NUSYM 2017

7th international symposium on nuclear symmetry energy

SEPTEMBER 4TH - 7TH / GANIL, CAEN, FRANCE

Isospin influence on Fragments production in ^{78}Kr + ^{40}Ca and ^{86}Kr + ^{48}Ca collisions at 10 MeV/nucleon

G. Politi for NEWCHIM/ISODEC collaboration

Dipartimento di Fisica e Astronomia

Sezione INFN - Catania, Italy

Outlook

Physics Case

Experimental Method

Main Results

Reaction Mechanisms

Fragment Kinematical Features and Charge Distributions

Reaction Cross Sections

Comparisons with theoretical models

Conclusions and Perspectives

Physics Case

Heavy-ion induced reactions with stable and radioactive beams are ideal to explore the nuclei under different stress conditions

Low energy regime E < 15 MeV/A is dominated by Compound Nucleus de-excitations in competition with binary processes (DIC, Quasi-Fission)

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Low energy regime E < 15 MeV/A is dominated by Compound Nucleus de-excitations in competition with binary processes (DIC, Quasi-Fission)

The isospin is expected to play a crucial role in the reaction dynamics:

N/Z ratio can influences:

- Fragments formation
- Reaction mechanisms
- Competition among the different decay channels of the CN

Physics Case

ISODEC Experiment in the LEA/COLLIGA framework

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

E/A=10 MeV/A

	^{118}Ba	^{134}Ba
E*(MeV)	215	270
(N/Z)tot	1.11	1.39

S. Pirrone et al., Journal of Physics: Conf. Series 515 (2014) 012018
G. Politi et al., JPS Conf. Proc. Vol. 6 (2015) 030082
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Comparison with

$^{78,82}Kr + ^{40}Ca \rightarrow ^{118,122}Ba$ INDRA detector at GANIL

E/A=5.5 MeV/A E* ≈ 100 MeV

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

Composite systems with higher E* -> effects on decay

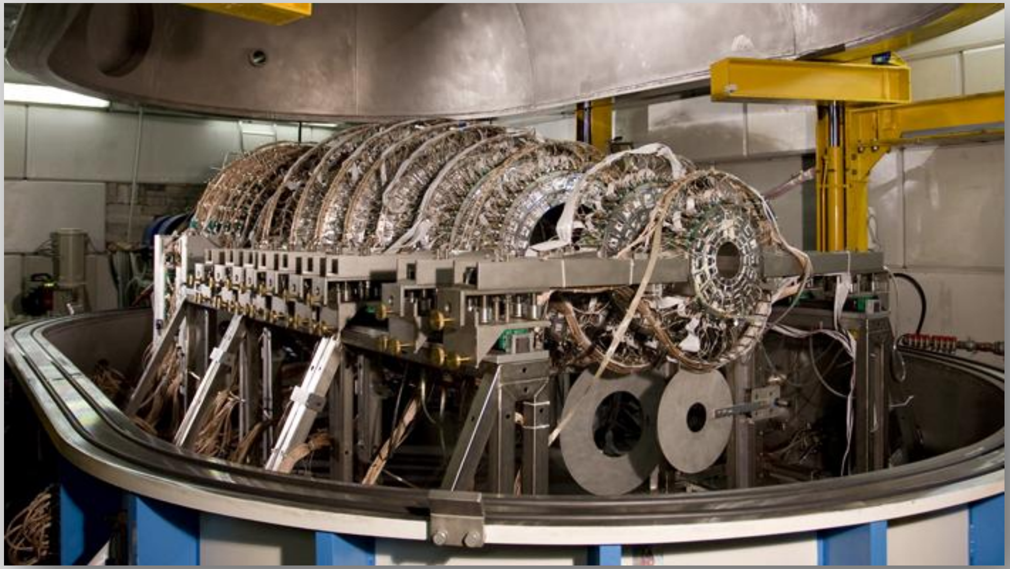
Larger domain of N/Z, maximum with stable beam

Experimental Method

Key observables: cross sections, multiplicities, angular and energy distributions of different reaction products

Good isotopic resolution, low energy threshold, high angular resolution and acceptance

CHIMERA device operating at INFN-LNS



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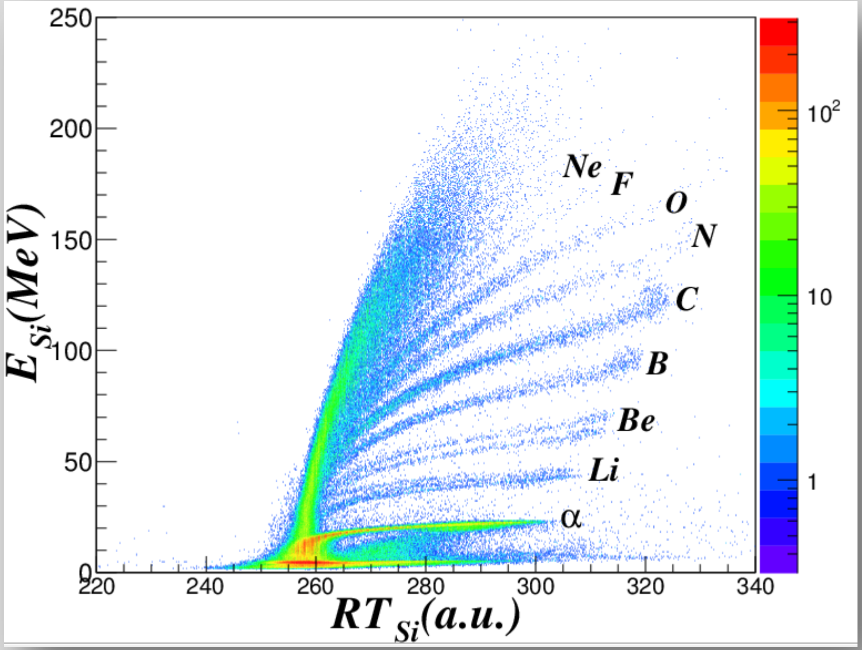
First measurement with pulse shape discrimination in Silicon detector

Fundamental in this energy regime

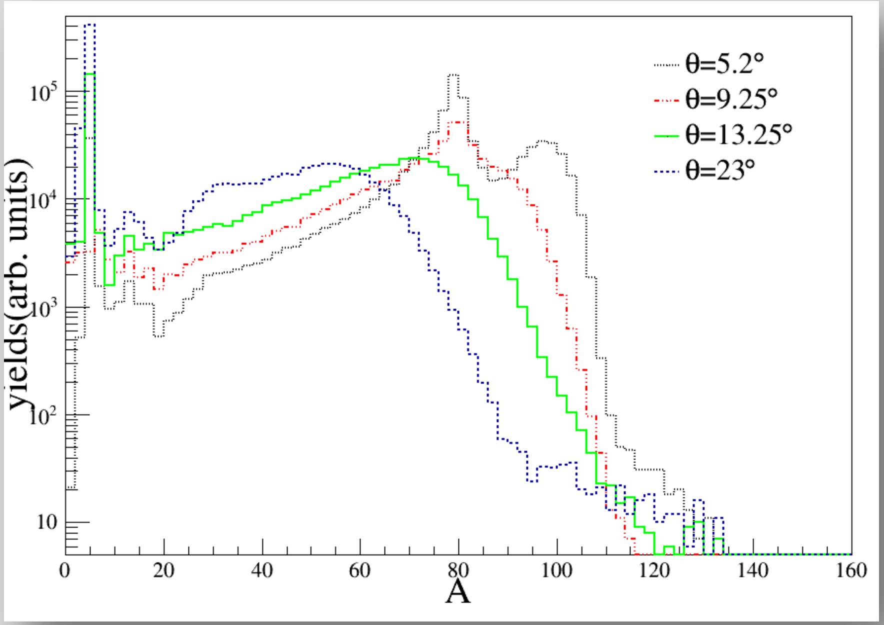


Main Results

Reaction Mechanisms

Inclusive events: mass distributions at different angles

Different processes (n-poor)



