Simulation Results for CLAS12 From gemc

G.P.Gilfoyle, M.Ungaro et al.

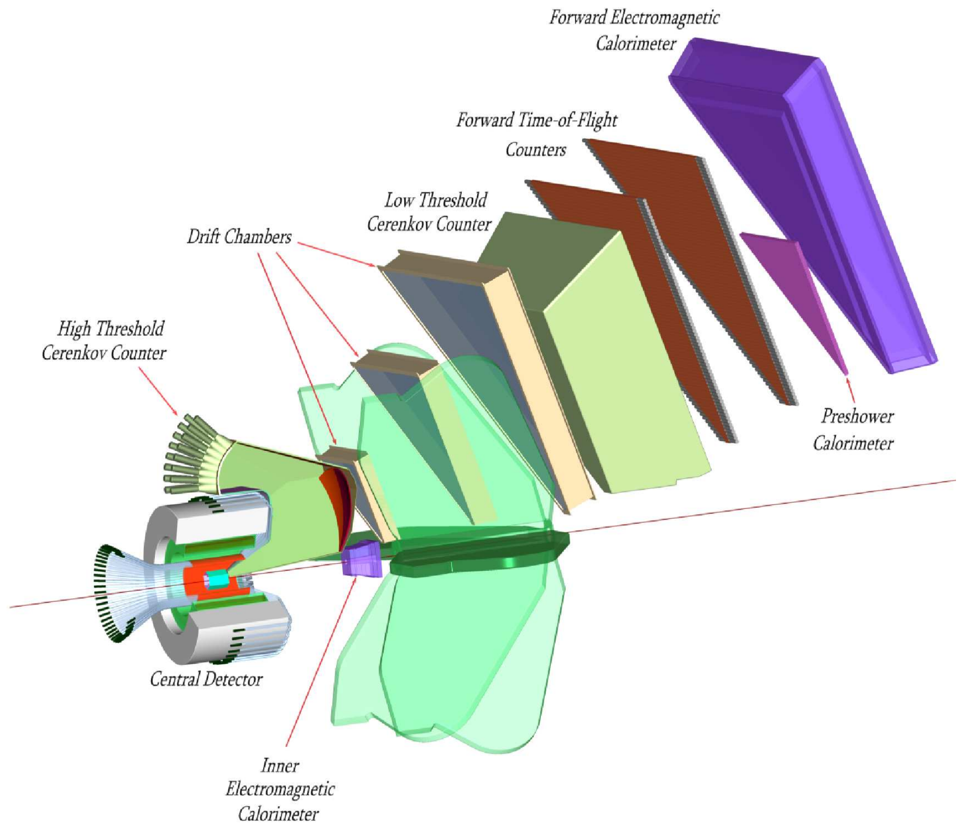
CLAS12 Software Group

Outline:

1. gemc Overview
2. Neutron efficiency in first TOF panel.
3. Electromagnetic calorimeter (EC) performance.
4. Hadron properties in the Silicon Vertex Tracker (SVT)
5. DVCS events in the SVT.
6. Background rates and Doses in the SVT.
7. CLAS12 Forward Tagger.
8. Conclusions.

CLAS12 Simulation

- Essential tool for design and analysis (*e.g.* acceptance calculations).
- Quality of the results may be limited by systematic uncertainties (not statistics).
- Will need about four times as much Monte Carlo data as CLAS12 collects.



The CLAS12 detector.

gemc

◇ Modern, object-oriented, Geant4-based simulation.

◇ Still in development stage.

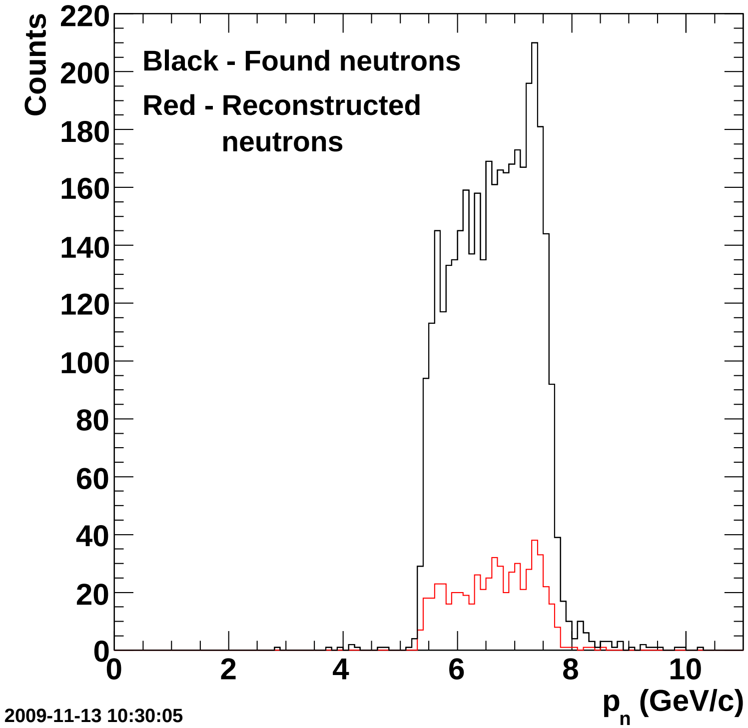
◇ Needed subsystems: ⟶

♣ Pre-shower calorimeter (PCal).

♣ Cerenkov counter (CC).

Neutron Efficiency in First TOF Panel

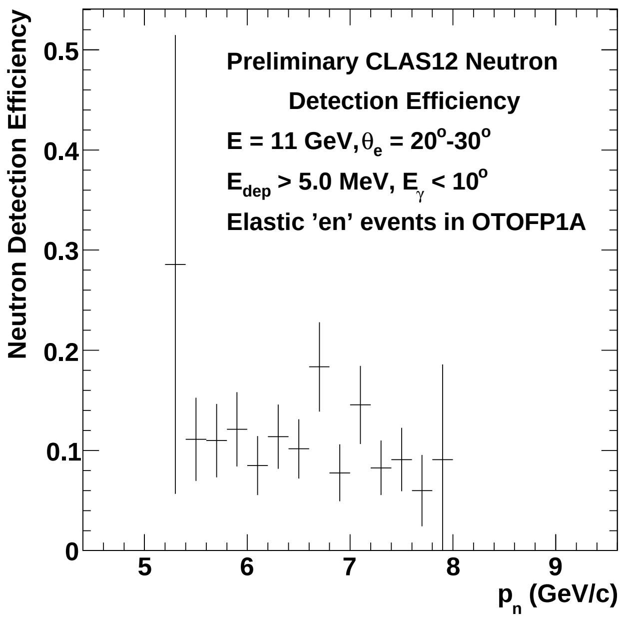
- Neutron detection efficiency (NDE) needed for E12-07-104 (G_M^n experiment) and others.
- Study first TOF panel (OTOFP1A); we have CLAS6 NDE measurements for these scintillators.
- Generate 'elastic' en events and process with gemc.
- Reconstruct electrons with Socrat.
- Found neutrons - Events where neutron is predicted to hit OTOFP1A using only electron information.

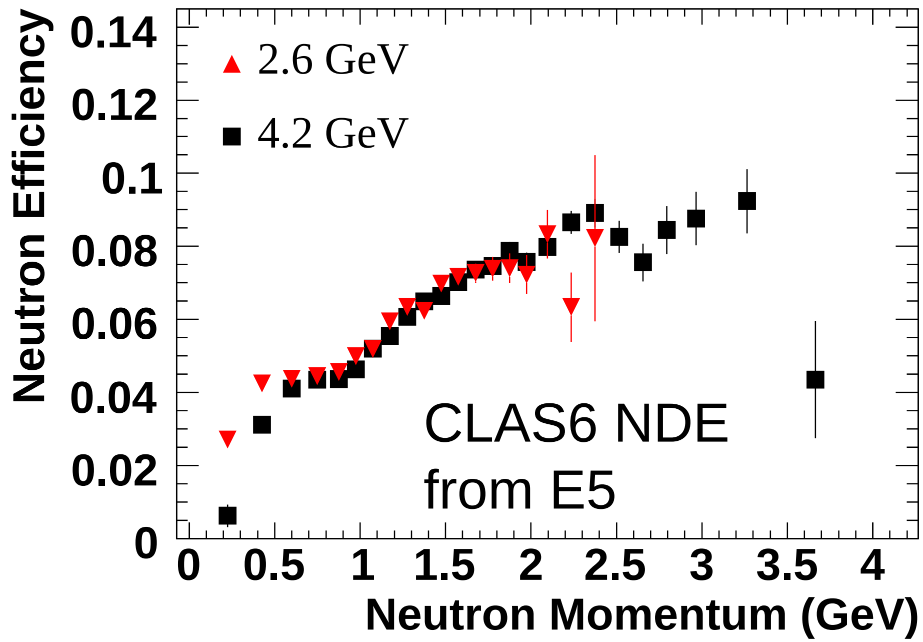


- Reconstructed neutrons - Apply cut on angle between the predicted neutron direction and vertex-to-TOF-hit vector ($\theta_\gamma < 10^\circ$) and require $E_{dep} > 5\ MeV$.

Neutron Efficiency in First TOF Panel

- Simulated NDE is about 10% at 6-8 GeV/c versus 9% at 3 GeV/c for CLAS6.

