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Isospin influence on the IMF production at low energy

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Physics Case and Context

Heavy-ion collisions (A_{CN} = 80-140) with stable and radioactive beams

Low energy regime E/A ≤ 15 MeV/A, dominated by Compound Nucleus formation and decay, in competition with binary processes (DIC, Quasi-elastic)

Exploring the effects of the isospin and of the neutron enrichment in the entrance channel, on the reaction mechanism, on the decay process and on the formation of complex fragments

Physics Case and Context

$^{78}Kr + ^{40}Ca \rightarrow ^{118}Ba^{*}$ "n-poor"

$^{86}Kr + ^{48}Ca \rightarrow ^{134}Ba^{*}$ "n-rich"

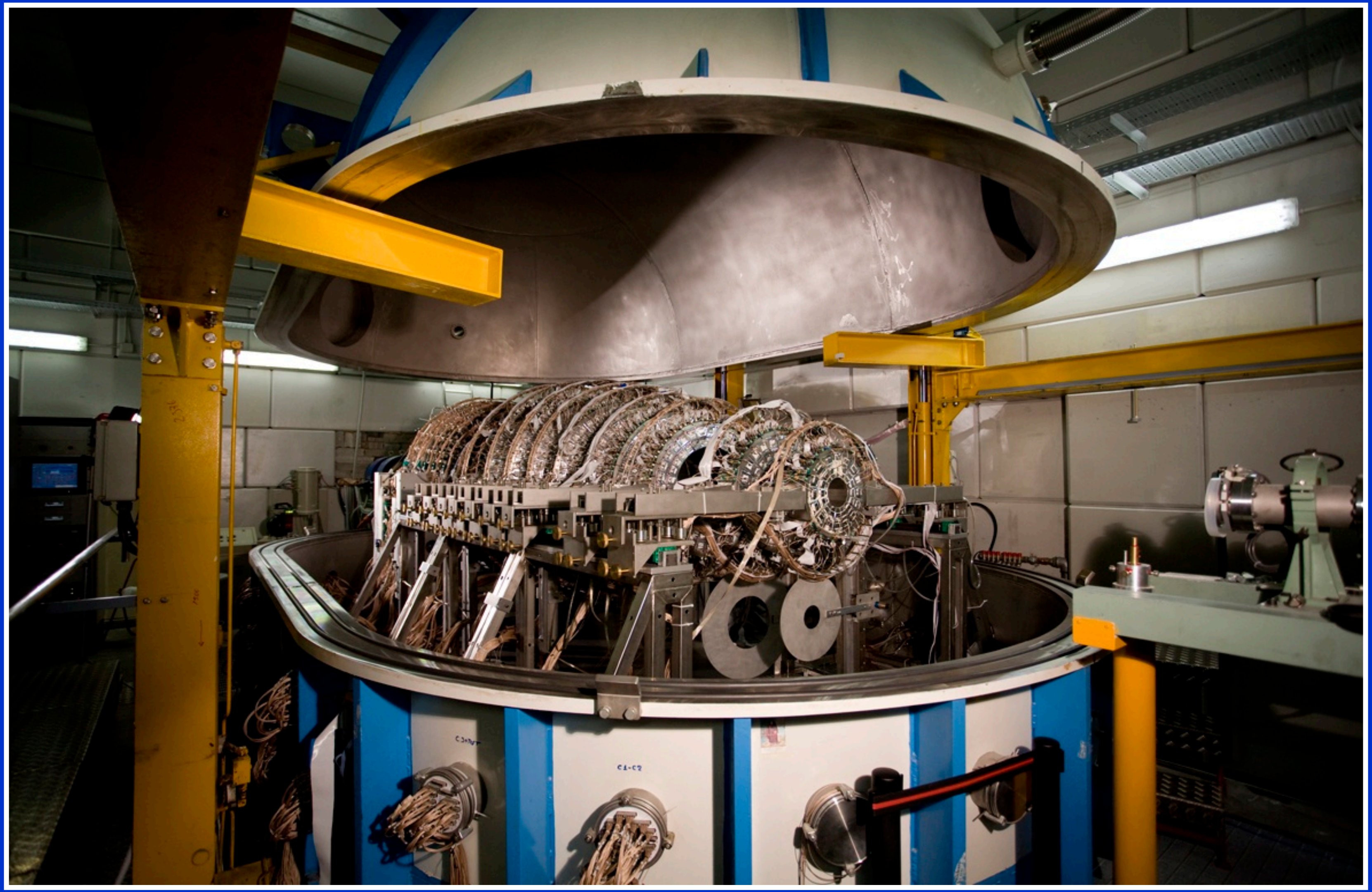
E = 10 AMeV

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

ΔN=16 neutrons

Study of the influence of isospin on the formation and emission of the Intermediate Mass Fragment (IMF Z≥3)

