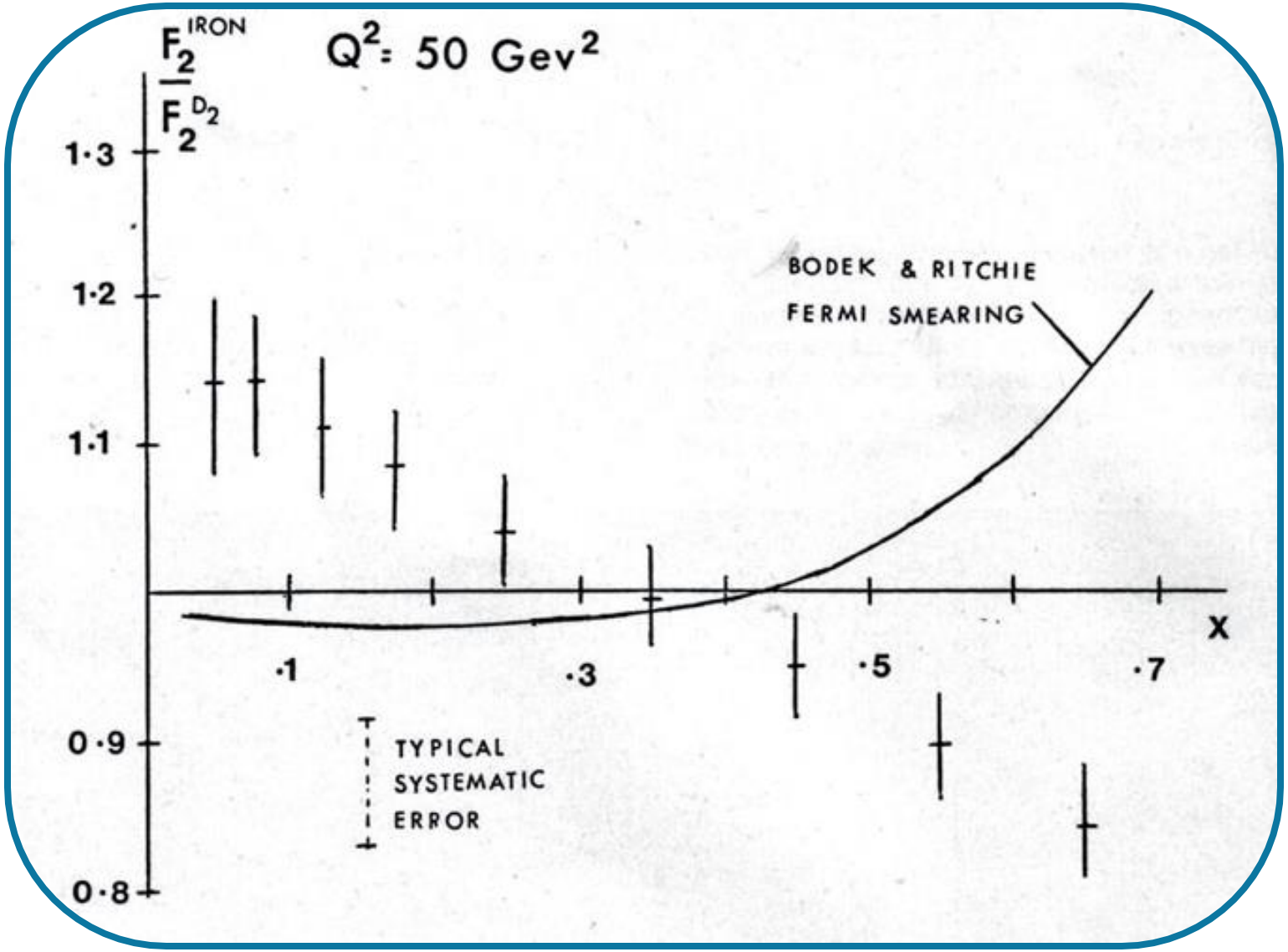
Measuring in-medium nucleon modification through spectator tagged DIS with the LAD experiment

Lucas Ehinger

On behalf of LAD Collaboration

The EMC Effect

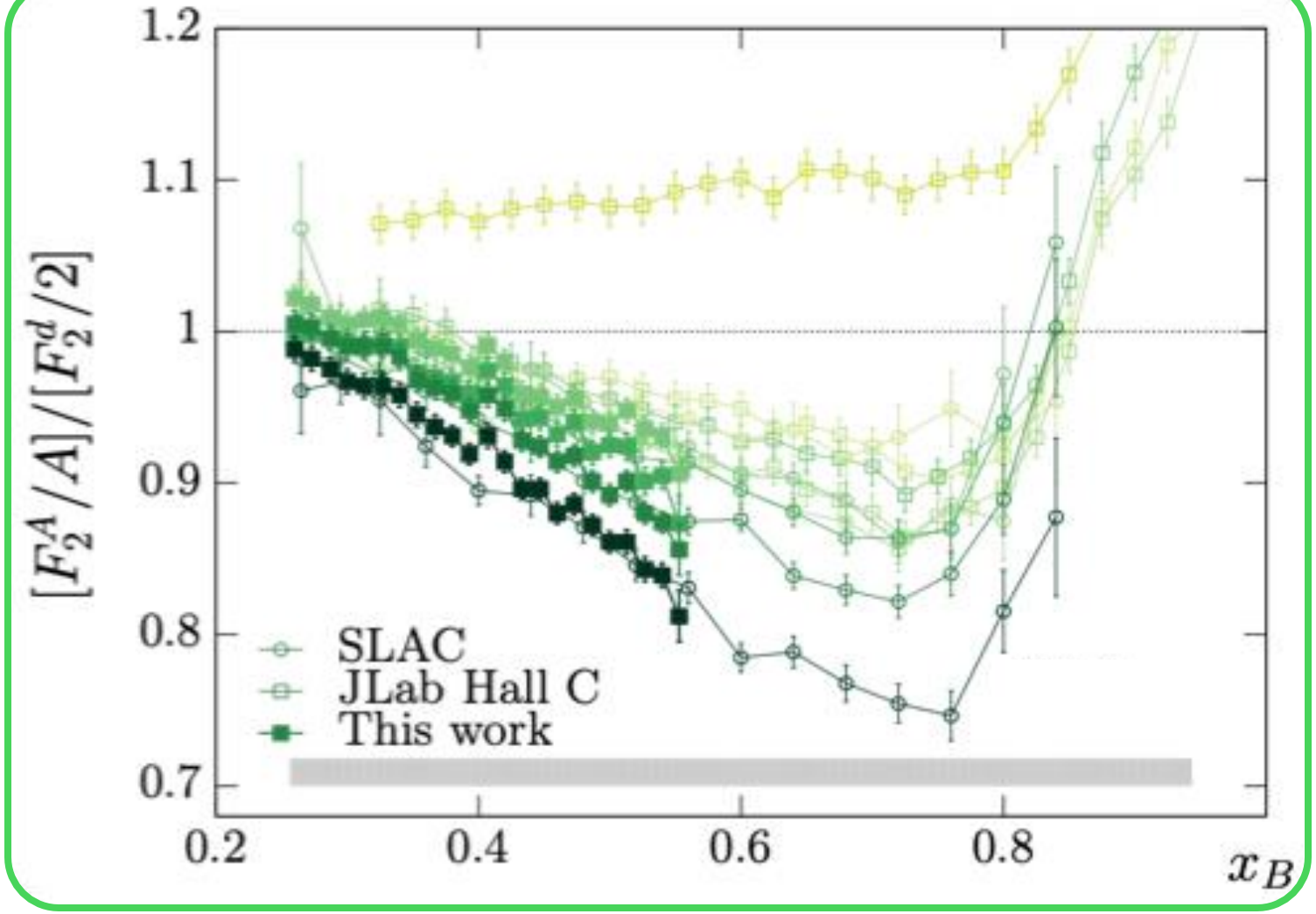
Aubert et al., PLB (1983)



The EMC Effect

- Bound nucleon ≠ free nucleon
- Present in all nuclei
- Discovered 1983
  - >40 years
  - >1,000 papers
  - **No accepted theoretical explanation**

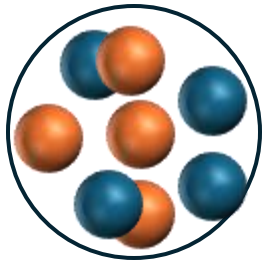
Schmookler et al., Nature (2019)



EMC Theories

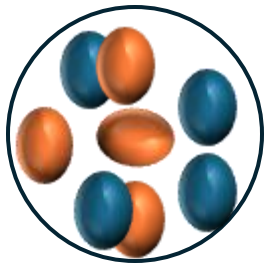
Traditional Nuclear Effects

- Fermi-motion
- Binding effects
- Meson exchange



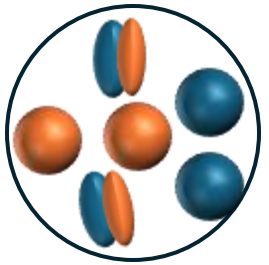
Mean-field Modification

- All nucleons modified equally
- Larger bound proton radius



SRC Modification

- Virtuality-dependent modification
  - SRCs are highly virtual



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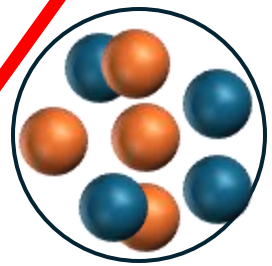

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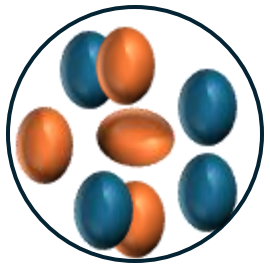

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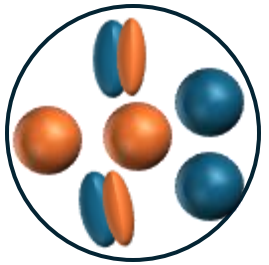

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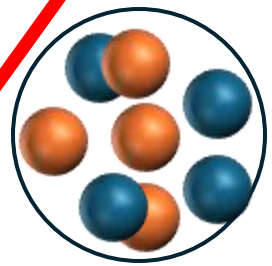

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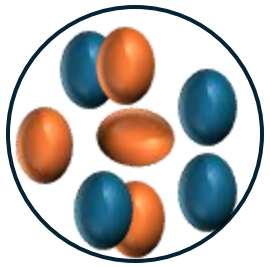

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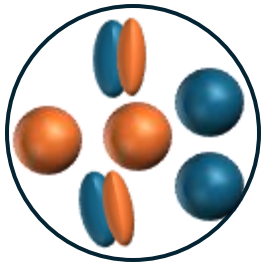
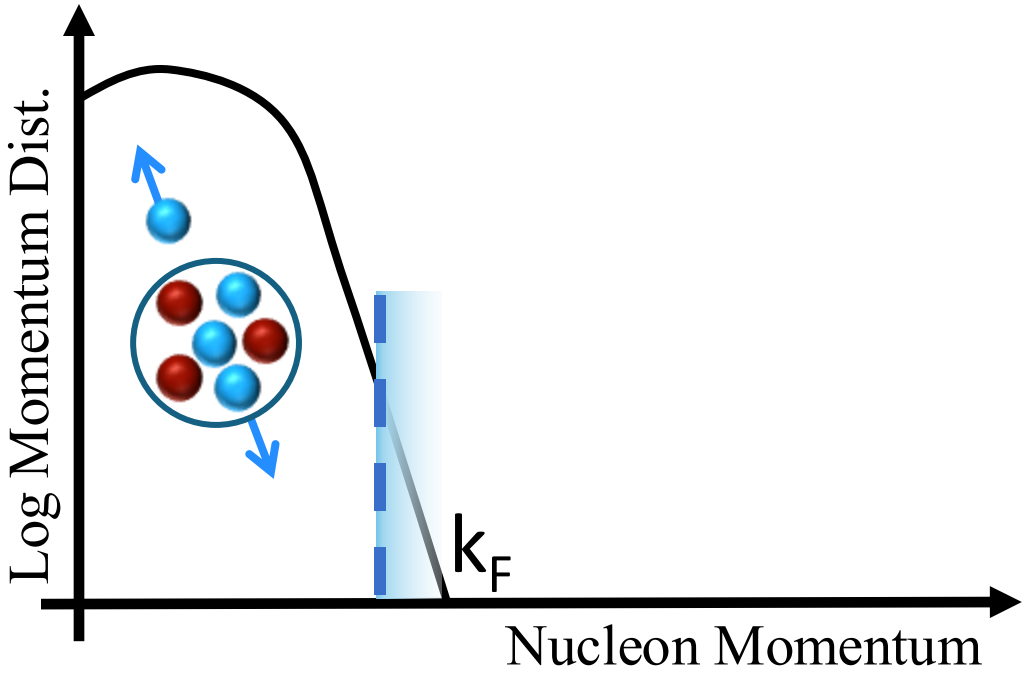
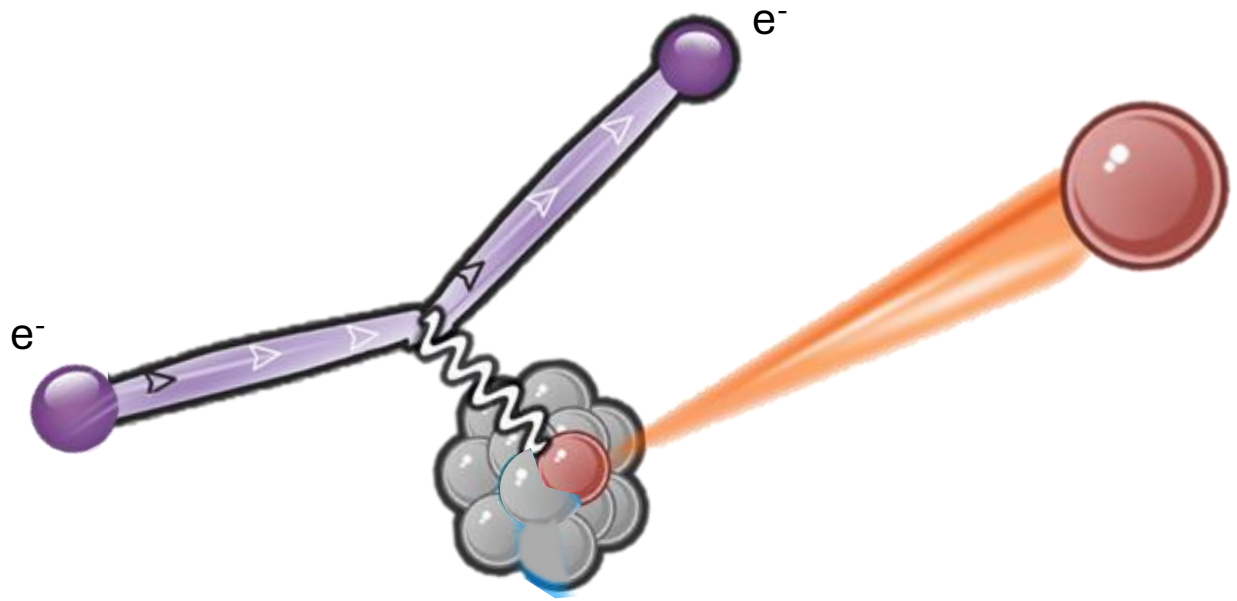
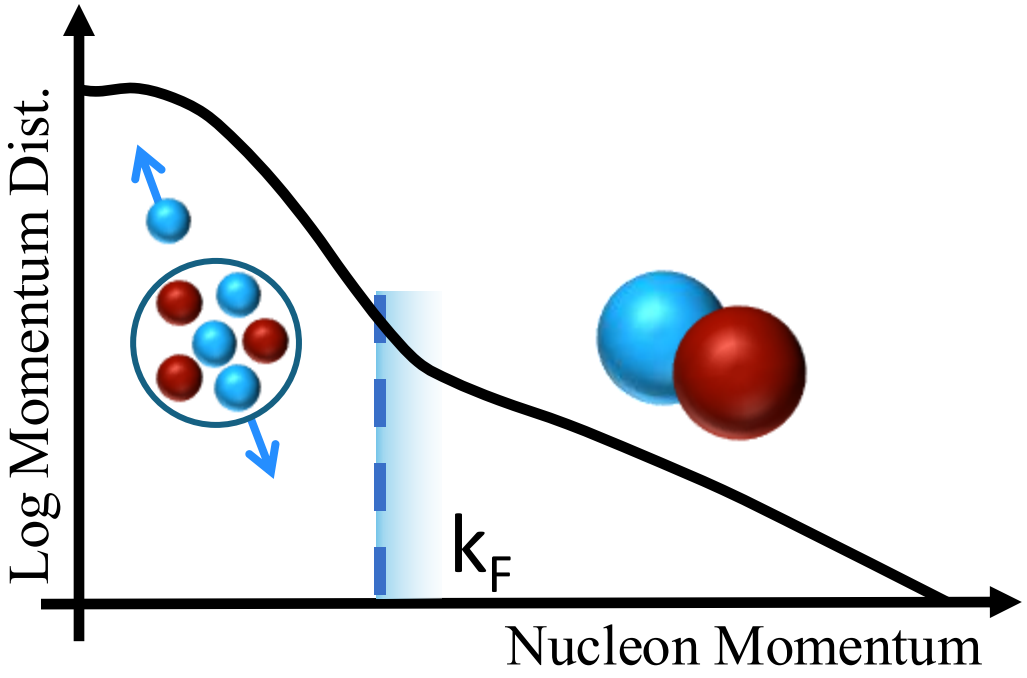