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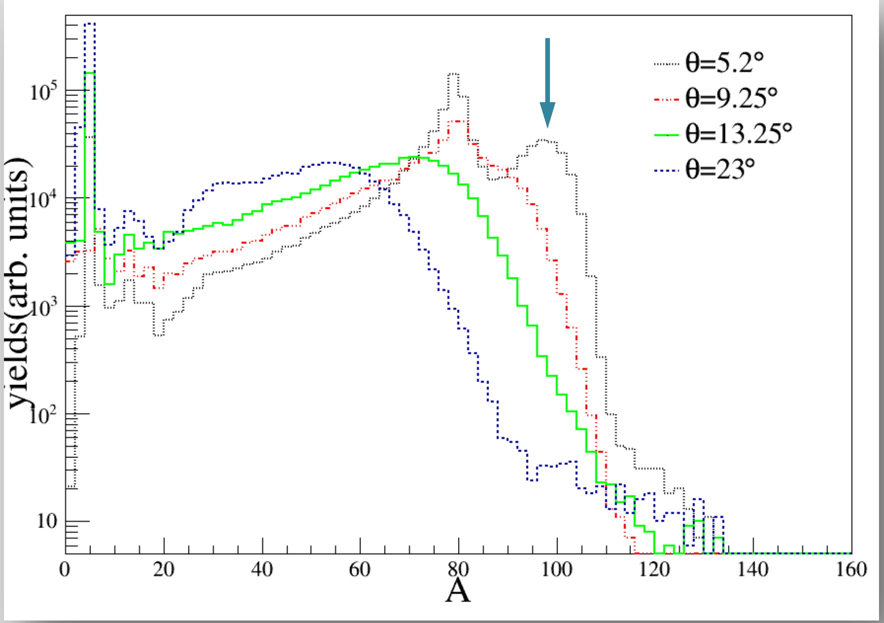
A ≈ 100 very forward angles



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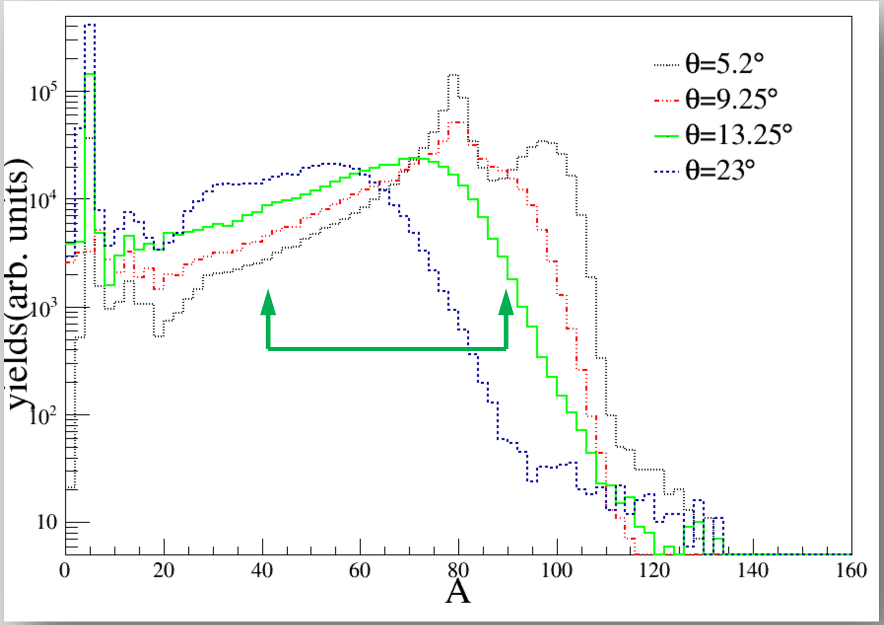
- fusion-fission channel
A ≈ 40–90 wider theta range



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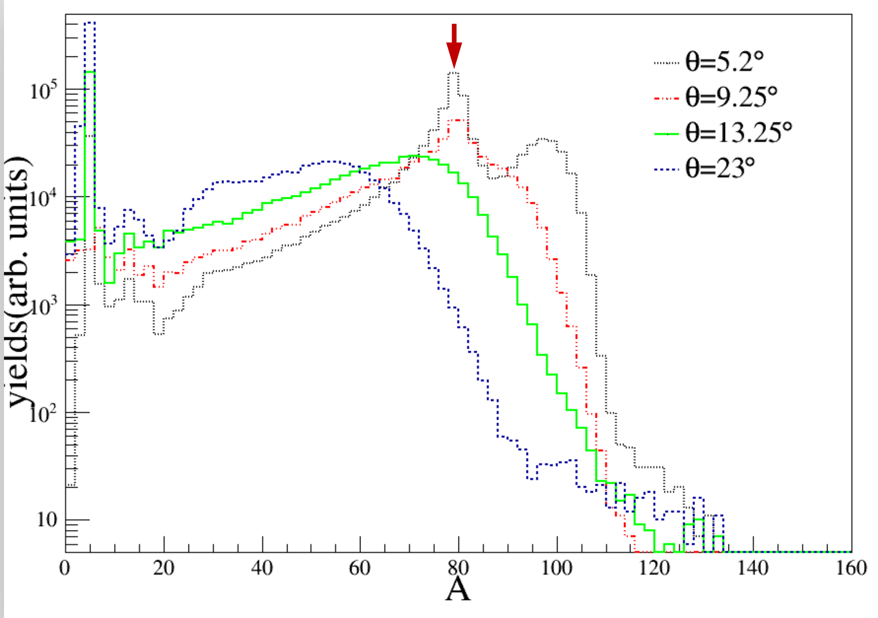


- fusion evaporation channel
A ≈ 100 very forward angles

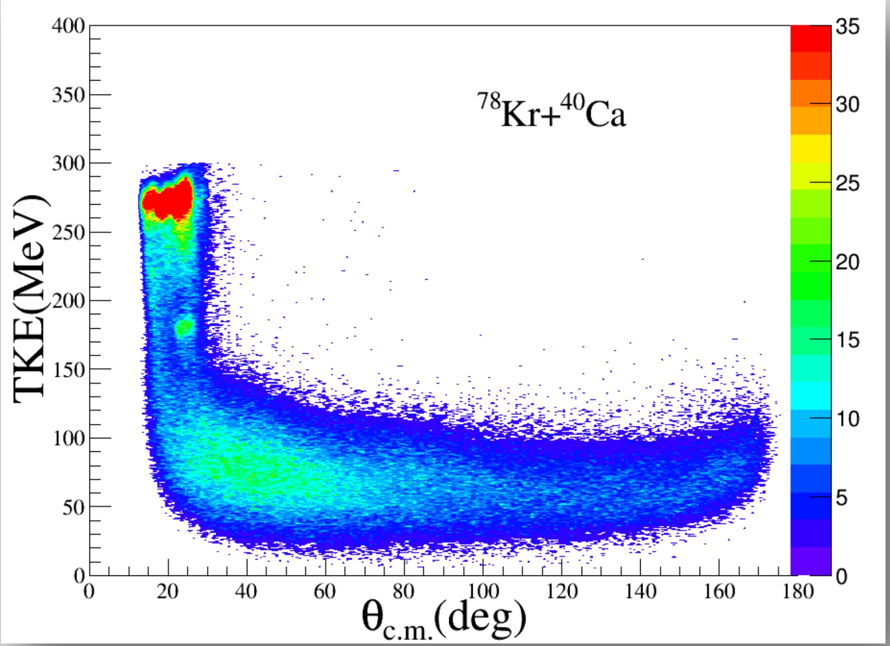
- fusion-fission channel
A ≈ 40–90 wider theta range

