Outline

- Characterization of sub-saturation density sources in HIC
- INDRA-FAZIA campaign @ GANIL
- Probing sources: in-medium properties and structure (data from Indra@GANIL and MSU expts)

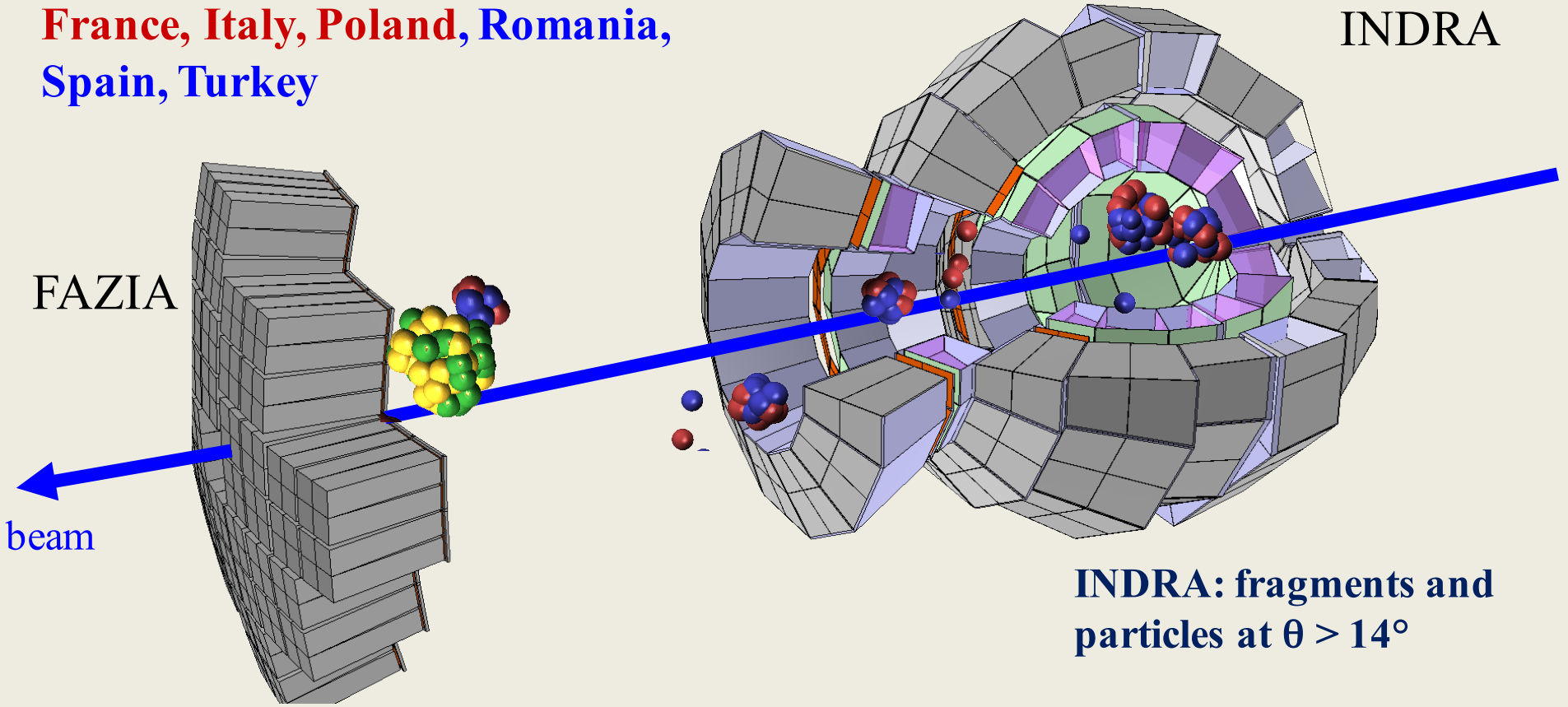
*Italy/France/Poland network

- ✓ Italy: INFN, Universities
- ✓ France: GANIL, IPN Orsay, LPC-Caen
- ✓ Poland: Krakow, Katovice

G.Verde, IPN Orsay/INFN-CT
A. Chbihi, GANIL

FAZIA-INDRA@GANIL

France, Italy, Poland, Romania, Spain, Turkey



INDRA: fragments and particles at θ > 14°

- **12 Blocks (192 telescopes)**
- **full Z & A identification of 1≤Z<25 at θ < 14°**

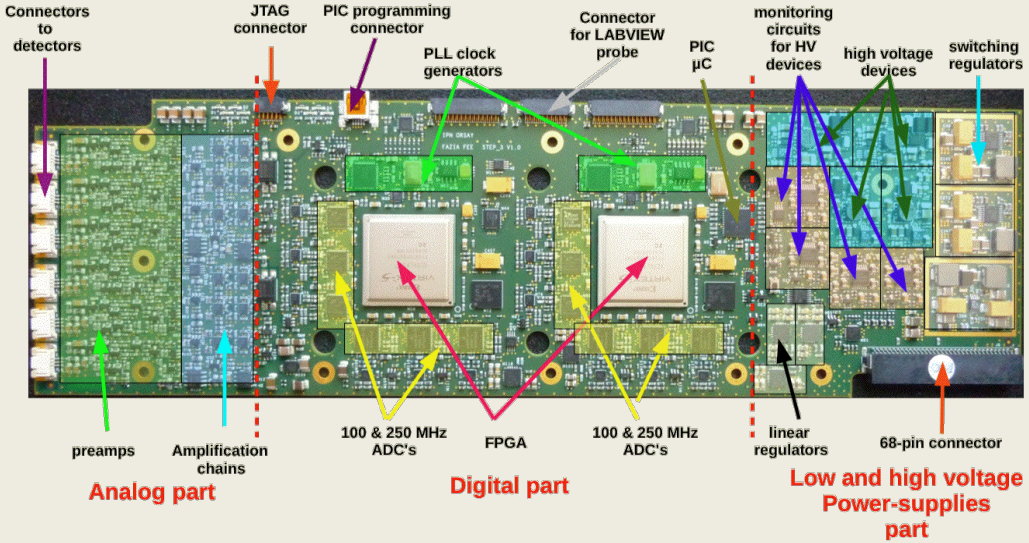
Campaigns expected in ≳ 2017-2019

Plans and physics

- Heavy-ion collisions with wide N/Z range:
  - **Stable beams at E/A=30-80 MeV**
  - **Mass, charge and isospin asymmetries**:
    ^{40,48}Ca+^{40,48}Ca, ^{124,136}Xe+^{58,64}Ni, others..
- Physics cases to address:
  - **Collective flow in central collisions*
  - Isospin diffusion/drift in mid-peripheral collisions
  - **Source characterization via correlation measurements*
  - **Clustering and structure in dilute nuclear matter*

FAZIA FEE cards @ IPNO

IPN Orsay: Design, construction



Thanks to LIA travel support to physicists and engineers!