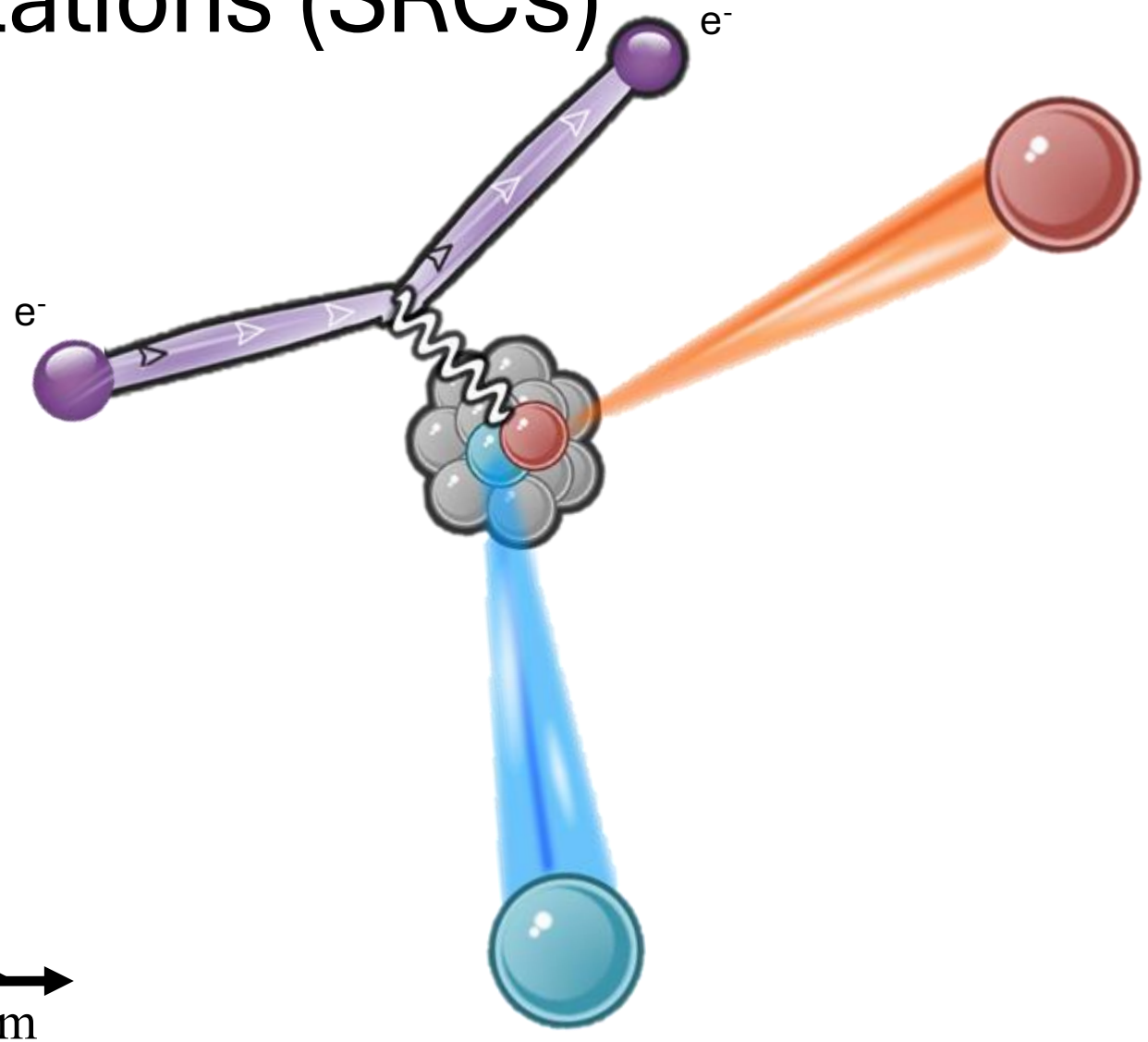
Shell Model





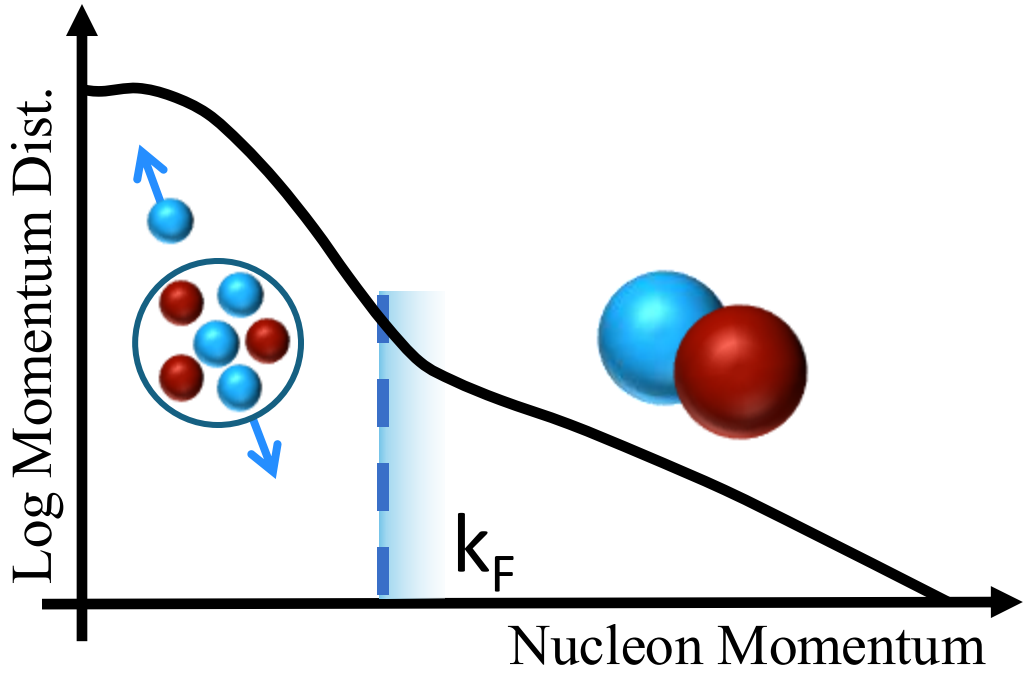
Short Range Correlations (SRCs)





Short Range Correlations

- High Momentum States
  - ~20% of nucleons
- Back-to-back momentum
- Mostly np pairs
- Deuteron-like scaling



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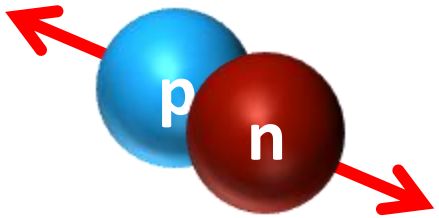

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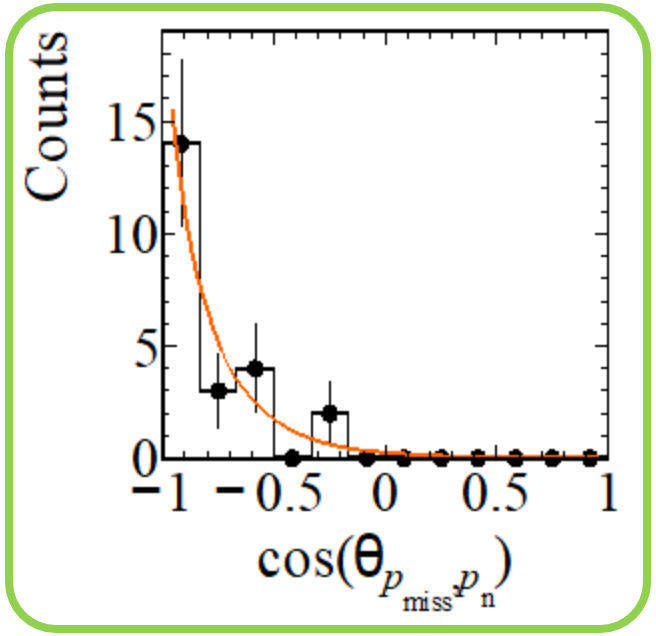
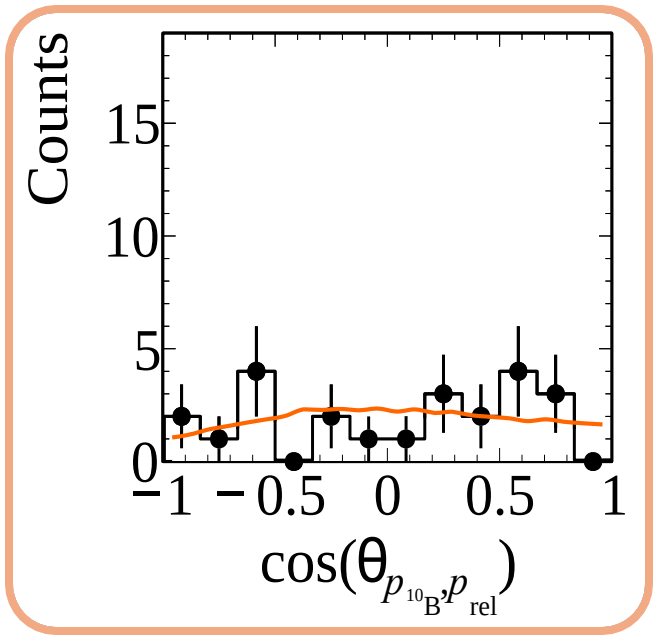
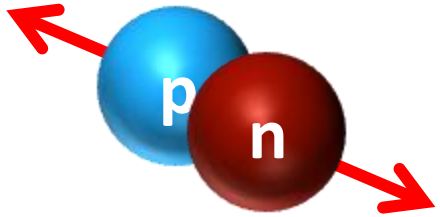


Mean Field



Patsyuk and Kahlbow et al., Nature Physics (2021)

Short Range Correlations



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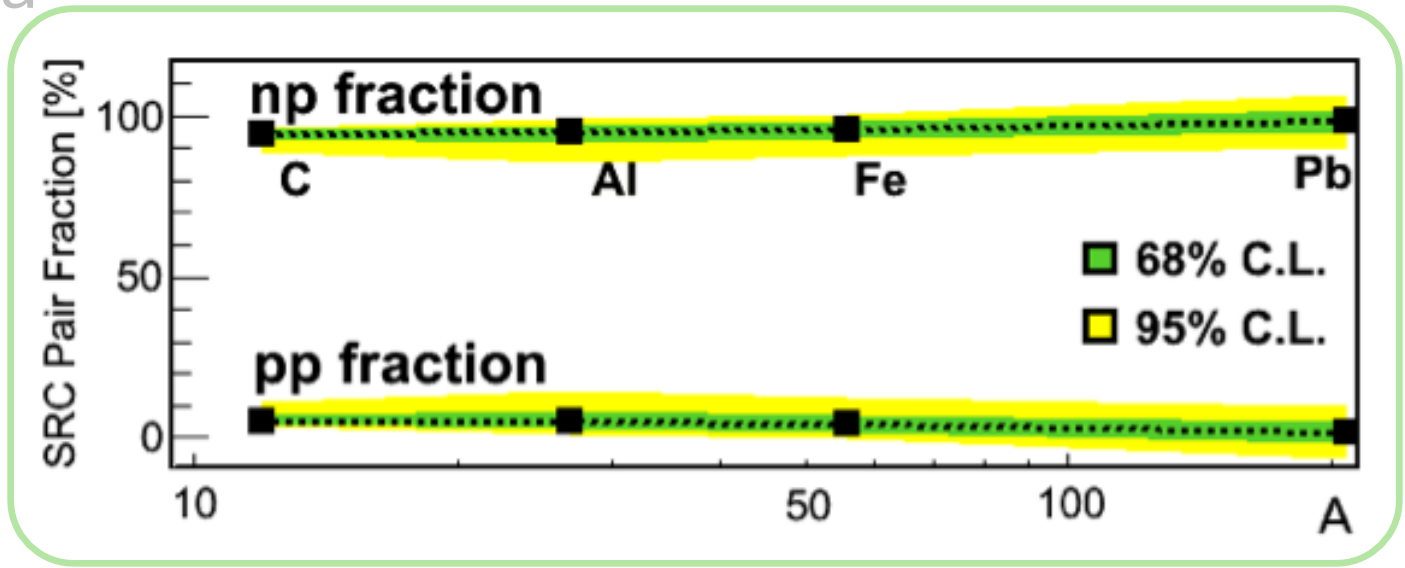

Hen et al., Science (2014)

