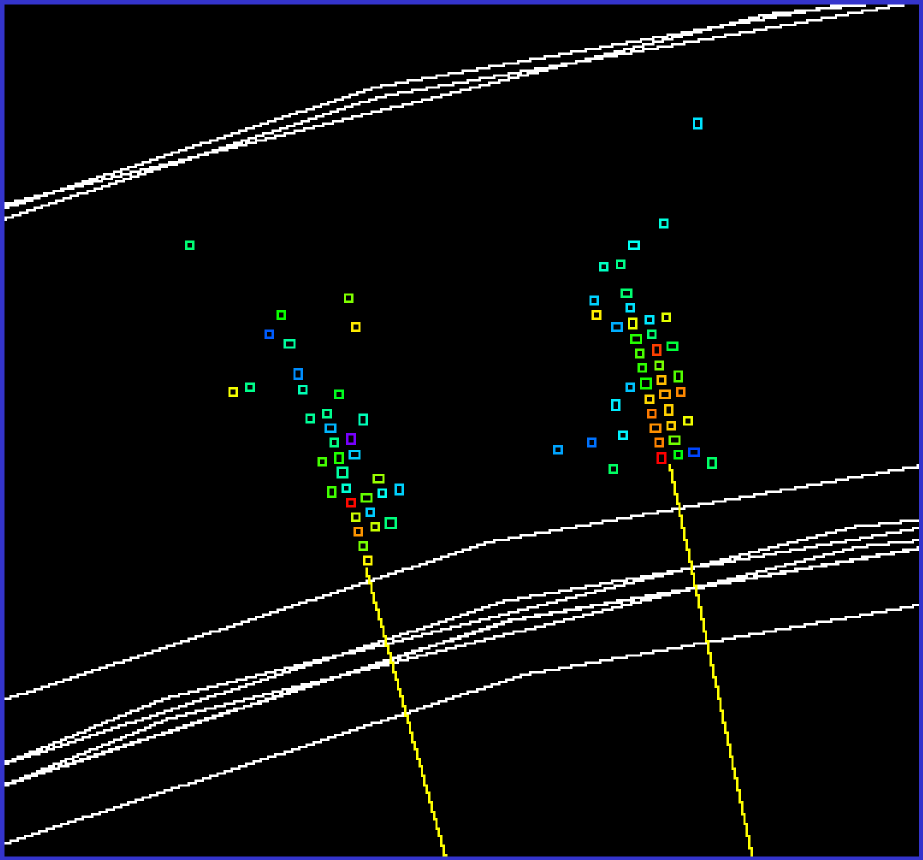
Investigating π^0 Kinematic Fits



Short update

(see Snowmass 05)

EM calorimeters under consideration have unprecedented potential for photon position resolution.
=> Can this be used to measure π^0 energies very well ?

R also relevant

Graham W. Wilson, University of Kansas

Outline

- π^0's and particle flow
- Kinematic fitting
- Improvements in π^0 energy resolution

π^0's and Particle Flow

- Particle Flow
  - Charged particles => TRACKER => 62%
  - **Photons => ECAL => 26%**
  - Neutral hadrons => HCAL => 12%

- Photons
  - Prompt Photons (can assume vtx = (0,0,0))
    - **π^0 (About 95% of the photon energy content at the Z)**
    - Eta, eta' etc.
    - Lone photons (eg. $\omega \rightarrow \pi^0 \gamma$)
  - Non-prompt Photons
    - $K^0_S \rightarrow \pi^0 \pi^0$
    - $\Lambda \rightarrow \pi^0 n$
- So, as you know, most photons do come from prompt π^0's, we do know the π^0 mass, and they interact in well understood ways !

Issues

- A) Proof of Principle *for the Intrinsic potential* of a 1-C constrained fit to m(π^0) for a single **isolated** π^0 with two spatially separated photons.
  - Can we get a fitter that works, and does it buy us anything in principle ? (Emphatic YES)
  - What detector parameters / design issues does it point to ?

- B) Practical *implementation* in the context of hadronic jets.
  - Major issue: combinatorics (9.6 π^0 per event at the Z). Algorithm for choosing appropriate pairings.
  - Relatively small background from non-prompt photons can presumably be discriminated against using cluster pointing.
  - Details of photon reconstruction in jets.

Proof of Principle (A) is now completed and very encouraging.

First steps towards assessing the potential in the context of B).

π^0 Kinematic Fitting

- For simplicity used the following measured experimental quantities:

  E_1 (Energy of photon 1)

  E_2 (Energy of photon 2)

  ψ_{12} (Opening angle of photons 1 and 2)

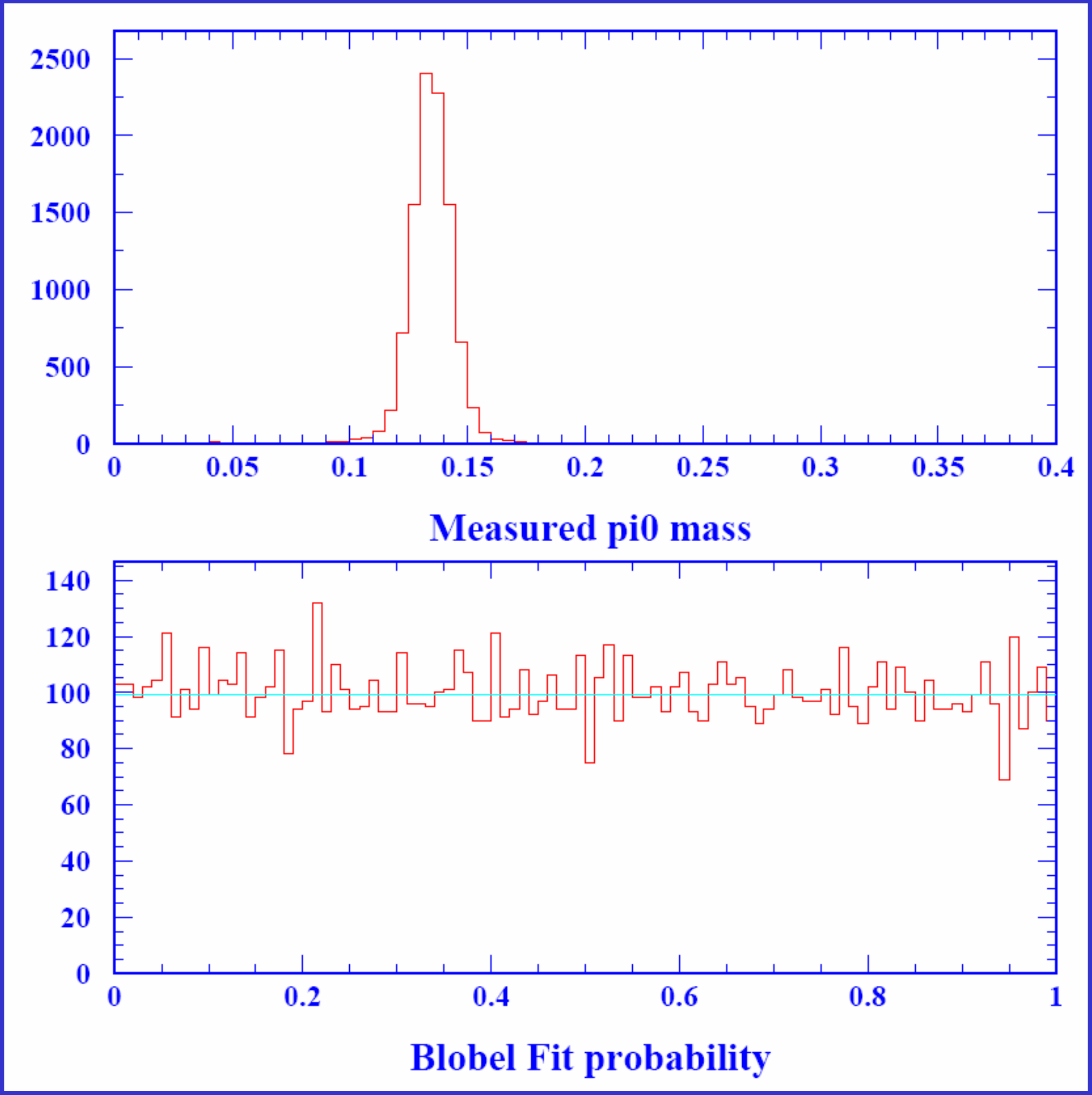
- Fit uses 3 variables and diagonal error matrix

