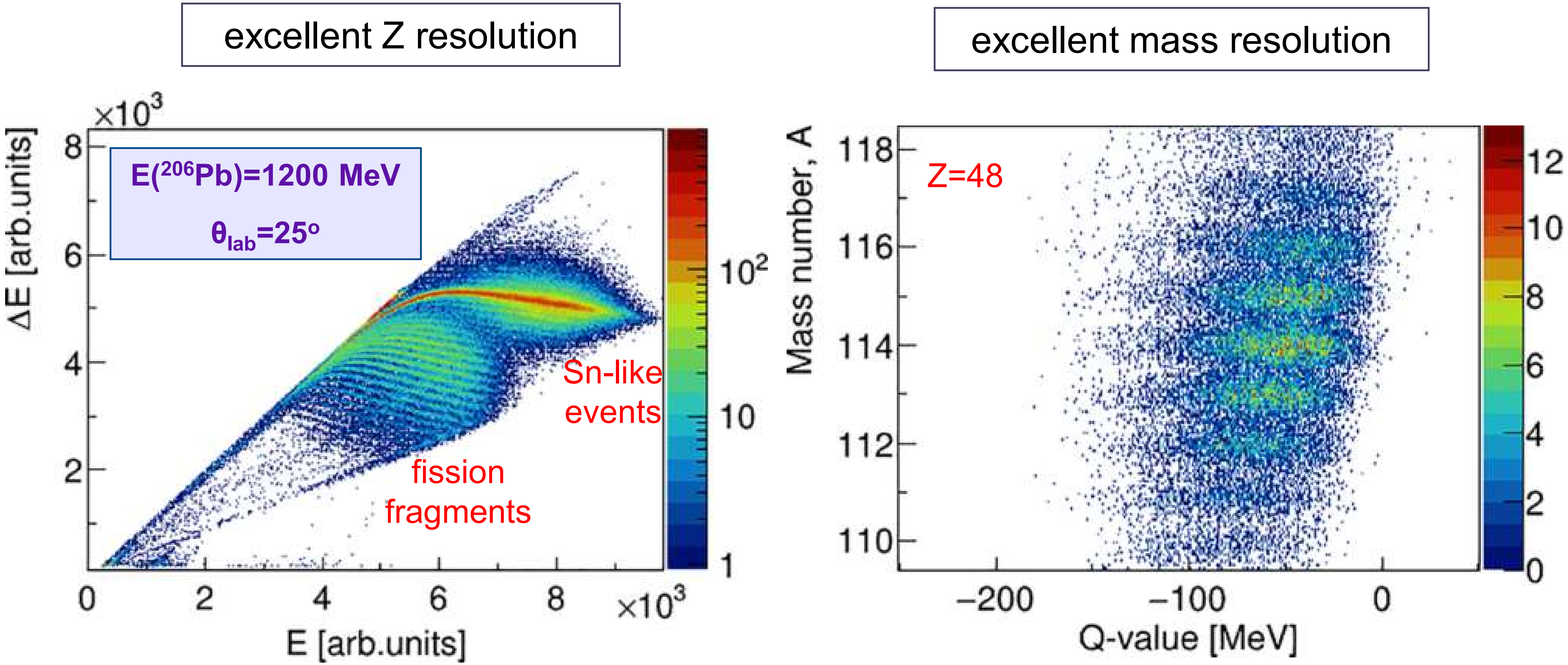


K.Sekizawa, Phys. Rev. C 96, 041601R (2008)

average A,Z,Q-value distributions measured with large area gas detectors show higher cross sections along the proton pick-up direction

TDHF calculations indicate a change of proton flux with bombarding energy and a dependence on nuclear orientation

Multinucleon transfer reactions in $^{206}Pb+^{118}Sn$



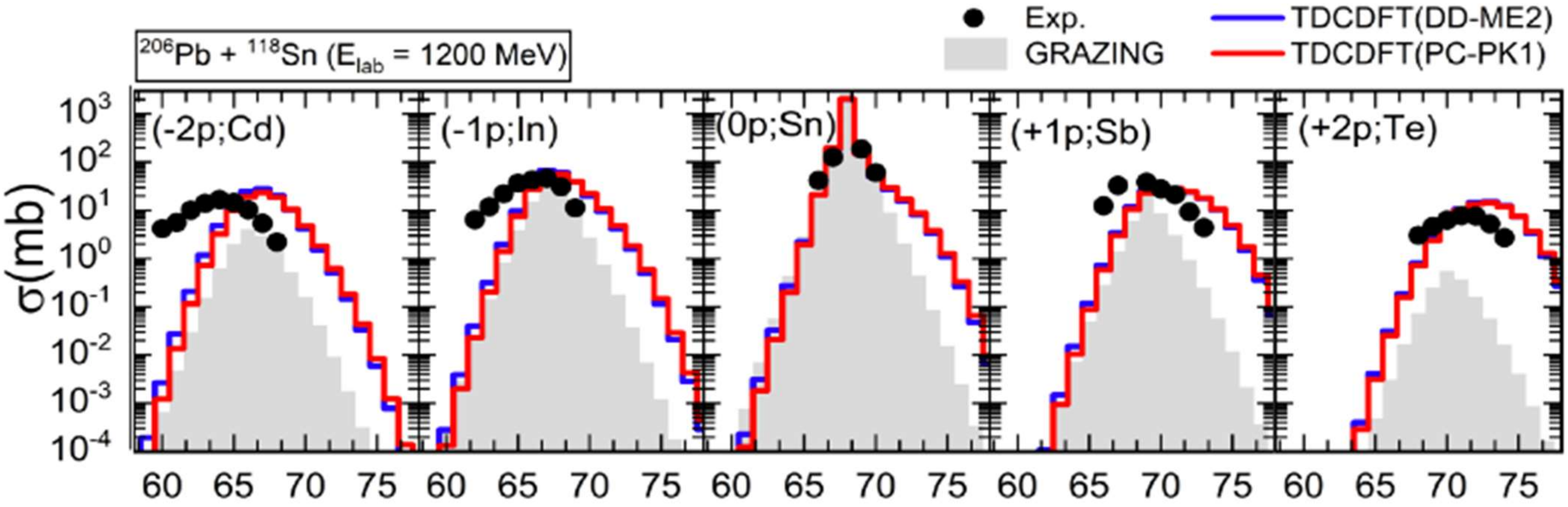
a wealth of transfer channels could be measured with high Z,A,Q-value resolutions with the large magnetic spectrometer PRISMA. Experimental differential and total cross sections have been compared with theoretical calculations and more reliable extrapolations can be made for the production of n-rich heavy partners