- third component
A ≈ 80 forward angle

kind of binary mechanism,
not completely relaxed in mass -> DIC

DIC mechanism typically observed in plot TKE – θ_{cm}

TKE reconstructed from fragment kinematical characteristics



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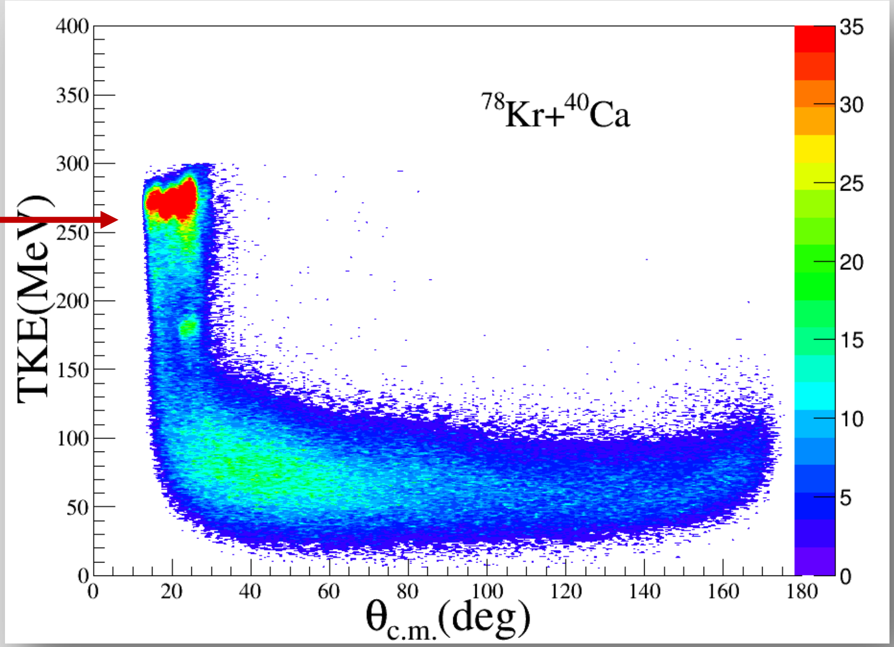
Dynamical mechanism with TKE > 150 MeV and small θ_{cm}



DIC mechanism typically observed in plot TKE – θ_{cm}

TKE reconstructed from fragment kinematical characteristics

Dynamical mechanism
with TKE > 150 MeV
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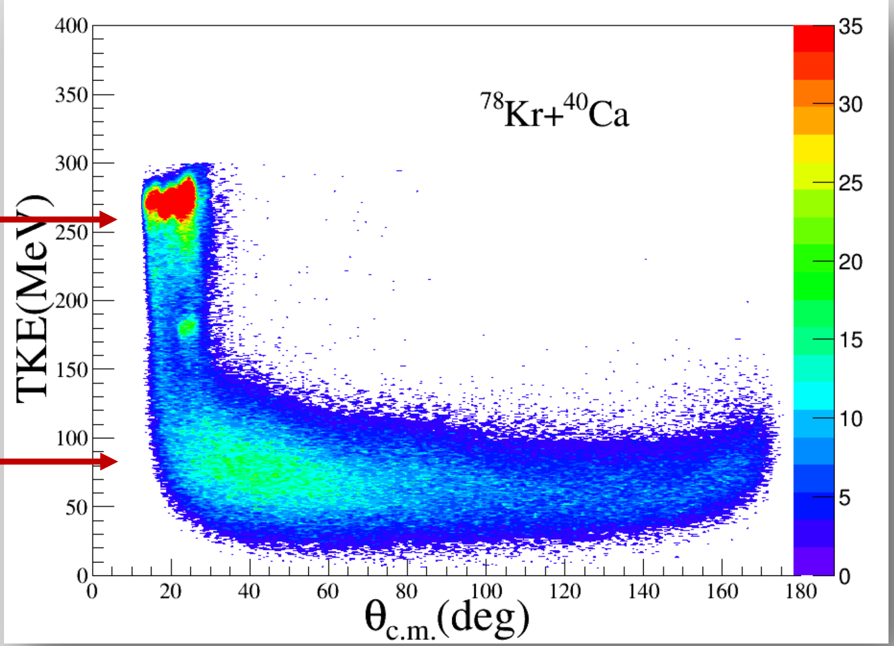
Relaxed process
with TKE ~ 85 MeV
for any angle



Value in agreement with a compilation of C. Beck et al. on fission energy release

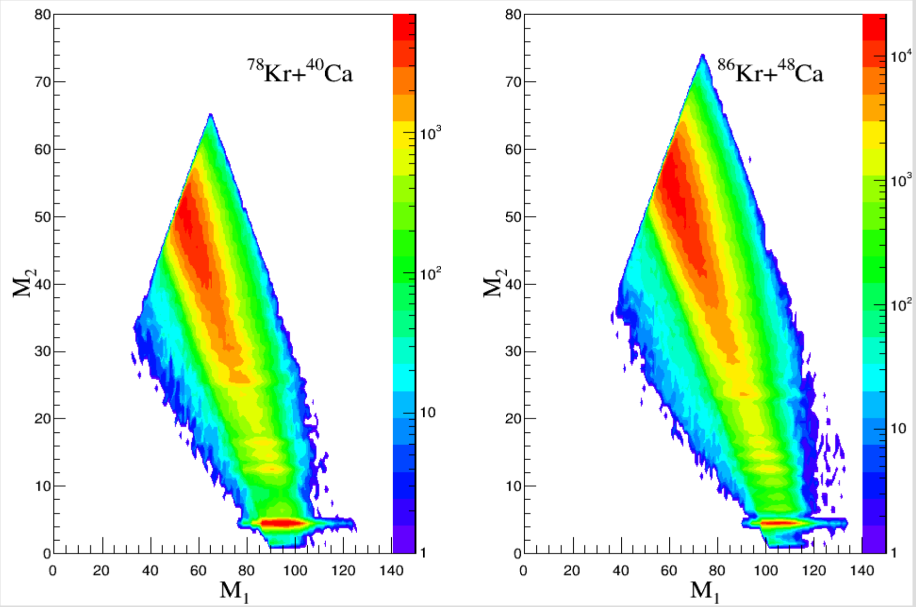
Analogue results for n-rich system, with DIC even more present

Main Results

Further information from Complete Events

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

Correlation between sizes of the two biggest fragments



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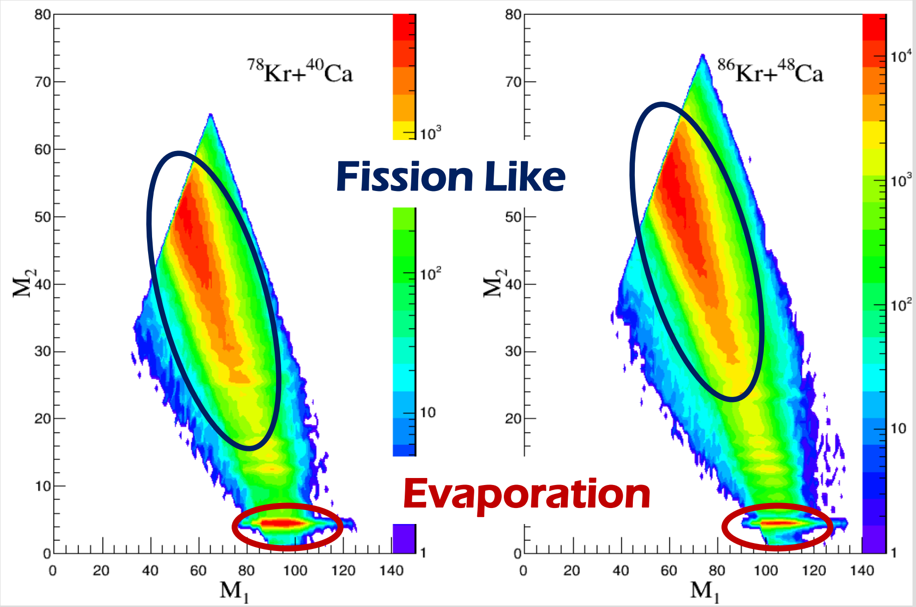

