2nd COPIGAL WORKSHOP
on Studies of Exotic Nuclei

June 4-6, 2012, Krakow, Poland

CHIMERA and the French - Italian - Polish connections

Giuseppe Politi

for the CHIMERA - EXOCHIM collaboration

Dipartimento di Fisica e Astronomia Università di Catania

Istituto Nazionale di Fisica Nucleare - Sezione di Catania

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Outline

- The CHIMERA device at LNS
- The “Polish” Campaigns
- The LEA - Colliga
- Summary & Perspectives

The CHIMERA device at INFN - LNS in Catania

Heavy-ion induced reactions with stable and radioactive beams are ideal to explore nucleus characteristics and parameters

These reactions are studied at INFN - LNS in Catania by means of

- Stable beams at low and intermediate energies 10 - 100 MeV/A
  produced by Tandem and Superconducting Cyclotron (CS)

- Exotic beams produced with ISOL method
  CS beam on production target -> Tandem acceleration

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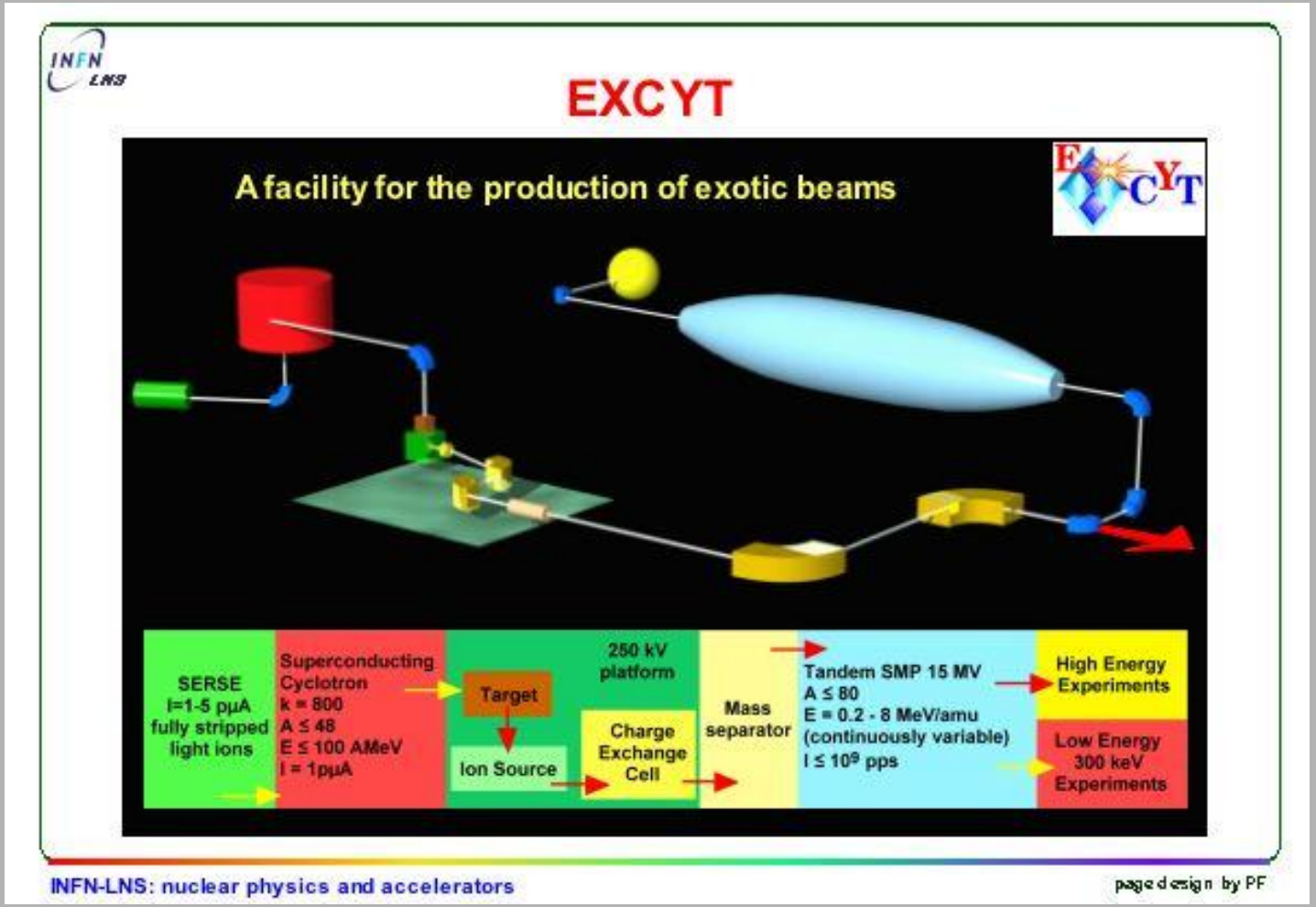
The LNS exotic beam ISOL production method - EXCYT



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CS beam on production target -> Tandem acceleration

- Exotic beams produced by in flight fragmentation
CS beam on production target -> magnetic fragment separator

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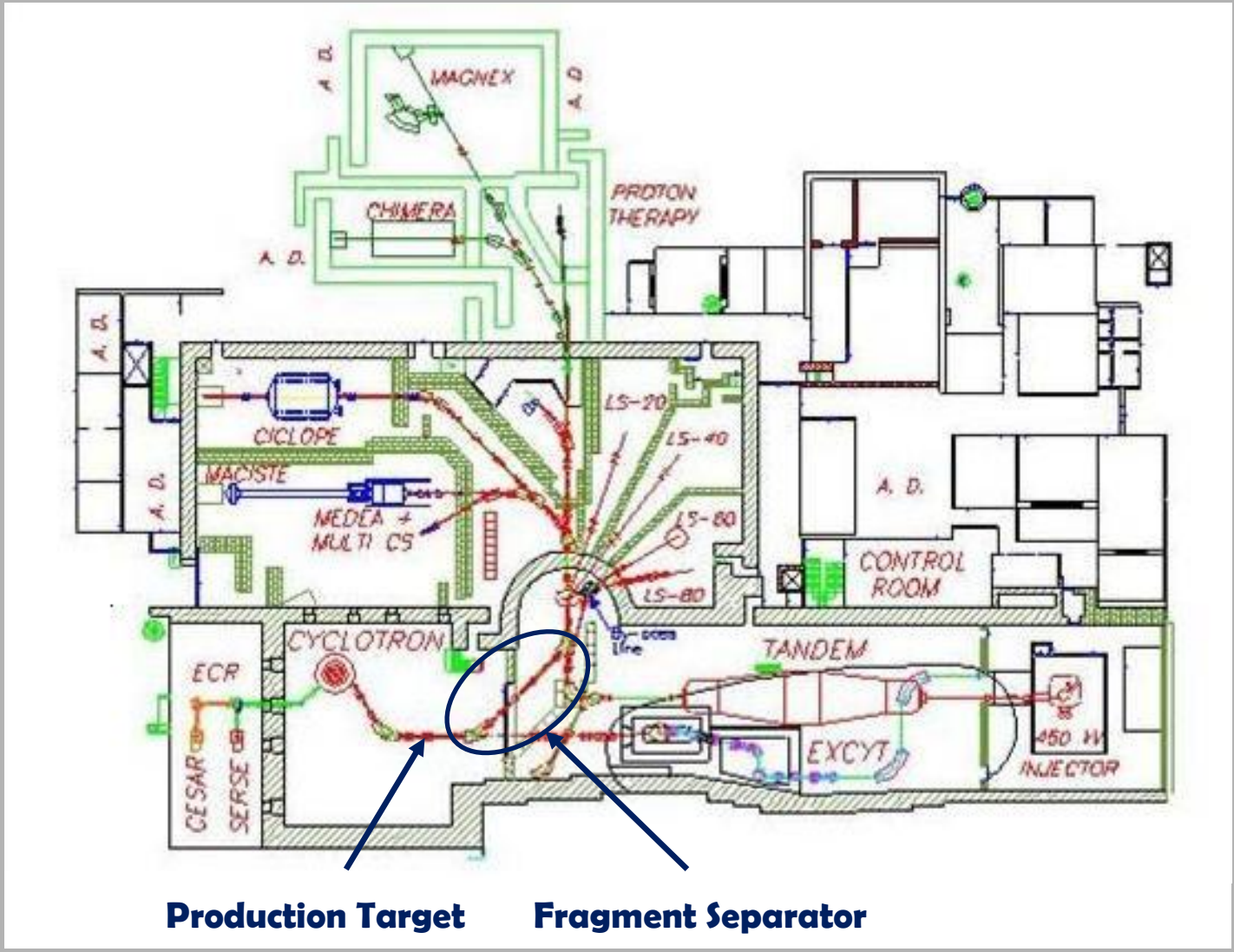
The LNS exotic beam in-flight production method



