

EoS at intermediate energy scales

- Equation of state of nucleonic matter (neutrons and protons)
 - $f(P, T, \rho_n, \rho_p)$ - Directly linked to nuclear forces between nucleons in the medium: explore in medium nuclear forces
 - How?
 - In the cosmos: compact stars and associated phenomenology (supernovae, neutron stars, multimessenger astronomy, ...) → talk by I. Vidaña
Astro Nuclear physics Vs. Nuclear Astro Physics
 - On earth: heavy-ion collisions at energies $E/A < 1000$ MeV (talks by Q. Fable, A. McIntosh, P. Russotto)
Laboratory controlled conditions: beam energy, combination of projectile and target masses/charges/isospin asymmetry
- No realistic way to derive nuclear matter properties directly from QCD
 - Ab-initio approaches: nuclear structure calculations + standard model symmetries
 - 😊 nuclear structure for only light nuclei and low excitation energies
 - 😢 no dynamics at the moment... difficult to compare to phenomenology of HIC

EoS and symmetry energy

$$E(\rho, \delta) = E(\rho, \delta = 0) + E_{sym}(\rho) \cdot \delta^2 + O(\delta^4)$$

Asymmetry term

$$\delta = \frac{\rho_n - \rho_p}{\rho_n + \rho_p}$$

$$\rho = \rho_n + \rho_p$$

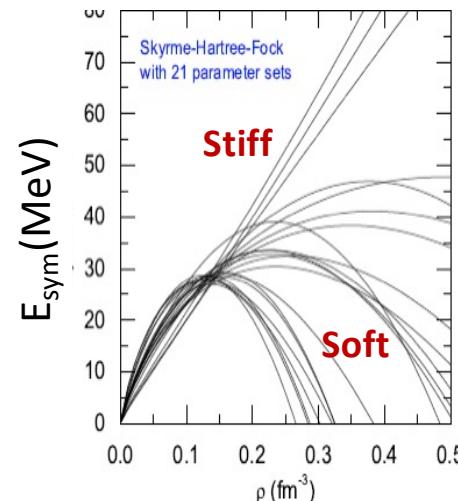
Many approaches... large
uncertainties....

...Especially at high densities
(three-body forces)

ZH Li, U. Lombardo, PRC74 047304 (2006)

Brown, Phys. Rev. Lett. 85, 5296 (2001)
Fuchs and Wolter, EPJA 30, 5 (2006)

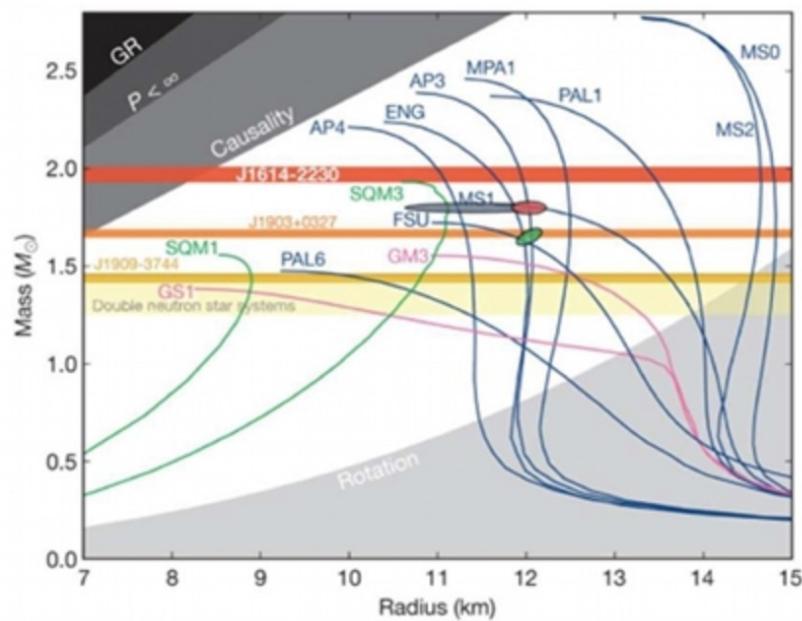
B.A. Li et al., Phys. Rep. 464, 113 (2008)



Esym enhanced in reactions with
large N/Z asymmetries (due to δ^2)

