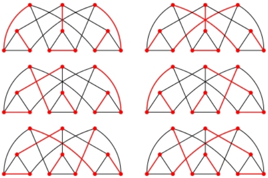
# Mass Constrained Fitting of Di-Photons

Graham W. Wilson

University of Kansas

February 23, 2016



Example graph. $n = 12$ photons. $m = 18$ viable meson pairings, $X \to \gamma\gamma$.
6 possible "perfect matches" with $r = n/2 = 6$ shown in red.

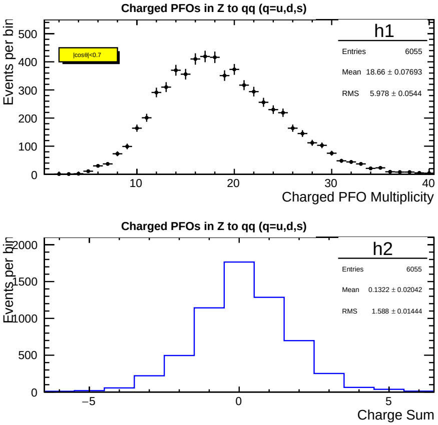
# Motivation: Advanced Particle Flow

Vision: Reconstruct event as fully as possible. Like a bubble chamber - but better. Improve beyond "perfect particle flow" using physics constraints such as mass-constraints, charge conservation, baryon-number conservation, and PID.

For jet energy, with no confusion $V_E = V_{CH} + V_{EM} + V_{NH}$, and one should be able to assign uncertainties per jet.

- KU focus - improve $V_{EM}$ using mass-constrained fits
- But even the charged PFOs have their issues $\rightarrow$

Would be good to "optimize" the detector including ultimate performance characteristics. So far - measured $V_E$ is often large compared to the intrinsic $V_{EM}$ - therefore observed improvements in *average* JER are currently modest.



# Marlin Processors

- GammaGammaCandidateFinder
  - Mass-constrained fits to Photon PFOs from Pandora
  - Output = GammaGammaCandidates
  - Run separately for $X = \pi^0$, $\eta$, $\eta'$
  - Individual photons may be paired with multiple candidates ...
  - Depend on quality of input quantities, values, errors, efficiency (GIGO) ..
- GammaGammaTruthFilter

  - Optional Filtering of GammaGammaCandidates based on MC info

  - Tag GammaGammaCandidates that really do have $X$ as a parent
- GammaGammaSolutionFinder

  - Choose "best" subset of GammaGammaCandidates using each photon at most once
- DistilledPFOCreator

  - Create set of "distilled" PFOs

  - Contains PandoraPFOs + GammaGammaCandidates with no double counting of PhotonPFOs (PhotonPFOs used in GammaGammaCandidates are removed)

arXiv:1203.2577 has writeup of previous studies.
About 95% of the photon energy content at the Z originate from $\pi^0$'s.

## Z Multiplicities (all flavours) (PDG)

| Meson ($X$) | $< n >$ | $B_{\gamma\gamma}$ | $< n > B_{\gamma\gamma}$ |
|---|---|---|---|
| $\pi^0$ | $9.42 \pm 0.32$ | 0.98823 | 9.31 |
| $\eta$ | $1.049 \pm 0.080$ | 0.3941 | 0.413 |
| $\eta^{'}(958)$ | $0.152 \pm 0.020$ | 0.0220 | 0.0033 |

$\pi^0$'s are ubiquitous. $\eta$ important for event completeness. $\eta^{'}(958)$ in general in this decay mode not expected to be tractable. NB. Higher mass mesons have more energetic energy spectrum.
Other sources of photons are ISR, FSR, bremsstrahlung, other minor decays (like $\omega(782) \rightarrow \pi^0\gamma$ and $\eta^{'}(958) \rightarrow \pi^+\pi^-\gamma$).

