Spin Asymmetries on the Nucleon Experiment

James Maxwell, Univ. of Virginia

SANE: TJNAF Hall C, E07-003

SANE Collaboration:

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Spokespersons: S. Choi (Seoul), Z-E. Meziani (Temple), O. A. Rondon (U. of Virginia)

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H.Baghdasaryan, V. Mamyan

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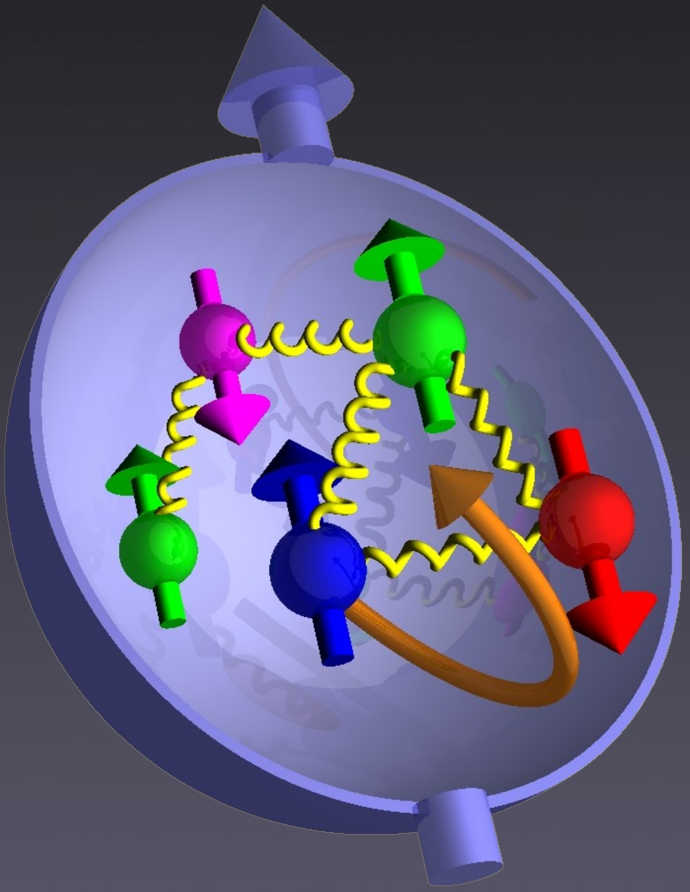
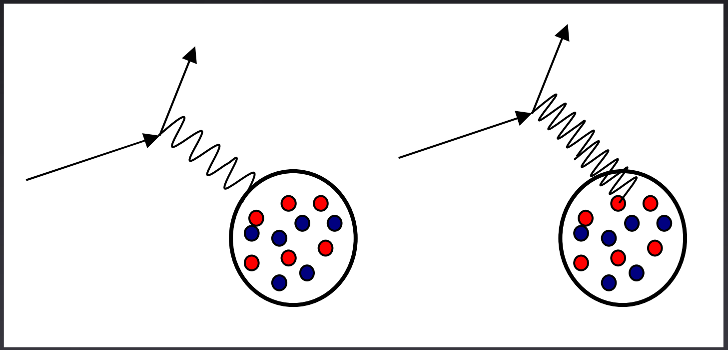
Nucleon Spin

- So, protons and neutrons are made of quarks, tied together by massless gluons. Huzzah!
- How do we account for the spin ½ of the nucleon?
- Inclusive measurements: Only about 25% of nucleon spin carried by quarks
- How do we represent the spin distribution in a proton or a neutron?



Scattering in Nuclear Physics

- Probing a nucleon deeply, need high energy photons
- Short wave-length ''photon beam'' provided virtually by high momentum lepton can resolve quarks



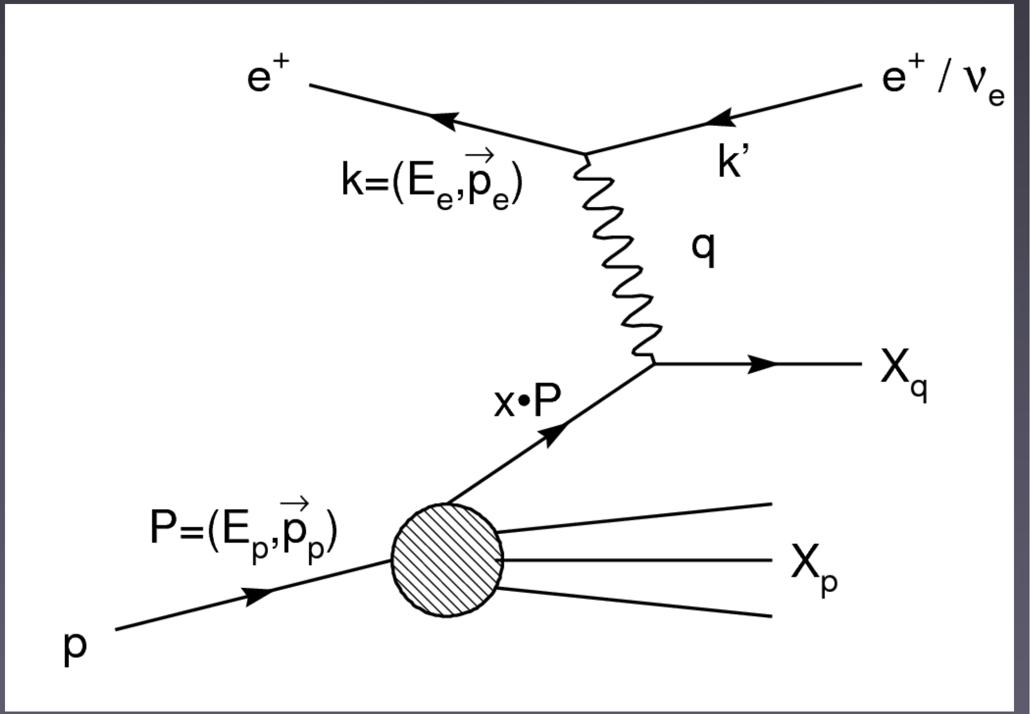
- Variables:

Square of 4-momentum transferred to target.

$$Q^2 = -q^\mu q_\mu$$

Bjorken *x:* In Breit frame, the fraction of the nucleon's momentum carried by the struck quark.

$$\chi = \frac{Q^2}{2M\nu}$$



Scaling and Structure Functions

- As we probe within the nucleus (Deep Inelastic Scaterring), scattering at each energy scale depends only on this dimensionless variable *x*: **Bjorken Scaling**

$$\frac{d^2\sigma}{d\Omega dE'} = \left(\frac{d^2\sigma}{d\Omega dE'}\right)_{point} f(E, E', \Theta) F_2(x)$$

- Quark distributions inside the nucleon are described by four such 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, $q_i^{\uparrow\downarrow}(x)$:

$$\boldsymbol{F_1(x)} = \frac{1}{2}\sum_i e_i^2 (q_i^{\uparrow}(x) + q_i^{\downarrow}(x)) \qquad \boldsymbol{g_1(x)} = \frac{1}{2}\sum_i e_i^2 (q_i^{\uparrow}(x) - q_i^{\downarrow}(x))$$

i = index of quark flavor

Transverse Spin Structure Function

- The Transverse SSF, g_2, dominates the cross section when the target spin is perpendicular to the lepton helicity
- g_2 is combination of twist-2 (q-q) and twist-3 (q-g) components

$$g_2(x,Q^2) = g_2^{WW}(x,Q^2) + \overline{g_2}(x,Q^2)$$

$$= -g_1 + \int_x^1 g_1(x')\frac{dx'}{x'} - \int_x^1 \frac{\partial}{\partial x'}\left[\frac{m}{M}\boldsymbol{h_T(x',Q^2)} + \xi(\boldsymbol{x',Q^2})\right]\frac{dx'}{x'}$$

  - g_2^{WW}(*W*andzura-*W*ilczek) part depends on g_1
  - h_T is transversity SSF
  - ξ represents twist-3 quark-gluon correlations.