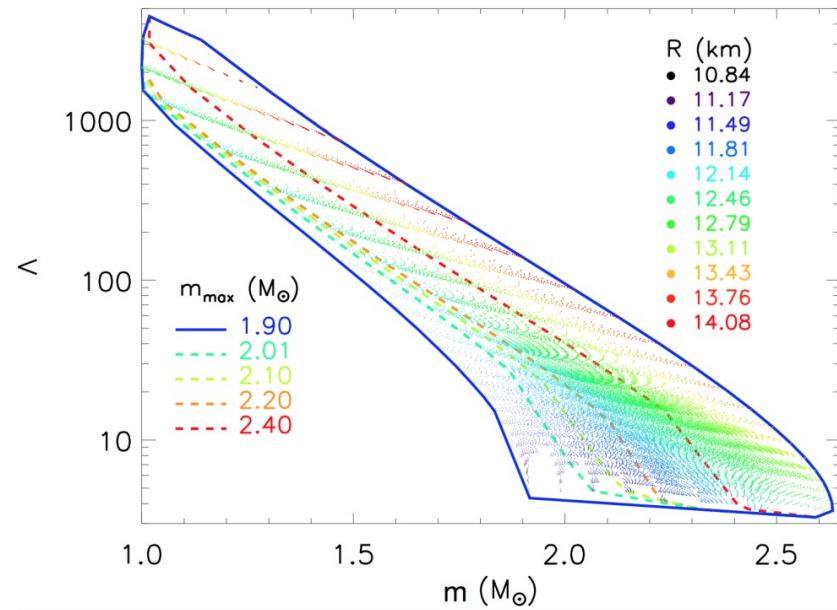
Neutron stars: laboratory for interdisciplinary research

EoS and Radius/Mass of neutron stars



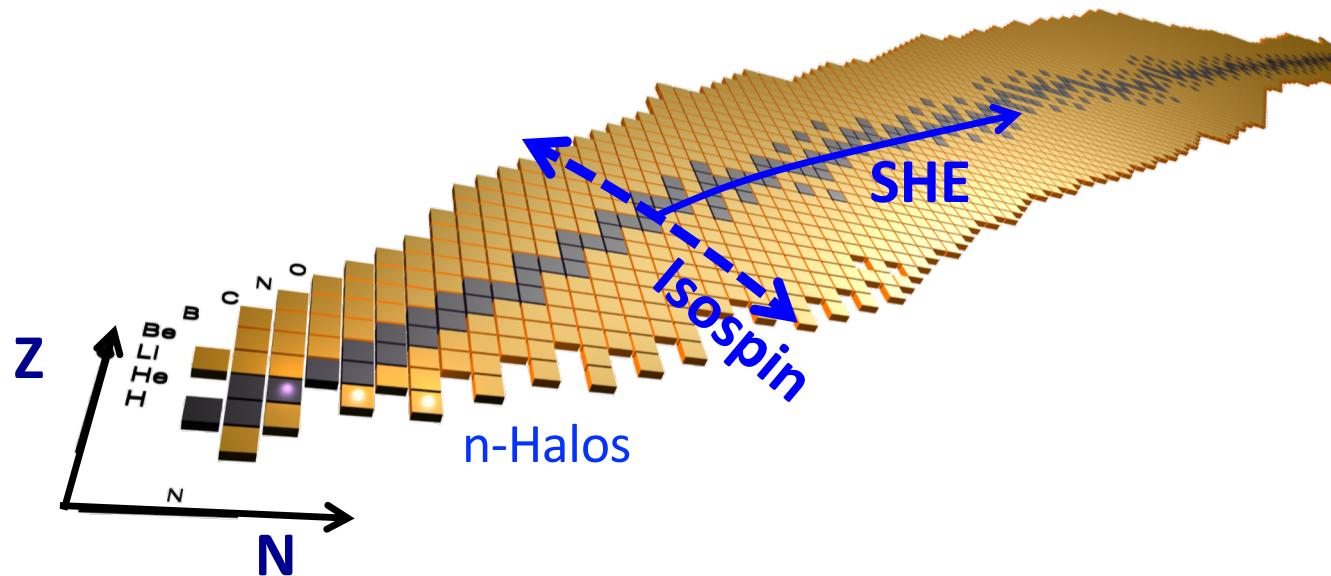
Astrophysical observations (ex. NICER space mission)

