cea irfu

Study of Short-Range Correlations (SRC) in exotic nuclei

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RESONANCE WPCF 2023

R3B FAIR GSI

université PARIS-SACLAY

P2IO Physique des 2 Infinis et des Origines

ANR AGENCE NATIONALE DE LA RECHERCHE

Outline

Introduction

- Short Range Correlations (SRCs);
- Quenching of the Spectroscopic Factors;
- EMC effect;
- How to probe SRCs;

JINR Experimental Program

- Dubna (JINR) test experiment;
- Derivation of observables to isolate SRC physics.

R3B Experimental Program

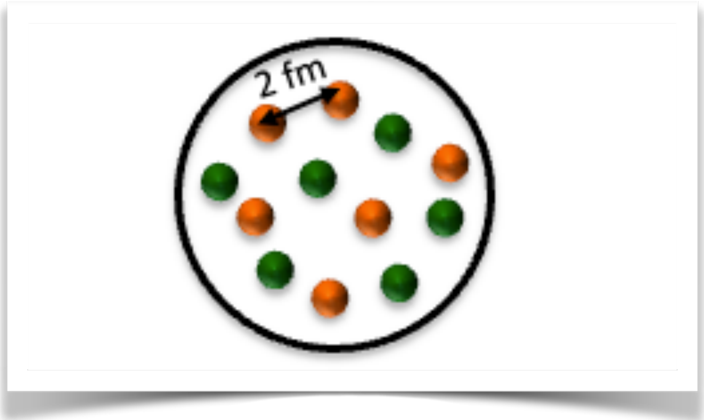
- Experimental Set-up;
- (p,2p) analysis;
- Derivation of observables to isolate SRC physics.

ONGOING ANALYSIS

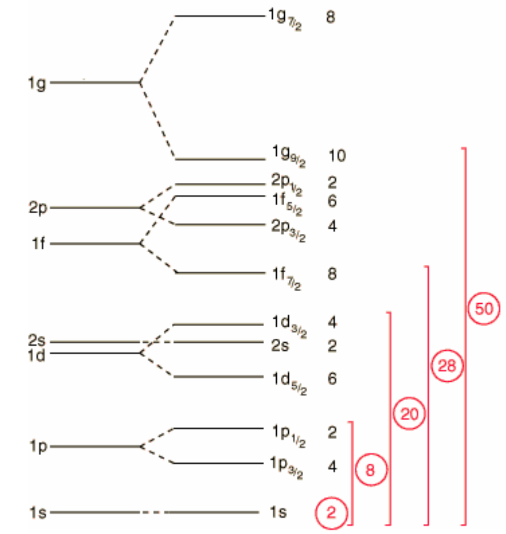
FAIR First Physics Program

What are Short Range Correlations?

INDEPENDENT PARTICLES

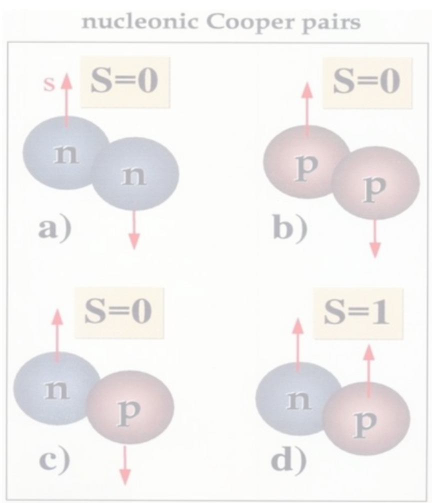


- Neutrons and protons move independently in well-defined quantum orbits;



LONG-RANGE CORRELATIONS

- Pairing and particle-vibration coupling;



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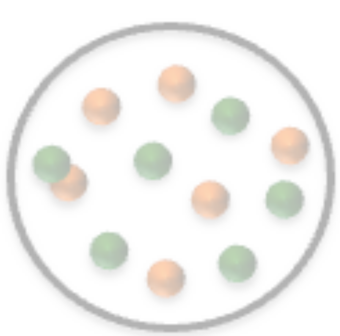

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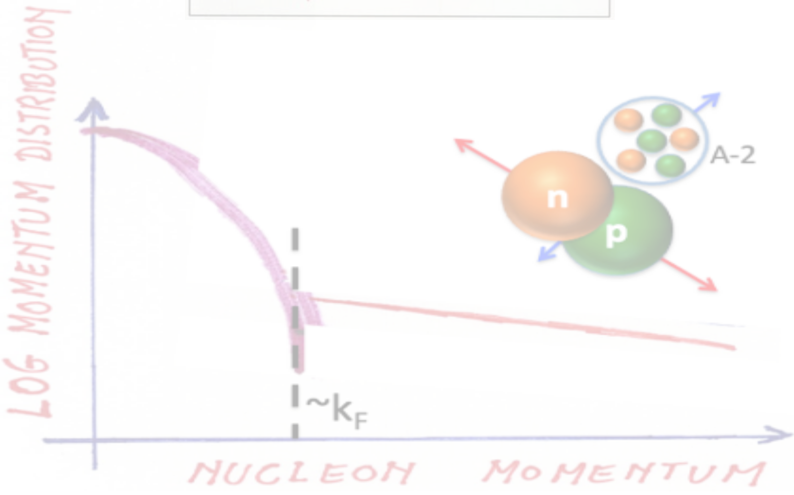

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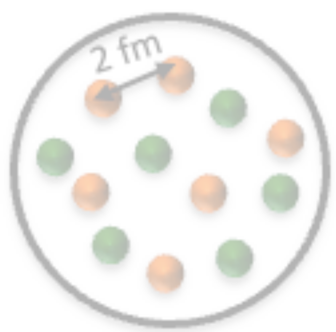

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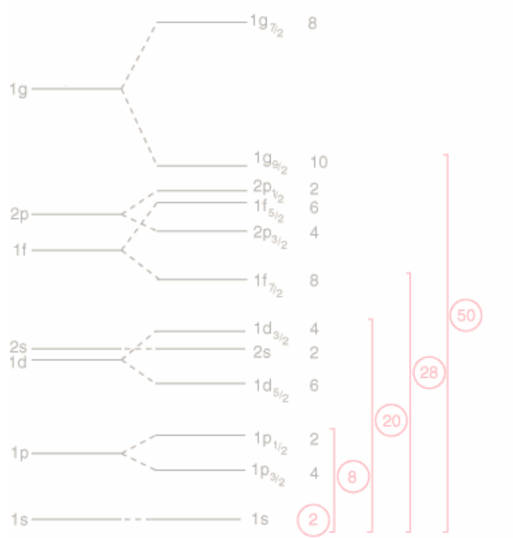

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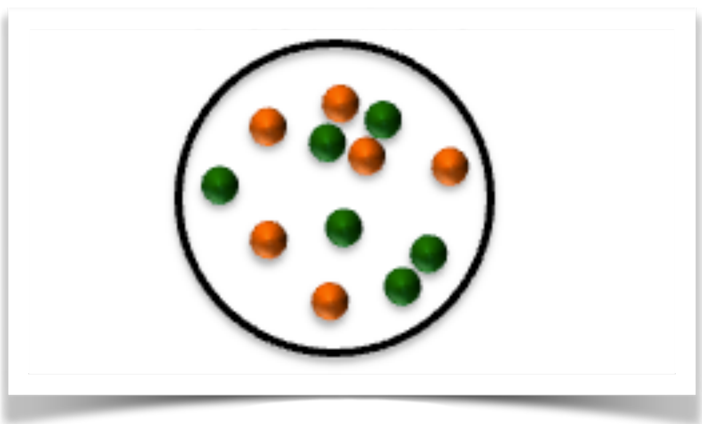

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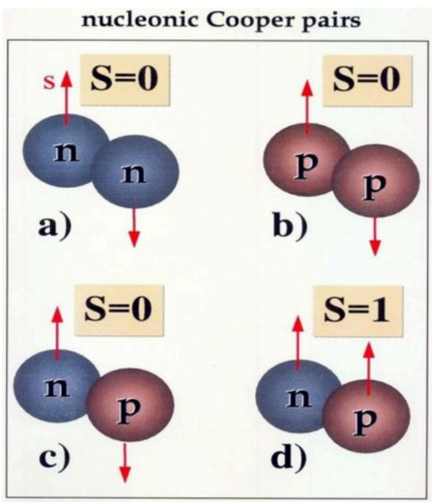

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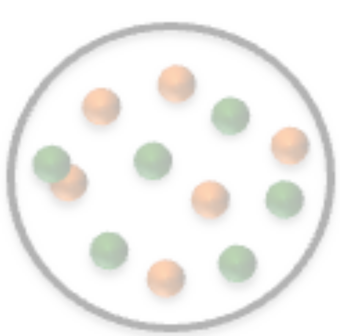

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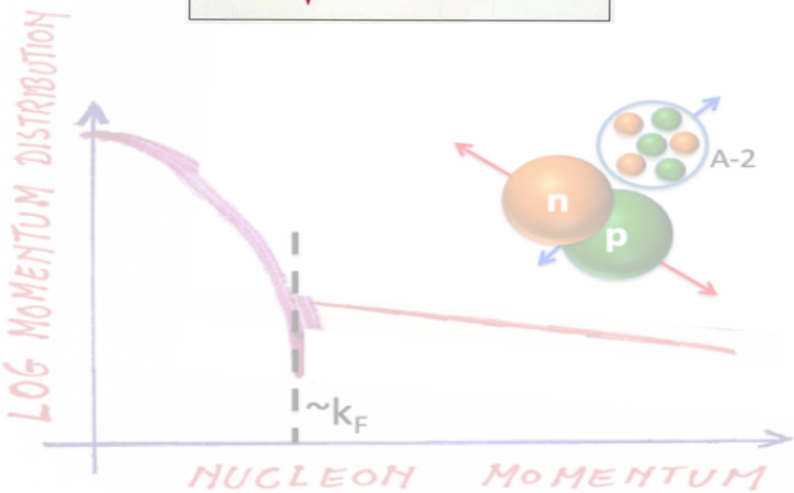

INTRODUCTION

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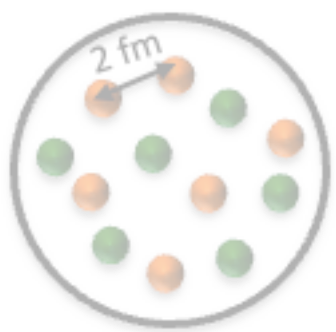

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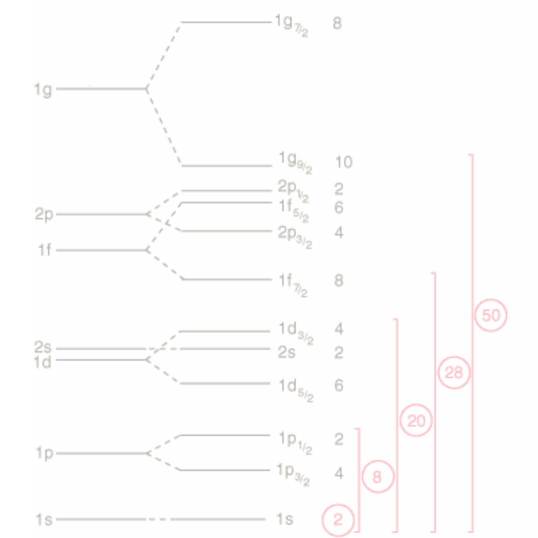

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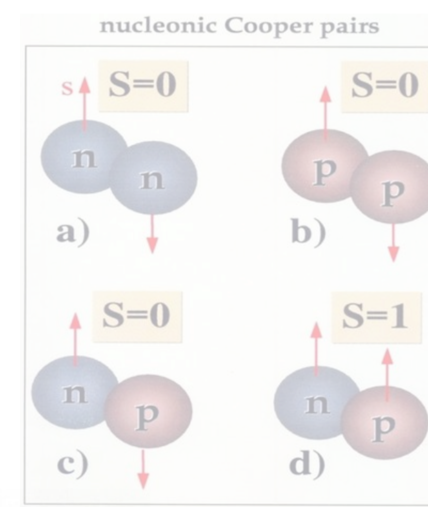

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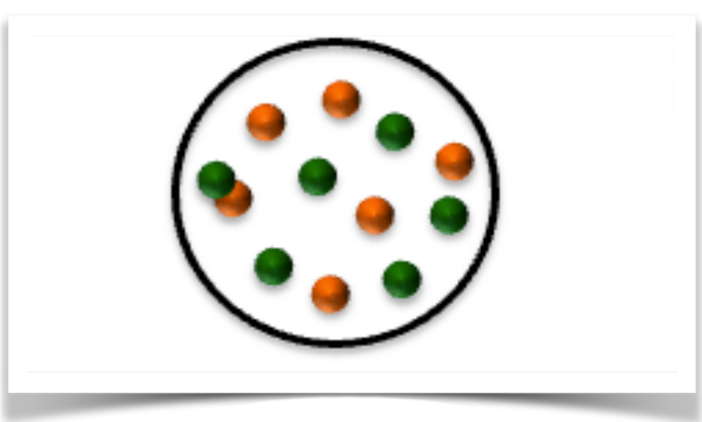

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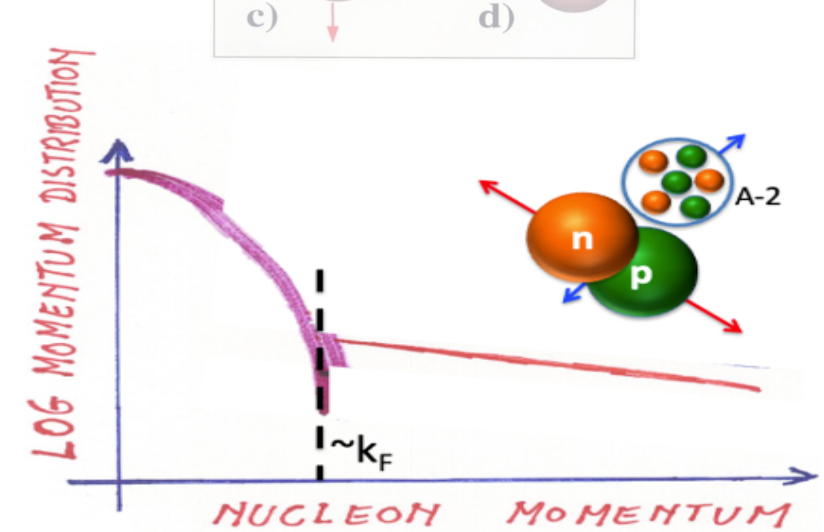

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- pp/pn ratio does not change with A;
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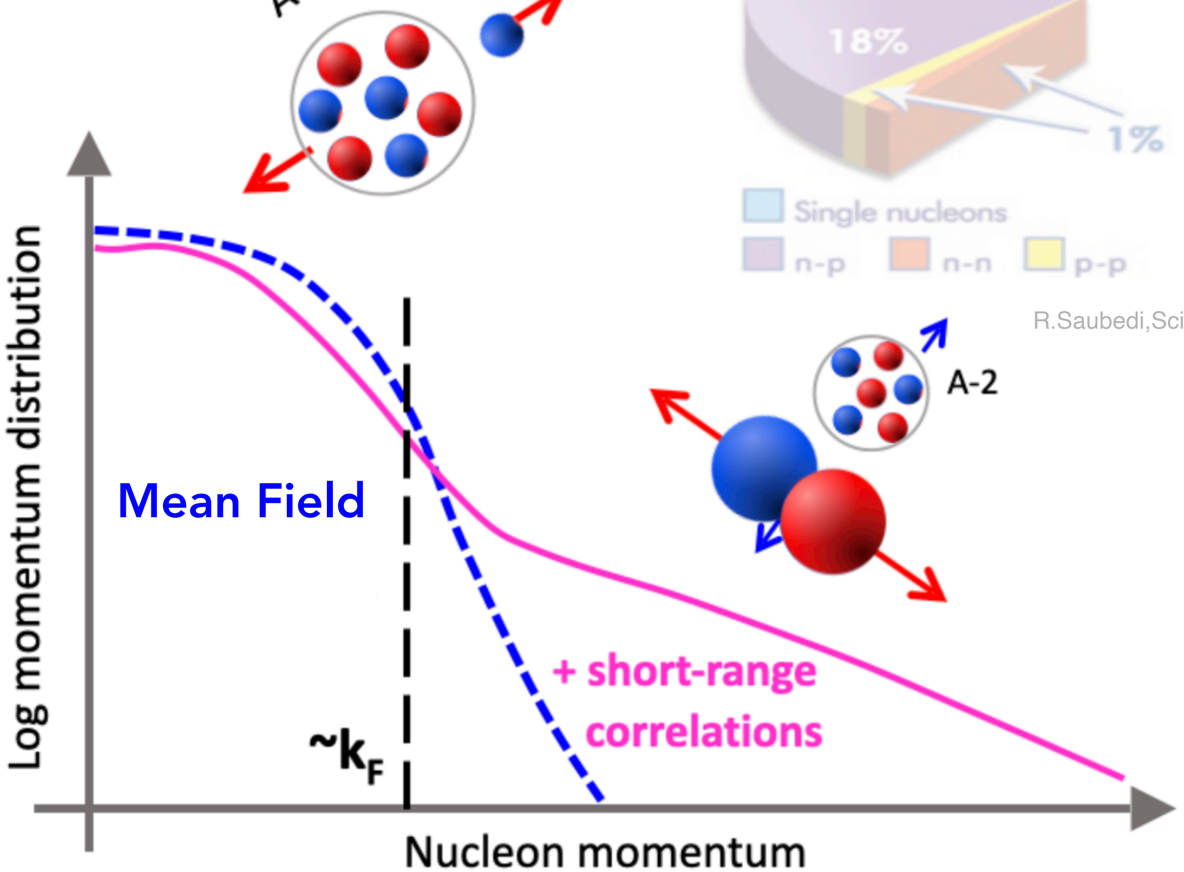
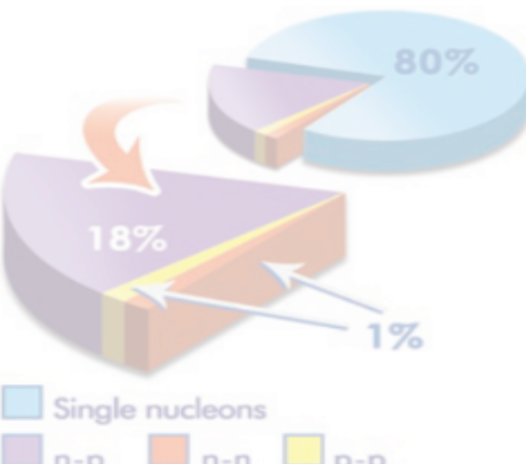
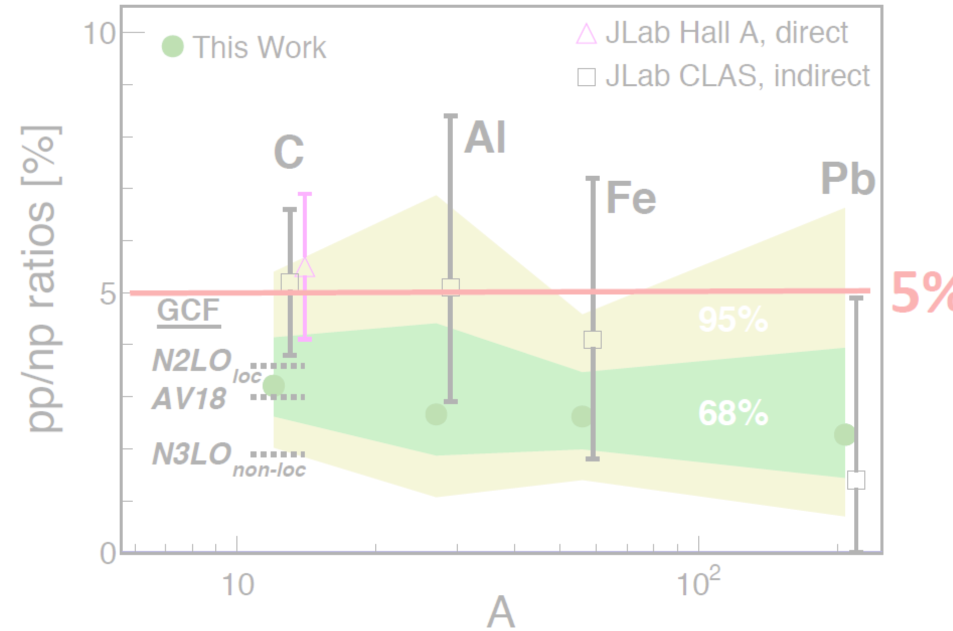


