Photon and Electron Reconstruction in an Ultra-High Granularity Forward Calorimeter

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Contents

Broad Outline

- **What are we doing today?**
- Presenting work on precision forward calorimeter at $\mathrm{e^+e^-}$ Higgs Factories
- **Why?**
- Physics goals require precision on luminosity, want to measure DiGammas too
- **How?**
- Use new detector, GLIP, and some new methods

Quick Context: Higgs Factories Luminosity Precision

- This talk focuses on applications at $\mathrm{e}^{+}\mathrm{e}^{-}$ Higgs Factories.
- Unless stated, assume ILC and ILD with $\sqrt{s} = 250$ GeV and 100 fb^{-1} of data.
- Luminosity is measured using Bhabhas and DiGammas
- Propagation of uncertainty... $\epsilon =$ precision

$$\frac{N_{Bha}}{\mathcal{L}} = \sigma_{Bha} \approx \frac{16\pi\alpha^2}{s\theta^2} \tag{1}$$

$$\epsilon(\mathcal{L}) \approx 2\sqrt{\epsilon(\sqrt{s})^2 + \epsilon(\theta)^2} \tag{2}$$

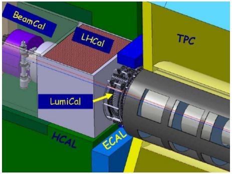
- First principles, luminosity precision depends on $\sqrt{s}$, θ precision

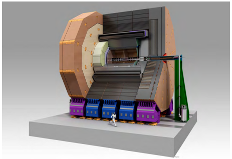
- Requirements for 10^{-3}:
- 350×10^{-6} for both $\sqrt{s}$, θ OR
- 500×10^{-6} (0.5 mrad) for θ , $<< 500 \times 10^{-6}$ for $\sqrt{s}$

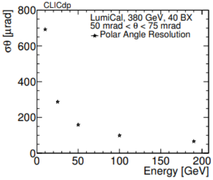
- Requirements for 10^{-4}:
- 35×10^{-6} for both $\sqrt{s}$, θ OR
- 50×10^{-6} (0.05 mrad) for θ , $<< 50 \times 10^{-6}$ for $\sqrt{s}$

Current State: ILD LumiCal

- $30\ X_0$, $1\ X_0$ layers, SiW Sandwich in $r\phi$ detector [1]
- Reco. using clustering and log-weighted sums (will explain later) [2]
- Ene. res. of $\frac{21\%}{\sqrt{E}}$ [1]
- θ design resolution of ≈ 0.1 mrad [2]
- θ tested resolution of ≈ 0.2 mrad [1]
- Acceptance 41-67 mrad [1]
- Moliere radius 8.0 mm [1]
- Length of 13 cm [3]
- Not designed for DiGammas!



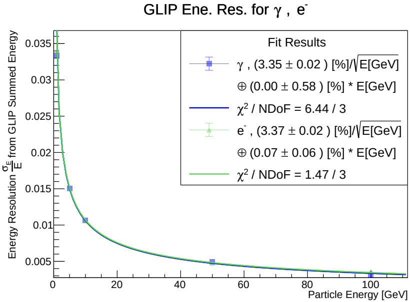




From A. Sailer [2]

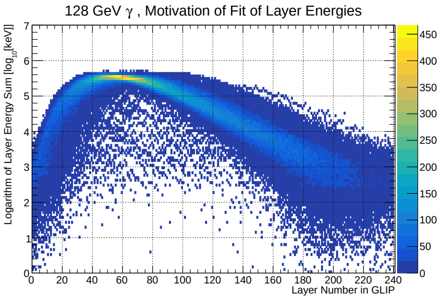
High Granularity Proposal: GLIP

- Granular Long Instrument for Precision (GLIP)
- Multiple designs, original here
- 40 X_0 , $1/6$ X_0 layers, 1mm Si, SiW sandwich in xy detector
- Reco. using various algorithms
- Ene. res. of $\approx \frac{3.36\%}{\sqrt{E}} + 0.02\%$
- θ resolution at least ≈ 0.2 mrad
- Moliere radius of 9.4 mm
- Length of 110 cm



Criticism of GLIP Proposal

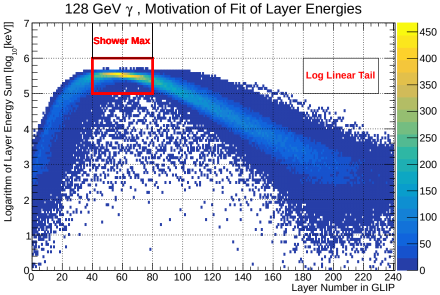
- Its too long!
- Ok, then! Different designs:
  - GRIP (“ Reduced “ “ “)
  - GHIP (“ Heavy “ “ “)
- Idea: what if we could “fit” the energy layer response and not need latEer layers?



