Update on Hall C experiments

by

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JLUO Satellite Meeting, April 16, 2023

Hall C Experiments

- PionLT, high ε part.
- CAFE experiment.
- XEM2 experiments (EMC and x > 1).
- D(e,e'p) experiment.
- Upcoming NPS experiments.

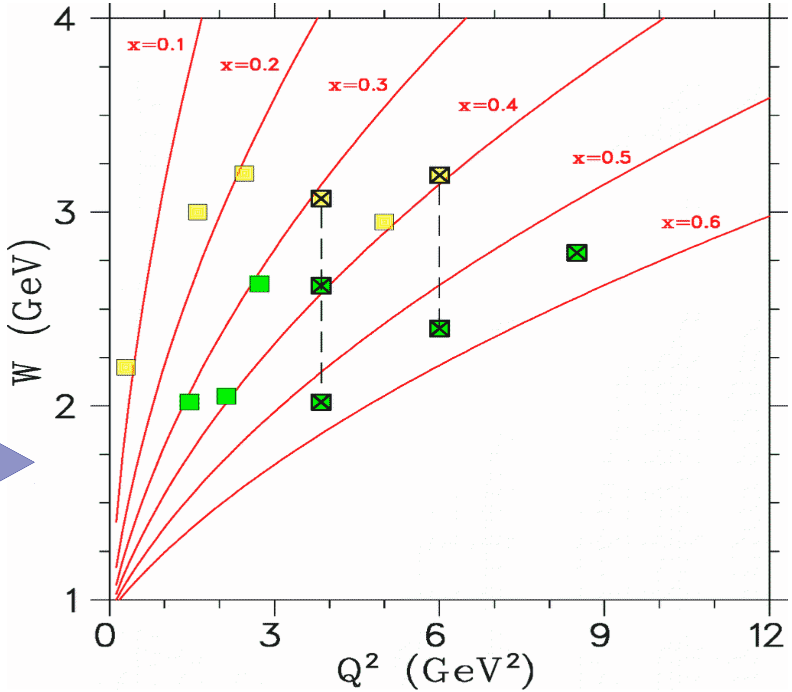
PionLT, High ε

E12-19-006: *Study of the L–T Separated Pion Electroproduction Cross Section at 11 GeV and Measurement of the Charged Pion Form Factor to High Q^2*

E12-06-101: *Measurement of the Charged Pion Form Factor to High Q^2*

E12-07-105: *Scaling Study of the L–T Separated Pion Electroproduction Cross Section at 11 GeV*

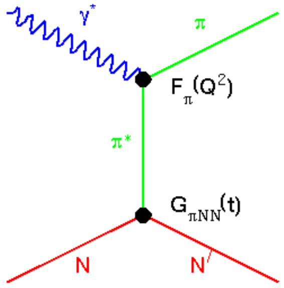
W versus Q^2 settings planned for the F_π experiment (yellow squares) and the "Pion Scaling" experiment E12-07-105 (green squares). The points instrumental in the higher Q^2 F_π extraction are indicated with 'X'. The red lines indicate fixed *x* values from 0.1 to 0.6. The dashed lines denote scans in *t* at fixed Q^2, which will be used to evaluate the dependence of the F_π extraction on *t*.



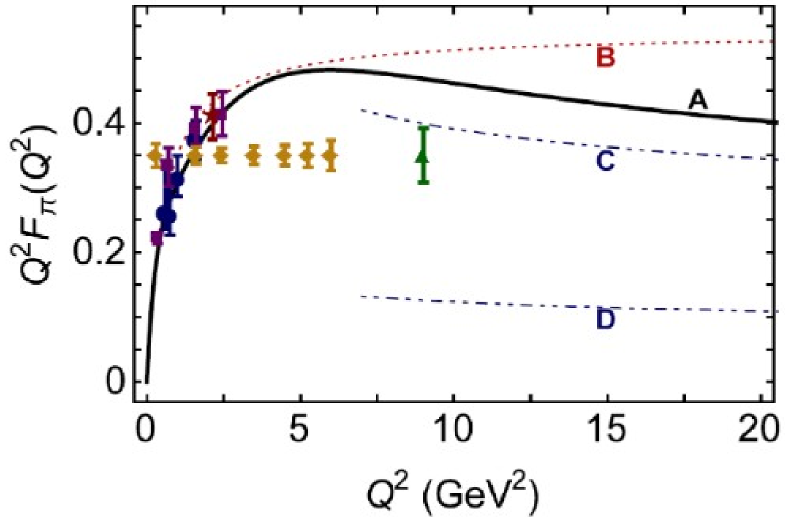
PionLT: Pion Form Factor

E12-06-101: *Measurement of the Charged Pion Form Factor to High Q^2*

- The π^+ electric form factor is a topic of fundamental importance to our understanding of hadronic structure.
- Because the pion's valence structure is relatively simple, the transition from "soft" (non-perturbative) to "hard" (perturbative) QCD is expected to occur at significantly lower values of Q^2 for F_π than for the nucleon form factors.
- There is an ongoing theoretical debate on the interplay of these hard and soft components at intermediate Q^2. Theoretical calculations yield essentially identical F_π predictions at low Q^2, and then progressively diverge.
- High quality experimental data are needed to help guide this discussion.



Experiment indirectly measures F_π employing electron scattering off the virtual π^+ (associated with the "pion cloud" of the proton).



Existing data (dark blue, purple) and projected uncertainties (yellow, green) for future data on the pion form factor. Curves are different theoretical calculations.

PionLT, Scaling Study

E12-07-105: *Scaling Study of the L–T Separated Pion Electroproduction Cross Section at 11 GeV*

- The extraction of Generalized Parton Distributions (GPDs) is one of the highest priority 12 GeV programs at JLab. The extraction of GPDs from pion electroproduction relies on the dominance of the longitudinal component assuming negligible transverse contributions.
- However, recent experimental results suggest that the transverse contribution of the cross section is still relatively large at $Q^2 = 2.45$ GeV^2, which, if also true at higher values of Q^2, would limit the interpretability of the data in terms of GPDs.
- Before considering the extraction of GPDs from pion electroproduction data, it is necessary to demonstrate that Q^2 scaling applies in the JLab 12 GeV kinematic regime.
- The goal of this experiment is to test the dominance of the longitudinal cross section in charged pion electroproduction by making a systematic measurement of the Q^2 dependence of the π^+ longitudinal and transverse cross sections.

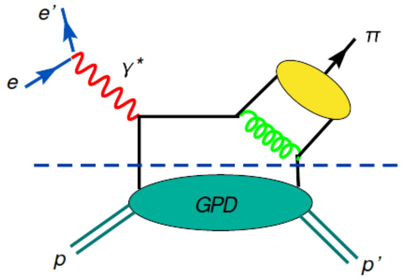
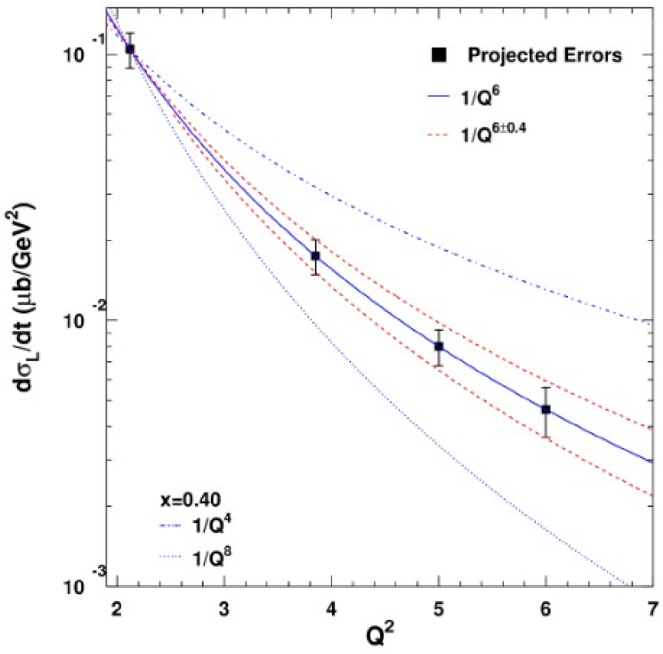


Diagram of the factorization theorem for longitudinally polarized photons in meson electroproduction.

