LCDRD Proposal Title was :

Investigation of ECAL Concepts Designed for Particle Flow

Today:

(G4 response …)

E, position resolution

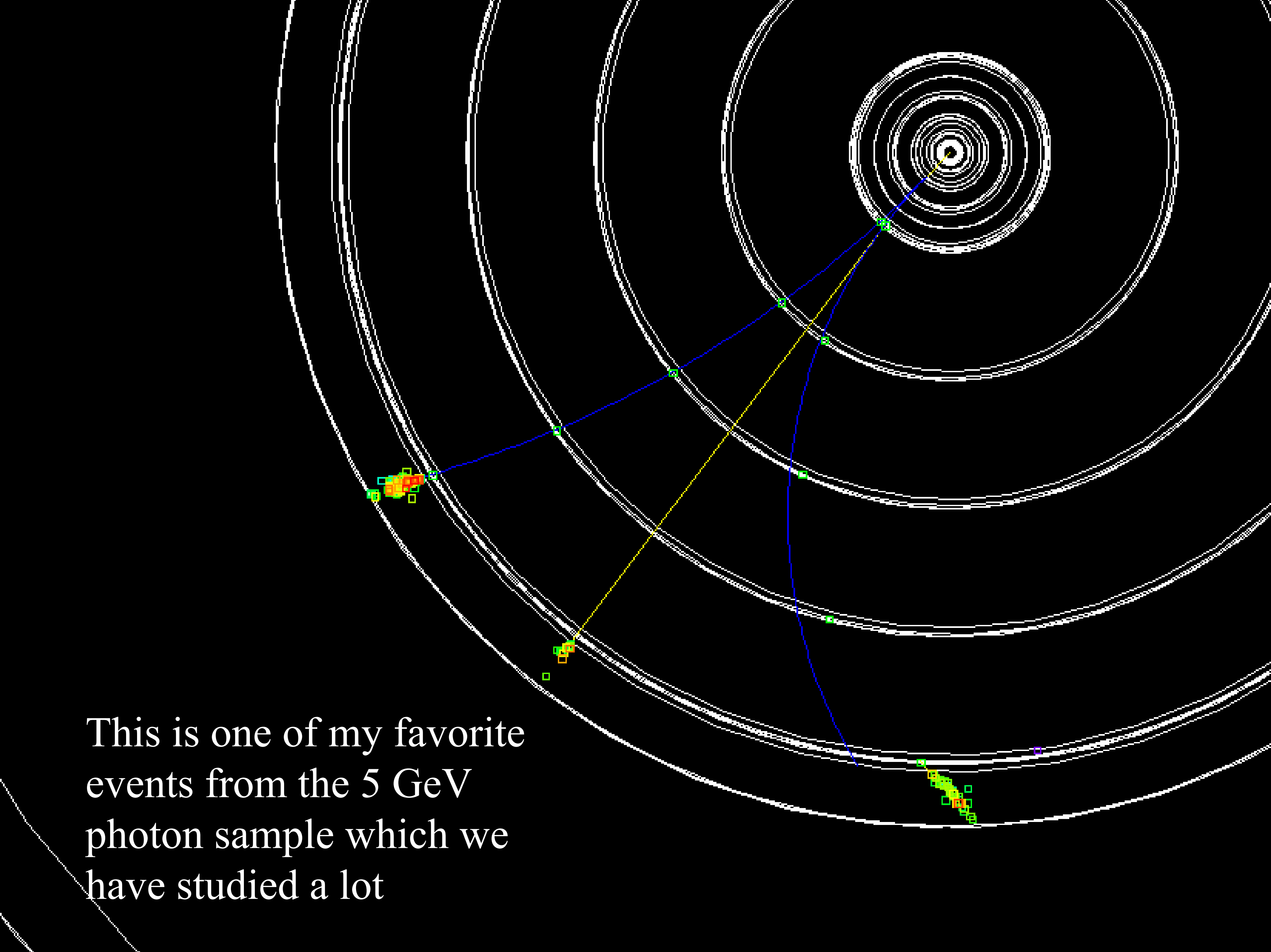
Clustering

H-Matrix

π^0 1-C Fit

Emphasis for now is on using and contributing to development of existing software with medium-term goals of detector optimization. At the calorimeter level, interested in all 3 concepts

Eric Benavidez, Graham W. Wilson, Univ. of Kansas



This is one of my favorite events from the 5 GeV photon sample which we have studied a lot

(GEANT4)

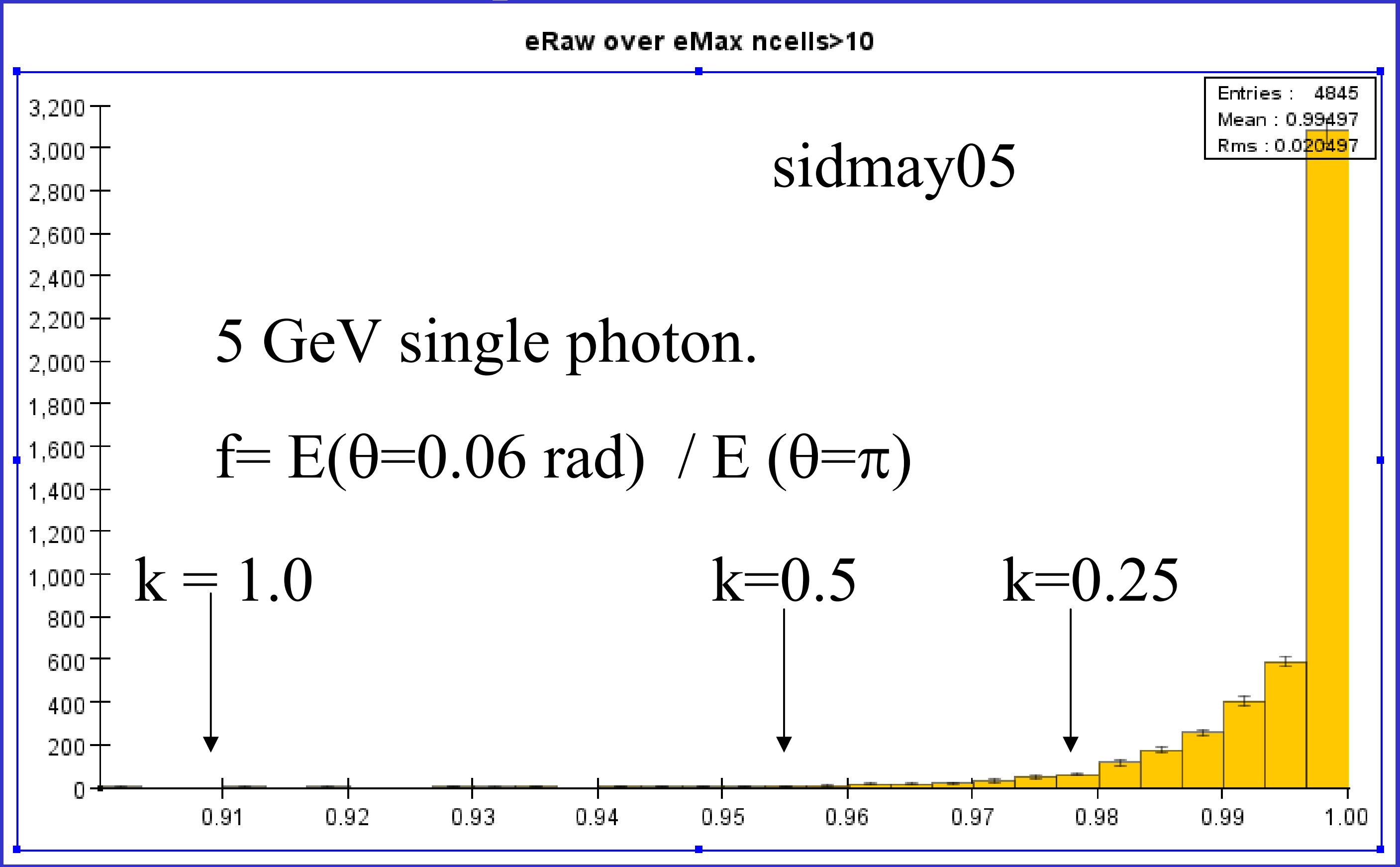
- Reminder that the ECAL resolution is too large in at least some of the simulations that have been carried out.
- See http://heplx3.phsx.ku.edu/~graham/sid_ECAL_G4.pdf
- Not sure what the status is on this, but I suspect it’s still not really resolved ? Could be mitigated by burning lots of CPU ….

Clustering Studies (Eric)

- See writeup and code at http://heplx3.phsx.ku.edu/~eric/project-code/
- Using Fixed Cone and Nearest-Neighbor Clusterers. Studies of parameters for photon-finding.
  - Reject conversions before ECAL in studies
- Energy and position resolution studies.
- Transverse discriminants.
  - mass

Fixed Cone Clustering

We measured a clustering "efficiency" for a given cone angle, as the fraction of photons which resulted in at most k σ of the actual deposited energy escaping the cone, where σ is the expected EM resolution.



For $\sigma/E = 20\%/\sqrt{E}$,

$k = 0.25$, corresponds to $f > 0.978$

Fixed Cone Clustering

We measured a clustering "efficiency" for a given cone angle, as the fraction of photons which resulted in at most k σ of the actual deposited energy escaping the cone, where σ is the expected EM resolution.

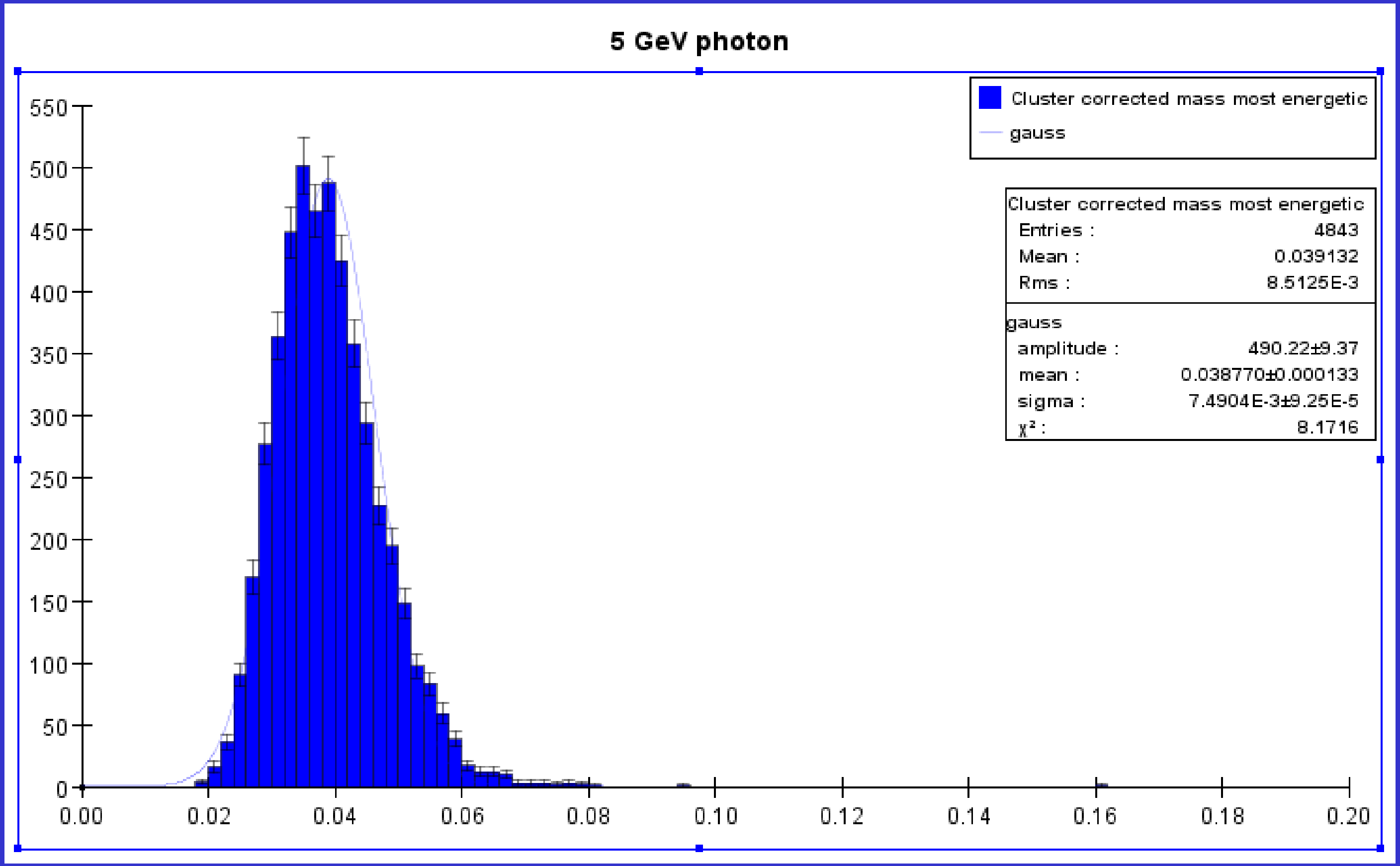
For photons, fixed cone algorithm:

Opening angle (rad)	k	Efficiency (%)	Energy (GeV)	σ (GeV)
0.03	0.10	16.5 ± 0.5	4.891 ± 0.007	0.441 ± 0.005
	0.25	44.7 ± 0.7		
	0.50	80.4 ± 0.6		
	1.00	98.72 ± 0.16		
0.06	0.10	81.7 ± 0.6	5.012 ± 0.007	0.448 ± 0.005
	0.25	96.2 ± 0.3		
	0.50	99.34 ± 0.12		
	1.00	99.88 ± 0.05		
0.09	0.10	91.3 ± 0.4	5.025 ± 0.007	0.445 ± 0.005
	0.25	98.64 ± 0.17		
	0.50	99.67 ± 0.08		
	1.00	99.92 ± 0.04		

Suggests a cone angle of 60 mrad to avoid deleterious effects on single EM particles.

