euroib'12

Influence of neutron enrichment on compound system formation and decay in ^{78}Kr + ^{40}Ca and ^{86}Kr + ^{48}Ca @ 10 AMeV

INFN

S.Pirrone - INFN Sezione di Catania
for EXOCHIM-ISODEC Collaboration

- **Physics Case and Context**

- **ISODEC Experiment**
  experimental method and first results

- **Conclusions and Perspectives**

Physics Case and Context

- Heavy ion collisions with stable and exotic beams
- Low energy regime E/A ≤ 15 MeV/A
- Fusion reaction mechanism

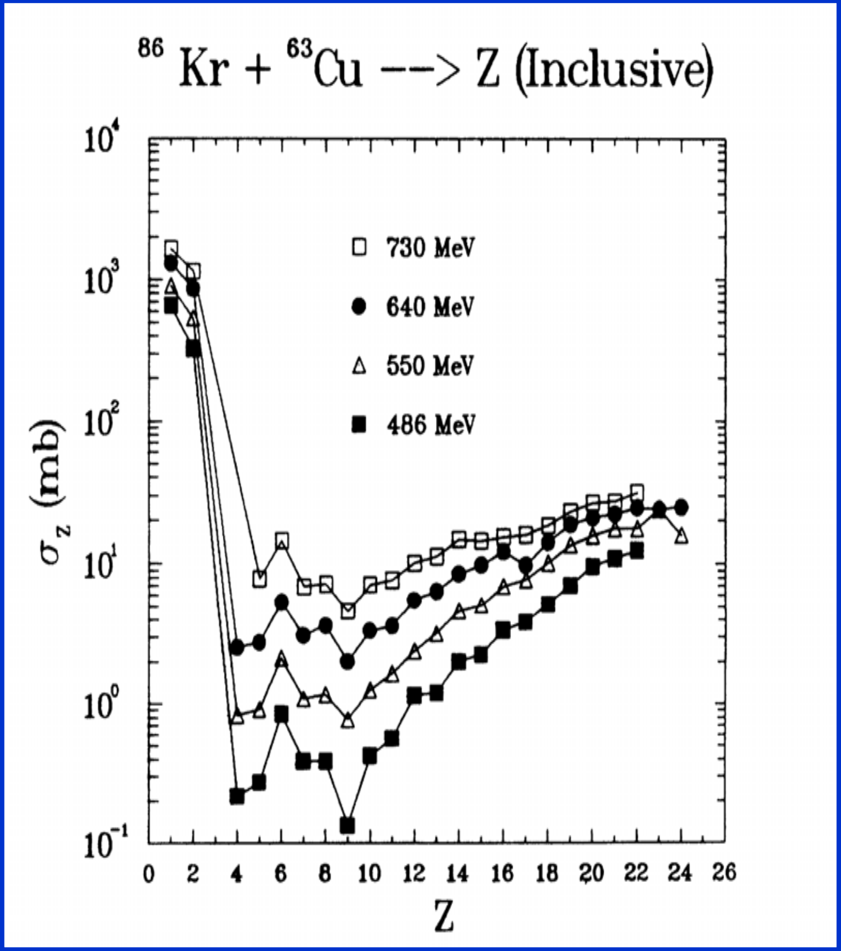
- For A=80-140, the reaction products are

LCP, FF, ER, and IMF ($3 \leq Z \leq 12$)

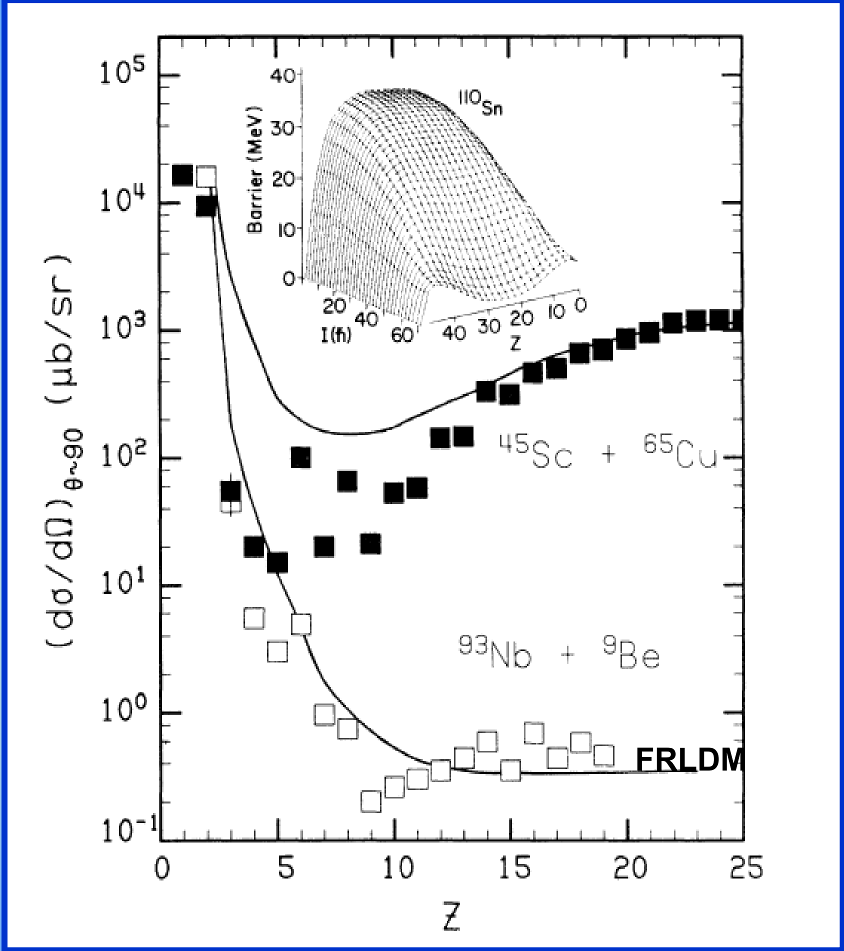
Decay modes and emission process are complex and strongly influenced by E*, angular momentum, asymmetry, N/Z composition, nuclear structure

Physics Case and Context

J.Boger et al, PRC49 (1994)



Sobotka et al, PRC36 (1987)



System	E_{lab} (MeV)	CN	E^* (MeV)	l_{crit}[a] (ħ)
^{93}Nb + ^{9}Be	782	^{102}Rh	78	34
^{45}Sc + ^{65}Cu	200	^{110}Sn	94	70

Even-Odd staggering effect in the IMF

Physics Case and Context

•The n-enrichment influence on the emission mechanism of complex fragments ($Z \geq 3$) and on the decay modes of compound system to extract information on:

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

Crucial for the modelizations of the nuclear collisions and of the de-excitation process

ISODEC - Scientific Program
ITA-FRA Collaboration

Spokes: J.P. Wieleczko GANIL, S. Pirrone INFN-CT
M. La Commara Univ. & INFN-Na, G. Politi Univ. & INFN-CT

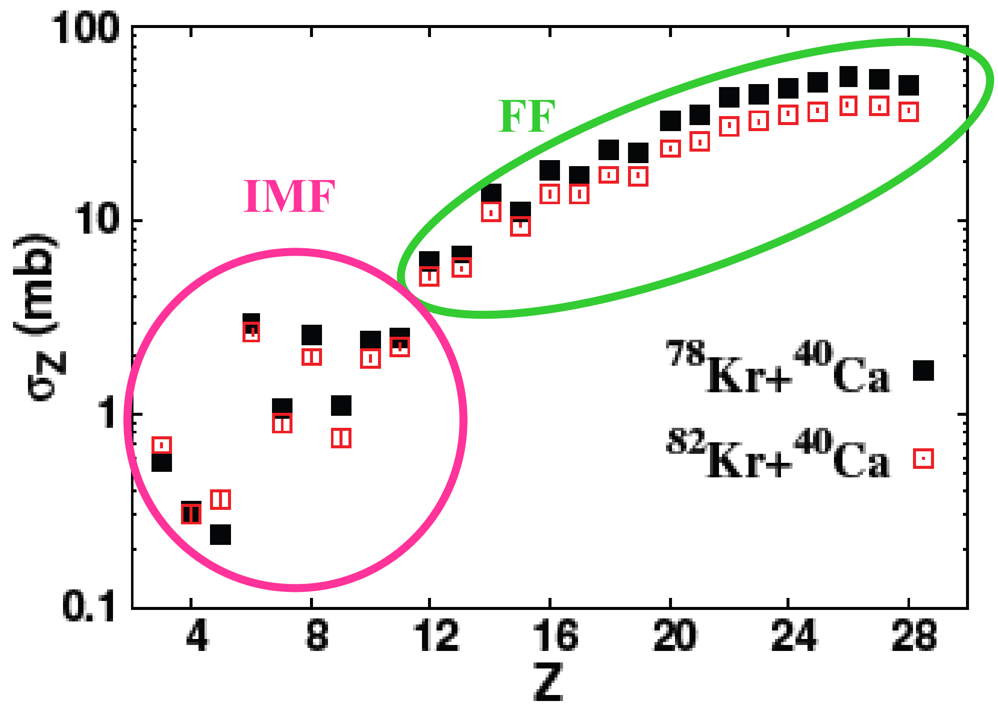
Stable Beams
-E475S@GANIL , with INDRA (2007)
-ISODEC@LNS , with CHIMERA (2010)

