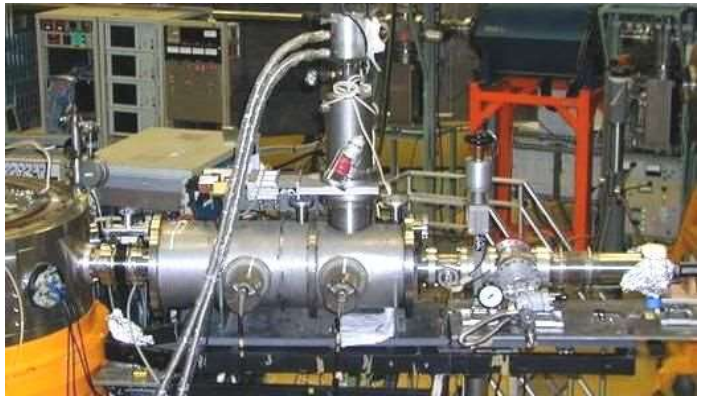
PRISMA-FIDES
"Heavy-ion reactions from grazing collisions to complete fusion"

The PRISMA-FIDES experiment at LNL includes 2 lines of research

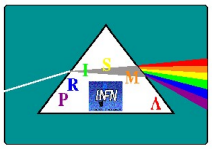
Quasi-elastic reactions
nucleon-nucleon correlations, sub-barrier transfer, coupling to fusion, n-rich isotope production and nuclear structure studies
using the magnetic spectrometer
PRISMA



Heavy-Ion fusion reactions
near V_B and at $E \ll V_B$
using the set-up **PISOLO** based on an electrostatic beam separator

PRISMA-FIDES
"Heavy-ion reactions from grazing collisions to complete fusion"

Continuation experiment for the years 2022-2024



GROUP COMPOSITION

L. Corradi (100%, Resp. Naz.), E.Fioretto (100%), A.M. Stefanini (ass. senior)
(INFN – LNL)

2.0 FTE

G.Montagnoli (100%, Resp. Loc.), M.Del Fabbro (100%), F.Scarlassara (100%)
(Univ. and INFN – Padova)

3.0 FTE

Collaboration with the Gamma group for the PRISMA-AGATA campaign

Some of the most recent scientific results

Physics Letters B 834 (2022) 137477

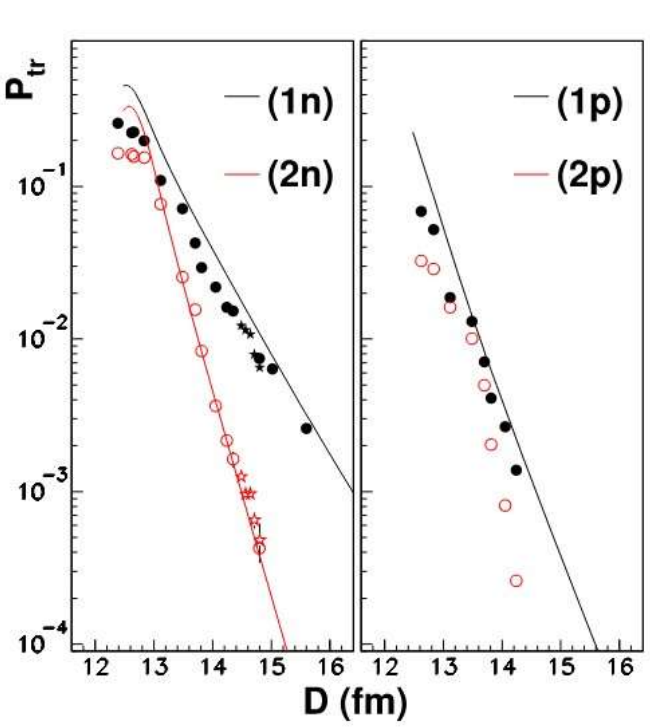
Contents lists available at ScienceDirect

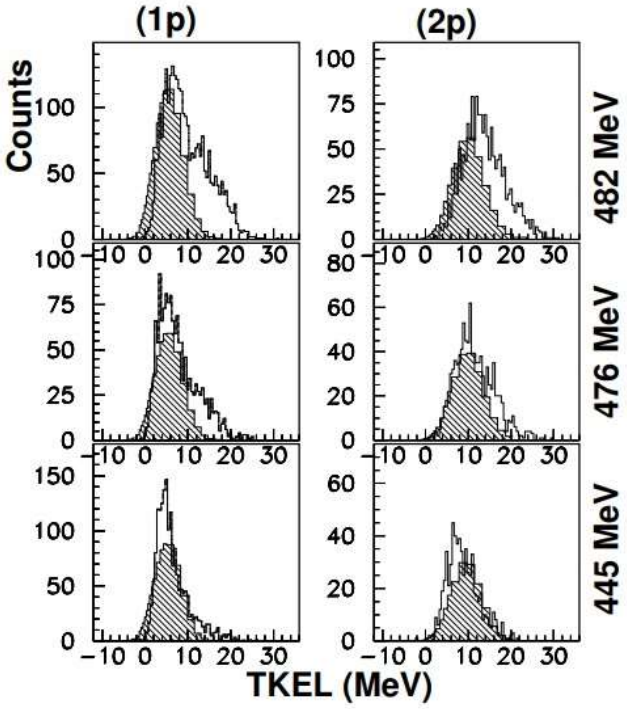
Physics Letters B

www.elsevier.com/locate/physletb

Evidence of proton-proton correlations in the ^{116}Sn + ^{60}Ni transfer reactions

L. Corradi [a,*], S. Szilner [b,*], G. Pollarolo [c], T. Mijatović [b], D. Montanari [d], E. Fioretto [a], A. Goasduff [a], D. Jelavić Malenica [b], G. Montagnoli [d], A.M. Stefanini [a]





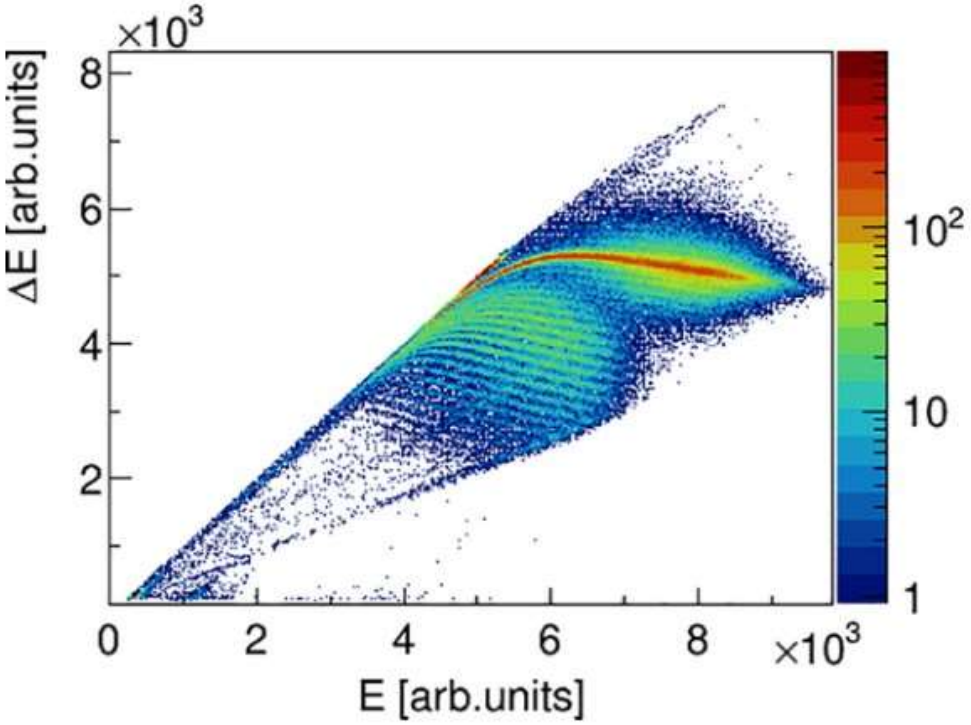
Measured with PRISMA a complete excitation function for both neutron and proton transfers at bombarding energies from above to well below the Coulomb barrier

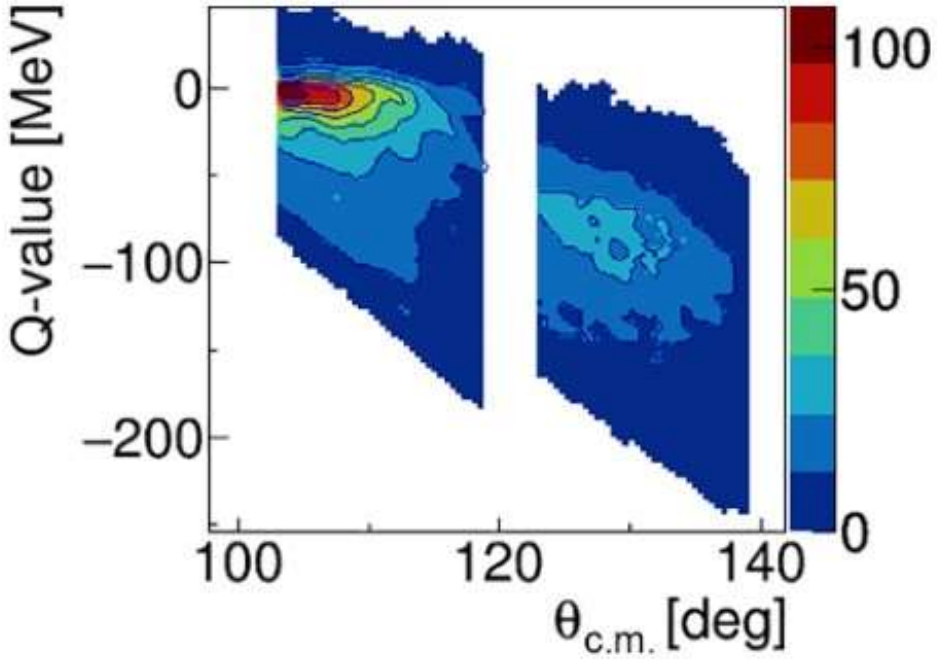
Data have been compared with microscopic calculations for neutrons and one proton transfer and with the GRAZING code for protons

