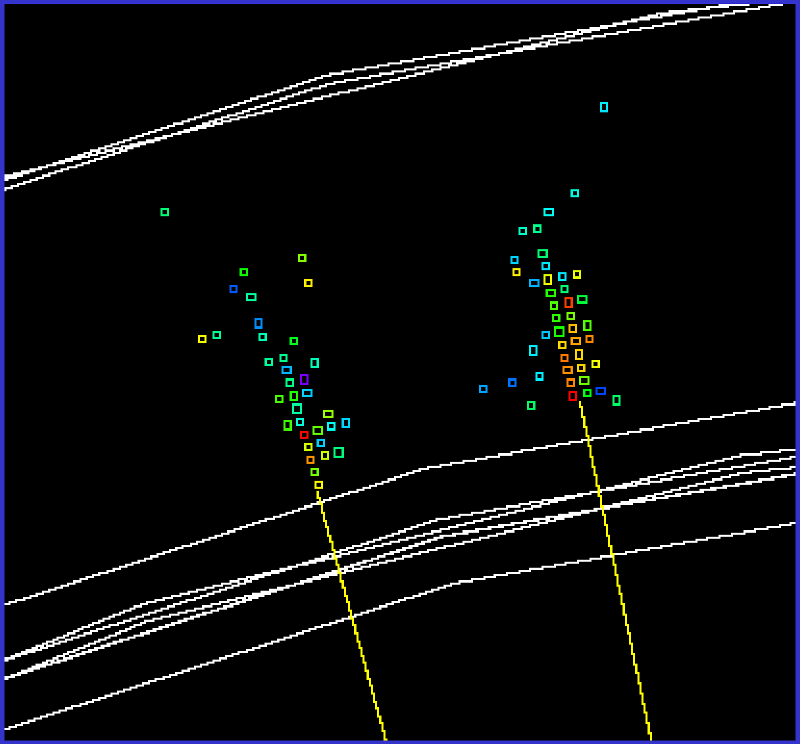
Using π^0 mass constraint to improve particle flow ?

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.

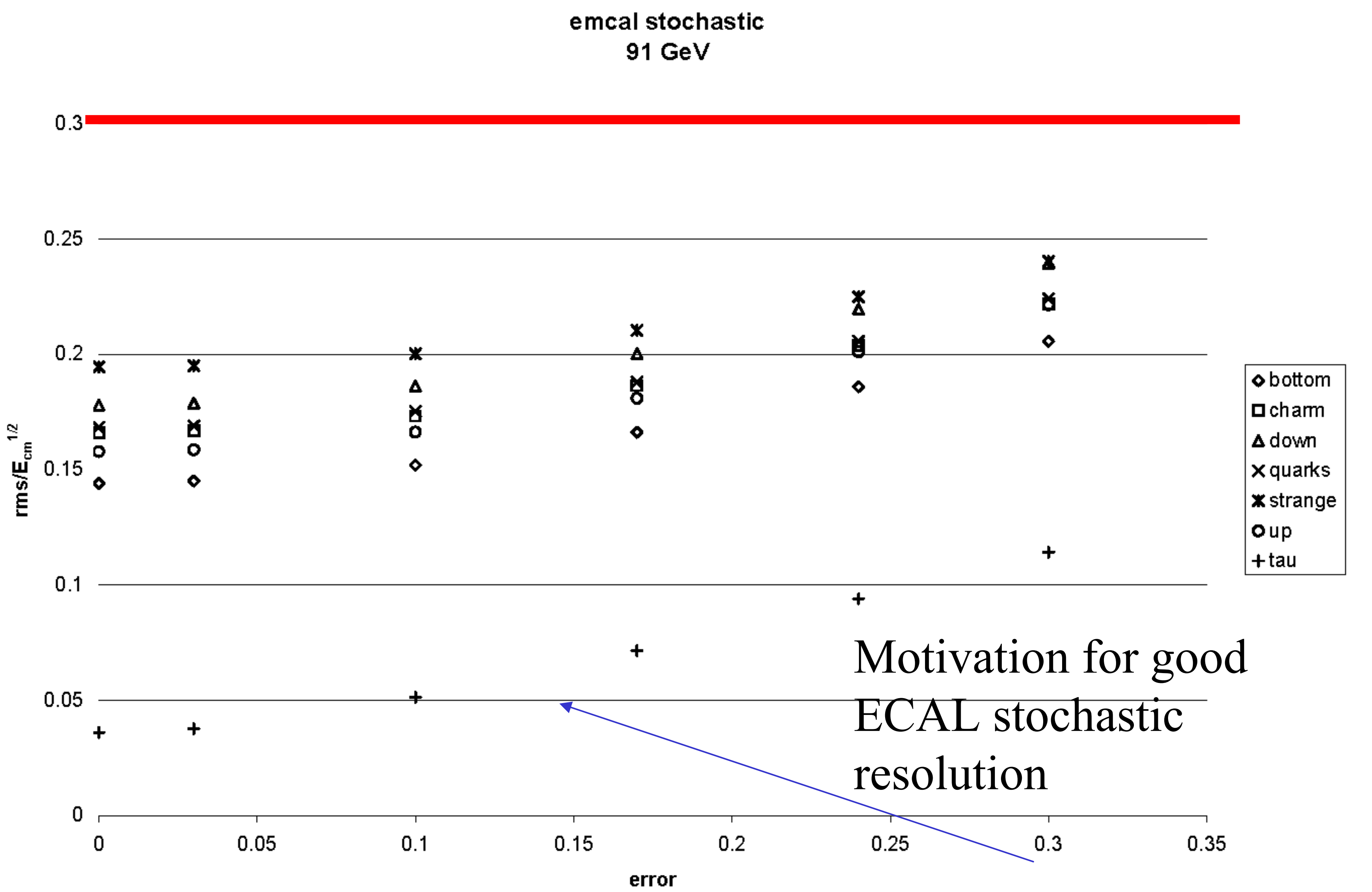


Graham W. Wilson, Univ. of Kansas, July 27th 2005

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 ? (My educated? guess was a factor of $\sqrt{2}$), and how does this affect the detector concepts ?

c_1


emcal stochastic
91 GeV
rms/E_cm^1/2
error
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
bottom
charm
down
quarks
strange
up
tau
Motivation for good ECAL stochastic resolution

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.
  - was hoping to get some insight into the analytic dependence on photon resolution assumptions, but problem was somewhat harder than I expected (had to solve a cubic)
  - 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

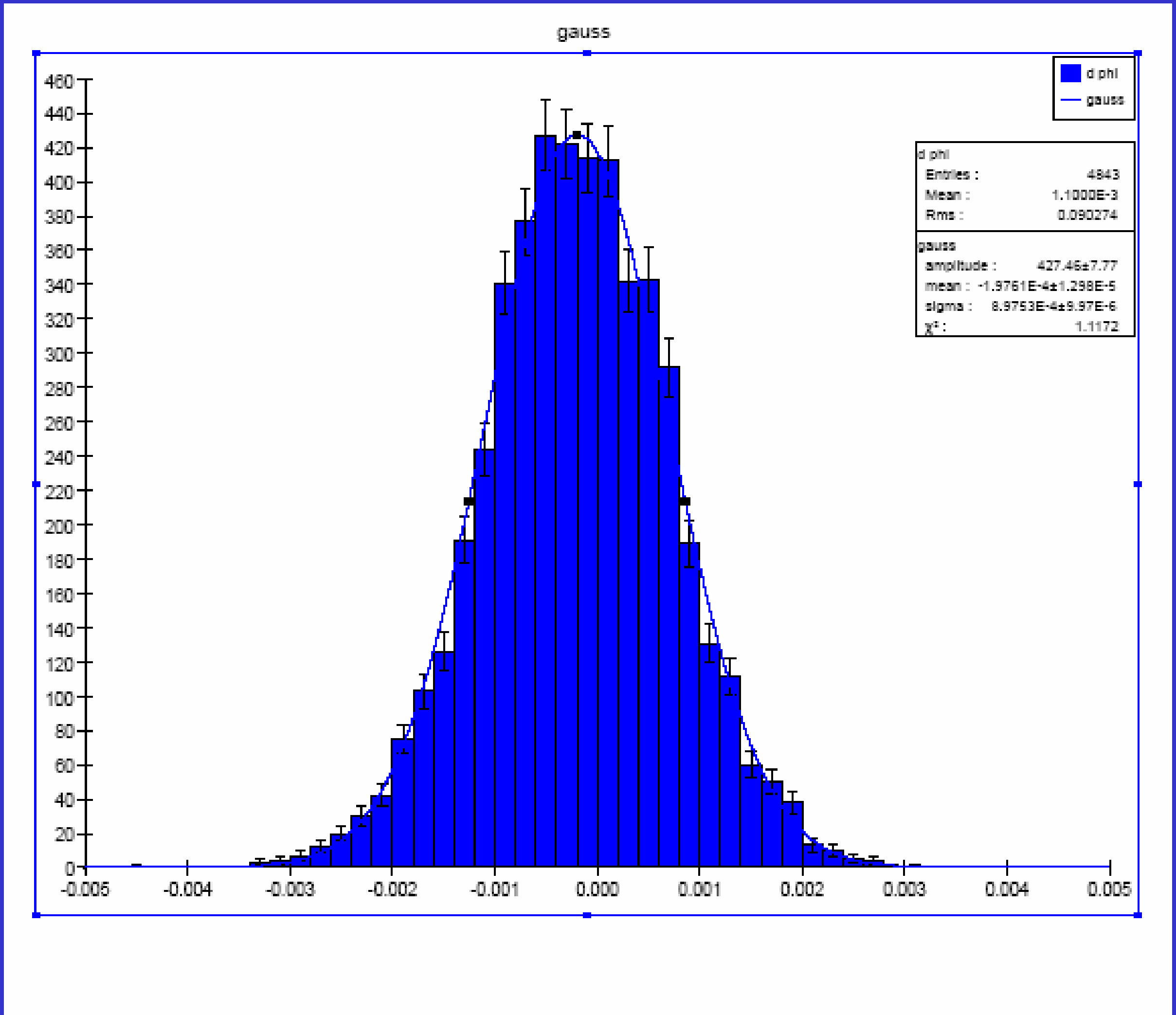
The relative importance of each depends on ($E_{\pi 0}$, a)

