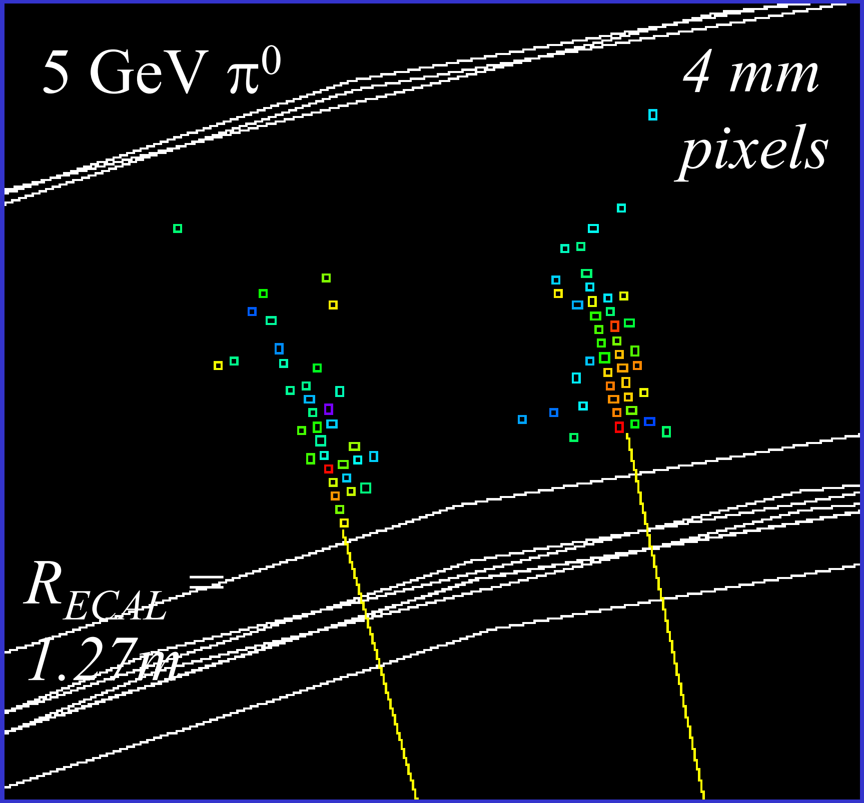
Impact of π^0 Reconstruction on PFA

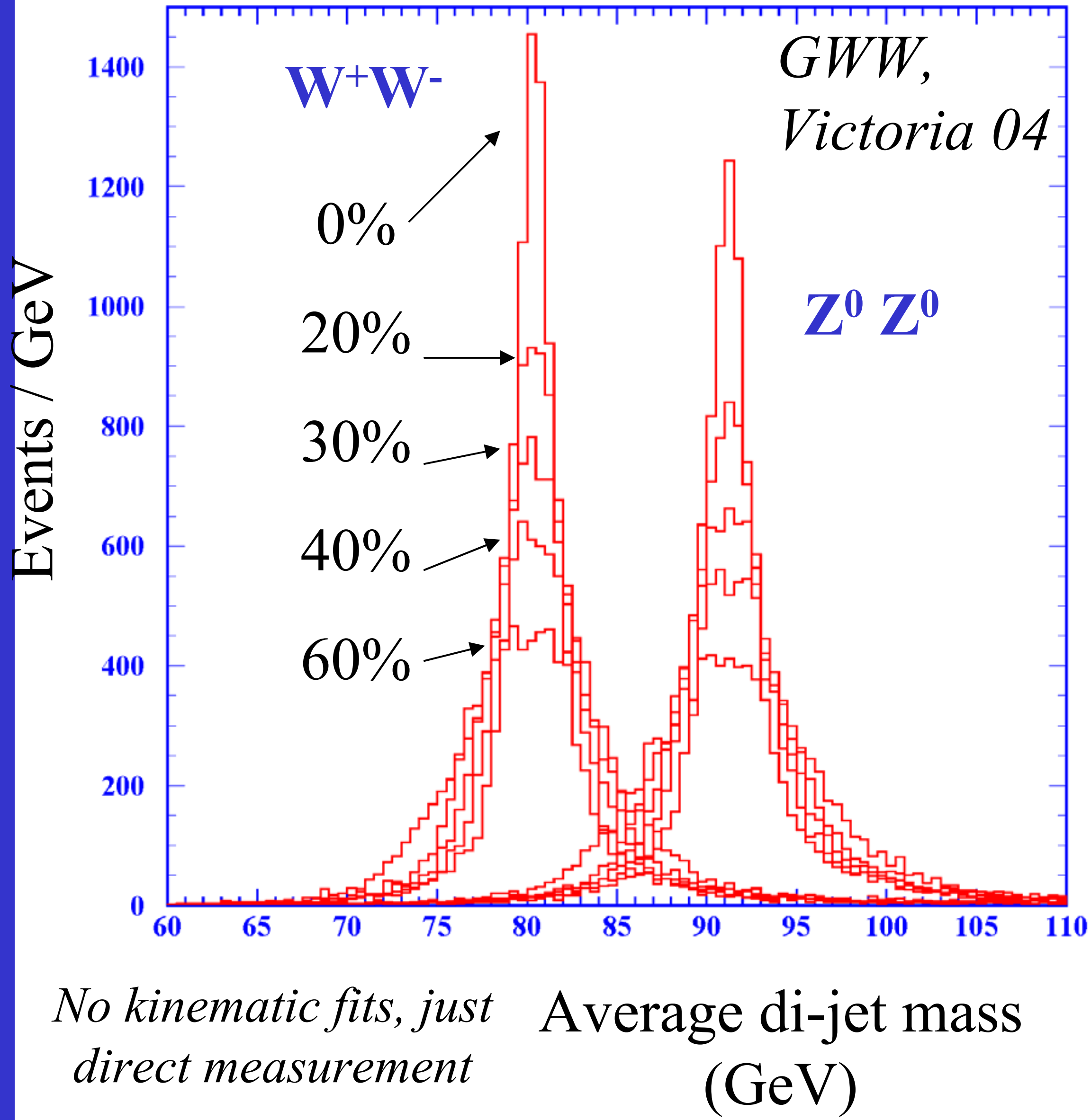


Graham W. Wilson, University of Kansas

Outline

- Big picture on jet energy resolution potential
  - “perfect particle flow” is not detector and technique independent.
  - Bubble-chamber like techniques have a potential role
    - Eg. particle ID may be important .
- Applying π^0 mass constraint to hadronic events.