For two proton transfer found large enhancement factors indicating strong nucleon-nucleon correlations

Transfer reactions in ^{206}Pb + ^{118}Sn: From quasielastic to deep-inelastic processes

J. Diklić,[1] S. Szilner,[1,*] L. Corradi,[2,†] T. Mijatović,[1] G. Pollarolo,[3] P. Čolović,[1] G. Colucci,[4,5] E. Fioretto,[2] F. Galtarossa,[4] A. Goasduff,[2] A. Gottardo,[2] J. Grebosz,[6] A. Illana,[2,7] G. Jaworski,[5] M. Jurado Gomez,[8] T. Marchi,[2] D. Mengoni,[4] G. Montagnoli,[4] D. Nurkić,[9] M. Siciliano,[2,10] N. Soić,[1] A. M. Stefanini,[2] D. Testov,[4] J. J. Valiente-Dobón,[2] and N. Vukman[1]





Measured with PRISMA an excitation function at two angular settings for multinucleon transfers at bombarding energies from above to well below the Coulomb barrier

At high energies a detailed study of the transition from quasi-elastic to deep inelastic processes as function of A, Z, Q-values of the reaction products has been done

Fusion of $^{12}C + ^{24}Mg$ at extreme sub-barrier energies

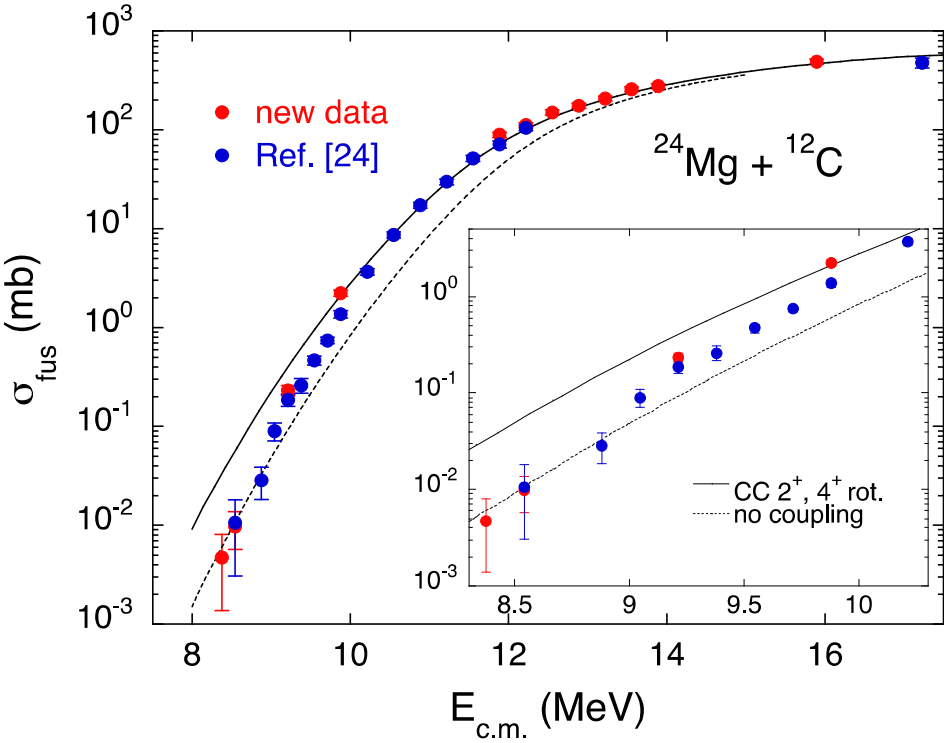
IOP Publishing

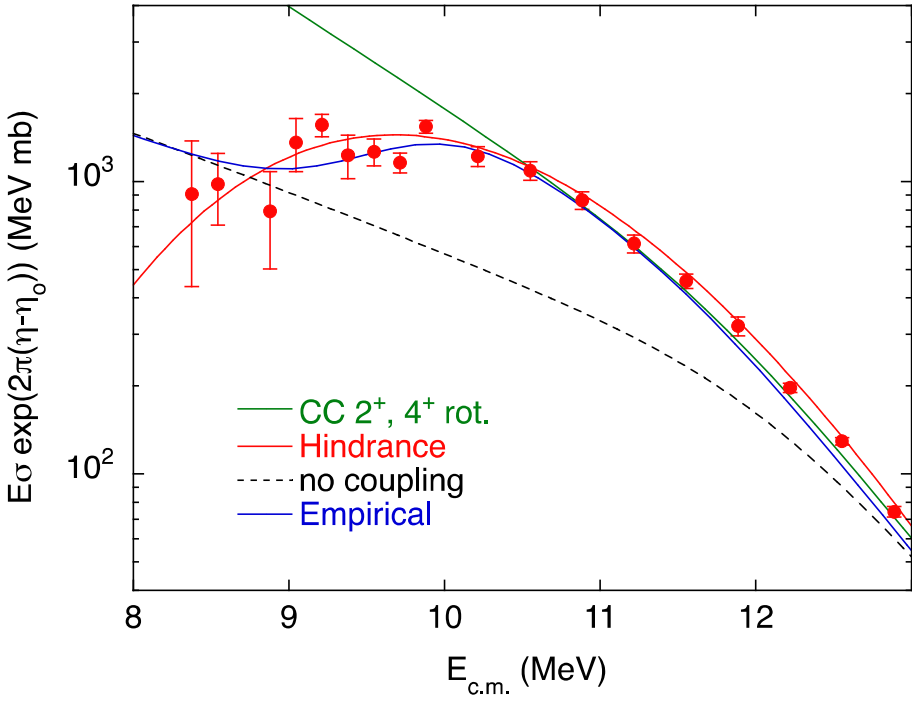
J. Phys. G: Nucl. Part. Phys. **49** (2022) 095101 (11pp)

Journal of Physics G: Nuclear and Particle Physics

https://doi.org/10.1088/1361-6471/ac7edd

G Montagnoli[1,*], A M Stefanini[2], C L Jiang[3], K Hagino[4], F Niola[1], D Brugnara[1,2], P Čolović[5], G Colucci[1], L Corradi[2], R Depalo[1], E Fioretto[2], A Goasduff[2], G Pasqualato[2], F Scarlassara[1], S Szilner[5] and I Zanon[2,6]





Measurements of **fusion cross sections** for **$^{24}Mg+^{12}C$** have been extended down to 4μb, confirming the presence of hindrance already at ~0.75mb.

The S-factor develops a clear maximum that is nicely fitted using both an empirical interpolation in the spirit of the adiabatic model, and the hindrance parametrisation

These results serve as a base for the understanding of the astrophysics reaction networks responsible for the energy production and elemental synthesis in **stellar environments**.

Sub-barrier fusion in $^{12}C + ^{26,24}Mg$: Hindrance and oscillations

A. M. Stefanini,[1] G. Montagnoli,[2] M. Del Fabbro,[2,3] D. Brugnara,[1] G. Colucci,[4] L. Corradi,[1] J. Diklić,[5] E. Fioretto,[1] F. Galtarossa,[2] A. Goasduff,[1] M. Mazzocco,[2] J. Pellumaj,[1,3] E. Pilotto,[1] L. Zago,[1] and I. Zanon[1]

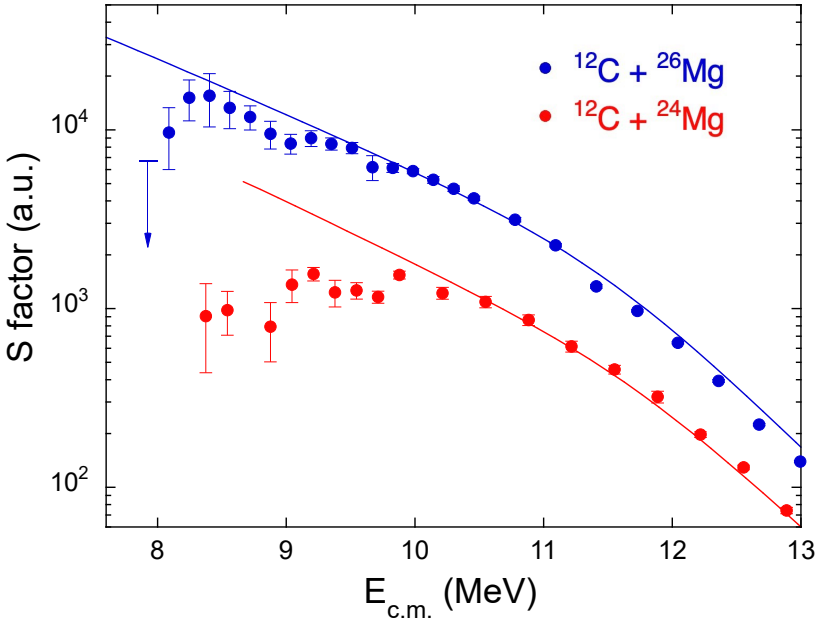
[1]*INFN, Laboratori Nazionali di Legnaro, I-35020 Legnaro, Italy*

[2]*Dipartimento di Fisica e Astronomia Università di Padova and INFN, I-35137 Padova, Italy*

