Measurements of the EMC Effect Using Parity-Violating Deep Inelastic Scattering

Seamus Riordan
University of Massachusetts, Amherst
sriordan@physics.umass.edu

July 10, 2014

Outline

- Motivation
- Proposed Experiment
- Anticipated Results and Systematics

Collaboration

Spokespeople

- Seamus Riordan - UMass
- Rakitha Beminiwattha - Syracuse

N. Hirlinger Saylor, K. S. Kumar, T. Kutz, R. Miskimen, S. Riordan*†, J. Wexler
University of Massachusetts, Amherst

R. Beminiwattha*, R. Holmes, and P. Souder
Syracuse University

S. Barkanova
Acadia University

I. C. Cloët
Argonne National Laboratory

K. Aniol
California State University, Los Angeles

P. Markowitz and M. M. Sargsian
Florida International University

A. Aleksejevs
Grenfell Campus of Memorial University

N. Kalantarians
Hampton University

D. McNulty
Idaho State University

V. Bellini, C. Sutera
INFN - Sezione di Catania

J. Beričič, S. Širca, and S. Štajner
Jožef Stefan Institute and University of Ljubljana, Slovenia

J. Dunne and D. Dutta
Mississippi State University

P. M. King and J. Roche
Ohio University, Athens, Ohio

L. El Fassi and Z. Zhao
Old Dominion University

R. Gilman, K. E. Mesick
Rutgers University

A. Deshpande
State University of New York, Stony Brook

O. Hen
Tel-Aviv University

J. Benesch, A. Camsonne, J. P. Chen, S. Covrig, D. Gaskell, J.-O. Hansen, C. E. Keppel, and Z. Zhao
Thomas Jefferson National Accelerator Facility

A. J. Puckett
University of Connecticut

P. Blunden
University of Manitoba

X. Bai, D. Di, K Gnavo, C. Gu, N. Liyanage, H. Nguyen, K. D. Paschke, V. Sulkosky, and X. Zheng
University of Virginia

F. R. Wesselmann
Xavier University of Louisiana

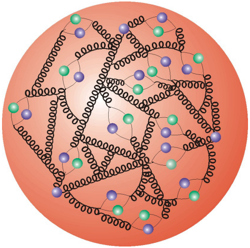
*Spokesperson

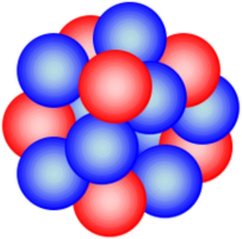
More collaborators welcome!

QCD in Nucleons and Nuclei

QCD Questions

- How do we reconcile the picture of quarks and gluons with nucleons and nuclei?
- What is the nature of bound nucleons and how are they modified?
- Is there a direct connection between nuclear and parton-level modification observables?





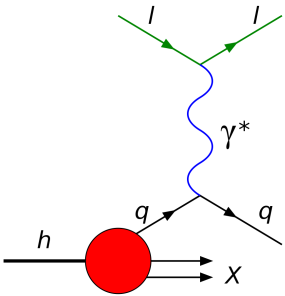
DIS

- DIS with leptons offers picture into partonic distributions

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

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

$$F_L \approx F_2 - 2xF_1$$



- 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

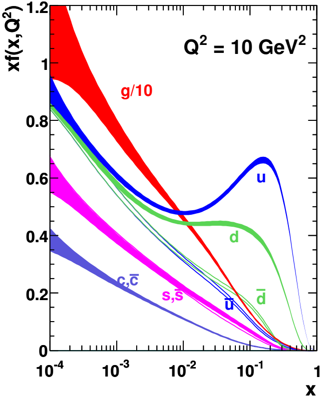
DIS

- DIS with leptons offers picture into partonic distributions

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

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

$$F_L \approx F_2 - 2xF_1$$



- 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

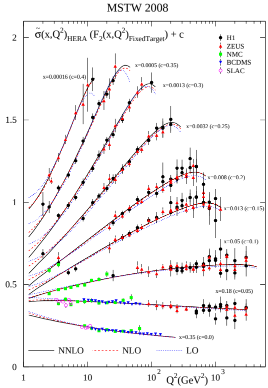
- DIS with leptons offers picture into partonic distributions

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

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

$$F_L \approx F_2 - 2xF_1$$

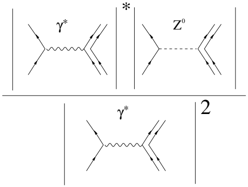
- Highly successful for our modern picture of quark degrees of freedom and pQCD
- PDFs have been well determined over a broad range after decades of study