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

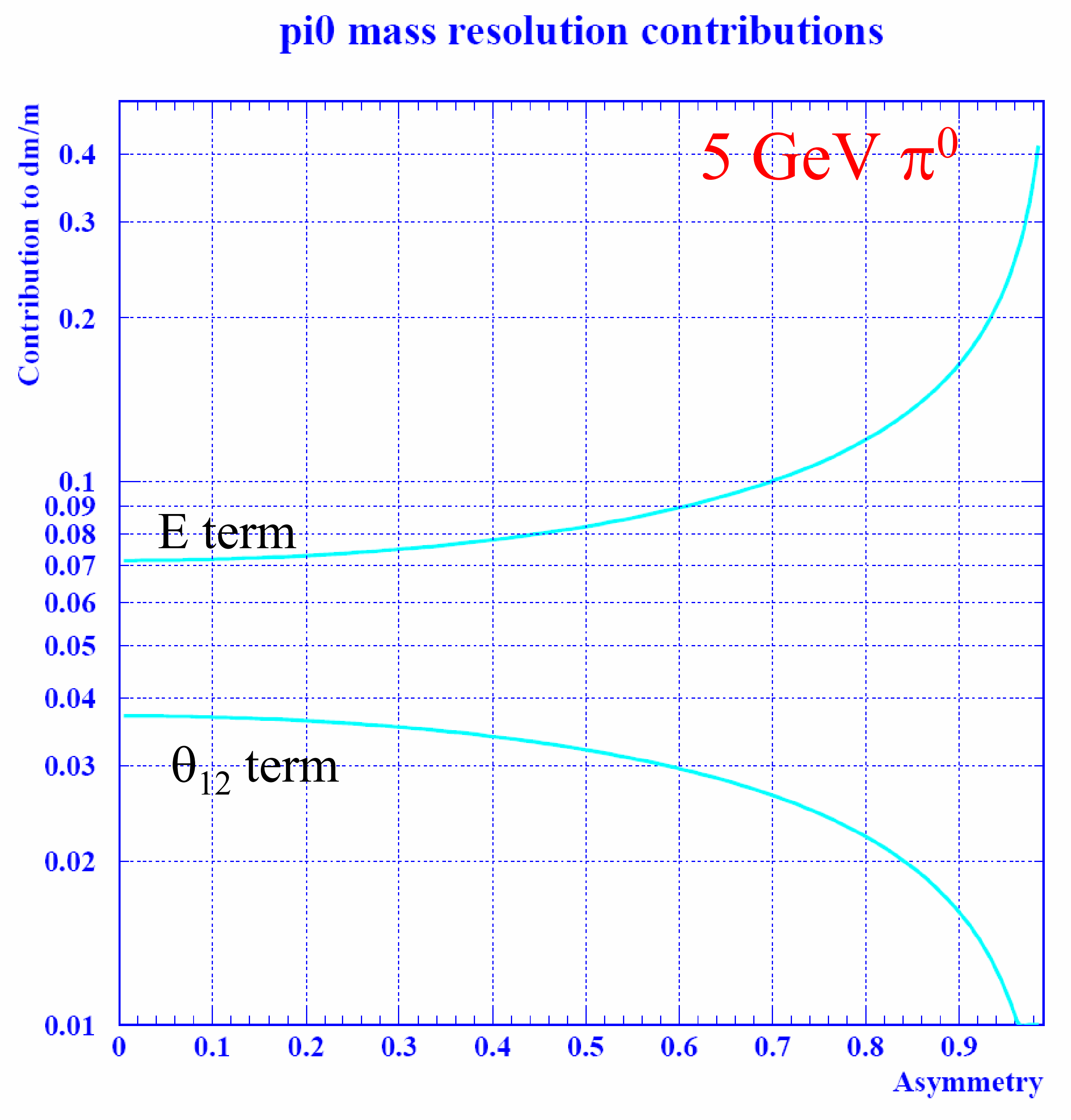
π^0 mass resolution

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



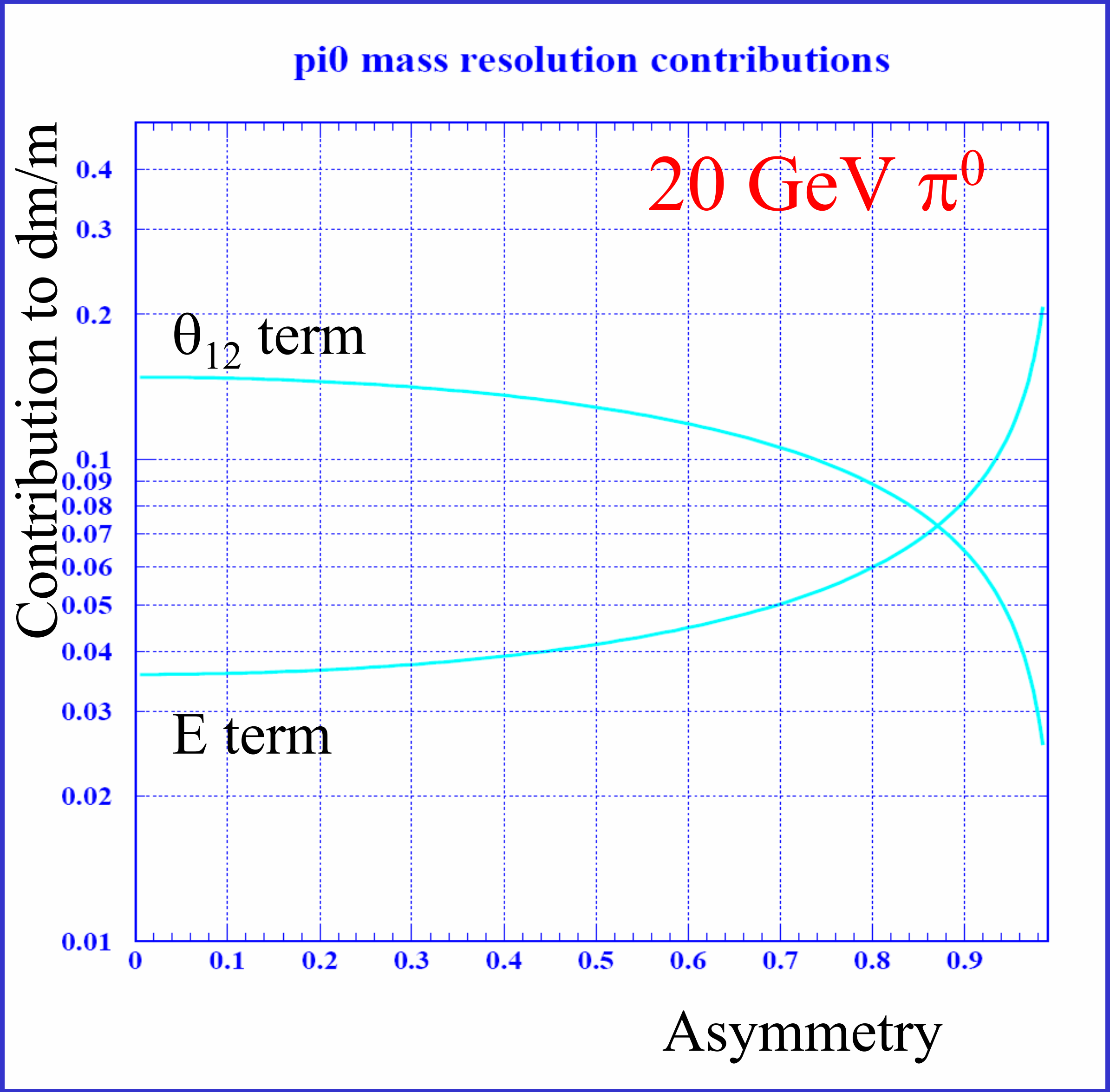
π^0 mass resolution

Plots assume:

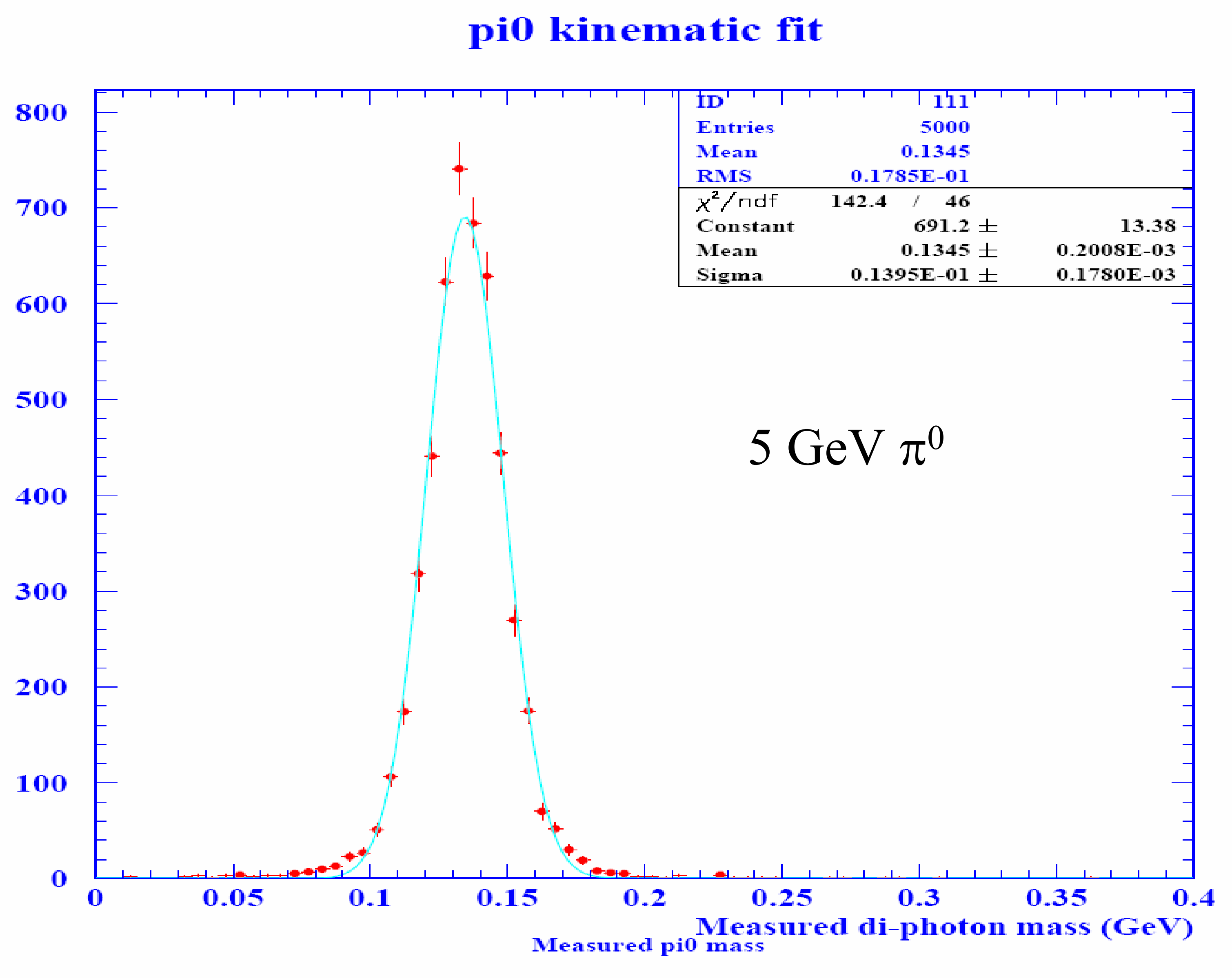
$c_1 = 0.16$ (SiD)

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

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



π^0 mass



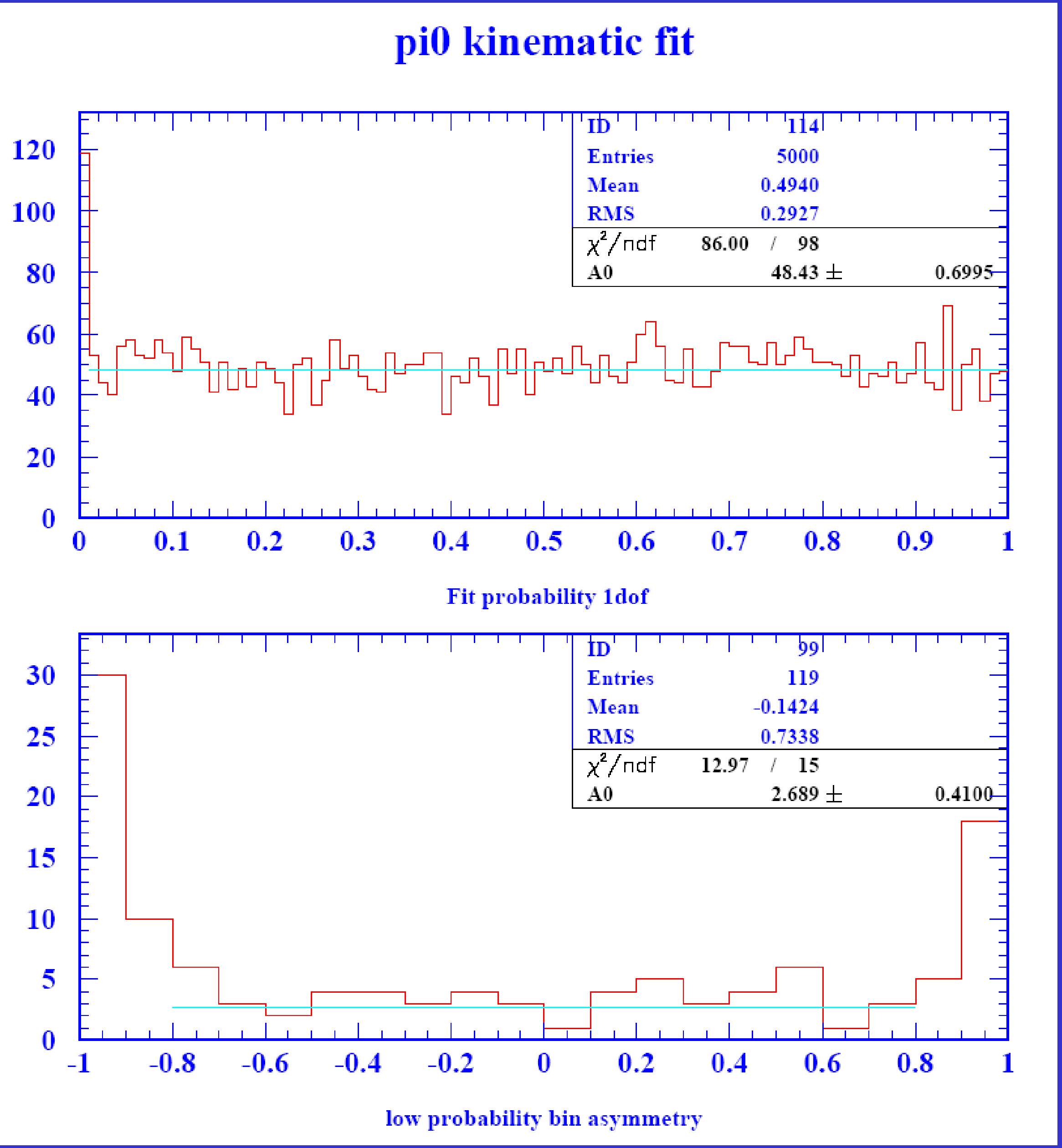
pi0 kinematic fit
ID 111
Entries 5000
Mean 0.1345
RMS 0.1785E-01
χ^2/ndf 142.4 / 46
Constant 691.2 ± 13.38
Mean 0.1345 ± 0.2008E-03
Sigma 0.1395E-01 ± 0.1780E-03
5 GeV π^0
800
700
600
500
400
300
200
100
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Measured di-photon mass (GeV)
Measured pi0 mass

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 ….