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The CHIMERA multidetector

4π device

1192 Telescopes

Si (300μm) - CsI(Tl)/PD

Forward part 1°<Θ<30°

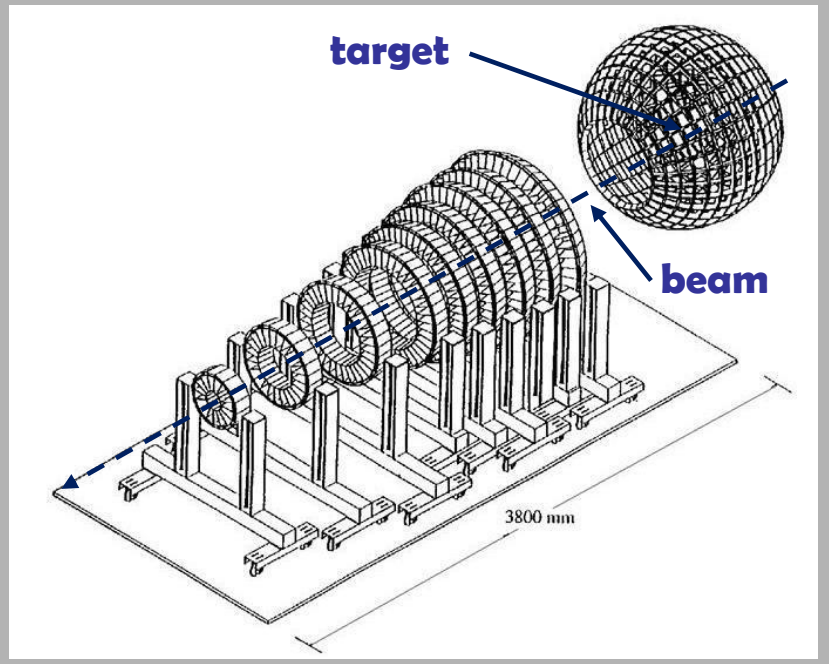
688 modules

9 Rings 100<d<350 cm

Backward part 30°<Θ<176°

504 modules

Sphere R=40 cm



94% efficiency and high granularity

Precise measurement of E, TOF, Velocity, θ/ϕ

Dedicated electronics and data acquisition for low energy threshold (~MeV) and high dynamical range

Silicon signal rise time measurement (2008)

Nucl. Phys. A 734 (2004) 544, IEEE NSS Conf. Rec. N28 (2006) 1140

Nuclear Physics News 22/1 (2012)

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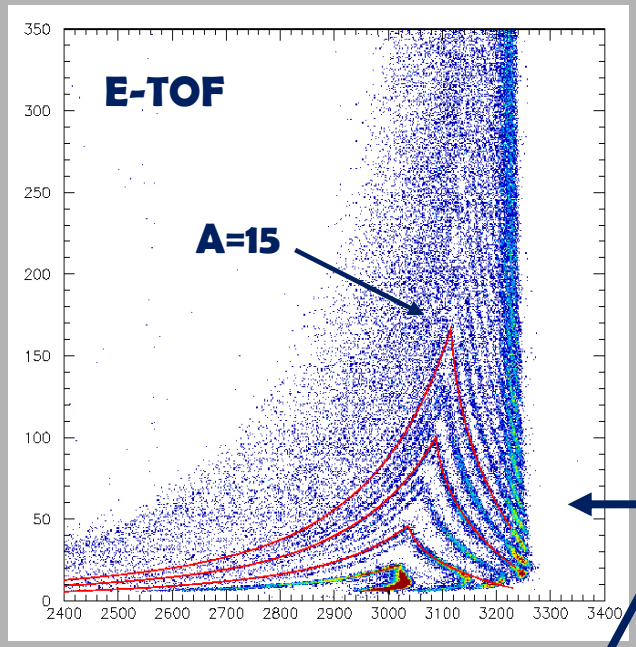
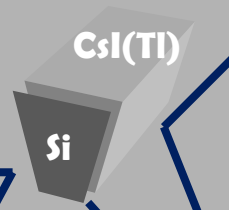
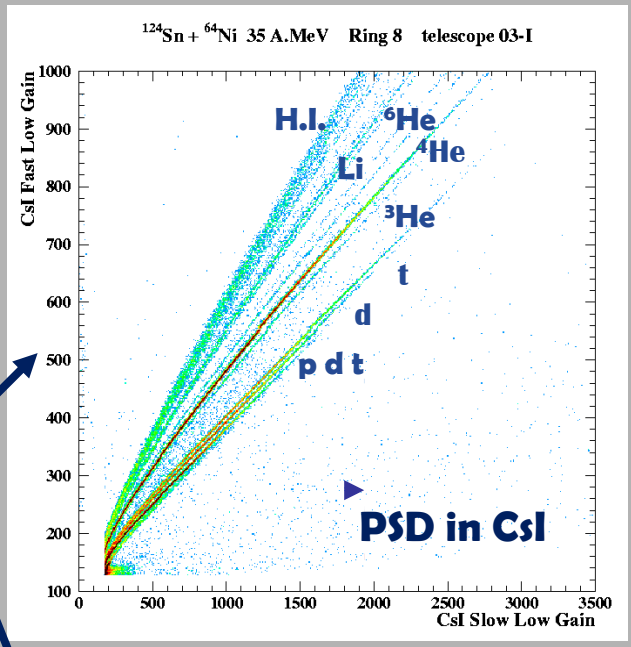
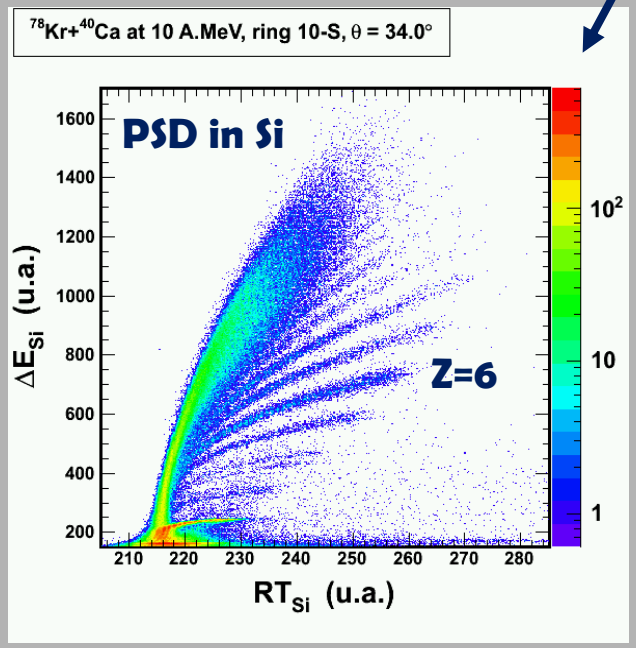
Nuclear Physics News 22/1 (2012)