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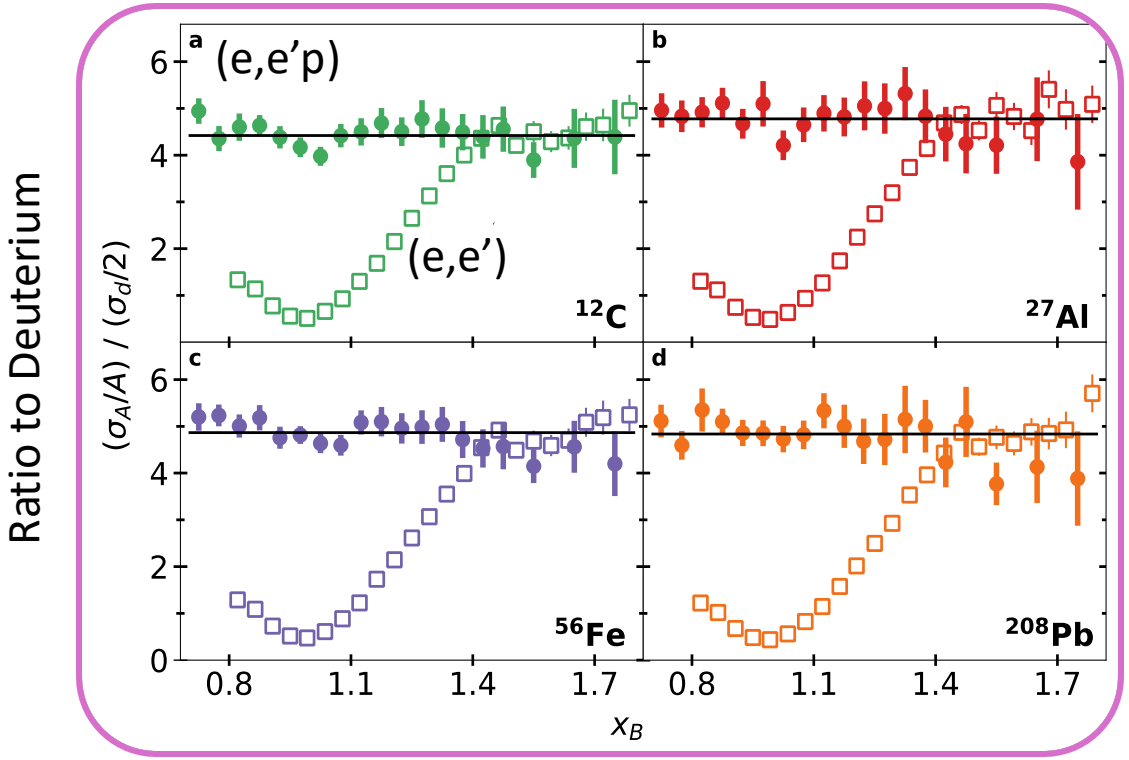
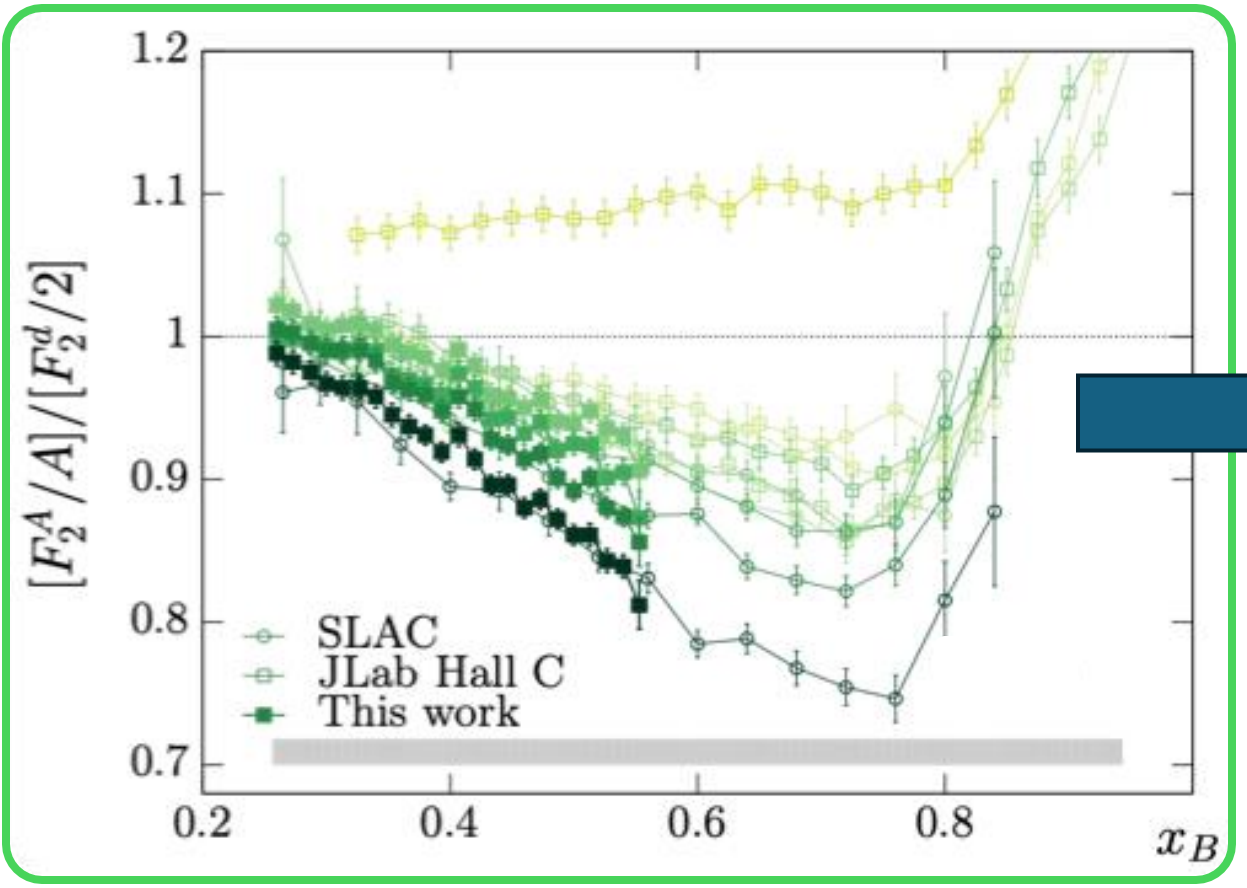


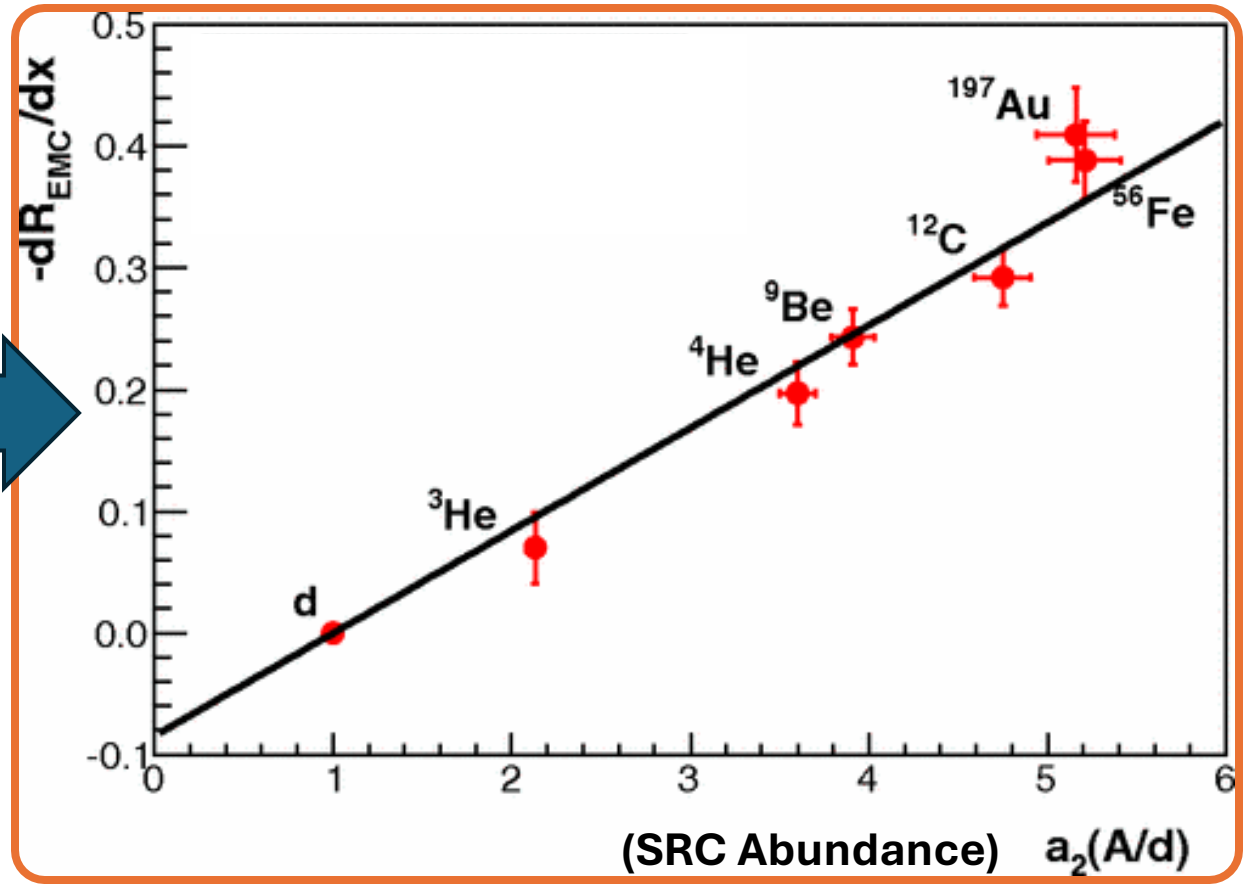
Korover and Denniston et al., PRC Lett. (2023)

SRC Modification is well supported

Schmookler et al., Nature (2019)

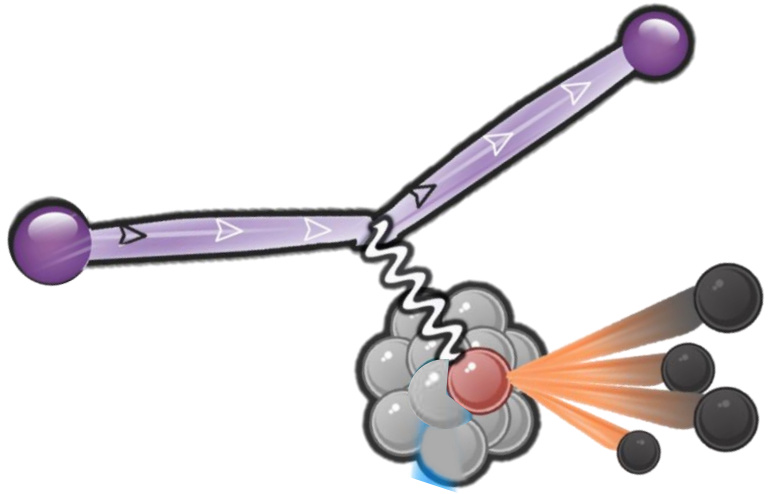


Hen et al., PRC (2012)



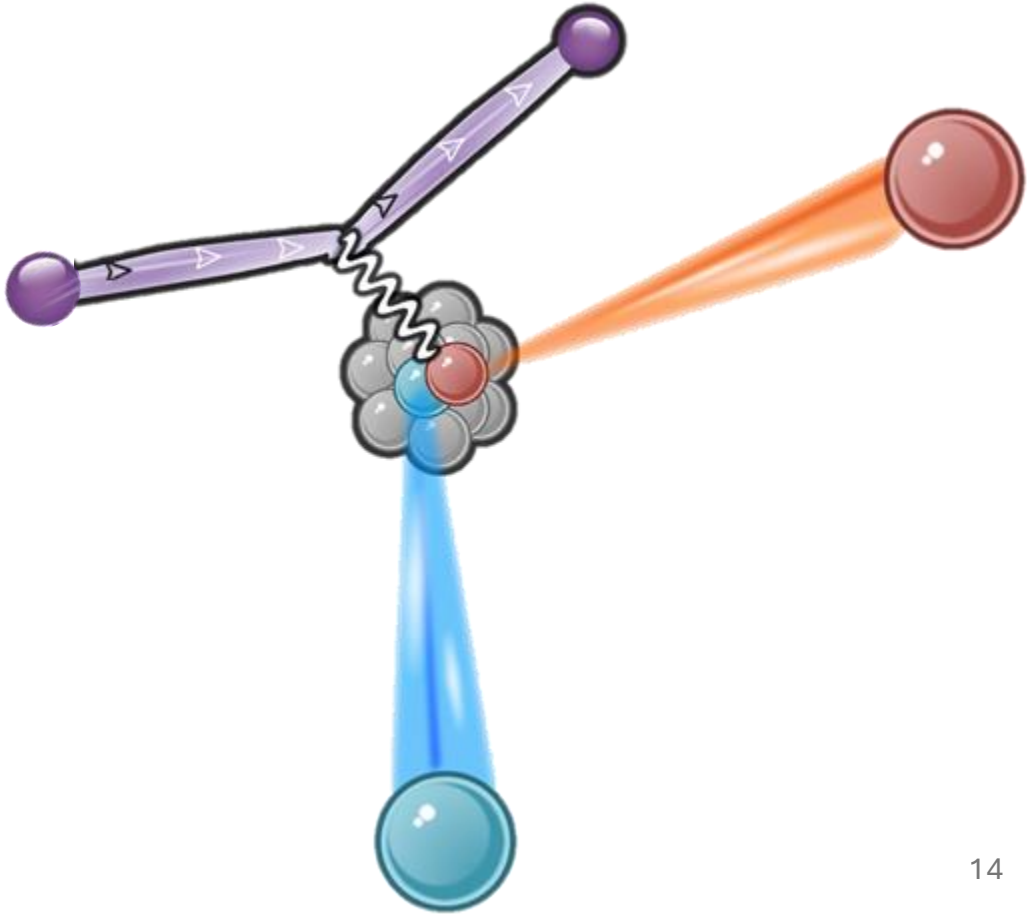
(Most) experiments measure

EMC Effect (inclusive DIS)

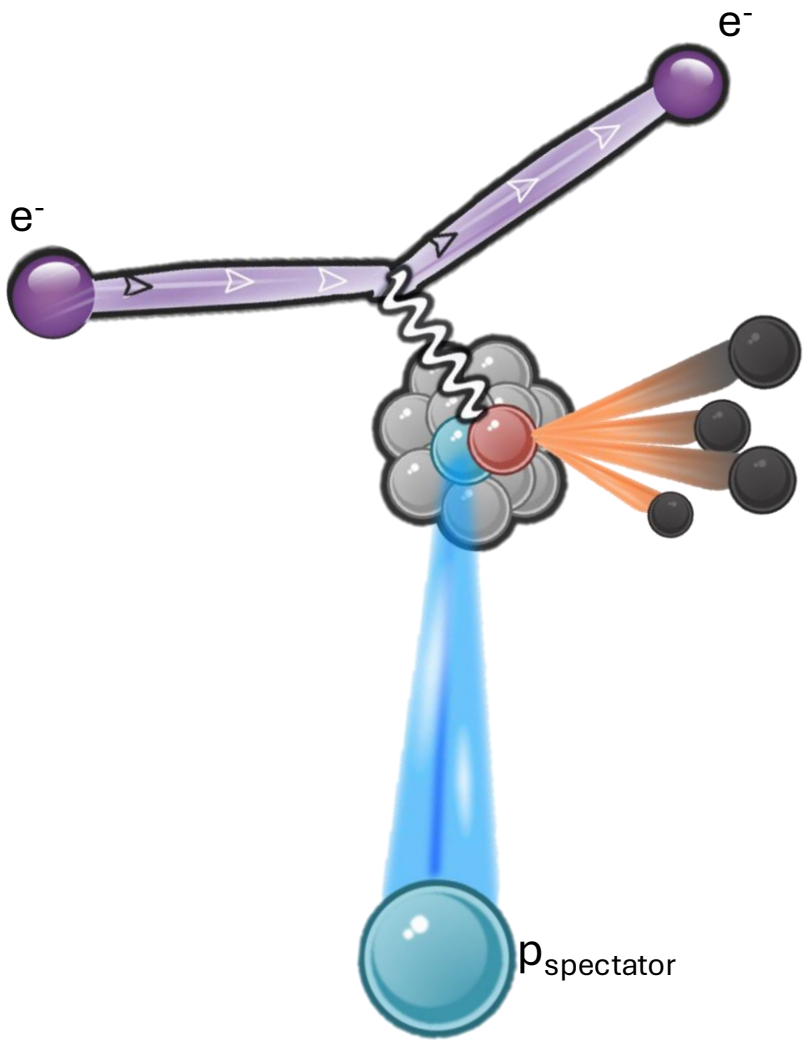


OR

SRC's (quasi-elastic)