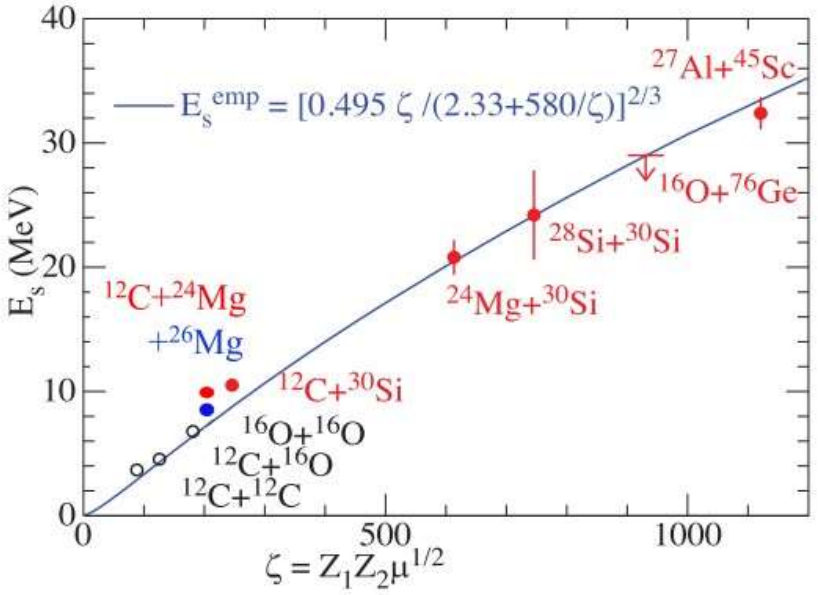
[3]*Dipartimento di Fisica e Scienze della Terra Università di Ferrara, I-44122 Ferrara, Italy*

[4]*Heavy Ion Laboratory, University of Warsaw, 02-093 Warszawa, Poland*

[5]*Ruđer Bošković Institute, HR-10002 Zagreb, Croatia*



The S factor maximum of $^{12}C + ^{26}Mg$ is narrow and at lower energy. Oscillations appear below the barrier



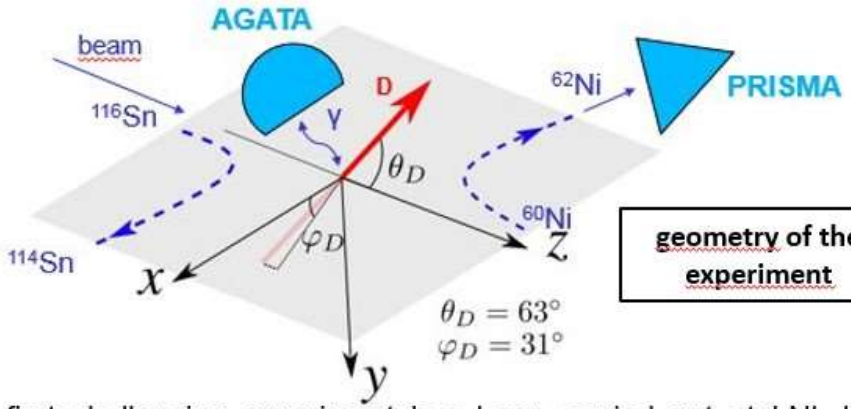
Systematics of threshold energies for hindrance in light systems

The Prisma-Agata campaign

157 days of beam on target carried out successfully since May 2022

Highlights : The Tiniest Superfluid Circuit in Nature

Search for a nuclear Josephson effect - PRISMA-AGATA experiment Feb. 2023

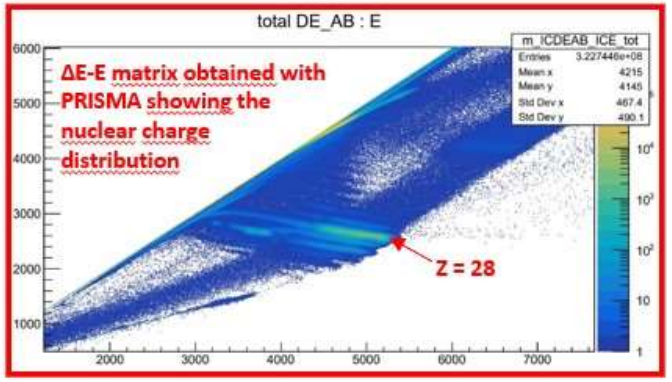


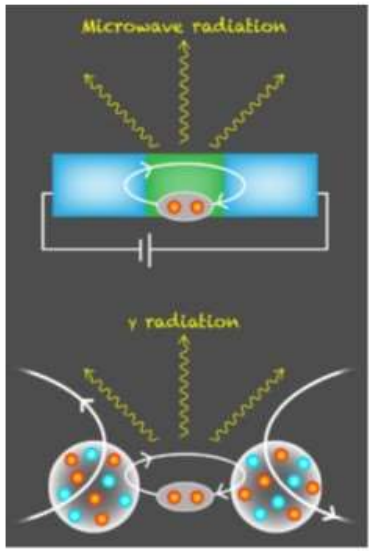
^{116}Sn beam PIAVE+ALPI, E_{lab} = 452.5 MeV, I = 3 pnA
target thickness 300 μg/cm2, Prisma θ_{lab} = 20°

geometry of the experiment

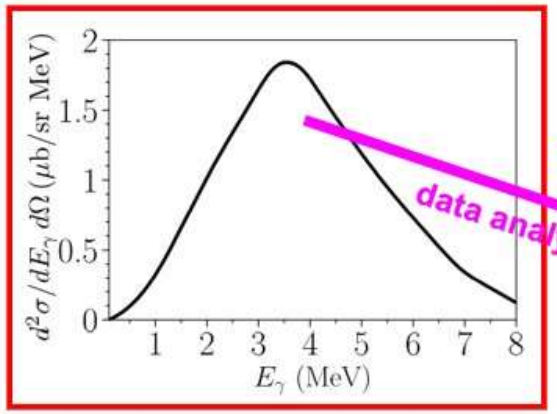
A first challenging experiment has been carried out at LNL looking at the possible existence of a gamma radiation emitted via a **dipole oscillation D** generated by the two neutron transfer process in the ^{116}Sn+^{60}Ni reaction at energies below the Coulomb barrier. This would evidence that two colliding nuclei behave like a Josephson junction, a device in which **Cooper pairs tunnel through a barrier between two superfluids**

examples of preliminary data





gamma ray strength function predicted by Broglia et al.



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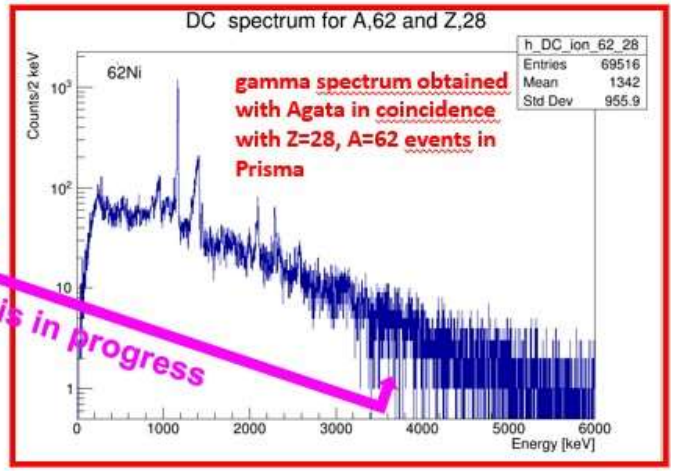
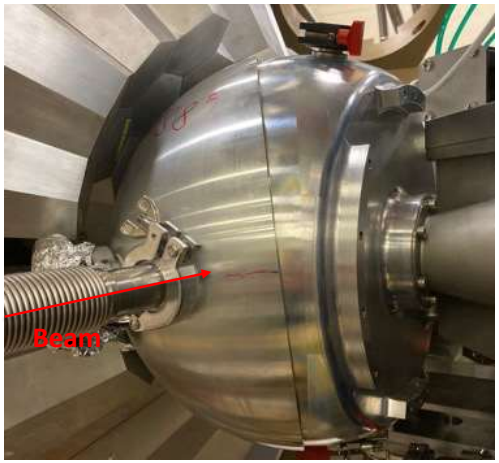
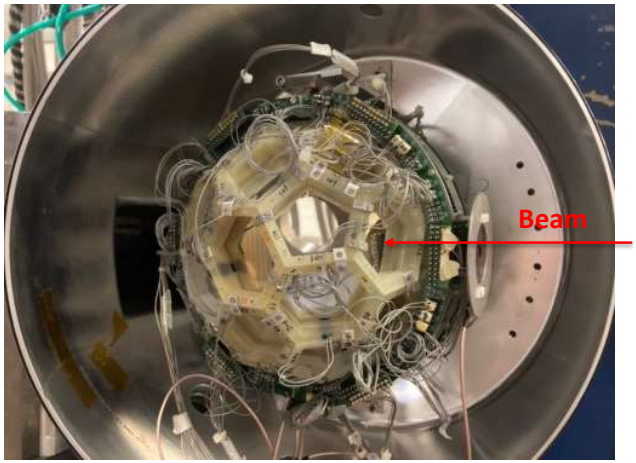


Data taken at INFN – Laboratori Nazionali di Legnaro Spokespersons L.Corradi, S.Szilner

