

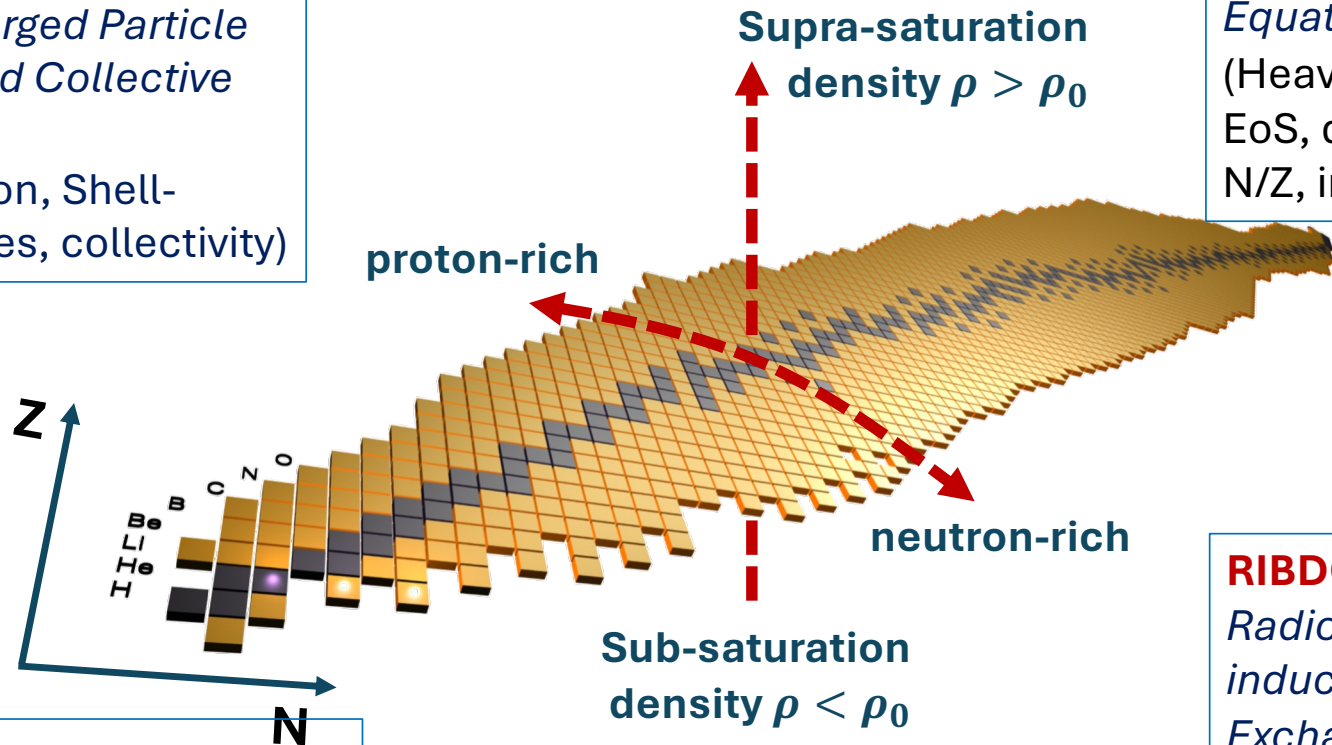
Outline

- The **MoU**
- **Intro to SYMEOS** and its synergies to other initiatives
(links to other talks at this meeting)
- **Intro to Femtoscopy (experimental view)** → talk by Isaac (theory view)

Nuclear systems under extreme conditions

GASPEC

Gamma and Charged Particle Spectroscopy and Collective excitations
(Spin, Deformation, Shell-model at drip-lines, collectivity)



NUSYC

Nucleosynthesis and Clustering
(low σ , r- and rp-process, clusters in exotic nuclei, ...)

SYMEOS

Symmetry Energy and Equation of State
(Heavy-ion collisions and EoS, density, temperature, N/Z, in-medium structure)

RIBDCE

Radioactive Ion Beam induced Double-Charge Exchange
(low σ , 0° measurements, few-body, 3-body forces, $0\nu\beta\beta$ decays)

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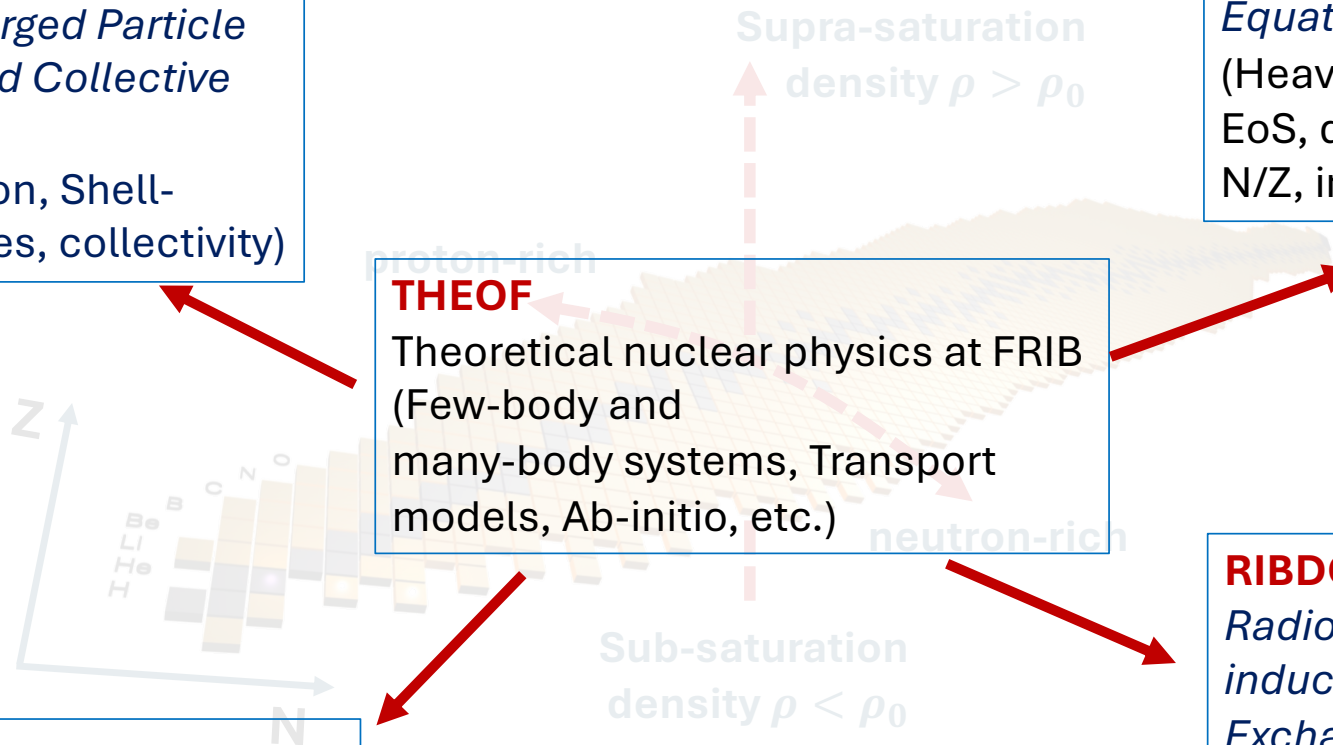
Theoretical nuclear physics at FRIB
(Few-body and many-body systems, Transport models, Ab-initio, etc.)

