OLYMPUS Collaboration Meeting, DESY, Nov. 30 – Dec. 1, 2009

Luminosity Monitor

Michael Kohl

Hampton University, Hampton, VA 23668
Jefferson Laboratory, Newport News, VA 23606

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Jefferson Lab

Proposed Experiment

- Electrons/positrons (100mA) in multi-GeV storage ring
  DORIS at DESY, Hamburg, Germany
- Unpolarized internal hydrogen target (buffer system)
  3×10^{15} at/cm^2 @ 100 mA $\rightarrow$ $L = 2\times10^{33}$ / (cm^{2}s)
- Large acceptance detector for e-p in coincidence
  BLAST detector from MIT-Bates available
- Measure ratio of positron-proton to electron-proton unpolarized elastic scattering to 1% stat.+sys.
- Redundant monitoring of (relative) luminosity (ratios) to ~1% per hour

Monitoring the Luminosities

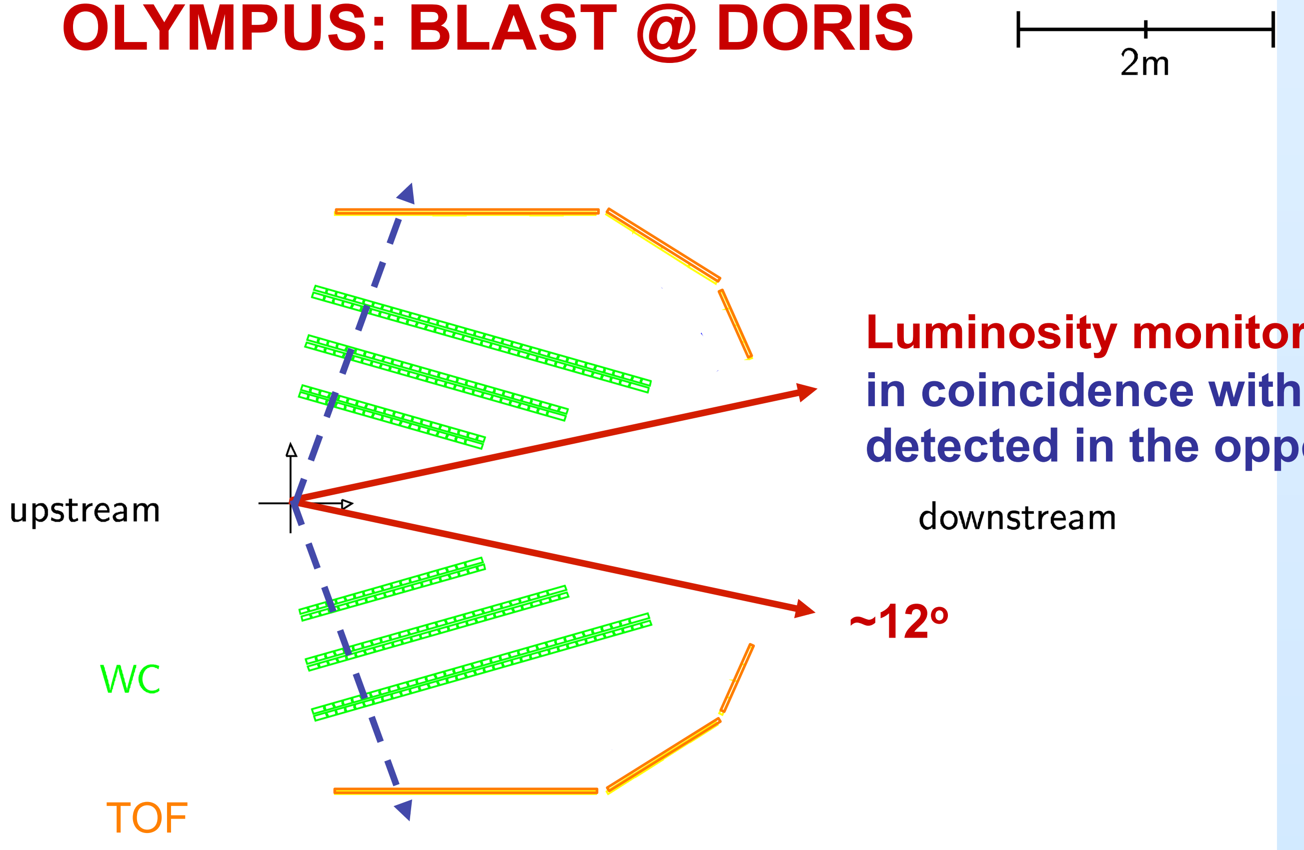
- **Pressure, temperature, flow, current measurements**
  - limited in precision

- **Moller/Bhabha scattering**
  - 1.3 degrees for symmetric Moller setup
  - difficult to establish with clear view to target

- **Small-angle elastic scattering**
  - high count rate, no TPE at high epsilon / low Q^2
  - single-arm and in coincidence with recoil proton

Control of Systematics

OLYMPUS: BLAST @ DORIS



Luminosity monitors for lepton in coincidence with recoil proton detected in the opposite sector

- Change BLAST polarity once a day
- Change between electrons and positrons regularly, randomly
- Left-right symmetry = redundancy

Forward Elastic Luminosity Monitor

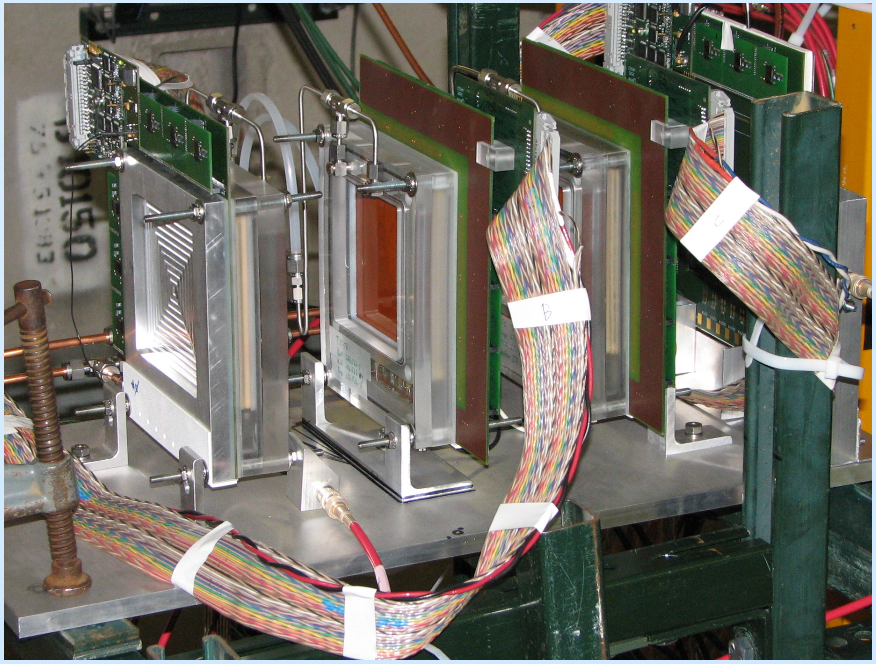
- Forward-angle electron/positron telescopes with good angular and vertex resolution
- Coincidence with proton in opposite sector of main detector
- Single-arm tracks
- Two telescopes with 3 triple-GEM detectors, left-right symmetric
- High rate capability

GEM technology

MIT protoype:

Telescope of 3 Triple GEM prototypes ($10 \times 10\ cm^2$) using TechEtch foils

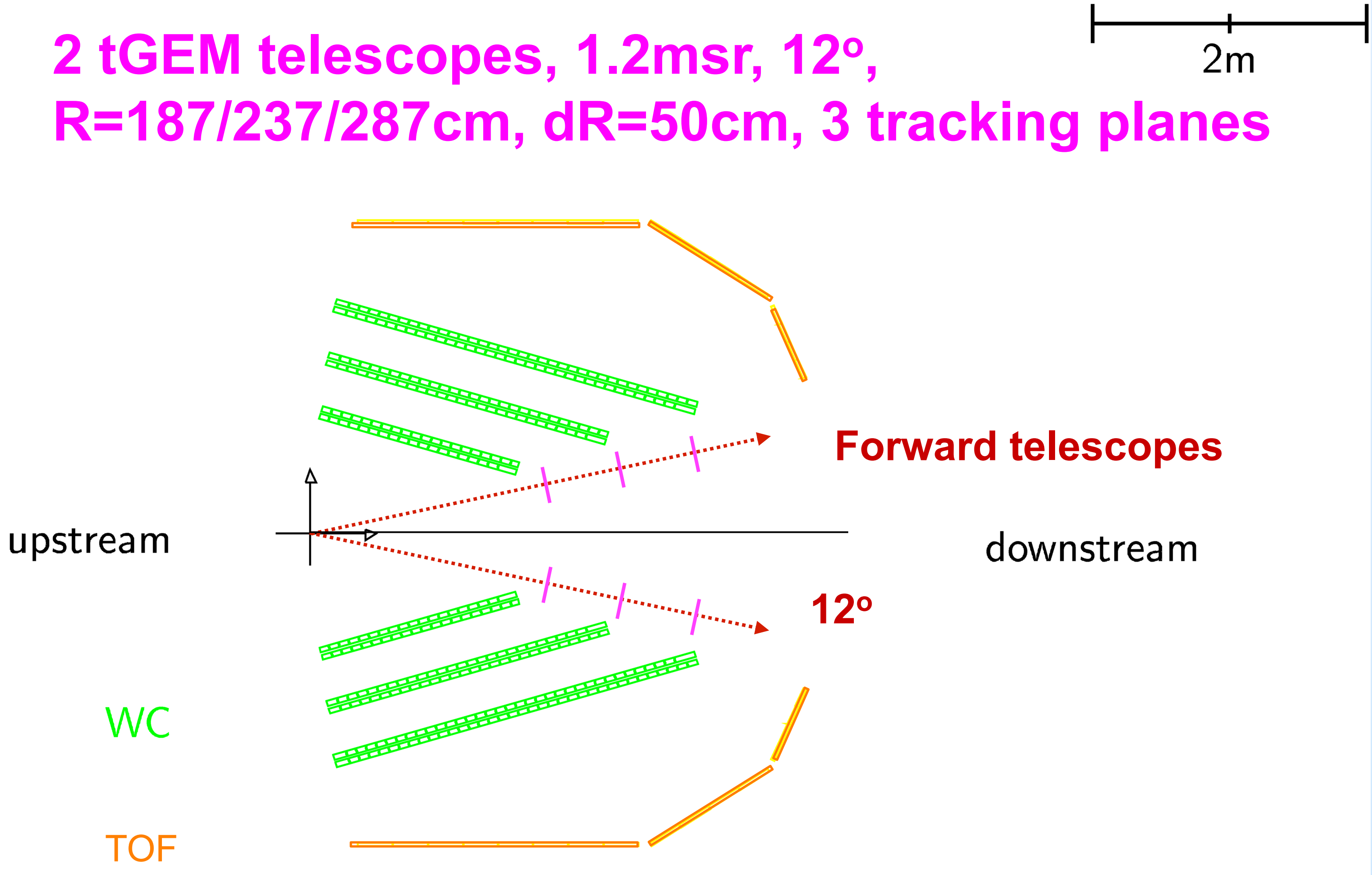
F. Simon et al., NIM A598 (2009) 432



Luminosity Monitors: Telescopes

Proposed version included in OLYMPUS TDR Sept. 2009

2 tGEM telescopes, 1.2msr, 12°, R=187/237/287cm, dR=50cm, 3 tracking planes



- **Geant4 simulation to optimize vertex resolution, solid angle and noise**

Luminosity Monitors: Count rate

Proposed version included in OLYMPUS TDR Sept. 2009

E_0 [GeV]	Q^2 [(GeV/c)^2]	$p_{e'}$ [GeV/c]	ϵ	θ_p	p_p [MeV/c]	Rate [h^{-1}]
4.5	0.801	4.073	0.9736	58.7°	992	1846
2.0	0.167	1.911	0.9774	71.8°	418	49792

Table 4.1: Kinematics and count rates of the luminosity control measurement for beam energies of 2.0 and 4.5 GeV at $\theta_e = 12°$. The assumed solid angle is 1.2 msr determined by the area of rearmost tracking plane farthest from the target.

- **Two symmetric GEM telescopes at 12°**
- **Two-photon effect negligible at high-ε / low-Q^2**
- **Sub-percent (relative) luminosity measurement per hour at 2.0 GeV**

- **Same readout pitch as in MIT prototype (635 μm)**
- **Number of electronics channels per telescope: 3x(100+100)/0.635 ~= 1000**
- **1.2 msr = 10 x 10 cm^2 at ~290 cm distance (rearmost plane)**
- **Three GEM layers with ~0.1 mm resolution with ~50 cm gaps → Match vertex resolution (z) of ~ 0.1 – 1 cm at 12° with proton in BLAST**

Providing GEM technology

- Collaboration HU-MIT
  - TechEtch/MIT to provide tested GEM foils
  - Test readout system
  - Assembly of detectors and testing at HU / HUPTI / Jlab

- Establishing a GEM Lab at Hampton University
  - Luminosity monitors for OLYMPUS (2009-2011)
  - C0 cylindrical and C1 planar GEM trackers for Time Reversal Experiment with Kaons (TREK) at J-PARC (~2013)
  - Augment 12 GeV program at Jlab (~2014)

- Funding:
  - Secured NSF Nuclear Physics/ARRA basic research grant ($405k) postdoc + travel; 1 graduate student supported by HU NSF group
  - Requested $125k within NSF MRI-R2 for luminosity monitors

Luminosity Monitors: Cost estimate

Proposed version included in OLYMPUS TDR Sept. 2009

Item	Amount	Cont.(%)	Total/k$	Remarks
Support frame	3	20	1.8	$500/frame (2+1 spare)
GEM chamber mechanics	9	20	10.8	$1000/chamber (6+3)
GEM foils 10×10 cm^2	40	20	9.6	$200/GEM foil (27+13)
Readout layer	9	20	21.6	$2000/board (6+3)
Hybrids	80	20	19.2	$200/hybrid (54+26)
APV25 chips	80	20	2.4	$25/chip (54+26)
Cables	18	20	2.2	Signal and HV (6+3)
FEE	2880	20	34.6	$10/channel (6+3)x320
Readout system	1		5.0	
HV distribution	9	20	0.5	$50/chamber
Power Supply		20	5.0	HV pods
Gas system	9	20	3.2	$300/line (6+3)
Misc. items			9.1	
Total			125.0	

Table 4.3: Cost estimate for the OLYMPUS luminosity monitors based on two plus one spare forward-angle GEM telescopes, each based on three triple-GEM detectors.

