International Workshop on Multi-facets of EOS and Clustering

INFN Istituto Nazionale di Fisica Nucleare

Nov 23 – 26, 2021 GANIL, Caen

Density evaluation in neck fragmentation at the Fermi energies

E.De Filippo, A.Pagano et al.
For CHIRONE collaboration CT-LNS-Me-Mi

1) INFN sezione di Catania, Italy
2) INFN-LNS, Catania Italy
3) Dipartimento di Fisica e Astronomia E. Majorana, Università di Catania, Italy
4) Dip. di Elettronica, Informazione e Bioingegneria, Politecnico di Milano and INFN Milano , Italy
5) Dipartimento di Scienze MIFT, Univ. di Messina, Messina, Italy

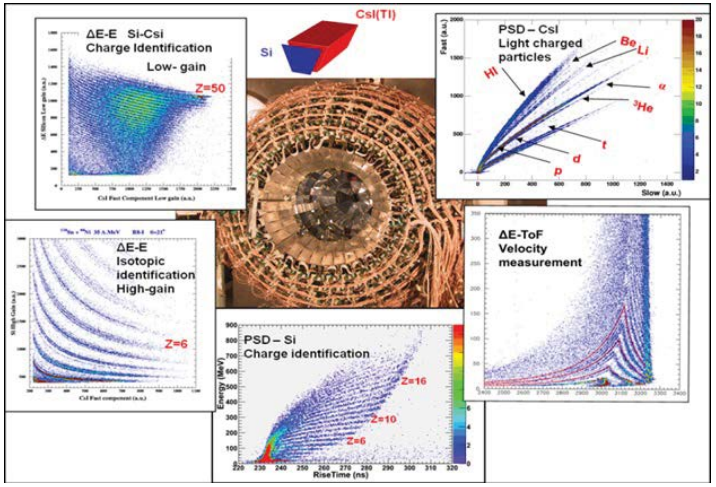
Foundation of the data analysis in:

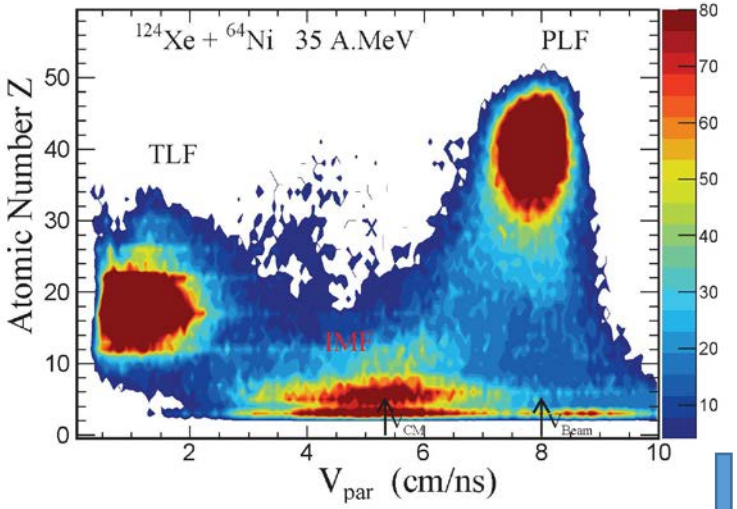
E. De Filippo, A. Pagano, J. Wilczy´nski et al., Phys. Rev. C 71, 044602 (2005)
E. De Filippo and A.Pagano, Eur. Phys.J.A50,32 (2014)
A. Pagano et al., Eur. Phys. J. A56, 102 (2020)
P. Russotto et al., Eur. J. A56, 12 (2020).
Theory:
V. Baran, M. Colonna, M. Di Toro, Nucl. Phys. A 730, 329 (2004)