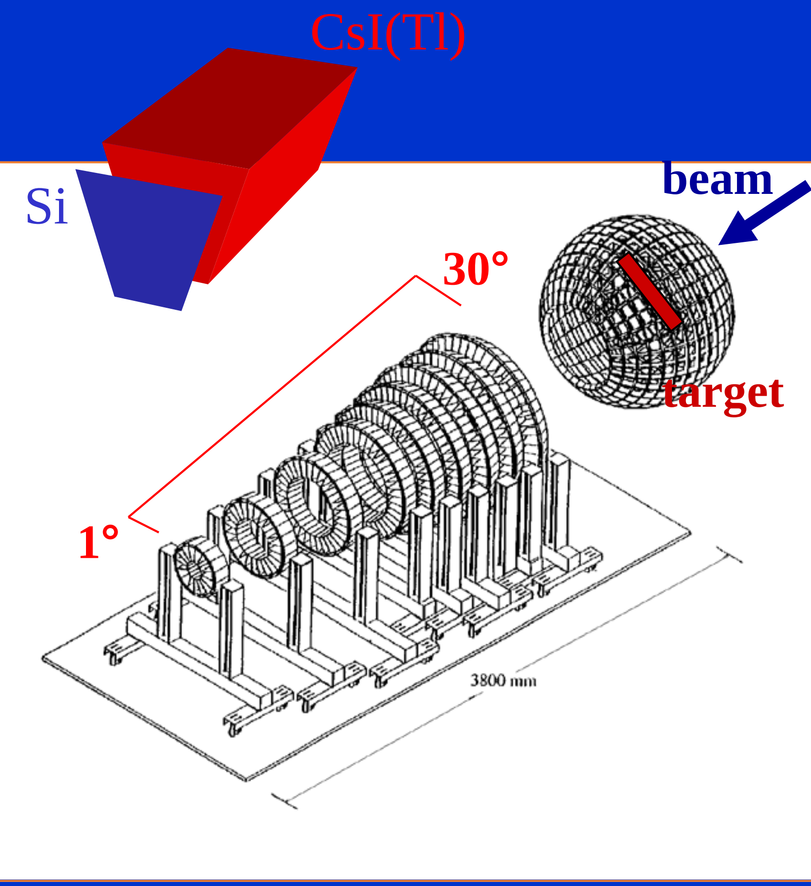
CHIMERA@LNS



A. Pagano et al., NPA681 (2001) 331

Experimental methods and results

CHIMERA - Charge Heavy Ion Mass and Energy Resolving Array



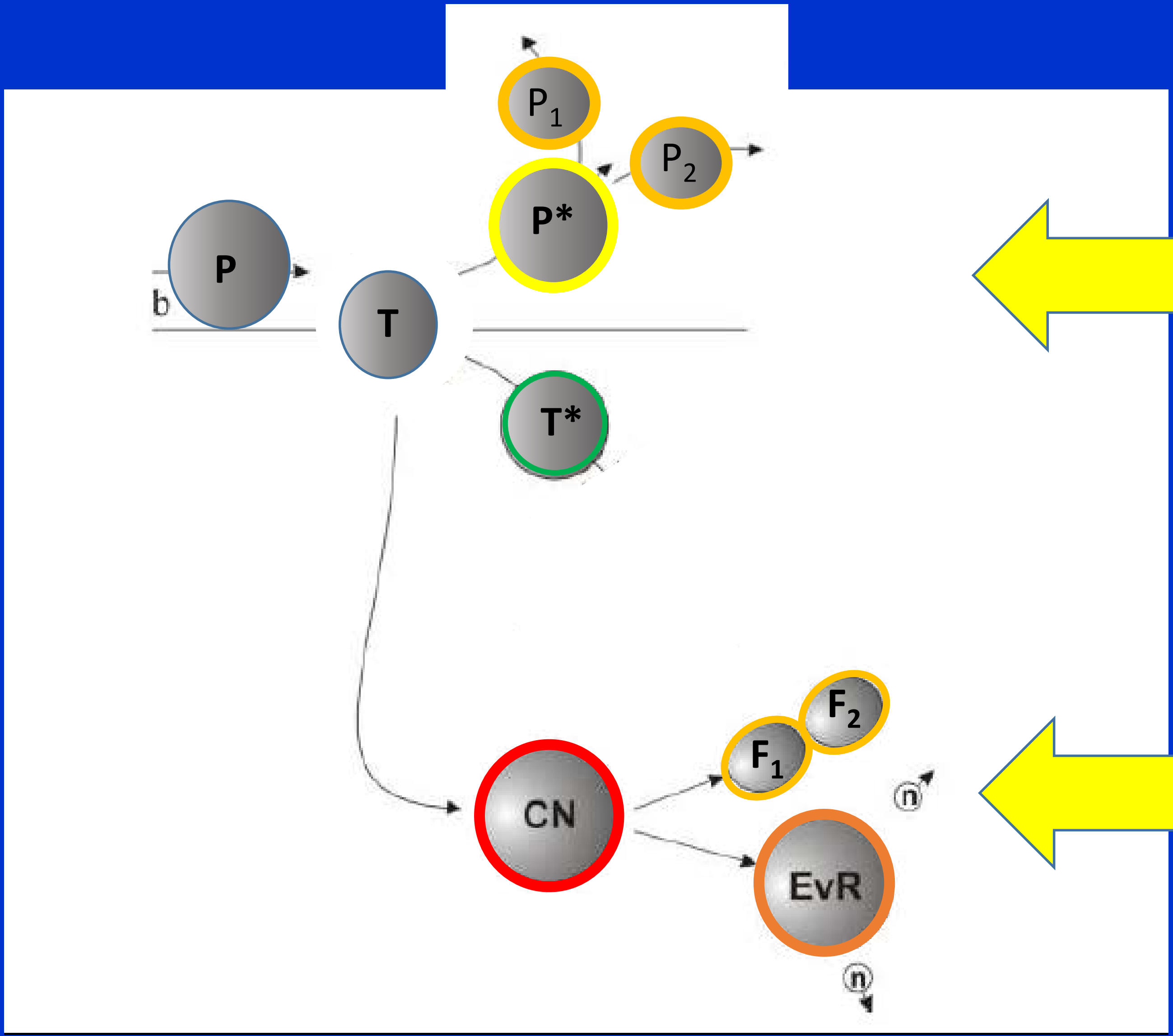
Granularity	1192 telescopes Si (300μm) +CsI(Tl)
Geometry	RINGS: 688 telescopes 100-350 cm SPHERE: 504 telescopes 40 cm
Angular range	RINGS: 1°< θ < 30° SPHERE: 30°< θ < 176° 94% of 4π
Identification method	ΔE-E E-TOF PSD in CsI(Tl) PSD in Si (upgrade 2008)
Experimental observables and performances	TOF 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

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

(TANDEM & CYCLOTRON Beams)

Physics Case and Context

Fragments production from two reaction mechanisms:



- Damped process: DIC followed by PL - break-up

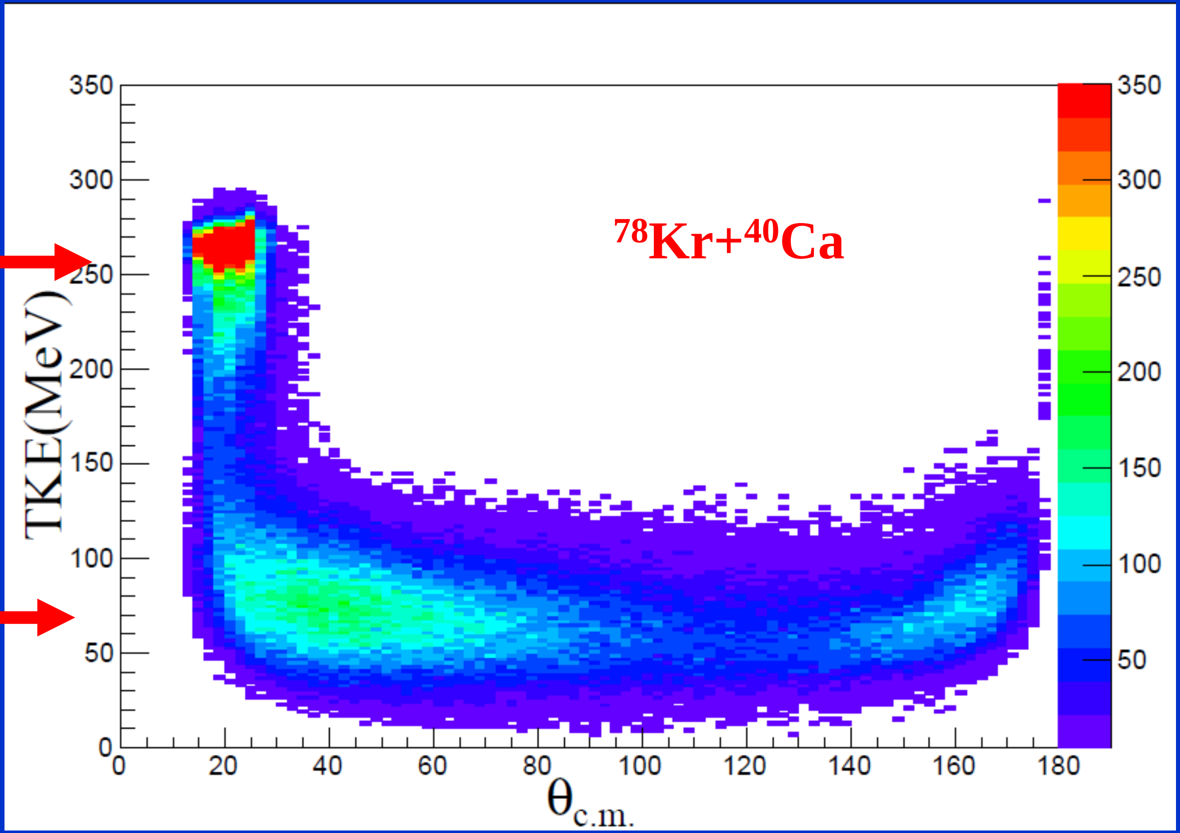
- Capture process: CN formation Fus-Fis or Fus-Evap decay modes

Experimental methods and results

Total Kinetic Energy of the binary system as a function of the emission angle in the cm, for $^{78}Kr+^{40}Ca$ (analogue result for n-rich system)

- Dynamic mechanism with TKE > 150 MeV and small ϑ_{cm}

- Relaxed process with TKE ~ 85 MeV for any angle



Value in agreement with a compilation of C. Beck et al. on fission energy release (C. Beck, A.S. de Toledo, Phys. Rev. C 53, (1996))

Capture process: CN formation and decay

G. Politi et al., JPS Conf. Proc. 6 (2015) 030082
B. Gnoffo, Il Nuovo Cimento C39 (2016) 275
S. Pirrone et al., Eur. Phys. J. A (2019) 55, 22

