# CIPANP 2018, Palm Springs

## New Measurements of the EMC Effect in Hall-C

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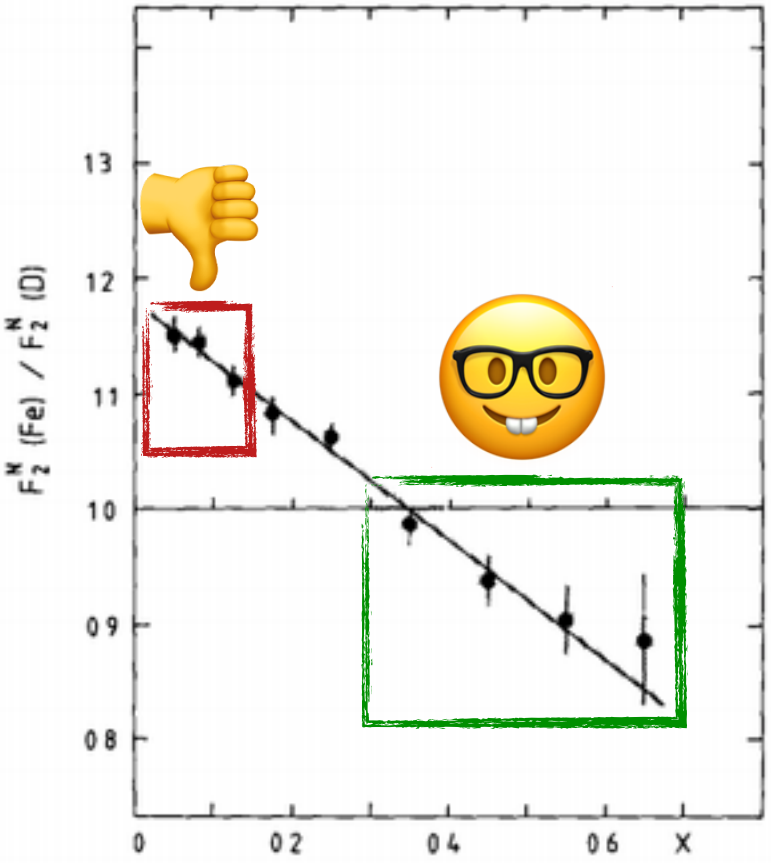
Jefferson Lab

05/30/2018

On Behalf of the F2/EMC Working Group

# EMC Effect

- The EMC effect has been heavily studied over the past 35 years
- First observed by the European Muon Collaboration (1983)
  - $F2_n$ for Fe and D
  - Ratio of DIS cross sections is not unity
  - Enhancement at x < 0.1 not observed in later experiments




JJ Aubert, et al., PLB, 123, 275-278, (1983)

# EMC Effect

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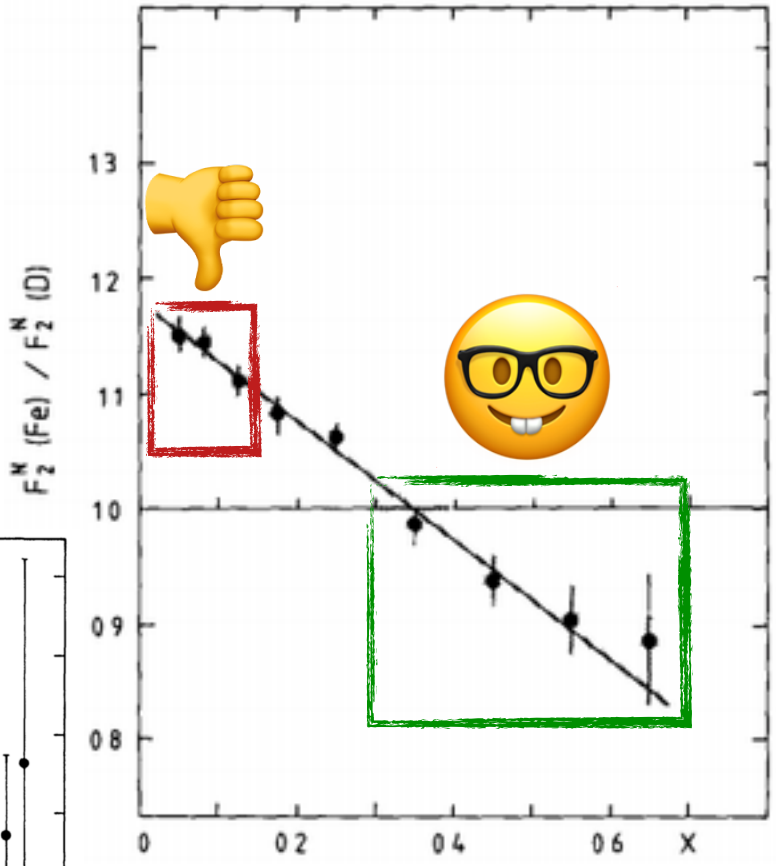
- First observed by the European Muon Collaboration (1983)
- Data mining of SLAC data ($^2$H, Al, Fe) revealed depletion in the EMC regime
- Enhancement at x < 0.1 not observed

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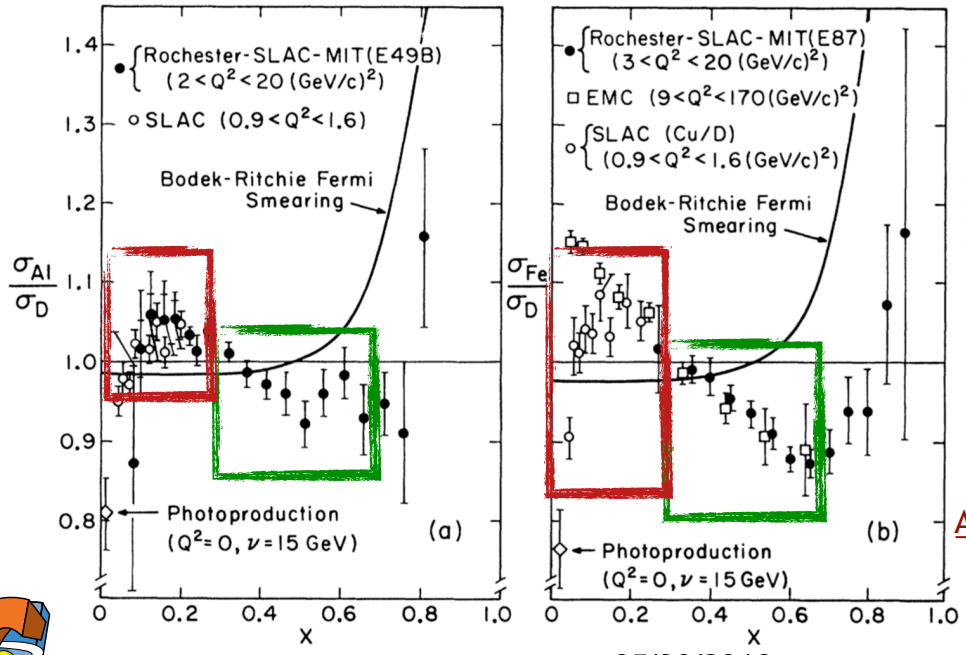
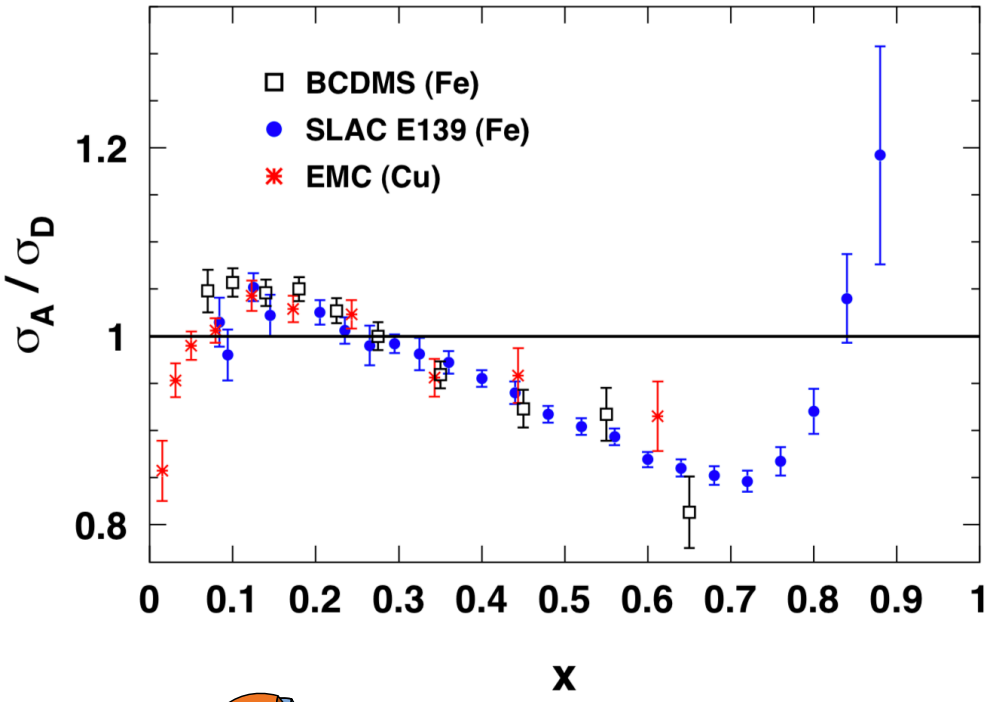
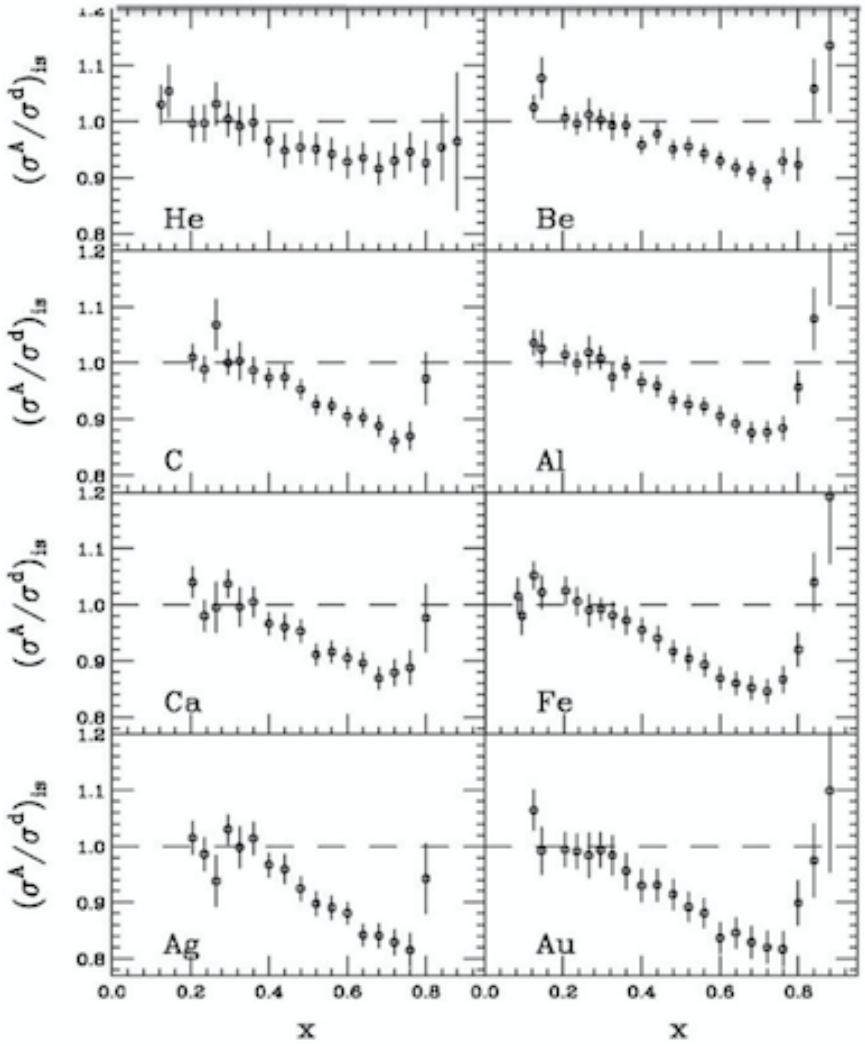



A. Bodek, et al., PRD, 50, 1431, (1983)

# EMC Effect

- SLAC E139 (1993) measured $\sigma_A/\sigma_D$ for a variety of nuclei ranging from A=4 to A=197
- The shape has universal x dependence