# GammaGammaCandidateFinder Cuts

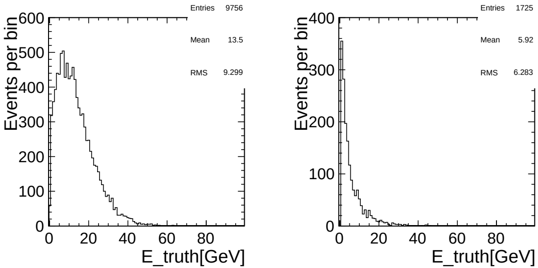
## Matching Studies Cuts

| Name | Cut | $\pi^0$ | $\eta$ | $\eta^{'}(958)$ |
|---|---|---|---|---|
| GammaMomentumCut | $E_{\mathrm{min}}$ (GeV) | 0.25 | 1.0 | 2.0 |
| FitProbabilityCut | $p_{\mathrm{fit}}$ | 0.005 | 0.05 | 0.10 |
| MaxDeltaMgg | $\Delta M_{\gamma\gamma}$ (GeV) | 0.04 | 0.14 | 0.19 |

## Resolution Studies Cuts

| Name | Cut | $\pi^0$ | $\eta$ | $\eta^{'}(958)$ |
|---|---|---|---|---|
| GammaMomentumCut | $E_{\mathrm{min}}$ (GeV) | 0.10 | 1.0 | 2.0 |
| FitProbabilityCut | $p_{\mathrm{fit}}$ | 0.0001 | 0.01 | 0.10 |
| MaxDeltaMgg | $\Delta M_{\gamma\gamma}$ (GeV) | 0.0805 | 0.20 | 0.19 |

Energies per event in $\pi^0$'s (left) and $\eta$'s (right). Use GammaGammaTruthFilter (based on ILDPerformance/pi0 from Jenny). Require GammaGammaPFOs have constituent photon PFOs (ie. clusters) with highest weight MCParticle energy contribution exceeding 10%. This needs to be a photon and both photon PFOs need to come from the same parent $X$ meson that decays to $\gamma\gamma$. $X$ also needs to be prompt (production vertex $< 10$ cm - against DIF and secondary interactions). Also allow conversions.




Mean n($\pi^0 \to \gamma\gamma$) = 4.1 Mean n($\eta \to \gamma\gamma$) = 0.19

Note: Often true photonic energy from $\pi^0$ does not pass these cuts. Most of the results today - rely on passing these cuts.

# GammaGammaSolutionFinder

Algorithms for choosing subsets of the set of GammaGammaCandidates. Note each subset has to use each constituent photon at most once. Implemented so far:

- Greedy Algorithm (Algorithm 1)
  - Sort GammaGammaCandidates by particle type (favour $\pi^0$ over $\eta$, and $\eta$ over $\eta$'(958))
  - Further sort each particle type by fit probability
  - Assign preferentially highest fit probability and lowest $X$ meson mass hypothesis candidates if the constituent PhotonPFOs have not yet been used
- Exhaustive Algorithm (Algorithm 2)

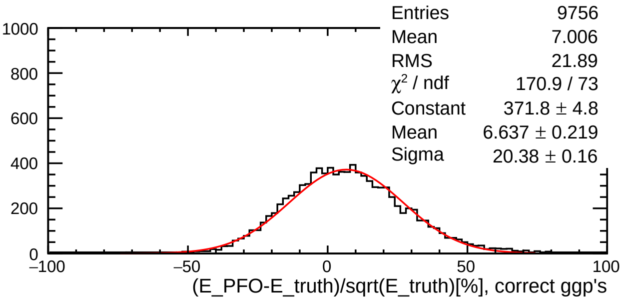
  —— Enumerate all possible subsets of GammaGammaCandidates that obey the one photon rule

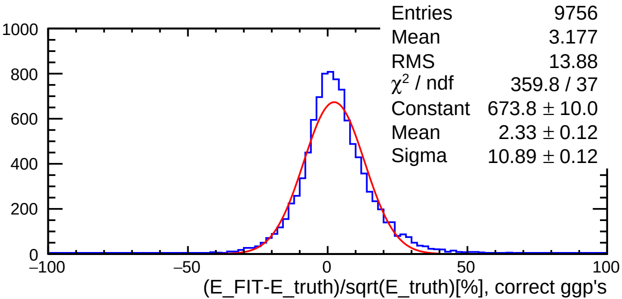
  —— If estimated combinatorics (mCr) too big - revert to Algorithm 1. (about 5.4% of Z's with cut at $10^9$)

