XXIV International Baldin Seminar
on High Energy Physics Problems
Relativistic Nuclear Physics & Quantum Chromodynamics
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JINR

Exclusive studies of Short Range Correlations (SRC) in nuclei

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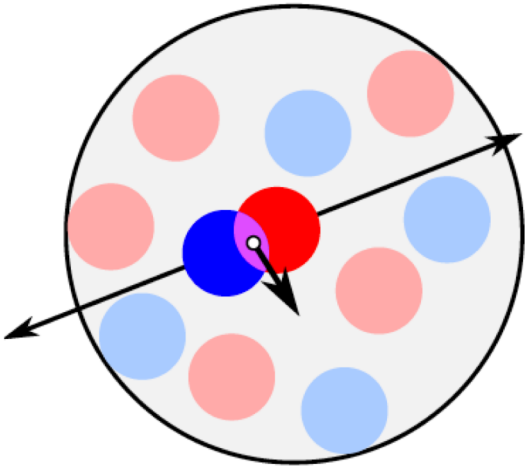
Short Range Correlated (SRC) pairs

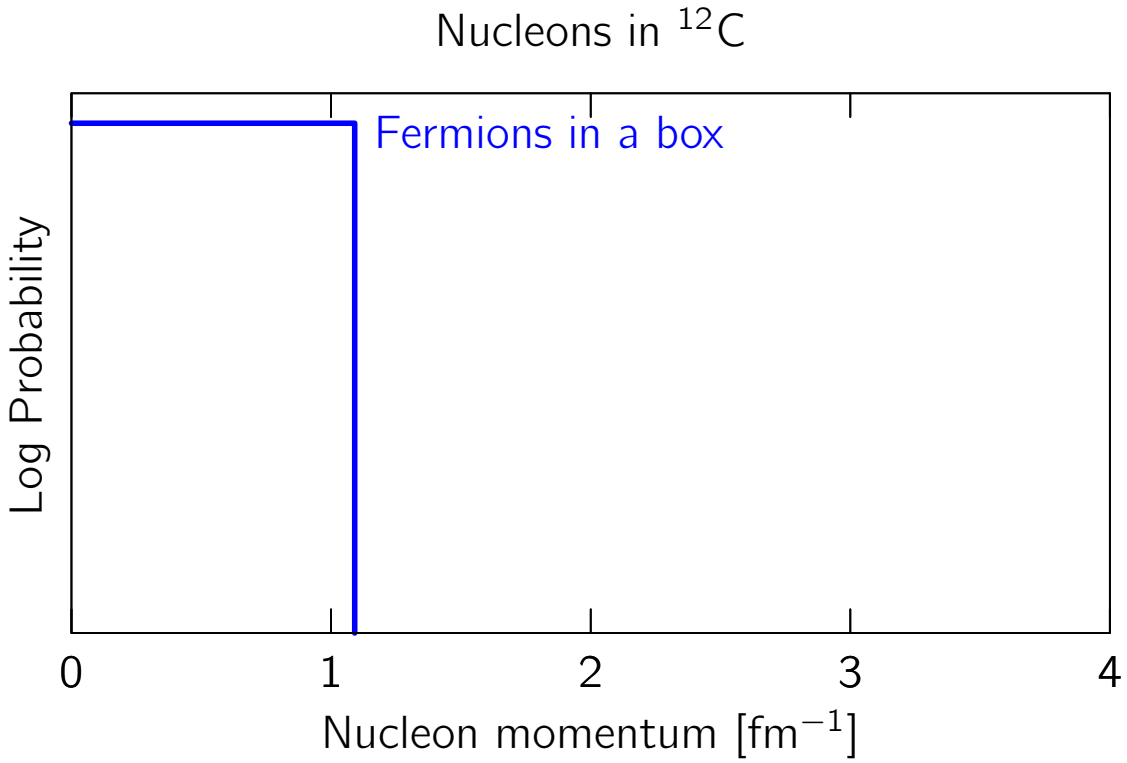


Relative momentum > 300 MeV/c

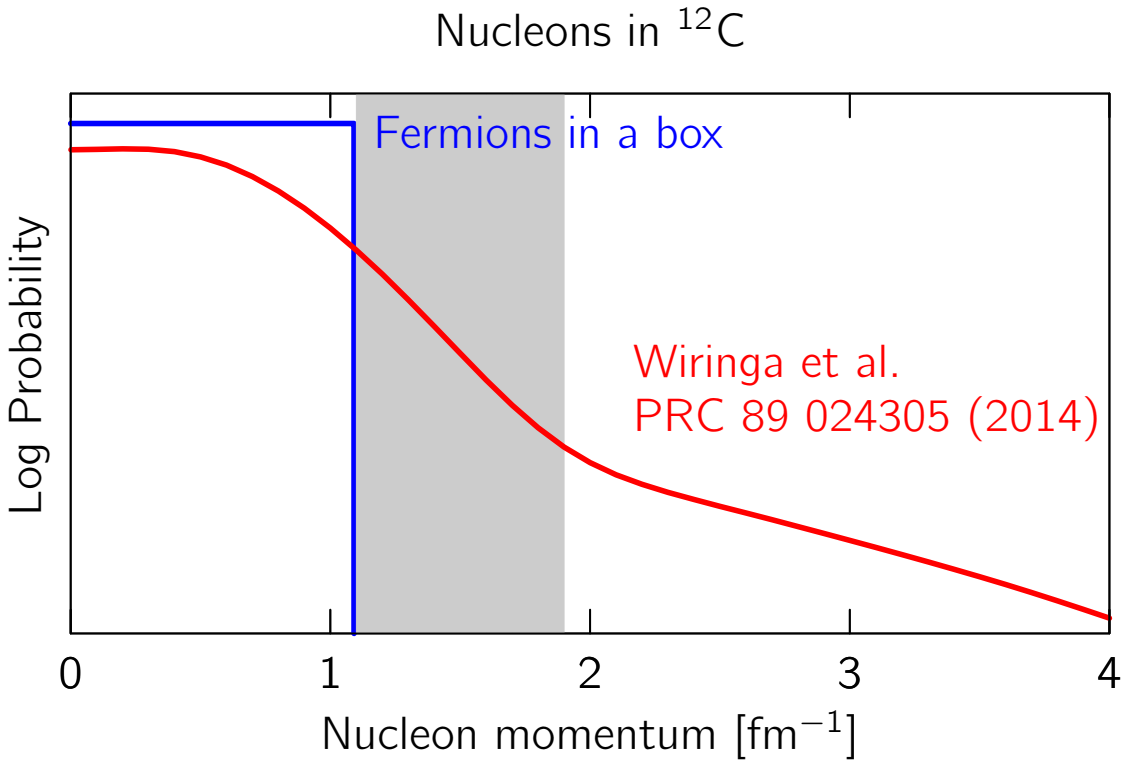
CM momentum O(150 MeV/c)

~20 % of nucleons

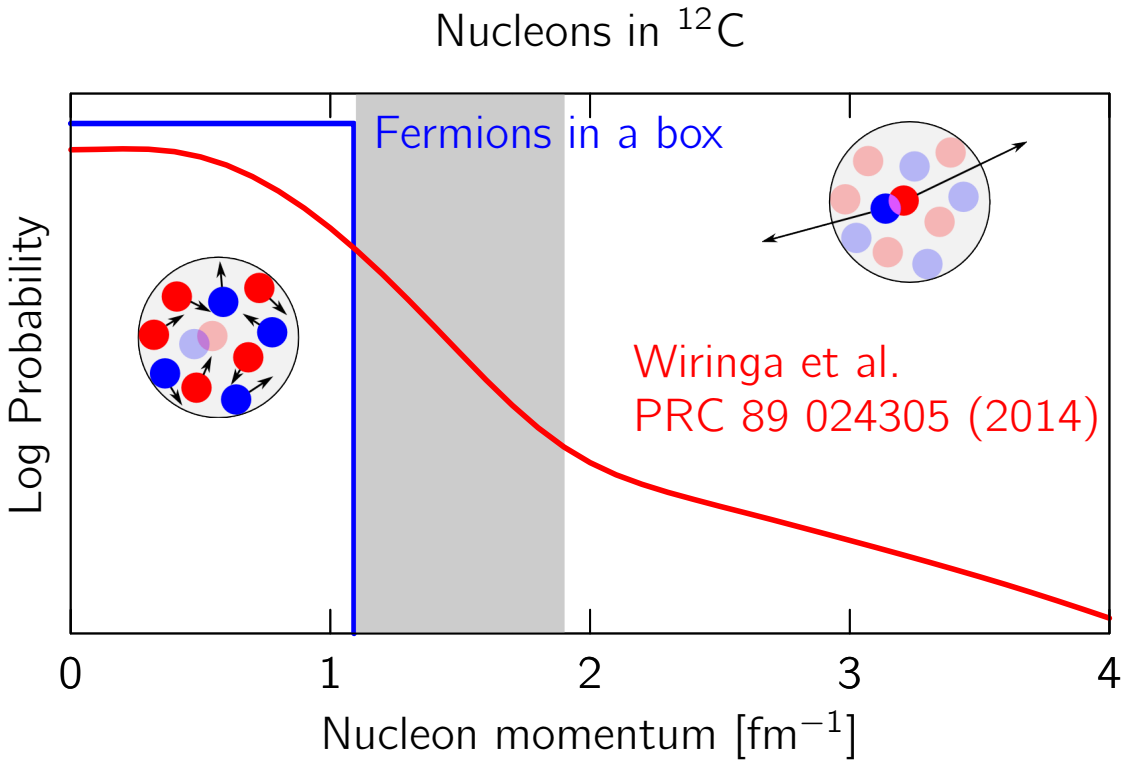
Nucleon momentum distribution for uncorrelated nucleons



In reality about 20% of nucleons have $k > k_F$



All nucleons with $k > k_F$ belong to SRC pairs



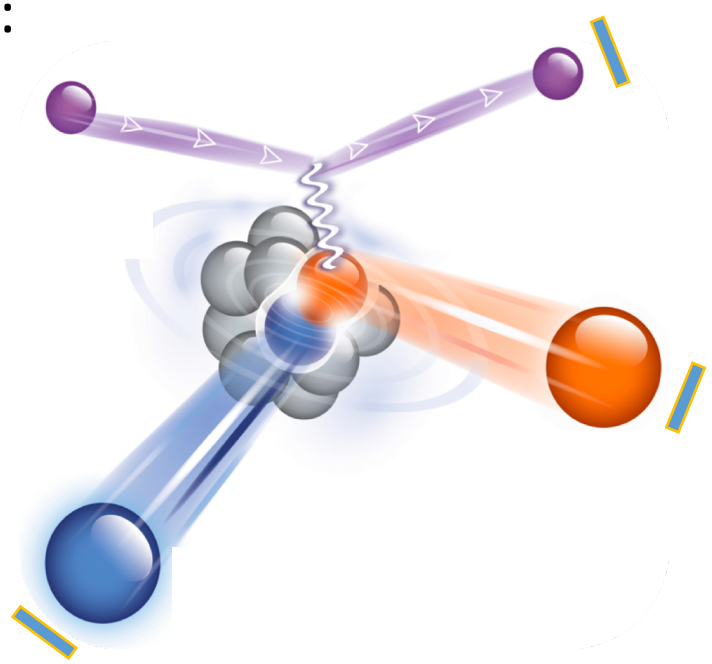
Exclusive hard scattering reactions are a perfect tool to study SRC properties

