SANE
Spin Asymmetries on the Nucleon Experiment
(TJNAF E03-109 / P07-003)

SANE Collaboration
U. Basel, Florida International U., Hampton U., Norfolk S. U., North Carolina A&T S. U.,
IHEP-Protvino, U. of Regina, Rensselaer Polytechnic I., Rutgers U., Seoul National U.,
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)
(E03-109 coauthor: G. Warren)

PAC31
January 29, 2007
Jefferson Lab

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 an inclusive double polarization measurement:
  - twist-3 effects from moments of g_2 and g_1:
    - d_2 matrix element = $\int_0^1 x^2 (3 g_2 + 2 g_1)\, dx$
  - comparisons with Lattice QCD, QCD sum rules, bag models, chiral quarks
  - Study x dependence (test nucleon models) and Q^2 dependence (evolution)
  - Exploration of "high" x region: A_1's approach to $x = 1$
  - Test polarized local duality for final state mass $W > 1.4$ GeV
- Method:
  - Measure inclusive spin asymmetries for two orientations of target spin relative to beam helicity (anti-parallel and near-perpendicular)
  - Detect electrons with novel large solid angle electron telescope **BETA**
- **JLAB is unique facility for measuring complete transverse spin structure**

Transverse Spin Structure Function

- Polarized longitudinal structure function has simple parton model interpretation

$$g_1(x) = \sum e_i^2 \Delta q_i(x), \qquad i = u, \bar{u}, d, \bar{d} \ldots$$

- g_2 is combination of twist-2 and twist-3 components:

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

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

  - *W*andzura-*W*ilczek g_2^{WW} depends on g_1; h_T is twist-2 chiral odd transversity
  - ξ represents quark-gluon correlations (twist-3).

- Transverse spin structure function g_T measures spin distribution normal to virtual γ

$$g_T = g_1 + g_2 = \int_x^1 \left[g_1 - \frac{\partial}{\partial x'} \left(\frac{m}{M} h_T + \xi \right) \right] \frac{dx'}{x'} = \frac{\nu}{\sqrt{Q^2}} F_1(x, Q^2) A_2(x, Q^2)$$

Transverse Spin Structure Sum Rules

- OPE: moments of g_1, g_2 related to twist-2 (a_N), twist-3 (d_N) matrix elements.

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

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

- d_N measure twist-3 contributions (related to for $m \ll M$ and h_T not too large.)

$$d_N(Q^2) = \frac{2(N+1)}{N}\int_0^1 x^N \overline{g_2}(x,Q^2)\,dx$$

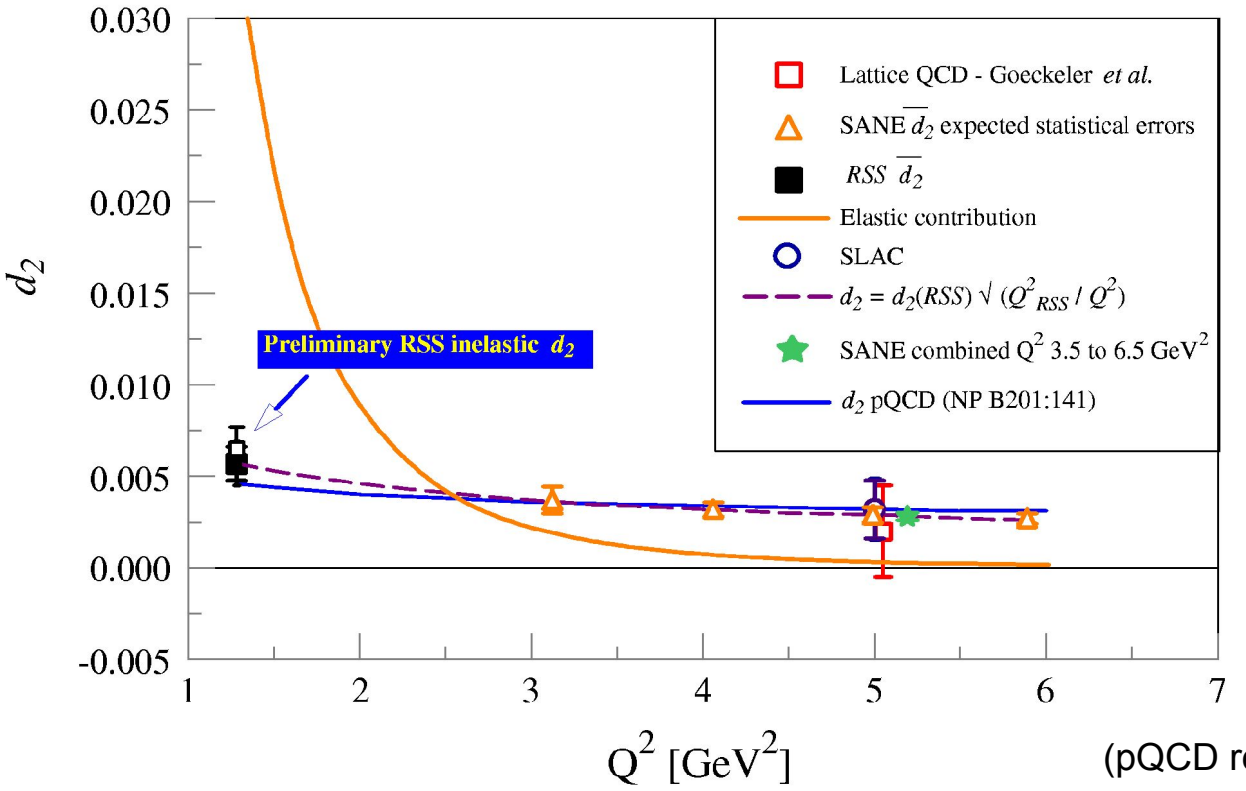
- Burkhardt-Cottingham
  - not from OPE

$$\int_0^1 g_2(x)\,dx = 0$$

- Efremov-Leader-Teryaev
  - valence quarks combining with $g_{2,1}^{\,n}$ from Hall A

$$\int_0^1 x\left(g_1^V(x) + 2\,g_2^V(x)\right)dx = 0$$

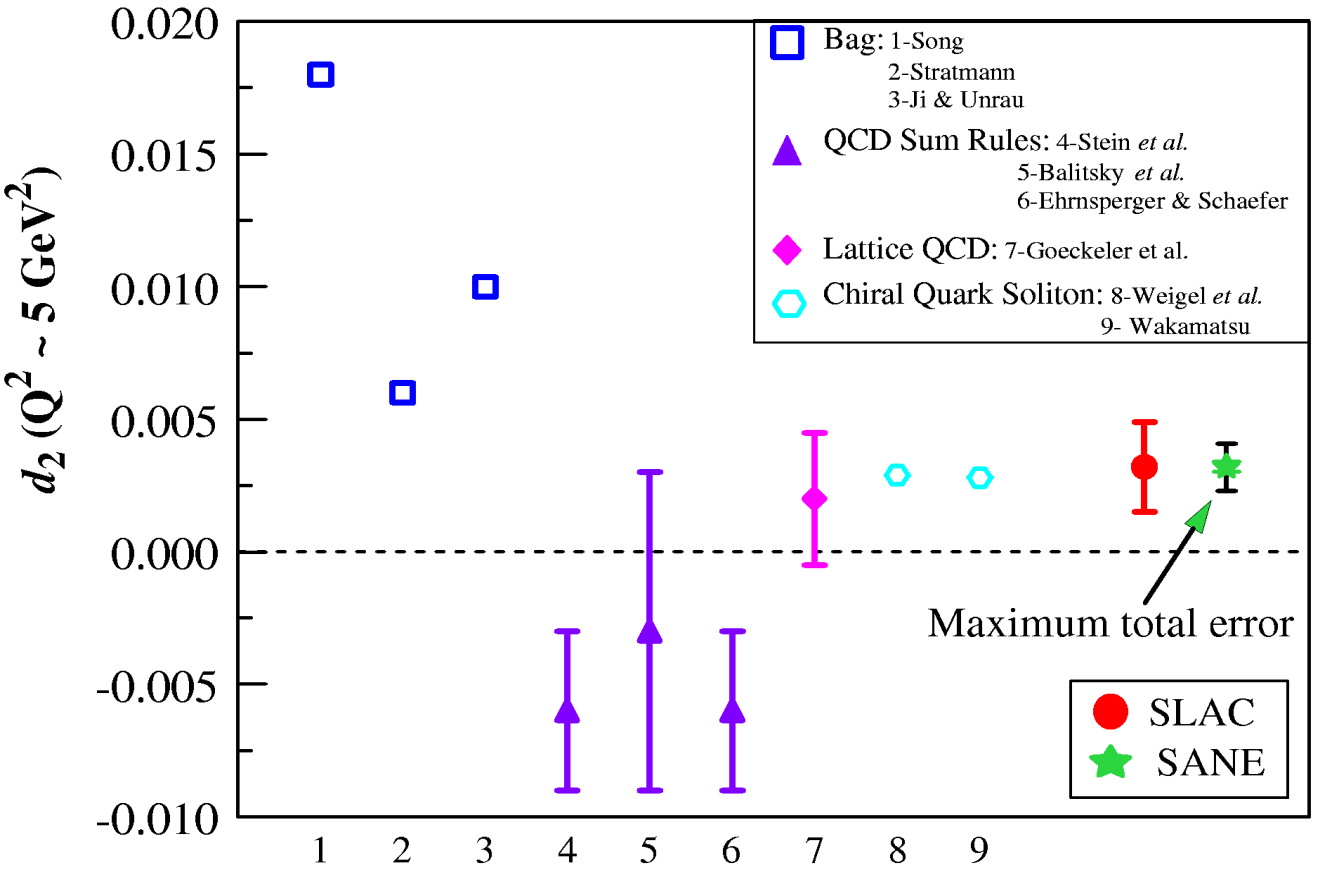
SANE Expected Results



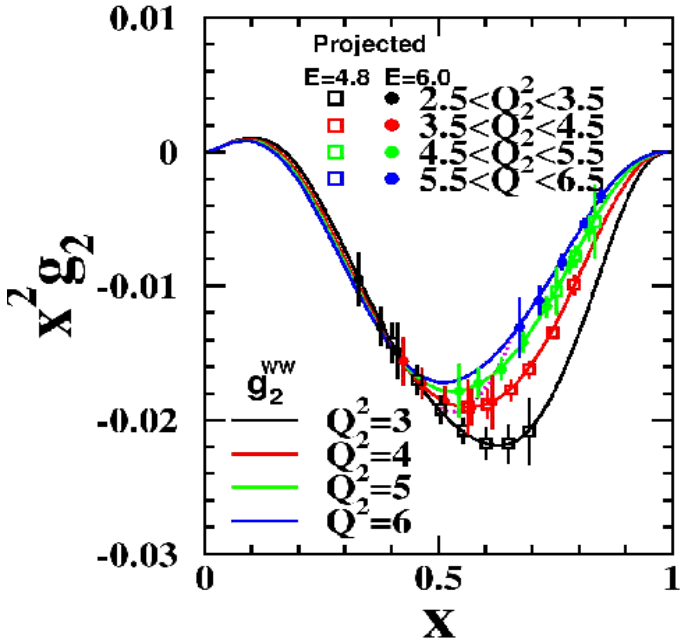
(pQCD ref. from A. Deur)

