Spin Asymmetries of the Nucleon Experiment

(PR03-109)

Glen Warren
Jefferson Lab

PAC 24
June 16, 2003

Outline

- Spin structure
- World's data of A_{1p} and g_2
- Method
- Physics
- Systematics, etc...
- Summary

Spin Structure

Deep inelastic lepton scattering data has yielded wealth of knowledge of nucleon structure. Quark distributions inside nucleon are described by four structure functions

- Structure functions: F_1, F_2 - cross section
- Spin Structure Functions: g_1, g_2 - polarization observables

In Quark-Parton Model, we can write F_1 and g_1 in terms of helicity dependent quark distribution functions, $q_i^{\pm}(x)$:

$$F_1(x) = \frac{1}{2}\sum_i e_i^2 [q_i^+ + q_i^-]$$

$$g_1(x) = \frac{1}{2}\sum_i e_i^2 [q_i^+ - q_i^-]$$

g_2

$g_2(x,Q^2)$ does not have as simple an interpretation as g_1. It can be divided into a twist 2 and a mixed twist term:

$$g_2 = g_2^{WW} + \overline{g_2}$$

where g_2^{WW} depends only on g_1 (twist 2):

$$g_2^{WW} = -g_1 + \int_x^1 g_1(y, Q^2)/y\, dy$$

$\overline{g_2}$ vanishes when all twist-3 (d_n) matrix elements vanish in **O**perator **P**roduct **E**xpansion (OPE), e.g.

$$d_2 = 3\int_0^1 x^2 \overline{g_2}(x, Q^2)\, dx$$

Thus, g_2 is interesting for its higher twist contributions.

$g_1, g_2 \leftrightarrow A_1, A_2$

The spin structure functions g_1 and g_2 are related to the asymmetries A_1 and A_2 by:

$$A_1 = \frac{\sigma^T_{1/2} - \sigma^T_{3/2}}{\sigma^T_{1/2} + \sigma^T_{3/2}} = \frac{1}{F_1}(g_1 - \gamma^2 g_2)$$

$$\gamma = 2Mx/Q$$

$$A_2 = \frac{2\sigma_{LT}}{\sigma^T_{1/2} + \sigma^T_{3/2}} = \frac{\gamma}{F_1}(g_1 + g_2)$$

Total photon nucleon helicity

Thus A_1 and A_2 depend on F_1, which helps to reduce the Q^2 dependence of these asymmetries.

At JLab energies, it is necessary to measure two types of asymmetries to extract g_1, g_2 *or* A_1, A_2 in a model independent manner.

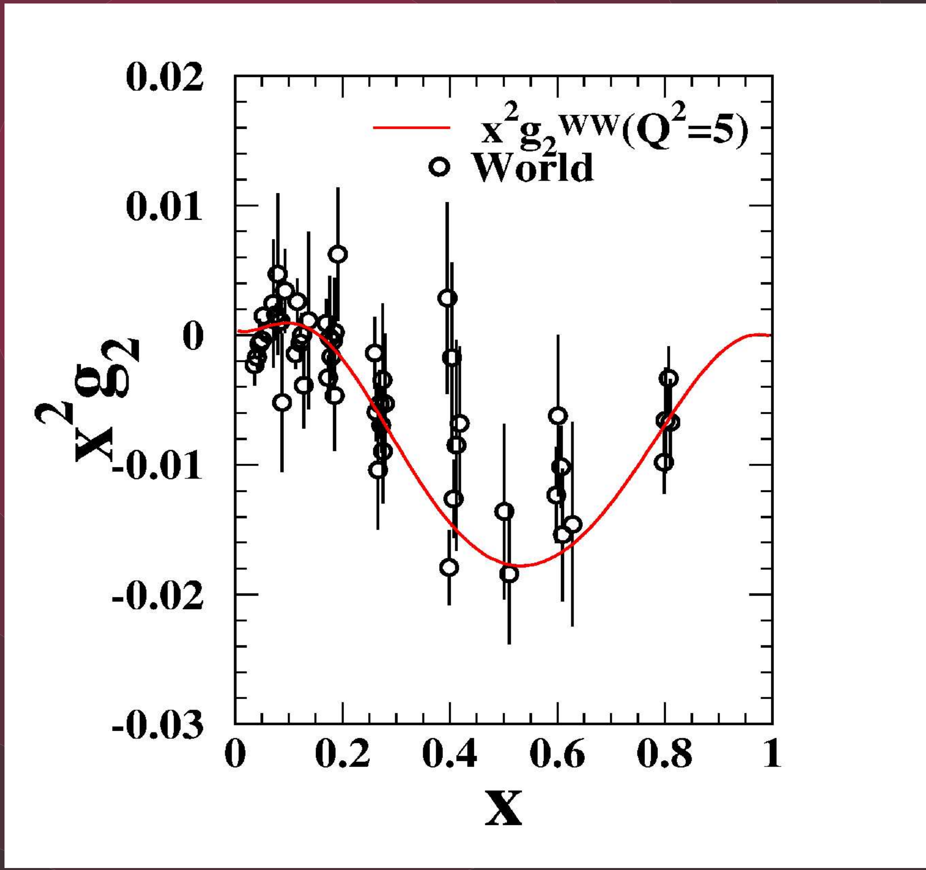
d_2

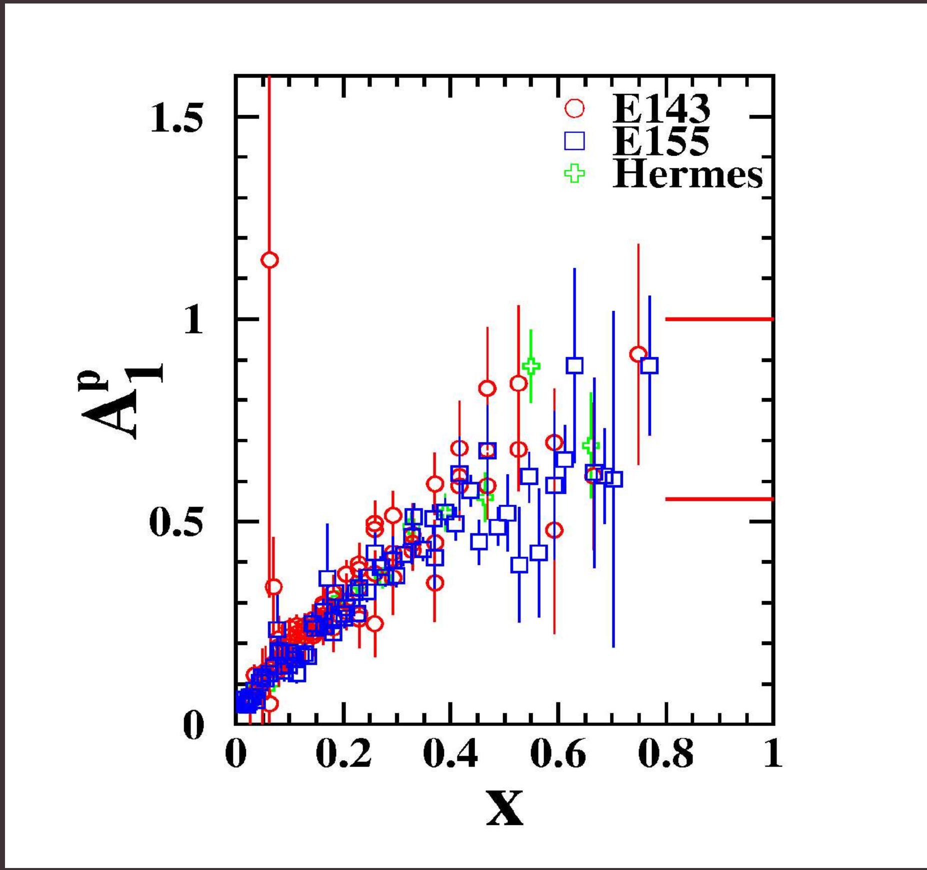
- d_2 is a measure of quark-gluon interactions (higher twists).
- Shown to measure response of color electric and magnetic fields to polarization of the nucleon:

$$d_2 = (2\chi_B + \chi_E)/3.$$

- As a moment, d_2 requires both Resonance and DIS data.
- Comparison to Lattice QCD:
  - LQCD can currently calculate moments at $Q^2 = 4$.
  - SANE covers Q^2 from 2.5 to 6.5, but has the widest coverage in x around $Q^2 = 4$.

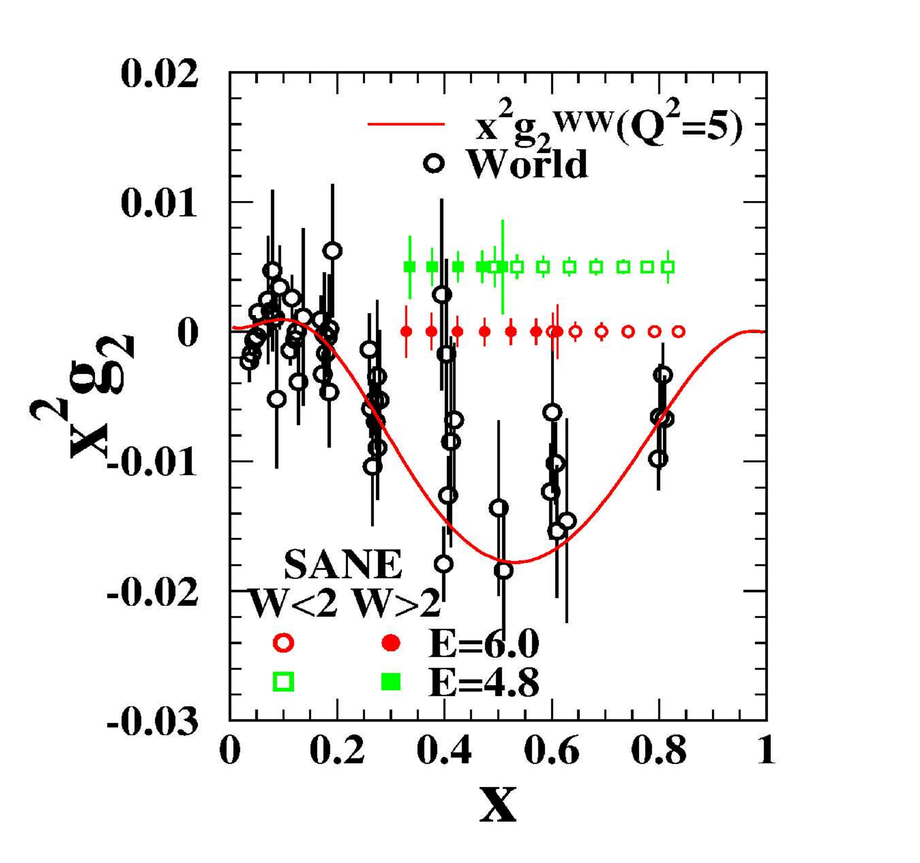
World's Data at High x

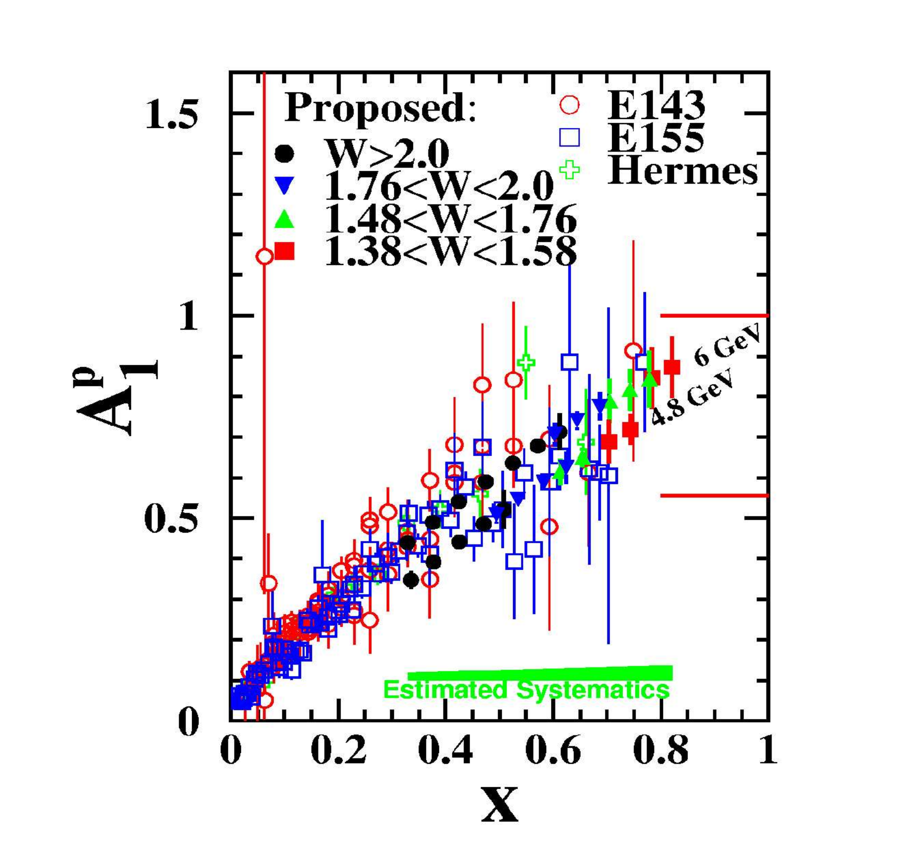




- g_2^{WW} is twist 2 - from g_1.
- Spread in g_2 at x~0.4, not clear if due to actual Q^2 dependence.
- Dominated by NH_3 experiments.
- CLAS data under analysis.

World and Projected Data





For JLab Energies, it is necessary to do two asymmetry measurements to extract A_{1p} and g_2 in a model independent way.

Extraction

Measure inclusive beam-target asymmetries with polarized electron beam and polarized proton target.