Twist-3 d_2

- QCD's Operator-Product Expansion (OPE):
  - relates $\boldsymbol{g_1}$, $\boldsymbol{g_2}$ moments with calculable twist-2 ($\boldsymbol{a_N}$), twist-3 ($\boldsymbol{d_N}$) matrix elements

$$\int_0^1 x^N g_1(x,Q^2)dx = \frac{1}{2}a_N + O(M^2/Q^2), \qquad N=0,2,4,\ldots$$

$$\int_0^1 x^N g_2(x,Q^2)dx = \frac{N}{2(N+1)}(d_N - \boldsymbol{a_N}) + O(M^2/Q^2), \quad N=2,4,\ldots$$

- $\boldsymbol{d_N}$ measures twist-3 contributions

$$d_2 = \int_0^1 x^2(2g_1 + 3g_2)dx = 3\int_0^1 x^2 \overline{g_2}(x,Q^2)dx$$

SANE Overview

- Proton spin structure function $g_2(x, Q^2)$, spin asymmetry $A_1(x, Q^2)$ at $2.5 \leq Q^2 \leq 6.5$ GeV^2 and Bjorken x of $0.3 \leq x \leq 0.8$
- Learn all we can about proton SSF's from an inclusive double polarization measurement
  - Twist-3 effects from SSF moments
  - Comparisons with Lattice QCD, QCD sum rules, bag models, chiral quarks
  - Exploration of "high" x region: A_1's approach to $x = 1$
  - Test polarized local duality for final state mass $W > 1.4$ GeV
- Will take place in 2008, in Hall C of Jefferson Lab, using highest available beam energy (6 GeV)

Expected Results: Spin Asymmetry

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

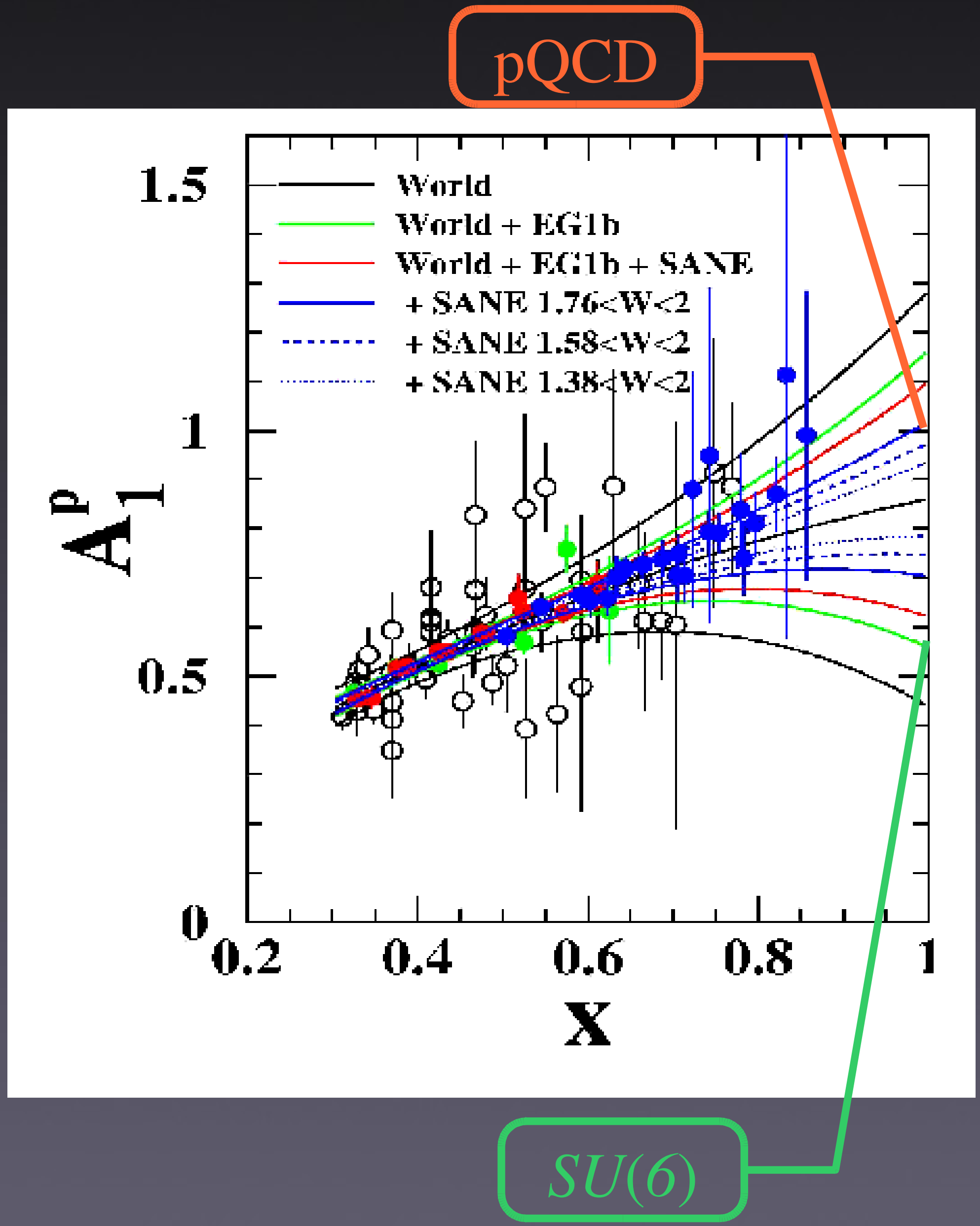
- Measuring the beam-target asymmetry for two values of the polarization angle w.r.t. the beam:

$$A_{\parallel} = \frac{\sigma^{(\uparrow\downarrow)} - \sigma^{(\downarrow\downarrow)}}{\sigma^{(\uparrow\downarrow)} + \sigma^{(\downarrow\downarrow)}}, \quad A_{\perp} = \frac{\sigma^{(\uparrow\rightarrow)} - \sigma^{(\downarrow\leftarrow)}}{\sigma^{(\uparrow\rightarrow)} + \sigma^{(\downarrow\leftarrow)}}$$

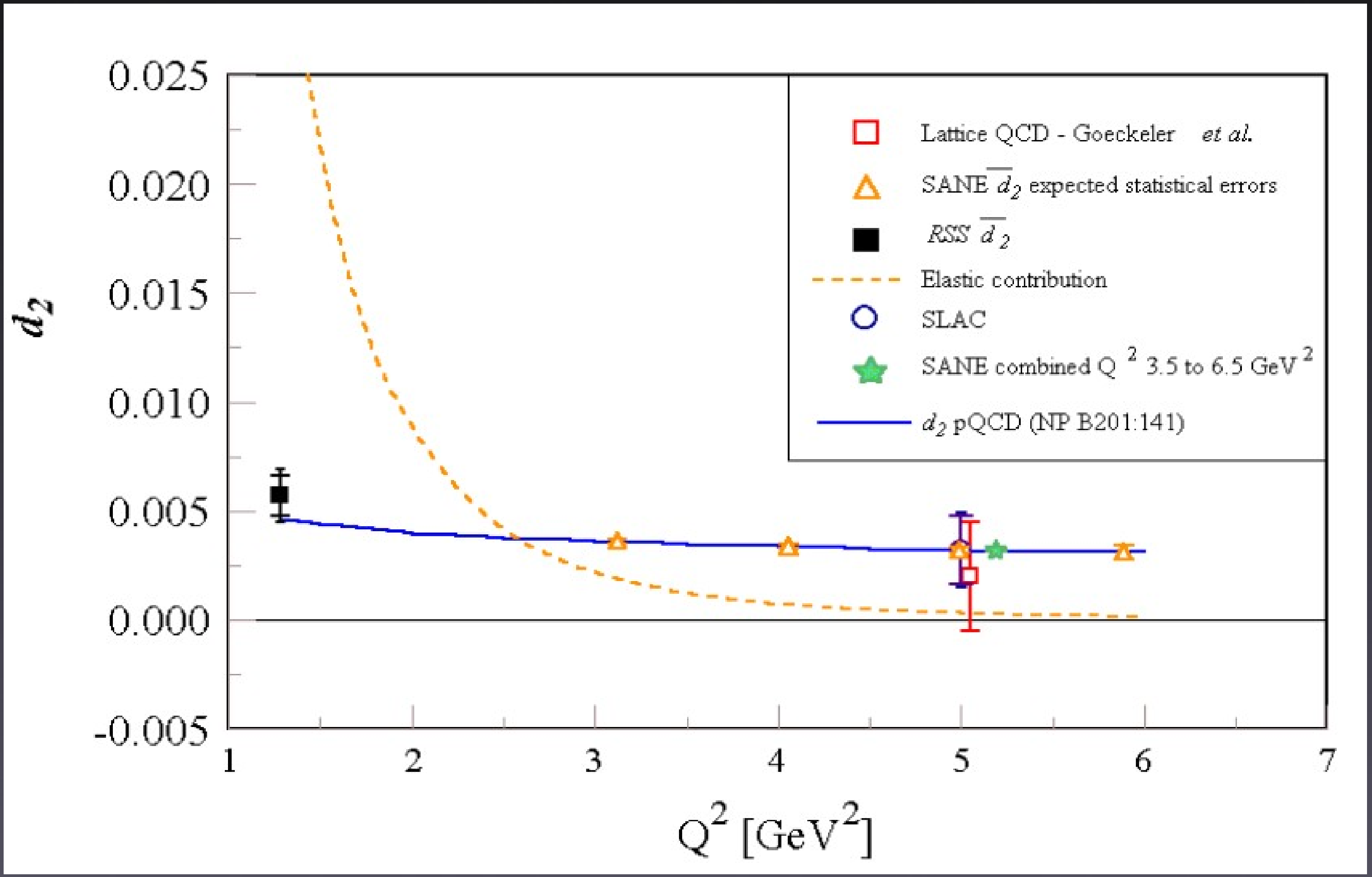
we can then extract

$$A_1 = \frac{1}{(E+E')D}\left((E - E'\cos\theta)A_{\parallel} - \frac{E'\sin\theta}{\cos\phi}A_{\perp}\right)$$

$$A_2 = \frac{\sqrt{Q^2}}{2ED'}\left(A_{\parallel} + \frac{E - E'\cos\theta}{E'\sin\theta\cos\phi}A_{\perp}\right)$$