For PFA application, a tighter cone is needed ?

Cluster Mass for Photons



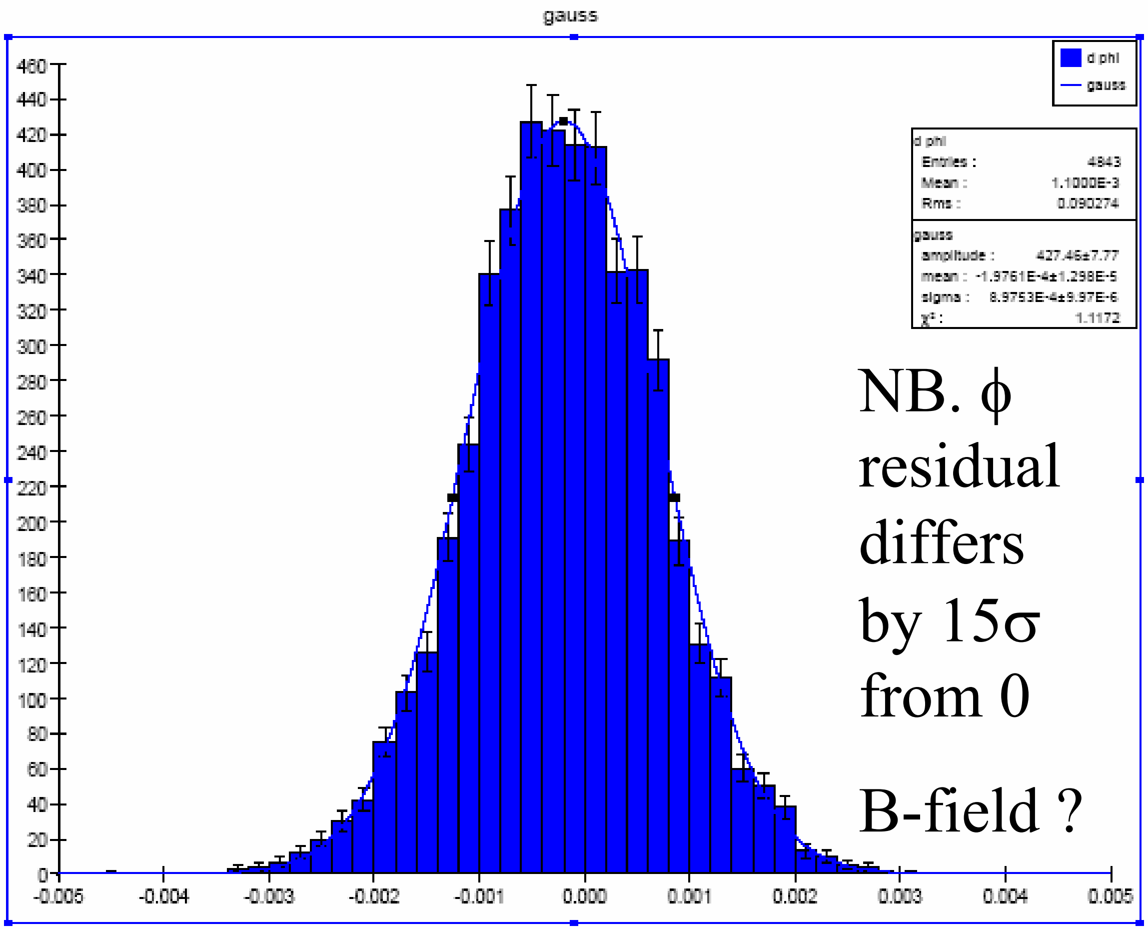
Cluster Mass (GeV)

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 ?

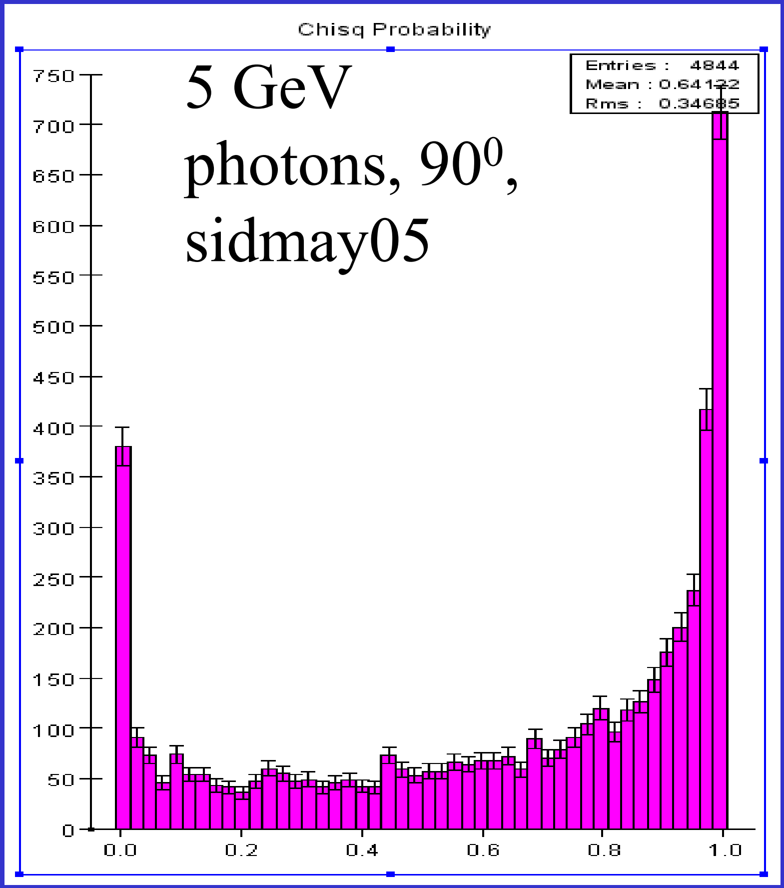
NB Previous study (see backup slide, shows that a factor of 5 improvement in resolution is possible, (using 1mm pixels !) at fixed R)

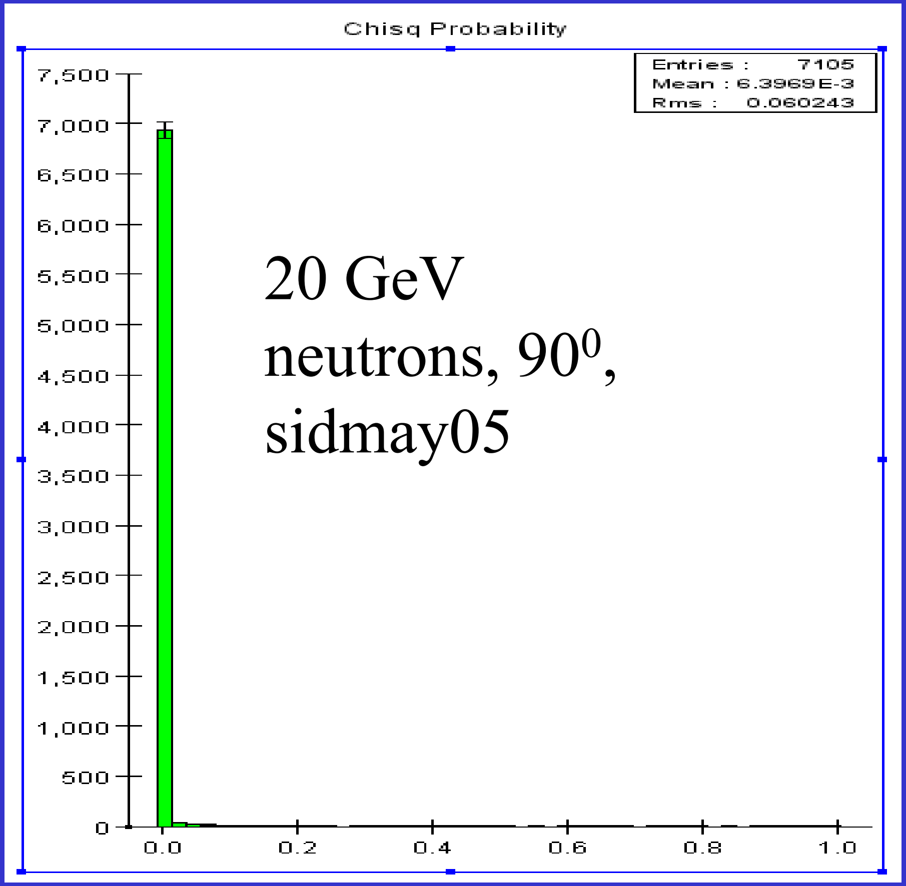
Longitudinal HMatrix

- Developed by Norman Graf.
- Compare observed fractional energy deposition per layer with the average behavior of an ensemble of photons including correlations.
- Current default implementation has a measurement vector with 31 variables: 30 fractional energies per layer and the logarithm of the energy.
- Method: calculate, $\chi^2 = D^T M^{-1} D$ where D is the difference vector, $D = (x_i - x_{ave})$ $(i=0,30)$ and M is the covariance matrix of the 31 variables.
- We're investigating the performance and are in a position to support development of other discriminants using the same technique, eg a transverse HMatrix.
  - Using FixedCone Clustering with θ=60 mrad.
- Currently it's a leading candidate for the photon-ID in the PFA, where high efficiency is a must (also see Steve Kuhlmann's talk).

Hmatrix Performance

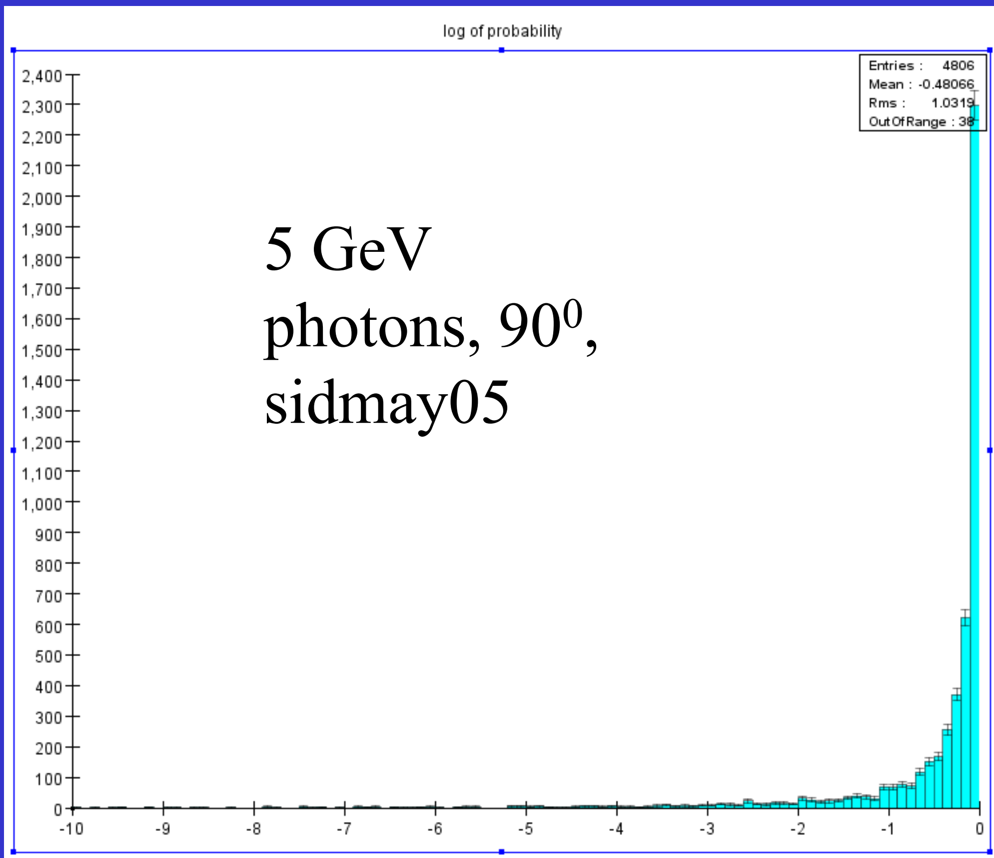
These photons used for evaluating the expected fractions and the covariance matrix, M.

