First Measurement of the Flavor Dependence of Nuclear PDF Modification Using Parity-Violating Deep Inelastic Scattering

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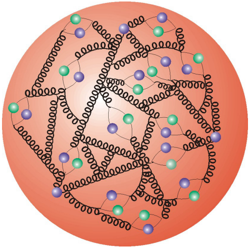
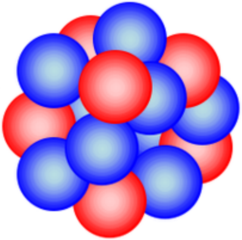
and the SoLID Collaboration

From QCD to Nucleons and Nuclei

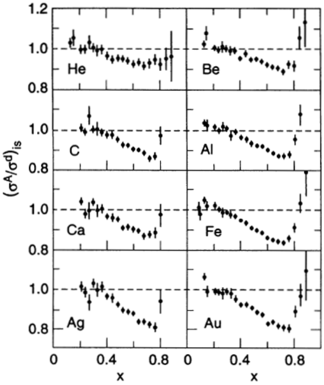
- How are protons and neutrons are modified when they are bound in a nucleus?
- How do we make the transition between QCD and nuclear physics?
- While the existence of nuclear modification of the pdfs is well established, important questions remain about the nature of the modification
- We have almost no experimental information on the spin- and flavor-dependence nuclear modification





EMC Effect and Nuclear Modification

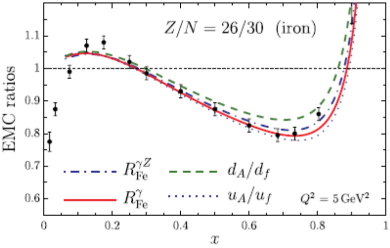
- Showed reduced presence of partons in $0.3 < x < 0.7$ but not due to simple binding effects - real modification of structure
- Generally greater effect as one pushes to higher A
- In the last several years, significant reason to believe that it differ for up- and down-quarks in non-isoscalar nuclei
- There is essentially no experimental evidence that supports or refutes this hypothesis

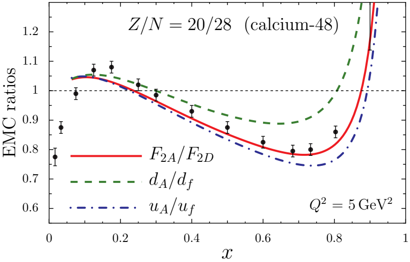


J. Gomez et *al.*, *PRD49 4348 (1994)*

Modeling Flavor Dependence

- At the quark level isovector nuclear forces affect the u and d quarks differently, leading to flavor-dependent modifications
- **Cloët-Bentz-Thomas (CBT)** predicts significant flavor dependent based on mean field calculations
  - Using explicit isovector terms (constrained by nuclear physics data such as the symmetry energy)
- CBT result significantly reduces NuTeV $sin^2\theta_W$ anomaly

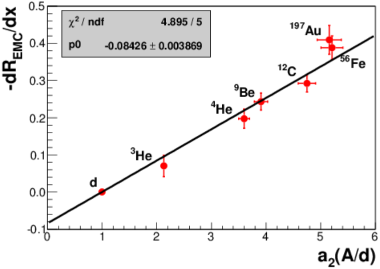




Cloet et *al.* PRL102 252301 (2009), Cloet et *al.* PRL109 182301 (2012)

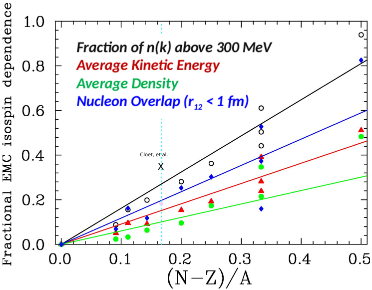
Isovector Dependence in SRC ?

- SRC show strong preference to n-p pairs over p-p pairs
- EMC effect shows correlation with SRCs
- Observed EMC-SRC correlation plus np dominance suggests mechanism for possible flavor dependence with limited sensitivity



ISOVECTOR DEPENDENCE IN SRC ?

Isospin dependence of the EMC effect vs. fractional neutron excess of the nucleus for the four scaling models based on GFMC calculations for $A <= 12$

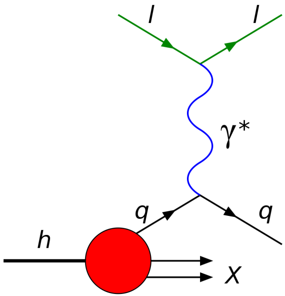


DIS

- DIS with leptons offers picture into partonic distributions

$$\frac{d^2\sigma}{d\Omega dE'} = \frac{4\alpha E'^2}{Q^4}\cos^2\frac{\theta}{2}\left(\frac{F_2(x,Q^2)}{\nu} + \frac{2F_1(x,Q^2)}{M}\tan^2\frac{\theta}{2}\right)$$

- Highly successful for our modern picture of quark degrees of freedom and pQCD
- PDFs have been well determined over a broad range after decades of study



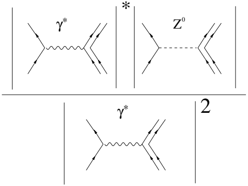
Structure Function (SF),

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

Flavor Dependence Observations with PVDIS

PVDIS probes flavor combinations $\rightarrow$ isovector properties

$$A_{\mathrm{PV}} \approx -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\left[a_1(x) + \frac{1-(1-y)^2}{1+(1-y)^2}a_3(x)\right], y = 1 - \frac{E'}{E}$$

$\sim$ 

$\sim 100 - 1000$ ppm

$$a_1(x) = -2g_A^e \frac{F_{2A}^{\gamma Z}}{F_{2A}^{\gamma}}, a_3(x) = -2g_V^e \frac{F_{3A}^{\gamma Z}}{F_{2A}^{\gamma}}$$

$F_{2A}^{\gamma Z}$: Structure functions arising from γZ interference and F_{2A}^{γ}: traditional DIS SF

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Expanding about symmetric nucleus limit

