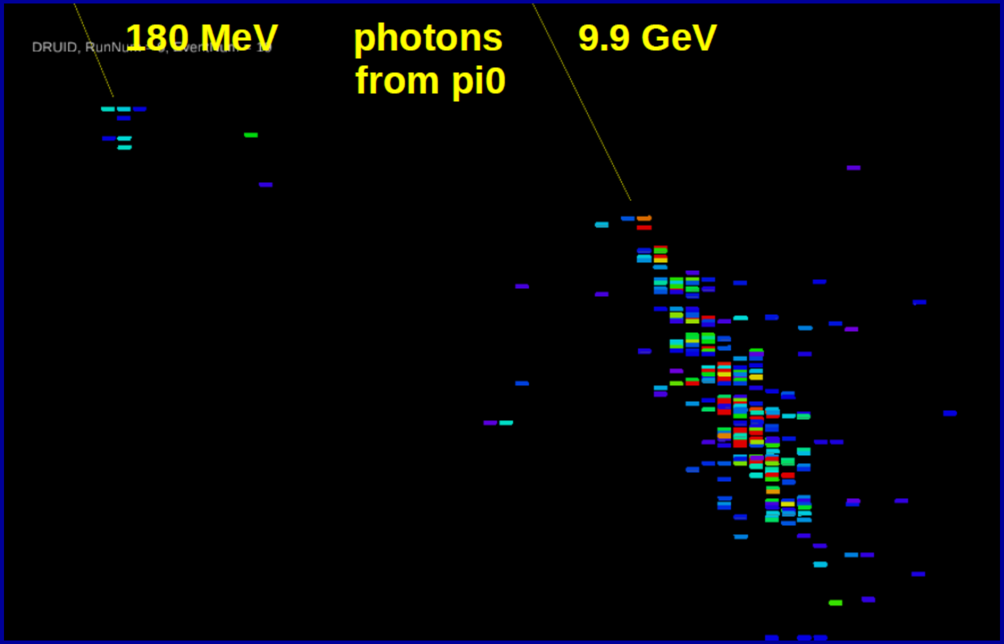
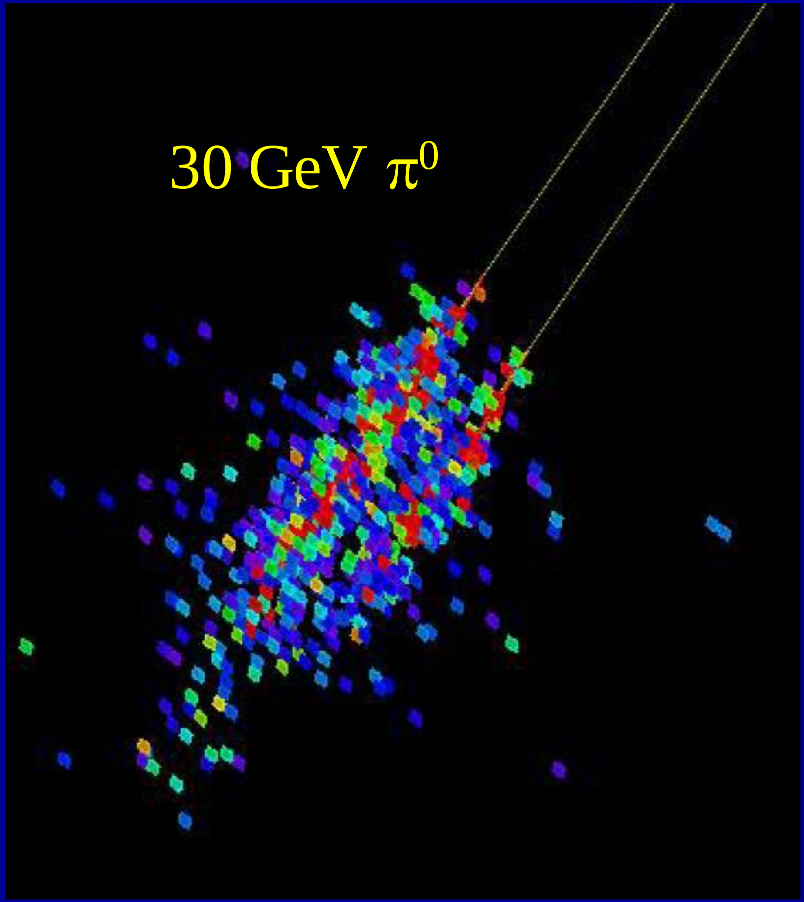
π^0 Reconstruction Tool Development





ILD High-Level Reco Workshop
Graham W. Wilson
University of Kansas
July 6th 2015

See talk at KEK meeting for more details

Physics Motivation

- High Energy π^0 (2-photons hard to separate)
  - For example, high energy tau reconstruction for CP violation via spin correlations in $H \rightarrow \tau\ \tau$ decays
  - Emphasizes separation of π, ρ, a_1 decays and the correct measurement of the electromagnetic energy.
- Ubiquitous π^0's.
  - Median π^0 energy in jets is 2 GeV – photons are usually well separated and measured independently. The average jet has 25% of the jet energy in 9 π^0s. So important part of the jet energy resolution.
  - Photon energies can be very low energy.
  - Can use π^0 mass constraint to improve jet energy resolution on an event-by-event basis IF photons can be efficiently reconstructed and correctly paired up.
  - See arXiV:1203.2577.
  - Very important for H and W mass measurement and the overall JER based detector optimization.