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

LEA COLLIGA agreement (GANIL & INFN LNL-LNS)
J.P. Wieleczko et al., LOI for Lea GANIL-LNL 2007
E.Bonnet , Lea Colliga Meeting, LNS 2008
S.P., Lea Colliga Meeting, Paris 2009
S.P., Lea colliga Meeting & SPES2010, LNL 2010
G.Politi, Lea Colliga Meeting, Orsay 2011

E475S INDRA @GANIL E = 5.5 AMeV

^{78,82}Kr + ^{40}Ca → ^{118,122}Ba* (~ 100 MeV)



3≤ θ ≤ 44° IC-Si-CsI
forward part

- Energy, angular and charge distribution of RP
- Cross section decay mode

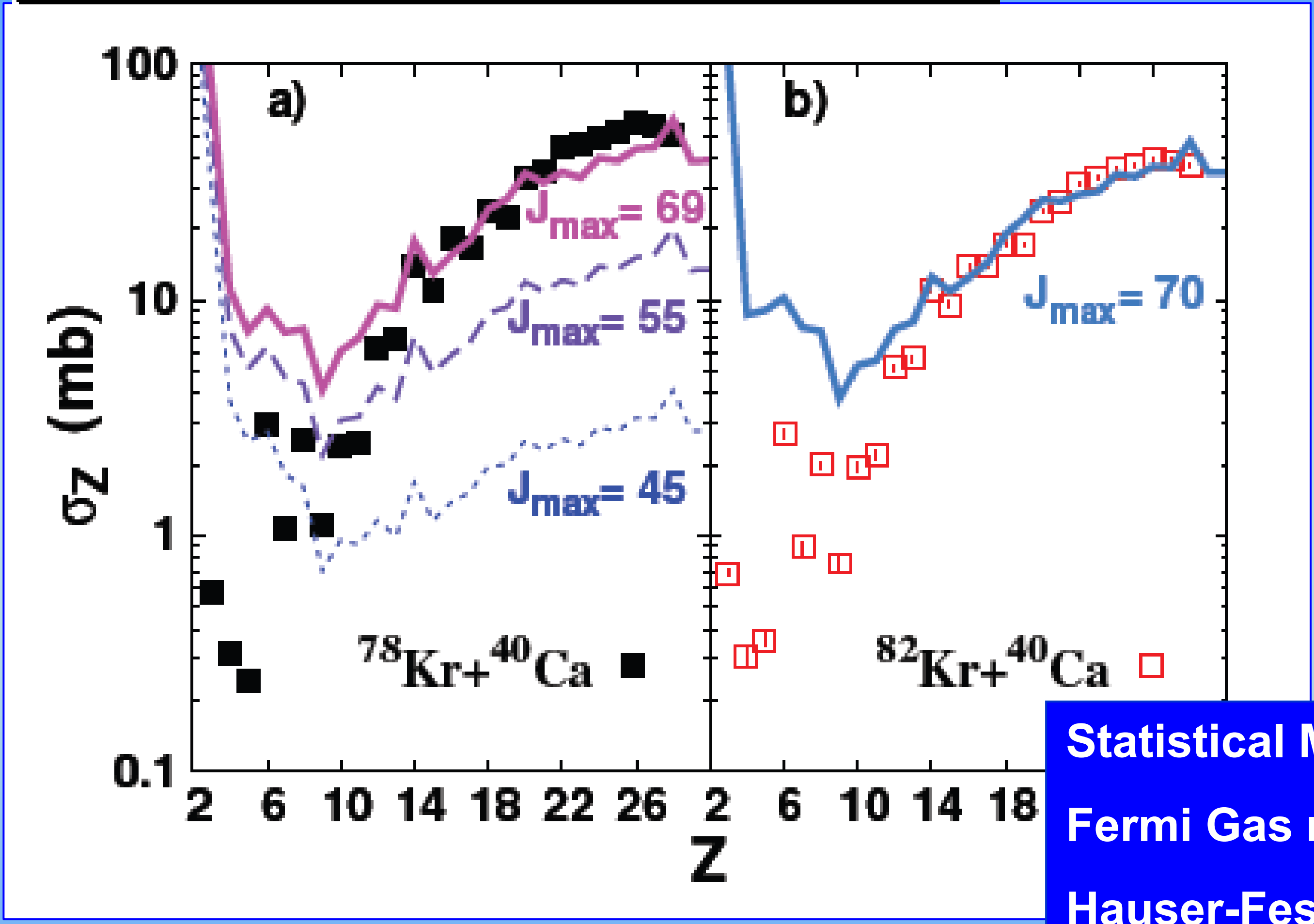
CN neutron rich (o)

- 30% less fission (Z ≥ 14)
- Less even-odd staggering of IMF (6 ≤ Z ≤ 12)

G. Ademard et al. PRC 83 (2011) 054619

Comparison with transition state model
GEMINI code

- *R.J.Charity et al, Nucl.Phys.A483 (1988)*
- *D.Mancusi et al, PhysRev C 82 (2010)*



G. Ademard et al.
PRC 83 (2011) 054619

Statistical Model

Fermi Gas model (level density)

Hauser-Feschbach for LCP's

Trantion state model for IMF Z>2

FRLDM barrier from Sierk

Structure effect NOT considered

Dynamical model

DNS in competition to CN

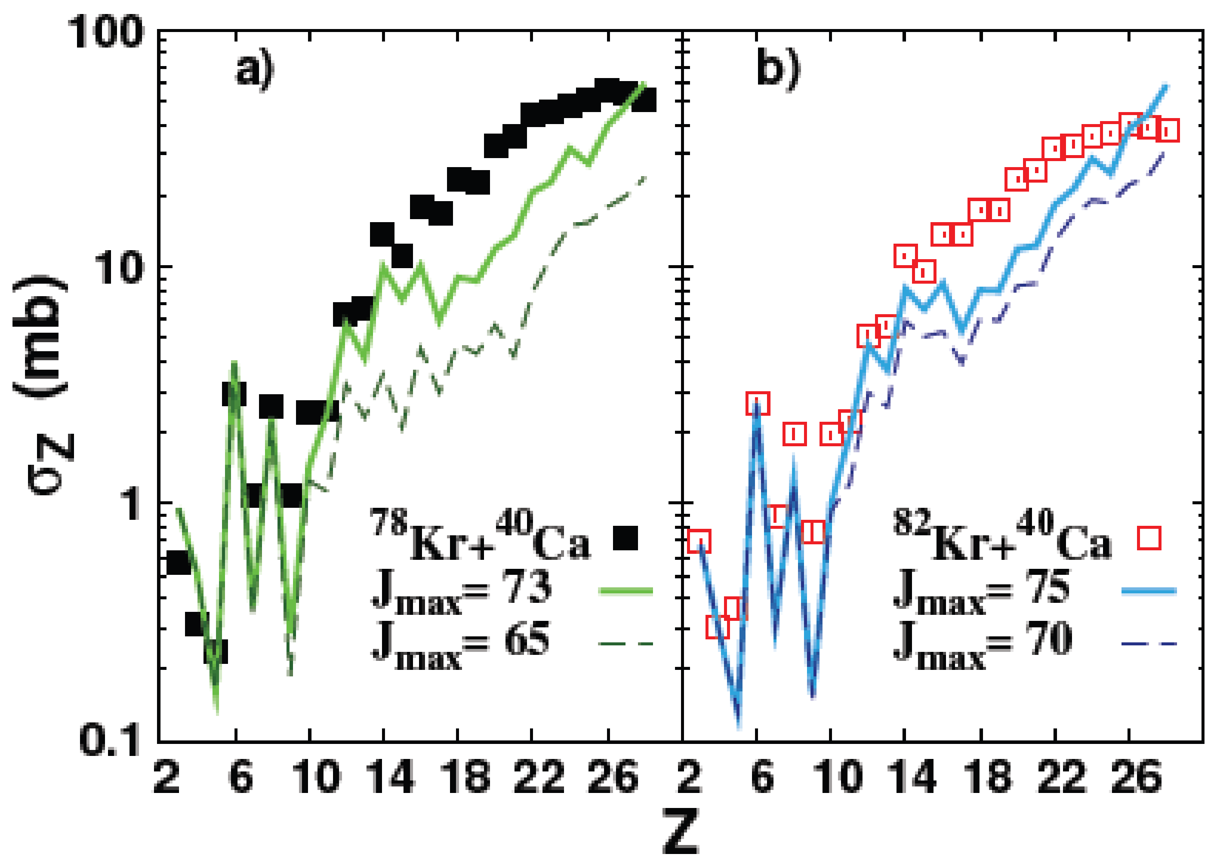
Quasi-fission phenomena

N/Z dependence not considered

DSN (di-nuclear system) -model

Sh.A.Kalandarov

et al. PRC82 (2010)



G. Ademard et al.
PRC 83 (2011) 054619

ISODEC CHIMERA@LNS E = 10 AMeV

$^{78,86}Kr + ^{40,48}Ca \longrightarrow ^{118,134}Ba^*$

- **Higher energy**

  Influence on the amplitude of the staggering, on the temperature of the emitting system.

