Electron Tagging with the BeamCal at 3 TeV CLIC

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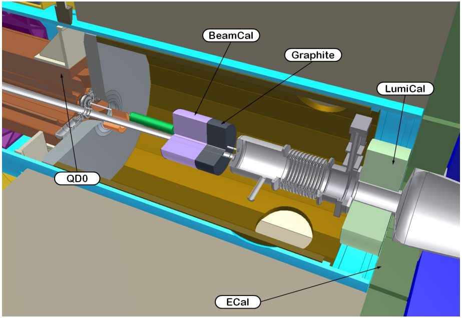
Outline

BeamCal Detector at CLIC

- Absorber for incoherent pairs, mask for downstream elements (QD0, BPM)
- Radiation hard sensors required (similar radiation levels as 0.5 TeV ILC)
- Tungsten sandwich calorimeter, Molière radius of about 1 cm
- Position (including 10 cm graphite): $Z = 3181$ mm to 3450 mm
- Radius: 32 mm to 150 mm
- Polar angle coverage: 10 mrad to 45 mrad
- Pad size 8×8 mm^2



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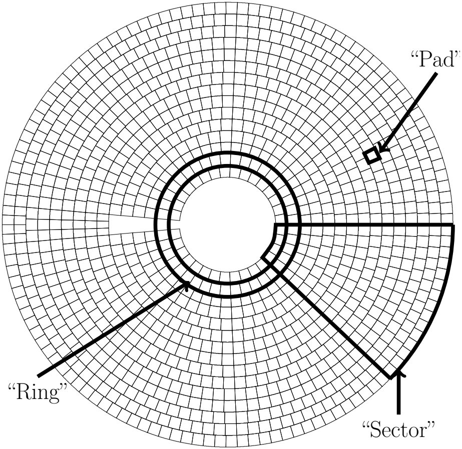
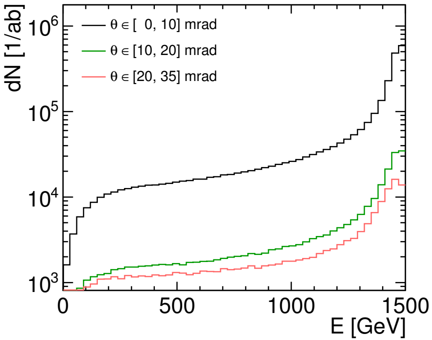


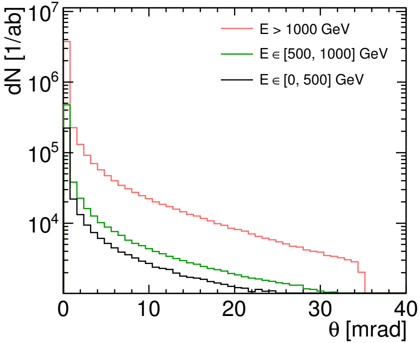
Why Electron Tagging?

- Searches for slepton pairs
- Event topology: lepton pair and missing energy
- Energy of lepton depends on mass difference between slepton and neutralino (here SuSy Point K' as at CLIC09 workshop)
  - $m_{\tilde{\tau}} = 896$ GeV
  - $m_{\tilde{\chi}^0} = 554$ GeV
  - Cross-section: 1.4 fb
- Largest cross-section of background: ee $\rightarrow$ ee$\tau\tau$
  - Total cross-section: 1.33 nb (from BDKRC/RADCOR, including lumi spectrum, $Q^2 > m_{\tau}^2$)
  - Cross-section growing with log(s), lower rate of low energy electrons
  - With 2 τ-leptons in the detector acceptance ($\theta > 20^{\circ}$) and no electrons above 35 mrad: 2.94 pb
- Tag electrons to reject this background

Two-Photon Spectator Electrons

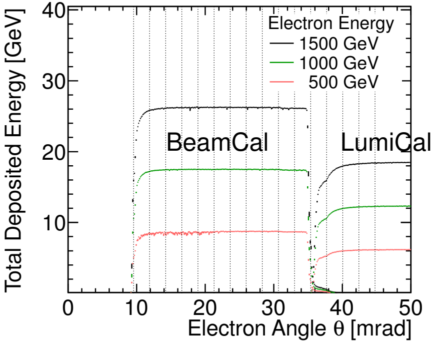
- Electrons from two-photon events: High energy electrons, and forward peaked
- Only events with two τ-leptons inside detector acceptance and no electrons above 35 mrad (assuming excellent electron in LumiCal and above)