O. Hen et al. (CLAS Collaboration), Science, 346 (6209):614, 2014.



R.Saubedi,Science,Vol 320, (2008)

np Dominance



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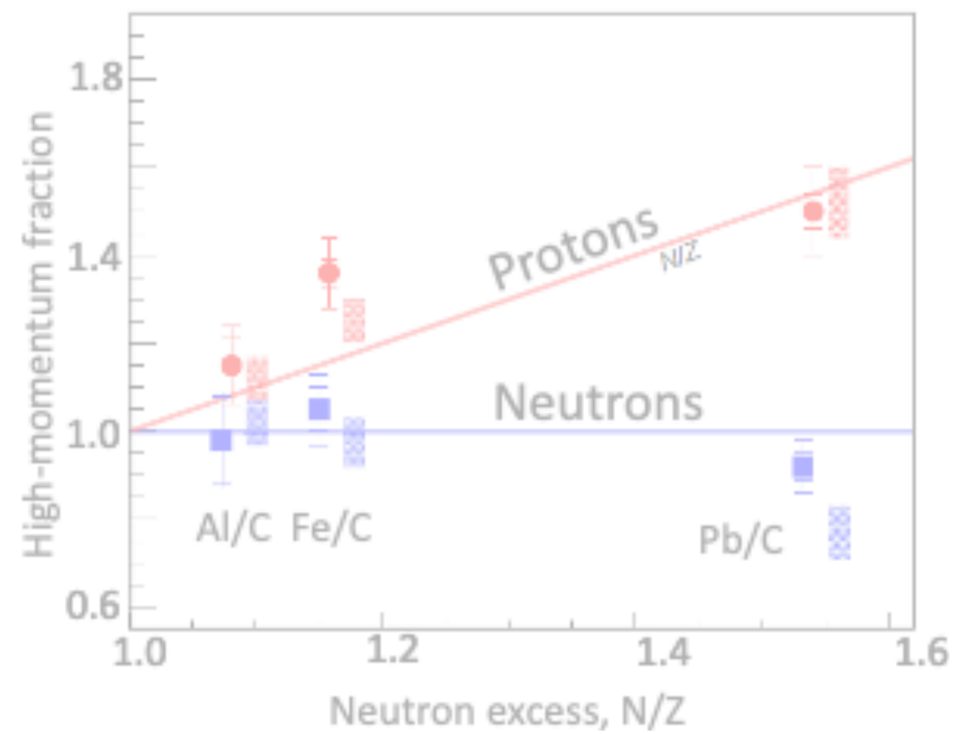

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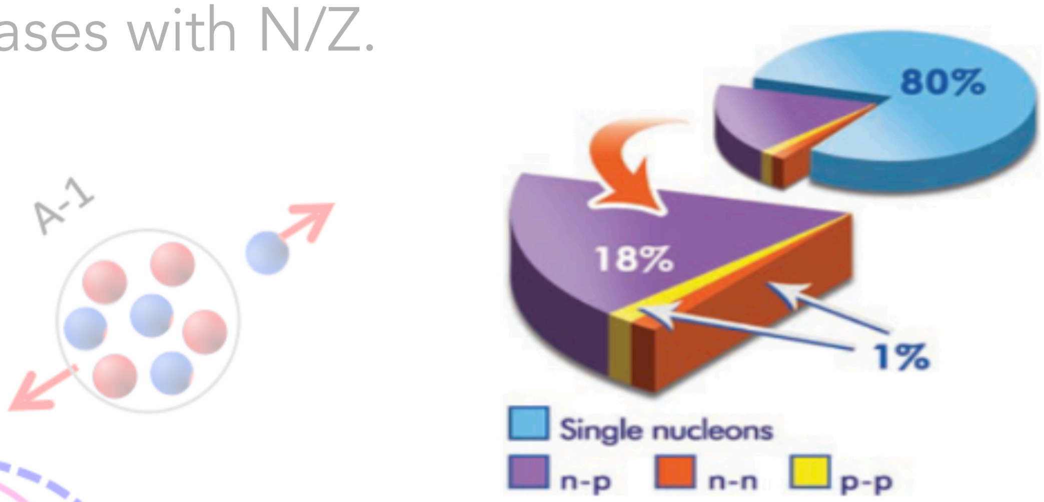

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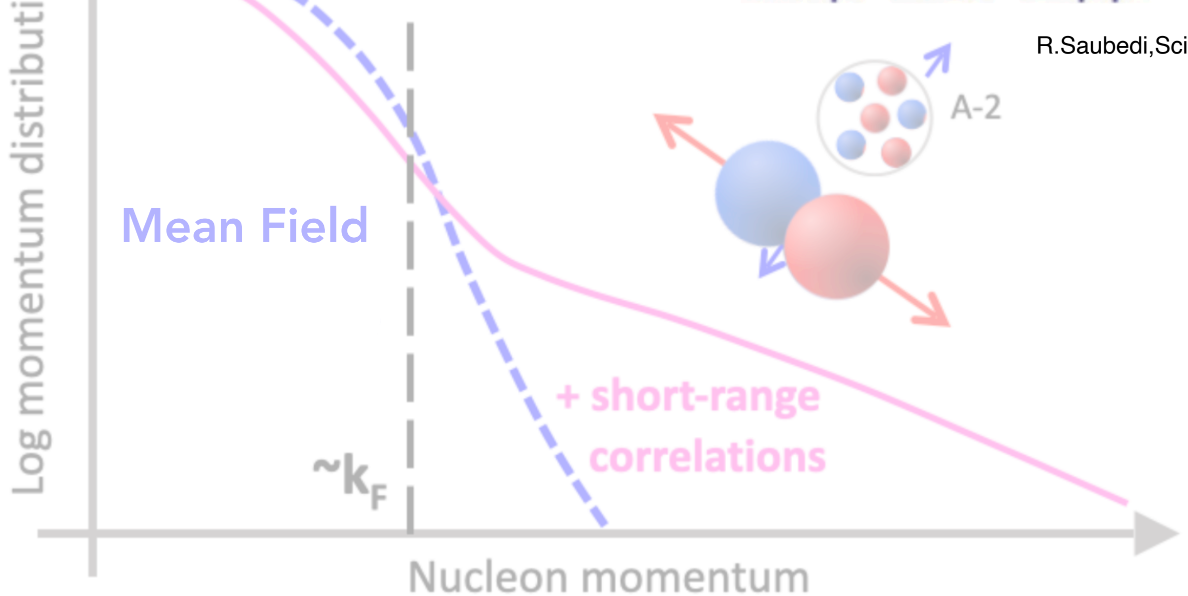

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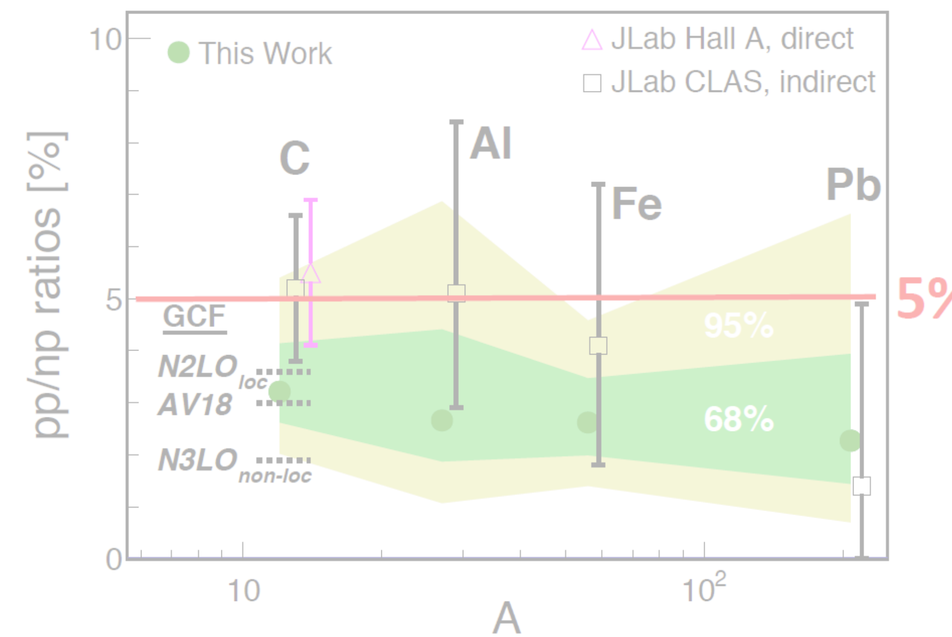

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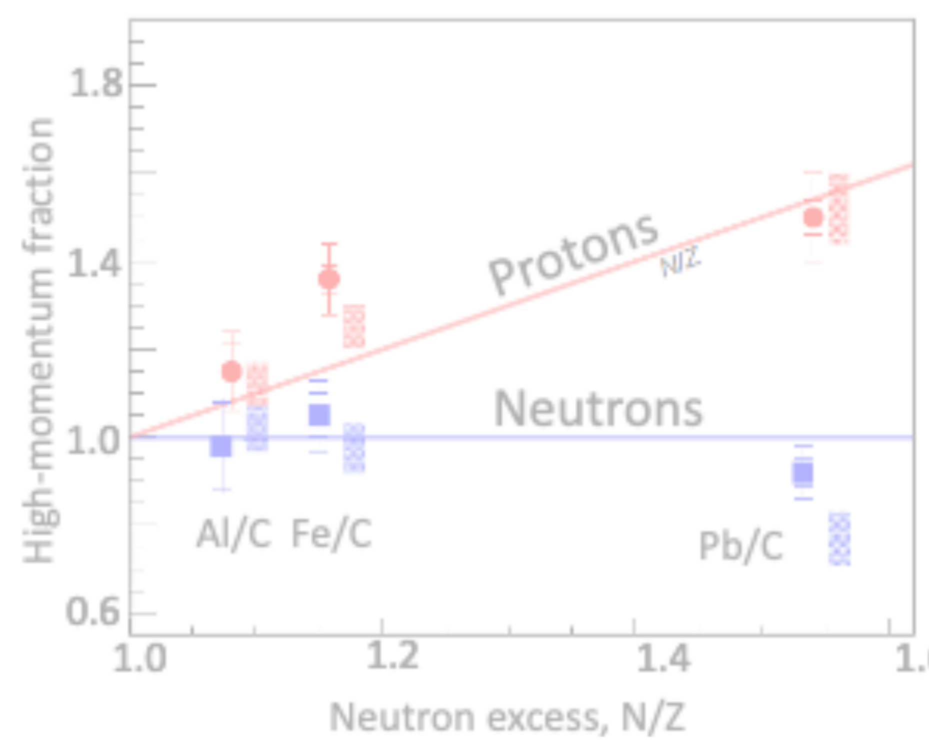

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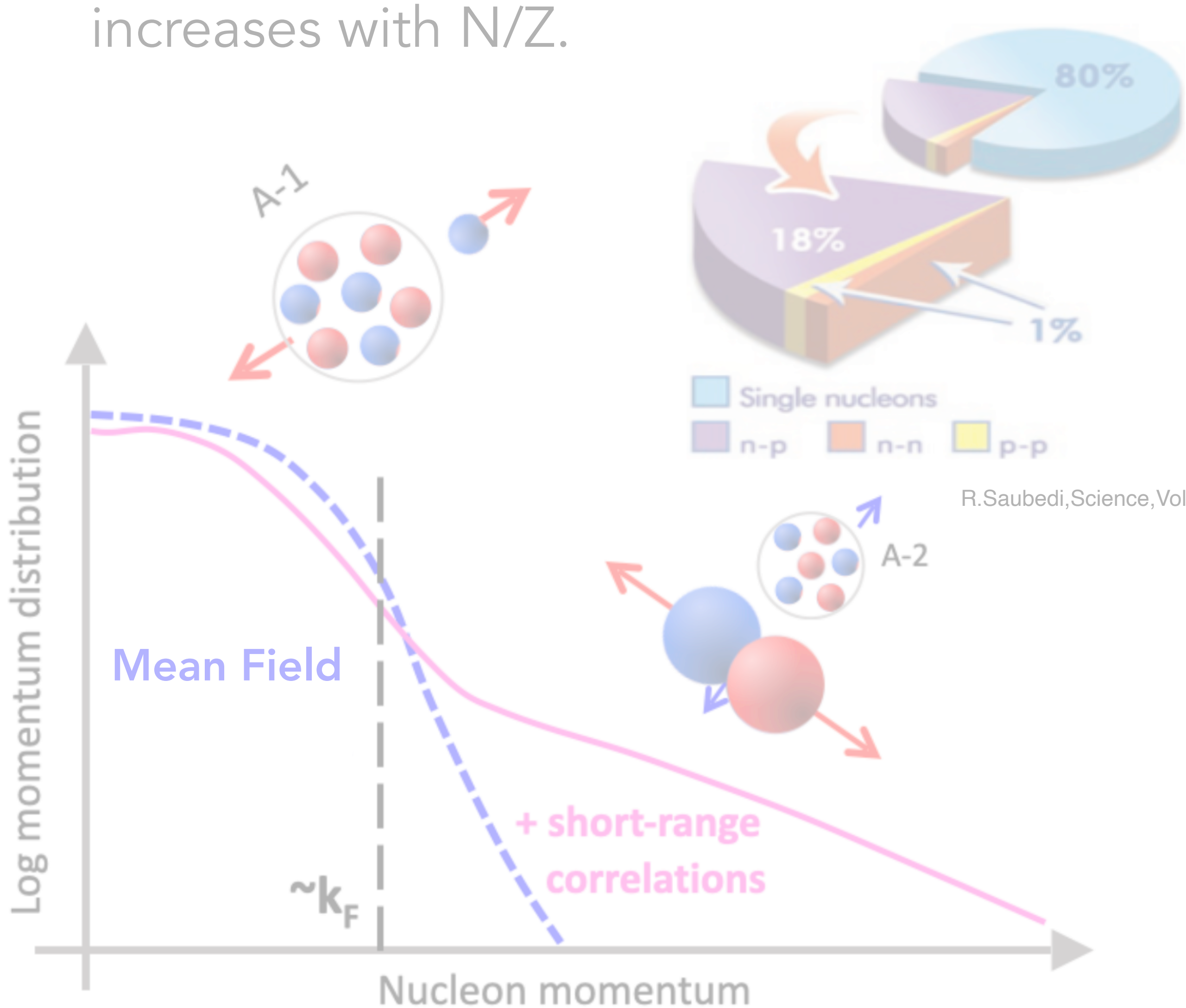

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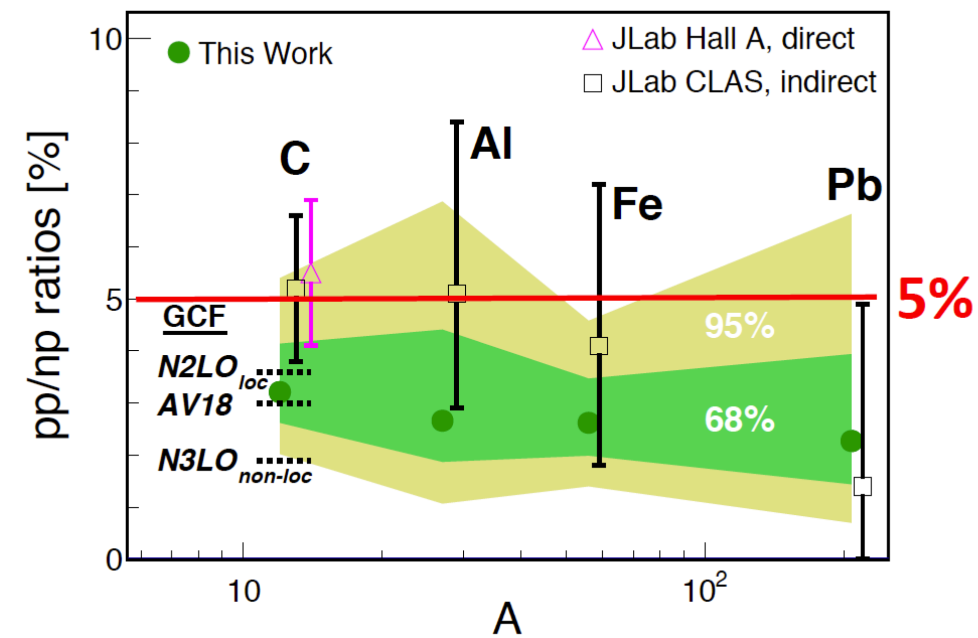