Interact with a single nucleon and
detect 3 particles (triple coincidence):

the scattered probe,

the knocked-out nucleon,

and the recoil



A(p, 2pn) – BNL
A(e, e'pp) - JLab
A(e, e'pn) - JLab

p(^{12}C, 2p A-2) - JINR

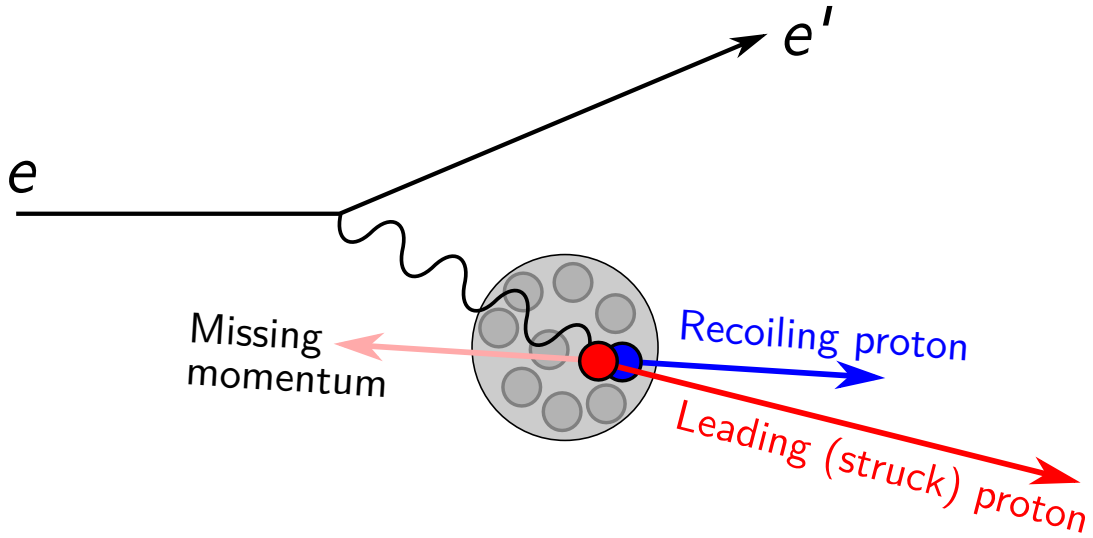
Choose kinematics where Final State Interactions (FSI) are confined to the pair

$x > 1.2$

$M_{miss} < 1.1$ GeV

$Q^2 > 1.8$ GeV^2

$\theta_{pq} < 25°$



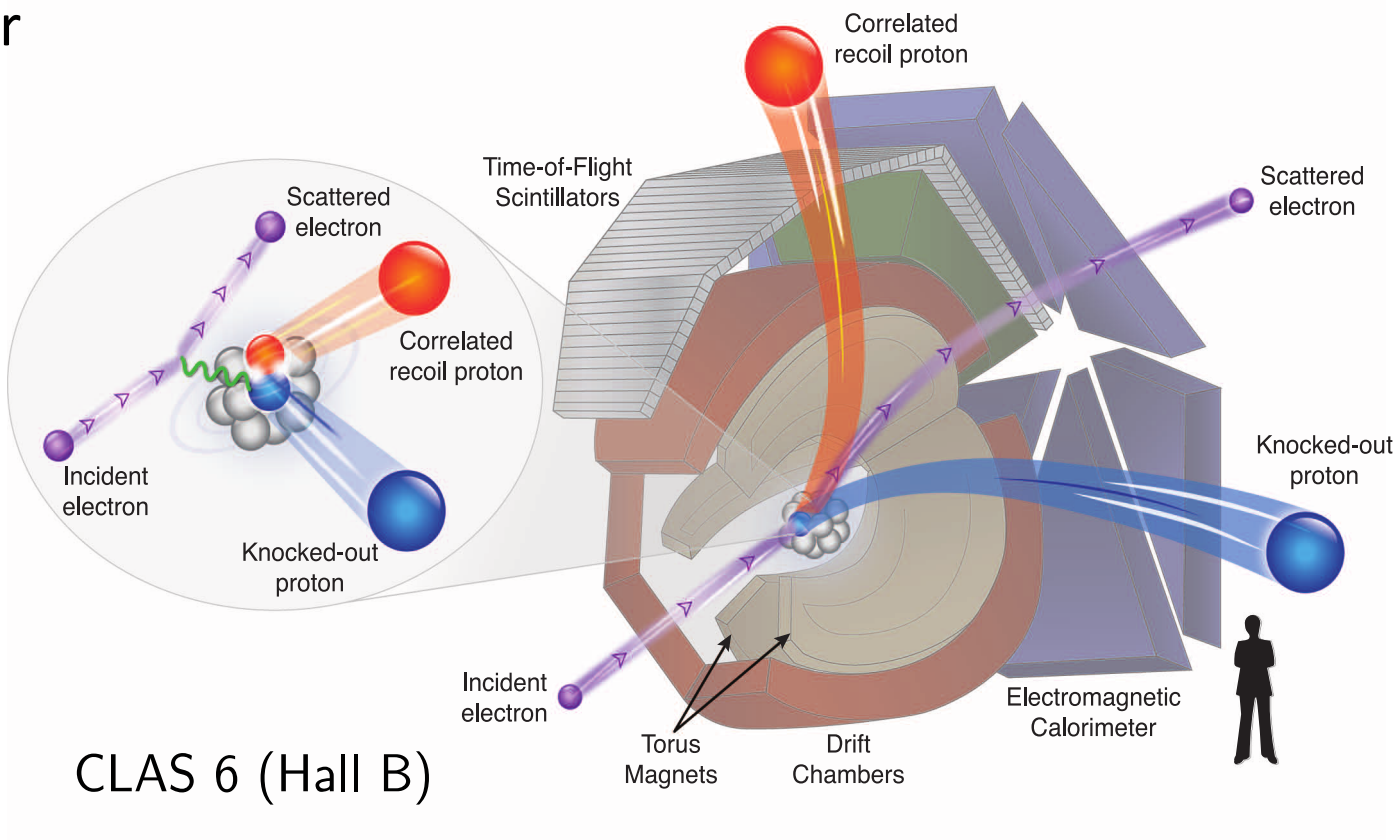
FSI do not impact isospin structure

FSI do not impact pair total momentum

JLab: CLAS-6 setup – base for the newest SRC results

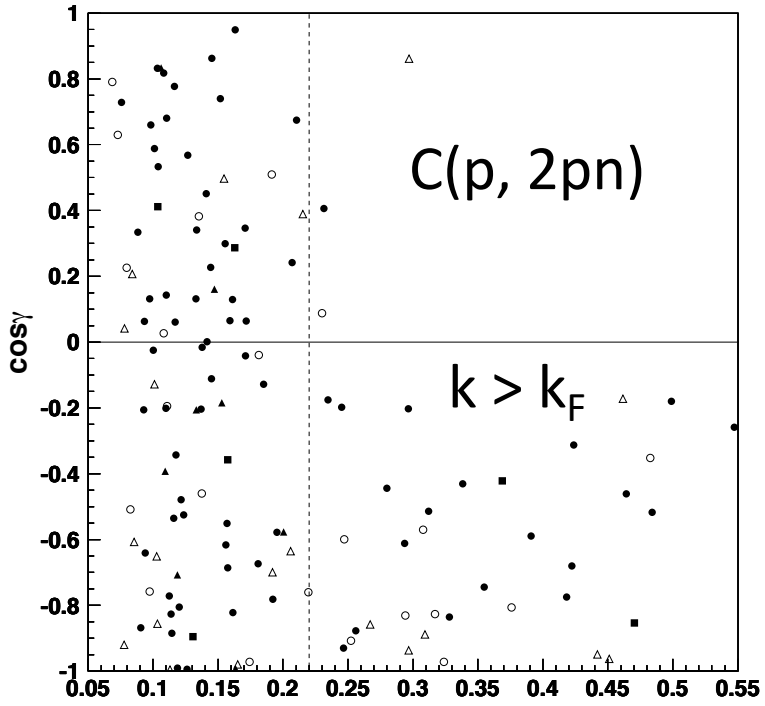
Large acceptance

Open trigger

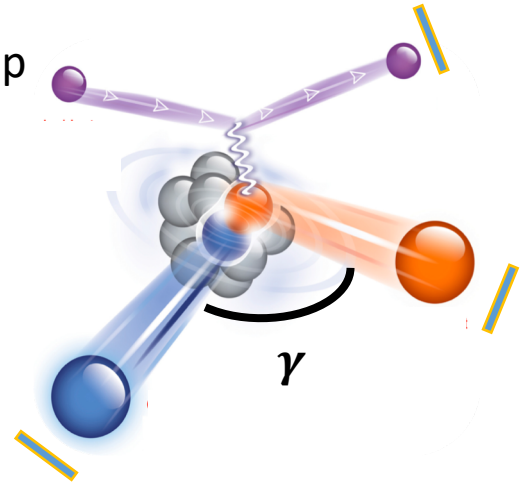


CLAS 6 (Hall B)

BNL: 92% of high momentum protons have a recoil



Recoil neutron momentum [GeV]

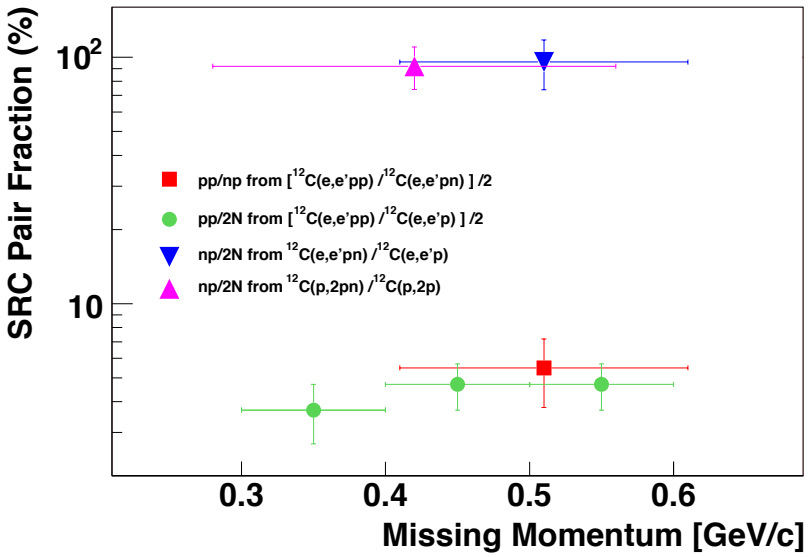


- Recoil has high momentum
- $k < k_F$ – isotropic, $k > k_F$ – back to back

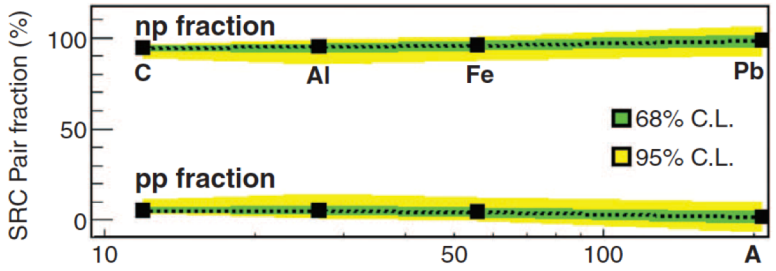
Aclander, PRL (1999); Tang, PRL (2003); Piasetzky, PRL (2006)