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Journal of Instrumentation

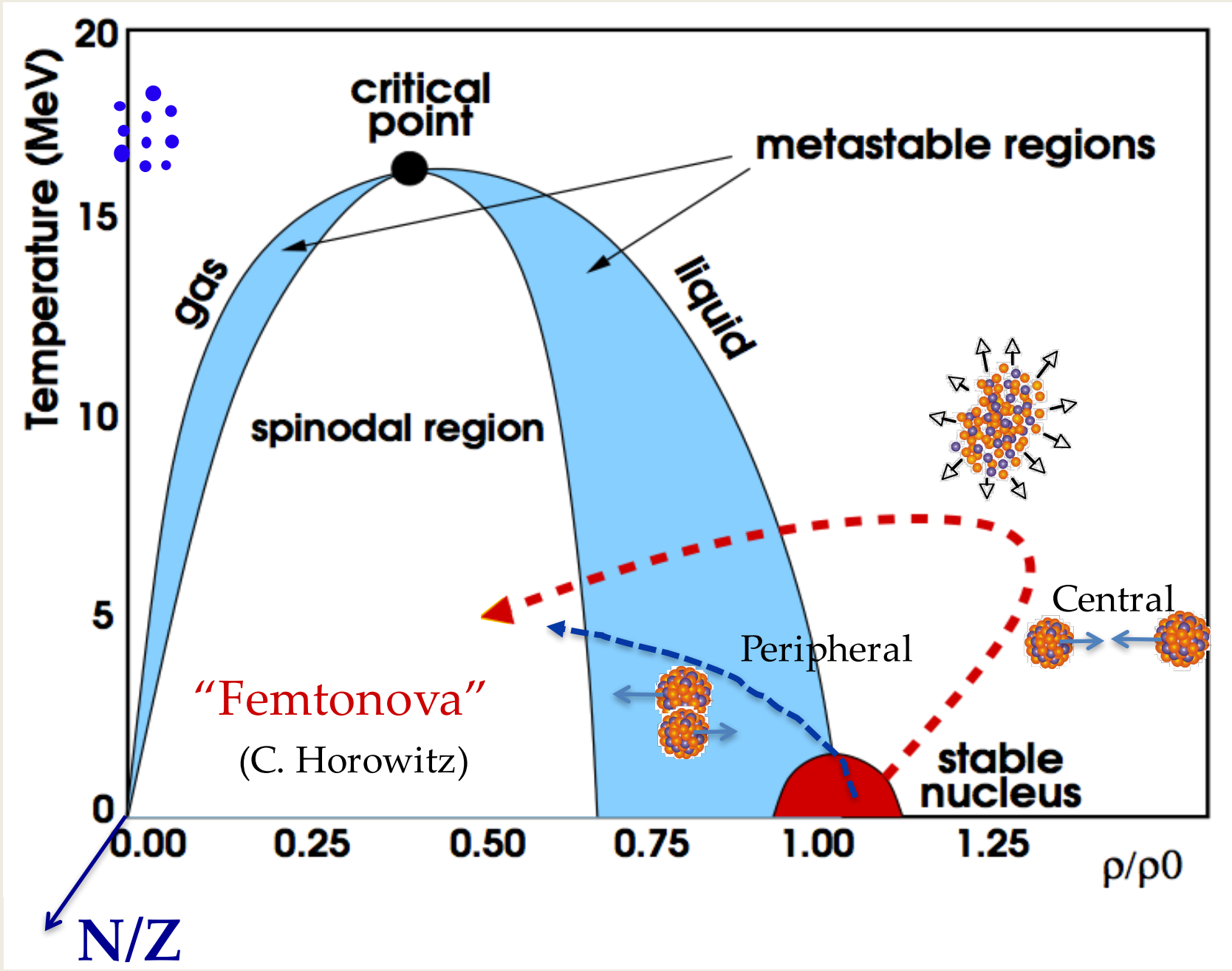
Front-end electronics for the FAZIA experiment

F. Salomon[1], P. Edelbruck[1], G. Brulin[1], B. Borderie[1], A. Richard[1], M.F. Rivet[1], G. Verde[1,6], E. Wanlin[1], A. Boiano[2], G. Tortone[2] Show full author list

Published 26 January 2016 • © 2016 IOP Publishing Ltd and Sissa Medialab srl
Journal of Instrumentation, Volume 11, January 2016
Topical Workshop on Electronics for Particle Physics

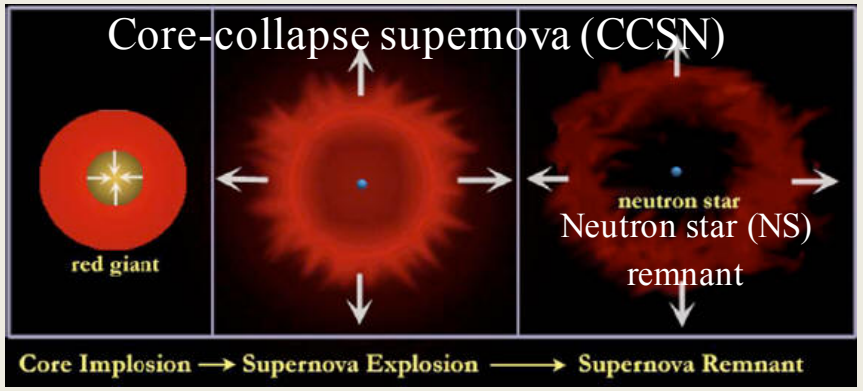
Article PDF

Structure of sub-saturation matter

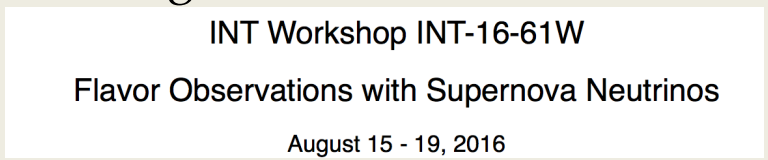


Supernovae neutrinos and EoS

April 2014, ECT* Trento



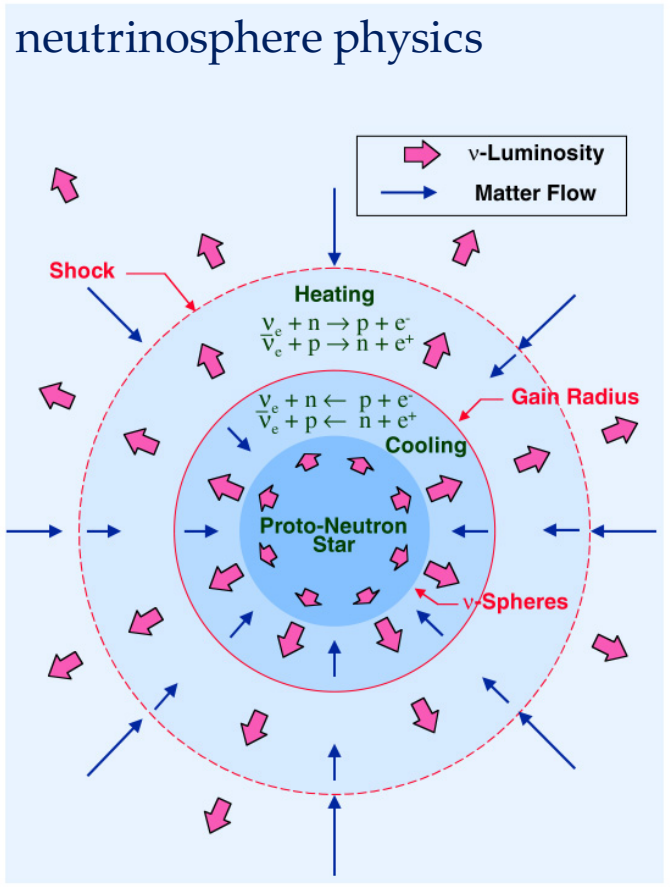
August 2016, INT Seattle

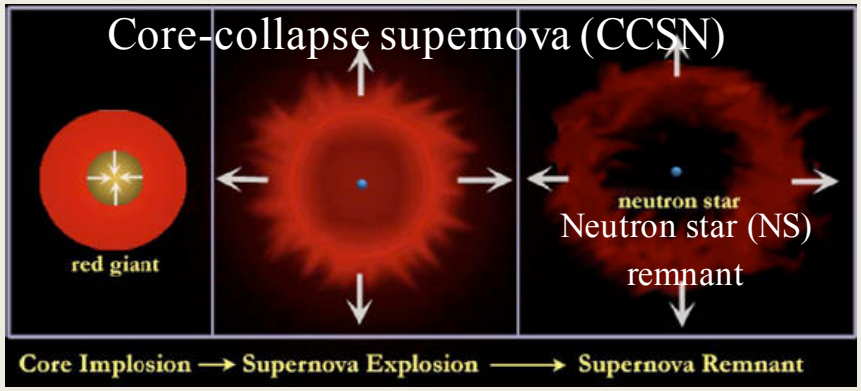


http://www.ectstar.eu/node/771
Org comm:
C. Horowitz, Indiana Univ. (USA)
J. Natowitz, Texas A&M (USA)
L. Roberts, Caltech (USA)
H. Wolter, Univ. of Munich (Germany)

http://www.int.washington.edu/PROGRAMS/16-61w/
Org comm:
C. Horowitz, Indiana Univ. (USA)
T. Janka, Max Plank Inst. (Germany)
S. Reddy, INT Seattle (USA)