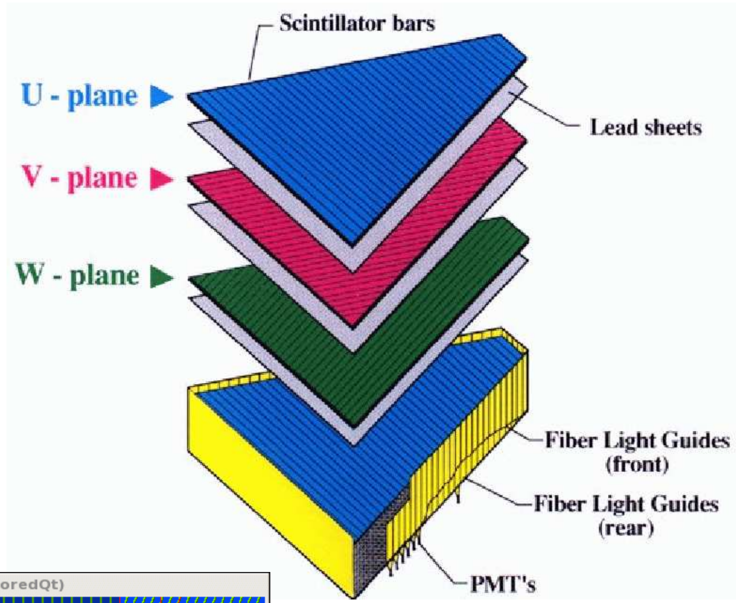


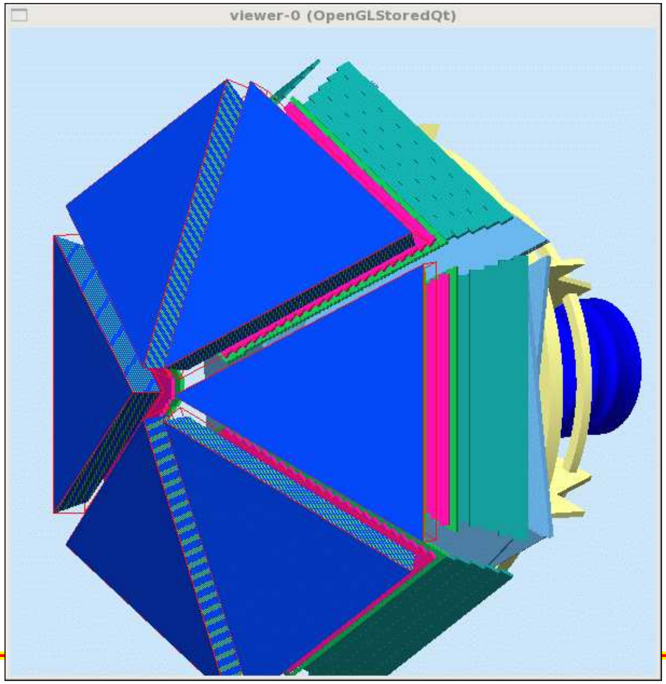


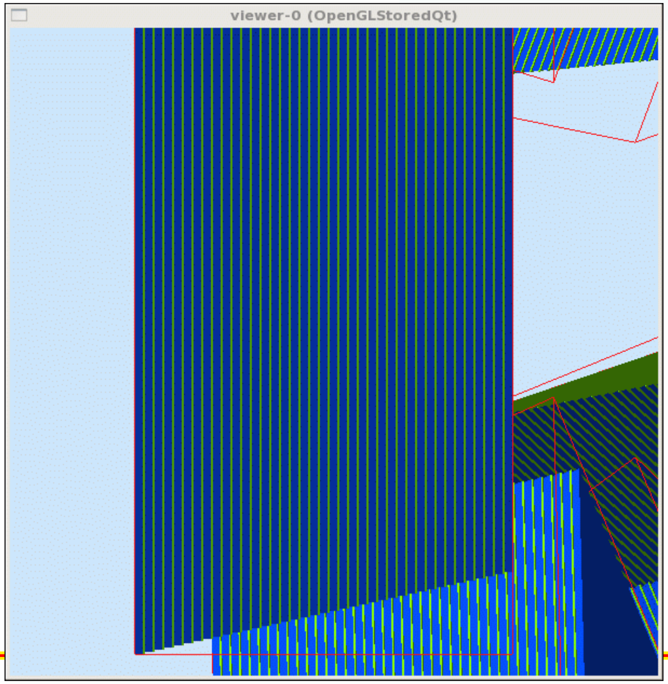
- To be done: timing cuts, p_n dependence, simulate $^1H(e, e'\pi^+n)$ reaction for tagged neutrons.

Electromagnetic calorimeter (EC) performance

- The CLAS6 EC will be re-used in CLAS12; placed $\approx 2\ m$ downstream.
- EC geometry.







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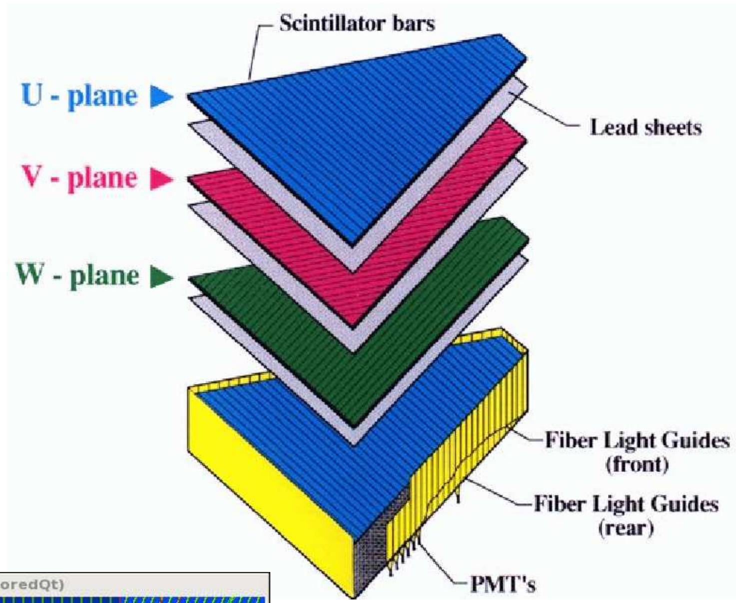
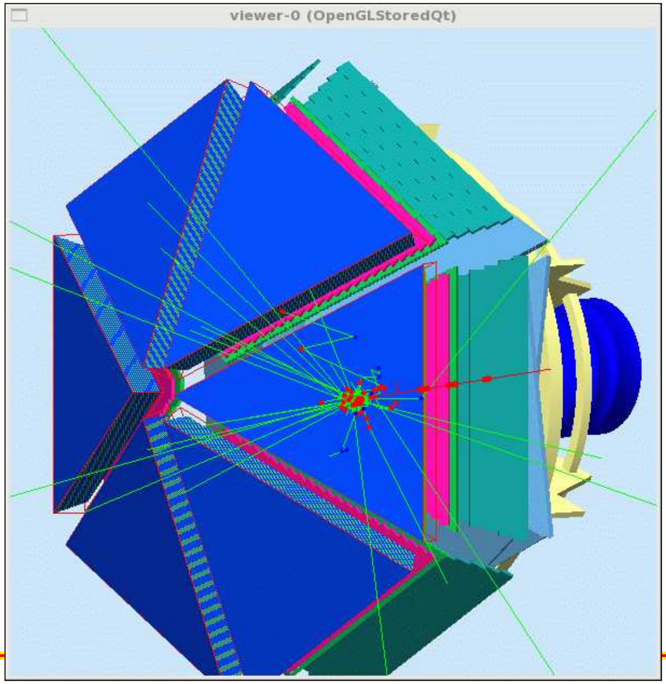
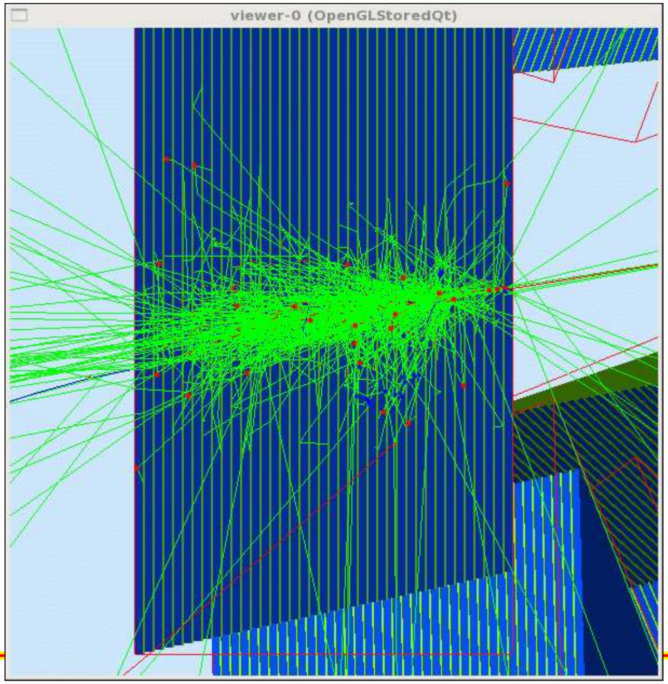
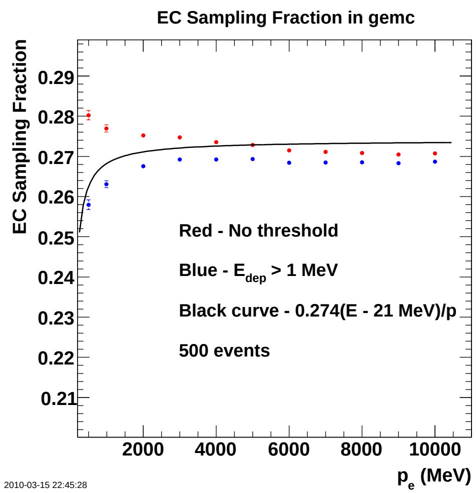


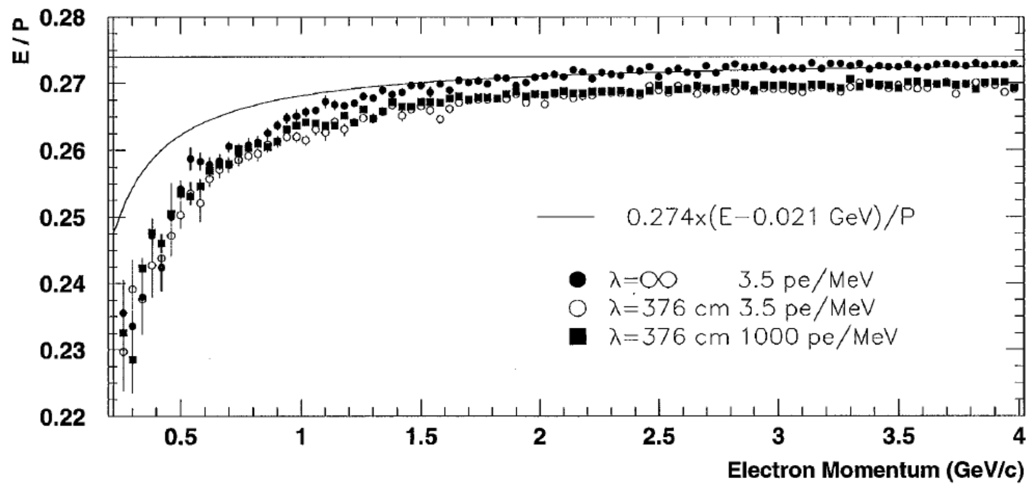




Comparison with CLAS6 - Sampling Fraction

1. CLAS6 results from EC NIM paper (NIM A460 (2001) 239-265) using GSIM.
2. Black curve in each plot based on ionization energy loss in materials preceding the EC.
3. Caveats: (1) electrons passed through different material, (2) $\vec{B}$ field off in the CLAS12 simulation and $\vec{B}$ field on in the CLAS6 simulation, (3) tracking used in CLAS6 simulation while Monte Carlo information used for CLAS12, (4) energy loss out the back, ...
4. Note different horizontal ranges.





gemc and GSIM sampling fractions are consistent to 10-15%.