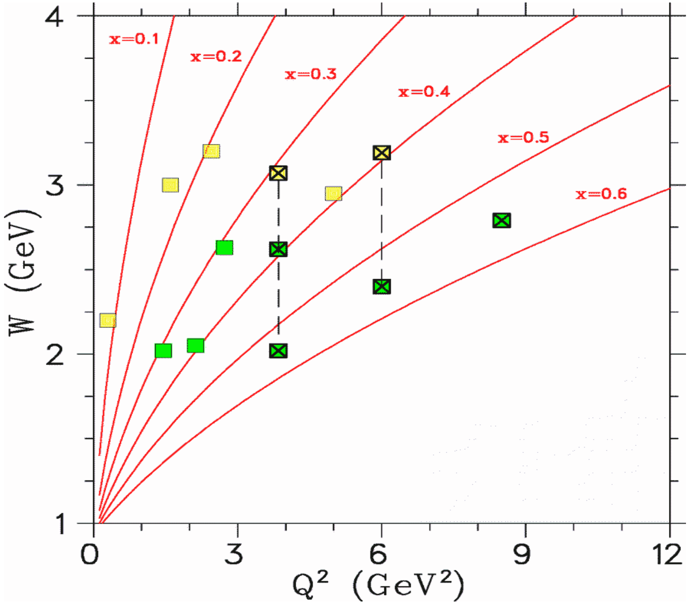


Projected uncertainties for the Q^2 dependence of σ_L at x_B =0.39. The data points are plotted to follow $1/Q^6$ scaling.

PionLT, High ε

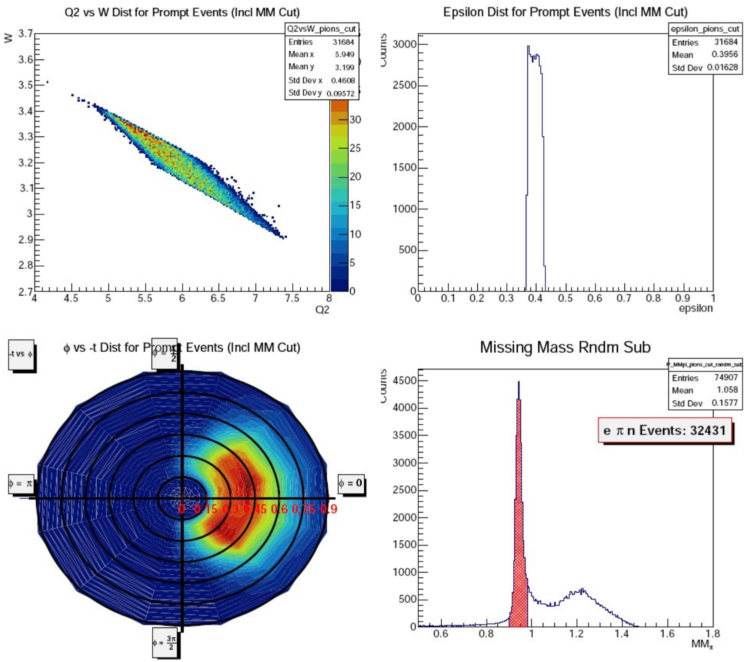
E12-19-006: *Study of the L–T Separated Pion Electroproduction Cross Section at 11 GeV and Measurement of the Charged Pion Form Factor to High Q^2*

- Ran from 08-June-2022 to 09-Sept-2022 to complete high ε part.
- At beginning of 5 pass (in June), low beam efficiency and difficulty getting 60-70uA. Need to extend the running about one month until Sept 9th.



Because of the slow 2022 start, some planned high Q^2 angle settings had to be skipped, but planned statistics was acquired for nearly all settings.

Completed 95% of 3-pass, 76% of 4-pass, and 88% of 5-pass data.



Online replay of full data set for:

$p(e,e'\pi^+)n$ 10.549 GeV

Q^2=6.00 GeV² W=3.19 GeV

θ_{SHMS}=5.65° ε=0.398

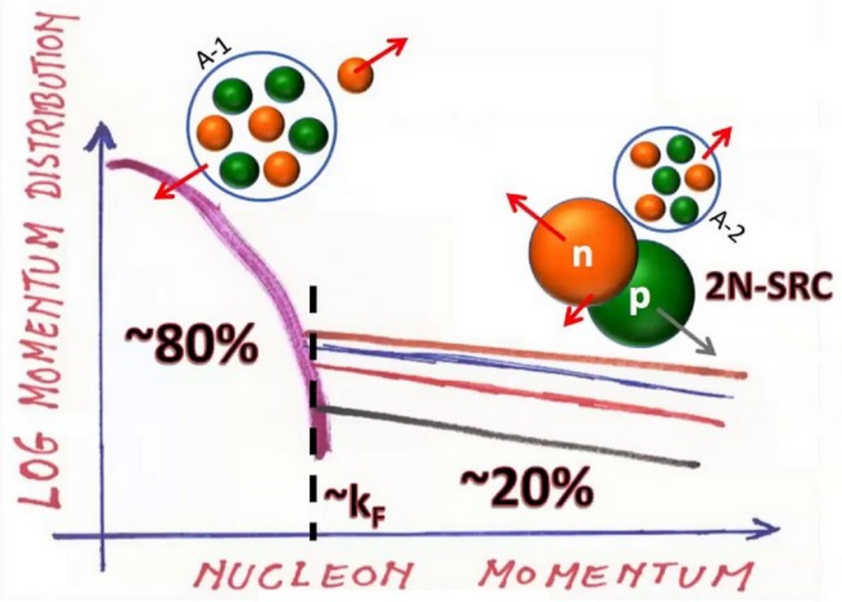
Acquired: July 11–16, 2022

CaFe Experiment

E12-17-005: *The CaFe Experiment: Short-Range Pairing Mechanisms in Heavy Nuclei*

- The mean field approximation describes bulk properties of nuclei (shell structure, excitation energies, spins and parities) remarkably well; however, only about 80% of nucleons occupy mean field orbitals.
- Remaining 20% of nucleons are involved in Short Range Correlations (SRC), which make up essentially all nucleons with momentum greater than k_F , and contribute most of the kinetic energy carried by nucleons in nuclei.
- Most of the SRC pairs are np pairs, which implies that in heavy neutron-rich nuclei the high-momentum tail contains the same amount of neutrons and protons, leaving the excess neutrons to occupy low-momentum states.
- Therefore, in neutron-rich nuclei, protons can have large average kinetic energy compared to neutrons, despite being the minority species.

Mean field and SRC



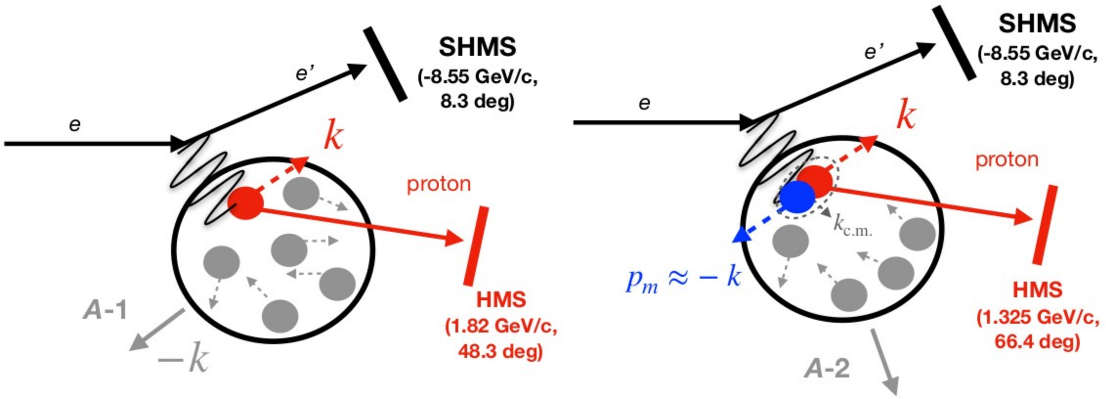
CaFe Experiment

E12-17-005: *The CaFe Experiment: Short-Range Pairing Mechanisms in Heavy Nuclei*

- Measuring coincidence A(e, e'p) cross sections in kinematics dominated by scattering off mean-field ($k \leq k_F$) and SRC pairs ($k \geq k_F$).
- Ran about 1 week in Sept 2022 + 1 day in Feb 2023.
- Targets ^{54}Fe, ^{40}Ca, ^{48}Ca, ^{12}C, ^{9}Be, ^{10}B, ^{11}B, ^{197}Au.

