The EMC PVDIS Experiment

A PAC 42 proposal
By
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Motivation

To constraint flavor-dependent nuclear medium modifications on nuclear parton distribution functions by using Parity-Violating Deep Inelastic Scattering (PVDIS)

Introduction

Parity violating asymmetry from the DIS electron quark scattering,

$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\left[a_2(x) + \frac{1-(1-y)^2}{1+(1-y)^2}a_3(x)\right]$$

Where $y = \frac{\nu}{E}$ and

$$a_2(x) = g_A^e \frac{F_1^{\gamma Z}}{F_1^{\gamma}} = 2\frac{\sum_i C_{1i} e_i (q_i + \bar{q}_i)}{\sum_i e_i^2 (q_i + \bar{q}_i)}$$

$$a_3(x) = g_V^e \frac{F_3^{\gamma Z}}{2F_1^{\gamma}} = 2\frac{\sum_i C_{2i} e_i (q_i - \bar{q}_i)}{\sum_i e_i^2 (q_i + \bar{q}_i)}.$$

Expand a1 about the limit $u_A = d_A$,

$$a_1 \simeq \frac{9}{5} - 4\sin^2\theta_W - \frac{12}{25}\frac{u_A^+ - d_A^+}{u_A^+ + d_A^+}$$

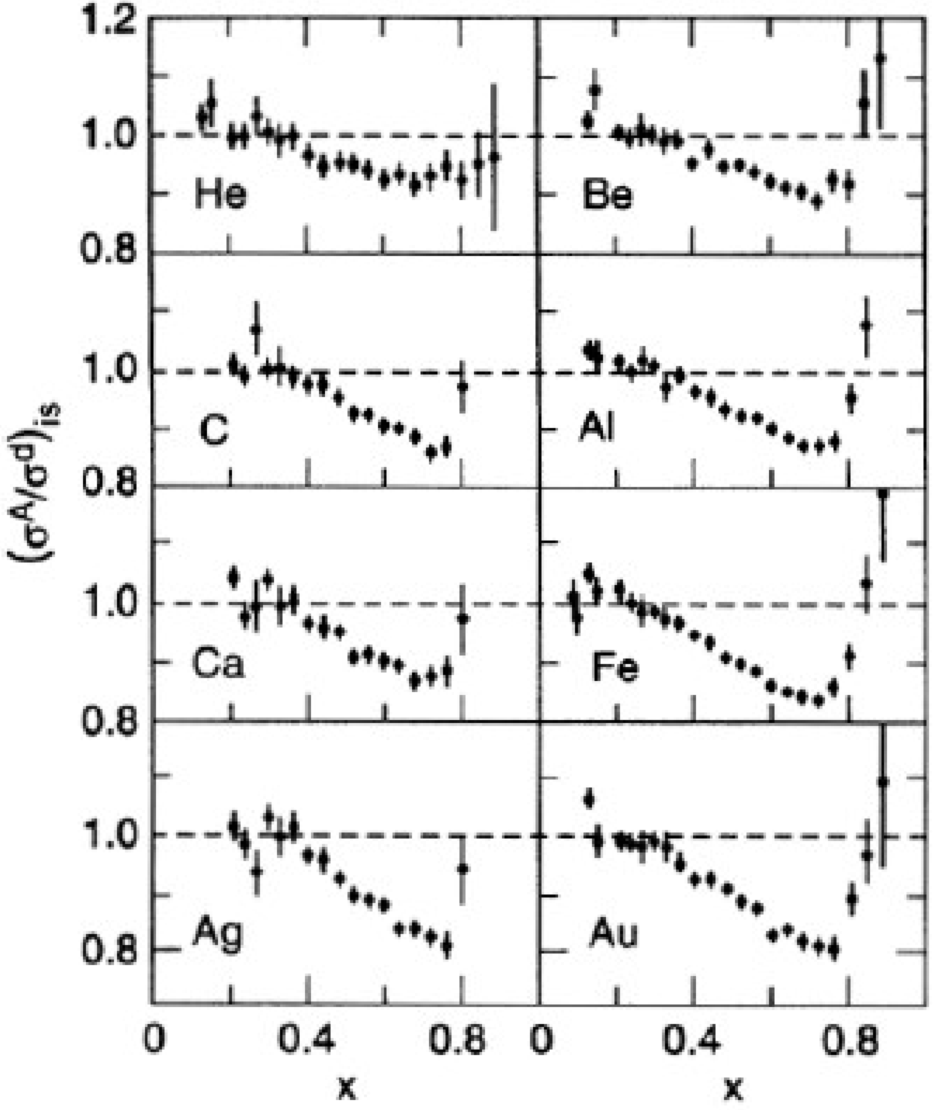
PVDIS asymmetry is a direct measurement of differences in the quark flavors

The $a_3(x)$ term only contributes about 5% to the asymmetry at our kinematics

Nuclear Modification

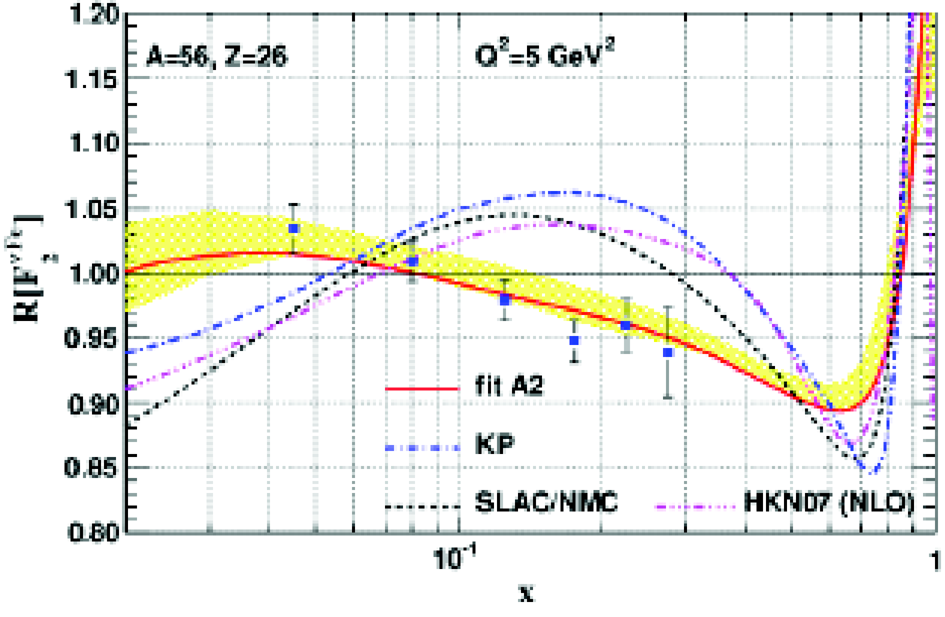
First observed by European Muon Collaboration EMC effect provided first direct evidence for modifications in quark distributions in nucleons bound in a nucleus.