Supernovae neutrinos and EoS





- Opacity of nuclear matter at **T>0** and $\boldsymbol{\rho < \rho_0}$ to out-coming neutrinos (SN dynamics, n/p abundance, …)
  → Role of light clusters (A<6)
- Weak processes

$$\nu_e + n \rightarrow p + e^-$$
$$\bar{\nu}_e + p \rightarrow n + e^+$$

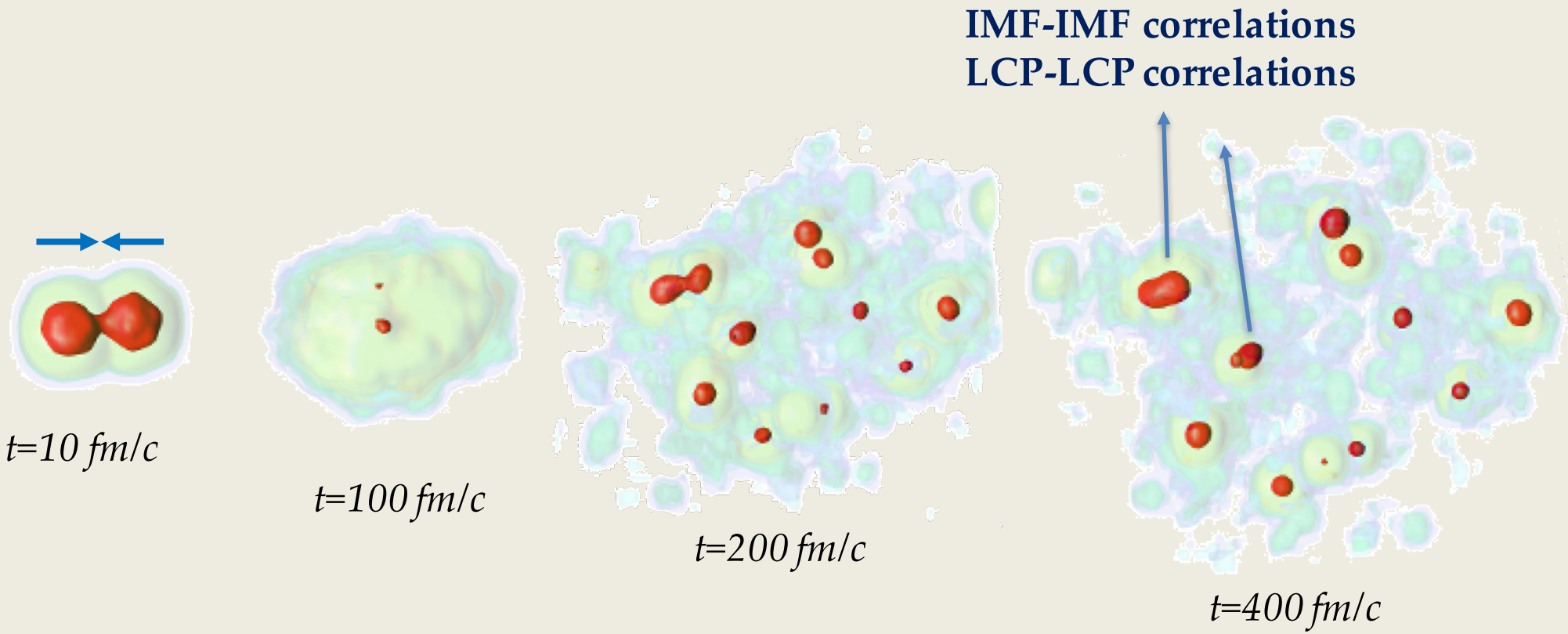
Neutrino-wind nucleosynthesis (νp-process)

