# SANE
# Spin Asymmetries on the Nucleon Experiment
## (Jefferson Lab E07-003)


SANE Collaboration

U. Basel, C. Newport U. Florida International U., Hampton U.,
Mississipi State U., Norfolk S. U., North Carolina A&T S. U.,
Ohio U., IHEP-Protvino, U. of Regina, Rensselaer Polytechnic I.,
Rutgers U., Seoul National U., Temple U., TJNAF, U. of Virginia,
College of William & Mary, U. of the Witwatersrand, Yerevan Physics I.

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



Hall C Users Meeting
January 19, 2008
Jefferson Lab

# SANE Physics (I)

- Measurement of
  - 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$^2$
  - 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 during 6 GeV operation**

# 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

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

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

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

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

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

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

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

# Transverse Spin Structure Sum Rules

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

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

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

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

$$d_N(Q^2) = \frac{2(N+1)}{N}\int_0^1 x^N \bar{g}_2(x,Q^2)\,dx$$

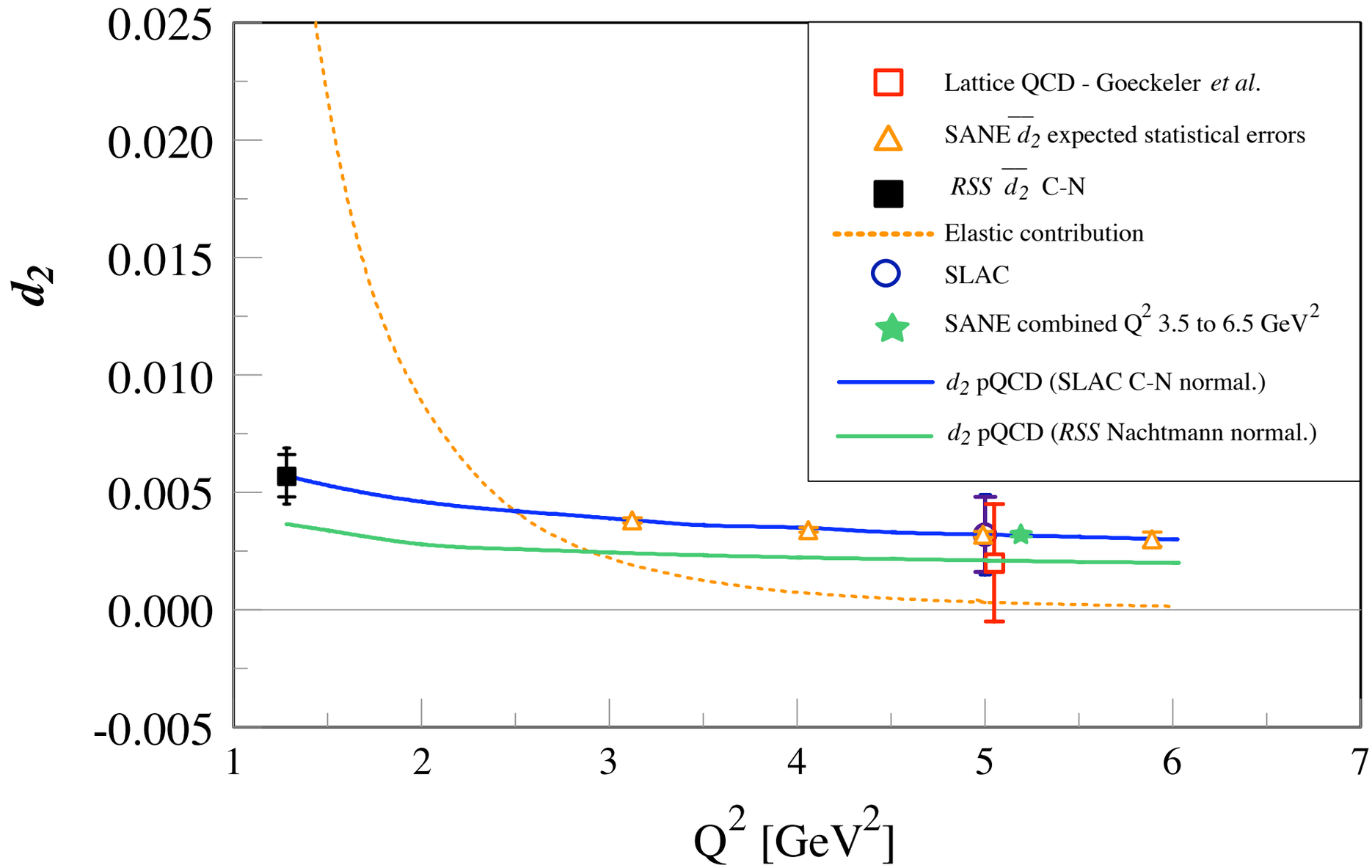
- Burkhardt-Cottingham
  - not from OPE

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

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

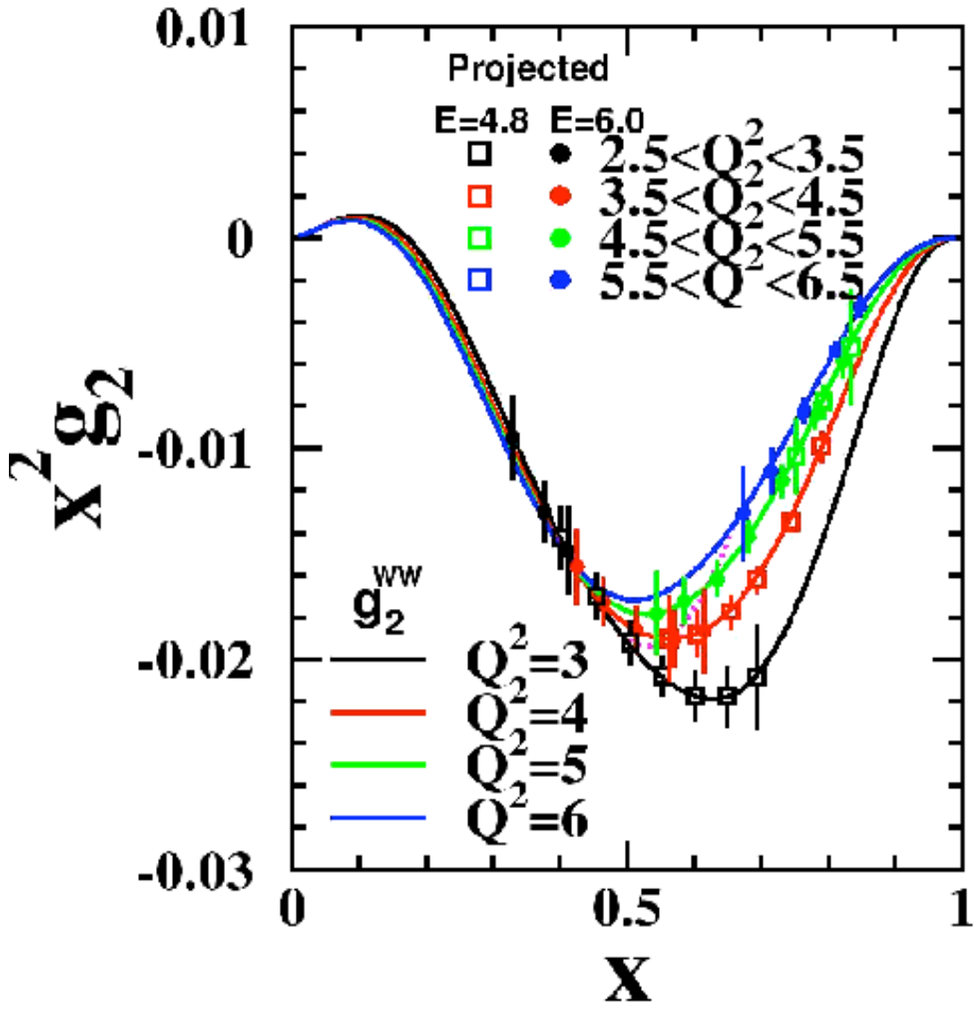
$$\int_0^1 x\left(g_1^V(x) + 2g_2^V(x)\right)\,dx = 0$$