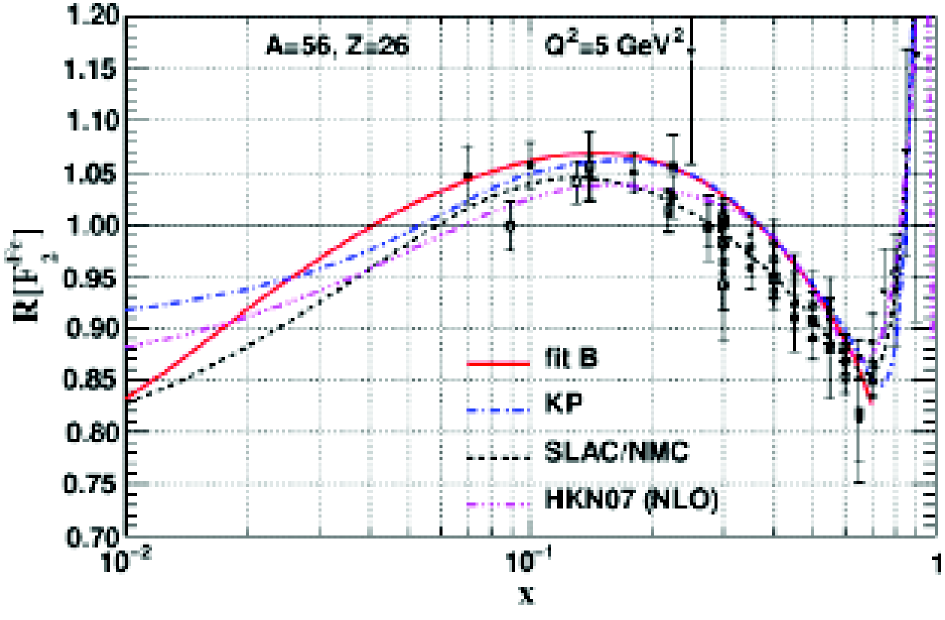
- A suppression in the range $0.3 < x < 0.8$ with a minimum around $x = 0.65$ dubbed the "EMC effect"
- An enhancement attributed to Fermi motion for $x > 0.9$
- A strong suppression for $x < 0.1$ from nuclear "shadowing"
- a small enhancement from $0.1 < x < 0.3$ or "anti-shadowing"



Potential Flavor Dependence Effects

- Form factor ratio, R discrepancies
  - Disagreement in form factor ratios F_2^A/F_2^D between charged lepton with Drell-Yan data (right plot) and charged current neutrino scattering (left plot) – arxiv:1208.6541 (2013)
  - Red solid line is a fit to data while others are different model calculations

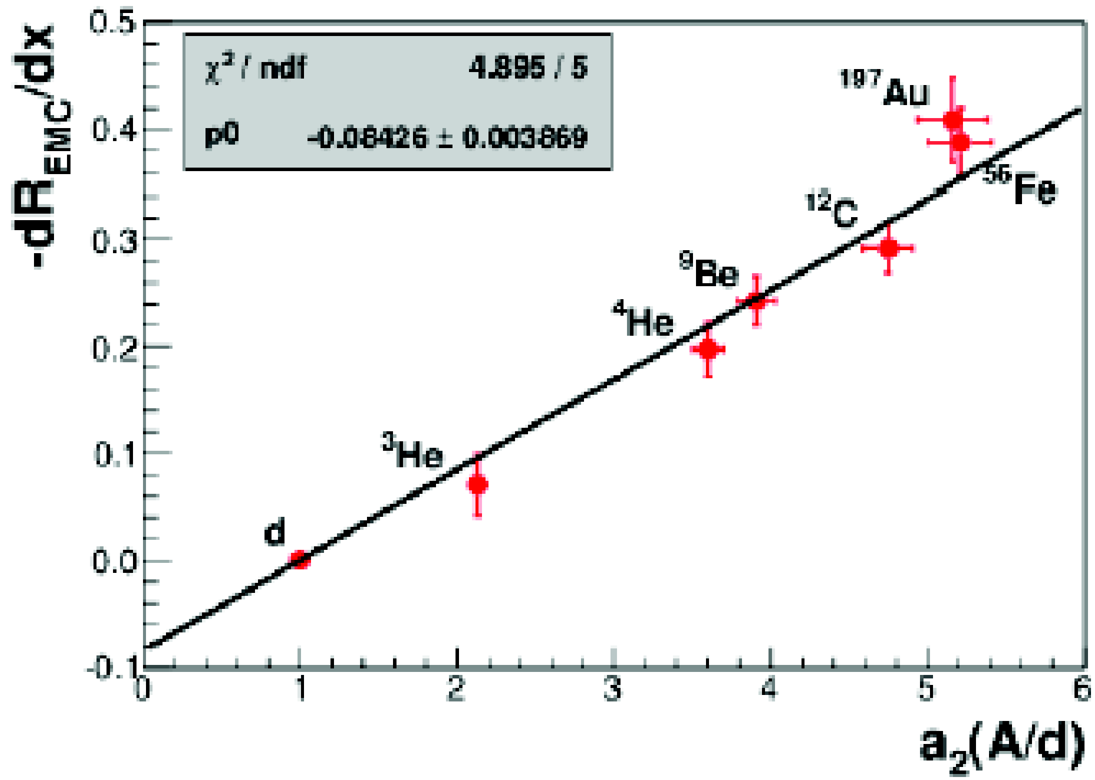




Potential Flavor Dependence Effects

Short Range Correlations (SRC)

- The empirical relationship between the short range correlation between nucleon in the nucleus and the slope of the EMC effect
  - PhysRevC.85.047301 (2012)
- Essentially ties nuclear physics with quark physics through empirical relationship