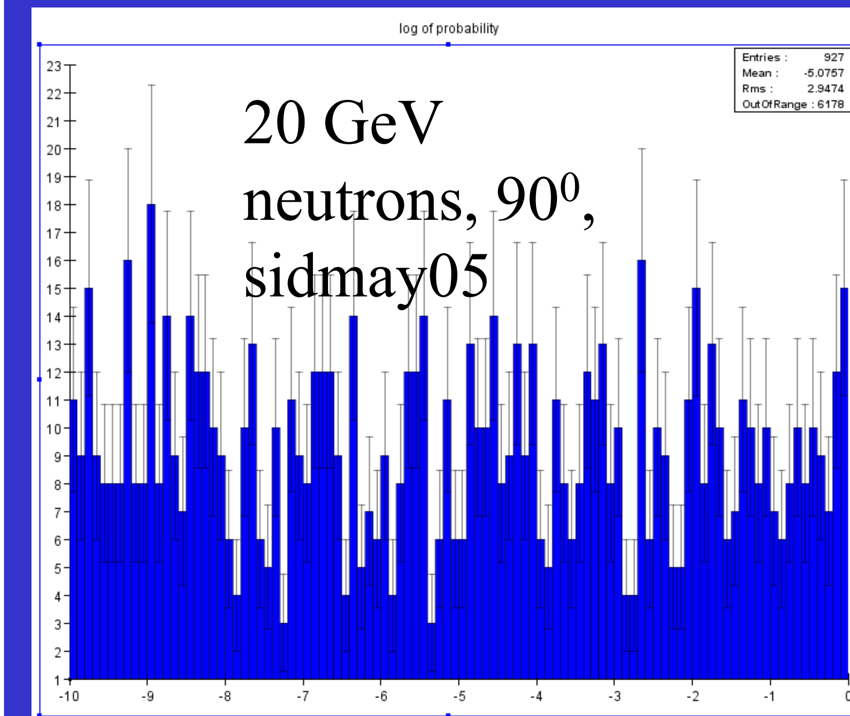




Not perfectly distributed ……………… but a lot of discrimination

Hmatrix Performance





Eg. cut at $p > 10^{-10}$ => eff (γ) = 99.2%, eff (n) = 9.3%

$p > 10^{-5}$ => eff (g) = 98% , eff (n) = 4.6%

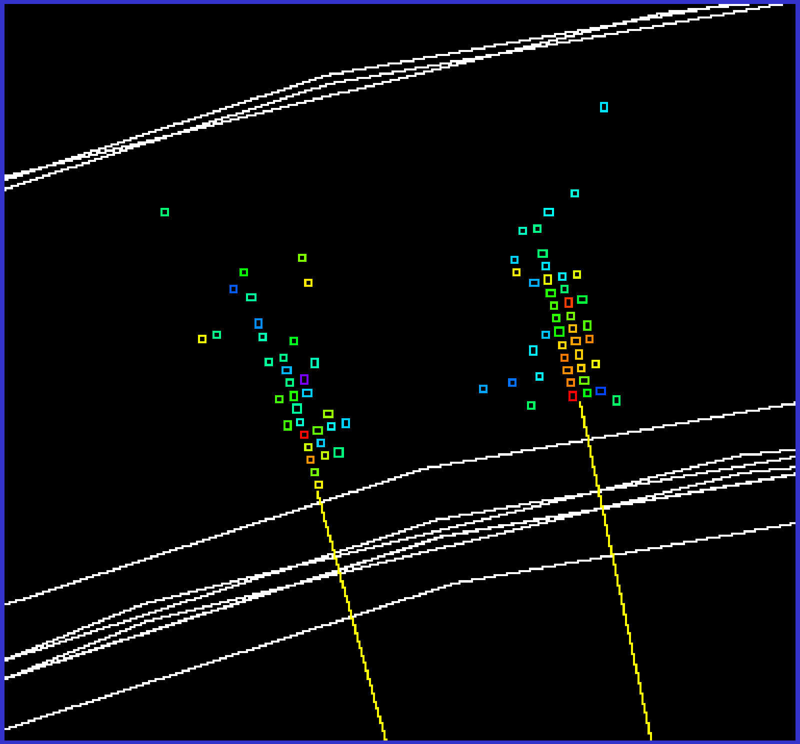
Using π^0 mass constraint to improve particle flow ?

Study prompted by looking at event displays like this one of a 5 GeV π^0 in sidmay05 detector.

Here photon energies are (3.1, 1.9 GeV), and clearly the photons are very well resolved.

Prompt π^0's make up most of the EM component of the jet energy.

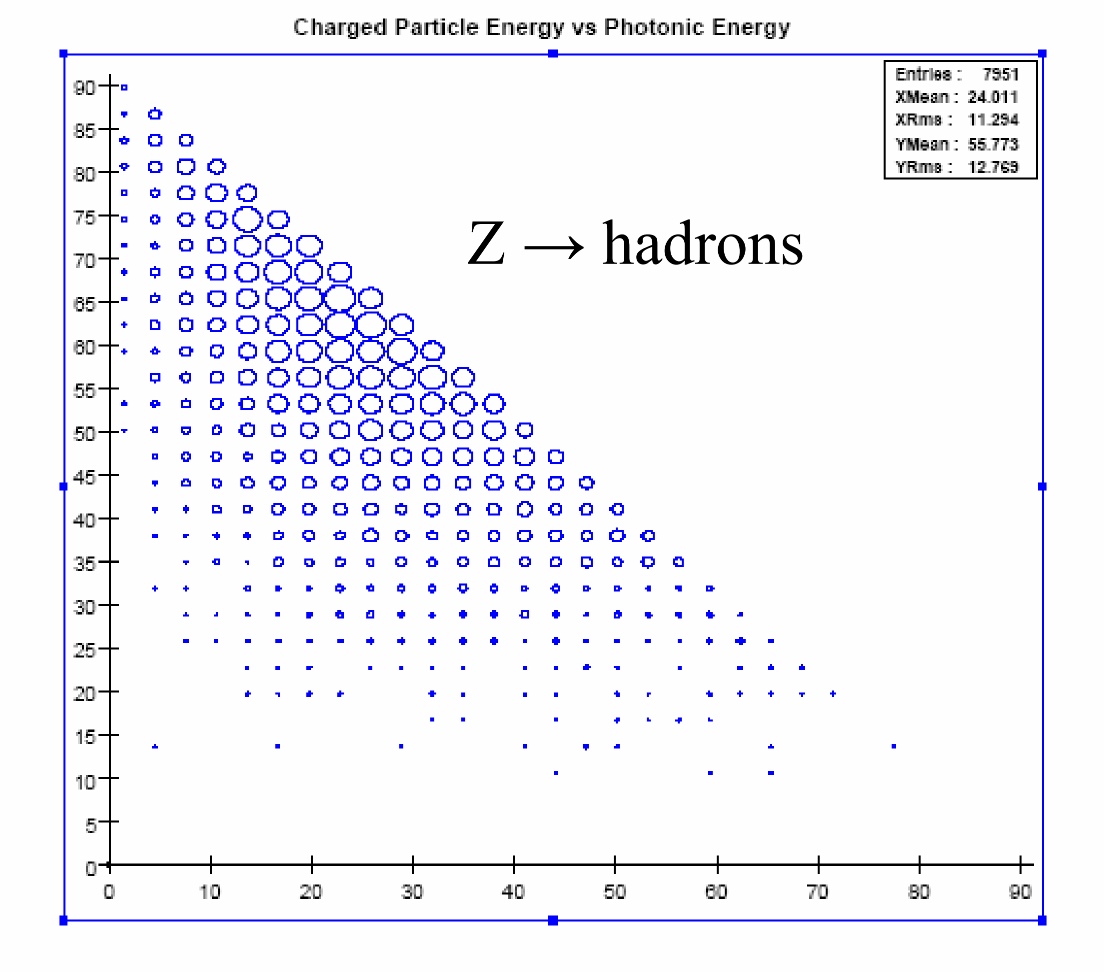
See slides at http://heplx3.phsx.ku.edu/~graham/gww_sid_july27.pdf



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.

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 $\pm$ 0.86	7.37 $\pm$ 0.24				
N_γ all x_E	20.97 $\pm$ 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 $\pm$ 0.63	4.80 $\pm$ 0.32	7.1 $\pm$ 0.8	8.38 $\pm$ 0.67		
N_{π^0} all x_E	9.55 $\pm$ 0.76	9.63 $\pm$ 0.64	9.2 $\pm$ 1.0	9.18 $\pm$ 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 $\pm$ 0.08	0.282 $\pm$ 0.022		0.70 $\pm$ 0.08		
N_η all x_E	0.97 $\pm$ 0.11			0.91 $\pm$ 0.11	1.00	0.92
N_η $x_p > 0.1$	0.344 $\pm$ 0.030	0.282 $\pm$ 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
  $\Delta m/m = c_1 /\sqrt{[(1\text{-}a^2)\, E_{\pi^0}]} \oplus 3.70\, \Delta\theta_{12} E_{\pi^0} \sqrt{(1\text{-}a^2)}$

  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)

