SANE
Spin Asymmetries on the Nucleon Experiment
(TJNAF E-03-109)

SANE Collaboration
U. Basel, Florida International U., Hampton U., Norfolk S. U., North Carolina A&T S. U.,
IHEP-Protvino, Kent S. U., U. of Regina, Rensselaer Polytechnic I., St. Norbert College,
Temple U., TJNAF, U. of Virginia, College of William & Mary, Yerevan Physics I.

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

Hall C Users' Meeting
January 7, 2006
Jefferson Lab

SANE Status - Organization

- Nine collaboration meetings: 11/03; 3/- 6/- 9/- 11/04; 1/- 4/- 9/- 12/05.
- Seven new collaborator groups since PAC:
  - Florida International U., Norfolk State U., U. of Regina, second U. of Virginia group, North Carolina A&T S.U., St. Norbert College, (WI) and Kent S. U.
- SANE poster for Hall C Open House prepared by
  - Brad Sawatzky and Florentin Butaru (Temple U.)
- Hall C schedule update:
  - 9/04: SANE tentatively to run in 2007
  - 12/05: SANE delayed to 2008 (27 PAC days)
- But:
  - Time lines still showing adequate lead time if run were in early 2007

SANE

Spin Asymmetries of the Nucleon Experiment

(E03-109)

U. Basel, Florida International U., Hampton U., Jefferson Lab, Norfolk S.U., IHEP-Protvino, Rensselaer Polytechnic I., Temple U., U. of Virginia, College of William & Mary, Yerevan Physics I.

Potential Physics from SANE

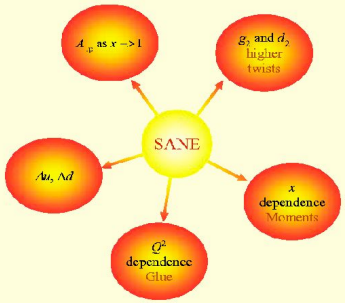
Electron scattering provides a powerful tool for studying the structure of the nucleus. The large *x* region (large transferred momentum) provides an window on proton structure in a regime where the sea quarks has been stripped away, potentially leading to insights into strong QCD and is essential for the determination of the nucleon spin structure functions (SSF).

The SSF's can be measured in inclusive inelastic scattering of polarized electrons on polarized nucleons. When the incident electron helicity is aligned with the target nucleon spin, the cross section is dominated by g_1, the *longitudinal* (||) SSF. When the target spin is perpendicular to the electron helicity, the cross section is dominated by g_2, the *transverse* (⊥) SSF. The conventional approach to extract g_1 and g_2 is to measure an *asymmetry* ($A = (\sigma_{\uparrow\downarrow} - \sigma_{\uparrow\uparrow}) / (\sigma_{\uparrow\downarrow} + \sigma_{\uparrow\uparrow})$) for each of the above cases ($A_\parallel$ and $A_\perp$, respectively) instead of the cross section difference. Along with a set of kinematic factors *(a,b,c,d)*, the spin structure functions g_1 and g_2 are related to the asymmetries by:

$$A_\perp = a(A_\parallel - bA_\perp) = \frac{1}{F_1}\left(g_1 - \gamma^2 g_2\right)$$

$$A_\parallel = a(cA_\parallel - dA_\perp) = \frac{\gamma}{F_1}\left(g_1 + g_2\right)$$

Our goal is to extract the proton A_1^p limited by systematic errors and a simultaneous statistics-limited measurement of g_2^p in the range $0.3 < x < 0.8$ at an average $Q^2 = 4.5$ (GeV/c)², in a model-independent fashion, from the measurement of the two asymmetries $A_\perp$ and $A_\parallel$ for two different orientations of the target magnetic field relative to the beam direction.



Why High *x* ? ($x = Q^2 / 2Mv$)

- Understanding higher order moments to compare to Lattice QCD and QCD predictions.
- Higher twist effects become more significant at higher *x*.
- Examine predictions as $x \to 1$ of A_1^p of pQCD and SU(6) models:
  - SU(6) symmetric $A_1^p \to 5/9$.
  - SU(6) broken and pQCD predicts $A_1^p \to 1$, but different reasons.
- Region in which sea quarks play only minor role.
- Existing data at large *x* is limited compared to lower *x* region.
- Need better data to better understand extrapolation to $x \to 1$.

Experimental Setup

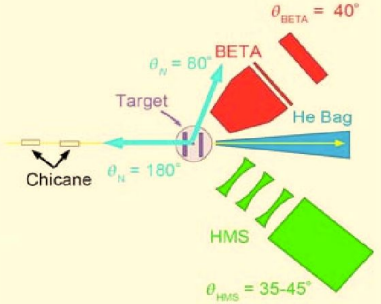
The experimental setup consists of the UVa polarized proton target, a total absorption electron telescope (BETA), the High Momentum Spectrometer (HMS), and the Hall C beam line with its now-standard augmentations to allow for 50-100 nA operations and several degrees of beam deflection by the target's magnetic field.

- The UVa target operates on the principle of Dynamic Nuclear Polarization, to enhance the low temperature (1K), high magnetic field (5T) polarization (up to 95%) in the NH_3 by microwave pumping. To minimize the source of systematic errors, its polarization direction is reversed after each anneal by adjusting the microwave frequency.

- BETA's low sensitivity to backgrounds, its high pixelization, low channel deadtime and large solid angle with adequate electron energy resolution make it ideal for large x measurements in DIS regime.

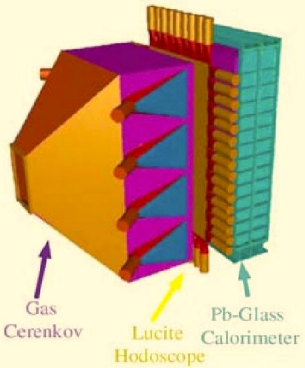
- While BETA can distinguish between charged and neutral particles, it is "blind" to the *sign* of the charge. Hence the measurement of charge-symmetric backgrounds will be carried out in parallel using the High Momentum Spectrometer (HMS).

- Two upstream chicane magnets are necessary to position the beam in the middle of the target for the non-parallel target field measurements.



Big Electron Telescope Array (BETA)

The BETA detector is based upon a 194 msr electromagnetic Calorimeter instrumented with Gas Cherenkov and Lucite Cherenkov (LC) detectors for clean electron identification, with a π^- rejection of at least 1000:1. A drift space between the Lucite Cherenkov and the Calorimeter makes BETA a *telescope* with sufficient resolution to isolate events well within the scattering chamber.



At a Glance:

- Energy resolution: $5\%/\sqrt{E(GeV)}$
- Assuming 3.6 cm (RMS) at LC:
  - Angular resolution: 2° (RMS)
  - Vertex resolution: 9.9 cm (RMS)

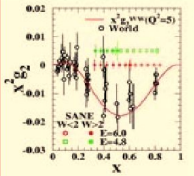
- dΩΔE of BETA > 100 times HMS for high *x* measurements

- Gas Cherenkov:
  - particle Identification (PID)
  - pions rejection

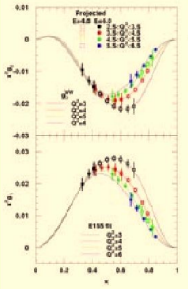
- Lucite Cherenkov:
  - redundant PID
  - tracking

- Pb-Glass Calorimeter:
  - hadron reduction

Expected Results



Projected results for g_2 compared to the world's data (black points), which are almost exclusively in the Deep Inelastic Scattering (DIS) region:
The red (green) points are the projected uncertainties from SANE for beam energy of 6.0 (4.8) GeV. The solid symbols denote SANE uncertainties in the DIS region, and the hollow ones are in the resonance region.



Statistical uncertainties in $x^2g_2^p$ and $x^2g_1^p$ in $\Delta Q^2 = 1\,(\mathrm{GeV/c})^2$ bins as a function of x:
We use the E155 fit to g_1/F_1 to calculate g_1 and g_2^{ww} for the solid lines. The projected uncertainties are shown as solid circles for 6.0 GeV and as hollow circles for 4.8 GeV.