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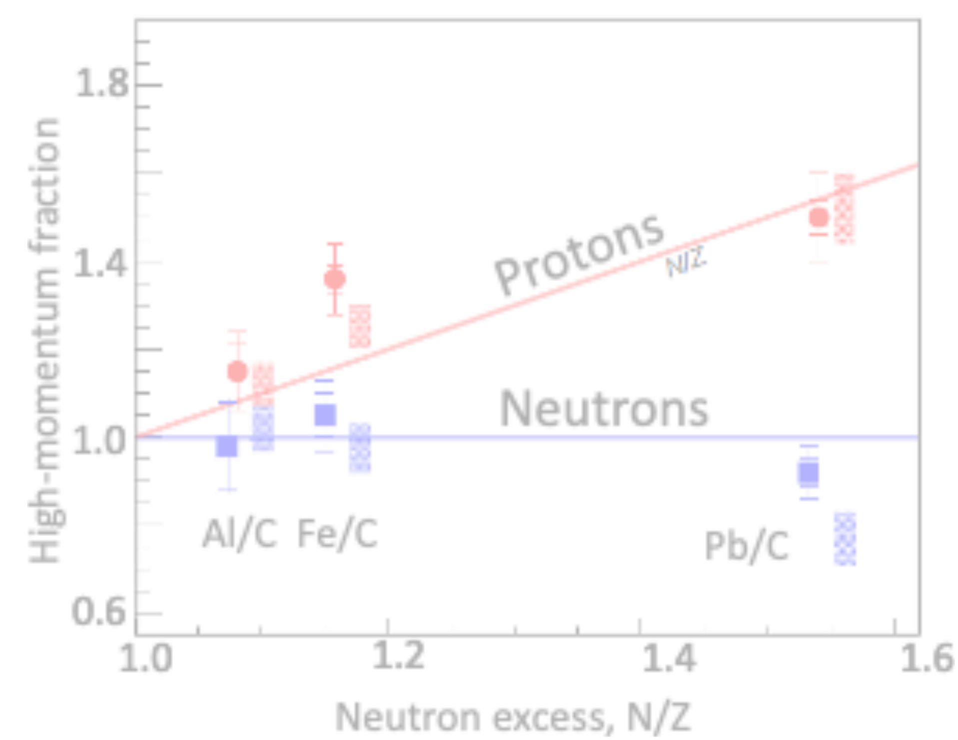

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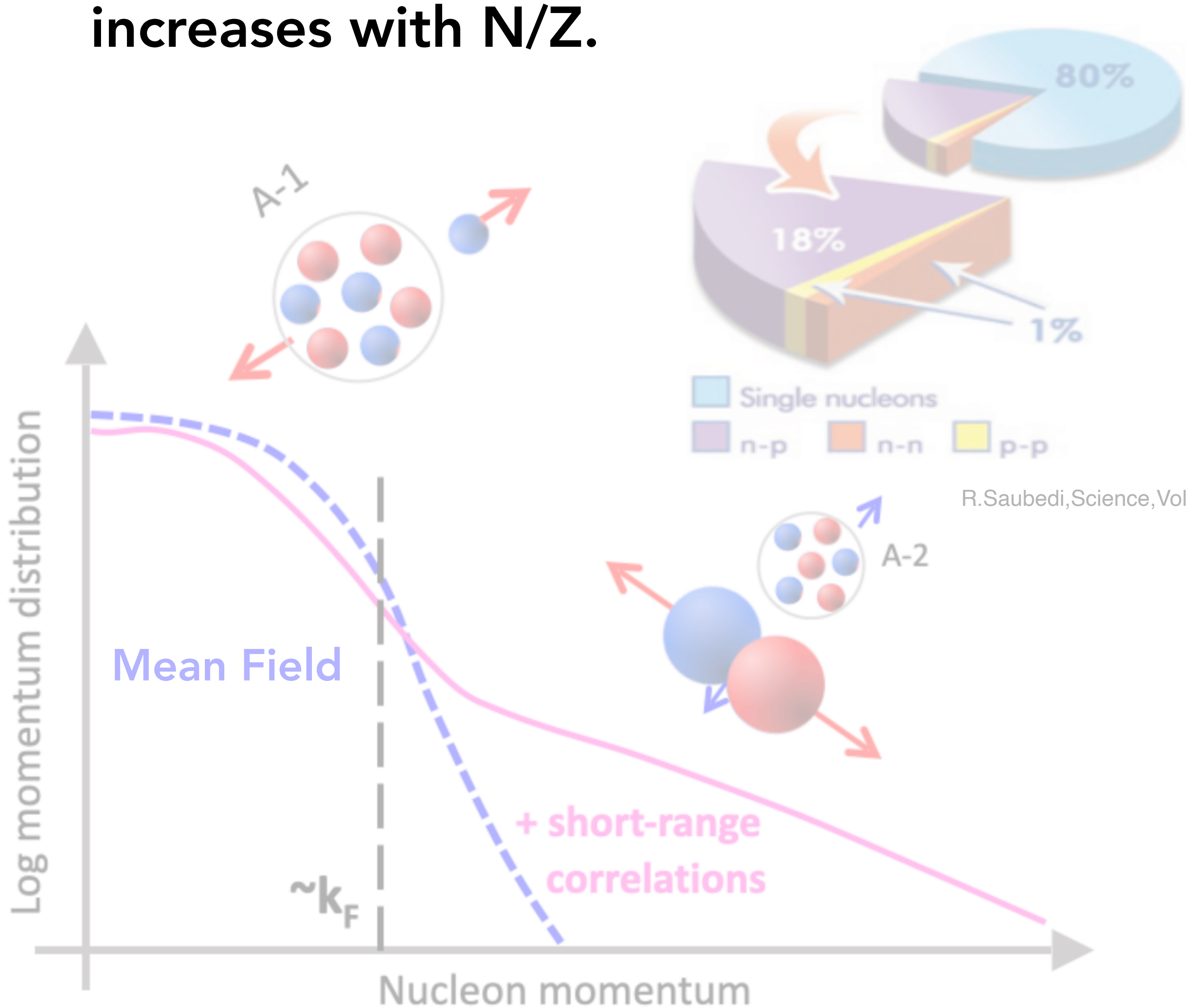

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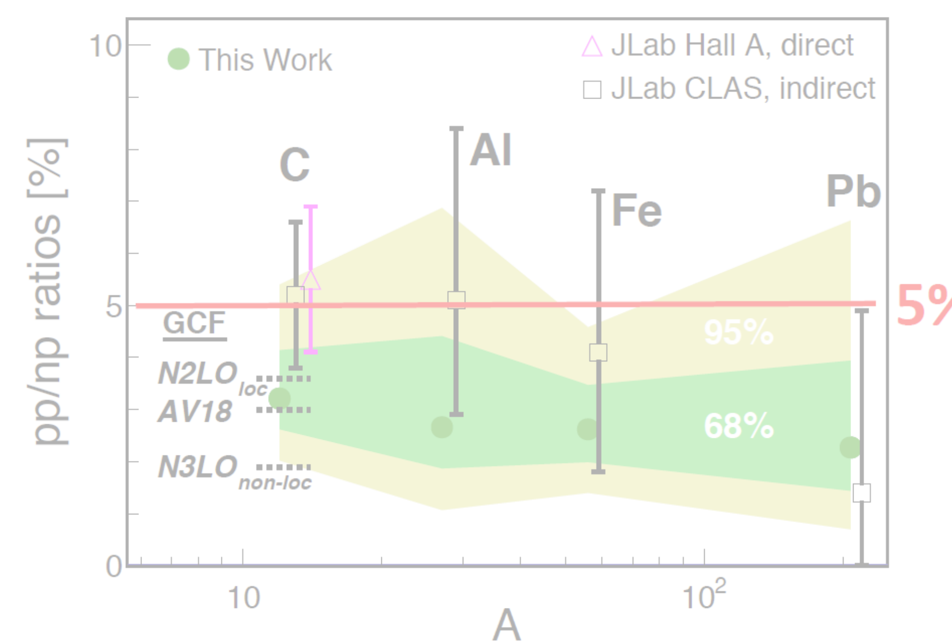

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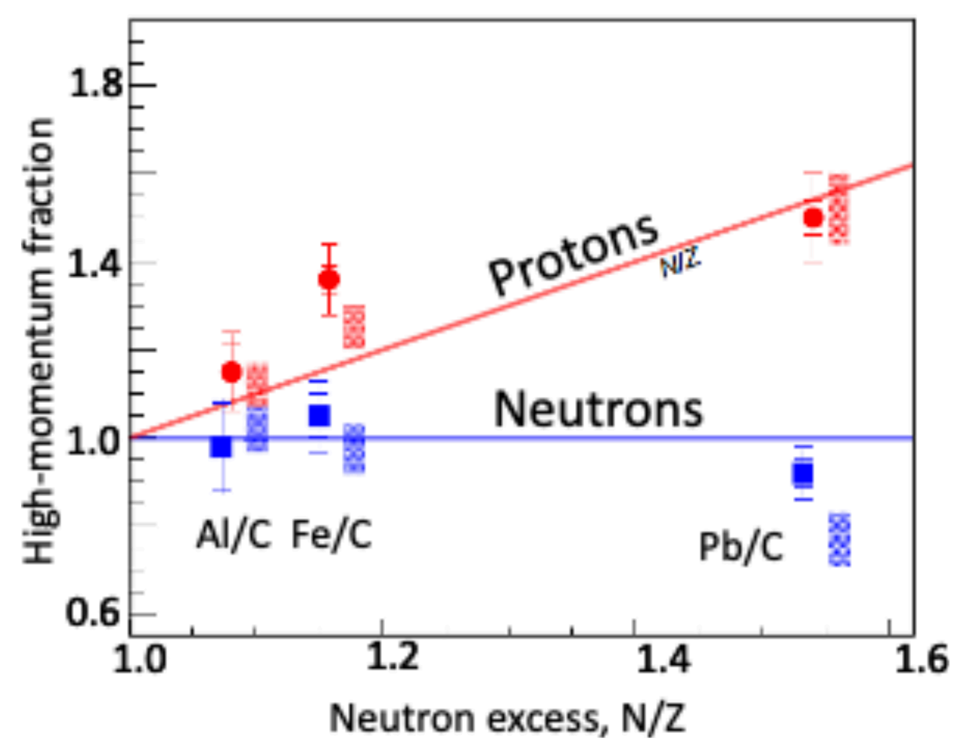

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Why study Short Range Correlations?

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Quenching of the spectroscopic factors

Equation Of State

EMC effect

Neutron stars

and many more …

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Why study Short Range Correlations?

Quenching of the spectroscopic factors

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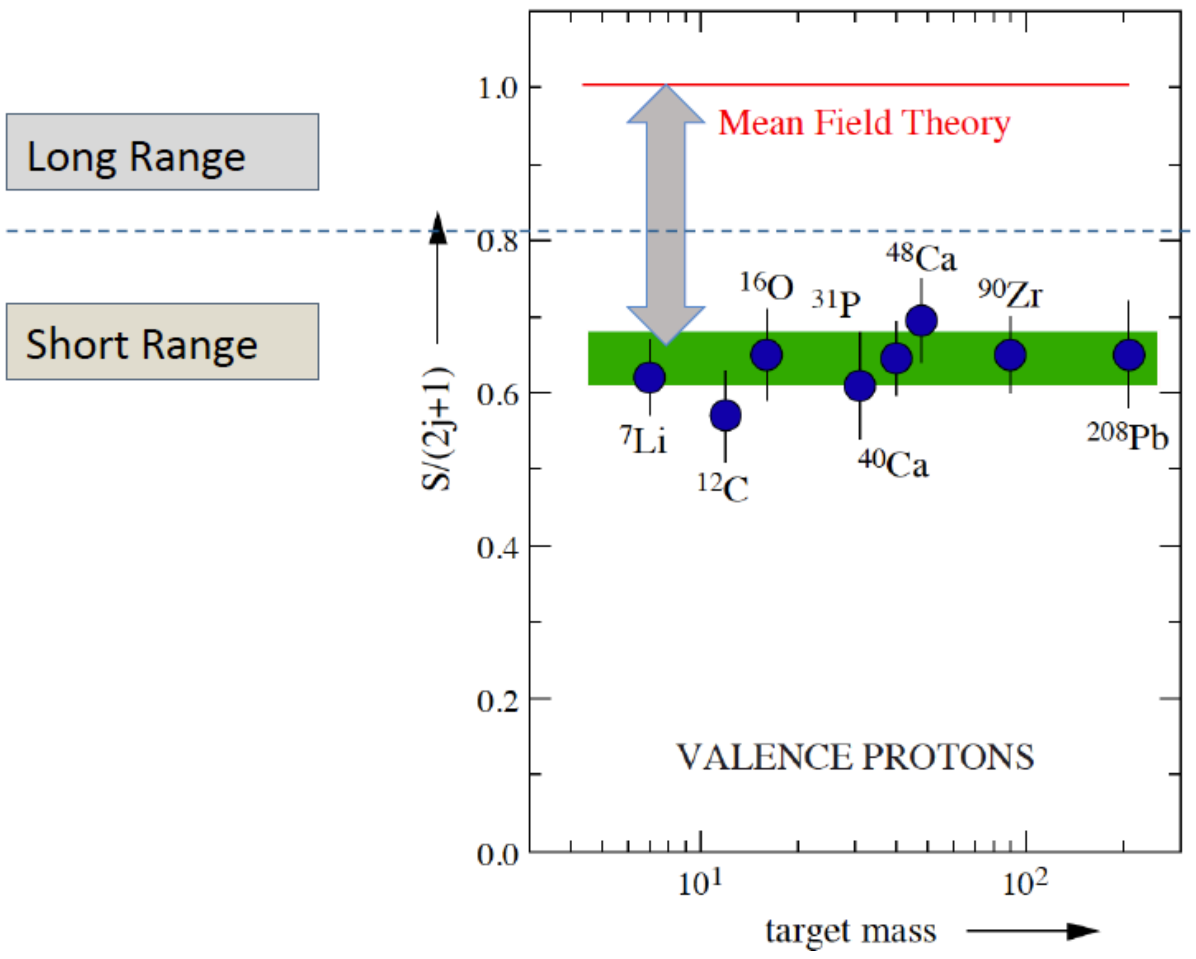
Quenching of the spectroscopic factors

Reduction of measured nucleon removal cross section with respect to the prediction of the mean-field theories

W.H. Dickhoff, C. Barbieri / Progress in Particle and Nuclear Physics 52 (2004) 377–496

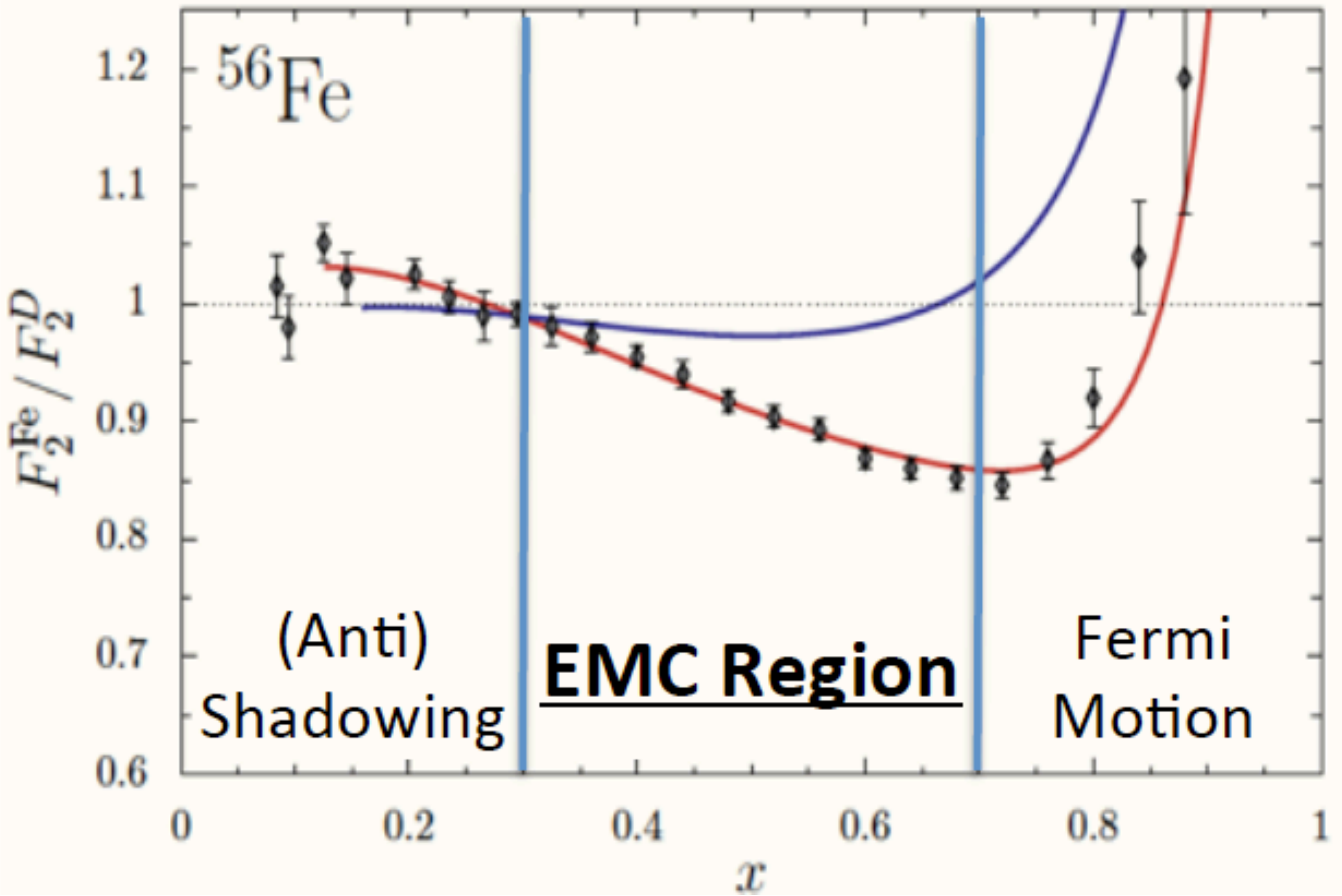


- ***Correlations*** *between nucleons* ***modify the mean-field approximation****;*
- *About 30% – 40% of the nucleons participate in NN correlations, which are distinguished into* ***long-range (LRC) and short-range (SRC);***
- *Are thought to be the reason for the quenching of SF observed in (e,e′p), (p,2p) and transfer reactions.*
- *Depletion of the single particle states below the Fermi momentum.*

EMC effect

The European Muon Collaboration (EMC) at CERN observed a ***decrease of per-nucleon electron deep inelastic cross-section in nuclei with A>2 compared to the deuteron****.*

- *Deviation of the per-nucleon DIS cross section ratio of nuclei relative to deuterium from unity.*
- *Universal shape for 0.3<x<0.7 and 3<A<197.*
- *No fully accepted theoretical explanation.*