ER production seems to be slightly more pronounced in n-poor

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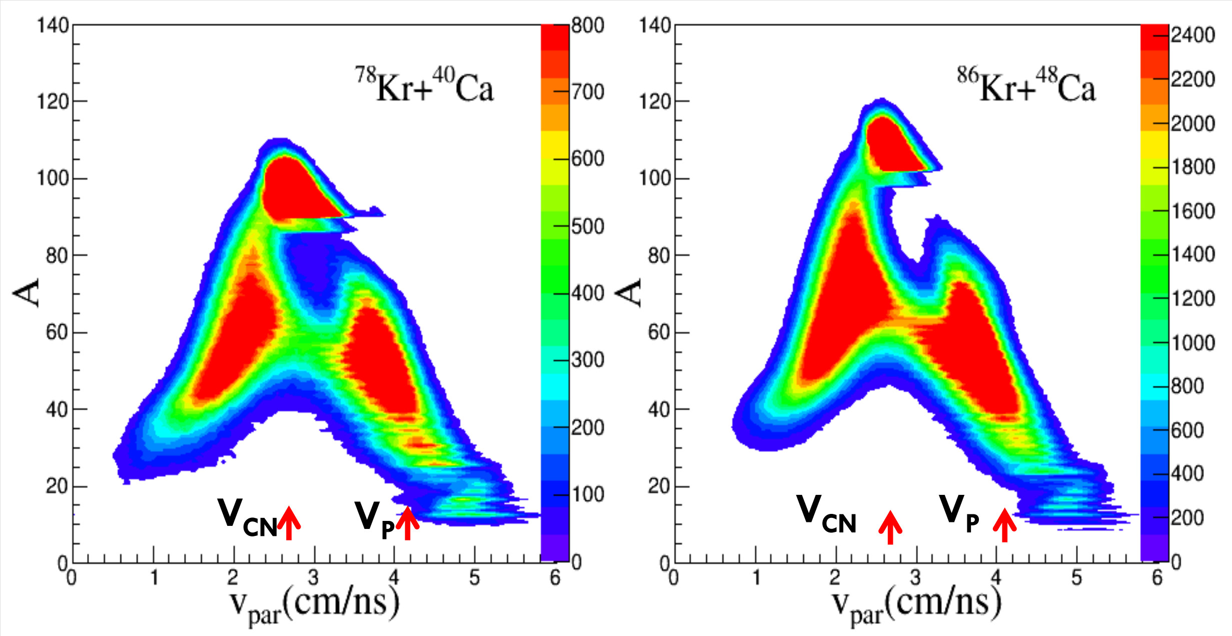
Correlation between fragment mass and parallel velocity



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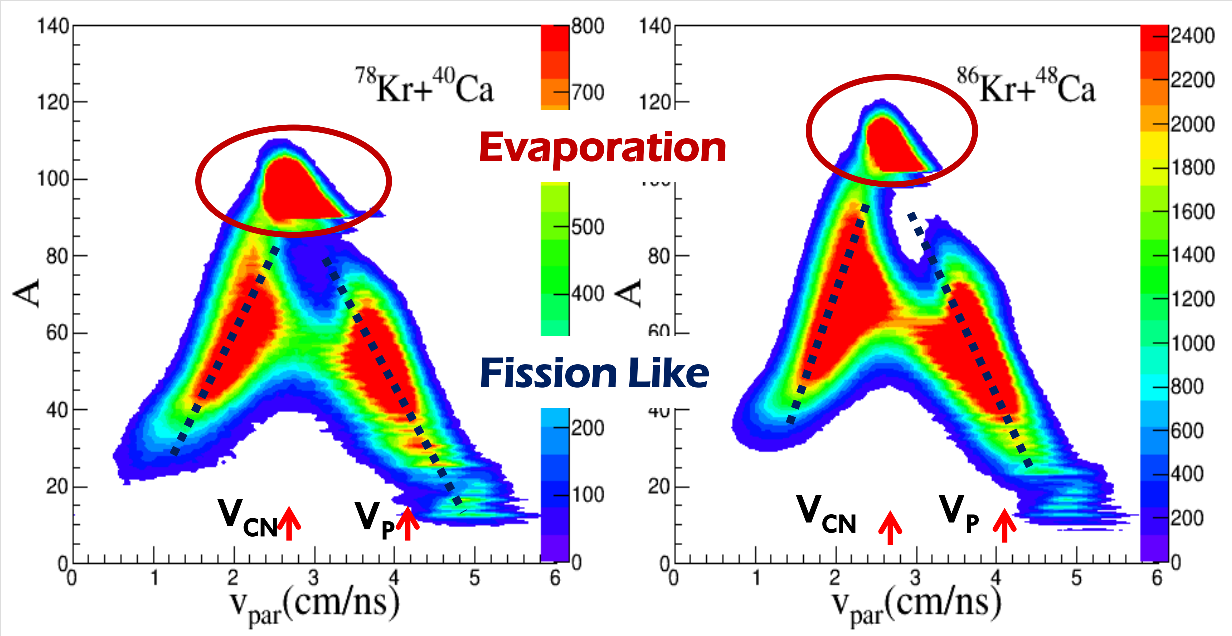


ER production seems to be enhanced in the n-poor system

Mostly Binary Decay is presents in both systems

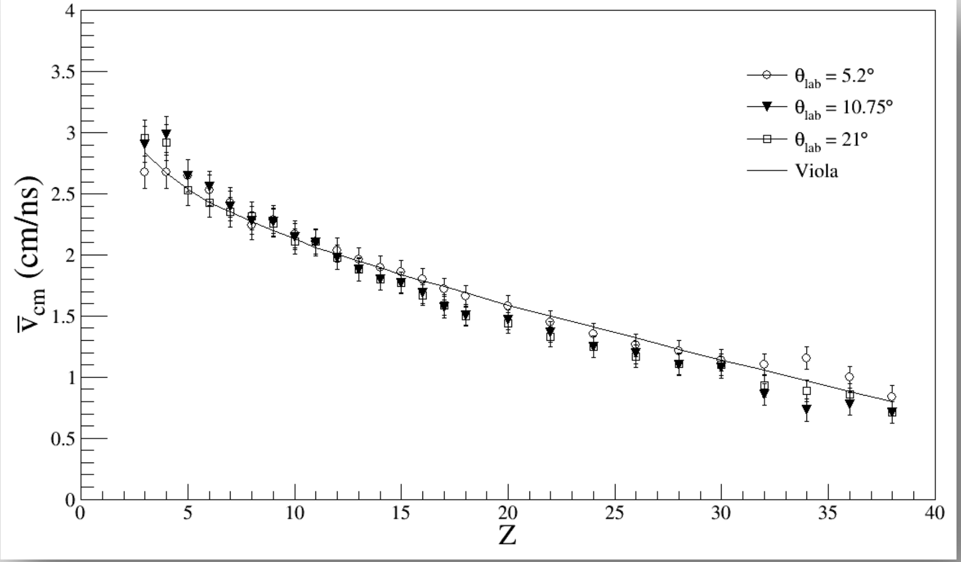
Fragment Kinematical Features and Charge Distributions