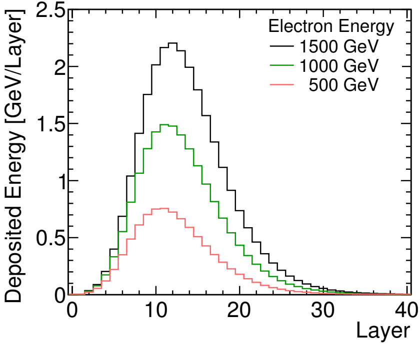




Signal from high Energy Electrons

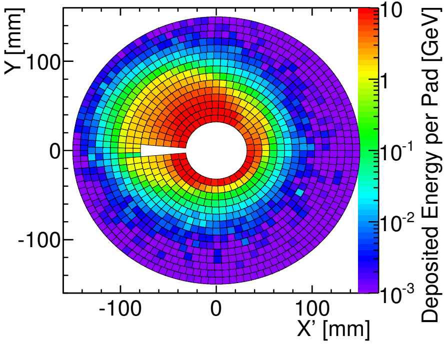
- Dense showers from electrons
- 26 GeV total deposited energy (in the sensitive material) from 1.5 TeV electron
- Reduced to 8 GeV for 0.5 TeV electrons
- Maximum near layer 10
- Maximum deposited energy per pad 2 GeV (1.5 TeV electrons) to 0.7 GeV (0.5 TeV electrons)





Background in the BeamCal

- Occupancy: Almost every pad sees a hit in every BX (coming every 0.5 ns)
- Energy deposits
  - From incoherent pairs: 33 TeV/BX
  - From $\gamma\gamma \to$ hadrons: 150 GeV/BX, will be ignored, other backgrounds also negligible
- Will have to integrate several BX during one sampling window
- Ideas for multiple readout during BX through correlated double sampling

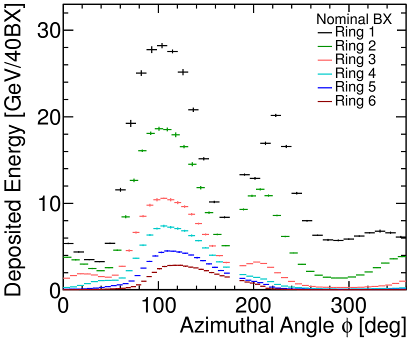


Layer 4: 10 BX (5 ns sampling window)

Background and Fluctuations

- Beam-offsets affect number and angular distribution of incoherent pairs
- Integrated 40 BX, maximum deposit 30 GeV in single pad in layer 10
- Lower average with mixed background samples (50% 0 nm offset, 50% 1 nm offset)
  - Each sampling window selects randomly from the available simulated BX
- Fluctuations of deposited energy from backgrounds important for tagging algorithm
  - Standard deviation $\sigma_{\mathrm{pad}}^{\mathrm{max}} \approx 0.4$ GeV to 0.5 GeV
  - Larger fluctuations for mixed background samples

Nominal only



Energy deposit for 40 BX of incoherent pair background in layer 10

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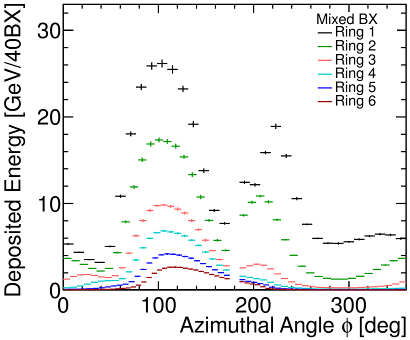

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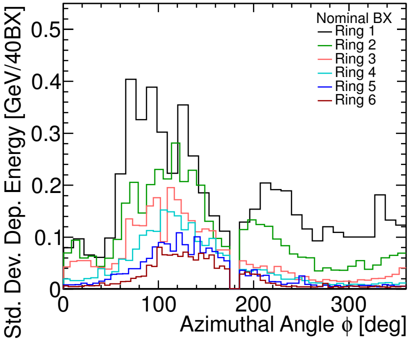