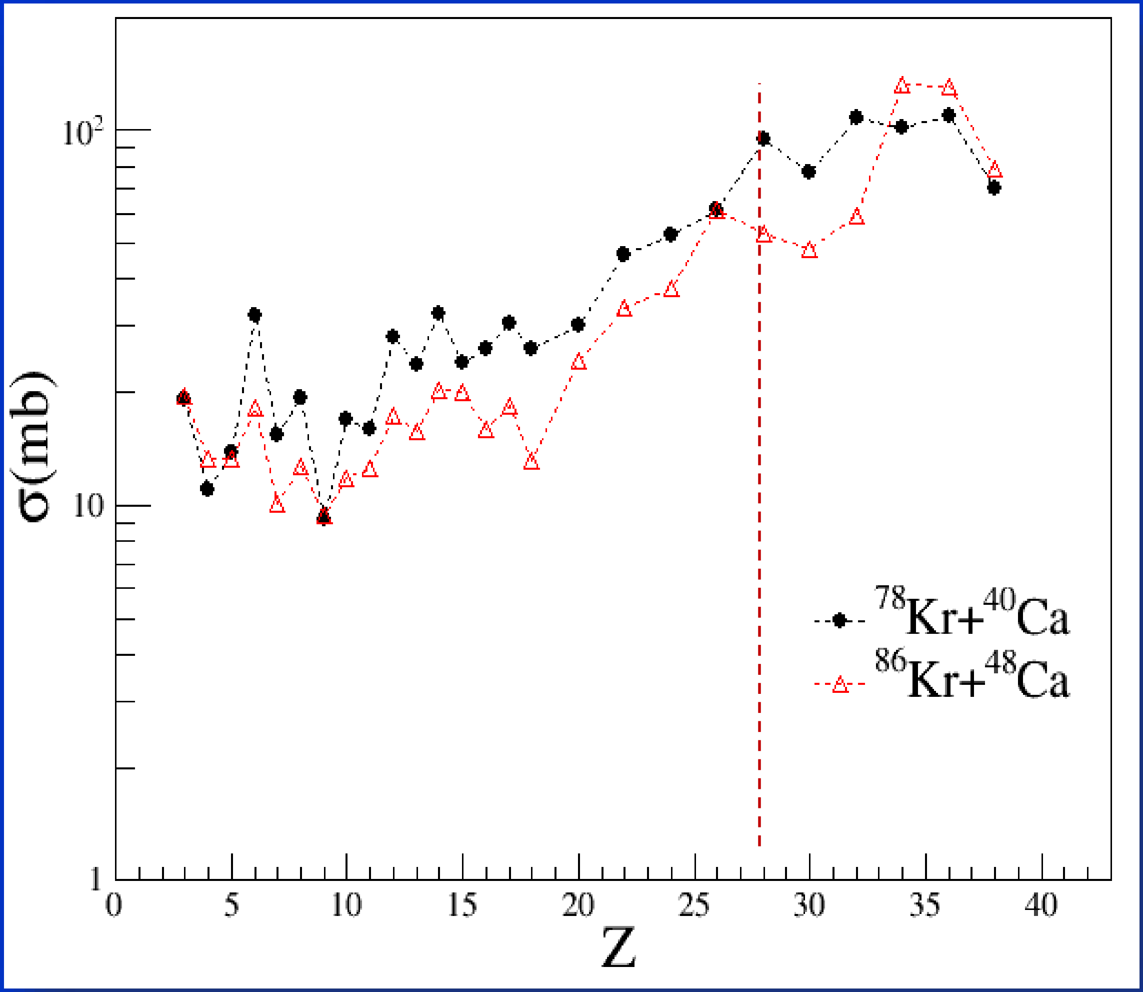
Experimental methods and results

IMF Charge Distribution (n-poor n-rich systems)

- **Fragments production globally favored for n-poor system**
- **Odd-even staggering behaviour, more pronounced in the n-poor system**

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

- **Charge distribution not symmetric with respect to $Z_{CN}/2=28$ → presence of dynamical process**

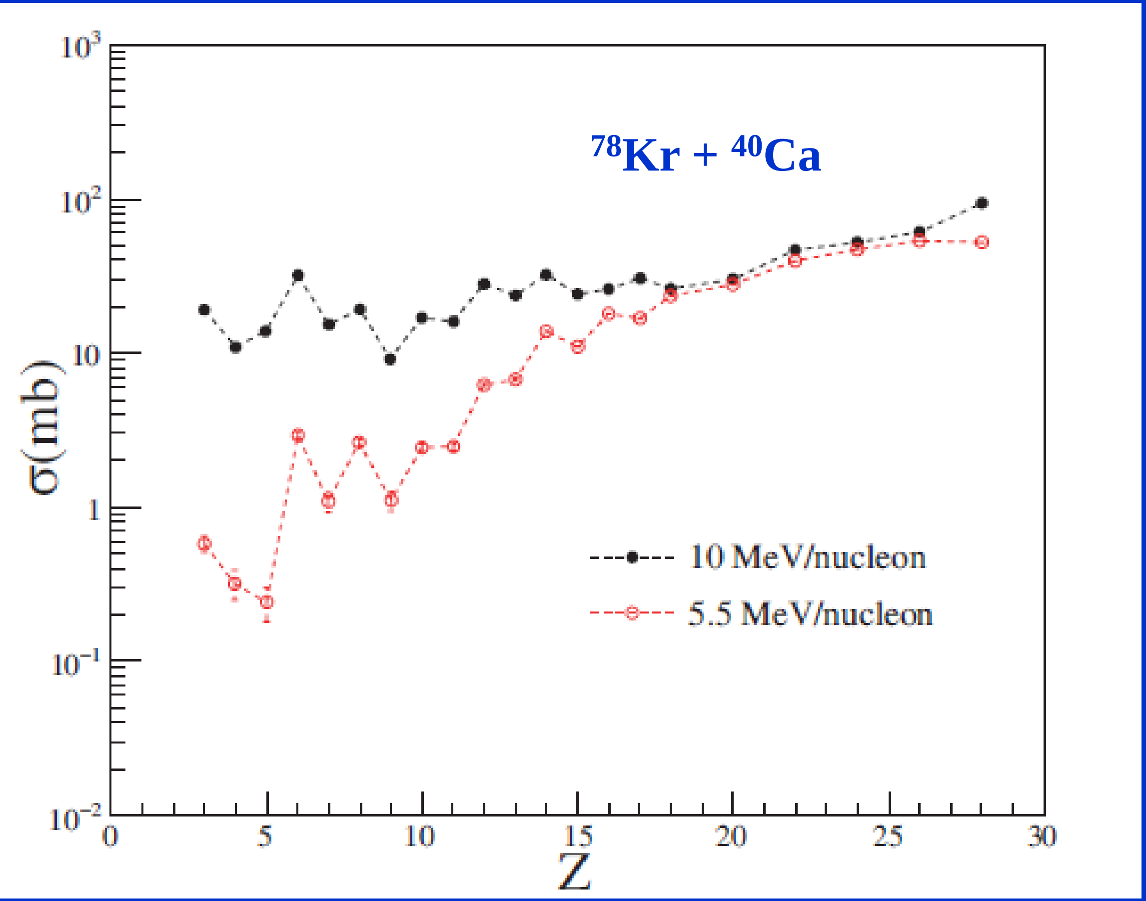


Experimental methods and results

IMF Charge Distribution (energy dependence)

Comparison for n-poor system at 5.5 MeV/A * and 10 MeV/A:

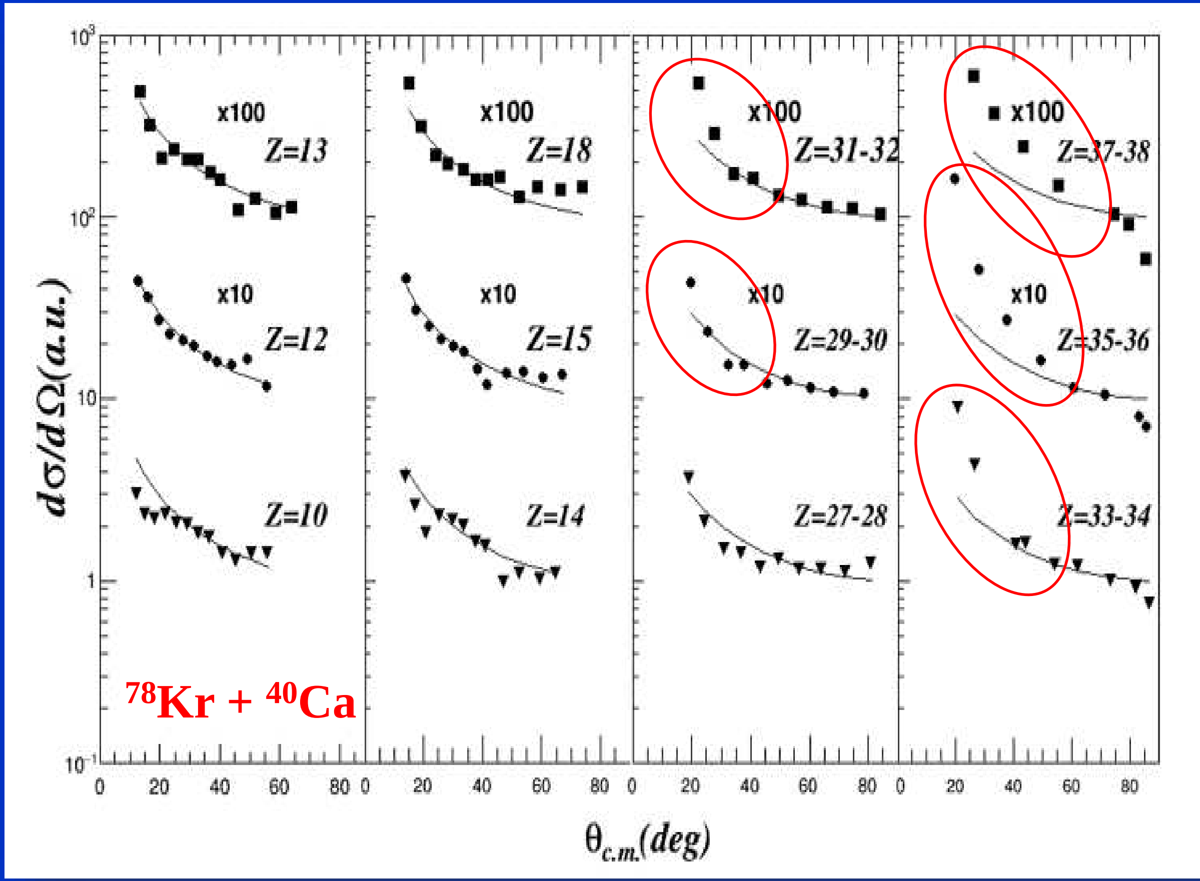
- Larger cross section and great production of IMF at higher energy



***G. Ademard et al., Phys. Rev. C 83, 054619 (2011)**
S. Pirrone et al., Eur. Phys. J. A (2019) 55, 22

Experimental methods and results

Angular distributions of fragments in CM frame



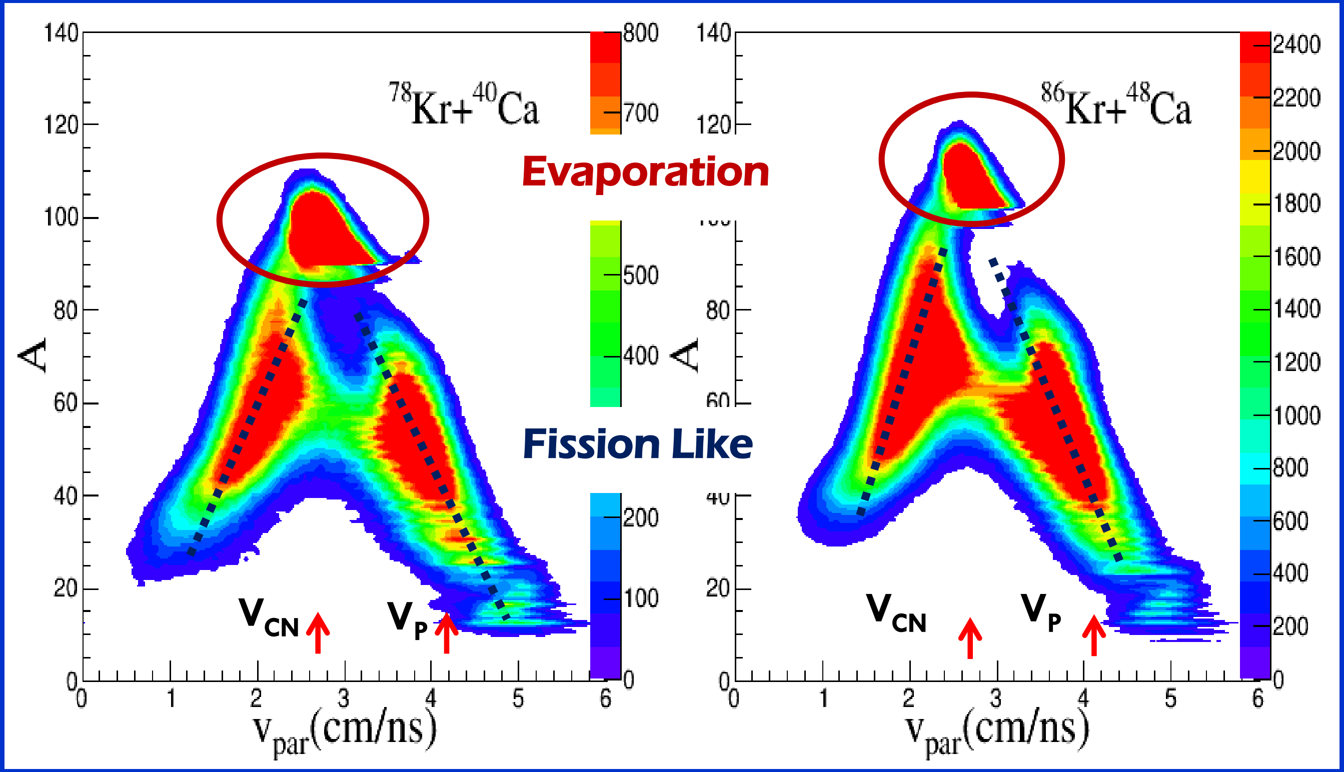
- 1/sinϑ behavior, expected for a production via a long lived system –> fission like mechanism from equilibrated source
- Z > 28 stronger contribution at smaller angles, confirming a not fully equilibrated binary mechanism

Experimental methods and results

Further information from Complete Events

multiplicity ≥ 2 $0.8\ M_{CN} \leq M_{tot} \leq 1.1\ M_{CN}$ $0.6 \leq p_{tot}/p_{beam} \leq 1$

Correlation between fragment mass and parallel velocity



Evaporation Residues and Fission Like fragments are evident in both systems

Experimental methods and results

Cross sections measurements

	σ_{ER} (mb)	σ_{FL} (mb)	σ_{fus} (mb)	σ_{reac}^{qp} (mb)
$^{78}Kr+^{40}Ca$	455±70	850±120	1305±190	2390±250
$^{86}Kr+^{48}Ca$	400±60	530±85	930±145	2520±260

