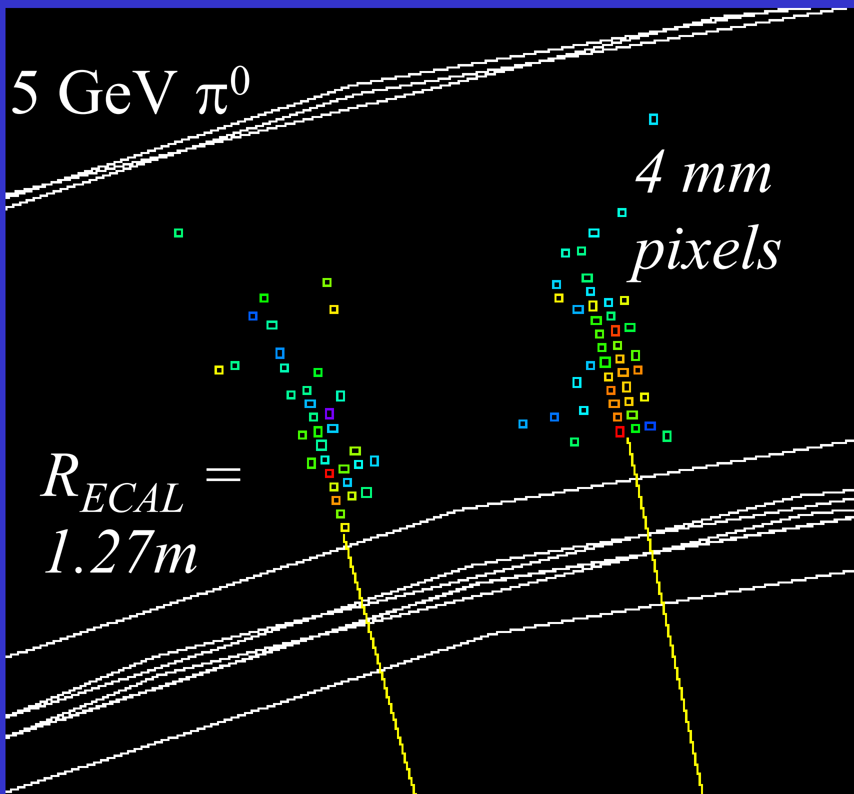
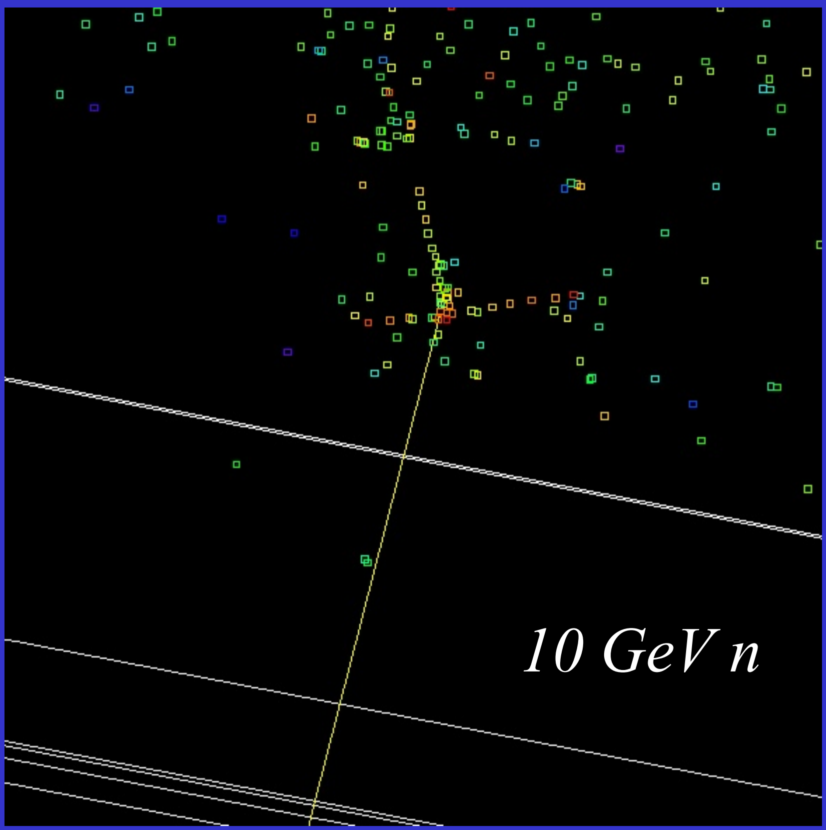
Impact of π^0 Reconstruction on PFA and Neutral-hadron TOF possibilities





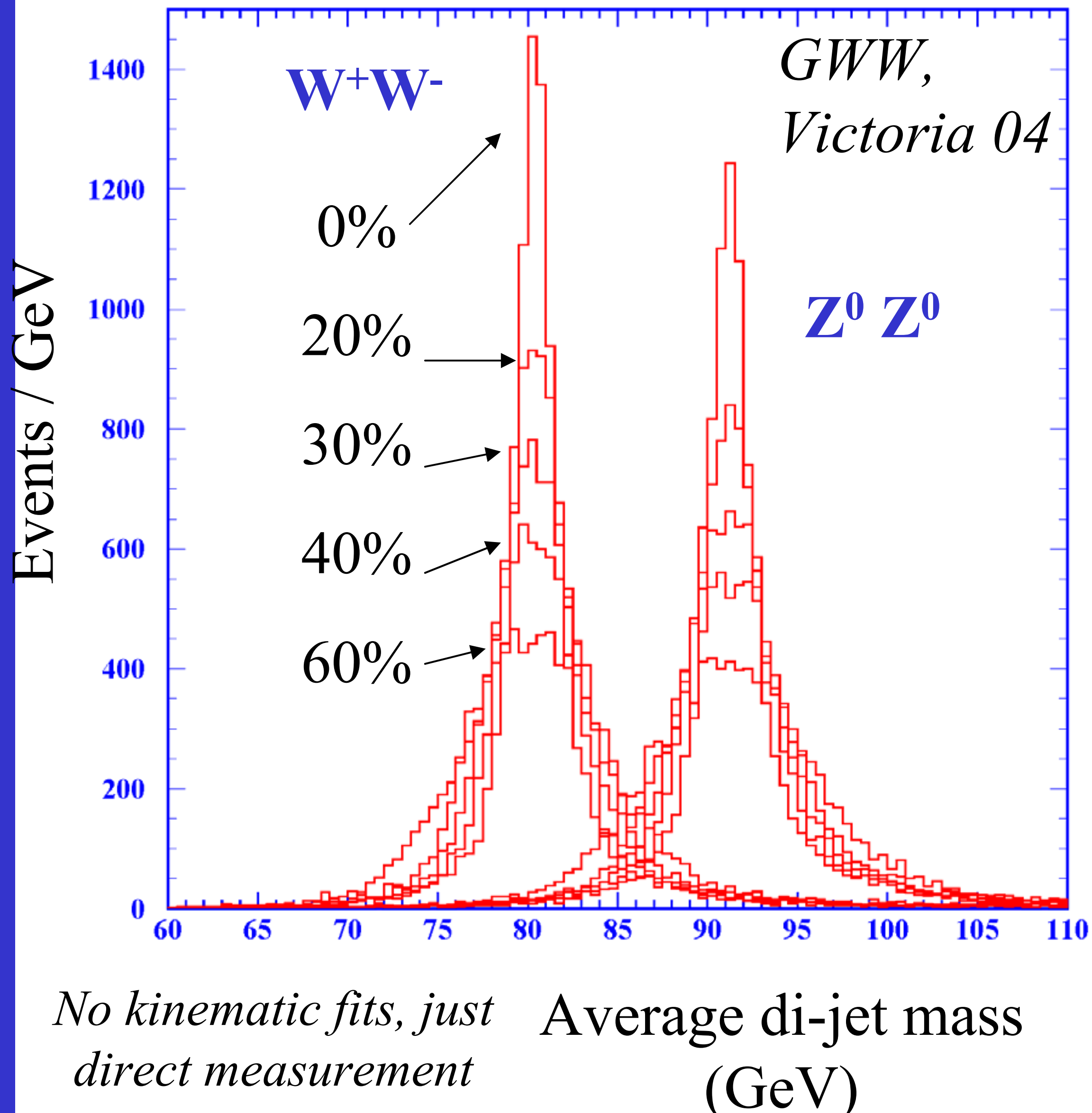
Graham W. Wilson, University of Kansas

LCWS07, Sim/reco session DESY Hamburg, June 2007

Outline

- Big picture on jet energy resolution potential
- Big detector
- Fast-timing ideas
- Applying π^0 mass constraint to hadronic events.

Di-jet mass distribution vs E_{jet} resolution



No kinematic fits, just direct measurement

Comparing $e^+e^- \rightarrow WW$ and

$e^+e^- \rightarrow ZZ$ at $\sqrt{s}$=300 GeV

$<E_{jet}> = 75$ *GeV*

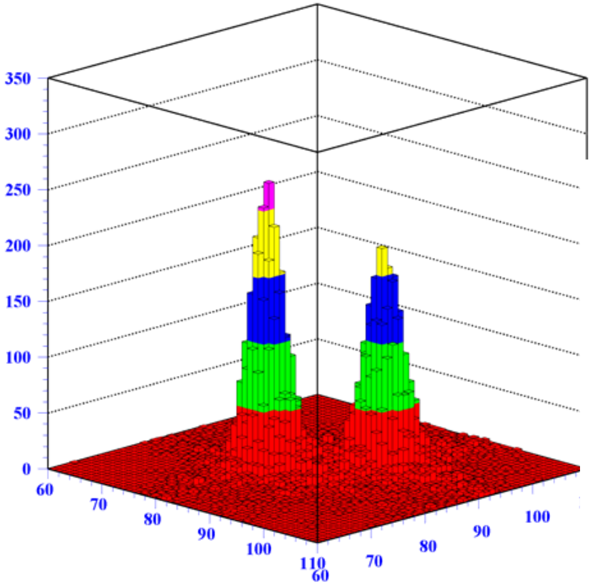
(hadronic decays only, assume WW:ZZ = 1:1 for illustration)

Reality = 7:1 !

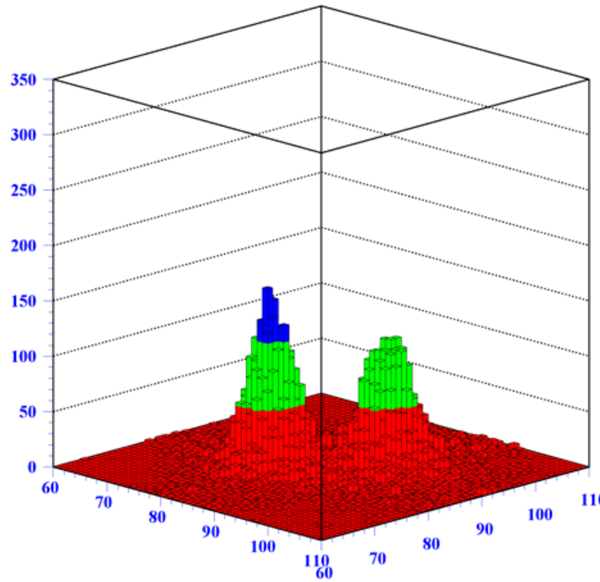
$\sigma(E_{jet})$ = xx%$\sqrt{E_{jet}}$(GeV)

30%$\sqrt{E_{jet}}$ is a good target. Physics (Γ_w=2 GeV) may demand even more !

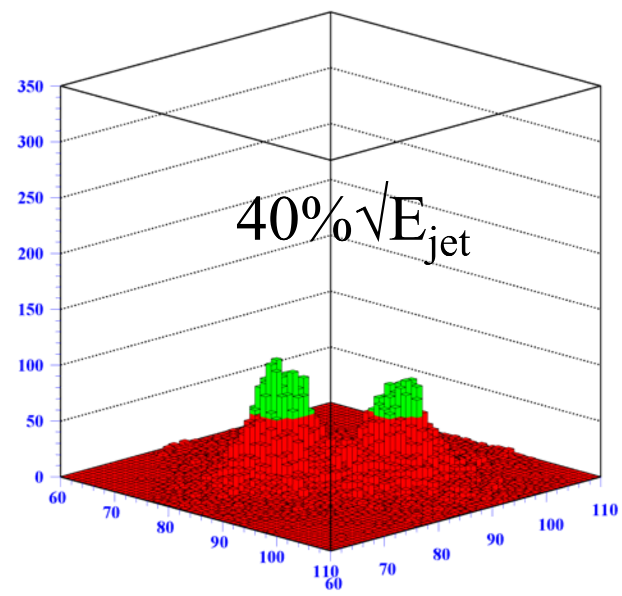
Wouldn't 20% be really something !



