LNS Users Meeting

Catania 2 December 2014

CHIMERA @ LNS

S.Pirrone INFN-Sezione di Catania

for CHIMERA Collaboration

Outline

-Recent Results and

Future perspectives of

CHIMERA experiments at LNS

- FARCOS correlator

- CHIMERA @ FRIBS – LNS high intensity project

EXOCHIM CNS3 2009-2014

39 Ricercatori/Tecnologi ~28 FTE
INFN Sezione di Catania (Resp.Nazionale)
Università di Catania
INFN- LNS
INFN -Gruppo coll. Messina
INFN- Sezione &University of Napoli
INFN-Sezione & University of Milano

	Pubblicazioni	talk	tesi
2008	11	19	1
2009	10	26	1
2010	16	19	2
2011	14	34	4
2012	13	29	6
2013	24	45	6

CHIMERA moved from Ciclope to its scattering chamber (2007-2008)

Upgrading Pulse shape on Si (2009)

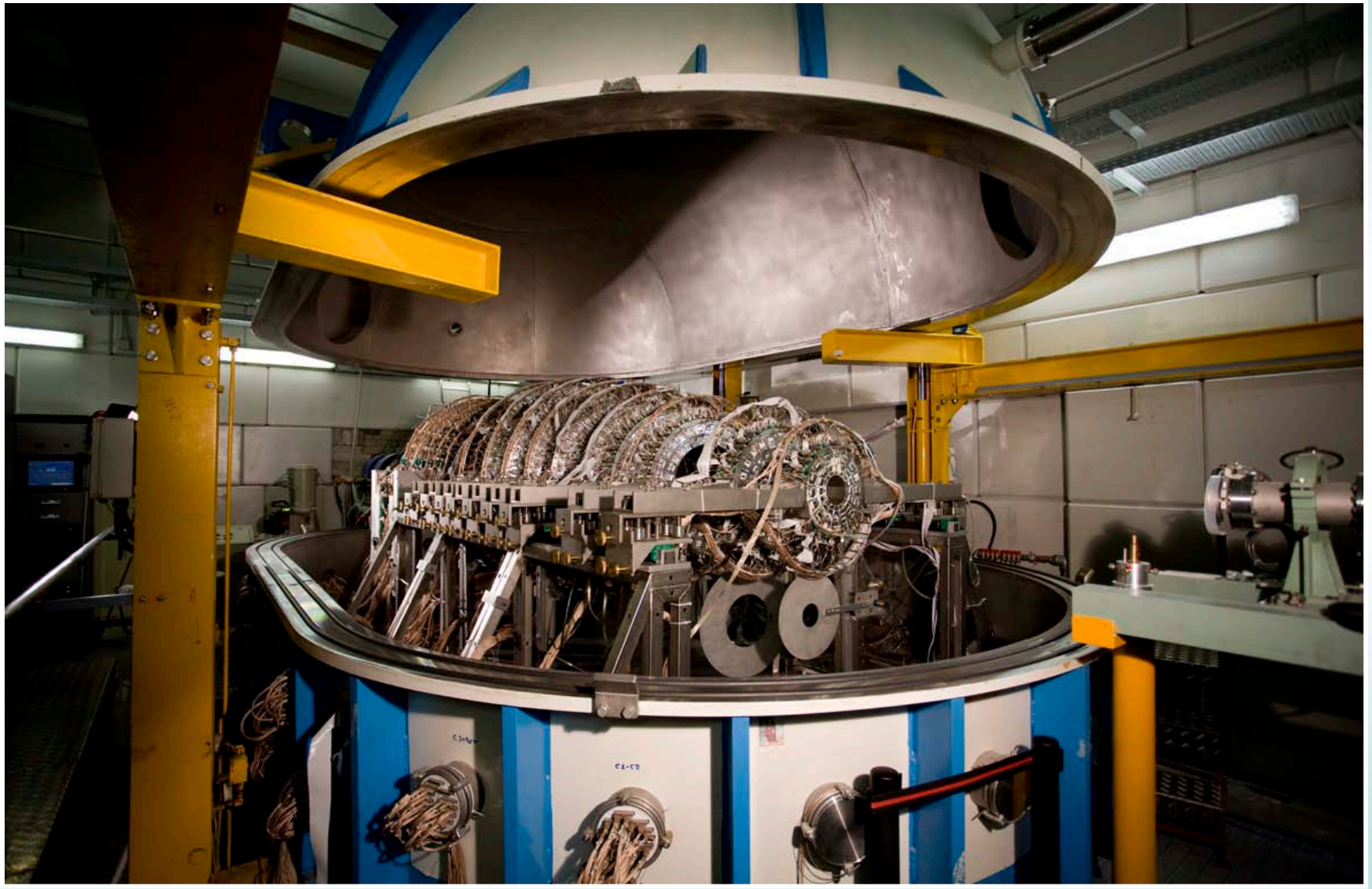
Stable beams exp @LNS : TIMESCALE,EQUILIBRATION,CORRELATION2008
LIMITING2 2009
BREAKUP - ISODEC 2010

CHIMERA@GSI (2010-2011)

Fragmentation Beam exp @LNS : UNSTABLE 2009, 2011
Timescale ZN Ni68, 2012

Misure con FARCOS: test Farcos 2012 - test neutroni 2012 - Inkiissy 2013
test Farcos-GET electronics 2014

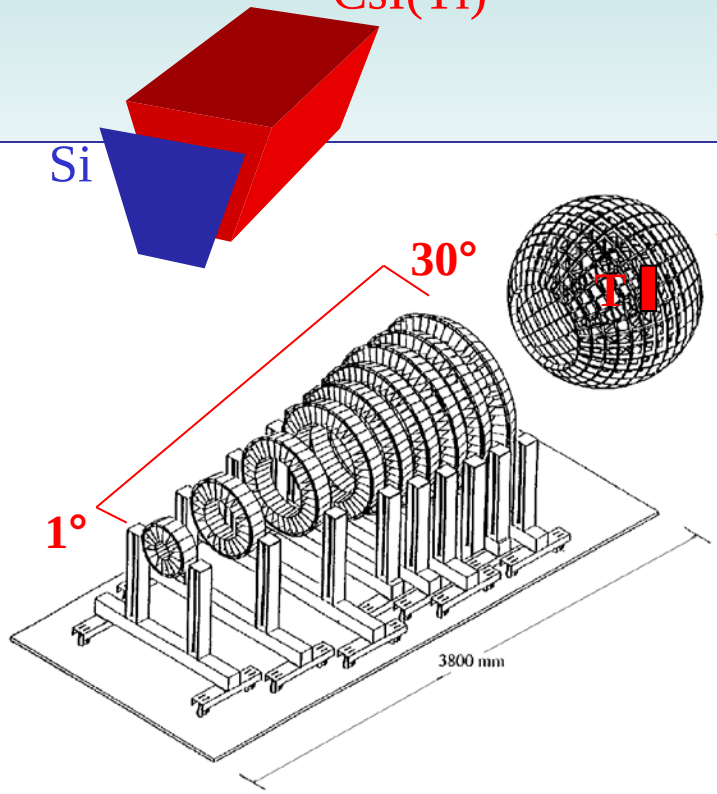
CHIMERA@LNS



A.Pagano et al., NPA734 (2004)

CHIMERA

Charge Heavy Ion Mass and Energy Resolving Array



Granularity	1192 telescopes Si (300μm) +CsI(Tl)
Geometry	RINGS: 688 telescopes 100-350 cm SPHERE: 504 telescopes 40 cm
Angular range	RINGS: $1° < \theta < 30°$ SPHERE: $30° < \theta < 176°$ 94% of 4π
Identification method	ΔE-E E-TOF PSD in CsI(Tl) PSD in Si (upgrade 2008)
Experimental observables and performances	TOF $\delta t \leq 1$ ns $\delta E/E$ LCP (Light Charge Particles) ≈ 2% $\delta E/E$ HI (Heavy Ions) ≤ 1% Energy, Velocity, A, Z, angular distributions
Detection threshold	≈ 1 MeV/A for H.I. ≈ 2 MeV/A for LCP

Dynamical range : from fusion, fusion-fission to multifragmentation reaction

Physics Case:

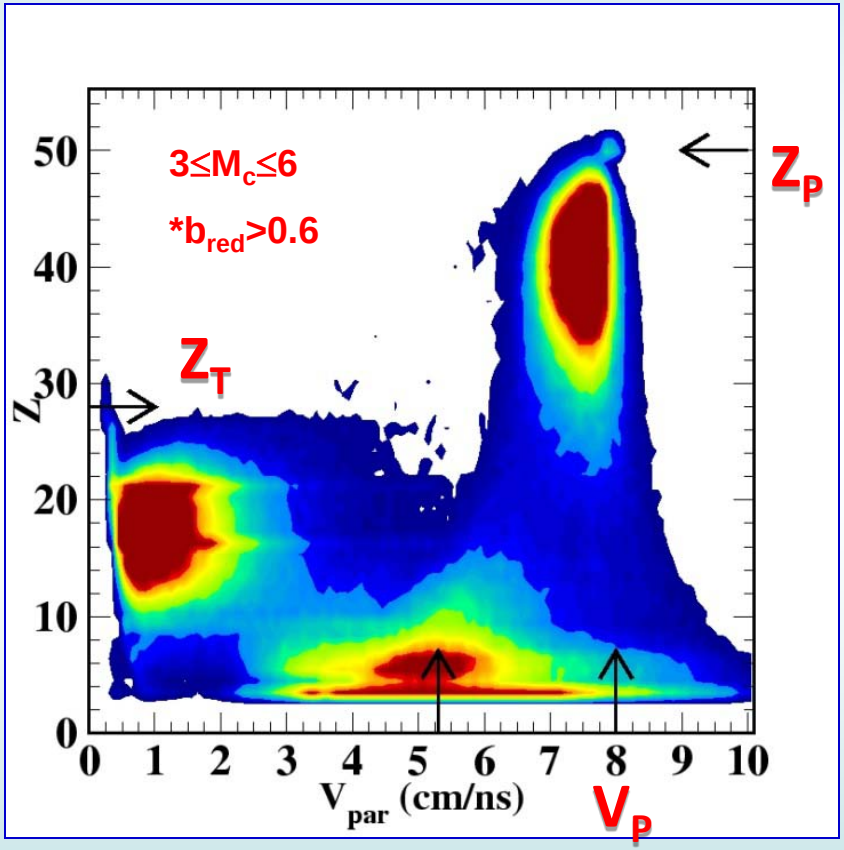
EOS, Symmetry Energy, Isospin influence on reaction mechanism

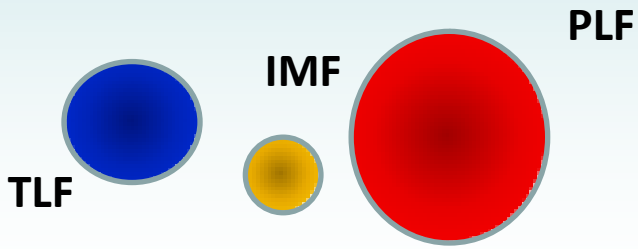
- Study of the systems $^{124}Sn+^{64}Ni$ and $^{112}Sn+^{58}Ni$ @35 A.MeV. *Neck emission, Time scale for fragment formation, fragment hierarchy, Dynamical fission (Chimera coll) LNS*
- Isospin dependence in the competition between incomplete fusion and dissipative binary reactions in $^{40}Ca,^{48}Ca$ + $^{40,48}Ca$, ^{46}Ti @25 AMeV *(Chimera coll.) LNS*
- Study of isospin diffusion in the reactions $^{124}Sn+^{124}Sn$, $^{124}Sn+^{112}Sn$, $^{112}Sn+^{124}Sn$, $^{112}Sn+^{112}Sn$ @35 MeV. *(MSU-Chimera coll.). LNS*
- Fast collinear partitioning of the ^{197}Au + ^{197}Au @15 A.MeV, system into three and four fragments of comparable size *(Chimera coll.) LNS*
- Exploring the isospin dependence on decay from compound nucleus in the reactions $^{78,86}Kr$ + $^{40,48}Ca$ @10 A.MeV *(Chimera-Indra coll.) LNS*
- Constraining the Symmetry Energy at Supra-Saturation Densities With Measurements of Neutron and Proton Elliptic Flow, Au+Au, $^{96}Zr+^{96}Zr$ and $^{96}Ru+^{96}Ru$ @400 A.MeV *(AsyEos-Chimera coll.) GSI*
- …….. *E.De Filippo and A.Pagano EPJ A50, 32, 2014*

TIMESCALE EXPERIMENT

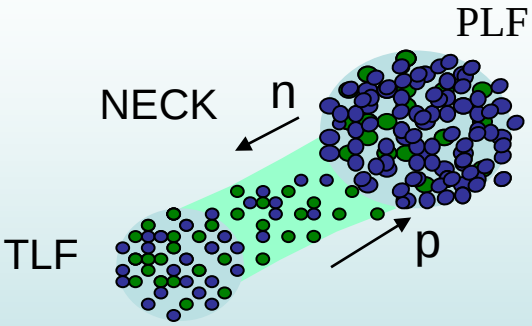
Ternary and semiperipheral events selection

$^{124,112}Sn + ^{58,64}Ni$ @ 35 AMeV





IMF , Z ≥ 3

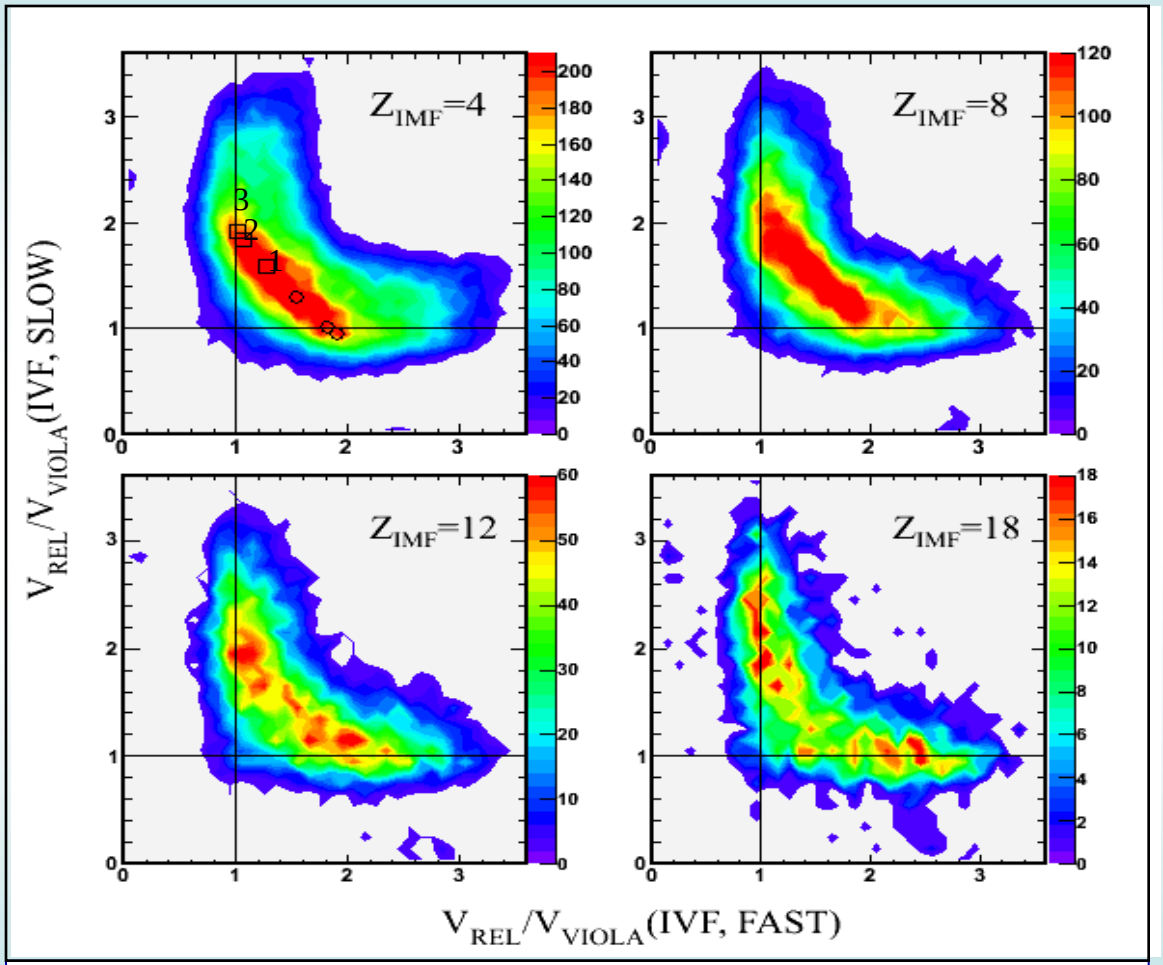


Neck formation

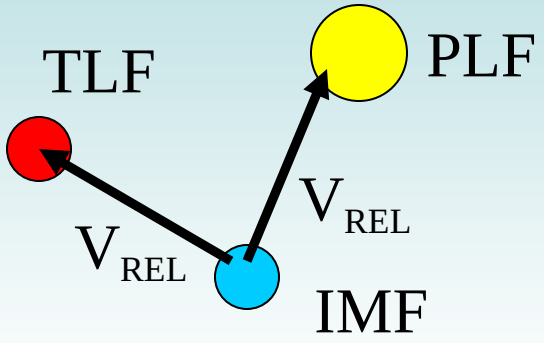
E.De Filippo et al. PRC71,44602 (2005)