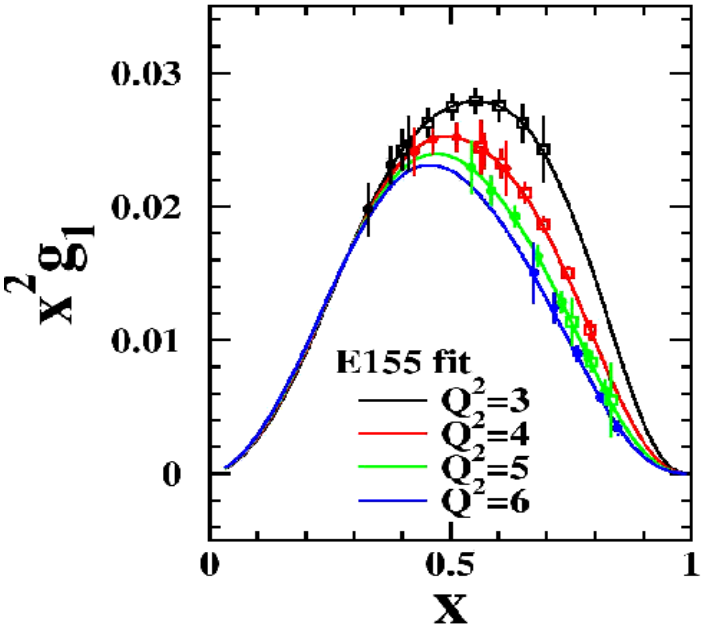
- SANE expected errors for $\overline{d_2} = \int_{xmin}^{xmax} x^2 (2g_1 + 3g_2) dx$
  - $\delta\overline{d_2}(Q^2 = 3\text{GeV}^2) = 7\text{x}10^{-4}$ for $0.29 < x < 0.85$
  - $\delta\overline{d_2}(Q^2 = 3.5 \text{ to } 6.5\ \text{GeV}^2) = 2\text{x}10^{-4}$ for $0.41 < x < 0.96$

SANE Expected Results (Ia)



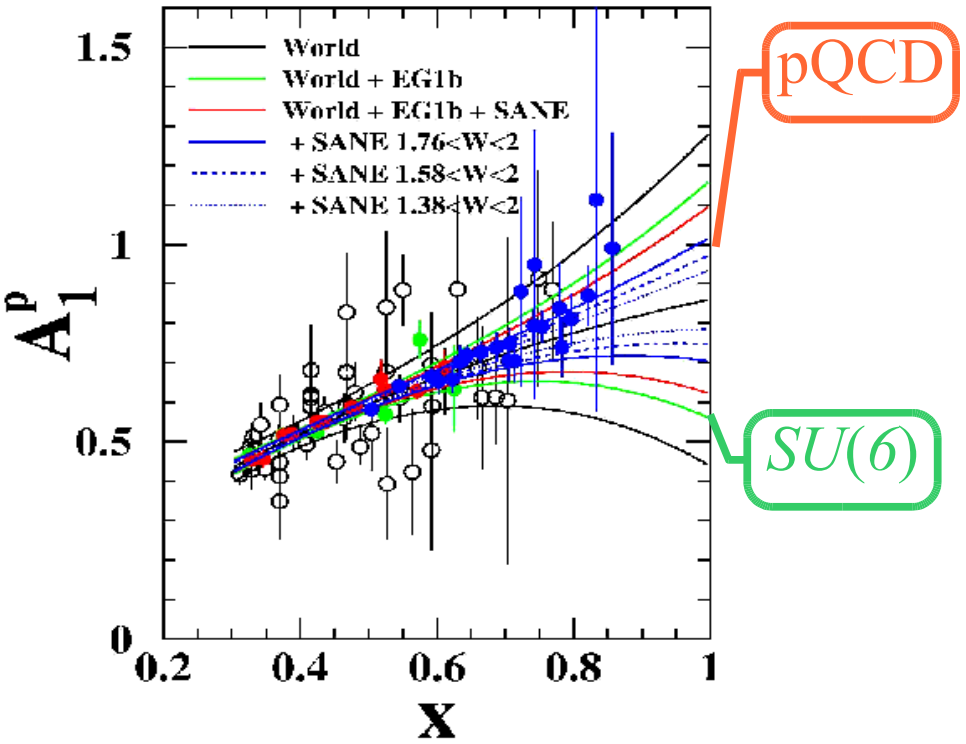
SANE Expected Results (II)

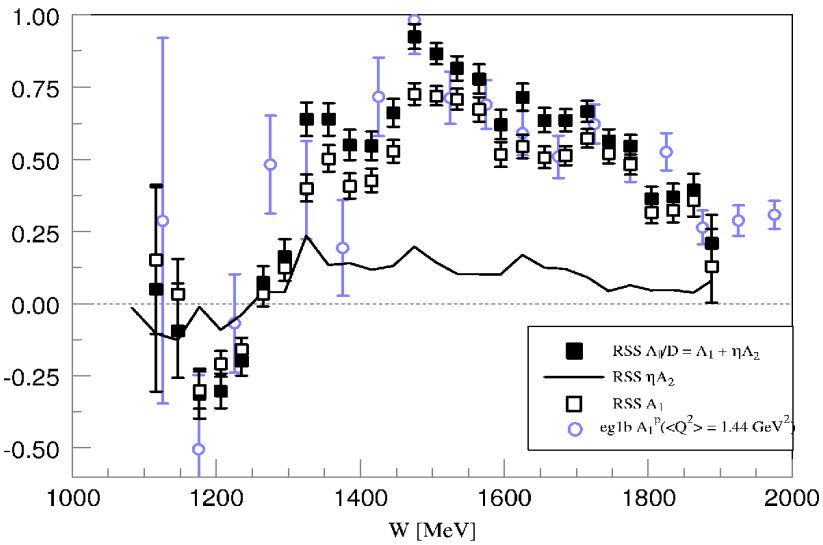




- x dependence at constant Q^2 and Q^2 dependence at fixed x (illustrative binning)
- data are concentrated in the region most sensitive to $x^2 g_{2,1}$
  - (estimates based on 75% beam and target polarization and 85 nA beam current)

SANE Expected Results (III)



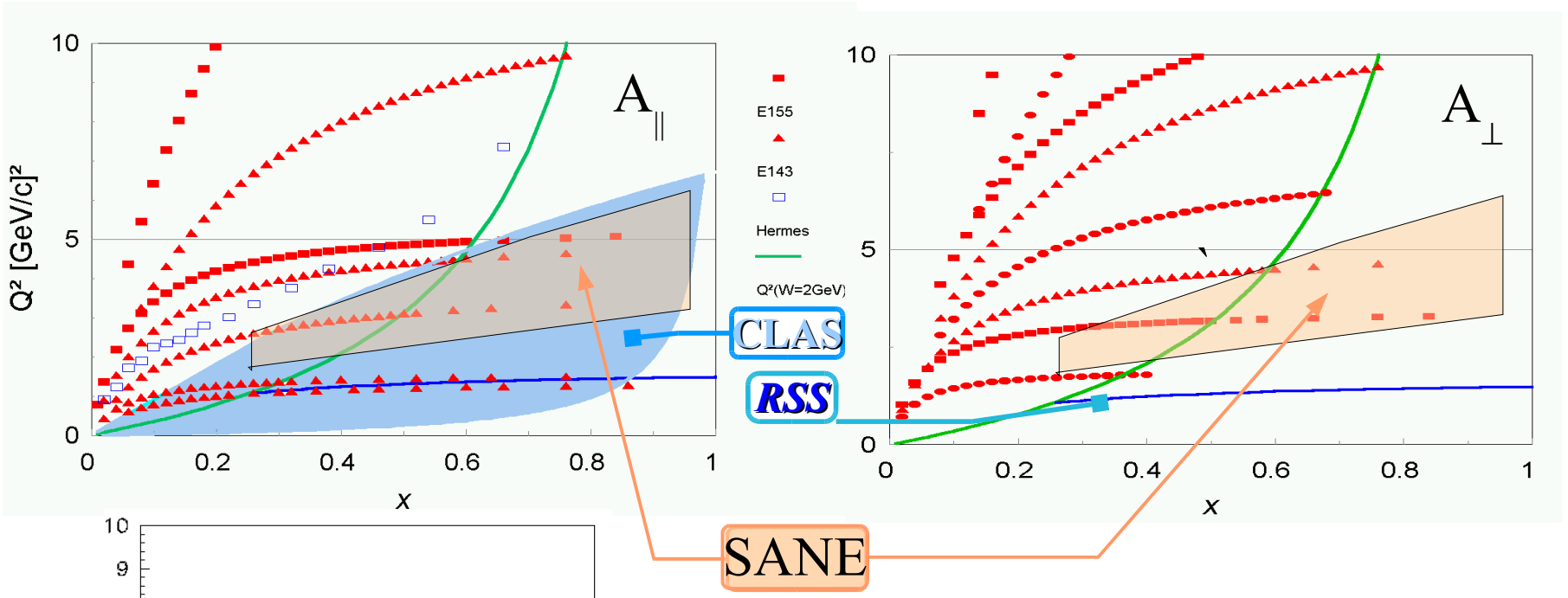


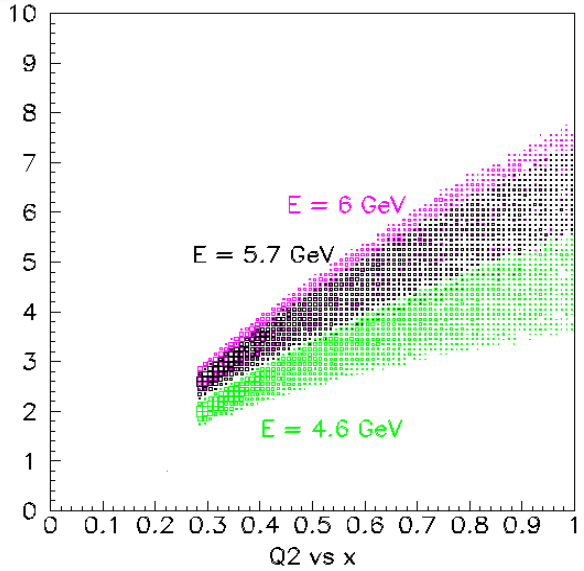
$$A_1 = \frac{1}{(E+E')D'}\left((E - E'\cos\theta)A_{\parallel} - \frac{E'\sin\theta}{\cos\phi}A_{\perp}\right)$$

