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New EMC Ratios in Lighter Nuclei Measured from Hall C JLab

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ODU Interview

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Outline

- Deep Inelastic Scattering (DIS)
- The EMC Effect
- Experiment Overview of E12-10-008 at Hall C
- Preliminary Result & Summary

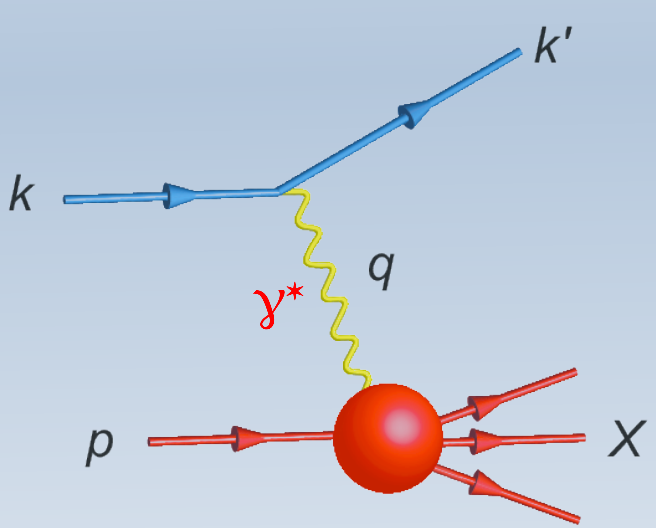
Electron Scattering and Nuclear Physics

Electron scattering is a powerful tool for studying the physics of nucleons in nuclei.

- EM interaction is much weaker than strong interaction.
- Electron probe the whole volume without bias.
- Interaction describe by the exchange of virtual photons and are precisely calculable in QED.

Electron scattering can be used to study

1. Quantum Chromodynamics (QCD)
2. Modification of Nucleon structure in Nuclei
3. Short Range Correlation (SRC)



Electron Scattering Kinematics

Useful quantities

Electron momentum transfer,

$$Q^2 = -(P_e - P_e')^2 = 4E_e E_e' \sin^2(\vartheta_e/2)$$

(ignoring lepton mass m_e)

Energy transfer,

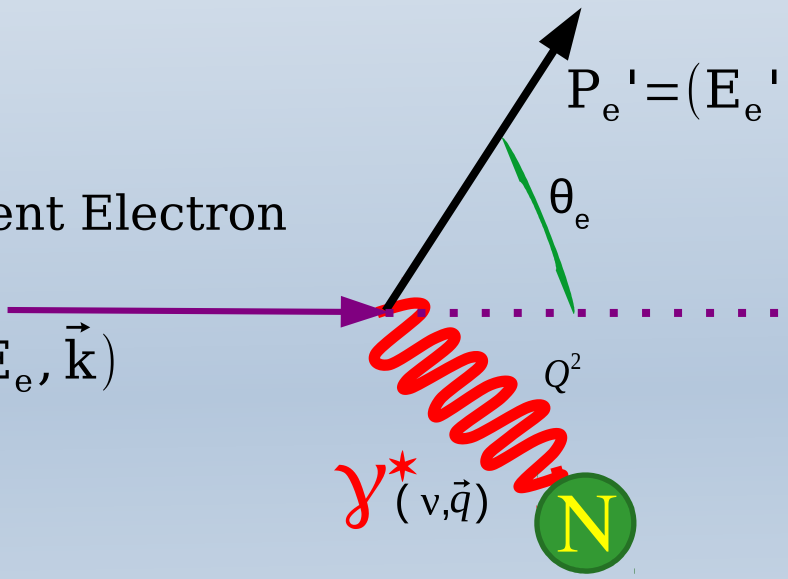
$$\nu = E_e - E_e'$$

Total Energy in CM

$W^2 = M^2 + 2M\nu - Q^2$ (Invariant Mass square)

Bjorken Scaling

$$x = \frac{Q^2}{2M\nu}$$ (fraction of longitudinal momentum carried by struck quark)



Scattered electron

$P_e' = (E_e', \vec{k}')$

θ_e

Incident Electron beam

$P_e = (E_e, \vec{k})$

Q^2

$\gamma^{*}(\nu, \vec{q})$

N

$P = (M, \vec{0})$

Fixed target with mass M

Electron-Nucleus Scattering Spectrum (schematic)

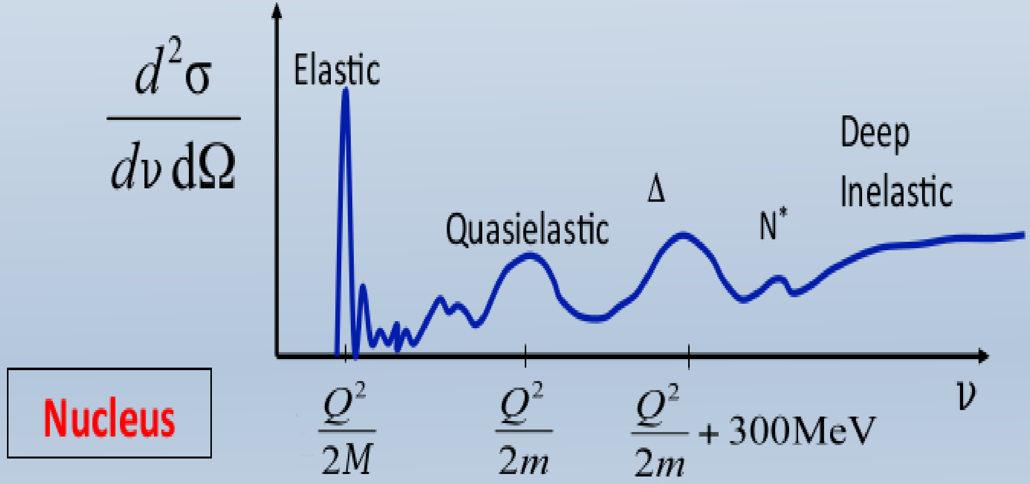
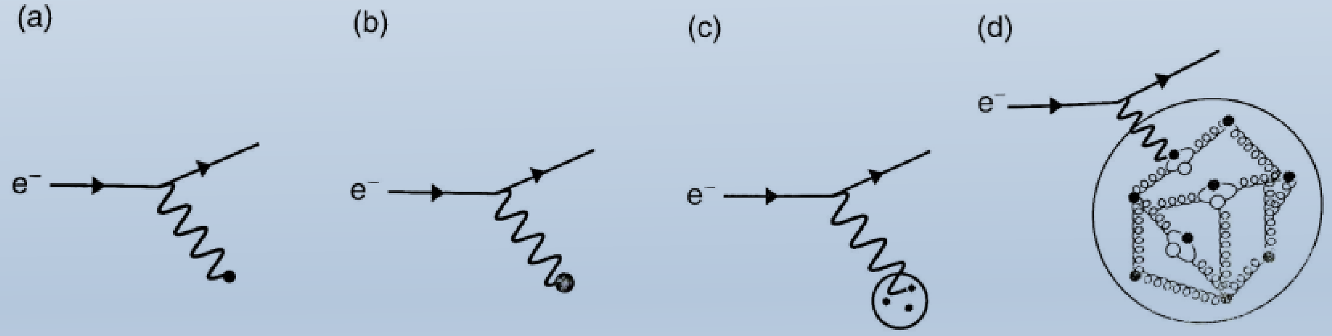


Fig: showing the main features of the excitation spectra for the electron scattering

- Elastic scattering: ν = nuclear recoil energy (nucleus remains intact)
- Quasi elastic: ν = elastic scattering off single nucleons inside nucleus
- Resonance : ν = energy to produce excited states of target nucleus
- Deep Inelastic: ν=energy to break up the nucleus

Electron Proton Scattering at high Q^2

de Broglie wavelength: $\lambda = h/q$

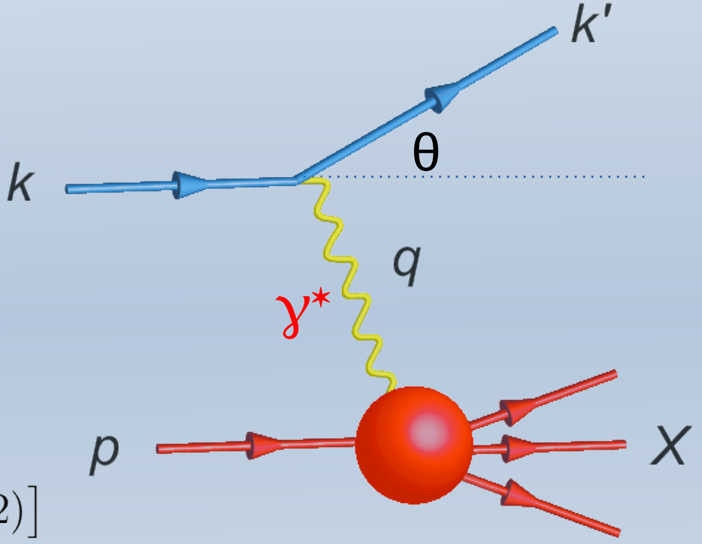


$\boldsymbol{\lambda \gg r_p}$ $\boldsymbol{\lambda \sim r_p}$ $\boldsymbol{\lambda < r_p}$ $\boldsymbol{\lambda \ll r_p}$

- At low Q^2 (momentum carried by photon is low), its wavelength is long compared with the size of the proton. It will see the proton as a point (a)
- At Medium Q^2, its wavelength is comparable to the size of proton. Photon begins to resolve the finite size of proton (b)
- At high Q^2, its wavelength is much shorter than the size of proton. Photon resolve the internal structure of the proton (c & d)

DIS Cross section

- Study of the partonic structure of the nucleon
- Can be described as inelastic scattering from non interacting, point like constituents in the nucleon



The x-sec for electron-nucleon scattering from the proton:

$$\frac{d^2\sigma}{d\Omega dE'} = \frac{\alpha^2}{Q^4}\frac{E'}{E}L_{\mu\nu}W^{\mu\nu}$$

In general, unpolarized differential cross-section in the lab frame can be written as:

$$\frac{d^2\sigma}{d\Omega dE'} = \frac{4\alpha^2 E'^2}{Q^4}\left[2W_1\left(\nu,Q^2\right)\sin^2(\theta/2) + W_2\left(\nu,Q^2\right)\cos^2(\theta/2)\right]$$

W_1 and W_2 parameterize the (unknown) structure of the proton

In the limit of large Q^2, structure functions scale

$$2MW_1\left(x,Q^2\right) = F_1(x), \quad x \equiv \frac{Q^2}{2(P\cdot q)}$$

$$\nu W_2\left(x,Q^2\right) = F_2(x) \qquad = \frac{Q^2}{2\,M\,\nu}\ \text{(lab frame)}$$

DIS Cross section

The total x-sec :

$$\frac{d^2\sigma}{d\Omega dE'} = \Gamma\left(\sigma_T(x,Q^2) + \epsilon\,\sigma_L(x,Q^2)\right) = \Gamma\sigma_T\,(1+\epsilon R), \quad R = \sigma_L/\sigma_T.$$

The flux of transverse virtual photons:

$$\Gamma = \frac{\alpha}{2\pi^2 Q^2}\frac{E'}{E}\frac{K}{1-\epsilon}, \qquad K = \nu(1-x)$$

Ratio of the longitudinal to transverse virtual photon polarizations:

$$\epsilon = \left[1 + 2\left(1+\frac{\nu^2}{Q^2}\right)\tan^2\frac{\theta}{2}\right]^{-1}.$$

The structure fns in terms of the experimental x-sec:

$$F_1(x,Q^2) = \frac{K}{4\pi^2\alpha} M\sigma_T(x,Q^2),$$

$$F_2(x,Q^2) = \frac{K}{4\pi^2\alpha}\frac{\nu}{(1+\nu^2/Q^2)}\left[\sigma_T(x,Q^2) + \sigma_L(x,Q^2)\right].$$

Typically,

$(\sigma_A/A)/(\sigma_D/2)$ and F^A_2/F^D_2 are assumed to be identical that is only true in the limit $\varepsilon = 1$ or $R_A - R_D = 0$:

$$\frac{\sigma_A}{\sigma_D} = \frac{F_2^A(x,Q^2)}{F_2^D(x,Q^2)}\frac{1+R_D}{1+R_A}\frac{1+\epsilon R_A}{1+\epsilon R_D};$$

$$\approx \frac{F_2^A(x,Q^2)}{F_2^D(x,Q^2)}\left[1 - \frac{\Delta R(1-\epsilon)}{(1+R_D)(1+\epsilon R_D)}\right].$$

Nuclear Effects in DIS

Typical nuclear binding energies: MeV
DIS scale : GeV

Naive expectation:

$$F_2^A(x) = ZF_2^p(x) + (A-1)\,F_2^n(x)$$

More sophisticated approach includes effects from Fermi motion

$$F_2^A(x) = \sum_i \int_x^{M_A/m_N} dy f_i(y) F_2^N(x/y)$$

F_2^N is the S.F of nucleon, $f_i(y)$ is the probability (normalized to 1) that a nucleon of mass m_N has a longitudinal momentum fraction $y=(p^0+p^z)/m_N$

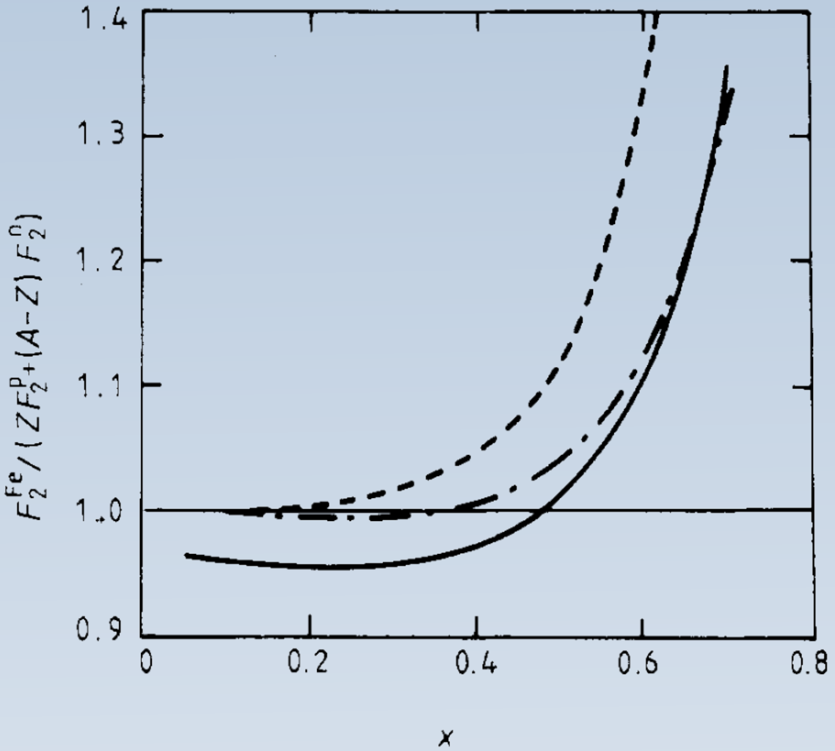


Fig: R P Bickerstaff and A W Thomas 1989
J. Phys. G: Nucl. Part. Phys 15 1523

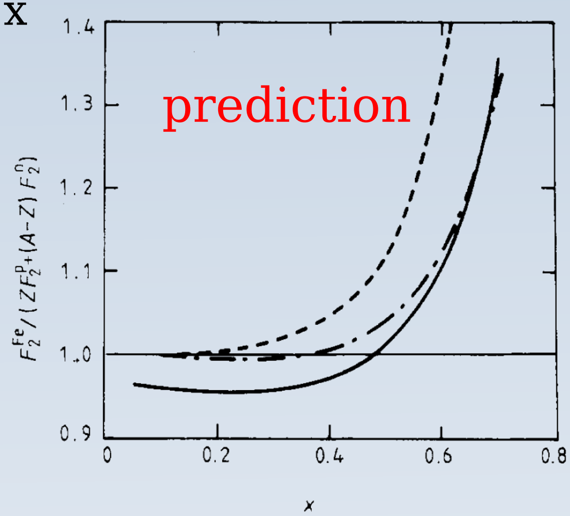
Bodek-Ritchie (1981) predictions for the fermi motion correction to the S.F of Fe.

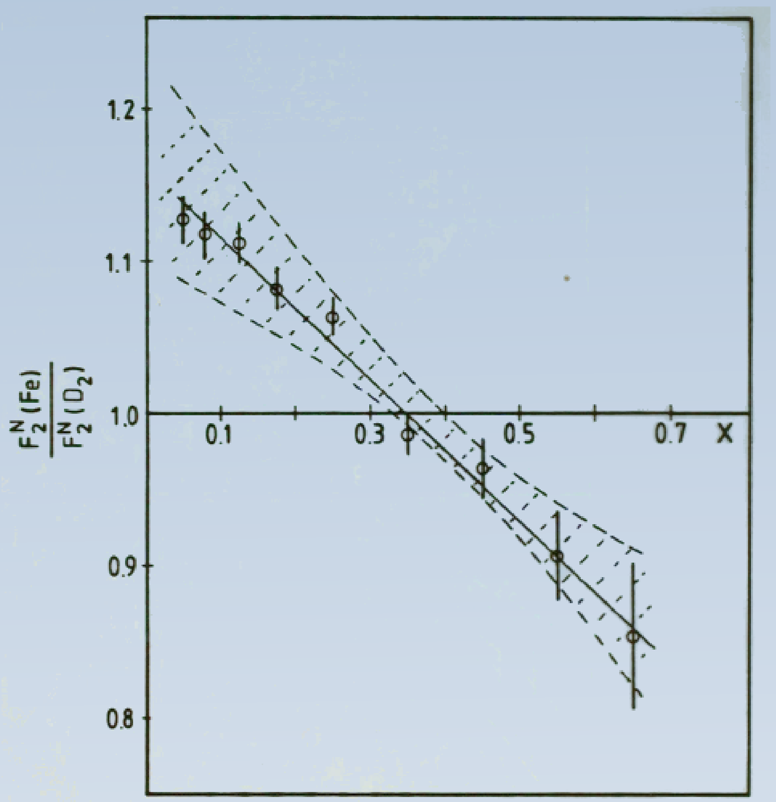
The EMC Effect

First published measurement of nuclear dependence of F_2 by the European Muon collaboration 1983

Observed 2 mysterious effects

- Significant enhancement at small x
- Depletion at large x





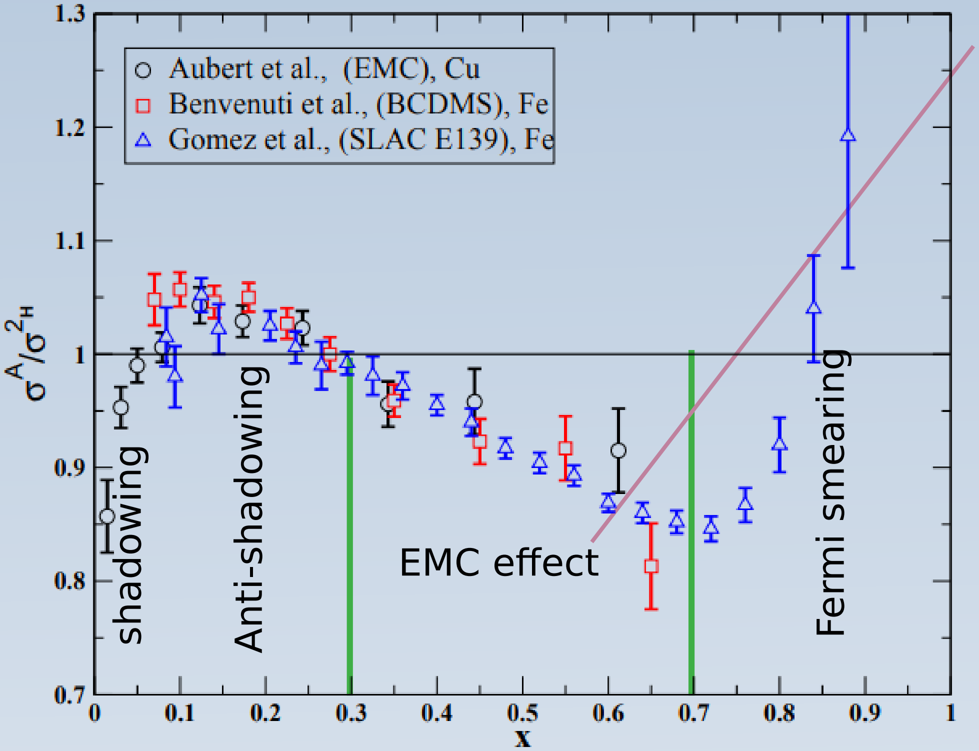
Aubert et. al, Phys Lett. B123, 275 (1983)

Importance of EMC Effect

- Understanding QCD
  - ✓ How does the nucleus emerge from QCD, a theory of quarks and gluons?
  - ✓ A goal is to understand the structure of bound nucleons.