My focus today is on "ubiquitous π^0s"

Example Mass-Constrained Fit

4 GeV π^0, 16%/$\sqrt{E}$, 0.5mrad

Variable	Measured	3-variable fit	6-variable fit	Pull
E_1	2.468 ± 0.253	2.385 ± 0.192	2.385 ± 0.192	-0.504
E_2	1.679 ± 0.196	1.605 ± 0.130	1.605 ± 0.130	-0.504
$2(1-\cos\psi_{12})$	$(4.765 \pm 0.0985) \times 10^{-3}$	$(4.759 \pm 0.0977) \times 10^{-3}$		-0.504
θ_1 (mrad)	1608.36 ± 0.50		1608.37 ± 0.50	0.504
θ_2 (mrad)	1619.11 ± 0.50		1619.10 ± 0.50	-0.504
ϕ_1 (mrad)	2196.86 ± 0.50		2196.84 ± 0.50	-0.504
ϕ_2 (mrad)	2128.60 ± 0.50		2128.62 ± 0.50	0.504
m_{π^0} (MeV)	140.5			
$\rho_{E_1 E_2}$		-0.9683	-0.9683	
E_{π^0}	4.147 ± 0.320	3.990 ± 0.074	3.990 ± 0.074	
χ^2/ν		0.2543/1		
p_{fit} (%)		61.4		

(Note: the 3 and 6-variable fits are equivalent in terms of energy variables)

Fitted π^0 Energy Resolution

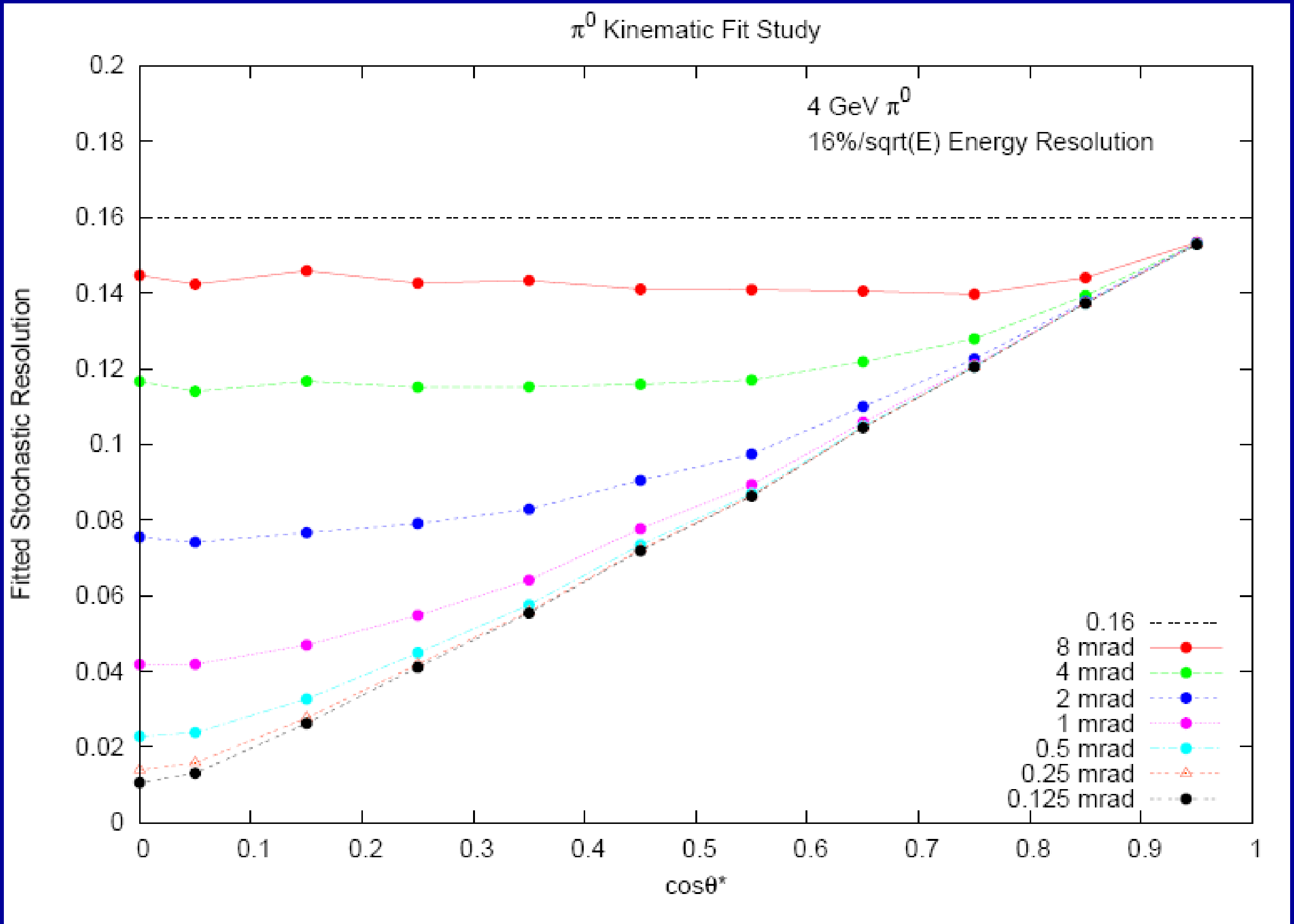
Use rms of fitted π^0 energy distribution.

π^0s are generated at fixed cosθ* values

4 GeV π^0

Later slides assume 0.25mrad.