J. Gomez, et al., PRD, 4348-4372, (1994)

# EMC Effect

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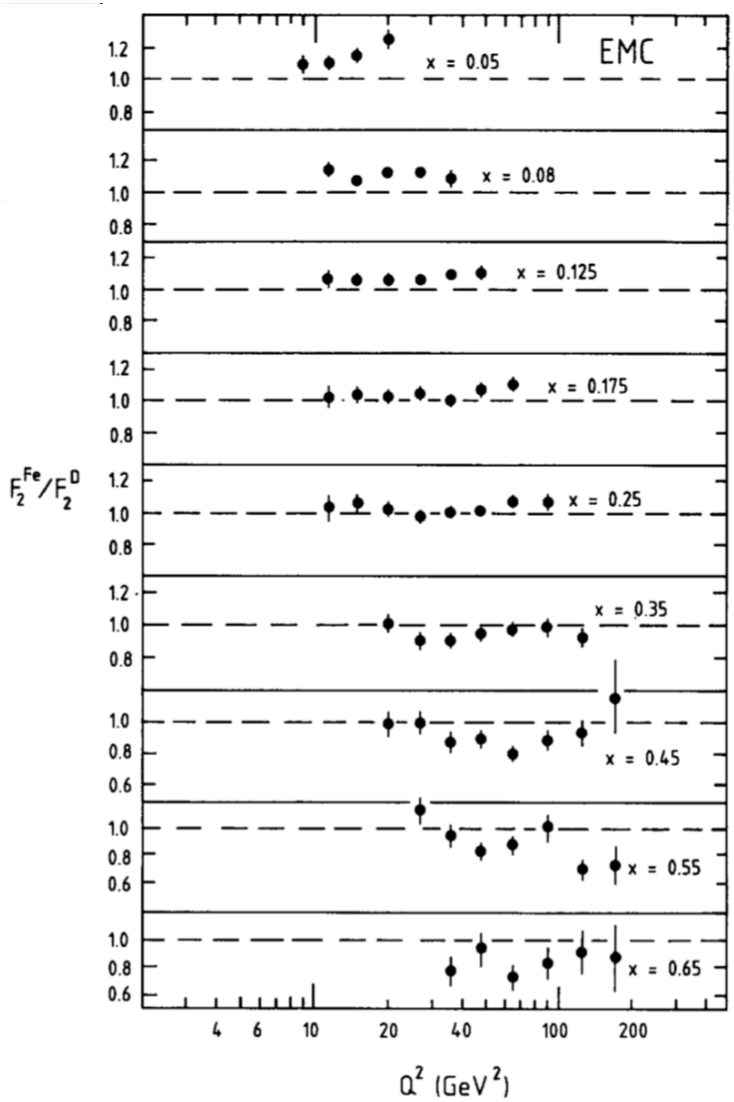
- The shape has universal x dependence
- $Q^2$ independent

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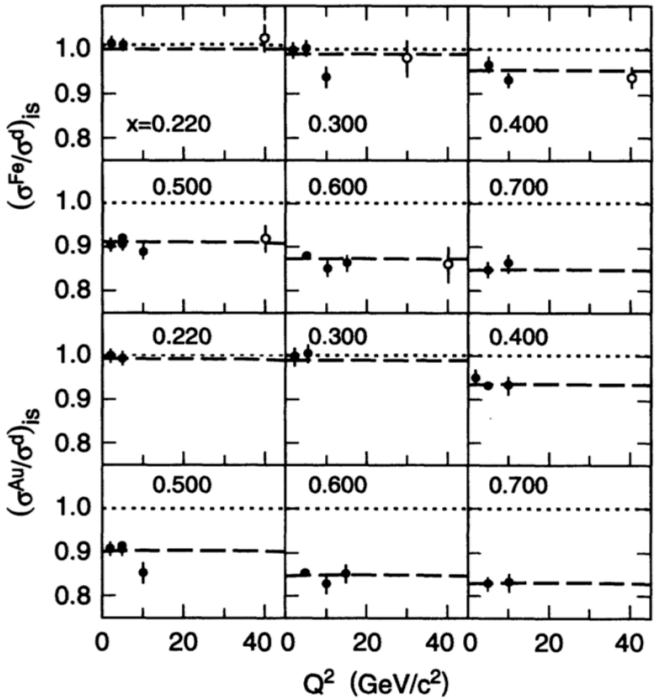
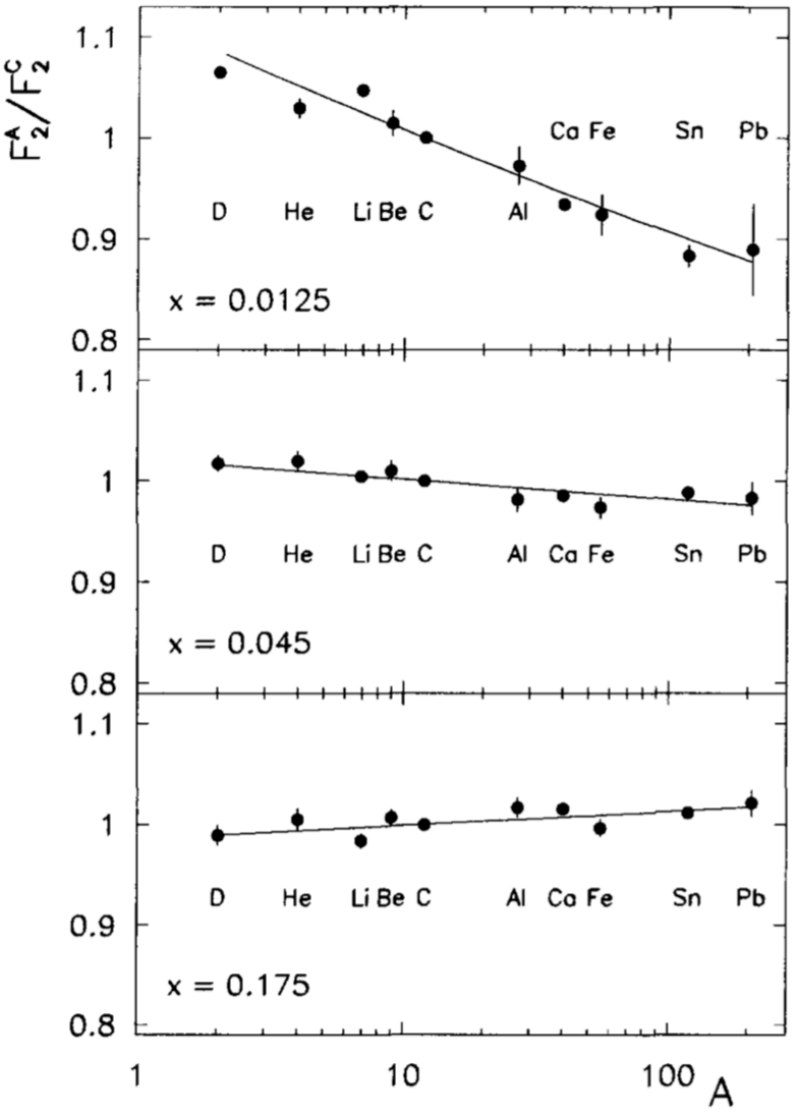


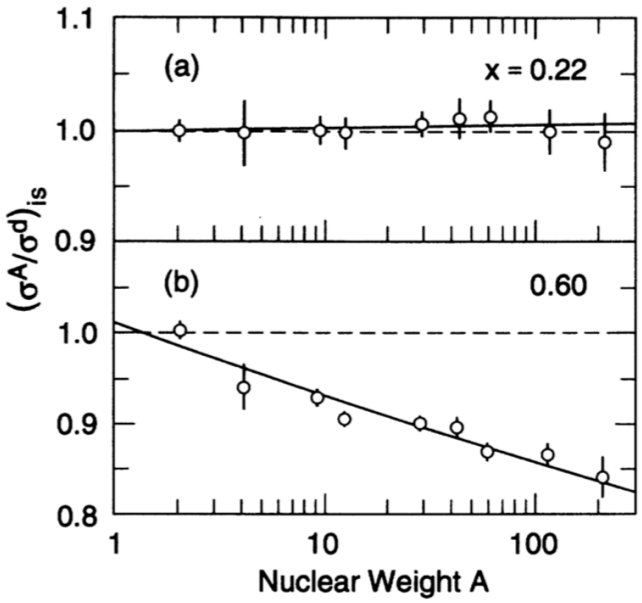

JJ Aubert, et al., Nucl. Phys. B, 293, 740, (1997)

# EMC Effect

- SLAC E139 (1993) measured $\sigma_A/\sigma_D$ for a variety of nuclei ranging from A=4 to A=197
- The shape has universal x dependence
- $Q^2$ independent
- The magnitude varies with A