Back to Inclusive normalized data

Average velocities in CM frame for fission fragments (n-poor)

Independent from emission angle and decreasing with Z

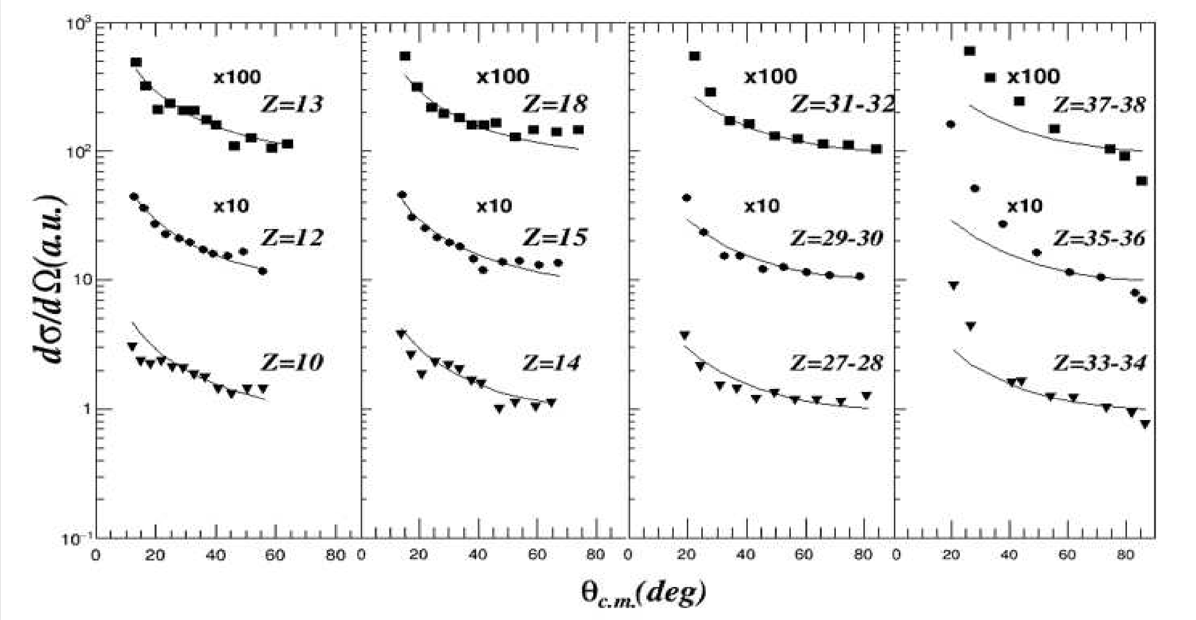
-> equilibrated process



Good agreement with Viola-Hinde systematic for fission

Regular behavior slightly disregarded for Z>30, maybe due to to the dynamical mechanism contribution

Angular distributions of fragments in CM frame (n-poor)



1/sinθ behavior, expected for a production via a long lived system –> fission like mechanism from equilibrated source

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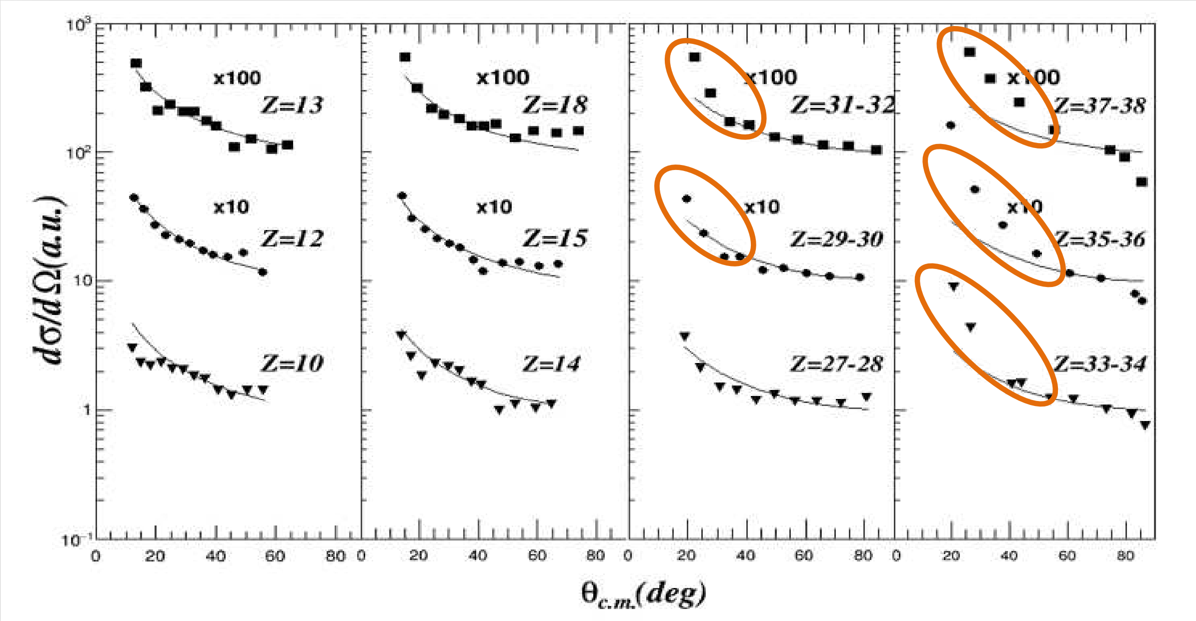
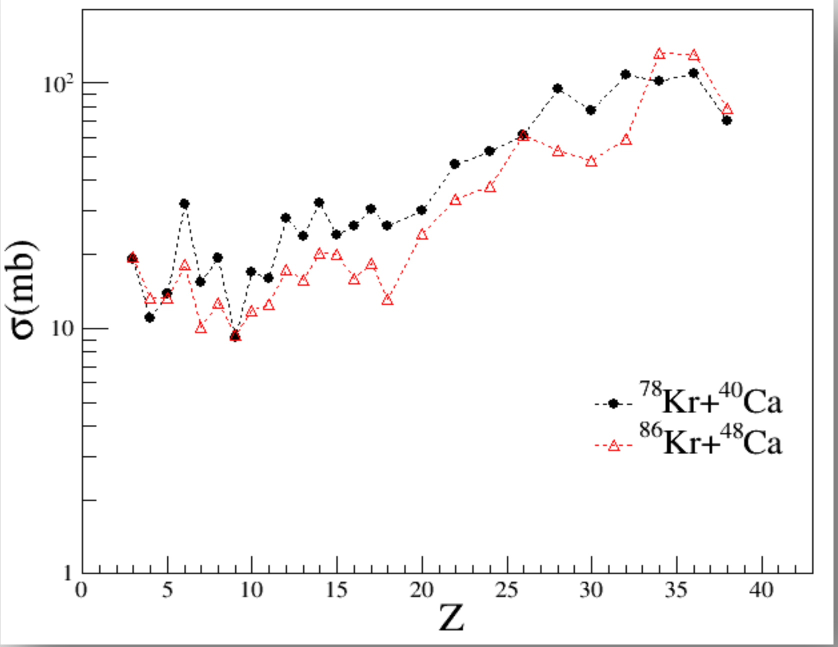


1/sinθ behavior, expected for a production via a long lived system –> fission like mechanism from equilibrated source

Z > 28 stronger contribution at smaller angles, confirming a not fully equilibrated binary mechanism

Integration of 1/sinθ angular distribution gives production cross sections for each Z