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SYSTERSE

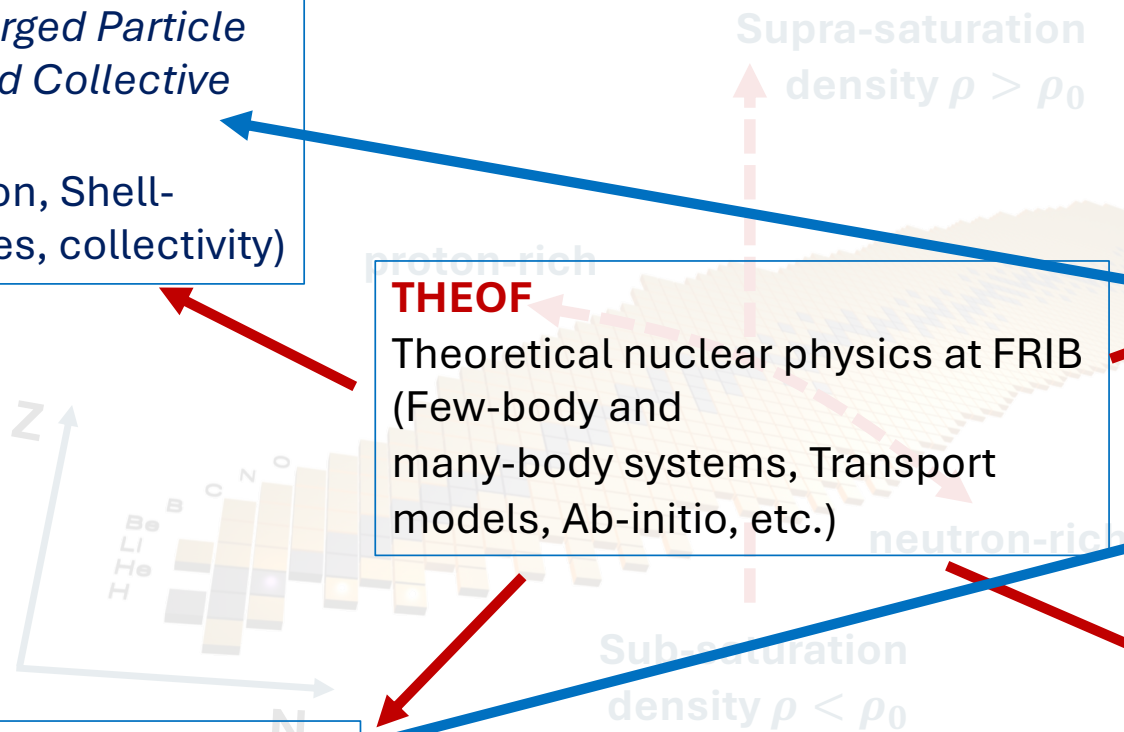
Front-End Solutions and SRO

NUSYC

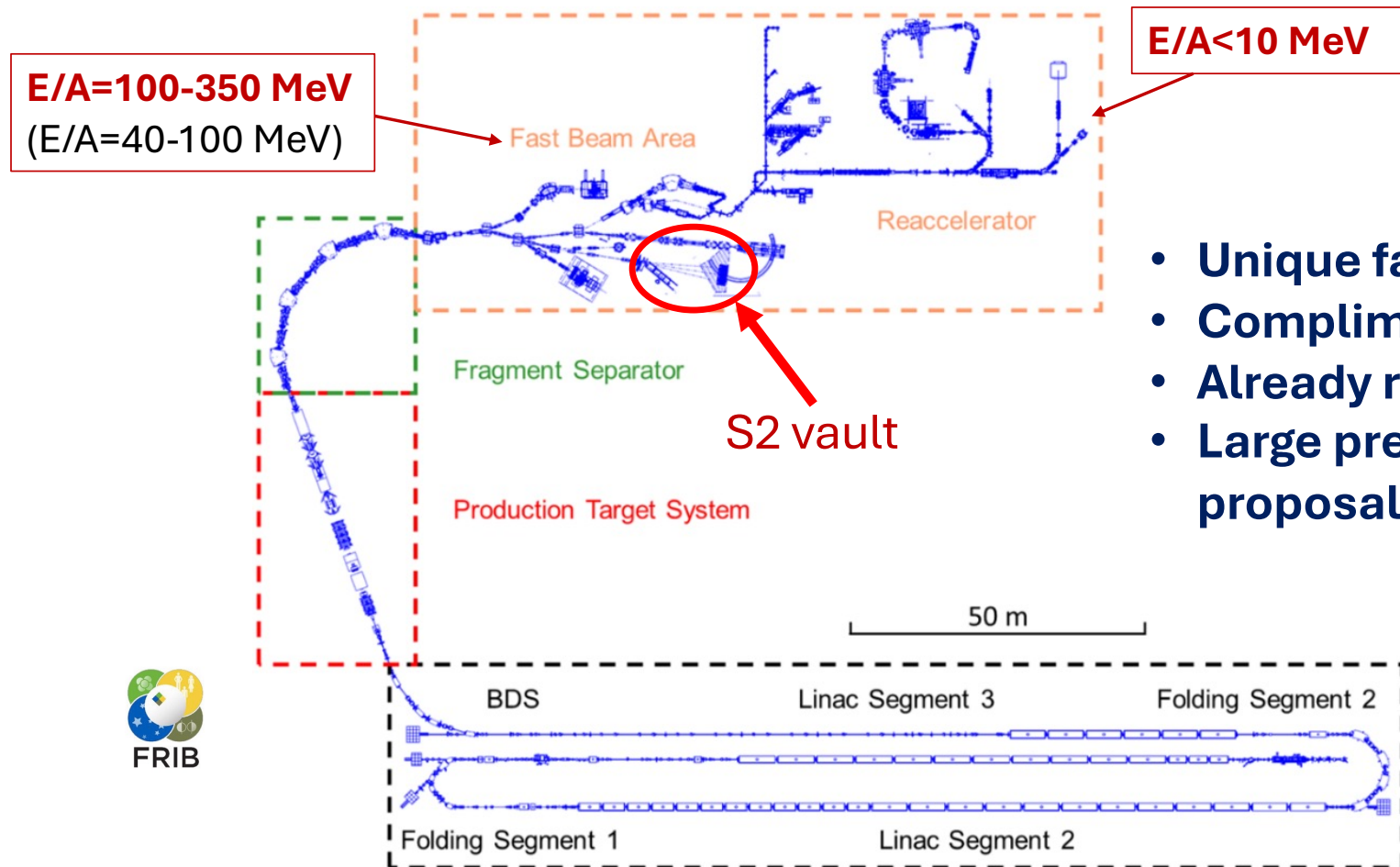
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FRIB (Facility for Radioactive Ion Beams @ MSU)



- **Unique facility**
- **Complimentary to EU facilities**
- **Already running**
- **Large pressure on PAC (!): proposals have to «perfect»**

See A. Spyrou's talk (yesterday)

History and status

- September 2024

INFN Visit to FRIB			
Facility for Rare Isotope Beams (FRIB)			
9/4 - 9/5/2024			
AGENDA			
Start	Duration	Agenda Item	Presenter
Wednesday, 4 September 2024 Rm. 2311			
9:15 AM	0:15	Arrival to FRIB (640 S Shaw Lane, East Lansing, MI 48824) Katie to escort to 2311	
9:30 AM	0:30	Welcome and FRIB Overview	Glasmacher
10:00 AM	0:30	Overview of INFN and its nuclear physics organization and program	Bettoni, Ciuchini, Giubellino
10:30 AM	0:15	Break	
10:45 AM	0:30	Overview of INFN FRIB connections and plans	Verde
11:15 AM	0:15	Opportunities to study the nuclear equation of state at FRIB	Brown
11:30 AM	0:15	Nuclear astrophysics program at FRIB	Spyrou
11:45 AM	0:15	Opportunities with gamma-ray spectroscopy at FRIB	Gade
12:00 PM	1:15	Hosted Lunch at FRIB	
1:15 PM	0:15	Theory connections	D. Lee
1:30 PM	0:30	FRIB's Graduate Program	Hergert
2:00 PM	1:00	Discussions	
3:00 PM	1:30	FRIB Tour	Glasmacher
4:30 PM			

Consensus about establishing a 10 years program... following a Lol approved by PAC

History and status

- September 2024
- October 2024 – March 2025: NUSDAF Lol submitted to PAC2 – Positive answer in March ‘25

Letter of Intent

INFN-NUSDAF (INFN - Nuclear Structure, Dynamics and Astrophysics at FRIB)

Giuseppe Verde¹, C. Agodi², M. Battaglieri⁹, M. Bondi¹, M. Cavallaro², M. Colonna², D. Gambacurta², A. Gottardo³, L. Lamia^{4,2}, S. Leoni^{5,6}, S. Pirrone¹, G. Pizzone^{2,4}, P. Russotto², S. Valdrè⁷, J.J. Valiente³, M. Viviani⁸

on behalf of the ASFIN, CHIRONE, EPIC, GAMMA, JLAB12, NUCL-EX, NUMEN, MONSTRE and NUCSYS groups of INFN
(see Appendix 3 for detailed list of institutes)

Kyle Brown¹⁰, Giordano Cerizza¹⁰, Zbigniew Chajecki¹¹, Alexandra Gade¹⁰, Dean Lee¹⁰, Artemis Spyrou¹⁰, Remco Zeger¹⁰

Local points of contact who agreed to collaborate and support these programs

¹INFN Catania, ²INFN Laboratorio Nazionali del Sud, ³INFN Laboratori Nazionali di Legnaro, ⁴University of Catania,

⁵University of Milan, ⁶INFN Milan, ⁷INFN Florence, ⁸INFN Pisa, ⁹INFN Genova

¹⁰FRIB, Michigan State University, ¹¹Western Michigan University

History and status

- September 2024
- October 2024 – March 2025: NUSDAF Lol submitted to PAC2 – Positive answer in March '25
- June 2025: first draft of MoU – answer in September by MSU – Positive
- September 2025 – Answer by Foreign relation officers at INFN – Positive
- October 2025 – started iteration for approval at CD

MoU between INFN and FRIB

Memorandum of Understanding

between

the Istituto Nazionale di Fisica Nucleare (Italy) and the **Michigan State University**, through its **Facility for Rare Isotope Beams** (USA)

