

The CaFe Experiment:

Isospin Dependence of Short-Range Correlations in Nuclei

C. Yero
(On behalf of the CaFe collaboration)

3rd SRC Collaboration Meeting

August 02 - 04, 2022

Proposal: PR12-16-004

Spokespeople: L. Weinstein (ODU), D. Higinbotham (JLab), O. Hen (MIT), E. Cohen (TAU)



CaFe Experiment Overview

■ 8-day measurement of $(e, e'p)$ cross sections on:
 d , [^9Be - ^{10}B - ^{11}B - ^{12}C], [^{40}Ca - ^{48}Ca - ^{54}Fe]

■ $A(e, e'p)$ at selected kinematics:

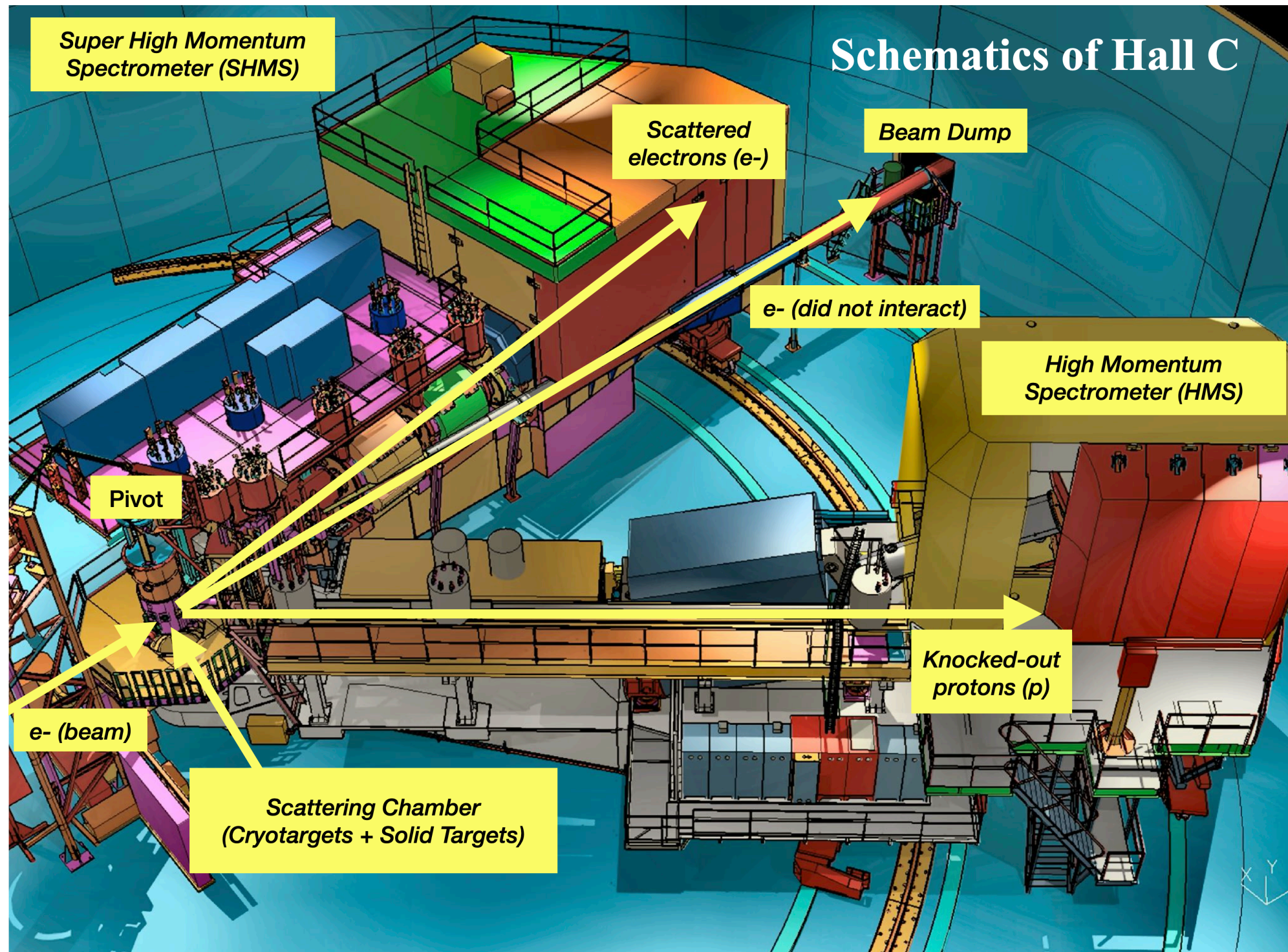
- ▶ mean-field (MF) nucleons ($k_{\text{rel}} < 250 \text{ MeV/c}$)
- ▶ short-range correlated (SRC) pairs ($k_{\text{rel}} \gtrsim 250 \text{ MeV/c}$)

■ what will CaFe extract?

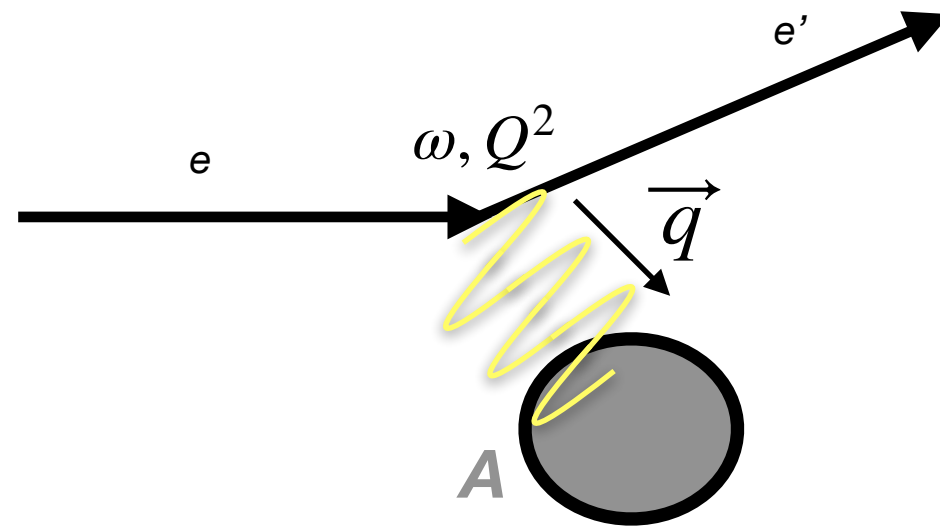
- ▶ absolute & reduced cross sections
=> distorted spectral function (not observable)
- ▶ single ratios SRC (high-p) / MF (low-p)
=> proton pairing probability
- ▶ double ratios (SRC/MF)_A1 / (SRC/MF)_A2
=> relative pairing probability of high-p protons in different nuclei

CaFe Experiment Overview

use standard Hall C HMS+SHMS spectrometer pair

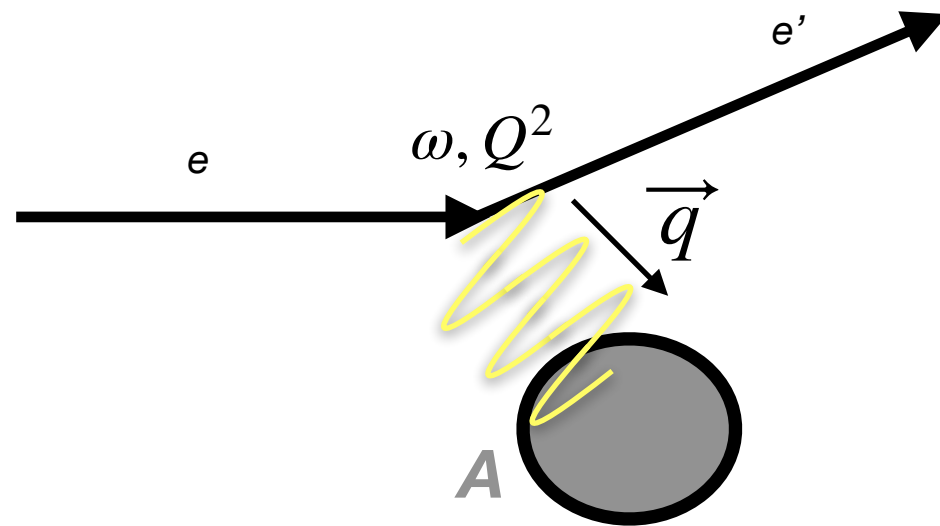


CaFe Experiment Overview



???

