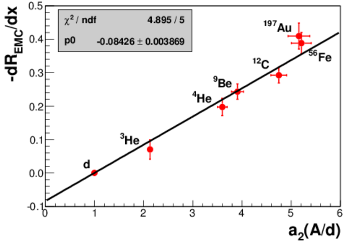
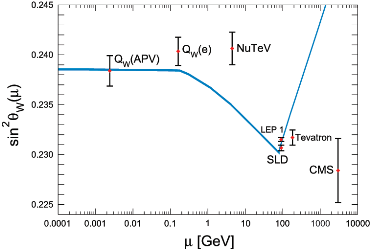
Isovector Dependence of the EMC Effect

December 4, 2016

- Flavor-modifying EMC effect in asymmetric nuclei is not well constrained and would represent new information on medium modification
- Existance of flavor dependence can reinforce intuitive ideas of EMC mechanisms e.g. local densities, nucleon overlap
- An SRC-EMC connection naturally predicts such an effect
- Such an isovector EMC effect consistent with SRC is in the right direction as CBT model and NuTeV

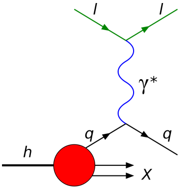




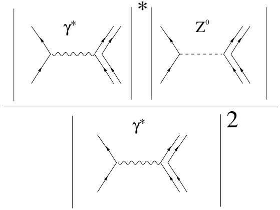
Experimental Access to Flavor in PDFs

Some popular proposals to study flavor dependence of EMC effect

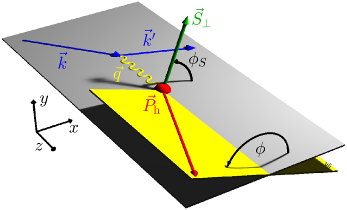
Leptonic DIS σ Ratios



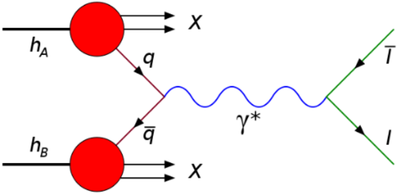
Parity-Violating DIS Asymmetry



SIDIS - π flavor tagging

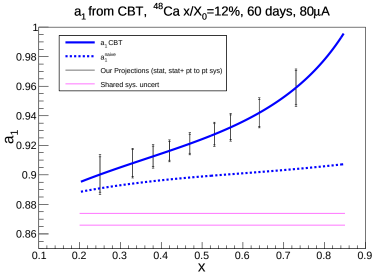


Drell-Yan - $\pi^{\pm}$,p on A

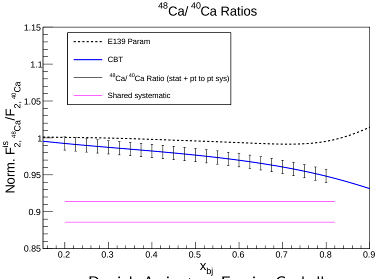


Competing Methods for Direct Measurement

PVDIS offers highest sensitivity and is required for full picture



Riordan, Arrington, Beminiwattha



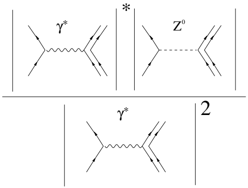
Daniel, Arrington, Fomin, Gaskell

	PVEMC (SoLID) Hall A, 2024?	EMC ^{48}Ca/^{40}Ca E12-10-008 Hall C, 2018?
Statistics	0.7-1.3%	0.8-1.1%
Systematics	0.5%	0.7%
Normalization	0.4%	1.4%
CBT x-dependence	5%	3%
CBT sensitivity	5.6σ	$< 3\sigma$

PVDIS

PVDIS proves new flavor combinations $\rightarrow$ isovector properties

$A_{\mathrm{PV}} \sim$



$\sim 100 - 1000$ ppm

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

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

Effective Weak Couplings

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

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

PVDIS

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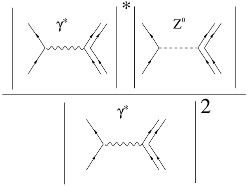
$A_{\mathrm{PV}} \sim$