Sub-saturation in-medium systems

BLOB

Space-time characterization of in-medium sources

- Density, Temperature, emission times, isospin asymmetry…



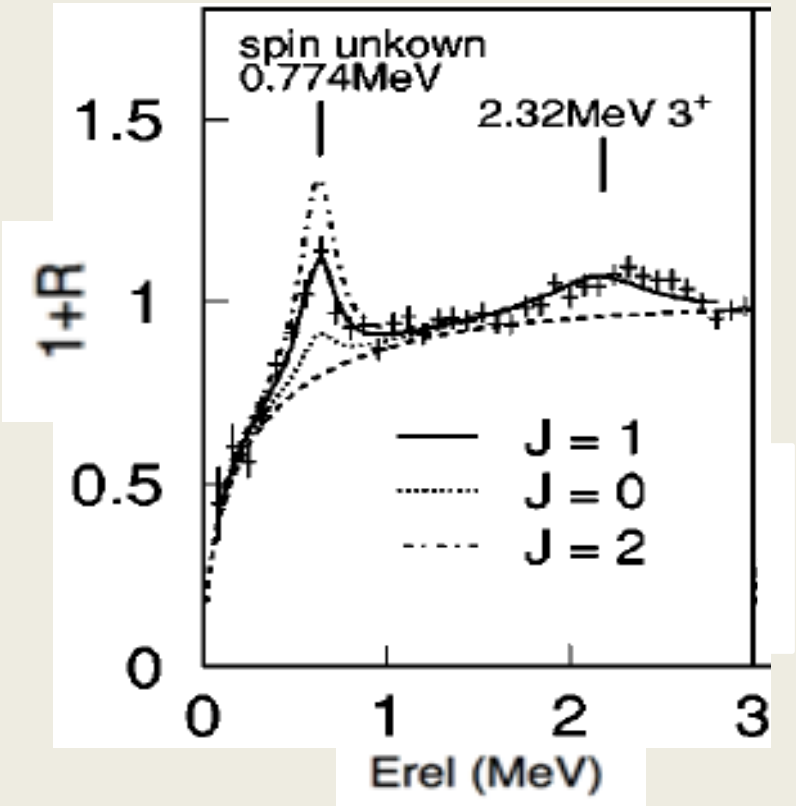
Central Xe+Sn E/A=56 MeV, b=0 fm

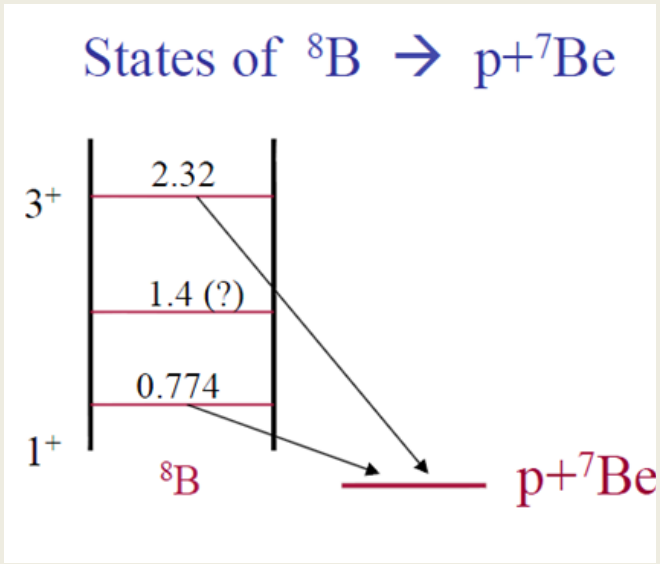
Spin of states

Decay
$^{8}B^{*} \rightarrow p + {}^{7}Be$

Xe+Au E=50 AMeV
central collisions

p-^{7}Be correlation function



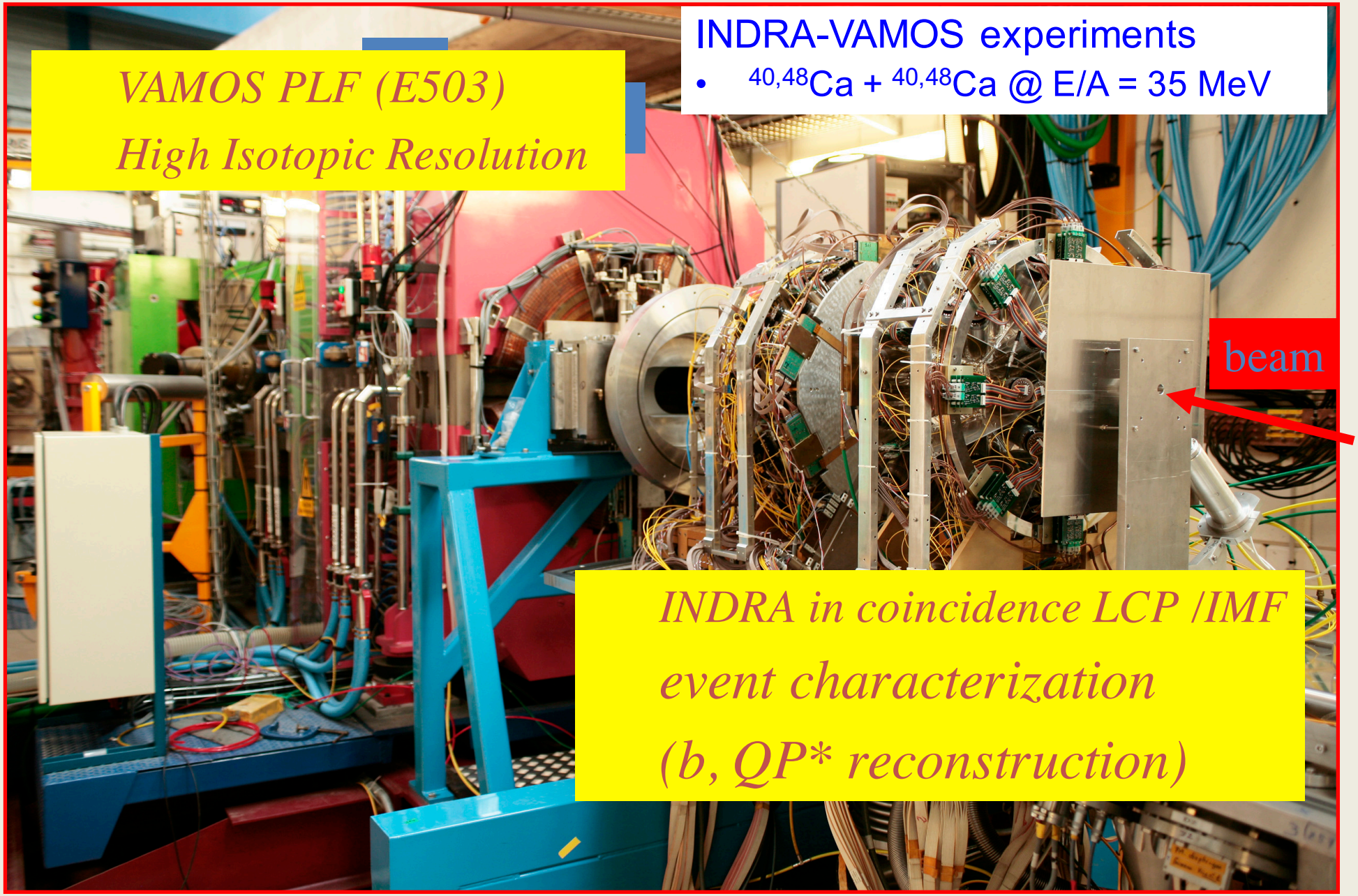


W.P. Tan et al. Phys. Rev. C69, 061304

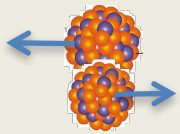
Resonance decays in dilute and hot expanding nuclear systems

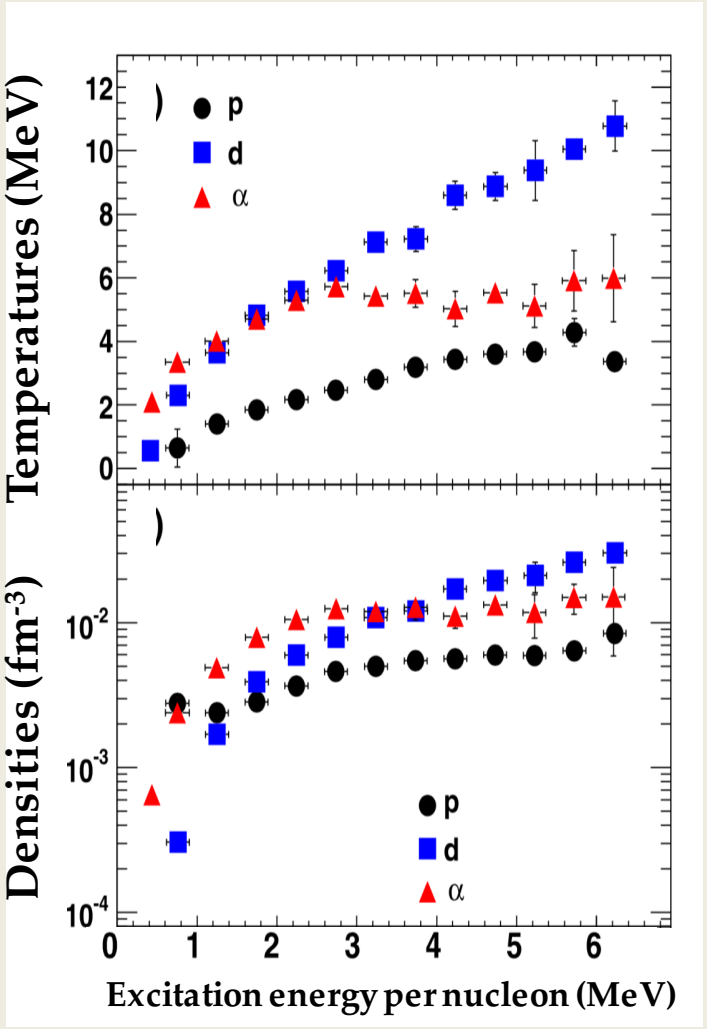
→ Need good characterization of medium

Densities in peripheral collisions



Densities in peripheral collisions





INDRA-VAMOS experiments

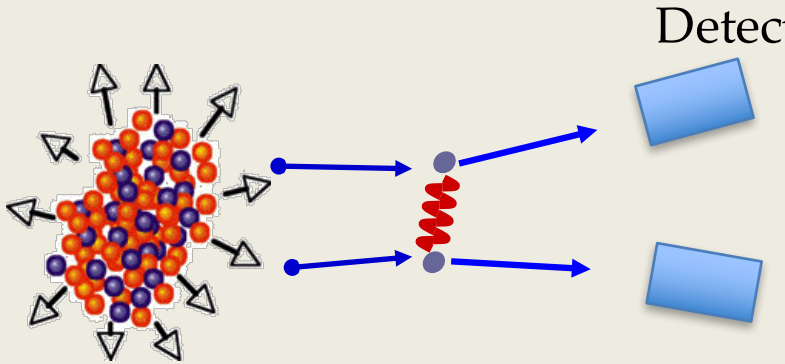
- $^{40}Ca + {}^{40}Ca$ @ E/A = 35 MeV

Decay of excited quasi-projectile

- Different particle species probe different densities: deuterons and alphas higher densities than protons (boson ≠ fermion?)
- Dynamical mechanisms in the decay of dilute and hot sources