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

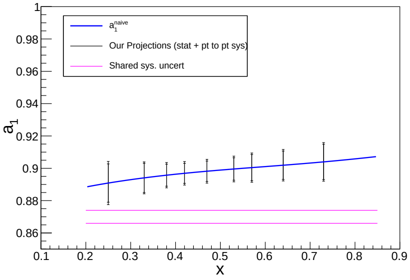
Therefore, a_1 will provide information about the flavor dependence of the nuclear quark distributions and a reliable extraction of the u and d quark distributions of a nuclear target

Flavor Dependence Observations with PVDIS

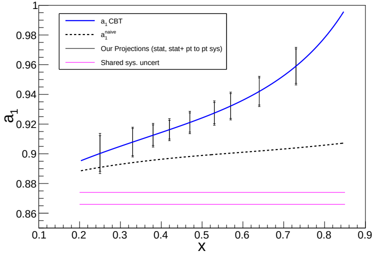
- Neutral currents will provide access to isovector observables
- Present data demands $\sim 1\%$ level for significant tests
- LD_2 will constrain CSV as isoscalar target (as well as $R^{\gamma Z}$)
- ^{48}Ca target will test isovector (IV) dependence - larger A gives larger EMC, larger $Z - N$ gives IV enhancement

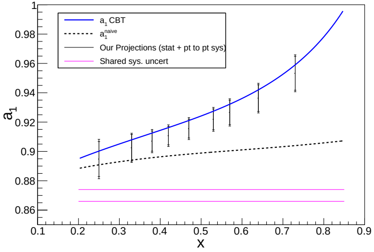
Symmetric nucleus limit

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



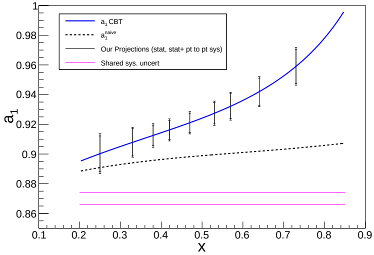
PVEMC Sensitivity

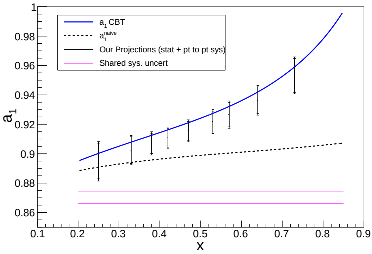




	PVEMC
Statistics	0.7-1.3%
Systematics	0.5%
Normalization	0.4%
data(CBT) vs. naive	8.0σ
data(CBT- $2\sigma_{norm}$) vs. naive	6.2σ

PVEMC Sensitivity

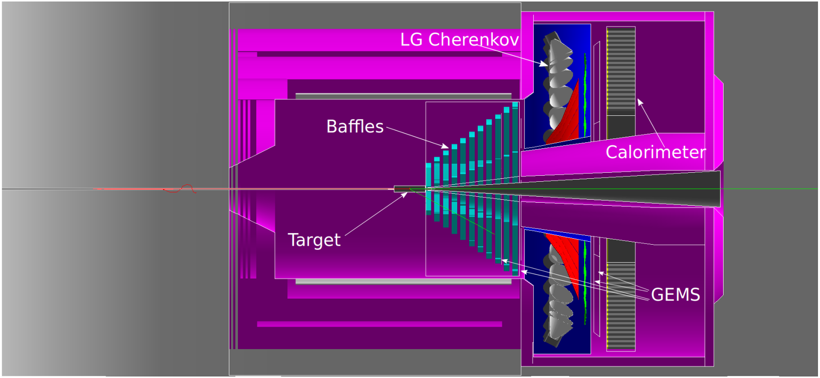




- PVDIS naturally sensitive to flavor *differences*
- PVEMC is cleaner and more precise than SIDIS and pionic Drell-Yan
  - Similar information, but without the same level of precision
- Experiments such as SRC helped motivate PVEMC and tie into results from this program
  - Spin EMC and tagged DIS from highly off-shell nucleons can provide complementary information
- PVEMC offers large sensitivity and is required for full picture

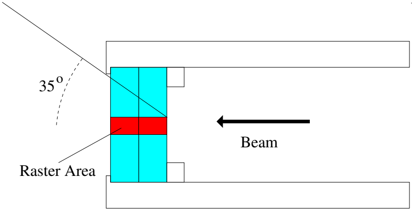
SoLID Configuration

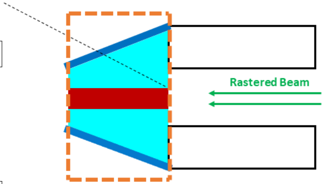
- Experimental configuration is identical to approved SoLID PVDIS measurement
- Lead baffles serve as momentum collimators
- GEMs, Cherenkov, and calorimeter provide tracking and PID
- ^{48}Ca Rates are lower compared to existing LD_2 measurement



Target - ^{48}Ca

- ^{48}Ca target provides good balance between asymmetric target and not too high Z
- Has very good thermal conductance and high melting point - have operational experience and updated design/protocols from previous program including CREX
- 12% radiator - photons and photoproduced pions are main background concerns
- We propose to use a 2.4 g/cm^2 ^{48}Ca target (reduced volume design on right), assumed to be 95% isotopically pure.





Target - ^{48}Ca Status

- The plan is to use the existing ^{48}Ca to form the new target.
- Target group estimates that recovery from existing supply would provide sufficient target material, but with 93% rather than 95%
- This would take some time, but work can begin after the experiment is approved
- No need to purchase any additional ^{48}Ca, **If** sufficient material is not recovered in which case a small additional amount may be purchased

Simulation Status

- Background simulations performed using same simulation framework used in PREX/CREX MOLLER and SoLID
- Only SoLID-PVDIS apparatus and hall enclosure in our simulation, no shielding enclosure for electronics yet.
- We will redo studies with ^{48}Ca target once everything is defined/optimized to estimate the radiation dose for electronics, hall and site boundary

Radiation Load in the Hall

- In the worse case scenario, localized radiation will not reach 1×10^{13} (1 MeV equiv Neutron)/cm^2
  - It's the level required for damage expected on 'Not Radiation-Hard' electronics.
- Dose to CLEO solenoid is estimated to be 0.1% of degradation threshold.
- Radiation dose to the hall is roughly factor of 2 above PVDIS-LD2.

