Experiments with FAZIA from LNS to GANIL

Giovanni Casini
INFN Sezione di Firenze

The physics motivation

Heavy-Ion Collisions at Fermi energies: explore the Equation of State (EoS) in a range of excitations, densities and n-p asymmetries.

1) Isovector properties of the EoS, Isospin diffusion/migration, symmetry energy, iso-yields, vaporization (low density)

2) Transport properties and connection to the transport models

Stopping and energy dissipation; *NN* cross-section; particles and cluster flows; *NN* and *multi*-body correlations in dense matter

See: Y.Zhang et at PRC 97 2018 output of the **CODE EVALUATION PROJECT**

3) Clustering and decays inside excited nuclear matter

In-medium properties of clusters, links between nuclear dynamics and nuclear structure

Investigation of EoS with collisions

isoscalar term isovector term

$$E(\rho,\delta=\frac{N-Z}{A})/A = E_0(\rho,\delta=0) + E_\delta(\rho,\delta)$$

$$E_\delta(\rho,\delta) = E_{sym}(\rho)\delta^2$$

$$E_{sym}(\rho) = \frac{1}{2}\left(\frac{\partial^2 E_\delta(\rho,\delta)}{\partial\delta^2}\right)_{\delta=0}$$

$$E_{sym}(\rho) = S + L_{sym}x + \frac{1}{2}K_{sym}x^2$$

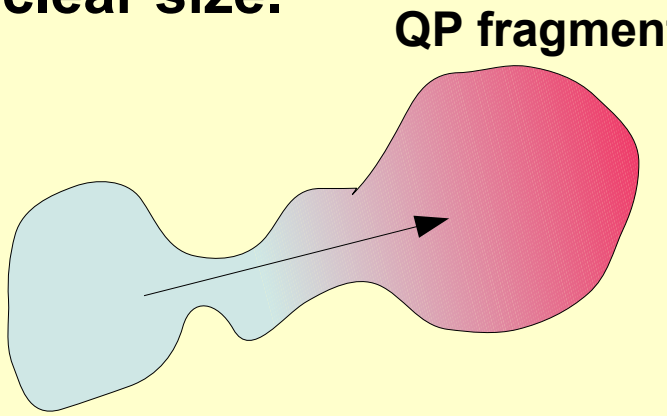
$$x = (\rho-\rho_0)/(3\rho_0)$$

e.g. L_{sym}=78(ave.) +-31(σ) MeV J.Margueron 2018

Density and Isospin gradients in HIC

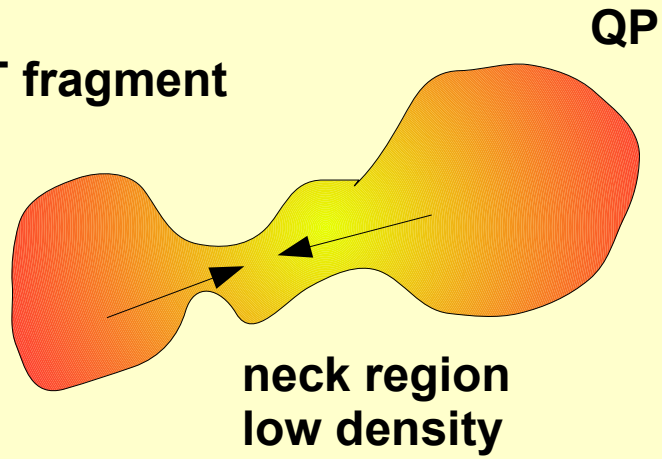
Semiperipheral reactions at Fermi energies produce regions at subsaturation densities (V.Baran et al. N.Phys A 730 2004)

"tuning" via a selection of impact parameter, beam energy and nuclear size.



DIFFERENT INITIAL n/p of beam and target ions

The neutron-proton flux is mainly governed by $E_{sym}(\delta=0)$



SAME INITIAL n/p of beam and target ions

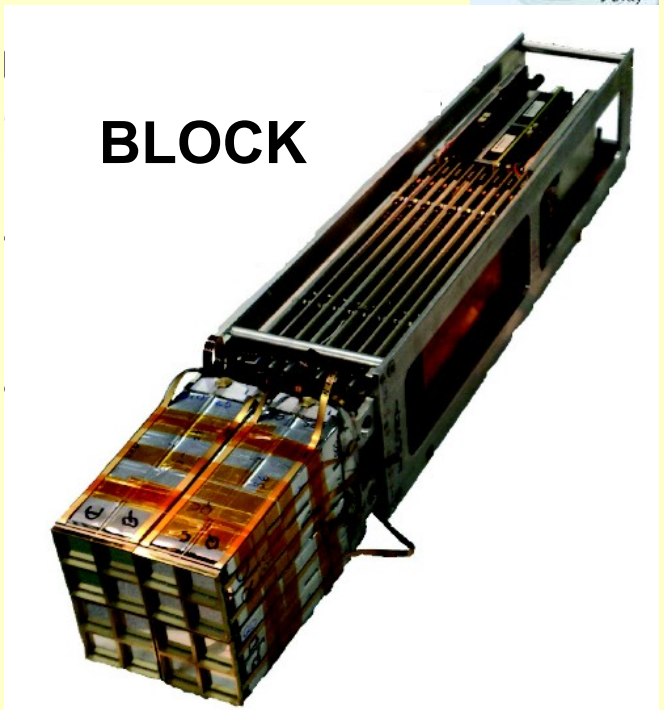
Density gradients: the neutron-proton flux is also ruled by L_{sym}

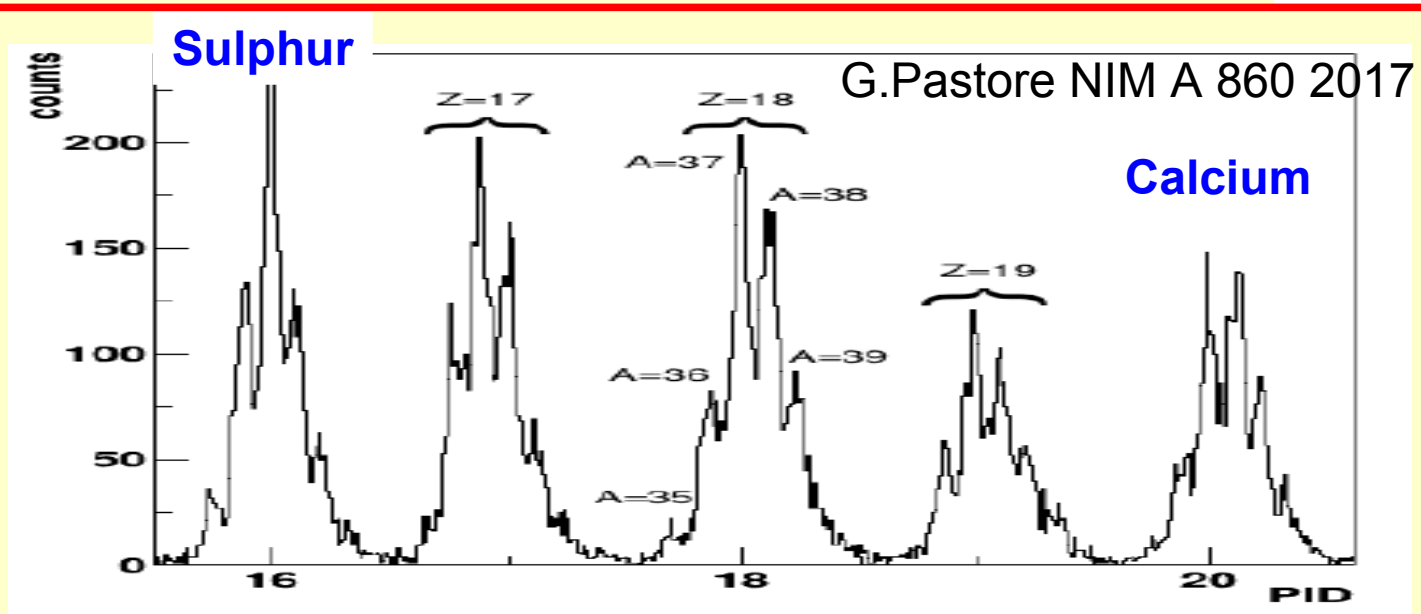
in reality both mechanisms play

The FAZIA detector

- **Silicons 300+500micron**
  (special nTD wafer with specific crystalline orientation cut, reverse mounting)
- **CsI(Tl) 10 cm**
  homogenous Tl doping (5%)
  custom Phodiodes for maximum active area
- **Telescope and Block**

Active area: 20x20mm2
Block (BLK): 16 telescopes, in a 4x4 matrix
ΔΩ for a BLK at 100cm: 6.4 msr
Granularity at 100cm: 1.2 deg

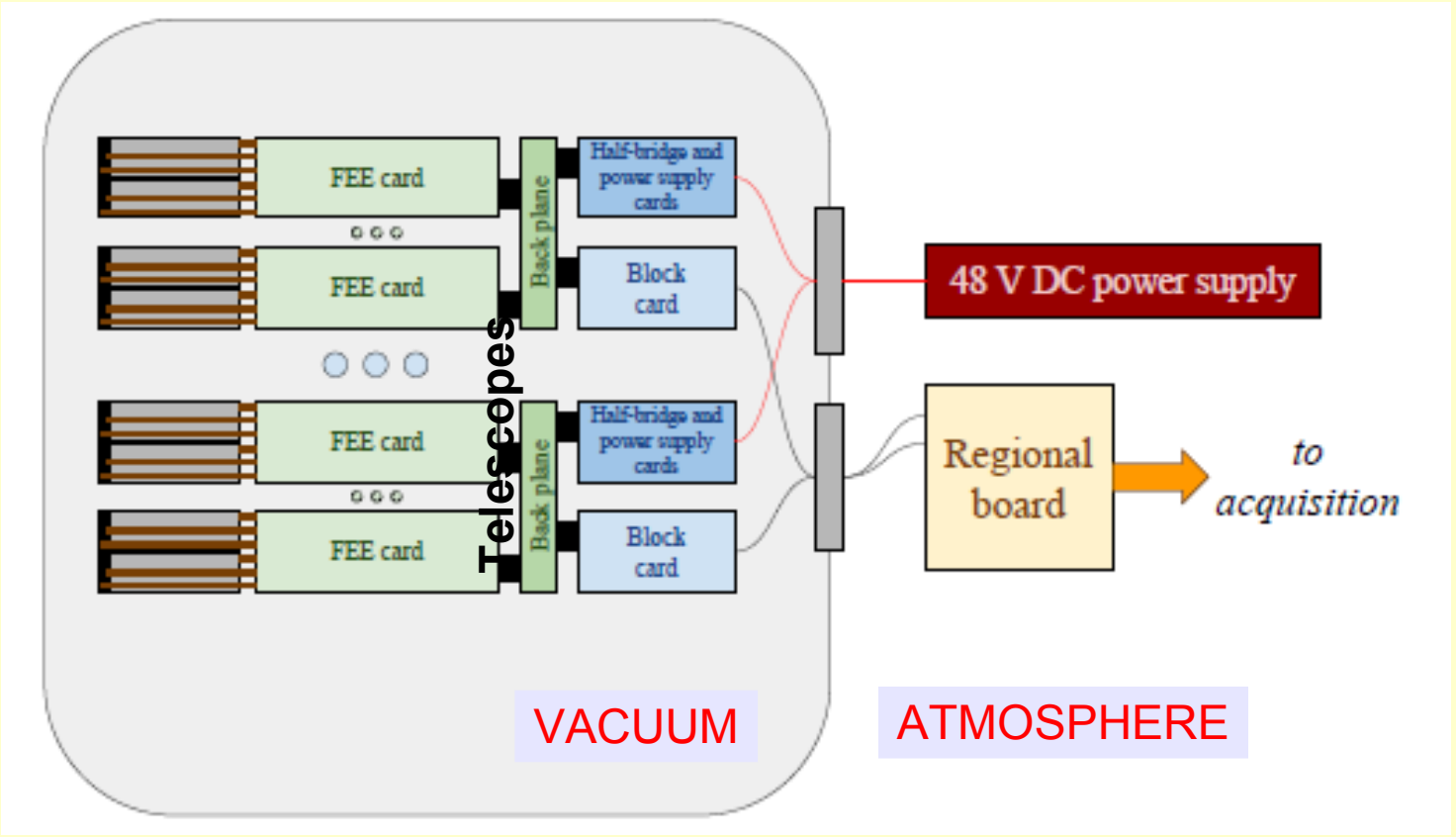




Pulse Shape Analysis
Using IMAX (max of current pulse)