Tidal deformabilities in neutron star mergers

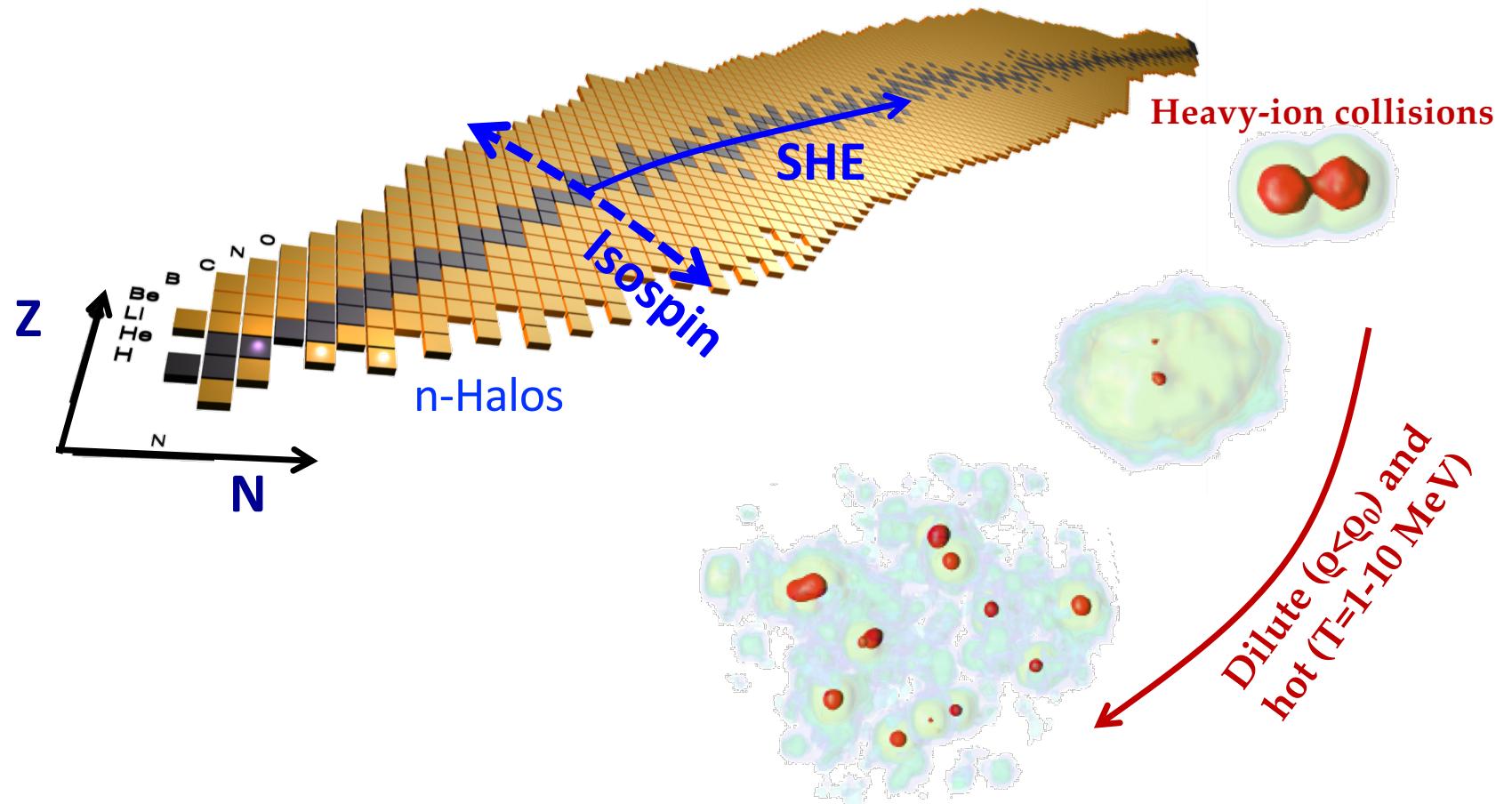


Gravitational Waves, r-process, ...