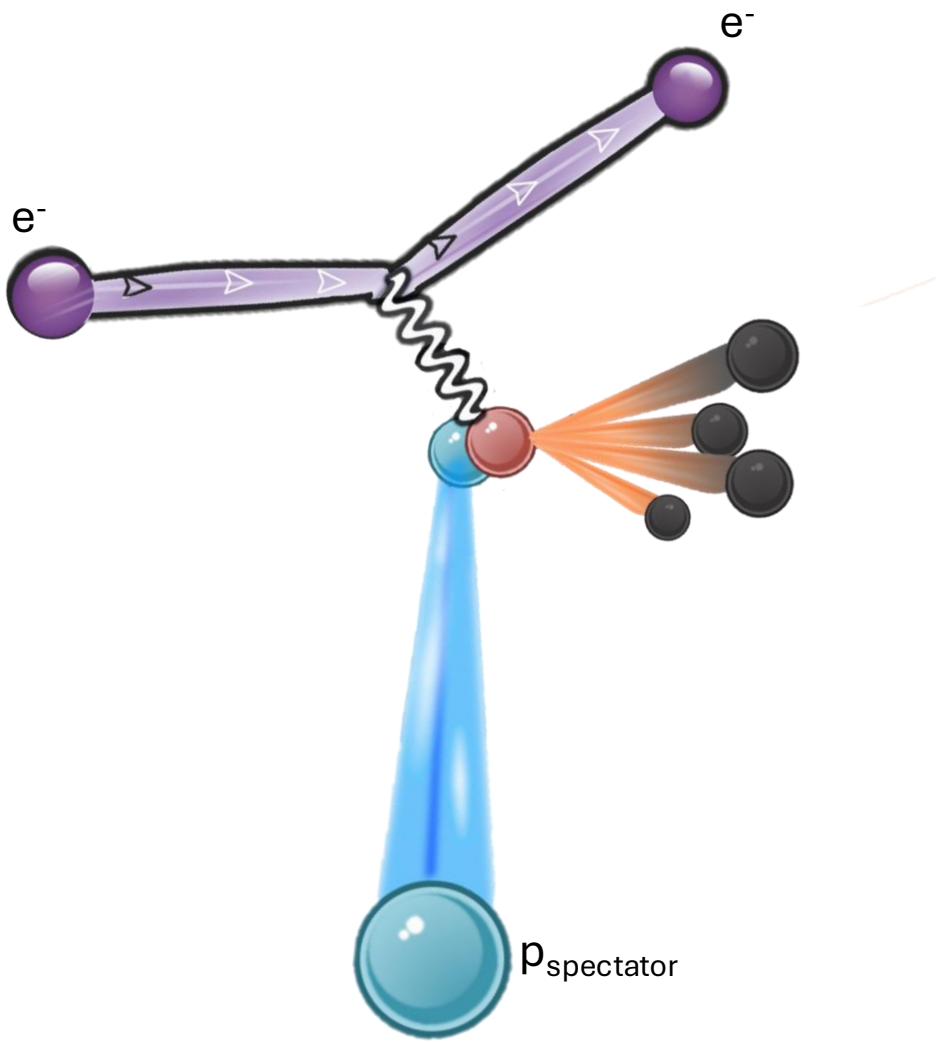


Spectator Tagged DIS



- Detect spectator nucleon
- Provides information on initial nucleon state
- (e,e’ p_s)

Spectator Tagged DIS



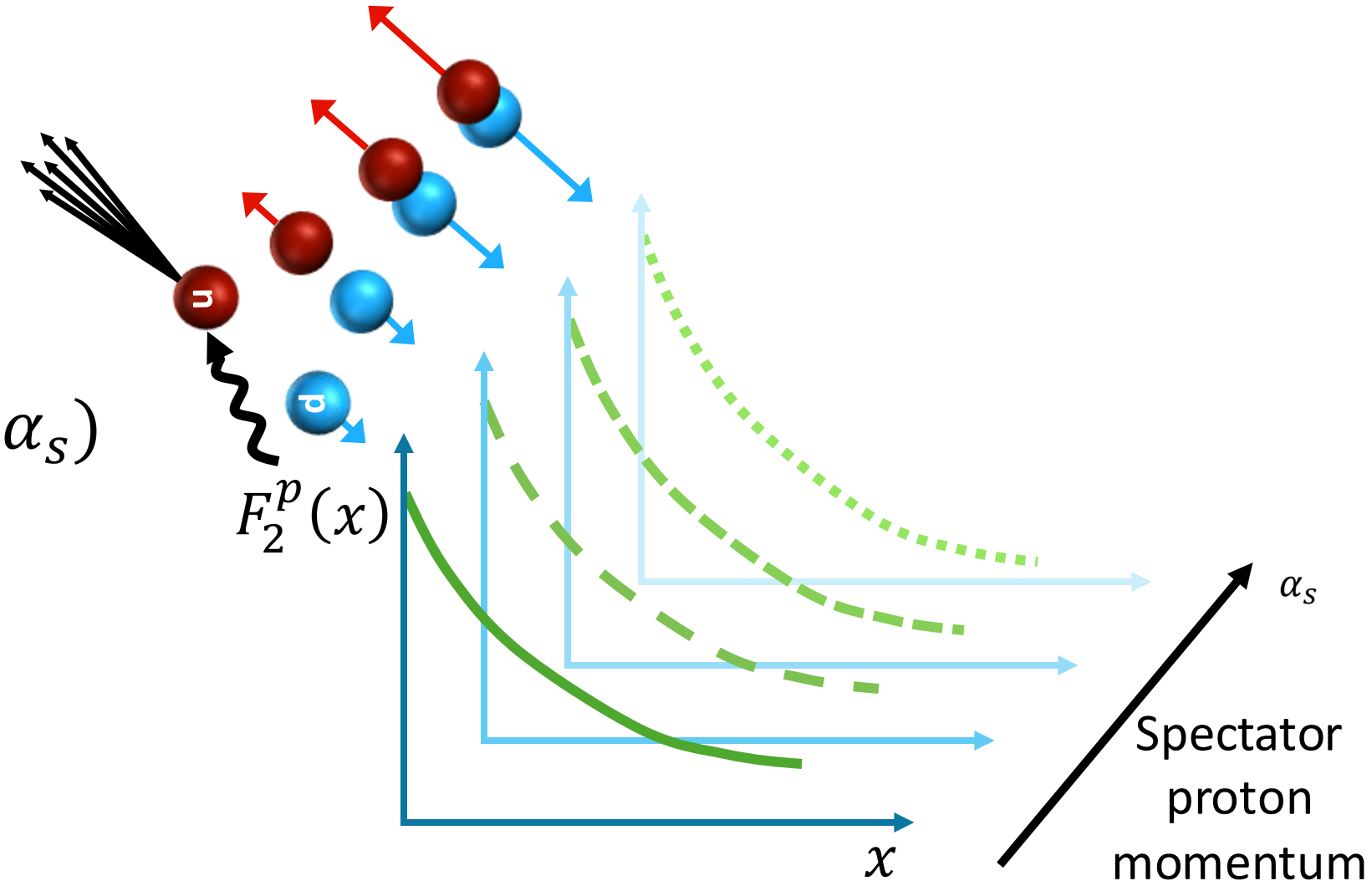
- Detect spectator nucleon
- Deuteron: Fully constrains initial nucleons

$$\vec{p}_{miss} \approx -\vec{p}_{recoil}$$

Spectator Tagged DIS

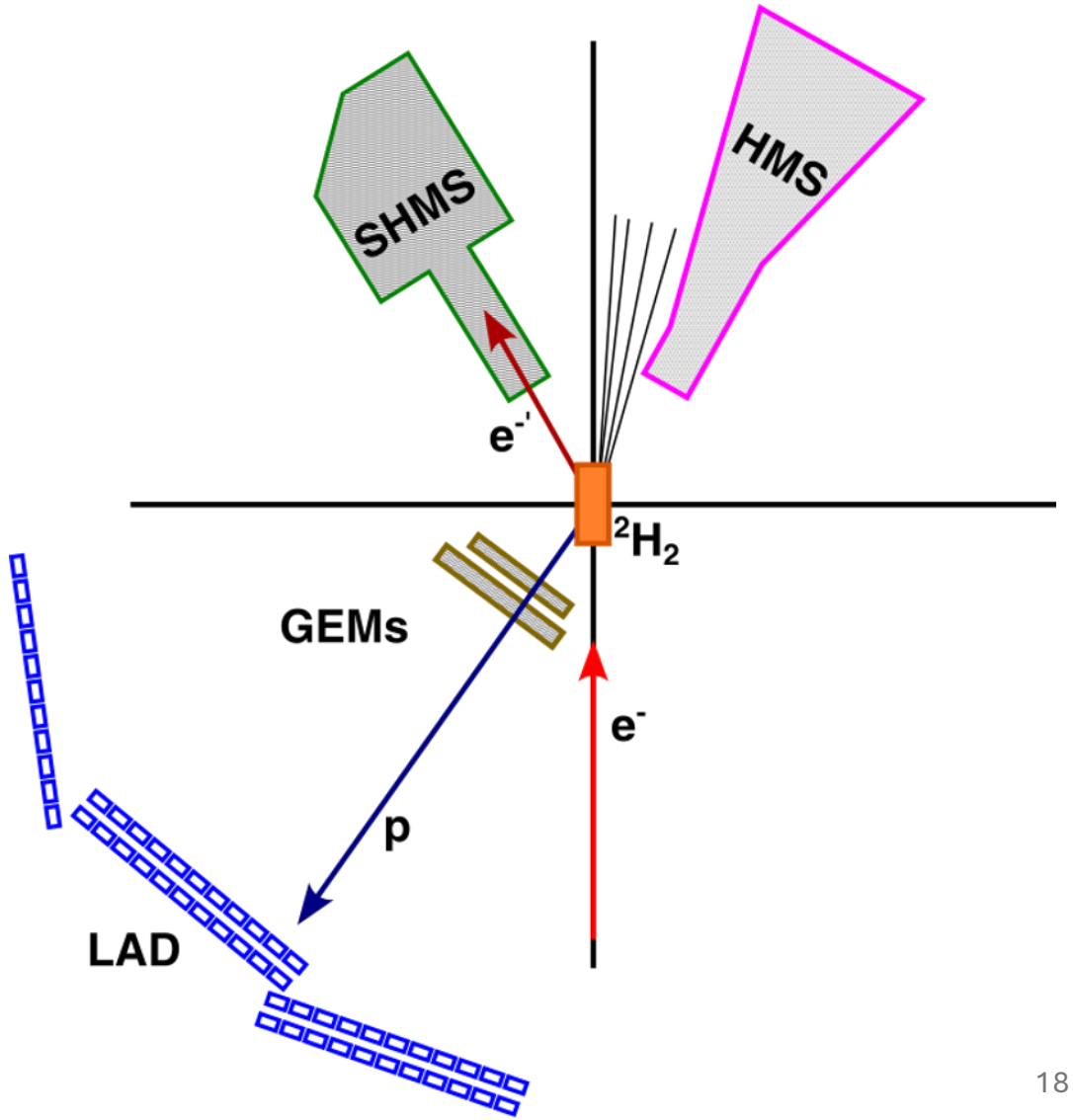
$$F_2(x, Q^2) \rightarrow F_2(x', Q^2, \alpha_s)$$

$$\alpha_s = \frac{E_s - p_s^z}{m_n}$$

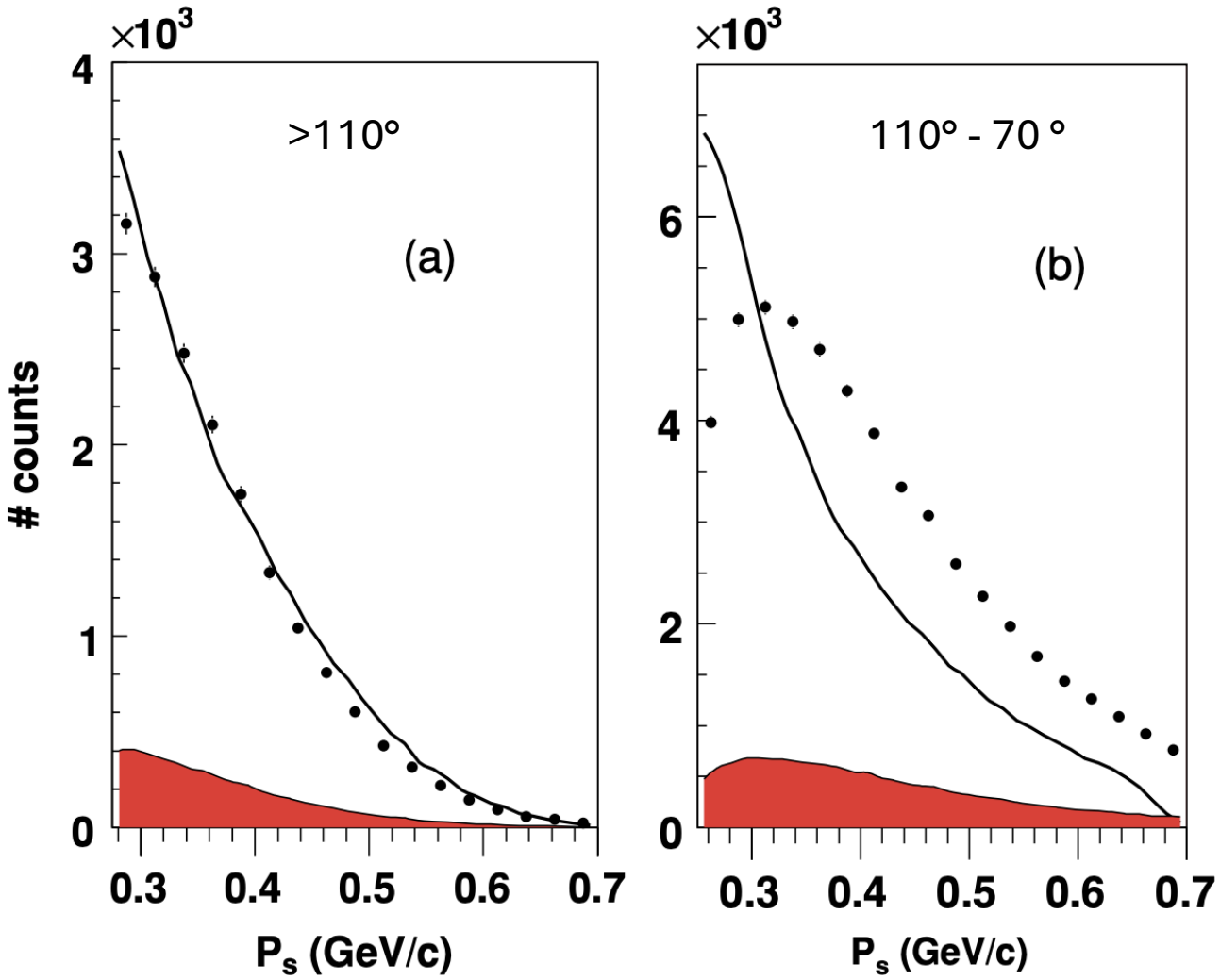


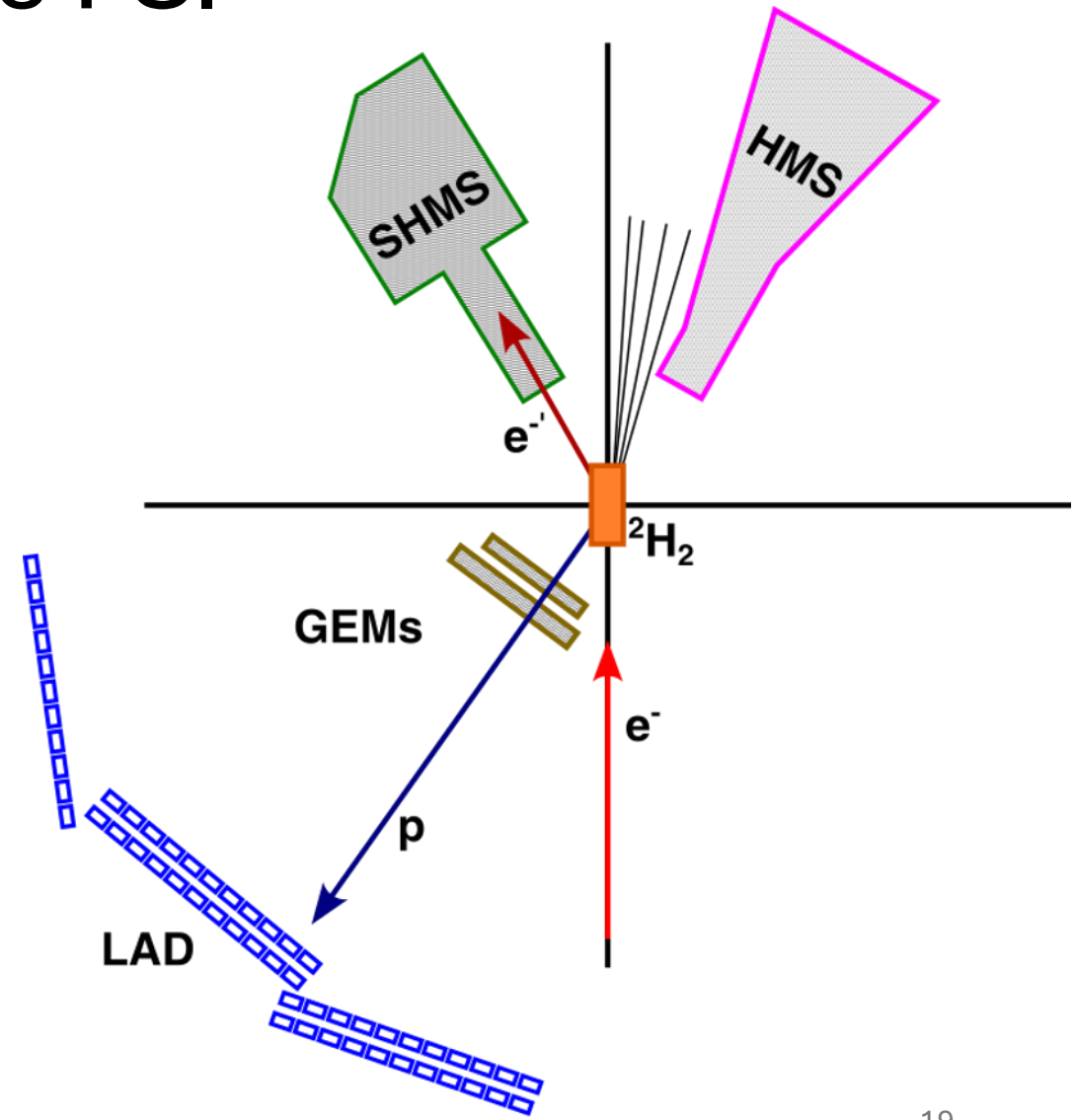
Large Acceptance Detector (LAD) Experiment