Comparison with CLAS6 - Resolution

1. CLAS6 results from EC NIM paper (NIM A460 (2001) 239-265) using GSIM.
2. Caveats: (1) electrons passed through different material, (2) $\vec{B}$ field off in the CLAS12 simulation and $\vec{B}$ field on in the CLAS6 simulation, (3) tracking used in CLAS6 simulation while Monte Carlo information used for CLAS12, (4) energy loss out the back, ...
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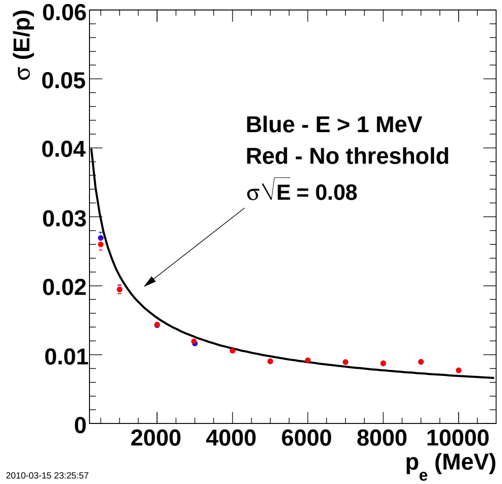
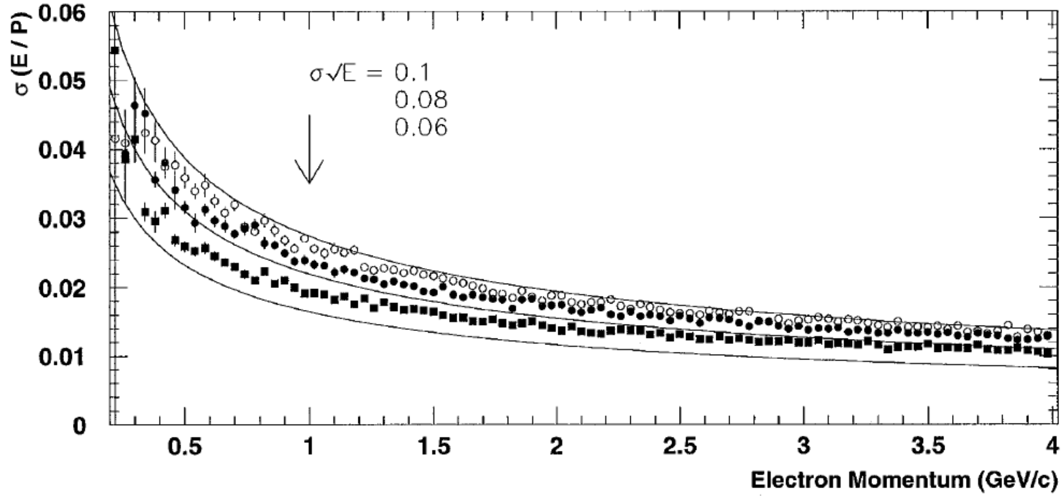
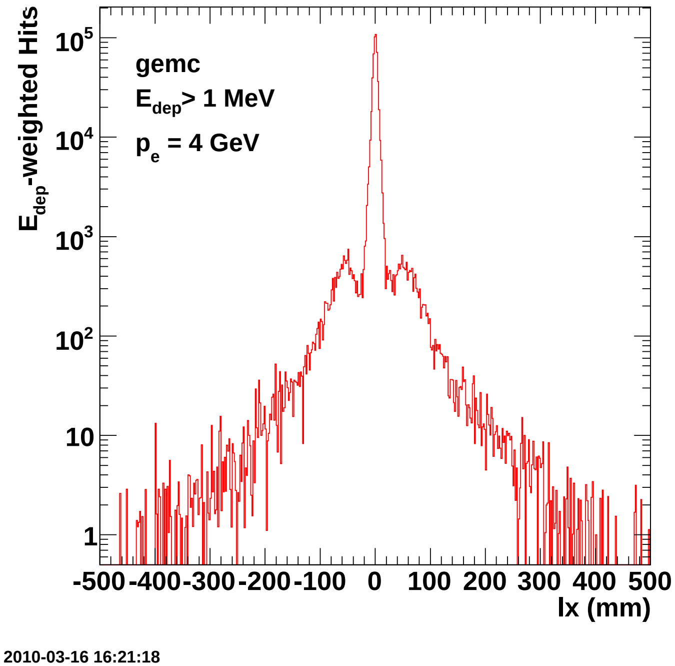


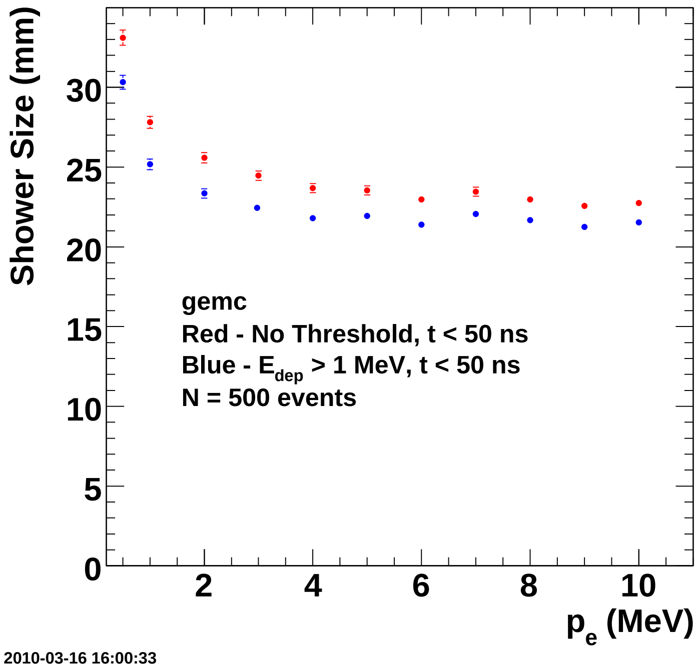


gemc and GSIM resolutions are consistent to 5-10%.

Comparison with CLAS6 - Shower Size

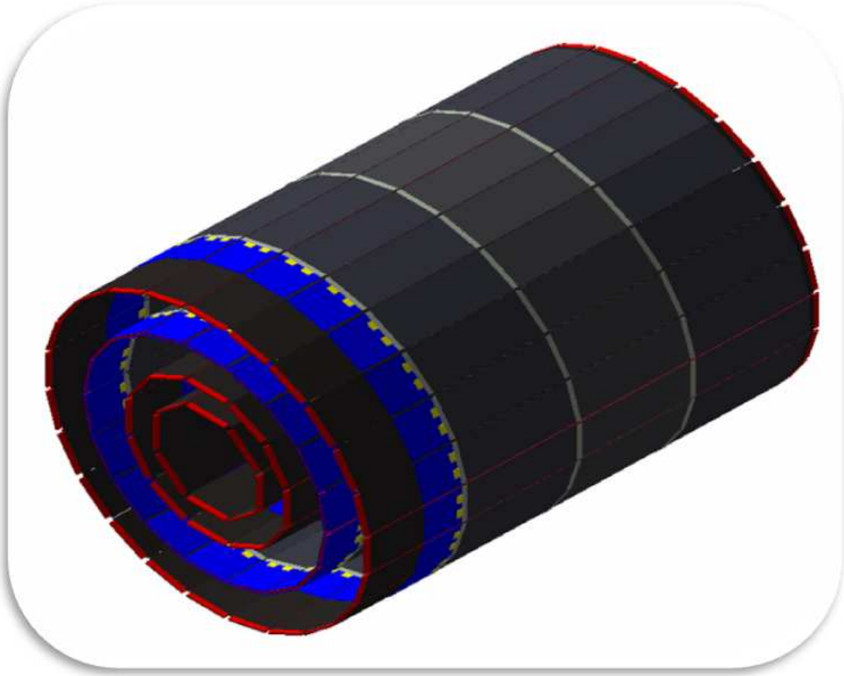
1. CLAS6 shower size ≈ 4 cm diameter for 2.4 GeV electron (*e.g.* 95% of shower energy contained within 2 cm of centroid (EC NIM paper).
2. Caveats: (1) electrons passed through different material, (2) $\vec{B}$ field off in the CLAS12 simulation and $\vec{B}$ field on in the CLAS6 simulation, (3) tracking used in CLAS6 simulation while Monte Carlo information used for CLAS12, (4) energy loss out the back, ...
3. Use E_{dep}-weighted distribution in local x for $\theta_e = 25°$, $\phi_e = 0°$.