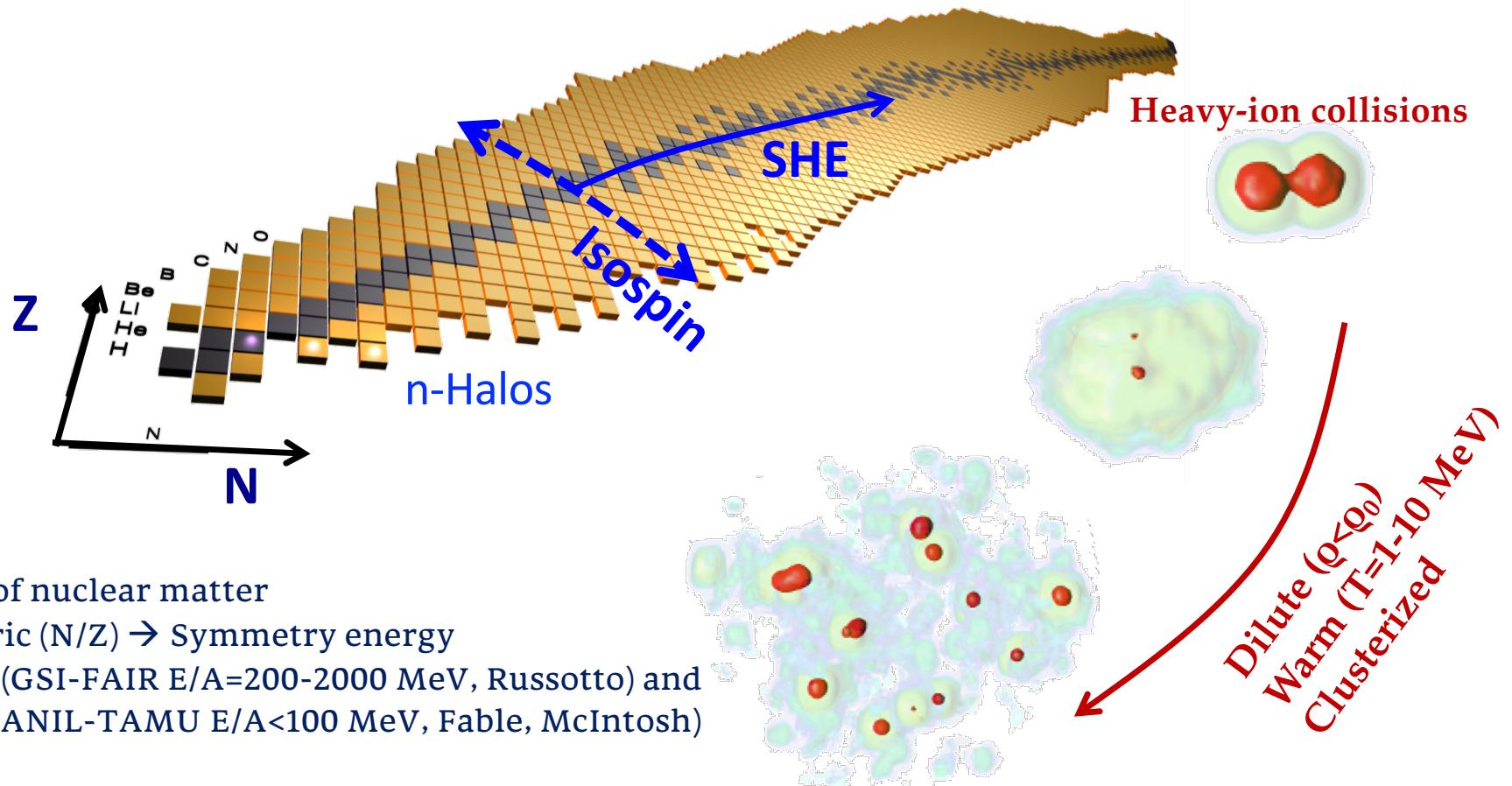
Laboratory based investigations: nuclear structure and dynamics



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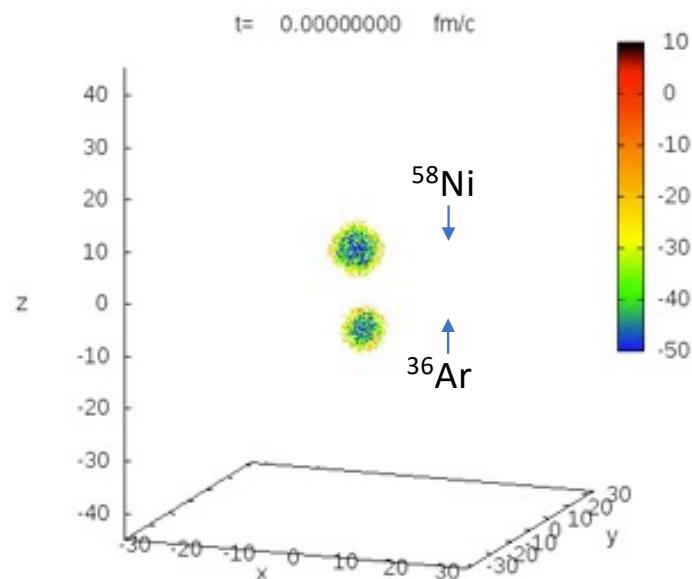


