CLAS12 Luminosity Upgrade

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Outline

Goal: Increase CLAS12 Running Luminosity

by an order of magnitude or more

Why?

- **More** physics!
- Access to smaller and more interesting cross sections
- 6 months Vs 6 years, or “time as grad student” Vs “entire of career”

Where to start?

- Identify and reproduce anticipated limit: $\mathcal{L} \simeq 10^{35}$ cm^{-2}s^{-1}
- Drift Chamber hit occupancy is a good place to start

How to proceed?

1. What **modifications** can make an improvement, e.g., better electronics/algorithms
2. What **supplemental** detectors can overcome these limitations?
3. What **replacement** detectors can overcome these limitations?

Outline

Hit Occupancy

Definition

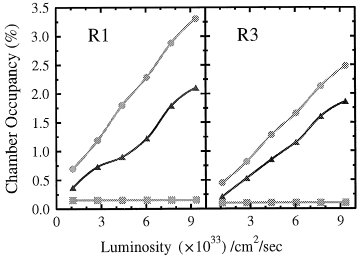
- Δt is the detector response time
- For the DC Δt is the longest drift time for the unit cell: $\Delta t \simeq 250 - 500$ ns
- The hit occupancy is the probability of at least one hit within the time interval Δt

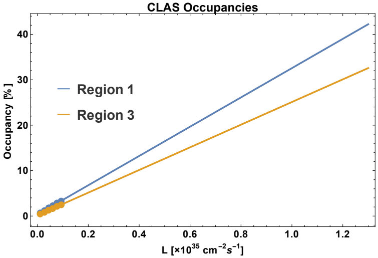
Occupancies above a few % lead to poor tracking efficiency

Mitigating high DC occupancy induced inefficiency:

- Unit cell size → drift time: CLAS12 DC has twice the segmentation
- Lower voltages/current → lower discriminator threshold: will not know until in the hall
- Beam current → run at lower luminosity
- Deal with it offline:
  - Overlapping hits → improve algorithms
  - Better resolution/vertexing/tracking → tighter cuts

CLAS Occupancies





CLAS12 Occupancy Estimates from CLAS

- Extrapolating to 10^{35} we should expect $\mathcal{L} \sim$ 20-30%
- Better segmentation $\rightarrow \mathcal{L} \sim$ 10-15%
- Shielding and other improvements $\rightarrow \mathcal{L} \sim 1\%$

Of course, CLAS $\neq$ CLAS12

All previous work predicts CLAS12 DC occupancies $\leq 1\%$ at $\mathcal{L} = 1 \times 10^{35}$ cm^{-2}s^{-1}

Outline

Simulations of $\mathcal{L} \simeq 1.0 \times 10^{35}$ cm^{-2}s^{-1}

Two different methods

Beam-on-target

Throw electrons from upstream electrons at the target

- Simplest approach
- Relies heavily on Geant4
- Computationally expensive

Explicit event generator

Generate events only in the phase space covered by the apparatus

- More sophisticated
- Must include most important processes
- Relatively fast

Some numbers for reference

Target LH2	Beam current I [nA]	e^- flux Φ_e [s^{-1}]	Luminosity $\mathcal{L}$ [cm^{-2}s^{-1}]
5 cm	100	6.24×10^{11}	1.3×10^{35}

Region	I	II	III
Δt	250 ns	400 ns	**500 ns**

Beam-on-target Method

With:

- $\Delta t = 500$ ns
- $N_e = \Phi_e \ \Delta t \simeq 312$k events per time interval
- N_S events simulated
- $N_O = \frac{N_S}{N_e}$ occupancy normalization

Compuatational Challenge

If a 1% occupancy is expected

- To get 10% relative uncertainty
- $N_{hits} \geq 100$ such that $\frac{1}{\sqrt{N_{hits}}} \leq 0.1$
- $100 \times 1\% = 100 \ N_e = 31.2$ M events for 100% hit probability
- $N_S = 100 N_e \times N_{hits} \sim 3.2 \times 10^9$

Need 3-4 billion events!

Some numbers for reference

Target LH2	Beam current I [nA]	e^- flux Φ_e [s^{-1}]	Luminosity $\mathcal{L}$ [$cm^{-2}s^{-1}$]
5 cm	100	6.24×10^{11}	1.3×10^{35}

Event Generator

Full Realistic Event Generator!