M. Arneodo, et al., Nucl. Phys. B, 481, 3, (1996)

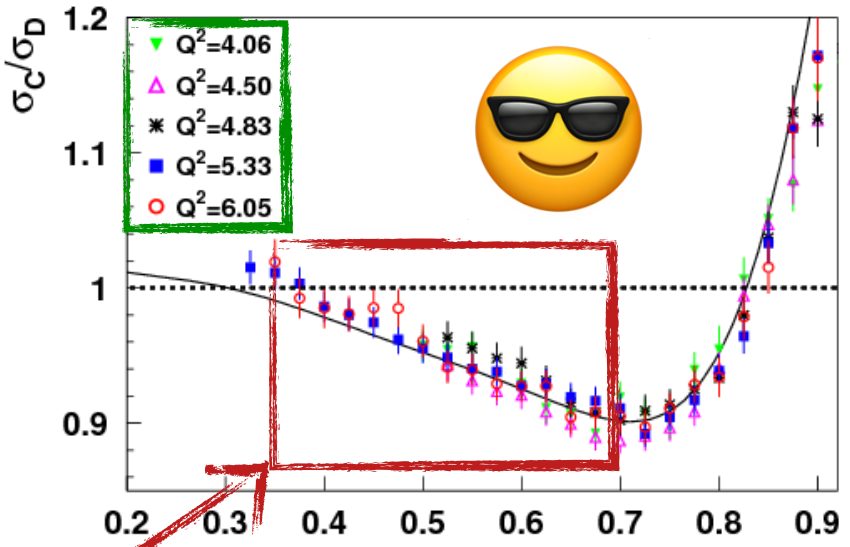


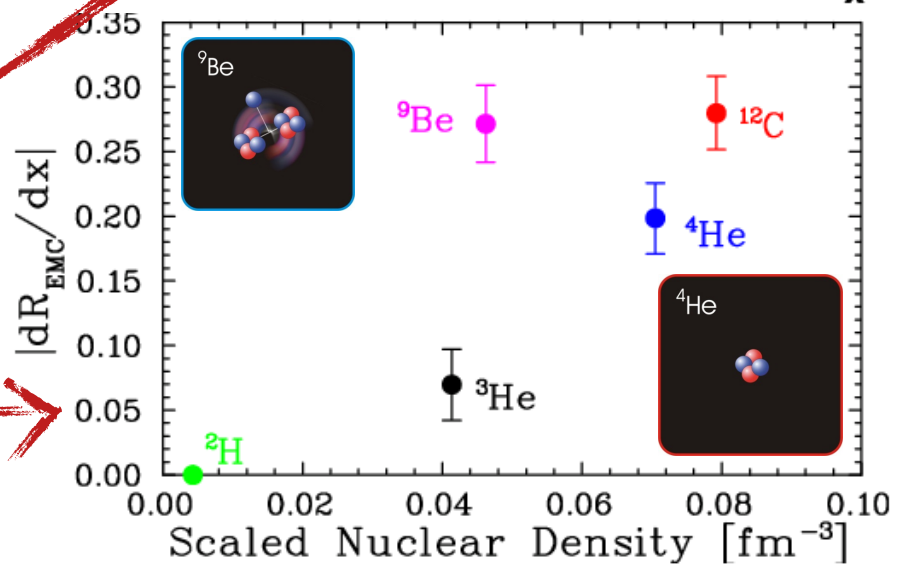

J. Gomez, et al., PRD, 4348-4372, (1994)

# EMC Effect at 6 GeV

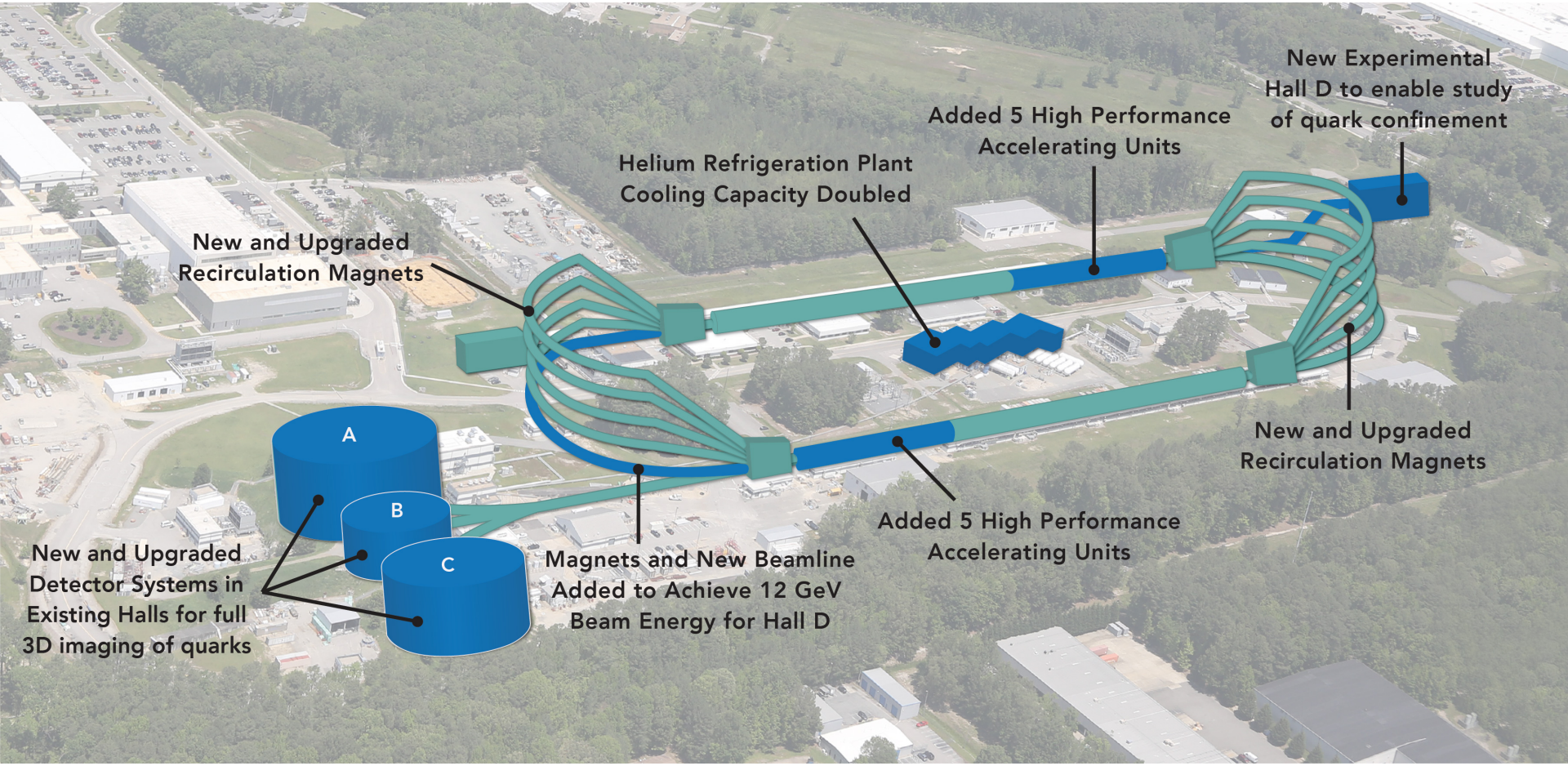
- JLab E03-103 (2004)
  - Measured the nuclear dependence of the inclusive cross section of a variety of light nuclei
    - $^2$H, $^3$He, $^4$He, $^9$Be,$^{12}$C
    - 0.3 < x < 0.9
    - $Q^2 \approx$ 3-6 GeV$^2$
  - Quantified slope of $\sigma_A/\sigma_D$ in the EMC region
  - EMC effect is correlated with local density and not average density




J. Seely, et al., PRL,103, 202301 (2009)



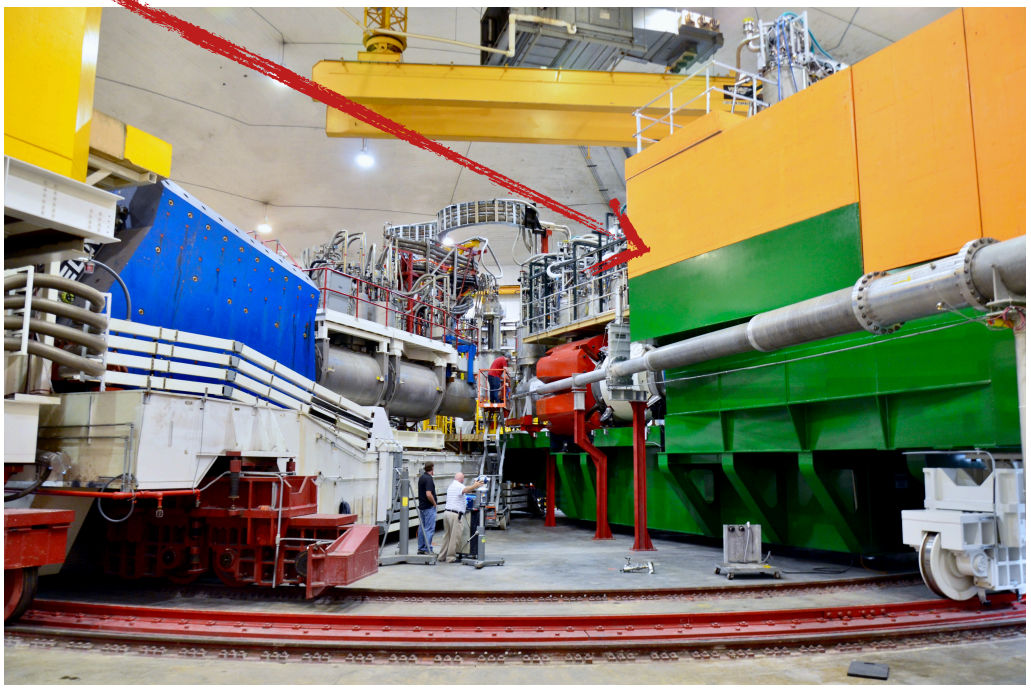
# Jefferson Lab 12 GeV Upgrade



# Hall C 12 GeV Upgrade

- Super High Momentum Spectrometer
  - HB, 3 Quads, Dipole
  - P ➛ 2 - 11 GeV
  - Resolution: δ < 0.1%
  - Acceptance: δ ➛30%, 4 msr
  - 5.5° < θ < 40°
  - Good e/π/K/p PID
- High Momentum Spectrometer
  - 3 Quads, Dipole
  - P ➛ 7.5 GeV
  - Resolution: δ < 0.1%
  - Acceptance: δ ➛18%, 6.5 msr
  - 10.5° < θ < 90°
  - Good e/π/K/p PID
- Minimum opening angle ~17°

- Well shielded detector huts
- 2 beam line polarimeters
- Ideal facility for:
  - Rosenbluth (L/T) separations
  - Exclusive reactions
  - Low cross sections (neutrino level)



# Hall C: SHMS & HMS

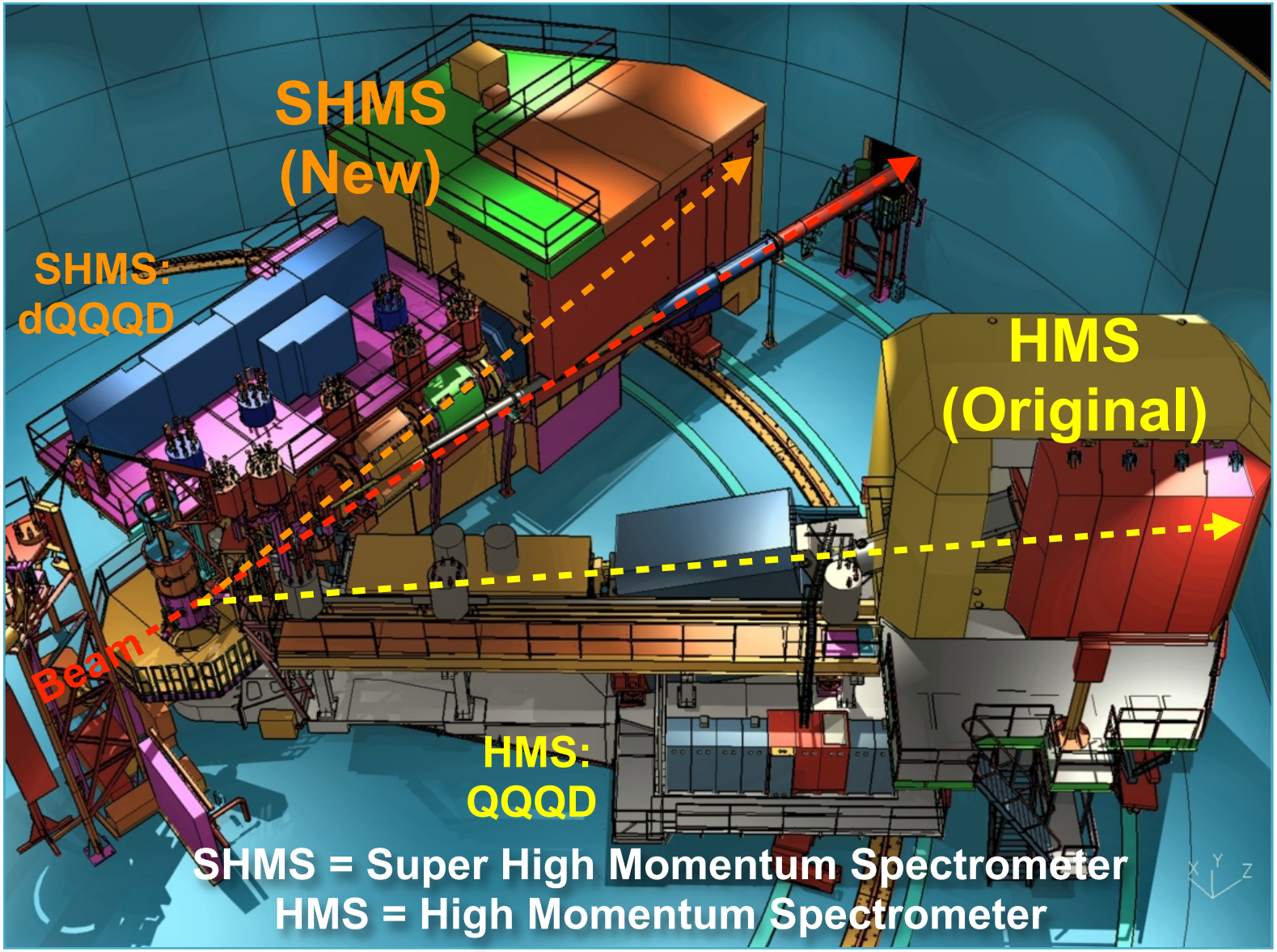
**SHMS:**
- 11-GeV Spectrometer
- Partner of existing 6–GeV **HMS**

**MAGNETIC OPTICS:**
- Point-to Point QQQD for easy calibration and wide acceptance.
- Horizontal bend magnet allows acceptance at forward angles (5.5°)