Laboratory based investigations: nuclear structure and dynamics



Jet fragmentation at intermediate energies: an example of complexity

BLOB (P. Napolitani, M. Colonna, PLB 797, 134833)



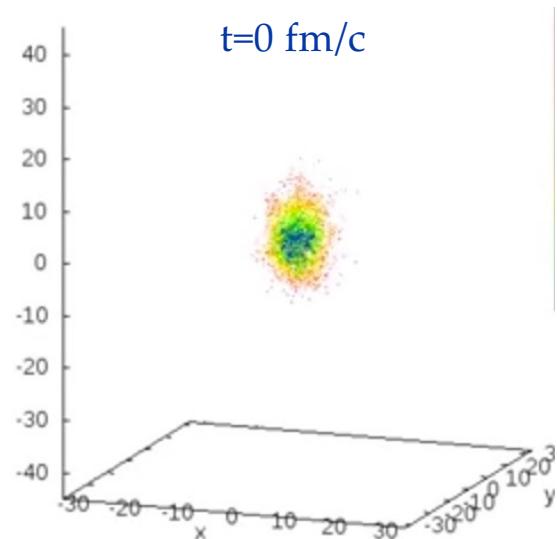
Transport models in intermediate energy heavy-ion collisions

$^{36}\text{Ar} + ^{58}\text{Ni}$

E/A=40 MeV

Jet fragmentation at intermediate energies

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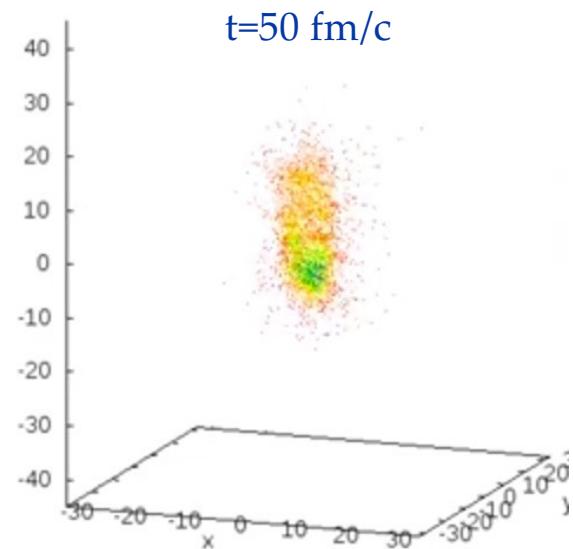


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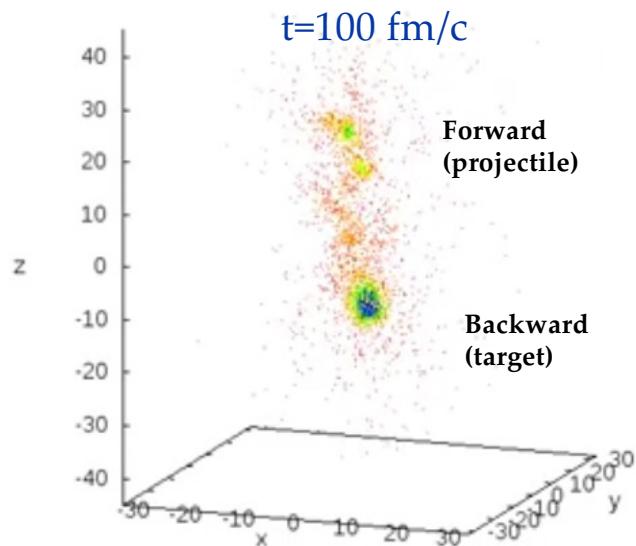