IONS STOPPED IN THE FIRST LAYER

The FAZIA system: flexible and versatile

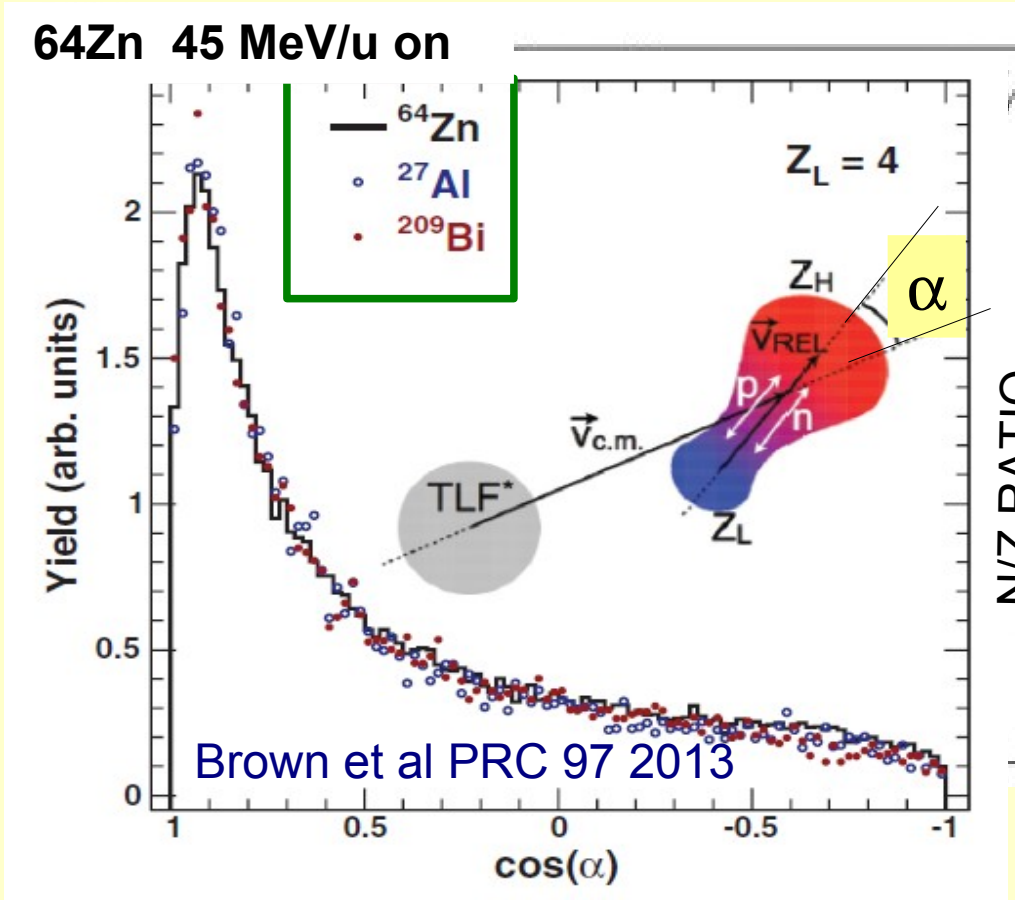


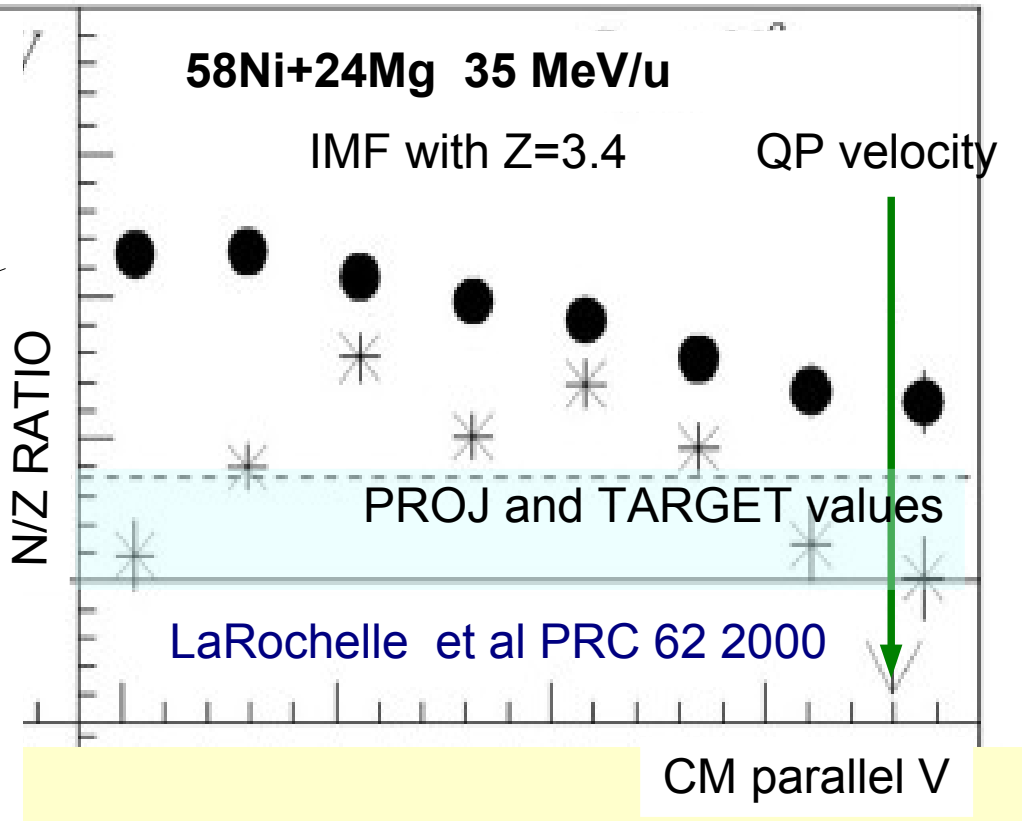
- **FEE**
  6-ch detectors (3ch x 2Telescopes)
  Preamps, pulser; HV bias gen/regulat/control;
  12 sampling ADC's, 2 FPGA, FIFO
- **BLOCK cards and HV generation cards**
- **Optical link to Regional Board**

Easy mounting/operation
3 I/O (used) connections: 48V, optical fiber, water pipes

Neck dynamics and neutron enrichment

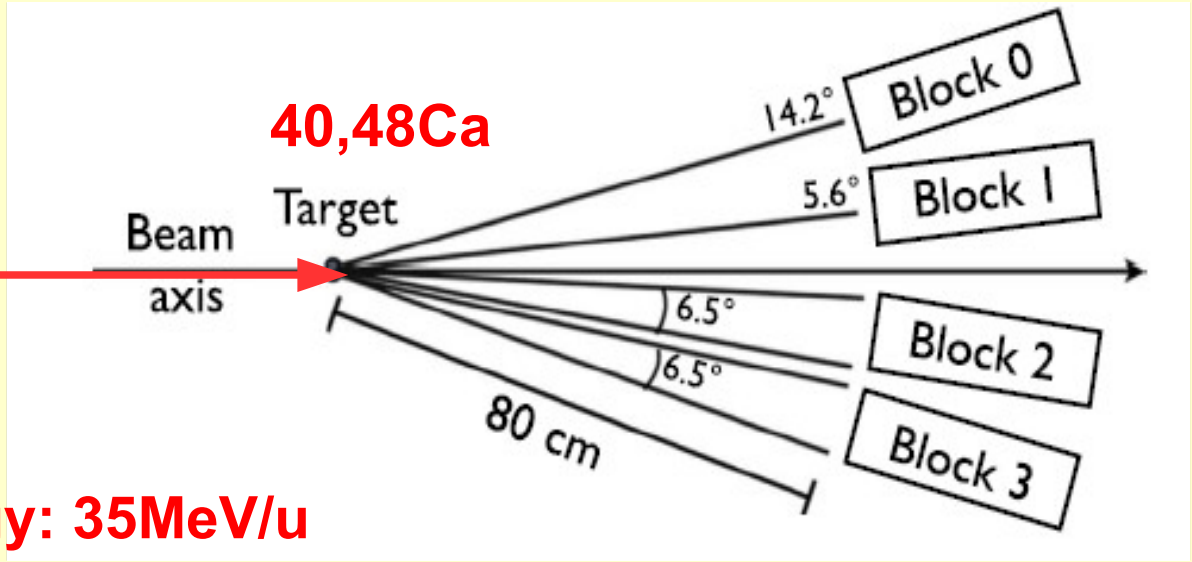
- **neck formation and rupture favour IMF at midvelocity**
- **preferential alignement of the final fragments**
- **neck region and local neutron enrichment**





ISOFAZIA experiment

PhD Thesis G.Pastore, Firenze 2017



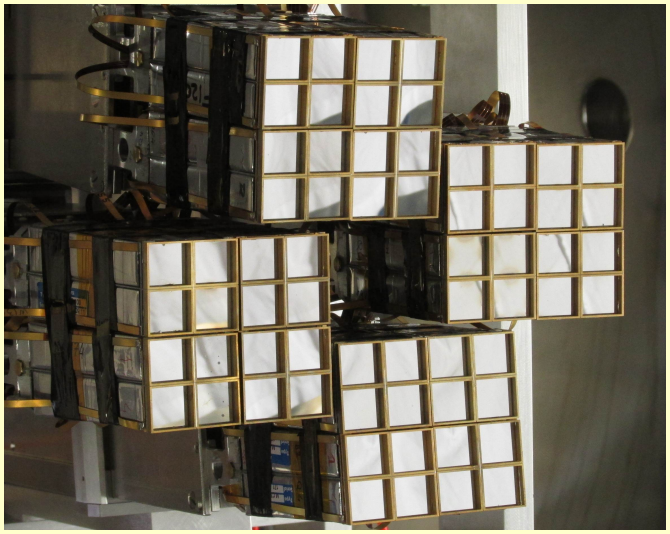
planar geometry

BEAM energy: 35MeV/u

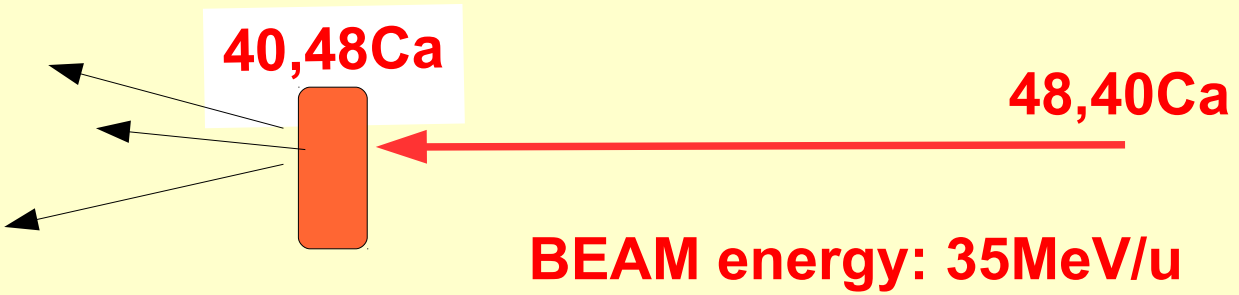
Study of **isospin dynamics** looking at the properties of the Quasi-Projectile (QP) remnant and of its decay products (in practice from Z=1 to Z around 20)