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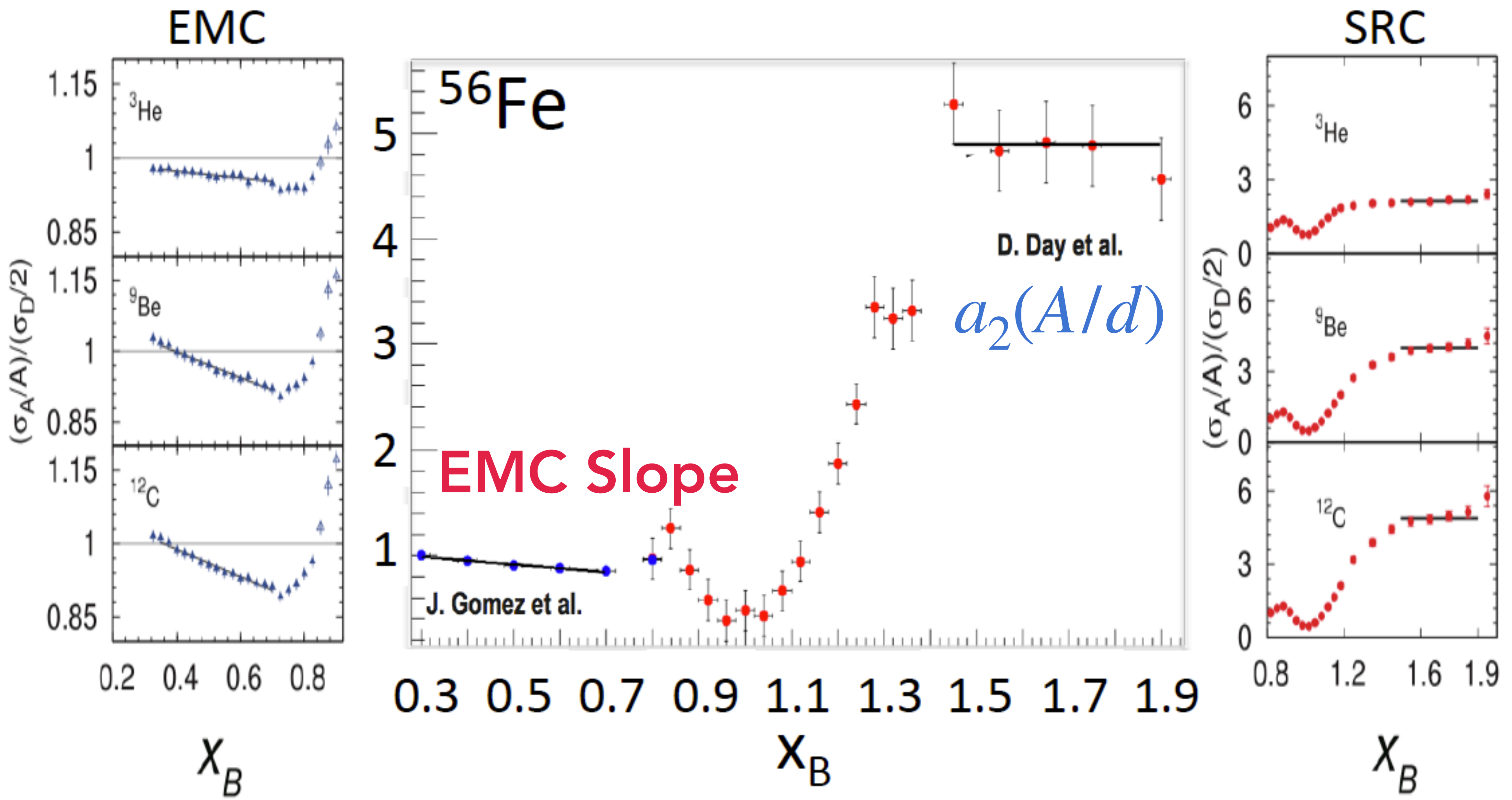
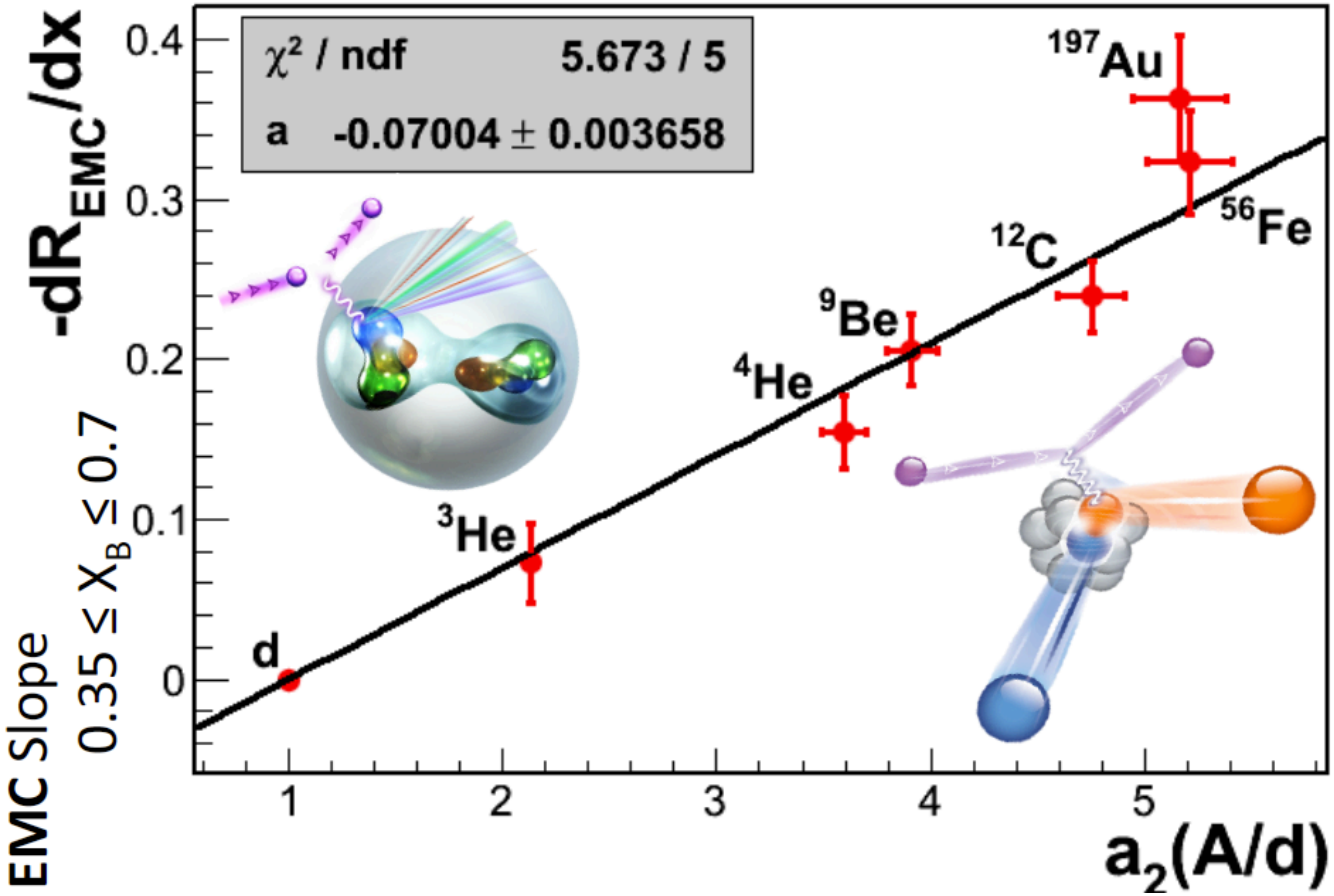


<u>SRC Data:</u>
L. Frankfurt et al. , Phys.Rev. C48 (1993) 2451
N. Fomin et al., Phys.Rev.Lett 108 (2012) 092502

<u>EMC Data:</u>
J. Gomez et al., Phys.Rev. D. 49, 4348 (1994)
J. Seely et al., Phys.Rev. Lett. 103, 202301 (2009)

EMC effect

EMC slopes versus the SRC scale factors. The two values are strongly linearly correlated.

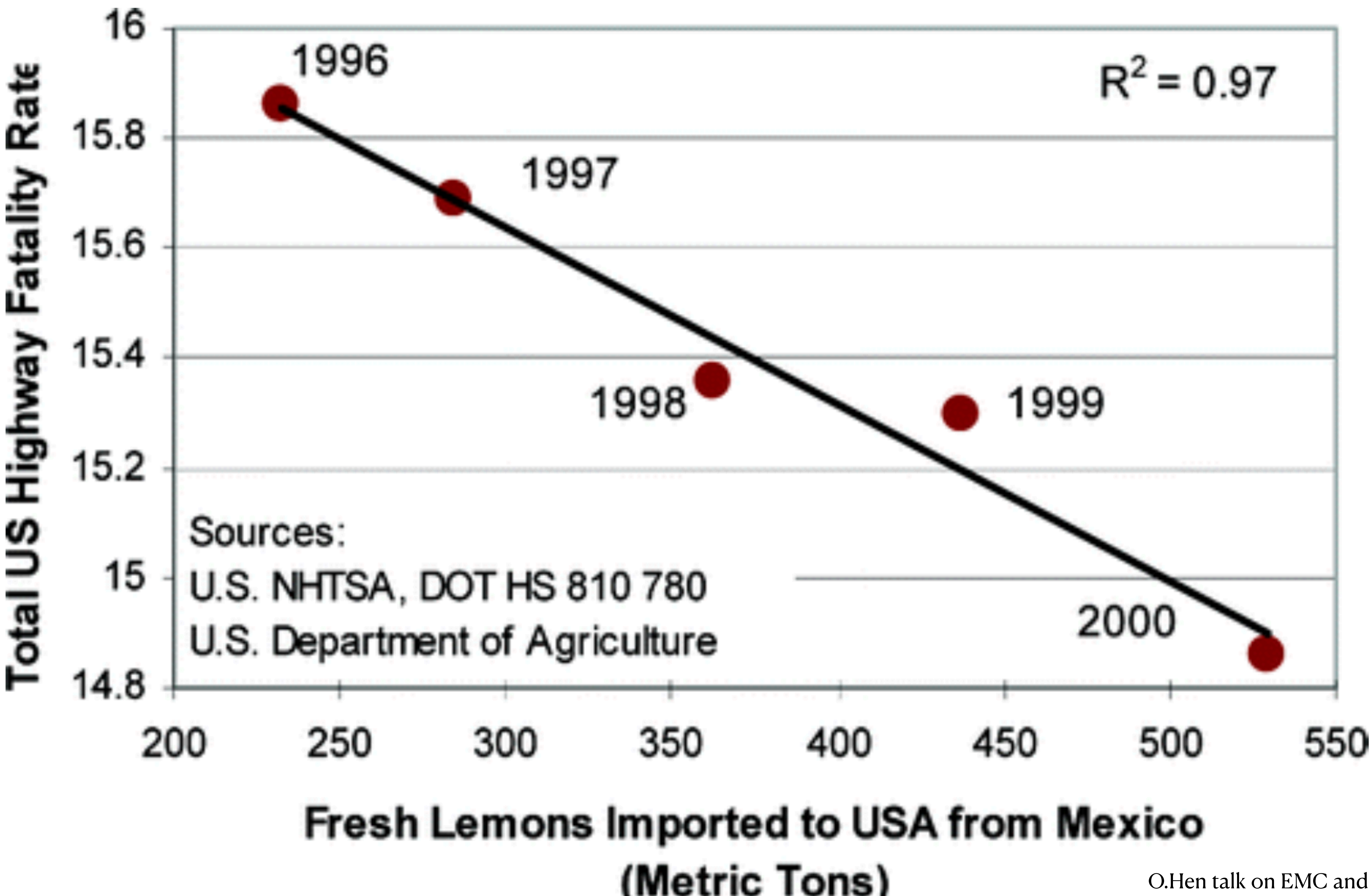


O. Hen et al., Int. J. Mod. Phys. E. **22**, 1330017 (2013).

O. Hen et al., Phys. Rev. C **85** (2012) 047301.

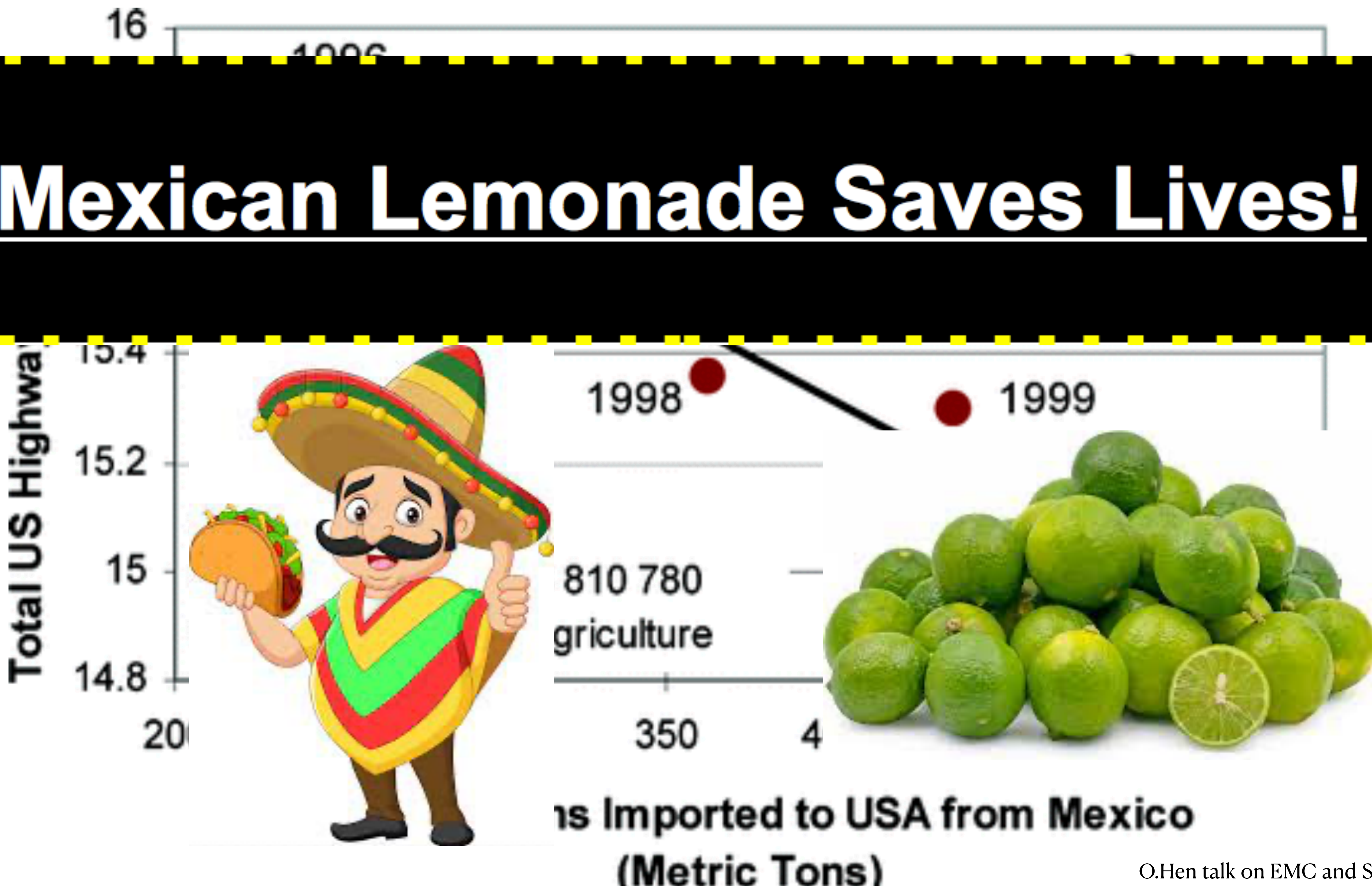
L. B. Weinstein, E. Piasetzky, D. W. Higinbotham, J. Gomez, O. Hen, R. Shneor, Phys. Rev. Lett. **106** (2011) 052301.

INTRODUCTION



O.Hen talk on EMC and SRC

Mexican Lemonade Saves Lives!



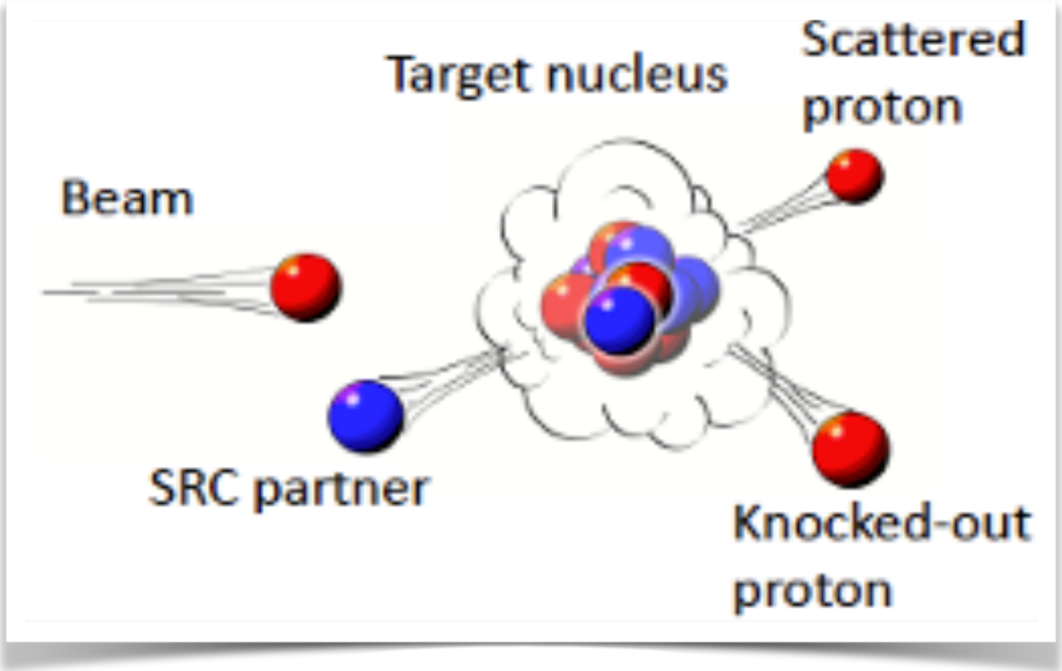
O.Hen talk on EMC and SRC

How we study Short Range Correlations?

PROBING SRC

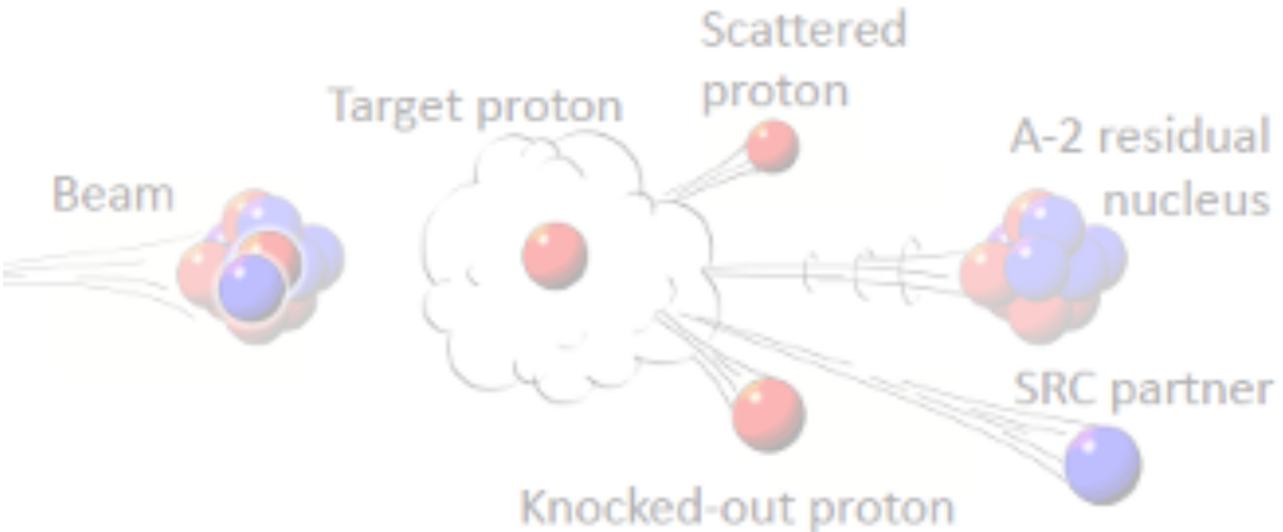
Direct kinematics

- ☑ P_{miss}, E_{miss}, P_{recoil};
- ☑ P_{cm} (indirectly);
- ✗ Fragment ID.