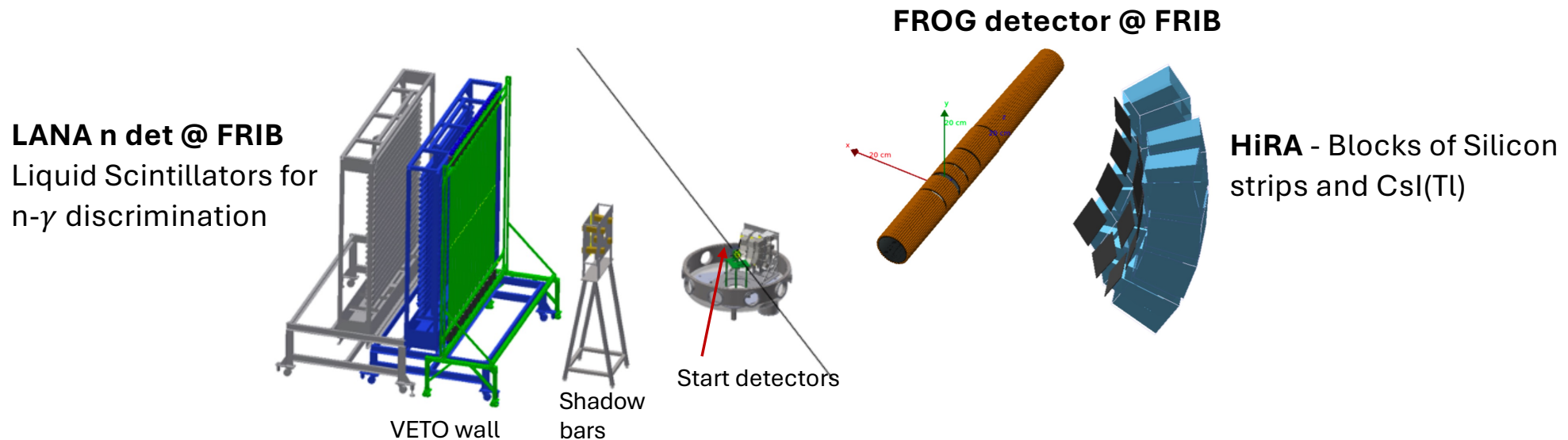
for a pluriannual cooperation in the field of fundamental research in nuclear physics

- *Scientific and Institutional Preamble*
- *13 Articles and 2 Annexes*

- The agreement concerns INFN in general (no references to individual divisions, groups, initiatives, experiments... very flexible)
- Duration: 10 years starting on Jan 1st, 2026
- Constitution of a bilateral CoMB (Collaboration Management Board): 50% INFN-50% FRIB
- **synergy between groups**
- Co-financing of postdocs, PhD students, undergraduate fellowships

Synergy within CSN3 – Share physics cases, equipment, human and financial resources (!)

First approved exp (58023): n/p effective mass splitting and symmetry energy $\rightarrow$ SYMEOS



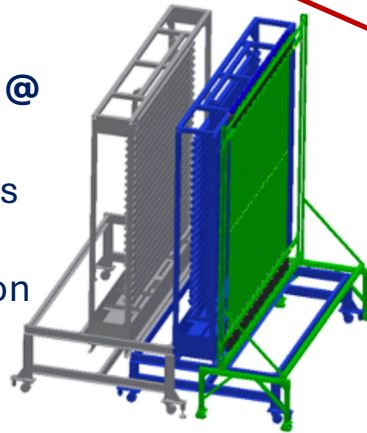
- First approved experiment (exp 58023/PAC1)
 $^{56}\text{Ni} + ^{58}\text{Ni}$, $^{70}\text{Ni} + ^{64}\text{Ni}$ $E/A = 175$ MeV (Schedule: summer 2026)
- Neutron and proton elliptic flow $\rightarrow$ probe of the interaction and E_{sym}
- Tests with FAZIA blocks underway (stay tuned on Simone's talk, today!)
- Participation welcome... in the spirit of NUSDAF

SYMEOS/RIBDCE - Future plans - multi-purpose setup

MONA-LISA n det @ FRIB

Plastic Scintillators
+ LANA
if n- γ discrimination
necessary

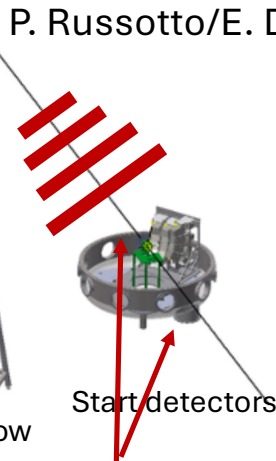
+ 4-5 Si-CsI(Tl) Chimera rings
Improve reaction plane and b



VETO wall



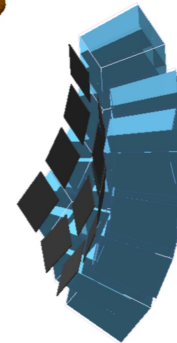
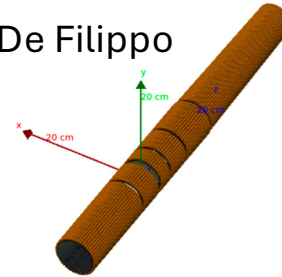
Shadow bars



Start detectors

+ FAZIA forward & backward
N/Z in spectators and participants (OSCAR?)

FROG detector @ FRIB



HiRA - Blocks of Silicon
strips and CsI(Tl)

+ FARCOS/NARCOS blocks
Increase correlators
(Silicon strips and CsI(Tl))

B. Gnoffo/E. Pagano/C. Zagami

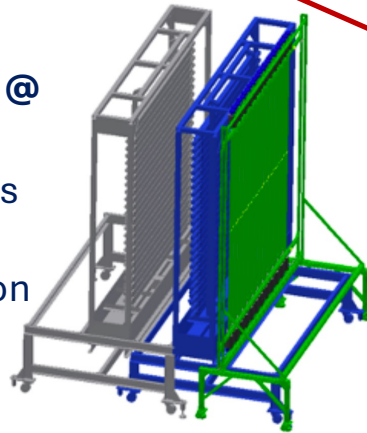
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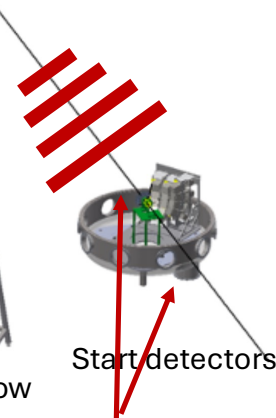


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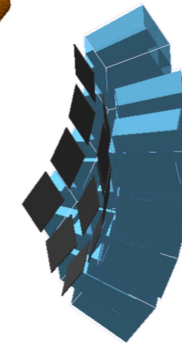
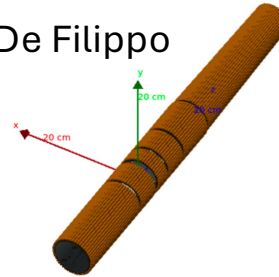
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P. Russotto/E. De Filippo



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Discussed at FRIB

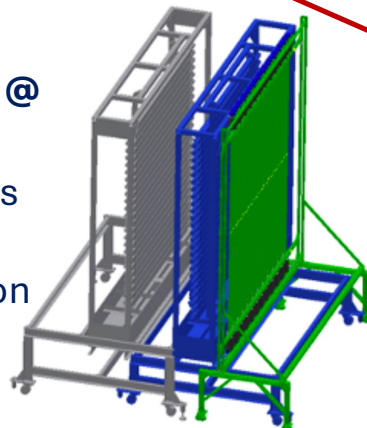
+ **Large reaction chamber... Cyclope-like?**

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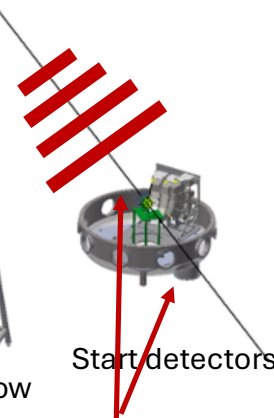


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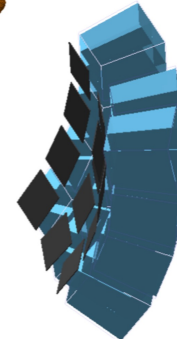
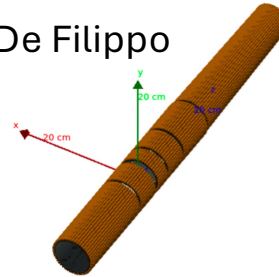
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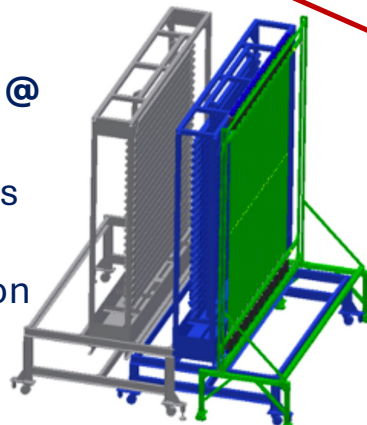
+ **Position-sensitive detectors? Gas/Si- pixel... → Femtoscopia and IMS**

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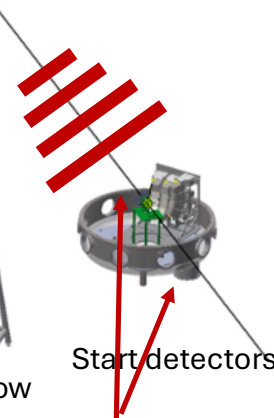


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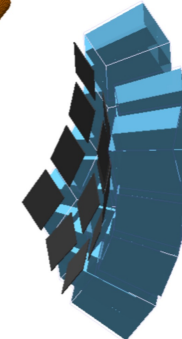
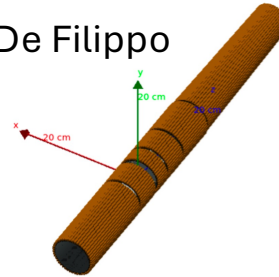
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M. Battaglieri/G. Cerizza