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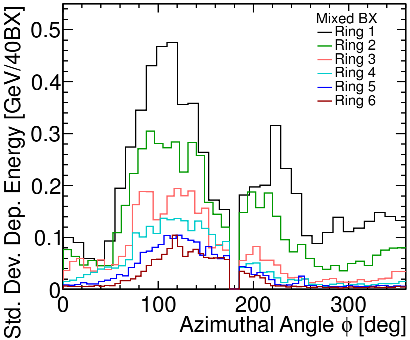

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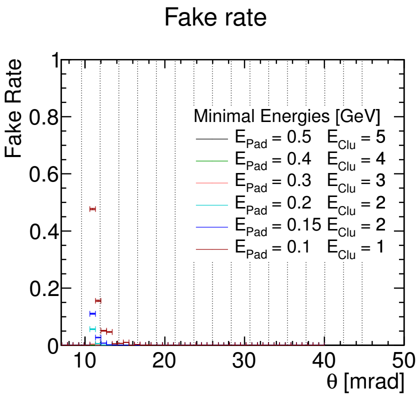
Tagging Algorithm

- Re-implemented algorithm existing in Marlin
- Basically:
  - Overlay signal with background from N BX
  - Subtract average energy deposit
  - Cluster pads which have significant energy deposit above background
  - Create electron candidates from clusters and select electrons based on cuts

Reconstruction Purity

- Simulated single electrons from 0.5 to 1.5 TeV
- Tuned cuts to reject all clusters not caused by these high energy electrons
- Started with single cut for all pads and clusters
- Chose cuts, so that no fake electron remains
- In the end: One fake electron cluster is found in 50k events
- Could also use a cut based on variance $\vec{\sigma}$ (e.g. $1 \times \vec{\sigma} \ldots 5 \times \vec{\sigma}$)



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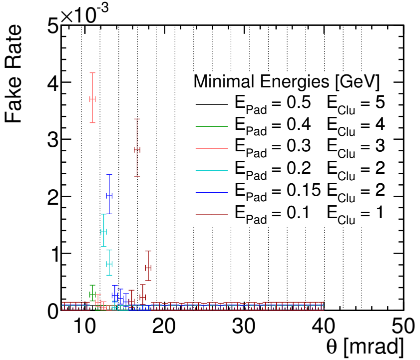
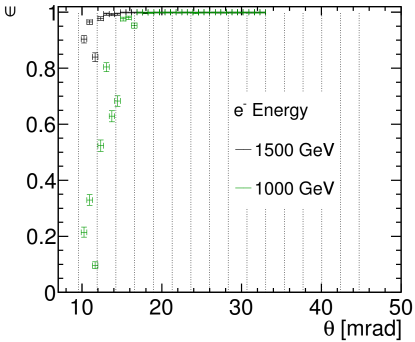
Zoom on lower limits of fake rate



Tagging Efficiency vs. Electron Energy

- Excluding events near the incoming beam pipe hole, and $\theta < 10$ mrad
- Efficiency depends on energy and angle
- Highest efficiency ($\varepsilon = 1_{-0.003}$)
- Near boundaries and between rings the efficiency drops

Electron Energy: 1.0 and 1.5 TeV



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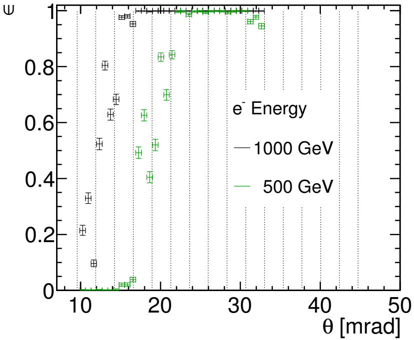

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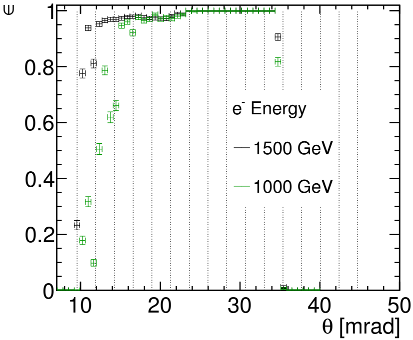