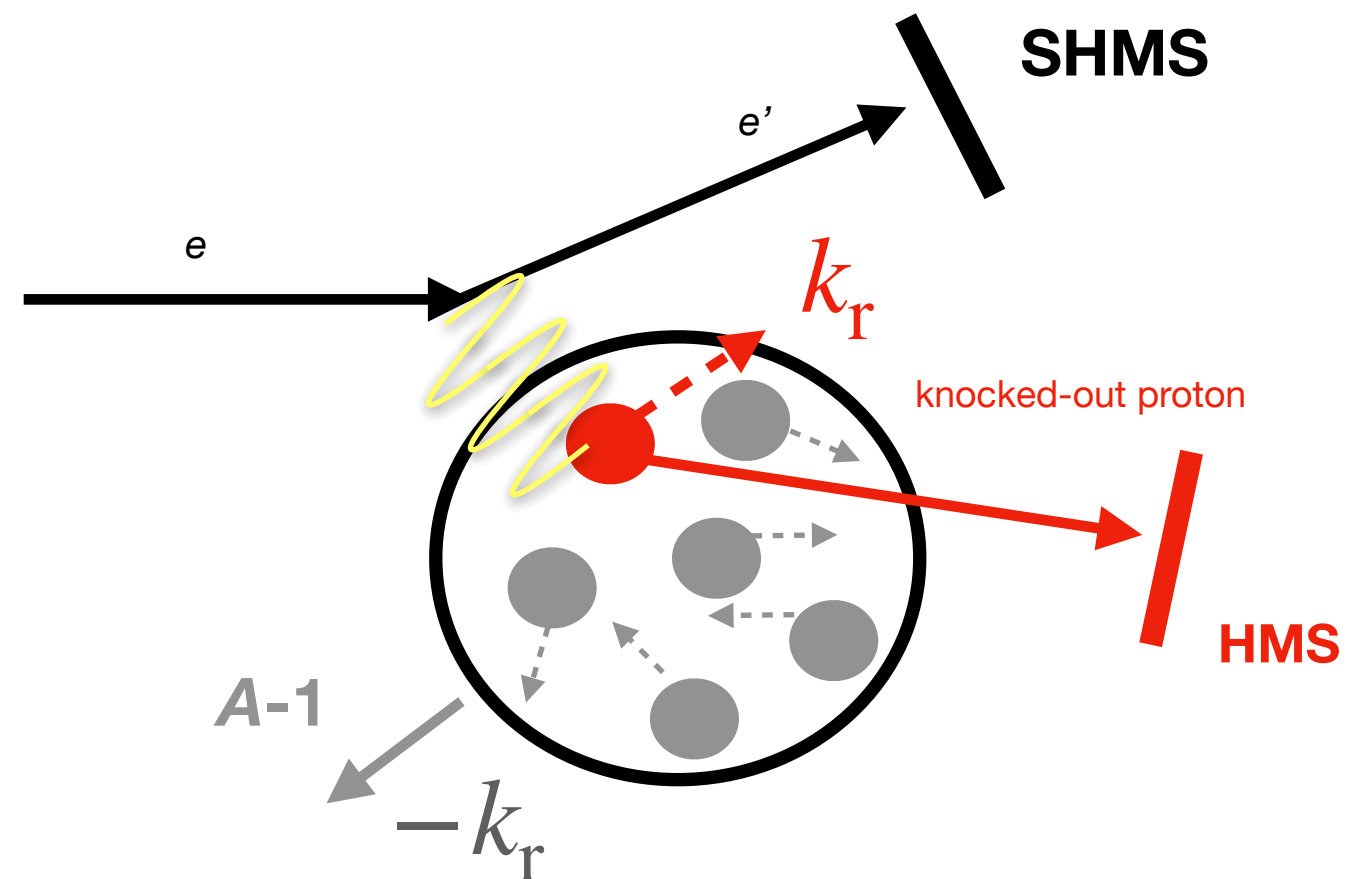
CaFe Experiment Overview



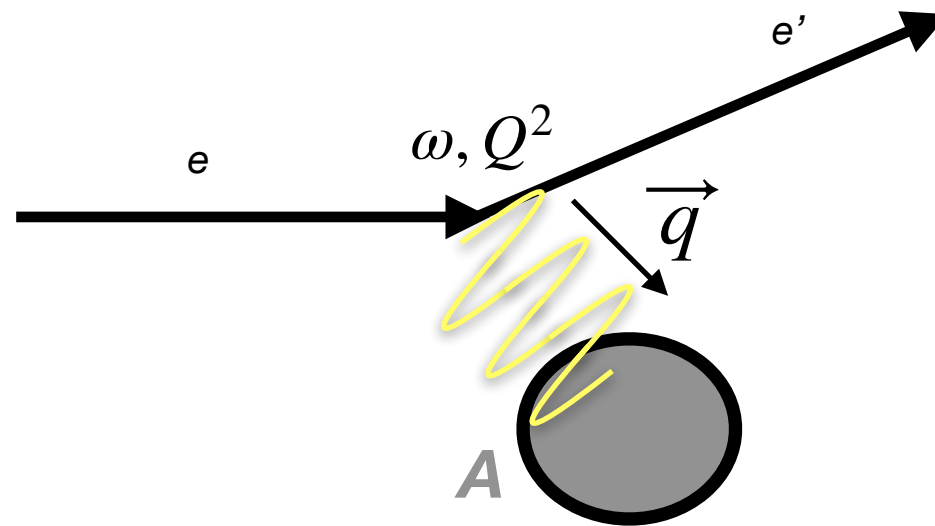
mean-field (MF) kinematics:

“Electron scattering off
MF nucleon”

$$(k_r < k_F \sim 250 \text{ MeV/c}),$$



CaFe Experiment Overview



mean-field (MF) kinematics:

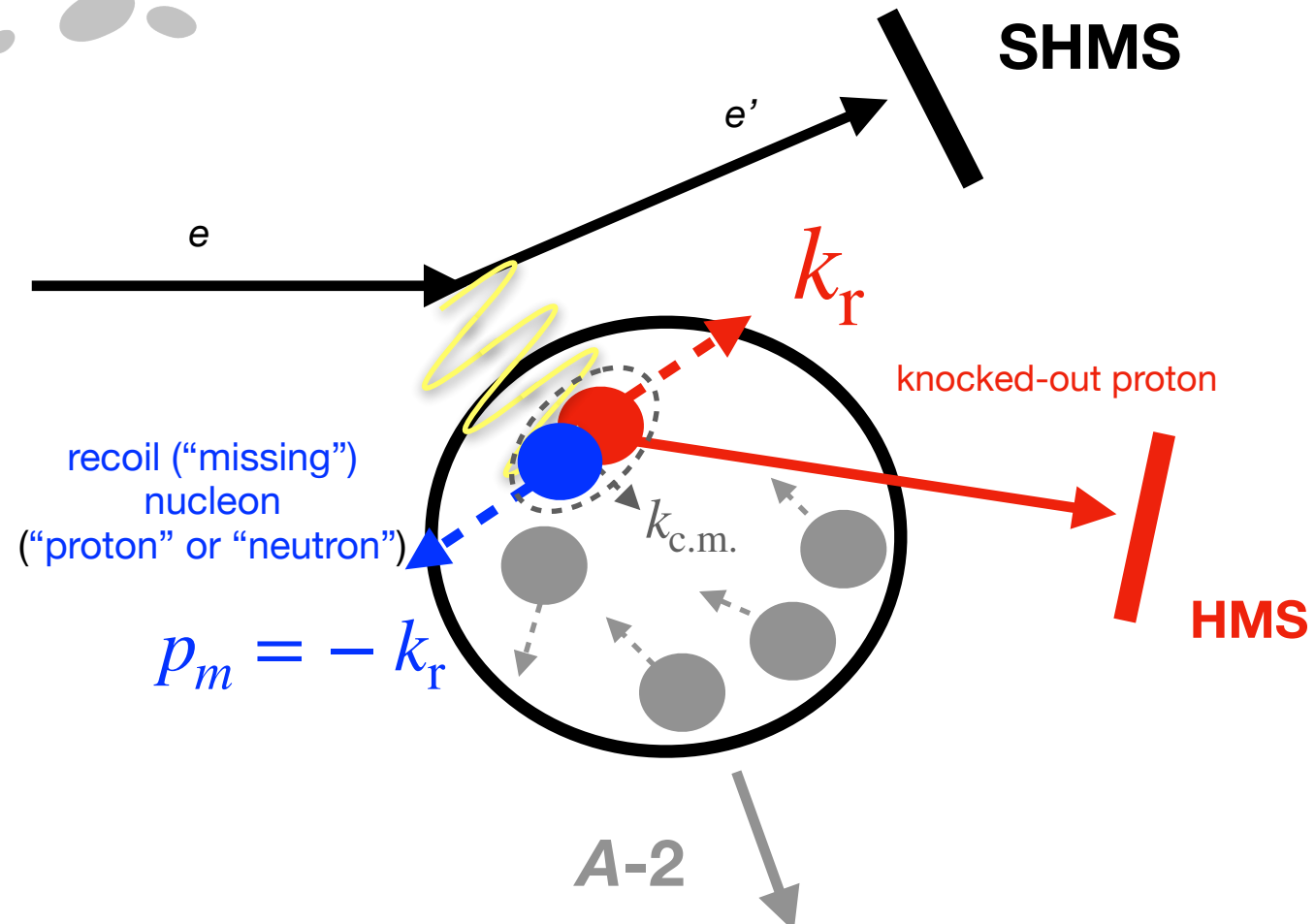
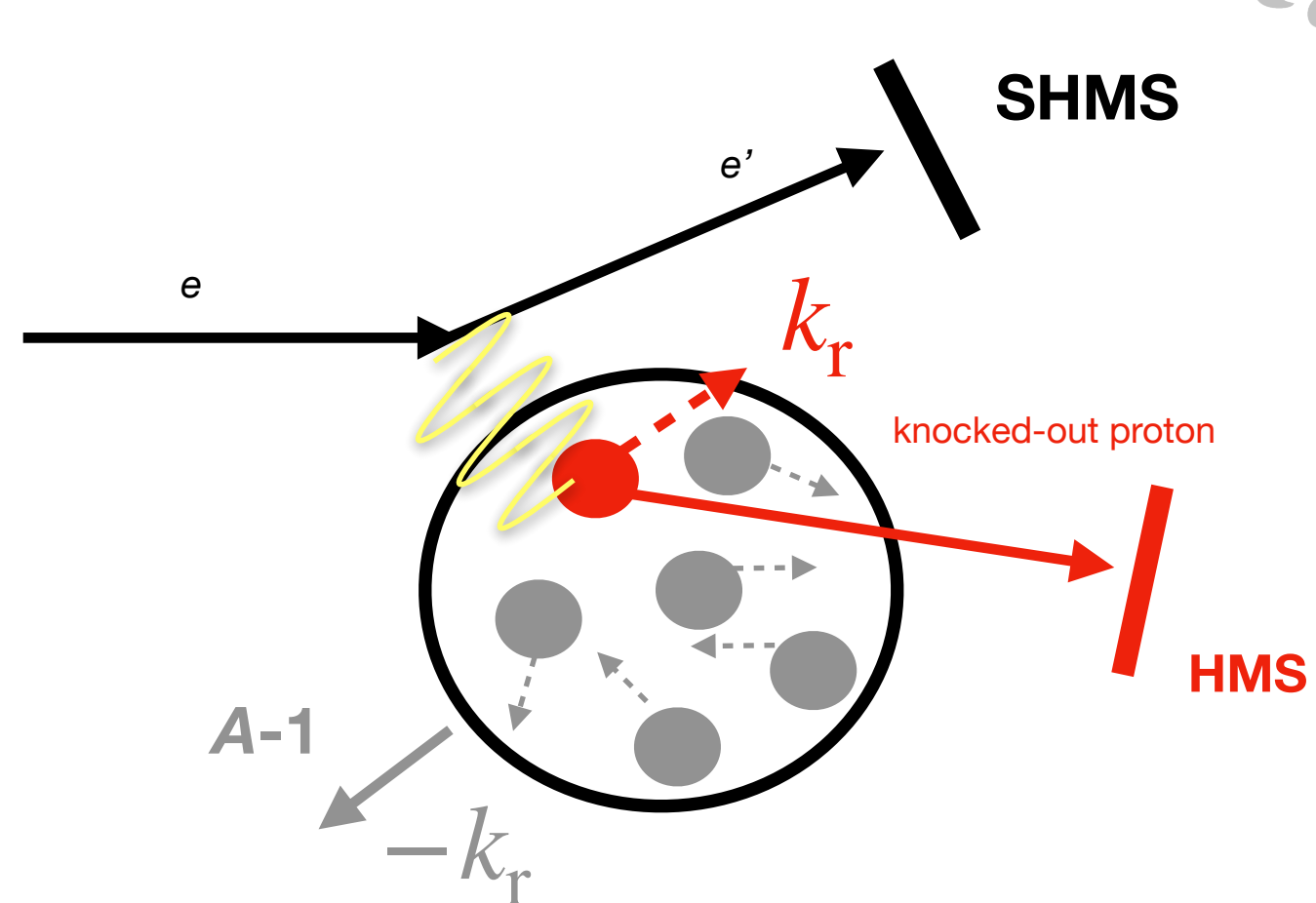
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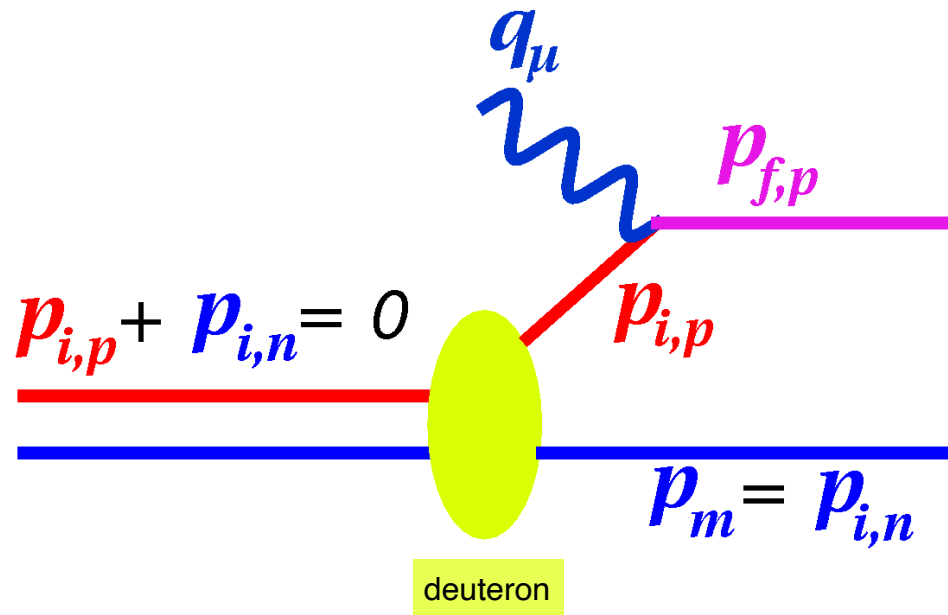
short-range correlation (SRC) kinematics:

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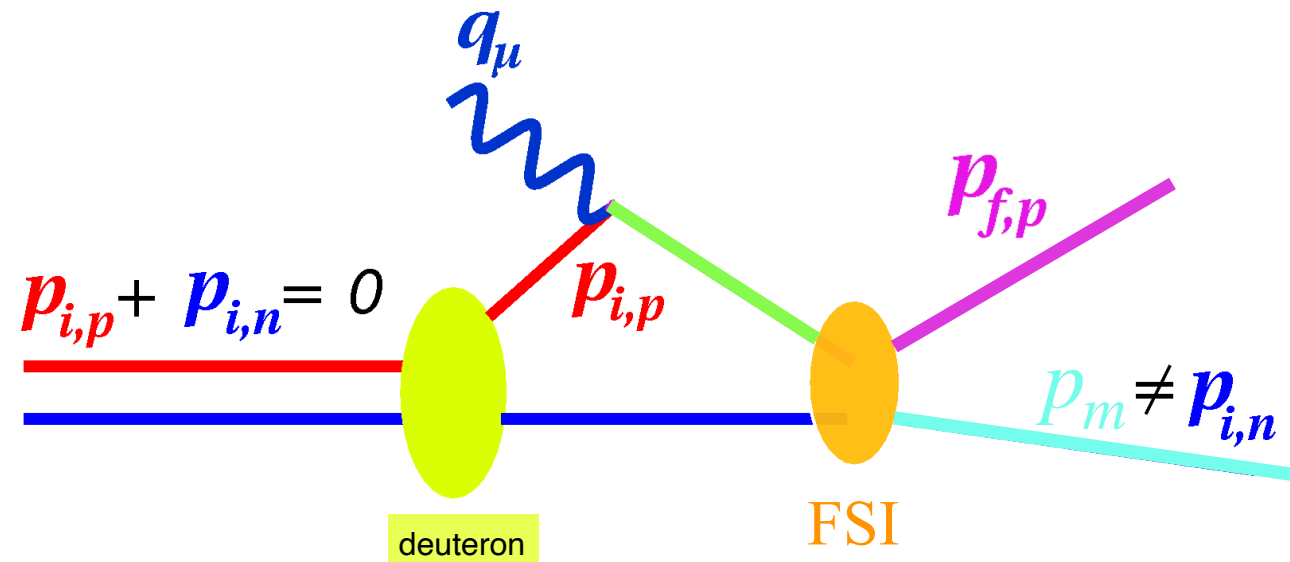
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CaFe Experiment Overview

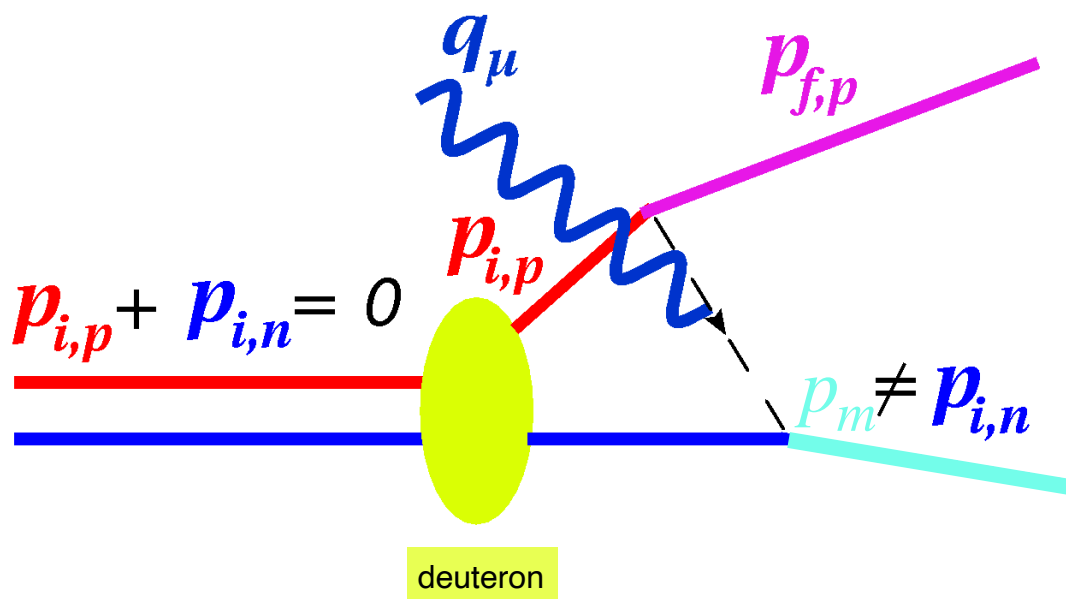


Plane Wave Impulse Approximation (PWIA)



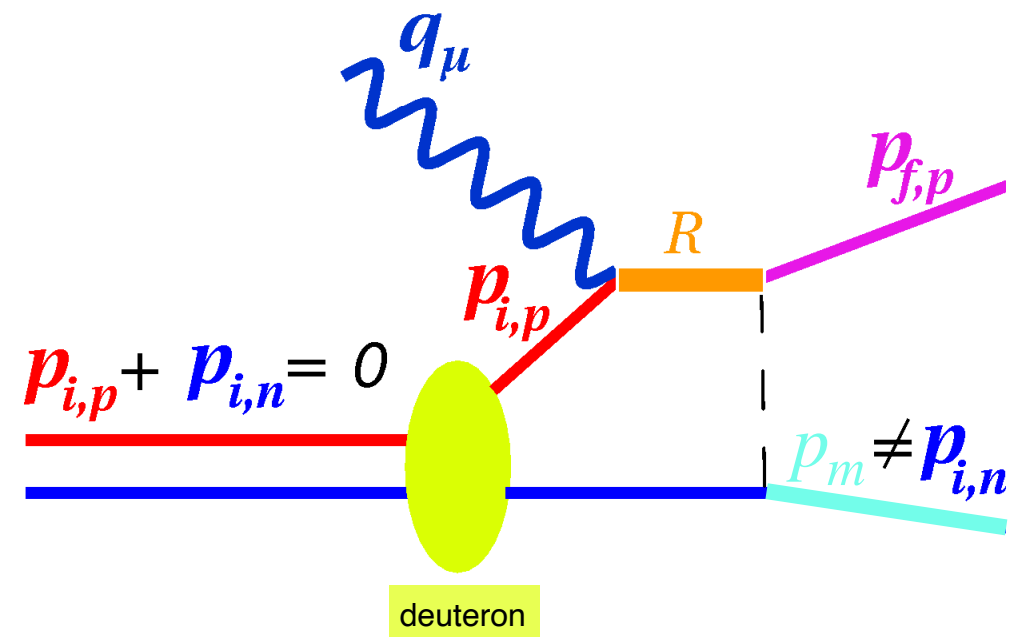
Final State Interactions (FSI)