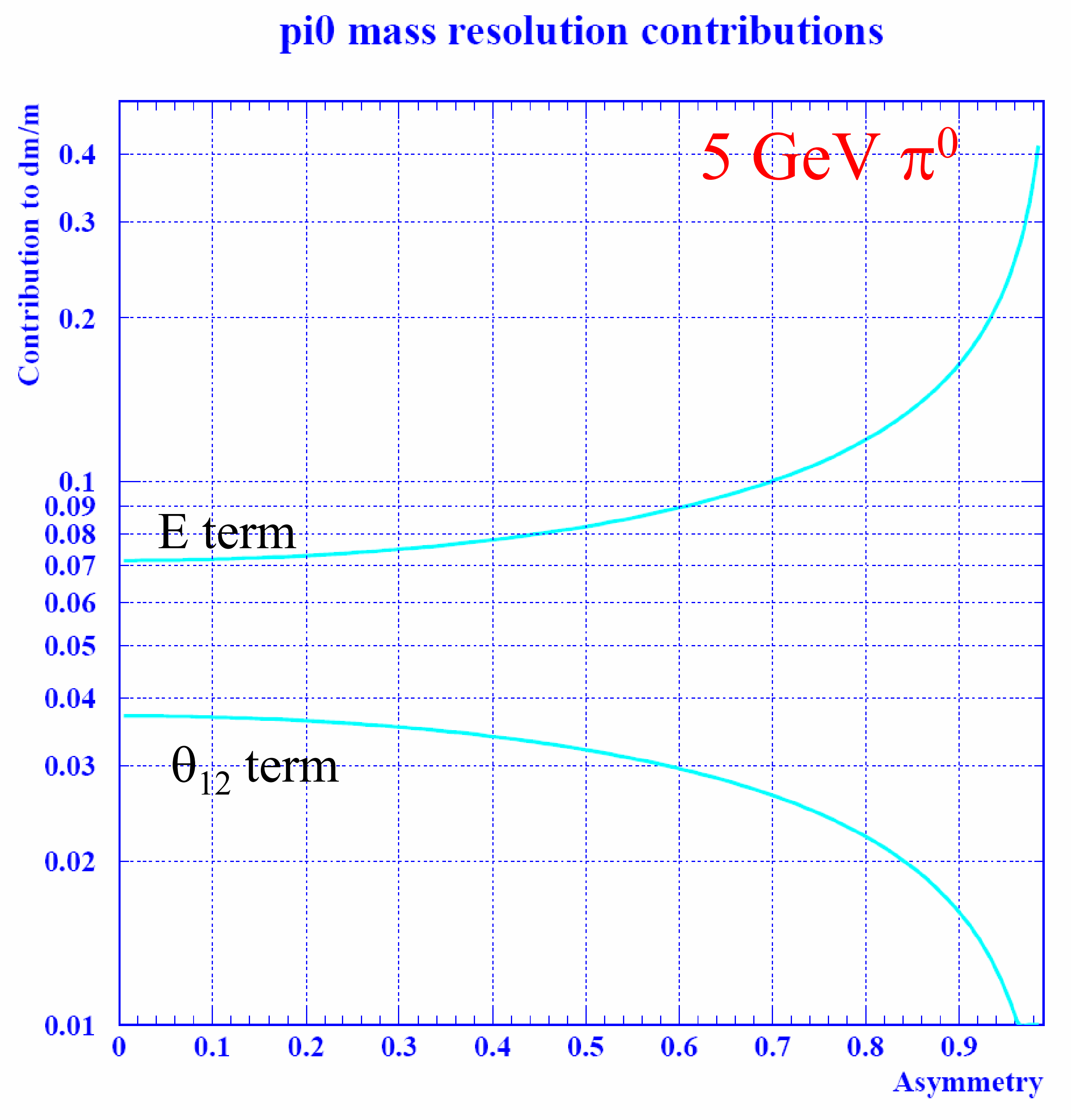
π^0 mass resolution

Plots assume:

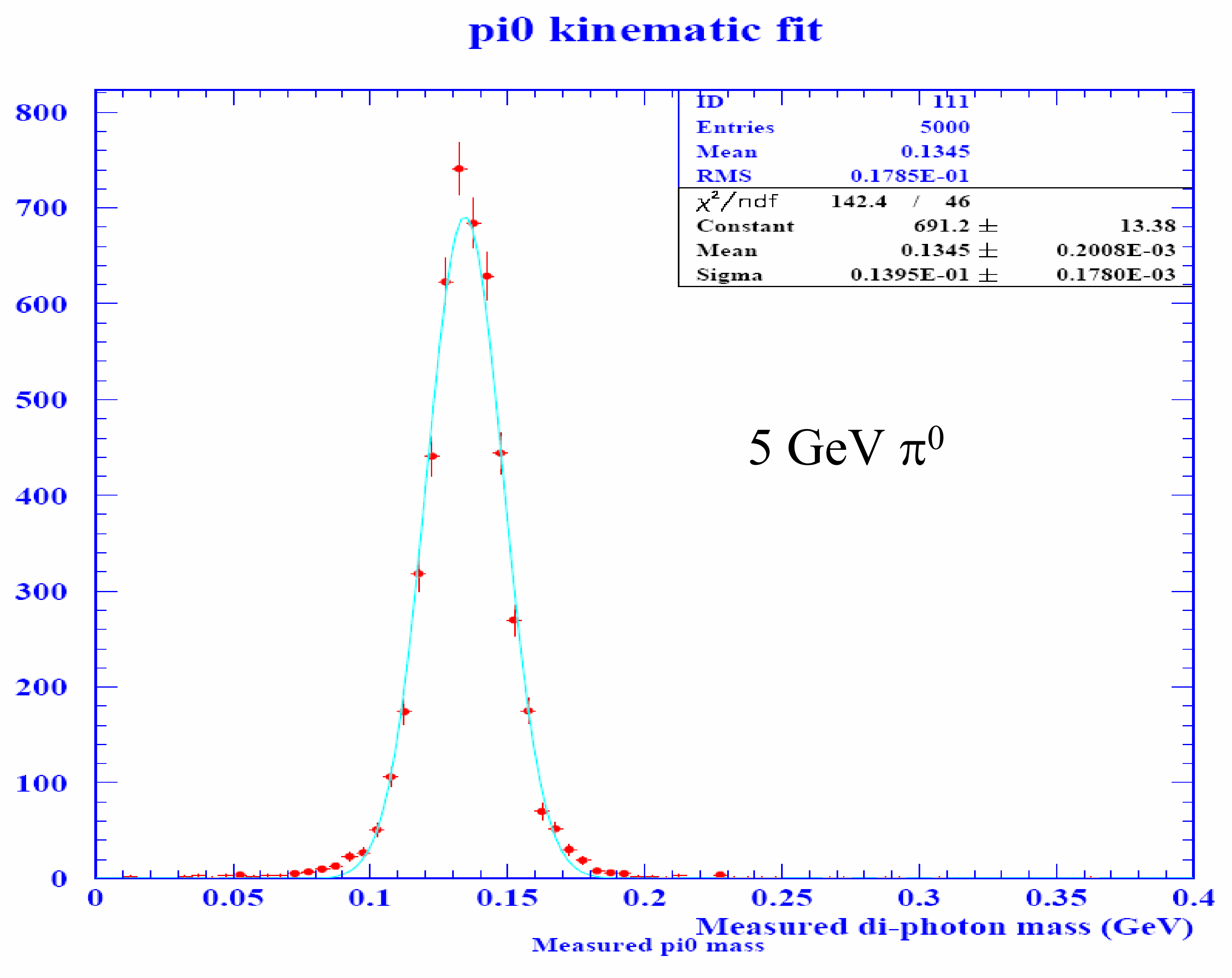
$c_1 = 0.16$ (SiD)

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

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



π^0 mass

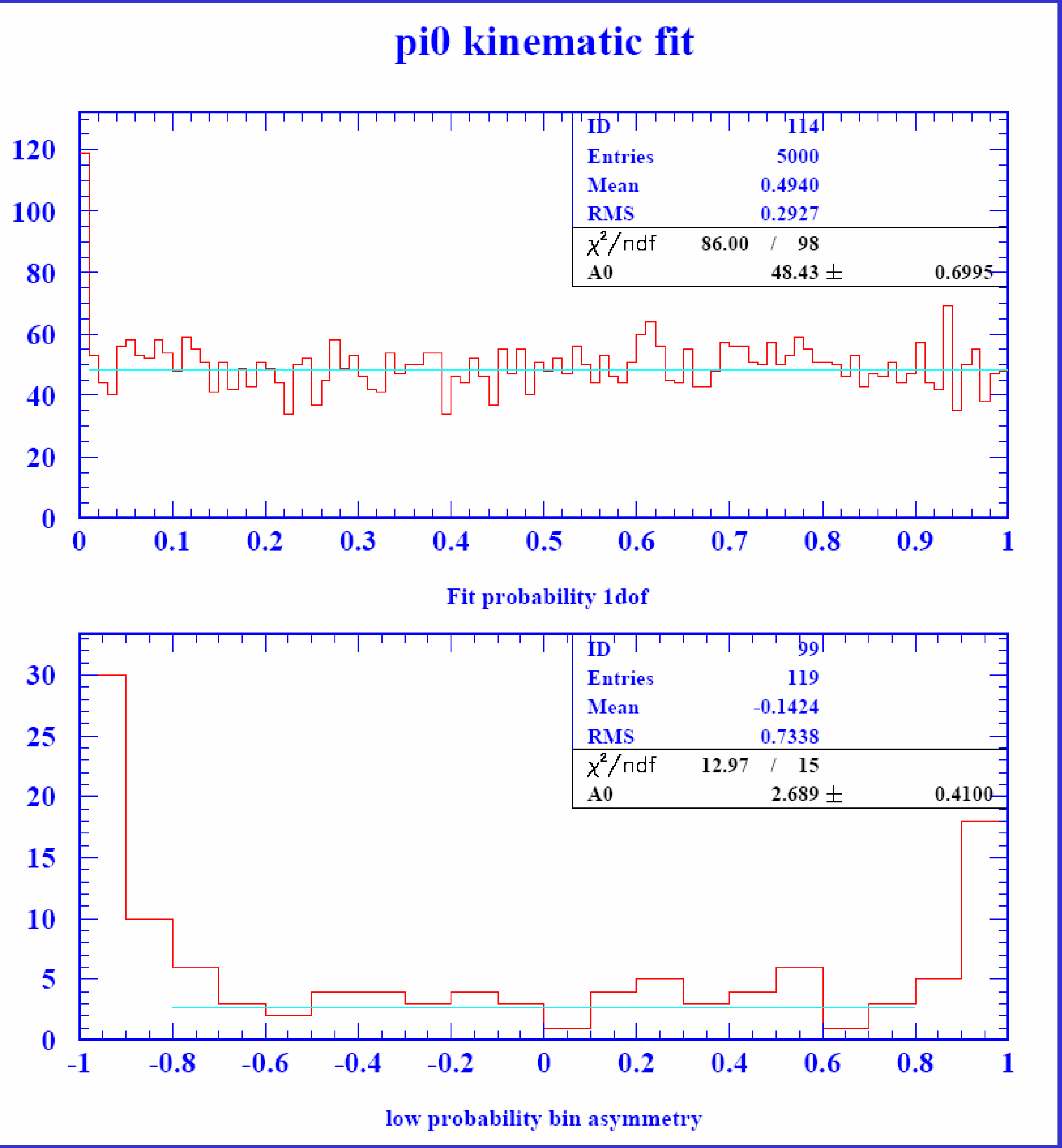

pi0 kinematic fit
ID 111
Entries 5000
Mean 0.1345
RMS 0.1785E-01
χ²/ndf 142.4 / 46
Constant 691.2 ± 13.38
Mean 0.1345 ± 0.2008E-03
Sigma 0.1395E-01 ± 0.1780E-03
5 GeV π⁰
0
100
200
300
400
500
600
700
800
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Measured di-photon mass (GeV)
Measured pi0 mass

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 ….

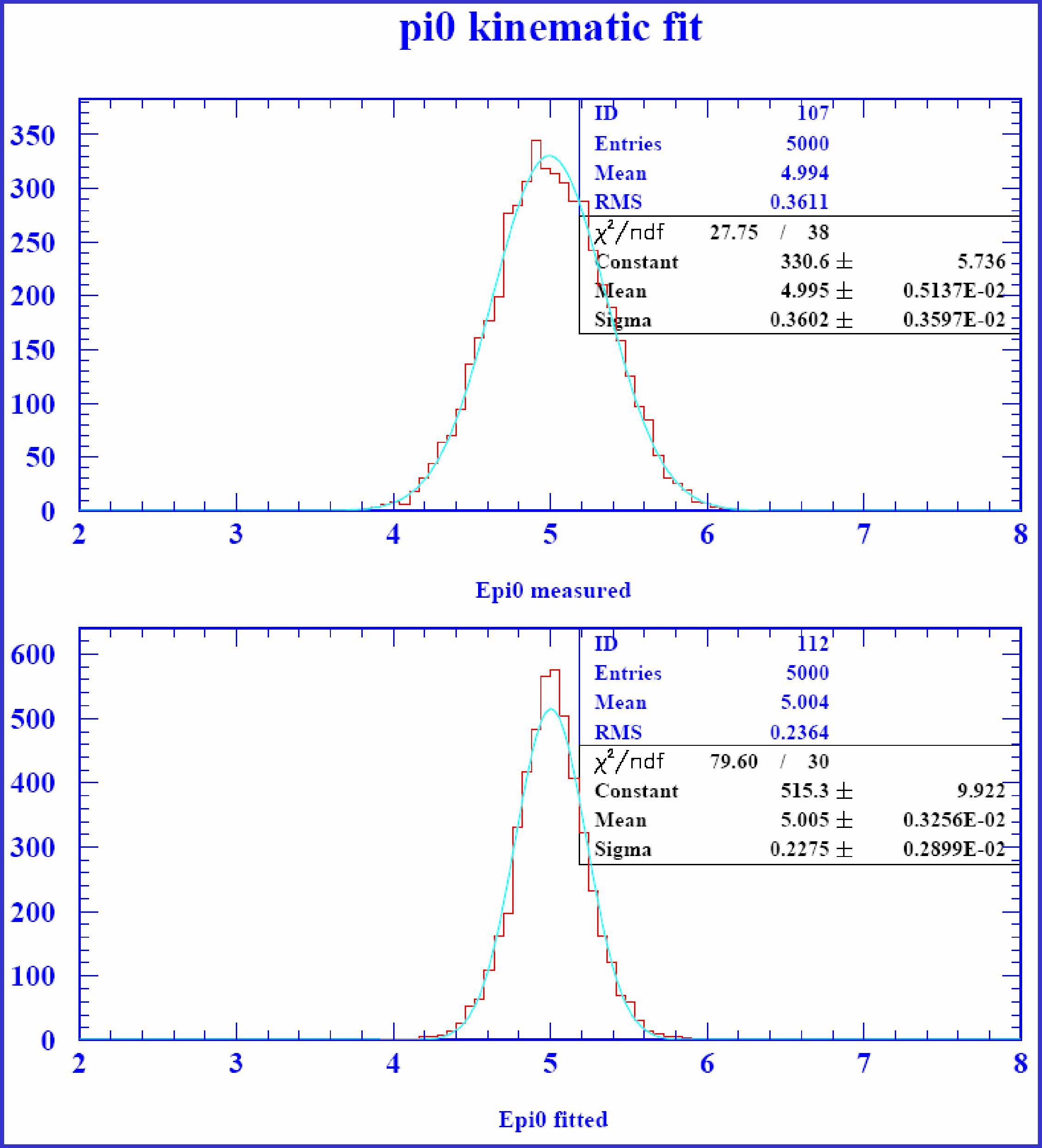


π^0 energy

Measured

Fitted (improves from 0.36 GeV to 0.23 GeV)