mean-field (MF): $k < 250$ MeV/c

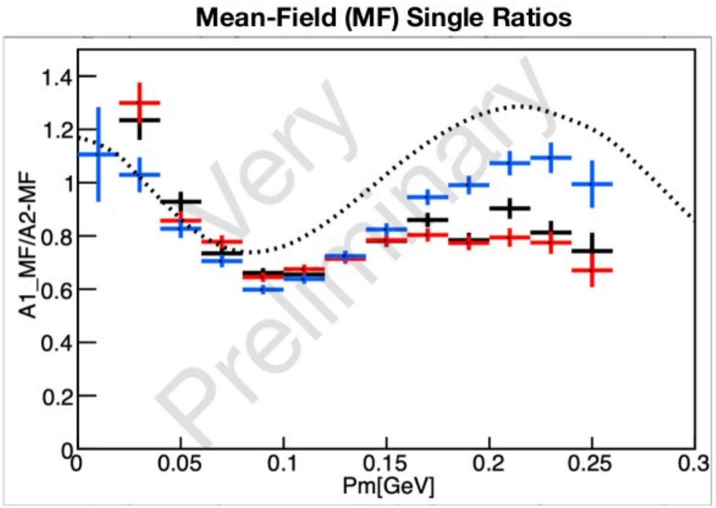
SRC: $350 < k < 700$ MeV/c

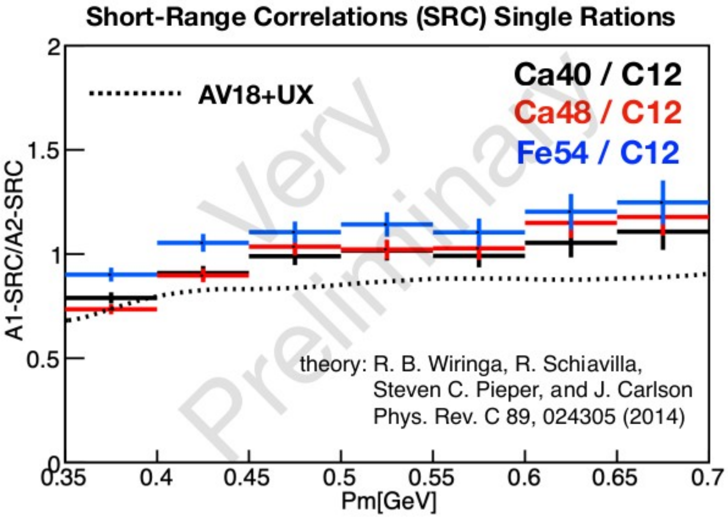


CaFe Preliminary Results

Event yields of nucleus ^{40}Ca, ^{48}Ca, and ^{54}Fe relative to ^{12}C, binned in missing momentum for Mean Field and SRC kinematics.

For MF kinematics, similar shapes between theory and data. For SRC kinematics, scaling behavior observed between A and ^{12}C.





Theory (dotted curve): ratio of momentum distributions for ^{40}Ca /^{12} C.

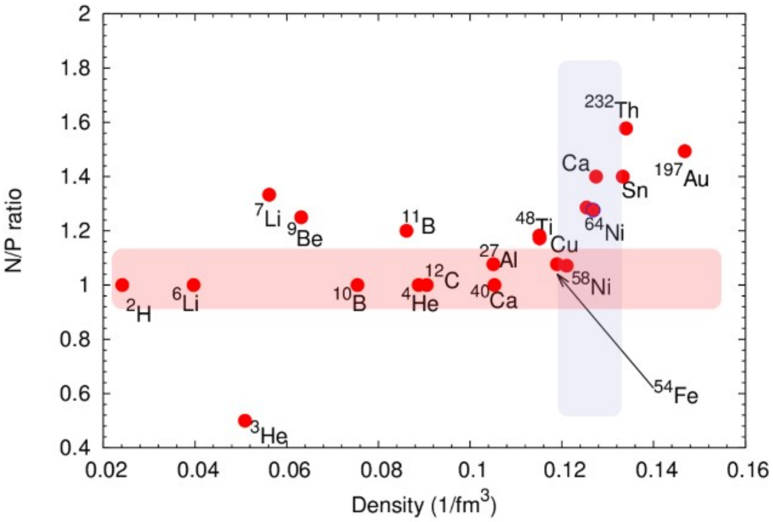
XEM2 Experiments (EMC and x > 1)

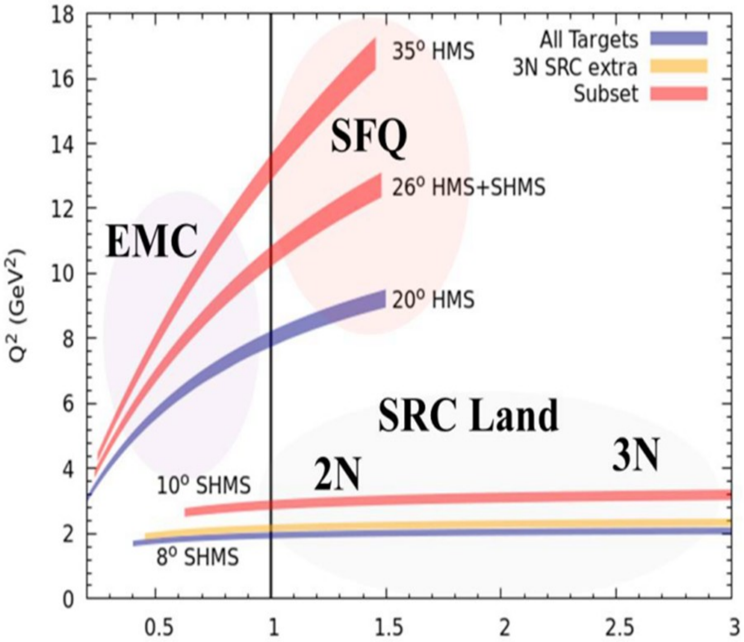
E12-10-008: *Detailed studies of the nuclear dependence of F_2 in light nuclei*

E12-06-105: *Inclusive Scattering from Nuclei at x > 1 in the quasielastic and deeply inelastic regimes*

Two experiments ran concurrently to take advantage of the physics synergy between the two experiments and to map out the SRC/EMC connection for the same nuclei.

Two experiments share the nuclear target list.



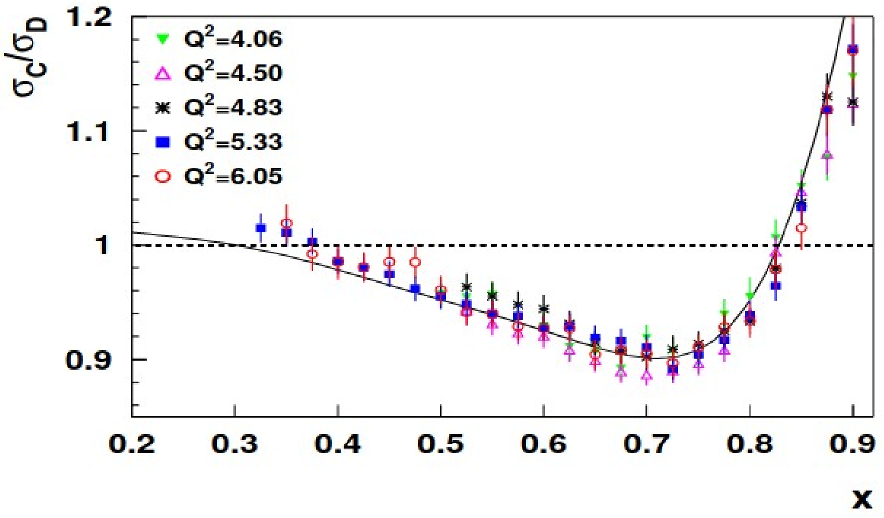


XEM2 Experiments: EMC effect

E12-10-008: *Detailed studies of the nuclear dependence of F_2 in light nuclei*

EMC effect: the suppression of high-momentum quarks in heavy nuclei.
There is as yet no clear consensus on origin of the EMC effect.

- EMC effect measurements at 20, 26, and 35 degrees from $^{1,2}H$, $^{3,4}He$, $^{6,7}Li$, ^{9}Be, $^{10,11}B$, ^{12}C, $^{40,48}Ca$, and ^{63}Cu for $0.1 < x < 1$.
- Test the idea that the local nuclear environment plays an important role in the modification of quark distributions (clustering effects).
- To better map out the A dependence of the EMC effect.
- A comparison of the EMC effect in ^{40}C and ^{48}Ca will, for the first time, be able to directly constrain the flavor dependence of the EMC effect.
- The measurements will provide a comprehensive and precise basis to test state of the art models that attempt to explain the observed nuclear dependence.



Results from previous 6 GeV experiment: EMC ratios for carbon [1], the curve is the SLAC parameterization.

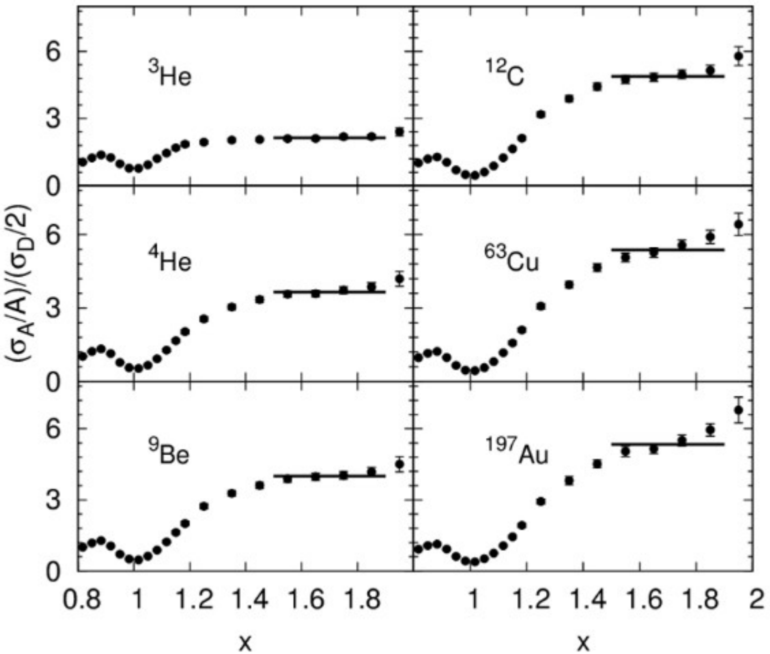
[1] J. Seely et al., Phys. Rev. Lett. 103, 202301(2009).