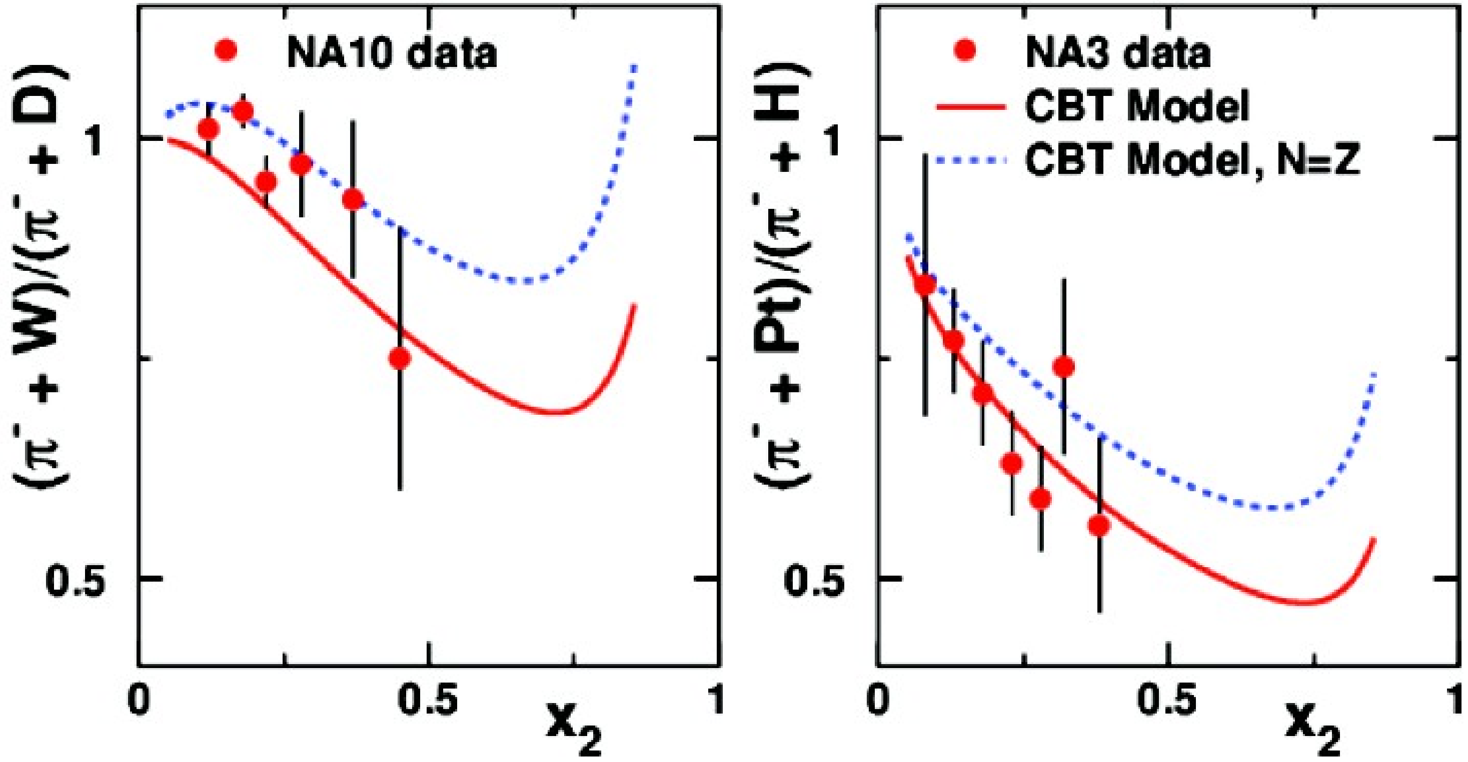


- The EMC slope is fitted against the SRC scaling factor $a_2(A/d)$
- Au and Fe deviation due to flavor dependence?

Potential Flavor Dependence Effects

Pionic Drell-Yan processes

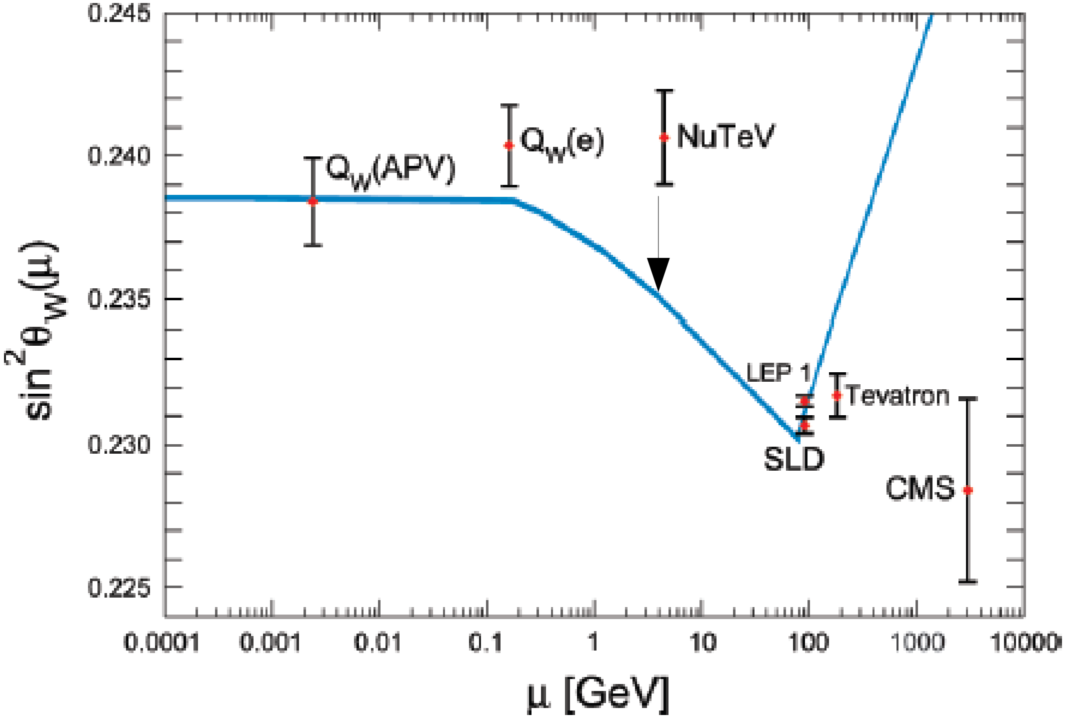
- Comparison of data with calculations using CBT model
- Existing data favors (weakly) a flavor dependence of the CBT model
  - See D. Dutta, J. C. Peng, I. C. Cloet and D. Gaskell, Phys. Rev. C 83, 042201 (2011)



Potential Flavor Dependence Effects

NuTeV anomaly

- A correction by a mean isovector field from the surrounding nucleus could account for remaining discrepancy – see PRL.102.252301 (2009)