  —— Choose subset consisting of $\pi^0$'s and $\eta$'s with the highest possible meson count which has the lowest global $\chi^2$

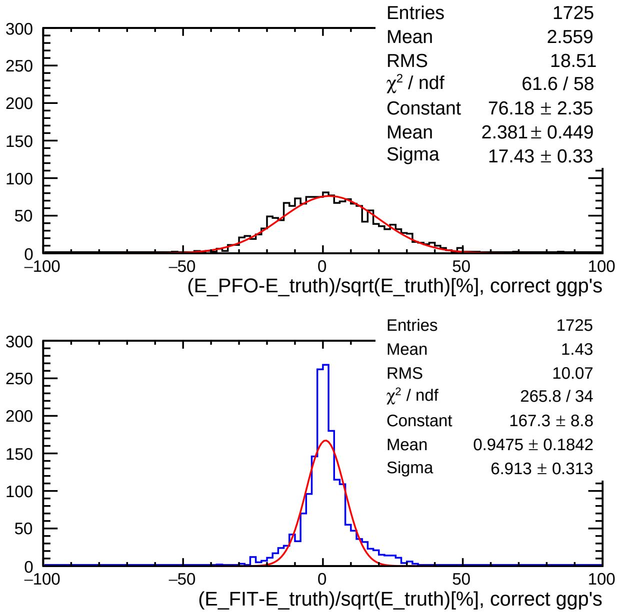
Expect more optimal algorithm should be tuned to find less $\eta$'s and be less aggressive in choosing the maximal meson number ($r$).