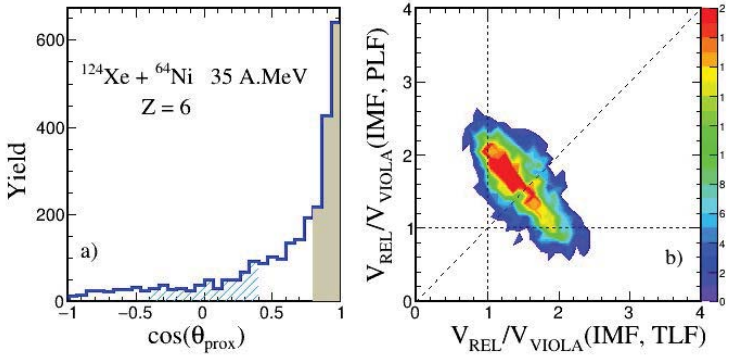
The aim of the work

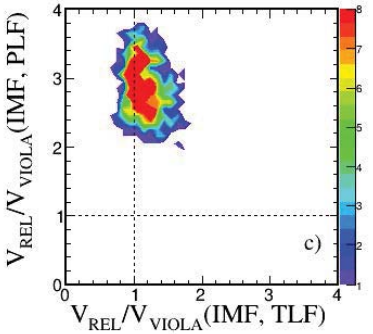
Density determinations of nuclear systems in thermal equilibrium or, alternatively, in fast evolving dynamical system (at a given instant of the evolution) is a way to constrain the dynamical phase or alternatively the thermal equilibrium phase (if any) based on some assumptions about the nuclear systems (shapes, excitations, decay path, ….) . In this short contribution i will illustrate a method to be applied to the so-called neck fragmentation reaction, where mostly of the reactions are ternary reactions coming from a partial overlap of the nuclear system generated in semi-peripheral collisions. The analysis is supported by simple, but transparent assumptions. Experimentally, It is based on the detection of the target like nucleus, the projectile-LIKE nucleus and an associated Intermediate mass fragment at mid-velocity (mostly triple coincidences) in a wide range of angular region (ideally in a 4pi geometry) as it is allowed by a 4pi detector system having very small detection threshold (~1 MeV) (like CHIMERA and INDRA).

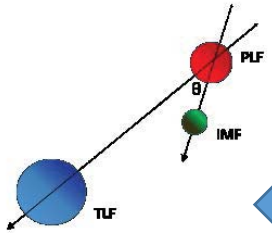
A brief of history of the analysis with CHIMERA:

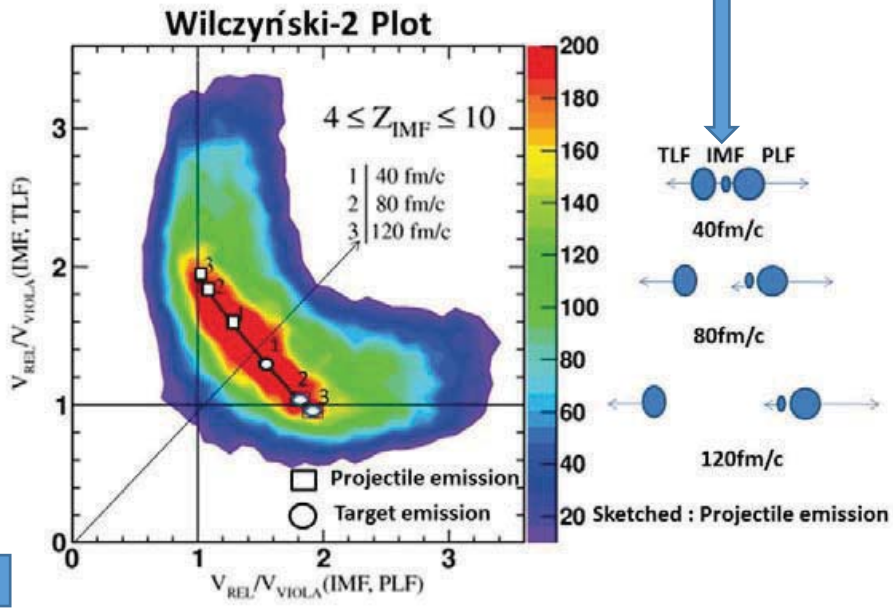








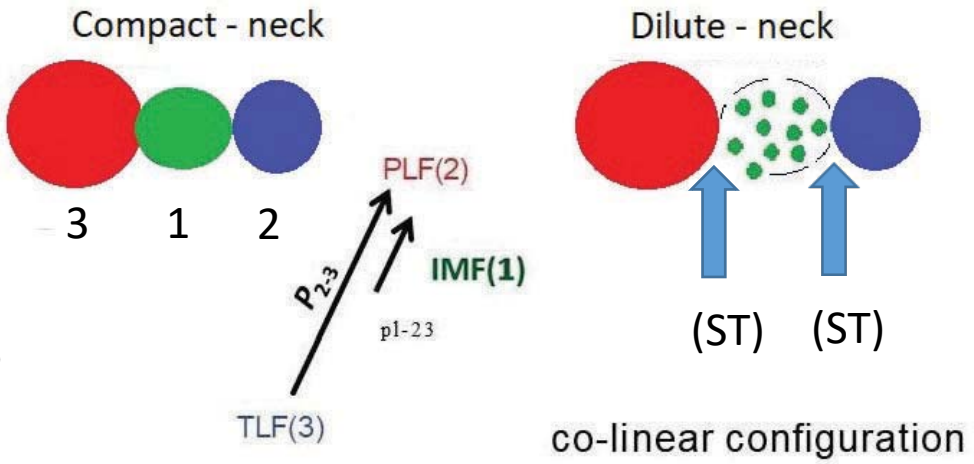




First interpretation of this plot for 12Sn+64Ni at 35MeV/Nucleon:
A.P. et al. Nuclear Physics A734 (2004) 504-5 11

The starting of the analysis (IDEA)

Simple representation of the ternary neck emission at the time of separation (t sep.)



$$E_{tot} = E_1 + E_2 + E_3 = \frac{P^2_{1-23}}{2\mu_{1-23}} + \frac{P^2_{2-3}}{2\mu_{2-3}}$$
$$= E_{1-23} + E_{2-3}$$

Kinematic (formulas) from:
G.G. Ohlsen, Nucl. Instrum. Methods 37, 240 (1965)

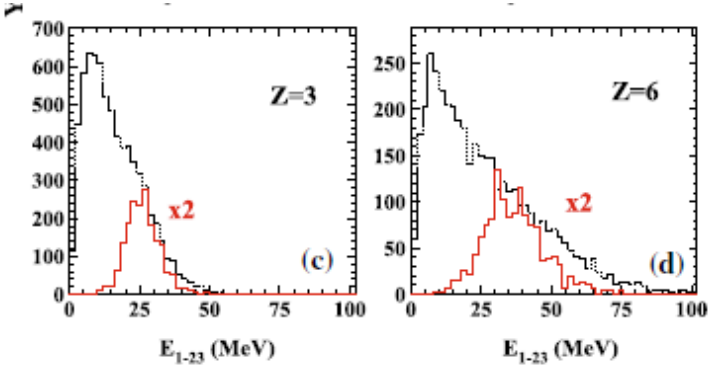
Neck separation dynamics:
a) Surface tension (ST) (1MeV/fm^2)
b) Coulomb repulsion (C)

Following this observation, the value $(E_{1-23})_{experimental}$ was compared with a pure "reduced" Coulomb repulsion E_{COUL} that is evaluated assuming different shape configurations of the nascent IMF at the moment of the earliest emission (supposed at $t = t_{sep.}$). Spherical shapes of PLF and TLF nuclei at normal density of radius $R = r_0 A^{1/3}$, where A is either the mass number of the PLF or TLF and

As a consequence, at the moment of IMF prompt emission, we take, as criterion, the simple ratio:

$$\frac{E_{(1-23)experimental=infinity}}{E_{COUL}} \sim 1$$

$$\left(E_{Coulomb(1-2)_{t_{sep.}}} + E_{Coulomb(1-3)_{t_{sep.}}}\right)_{\rho} = E_{COUL}.$$



Results for 124Sn+64Ni reactions:

$$\frac{E_{(1-23)experimental=infinity}}{E_{COUL}} \sim 1$$

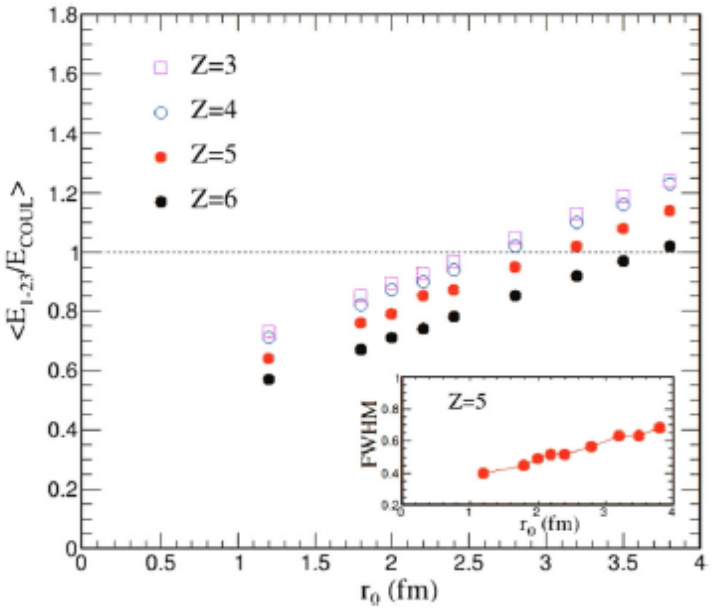


Fig. 8 Dependence of the peak position of the ratio $\frac{(E_{1-23})_{Exp.}}{E_{COUL}}$ on the value of the reduced radius r_0 ranging from 1.2 fm (compact configuration) to ~ 4.0 fm (super dilute configuration). Insert shows the FWHM of the spectrum for the Z = 5 as an example

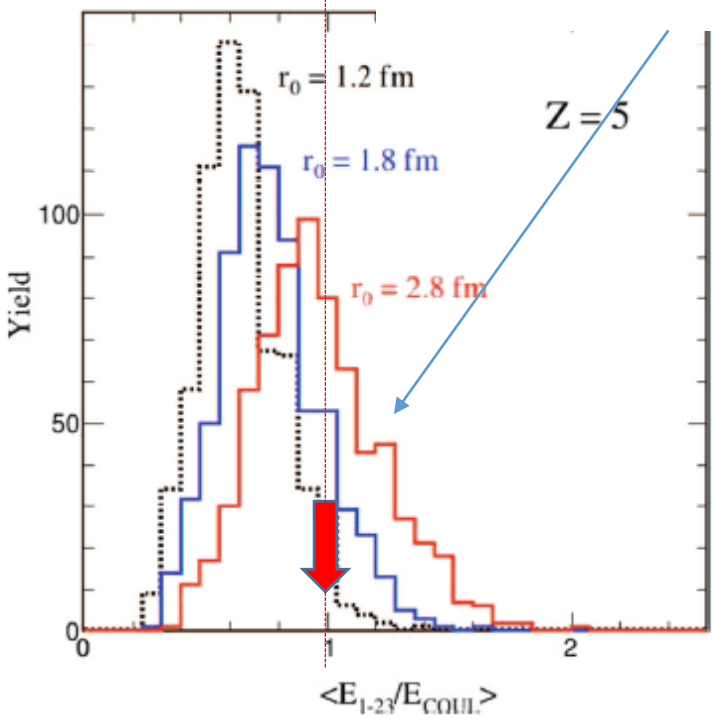
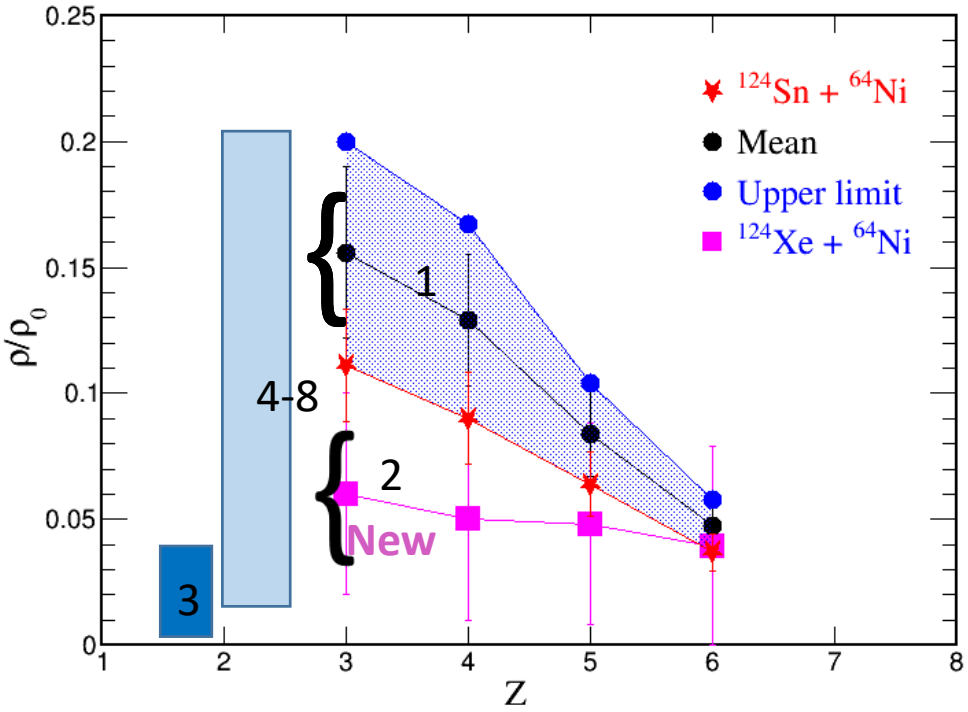
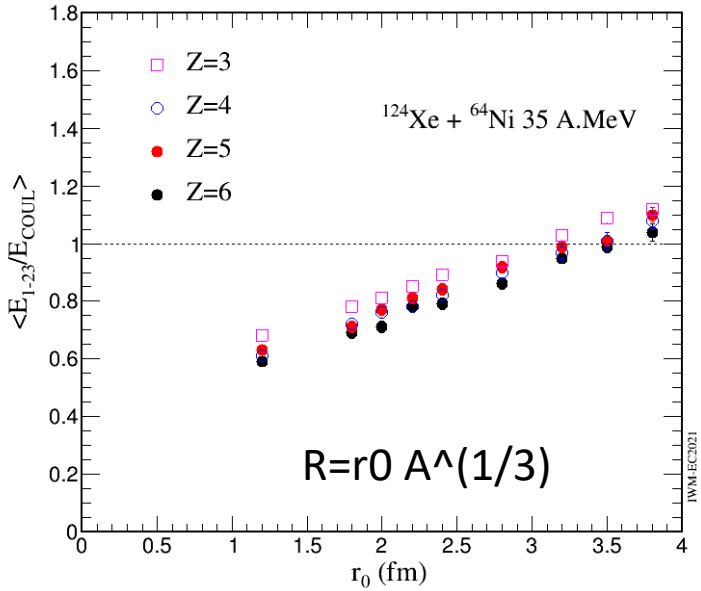