TIME SCALE: Emission Chronology by velocity correlation

$^{124}Sn+^{64}Ni$ 35 MeV/A



Emission chronology: light fragments are produced earlier (~40 fm/c) than heavier ones (~120 fm/c)



Relative velocities are expressed in relationship with the Viola vel (pure Coulomb repulsion)

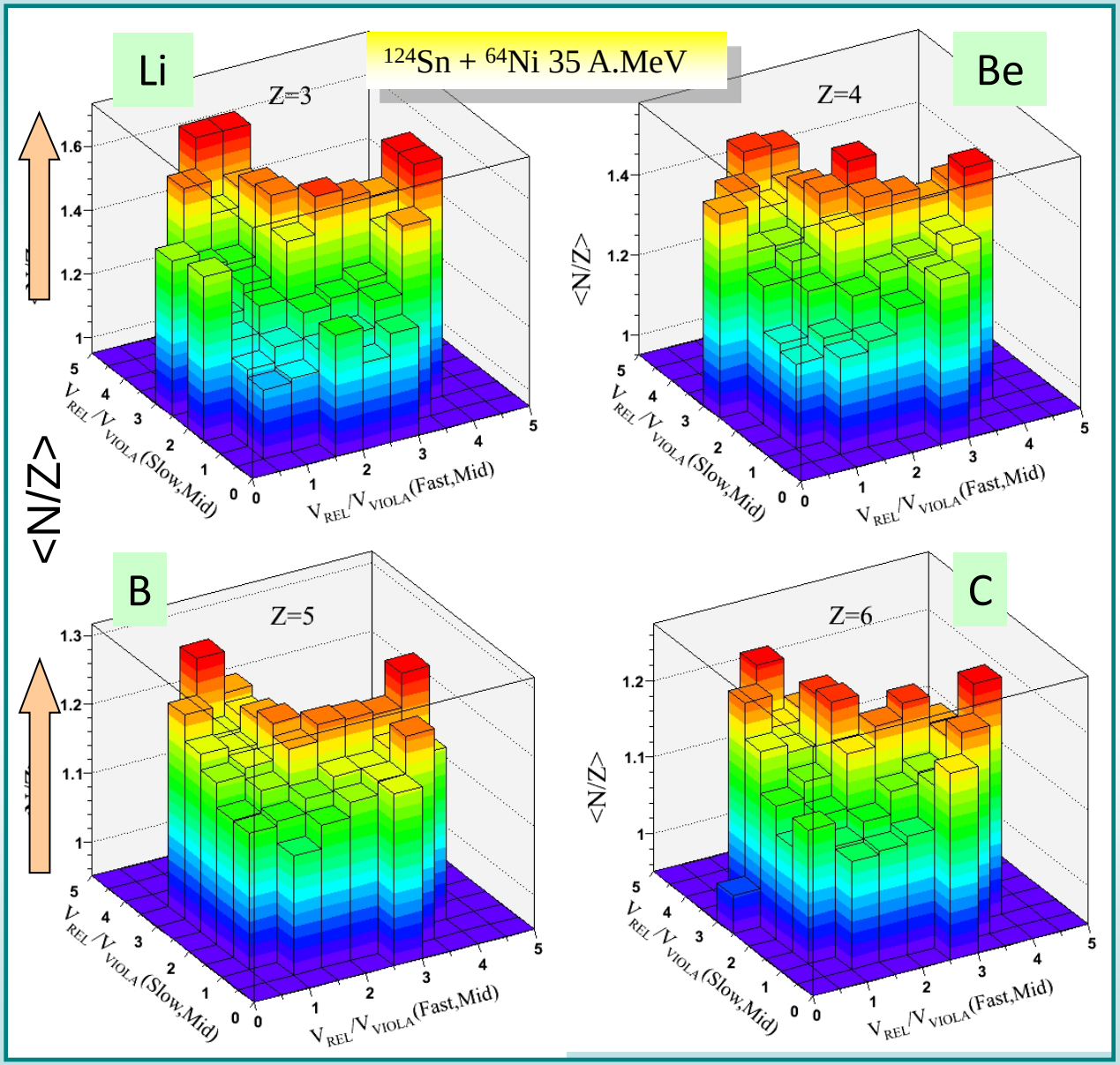
Viola et al NPA 472, 318 (1987)

$v_{rel}/v_{viola} = 1$ $t \geq 120$ fm/c

$v_{rel}/v_{viola} \neq 1$ $t \sim 40$ fm/c

E.De Filippo et al, PRC86 014610 2012

Correlations with IMFs (Z ≤ 8) isotopic properties

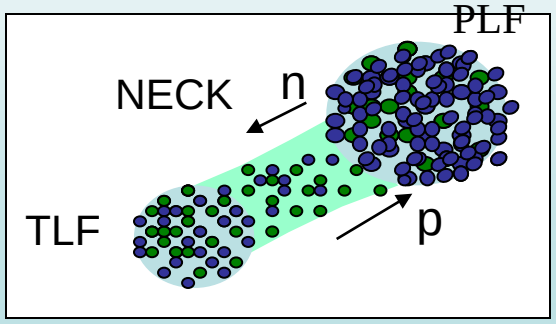


The correlation shows that the greatest **neutron enrichment** is linked to greater deviations from Viola systematics, that is to **fast prompt emission** of IMF.

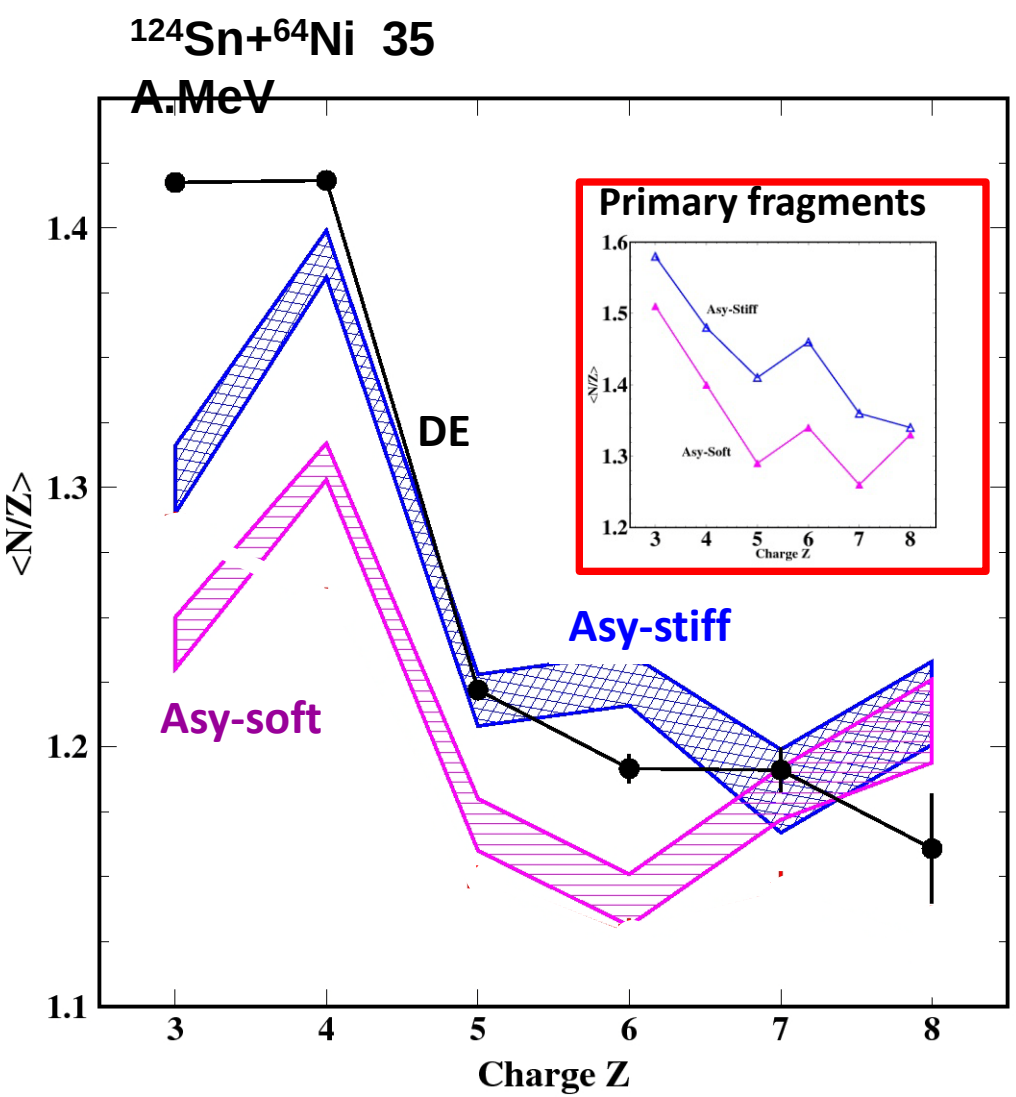
We can select

Dynamical emission

Statistical emission



Stochastic Mean Field (SMF) + GEMINI calculation

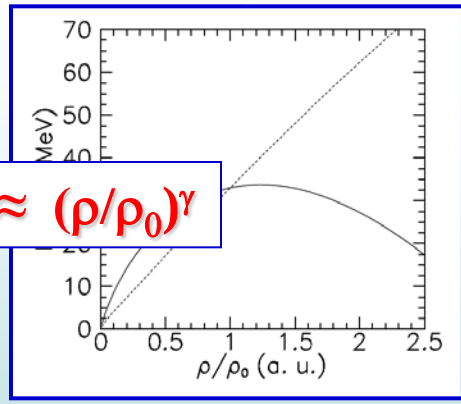


SMF - microscopic approach that describe the evolution of systems by Boltzmann-Nordheim-Vlasov transport equation.

The model includes nuclear mean field dynamics and effect of fluctuations.

V. Baran et al. Nucl. Phys. A730 329 (2004).

- **Dynamically emitted particles**



$E_{sym}(\rho) \approx (\rho/\rho_0)^{\gamma}$

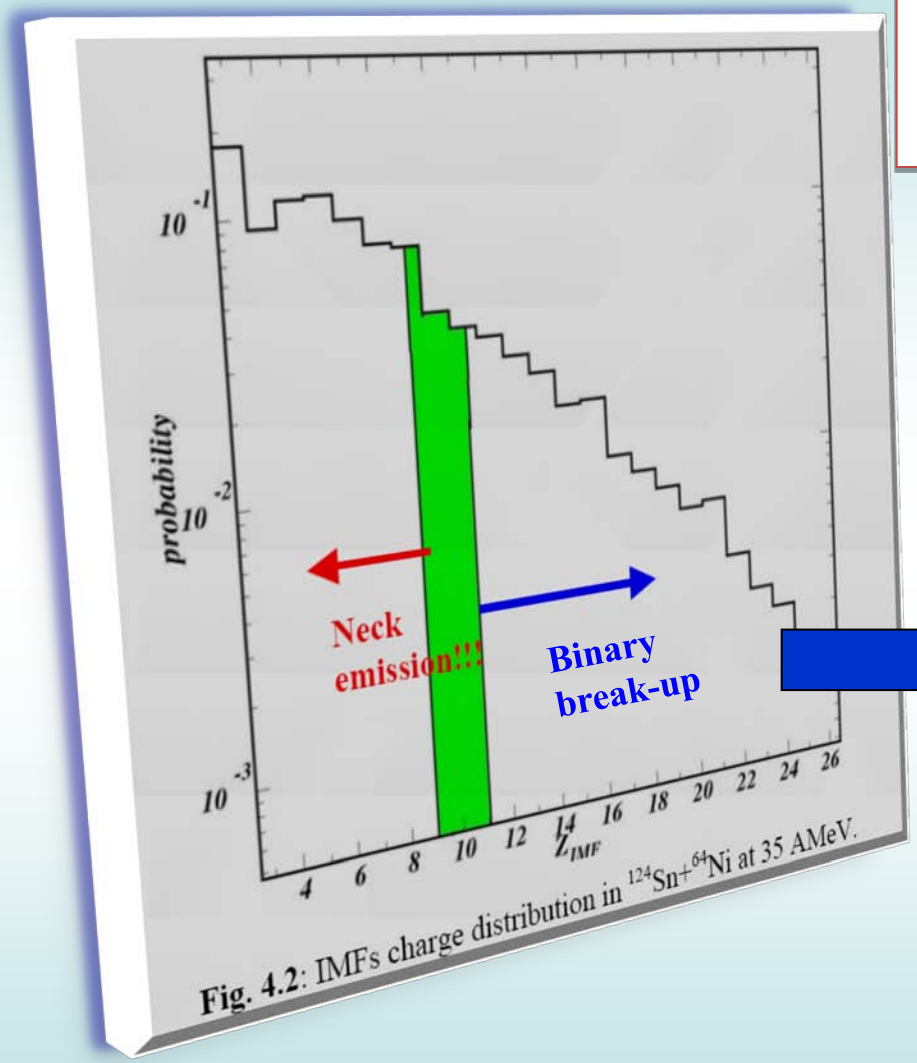
Data consistent with γ ≈ 1 Asystiff

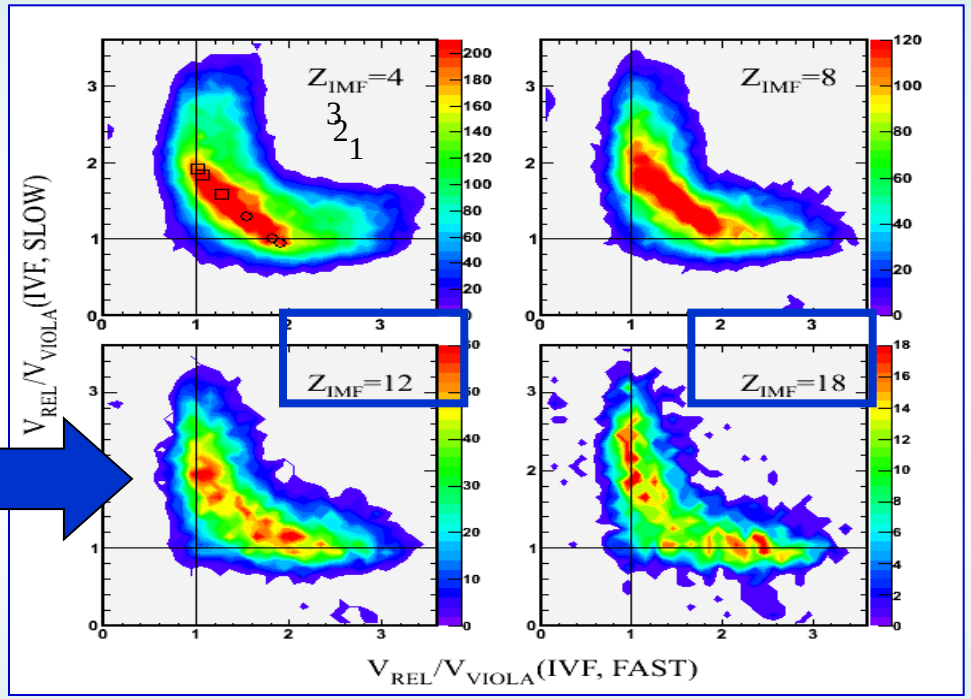
E.De Filippo et al, PRC86 014610 2012

Calculations performed by: M. Colonna

From early prompt neck fragmentation to PLF dynamical fission

Ternary events associated to the emission of heavy fragments coming from PLF break-up/fission and appearing at a longer time of emission