P. Marini, H. Zheng, M. Boisjoli, G. Verde, A. Chbihi et al.
Phys. Lett. B 756, 194 (2016)

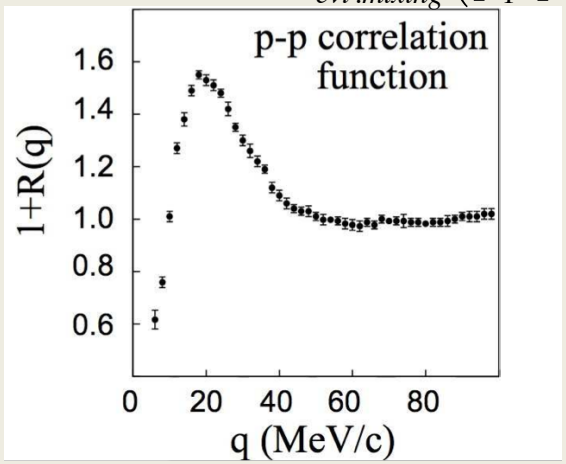
Femtoscopy and Imaging correlations



$$R(\vec{q}) = \int d\vec{r} \cdot S(\vec{r}) \cdot K(\vec{r}, \vec{q})$$

Structure properties K(r,q) affected by medium properties (size, density, lifetime) of emitting source

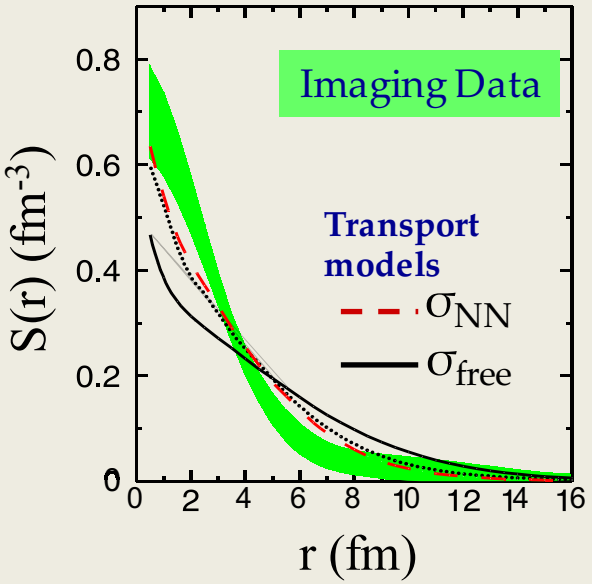
$$1 + R(q) = k \cdot \frac{\Sigma Y_{coinc}(\vec{p}_1, \vec{p}_2)}{\Sigma Y_{evt.mixing}(\vec{p}_1, \vec{p}_2)}$$



$$q = \mu |\vec{v}_1 - \vec{v}_2|$$

FSI: Nuclear and Coulomb
Fermions: asnti-symmetrized WF

Emitting Source S(r)

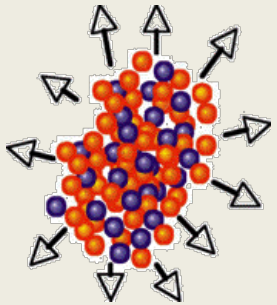


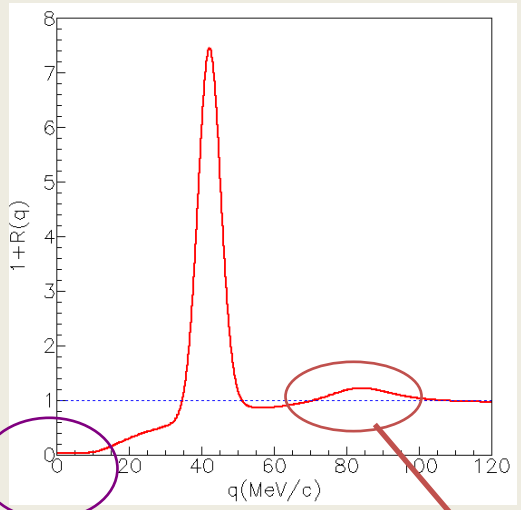
Source spatial extent
→ emission volume…