- Part of `InSANE` libraries, which uses FOAM for sampling
- Most processes are already included
- Simple to add new cross sections
- Output in any format (LUND, ROOT, PROMC...)
- Save event generator to ROOT file! For later reference or to generate more events without initial integration.

$$\sigma^{\text{total}} = \sum_{x\in\{\text{processes}\}} \int_{V_x} \left(\frac{\mathrm{d}\sigma_x}{\mathrm{dp}^3}\right) \mathrm{dp}^3 = \sum_{x\in\{\text{processes}\}} \sigma_x^{\text{total}}$$

Reconstruction Challenge

See if you can pick out DVCS events while rejecting background (without looking at the input events!)
Just ask me for the LUND files

About the Event Generator

InSANE C++ libraries

Luminosity

$$\mathcal{L} = \sum_m \mathcal{L}_m = \sum_m \mathrm{I}\rho_m \mathrm{l}_m$$

Rate

$$R_{m,x} = \mathcal{L}_m \sigma_{m,x}^{\text{total}}$$

Random Sampling

1. A Phase Space Sampler, $S_{m,x}$, is created for each material and process.
2. Randomly choose a sampler with probabababilty $R_{m,x}/R_{Total}$
3. The selected sampler generates an event following the probabilty distribution given by the cross sections.

- Phase Space Sampler uses the FOAM libraries.
- Initialization gives $\sigma_{m,x}^{\text{total}}$
- Initialization is expensive
- ROOT streamers allow initialized event generator to be saved to file.
- Same event generator can be read from file without the need for initialization.

Lots of other nice features not mentioned...

Explicit Event Generation Method

Cross Sections

$$\sigma^{\text{total}} = \sum_{x\in\{\text{processes}\}} \int_{V_x} \left(\frac{\mathrm{d}\sigma_x}{\mathrm{dp}^3}\right) \mathrm{dp}^3 = \sum_{x\in\{\text{processes}\}} \sigma_x^{\text{total}}$$

Beam Energy	6 GeV	11 GeV
Process	Total XS (nb)	
Møller	22773000.572239	75008636.537296
DIS + radiative tail	127.914648	82.767614
Elastic e-p	5511220.139609	3670739.949604
Elastic radiative tail	24705.403258	12943.687891
π^0 electro-production	14802.150817	17908.403986
π^0 photo-production	568.685398	852.371847
π^+ electro-production	4031.702761	5536.473200
π^+ photo-production	282.355507	486.826279
π^- electro-production	2806.398047	3843.281962
π^- photo-production	198.505161	341.970751
Total	2.83317×10^7	7.87214×10^7

Not shown

Each process has a relevant phase space defined for each final state particle.

Event Generator

Beam Energy	E	6 GeV	11 GeV
Events Simulated	N_{events}	1000000	1000000
Simulated time	$t_{\text{simulated}}$	0.26508 ms	0.09540 ms
Occupancy Norm	$N_{\text{o}}(\Delta t = 500\text{ns})$	1886 events/hit	5240 events/hit
Luminosity	$\mathcal{L}$	1.33×10^{35} cm^{-2} s^{-1}	1.33×10^{35} cm^{-2} s^{-1}
Beam Current	I	100 nA	100 nA
e flux	Φ_e	6.2422×10^{11} s^{-1}	6.2422×10^{11} s^{-1}

Occupancy Calculation

$$N_{\text{o}} = \Delta t \left(\frac{N_{\text{events}}}{t_{\text{simulated}}} \right)$$