- Neutron structure function
  - ✓ Almost all the information on neutron structure functions comes from deuterium data
  - ✓ Nuclear effects in deuterium is relevant for extraction of neutron information
  - ✓ Nuclear effects also matter for purpose of extracting the ratio $\frac{F_2^n}{F_2^p}$ (^{3}H/^{3}He).

The EMC Effect (subsequent Measurement)



Quark distribution in nuclei are modified

- A program of dedicated measurements conducted at EMC(1983), BCDMS(1987), SLAC(1994).
- The resulting data is remarkably consistent over a large range of beam energies and measurement techniques.

Origins of the EMC Effect

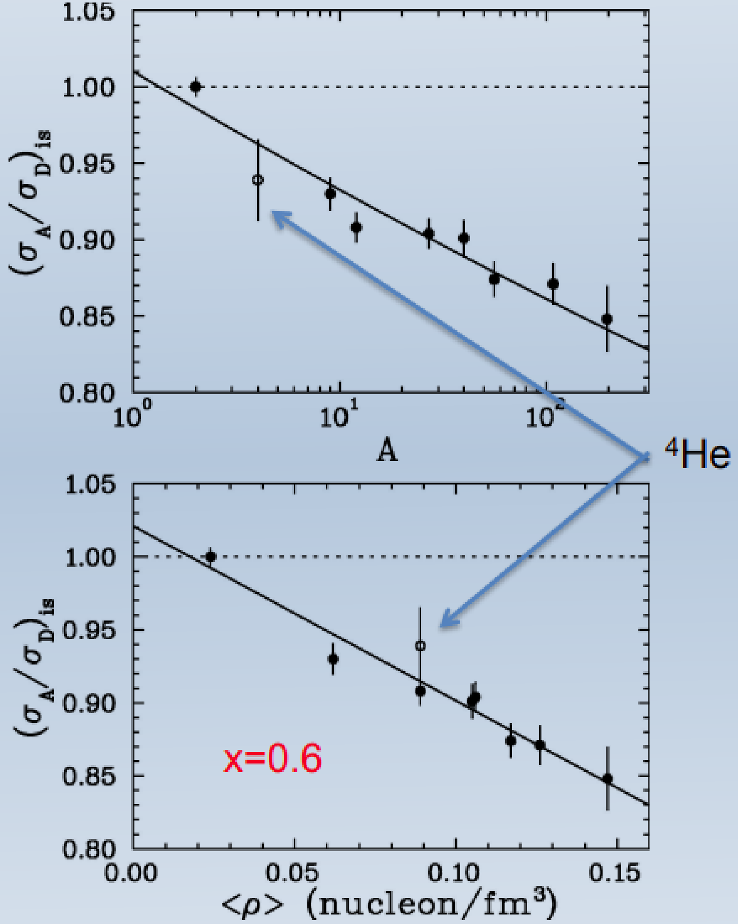
- The EMC effect cannot be described by calculations that include only “conventional” nuclear effects like fermi motion or binding (only when introducing off-shell effects)
- Early calculations using more interesting sources, like multi-quark clusters or dynamical re-scaling often treated the nucleus in a very simple manner (Fermi gas).
- More recent calculations describe the nucleus including QCD from the outset (Quark-meson coupling)
- The ideal model would include best description of the nucleus, and then incorporate “extra” effects as needed

The EMC Effect: Existing data at large x

SLAC E139 studied the *Nuclear dependence of the EMC effect at fixed x

- **SLAC E139**
  - Most precise large x-data
  - Nuclei from A = 4 to 197
- **Conclusions from SLAC E139**
  - Q^2-independent
  - Universal x-dependence for all A
  - A-dependent magnitude
    - Scales with log(A)
    - Scales with average density

***Nuclear dependence** is interesting as it helps to provide more information to test models



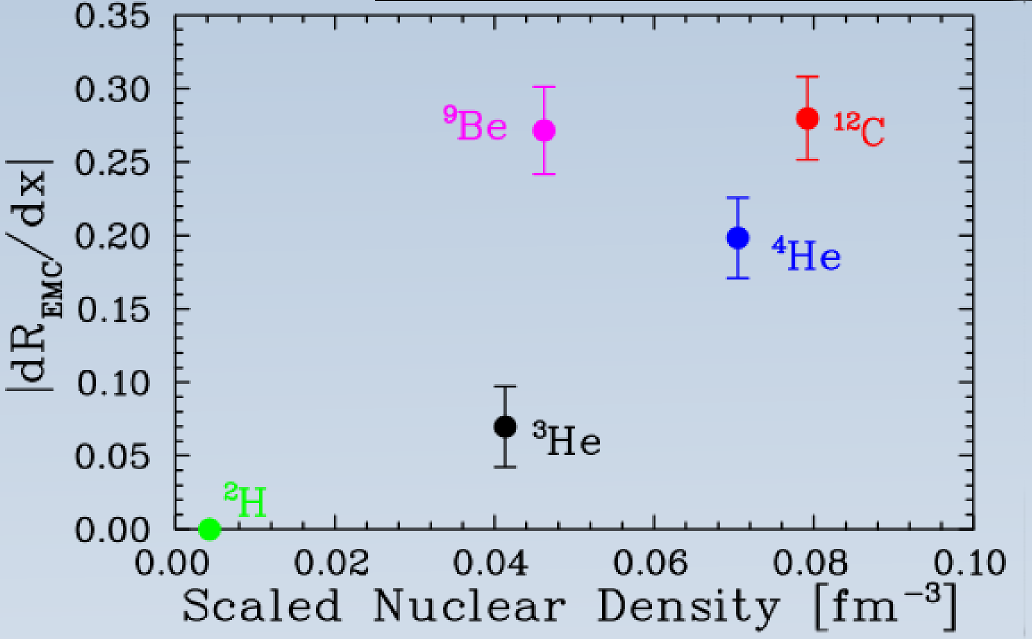
Gomez et al, PRD 49, 4348 (1994)

Motivation: Jlab E03-103

Measured σ_A/σ_D for ^{3}He, ^{4}He, Be, C

- ^{3}He, ^{4}He, C EMC effect scales well with density
- **^{9}Be** does not fit the trend

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



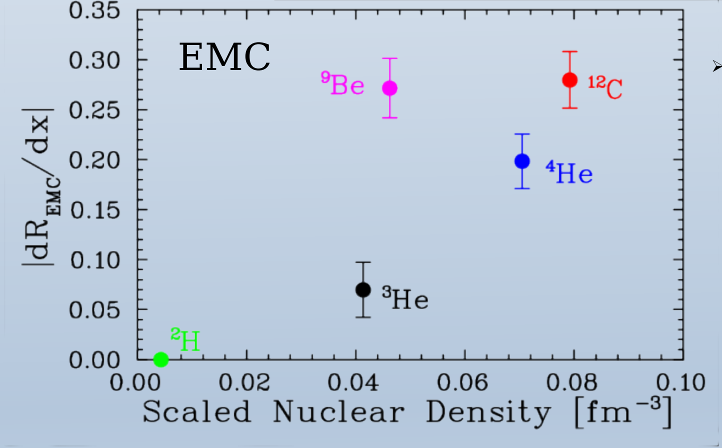
Conclusion:

- Both A and ρ dependent fits fail to describe these light nuclei
- Suggest that the EMC Effect does not scale with average nuclear density
- Hints that the effect may be driven by local environment

^{9}Be structure : 2α + n

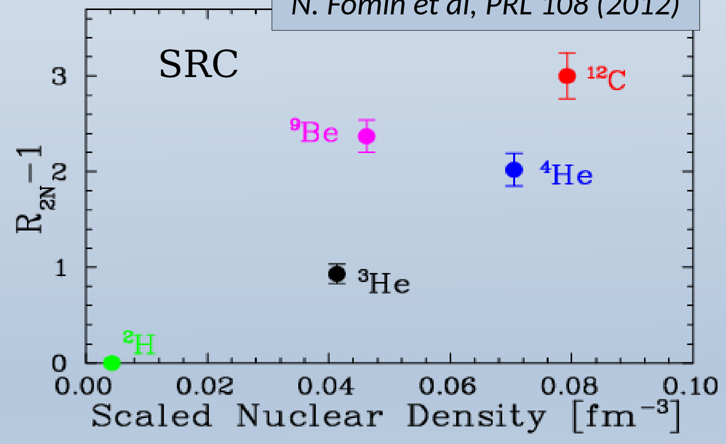
Motivation: SRC & EMC correlation

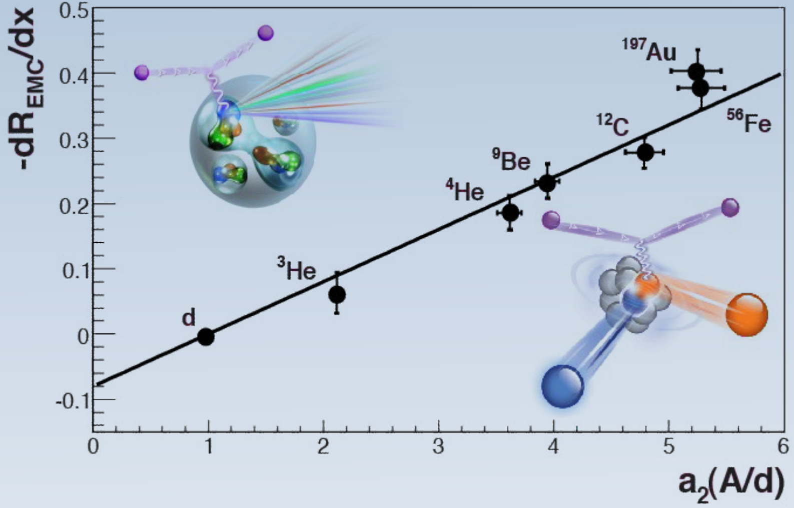
J. Seely, et al., PRL103, 202301 (2009)



- EMC-SRC connection became more intriguing with the addition of Be SRC data from JLab

N. Fomin et al, PRL 108 (2012)





L. Weinstein, et al, PRL, 106, 052301 (2011)
O. Hen, et al, PRC 84, 047301 (2012)
J. Arrington, A. Daniel, D. Day, N. Formin, D. Gaskell, Solvignon, PRC 86, 065204 (2012)
N. Fomin, et al, PRL 108, 092052 (2012)

Motivation: SRC & EMC correlation

Broadly two classes of hypotheses:

- High Virtuality (HV) – EMC effect being driven by highly virtual (very off-shell) nucleon
- Local density (LD) – EMC effect driven by the presence of nucleons in close proximity

A recent work : model modification of the nuclear S.F (F_2^A) as entirely due to modification of np-SRC pairs (n^A_{SRC})

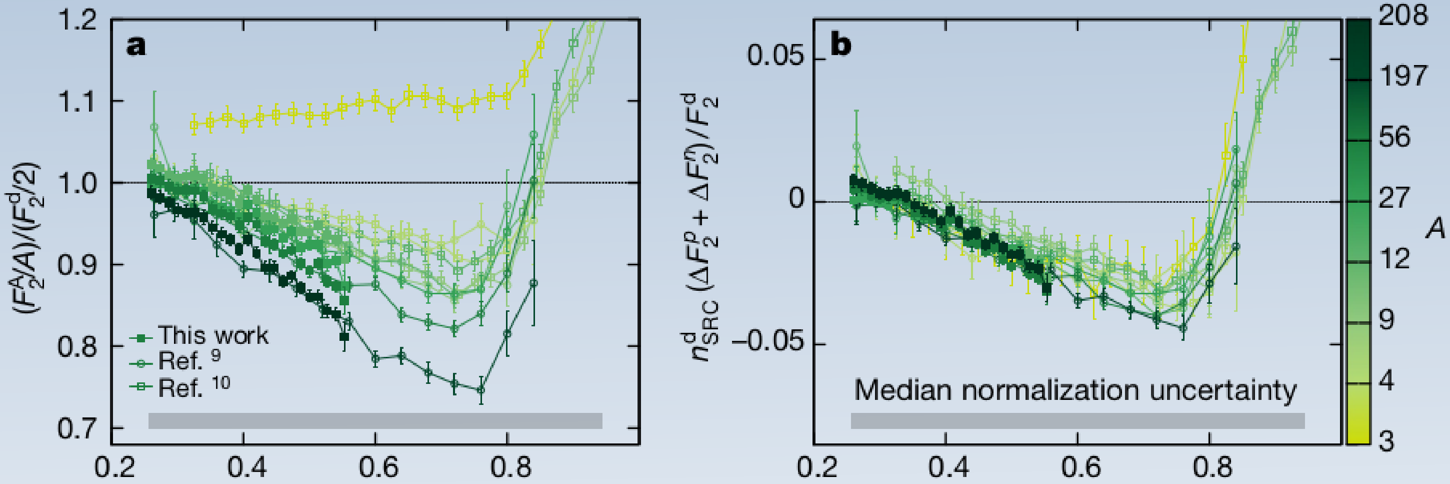
$$F_2^A = (Z - n_{SRC}^A) F_2^p + (N - n_{SRC}^A) F_2^n + n_{SRC}^A (F_2^{p*} + F_2^{n*}) = Z F_2^p + N F_2^n + n_{SRC}^A (\Delta F_2^p + \Delta F_2^n) \,;\ \Delta F_2^n = F_2^{n*} - F_2^n$$

Avg modified S.F

Universal modification function: $F_{univ}^{HV} = \dfrac{(\sigma_A/\sigma_D) - (Z-N)\frac{F_2^p}{F_2^d} - N}{(A/2)a_2 - N}$

(iso-spin dependent)

B. Schmookler et al. Nature (2019)



Motivation to E12-10-008

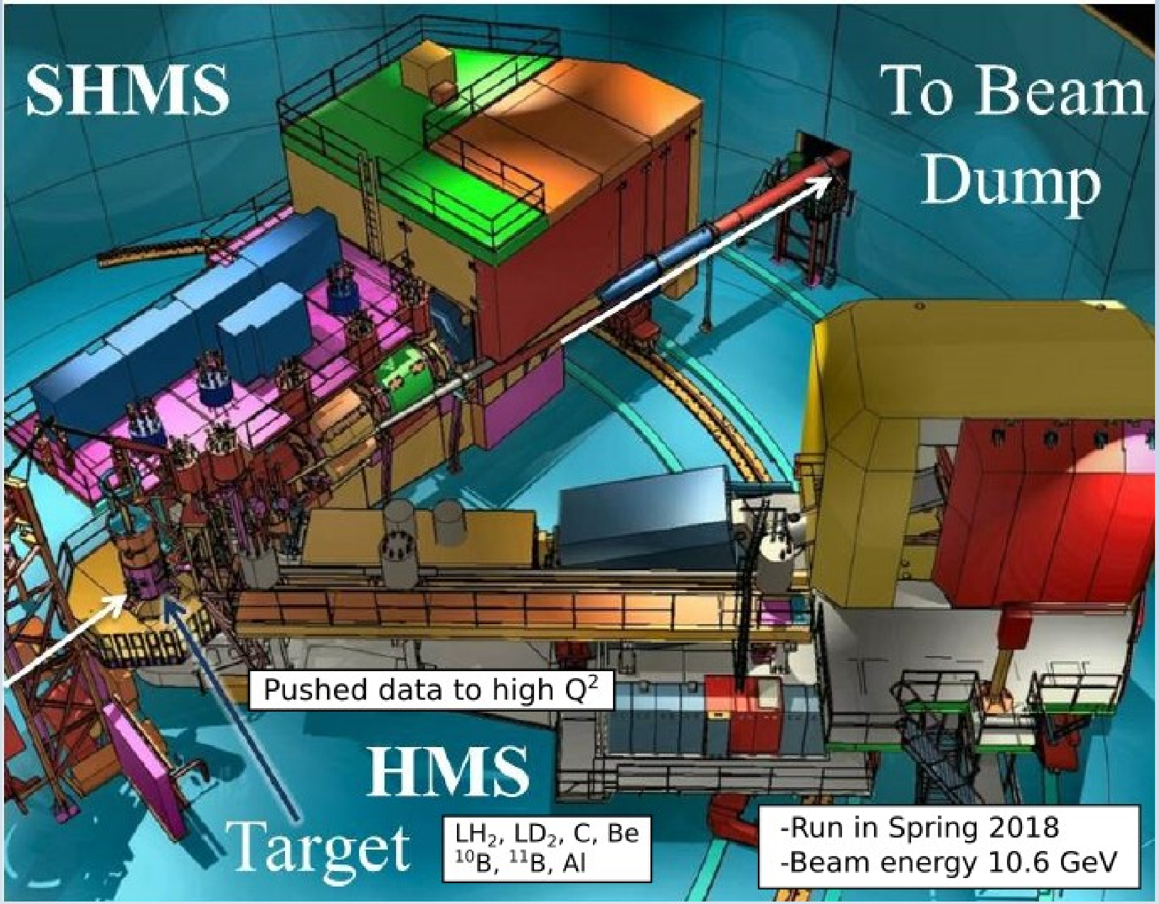
- Pushed to higher Q^2, expand range in x (both high and low)
- Investigate the influence of local environment on the observed nuclear dependence with additional light nuclei.
- To map out the SRC/EMC connection for the additional light nuclei.