J. Diklic et al., Phys. Rev. C 107, 014619 (2023)

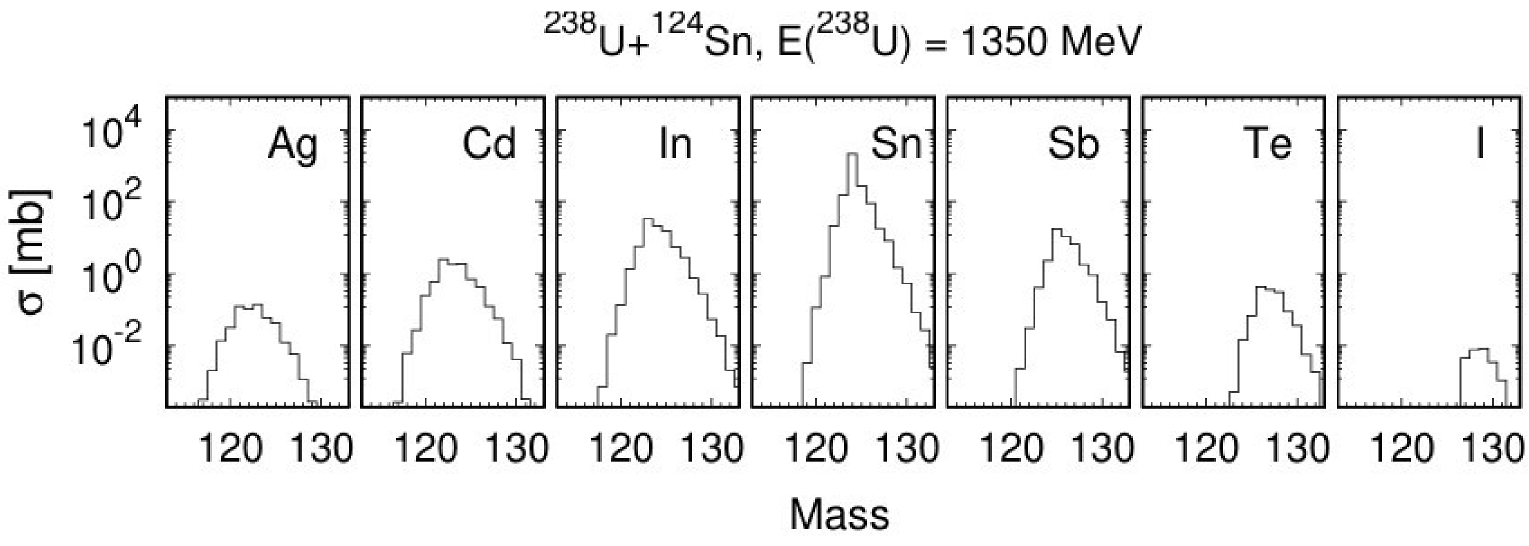
PHYSICAL REVIEW C **109**, 024614 (2024)

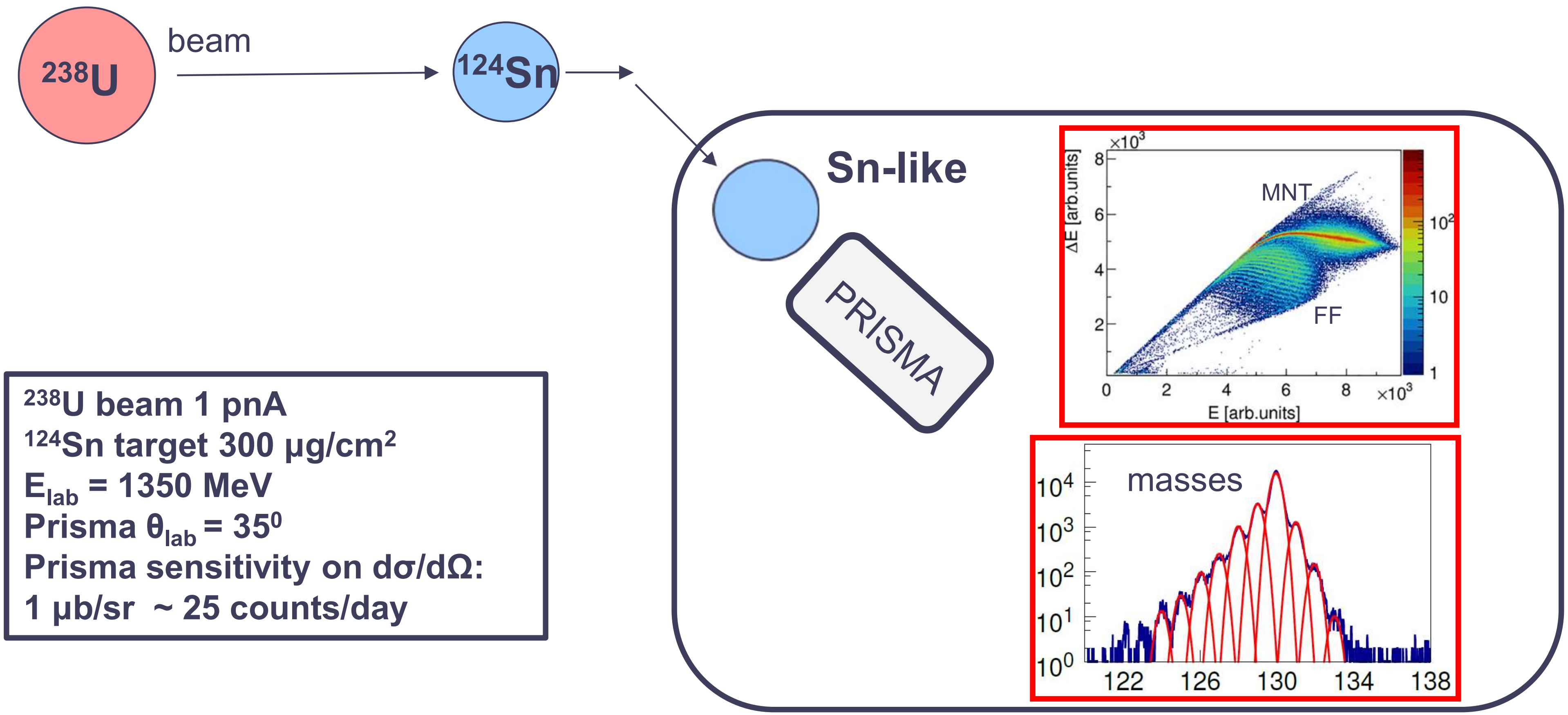
Multinucleon transfer with time-dependent covariant density functional theory

D. D. Zhang,[1] D. Vretenar,[2,1,*] T. Nikšić,[2,1] P. W. Zhao,[1,†] and J. Meng[1,‡]



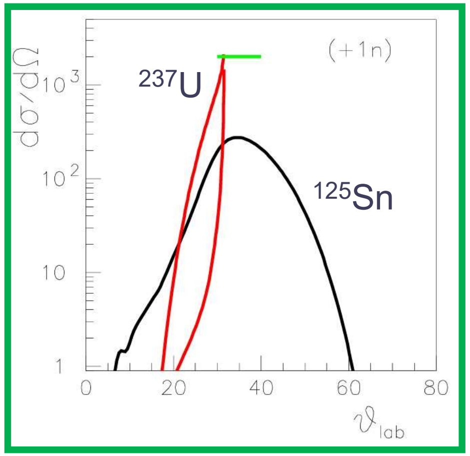
$^{238}U + ^{124}Sn$ MNT measurement

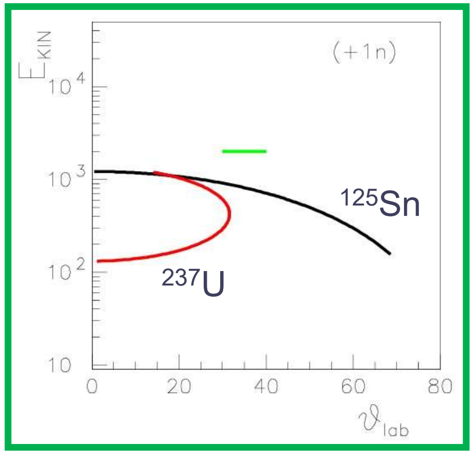




^{238}U beam 1 pnA
^{124}Sn target 300 μg/cm^2
E_{lab} = 1350 MeV
Prisma θ_{lab} = 35^0
Prisma sensitivity on dσ/dΩ:
1 μb/sr ~ 25 counts/day