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

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

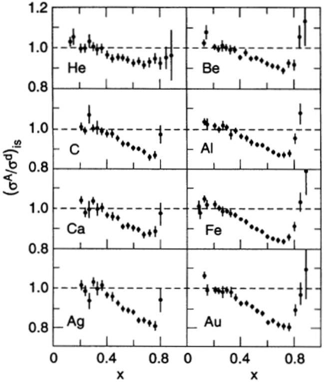
$$C_{1d} = \frac{1}{2} - \frac{2}{3}\sin^2\theta_W = 0.34 \qquad C_{2d} = \frac{1}{2} + 2\sin^2\theta_W = 0.03$$

EMC Effect

Nuclear Modification

- First observed in 1984 by EMC collaboration
- Showed reduced presence of partons in $0.3 < x < 0.7$
- Generally greater effect as one pushes to higher A
- Not due to simple binding effects - real modification of structure

General assumption of $u \leftrightarrow d$ for $p \leftrightarrow n$
PVDIS can test this



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

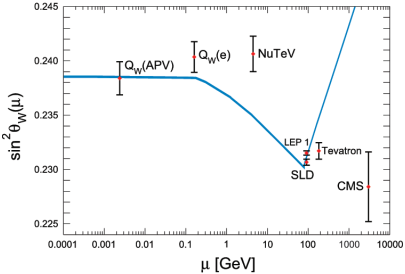
Isovector Dependence? - NuTeV

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

Pachos-Wolfenstein relation:

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

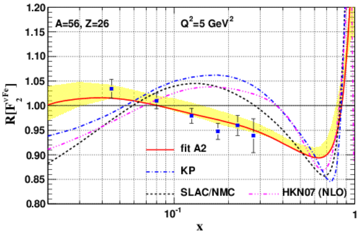
$$= \lim_{\to \mathrm{i.s.}} \frac{1}{2} - \sin^2\theta_W$$

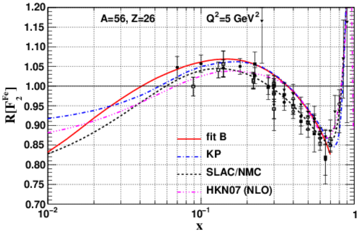


- Asymmetric nuclei (iron) need corrections
- CSV or IVEMC could play very important role and are not well constrained by data

Isovector Dependence? - Partitioned Fits

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

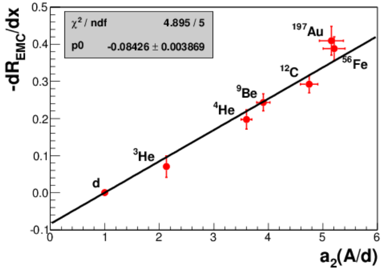


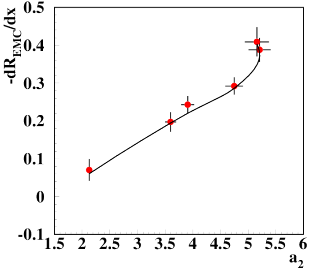


I. Schienbein et *al.* PRD77 054013 (2008); I. Schienbein et *al.* PRD80 094004 (2009)

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
- Preliminary models make predictions of deviations for asymmetric nuclei

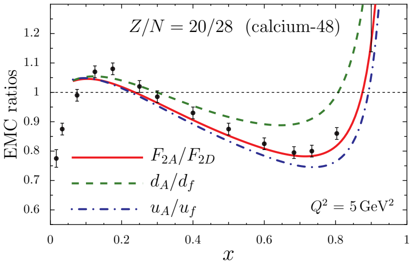


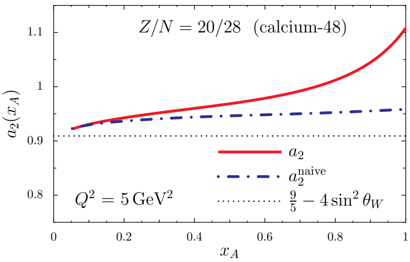


M. M. Sargsian arXiv:1209.2477 [nucl-th]

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 symmetry energy
- Few percent effect in a_2, larger at larger x

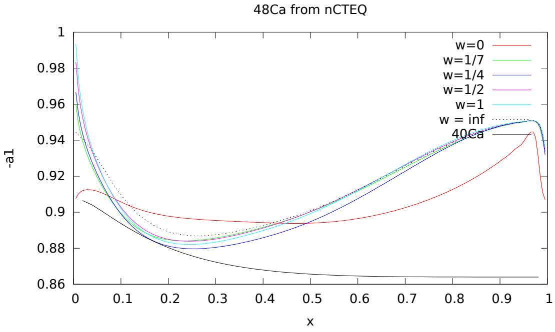




Cloet et *al.* PRL102 252301 (2009), Cloet et *al.* PRL109 182301 (2012)