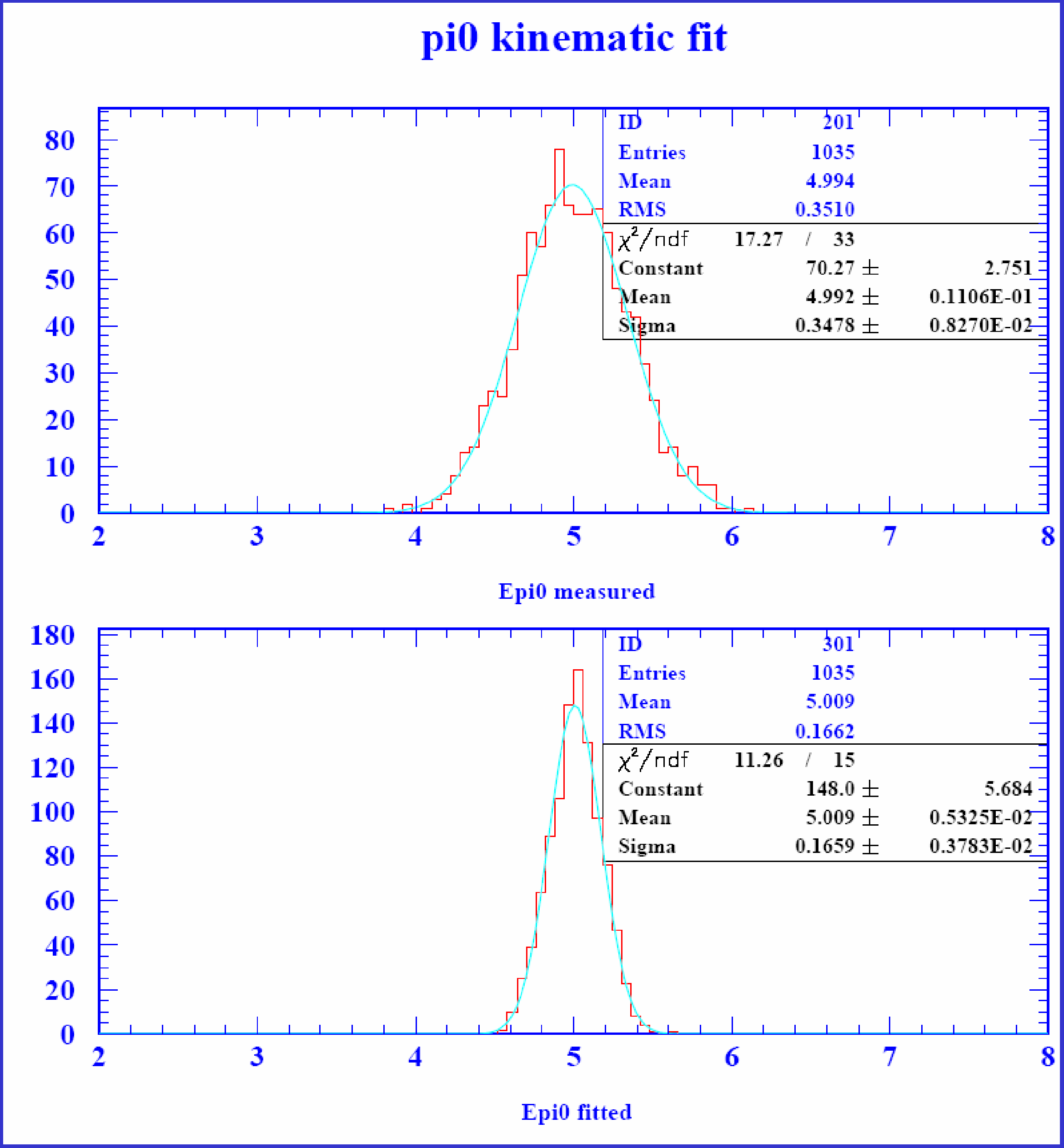
(factor of 0.64 !!)



π^0 energy for |a| < 0.2

Improvement most dramatic :

0.35 -> 0.17



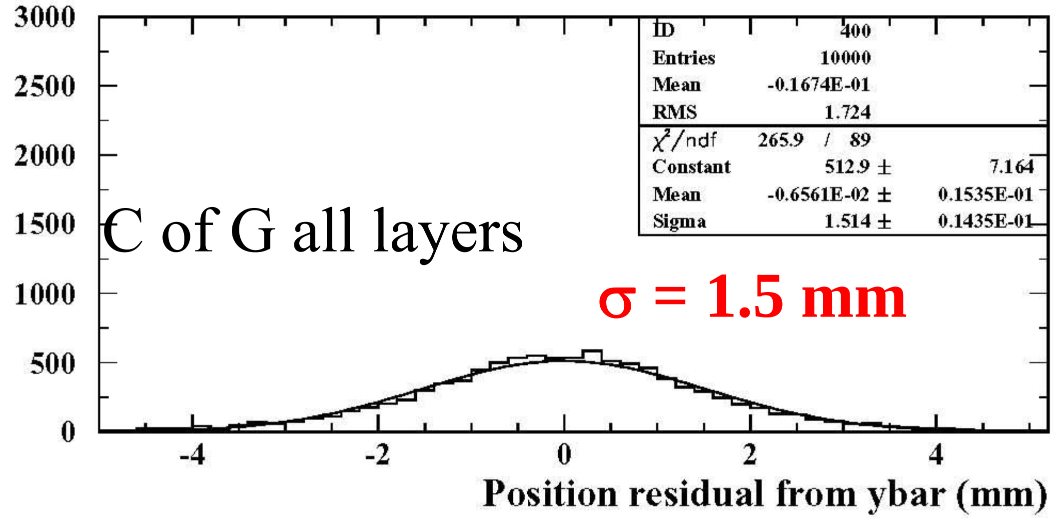
Position resolution from simple fit

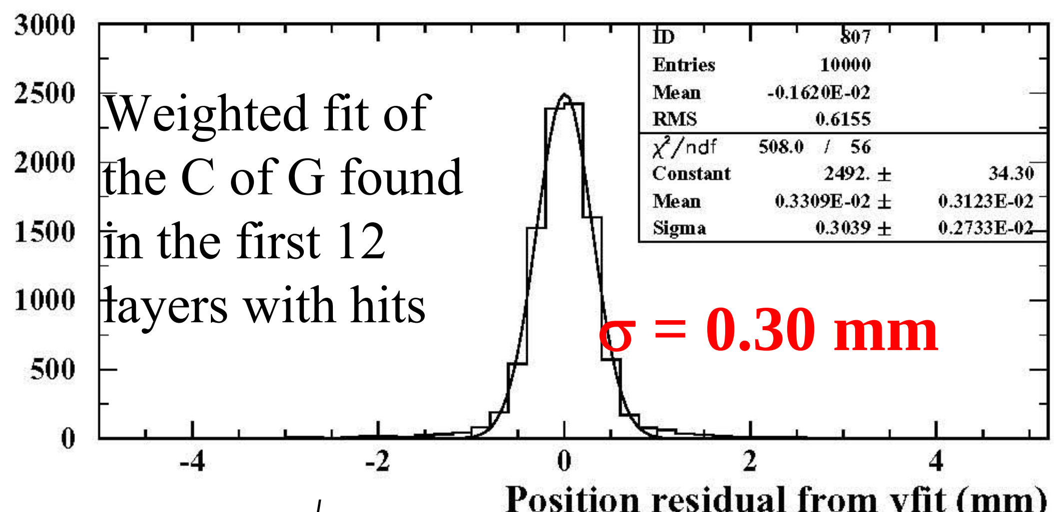
Neglect layer 0 (albedo)

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!*

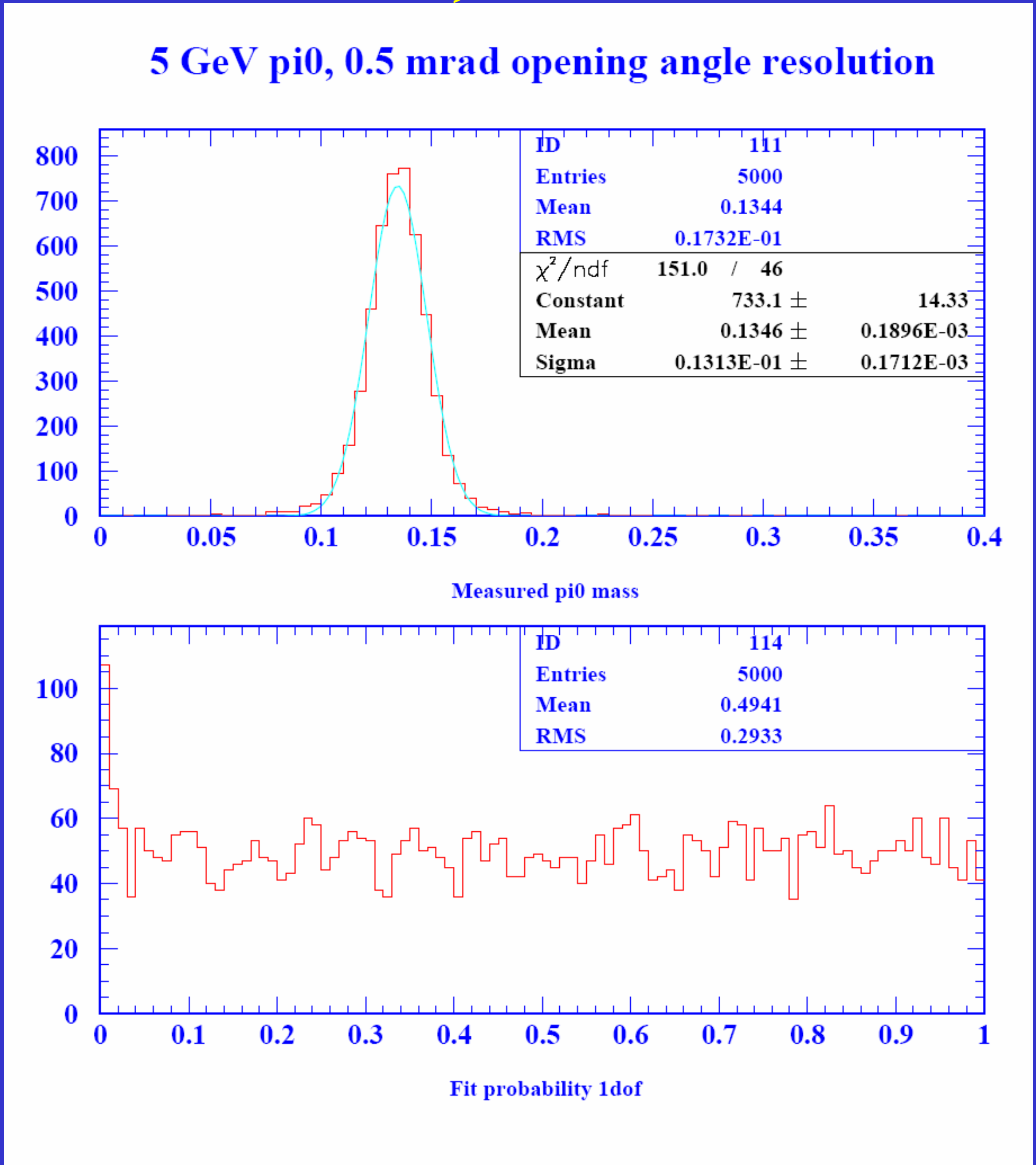
1 GeV photon, G4 study (GWW)





Still just d/√12 !