The measured asymmetry is related to A_1 and A_2 by the target polarization w.r.t. the beam (θ_N):

$$A_{meas}(\theta_N) = \alpha A_1[\ \cos(\theta_N) - \rho\sin(\theta_N)] + \beta A_2[\rho\cos(\theta_N) + \ \sin(\theta_N)]$$

$$\alpha = \alpha(E, E', \theta, R)$$
$$\beta = \beta(E, E', \theta, R)$$
$$\rho = \rho(E, E', \theta)$$

By measuring the beam-target asymmetry for two values of θ_N, we can extract A_1 and A_2.

- Most sensitive to A_1 for $\theta_N = \theta_q$ $\quad A_{meas} \sim A_{\parallel}$ - field $\parallel$ beam
- Most sensitive to A_2 for $\theta_N \approx 90^\circ$ $\quad A_{meas} \sim A_{\perp}$ - field $\perp$ beam

Geometry of target magnet prevents 90˚ measurement, instead we will use 180˚ and 80˚.

Experimental Setup

Target

- UVa NH3 target
- 5 T field

Beamline

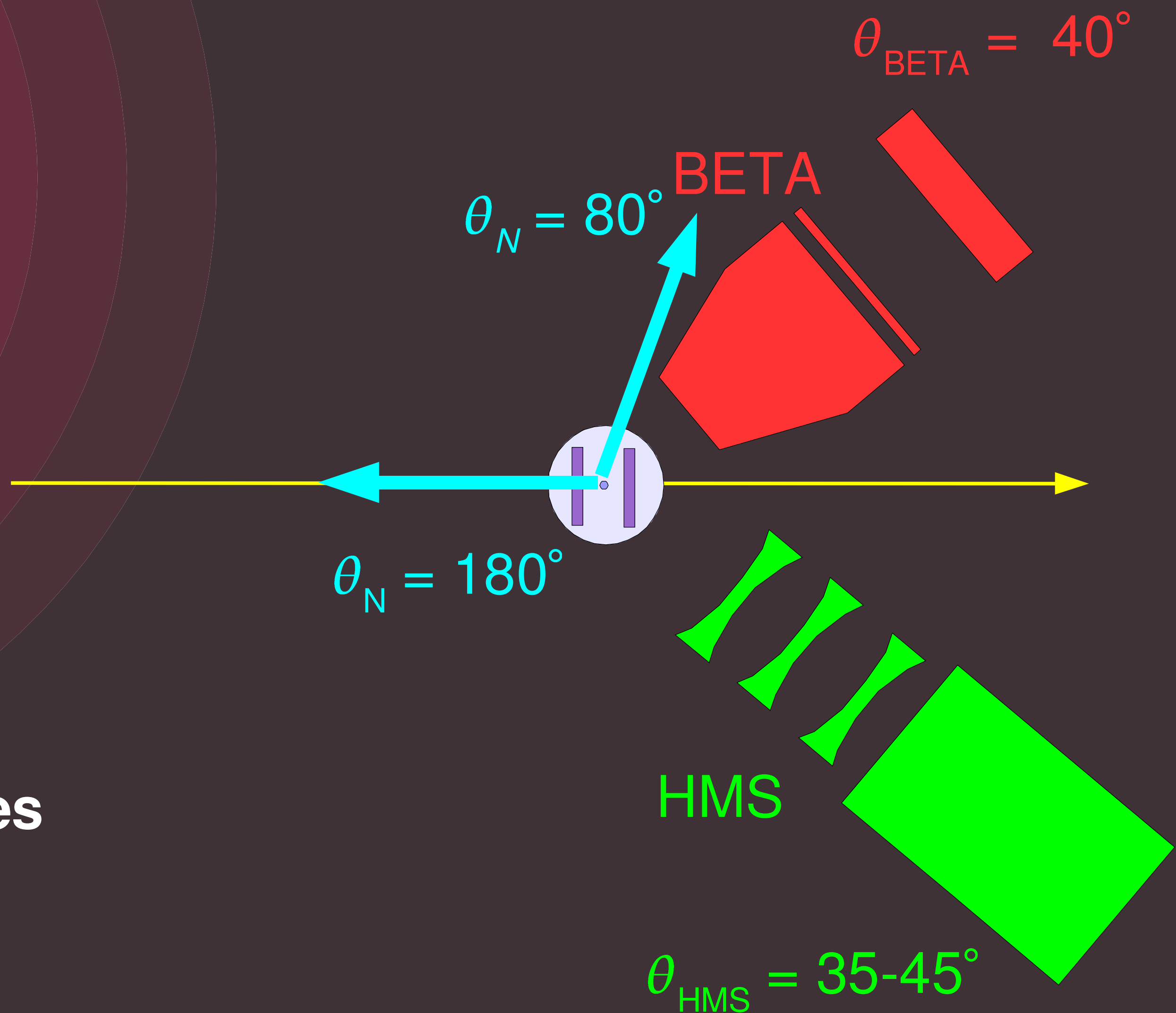
- Chicanes
- SEM
- He Bag

Electron Arm

- BETA

Background Studies

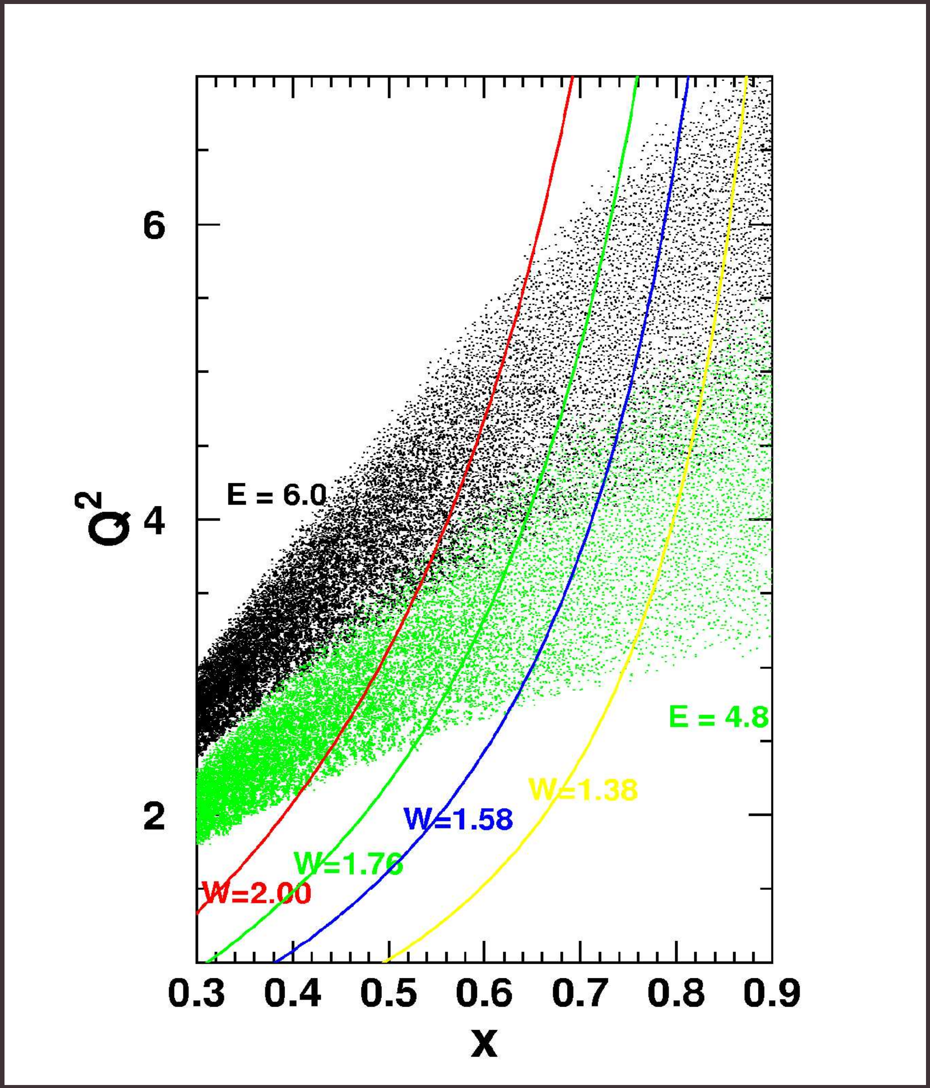
- HMS



Two Beam Energies

We propose to take measurements at beam energies of 4.8 and 6.0 GeV because:

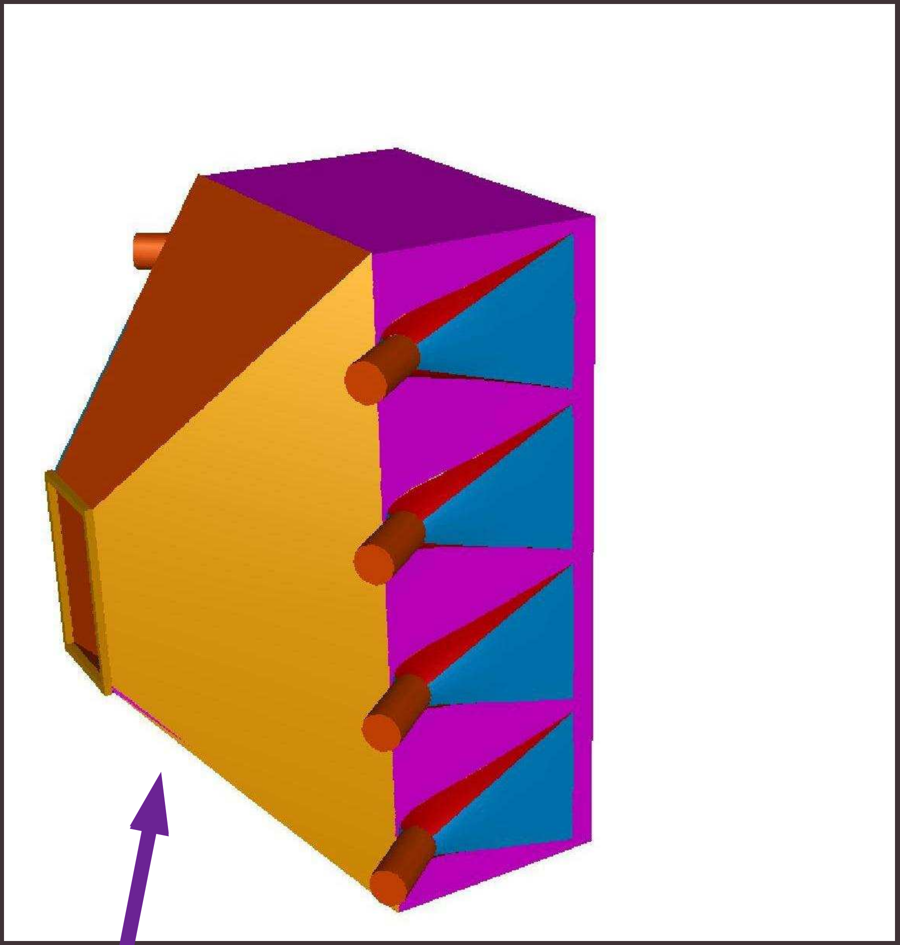
- More thorough coverage of kinematics:
  - Study Q^2 dependence for constant x.
  - Study x dependence for constant Q^2.
- Provides limited test of local duality for spin observables. If observed, can significantly extend maximum x for A_{1p}.



Big Electron Telescope Array (BETA)

Designed to be insensitive to backgrounds and have good Particle ID. Target field screens much of low energy background.

Gas Cerenkov
- Particle Identification
- Minimal knock-on



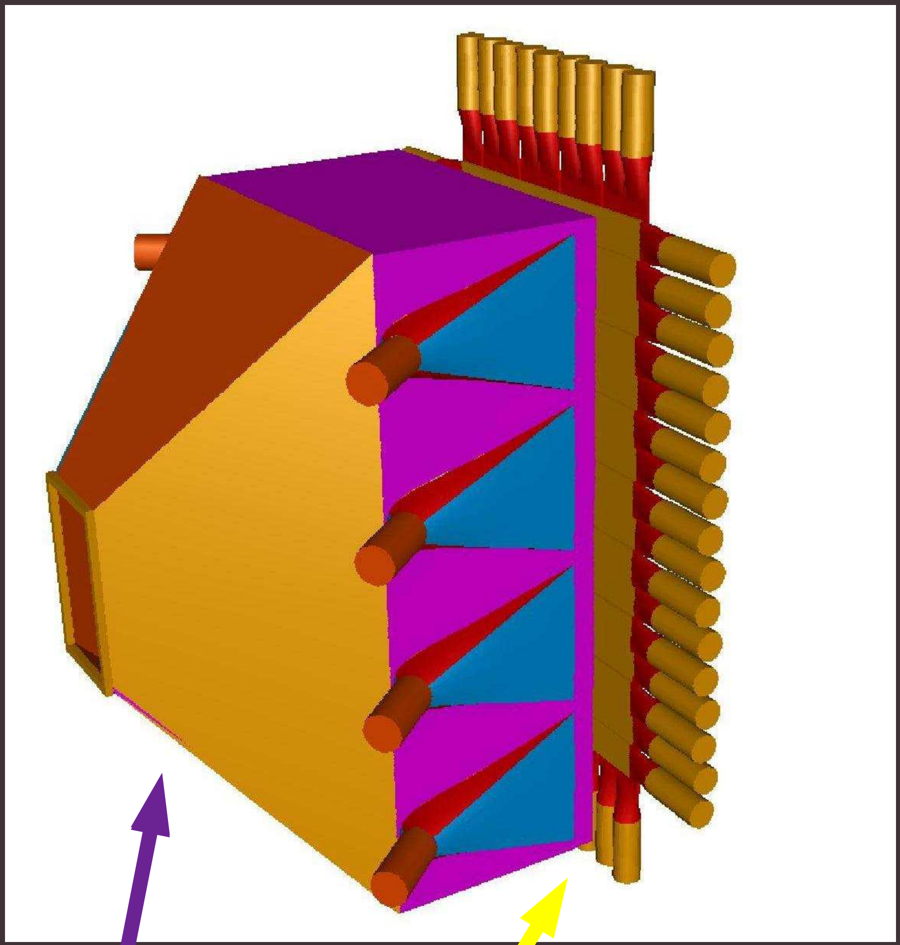
Gas Cerenkov

Big Electron Telescope Array (BETA)

Designed to be insensitive to backgrounds and have good Particle ID. Target field screens much of low energy background.