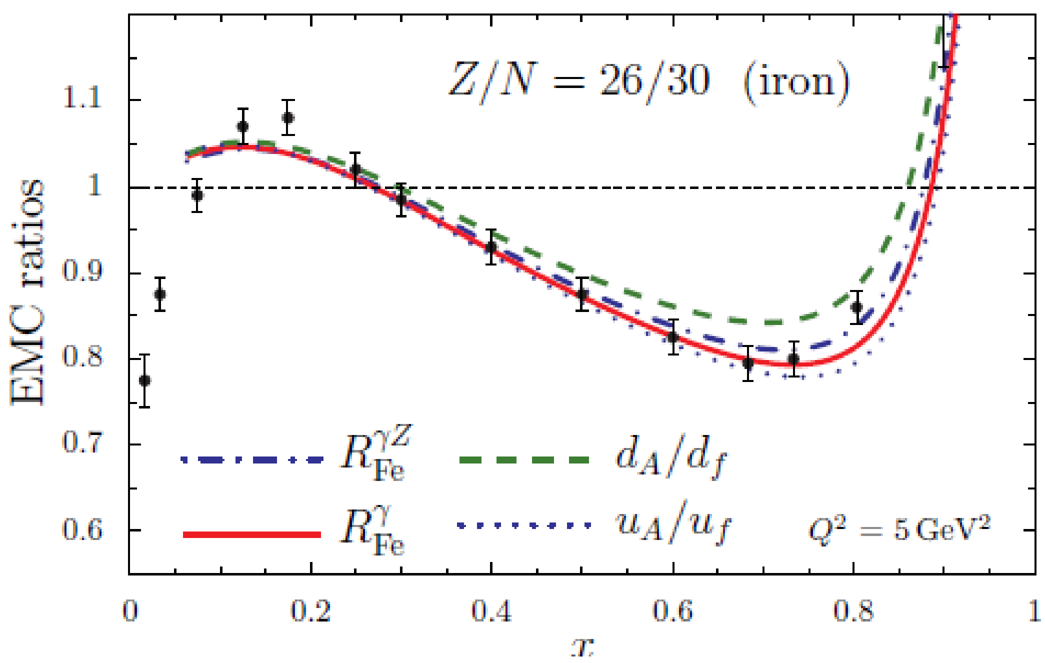


Flavor Dependent Model Calculations

- A calculation based on Nambu-Jona-Lasinio Model describes the medium modification to quark distribution
  - Cloet-Bentz-Thomas (CBT) model - *I. C. Cloet, W. Bentz and A. W. Thomas, Phys. Rev. Lett. 109, 182301 (2012)*
- An isovector mean field is introduced and the free parameters are constrained to reproduce experimental observables
- CBT model makes a novel prediction
  - Distinct nuclear modifications for u and d quarks in $N \neq Z$ nuclei
- So far model has been successful in predicting quark distributions for EMC effect
- Other models
  - Higher order QCD evolution, strange sea asymmetry, charge symmetry violation, or nuclear shadowing

EMC Predictions from CBT

- EMC effect can be predicted through isovector parton distribution modifications
  - Flavor dependent models can predict isovector field when an excess of neutrons or protons presents in the nucleus



PVDIS $a_2(x)$ from CBT

- CBT Model prediction for PVDIS $a_2(x)$ term for ^{48}Ca is shown here – see PRL.109.182301 (2012)
- The effect clearly show an enhancement over naive $a_2(x)$ calculation
- The difference is on the order of 1 − 5% for 0.2 < x < 0.7
  - A model estimation like this can be tested experimentally to a few sigma