Overview of the Experiment

- Hall C Comissioning experiment

- Electrons detected in both SHMS & HMS

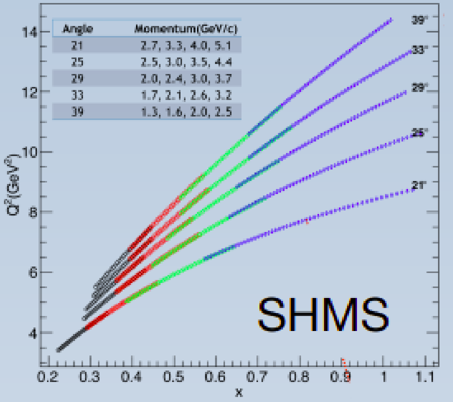
- Detector package
    - Drift Chamber
    - Hodoscopes
    - Cherenkovs
    - Calorimeter



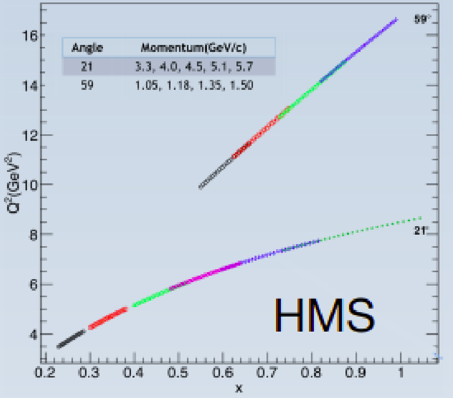
Pushed data to high Q^2

LH_2, LD_2, C, Be
^{10}B, ^{11}B, Al

-Run in Spring 2018
-Beam energy 10.6 GeV



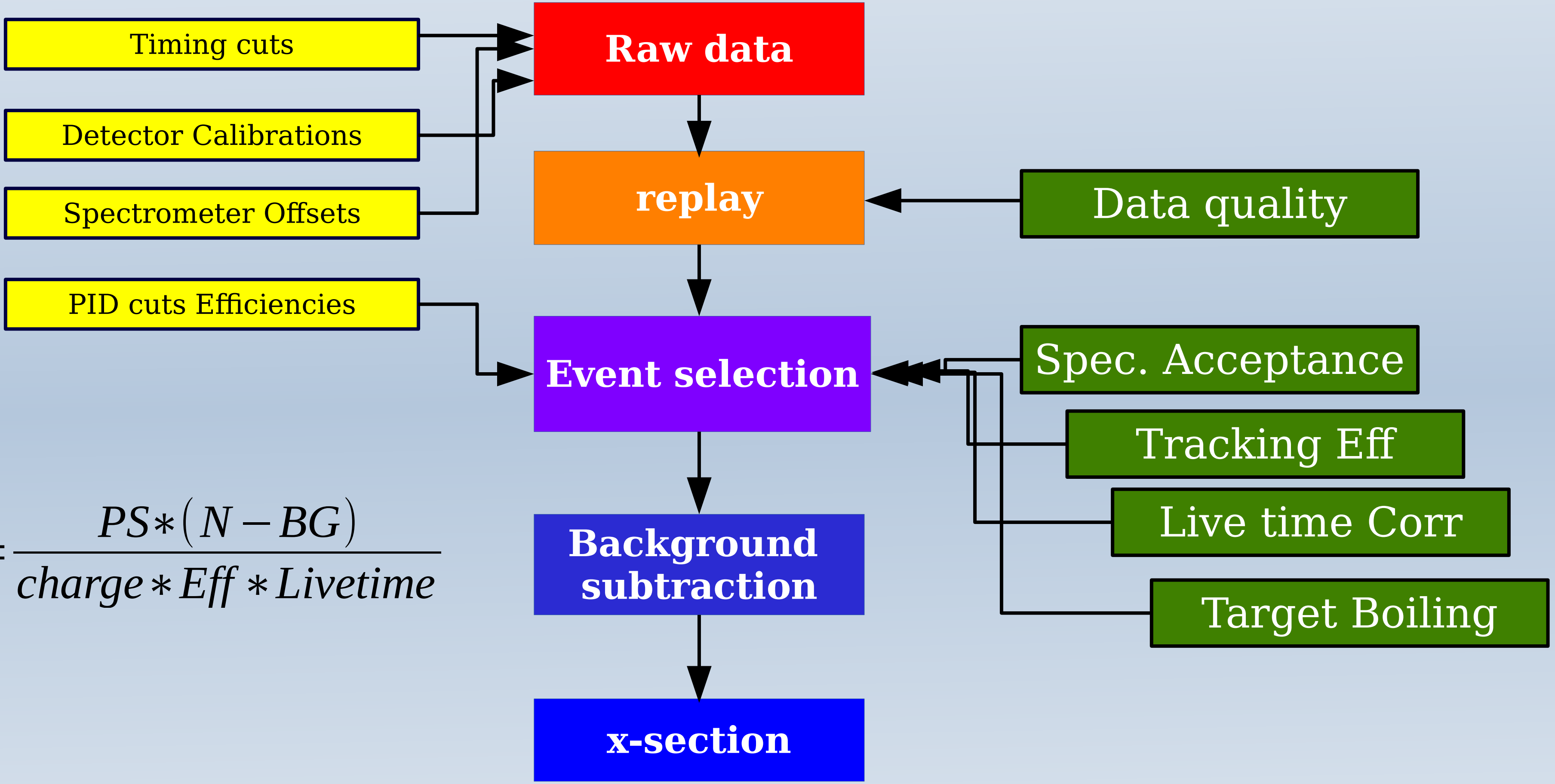
Angle	Momentum(GeV/c)
21	2.7, 3.3, 4.0, 5.1
25	2.5, 3.0, 3.5, 4.4
29	2.0, 2.4, 3.0, 3.7
33	1.7, 2.1, 2.6, 3.2
39	1.3, 1.6, 2.0, 2.5



Angle	Momentum(GeV/c)
21	3.3, 4.0, 4.5, 5.1, 5.7
59	1.05, 1.18, 1.35, 1.50

First measurement of EMC ratio in ^{10}B, ^{11}B

Analysis Workflow



Timing cuts

Detector Calibrations

Spectrometer Offsets

PID cuts Efficiencies

Raw data

replay

Event selection

Background subtraction

x-section

Data quality

Spec. Acceptance

Tracking Eff

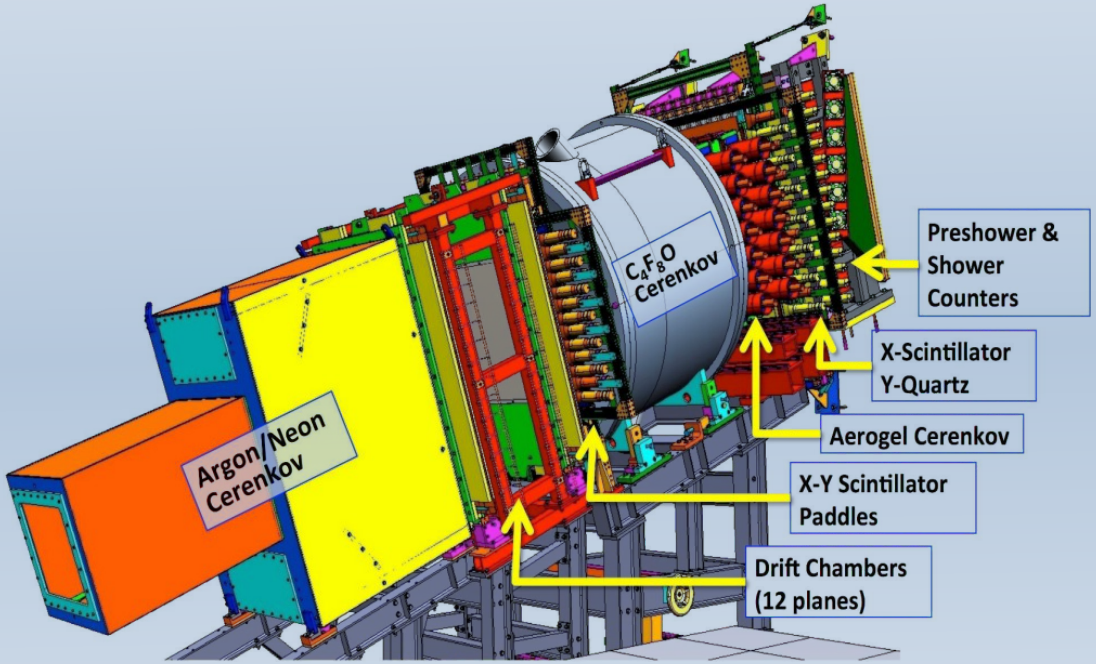
Live time Corr

Target Boiling

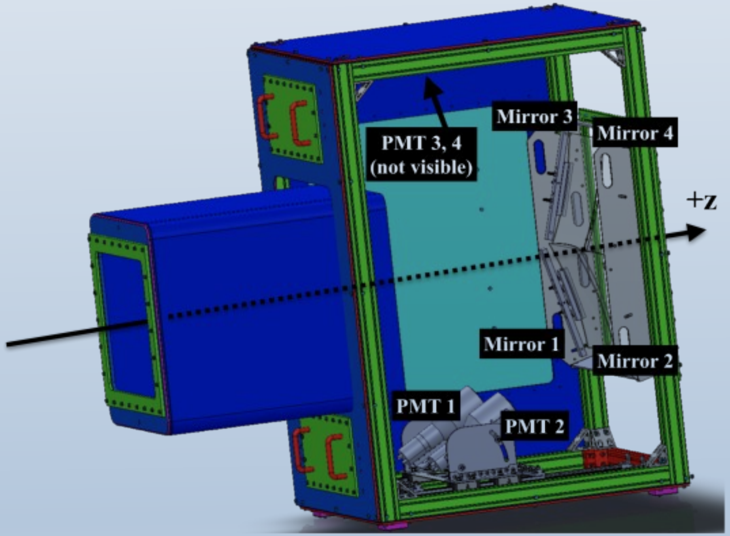
$$Y_{\exp} = \frac{PS * (N - BG)}{charge * Eff * Livetime}$$

$$\left(\frac{d\sigma}{d\Omega dE'}\right)_{\mathrm{exp}} = \frac{Y_{\mathrm{exp}}}{Y_{\mathrm{sim}}}\left(\frac{d\sigma}{d\Omega dE'}\right)_{\mathrm{model}}$$

Nobel Gas Cherenkov



SHMS detector stack



- Located in front of drift chamber
- A rectangular tank (2.5m x 0.8m)
- 4 spherical mirrors
- 1 atm pressure
- Filled with CO_2
- Pion threshold of ~ 4.4 GeV

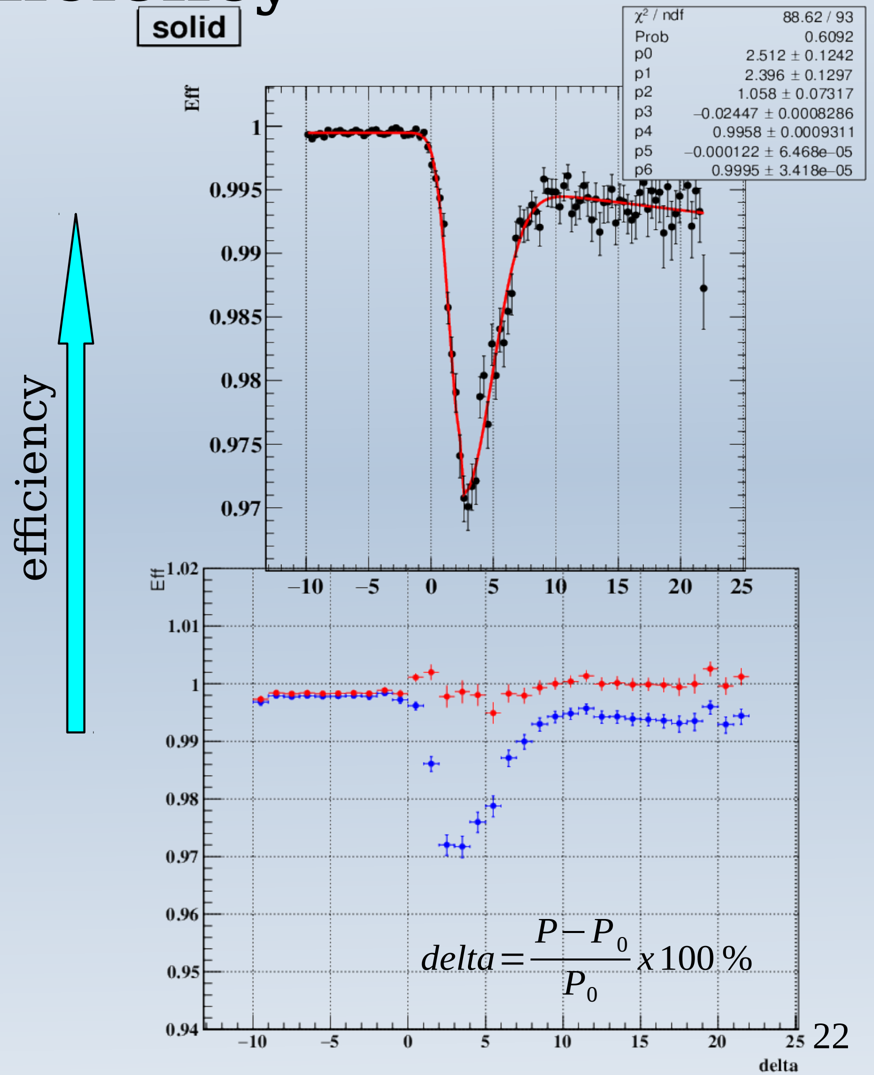
Nobel Gas Cherenkov Cut Efficiency

- ngcer$_{npe}$ > 2.0 efficiency is tested
- Some fraction of electron is lost due to this cut and we need to account for that inefficiency
- Pure sample of electrons are prepared without using Cherenkov

$$\epsilon_{eff}^{cut} = \frac{N_{(all\&(ngcer_{npe}>2.0))}}{N_{all}}$$

Here, N$_{(all)}$ is total # of electrons passing our nominal cuts.

- Parameterized Cherenkov efficiency (curve) applied to production runs



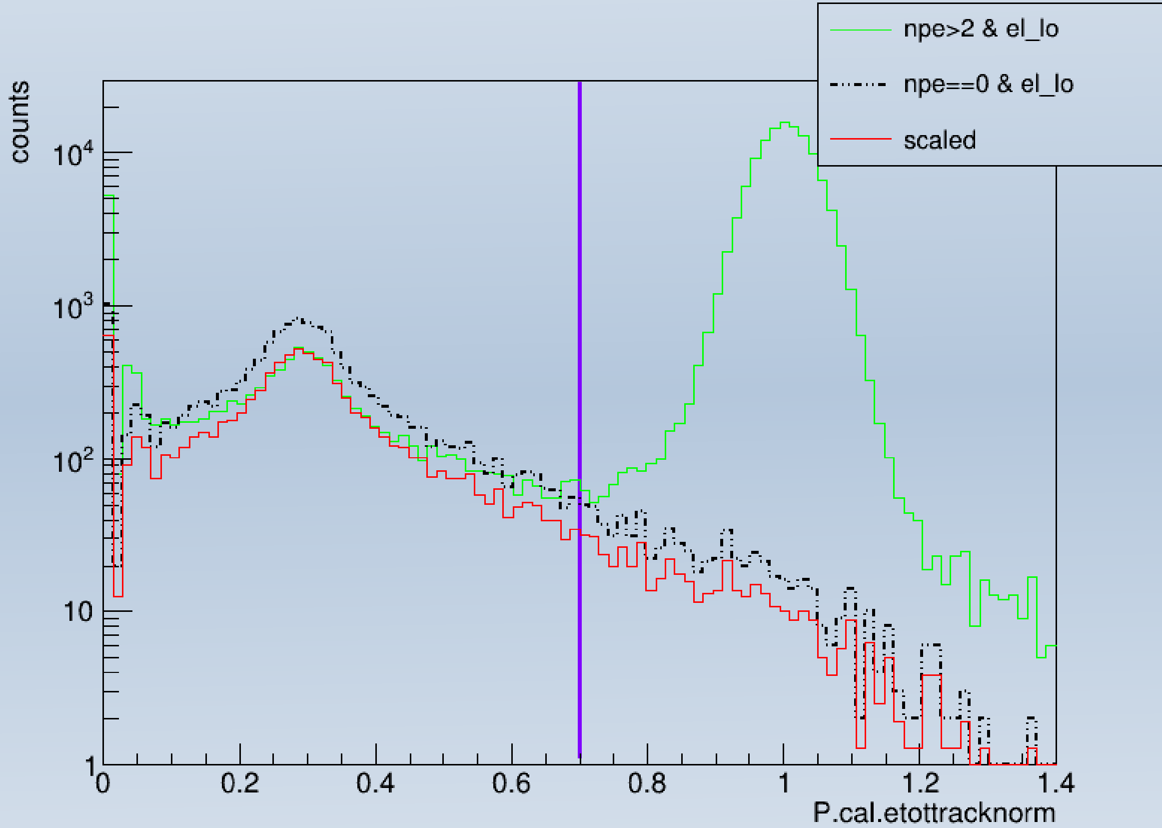
$$delta = \frac{P - P_0}{P_0} x\,100\,\%$$

Background Correction: Pion Contamination

- Pions that pass the electron cuts need to be removed from yields
- Green histogram - electron distribution
- Black histogram - pion distribution
- Red histogram is scaled histogram
- Number of events in the normalized calorimeter distribution that pass

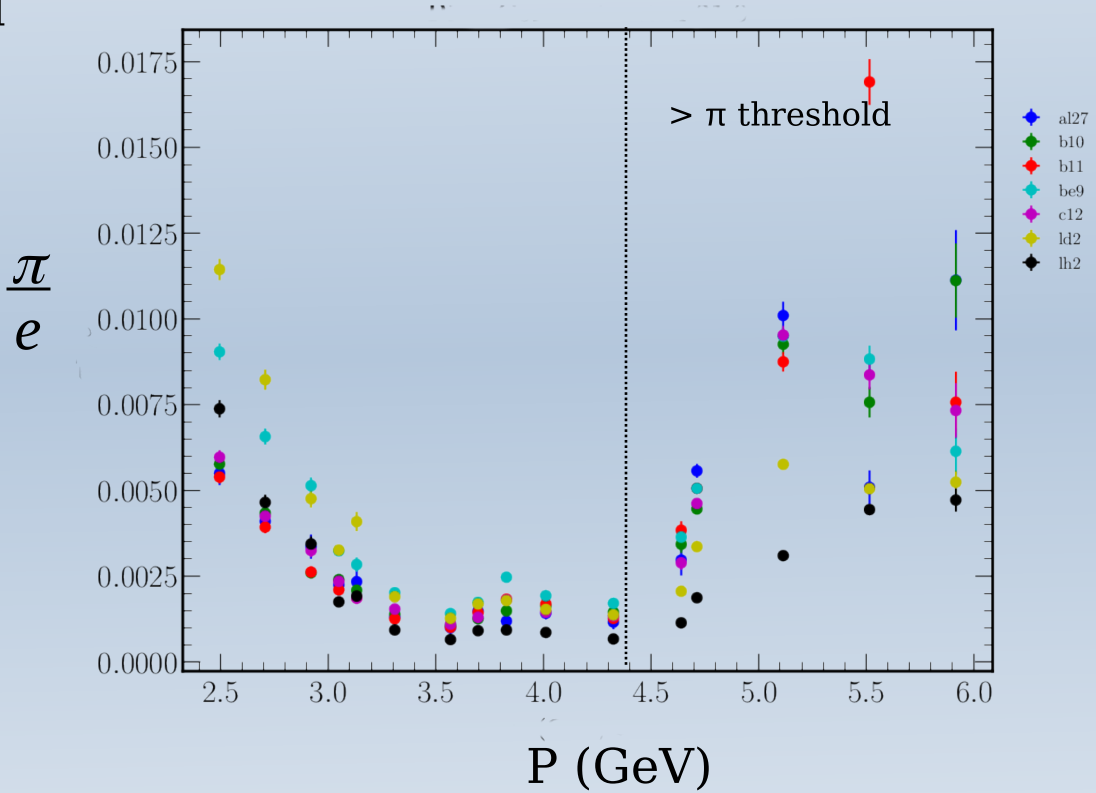
$$\frac{E_{calorimeter}}{E'} > 0.7$$

represents the pion contamination



Background Correction: Pion Contamination

- π/e ratio was calculated and parameterized as function of E’ (P) .
- Analysis was done for each target (point+extended)
- Distribution shows a nice drop as momentum increases
- Increased in pion contamination after 4.5 GeV is due to fact pion threshold for cherenkov is ~ 4.4 GeV