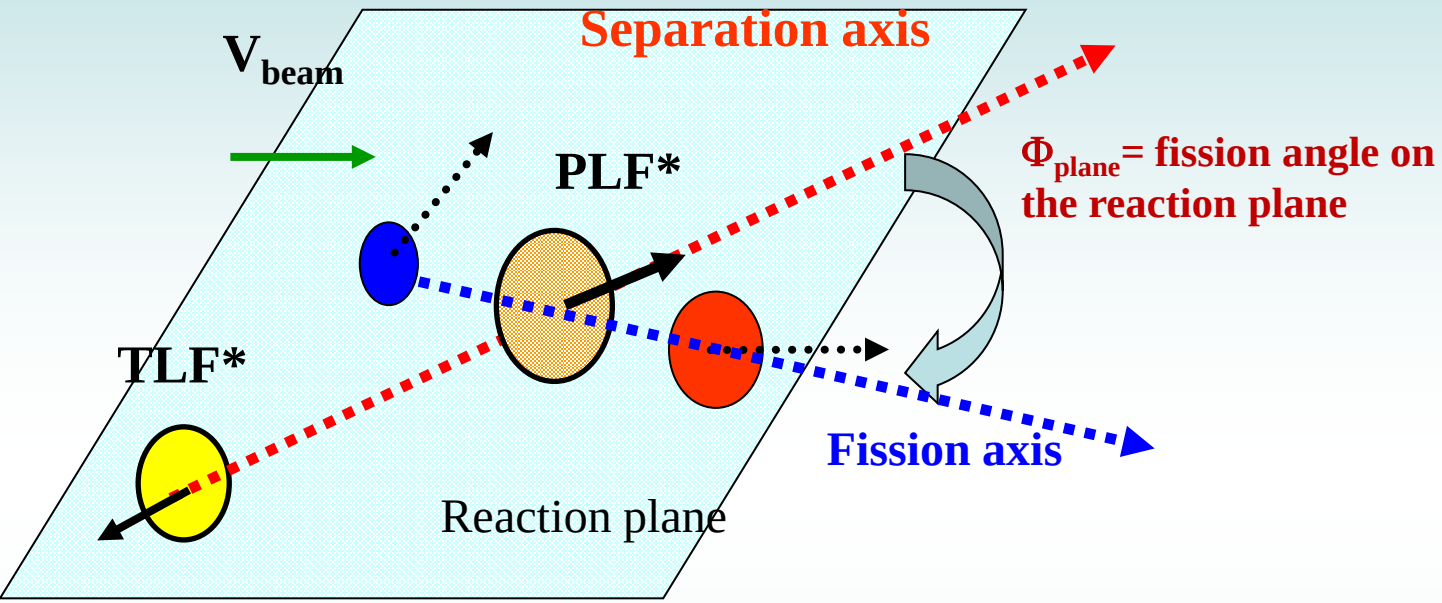
The time-scale of the process is one of the the signature among different mechanisms:

1)Early neck fragmentation (40-120 fm/c)
2)Dynamical fission (120-300 fm/c)
3)Statistical fission (>1000 fm/c)

P. Russotto et. al. Phys. Rev. C81, 064605 (2010)

Dynamical Fission: in $^{124}Sn+^{64}Ni$ and $^{112}Sn+^{58}Ni$ @35 A.MeV

$A_P=A_H+A_L$



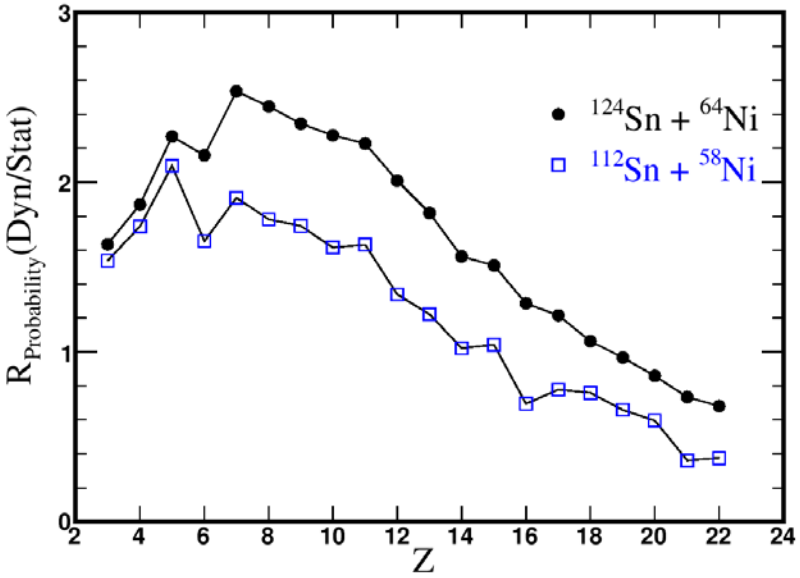
Φ_{plane} = fission angle on the reaction plane

Statistical fission is characterized by isotropic fission fragment angular distribution,

Dynamical Fission is characterized by fast AL fragment emission preferentially backwards in the PLF reference system, i.e., towards the target nucleus

E. De Filippo et al., Isospin collaboration, Phys. Rev. C71, 064604 (2005)
P. Russotto et al., Int. J. Mod. Physics E15 410 (2006)
P. Russotto et. al. Phys. Rev. C81, 064605 (2010)

Dyn/Stat Fission components for $^{124}Sn+^{64}Ni$ and $^{112}Sn+^{58}Ni$

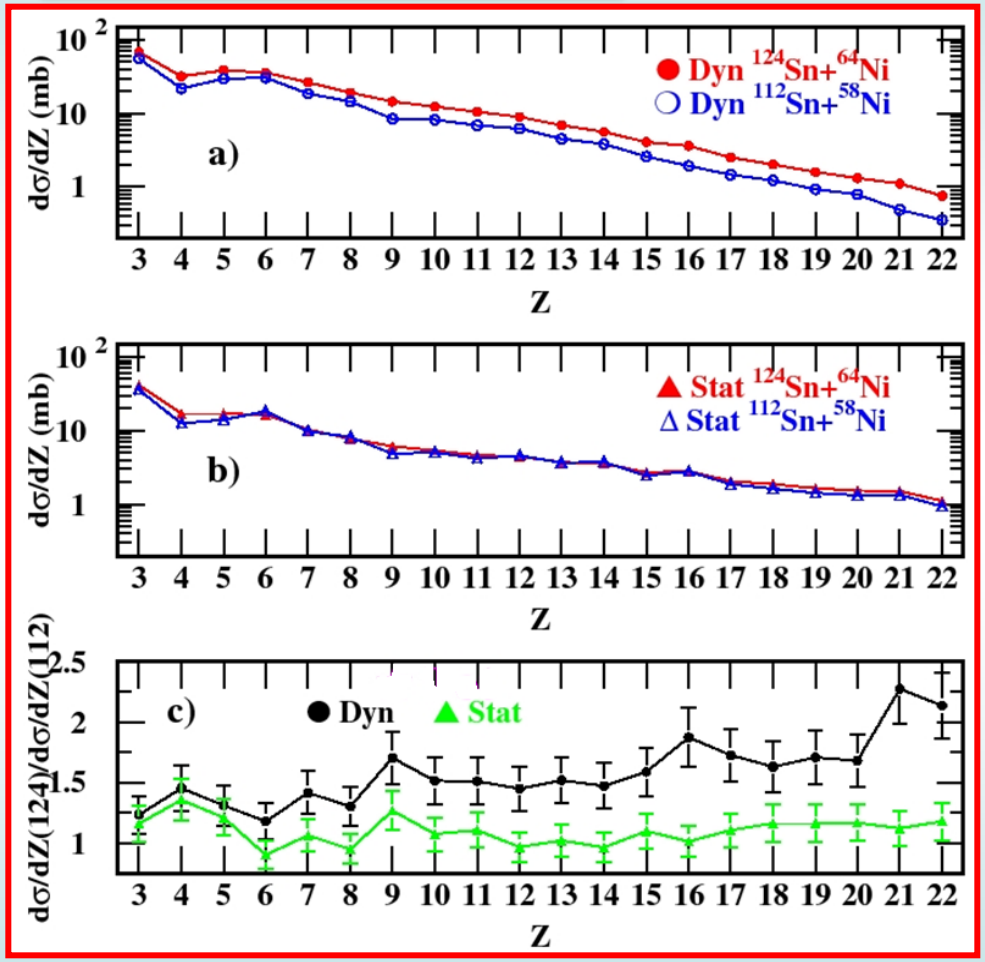


Probability ratio of dynamical and statistical fission components

Dynamical component: enhanced in the n- rich system

Statistical component: almost equal for n-rich, n-poor systems

IMFs Cross-sections



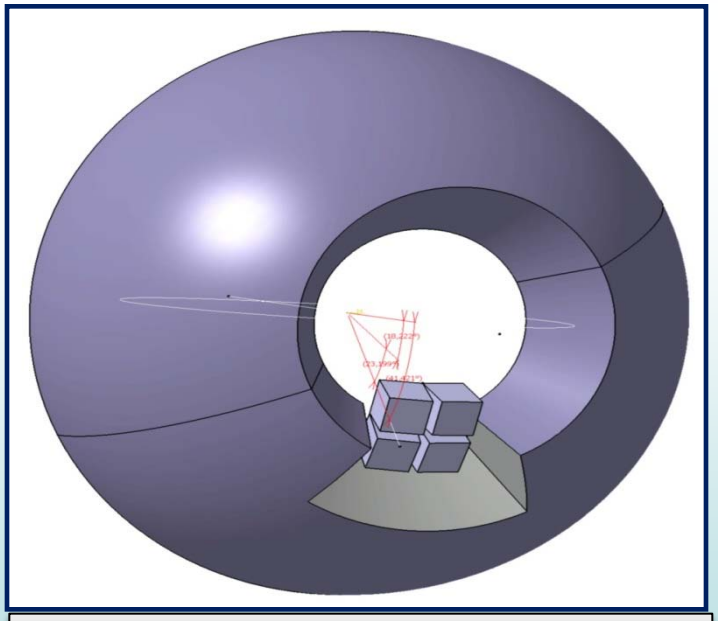
P. Russotto et al. , submitted, PRC (2014)

The InKiIsSy (INverse KInematics ISobaric Systems-P.Russotto) Apr.2013

Size or Isospin effects?
^{124}Xe+^{64}Zn @ 35 AMeV
-same mass of the n-rich ^{124}Sn+^{64}Ni system,
-N/Z near to the n-poor ^{112}Sn+^{58}Ni system

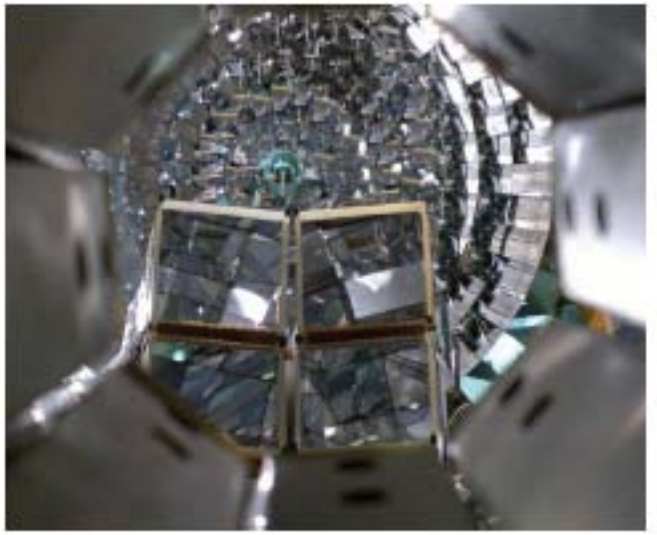
System	N/Z Projectile	N/Z target	N/Z compound
^{124}Sn+^{64}Ni	1.48	1.29	1.41
^{124}Xe+^{64}Zn	1.30	1.13	1.24
^{112}Sn+^{58}Ni	1.24	1.07	1.18

A new setup: the 4π CHIMERA + FARCOS 1° cluster prototype



4 telescopes 25 cm from the target

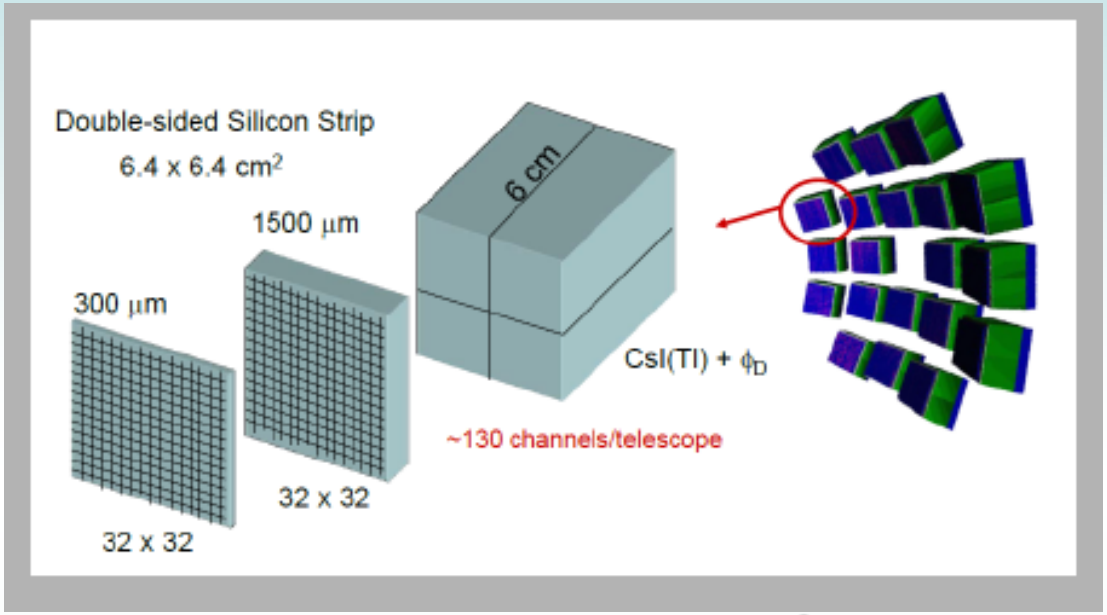
$\theta_{lab} \sim 16\text{-}44$ deg $\Delta\phi \sim 45$ deg



Analysis in progress.....

FARCOS project

Femptoscope ARray for COrrelation and Spectroscopy



High energy and angular resolution **(Δϑ<1°)**

Low thresholds **(<1 MeV/A):**

Pulse-shape on first Si layer for low energy experiments

High counting rate **(1KHz)**

Large Dynamic range **(20MeV to 2GeV)**

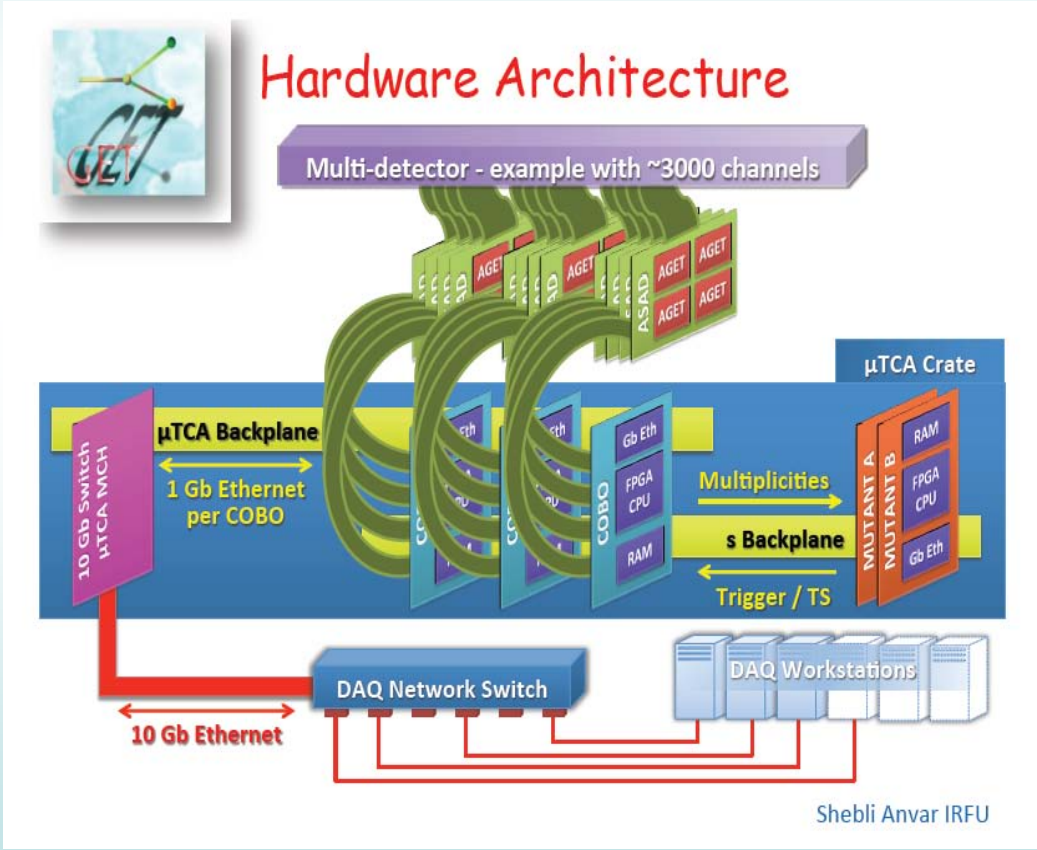
Flexibility, Modularity, Trasportability