XEM2 Experiments: x > 1

E12-06-105: *Inclusive Scattering from Nuclei at x > 1 in the quasielastic and deeply inelastic regimes*

Short Range Correlations (SRC) are the main source of high-momentum nucleons. Scaling is expected in the x > 1.4 region, where the electrons scatter from a SRC high-momentum nucleon.

- Measurements of inclusive scattering from nuclei at x > 1 for probing high momentum nucleons. The distribution of high momentum nucleons is related to the SRC in nuclei.
- Aims to scan across all target nuclei and obtain precision A/D cross-section ratios to study 2N SRCs as well as to further scrutinize the SRC/EMC connection.
- Aims to make the first observation of the 3N scaling plateau (3N SRC).
- Probing high momentum quarks for larger Q^2 for 1 < x < 1.5. The distribution of "super-fast quarks" in nuclei is sensitive to short range structure in nuclei, including the possible contribution of non-hadronic components, such as six-quark bags.
- The ability to vary N/Z at approximately constant values of A allows for sensitive and model-independent tests of isospin dependence of both 2N SRCs and EMC effect (which shares the nuclear target list of this experiment).



Results from previous 6 GeV experiment: inclusive A/D cross-section ratios [2].

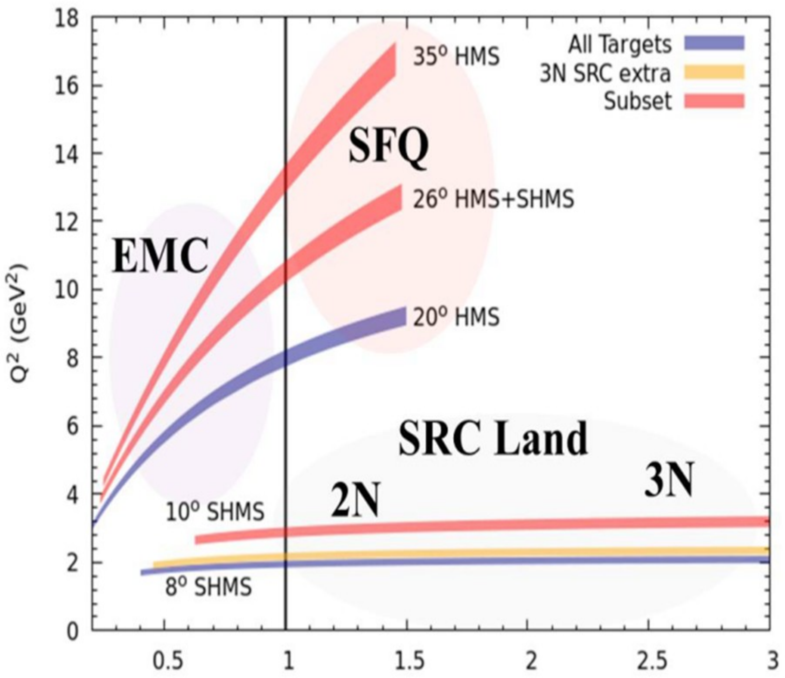
[2] N. Fomin et al., Phys. Rev. Lett 108, 092502 (2012).

XEM2 Experiments (EMC and x > 1)

Ladder 1

Loop 1 10cm
Loop 2 10cm
Optics 1 +/- 8cm
10cm Dummy
Beryllium
Ca40
Ca48
Carbon
B4C-11
B4C-10
Sn
Ti
Fe
Ag
Th
Ni-58
Ni-64
Hole

- Experiments ran from 29-Sep-2022 to 20-Feb-2023.
- Runplan adapted to account for reduced running time and lower currents.
- Enough nuclear targets to necessitate a ladder switch (Nov 28th).

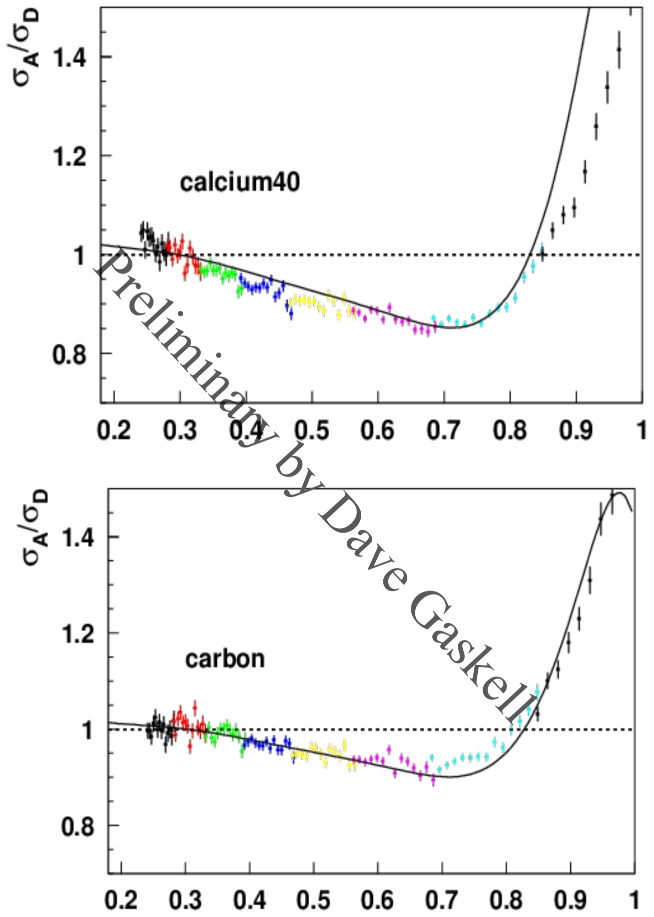


Ladder 2

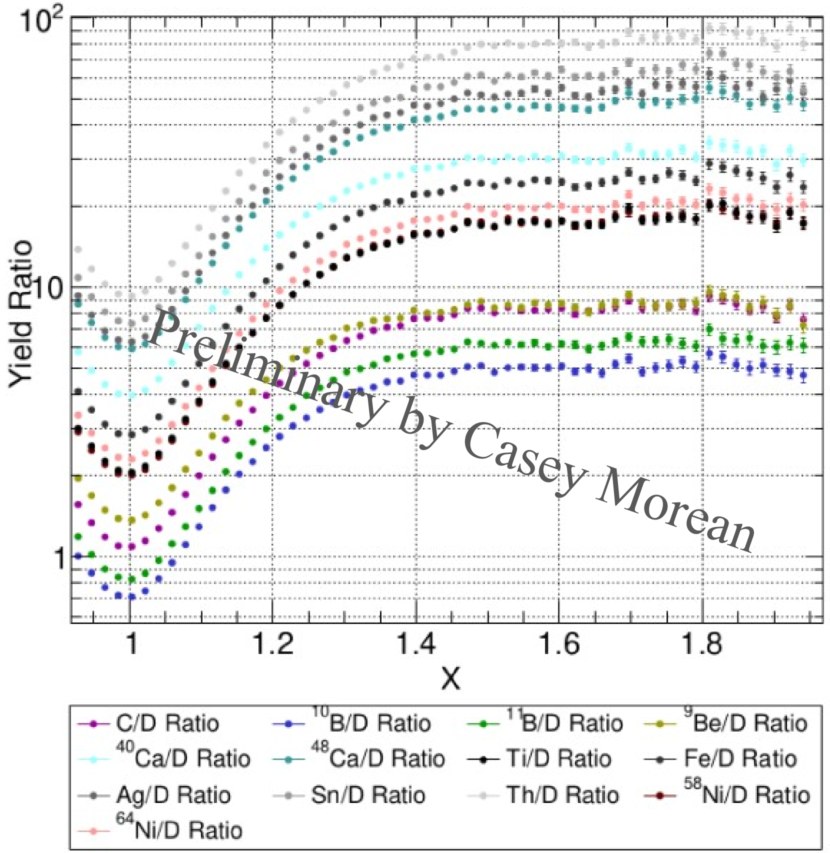
He-3 10cm
He-4 10cm
Optics 1 +/- 8cm
10cm Dummy
Li-7
Li-6
Beryllium
Carbon
B4C-11
B4C-10
Aluminum
Copper
Titanium
Iron
Gold
Ca-40
Empty
Hole