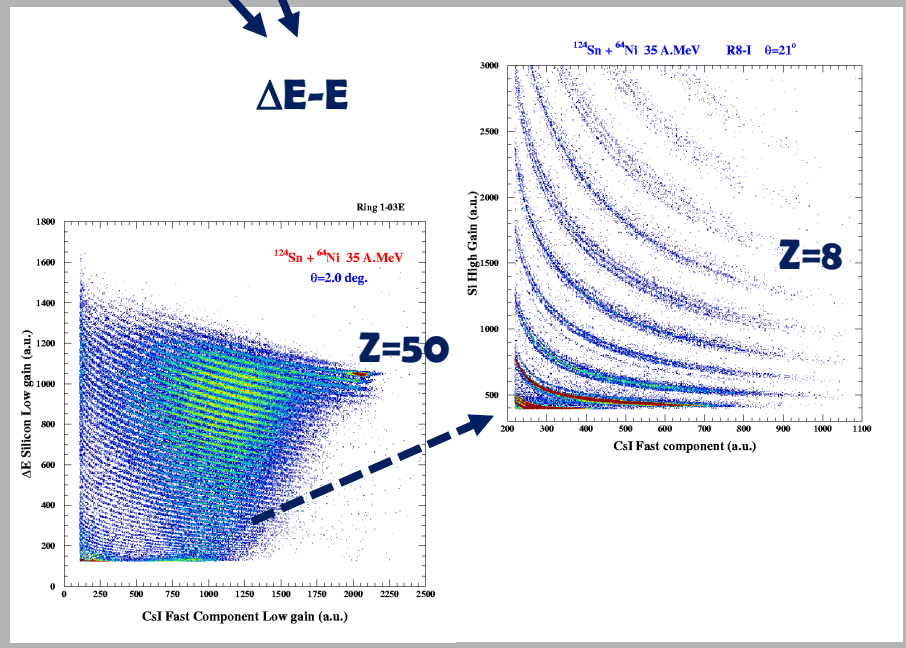
Identification methods:











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The "Polish" Campaigns

Polish collaborators have been working inside the CHIMERA group since the beginning, in different general tasks:

- **detector and electronic characteristics studies during the realization of the apparatus**

- **analysis and calibration software for CsI(Tl) detectors, used in data analysis of various campaigns**

- **software for simulation filtering according to global detector characteristics**

Nucl. Instr. and Meth. A 489 (2002) 257, Nucl. Instr. and Meth. A 490 (2002) 251

Nucl. Phys. A734 (2004) 504

The "Polish" Campaigns

Selection of experiments performed following different research lines, with strong contribution from *polish side* of Chimera

Study of the systems $^{124}Sn+^{64}Ni$ and $^{112}Sn+^{58}Ni$ a 35 MeV/A in inverse and direct kinematics:

- **Time scale for fragment formation**
- **Dynamical fission**
- **Isospin effects in peripheral and central collisions**

Breakup of very heavy nuclear systems created in Au + Au collisions at 15 MeV/A

Research of Exotic Shapes nuclei formed in Au + Au collisions at 25 MeV/A

Study of EOS symmetry term at high density with peripheral high energy collisions -> ASY - EOS collaboration at GSI

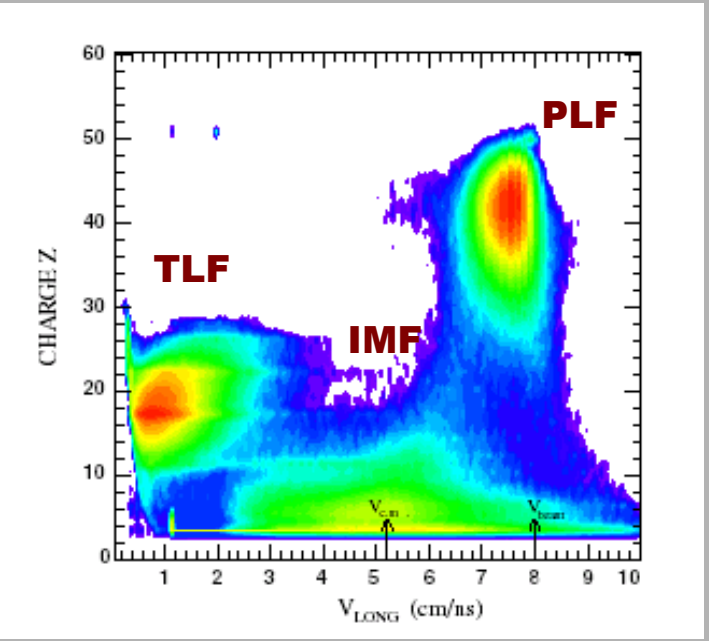
Exotic beam in-flight production line for CHIMERA

Time scale for fragment formation

Peripheral reactions $^{124}Sn + ^{64}Ni$ @ 35 MeV/A 1°-30°

Well reconstructed ternary events

-> PLF - TLF - IMF



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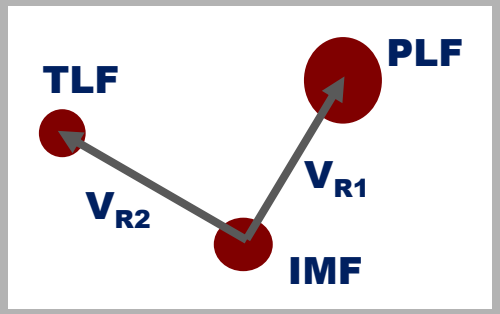
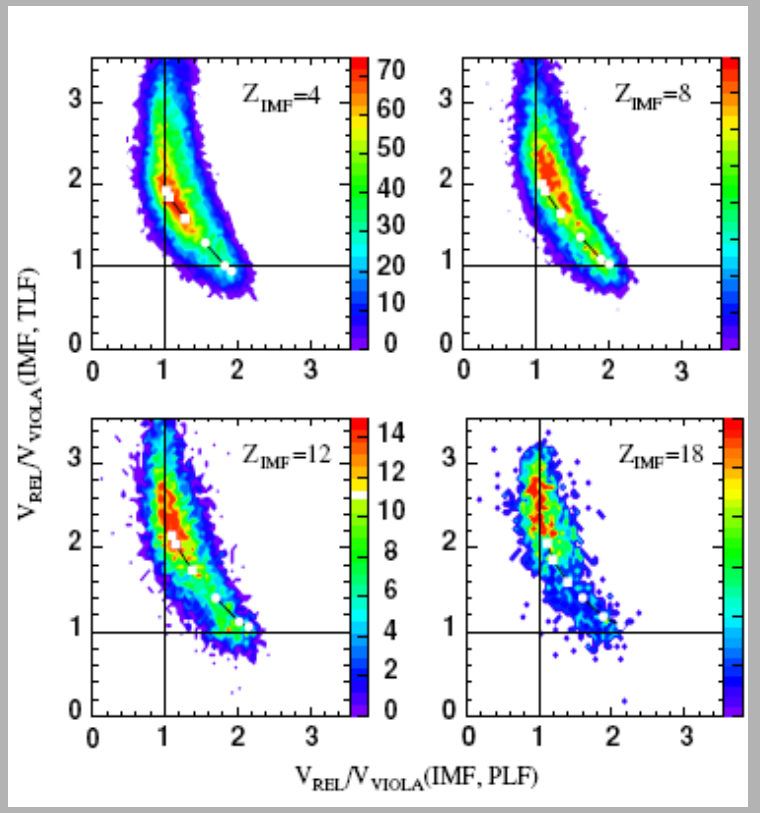
Time scale for fragment formation

Peripheral reactions $^{124}Sn + ^{64}Ni$ @ 35 MeV/A 1°-30°

Well reconstructed ternary events
-> PLF - TLF - IMF

IMF emission time deduced by relative velocity correlation
V_{R2}(IMF-TLF) vs V_{R1}(IMF-PLF)





$V_{R1} \div V_{R2} = 1$ sequential emission from TLF÷PLF

$V_{R1} \div V_{R2} \neq 1$ prompt emission from other source

Light IMFs emitted within 40 – 80 fm/c

Heavy IMFs within 120 fm/c or later

PRC 71 (2005) 044602

Dynamical fission

Peripheral reactions $^{124}Sn + ^{64}Ni$ and $^{112}Sn+^{58}Ni$ @ 35 MeV/A 1°-30°

PLF splitting into two main fragments ($Z1_{FF} + Z2_{FF} = 37–57$)

More asymmetric splitting -> neck fragmentation

Splitting comparable fragments (AH/AL < 4.6)

-> fast sequential process: fission after collision in 100 < t < 300
PLF undergo dynamical fission into two aligned fragments

-> equilibrated fission, slower by one or two orders of magnitude

The contribution of dynamical fission DF depends rather weakly on kinetic energy loss and increases with mass asymmetry

Equilibrated fission does not depends on N/Z

Dynamical fission is about twice more probable for the neutron-rich system as compared with the neutron-poor one