- variation of: **neutron content of the target** N/Z=1 and 1.4
- variation of: QP decay mode (**evaporation, fissionlike**)
- comparisons with **transport model** predictions

FAZIASYM experiment



PhD Thesis A.Camaiani, Firenze, in progress

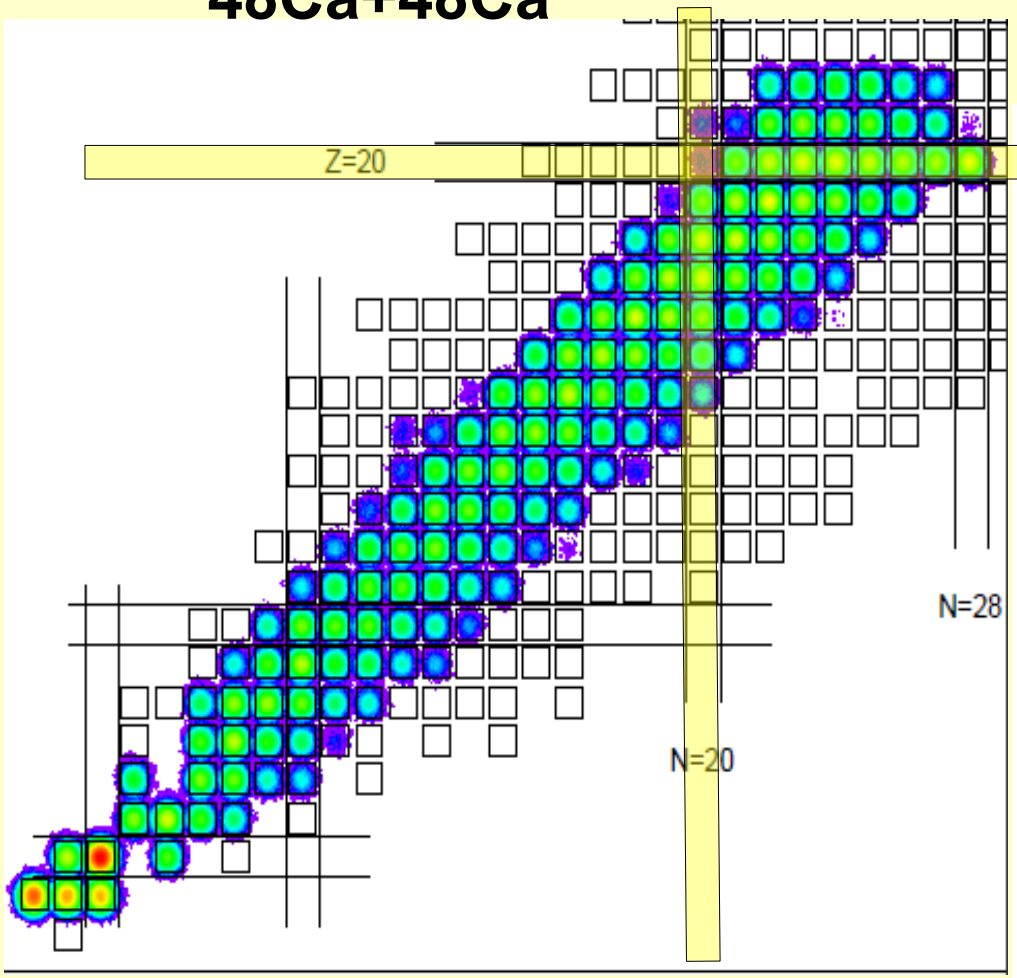


Again we study **isospin dynamics** measuring the properties of the QP and of its decay products (from Z=1 to the charge of the QP)

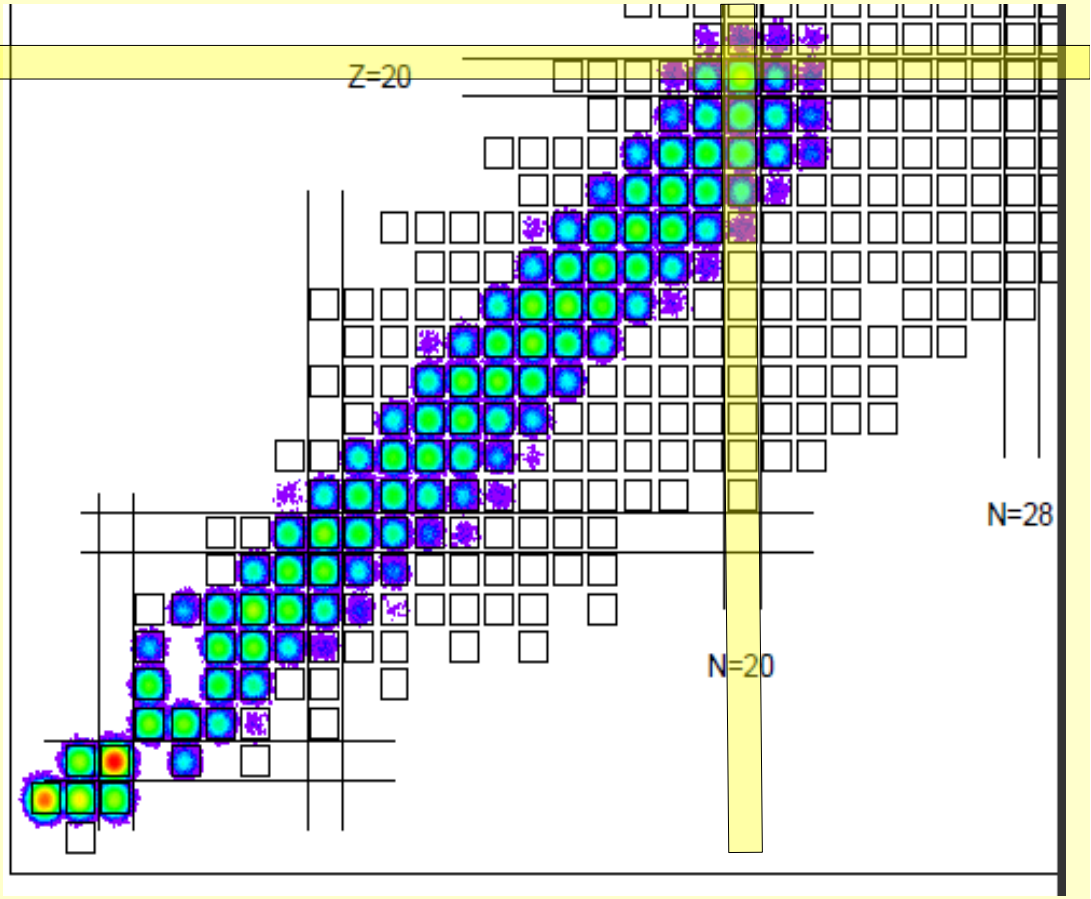
- variation of: **neutron contents of the proj/targ** N/Z=1 and 1.4
- variation of: QP decay mode (**evaporation, fissionlike**)
- looking at specific **N=Z dominated channels** (alpha rich neck?)
- comparisons with **transport model** predictions

Nuclide charts observed by FAZIA

48Ca+48Ca



40Ca+40Ca

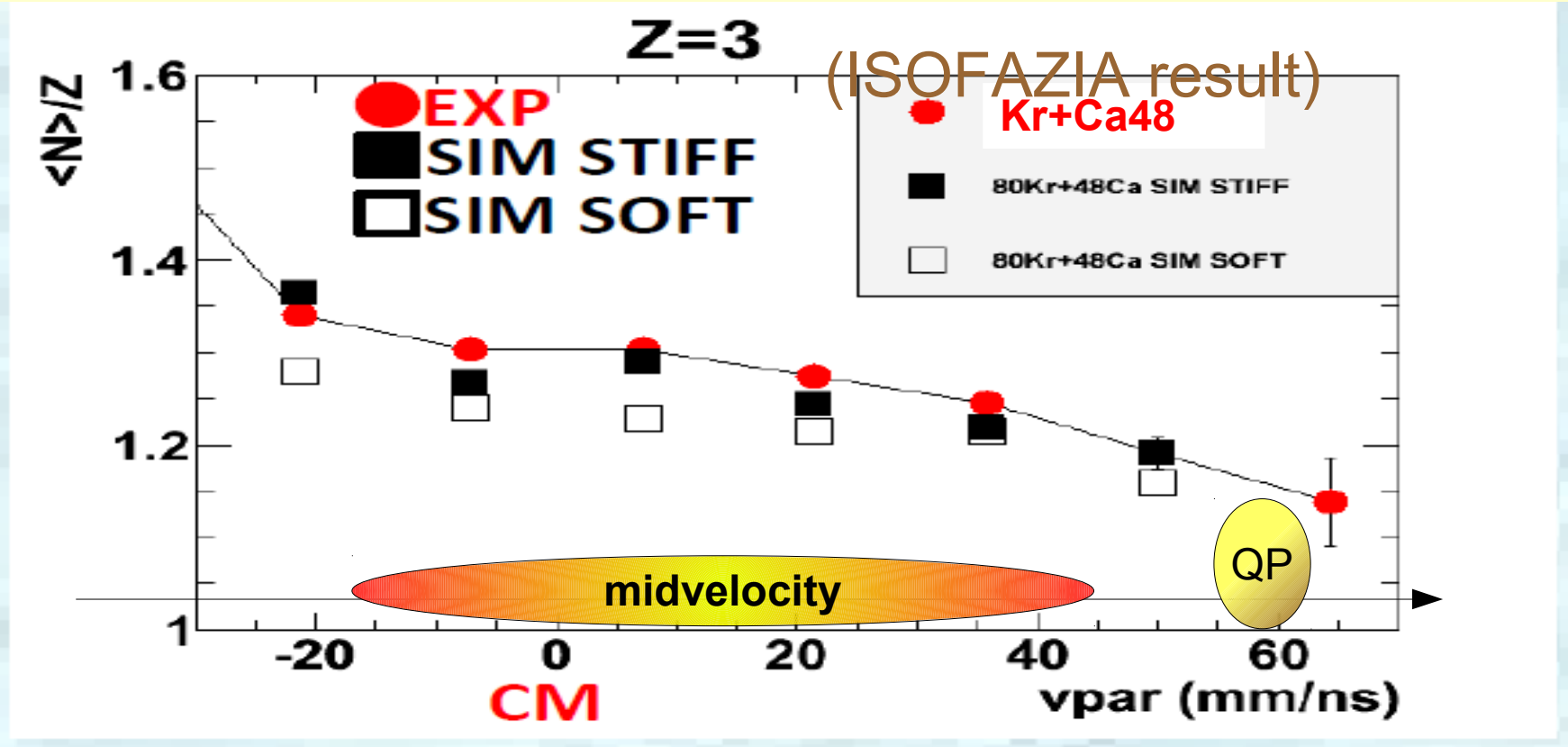


FAZIASYM EXPERIMENT at LNS, Catania

neutron abundance of neck (ISOFAZIA result)

Once more confirmed the **neutron enrichment of the midvelocity region**. Effect interpreted as due to isospin drift (see also e.g. De Filippo PRC 86, 2012)

S.Piantelli at IWM-MC 2018 and PhD Thesis G.Pastore, Firenze 2017



AMD+Gemini calculations show slight sensitivity to the asy-stiffness of the EOS (weak indication for a very stiff behaviour $L_{sym} \sim 100$)

New approach to fast fission (FaziaSym result)