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

- Constrain extrapolations of A_1^p to $x = 1$ within +/- 0.1 (using duality)
- Both $A_{\parallel}$ and $A_{\perp}$ are required to get accurate, model-free A_1: $A_2 > 0$
- SANE's measured A_2 will contribute to improve world's A_1 data set

World data on $A_{\parallel}$, $A_{\perp}$ and SANE kinematics





- Two beam energies: > **5.7 GeV**, **4.6 GeV**
  - (small loss from **6 GeV**)
- Very good high ***x*** coverage with detector at 40°
  - (plot at left from GEANT simulation)

SANE Design

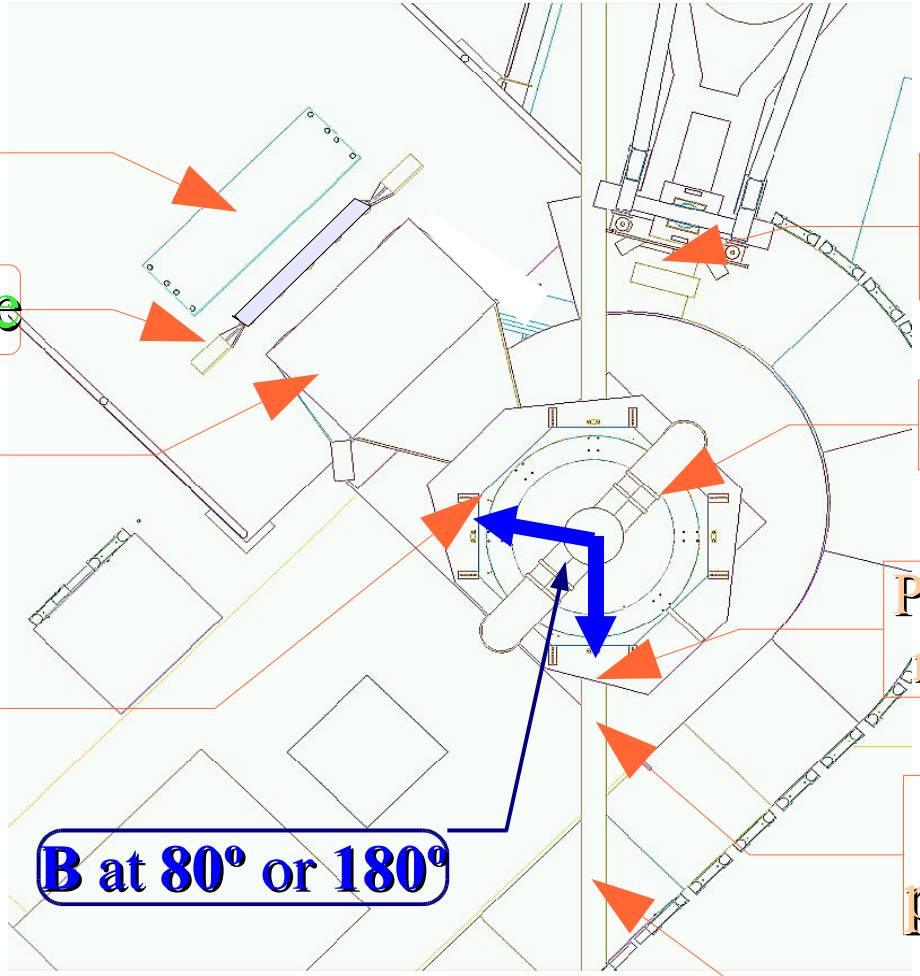
BETA (40º)

BigCal
w. Gain Monitor

Lucite Hodoscope

Gas Cherenkov

Forward
Hodoscope



HMS (13°- 48°)
calibrations, backgd.

Polarized Target

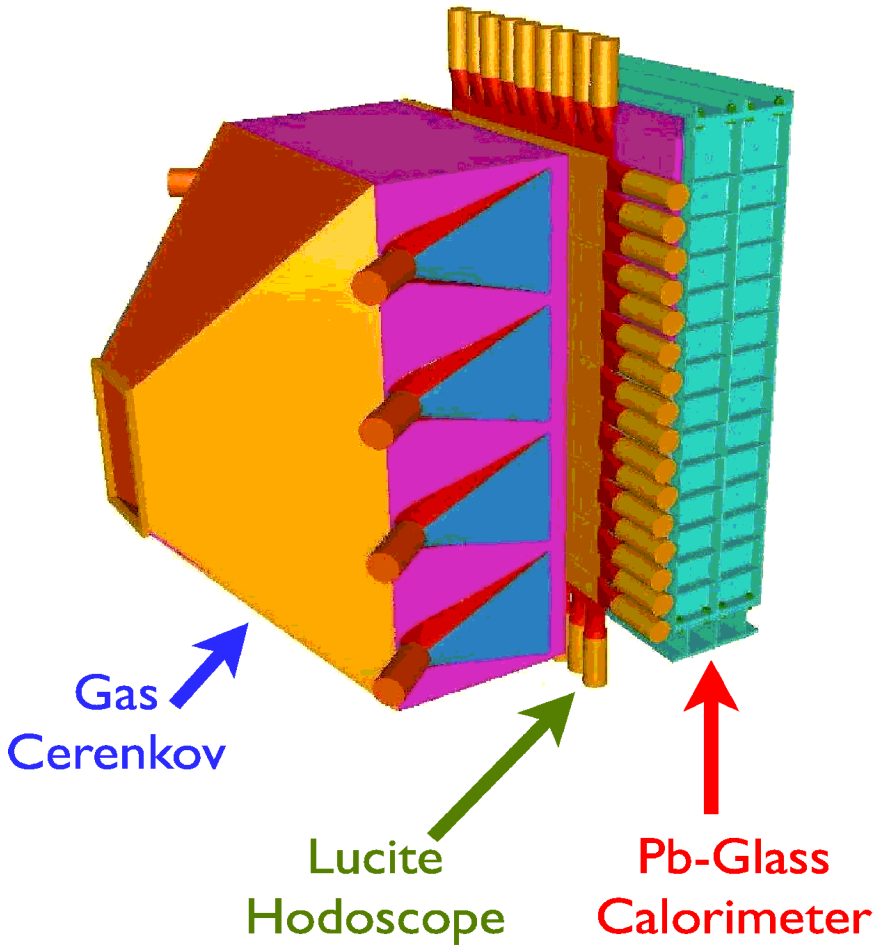
Polarized Compton
radiator (~20 cm)

Target Beam
position monitor

Beam Line

Big Electron Telescope Array - BETA

- **BigCal** lead glass calorimeter:
  main detector, being built for *GEp-III.*
- **Gas Cherenkov**: additional pion rejection
- Tracking **Lucite hodoscope**
- BETA's characteristics
  - Effective solid angle = 0.194 sr
  - Energy resolution 5%/$\sqrt{E}$(GeV)
  - angular resolution < 0.8°
  - 1000:1 pion rejection
- Added: **forward hodoscope**
  - vertex resolution ~ 5 mm
  - angular resolution ~ 1 mr
- Target field sweeps low *E* background



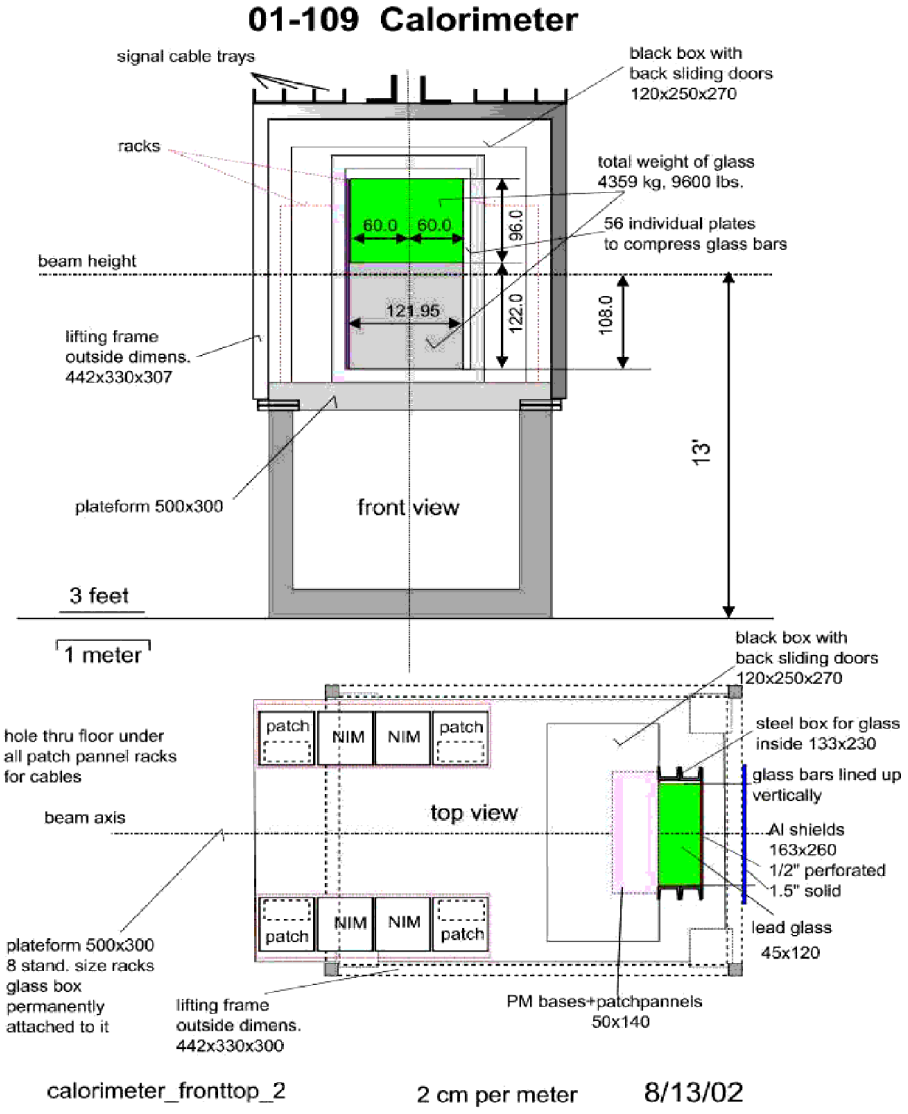
(Reference design)