JLab: np-pairs dominate pp by a factor of 20

^{12}C(e, e'pn), ^{12}C(e, e'pp)



C, Al, Fe, Pb (e, e'pp) or (e, e'p)

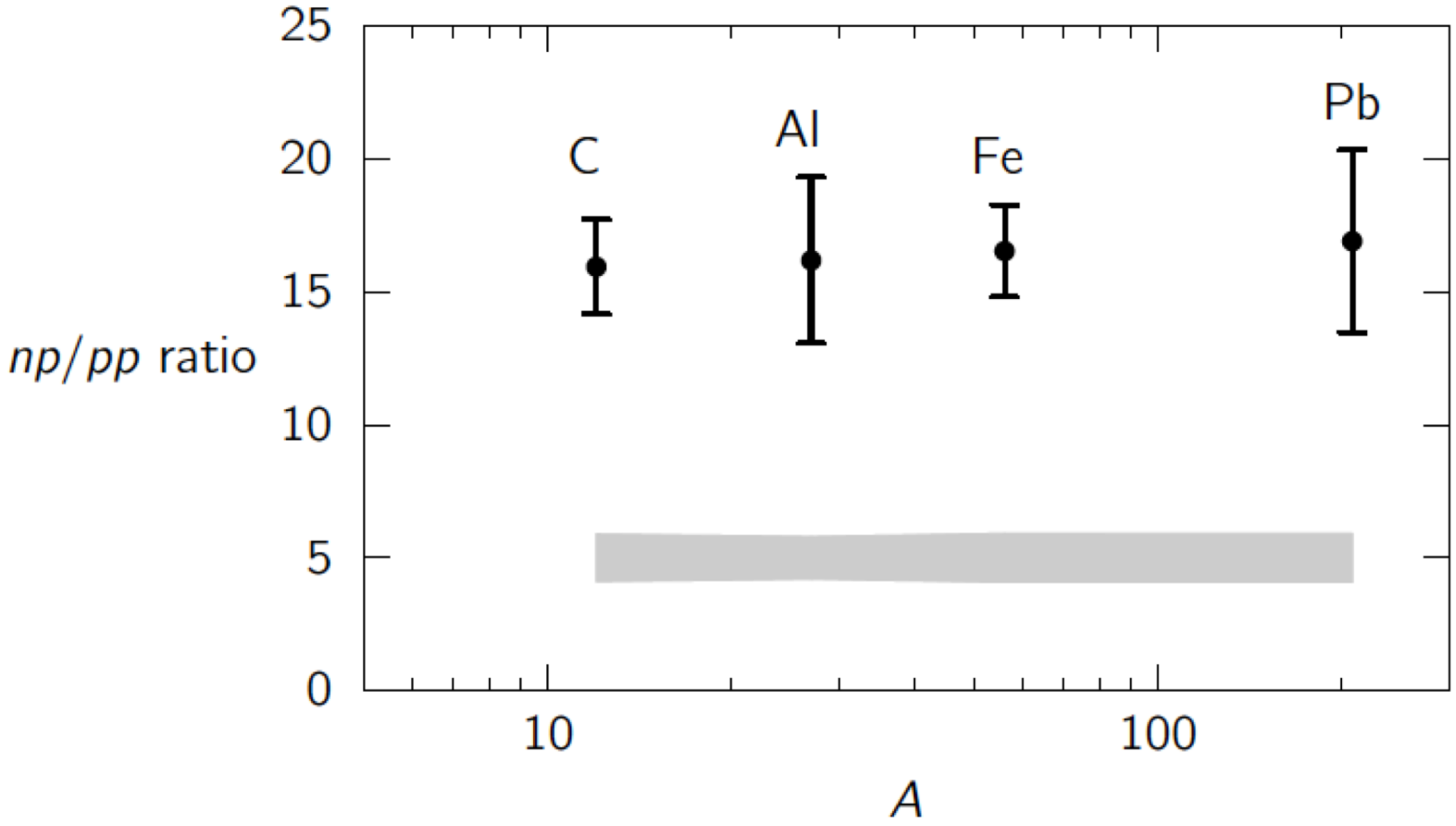


O. Hen et al, Science 346, 614 (2014)

"np-dominance" --> tensor, spin-dependent interaction within SRC

Piasetzky, PRL (2006); Shneor, PRL (2007); Subedi, PRL (2008)

np-dominance established for a wide range of A



Duer, Nature 560 (2018)

Where we stand:

SRC exist in nuclei and account for

~ 20 % on nucleons

~ 100% of high momentum (k > kF) nucleons

Have high relative momentum and low c.m. momentum

np-dominance is established for C, Al, Fe, Pb

Tensor, spin-dependent interaction within SRC

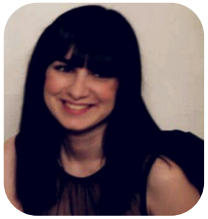
We would like to know more about SRC:

np-dominance for ALL nuclei?
Asymmetric nuclei?
Neutron-rich systems?

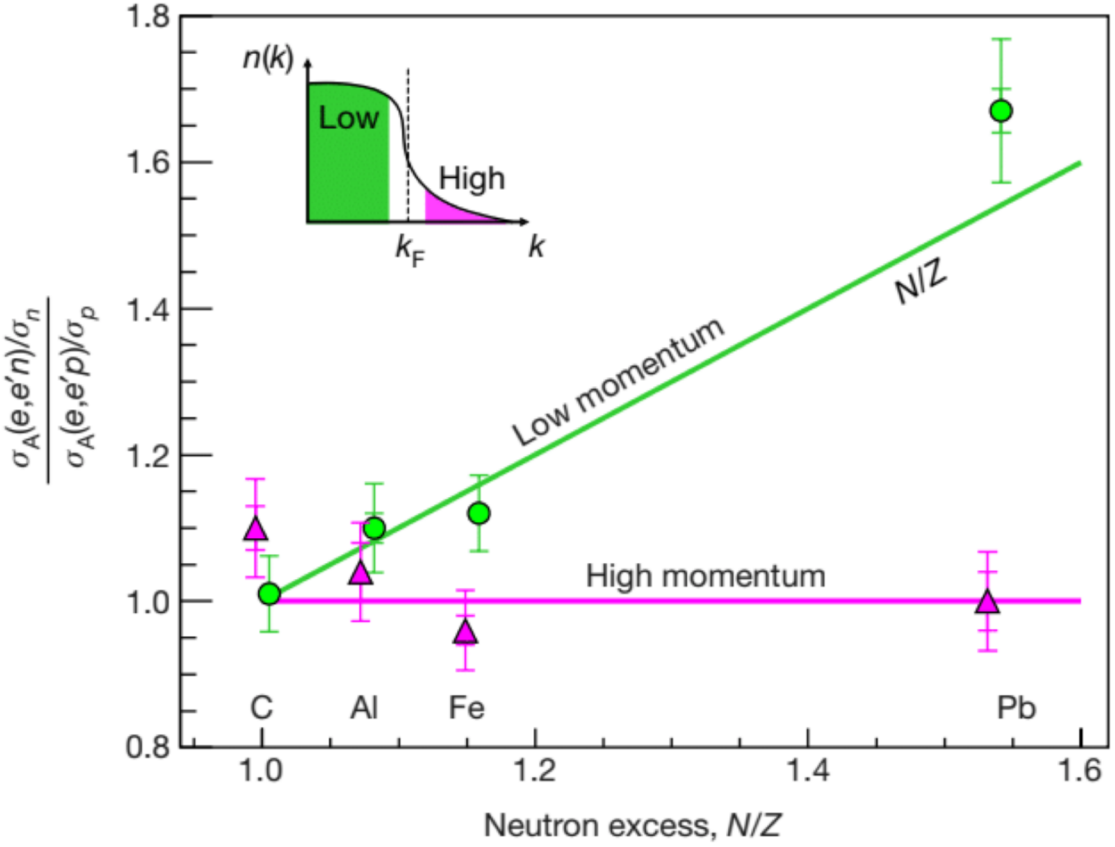
How SRC pairs interact with the rest of the nucleus?
How are SRC pairs formed?
Insight to the NN repulsive core?

How the structure of a nucleon is modified within the nucleus (EMC)?

Recent analyses of exclusive electron scattering on asymmetric nuclei (CLAS-6 data)



n/p ratio for high-momentum nucleons is constant with asymmetry



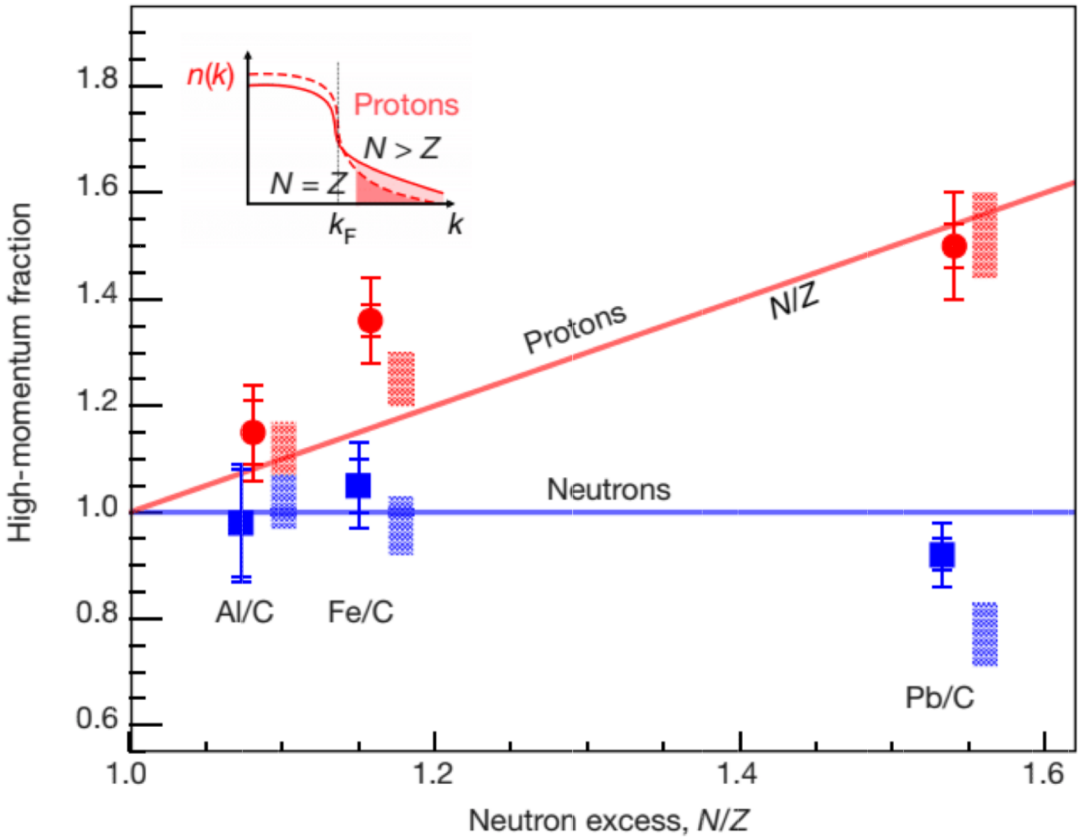
Duer, Nature 560 (2018)