PRC 71 (2005) 064604, PRC 81 (2010) 064605

Isospin effects in peripheral collisions

Systems $^{124}Sn + ^{64}Ni$ and $^{112}Sn + ^{58}Ni$ @ 35 MeV/A 1°-30°

Centrality dependence tested for several “b” estimators

- Yields of ^{1}H and ^{3}He in the n-poor system are strongly enhanced with respect to the n-rich system
- Yields of ^{3}H, ^{6}He, $^{7,8}Li$ are suppressed at all impact parameters
- Yields of ^{2}H, ^{4}He, ^{6}Li are almost the same for both systems
- N/Z ratio of intermediate mass fragments is correlated with the neutron richness of the system and is weakly dependent on the centrality of the collision
- Neutron richness of the detected fragments increases strongly with decreasing rapidity in the range V_{PLF} -> V_{CM}

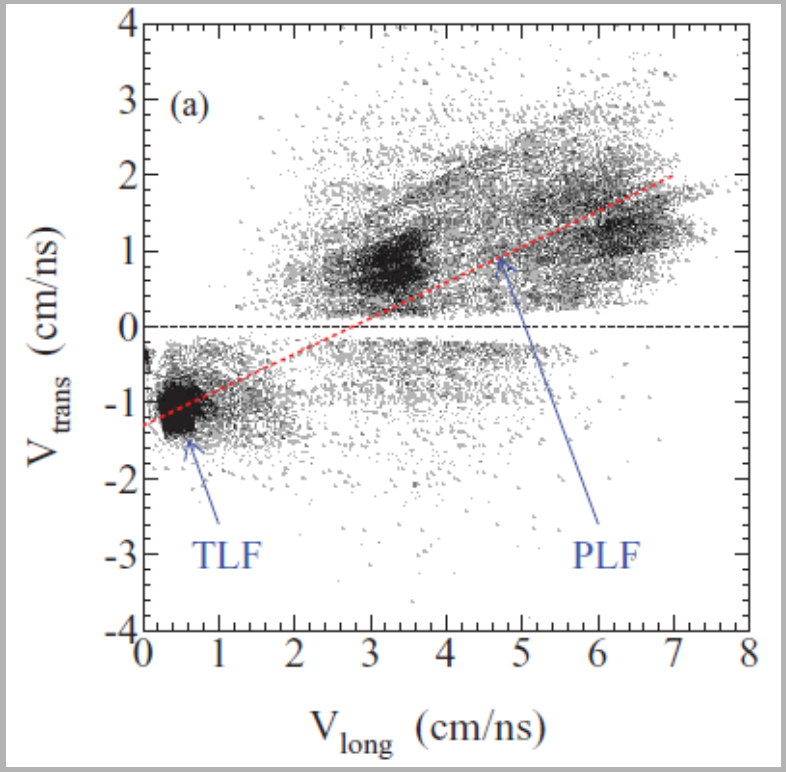
The gross features of experimental data are reproduced by quantum molecular dynamics model calculations

PRC C 77 (2008) 014610

Breakup of very heavy nuclear systems created in Au + Au

New reaction mechanism of violent re-separation of the colliding system into three or four fragments with comparable size

Deep-inelastic binary process at small impact parameters
-> Formation of PLF and TLF that undergo to a very fast breakup into two fragments



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-> Formation of PLF and TLF that undergo to a very fast breakup into two fragments

Fragments aligned -> 70 - 100 fm/c from PLF-TLF formation

Process related to the incomplete energy dissipation
-> improvement in theoretical description of dissipative phenomena in moderately heated nuclear matter

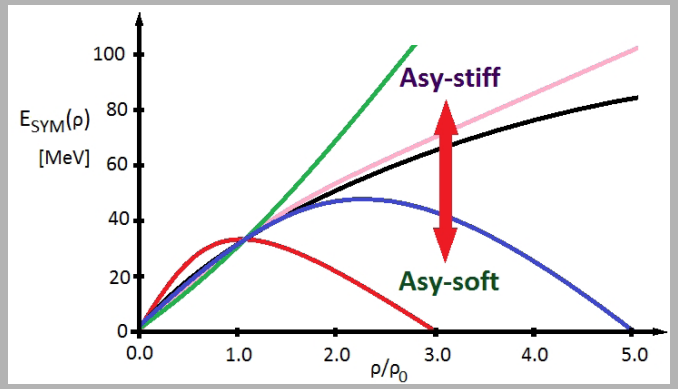
PRL 101 (2008) 262701, PRC 81 (2010) 024605, PRC 81 (2010)067604

ASY - EOS collaboration at GSI

Study of the symmetry energy term of EOS at supra-saturation density

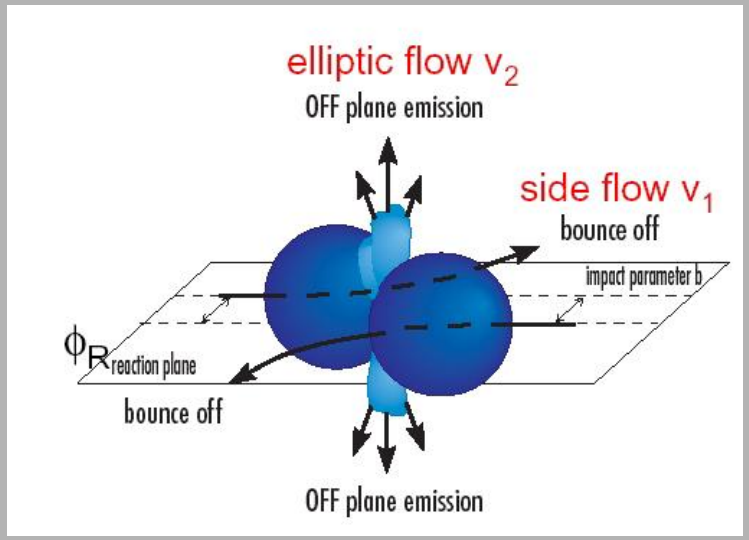
-> $\rho > \rho_o$

$E_{sym}(\rho)$ strongly debated



Different experimental observables depend on E_{sym}

Difference of elliptic flow between neutrons and protons carries information about the symmetry term E_{sym}



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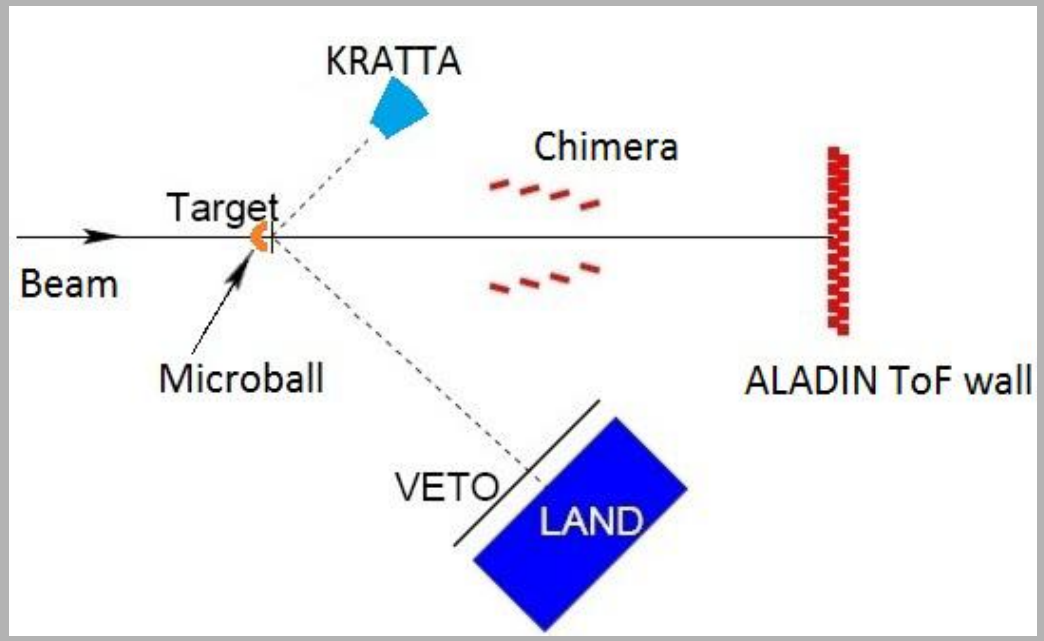
Phys. Lett. B 697 (2011) 471