Correlations in expanding sources

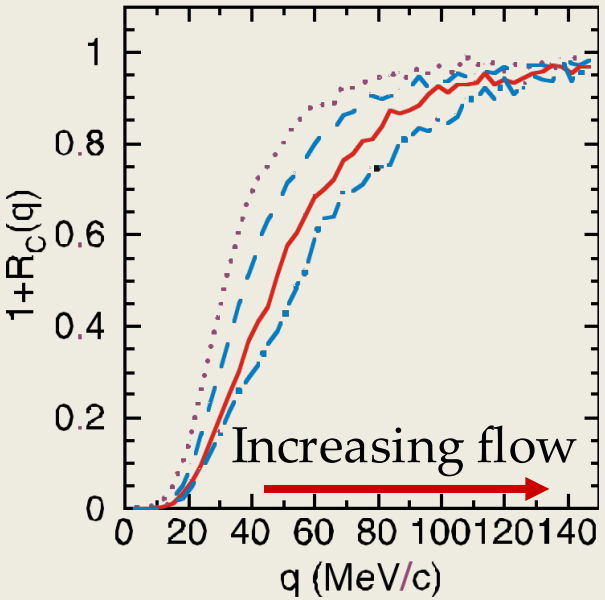
Thermal + Collective motion

$$\vec{v} = \vec{v}_{th} + \vec{v}_{coll}(\vec{r})$$

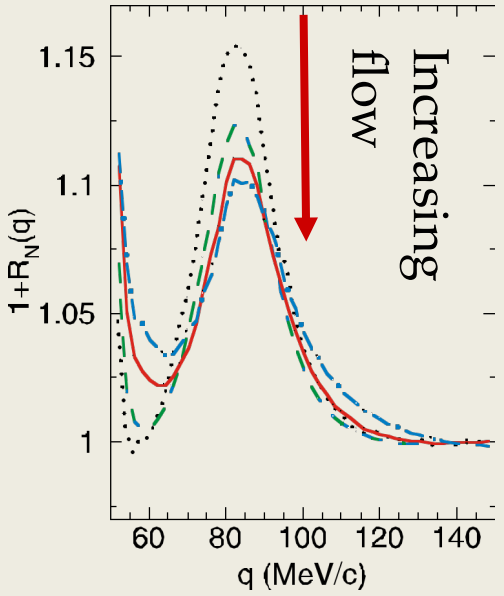




Coulomb correlations



Nuclear correlations

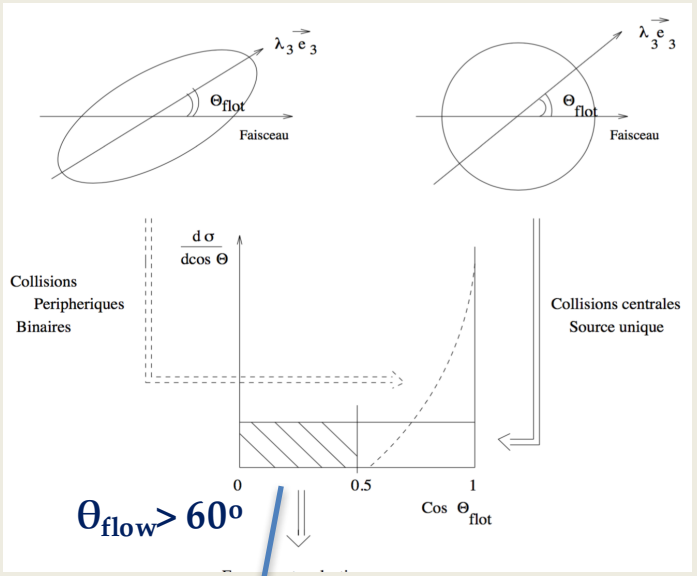


IMF-IMF correlations: compact/central sources

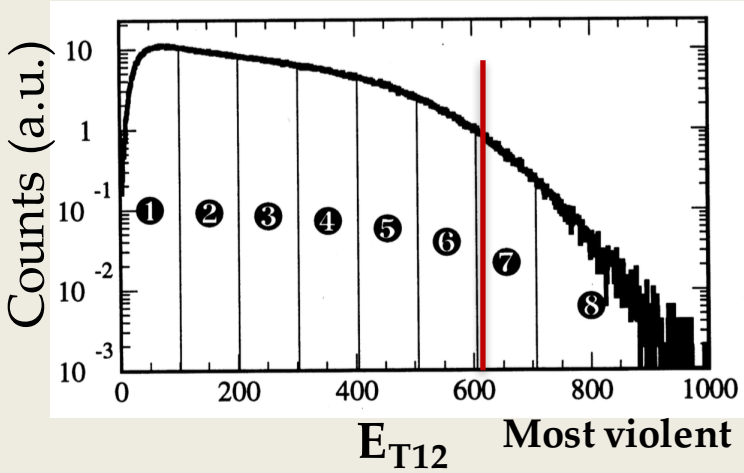
Xe+Sn E/A=50 MeV INDRA

Event characterization

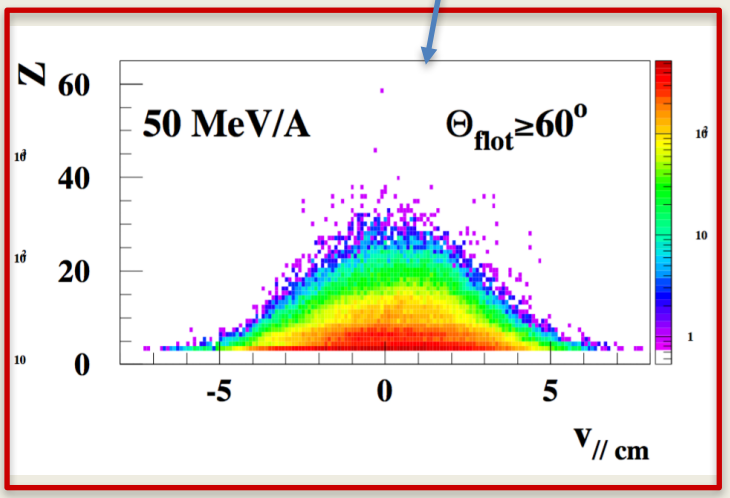
- Central (high Et12) Vs. Compact
- Orientation of event ellipsoid: θ_{flow}
- Disadvantage: significant reduction in statistics… correlations?



Most violent

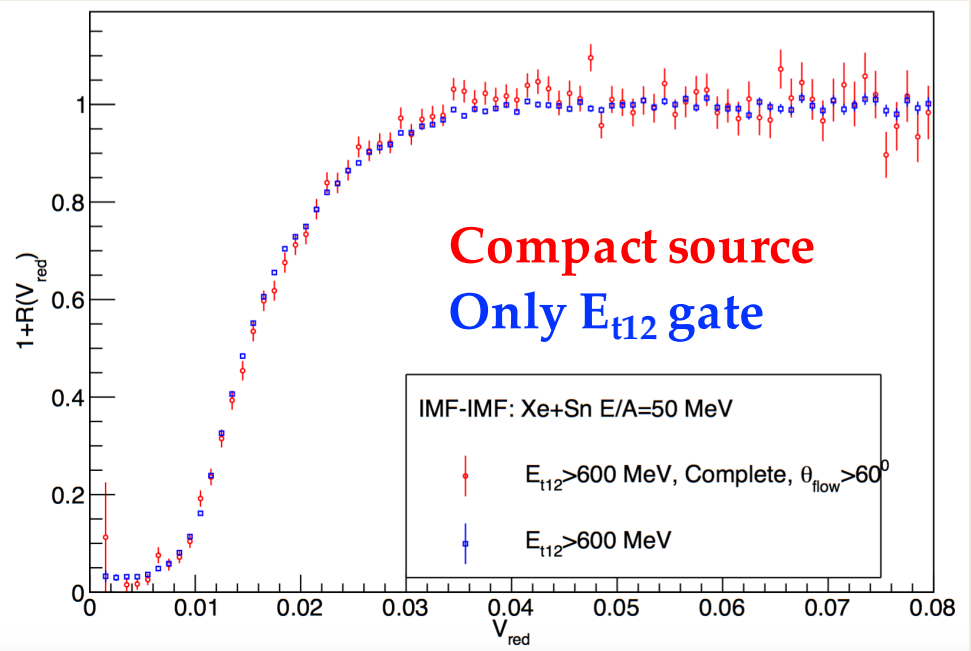


Most compact



IMF-IMF correlations: compact/central sources

Xe+Sn E/A=50 MeV INDRA



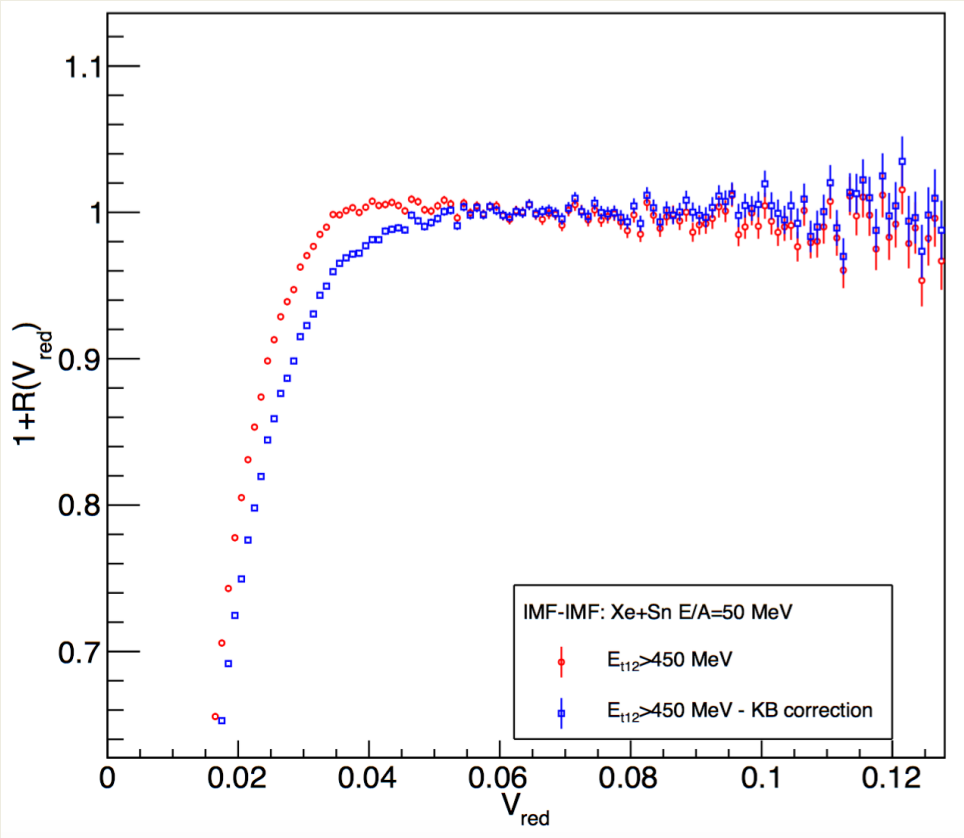
$$V_{red}=V_{rel}/(Z1+Z2)^{1/2}$$

Removing theta_flow and completeness condition → no effect

- 1+R(V_{red}) at small V_{red} dominated by single source emission
- E_{t12} filter: higher statistics and no autocorrelations with IMF-IMF

IMF-IMF correlations: compact/central sources

Xe+Sn E/A=50 MeV INDRA



Single-particle source characterization

Event-by-event fluctuations and Kinematic Blurring (KB) correction

Strong deformations may be induced nu event-by-event fluctuations → Physical fluctuations!