Coupling to 4π detectors or spectrometers

Integrated Electronics **(GET)**

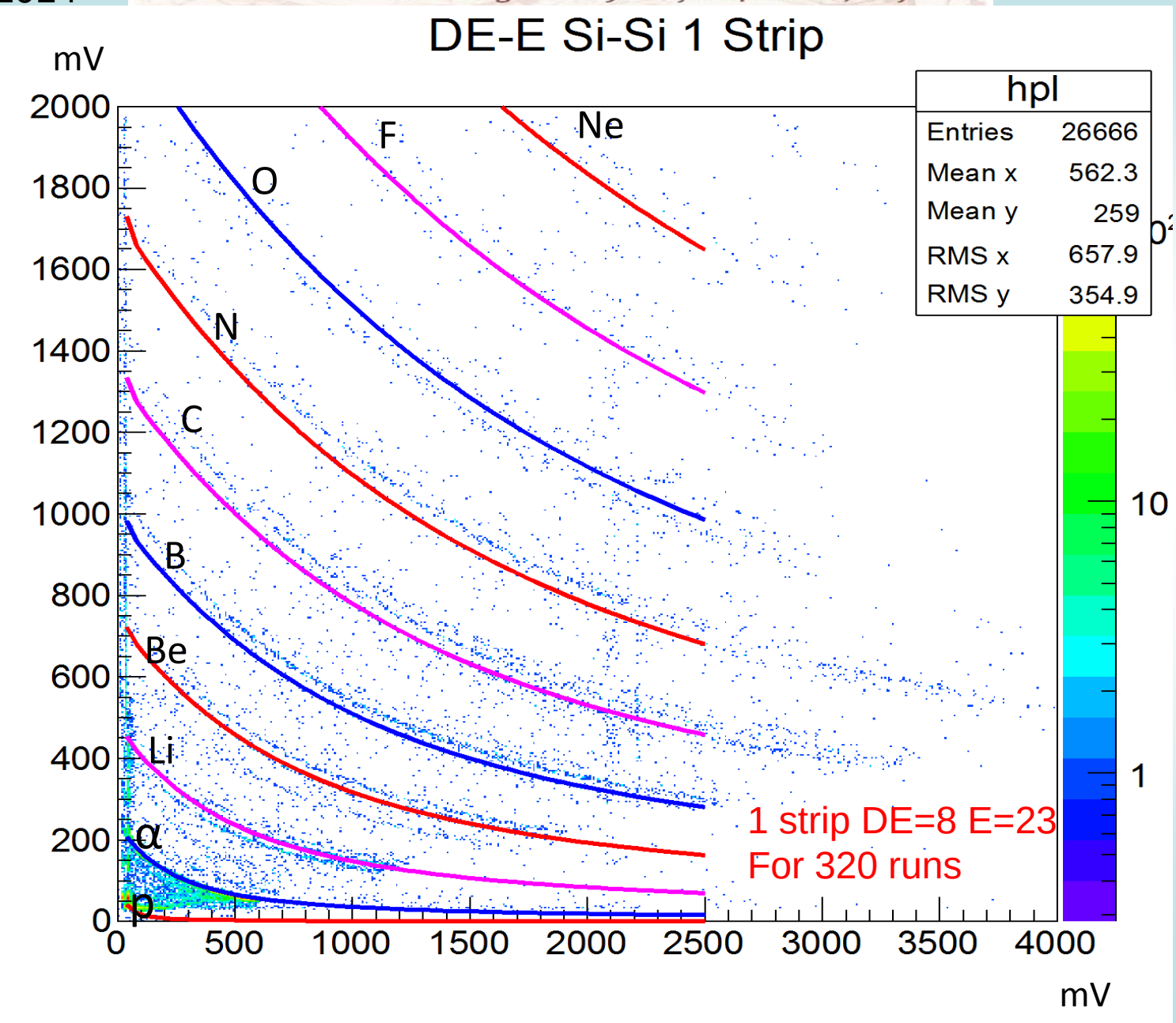
GET: General Electronics for TPC

- Especially designed for TPC (gas detectors) to be used with radioactive beams at E/A=5-350 MeV
- Integrated and low power consuming
- Wide dynamic range (LCP&HI)
- Configurable
- Digitalization of signals
- Might work on photodiodes readout of CsI(Tl) crystals in Chimera and Farcos



International Workshop on Multi facets of Eos and Clustering
IWM-EC 2014
6th – 9th May 2014 Catania, Italy

E. V. Pagano
Univ. of Catania & LNS-INFN



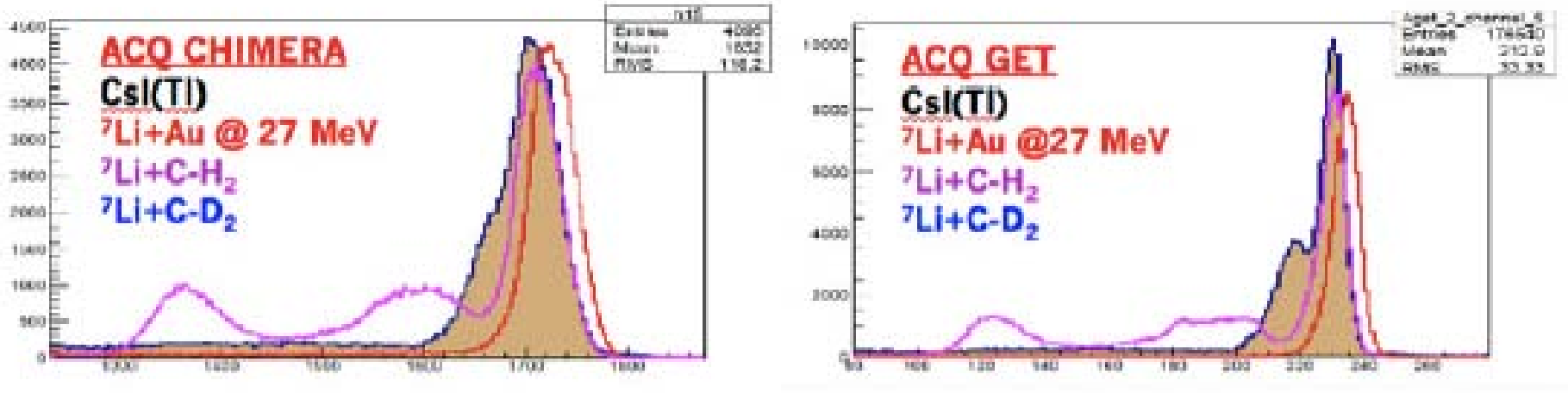


Figure 6: Test of CsI(Tl) crystals. The beam is 7Li @ 27 MeV and the three colours are related to the three different target, red Gold target, violet CH_2 and blue CD_2.

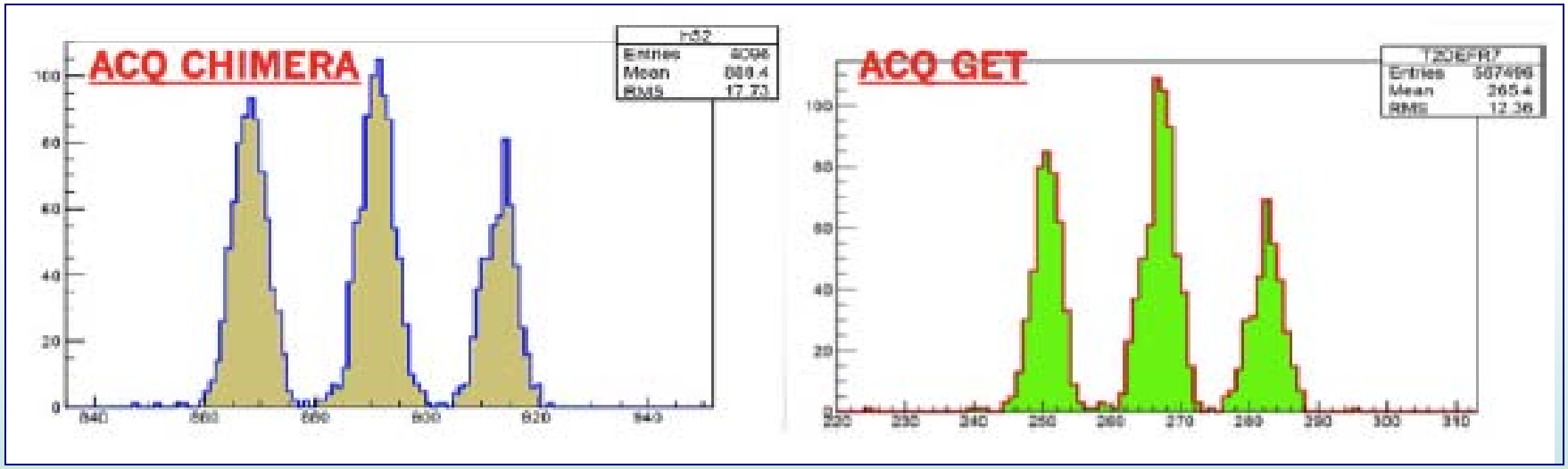
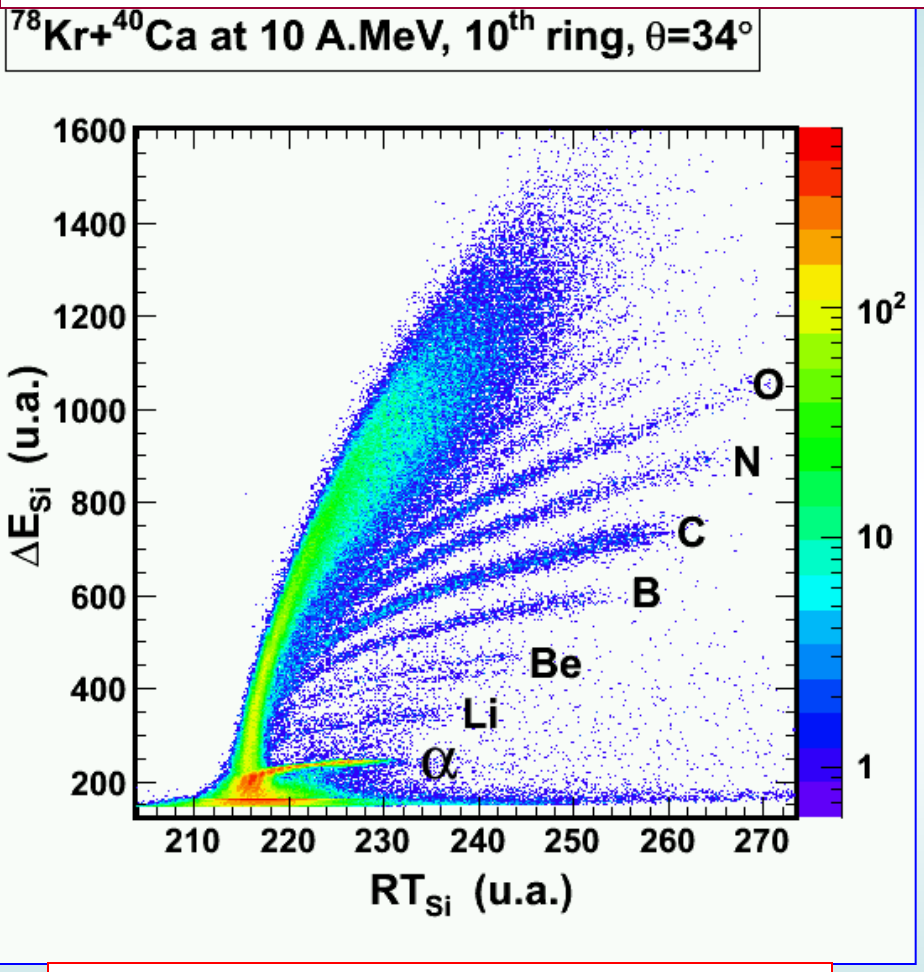


Figure 7: Test of DSSSD. In this test the pick are related to the Alpha particles emitted from a typical three pick alpha source.

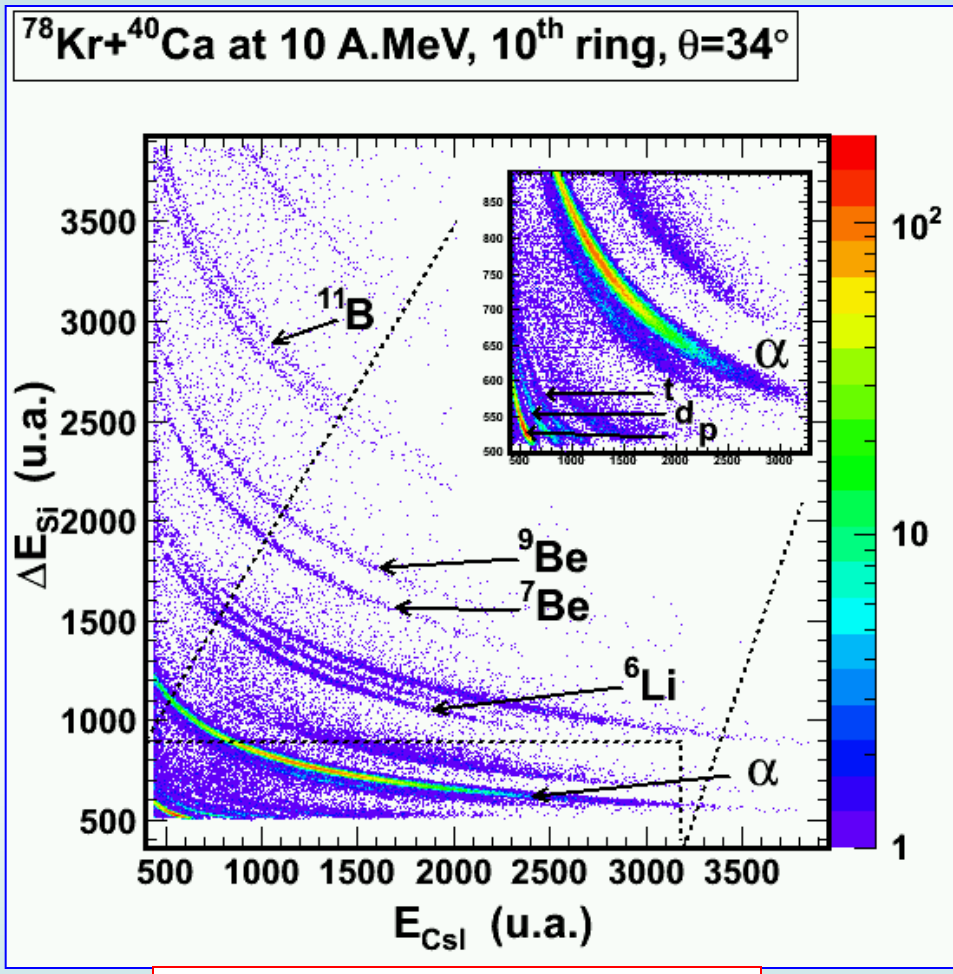
E.V. Pagano et al. IWM2014 proc. To be published

ISODEC CHIMERA@LNS

$^{78}Kr + ^{40}Ca$, $^{86}Kr + ^{48}Ca$ E = 10 AMeV



PSD in Silicon

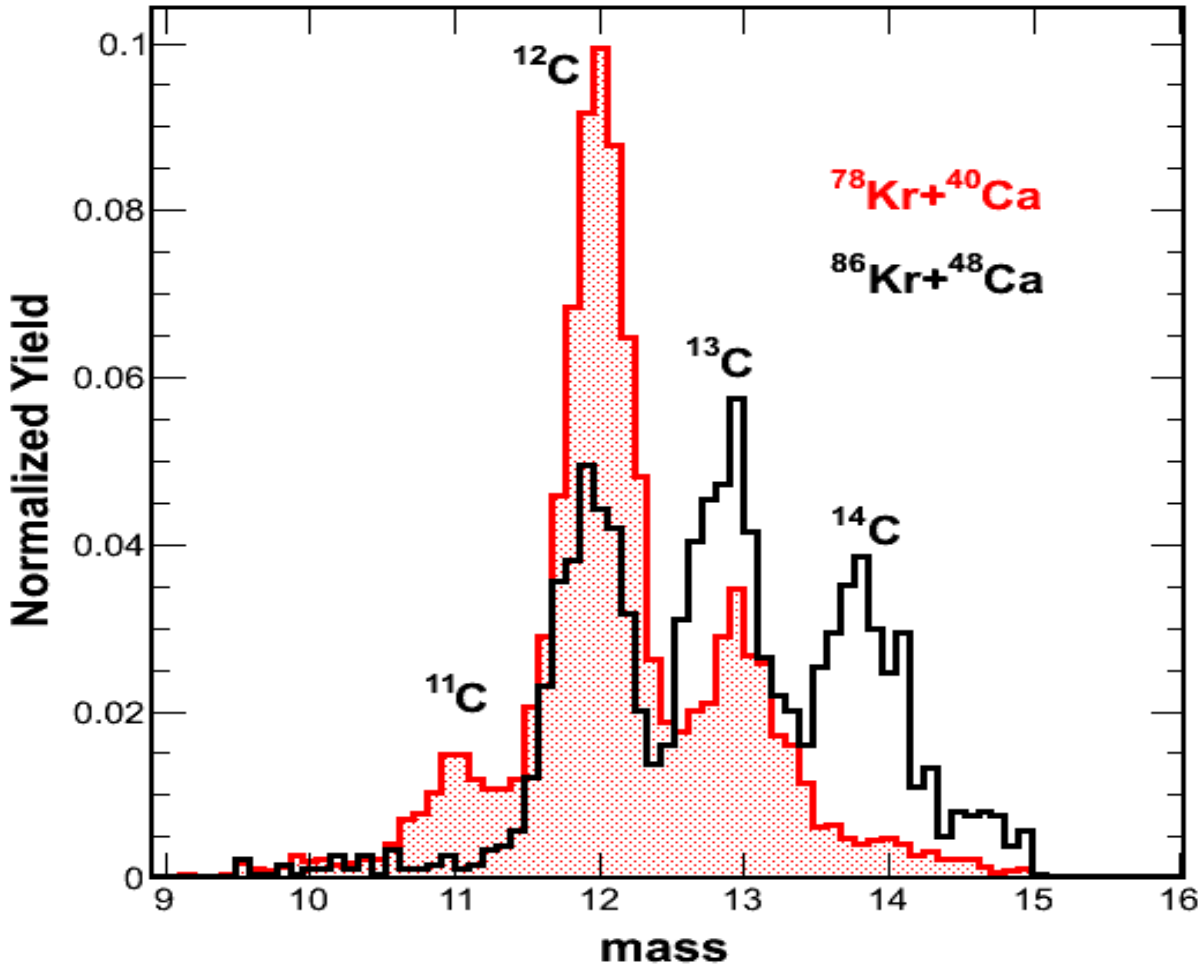


ΔE-E , Si-CsI(Tl)