ASY - EOS collaboration at GSI

Systems: $^{197}Au+^{197}Au$, $^{96}Zr + ^{96}Zr$, $^{96}Ru + ^{96}Ru$ @ 400 AMeV

Experimental set-up at cave C of GSI



CHIMERA R4-R7 + TOF Wall - multiplicity filter, reaction plane

LAND - proton and neutron flows

Microball - backward emitted particles

KRATTA: KRAkow Triple Telescope Array - LCP and IMF

35 modules -> Thin and thick CsI(Tl) crystals + 3 PDs

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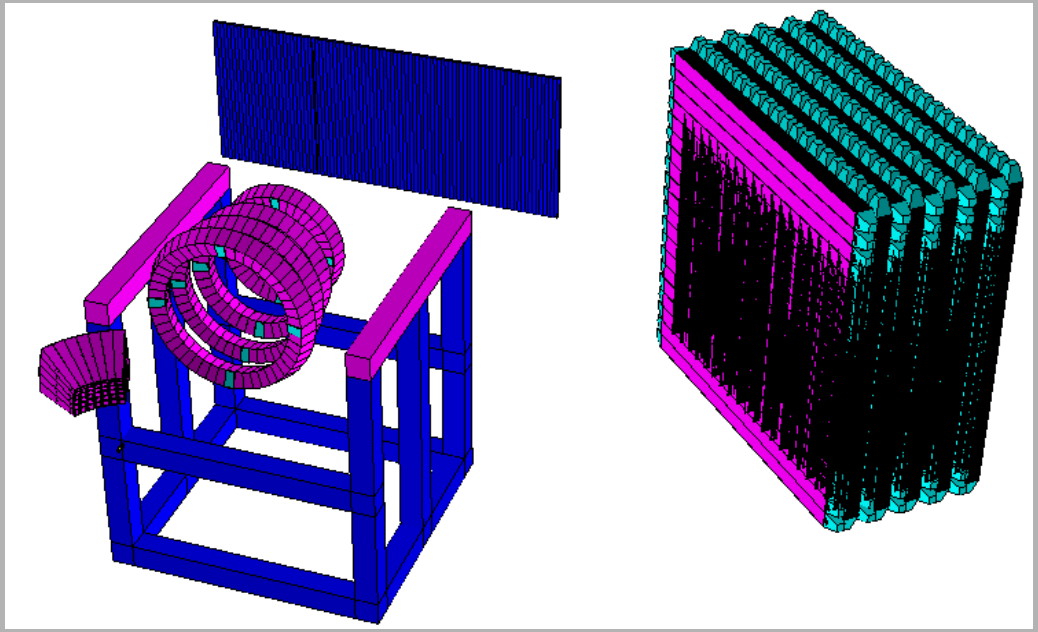

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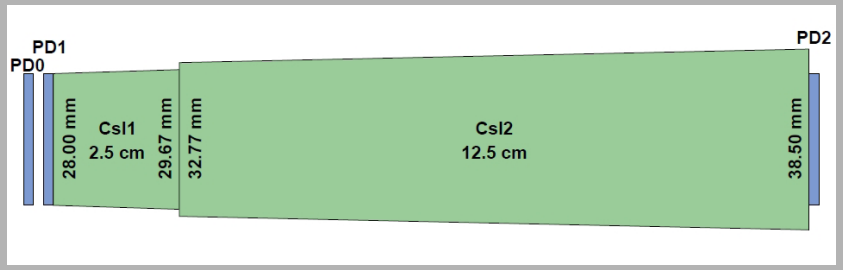

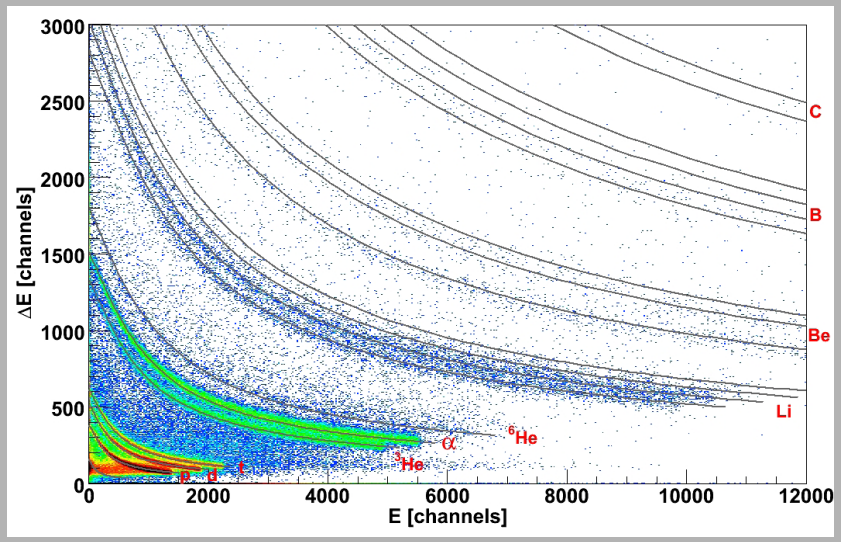

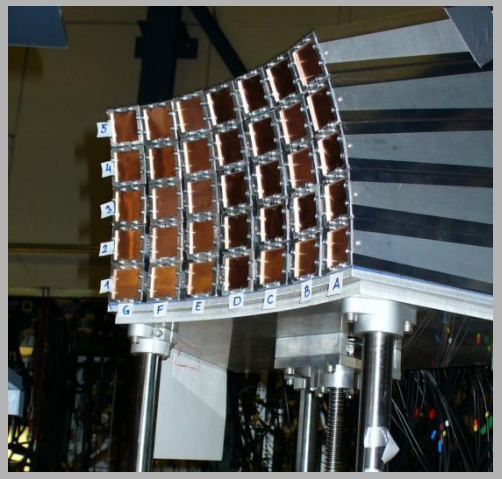

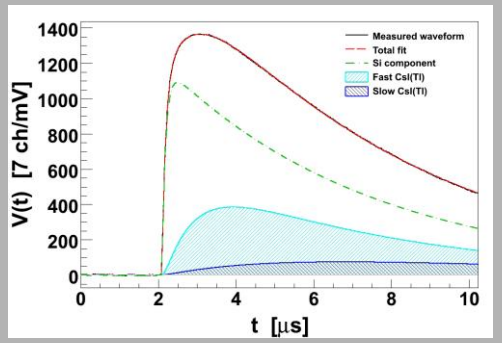

Isotopic resolution from ΔE - ΔE - E and pulse shape discrimination in a wide range of energies