XEM2 Experiments: Preliminary Results

EMC ratios



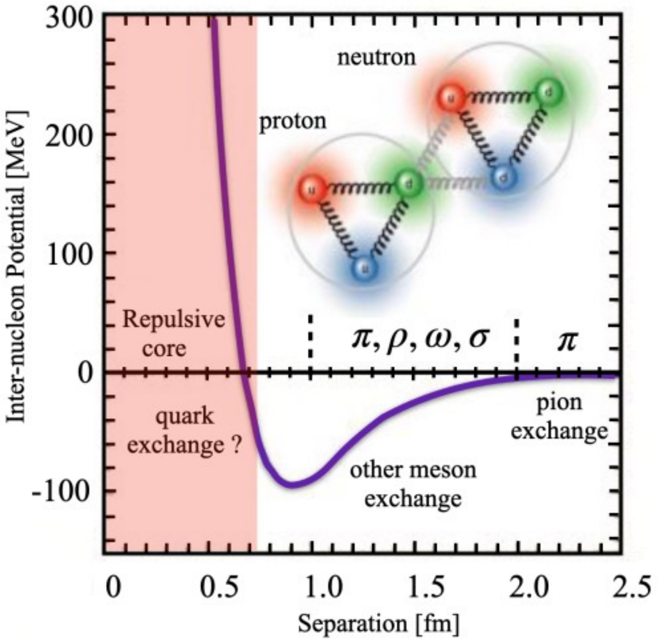
2N SRC plateaus



D(e,e’p) Experiment

E12-10-003: *Deuteron Electro-Disintegration at Very High Missing Momentum*

- Probing two nucleon dynamics at short space-time distances, where the repulsive core of the strong interaction becomes dominant.
- The most direct way to study the short-range structure of the deuteron wave function is via the exclusive deuteron electrodisintegration reaction at internal momenta $p_r > 300$ MeV/c.
- E12-10-003 ran for 3 of the approved 21 PAC days in April 2018. The results of the first part of the experiment were published in 2020 [3].
- The main conclusion of Ref.[3] is that the data has a strikingly different dependence on the missing momentum above 700 MeV/c compared to any of the theory calculations.

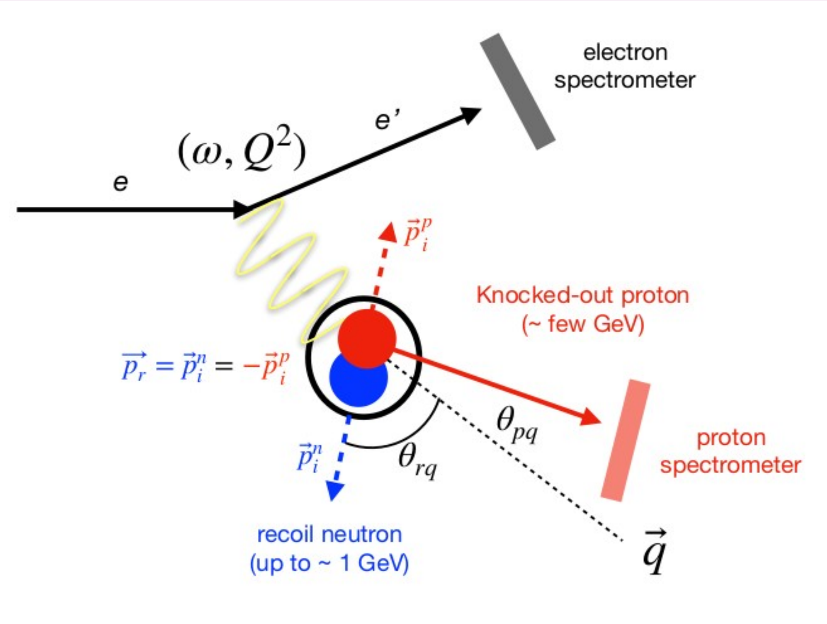


[3] C. Yero et al. [Hall C], Phys. Rev. Lett. 125, no.26, 262501 (2020).

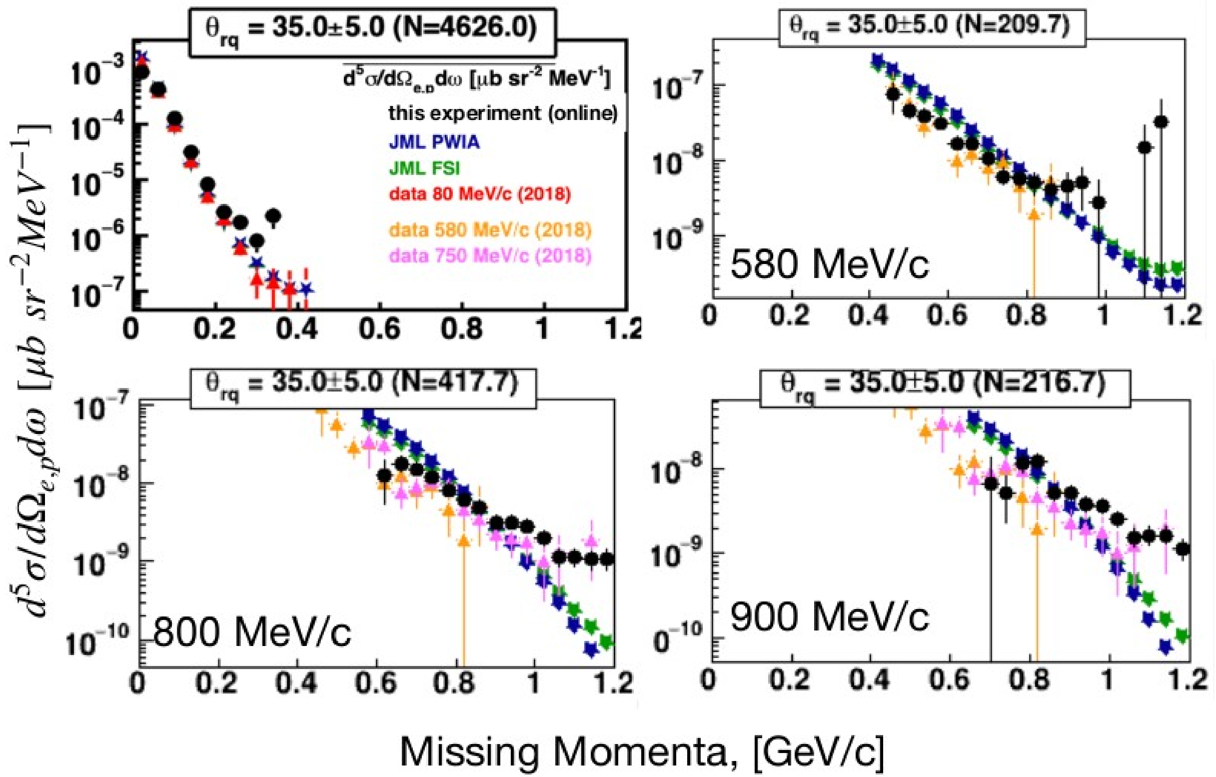
D(e,e'p) Experiment

E12-10-003: *Deuteron Electro-Disintegration at Very High Missing Momentum*

- Measure exclusive D(ee'p)n cross sections at $Q^2 = 4.25$ GeV^2, $\theta_{nq} = 35$ deg, and $p_{miss} = 120, 580, 800,$ and 900 MeV/c.
- At the selected kinematic settings, MECs and ICs are suppressed and FSIs are under control. The cross section is dominated by PWIA and sensitive to the short-range part of the deuteron wave function (high-momentum components).
- Experiment ran from 25-Feb-2023 to 20-Mar-2023.
- Difficulties delivering beam to Halls A and C and the same time (issue with the 4th pass separator). Difficulties delivering 70 uA.



D(e,e’p) Preliminary Results



Absolute d(e, e’p) experimental cross-sections (very preliminary by Carlos Yero) for P_m= 120, 580, 800, and 900 MeV/c settings.

Corrections applied:
√ normalized by total charge,
√ detector/daq inefficiencies,
√ radiative corrections.

Corrections NOT applied:
✗ target boiling,
✗ proton absorption,
✗ Bin-centering.