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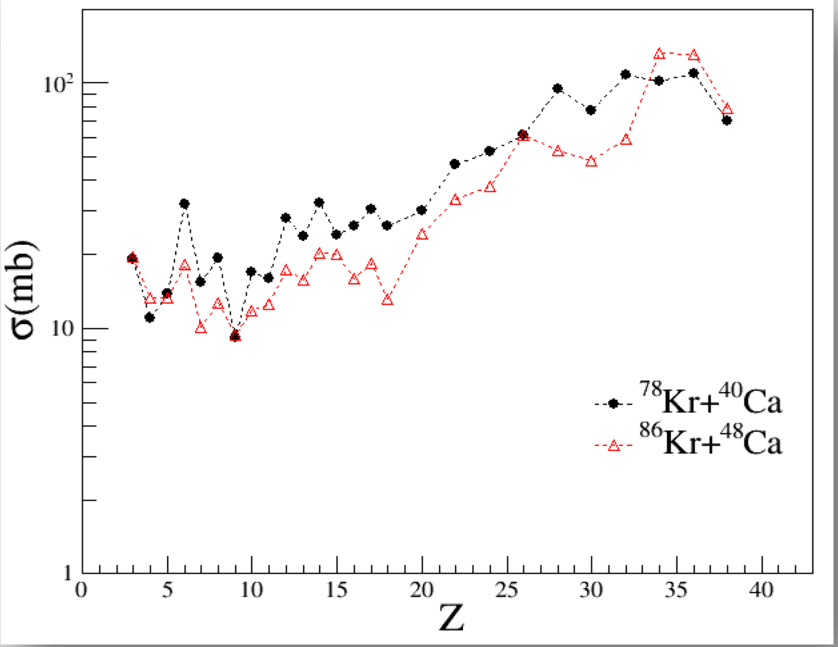

Strong even-odd staggering effect -> preference for even value of Z the atomic number, because of the larger binding

Staggering more pronounced for the neutron poor system, in particular for Z ≤ 10

Fragments production globally favored for n-poor

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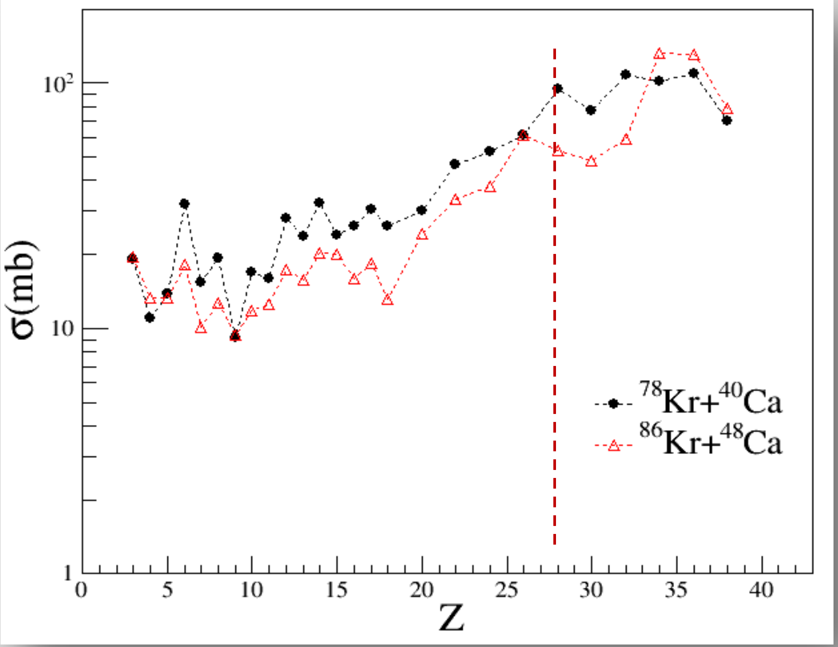

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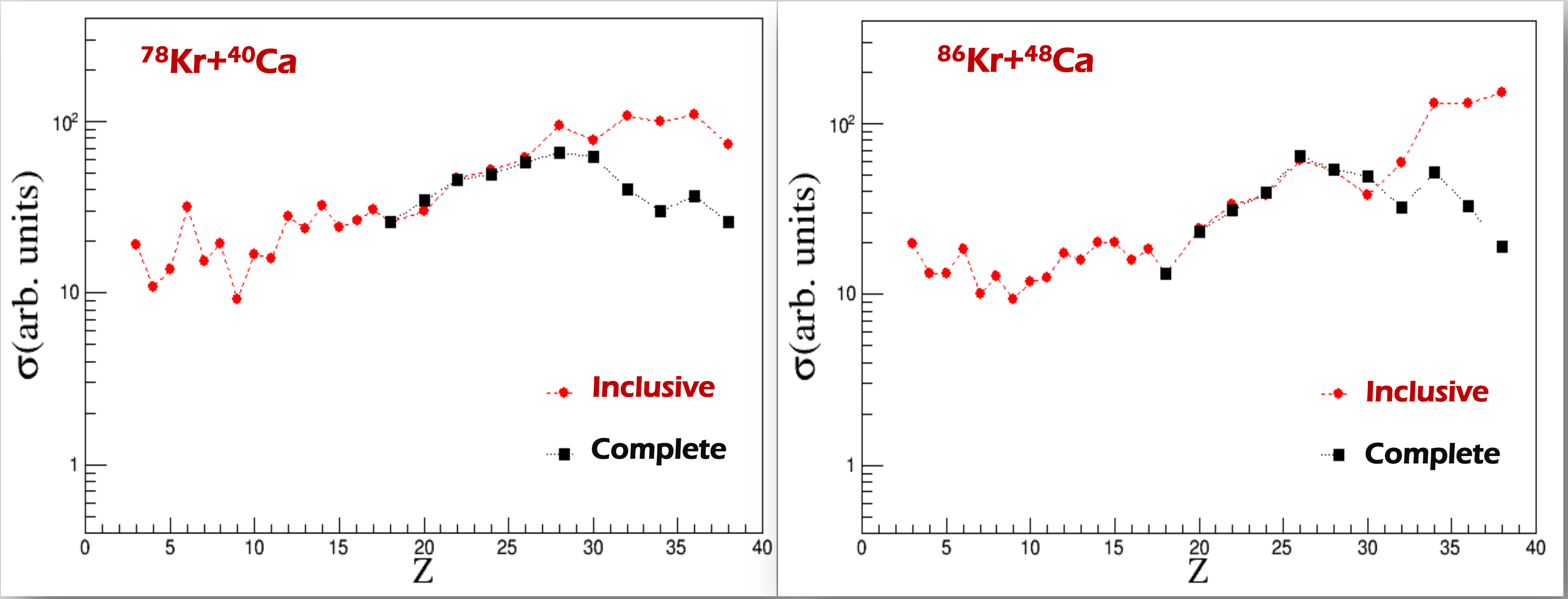
Charge distribution asymmetric with respect to $Z_{CN}/2=28$

Possible contamination of DIC for heavier fragments even with 1/sinθ behaviour -> process not fully relaxed in mass

Main Results

Selection of complete events to get rid of very dissipative binary collisions (TLF not detected)