suppressed at specific $\theta_{nq} < 40$ deg



Meson-Exchange Currents (MEC)

suppressed at $Q^2 > 1(\text{GeV}/c)^2$



Isobar Configurations (IC)

suppressed at $x_{Bj} > 1$

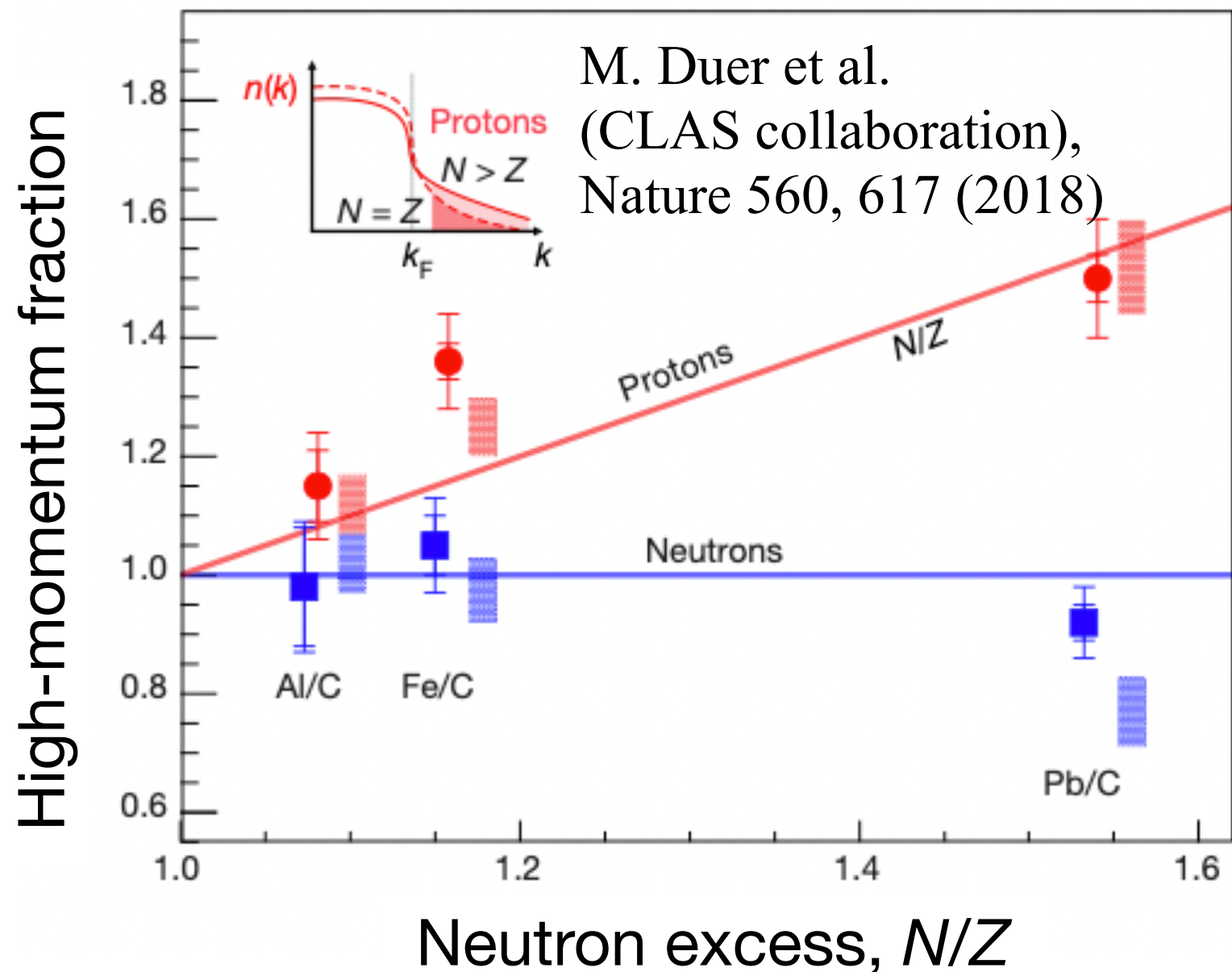
Which nucleons form SRC pairs?

SRC pairs:

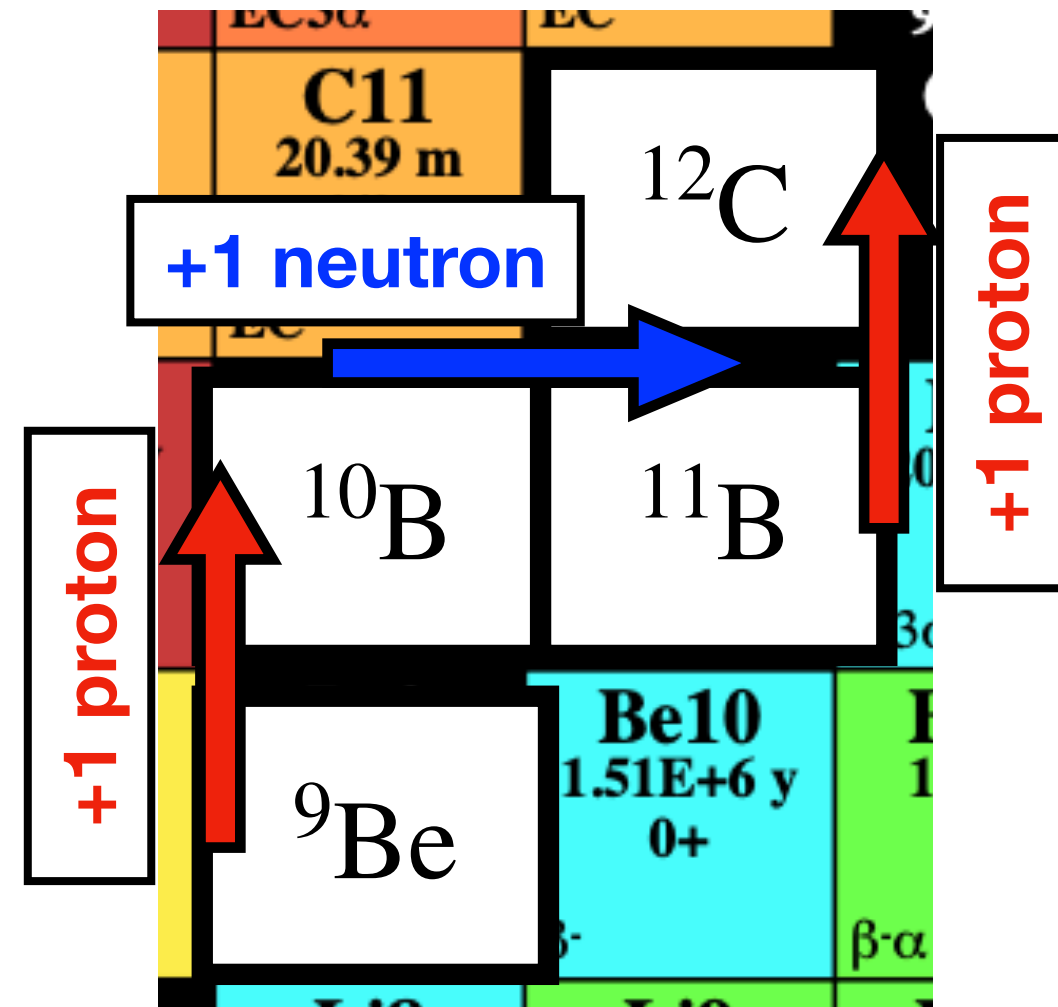
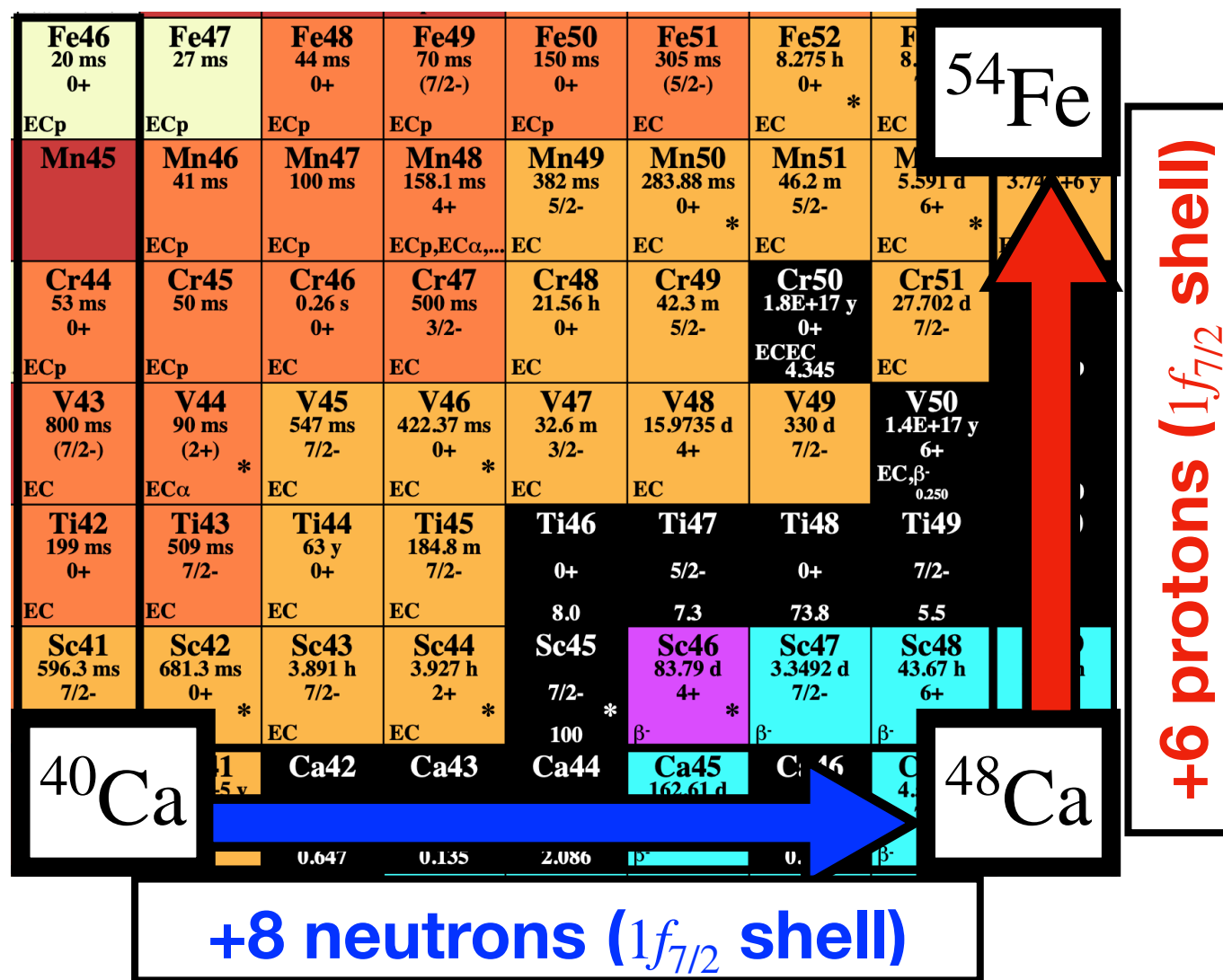
- ▶ account for almost all high momentum nucleons in nuclei
- ▶ are predominantly np