# $\pi^0$ Fits - Z Event Stochastic EM Energy Resolution

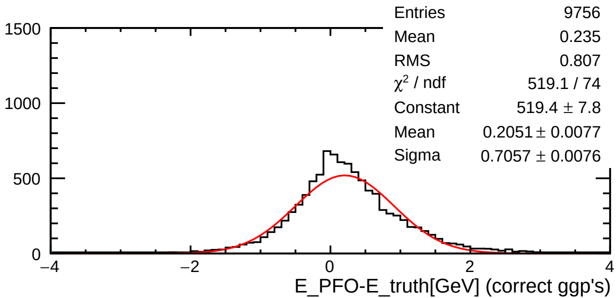


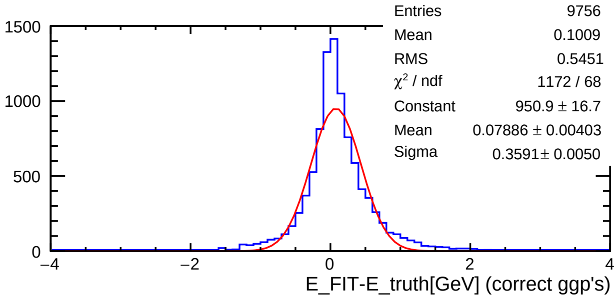



# $\eta$ Fits - Z Event Stochastic EM Energy Resolution

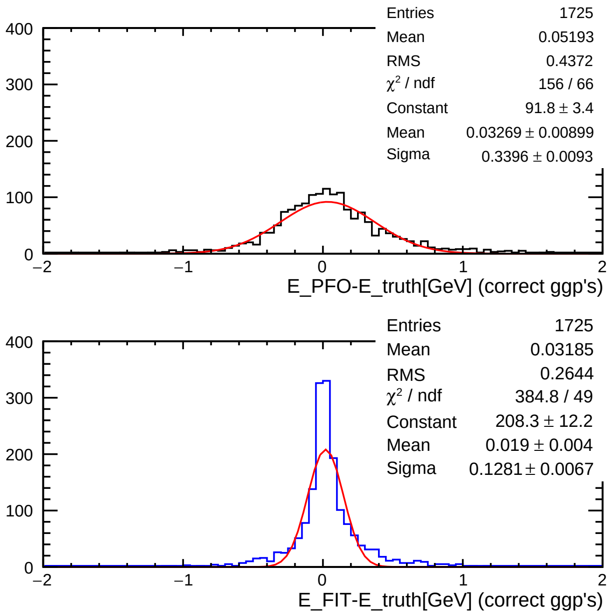


# $\pi^0$ Fits - Z Event EM Energy Residual



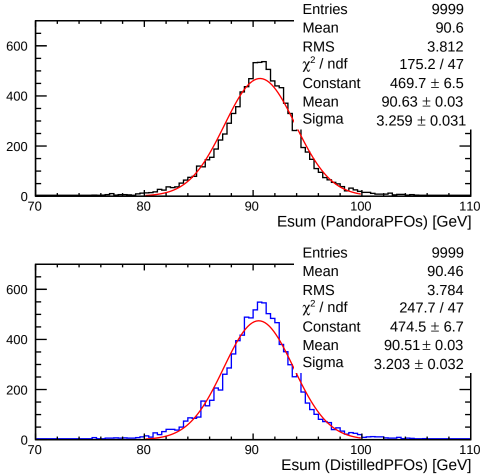



# $\eta$ Fits - Z Event EM Energy Residual



# Jet Energy Resolution on Z's

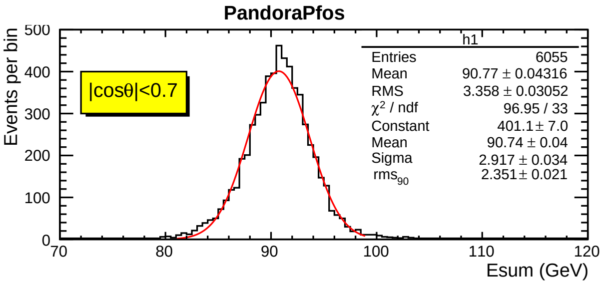
Cheated $\pi^0$ only. All polar angles.

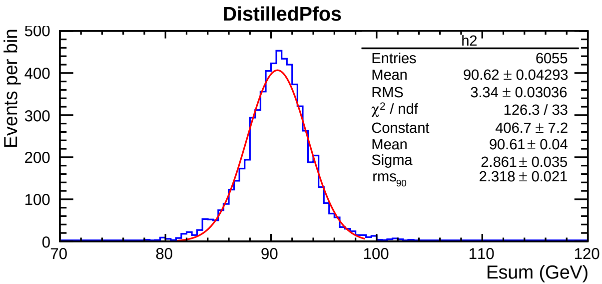



Some (small) improvement on *average*. There may be some issues with photonPFO energy not from $X$ needing to be accounted properly.

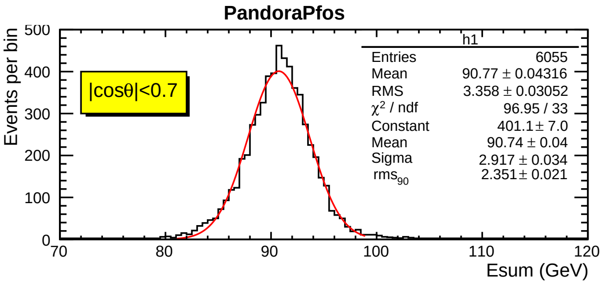
# Jet Energy Resolution - Compare with Pandora

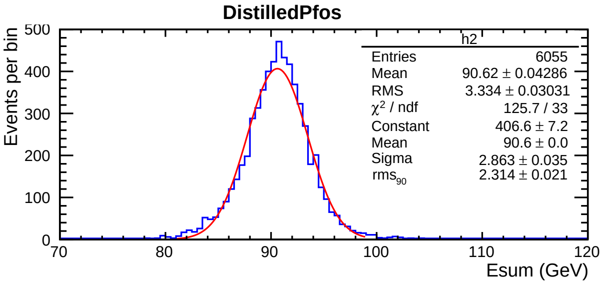
Cheated $\pi^0$ only. (also add in MC neutrino energy for A-A comparison)