- D(e,e'p_s)
- HMS/SHMS for electron
- Install two new detectors
  - Scintillating bars
  - GEMs



Backward angles minimize FSI

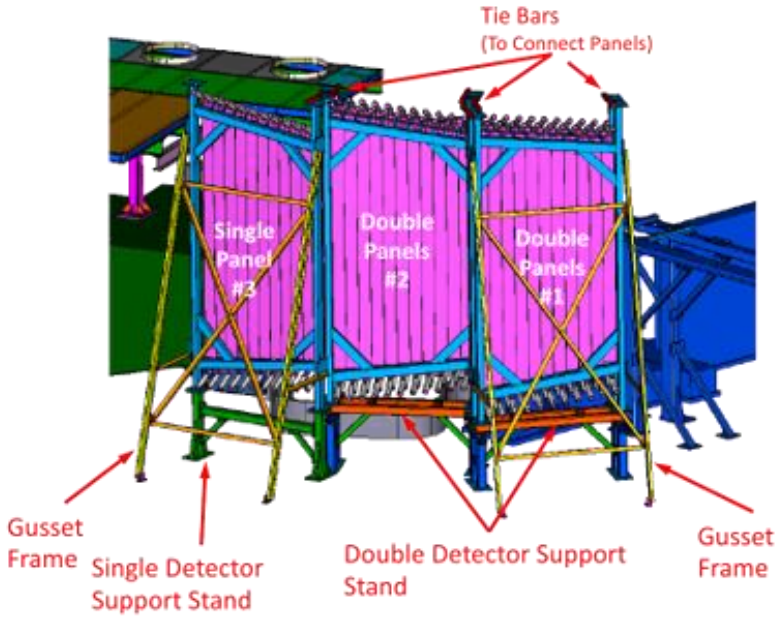


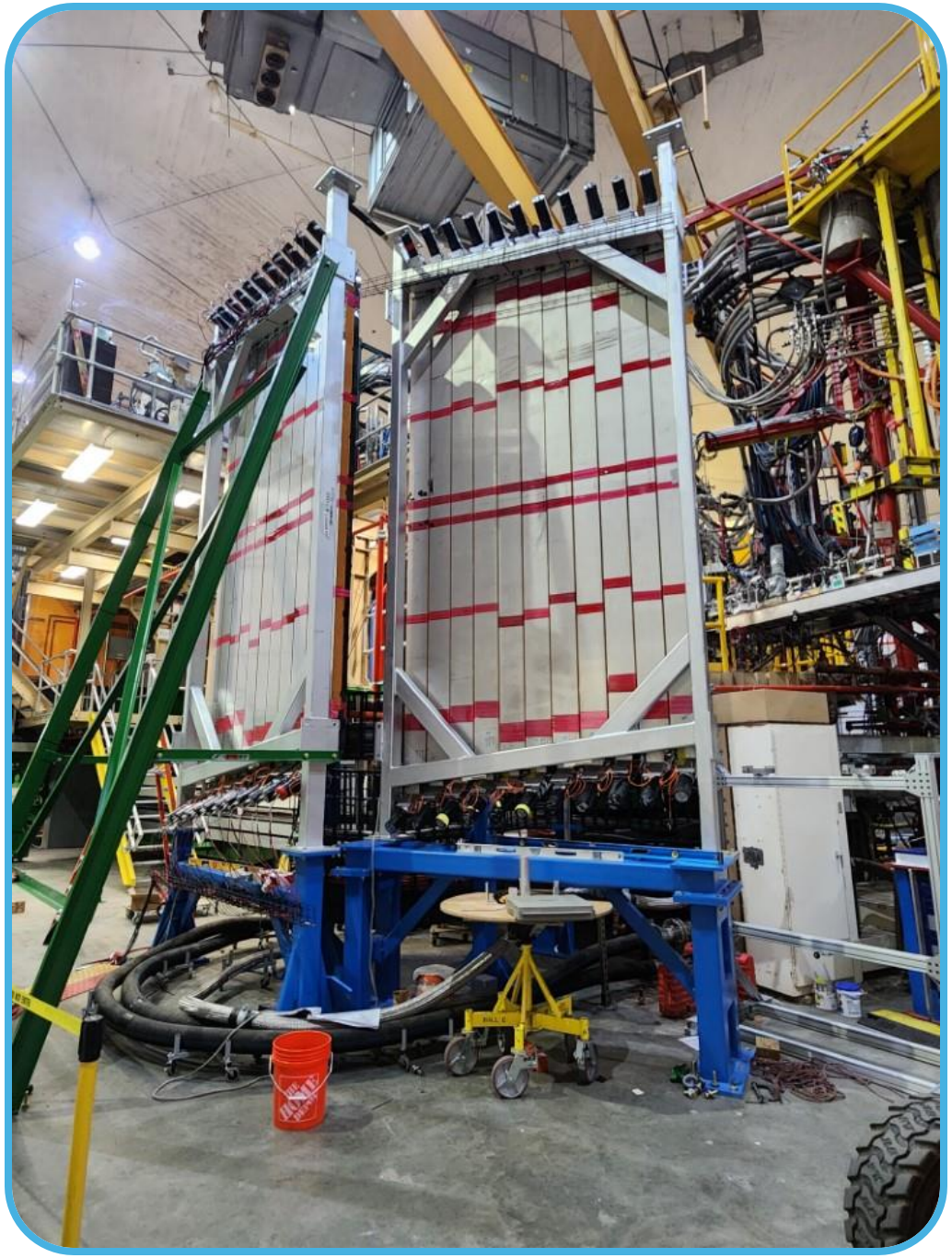


A. V. Klimenko et al., PRC (2006)

LAD: Scintillator Bars

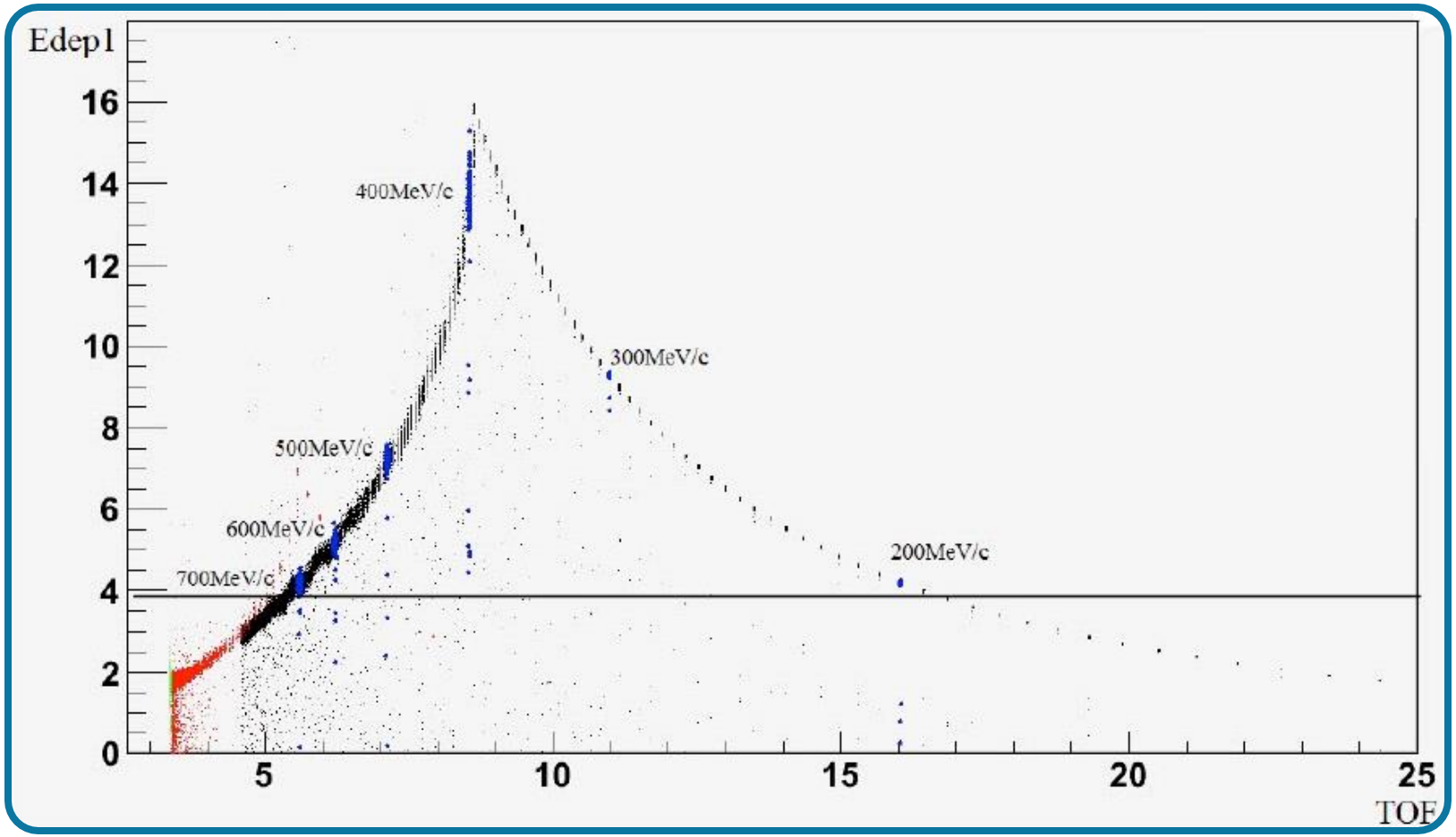
- Refurbished from CLAS-6 ToF
- 5 Panels
  - 2 double, 1 single plane





LAD: Scintillator Bars

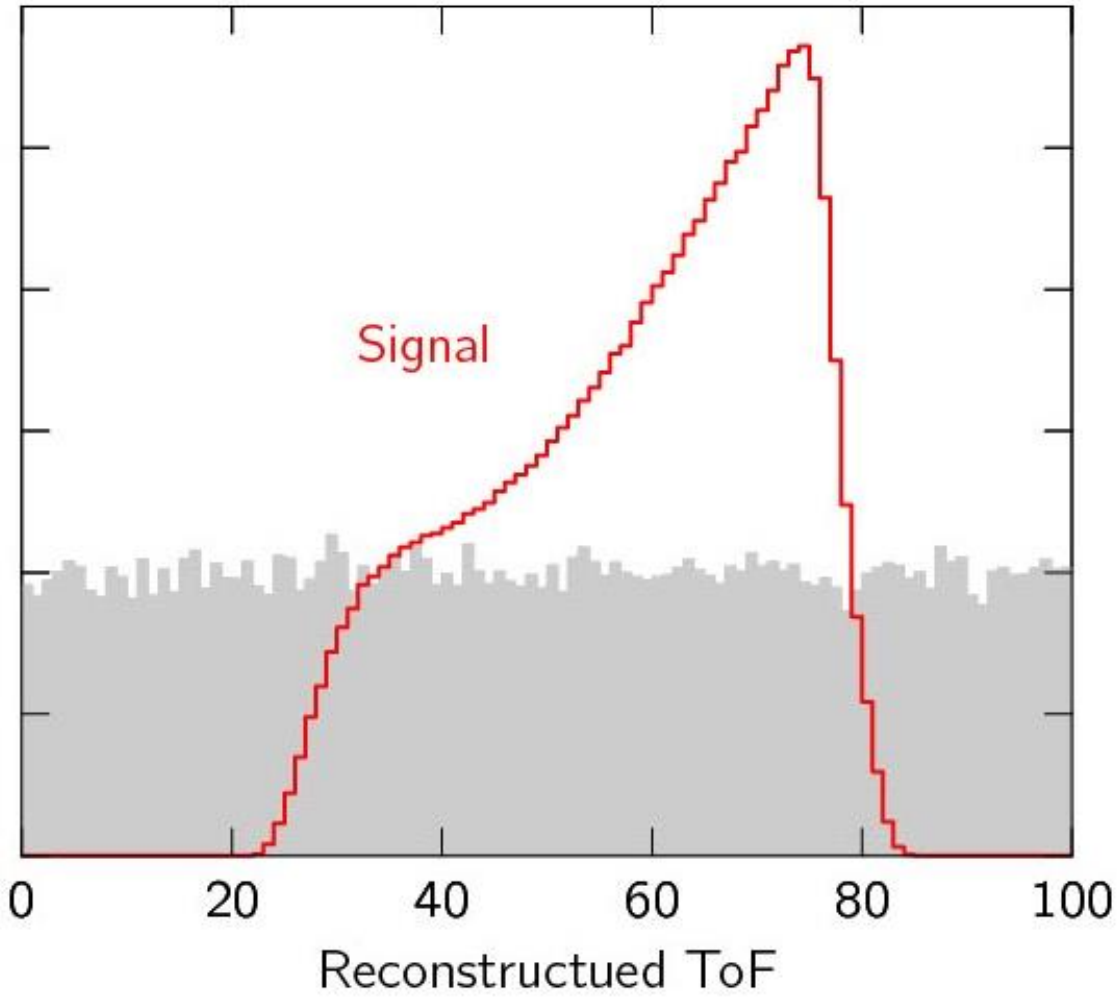
- PID through timing & energy
- Laser calibration