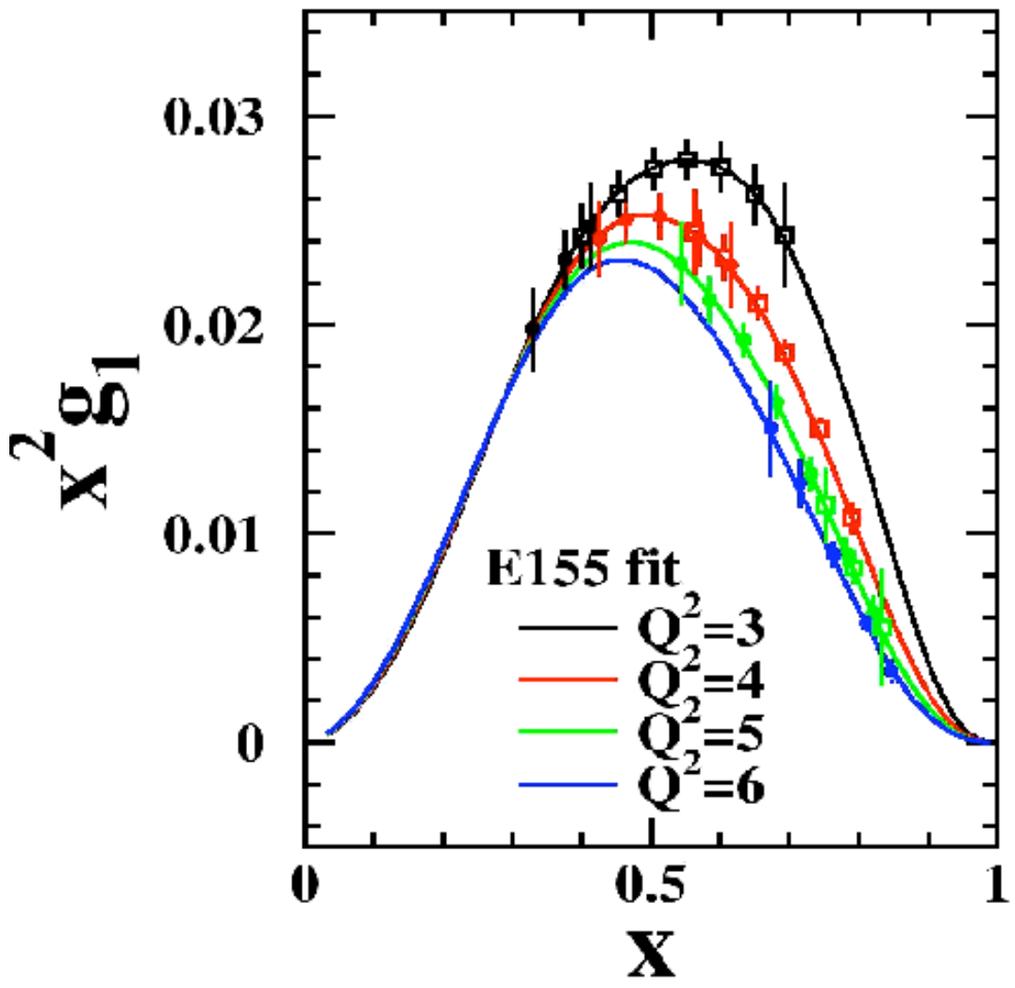
# SANE Expected Results




- SANE expected errors for $\bar{d}_2 = \int_{x_{\min}}^{x_{\max}} x^2 \left(2g_1(x) + 3g_2(x)\right)\, dx$
  - $\delta\bar{d}_2/d_2(Q^2 = 3\text{GeV}^2) = 4\%, \quad 0.29 < x < 0.85$
  - $\delta\bar{d}_2/d_2(3.5 \text{ to } 6.5\text{GeV}^2) = 2.5\%, \quad 0.41 < x < 0.96$

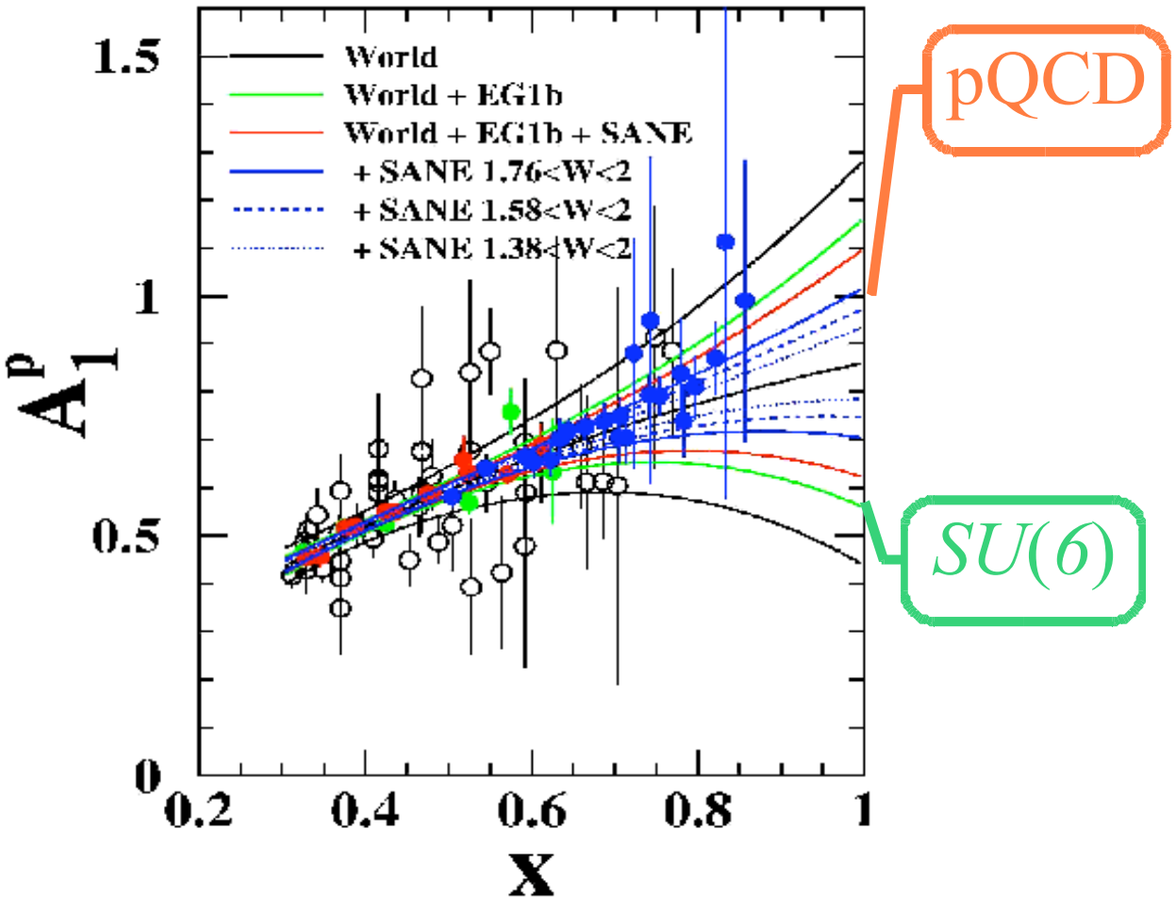
# SANE Expected Results (II)

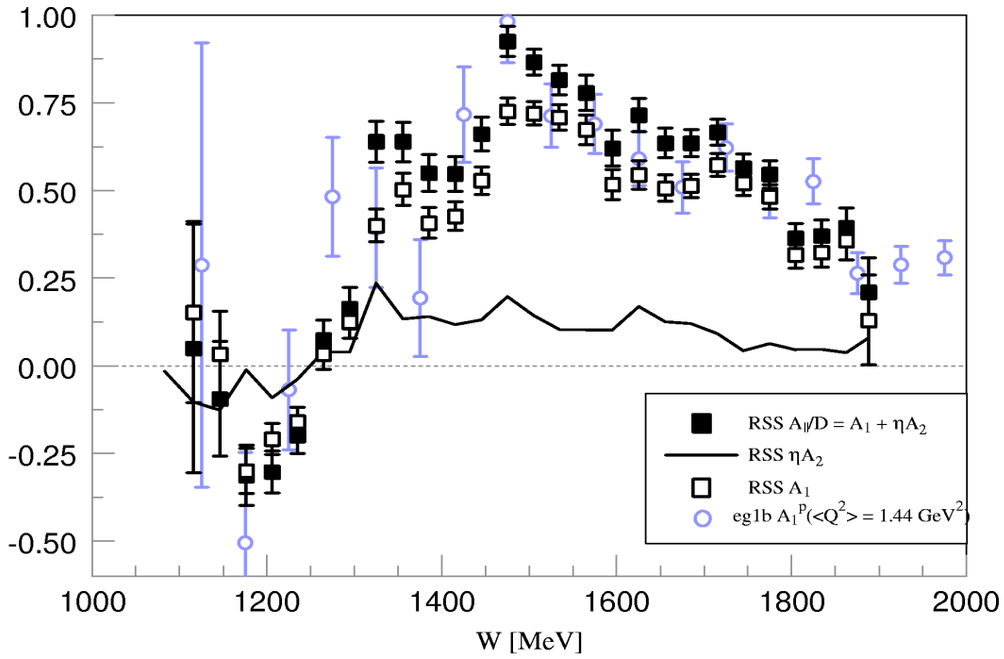



- ***x*** dependence at constant $Q^2$ and $Q^2$ dependence at fixed ***x*** (illustrative binning)
- data are concentrated in the region most sensitive to $x^2 g_{2,1}$
  - (estimates based on 75% beam and target polarization and 85 nA beam current)