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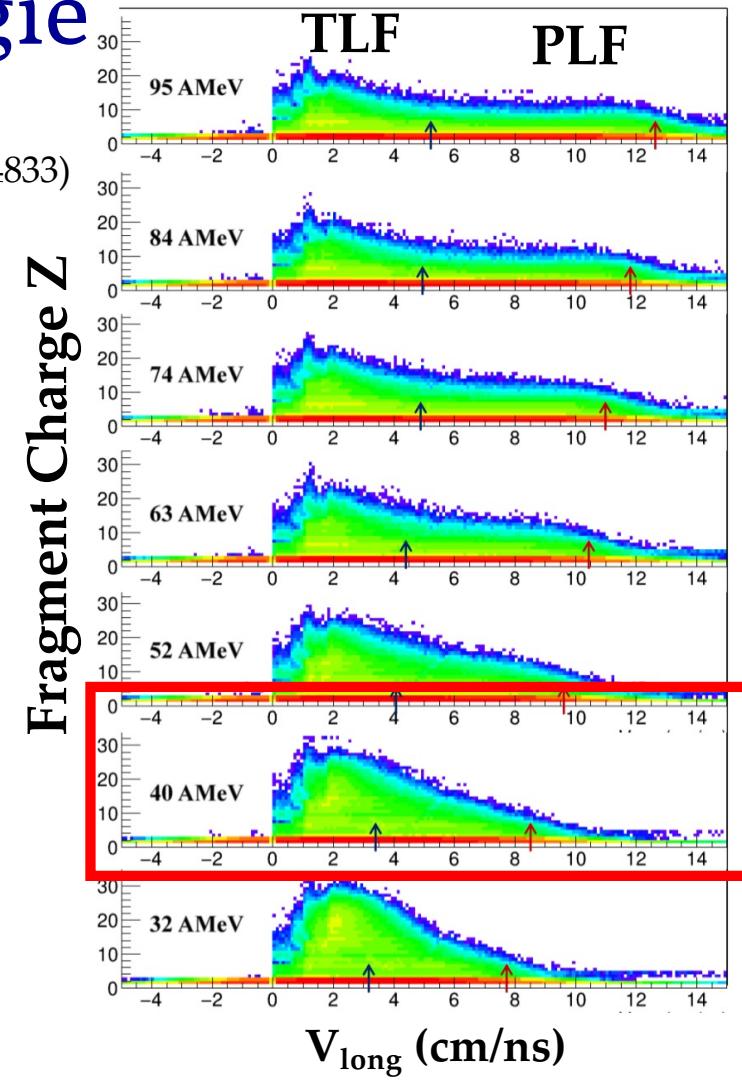
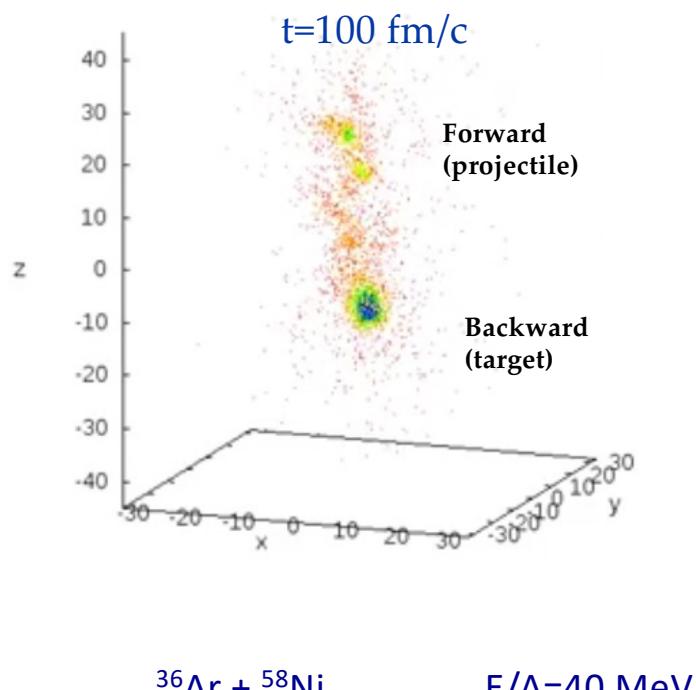