$\sim 100 - 1000$ ppm

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

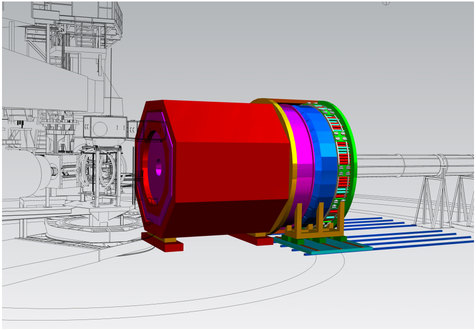
Symmetric nucleus limit

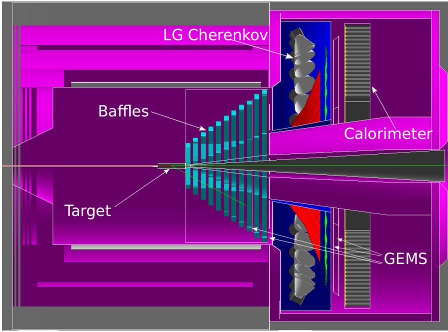
$$a_1 \simeq \frac{9}{5} - 4\sin^2\theta_W - \frac{12}{25}\frac{u_A^+ - d_A^+}{u_A^+ + d_A^+} + \ldots$$

where $u_A = u$ in p *and* u in n

SoLID for PVDIS

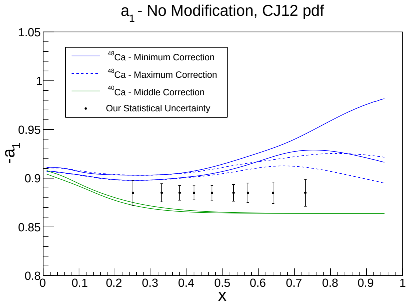
- SoLID offers only real method to obtain necessary precision without new facilities
- Ability to capitalize on JLab limits of energy and luminosity
- Experimental configuration practically identical and similarly challenging to approved SoLID PVDIS measurement (70 days)
- Already deferred twice by PAC - at least want $^{48}\mathrm{Ca}/^{40}\mathrm{Ca}$ first
- SoLID not yet formal project, ∼\$60M, realistically wouldn't start production until at least 2024

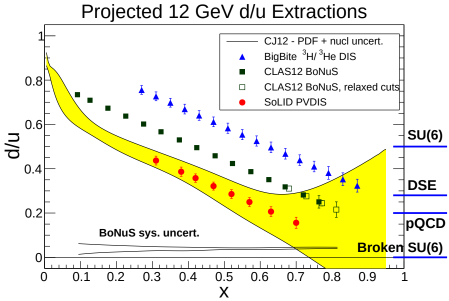




Systematics

- 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
- Charge symmetry violation competing effect will also be explored to better precision
- Existing free PDFS (recent CJ12) have poor d/u constraint





PAC Statements

SIDIS (E12-09-004) - Kafidi, Dutta, Gaskell

- PAC 34 - Deferred (with Regret)
  - Cite " Whilst this of interest ... needs to understand the SIDIS process more completely"
  - Worried about systematics from hadronization in interpretation

PVDIS (Our proposal)

- PAC 42 - Deferred
  - "novel and well developed proposal"
  - Site boundary radiation limits were a concern (since addressed)
  - Cross section measurement sensitivity wasn't formally studied
- PAC 44 - Deferred Again
  - Informally - workshop to organize between efforts and converge theory, radiation effects on the hall, target cost, sensitivity
  - "The PAC finds the proposed physics to be interesting but believes that information from experiment E12-10-008 (^{48}Ca/^{40}Ca) should be available before committing the substantial beam and financial resources necessary for this experiment."