Gas Cerenkov
- Particle Identification
- Minimal knock-on

Lucite Cerenkov
- Redundant PID
- Tracking



Big Electron Telescope Array (BETA)

Designed to be insensitive to backgrounds and have good Particle ID. Target field screens much of low energy background.

Gas Cerenkov

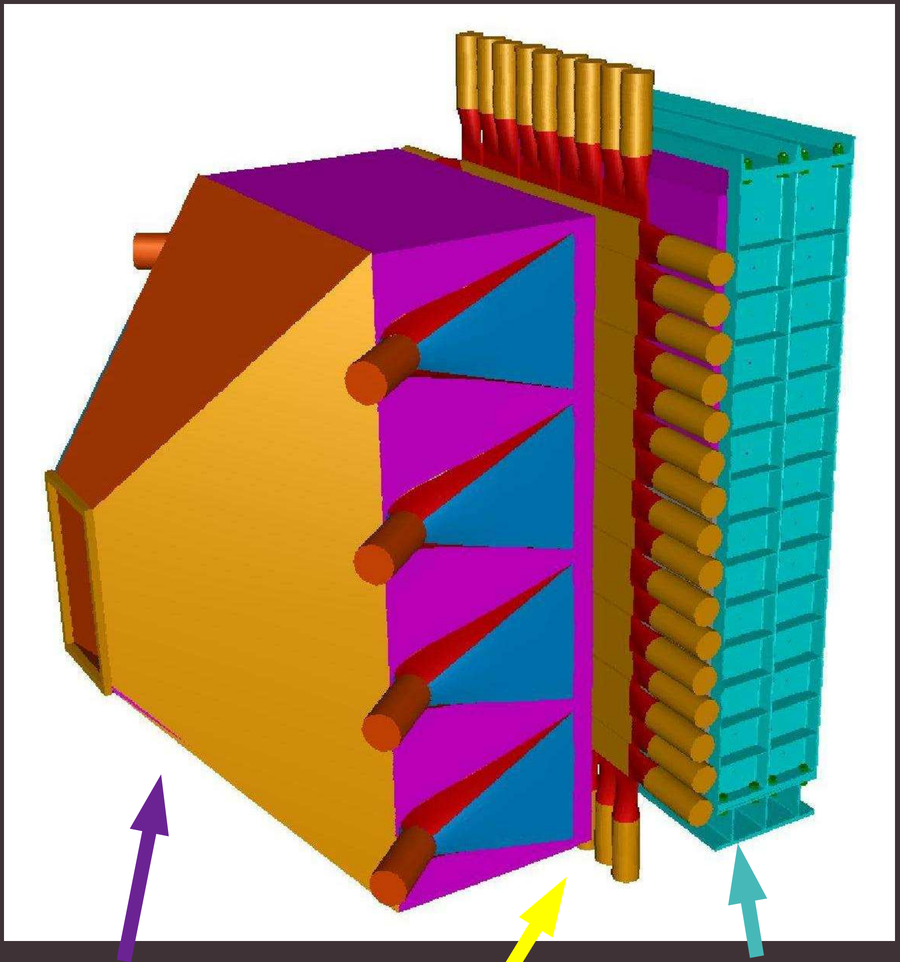
- Particle Identification
- Minimal knock-on