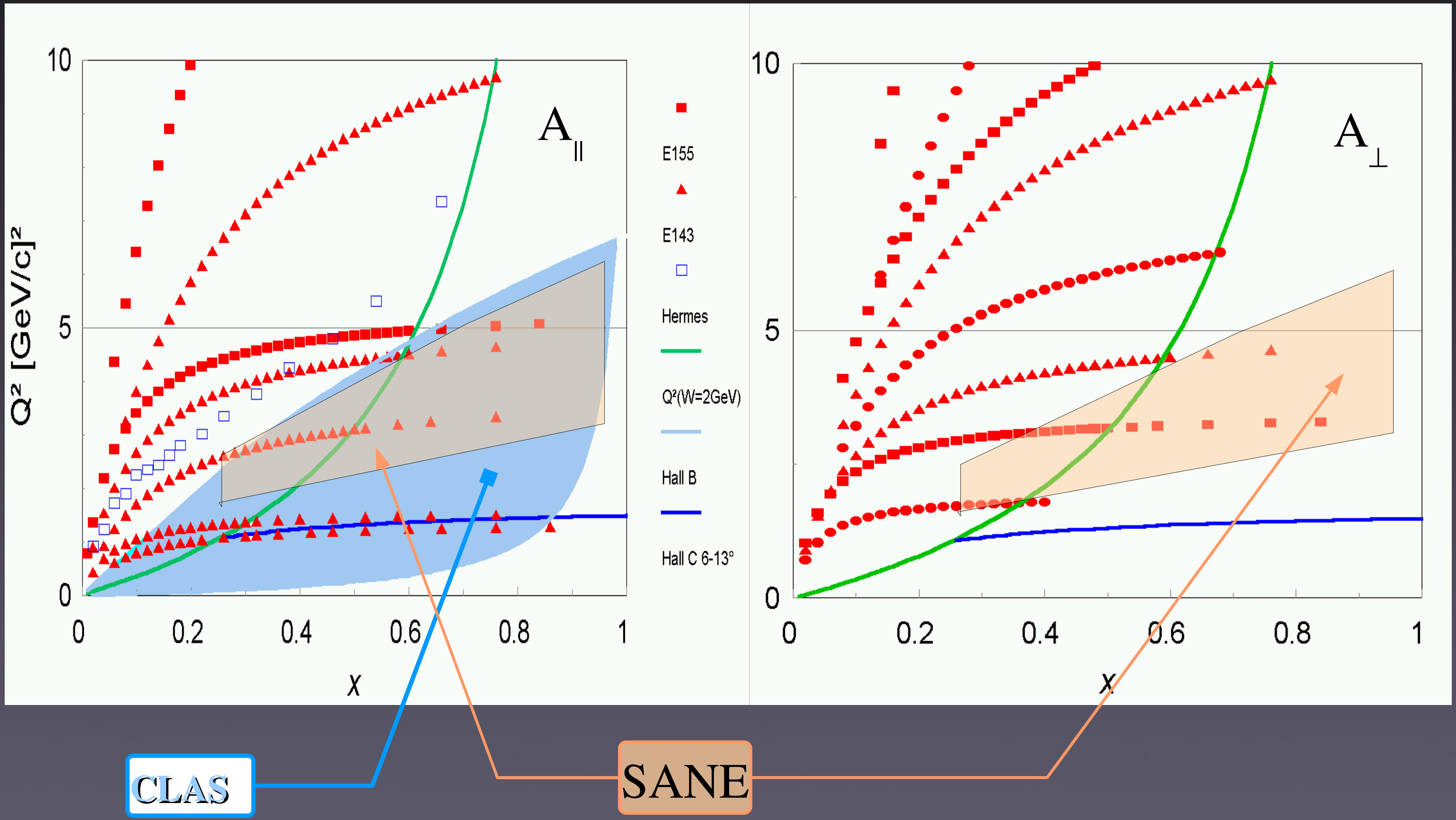
Expected Results (cont.)



SANE expected errors for $\bar{d}_2 = \int_{xmin}^{xmax} x^2 (2g_1 + 3g_2) dx$

- $\delta\bar{d}_2/d_2(Q^2 = 3\text{GeV}^2) = 4\%$ for $0.29 < x < 0.85$
- $\delta\bar{d}_2/d_2(Q^2 = 3.5 \text{ to } 6.5\text{ GeV}^2) = 2.5\%$ for $0.41 < x < 0.96$