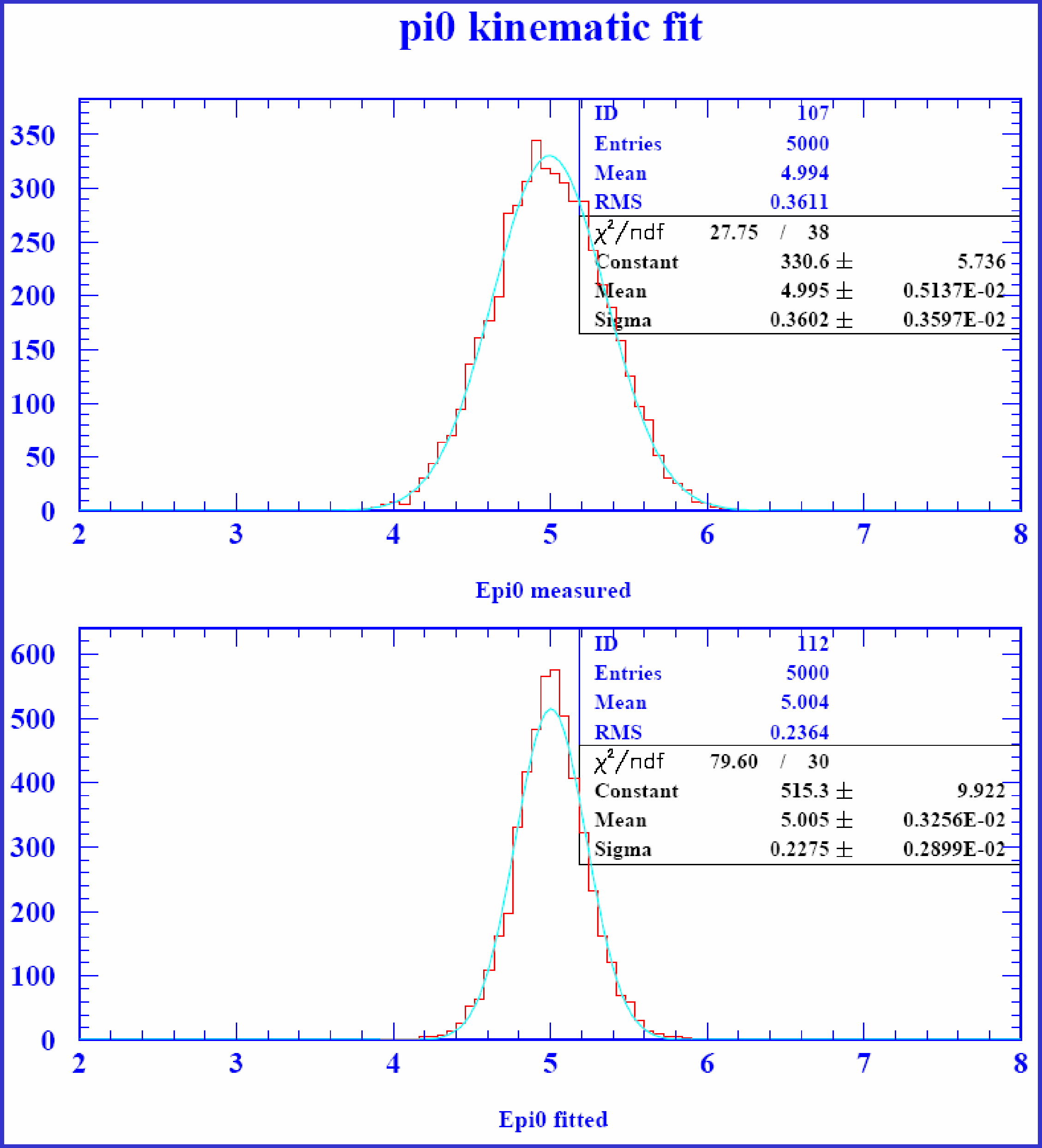


π^0 energy

Measured

Fitted (improves from 0.36 GeV to 0.23 GeV)

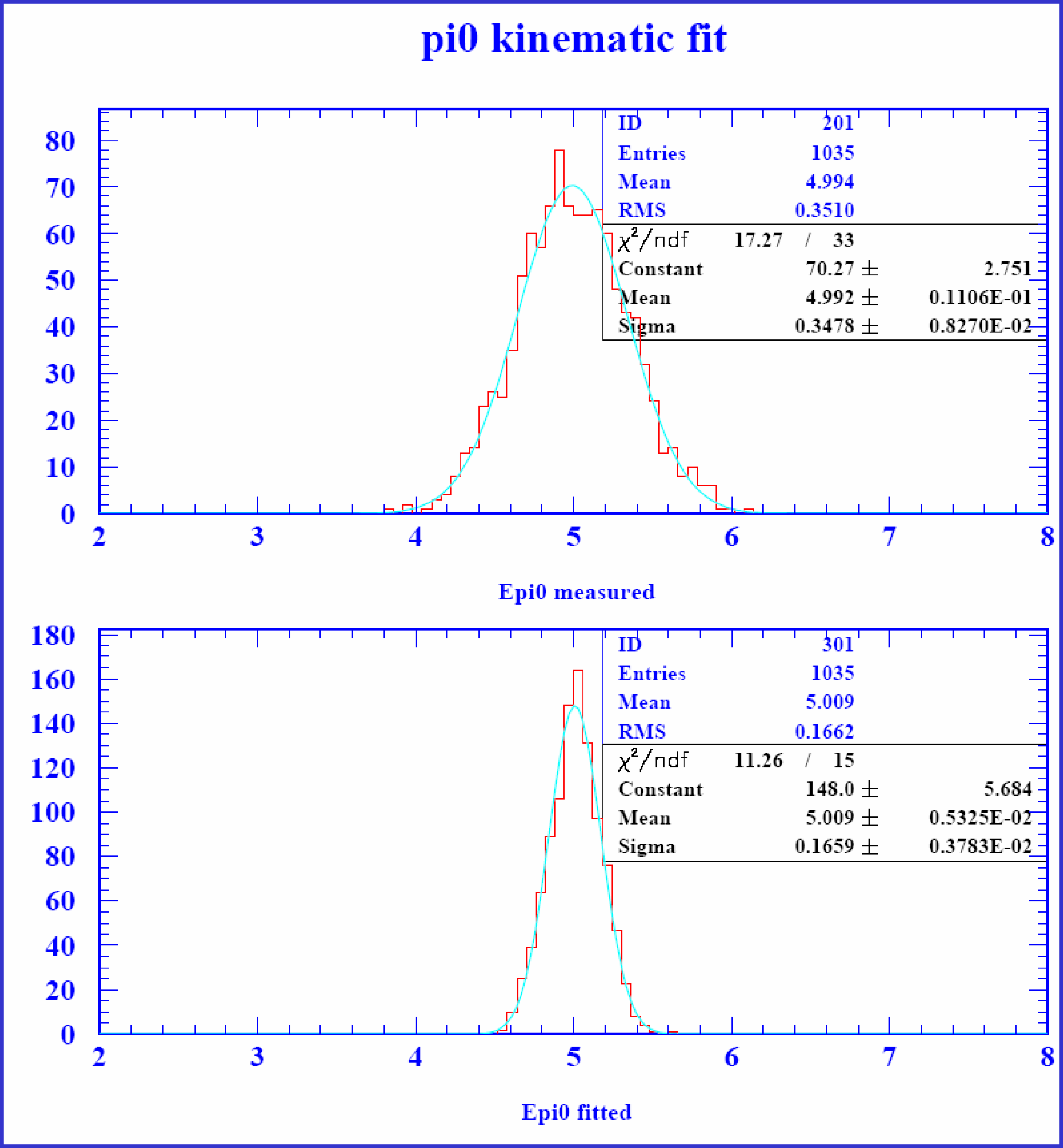
(factor of 0.64 !!)