Cross sections normalized to value for Z = 18

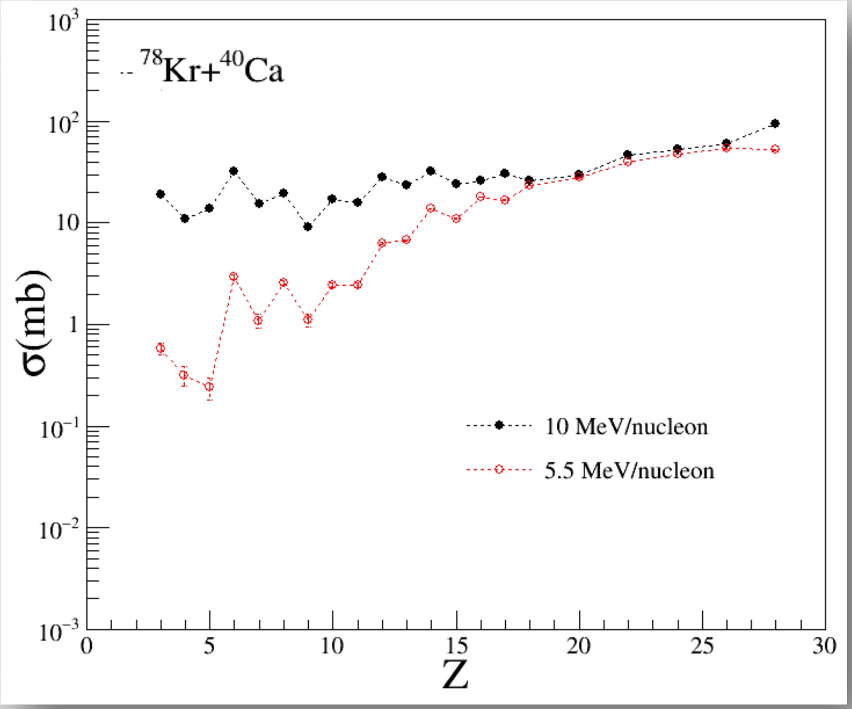


DIC process influence on fragment production starting from Z > 26 - 28

Comparison for n-poor system at 5 MeV/A for Z < 30

Larger cross section at higher energy

Difference decreasing with increasing of Z



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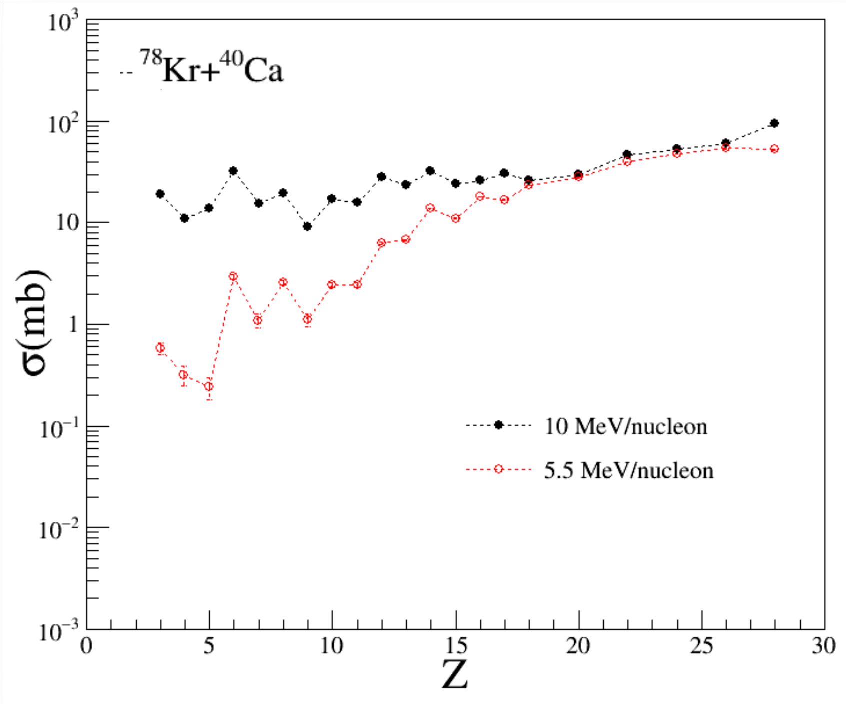

Lower energy -> favored decay mode is evaporation

Higher energy -> fusion-fission channel prevails on, with a stronger production of fragments

Reaction Cross sections

Process cross sections deduced from $\sigma(z)$

- Fusion Evaporation - **ER**: Z > 41/45 subtracting **FL** for heavy fragments
- Fission Like - **FL**: Z = 3 - 28/26 -> corrected for **DIC**
- Reaction: elastic scattering (quarter point recipe)

	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
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Fusion Evaporation similar in the two systems

Fission Like more present for n-rich systems

Fusion reaction cross sections (σ_{ER} + σ_{FL}) in good agreement with a recent systematic study of Eudes et al.

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Difference σ_{Reac} - σ_{Fus} probably due to the DIC, more pronounced for the n-rich system

Difference in σ_{FL} between n-rich and n-poor higher than in the low energy case, with only 4n difference rather than 16n

Comparison with Models

Di Nuclear System - JINR Dubna & INP Tashkent

Dynamical evolution of the composite system is considered

Nucleon exchange drives towards compact configurations:

- **CN decaying by evaporation or fission**
- **DiNuclear system leading to QF**

Decay process is then traced
until all fragments become cold

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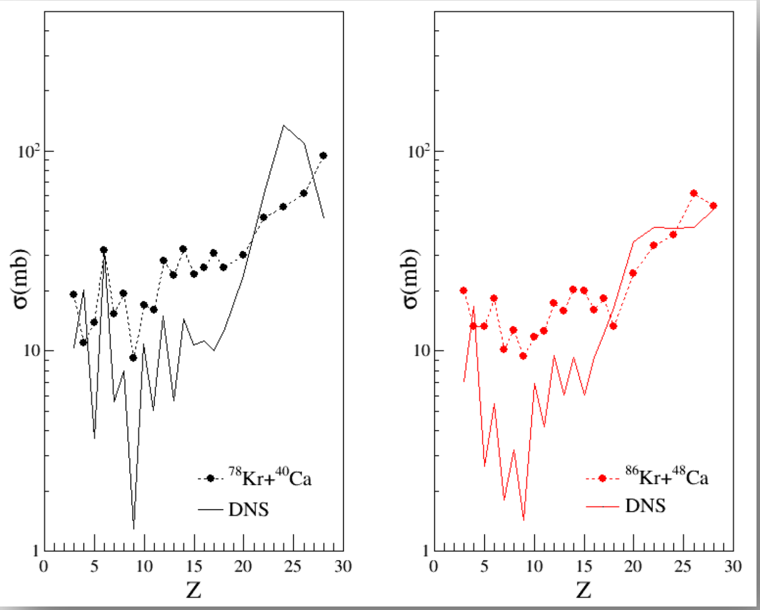
S.A. Kalandarov et al. PRC 93 (2016) 024613

Staggering is reproduced

Cross sections are slightly under estimated



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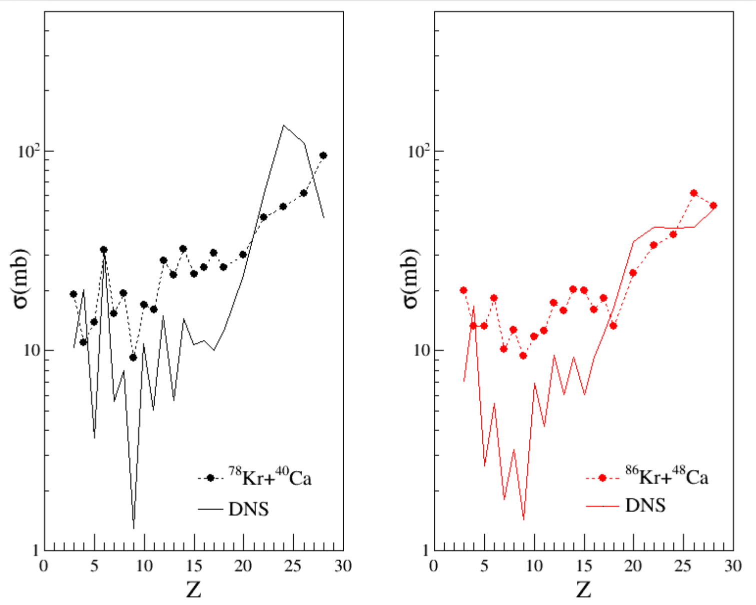