From GEANT4 simulation of GLIP gamma events

GRIP the Energy Layer Fits

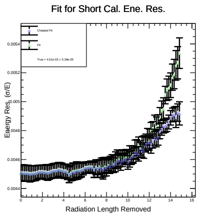
- Fit the energy layer response!
- Algorithm:
  - Find shower max (better measured than shower start)
  - Go to end of detector
  - Cut off M layers (to simulate truncation)
  - Fit the remaining layers to Gamma function
- Have true and "cheated" fit result
- "cheated" is only sensitive to model choice

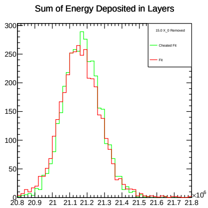


From GEANT4 simulation of GLIP gamma events

GRIP the Fit Results

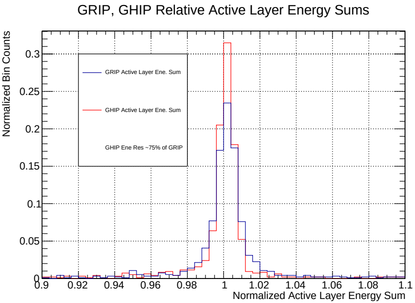
- Decrease in energy resolution but can truncate at least 15 X0 down to 25 X0
- Energy resolution worsened by 18%
- 0.45% to 0.53%
- Reduces GLIP length to 69 cm!
- So GRIP would be much shorter!
- "cheated" result indicates that the model can be much better too





GHIP , A heavier LumiCal

- Can reduce length by using more than $\frac{1}{6}X_0$ but will lose energy resolution
- Alternative – Use 1mm CdTe pads to supplement ene. res. of SiW
- Go to $\frac{1}{3}X_0$
- Si will still be small for space/angle res.
- Reduces GLIP length to 49 cm!
- Energy resolution improves , 75% of GRIP

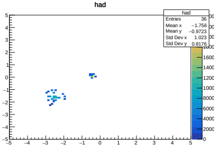


Changing focus to angle reconstruction!

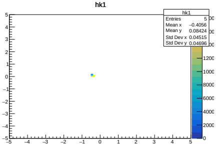
How to measure angles?

- ILD LumiCal uses layer clustering (here kMeans) and Log-Weighting (LW)
- This will be the “standard”
- Will also propose alternative – MSR
- Minimal Stochastic Reconstruction (MSR) uses local event variance to find least varying measurement

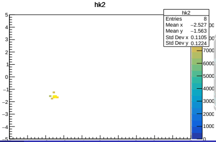
Toy MC of Hits



kMeans + LW Cluster 1



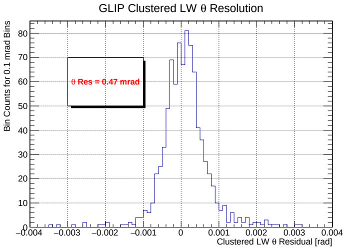
kMeans + LW Cluster 2

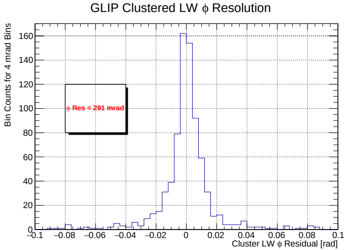


Algorithm of Standard Method (LW)