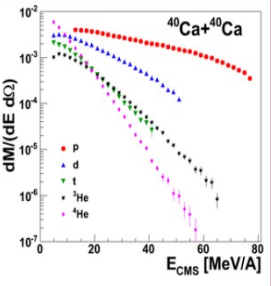
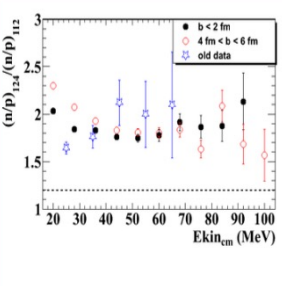
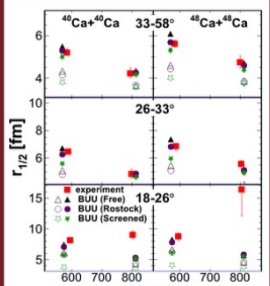
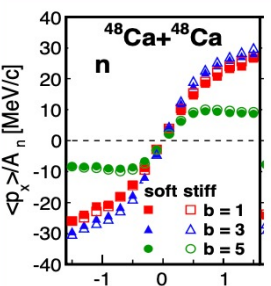
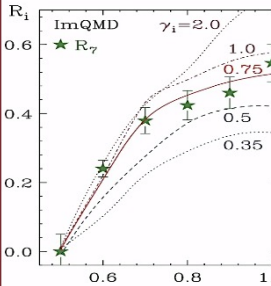
+ **Electronics/DAQ – new solutions strongly needed...**

SYMEOS: Transport Properties Vs. Observables

Observables

Transport
model
ingredients



	Spectra	(Double-) ratios	Femtoscscopy	Flow	Isospin diffusion
					
Symmetry energy		✓		✓	✓
Effective mass		✓		?	?
Cross section	✓	✓	✓	✓	✓
Cluster production	✓	✓	✓	✓	✓

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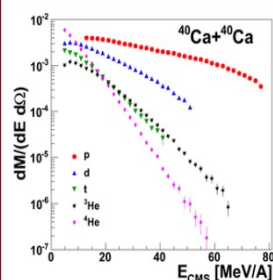
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Effective
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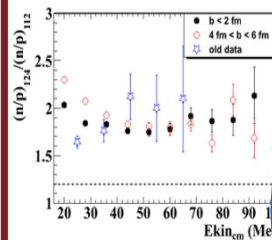
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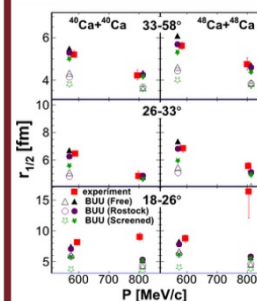
Spectra



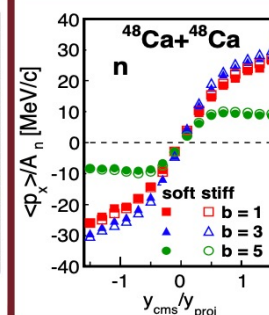
(Double-)
ratios



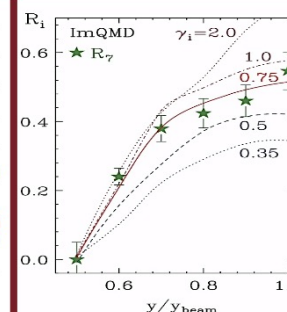
Femtoscscopy



Flow



Isospin
diffusion



INFN
Gain



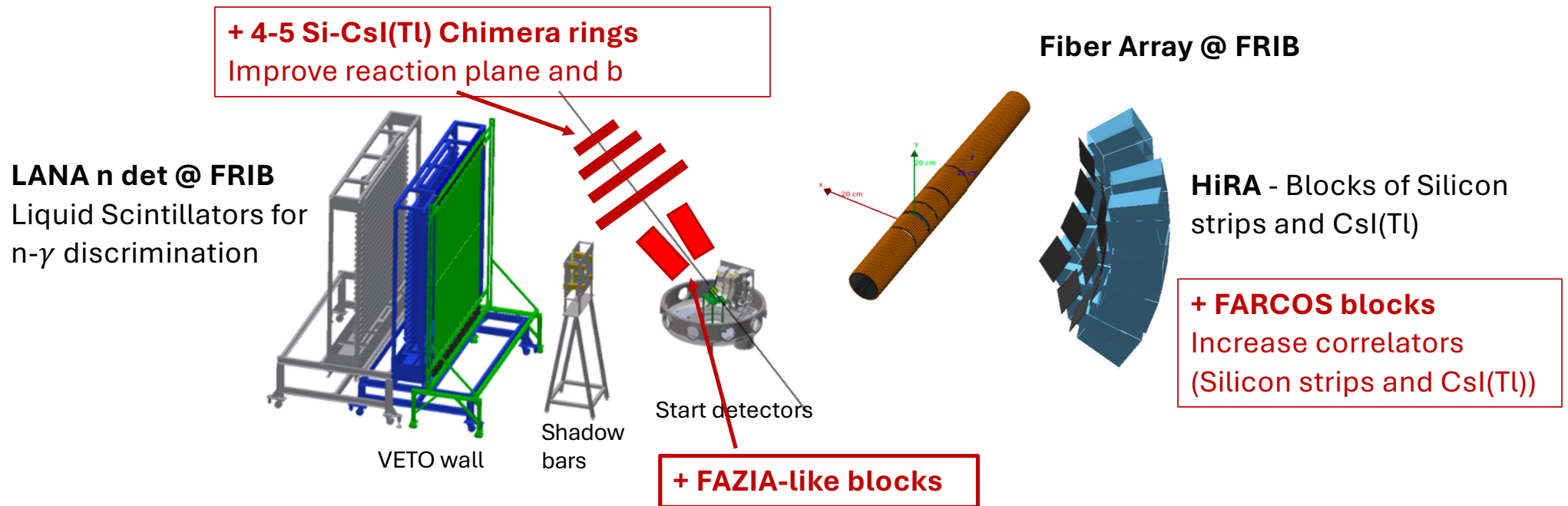
?

?



RIBDCE/SYMEOS synergy

Talk by F. Cappuzzello (yesterday)



First case: $t + {}^3\text{He} \rightarrow 3n + 3p$

3p detected with FAZIA blocks

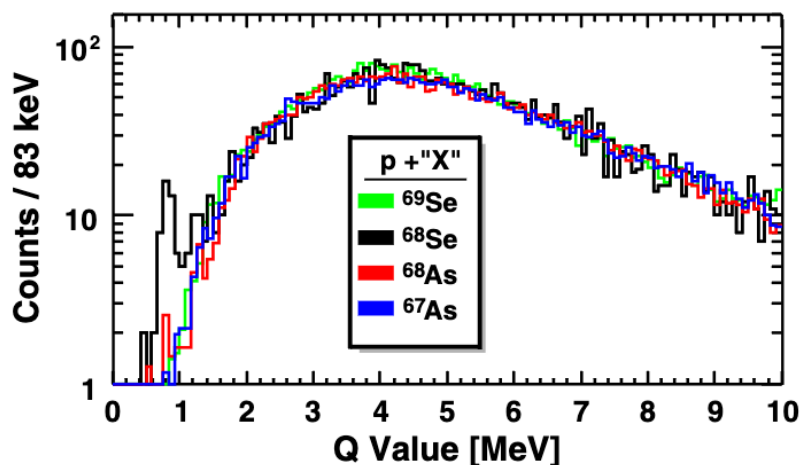
SYMEOS/NUSYC: IMS close to the rp-process region

Decay of p-rich nuclei $\rightarrow$ relevant for rp-process

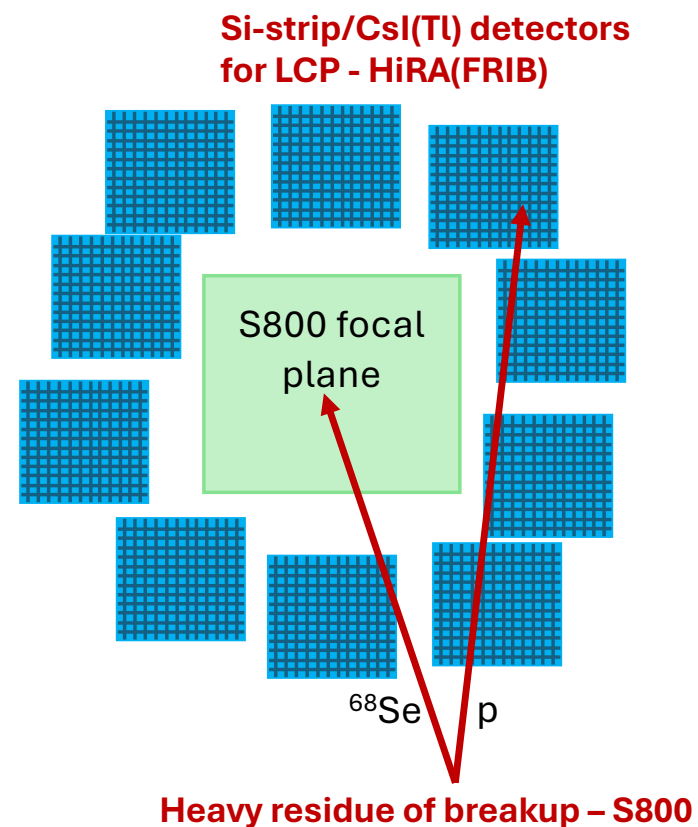
Ground-State Proton Decay of ^{69}Br and Implications for the ^{68}Se
Astrophysical Rapid Proton-Capture Process Waiting Point