Cross-section extraction

Yield is converted to x-sec via the Monte-Carlo ratio method:

Experimental Yield

Simulated Yield
evaluated at
Born Level

$$\left(\frac{d\sigma}{d\Omega dE'}\right)_{\mathrm{exp}} = \frac{Y_{\mathrm{exp}}}{Y_{\mathrm{sim}}}\left(\frac{d\sigma}{d\Omega dE'}\right)_{\mathrm{model}}$$

Monte-Carlo yield

Data VS MC Comparison (SHMS)

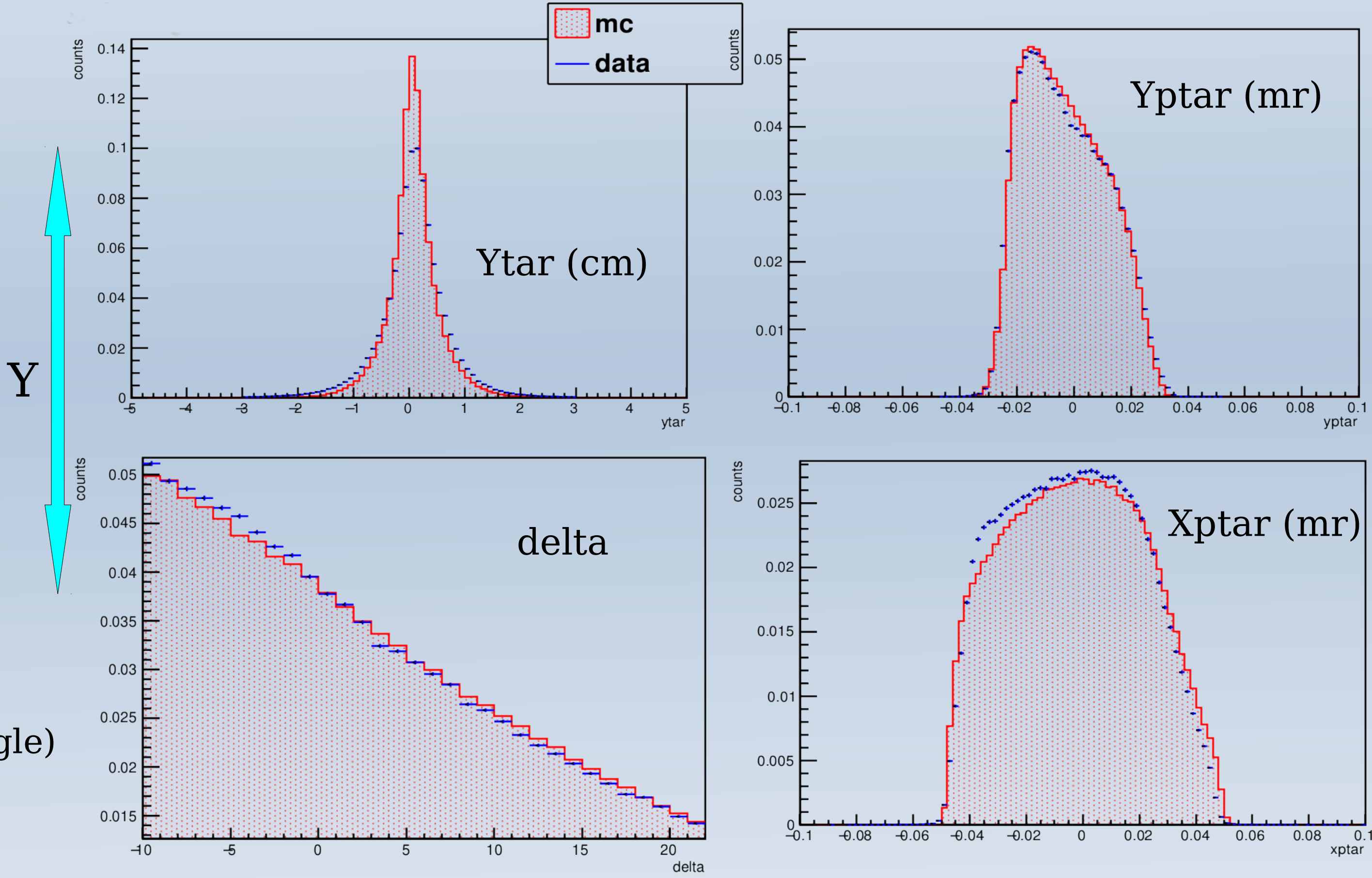
Reconstructed variable for Carbon at 4 GeV at 21^0 is shown.

Efficiency corrected
charge normalized yield

$$Y = \frac{N}{\varepsilon Q_{tot}}$$

N = tot # of events
ε = tot combines eff.
Q_{tot} = tot accumulated charge in mC

- Delta = $\frac{P-P_0}{P_0} x\,100\,\%$
- Yptar = $\frac{dy}{dz}$ (in plane angle)
- Xptar = $\frac{dx}{dz}$ (out of plane angle)

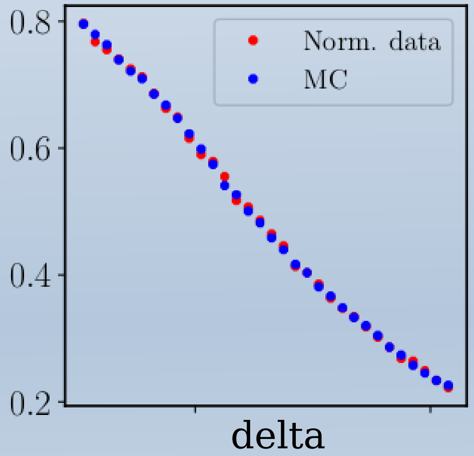


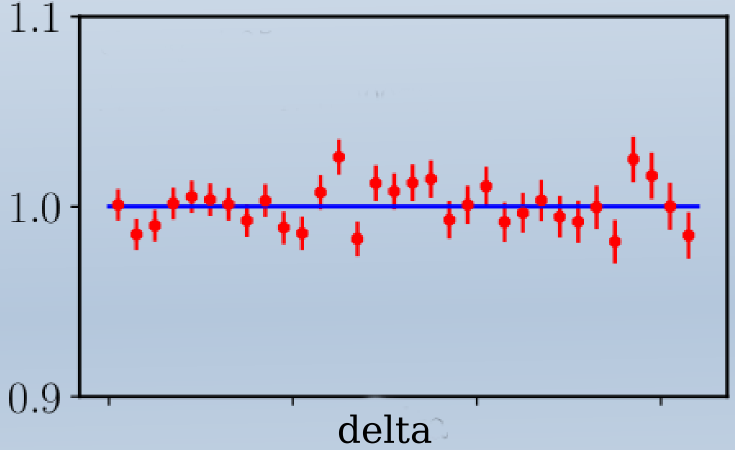
Cross-section extraction

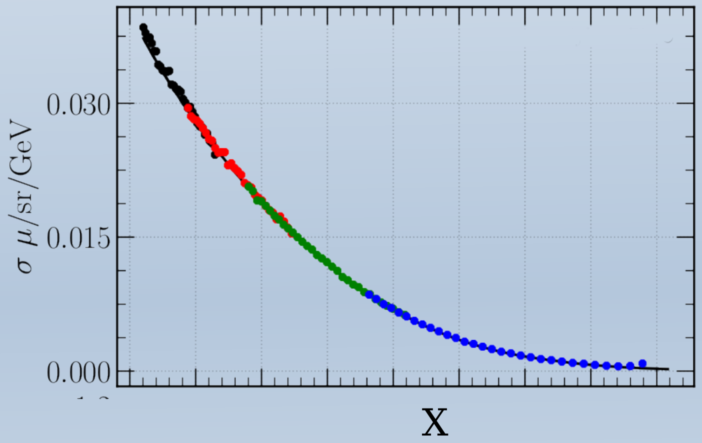
$$\left(\frac{d\sigma}{d\Omega dE'}\right)_{\text{exp}} = \frac{Y_{\text{exp}}}{Y_{\text{sim}}}\left(\frac{d\sigma}{d\Omega dE'}\right)_{\text{model}}$$

Ratio data/MC

Multiply each bin by σ_{model}







1) MC (weighted with radiative x-sec) and corrected data yields are binned in delta (1% delta)

2) Take ratio of data and MC

3) Multiply each bin by model to get x-section

Nuclear Model :

sig_born_total = sig_born_inel + sig_born_qe

x< 0.78 = nuclear x-sec is INEFT fit to deuterium times emc_fit

x>0.78 = smearing (single iteration to improve agreement of inelastic model with data)

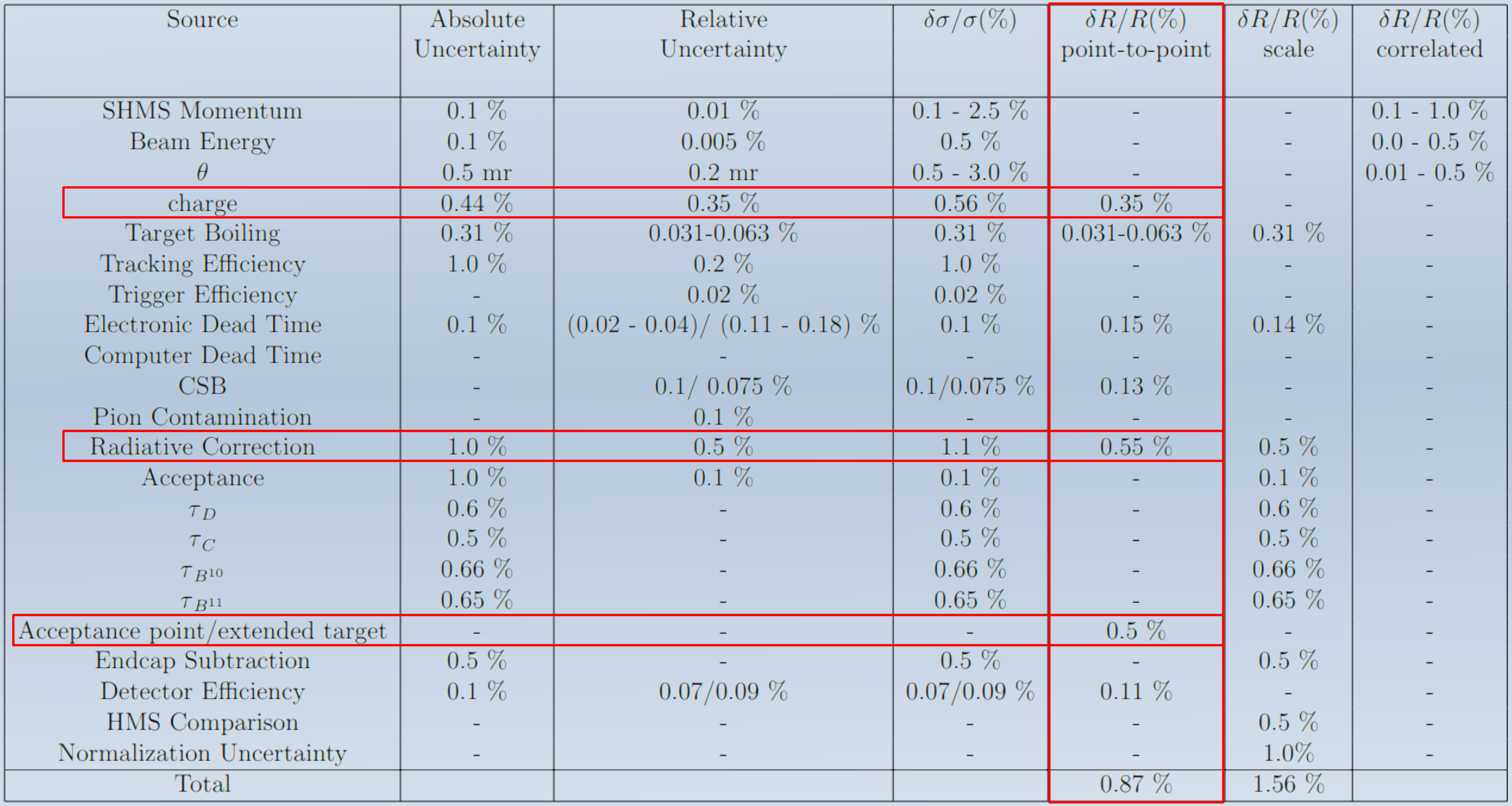
QE = Peter’s F1F2QE09 based on super scaling fit

Result & Discussion

Systematic uncertainties :

- Point to point (independent of target & x bins)
- x-correlated (vary in size with x, impact all points simultaneously)
- Normalization (contribute to all point collectively, affecting over all scale)

Result & Discussion

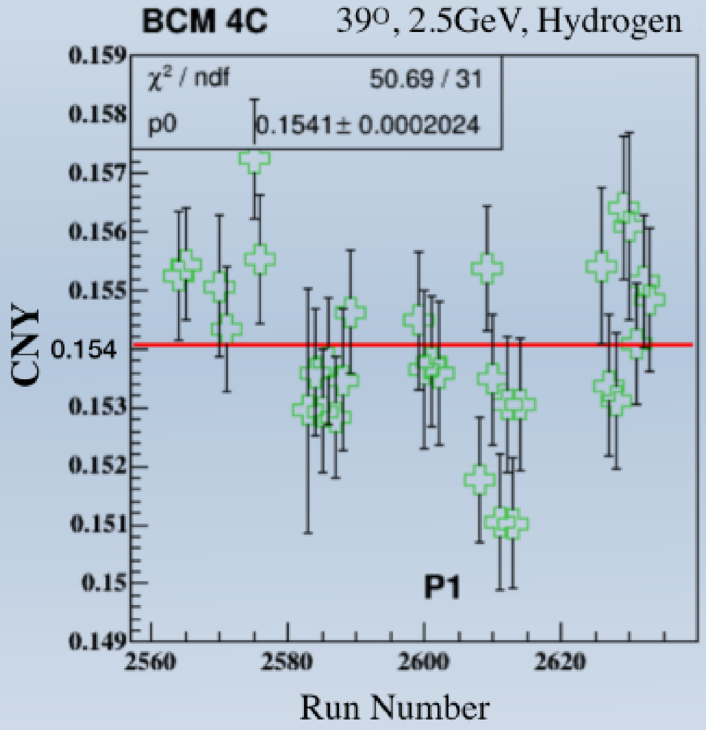


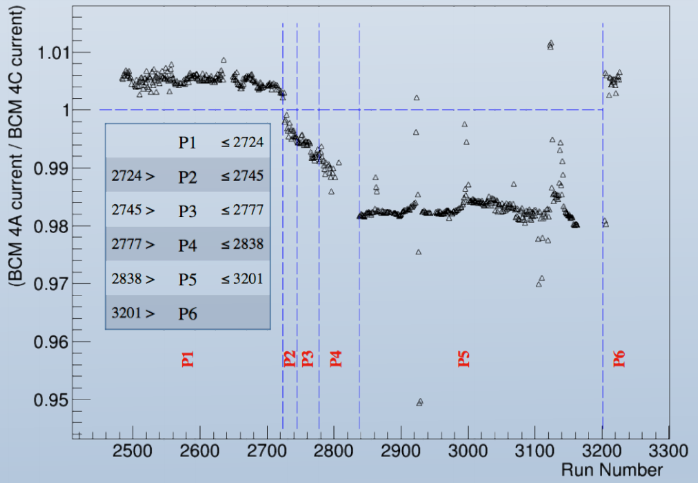
Source	Absolute Uncertainty	Relative Uncertainty	$\delta\sigma/\sigma(\%)$	$\delta R/R(\%)$ point-to-point	$\delta R/R(\%)$ scale	$\delta R/R(\%)$ correlated
SHMS Momentum	0.1 %	0.01 %	0.1 - 2.5 %	-	-	0.1 - 1.0 %
Beam Energy	0.1 %	0.005 %	0.5 %	-	-	0.0 - 0.5 %
θ	0.5 mr	0.2 mr	0.5 - 3.0 %	-	-	0.01 - 0.5 %
charge	0.44 %	0.35 %	0.56 %	0.35 %	-	-
Target Boiling	0.31 %	0.031-0.063 %	0.31 %	0.031-0.063 %	0.31 %	-
Tracking Efficiency	1.0 %	0.2 %	1.0 %	-	-	-
Trigger Efficiency	-	0.02 %	0.02 %	-	-	-
Electronic Dead Time	0.1 %	(0.02 - 0.04)/ (0.11 - 0.18) %	0.1 %	0.15 %	0.14 %	-
Computer Dead Time	-	-	-	-	-	-
CSB	-	0.1/ 0.075 %	0.1/0.075 %	0.13 %	-	-
Pion Contamination	-	0.1 %	-	-	-	-
Radiative Correction	1.0 %	0.5 %	1.1 %	0.55 %	0.5 %	-
Acceptance	1.0 %	0.1 %	0.1 %	-	0.1 %	-
τ_D	0.6 %	-	0.6 %	-	0.6 %	-
τ_C	0.5 %	-	0.5 %	-	0.5 %	-
$\tau_{B^{10}}$	0.66 %	-	0.66 %	-	0.66 %	-
$\tau_{B^{11}}$	0.65 %	-	0.65 %	-	0.65 %	-
Acceptance point/extended target	-	-	-	0.5 %	-	-
Endcap Subtraction	0.5 %	-	0.5 %	-	0.5 %	-
Detector Efficiency	0.1 %	0.07/0.09 %	0.07/0.09 %	0.11 %	-	-
HMS Comparison	-	-	-	-	0.5 %	-
Normalization Uncertainty	-	-	-	-	1.0%	-
Total				0.87 %	1.56 %	

Table 1.1: Systematic Uncertainties.