# SANE Expected Results (III)



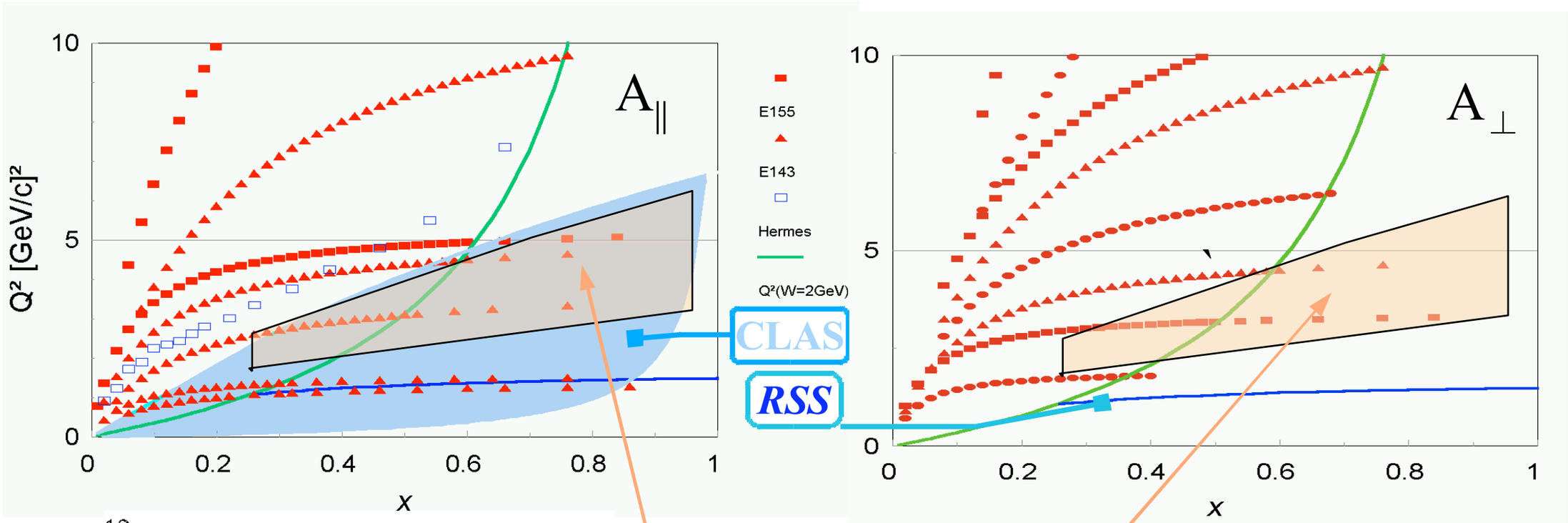



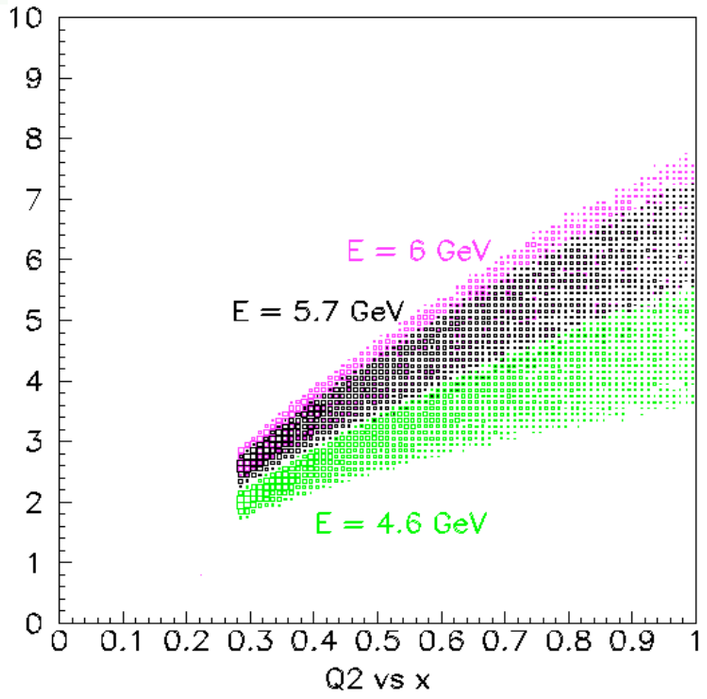

$$A_1 = \frac{1}{(E+E')D'}\left((E - E'\cos\theta)A_{\parallel} - \frac{E'\sin\theta}{\cos\phi}A_{\perp}\right)$$

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

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

# World data on $A_{||}$, $A_{\perp}$ 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

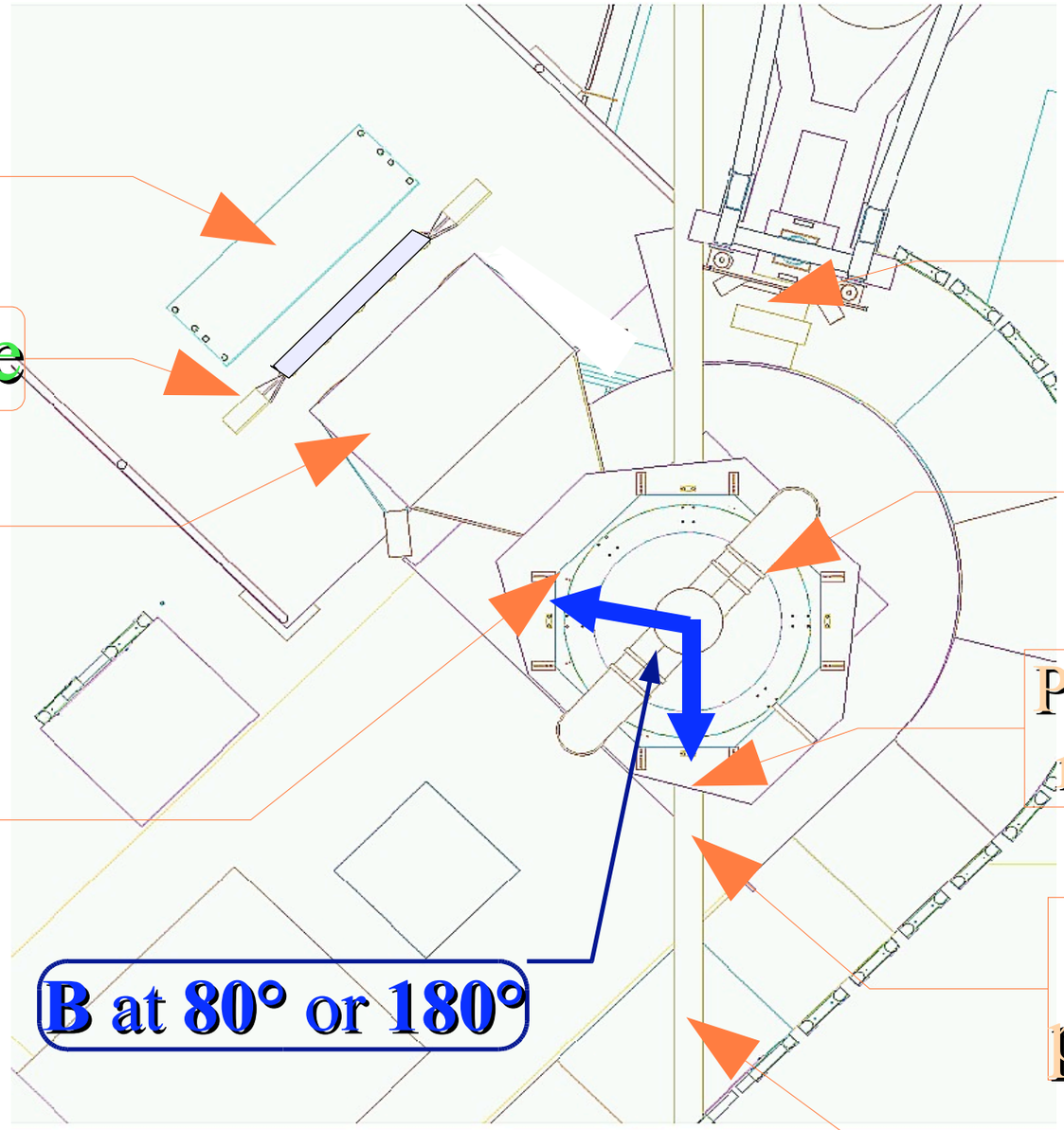
BETA (40°)

BigCal
w. Gain Monitor

Lucite Hodoscope

Gas Cherenkov

Forward
Hodoscope




HMS (13°- 48°)
calibrations, backgd.

Polarized Target

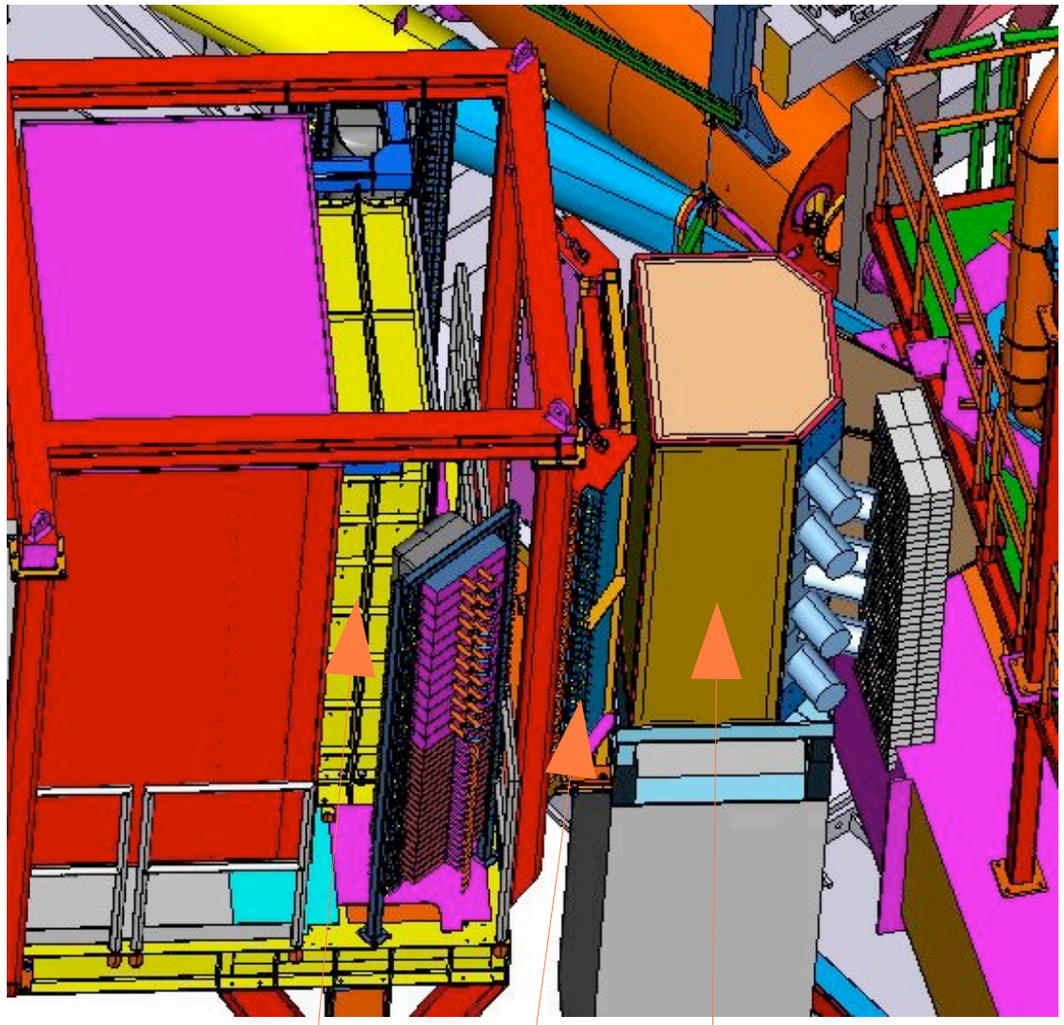
Polarized Compton
radiator (~20 cm)

