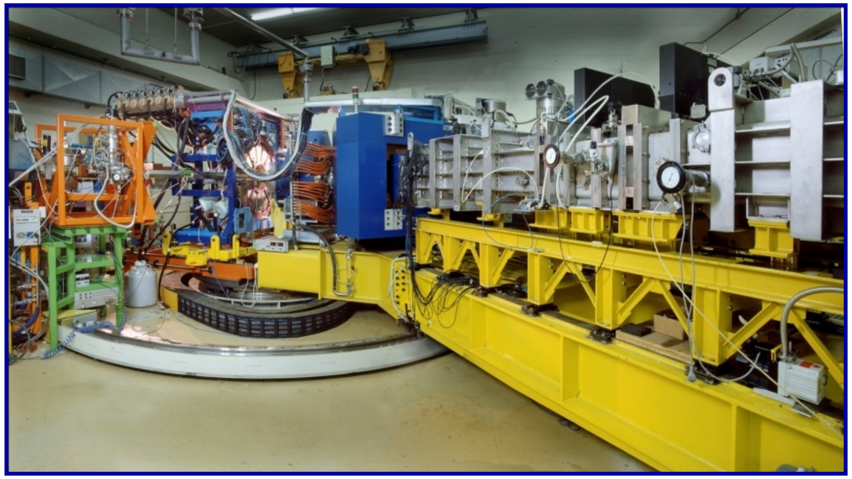
Nucleus Nucleus 2015

21-26 June 2015

Recent experiments in inverse kinematics with the magnetic spectrometer PRISMA



E. Fioretto

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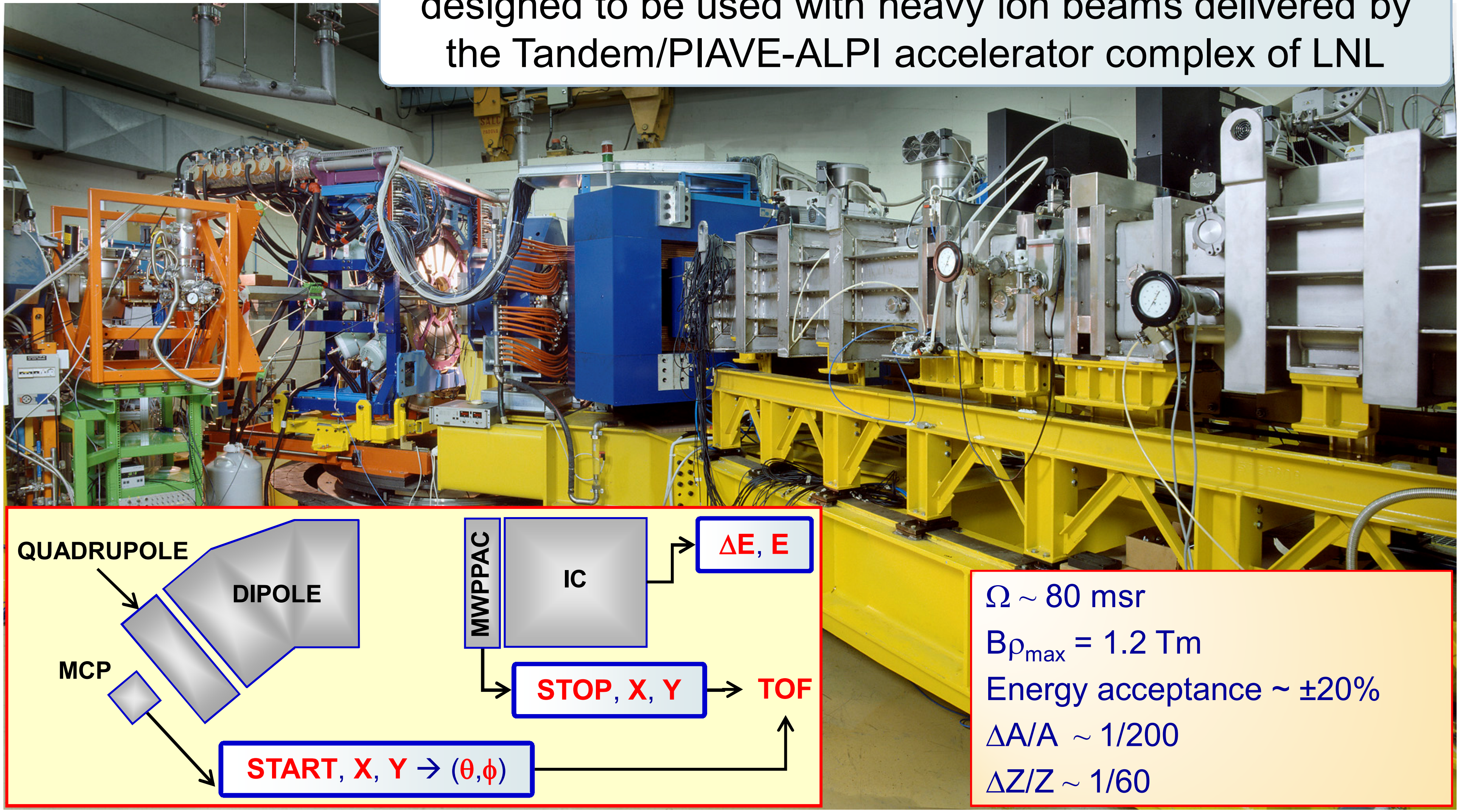
Outline

- The large solid angle magnetic spectrometer PRISMA
- Inverse kinematics reactions with the large acceptance magnetic spectrometer PRISMA
  - Transfer reactions at sub-barrier energies
    - $^{96}Zr+^{40}Ca$ (closed shell nuclei)
    - $^{116}Sn+^{60}Ni$ (superfluid nuclei)
  - Population of neutron-rich nuclei via multinucleon transfer reactions
    - Neutron rich nuclei at N=82 and N=126
    - How to explore the neutron rich heavy region of the nuclear chart via multinucleon transfer reactions (MNT)
    - The LNL test experiment: $^{197}Au+^{130}Te$
- Summary

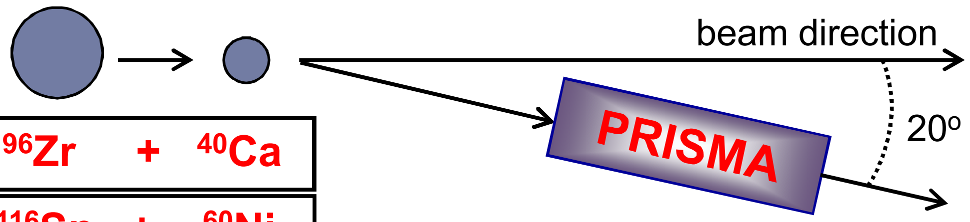
The PRISMA spectrometer

<u>PRISMA : a large acceptance spectrometer</u>
designed to be used with heavy ion beams delivered by the Tandem/PIAVE-ALPI accelerator complex of LNL



$\Omega \sim 80$ msr
$B\rho_{max} = 1.2$ Tm
Energy acceptance ~ ±20%
$\Delta A/A \sim 1/200$
$\Delta Z/Z \sim 1/60$

Sub-barrier transfer measurements



Reactions
^{96}Zr + ^{40}Ca
^{116}Sn + ^{60}Ni

Ground state Q-values

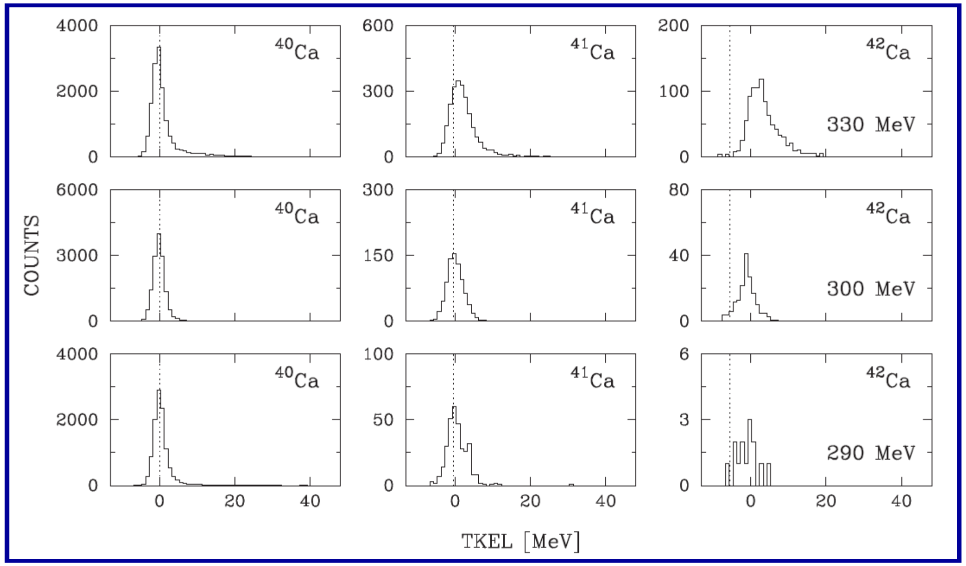
	+1n	+2n	+3n	+4n
$^{96}Zr + ^{40}Ca$	+ 0.51	+ 5.53	+ 5.24	+ 9.64
$^{116}Sn + ^{60}Ni$	- 1.74	+ 1.31	- 2.15	- 0.24