$20\%\sqrt{E_{jet}}$



$30\%\sqrt{E_{jet}}$



$40\%\sqrt{E_{jet}}$

Example detector model which should be able to achieve the π^0 performance indicated here.

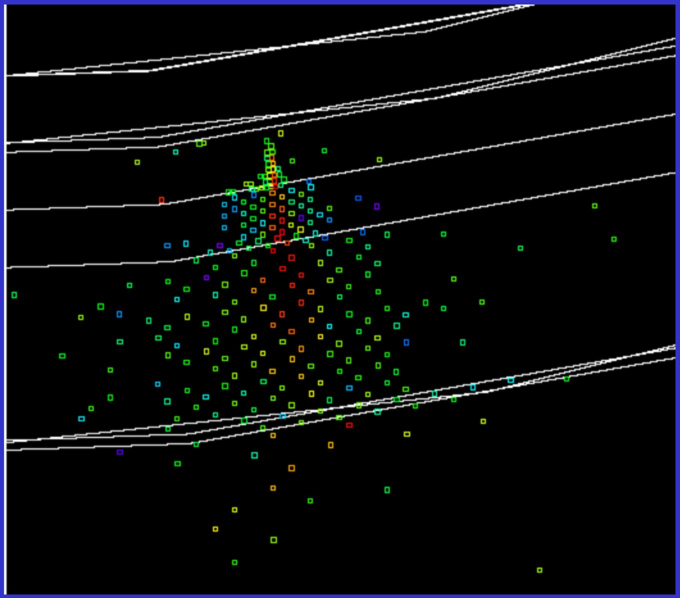
A radially staggered buildable analog calorimeter with exquisite granularity, with no cost optimization using Tungsten. B = 3T.

With M. Thomson.
Acknowledgements to N. Graf

frankyaug05

(W was cheaper in 05..)

	R(m)	Nlayers	X0	Active	Cell-size (mm)
EM Barrel 1:	2.10	10	0.5	Si	2.5 × 2.5 × 0.32
EM Barrel 2:	2.13	10	0.5	Si	10 × 10 × 0.32
EM Barrel 3:	2.16	20	0.5	Sc	20 × 20 × 2
HCAL:	2.255	50	2.0	Sc	40 × 40 × 2



50 GeV photon

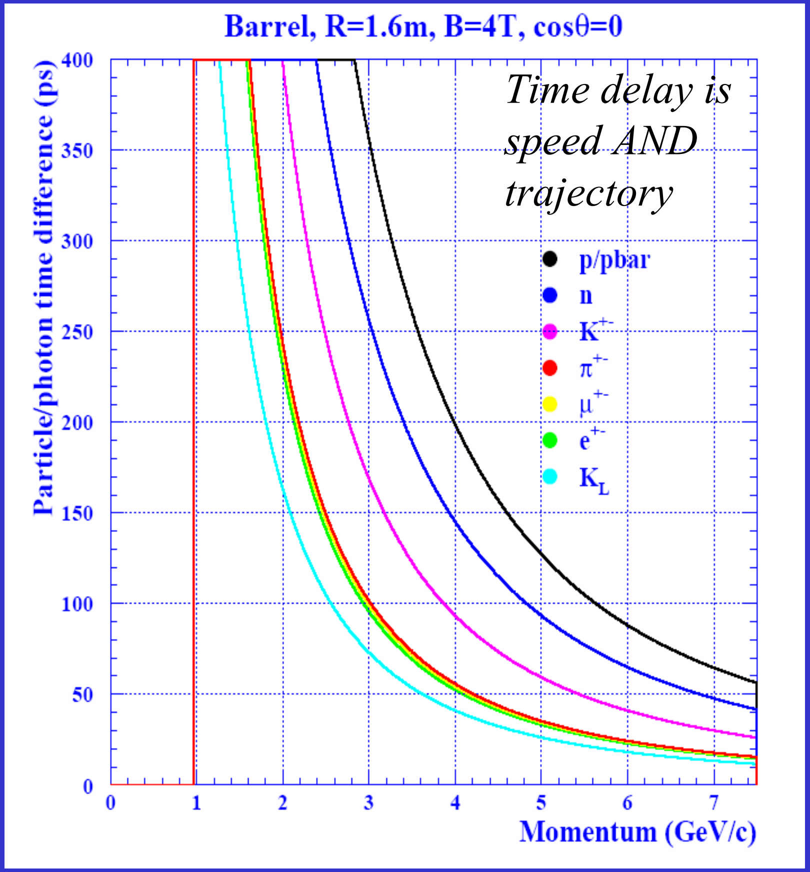
Choices made based on then current R&D work, driven by making a sensible, robust design with aggressive performance and minimizing Silicon area in a GLD-scale detector.

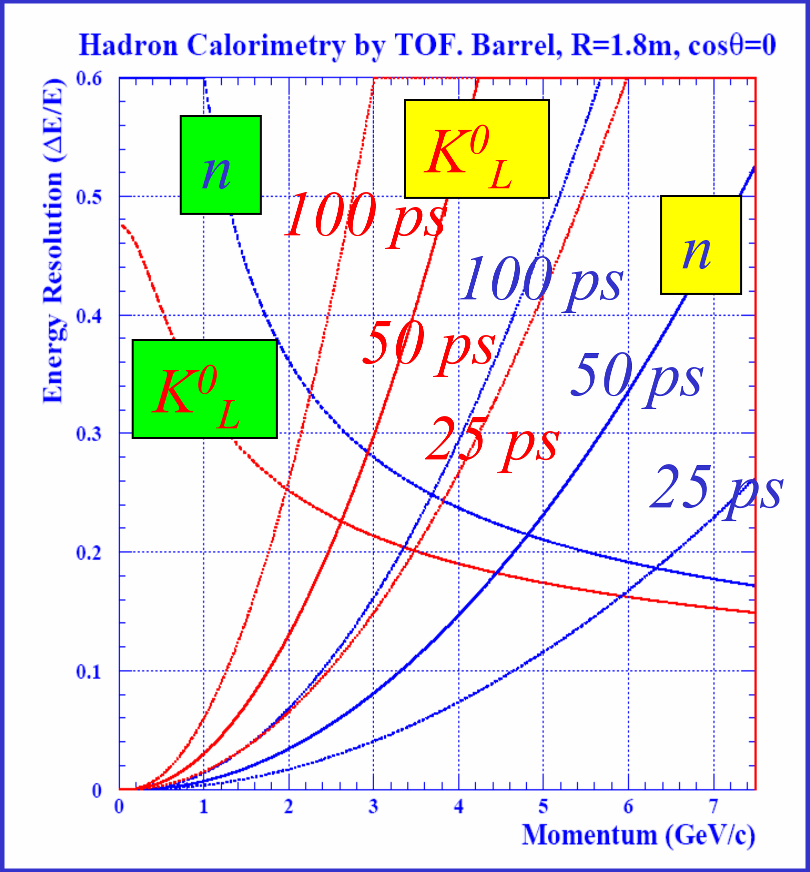
Expect: $\sigma_E/E = 11\%/\sqrt{E}$ at low energy

Fast Timing / Temporal Calorimetry

Idea: time resolution at below the 100 ps level is easily achievable with dedicated detectors. Can it be applied in a useful way in an ILC detector ?

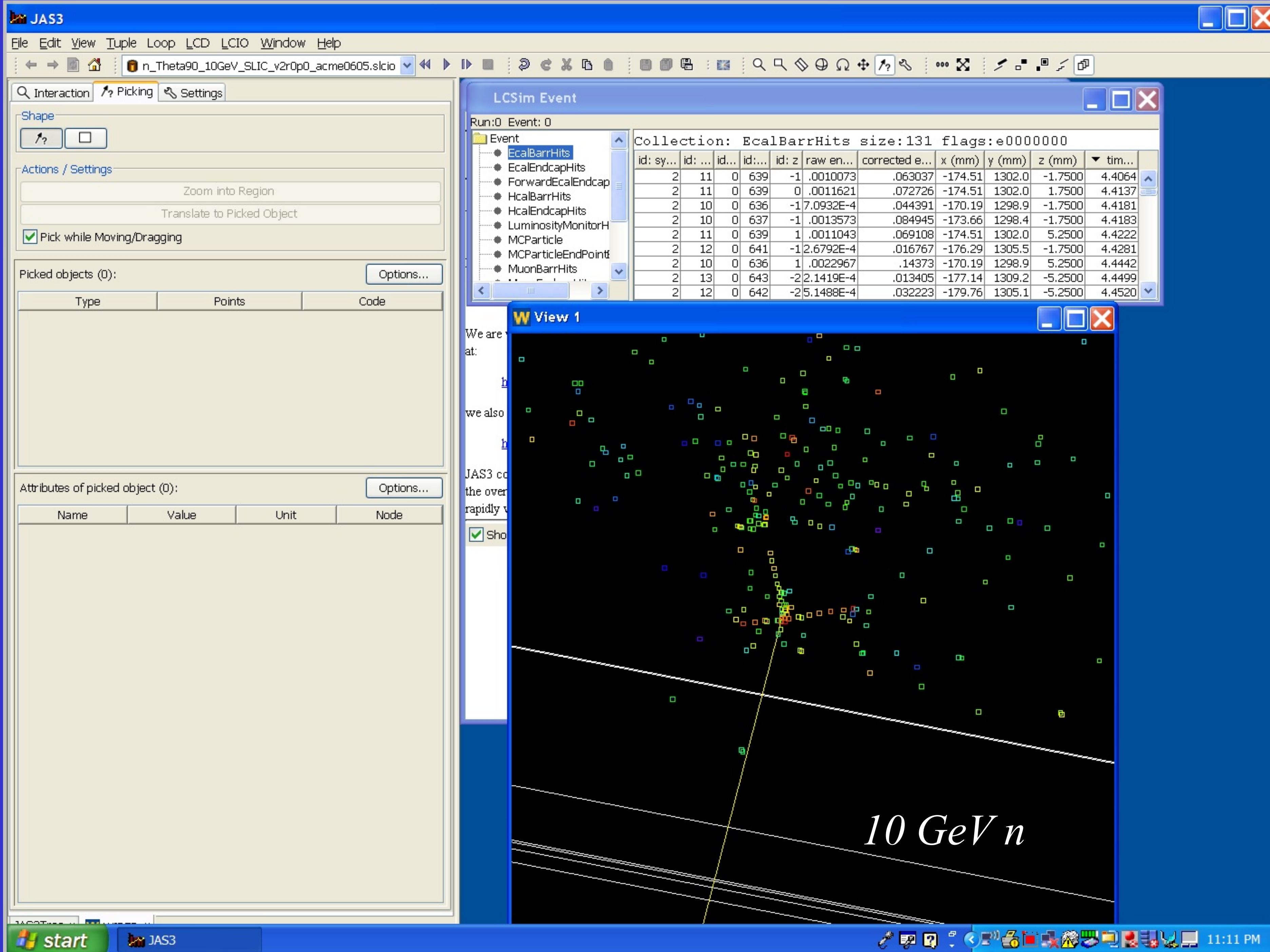
Can TOF help measure neutral hadrons at low p ?





Can help resolving γ/π. (PID by TOF possible – but redundant with dE/dx in a TPC-based detector). Resolve confusion.