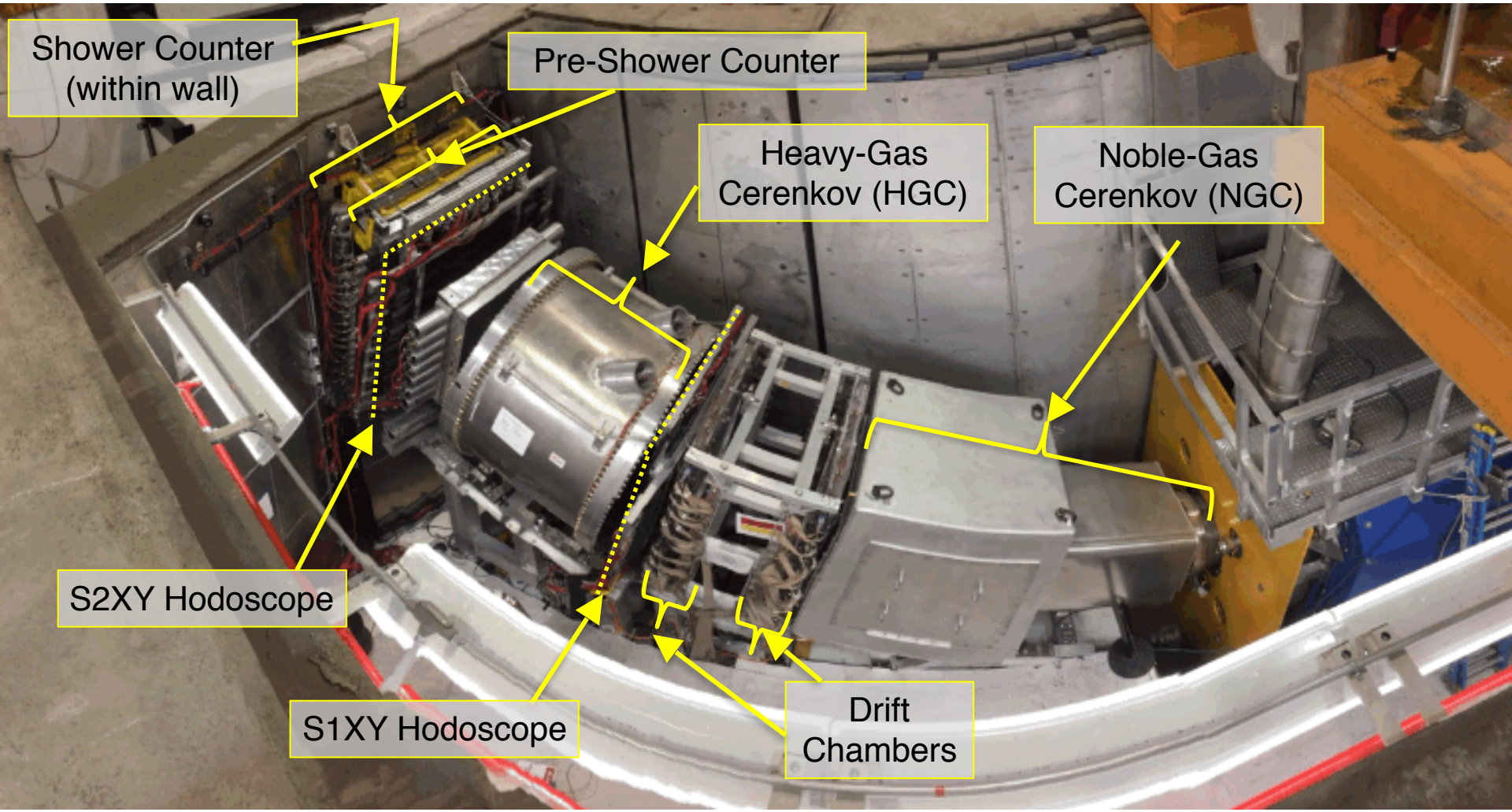
**Detector Package:**
- Drift Chambers
- Hodoscopes
- Cerenkovs
- Calorimeter
- All derived from existing HMS/SOS detector designs

**Well-Shielded Detector Enclosure**

**Rigid Support Structure**
- Rapid & Remote Rotation
- Provides Pointing Accuracy & Reproducibility demonstrated in HMS



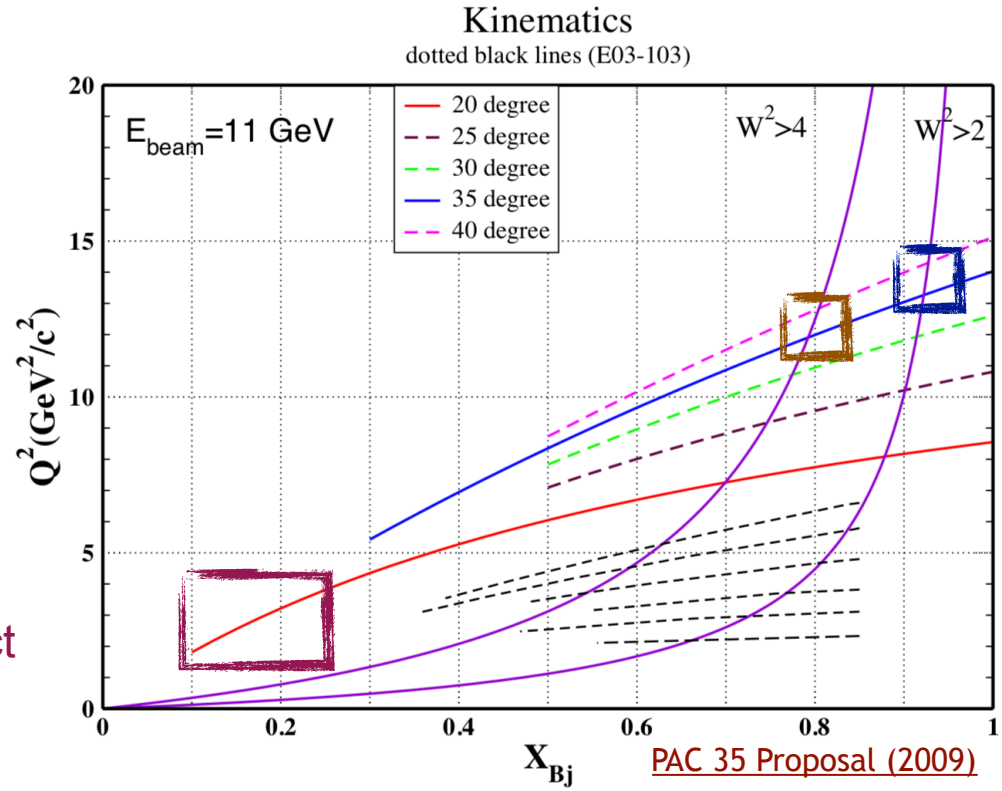
# SHMS Detector System



# EMC Effect at 12 GeV: E12-10-008

- E12-10-008: Detailed studies of the nuclear dependence of $F_2$ in light nuclei
- Inclusive electron scattering measurements from several nuclei over a broad range in x
  - $0.1 < x < 0.9$
  - Up to $Q^2 \approx 15$ GeV$^2$
  - Light nuclei: $^{1}$H, $^{2}$H, $^{3}$He, $^{4}$He, $^{6,7}$Li, $^{9}$Be, $^{10,11}$B, $^{12}$C
  - Medium/Heavy nuclei: Al, $^{40,48}$Ca, Ti, $^{54}$Fe, $^{58,64}$Ni, Cu, Ag, Sn, Au, Th
- 11 GeV beam increases the region of precise scaling
  - $x = 0.6 \rightarrow 0.8$ for $W^2 > 4$ GeV$^2$
  - $x \rightarrow 0.92$ for $W^2 > 2$ GeV$^2$
- Data as $x \rightarrow 0.1$ will facilitate the comparison of the shape of the EMC effect on light nuclei

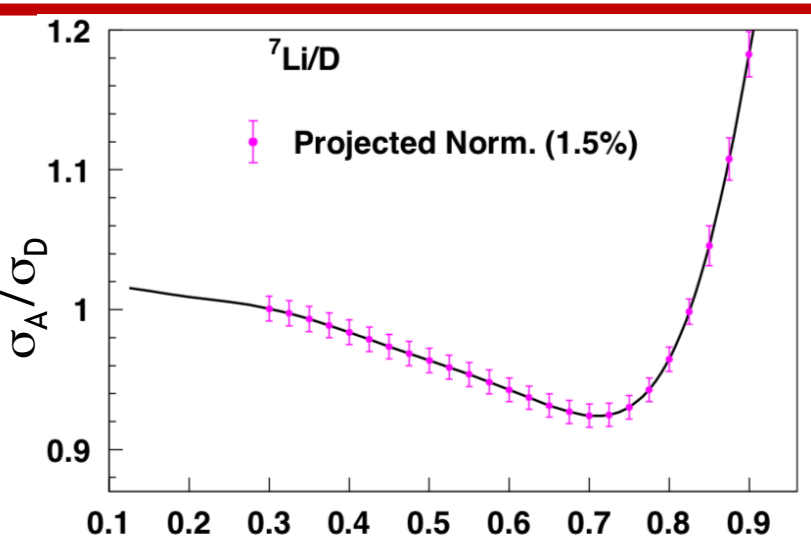
- All targets taken at $\theta = 20^\circ$ in order to test for nuclear dependence
  - Larger $Q^2$ than 6 GeV measurements
- A subset of large $\theta$ provides for $Q^2$ dependence tests while pushing to large x



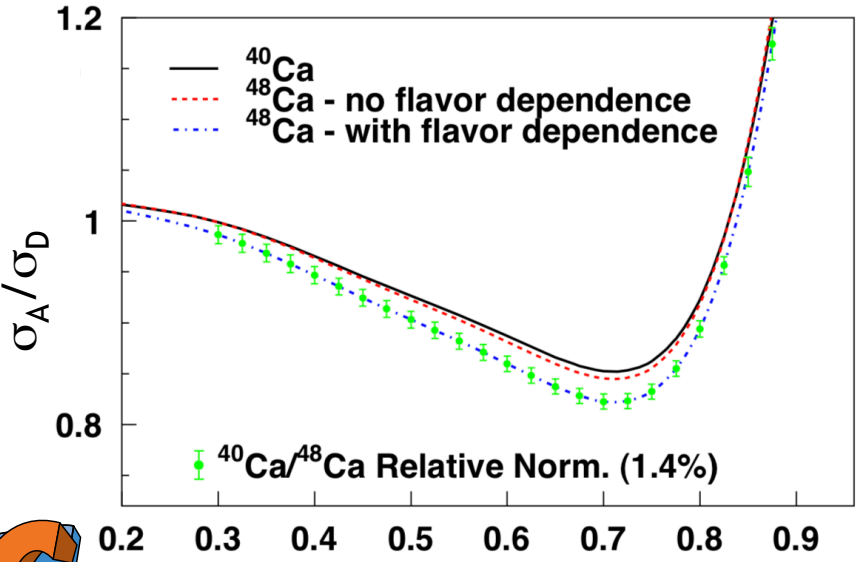

PAC 35 Proposal (2009)

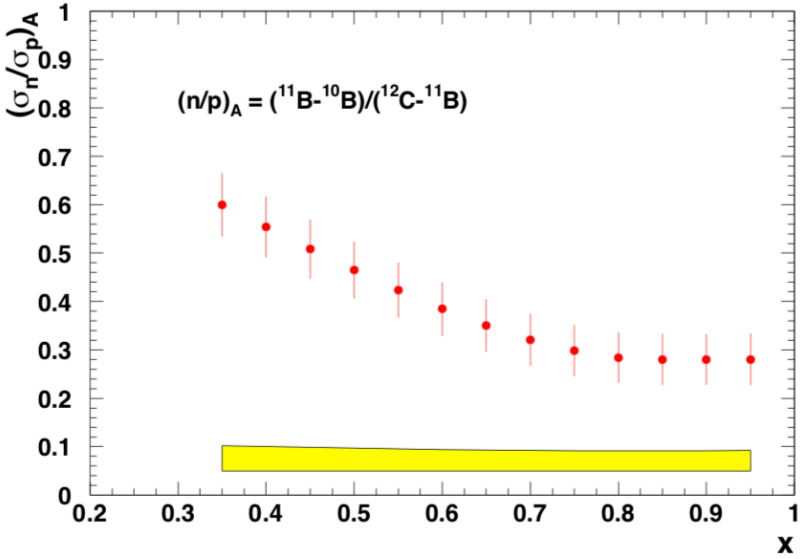
# E12-10-008: Looking Forward

- E12-10-008 will provide new data on previously unmeasured nuclei which are subject to significant clustering behavior
  - $^{6,7}$Li yields large differences between scaling with A and local density
- Extraction of single nucleon structure functions & n/p ratios
  - $^{6}$Li-$^{7}$Li, $^{10}$B-$^{11}$B, $^{11}$B-$^{12}$C
- Probe flavor dependence of the EMC effect with measurements on $^{40,48}$Ca
  - Provides significant variation in the n/p ratio in the nucleus while maintaining similar mass and density




PAC 35 Proposal (2009)



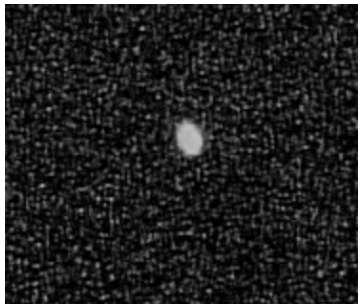



# E12-10-008: Commissioning Run

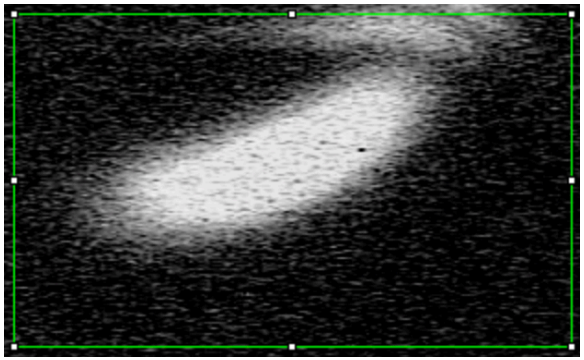
- E12-10-008 ran congruently with a group of 4 commissioning experiments which started 2/01/18
- First data was collected for E12-10-008 on 2/20/18 with both the HMS & SHMS
- Conducted in parallel with E12-10-002: Inclusive H,D(e,e')
- The commissioning run period for E12-10-008 lasted ≈ 76 hrs
- $E_{beam}$ = 10.589 GeV, θ = 21°

| SHMS P (GeV) | $x_{Bj}$ | $Q^2$ (GeV²) |
|---|---|---|
| -2.7 | 0.25 | 3.79 |
| -3.3 | 0.34 | 4.64 |
| -4.0 | 0.45 | 5.62 |
| -5.1 | 0.69 | 7.16 |