$^{238}U+^{124}Sn$ MNT measurement





^{238}U beam ^{124}Sn

U-like

NOSE

U-like

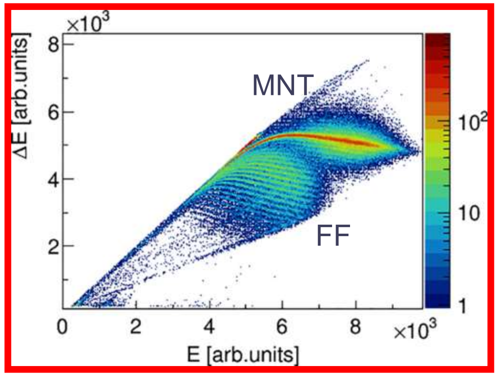
kinematic coincidence:

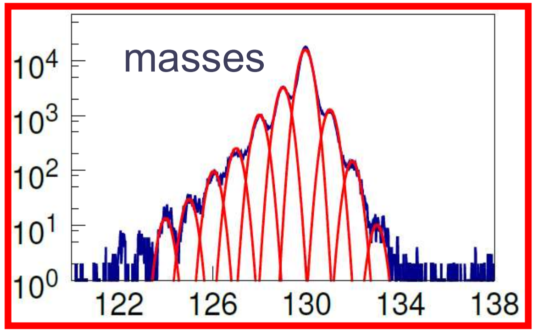
light – heavy mass-mass correlation

determination of transfer induced fission probability

Sn-like

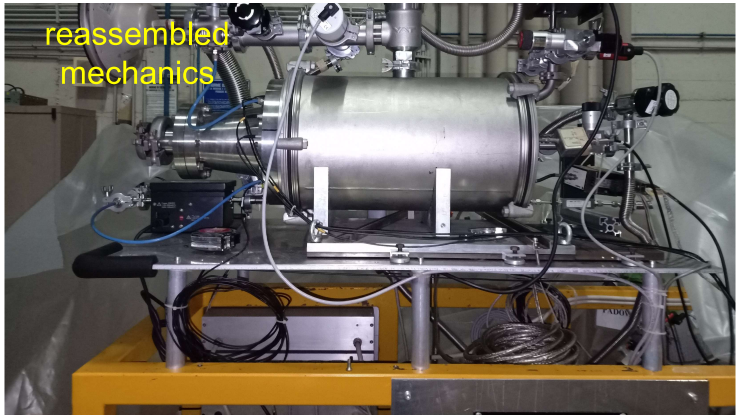
PRISMA

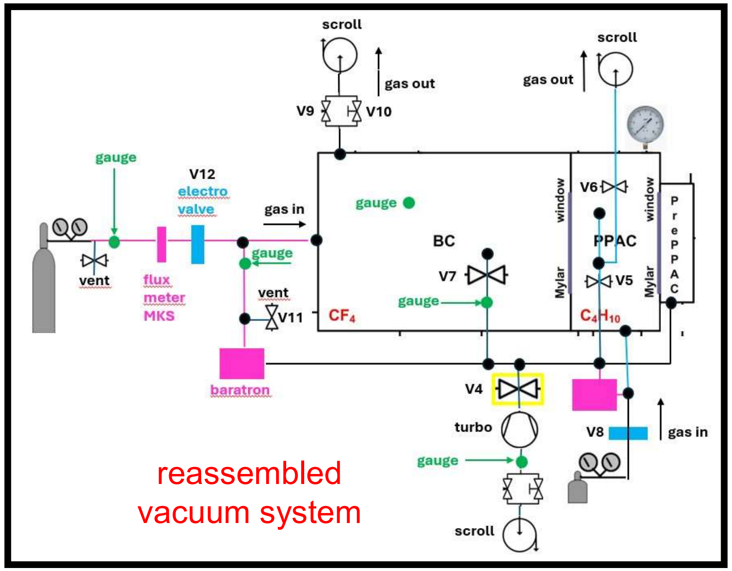


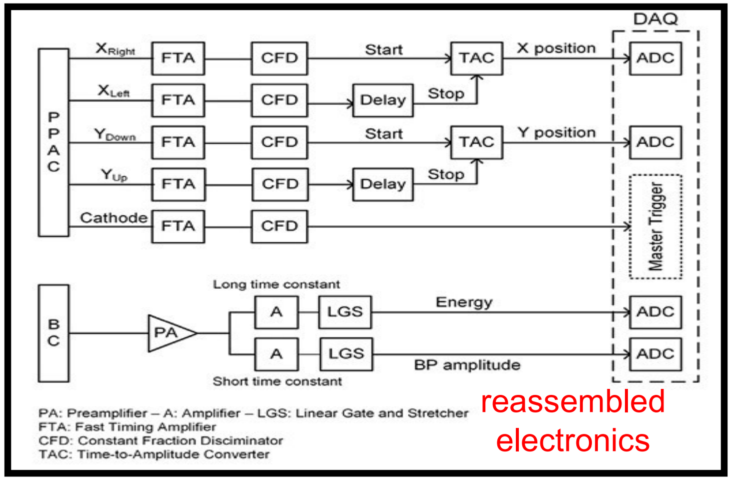


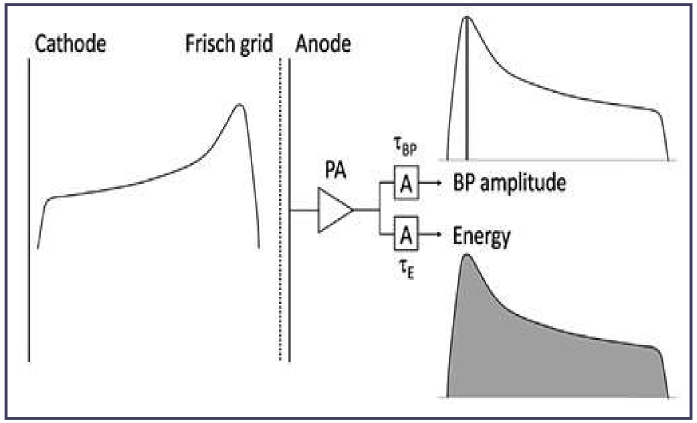
^{238}U beam 1 pnA
^{124}Sn target 300 μg/cm^2
E_{lab} = 1350 MeV
Prisma θ_{lab} = 35^0
Nose θ_{lab} = 35^0
Prisma sensitivity on dσ/dΩ:
1 μb/sr ~ 25 counts/day

Second arm (NOSE)