S. Pirrone et al., Eur. Phys. J. A (2019) 55, 22

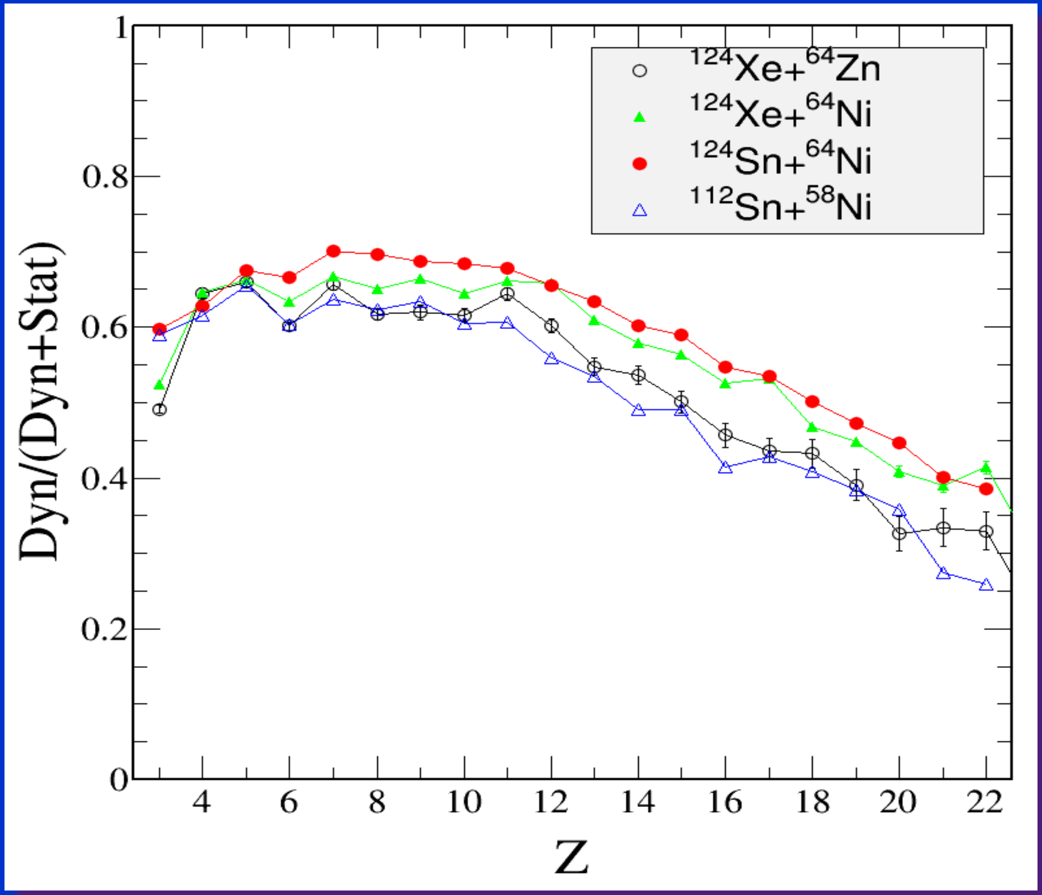
- **Fusion-Evaporation process is comparable for the two systems**
- **Fission-Like process prevails for the n-poor system**
- **Difference σ_{Reac} - σ_{Fus} more pronounced for the n-rich system (more DIC)**

Damped process:
DIC followed by PL break-up

P. Russotto et al., Phys. Rev C91, 014610 (2015)
B.Gnoffo et al. , IL NUOVO CIMENTO 41 C (2018) 177

Dynamical and statistical PL break-up @35 MeV/A

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



We are able to select the PL Break-up mechanism, and to distinguish the statistical and dynamical components

Dynamic contribution is favoured for n-rich systems

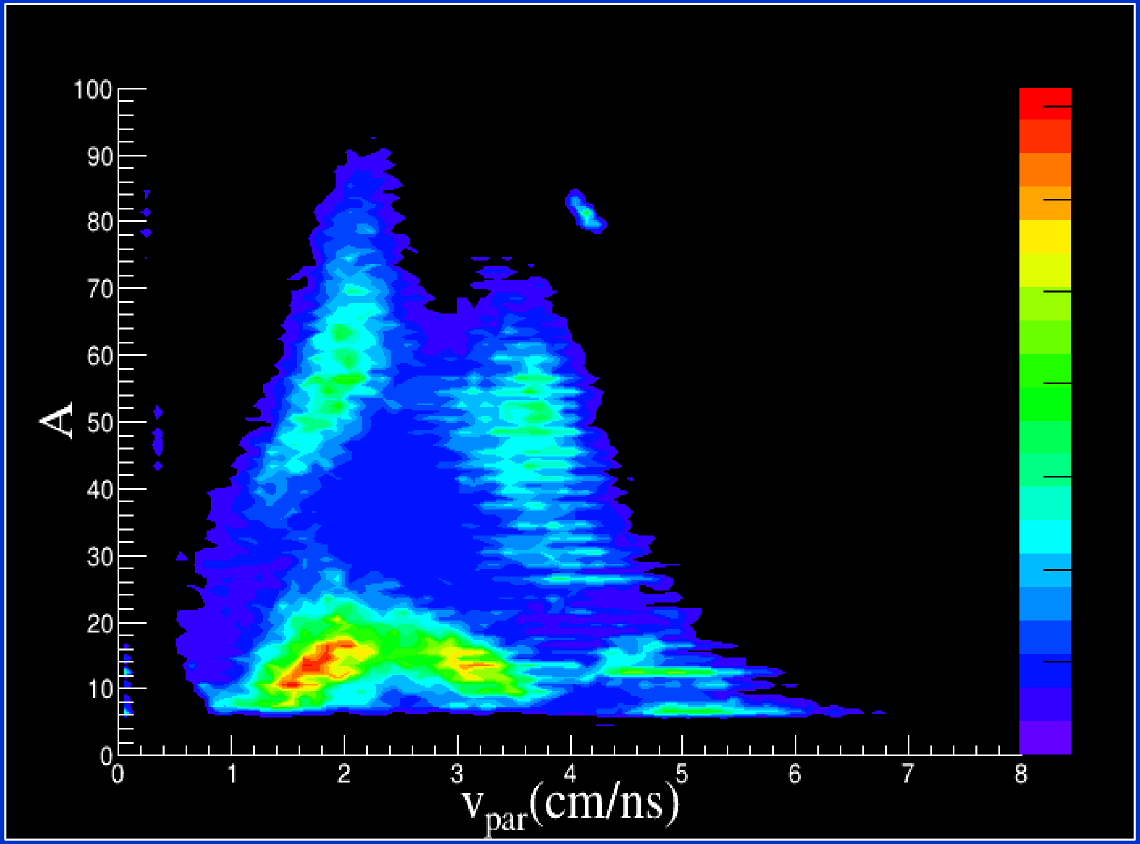
Results are independent from size effects

P. Russotto et al., Phys. Rev C91, 014610 (2015)
P. Russotto et al., submitted to Eur. Phys. J. A

Experimental methods and results

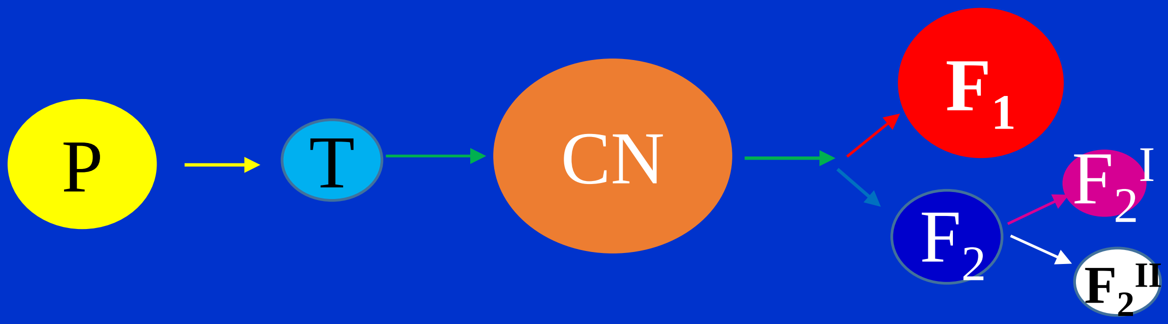
Projectile Break-Up in ^{78}Kr + ^{40}Ca and ^{86}Kr + ^{48}Ca at 10 MeV/A