HCAL (LDC DOD) TOF



JAS3
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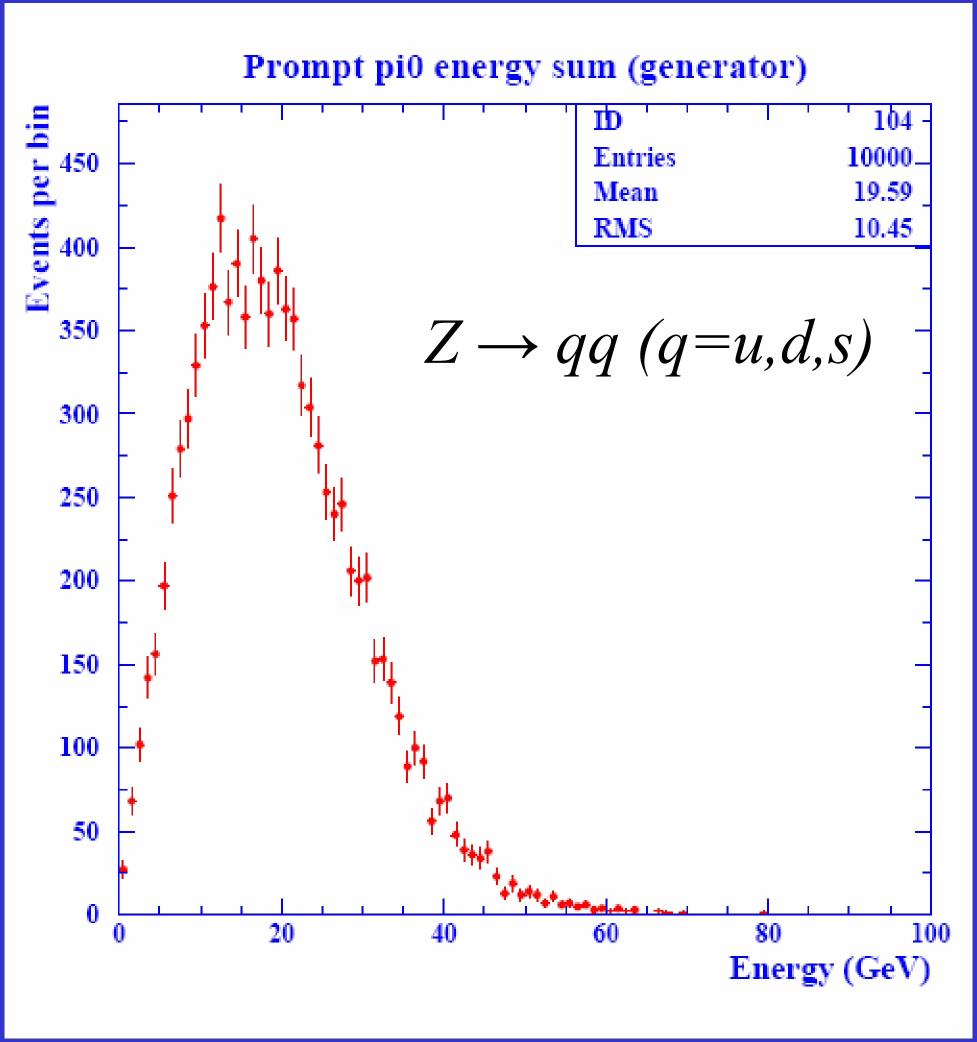
2 11 0 639 -1 .0010073 .063037 -174.51 1302.0 -1.7500 4.4064
2 11 0 639 0 .0011621 .072726 -174.51 1302.0 1.7500 4.4137
2 10 0 636 -1 7.0932E-4 .044391 -170.19 1298.9 -1.7500 4.4181
2 10 0 637 -1 .0013573 .084945 -173.66 1298.4 -1.7500 4.4183
2 11 0 639 1 .0011043 .069108 -174.51 1302.0 5.2500 4.4222
2 12 0 641 -1 2.6792E-4 .016767 -176.29 1305.5 -1.7500 4.4281
2 10 0 636 1 .0022967 .14373 -170.19 1298.9 5.2500 4.4442
2 13 0 643 -2 2.1419E-4 .013405 -177.14 1309.2 -5.2500 4.4499
2 12 0 642 -2 5.1488E-4 .032223 -179.76 1305.1 -5.2500 4.4520
View 1
10 GeV n
start
JAS3
11:11 PM

Possible Detectors ?

- State-of-the-art: MCP-PMT, σ_t = 5 ps measured using Cerenkov light in 10mm quartz, K. Inami et al, NIM A 560 (2006) 303.
  - Also see emerging "fast-timing" initiatives. (Fritsch, LeDu)
- Cerenkov layers – also designed for C-based compensation.
- Ultra-fast scintillator pads with direct-coupled thin B-field tolerant photo-detectors tiled in a few layers through the calorimeter ??
  - Eg. quenched scintillators with FWHM of 400 ps per γ. (BC-422Q)
  - Will do time resolution studies with this.
- RPCs, Pestov
- Scintillating fibers.

Prompt EM energy component of jets



Dominated by π^0's.

Defined as prompt if they are produced within 10 cm of the IP.

On ***average****, with 16%/√E EM energy resolution, the intrinsic EM resolution contribution to the jet energy is 0.71 GeV corresponding to 7.4%/√Ejet.*

Can potentially reduce this contribution using π^0 mass constraint. May drive ultra-fine position resolution (eg. MAPS) and/or lead to an option of saving some Silicon layers.

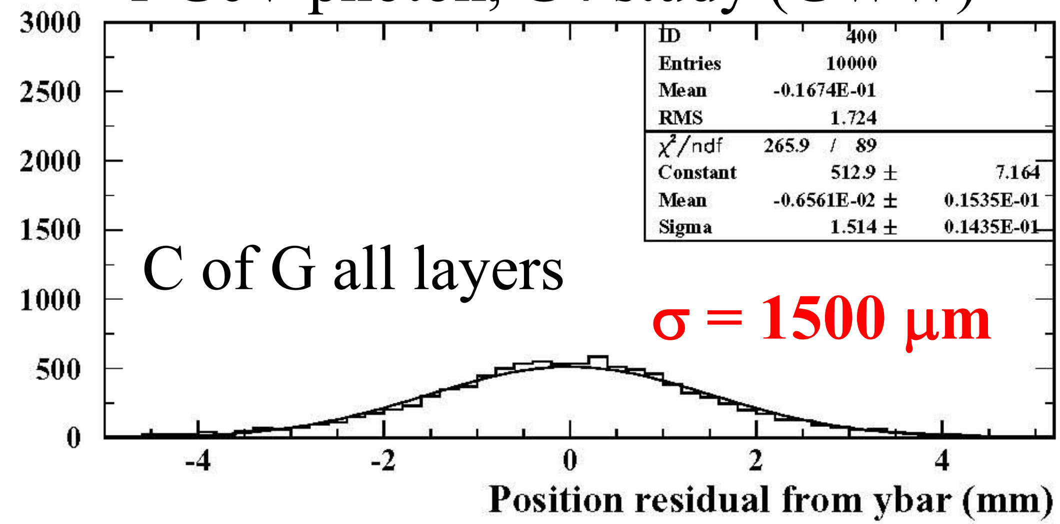
Position resolution from simple fit

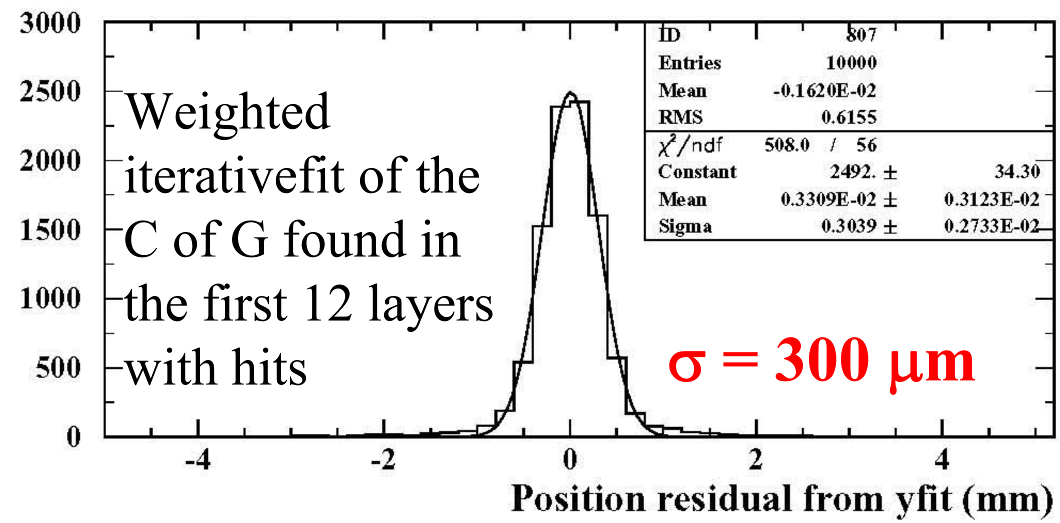
Key: measure the shower really well near the conversion point ($\gamma \rightarrow e^+e^-$)

*2004 study with 1mm*1mm Si pixels (pre-MAPS I thought this was unbuildable …) and 42 layers with sampling every 5/7 X_0*

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

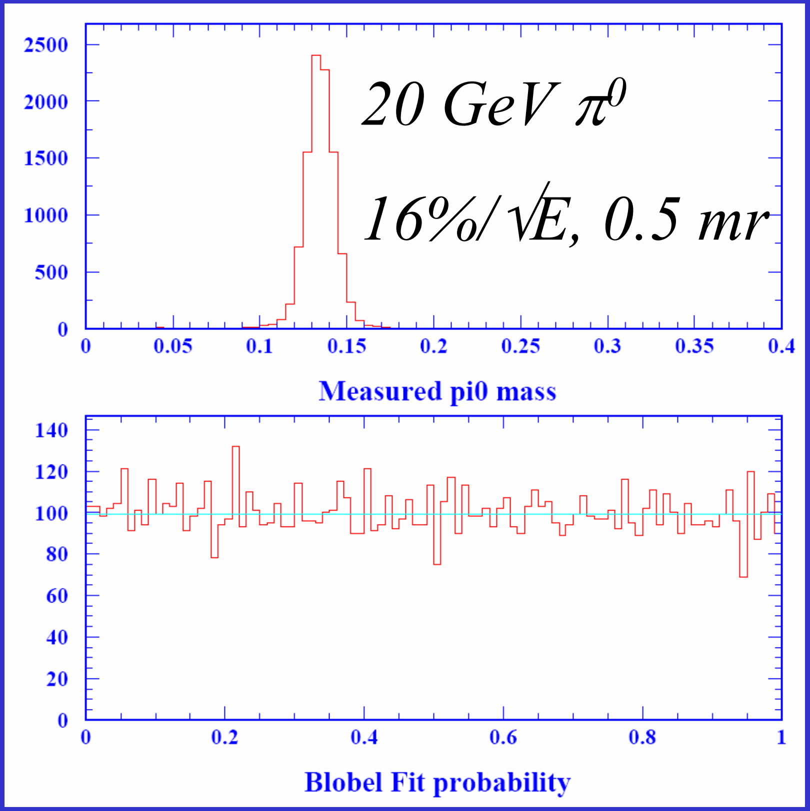
1 GeV photon, G4 study (GWW)

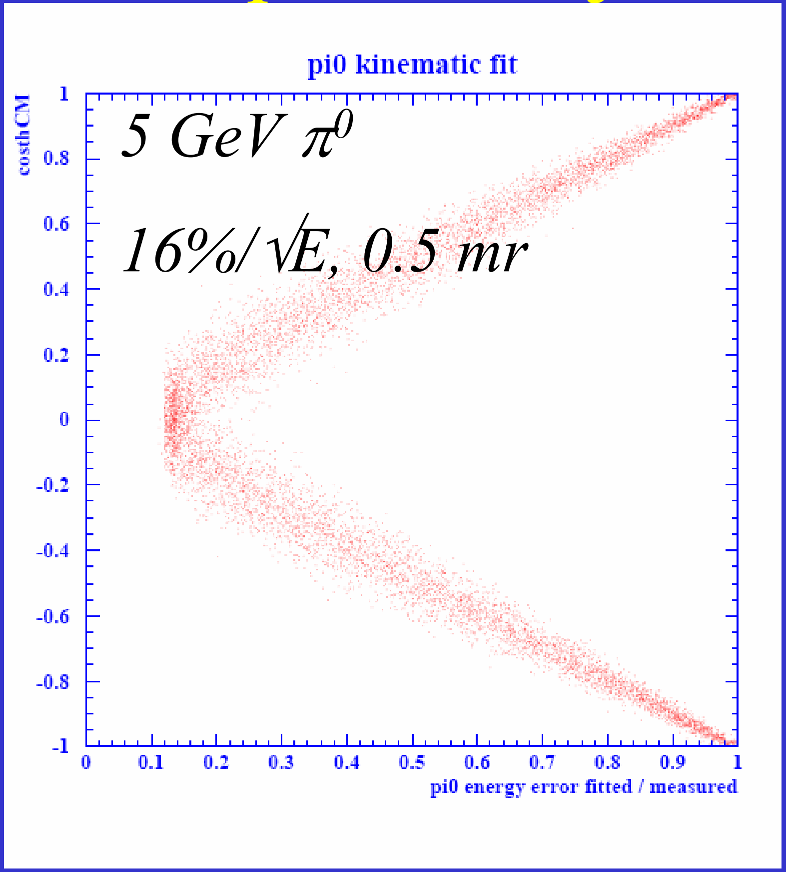




Still just d/√12 !