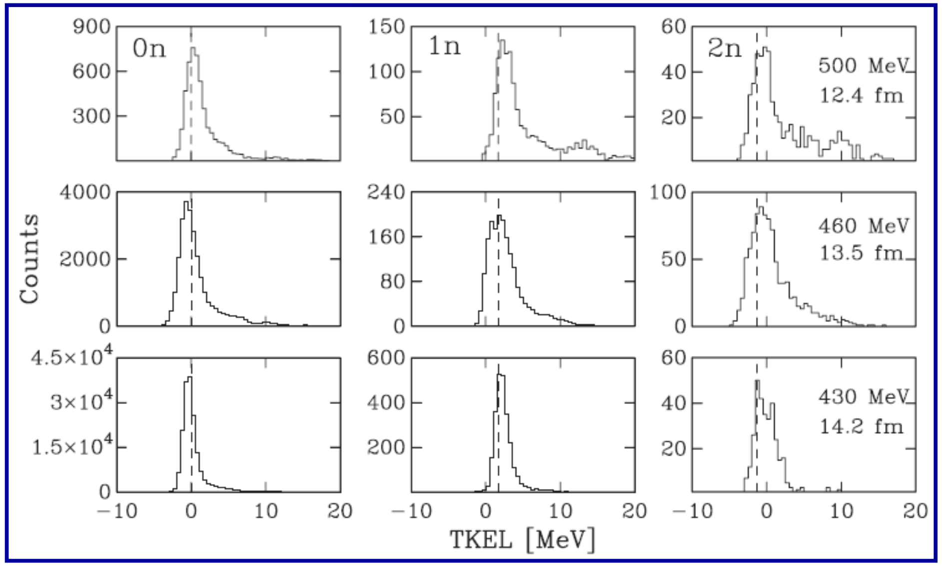
Excitation functions measured down to 25 % below the Coulomb barrier

E_{beam} = 330 MeV – 275 MeV
D= 12.3 - 15.4 fm

TKEL distributions

E_{beam} = 500 MeV – 410 MeV
D= 12.3 - 15.0 fm

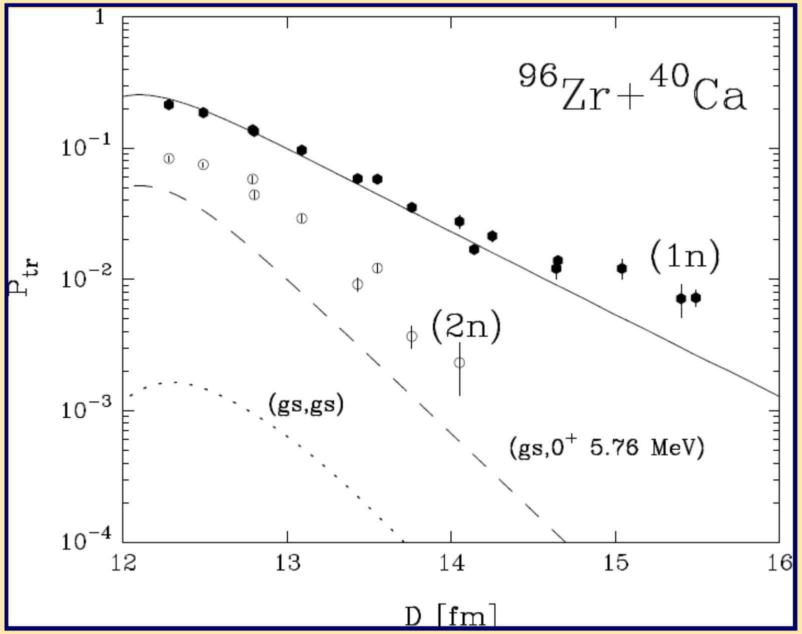




Transfer probabilities

Comparison between experimental data and microscopic calculations

$Q_{g.s.}$ for +2*n* + 5.5 MeV, far from Q_{opt} (~ 0 MeV)



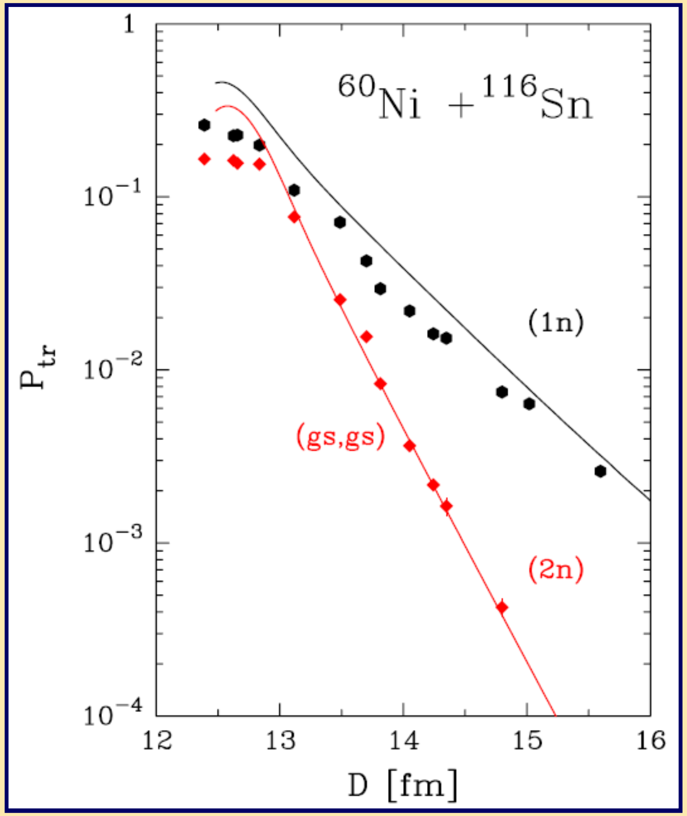
$$\frac{P_{tr}}{\sin(\theta_{c.m.}/2)} \propto \exp(-2\alpha D)$$

$$\alpha = \sqrt{\frac{2\mu B}{\hbar^2}}$$

$$D = \frac{Z_1 Z_2 e^2}{2E_{c.m.}}\left(1 + \frac{1}{\sin(\theta_{c.m.}/2)}\right)$$

L. Corradi et al,
Phys. Rev. C 84 (2011) 034603

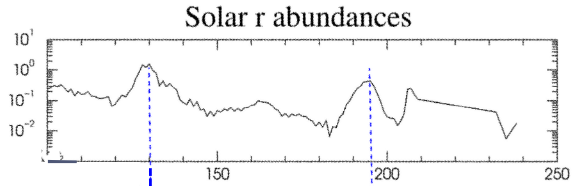
$Q_{g.s.}$ for +2n very close to Q_{opt} (~ 0 MeV)



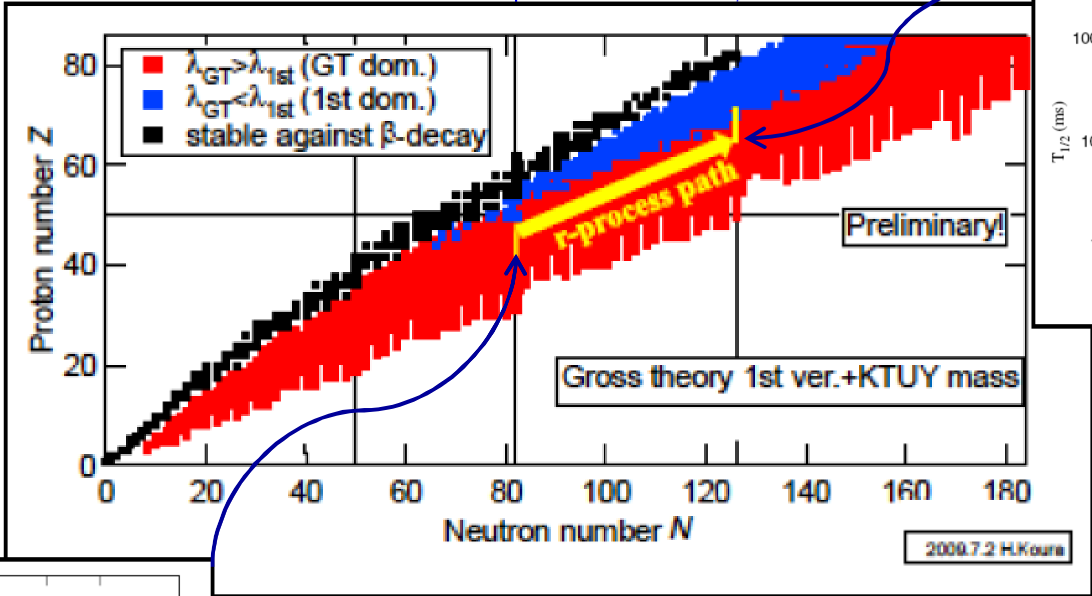
D. Montanari et al,
Phys. Rev. Lett. 113 (2014) 052501