Inverse kinematics

- ☑ P_{miss}, E_{miss}, P_{recoil};
- ☑ p_{cm} (directly);
- ☑ Fragment ID;
- ☑ Exotic nuclei;
- ☑ Higher cross-section for protons;
- ISI/FSI challenges data interpretation.



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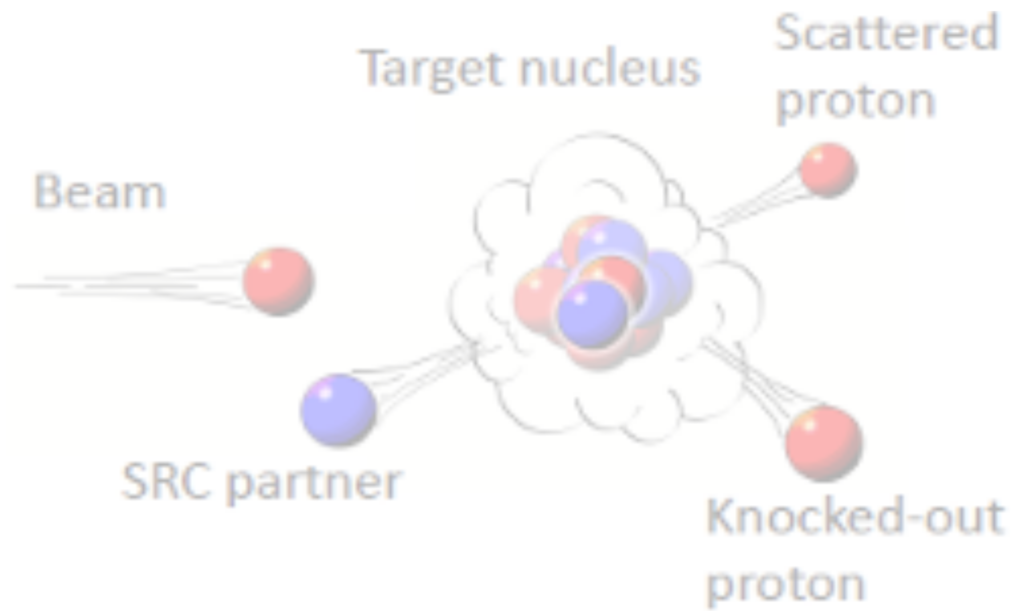

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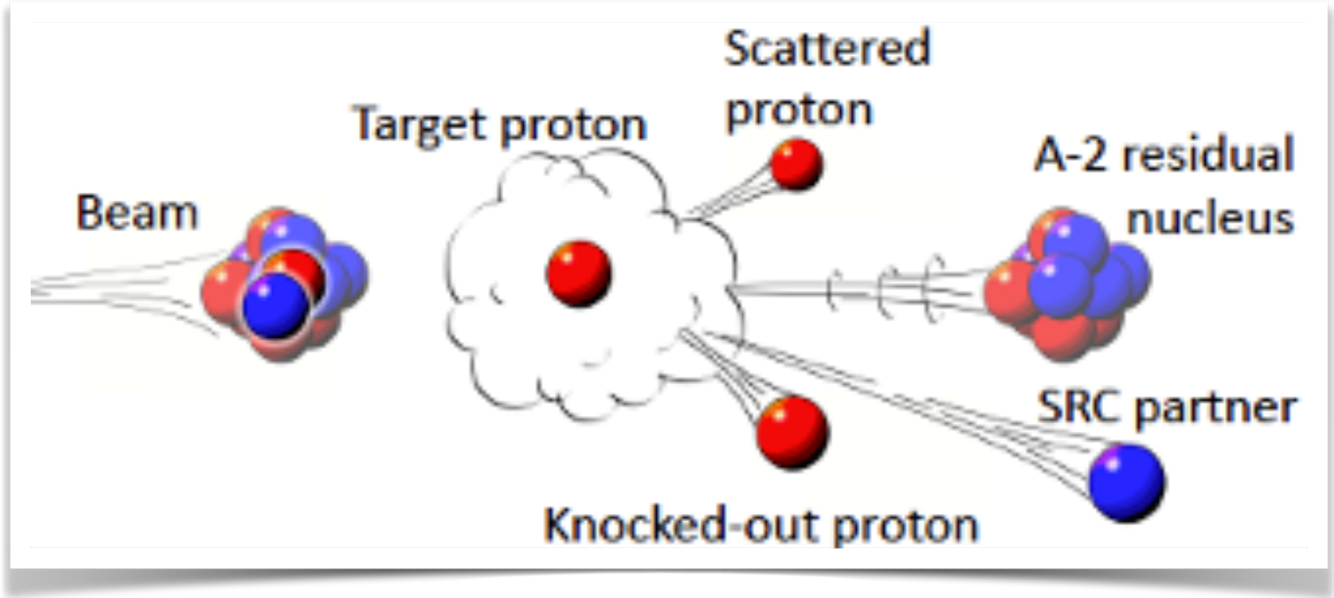


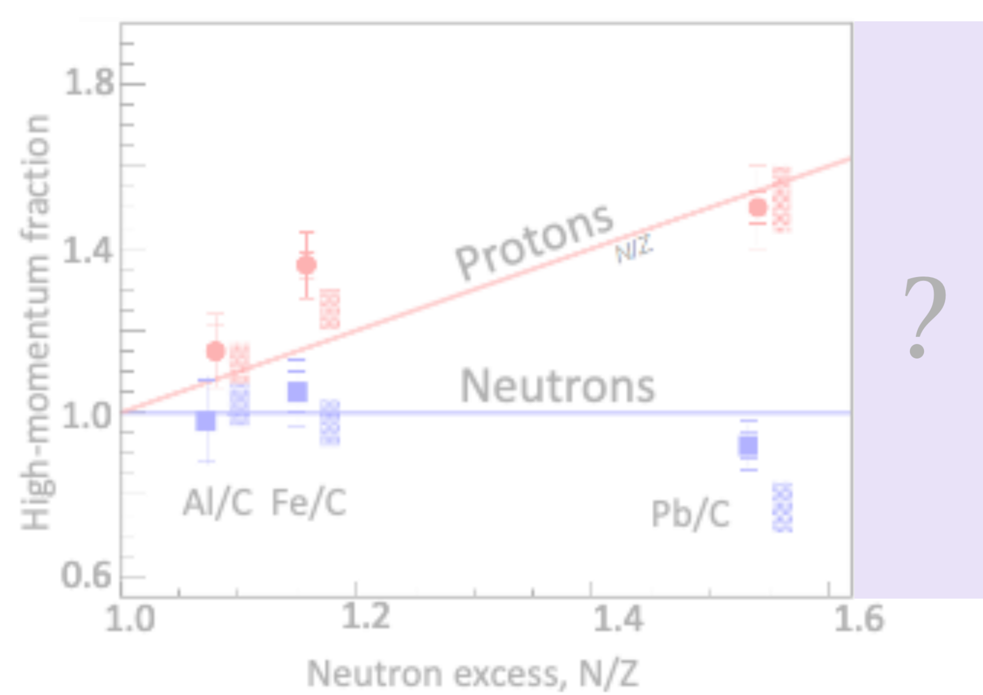
Proton scattering experiments

- **BM@N (JINR) pilot experiment (2018);**
- R^3B (GSI) Experiment (May 2022);
  - Probe SRC in an exotic nucleus for the first time;
- FAIR First Physics LoI.

Motivations R3B Experiment

- Existing trend based on a few points;
- behaviour can depend on shell structure (open/closed shell effects);
- mass and N/Z excess cannot be disentangled with stable nuclei.

- **New measurement at N/Z = 1.67 (^{16}C), above the largest available N/Z and at a much smaller mass.**



Adapted from M. Duer et al. (CLAS Collaboration), Nature, 560:617, 2018.

BM@N Experimental Set-up

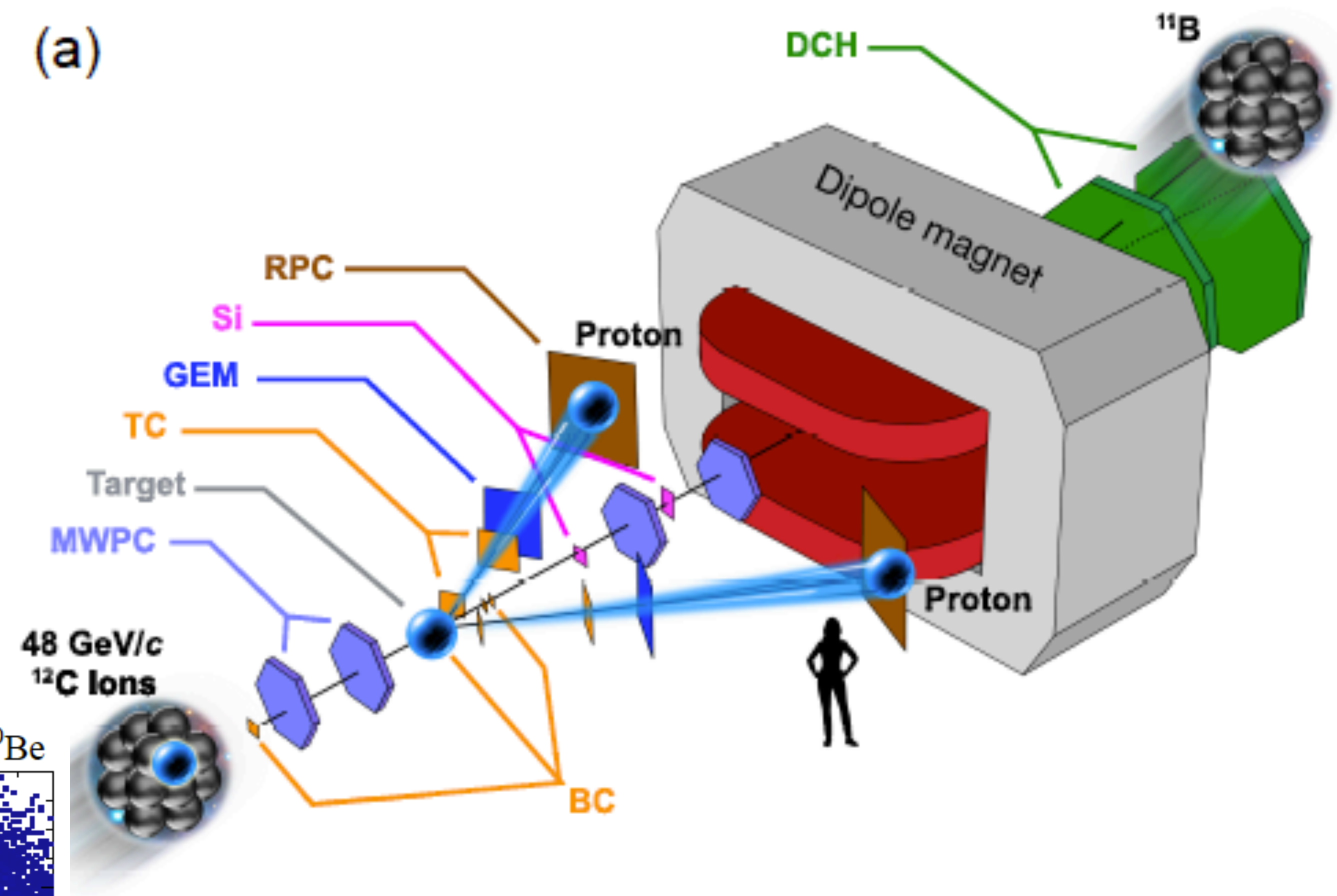
$^{12}C(p,2pN)$

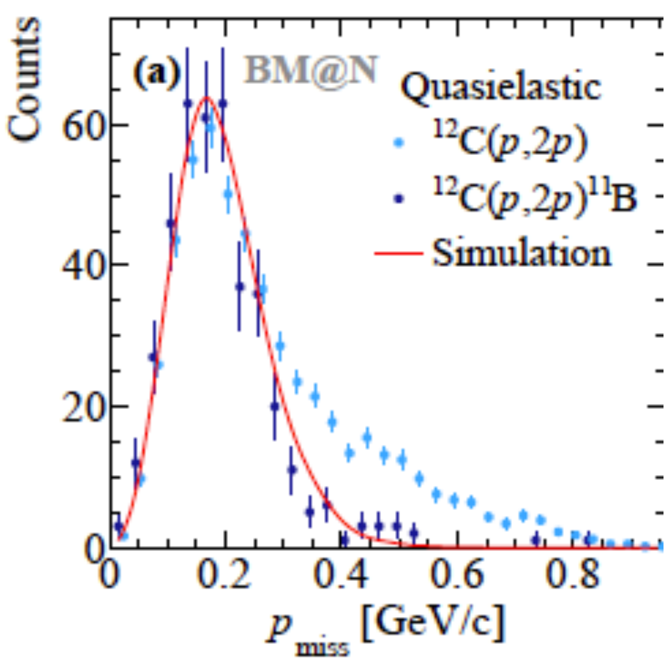
Joint Institute for Nuclear Research (JINR), 4 GeV/c/u Carbon beam

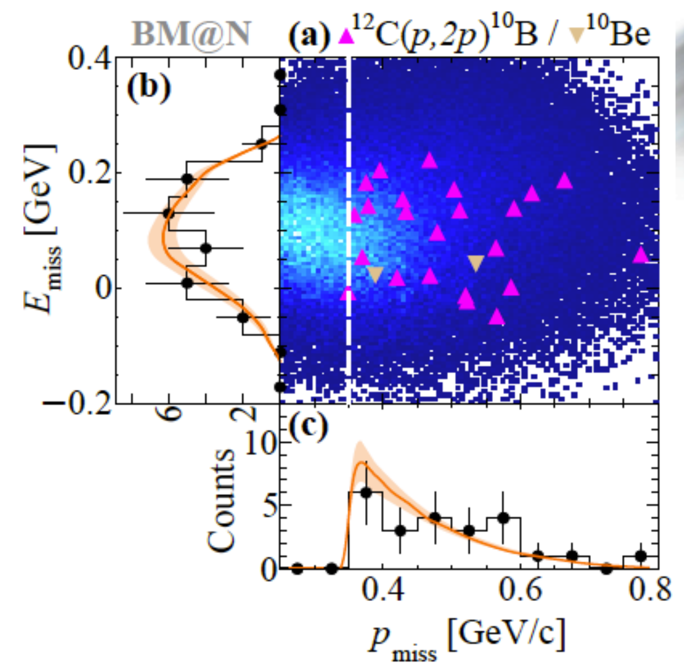
JINR Experiment

- Test experiment;
- Test if SRCs are accessible in proton scattering in inverse kinematics;
- Study sensitivity to ISI/FSI induced distortions;
- Selectivity of the QF mechanism: **proton missing mass M_{miss} and missing momentum P_{miss};**

(a)







- tracking and momentum of the **two scattered protons** under large laboratory angles with two-arm spectrometer (TAS);
- **pair-recoil nucleon** (n or p) momentum;
- **A-2 fragment momentum.**

Proton scattering experiments

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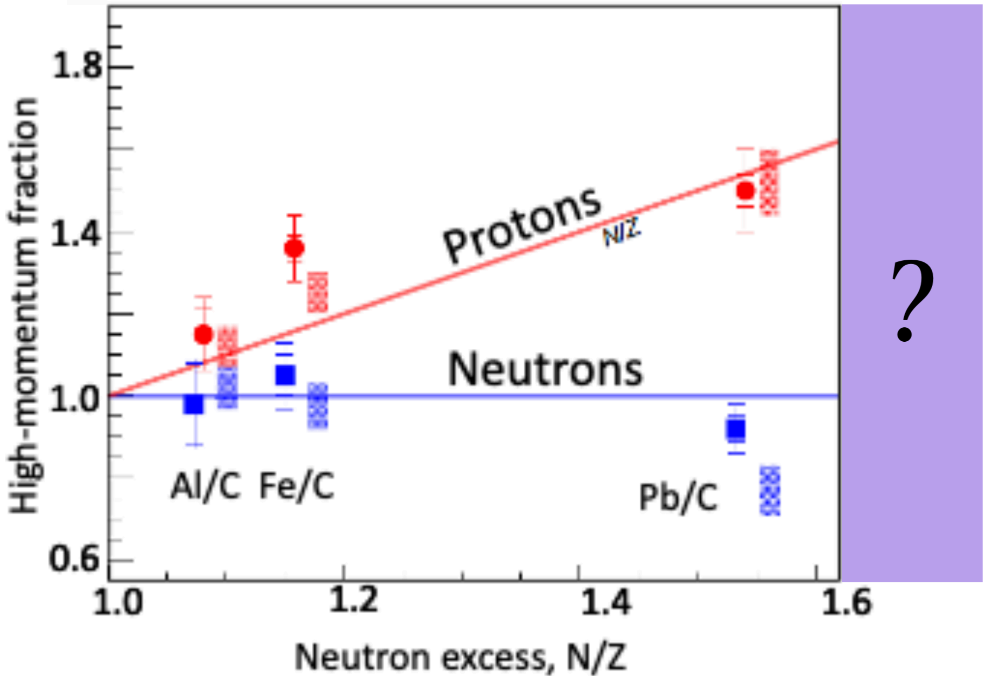