Result & Discussion

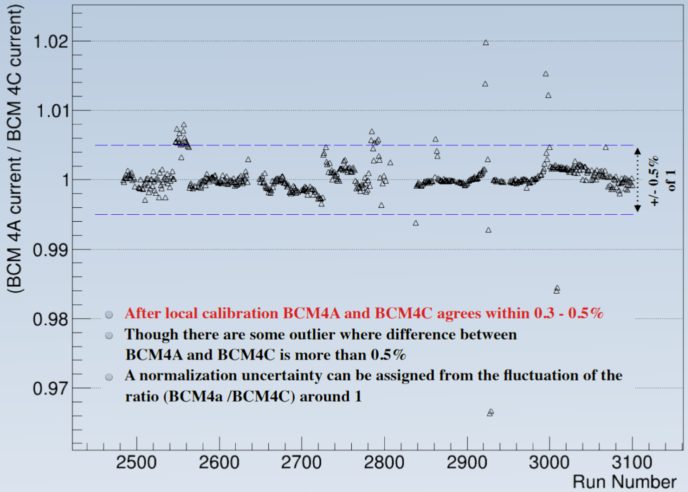
Uncertainty on charge





	P1	≤ 2724
2724 >	P2	≤ 2745
2745 >	P3	≤ 2777
2777 >	P4	≤ 2838
2838 >	P5	≤ 3201
3201 >	P6	

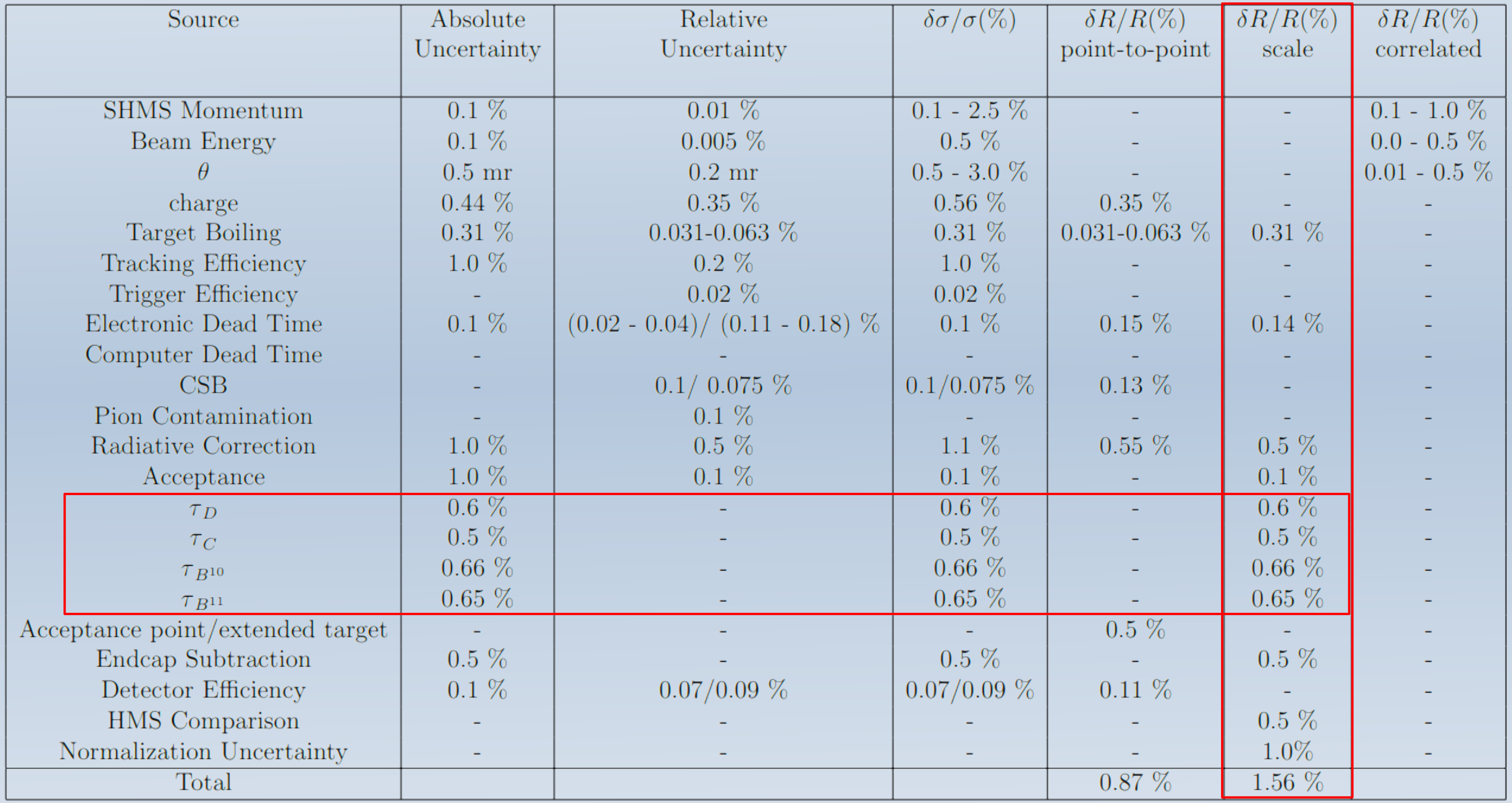
Run Numver vs (BCM 4A current / BCM 4C current)



- After local calibration BCM4A and BCM4C agrees within 0.3 - 0.5%
- Though there are some outlier where difference between BCM4A and BCM4C is more than 0.5%
- A normalization uncertainty can be assigned from the fluctuation of the ratio (BCM4a /BCM4C) around 1

Fig credit : Deb Biswas

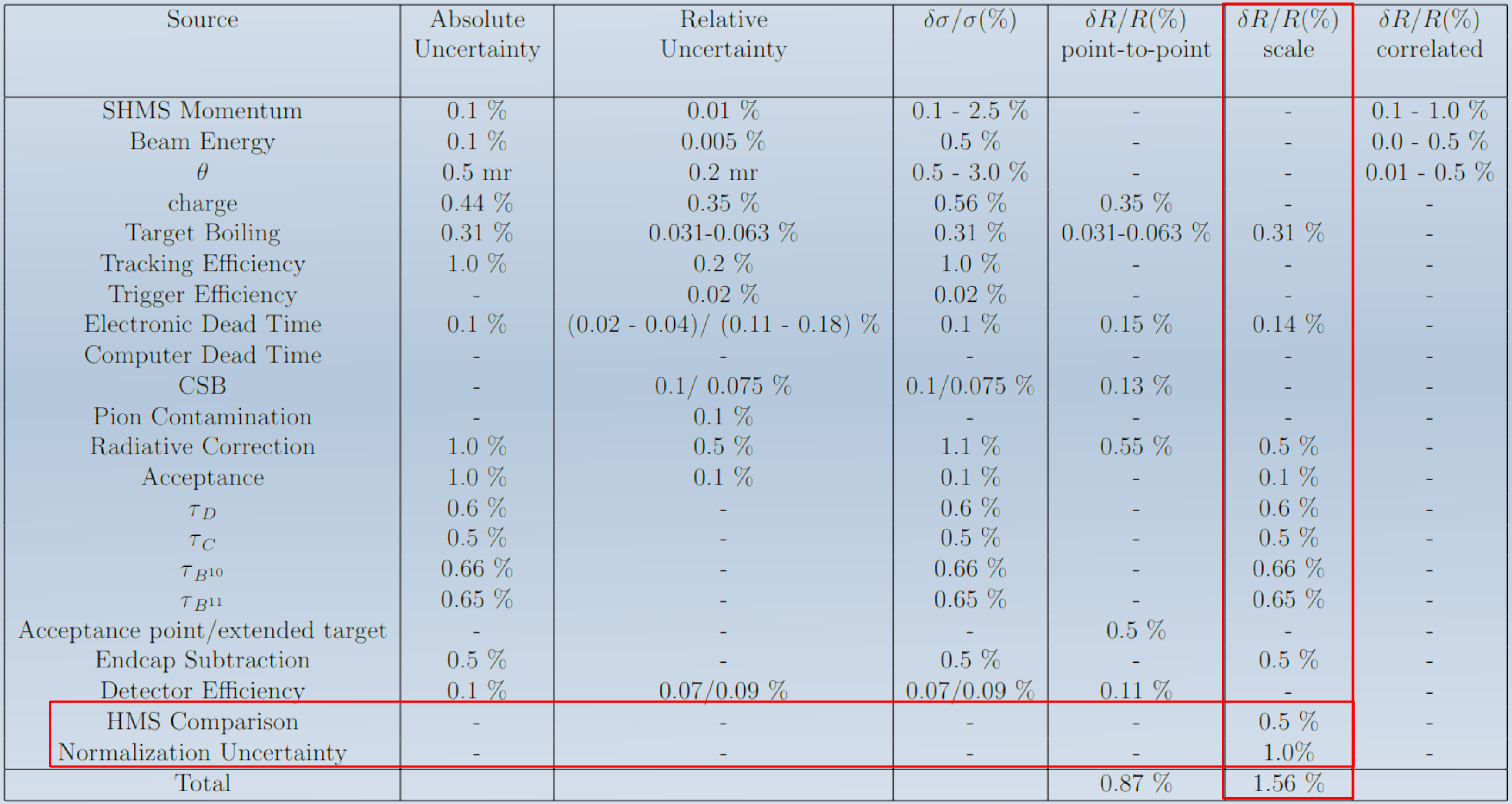
Result & Discussion



Source	Absolute Uncertainty	Relative Uncertainty	$\delta\sigma/\sigma(\%)$	$\delta R/R(\%)$ point-to-point	$\delta R/R(\%)$ scale	$\delta R/R(\%)$ correlated
SHMS Momentum	0.1 %	0.01 %	0.1 - 2.5 %	-	-	0.1 - 1.0 %
Beam Energy	0.1 %	0.005 %	0.5 %	-	-	0.0 - 0.5 %
θ	0.5 mr	0.2 mr	0.5 - 3.0 %	-	-	0.01 - 0.5 %
charge	0.44 %	0.35 %	0.56 %	0.35 %	-	-
Target Boiling	0.31 %	0.031-0.063 %	0.31 %	0.031-0.063 %	0.31 %	-
Tracking Efficiency	1.0 %	0.2 %	1.0 %	-	-	-
Trigger Efficiency	-	0.02 %	0.02 %	-	-	-
Electronic Dead Time	0.1 %	(0.02 - 0.04)/ (0.11 - 0.18) %	0.1 %	0.15 %	0.14 %	-
Computer Dead Time	-	-	-	-	-	-
CSB	-	0.1/ 0.075 %	0.1/0.075 %	0.13 %	-	-
Pion Contamination	-	0.1 %	-	-	-	-
Radiative Correction	1.0 %	0.5 %	1.1 %	0.55 %	0.5 %	-
Acceptance	1.0 %	0.1 %	0.1 %	-	0.1 %	-
τ_D	0.6 %	-	0.6 %	-	0.6 %	-
τ_C	0.5 %	-	0.5 %	-	0.5 %	-
$\tau_{B^{10}}$	0.66 %	-	0.66 %	-	0.66 %	-
$\tau_{B^{11}}$	0.65 %	-	0.65 %	-	0.65 %	-
Acceptance point/extended target	-	-	-	0.5 %	-	-
Endcap Subtraction	0.5 %	-	0.5 %	-	0.5 %	-
Detector Efficiency	0.1 %	0.07/0.09 %	0.07/0.09 %	0.11 %	-	-
HMS Comparison	-	-	-	-	0.5 %	-
Normalization Uncertainty	-	-	-	-	1.0%	-
Total				0.87 %	1.56 %	

Table 1.1: Systematic Uncertainties.

Result & Discussion

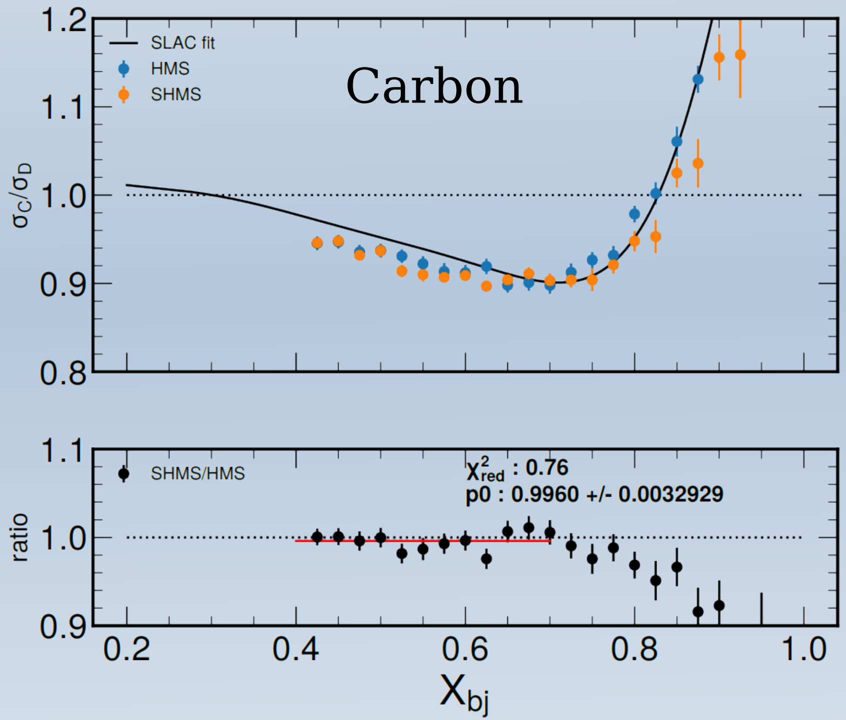


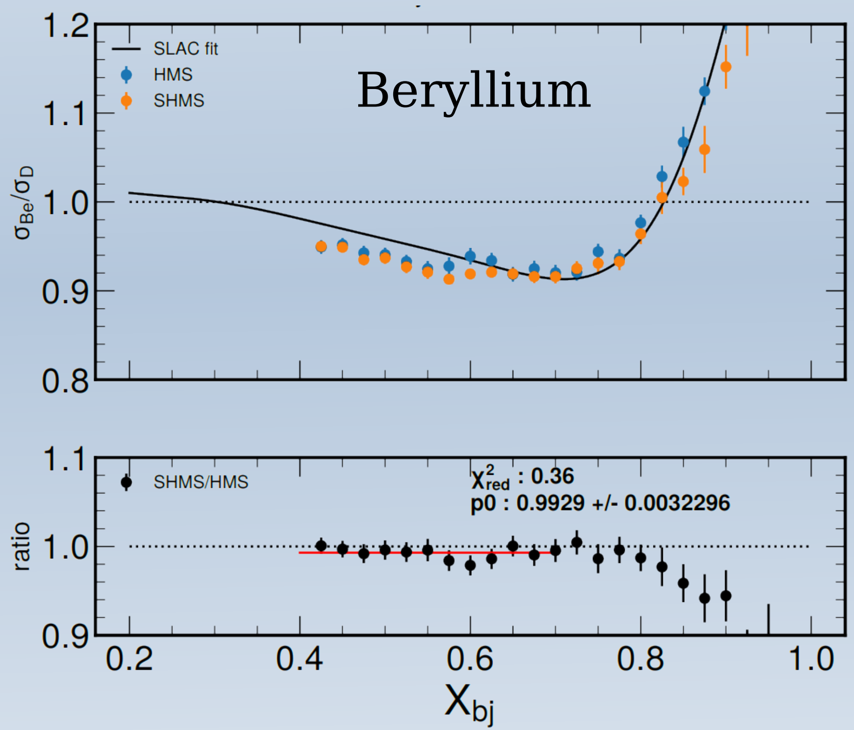
Source	Absolute Uncertainty	Relative Uncertainty	$\delta\sigma/\sigma(\%)$	$\delta R/R(\%)$ point-to-point	$\delta R/R(\%)$ scale	$\delta R/R(\%)$ correlated
SHMS Momentum	0.1 %	0.01 %	0.1 - 2.5 %	-	-	0.1 - 1.0 %
Beam Energy	0.1 %	0.005 %	0.5 %	-	-	0.0 - 0.5 %
θ	0.5 mr	0.2 mr	0.5 - 3.0 %	-	-	0.01 - 0.5 %
charge	0.44 %	0.35 %	0.56 %	0.35 %	-	-
Target Boiling	0.31 %	0.031-0.063 %	0.31 %	0.031-0.063 %	0.31 %	-
Tracking Efficiency	1.0 %	0.2 %	1.0 %	-	-	-
Trigger Efficiency	-	0.02 %	0.02 %	-	-	-
Electronic Dead Time	0.1 %	(0.02 - 0.04)/ (0.11 - 0.18) %	0.1 %	0.15 %	0.14 %	-
Computer Dead Time	-	-	-	-	-	-
CSB	-	0.1/ 0.075 %	0.1/0.075 %	0.13 %	-	-
Pion Contamination	-	0.1 %	-	-	-	-
Radiative Correction	1.0 %	0.5 %	1.1 %	0.55 %	0.5 %	-
Acceptance	1.0 %	0.1 %	0.1 %	-	0.1 %	-
τ_D	0.6 %	-	0.6 %	-	0.6 %	-
τ_C	0.5 %	-	0.5 %	-	0.5 %	-
$\tau_{B^{10}}$	0.66 %	-	0.66 %	-	0.66 %	-
$\tau_{B^{11}}$	0.65 %	-	0.65 %	-	0.65 %	-
Acceptance point/extended target	-	-	-	0.5 %	-	-
Endcap Subtraction	0.5 %	-	0.5 %	-	0.5 %	-
Detector Efficiency	0.1 %	0.07/0.09 %	0.07/0.09 %	0.11 %	-	-
HMS Comparison	-	-	-	-	0.5 %	-
Normalization Uncertainty	-	-	-	-	1.0%	-
Total				0.87 %	1.56 %	

Table 1.1: Systematic Uncertainties.