S. P. et al., Proc. of FUSION11, EPJ Web of Conf. 17, 16010 (2011)

G. Politi et al., Proc. of CNR11 EPJ Web of Conf. 21, 02003 (2012)

IMF Mass Distribution



Different isotopic compositions and relative enrichment for the same Z in the two systems

- Influence of the Isospin (N/Z)
- influence of nuclear pairing force
- influence of structure effects

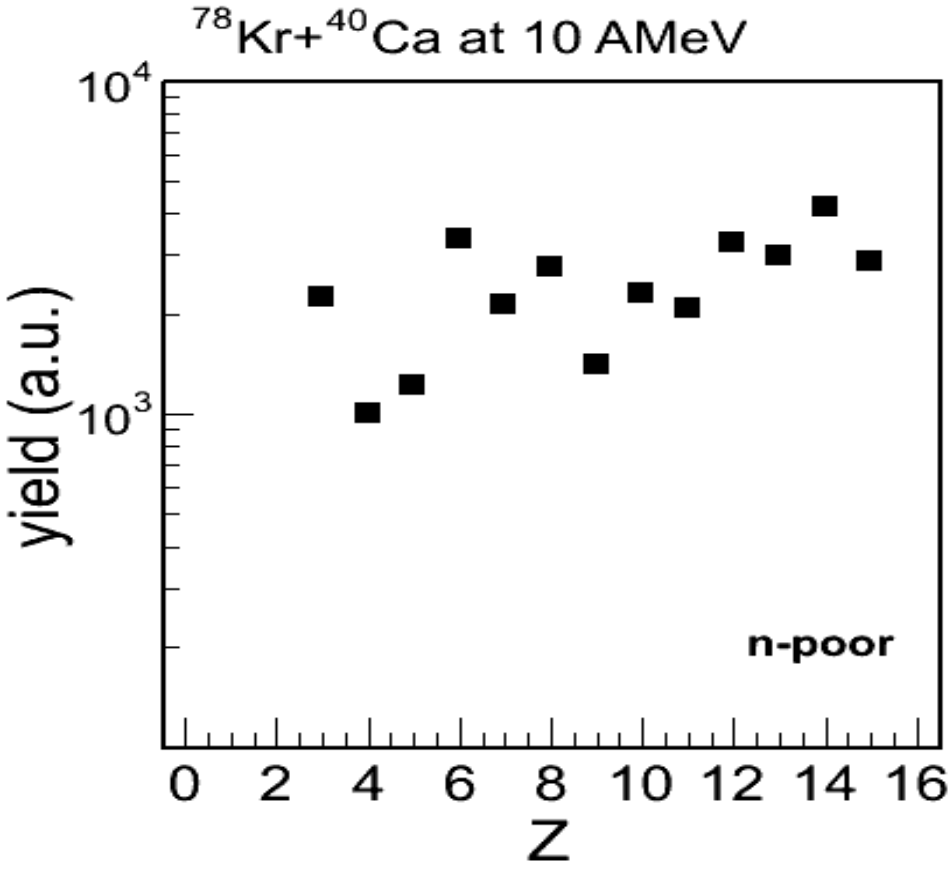
(M. D'Agostino et al., NPA 861 (2011) 47)

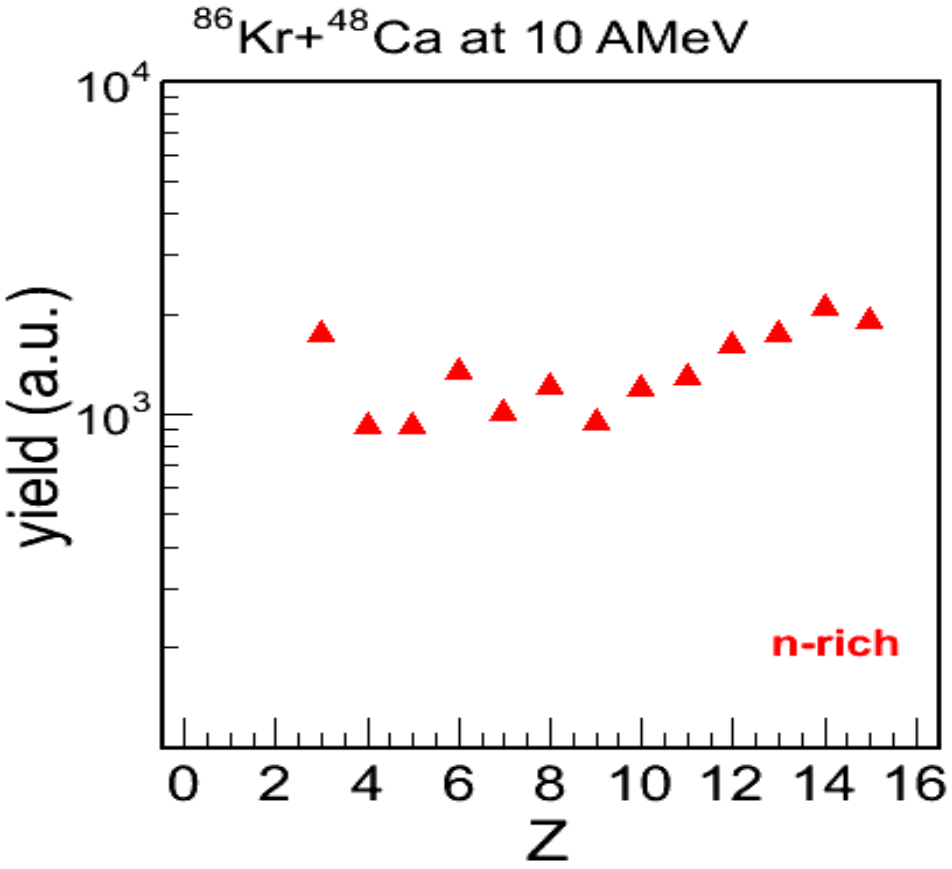
Normalized Yields Comparison
$10.5° \leq \vartheta \leq 15.5°$

GEMINI++ (M.Trimarchi)

DNM (S.Kalandarov)

In agreement : I. Lombardo et al., *PRC 84* ,(2011), 024613 , G. Casini et al., *PRC* 86, (2012), 011602





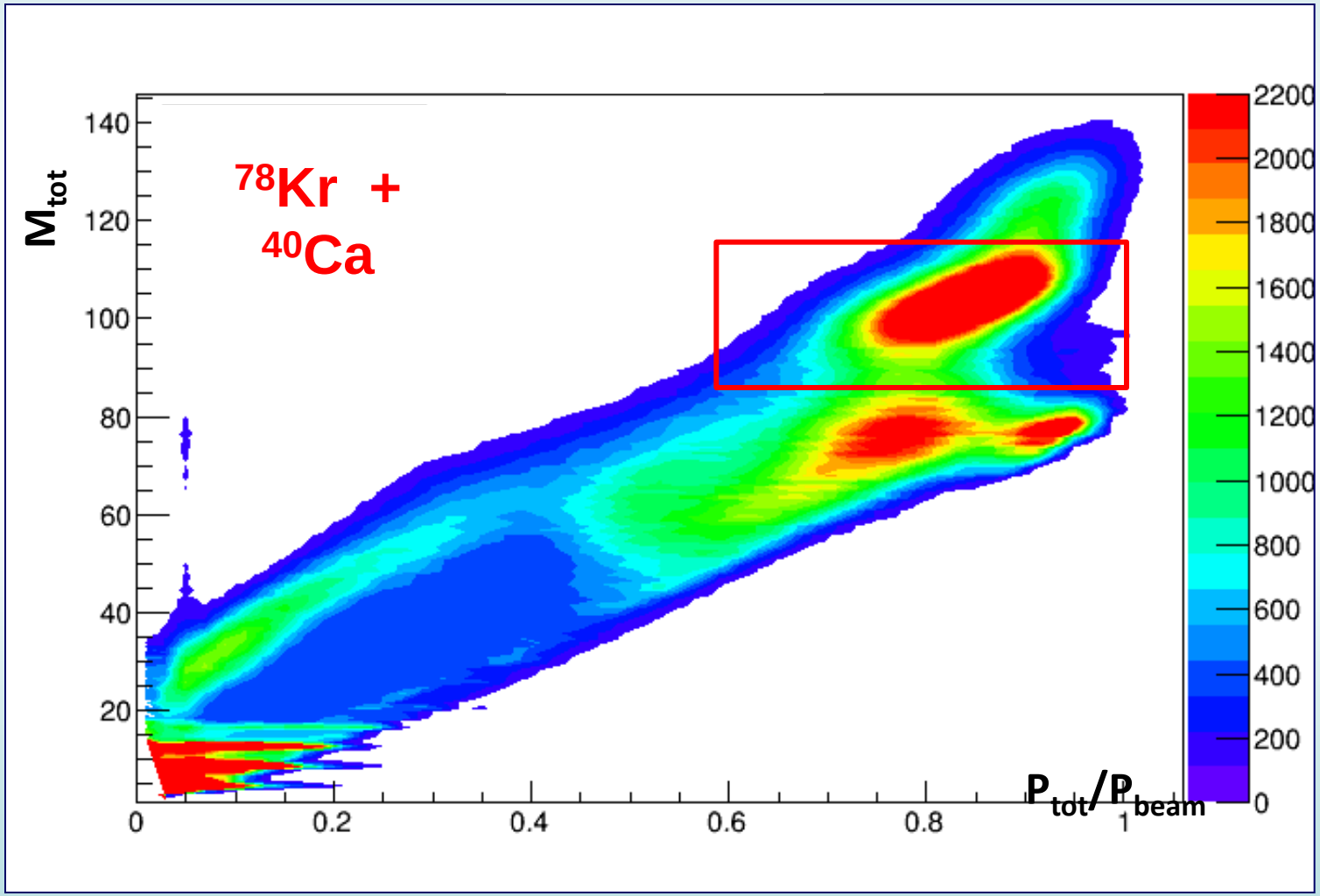
S.P. et al, Proc of Echic2013, IOP Conf series, (2014)

COMPLETE EVENT SELECTION

Multiplicity > 1

$0.8\ M_{CN} \leq M_{tot} \leq M_{CN}$

$0.6 \leq p_{tot}/p_{beam} \leq 1$



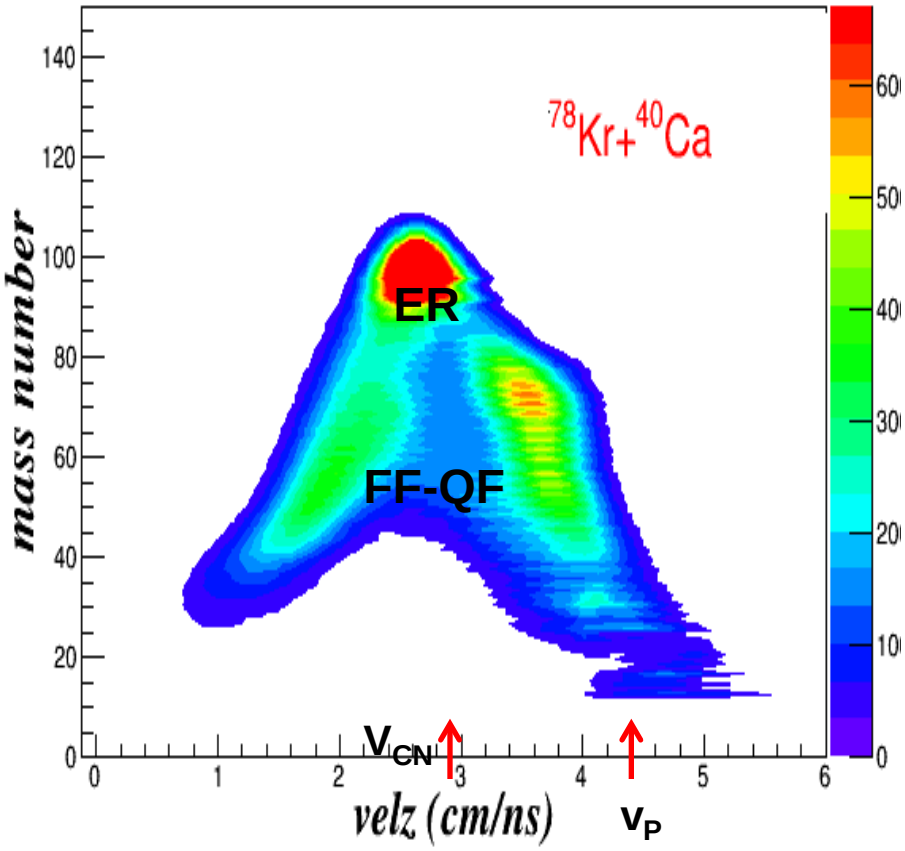
B.Gnoffo et al. SIF2014-Pisa

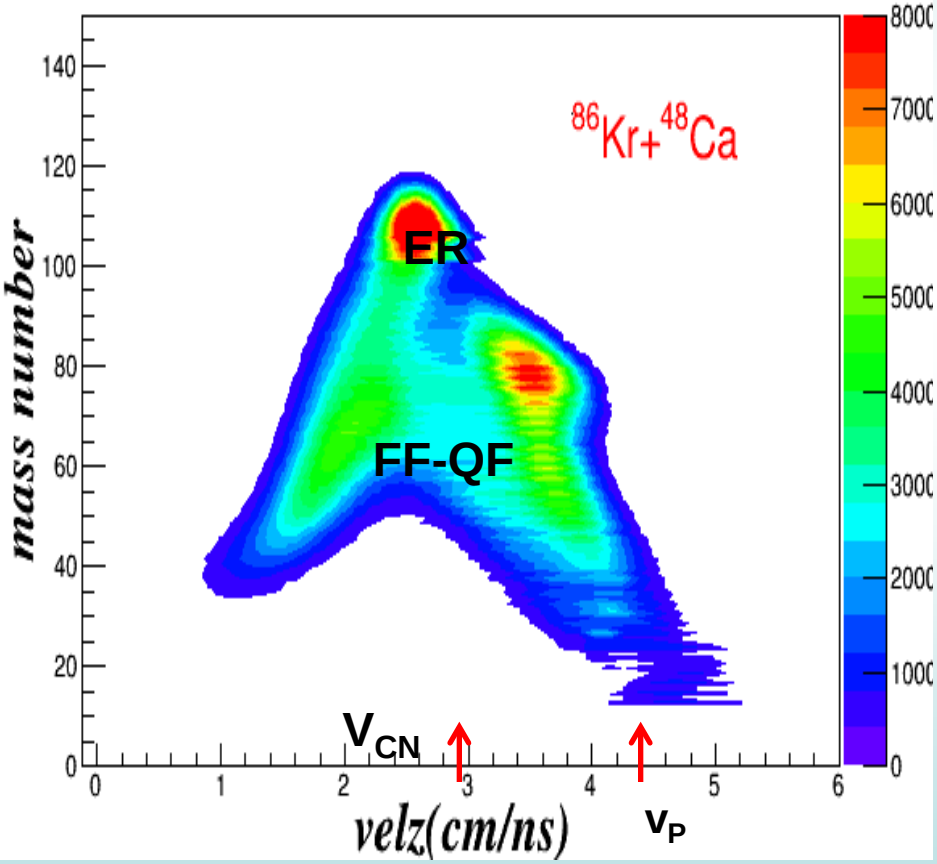
SELECTED COMPLETE EVENTS

Influence of isospin/n-enrichmnt on reaction mechanism

more fusion-evaporation in the n-poor system and less FF contribution respect to n-rich