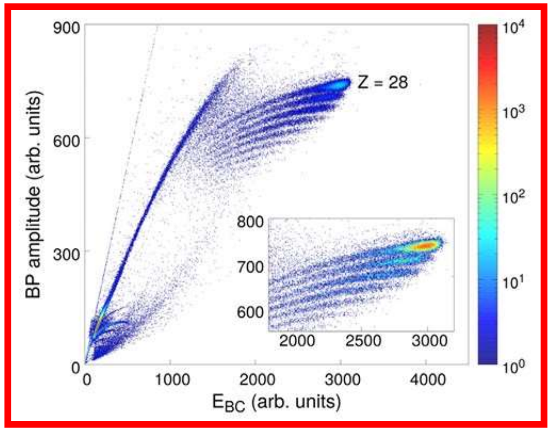


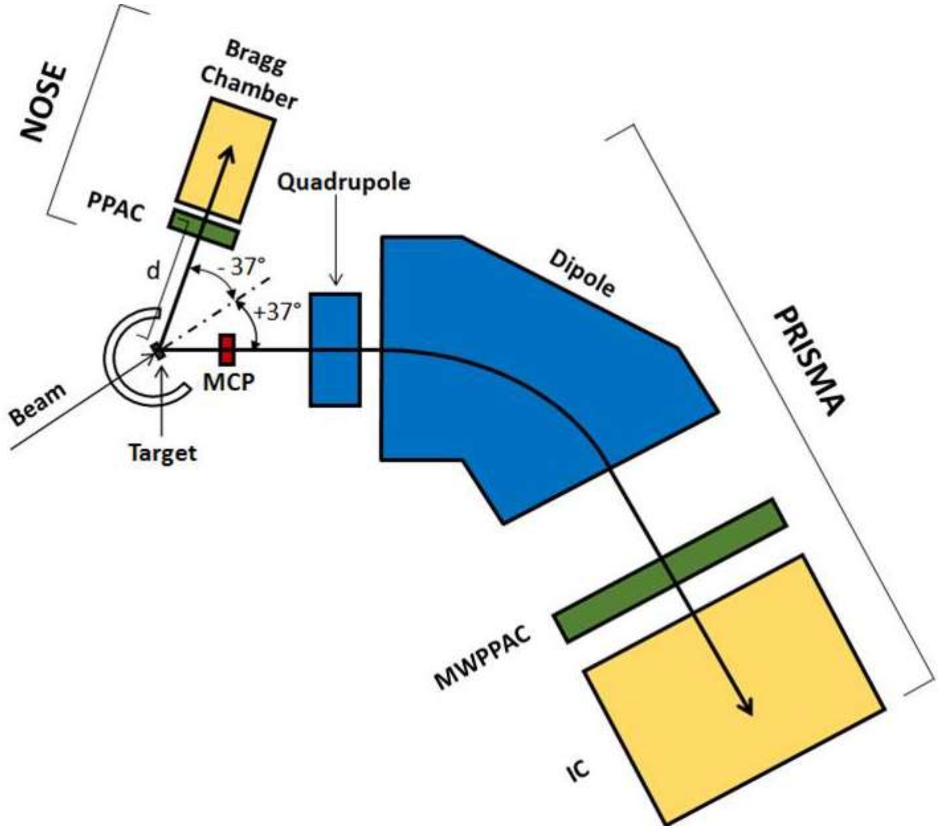






Bragg peak vs energy

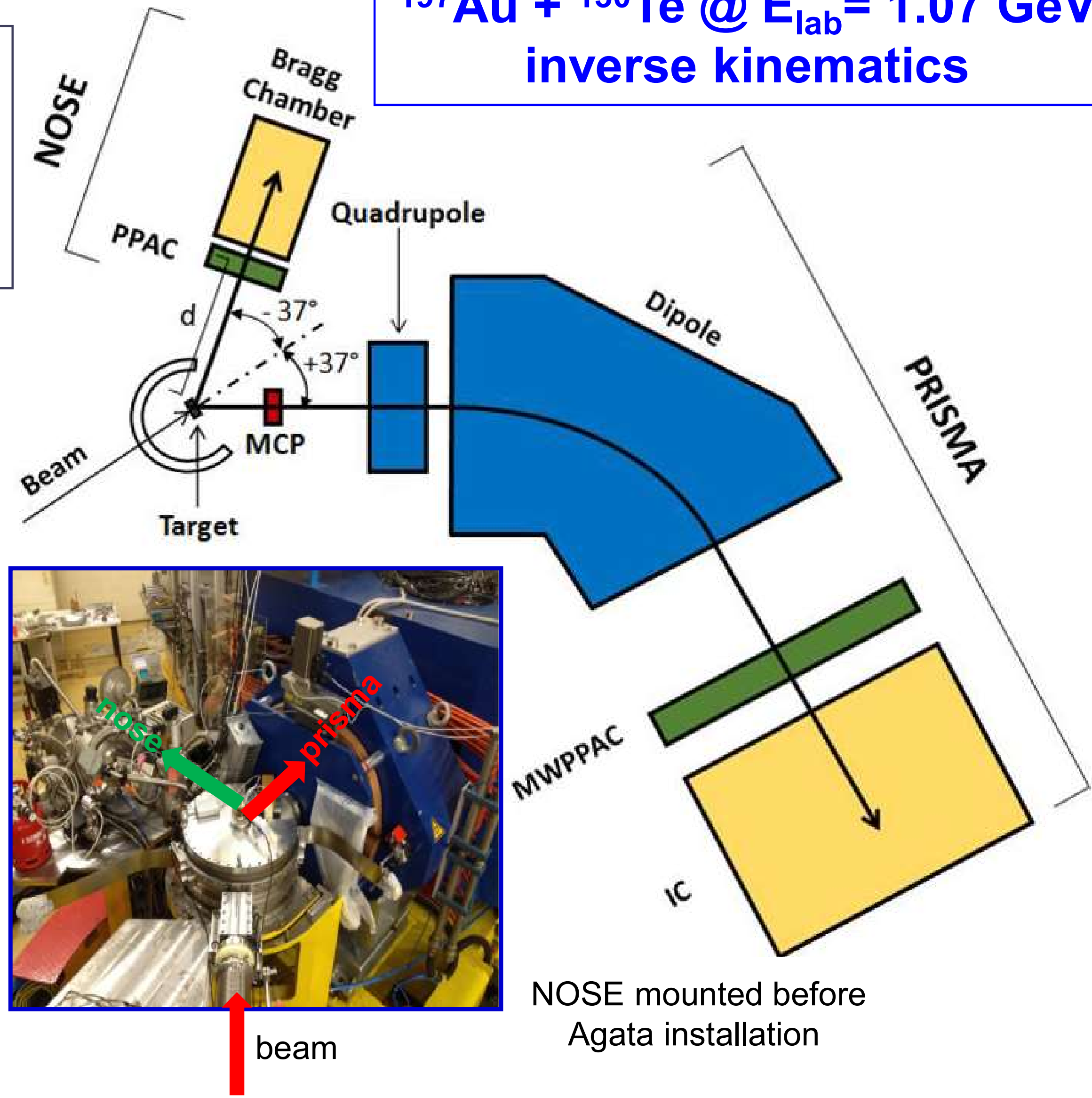




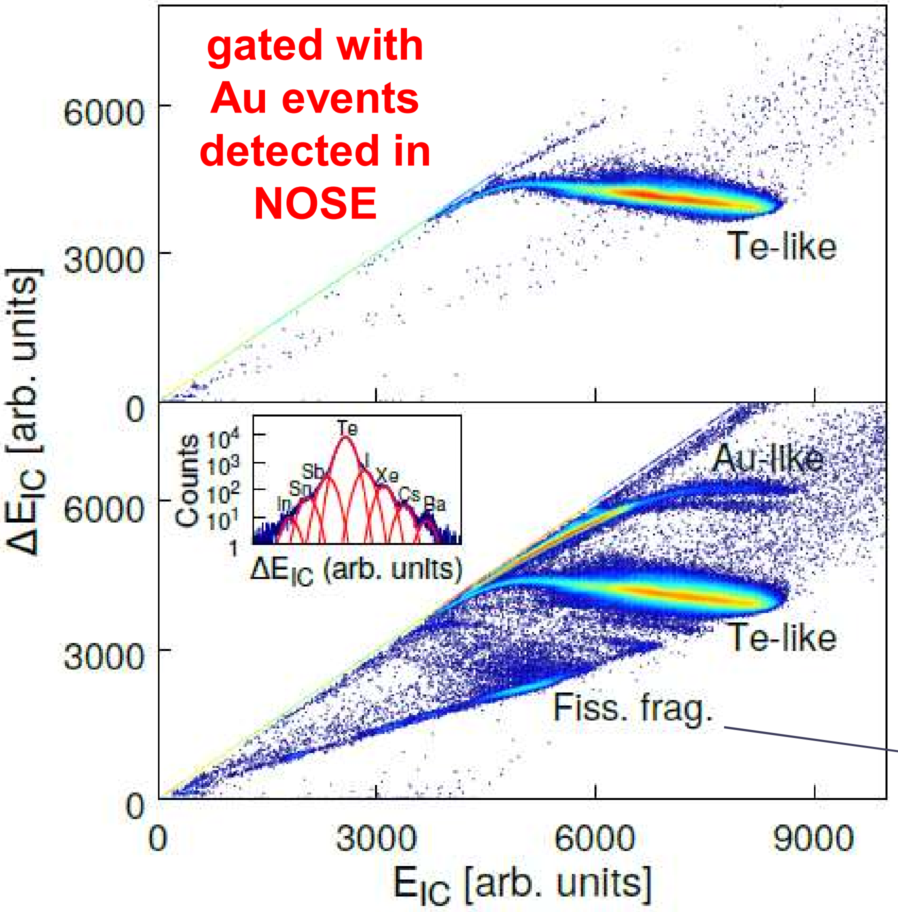
The $^{197}Au+^{130}Te$ experiment with the PRISMA spectrometer

PRISMA spectrometer used in high resolution kinematic coincidence with a second time-of-flight system (NOSE)