Limited by Random Coincidence Background

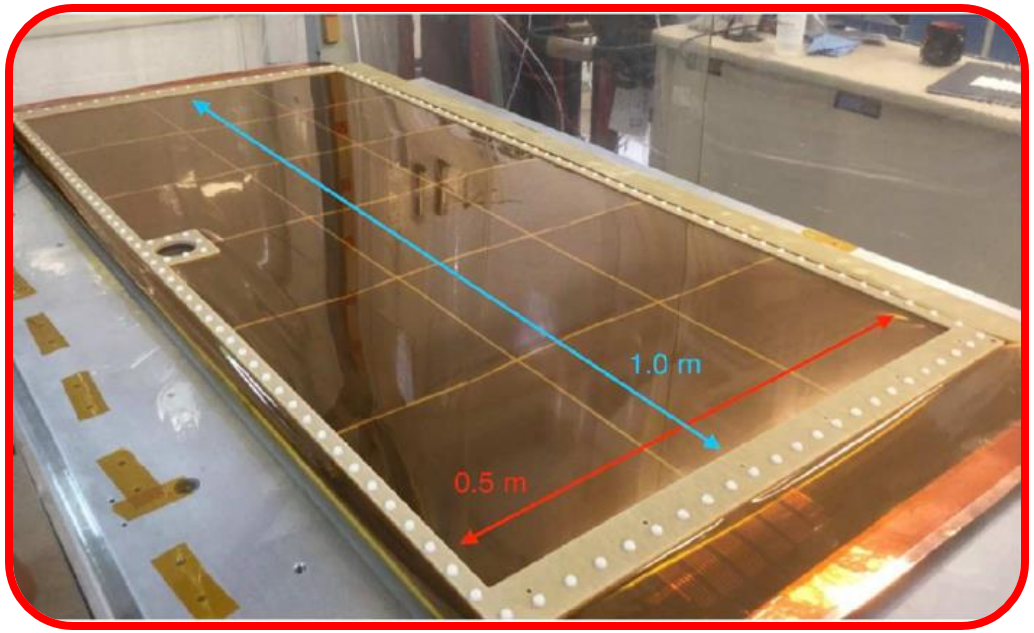
$$\frac{\delta N}{N} = \frac{\sqrt{S+B}}{S}$$

Background rejection is vital



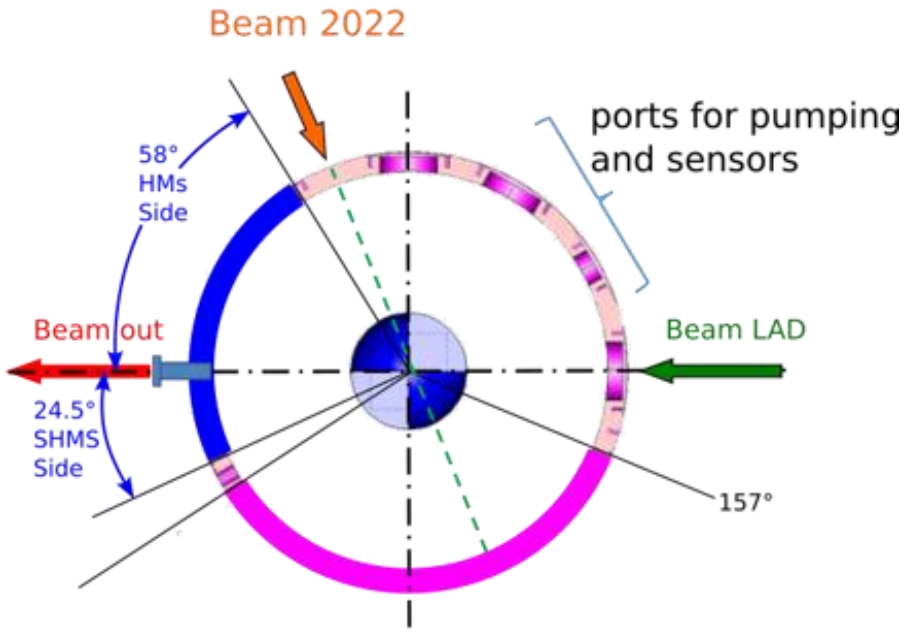
LAD: GEMs

- Two layers
- Aid in vertexing
- Reused from PRAD

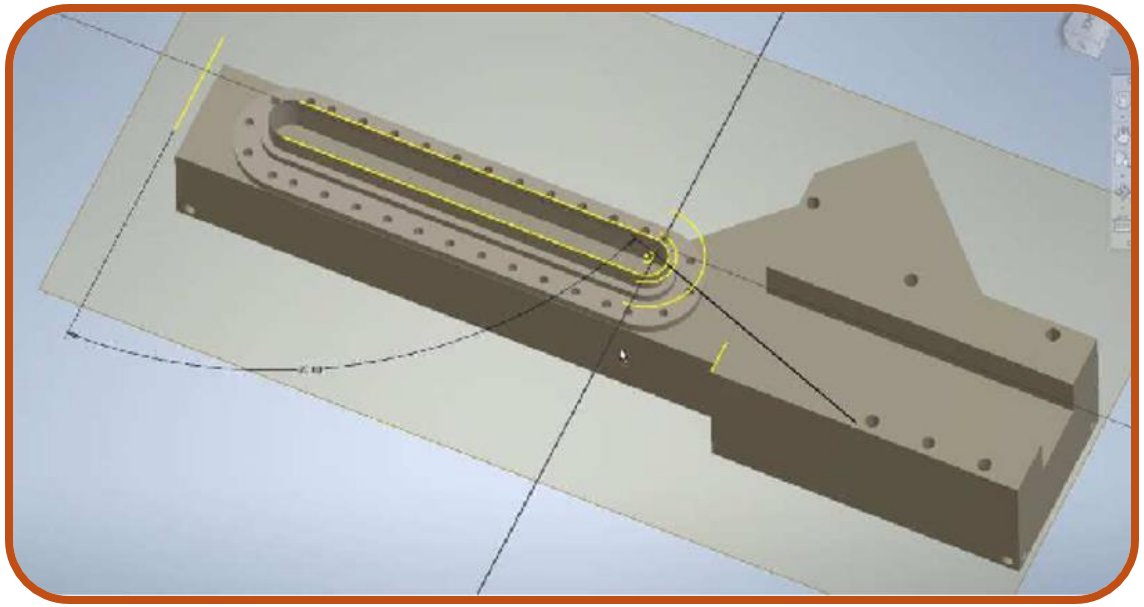


LAD Target & Scattering Chamber

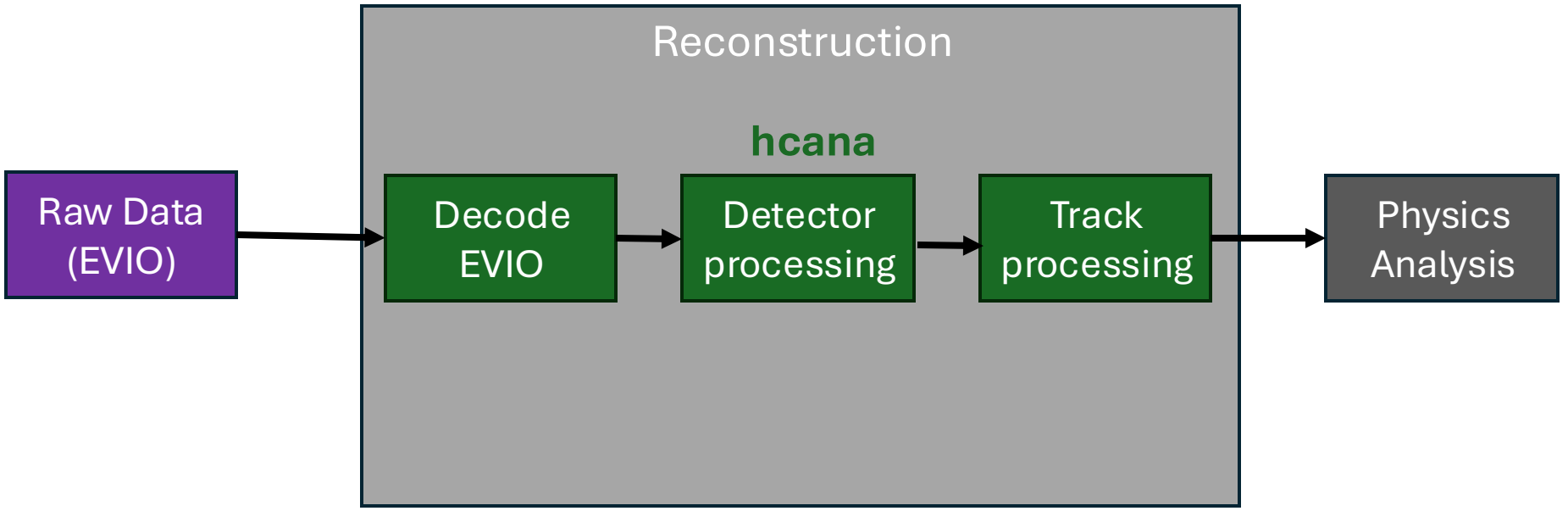
- Scattering chamber modified to accommodate backward angles



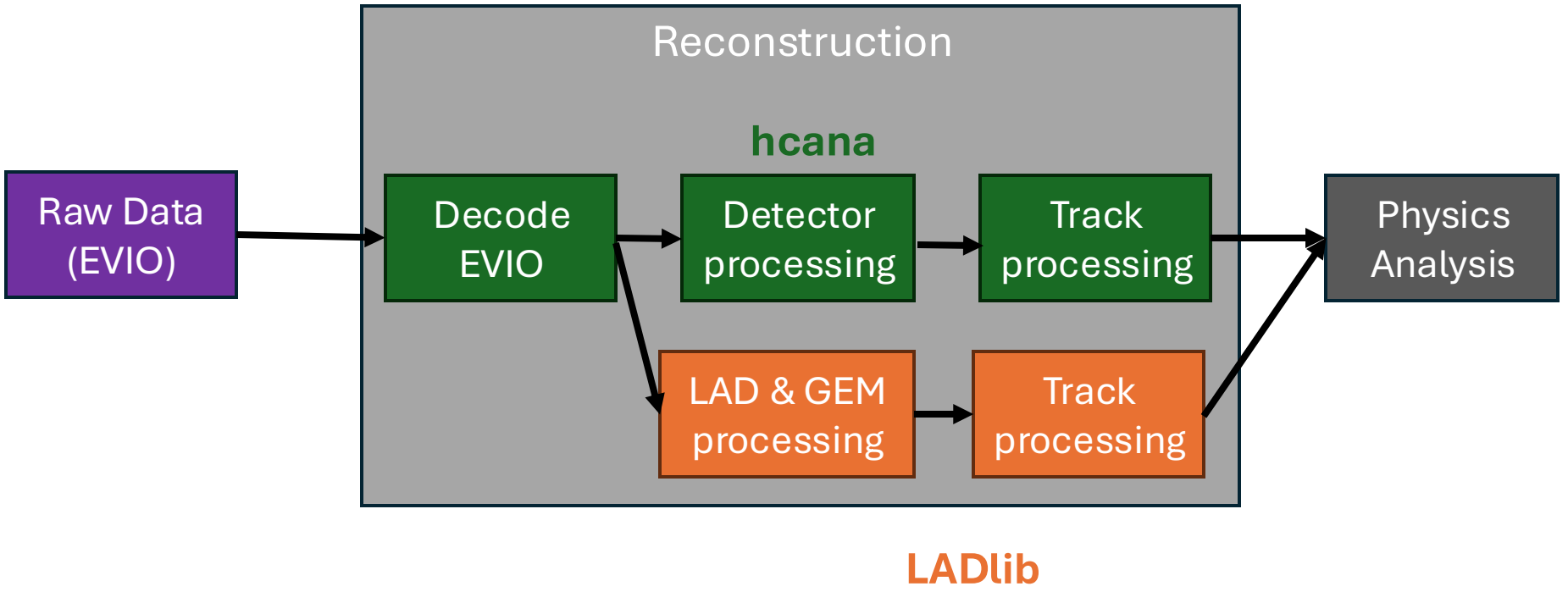
- LD2 Production
- Calibration
  - H2, Empty, C-multifoil



Software


Reconstruction
hcana
Raw Data (EVIO)
Decode EVIO
Detector processing
Track processing
Physics Analysis

Software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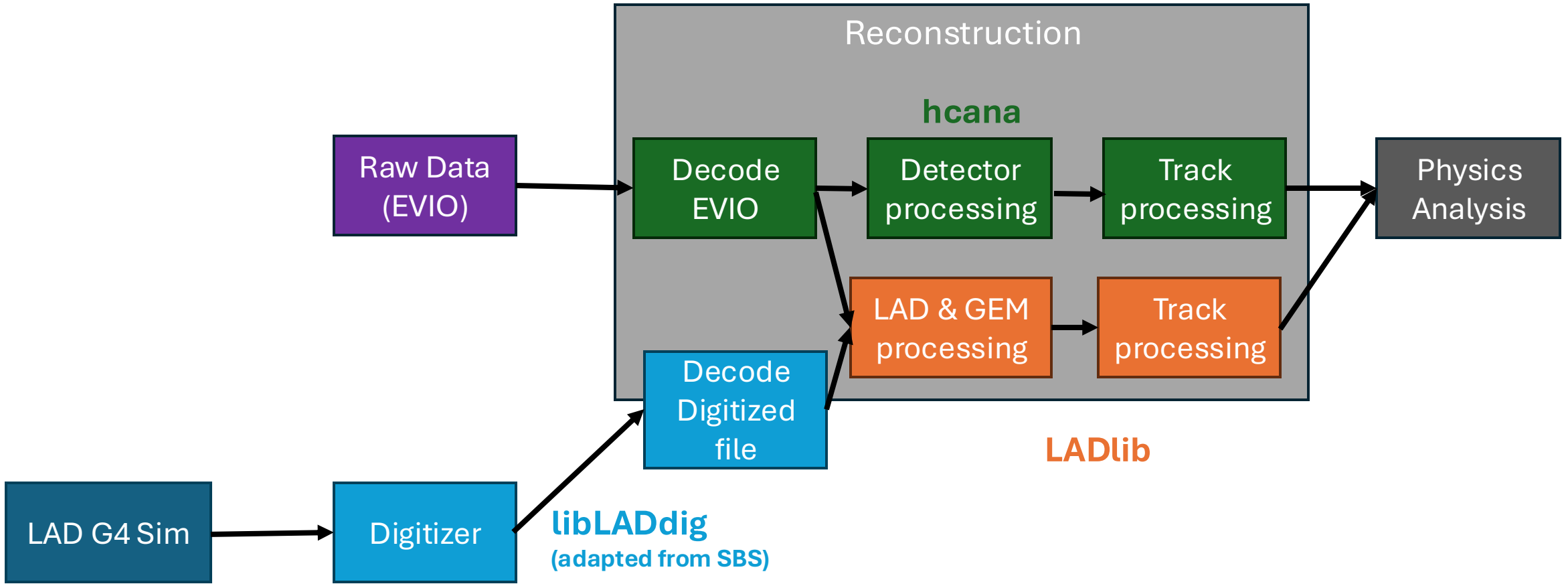
LAD & GEM processing
Track processing
LADlib

