# Beyond the Born Approximation: A Precise Comparison of Positron-Proton and Electron-Proton Elastic Scattering in CLAS

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for the PR-07-005 collaboration

Exclusive Reactions at High Momentum Transfer

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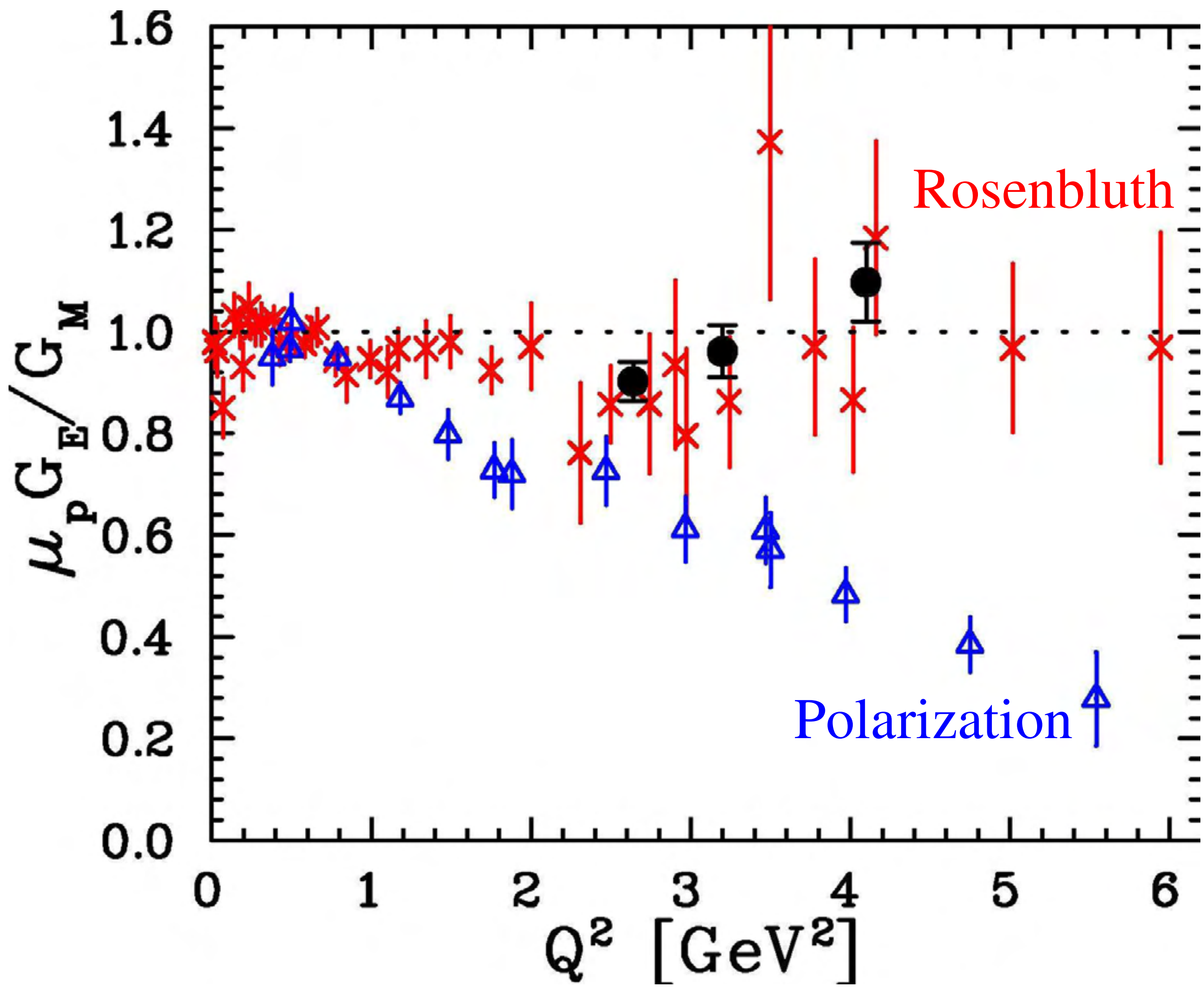
# The Proton Charge Form Factor

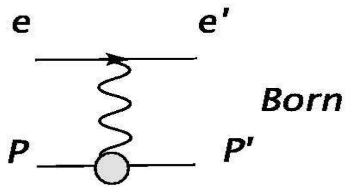



$G_E$ contribution to cross section is small (~5%).

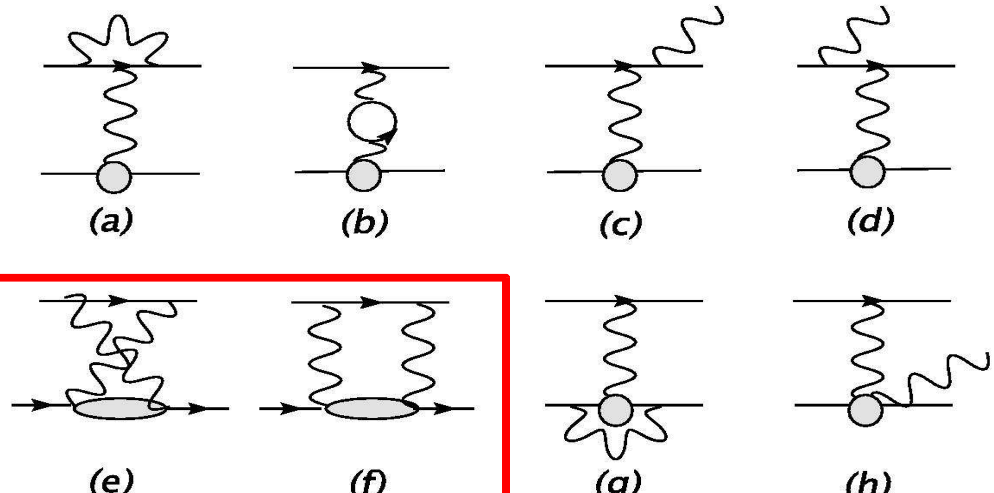
$2\gamma$ exchange is the leading candidate to explain discrepancy.

# How to measure TPE:

compare electron and positron elastic scattering on the proton




$A_{Born} \sim e^{\pm} = \pm 1$




$A_{2\gamma} \sim (e^{\pm})^2 = +1$

$$\sigma(e^{\pm}) \propto |A_{Born} + A_{2\gamma} + \ldots|^2$$
$$\sigma(e^{\pm}) \propto |A_{Born}|^2 \pm 2 A_{Born} Re(A_{2\gamma})$$

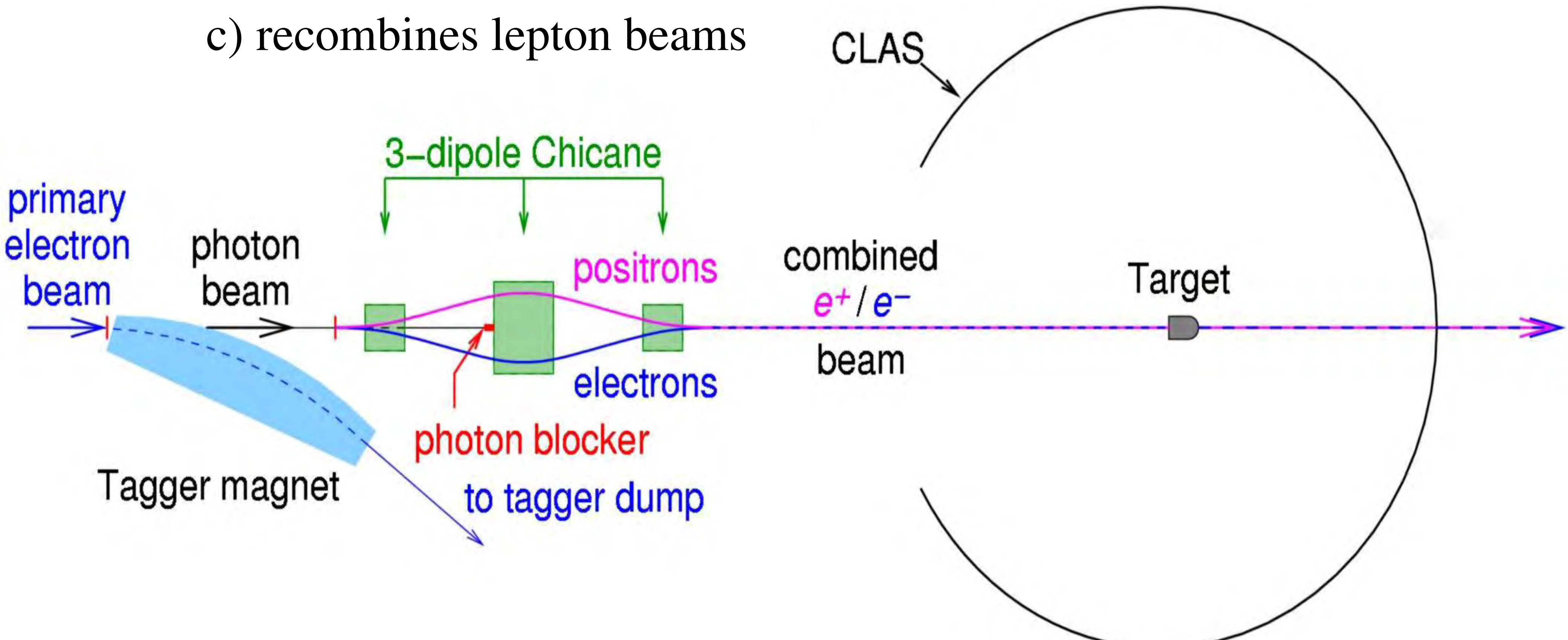
$$R = \frac{\sigma(e^+)}{\sigma(e^-)} \approx 1 - \frac{4Re(A_{2\gamma})}{A_{Born}}$$

R measures the real part of the two-photon amplitude

# Experimental Technique

# Making Positrons in Hall B

1. Electron beam hits radiator foil, producing photon beam
2. Photon beam strikes converter foil. e-/e+ pairs are produced.
3. Magnetic chicane:
   a) separates lepton beams
   b) blocks photon beam
   c) recombines lepton beams



# Experiment Features

- Identical e+/e− beams
- Continuous beam energy distribution
  - Wide $Q^2$ and angle ( $\varepsilon$ ) coverage
- Simultaneous cross section measurements
  - Minimize systematic uncertainty
  - Allows 1% measurement of e+/e− cross section ratio
- Opposite sector trigger selects candidate elastic events.
- Overdetermined elastic kinematics provide effective background rejection and determine incident beam energy.

# TPE Timeline

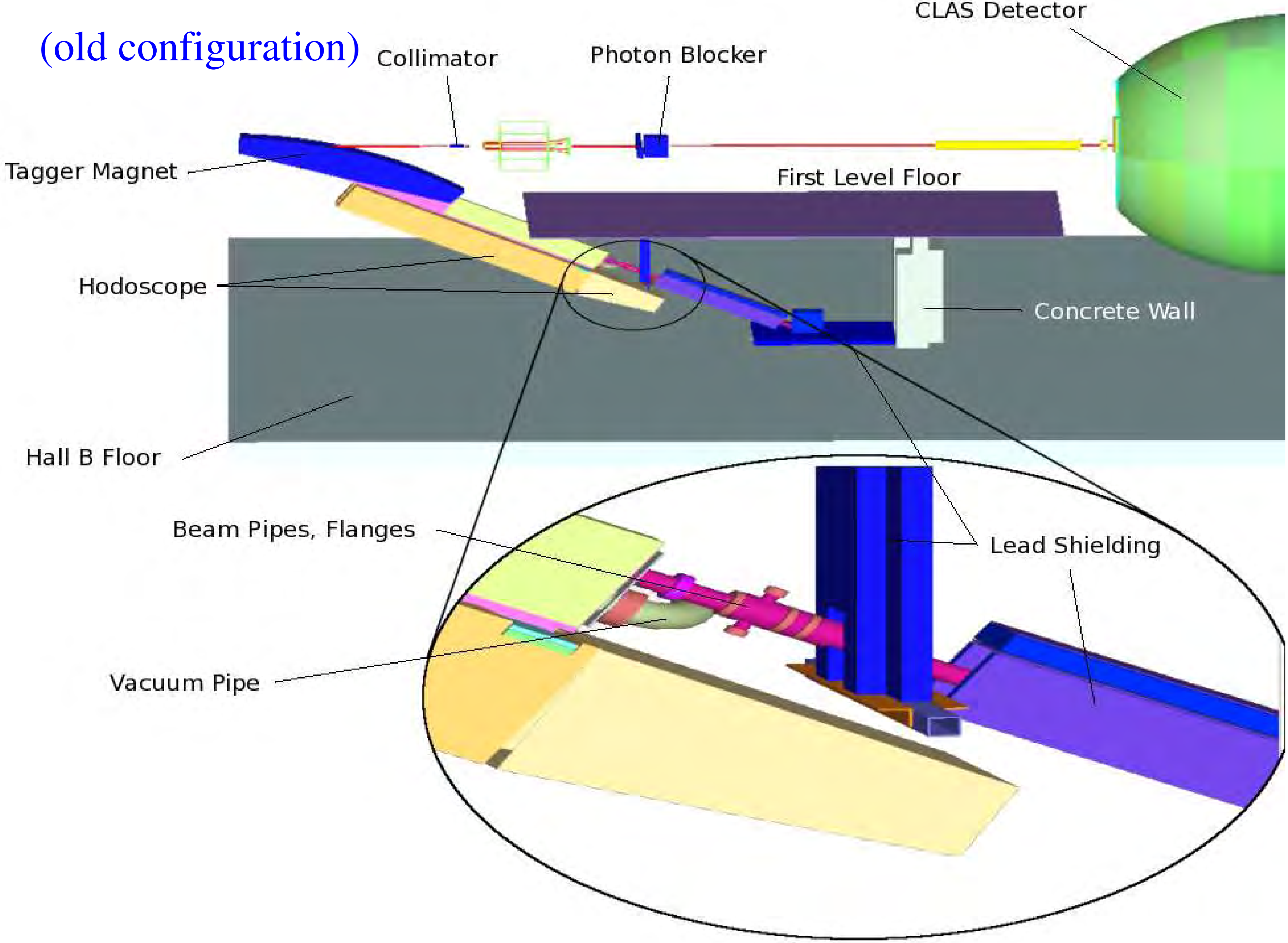
- Engineering test run, summer 2005: measure background rates in Hall B.