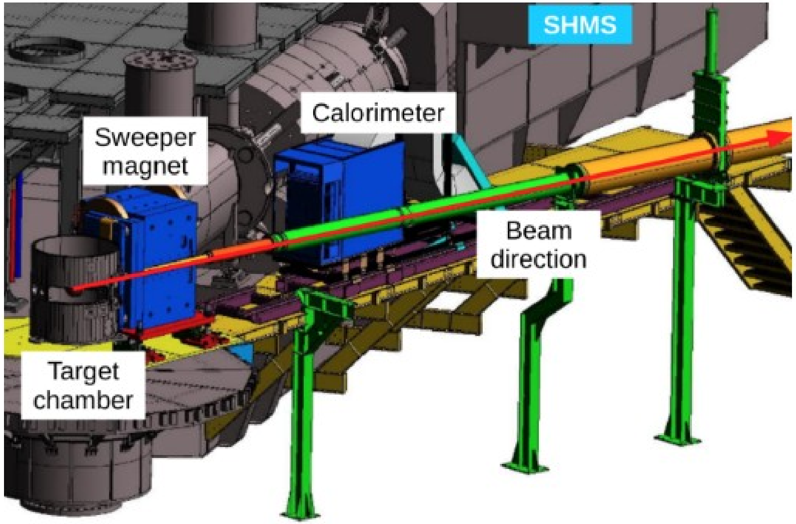
Upcoming NPS experiments

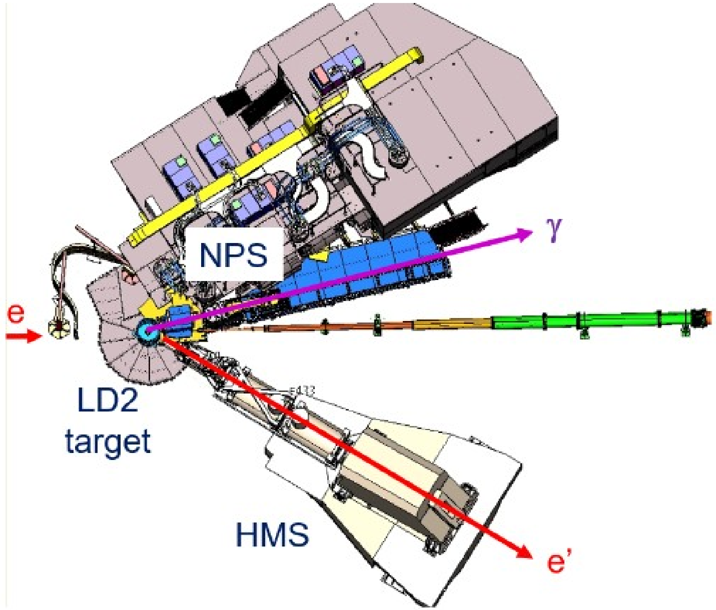
Two experiment using the Neutral Particle Spectrometer (NPS) will run from July 20th 2023 to March 2024.

E12-13-010: *Exclusive Deeply Virtual Compton and Neutral Pion Cross-Section Measurements in Hall C*

E12-22-006: *Deeply Virtual Compton Scattering off the neutron with the Neutral Particle Spectrometer in Hall C*

Installation of NPS is ongoing (from March 20 to July 20, 2023).





Neutral Particle Spectrometer (NPS)

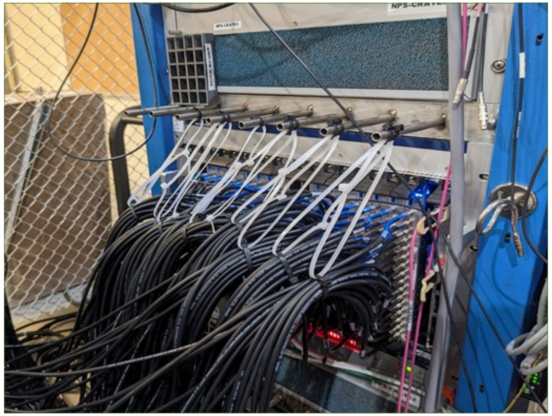
Neutral Particle Spectrometer

- Sweeping Magnet with calorimeter. Magnet and power supply have been tested.
- NPS attached to SHMS carriage to allow easy angle change. The calorimeter is on rails.
- 1080 Lead-Tungstate blocks in calorimeter to detect photons.

Miktat Imre and Carlos Domingues installing PMT/bases assemblies

Front view

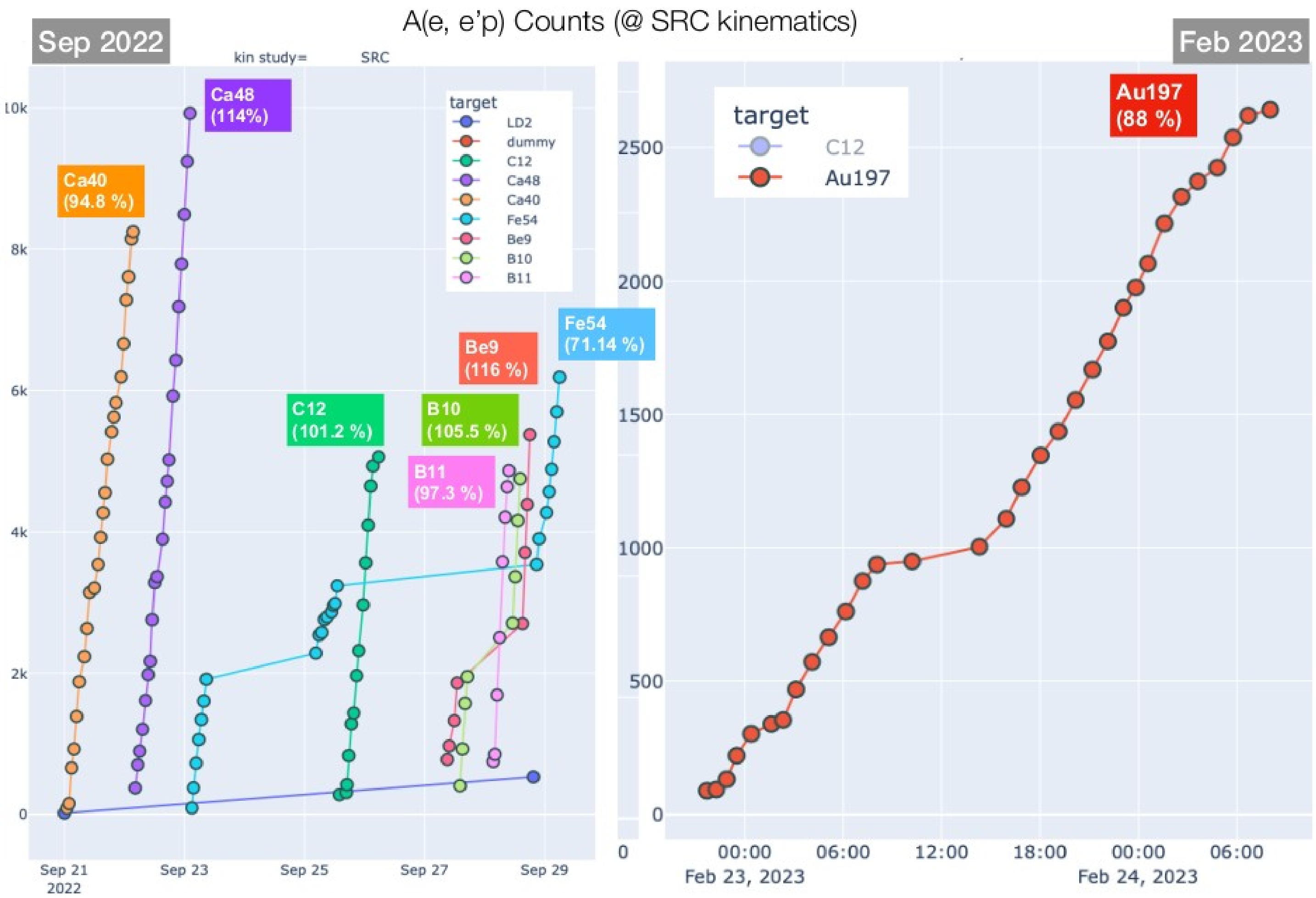
- Calorimeter is cabled up.
- Cosmic and LED testing is ongoing.



Signal cables to the FADC

Thank you!