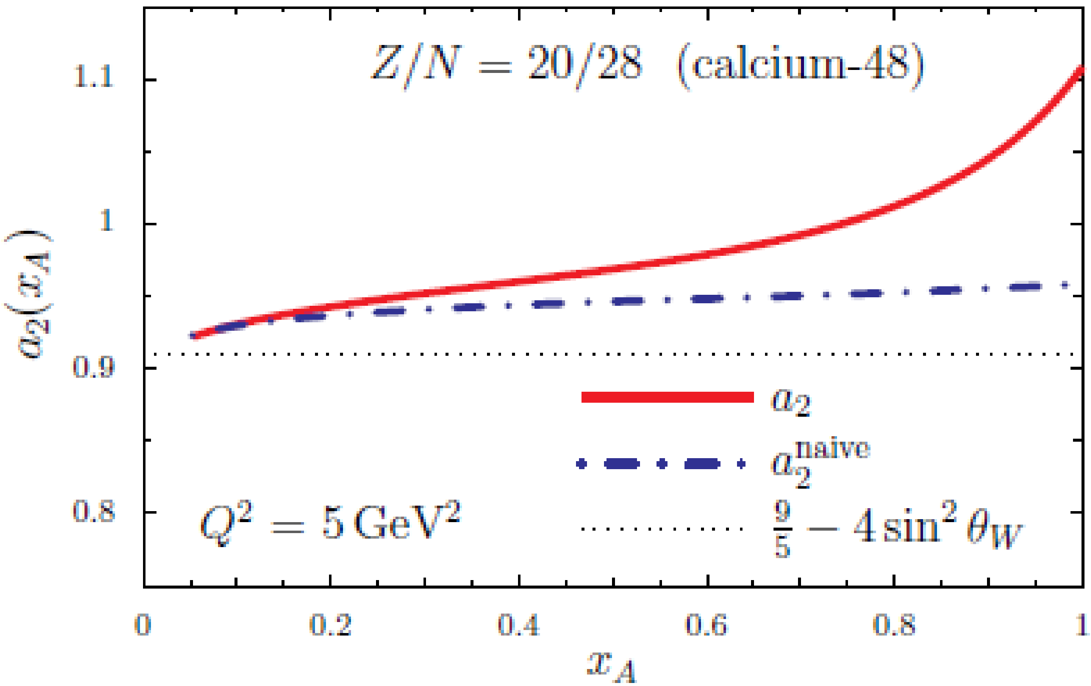
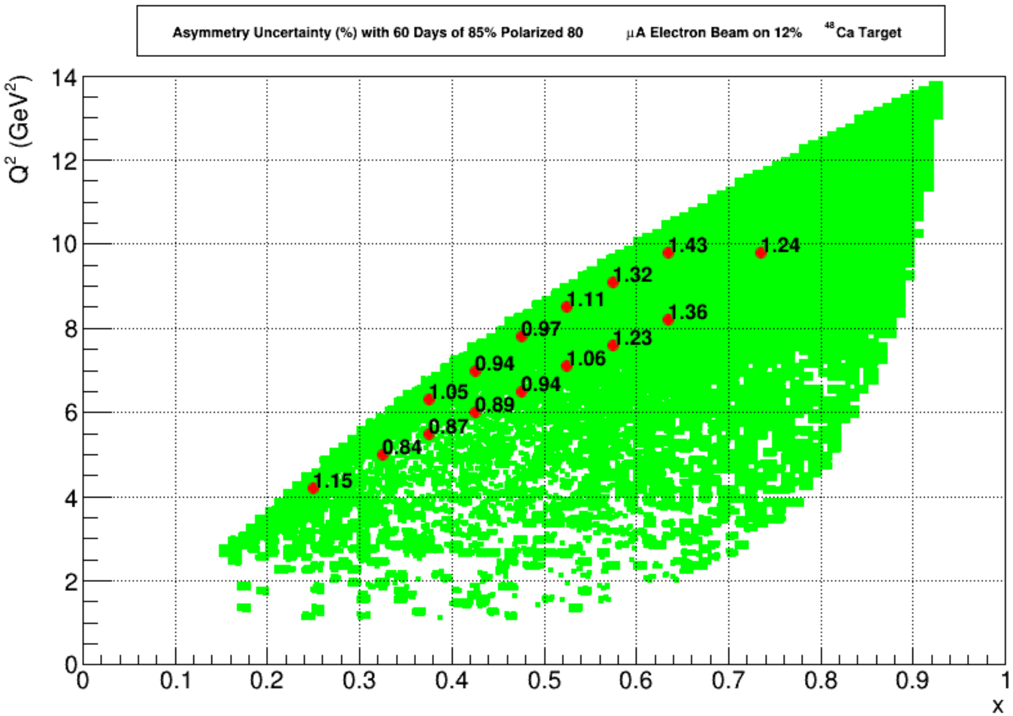
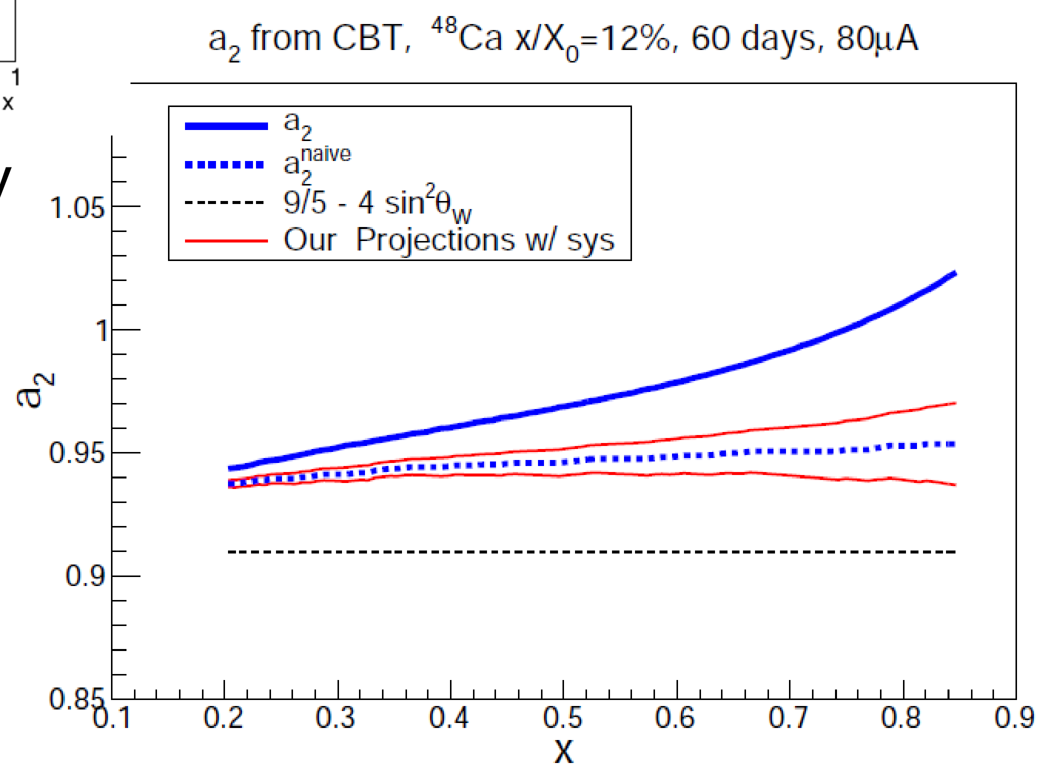


Figure of Merits



- Propose a 12% ^{48}Ca target in SoLID PVDIS apparatus
- 11 GeV, 80 uA, logitudinally polarized electron beam
- From 60 days 0.8% to 1.1% statistical uncertainty for 0.2 < x < 0.7



- Interpolate the form between any isovector EMC model and naive prediction
- Estimate the reach of our measurement for the model
- Our overall sensitivity to CBT model is over 4σ