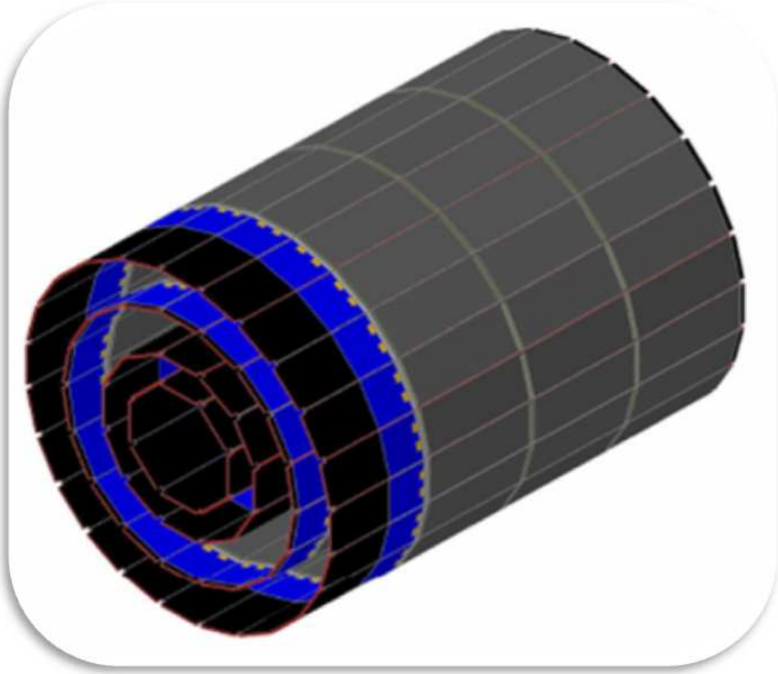


gemc and GSIM shower sizes are consistent to 5-10%.

BST Geant4 Implementation

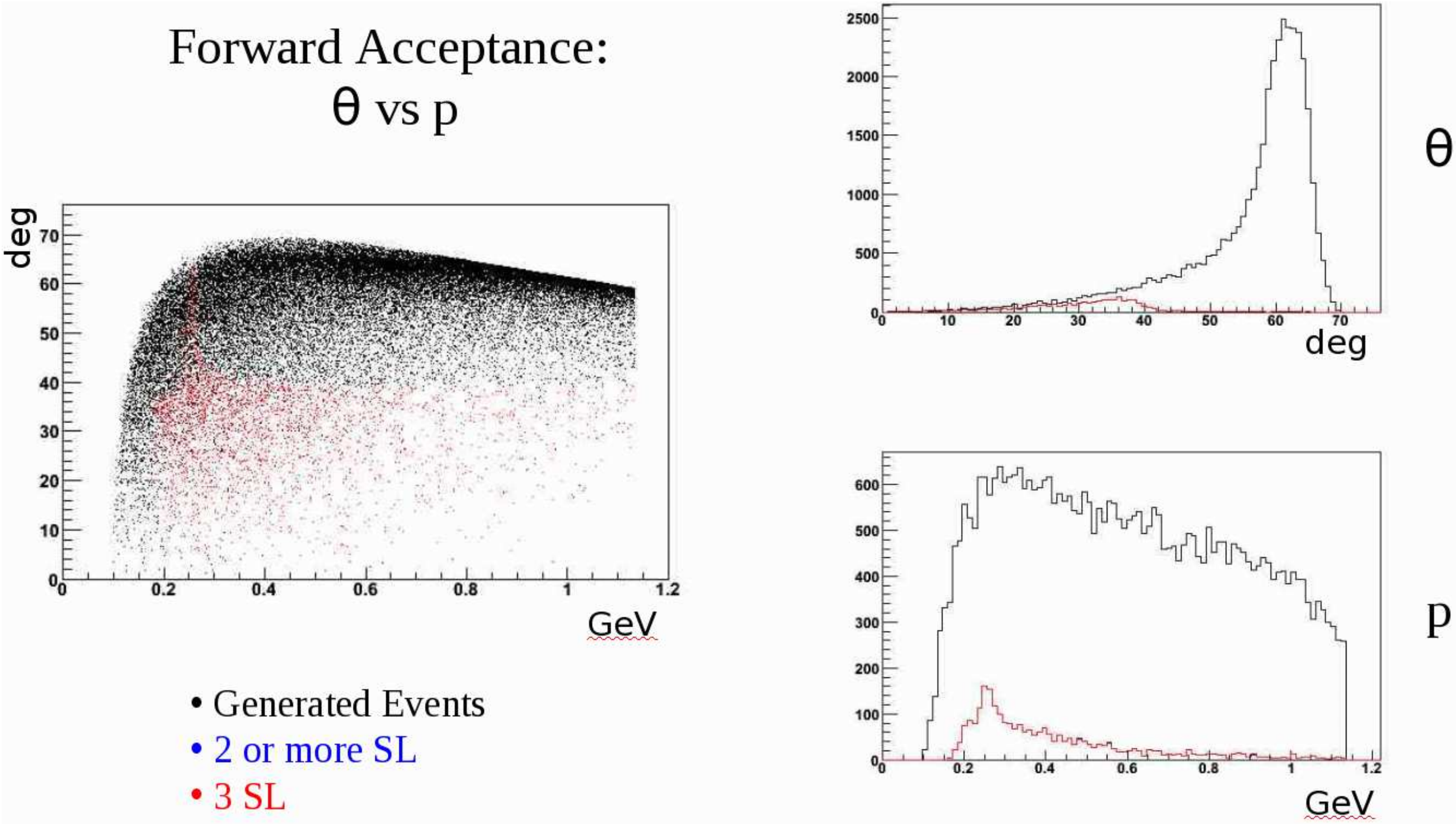


Geant4



Design

DVCS events in the SVT.



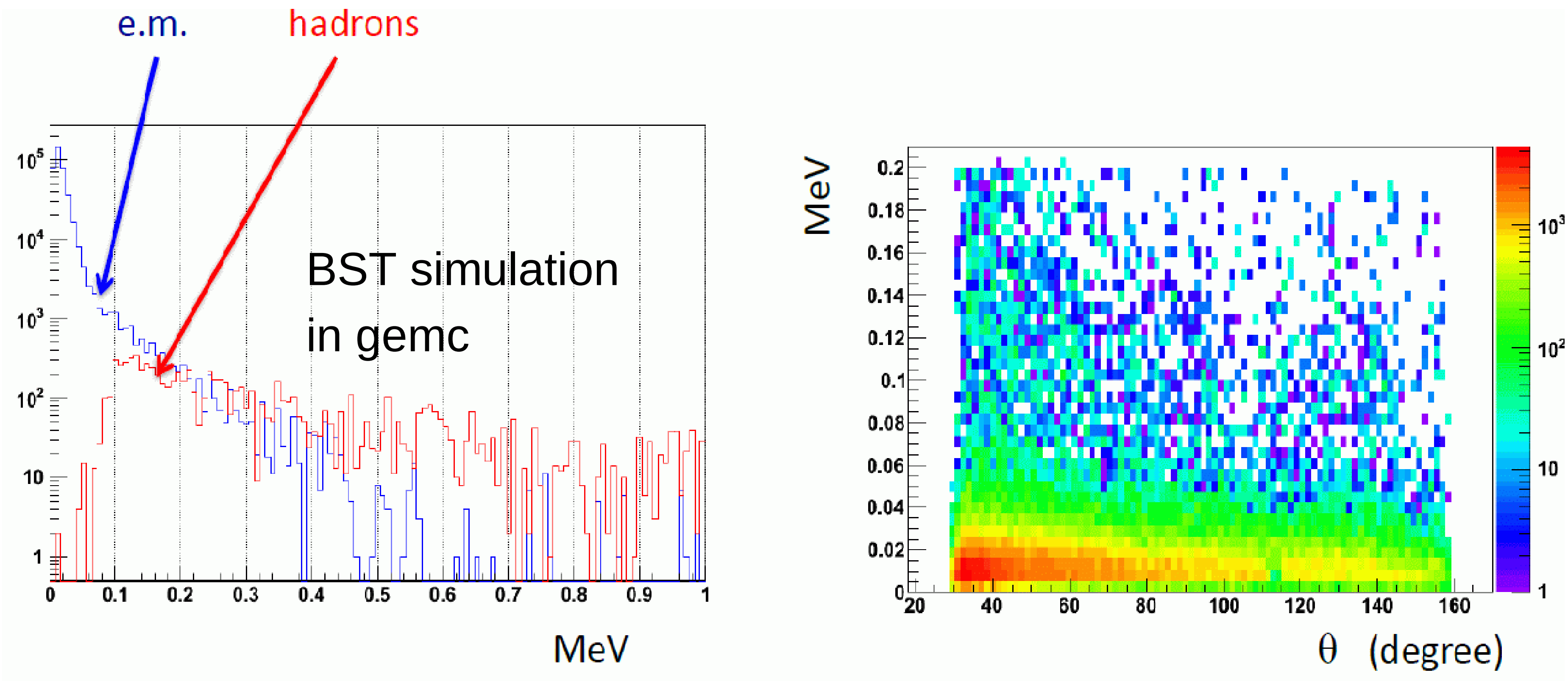
Study of acceptance for DVCS events in the Forward Silicon Tracker (FST) of the SVT. Similar study made of the Barrel Silicon Tracker (BST).

Event rates in the SVT.