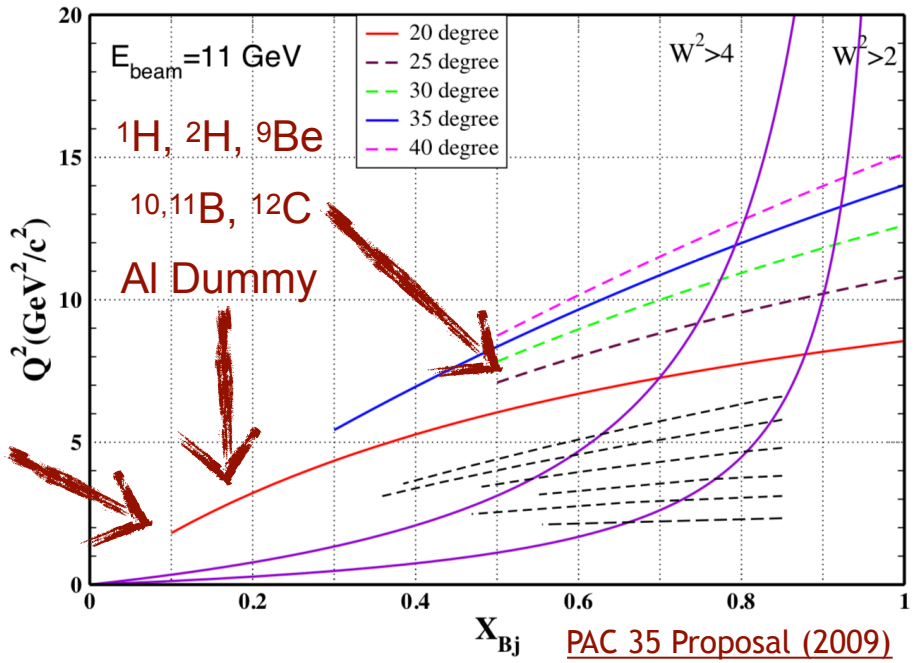
YAG



Beam Dump

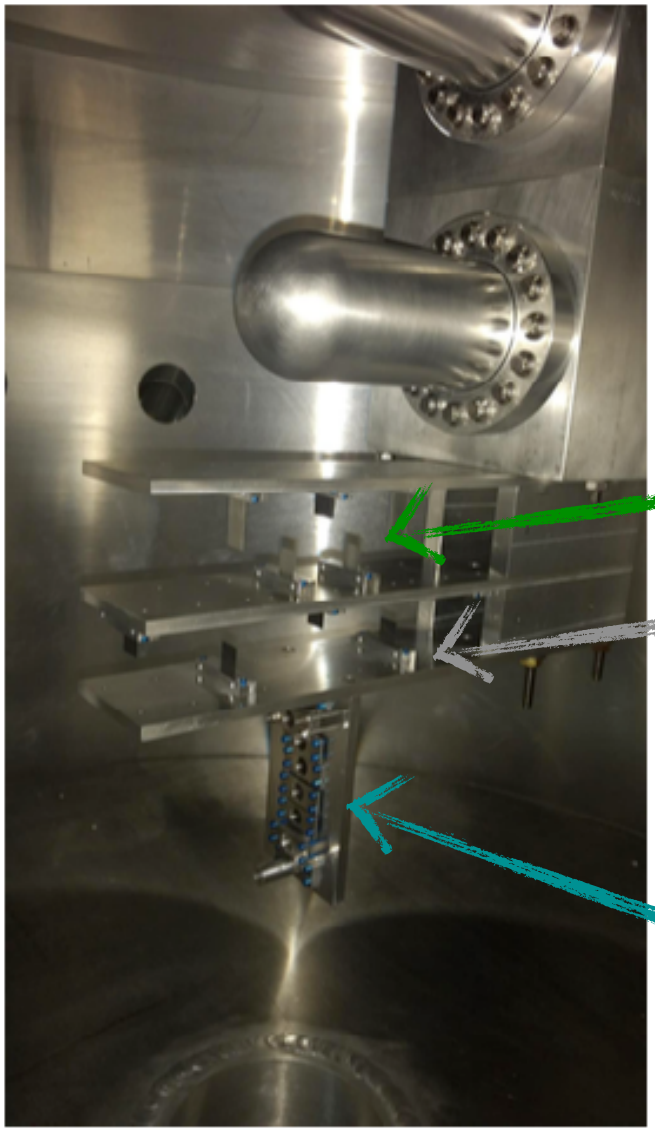


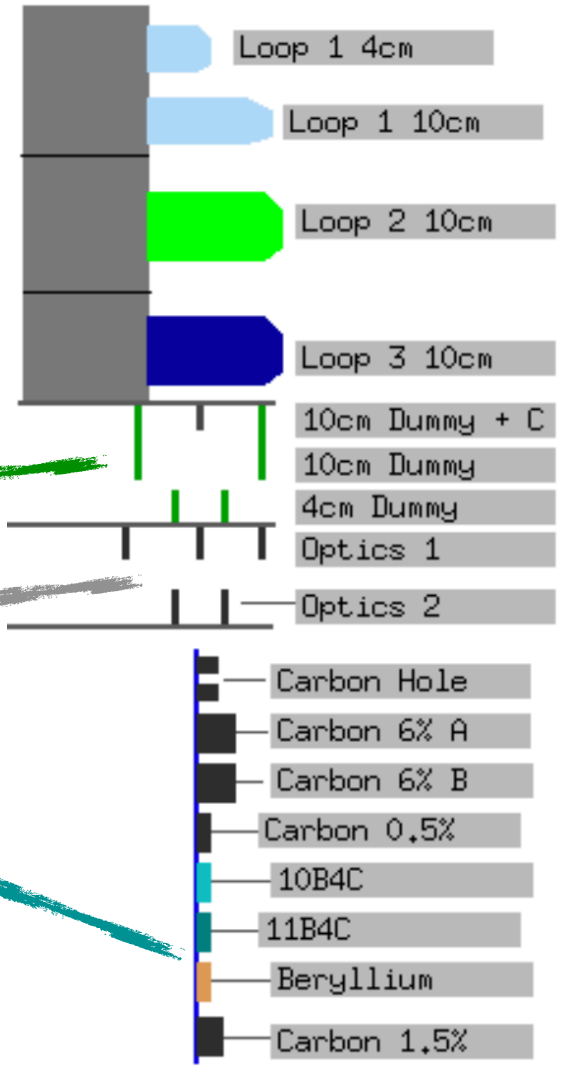
Kinematics
dotted black lines (E03-103)

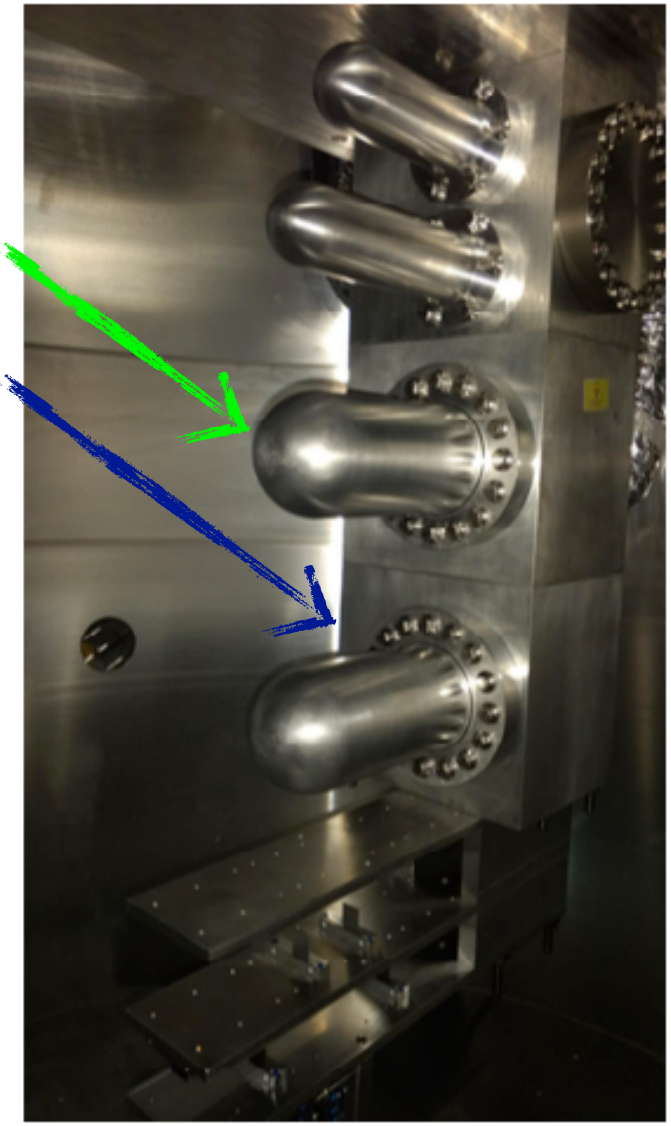



PAC 35 Proposal (2009)

# E12-10-008: Target Ladder

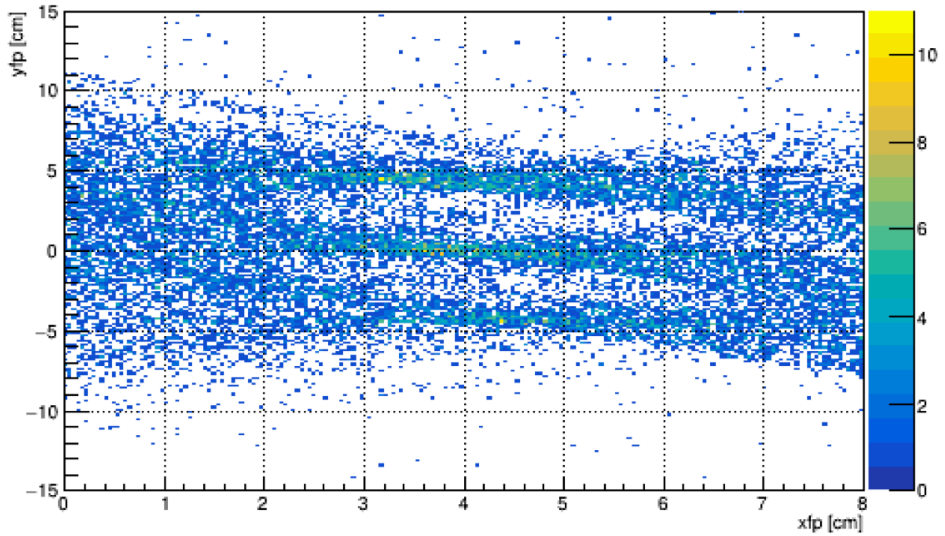




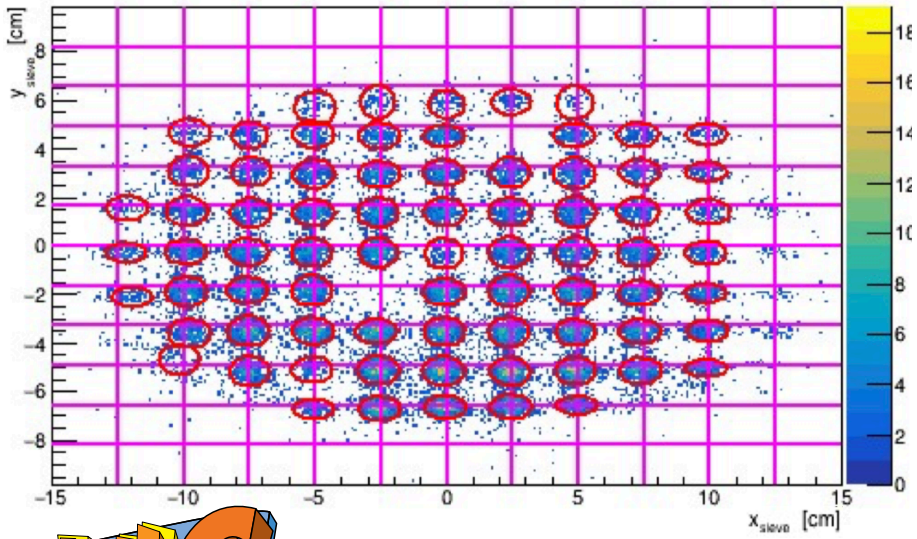



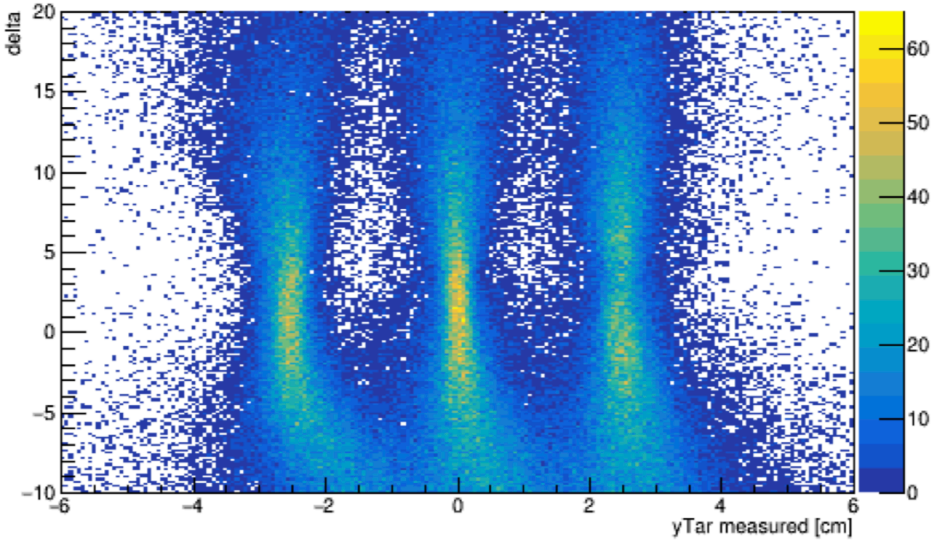
# E12-10-008: SHMS Optics

- Events at the interaction point are reconstructed with focal plane quantities and COSY model
- Event selection conducted via utilizing the central sieve
- Minimization procedure determines the optimized reconstruction matrix elements