Kinematics and World Data



Experimental Setup

Target

- UVa Polarized NH_3
- B = 80°, 180°

Electron Arm

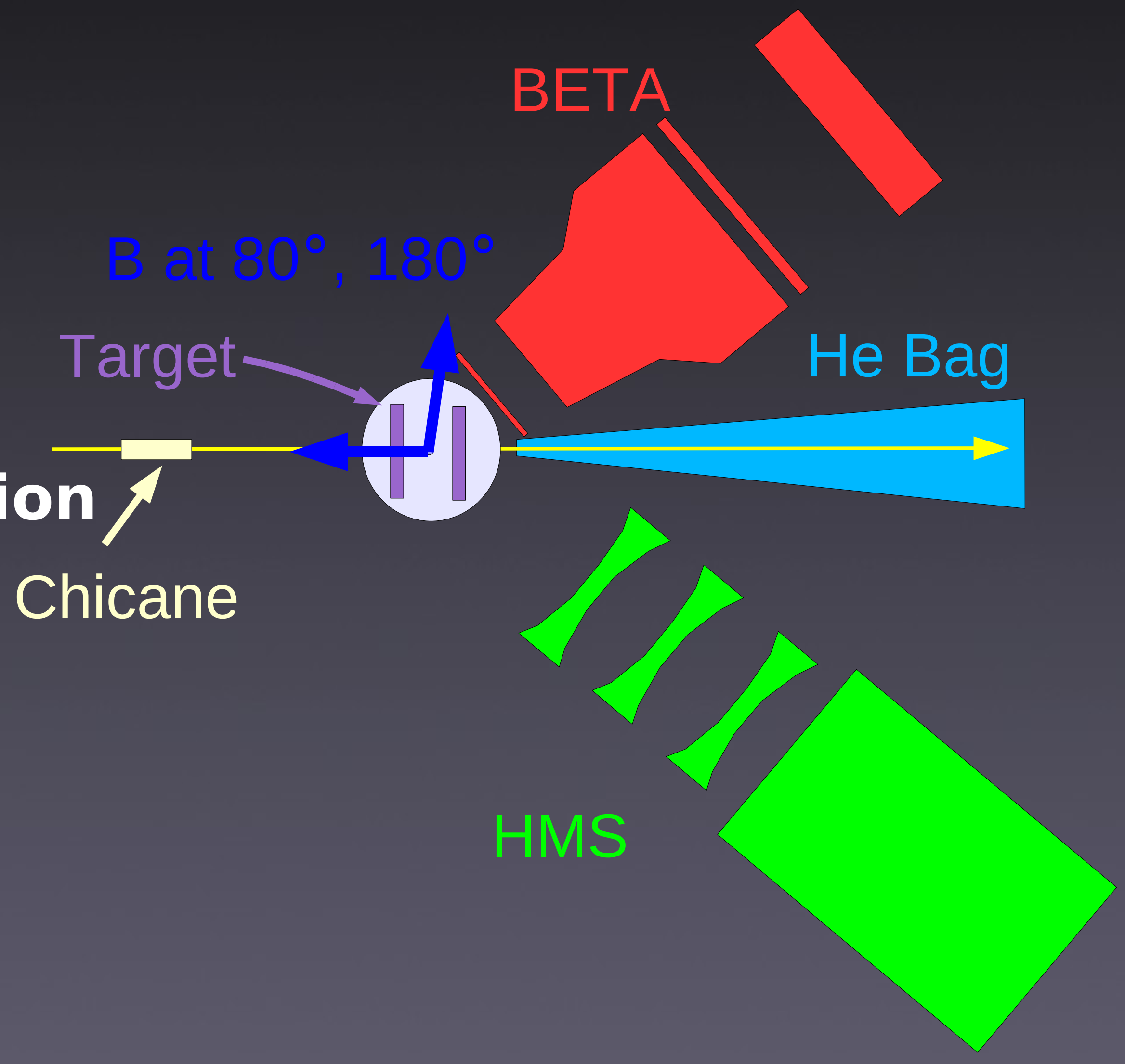
- BETA

Background, Calibration

- HMS

Beamline

- Polarization >75%
- Chicane (for B=80°)
- He Bag

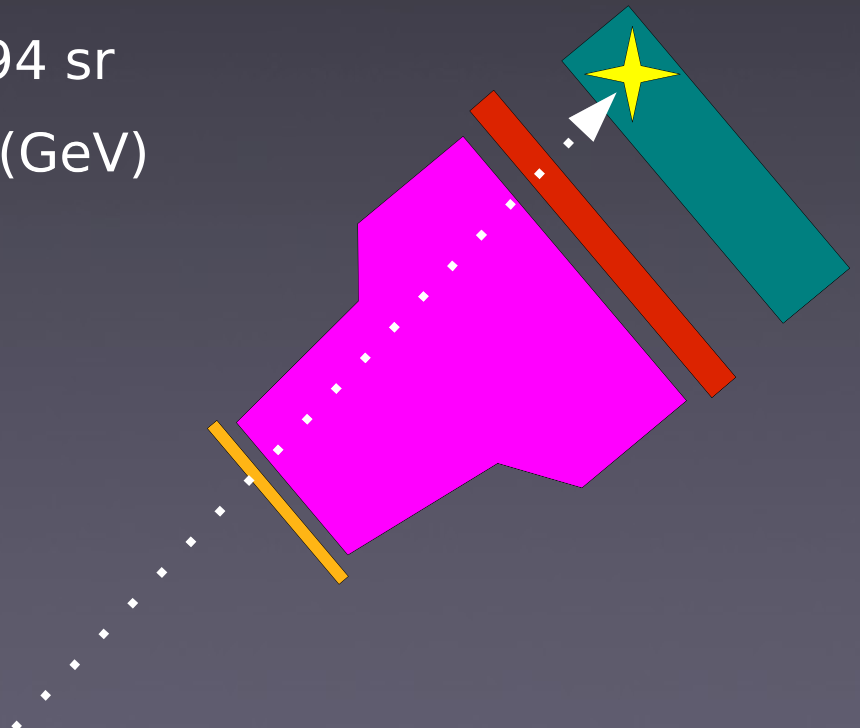


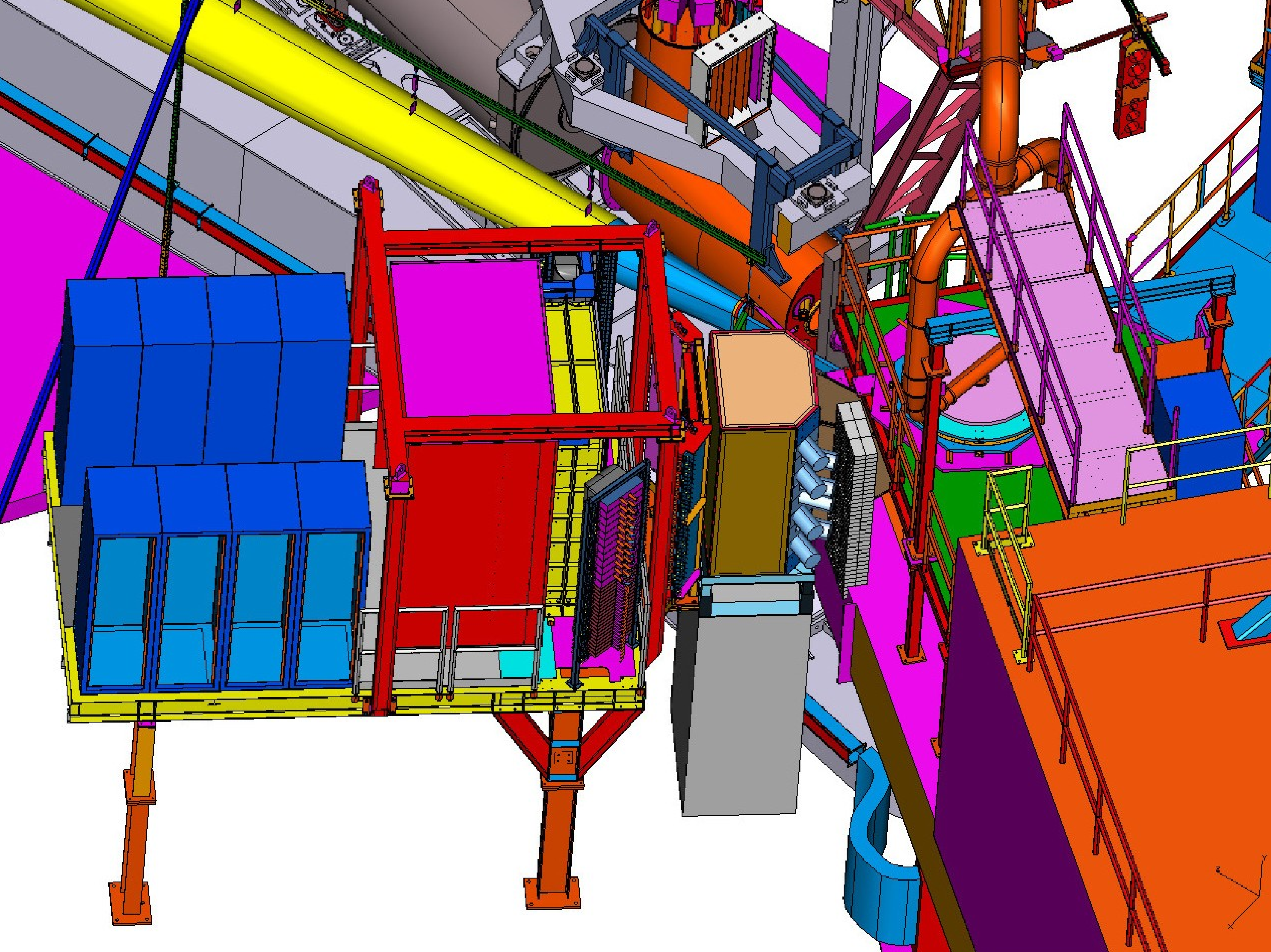
Big Electron Telescope Array

- Big Cal Calorimeter (GEp-III): Energy, Position
- Lucite Hodoscope: Position, Background Reduction
- Gas Cerenkov: Electron Detection, Pion rejection
- Front Hodoscope: Low Q^2 Electron/Positron Differentiation

Characteristics:

- Effective solid angle of 0.194 sr
- Energy resolution of 5%/√E(GeV)
- Angular resolution ~ 1mr
- Vertex Resolution ~ 5mm
- 1000:1 pion rejection



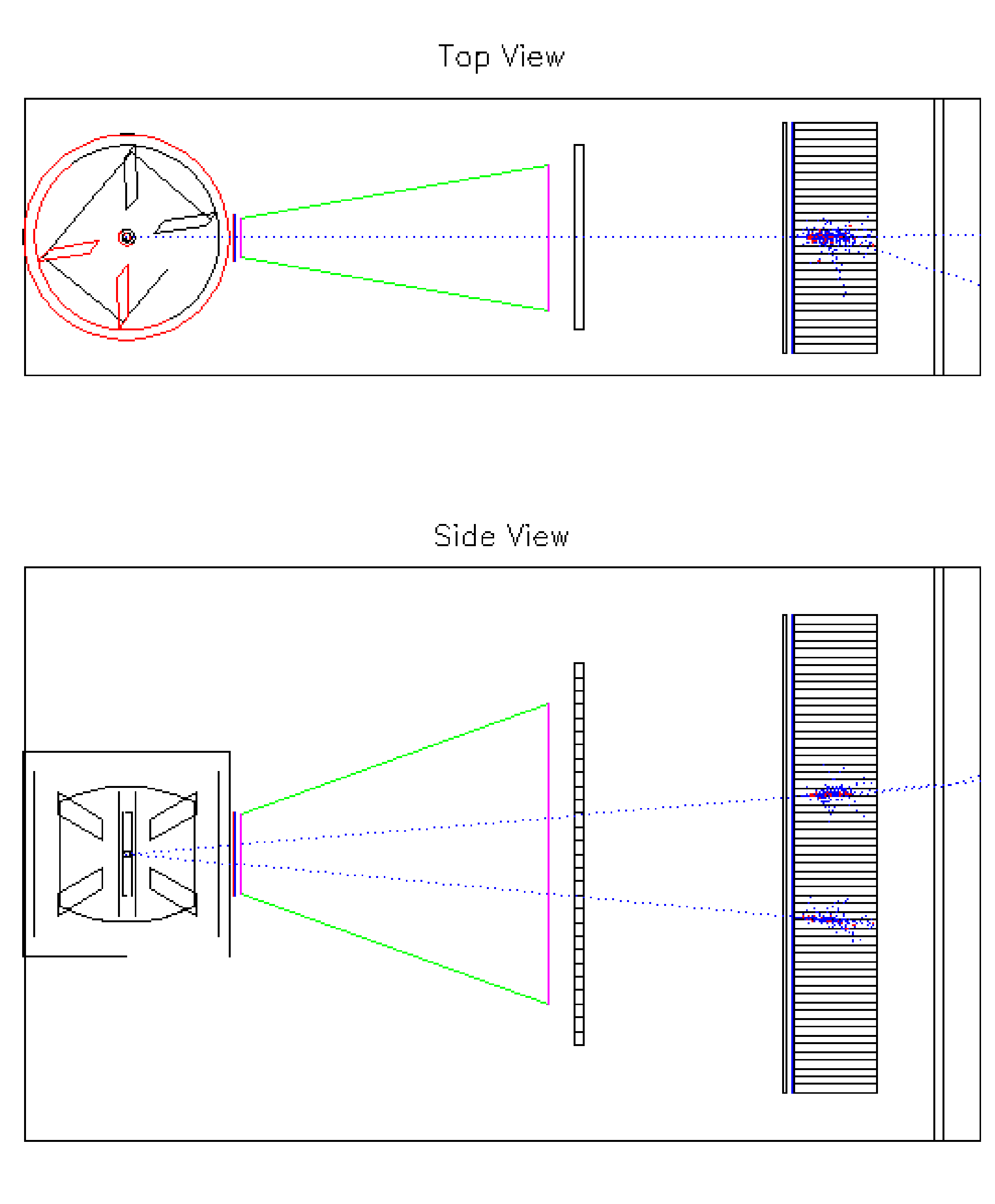


BigCal

- Final Destination: Shower
- Energy, Position Resolution
- Built for GEp-III
- **Big**: 1744 Pb-glass bars
  - 1024 3.8x3.8cm^2 (Protvino)
  - 720 4x4cm^2 (Yerevan)
- Expertise from GEp