SANE Status - Subsystems

- BigCal
  - Operation: William & Mary, Protvino, Rensselaer, UVA, Hall C
  - Trigger: Rutgers U.
  - Gain Monitor: UVA
  - Calibration: U. Regina
- Gas Cherenkov: Temple U.
- Forward Tracking Hodoscope: Norfolk S.U., Hall C
- Lucite Hodoscope: North Carolina A&T S.U.
- Polarized Target: UVA, JLab
- Shielding design: Seoul U.
- HMS: Yerevan P. I.
- Target Beam Position Monitor: U. Basel, UVA
- Beam Line: Hall C, UVA

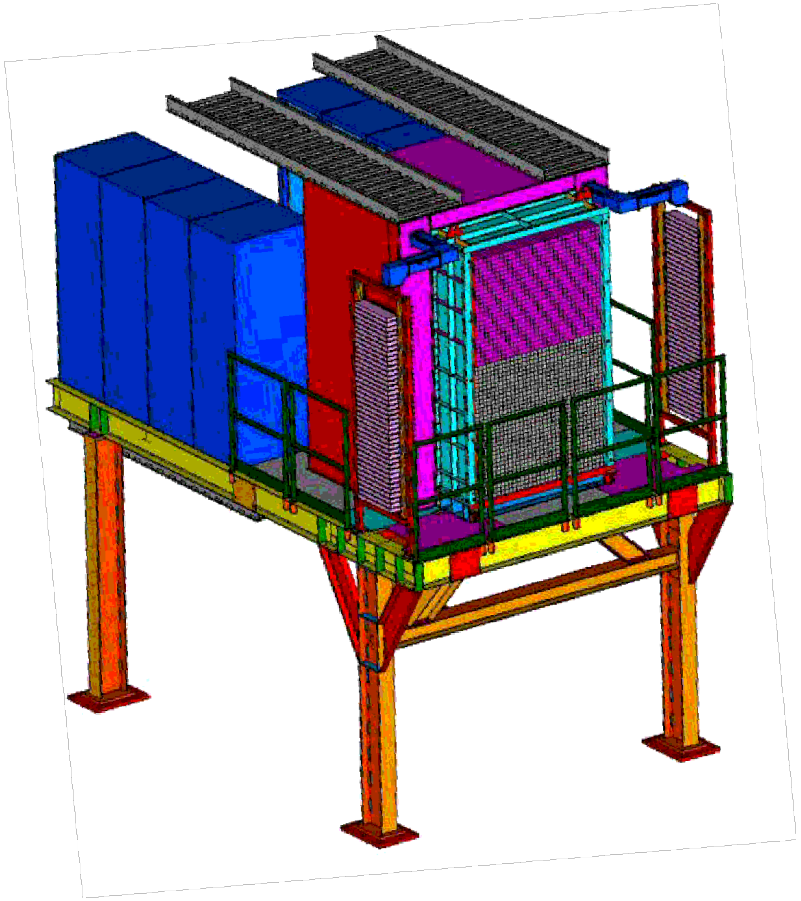
SANE Status - Subsystems(I)

- 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 cosmic ray tests, cabling
- Ongoing: DAQ setup, tube response to cosmics vs gain monitor system, gain monitor final design/installation



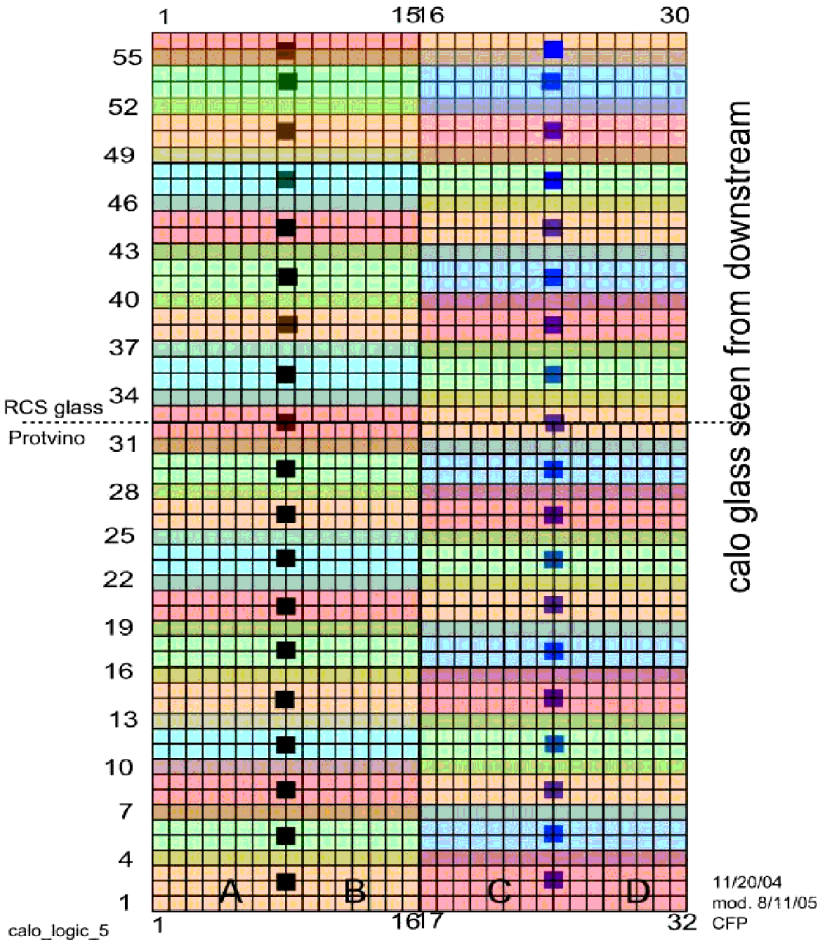
SANE Status - Subsystems(II)

- 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 cosmic ray tests, cabling
- Ongoing: DAQ setup, tube response to cosmics vs gain monitor system, gain monitor final design/installation



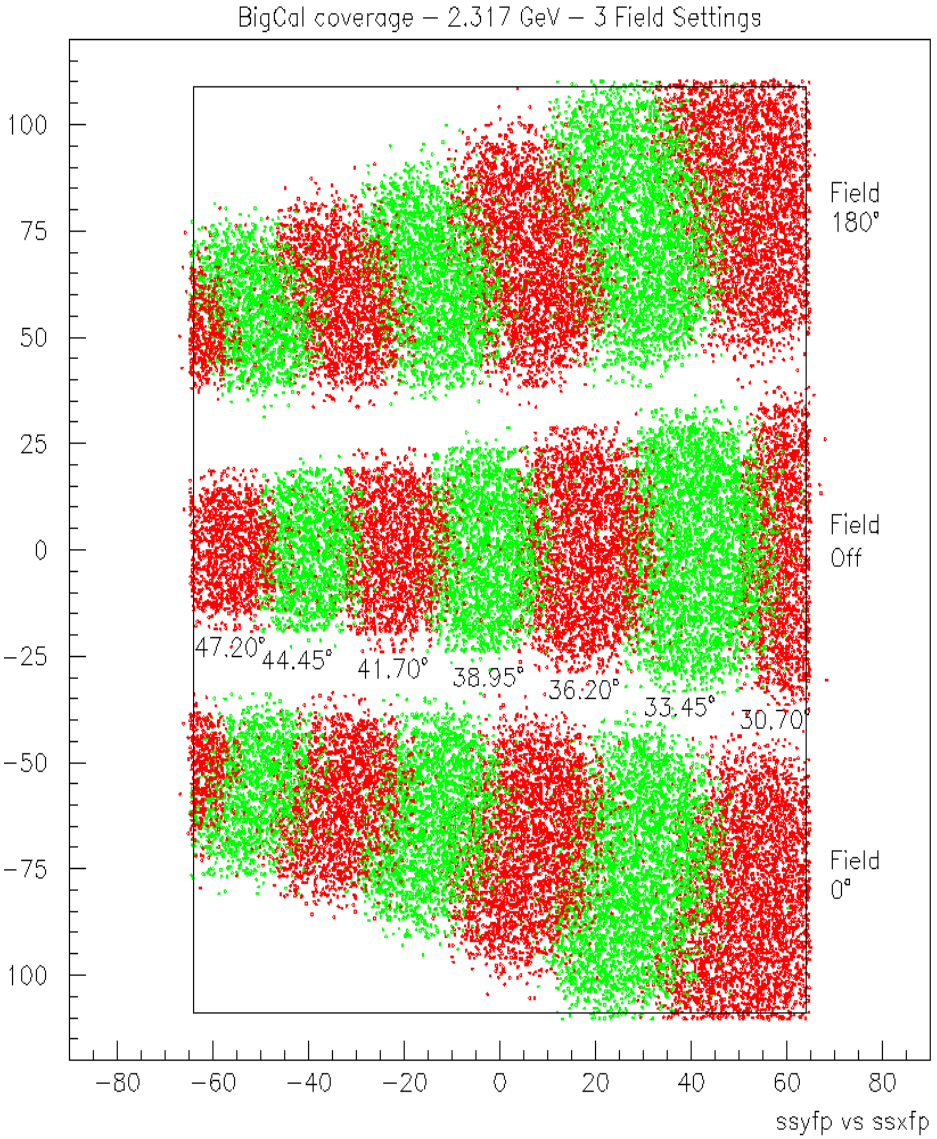
SANE Status - Subsystems(III)

- 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 39 second summing modules.
  - every fourth row duplicated in second summing modules
- MC trigger simulations show good efficiency with overlaping groups
- For SANE: integrate BETA's particle generator with IHEP-A. Puckett BigCal code