- Test run, October 2006: produce mixed lepton beam, validate simulations collect e-p and e+p data.

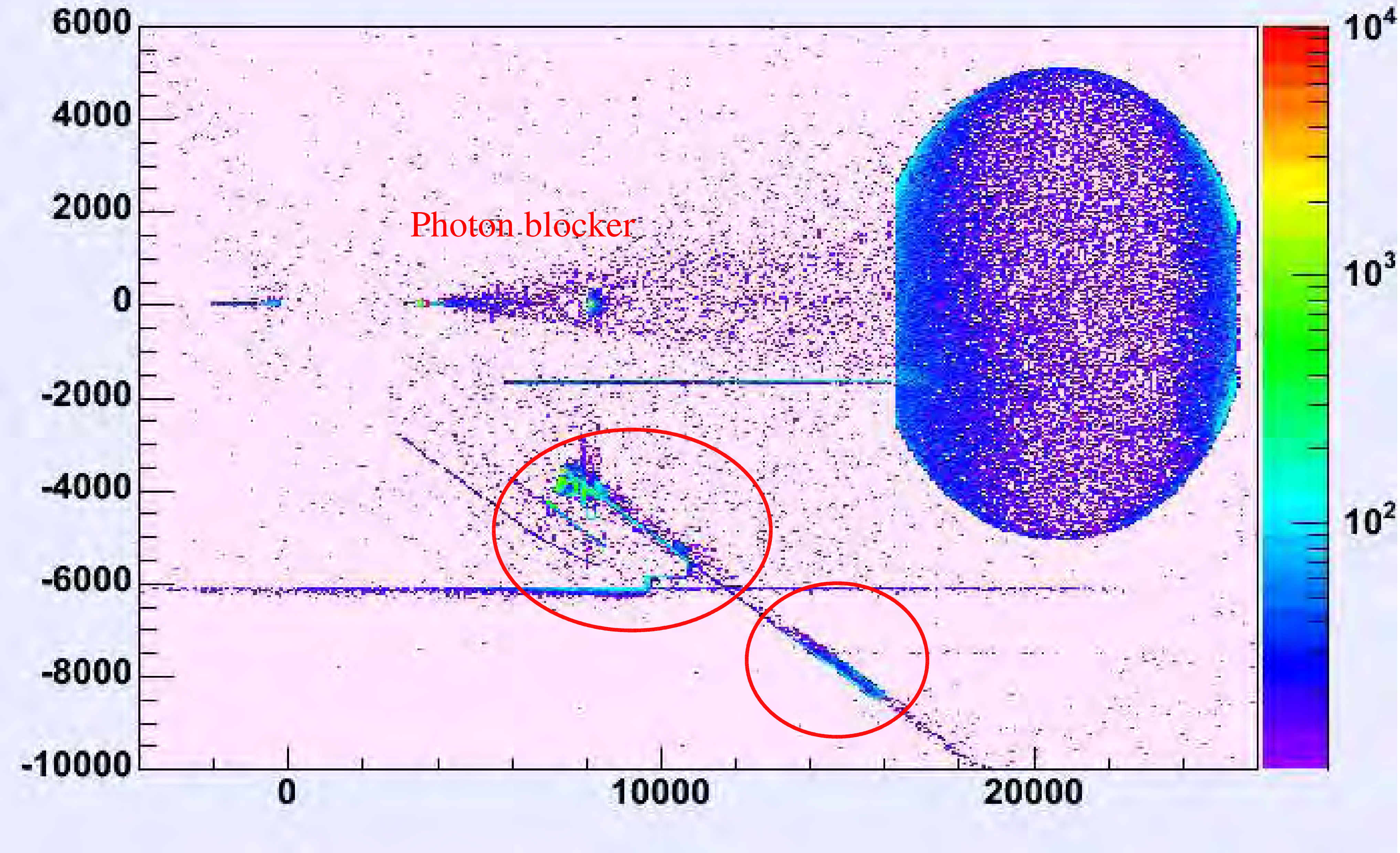
- Approved by PAC31 for 30 days of beam time, tentatively scheduled for late 2008.

# Detailed GEANT4 simulation

(old configuration)



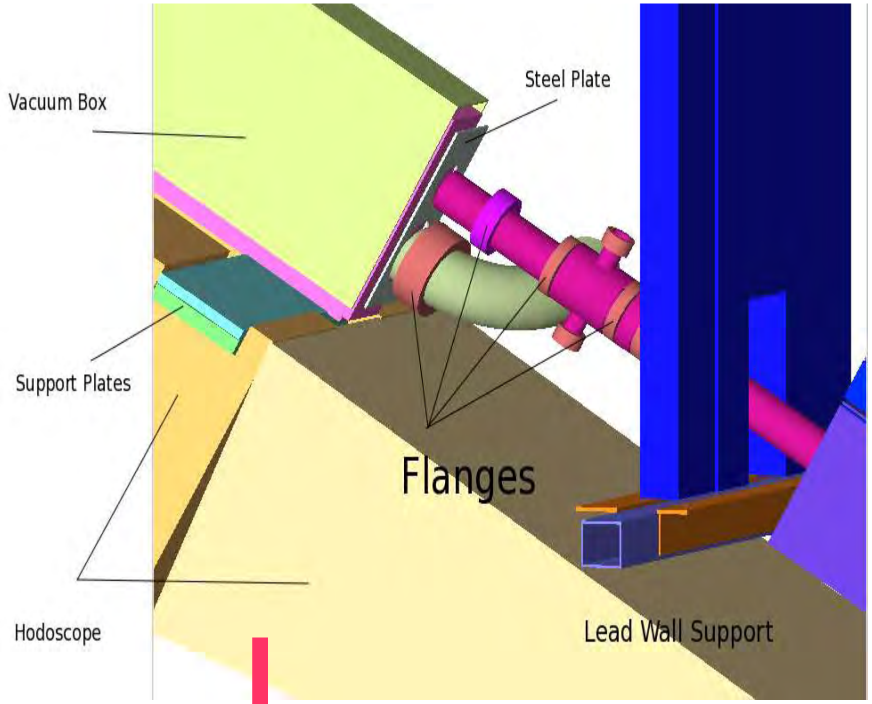
# GEANT4 simulation – vertex origin of hits on TOF
Old (2005) Test Run

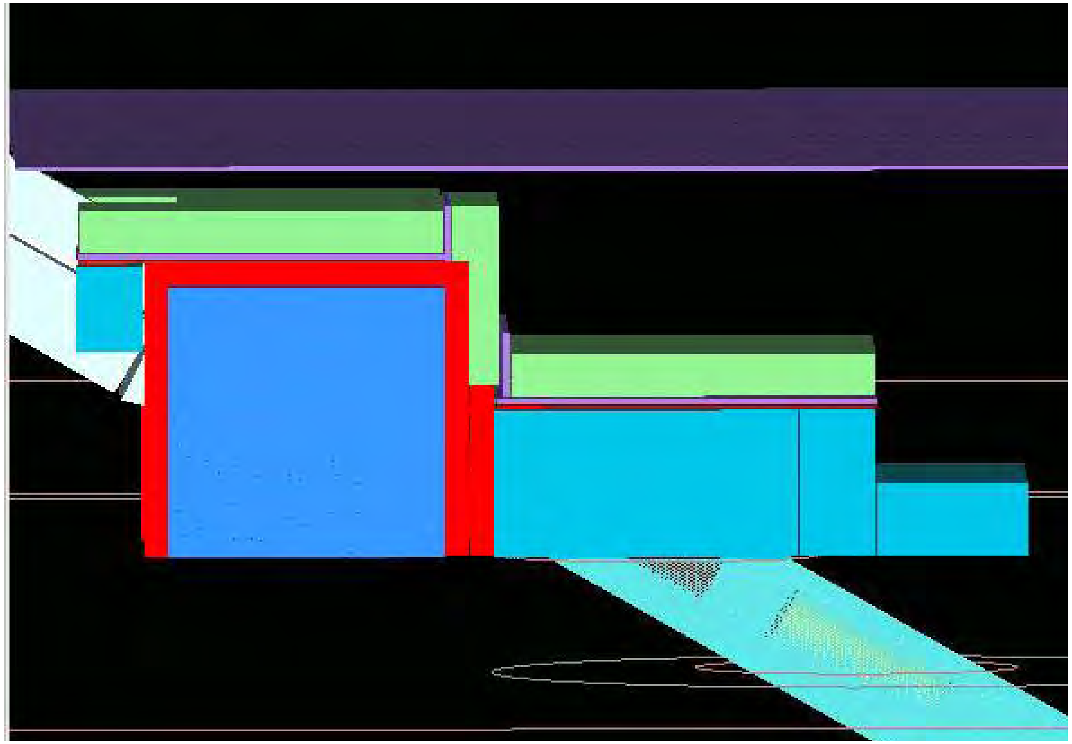


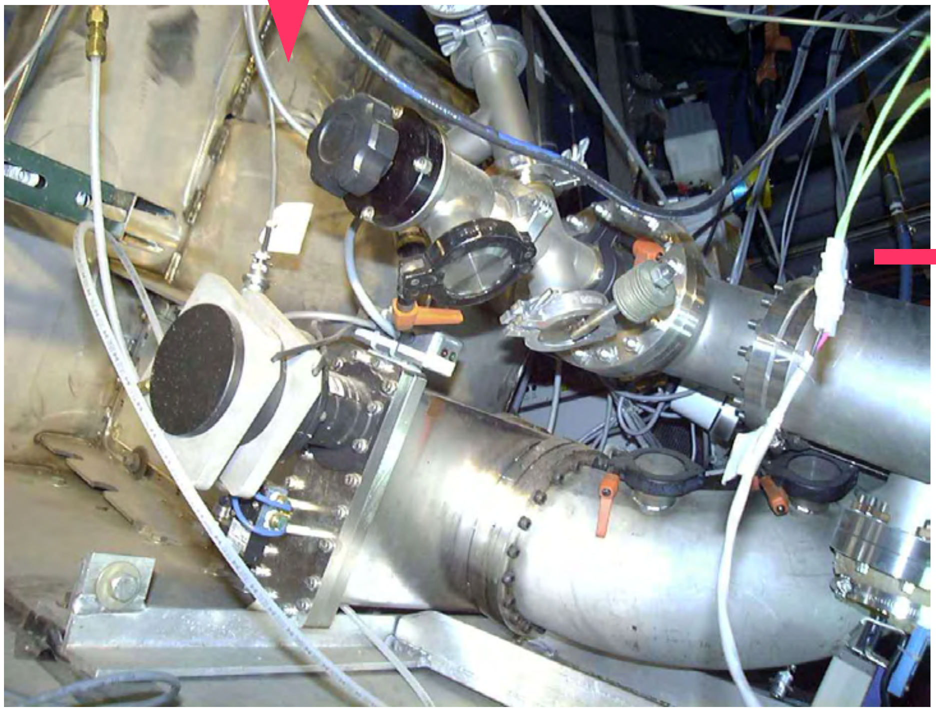
Old

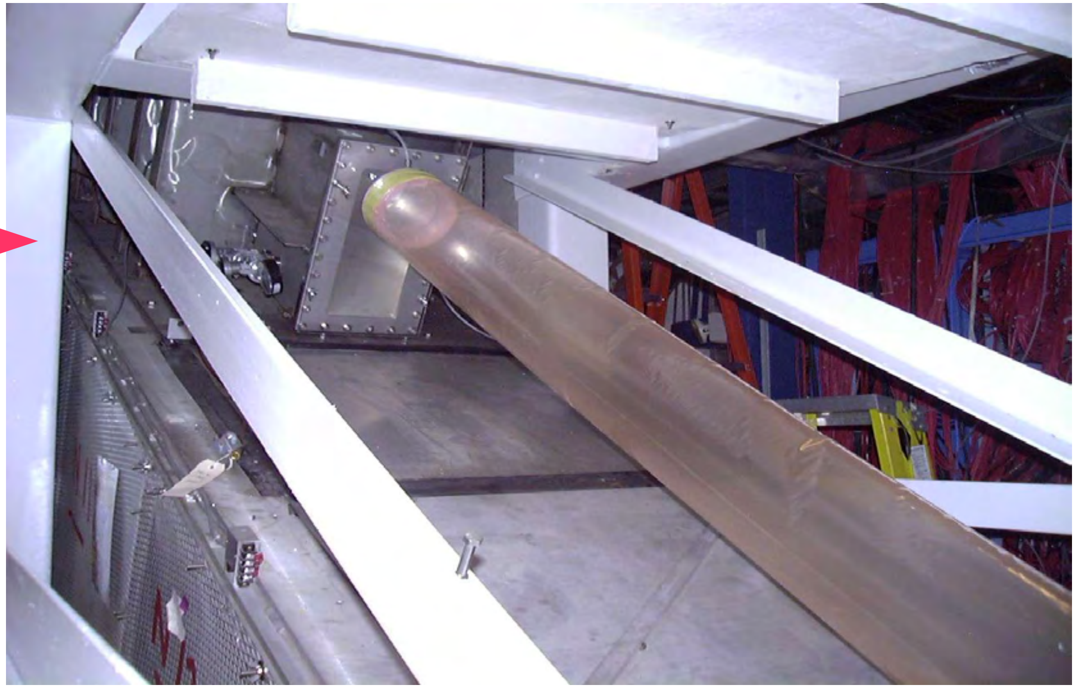
# Tagger Modifications

New







# Analysis of Test Run Data:

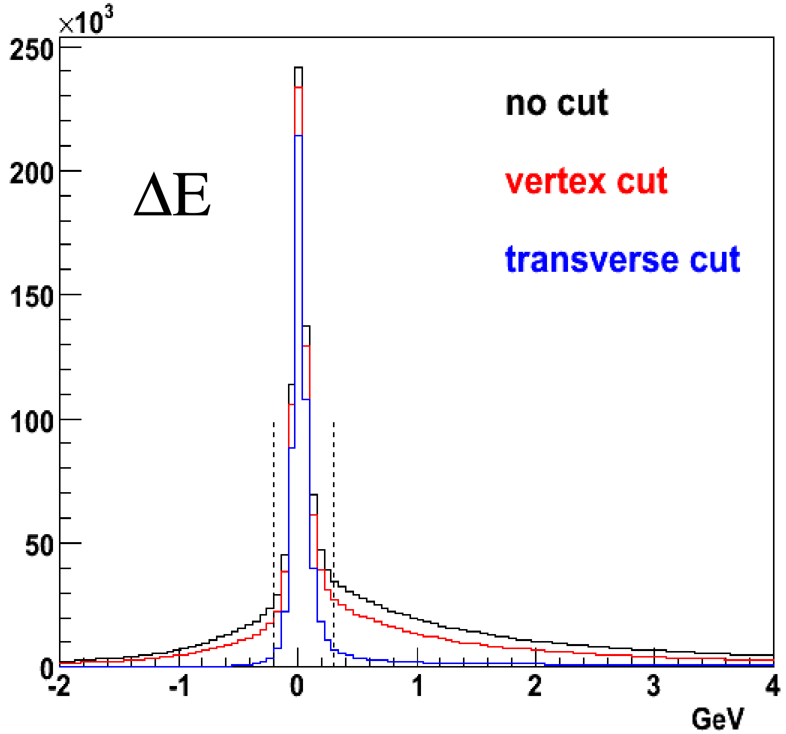
Two-track events, preliminary calibration using g13 data