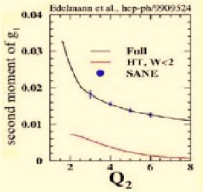
SANE enhancements:
- Smaller data uncertainties and *x* binning of points.
- Kinematic coverage is precisely where x^2g_2 is the largest (important in determining second moments).
- Data for all momenta are collected simultaneously for a given target field direction (point-to-point systematics of SANE are significantly reduced in this manner).

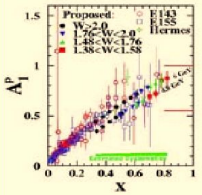
By measuring the *second moments* of g_1 and g_2 we can determine d_2 as:

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

When fitting the moments, we will include the world's data when it falls within the Q^2 bin. This will be particularly important in the low *x* region where SANE cannot provide data.

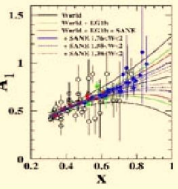
- Expected error on d_2 (Q^2 = 2.5 to 6 GeV²) = 0.0009 (1/2 of the current world error).





Published world data for A_1^p for high x and SANE projected uncertainties for both beam energies:
- The $E = 4.8$ GeV points have been shifted down for clarity
- The two horizontal lines extending below $x = 1$ represent the *pQCD* (upper line) and *SU(6)* symmetric (bottom line) predictions for A_1^p at $x = 1$.
- The transverse target data from *SANE* would enable a model independent extraction of A_1 and g_1 from both *SANE* and *CLAS (EG1b)* data.

Potential impact of the SANE data on our understanding of A_1^p as $x \to 1$:
- *World's* published data, *EG1b* estimated data and *SANE* projected data together reduce the uncertainty in A_1^p as $x \to 1$ by 50% compared to the fit to the world's data alone.
- Further improvements in the SANE statistical uncertainties would not significantly reduce the uncertainty in A_1^p as $x \to 1$ due to the lack of significant statistics for x > 0.6 in the DIS region.



SANE Physics

- Measure proton spin structure function $g_2(x, Q^2)$ and spin asymmetry $A_1(x, Q^2)$ at four-momentum transfer $2.5 \leq Q^2 \leq 6.5$ GeV^2 and Bjorken x $0.3 \leq x \leq 0.8$

REPORT TO THE
NUCLEAR SCIENCE ADVISORY
COMMITTEE

Submitted by the
SUBCOMMITTEE ON PERFORMANCE
MEASURES

November 18, 2003

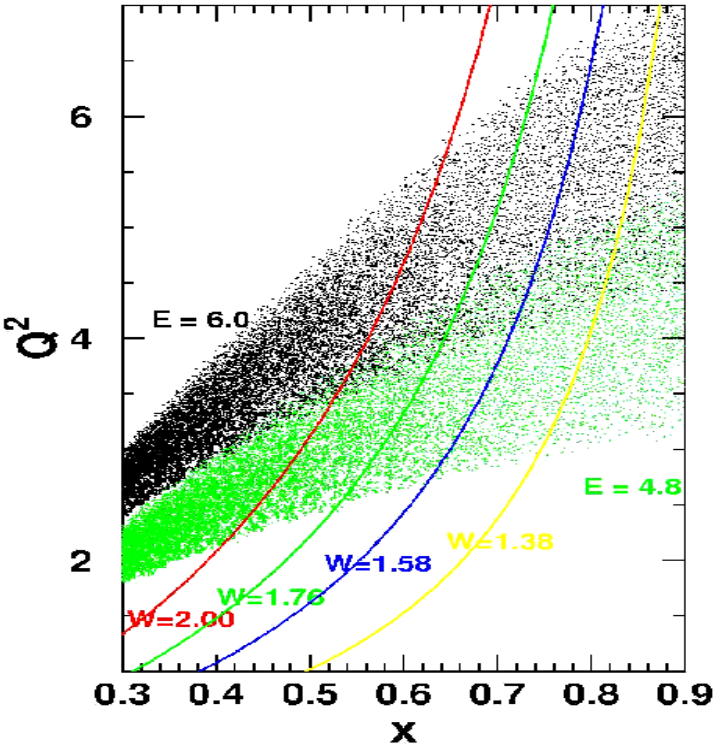
2011	Measure the lowest moments of the unpolarized nucleon structure functions (both longitudinal and transverse) to 4 GeV^2 for the proton, and the neutron, and the deep inelastic scattering polarized structure functions $g_1(x, Q^2)$ and $g_2(x,Q^2)$ for x=0.2-0.6, and $1 < Q^2 < 5$ GeV^2 for both protons and neutrons.

- **Meets or Exceeds DOE 2011 Milestone for Proton Spin Structure, IF**
  - **SANE takes data no later than 2008**

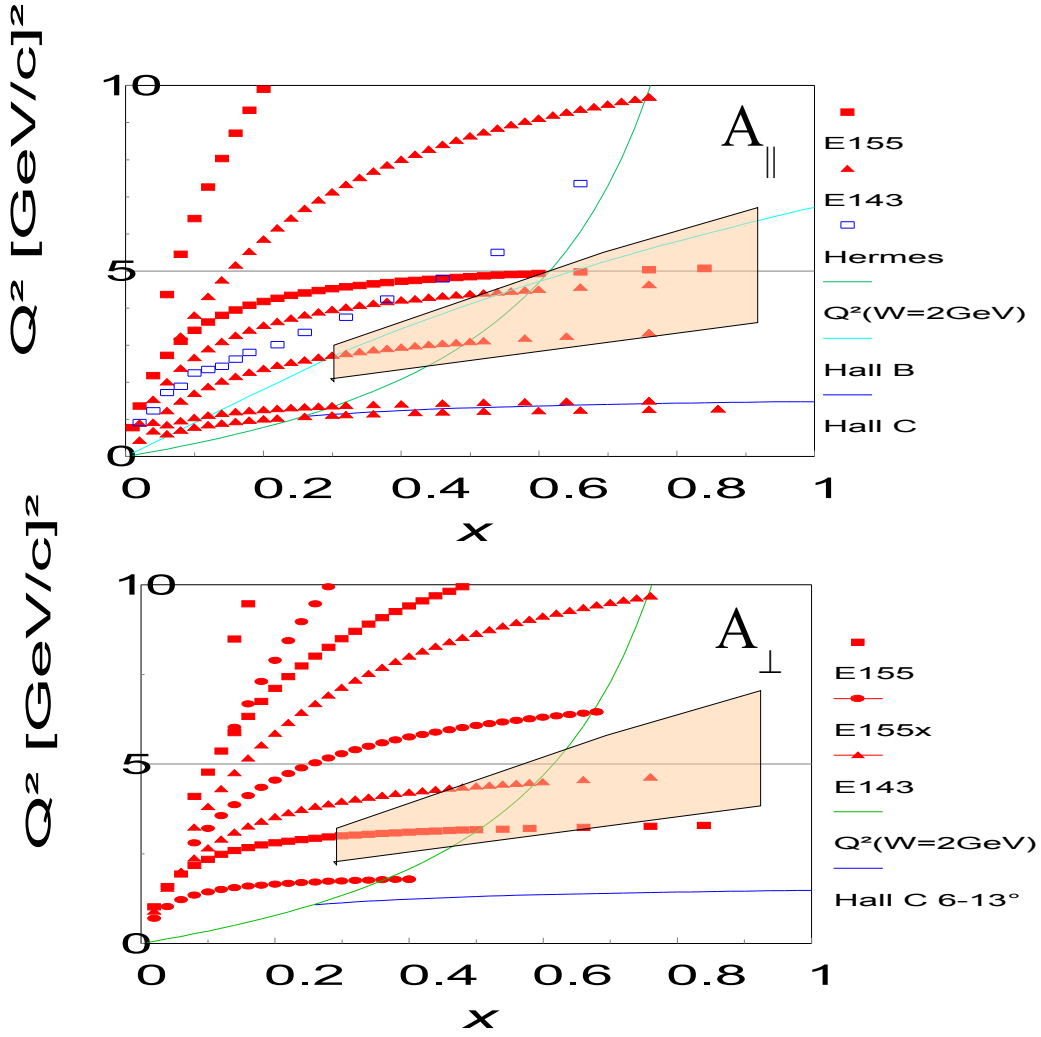
SANE Physics (II)