Questions to be Resolved

- Need community to really make strong statement on *needs*
  - What is the coherent story between all programs?
  - What are the experiments that must be done? What sensitivity do we demand from them?
- What other modeling or calculations can be done for predictions? What is constrained with new measurements?
- What are optimal observables or information extraction from models? (Ratios, slopes, differences, global fits, etc)
- Explore different interpretation scenarios with results from
  - DIS with $^{48}\mathrm{Ca}/^{40}\mathrm{Ca}$
  - PVDIS $^{48}\mathrm{Ca}$ (or maybe other far future targets e.g. $^{9}\mathrm{Be}$?)
  - Approved SoLID CSV PVDIS on LD_2
  - Neutrino, Drell-Yan Data - Existing and future (e.g. COMPASS, DUNE)
  - Inclusive and exclusive SRC with (a)symmetric nuclei
  - Beyond the Standard Model Studies (e.g. LHC, $\sin^2\theta_W$, dark matter searches)

Questions to be Resolved

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  - What are the experiments that must be done? What sens…
- What ot… for predictic… ements?
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  - DIS
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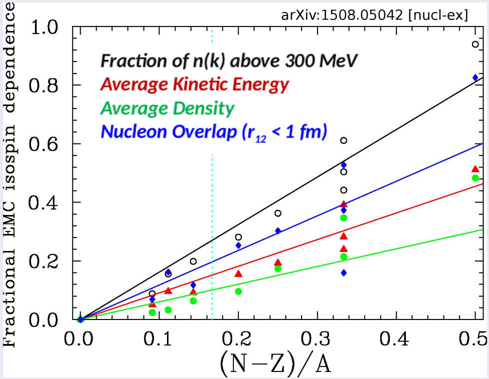
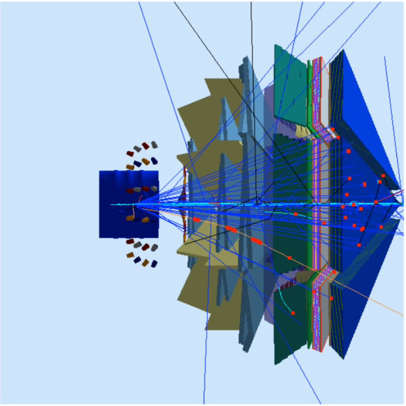
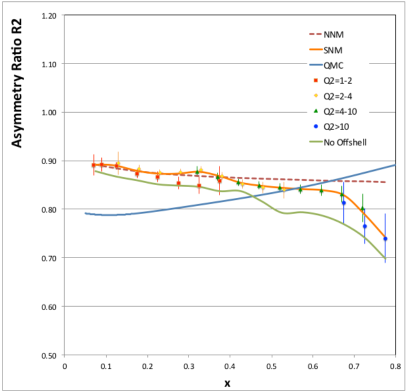
QMC EMC Modification Predictions



BACKUP

Spin-Dependent EMC





- 50 days 11 GeV polarized e^- beam on polarized ^{7}Li (with other targets for systematics)
- Approved E12-14-001 CLAS12 at JLab - Brooks, Kuhn
- Measures double spin asymmetry $A_{\parallel}^{^7\mathrm{Li}} \approx g_1^{^7\mathrm{Li}} / F_1^{^7\mathrm{Li}}$

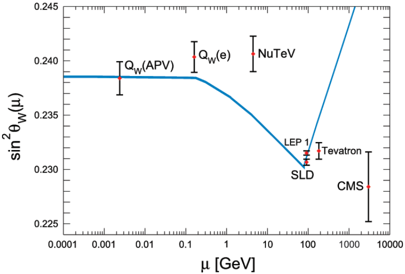
Isovector Dependence? - NuTeV

- Neutrino scattering (charged current and neutral current) is sensitive to different flavor combinations

Pachos-Wolfenstein relation:

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

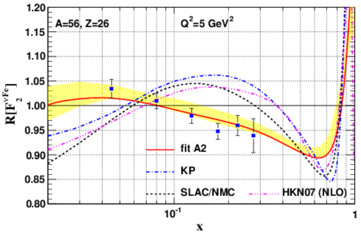
$$= \lim_{\to \mathrm{i.s.}} \frac{1}{2} - \sin^2\theta_W$$