Tasks & Timeline for LuMo Construction

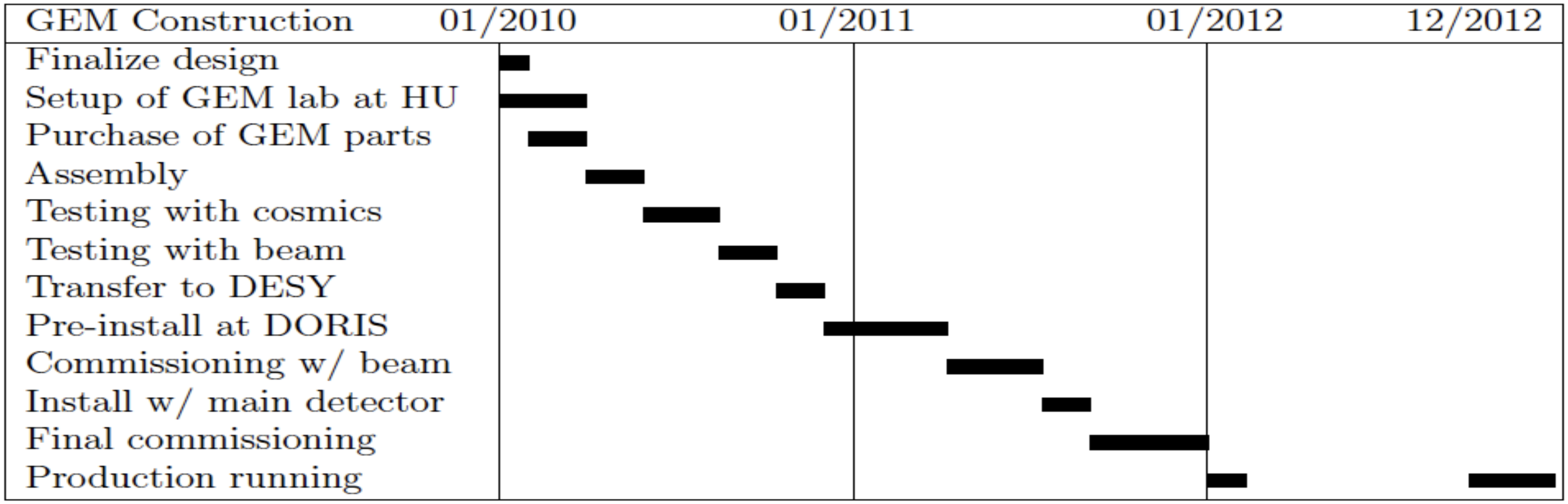


Table 4.2: Work plan for GEM luminosity monitor construction activities.

- **New research building at HU to be move-in ready begin of 2010**
- **Expect MRI-R2 grant early next year, equipment funds**
- **Testing with beam possible at HUPTI or Jlab in fall 2010**
- **Development of analysis software / integrate into OLYMPUS analysis**

Control of Systematics

Simple scheme to cancel detector efficiencies

$$N_{ij} = L_{ij}\sigma_i\kappa^p_{ij}\kappa^l_{ij}$$

i = e+ or e-
j= pos/neg polarity

Geometric proton efficiency: $\kappa^p_{\mathrm{e}+j} = \kappa^p_{\mathrm{e}-j}$

$$\frac{N_{\mathrm{e}+j}/L_{\mathrm{e}+j}}{N_{\mathrm{e}-j}/L_{\mathrm{e}-j}} = \frac{\sigma_{\mathrm{e}+}}{\sigma_{\mathrm{e}-}} \cdot \frac{\kappa^l_{\mathrm{e}+j}}{\kappa^l_{\mathrm{e}-j}}$$

Ratio in single polarity j

Geometric lepton efficiency: $\kappa^l_{\mathrm{e}++} = \kappa^l_{\mathrm{e}--}$ and $\kappa^l_{\mathrm{e}+-} = \kappa^l_{\mathrm{e}-+}$

Control of Systematics

Super ratio:

$$\left[\frac{N_{e^+ +}/L_{e^+ +}}{N_{e^- +}/L_{e^- +}} \cdot \frac{N_{e^+ -}/L_{e^+ -}}{N_{e^- -}/L_{e^- -}}\right]^{\frac{1}{2}} = \frac{\sigma_{e^+}}{\sigma_{e^-}}$$

Cycle of four states ij
Repeat cycle N times -> reduction of systematics by $\sqrt{N}$

- Change between electrons and positrons once a day
- Change BLAST polarity regularly, randomly
- Left-right symmetry = redundancy

Monte Carlo studies

- Further (small) corrections for individual acceptances
- Small effects by backgrounds and inefficiencies
- Effects from beam sizes and offsets (~1%/mm)

Luminosity Monitoring

Analogous scheme applied to monitor luminosity

- **Forward-angle (high-epsilon, low-Q) elastic scattering ($\sigma_{e+} = \sigma_{e-}$)**
- **Measure L_{ij} relatively (i.e. N_{ij}^{fwd}) and continuously to ~1%/hour**

At forward angle:

$$\frac{N^{fwd}_{e^+ +}}{N^{fwd}_{e^- +}} \cdot \frac{N^{fwd}_{e^+ -}}{N^{fwd}_{e^- -}} = \frac{L_{e^+ +}}{L_{e^- +}} \cdot \frac{L_{e^+ -}}{L_{e^- -}}$$

Control of Systematics

Super ratio:

$$\frac{\sigma_{e^+}}{\sigma_{e^-}} = \left[\left(\frac{N_{e^+ +}}{N_{e^- +}} \cdot \frac{N_{e^+ -}}{N_{e^- -}}\right) \Big/ \left(\frac{N^{fwd}_{e^+ +}}{N^{fwd}_{e^- +}} \cdot \frac{N^{fwd}_{e^+ -}}{N^{fwd}_{e^- -}}\right)\right]^{\frac{1}{2}}$$

Cycle of four states ij
Repeat cycle many times

- Change between electrons and positrons once a day
- Change BLAST polarity regularly, randomly
- Left-right symmetry = redundancy

Montecarlo studies

- Further (small) corrections for individual acceptances
- Effects by backgrounds and inefficiencies
- Effects from beam sizes and offsets

Differential cross section

Event counts:

$$dN = \kappa^p(t)\kappa^l(t)\dot{L}(t)dt \, \frac{d\sigma}{d\Omega}(\theta_e)a(x_k)d^n x$$

$a(x_k)$ = Acceptance function

Bin-averaged differential cross section:

$$\left\langle \frac{d\sigma}{d\Omega} \right\rangle = \frac{N}{\int_{\Delta T} \kappa^p(t)\kappa^l(t)\dot{L}(t)dt \, \int_{\Delta V} a(x_k)d^n x}$$

$$A = \Delta\Omega = \int_{\Delta V} a(x_k)d^n x$$

Phase space integral

Require acceptance simulation to determine phase space integral numerically!

Control of Systematics

MORE REALISTICALLY:

i = e+ or e-
j= pos/neg polarity

$$N_{ij} = L_{ij}\sigma_i\kappa^p_{ij}\kappa^l_{ij}A_{ij}$$

A = Acceptance function
(phase space integral)

Proton "detection" efficiency: $\kappa^p_{\mathrm{e}+j} = \kappa^p_{\mathrm{e}-j}$

$$\frac{N_{\mathrm{e}+j}/L_{\mathrm{e}+j}}{N_{\mathrm{e}-j}/L_{\mathrm{e}-j}} = \frac{\sigma_{\mathrm{e}+}}{\sigma_{\mathrm{e}-}} \cdot \frac{\kappa^l_{\mathrm{e}+j}}{\kappa^l_{\mathrm{e}-j}} \cdot \frac{A_{\mathrm{e}+j}}{A_{\mathrm{e}-j}}$$

Ratio in single polarity j

Lepton detection efficiency: $\kappa^l_{\mathrm{e}++} = \kappa^l_{\mathrm{e}--}$ and $\kappa^l_{\mathrm{e}+-} = \kappa^l_{\mathrm{e}-+}$

Triple ratio

Triple Super Ratio:

$$\frac{\sigma_{e^+}}{\sigma_{e^-}} = \left[\frac{N_{e^+ +} N_{e^+ -}}{N_{e^- +} N_{e^- -}} \Big/ \left(\frac{L_{e^+ +} L_{e^+ -}}{L_{e^- +} L_{e^- -}} \cdot \frac{A_{e^+ +} A_{e^+ -}}{A_{e^- +} A_{e^- -}} \right) \right]^{\frac{1}{2}}$$

Ratio of counts

Ratio of luminosities

Ratio of acceptances (phase space integrals)

Cycle of four states ij
Repeat cycle many times

- **Separately determine three super ratios**
- **Blinding of final result until put together**
- **Left-right symmetry = redundancy**

Luminosity Monitoring

MORE REALISTICALLY:

- **Forward-angle (high-epsilon, low-Q) elastic scattering ($\sigma_{e+} = \sigma_{e-}$)**
- **Measure L_{ij} relatively (i.e. N_{ij}^{fwd}) and continuously to ~1%/hour**

`At forward angle:`

$$\frac{N^{fwd}_{e^+ +}}{N^{fwd}_{e^- +}} \cdot \frac{N^{fwd}_{e^+ -}}{N^{fwd}_{e^- -}} = \frac{L_{e^+ +}}{L_{e^- +}} \cdot \frac{L_{e^+ -}}{L_{e^- -}} \cdot \frac{A^{pe^+(fwd)}_{e^+ +}}{A^{pe^-(fwd)}_{e^- +}} \cdot \frac{A^{pe^+(fwd)}_{e^+ -}}{A^{pe^-(fwd)}_{e^- -}}$$

Control of Systematics

MORE REALISTICALLY:

`Super ratio ("triple ratio"):`

$$\frac{\sigma_{e^+}}{\sigma_{e^-}} = \left[\left(\frac{N_{e^+ +}}{N_{e^- +}} \cdot \frac{N_{e^+ -}}{N_{e^- -}}\right) \Big/ \left(\frac{N^{fwd}_{e^+ +}}{N^{fwd}_{e^- +}} \cdot \frac{N^{fwd}_{e^+ -}}{N^{fwd}_{e^- -}}\right)\right]^{1/2}$$

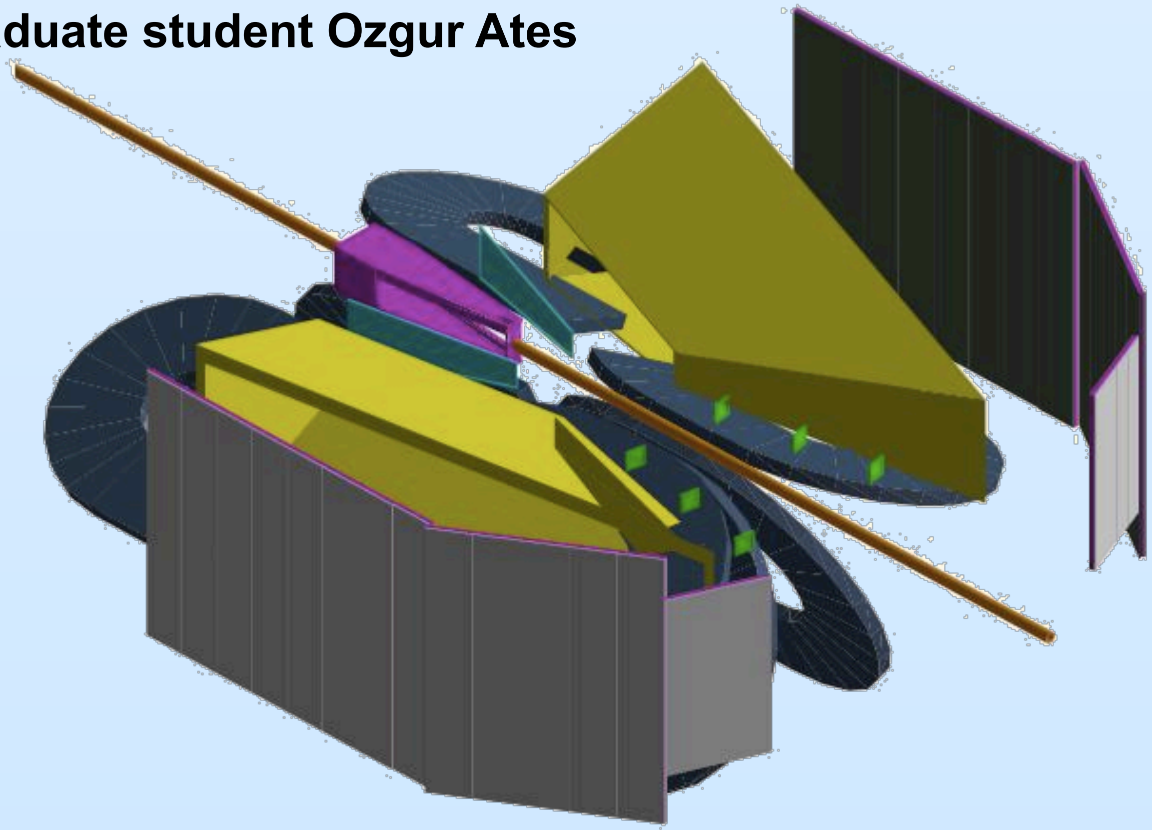
$$\Big/ \left[\left(\frac{A^{pe^+}_{e^+ +}}{A^{pe^-}_{e^- +}} \cdot \frac{A^{pe^+}_{e^+ -}}{A^{pe^-}_{e^- -}}\right) \Big/ \left(\frac{A^{pe^+ (fwd)}_{e^+ +}}{A^{pe^- (fwd)}_{e^- +}} \cdot \frac{A^{pe^+ (fwd)}_{e^+ -}}{A^{pe^- (fwd)}_{e^- -}}\right)\right]^{1/2}$$

`Cycle of four states ij`
`Repeat cycle N times -> reduction of systematics by √N`