See backup slide for exact angular resolution definition

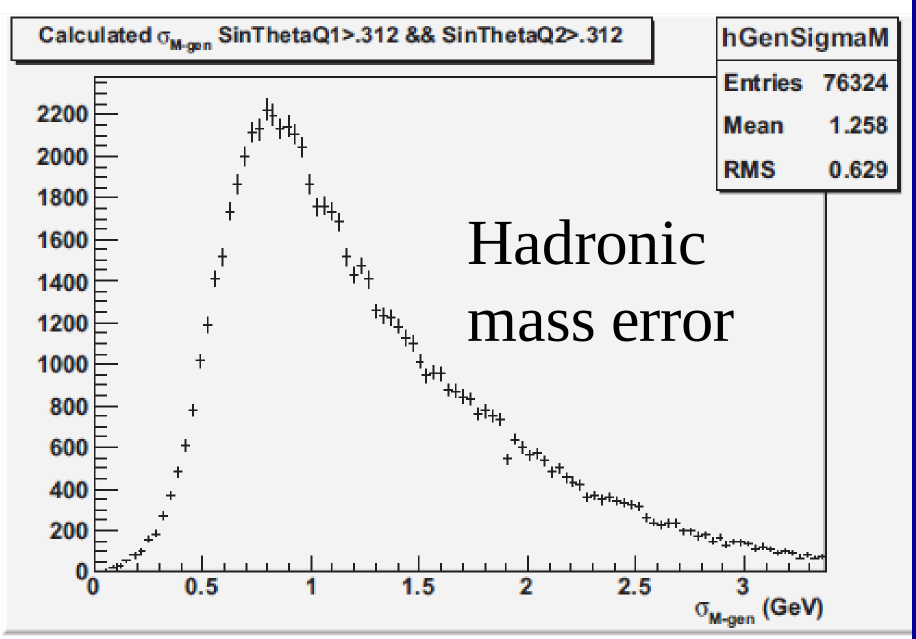


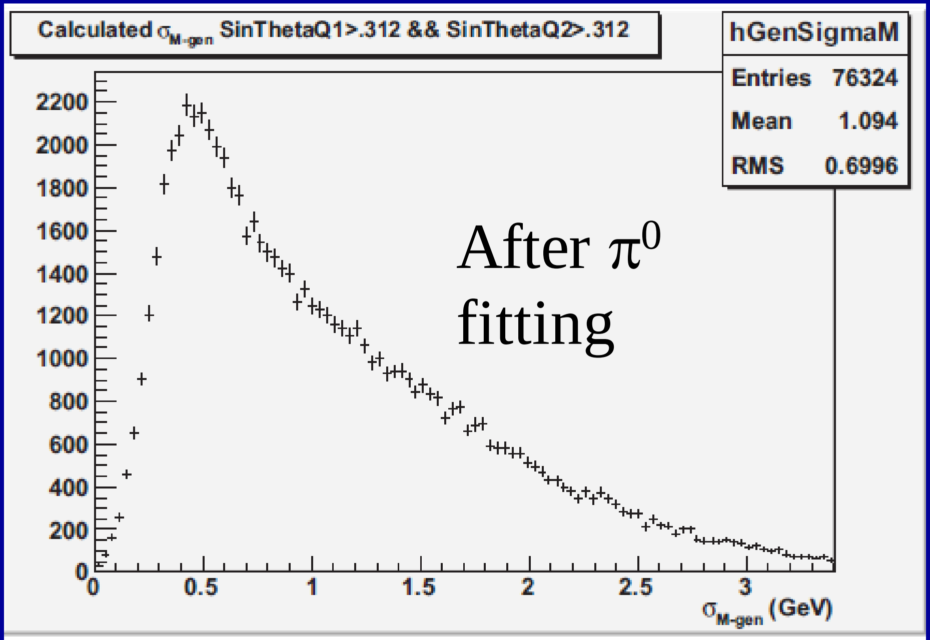
Event-Specific Hadronic Mass Resolution

B. van Doren

$$e^+e^- \rightarrow u\bar{d}e^-\bar{\nu}_e$$

$\sqrt{s}$=500 GeV





Assumes individual particles are reconstructed, resolved and measured with perfect efficiency, intrinsic detector resolutions and perfect mass assignments.
(Also no confusion: valid for low jet-energy and jet multiplicity environment)

Many experimental systematics need to be included: including effects like multiple interactions ($\gamma\gamma \rightarrow$ hadrons)

Motivation

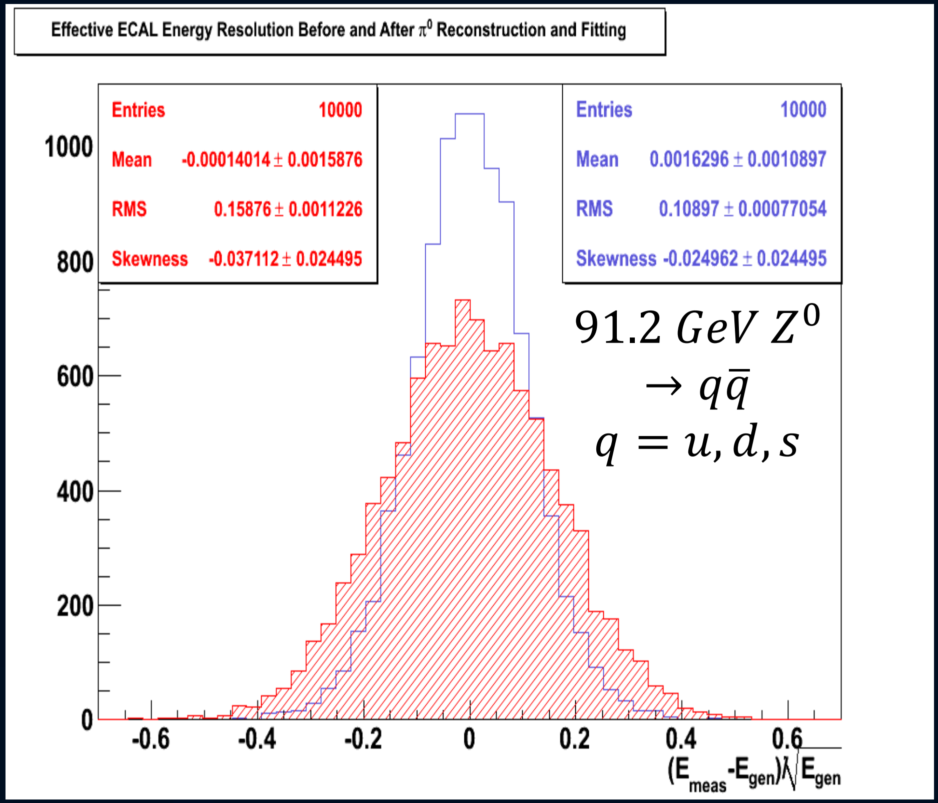
B. van Doren

95% of photons are created as pi-zero decay products

4% of photons are from etas

IF pi-zeroes and etas can be reconstructed one can perform mass constrained fits to improve the measurement resolution of the photons in hadronic jets

Example improvement when ALL pi-zeroes in $91.2\ GeV\ Z^0 \rightarrow q\bar{q}$ ($q = u, d, s$) are reconstructed and mass constrained fits are performed.