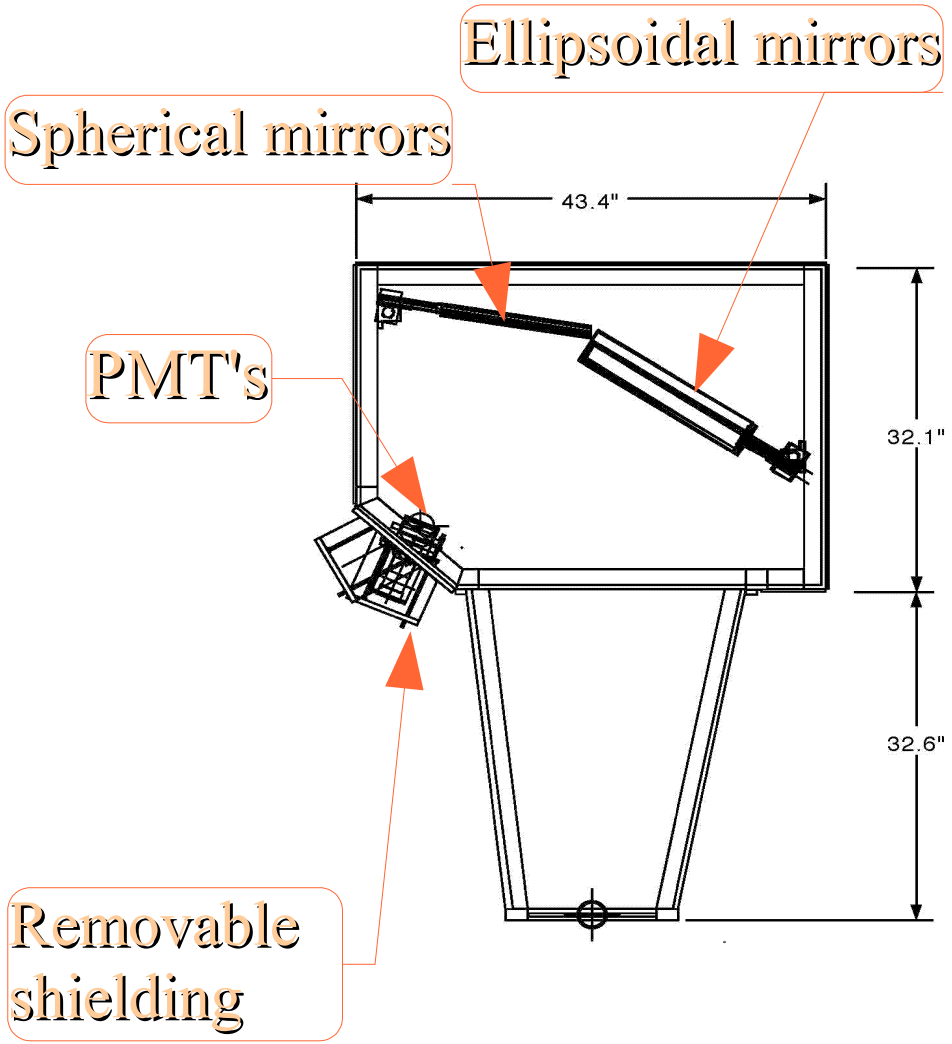
SANE Status - Subsystems(IV)

- BigCal Energy Calibration:
  - e+p elastic coincidences with p detected in HMS, NH_3 target, 1 μA
  - one pass with target field off
  - two passes with full field on, pointing in opposite directions along beam, two passes with half field on
  - 2.3 GeV beam, no beam deflection
  - 90% coverage of BigCal (5 passes; 75% with 3 passes)
  - 47 h (5 passes, 100% efficiency) or 29 h (3 passes)
- Continuous π^0 mass reconstruction



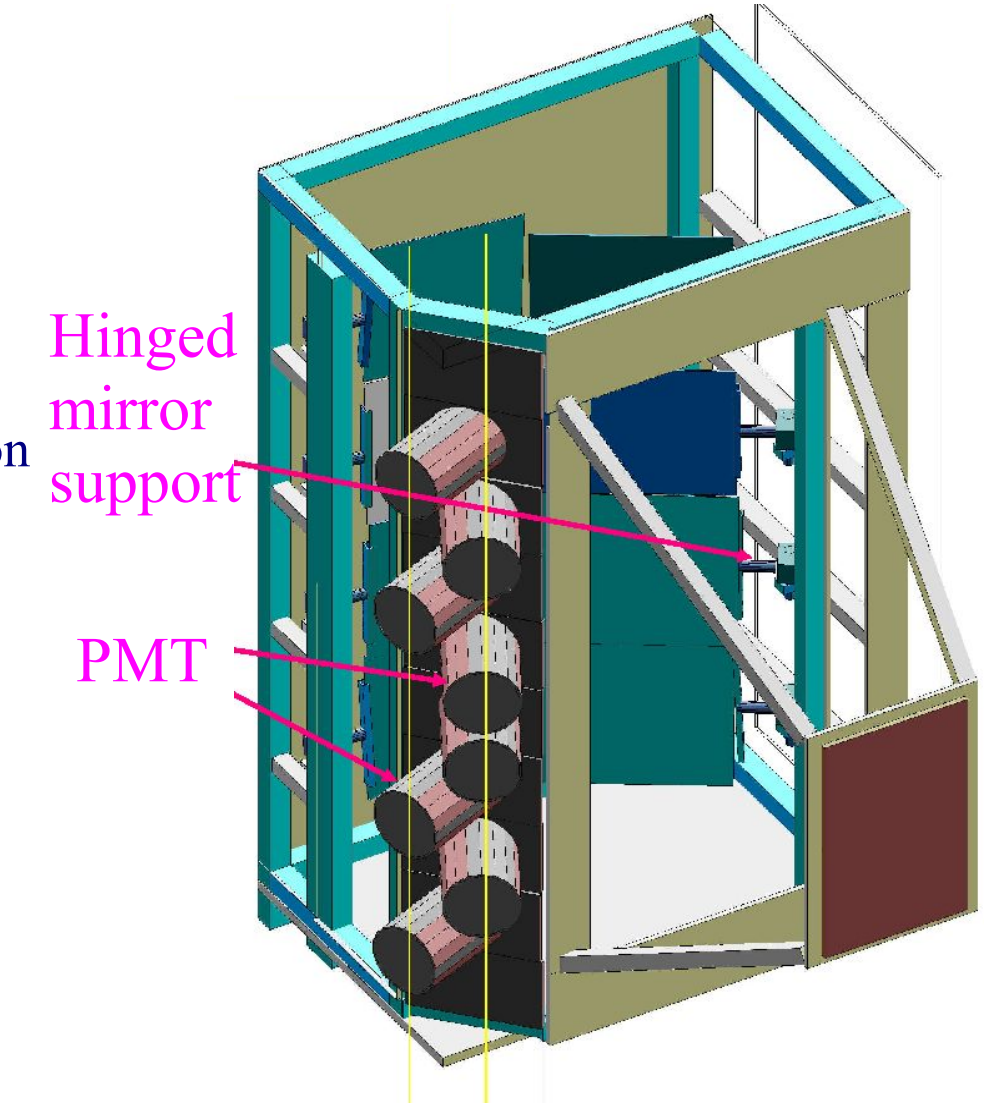
SANE Status - Subsystems (V)

- Temple U.'s modular design of gas Cherenkov:
  - four spherical mirrors
  - four ellipsoidal mirrors
  - eight 3" PMT's on side far from beam
  - shielded for 50:1 magnetic field reduction
  - Mirror section decouples from upstream drift section
  - PMT positions adjustable in multiple ways
- Frame built by Alpha Tool (NJ) delivered
- Mirrors shipped to CERN for coating
- Photonis PMT's on hand
- Used only Temple grant funds



SANE Status - Subsystems (VI)

- Temple U.'s modular design of gas Cherenkov:
  - four spherical mirrors
  - four ellipsoidal mirrors
  - eight 3" PMT's on side far from beam
  - shielded for 50:1 magnetic field reduction
  - Mirror section decouples from upstream drift section
  - PMT positions adjustable in multiple ways
- Frame built by Alpha Tool (NJ) delivered
- Mirrors shipped to CERN for coating
- Photonis PMT's on hand
- Used only Temple grant funds



SANE Status - Subsystems (VII)

- Temple U.'s modular design of gas Cherenkov:
  - four spherical mirrors
  - four ellipsoidal mirrors
  - eight 3" PMT's on side far from beam
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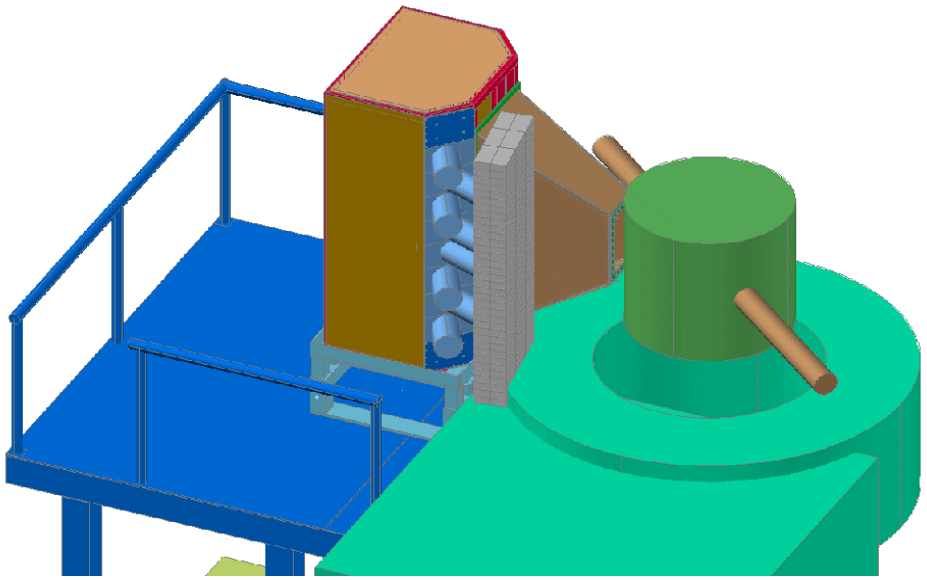
  - PMT positions adjustable in multiple ways



- Frame built by Alpha Tool (NJ) delivered
- Mirrors shipped to CERN for coating
- Photonis PMT's on hand
- Used only Temple grant funds

SANE Status - Subsystems (VIII)

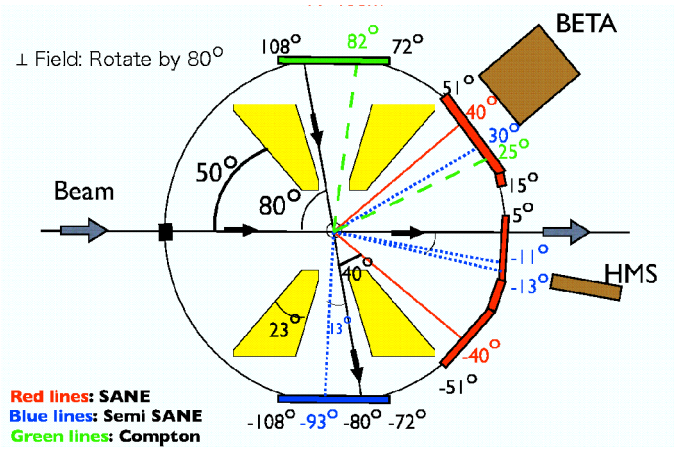
- Forward tracking hodoscope
  - Next to target OVC, much improved tracking resolution vs. reference design
  - covers full BETA solid angle with small device (40 cm x 22 cm)
  - charge sign separation for momenta < 1 GeV/c, background rate ~ 10 kHz/bar
  - Wavelengh shifting fibers glued on scintillator
    - 73 400(L) x 3(W) x 3(T) mm^3 vertical bars (*x*-coordinate)
    - 2 x133 220(L) x 3(W) x 3(T) mm^3 horizontal bars (*y*-coordinate)
    - ½ bar width overlap between *y* planes
    - resolution (sigma) ~ 0.9 mm
  - Readout by five 64-anode PMT's (Hamamatsu H7546B), on order
    - All 339 TDC channels available, 370 bars on hand, checking cables
  - Prototype tests Spring '07, full device tests Fall 2007.