  $\mathbf{x} = (E_1, \; E_2, \; 2(1 - \cos\psi_{12}))$

and the constraint equation

$$m_{\pi^0}^2 = 2 E_1 E_2 (1 - \cos\psi_{12}) = x_1 x_2 x_3$$

20 GeV π^0

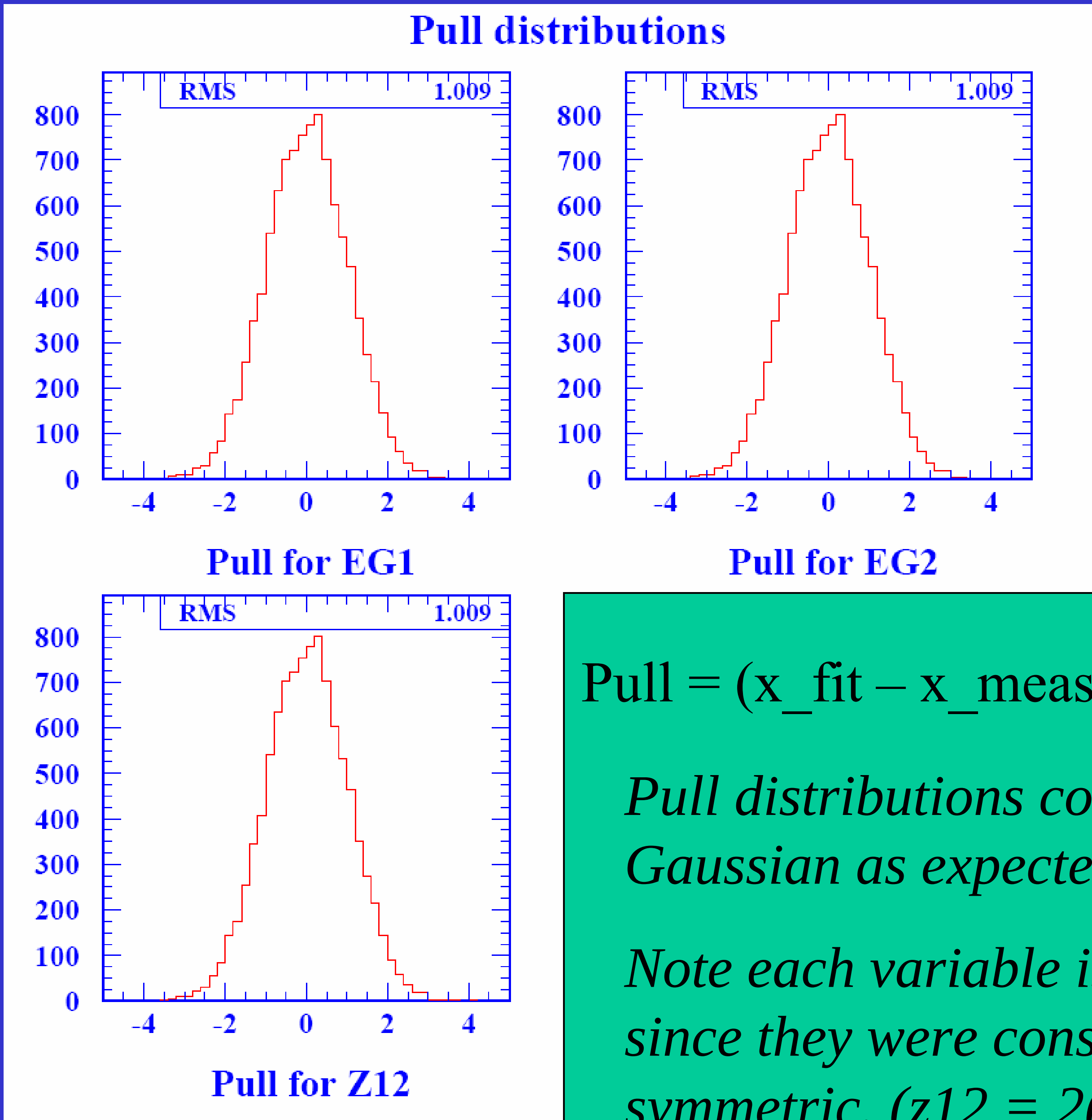


Use toy single π^0 MC with Gaussian smearing for studies.

Energy resolution per photon $=16\%/\sqrt{E}$.

Error on $\psi_{12}=0.5$mrad

A rare thing: a really flat probability distribution !!!



$$\text{Pull} = (x\_fit - x\_meas)/\sqrt{(\sigma\_meas^2 - \sigma\_fit^2)}$$

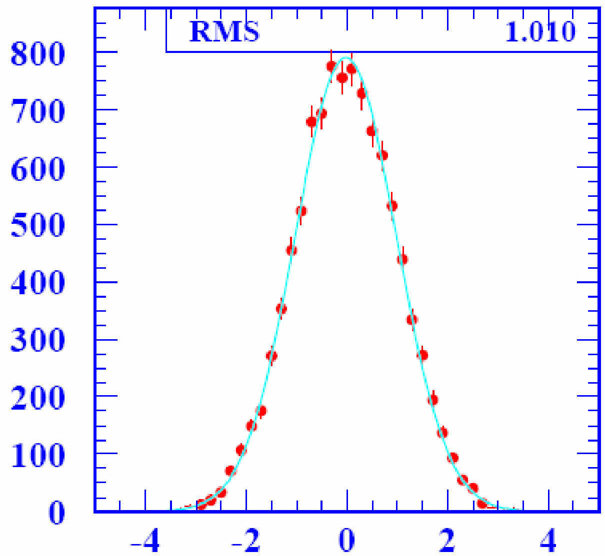
Pull distributions consistent with unit Gaussian as expected.

Note each variable is identical per event, since they were constructed to be symmetric. (z12 = 2(1-cos ψ12))

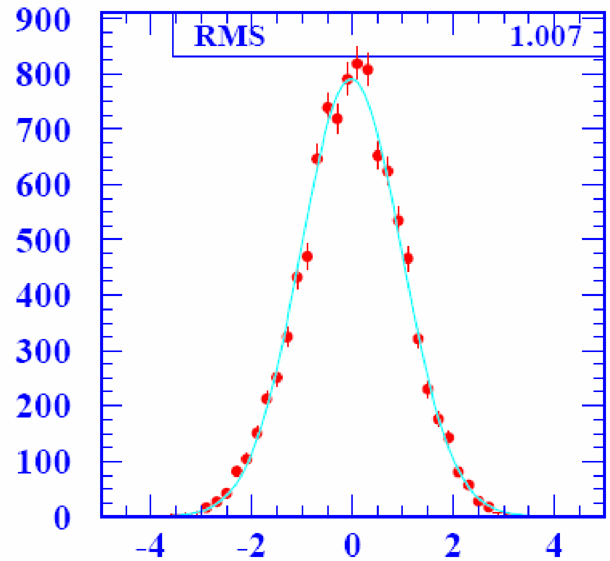
Recent Changes

- Blobel fitter in addition to analytic fit (both F77 for now)
  - consistent
- Technical details
  - $\cos\theta^* = (1/\beta)\,(E_1 - E_2) / E_{\pi^0}$
  - Error truncation for low energies – avoid –ve energies …
  - Using simulated error rather than measured error
  - Now have ***perfect*** probability and pull distributions
    - (at Snowmass had some pesky events in a low probability spike)
- Error propagation after kinematic fit
  - Demonstration that for each π^0 in the event we could not only improve the π^0 energy resolution, but would know the error.

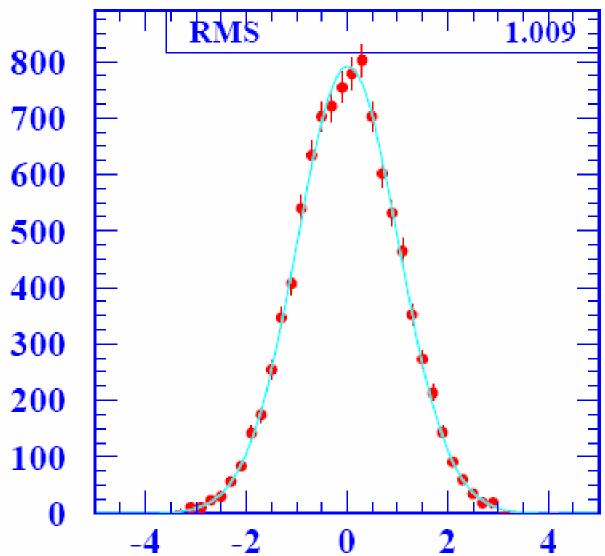
Pull distributions



Measured pi0 energy pull cf gen



Fitted pi0 energy pull cf gen



Fitted pi0 energy Pull cf measured

=> You should also be able to believe the errors on the fitted energies of each π^0

Results

For the Proof of Principle study there are:

Two relevant π^0 kinematic parameters:

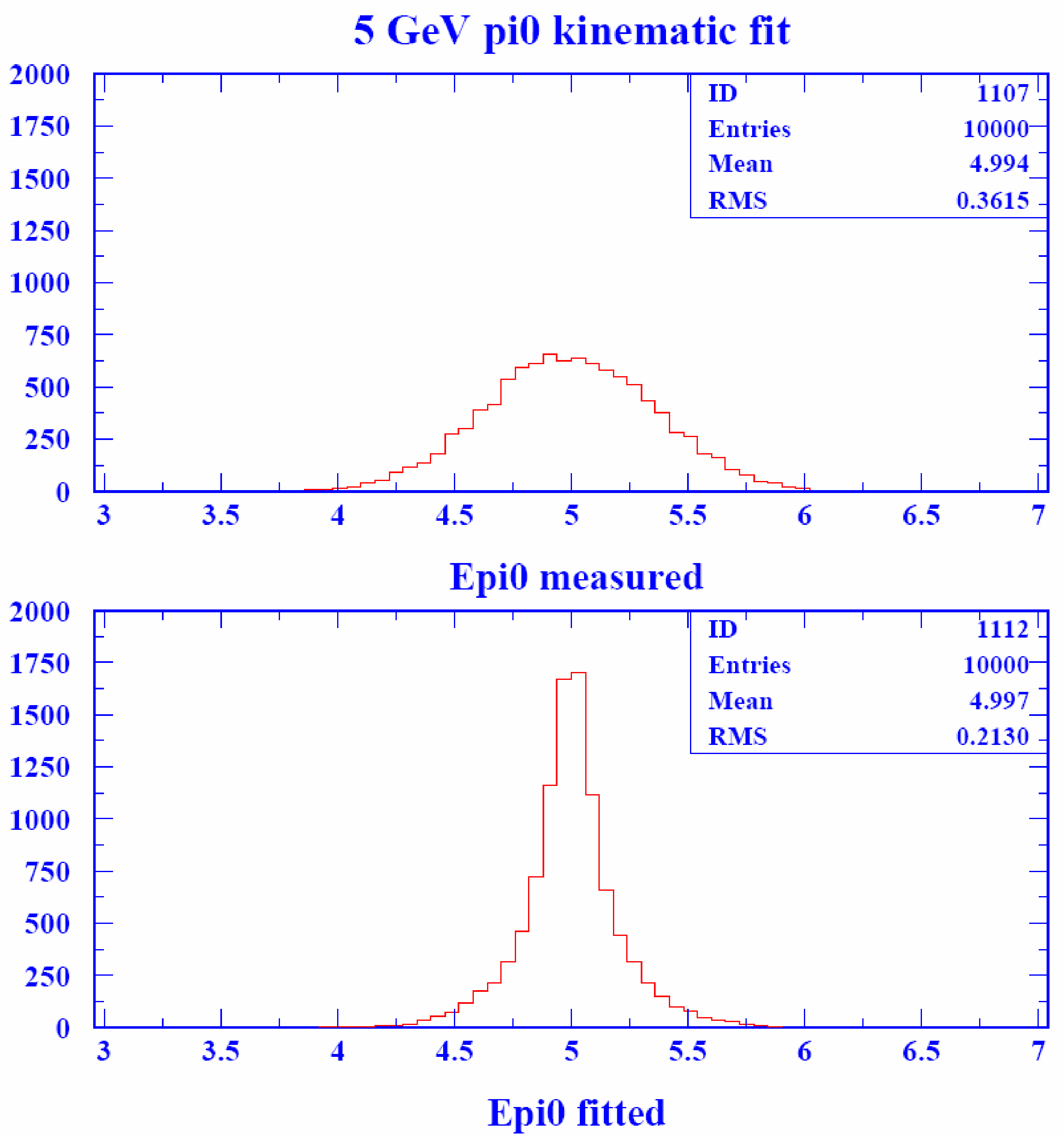
i) $E(\pi^0)$

ii) $\cos\theta^*$ (cosine of CM decay angle)