Target Beam
position monitor

Beam Line

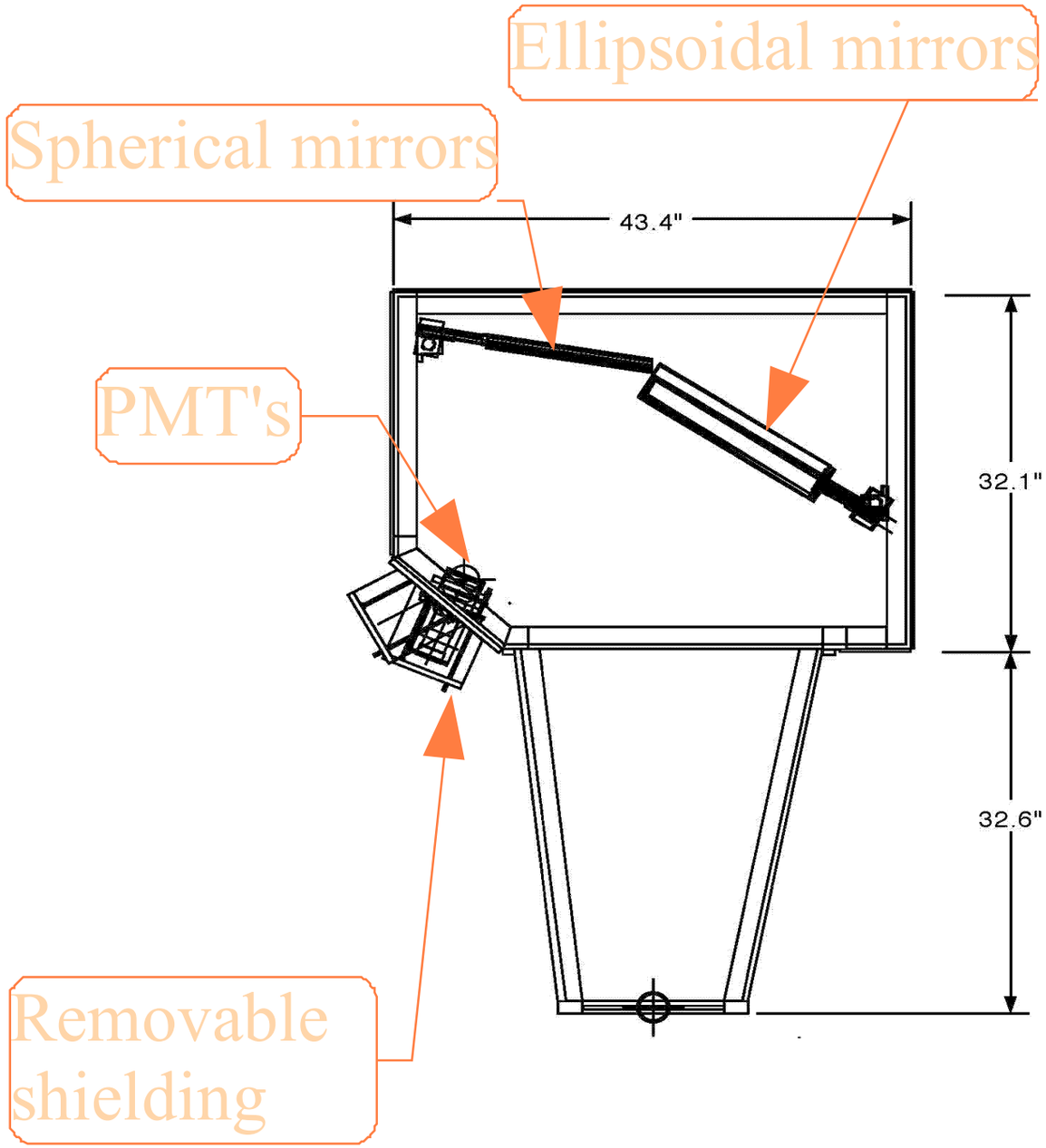
# Big Electron Telescope Array - BETA

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



# SANE Status - Subsystems (I)

- 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 tested and ready
- Photonis PMT's on hand
- Used only Temple grant funds



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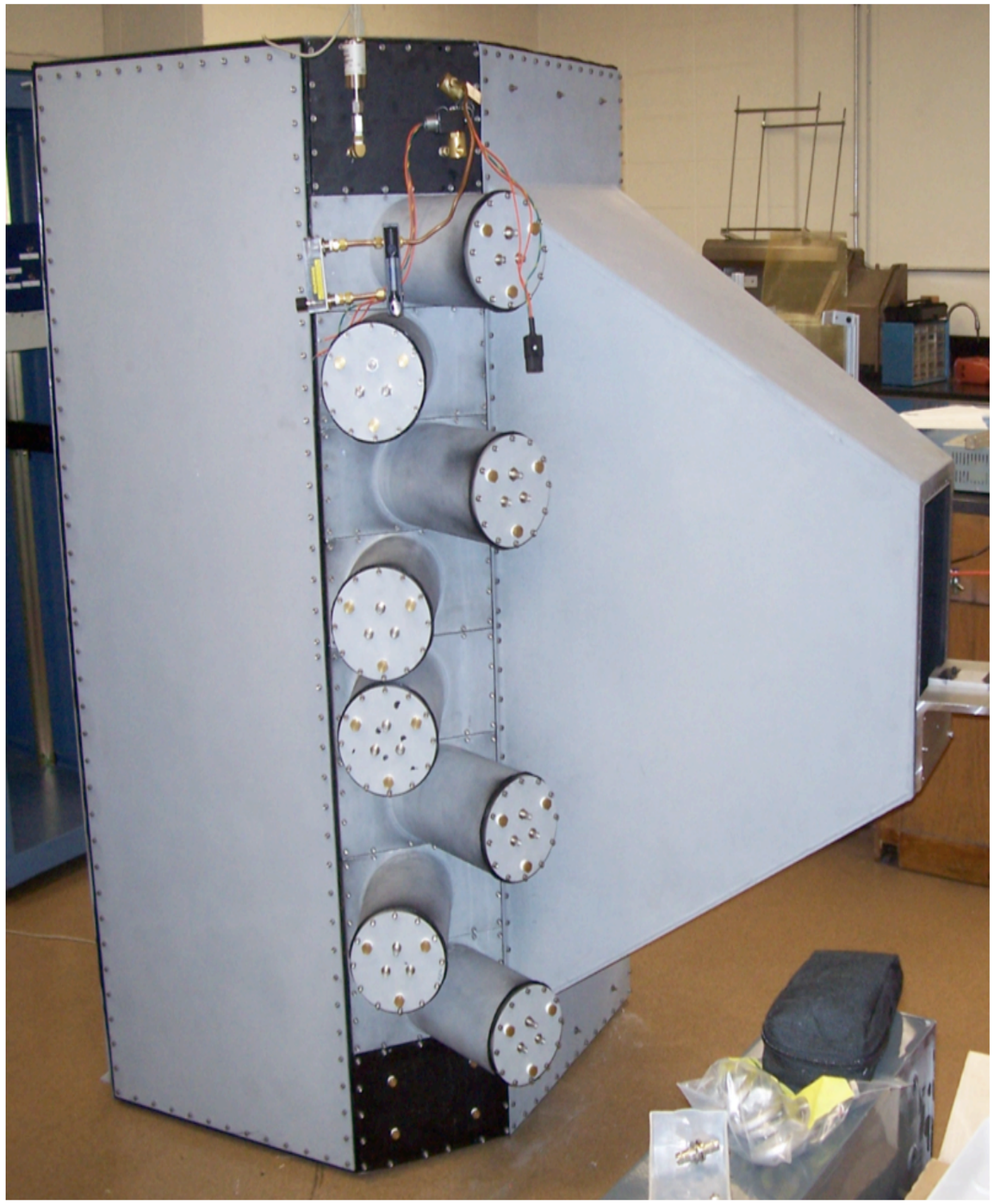