5 GeV π^0, 4 times better θ_{12} resolution



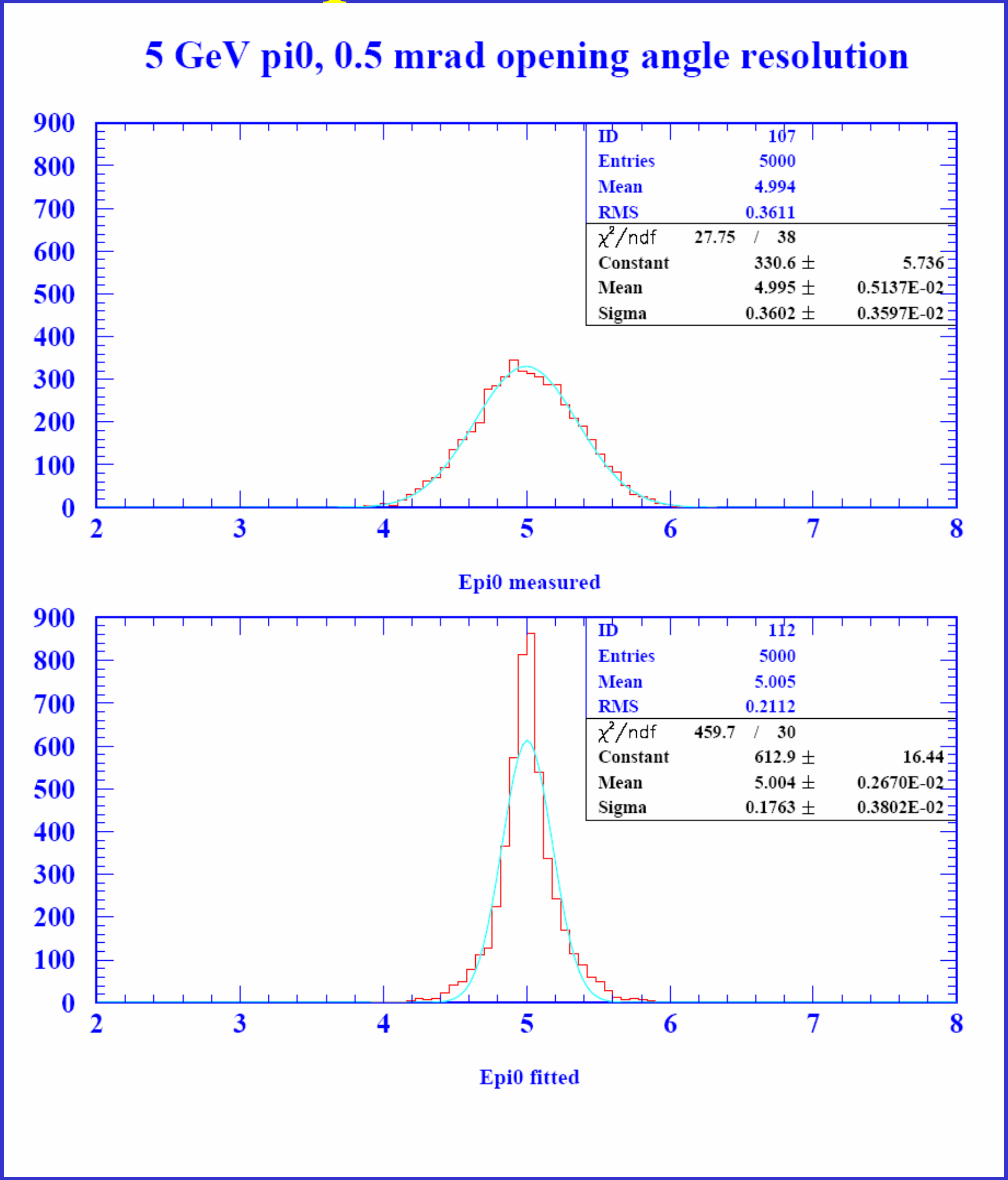
Not much change in mass resolution (dominated by E-term)

Fit still works.

π^0 energy resolution improvement

Dramatic !

Factor of 2 for ALL asymmetries.

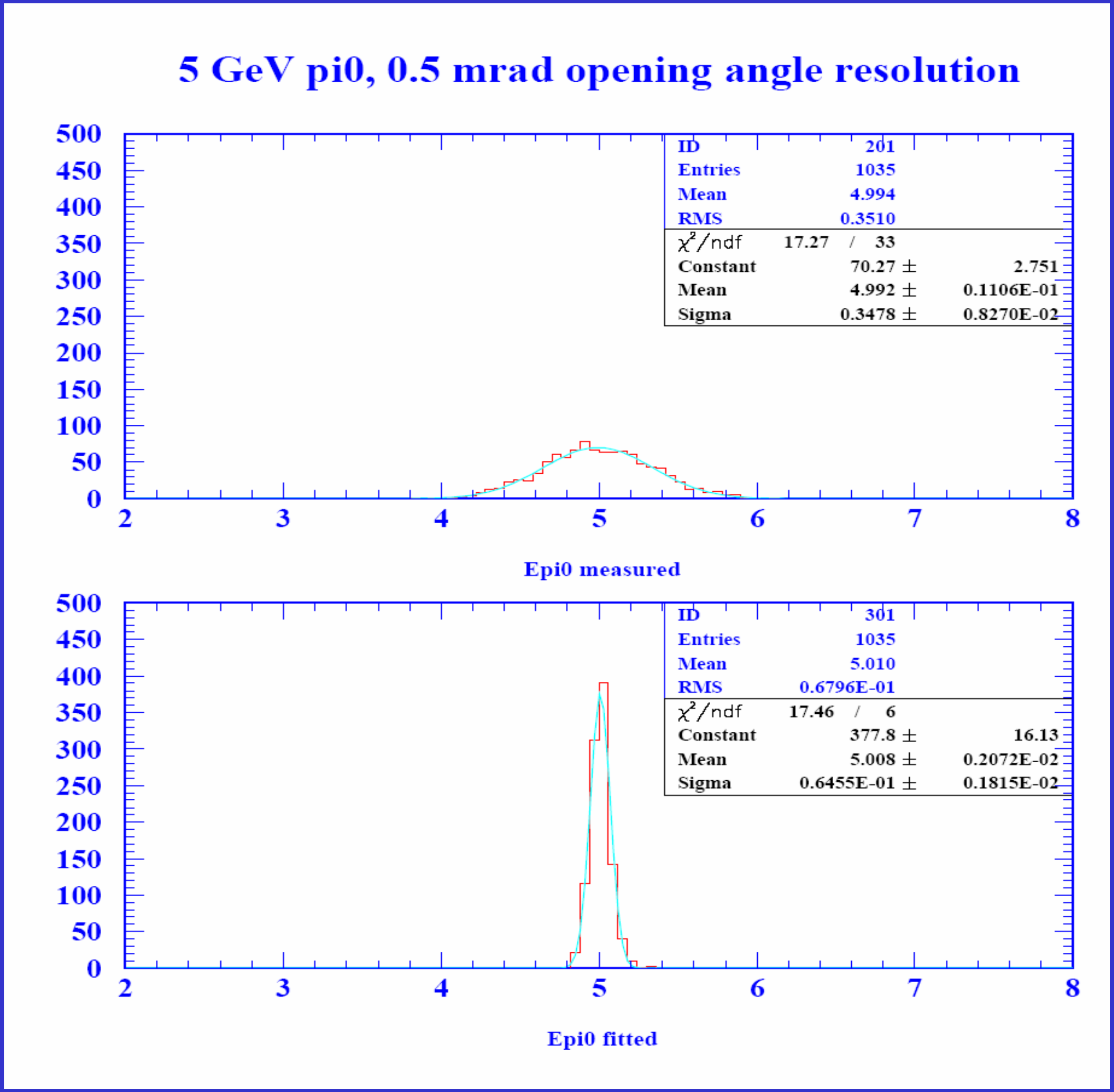


π^0 energy resolution improvement

|a| < 0.2

Improves by a factor of 0.35/0.065.

i.e. a factor of 5 !



π^0 1-C Fit Conclusions

- π^0 constrained fit has a lot of potential to improve the π^0 energy resolution.
- Will investigate in more detail actual γ–γ separation capabilities.
  - Puts a high premium on angular resolution if this is as useful as it looks.
- Looks worthwhile to also look into the assignment problem.
- May have some mileage for reconstructing the π^0's in hadronic interactions.

Talk Summary

- Several topics developed over the summer.
- Now up to speed on some of the reconstruction software. Together with Carsten Hensel, we expect to be able to contribute to several interesting topics during Snowmass.