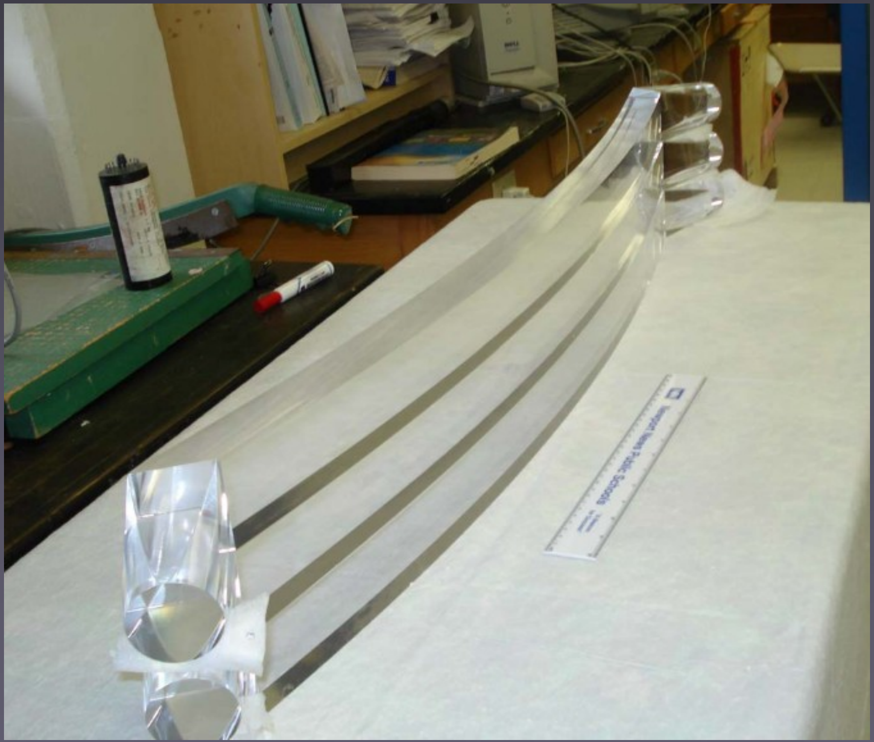
BigCal Calibration

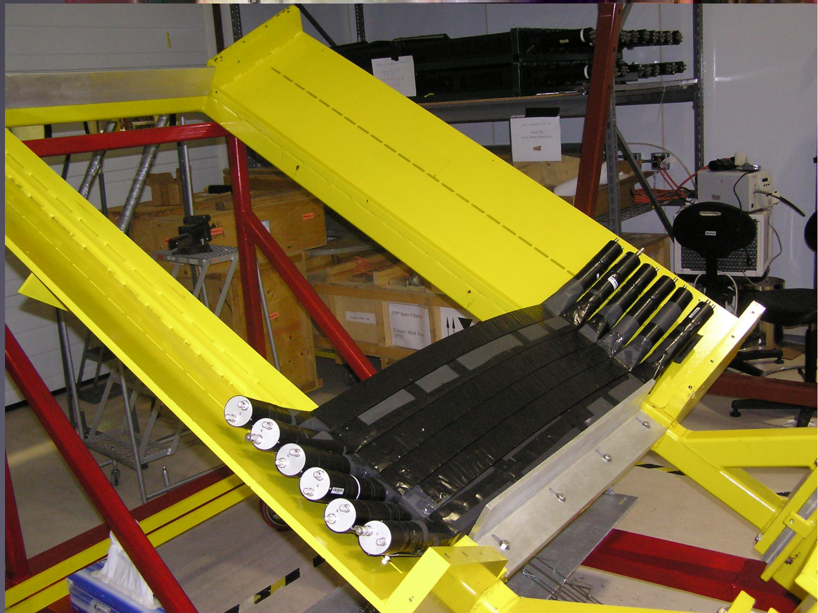
- Before run: *ep* elastic coincidences with HMS
  - HMS will give momentum of proton, determining electron
- Neutral Pion mass measurement
  - Catching both photons in BigCal will allow mass reconstruction
  - Will allow monitor of calibration throughout experiment



Lucite Hodoscope

- 28 Scintillating acrylic glass bars, 240cm from target
- Position; insensitive background from outside target chamber
- Curved to 240 cm to allow normal incidence from target
- A. Ahmidouch, S. Danagoulian, collaborators from NC A&T State U.