KRATTA: KRAkow Triple Telescope Array - LCP and IMF

35 modules -> Thin and thick CsI(Tl) crystals + 3 PDs

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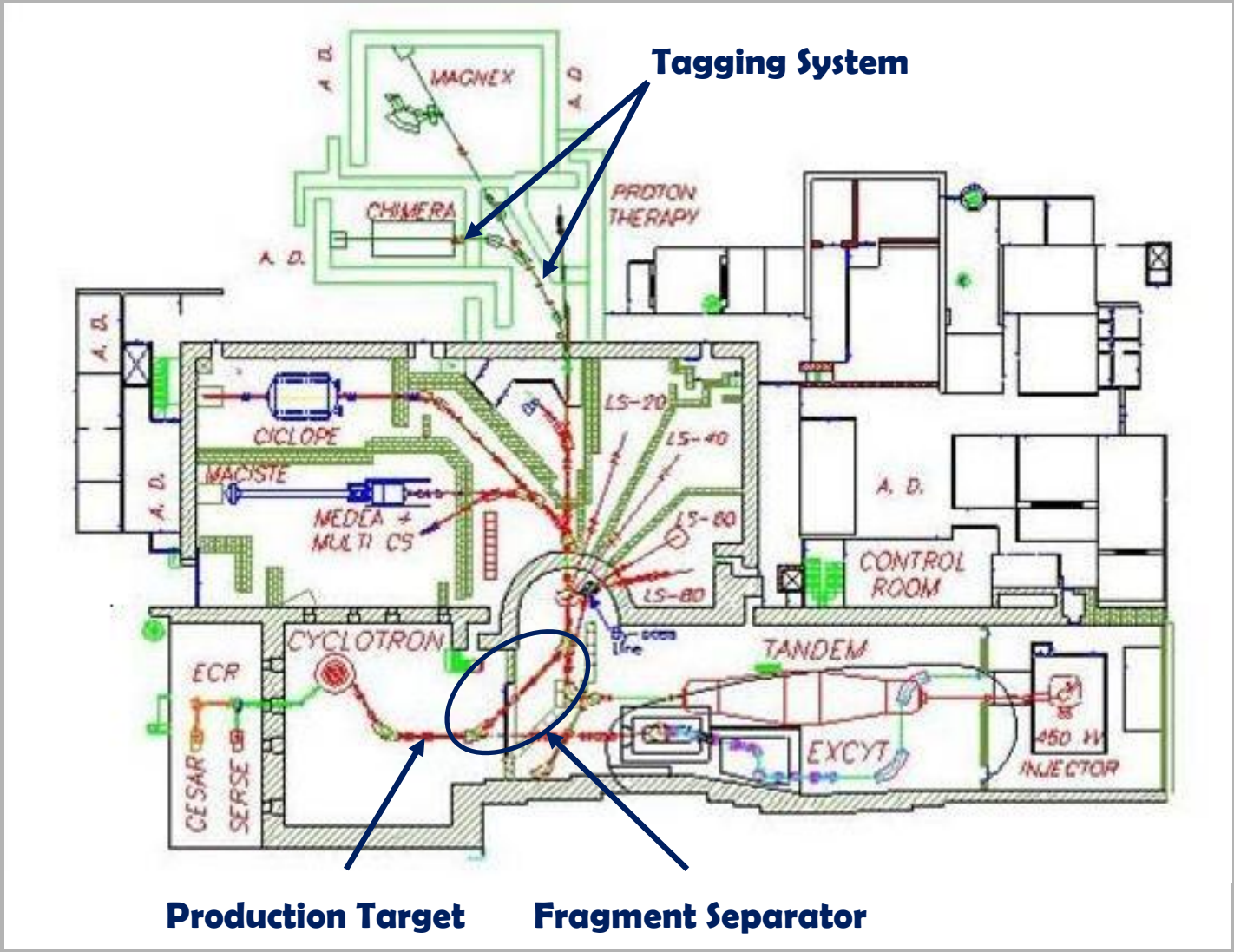
Exotic beam in-flight production line for CHIMERA



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Exotic beam in-flight production line for CHIMERA

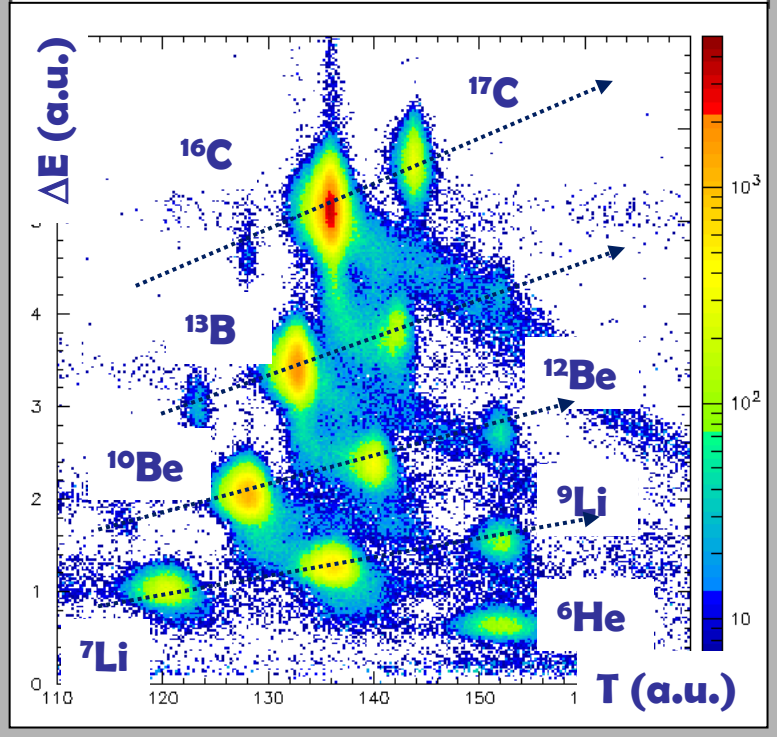
Tagging system selects the appropriate beam among all the particles going through the Fragment Separator

TOF with MCP Start -> Silicon detector Stop

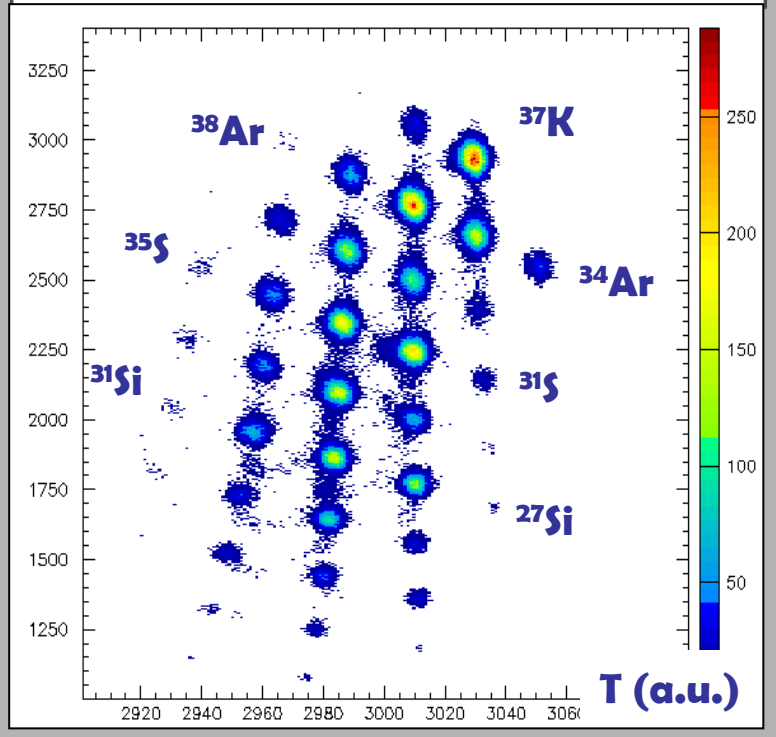
Energy loss ΔE in Silicon detector before reaction target

Nucl. Phys. B (Proc. Suppl.) 215 (2011) 272

^{18}O 55 MeV/A primary beam (10^{11} p/s)
^{16}C 60 Khz E ~ 50 MeV/A



^{36}Ar 25 MeV/A primary beam
^{37}K 14 Khz E ~ 20 MeV/A



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The LEA - Colliga

Most of the CHIMERA experiments includes since the beginning different French Institutions

Second LEA - Colliga meeting, Catania October 2008

A. Pagano "Selected aspect of Dynamical signals in fragmentation reactions as seen by CHIMERA"

Fragment emission: from dynamical to statistical MF
-> time scale measurement with relative velocity correlations

Isospin signals in dynamical emission: N/Z hierarchy effects
-> N/Z enrichment of early produced fragment

More recently some new research projects have been carried on in the framework of the LEA - COLLIGA

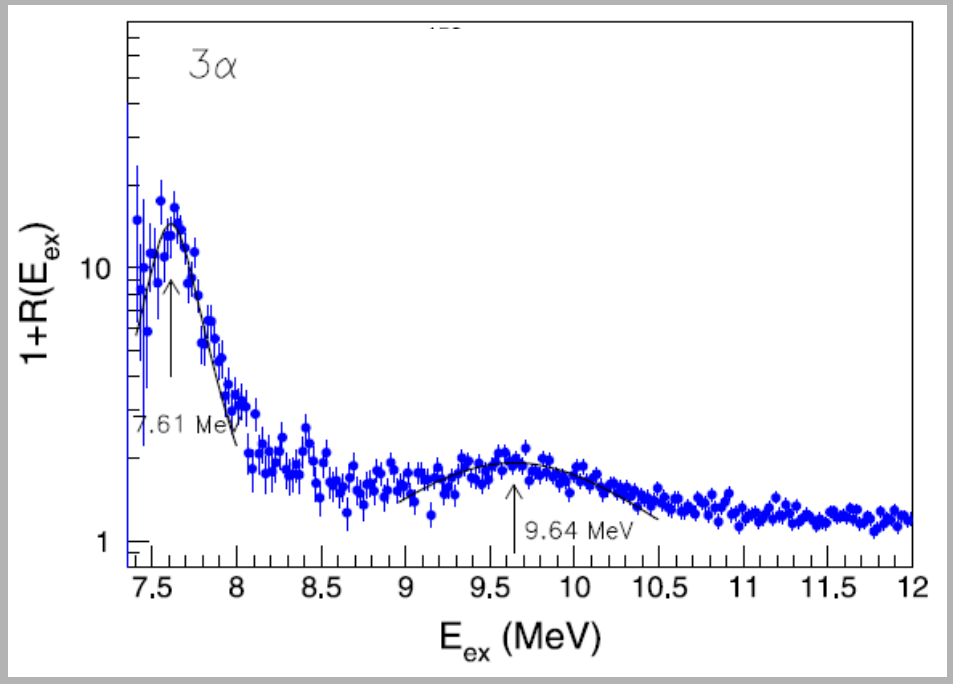
The Bose Condensation

Search for alpha particle condensation, very dilute 3α state of ^{12}C
-> Hoyle state predicted in '50s