ER = Evap. Residues
FF = Fission fragments
QF = deep inelastic/quasi fission





B.Gnoffo et al. SIF2014-Pisa
G. Politi et al., proc of ARIS14 to be published 2015

Second SPES International Workshop

26-28 May 2014

INFN Laboratori Nazionali di Legnaro

SPES Letter Of Intent

Isospin dependence of compound nucleus formation and decay

E. DeFilippo INFN - Catania
J. D. Frankland GANIL - Caen
S. Pirrone INFN - Catania
G. Politi Università and INFN - Catania
P. Russotto INFN - Catania

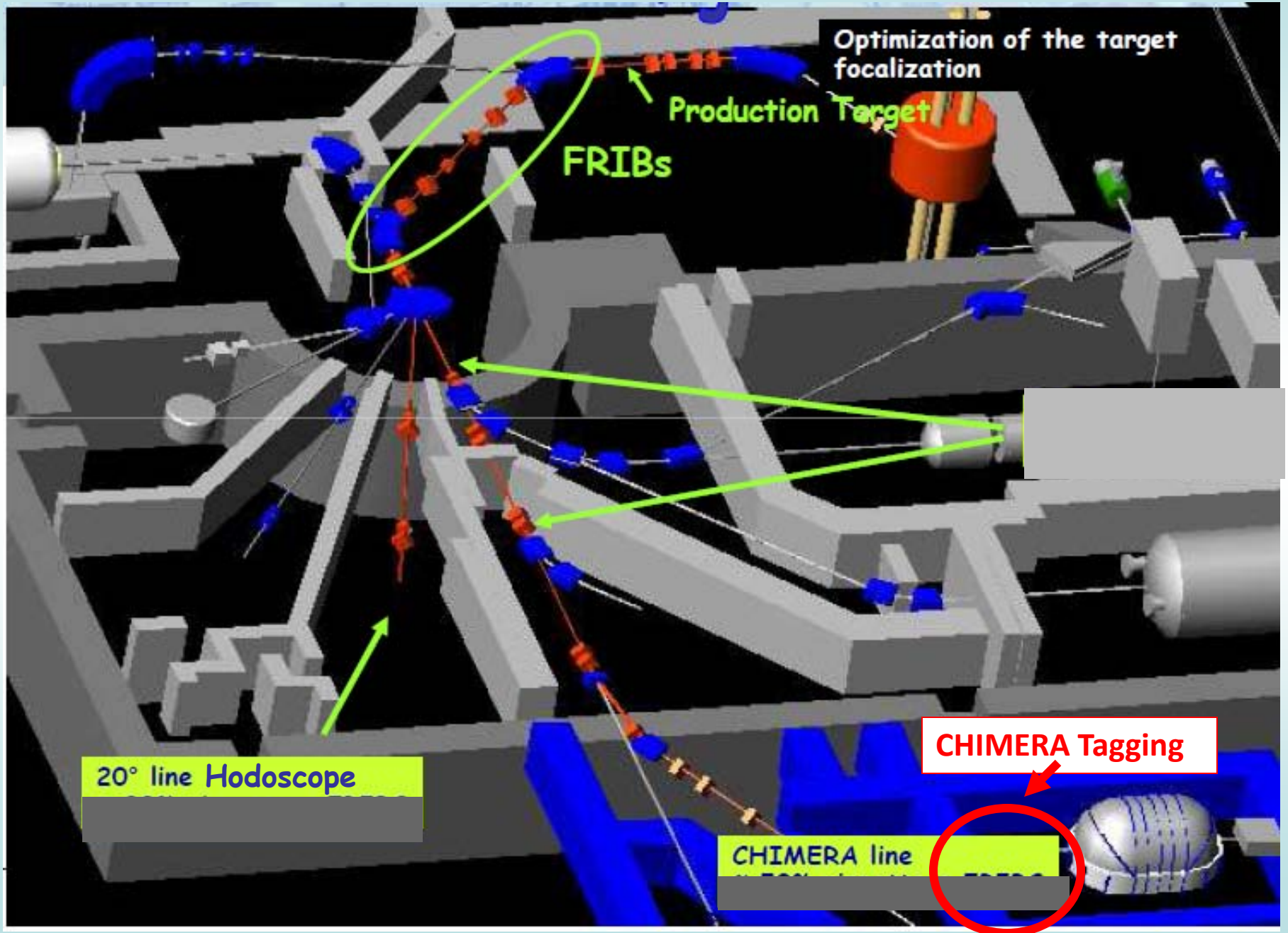
New systems with higher N/Z would bring new insights

^{90,94}Kr + ^{40,48}Ca 10 AMeV

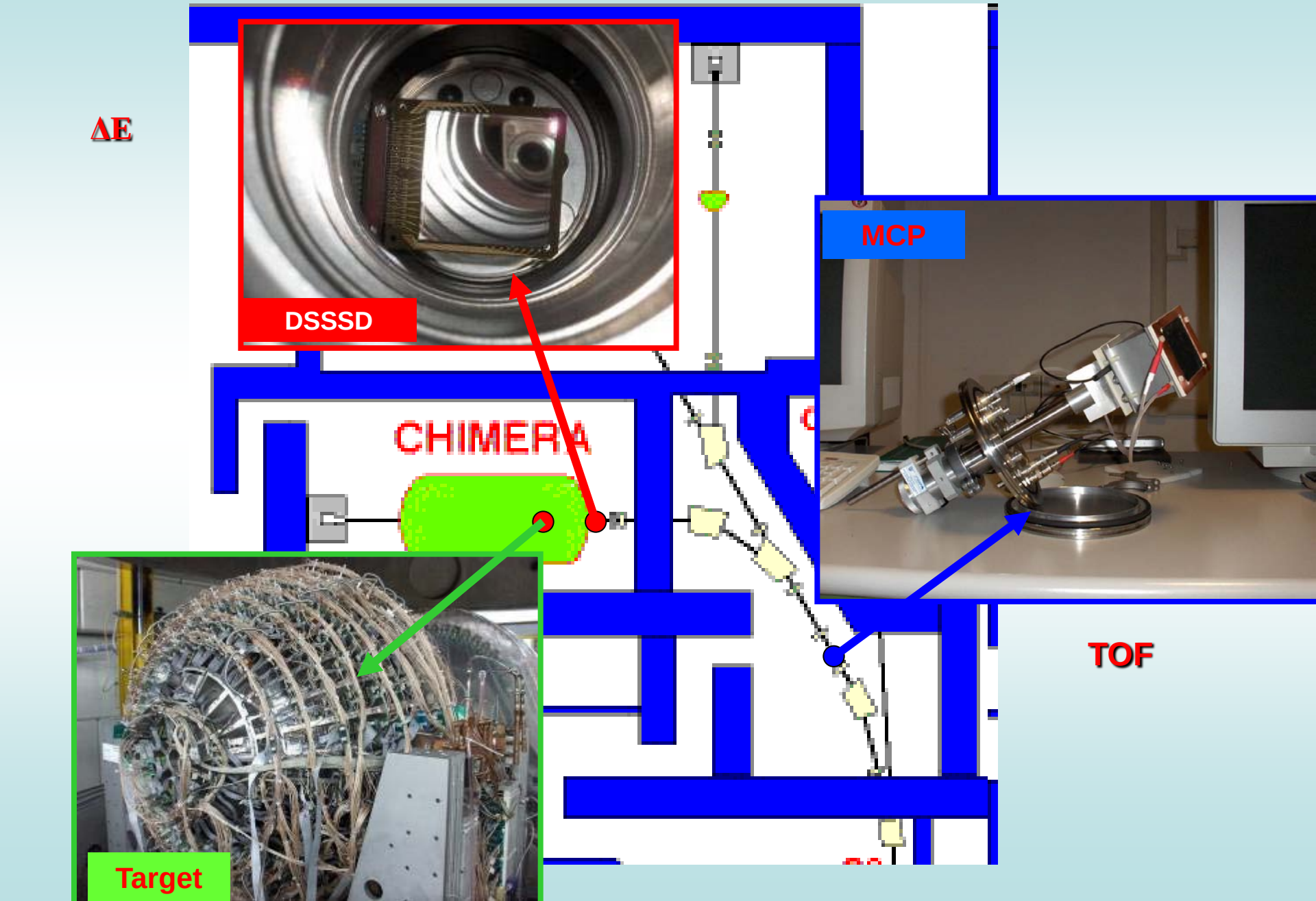
Fragmentation Beams @LNS

***Chimera group,** since 2005, works to test the production of new beams and to realize new experiments @LNS with radioactive beams at intermediate energy.*

In-flight fragmentation beams @ LNS

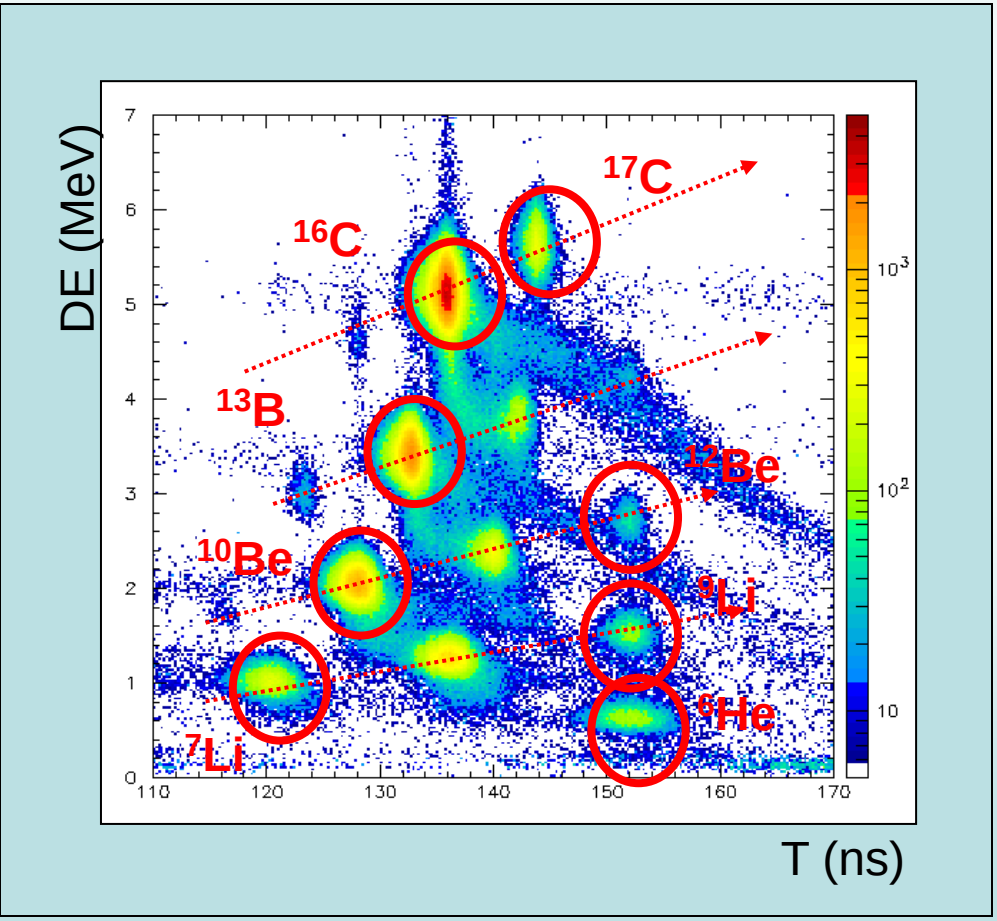


CHIMERA beam line – tagging system



In-flight fragmentation beams @ LNS
Production Tests at the CHIMERA beam line

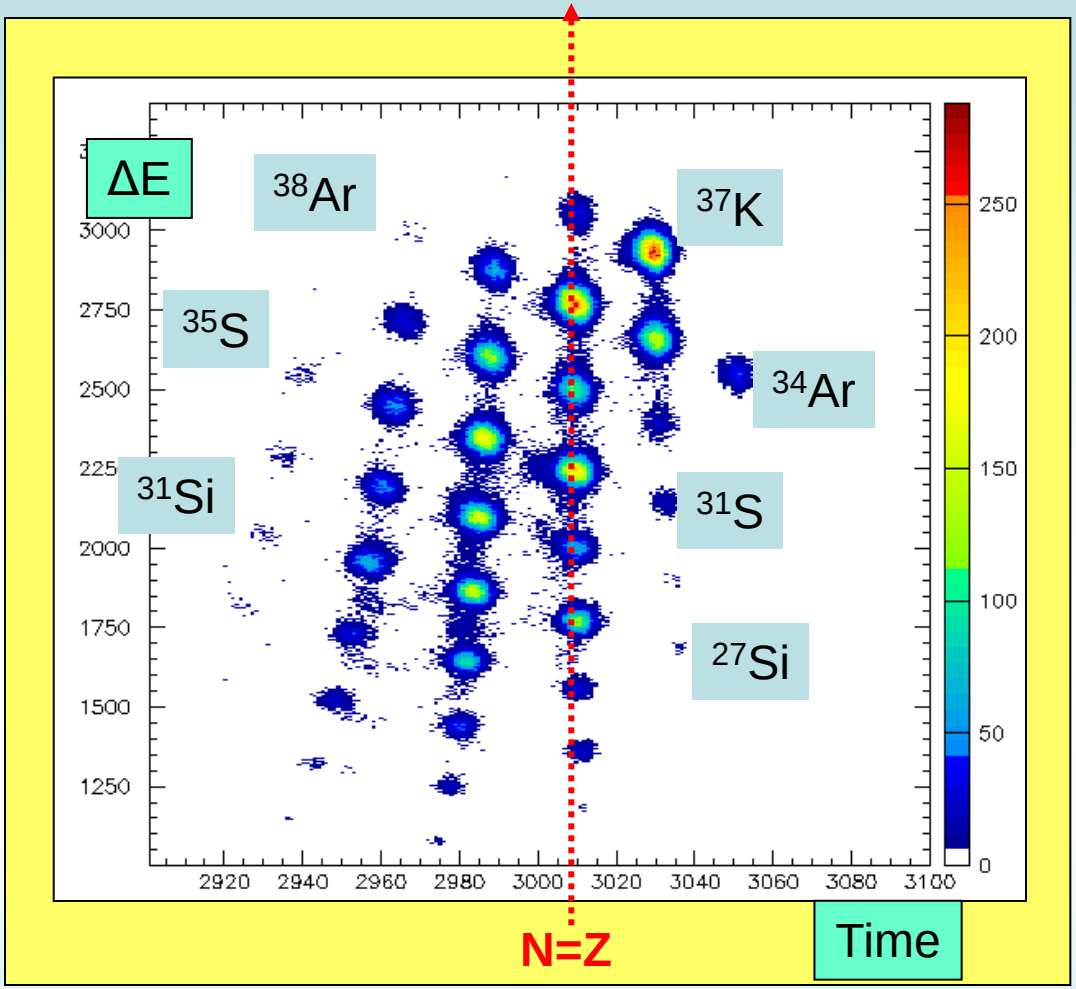
^{18}O + ^{9}Be (1.5 mm) at 55 MeV/A



Primary beam 88W, 5.5x10^{11} p/s

	Khz	
^{16}C	40	
^{17}C	4	
^{13}B	23	
^{11}Be	6	Setting Bρ=2.71 Tm
^{10}Be	21	
^{8}Li	11	

E of secondary beam 40-50 MeV/A



^{36}Ar + ^{9}Be (0.5 mm) 42 MeV/A,

primary beam 25W - 1x10^{11} p/s

	Khz	
^{37}K	14.0	
^{36}Ar	12.0	
^{35}Ar	8.5	
^{34}Ar	1.8	magnetic setting
^{33}Cl	1.5	
^{34}Cl	6.5	
^{31}S	0.8	
^{32}S	10.0	
^{28}Si	5.0	
^{29}Si	6.5	