Estimate fraction of SRC nucleons in asymmetric nuclei

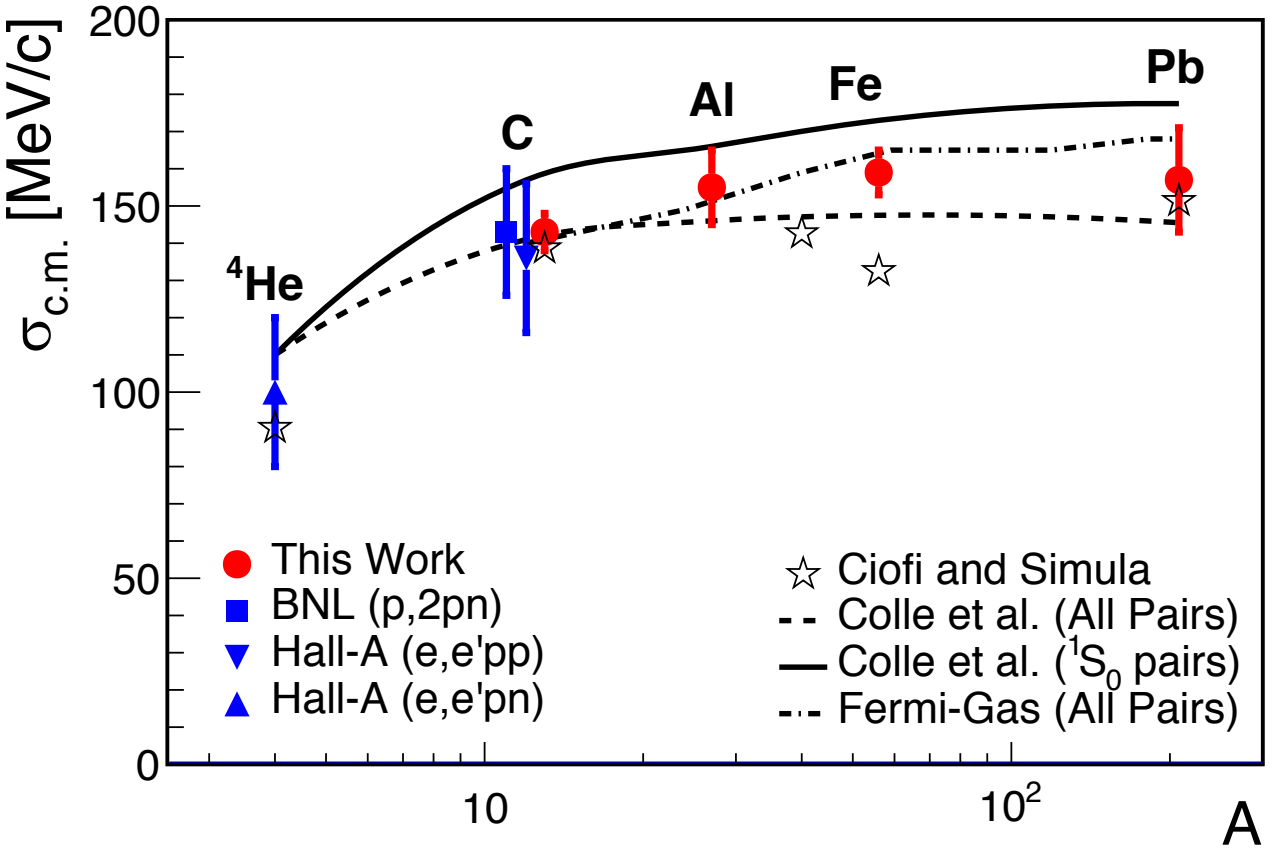
$$\text{SRC Fraction} \equiv \frac{\sigma^{A}_{\text{SRC}}(e,e'N)}{\sigma^{A}_{\text{MF}}(e,e'N)} \Big/ \frac{\sigma^{C}_{\text{SRC}}(e,e'N)}{\sigma^{C}_{\text{MF}}(e,e'N)}$$

Adding neutrons increase the fraction of high-momentum protons

$$\text{SRC Fraction} \equiv \frac{\sigma^{A}_{\text{SRC}}(e,e'N)}{\sigma^{A}_{\text{MF}}(e,e'N)} \Big/ \frac{\sigma^{C}_{\text{SRC}}(e,e'N)}{\sigma^{C}_{\text{MF}}(e,e'N)}$$



The CM momentum distribution of SRC pairs can tell us about pair formation

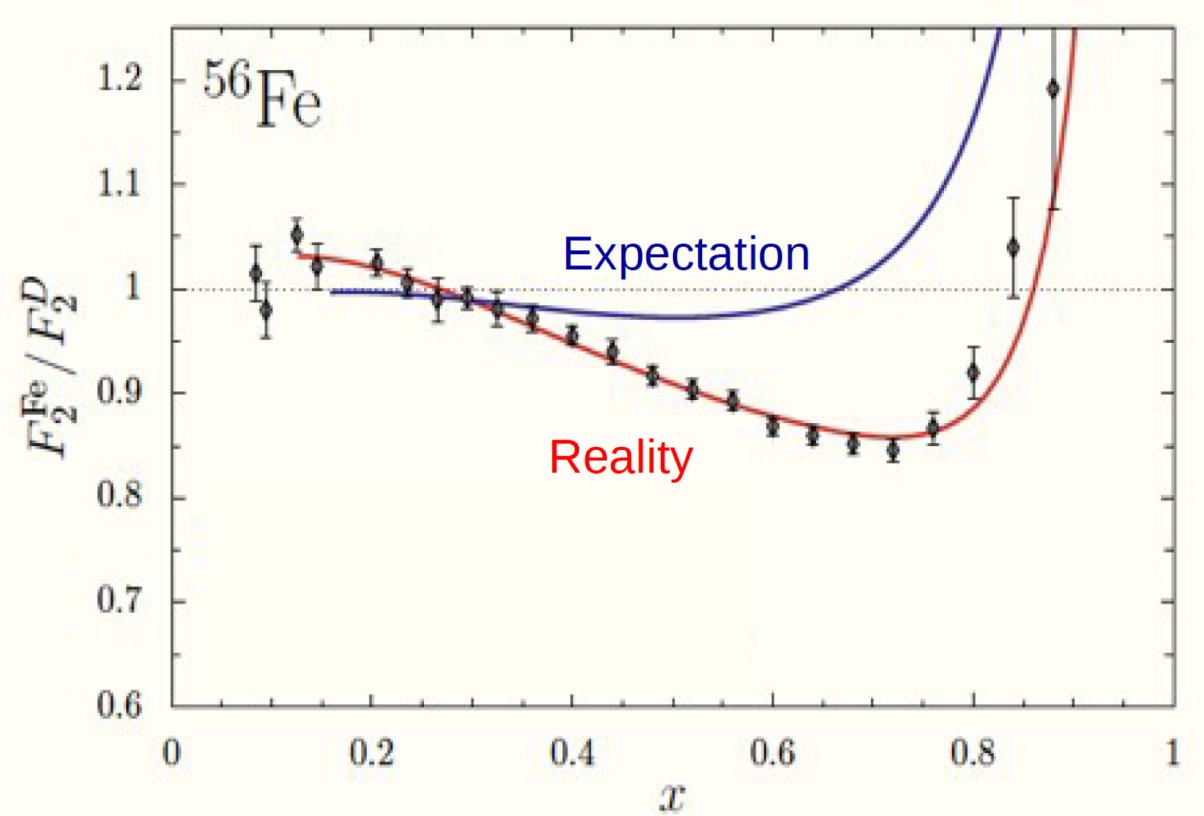


Cohen, PRL 121 (2018)

The EMC (European Muon Collaboration) effect

Modification of per-nucleon DIS cross section

Modification of quark and gluon distribution for bound nucleons (F_2^A)



Aubert et al., PLB (1983); Ashman et al., PLB (1988); Arneodo et al., PLB (1988); Allasia et al., PLB (1990); Gomez et al., PRD (1994); Seely et al., PRL (2009); Schmookler et al., submitted (2018)

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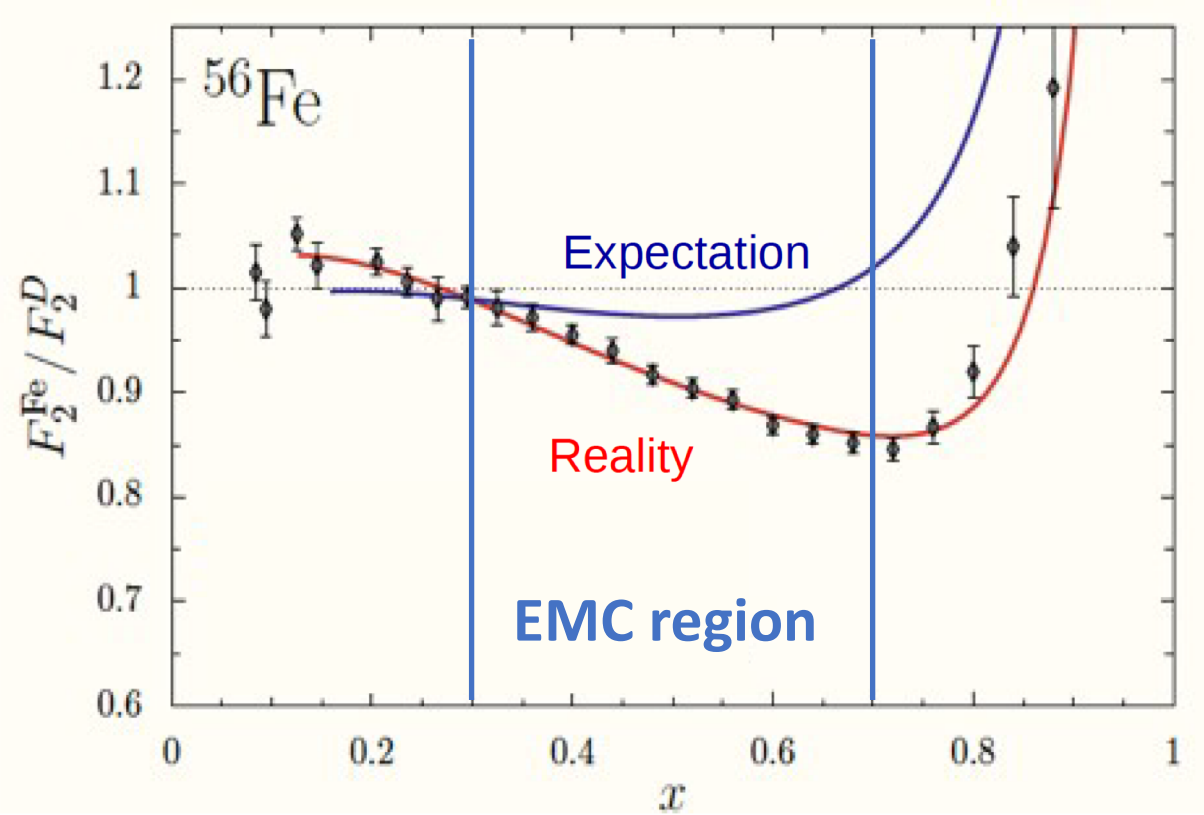