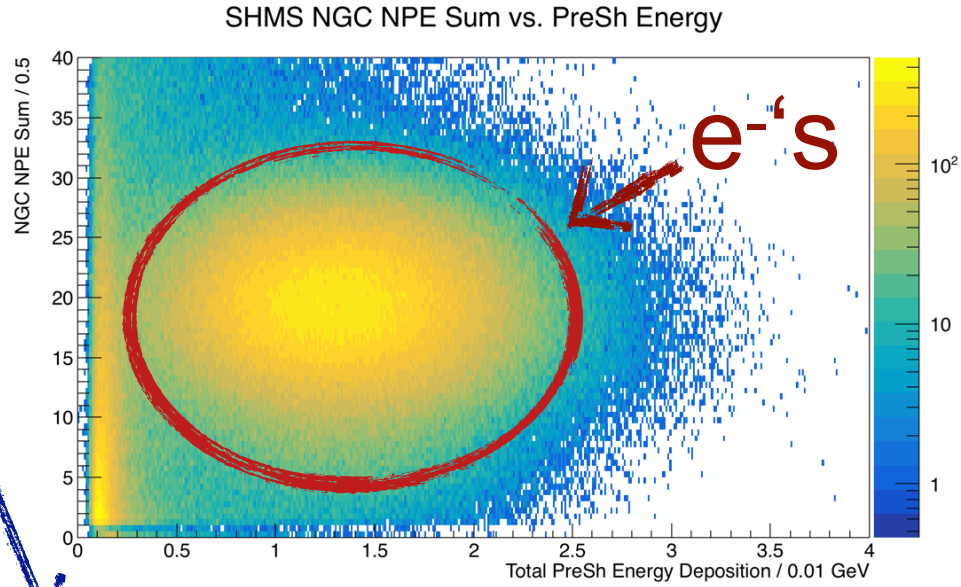

Plots Courtesy of H. Szumilla

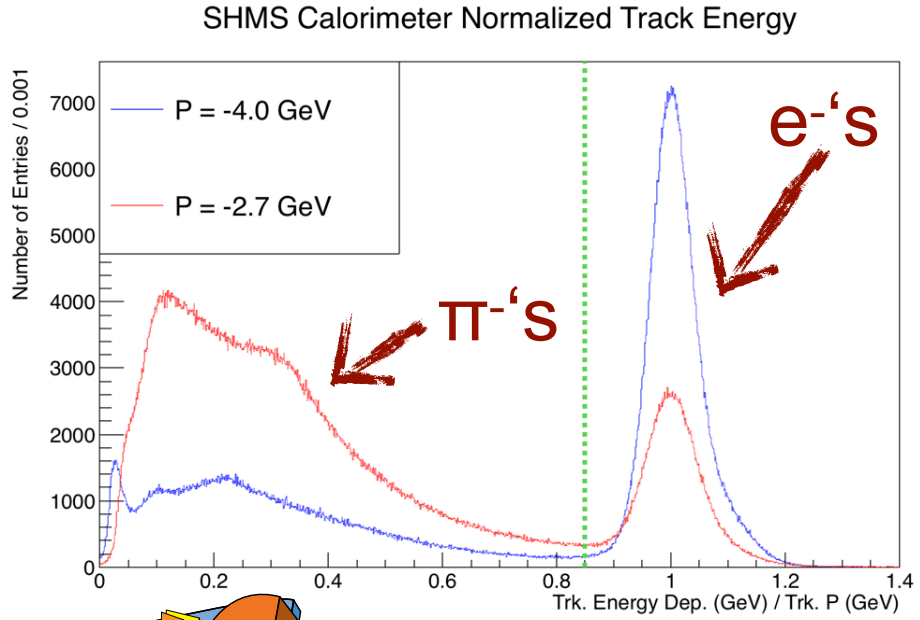


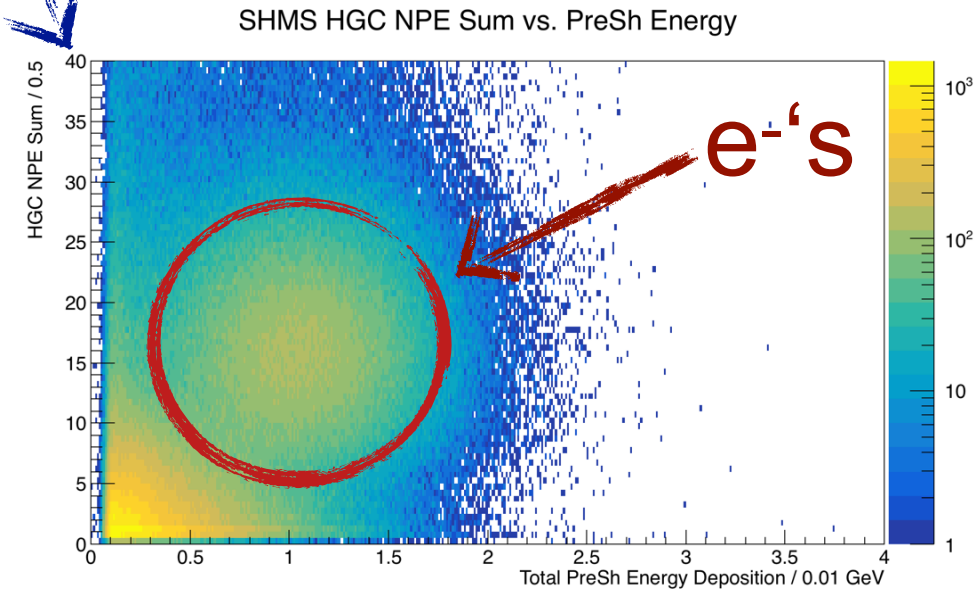



# E12-10-008: SHMS PID

- Ar Noble Gas Cherenkov
- $C_4F_8O$ Heavy Gas Cherenkov
- Lead Glass Calorimeter
  - Planar Pre-Shower (28)
  - Fly's Eye Shower (224)

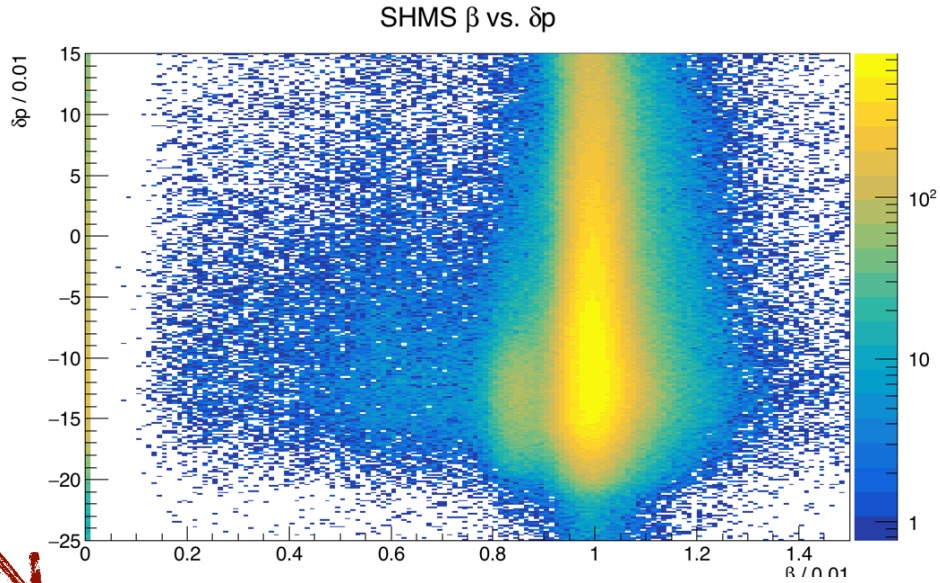


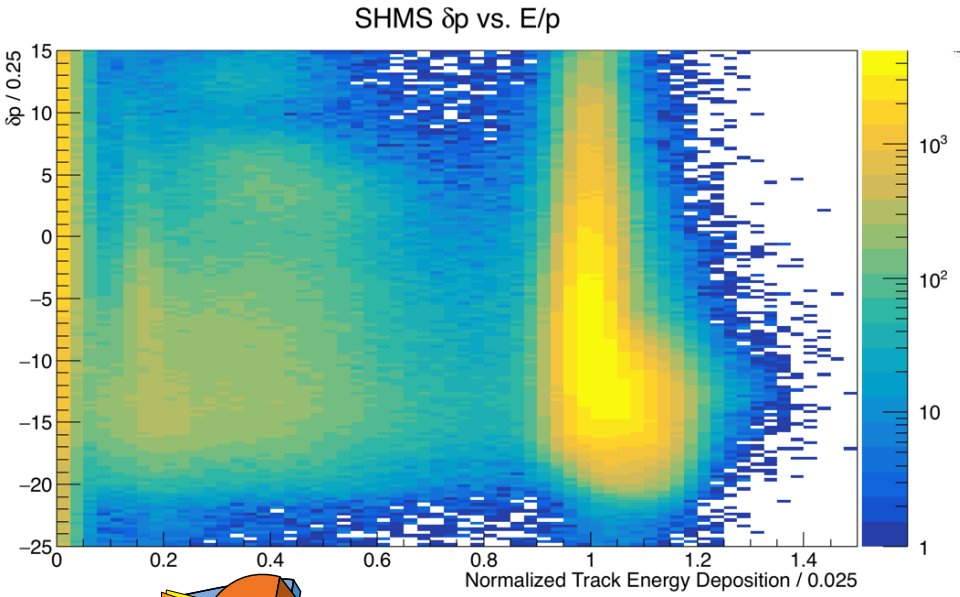



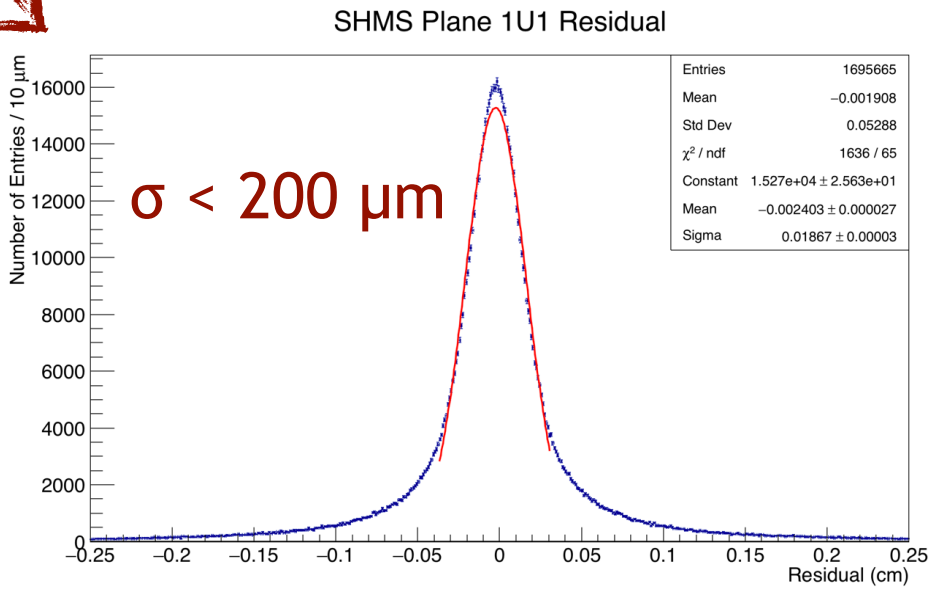



# E12-10-008: SHMS Detector Performance

- Hodoscope
  - 2-pairs of X-Y planes
- Drift chambers (x2)
  - 12 planes, U-X-V arrangement