Result & Discussion

Cross check with HMS – limited x range





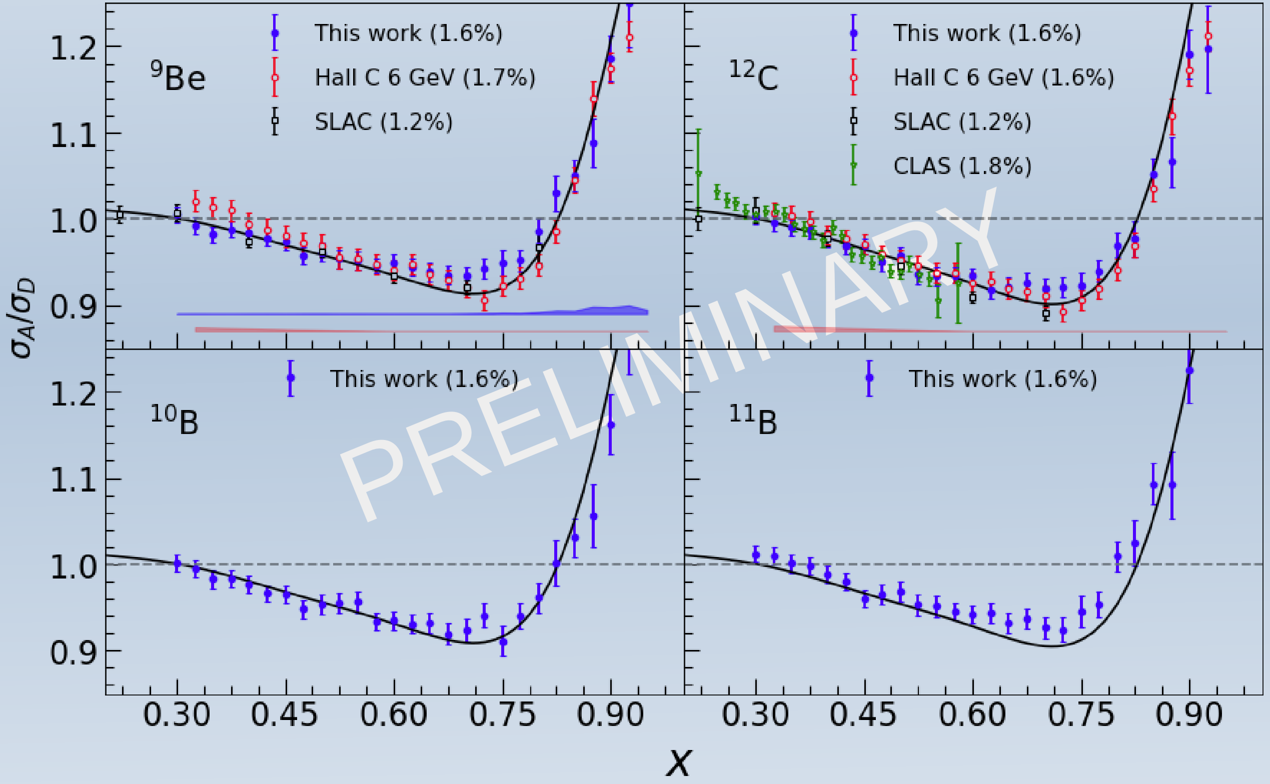
Result & Discussion

Normalization Uncertainty:

- EMC ratio systematically off by 2% than previous measurement
- Exists for all solid targets
- Possibly due to unknown effect with respect to the deuterium (thickness, density)
- From previous data, empirical observation, EMC ratio is 1 at $x = 0.3$, independent of target
- Used the extracted normalization factor
- Limitation on precision of previous world data at $x = 0.3$, 1% uncertainty is added
- Slope has very small sensitivity to overall normalization of the EMC ratios.

Result & Discussion

- Ratio of x-sec per nucleon vs *x*
- Error bars include statistics combined with point-to-point systematic errors.
- The normalization error for each experiment is noted in the label
- The red and blue band denotes x-correlated error the Jlab Hall C 6 GeV and for this experiment.
- The solid black curve is the A-dependent fit of the EMC effect from SLAC 139.



N.B Paper is submitted to PRL

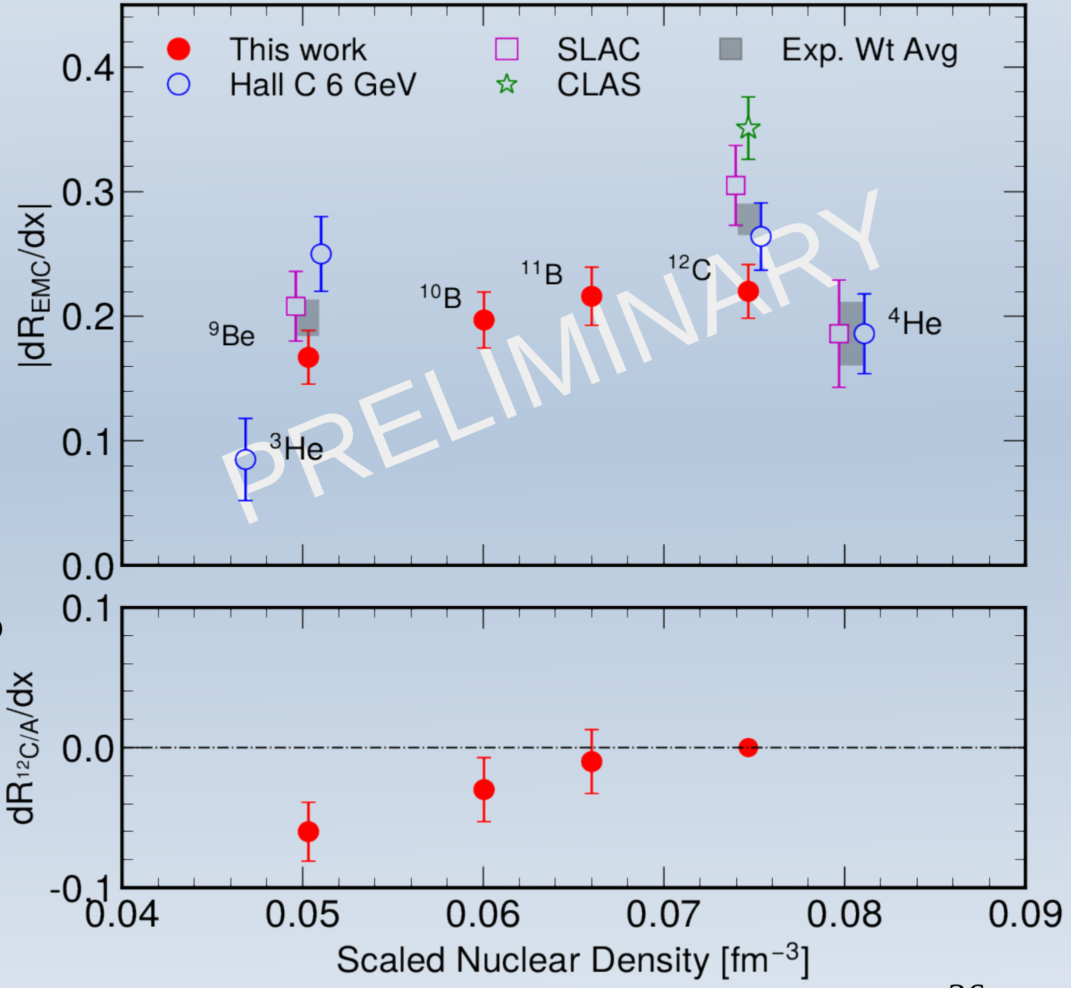
Result & Discussion

Top:

- * Size of the EMC effect vs scaled Nuclear density.
- Some points have been offset horizontally for visibility.
- Grey band denotes weighted average for all experiments shown for a given target

Bottom:

- Slope extracted from x-section ratios of ^{12}C to ^{9}Be, ^{10,11}B from this experiment.



* Size of the EMC effect: slope from x-sec ratio $0.3 < x < 0.7$
scaled Nuclear density = $\rho^*(A-1)/A$

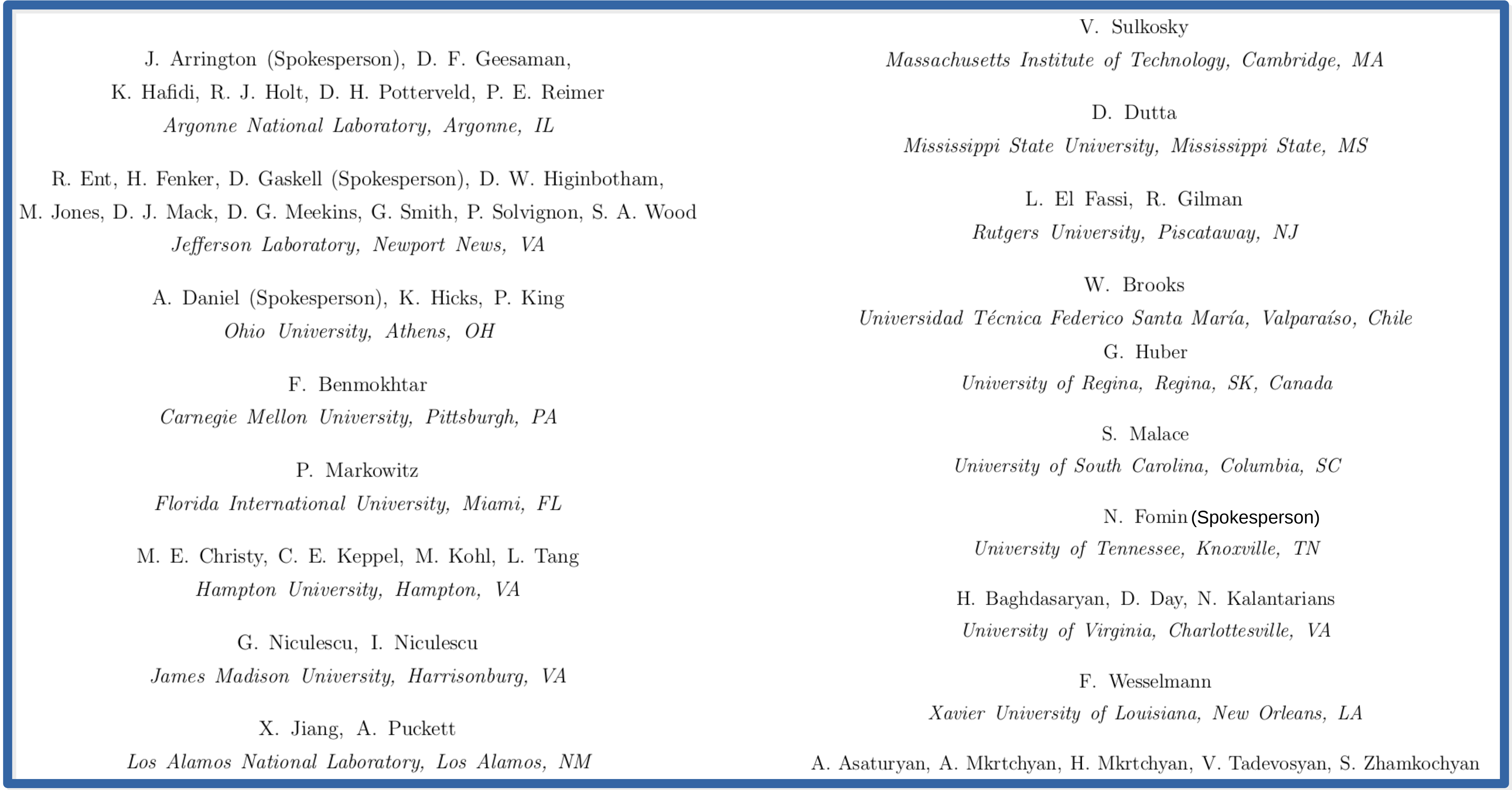
Summary

- The First measurements of the EMC effect in ^{10}B and ^{11}B
- New information on the nuclear dependence of the EMC effect
- Strengthen the hypothesis that the EMC effect driven by local density

Acknowledgment

- Dipangkar Dutta (Advisor)
- Dave Gaskell (Spokesperson + Advisor)
- John Arrington (Spokesperson)
- Nadia Fomin (Spokesperson)
- The funding Agency
- The accelerator group

Thank you



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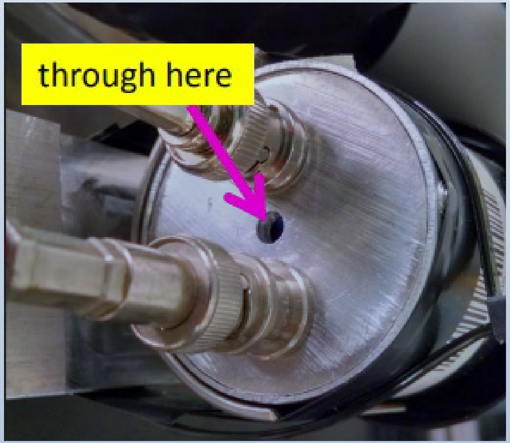
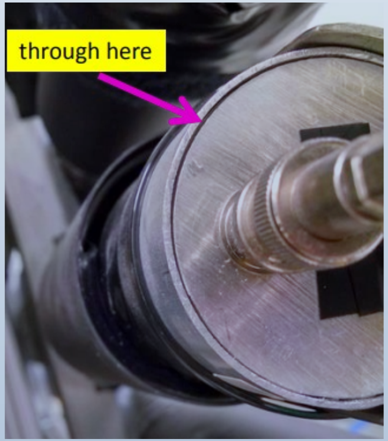
BackUp

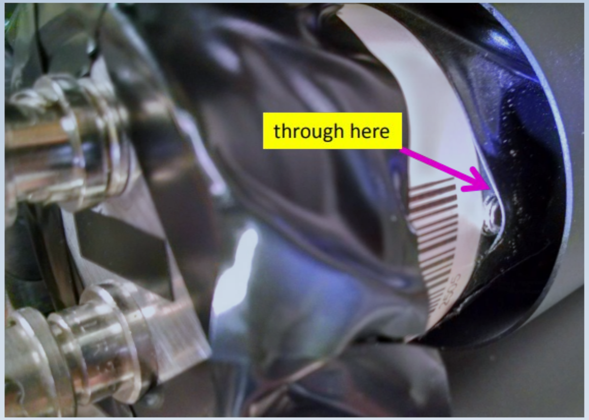
Project beside my Ph.D:

SHMS scintillators work:

- Light leak
  - 3 Major source
    - Through central hole
    - Through gaps between back plates and walls of base
    - Through gaps in tapping around base



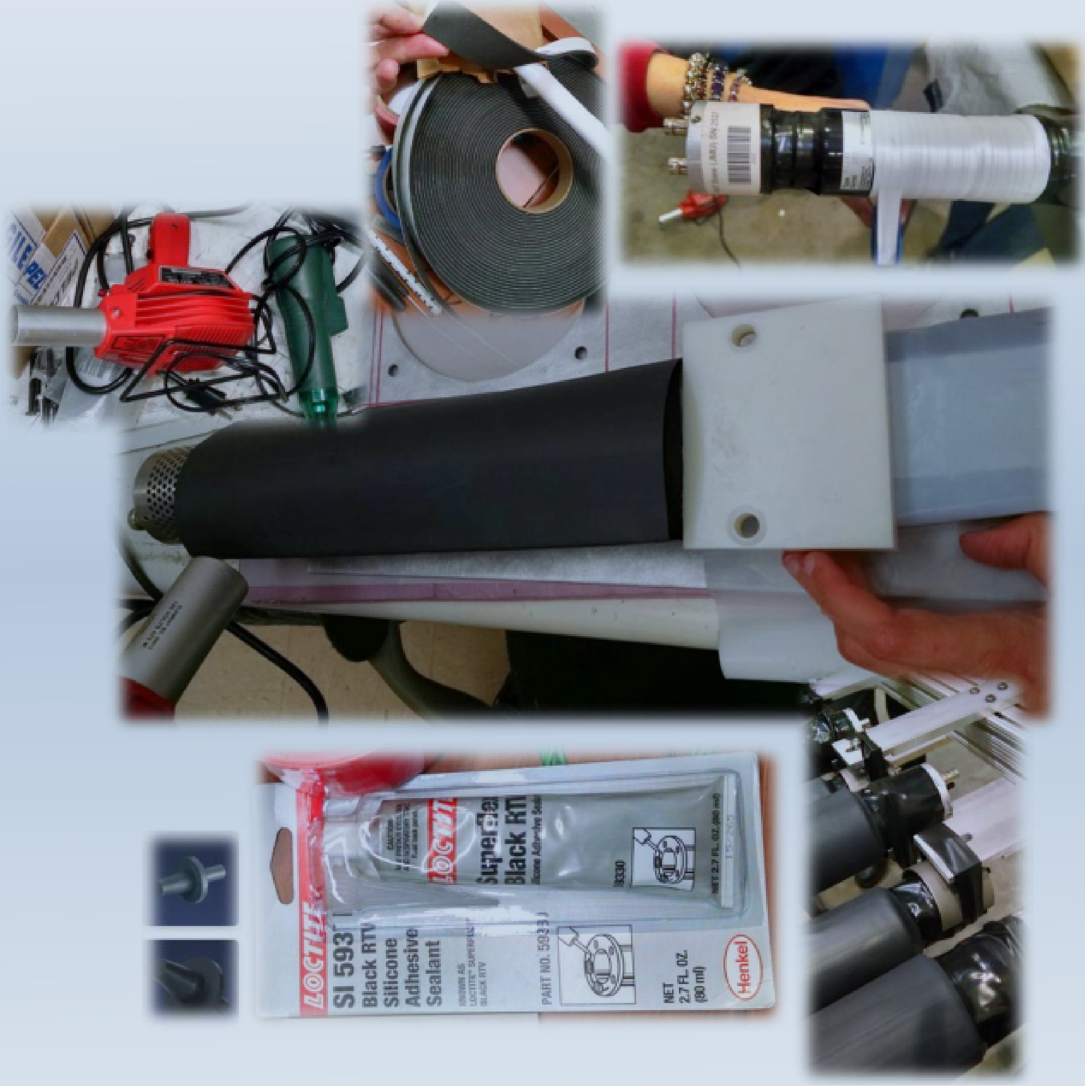




Project beside my Ph.D:

SHMS scintillators work:

- Solution
  - Apply teflon at the cathode
  - Tape over teflon
  - Wrap foam at the ends of the PMT to support
  - Position mu-metal
  - Put on the heat shrink
  - Apply silicone around boundary at the back



Project beside my Ph.D:

SHMS Quartz Bar:

- Problem : gassy PMTs & optical coupling
- Solution : replace PMTS & make thin but strong RTV couplings (~ 50 microns)

Steps :

- Pulled the old PMTs from the bar
- Cleaned the bars
- Made many RTV couplings
- Put together bench tests to check the bars with cosmics
- Tested the new PMTs to get the gain vs voltage curve
- Final assembly of the new PMT on the bars
- Tested all the bars with cosmics on the bench

Project beside my Ph.D:

Large Acceptance Calorimeter

- Identify the bad PMTs
- Replace with new ones

Neutral Particle Spectrometer


Pic courtesy : Vladimir

Preparing the crystal

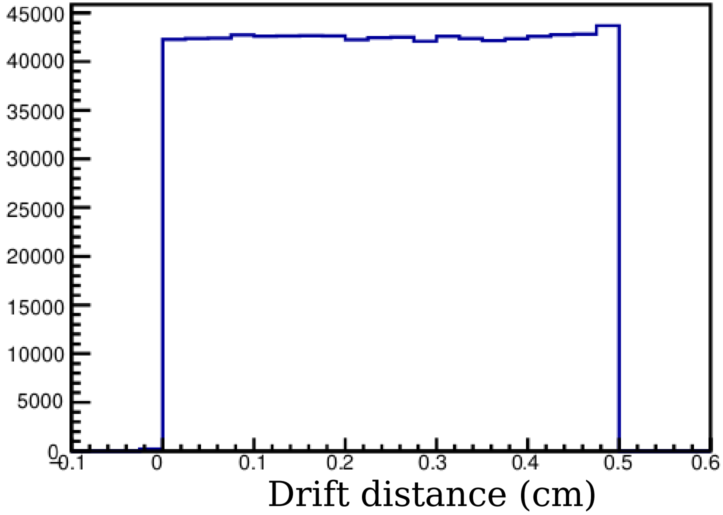
- Cleaning Crystal ($PbWO_4$)
- Wrapping with reflector
- Wrapping with tedlar

