Simulation Results for CLAS12 From gemc

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CLAS12 Software Group

Outline:
1. gemc Overview
2. Neutron efficiency in first TOF panel.
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.

**gemc**

- Modern, object-oriented, Geant4-based simulation.
- Still in development stage.
- Needed subsystems:  
  - Pre-shower calorimeter (PCal).
  - Cerenkov counter (CC).

The CLAS12 detector.
Neutron Efficiency in First TOF Panel

- Neutron detection efficiency (NDE) needed for E12-07-104 ($G^m_M$ 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 $E_{dep} > 5 \text{ MeV}$.
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.
The CLAS6 EC will be re-used in CLAS12; placed \( \approx 2 \, m \) downstream.

EC geometry.
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.

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3. Note different horizontal ranges.

![Graph showing resolution comparison]

gemc and GSIM resolutions are consistent to 5-10%.
Comparison with CLAS6 - Shower Size

1. CLAS6 shower size $\approx 4 \text{ cm}$ 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 $E_{\text{dep}}$-weighted distribution in local $x$ for $\theta_e = 25^\circ$, $\phi_e = 0^\circ$.

![Graph showing E_{\text{dep}}-weighted distribution in local x](image)

- gemc
- E_{\text{dep}} > 1 \text{ MeV}
- $p_e = 4 \text{ GeV}$
- Red - No Threshold, t < 50 ns
- Blue - E_{\text{dep}} > 1 \text{ MeV}, t < 50 ns
- N = 500 events

![Shower Size (mm) graph](image)

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

2010-03-16 16:00:33
Simulations of the Silicon Vertex Tracker (SVT)

BST Geant4 Implementation

Geant4

Design
DVCS events in the SVT.

Forward Acceptance: $\theta$ vs $p$

- Generated Events
- 2 or more SL
- 3 SL

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

$\rightarrow$ Rate $= 4.7 \times 10^{11} \text{ electrons/s}$
$\rightarrow$ SVT time window: 132 ns $\rightarrow$ 62,500 electrons/event
Event rates in the SVT.

No Energy Cut

\[ \text{E Dep} > 0 \]

\[ \text{E Dep} > 20 \text{ KeV} \]

One event at Full Luminosity

Event Display

\[ = \text{hit} \]

\[ = \text{original proton} \]
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.

<table>
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<tr>
<th>GeV/(s − cm^2)</th>
<th>kilorad/year</th>
<th>Solenoid</th>
</tr>
</thead>
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<td>48.00</td>
<td>363.8</td>
<td>Off</td>
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<tr>
<td>3.56</td>
<td>27.042</td>
<td>On</td>
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</table>
Forward Tagger in CLAS12.

**Forward Tagger**

*Low*\(Q^2\) *electro-scattering*

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

- **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 \(10^8\) \(\gamma/s\)) 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
Forward Tagger in CLAS12.

**Forward Tagger**

*Low Q^2* electro-scattering

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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 \((ep \rightarrow e'\pi^+n)\).
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 $p_e$, $\theta_e = 25^\circ$, $\phi_e = 0^\circ$.
      iii. Convert EVIO output to Root Trees.
      iv. Histogram the deposited energy.
      v. Scan $p_e$ (0.5 − 10 GeV).

2. Integrate the distribution of $E_{dep}$ and divide by $p_e$ to get the sampling fraction.

$$f_s = \frac{\sum n_i E_{dep}^i}{E_e}$$

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 → inner; layer 16-39 → outer.
   - View: use $\text{layer} \% 3$ to determine view from layer.
   - Strip: 36 strips in each layer.

\[ P = (x, y) \text{ (the hit)} \]
\[ A = (x_A, y_A) = (0, -pDy_1) \]
\[ B = (x_B, y_B) = (pDx_2, pDy_1) \]
\[ C = (x_C, y_C) = (-pDx_2, pDy_1) \]

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

\[ \text{strip} = \left\lfloor \frac{|\hat{r}_2|}{36} \right\rfloor + 1 \]
Electromagnetic calorimeter (EC) performance

3. ADC signal.
   (a) Calculate expected number of photons from deposited energy (3.5 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 $\overline{r_1}$: $\overline{r_1} = \overline{r_0} + l\hat{r}_V$
   where $\hat{r}_V = \frac{\overrightarrow{B-A}}{|\overrightarrow{B-A}|}$.
   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

   \[ y_-(L) = A_- + B_- (L - 1) \quad \text{(vertex)} \]
   \[ y_+(L) = A_+ + B_+ (L - 1) \quad \text{(top)} \]

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

   \[ y + x \tan \theta = y_-(L_-) \quad y - x \tan \theta = y_-(L) \]

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:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
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<tbody>
<tr>
<td>pDx1</td>
<td>Half x length of the side at y=-pDy1 of the face at -pDz</td>
</tr>
<tr>
<td>pDx2</td>
<td>Half x length of the side at y=+pDy1 of the face at -pDz</td>
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<tr>
<td>pDz</td>
<td>Half z length</td>
</tr>
<tr>
<td>pTheta</td>
<td>Polar angle of the line joining the centres of the faces at -/+pDz</td>
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<tr>
<td>pPhi</td>
<td>Azimuthal angle of the line joining the centre of the face at -pDz to the centre of the face at +pDz</td>
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<td>pDy2</td>
<td>Half y length at +pDz</td>
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<tr>
<td>pDx4</td>
<td>Half x length of the side at y=+pDy2 of the face at +pDz</td>
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<tr>
<td>pAlp2</td>
<td>Angle relative to the y axis from the centre of the side (upper endcap)</td>
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<tr>
<td>pAlp1</td>
<td>Angle with respect to the y axis from the centre of the side (lower endcap)</td>
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<tr>
<td>pDy1</td>
<td>Half y length at -pDz</td>
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</table>
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...

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Total Energy Deposited
Average global x position
Average global y position
Average global z position
Average local x position
Average local y position
Average local z position
Average time
Particle ID
x coordinate of primary vertex
y coordinate of primary vertex
z coordinate of primary vertex
Energy of the track at the entrance point
Mother Particle ID
x coordinate of mother vertex
y coordinate of mother vertex
z coordinate of mother vertex
sector
layer
ADCL
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.

14. First histograms from gemc → gemc_evio2root for electrons.

   Defining an electron: $t < 50\ ns$, $N_{EC} < 40$, $E_{dep} > 5\ MeV$, $PID = 11$
15. First histograms from gemc→gemc_evio2root for neutrons.

Defining a neutron:  
\[ t < 50 \text{ ns}, \quad N_{EC} < 40, \quad E_{dep} > 5 \text{ MeV}, \quad PID = 2112 \]
Hadron properties in the Silicon Vertex Tracker (SVT)

Generated Events:

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

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

Generated $\theta$ versus primary $z$ vertex.