Comprehensive study of applying mass-constrained fit for π^0's to improve the energy resolution of the *prompt* EM component of jets





See talk at Valencia meeting for more details. Proof of principle of the intrinsic potential per π^0.

NOTE: Not only does the resolution improve, the resolution is known per pair

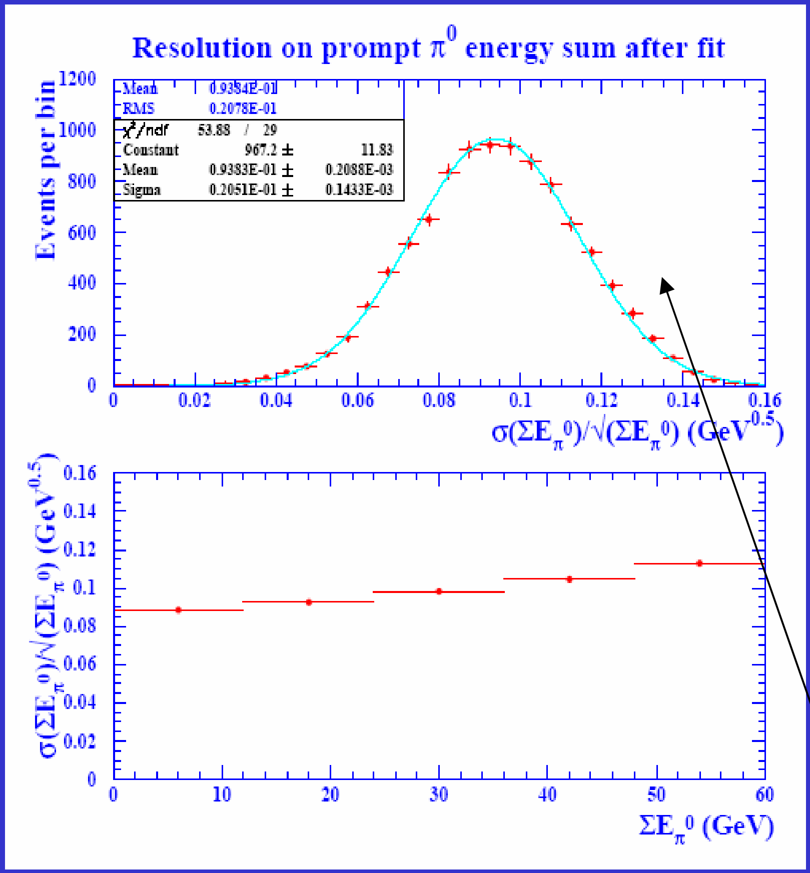
Practical Implementation for Hadronic Events

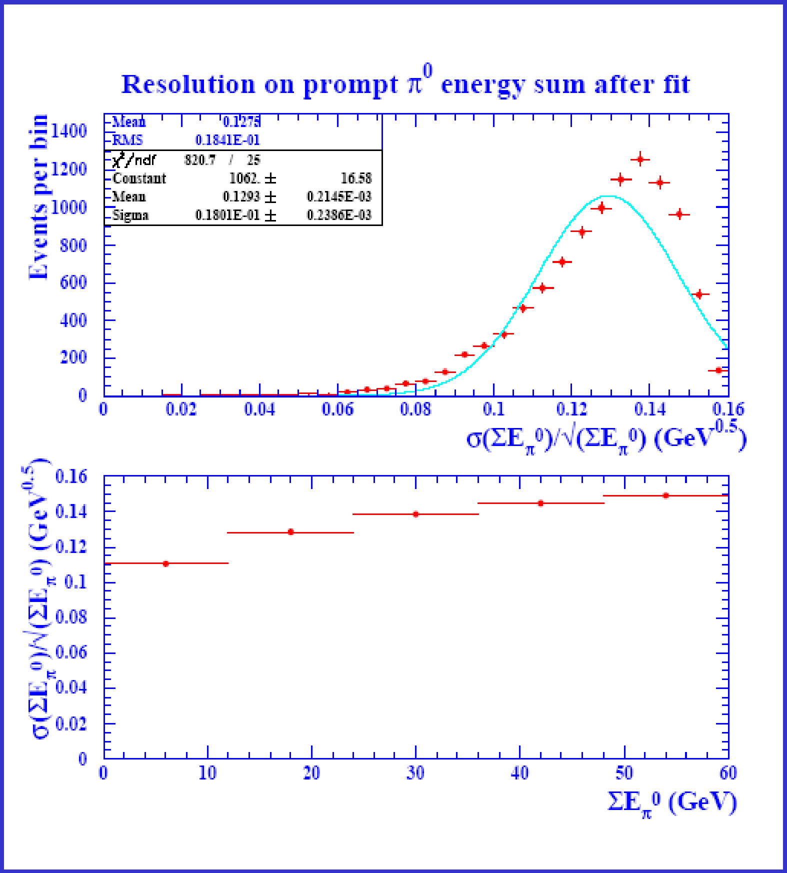
- 1. Assume perfect pairing of photons to π^0s.
  - Estimate improvement.
  - Study implications for detector.
- 2. Implement an assignment algorithm which associates sibling photon pairs to parent π^0s.
  - Now have a first implementation which can probably be improved considerably. Lots of work still to do here.
- 3. Implement in the context of full simulation of a particular detector model.
  - Need to care about photon calibration, resolution functions, purity, efficiency etc. (Clermont-Ferrand group, is working on this aspect for LDC). See P. Gris talk, work by C. Carloganu.

Applying mass-constraint to Z → hadrons

Assumes ***perfect pairing*** *of sibling photons to parent* π^0

(currently restrict to prompt π^0*s defined as originating within 10 cm of IP)*





16%/√E, $\Delta\psi_{12}$*=0.5mr* *16%/√E,* $\Delta\psi_{12}$*=8mr*

Potential to improve resolution on average to 9.4%/ √E

Summary on potential with perfect pairing

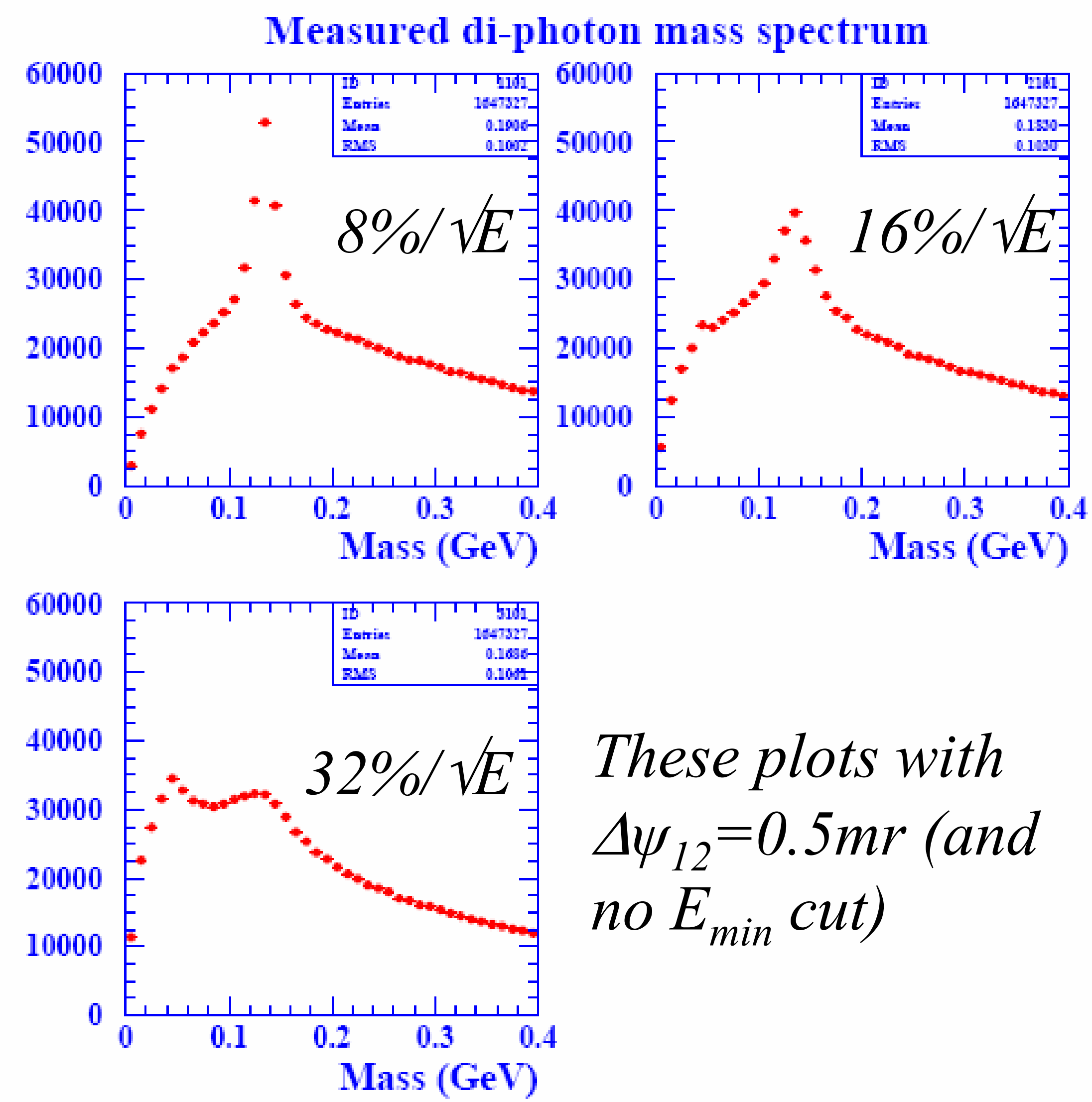
ECAL Energy Resolution (%)	No fit	Fit (0.5 mrad)	Fit (2 mrad)	Fit (8 mrad)
8.0	8.0	4.9	5.8	6.8
16.0	16.0	9.4	10.7	12.7
32.0	32.0	18.3	19.9	23.4

Table 1: *Average normalized fractional energy resolution (%) on the total prompt π^0 energy in light-quark Z events with and without kinematic fitting for different assumptions on the ECAL energy resolution stochastic term, and the di-photon opening angle resolution assuming perfect pairing in the kinematic fit. Errors are less than 0.1%.*

(will pause to digest this later in talk)