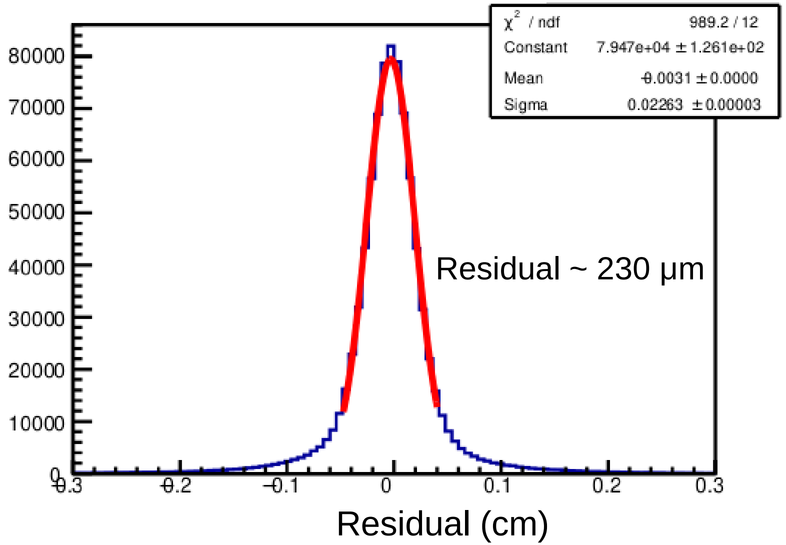
Calibration

Drift Chamber

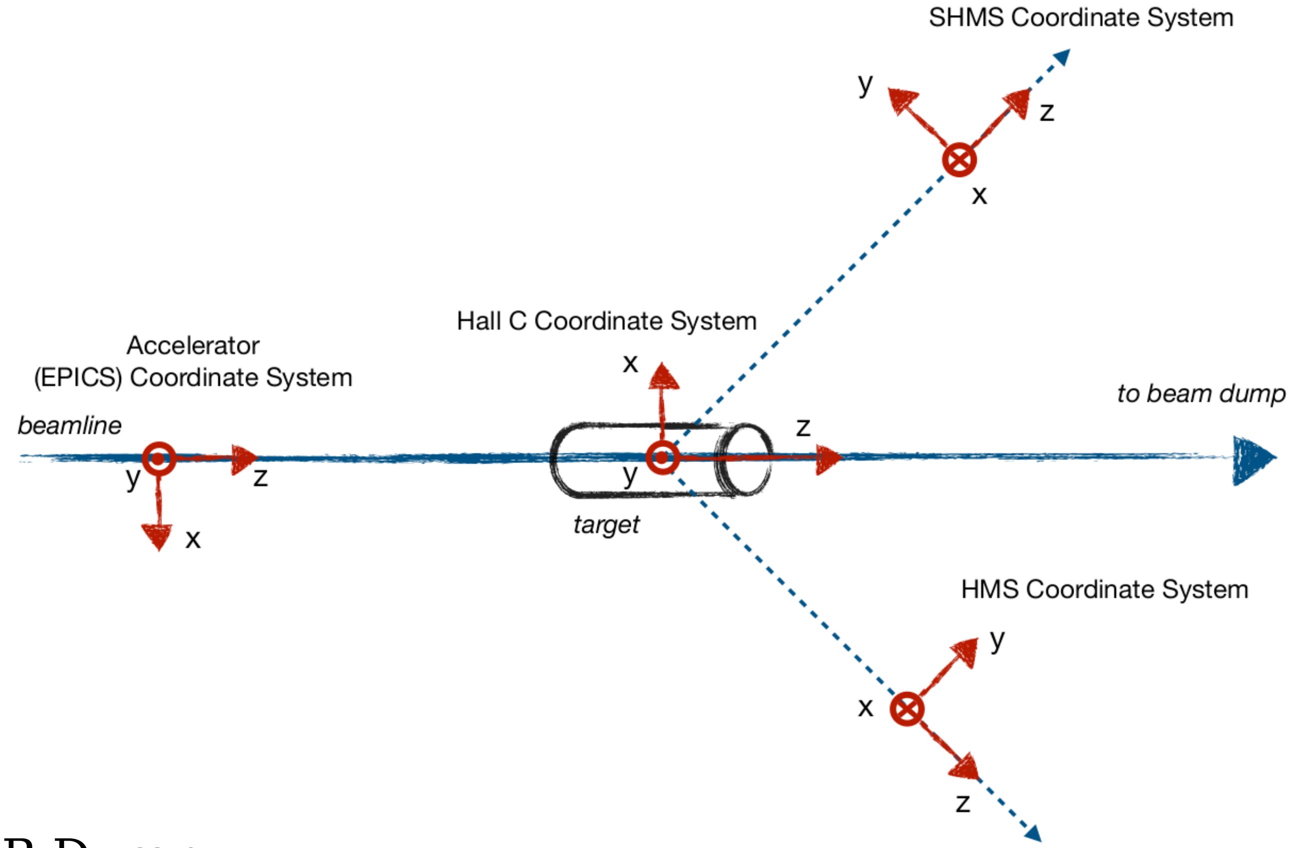
- TDC values averaged over all wires forms drift time distribution – turned into drift distance

- Calibrations checked against Drift Distance plots and residuals – ‘good’ calibration produces flat drift distance





Residual ~ 230 μm



Courtesy plot :B Duran

Analysis Status: Isoscalar correction

- Proton and neutron have different x-sections, x-sections for nuclei with z ≠A/2 will significantly differ from that of nuclei with z =A/2 (Isoscalar)

- Needs to correct for excess of neutrons or protons. The multiplicative correction factor is,

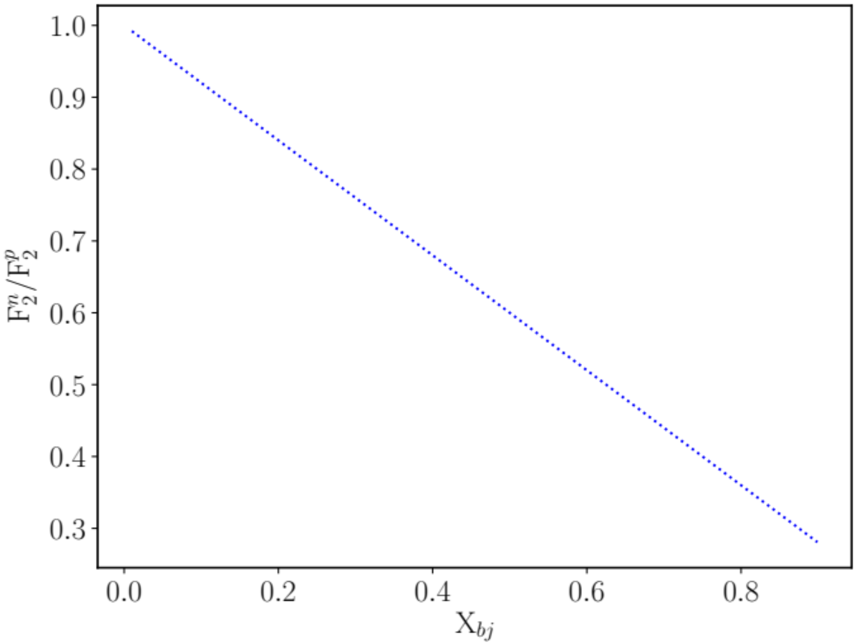
$$f_{iso}^{A} = \frac{\frac{1}{2}\left(1 + F_2^n/F_2^p\right)}{\frac{1}{A}\left(Z + (A-Z)F_2^n/F_2^p\right)}$$

- Since there is no free neutron target, extraction of F_2^n/F_2^p is always model-dependent

- Currently using SLAC Parameterization:

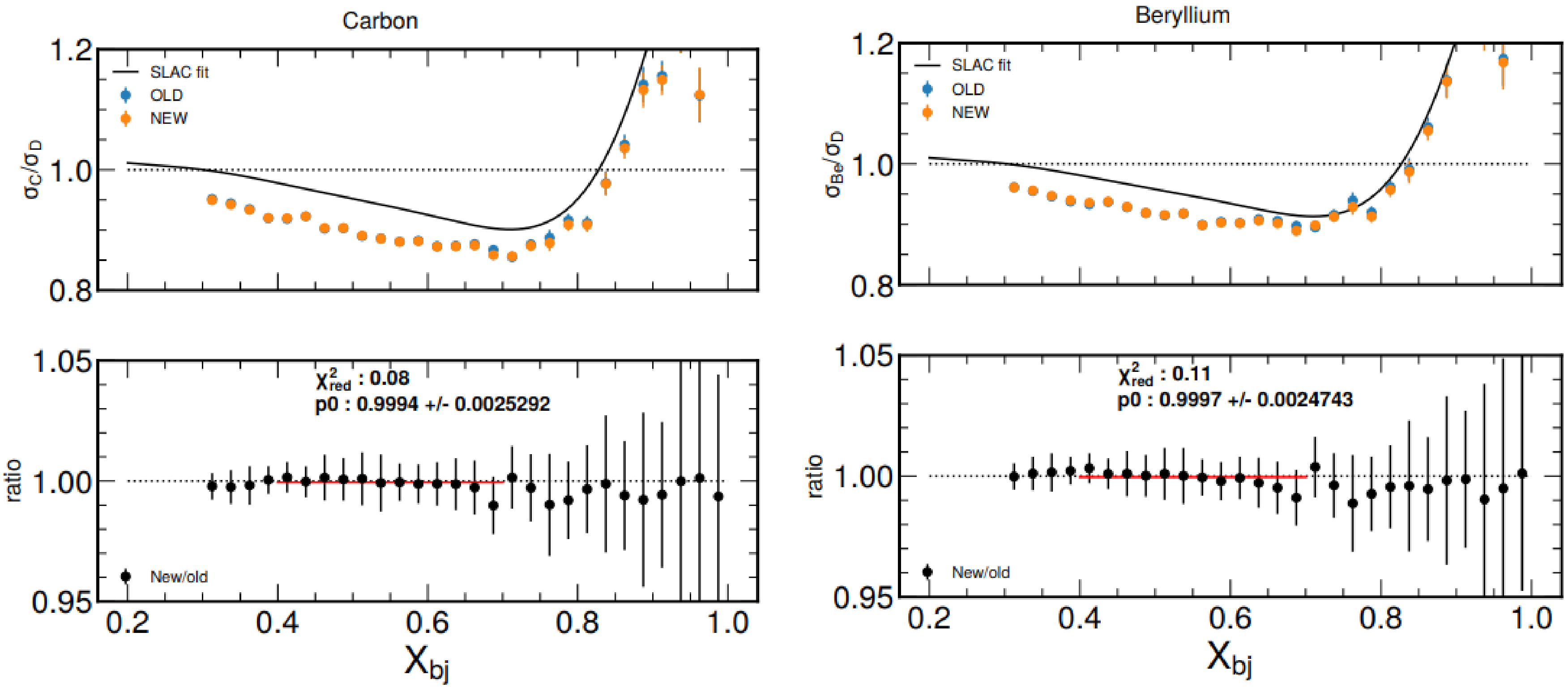
$$F_2^n/F_2^p = 1 - 0.8 * X_{Bj}$$

SLAC Parameterization



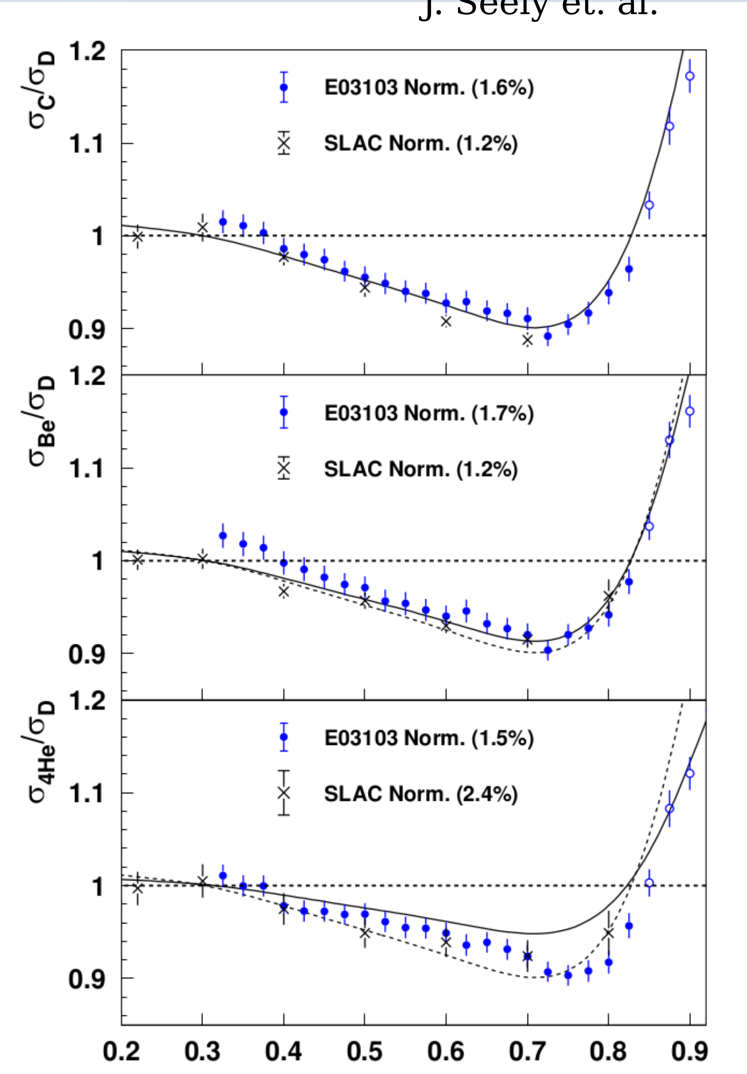
Update

Old = with Cherenkov
New = no Cherenkov with cal >0.9



Note: Need to fix the error in the bottom plot, as I was treating them 2 statistically independent data set

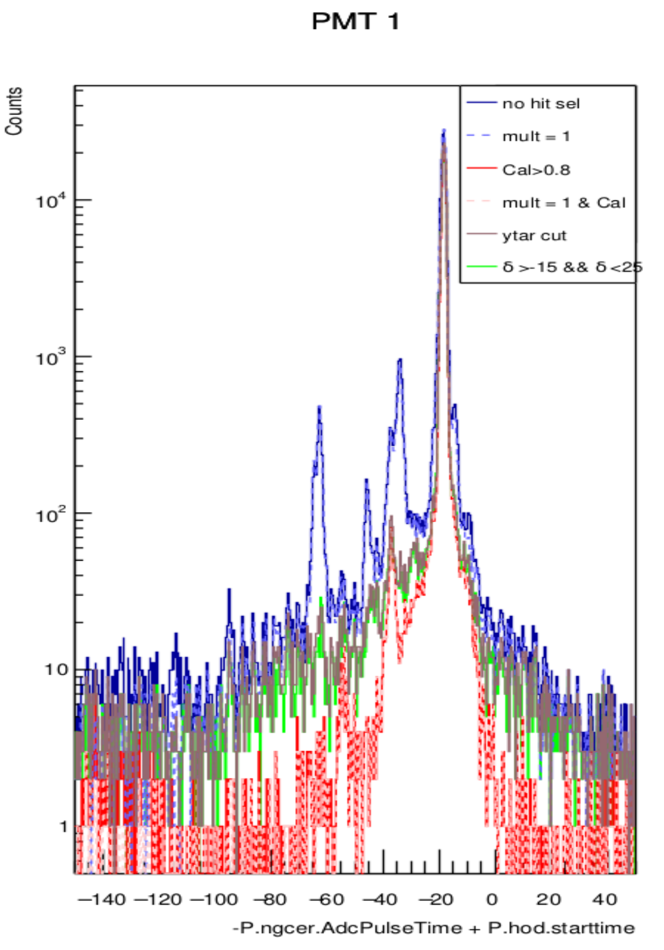
J. Seely et. al.


σ_C/σ_D
E03103 Norm. (1.6%)
SLAC Norm. (1.2%)
σ_{Be}/σ_D
E03103 Norm. (1.7%)
SLAC Norm. (1.2%)
σ_{4He}/σ_D
E03103 Norm. (1.5%)
SLAC Norm. (2.4%)
1.2
1.1
1
0.9
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

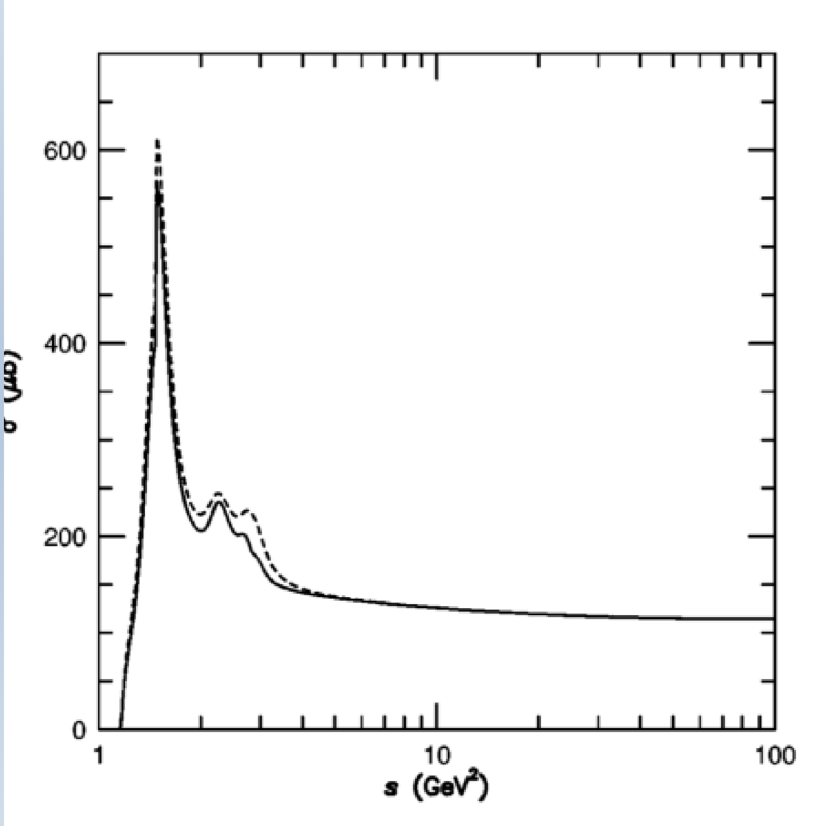
Timing Cuts

Timing window

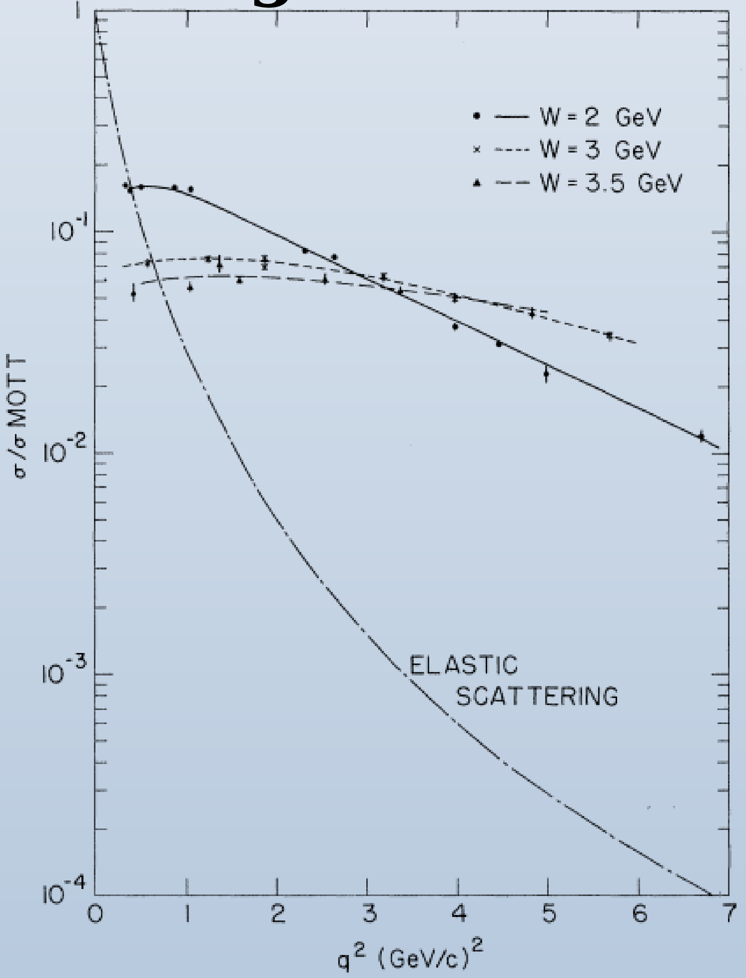
- Choosing appropriate time windows for each detector is important for hit selection
- Want to capture prompt peak signal and minimize background
- Sometimes signal is clean, sometimes window selection is not trivial