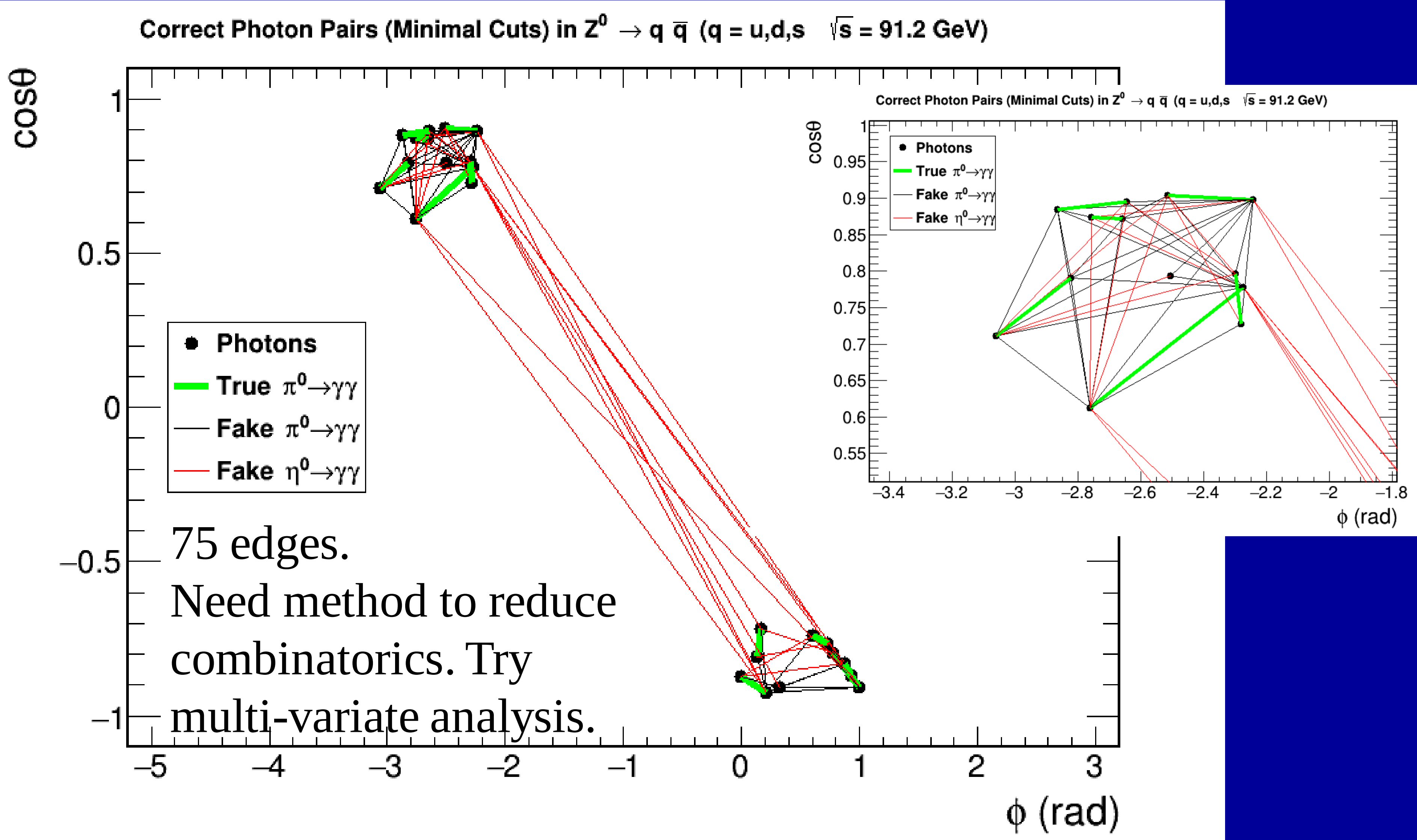
When photon response is modeled in a toy Monte-Carlo environment as $\sigma_E = 0.16\sqrt{E}$ with angular resolution of 0.25 mrad, average event by event resolution of photon portion becomes $0.109\sqrt{E}$

Photons account for on average 24.8 GeV of the total 91.2 GeV in the events

Assumes 100% photon reconstruction efficiency above 50 MeV and p_{fit}>0.1%

Event 4 (typical)

Graph vertices are photons. Graph "edges" are consistent (p_{fit}>0.1%) with pairing of the two photons to a π^0 or η^0