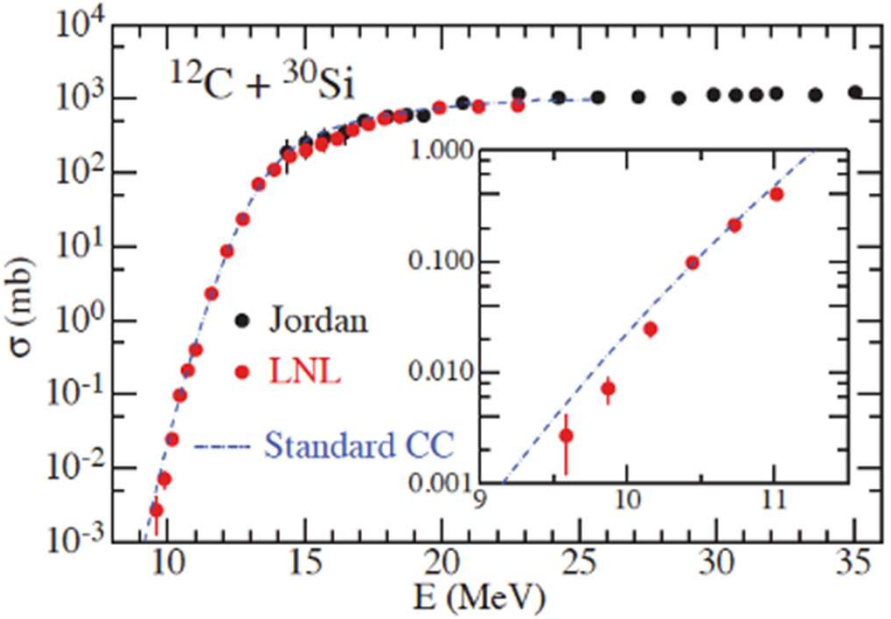
Highlights : sub-barrier fusion cross sections using AGATA+Euclides



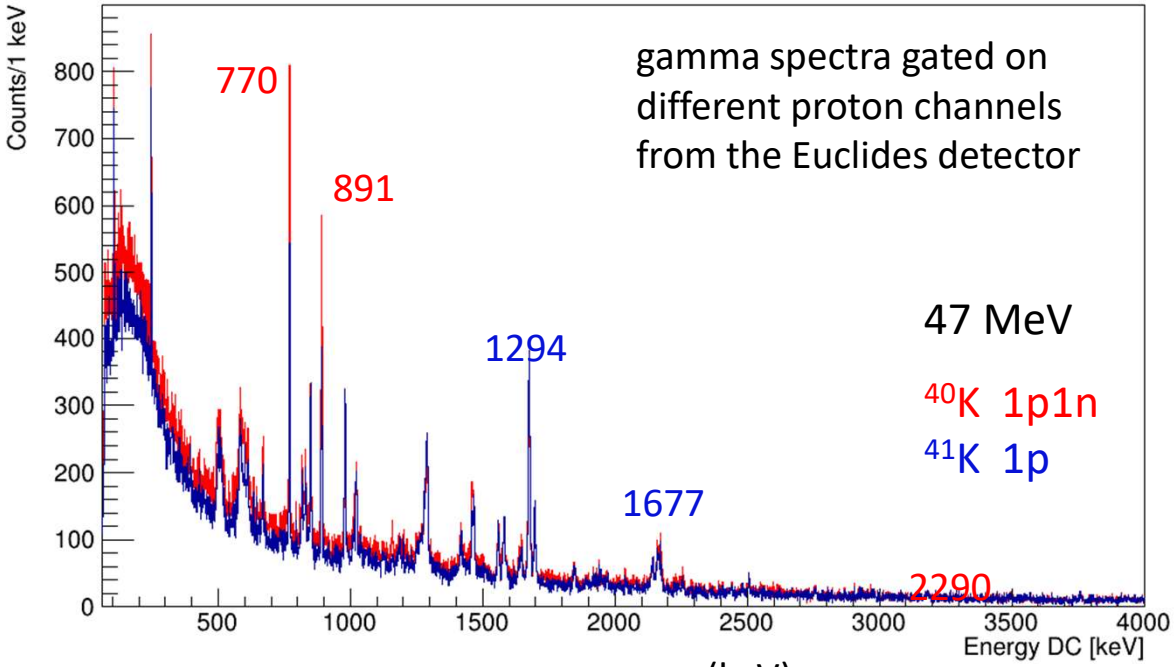


The existence of fusion hindrance in the light heavy-ion systems of astrophysical interest is not well established

The experiment has been performed, using the system ^{12}C + ^{30}Si in inverse kinematics



G.Montagnoli et al., PRC 97, 024610 (2018)



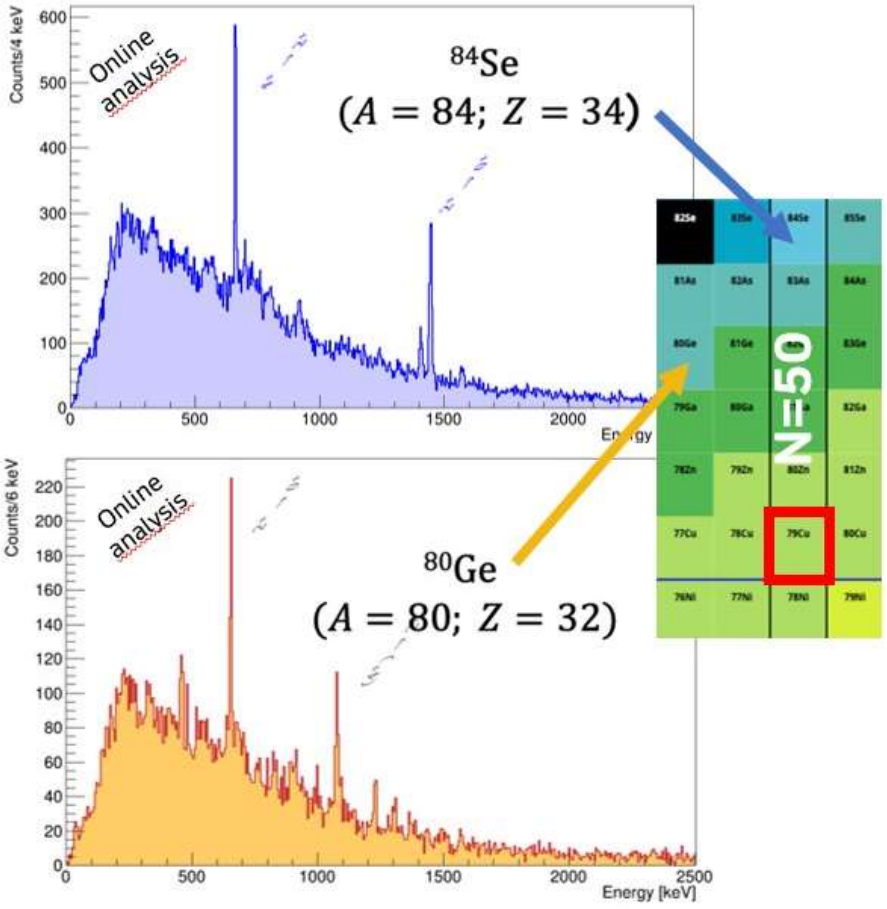
γ-ray energy (keV)

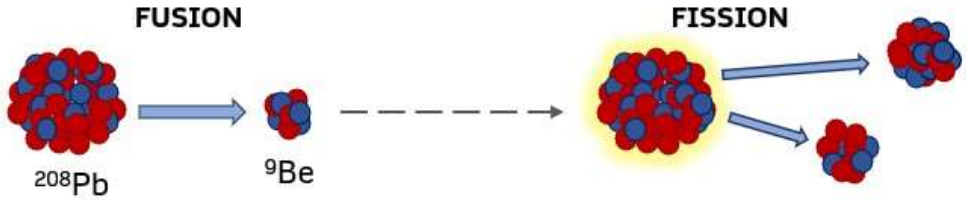
Highlights : high resolution detection of neutron-rich fission fragments

First AGATA Physics Campaign

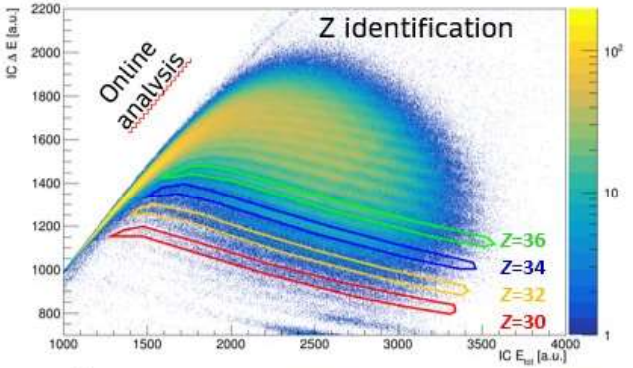
Fusion-fission reactions for N=50 studies

$^{9}Be + ^{208}Pb$ (1.3 GeV)