$$t_{\text{simulated}} \simeq \frac{N}{\sigma_{tot}} \frac{e}{\text{I } L\rho}$$

$$\text{Occupancy} = \frac{N_{hit}}{N_{\text{o}}}$$

Maximum Drift Times

R1 : 250 ns
R2 : 400 ns
R3 : 500 ns

Outline

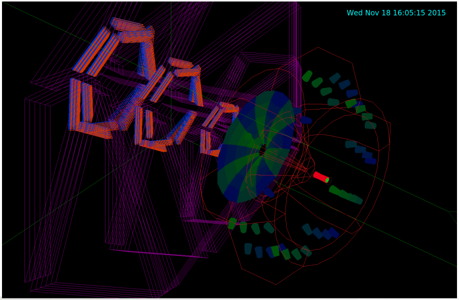
c12sim - CLAS12 Simulation

A Geant4 Simulation

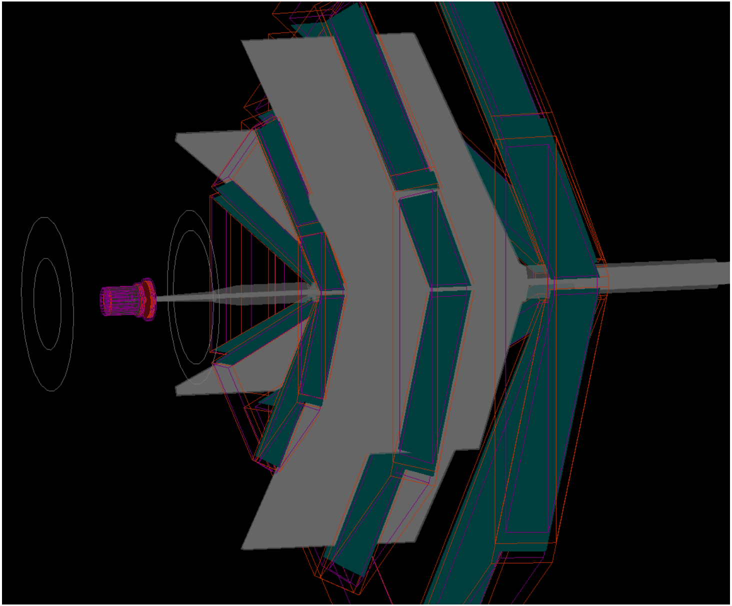
- New simulation dedicated to CLAS12
- Fast pure Geant4 implementation (no GEMC used)
- Additionally a set of analysis libraries being developed, `clasdigi`

Status

- HTCC, DC, SVT, MVT, beamline Moller shield, Solenoid, Torus
- Same beamline shield as GEMC via GDML



c12sim - CLAS12 Simulation



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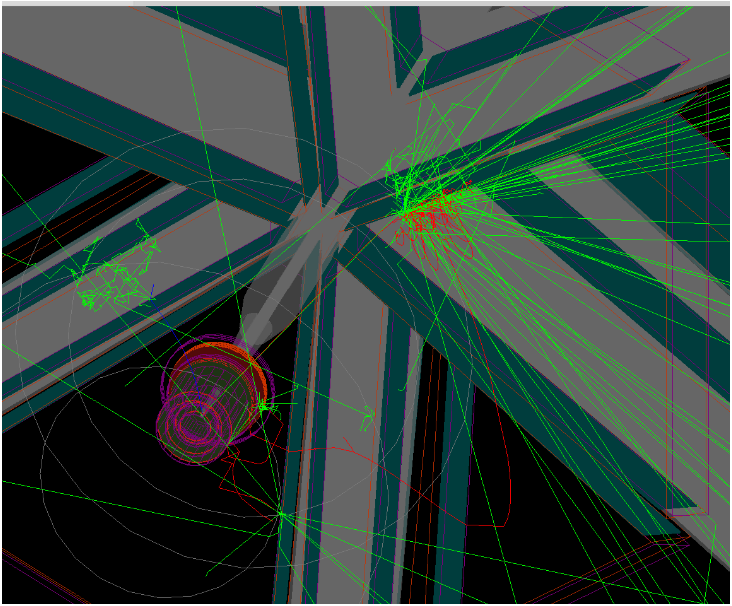