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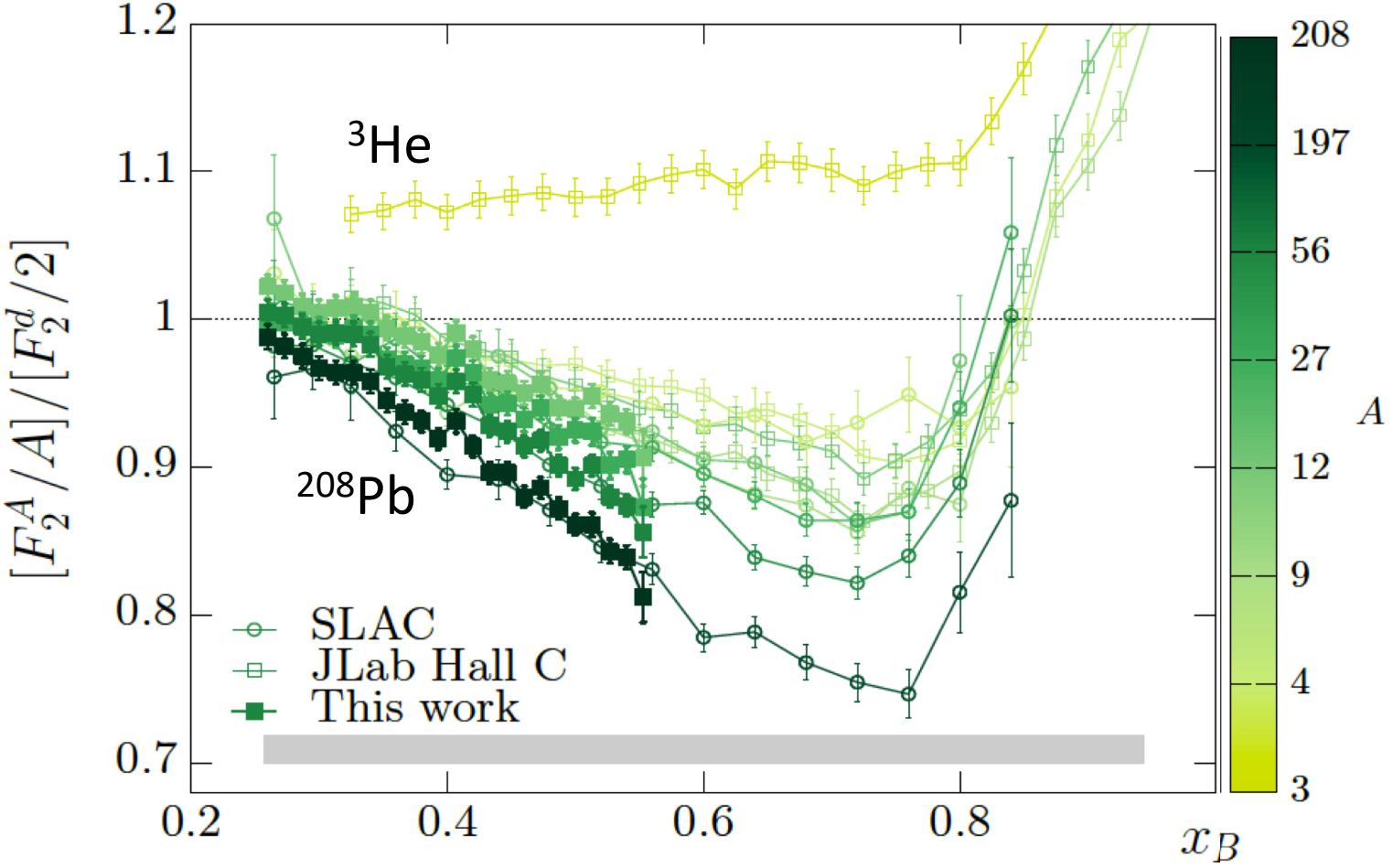
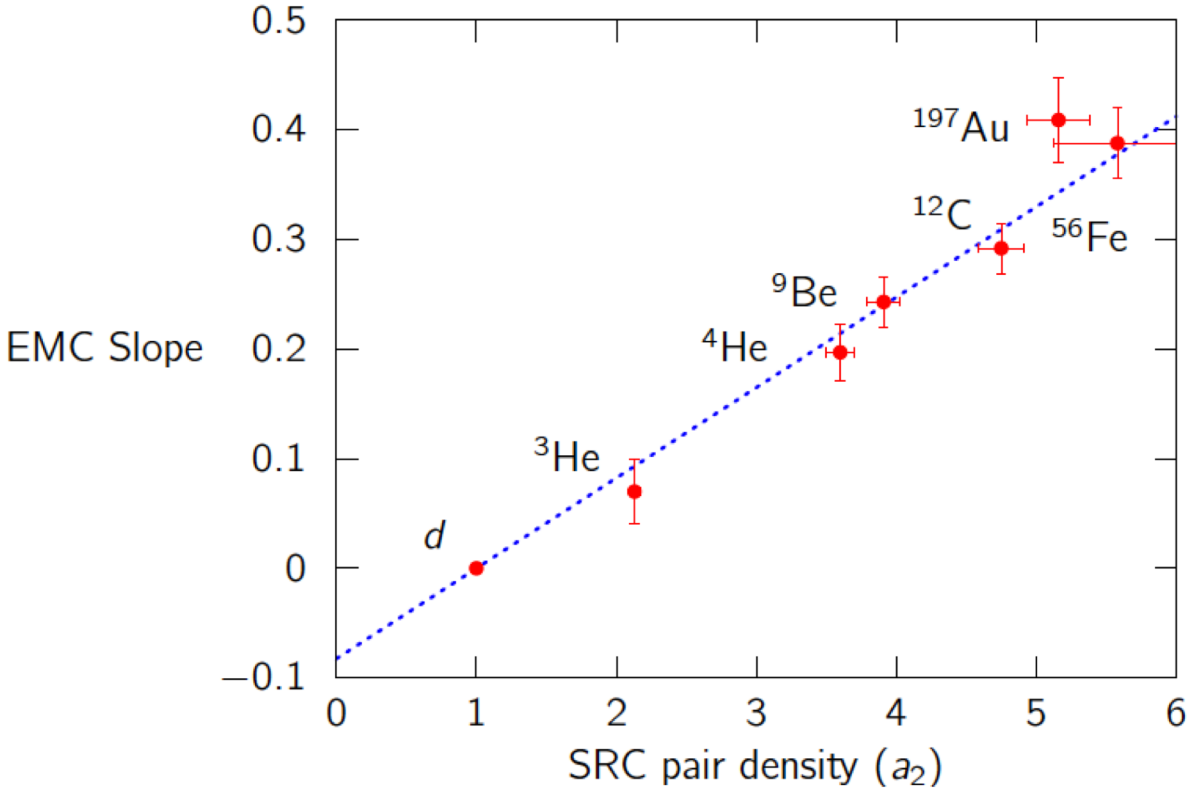
EMC effect for different nuclei

SLAC and JLab data



Schmookler, submitted for publication

Can EMC effect be explained by heavily modified SRC pairs?



Assume modifications of F_2^A are caused by only SRC

Weinstein et. al, PRL (2011)

Nuclear structure function F_2^A:

$$F_2^A = n_{SRC}^A (F_2^{p*} + F_2^{n*}) + (Z - n_{SRC}^A) F_2^p + (N - n_{SRC}^A) F_2^n$$

Modified SRC nucleons

Unmodified nucleons

$$F_2^A = Z F_2^p + N F_2^n + n_{SRC}^A (\Delta F_2^p + \Delta F_2^n)$$

Difference between modified and non-modified nucleons in SRC pairs – nucleus-independent ??

Structure functions F_2^A and F_2^d:

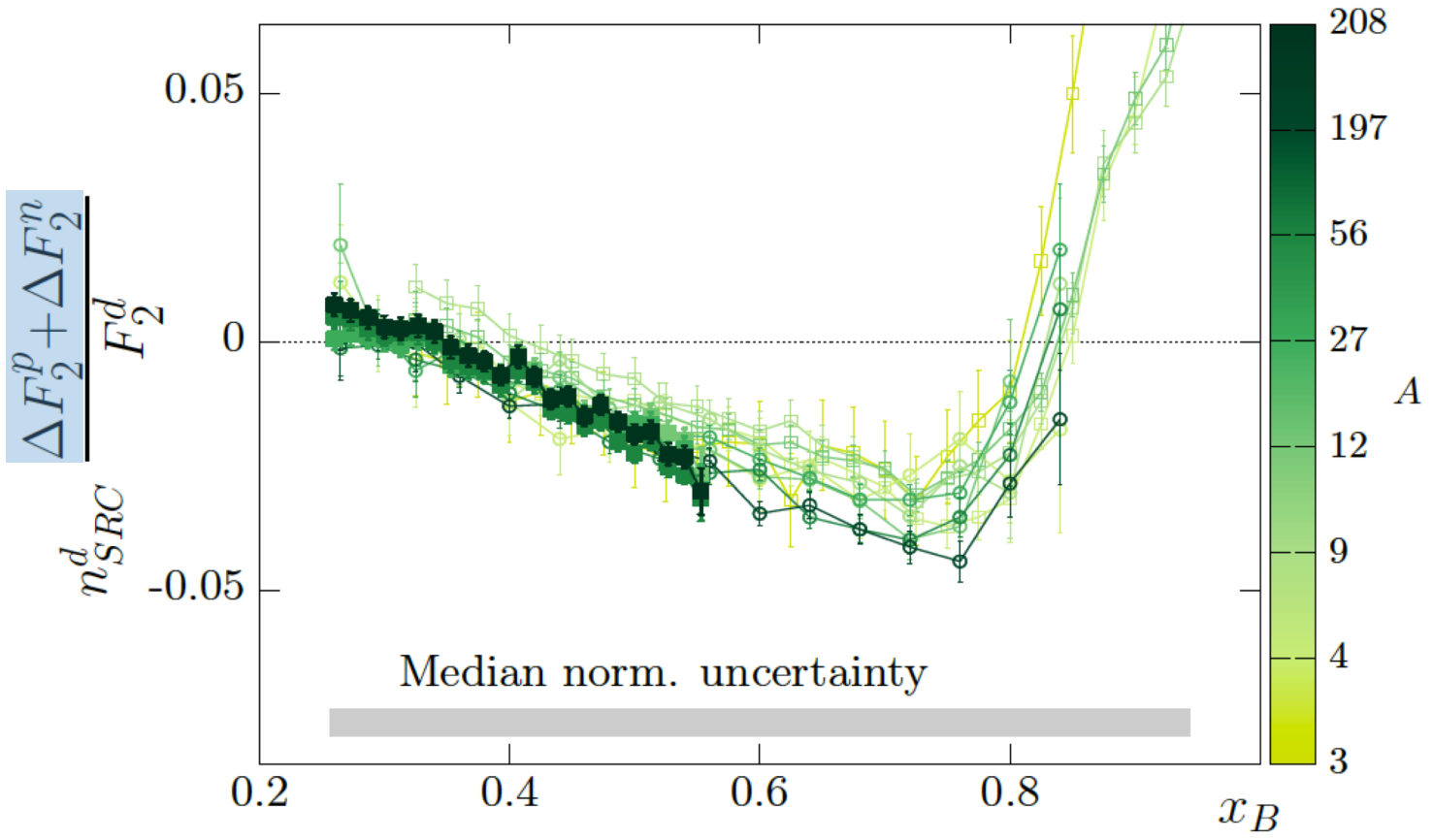
Nucleus A :

$$F_2^A = ZF_2^p + NF_2^n + n_{SRC}^A(\Delta F_2^p + \Delta F_2^n)$$

Deuteron:

$$F_2^d = F_2^p + F_2^n - n_{SRC}^d(\Delta F_2^p + \Delta F_2^n)$$

Extract relative modifications of SRC pairs



Much has been learned from very few events

experiment	nuclei	pairs	Pmiss [MeV/c]	# of pp-events	# of np-events	# of nn-events
EVA/BNL	^{12}C	pn only	300-600	**0**	**16**	**-**
E01-015/ JLab	^{12}C	pp and np	300-600	**263**	**179**	**-**
E07-006/ JLab	^{4}He	pp and np	400-850	**50**	**223**	**-**
CLAS/JLab	C, Al, Fe, Pb	pp and np	300-700	**~ 400 / nucleus**	**~200 / nucleus**	**-**

proton beam A(p, 2pN)