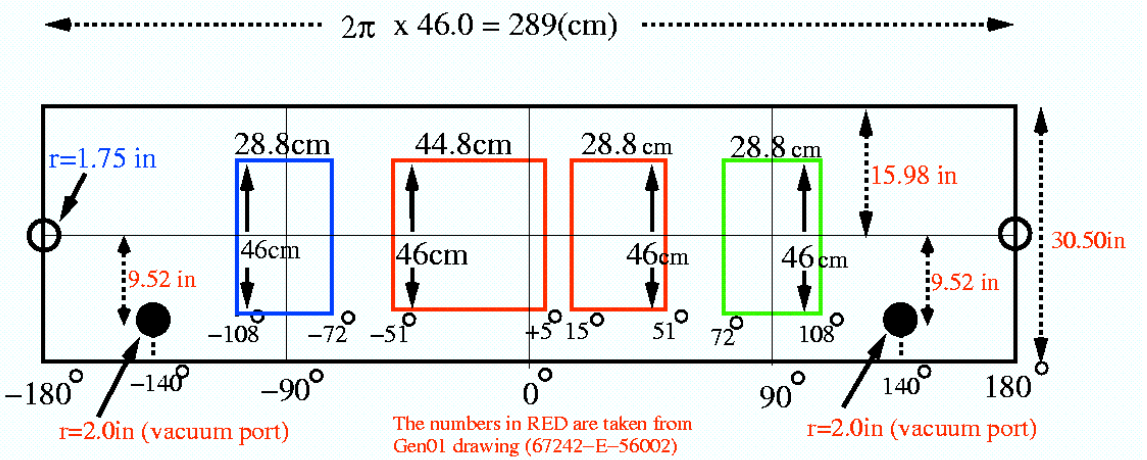
SANE Status - Subsystems (IX)

- Lucite Hodoscope current design
  - 28 80(L) x 6 (W) x 3.8 (T) cm^3 horizontal bars
    - curved bars to maximize light collection and angular selection
    - angled ends to maximize light collection
  - 2" PMT's at both ends: horizontal position by mean time; 32/60 purchased
  - Improves reference design's vertex and angular resolution by better than factor of 2: 4 cm *x* by 8 cm *y* RMS vertex, 0.8° angular resolutions
  - Need 56 electronics channels (TDC, discriminator, ADC, HV, cables)
  - Need frame design, construction
  - Prototype tests in 04/2007, construction 07-08/2007, fully tested 12/2007
  - Single layer design and planed tests address TAC concerns

SANE Status - Subsystems (X)

- Polarized target outer vacuum can (OVC) design completed
  - multi-use can (SANE, Semi-SANE, Compton)
  - Hall C has completed stress analysis of can
    - window thickness under design
- Nitrogen shield design completed
- OVC expected ready to start fabrication by March 2007.
  - 4 months fabrication, followed by Lab tests, 6 weeks installation

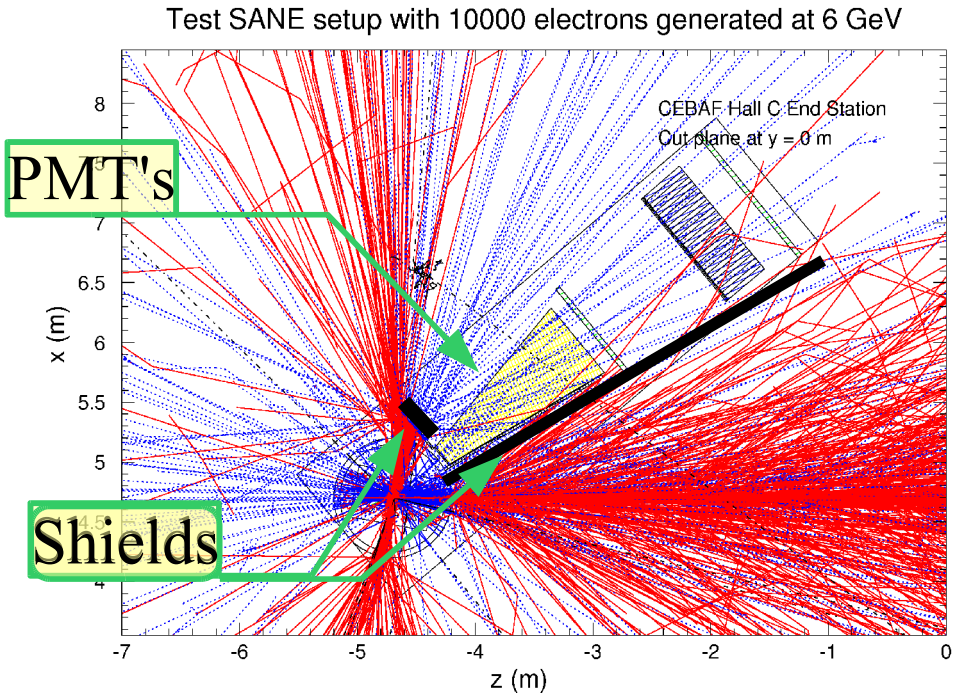


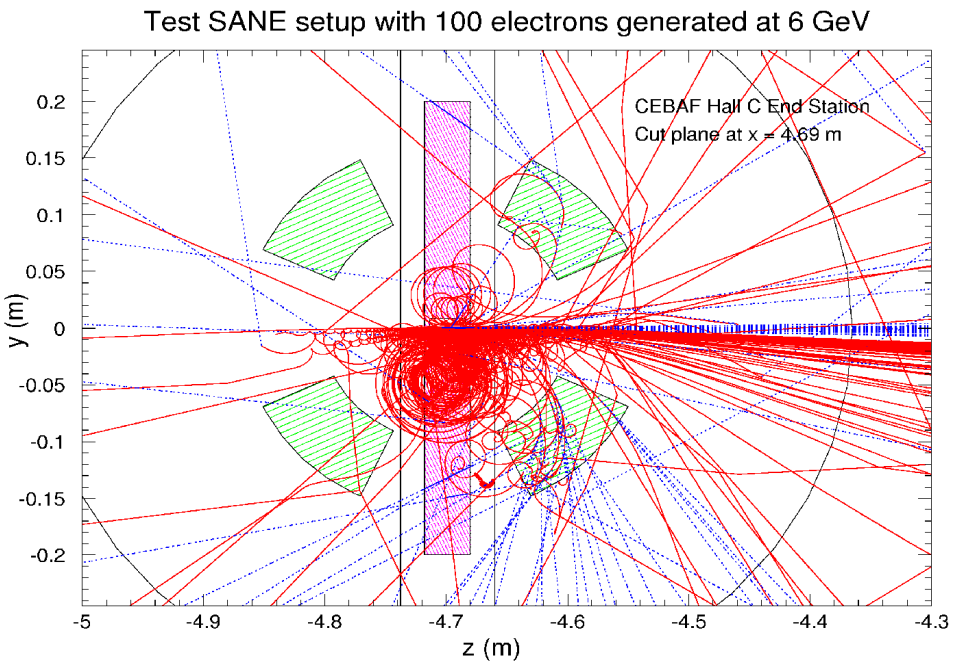


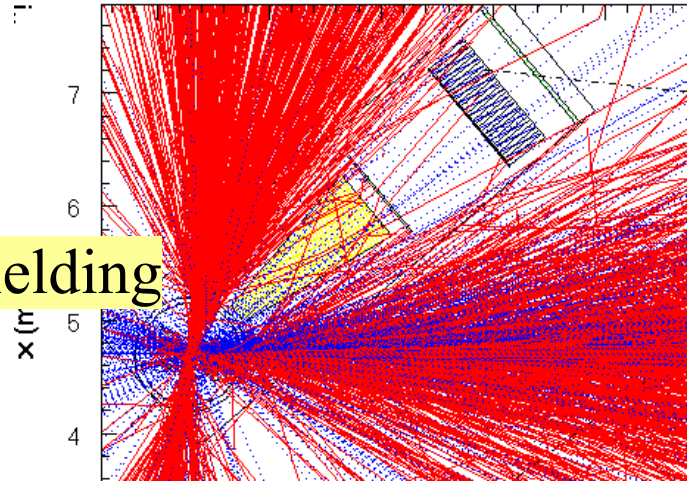
SANE Status - Subsystems (XI)

- BigCal Gain Monitor: Lucite Plate excited by laser light
  - UVA project (D. Počanić group; built similar one for Hall B's RadPhi)
  - successful tests of BigCal glass response to Lucite light done with prototype plate
  - integration with BigCal planned for 2007
- Target Beam Position Monitor (Secondary Emission Monitor):
  - needed to determine beam raster position (1 cm radius spiral)
  - refurbished at U. Basel (used in *GEn01* and *RSS*)
  - electronics box will be moved away from above beam line
- Downstream beam line:
  - He gas bag plus short beam pipe section
  - minimal modification of E-01-006 (*RSS*) design

Beam Line Background Studies (Seoul U.)