A. M. Rogers, M. A. Famiano, W. G. Lynch, M. S. Wallace, F. Amorini, D. Bazin, R. J. Charity, F. Delaunay, R. T. de Souza, J. Elson, A. Gade, D. Galaviz, M.-J. van Goethem, S. Hudan, J. Lee, S. Lobastov, S. Lukyanov, M. Matoš, M. Mocko, H. Schatz, D. Shapira, L. G. Sobotka, M. B. Tsang, and G. Verde

Phys. Rev. Lett. **106**, 252503 – Published 24 June 2011

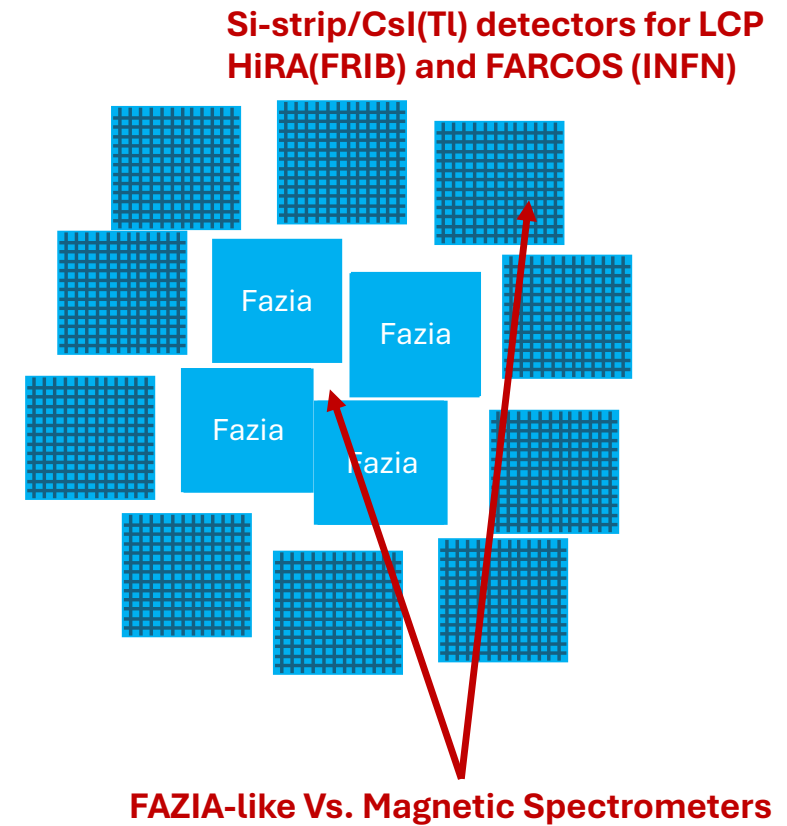
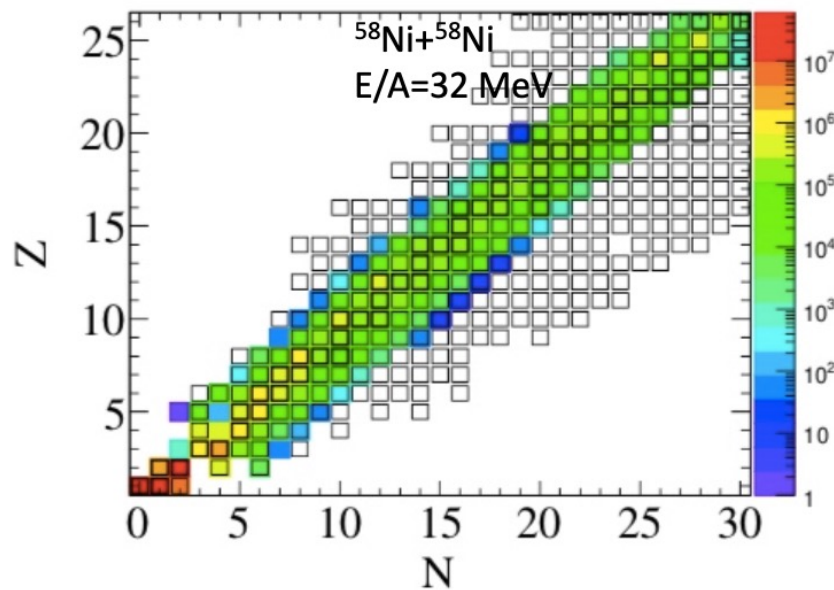


HiRA Si-strip
+
S800 magnetic spectrometer



SYMEOS/NUSYC: IMS close to the rp-process region

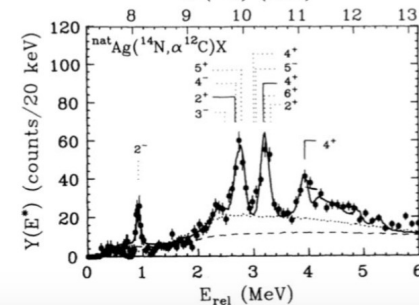
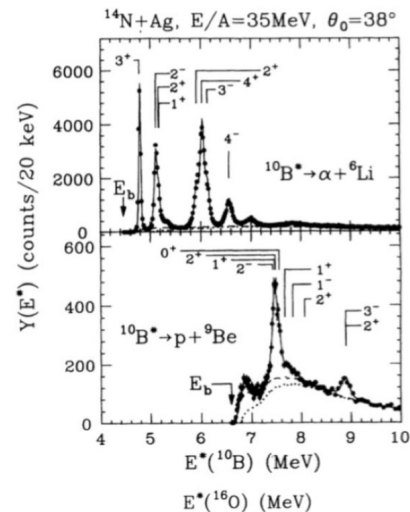
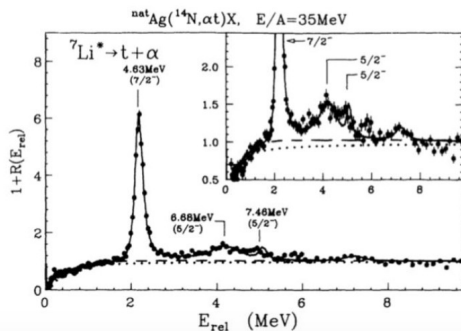
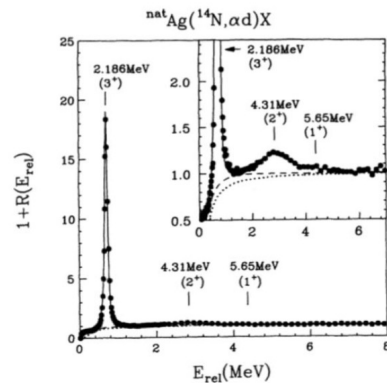
FAZIA – spectrometer-like performances (selected physics cases)



Femtoscopy and IMS

MSU data (30 years ago)

Si-NaI + SWPC



N + Ag E/A=35 MeV Central

$^{12}\text{N} \rightarrow ^{11}\text{C} + p$

$^{10}\text{B} \rightarrow ^6\text{Li} + \alpha, ^8\text{Be} + d, ^9\text{Be} + p$

$^{12}\text{C} \rightarrow ^8\text{Be} + \alpha, \alpha + \alpha + \alpha$

... and many more in one single experiment

Need efforts to increase angular resolution

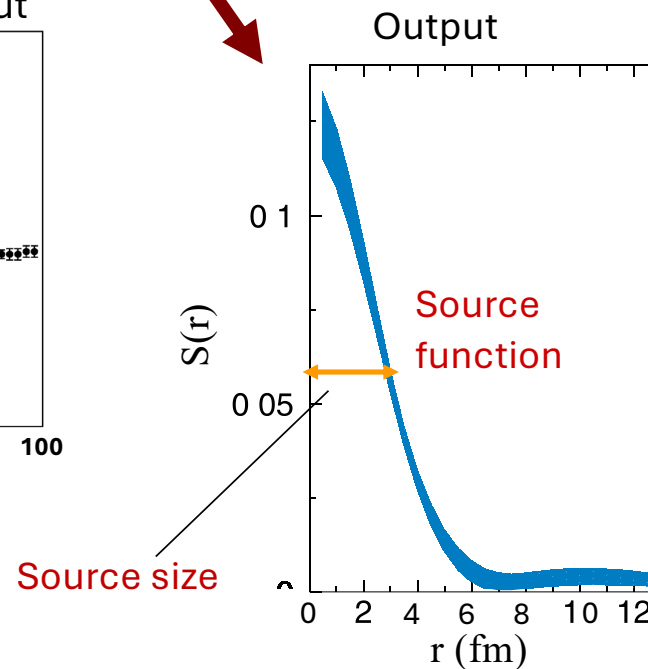
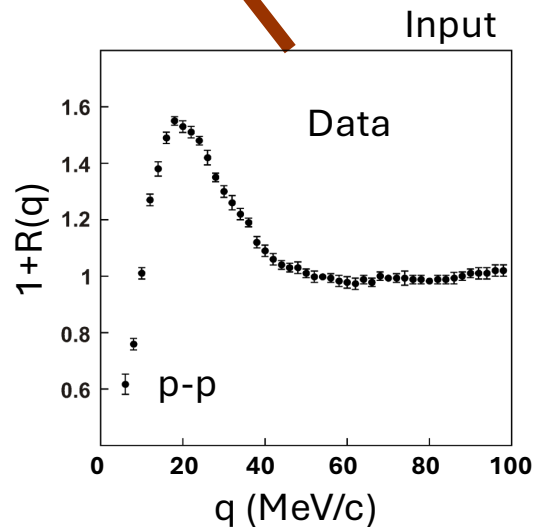
- Gas detectors? FIASCO-like vs new tech.
- Si-pixels? CALIFA@GSI using MAPS...