CaFe will answer:

- Which nucleons form pairs?
- How does adding neutrons speed up protons?
- How does NN -SRC pairing change with A and N/Z ?



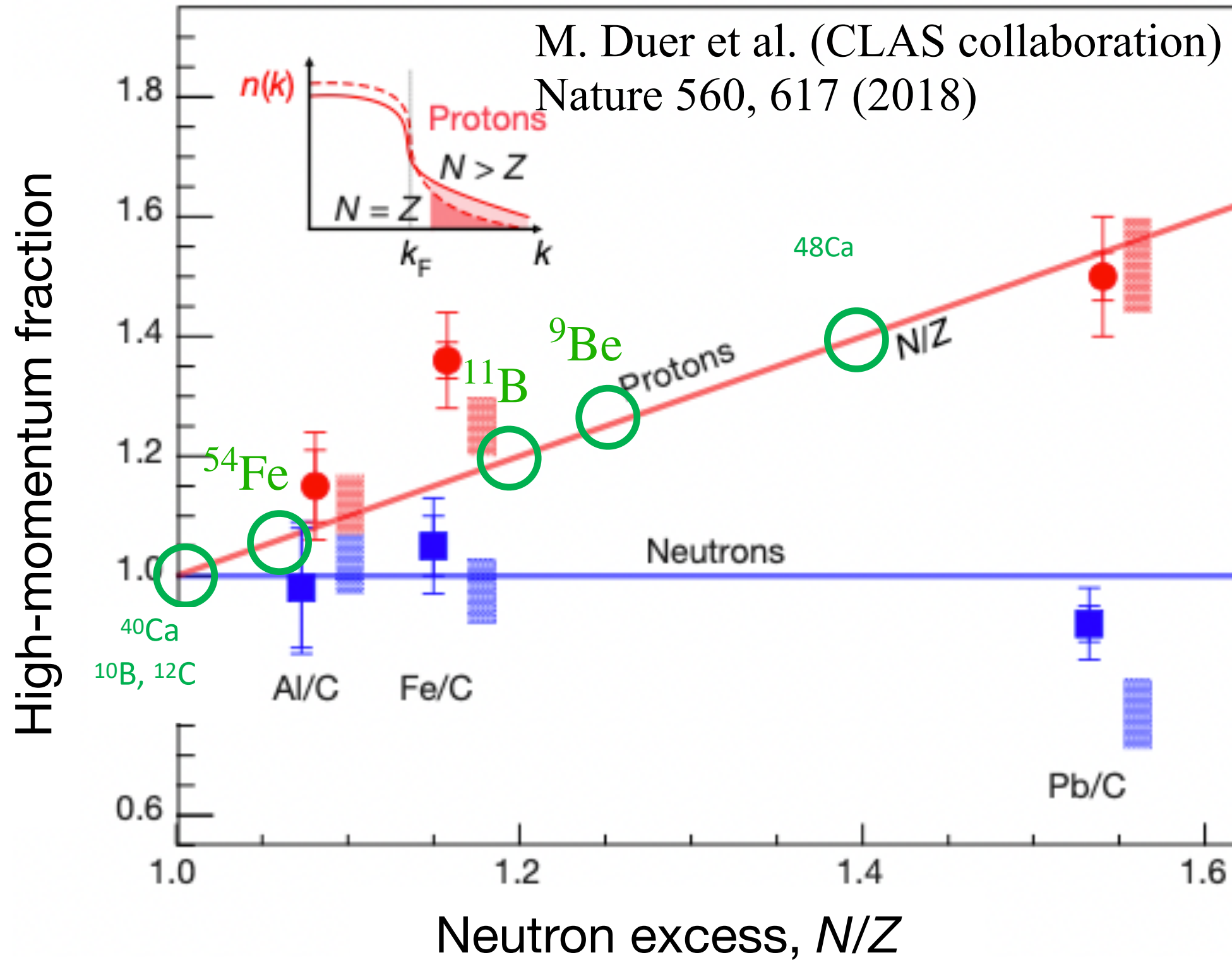
Which Nuclei to Investigate ?



Which nucleons form pairs?

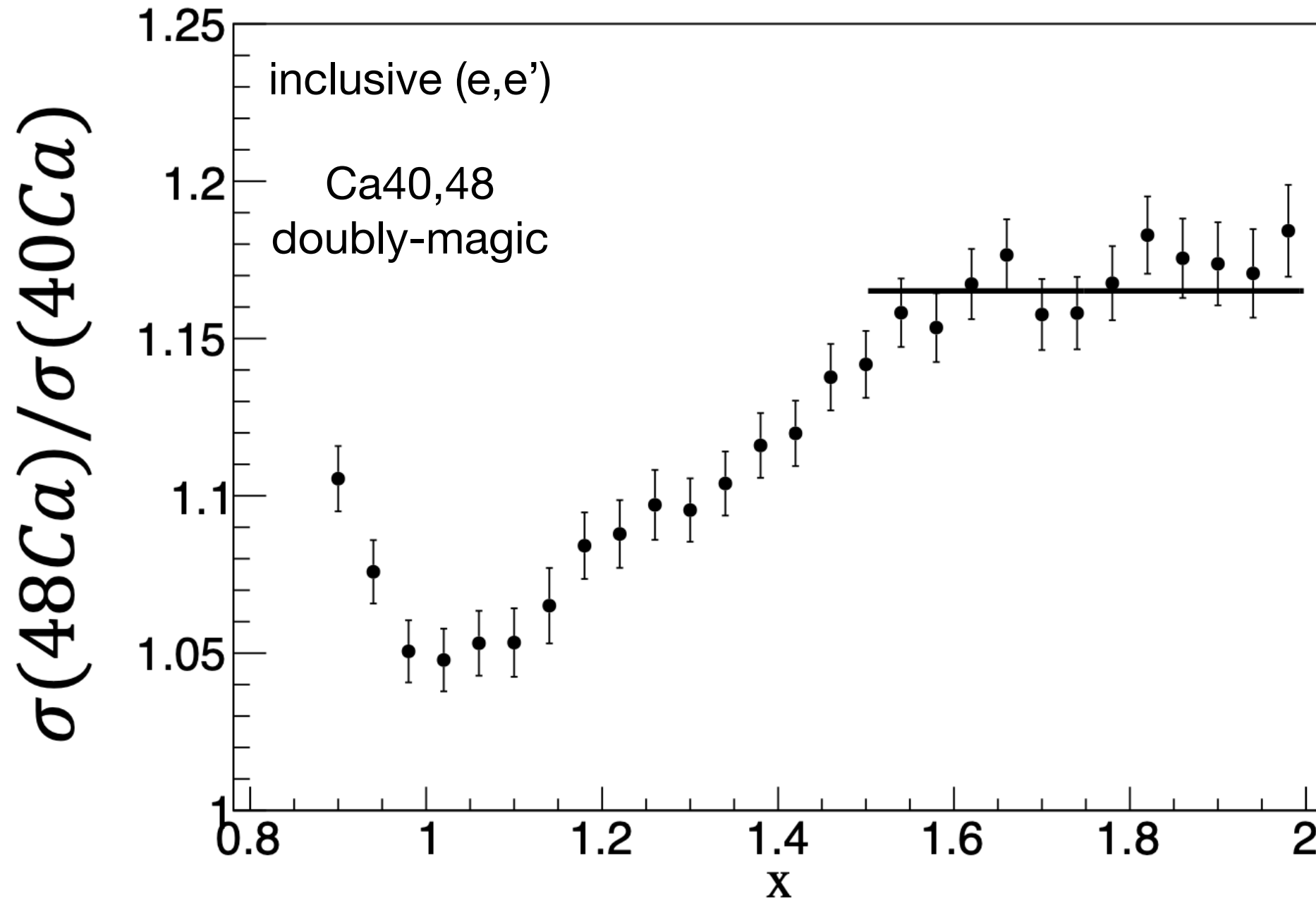
- How does adding $+8$ $1f_{7/2}$ neutrons to a $2s1d$ closed shell ^{40}Ca change the proton pairing?
- How does adding $+6$ $1f_{7/2}$ protons to ^{48}Ca change the proton pairing?
- What about $+1p$, $+1n$ nuclei? $^9\text{Be} \rightarrow ^{10}\text{B} \rightarrow ^{11}\text{B} \rightarrow ^{12}\text{C}$