CLAS12 Luminosity: $L = 10^{35}\ electrons/s - cm^2$ and
CLAS12 LH2 target: $l_T = 5\ cm$, $\rho = 0.0708\ gm/cm^3$

$$\rightarrow Rate = 4.7 \times 10^{11} electrons/s$$

$\rightarrow$ SVT time window: 132 ns $\rightarrow$ 62,500 electrons/event



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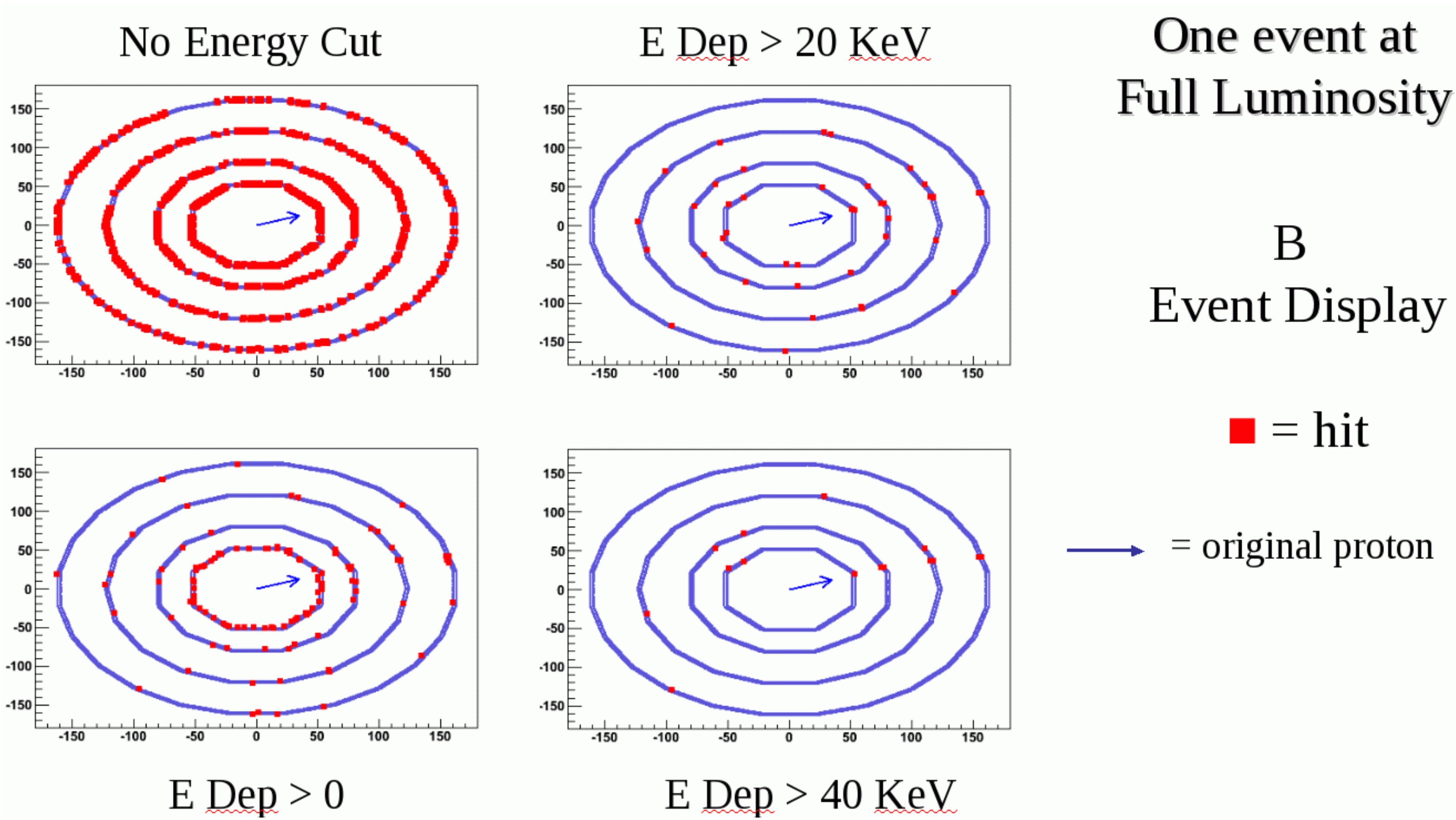
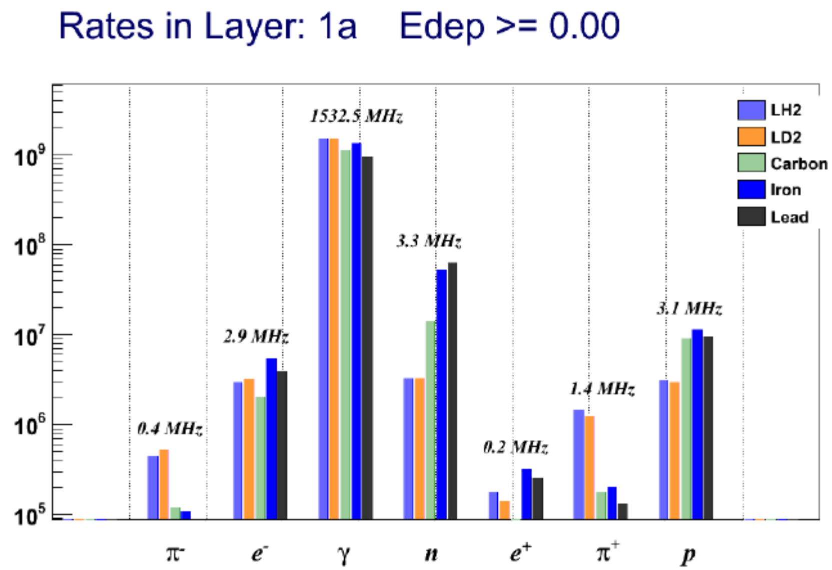
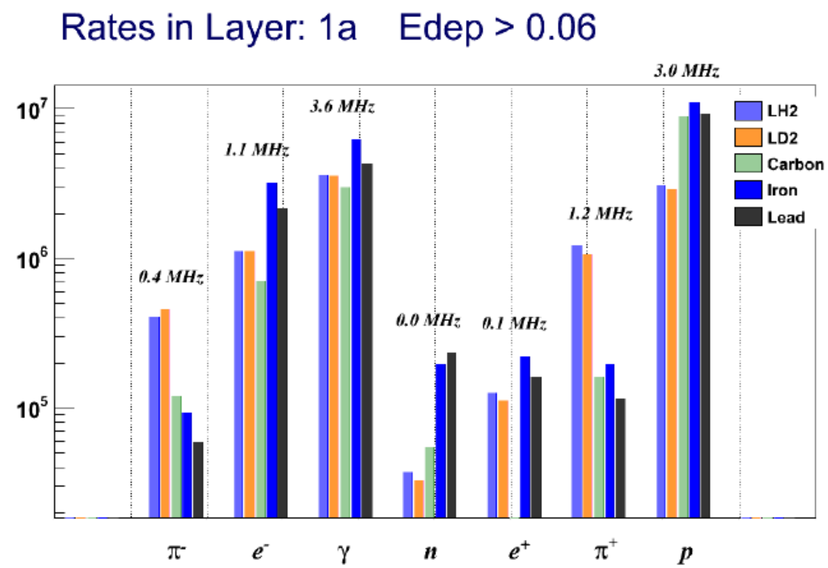


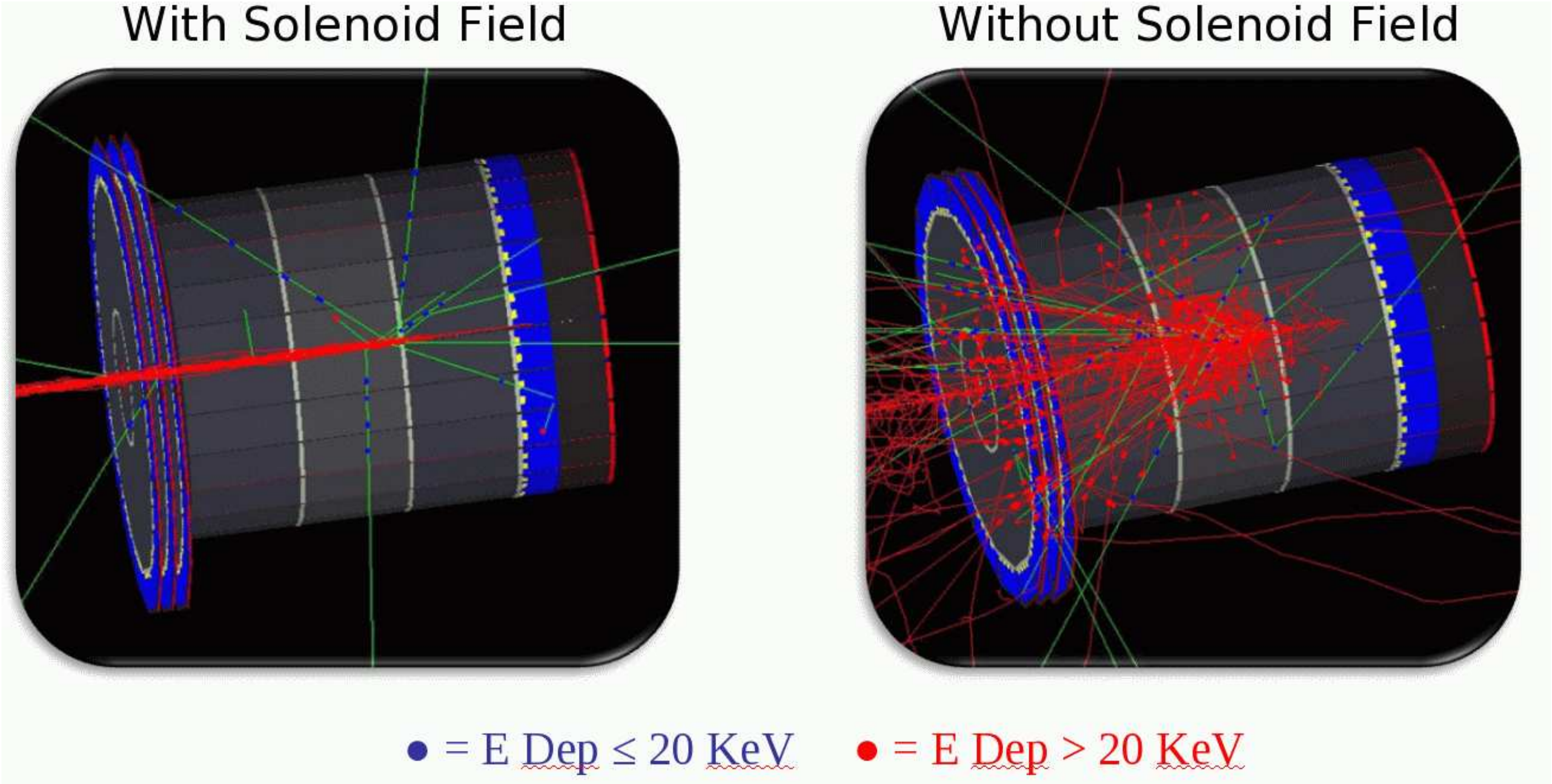
Event rates in the SVT.

Effect of cut on deposited energy in layer 1a of the BST.





Event rates in the SVT.



Fluence and Dose results for Layer 1a of FST.

GeV/$(s - cm^2)$	kilorad/year	Solenoid
48.00	363.8	Off
3.56	27.042	On

Forward Tagger in CLAS12.