# Cuts identifying elastic events

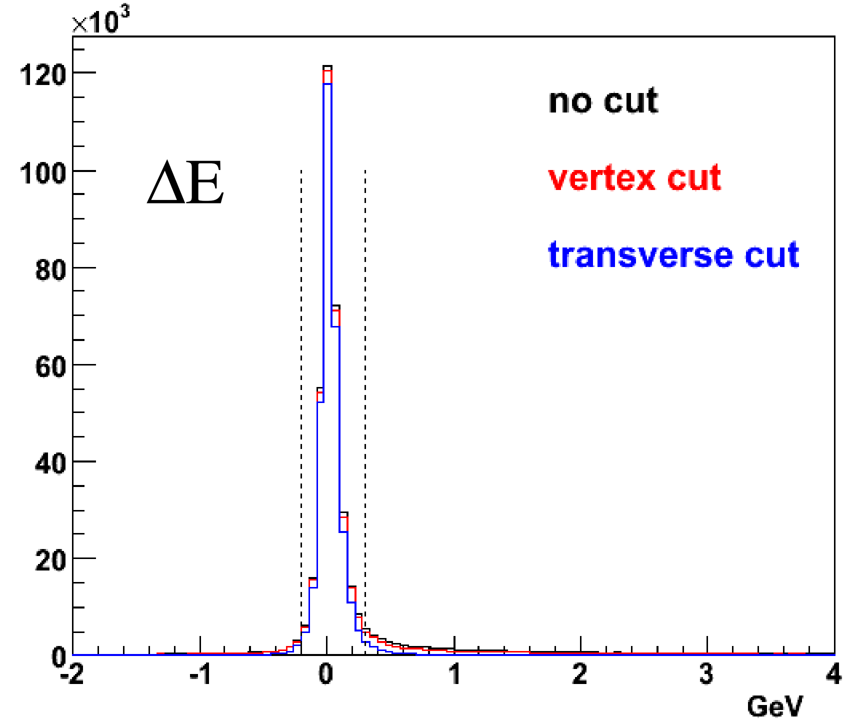
- Beam energy:
  - Calculate E from total momentum along beamline direction
  - Calculate E from particle angles (assume elastic scattering)
  - $\Delta E = E(P_{1z}, P_{2z}) - E(\theta_1, \theta_2)$
  - $\Delta E = 0$ for elastic scattering
- Transverse momentum
  - Determine angle between total final state momentum and beamline direction, $\theta_B$
  - $\theta_B = 0$ for elastic scattering
- No timing cuts

# Cuts

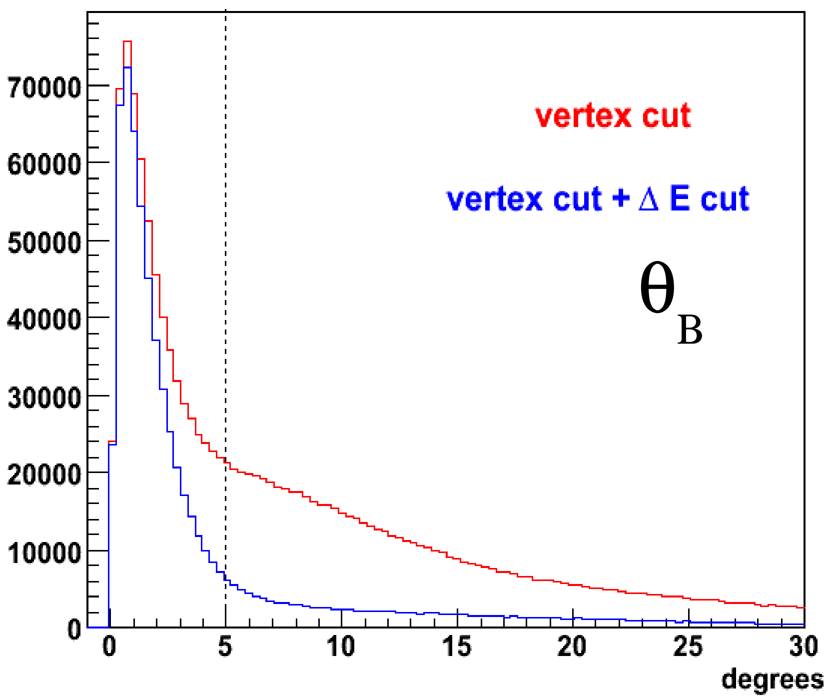
one negative, one positive: (e-,e-p)?



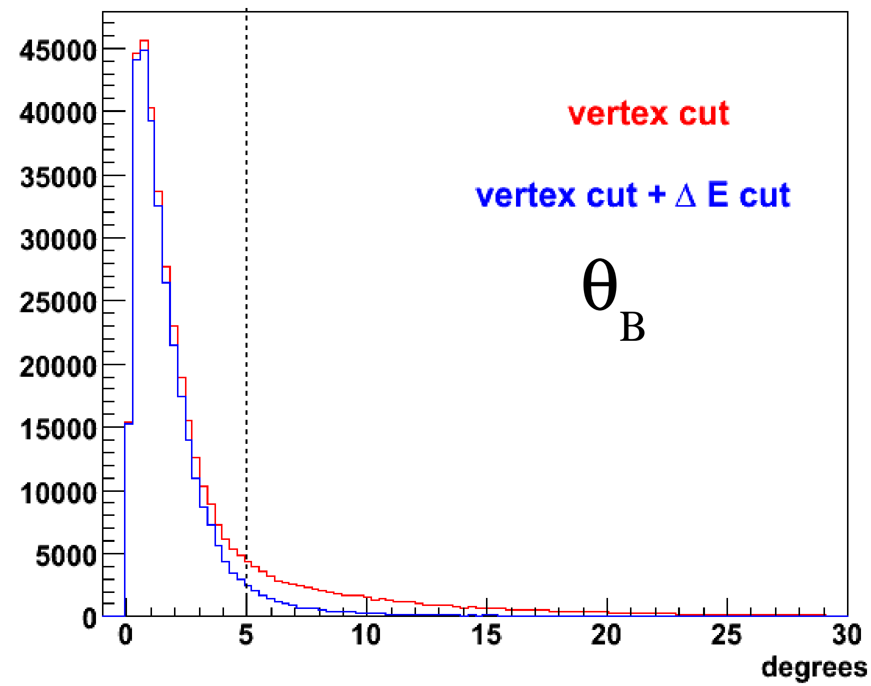

two positive: (e+,e+p)?




one negative, one positive

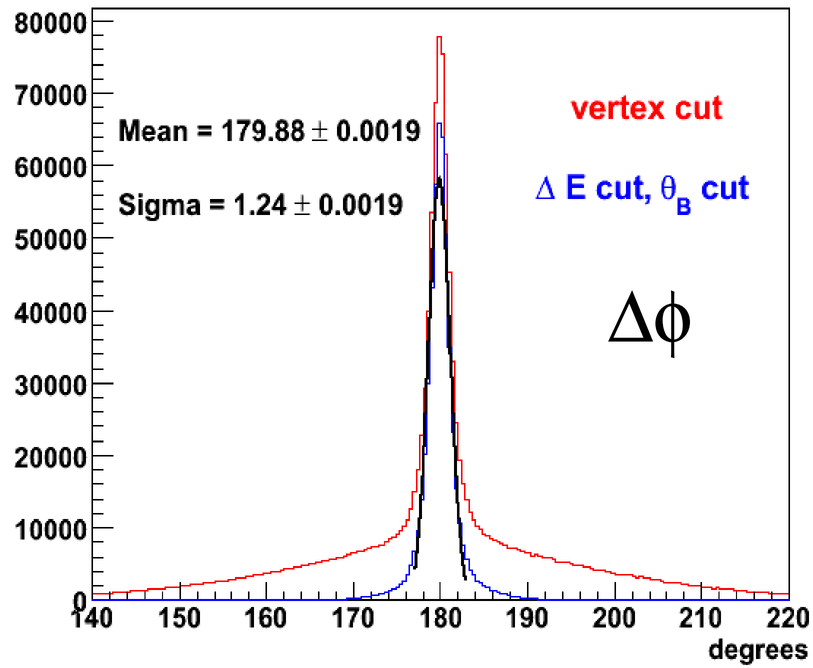



two positive

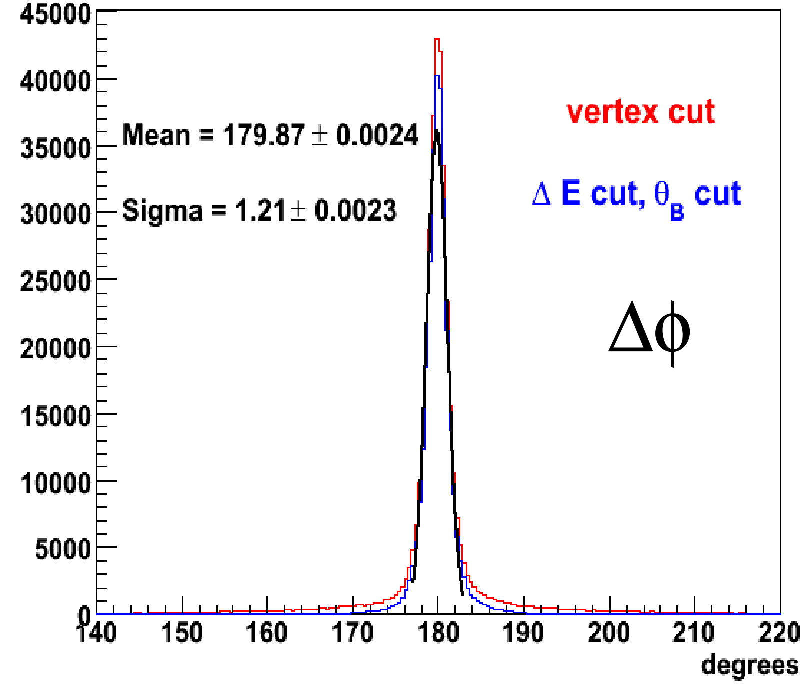


# Results

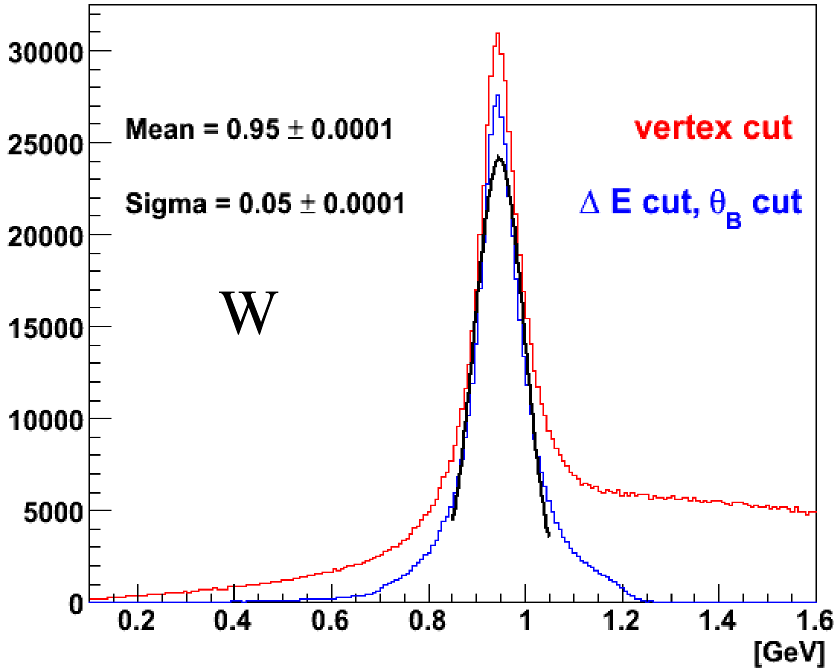
one negative, one positive: (e-,e-p)?



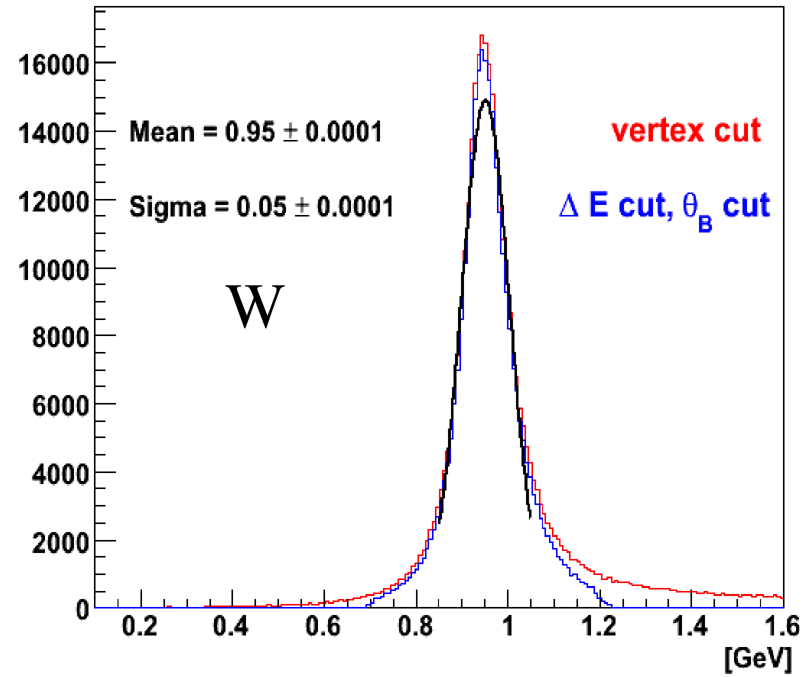

two positive: (e+,e+p)?




one negative, one positive




two positive



# Test Run Results

- Large background sources have been identified and significantly reduced in the 2006 test run.
- Tagger beamline background has been reduced by a factor of ~20 by improved tagger construction and shielding around the tagger and tagger dump.
- Simulation reproduces data on background sources.
- e-p and e+p elastic events have been observed.