$^{197}Au + ^{130}Te$ @ E_{lab}= 1.07 GeV inverse kinematics



NOSE mounted before Agata installation



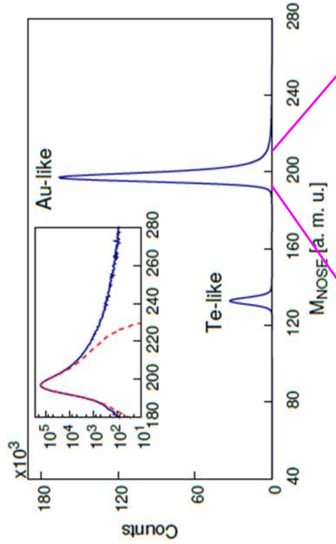
fission events derive probably from transfer induced fission or quasi fission

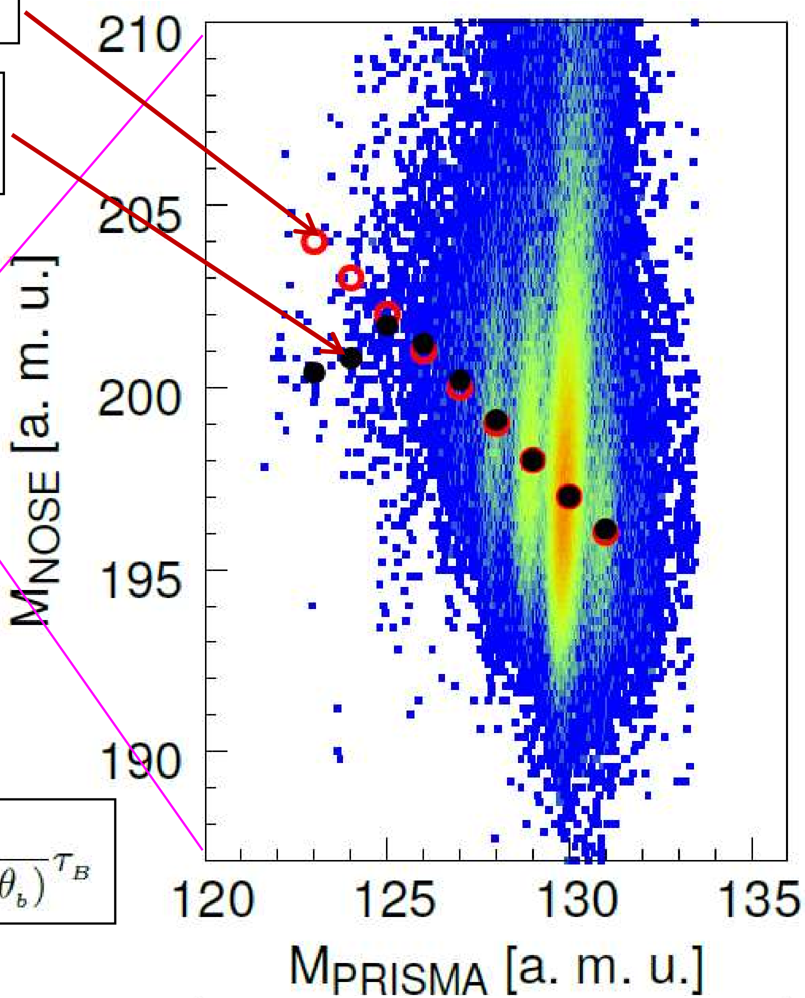
F.Galtarossa et al., Phys. Rev. C97(2018)054606