π^0 energy for |a| < 0.2

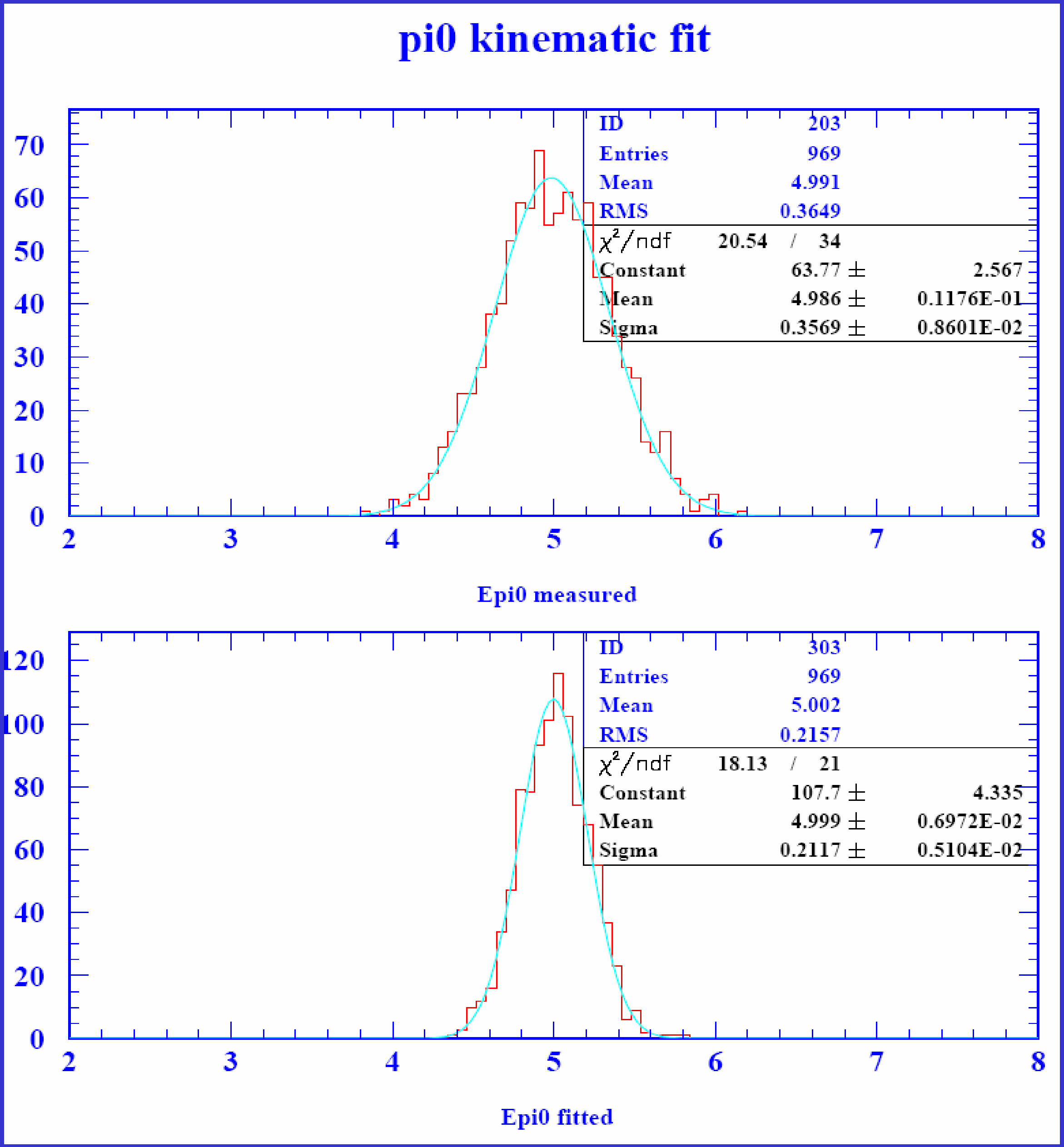
Improvement most dramatic :