- Goal is to learn all we can about proton SSF's from inclusive measurement:
  - Study x and Q^2 dependence
  - Twist-3 effects from moments of g_2 and g_1, comparison with Lattice QCD
  - Exploration of "high x" region: A_1 approach to $x = 1$
  - Test polarized local duality for $W > 1.4$ GeV
- Method:
  - Measure inclusive spin asymmetries for two orientations of target spin relative to beam helicity (anti-parallel and near-perpendicular)
  - Detect electrons with large solid angle electron telescope **BETA**

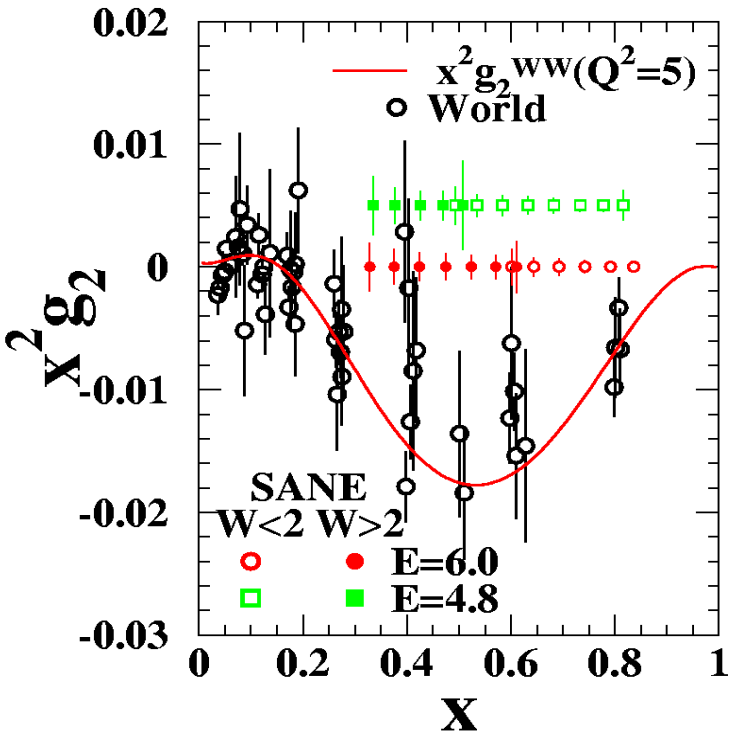
SANE Kinematics

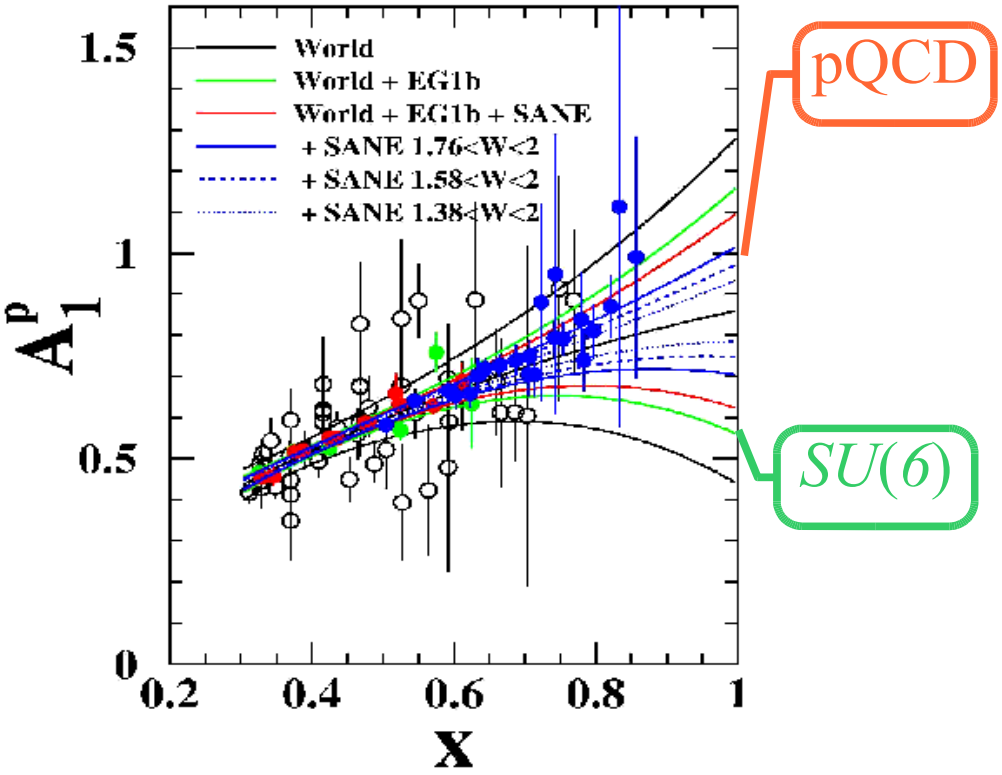


- Two beam energies:
  - **6 GeV**, **4.8 GeV**
- Very good high ***x*** coverage with detector at 40°



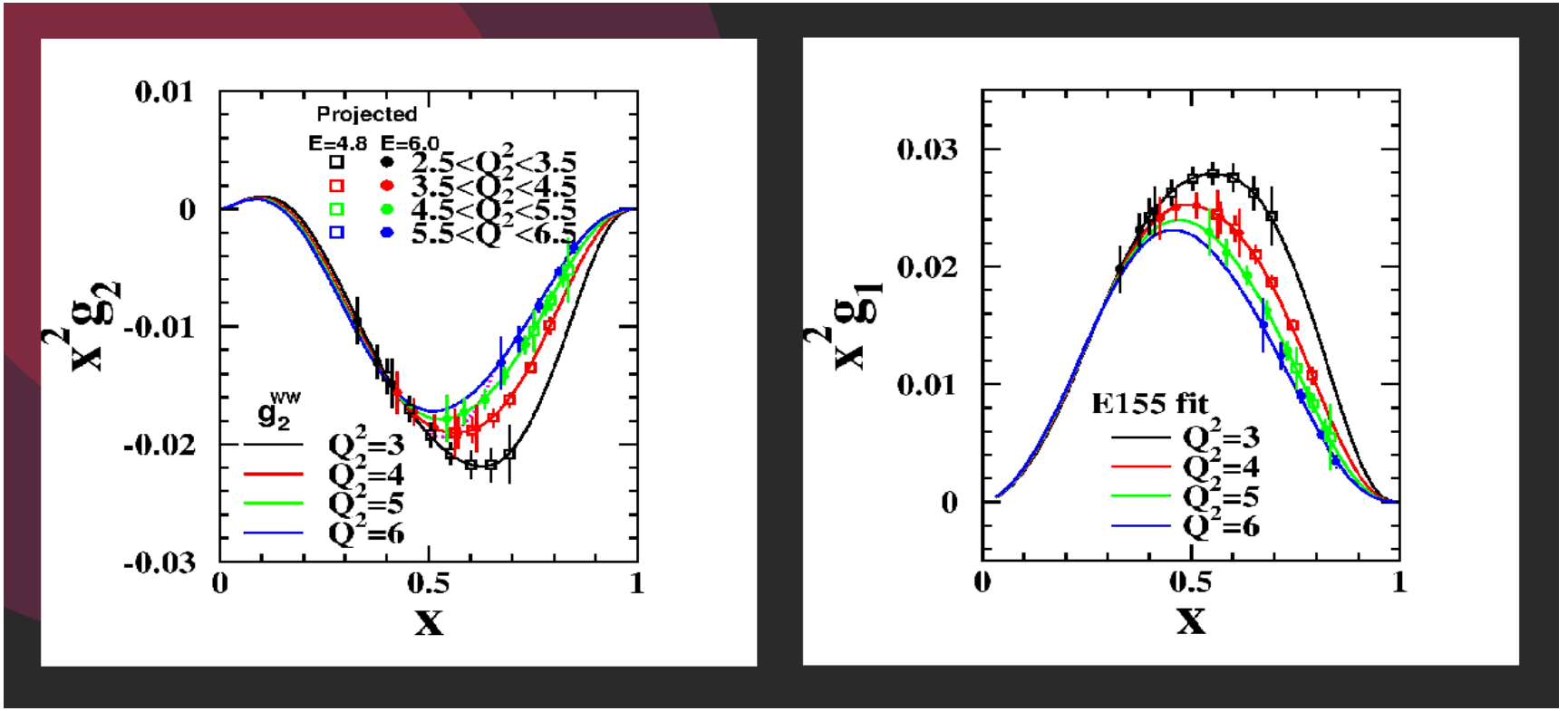
SANE Expected Results





- DIS data for ***x*** up to 0.6 (with 6 GeV)
- Constrain extrapolations of A1p to $x = 1$ within +/- 0.1 (using duality)