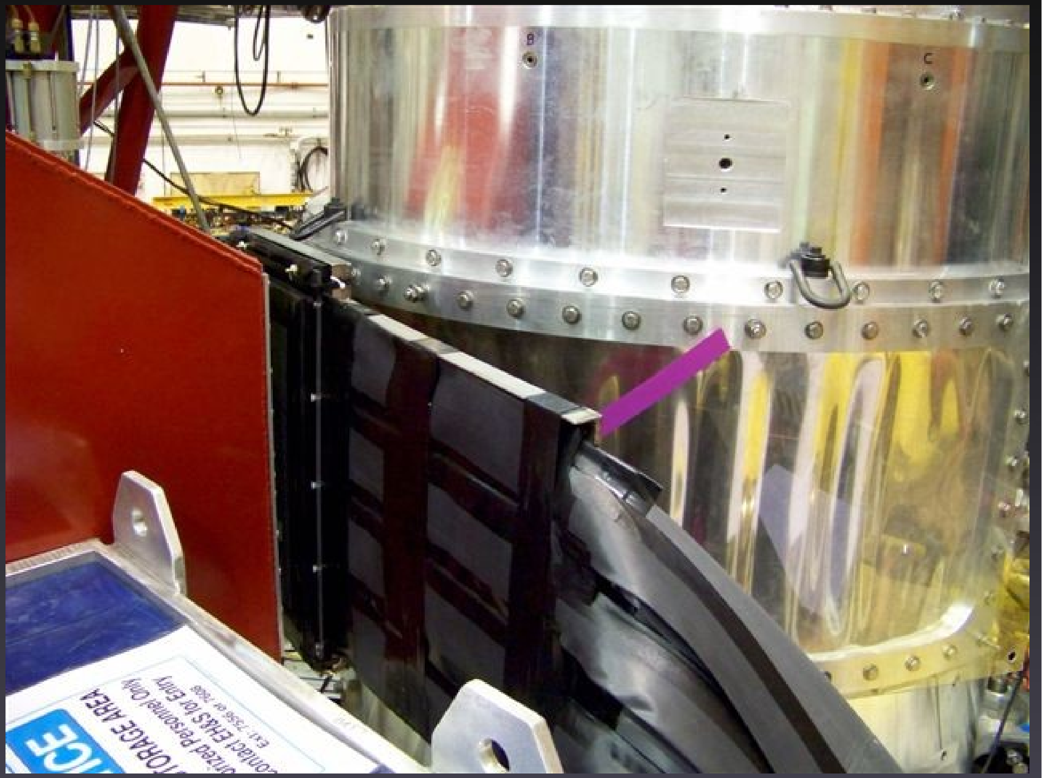


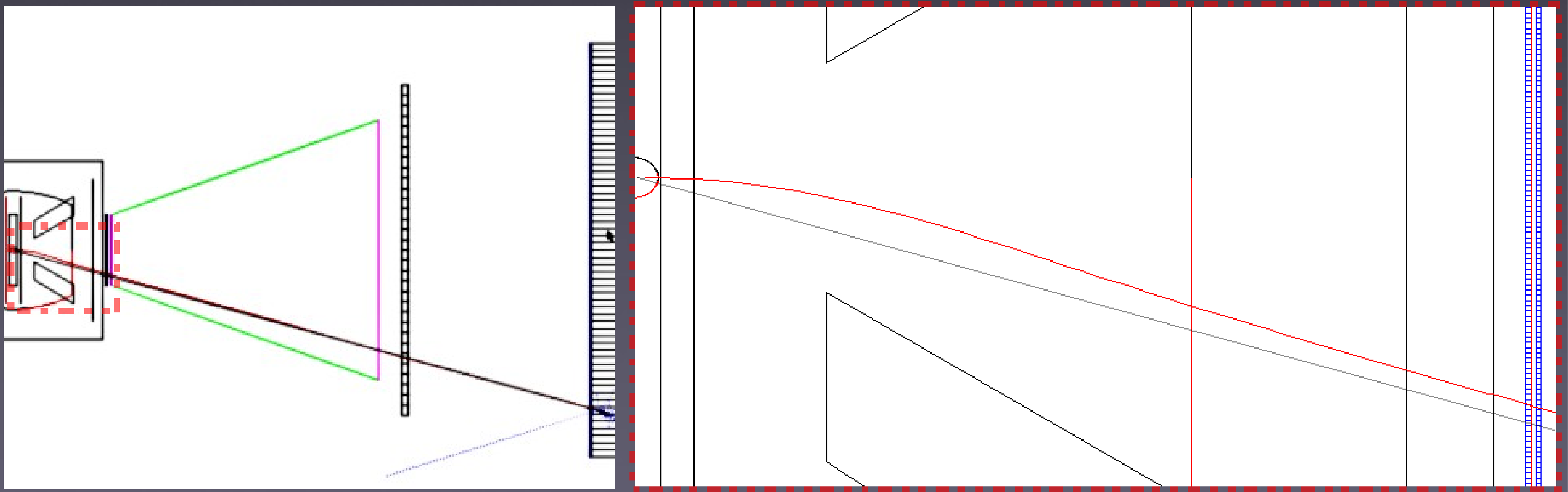
Gas Čerenkov Detector

- Efficient electron detection, Pion rejection 1000:1
- Dry nitrogen radiator n=1.000279
- 4 spherical and 4 toroidal mirrors with 8 3“ photomultiplier tubes
- Z.-E. Meziani and Temple Collaborators

Front Tracker

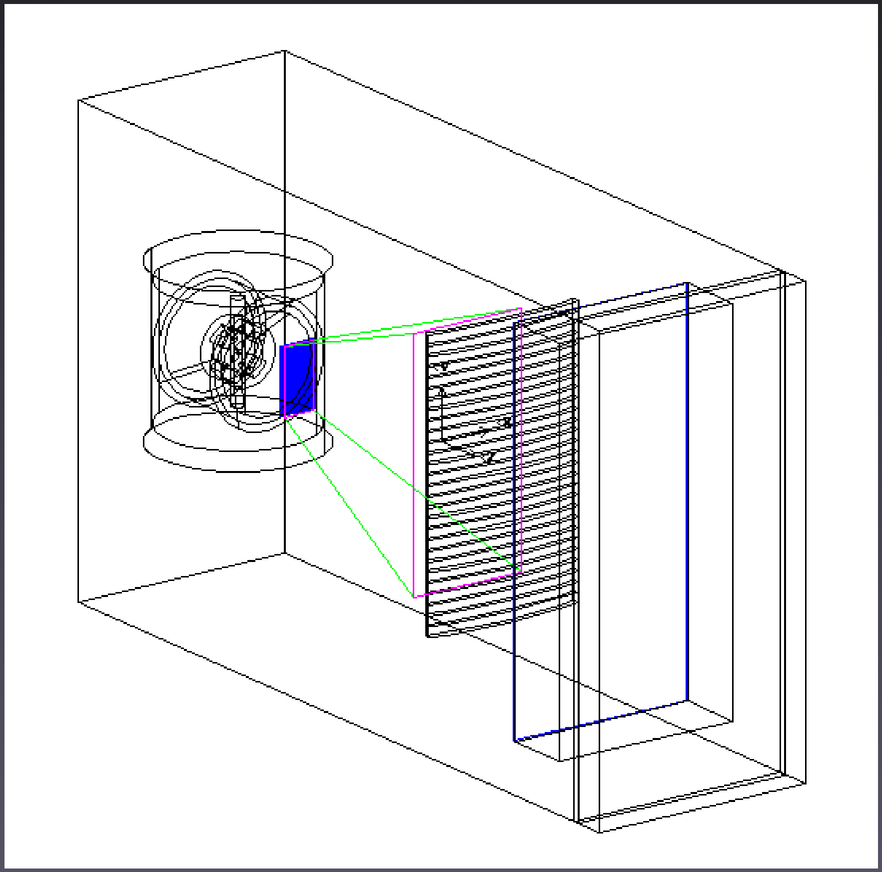
- Bicron Plastic Scintillator detector in front of Cerenkov, just 50cm from target
- 3 Y-planes (133 bars), 1 X plane (73)
- Electron or positron?
- 5T target magnet bend path
- Position measurement close to target field
- M. Khandaker (Norfolk S.U.), C.Butuceanu (U. Regina)