Experiment	Hall (rem/h)	Ceiling (rem/h)
^{48}Ca at 80 uA	24.5	2.3
LD2 at 50 uA	10.2	1.2

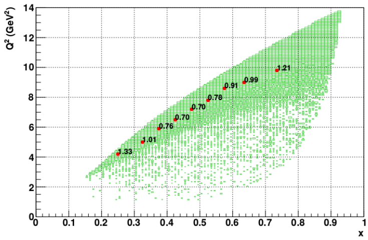
Site Boundary

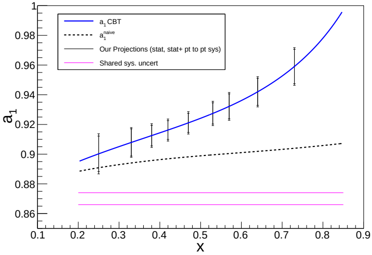
Experiment	Hall Top Neutron Dose (m^{-2})	Estimated Boundary Dose (mrem)	Measured Boundary Dose (mrem)
PREX-I	4.50E+12	4.2	1.3
PREX-II	5.80E+12	2.0	1.2
CREX	1.50E+13	1.8	1.0
LD-PVDIS 6 GeV	1.90E+12	0.7	n/a
LD-PVDIS 11 GeV	3.40E+12	1.3	n/a
^{48}Ca-PVDIS 11 GeV	6.00E+12	2.5	n/a

These benchmarks have shown that Geant4 simulations have improved over the years to consistently match (but still overestimate by a factor of about 2) the expected boundary dose

Projections

- Requesting 66 days at 80 μA 11 GeV production (plus 15 days for commissioning, optics runs, background studies, and polarimetery) to get $\sim$1% stat uncertainties on A_{PV} across a broad range of x
- In the context of the CBT model, This provides $\sim 8\sigma$ sensitivity to CBT model
- Significant ability to differentiate between different predictions
- *This provides new and useful constraints in a sector where there is little data*





Systematic and Experimental uncertainties

- Charge symmetric background ($\pi^0 \rightarrow e^+e^-\gamma$)
- Hadronic and Nuclear uncertainties (HT, CSV, PDF uncertainties, and free PDF nuclear model uncertainties)
- Radiative working group has been established for PVDIS to work on these systematic contributions
- Systematic errors:

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

- Statistical uncertainty dominates any given bin

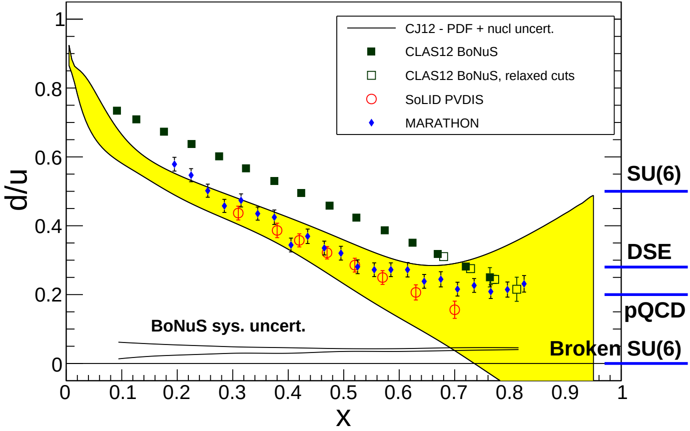
Systematic Errors: Pions

- Excellent π^- to e^- ratio when the coincidence trigger between calorimeter and Cerenkov is applied but
- We proposed to measure pion rate and asymmetry from dedicated runs to apply a correction for residual pion contamination in electron data.
- We assumed zero pion asymmetry as a conservative estimate
  - As it was measured to be smaller but same sign as $A_{PV}(DIS)$ in a previous measurement
- Based on estimated pion contamination and asymmetry, we assign a systematic error of 0.1-0.5% bin-to-bin, larger at larger x

Systematic Errors: d/u

- At low x values, the full range of the CJ12 fit provides uncertainties in a_1 around the $\pm 0.2\%$ level
- The combined uncertainty from the fit and model dependence at larger x (0.55-0.65) is 0.6-1.0% but
- Either PVDIS-hydrogen data by itself, or global analyses including MARATHON and BoNUS results, should provide the necessary reduction to reach $\pm 0.2\%$ level
- The PVDIS data on hydrogen will provide a measurement of d/u, free from nuclear corrections

Systematic Errors: d/u



Anticipated data for measurements on d/u, see text for references. Recently published MARATHON results are also shown

Beam Time Request

We request 66 days of production data at 11 GeV at 80 $\mu\mathrm{A}$ with full beam polarization. We also request time for commissioning, calibration and background runs, and polarimetry, summarized in Table

	Time (days)	E (GeV)	Current (μA)
^{48}Ca Production	66	11	80
Optics	2	4.4	Up to 80
Positive polarity	4	11	80
Moller Polarimetry	4	11	2
Commissioning	5	11	Up to 80
Total	81		

Our Motivation to Submit Again

- The PAC 44 Proposal deferred by PAC in light of DIS the ^{48}Ca/^{40}Ca ratio measurement (E12-10-008)
- A detailed examination shows that the E12-10-008 ^{48}Ca/^{40}Ca measurement cannot provide 3σ evidence for a flavor-dependent EMC effect unless the effect is significantly larger than any of the models we have considered
- We are aware of no other JLab measurements currently planned or under discussion can provide the sensitivity proposed by this measurement
- We show that the PVEMC measurement will be critical to understanding flavor dependence in nuclei no matter what is observed in the ^{48}Ca/^{40}Ca ratios
- Provided additional detail on the radiation in the hall and at the site boundary

Summary

- It is critical to have a measurement that can cleanly isolate the flavor dependence of the EMC effect, independent of other nuclear effects, and with the precision to quantify the flavor dependence
- PVDIS on asymmetric target offers one of the most direct, precise, and theoretically clean way to isolate the flavor dependence of the EMC effect
- 66 days production will offer critical new information, help test leading hypotheses, and help elucidate the NuTeV anomaly
- Important input to parameterization of the EMC effect and to guide detailed calculations of the underlying physics.
- Helps understand PDFs for nuclei
  - Relevant for many high-energy lepton-scattering and nuclear collision measurements.