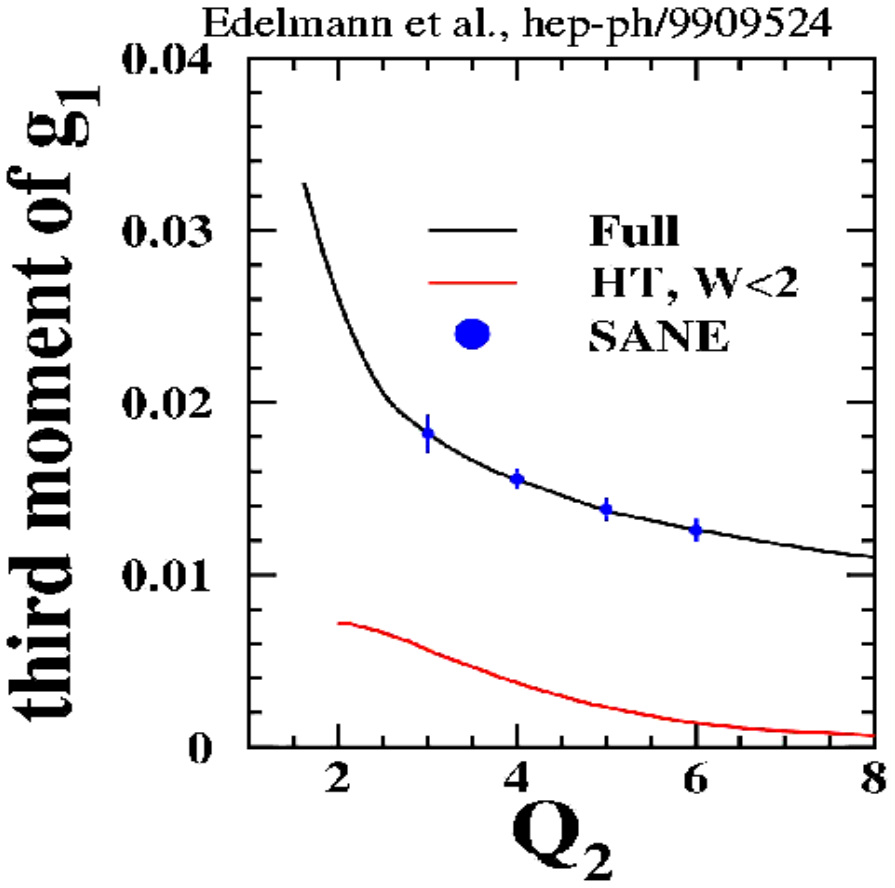
SANE Expected Results (II)



- x dependence at constant Q^2 and Q^2 dependence at fixed x
- data are concentrated in the region most sensitive to $x^2 g_{2,1}$

SANE Expected Results (III)

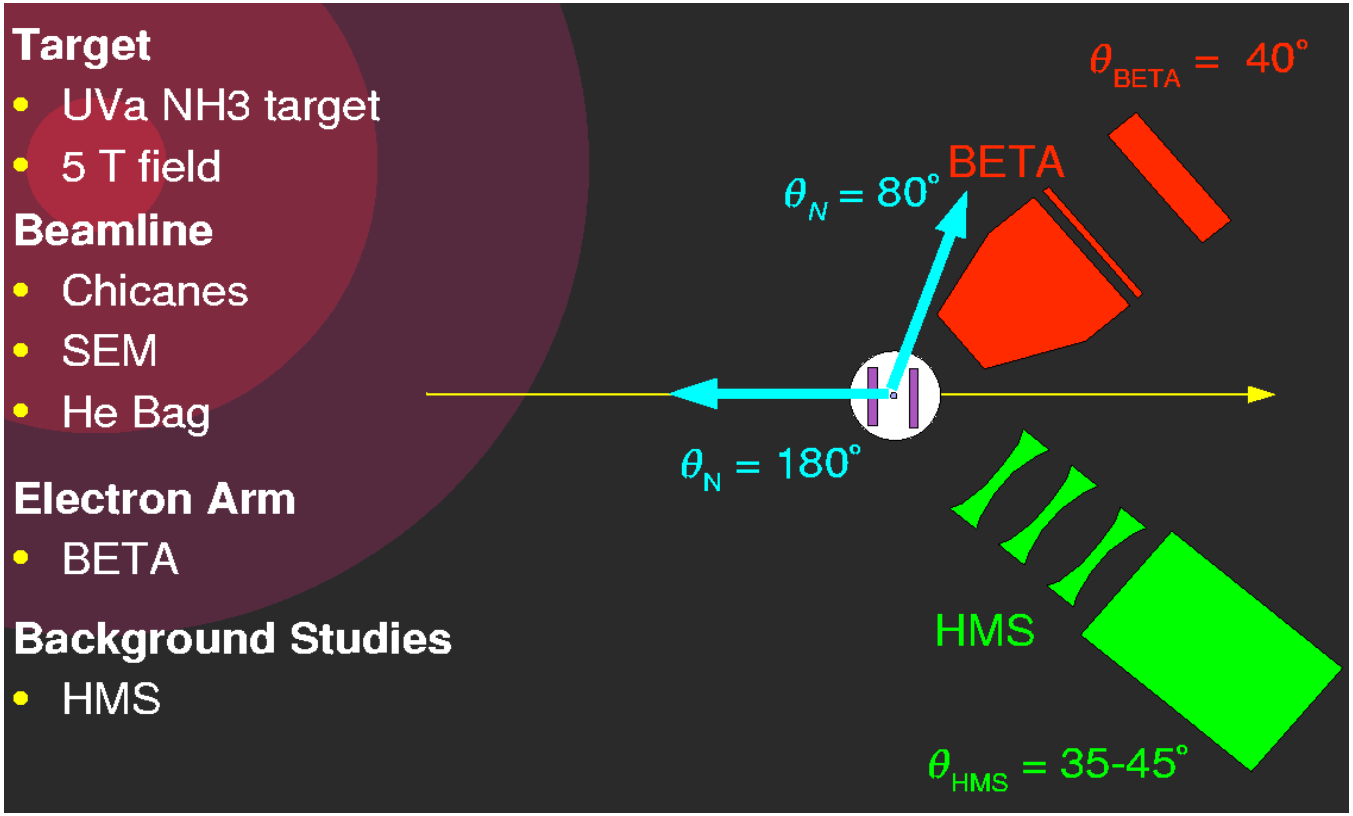
- Twist-3 matrix element
  $d_2 = \int_0^1 x^2 (2g_1 + 3g_2)\, dx$
  calculable in Lattice QCD
- SANE expected error on
  $d_2(Q^2 = 2.5 \text{ to } 6.5 \text{ GeV}^2) = 0.0009$
  (½ the current world error)



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)