$^{197}Au+^{130}Te$: mass-mass correlation matrix

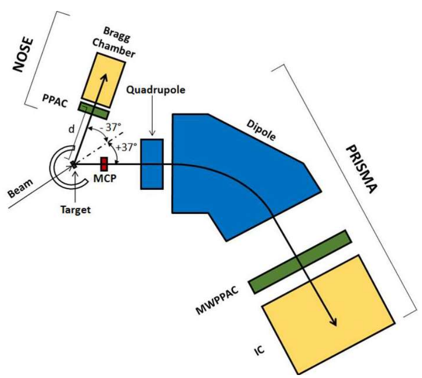
centroids of primary fragments

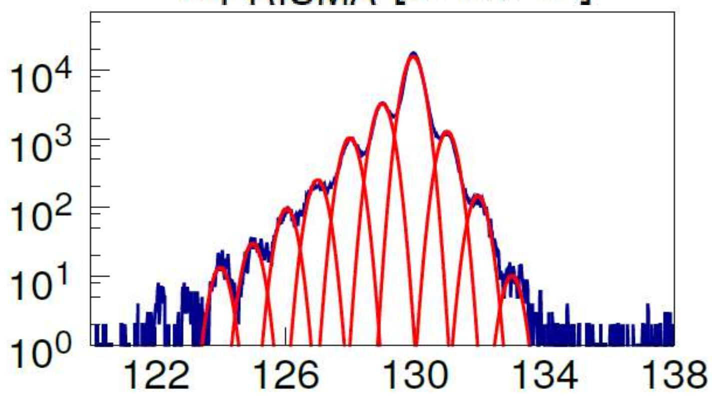
experimental centroids



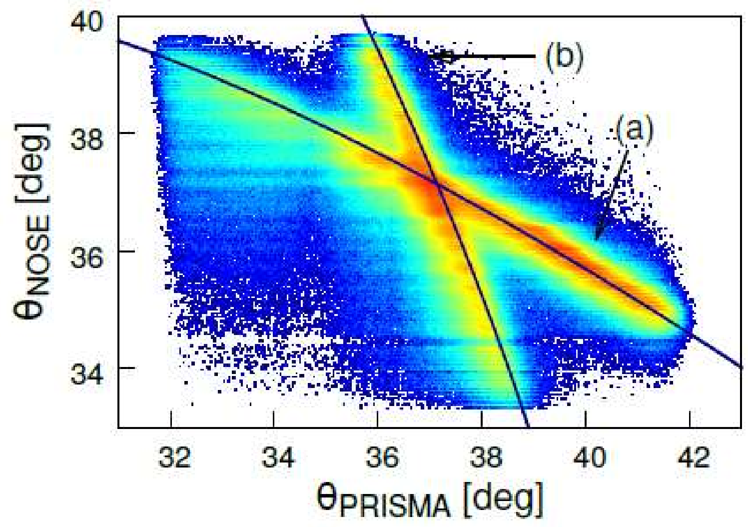


$$M_B = \frac{p_0}{d}\frac{sin\theta_b}{sin(\theta_B+\theta_b)}\tau_B$$





angle-angle correlation matrix

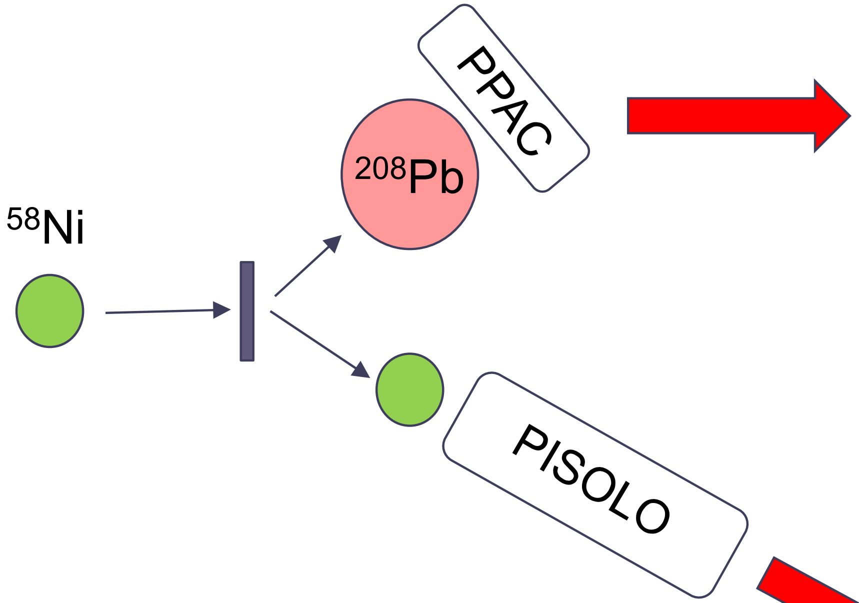


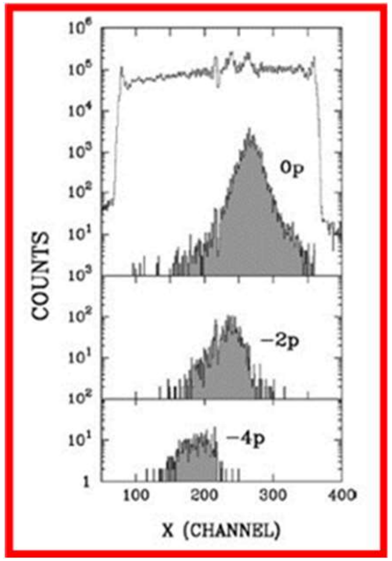
high resolution kinematic coincidence

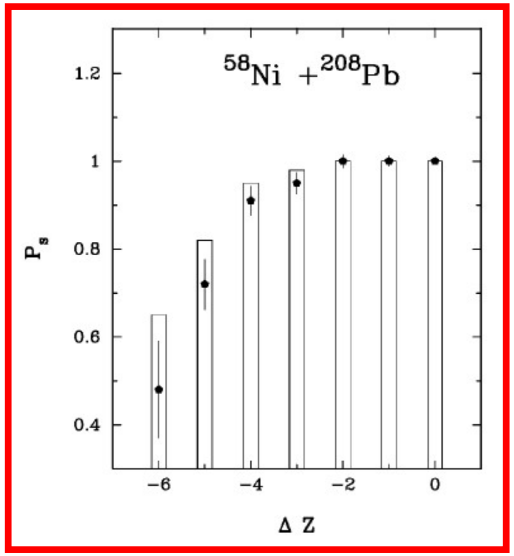
the identification in mass of the light fragment with high resolution allows to separate the mass distribution of the heavy partner in well defined bands, whose centroids and widths depend on secondary processes

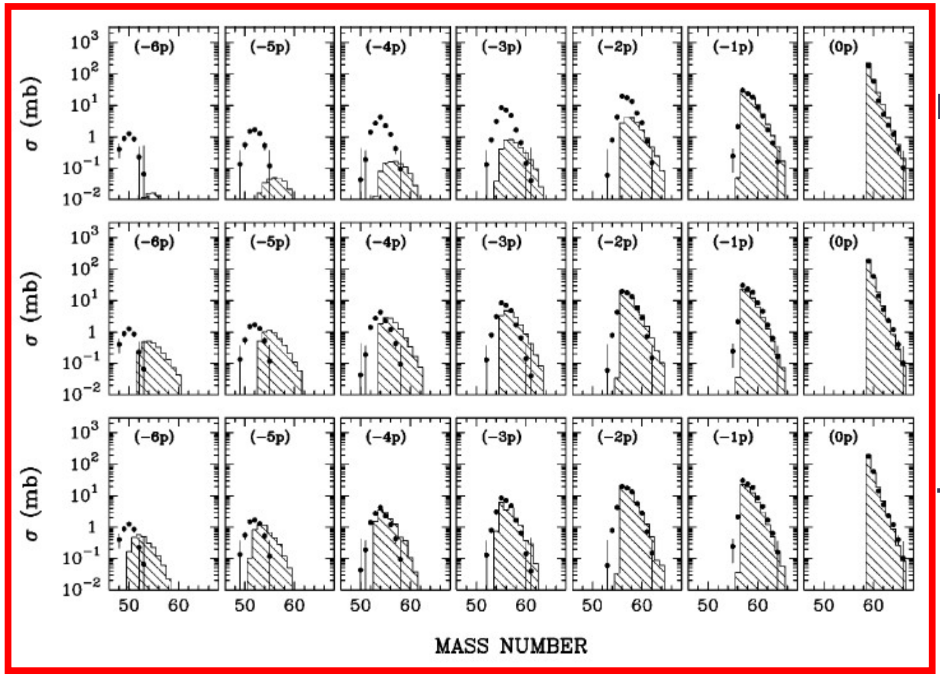
F.Galtarossa et al., Phys. Rev. C 97 (2018) 054606

Detection of light and heavy transfer products in $^{58}Ni+^{208}Pb$









ind. part. tr. only

+ pair mode

+ evap

fission probability of heavy partners determined from the ratio of binary coincidences to singles