And two relevant detector parameters:

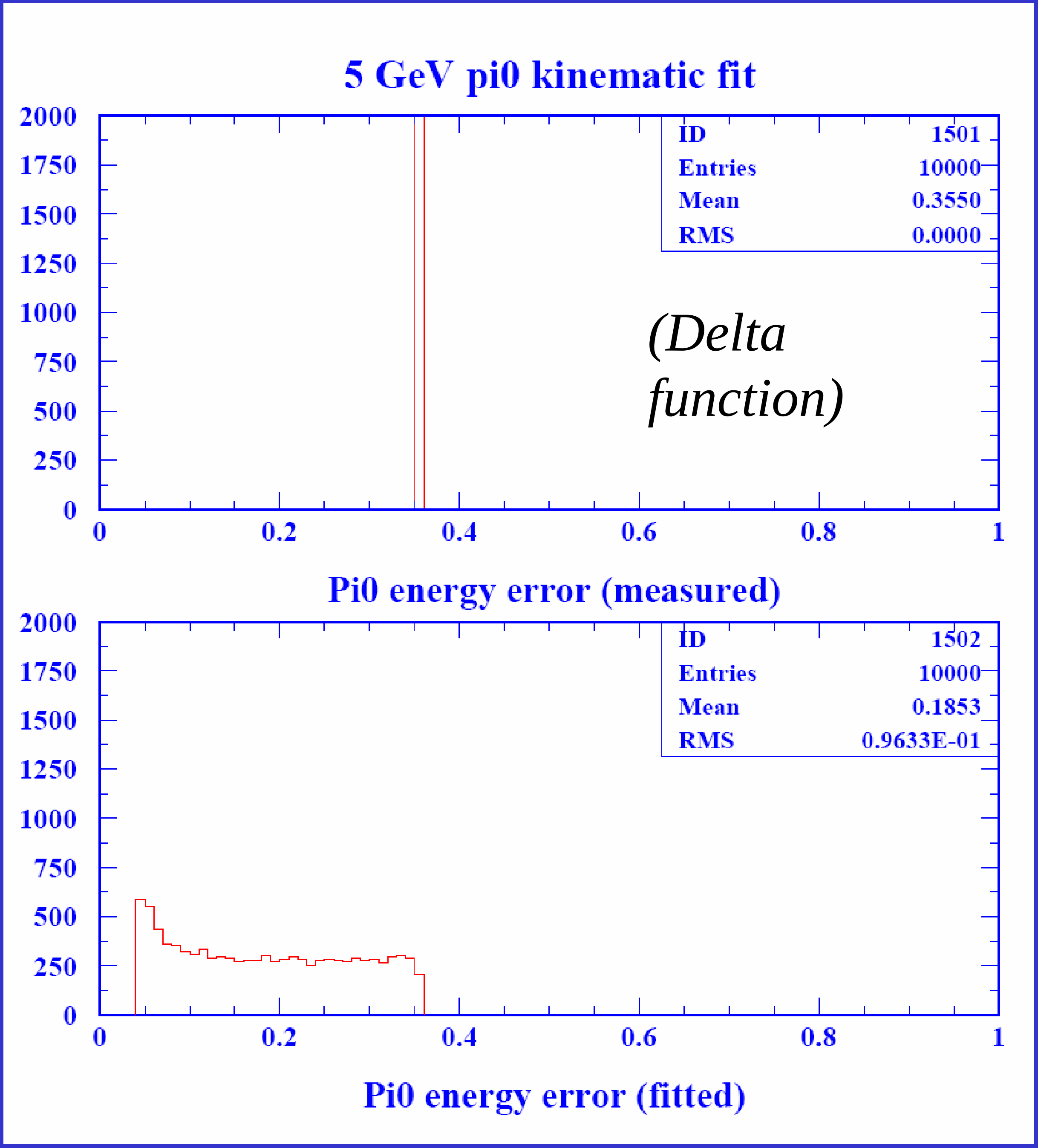
i) Photon fractional energy resolution ($\Delta E/E$)

ii) Opening angle resolution ($\Delta\psi_{12}$)