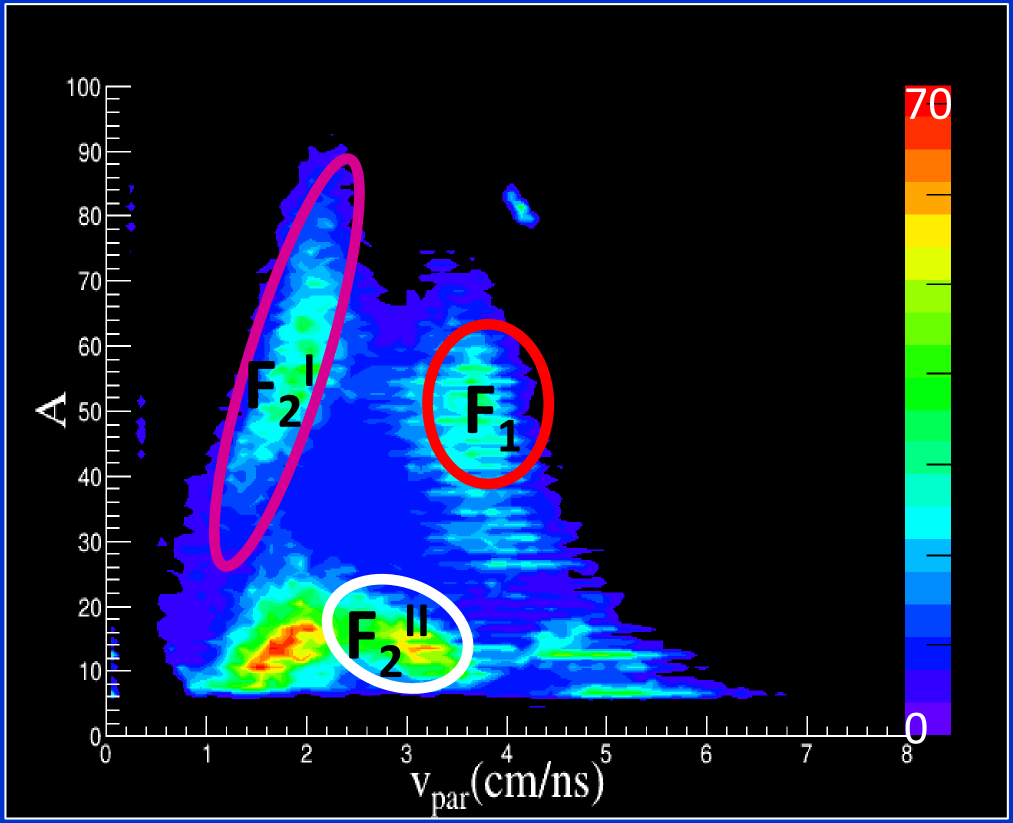
Selection of events with 3 fragments (IMF, Z ≥ 3)



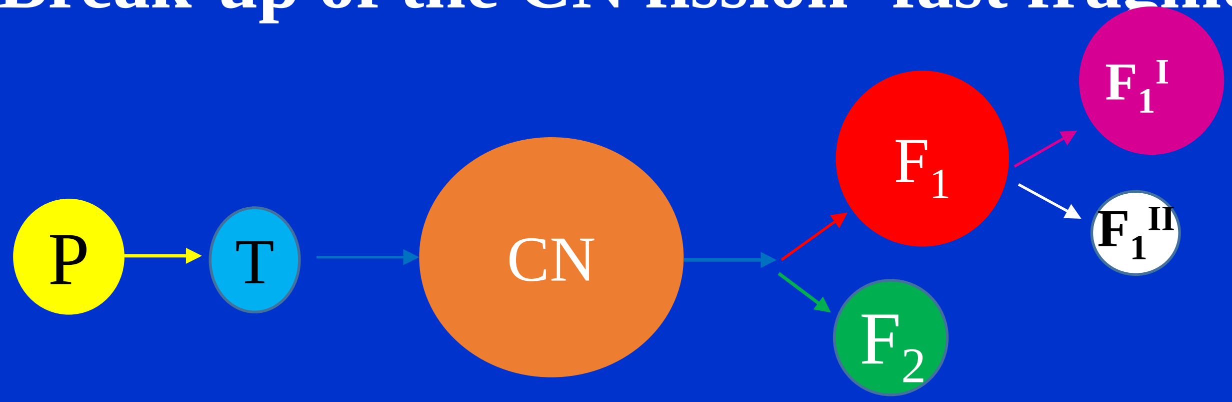
Mass A versus parallel velocity V_{par} of Fragments

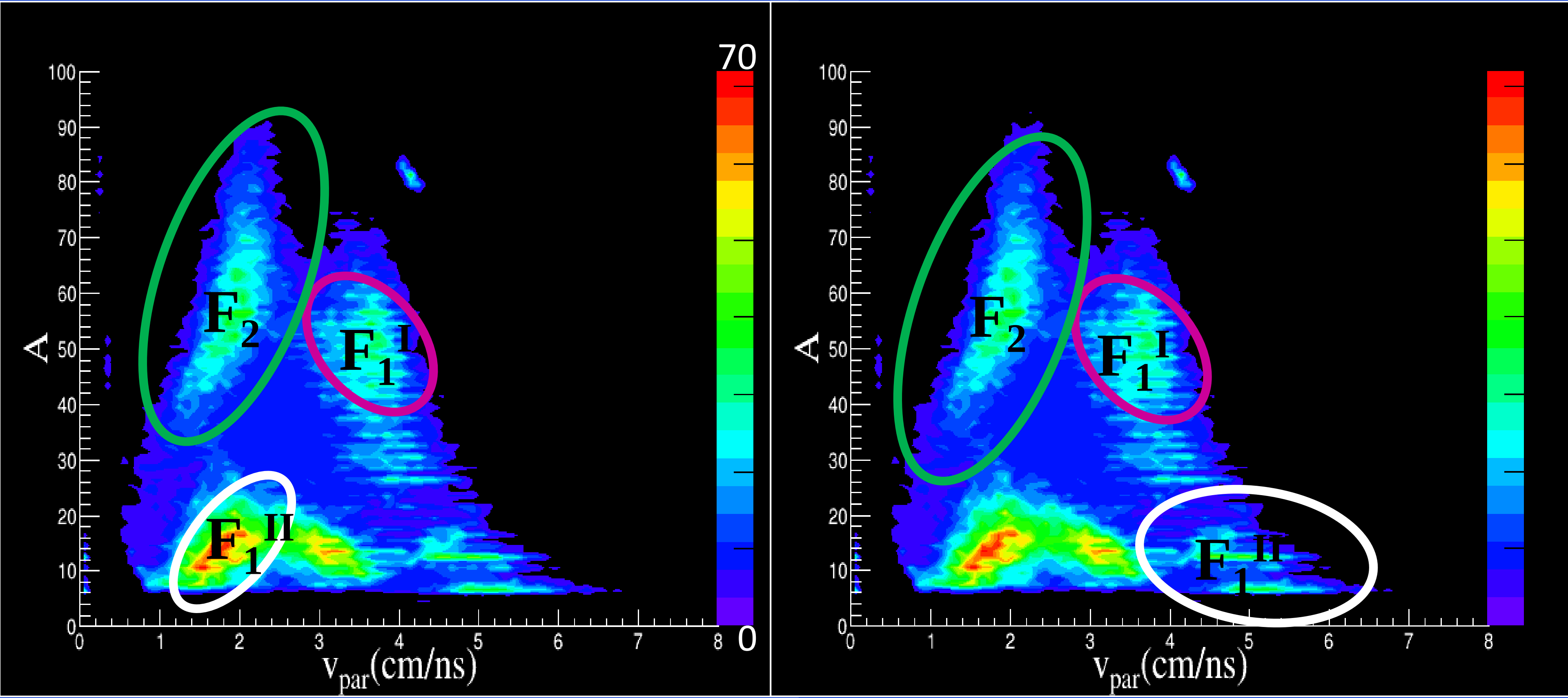
Break-up of the CN fission-slow fragment