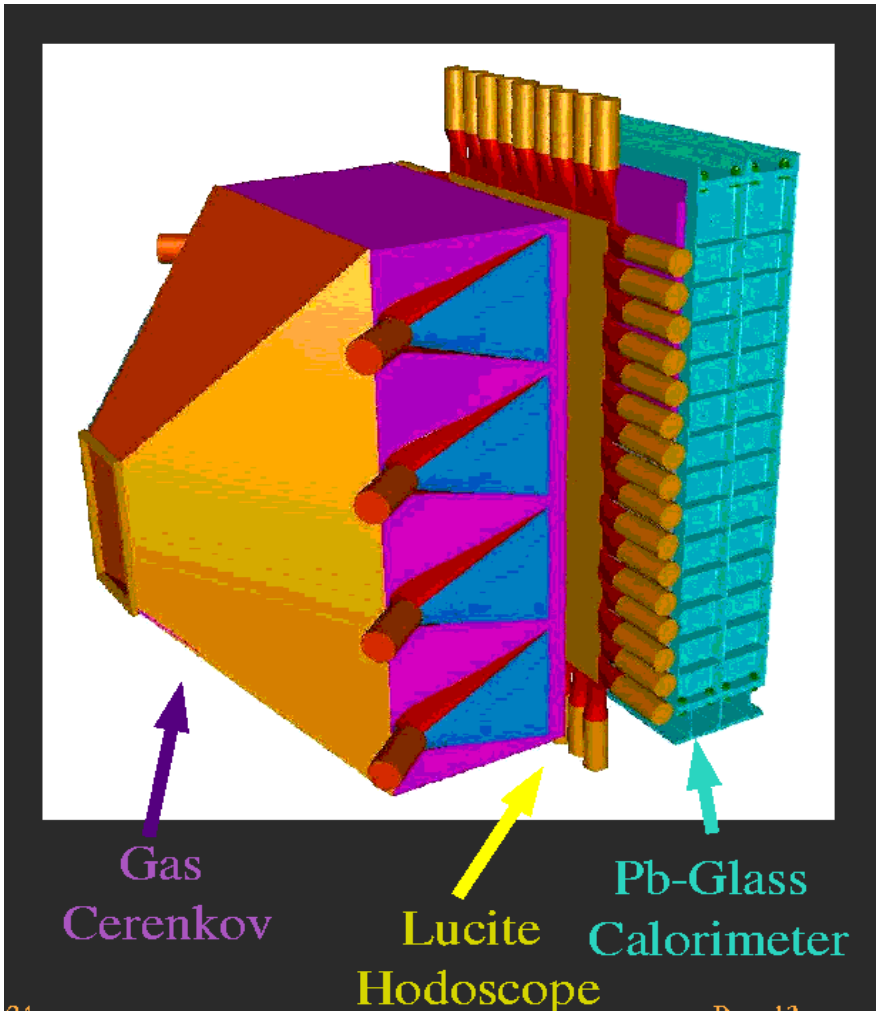
SANE Layout



- Target field aligned to measure Parallel and near-Perpendicular asymmetries

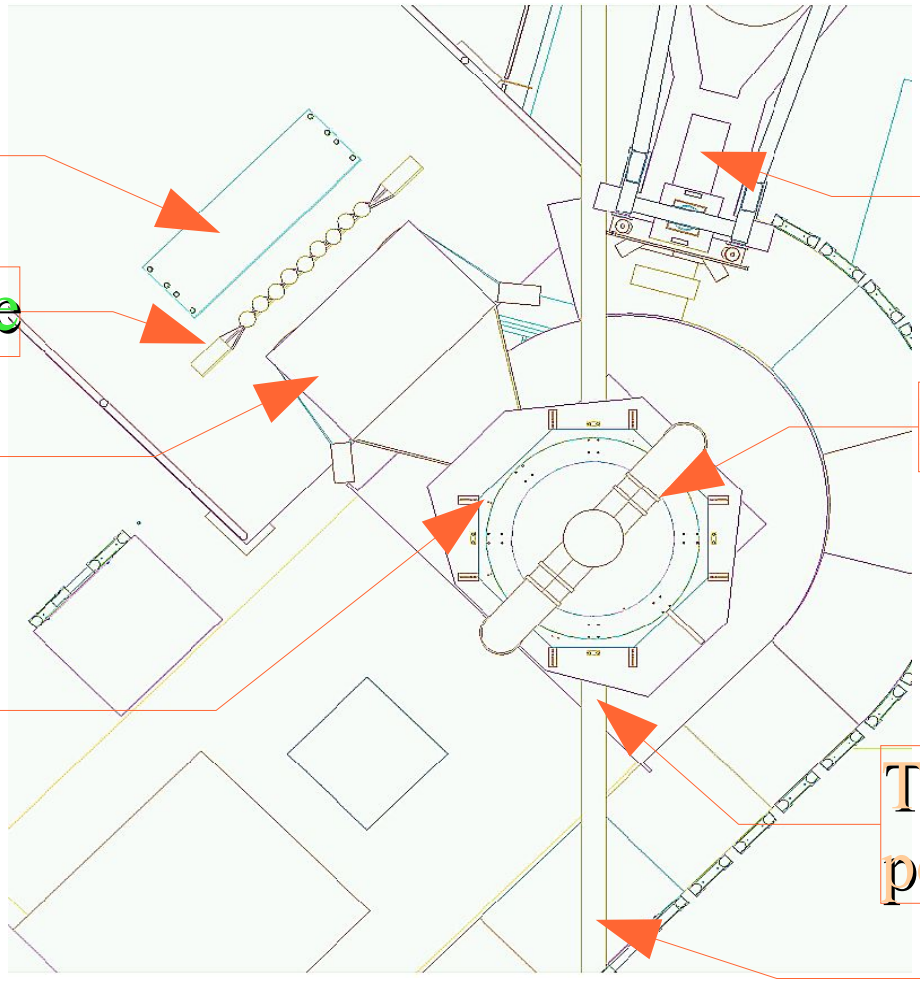
Big Electron Telescope Array - BETA

- BigCal lead glass calorimeter:
  main detector, being built for *GEp-III*.
- Gas Cherenkov: additional pion rejection
- Tracking Lucite hodoscope (Cherenkov)
- Target field sweeps low *E* background
- BETA's characteristics
  - Effective solid angle = 0.194 sr
  - Energy resolution $5\%/\sqrt{E}$(GeV)
  - angular resolution = 2°
  - 1000:1 pion rejection
- Added: front quartz hodoscope
  - from geometry only
    - vertex resolution ~ 4 mm
    - angular resolution ~ 1 mr



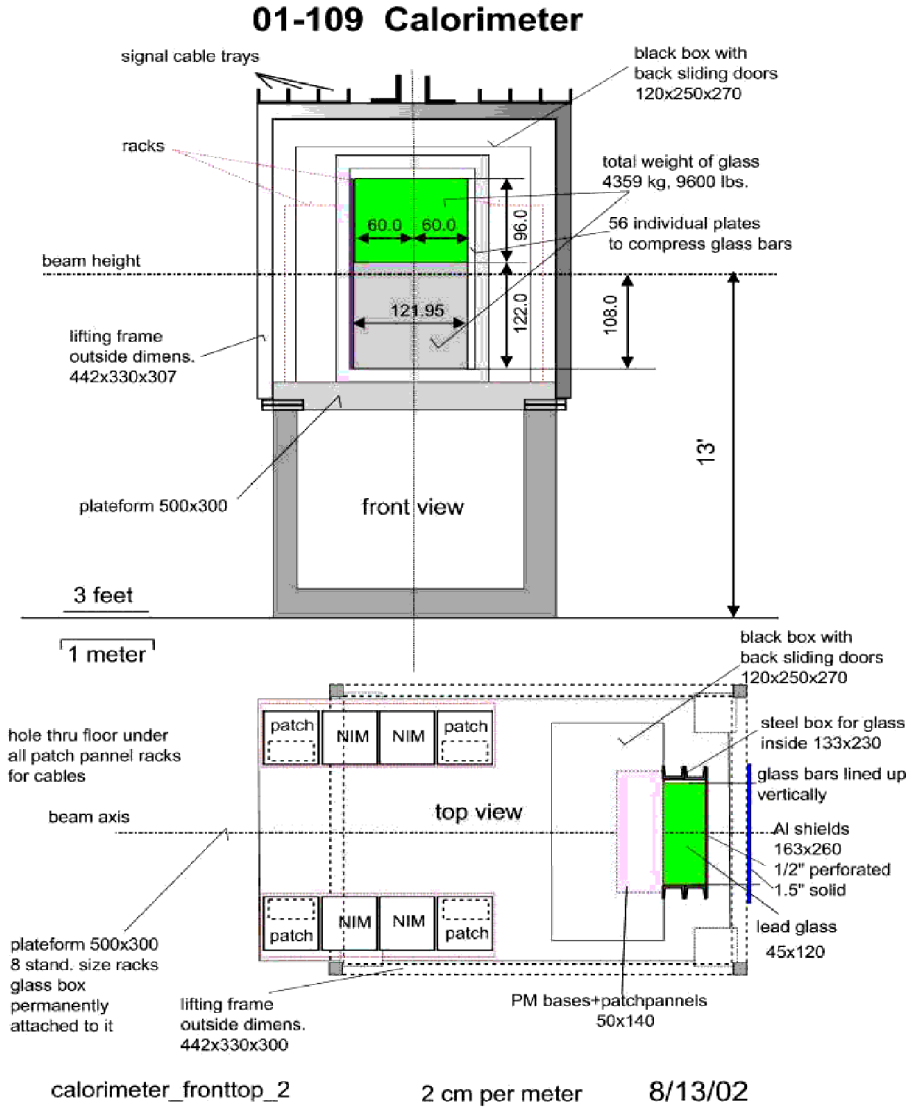
SANE Current Design (1/06)