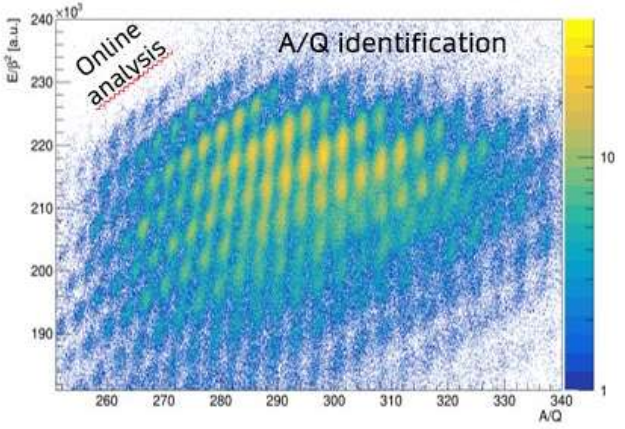




AGATA + PRISMA



View of AGATA from the target position

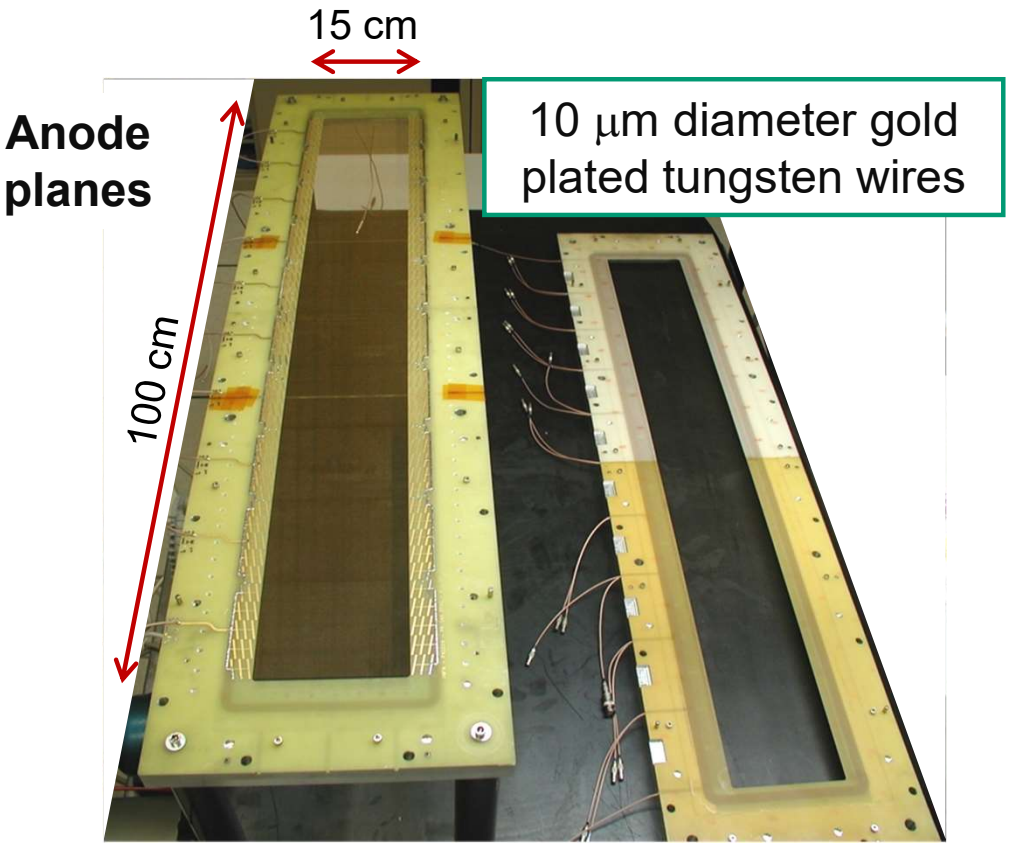


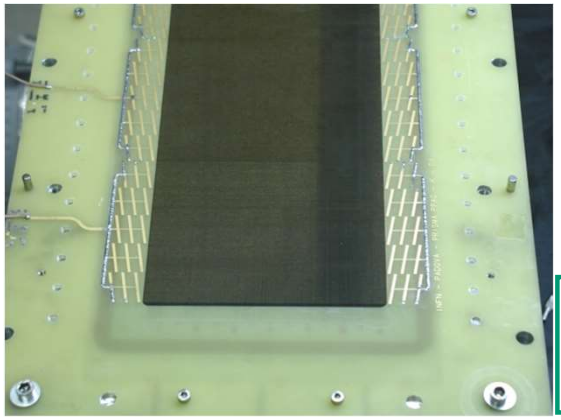
A. Gottardo et al.

Recent detector developments of the PRISMA group

PRISMA : development of a more efficient MWPPAC

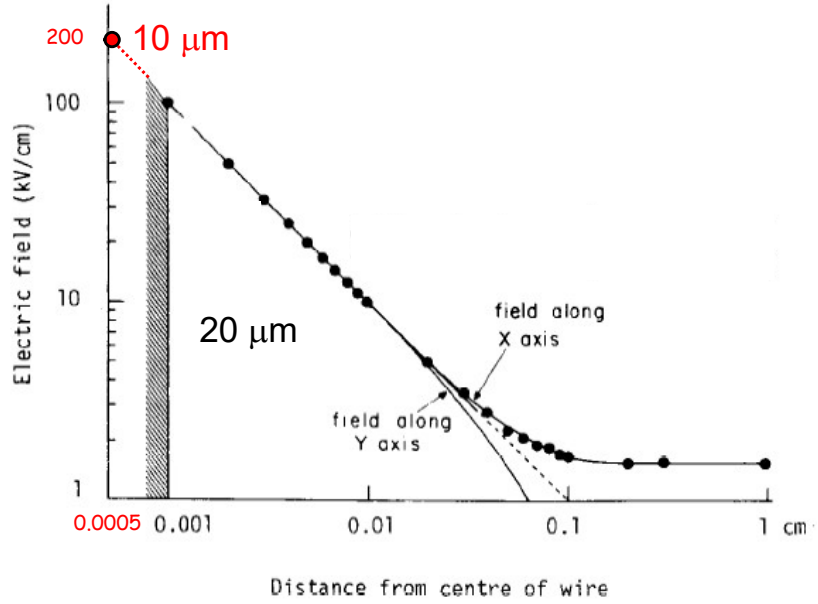
E.Fioretto

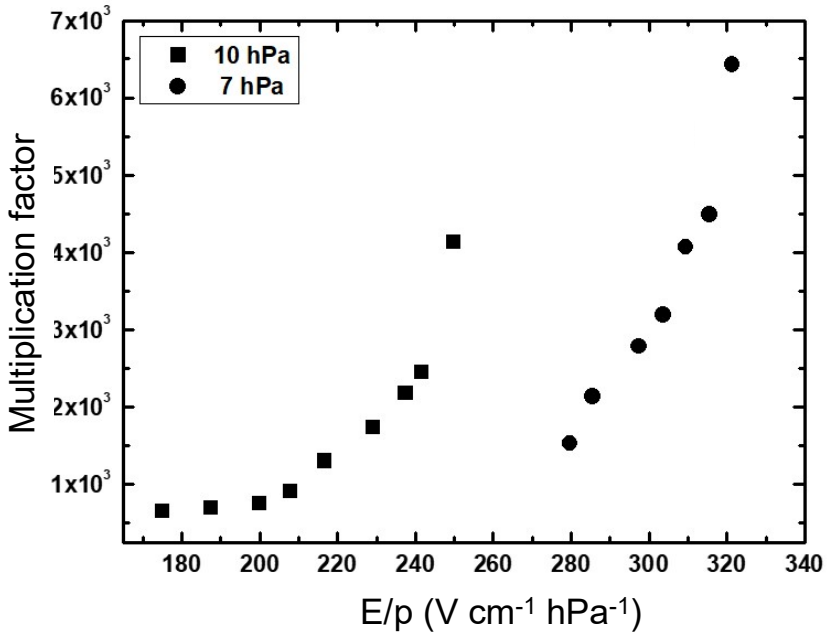




Cathode

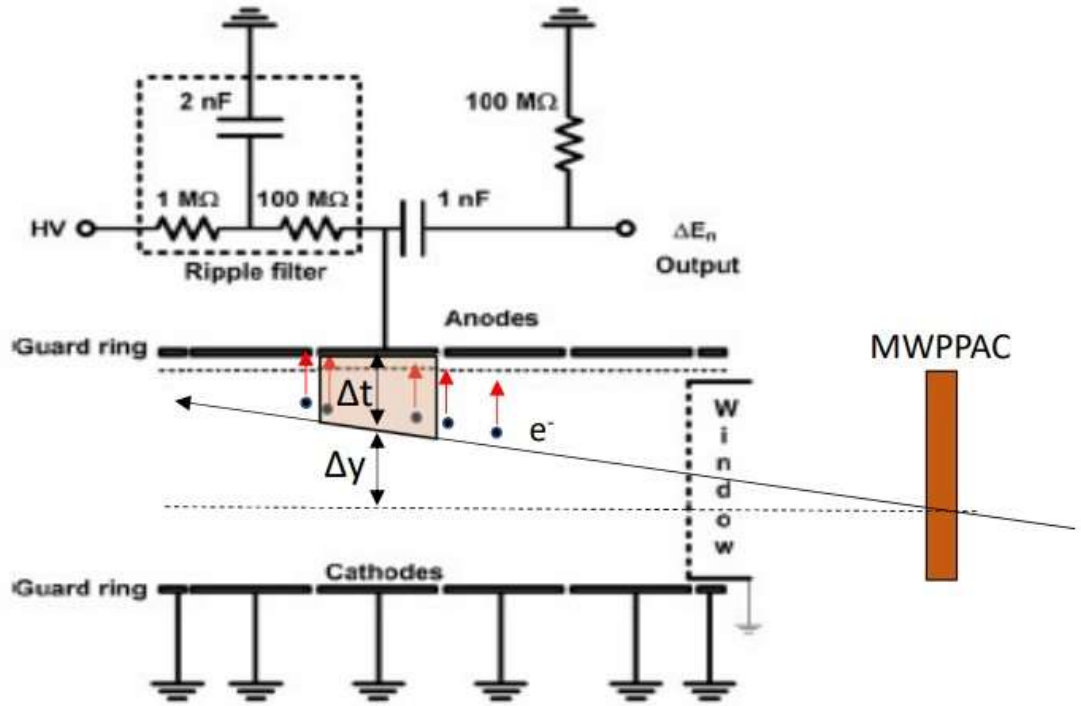
3300 gold plated tungsten wires





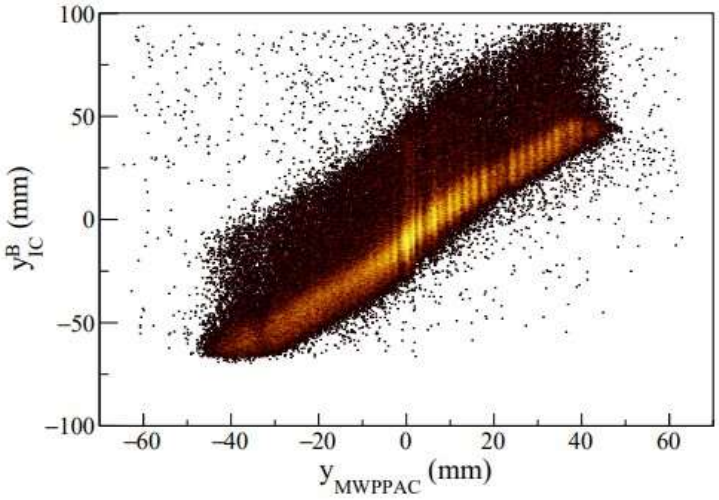
Detector efficiency improved from less than 1% to about 43% for ^{16}O @ 50 MeV