Lucite Cerenkov

- Redundant PID
- Tracking

Pb-Glass Calorimeter

- Calorimetry
- Hadron reduction



Physics from SANE

Precision g_2

d_2

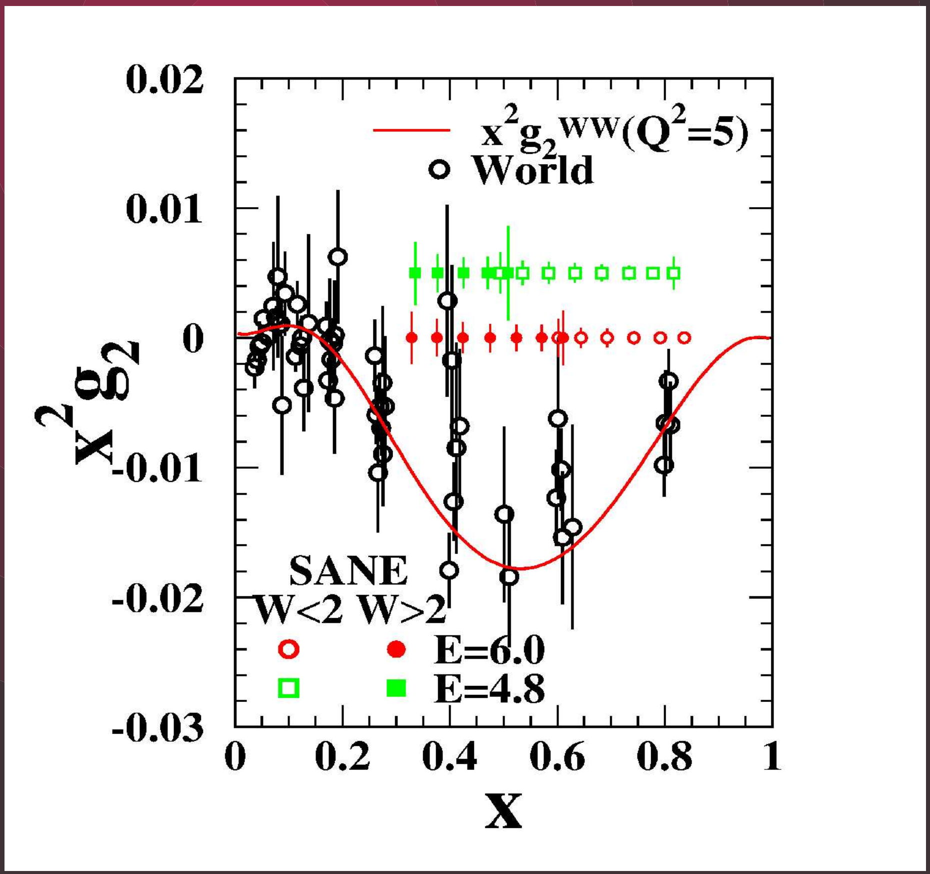
x, Q^2, W
Dependence

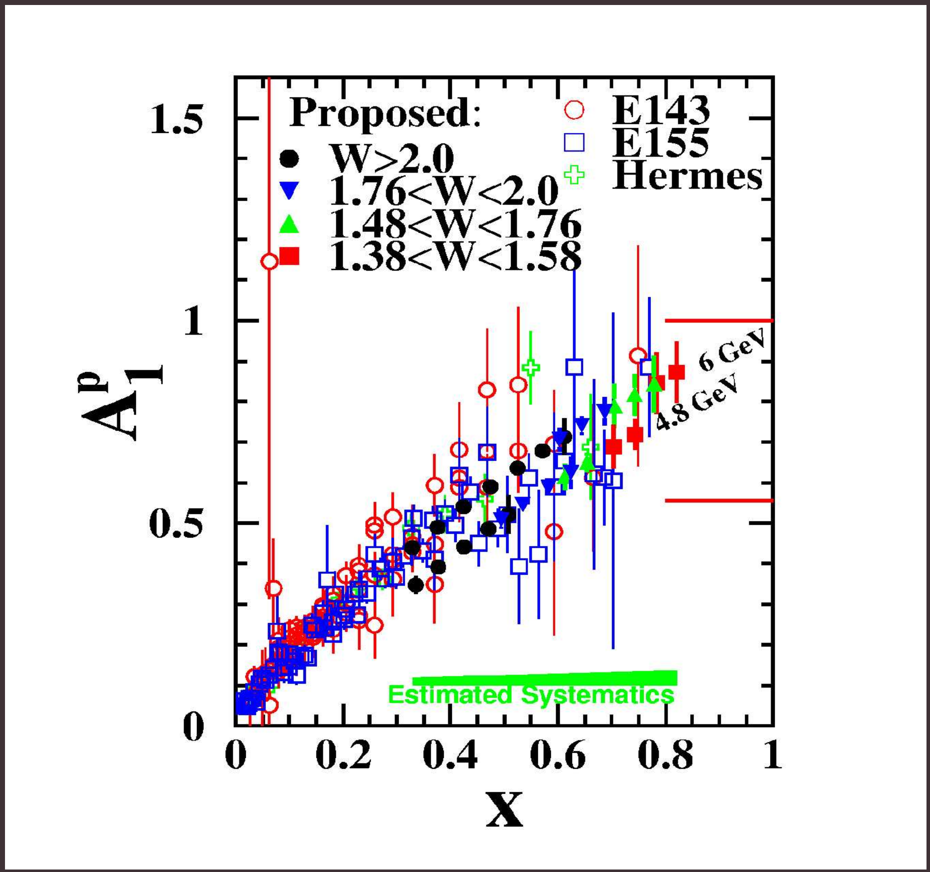
SANE

A_{1p} as $x \rightarrow 1$

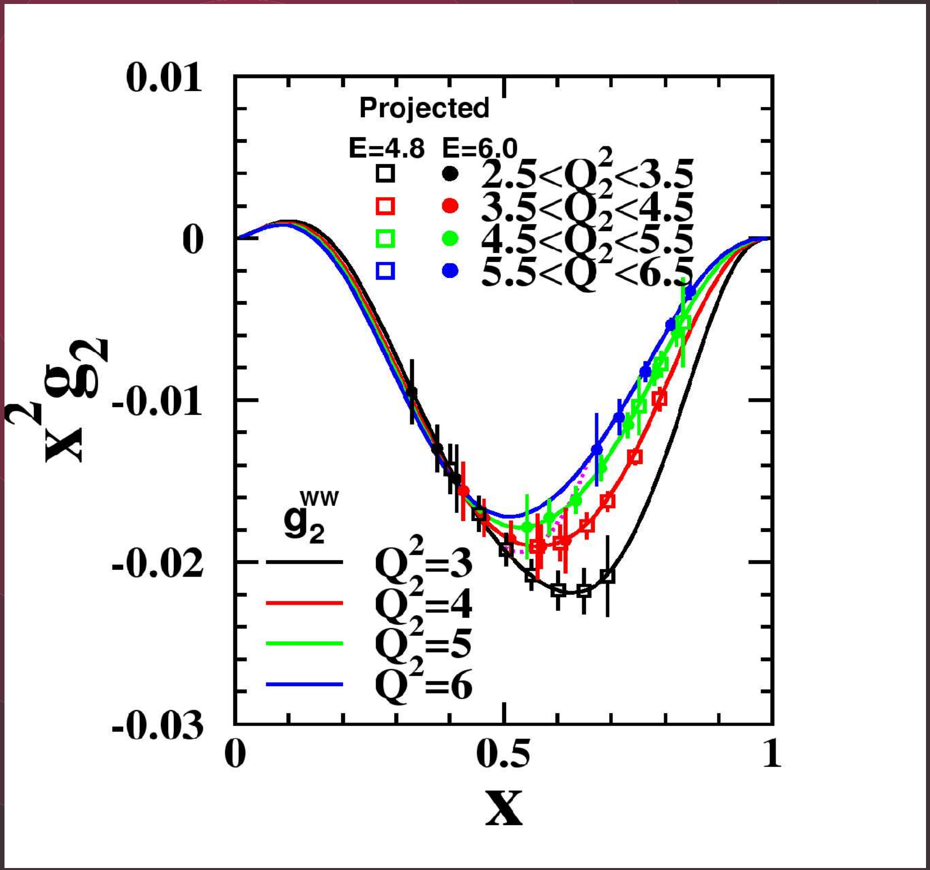
Spin Duality

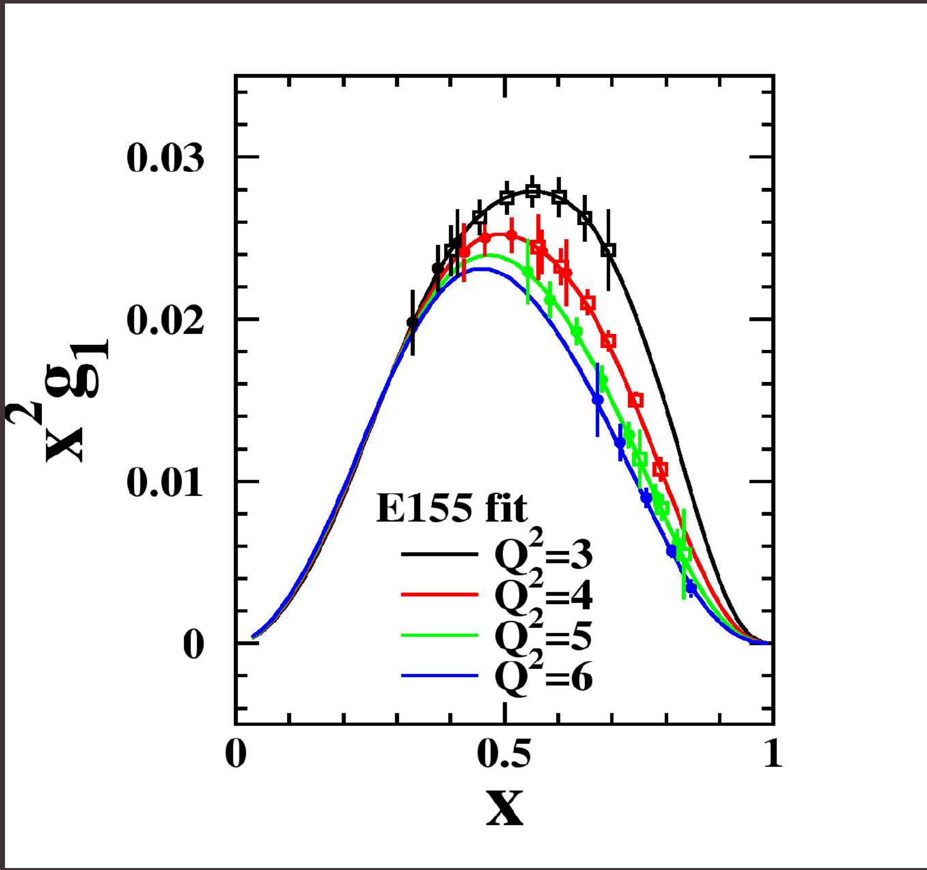
Precision Data





Q^2 Dependence





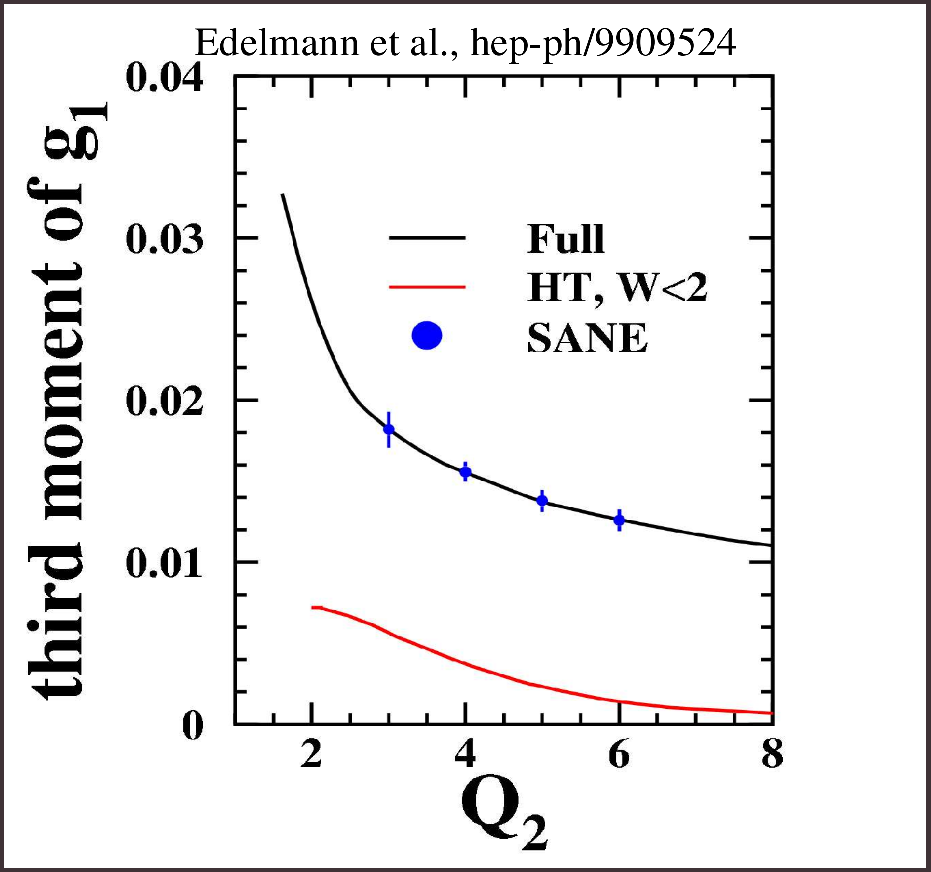
- Spin structure data binned in x and Q^2 to demonstrate capabilities of SANE.
- Two beam energies allows for more thorough coverage in x at given Q^2.

Moments(Q^2)

Uncertainty in Moments

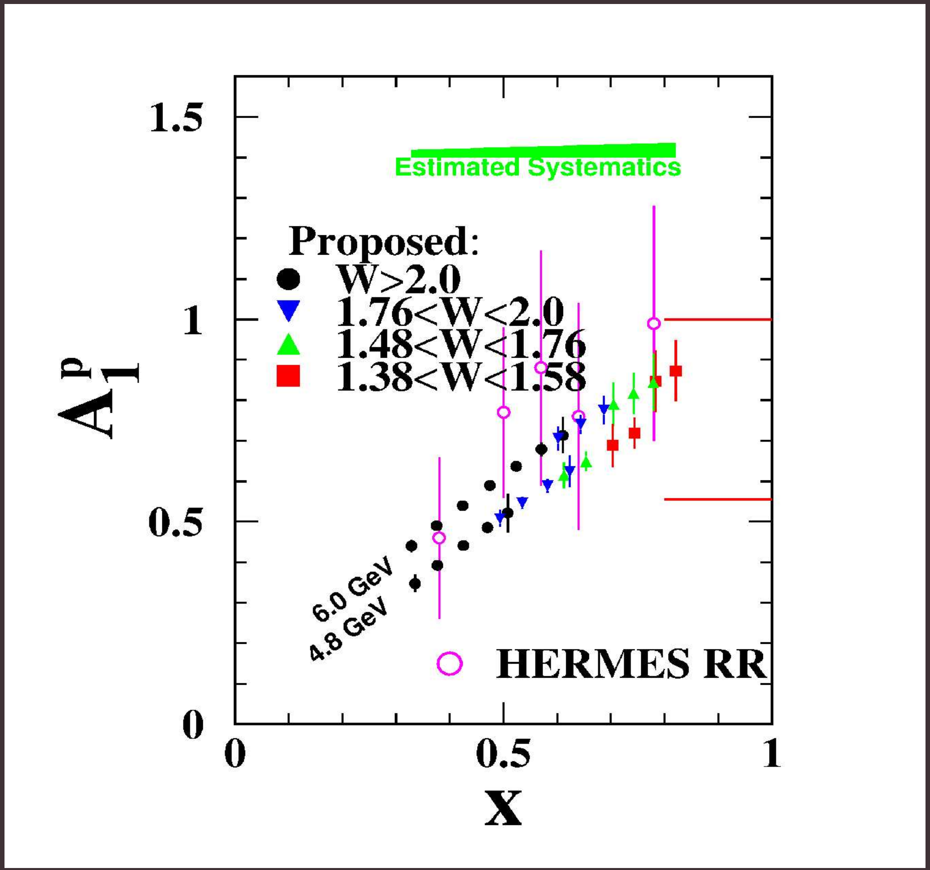
Q2 Range	absolute	relative
	$\int x^2 g_1\,dx$	
2.5-3.5	0.0011	7.6%
3.5-4.5	0.0006	4.7%
4.5-5.5	0.0007	5.4%
5.5-6.5	0.0007	5.9%
	$\int x^2 g_2\,dx$	
2.5-3.5	0.0013	13.1%
3.5-4.5	0.0005	5.8%
4.5-5.5	0.0007	8.1%
5.5-6.5	0.0007	9.1%
World 2-18	0.0006	8.3%
	d_2	
2.5-4.5	0.0011	35%
4.5-6.5	0.0014	45%
2.5-6.5	0.0009	27%
World 2-18	0.0017	53%

- Make connection to Lattice QCD:
  - Lattice calculations at Q^2=4.
- Study effect of higher twists.



Test of Spin Duality

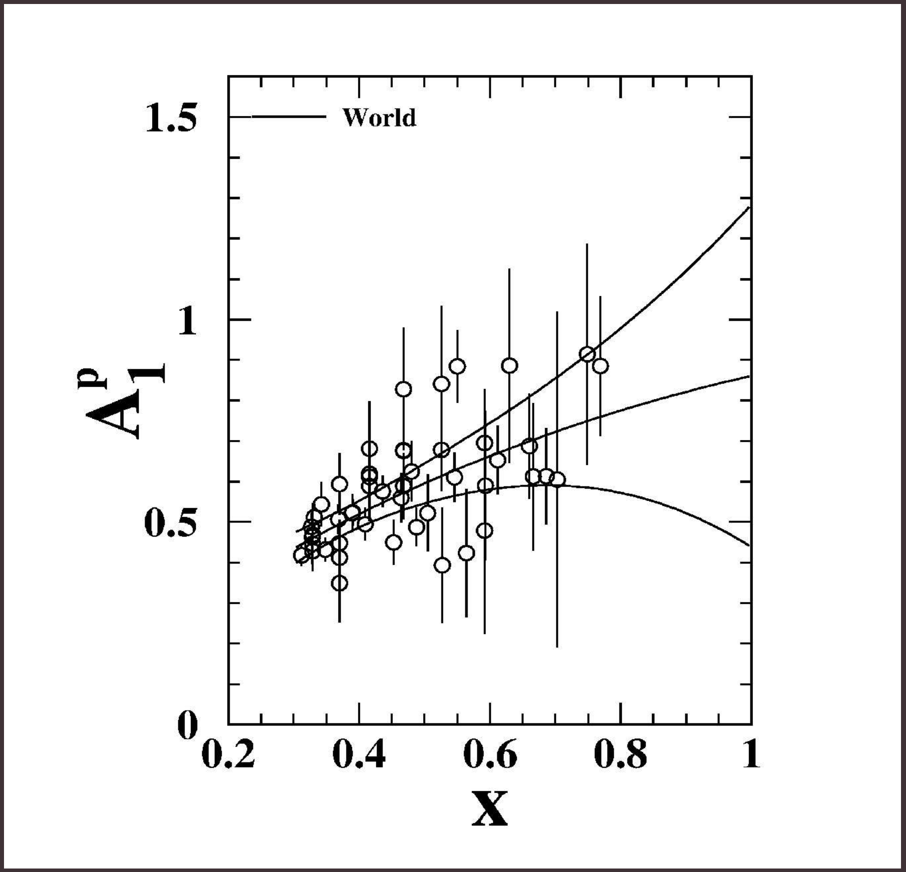
- HERMES observes spin duality in A_1^p with resonant region data of $\delta A/A \sim 0.3$ (*Phys. Rev. Lett.*, 2003).
- Two beam energies of SANE will permit limited test of spin duality.
- SANE will be able to do better than $\delta A/A \sim 0.1$.
- Transverse measurements of SANE in Resonance region allow for model independent test.



A_1^p as $x \to 1$

Extrapolated A_1^p data using $\alpha x^{\beta}(1+\gamma x^2)$. Fit to:

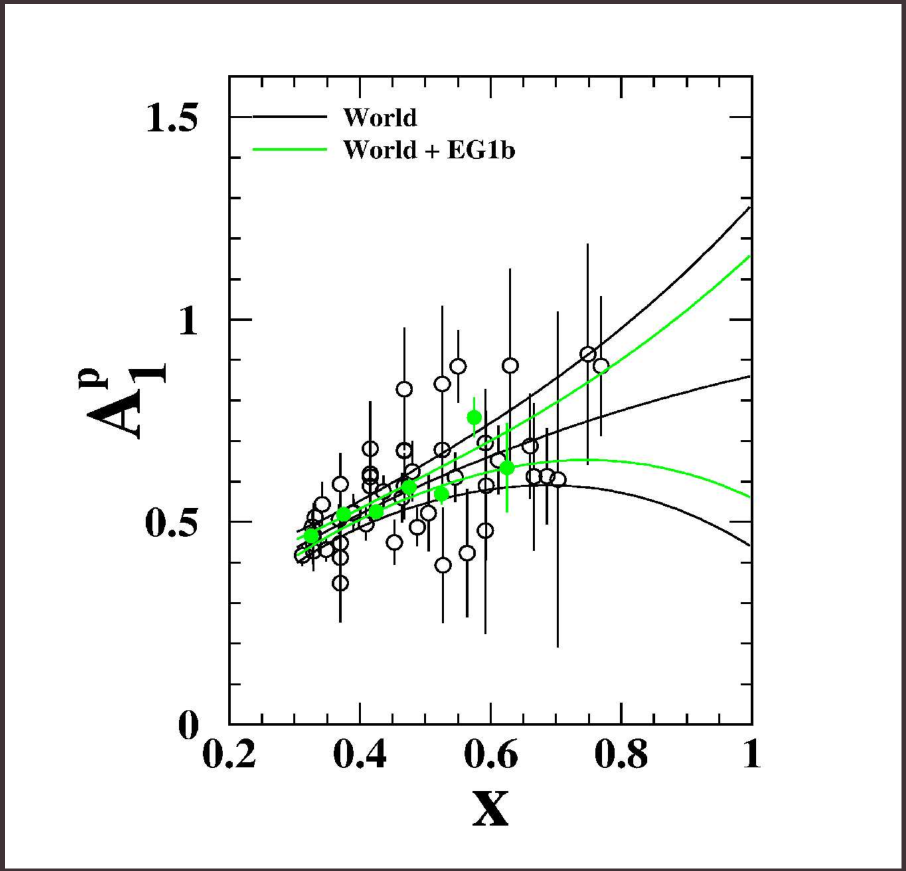
- World's Data.