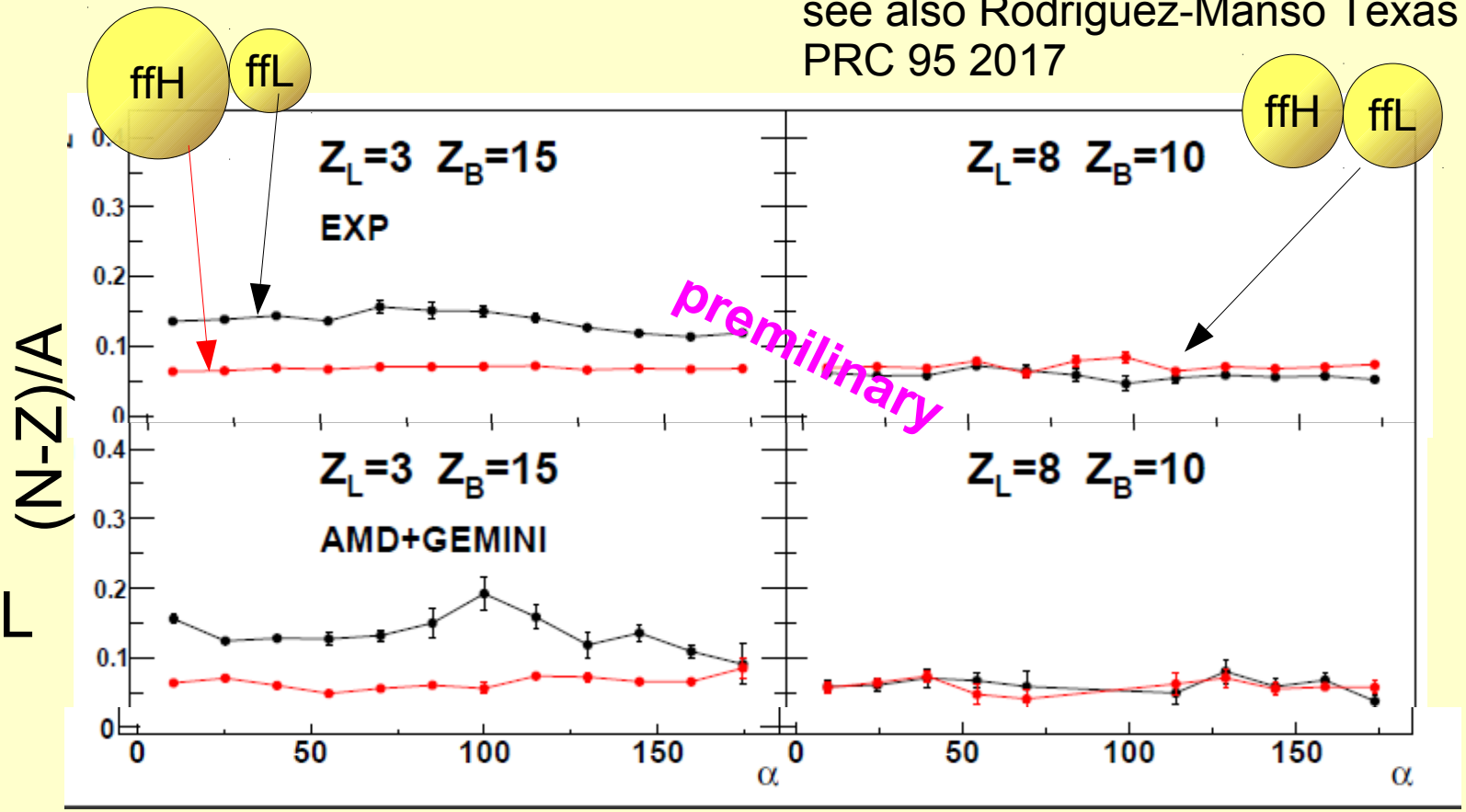
Permitted by the coincident measurement of A,Z of both fragments. FAZIA is (almost) unique in this respect.

PhD Th. A.Camaiani in progress

see also Rodriguez-Manso Texas A&M PRC 95 2017

EXP

MODEL



Can we t
a kind of
the exam
LHC com

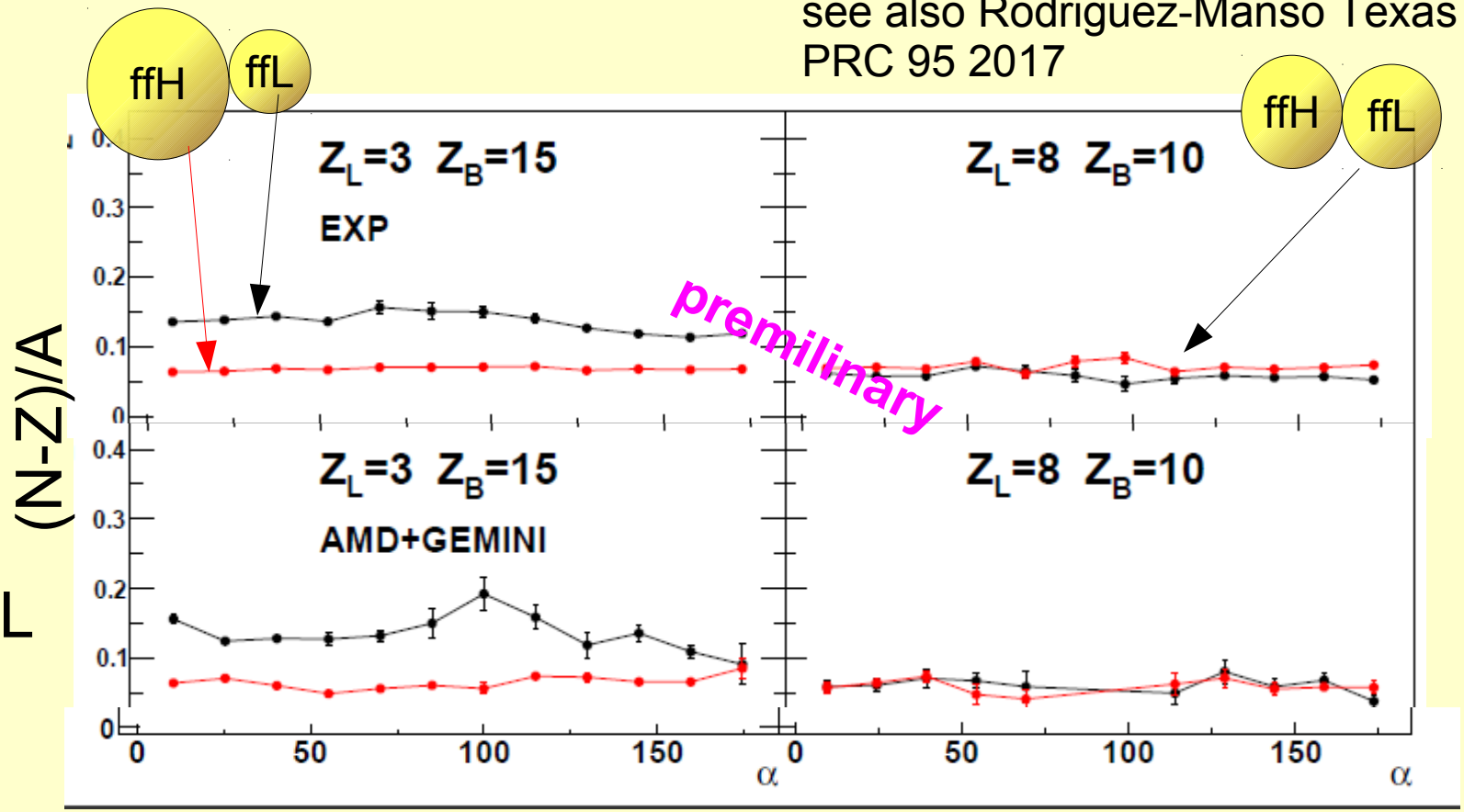
IMPORTANT: extensive simulations AMD+Gemini to keep systematics under control and then to further study fission time-scales vs. isospin equilibration and EOS asy-stiffness

New approach to fast fission (FaziaSym result)

Permitted by the coincident measurement of A,Z of both fragments. FAZIA is (almost) unique in this respect.

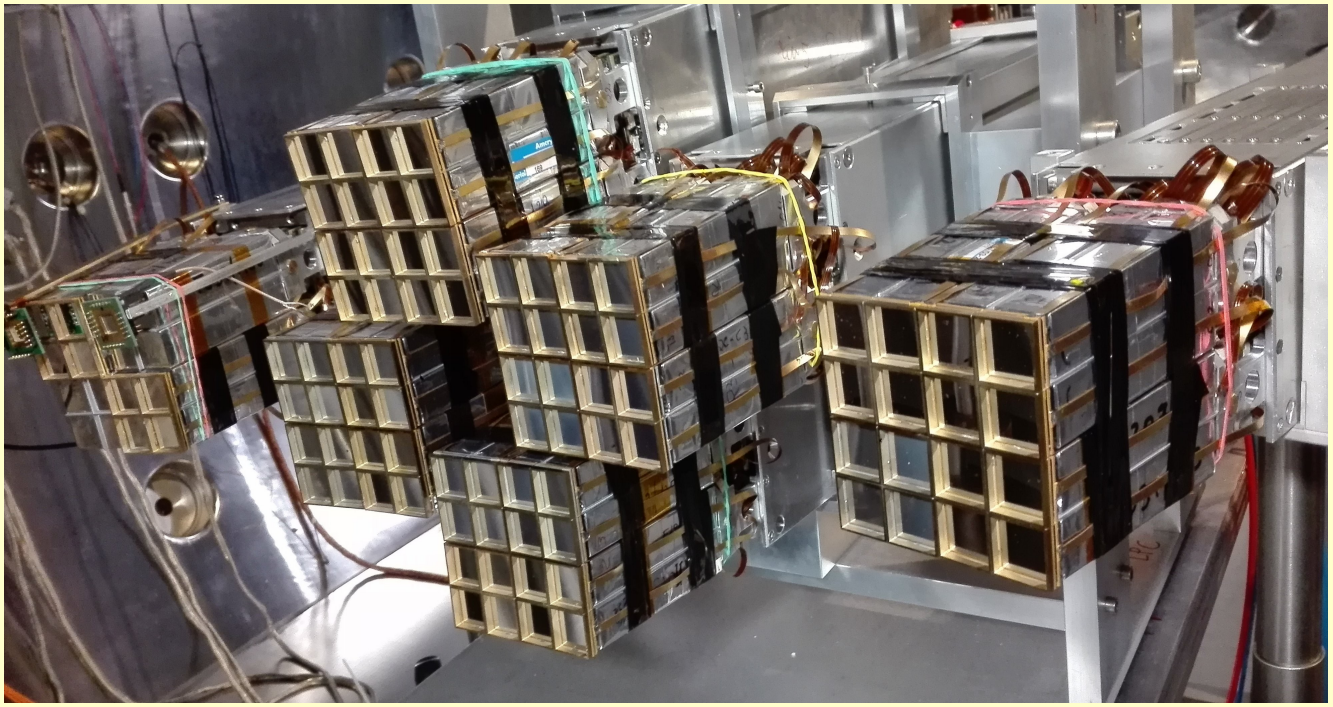
PhD Th. A.Camaiani in progress

see also Rodriguez-Manso Texas A&M PRC 95 2017



just a crude idea……**Can we think of a kind of TIER on the example of LHC for best use of computing resources in our Eurisol area?**

The last experiments at LNS



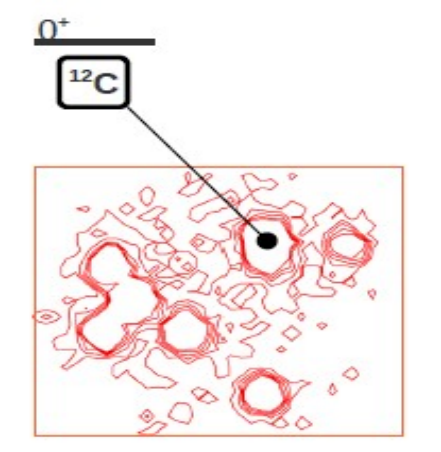
configuration of six blocks at 100cm distance from target