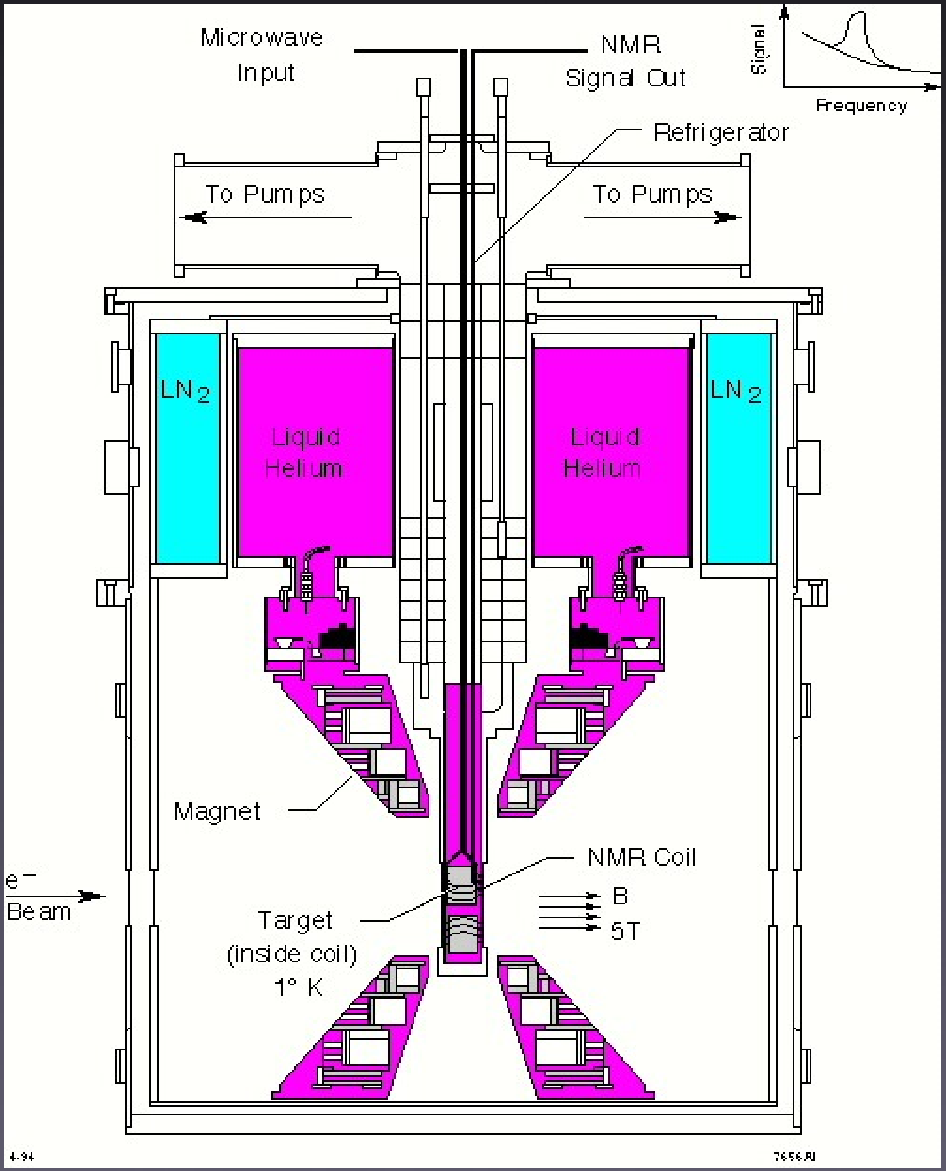
Simulation

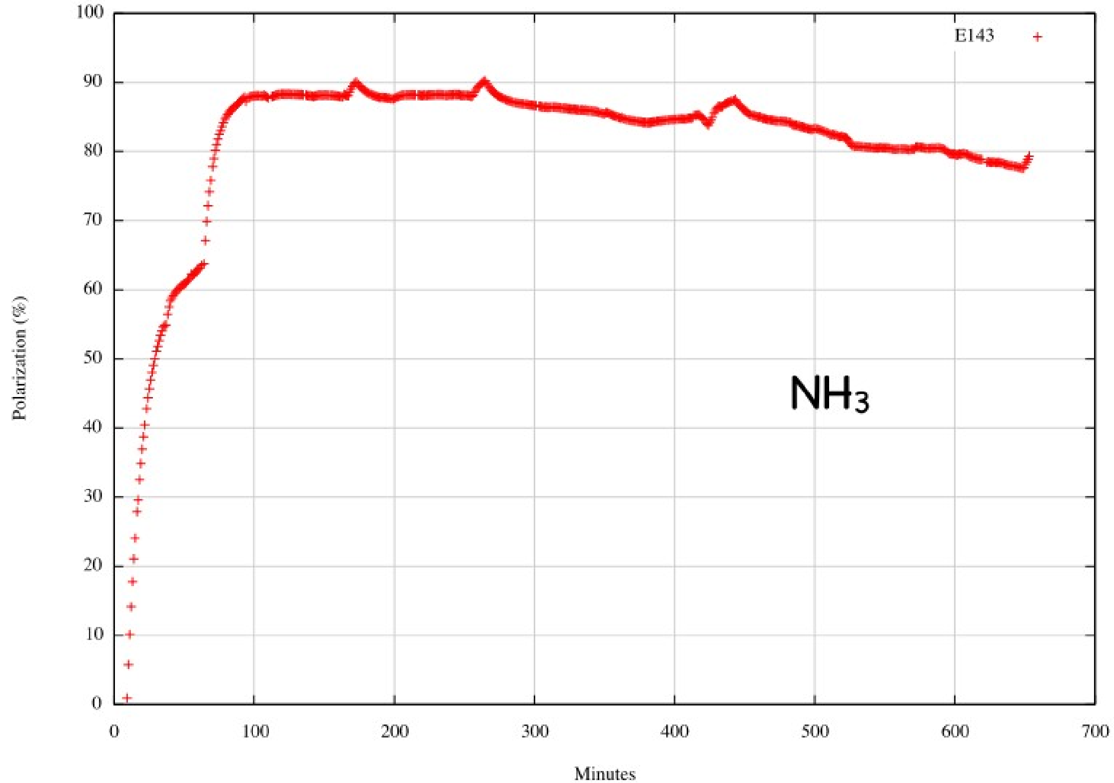
- Geant3 (BETA) and Geant4 (Cerenkov, Temple U)
- Anticipate detector response
  - Event generation in increasingly realistic detector geometry
  - Reconstruction to process created ntuple
- Being reworked to interface directly to analyzer ntuple
- G. Warren, J. Maxwell, H.Baghdasaryan, O. Rondon

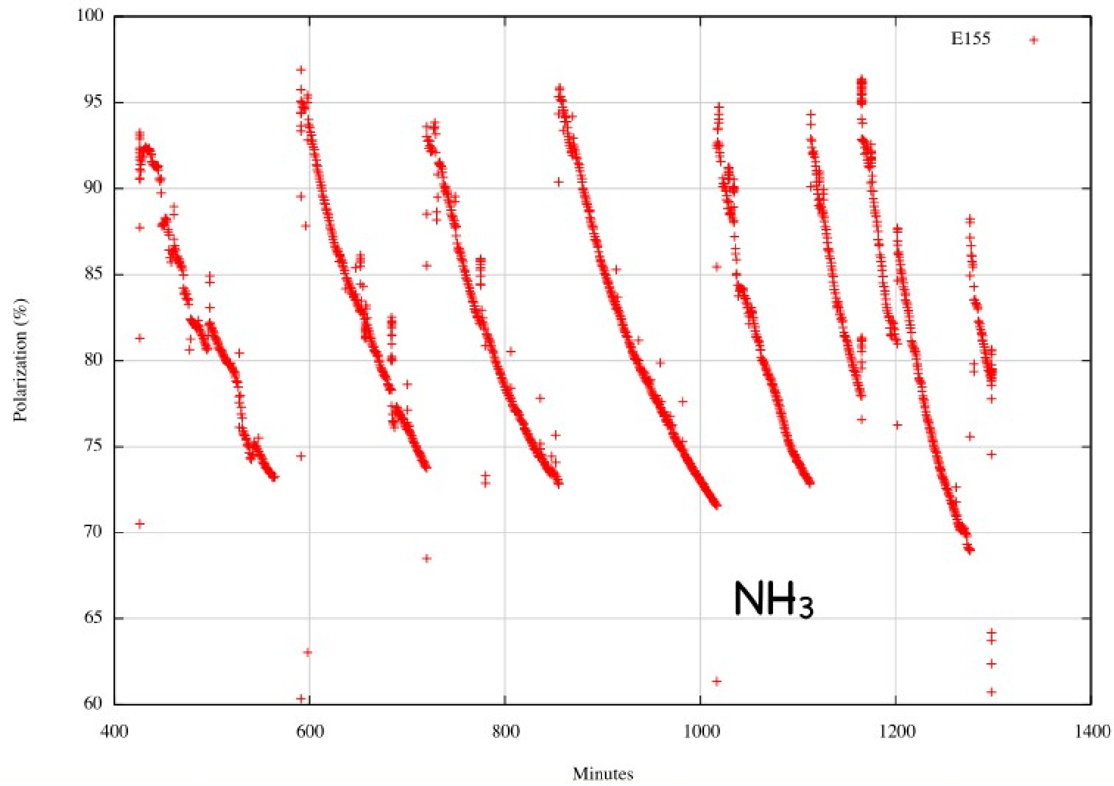


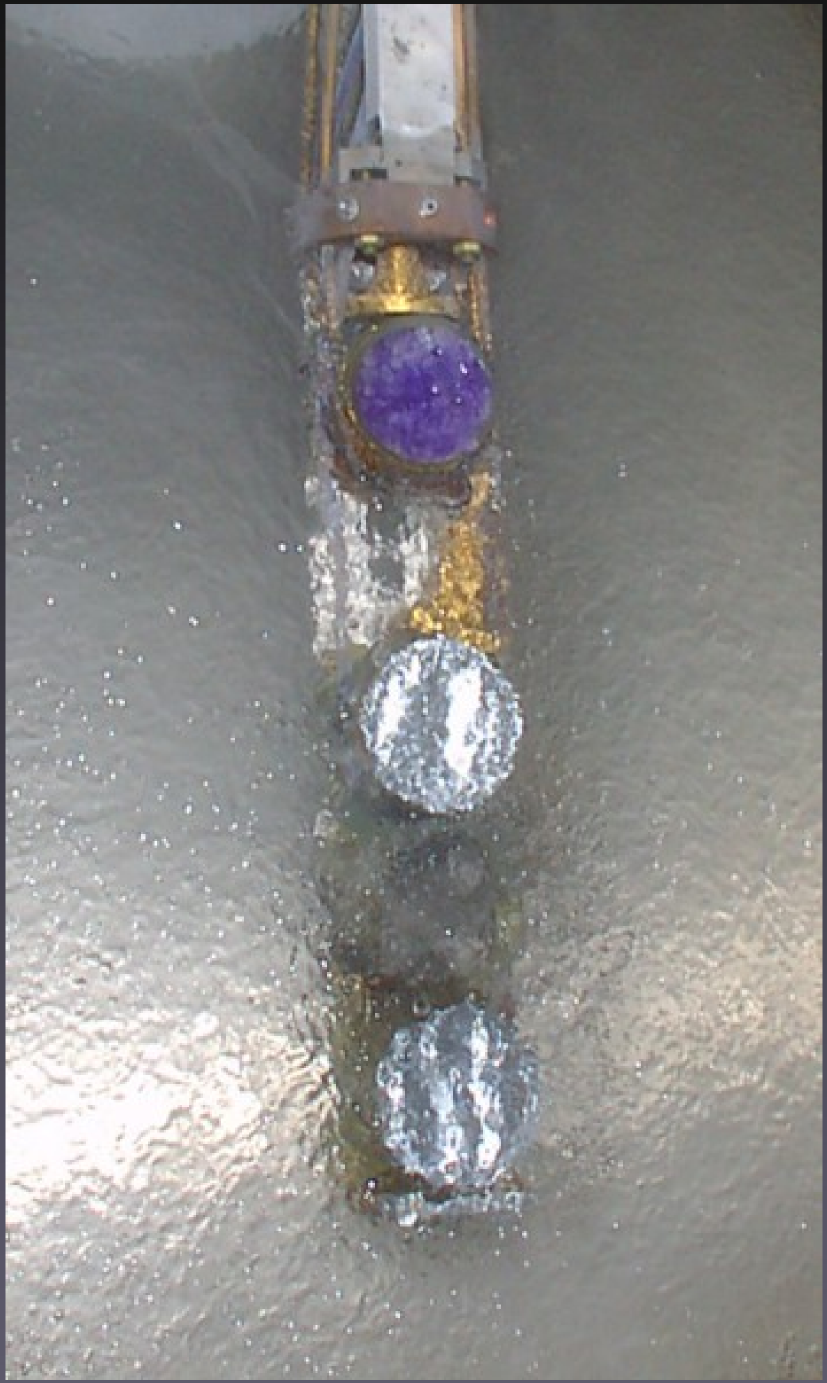
UVa Polarized Target

- Dynamic Nuclear Polarization
  - Hyperfine transitions induced by microwave pumping
- Typical characteristics:
  - B field of 5 T
  - Frozen Solids: NH_3
  - NMR measures polarization
  - $I_{beam} \approx 80$ nA
  - Average in-beam proton polarization ~70%
  - "Open" Geometry




E143
NH3
Polarization (%)
Minutes
0
10
20
30
40
50
60
70
80
90
100
0
100
200
300
400
500
600
700


E155
NH3
Polarization (%)
Minutes
60
65
70
75
80
85
90
95
100
400
600
800
1000
1200
1400