A_1^p as $x \rightarrow 1$

Extrapolated A_1^p data using $\alpha x^{\beta}(1+\gamma x^2)$. Fit to:

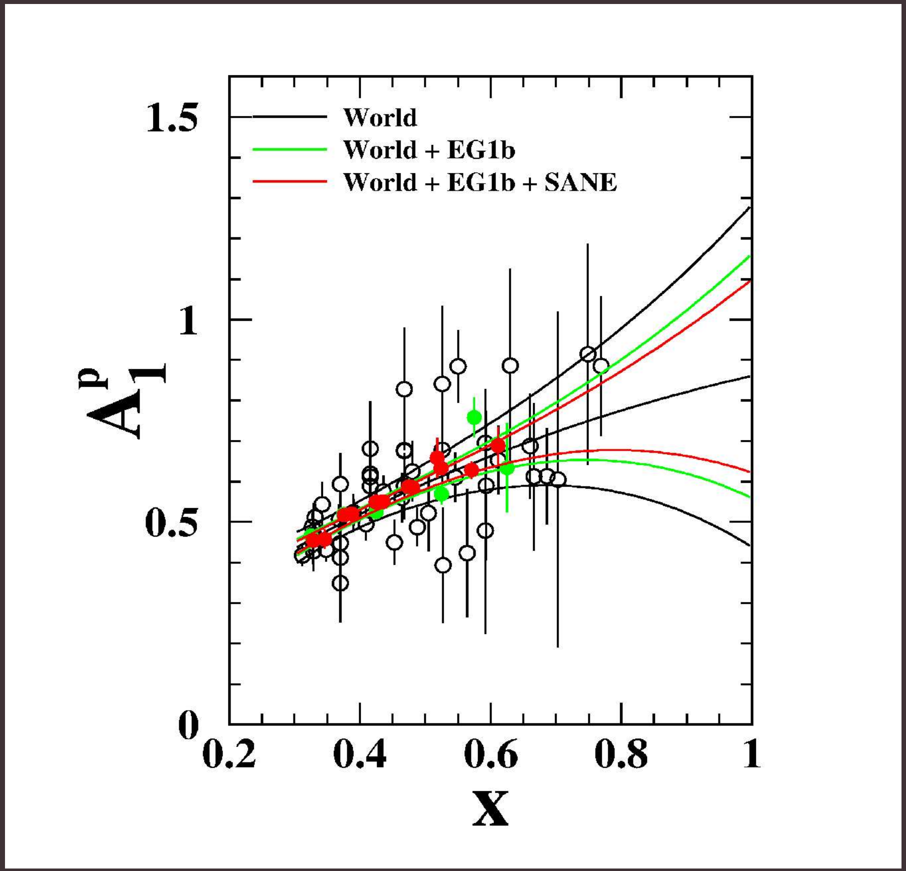
- World's Data.
- World + Estimated EG1b:
  - EG1b improves uncertainty w.r.t World data by 30%.



A_1^p as $x \rightarrow 1$

Extrapolated A_1^p data using $\alpha x^\beta(1+\gamma x^2)$. Fit to:

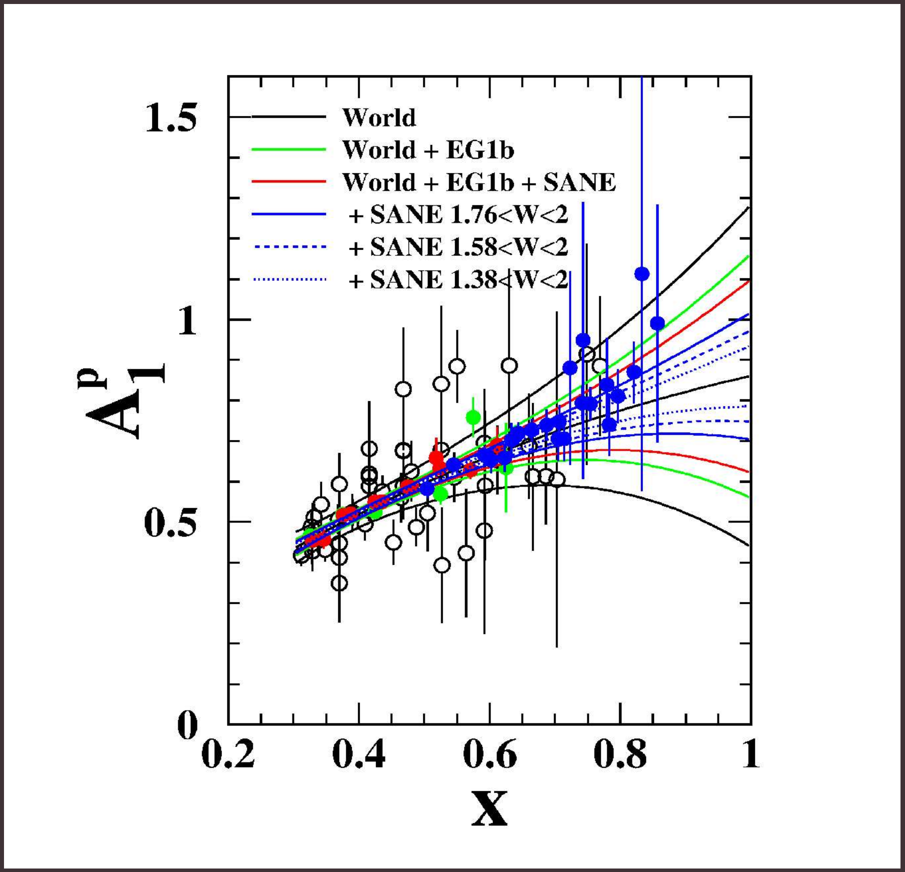
- World's Data.
- World + Estimated EG1b:
  - EG1b improves uncertainty w.r.t World data by 30%.
- World + Estimated EG1b + Projected SANE:
  - SANE improves uncertainty w.r.t World+EG1b by 20%.



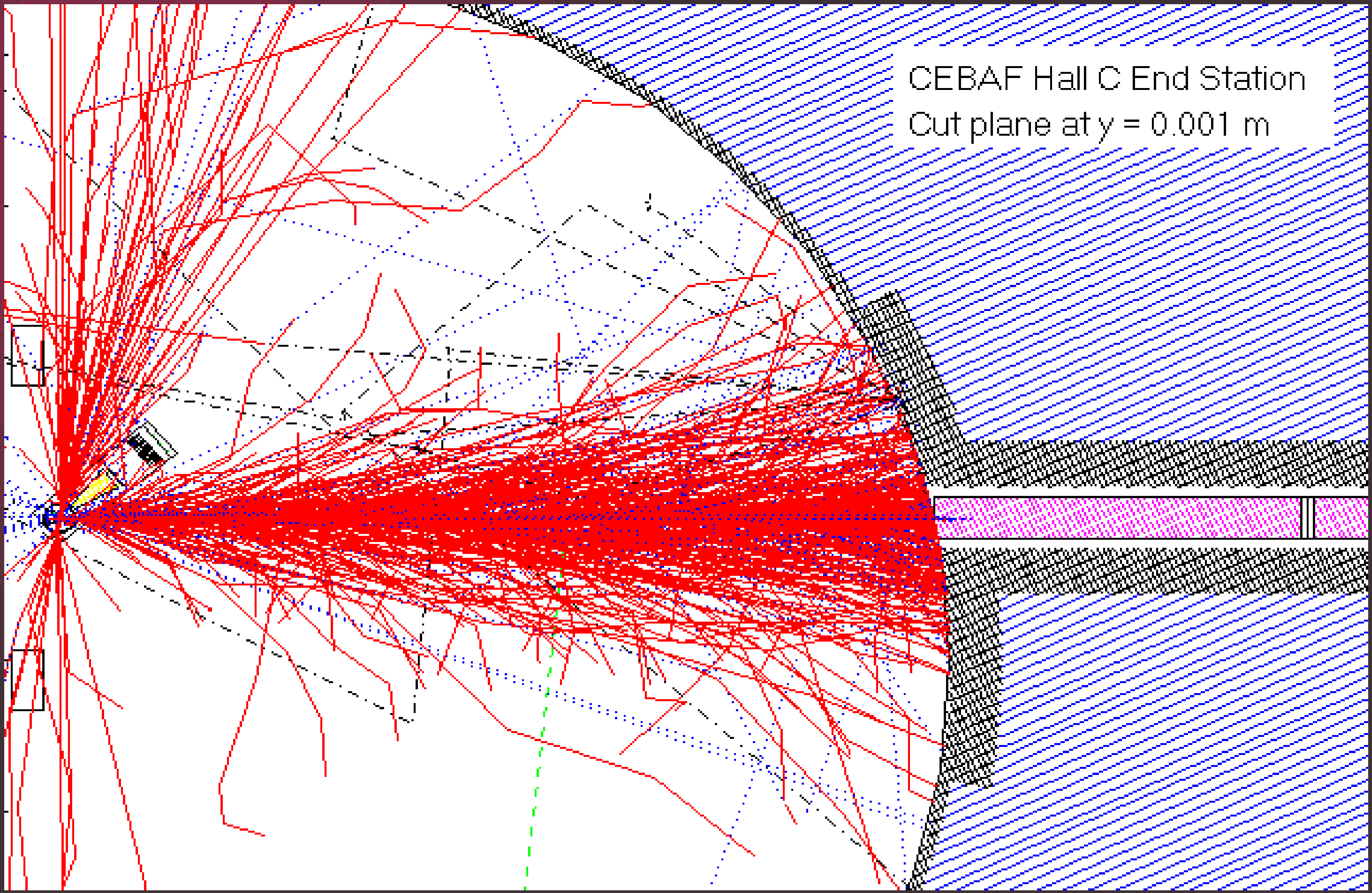
A_1^p as $x \rightarrow 1$

Extrapolated A_1^p data using $\alpha x^\beta(1+\gamma x^2)$. Fit to:

- World's Data.
- World + Estimated EG1b:
  - EG1b improves uncertainty w.r.t World data by 30%.
- World + Estimated EG1b + Projected SANE:
  - SANE improves uncertainty w.r.t World+EG1b by 20%.
- If demonstrate spin duality, can improve extrapolation significantly.



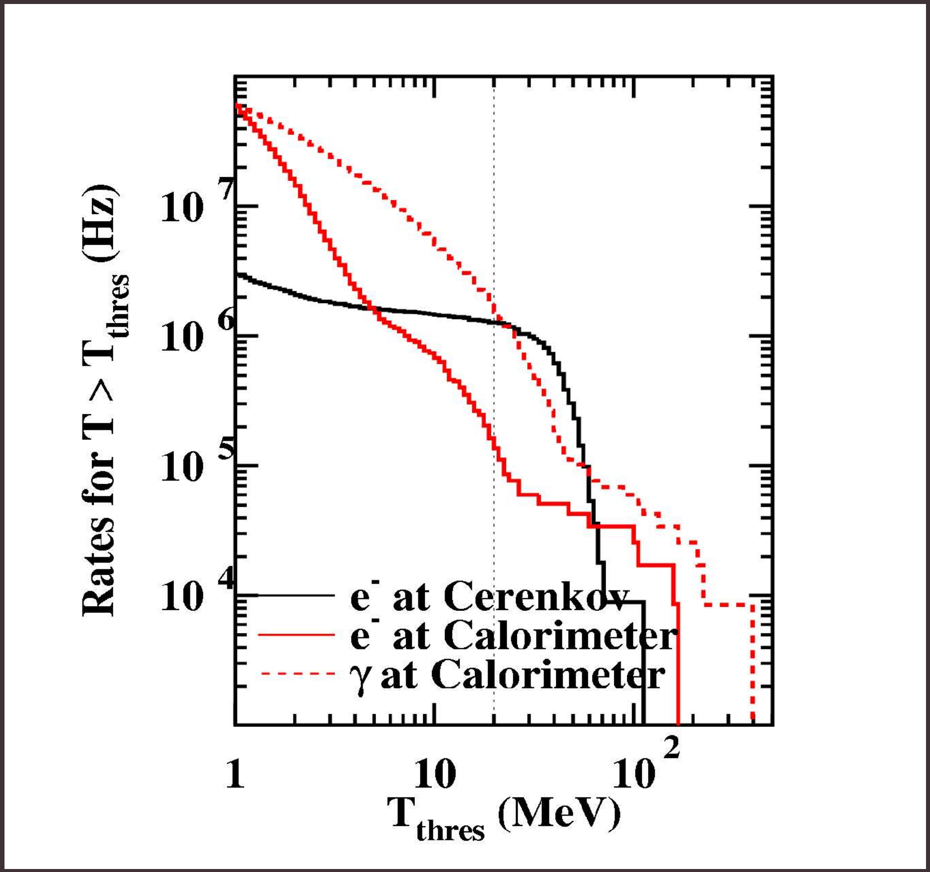
Beam Line Background Studies



Beam Line Background Studies

Conducted preliminary beam line background studies using simulation package of Pavel Degtiarenko.

- *Parallel field:* no problems with BETA at 40°.
- *Transverse field:* a large fraction of electrons escape pathologically into BETA:
  - expect at most 200 kHz/PMT for Gas Cerenkov.
  - Pileup, trigger rates, detector rates all remain manageable.
  - These numbers are conservative... will probably have a reduction of at least 2 in Cerenkov rates.