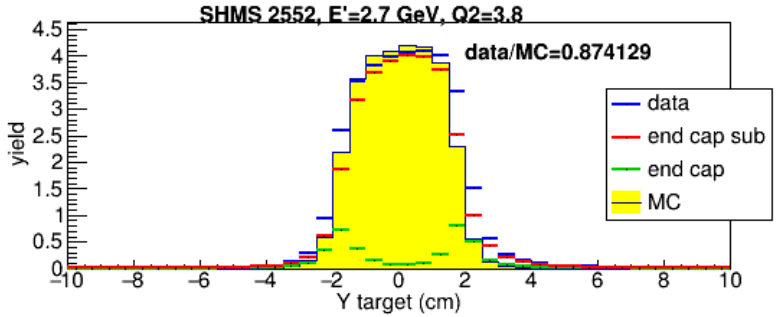


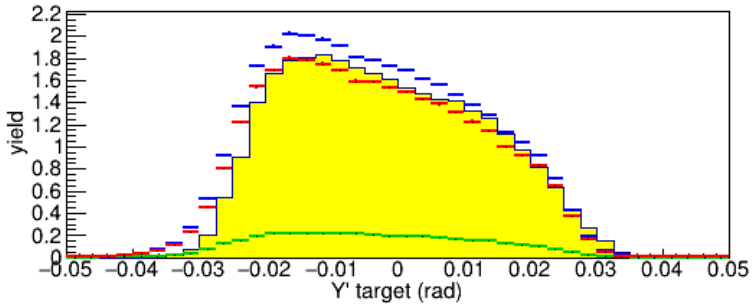



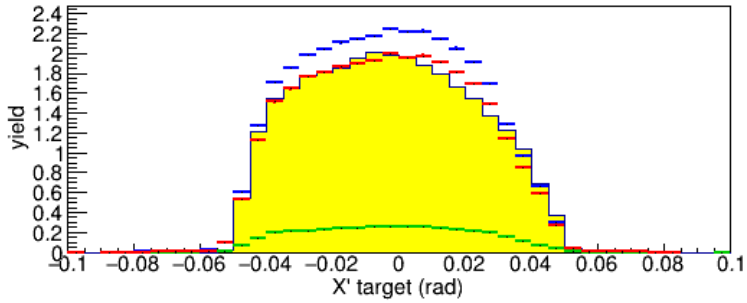



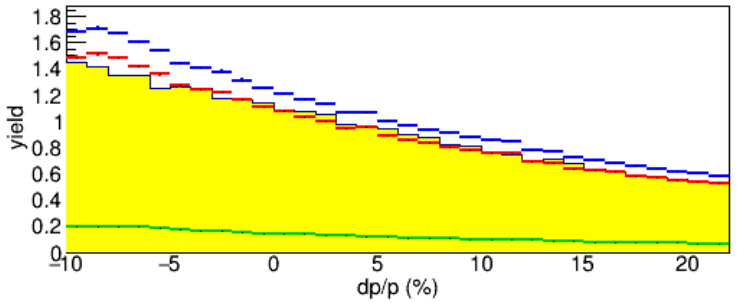
# E12-10-008: Data to Monte-Carlo Comparison

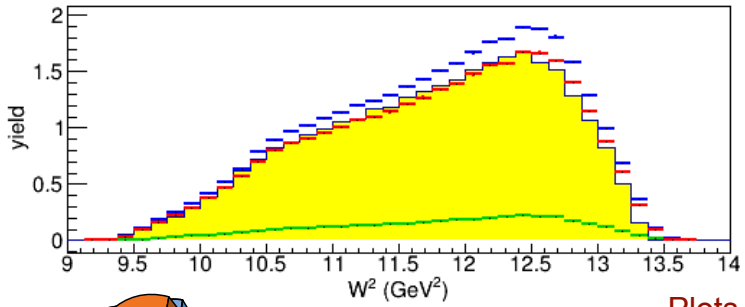
## SHMS: P = -2.7 GeV, $Q^2$ = 3.8 $GeV^2$, $LH_2$ Target

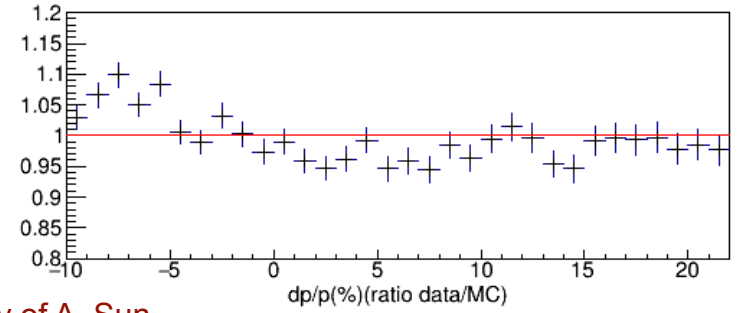


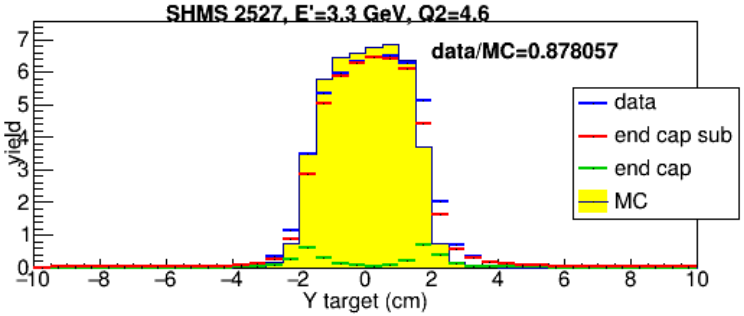



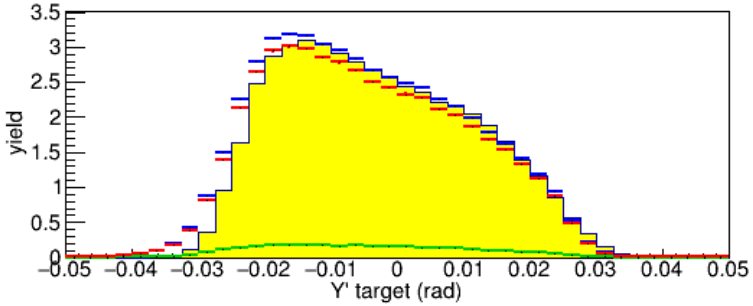



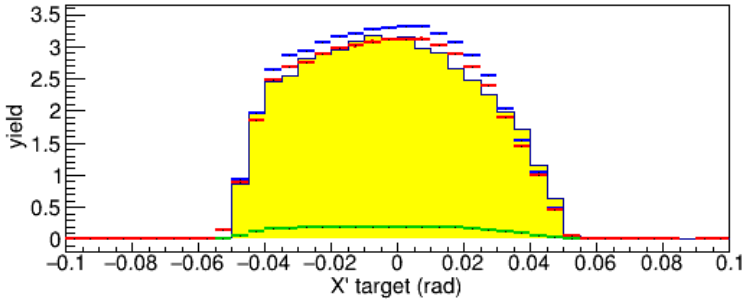

Plots Courtesy of A. Sun

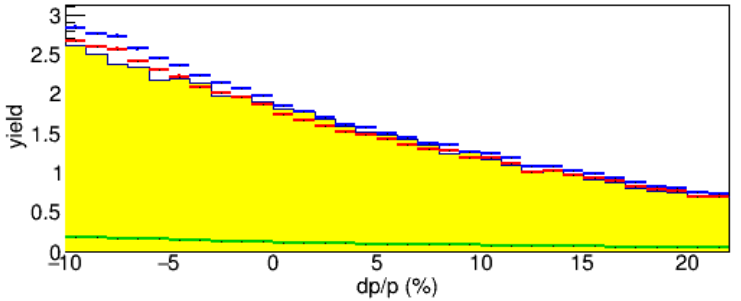
# E12-10-008: Data to Monte-Carlo Comparison

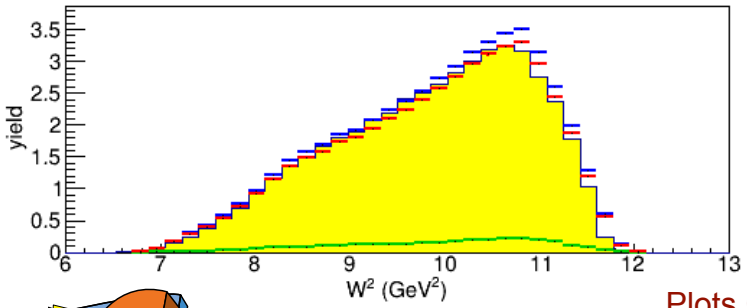
## SHMS: P = -3.3 GeV, $Q^2$ = 4.6 $GeV^2$, $LD_2$ Target

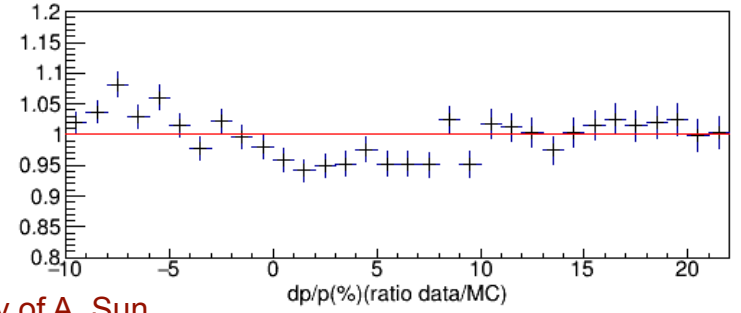


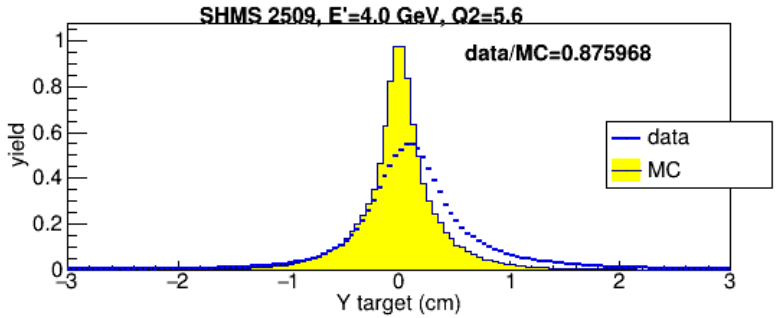



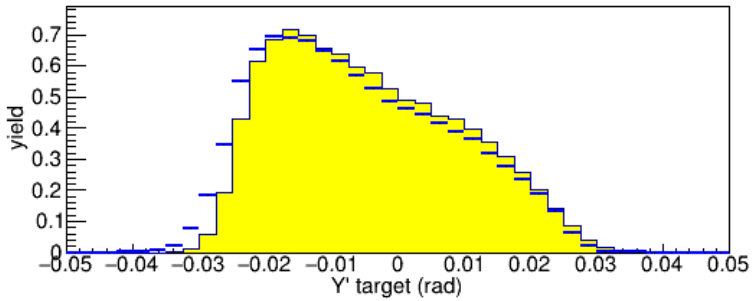



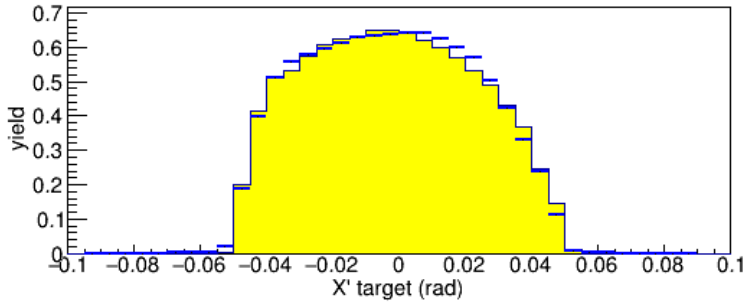

Plots Courtesy of A. Sun

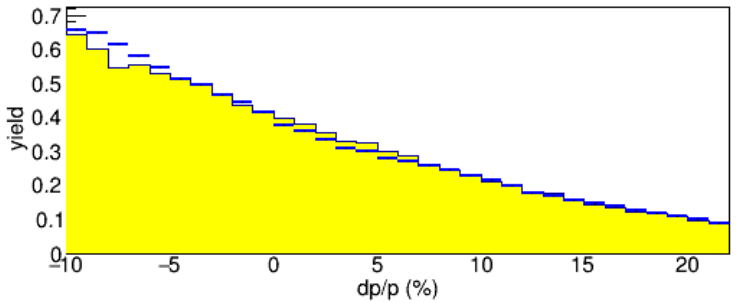
# E12-10-008: Data to Monte-Carlo Comparison