Electron beam A(e, e'pN)

A new CLAS-12 proposal aims to add order of magnitude more data

Extended LD2 target, He, C, Si, ^{40}Ca, ^{48}Ca, Sn, Pb

~ **O (10k)** events per target, np and pp pairs

11 GeV e- beam; 10^{35} cm^{-2} s^{-1}

~60% azimuthal coverage with neutron detector

SRC proposal for CLAS-12 was accepted with an A rating!

Some highlights from the CLAS-12 proposal

Disentangle mass and asymmetry effects on np-dominance

Measure EMC effect and tag the recoil –
simultaneous measurement of SRC and EMC

SRC in inverse kinematics at JINR
A(p, 2p n A-2) : **detecting the nuclear remnant**

4 GeV/c ^{12}C beam on LH target

Probe universality

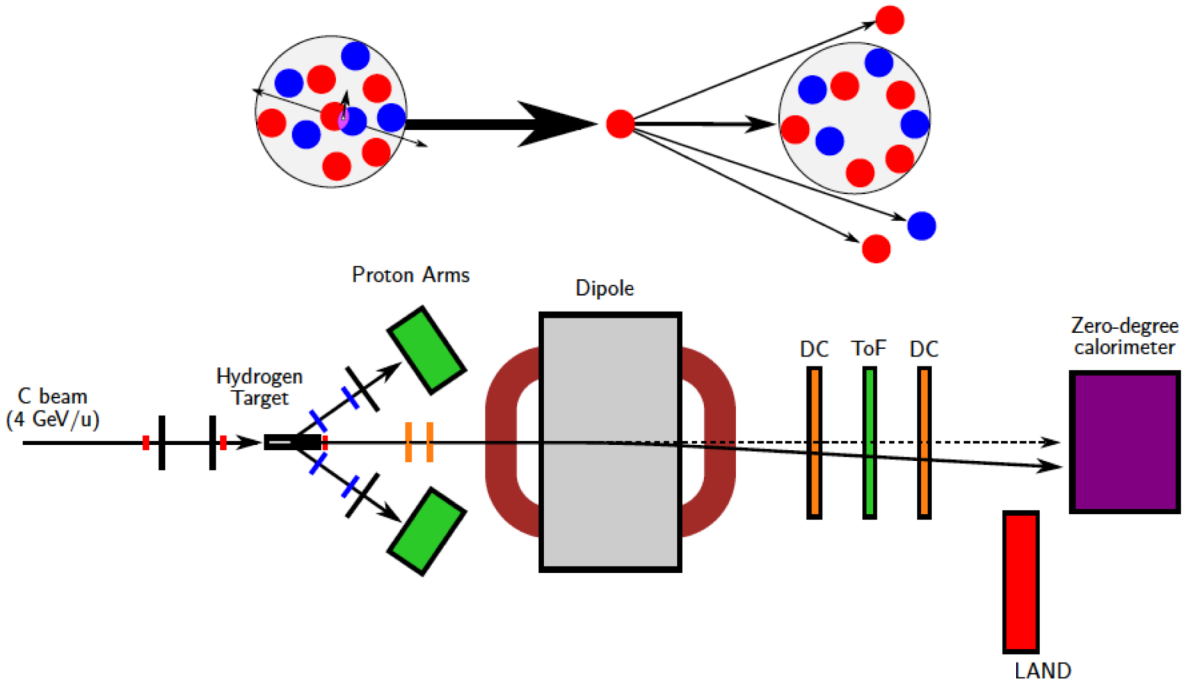
Detect 4 particles:

the scattered probe,

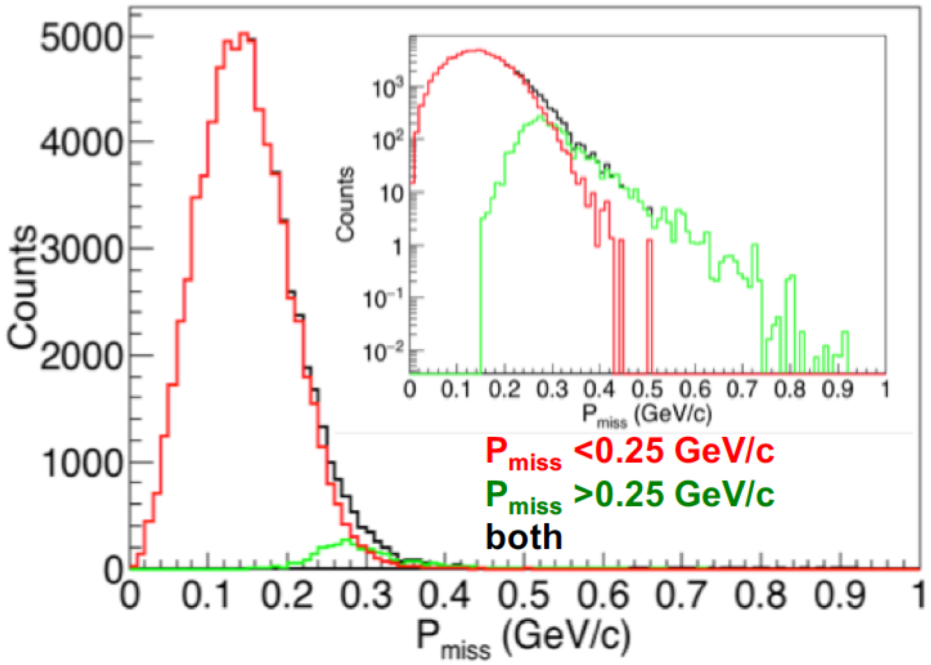
the knocked-out nucleon,

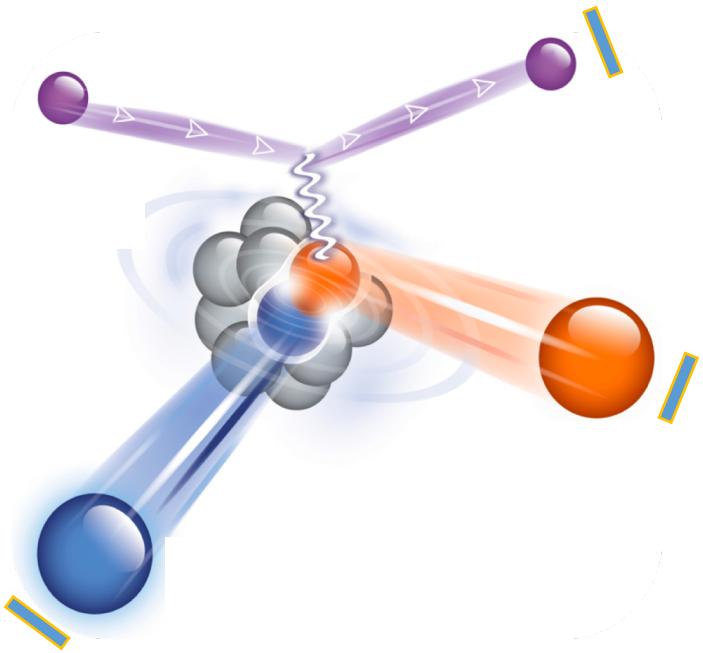
the recoil,

and the **A-2 system**!



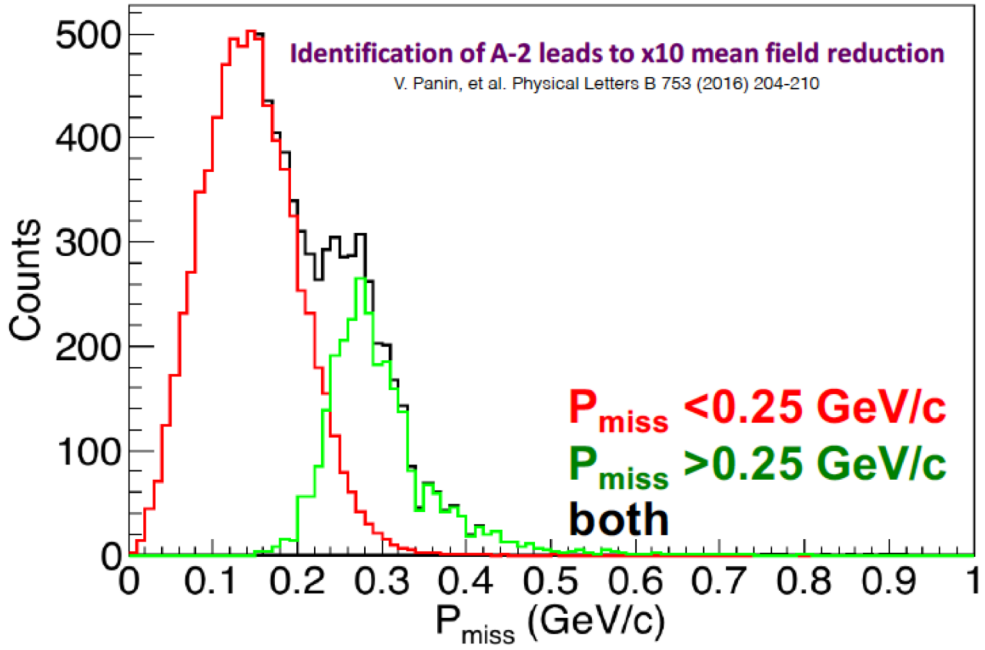
Detecting the A-2 system is essential for rejecting non-SRC background