Need some deep thinking on this

Femtoscscopy: imaging correlation functions

Koonin-Pratt equation

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

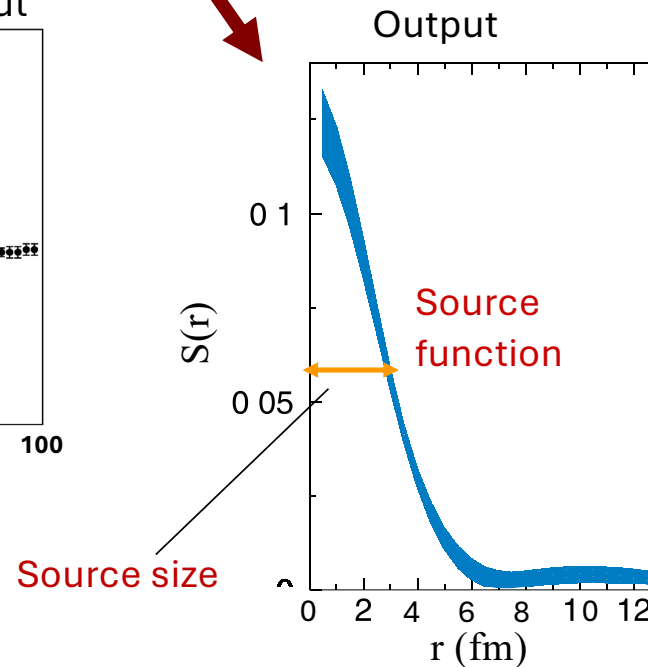
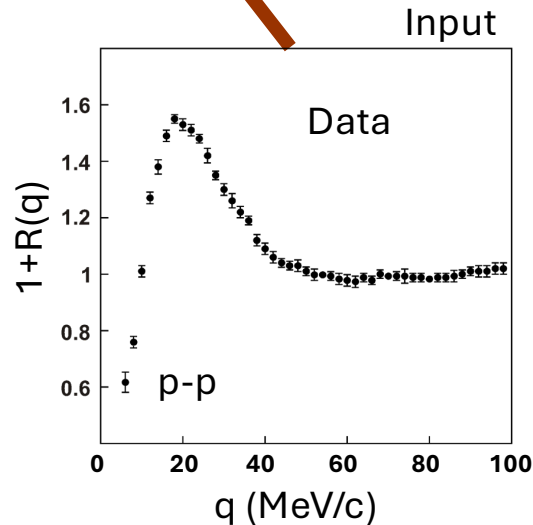


- Probes of transport models (σ_{NN} , E_{sym} , ...)
- Emission chronology

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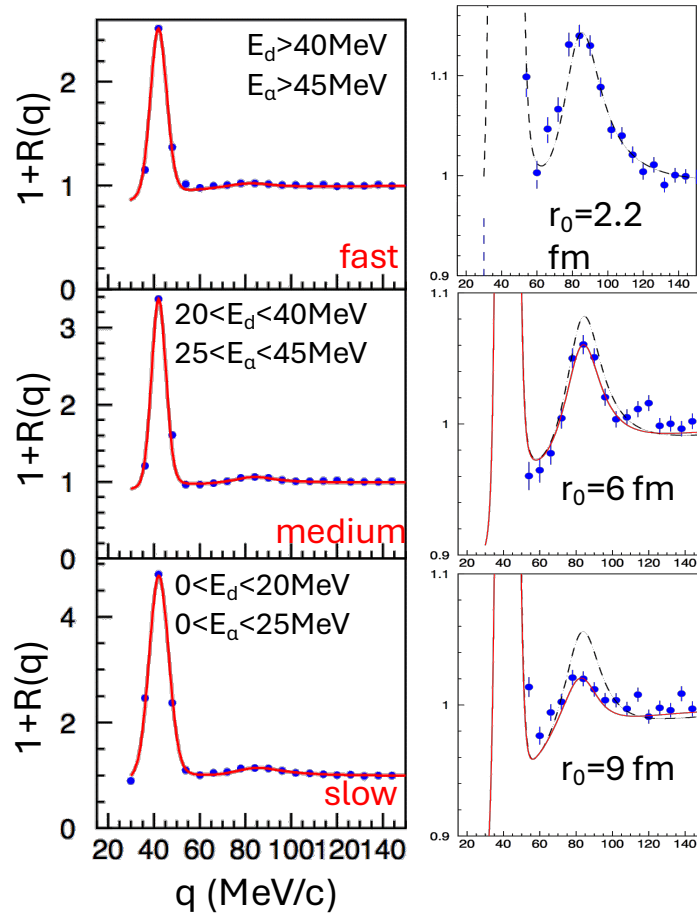


- Probes of transport models (σ_{NN} , E_{sym} , ...)
- Emission chronology and hierarchy in isotope production
- Short-range correlations

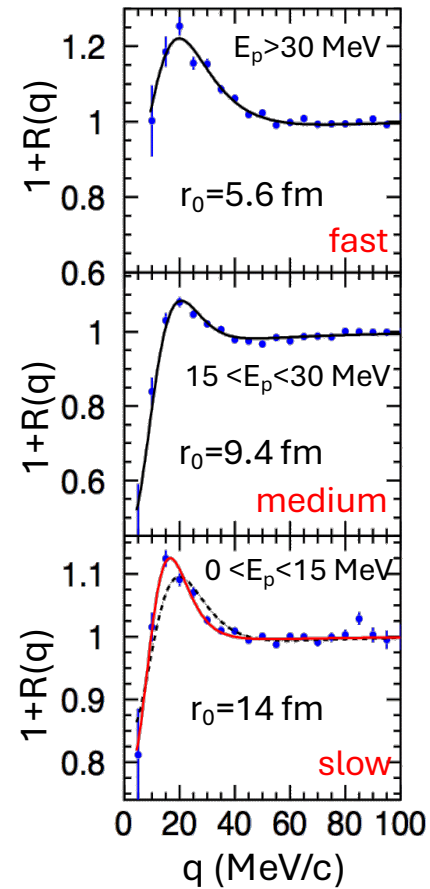
Extend to clusters correlations

Deuteron-Alpha – ${}^6\text{Li}$ production

Xe+Au E/A=50 MeV $b_{\text{red}} < 0.3$



Proton-Proton

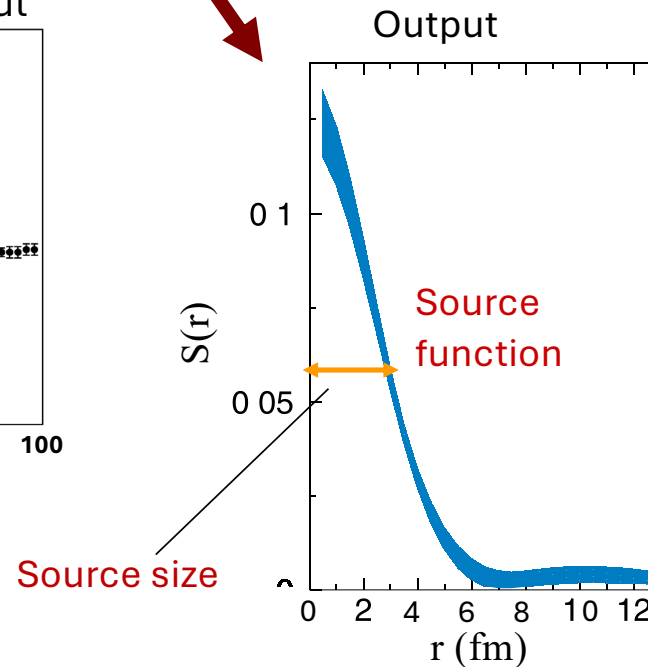
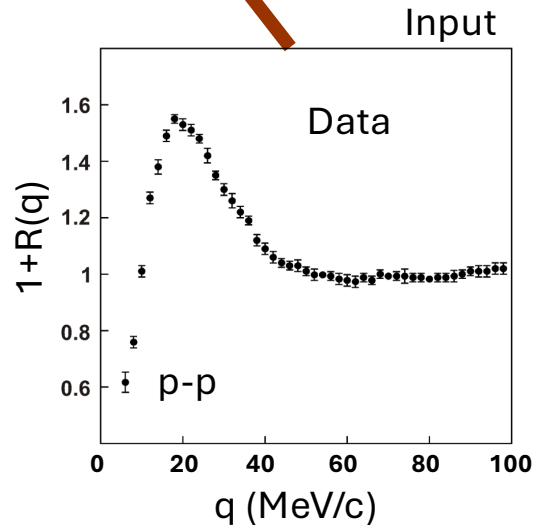