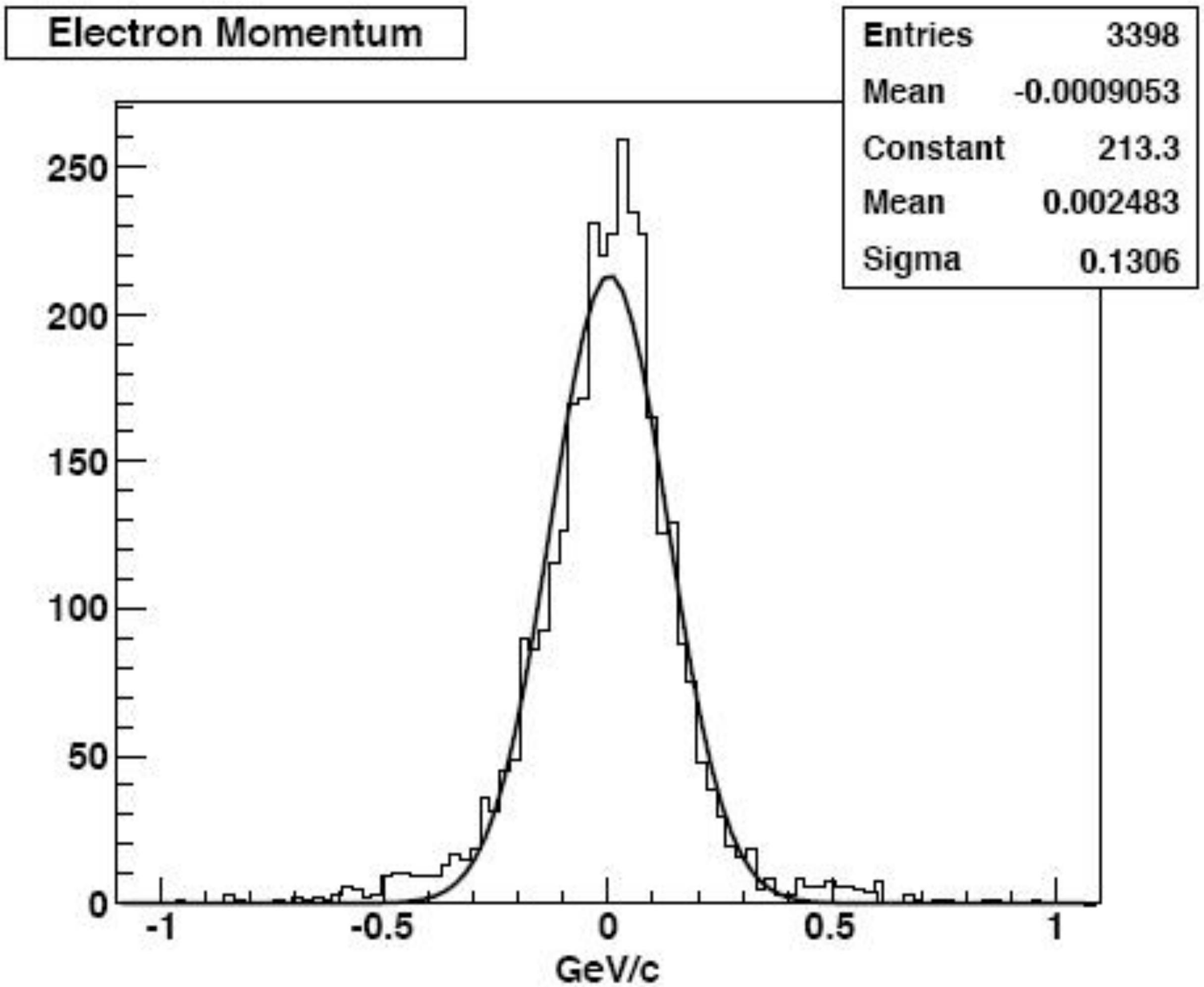
- Change between electrons and positrons every other day
- Change BLAST polarity regularly, randomly
- Left-right symmetry = redundancy
- Determine ratios of phase space integrals from Monte-Carlo simulation

Monte Carlo Studies

- GEANT4 simulation: OLYMPUS.cc as of August 2009
- Specify design parameters
  - Size and locations of tracking planes; resolutions and residuals
  - Phase space integral(s) / acceptance (solid angle)
  - Effects of beam size and offsets on systematics
  - HU graduate student Ozgur Ates