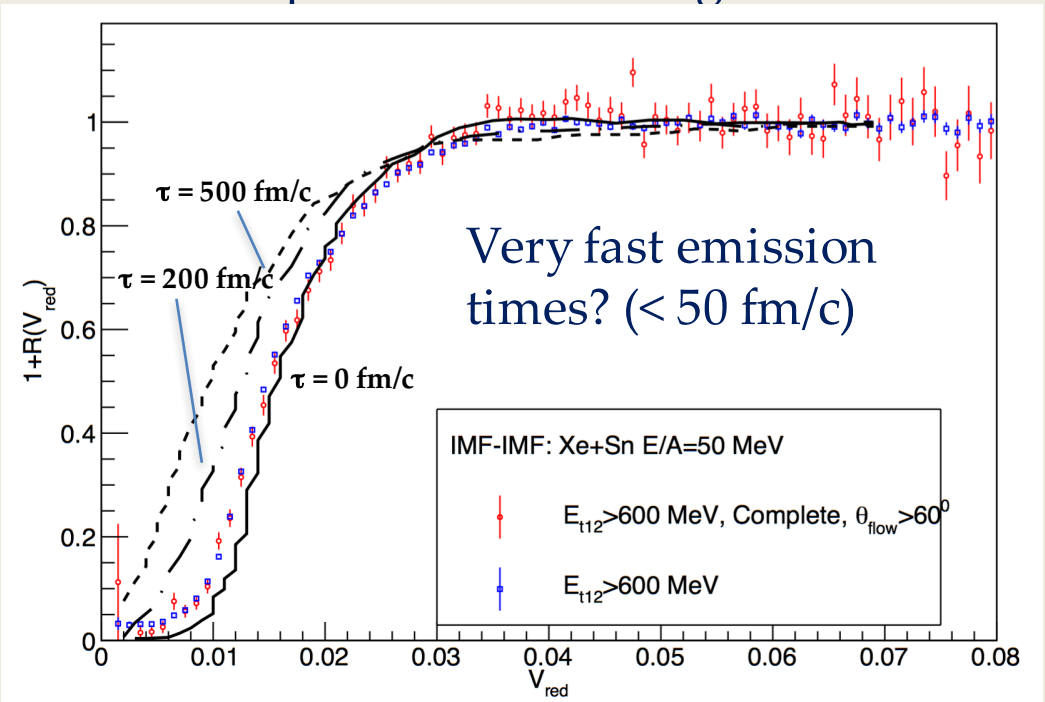
Very fast emission times? (< 50 fm/c)

Emission times

BLOB simulations → Emission and in-medium propagation times

P. Napolitani, M. Colonna

Comparisons to existing tabulated



Preliminary

Mostly spatially dominated?

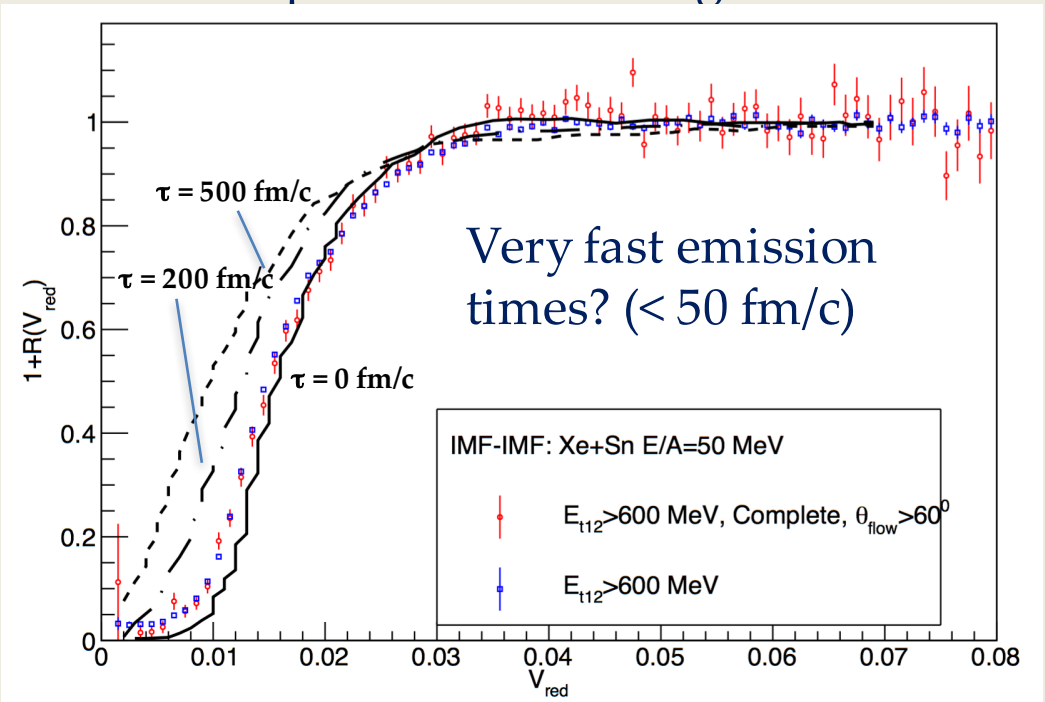
- CoulTraj and Imaging analysis to deduce spatial profiles and densities (in progress)
- Characterization of dilute source (3D imaging for deformations)

Emission times

BLOB simulations → Emission and in-medium propagation times

P. Napolitani, M. Colonna

Comparisons to existing tabulated



Preliminary

Mostly spatially dominated?

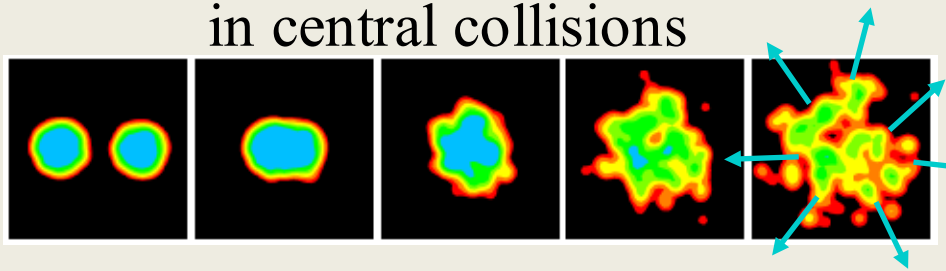
- CoulTraj and Imaging analysis to deduce spatial profiles and densities (in progress)
- Characterization of dilute source (3D imaging for deformations)

Need collective flow corrections →

Femto-Flowave Model (G. Verde, PLB, 2007)