Di-jet mass distribution vs E_{jet} resolution



No kinematic fits, just direct measurement

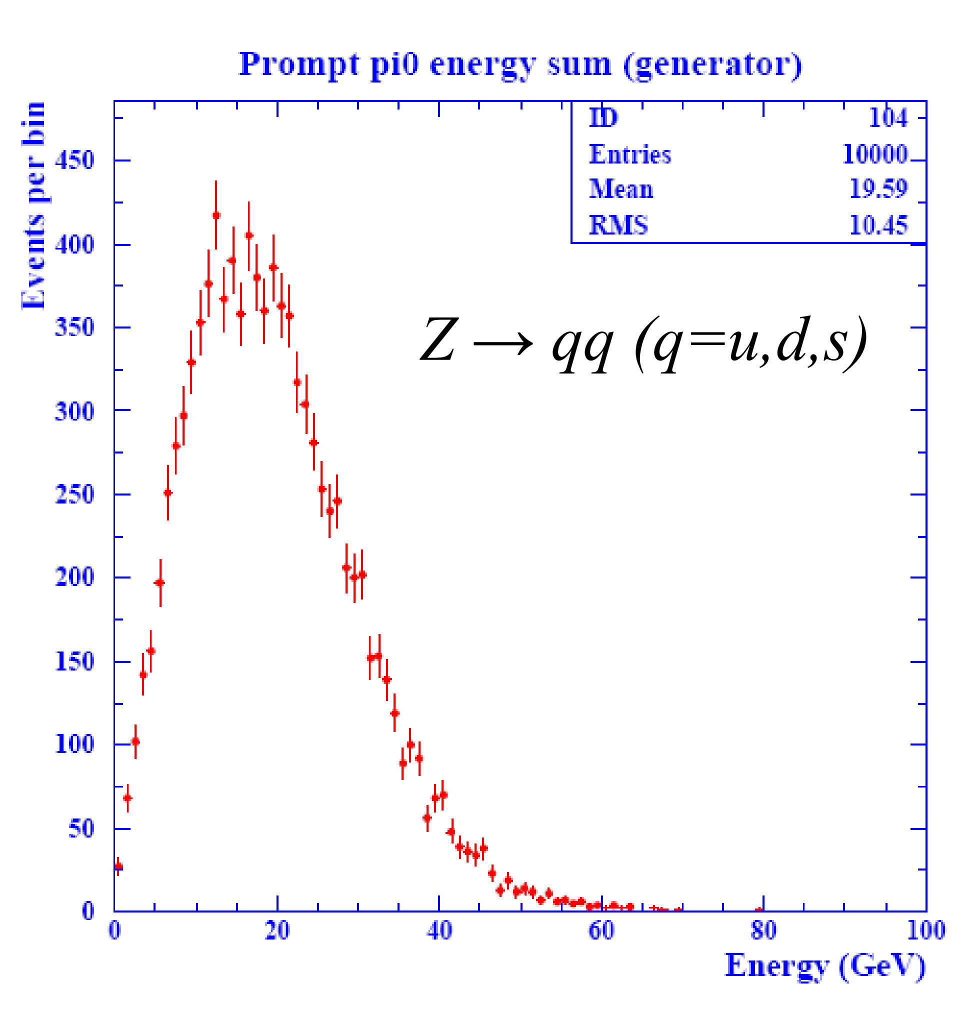
Comparing $e^+e^- \rightarrow WW$ and

$e^+e^- \rightarrow ZZ$ at $\sqrt{s}=300$ GeV
$<E_{jet}> = 75$ GeV
(hadronic decays only, assume WW:ZZ = 1:1 for illustration)

Reality = 7:1 !
$\sigma(E_{jet}) = xx\%\sqrt{E_{jet}}(\mathrm{GeV})$

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

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 $16\%/\sqrt{E}$ EM energy resolution, the intrinsic EM resolution contribution to the jet energy is 0.71 GeV corresponding to $7.4\%/\sqrt{E_{jet}}$.*

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.