BACKUP

DIS

- DIS with leptons offers picture into partonic distributions

$$\frac{d^2\sigma}{d\Omega dE'} = \frac{4\alpha E'^2}{Q^4}\cos^2\frac{\theta}{2}\left(\frac{F_2(x,Q^2)}{\nu} + \frac{2F_1(x,Q^2)}{M}\tan^2\frac{\theta}{2}\right)$$

- Highly successful for our modern picture of quark degrees of freedom and pQCD
- PDFs have been well determined over a broad range after decades of study

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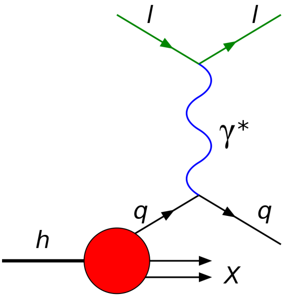

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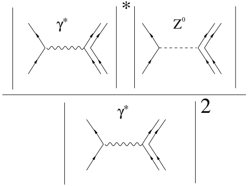
$\sim$ 

$\sim 100 - 1000\ \mathrm{ppm}$

$$a_1(x) = -2g_A^e\frac{F_{2A}^{\gamma Z}}{F_{2A}^{\gamma}}, a_3(x) = -2g_V^e\frac{F_{3A}^{\gamma Z}}{F_{2A}^{\gamma}}$$

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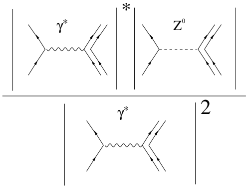
$\sim$ 

$\sim 100 - 1000$ ppm

$$a_1(x) = 2\frac{\sum_i C_{1q_i} e_{q_i} q_i^+}{\sum_i e_{q_i}^2 q_i^+}, a_3(x) = 2\frac{\sum_i C_{2q_i} e_{q_i} q_i^-}{\sum_i e_{q_i}^2 q_i^+}$$

e_{q_i} is the quark charge, $q_i^+(x) = q_i(x) + \bar{q}_i(x)$ and $q_i^-(x) = q_i(x) - \bar{q}_i(x)$

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$$a_1(x) = 2\frac{\sum C_{1q} e_q (q+\bar{q})}{\sum e_q^2 (q+\bar{q})}, a_3(x) = 2\frac{\sum C_{2q} e_q (q-\bar{q})}{\sum e_q^2 (q+\bar{q})}$$

Effective Weak Couplings

$$C_{1u} = -\frac{1}{2} + \frac{4}{3}\sin^2\theta_W = -0.19 \qquad C_{2u} = -\frac{1}{2} + 2\sin^2\theta_W = -0.03$$

$$C_{1d} = \frac{1}{2} - \frac{2}{3}\sin^2\theta_W = 0.34 \qquad C_{2d} = \frac{1}{2} + 2\sin^2\theta_W = 0.03$$

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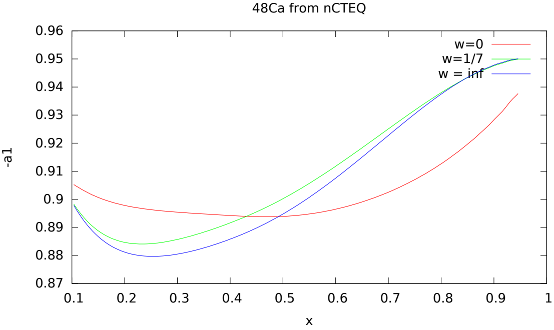
Expanding about symmetric nucleus limit

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

Therefore, a_1 will provide information about the flavor dependence of the nuclear quark distributions and a reliable extraction of the u and d quark distributions of a nuclear target

Modeling - nPDFs

- Varying weights in fits between lepton/Drell Yan and ν can show tension between data sets
- nCTEQ fits show dramatic differences in a similar vein at CBT
- Few percent effect in a_2



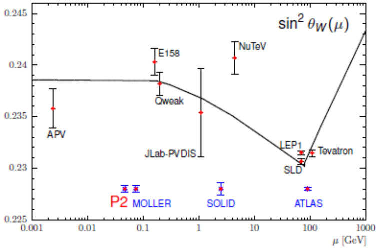
Isovector Dependence in NuTeV Anomaly

- Neutrino scattering (charged and neutral currents) is sensitive to different flavor combinations including Isovector EMC (IVEMC)

Pachos-Wolfenstein relation:

$$R_{\mathrm{PW}} \equiv \frac{\sigma(\nu_\mu N \to \nu_\mu X) - \sigma(\bar{\nu}_\mu N \to \bar{\nu}_\mu X)}{\sigma(\nu_\mu N \to \mu^- X) - \sigma(\bar{\nu}_\mu N \to \mu^+ X)}$$

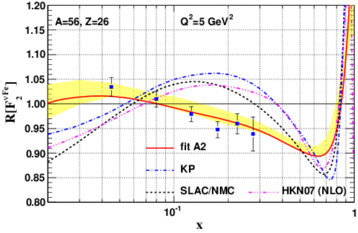
$$= \lim_{\to \mathrm{i.s.}} \frac{1}{2} - \sin^2\theta_W$$

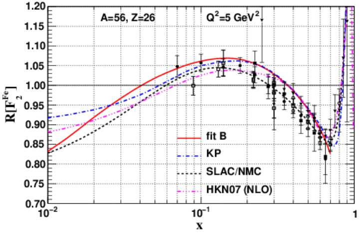


- The impact of the flavor-dependent nuclear PDF modification on the NuTeV anomaly was evaluated in the Cloët-Bentz-Thomas (CBT) model
- CSV or IVEMC could play very important role and **are not well constrained by data**

Isovector Dependence in Nuclear PDF

- Nuclear correction ratio for structure functions F_2^{Fe}/F_2^{D}
- Comparison between lepton/Drell Yan ($l^{\pm}A$) and neutrino (νA) data show significant discrepancies in nuclear corrections using common PDFs
- The nuclear corrections for the $l^{\pm}A$ and νA processes are different: Flavor dependent nuclear effects?