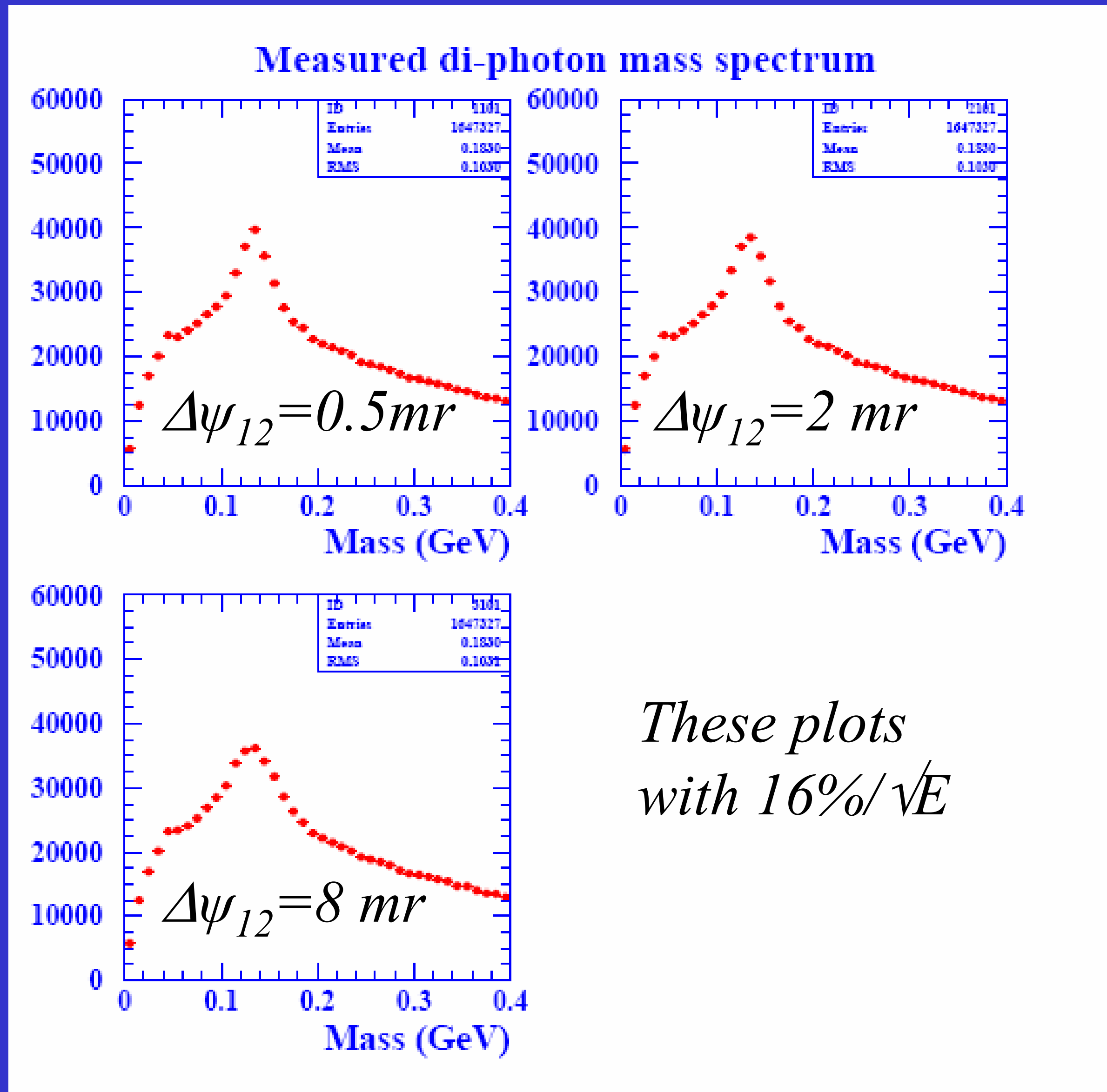
Include (vast) combinatorics

$<n_{\pi 0}> = 8.6$



These plots with $\Delta\psi_{12}$=0.5mr (and no E_{min} cut)

Same, but vary opening angle resolution



Assignment Algorithm

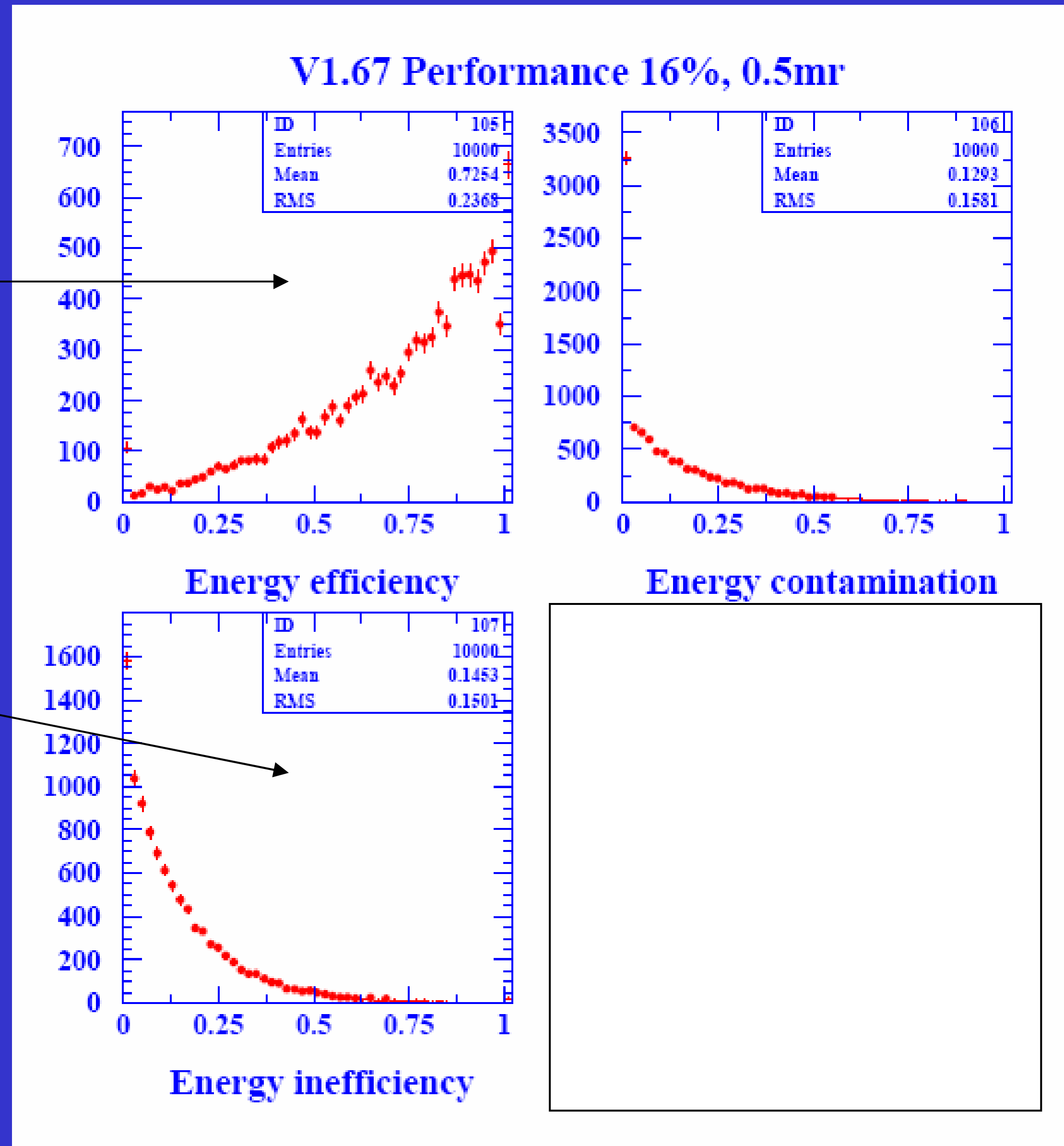
- Very basic so far. (Snap-shot)
- $E_\gamma > 0.1$ GeV
- $p_{fit} > 1\%$
- Form $\chi^2_{mass} = [(m - m(\pi^0))/0.07]^2 \rightarrow p_{mass}$
- Use a discriminant, $D = p_{fit}\, p_{mass}\, E_{\pi 0} / \sigma_m$
- Using energy sorted photons, assign photons to pairings if they have the highest D for both photons.
- Unassigned photons, contribute with their normal measured energy.
- Performance may be strongly dependent on the actual combinatorics.
- Have also looked into a more global method of assignment using assignment problem methodology. Currently pondering how to enforce one-to-one assignment, while taking advantage of N^3 rather than N! scaling of standard techniques.

Performance

Fraction of prompt π^0 *energy correctly fitted,* ε_c

Fraction of prompt π^0 *energy wrongly fitted,* ε_W

Fraction of prompt π^0 *energy unfitted,* ε_{UF}



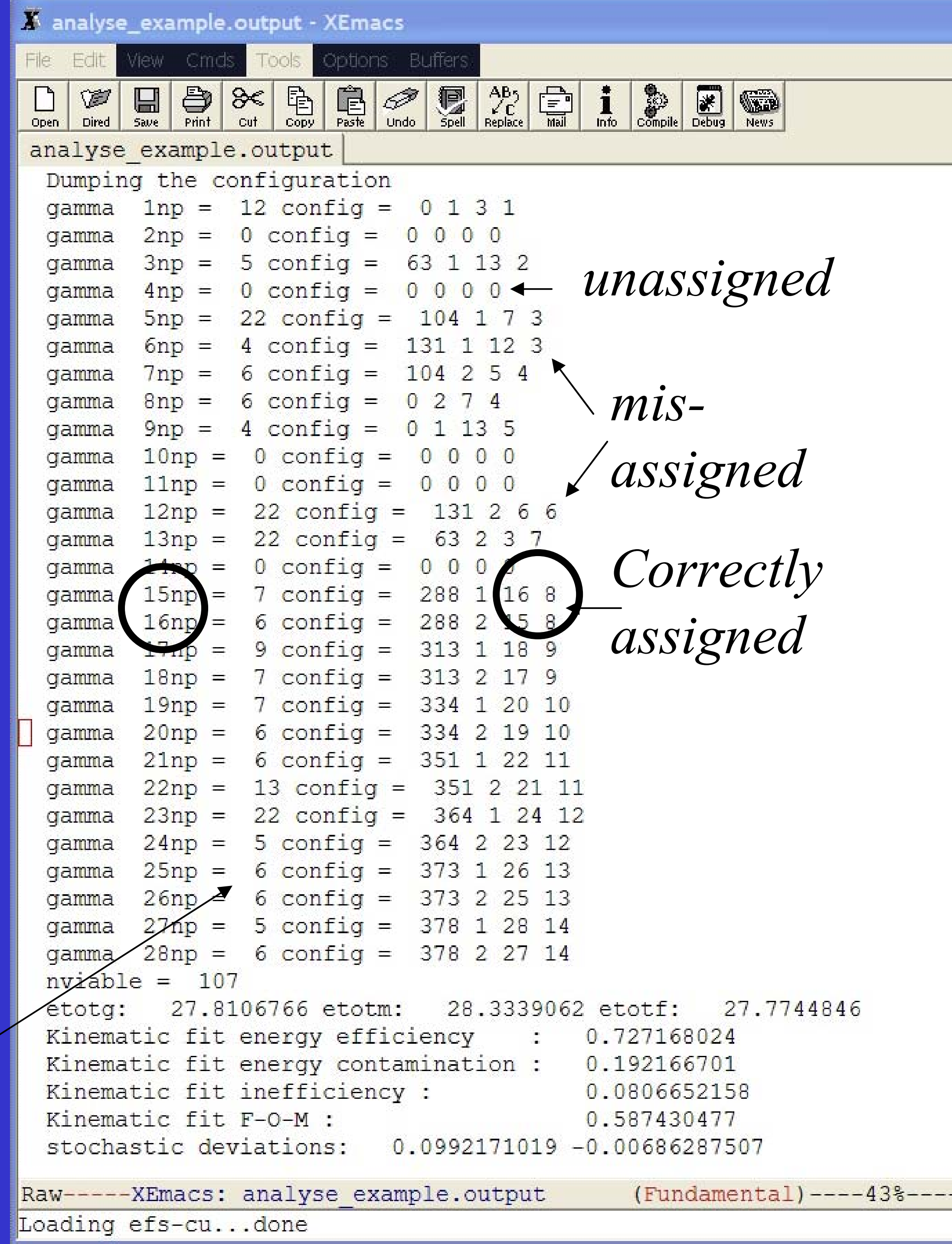
Typical Event

(selected as having performance similar to the average).