Most of the fragments comes from the quasi-fission process, strongly affected by the J_{max}

Underestimation indicates fusion and quasi-fission events also at b larger than in the model

GEMINI++

Statistical model code considering fusion, CN formation, evaporation, fission and sequential binary- decay

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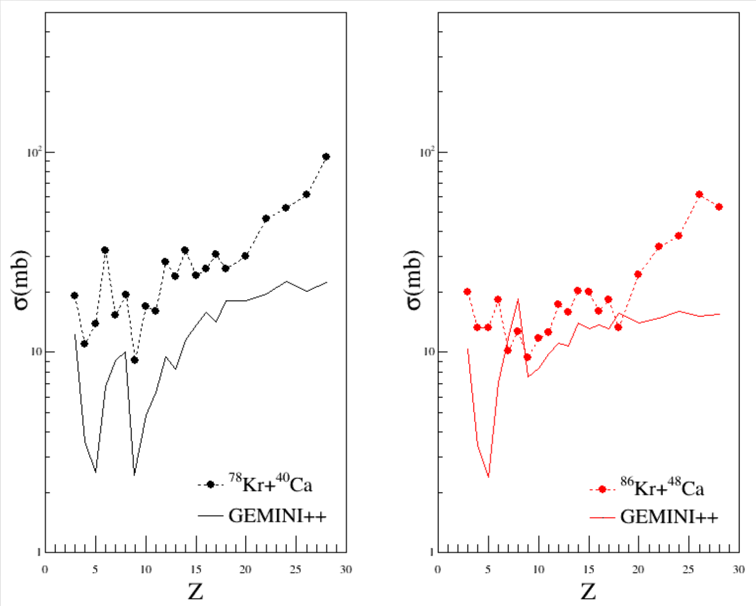
Statistical model code considering fusion, CN formation, evaporation, fission and sequential binary- decay

J_{max} and level density parameter used for DNS

Lower fragments yield, probably due to absence in the model of

- **quasi fission**
- **incomplete fusion**
- **pre-equilibrium**

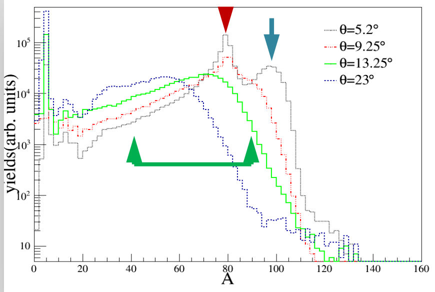


Conclusions and Perspectives

ISODEC Experiment ^{86}Kr + ^{40,48}Ca -> ^{118,134}Ba E/A=10 MeV/A

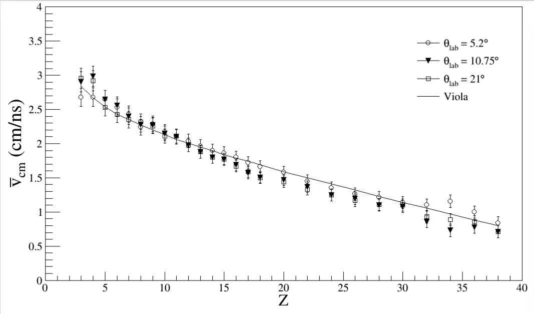
CHIMERA detector at LNS-INFN Catania - LEA/COLLIGA

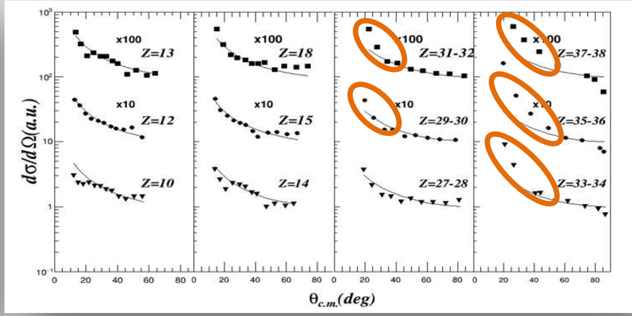
N/Z ratio and energy effects on reaction mechanisms



Contributions from different reaction mechanisms ER FL DIC

Kinematical characteristics typical of an energy equilibrated system





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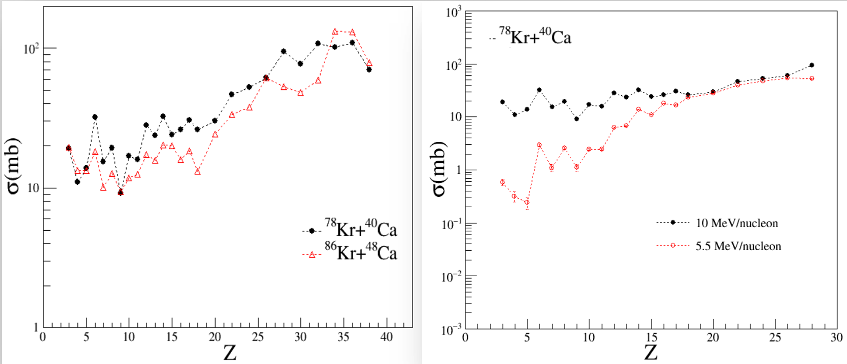

Charge distributions

Staggering in cross sections

DIC effects Z>28-30

More fragments for n-poor and at higher E

Process cross sections

Evaporation comparable

Fission more present for n-poor

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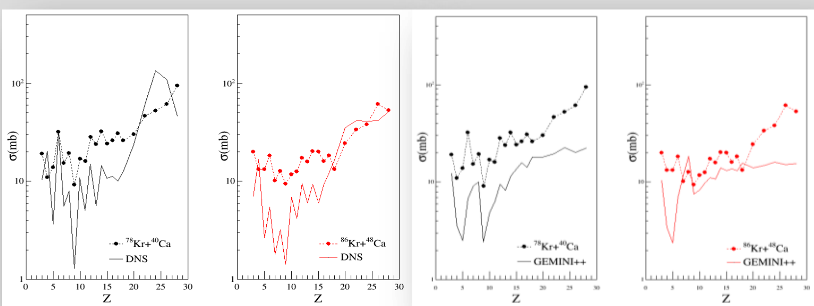

Comparison with models

Underestimation of the sigma

larger b should contribute

DNS seems to works better

-> important contribution of quasi-fission events

Further analysis to be done:

- Study of three fragments events and in particular Projectile like Fragment fission, already analyzed at higher energy
- Analysis of Deep Inelastic Contribution as a function of N/Z
- Analysis of LCP energy spectra in coincidence with ER and FF -> secondary decay, source characteristics (Z. Xiao)
- Refinement of theoretical calculations: comparison with a microscopic transport models to see relation among different mechanisms as a function of impact parameter, possible effect of N/Z (E_{sym})
- Further GEMINI++ calculations for particle energy spectra in order to have information on “a” parameter (P. St-Onge)

Letter Of Intent presented at 3rd SPES Workshop - Oct 2016

Isospin dependence of compound nucleus formation and decay

E. De Filippo INFN Catania - J. D. Frankland GANIL - S. Pirrone INFN Catania
G. Politi Università and INFN Catania - P. Russotto INFN LNS

Study of isospin effects on the reaction mechanisms with RIB delivered by SPES at LNS

- compound nucleus formation and decay
- competition between Statistical and Dynamical Fission

Interest in the intermediate mass: Kr, Cs, Sn beams on Ca Ni Sn

-> broad domain in n/p ratio in entrance and compound system

In particular

- $^{88-94}$Kr with 10^5 - 10^7 pps @ E/A = 10 - 12 MeV/A

Thank you all for the attention