BETA



SANE Status – Subsystems(I)

- BigCal Calorimeter for ***GEp-III***
- 1744 lead crystals, all PMT's and bases installed
- 3 platforms: Glass and mutiplexers, cables and floor electronics
- Replaced optical grease couplings between PMT and glass with silicone cookies.
- Added permanent perforated Al front plate with 1744 5mm holes
- Completed 2nd. round of cosmic ray tests on Protvino glass, RCS glass in progress
- Three IHEP physicists worked 6 mos. in 2005; two others coming in 2006.



SANE Status – Subsystems(II)

- BigCal Calorimeter for ***GEp-III***
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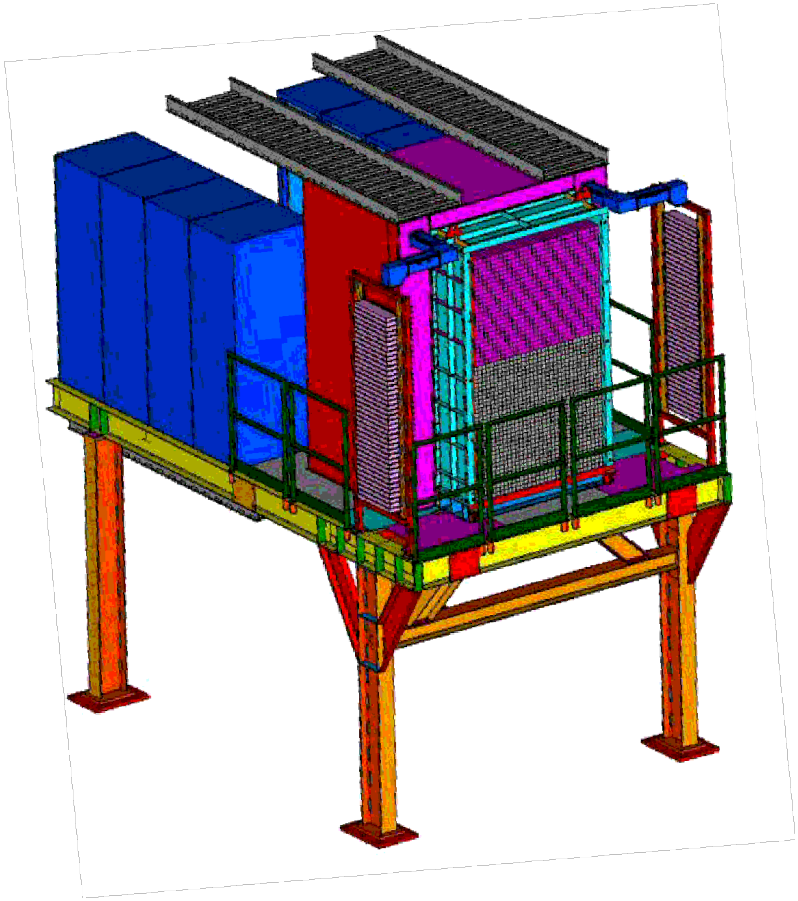
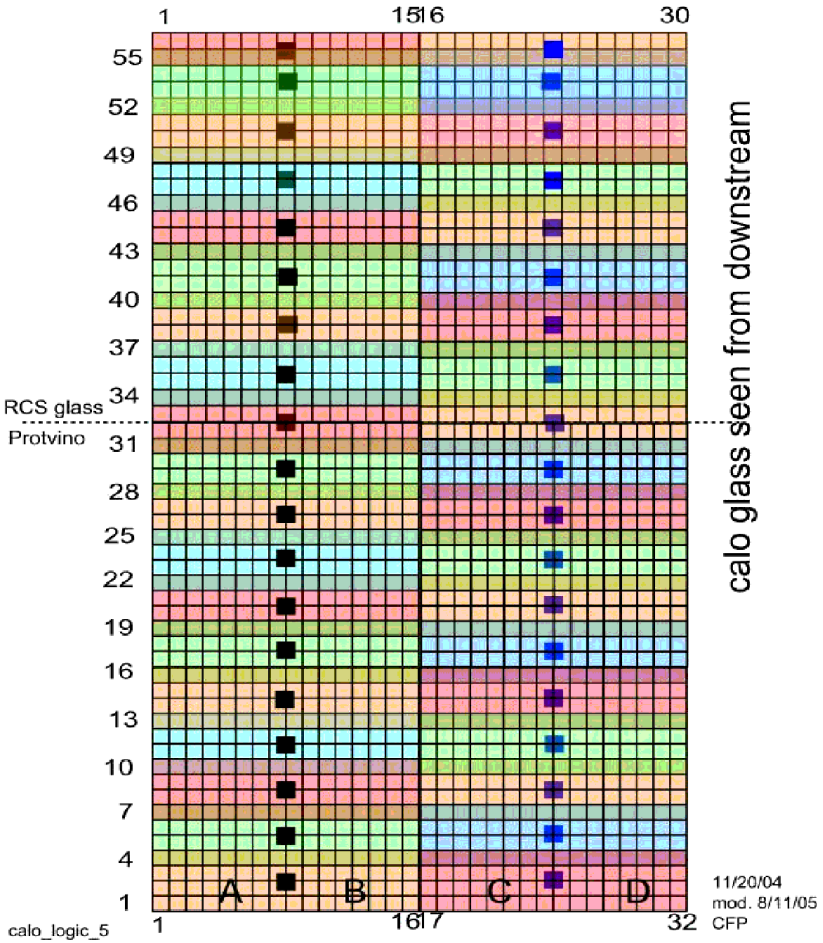