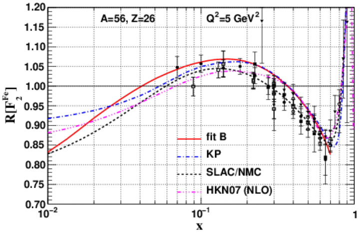


- Asymmetric nuclei (iron) need corrections
- CSV or IVEMC could play very important role and are not well constrained by data

Isovector Dependence? - Partitioned Fits

- Existing fits to world data show controversy
- Studies partitioning data between lepton/Drell Yan and ν show significant incompatibilities in nuclear corrections using common PDFs

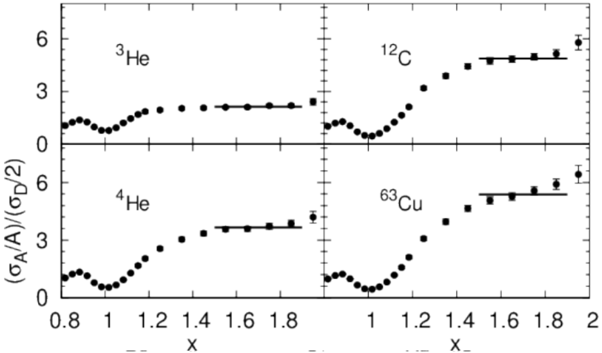




I. Schienbein et *al.* PRD77 054013 (2008); I. Schienbein et *al.* PRD80 094004 (2009)

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



Isovector Dependence? - SRC

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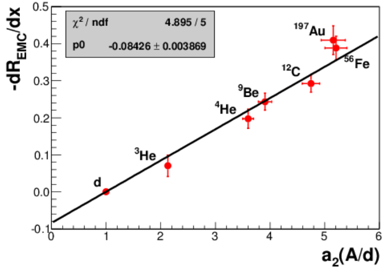
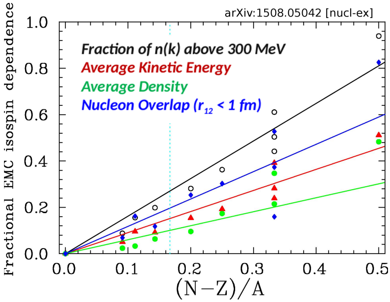
- Also show strong correlation to “plateau” parameter for $x > 1$ SFs
- Preliminary models make predictions of deviations for asymmetric nuclei

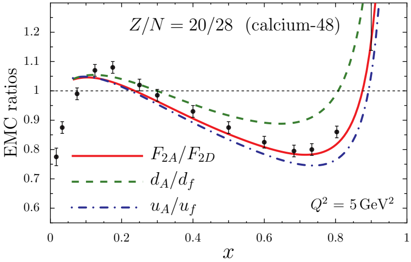


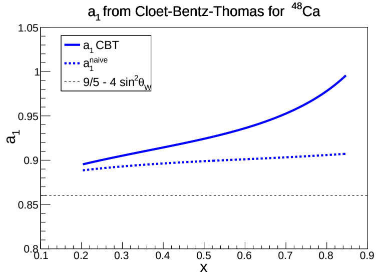


Arrington, EPJ Web Conf. 113, 01011 (2016)

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_2, larger at larger x

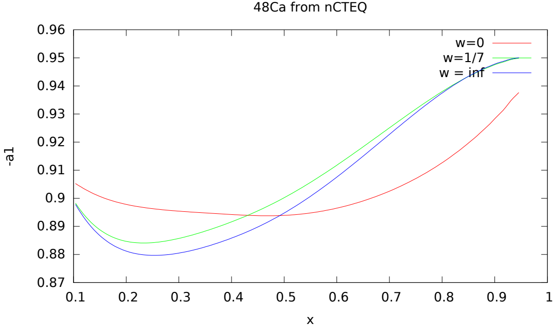




Cloet et *al.* PRL102 252301 (2009), Cloet et *al.* PRL109 182301 (2012)