FAZIACOR: 32S and 20Ne+12C @ 25-45MeV/u (completed march 2017)
FAZIAPRE: 40,48Ca+12C @ 25-40MeV/u (completed may 2018)

- **alpha-cluster decay modes, sequential vs. direct (in primis 12C Hoyle state).**
- **resonance decay modes in the hot nuclear environment**
- **fast particle emissions vs isospin dynamics with increasing bombarding energy**

Nuclear resonances in hot environment

Spectroscopy of hot Fragments created during the nuclear reactions

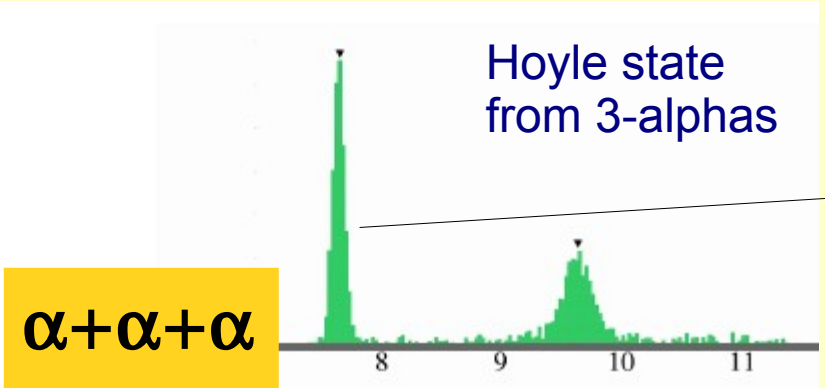


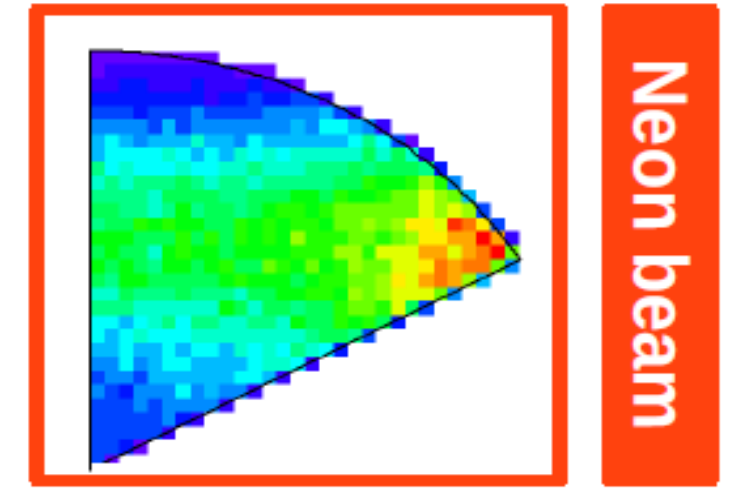
Nature of the decay of 12C Hoyle-state: only via 8Be?
Also Direct? Is it affected by the nuclear medium?

FAZIACOR

20Ne,32S+C@25MeV/u

analysis by D.Gruyer





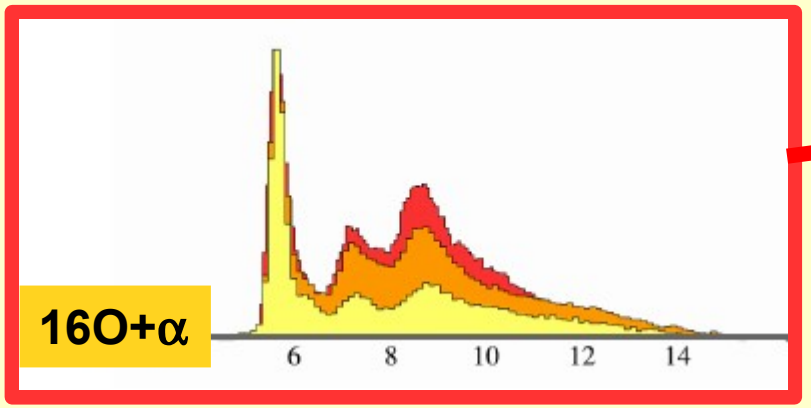
Dalitz plot compatible with sequential emission

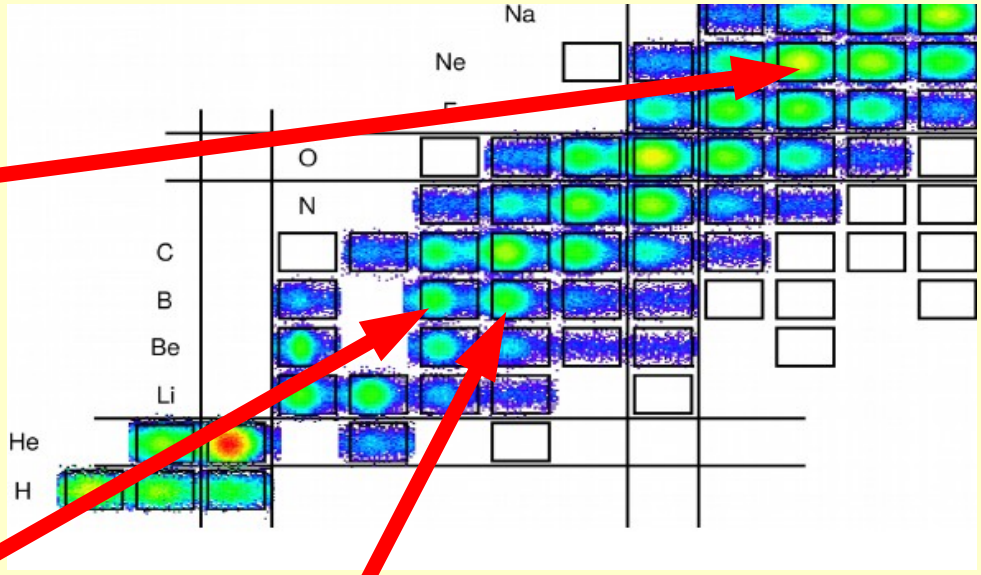
PRELIMINARY

apparently almost 100% decay occur through 8Be

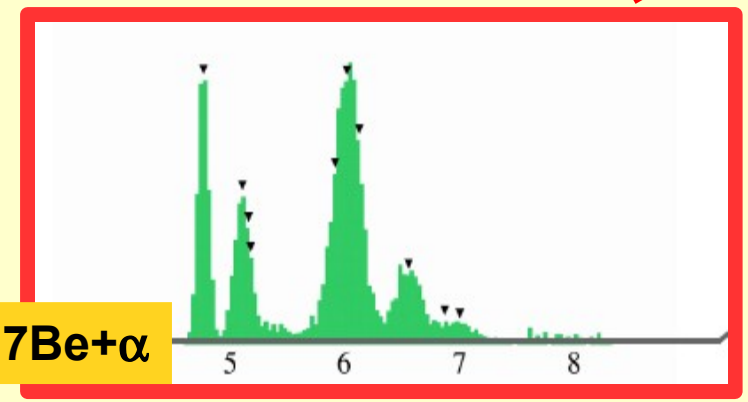
Multifragment spectroscopy

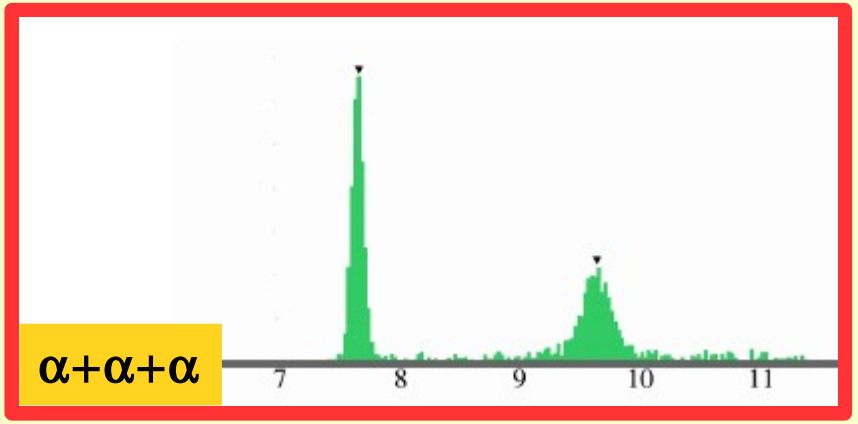
Various cases of hot fragments above particle emission threshold





D.Gruyer and G.Verde
FAZIA COR

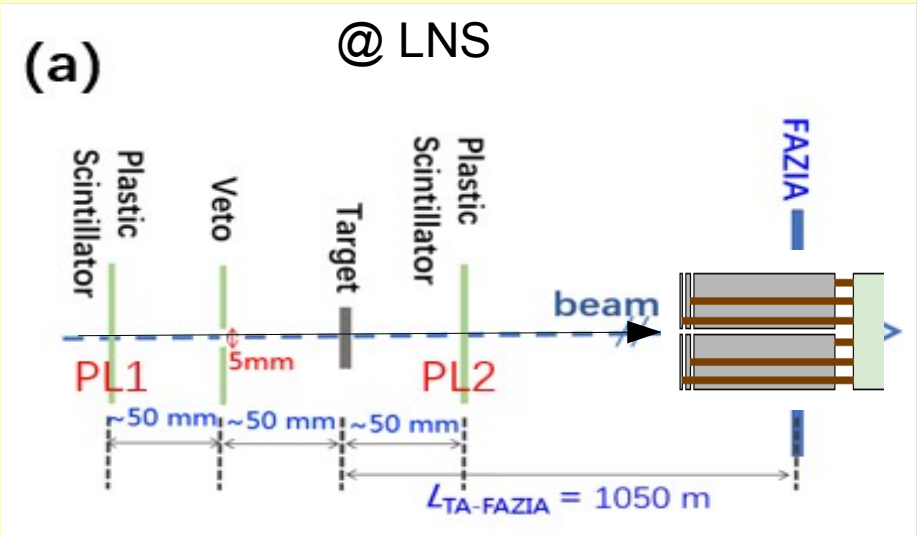




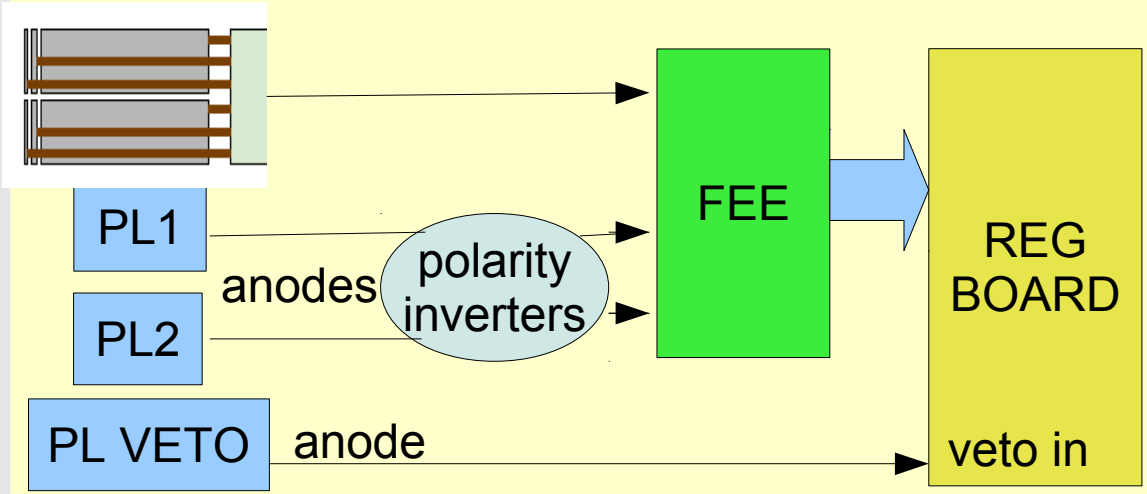
Transmission-type Experiment

FAZIA ZERO experiment (B.Sun Behang Univ)
12C+12C at 60-80 MeV/u, this july

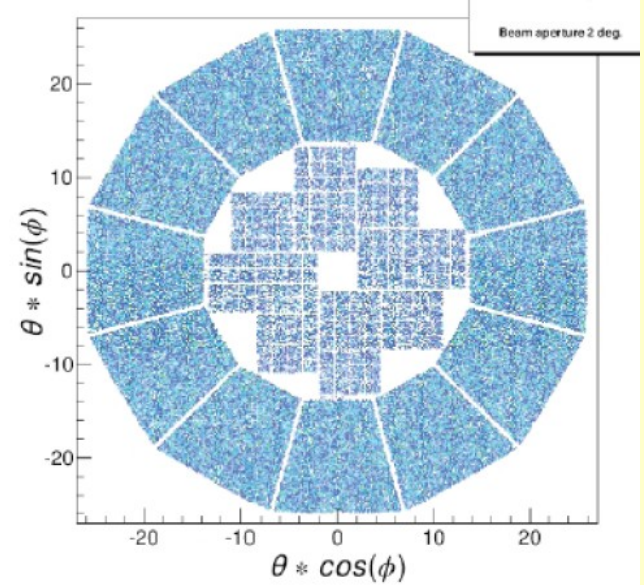
- Total reaction cross-section TCS and charge-changing cross-section CCCS allow to determine the **nuclear and charge radii.** Their difference gives access to **nuclear skin** (sensitive to Lsym next to the saturation density)
- Neutron skin and neutron star radius related both to EOS (Fattoyev ArXiv:171106615)
- Single experiment with FAZIA (at zero deg) gives TCS and CCCS!