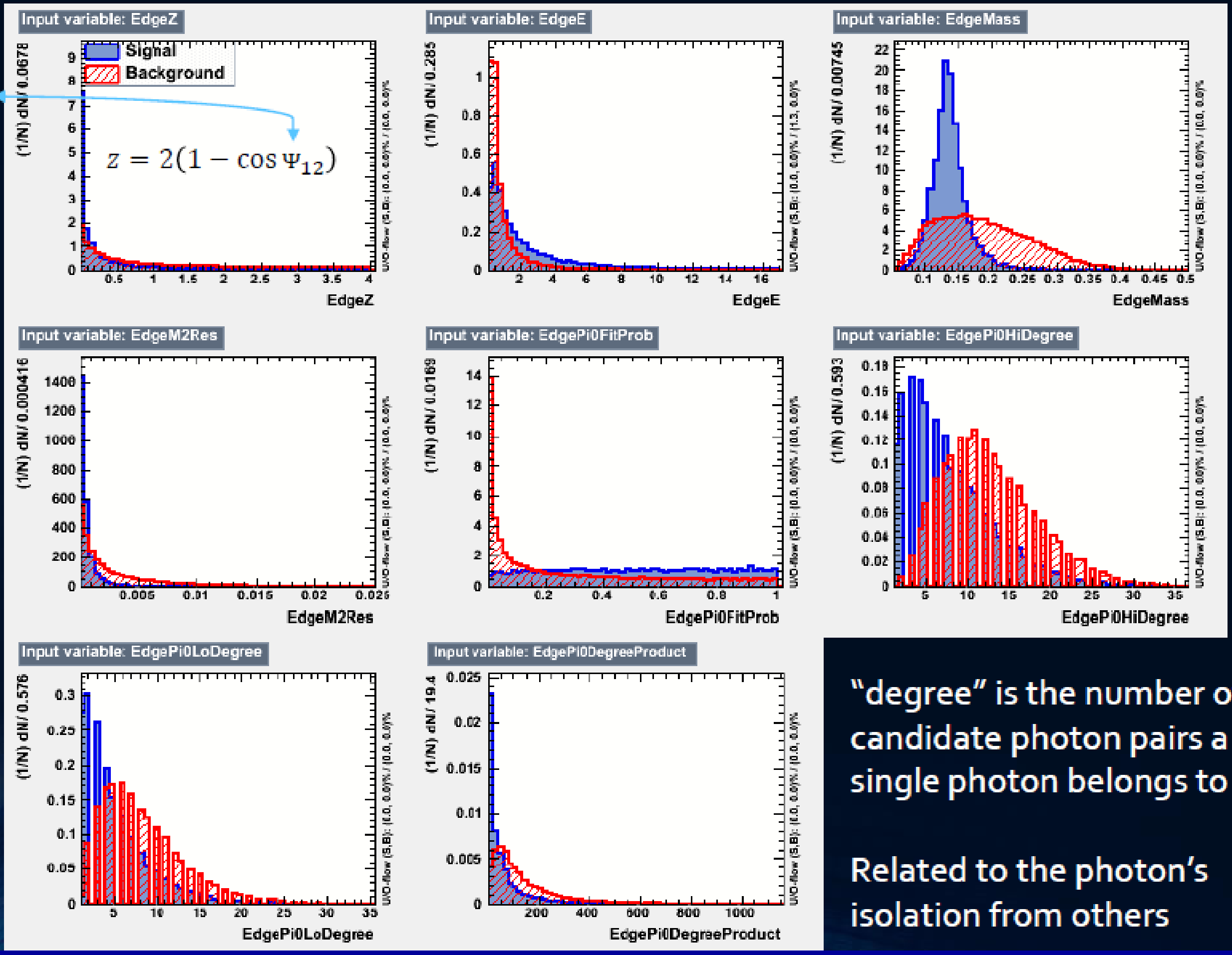


75 edges.
Need method to reduce combinatorics. Try multi-variate analysis.