Software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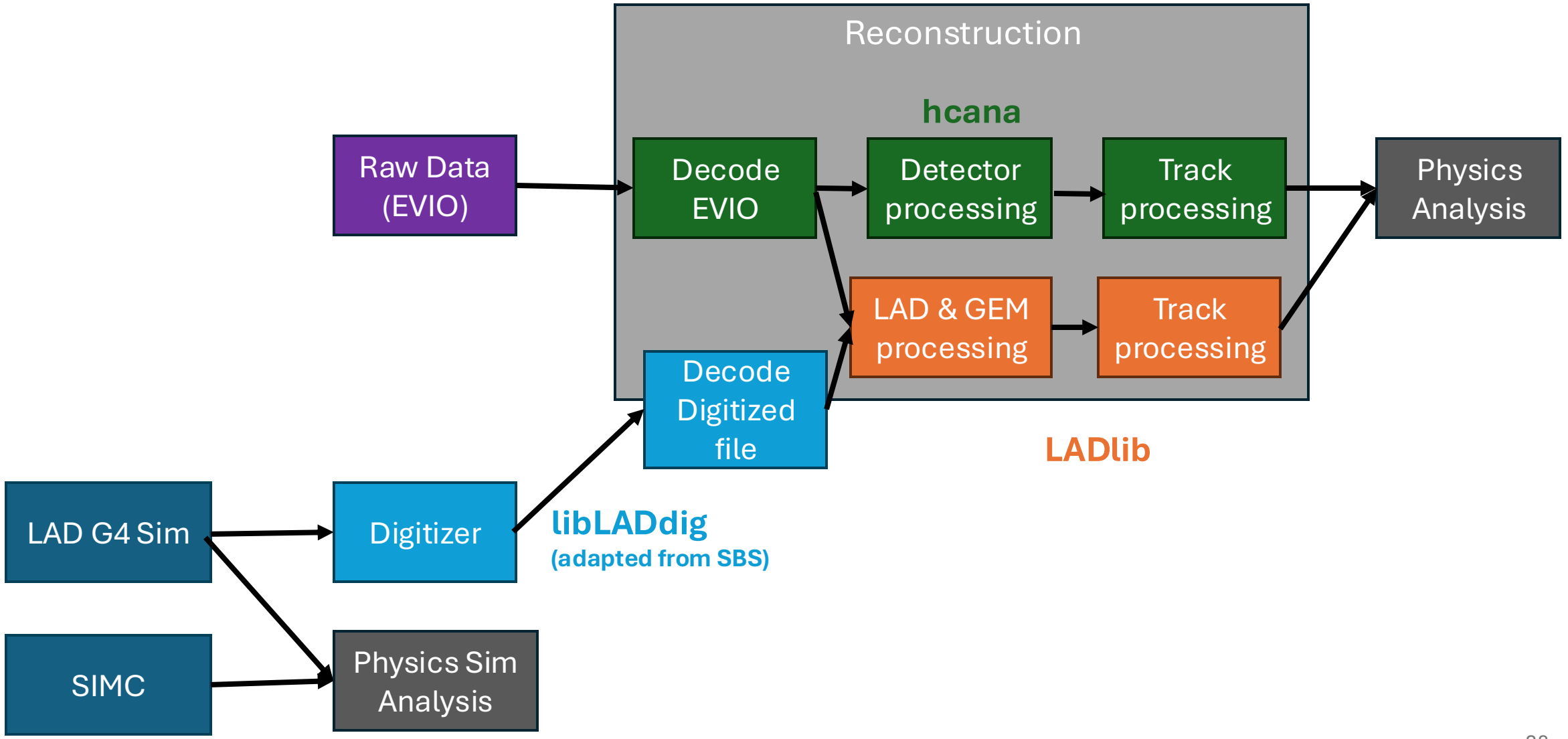
Detector processing
Track processing
Physics Analysis
LAD & GEM processing
Track processing
Decode Digitized file
LADlib
LAD G4 Sim
Digitizer
libLADdig
(adapted from SBS)

Software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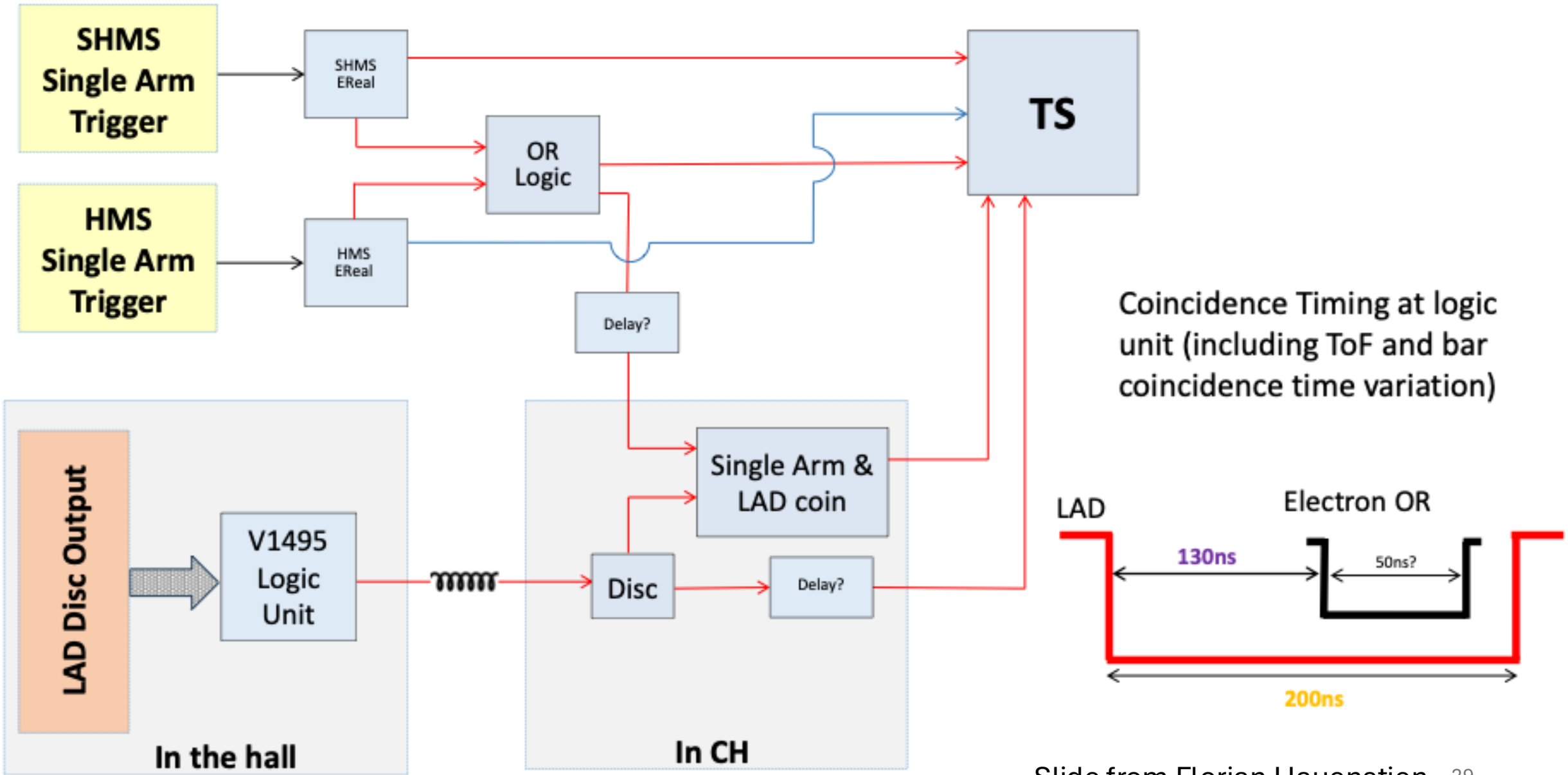
Decode Digitized file
LADlib
LAD G4 Sim
Digitizer
libLADdig
(adapted from SBS)
SIMC
Physics Sim Analysis

Trigger Setup for coincidence and singe arm triggers

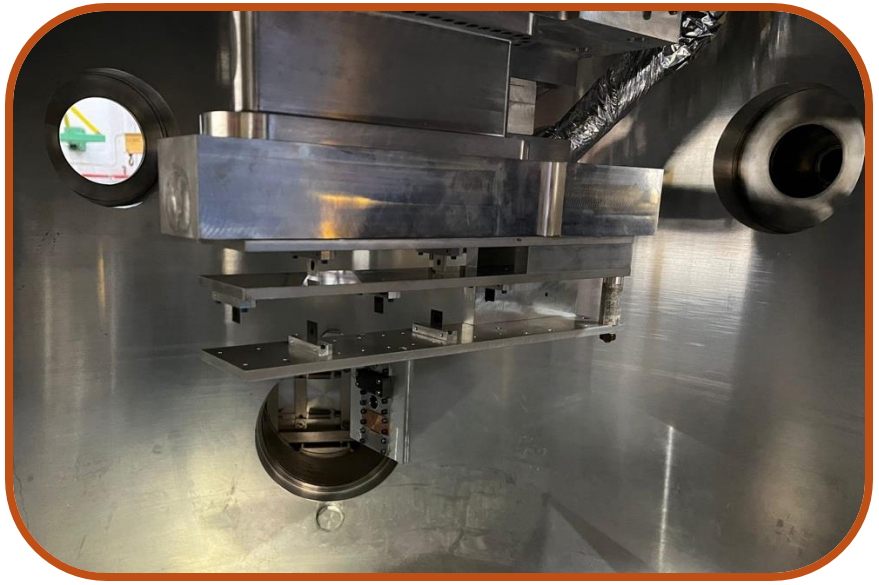


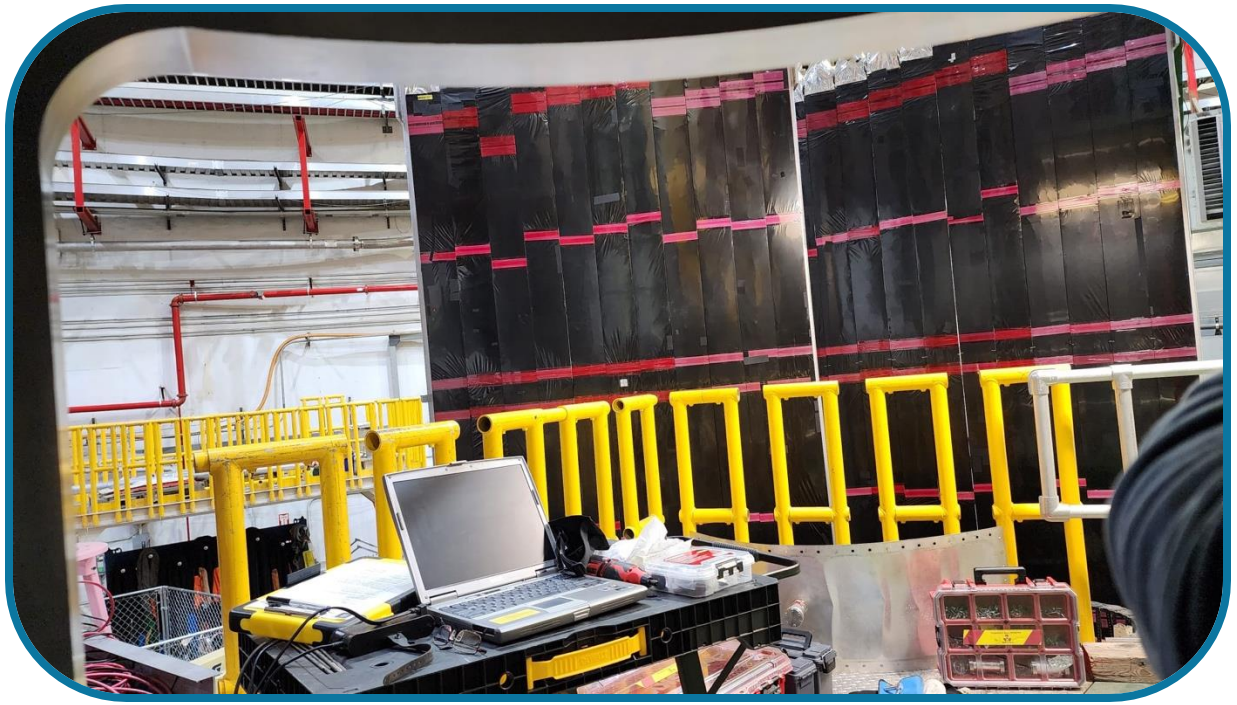
Coincidence Timing at logic unit (including ToF and bar coincidence time variation)

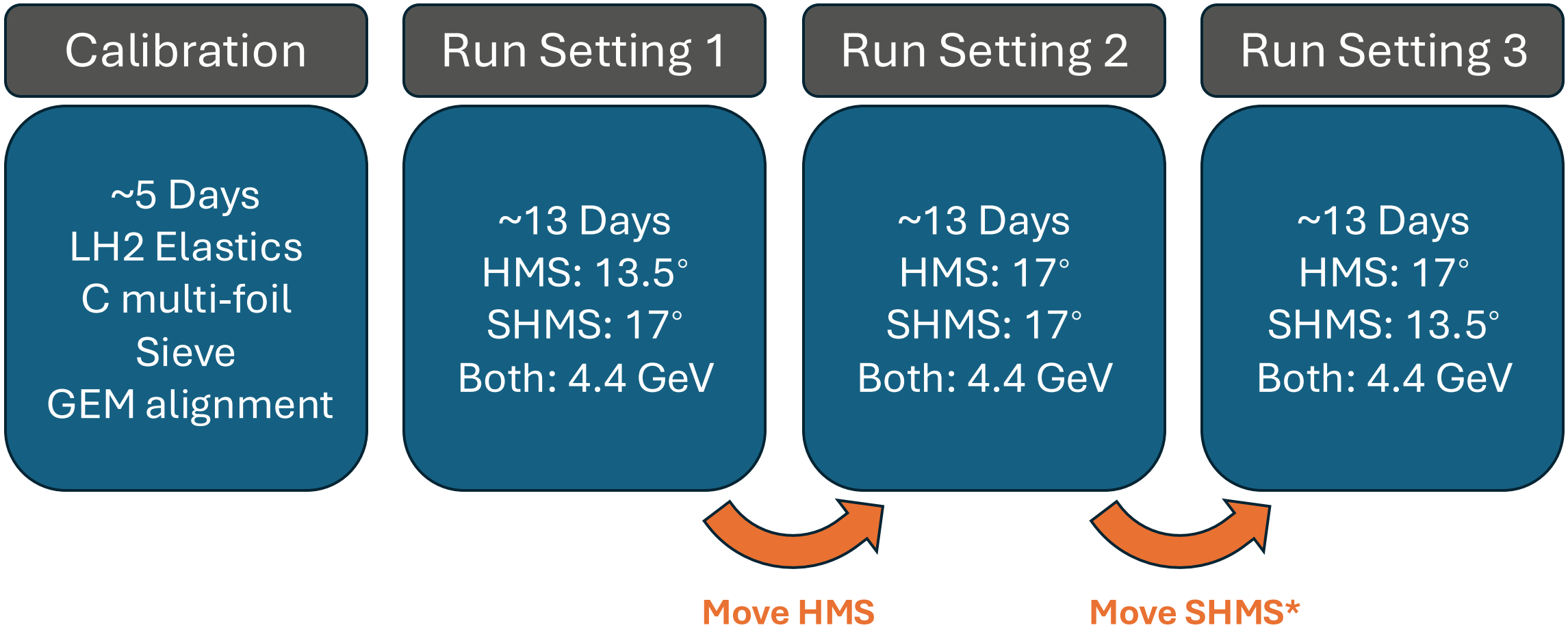
Slide from Florian Hauenstien

Experimental Run Conditions

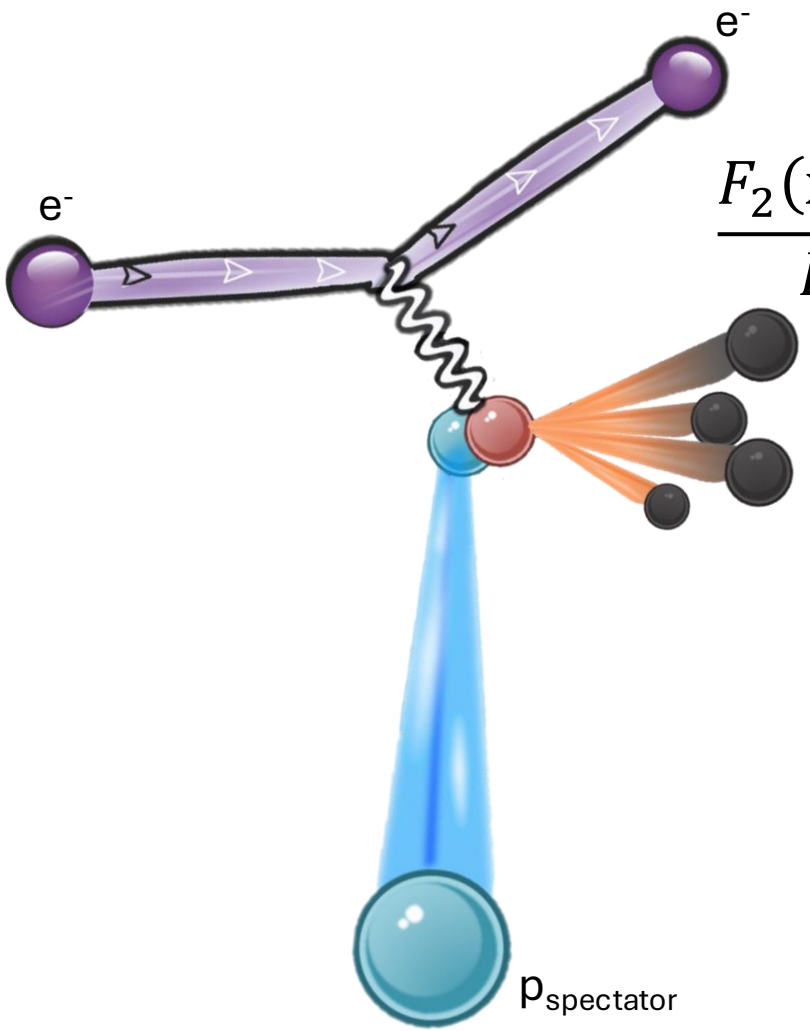
- Jefferson Lab E12-11-107 (LAD)
- 34 PAC Days (Feb 2025 – May 2025)
- Beam Energy: 11 GeV
- Current: ~1 μA
- Target: 20 cm liquid D2
- Luminosity: 1.2×10^{37} cm^{-2} s^{-1} per nucleon