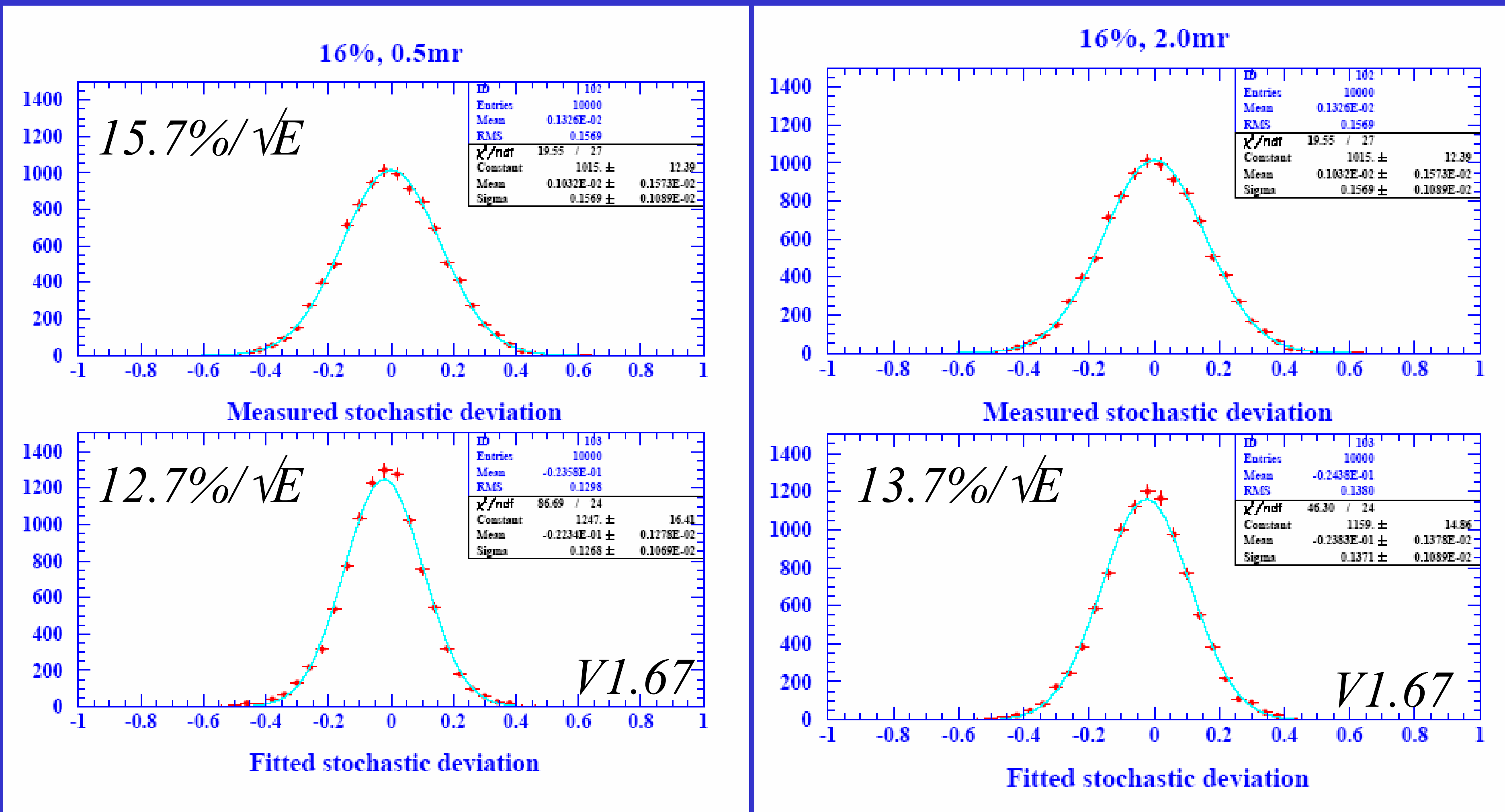
This one has $\Sigma E_{\pi 0} = 28$ GeV, $n_{\pi 0}=14$, so $n_{\gamma}=28$, $n_{\gamma\gamma} = 378$, and in total 107 $\gamma\gamma$ combinations passing the kinematic fit cuts.

The stochastic deviation in this particular event improves from + 9.9%/√E to – 0.07%/√E

Number of viable pairings for this photon



Current Results (10k Z events)



I believe this can still be improved substantially

Summary on potential of π^0 mass-constraint in hadronic events ($\sqrt{s}=m_Z$)

1. Perfect pairing

ECAL Energy Resolution (%)	No fit	Fit (0.5 mrad)	Fit (2 mrad)	Fit (8 mrad)
8.0	8.0	4.9	5.8	6.8
16.0	16.0	9.4	10.7	12.7
32.0	32.0	18.3	19.9	23.4

Table 1: *Average normalized fractional energy resolution (%) on the total prompt π^0 energy in light-quark Z events with and without kinematic fitting for different assumptions on the ECAL energy resolution stochastic term, and the di-photon opening angle resolution assuming perfect pairing in the kinematic fit. Errors are less than 0.1%.*

(uses fit to the error distribution from the fit)

2. Assignment algorithm 1.67

Using fitted σ of deviation on same 10k events

7.9	6.3	6.9	7.5
15.7	**12.7**	13.7	14.8
31.0	25.9	27.0	29.0

Summary

- EM calorimeter contribution to the jet energy resolution can plausibly be considerably improved using π^0 mass constraint in detector designs with fine granularity ECAL.
- Fast-timing has a lot of potential.
  - Particle ID, confusion mitigation, neutral hadron reconstruction.
  - Worthwhile to evaluate performance/feasibility of some of the possible approaches. Are you interested ?

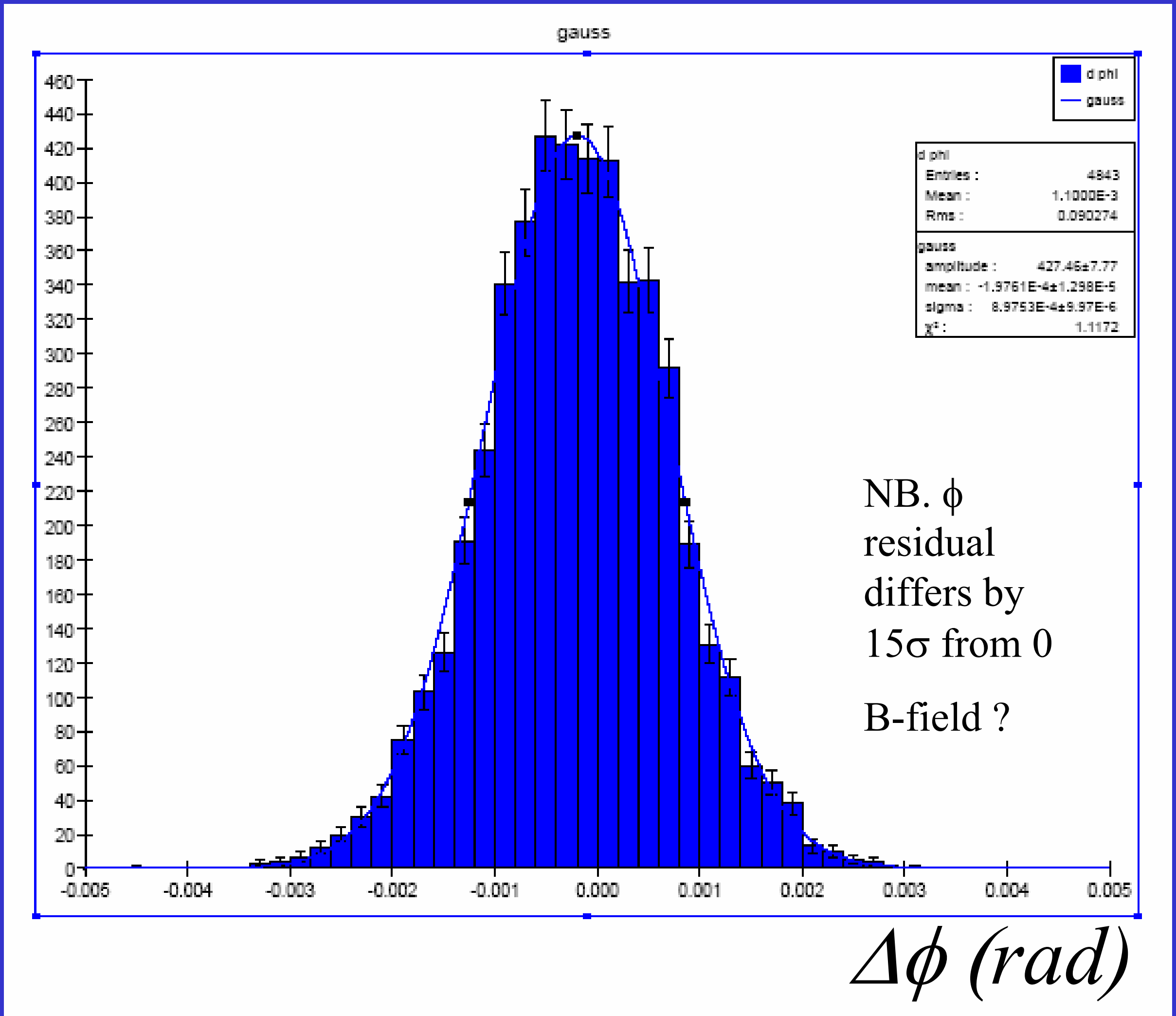
Backup Slides

Angular Resolution Studies

5 GeV photon at 90°, sidmay05 detector (4 mm pixels, R=1.27m)

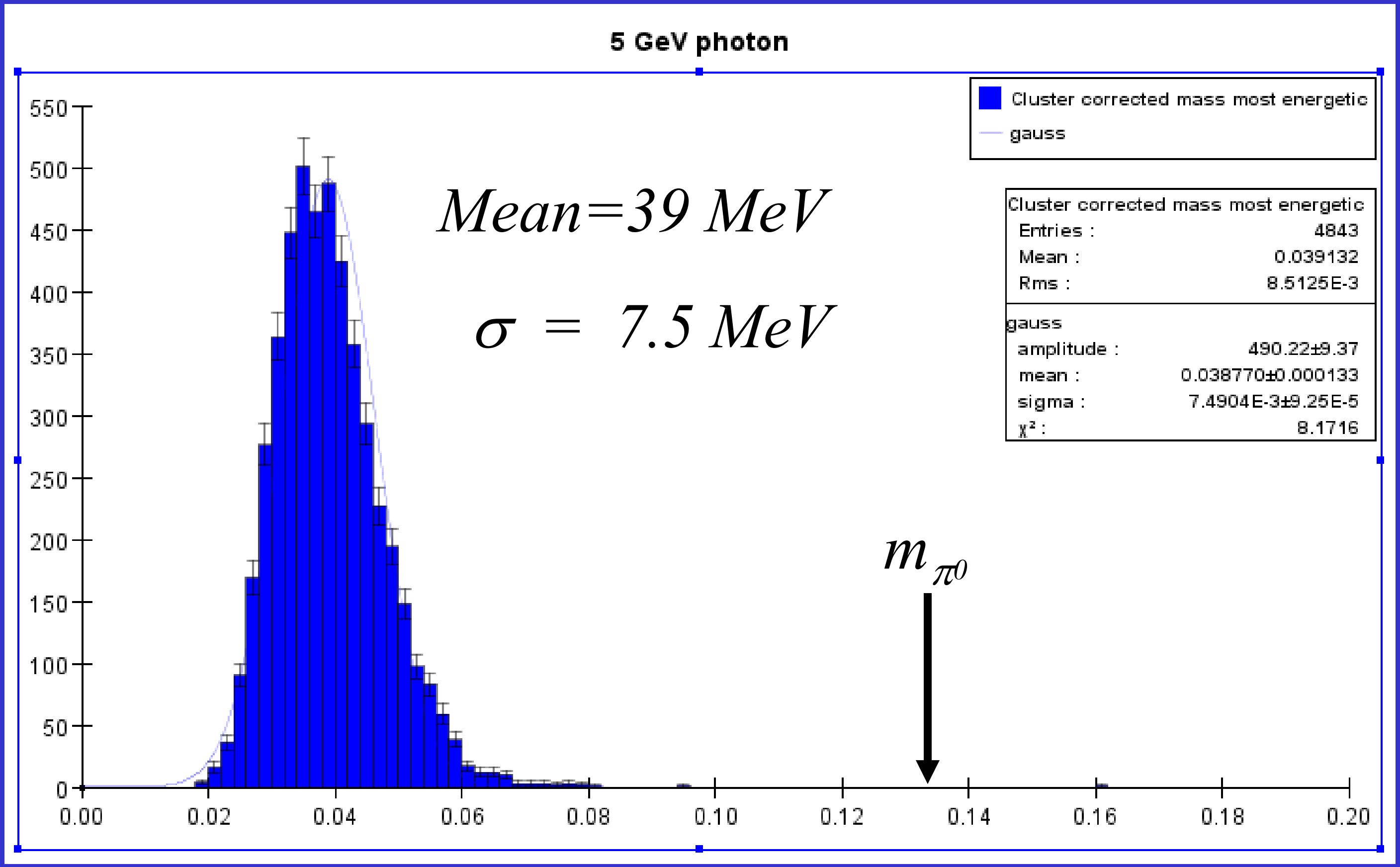
Phi resolution of 0.9 mrad ***just*** using cluster CoG.