Update from Brian

Multivariate Classification – Input Features

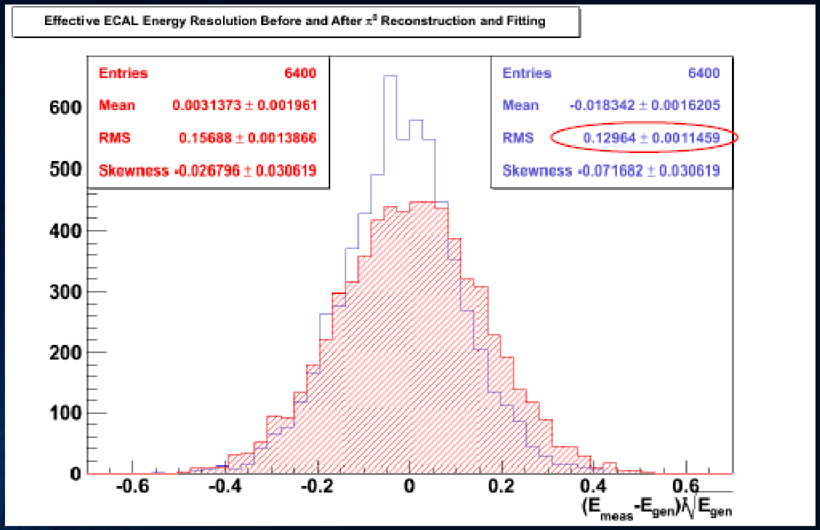
Opening angle

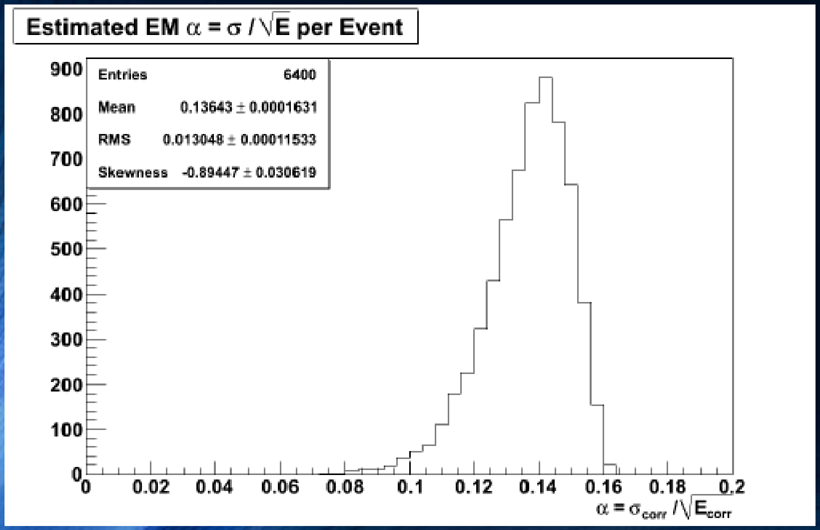


"degree" is the number of candidate photon pairs a single photon belongs to

Related to the photon's isolation from others

Update from Brian





Summary

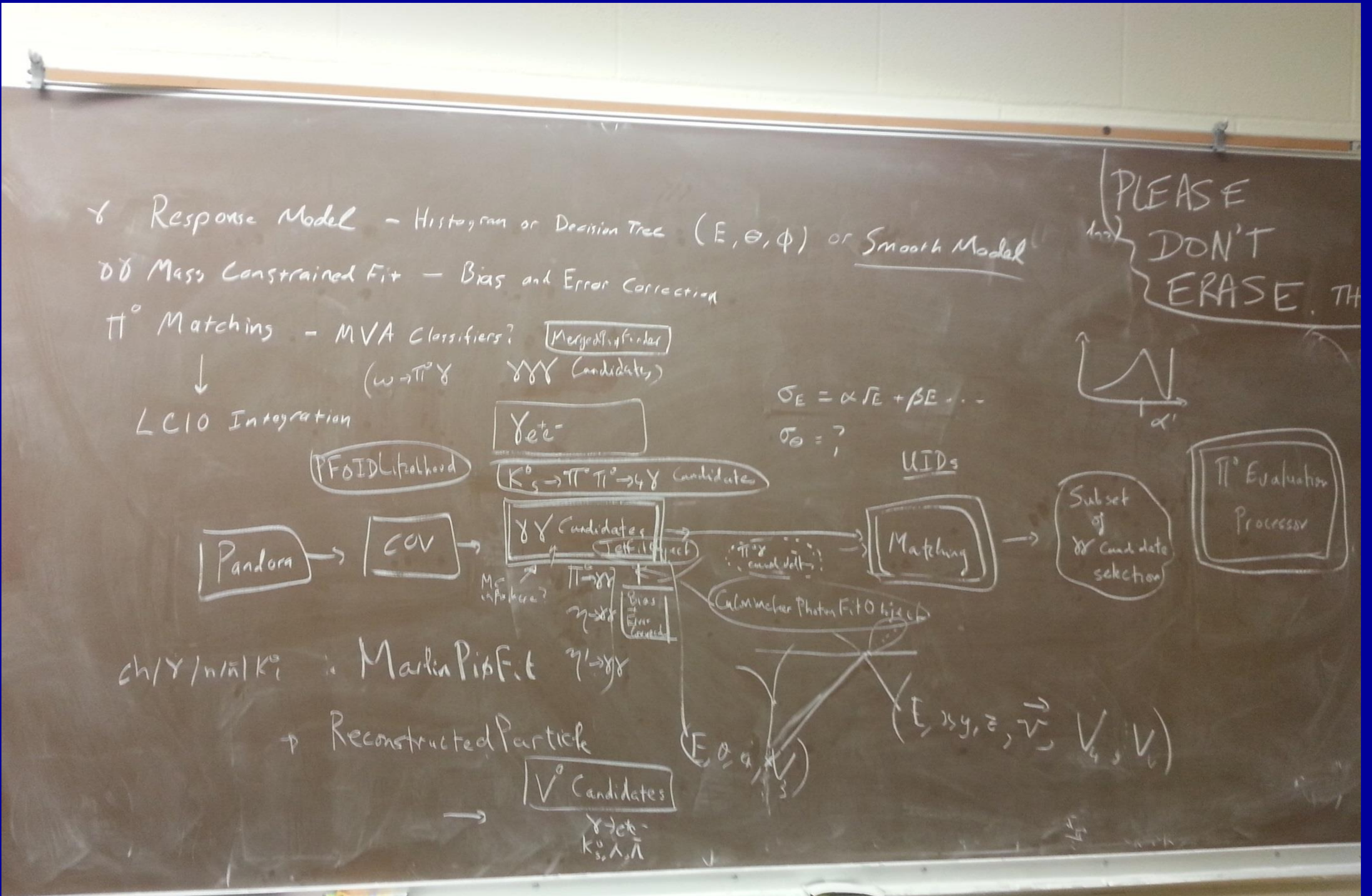
- Next generation particle detectors enable more sophisticated analysis due to the isolation and identification of individual particles
- Can achieve improvement to ECAL performance by identifying and performing mass constrained fits for pi-zeroes
- Improved estimates of pi-zero energy resolution can be achieved using modified regression trees
- Identification of pi-zeroes can be achieved with multivariate classifiers (provided by TMVA)
- Further improvements are likely possible in classification and energy bias correction

51

Getting More Realistic / Doing Even Better

- Photon efficiency especially at low energy is likely critical
  - For "solving" the problem – not so much for improving the resolution (asymmetric decays don't help so much)
  - Difficult in a sampling calorimeter…
- Photon conversions
  - Opportunity to confer tracking resolution on the non-converted partner photon
  - Could consider increasing the conversion probability??
    - while not harming too much the tracking (mini pair-spectrometer before the ECAL ?).
- Dalitz decays ($\pi^0 \rightarrow \gamma\, e^+e^-$)
- Non-prompt π^0 from K^0_S and Lambdas.
- An ECAL such as one with MAPS sensors would be well suited to achieving the ultimate ψ_{12} resolution.

Plan


PLEASE DON'T ERASE. TH
γ Response Model - Histogram or Decision Tree (E, θ, φ) or Smooth Model
γγ Mass Constrained Fit - Bias and Error Correction
π° Matching - MVA Classifiers?
LCIO Integration
MergedPi0Finder
γγγ Candidates
σE = α√E + βE . . .
UIDs
PFOIDLikelihood
γe+e-
Pandora
COV
γγ Candidates
Matching
Subset of γγ Candidate selection
π° Evaluation Processor
MarlinPi0Fit
ReconstructedParticle
V° Candidates
K°s, Λ, Λ̄

Concrete Plan

- Develop 3 Marlin Processors
  - GammaGammaResonanceCandidateFinder
    - Input: Photons + Cov Matrix
    - Output: ReconstructedParticles Collection with UIDs for Photons
    - May need room for extra info in RP.
  - GammaSolutionFinder
    - Input from above
    - Output: matching solution
    - Algorithm likely not full TMVA at this stage
  - GammaFittingPerformanceEvaluator

Brian has the elements of these in a stand-alone “IPR” library.

General Software Questions/Issues

- Availability of covariance matrix for input to Pi0Fitter. (ReconstructedParticle Photons or Calorimeter Clusters or Conversions ..)
- Need Unique ID of photons in RP π^0s
  - So that multiple graph solutions can be explored – and the $\gamma\gamma$ candidate reconstruction/fitting can be separated from the matching problem.
- What is the plan for V0s?
  - Suspect current algorithms not very efficient
- What is the policy on multiple hypotheses?
- Would like to integrate external library
  - LEMON graph library

R&D – things I'm keen on working on too

- Eventual highly performant implementation depends also on
  - High efficiency photon reco especially at low energy (GARLIC, Pandora, ….)
  - Best possible photon shower position resolution
    - See my talk on photon shower fitting from LCWS11
  - Shower position based π^0 fit. (x,y,z,E, **v**)
  - Reconstruction of photon conversions (V0's)
  - Reconstruction of Dalitz decays ($\pi^0 \rightarrow e^+ e^- \gamma$)
    - Essentially special case of conversions.
  - PFO Uncertainties