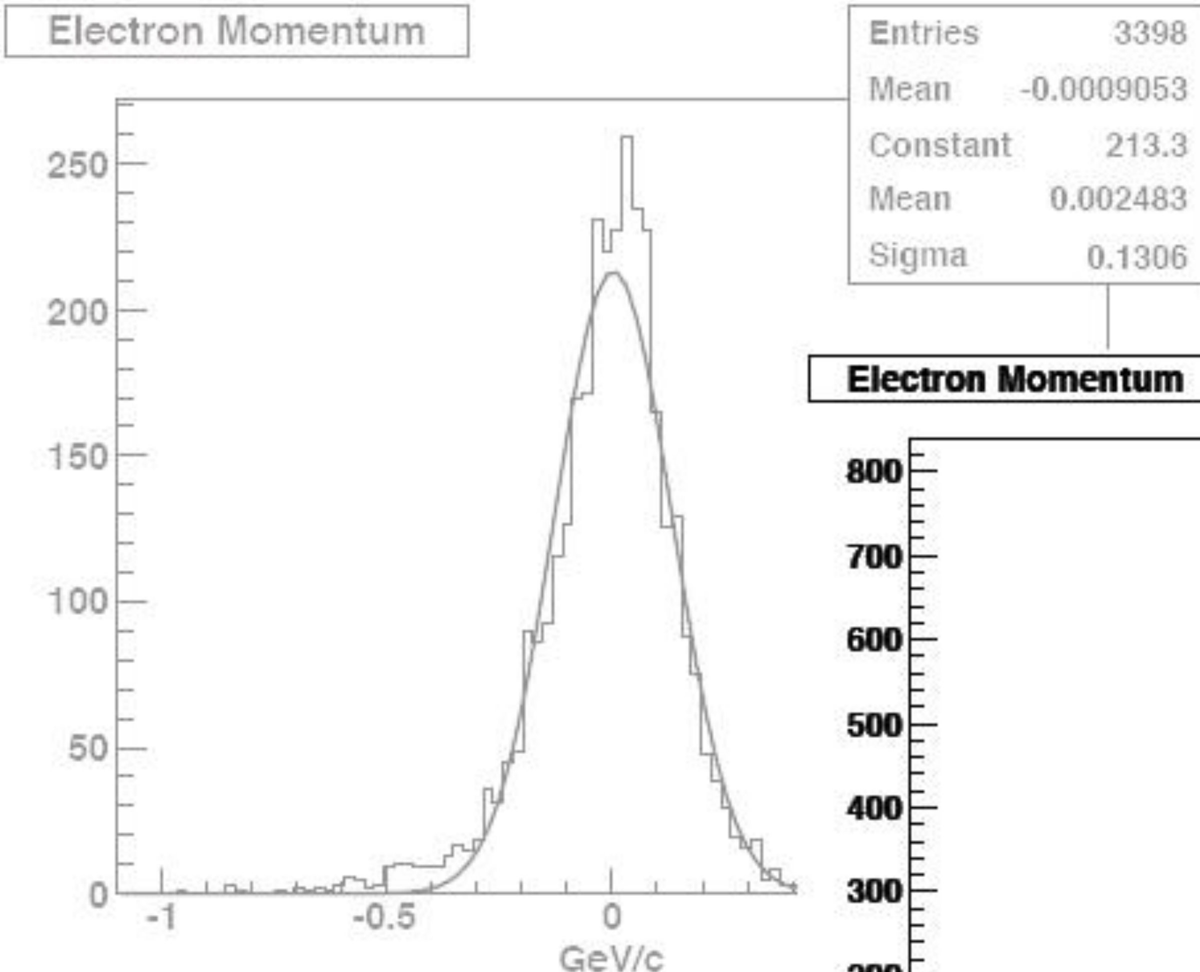
Electron Momentum Resolution



130 MeV

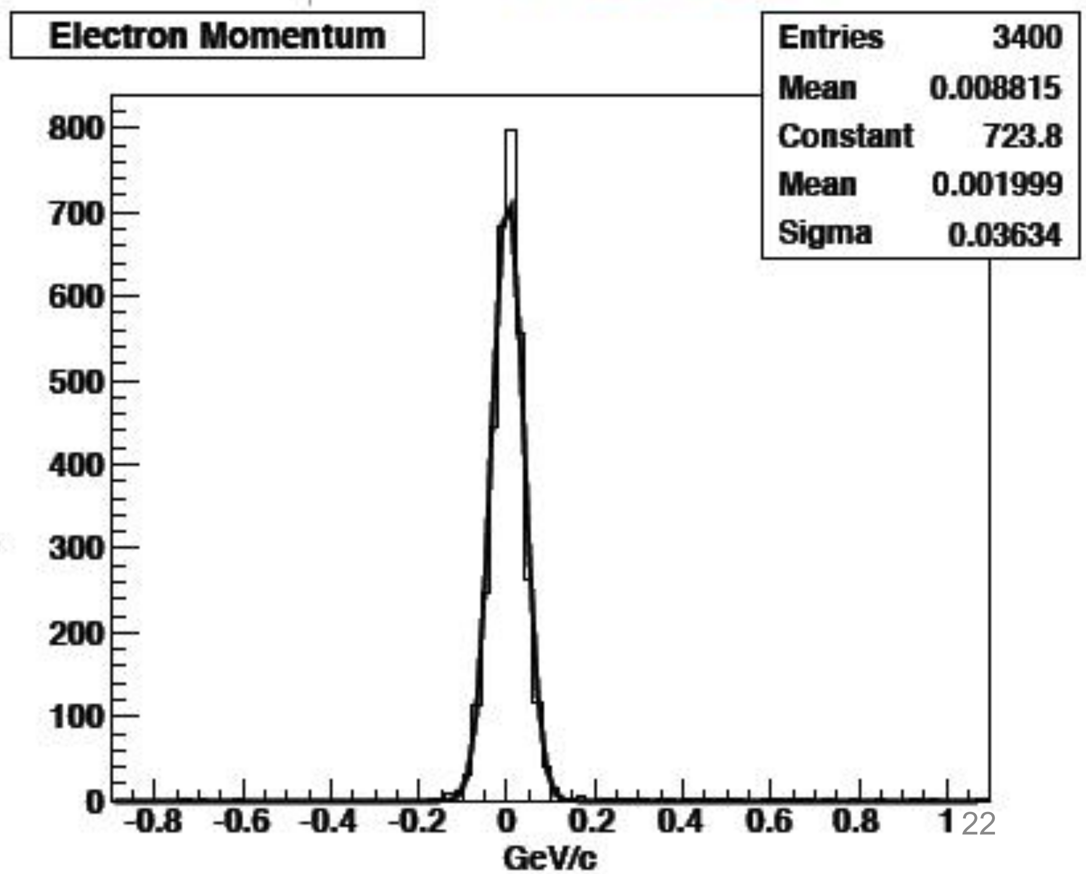
D. Hasell/Sept. 2009

Electron Momentum Resolution



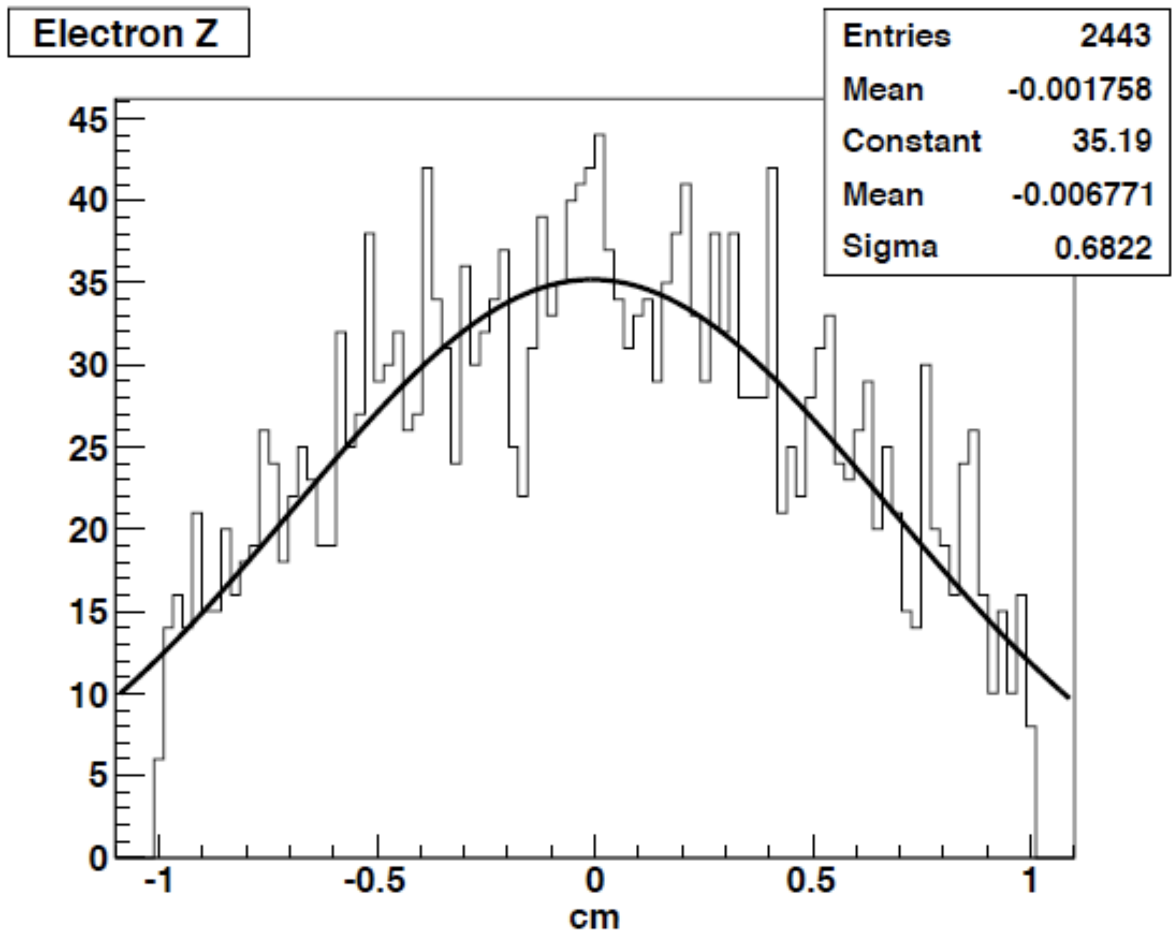
130 MeV

36 MeV
with GEM



D. Hasell/Sept. 2009

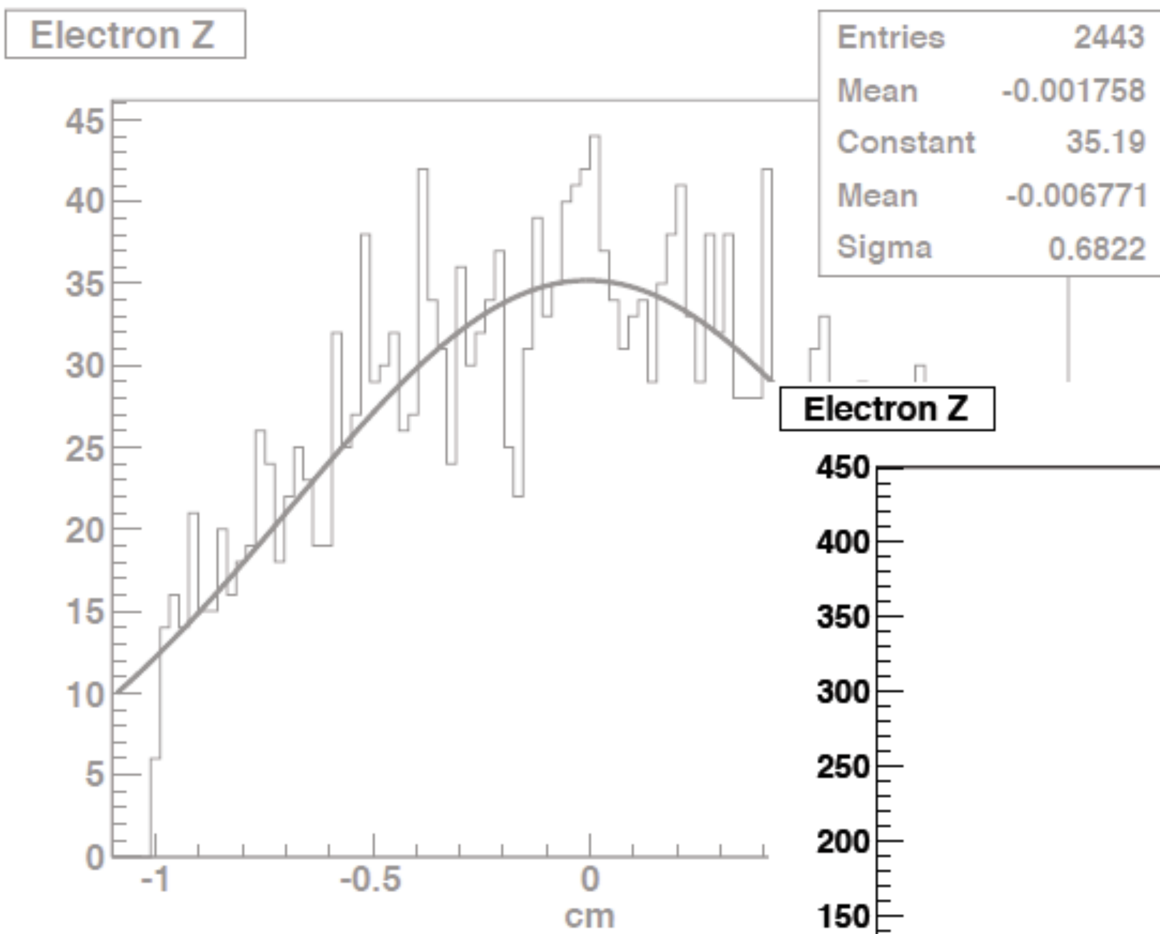
Electron Vertex Resolution



0.7 cm

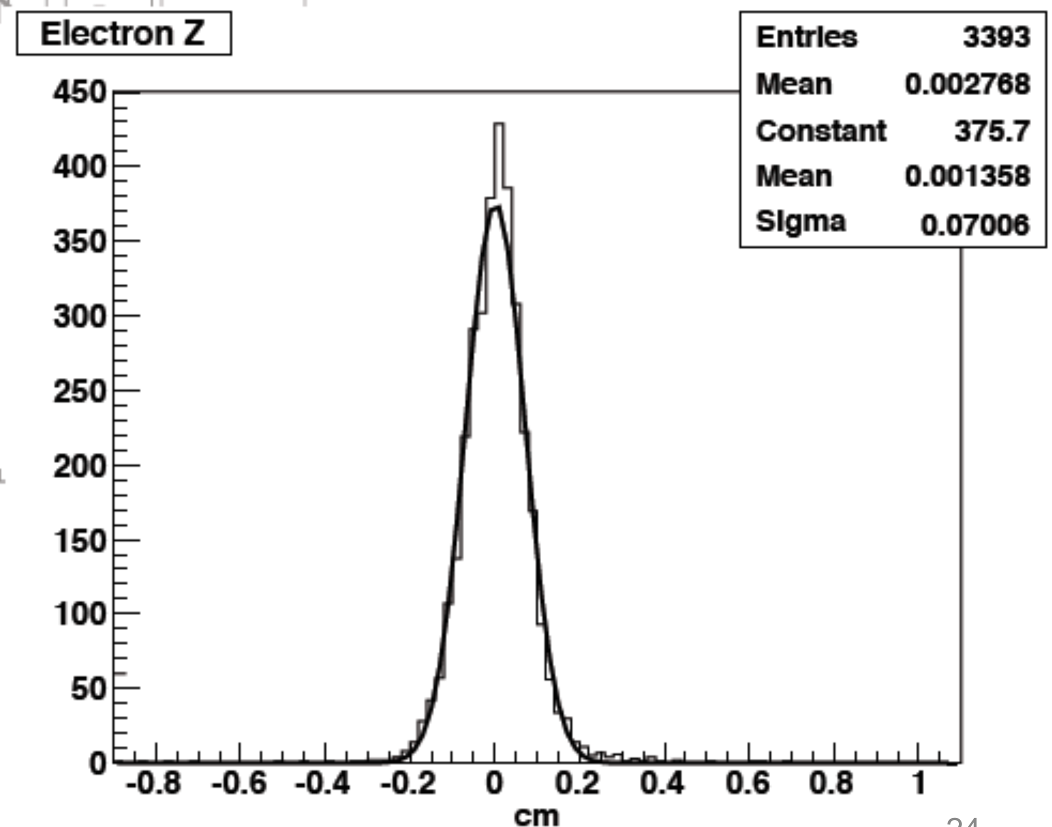
D. Hasell/Sept. 2009

Electron Vertex Resolution



0.7 cm

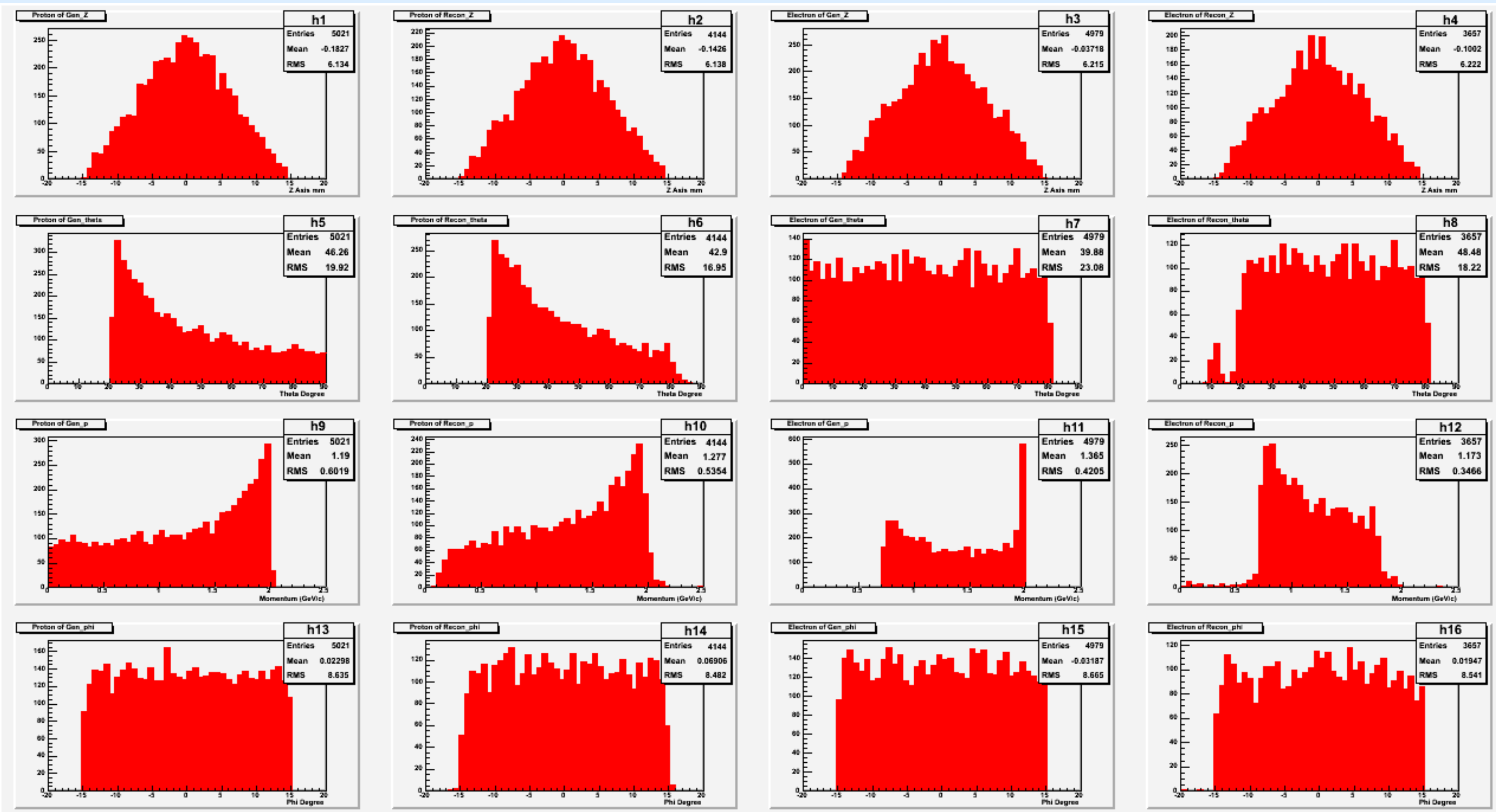
0.07 cm
with GEM



D. Hasell/Sept. 2009

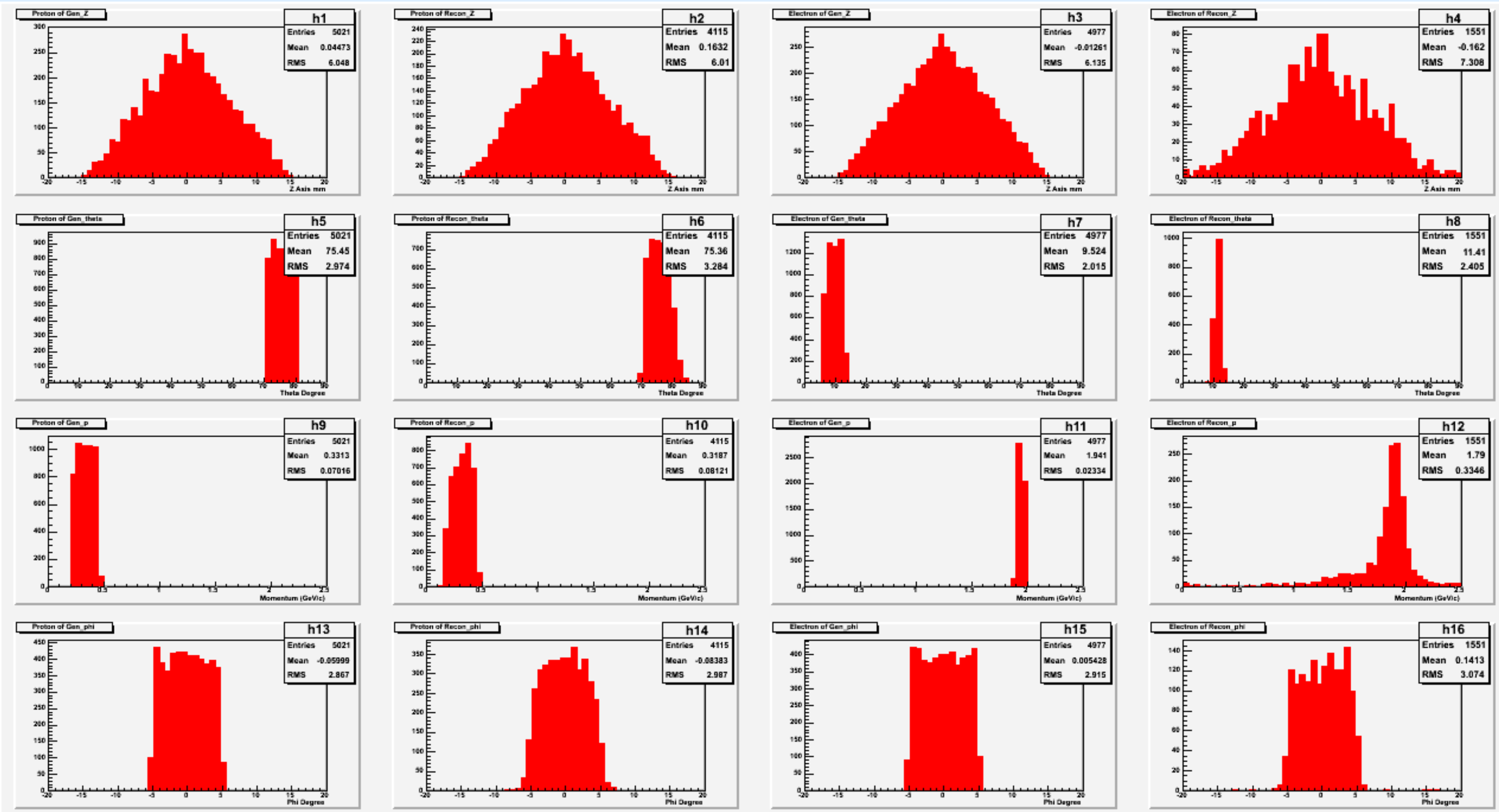
Event distributions

- Generated and reconstructed variables Z, Theta, P, Phi proton/electron
- All events (LuMo + BLAST)