0.35 -> 0.17



π^0 energy for $0.4<|a|<0.6$

Improvement from 0.36 to 0.21

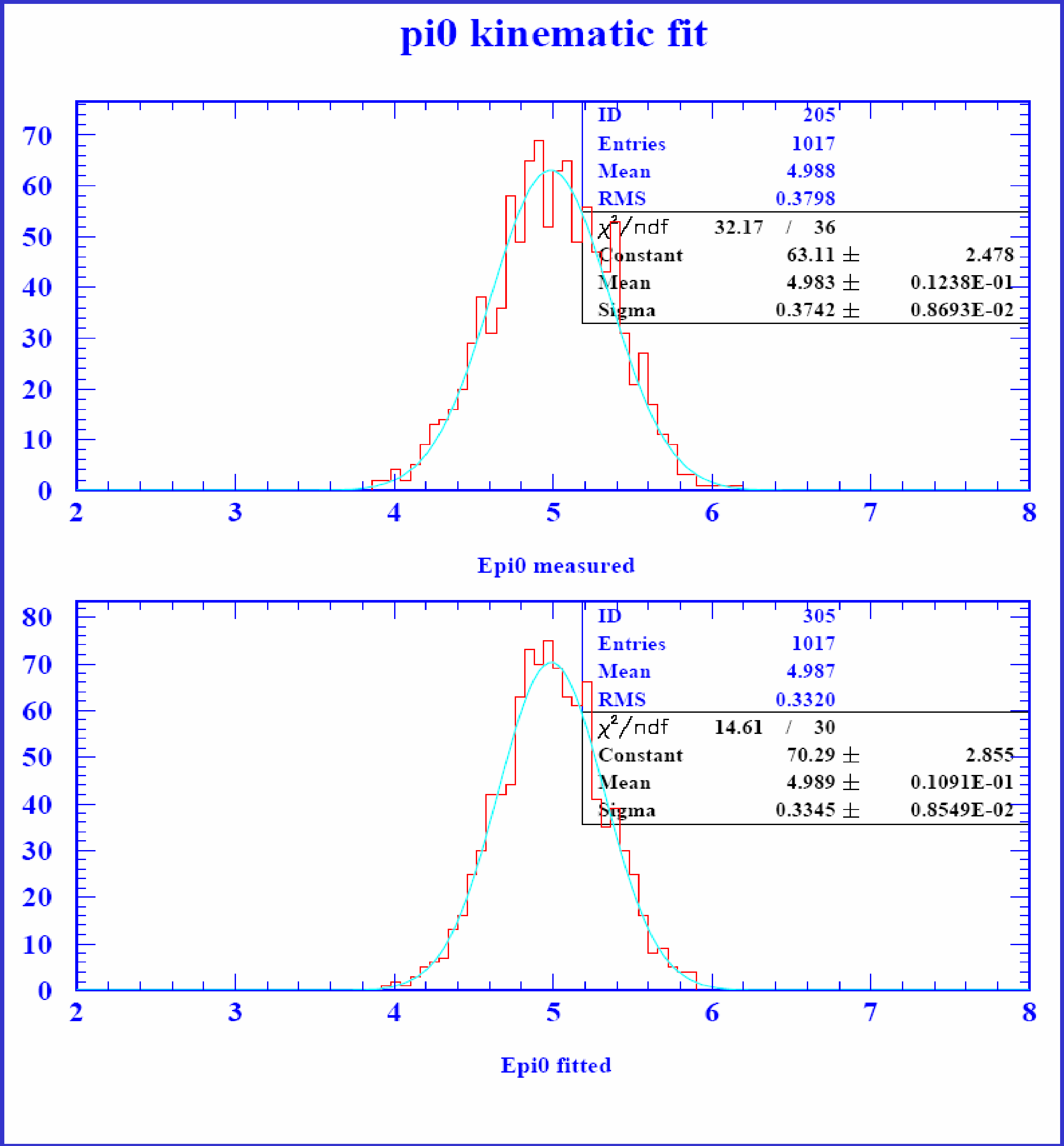


π^0 energy for |a| > 0.8

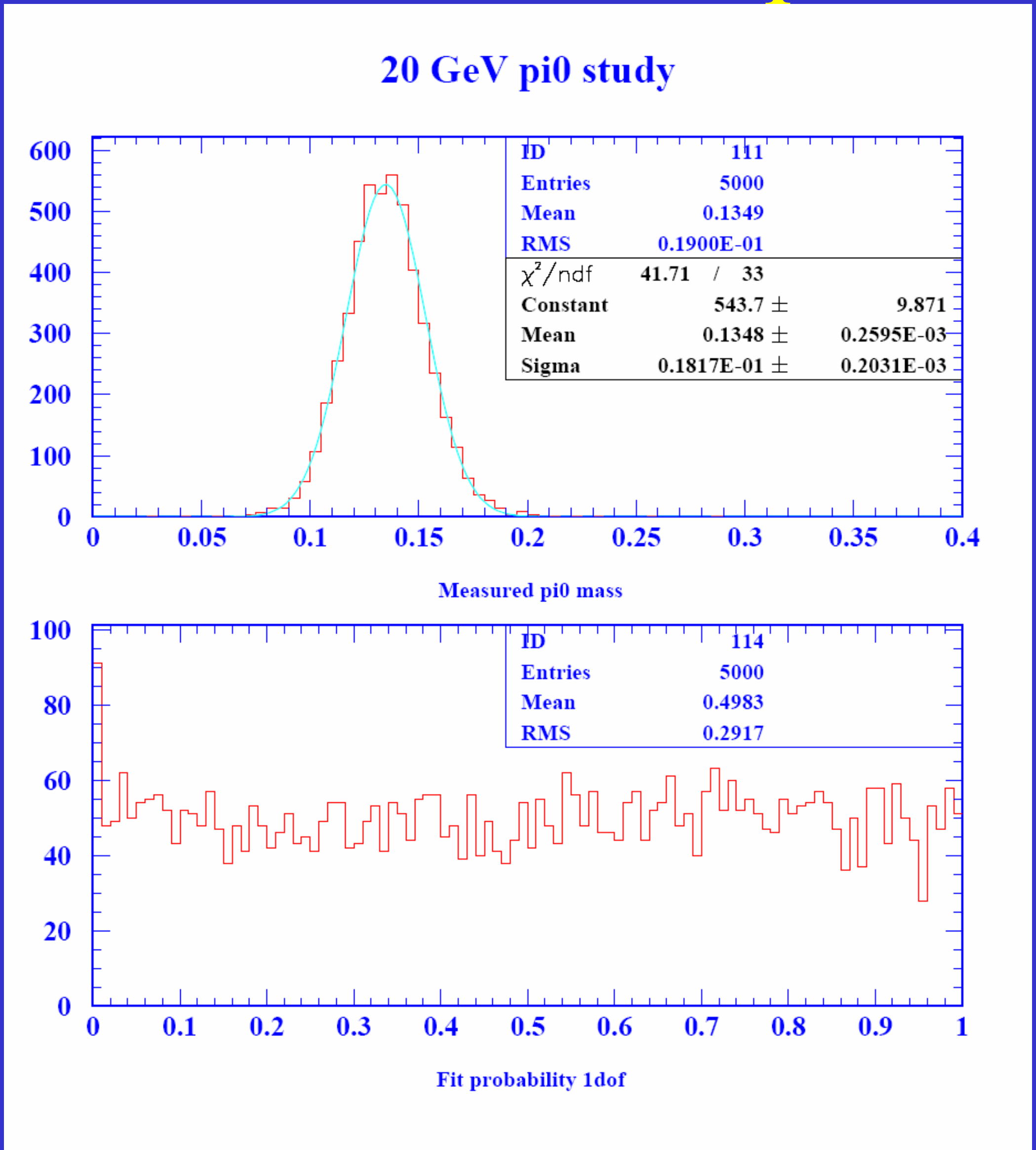
Improvement not so great.

(as expected)

0.37 -> 0.33



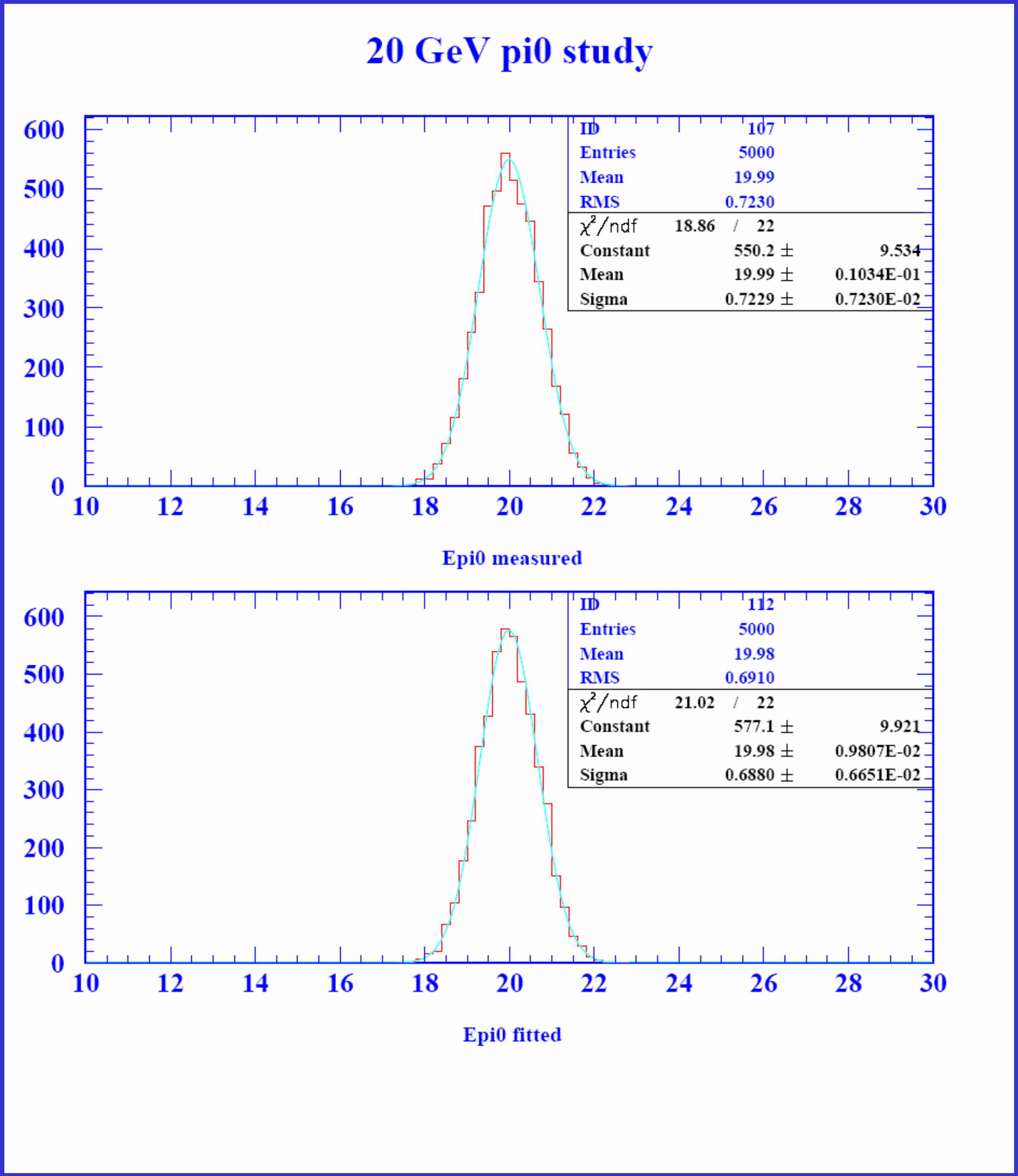
20 GeV π^0, same resolution assumptions



Mass resolution degrades as expected.

Constrained fit still works OK.