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



NB. Previous study (see backup slide), shows that a factor of 5 improvement in resolution is possible at fixed R using longitudinally weighted "track-fit".

Cluster Mass for Photons



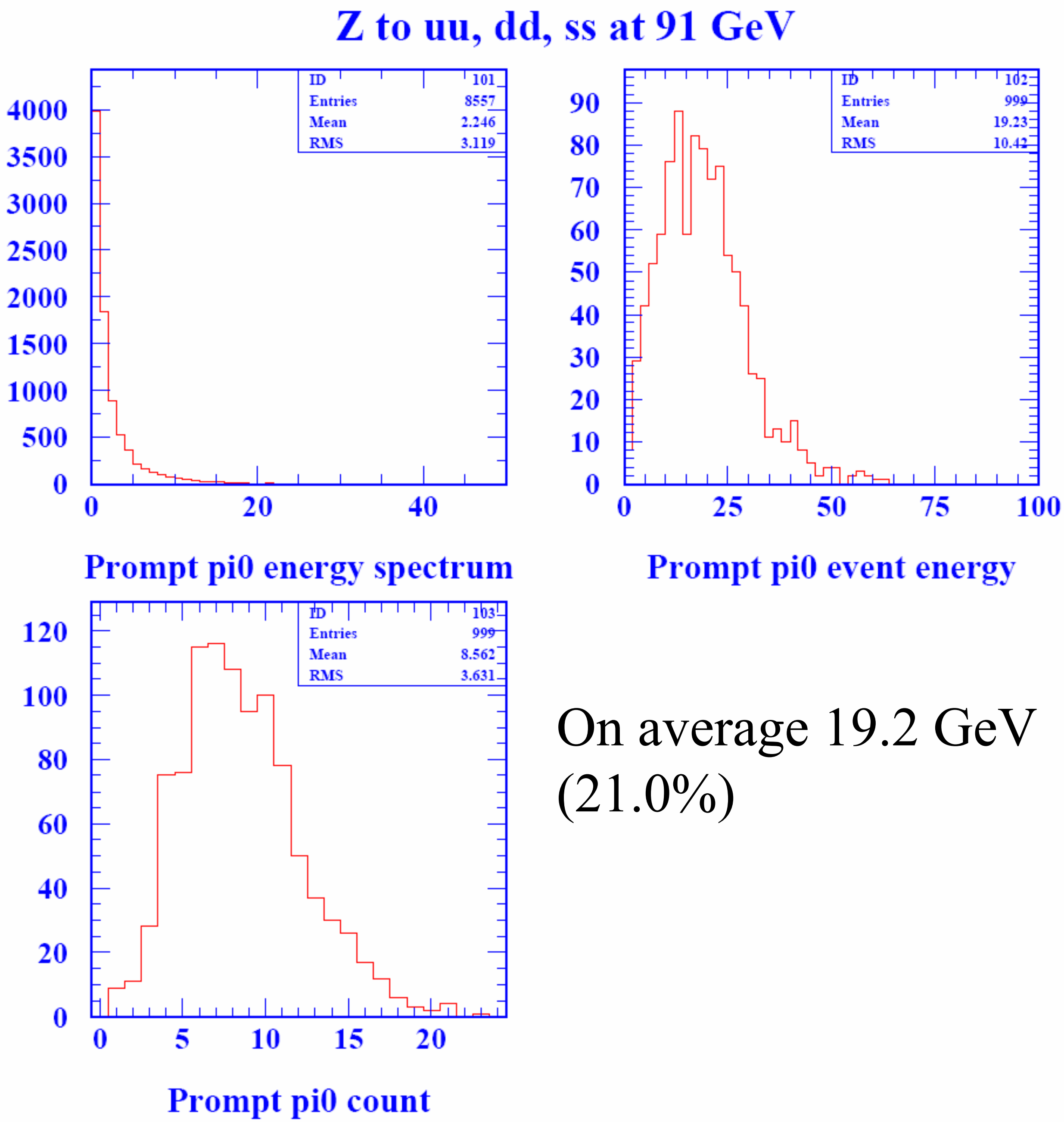
Cluster Mass (GeV)

Of course, photons actually have a mass of zero.

The transverse spread of the shower leads to a non-zero cluster mass calculated from each cell.

Use to distinguish single photons from merged π^0's.

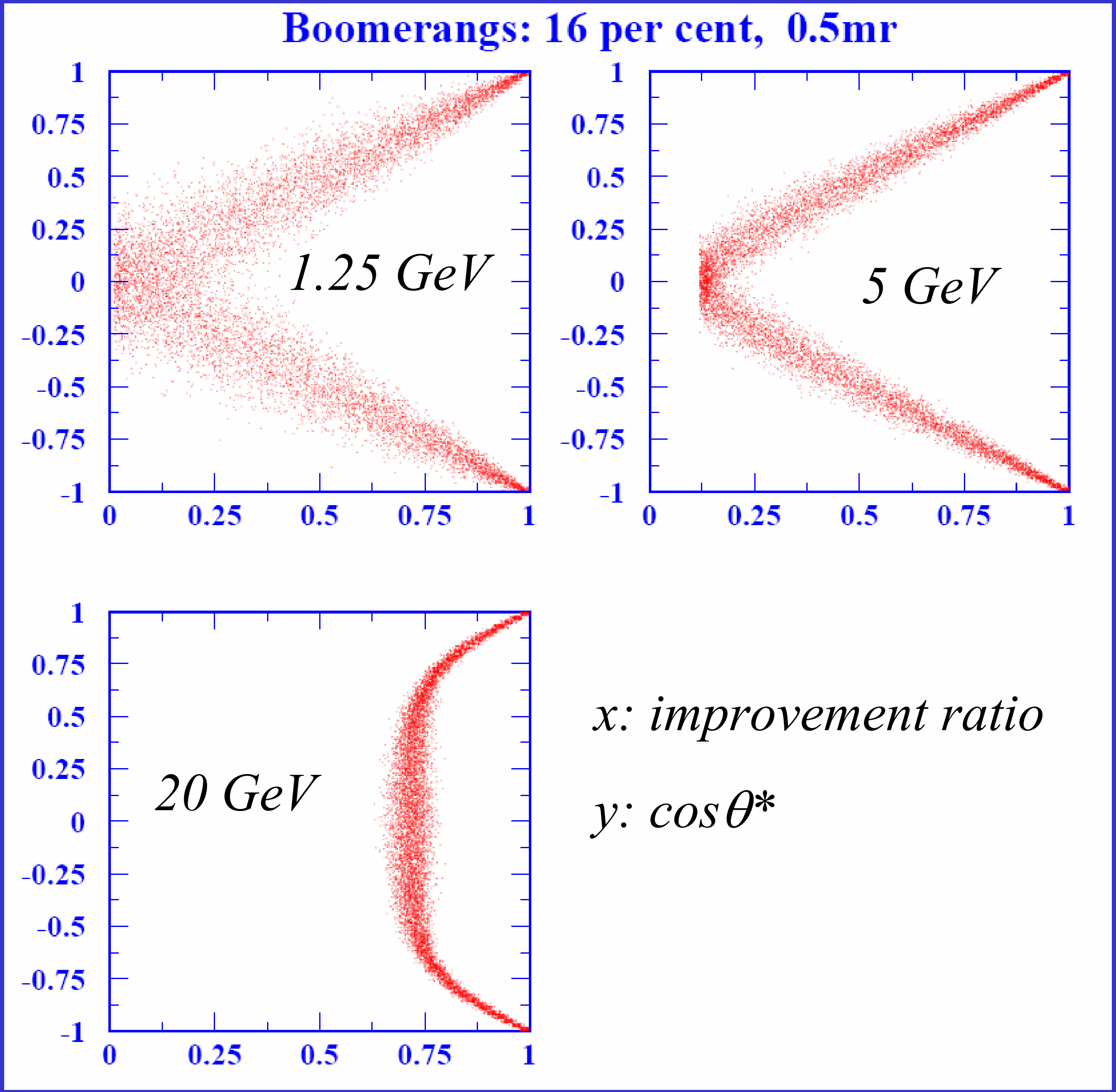
Performance depends on detector design (R, R_M, B, cell-size, …)



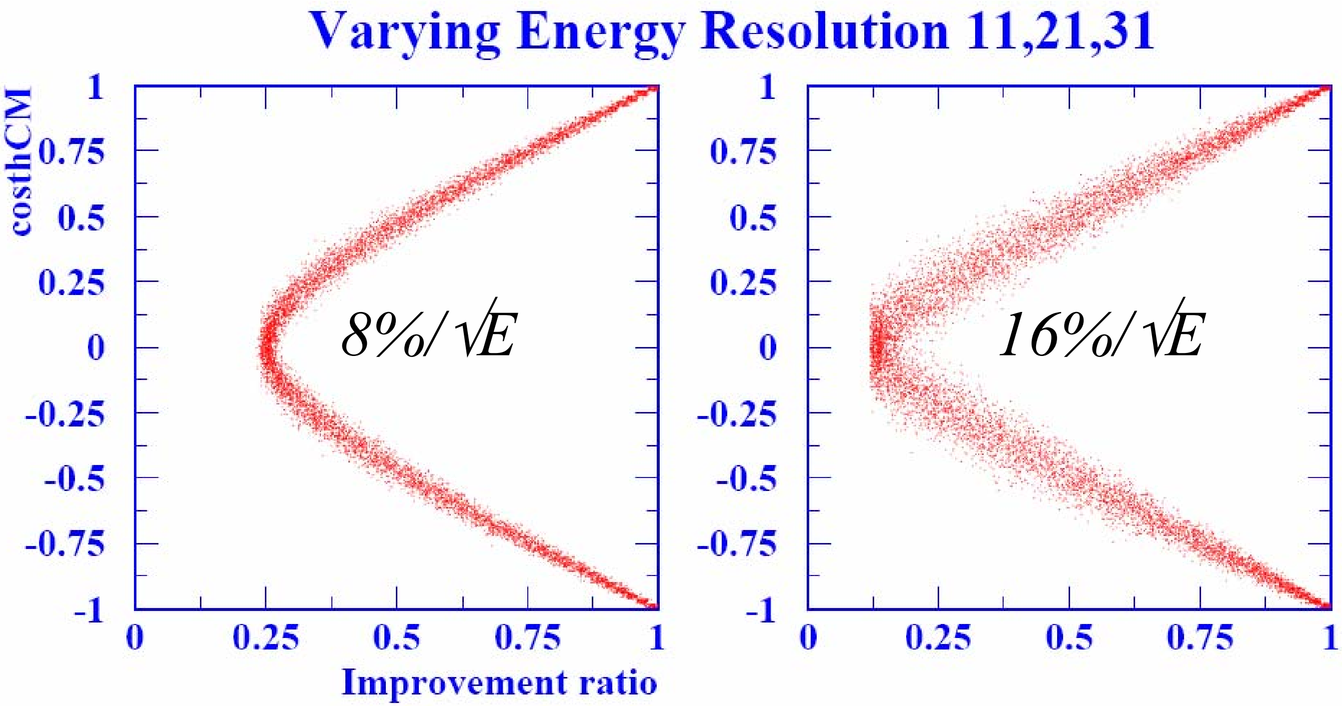
On average 19.2 GeV (21.0%)

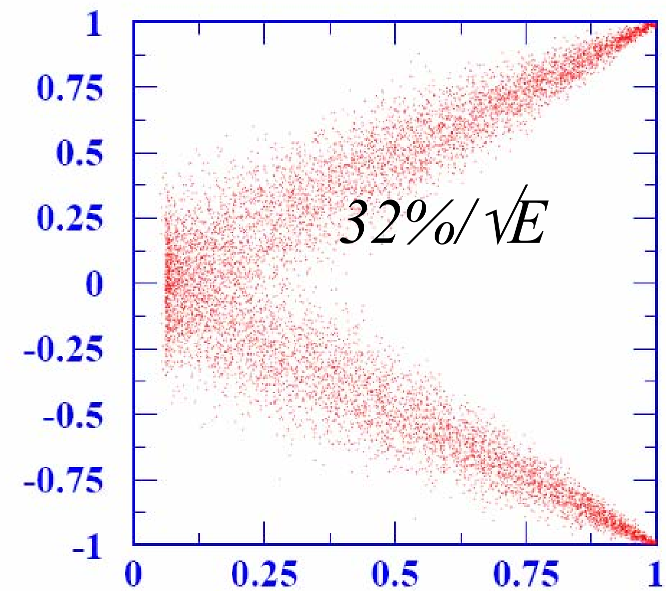
NB generator has ISR and beamsstrahlung turned off.