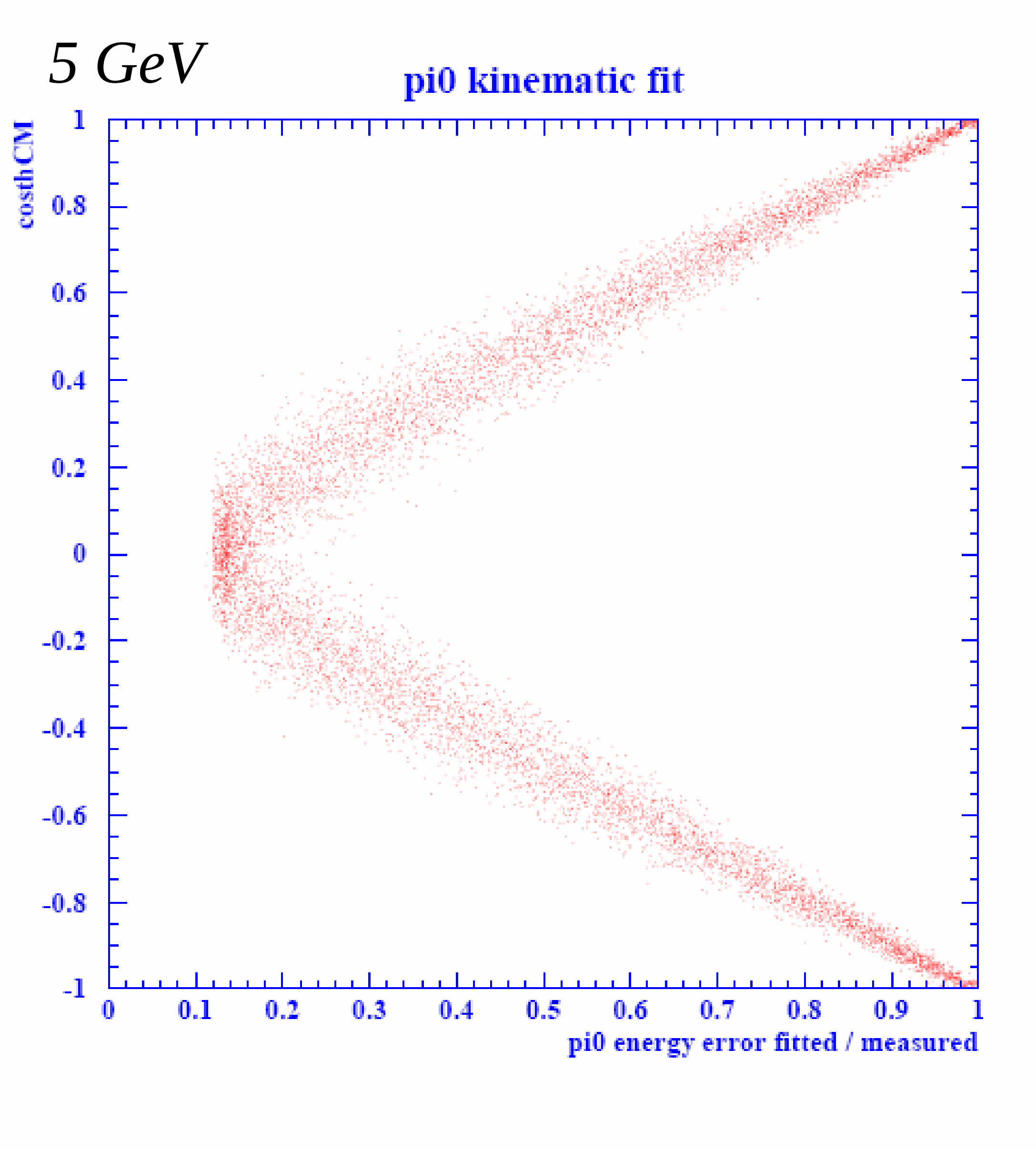


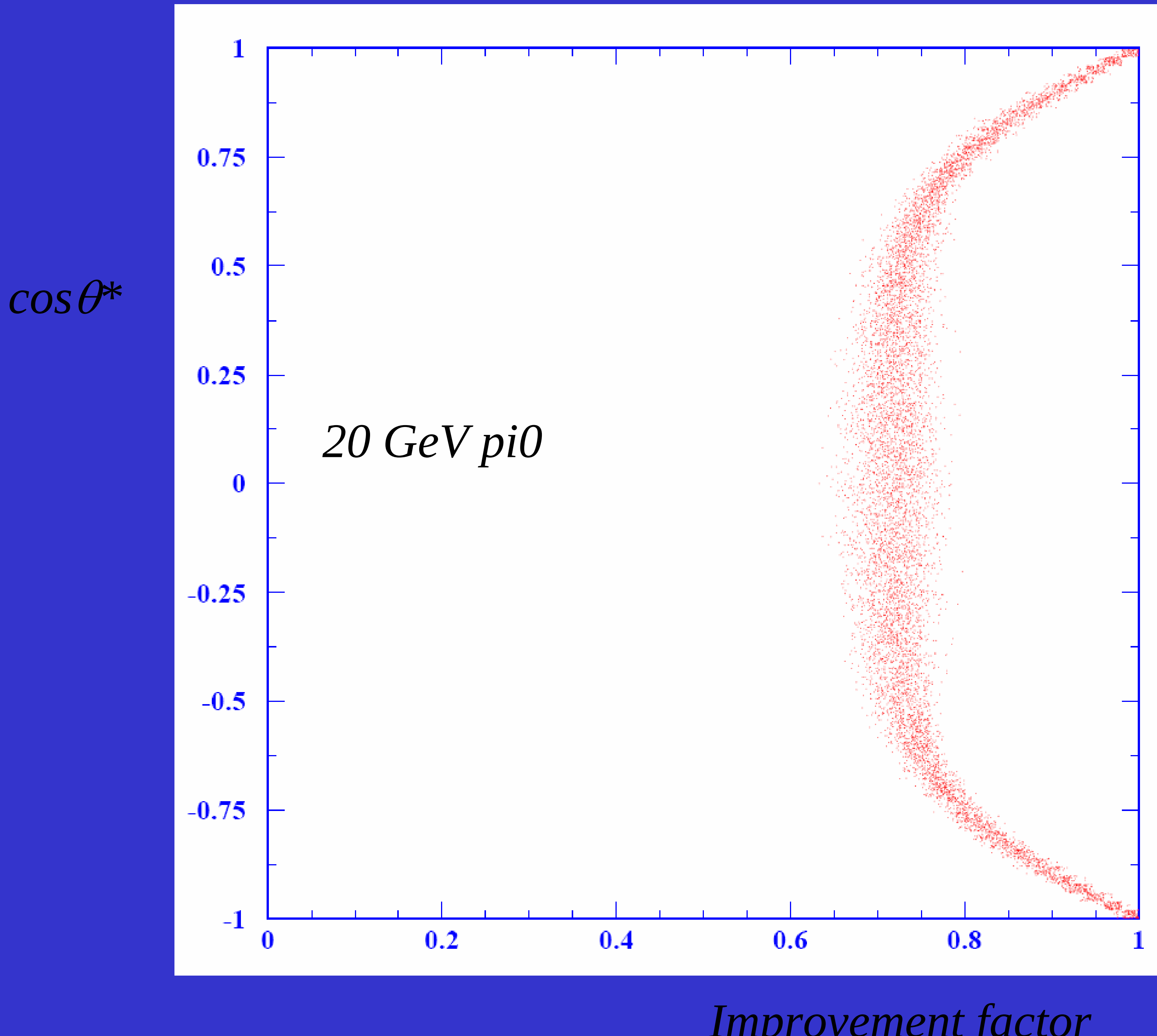
DRAMATIC IMPROVEMENT

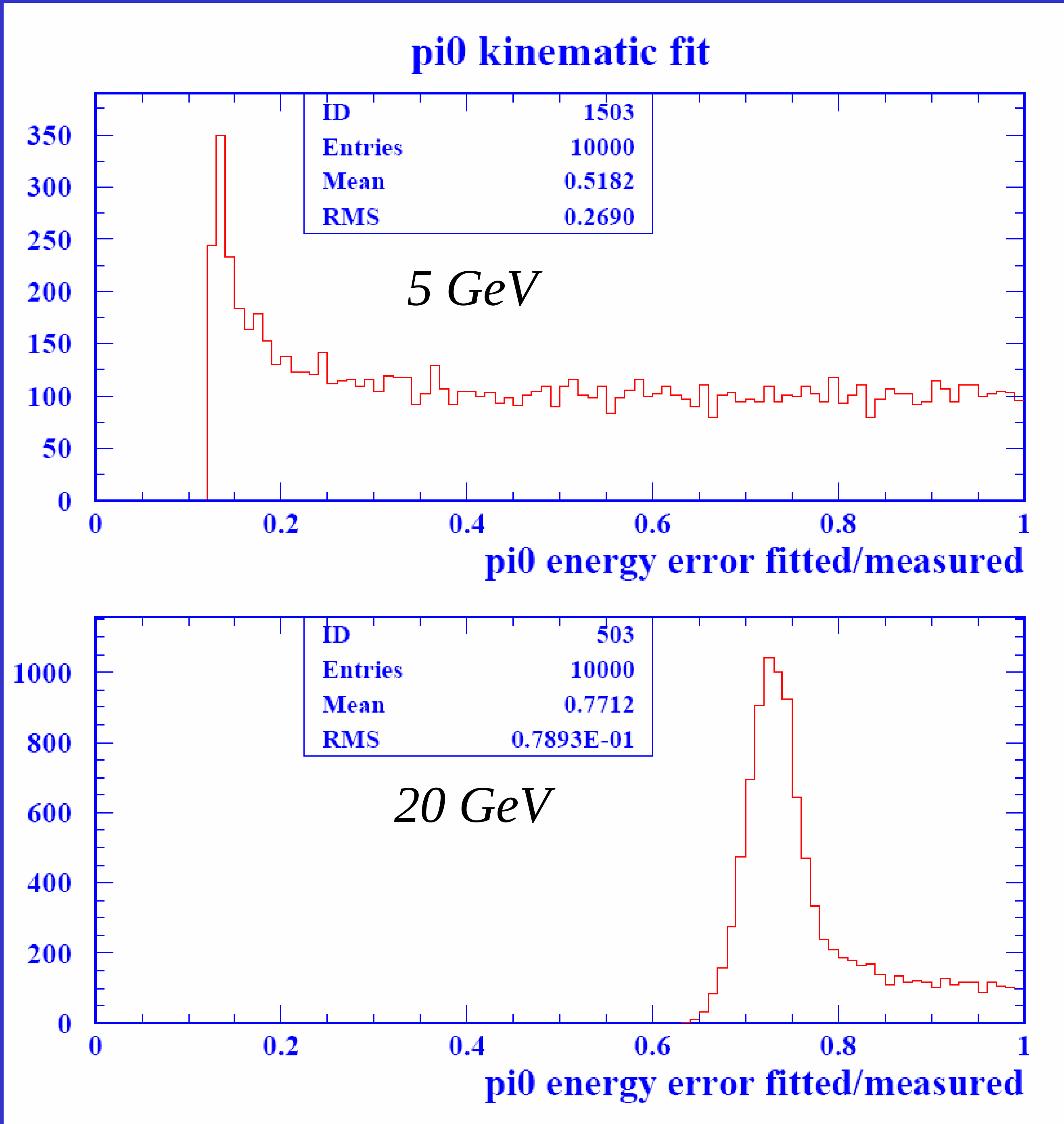
But this plot is not really a good representation of what is going on.



Now, will use the π^0 energy error ratio (fitted/measured) as the estimator of the improvement.


5 GeV
pi0 kinematic fit
costhCM
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
pi0 energy error fitted / measured


$\cos\theta^*$
20 GeV pi0
Improvement factor
1
0.75
0.5
0.25
0
-0.25
-0.5
-0.75
-1
0
0.2
0.4
0.6
0.8
1

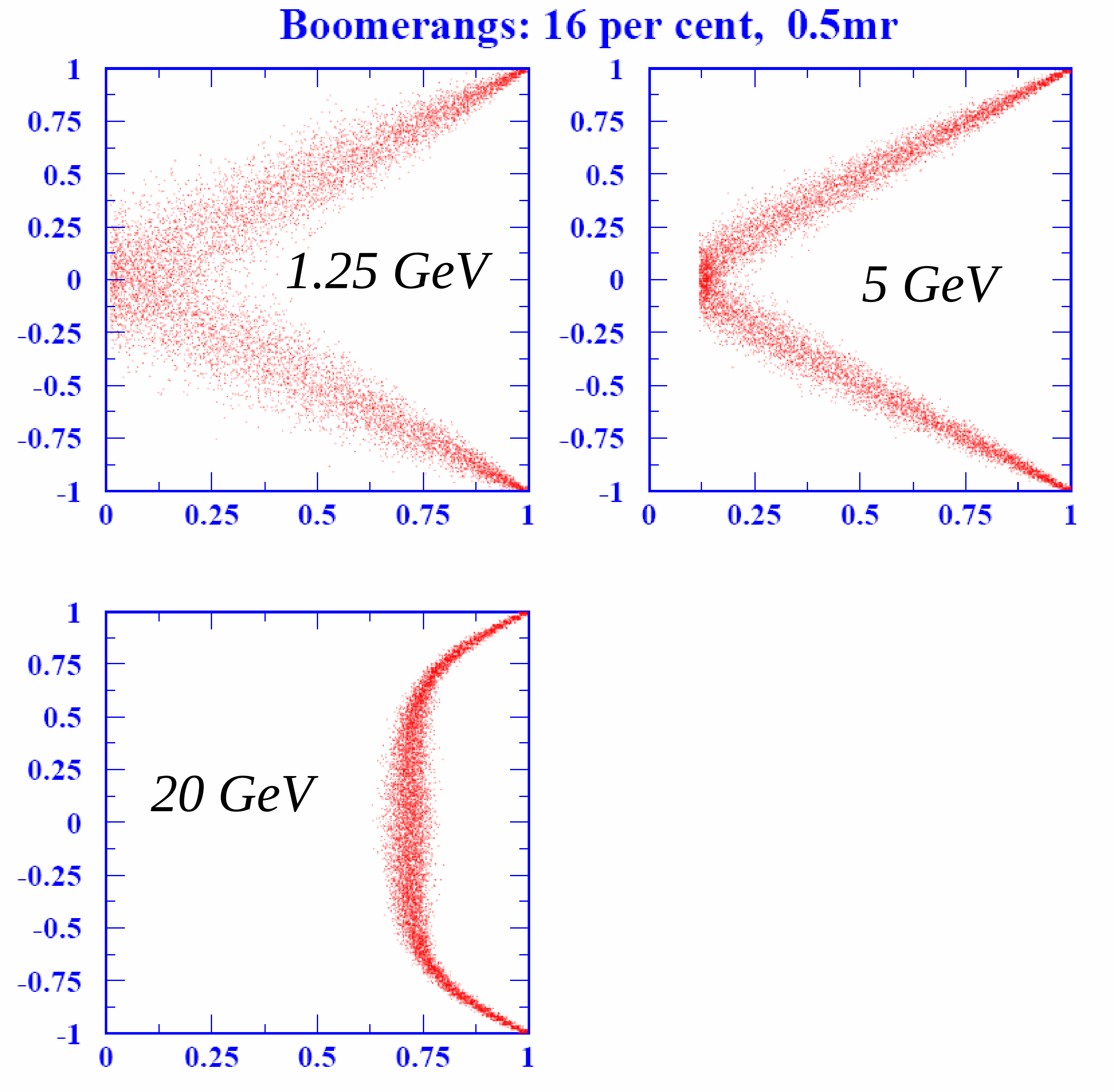


Improvement by up to a factor of 7 !

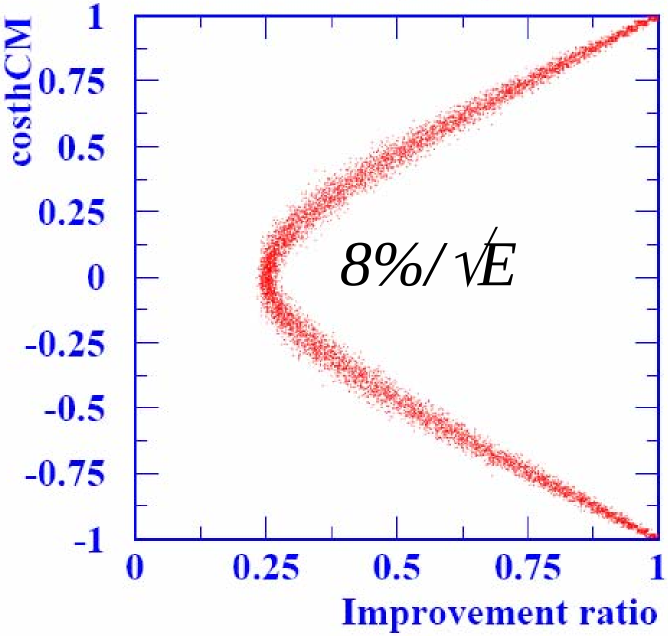
On average factor of 2.