Y position determination of the IC via drift time method



TAC drift time spectrum taken in tests with ^{58}Ni @ 225 MeV

start: MWPPAC cathode
stop: IC anode



A matrix of Y_{MWPPAC} vs Y_{IC} has been constructed, showing a quite good linearity and demonstrating the good planarity of the ion trajectories at the focal plane

The Y-Y correlation should help in improving the Z resolution of the IC because one can partially correct for the tilted trajectories

Nuclear Inst. and Methods in Physics Research, A 899 (2018) 73–79

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

A gas detection system for fragment identification in low-energy heavy-ion collisions

E. Fioretto [a,*], F. Galtarossa [a,b], L. Corradi [a], H.M. Jia [c], F. Collini [d], T. Marchi [e], G. Colucci [d], T. Mijatović [f], G. Montagnoli [d], D. Montanari [g], F. Scarlassara [d], A.M. Stefanini [a], E. Strano [d], S. Szilner [f], G. Pasquali [h], J. Grebosz [i]

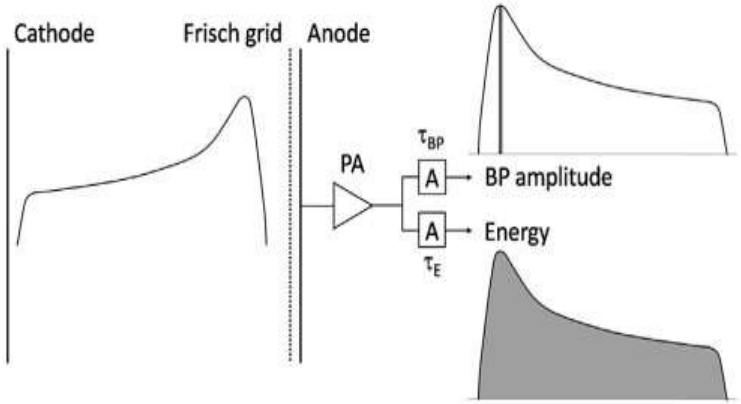
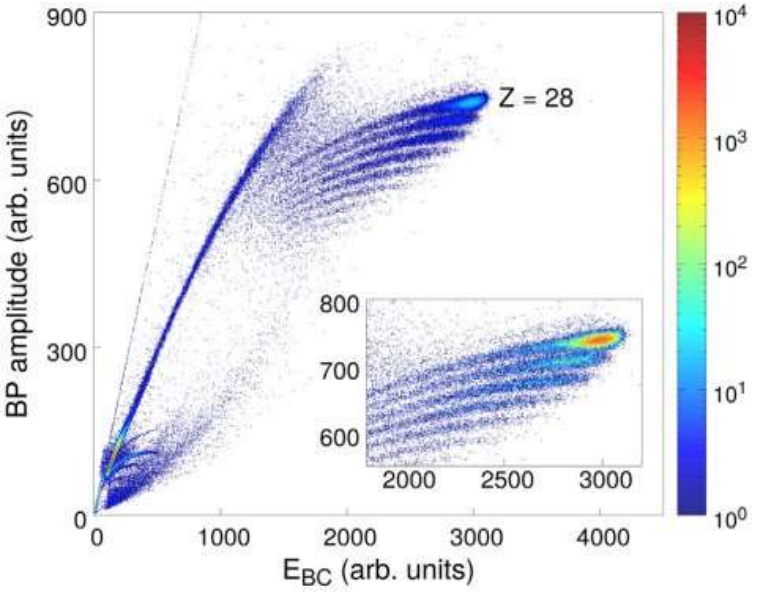


illustration of the Bragg Curve Spectroscopy principle

inner structure of the Bragg chamber

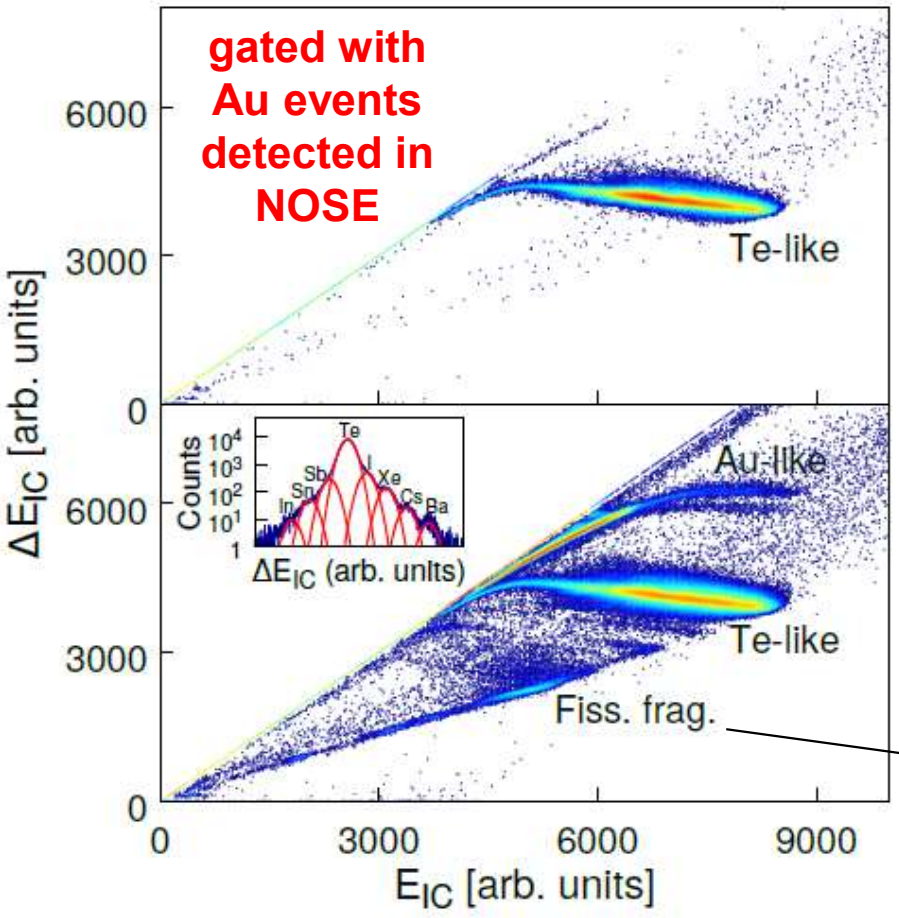


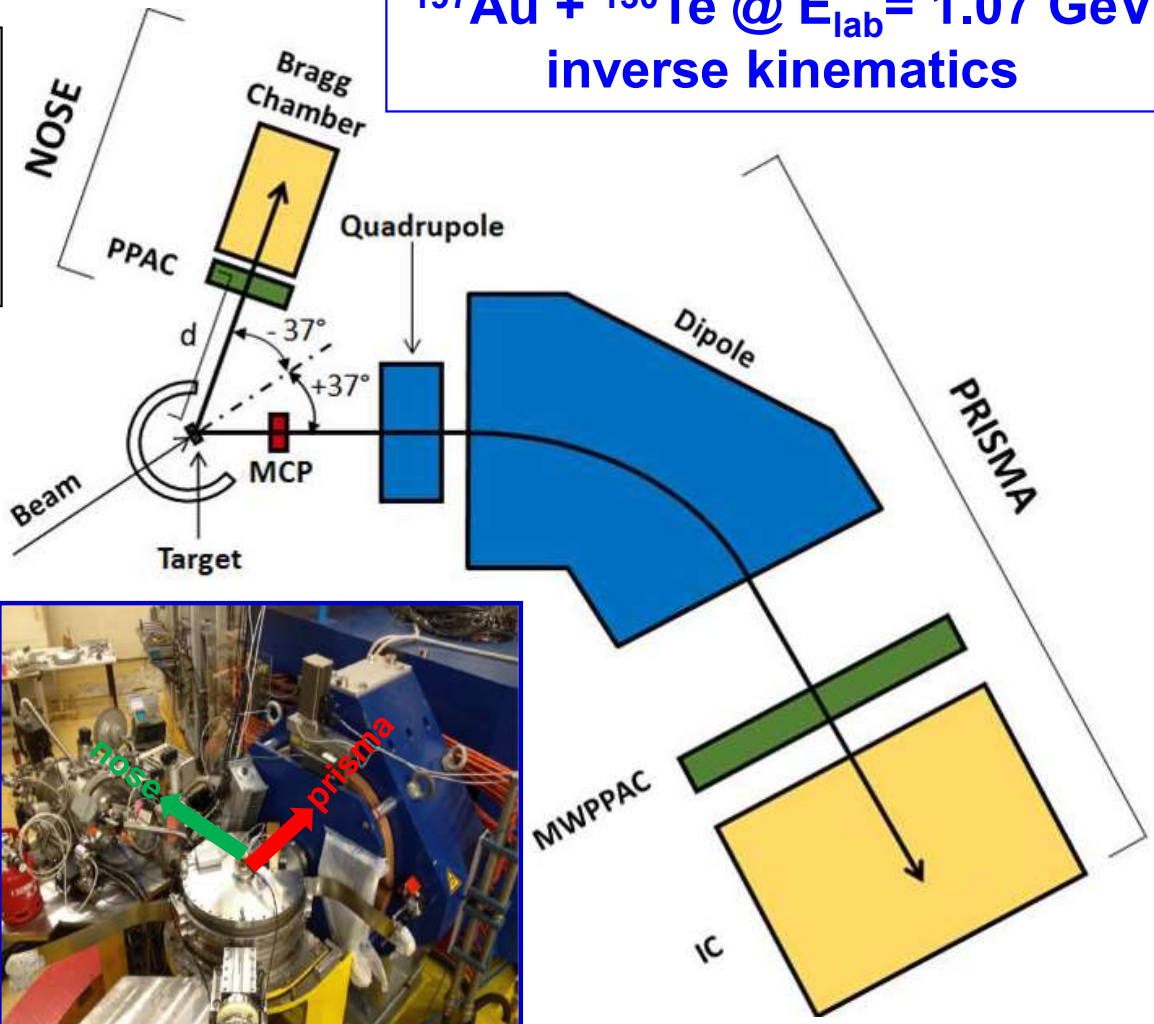
anode signals processed with digital electronics