Energy secondary beams 20-25 MeV/A

^{70}Zn + ^{9}Be (0.25 mm) 40 MeV/A,

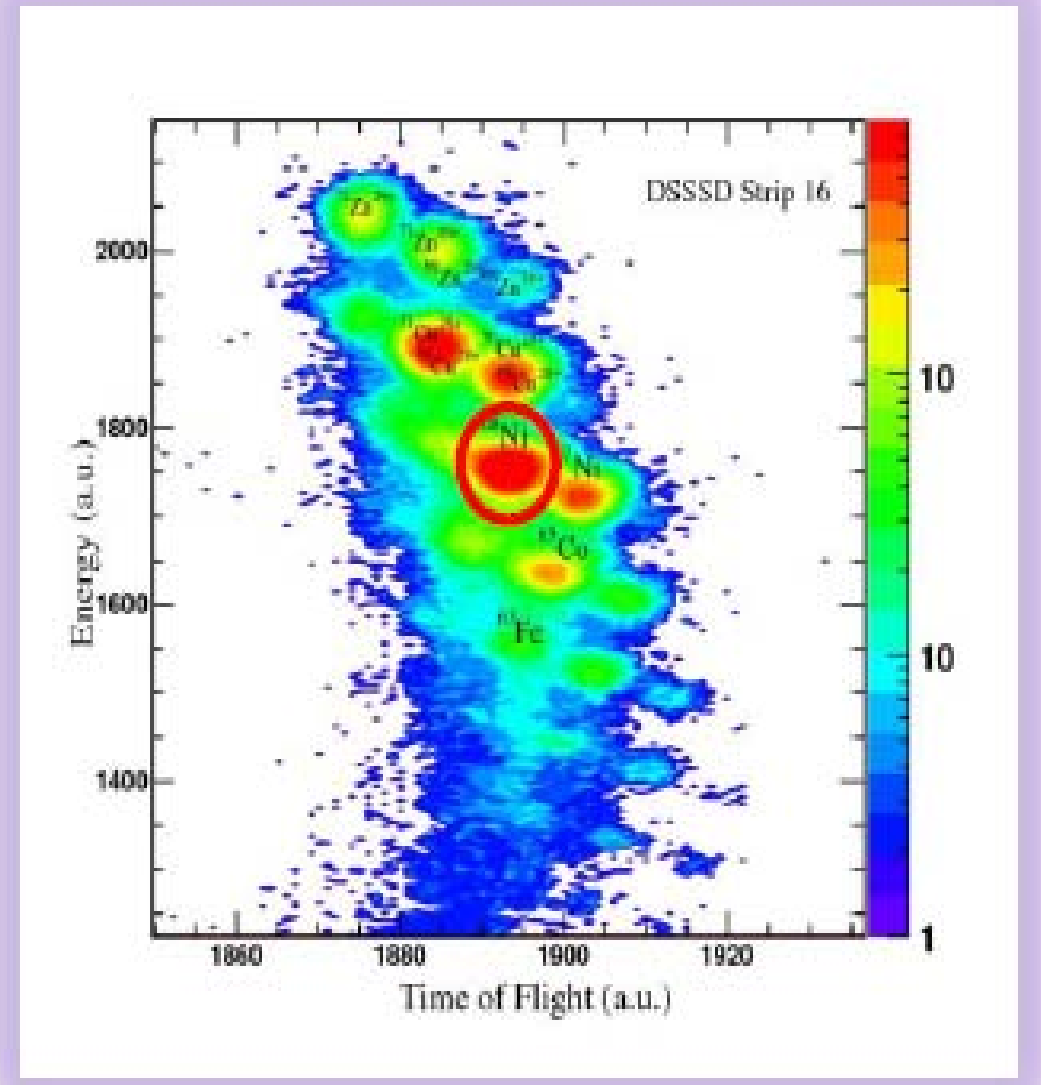


Fig.4 Identification scatter plot of ^{68}Ni fragm ıtation beam

primary beam 100W

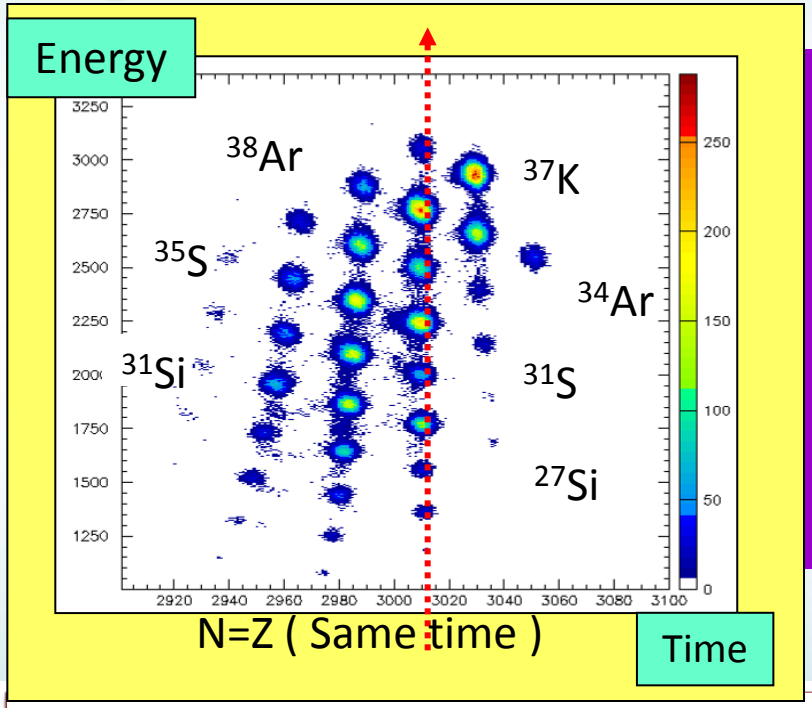
^{68}Ni
Rate 20kHz
Energy 28 MeV/A

Search for iso-scalar excitation of the PIGMY resonance in ^{68}Ni nuclei

G.Cardella, E.G.Lanza
for the EXOCHIM coll.

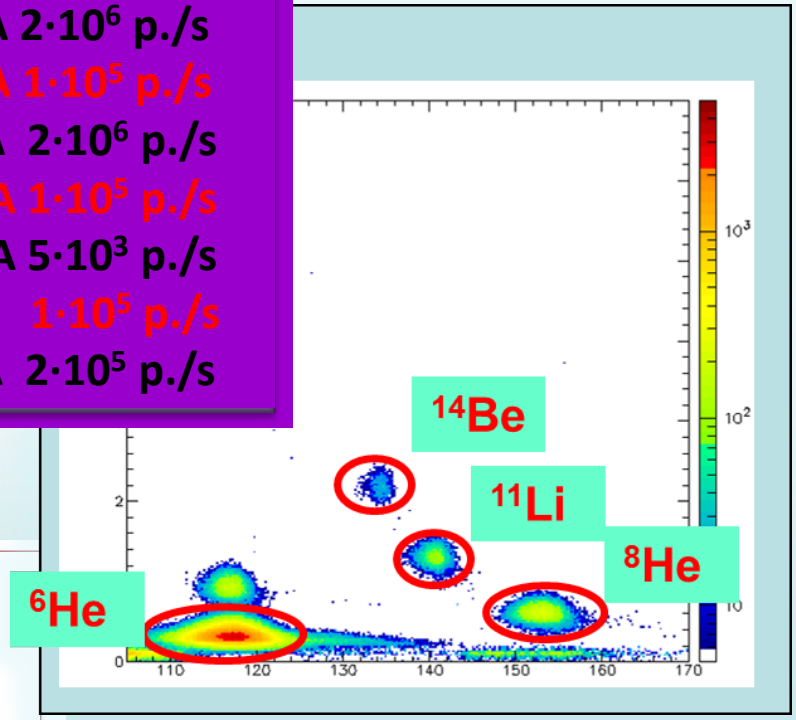
LNS FRIBS UPGRADING

Increasing the primary beam intensity of the CS will produce an equivalent increase of the exotic nuclei intensity produced by in flight fragmentation in FRIBS



Some examples are:

- ^{68}Ni 30MeV/A 2·10^{6} p./s
- ^{34}Ar 30MeV/A 1·10^{5} p./s
- ^{11}Be50MeV/A 2·10^{6} p./s
- ^{12}Be 50MeV/A 1·10^{5} p./s
- ^{14}Be 50MeV/A 5·10^{3} p./s
- ^{11}Li 50MeV/A 1·10^{5} p./s
- ^{8}He 50MeV/A 2·10^{5} p./s



We coud have fragmentation beams with very good intensities getting a UNIQUE facility in EUROPE to deliver EXOTIC beams at intermediate energies

CHIMERA collaboration

NEWCHIM CNS3 2015-2019

Sperimentazione con fasci stabili – LNS

Dinamica delle reazioni - Cronologia dell'emissione – EOS Energia di Simmetria ($\rho<\rho_0$)

Influenza dell'isospin sui meccanismi reazione - **Cluster –Condensati di bose**

Sperimentazione con fasci esotici LNS :

-Fasci esotici di energia intermedia per frammentazione in volo LNS

-Struttura nucleare (coincidenze cinematiche) –studio di risonanze – Strutture a cluster -

Sperimentazione con fasci esotici SPES:

Estensione studi influenza dell'isospin meccanismi dui reazione (LOI ISODEC)

Sperimentazione con fasci stabili – GSI

EOS Energia di Simmetria ($\rho>\rho_0$)

Sperimentazione con fasci stabili GANIL (INDRA/MUST")

Cluster –Condensati di bose - EOS Energia di Simmetria

Realizzazione di FARCOS (correlatore per particelle cariche)

Studio implementazione segnale neutronico (CHIMERA/FARCOS)

Upgrade CHIMERA (digitalizzazione - studio riv γ – nuova elettronica per CsI)

2015 – approved experiment @LNS

CHIMERA-FARCOS

CLIR : break-up ^{16}C and other fragmentation beams

8HE: test - experiment to produce ^{8}He and study of the resonance ^{9}He formed in 1n trasfer reaction with deuterated target

PIGMY: Search for iso-scalar excitation of the PIGMY resonance in ^{68}Ni nuclei

SIKO: search of alpha-gas states in ^{28}Si (^{16}O + ^{12}C)

2016/2017– proposing experiment @LNS

Some proposals are in progress on experiments by using

CHIMERA - FARCOS

In international collaboration, among these:

- **NEWBOSE – Orsay (Ad. R. Raduta et al., PLB 705 (2011) 65)**

- **cluster structure in ^{20}Ne**

- **EOS & symmetry energy (coalescence/clustering/ femtoscopy)**

LNS - TAMU - GANIL (MUST2/FARCOS CHIMERA/INDRA)

Shorter term campaigns –Fermi energies

Reaction systems at GANIL

N/Z-scan and A-scan:

- 40Ca + 40Ca, 48Ca + 48Ca
- 58Ni + 58NiCa, 64Ni + 64Ni E/A=40 - 80 MeV
- 112Sn + 112Sn, 124Sn + 124Sn
- 58Ni + 40Ca, 64Ni + 48Ca (coalescence vs femtoscopy)

N/Z-scan:

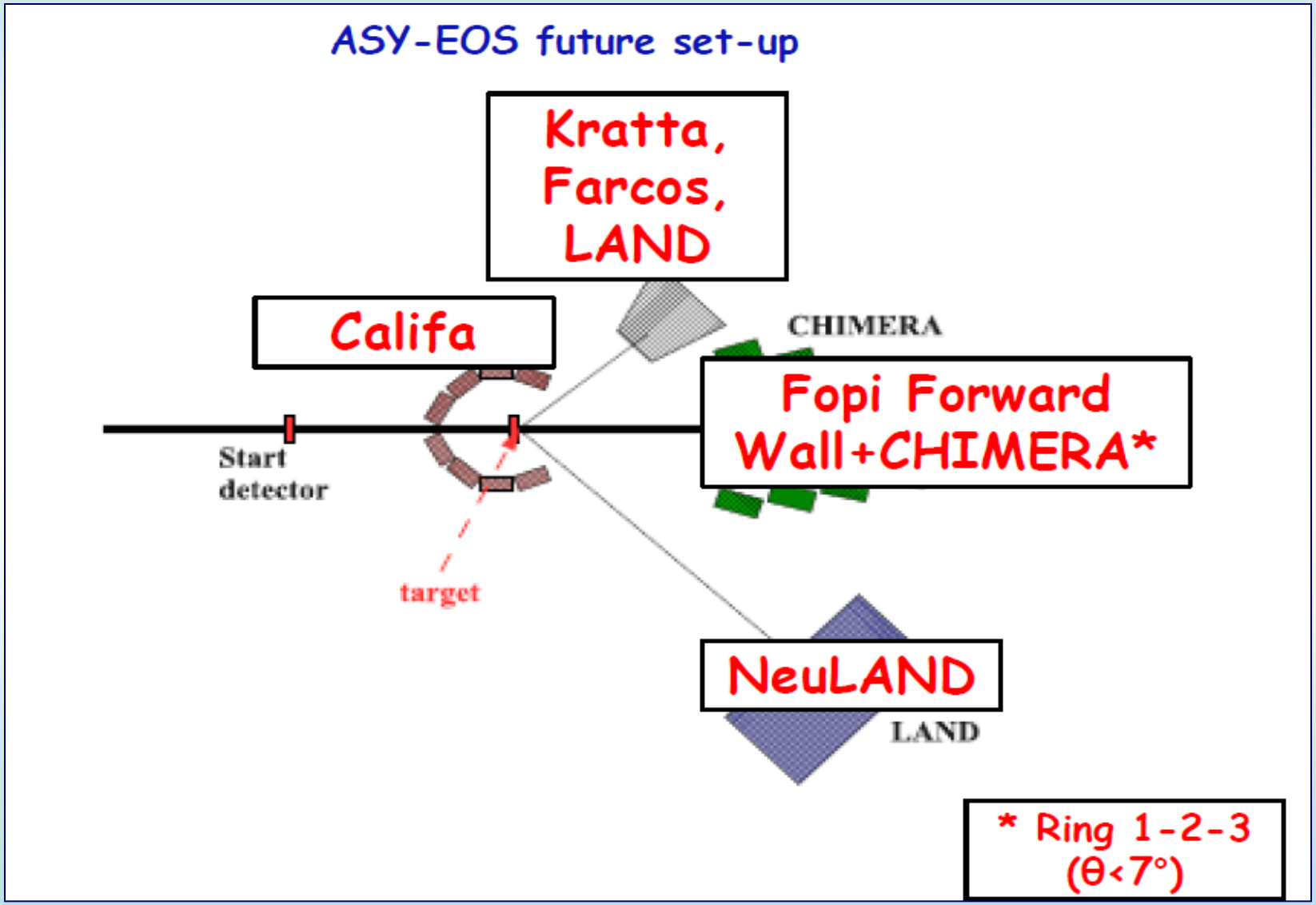
- 48Ca + 48Ca, 48Ti + 48Ti E/A=40 – 80MeV
- 96Zr + 96Zr, 96Ru + 96Ru E/A=25 - 60 MeV

Reaction systems at LNS

N/Z-scan and A-scan:

- 40Ca + 40Ca, 48Ca + 48Ca
- 58Ni + 58NiCa, 64Ni + 64Ni E/A=25 - 40 MeV
- 112Sn+112Sn, 124Sn+124Sn
- 58Ni + 40Ca, 64Ni + 48Ca (coalescence vs femtoscopy)
- FRIBS beams: direct reactions and invariant mass spectroscopy

Al GSI attività possibile con fasci stabili e NEULAND
Per nuovi fasci radioattivi si dovrà attendere il 2019 con R3B



SPES@LNL experiment 2018-19 or after CHIMERA+FARCOS ?

Coupling with other apparata?

Second SPES International Workshop

SPES exotic beams for science

26-28 May 2014

INFN Laboratori Nazionali di Legnaro

SPES Letter Of Intent

Isospin dependence of compound nucleus formation and decay

E. DeFilippo INFN - Catania

J. D. Frankland GANIL - Caen

S. Pirrone INFN - Catania

G. Politi Università and INFN - Catania

P. Russotto INFN - Catania

Conclusion & Perspective

Recent selected results were presented in the framework of *Dynamics reaction and Isospin Physycs* obtained from experiments with stable beams at intermediate and low energies and by using the 4π CHIMERA detector @INFN-LNS.

In preparation experiment with *detectors at high specialization*, (CHIMERA + FARCOS correlator) by using stable beams and *Fragmentation beams* @LNS inside International Collaborations.

In the meantime, CHIMERA group is working to plan experiments also in collaboration with other laboratories (LNL-GANIL-GSI) in an appropriate time schedule.