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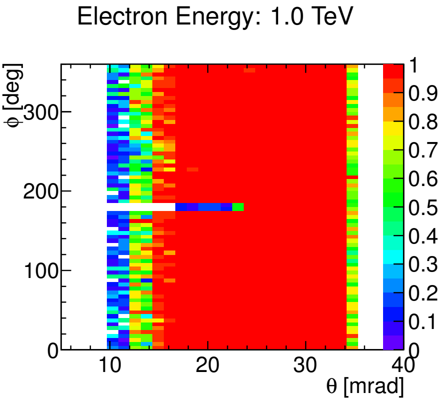
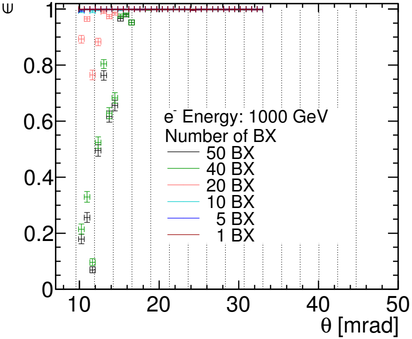


Tagging Efficiency vs. Number of BX

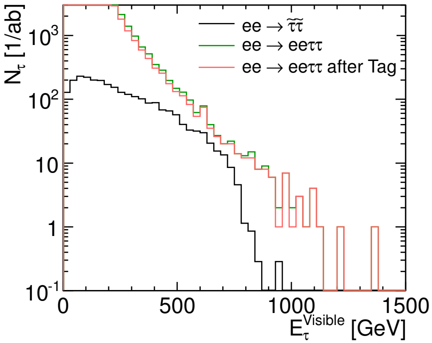
- For differently sized sampling windows
- For each case tuned cuts to reduce fakes
- Up to 10 BX basically every electron found
- Small difference between 40 and 50 BX (but background sample is limited)

1 TeV electrons



Electron Tagging and Stau Signal

- Qualitative Generator level study only
  - $e^+e^- \to \tilde{\tau}^+\tilde{\tau}^-$
  - $e^+e^- \to e^+e^-\tau\tau$
- Apply electron tagging efficiencies from full simulation studies
- Reject two-photon events if one electron found in the BeamCal
- Tagging by itself insufficient to remove two-photon background
- Anyway, cuts are needed to remove other SM background

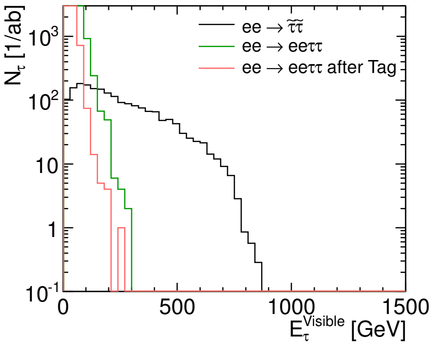


Applying additional Cuts

Chose cuts that remove 10% of signal, angular cuts do not bias stau sample

- Acollinearity $< 70.5^\circ$
- Acoplanarity $> 9.3^\circ$
- $\theta_{\text{miss}} > 30.5^\circ$

Need additional cut to further reduce background



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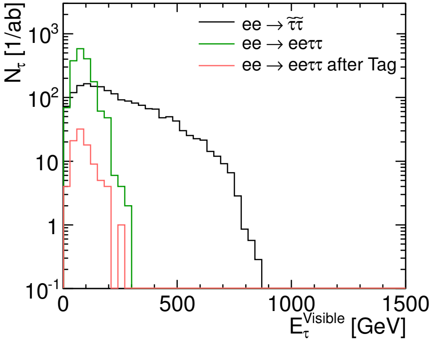
- Sum of transverse momenta of taus $p_T^{\text{Sum}} = p_T^1 + p_T^2 > 115.5$ GeV (removes 5% of signal)



Remaining events

Cut	$e^+e^- \to \tilde{\tau}^+\tilde{\tau}^-$	$e^+e^- \to e^+e^-\tau\tau$	
		Before tag	After tag
Without cuts	1261	2914251	2643332
Acollinearity	1139	1465347	1317124
Acoplanarity	1125	675960	432541
Angle of missing momentum	1133	683375	531055
Angular cuts combined	956	228218	117956
Sum of transverse momenta	1186	40345	34293
All cuts combined	902	864	47