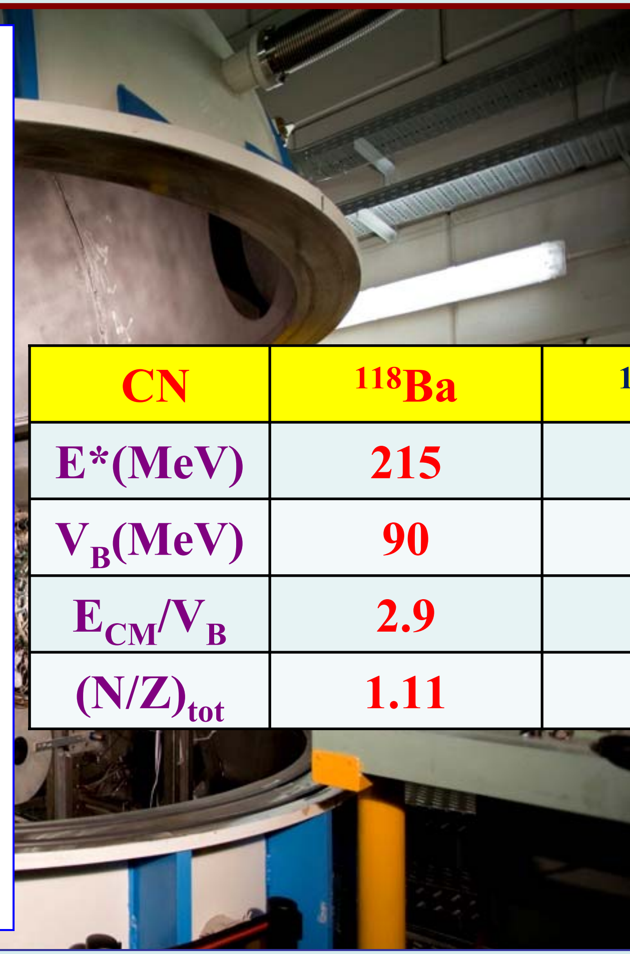
- **Isotopic separation of IMF**

  to investigate the staggering effects looking at the isotopic distribution of IMF.

- **Exploration of a larger domain in N/Z of the system (stable beam!)**

  to study the dependence from the N/Z on the mechanism of complex fragment emission from CN

- **Exclusive measurements in a large angular range**



CN	^{118}Ba	^{134}Ba
E*(MeV)	215	270
V_B(MeV)	90	87
E_{CM}/V_B	2.9	3.5
$(N/Z)_{tot}$	1.11	1.39

S.P. et al., EPJ Web of Conf. 17,16010 (2011)
S.P. et al, Web Proc. of the ARIS11, Louven, 2011
G.Politi et al, EPJ Web of Conf. 21 (2012) 02003
M.La Commara et al., Proc.of the IWM2011, GANIL,Caen, France (in press) 2012

^{118,134}Ba * (E*=250 MeV)

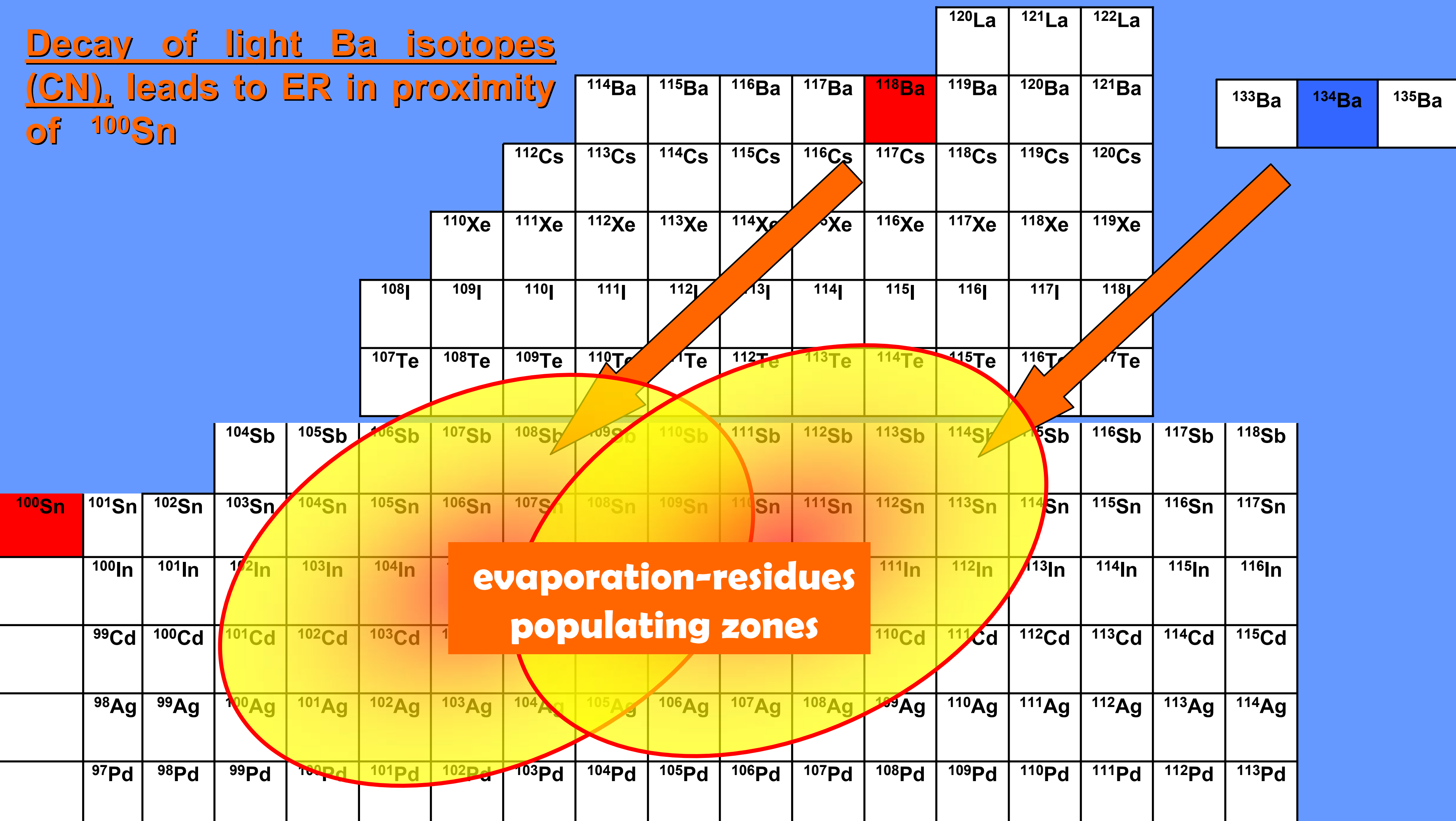
^{58}Ni+^{50}Cr and ^{58}Ni+^{58}Ni @ 5 A·MeV