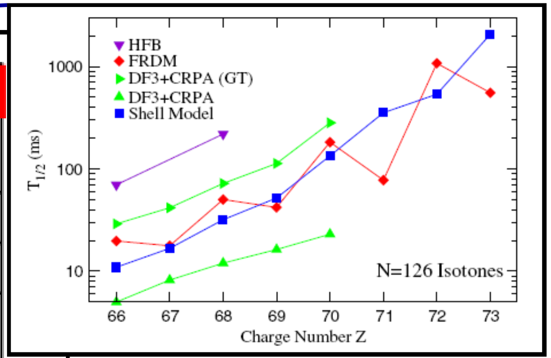
Neutron rich nuclei at N=82 and N=126

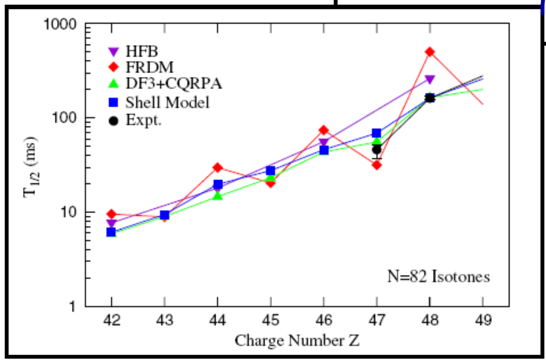
r-process and the importance of N = 82,126 shells



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





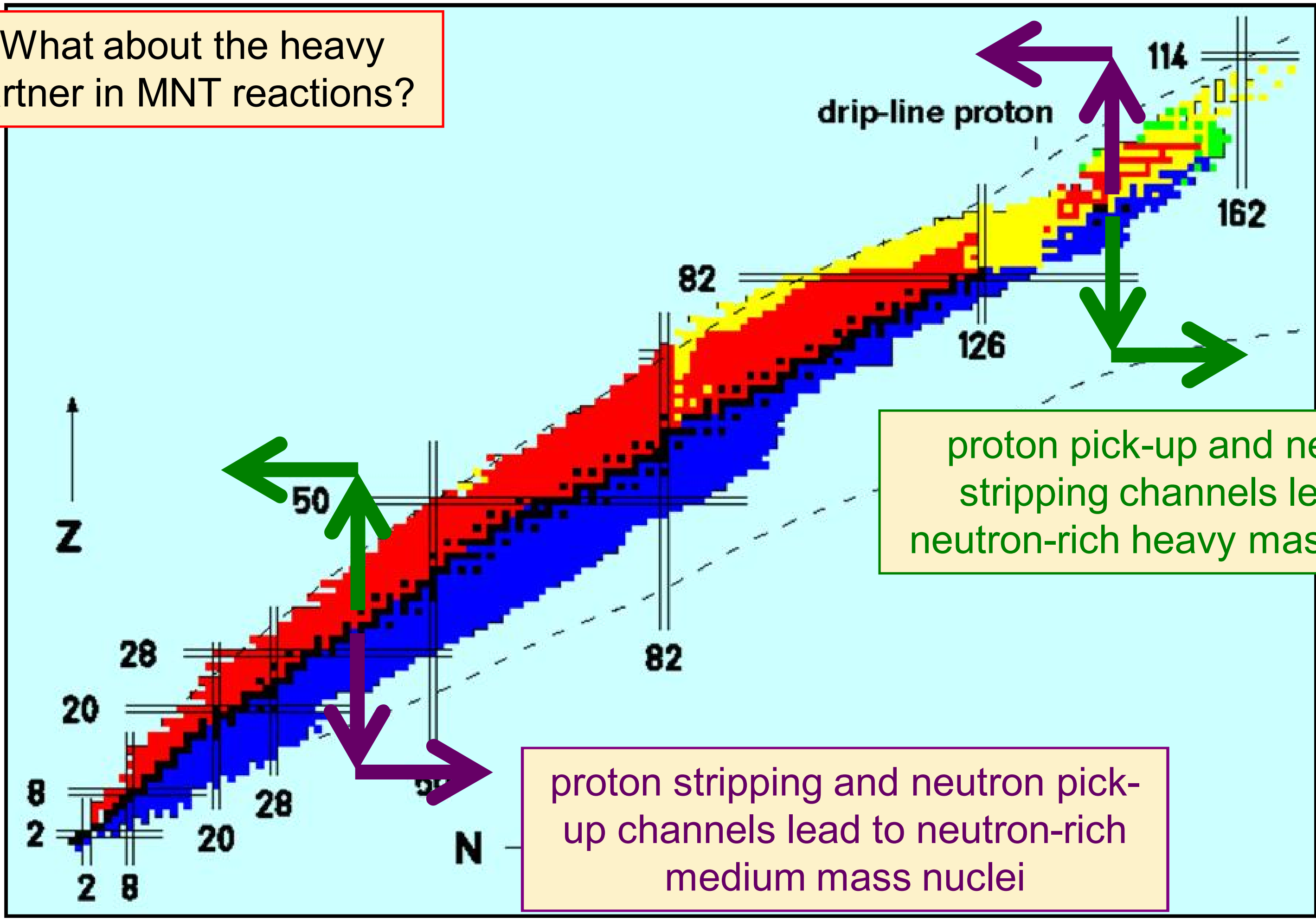


For nuclei with **N=82** on the r-process path the allowed **Gamow-Teller** (GT) **transitions are dominant**.

In the neutron shell closure **N=126** the **first forbidden transitions compete with the allowed transitions**, therefore the β-decay lifetimes are difficult to predict.

Population of neutron rich heavy nuclei via MNT

What about the heavy partner in MNT reactions?



proton pick-up and neutron stripping channels lead to neutron-rich heavy mass nuclei

proton stripping and neutron pick-up channels lead to neutron-rich medium mass nuclei

Certain regions of the nuclear chart, like that below ^{208}Pb or in the actinides, can be hardly accessed by fragmentation or fission reactions, and multinucleon transfer represents a complementary mechanism to approach those neutron rich areas.

Exploring the neutron rich heavy region via MNT

Two kinds of experiments need to be done

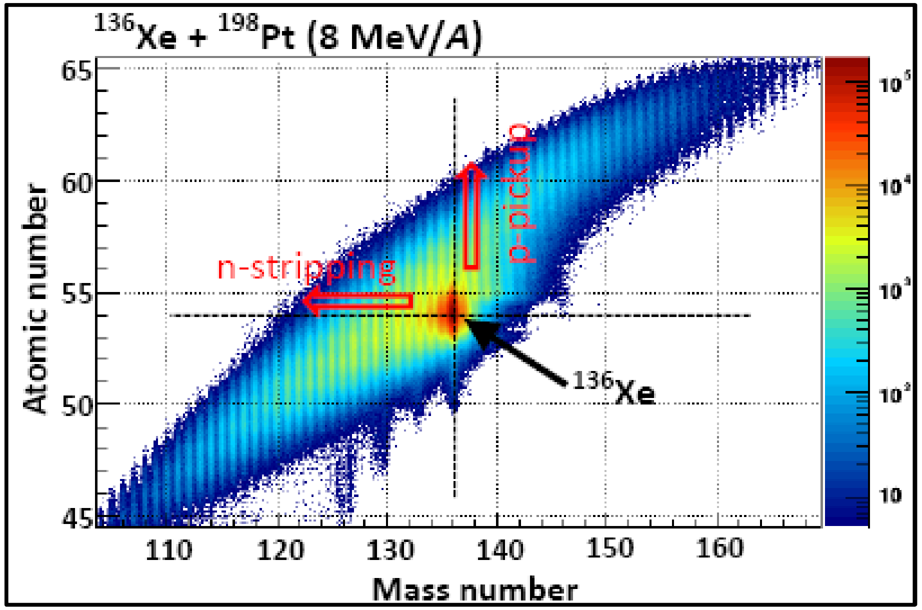
- **γ-particle coincidences**: tagging of the light partner with high resolution spectrometers and detecting coincident γ-rays Doppler corrected for the heavy partner
- **High resolution kinematic coincidences** between binary partners (direct or inverse kinematics)

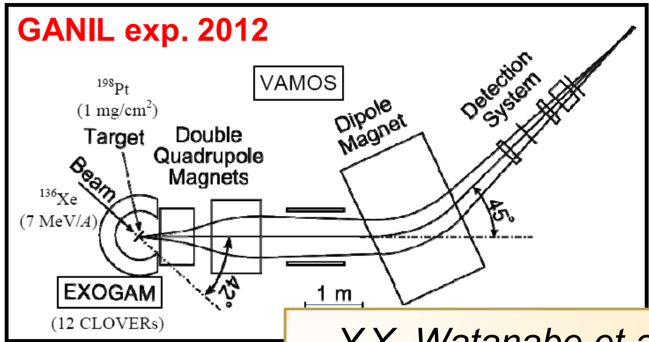
Onset of secondary processes

Evaporation and **transfer induced fission** shift the final yield to lower mass values. It is therefore extremely important to get quantitative information on the final yield distributions and compare them with theoretical predictions.