Fig. 9 Computed spectra of ratio $\frac{(E_{1-23})_{Exp.}}{E_{COUL}}$ for the boron element, for three values of the reduced radius r_0 = 1.2, 1.8, and 2.8 fm

Density extracted from the data:



Summary of present analysis:



1) Eur. Phys. J. A 56:102 (2020) (review)
2) IWM_EC Ganil (2021)
3) L. Qin et al., Phys. Rev. Lett. 108, 172701 (2012)

Neck-fragmentation

4) R. Wada et al., Phys. Rev. C 85, 064618 (2012)
5) Low Density In-Medium for Light Clusters?:
6) ……..

Central collisions(multi-fragmentation)

7) M. Hempel, et al., Phys. Rev. C 91, 045805 (2015).
7)] R. Bougault et al., J. Phys. G 47, 025103 (2020).
8) H.Pais et al. Phys. Rev. Lett. 125, 012701 –2020

cluster

Conclusions

In this brief report a simple (probably too simple?) method to evaluate nuclear density in semi-peripheral neck – like fragmentation reactions - has been discussed. From the point of view of the experimental analysis, the detection of triple coincidence in a very large angular range (4 pi) : a PLF a TLF and IMF is required.

Values of the extracted density ranging between 0.05 and 0.2 of the normal density have been quoted. They are compared with some experimental analysis obtained in central collisions where an expansion of a compressed systems is assumed in order to produce clusters in a multi fragmentation process.

We believe that the extracted values of density are in agreement with transport calculations predictions (non fully proved) (see Eur. Phys. J. A 56:102 (2020 and (*)) although further investigations are needed. Essentially reverse kinematics has been investigated by Sn and Xe induced reactions in this work. A more stringent test will be performed by extending the analysis to direct kinematics reactions.

(*) V. Baran, M. Colonna, M. Di Toro, Nucl. Phys. A 730, 329 (2004)

T.Y