Estimated Systematics for 6 GeV

Radiative Corrections	1.5%
Dilution Factor	2.0%
Target Polarization	2.5%
Beam Polarization	1.0%
Nitrogen Correction	0.4%

	A1p		g2	
	x=0.3	*x*=0.6	*x*=0.3	*x*=0.6
R	0.8%	1.2%	1.5%	1.3%
Kinematics	0.4%	0.5%	2.7%	4.5%
Background	1.0%	1.0%	3.7%	1.8%
Local	2.1%	2.3%	4.0%	4.1%
Global	3.3%	3.3%	4.6%	4.7%
Total	4.2%	4.0%	6.8%	6.7%

Beam Time request

Production	6.0	180	100	
	6.0	80	200	
	4.8	180	70	
	4.8	80	130	
	2.4	-	10	
Systematics	Packing Fraction		20	
	Mollers		21	
	Total beam time		551	(23 d)
Overhead	Anneals		62	
	Energy Change		48	
	Target Rotation		48	
	Stick Changes		48	
	Total Overhead		206	(9 d)
	Requested Time		654	(27 d)

Collaboration

J.-P. Chen, R. Ent, D. Gaskell, J. Gomez, D. Higinbotham, M. Jones, D. Mack, J. Roche, G. Smith, G. Warren, B. Wojtsekhowski, S. Wood
Jefferson Lab

D. Day, N. Liyanage, P. McKee, O. Rondon, F. Wesselmann, H. Zhu
University of Virginia

E. Christy, C. Keppel
Hamption University

T. Averett
College of William and Mary

A. Vasiliev
Institute for High Energy Physics, Protvino

V. Kubarovsky
Renssekaer Polytechnic Institute

T.A. Forest
Louisiana Tech University

S. Choi, Z.-E. Meziani
Temple University

J. Jourdan, M. Kotulla, D. Rohe
University of Basel, Switzerland

A. Agalaryan, R. Asaturyan, H. Mkrtchyan, S. Stepanyan, V. Tadevosyan
Yerevan Physics Institute, Armenia

Spin Structure Physics
→ JLab, Temple, UVa,W&M

Detectors
→ Yerevan, LA Tech, JLab

Calorimeter
→ Protvino

Target
→ JLab, UVa

Summary

SANE : Spin Asymmetries of the Nucleon Experiment

Physics:

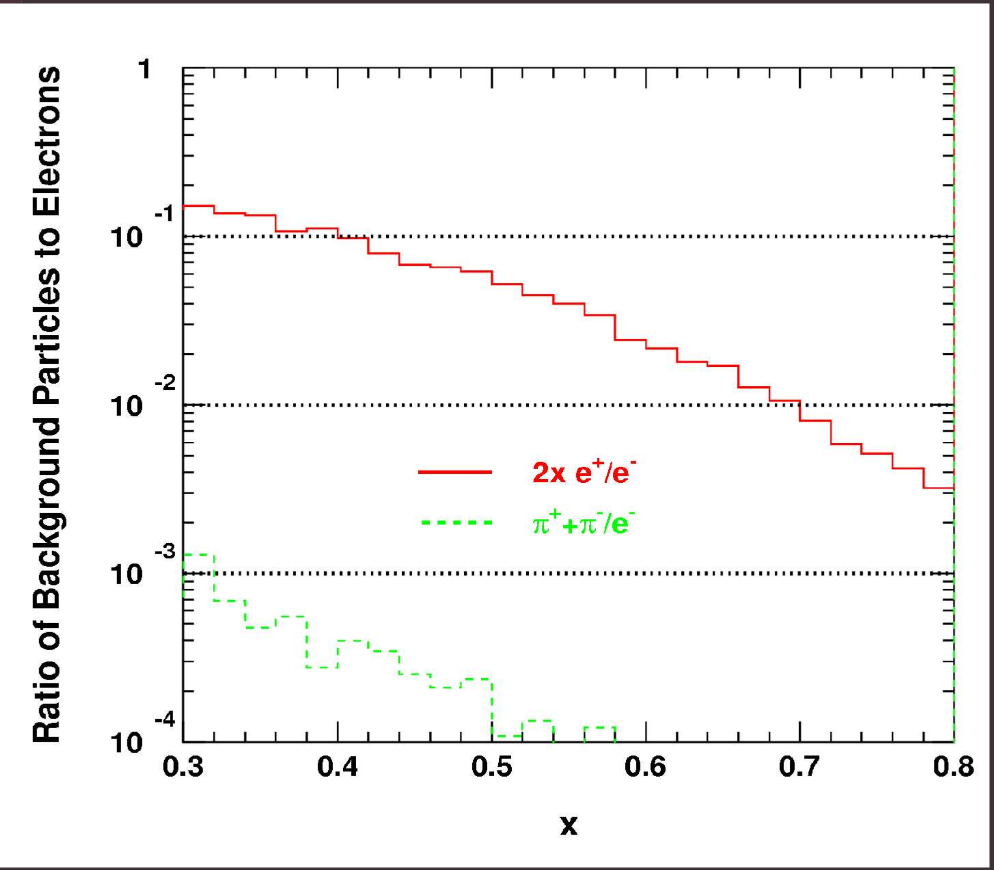
- Precision measurement of fundamental quantity, g_2 , in practically unmeasured region; complements CLAS.
- Q^2 study of third moments.
- d_2 measurement equivalent of ½ of current uncertainty.
- Kinematics in realm of Lattice QCD calculations.
- Physics spin-offs:
  - Limited test of local duality,
  - Data to aid in extrapolation of A_{1p} to x=1.

BETA

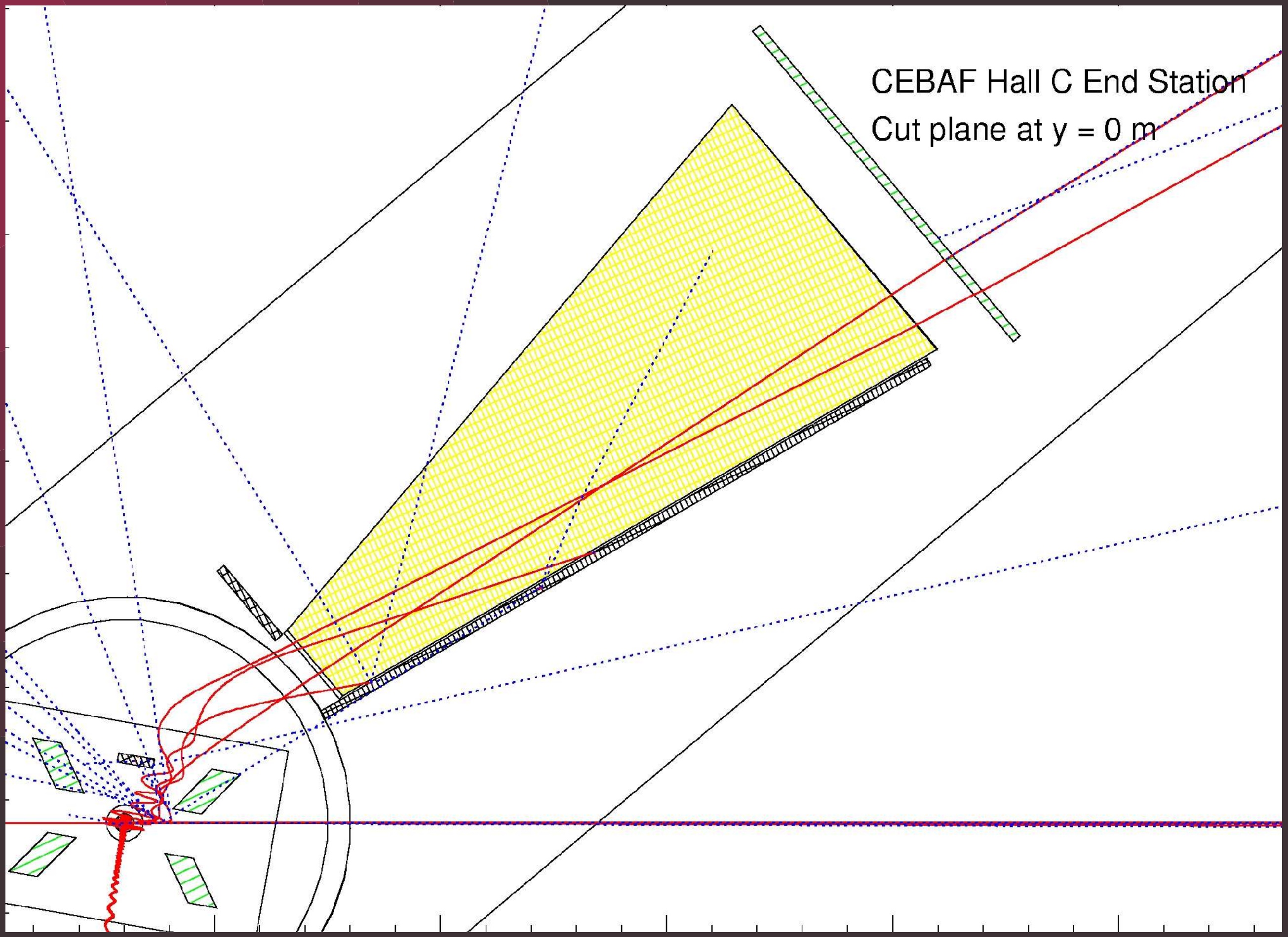
- Designed to handle high rates of low energy background.
- Multi-purpose device: SANE, Flavor Decomposition, GPDs, Transversity (hint, hint) ...
  - similar technique could be used at 12 GeV

Background Rates

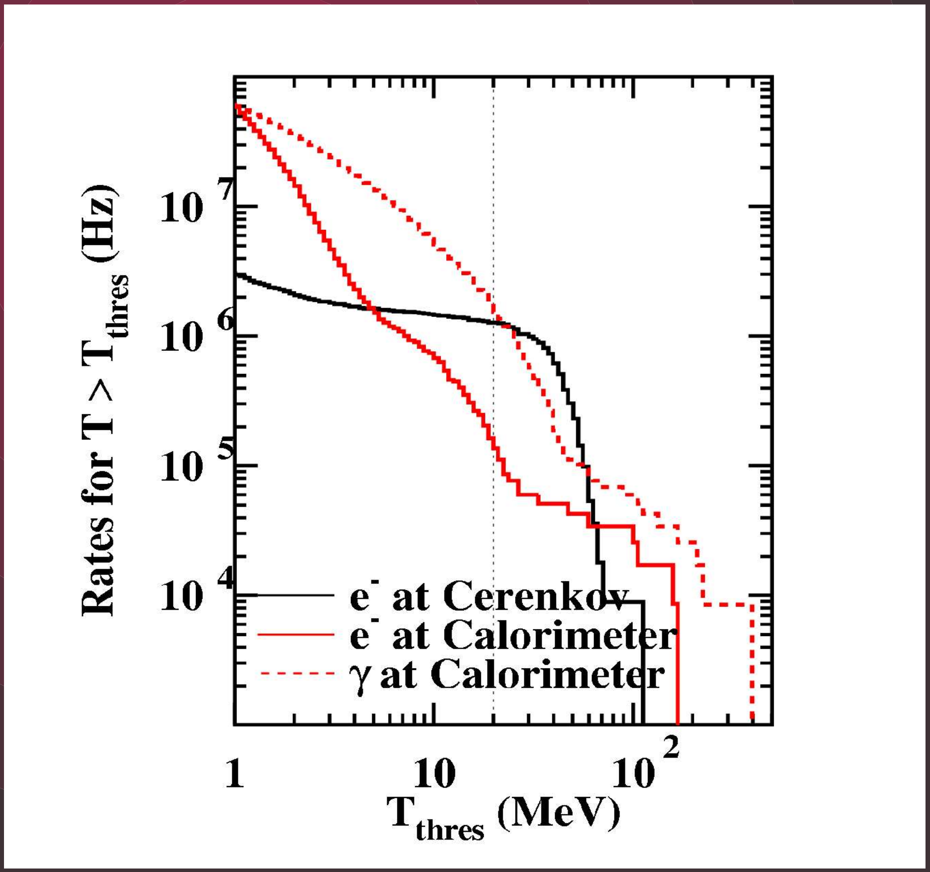
- Dominated by charge-symmetric processes, mostly $\pi^0 \rightarrow \gamma\, e^+ e^-$.
- Measure ratio of rates in HMS.
- Measure ratio of asymmetries using events with γ, $\gamma\gamma$ and $e^+ e^-$ in BETA and use CLAS data.
- Hadron backgrounds measured by ignoring Gas Cerenkov in trigger.
- Reduce Positron Rates by increasing energy threshold



Shielding of BETA



Beam Line Background Studies



As a result of background in transverse mode:

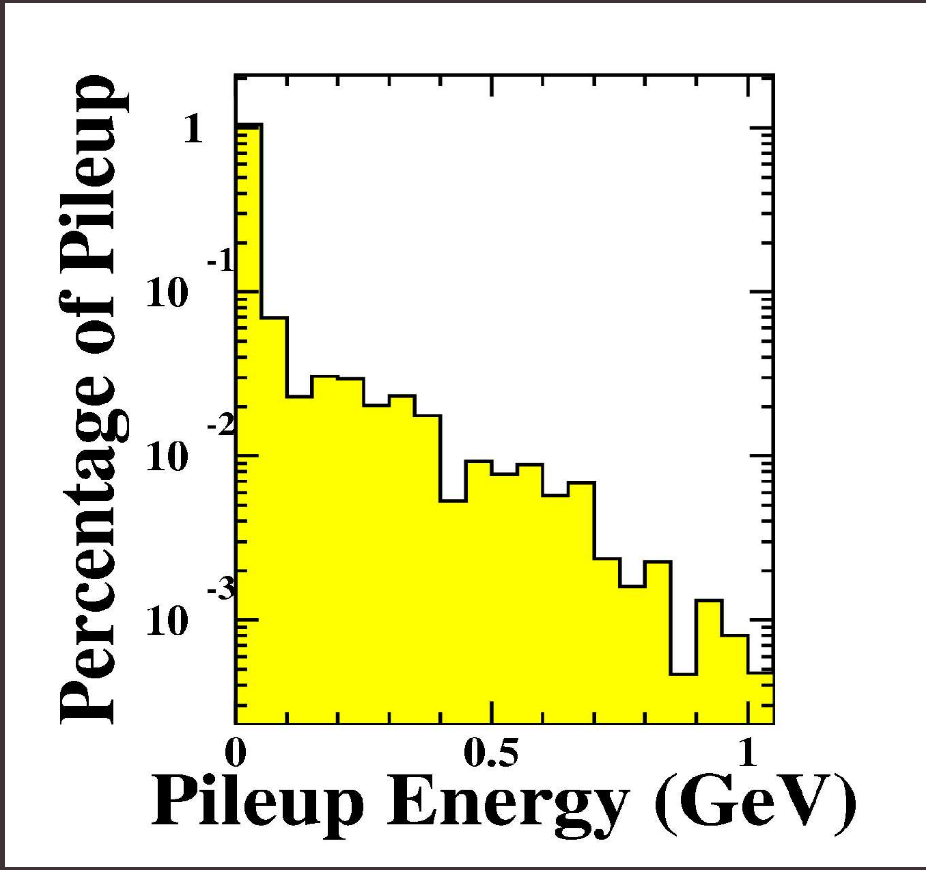
- increase online CAL threshold to 900 MeV to bring trigger rate < 1kHz. *No impact on physics*.
- Slightly increased pileup: 0.8% above 10 MeV, but 0.01% above 50 MeV.
- Increased accidentals between gas Cerenkov and CAL: < 5%, *but uncertainty in correction will be <0.5% of true rate*.