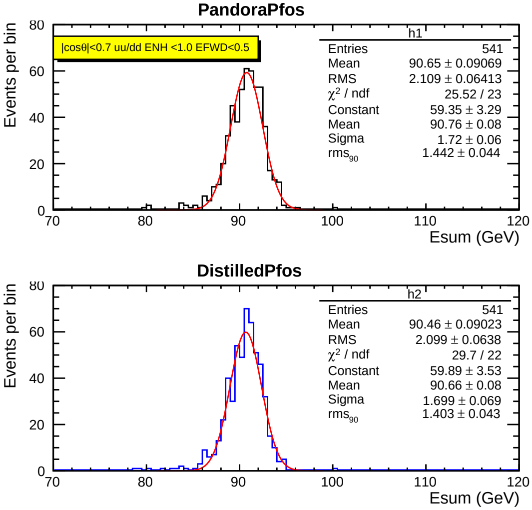
Cheated $\pi^0$ and $\eta$. (also add in MC neutrino energy for A-A comparison)



# Jet Energy Resolution - Compare with Pandora

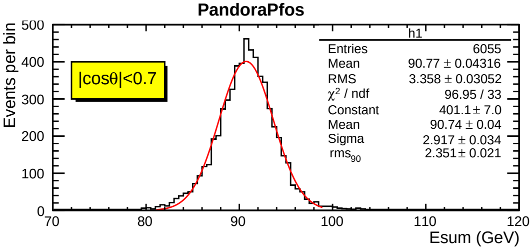
Cheat on $\pi^0$ and $\eta$. (also add in MC neutrino energy for A-A comparison)

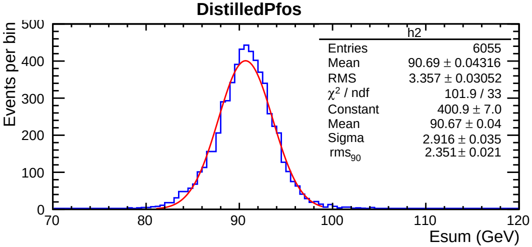



With cuts to select events likely to have better than average energy resolution.

# Jet Energy Resolution - Compare with Pandora

No cheating. (also add in MC neutrino energy for A-A comparison)




Gains made on the cheated subset - are compensated by mistakes.

# To Do List on GammaGammaPFOs

- Revisit and test photon error modelling
- Check and improve efficiency and purity of photon reconstruction
- Implement and test cluster position based errors from Mikael
- Implement Edmonds style polynomial time algorithm
- Teach GammaGammaSolutionFinder (GGSF) to be more discriminating
- Measure Efficiency and Purity of GGSF
- Quantify how much in some events it becomes hopeless ...
- Implement MVA approach developed by Brian
- Develop further related ILDPerformance processors

# Ideas/Plans

- Test performance with ECAL models with better/worse granularity
- Include $\pi^0$ Dalitz decays and converted photons - confer tracking resolution on photons! (with Justin)
- Above needs understood (soft) electron reconstruction and possibly PID
- Include $\pi^+\pi^-\pi^0$. Check feasibility ..
- Include $\pi^+\pi^-\gamma$. Check feasibility ..
- Treatment of non-prompt $\pi^0$'s. K0S to pi0 pi0 and Lambda to n pi0 .... Cluster direction?
- General generator level feasibility study including combinatorics. Where do all the neutral hadrons come from ?

# Summary

- Demonstrated improvement in resolution on $\pi^0$ and $\eta$ with full simulation cheating the pairing problem and selecting clusters that should be less confused.
- EM resolution improves to $10.9\%/\sqrt{E}$ for $\pi^0$
- EM resolution improves to $6.9\%/\sqrt{E}$ for $\eta$ (non-Gaussian)
- PhotonPFO resolution (no fits) is quite biased - extra energy..
- Observed impact on JER on *average* currently small even with pairing cheating - despite significant improvements on EM resolution
- Still optimistic that a mature implementation will yield significant benefit for physics - but still needs to be clearly demonstrated
- There may be issues associated with energies in photon clusters not from the photon - and calibration repercussions

# Backup Slides