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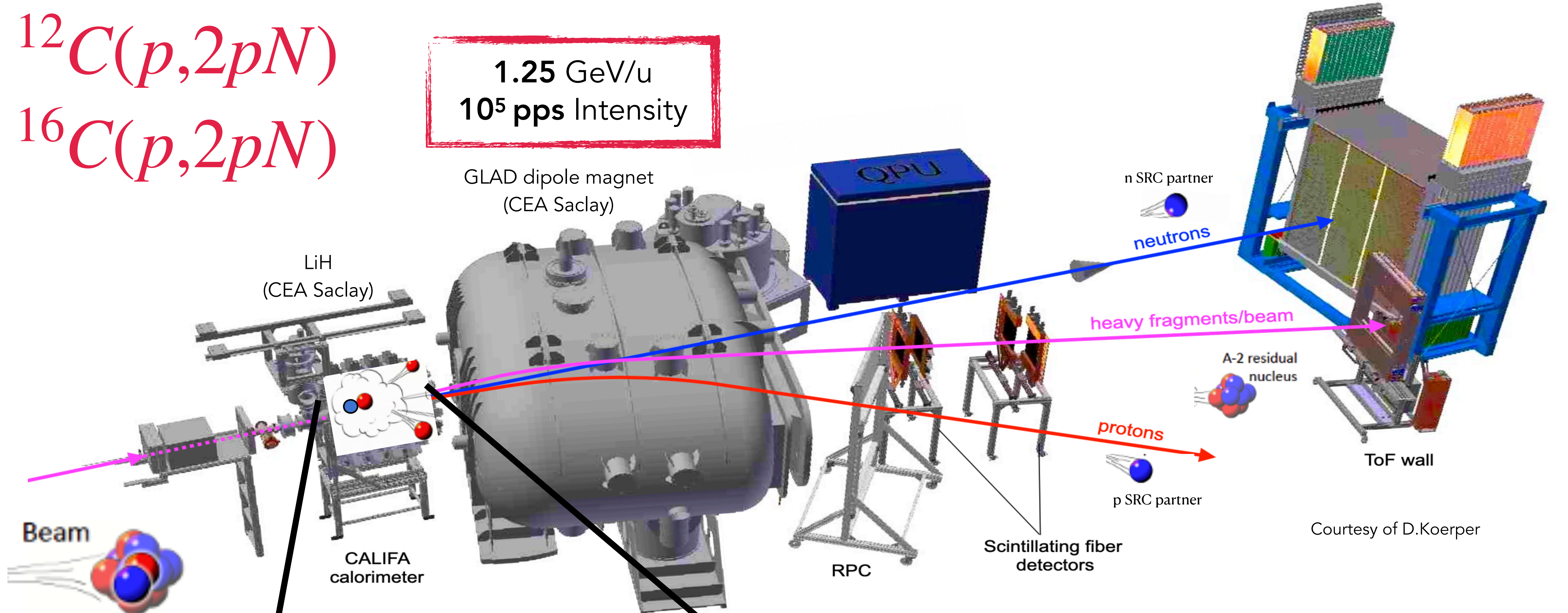
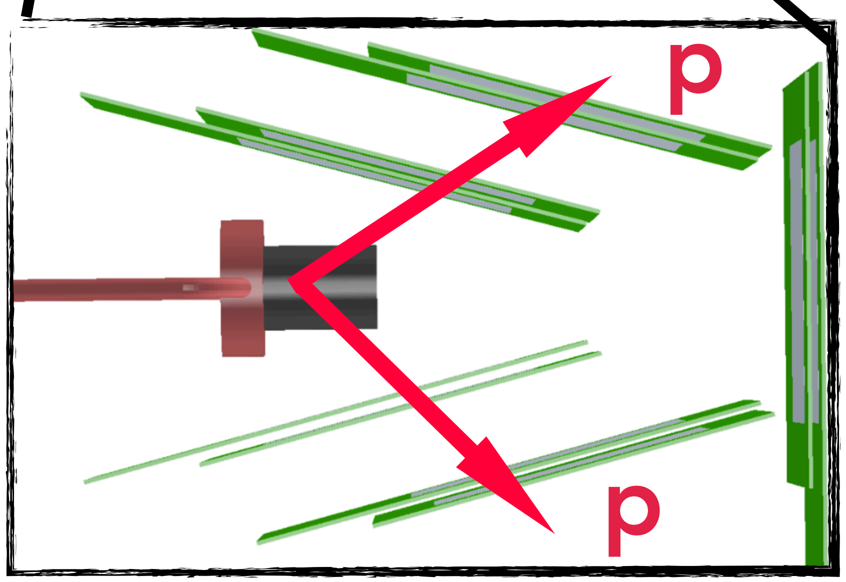
R^3B Experimental Set-up

$^{12}C(p,2pN)$

$^{16}C(p,2pN)$

1.25 GeV/u
10^5 **pps** Intensity





- tracking and momentum of the **two scattered protons** under large laboratory angles (Silicon + Calorimeter);
- **pair-recoil nucleon** (n or p) momentum;
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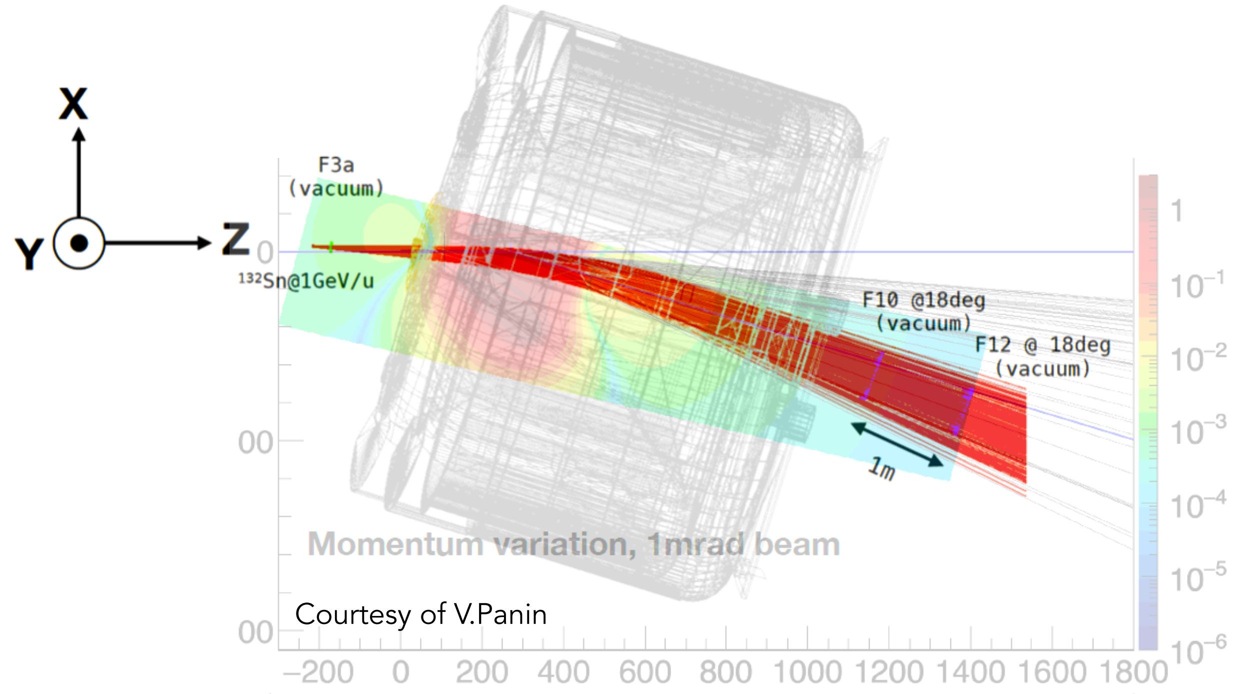
Fragment analysis: MDF Tracking

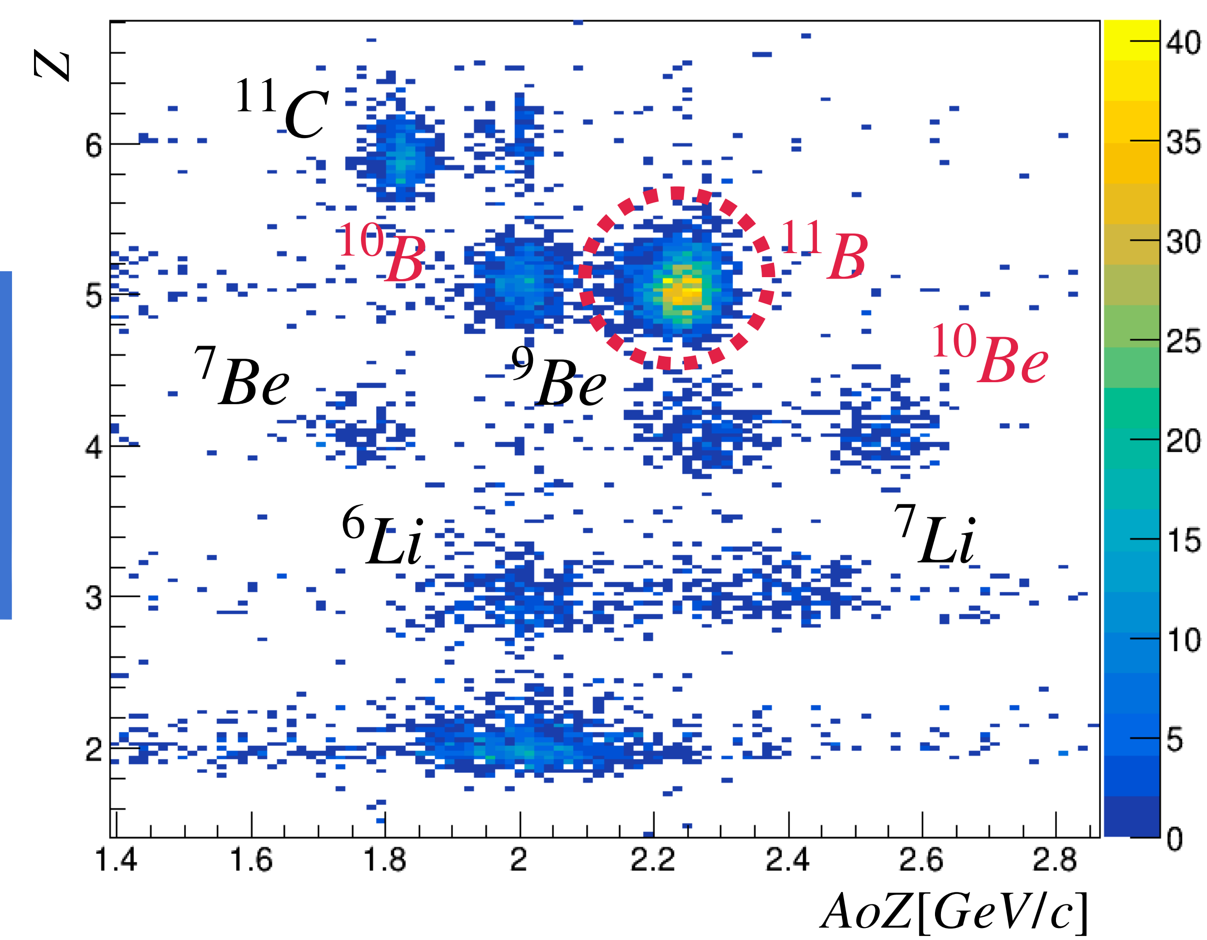


Multi-Dimensional Fit (MDF)

- Find an expression to correlate particle hit positions with their momentum;
- The function can then be used to compute the quantity of interest (**mass, momentum and angles**).

12C Fragments PID

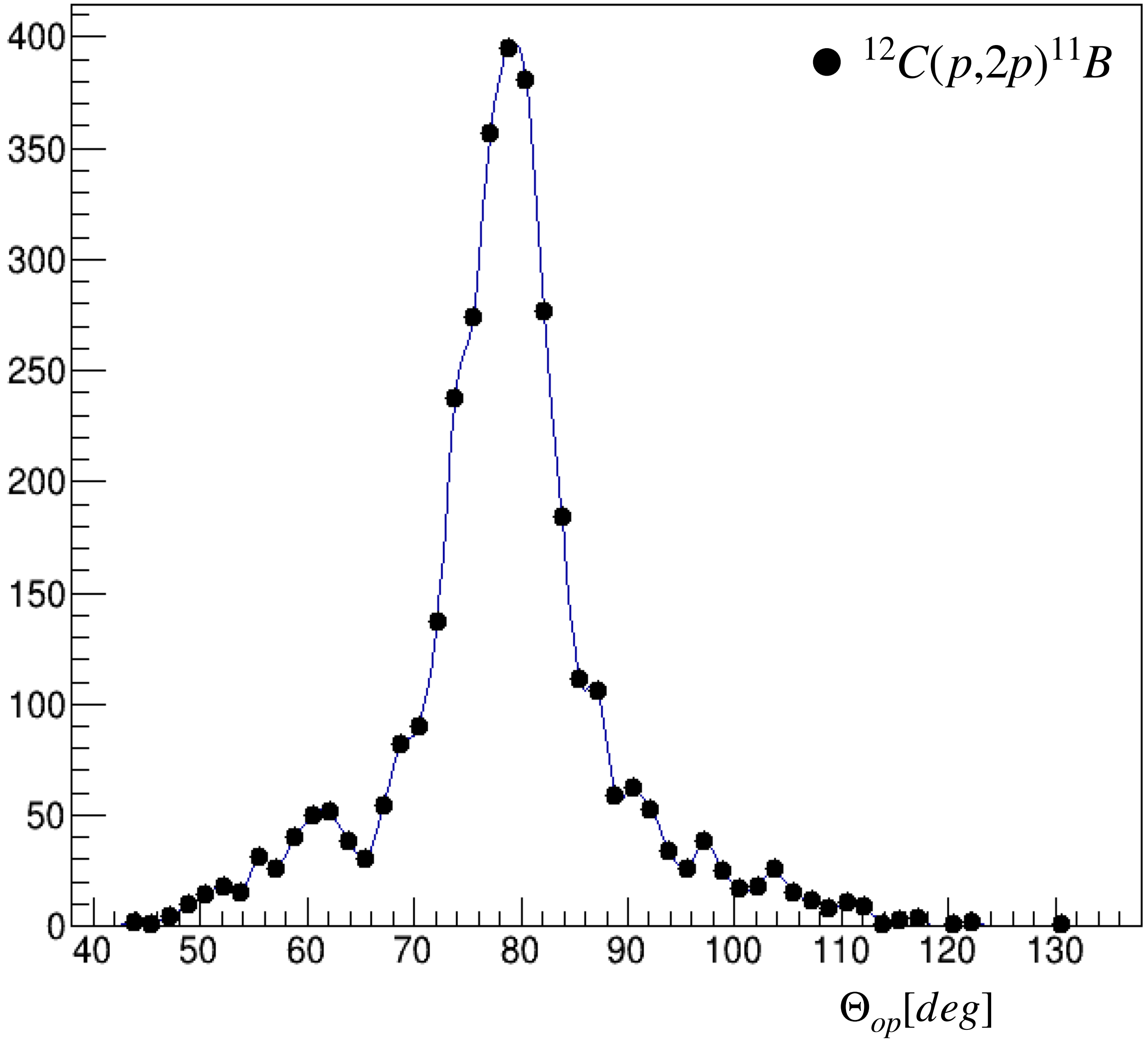
- ^{11}B associated with ***(p,2p)*** reaction channel;
- ^{10}B contains information on ***np*** pairs;
- ^{10}Be contains information on ***pp*** pairs;



(p,2p) analysis for ^{12}C

Opening Angle

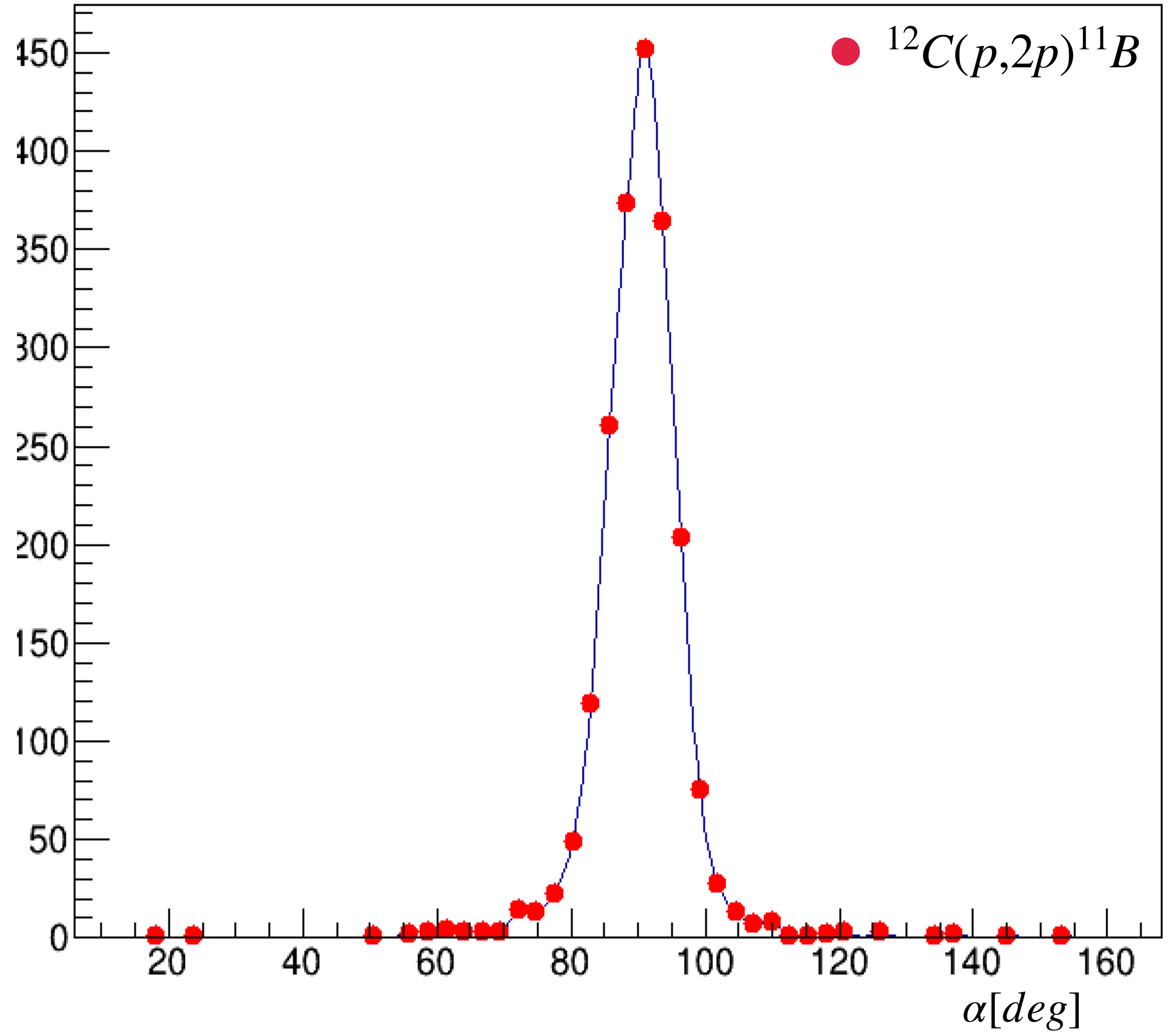
- In-plane Opening Angle between the two scattered protons;
- Selection of ^{11}B fragment;



Alpha Angle

$$\cos\alpha = \frac{\mathbf{p_1}\times\mathbf{p_2}}{|p_1\times p_2|}\cdot\frac{\mathbf{P}-\mathbf{Q}}{|P-Q|}\approx 0$$

- Angle between the (p,2p) reaction plane and ^{12}C-^{11}B plane;