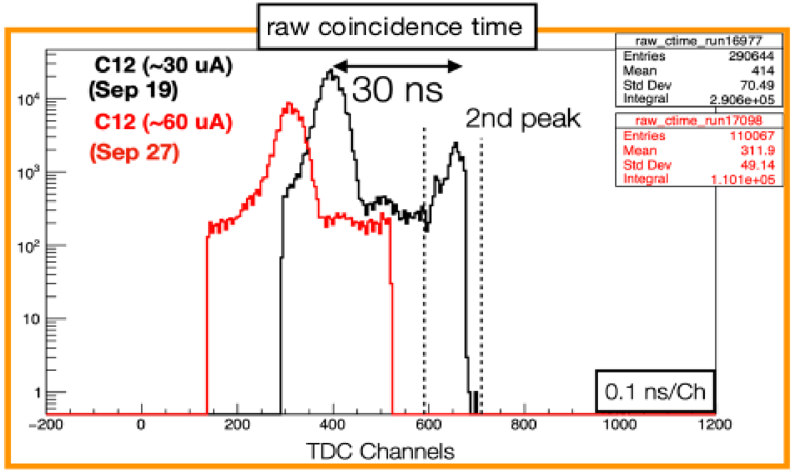
CaFe Collected Statistics

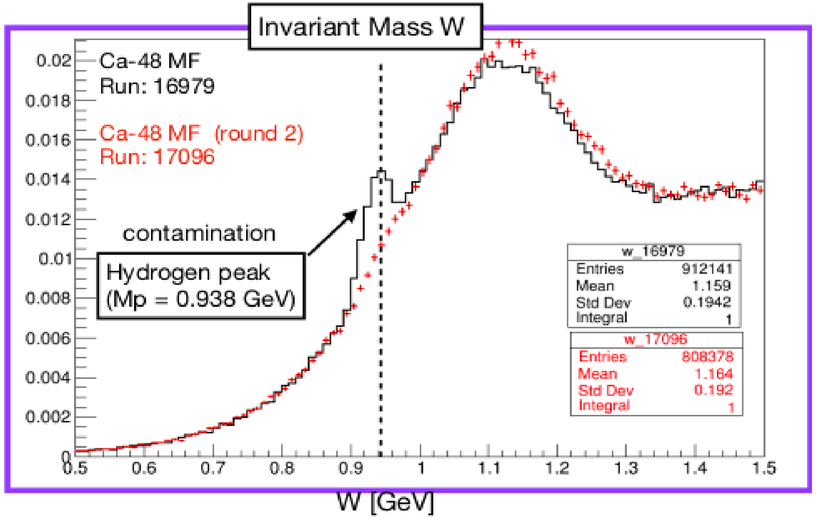


CaFe Experimental Challenges

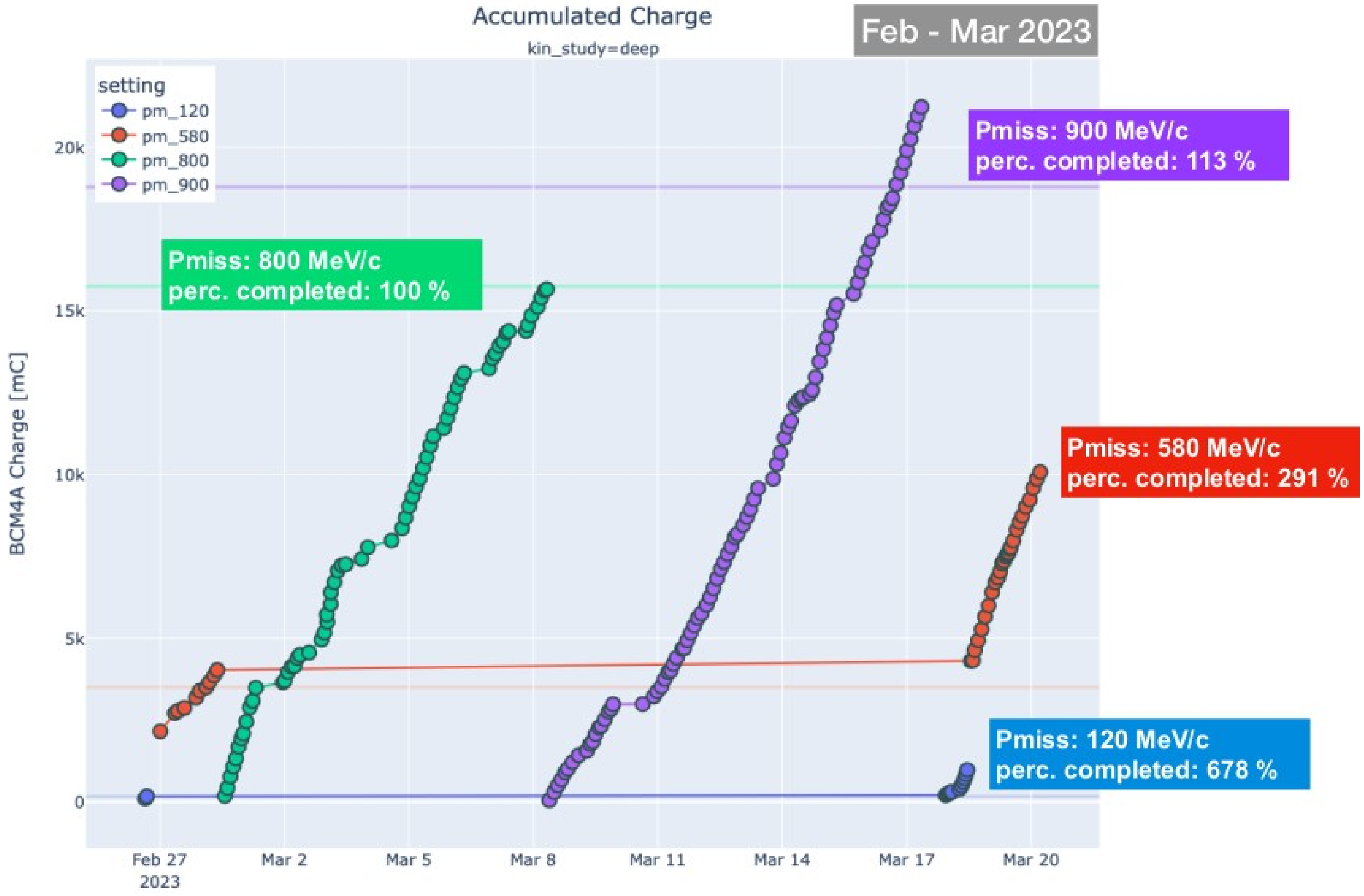
- **hardware trigger timing**
  - e- trigger components ('OR') offset by +30 ns
    - caused a +30 ns shift of real *ep* coincidences which were either lost
    - lost coincidences corrected as part of total DAQ deadtime

- **Ca48 mineral oil contamination**
  - hydrogen peak present (+ other ? elements) in Ca48 invariant mass spectrum (early run)
  - Data re-taken at later time, and contamination had mostly been 'washed away'
  - contamination was quantified and corrected
    - Chemical analysis of contamination oil still needed to confirm chemical composition and verify correction





D(e,e'p) Collected Statistics

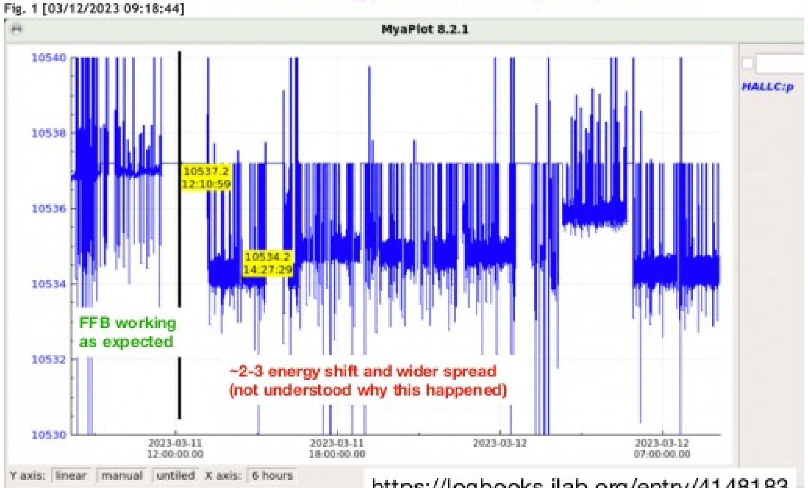


D(e, e’p) Experimental Challenges

- **SHMS Q1 magnet vacuum loss**
  - due to existing leak (known issue)
  - ~ 1.5 shifts lost
  - Vacuum restored by itself
    (ice build-up covered leak)

- **fast energy feedback (FFB) issue**
  - Purpose of fast feedback to lock beam energy
  - Turning on feedback caused a ~2-3 MeV shift
    (currently not understood why this happened)
  - feedback could not be used for entire run