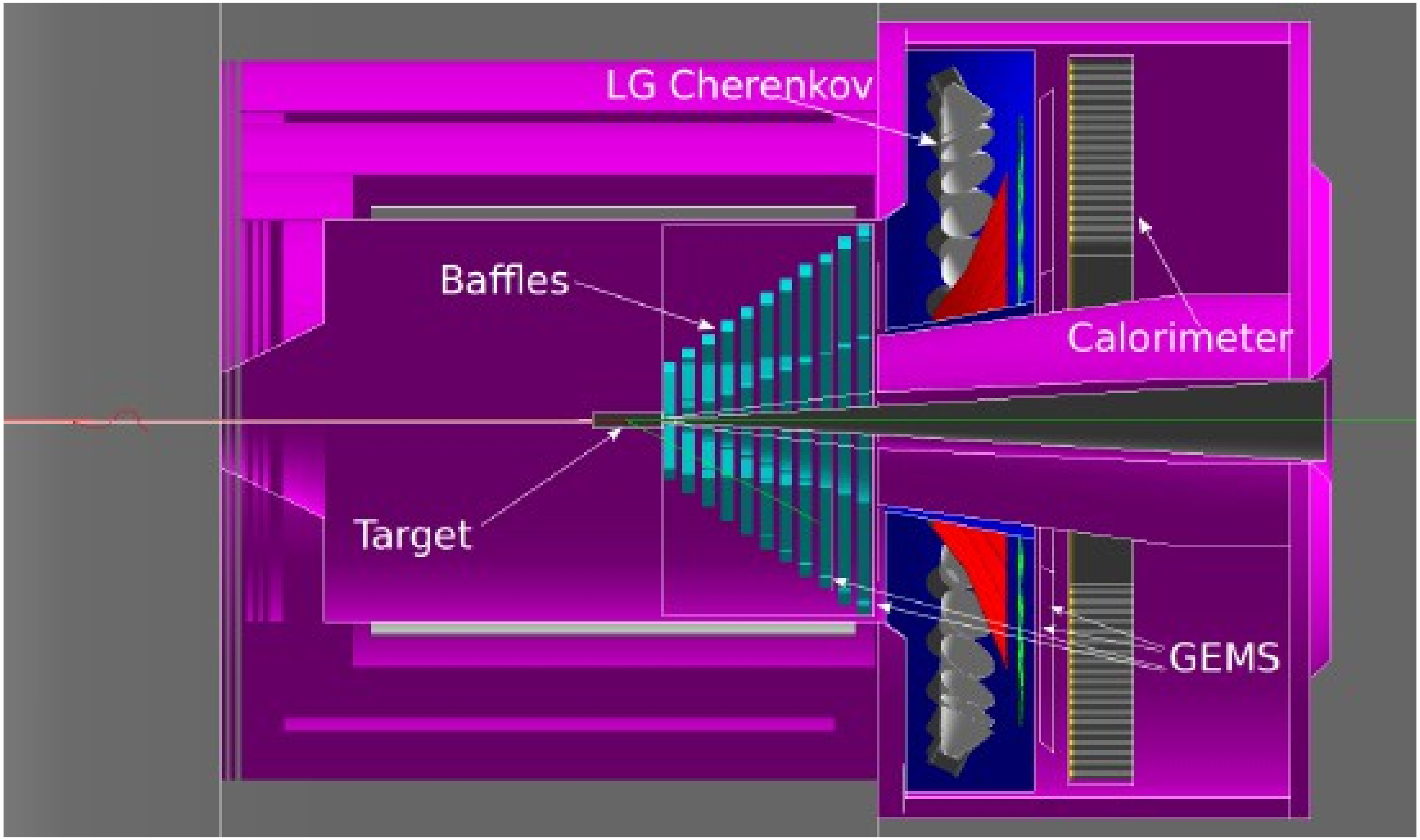
Experimental Design

- Propose to use the SoLID PVDIS apparatus by replacing the deuterium target (LD_2) with 12% ^{48}Ca target
- A counting mode PVES experiment
- Less demanding specs than PVDIS with LD_2
  - Solid target with excellent thermal qualities
  - Better acceptance and collimation with the thin target
  - Generating lower rates due to less total mass in the target

SoLID PVDIS Apparatus

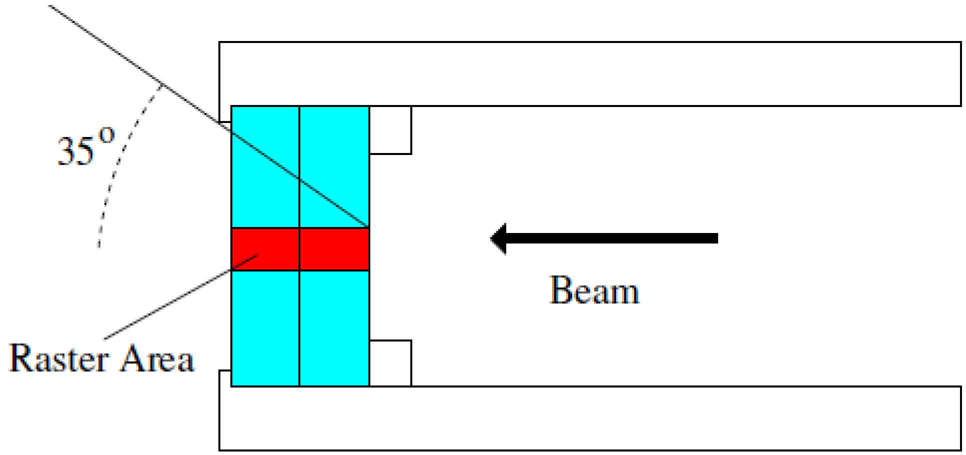
- Large acceptance, high luminosity spectrometer and detector system
  - Large azimuthal acceptance with segmented to 30 sectors to handle high trigger rates
  - scattering angles from 22-35^{o}, and momentum acceptance from 1 to 7 GeV
- PVDIS configuration
  - A 1.5 T solenoidal magnet
  - Set of lead collimators, “baffles” to block line of sight photons and low momentum particles
  - High luminosity tracking GEM detectors
  - A light gas Cherenkov detector for pion rejection
  - EM calorimeter (preshower+shower) as primary trigger and for further pion rejection

SoLID PVDIS Apparatus



^{48}Ca Target

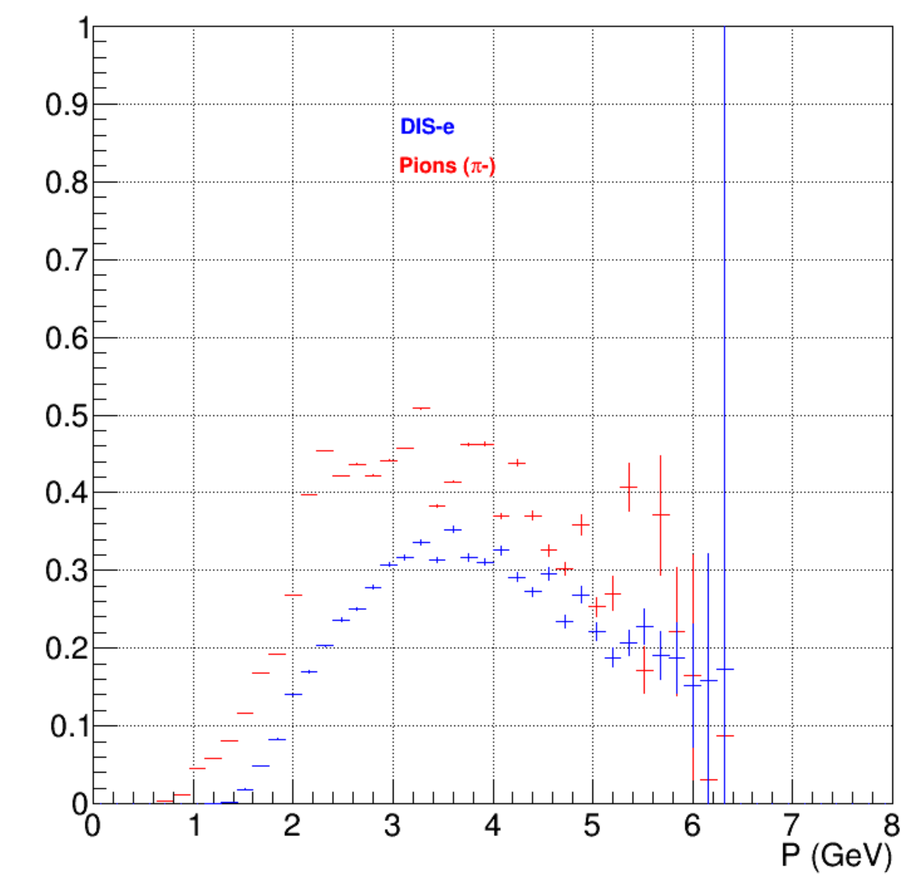
- Two CREX style ^{48}Ca disks housed in vacuum enclosure
  - 2.4 g/cm2 → 12% radiator
  - Helps to do better tracking for radiative corrections
  - Mounted in a frame with that allow up to 35^{o} scattered electrons with 4 x 4 mm^{2} raster
- Calcium has good thermal properties
  - 840^{o} C melting point and a high thermal conductivity of 200 W/m/K
  - At 80 μA, power deposit on the target is about 600 W
- Auxiliary targets (C and Al) for calibrations and to cross check radiative corrections