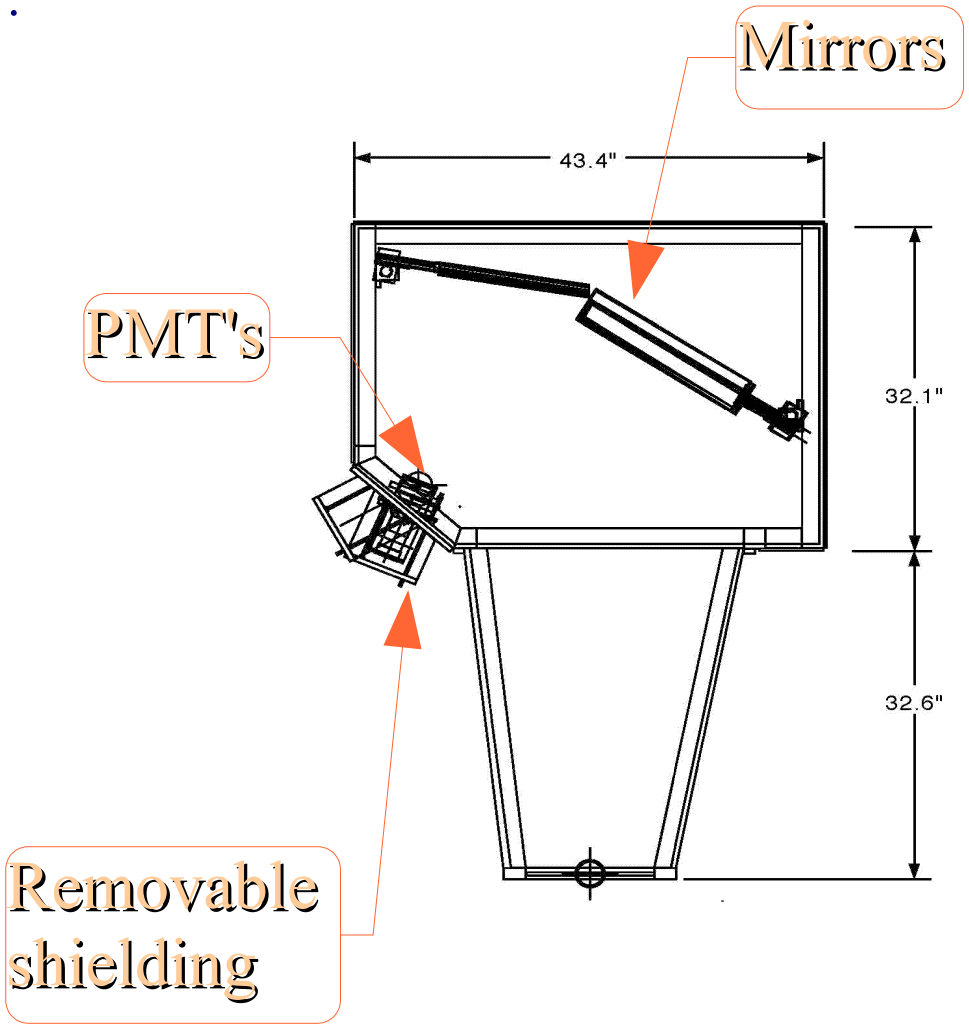
SANE Status – Subsystems(III)

- BigCal Trigger for ***GEp-III***:
  - signals from every 8 crystals summed by 244 first summing modules
    - 5x signals to ADC's
    - 1x signals to second level
  - every 8 first modules added in 38 second summing modules.
  - every fourth row duplicated in second summing modules
  - all modules in hand at JLab
- MC trigger simulations (V. Kravtsov) show good efficiency with overlaping groups
- For SANE: integrate P. Degtiarenko particle generator for BETA with IHEP A. Puckett code



SANE Status - Subsystems (IV)

- Temple U.'s modular design of gas Cherenkov:
  - 4 spherical mirrors
  - 4 elliptical mirrors
  - 8 3" PMT's on side far from beam
  - Mirror section decouples from upstream drift section
  - PMT positions can be adjusted in multiple ways
- Frame being built by Alpha Tool (NJ)



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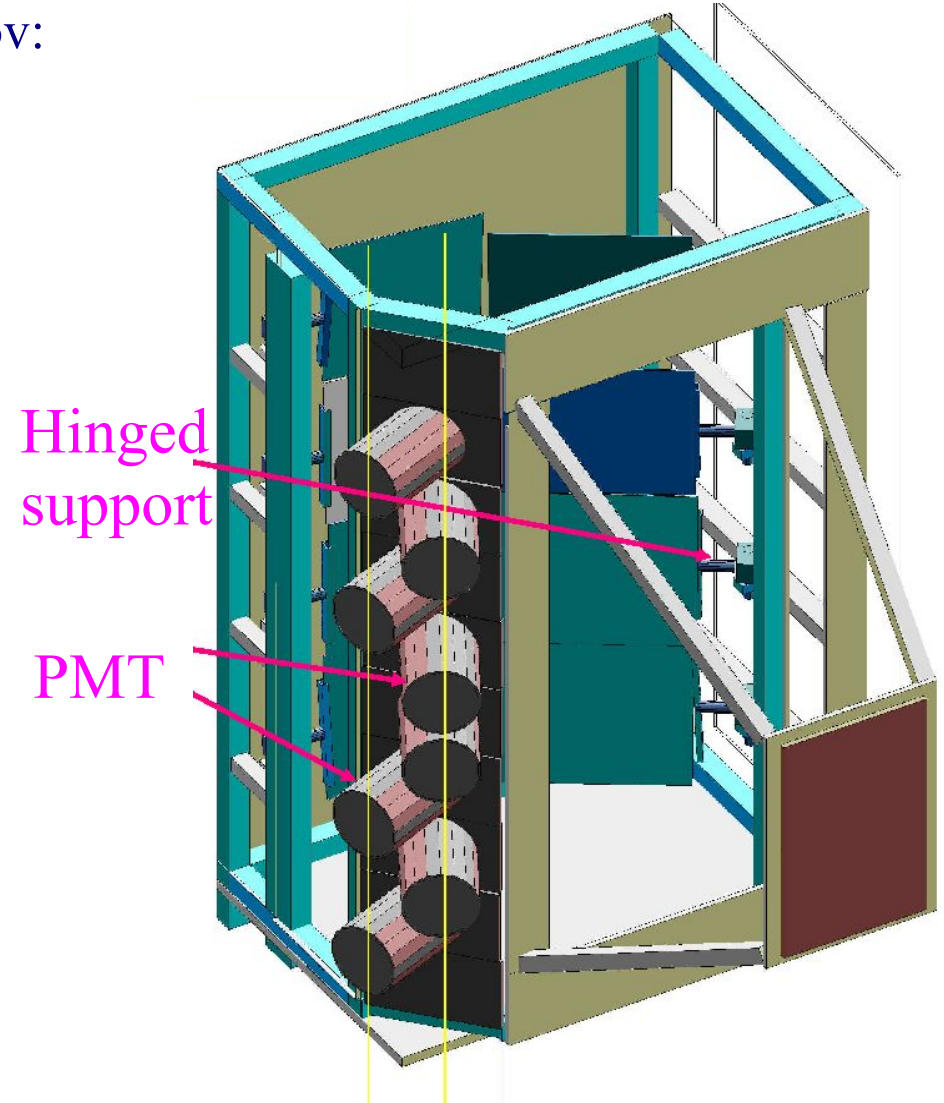
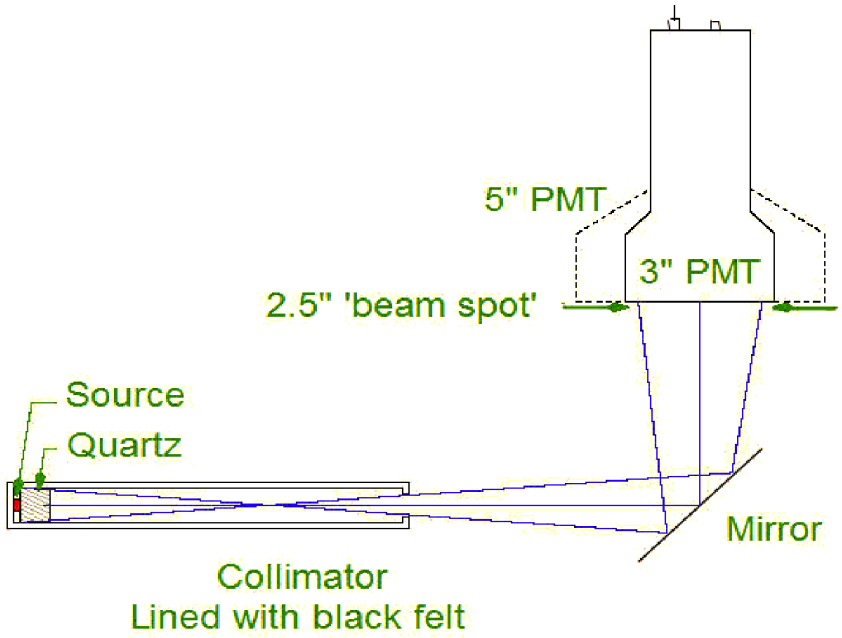