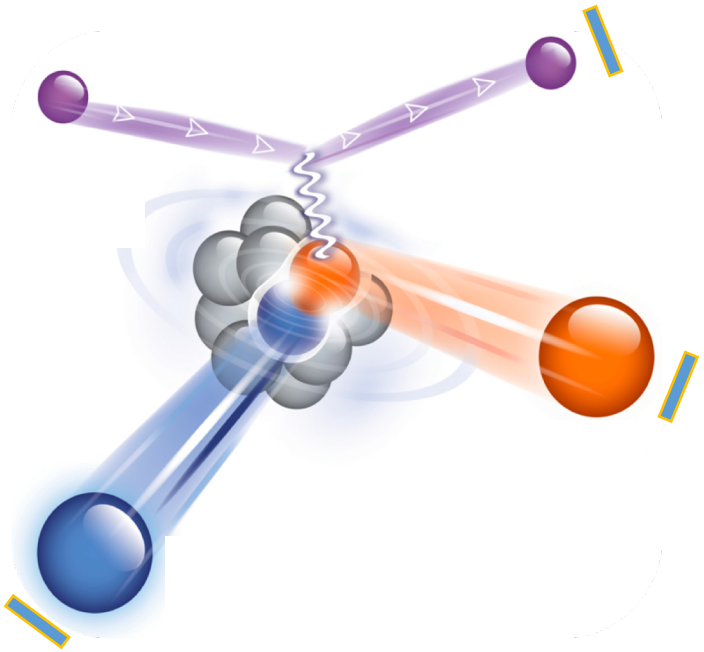




P_{miss} – momentum of the struck nucleon before interaction

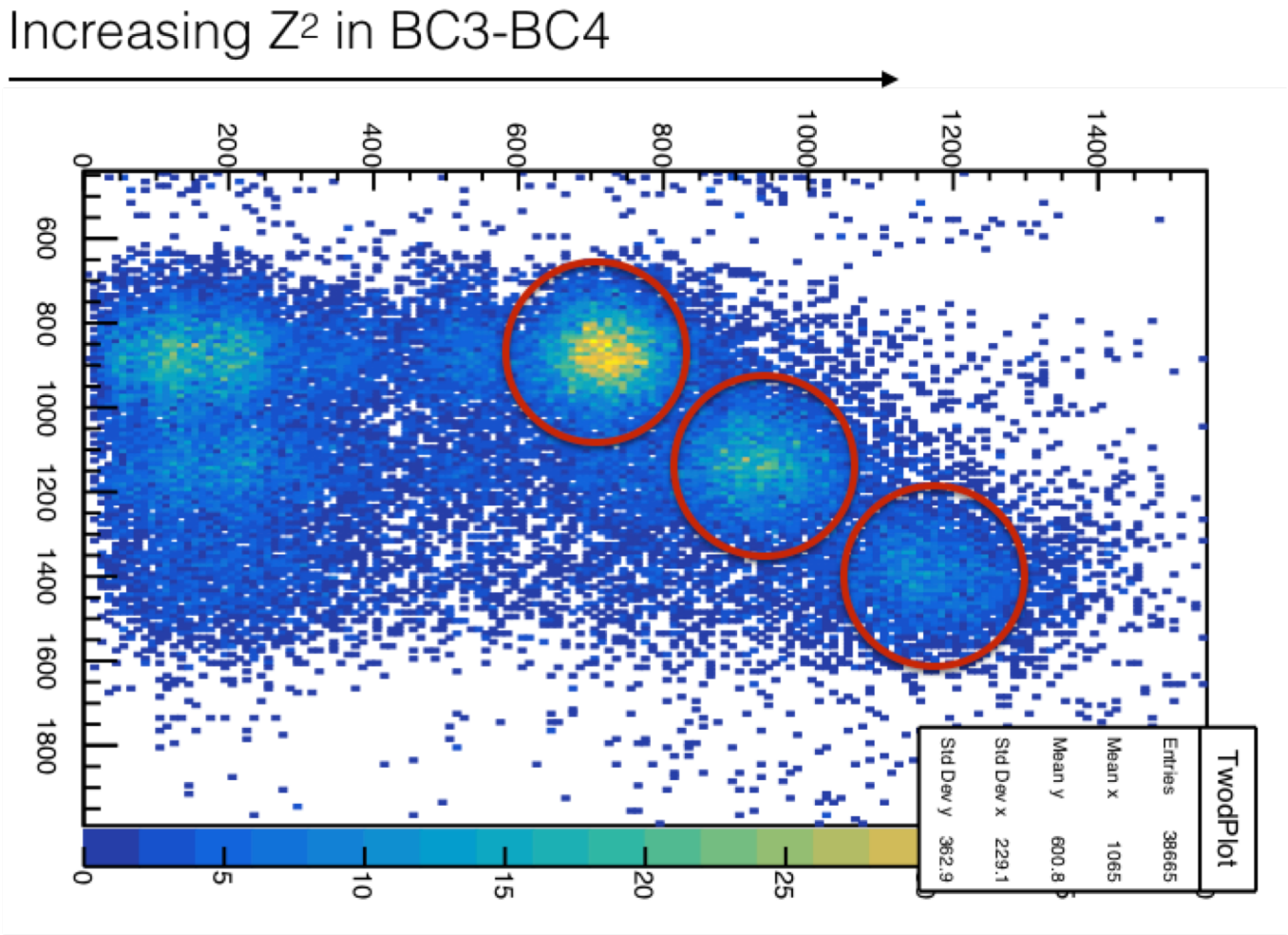
Identification of A-2 rejects the mean field component by 10 times