Projected CaFe Results



A Closer Look at Calcium 40, 48

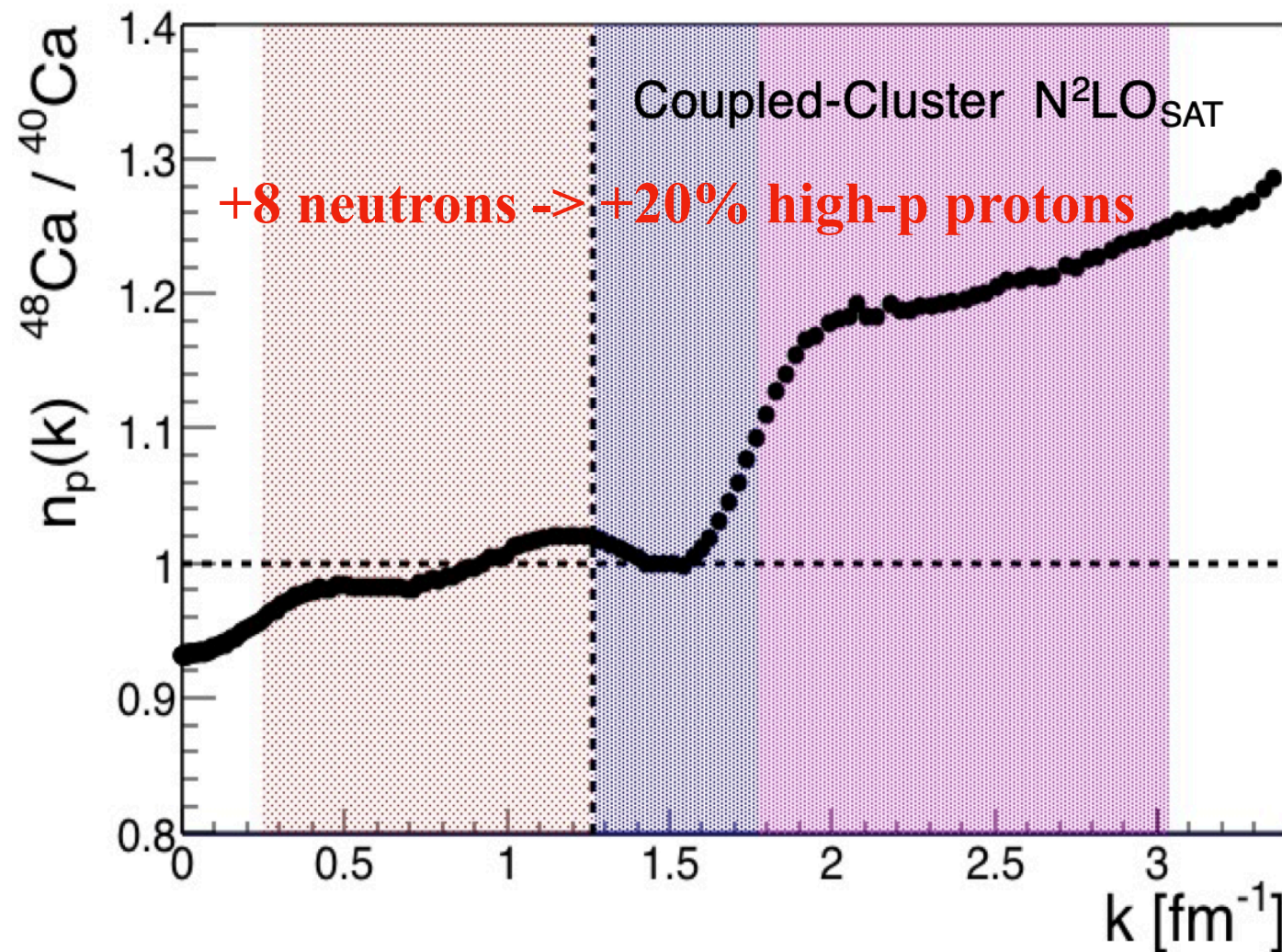
- ▶ more *NN*-SRC pairs formed in Ca-48 compared to Ca-40 ($R \sim 1.17$)
- ▶ inclusive (e, e') data cannot distinguish *pp*, *nn*, *np*-pairs → **$(e, e'p)$ needed !**



D. Nguyen et al. (Hall A Collaboration), PRC **102**, 064004 (2020)

Ab-initio Calculations (Medium Nuclei)

■ CaFe measurement will test validity of *ab-initio* theory calculations



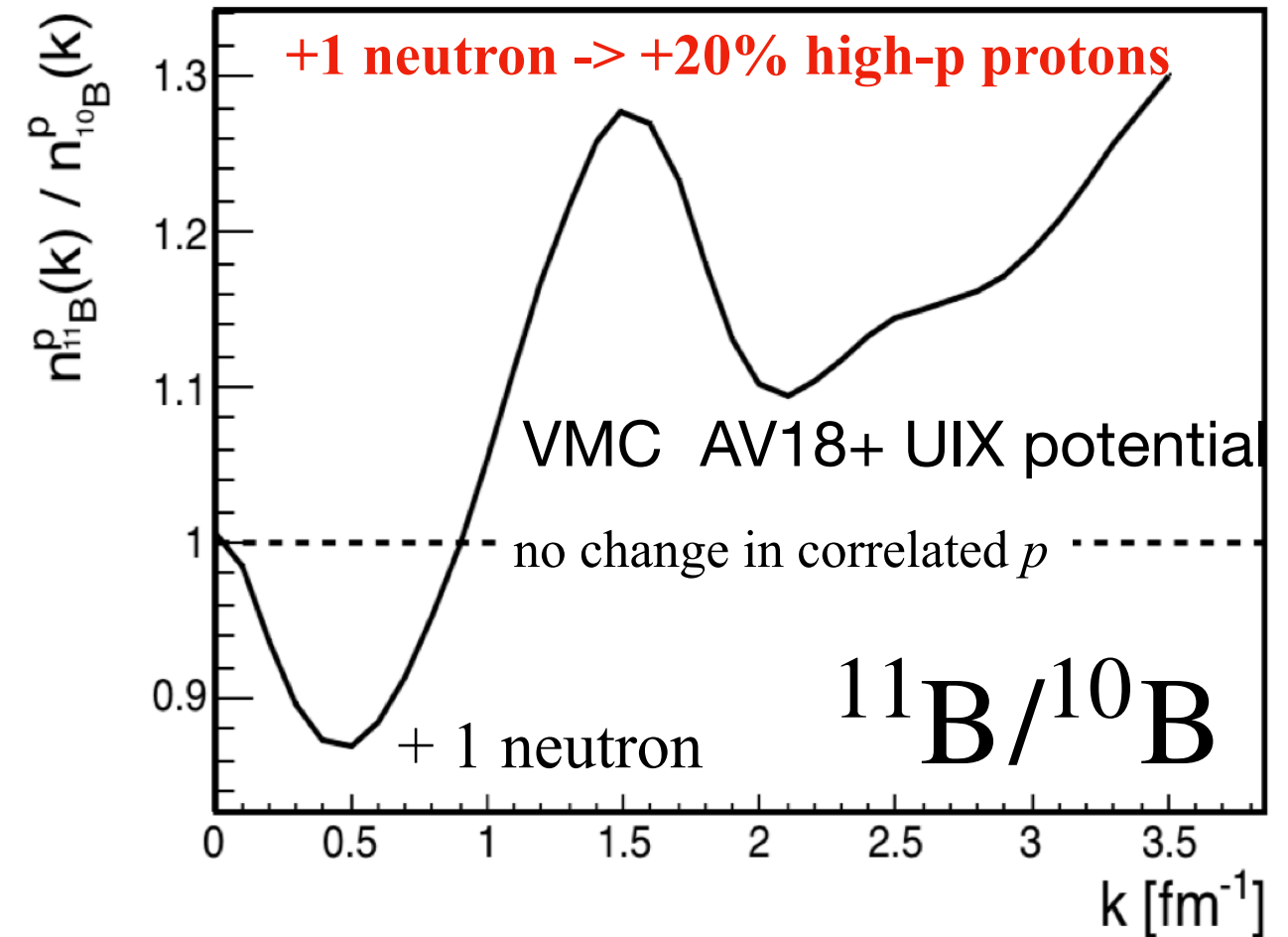
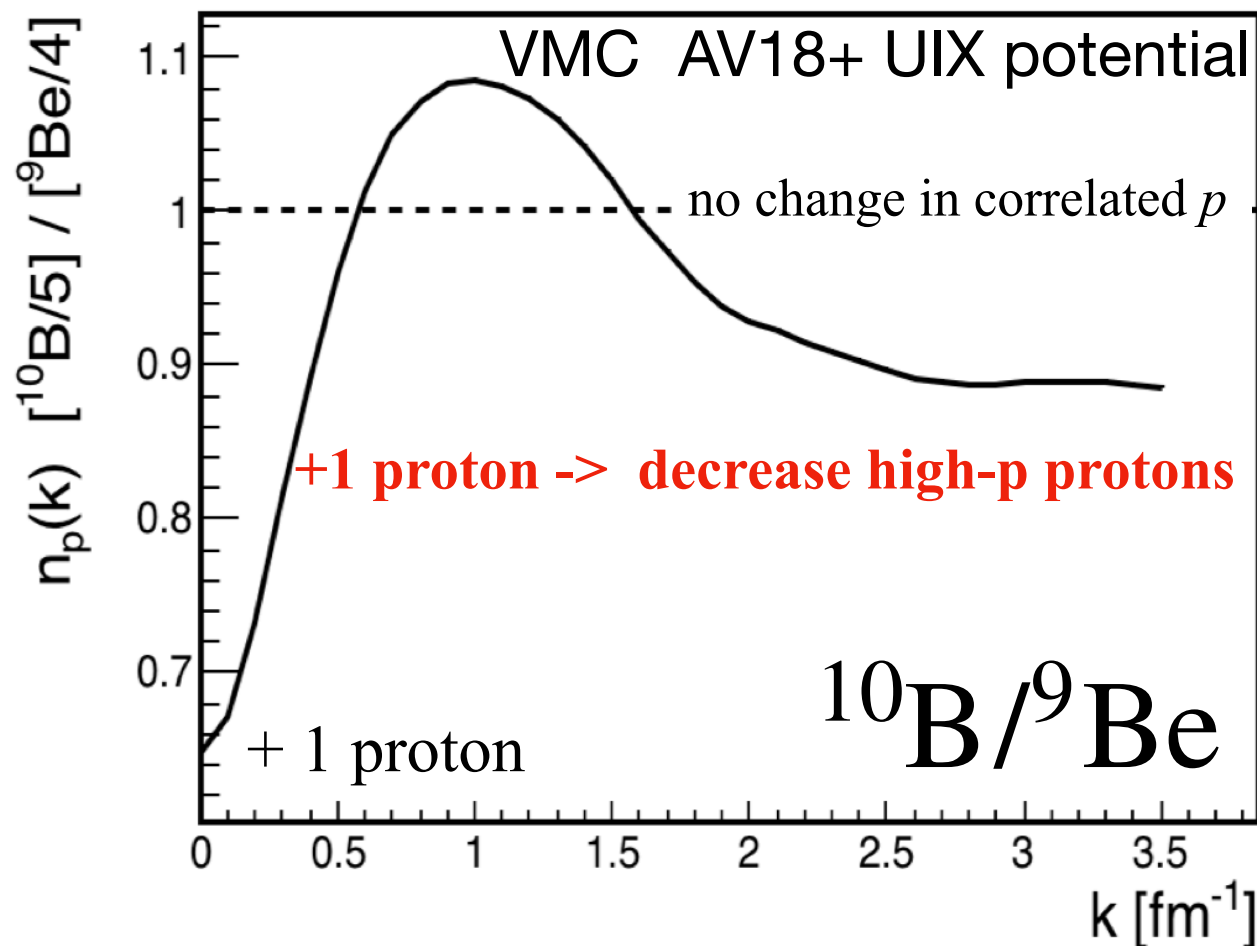
G. Hagen et al., Nature Phys.
12, 186 (2015), 1509.07169.