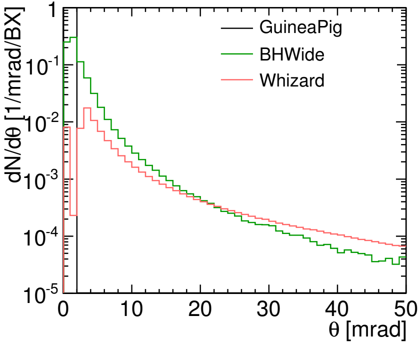
Summary

- Electron tagging is possible at CLIC, even with moderately large sampling windows of 25 ns, and moderate background fluctuations
- For larger angles ($\theta \approx 20$ mrad) all electrons with $E > 0.5$ TeV found
- Shorter sampling windows is better
- At low angles boundaries between rings reduce efficiencies
- Cuts tuned for minimal fake rate, but few percent probably acceptable
- Looked only down to 500 GeV electrons
- Electron tagging at 3 TeV CLIC is feasible and can help reject two-photon background

Backup Slides

Bhabha Event Rate in the BeamCal

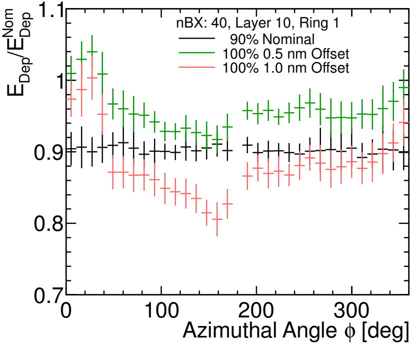
- Radiative Bhabhas with huge cross-section
- Longitudinal boost can give lower energy electron large angle
- Compared GUINEAPIG/BHWIDE/WHIZARD
- GP underestimates rate at interesting angles > 10 mrad
- WHIZARD and BHWIDE are similar, but WHIZARD $Q^2 > 4$ GeV also cuts 400 GeV at 10 mrad ($p_t = 4$ GeV particles)

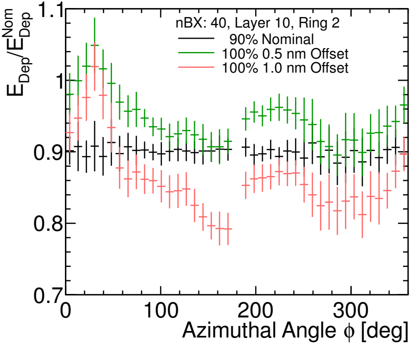


Rate of electrons with more than 100 GeV in the BeamCal

Background and Vertical Beam Offsets

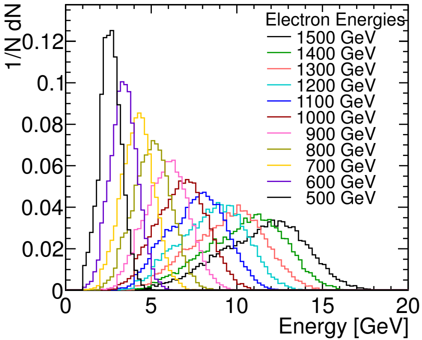
- Energy distribution in the BeamCal from pairs affected by vertical offset in bunch crossing (due to deflection of incoherent pairs)
- For small offsets (ca. 1 nm) constant in some, decreased in other parts
- Mixing of background events leads to larger fluctuation of backgrounds





Energy Resolution

- Electron cluster energy distribution
  - Somewhat Gaussian shaped (better at lower energies)
- Calculate calibration between electron and cluster energy
  - Linear in this region (0.5 to 1.5 TeV)
- And energy resolution: $100\%/\sqrt{E[\mathrm{GeV}]} + 20\%$



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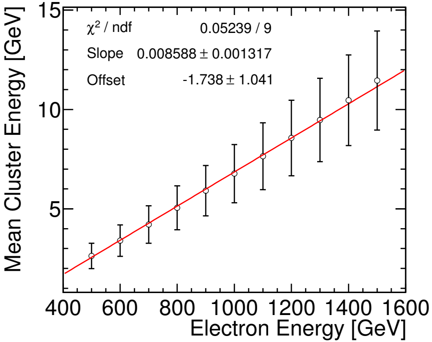