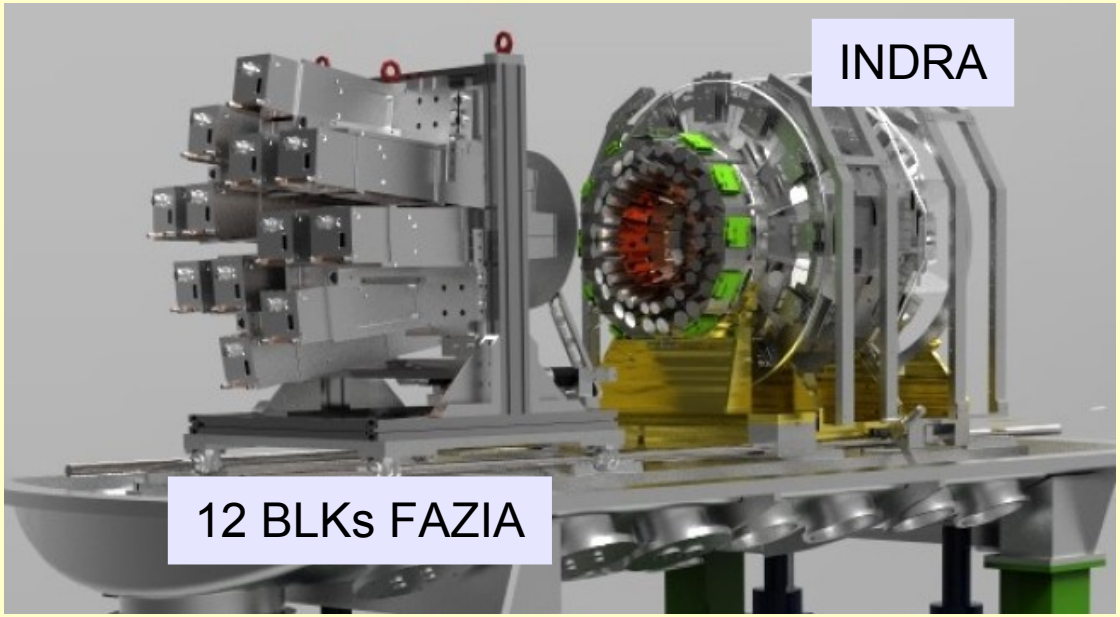


GOOD TEST for the versatiliity of the FAZIA system: new configuration and a coupling with different detectors



Coupling FAZIA and INDRA at GANIL





FAZIA will cover the forward region 2-12deg; beyond we will use the INDRA telescopes

Memomandum of Understandings on FAZIA_INDRA just now approved by parties

2018

- Two FAZIA blocks now mounted in the INDRA vacuum chamber
- Commissioning with parasitic beams is on going (24 june 2018 till end july)
- Proposal to the PAC sent just now

2019

- Start measurements with FAZIA+ INDRA

Scientific reach with FAZIA_INDRA

first proposed experiment : 58,64Ni+58,64Ni @ 32 and 52MeV/u

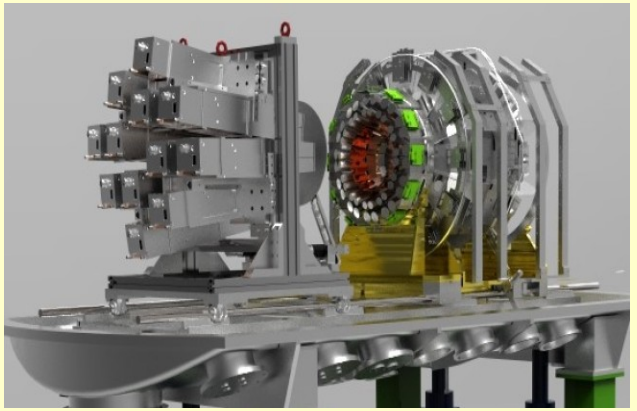
Proposal for the GANIL PAC

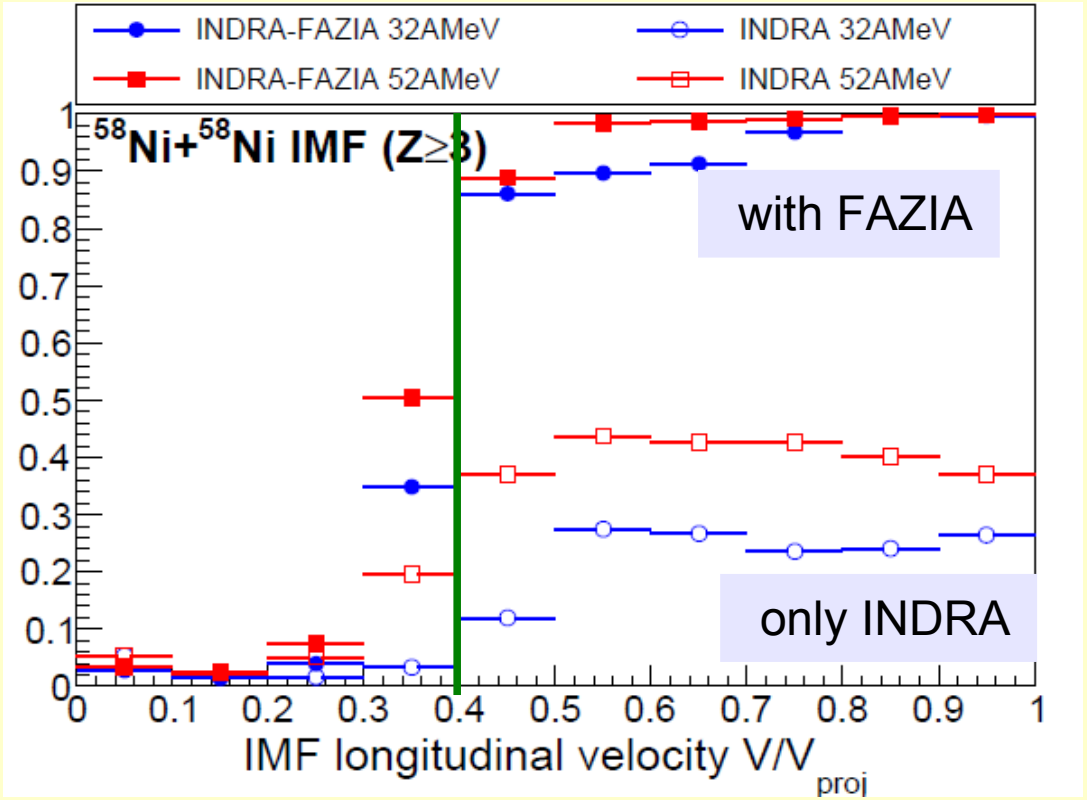
Isospin transport and the Density Dependence of the Symmetry Energy

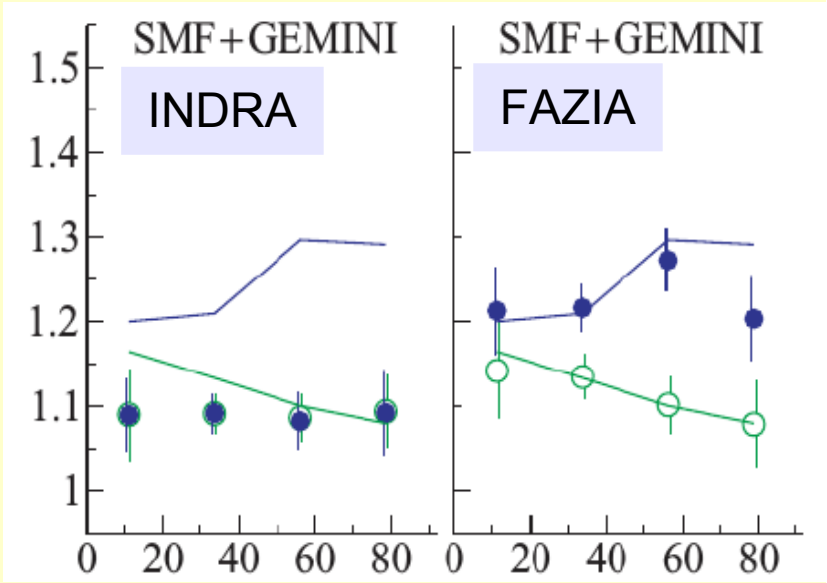
INDRA-FAZIA collaboration

June 15, 2018

O.Lopez & S.Piantelli
for FAZIAColl.