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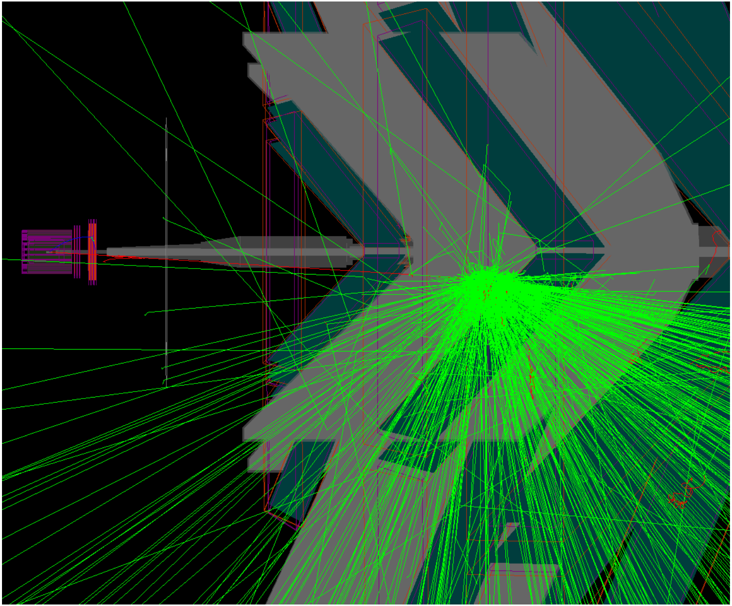
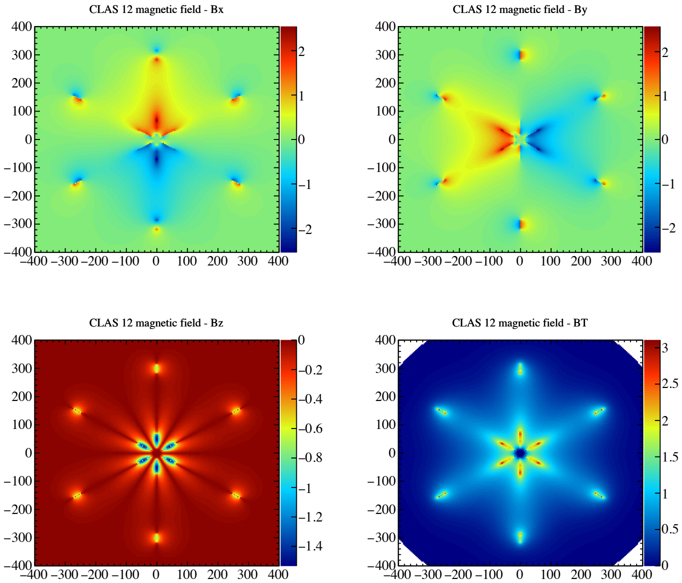


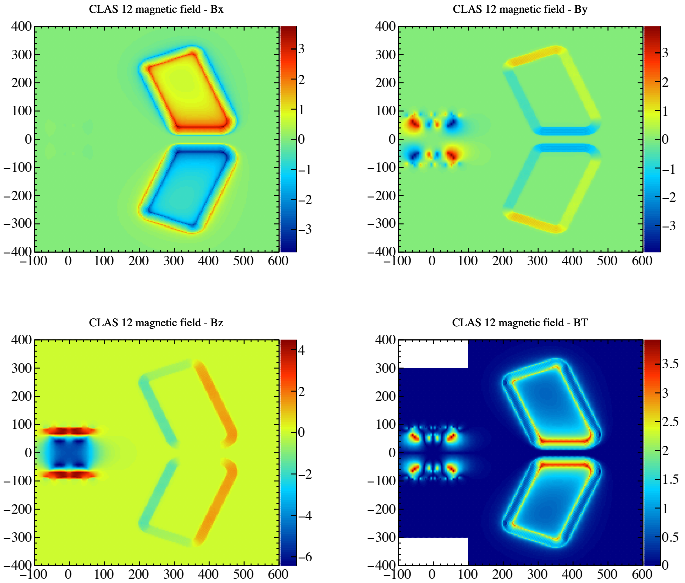
Magnetic Field

clasdigi



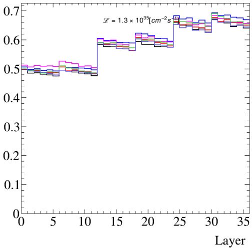
Magnetic Field

clasdigi

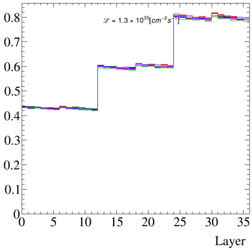


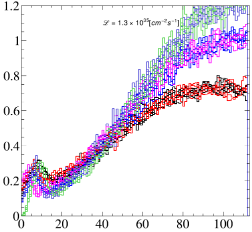
Hit Yields: Event Generator Vs. Beam-on-target

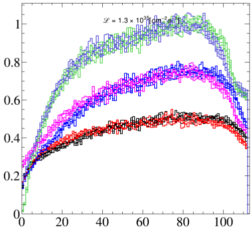
Event Generator



Beam-on-target







Self consistent check

Both methods produce roughly the same result.
Angular dependence different but averages out.

Summary

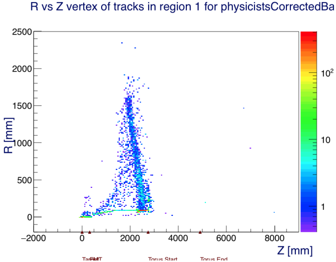
- Full and realistic event generator developed
- Event generator validated by beam-on-target method
- New simulation dedicated to CLAS12 available
- Additional analysis libraries also available `clasdigi`
- Event Generator can be used for quick design feedback
- Need to understand the source of a significant difference between `GEMC` and `c12sim`

Thank You!