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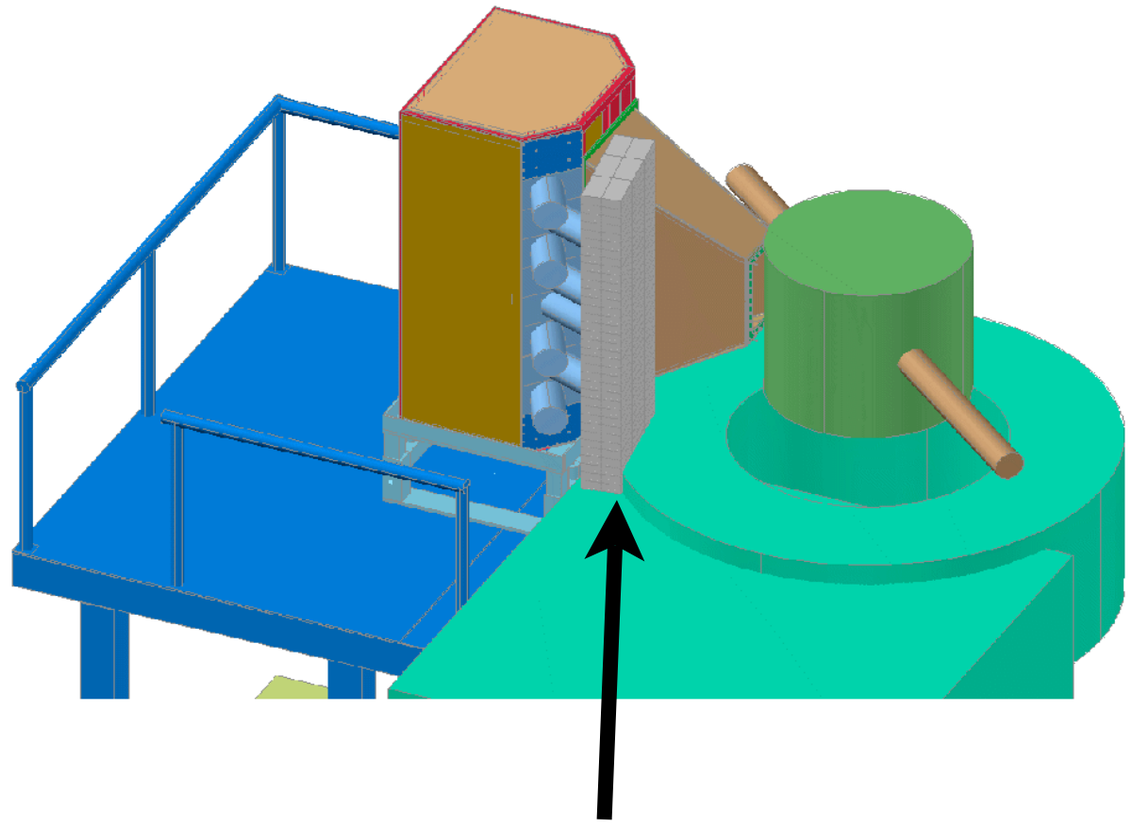
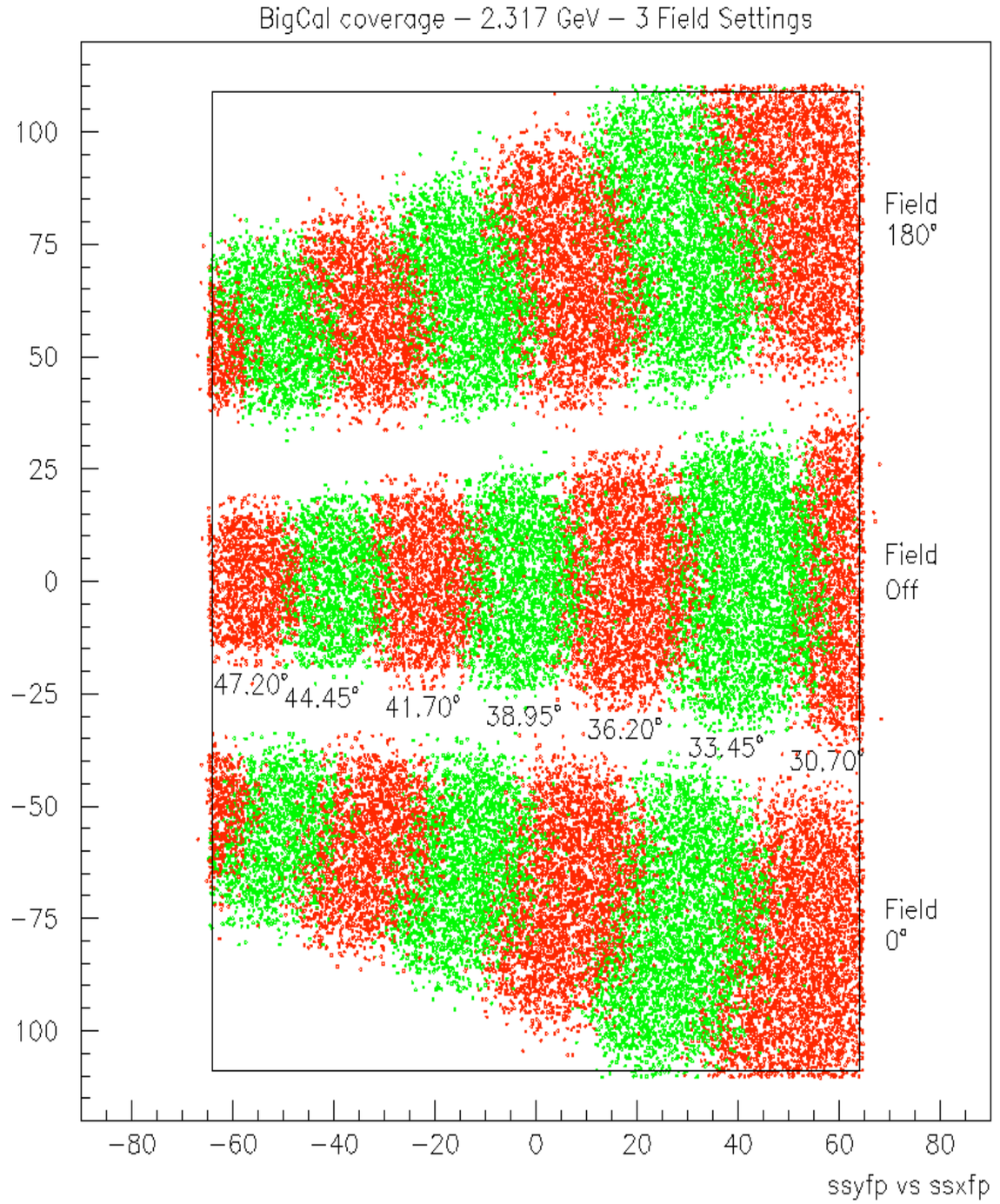


# SANE Status - Subsystems(II)

- 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 $\pi^0$ mass reconstruction



# SANE Status - Subsystems (III)

- Forward tracking hodoscope
  - Next to target OVC, much improved tracking resolution vs. reference design
  - covers full BETA solid angle with small device (38 cm x 21 cm)
  - charge sign separation for momenta < 1 GeV/c, background rate ~ 10 kHz/bar
  - Wavelengh shifting fibers glued on scintillator
    - 72 400(L) x 3(W) x 3(T) $mm^3$ vertical bars ($x$-coordinate)
    - 2 x128 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 328 TDC channels available, 370 bars on hand, checking cables
  - Based on Nov. 2007 in-beam test results,
    - 1 more $y$-plane added, double fiber reading from $x$-plane
    - Additional required PMT's are on order

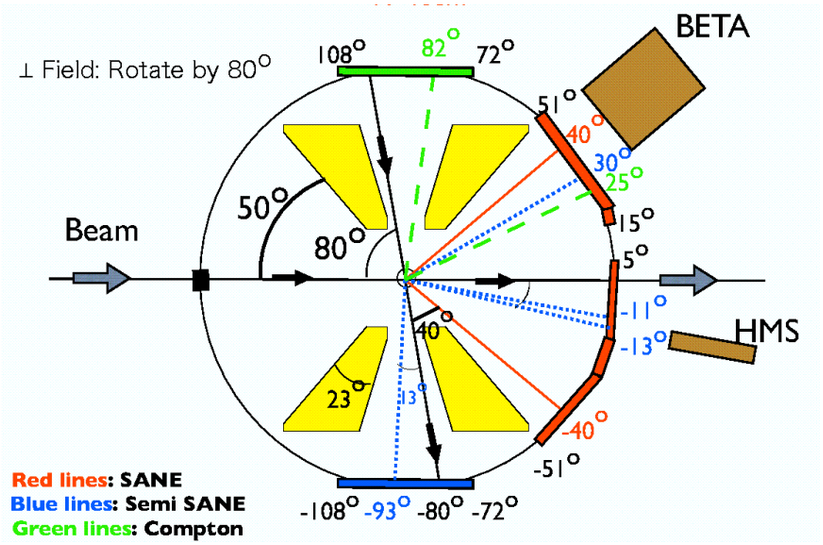
# SANE Status - Subsystems (IV)

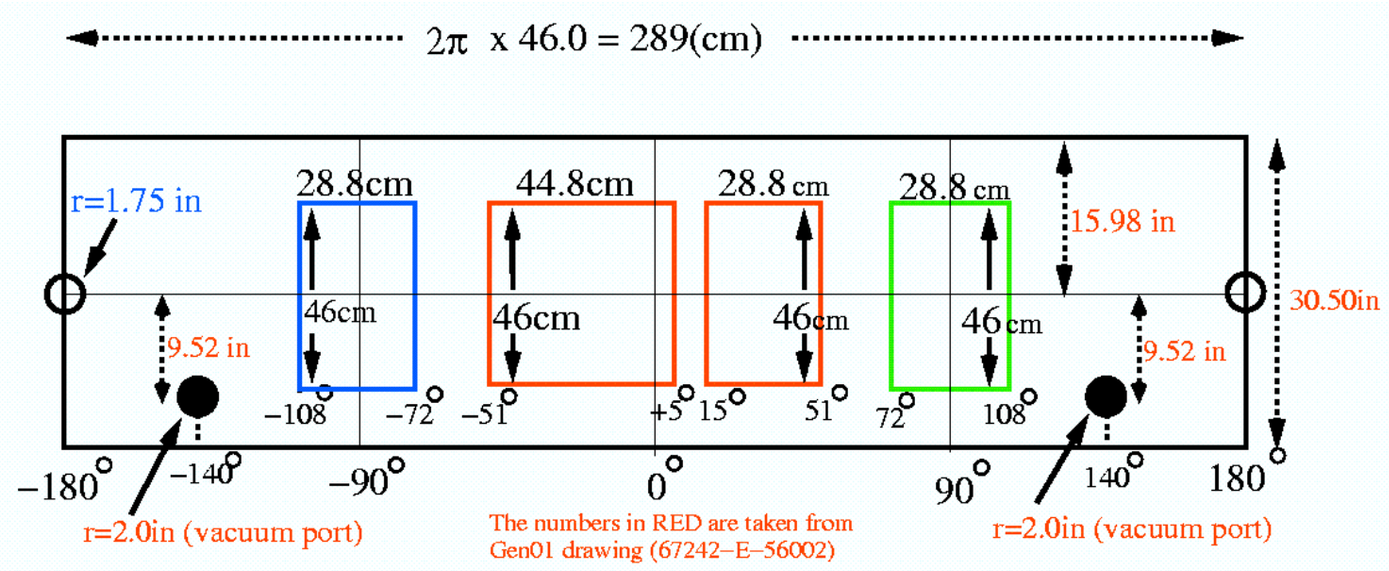
- Lucite Hodoscope current design
  - 28 80(L) x 6 (W) x 3.8 (T) $cm^3$ horizontal bars
    - curved bars to maximize light collection and angular selection
    - angled ends to maximize light collection
  - 2" PMT's at both ends:
    - horizontal position by mean time
    - All the necessary PMT's on hand
  - 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
  - 60 electronics channels (TDC, discriminator, ADC, HV, cables), most of them available
  - Construction in progress (EEL Building)