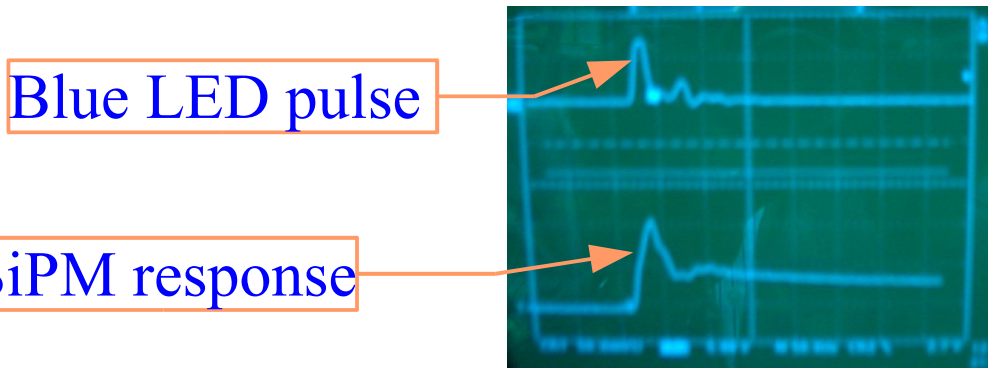
SANE Status - Subsystems (V)

- Tested sample mirror for three gases, N_2, CO_2 and air, and two PMT types:
  - Burle: ~82% reflectivity (expected)
  - Photonis: ~97% (under review)
- Readout may use flash ADC's (S. Wood report, 6/04)
- Dedicated tests of the Cherenkov are planned during GEp-III



SANE Status – Subsystems (VI)

- Forward tracking hodoscope
  - Next to target OVC, much improved tracking resolution vs. reference design
  - Quartz as Cherenkov material:
    - 36 35x5x3 mm^3 vertical bars x 2x64 20x5x3 mm^3 horizontal bars
    - SaintGobain Spectrasil 2000 test bars 35x5x3 mm^3
    - Attenuation tests using GEp-III setup in EEL
  - SiPM 3x3 mm^2 light detectors purchased by Hall C for tests, operate at 2 T
  - UVA purchased Channel PM with response in UV, quartz window
- M. Khandaker (NSU) leads project
- P. Bosted proposed device

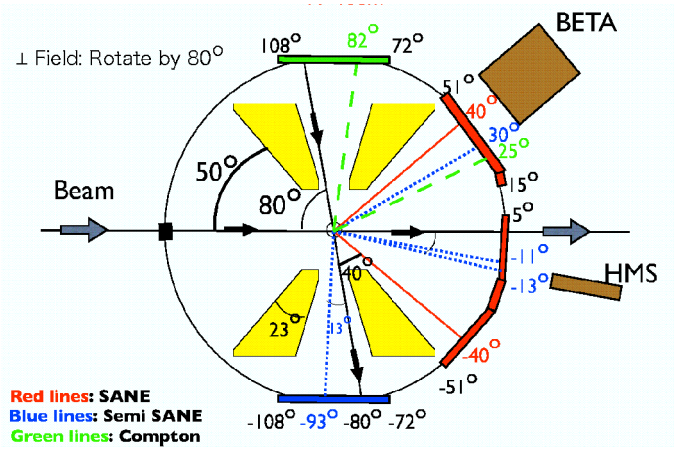


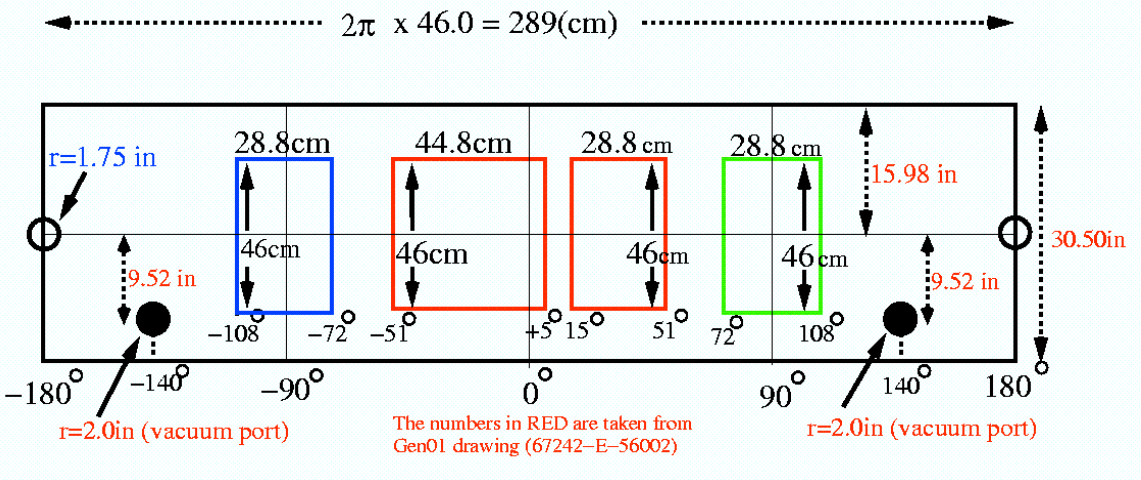
SANE Status - Subsystems (VII)

- Lucite Hodoscope reference design
    - 8 160x10x1.2 cm^3 vertical bars x 16 80x10x2.5 cm^3 horizontal bars
- Sam Danagoulian and Abdellah Ahmidouch of N.C. A&T State joined SANE with plan to build hodoscope
- N.C. A&T preliminary design uses 32 5-cm wide, 3.8 cm thick horizontal bars
  - Horizontal position determined from mean timing with 1” PMT's at both ends
  - Improves reference design vertex and angular resolution by better than factor of 2 to 4cm *x* by 8 cm *y* RMS vertex and 1° angular resolutions
  - Michael Olson, St. Norbert College (WI) interested in contributing with expertise
  - Kent S. U. graduate students (M. Petratos) will help

SANE Status - Subsystems (VIII)

- Polarized target outer vacuum can (OVC) design completed
  - S. Tajima (UVA) submitted apertures design to Hall C engineering staff
  - Hall C has completed FE analysis of can
    - minimum working thickness is ¼", recommended > = ½".
    - window thickness under design
- Nitrogen shield apertures design completed, support design in progress
- OVC expected ready for bids by March 2006. **Hall C funds available.**





SANE Status - Subsystems (IX)

- Gain Monitor: Lucite Plate excited by laser light
  - UVA (D. Počanić group) built similar for Hall B's RadPhi.
  - bench tests of glass response to Lucite light at UVA
  - integration with BigCal planned for 2005, postponed for 2006 due to BigCal light coupling and glass shifting
  - E. Frlez (UVA) and IHEP-Protvino will work on gain monitor
- Target Beam Position Monitor (Secondary Emission Monitor):
  - needed to determine beam raster position
  - sent to U. Basel for refurbishing and modification of electronics
  - electronics box will be moved away from above beam line

SANE Status - Progress on Open Issues as of 1/05

- Backgrounds and their reduction:
  - from target: pion and positron rejection/identification
    - V. Dharmawardane reviewed pair systematics: >20% error for E'<1.1 GeV, need to reduce background with software cut
    - But, in given x-Q^2 bin rate is dominated by small angle, high momentum events, so low E' cuts have small impact on statistics
    - P. Bosted: precision π° asymmetry possible with 0.7 GeV threshold; can be used to make pair symmetric asymmetry systematics negligible
- BigCal absolute energy calibration
  - *e-p* elastic scattering with HMS: kinematics and running time optimization
    - G. Huber analysis: 2-3 days of field on (2 polarities) / field off runs, detailed simulations to follow

SANE Status - Open Issues

- Backgrounds and their reduction:
  - from beam line: detailed simulation and shielding design:
    - Seonho Choi will direct student at Seoul U.
- BigCal absolute energy calibration
  - π° mass reconstruction: simulation and on-line code
- Target material: $^{14}NH_3$ or ^{7}LiH?
  - ^{7}LiH has superior radiation resistance, but in-beam polarization uncertain.
- Target platform design, integration with BETA stands

SUMMARY
Steady progress over 2 years
Could install by year's end if beam schedule allowed