N~Z Wigner and Congruence energy

J. Gómez del Campo et al., PRC 57 (1998) R457
MLC et al., NPA 669 (2000) 43

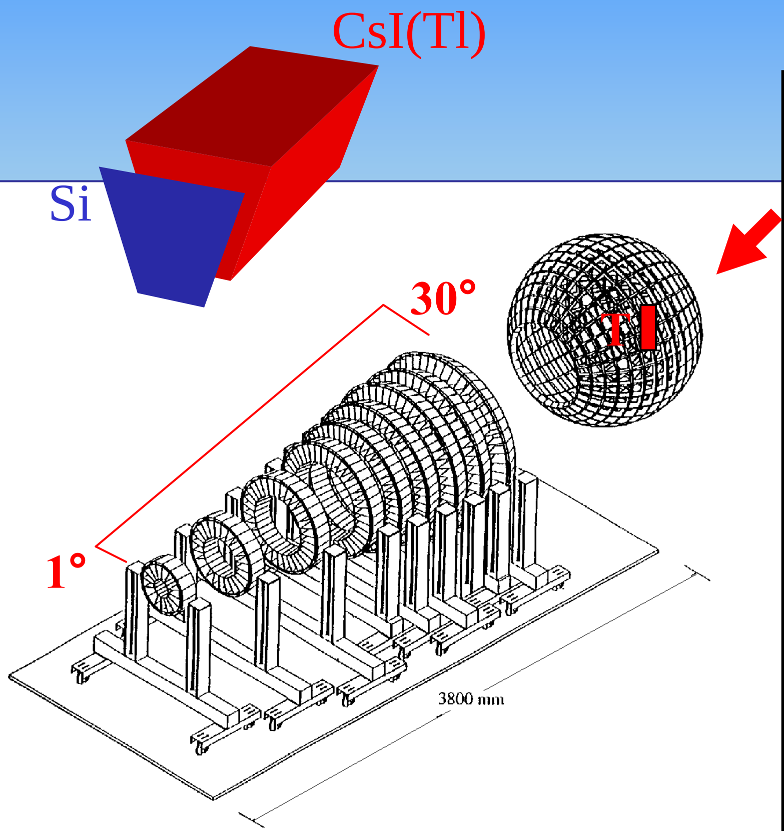
N>Z Symmetry Energy

Decay of light Ba isotopes (CN), leads to ER in proximity of ^{100}Sn



CHIMERA

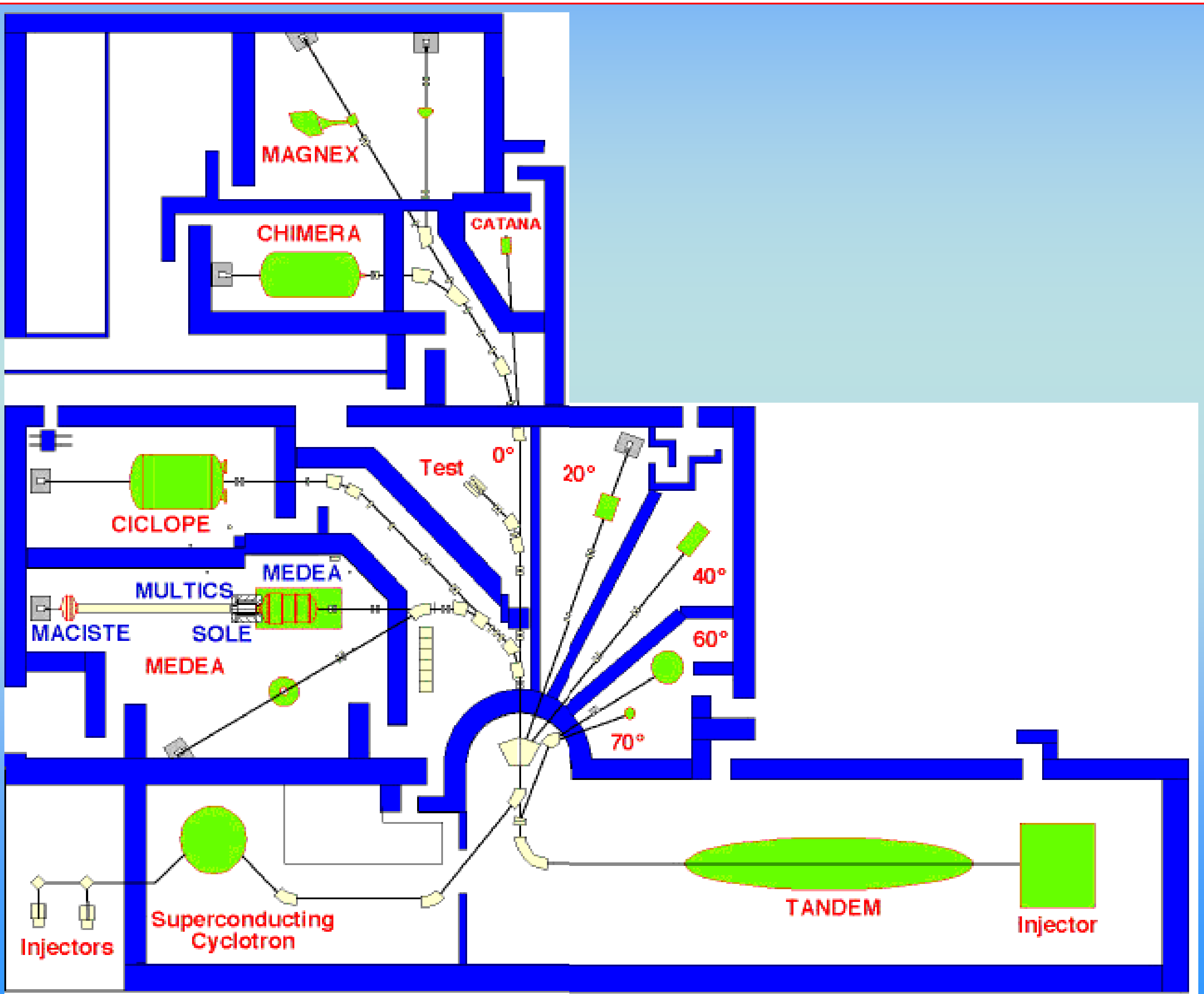
Charge Heavy Ion Mass and Energy Resolving Array



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

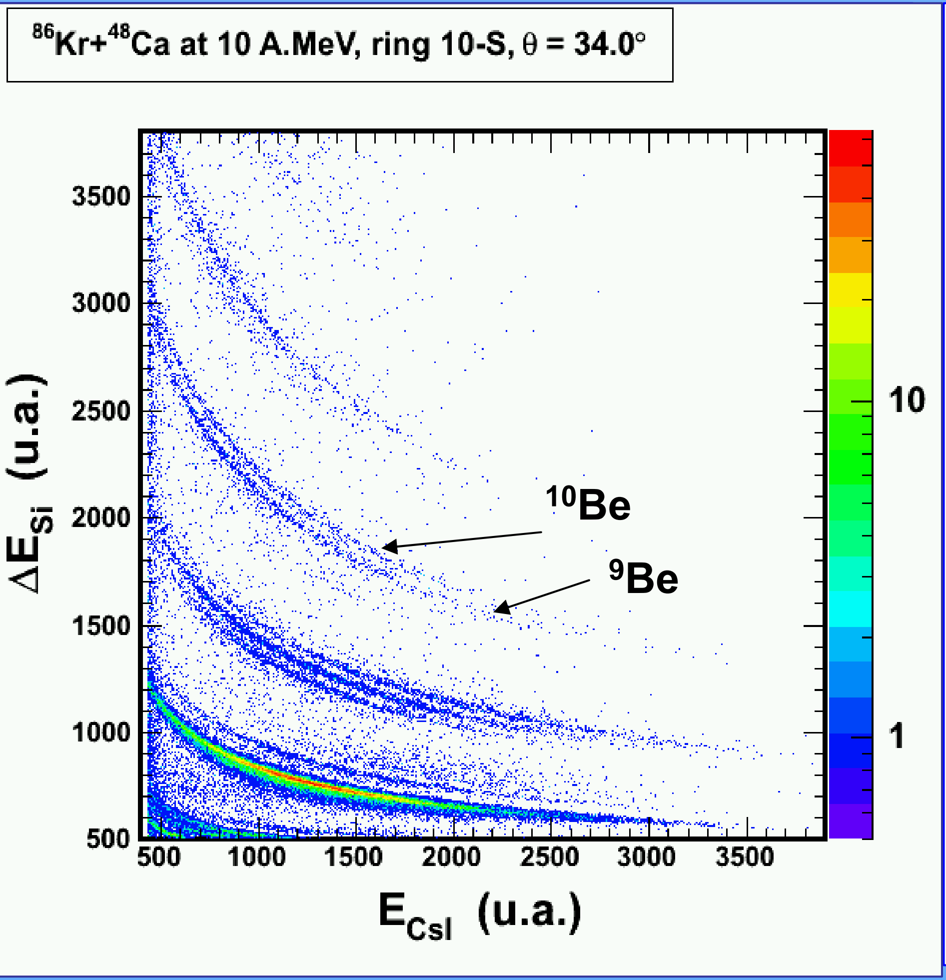
Experiment performed at INFN-LNS in Catania – ITALY