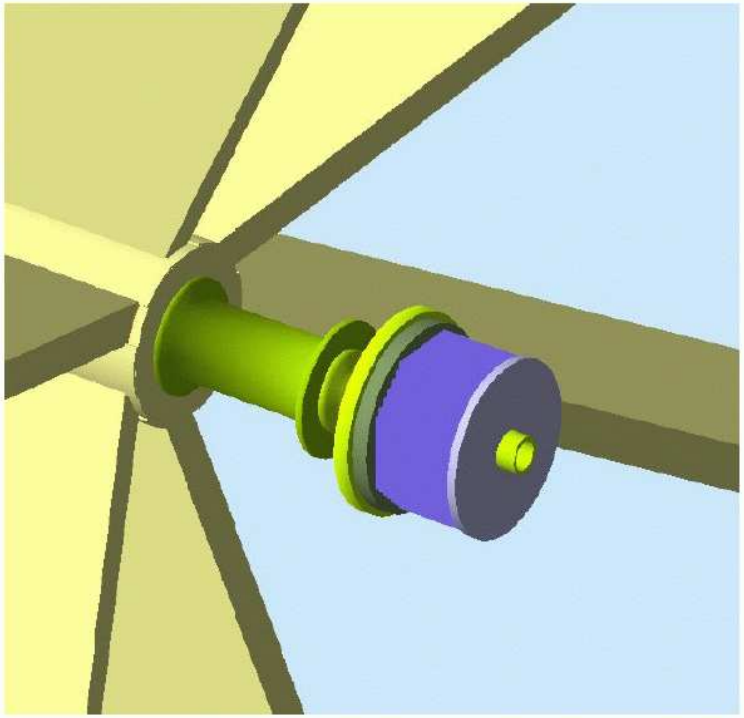
Forward Tagger

LowQ² electro-scattering

- **Extended CLAS12 physics program**
  Meson spectroscopy on H2 (search for exotics), nuclear targets (coherent and incoherent photo-production), heavy baryon spectroscopy (Ω and Ξ)

- **Extended CLAS12 acceptance for electrons**
  Covering angles between 2-5 deg. by an 'inner' calorimeter + multi layers of tracking chambers

High intensity, linear polarized quasi-real photon beam (up to 10^8 γ/s) in 7-11 GeV range



- **LOI-10-001 and 004 approved by PAC35 and full proposal encouraged**

- **R&D in progress**
  - Calorimeter: crystal (PbWO, LYSO, sampling cal.), read-out (APD, SiPM)
  - Tracking: extended CLAS12 forward tracker under investigation
  - Background rates estimates
  - Test of full PWA analysis for benchmarks channels

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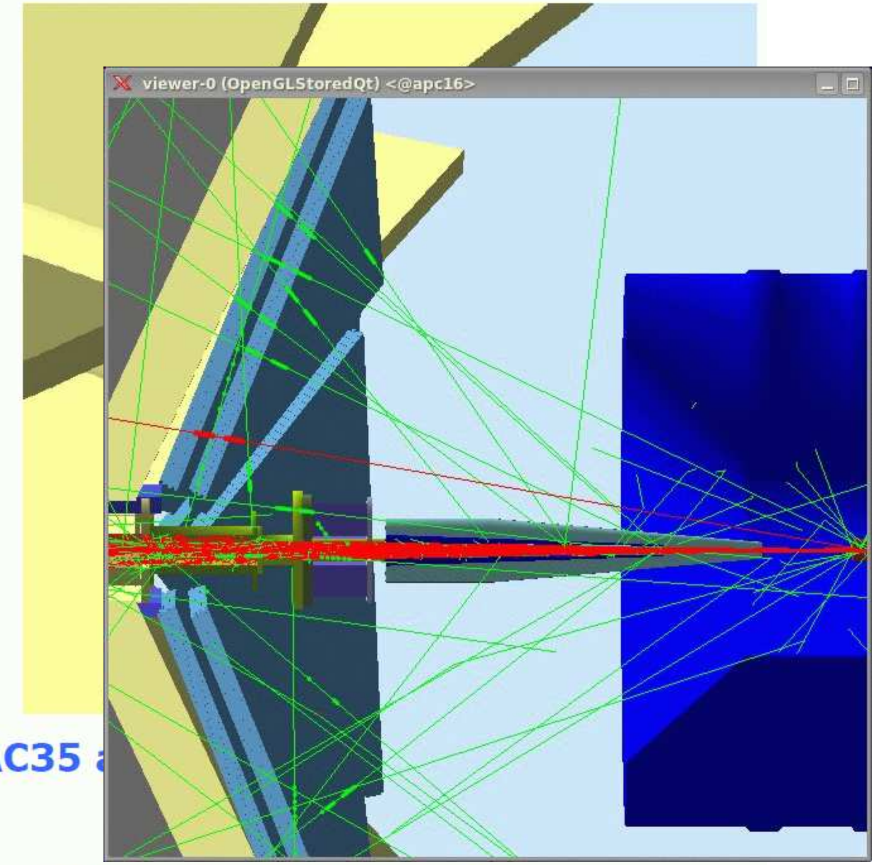

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Conclusions

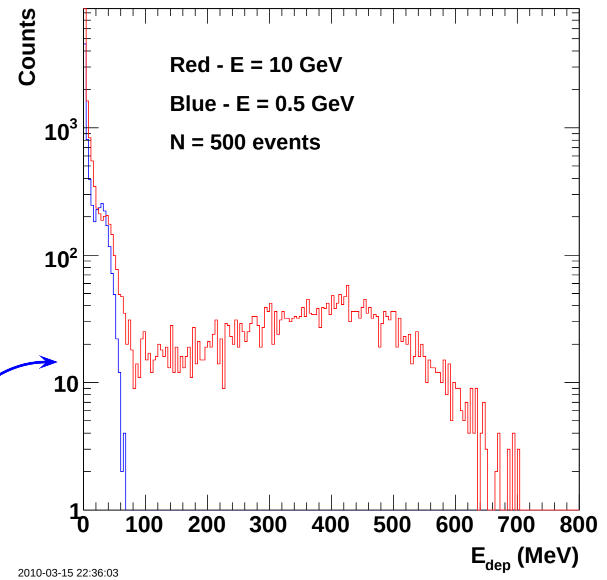
- Preliminary simulation of TOF NDE measurement consistent with CLAS6 results.
- EC simulation consistent with CLAS6 measurements.
- Simulation of DVCS events and protons and mesons in the SVT validate design.
- Background studies show that solenoid field will suppress background events and extend SVT lifespan.
- Studies of forward tagger are encouraging and a full proposal will be forthcoming.
- To do:
  - PCal (Mike Wood)
  - Cerenkov counters.
  - Full simulation of tagged neutrons for NDE ($ep \rightarrow e'\pi^+ n$).

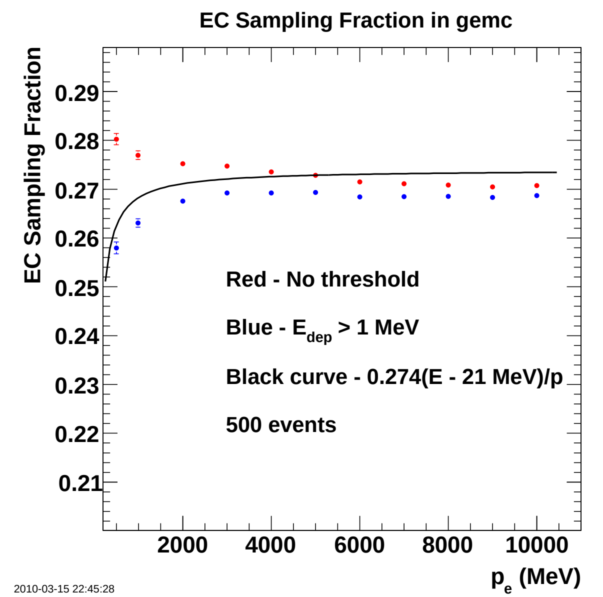
Additional Slides

Electromagnetic calorimeter (EC) performance

1. Sampling Fraction (f_s)
   (a) Ratio of energy deposited in the EC to the energy of the electron (E/p).
   (b) Test conditions for gemc:
      i. No $\vec{B}$ field (new option for gemc).
      ii. Fix electron momentum p_e, $\theta_e = 25°$, $\phi_e = 0°$.
      iii. Convert EVIO output to Root Trees.
      iv. Histogram the deposited energy.
      v. Scan p_e $(0.5 - 10\ \mathrm{GeV})$.
2. Integrate the distribution of E_{dep} and divide by p_e to get the sampling fraction.

   $f_s = \frac{\sum n_i E^i_{dep}}{E_e}$ where n_i is the number of counts in the top panel.
3. Drop observed at low p_e due to threshold on E_{dep}.





Electromagnetic calorimeter (EC) performance

1. Modified the identifiers in the geometry database to reflect stacking (inner/outer) and views (U, V, W) of the EC.
2. As the track is integrated determine the identifiers of the ‘hit’ at each step:
   - Sector: already known.
   - Stack: layers 1-15 $\rightarrow$ inner; layer 16-39 $\rightarrow$ outer.
   - View: use $layer % 3 to determine view from layer.
   - Strip: 36 strips in each layer.