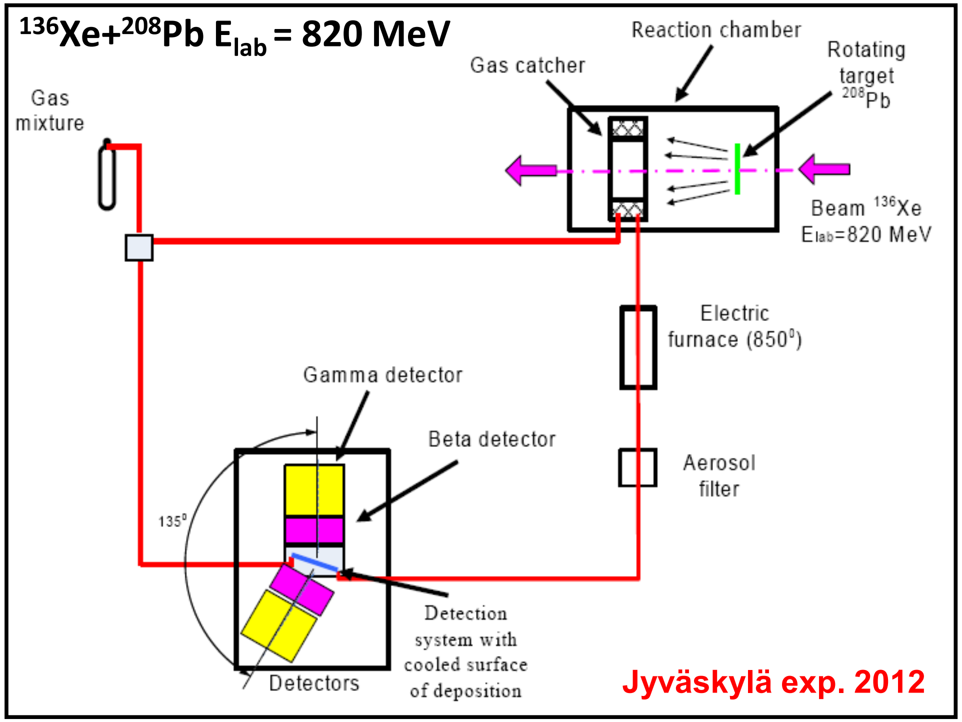
Exploring the N=126 region via MNT

Production of heavy neutron rich nuclei in the region of neutron closed shell N=126 populated via multinucleon transfer reactions





Y.X. Watanabe et al., EMIS 2012
Nucl. Instr. Meth. B 317 (2013) 752

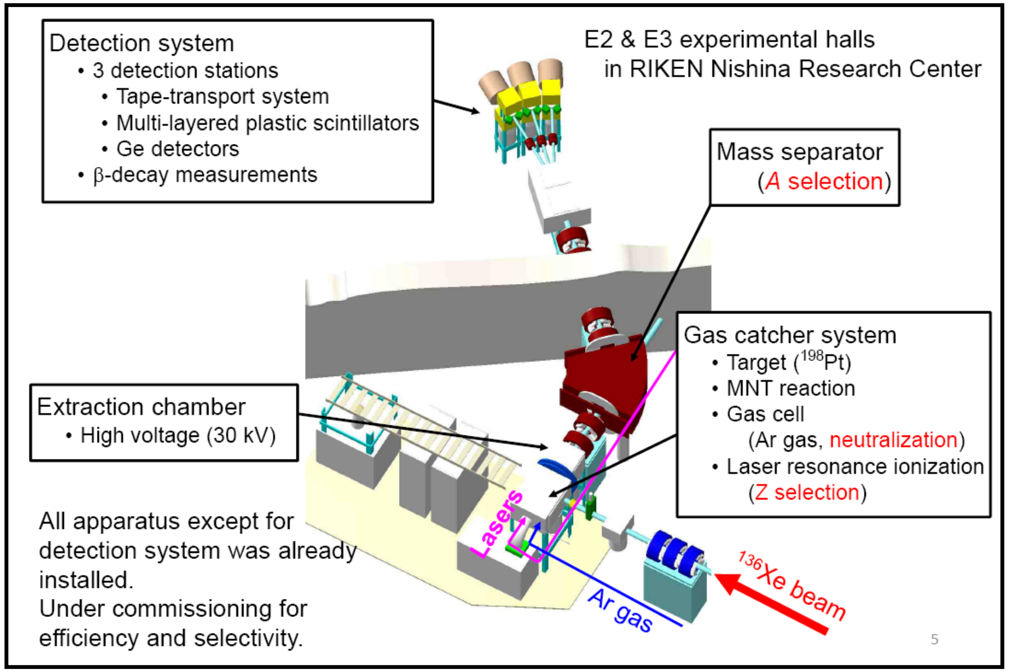


Integral measurement to detect heavy transfer reaction products below the Pb region
E.Kozulin, V. Zagrebaev et al.

K. Novikov et al., ECHI2013
J. of Phys.: C.S. 515 (2014) 012016

Exploring the N=126 region via MNT

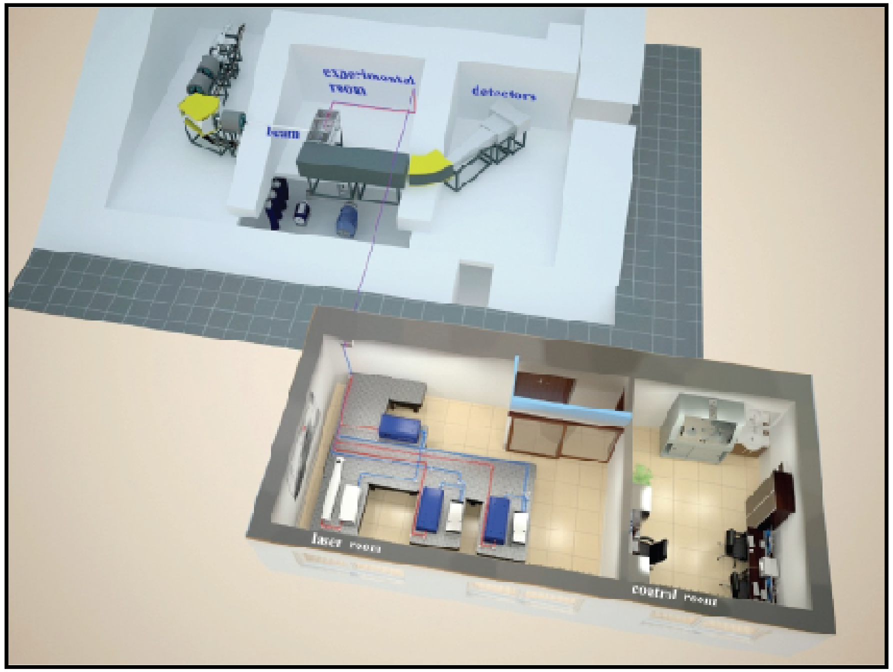
KEK Isotope Separator System (KISS) for β-decay spectroscopy of neutron rich nuclei with A~200 and N~126



KEK Laboratory, Tsukuba (J)

Y.X. Watanabe et al., 16th ASRC Intern. Workshop 18-20 March 2014 ,Tokai (J)

Gas cell and Laser ion & Separation (GaLS) setup for β spectroscopy of neutron rich nuclei at N~126



Flerov Laboratory, DUBNA (RUS)

S. Zemlyanoy et al., FUSION14 ,24-28 February 2014, New Delhi (IND)

The LNL test experiment: $^{197}Au+^{130}Te$

$^{197}Au+^{130}Te$ E_{lab}=1070 MeV

Goal: to populate neutron rich nuclei close to A ~ 130 and A ~ 200

Via proton stripping and neutron pick-up one gets neutron rich nuclei around A~130.
In particular, the (-2*p*+4*n*) channel from ^{130}Te would lead to the benchmark nucleus ^{132}Sn