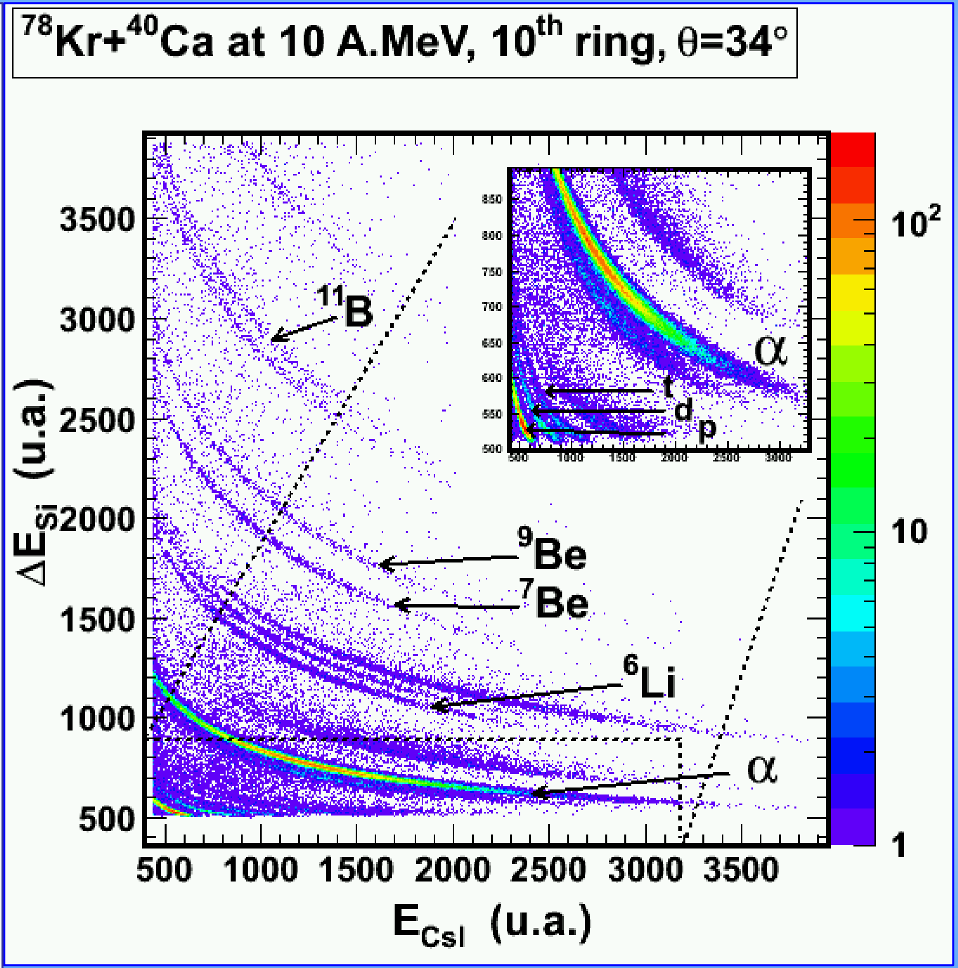
Beams of ^{78,86}Kr delivered by Superconducting Cyclotron (i ~ 1 nA) impinging on ^{40,48}Ca targets (1 mg/cm^2) realized by INFN-LNL target service



IMF Isotopic Identification

ΔE-E , Si-CsI(Tl)