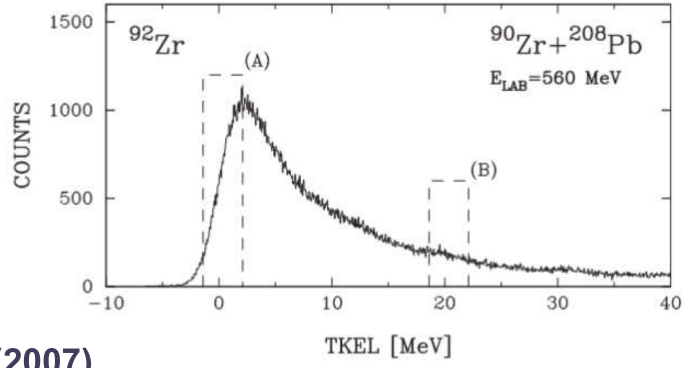
GRAZING and CWKB calculations for transfer cross sections → excitation energy and angular momentum of Ni, Pb → PACE2 → transfer induced fission

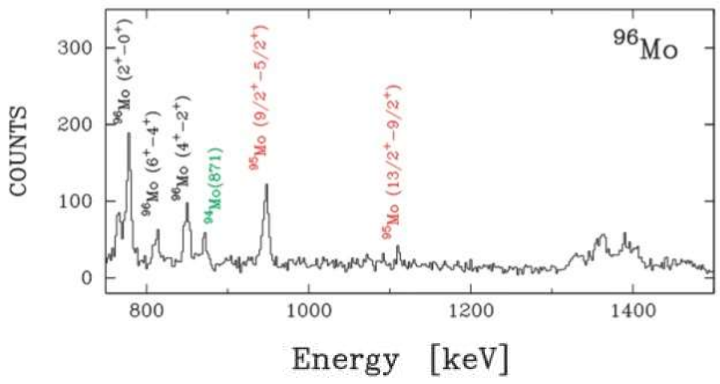
L.Corradi et al, Phys.Rev.C 66 (2002) 024606

why AGATA is fundamental for this $^{238}U+^{124}Sn$ MNT measurement

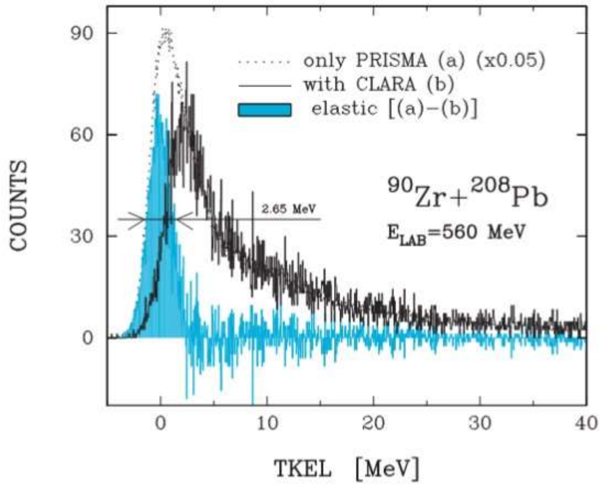
quantify the TKEL dependence of the transfer strength to excited states and the effects of evaporation

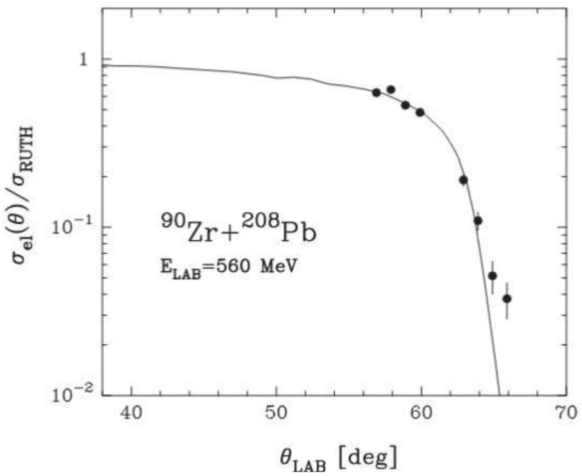
S.Szilner et al., PRC76,024604(2007)





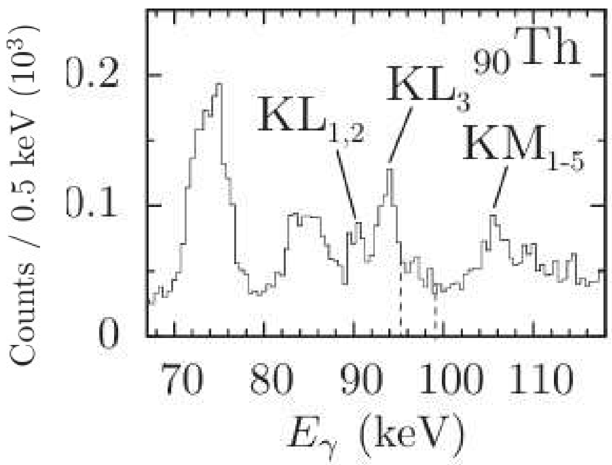
determine the elastic/inelastic strength, important for reaction models. Fission is the main source of depletion from quasi-elastic channels