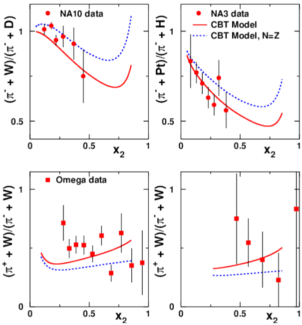




I. Schienbein et *al.* PRD77 054013 (2008); I. Schienbein et *al.* PRD80 094004 (2009)

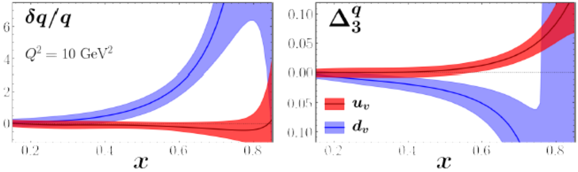
Drell-Yan and flavor-dependent EMC effect

- Preference in existing pion induced Drell-Yan production ratios for flavor-dependent models over flavor-independent models
- The impact of the flavor-dependent nuclear PDF modification was evaluated in the Cloët-Bentz-Thomas (CBT) model
- CSV or Isovector EMC (IVEMC) could play very important role and **are not well constrained by data**



D. Dutta, J. C. Peng, I. C. Cloet, and D. Gaskell. PRC, 83:042201, 2011

Isovector EMC Effects from MARATHON



Preliminary Results

- The impact of the MARATHON data on the off-shell corrections is shown in left
- The strength of the isovector EMC (IVEMC) effect for u and d quarks
- A nonzero and opposite sign for u and d quarks strongly suggests the presence of an IVEMC effect.

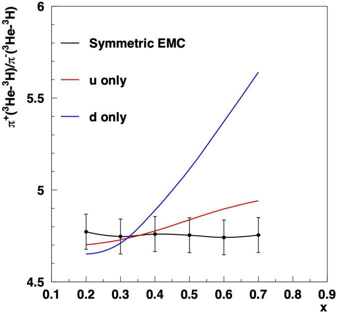
Isovector EMC effect from global QCD analysis with MARATHON data. (2021) arXiv:2104.06946

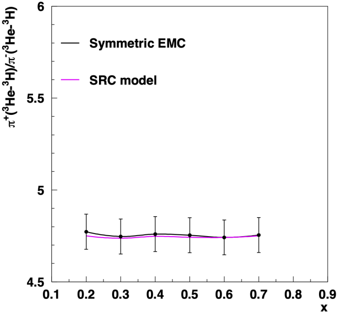
SIDIS

- Semi-inclusive deep inelastic scattering provides access to quark flavors with an electromagnetic probe by tagging pions in the final state of the reaction.
- A super-ratio of π^-/π^+ between deuterium and an asymmetric nuclear target would be sensitive to variations in the flavors
- Proposal PR12-09-004 aimed to use a comparison of π^+ and π^- production from Au to look for flavor dependence in the EMC effect.
  - The proposal was deferred, in large part due to questions about how well the data could be interpreted in terms of flavor dependence,
- A Letter of Intent for CLAS (LOI12-19-005) examined the possibility of making such a measurement via the comparison of π^+ and π^- production in ^{3}H and ^{3}He.

SIDIS

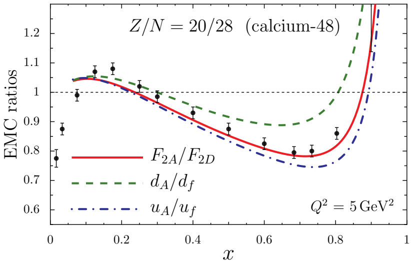
- The prediction from a flavor-independent EMC effect (black curve) compared to the an extreme projection assuming that the EMC effect is carried entirely by the up (red curve) or down (blue curve) quarks (left plot)
- The same observable assuming the flavor dependence (magenta curve), indicating no sensitivity in this more realistic flavor dependence (right plot)

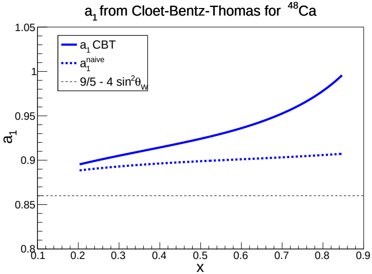




Modeling - CBT Model

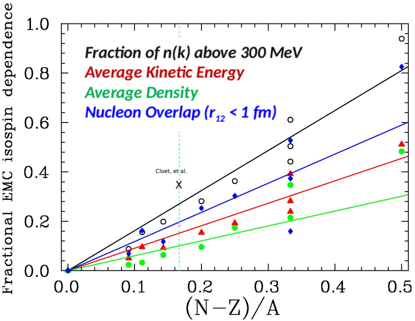
- Cloet et *al.* make predictions based on mean field calculations which give reasonable reproductions of SFs
- Explicit isovector terms are included constrained by nuclear physics data such as the symmetry energy
- Few percent effect in a_1, larger at larger x



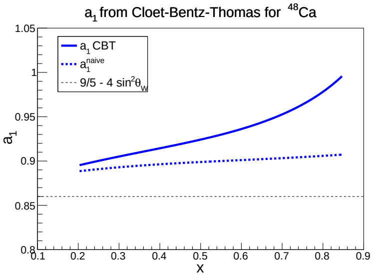


Cloet et *al.* PRL102 252301 (2009), Cloet et *al.* PRL109 182301 (2012)

- simple scaling models yield a results varying from 50% to 110% of the CBT calculation

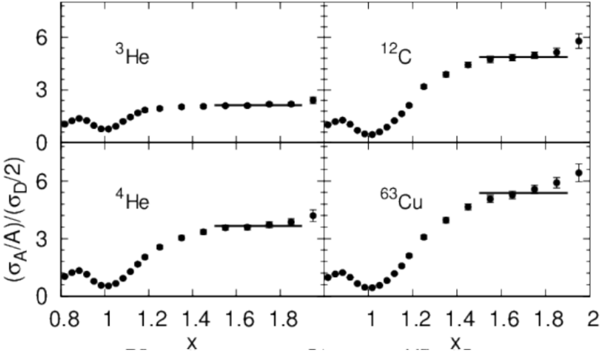


EPJ Web Conf., 113:01011, 2016



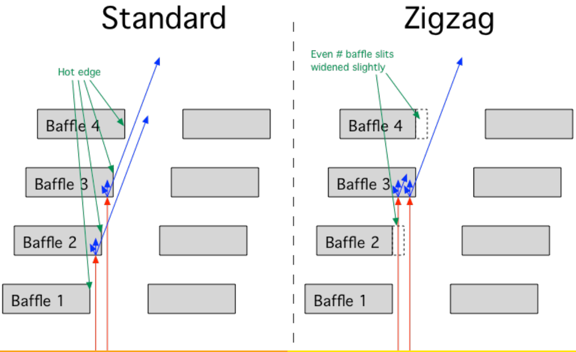
Isovector Dependence? - SRC

- SRC show strong preference to n-p pairs over p-p pairs
- Also show strong correlation to "plateau" parameter for $x > 1$ SFs