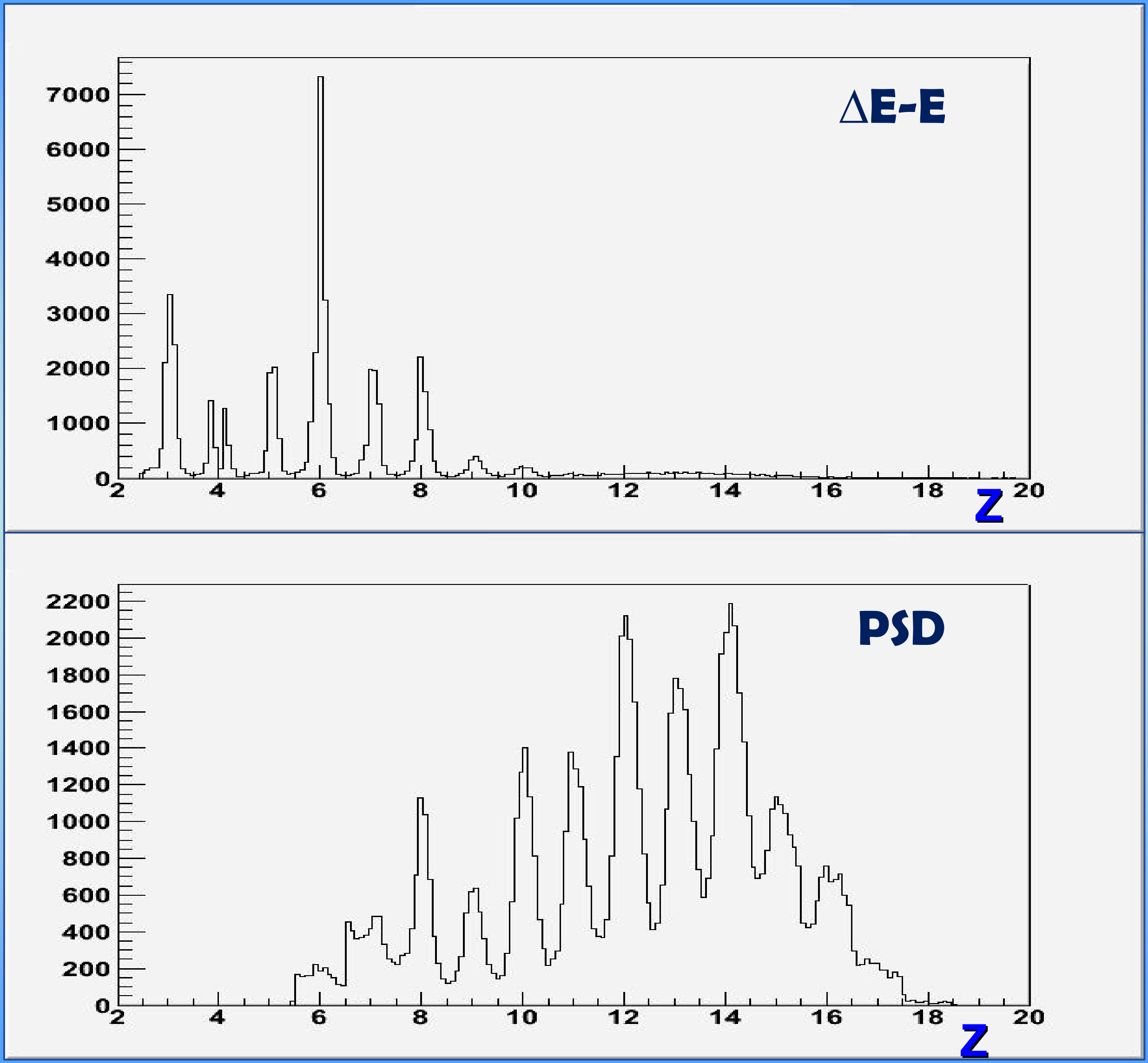




n-rich

n-poor

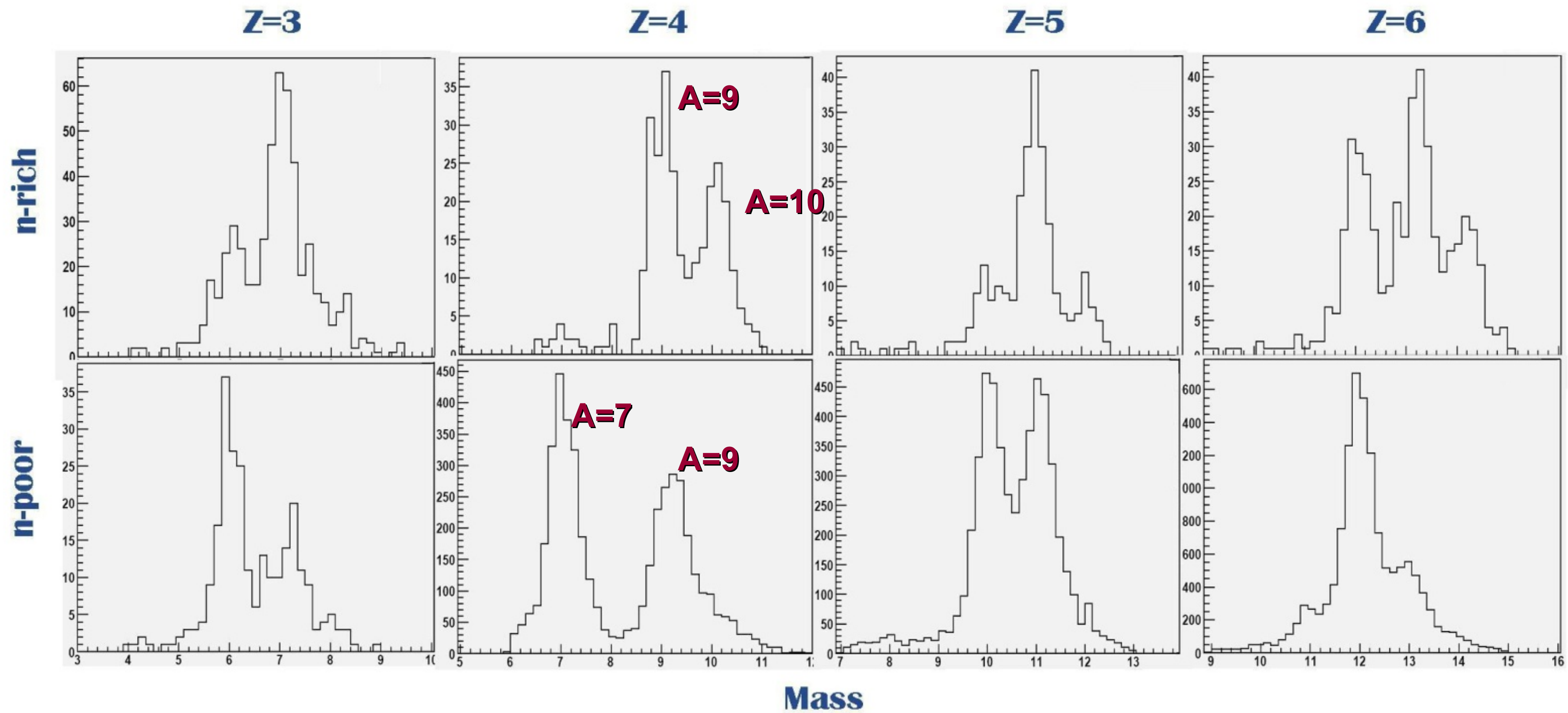
Charge Identification



$^{78}Kr + ^{40}Ca$, 10 AMeV, ϑ=12°

IMF Mass Identification

Li **Be** **B** **C**



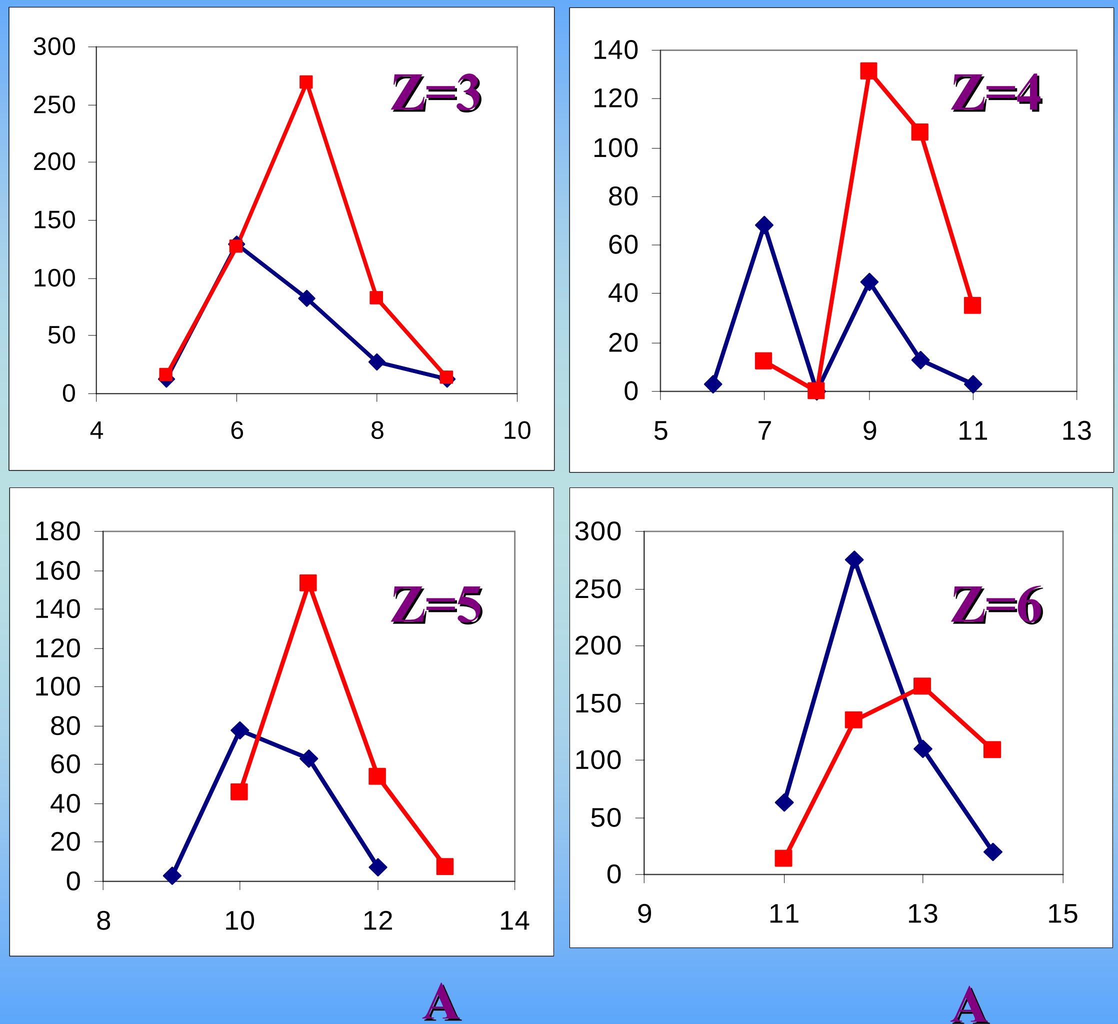
n-rich	$^{86}Kr + {}^{48}Ca$	10 AMeV, ϑ=12°
n-poor	$^{78}Kr + {}^{40}Ca$	