# Test Run Results: Luminosity

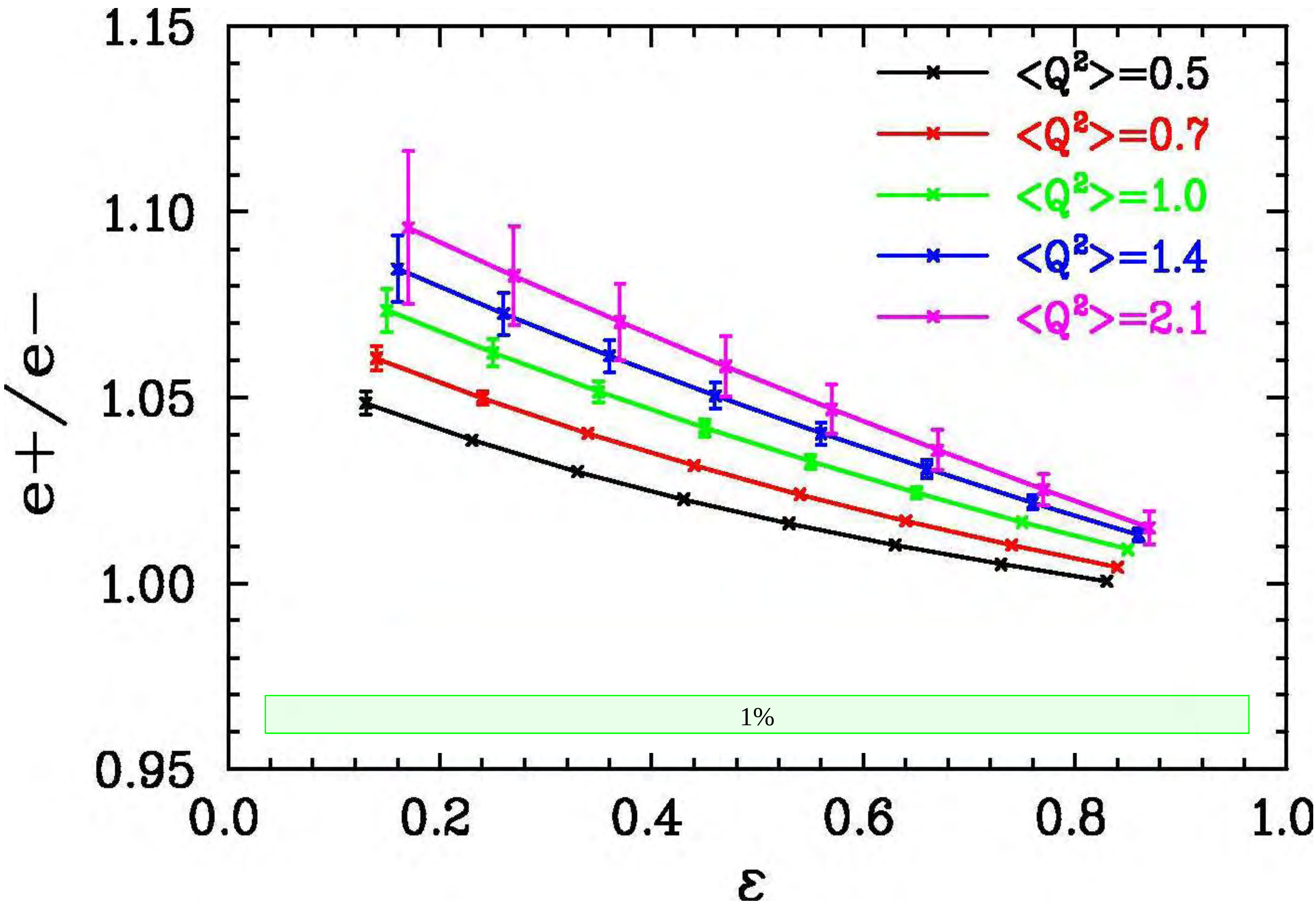
Maximum luminosity achieved:

- 80 nA 3.3 GeV electrons
- 0.5% radiator, 5% converter
- Lepton current at target: 20 pA (80nA*0.5%*5%)

  Luminosity limited by R1 DC occupancy.

- Luminosity and backgrounds agree with simulations.
- Factor of ~20 improvement on previous test runs

# Anticipated uncertainties



# Summary:

- Rosenbluth and Polarization transfer experiments measure $G_E$ that differ by a factor of ~5 at $Q^2$ = 6. Two Photon Exchange can explain the discrepancy.

- The $e^+p/e^-p$ ratio is the only way to measure the real part of the TPE amplitude.

- The TPE 2006 Engineering Test Run:
  - Produced a mixed electron/positron beam
  - Validated detailed GEANT4 beamline and tagger simulation
  - Observed $e^+p$ and $e^-p$ elastic scattering events
  - PAC31 approval for 30 days of beam time

# Backup Slides

# The Formalism

General 1- and 2-photon exchange amplitude

$$A = \frac{e^2}{Q^2}\bar{u}(k')\gamma_\mu u(k)$$

2: $$\times \quad \bar{u}(p')\left[\tilde{G}_m\gamma^\mu - \tilde{F}_2\frac{P^\mu}{M} + \tilde{F}_3\frac{\gamma\cdot K P^\mu}{M^2}\right]$$

1: $$\times \quad \bar{u}(p')\left[G_m\gamma^\mu - F_2\frac{P^\mu}{M} + \qquad\qquad\right]$$

General 1- and 2-photon exchange cross section

1: $$\frac{d\sigma}{d\Omega} \propto [\tau G_m^2 + \epsilon G_E^2]$$

2: $$\frac{d\sigma}{d\Omega} \propto [\tau\tilde{G}_m^2 + \epsilon\tilde{G}_E^2 + 2\epsilon(\tau|\tilde{G}_m| + |\tilde{G}_E\tilde{G}_m|)Y_{2\gamma}]$$

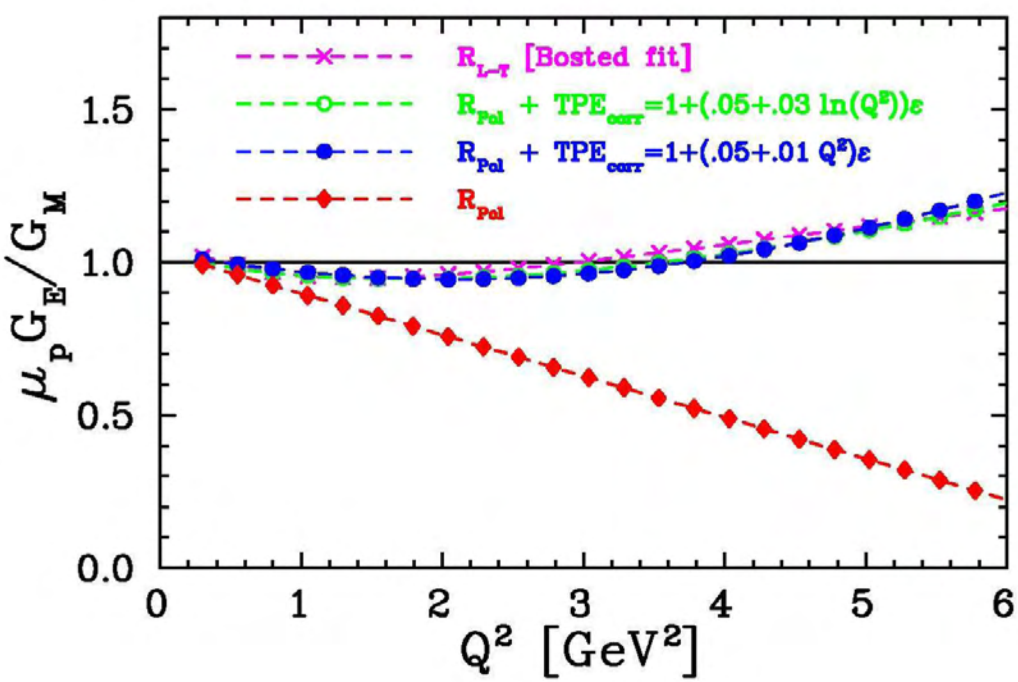
$$Y_{2\gamma} \propto \mathcal{R}\left(\frac{\tilde{F}_3}{|\tilde{G}_m|}\right)$$

Thus we have

- Another $\varepsilon$ dependent term
- Modified $G_E$ and $G_M$

Guichon and Vanderhaegen, PRL 91 (03) 142303

# Phenomenology



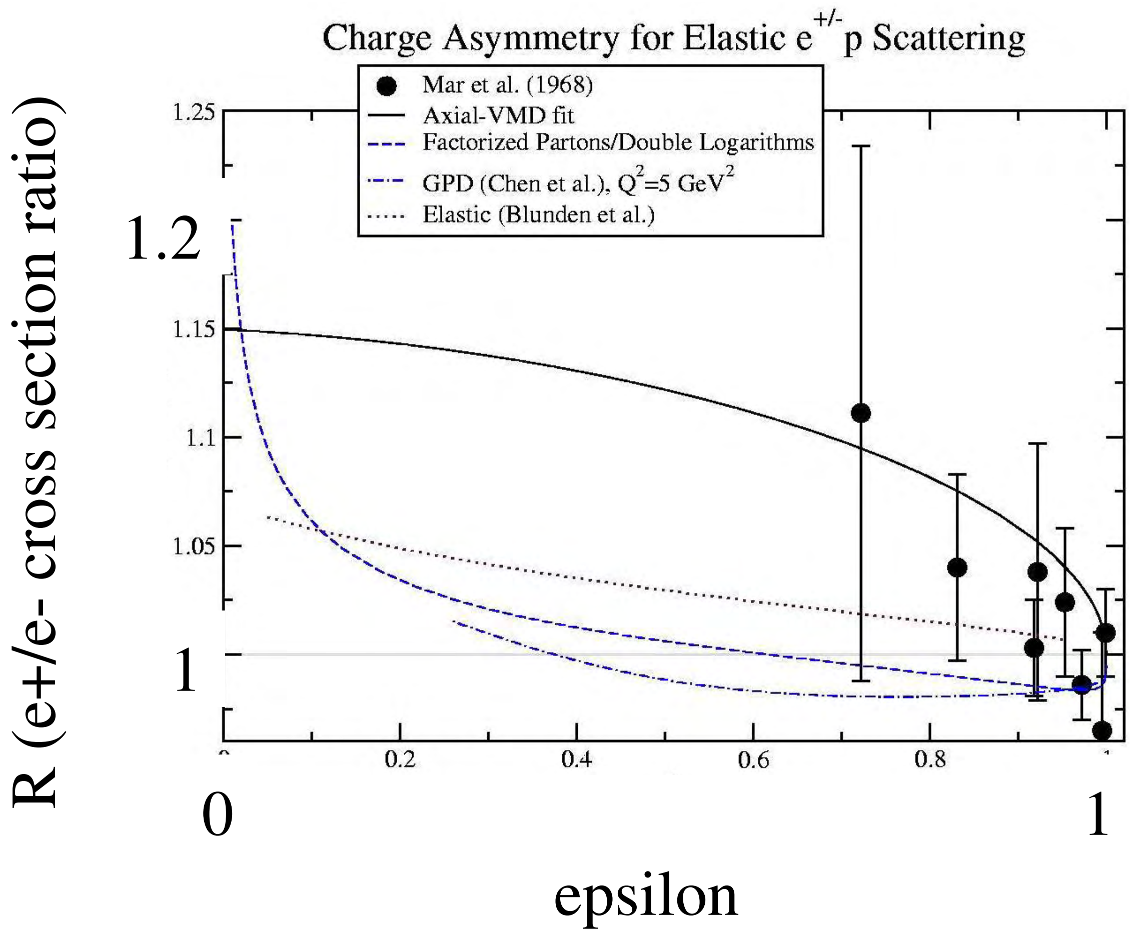

Rosenbluth result with Polarization-transfer FF + few % TPE

Polarization-transfer FF

Adding a small (few %), epsilon-dependent term to the cross section will

- Not change the polarization-transfer results
- Drastically change the Rosenbluth results