Backups

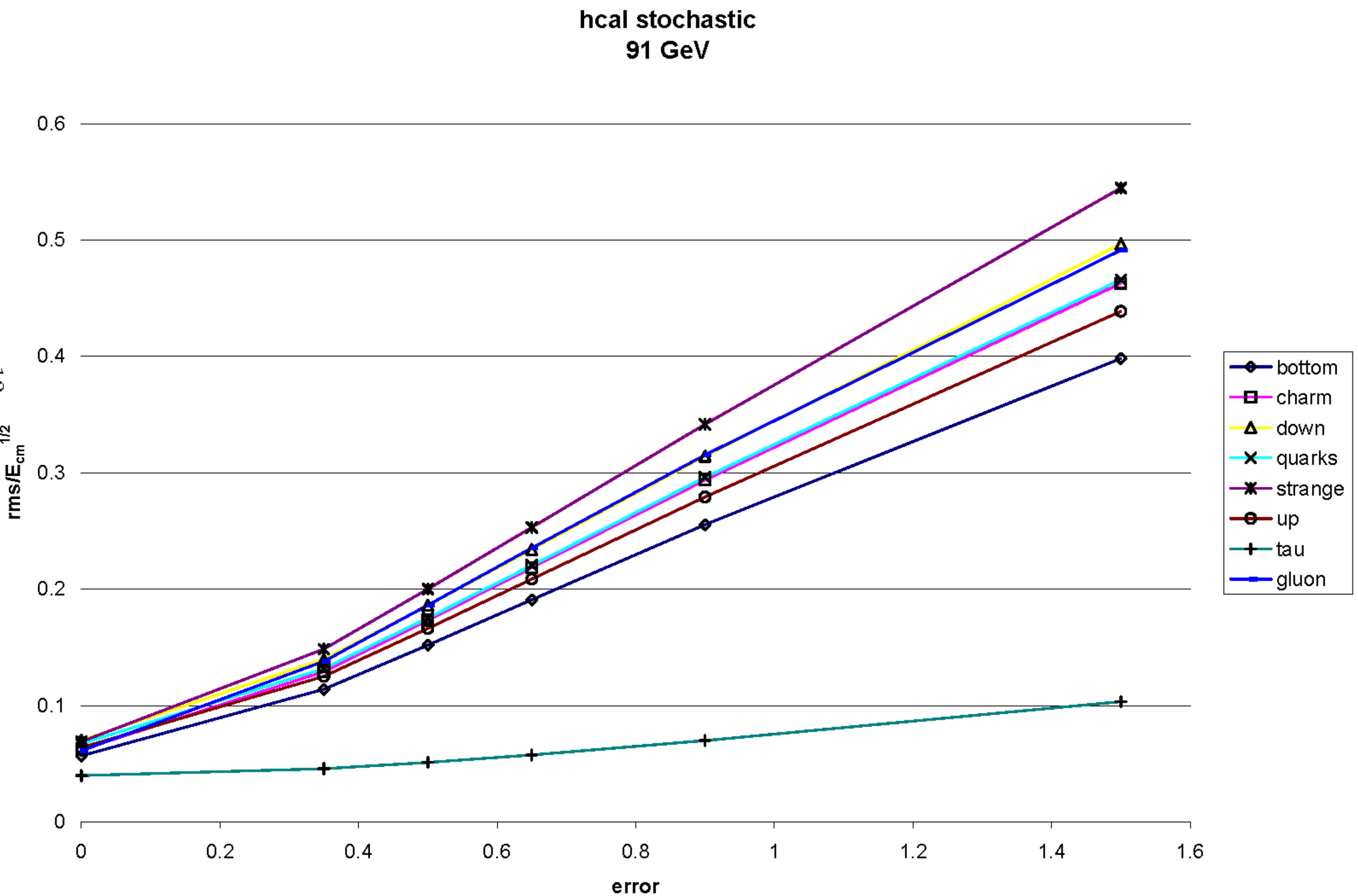
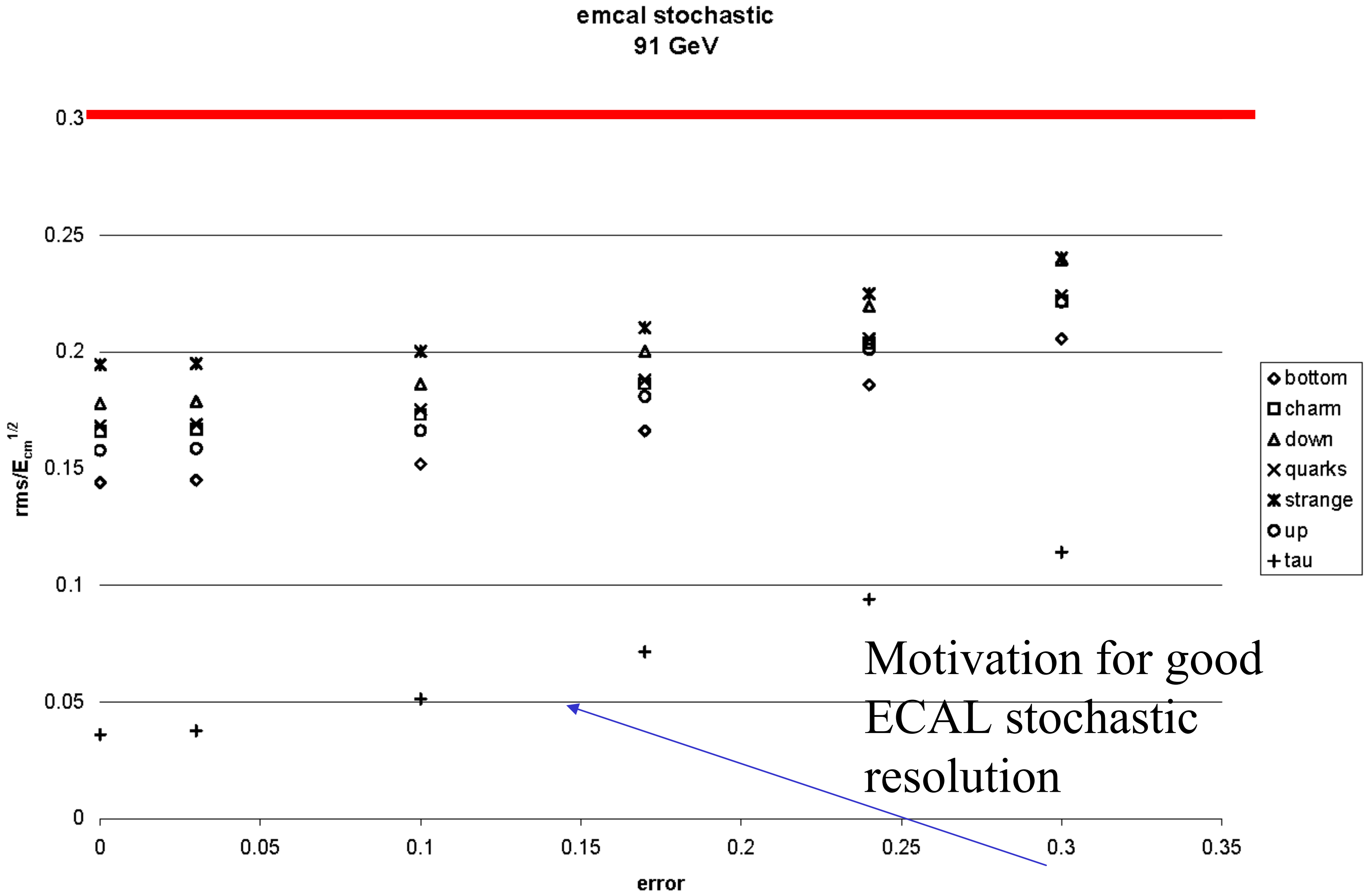

hcal stochastic
91 GeV
0.6
0.5
0.4
0.3
0.2
0.1
0
rms/$E_{cm}^{1/2}$
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
error
bottom
charm
down
quarks
strange
up
tau
gluon