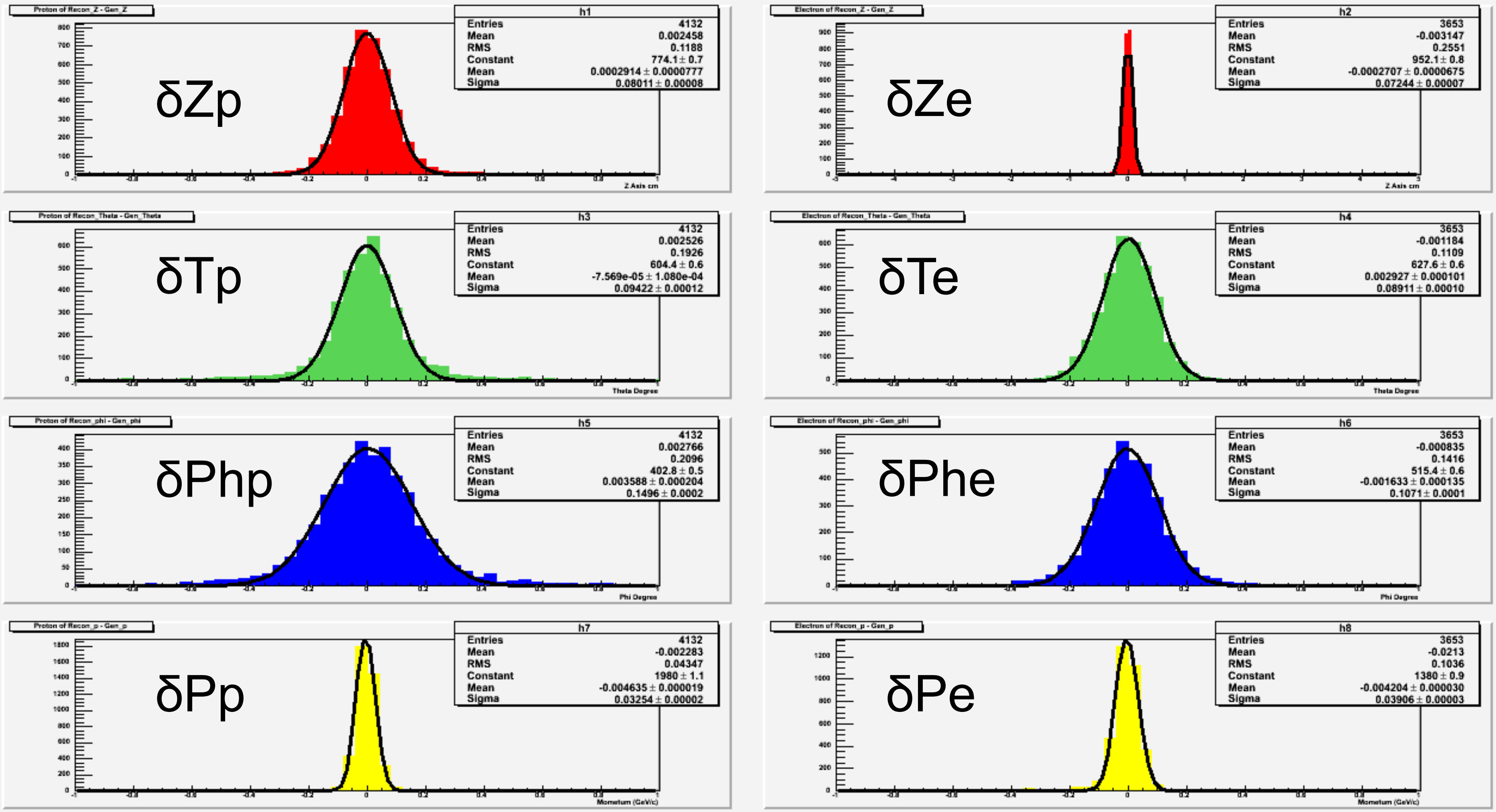
Resolution study

- Generated and reconstructed variables Z, Theta, P, Phi proton/electron
- All events (LuMo + BLAST) versus LuMo only (gen. 8-13 deg. + tagged)



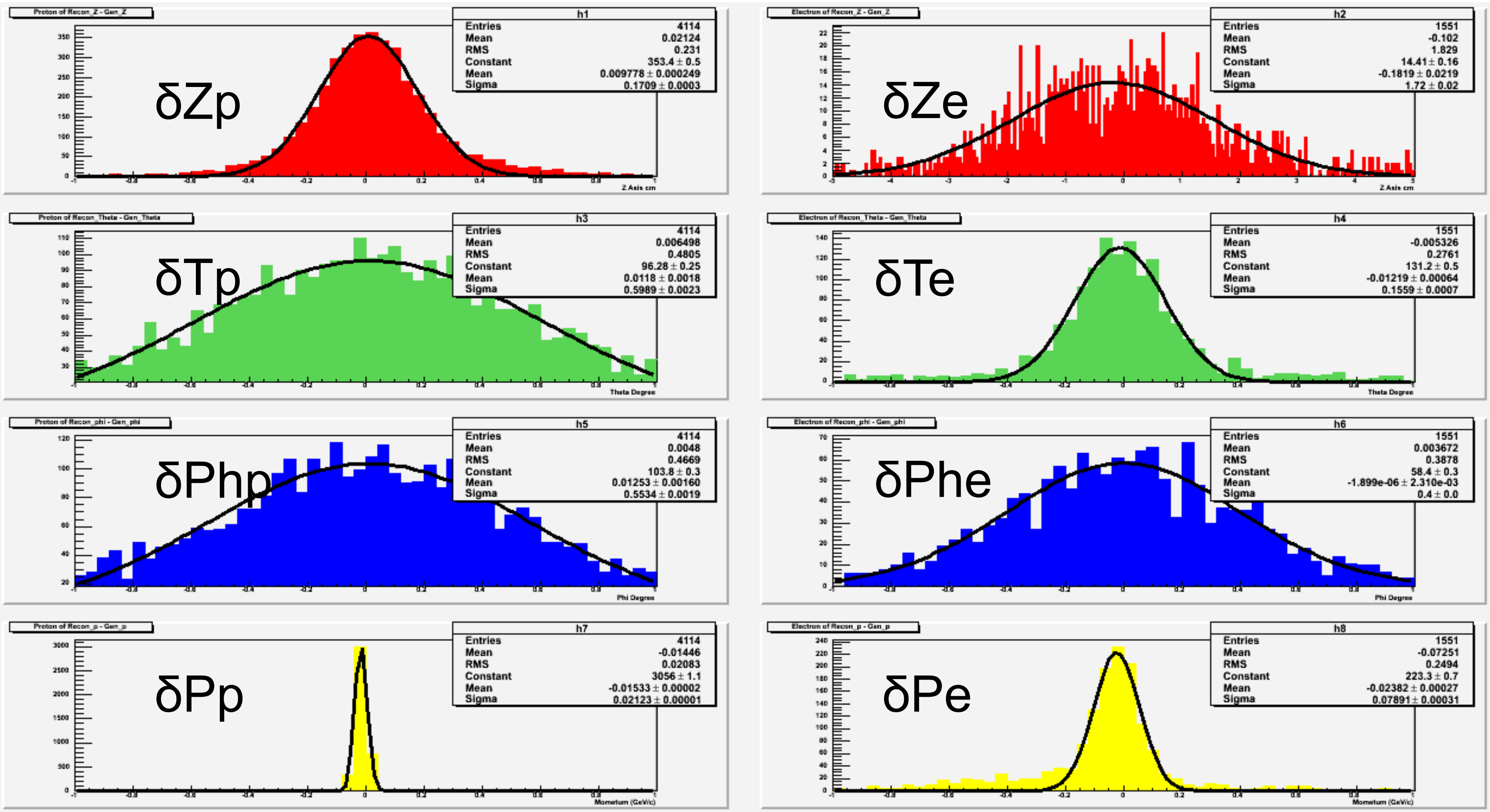
Resolution: generated-reconstructed

100mu, 50cm, LuMo+BLAST (Te=0-80 dg, Phe=+-15 dg)



Resolution: generated-reconstructed

100mu, 50cm, LuMo only (Te=6-13 dg, Phe=+-5 dg)



Resolutions

Left Sec. RESOLUTIONS	Proton DeltaZ	Electron DeltaZ	Proton DeltaTheta	Electron DeltaTheta	Proton DeltaPhi	Electron DeltaPhi	Proton DeltaP	Electron DeltaP
Config 0 100mu/50cm LuMo+BLAST	0.80 mm	0.72 mm	0.094 Deg.	0.089 Deg.	0.14 Deg.	0.10 Deg.	32 MeV	39 MeV
Config 3 100mu/50cm	1.70 mm	1.68 cm	0.59 Deg.	0.15 Deg.	0.55 Deg.	0.39 Deg.	21 MeV	78 MeV
Config 4 100mu/10cm	1.16 mm	5.17 cm	0.57 Deg.	0.39 Deg.	0.57 Deg.	0.40 Deg.	21 MeV	260 MeV
Config 5 50mu/50cm	1.79 mm	1.65 cm	0.57 Deg.	0.16 Deg.	0.55 Deg.	0.38 Deg.	21 MeV	77 MeV
Config 6 50mu/10cm	1.75 mm	3.74 cm	0.62 Deg.	0.29 Deg.	0.57 Deg.	0.38 Deg.	21 MeV	237 MeV

- **Large differences for LuMo+BLAST versus LuMo-only**
- **Minor improvement with 50mu resolution versus 100mu**
- **Significant improvement with 50cm gaps instead of 10cm**

Study of Elastic Scattering

- FOUR VECTORS:
- e=(E,Pe) E^2= (me^2) + (Pe^2)
- e'=(E',Pe') E'=|Pe'| and E=|Pe|
- p=(M,0), E=2 GeV and M=0.938 GeV
- p'=(Ep,Pp)

- CONSERVATION LAWS:

Energy: E – E' = Ep – M

Transverse : E' Sin(Te)=Pp Sin(Tp)

Longitudinal: E – E'Cos(Te)=Pp Cos(Tp)

*** Ep^2= Pp^2+M^2

Monte Carlo Studies

- Resolutions
  - Generated and reconstructed variables Theta, Phi, P, Z electron/proton

- Residuals: Redundancy of variables / elastic scattering
  - 4 variables: Pe, Pp, Te, Tp
  - 3 constraints: 3 conservation equations
    4 – 3 = 1 (DEGREES OF FREEDOM)

    TeTp: Te – Te(Tp)

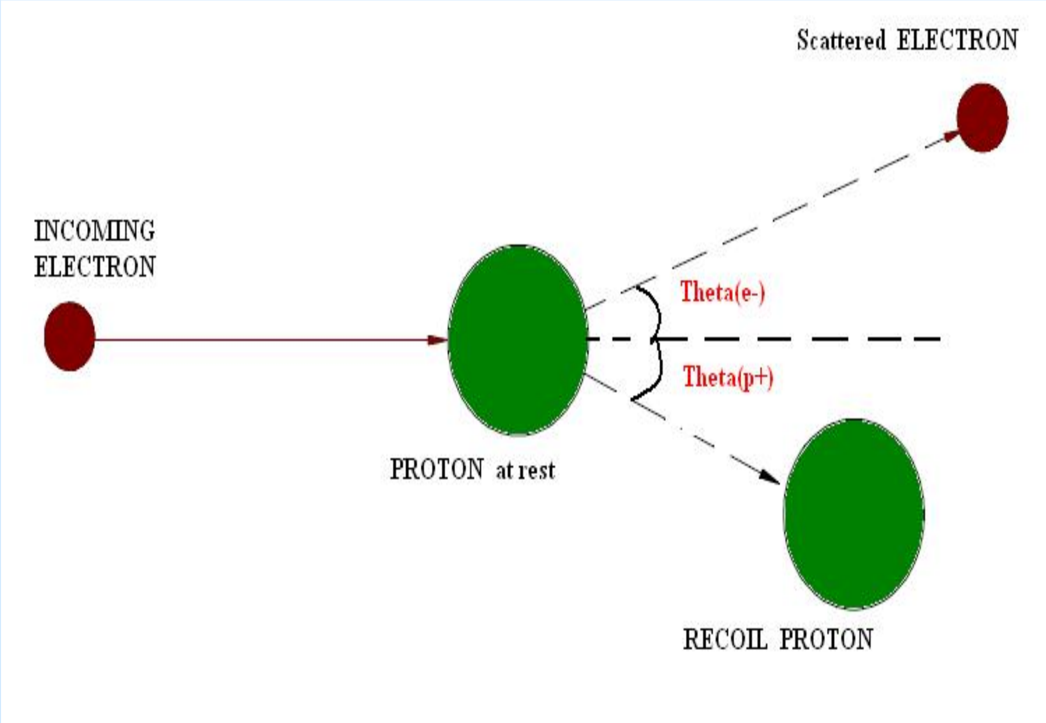
    TePe: Te – Te(Pe)

    TePp: Te – Te(Pp)

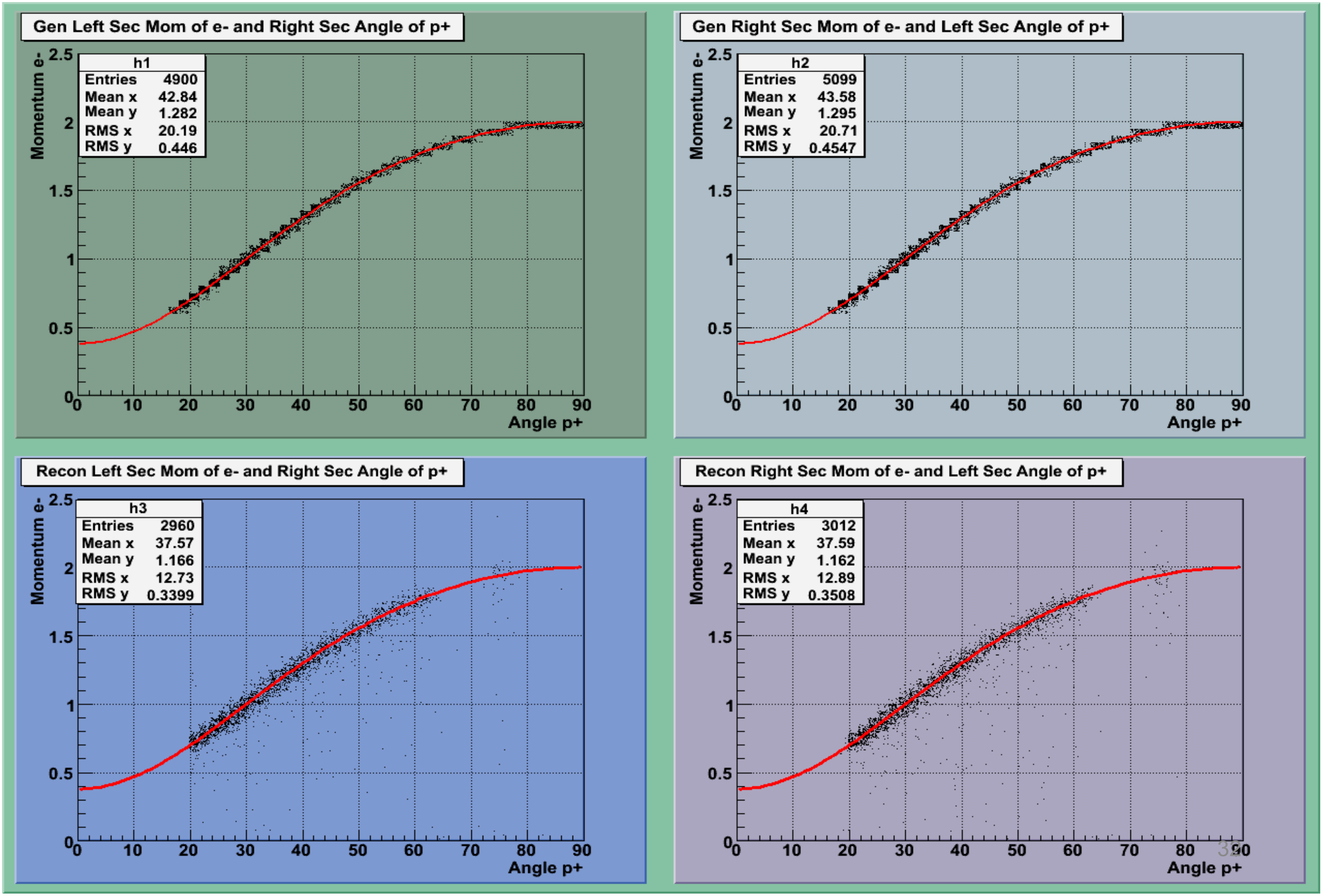
  - Coplanarity:

    PhePhp: Phe – Php – 180

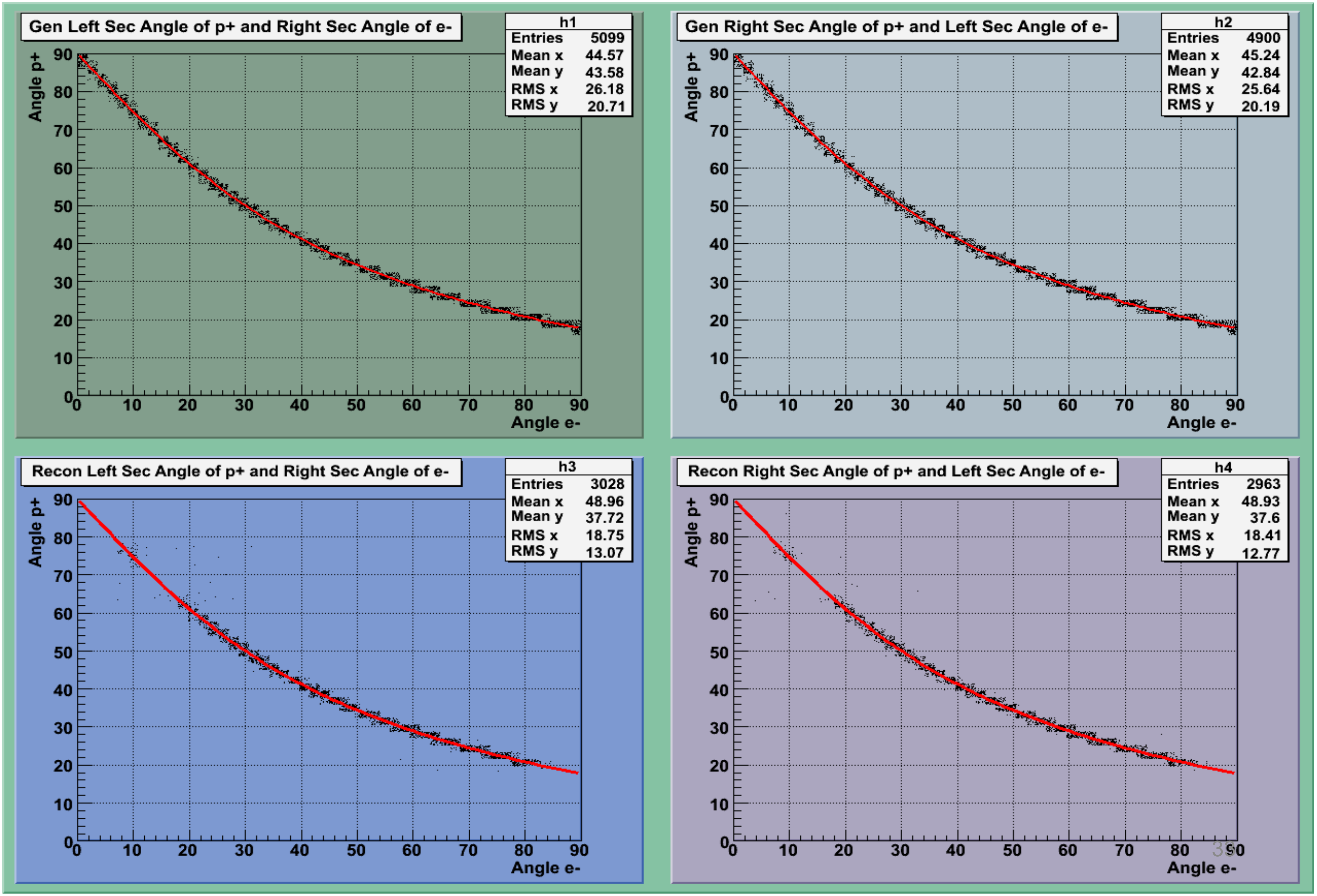
  - Common vertex:
    ZeZp: Ze – Zp



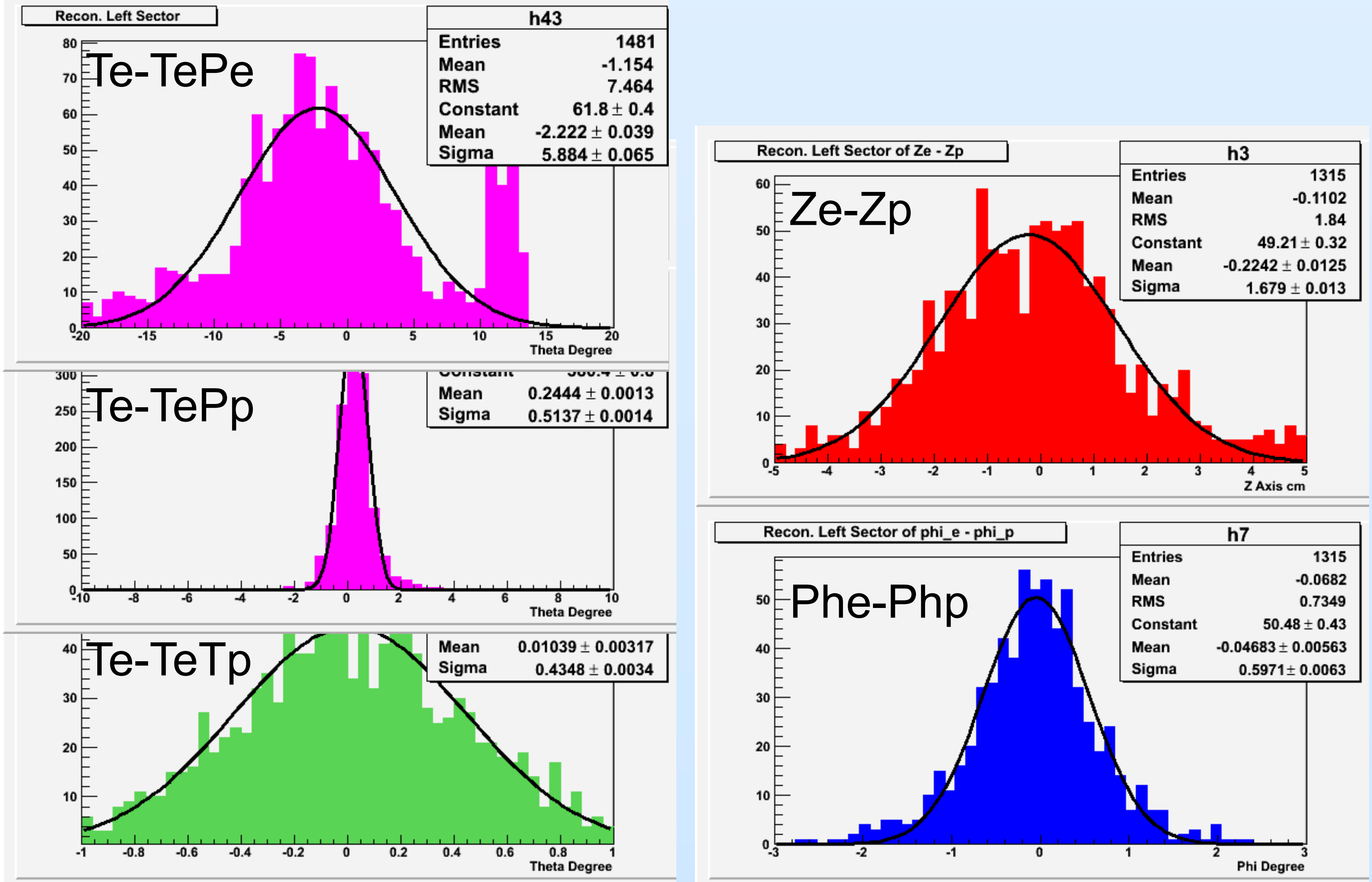
PeTp: Data Points(Pe:Tp) and Calculation(PeTp)



TpTe: Data Points(Tp:Te) and Calculation(TpTe)



Residuals (100mu/50cm)



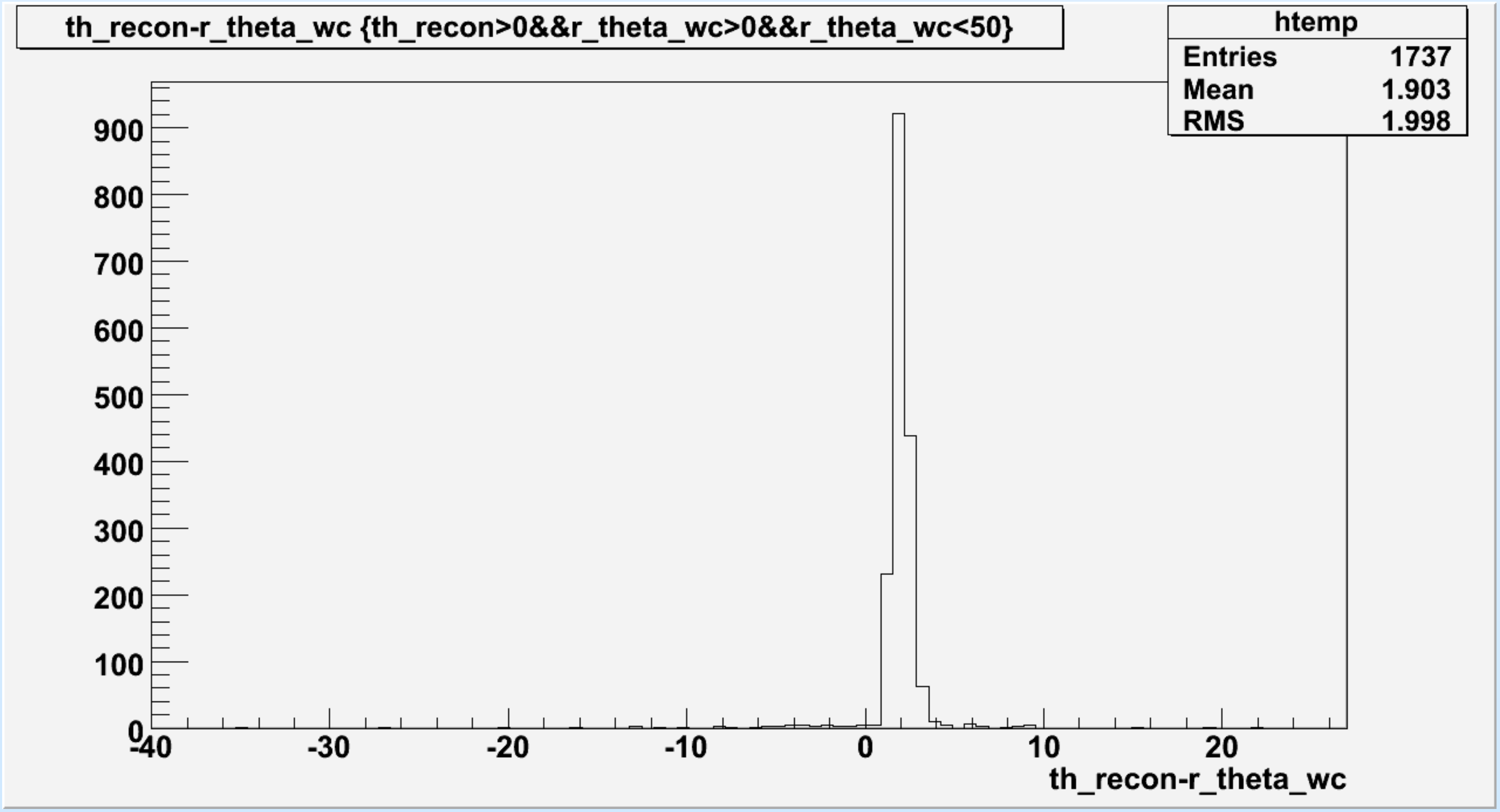
Residuals

Left Sec. RESIDUALS	PpTp/ MeV	PeTe/ MeV	PePp/ MeV	TpTe/ Deg.	PpTe/ MeV	PeTp/ MeV	TeTp/ Deg.	TePp/ Deg.	PpPe/ MeV	TpPp/ Deg.	TePe/ Deg.	TpPe/ Deg.	ZeZp	PhePhp /Deg.
Config 0 100mu/50cm LuMo+BLAST	32	39	48	0.10	34	39	0.17	1.41	57	0.94	2.18	1.34	1.13 mm	0.18
Config 3 100mu/50cm	27	80	78	0.54	21	81	0.43	0.51	203	0.99	5.80	7.29	1.67 cm	0.58
Config 4 100mu/10cm	27	271	267	0.73	25	267	0.54	0.59	97	0.99	1.30	2.1	5.08 cm	0.60
Config 5 50mu/50cm	26	81	82	0.55	22	81	0.44	0.52	180	0.99	5.90	6.50	1.64 cm	0.65
Config 6 50mu/10cm	26	235	237	0.63	24	235	0.45	0.58	177	0.97	1.35	1.90	3.78 cm	0.58

- Lepton momentum Pe is a poor constraint
- TeTp and TePp residuals are balanced for LuMo-only events (TeTp preferred over TePp for LuMo+BLAST events)
- Substantial improvement for vertex residual w/ 50cm gaps instead of 10cm
- Minor improvement with 50mu resolution

Deflection Angle

- Bending of lepton track due to presence of magnetic field: ~2 degrees
- Studying hit distributions at tracking planes to check for acceptance losses



Conclusions

- **Distance between tracking planes mostly affects δZe**
- **Intrinsic resolution, too, mostly affects δZe**
- **δZe always >> than corresponding δZp -> maximize gaps (distance)**
- **Solid angle ~1/dist^2 -> minimize distance**
- **Elastic count rate still sufficient w/ 50cm gaps**
- **Least distance of first element 187cm for clearance**
- **Bending angle is small enough so does not limit acceptance -> acceptance (solid angle) determined by rearmost tracking element**

- **Intrinsic resolution significantly affecting Ze, but only for small (10cm) gaps (not yet dominated by multiple scattering)**

Current conclusion: use large gaps (50cm) and <100mu resolution

(still checking more modest resolution)

Next Steps

- Started to work on GEANT4 simulation
  (Ozgur Ates, HU graduate student of HU nuclear physics group)
  -> LuMo design parameters: location (solid angle), resolution

- Finalize design parameters (geometry) and specifications (No. of channels) until end of this year

- Simulations of phase space integral(s), acceptance; expected counts

- Study of systematic effects (beam offset, slope, width; etc.) on counts per bin

- Simulation of backgrounds

Backup slides

Resolutions (old)

Left Sec. RESOLUTIONS	Proton DeltaZ	Electron DeltaZ	Proton DeltaTheta	Electron DeltaTheta	Proton DeltaPhi	Electron DeltaPhi	Proton DeltaP	Electron DeltaP
Configuration 0	0.80 mm	0.72 mm	0.094 Deg.	0.089 Deg.	0.14 Deg.	0.10 Deg.	32 MeV	39 MeV