Background Suppression with Baffles

- raytraced electron trajectories used in baffle width design that was fine-tuned to the solenoid field such that acceptance is optimized to allow charge particles in the acceptance while disfavoring particles outside that range
- Baffle design on left was improved by opening up the slits in the even-numbered plates to have reduced background design shown on right



GEM Rates

GEM plane	LD_2 background ($kHz/mm^2/\mu A$)	^{48}Ca EM background ($kHz/mm^2/\mu A$)	^{48}Ca EM background (no baffles) ($kHz/mm^2/\mu A$)
1	6.8	4.8	49.4
2	3.0	2.1	32.3
3	1.1	0.8	9.9
4	0.7	0.5	6.4

ECal Trigger Rates

region	full	high	low
rate entering the EC (kHz)			
e^-	240	129	111
π^-	5.9×10^5	3.0×10^5	3.0×10^5
π^+	2.7×10^5	1.5×10^5	1.2×10^5
$\gamma(\pi^0)$	7.0×10^7	3.5×10^7	3.5×10^7
p^+	4.8×10^5	2.1×10^5	2.7×10^5
sum	7.1×10^7	3.6×10^7	3.6×10^7
Rate for $p < 1$ GeV (kHz)			
sum	8.4×10^8	4.2×10^8	4.2×10^7
trigger rate for $p > 1$ GeV (kHz)			
e^-	152	82	70
π^-	4.0×10^3	2.2×10^3	1.8×10^3
π^+	0.2×10^3	0.1×10^3	0.1×10^3
$\gamma(\pi^0)$	3	3	0
p	1.6×10^3	0.9×10^3	0.7×10^3
sum	5.9×10^3	3.3×10^3	2.6×10^3
trigger rate for $p < 1$ GeV (kHz)			
sum	2.8×10^3	1.4×10^3	1.4×10^3
Total trigger rate (kHz)			
total	8.7×10^3	4.7×10^3	4.0×10^3

Cerenkov Trigger Rates

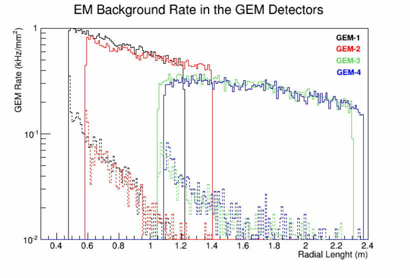
	Total Rate for $p > 0.0$ GeV (kHz)	Rate for $p > 3.0$ GeV (kHz)
DIS	240	73
π^-	5.9×10^5	1.6×10^3
π^+	2.7×10^5	40
$\gamma(\pi^0)$	7.0×10^7	40
p	4.8×10^5	4
Sum	7.1×10^7	1.7×10^3

Trigger Rate from Cherenkov (kHz)

	Trigger Rate for $p > 1.0$ GeV (kHz)	Trigger Rate for $p > 3.0$ GeV (kHz)
DIS	223	66
π^-	193	49
π^+	22	1.6
$\gamma(\pi^0)$	0	0
p	0	0
Sum	438	116

Rates and Backgrounds

- Trigger defined by coincidence between Cherenkov and shower - 150 kHz total anticipated with background (well below SoLID spec)
- Pion contamination no worse than 4% in any given bin (worst at high x)
- GEM rates comparable to or smaller than design for LD_2



Particle	DAQ Coin. Trig.Rate (kHz)	
	$P > 1$ GeV	$P > 3$ GeV
DIS e^-	144	61
π^-	11	7
π^+	0.4	0.2
Total	155	68

Solenoid Shielding Effect

Iron of magnet is significant shield of neutrons that contribute to site boundary limits

	^{48}Ca Flux (Hz/μA)	^{48}Ca Dose (80 μA for 66 days) (m^{-2})	LD_2 Flux (Hz/μA)	LD_2 Dose (50 μA for 60 days) (m^{-2})
with Solenoid Self- Shielding	2.93E+07	6.02E+12	2.62E+07	3.36E+12
without Solenoid Self- Shielding	5.55E+08	1.14E+14	3.53E+08	4.53E+13

Induced Radiation

Radiation from this experiment is on the level of the existing LD_2 measurement

		Radiation Power in the Hall	
Radiation Type	E-Range (MeV)	^{48}Ca (W/μA)	LD_2 (W/μA)
$e^{\pm}$	$E < 10$	0.11	0.11
	$E > 10$	0.18	0.16
n	$E < 10$	0.0002	0.0003
	$E > 10$	0.005	0.010
γ	$E < 10$	0.02	0.02
	$E > 10$	0.04	0.04

Radiation on ECal

Table: Neutrons Flux at the Front of the ECAL

	E range (MeV)	^{48}Ca Flux (Hz/cm2)	LD_2 Flux (Hz/cm2)
Neutrons	$E < 10$	1.68E+06	1.72E+06
	$E > 10$	3.66E+04	3.30E+04
Total		1.72E+06	1.75E+06

- Total dose (neutron and EM) similar to LD_2
- Estimated to be less than 40 kRad on the ECAL due to this proposal
- Total estimated dose based on current SoLID program is less than 200 kRad
- ECAL is rated for 400 kRad total dose before degradation

Superconducting Coil Radiation Dose

- The degradation happens above 2×10^{17} neutrons/cm2 (L. Zana: Director's Review 2019)
- The dose from each (LD2 or ^{48}Ca) experiment is $\sim 0.1\%$ of degradation threshold.
- CLEO maximum luminosity was $10^{32} cm^{-2} s^{-1}$ while SoLID-PVDIS will run at about $10^{39} cm^{-2} s^{-1}$