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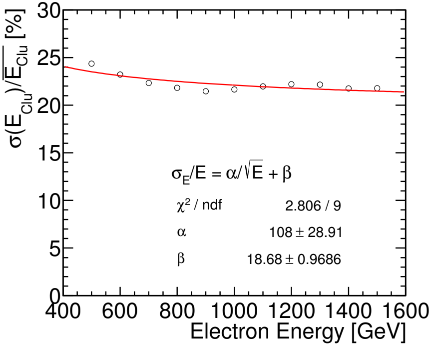
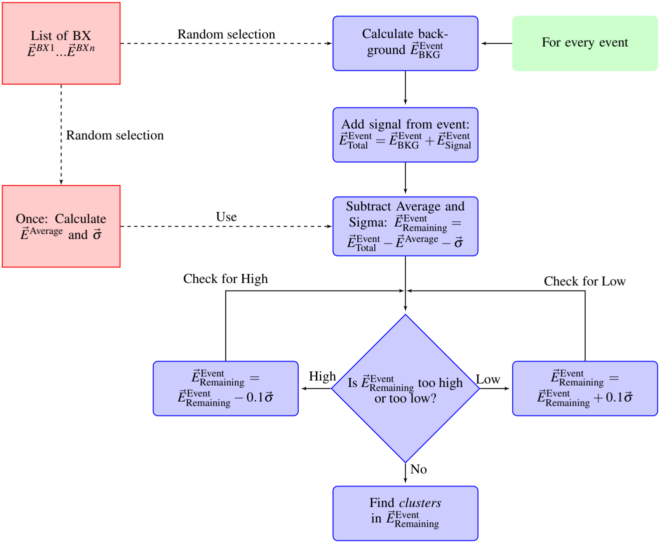
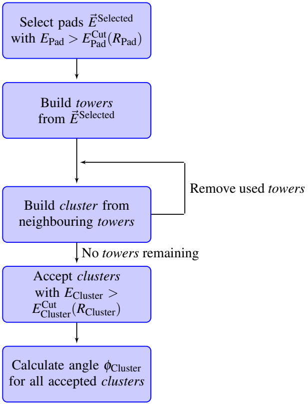


Tagging Algorithm



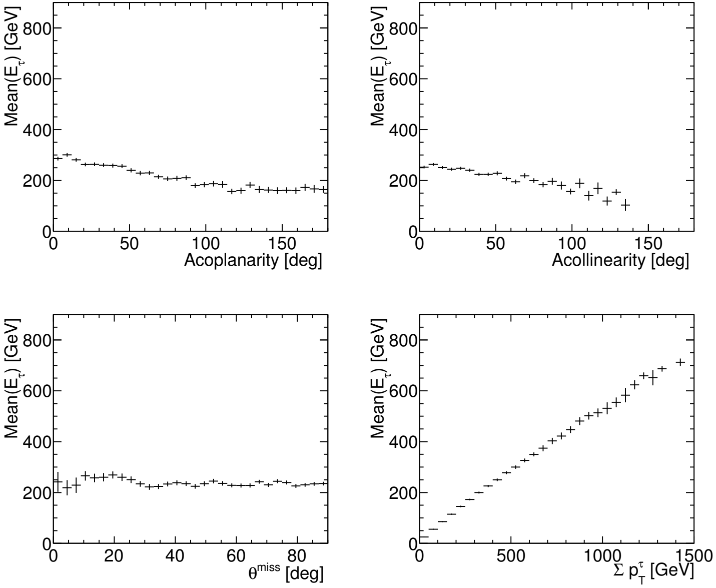
- Event: One sampling window
- $\vec{E}$: Pad energies

Tagging Algorithm II



- Only select pads in layer 10 and behind
- $E^{\text{cut}}_{\text{pad}}$ depends on ring R of pad
- *Towers* are pads in the same ring and at the same ϕ in different layers
- *Tower* needs at least 4 pads
- Largest *Tower* is used as first seed for search

Cut Variables I



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