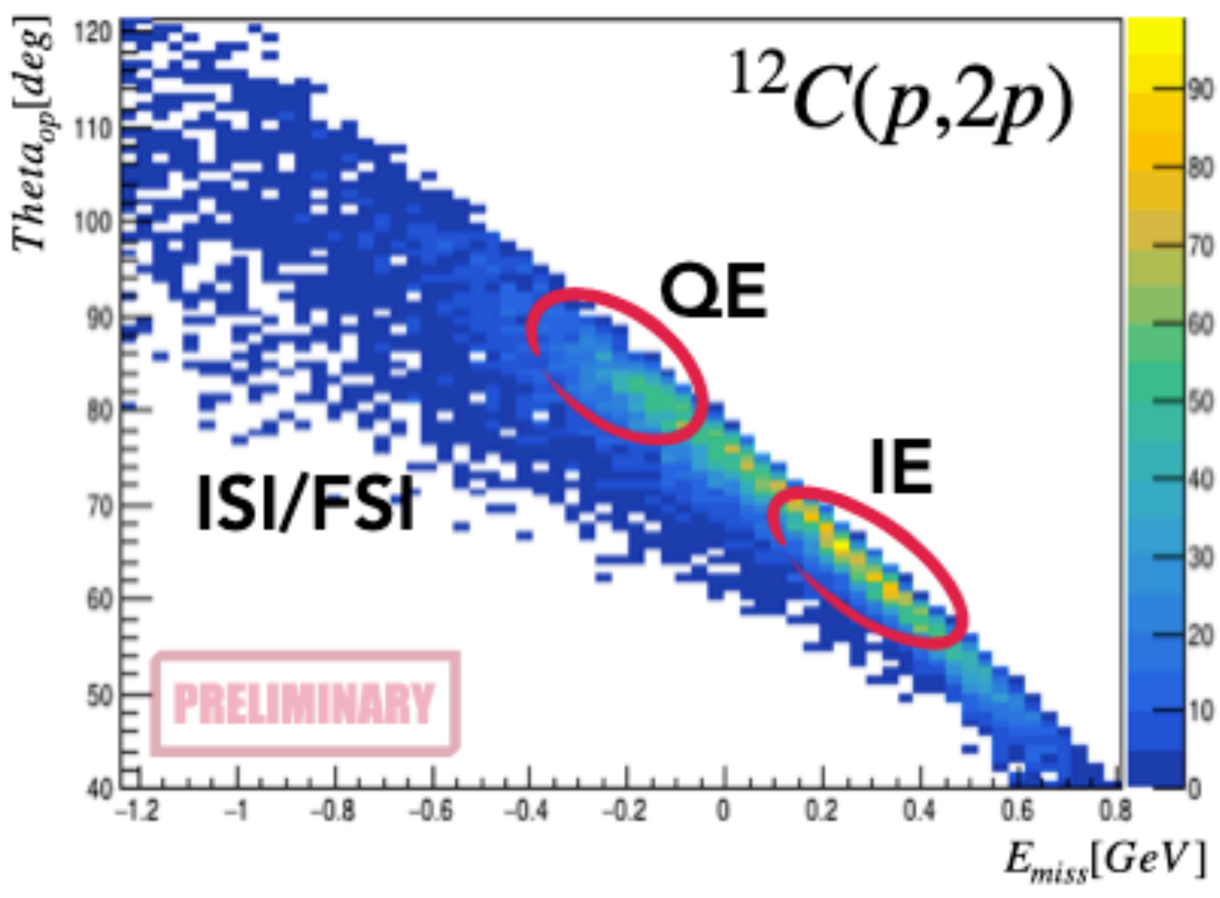


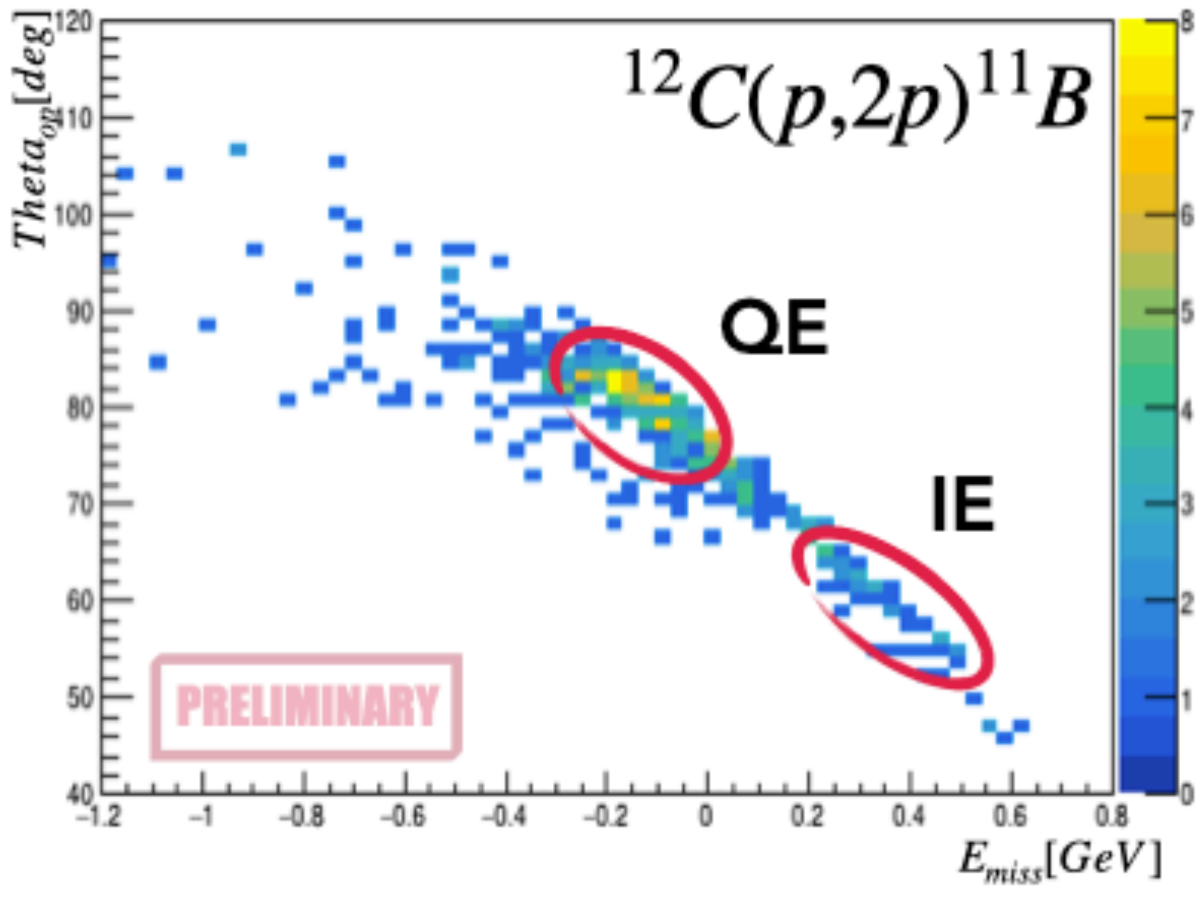
Quasi-Elastic event identification

PRELIMINARY

Missing energy vs Opening angle

- The ^{11}B detection is shown to select the **QE part of the reaction**;
- Similar to BM@N (JINR) experiment.





Quasi-Elastic event identification

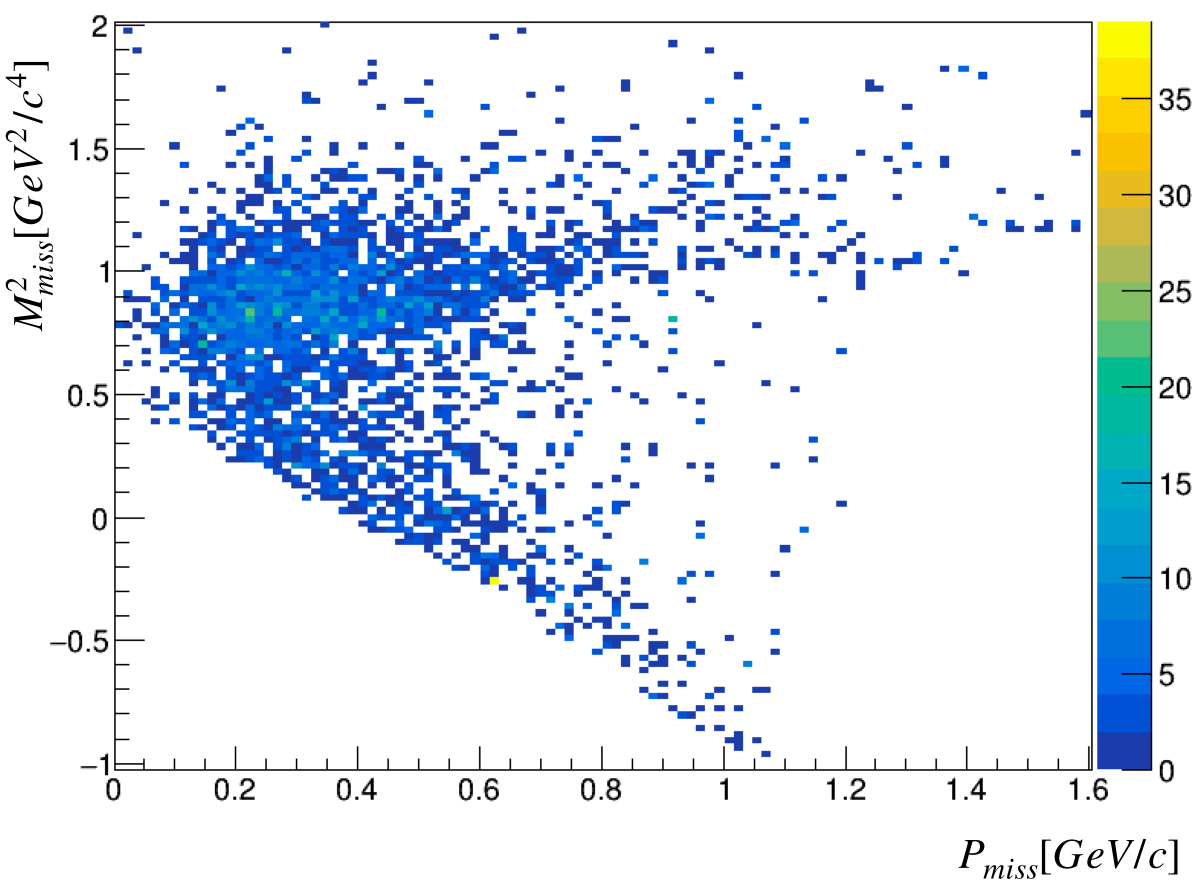
PRELIMINARY

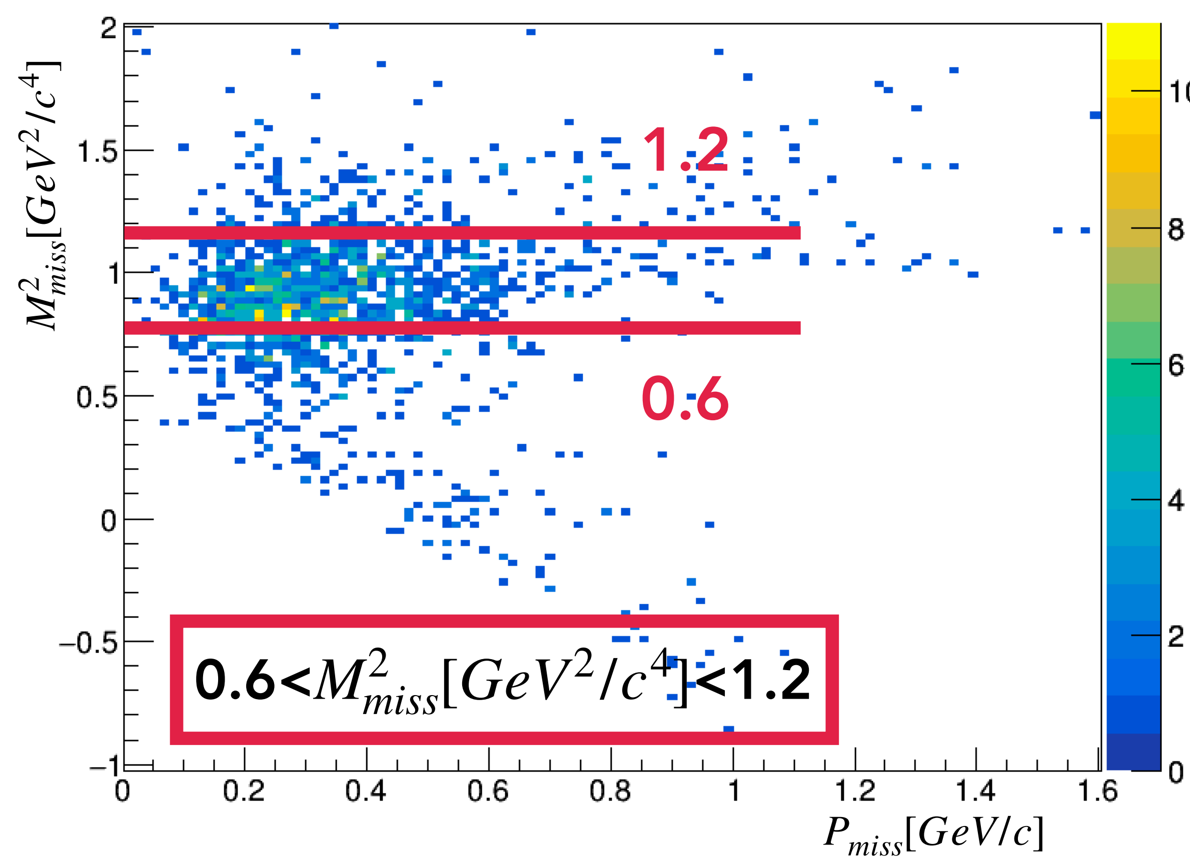
Missing mass vs Missing momentum

- The ^{11}B detection is shown to select the **QE part of the reaction**;
- Similar to BM@N (JINR) experiment.

* No selection of ^{11}B fragment;
* (p,2p) reconstructed with FOOT detectors;

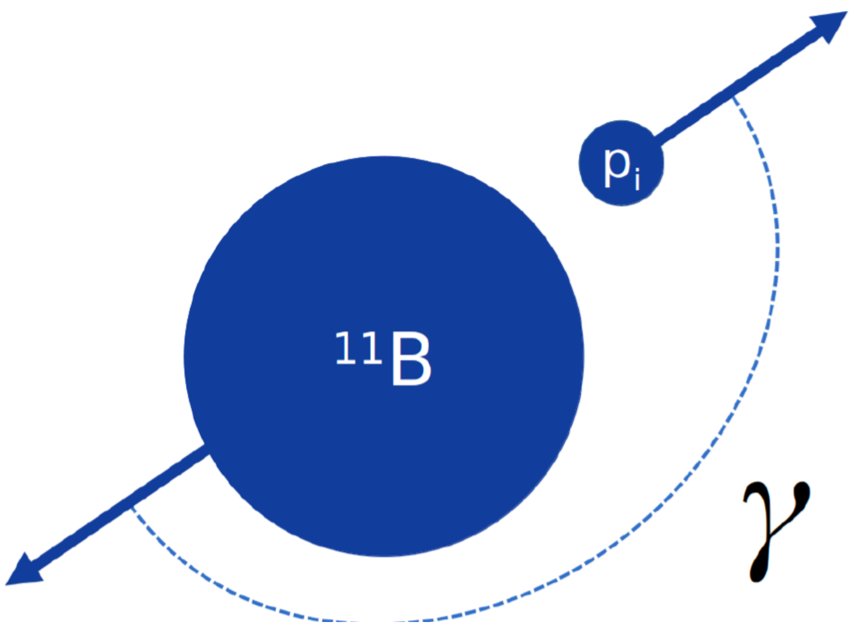
* Selection of ^{11}B fragment;
* (p,2p) reconstructed with FOOT detectors;

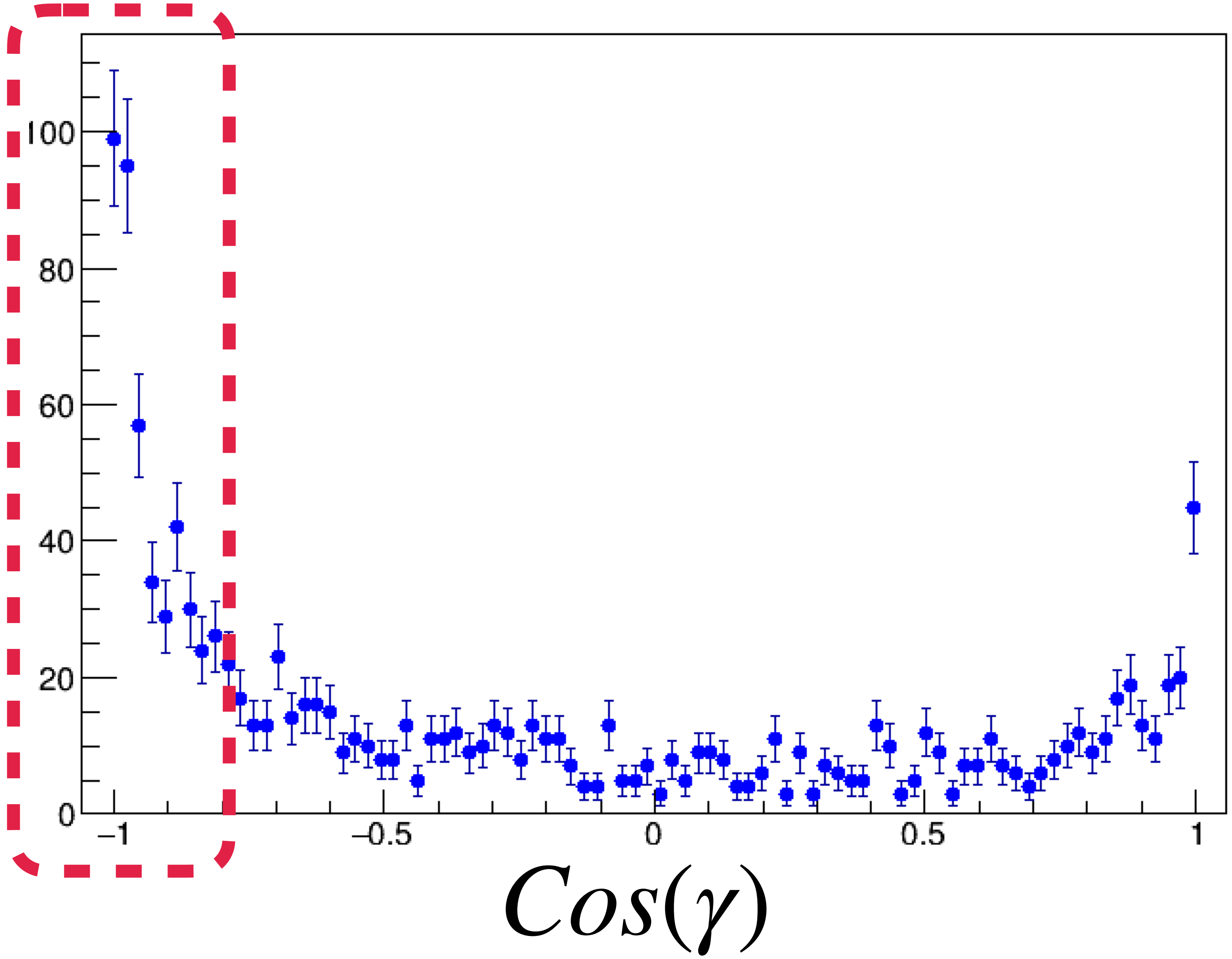




Quasi-Elastic event identification

Distribution of the cosine of the opening angle between the missing and fragment momentum in the plane transverse to the beam