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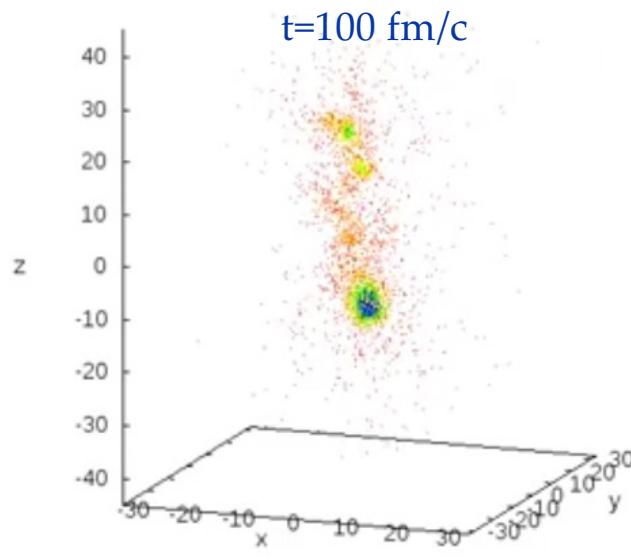
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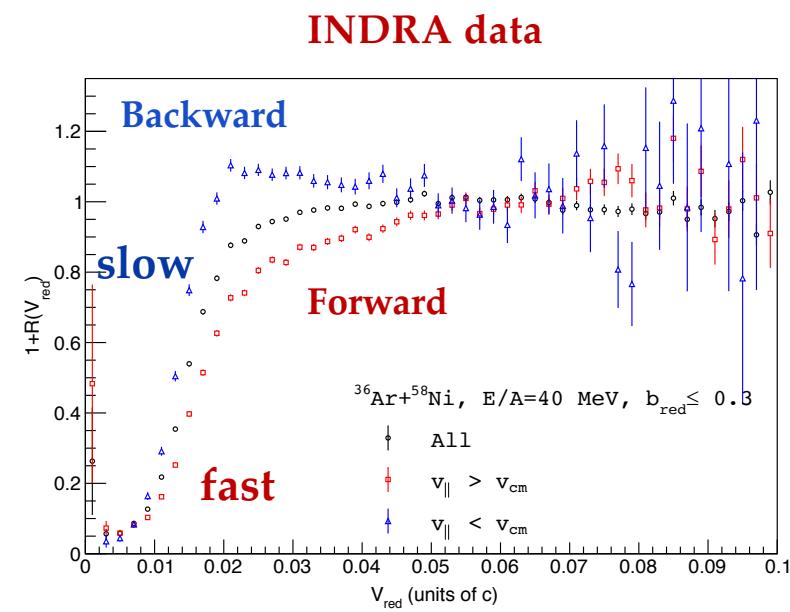


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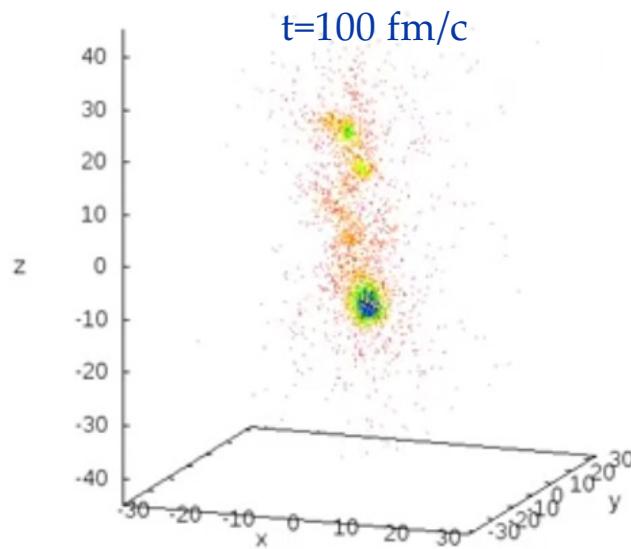
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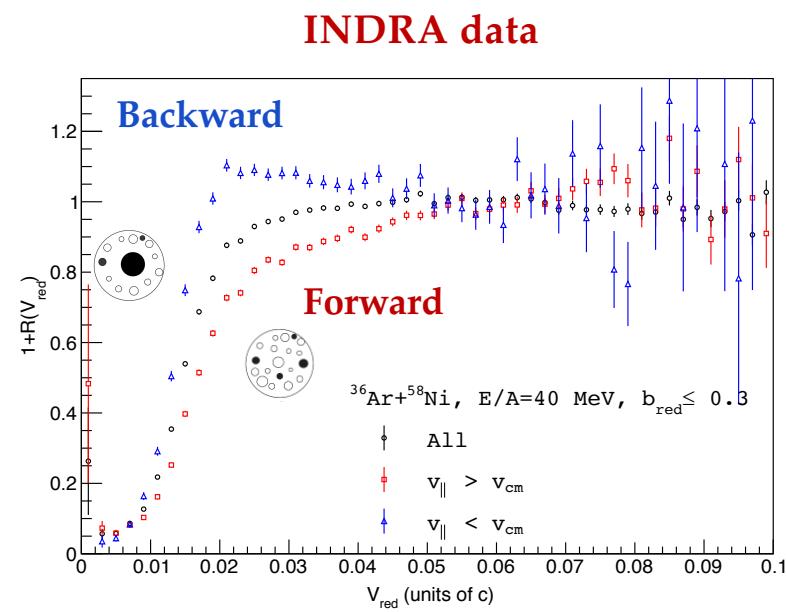