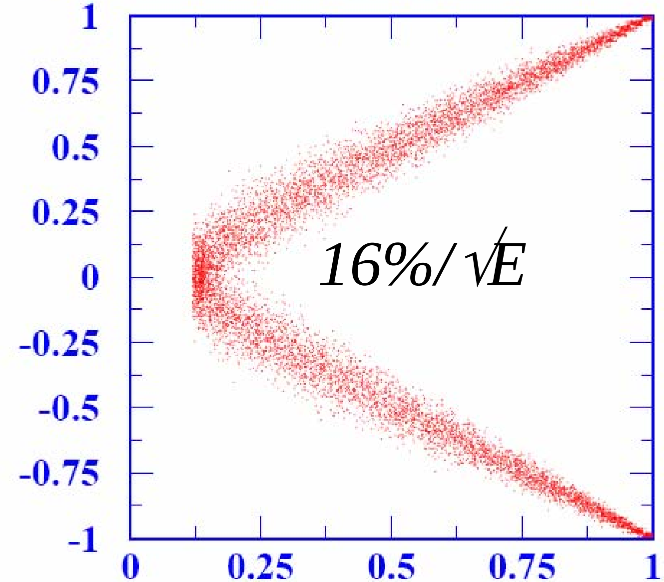
Improves by a factor of 1.3 on average.

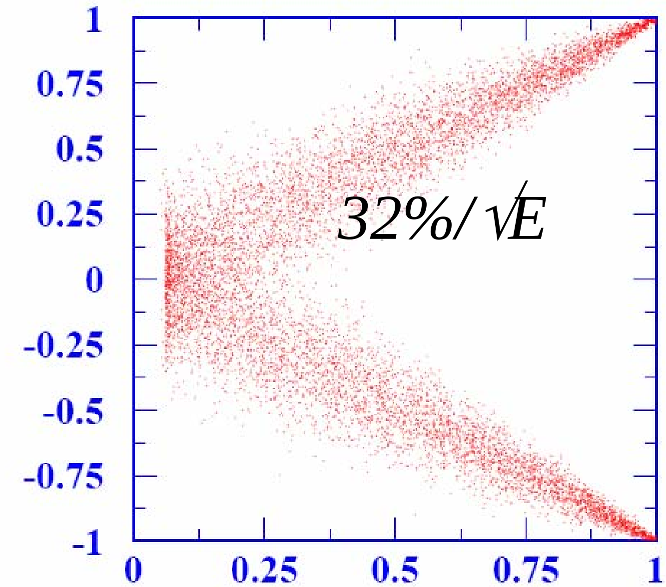
Dependence on π^0 energy



Varying Energy Resolution 11,21,31







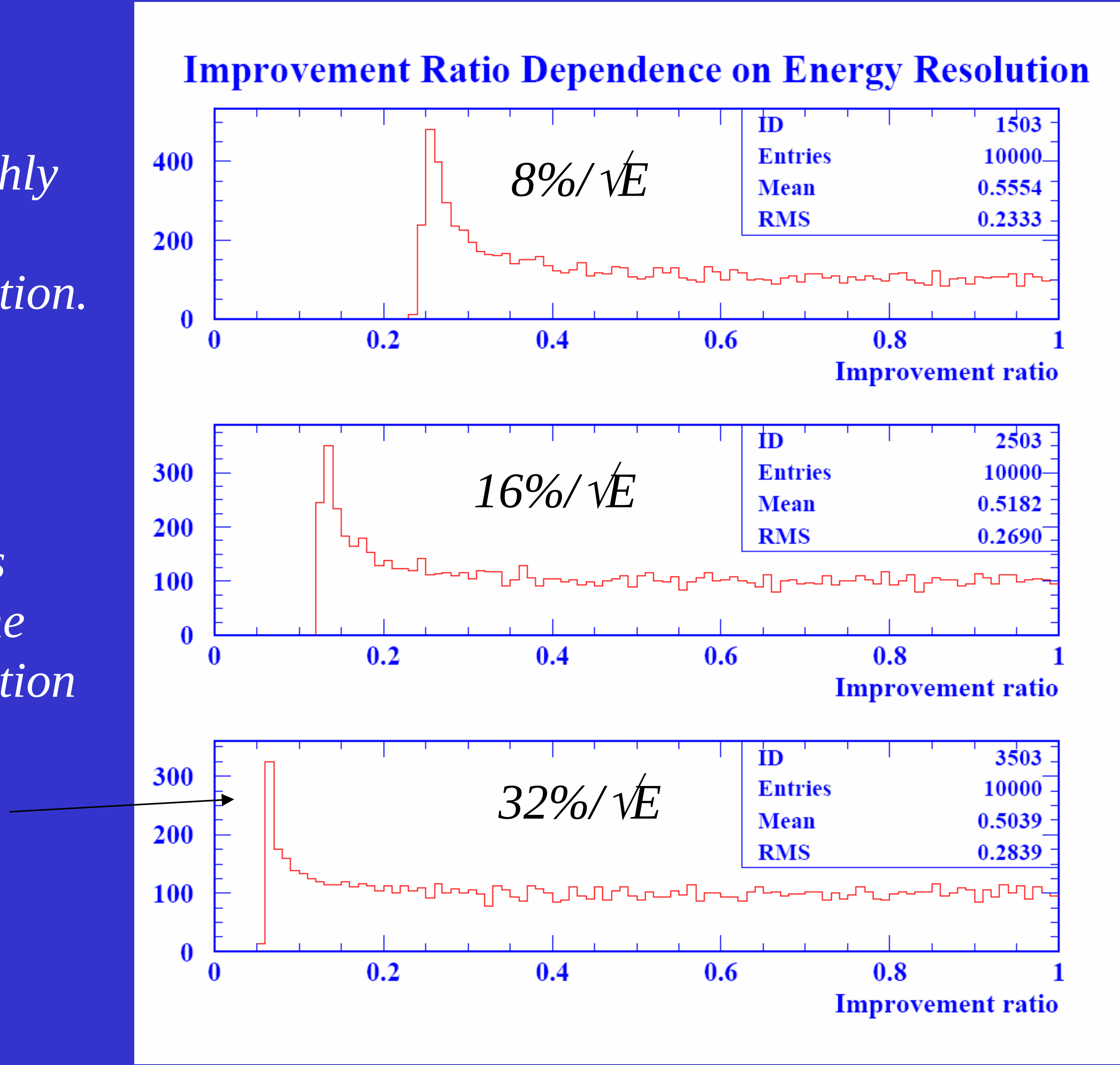
Improvement factor (x-projection) ***DOES*** *depend on Energy resolution (for this π^0)*

- But on average the dependence is only weak (see next slide)

This slide has been corrected from that in the original presentation

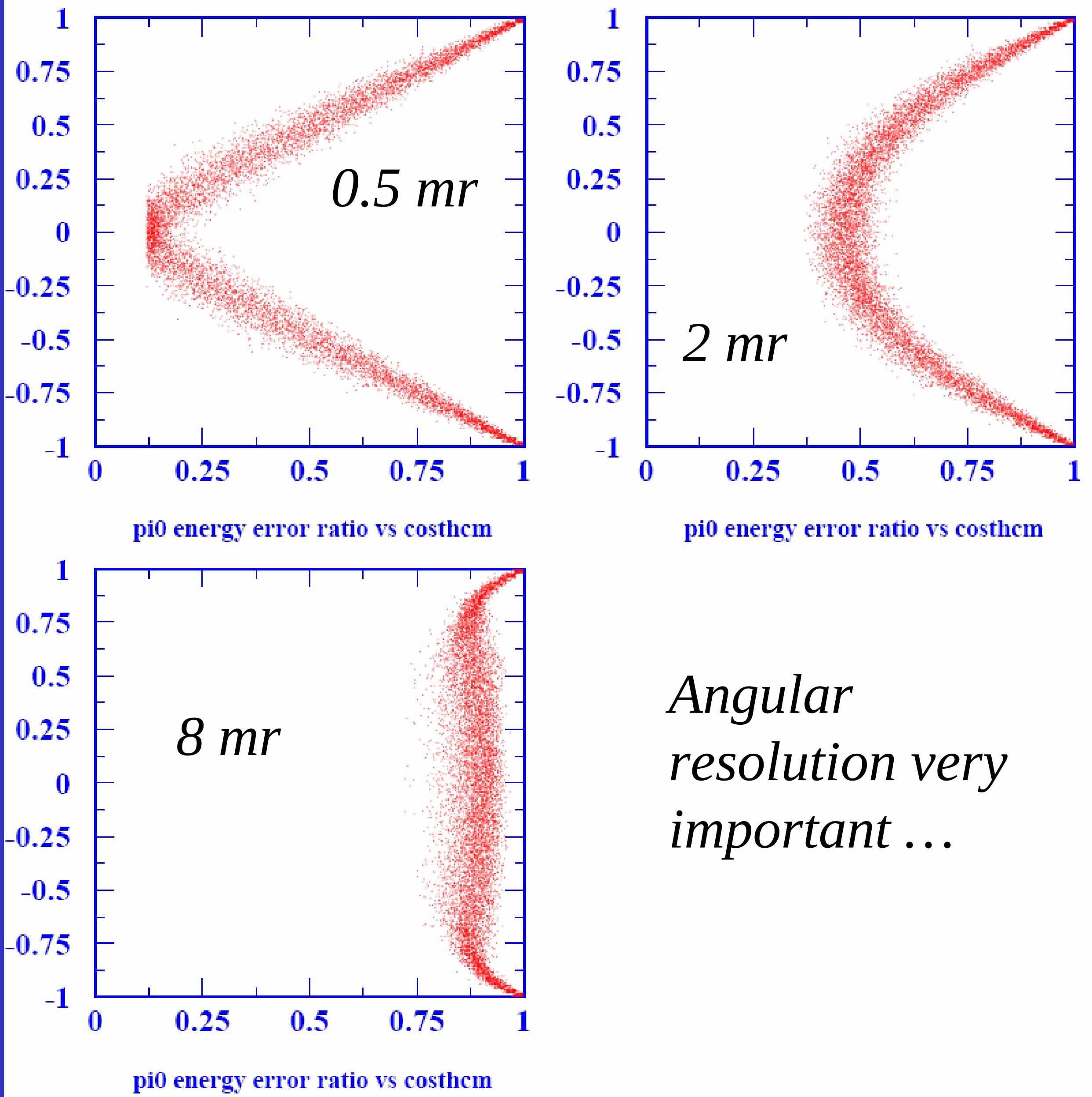
Average improvement factor not highly dependent on energy resolution.