PFO Uncertainties / Interpretation

- "Neutral Hadrons"
  - Actually charged particle satellite =>IGNORE
  - Actually a photon – use EM calibration
  - K0_L
  - Neutron
  - Anti-neutron

- "Photons"
- \- ditto … though likely less important

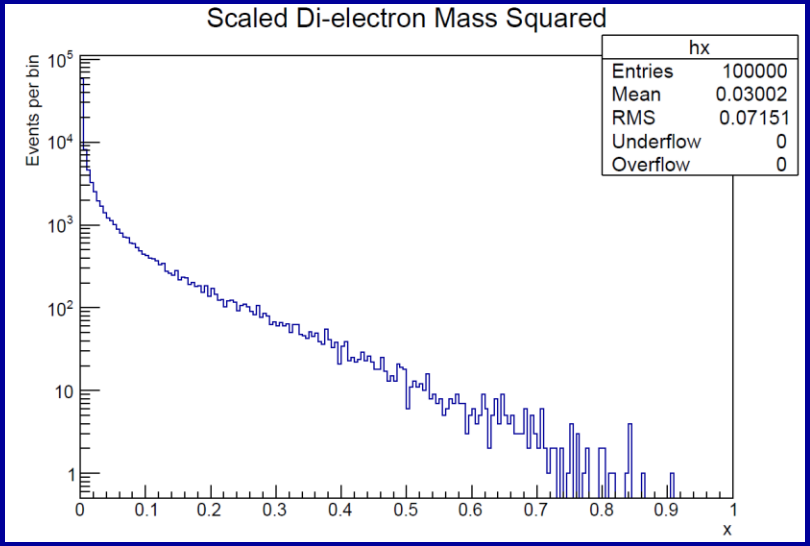
- How much does Pandora – split energy contributions ?

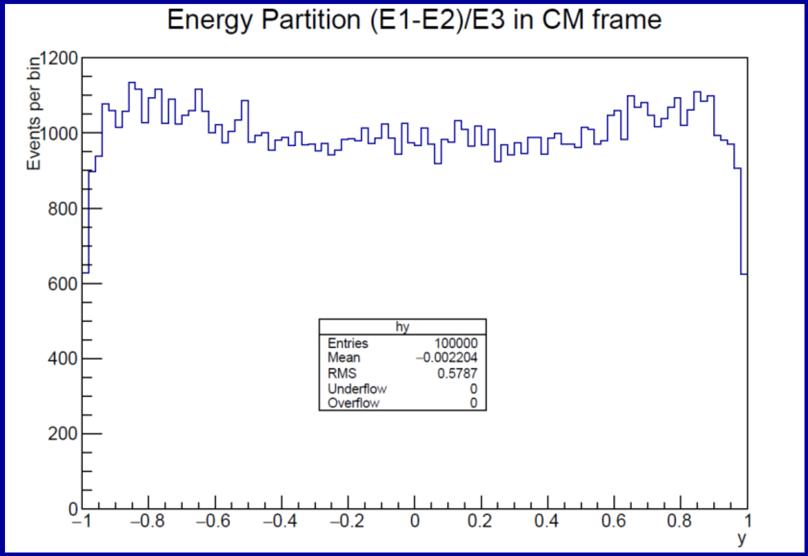
My feeling is that one way of measuring the confusion is to use re-simulation of individual events (See talk from Geneva meeting (2011?))

Dalitz Decays ($\pi^0 \rightarrow e^+ e^- \gamma$)

Prototype for $\gamma\ \gamma_C$ performance

With new student,
Justin Anguiano





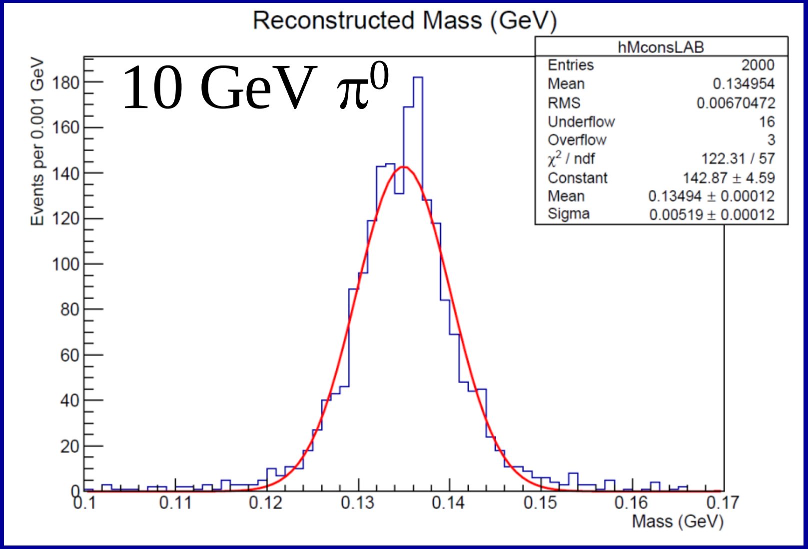
$x = [M(ee) / M(\pi 0)]^2$

Dalitz Decays $\pi^0 \to e^+ e^- \gamma$ Contd.

$$z_{ij} = 2(1 - cos\psi_{ij})$$

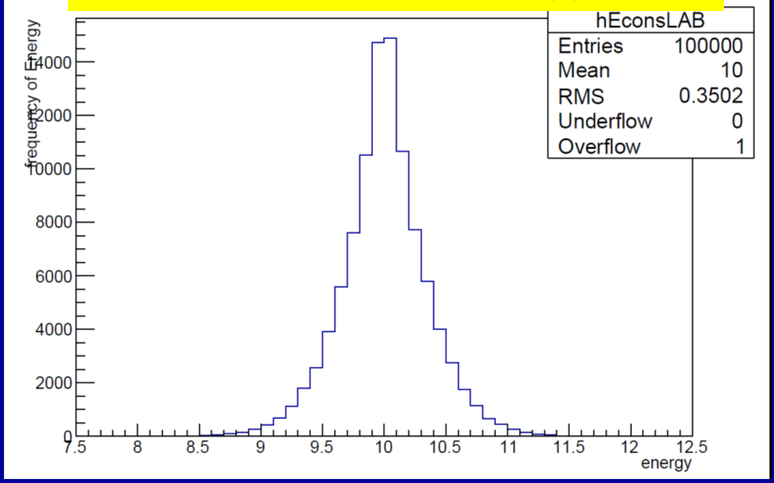
$$2{m_e}^2 + p_1\, p_2\, z_{12} + p_2\, E_3\, z_{23} + E_3\, p_1\, z_{31} = m^2$$