# Lucite Hodoscope under construction

# SANE Status - Subsystems (V)

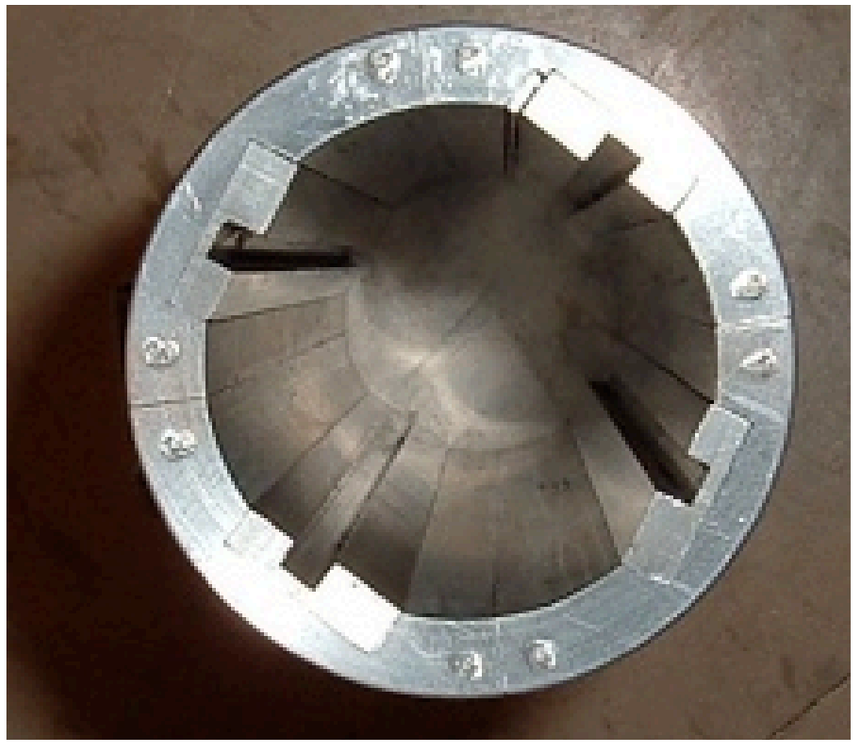
- Polarized target re-assembly in progress in EEL building
- Polarized target outer vacuum can (OVC) delivered to JLab
  - multi-use can (SANE, Semi-SANE, Compton)

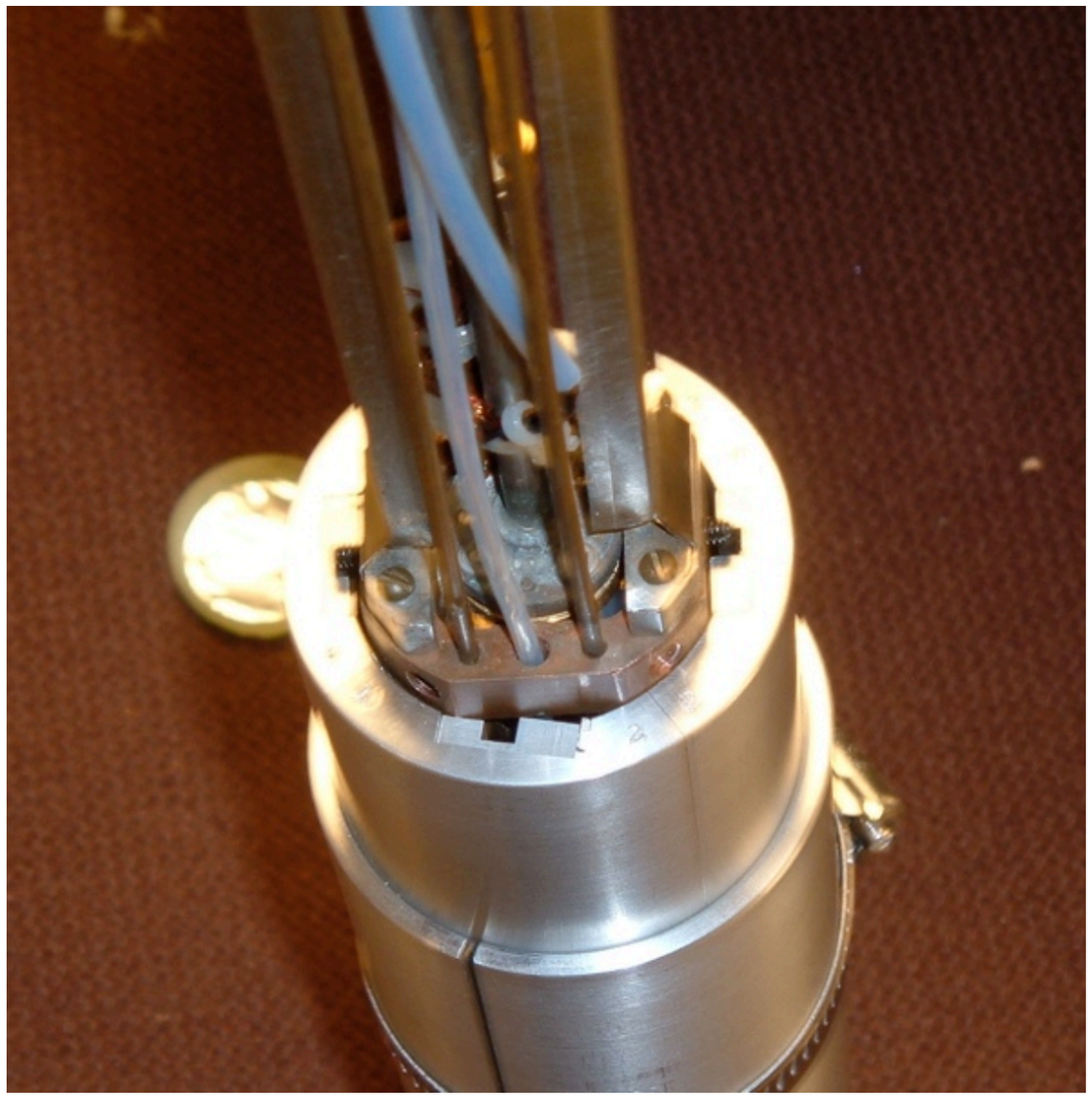


# Target Insert Sleeve Modifications

- Redesigned and manufactured to avoid misalignment of the target stick which occurred during Gen0-1 and RSS