Pion Photo production



Scaling Observed in SLAC e-P scattering



M. Briedenbach et al
Phys Rev Lett 23, 935 (1969)

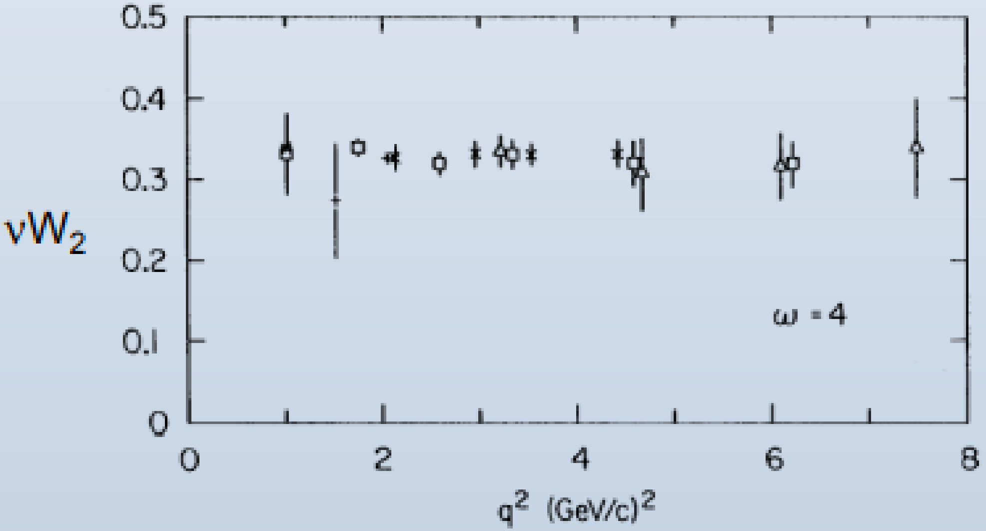
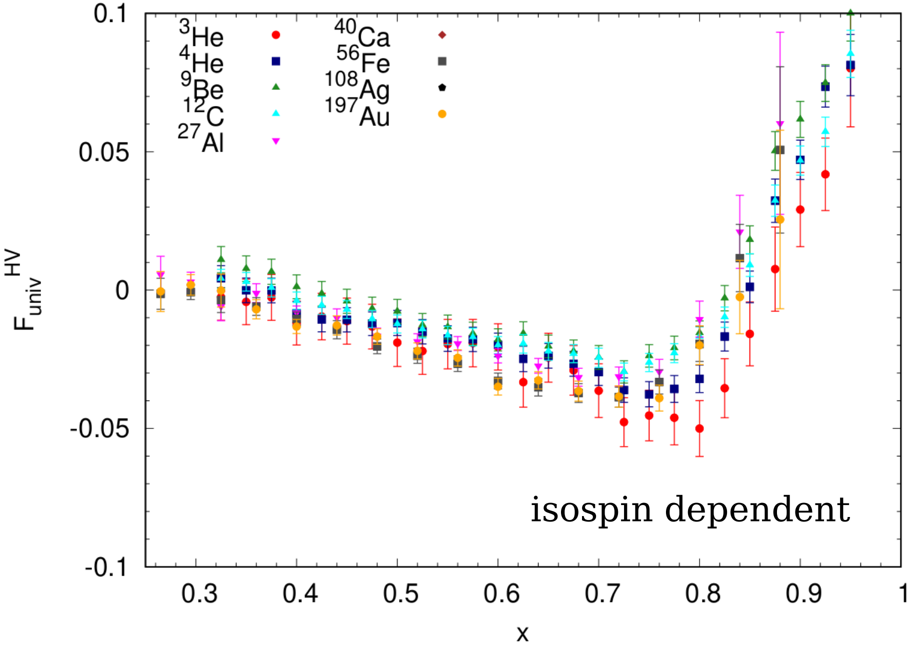


Fig: Quark and Leptons by Halzen & Martin

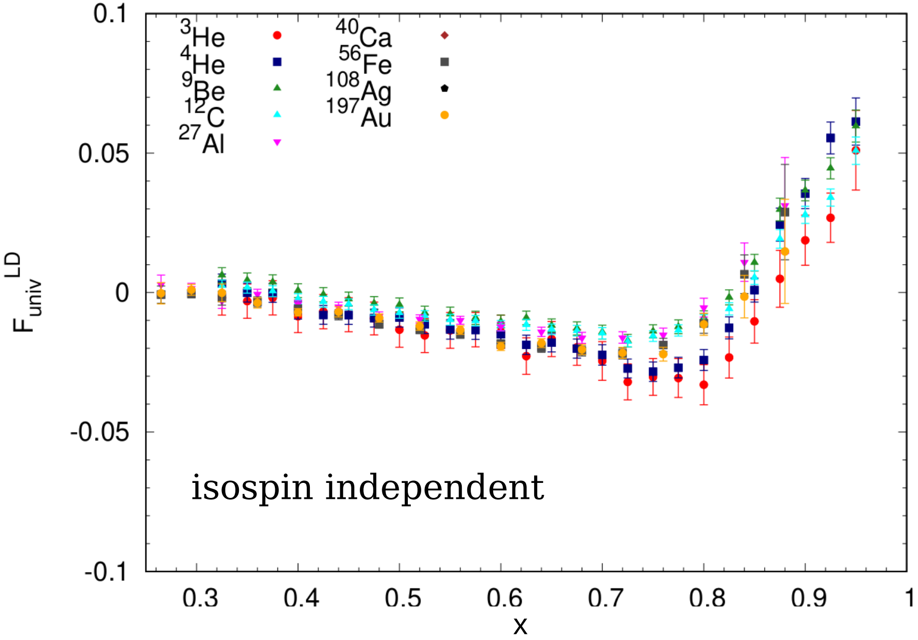
- The ratio σ/σ_{mott} : no Q^2 dependence
- Structure function, νW_2 (F_2) has no Q^2 dependence
- What does this mean?
    - Scattering against something point like.

Motivation: SRC & EMC correlation



isospin dependent

Arrington/Fomin PRL (2019)



isospin independent

Extract universal functions to test both HV and LD hypotheses

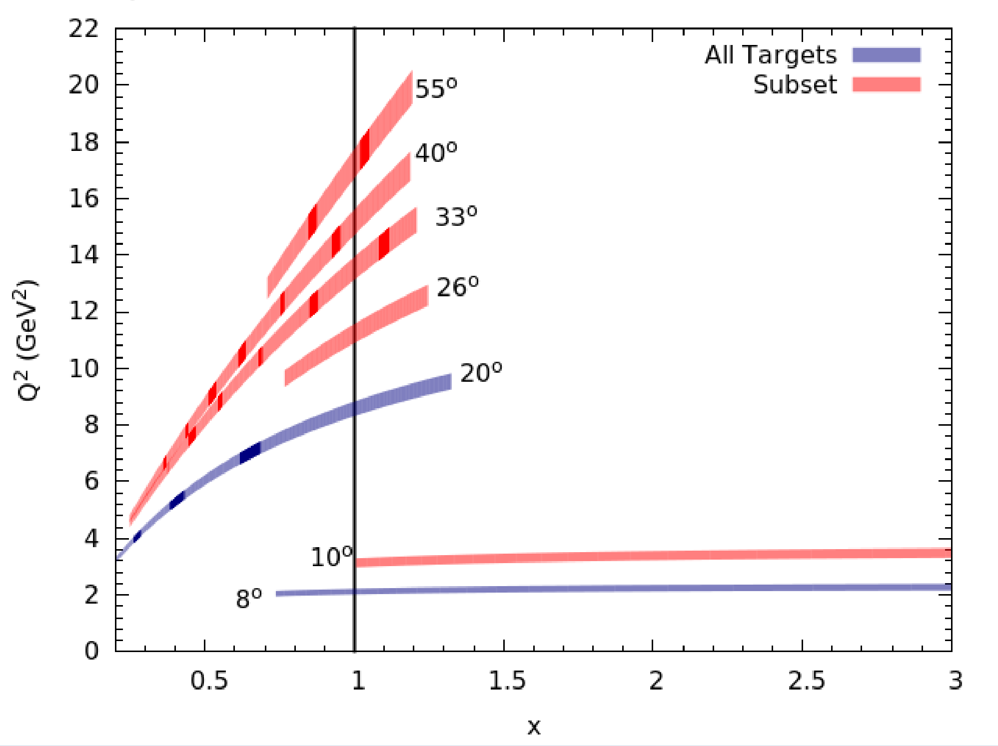
Quantitative understanding requires additional light nuclei

Future Measurement: E12-10-008 Phase – II Kinematic Overview

Spectrometer	Angle	Momentum (GeV/c)	Beam Energy (GeV)
SHMS	8 - 33	1.4 - 10.6	11
HMS	20 - 55	1.4 - 6.4	11

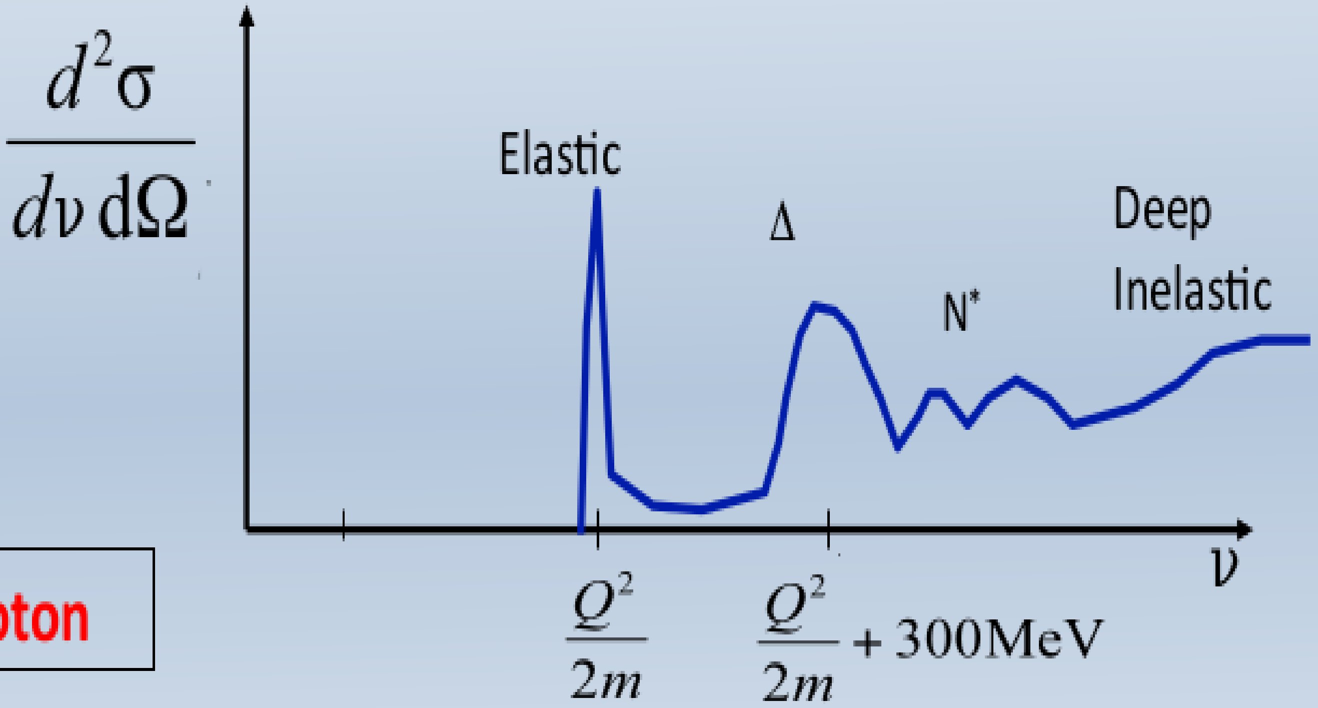
- Runs concurrently with E12-06-105 (x>1)
- Covers range of angles
- HMS and SHMS run in parallel
- 23 PAC days for Phase I and Phase II
    - 2 days completed spring 2018 (Phase I)

*** Running Aug 27, 2022**



- Plot shows kinematics coverage for EMC and x>1.
- The lower x represent the EMC effect data

Electron-Nucleon Scattering Spectrum (schematic)



Proton

Fig: Schematics showing the main features of the excitation spectra for the electron scattering

Quark-Parton Model

- First proposed by Richard Feynman
- The nucleon is made of point-like free quarks with spin ½
- Scattering off the nucleon is incoherent sum of elastic scattering of quarks
- The probability, f(x) for a quark to carry momentum fraction x, does not depend on the process or nucleon energy but it is intrinsic property for high energy nucleon
- This model explains Q^2 independence in Structure functions (‘Bjorken scaling’)

Quark-Parton Model

In this model, structure fns F_1 and F_2 are expressed in terms of the quarks and anti-quarks distribution functions as:

$$F_2(x) = 2xF_1 = x\sum_q e_q^2(q(x) + \bar{q}(x)),$$

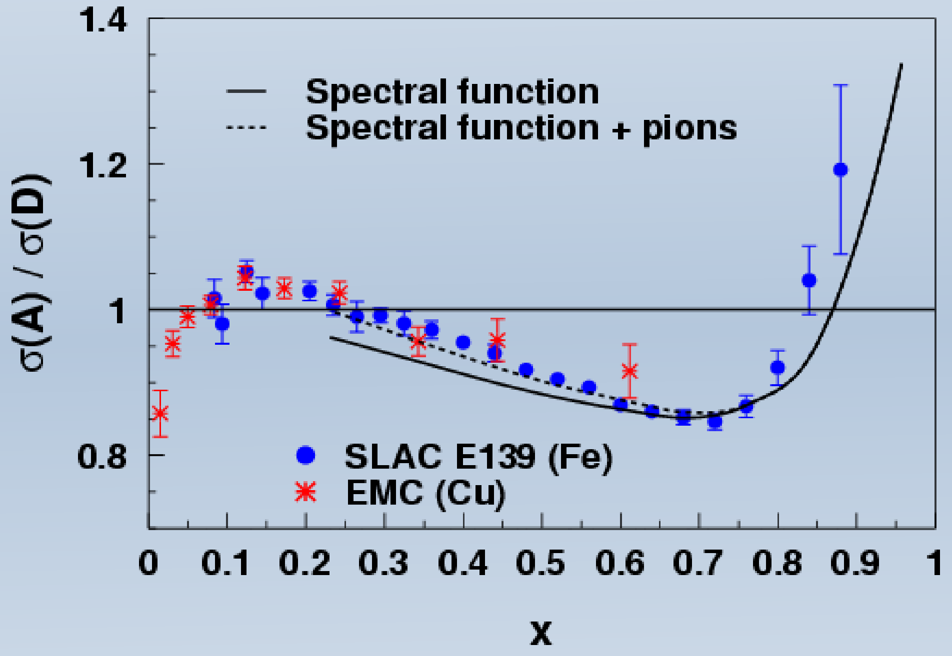
where,

e_q are the quark charges

q_x gives the probability that a quark flavor of q carries momentum lies in the range [x, x+dx] and sum runs over all quark flavor

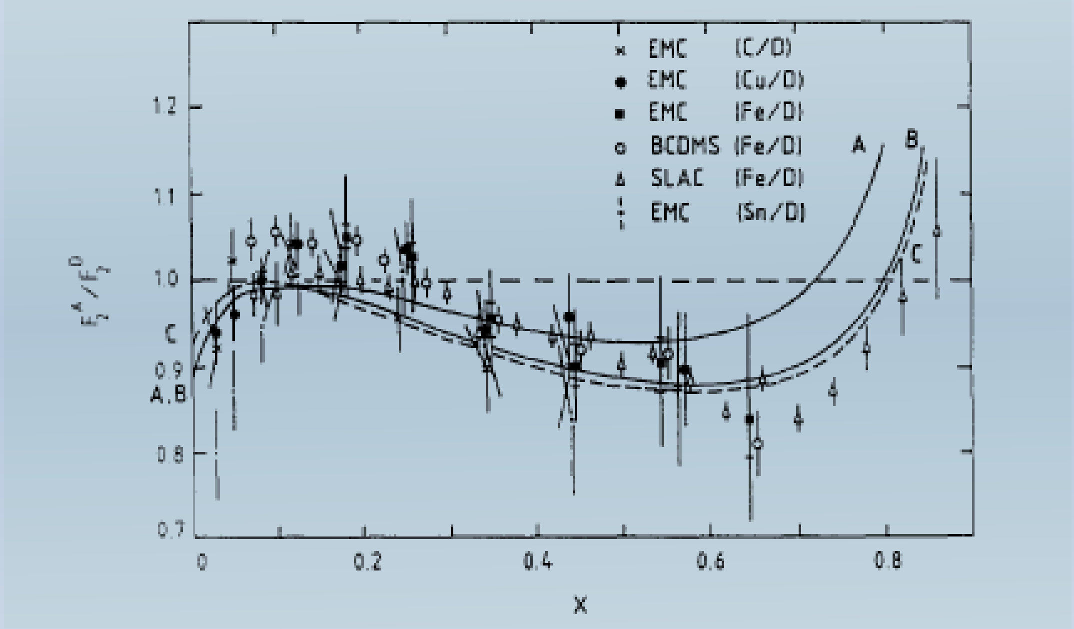
Calculation of the EMC Effect

Benhar, Pandharipande, and Sick
Phys. Lett. B410, 79 (1997)



Conventional Models

K.E. Lassila and U.P. Sakhatme
Phys. Lett. B209, 343 (1988)



Exotic Models
(multi-quark cluster)

CEBAF : The Continuous Electron Beam Accelerator Facility

Future Measurement: E12-10-008 Phase – II Kinematic Overview

- Target Choice motivated by physics impact
  - To study A dependence at fixed N/Z
  - To study N/Z dependence at fixed A

- Focus on target ratios
  - Light nuclei: cluster structure (Reliable calculation of nuclear structure)
  - Heavier nuclei: vary N/Z

- Large range of nuclei will test the proposed universal modification function of SRC-EMC correlation