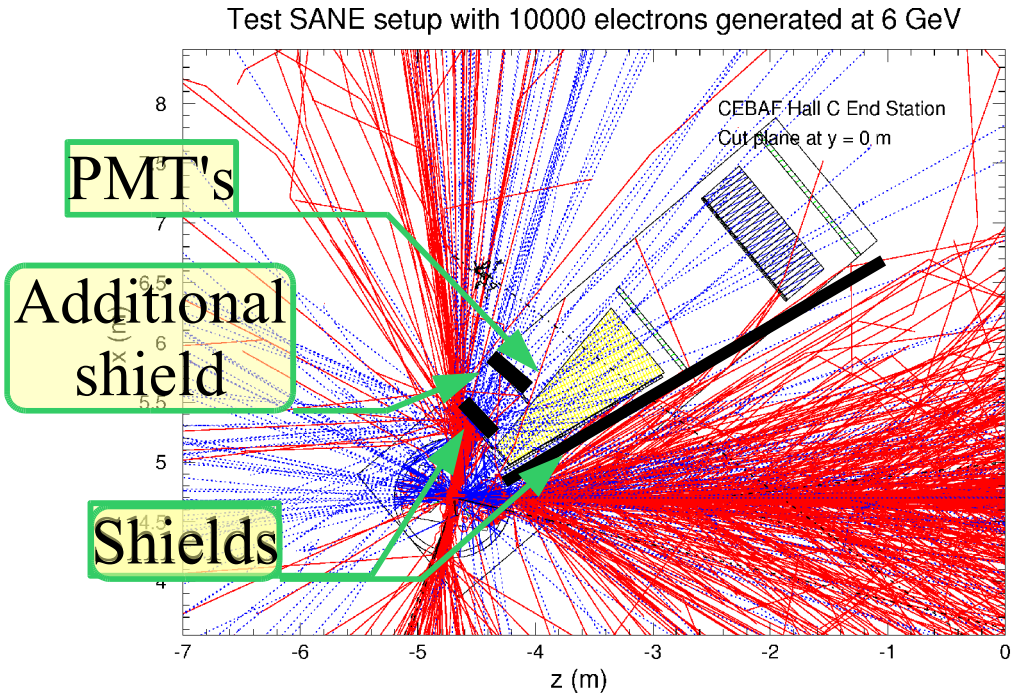


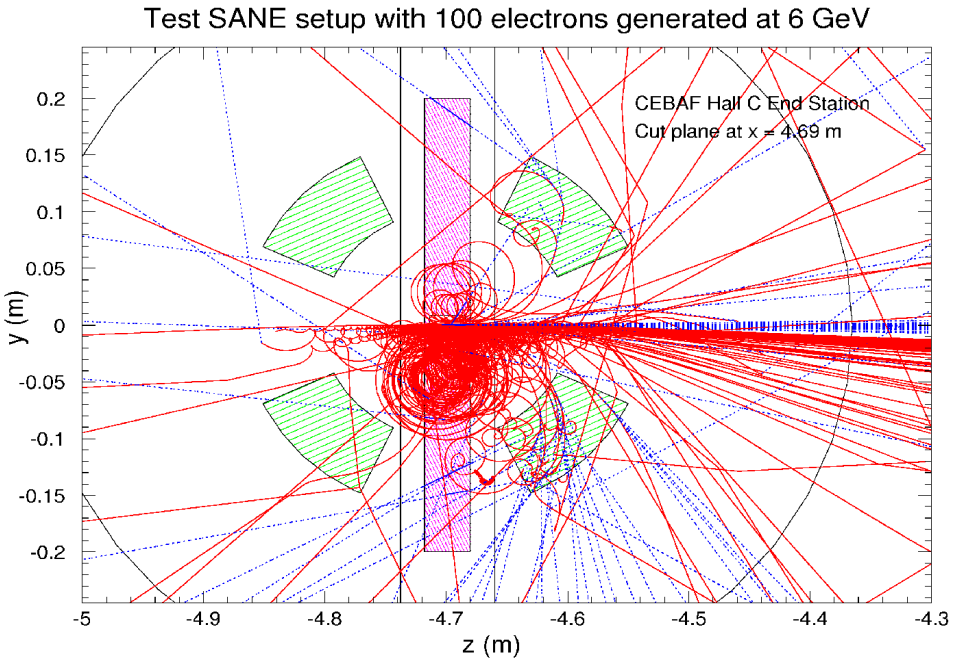


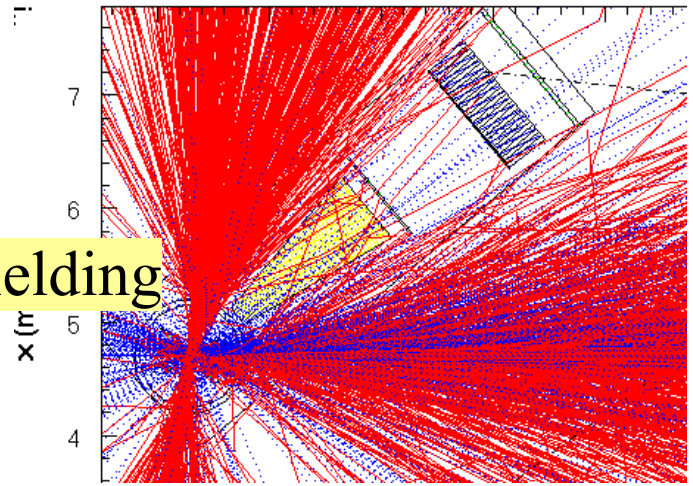


- Top and side views
- Field at 80 degrees
  - Red: electrons, Blue: photons
- .MCWORKS code (P. Degtiarenko) and BETA GEANT (G. Warren)

Beam Line Background Studies (Seoul U.)







- Top and side views
- Field at 80 degrees
  - Red: electrons, Blue: photons
- .MCWORKS code (P. Degtiarenko) and BETA GEANT (G. Warren)

Beam Time Request

2003 Request

	Energy	θ_N	Time (h)	
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)

2007 Request

	Energy	θ_N	Time (h)	
Calibration	2.3	off, 0, 180	47	
Production	4.6	180	70	
	4.6	80	130	rotate
	5.7	80	200	
	5.7	180	100	rotate
Systematics	Packing Fraction		20	
	Mollers		21	
	Total beam time		588	(24.5 d)
Overhead	Anneals		62	
	Energy Change		48	
	Target Rotation		48	
	Stick Changes		48	
	Total Overhead		206	(9 d)
	Requested Time		654	(27 d)
Commissioning	TAC recommended		14 calendar days	

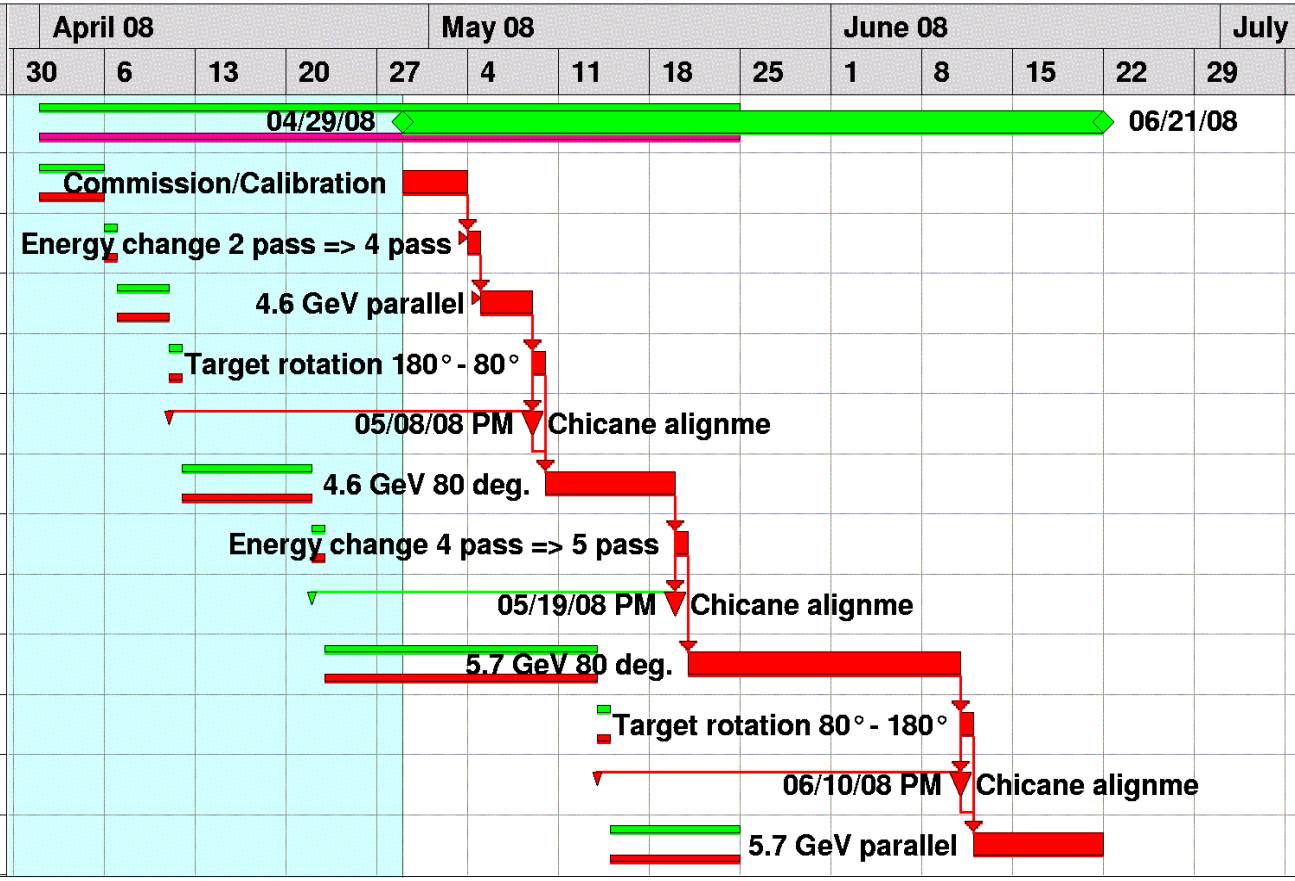
Updated Preliminary Run Plan

Start: 04/29/08
Finish: 06/22/08

SANE Run
Gantt View: Gantt Table

Page #1

?	Activity Name	Duration	Start
1	SANE Run	54	04/29/08
2	Commission/Calibration	5	04/29/08
3	Energy change 2 pass => 4 pass	1	05/04/08
4	4.6 GeV parallel	4	05/05/08
5	Target rotation 180° - 80°	1	05/09/08
6	Chicane alignment	0	05/08/08
7	4.6 GeV 80 deg.	10	05/10/08
8	Energy change 4 pass => 5 pass	1	05/20/08
9	Chicane alignment (if needed)	0	05/19/08
10	5.7 GeV 80 deg.	21	05/21/08
11	Target rotation 80° - 180°	1	06/11/08
12	Chicane alignment	0	06/10/08
13	5.7 GeV parallel	10	06/12/08



SANE Membership - 1/07

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SANE Status - 1/2007

- Twelve collaboration meetings since 11/2003, latest on 12/1/2006
- Submitted Beam Request on 9/14/06
- Hall C schedule: SANE tentatively to start in 5/2008 (?)
  - Time lines show adequate lead time for 2008 run
- Readiness review in 2007
- E03-109 Conditional approval:
  - enhanced BETA has significantly improved background rejection
  - all detectors will be beam tested before installation
  - GEANT simulation based shielding design ongoing