BUT the maximum possible improvements increase as the energy resolution is degraded.



This slide has been added

5 GeV pi0, 16%, vary ang resolution



Angular resolution very important …

Summary

- Proof of principle of kinematic fit for π^0 reconstruction done.
  - Kinematic fit infrastructure now a solid foundation.
  - Well understood errors on each π^0.
- Still lots of work to do to assess impact on jet energies in a realistic situation.
- Potential for a factor of two improvement in the energy resolution of the EM components of jets.

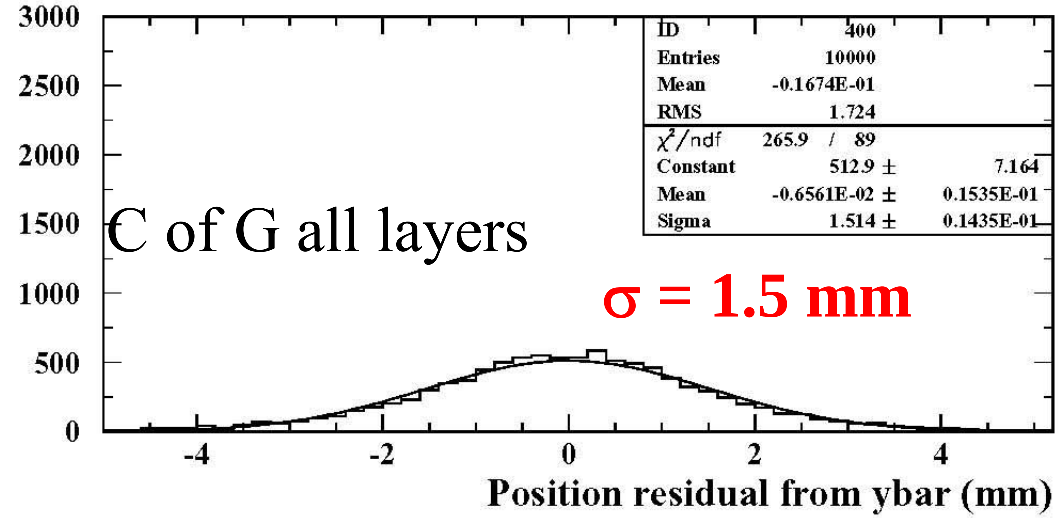
Backups

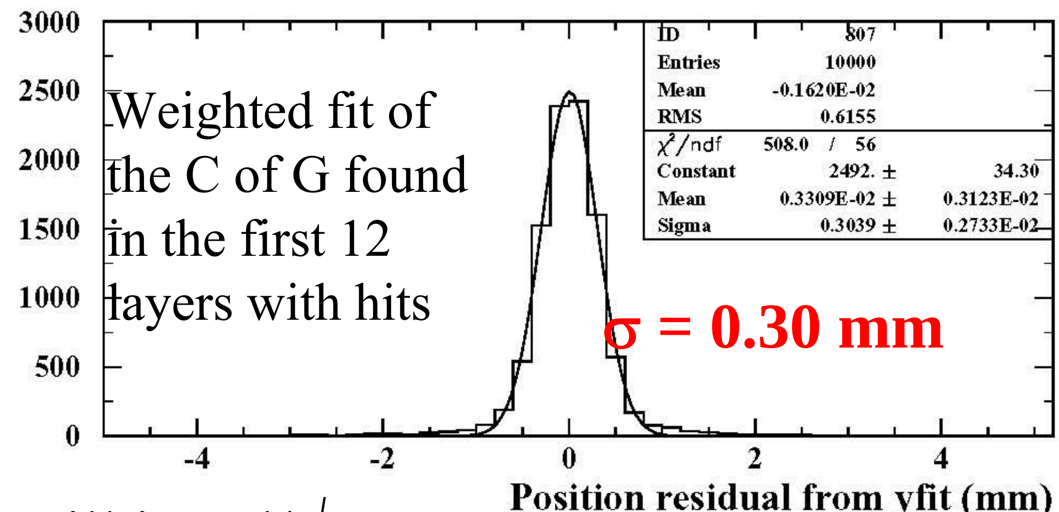
Position resolution from simple fit

1 GeV photon, G4 study (GWW)

Neglect layer 0 (albedo)

Using the first 12 layers with hits with E>180 keV, combine the measured C of G from each layer using a least-squares fit (errors varying from 0.32mm to 4.4mm). Iteratively drop up to 5 layers in the "track fit".





*Position resolution does indeed improve by a factor of **5** in a realistic 100% efficient algorithm!*

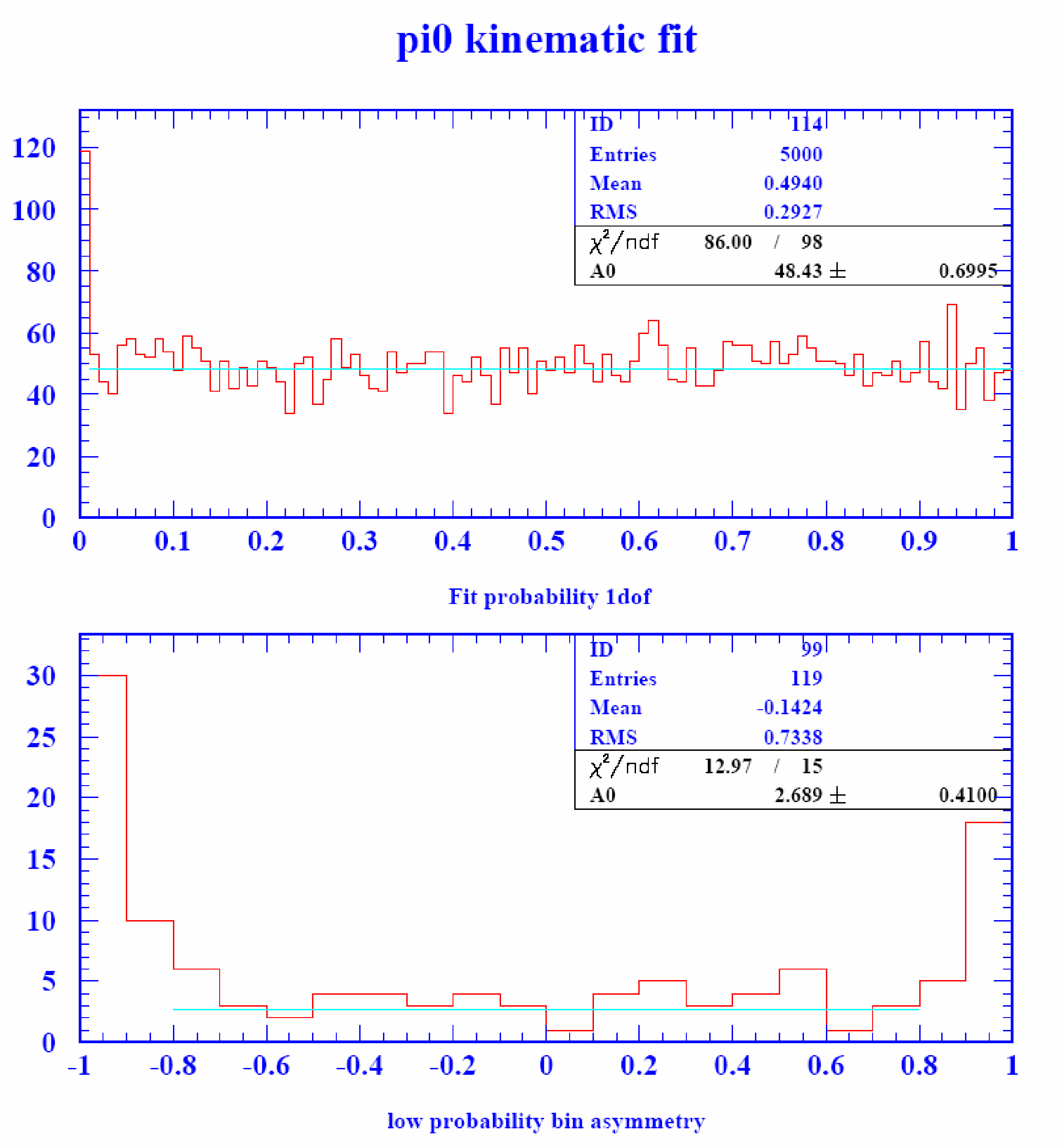
Still just d/√12 !

Old Fit quality

Probability distribution flat (as expected).

$a = (E_1 - E_2)/(E_1 + E_2)$

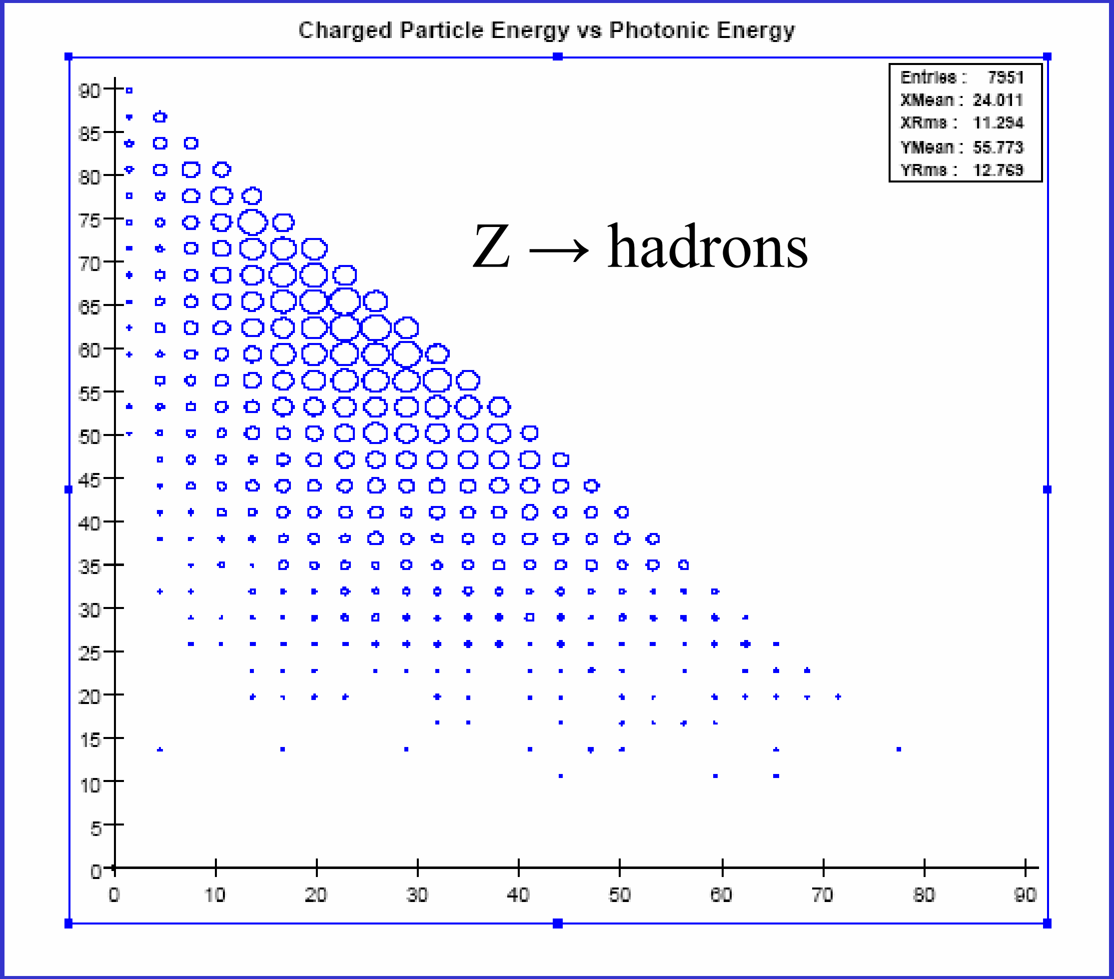
Spike at low probability corresponds to asymmetric decays ($|a| \approx 1$). I think I need to iterate using the fitted values for the error estimation ….