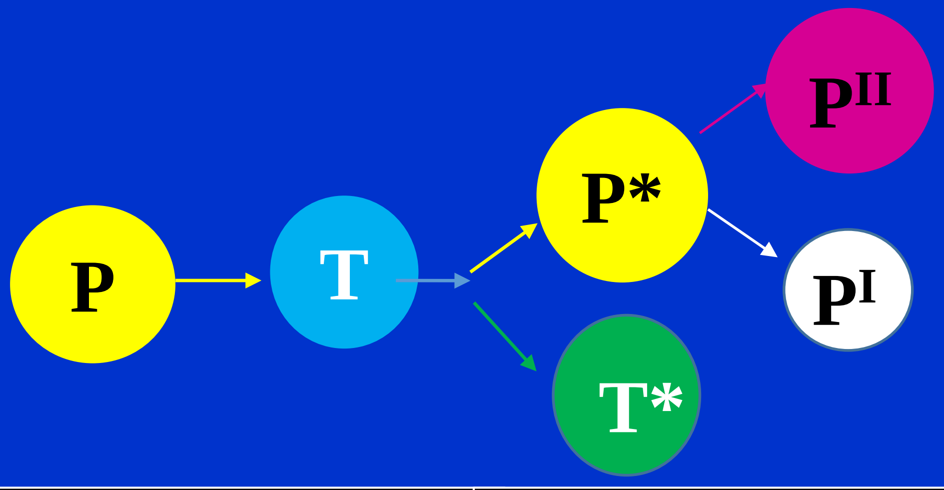


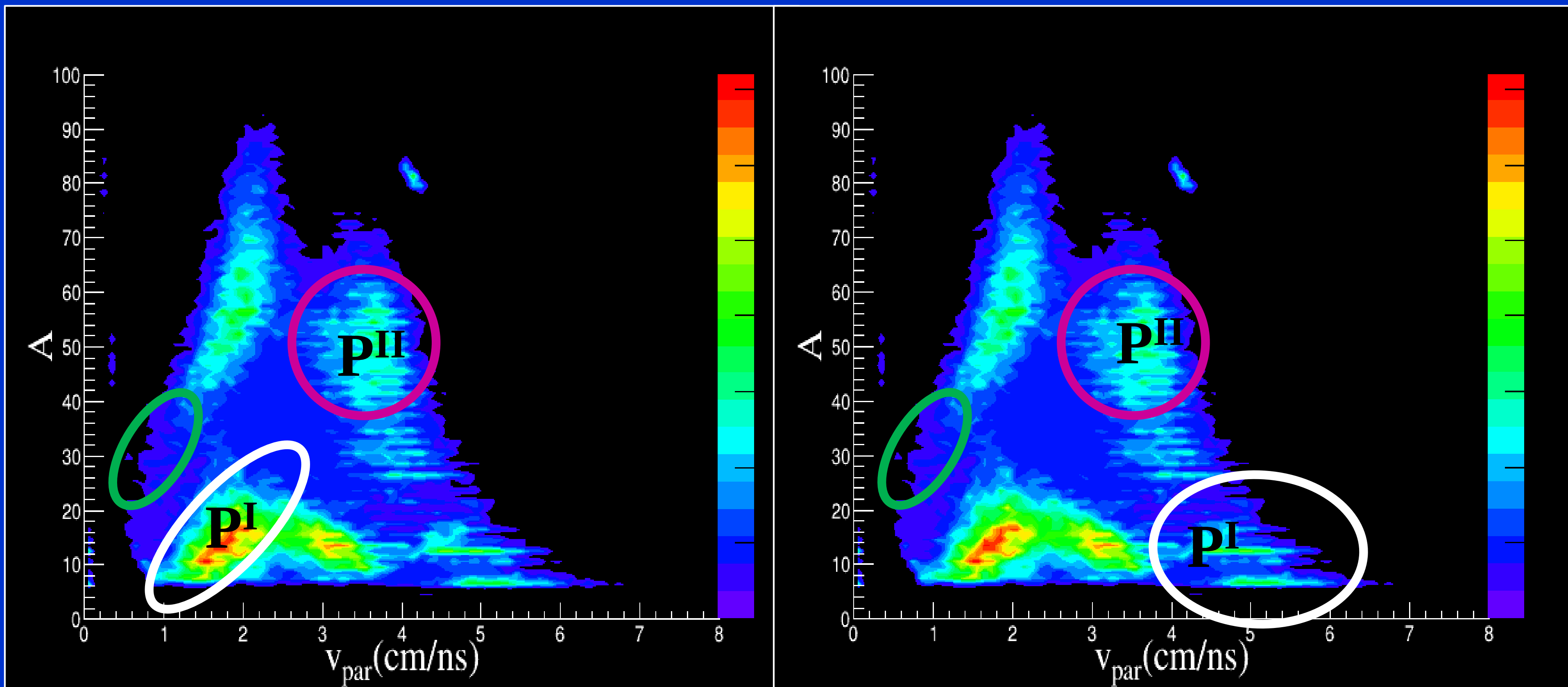
Break-up of the CN fission- fast fragment





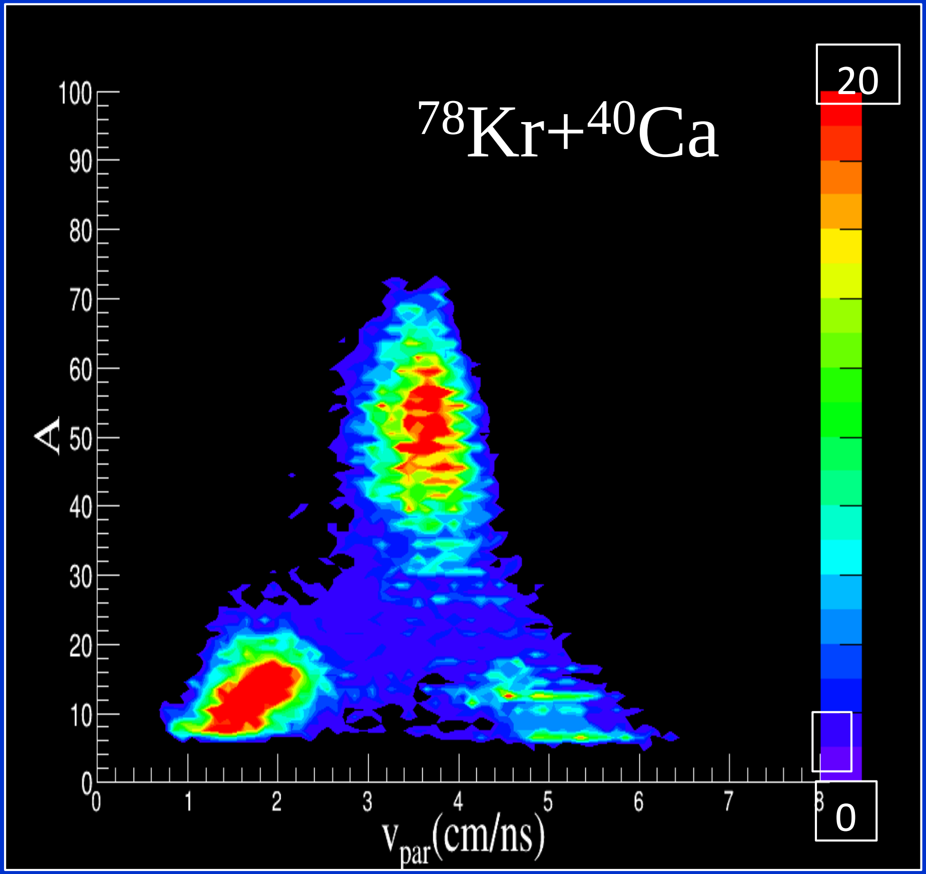
Break-up of the Projectile-Like-Fragment