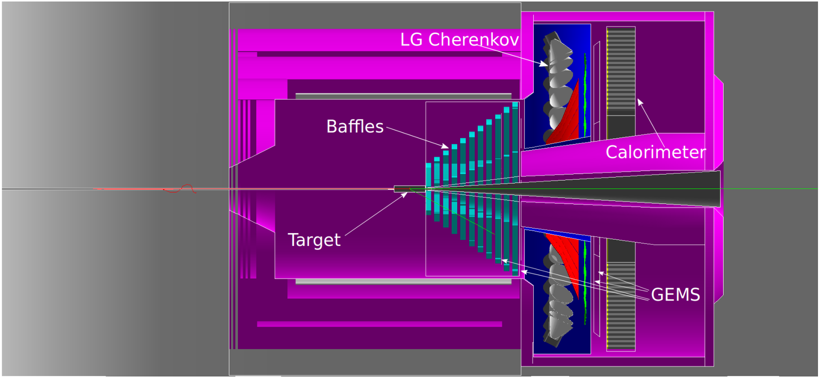
Modeling - nPDFs

- 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



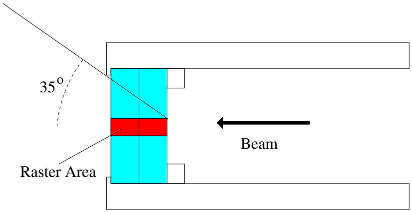
Configuration

- Experimental configuration practically identical to approved SoLID PVDIS measurement
- Lead baffles serve as momentum collimators
- GEMs, Cherenkov, and calorimeter provide tracking and PID
- Rates are better or comparable to existing LD_2 measurement



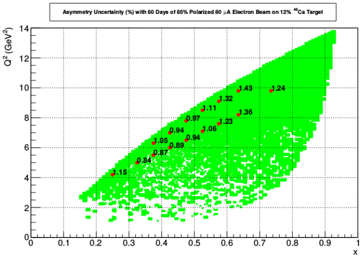
Target - ^{48}Ca

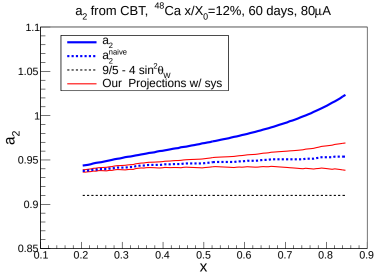
- ^{48}Ca target provides good balance between asymmetric target and not too high Z
- Has very good thermal conductance and high melting point, uses LH_2 cooling - will be tested with similar CREX target
- 12% radiator - photons and photoproduced pions are main background concerns



Projections

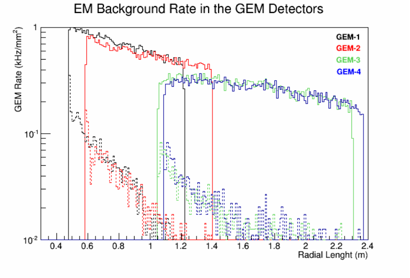
- Requesting 60 days at 80 μA 11 GeV production (71 days total) to get $\sim$1% stat uncertainties across a broad range of x
- In the context of the CBT model, this is few sigma in very simple interpolation model
- *This provides new and useful constraints in a sector where there is little data*





Rates and Backgrounds

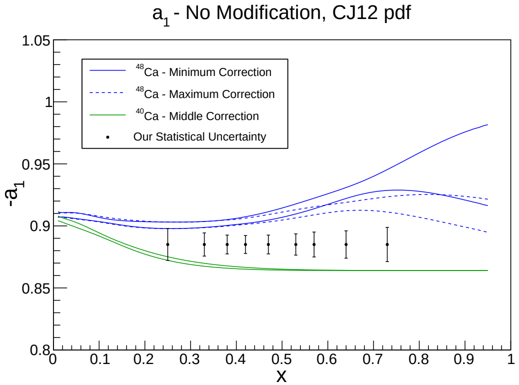
- Trigger defined by coincidence between Cherenkov and shower - 150 kHz total anticipated with background (well below SoLID spec)
- Pion contamination no worse than 4% in any given bin (worst at high x)
- GEM rates comparable to or smaller than design for LD_2



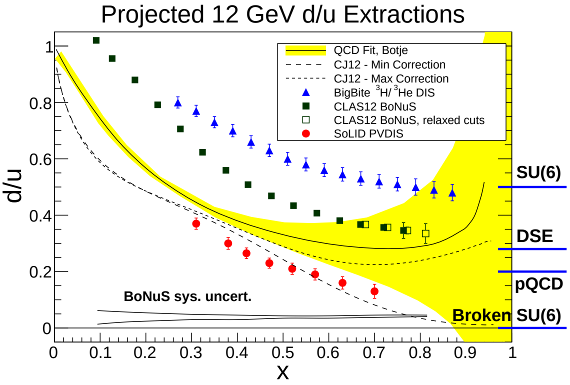
Particle	DAQ Coin. Trig.Rate (kHz)	
	$P > 1$ GeV	$P > 3$ GeV
DIS e^-	144	61
π^-	11	7
π^+	0.4	0.2
Total	155	68