PFA "Dalitz" Plot

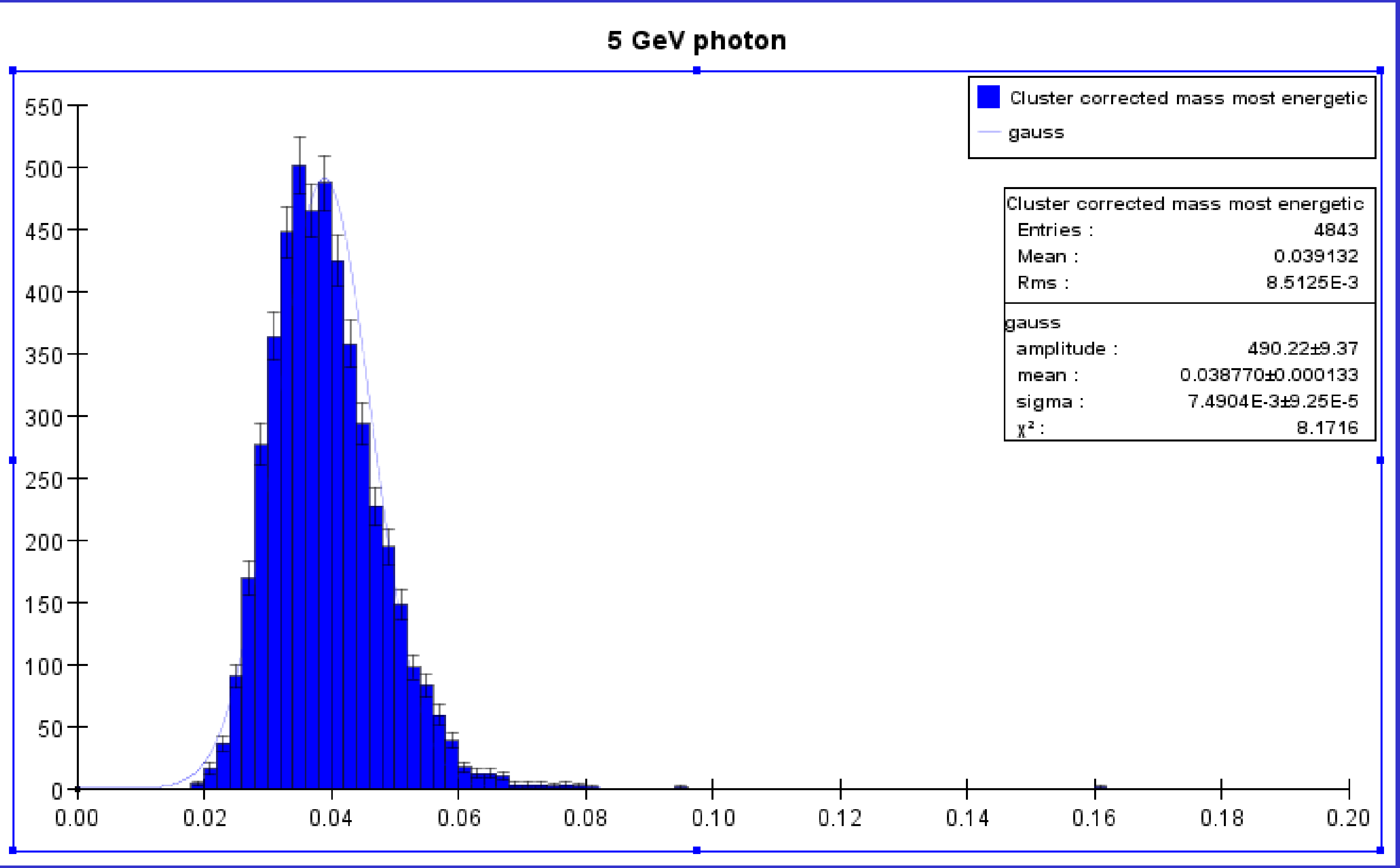
Also see: http://heplx3.phsx.ku.edu/~graham/lcws05_slacconf_gwwilson.pdf

"On Evaluating the Calorimetry Performance of Detector Design Concepts", for an alternative detector-based view of what we need to be doing.



On average, photonic energy only about 30%, but often much greater.

Cluster Mass for Photons



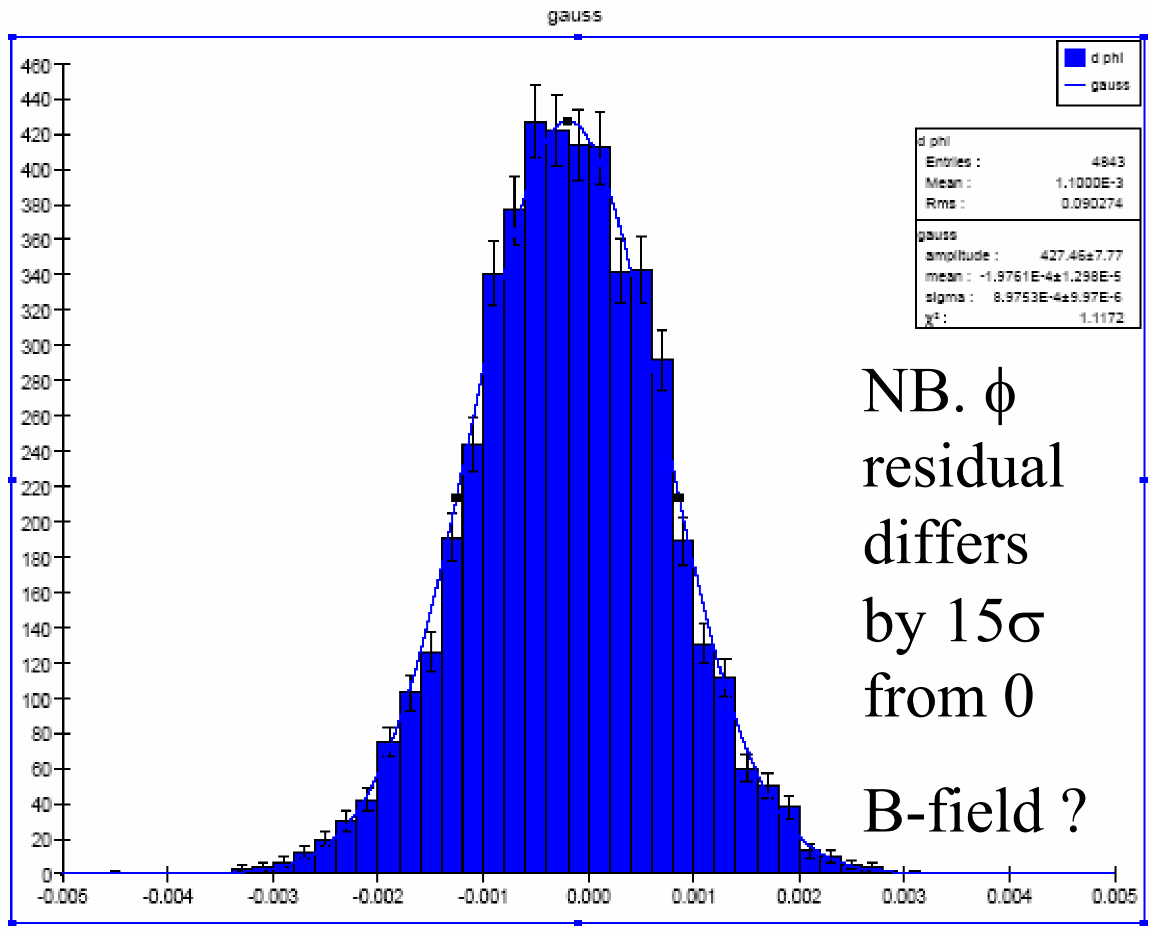
Cluster Mass (GeV)

Angular Resolution Studies

5 GeV photon at 90°, sidmay05 detector.

Phi resolution of 0.9 mrad ***just*** using cluster CoG.

=> θ_{12} resolution of 2 mrad is reasonable for spatially resolved photons.



NB. ϕ residual differs by 15σ from 0

B-field ?

NB Previous study (see backup slide, shows that a factor of 5 improvement in resolution is possible, (using 1mm pixels !) at fixed R)

γ, π^0, η^0 rates measured at LEP

	Experimental results				JETSET 7.4	HERWIG 5.9
	OPAL	ALEPH [6]	DELPHI [9]	L3 [10–12]		
photon						
x_E range	0.003-1.000	0.018-0.450				
N_γ in range	16.84 ± 0.86	7.37 ± 0.24				
N_γ all x_E	20.97 ± 1.15				20.76	22.65
π^0						
x_E range	0.007-0.400	0.025-1.000	0.011-0.750	0.004-0.150		
N_{π^0} in range	8.29 ± 0.63	4.80 ± 0.32	7.1 ± 0.8	8.38 ± 0.67		
N_{π^0} all x_E	9.55 ± 0.76	9.63 ± 0.64	9.2 ± 1.0	9.18 ± 0.73	9.60	10.29
η						
x_E range	0.025-1.000	0.100-1.000		0.020-0.300		
N_η in range	0.79 ± 0.08	0.282 ± 0.022		0.70 ± 0.08		
N_η all x_E	0.97 ± 0.11			0.91 ± 0.11	1.00	0.92
N_η $x_p > 0.1$	0.344 ± 0.030	0.282 ± 0.022			0.286	0.243

Consistent with JETSET tune where 92% of photons come from π^0's.