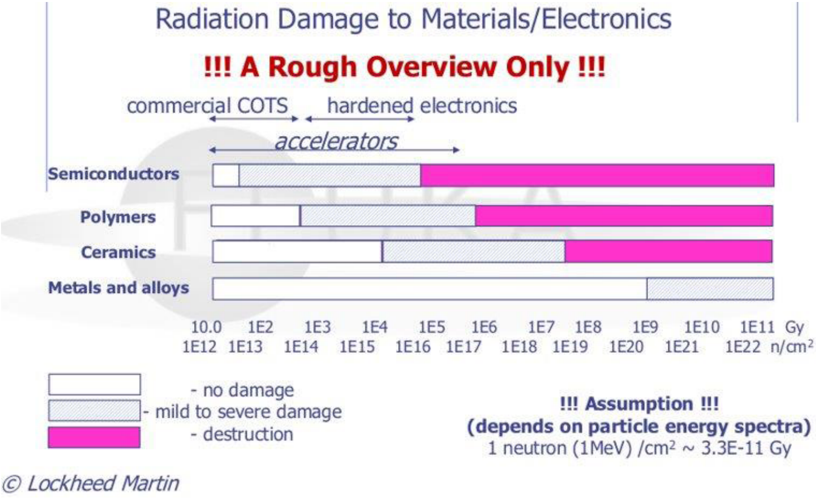
Radiation Load in the Hall

- The worse case scenario localized radiation will not reach 1×10^{13} (1 MeV equiv Neutron)/cm^2
  - It's level required for damage expected on 'Not Radiation-Hard' electronics.
- Dose to CLEO solenoid is estimated to be 0.1% of degradation threshold.
- Radiation dose to the hall is roughly factor of 2 above PVDIS-LD2.

Experiment	Hall (rem/h)	Ceiling (rem/h)
^{48}Ca at 80 uA	24.5	2.3
LD2 at 50 uA	10.2	1.2

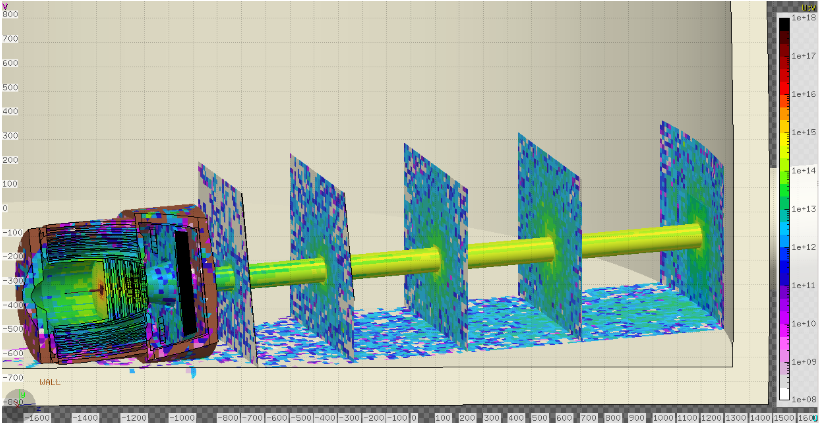
Radiation Load in the Hall

Level required for damage expected on ‘Not Radiation-Hard’ electronics is 1×10^{13} (1 MeV equiv Neutron)/cm^2



Radiation Load in the Hall

The dose of 1×10^{13} (1 MeV equiv Neutron)/cm^2 only around downstream beam-pipe



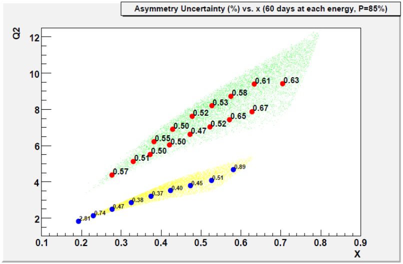
Radiation Load in the Hall: Overall

- Radiation dose in the hall and at the ceiling is simulated for ^{48}Ca and deuterium (LD2) targets.
- The peak radiation dose observed will always be around areas surrounding the beamline downstream of the SoLID apparatus.

Experiment	Hall (rem/h)	Ceiling (rem/h)
^{48}Ca at 80 uA	24.5	2.3
LD2 at 50 uA	10.2	1.2

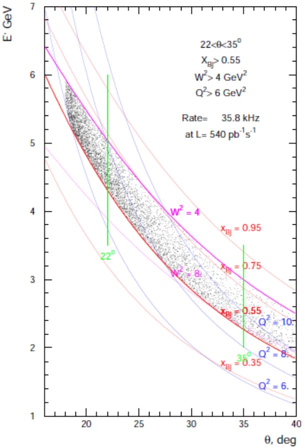
Systematics

- Higher twist effects will also be constrained by LD_2 using same kinematics, but also 6.6 GeV beam
- Charge symmetry violation will also be explored to better precision
- Nuclear dependence of $R^{\gamma Z}$ is an open question but we addressed with best possible information available at the moment in our response



SoLID-PVDIS Acceptance

- The useful kinematic range of the scattered electrons
- The acceptance in the scattering angle θ is limited at $\theta > 18^o$ by the $Q^2 > 6GeV^2$ cut



Systematic Errors: Radiative Corrections

- To aid with the determination of radiative effects, independent aluminum targets with $x/X_0 = 1\%$, 5%, and 10% will be included. (SoLID-PVDIS LD2)
- These will aid in the verification of scattering rate distributions under different radiative conditions and the overall unfolding procedure

EM Radiative Correction

- We have a good momentum acceptance to measure these events to sufficient accuracy within the Q^2 acceptance of the measurement.
- Beam time includes lower beam energy systematic studies that have access to lower W and Q^2 regions
- We anticipate that A/Q^2 will be roughly constant everywhere.
- Using measurements and the theory for radiative corrections the error on the radiative corrections can be controlled
- We assign a $0.1\% - 0.5\%$ bin-to-bin systematic, worse for small x

Weak Radiative Correction

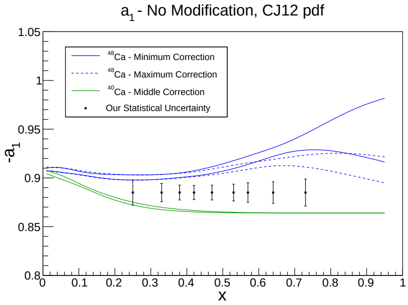
Weak radiative corrections will be calculated for our kinematics and are not likely to change in a way that is sensitive to this experiment.