These numbers are conservative... will probably have a reduction of at least 2 in Cerenkov rates.

Pileup In Calorimeter

Closely examined pileup in Calorimeter:

- Considered 9 block cluster with 100 ns time window.
- Eliminated events in which there was an identifiable and separate second cluster.
- Included beam line pileup.
- Total pileup is above 10 MeV is 1.3%, above 50 MeV is 0.25%.



Pileup is not a problem.

Rates in BETA

Gas Cerenkov (> 20 MeV)

E	e±	π±	Trig
4.8	28.1	242.0	30.5
4.8	1590.0	223.0	1592.2
6.0	25.3	255.0	27.9
6.0	1510.0	236.0	1512.4

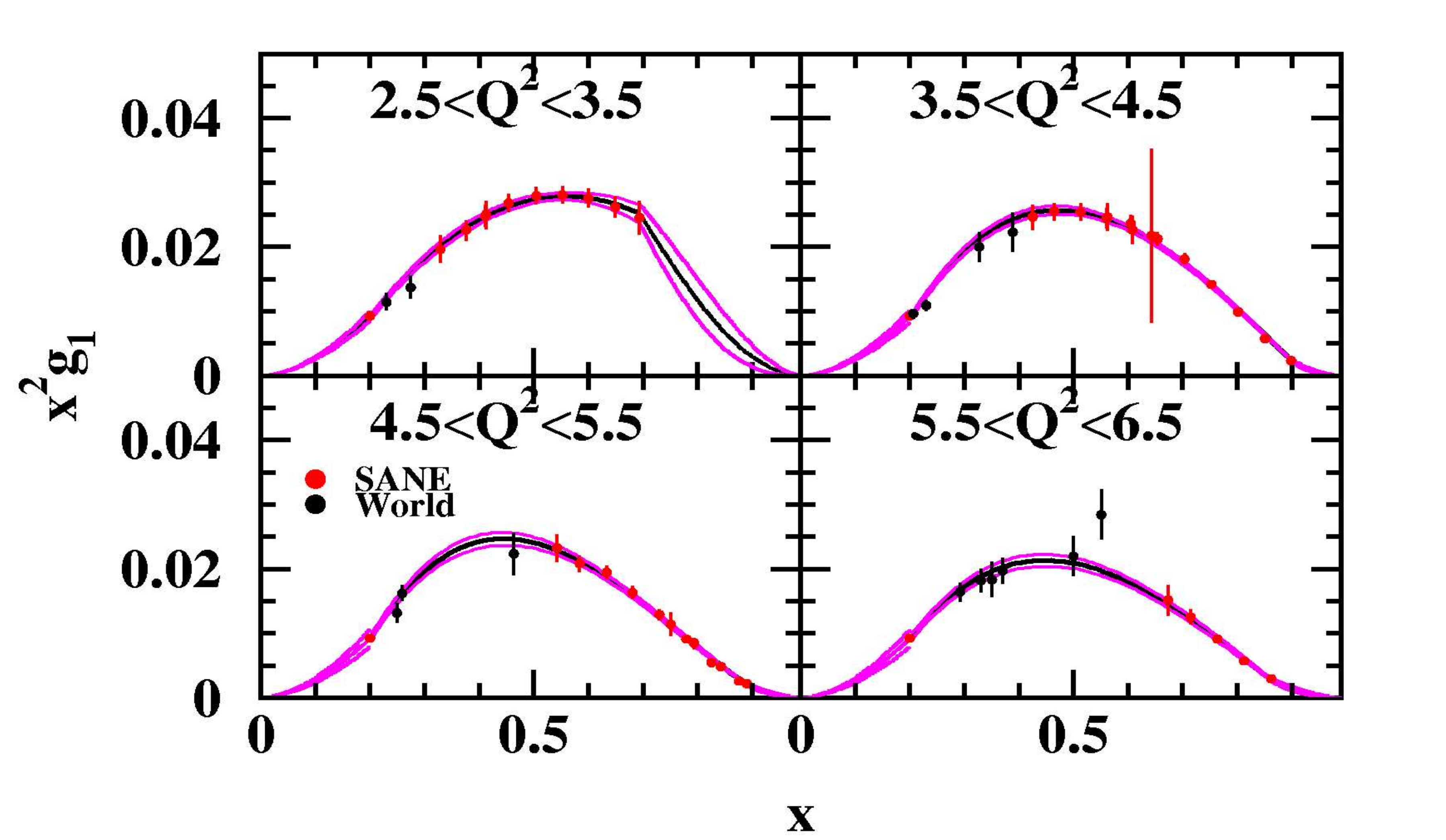
Calorimeter (> 900 MeV)

E	e±	π±	π0+N	Trig
4.8	0.3	1.0	7.2	8.5
4.8	0.3	1.0	7.1	8.4
6.0	0.3	1.1	8.1	9.5
6.0	0.3	1.2	8.0	9.4

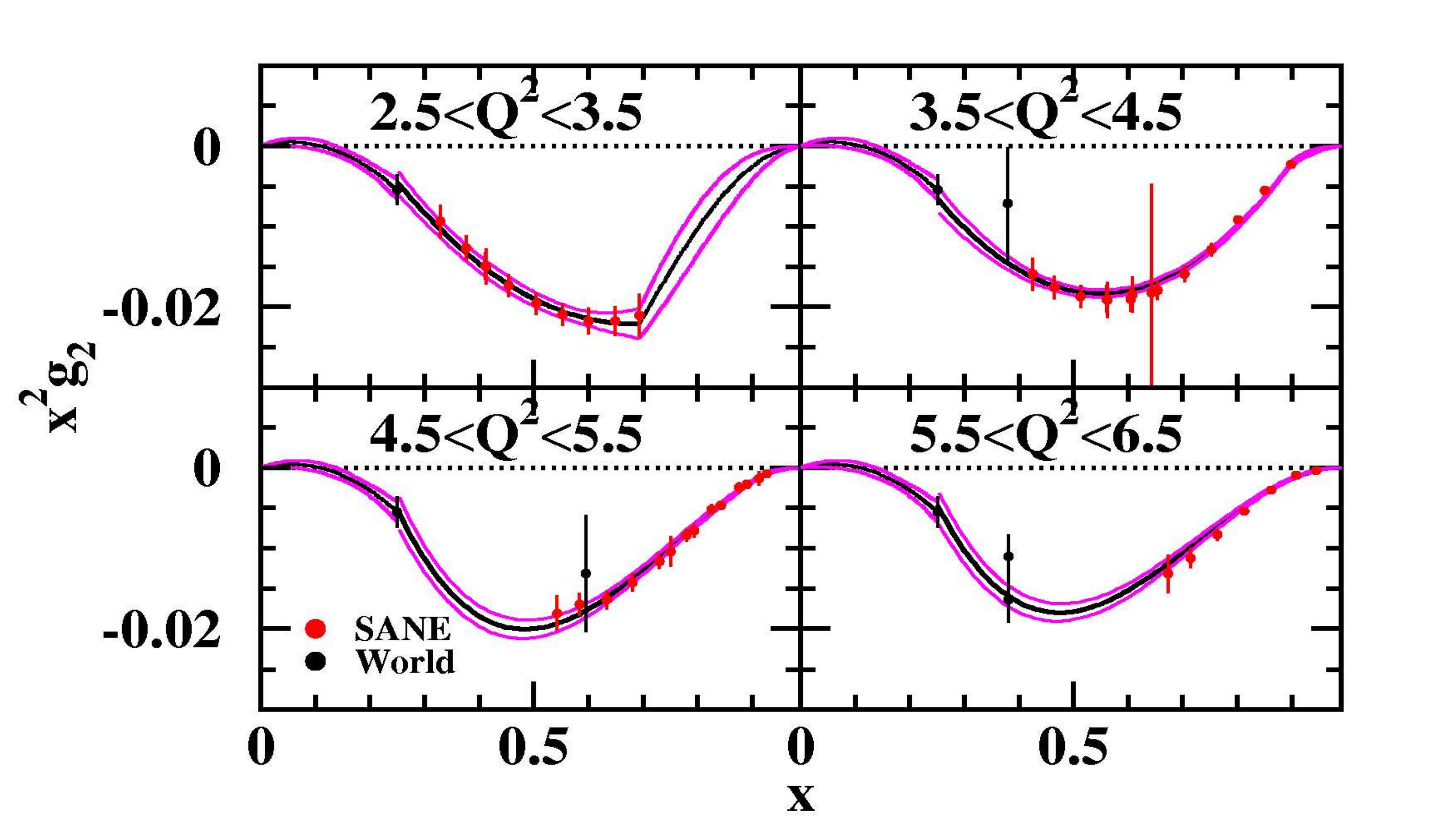
BETA Trigger Rates

E	True	Accd	offline A/T
4.8	0.31	0.03	0.0%
4.8	0.31	1.34	0.6%
6.0	0.31	0.03	0.0%
6.0	0.31	1.43	0.6%

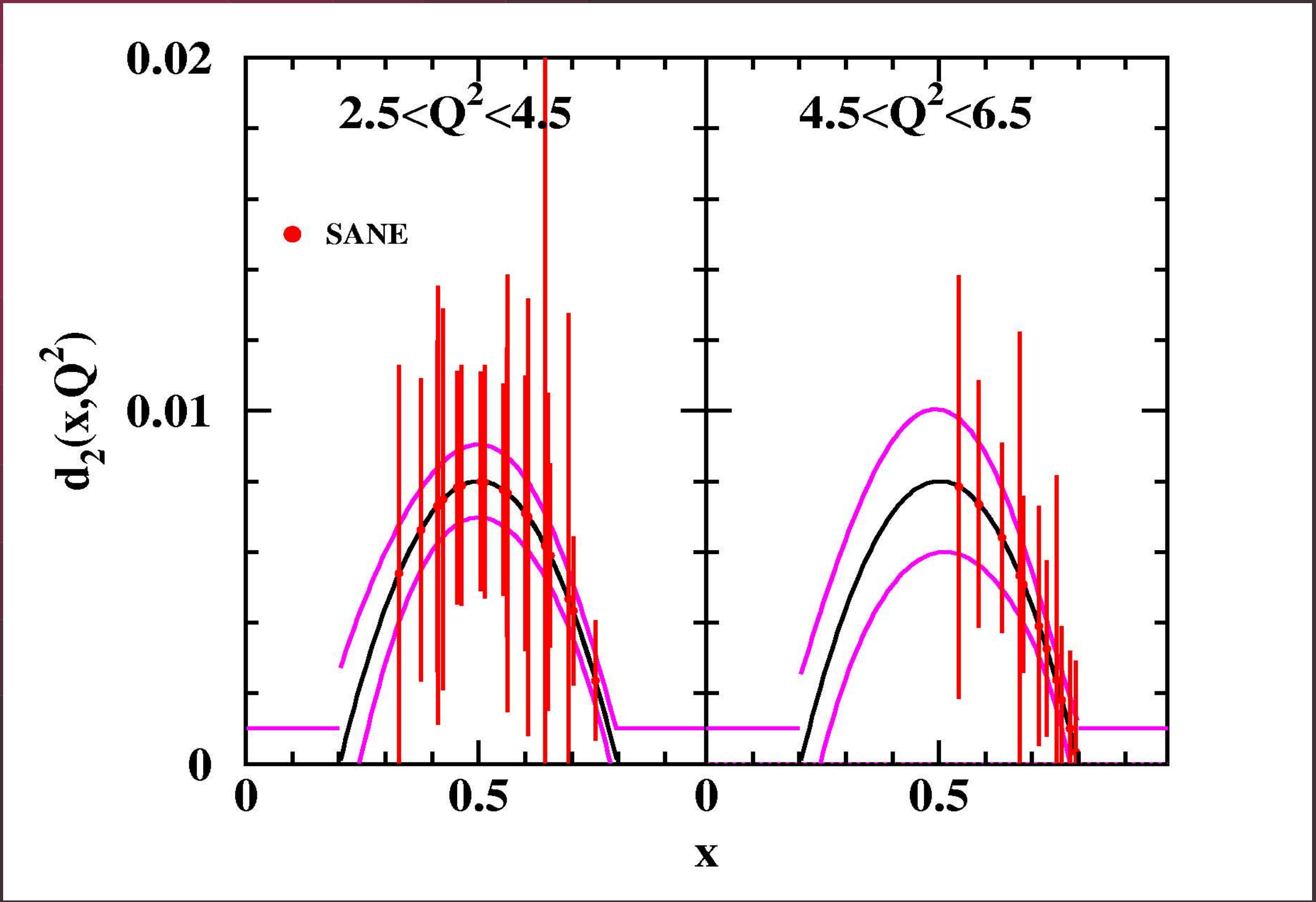
Third Moment of g_1



Third Moment of g_2



Intregrals for d_2



Systematics

Calorimeter Gains:

- Calibrated by measuring π^0 mass from double γ events. Cross checked with proton elastics (using HMS in coincidence).
- Monitored through Lucite light system, punch-through pions and cosmics.

Background:

- Dominated by charge-symmetric processes, mostly $\pi^0 \rightarrow \gamma e^+ e^-$.
- Measure ratio of rates in HMS; measure ratio of asymmetries using events with γ, $\gamma\gamma$ and $e^+ e^-$ in BETA and use CLAS data.
- Hadron backgrounds measured by ignoring Gas Cerenkov in trigger.