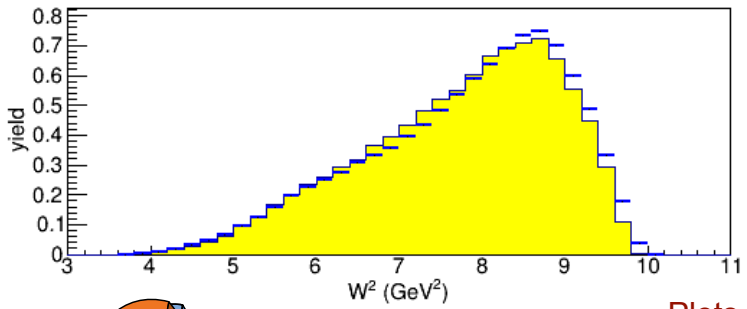
## SHMS: P = -4.0 GeV, $Q^2$ = 5.6 $GeV^2$, $C_{12}$ Target

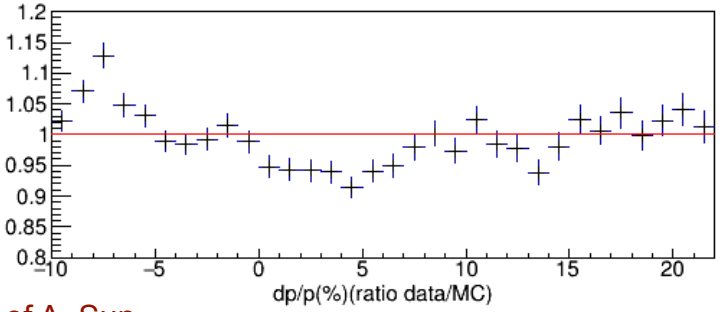


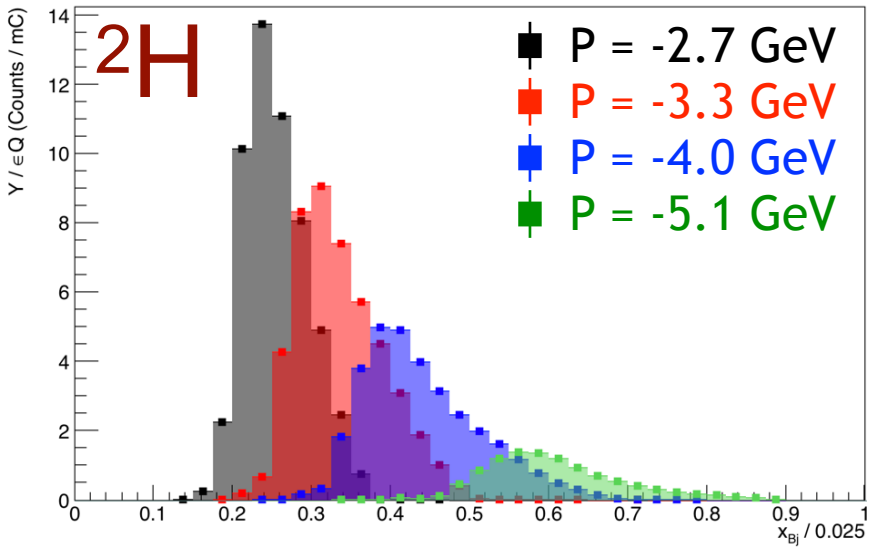



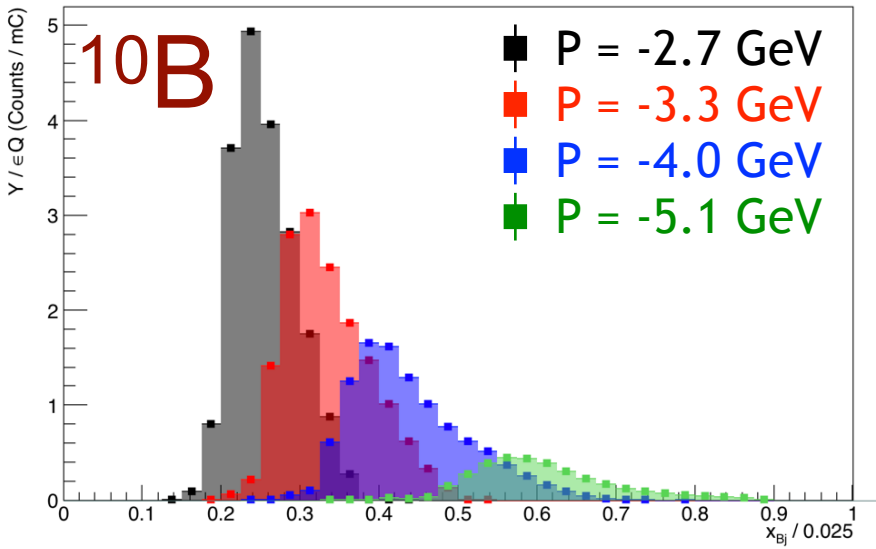



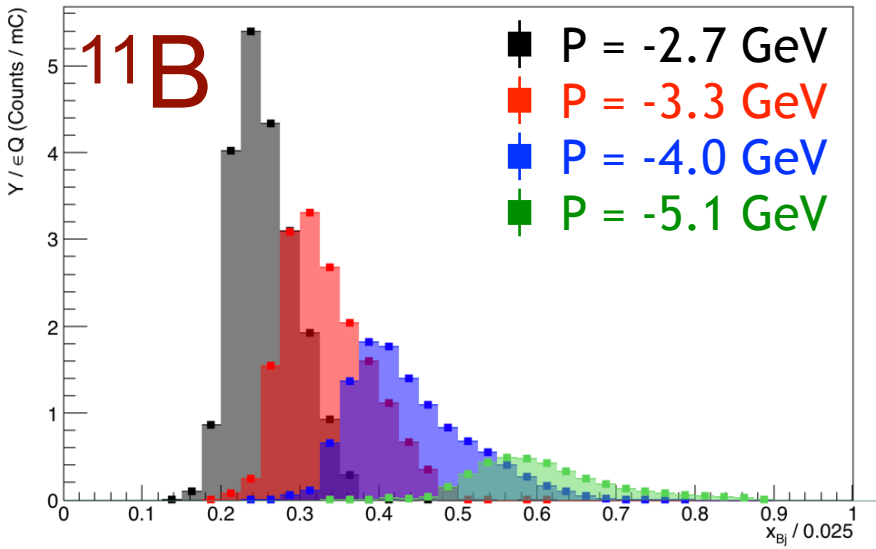




Plots Courtesy of A. Sun

# E12-10-008: SHMS Normalized Yields




- Good coverage in x (0.15 < x < 0.9)
- Sizable amount of overlap in order to understand the acceptance
- Nominal x binning (0.025) provides good statistics over a wide x range
  - < 1% statistical error

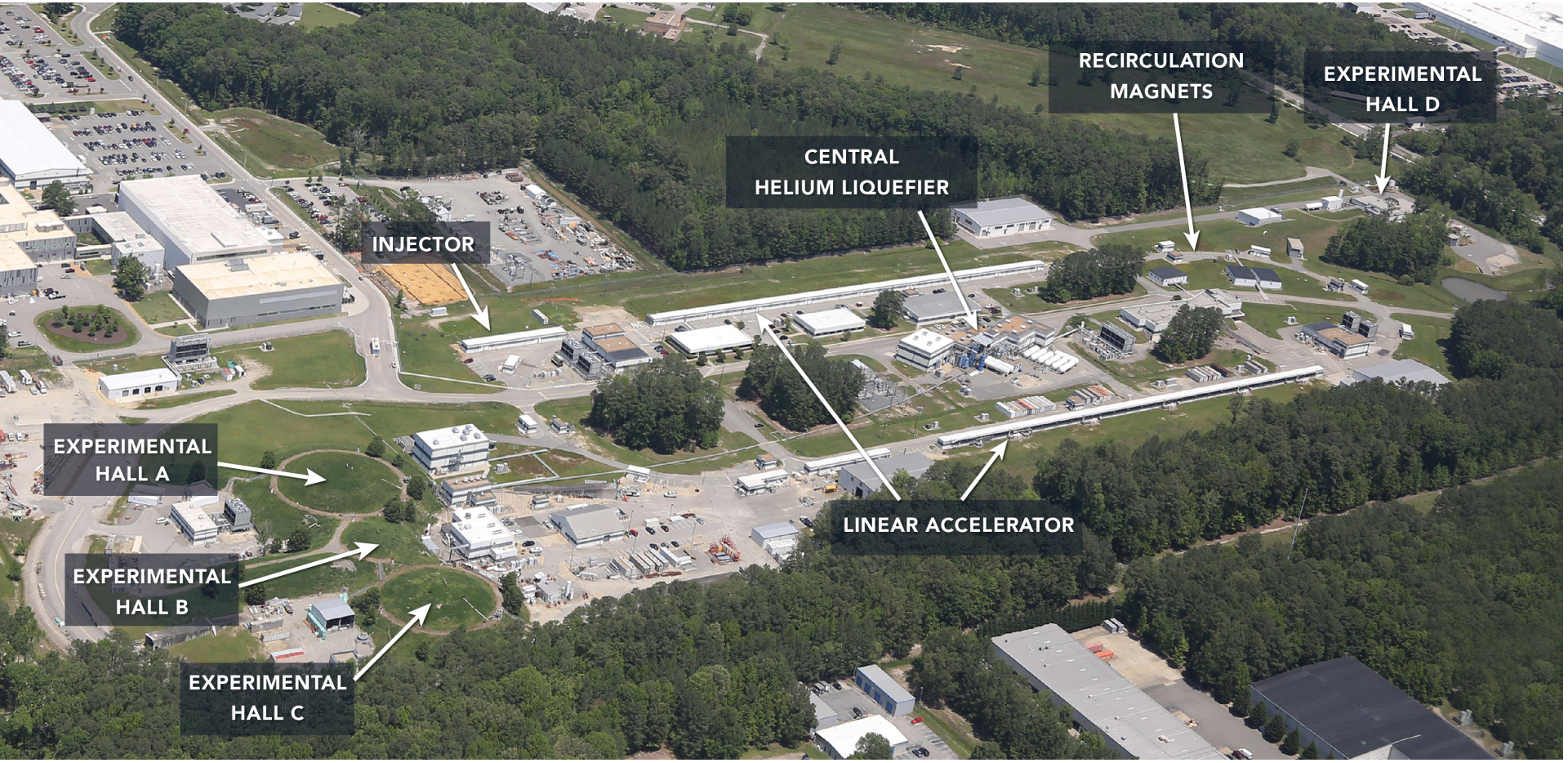
# EMC Effect at 12 GeV Summary

- Four, 12 GeV upgrade commissioning experiments were conducted in Hall-C during the Spring 2018 run
- E12-10-008 collected high statistics data on a variety of light and novel nuclei ($A \leq 12$) with both the HMS and SHMS spectrometers
  - Will provide initial measurements of $Q^2$ dependence at large x
- Initial studies indicate the all detectors performed well and good detector/tracking efficiencies have been observed
- Analysis to better understand efficiencies and acceptance effects in both spectrometers are being actively pursued
- Extraction of EMC ratios is currently ongoing

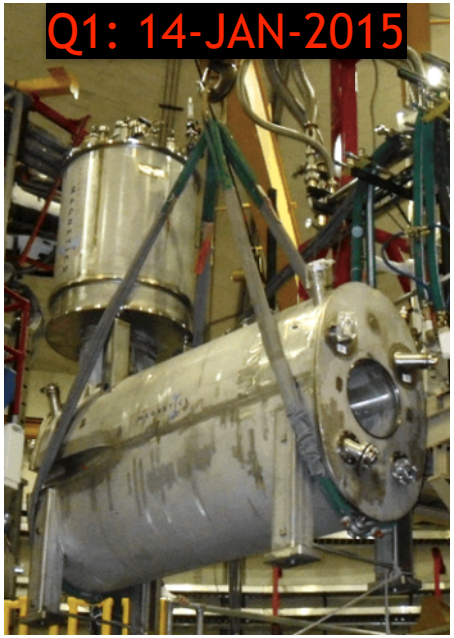
# CIPANP 2018, Palm Springs

# Backup Slides

# Jefferson Lab 12 GeV Upgrade



# SHMS Magnet Installation






# Slide Title