Talk by S. Burrello

Femtoscscopy: imaging correlation functions

Koonin-Pratt equation

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



- Probes of transport models (σ_{NN} , E_{sym} , ...)
- Emission chronology and hierarchy in isotope production
- Short-range correlations

Femtoscscopy: probing the interaction

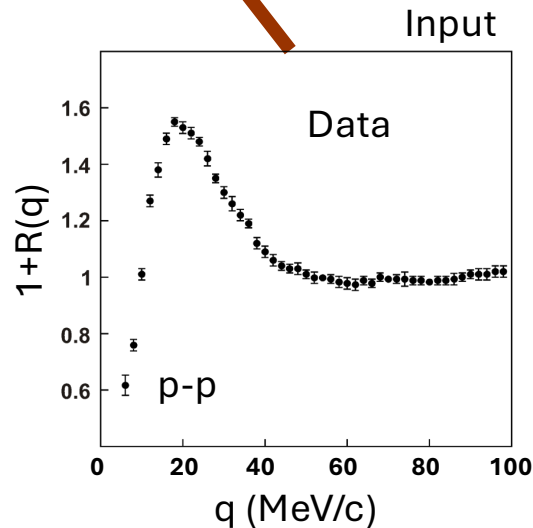
Koonin-Pratt equation

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

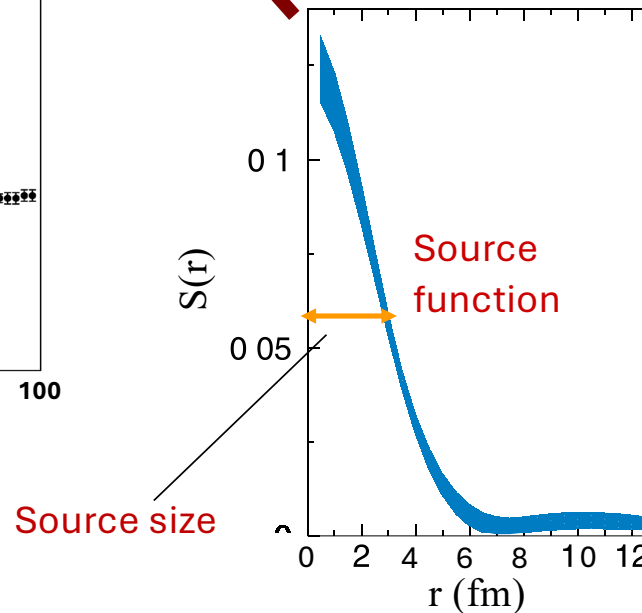
Unknown
to extract

NN or N-Cluster
interaction

Esym → neutron stars



Another experimental input



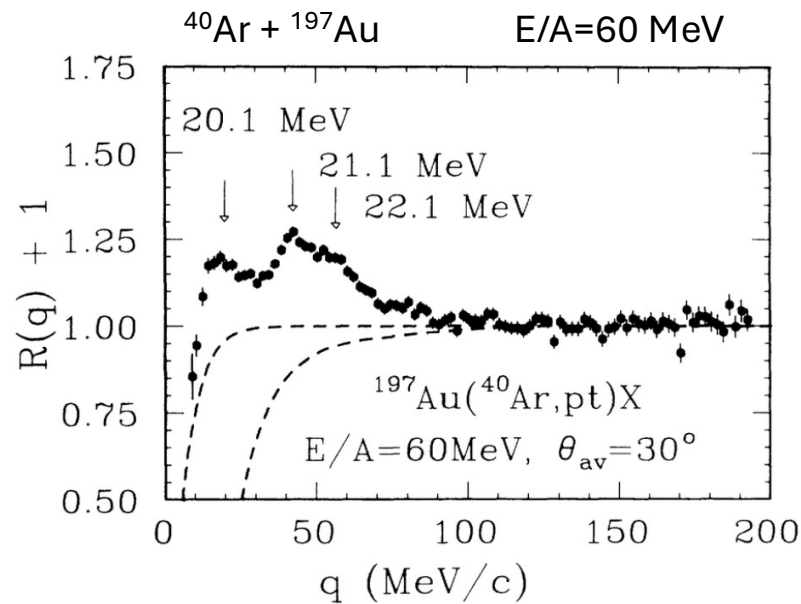
See Isaac Vidana's talk

Talk by L. Marcucci
Yesterday

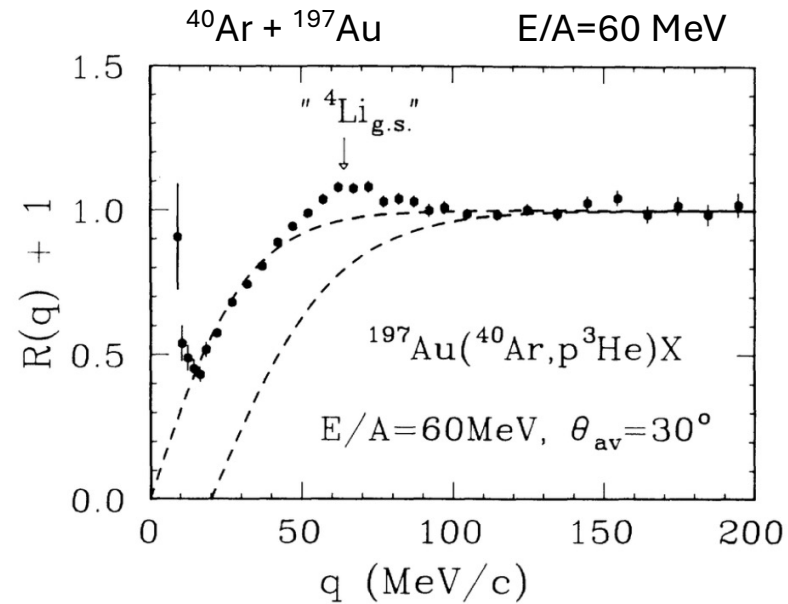
Talk by Isaac Vidana
Today

Talk by S. Burrello
Today

IMS of ^4He and ^4Li : proton-cluster interaction



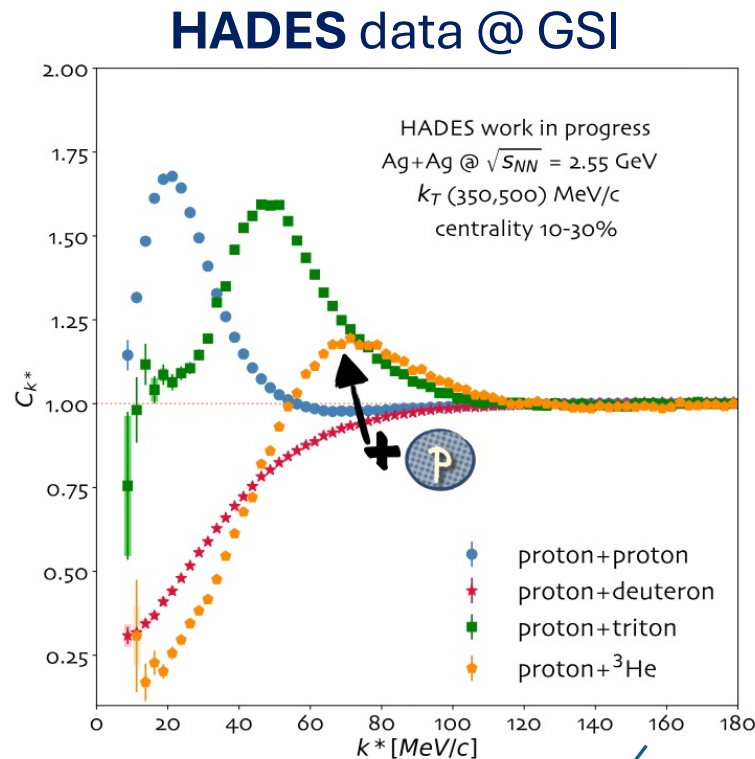
p-t



p- ^3He

Very interdisciplinary...