Via proton pick-up and neutron stripping one gets neutron rich nuclei around A~200.
In particular, the (+3*p*-4*n*) channel from ^{130}Te would lead to ^{198}Os and beyond

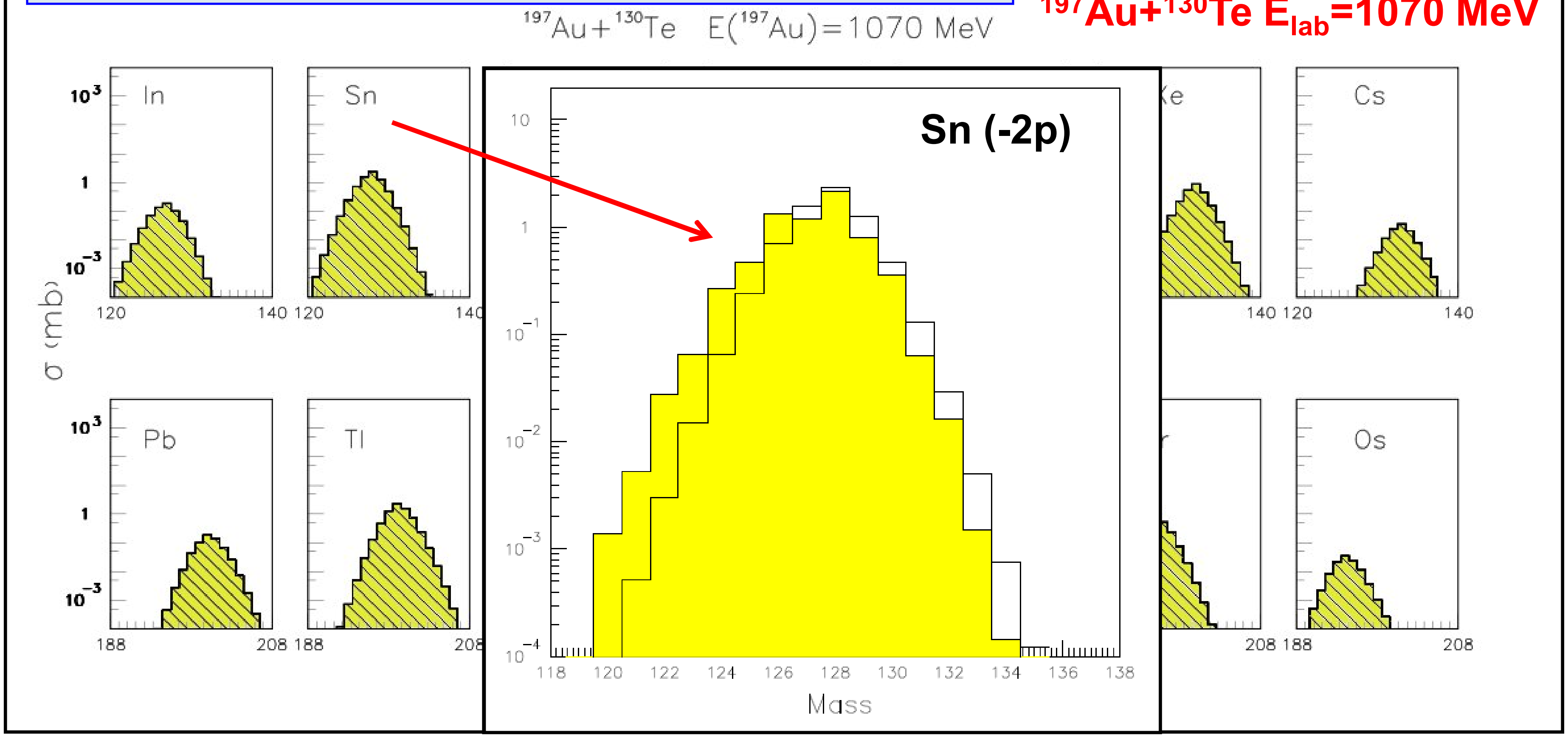
L.Corradi, E. Fioretto, S.Szilner et al., PRISMA exp.

GRAZING code calculations

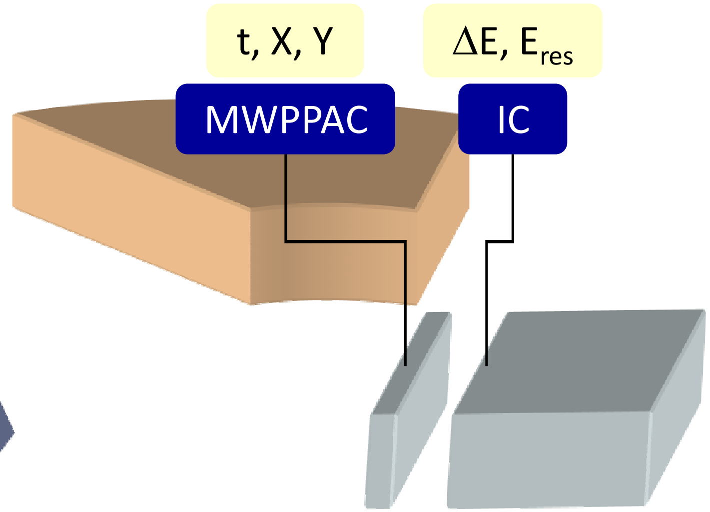
$^{197}Au+^{130}Te$: theoretical total cross sections for the light and heavy transfer products

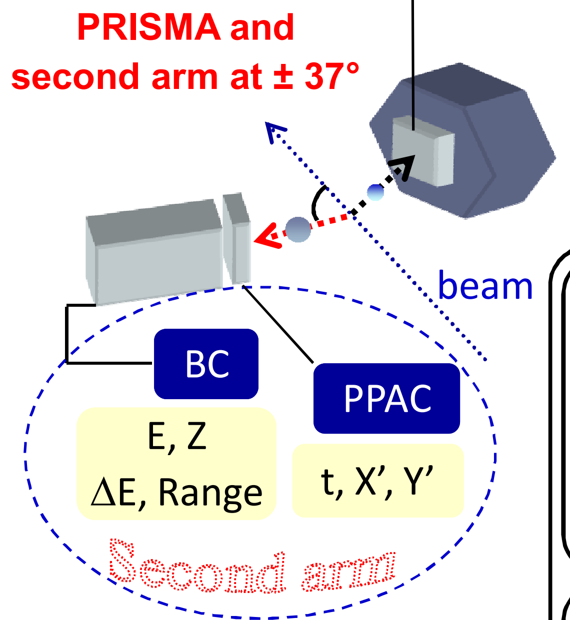
The yields of light and heavy reaction products can be directly compared

$^{197}Au+^{130}Te$ E_{lab}=1070 MeV



Kinematic coincidence measurements





Experimental parameters

PRISMA

PLF or **TLF** in PRISMA (tagging)

x, y at the entrance (MCP) } **Trajec.**

X, Y at the FP (MWPPAC) }

TOF (MCP-MWPPAC) + **E** (IC) → A_{PLF}

ΔE, E (IC) → Z_{PLF}

2nd arm

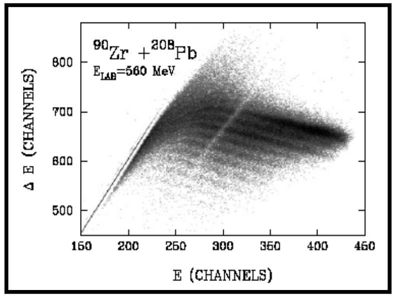
TLF or **PLF** in the KC detector

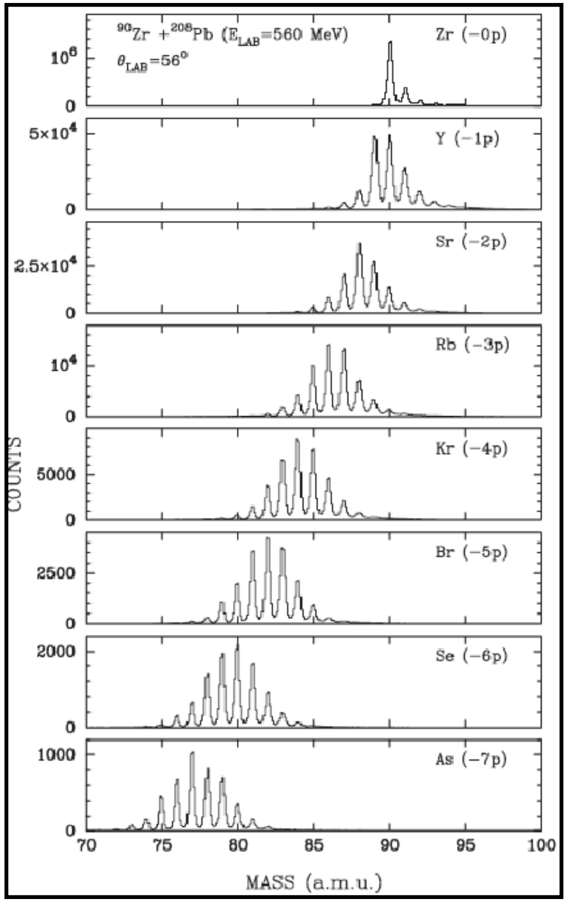
X', Y' at KC angle (PPAC) → (θ_{TLF}, ϕ_{TLF})