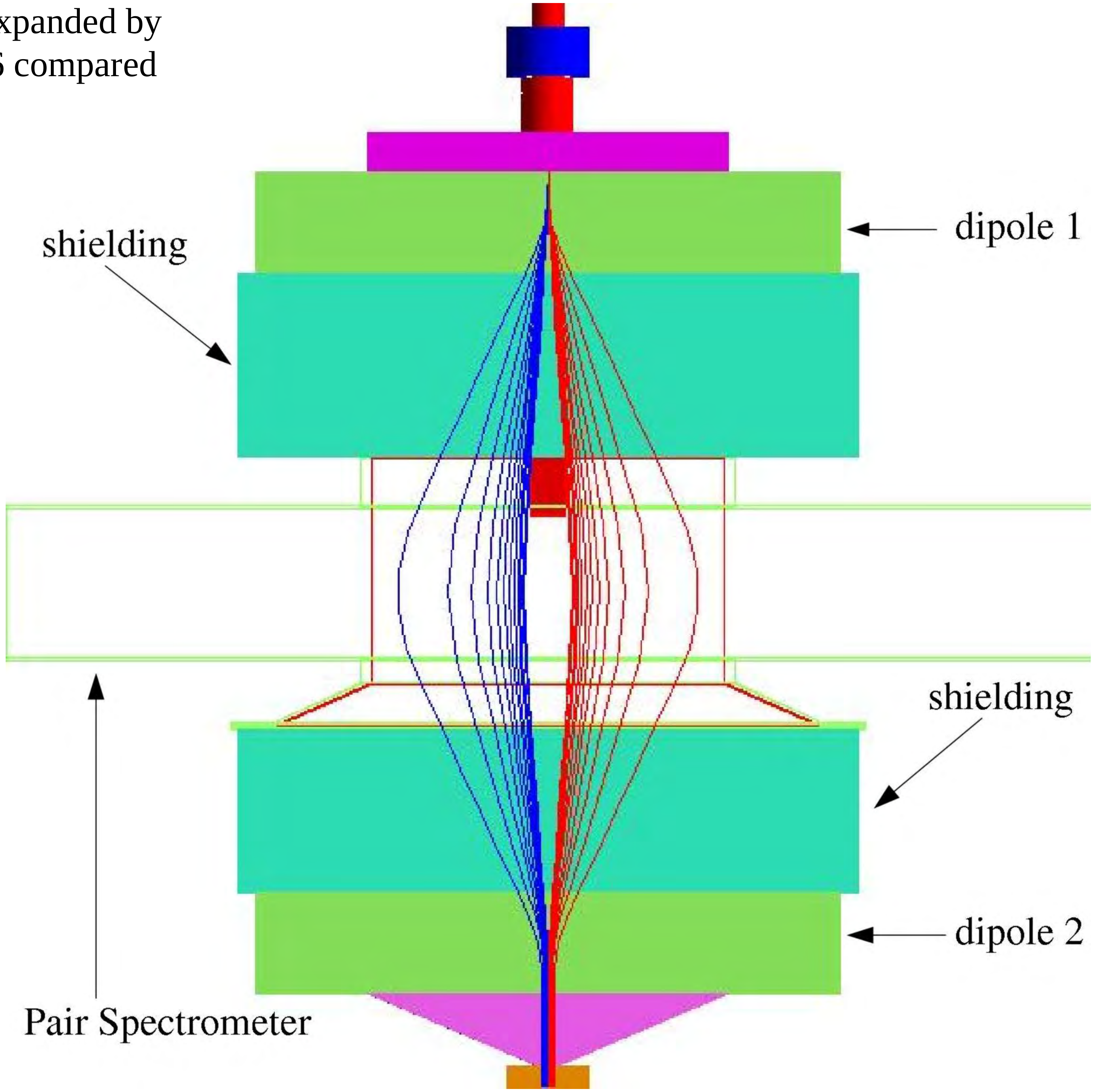
# Existing e+/e- cross section ratios (Q2 > 1)