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



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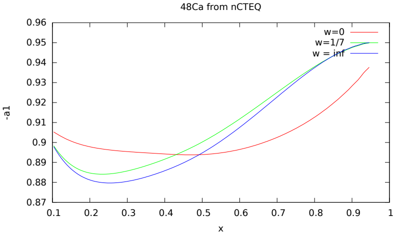
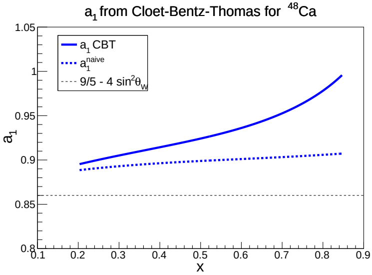


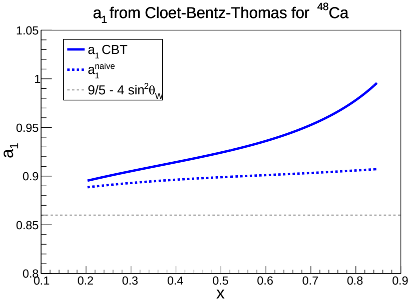


Where to get constraint

- 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 $R^{\gamma Z}$)
- Asymmetric target will test isovector dependence - larger A gives larger EMC, larger $Z - N$ gives IV enhancement

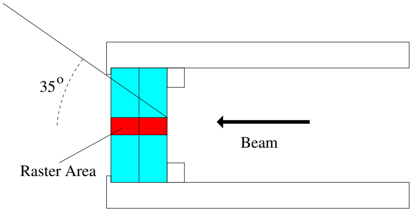
Symmetric nucleus limit

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



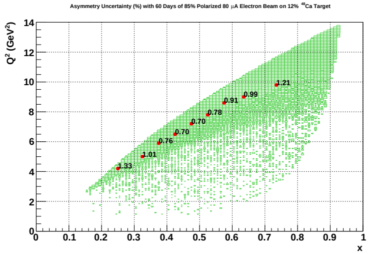
Target - ^{48}Ca

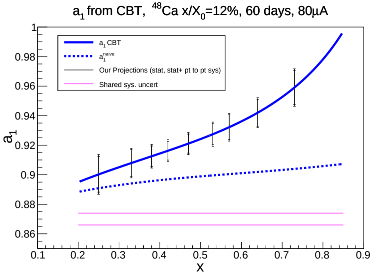
- ^{48}Ca target provides good balance between asymmetric target and not too high Z
- Has very good thermal conductance and high melting point - have operational experience with previous program and upcoming CREX
- 12% radiator - photons and photoproduced pions are main background concerns



Projections

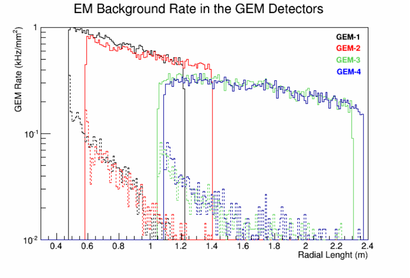
- Requesting 60 days at 80 μA 11 GeV production (71 days total) to get $\sim$1% stat uncertainties across a broad range of x
- In the context of the CBT model, this is few sigma in very simple interpolation model
- *This provides new and useful constraints in a sector where there is little data*





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

Systematics and Experimental uncertainties

- Polarimetry and pions are main contributions
- Radiative working group has been established for PVDIS
- Total errors:

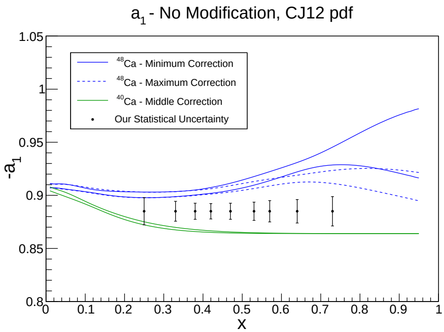
Effect	Uncertainty [%]
Polarimetry	0.4
$R^{\gamma Z}/R^{\gamma}$/HT	0.2
Pions (bin-to-bin)	0.1-0.5
Radiative Corrections (bin-to-bin)	0.5-0.1
Total for any given bin	~0.5-0.7

- Statistical uncertainty dominates any given bin

Summary

- Nuclear modification has many open important questions for our understanding of QCD
- PVDIS on asymmetric targets offers best opportunity to uncover isovector dependence in modification
- 60 days production will offer critical new information, help test leading hypotheses, and help resolve the NuTeV anomaly
- Proposal deferred twice by PAC in light of DIS ratio measurement

Why not ^{40}Ca?