Figure 4

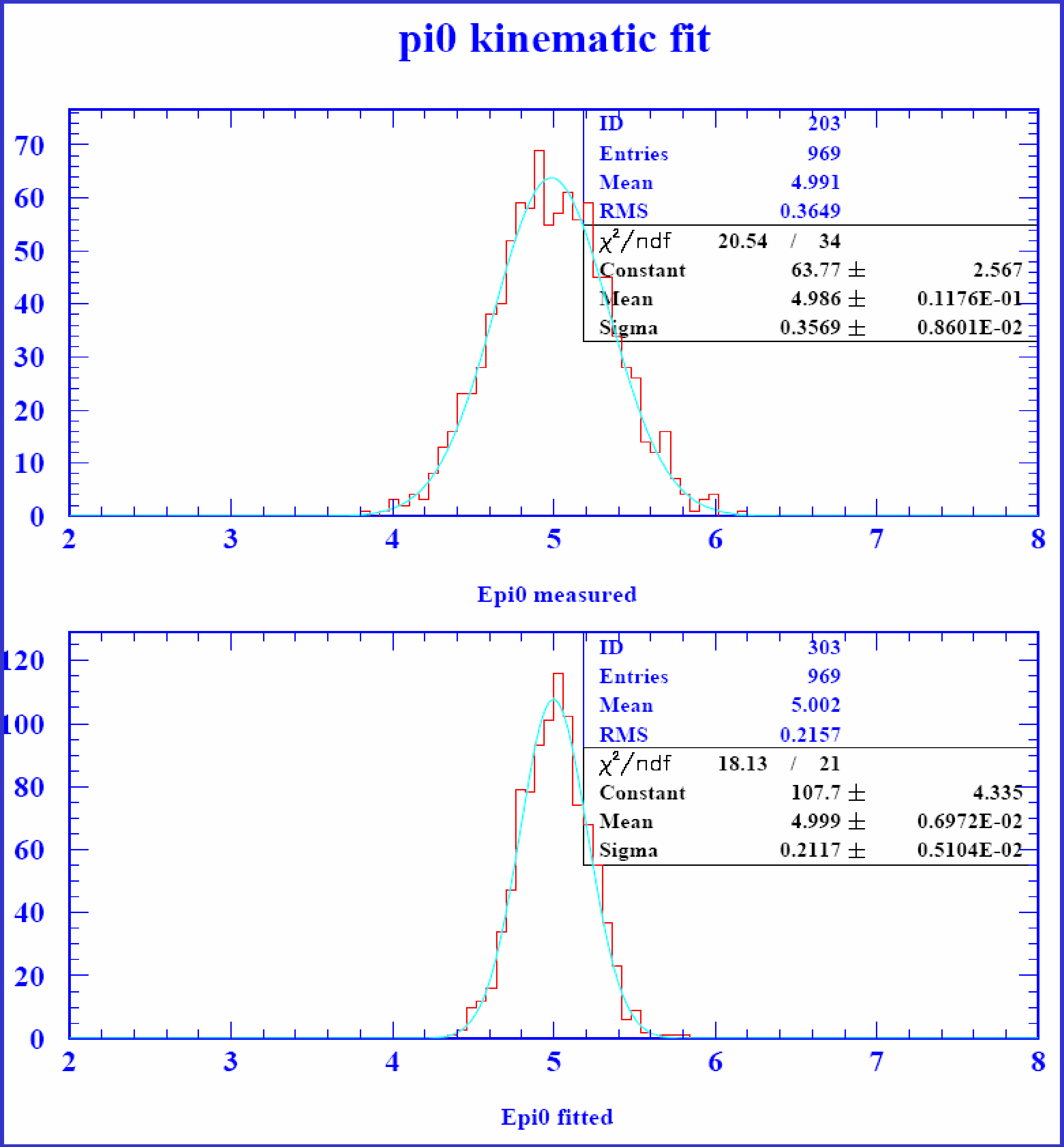
c_1



Motivation for good ECAL stochastic resolution

π^0 energy for $0.4<|a|<0.6$

Improvement from 0.36 to 0.21

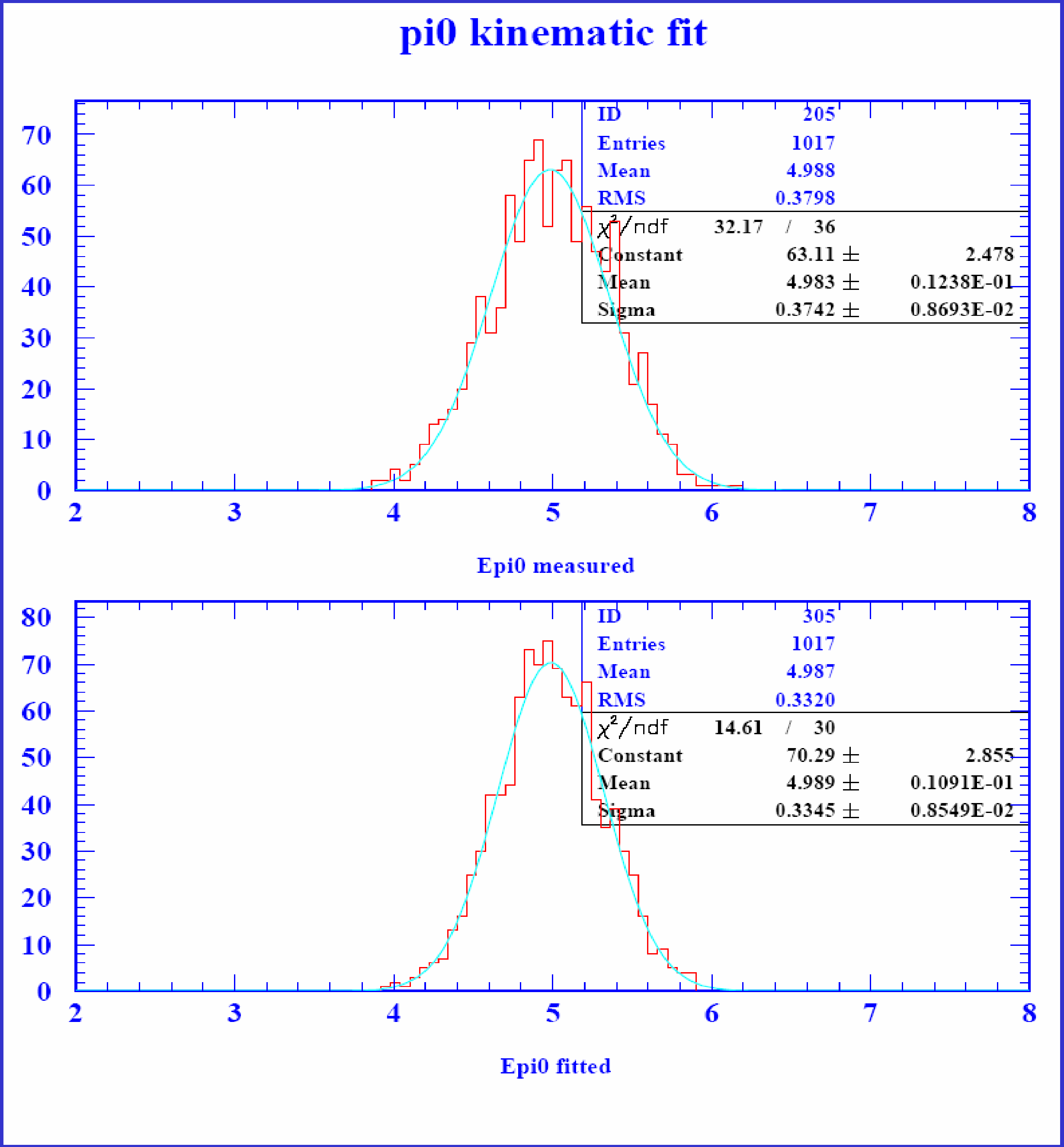


π^0 energy for |a| > 0.8

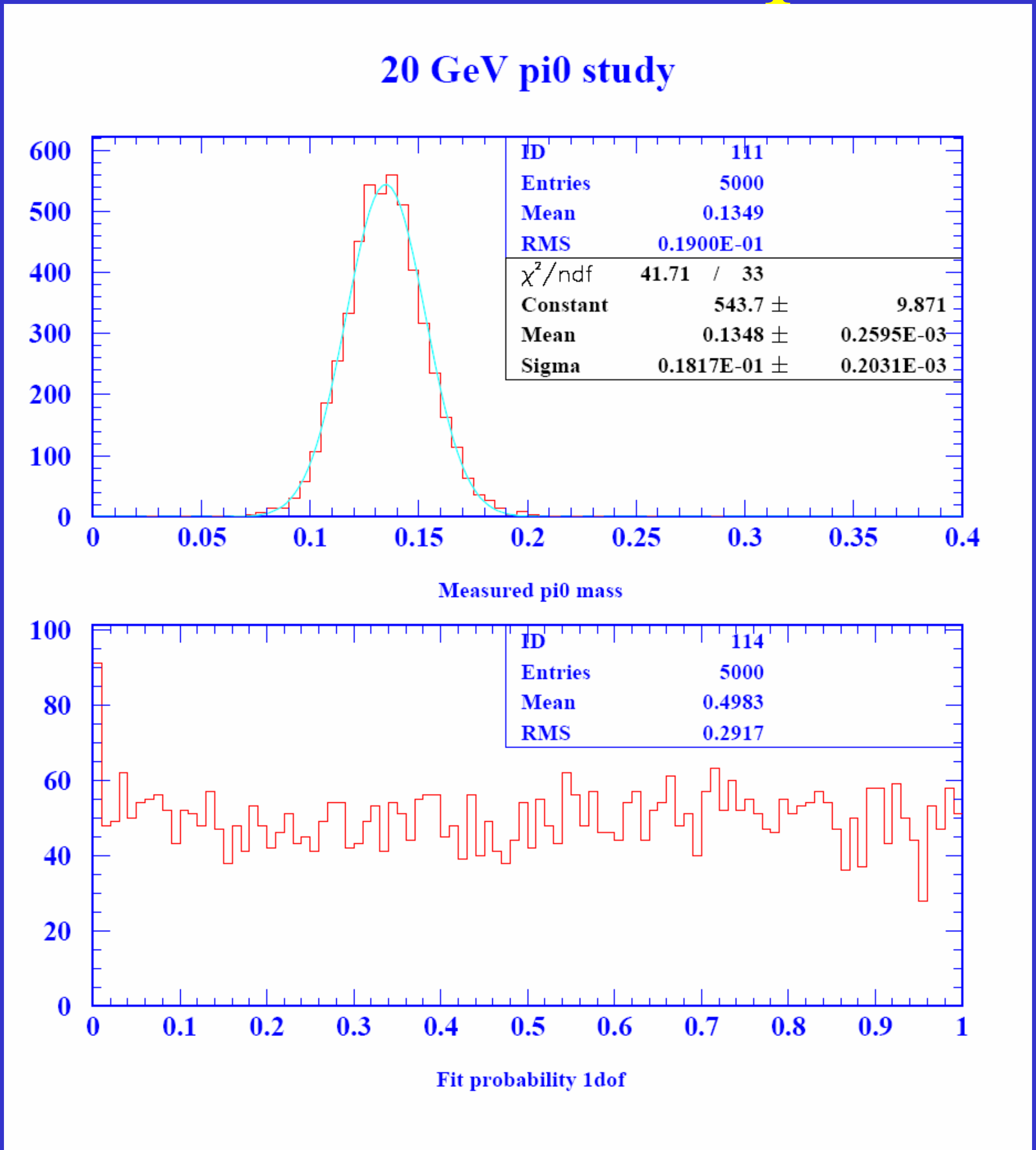
Improvement not so great.

(as expected)

0.37 -> 0.33



20 GeV π^0, same resolution assumptions



Mass resolution degrades as expected.

Constrained fit still works OK.

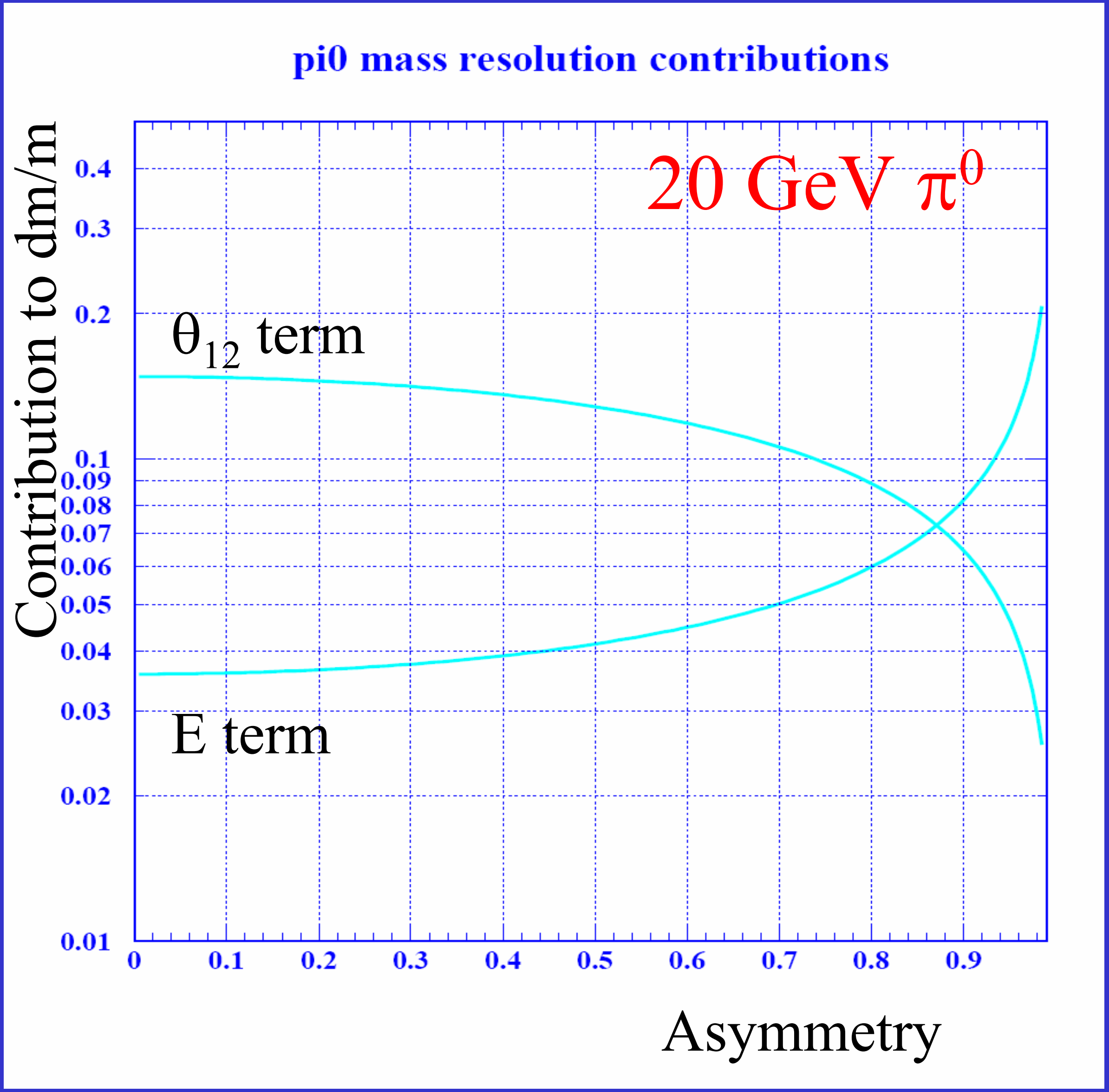
π^0 mass resolution

Plots assume:

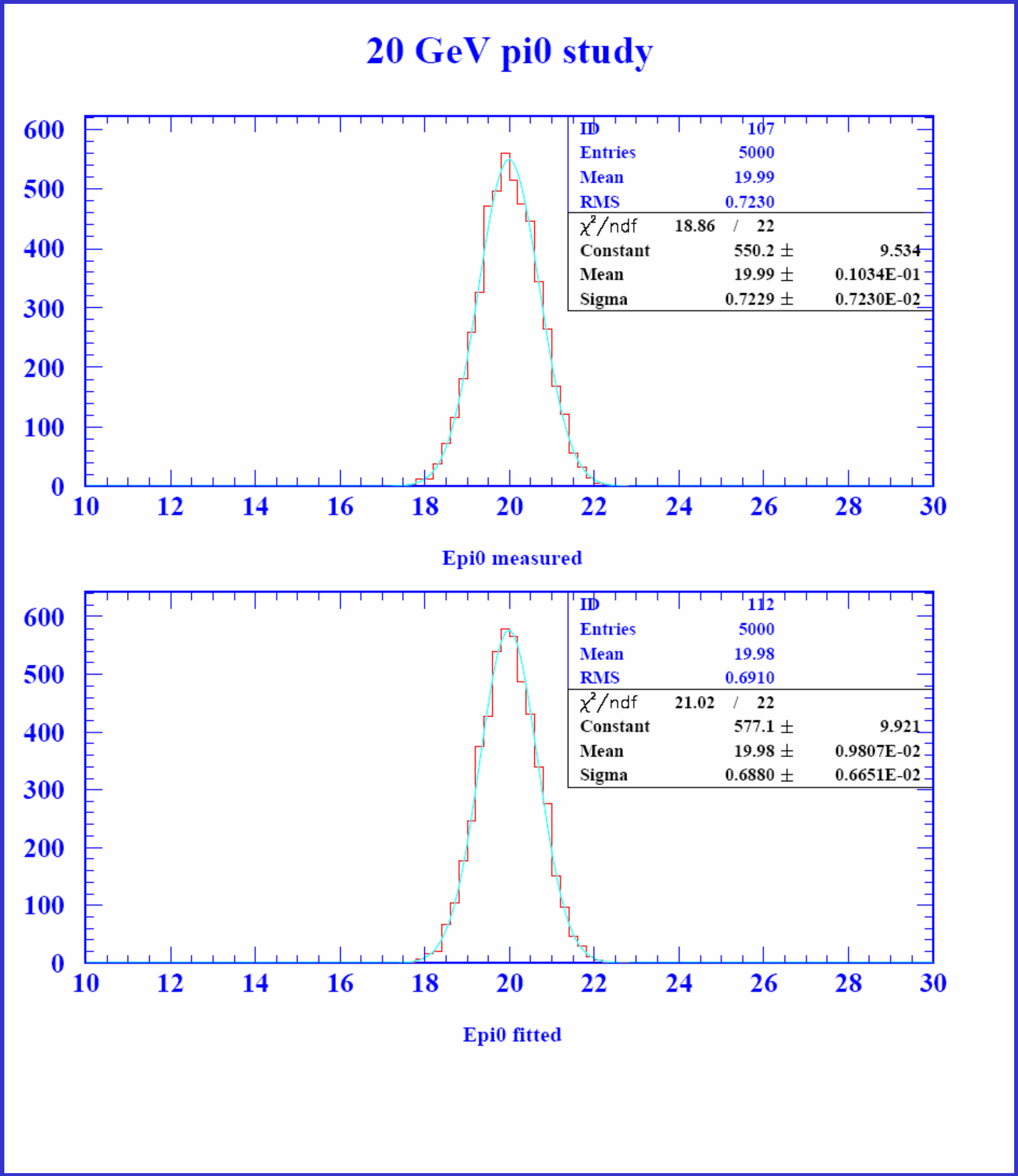
$c_1 = 0.16$ (SiD)

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

For these detector resolutions, 20 GeV π^0 mass resolution dominated by the θ_{12} term (=> KF less helpful)



20 GeV π^0, same resolution assumptions



Constrained fit

$\Rightarrow$ No significant improvement.

(as expected)