^{40}Ca + ^{12}C at 25 MeV/A studied with CHIMERA device:
forward emitted secondary products of QP -> $^{12}C^*$, $^{16}O^*$

Multi Particle Correlation to select 3α excited states
and their de-excitations
-> energy level

New proposition to
next LNS-PAC



Phys. Lett. B 705 (2011) 65

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ISODEC Experiment

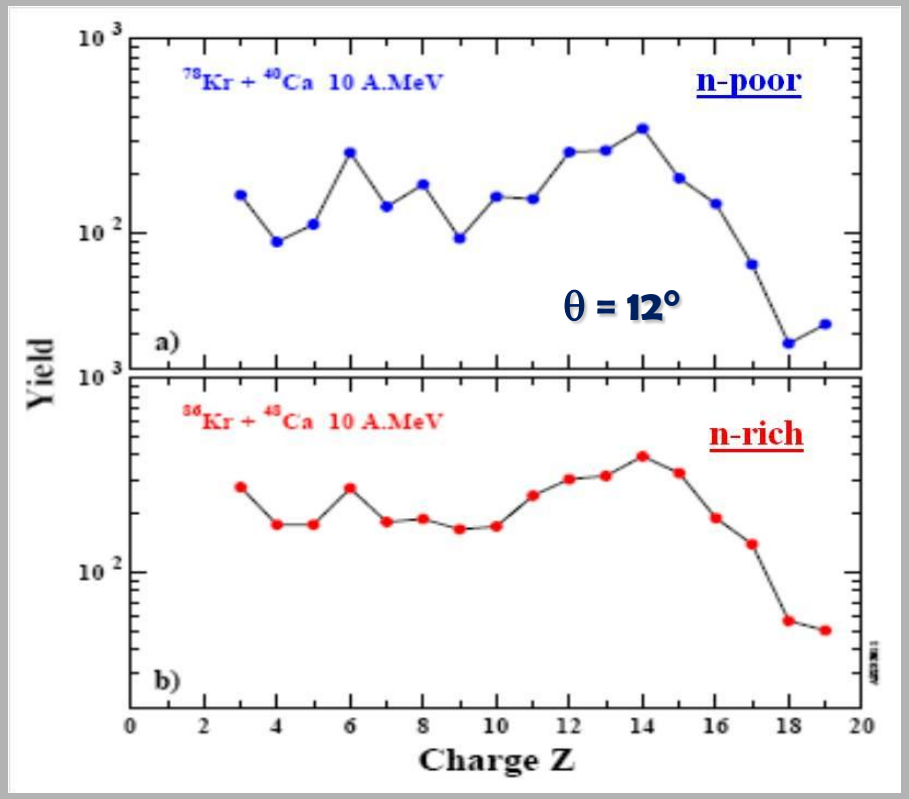
Isospin dependence of the decay modes of medium mass nuclei formed by fusion processes; ^{118,134}Ba with ^{78,86}Kr+^{40,48}Ca 10 MeV/A

First experiment of CHIMERA in this energy domain

Problematic also studied in a French-Polish project

Staggering in IMF yield that decreases for n-rich system

- influence of nuclear pairing forces on the neutron and proton binding energy
- Possible structure effects



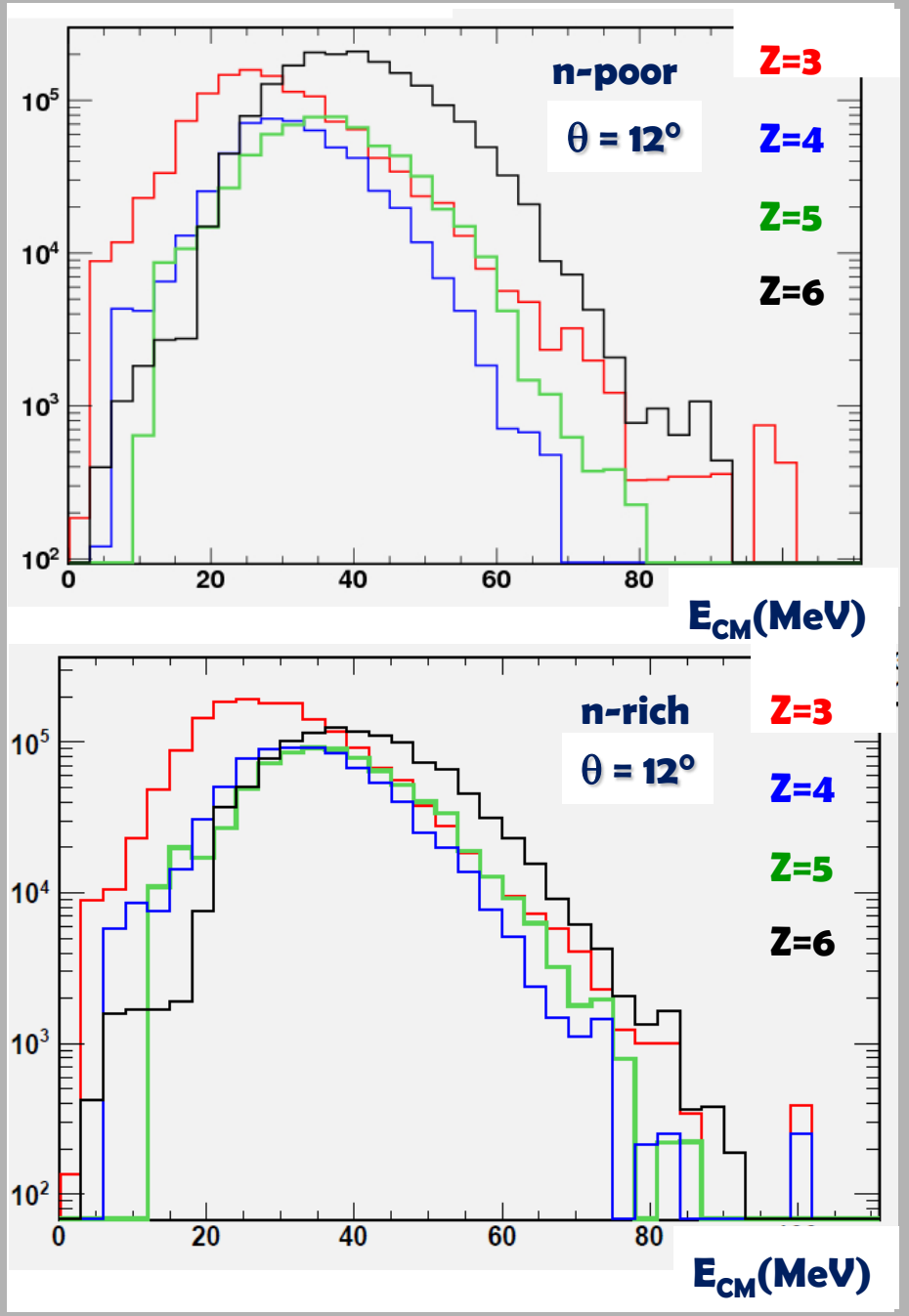
EPJ Web of Conf. 17 (2011) 16010, EPJ Web of Conf. 21 (2012) 02003

ISODEC Experiment

IMF Energy spectra in CM

Differences in Energy Spectra depend on:

- different sources decay
- presence of different masses for Z
- influence of nuclear pairing forces on the last steps of disintegration chain
- influence of symmetry energy term



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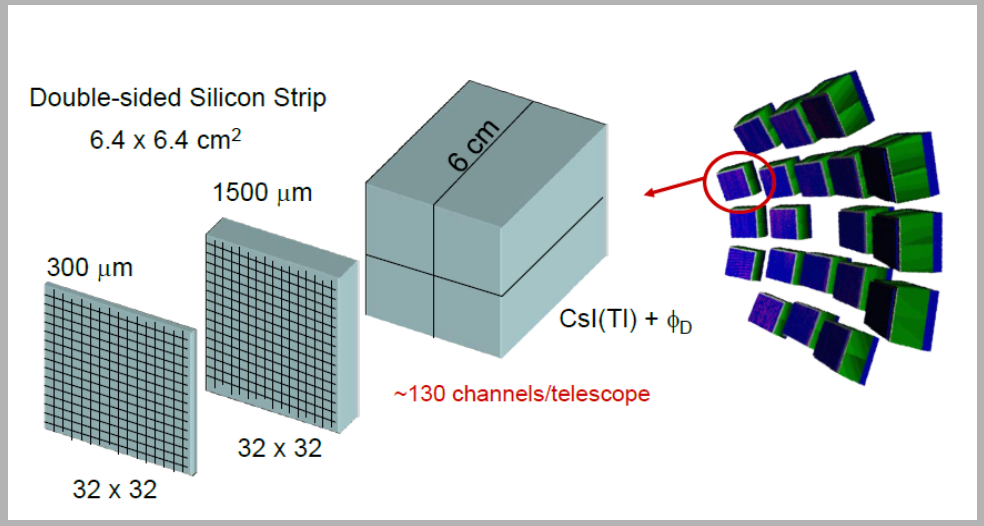
The FARCOS project

FARCOS: Femtoscope ARray for COrrelations and Spectroscopy



E, TOF, Rise Time - Digital Sampling -> integrated electronics

High angular resolution (<0.5° at 60cm)

Detect both light and heavy fragments

Flexibility and transportability: coupling to 4π detectors, magnetic spectrometers, other correlators, neutron detectors

Adapted to low energy experiments (SPIRAL2, SPES) with pulse-shape on silicon – digital sanpling

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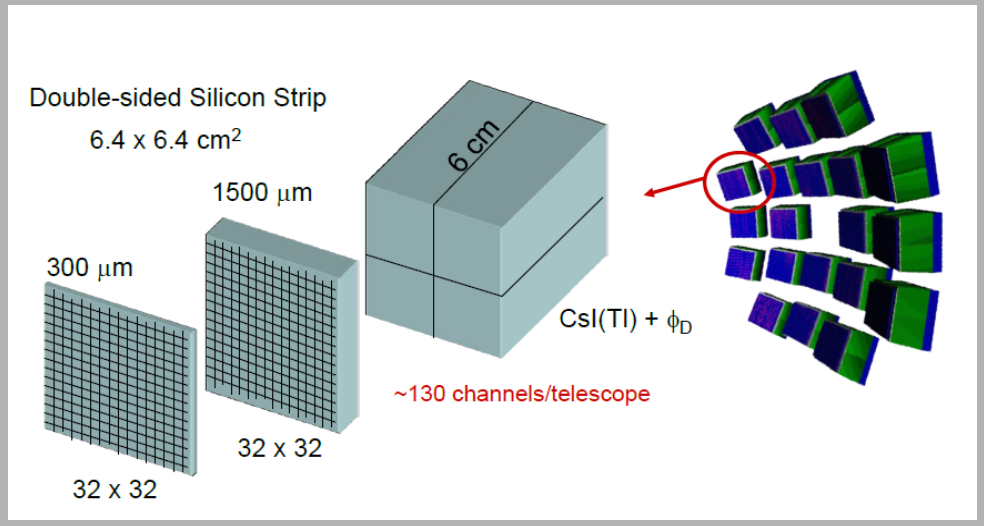

Test running in July with 2 modules and CHIMERA Elec&DAQ

10 (or more) modules to be built in the next years

Lot of potential physics cases

- Dynamics
  - Femtoscopy and imaging in heavy-ion collisions
- Spectroscopy of exotic nuclei
  - In heavy-ion collisions: Multi-Particle Correlation Spectroscopy
  - In light-ion direct reactions

Summary & Perspectives

CHIMERA is a multidetector still operating with stable and radioactive beams at intermediate and low energies

Strong interaction of CHIMERA collaboration with French and Polish Institutions during all these years

-> different research lines followed with successful results

-> many projects are still in progress (Colliga)

-> always open to new propositions

Direct link possible with some Copigal projects

Collaboration Agreement IN2P3 - COPIN for 2011

- 09-136 "Influence of neutron excess on binary decay from CN"

-> natural complement of ISODEC experiment

LOI presented for SPES: $^{88-92}$Kr E/A = 12 MeV/A

Summary & Perspectives

FARCOS will be a powerful device open to different physic cases on nuclear spectroscopy, dynamics and thermodynamics, to be studied with low and high energy radioactive beams

-> coupling with other devices in different laboratories

-> some experiments will be presented for the next LNS-PAC

-> now open to new propositions

There is room in CHIMERA collaboration for new interactions with French and Polish communities in Catania and in other laboratories

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The CHIMERA - EXOHIM collaboration

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2 INFN LNS
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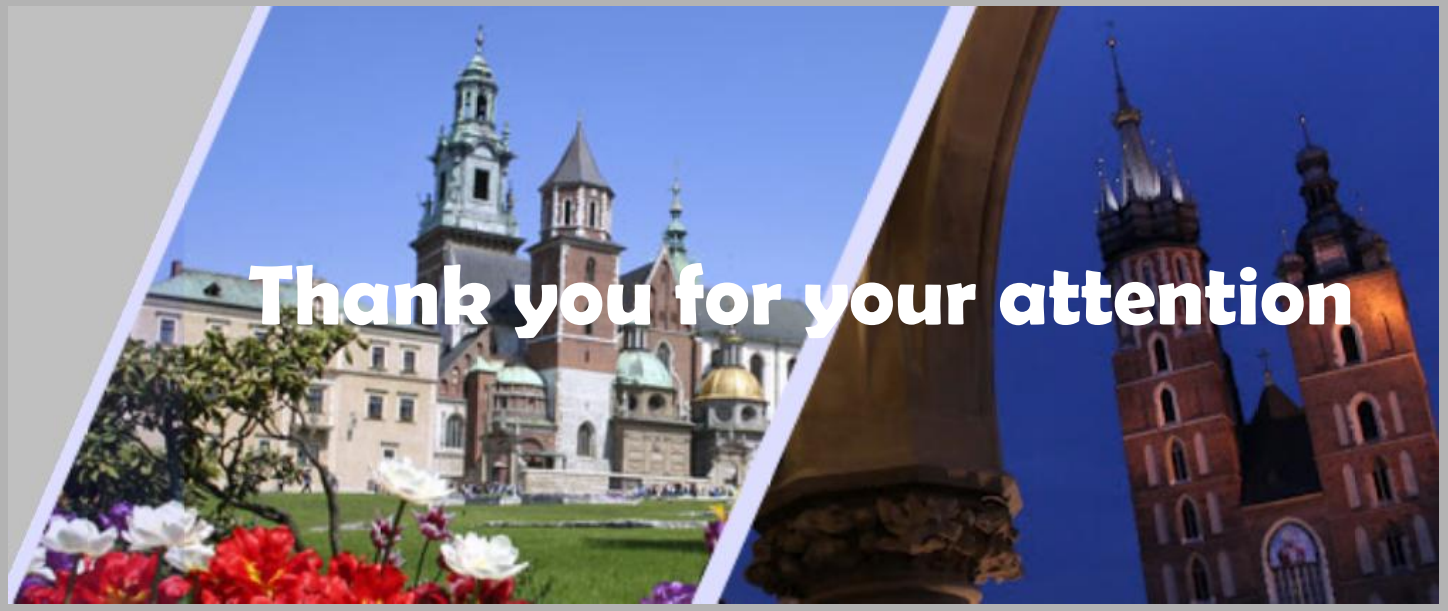
Thank you for your attention