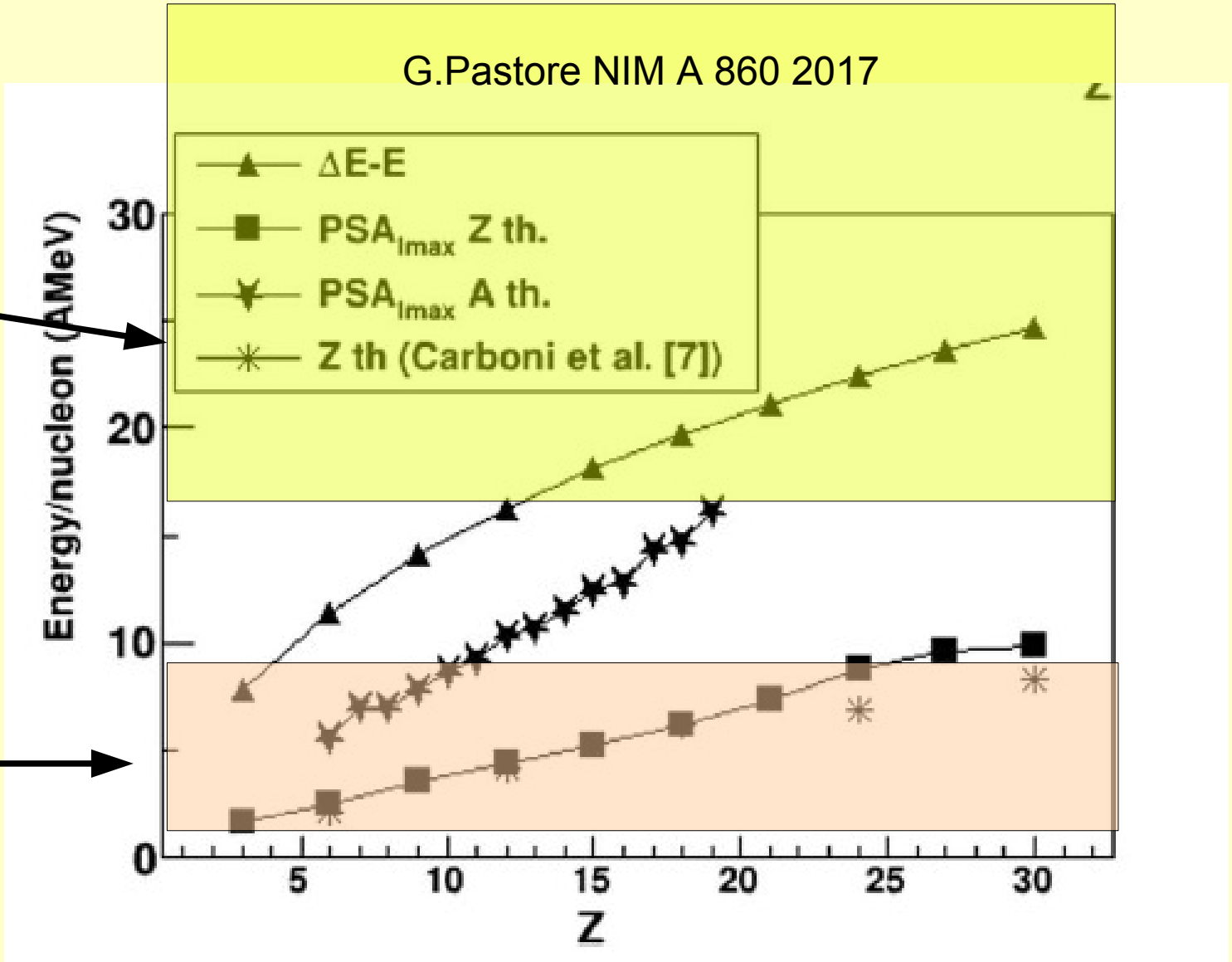




Where we are with thresholds

region of the In-Flight Facilities (Fermi range) and of "Great Eurisol" (A.Facco's label)

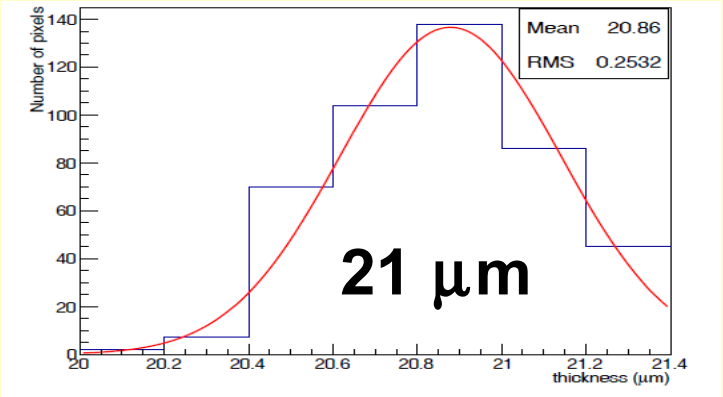
region of the ISOL Facilities



Possible improvements

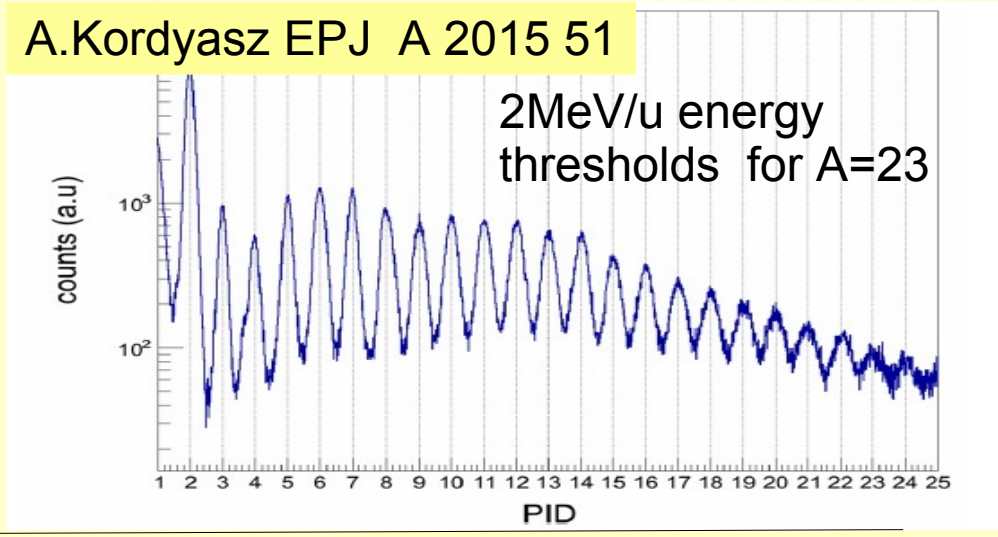
Use of thin first layers to lower the DE-E threshold

Si



very uniform 20x20mm2 epitaxial Si (Fazia-like) pad

A.Kordyasz EPJ A 2015 51

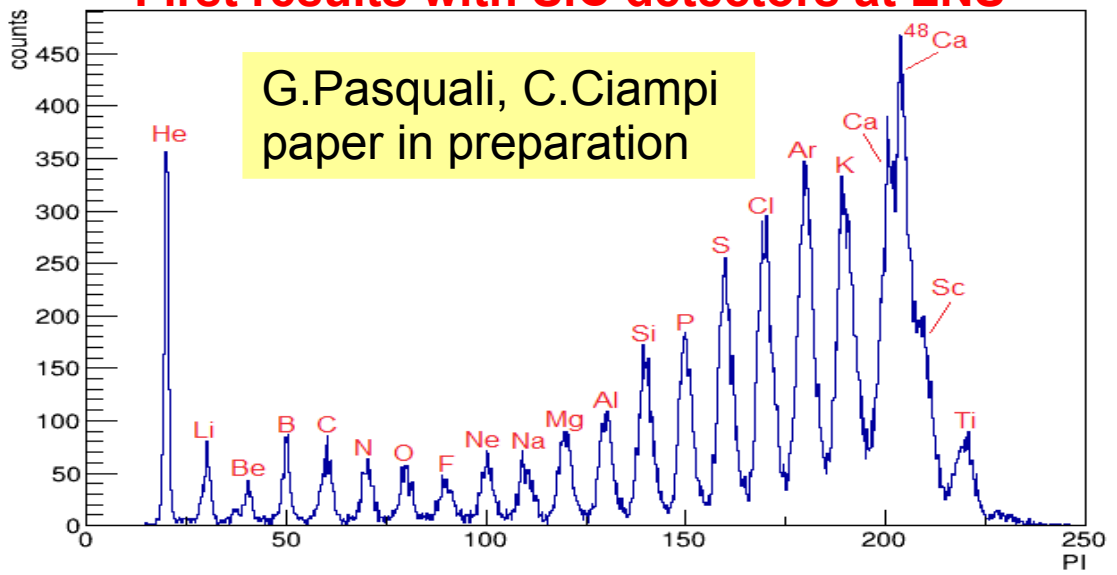


INFN funded

SiCilia project **S.Tudisco et al.**

First results from a DE-E telescope where the first layer is a very thin (10µm) **SiC** epitaxial detector

First results with SiC detectors at LNS



Possible improvements

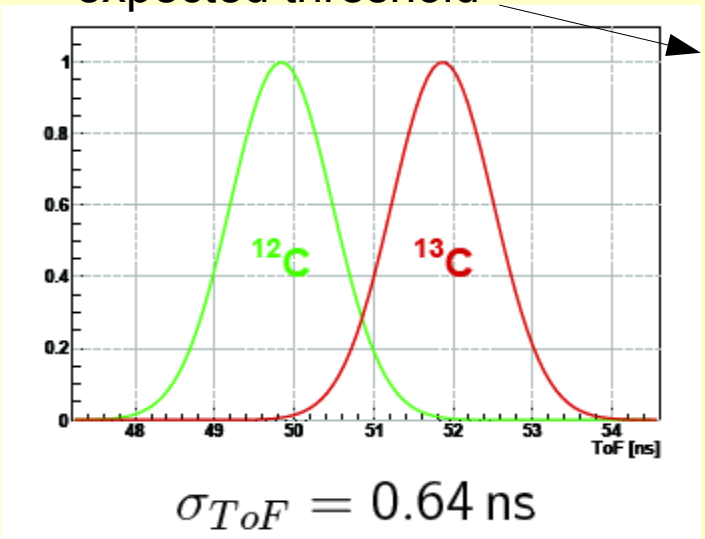
Reduce E-thresolds for mass determination
usinig **Time of Flight**

S.Valdrè INFN Fi
IWM_MC 2018

- Efforts to improve the signal synchronization (the common clock to ADC allows around 1ns)
- Validated a method using fast infrared LED to synchronize Si1 of FAZIA during the experiments (accuracy 10ps)
- Already verified E-th for proton discrimination down to 2MeV

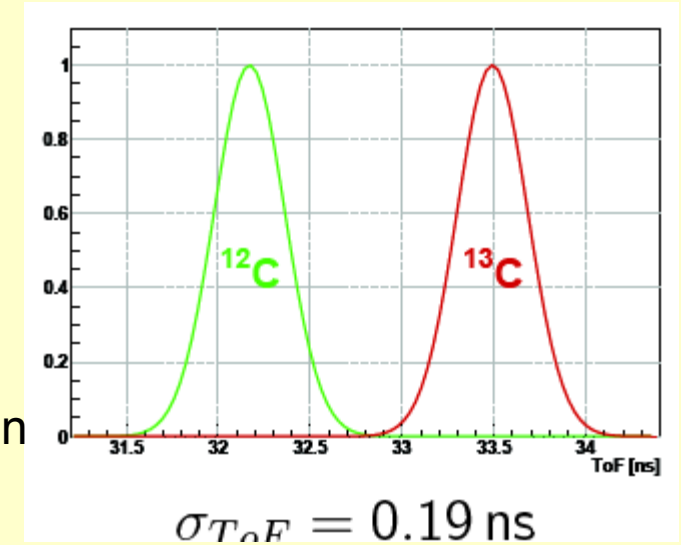
Predictions based on recent results

expected threshold



25 MeV Carbon
2.1MeV/u

60 MeV Carbon
5MeV/u



Conclusions: FAZIA towards EURISOL

A new detection system based on solid state telescopes has been built with excellent ion identification capability, by optimizing the DE-E and PSA techinques