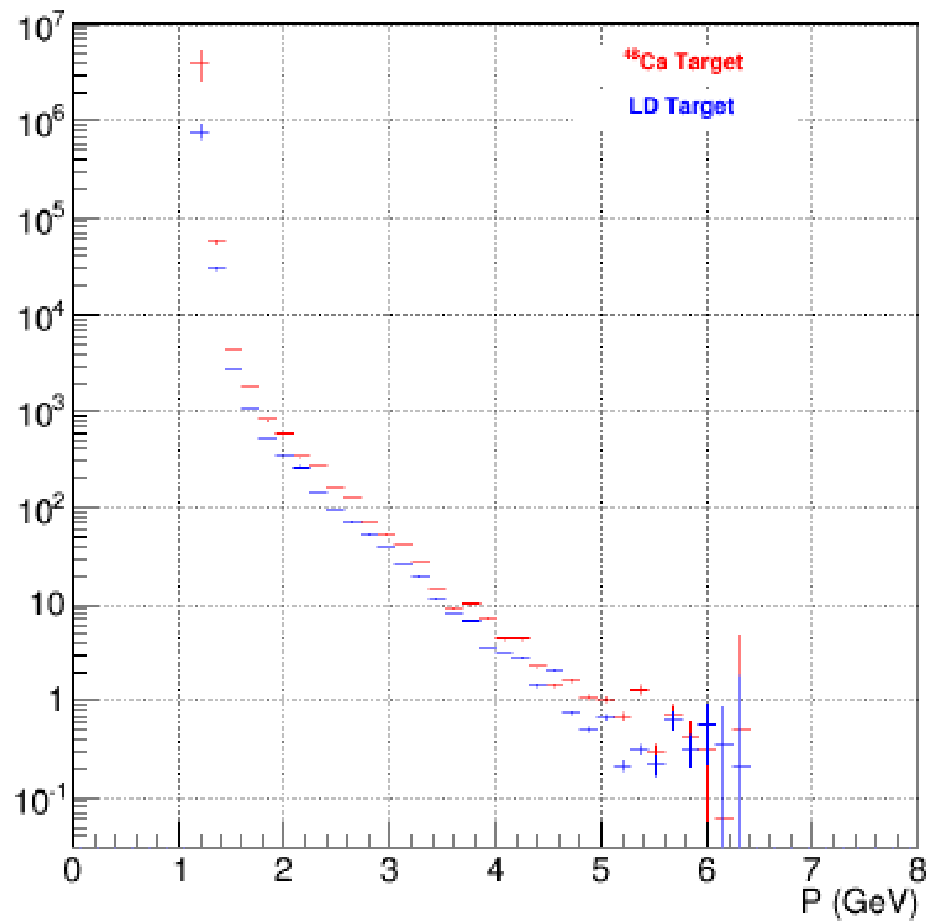
Momentum Acceptance and Rates

Momentum range (GeV)	^{48}Ca (kHz)	LD_2 (kHz)
DIS Total	228	441
W > 2.0 GeV, $x_{Bjk} > 0.20$	207	417
W > 2.0 GeV, $x_{Bjk} > 0.55$	15	33
W > 2.0 GeV, $x_{Bjk} > 0.65$	3	9