Calibration
~5 Days
LH2 Elastics
C multi-foil
Sieve
GEM alignment
Run Setting 1
~13 Days
HMS: 13.5°
SHMS: 17°
Both: 4.4 GeV
Run Setting 2
~13 Days
HMS: 17°
SHMS: 17°
Both: 4.4 GeV
Run Setting 3
~13 Days
HMS: 17°
SHMS: 13.5°
Both: 4.4 GeV
Move HMS
Move SHMS*
*and GEMS

Observables



$$\frac{F_2(x', Q^2, \alpha_s)_{\text{bound}}}{F_2(x, Q^2)_{\text{free}}} = \frac{F_2^n(\alpha_s, x')_{\text{bound}}}{F_2^n(\alpha_s, x_0')_{\text{bound}}} \times \frac{F_2^n(\alpha_s, x_0')_{\text{free}}}{F_2^n(\alpha_s, x')_{\text{free}}} \times R_{\text{FSI}}$$

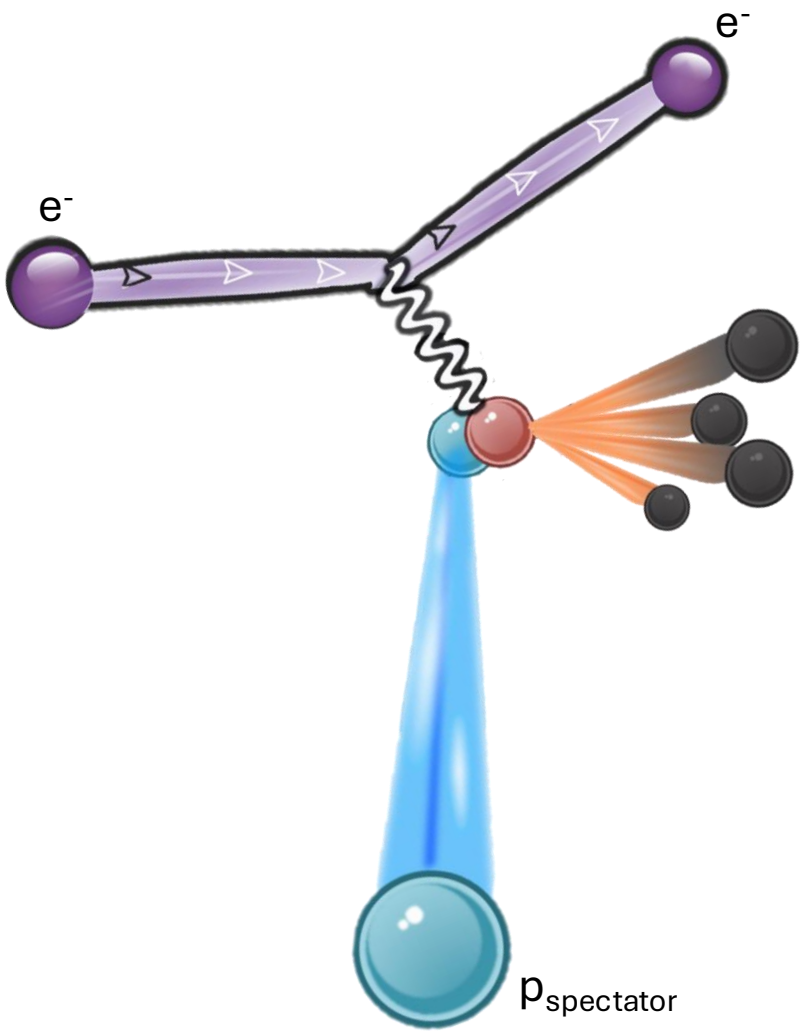
(Tagged DIS data) (Simulation)

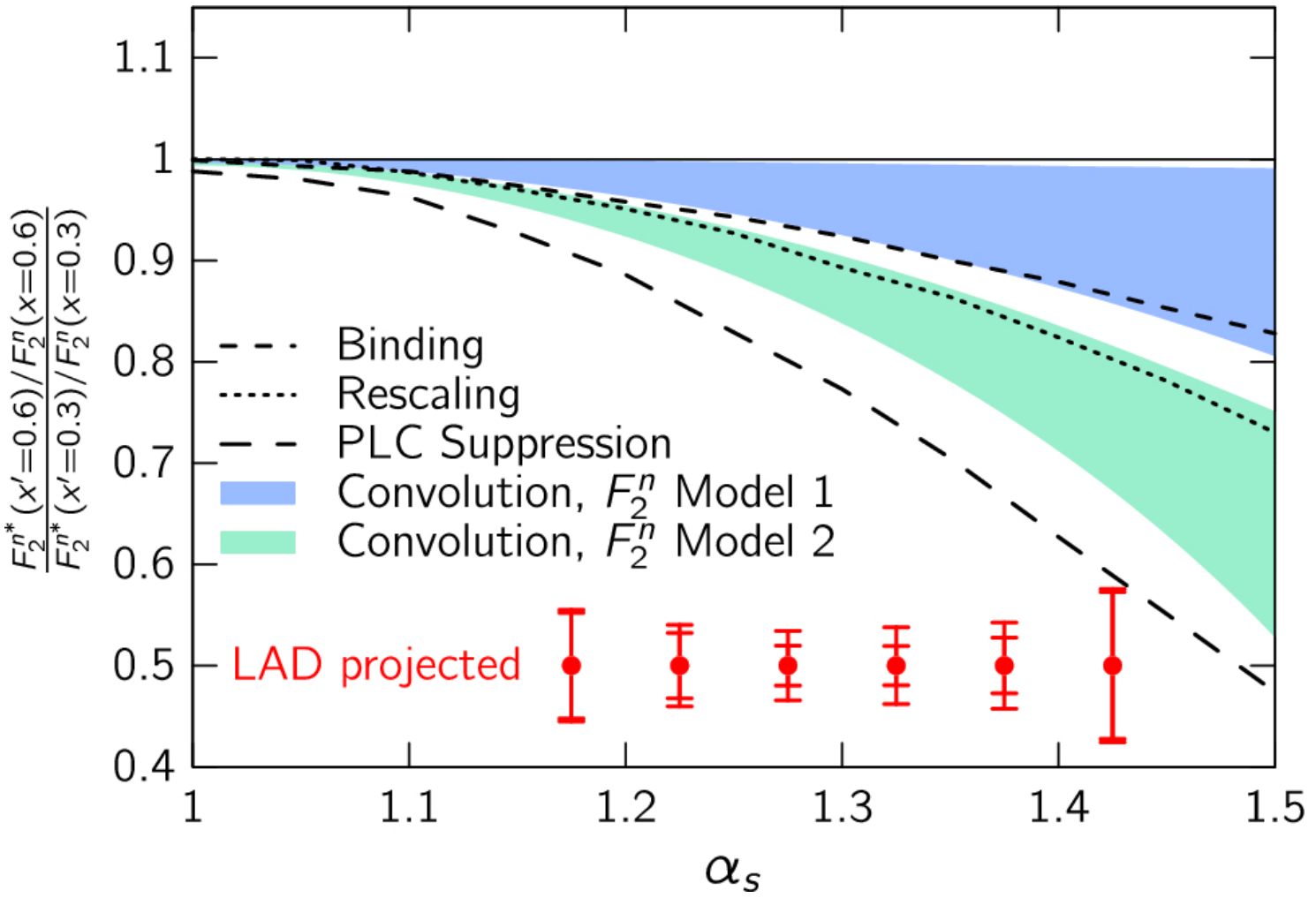
$$x_0 \approx 0.3$$

$$F_2^n(\alpha_s, x_0')_{\text{bound}} \approx F_2^n(\alpha_s, x_0')_{\text{free}}$$

Projected Sensitivity

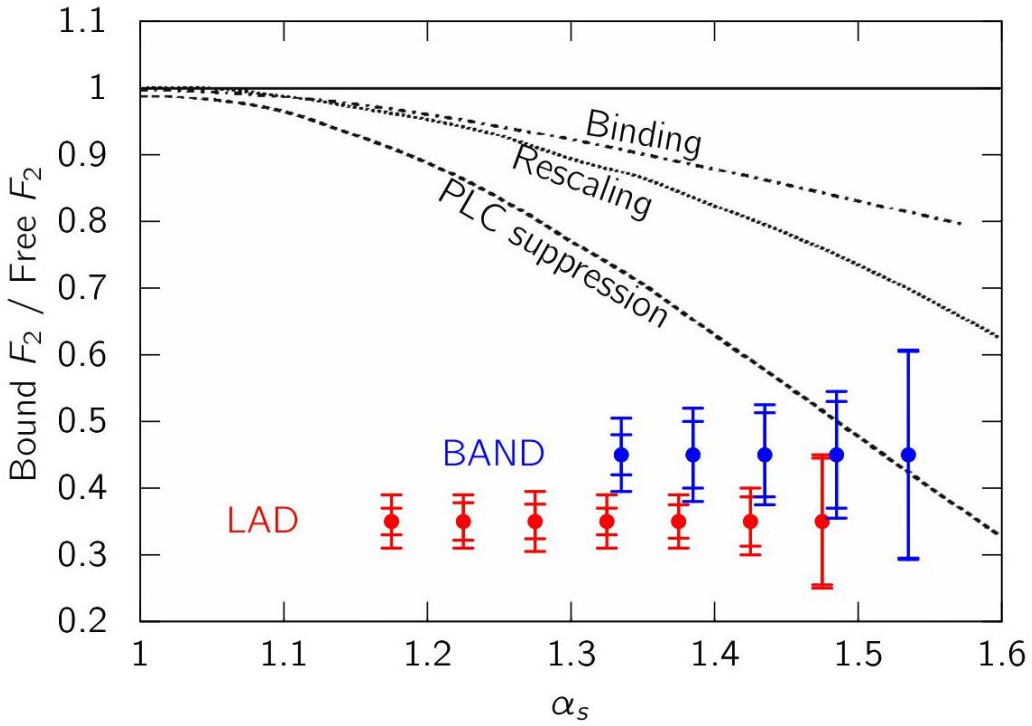
Hauenstein et al., EPJA (2024)

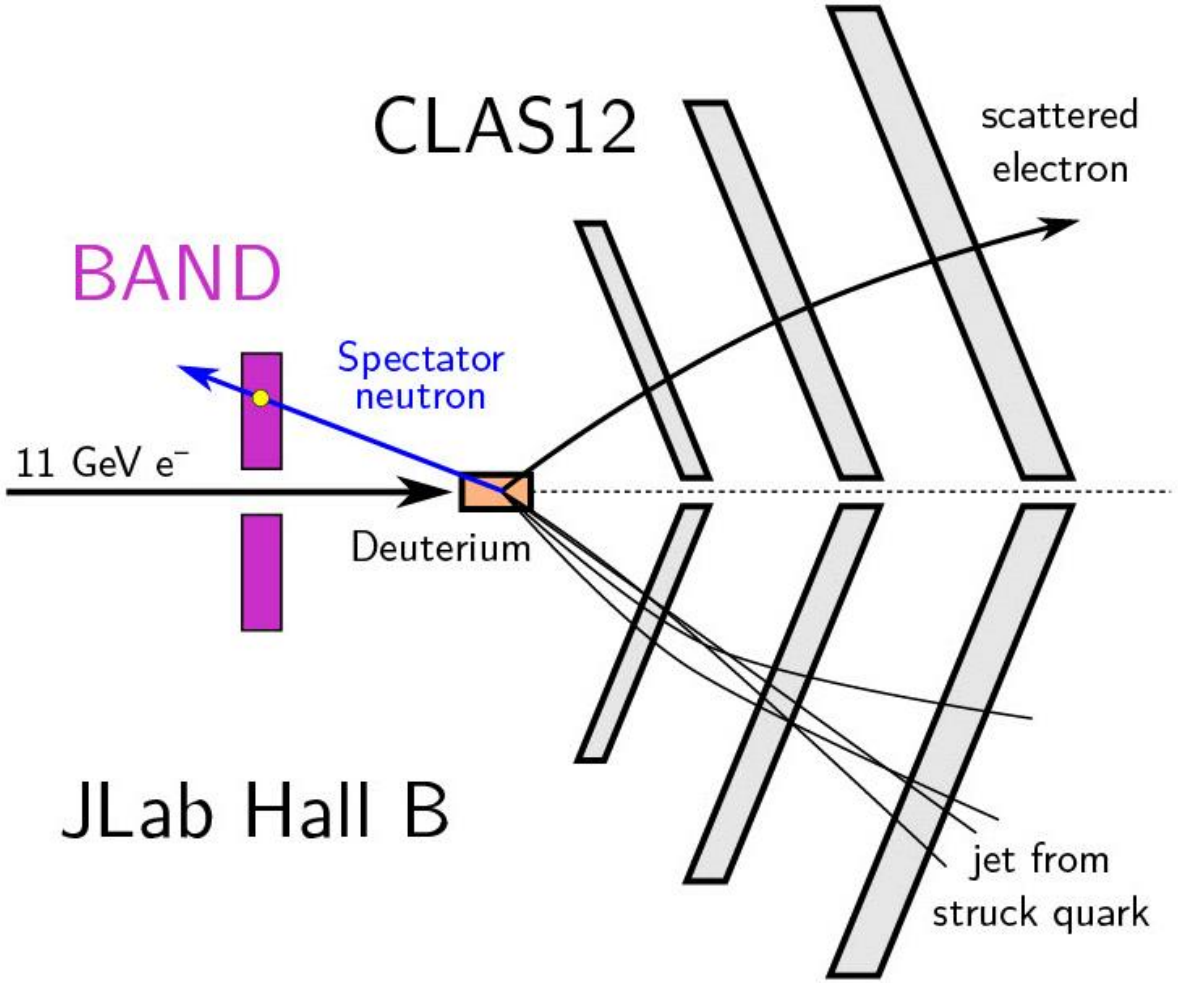




Backwards Angle Neutron Detector (BAND)

- Recoil neutron
  - Measure proton F_2
- Took data 2019/2020





Thank you











Thank you & Shifts!

Feb 14 – May 7 (?????)

(10 shift requirement for publication)

https://misportal.jlab.org/mis/apps/physics/shiftSchedule/index.cfm?experimentRunId=HALLC-LAD

EXPERIMENTAL HALL C

Meetings

- Hall C Winter Meeting, Jan 13-14, 2025 Registration
- NPS collaboration meeting, July 17-18, 2024
- Hall A/C Summer Meeting, July 15-16, 2024 Registration
- Hall C Winter Meeting, Jan 18-19, 2024
- Previous meetings
- User Working Group meetings

Run Information - Jan 2025 - July 2025

- LAD Shift Sign-up (Read-only Shift Schedule)
- Hall C Electronic Logbook
- Run Safety Documents