IMF Mass Distribution

n-poor

n-rich

θ= 10°-13°

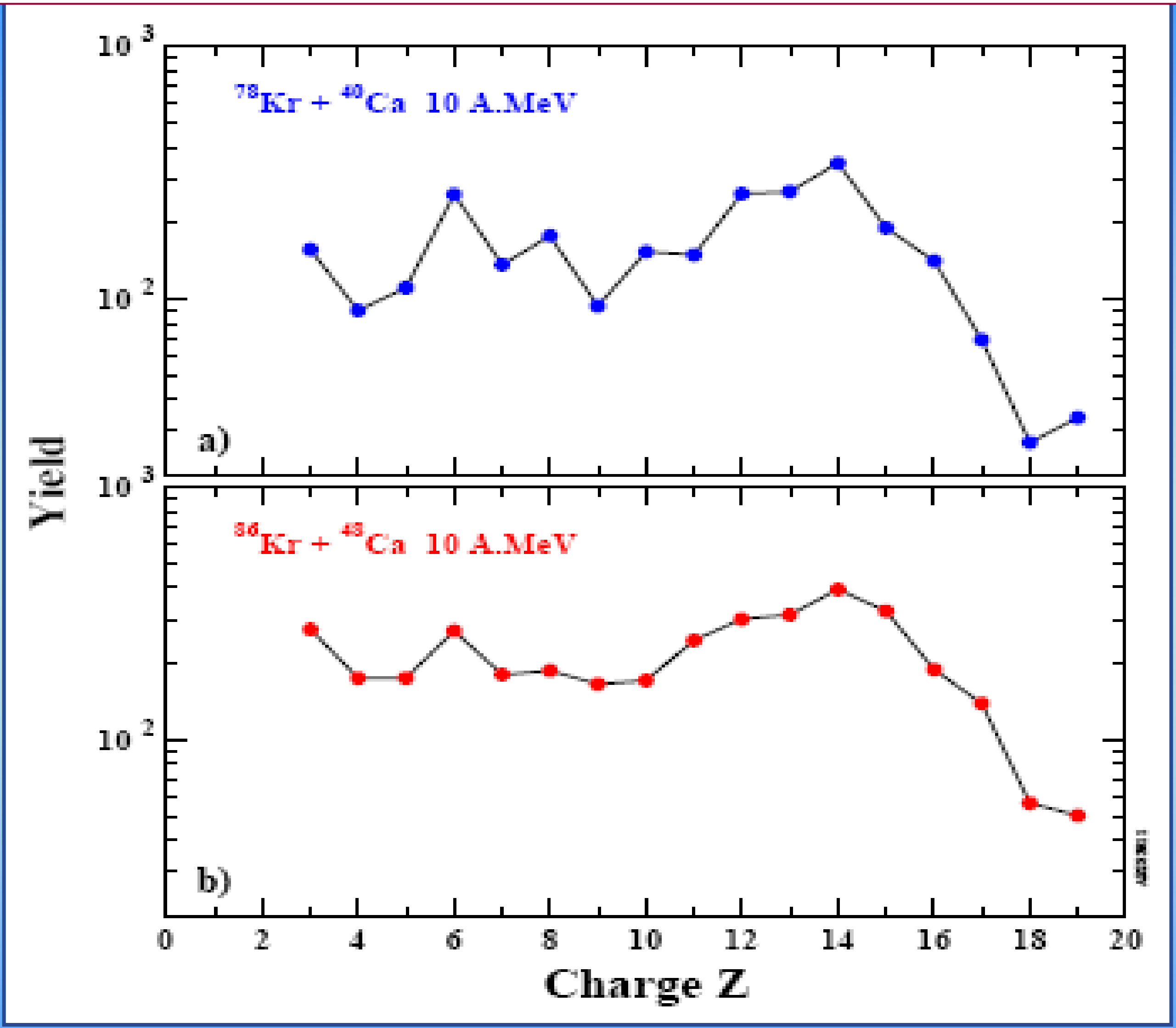


Charge Distribution

ϑ=12°

n-poor

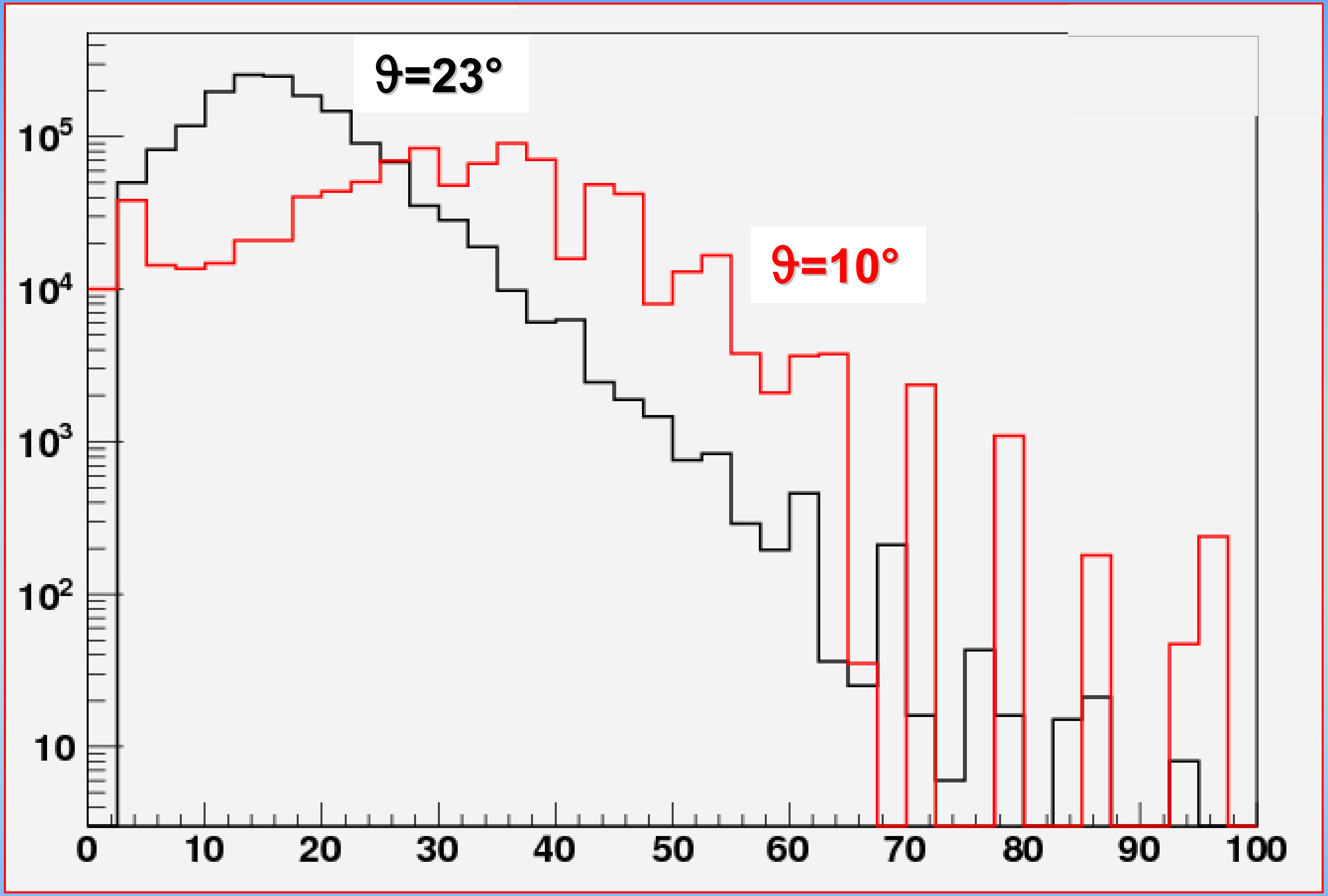
n-rich



Staggering in IMF Z-distribution decreases for n-rich systems

- influence of **nuclear pairing forces** on the neutron and proton binding energy
- **structure effects** (*M. D'Agostino et al., NPA 861 (2011) 47*)

α Energy Spectra



Ecm (MeV)

n-poor sistem

Preliminary Results

IMF Energy Spectra (CM)

$\vartheta=12°$

Variation in yield, width, center position and asymmetry of the IMF Energy Spectra are connected to:

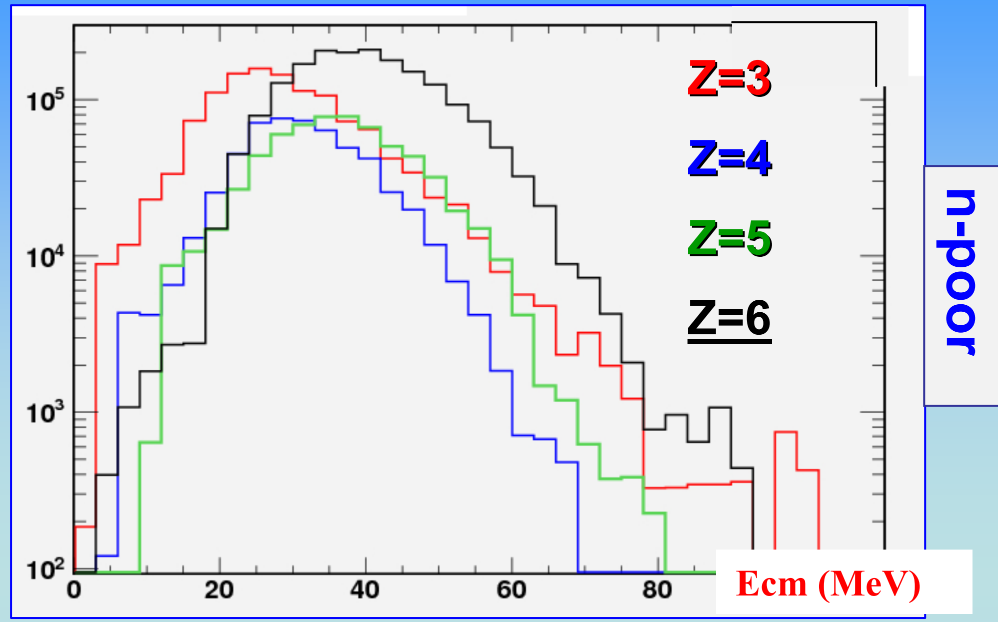
-different sources decay

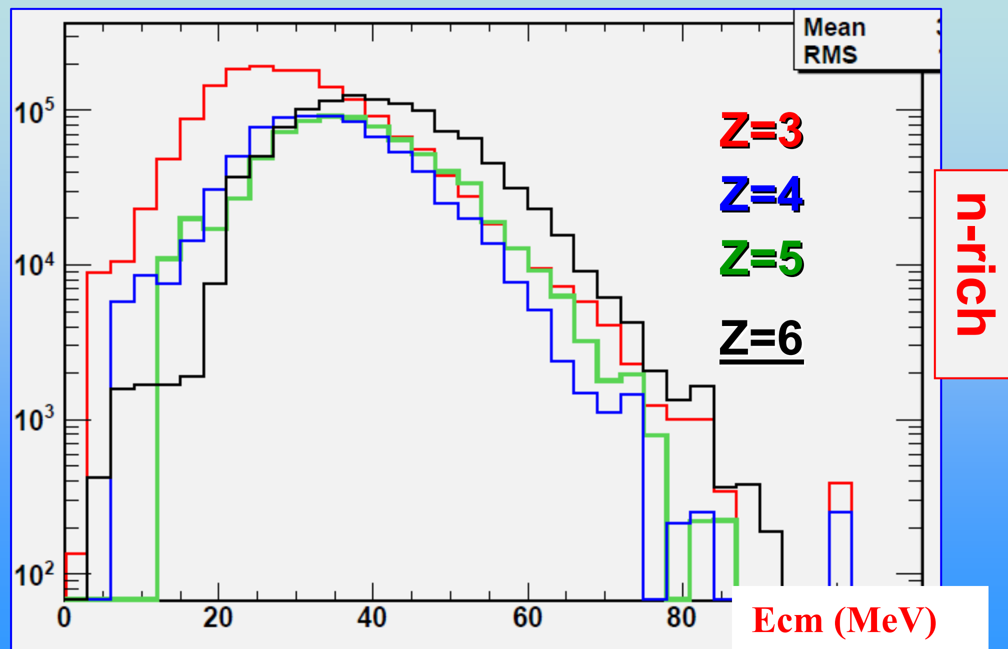
-presence of different masses for Z

-influence of nuclear pairing forces

-influence of symmetry energy term

To be studied also by looking at the isotopic composition



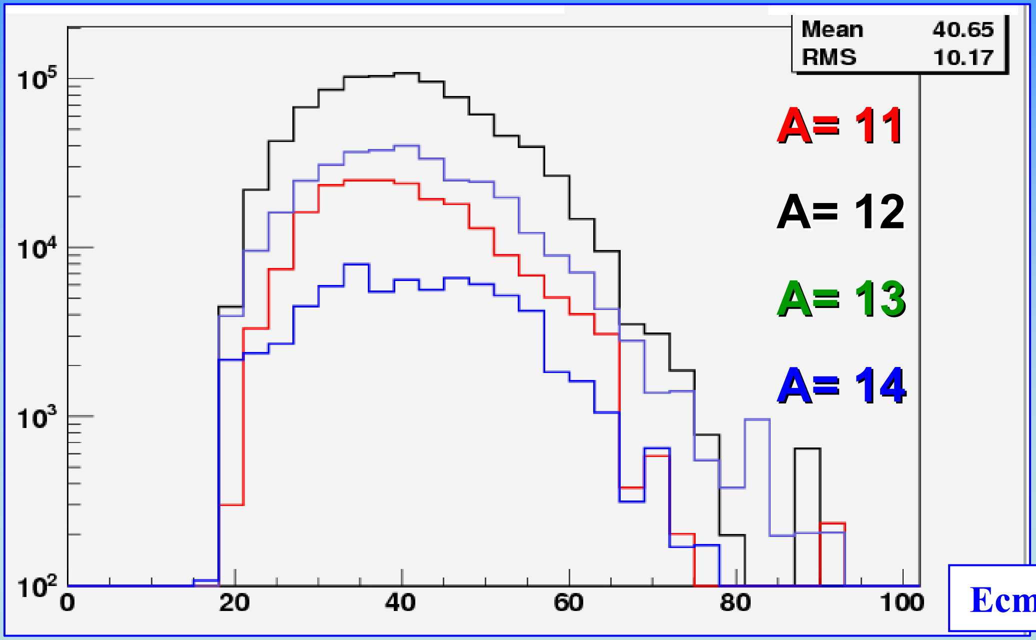


Preliminary Results

Carbon Isotopes Energy Spectra (CM)

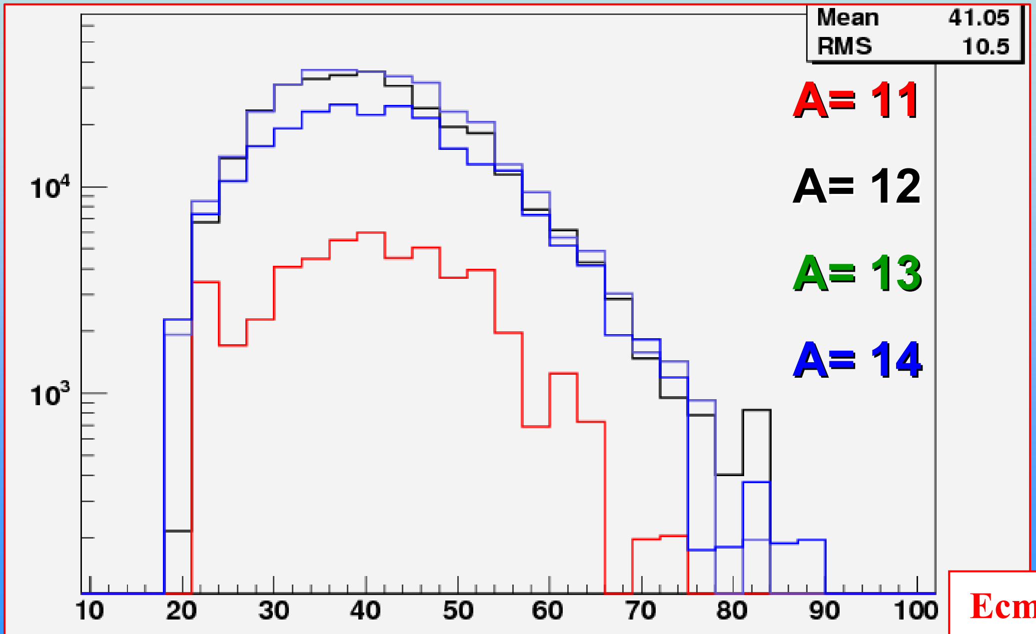
ϑ=12°

n-poor



Ecm (MeV)

n-rich



Ecm (MeV)

Preliminary Results

Conclusions

• Results of the Inclusive measurements on the n-rich n-poor systems formed in

$$^{78,86}Kr + ^{40,48}Ca \longrightarrow ^{118,134}Ba \qquad E = 10\ AMeV$$

were presented, putting in evidence the influence of the n-enrichment on:

- IMF Charge distribution (staggering effects)
- IMF Mass distribution
- IMF Energy Spectra

•The analisys is in progress on:

- IMF Angular distributions
- ER – FF identification
- Absolute cross sections for different reaction mechanisms
- Exclusive Measurements (coincidence LPC-FF,LPC-ER)
- Comparison with theoretical (statistical and dynamic) models

•Besides….

SPES exotic beams for science

SPES workshop-LNL October 2010

LOI@SPES E =10 AMeV

$^{88-92}$Kr + ^{40,48}Ca ⟶ $^{128, 140}$Ba* (~320 MeV)

Element	A	Z	N	T1/2 s	RIBs at 260KeV	Re-accelerated RIBs	q+	Max E/A	
Kr	81	36	45	7.23E+12	4,44E+05	8,88E+03	15	11,8	FEBIAD source xxx
Kr	85	36	49	3.39E+08	5,93E+08	1,19E+07	15	11,8	
Kr	87	36	51	4.58E+03	2,97E+09	5,94E+07	15	11,6	
Kr	88	36	52	1.02E+04	4,04E+09	8,08E+07	15	11,4	
Kr	89	36	53	1.89E+02	3,99E+09	7,98E+07	15	11,2	
Kr	90	36	54	3.23E+01	4,37E+09	8,74E+07	15	11,2	
Kr	91	36	55	8.57E+00	2,12E+09	4,24E+07	15	11	
Kr	92	36	56	1.84E+00	6,89E+08	1,38E+07	15	11	
Kr	93	36	57	1.29E+00	2,28E+08	4,57E+06	15	10,8	
Kr	94	36	58	2.00E-01	2,49E+07	4,99E+05	15	10,8	
Kr	95	36	59	7.80E-01	1,14E+07	2,29E+05	15	10,6	
Kr	96	36	60	3.20E-01	1,47E+06	2,94E+04	15	10,6	
Kr	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

- **CHIMERA@LNL**
- **Part of CHIMERA coupled to detectors @LNL**
- **Neutron detector**

Perspectives

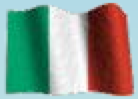
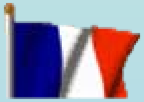
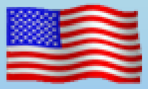
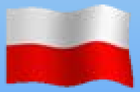
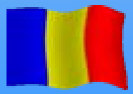
Obtained results by using stable beams @GANIL and @LNS suggest to extend and improve the measurements with exotic beams, to study nuclear fundamental properties in an exotic domain of the nuclear chart.

•CHIMERA@LNL – CHIMERA + other detectors - New Arrays are proposed to realize the experiment.

•SPES@LNL will be a very suitable facility for this program

EXOCHIM – ISODEC collaboration

S.P.[1], G.Politi[1,2], M.LaCommara[3,4], J.P.Wieleczko[5], G.Ademard[5], E.DeFilippo[1], M.Vigilante[3,4], F.Amorini[6], L.Auditore[7,8], C.Beck[9], I.Berceanu[10], E.Bonnet[5], B.Borderie[11], G.Cardella[1], A. Chbihi[5], M.Colonna[6], A.D'Onofrio[4,12], J.D.Frankland[5], E.Geraci[2,1], E.Henry[13], E.LaGuidara[1,14], G.Lanzalone[15,6], P Lautesse[16], D.Lebhertz[5], N.LeNeindre [17], I.Lombardo[4], D.Loria[7,8], K.Mazurek[5], A.Pagano[1], M.Papa[1], E.Piasecki[18], F.Porto[2,6], M.Quinlann[13], F.Rizzo[2,6], E.Rosato[3,4], P.Russotto[2,6], W.U.Schroeder[13], G.Spadaccini[3,4], A.Trifirò[7,8], J.Toke[13], M.Trimarchi[7,8], G.Verde[1]

1) INFN - Catania, Italy
2) Dipartimento di Fisica e Astronomia, Università di Catania, Italy
3) Dipartimento di Scienze Fisiche, Università Federico II Napoli, Italy
4) INFN - Napoli, Italy
5) GANIL - Caen, France
6) INFN LNS - Catania, Italy
7) Dipartimento di Fisica, Università di Messina, Italy
8) INFN Gruppo Collegato di Messina, Italy
9) IN2P3 - IPHC Strasbourg, France
10) IPNE, Bucharest, Romania
11) IN2P3 - IPN Orsay, France
12) Dipartimento di Scienze Ambientali - Seconda Università di Napoli, Caserta, Italy
13) University of Rochester, USA
14) Centro Siciliano Fisica Nucleare e Struttura della Materia, Catania, Italy
15) Università Kore, Enna, Italy
16) IN2P3 - IPN Lyon, France
17) IN2P3 - LPC Caen, France
18) University of Warsaw, Poland