Why High x?

$$x = Q^2/2M\nu$$

- Examine predictions of $x \to 1$ of A_{1p} of pQCD and SU(6) models:
  - SU(6) symmetric $A_{1p} \to 5/9$,
  - SU(6) broken and pQCD predicts $A_{1p} \to 1$, but different reasons.
- Higher twist effects become more significant at higher x.
- Region in which sea quarks play only minor role.
- Understanding higher order moments to compare to Lattice QCD and QCD predictions.
- Existing data at large x is limited compared to lower x region. Region is“ statistically challenged”.

Gas Cerenkov

N_2 Gas

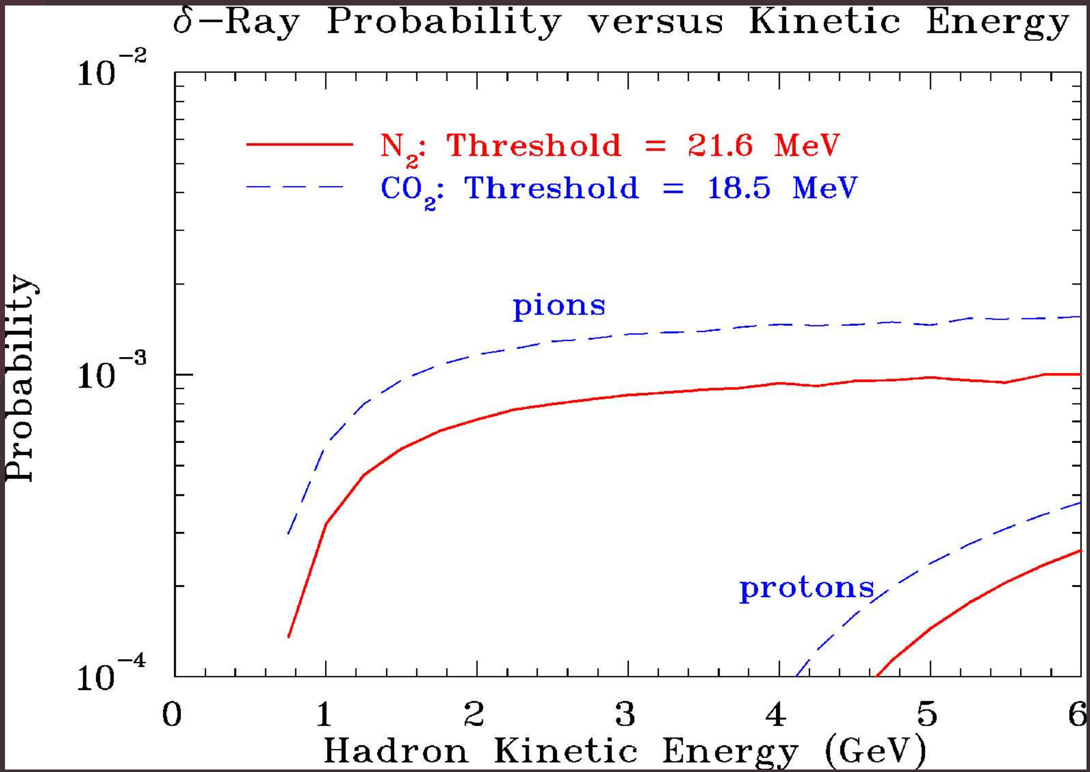
- Reduced knock-on's
- At STP, pion threshold is 5.8 GeV/c

Point-to-Point focusing

- Easy alignment of mirrors
- Further reduction of background

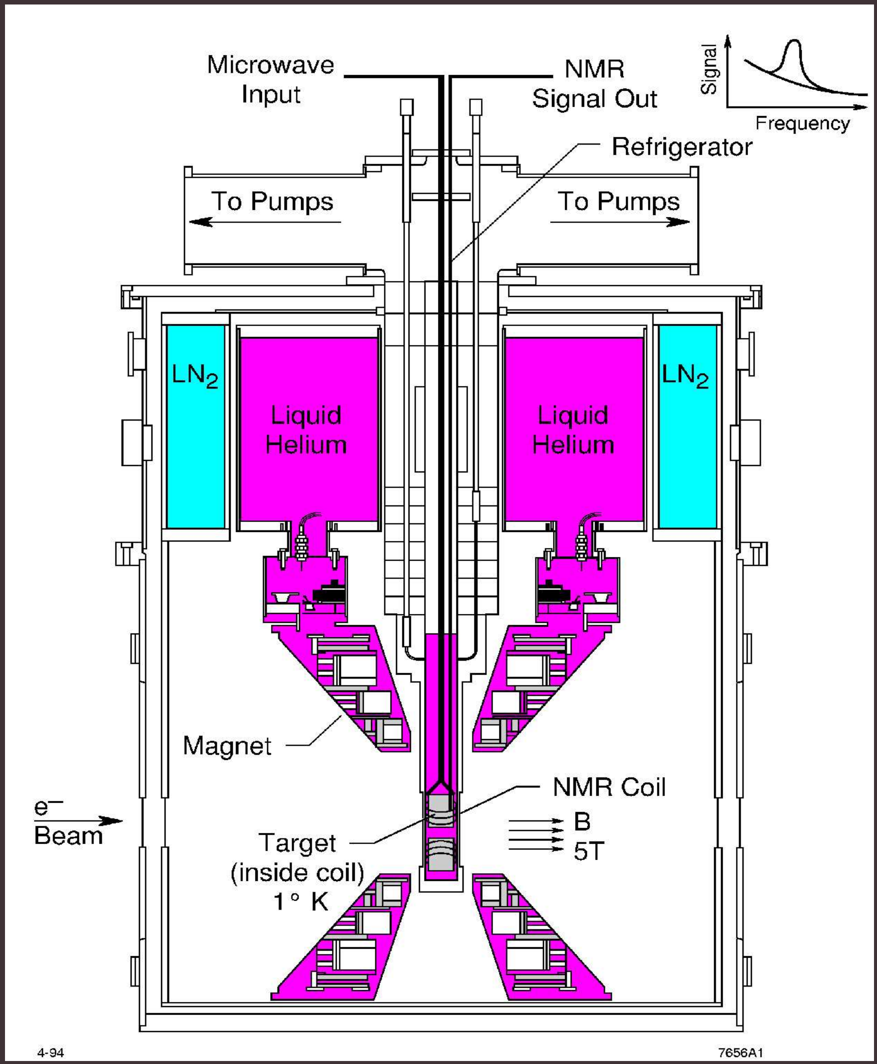
PMTs

- 8 Mirrors and PMTs
- Baffled
- Apply tight electron cuts
- Expected 17-20 photoelectrons



UVa Polarized Target

- Dynamic Nuclear Polarization
- 5 T Field
  - can steer beam
  - affect optics of scattered electrons
- 1 K evaporative refrigerator
- Composite target: N+H+He
  - asymmetry is diluted by unpolarized materials
- Measure target polarization
  - calibration: thermal equilibrium
  - monitoring: NMR



BETA

Tracking Resolutions

Angle	2°
Vertex	10 cm

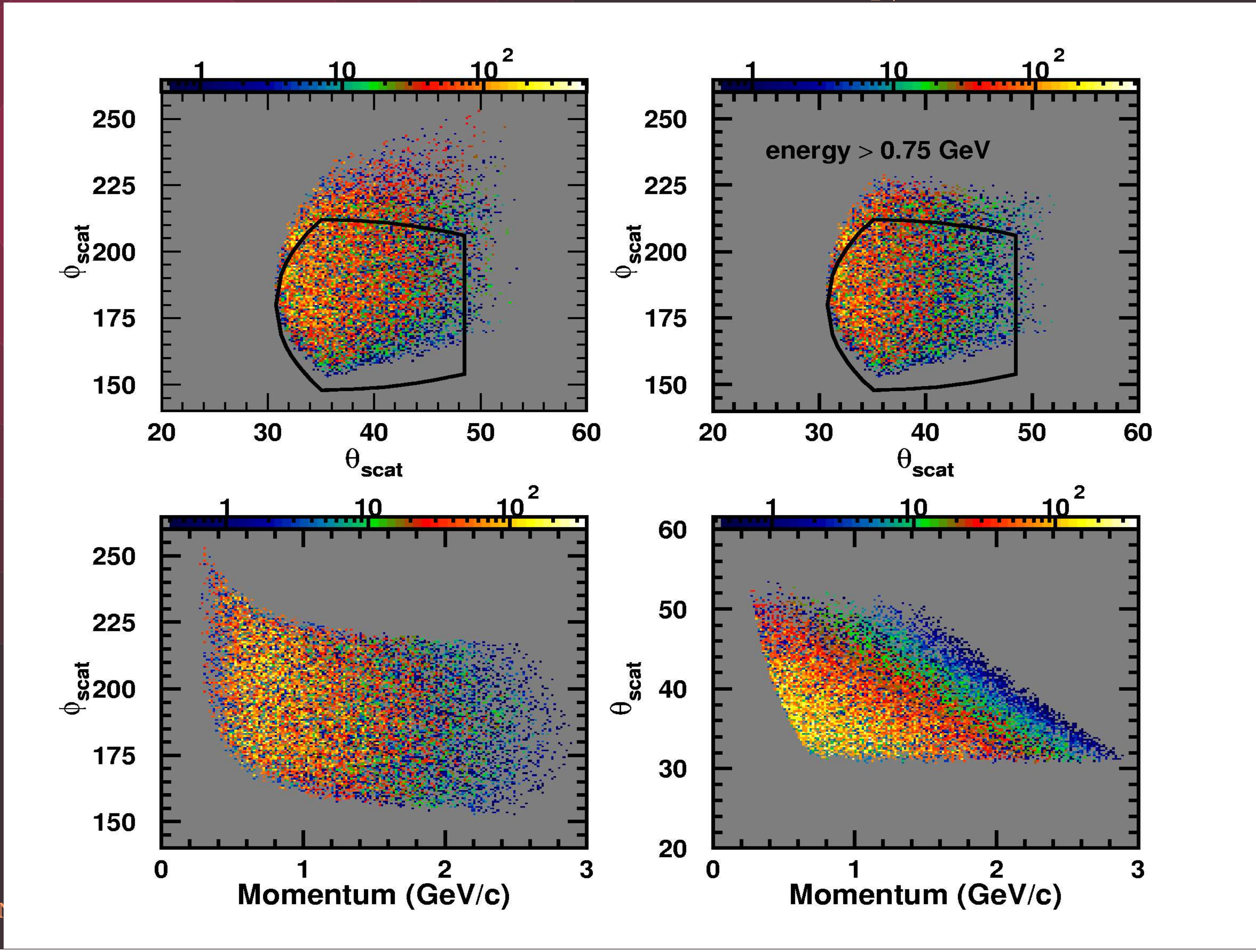
Reconstruction Resolutions

Angle	3-17 mrad
Momentum	45-70 MeV

Particle Rejection

Pions	>1000
Protons	>10000

Acceptance: E = 6.0, $\theta_N = 180$



BigBite and BETA

	BigBite	BETA
Solid Angle	~75 msr	207 msr
Detector Package	Calorimeter Gas Cerenkov wire chambers (2)	Calorimeter Gas Cerenkov Lucite Cerenkov
Dispersion	Open Dipole	None
Advantages	Better Resolution	<u>Built for high rates</u>
Disadvantages	Interaction of fringe field with target field	

Technical Comments, part I

1) Overhead has been included in the beam time request including time to calibrate the new "BETA" detector proposed. Additional survey time for beam line chicane changes has not been included, but may occur in conjunction with target anneals etc.

Adjust and survey time of the chicane is included in the target rotation time.

2) This is a large installation experiment, albeit a standard one requiring the polarized target and associated beam l chicane. Installation time has not been included, and is estimated to be 2-3 months. Deinstallation is estimated to be one month.

3) Strong technical support is assumed from the JLab Target Group for the installation, calibration, and operation of the polarized target. We do note that this may be alleviated by the strong involvement on this proposal by the UVa group.

Technical Comments, part II

4) Compared to the Gep-III calorimeter, this experiment adds the requirement of gain monitoring. The plans outlined in this proposal can be accommodate into the present designs for this calorimeter. The detector package is further augmented by a gas cerenkov and a lucite detector for particle identification. The experiment relies on the rejection of pions using the gas cerenkov. The required rejection factor is aggressive, but seems achievable at the cost of some electron inefficiency.

Excellent pion rejection is a matter of good design and quality control. It is not a matter of new invention. For the x>1 analysis, John Arrington found a 500:1 rejection in the HMS Cerenkov. He was able to predict this level of rejection using the same analytic expressions and figures as in our proposal. Considering the amount of material in front of the HMS gas Cerenkov, there is nothing controversial about our goal of 1000:1. Even at 500:1, the experiment still works.

5) New equipment required for this experiment would consist of a Lucite detector and a gas cerenkov, with some 60 PMT's total with associated infrastructure (cables, electronics), a pulsed laser for gain monitoring a cerenkov gas system, and likely additional TDC's. All are straightforward.

Technical Comments, part III

6) The experiment takes advantage of the magnetic field, used to polarize the target, to eliminate background from low-energy charged particles. A realistic Monte Carlo is used to estimate these backgrounds.

7) The experiment will require a low current dump in the Hall for the non-parallel field measurements. This technique has before been used for the E93-026 experiment.

8) Electronics for the BETA device will be almost entirely in the Hall. Experience with this, and whether a shield house is needed, will come from the Gep-III E01-109 experiment.

9) The HMS is used both to detect protons from elastic scattering and to measure positron rates following charge-symmetric processes.

10) Since HMS is not used all the time, and both beam energies and target configurations seem compatible with PR03-111, part of this experiment may run concurrent with PR03-111, assuming a second independent DAQ system.