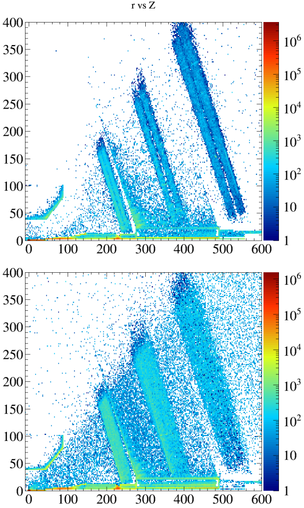
Backup

Hit sources

GEMC (M. Ungaro)

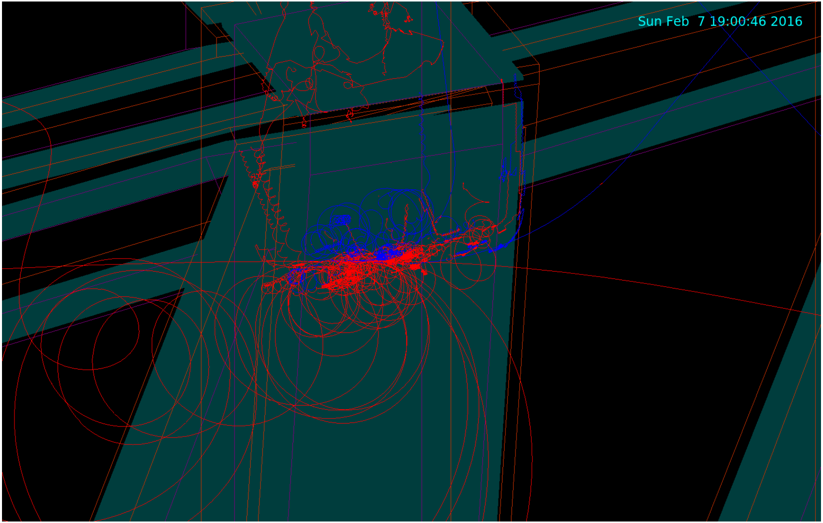


c12sim



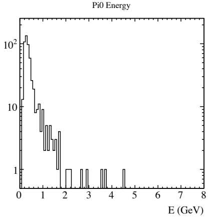
Curler Events

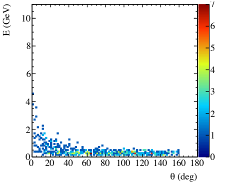
Single event with a large number of hits