20 GeV π^0, same resolution assumptions

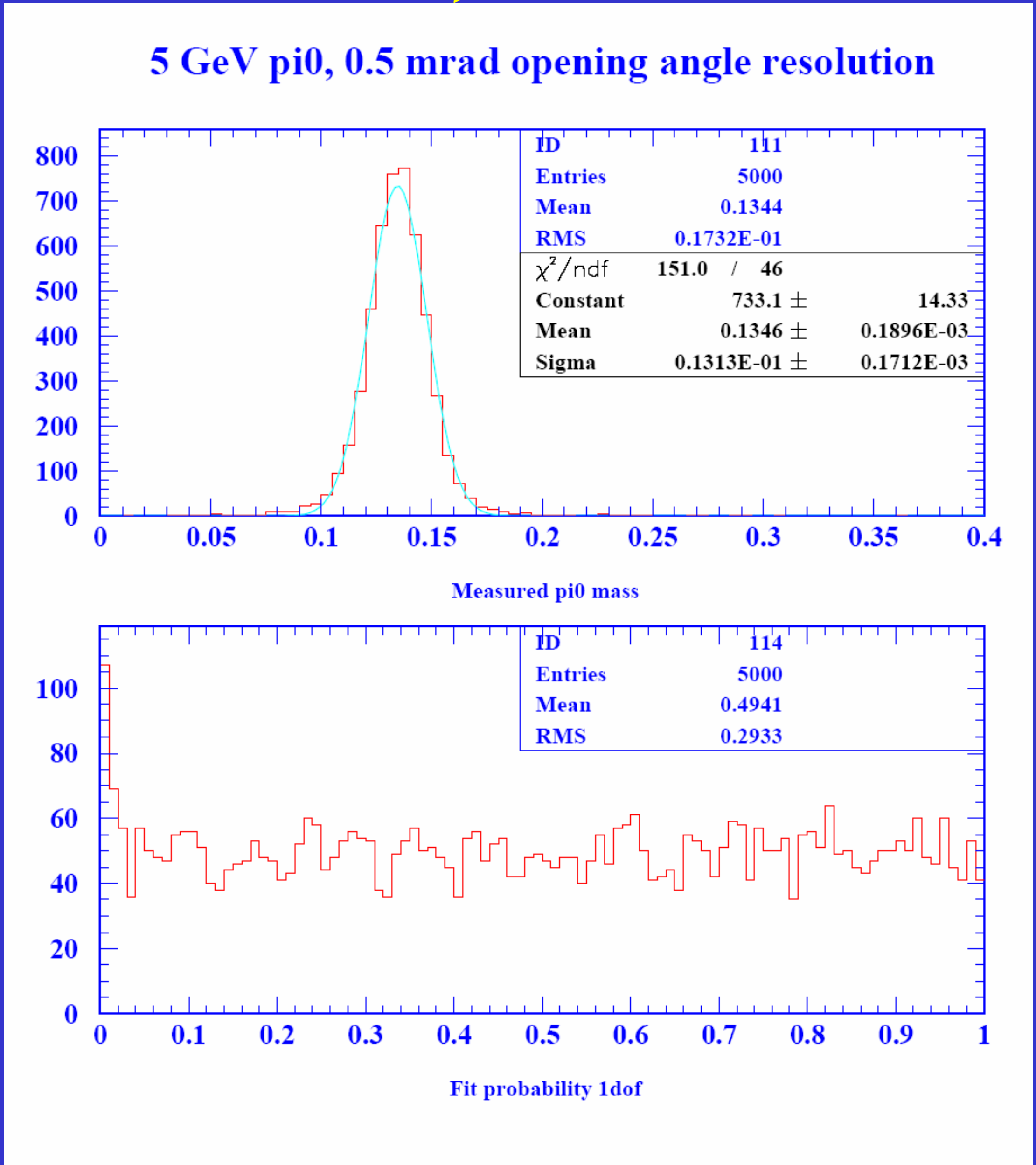


Constrained fit

$\Rightarrow$ No significant improvement.

(as expected)

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



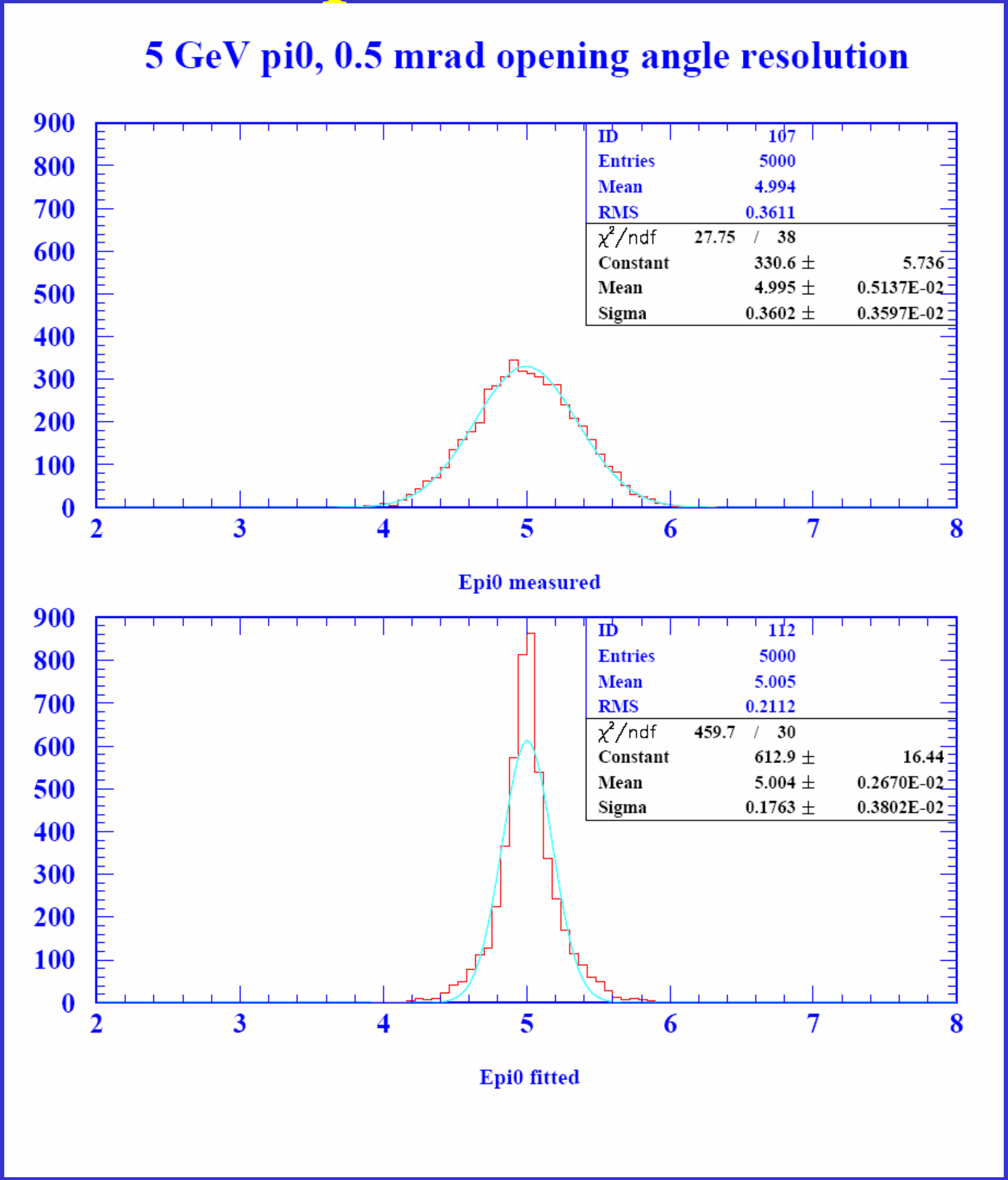
Not much change in mass resolution (dominated by E-term)

Fit still works.

π^0 energy resolution improvement

Dramatic !

Factor of 2 for ALL asymmetries.

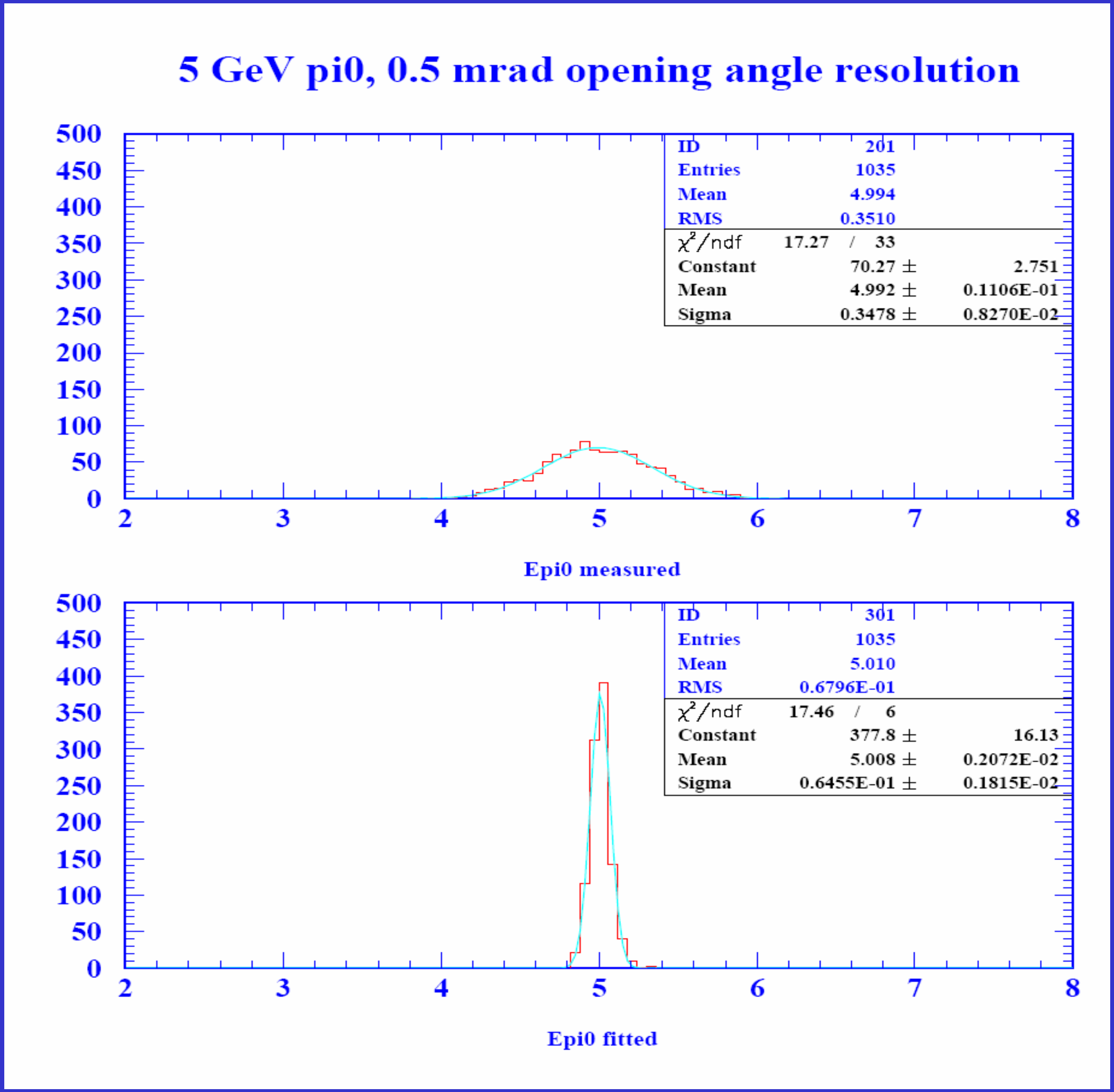


π^0 energy resolution improvement

|a| < 0.2

Improves by a factor of 0.35/0.065.

i.e. a factor of 5 !