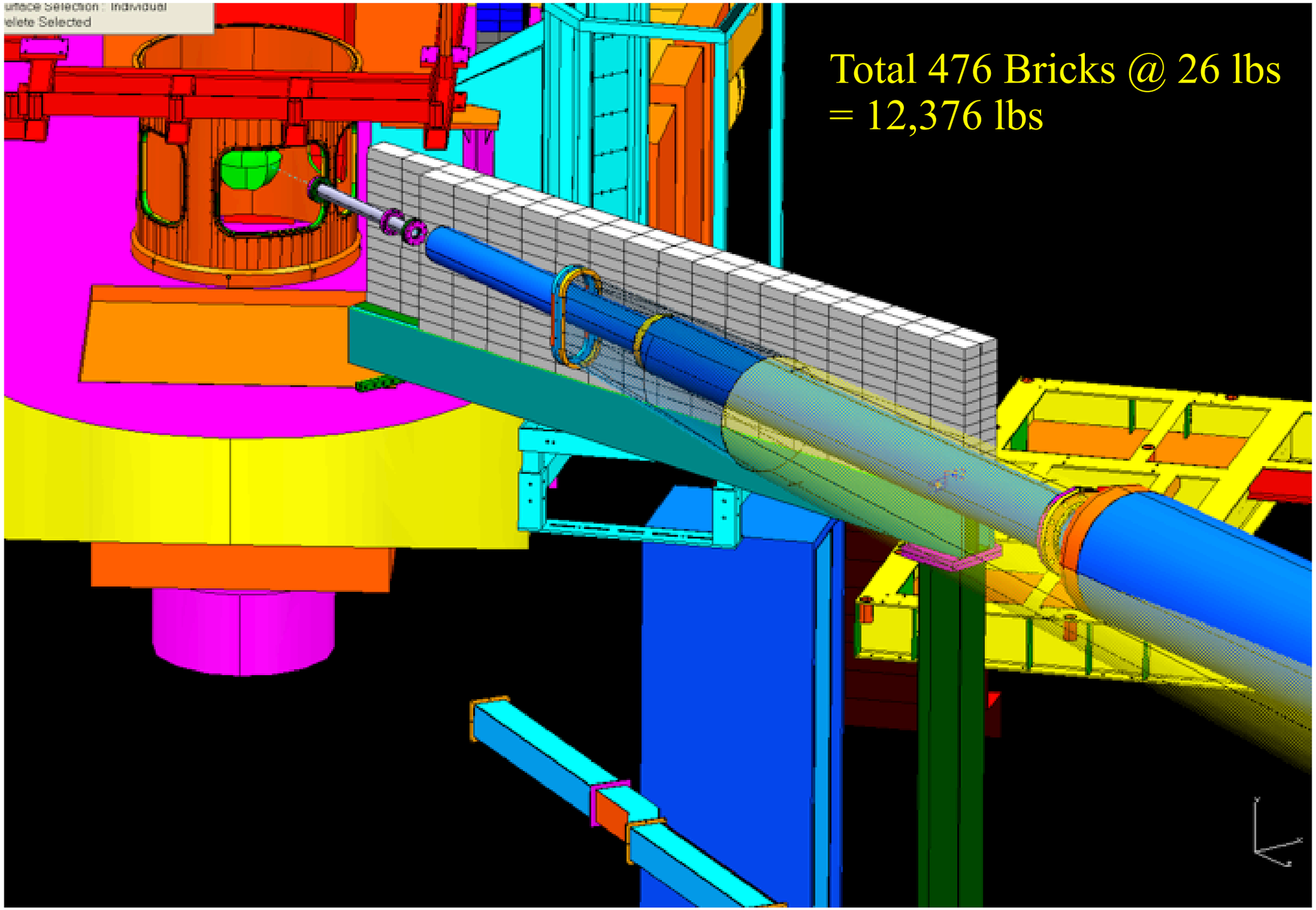




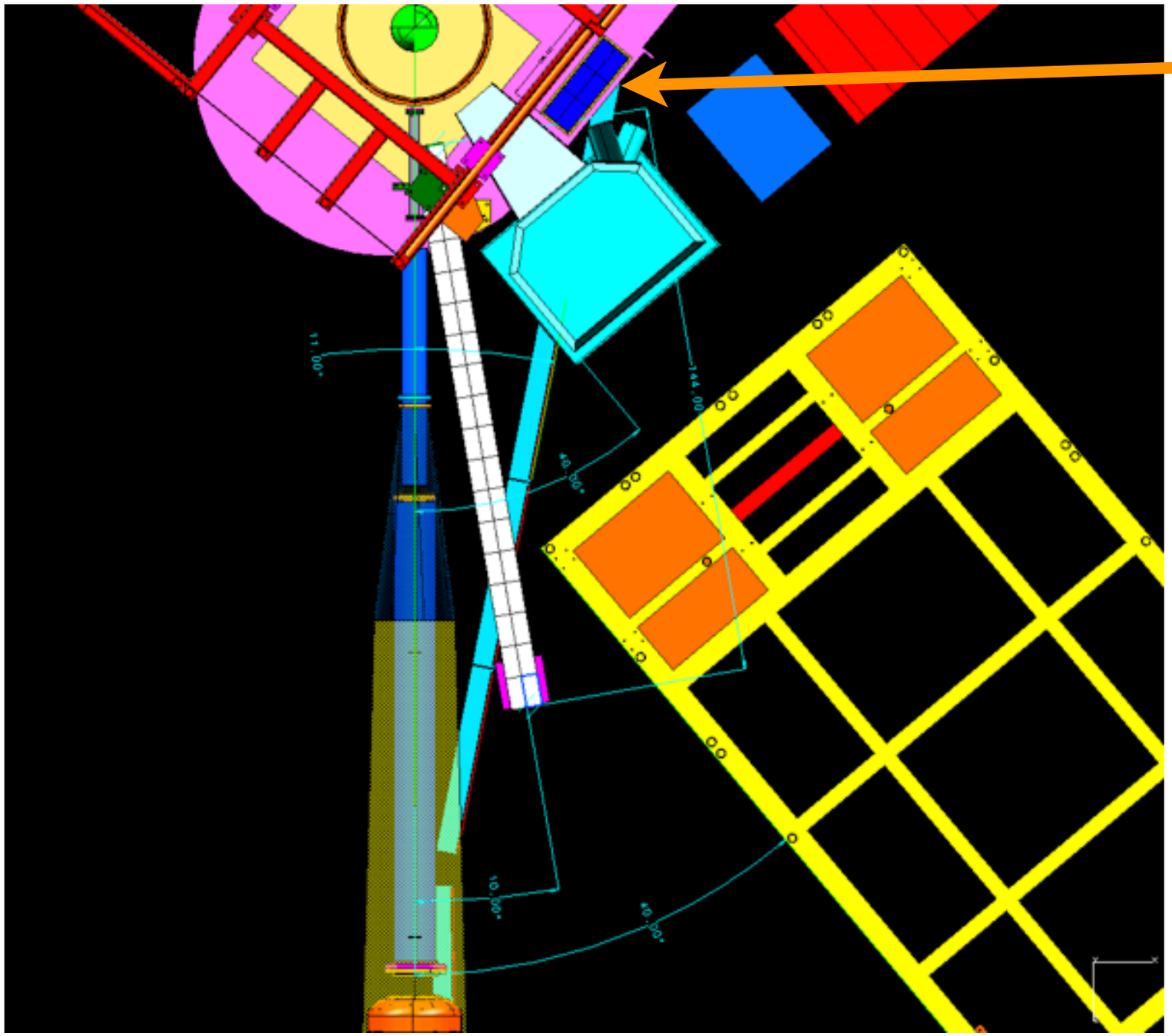
# SANE Status - Subsystems (VI)

- BigCal Gain Monitor: Lucite Plate excited by laser light
  - UVA project (D. Pocanic  group; built similar one for Hall B's RadPhi)
  - successful tests of BigCal glass response to Lucite light done with prototype plate
- 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

# Beamline Shield

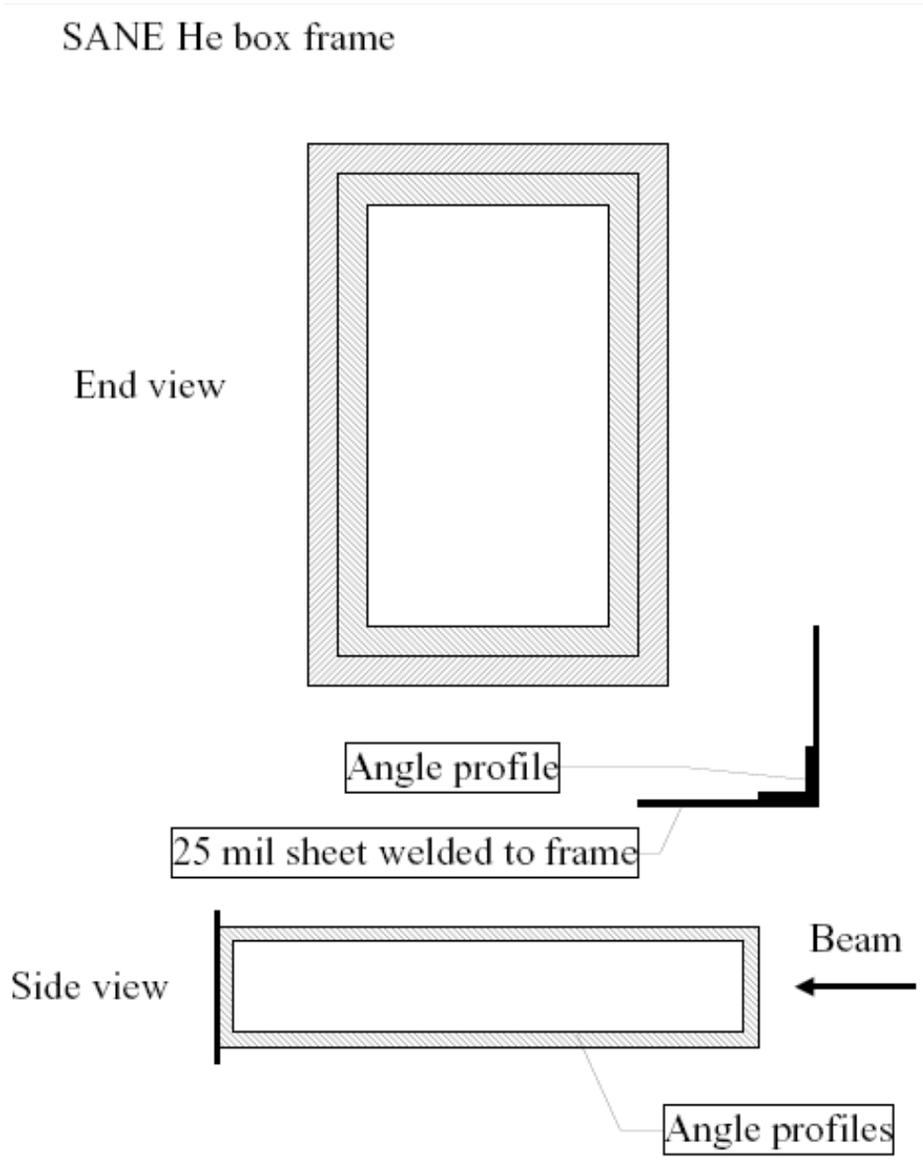


# Protecting Cerenkov PMT's

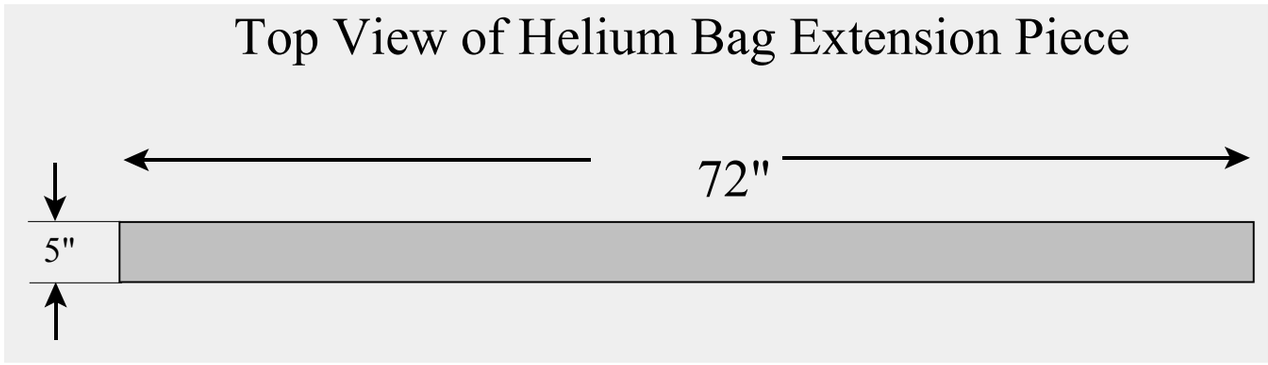


- 20cm Pb wall in front of PMT stacks

# He Bag Extension Piece




- Dimension:
  72” long x 8” high x 5” wide
- 3” width on beam left side and
  2” on beam right
- Background simulation shows
  an increase of background by 5%
  compared to no extension piece



# SANE Manpower: Collaboration

| Initial | Name | Institution |
|---|---|---|
| J. | Jourdan | BASEL |
| M. | Kotulla | BASEL |
| I. | Sick | BASEL |
| E. | Brash | CNU |
| E. | Jensen | CNU |
| A. | Marsh | CNU |
| W. | Boeglin | FIU |
| S. | Dhamija | FIU |
| P. | Markowitz | FIU |
| J. | Reinhold | FIU |
| I. | Albayrak | Hampton |
| E. | Christy | Hampton |
| C. | Keppel | Hampton |
| V. | Tvaskis | Hampton |
| P. | Bosted | JLab |
| J.-P. | Chen | JLab |
| V. | Dharmawardarne | JLab |
| R. | Ent | JLab |
| D. | Gaskell | JLab |
| J. | Gomez | JLab |
| D. | Higinbotham | JLab |
| M. | Jones | JLab |
| D. | Mack | JLab |
| G. | Smith | JLab |
| B. | Wojtsekhowski | JLab |
| S. | Wood | JLab |

| Initial | Name | Institution |
|---|---|---|
| J. | Dunne | MSU |
| D. | Dutta | MSU |
| A. | Ahmidouch | NCAT |
| S. | Danagoulian | NCAT |
| C. | James | NCAT |
| M. | Jones | NCAT |
| S. | Vilayoung | NCAT |
| M. | Khandaker | NSU |
| F. | Wesselmann | NSU |
| P.M. | King | Ohio |
| J. | Roche | Ohio |
| A.M. | Davidenko | Protvino |
| Y.M. | Goncharenko | Protvino |
| V.I. | Kravtsov | Protvino |
| Y.M. | Melnik | Protvino |
| V.V. | Mochalov | Protvino |
| A. | Vasiliev | Protvino |
| C. | Butuceanu | Regina |
| G. | Huber | Regina |
| V. | Kubarovsky | RPI |
| R. | Gilman | Rutgers |
| X. | Jiang | Rutgers |
| S. | Choi | Seoul |
| Ho-young | Kang | Seoul |
| Hyekoo | Kang | Seoul |
| Byungwuek | Lee | Seoul |
| Yoomin | Oh | Seoul |
| Jeongseog | Song | Seoul |