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





beam

NOSE mounted before Agata installation

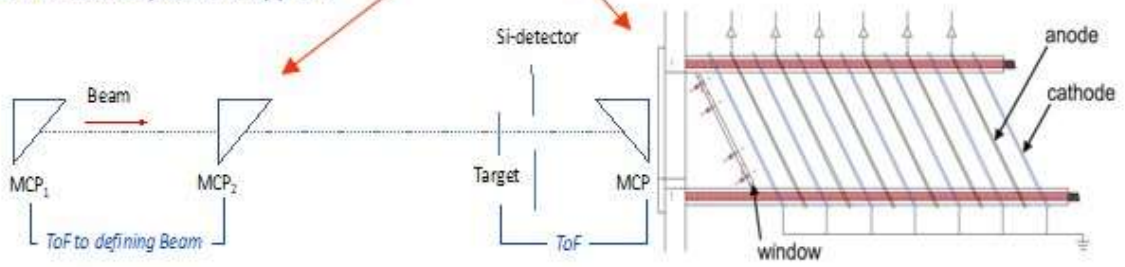
fission events derive probably from transfer induced fission or quasi fission

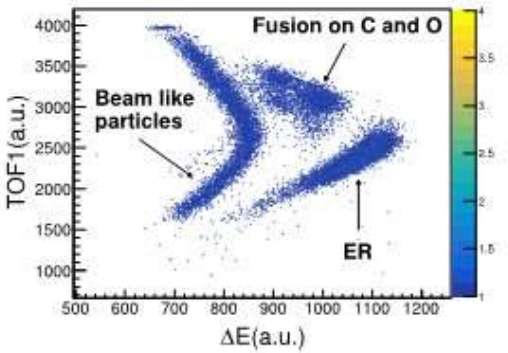
F.Galtarossa et al., Phys. Rev. C97(2018)054606

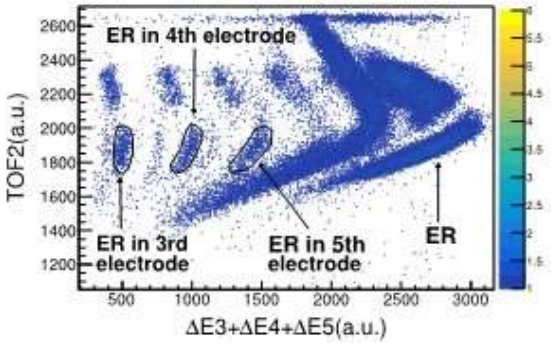
New set-up for fusion studies with SPES beams detecting ER at 0°

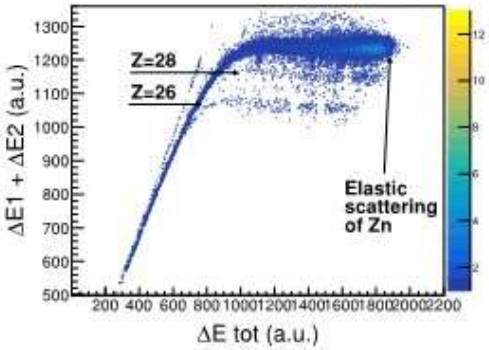
Position sensitive MCP detectors and a fast ionization chamber with tilted electrodes

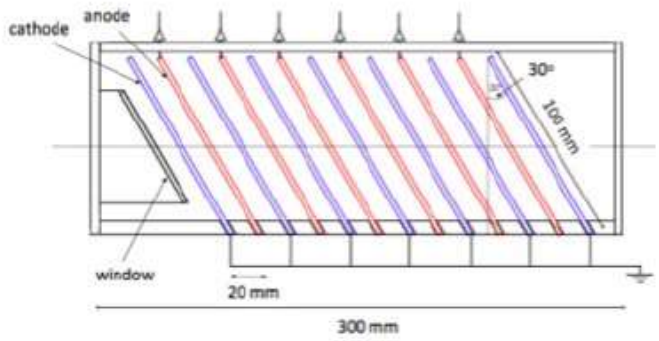
G. Colucci LNL Annual Report 2017, p. 77

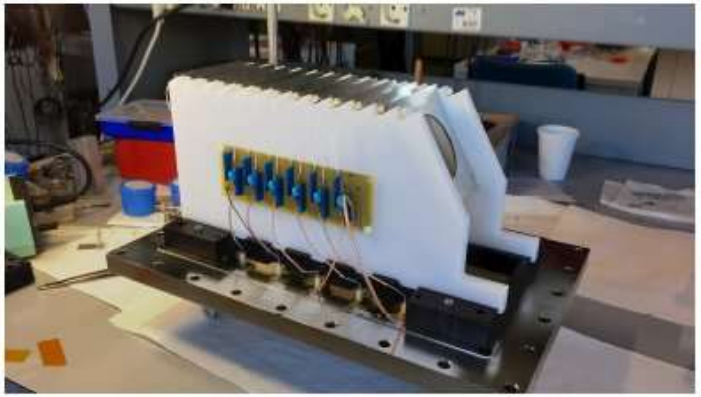












G. Colucci et al.

PRISMA planned activity until 2025

Continue the campaign of measurements with PRISMA+AGATA in collaboration with international groups using the TAP beams

Perform measurements using the being developed 238U beams (second half of 2025)

Continue the study of multinucleon transfer processes ar sub-barrier energies

Continue the study of hindrance phenomena in deep sub-barrier fusion reactions for suitable medium-light ion reactions

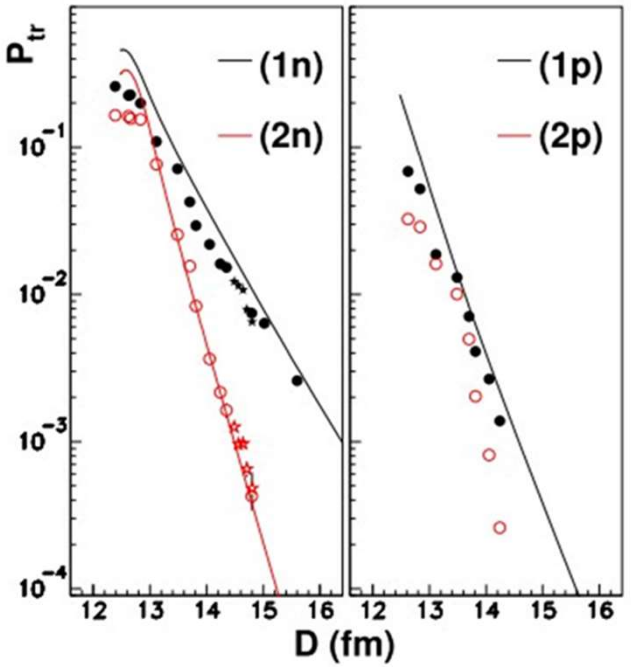
Carry on the data analysis of the various systems already measured or scheduled

Prisma : the near future

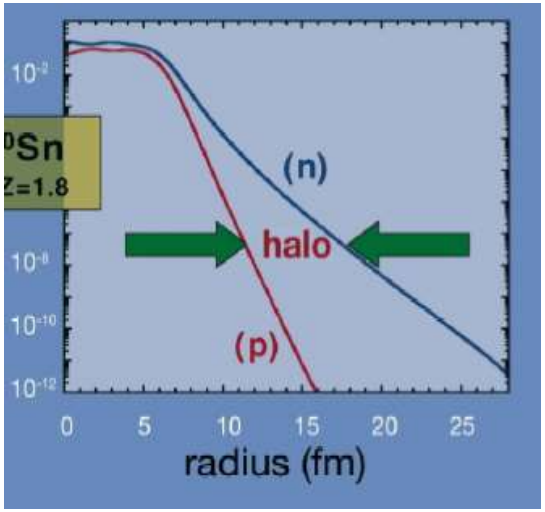
Heavy ion transfer reactions at very forward angles

The successful implementation of ion detection with the PRISMA spectrometer placed at forward angles using inverse kinematic reactions at sub-barrier energies (**in the figure an example is shown of transfer probabilites as function of the distance of closest approach**) paves the road for measurements with even higher sensitivity, especially needed when dealing with low intensity radioactive beams

Improving existing techniques and developing new devices for a complete ion identification in transfer reactions at very forward angles is important for a variety of challenging studies