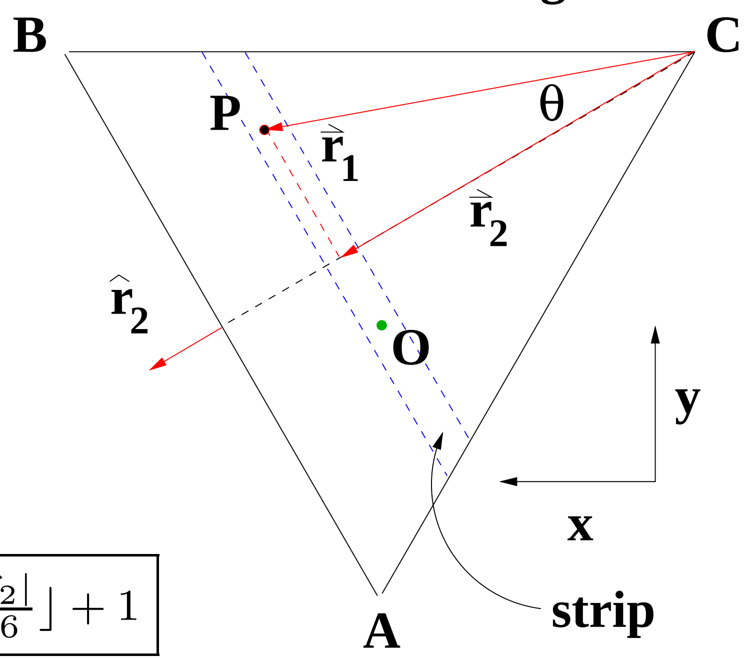
$\vec{P} = (x, y)$ (the hit)

$$\vec{A} = (x_A, y_A) = (0, -pDy1)$$
$$\vec{B} = (x_B, y_B) = (pDx2, pDy1)$$
$$\vec{C} = (x_C, y_C) = (-pDx2, pDy1)$$

$$\vec{r}_1 = \vec{P} - \vec{C}$$
$$\hat{r}_2 = \frac{(y_B - y_A, x_A - x_B)}{\sqrt{(y_B - y_A)^2 + (x_A - x_B)^2}}$$
$$\cos\theta = \frac{\vec{r}_1 \cdot \hat{r}_2}{|\vec{r}_1|}$$
$$|\vec{r}_2| = |\vec{r}_1| \cos\theta$$

$$strip = \lfloor \frac{|\vec{r}_2|}{36} \rfloor + 1$$

V View from Target



Electromagnetic calorimeter (EC) performance

3. ADC signal.

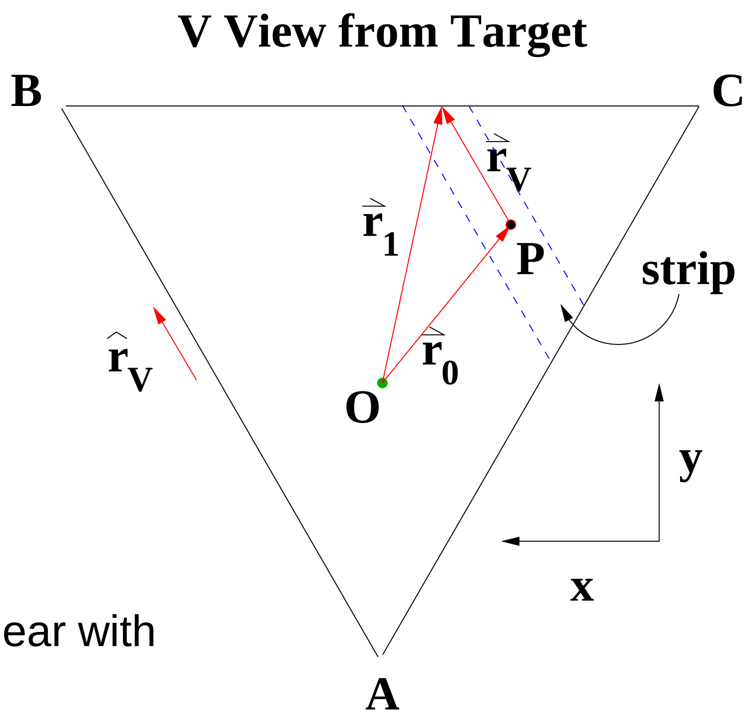
   (a) Calculate expected number of photons from deposited energy ($3.5\ \mathrm{photons/MeV}$).

   (b) Use Poisson statistics to simulate the number of photons.

   (c) Apply photon attenuation ($\lambda_0 = 3760\ mm$).

   $$\vec{P} = (x, y)$$
   $$\vec{A} = (x_A, y_A) = (0, -pDy1)$$
   $$\vec{B} = (x_B, y_B) = (pDx2, pDy1)$$
   $$\vec{C} = (x_C, y_C) = (-pDx2, pDy1)$$

   Equation of $\overline{BC}$: $y = y_{BC} = pDy1$.
   Equation of $\vec{r}_1$: $\vec{r}_1 = \vec{r}_0 + l\hat{r}_V$
   where $\hat{r}_V = \frac{\vec{B}-\vec{A}}{|\vec{B}-\vec{A}|}$.
   Set $y_{BC} = y_1$ and solve for l.



   (d) Apply PMT gain (10 channels/MeV) and smear with PMT resolution (use GSIM parameters).

4. TDC signal - convert time of hit to TDC signal using 20 ns/channel.

Adding the EC to the CLAS12 Simulation

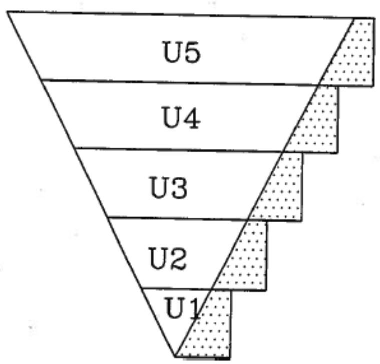
1. The CLAS6 EC geometry - defined by R. Minehart in `http://www.jlab.org/~gilfoyle/CLAS12software/CLAS6ECgeometry.pdf`

2. Active region defined by the following equations. The vertex of the triangle at small scattering angle and the top of the triangle at large scattering angle are

$$y_-(L) = A_- + B_-(L-1) \ \ (vertex) \qquad y_+(L) = A_+ + B_+(L-1) \ \ (top)$$

   where L is the layer number, $A_- = -1829.74\ mm$, $B_- = -4.3708\ mm$, $A_+ = 1899.56\ mm$, and $B_+ = 4.5419\ mm$. The other two lines defining the active region are the following where $\tan\theta = 1.95325$.

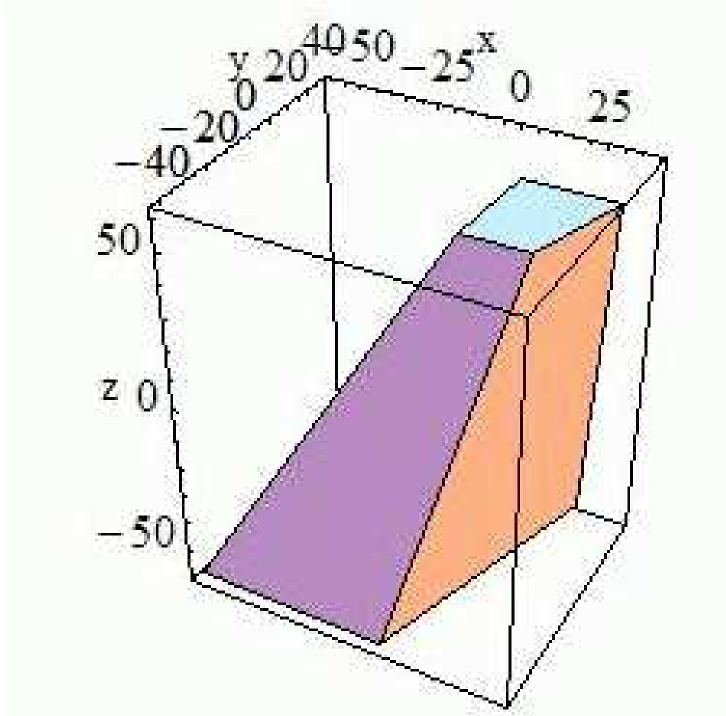
$$y + x\tan\theta = y_-(L_-) \qquad y - x\tan\theta = y_-(L)$$



3. EC still at $\theta = 25^\circ$ to a perpendicular to the beamline and the same distance from the beam.
4. EC farther downstream from the target center than CLAS6. Normal distance from target center to upstream face is 7217.23 mm (JJ Roberts and D. Kashy). See `http://clasweb.jlab.org/wiki/index.php/Clas12_EC#Geometry`

Adding the EC to the CLAS12 Simulation

5. To add a new volume (the EC) to gemc:
   (a) Generate the parameters for a generic trapezoid (G4Trap) in Geant4.
   (b) Insert into a perl script (see `gemc/production/database_io/clas12/geo/ec/ec_build.pl`).
   (c) Execute '`go_tables user_geometry`' which reads the geometry values in `ec_build.pl` and inserts the values in the `user_geometry` database.
   (d) Use the `-DATABASE=user_geometry` option when running gemc.
   (e) BEWARE! Spaces versus tabs can muck up the mysql database.

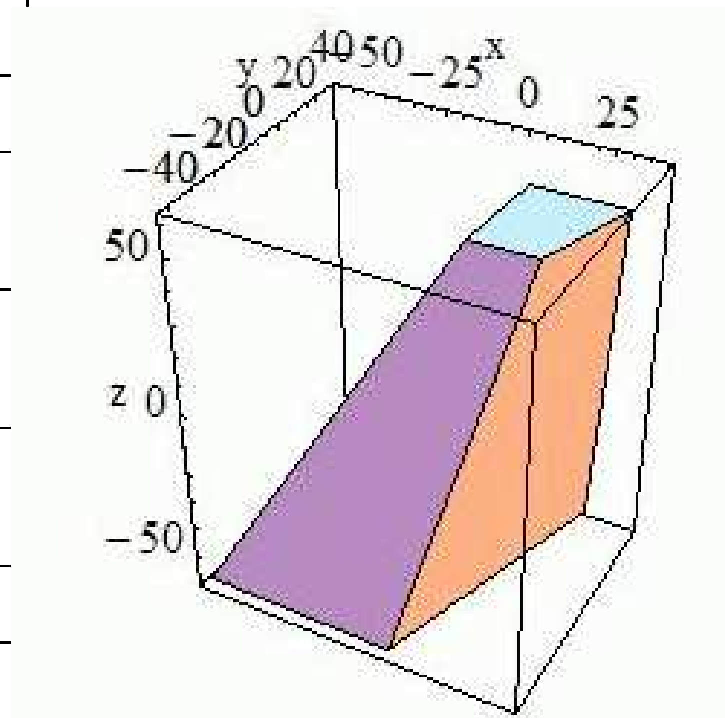


6. Treating each active layer in the EC as a single trapezoid. The strips will be defined during digitization.

Adding the EC to the CLAS12 Simulation

7. Geant4 G4trap geometry parameters:

pDx1	Half x length of the side at y=-pDy1 of the face at -pDz	pDx2	Half x length of the side at y=+pDy1 of the face at -pDz
pDz	Half z length	pTheta	Polar angle of the line joining the centres of the faces at -/+pDz
pPhi	Azimuthal angle of the line joining the centre of the face at -pDz to the centre of the face at +pDz	pDx3	Half x length of the side at y=-pDy2 of the face at +pDz
pDy2	Half y length at +pDz		
pDx4	Half x length of the side at y=+pDy2 of the face at +pDz		
pAlp2	Angle relative to the y axis from the centre of the side (upper endcap)		
pAlp1	Angle with respect to the y axis from the centre of the side (lower endcap)		
pDy1	Half y length at -pDz		



Adding the EC to the CLAS12 Simulation

8. Add the EC banks to the simulations.

   (a) In `gemc/production/database_io/clas12/banks/` create `ec.bank` (see below) and edit `clas12_hits_def.txt`.