SUMMARY

Steady progress over 3 years

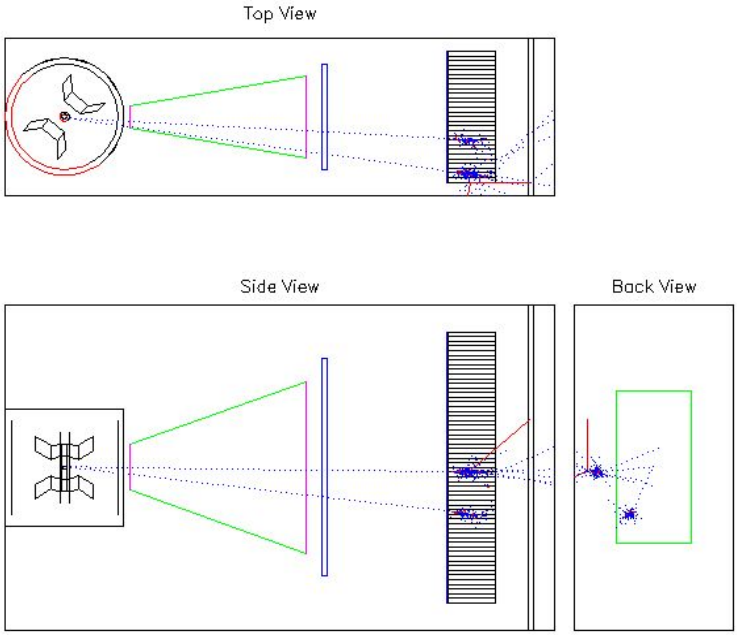
Could install by year's end if beam schedule allowed

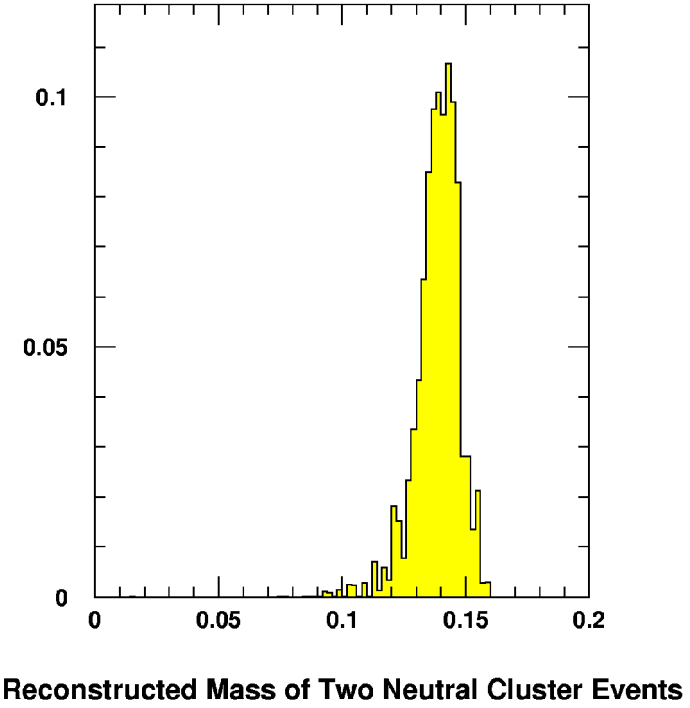
SANE is pioneering spin physics with large non-magnetic detectors

SANE Status – Other Items

- Update of SANE and BETA's GEANT
  - UVA dissertation student J. Maxwell working on G. Warren's legacy
- Backgrounds from target: pion and positron rejection/identification
  - charge sign for $p < 1$ GeV/c will be identified with front hodoscope
  - V. Dharmawardane reviewed reference estimates, >20% rate for $E'<1.1$ GeV, reduce background with software cut
  - P. Bosted: precision π^0 asymmetry possible with 0.7 GeV/c threshold; can be used to make pair symmetric asymmetry systematics negligible
  - HMS will be used to measure accurate pair rates
- Target material: $^{14}NH_3$. UVA working on better freezing method. Irradiation in 2007.
- Target platform design, integration with BETA stands in the works with Hall C engineering and design group, Temple, UVA and Hall C physics providing input

BigCal's neutral pion mass reconstruction





- Use π^0 mass reconstruction to: continuously calibrate BigCal,
  - calibrate blocks not covered in *e*+*p* elastic procedure (~10%)
  - measure asymmetry with >0.7 GeV/c threshold to control the pair symmetric background
  - GEANT simulated π^0 events in BETA: sigma ~ 10 MeV

Systematics

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%

Systematics for 4.8 GeV are very similar

*Measure packing fraction with HMS, new cross sections from Hall C
** Using new fit for R from Hall C will improve on these estimates

TAC Comments

- BETA commissioning:
  - all detectors expected to be fully built and tested in beam before installation
  - largely parallel tasks of BigCal calibration and commissioning of others detectors
  - we welcome additional recommended 14 calendar days, hope will need only part
- Installation time:
  - with adequate planning can be done in 6 weeks
  - multiple experiments sharing polarized target and BETA should be considered
- Five-pass beam energy >5.7 GeV and corresponding 4- and 2-pass are OK
- Rear (Lucite) hodoscope design simplified to single plane. All detectors to be finished and tested by 12/2007.
- Main trigger will be OR of Calorimeter and Cherenkov. Electronic channel and cable needs have been listed in response to TAC
- Downstream beam line engineering drawings available (from *RSS*)
- Polarized target fringe field intensity at PMT locations under control

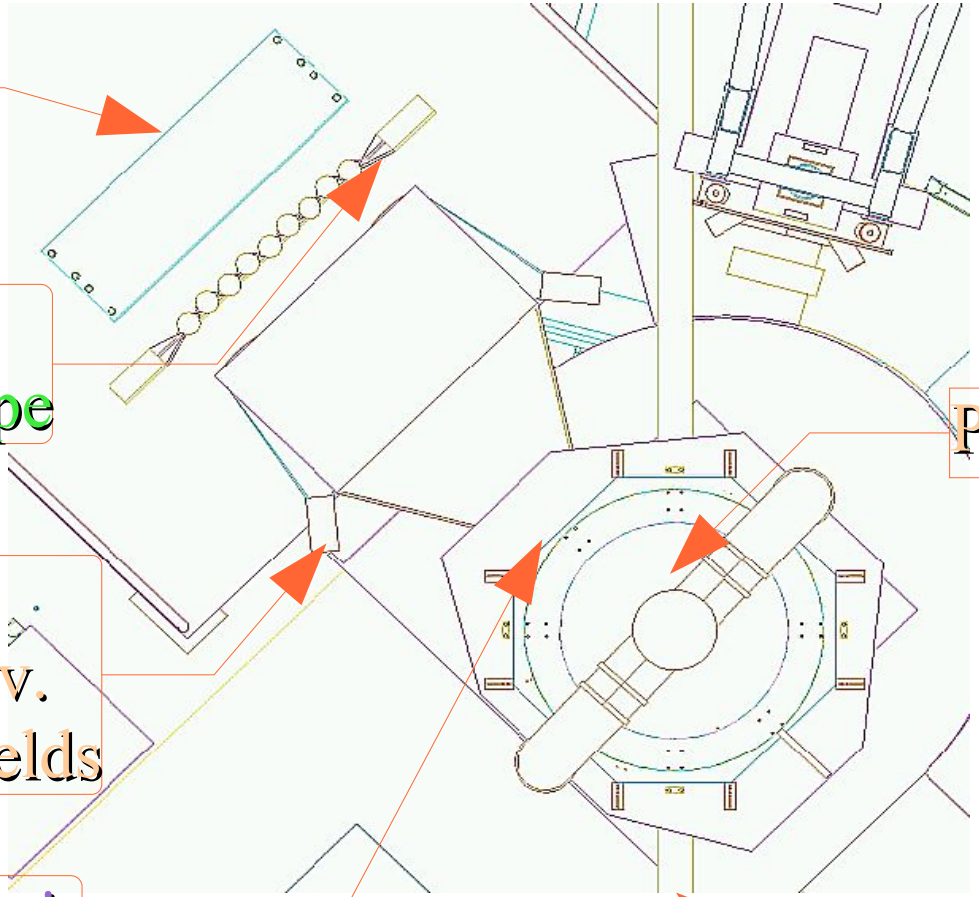
TAC report: residual target field

< 9 G
at BigCal

< ~ 30 G
at Lucite Hodoscope

~ 100 G
at gas Cherenkov.
50:1 magnetic shields

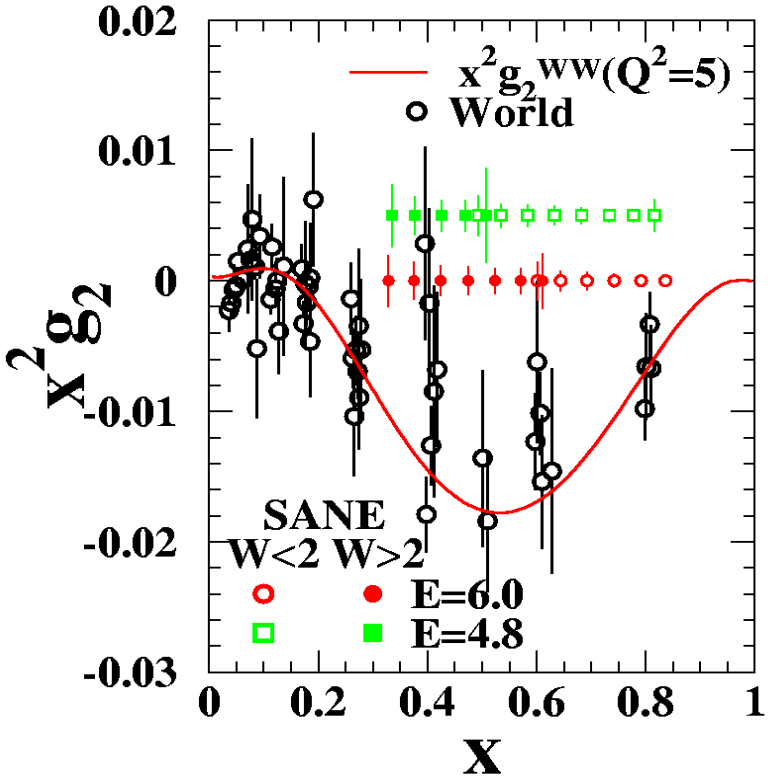
Forward Hodoscope's
PMT's far from target



Polarized Target

Beam Line

SANE Expected Results (IV)



- DIS data for ***x*** up to 0.6 (with 6 GeV)