ΔTOF (MCP-PPAC)

E, Z (BC)

→ **PLF-TLF discrimination**

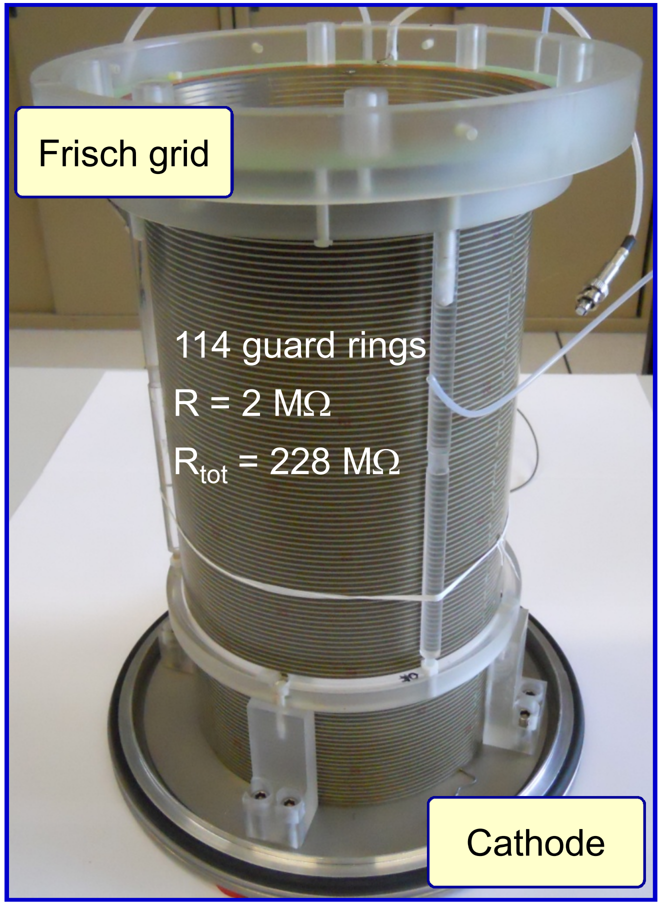




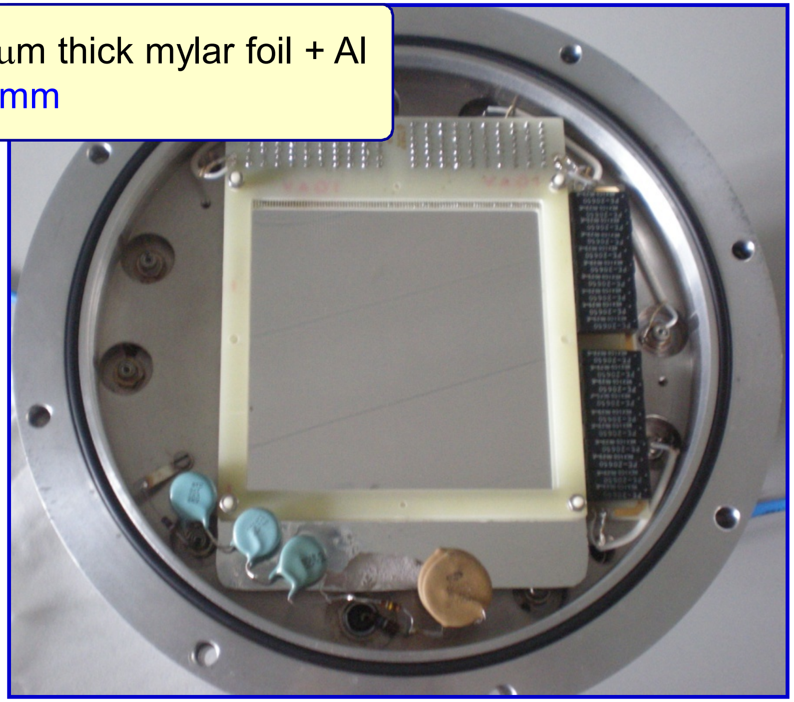
12th International Conference on Nucleus-Nucleus Collisions
Catania, 21-26 June 2015

E. Fioretto – LNL

The second arm of PRISMA



Cathode → 1.5 μm thick mylar foil + Al
$d_{cathode-anodes}$ = 2 mm



$d_{cathode-FG}$ = 32 cm

⬇

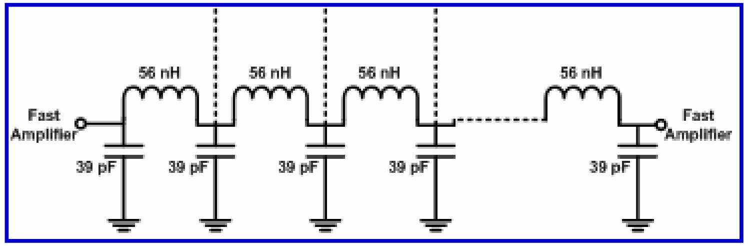
Filling gas : fast and high stopping power