Fast energy feedback (FFB) issue

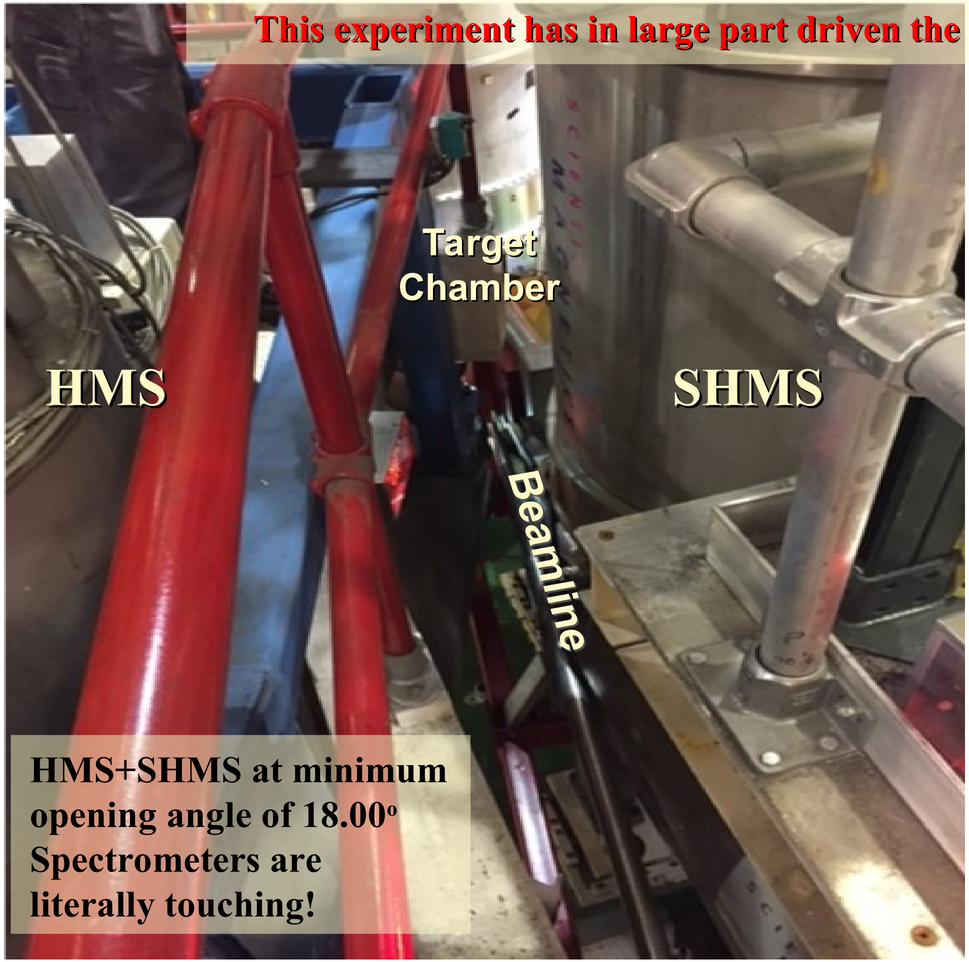


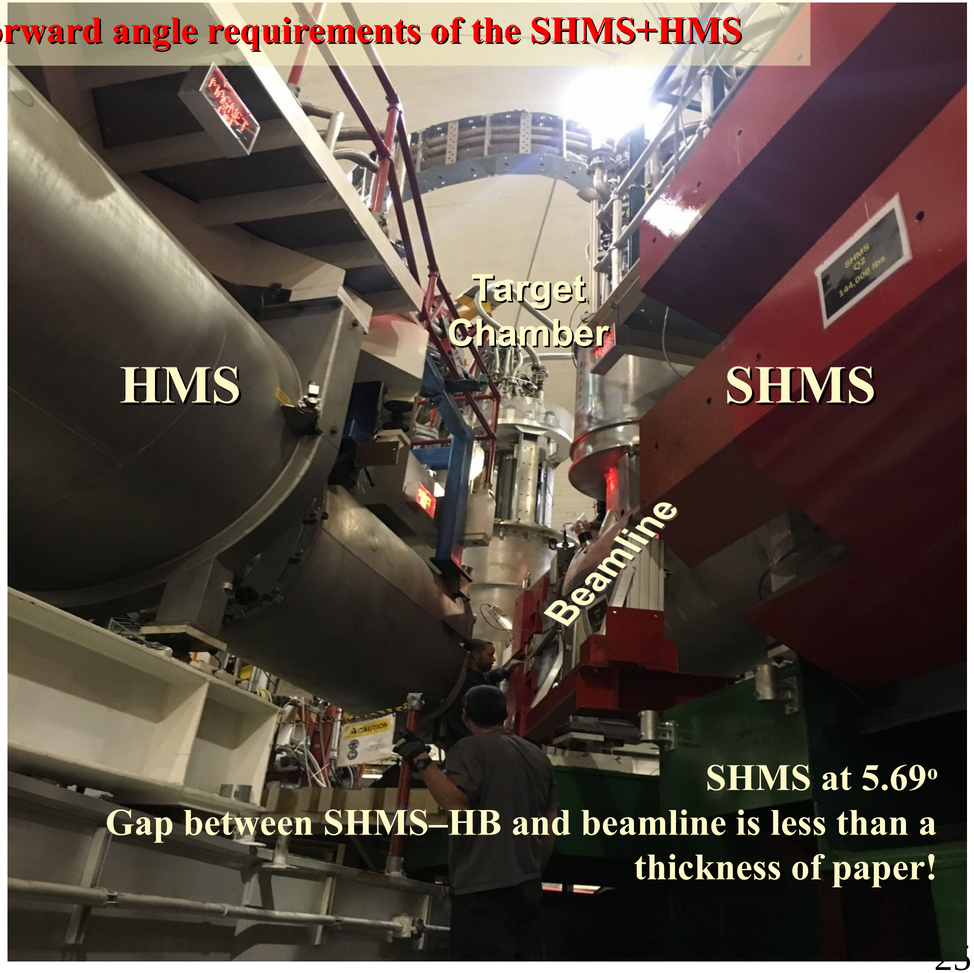
https://logbooks.jlab.org/entry/4148183

SHMS Q1 magnet vacuum loss

PionLT Forward Angle Requirements

This experiment has in large part driven the forward angle requirements of the SHMS+HMS





L/T–separation Realities

- **L/T-separations are a critical part of the experiment**
  - Pion form factor determined from t-dependence of $d\sigma_L/dt$
  - **Error in $d\sigma_L/dt$ magnified by $1/\Delta\varepsilon$,** where high ε data are taken in 2022, and low ε data were obtained in 20 week 2021–22 run
  - **2022 data required high Linac gradient**, as otherwise $\Delta\varepsilon$ significantly degraded for high Q^2 data, leading ~50% increase in projected errors

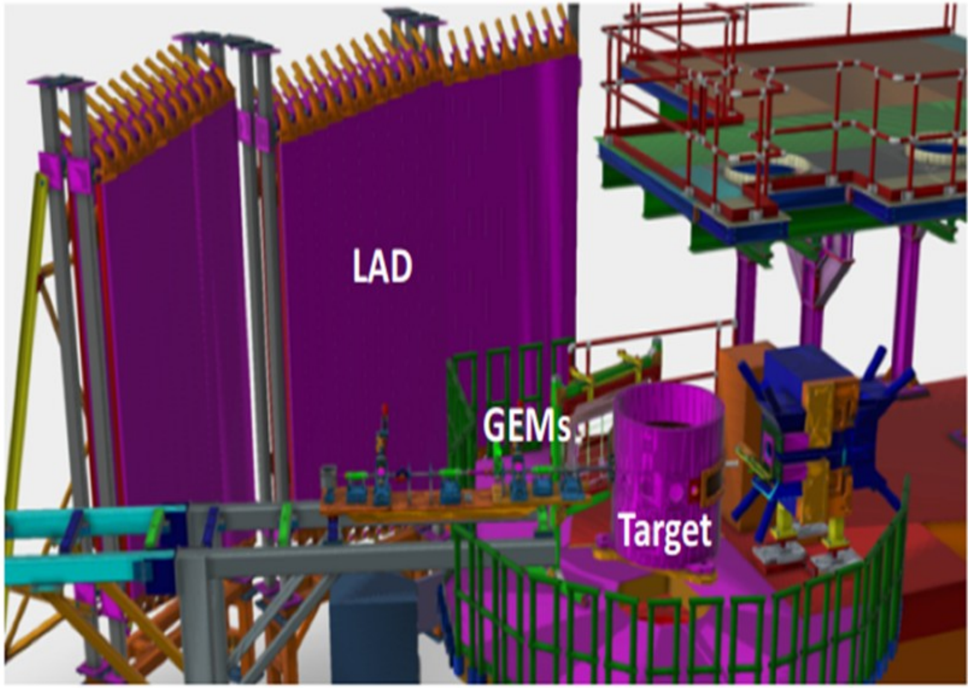
$$\frac{d^2\sigma}{dt\,d\phi} = \varepsilon \frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt} + \sqrt{2\varepsilon(\varepsilon+1)}\,\frac{d\sigma_{LT}}{dt}\cos\phi_\pi + \varepsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi_\pi$$

$$\frac{\Delta\sigma_L}{\sigma_L} = \boxed{\frac{1}{(\varepsilon_1 - \varepsilon_2)}}\left(\frac{\Delta\sigma}{\sigma}\right)\sqrt{(R+\varepsilon_1)^2 + (R+\varepsilon_2)^2} \qquad \text{where } R = \frac{\sigma_T}{\sigma_L}$$

- **Run started June 9, 2022, but Accelerator had many difficulties delivering high current 5–pass beam at high gradient**
- **Our sensitivity to the gradient meant that we did not have option to reduce 5–pass beam energy to improve beam reliability**

Hall C Plans to run July 2024 to March 2025

The experiment studies the D(ee'p_s) reaction which detects electron in SHMS or HMS and the spectator proton in the Large Acceptance Detector (LAD) scintillator planes and GEMs. LAD to be installed in April-July 2024.



Run experiments

- E12-11-107 Spectator tagged DIS d(e,e'p_s)
- E12-06-104 $R=s_L/s_T$ in SIDIS on 1H and 2H
- E12-06-107 Pion color transparency