- above relative momenta $\sim 300 \text{ MeV}/c$, CCN2LO calculation predicts $\sim 20\%$ increase in high-p protons (np -dominance)
- how adding +6 protons ($\text{Ca}48 \rightarrow \text{Fe}54$) change the above result?

Ab-initio Calculations (Light Nuclei)

■ CaFe measurement will test validity of *ab-initio* theory calculations

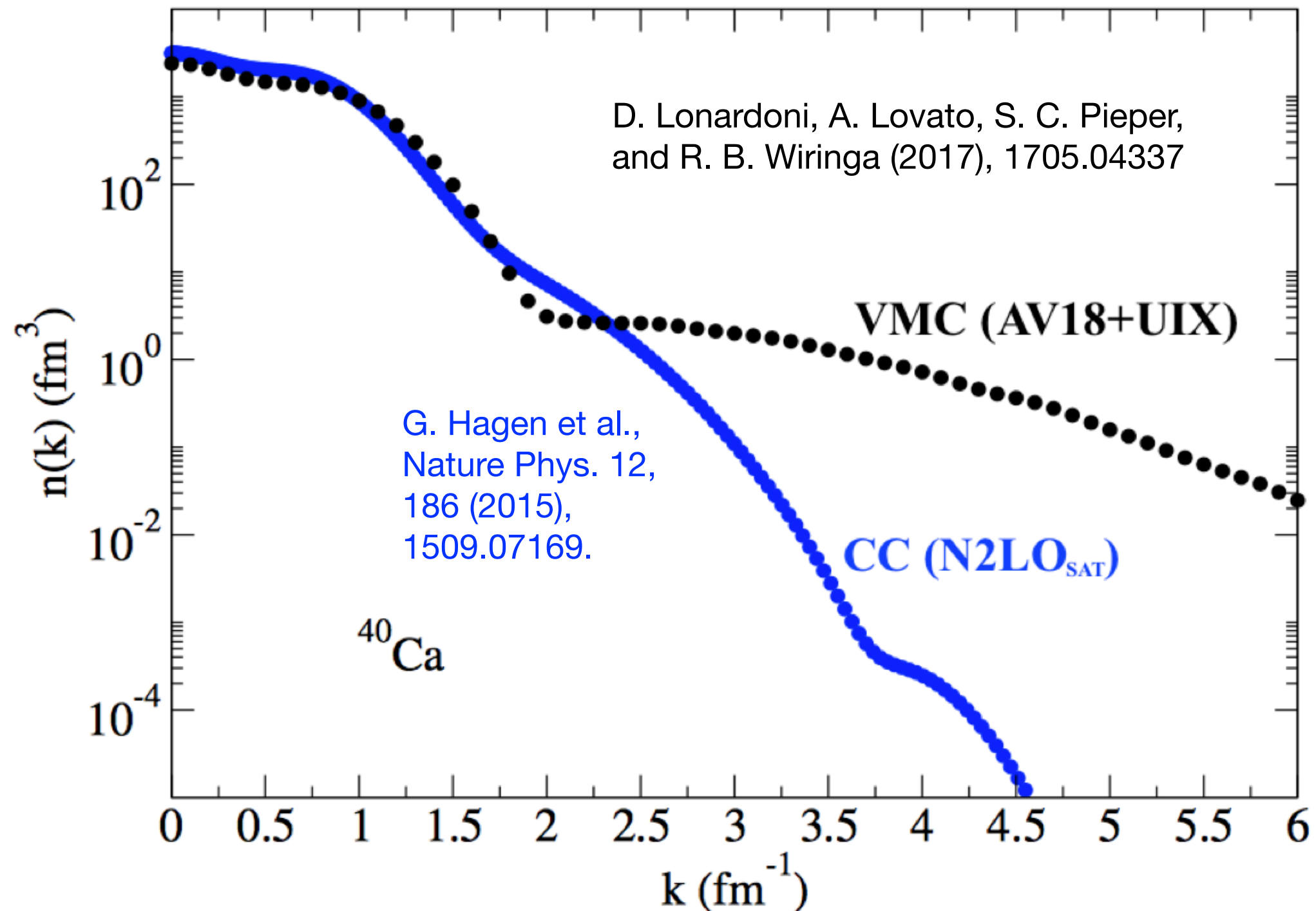
D. Lonardoni, A. Lovato, S. C. Pieper, and R. B. Wiringa (2017), 1705.04337



- de-couple single $+1p$ from $+1n$ contributions in SRC-pair formation
- how adding $+1p$, $+1n$ in light nuclei compare to $+6p$, $+8n$ in medium nuclei ?

Momentum Distributions

■ CaFe measurement will test validity of *ab-initio* theory calculations



Summary

- ▶ 8-day (e, e'p) cross-section measurement on light → medium nuclei
- ▶ detailed study of *NN*-SRC pairing by de-coupling proton/neutron contributions (e.g. extract ratios, absolute cross-sections)
- ▶ test validity of *ab-initio* theory calculations (ratios and absolute or reduced cross sections)

"This material is based upon work supported by the National Science Foundation under Grant No. 2137604"

Holly Szumila-Vance (Staff) Florian Hauenstein (Staff)



Dien Nguyen (Isgur Fellow)



Carlos Yero (NSF Fellow)



- CaFe 4 PAC (8 real days): Sep 20 - Sep 27, 2022

Please visit our [CaFe Wiki](#) for more information.



Noah Swan (PhD student)