CF_4 → ~10 cm/μs at 1 $Vcm^{-1}Torr^{-1}$

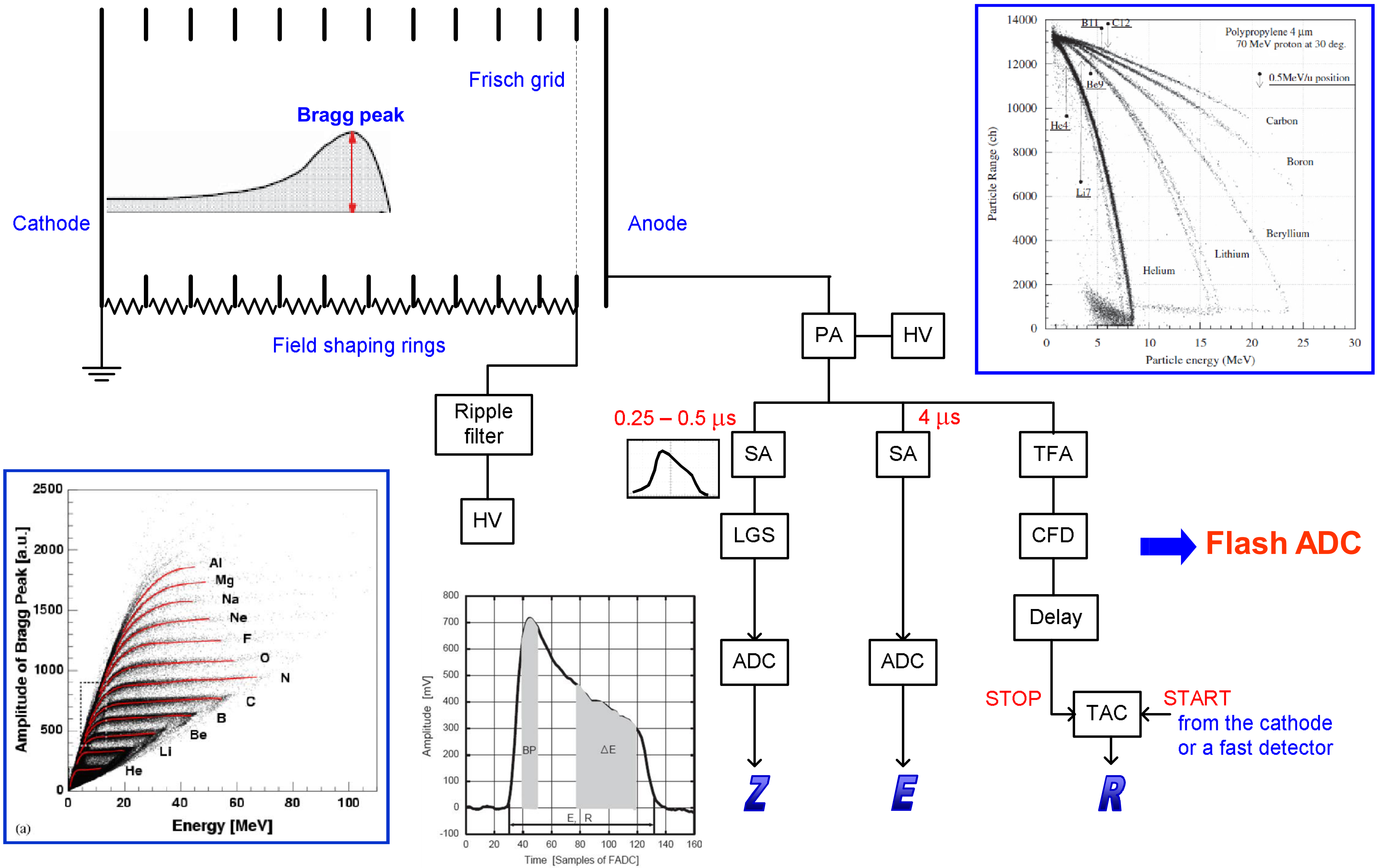
X and Y anode wire planes

10 μm diameter - 1 mm spacing

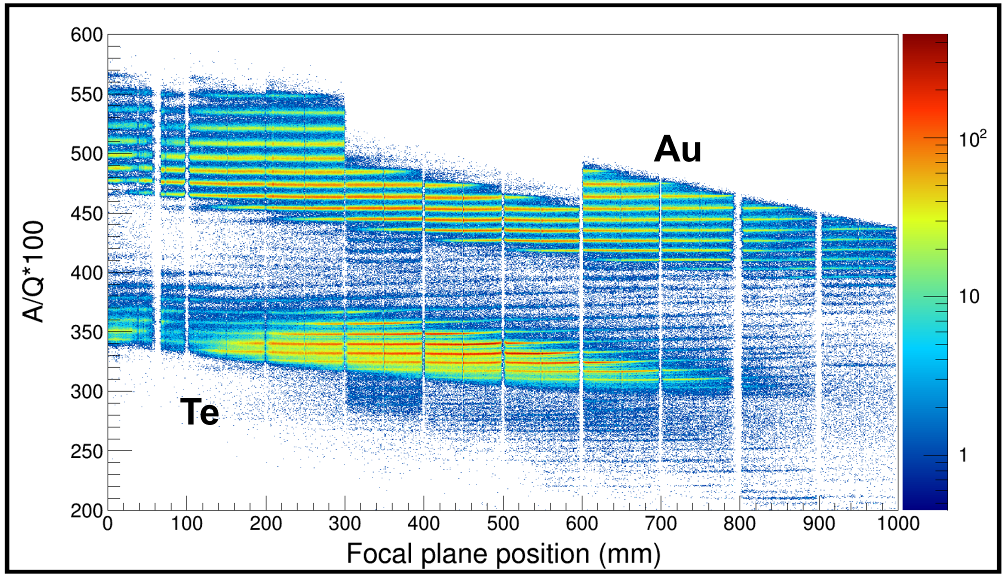
delay-line readout →1ns

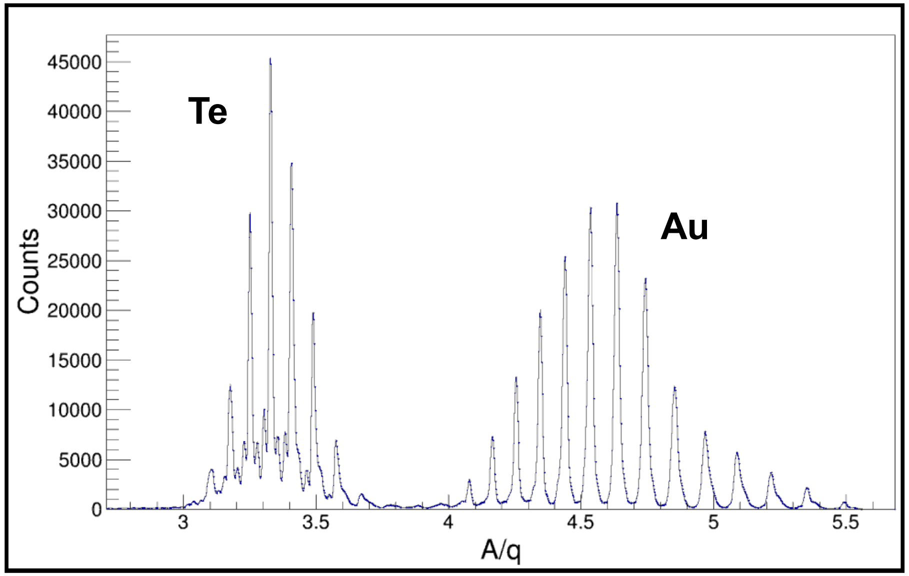


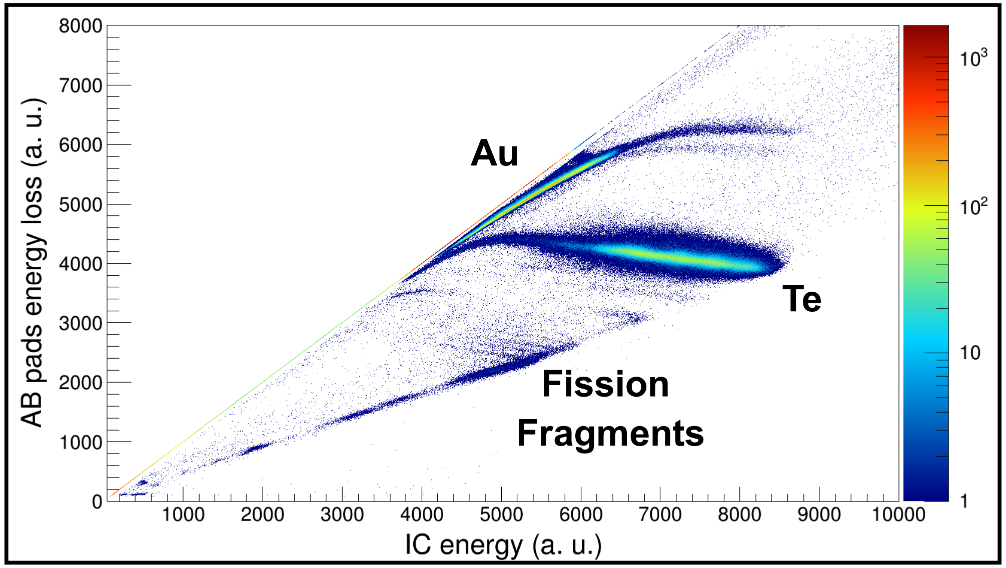
Bragg Curve Spectroscopy

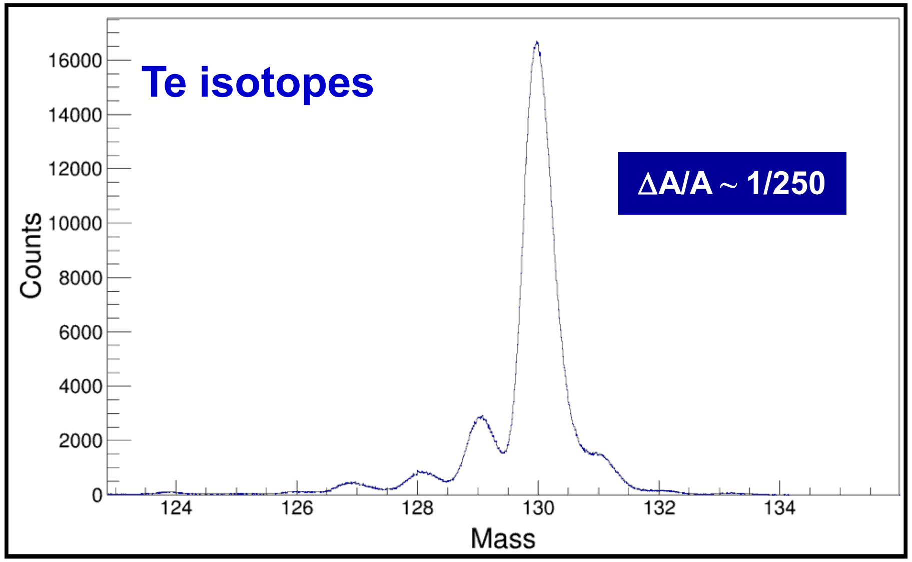


Preliminary data analysis (PRISMA)