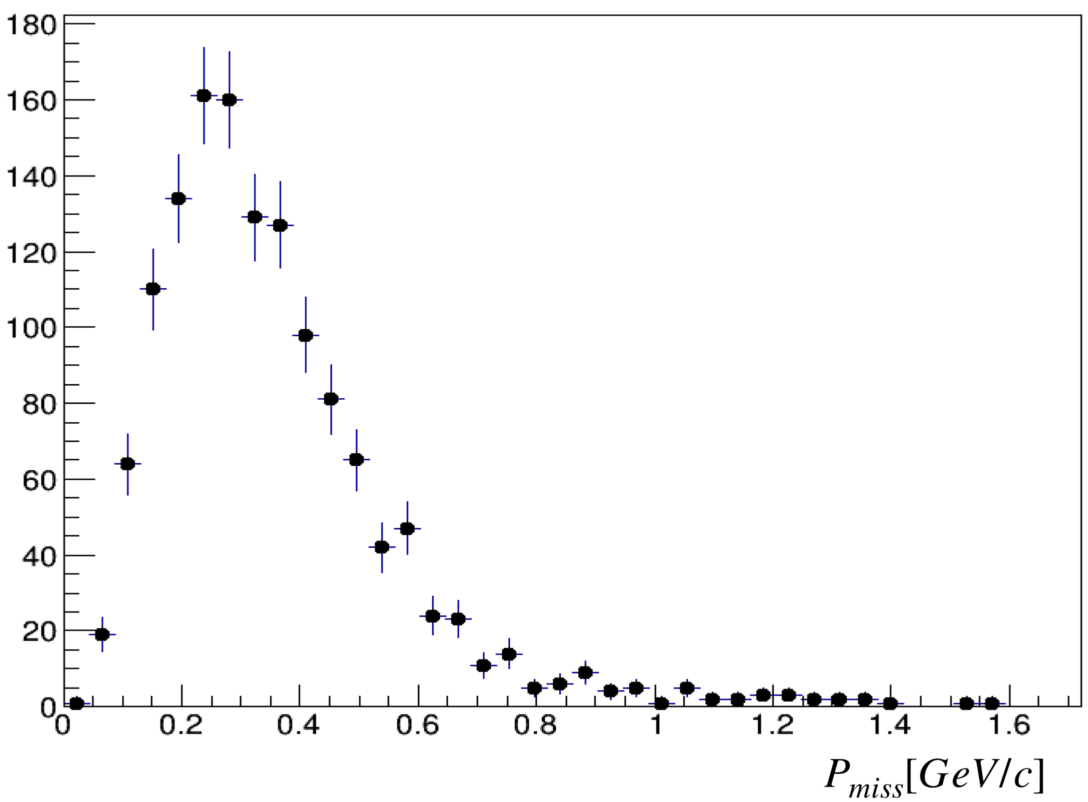
- ✱ Back to back emission signature of QE reaction mechanism.

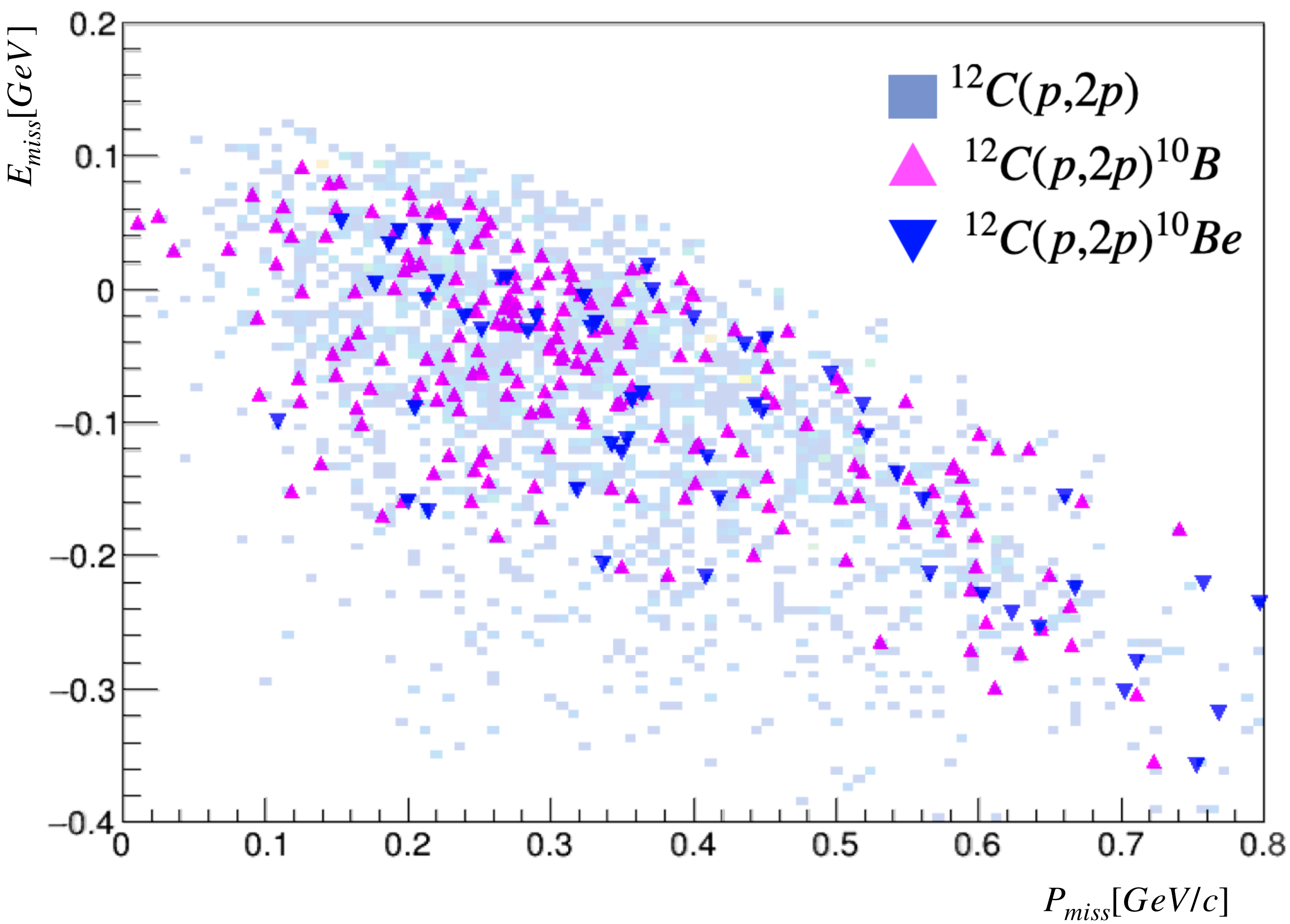
Hard Break-up of SRC pairs

PRELIMINARY

- Study SRCs by measuring $^{12}C(p,2p)^{10}B$ and $^{12}C(p,2p)^{10}Be$;
- SRC breakup reactions produce ^{10}B and ^{10}Be fragments when interacting with a ***pn*** or a ***pp*** pair ;
- Fragment selection guarantees exclusion of secondary scattering processes;
- Direct experimental probe for the interaction between the SRC pair nucleons and the residual A-2 nucleons.

* Missing momentum derived from 2 scattered protons ;
* Selection of ^{10}B (pn) and ^{10}Be (pp) fragment;
* $0.6<M^2_{miss}[GeV^2/c^4]<1.2$ to ensure QE reaction mechanism;





What's next?

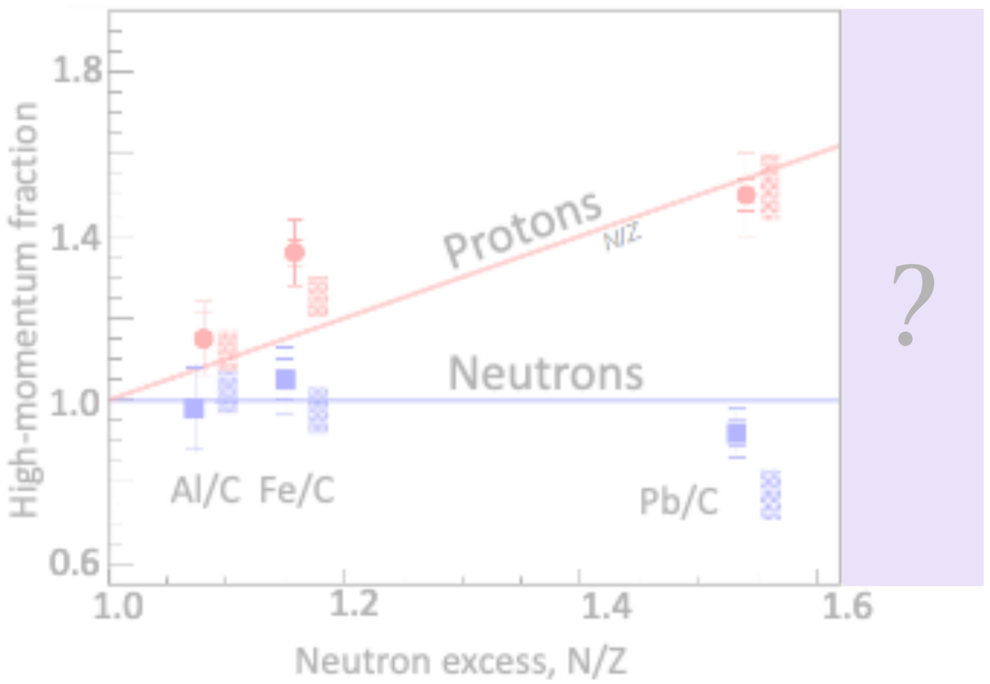
Proton scattering experiments

- BM@N (JINR) pilot experiment (2018);
- R^3B (GSI) Experiment (May 2022);
  - Probe SRC in an exotic nucleus for the first time;
- **FAIR First Physics LoI.**

Motivations R3B Experiment

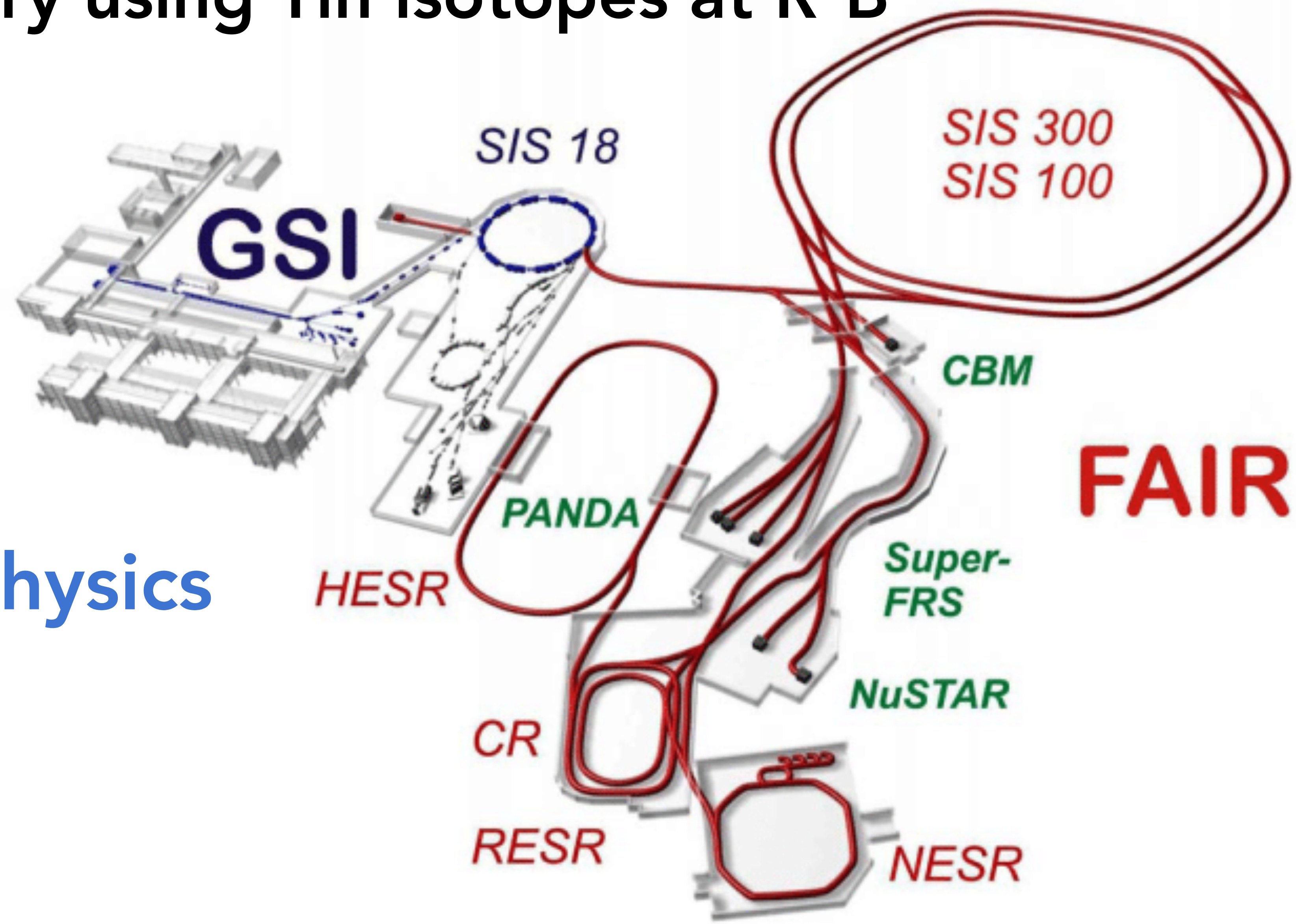
- Existing trend based on a few points;
- behaviour can depend on shell structure (open/closed shell effects);
- mass and N/Z excess cannot be disentangled with stable nuclei.

- **New measurement at N/Z = 1.67 (^{16}C), above the largest available N/Z and at a much smaller mass.**



Adapted from M. Duer et al. (CLAS Collaboration), Nature, 560:617, 2018.

Short-Range Correlations as a function of mass and N/Z asymmetry using Tin isotopes at R³B



LoI for FAIR First Physics

R3B FAIR GSI

T.Aumann, M.Duer (TU Darmstadt), J.Benlliure, D.Cortina (University of Santiago de Compostela), A.Corsi (CEA Saclay), O.Hen, J.Kahlbow (MIT), V.Panin (GSI), S.Paschalis, M.Petri (York University), E.Piasetzky (Tel Aviv University), …..

Perspectives

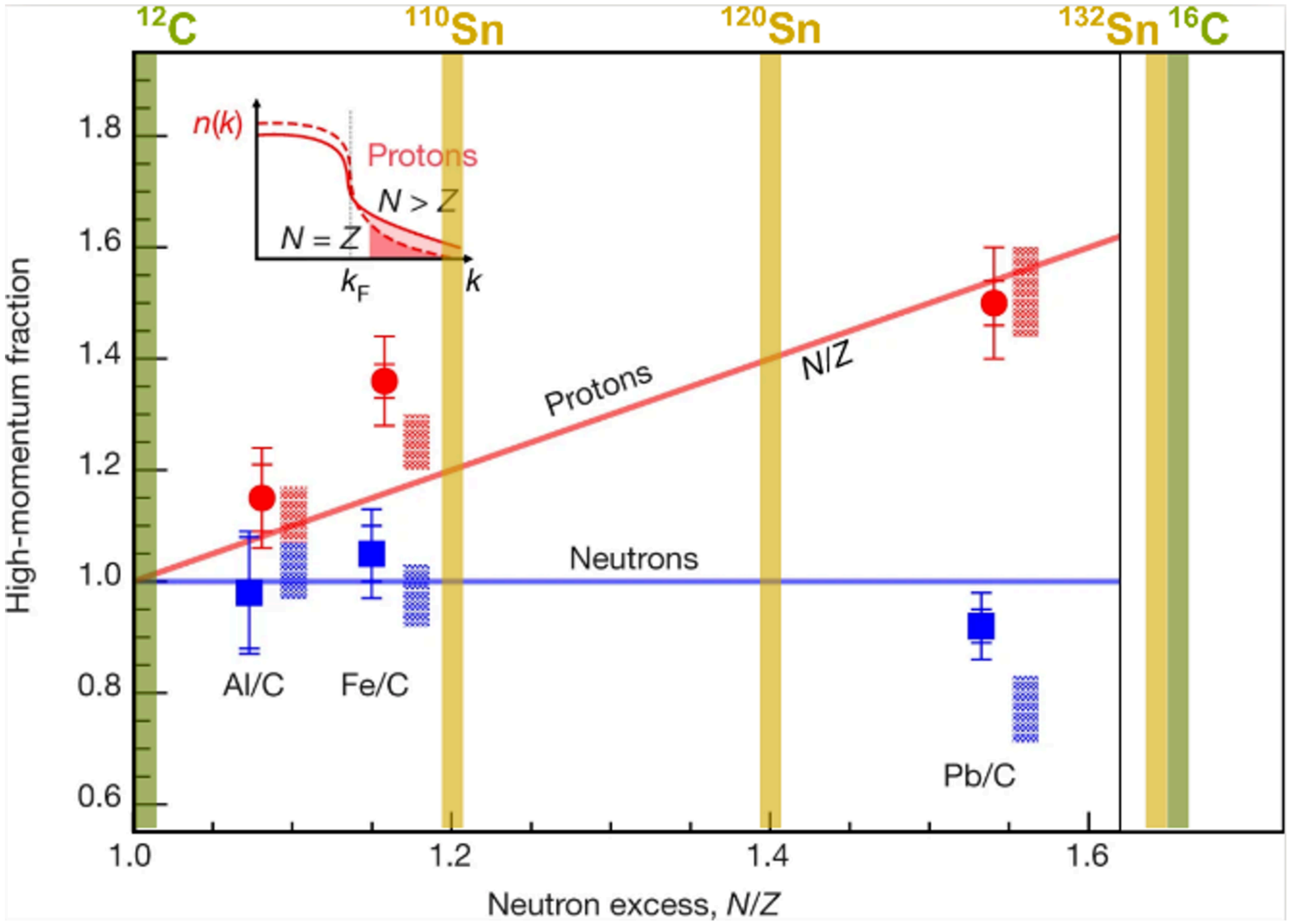
GOAL: probe pair ratios, relative and center of mass momentum, and fragment final state in at and around magic numbers, at different A and N/Z.

- ^{110,120,132}Sn @ 1 GeV/u on 5 cm LH2 target;
- ^{132}Sn from ^{238}**U coulex**, ^{110,120}Sn from ^{136}**Xe fragmentation.**

-**132Sn**: doubly magic, n-rich;

-**120Sn**: ref. Channel with e scattering (and same N/Z as 48Ca);

-**110Sn**: small N/Z.



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Thanks for your attention!

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R3B FAIR GSI

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P2IO Physique des 2 Infinis et des Origines

LIP