IMF-IMF correlation functions: Coulomb FSI dominates
→ Emission times (low V_{red})

Jet fragmentation at intermediate energies

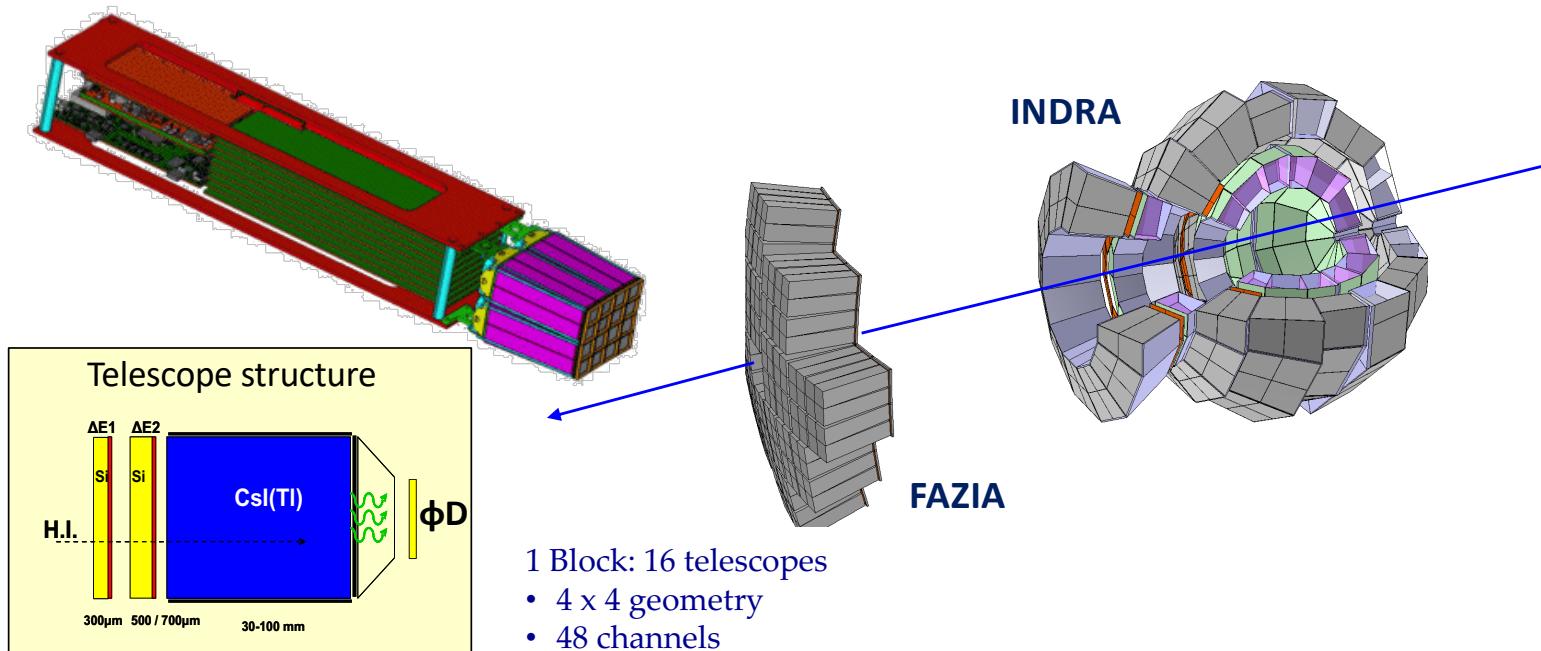


- **Projectile region:** fast volume emission (explosive) → homogeneous fragmentation
- **Target region:** long time-scales and surface evaporative → inhomogeneous fragmentation



IMF-IMF correlation functions: Coulomb FSI dominates
→ Emission times (low V_{red})
→ Charge splitting topology

INDRA-FAZIA @ GANIL



Very high isotopic resolution → Esym
4pi coverage → high quality and efficient
event characterization

Campaigns: 2019-2023