The CHIMERA group strongly support

the "high intensity beam" project of this Laboratory

NEWCHIM EXPERIMENT

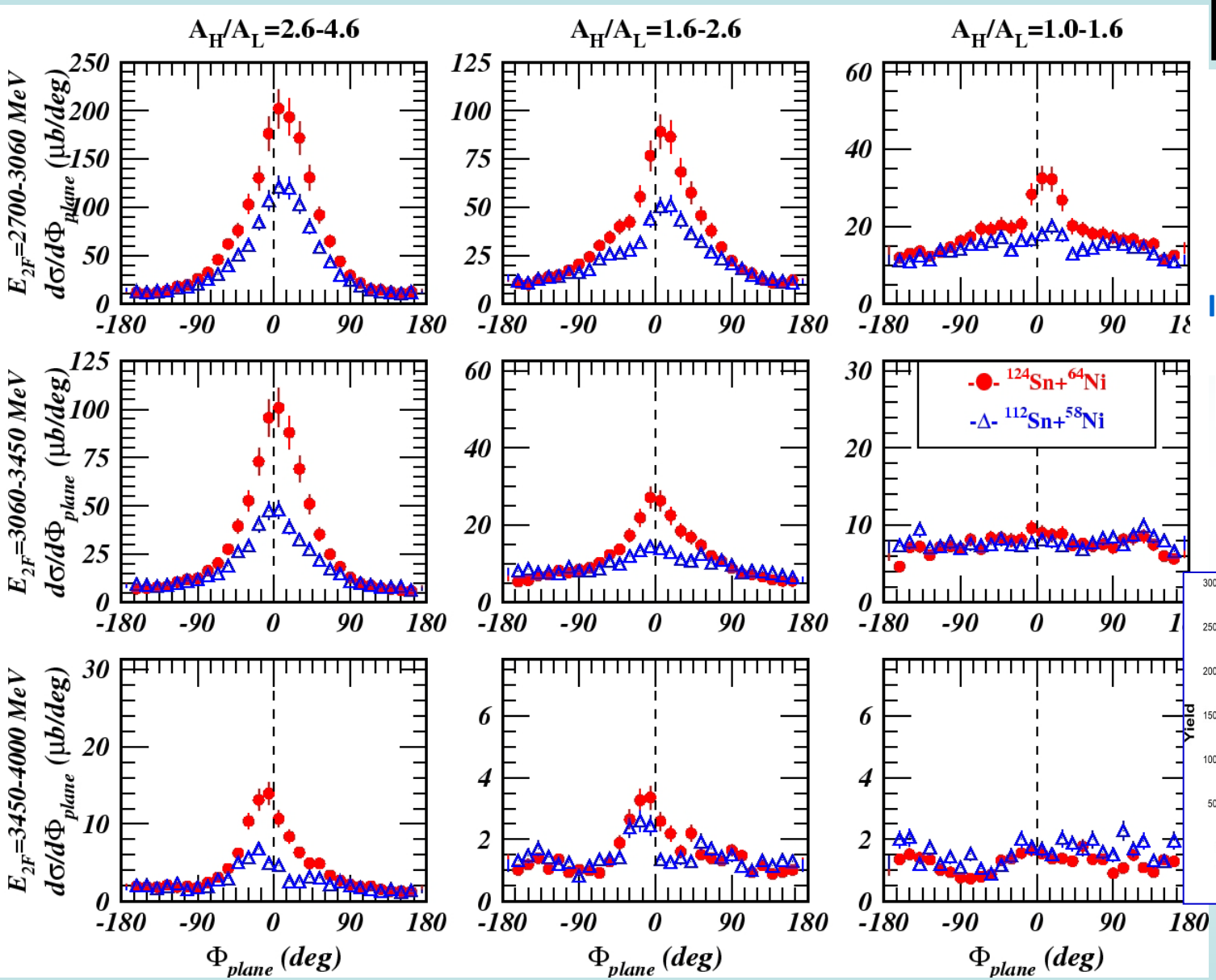
L.Acosta[1,8], L.Auditore[4], G.Cardella[1], A.Castoldi[5], E.De Filippo[1], A.D'Onofrio[6], L.Francalanza[2,3], E.Geraci[1,3], B.Gnoffo[1] , C.Guazzoni[5], M.La Commara[6], E.La Guidara[1,8], G.Lanzalone[2,7], R.La Torre[6], I.Lombardo[6], C.Maiolino[2], S.Norella[4], A.Pagano[1], E.V.Pagano[2,3], M.Papa[1], T.Parsani[5], S.Pirrone[1], G.Politi[1,3], F.Previdi[5], L.Quattrocchi[4], F.Rizzo[2,3], E.Rosato[6], A.Ruggeri[4], P.Russotto[1], G.Spadaccini[6], M.L.Sperduto[1,3], A.Trifirò[4], M.Trimarchì[4], G.Verde[1], M.Vigilante[6].

1 INFN Sezione di Catania
2 INFN LNS
3 Dipartimento di fisica e astronomia Università di Catania
4 INFN_gr. Coll. Messina and Dipartimento di fisica Università Messina
5 INFN- Sezione di Milano and Politecnico di Milano
6 INFN-Sezione di Napoli and Dip. di fisica Università di Napoli Federico II
7 Università Kore Enna
8 Dep. De Fisica Aplicada Universidad de Huelva, Spain

Fission-like fragments angular cross sections (I)

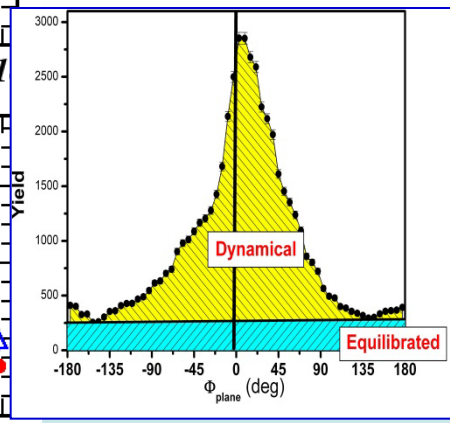
● $^{124}Sn+^{64}Ni$

△ $^{112}Sn+^{58}Ni$



Forward peaked Dynamical Fission cross section is greater in the neutron rich system →

(a factor ~2) !



Φ_{plane}=fission angle in the reaction plane

P. Russotto et al., PRC 81 064605 (2010)

ISODEC - Scientific Program

" Isospin dependence (N/Z) of the formation and emission mechanism of complex fragments (IMF, Z≥3) from CN to get information on:

level density, (thermal properties, E*, $m_{effective}$)
fission barrier, (Symmetry, congruence and Wigner E terms)
viscosity, (coupling collective – intrinsic modes, Fermi level)"

Stable Beams
-E475S@GANIL , with INDRA (2007)
-ISODEC@LNS , with CHIMERA (2010)

Next Exotic Beams
-Loi for SPES@LNL
-Next proposal for SPIRAL2@GANIL


ITA-FRA Collaboration
Lea - Colliga

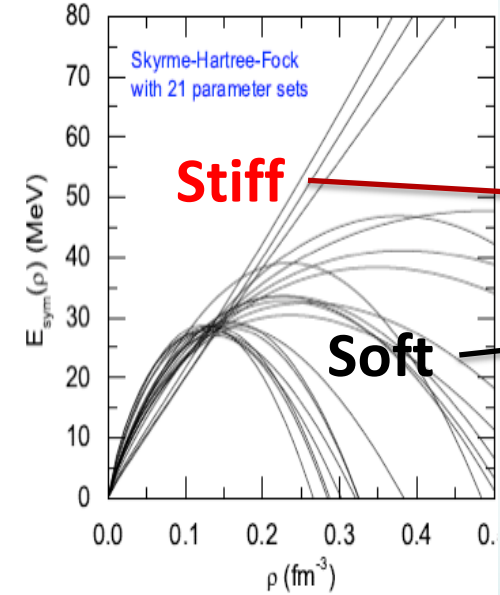
S. P. et al., Proc. of FUSION11, EPJ Web of Conf. 17, 16010 (2011)
G. Politi et al., Proc. of CNR11 EPJ Web of Conf. 21, 02003 (2012)
M.La Commara et al., Proc. of IWM2011, EPJ Web of Conf. 11, 00022 (2012)
S. P. et al.,Proc of ICRTNP2012, AIP Conf. Proc. 1524, 7-10 (2013)
M.La Commara et al., Proc. Of INPC2013, to be published (2014)
S.P. et al, Proc of Echic2013, IOP Conf series, to be published (2014)

Symmetry energy and correlation functions

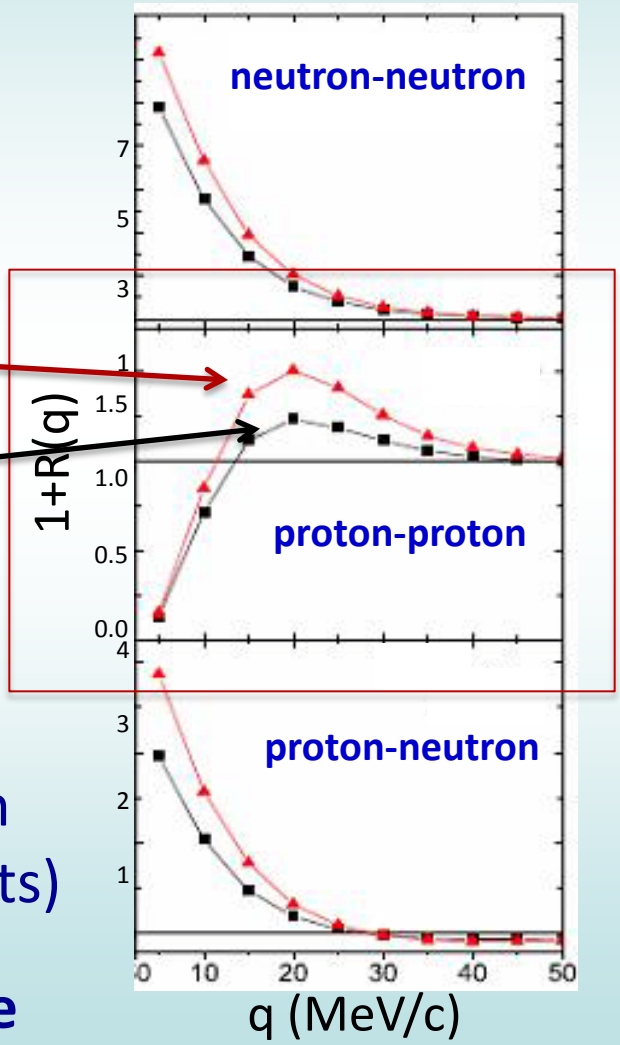
IBUU simulations

$^{52}Ca+^{48}Ca$ E/A=80 MeV Central collisions

Lie-Wen Chen et al., PRL (2003), PRC(2005)



Correlation functions



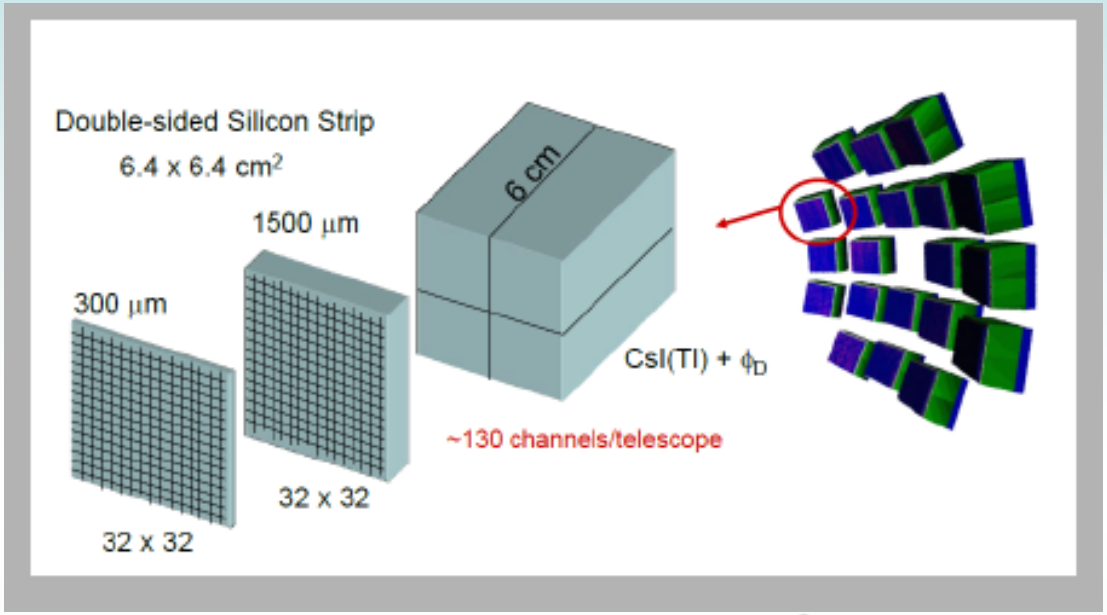
- Proton-proton correlation sensitive to Esym
- nn and np also… but difficult… (later projects)

→ …meanwhile use: **t-^{3}He, t-t and ^{3}He-^{3}He**

By G.Verde

FARCOS project

Femptoscope ARray for COrrelation and Spectroscopy



High energy and angular resolution (Δθ<1°)

Low thresholds

Pulse-shape on t ments

High counting ra

Large Dynamic r

Flexibility, Modularity, Trasportability

Coupling to 4π detectors or spectrometers

Integrated Electronics (GET)

The project is going to be realized with 20 telescopes

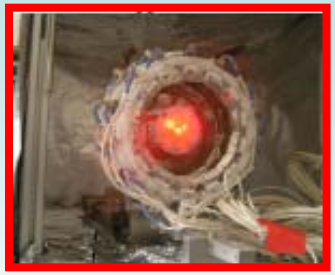
Supported by INFN- CNS3

NEWCHIM exp 2015-2019

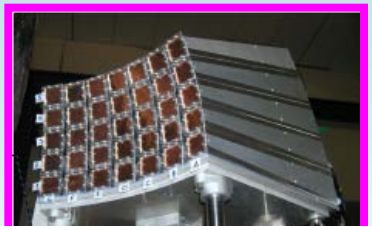
1M€ in 5 years

ASY-EOS S394 experiment @ GSI Darmstadt (May 2011)

Au+Au, ^{96}Zr+^{96}Zr , ^{96}Ru+^{96}Ru @ 400 AMev

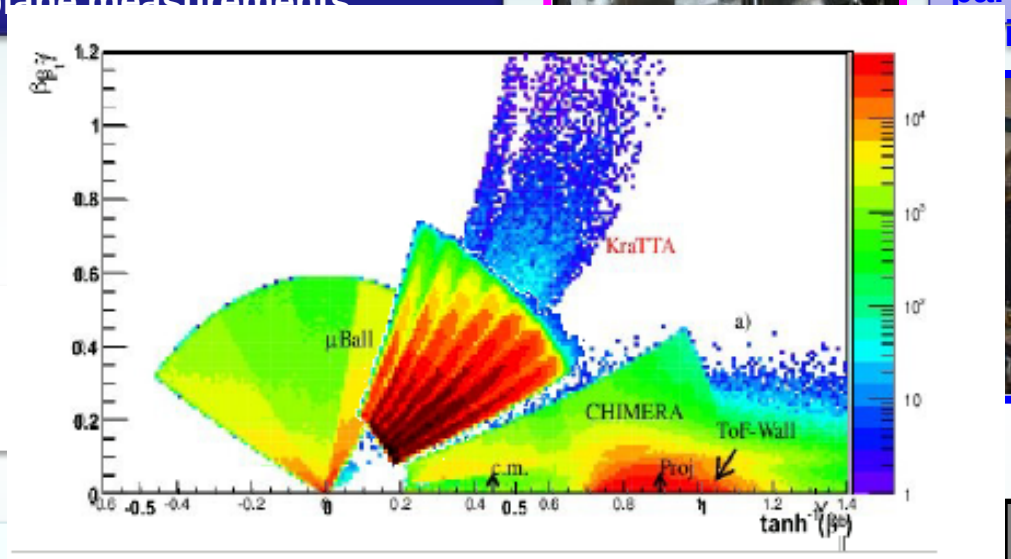


µBall: 4 rings 50 CsI(Tl), Θ>60°. Discriminate target vs. reactions with air. Multiplicity and reaction plane measurements

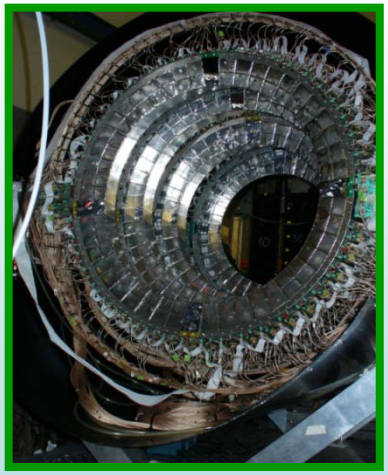


KraTTA: 35 (5x7) triple telescopes (Si-CsI-CsI) placed at 21°<Θ<60° with digital readout . Light particles and IMFs emitted at midrapidity

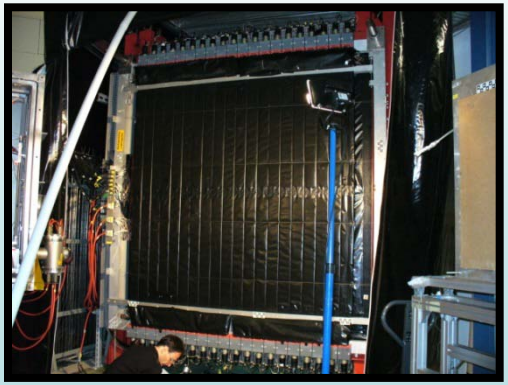
Shadow bar: evaluation of background neutrons in LAND



TOFWALL: 96 plastic bars; ToF, ΔE, X-Y position. Trigger, impact parameter and reaction plane determination



rings, high granularity CsI(Tl), 352 detectors 7°<θ<20° + 16x2 pads silicon detectors. Light charged particle identification by PSD. Multiplicity, Z, A, Energy: impact parameter and reaction plane determination



LAND: Large Area Neutron Detector . Plastic scintillators sandwiched with Fe 2x2x1 m³ plus plastic veto wall. New Taquila front-end electronics. Neutrons and Hydrogen detection. Flow measurements

Last results

Au+Au @ 400 AMeV
b<7.5 fm

Neutrons:
(Au+Au)-(Au+Au with SB)+
-(Au+EF)+(Au+EF with SB)

Charged Particles:
(Au+Au)-(Au+EF)