VOL NTEER

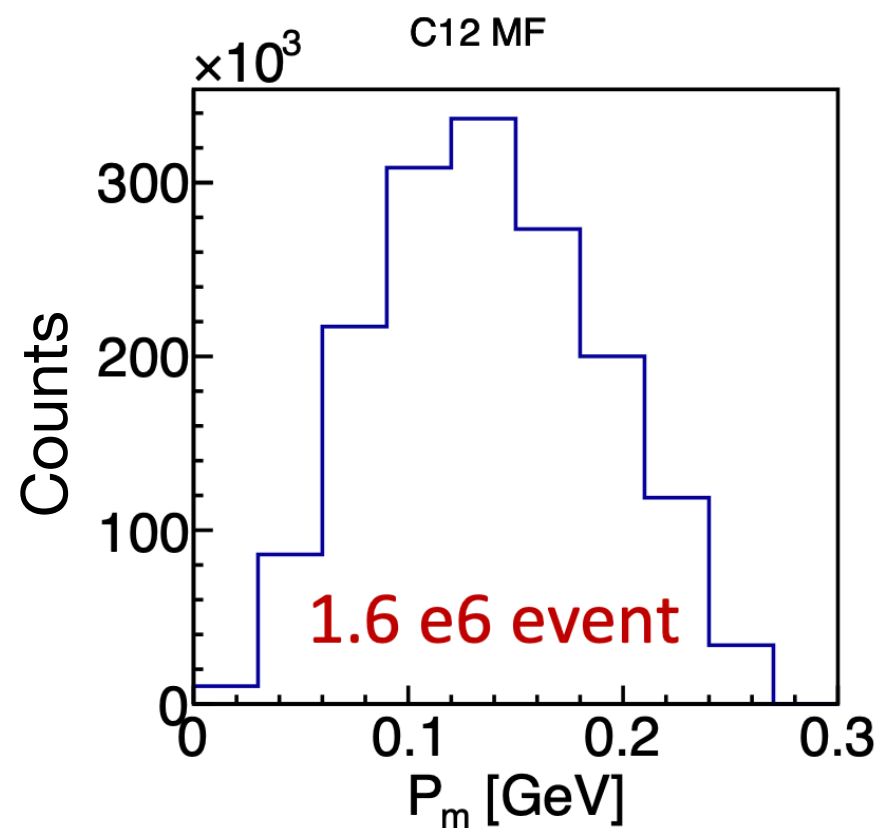
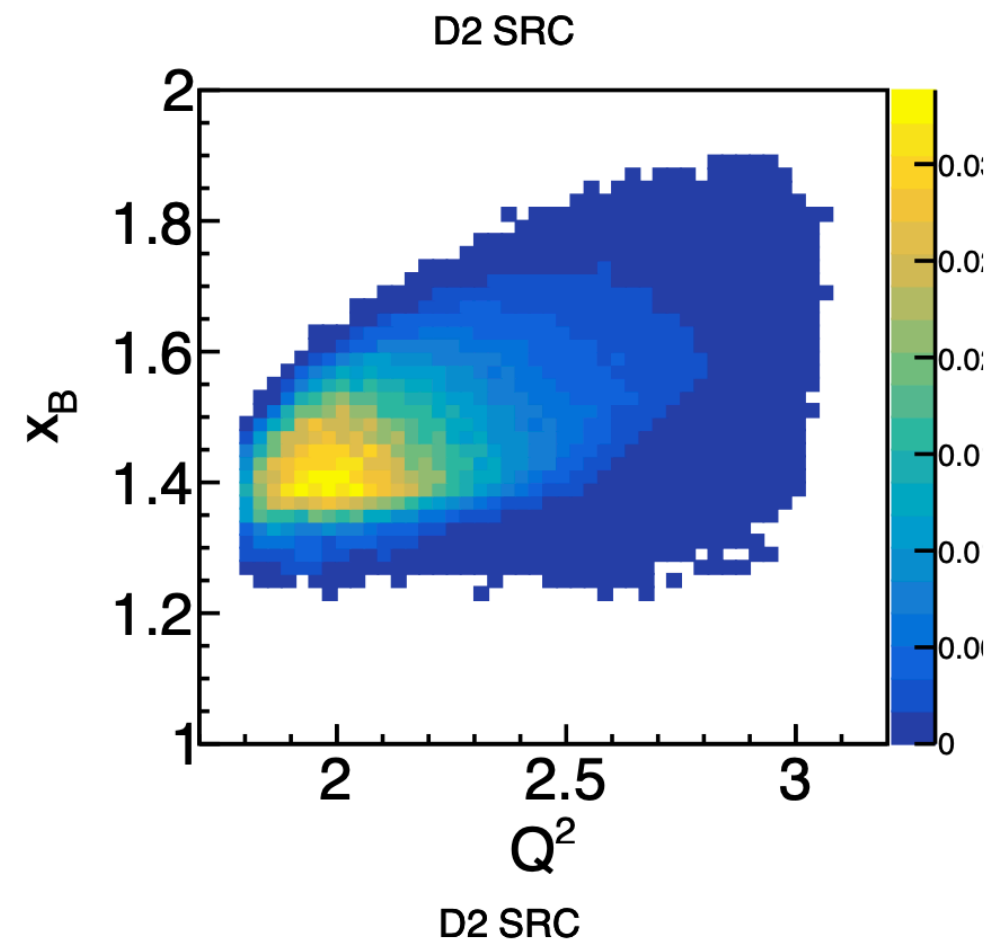
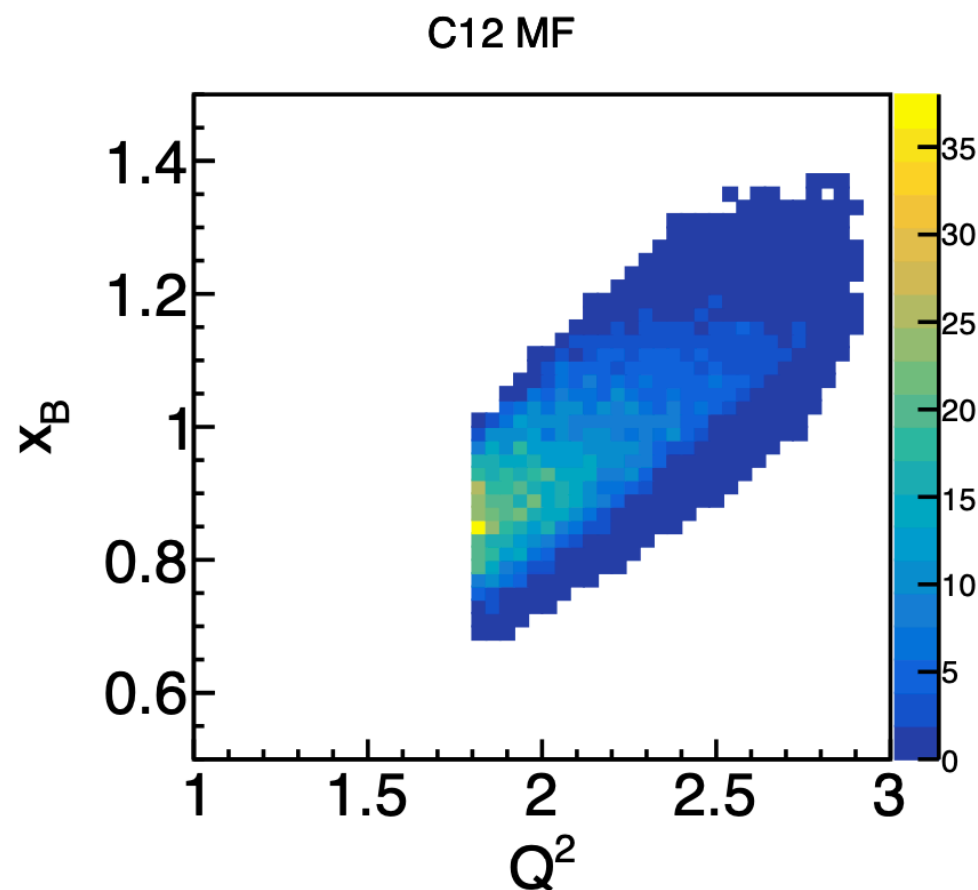
all that's missing is U!

Back-Up Slides

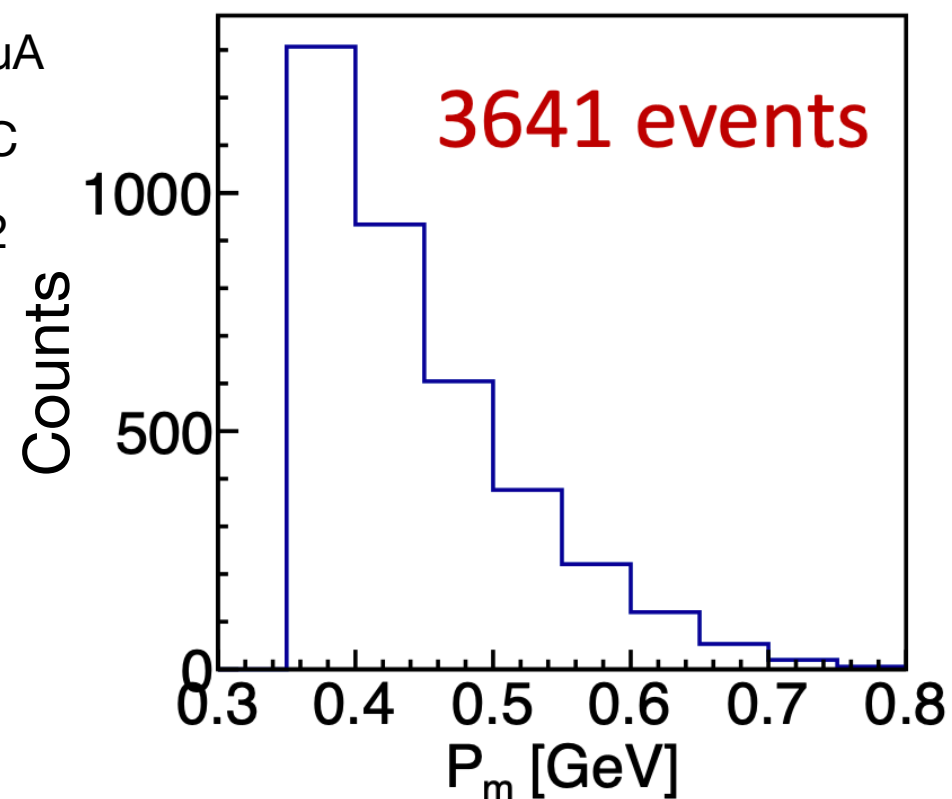
CaFe Central Kinematics

	Ebeam (GeV)	E' (GeV)	θ_e Degree	$ P_p $ GeV	θ_p Degree	Pm GeV	Q2_center
SRC	10.6	8.55	8.3	1.325	66.4	0.4	2.1
MF	10.6	8.55	8.3	1.820	48.3	0.15	2.1

CaFe Kinematics Coverage



8 PAC hrs @ 40 uA
 Charge: 1152 mC
 $\rho_{target} = 1 \text{ g/cm}^2$
 $T_{C12} = 0.56$
 $T_{D2} = 1.0$



CaFe Count Rate Estimates

- Beam setup/checkout/MF kinematics
 - Calibration (BCM, boiling?, Optics, hydrogen?)
 - SRC kinematics (HMS move and magnet change)
 - SRC kinematics checkout
 - Overall target changes (MF and SRC)
- 5h PAC
4h PAC
2h PAC
3h PAC
2.5 PAC

}

Com + Calib Time
16.5 PAC hours

+ MF data taking
4.5 PAC hours

Run plan (PAC hour): SRC data taking (75 PAC hours)

Target	Run Hour SRC (PAC hour)	Number of event (SRC)	Run hour MF (PAC hour)	Number of event (MF)
D2	7	5.3k	0.5	250k
C12	7	5.0k	0.5	52k
Ca48	12	8.7k	0.5	53k
Ca40	12	8.7k	0.5	53k
Fe54	20	8.7k	1.0	55k
Be9	4	4.6k	0.5	98k
B10	6.5	4.5k	0.5	57k
B11	6.5	5.0k	0.5	63k

TOTAL: 16.5 + 4.5 + 75 = 96 PAC hours = 4 PAC days