   (b) Execute `go_tables` and `go_hits` in the same area to make entries in `clas12_banks` database.

   (c) In `gemc/production/hitprocess/` create `EC_hitprocess.cc` and `EC_hitprocess.h` and edit `Clas12_HitProcess_MapRegister.cc` to include the EC.

   (d) Recompile.

   (e) Talk to Mauri, fix your mistakes, and recompile...

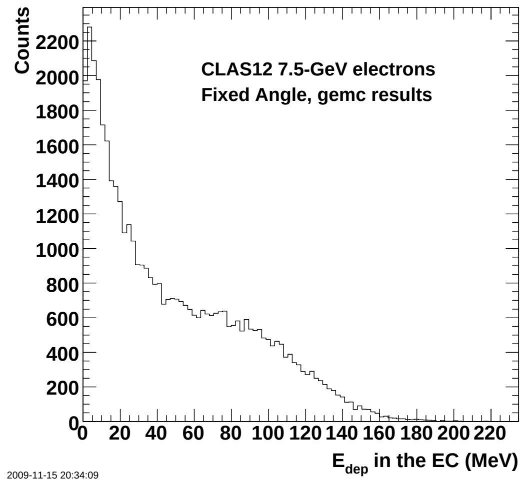
ETot	1	1	1	Total Energy Deposited
<x>	2	1	1	Average global x position
<y>	3	1	1	Average global y position
<z>	4	1	1	Average global z position
<lx>	5	1	1	Average local x position
<ly>	6	1	1	Average local y position
<lz>	7	1	1	Average local z position
<t>	8	1	1	Average time
pid	9	1	1	Particle ID
vx	10	1	1	x coordinate of primary vertex
vy	11	1	1	y coordinate of primary vertex
vz	12	1	1	z coordinate of primary vertex
E	13	1	1	Energy of the track at the entrance point
mpid	14	1	1	Mother Particle ID
mvx	15	1	1	x coordinate of mother vertex
mvy	16	1	1	y coordinate of mother vertex
mvz	17	1	1	z coordinate of mother vertex
sector	18	1	1	sector
layer	19	1	1	layer
ADCL	20	0	1	ADCL
ADCR	22	0	1	ADCR

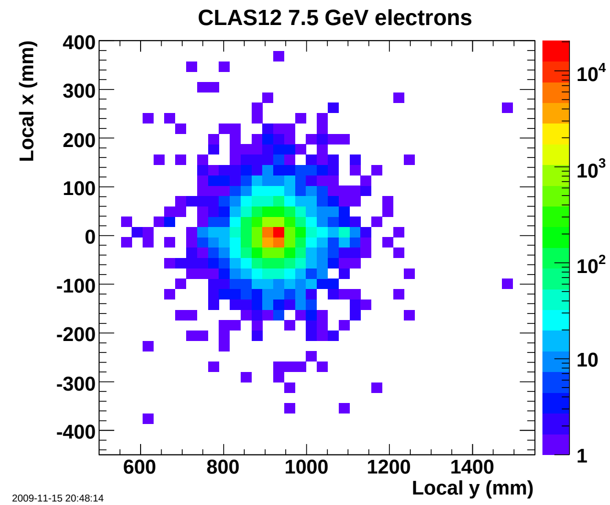
Adding the EC to the CLAS12 Simulation

12. Add the code to gemc to process an EC event; simplified version now.
13. Modify and add functions to `gemc_evio2root` to include EC events in `gemc_evio2root/src/`:
    (a) Create `ec_hit.cc` and `ec_hit.h` to handle Geant4 hit information.
    (b) Edit `root_tree.cc`, `root_tree.h`, and `gemc_evio2root.cc` to include EC information.

Defining an electron: $t < 50\ ns$, $N_{EC} < 40$, $E_{dep} > 5\ MeV$, $PID = 11$

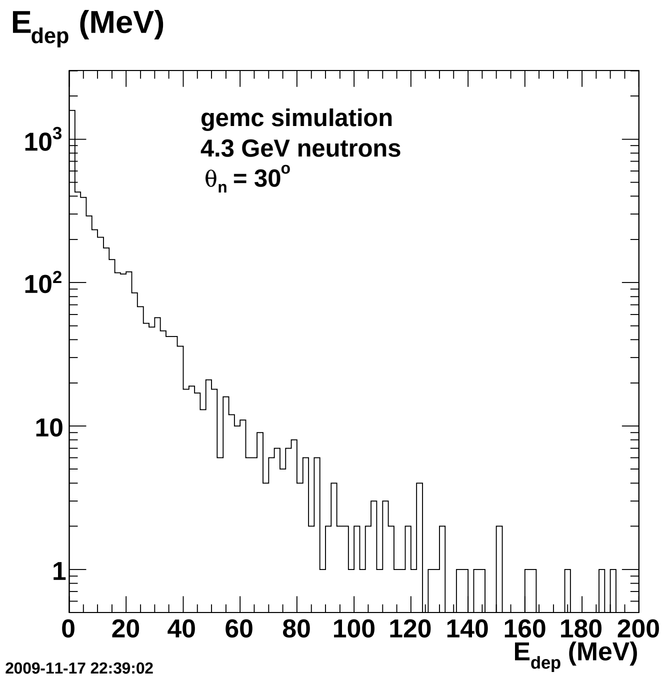
14. First histograms from gemc$\longrightarrow$ gemc_evio2root for electrons.

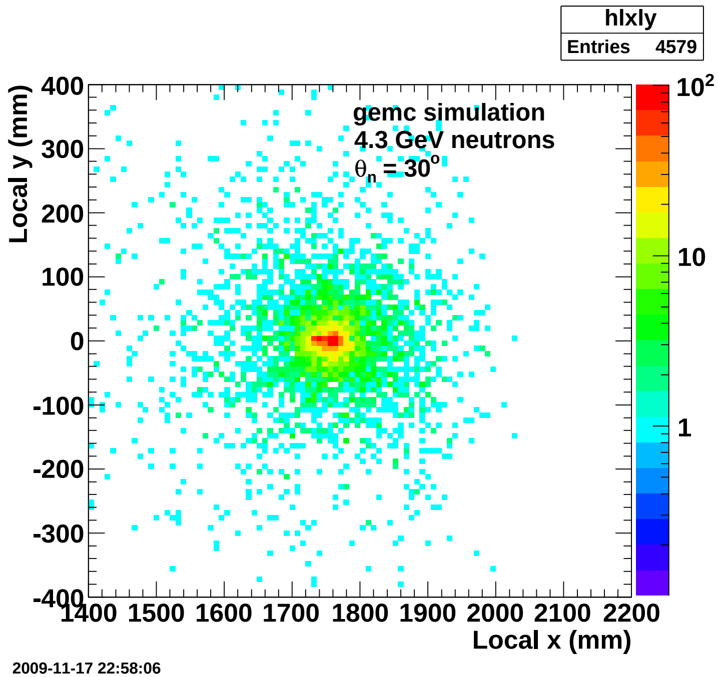




Adding the EC to the CLAS12 Simulation

15. First histograms from gemc→gemc_evio2root for neutrons.





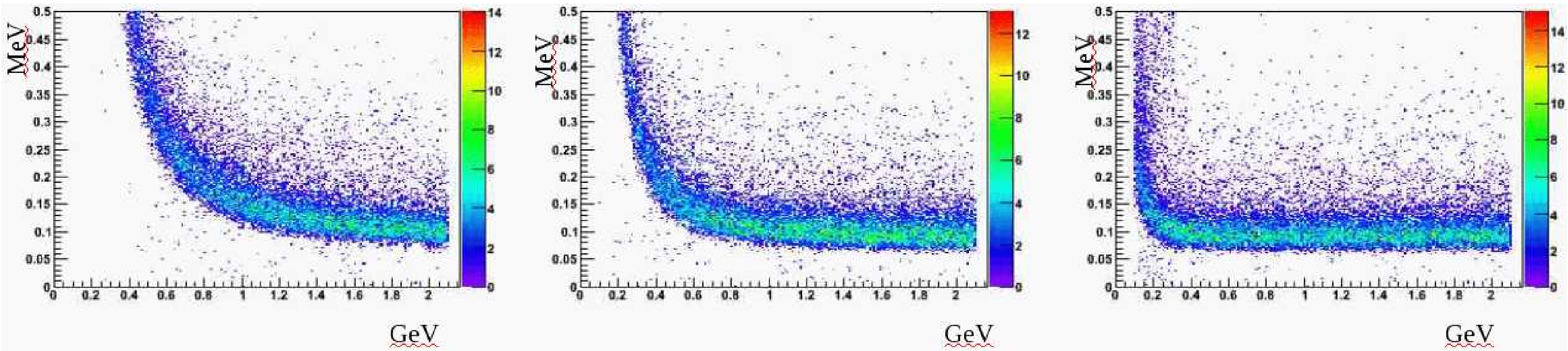
Defining a neutron: $t < 50\ ns$, $N_{EC} < 40$, $E_{dep} > 5\ MeV$, $PID = 2112$

Hadron properties in the Silicon Vertex Tracker (SVT)

Generated Events:

100,000 protons/kaons/pions	momentum: 0.1 to 2.1 GeV	θ: 0-160° uniform
Longitudinal Vertex: 5 cm uniform	Transverse Vertex: 1 mm uniform	ϕ: 0-360° uniform

Deposited energy (E_{dep}) in MeV versus Particle Momentum (p) in GeV.



Protons K^+ π^-

Generated θ versus primary z vertex.