Some fraction is non-prompt, from K^0_S, Λ decay

9.6 π^0 per event at Z pole

Investigating π^0 Kinematic Fits

- Standard technique for π^0's is to apply the mass constraint to the measured $\gamma\gamma$ system.
- Setting aside for now the combinatoric assignment problem in jets, I decided to look into the potential improvement in π^0 energy measurement.
- In contrast to "normal ECALs", the Si-W approach promises much better measurement of the $\gamma\gamma$ opening distance, and hence the opening angle at fixed R. This precise $\theta_{\gamma\gamma}$ measurement therefore potentially can be used to improve the π^0 energy resolution.
- How much ?, and how does this affect the detector concepts ?

Methodology

- Wrote toy MC to generate 5 GeV π^0 with usual isotropic CM decay angle ($dN/d\cos\theta^* = 1$).
- Assumed photon energy resolution (σ_E/E) of $16\%/\sqrt{E}$.
- Assumed γ–γ opening angle resolution of 2 mrad.
- Solved analytically from first principles, the constrained fit problem under the assumption of a diagonal error matrix in terms of (E_1, E_2, $2(1-\cos\theta_{12})$), and with a first order expansion.
  - Note. $m^2 = 2\, E_1\, E_2\, (1 - \cos\theta_{12})$
- π^0 kinematics depends a lot on $\cos\theta^*$. Useful to define the energy asymmetry, $a \equiv (E_1-E_2)/(E_1+E_2) = \cos\theta^*$.

π^0 mass resolution

- Can show that for $\sigma_E/E = c_1/\sqrt{E}$ that
  $\Delta m/m = c_1 /\sqrt{[(1-a^2)\, E_{\pi^0}]} \oplus 3.70\, \Delta\theta_{12} E_{\pi^0} \sqrt{(1-a^2)}$

  So the mass resolution has 2 terms
  i) depending on the EM energy resolution
  ii) depending on the opening angle resolution

  The relative importance of each depends on ($E_{\pi 0}$, a)

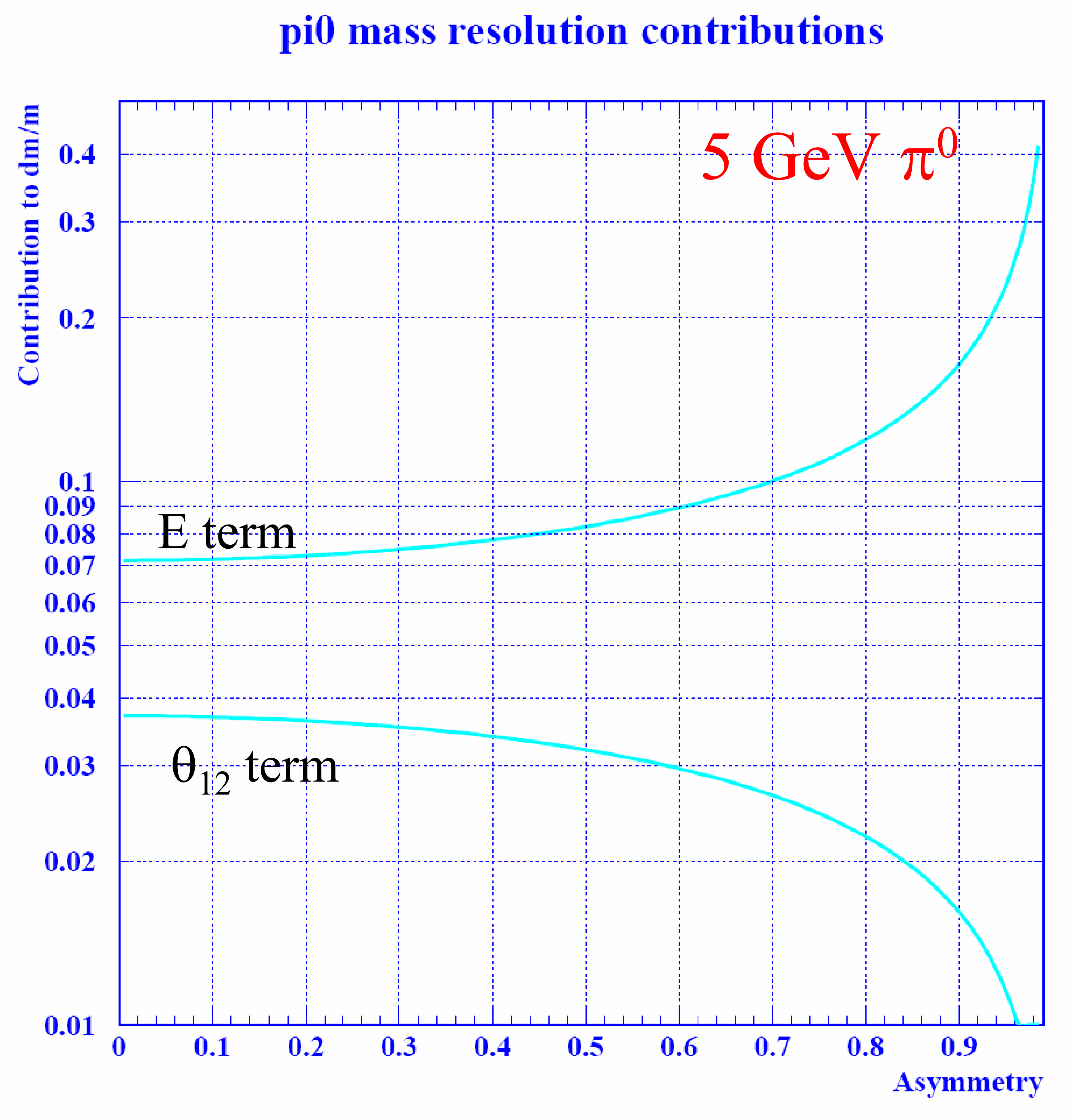
π^0 mass resolution

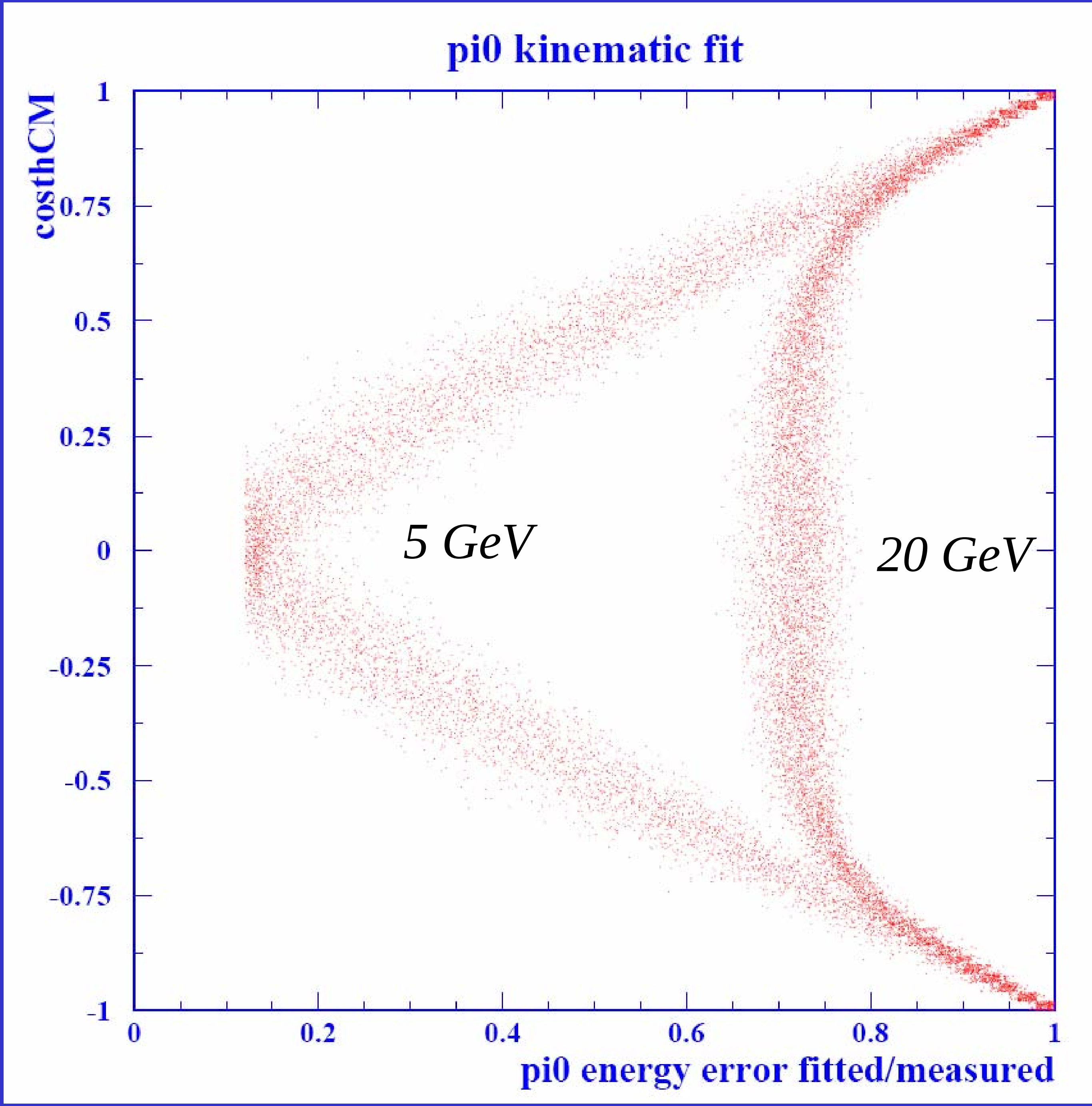
Plots assume:

$c_1 = 0.16$ (SiD)

$\Delta\theta_{12} = 2$ mrad

For these detector resolutions, 5 GeV π^0 mass resolution dominated by the E term





5 GeV and 20 GeV curves are superimposed.