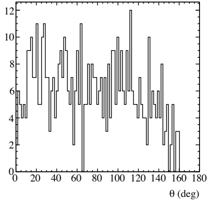


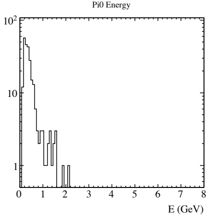
Generated Events

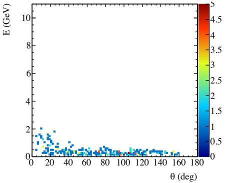
π^0 production

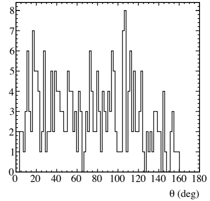






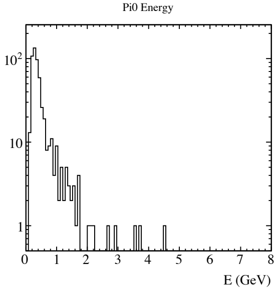


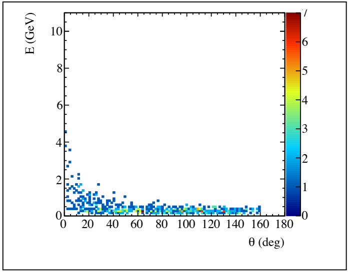


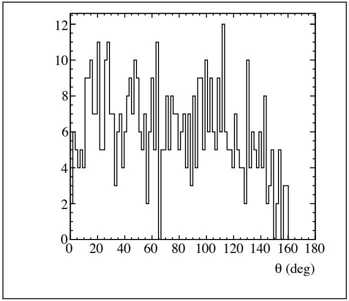


Generated Events

Inclusive π^0

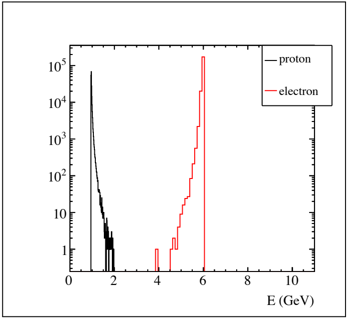


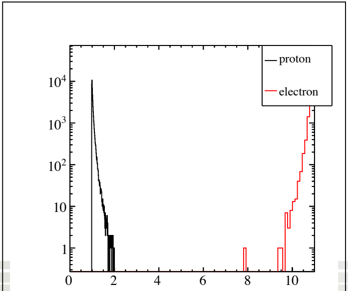


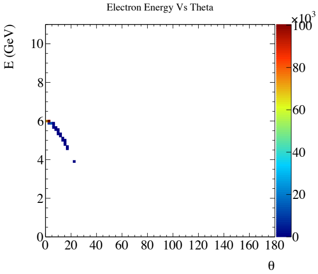


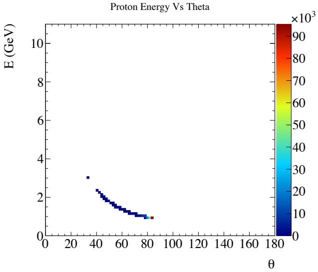
Generated Events

Elastic scattering



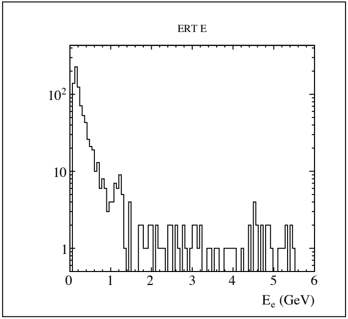


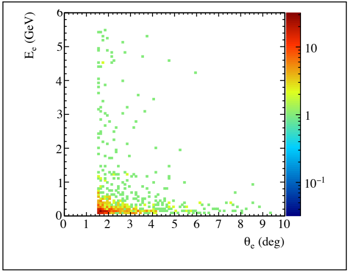


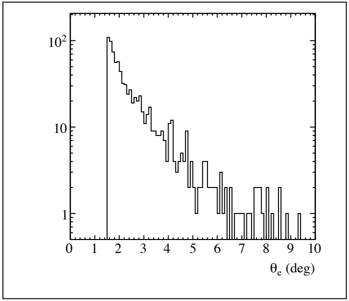


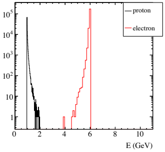
Generated Events

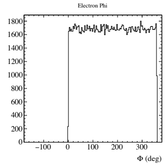
Elastic Radiative Tail

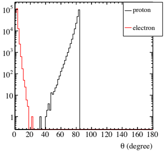


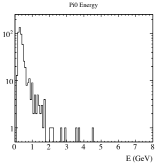


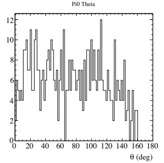


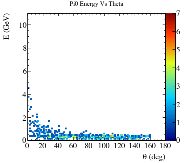

proton
electron
E (GeV)

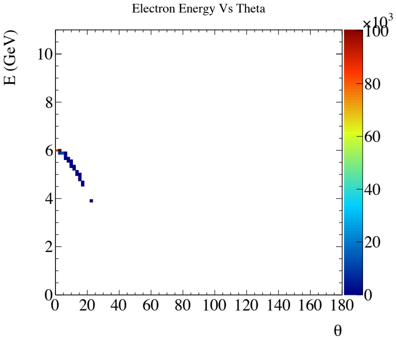

Electron Phi
Φ (deg)

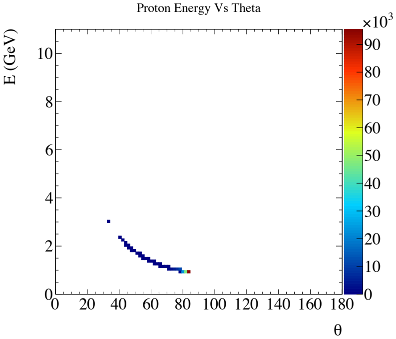

proton
electron
θ (degree)


Pi0 Energy
E (GeV)


Pi0 Theta
θ (deg)


Pi0 Energy Vs Theta
E (GeV)
θ (deg)


Electron Energy Vs Theta
E (GeV)
θ
×10^3


Proton Energy Vs Theta
E (GeV)
θ
×10^3