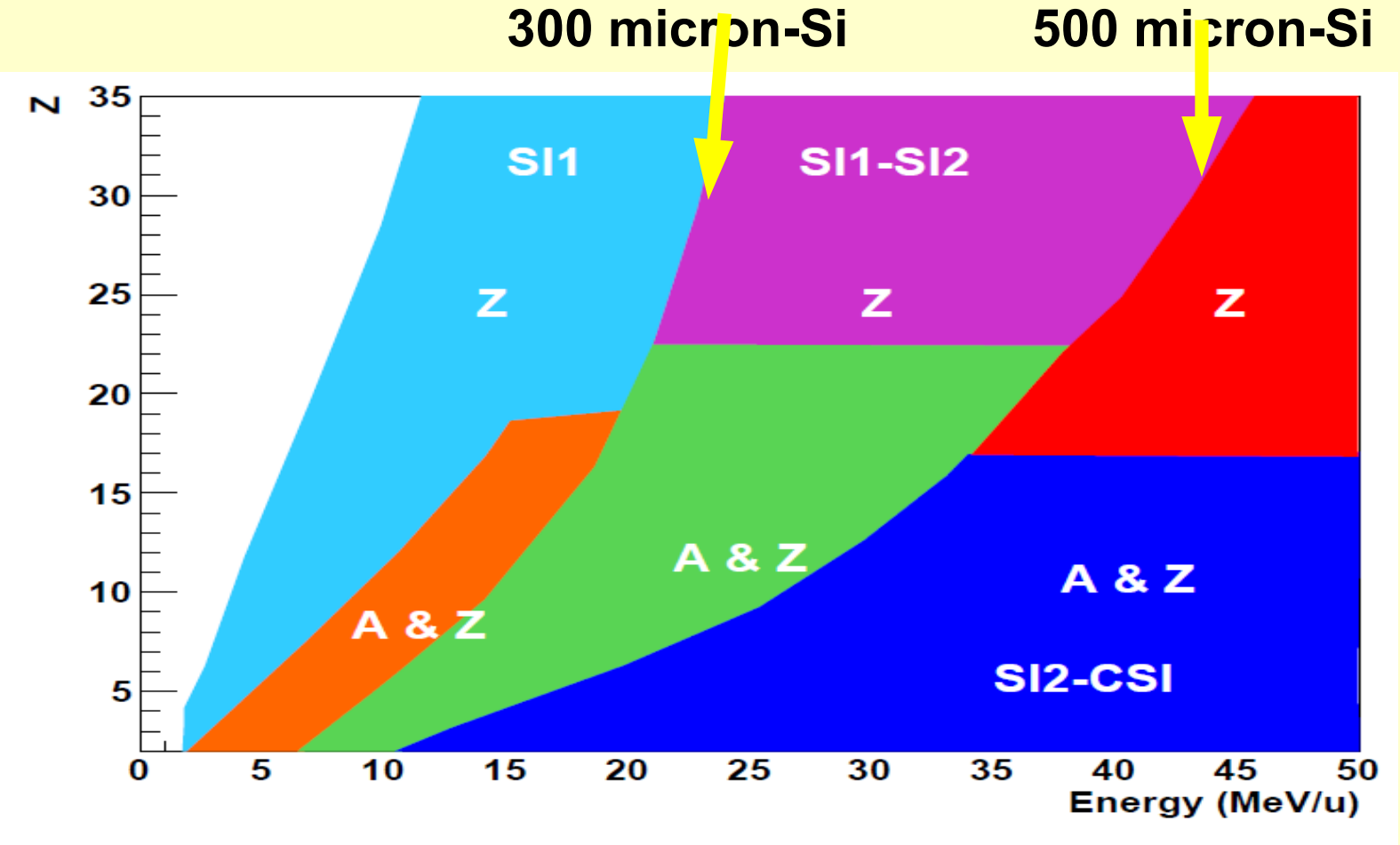
Various experiments done at LNS demonstrated the versatility and flexibility of FAZIA

The commissioning of the FAZIA-INDRA setup is ongoing and this is the ouverture of the activity for next 4-5 years at GANIL with Fermi energies stable (and LISE ?) beams

The obtained perfomances are optimal above 20MeV/u. At the lower energies of ISOL facilities, the threshold for isotopic separation of IMF Z>4 is an issue and future efforts will be done on that

The great FAZIA versatility permits further experimental collaborations and to exchange our (hardware and software) expertise along the road to EURISOL

The accessible (Z,A) regions

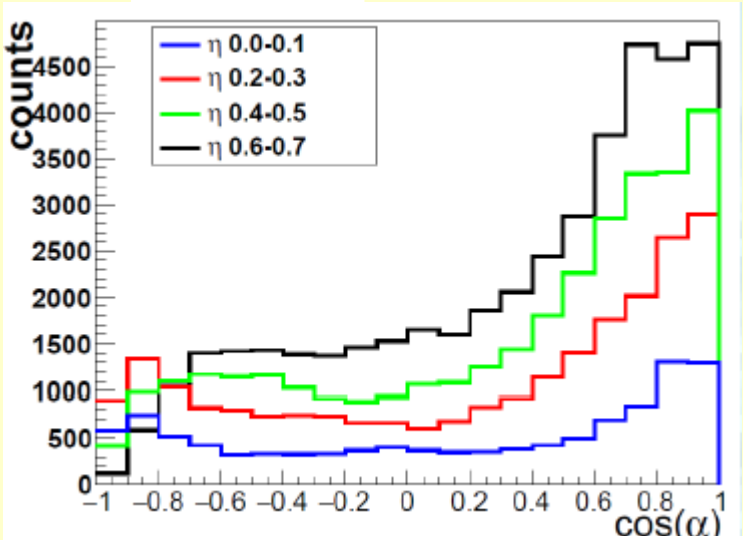


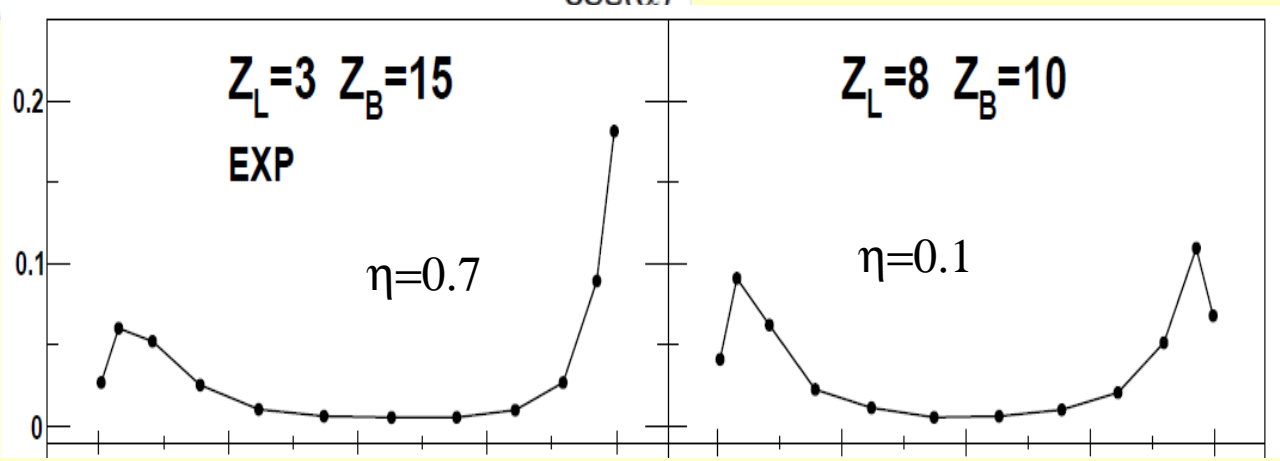
charge identification from 2 MeV/u (for Z = 6)
isotopic discrimination from 5 MeV/u (for Z = 6)

neck emissions

preferential aligned configuration where a small fragment is in between QP and QT

Kr+Ca48





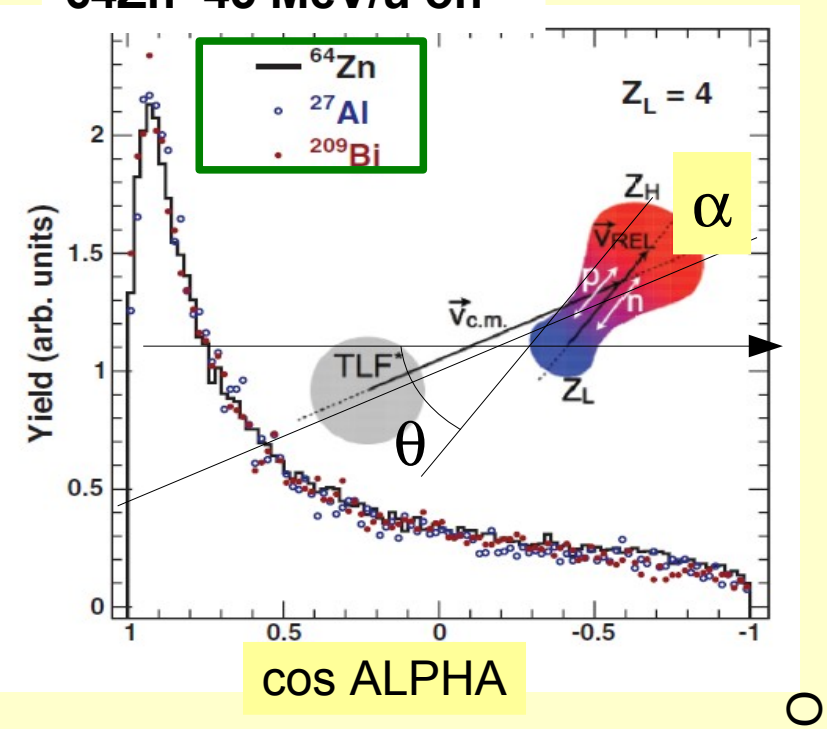
48Ca+48Ca

6 sampling ADCs per telescope

Si 1	14 bit, 100 MHz	4 GeV full-scale charge signal	QH1
	14 bit, 250 MHz	250 MeV full-scale charge signal	QL1
	14 bit, 250 MHz	current signal	I1
Si 2	14 bit, 100 MHz	4 GeV full-scale charge signal	Q2
	14 bit, 250 MHz	current signal	I2
CsI(Tl)	14 bit, 100 MHz	300 MeV Si-eq. f.s. charge signal	Q3

Neck dynamics and neutron enrichment

64Zn 45 MeV/u on

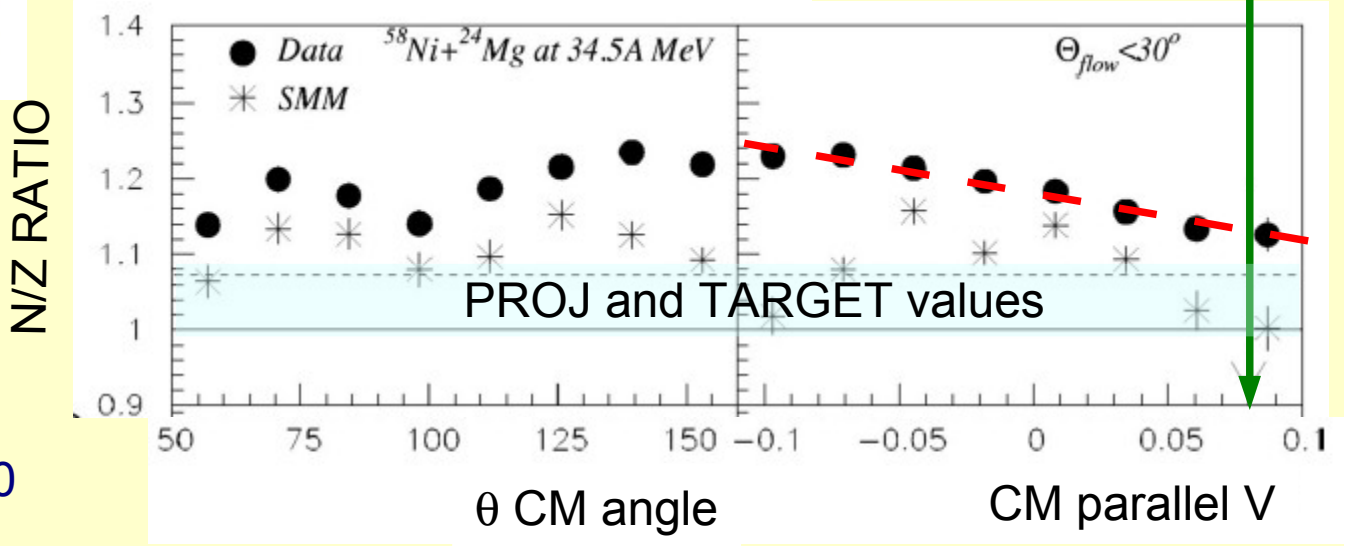


Brown et al PRC 97 2013

Semiperipheral reactions

- neck formation and rupture favour IMF at midvelocity
- preferential alignement of the final fragments
- neck region at subsaturation densities
- isospin drift can be responsible of neutron enrichment of neck matter

58Ni+24Mg 35 MeV/u IMF with Z=3.4



LaRochelle et al PRC 62 2000