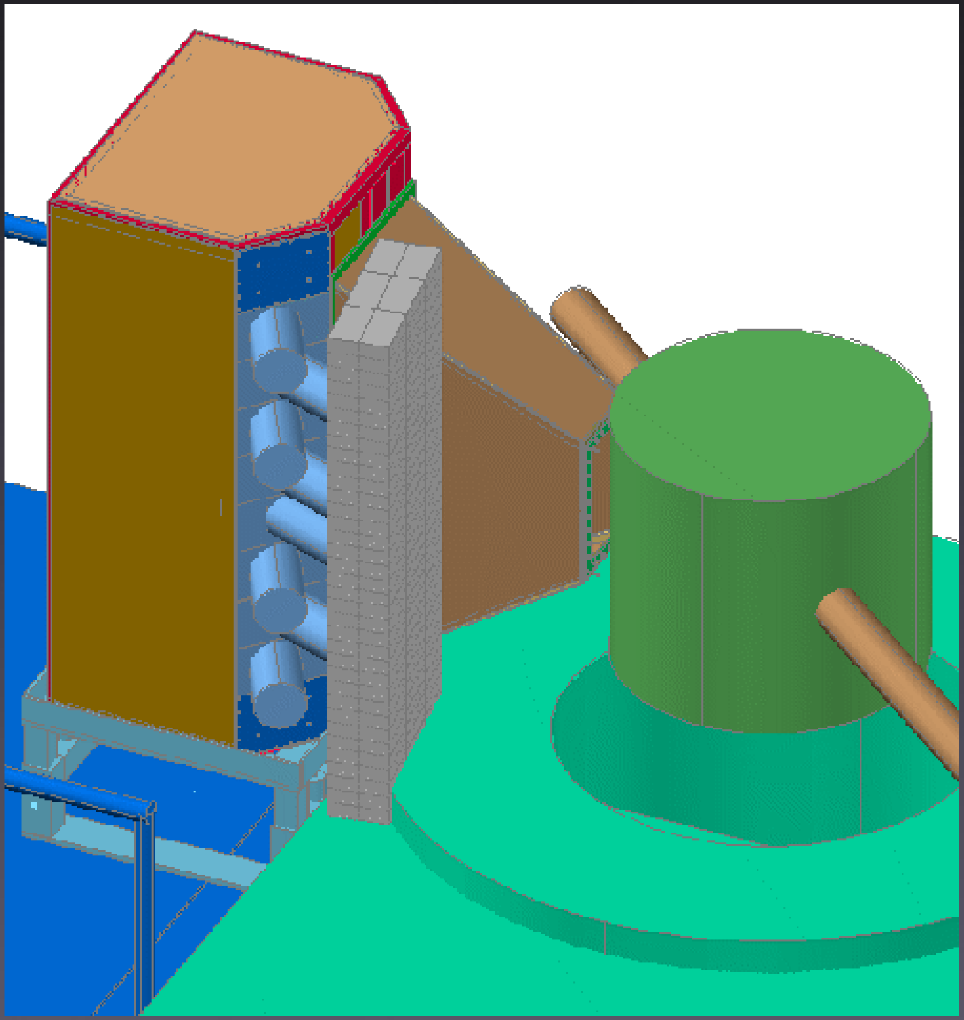


SANE Test Run

- Time allotted before the resumption of GEp
- Hodoscope mounted to BigCal frame, Cerenkov and Tracker mounted to stand, wired
- March 30th to April 3rd
- BETA fully formed for the first time, took data with beam, analyzer tested
- Large amounts of data from all detectors, promising first steps

Status Summary

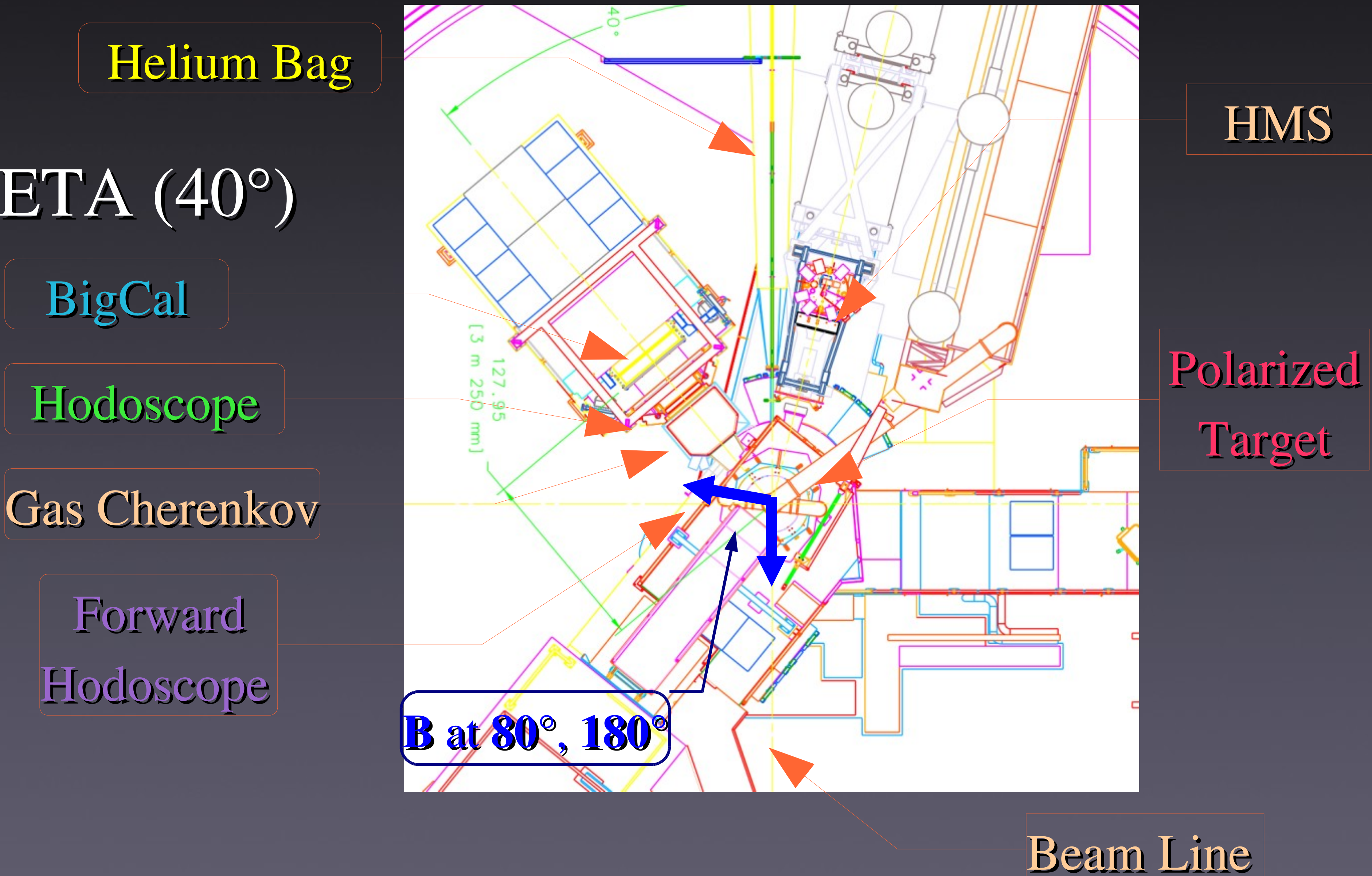
- PAC31 re-approved SANE as E07-003 with ''A'' rating
- 27 days plus 14 calendar days of commisioning (70 days on the floor)
- Scheduled to install June, run October until the end of the year
- Jonathan and I moving to Newport News in May to commence full-time target work in test lab



Questions?

Experimental Design

BETA (40°)



Asymmetry A_1

- Spin Asymmetry A_1 is related to the SSF's by way of the unpolarized structure function F_1:

$$A_1(Q^2,\nu)=\frac{\sigma^T_{1/2}-\sigma^T_{3/2}}{\sigma^T_{1/2}+\sigma^T_{3/2}}=\frac{1}{F_1}(g_1-\gamma^2 g_2) \qquad \gamma^2=\frac{4M^2x^2}{Q^2}$$

- UVa Polarized Target at JLab allows measurement of $\mathbf{A}_\perp$, as well as $\mathbf{A}_\parallel$, from which we extract $\mathbf{A_1}$, $\mathbf{A_2}$:

$$A_1=\frac{C}{D}(A_\parallel-dA_\perp) \qquad A_2=\frac{C}{D}(c'A_\parallel+d'A_\perp)$$

- Where C is the longitudinal polarization of the virtual photon, and D is the virtual photon depolarization

Structure Functions

- Quark distributions inside the 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, $q_i^{\uparrow\downarrow}(x)$:

$$\boldsymbol{F_1(x)} = \frac{1}{2}\sum_i e_i^2 \left(q_i^{\uparrow}(x) + q_i^{\downarrow}(x)\right)$$

$$\boldsymbol{g_1(x)} = \frac{1}{2}\sum_i e_i^2 \left(q_i^{\uparrow}(x) - q_i^{\downarrow}(x)\right)$$

i = index of quark flavor