$$w_i = Max[0.0, W_0 + \log(\frac{E_i}{\sum_i E_i})] \quad (3)$$

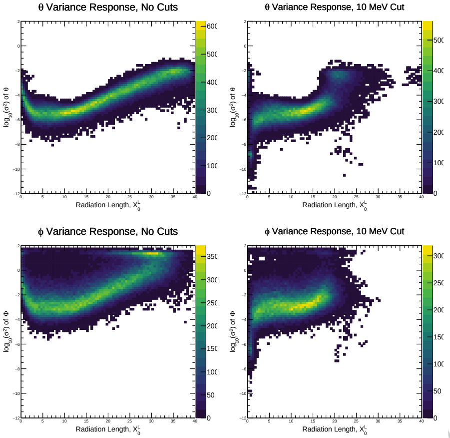
- FCAL collab: W_0 optimizes near 3.4 [2]
- Log-Weighting (LW) method algorithm
  - Start with layer N
  - Cluster layer N in θ, ϕ using LW
  - Repeat till all clusters done
  - Take average of θ, ϕ clusters





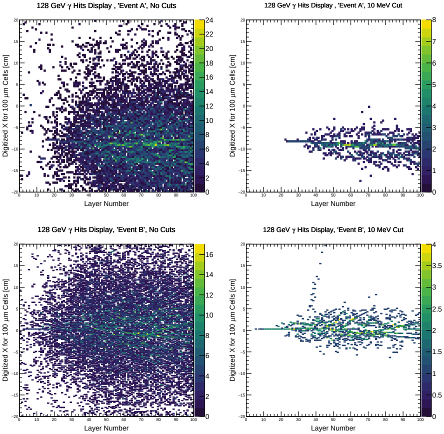
Motivation of MSR

- Algorithm for computing MSR variable
  - Start with layer N+M
  - Look back and forward M layers (i.e. fraction of X_0)
  - Measure desired variable (with cuts) in each layer
  - Compute variance of N layer wrt local layers
  - Increment N by 1 and repeat till no more layers
  - Return estimate where variance is minimum
- See plots ... energy cut has significant effect



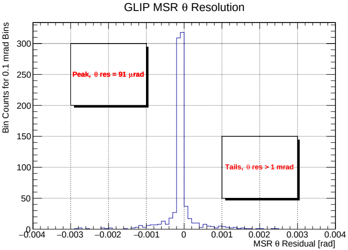
Example Event Display

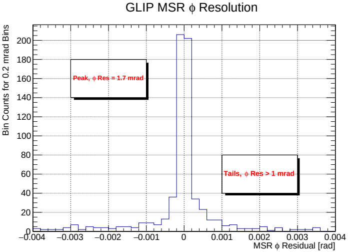
- Energy cut of hits can reveal shower structure
- MSR , LW both sensitive to this due to energy cuts



Result, Future of MSR Method

- MSR at least x2 better than clustered LW in θ resolution
- MSR at least 10x better in ϕ resolution
- Future: Check complimentarity to standard method , looks like some events MSR measures poorly
- If good, could use in boosted decision tree with standard to achieve greater resolution?





Summary

- Current ILD LumiCal is likely insufficient on energy resolution and angle/space resolution for 10^{-4} on Luminosity (and DiGammas!)
- Highly granular GLIP , or some variant, can reach energy resolution and may be able to reach space/position resolution for 10^{-4} on Luminosity and use DiGammas
- New method, MSR, shows better performance to current standard for angle/space reconstruction
- 2x better in θ, 10x better in ϕ
- WIP: Preliminary work indicates cell size doesn't need to be as small as possible. Limited by reco. method.
  Find the point of diminishing returns!

Acknowledgement

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References

[1] I. Levy "Detector R&D towards realistic luminosity measurement at the forward region of future ee linear colliders" (2019)
[2] A. Sailer "LumiCal and BeamCal Reconstruction" 32nd FCAL Workshop (2018)
[3] The ILD Concept Group "Internation Large Detector INTERIM DESIGN REPORT" arXiv:2003.01116v1 [physics.ins-det] 2 Mar 2020
[4] Brendon Madison and Graham W. Wilson. "Center-of-mass energy determination using e+e $\rightarrow$ +() events at future e+e colliders". In: Snowmass 2021. Sept. 2022. arXiv: 2209.03281 [hep-ex].
[5] Brendon Madison. Brendonmadison/GP2X: Guinea pig to X , X being a difermion event generator . takes initial beam dynamics from Guineapig and uses them to boost the final state difermions according to their center of mass energies. url: https://github.com/BrendonMadison/GP2X.