Momentum Acceptance for ^{48}Ca Target



π^- to e^- Ratio for ^{48}Ca and LD Target

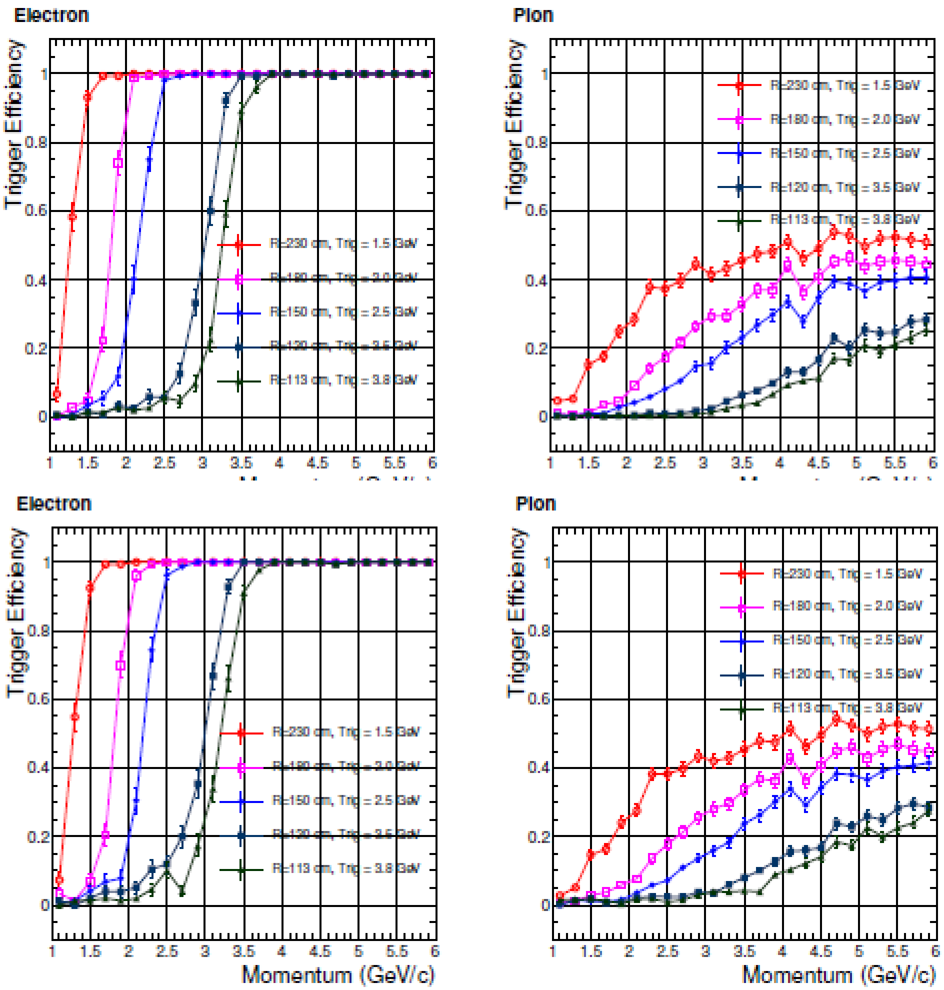


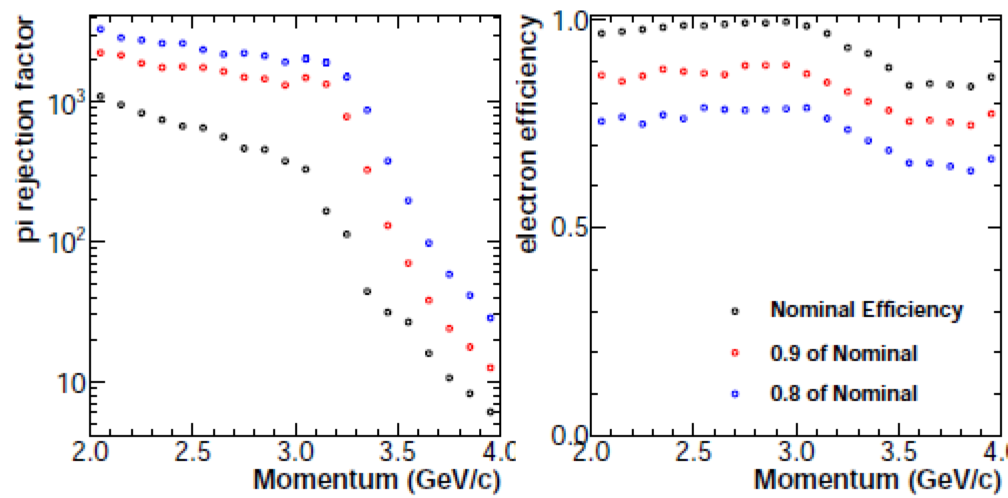
Background Suppression

Trigger efficiencies based on simulations based on DIS events with realistic background incident on Ecal and Cherenkov

Gas Cherenkov Performance

EM Calorimeter Performance





Readout Rate (kHz) P > 1 GeV		
	^{48}Ca	LD_2
DIS e^-	144	321
π^-	11	20
π^+	0.4	1
Total	155	342

Systematic Errors

- Polarimetry
  - Compton polarimeter anticipated error of 0.4%
  - Additional checks can be made using the Møller polarimeter
- Pion contamination is about 4%
  - It is worst at highest x
  - Will measure the Pion contamination and asymmetry using dedicated pion triggers
  - We assign 0.1 - 0.5% bin-to-bin systematic error

Systematic Errors

- EM radiative corrections
  - We measure up to resonant and elastic events to determine contributions from them
  - Initial simulations were done with and without radiative losses at the scattering vertex
    - Compared DIS rates and asymmetry variations
  - Based on these initial estimates we assign 0.5 - 0.1% bin to bin systematic
- Electroweak radiative corrections
  - EW effective quark couplings (C_{ij}) at our kinematics needs to be computed as readily available couplings values are estimated at $Q^2 \rightarrow 0$
- Radiative corrections (EM and EW) for our kinematics will be computed by theory collaborators

Potential Systematic Errors

- Hadronic and Nuclear effects
  - Higher twists (HT) and Charge Symmetry Violations (CSV) will greatly constrained by SoLID PVDIS program with hydrogen and deuterium
  - If large CSV effect observed, this will motivate for a isoscalar ^{40}Ca measurement.
- $a_2(x)$ uncertainties from free PDF
  - We have estimated the PDF uncertainty on naive $a_2(x)$ calculation is below our statistical uncertainty for $0.2 < x < 0.7$
- Presence of these systematic errors can reduce our sensitivity to isovector EMC effects but then models within PDF fits will require modification justifying our measurement

Systematic Error Summary on A_{PV}

Effect	Uncertainty [%]
Polarimetry	0.4
$R^{\gamma Z}/R^{\gamma}$	0.2
Pions (bin-to-bin)	0.1-0.5
Radiative Corrections (bin-to-bin)	0.5-0.1
Total for any given bin	$\sim$0.5-0.7

Beam Time Request

We request 60 days of production data at 11 GeV at 80 μA with full beam polarization

	Time (days)	E (GeV)	Current (μA)
^{48}Ca Production	60	11	80
Optics	2	4.4	Up to 80
Moller Polarimetry	4	11	2
Commissioning	5	11	Up to 80
Total	71		

Summary

- Using the PVDIS SoLID configuration with a ^{48}Ca target we will obtain 0.8 - 1.1% stat. and about 0.7% syst. precise asymmetry measurements
- Proposed measurement will constrain possible flavor-dependent nuclear medium modification effects on quarks
  - Test available models (CBT etc.) or develop new models
- Will help to understand EMC effect and NuTeV anomaly
- Provide necessary corrections for neutrino scattering and Drell-Yan processes
- By combining multiple experiments, more robust constraints can be imposed
  - PVDIS on light nuclei : SoLID PVDIS on LH_2 and LD_2
  - DIS cross section measurements : E12-10-008
  - Drell-Yan : @COMPASS?
- Up-to date proposal http://www.jlab.org/~riordan/emcpvdis_prop.pdf

Supplementary

Hall Radiation Levels

Breakdown of relative radiation flux/dose increase in ^{48}Ca with respect to deuterium seen by a cylindrical detector in the hall. Notice same relative increase for flux/dose since both deuterium and ^{48}Ca dosages are estimated for 60 days.

Radiation Type	E-Range (MeV)	Relative Flux Increase From LD_2 (%)	Relative Dose Increase From LD_2 (%)
$e^{\pm}$	$E < 10$	53.4	53.4
	$E > 10$	89.0	89.0
n	$E < 10$	3.6	3.6
	$E > 10$	22.8	22.8
γ	$E < 10$	77.3	77.3
	$E > 10$	47.8	47.8