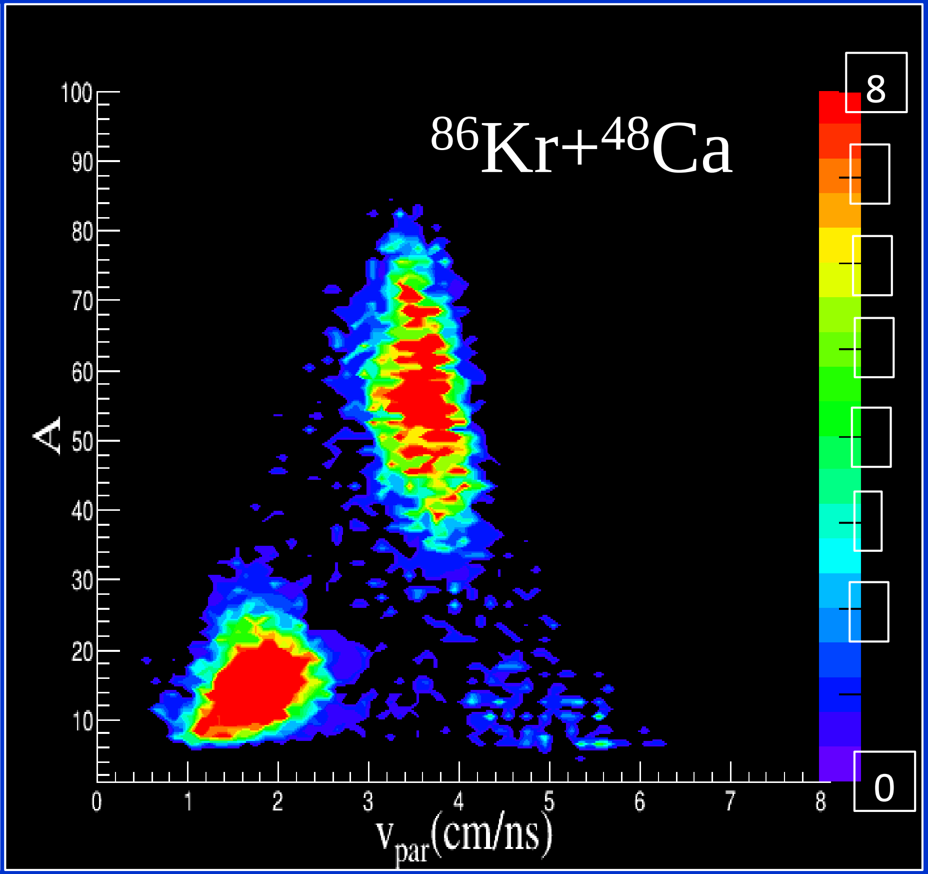




Experimental methods and results

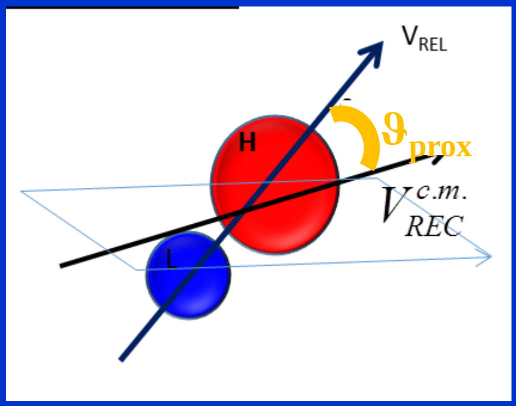
Among the different combinations, a kinematical method is used to select only fragments produced in PL Break-up

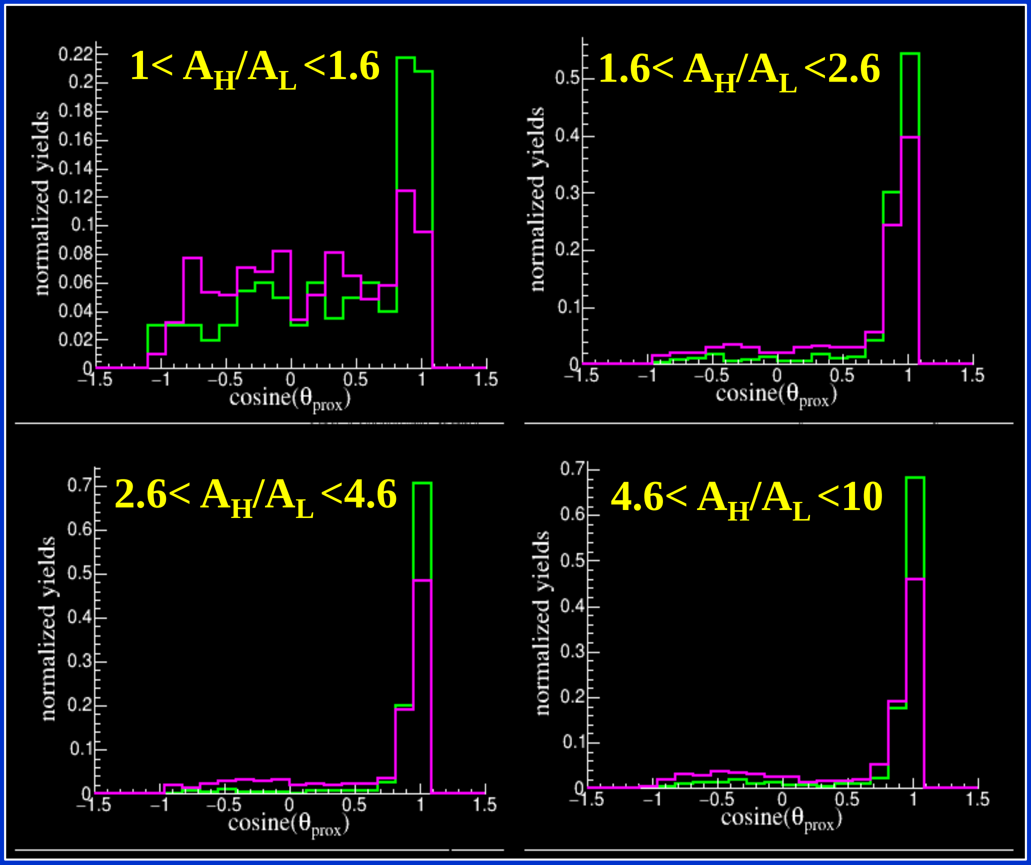




Experimental methods and results

«Dynamic Nature» of PL Break-Up mechanism





ϑ_{prox}, angle between the two PL Break-Up fragments, A_H and A_L

Preliminary results

$Cos\vartheta_{prox}$ distribution of the PL BreakUp fragments for different value A_H/A_L, for $^{78}Kr+^{40}Ca$ and $^{86}Kr+^{48}Ca$

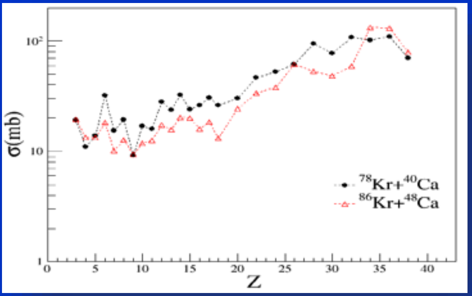
Presence of two components, one isotropic, coming from relaxed process, and the other one with aligned fragments, suggesting dynamical effects.

Dynamical component prevails for the n-rich system, as in the case @35 MeV/A

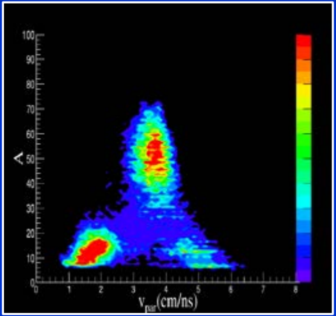
Conclusions

Main results of the analysis on the IMF production and isospin dependence in the $^{78}Kr+^{40}Ca$ and $^{86}Kr+^{48}Ca$ at 10 MeV/A have been presented.

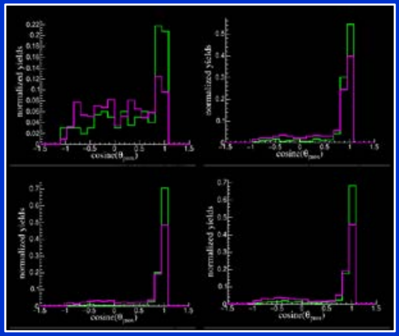
- IMF coming from Capture Process, Fusion-Fission and Fusion Evaporation decay mode



- IMF coming from Damped Collision, PL BreakUp, (kinematical method)



- Evidence of Dynamical effects, more pronounced for the n-rich system, $^{86}Kr+^{48}Ca$, in agreement with the results obtained at higher energy



Outlook

Further analysis to be done:

- Analysis of Deep Inelastic Contribution as a function of N/Z

- Analysis of LCP energy spectra in coincidence with ER and FF, to better distinguish dynamic nature of the processes

- Theoretical calculations with a microscopic transport models to see relation among different mechanisms as a function of N/Z

- Extend this research by using radioctive beams at SPES

LOI@SPES

E.De Filippo, J.Frankland, S.Pirrone, G.Politi, P.Russotto

^{92}Kr + ^{40,48}Ca 10 AMeV

^{132,140}Ba* E* ~ 320 MeV $(N/Z)_{CN}$ =1.5

NEWCHIM Collaboration

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