^{40}Ca in CJ12 nPDF fit is green curve

- Would require similar beamtime commitment (60 days)
- ^{40}Ca tests isoscalar prediction - but isoscalar PDFs significantly cancel!
- 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

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

Site Boundary

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

	^{48}Ca Flux (Hz/μA)	^{48}Ca Dose ($80\ \mu$A for 60 days) (m^{-2})	LD_2 Flux (Hz/μA)	LD_2 Dose ($50\ \mu$A 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

- Calculated to be factor of 2 smaller than CREX

Site Boundary

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

Experiment	Estimated DOSE (m^{-2})	(mrem)	Measured DOSE (mrem)
PREX-I	4.50E+12	4.2	1.3
PREX-II	5.80E+12	5.4	n/a
CREX	1.50E+13	9.2	n/a
PVDIS-LD_2	3.40E+12	3.2	n/a
PVDIS-^{48}Ca	6.00E+12	5.6	n/a

- Calculated to be factor of 2 smaller than CREX

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 100 kRad on active components

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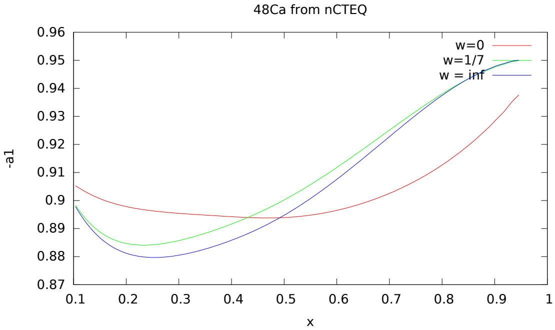


GEM Rates

GEM plane	LD_2 background (kHz/mm^2/μA)	^{48}Ca EM background (kHz/mm^2/μA)	^{48}Ca EM background (no baffles) (kHz/mm^2/μA)
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

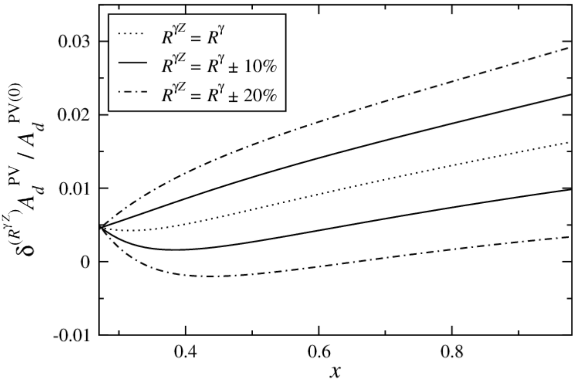
	Total Rate for $p > 0.0$ GeV (kHz)	Rate for $p > 3.0$ GeV (kHz)
DIS	240	73
π^-	5.9×10^5	1.6×10^3
π^+	2.7×10^5	40
$\gamma(\pi^0)$	7.0×10^7	40
p	4.8×10^5	4
Sum	7.1×10^7	1.7×10^3

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

Radiation

		Incident Radiation Power	
Radiation Type	E-Range (MeV)	^{48}Ca (W/μA)	LD_2 (W/μA)
$e^{\pm}$	$E < 10$	0.13	0.13
	$E > 10$	0.19	0.17
n	$E < 10$	0.0001	0.0006
	$E > 10$	0.02	0.04
γ	$E < 10$	0.02	0.02
	$E > 10$	0.04	0.05



$R^{\gamma Z} = R^{\gamma}$
$R^{\gamma Z} = R^{\gamma} \pm 10\%$
$R^{\gamma Z} = R^{\gamma} \pm 20\%$
0.03
0.02
0.01
0
-0.01
0.4
0.6
0.8
x
$\delta^{(R^{\gamma Z})} A_d^{PV} / A_d^{PV(0)}$