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.

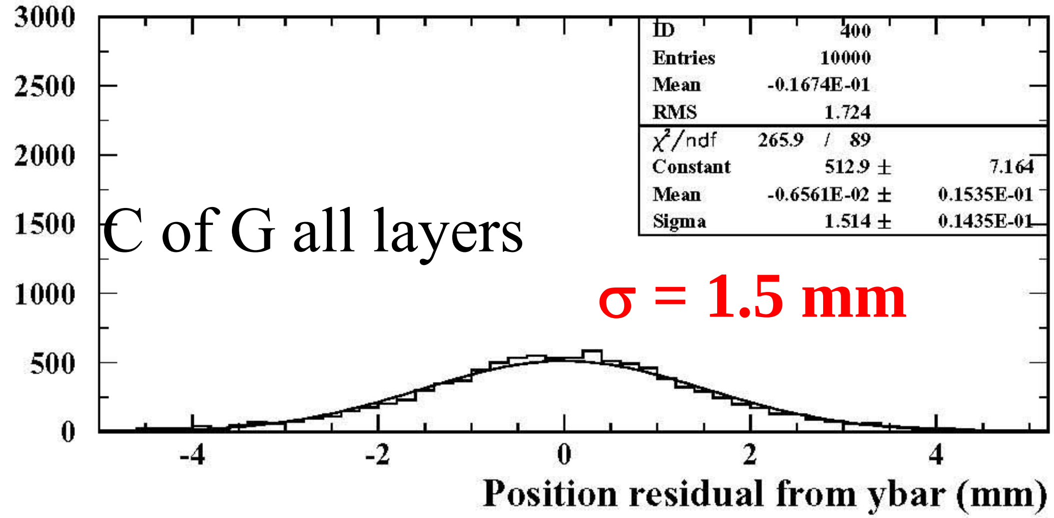
Backups

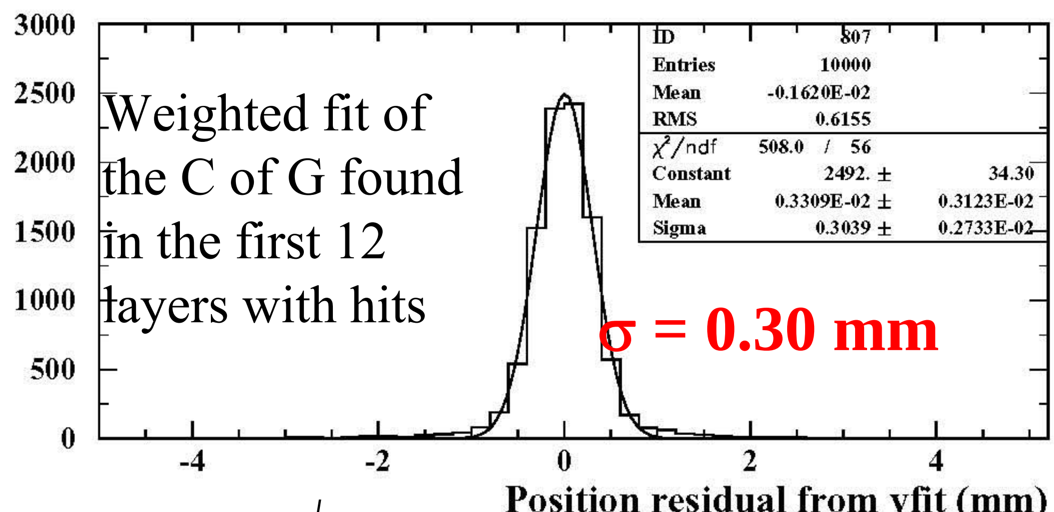
Position resolution from simple fit

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!*





Still just d/√12 !

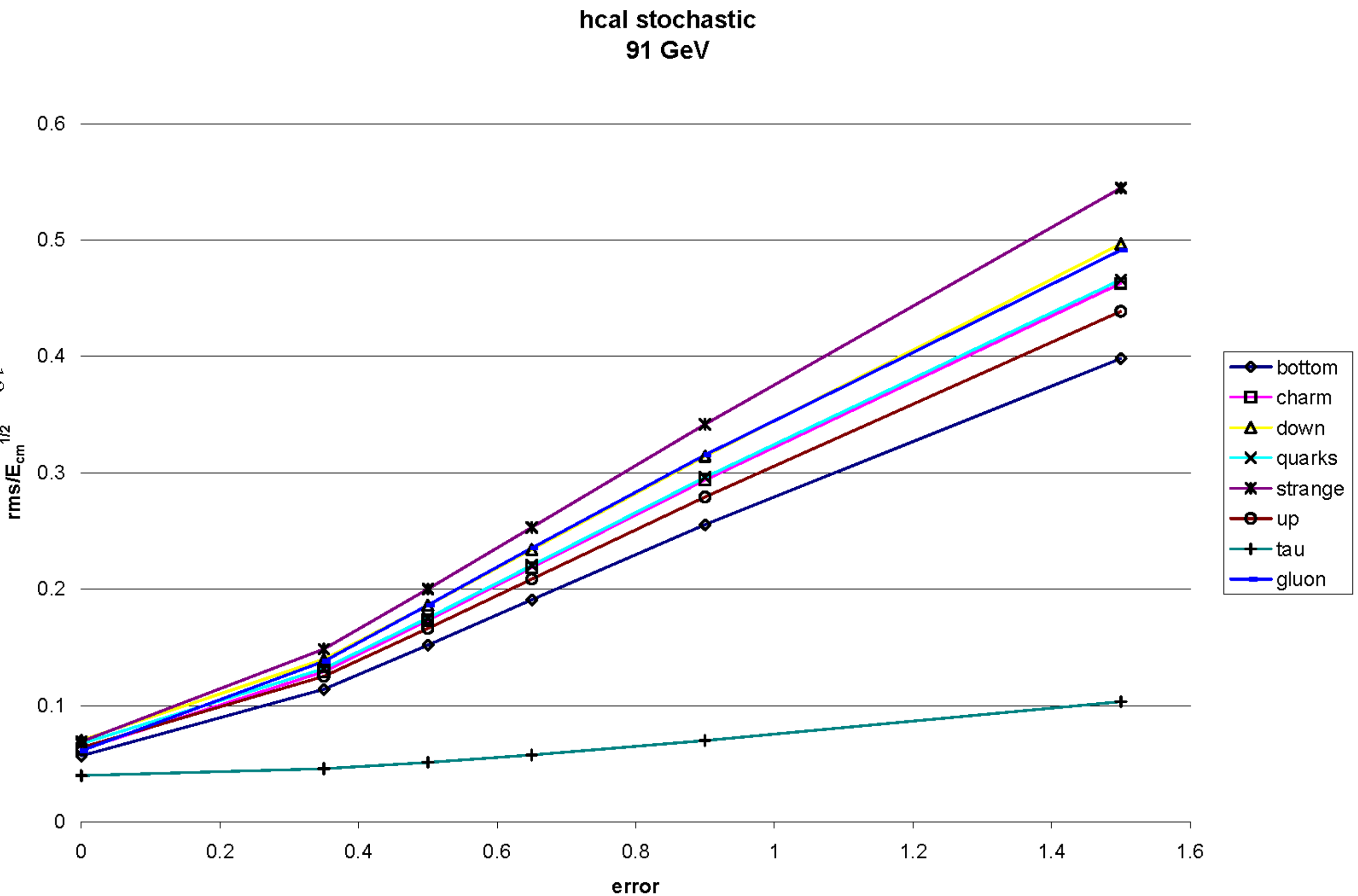

hcal stochastic
91 GeV
rms/E_cm^1/2
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
error
bottom
charm
down
quarks
strange
up
tau
gluon

Figure 4