| Initial | Name | Institution |
|---|---|---|
| A. | Lukhanin | Temple |
| W. | Armstrong | Temple |
| Z.-E. | Meziani | Temple |
| B. | Sawatzky | Temple |
| H. | Baghdasarian | UVA |
| M. | Bychkov | UVA |
| M. | Commisso | UVA |
| D. | Crabb | UVA |
| D. | Day | UVA |
| E. | Frlez | UVA |
| K. | Kovacs | UVA |
| N. | Liyanage | UVA |
| V. | Mamyan | UVA |
| J. | Maxwell | UVA |
| J. | Mulholland | UVA |
| D. | Pocanic | UVA |
| O. | Rondon | UVA |
| K. | Slifer | UVA |
| L.C. | Smith | UVA |
| L. | Pentchev | W&M |
| S.H. | Cowell | Witwatersrand |
| M.M. | Dalton | Witwatersrand |
| G. | Mbianda-Njencheu | Witwatersrand |
| A. | Asaturyan | Yerevan |
| A. | Mkrtchyan | Yerevan |
| H. | Mkrtchyan | Yerevan |
| V. | Tadevosyan | Yerevan |

19 institutions - 77 confirmed names

2 PhD students - 2MS students

# SANE Manpower: Subsystems

| Subsystem | Component | Manager | Experts | Institution |
|---|---|---|---|---|
| BigCal | Operation | L. Pentchev | M. Jones<br>Protvino<br>Yerevan | William & Mary<br>Hall C<br>Protvino<br>Yerevan P. I. |
| | Trigger | R. Gilman | X. Jiang<br>P. Bosted | Rutgers U.<br>Hall C |
| | Gain Monitor | E. Frlez | | UVA |
| | Calibration | G. Huber | C. Butuceanu<br>O. Rondon | U. Regina<br>UVA |
| Gas Cherenkov | | Z-E. Meziani | W. Armstrong<br>B. Sawatzky<br>O. Lukhanin | Temple U.<br>Temple U.<br>Temple U. |
| Forward Tracking Hodoscope | | M. Khandaker | P. Bosted<br>C. Butuceanu | Norfolk S.U.<br>Hall C<br>U. Regina |
| Lucite Hodoscope | | A. Ahmidouch | S. Danagoulian | North Carolina A&T S.U. |
| Polarized Target | | D.G. Crabb | D.B. Day<br>K. Slifer<br>M. Seely<br>C. Keith<br>G. Smith | UVA<br>UVA<br>JLab<br>JLab<br>Hall C |
| Beam Line | | J. Dunne | | Mississippi State U. |
| | Raster | | Chen Yan | Hall C |
| | BCM | | D. Mack | Hall C |
| | Target BPM -SEM | F. Wesselmann | M. Steinacher | Hampton<br>Basel |
| Shielding design | | S. Choi | H-Y.Kang | Seoul National U. |
| HMS | | H. Mkrtchyan | Yerevan<br>Hall C<br>C. Keppel | Yerevan P. I.<br>Hall C<br>Hampton |
| Moller | | D. Gaskell | T. Horn | Hall C |
| BETA Simulation | | H. Baghdasaryan | J. Maxwell<br>O. Rondon | UVA<br>UVA |

# Beam Time Request

| | Energy | $\theta_N$ | Time (h) | |
|---|---|---|---|---|
| **Calibration** | 2.4 | off, 0, 180 | 60 | (Full and ½ field) |
| **Production** | 4.8 | 180 | 70 | |
| | 4.8 | 80 | 130 | Target rotation |
| | 6.0 | 80 | 200 | |
| | 6.0 | 180 | 100 | Target rotation |
| **Systematics** | Packing Fraction | | 20 | |
| | Mollers | | 21 | |
| | Total beam time | | 601 | |
| **Overhead** | Anneals | | 62 | |
| | Energy Change | | 48 | |
| | Target Rotation | | 48 | |
| | Insert Changes | | 48 | |
| | Total Overhead | | 206 | |

**Commissioning** 14 calendar days

**Total** 70 calendar days

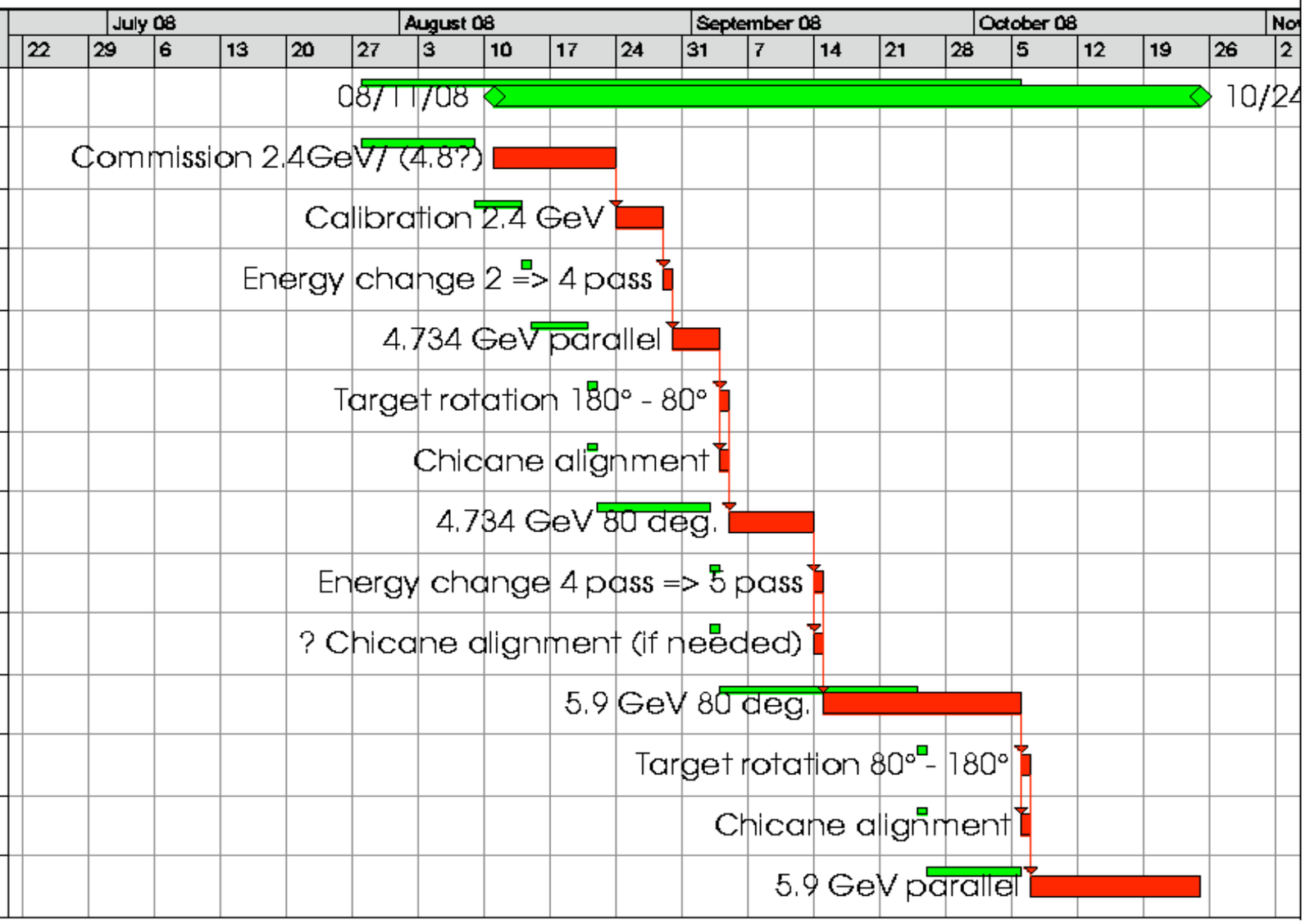
# Updated Preliminary Run Plan

**Start: 08/11/08**
**Finish: 10/25/08**
**Today:11/07/07**

**SANE Run**



| ? | | Activity Name | Duration | Start |
|---|---|---|---|---|
| 1 | — | ***SANE Run*** | 75 | 08/11/08 |
| 2 | | Commission 2.4GeV/ (4.8?) | 13 | 08/11/08 |
| 3 | | Calibration 2.4 GeV | 5 | 08/24/08 |
| 4 | | Energy change 2 => 4 pass | 1 | 08/29/08 |
| 5 | | 4.734 GeV parallel | 5 | 08/30/08 |
| 6 | | Target rotation 180° - 80° | 1 | 09/04/08 |
| 7 | | Chicane alignment | 1 | 09/04/08 |
| 8 | | 4.734 GeV 80 deg. | 9 | 09/05/08 |
| 9 | | Energy change 4 pass => 5 pass | 1 | 09/14/08 |
| 10 | | ? Chicane alignment (if needed) | 1 | 09/14/08 |
| 11 | | 5.9 GeV 80 deg. | 21 | 09/15/08 |
| 12 | | Target rotation 80° - 180° | 1 | 10/06/08 |
| 13 | | Chicane alignment | 1 | 10/06/08 |
| 14 | | 5.9 GeV parallel | 18 | 10/07/08 |



# Summary

- Proton transverse spin structure functions
  - Almost uncharted territory, rich in new physics
  - Reaching one of the DOE milestones
  - Jefferson Lab @ 6 GeV is a unique opportunity within a foreseeable future
- SANE will be ready as scheduled (Fall, 2008)
  - Readiness Review completed (2007)
  - Working meetings every two weeks checking the progress
  - Most of the hardware acquired, construction/assembly phase
  - Full detector beam tests for Cerenkov & Hodoscope in April.
  - Enough experience from previous successful expts. RSS & GEp-III
- SANE is a pioneering spin physics program with large non-magnetic detectors