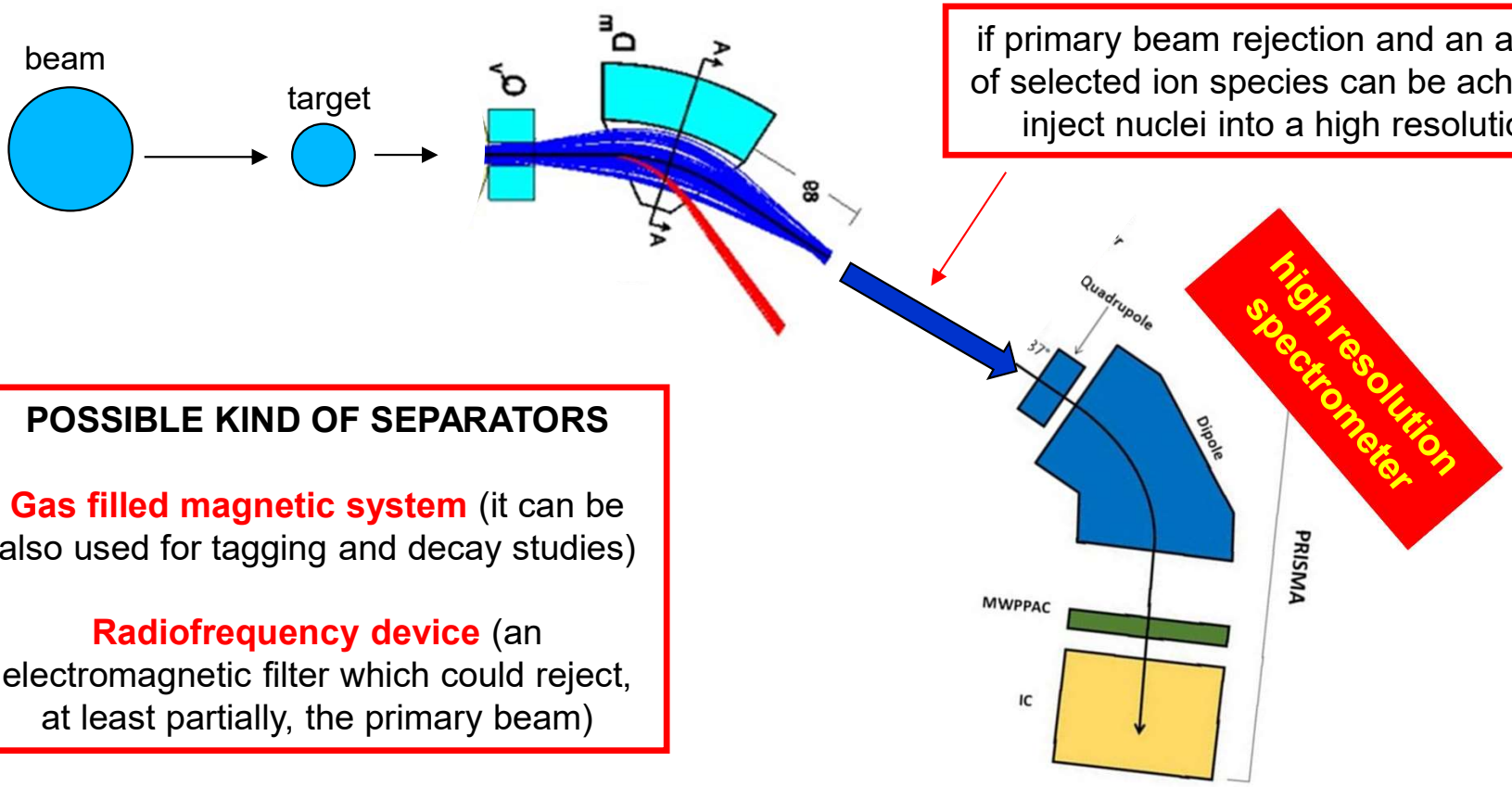
L.Corradi et al., PLB834(2022)137477
Montanari et al., PRL113(2014)052501



nucleon-nucleon correlations at sub-barrier energies, nuclear Josephson effect, onset of density dependent forces in neutron rich nuclei, neutron density profile

Population of neutron-rich heavy nuclei near N=126 shell and in the transactinide region

Options to be investigated for ion detection at very forward angles



if primary beam rejection and an acceptable focusing of selected ion species can be achieved one can then inject nuclei into a high resolution spectrometer

POSSIBLE KIND OF SEPARATORS

Gas filled magnetic system (it can be also used for tagging and decay studies)

Radiofrequency device (an electromagnetic filter which could reject, at least partially, the primary beam)

Especially with the SPES beams one can take advantage of inverse kinematic reactions, due to the large detection efficiency (kinematic boost) and high A,Z,Q resolution (high ion kinetic energy). However, at forward angles one faces serious problems, like the large kinematic spread and the primary beam rejection

One may think to a (first stage) separator which can be used not only in stand-alone configuration, but designed in such a way to collect and focus ions of the wanted kind (like the deep inelastic ones) for further manipulation, e.g. followed by a high resolution PRISMA-like device for full ion identification or to stop the products to study their decays

Ion detection with gas filled magnetic spectrometers at very forward angles

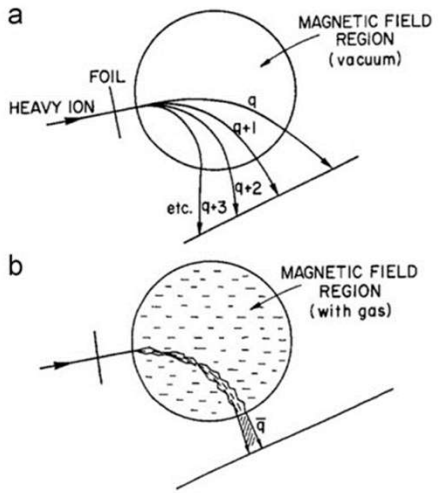
The option of using a magnetic spectrometer in a gas filled mode for deep inelastic processes has been studied and the results suggest that it is worth to pursue further developments

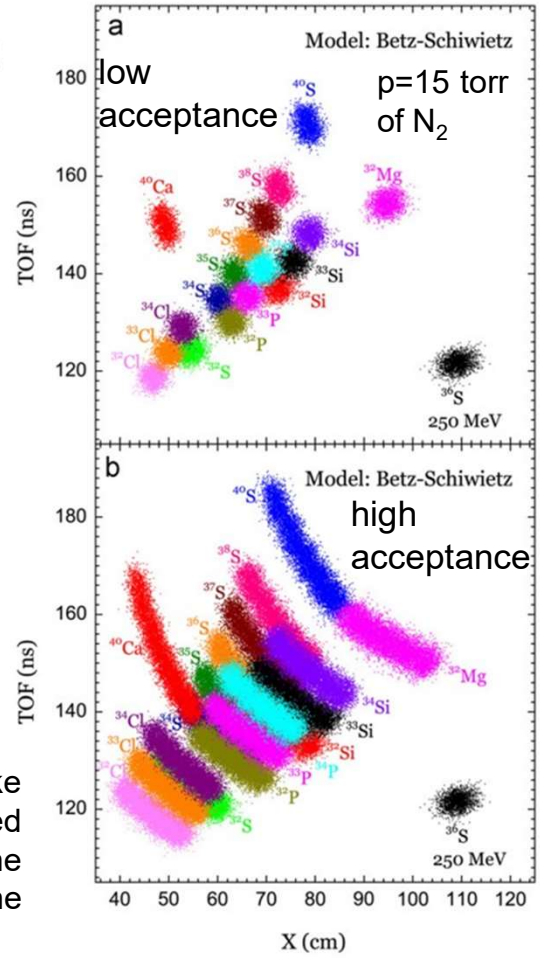
Split pole (ANL)

$^{36}S+^{208}Pb$ E_{lab}= 250 MeV

$$\bar{q}(v, Z) \propto vZ^{\gamma} \quad \gamma \sim 0.45$$

$$B\rho = mv/\bar{q} \propto m/Z^{\gamma}$$

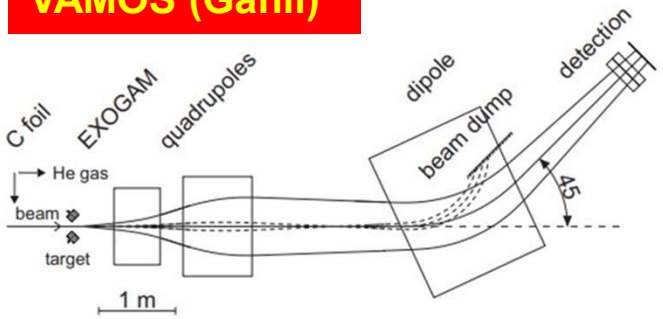




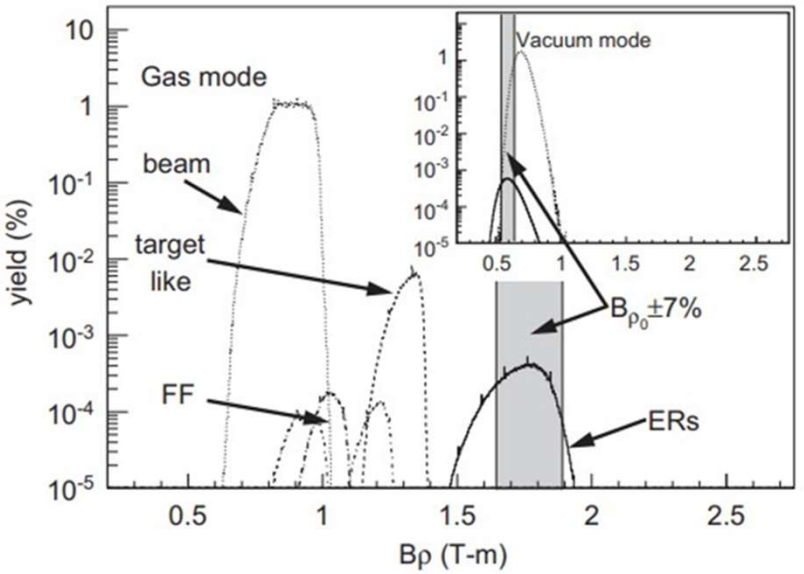
simulations show that beam-like particles are well separated from DIC products, although the energy spread deteriorates the A and Z separation

J.M.Figueira et al., NIM A670(2012)32

VAMOS (Ganil)



$^{40}Ca+^{150}Sm$ E_{lab}= 196 MeV



calculated magnetic rigidities of the reaction products with the spectrometer filled with He gas at p=0.6 mbar

C.Schmitt et al., NIM A621(2010)558