Dependence on π^0 energy



5 GeV π^0





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

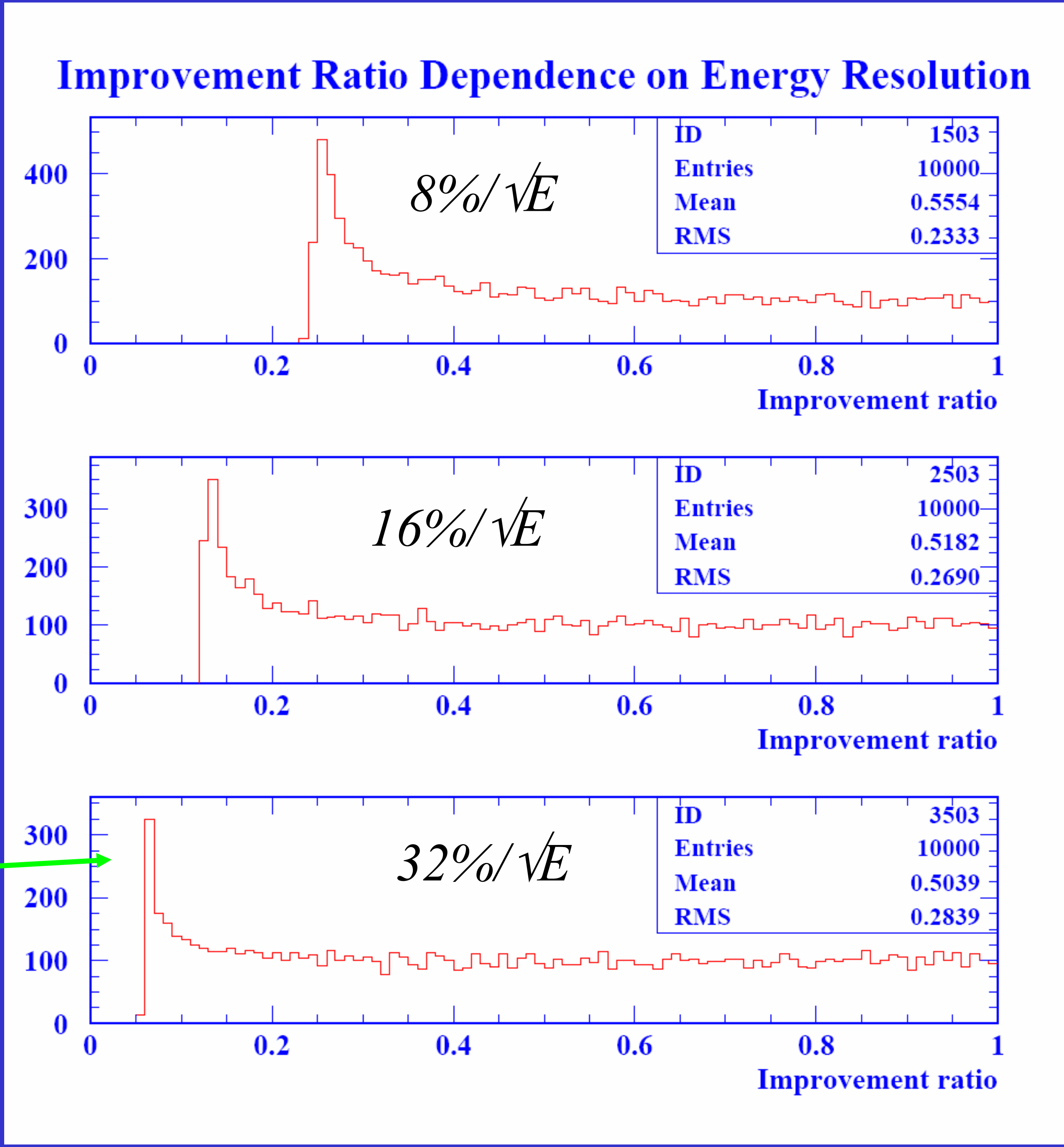
- But on average the dependence is only weak (see next slide)

This slide has been corrected from that presented at Vancouver

5 GeV π^0

Average improvement factor not highly dependent on energy resolution.

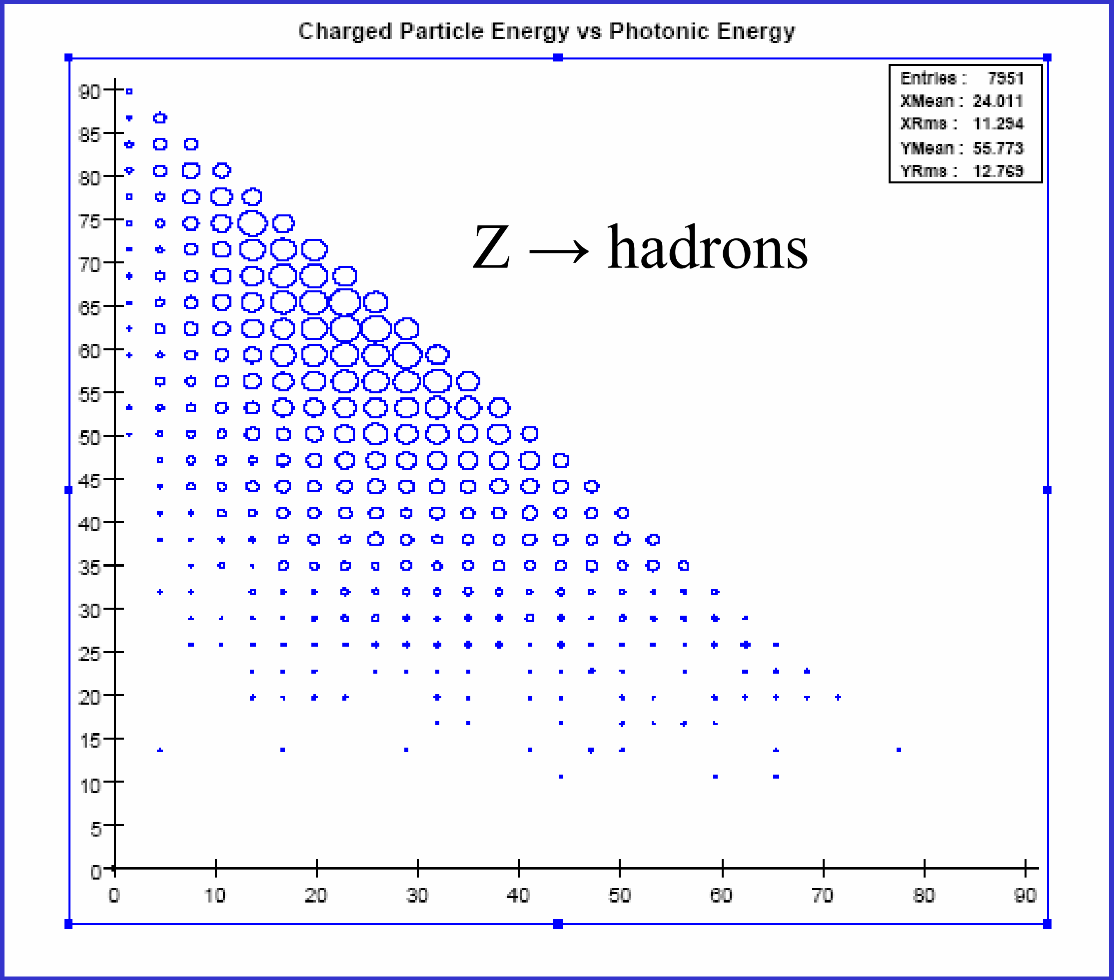
BUT the maximum possible improvements increase as the energy resolution is degraded.



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 ± 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

2. π^0 Kinematic Fitting

- For simplicity used the following measured experimental quantities:

  E_1 (Energy of photon 1)

  E_2 (Energy of photon 2)

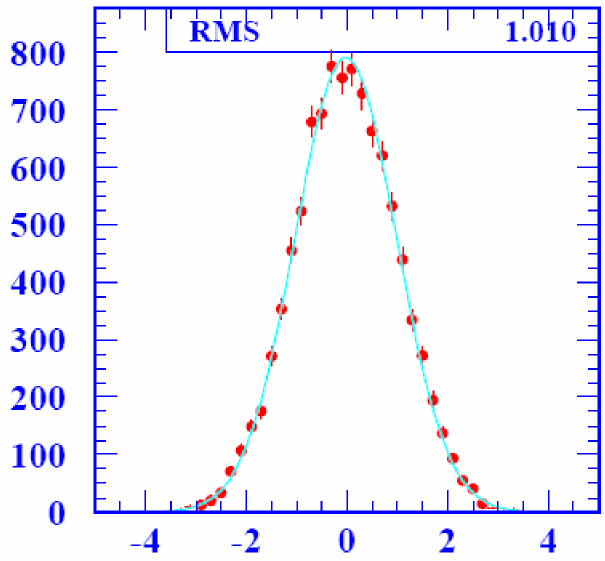
  ψ_{12} (3-d opening angle of photons 1 and 2)

- Fit uses
  - 3 variables, $\mathbf{x} = (E_1, \; E_2, \; 2(1 - \cos\psi_{12}))$
  - a diagonal error matrix

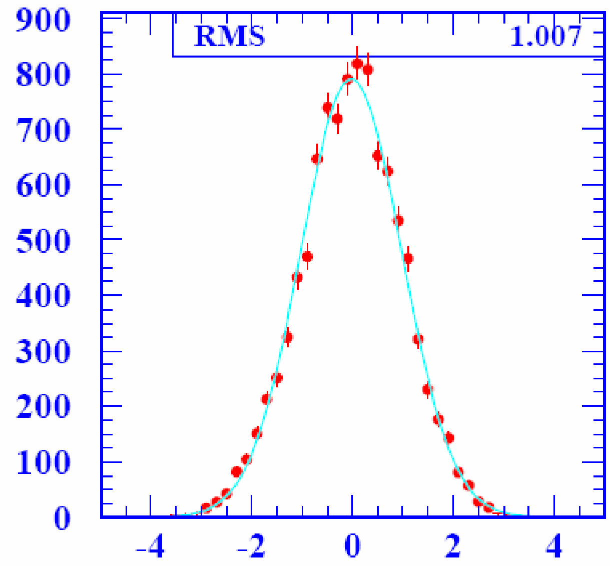
    (assumes individual γ's are completely resolved and measured independently)
  - and the constraint equation

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

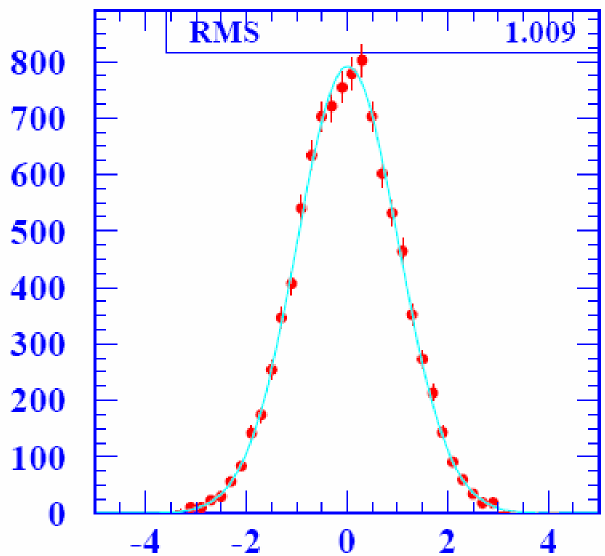
Pull distributions



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