Right Sec. RESOLUTIONS	Proton DeltaZ	Electron DeltaZ	Proton DeltaTheta	Electron DeltaTheta	Proton DeltaPhi	Electron DeltaPhi	Proton DeltaP	Electron DeltaP
Configuration 0	0.82 mm	0.70 mm	0.090 Deg.	0.092 Deg.	0.14 Deg.	0.10 Deg.	31 MeV	38 MeV

Left Sec. RESOLUTIONS	Proton DeltaZ	Electron DeltaZ	Proton DeltaTheta	Electron DeltaTheta	Proton DeltaPhi	Electron DeltaPhi	Proton DeltaP	Electron DeltaP
Configuration 1	1.13 mm	1.56 mm	0.33 Deg.	0.09 Deg.	0.34 Deg.	0.30 Deg.	25 MeV	38 MeV
Configuration 2	1.10 mm	1.51 mm	0.33 Deg.	0.14 Deg.	0.34 Deg.	0.30 Deg.	24 MeV	32 MeV

Right Sec. RESOLUTIONS	Proton DeltaZ	Electron DeltaZ	Proton DeltaTheta	Electron DeltaTheta	Proton DeltaPhi	Electron DeltaPhi	Proton DeltaP	Electron DeltaP
Configuration 1	1.10 mm	1.64 mm	0.33 Deg.	0.10 Deg.	0.33 Deg.	0.29 Deg.	24 MeV	40 MeV
Configuration 2	1.12 mm	1.35 mm	0.34 Deg.	0.14 Deg.	0.34 Deg.	0.31 Deg.	25 MeV	32 MeV

Left Sec. RESO. Of Lumi	Proton DeltaZ	Electron DeltaZ	Proton DeltaTheta	Electron DeltaTheta	Proton DeltaPhi	Electron DeltaPhi	Proton DeltaP	Electron DeltaP
Configuration 3	1.70 mm	1.68 cm	0.59 Deg.	0.15 Deg.	0.55 Deg.	0.39 Deg.	21 MeV	78 MeV
Configuration 4	1.16 mm	0.88 cm	0.57 Deg.	0.39 Deg.	0.57 Deg.	0.40 Deg.	21 MeV	20 MeV

Right Sec. RESOLUTIONS	Proton DeltaZ	Electron DeltaZ	Proton DeltaTheta	Electron DeltaTheta	Proton DeltaPhi	Electron DeltaPhi	Proton DeltaP	Electron DeltaP
Configuration 3	1.71 mm	1.66 cm	0.59 Deg.	0.15 Deg.	0.55 Deg.	0.42 Deg.	21 MeV	80 MeV
Configuration 4	1.77 mm	0.78 cm	0.58 Deg.	0.39 Deg.	0.52 Deg.	0.39 Deg.	21 MeV	20 MeV

Left Sec. RESO. Of Lumi	Proton DeltaZ	Electron DeltaZ	Proton DeltaTheta	Electron DeltaTheta	Proton DeltaPhi	Electron DeltaPhi	Proton DeltaP	Electron DeltaP
Configuration 5	1.79 mm	1.31 cm	0.57 Deg.	0.16 Deg.	0.55 Deg.	0.38 Deg.	21 MeV	76 MeV
Configuration 6	1.75 mm	0.75 cm	0.62 Deg.	0.29 Deg.	0.57 Deg.	0.38 Deg.	21 MeV	19 MeV

Right Sec. RESOLUTIONS	Proton DeltaZ	Electron DeltaZ	Proton DeltaTheta	Electron DeltaTheta	Proton DeltaPhi	Electron DeltaPhi	Proton DeltaP	Electron DeltaP
Configuration 5	1.83 mm	1.24 cm	0.58 Deg.	0.14 Deg.	0.59 Deg.	0.40 Deg.	21 MeV	71 MeV
Configuration 6	1.77 mm	0.73 cm	0.61 Deg.	0.27 Deg.	0.55 Deg.	0.38 Deg.	21 MeV	20 MeV

Resolutions (old)

Left Sec. RESOLUTIONS	Proton DeltaZ	Electron DeltaZ	Proton DeltaTheta	Electron DeltaTheta	Proton DeltaPhi	Electron DeltaPhi	Proton DeltaP	Electron DeltaP
Config 0: 100mu/50cm (all LuMo +BLAST)	0.80 mm	0.72 mm	0.094 Deg.	0.089 Deg.	0.14 Deg.	0.10 Deg.	32 MeV	39 MeV
Config 3: 100mu/10cm	1.70 mm	1.68 cm	0.59 Deg.	0.15 Deg.	0.55 Deg.	0.39 Deg.	21 MeV	78 MeV
Config 4: 100mu/50cm	1.16 mm	0.88 cm	0.57 Deg.	0.39 Deg.	0.57 Deg.	0.40 Deg.	21 MeV	20 MeV
Config 5: 50mu/10cm	1.79 mm	1.31 cm	0.57 Deg.	0.16 Deg.	0.55 Deg.	0.38 Deg.	21 MeV	76 MeV
Config 6: 50mu/50cm	1.75 mm	0.75 cm	0.62 Deg.	0.29 Deg.	0.57 Deg.	0.38 Deg.	21 MeV	19 MeV

- **Large differences for LuMo+BLAST versus LuMo-only**
- **Minor improvement with 50mu resolution versus 100mu**
- **Significant improvement with 50cm gaps instead of 10cm**

Residuals (old)

Left Sec. RESIDUALS	PpTp	PeTe	PePp	TpTe	PpTe	PeTp	TeTp	TePp	PpPe	TpPp	TePe	TpPe	ZeZp	PhiePhip
Configuration 0	32 MeV	39 MeV	48 MeV	0.10 Deg.	34 MeV	39 MeV	0.17 Deg.	1.41 Deg.	57 MeV	0.94 Deg	2.18 Deg.	1.34 Deg.	1.13 mm	0.18 Deg.

Right Sec. RESIDUALS	PpTp	PeTe	PePp	TpTe	PpTe	PeTp	TeTp	TePp	PpPe	TpPp	TePe	TpPe	ZeZp	PhiePhip
Configuration 0	32 MeV	39 MeV	47 MeV	0.10 Deg.	33 MeV	39 MeV	0.17 Deg.	1.46 Deg.	58 MeV	0.93 Deg	2.17 Deg.	1.39 Deg.	1.11 mm	0.18 Deg.

Left Sec. RESIDUALS	PpTp	PeTe	PePp	TpTe	PpTe	PeTp	TeTp	TePp	PpPe	TpPp	TePe	TpPe	ZeZp	PhiePhip
Configuration 1	26 MeV	38 MeV	43 MeV	0.31 Deg.	23 MeV	39 MeV	0.25 Deg.	0.56 Deg.	69 MeV	0.91 Deg	1.78 Deg.	2.11 Deg.	1.65 mm	0.45 Deg.
Configuration 2	26 MeV	32 MeV	38 MeV	0.35 Deg.	24 MeV	34 MeV	0.32 Deg.	0.64 Deg.	57 MeV	0.88 Deg.	1.47 Deg.	1.5 Deg.	1.90 mm	0.44 Deg

Right Sec. RESIDUALS	PpTp	PeTe	PePp	TpTe	PpTe	PeTp	TeTp	TePp	PpPe	TpPp	TePe	TpPe	ZeZp	PhiePhip
Configuration 1	26 MeV	41 MeV	44 MeV	0.32 Deg.	25 MeV	39 MeV	0.24 Deg.	0.60 Deg.	72 MeV	0.82 Deg	1.69 Deg.	2.15 Deg.	1.72 mm	0.43 Deg.
Configuration 2	26 MeV	32 MeV	38 MeV	0.40 Deg.	24 MeV	32 MeV	0.28 Deg.	0.66 Deg.	70 MeV	0.84 Deg.	1.30 Deg.	1.8 Deg.	1.51 mm	0.47 Deg

Left Sec. RESi of Lumi	PpTp	PeTe	PePp	TpTe	PpTe	PeTp	TeTp	TePp	PpPe	TpPp	TePe	TpPe	ZeZp	PhiePhip
Configuration 3	27 MeV	80 MeV	78 MeV	0.54 Deg.	21 MeV	81 MeV	0.43 Deg.	0.51 Deg.	203 MeV	0.99 Deg	5.80 Deg.	7.29 Deg.	1.67 cm	0.58 Deg.
Configuration 4	27 MeV	20 MeV	20 MeV	0.73 Deg.	25 MeV	21 MeV	0.54 Deg.	0.59 Deg.	97 MeV	0.99 Deg.	1.30 Deg.	2.1 Deg.	1.01 cm	0.60 Deg.

Right Sec. RESi of Lumi	PpTp	PeTe	PePp	TpTe	PpTe	PeTp	TeTp	TePp	PpPe	TpPp	TePe	TpPe	ZeZp	PhiePhip
Configuration 3	27 MeV	81 MeV	78 MeV	0.60 Deg.	23 MeV	79 MeV	0.40 Deg.	0.52 Deg.	185 MeV	0.83 Deg	4.80 Deg.	6.80 Deg.	1.67 cm	0.61 Deg.
Configuration 4	27 MeV	21 MeV	20 MeV	0.76 Deg.	24 MeV	20 MeV	0.50 Deg.	0.63 Deg.	96 MeV	0.82 Deg.	1.21 Deg.	2.1 Deg.	0.89 cm	0.58 Deg.

Left Sec. RESi of Lumi	PpTp	PeTe	PePp	TpTe	PpTe	PeTp	TeTp	TePp	PpPe	TpPp	TePe	TpPe	ZeZp	PhiePhip
Configuration 5	26 MeV	81 MeV	82 MeV	0.55 Deg	22 MeV	81 MeV	0.44 Deg.	0.52 Deg.	180 MeV	0.99 Deg.	5.90 Deg.	6.50 Deg.	1.39 cm	0.65 Deg.
Configuration 6	26 MeV	20 MeV	20 MeV	0.63 Deg.	24 MeV	21 MeV	0.45 Deg.	0.58 Deg.	98 MeV	0.97 Deg.	1.35 Deg.	1.9 Deg.	0.96 cm	0.58 Deg.

Right Sec. RESi of Lumi	PpTp	PeTe	PePp	TpTe	PpTe	PeTp	TeTp	TePp	PpPe	TpPp	TePe	TpPe	ZeZp	PhiePhip
Configuration 5	26 MeV	76 MeV	78 MeV	0.67 Deg.	23 MeV	76 MeV	0.38 Deg.	0.52 Deg.	191 MeV	0.80 Deg.	5.50 Deg.	6.90 Deg.	1.24 cm	0.62 Deg.
Configuration 6	26 MeV	21 MeV	20 MeV	0.64 Deg.	23 MeV	20 MeV	0.44 Deg.	0.56 Deg.	95 MeV	0.86 Deg.	1.27 Deg.	2.0 Deg.	0.83 cm	0.62 Deg.

Residuals (old)

Left Sec. RESIDUALS	PpTp/ MeV	PeTe/ MeV	PePp/ MeV	TpTe/ Deg.	PpTe/ MeV	PeTp/ MeV	TeTp/ Deg.	TePp/ Deg.	PpPe/ MeV	TpPp/ Deg.	TePe/ Deg.	TpPe/ Deg.	ZeZp	PhiePhi p/Deg.
Config 0: 100mu/50cm	32	39	48	0.10	34	39	0.17	1.41	57	0.94	2.18	1.34	1.13 mm	0.18
Config 3: 100mu/10cm	27	80	78	0.54	21	81	0.43	0.51	203	0.99	5.80	7.29	1.67 cm	0.58
Config 4: 100mu/50cm	27	20	20	0.73	25	21	0.54	0.59	97	0.99	1.30	2.1	1.01 cm	0.60
Config 5: 50mu/10cm	26	81	82	0.55	22	81	0.44	0.52	180	0.99	5.90	6.50	1.39 cm	0.65
Config 6: 50mu/50cm	26	20	20	0.63	24	21	0.45	0.58	98	0.97	1.35	1.9	0.96 cm	0.58

- **Lepton momentum Pe is a poor constraint**
- **TeTp and TePp residuals are balanced for LuMo-only events (TeTp preferred over TePp for LuMo+BLAST events)**
- **Substantial improvement with 50cm gaps instead of 10cm**
- **Minor improvement with 50mu resolution**