Systematics

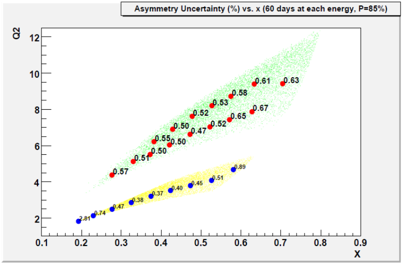
- Many potential nuclear effects come into play as this sector is not presently well constrained
- Requires measurements from LD_2 and LH_2 for information on size of nuclear effects
- Existing free PDFS (recent CJ12) have poor d/u constraint



- 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
- Will be constrained by LH_2

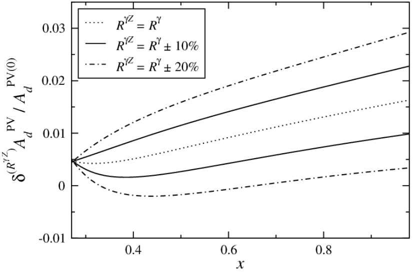


- Many potential nuclear effects come into play as this sector is not presently well constrained
- Requires measurements from LD_2 and LH_2 for information on size of nuclear effects
- Higher twist effects will also be constrained by LD_2 using same kinematics, but also 6.6 GeV beam
- Charge symmetry violation will also be explored to better precision (and if they are large, ^{40}Ca may become interesting)



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
- Nuclear dependence of $R^{\gamma Z}$ is an open question, ^{40}Ca again may be interesting



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	$\sim$0.5-0.7

- Statistical uncertainty dominates any given bin

Summary

- Nuclear modifcation has many open important questions for our understanding of QCD
- PVDIS on asymmetric targets offers exciting opportunity to uncover isovector dependence in modification
- 60 days production will offer powerful constraints, help resolve the NuTeV anamaly, and test leading models to several sigma

BACKUP

GEM Rates

GEM plane	LD_2 background ($\mathrm{kHz/mm^2/\mu A}$)	^{48}Ca EM background ($\mathrm{kHz/mm^2/\mu A}$)	^{48}Ca EM background (no baffles) ($\mathrm{kHz/mm^2/\mu A}$)
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 Rates

Momentum range (GeV)	π^- (MHz)	π^+ (MHz)	$\pi^0(\gamma)$ (MHz)	Proton (MHz)	EM $(\gamma, e\pm)$ (GHz)
$p > 0.0$ GeV	618	283	70123	483	844
$p > 0.3$ GeV	439	153	438	417	n/a
$p > 1.0$ GeV	123	18	37	51	0.0
$p > 3.0$ GeV	2	0.01	0.04	0.004	0.0

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

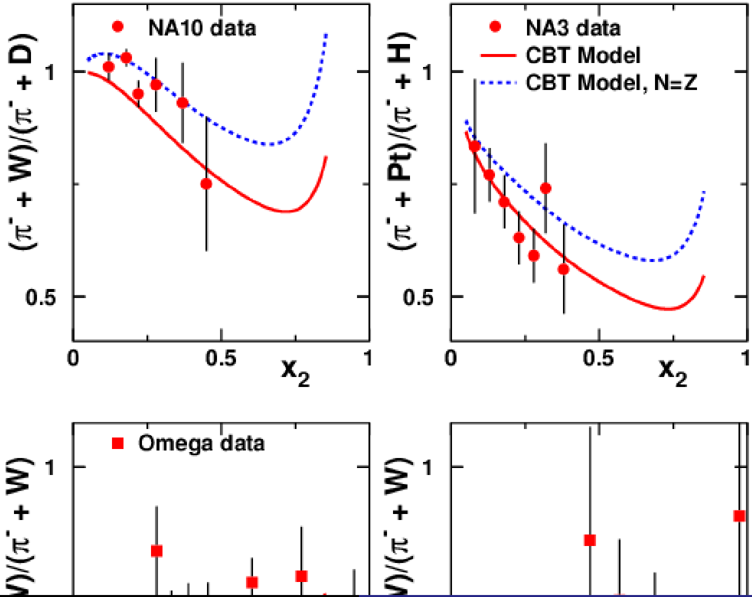
Trigger Rate from Cherenkov (kHz)

	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

Drell-Yan



NA10 data
$(\pi^- + W)/(\pi^- + D)$
1
0.5
0
0.5
1
x_2
NA3 data
CBT Model
CBT Model, N=Z
$(\pi^- + Pt)/(\pi^- + H)$
1
0.5
0
0.5
1
x_2
Omega data
$(\pi^- + W)$
1
$(\pi^- + W)$
1