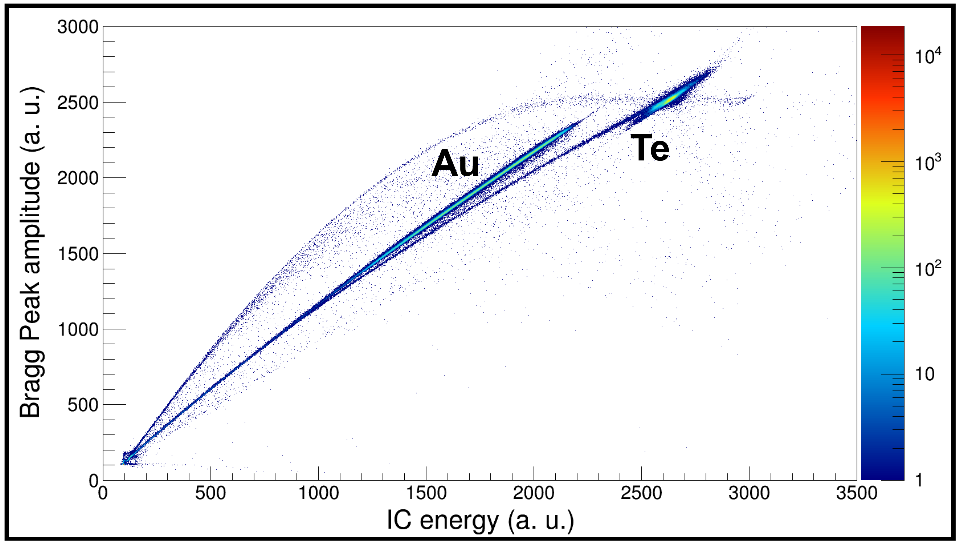


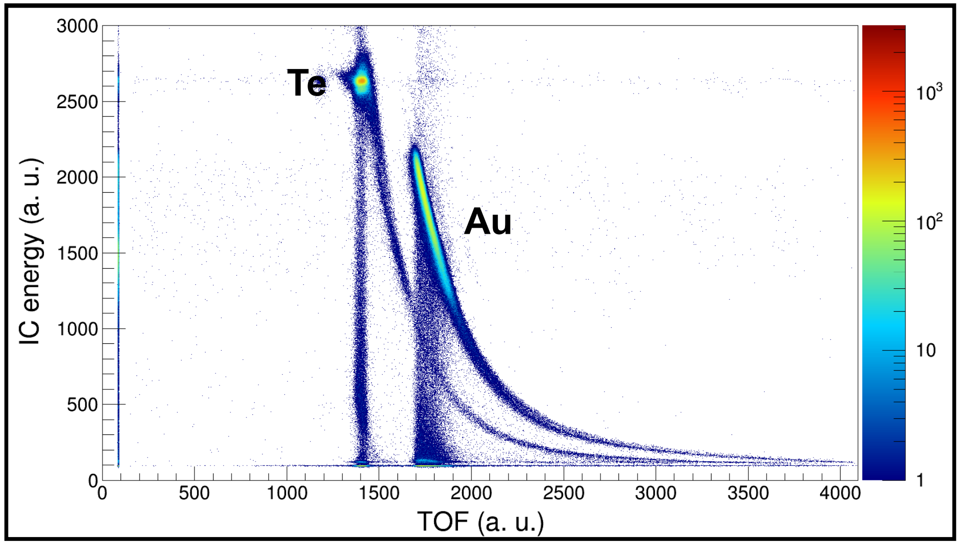


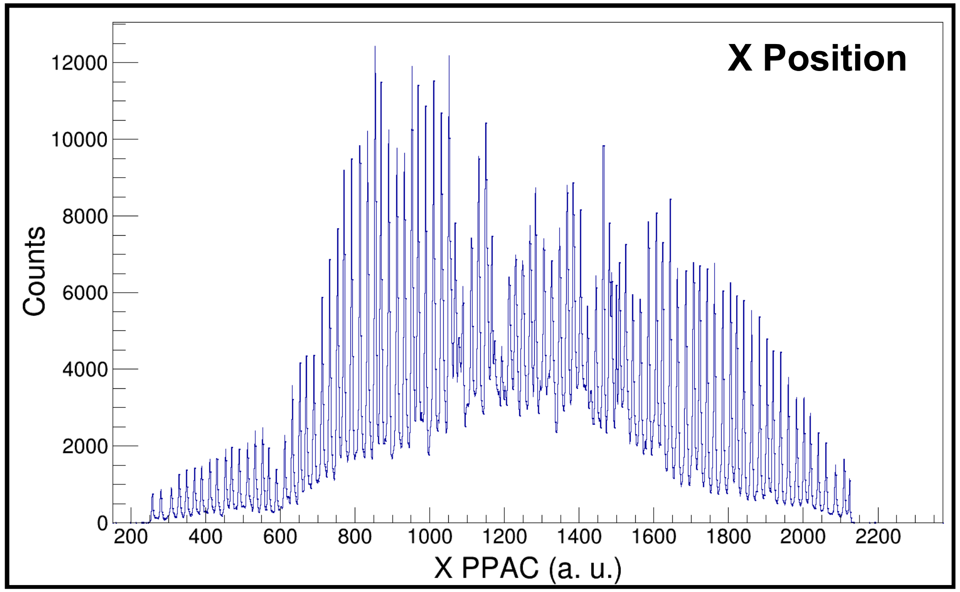


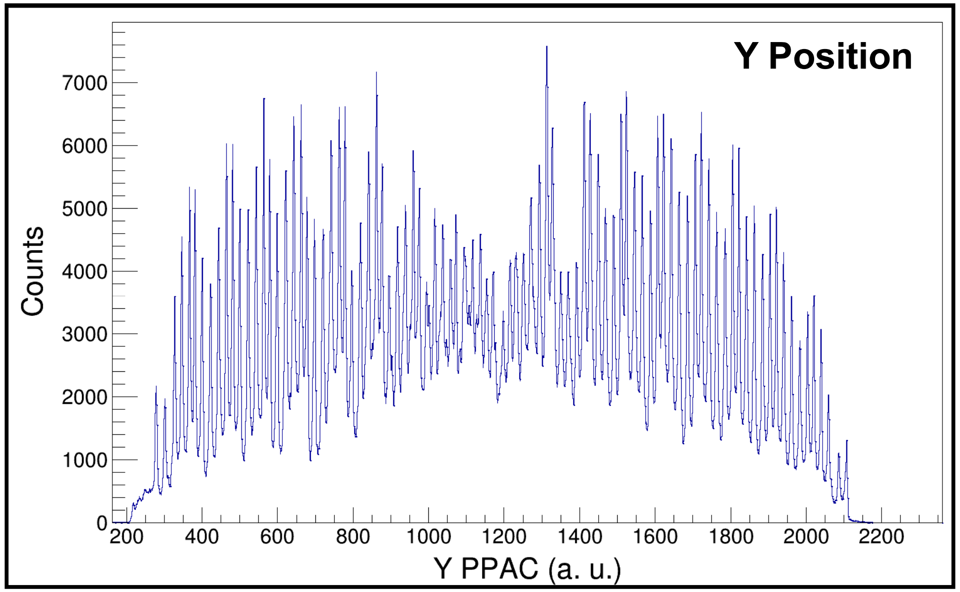


Preliminary data analysis (Second arm)









Summary

- **Sub-barrier transfer reactions in inverse kinematics**

  - **$^{96}Zr+^{40}Ca$ and $^{116}Sn+^{60}Ni$ have been studied with the magnetic spectrometer PRISMA at forward angles in order to have recoils with enough kinetic energy and good efficiency.**
    Transfer probabilities are well reproduced for the first time with heavy ions (in absolute values and in slope) by microscopic calculations which include nucleon-nucleon correlations.

    S. Szilner
    Aula Azzurra MON 15:15

- **Population of neutron rich heavy nuclei via MNT reactions**

  - **A test experiment has been carried out at LNL to populate neutron rich nuclei close to A ~ 130 and A ~ 200. To this end a second arm has been installed in target area of PRISMA for kinematic coincidence measurements.**
    Good quality data have been collected and their analysis is still in progress.

Collaborations

E. Fioretto, L. Corradi, S. Szilner, D. Montanari,
F. Galtarossa, A.M. Stefanini, G. Montagnoli,
F. Scarlassara,G. Pollarolo, S. Courtin, A. Goasduff,
F. Haas, D. Jelavić Malenica, C. Michelagnoli,
T. Mijatović, N. Soić, C. Ur, J.J. Valiente-Dobon

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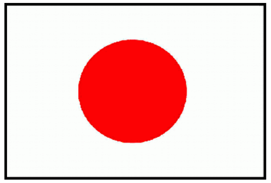
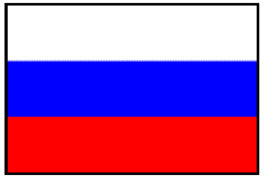
Università di Torino and INFN, Italy
IPHC, Strasbourg, France
IFIN-HH, Bucharest, Romania

Very recent experiments performed at LNL within Trans-EU International Collaborations



KEK -Tsukuba



FLNR - Dubna