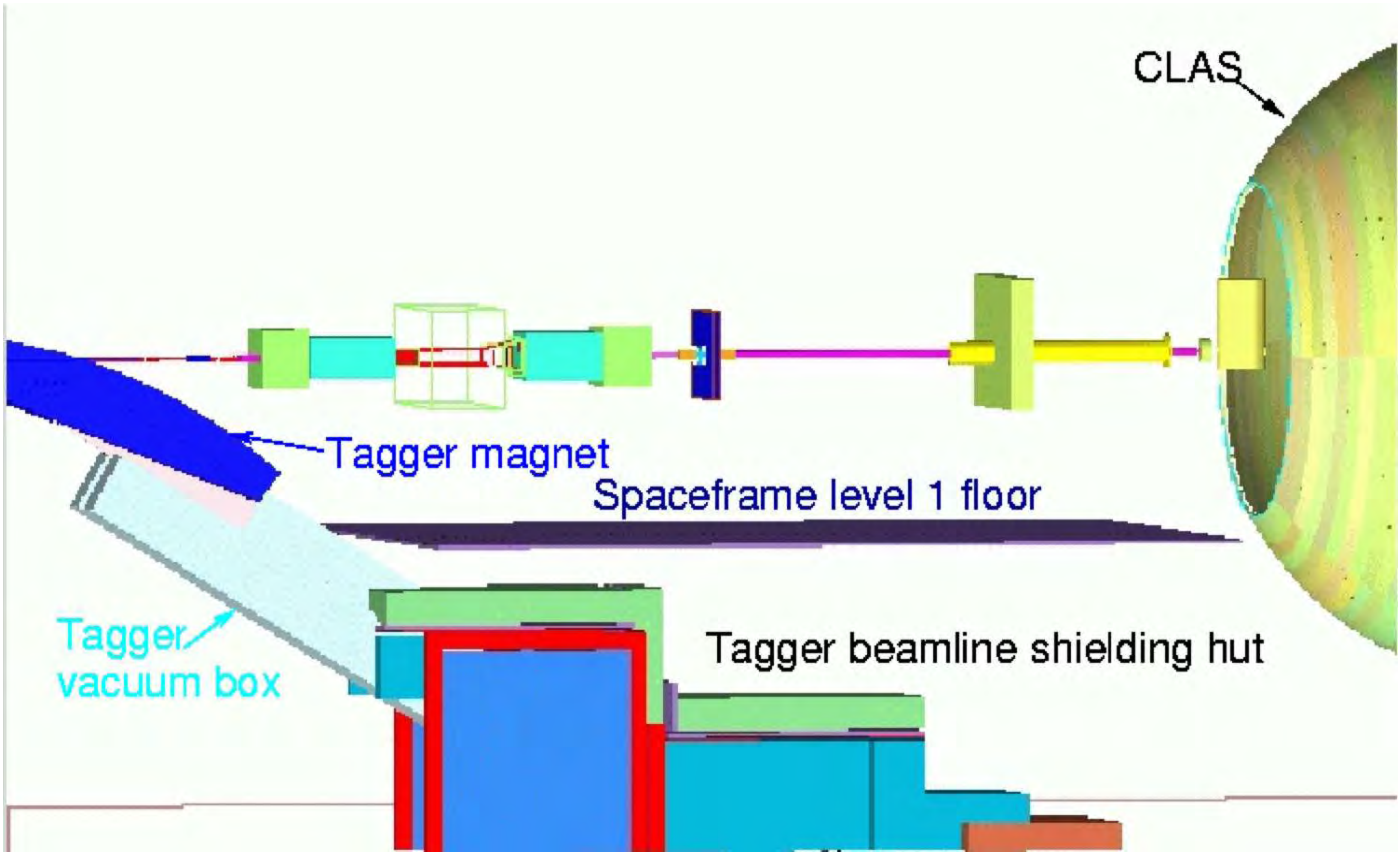


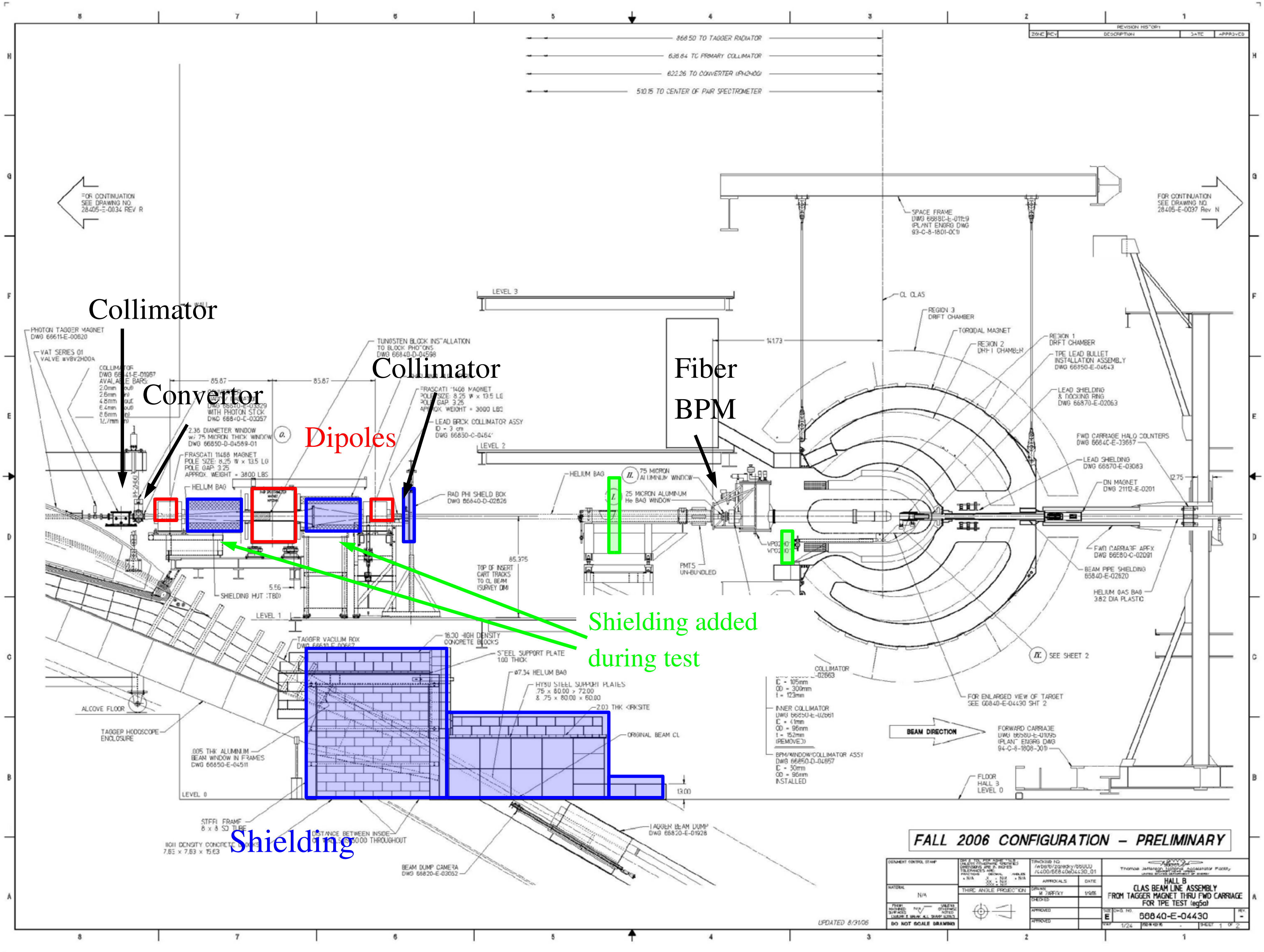

Data: Mar *et al*, PRL **21** (1968) 482

Doesn't constrain much

X scale is expanded by a factor of 6 compared to Y scale

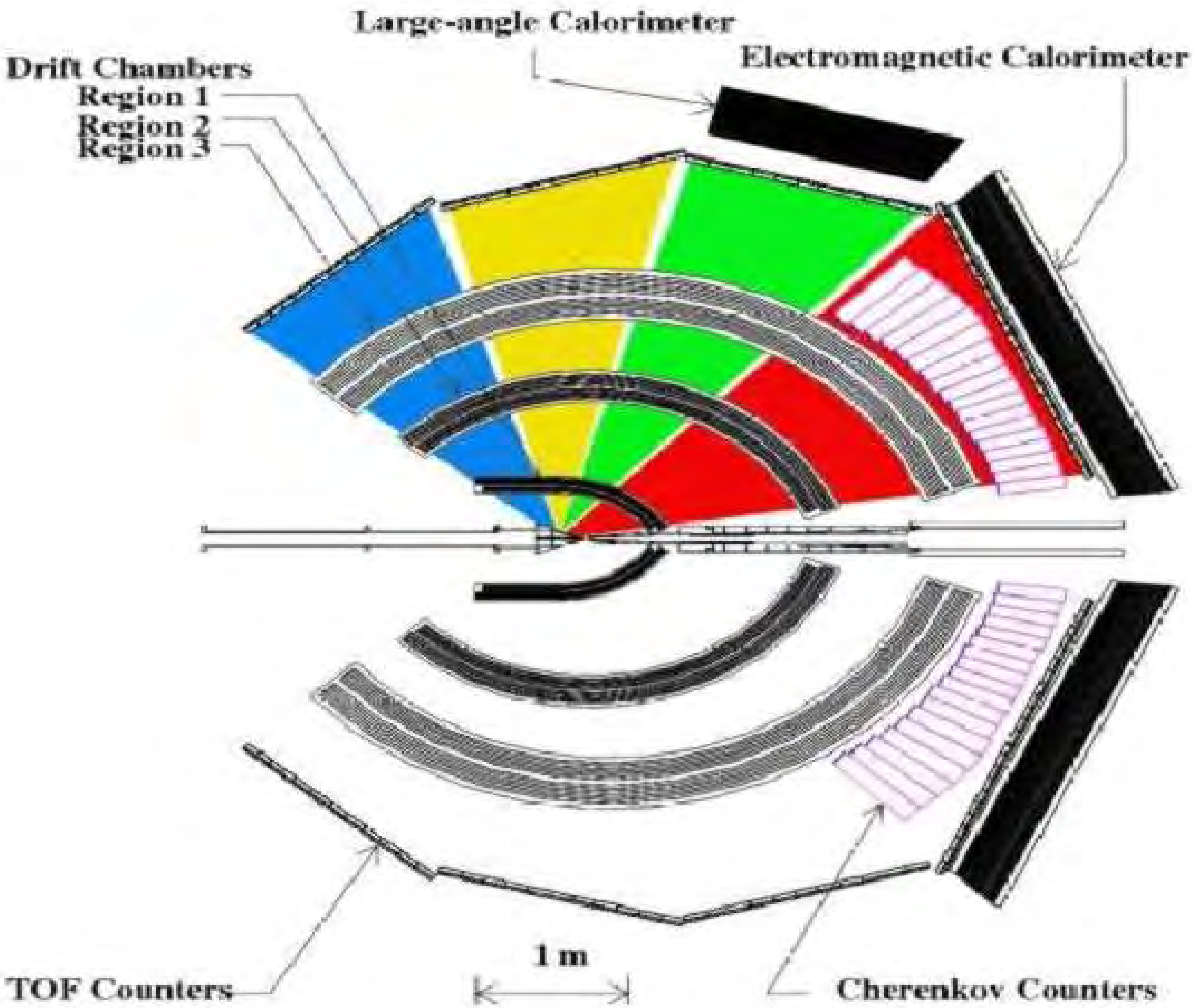


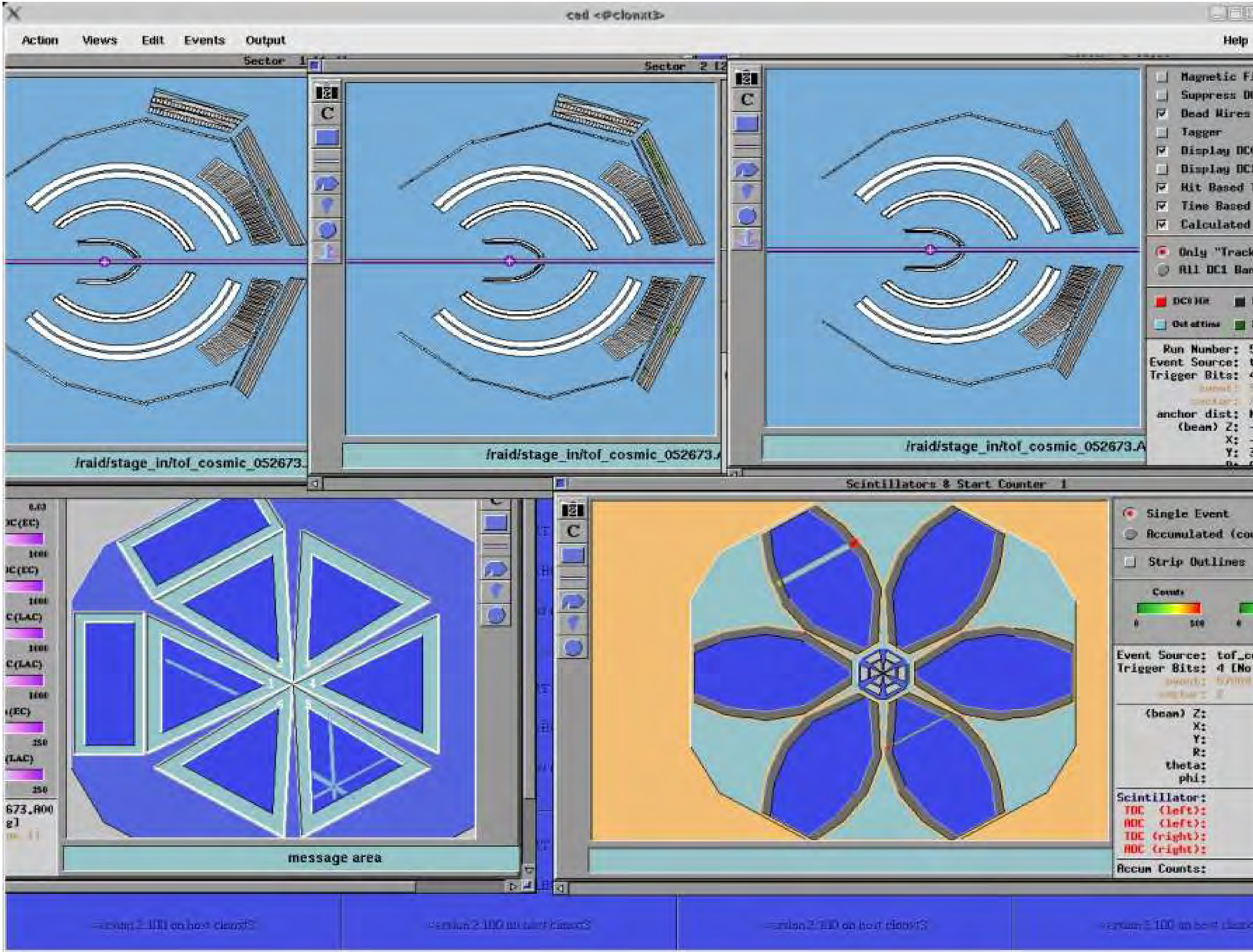

CLAS
Tagger magnet
Spaceframe level 1 floor
Tagger
vacuum box
Tagger beamline shielding hut



Collimator
Convertor
Collimator
Dipoles
Fiber
BPM
Shielding added
during test
Shielding
FALL 2006 CONFIGURATION – PRELIMINARY
BEAM DIRECTION
868.50 TO TAGGER RADIATOR
638.64 TO PRIMARY COLLIMATOR
622.26 TO CONVERTER (PH2400)
510.15 TO CENTER OF PAIR SPECTROMETER
HALL B
CLAS BEAM LINE ASSEMBLY
FROM TAGGER MAGNET THRU FWD CARRIAGE
FOR TPE TEST (eg5a)
66840-E-04430

# Opposite sector trigger





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Action
Views
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Sector 1
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Suppress DC
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Tagger
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Run Number: 52
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Trigger Bits: 4
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(beam) Z:
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/raid/stage_in/tof_cosmic_052673.
/raid/stage_in/tof_cosmic_052673.A
message area
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Trigger Bits: 4 [No
(beam) Z:
X:
Y:
R:
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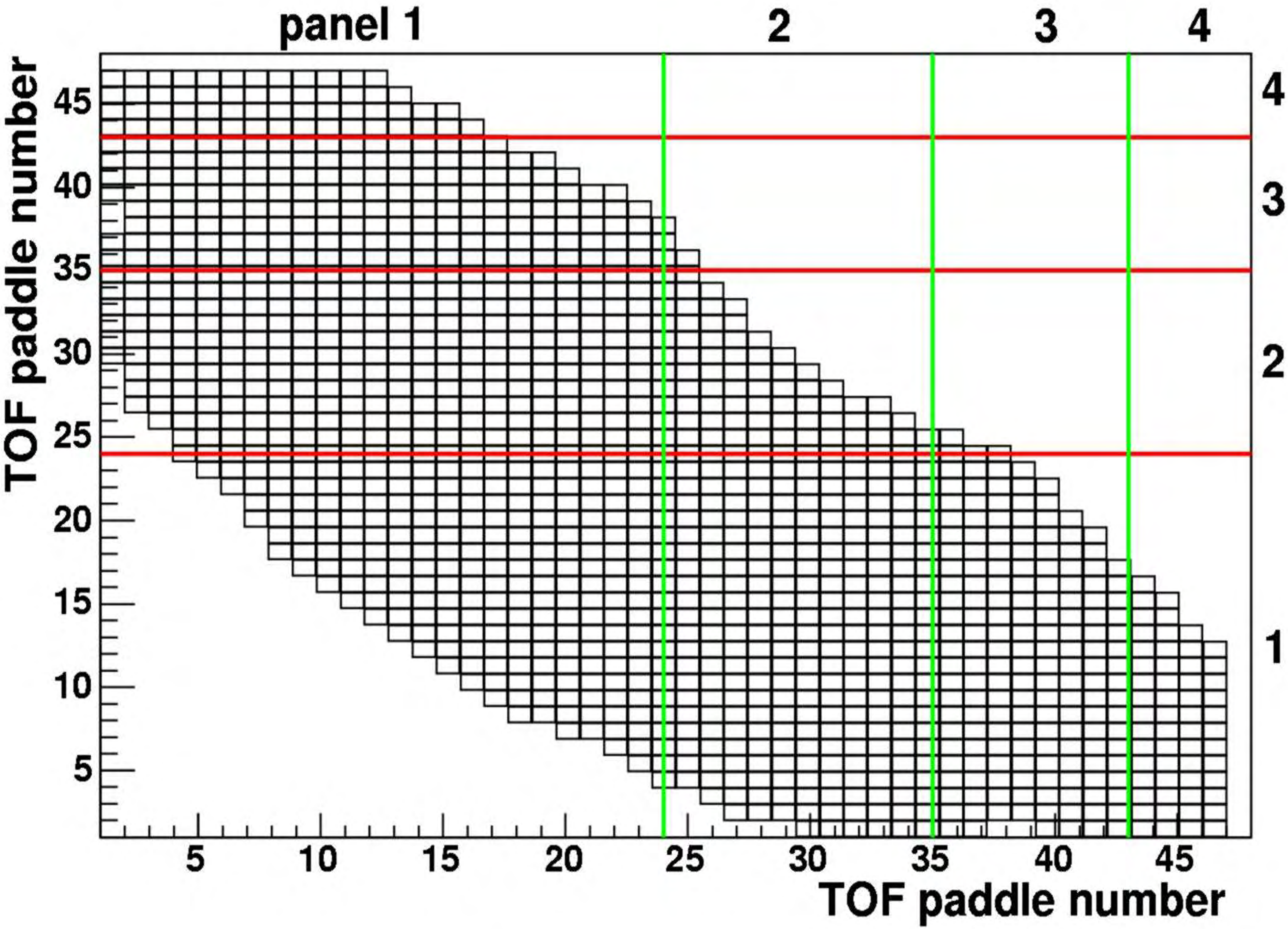
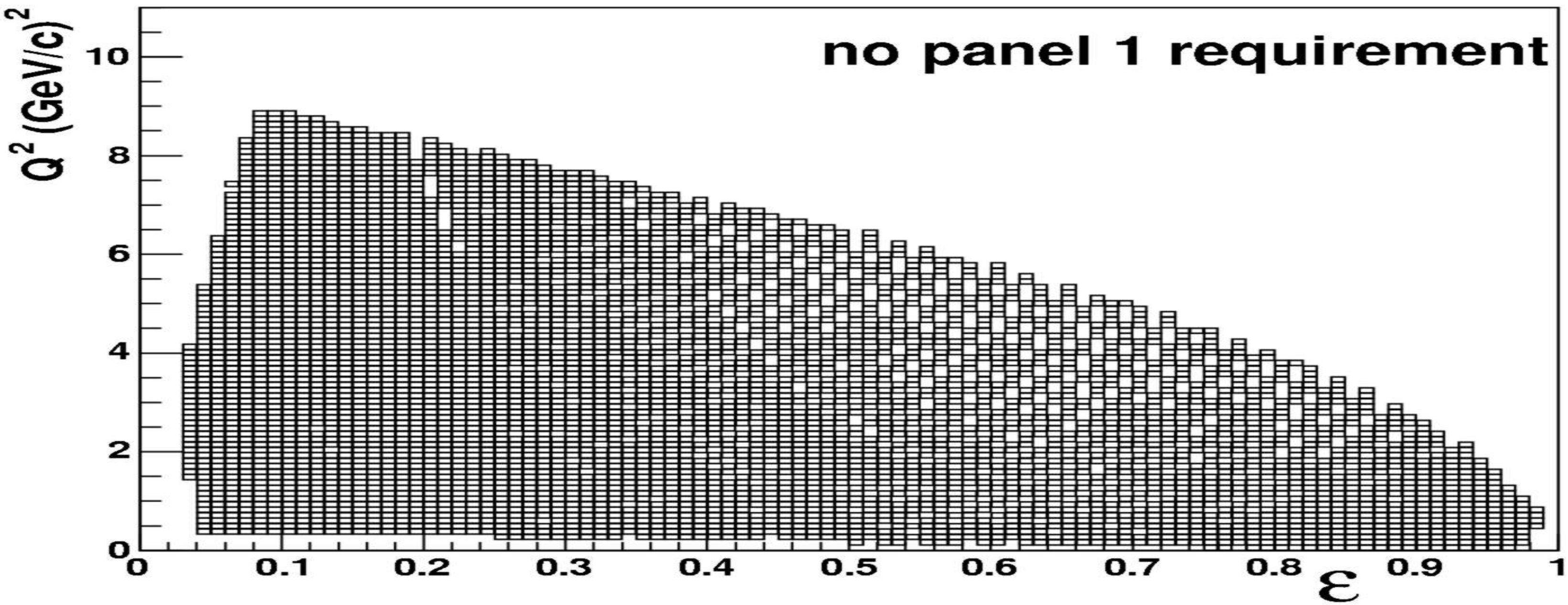
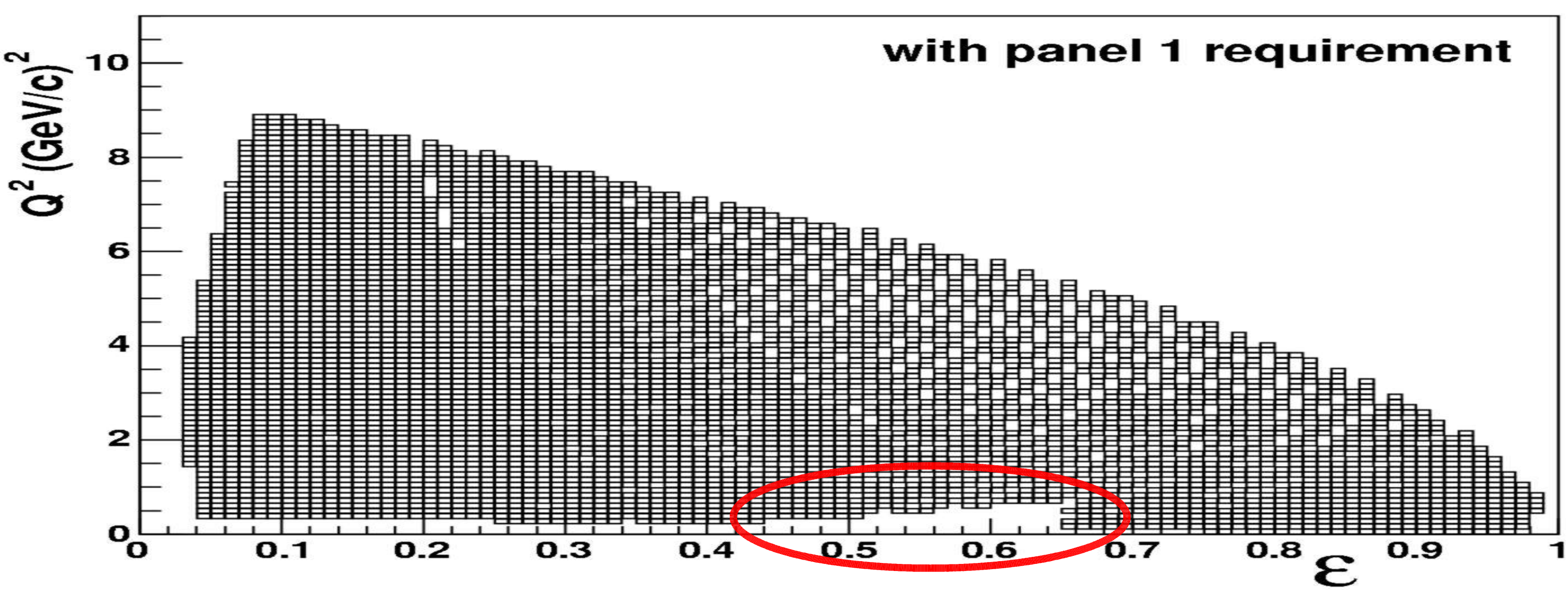
phi:
Scintillator:
TDC (left):
ADC (left):
TDC (right):
ADC (right):
Accum Counts:

Allowed opposite sector paddle correlations, $I_{torus} = 1250A$



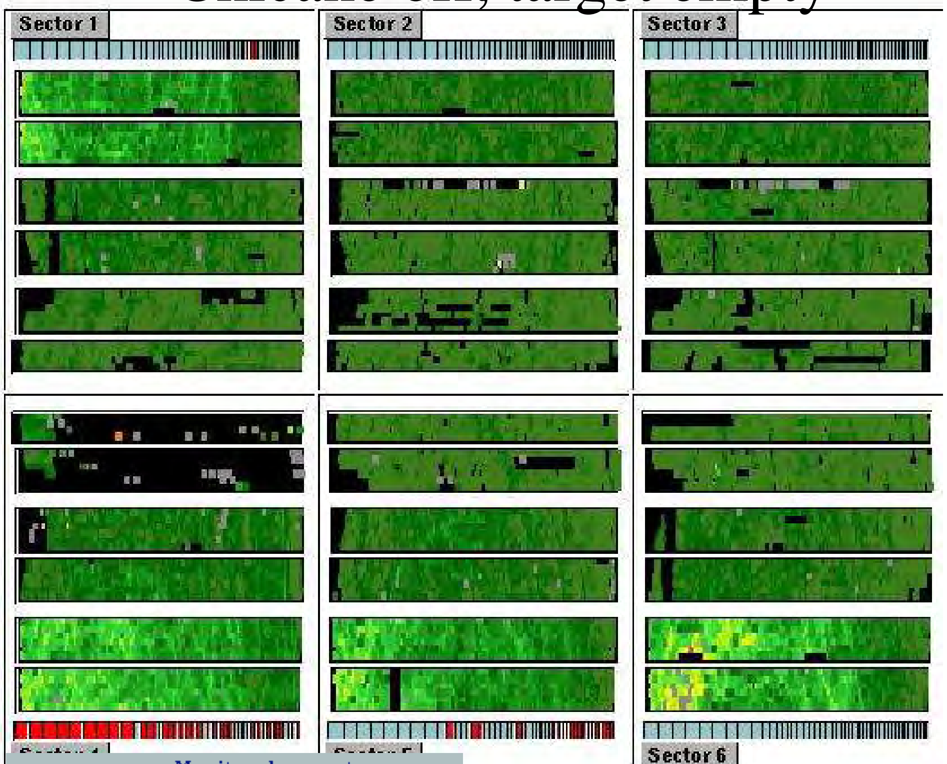
# Opposite sector trigger kinematic coverage

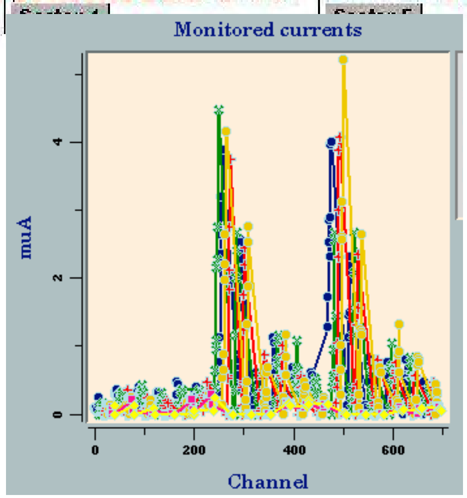


# Chicane-related background: Region I occupancy increases

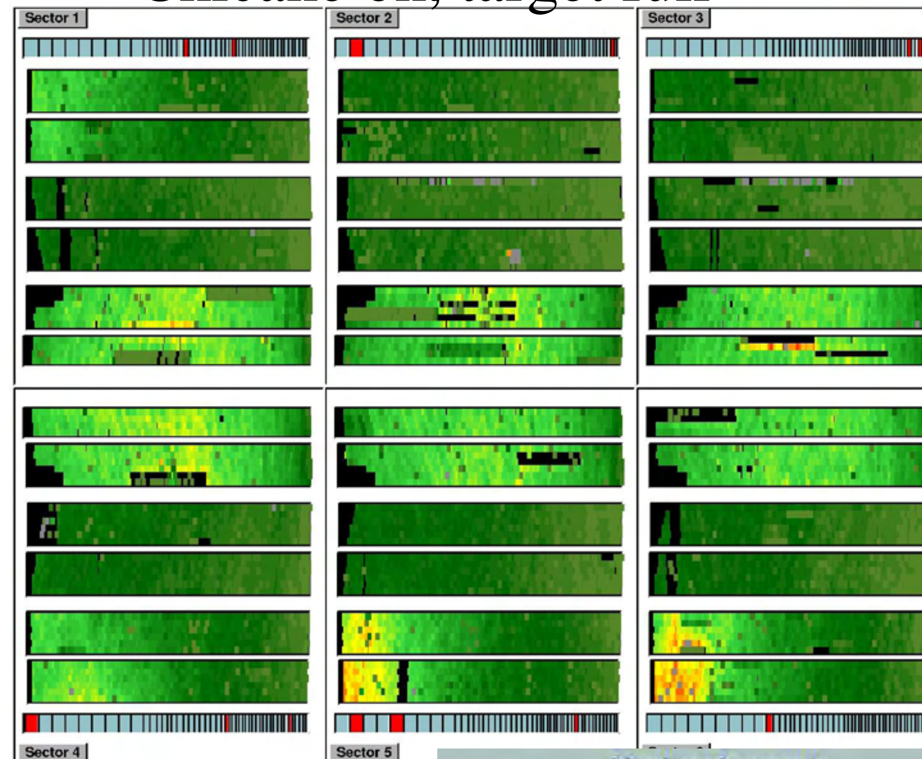
## Chicane off, target empty



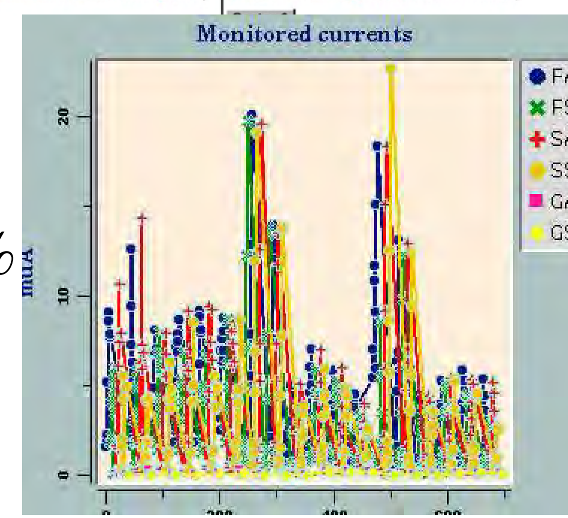




150 nA x 0.05%
(7.5 nA%)

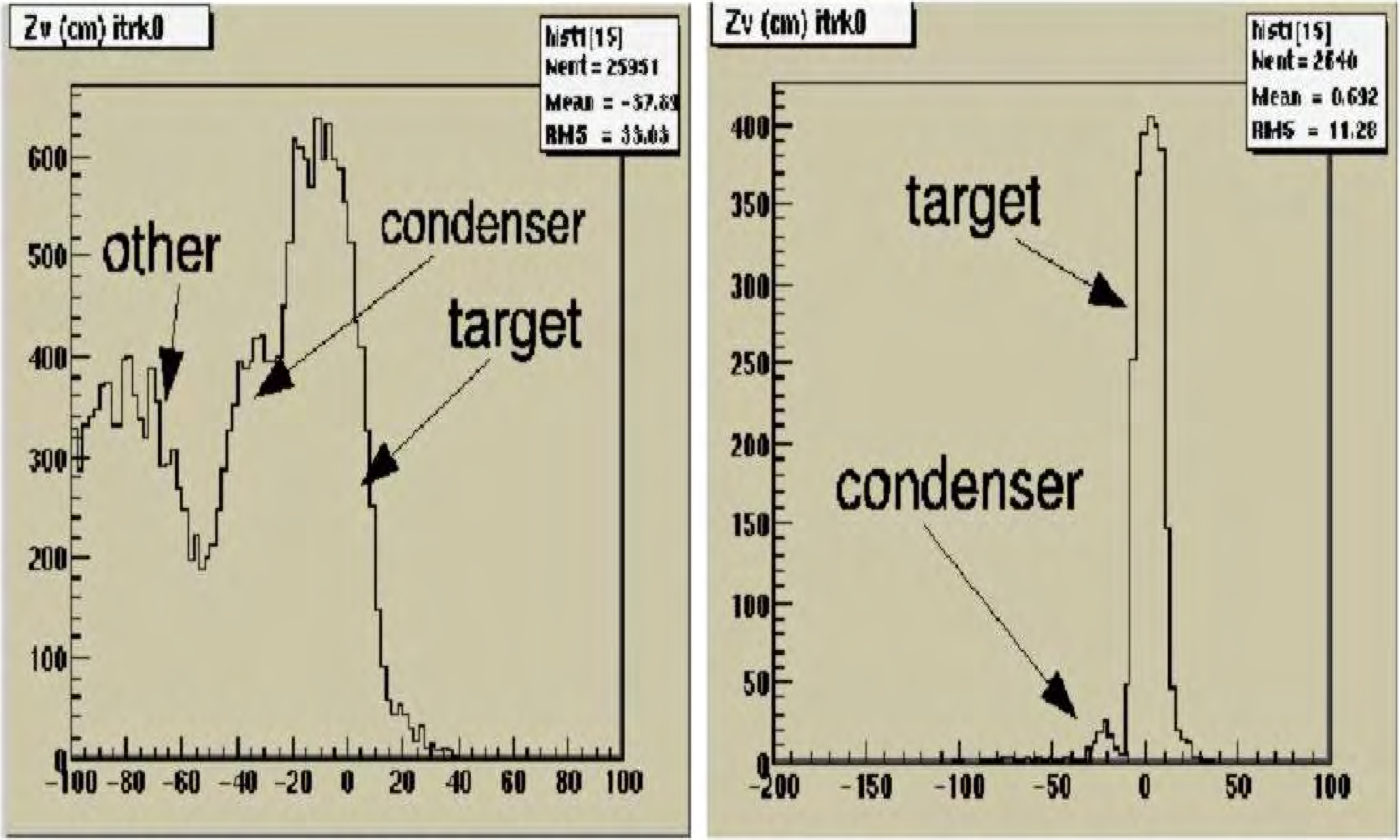
## Chicane on, target full




80 nA x 0.45%
(36 nA%)



# Online vertex reconstruction (6 superlayer tracks)




Track Vertex (cm)

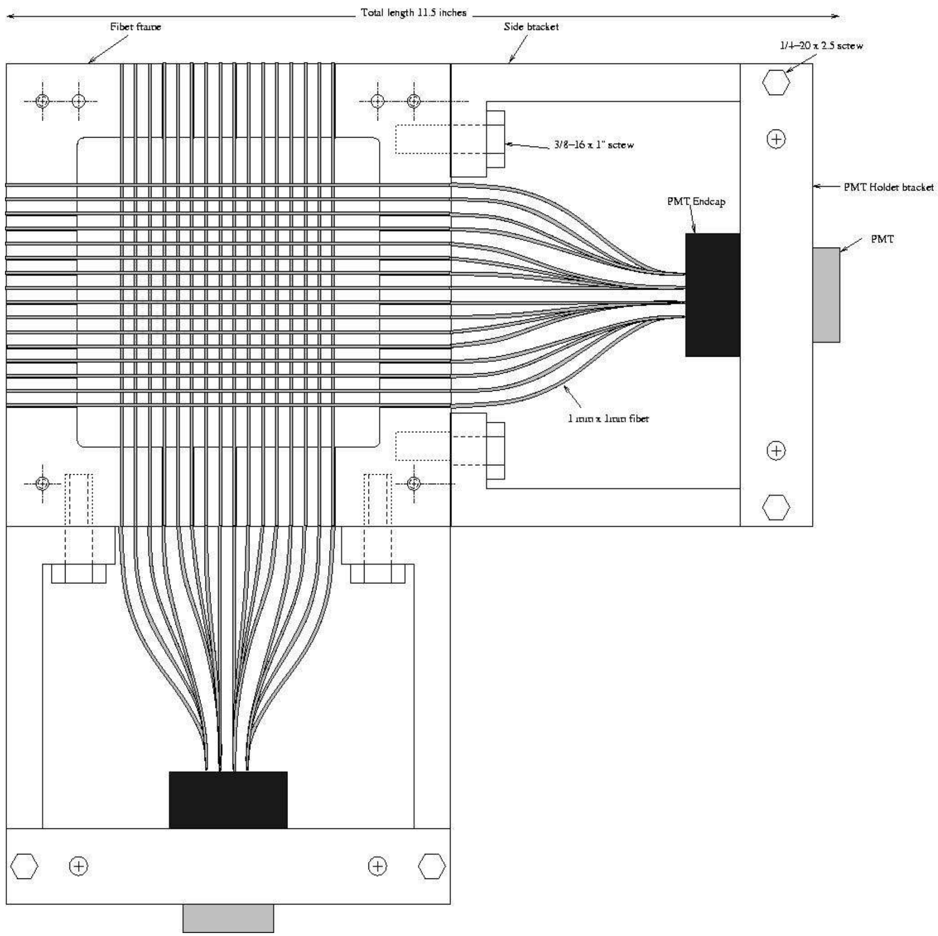
before decreasing collimator size and adding shielding