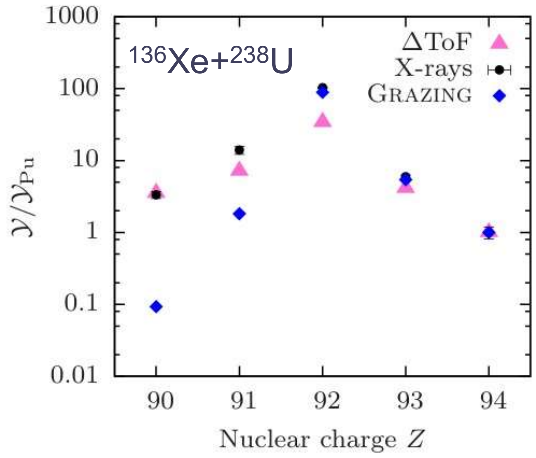


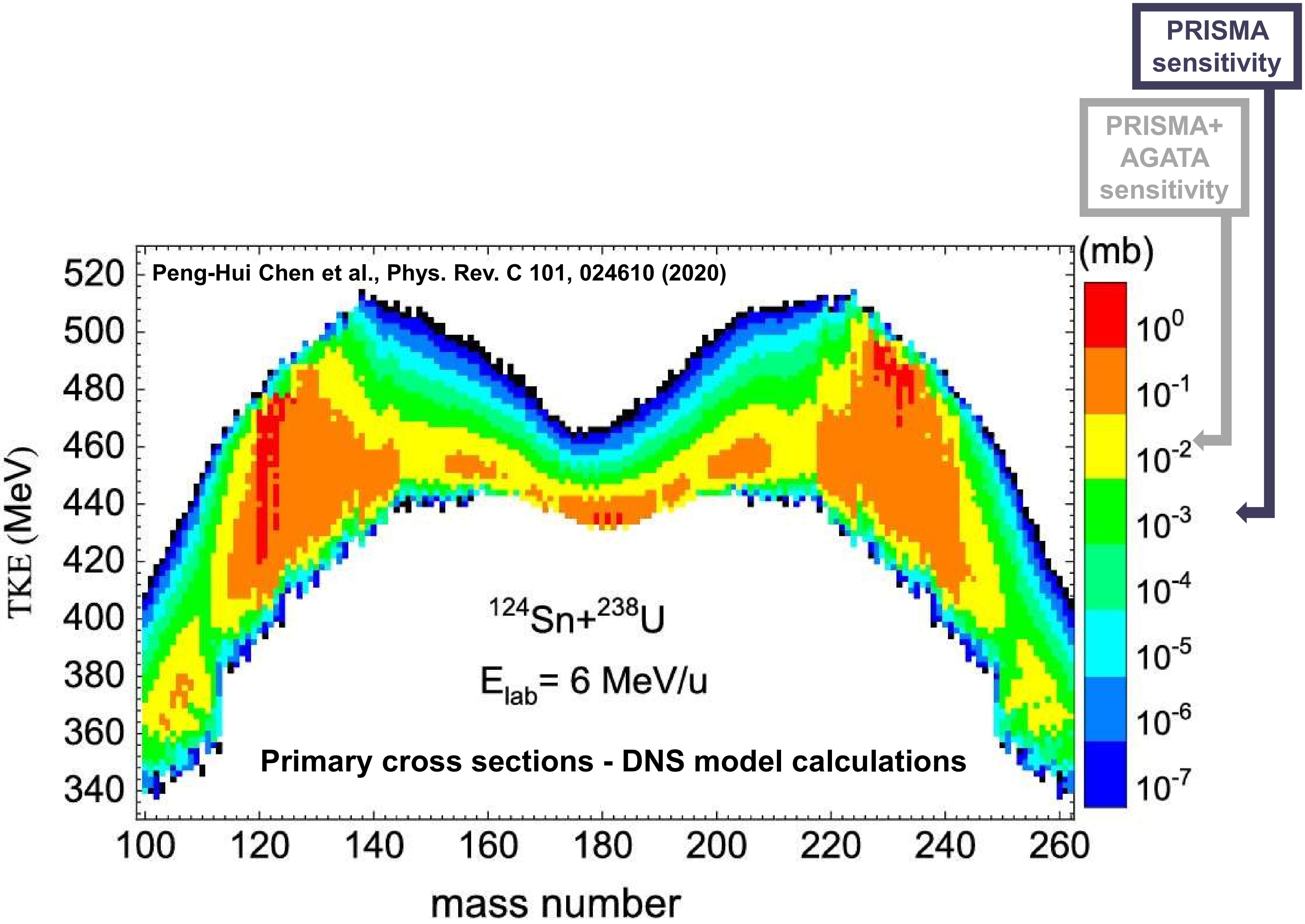


X-ray coincident detection for Z determination of the heavy partner and corresponding yields

A.Vogt et al., PRC92,024619(2015)

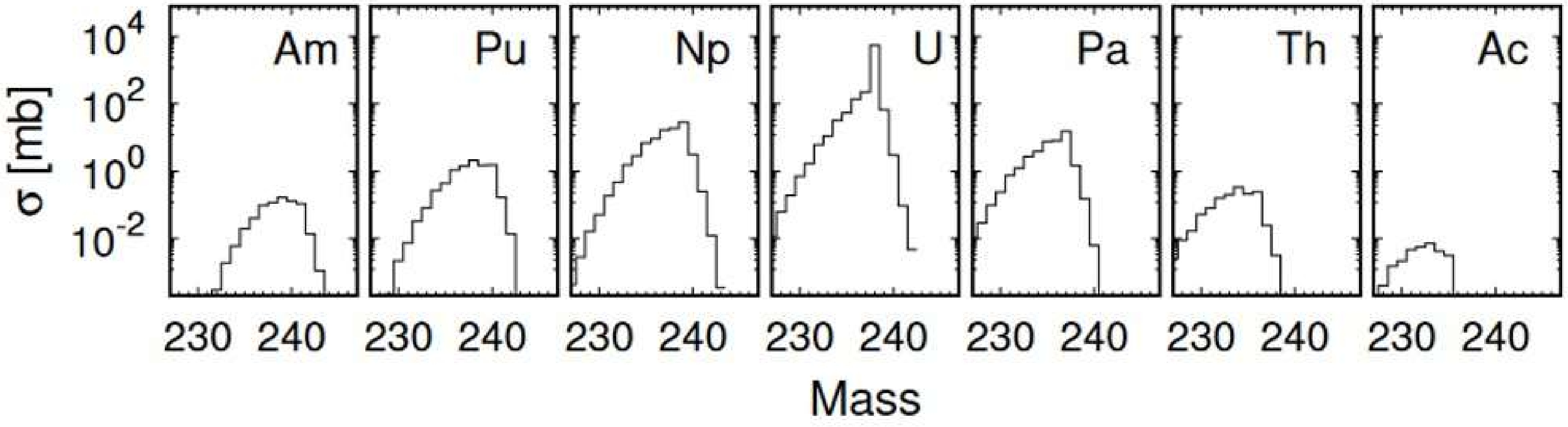






PRISMA sensitivity
PRISMA+ AGATA sensitivity
(mb)
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
Peng-Hui Chen et al., Phys. Rev. C 101, 024610 (2020)
TKE (MeV)
520
500
480
460
440
420
400
380
360
340
$^{124}Sn+^{238}U$
E_{lab}= 6 MeV/u
Primary cross sections - DNS model calculations
100
120
140
160
180
200
220
240
260
mass number

Some nuclear regions which are interesting for spectroscopy



nuclei around 228-232U are predicted to exhibit a transition from octupole vibrations to g.s. octupole deformation. In the neutron-rich region we can complete the g.s. rotational bands (high angular momenta)

in the Th chain one does not know yet the full set of E2 and E3 matrix elements

232Pu	233Pu	234Pu	235Pu	236Pu	237Pu	238Pu	239Pu	240Pu	241Pu	242Pu	243Pu	244Pu
231Np	232Np	233Np	234Np	235Np	236Np	237Np	238Np	239Np	240Np	241Np	242Np	243Np
230U	231U	232U	233U	234U	235U	236U	237U	238U	239U	240U	241U	242U
229Pa	230Pa	231Pa	232Pa	233Pa	234Pa	235Pa	236Pa	237Pa	238Pa	239Pa	240Pa	241Pa
228Th	229Th	230Th	231Th	232Th	233Th	234Th	235Th	236Th	237Th	238Th	239Th	

Light and heavy transfer products in $^{238}U+^{124}Sn$

physics goal
study the A,Z,Q-value distributions and associated σ for the population of nuclei around Z=92 → comparison with state-of-art theories

best possible characterization of the heavy partner via high resolution kinematic coincidences Prisma-Nose

→ construction of light-heavy mass-mass correlations (evaporation)
→ measurement of transfer induced fission probability
→ γ-ray detection of binary partners with Agata (inelastic, transfer strength to excited states, identification of evaporative processes)

a well taken case

- average cross sections available from low resolution measurements (reference)
- neutron rich beam-target combination suitable for the population of pick-up and stripping channels at the same time
- mass of Sn-like nuclei can be clearly identified with Prisma
- grazing angles for Sn- and U-like nuclei quite the same in inverse kinematics

→ it well fits with the geometrical constraints of PRISMA+NOSE
→ interchange of ion detection with Prisma and Nose for yields checks

Beam time request : 14 days

^{238}U beam 1 pnA
^{124}Sn target 300 μg/cm^2
E_{lab} = 1350 MeV
Prisma $\theta_{lab} = 35^0$
Nose $\theta_{lab} = 35^0$

experimental conditions

Prisma sensitivity on $d\sigma/d\Omega$:
1 μb/sr ~ 25 counts/day

assuming 8-10 masses for the (4p) channel → 10 days of beam time to accumulate a 20% statistical error on the average of the mass yields

measurement

Setting up Prisma+Nose+Agata
→ 2 days

Bρ scanning to check transmission (DIC components)
→ 2 days

additional needs