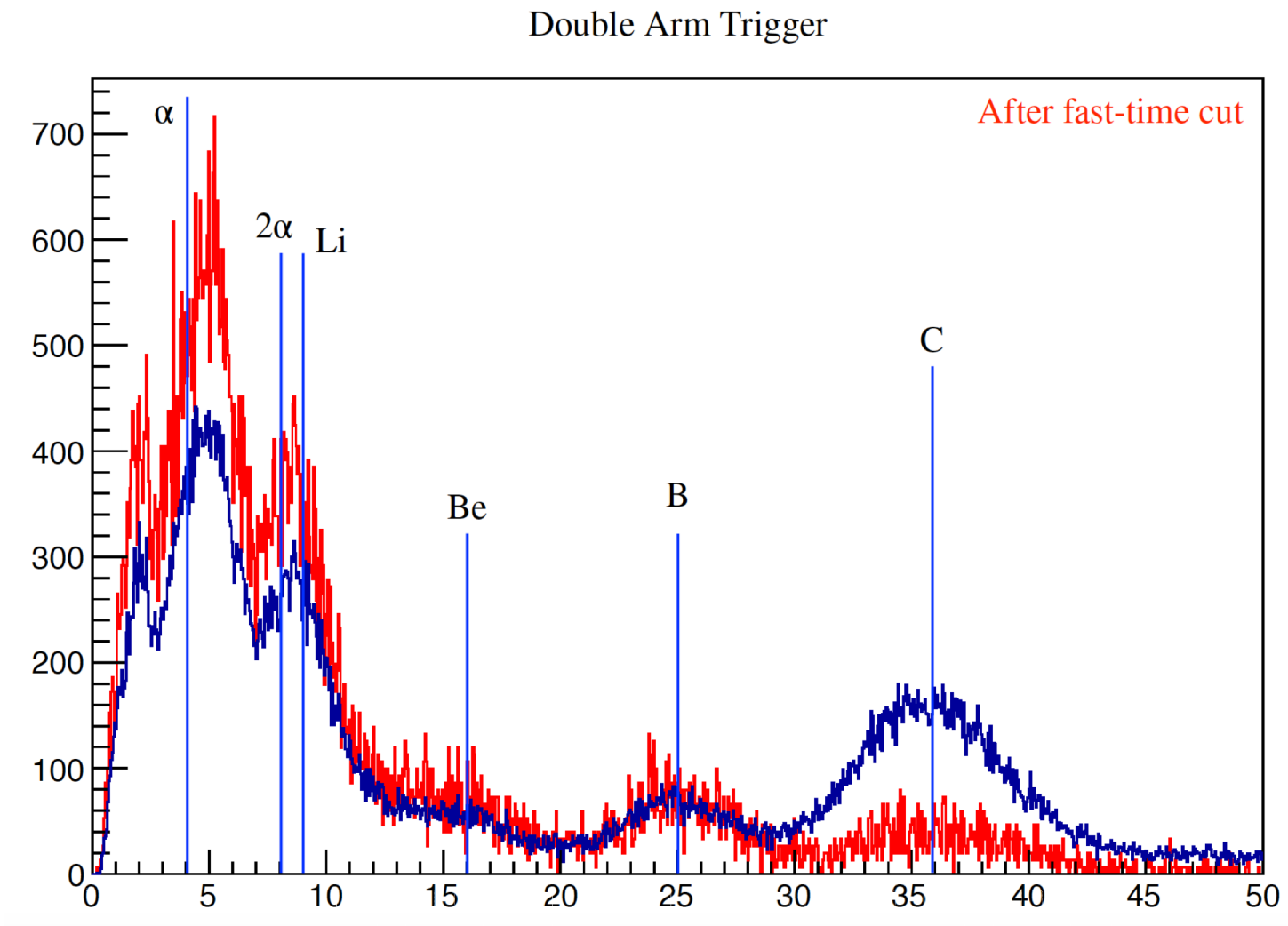


P_{miss} – momentum of the struck nucleon before interaction

Z from the scintillator counter: calibration

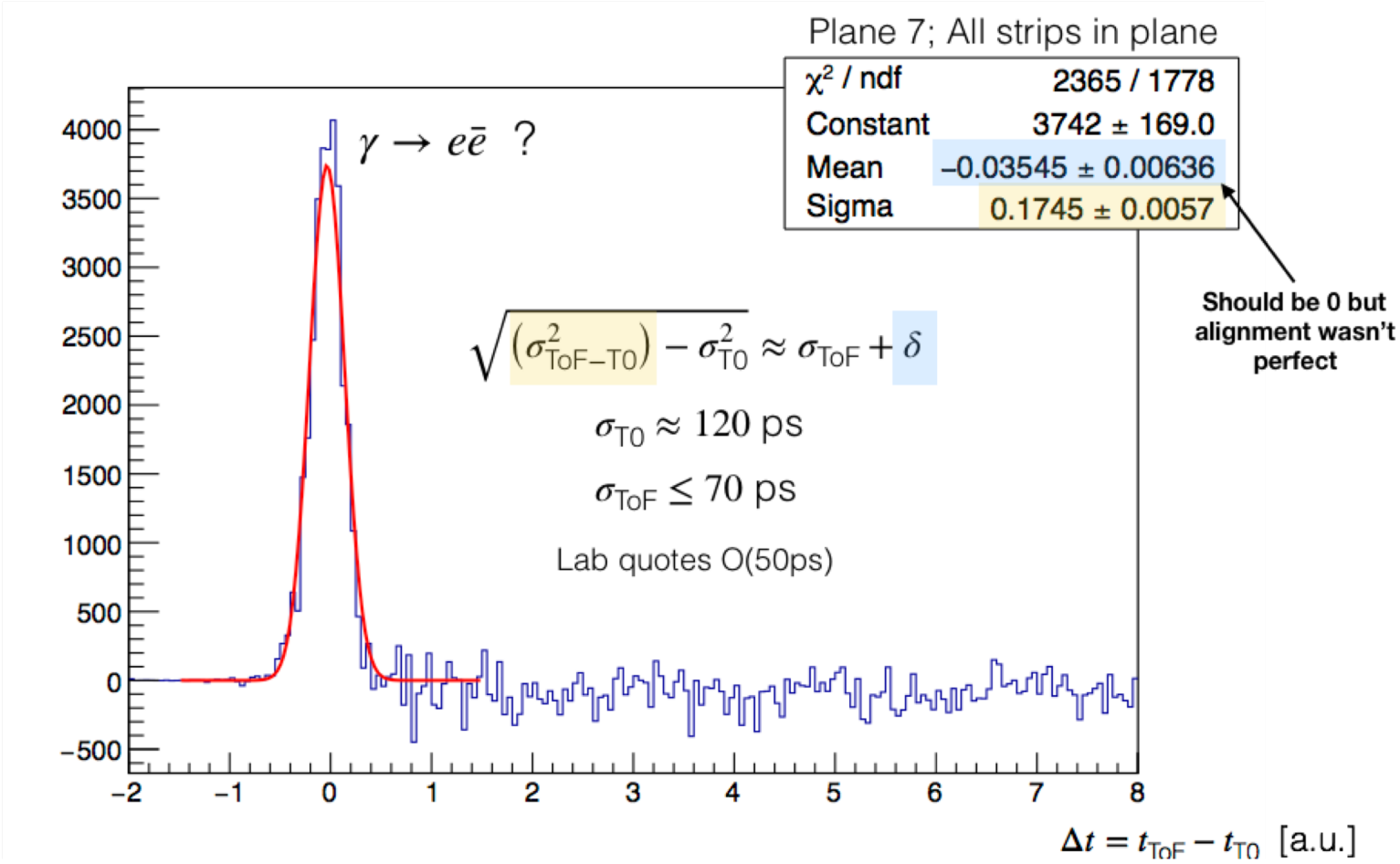


Residual nucleus can be identified from dE/dx

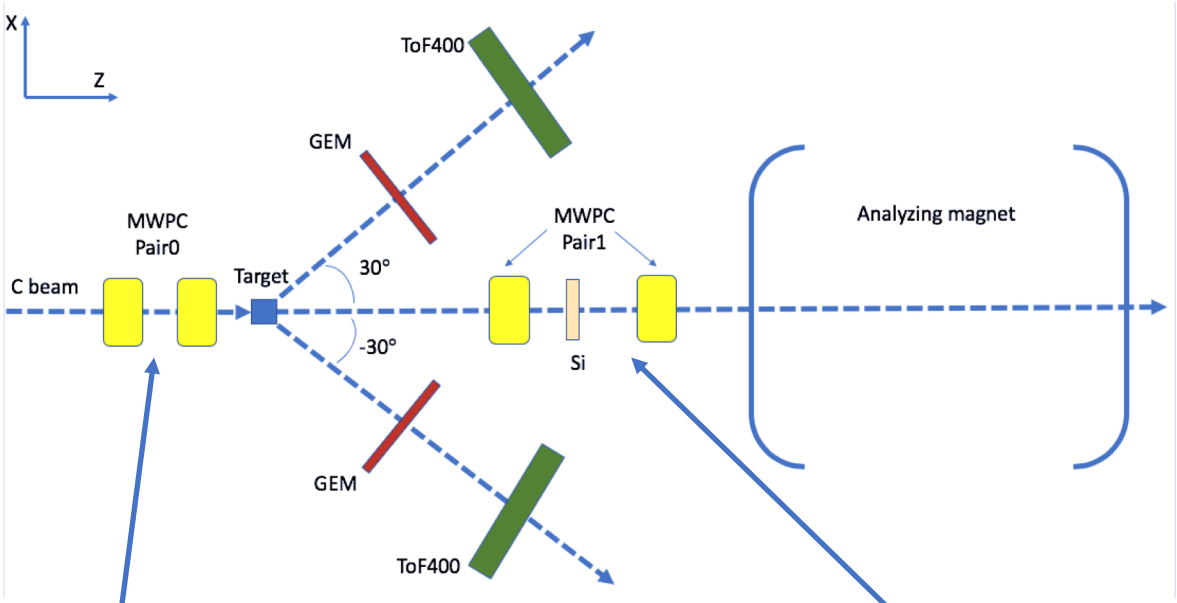


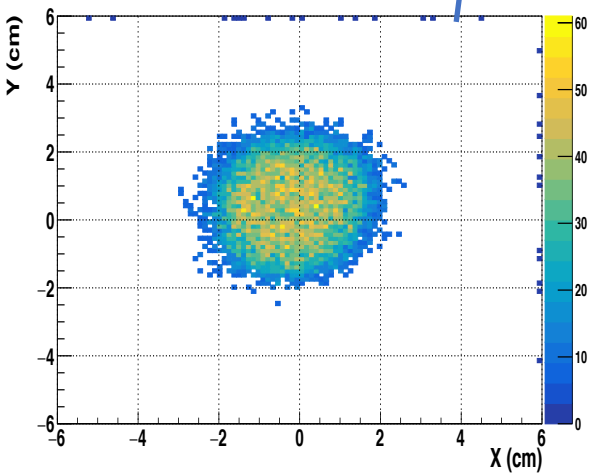
Analysis is going on: TOF400 calibration

After strip alignment, clustering, time-walk (T0 and ToF400)
Pb Wall Data - No-Pb Wall Data

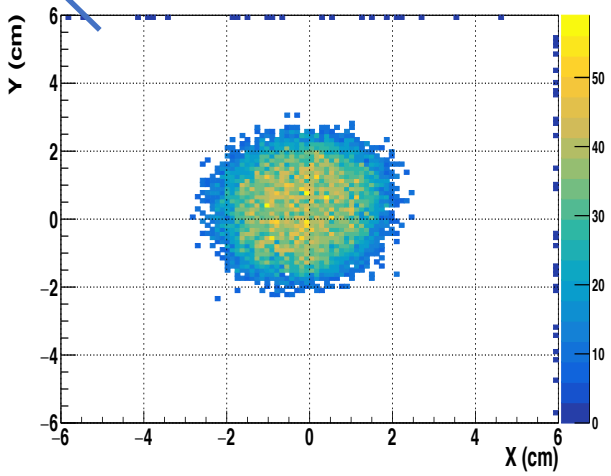


Analysis is going on: MWPC reconstruction





^{12}C beam
Empty target

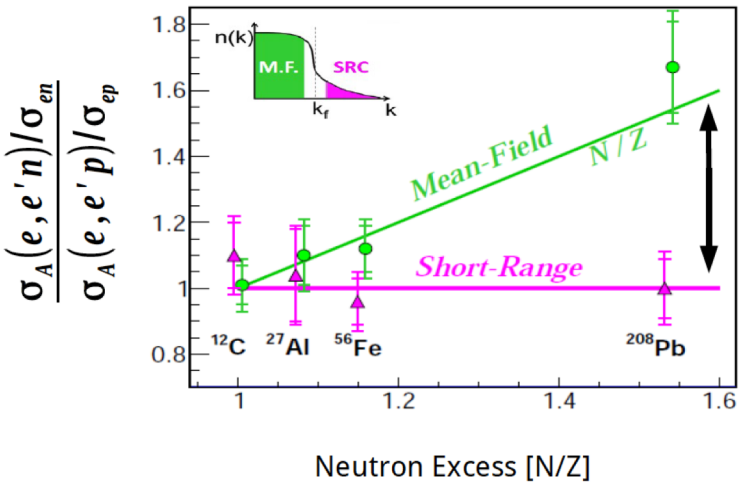


Conclusions

SRC is a vibrant fast developing field of studies on the border between nuclear and particle physics

New insights about SRC:

np dominance confirmed over a wide range of A



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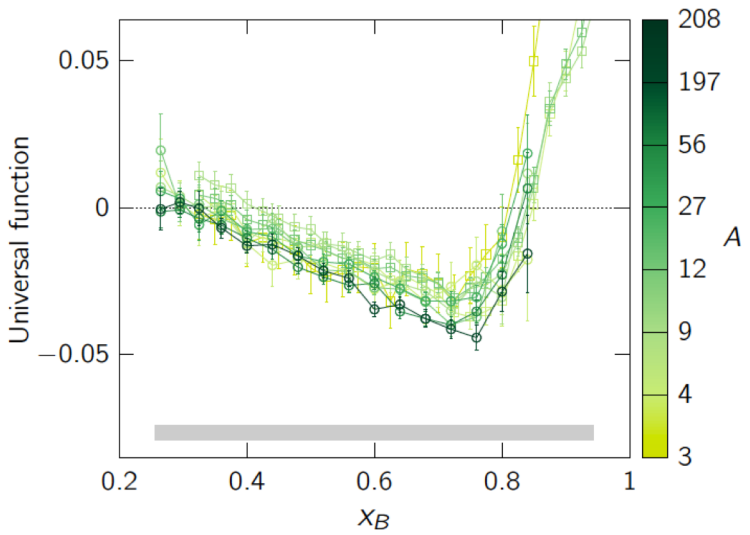
SRC hypothesis for EMC explanation is stronger with the new data



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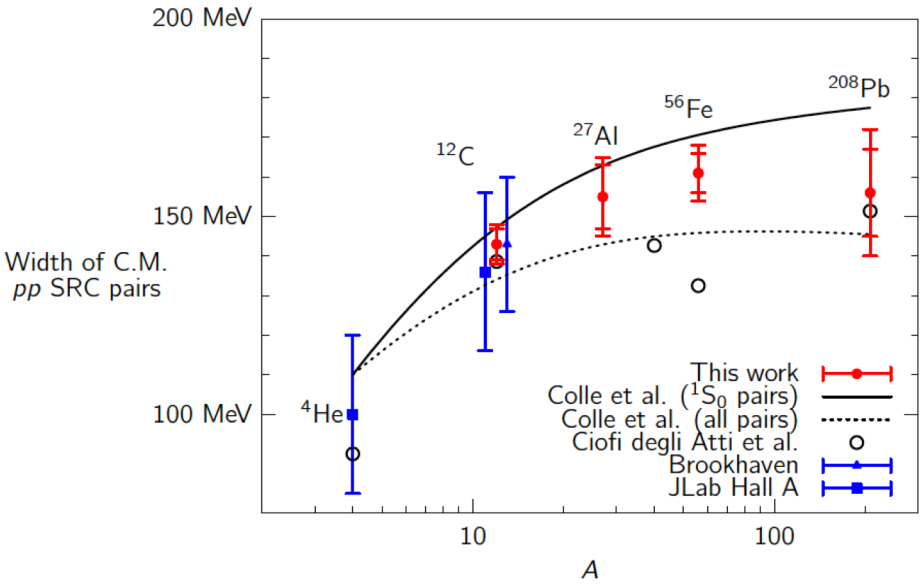

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SRC is a vibrant fast developing field of studies on the border between nuclear and particle physics

New insights about SRC:

- np dominance confirmed over a wide range of A
- SRC hypothesis for EMC explanation is stronger with the new data
- SRC pair formation and NN repulsive core

New exclusive experiments are designed to test new SRC ideas:

- disentangle mass and asymmetry, EMC/SRC (JLab)
- detect the residual nucleus for the first time (JINR)

The SRC World

+ BM@N Collaboration

Looking at Z2 After Target

1 and 2 tracks look identical — need to clean up selection
3 tracks is different event topology