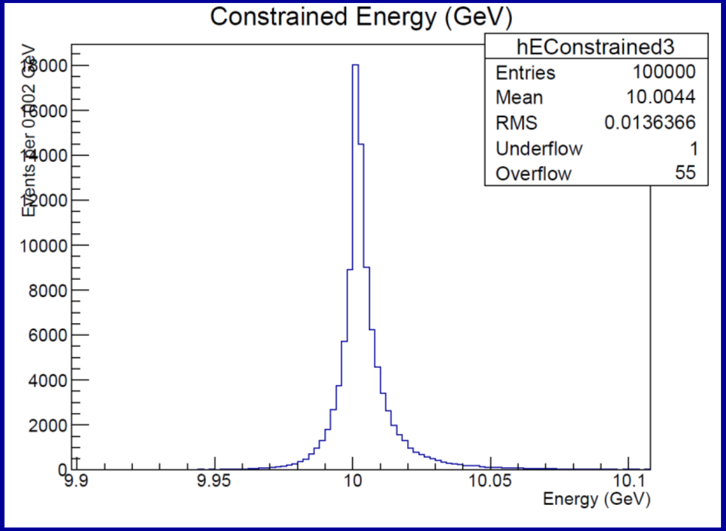
First step: assume ILD p and EM resolution. Angles measured perfectly .. no bremsstrahlung …



$$E_3 = \frac{m^2 - 2{m_e}^2 - p_1\, p_2\, z_{12}}{p_1\, z_{31} + p_2\, z_{23}}$$

Measured π^0 energy

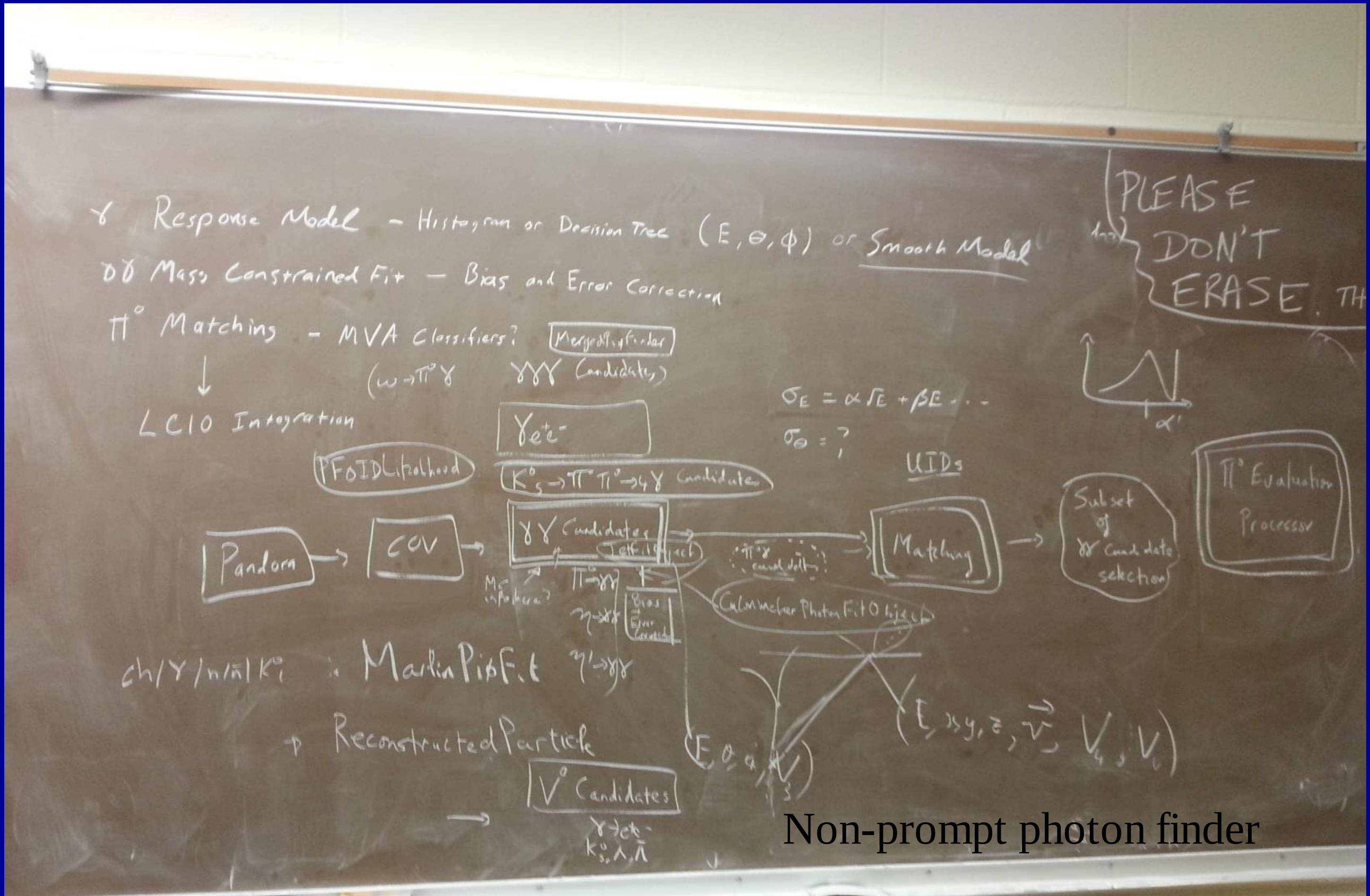




Expect photon angle resolution is important

Summary

- Lots to do – but much of it is fun.



Non-prompt photon finder