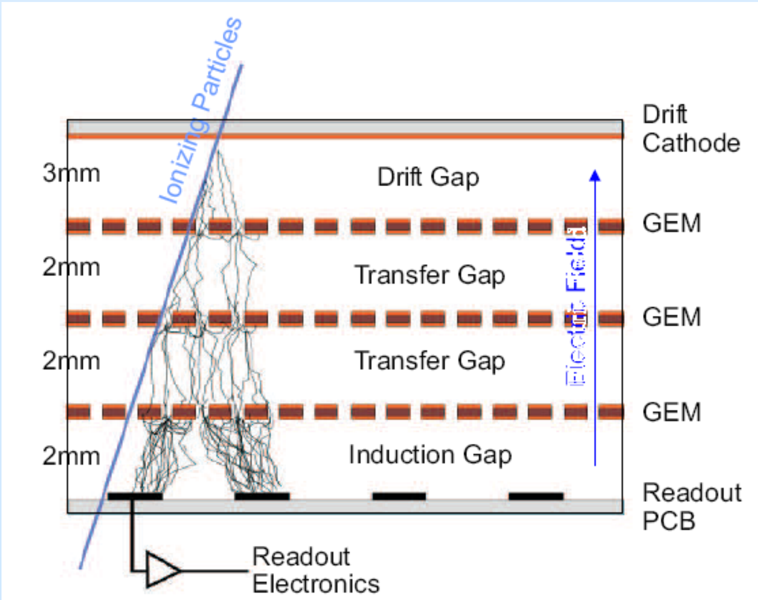
Principle of GEM Detectors

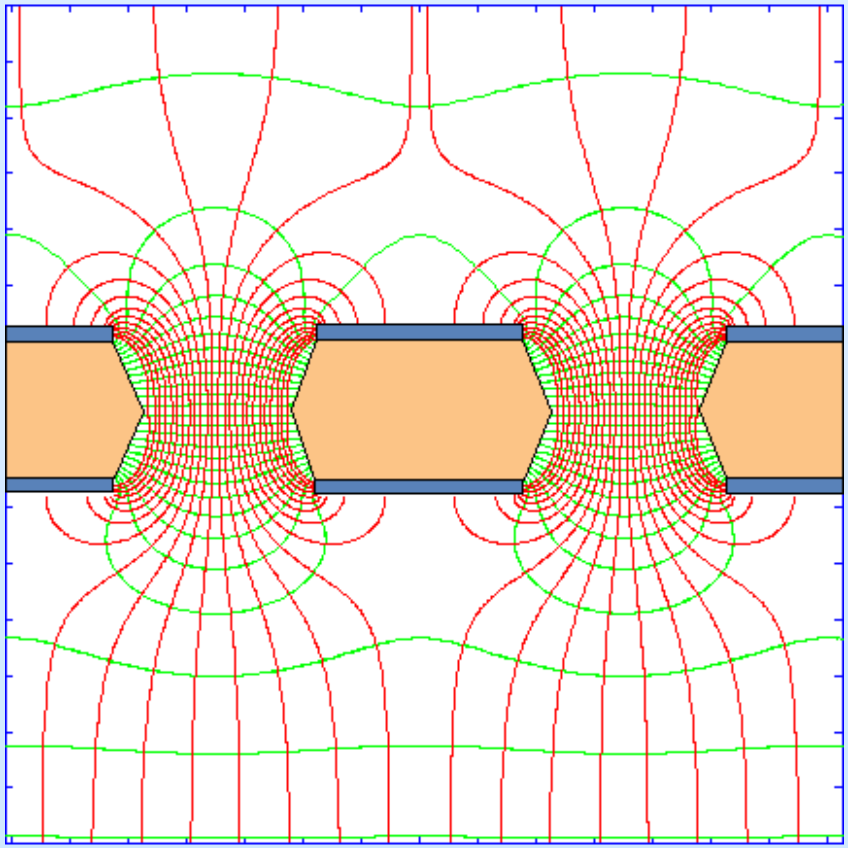
- GEM = Gas Electron Multiplier

  introduced by F. Sauli in mid 90's, F. Sauli et al., NIMA 386 (1997) 531

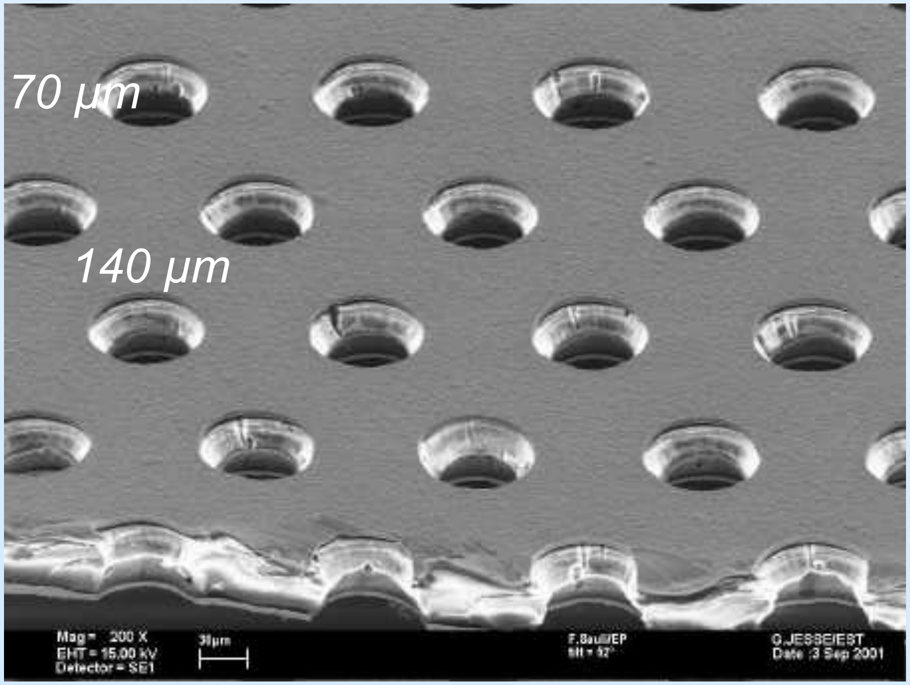
- Copper layer-sandwiched kapton foil with chemically etched micro-hole pattern

  ⇨ gas amplification in the hole



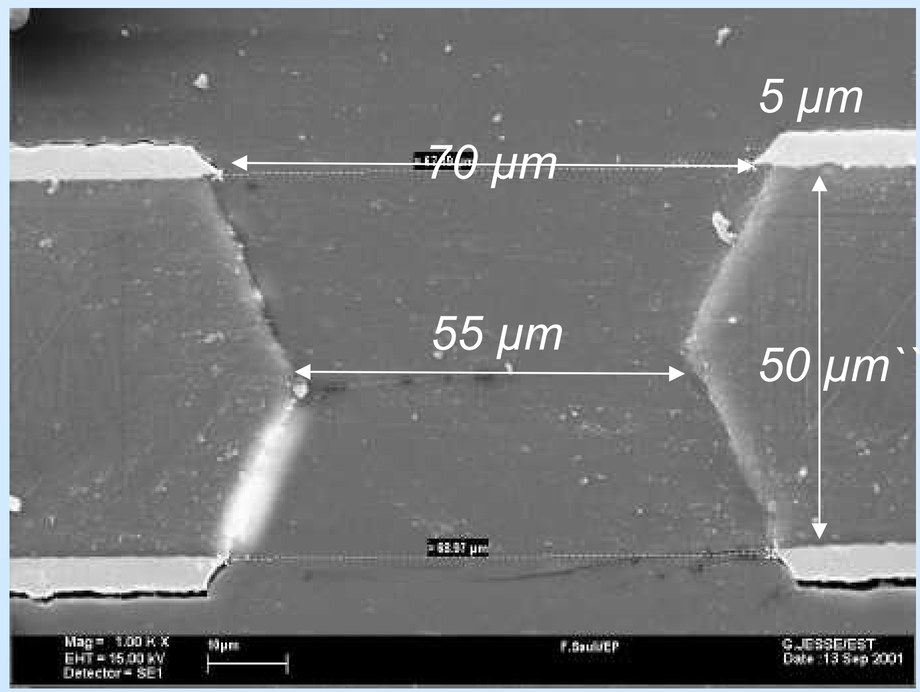


GEM foils



Typically 5μm Cu on 50μm kapton

~10^4 holes/cm^2



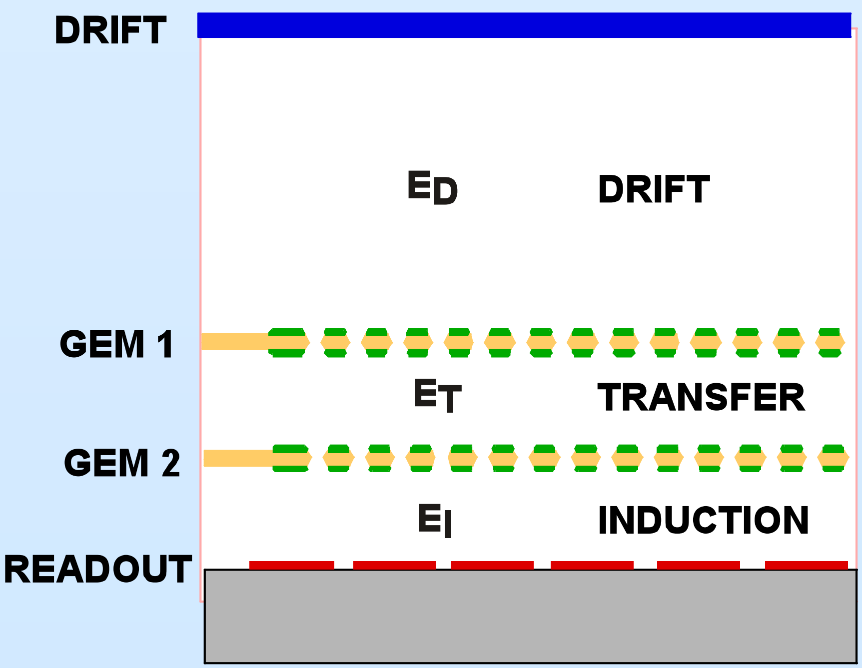
Chemical etching
- R. De Oliveira (CERN-EST)
- **TechEtch (MIT)**
- 3M Corporation

Laser drilling
- Tamagawa (RIKEN)

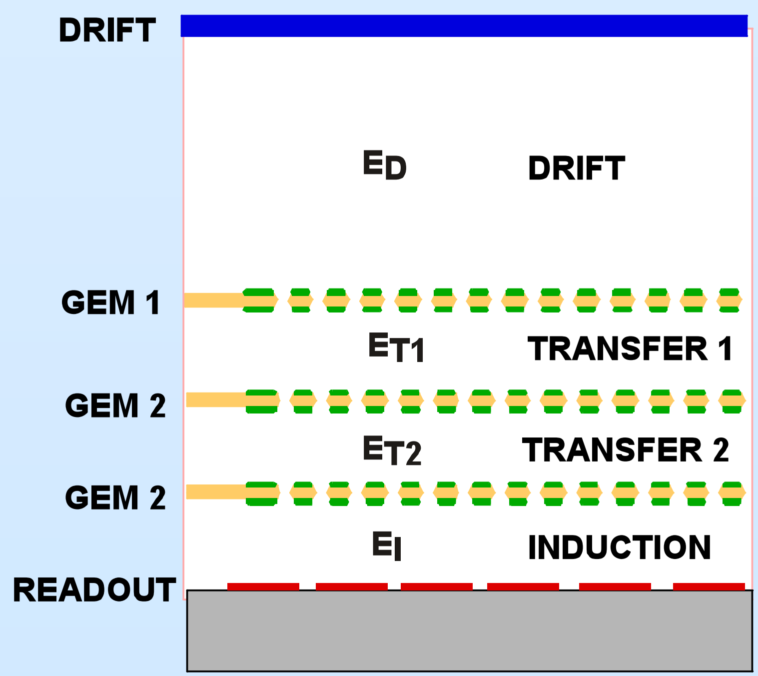
Multi-GEM Detectors

- GEMs can be cascaded for higher gain
- Gain of 10^4 needed for efficient MIP detection

Double GEM



Triple GEM

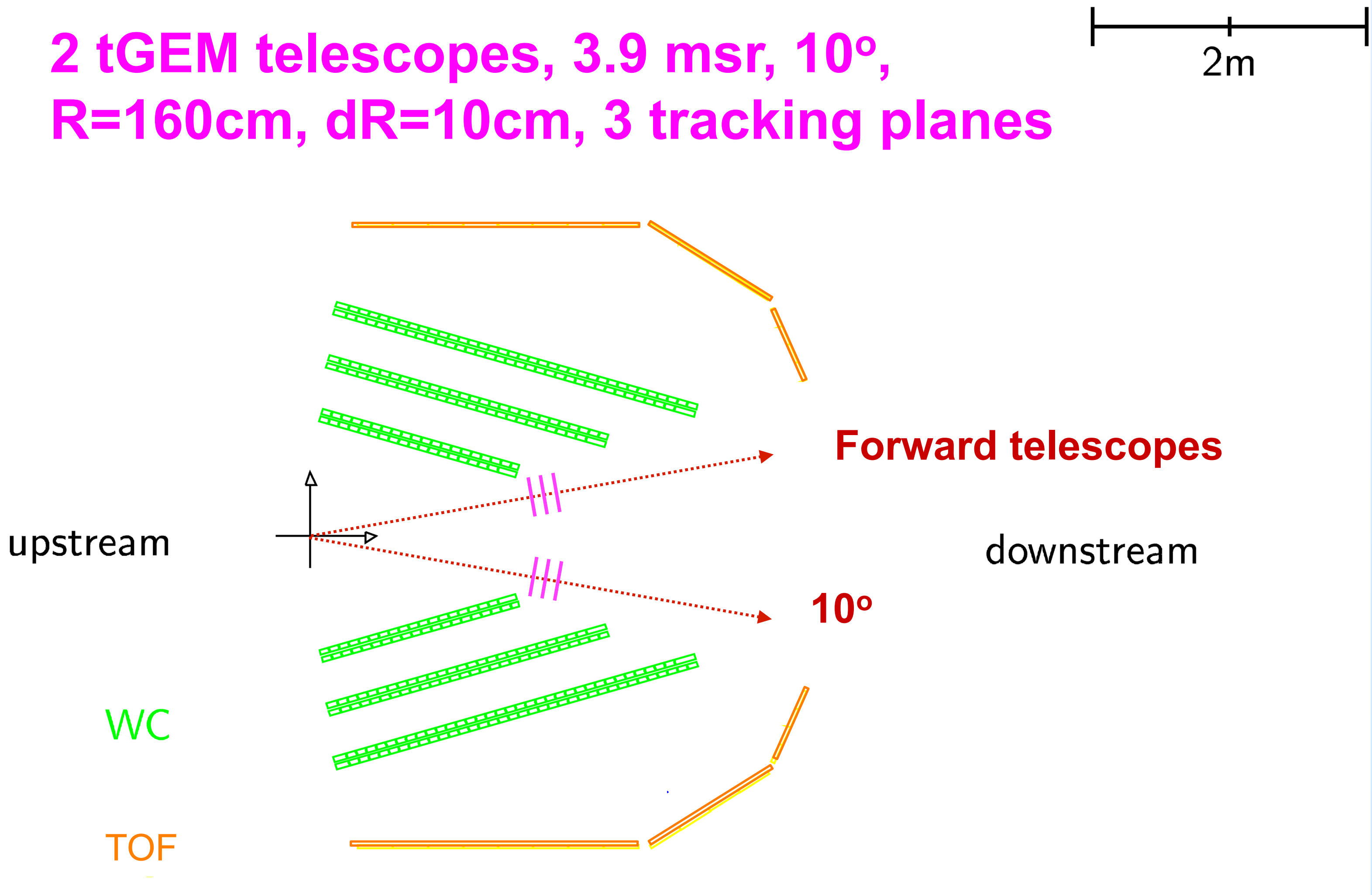


C. Buettner et al., Nucl. Instr. and Meth. A 409(1998)79
S. Bachmann et al., Nucl. Instr. and Meth. A 443(1999)464

Luminosity Monitors: Telescopes

Proposed version included in OLYMPUS proposal Sept. 2008

2 tGEM telescopes, 3.9 msr, 10°, R=160cm, dR=10cm, 3 tracking planes



Luminosity Monitors: Count rate

Proposed version included in OLYMPUS proposal Sept. 2008

E_0 [GeV]	Q^2 [(GeV/c)^2]	$p_{e'}$ [GeV/c]	ϵ	θ_p	p_p [MeV/c]	Rate [h^{-1}]
4.5	0.574	4.194	0.9825	63.1°	816	21286
2.0	0.118	1.937	0.9844	74.7°	349	402173

Table 1.1: Kinematics and count rates of the luminosity control measurement for beam energies of 2.0 and 4.5 GeV at $\theta_e = 10°$. The assumed solid angle is 3.9 msr.

- **Two symmetric GEM telescopes at 10°**
- **Two-photon effect negligible at high-ε / low-Q^2**
- **Sub-percent (relative) luminosity measurement per hour for all energies**

- **3.9 msr = 10 x 10 cm^2 at ~160 cm distance**
- **Three GEM layers with ~0.1 mm resolution with ~10 cm gaps**
  → Vertex resolution (z) of ~1cm at 10° to match that of proton in BLAST
- **Same readout pitch as in MIT prototype (635 μm)**
- **Number of electronics channels per telescope:**
  3x(100+100)/0.635 ~= 1000