Radial flow with FAZIA-INDRA campaign at GANIL

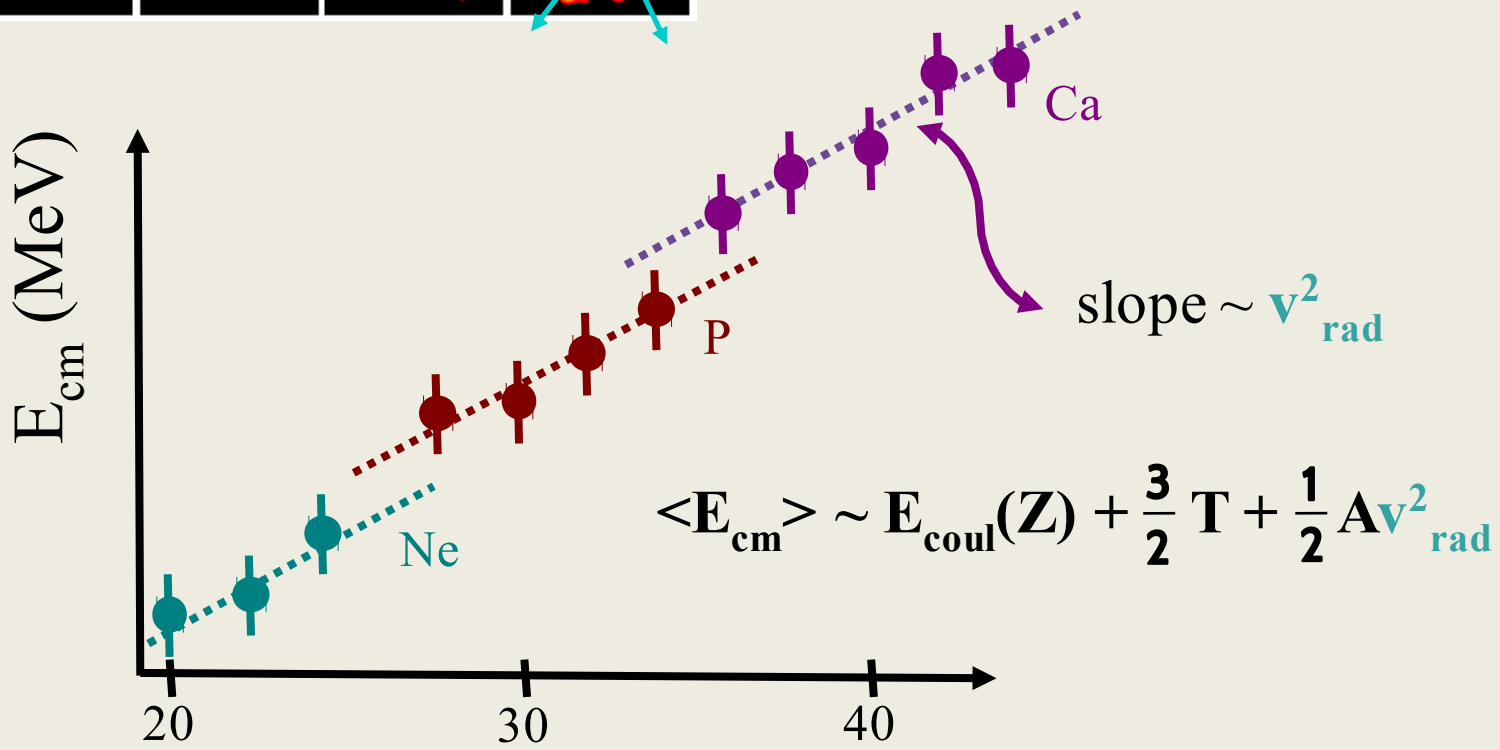
Direct measurements of radial flow in central collisions



Expansion/ flow

Stopping

Fragment/ cluster A & Z



Disentangle thermal and collective motion

Flow corrected IMF-IMF correlations

FAZIA

Planning

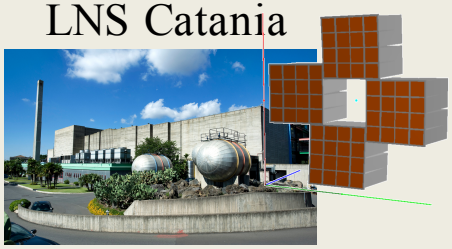
Restart CSS2 beams ?

PAC ?

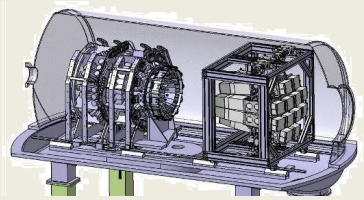
2015 2016 2017 2018 2019

Experiment(s) ?

Experiments with 4 blocks LNS Catania



Installation & tests in D5



+ restarting INDRA

LIA support!!!

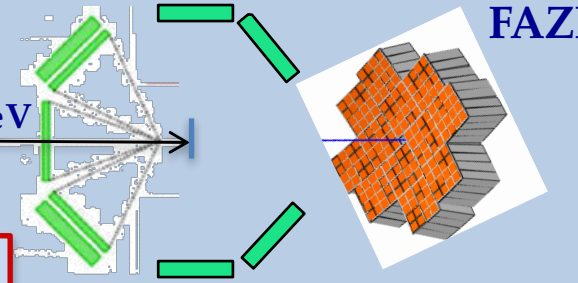
Outlook at present and future

>2019

Correlators

FAZIA

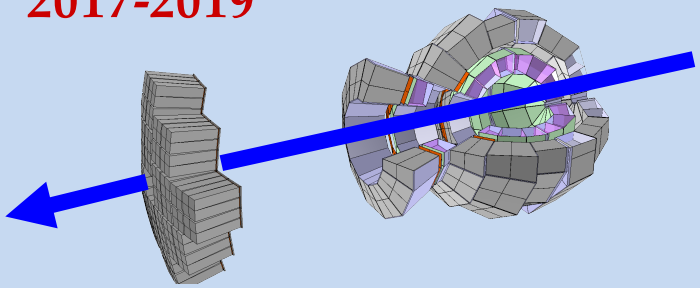
RIBs LISE
E/A=30-80 MeV



FAZIA-LISE

LoIs submitted

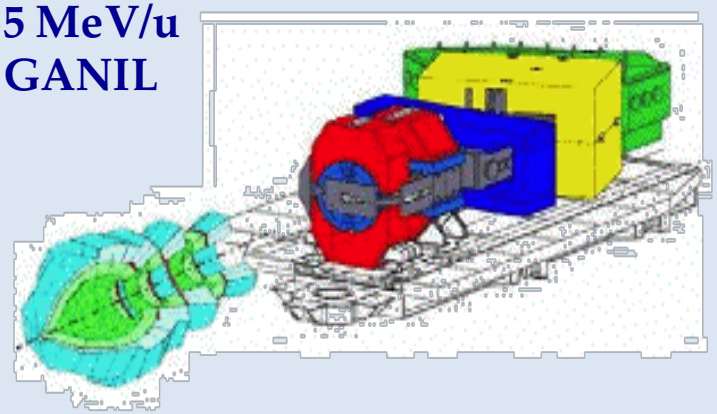
2017-2019



INDRA-FAZIA

$^{40,48}Ca+^{40,48}Ca$
35 MeV/u
GANIL

2006-2007



INDRA-VAMOS

Future evolution of project

- Integration of position sensitive detectors: better correlation measurements
- Increase of solid angle: compact source studies require coverage
  - Theta: 20-90 degrees in lab frame
  - Phi: full coverage (avoid distortions)

LIA-based collaboration

Italy: INFN-BO, INFN-CT, INFN-FI, INFN-NA, INFN-LNS, INFN-LNL
France: LPC-Caen, GANIL, IPN Orsay
Poland: Katovice, Krakow
...

Thank you for all support provided by LIA COLL-AGAIN!
very important contribution for travel money to run experiments and have collaboration meetings in Italy and France