after improvements

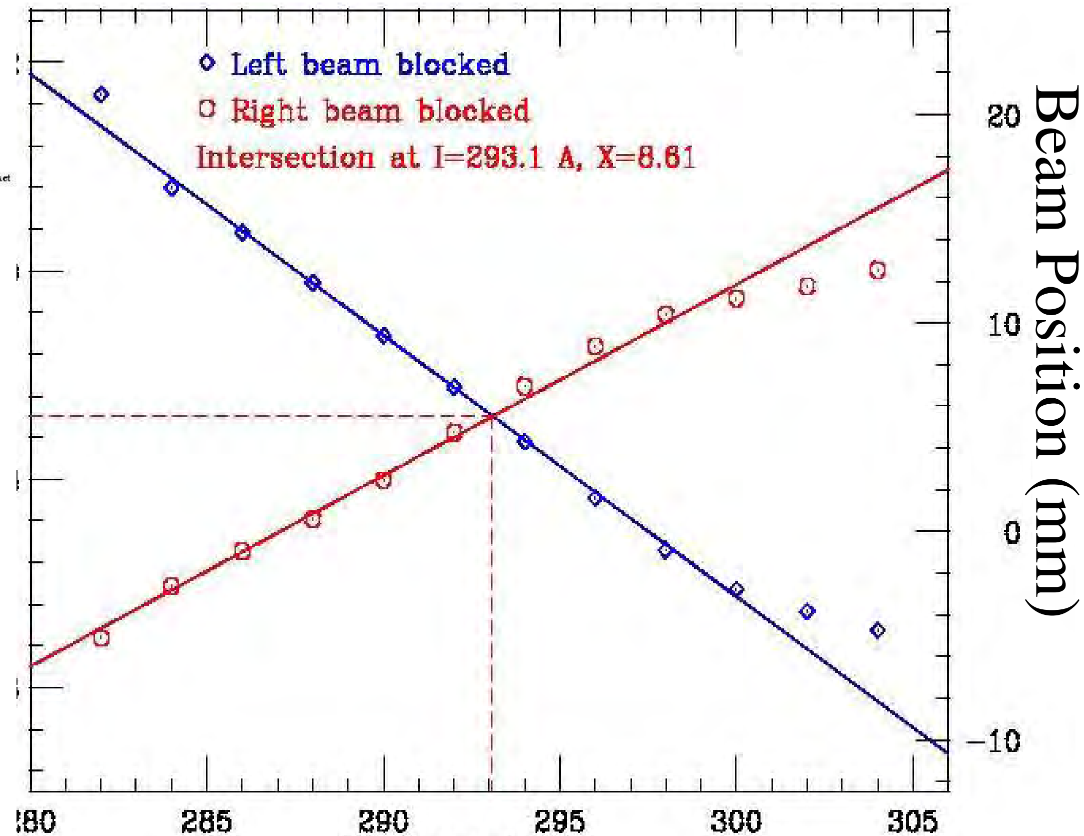
# We see positron and electron beams

- Block one lepton beam
- Scan chicane dipoles 1&3
- Watch the beam move

- Block the other beam
- Scan the chicane
- Watch the beam move

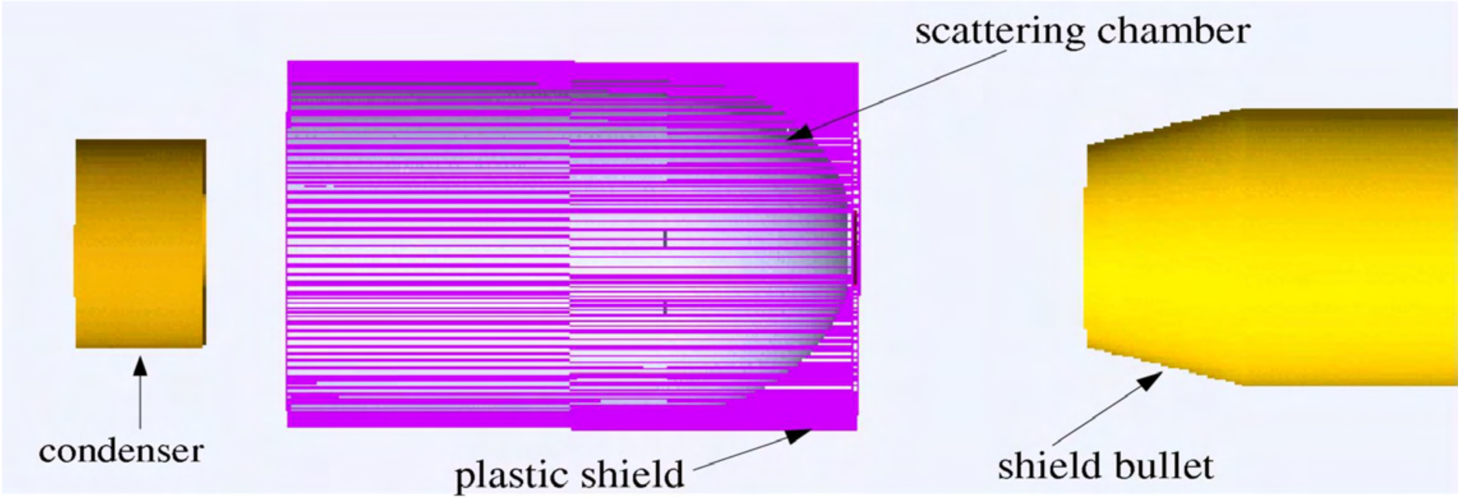


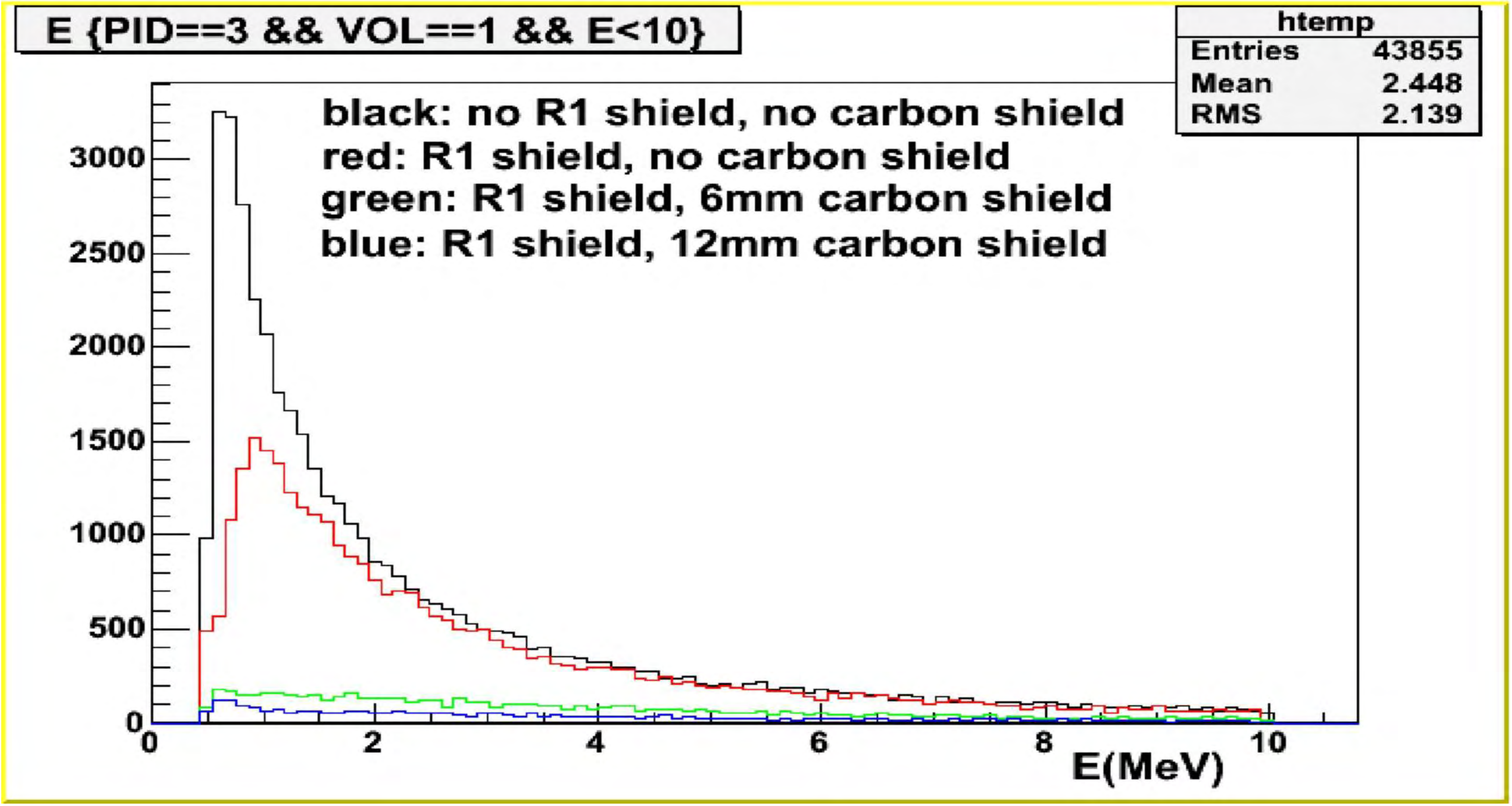

Beam Position Monitor
(before target)



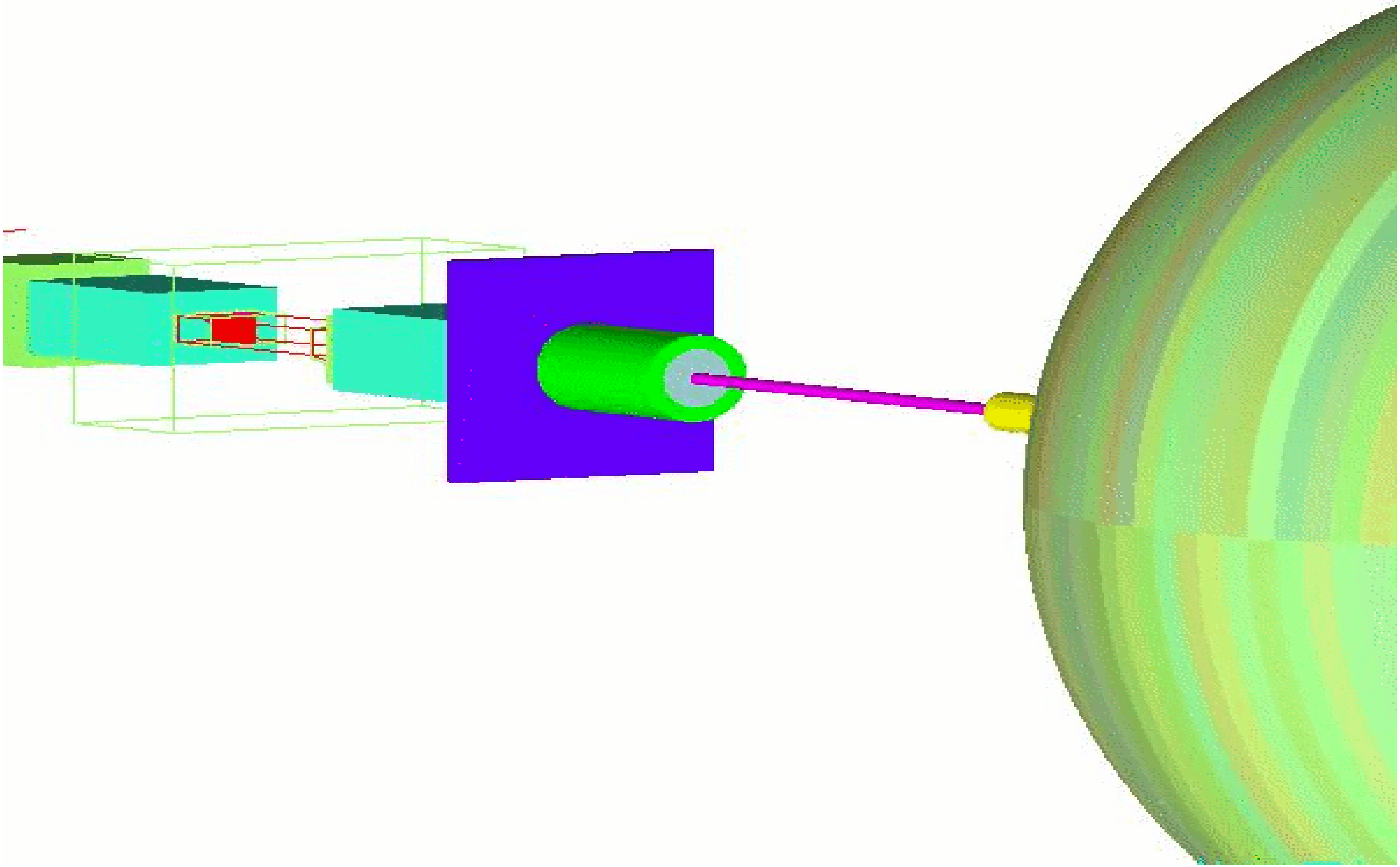

Current, Dipole 1 and 3 (A)

# Region 1 shielding options



# Improved shielding and collimation at chicane exit



# How to achieve proposal luminosity

- Proposal lepton current at target: 500 pA
- Test run achieved 4% of proposal luminosity

Improvements:

- Decrease beam-pipe scattering (factor of 6)
  - Rebuild heat exchanger and/or
  - Improve collimation of lepton beams
  - We know how to make this improvement
- Further simulations to improve shielding
  - Tagger and dump (factor of 2)
  - Upstream collimator (factor of 1.5 to 2)
  - Shield wall at torus cryo-ring
  - Intra-chicane shielding
  - We have the simulation tools to do this

# Anticipated running conditions and beamtime request

| Item | Value |
|---|---|
| Primary electron beam energy | 5.7 GeV |
| Primary electron beam current | 0.5 $\mu A$ |
| Radiator thickness | $1\% X_o$ |
| Converter thickness | $5\% X_o$ |
| Cryogenic hydrogen target length | 40 cm |
| Torus current | 1000 A |
| PAC days for data acquisition | 27 |
| Additional days for flux measurement and torus polarity changes | 3 |
| Additional days for commissioning of all devices | 5 |
| **Total PAC days requested** | **35** |

# Luminosity Summary

| Item | PAC 26 proposed | Test Run achieved | Widen cryo-apertures | further sims and shielding |
|---|---|---|---|---|
| Primary electron beam energy (GeV) | 5.7 | 3.3 | 5.7 | 5.7 |
| Primary electron beam current ($\mu$A) | 1.0 | 0.08 | 0.24 | 0.5 |
| Radiator thickness ($\%X_o$) | 5 | 0.5 | 0.5 | 1.0 |
| Photon collimator aperture (mm) | 2 | 12.7 | 12.7 | 12.7 |
| Converter thickness ($\%X_o$) | 2 | 5 | 5 | 5 |
| Cryogenic hydrogen target length (cm) | 20 | 20 | 40 | 40 |
| Luminosity (fraction of PAC 26 proposal) | 1 | 0.04 | 0.24 | 1 |

# Anticipated Systematic Errors

| Source | Error (%) |
|---|---|
| $e^+/e^-$ flux differences | 0.2 |
| Proton acceptance differences | 0 |
| $e^+/e^-$ momentum measurement | 0.1 |
| $e^+/e^-$ geometrical acceptance differences | $< 1$ |
| $e^+/e^-$ detector efficiency differences | 0.1 |
| inelastic contamination | 0.1 |
| Total | $< 1$ |