IMS of ^4He and ^4Li : proton-cluster interaction



Recent work by pp and pPb by **ALICE** on

$\bar{p} - \bar{t}$ correlations $\rightarrow \overline{^4\text{He}}$ resonances
 $\bar{p} - \overline{^3\text{He}}$ correlations $\rightarrow \overline{^4\text{Li}}$ resonances

Matter Vs. Anti-Matter in
proton-cluster interactions

In-medium dependence of proton-cluster interactions
(beam energy scan - FRIB Vs. GSI/FAIR)

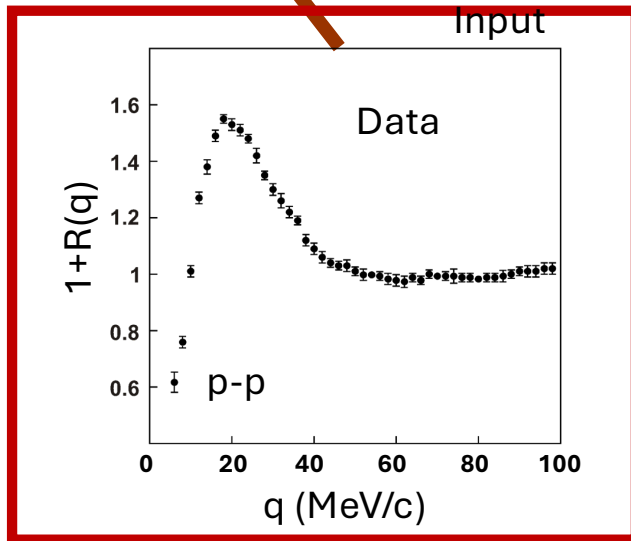
Femtoscscopy: Experimental needs

Koonin-Pratt equation

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

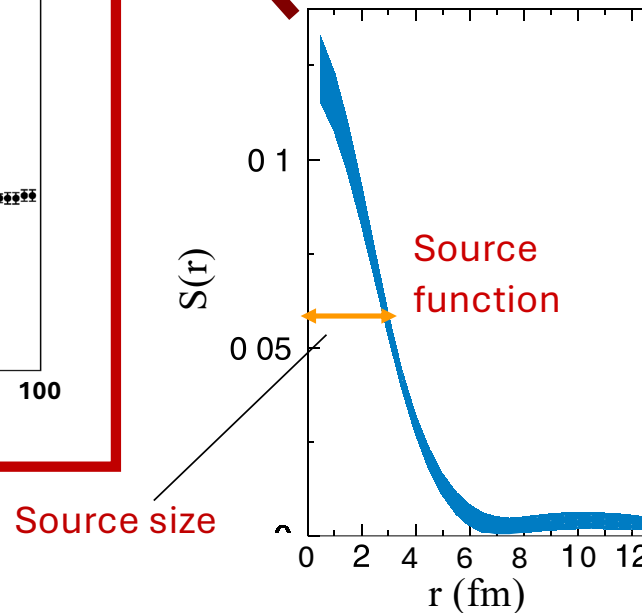
Unknown
to extract

→ NN or N-Cluster
interaction
Esym → Neutron Stars



See Isaac Vidana's talk

Another experimental input

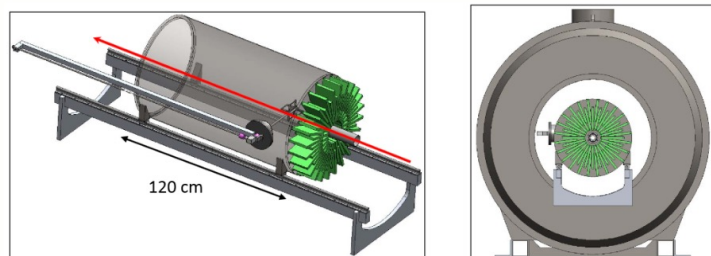


Source function
«measured» with other
observables

- **4pi detectors needed!**
- **New generation TPCs**
See talk by K. Brown
+ Ancillary detectors for
Femtoscscopy → R(q)

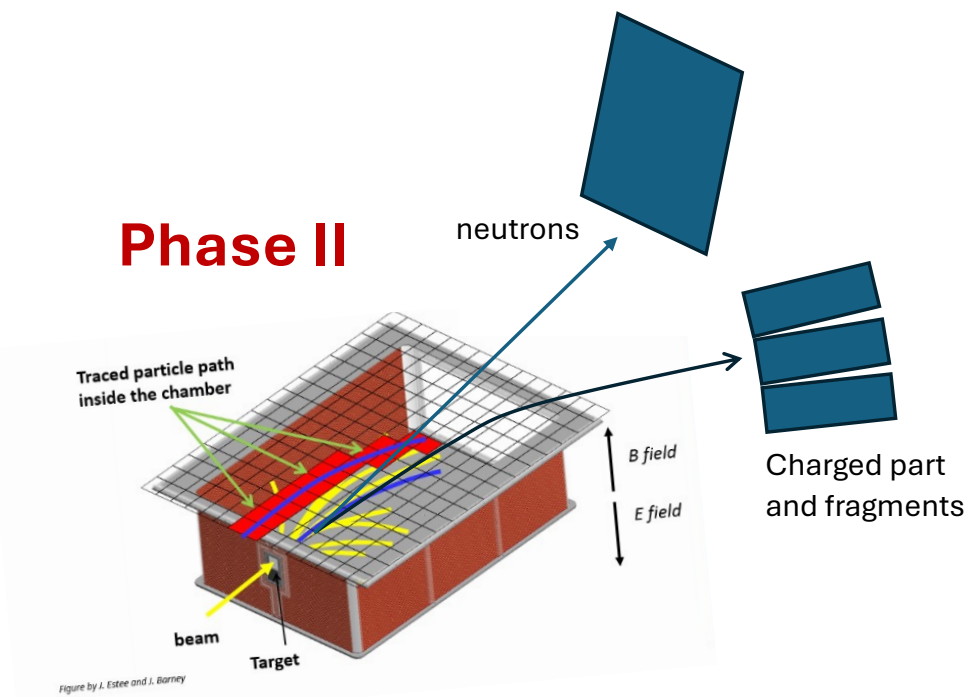
TPCs @ FRIB – Important for EoS and Femtoscopy

Phase I



Kyle. Brown's talk – stay tuned! (...and awake)

Phase II

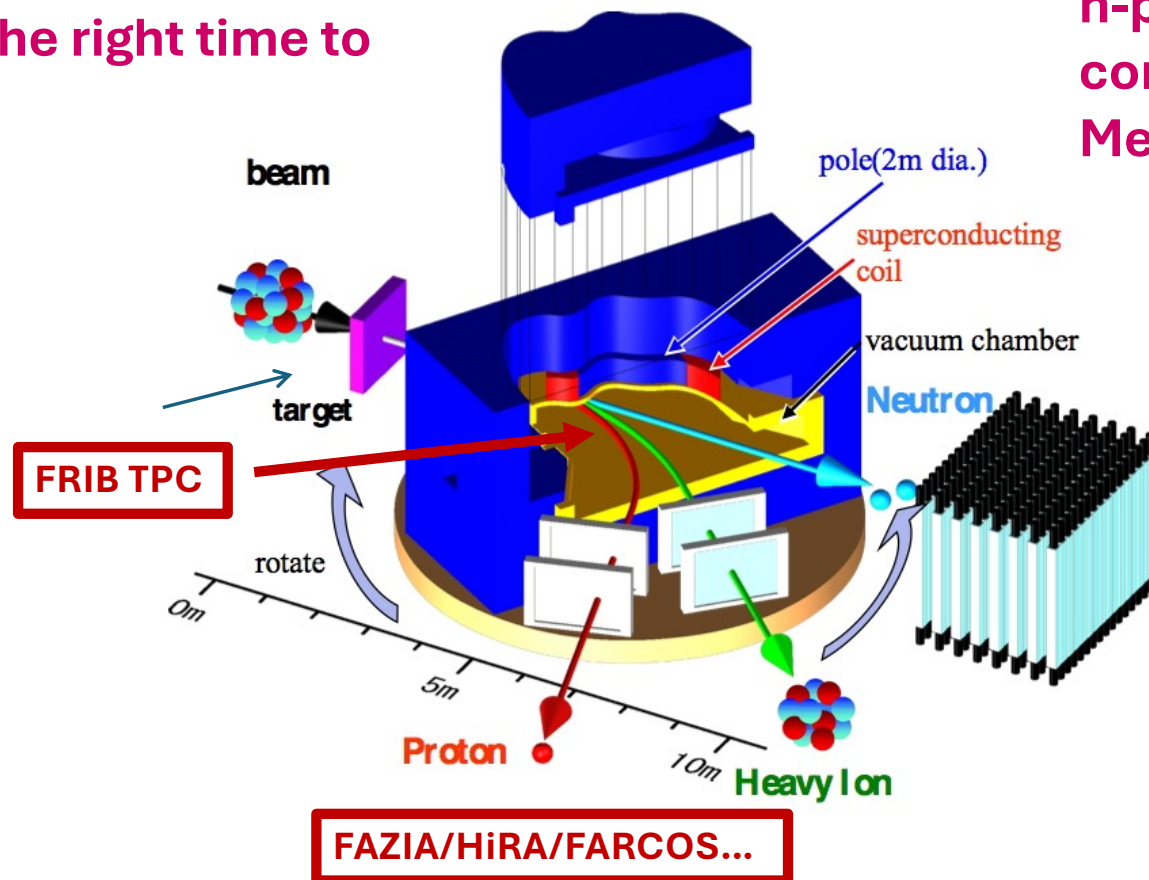


- Spirit-like geometry or AT-TPC-like geometry?
- Important to consider position of pad plane (depending on square or cylindric geometry)

Probing sources and neutron-cluster interactions

FRIB: maybe the right time to finally do it!

n-p, n-n and p-p correlations at $E/A > 100$ MeV



Challenges to think about

- Large reaction chamber – neutron «transparency» at forward angles
- 4π coverage for event characterization (reaction plane, impact parameter, Femtoscopy and IMS)
- High angular resolution → pixelation and/or position sensitive gas detectors – tracking capabilities
- Neutron-proton correlations (cross-talk, sweeper magnets, ...)
- New TPCs at FRIB and ancillary detectors (charged particles and neutrons) → see K. Brown's talk (today)
- Electronics – PSD, ASIC, SRO... sustainable solutions with shared expertise → NextGenDD initiative, see Marco's and Giordano's talks at SYSTERSE session (today)