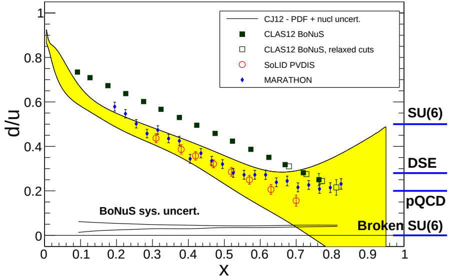
Systematic Errors: d/u

- At low x values, the full range of the CJ12 fit provides uncertainties in a_1 around the $\pm 0.2\%$ level
- The combined uncertainty from the fit and model dependence at larger x (0.55-0.65) is 0.6-1.0% but
- Either PVDIS-hydrogen data by itself, or global analyses including MARATHON and BoNUS results, should provide the necessary reduction to reach $\pm 0.2\%$ level
- The PVDIS data on hydrogen will provide a measurement of d/u, free from nuclear corrections

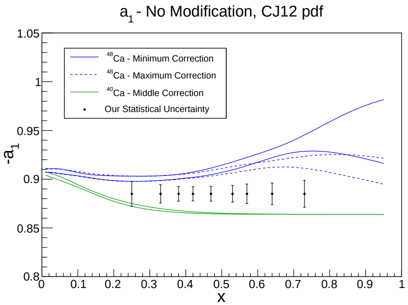
SYSTEMATIC: d/u

- Many potential nuclear effects come into play as this sector is not presently well constrained
- Requires measurements from LD_2 and LH_2 for information on size of nuclear effects
- Existing free PDFS (recent CJ12) have poor d/u constraint





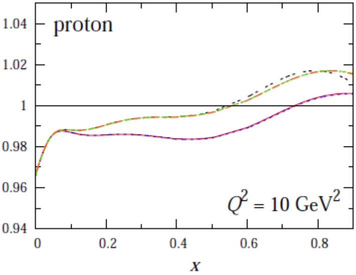
SYSTEMATIC: d/u, FREE PDF ERROR AND CSV

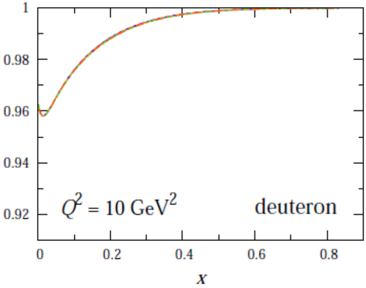


- Existing SoLID program has LD_2 planned which is sensitive to and constrains on a similar level effects such as charge symmetry violation
- ^{40}Ca would be useful if we need to search for effects such as modification-induced CSV - presently hard to argue for a commitment
- Would require similar beamtime commitment (60 days)
- ^{40}Ca tests isoscalar prediction - but isoscalar PDFs significantly cancel! (^{40}Ca in CJ12 nPDF fit is green curve)

Systematic Errors: $R^{\gamma Z}/R^{\gamma}$

- The impact of target mass effects on the difference between $R_{\gamma Z}$ and R_{γ} is shown
- Expected difference is, at most 4% in the x range sampled by this proposal, corresponding to a 0.2% uncertainty on a_1.
- Caveat: There is some additional uncertainty due to the impact of non-perturbative contributions





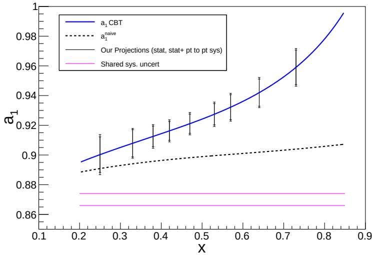
Phys.Rev.D 84 (2011) 074008

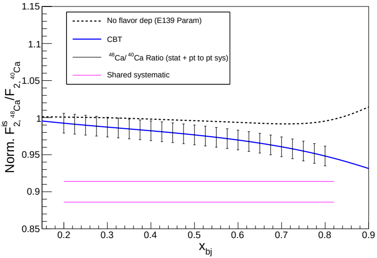
Polarimetry

- Two independent polarimeters will be deployed for this experiment.
- A continuous monitoring by the upgraded Compton polarimeter is anticipated to give 0.4% systematic uncertainty
- The Møller polarimeter will provide an additional invasive measurements periodically with a projected uncertainty of about 0.8% (Will improve after MOLLER).

PVEMC vs. ^{48}Ca/^{40}Ca Ratios

PVDIS offers highest sensitivity and is required for full picture

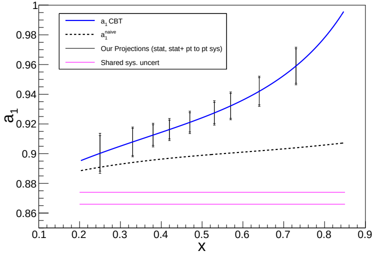


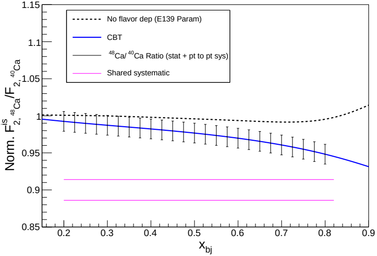


	PVEMC (this prop.)	EMC E12-10-008
Statistics	0.7-1.3%	0.8-1.1%
Systematics	0.5%	0.7%
Normalization	0.4%	1.4%
slope in x	3.7σ	2.0σ
slope at $x = 0.7$	5.5σ	2.1σ
IVEMC vs. naive hypothesis	6.2σ	$<2\sigma$
min vs. max IVEMC	4.4σ	N/A

PVEMC vs. ^{48}Ca/^{40}Ca Ratios

PVDIS offers highest sensitivity and is required for full picture





- PVDIS naturally sensitive to flavor *differences*
- DIS and PVDIS allows for flavor determination
- Other processes such as tagged SIDIS and π Drell-Yan offer complementary information
- Experiments such as SRC help motivate and tie into this program