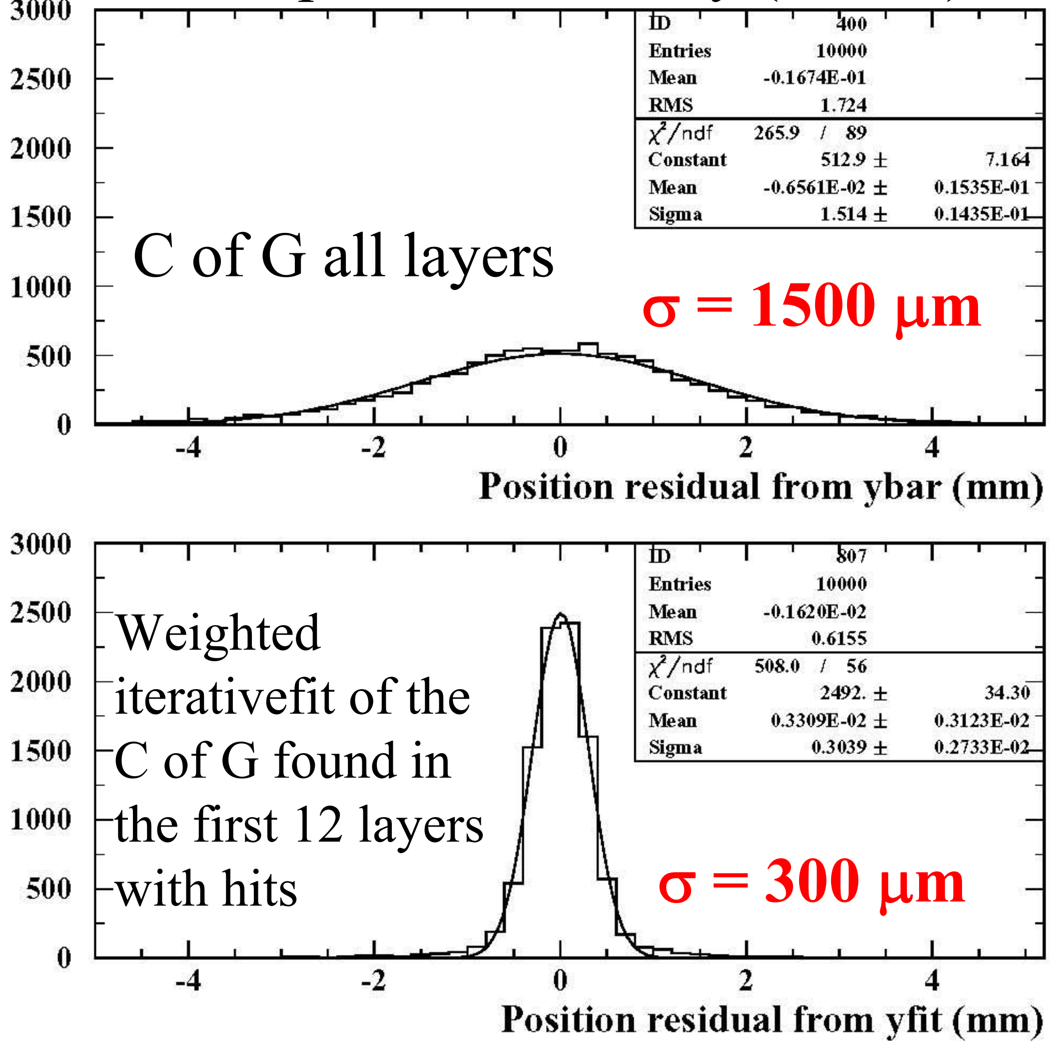
Position resolution from simple fit

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

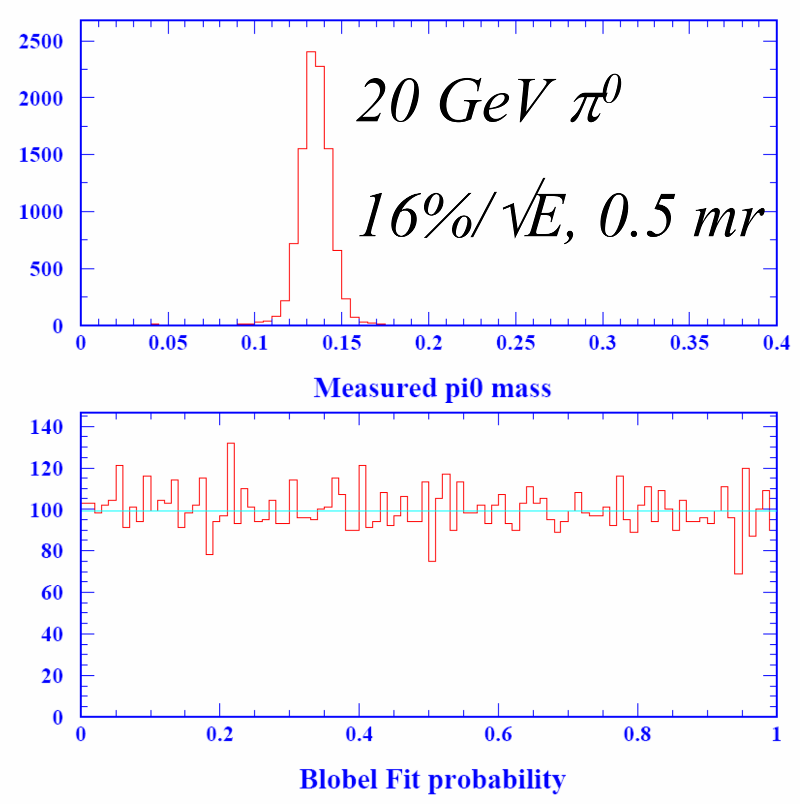
Position resolution does indeed improve by a factor of **5** *in a realistic 100% efficient algorithm!*

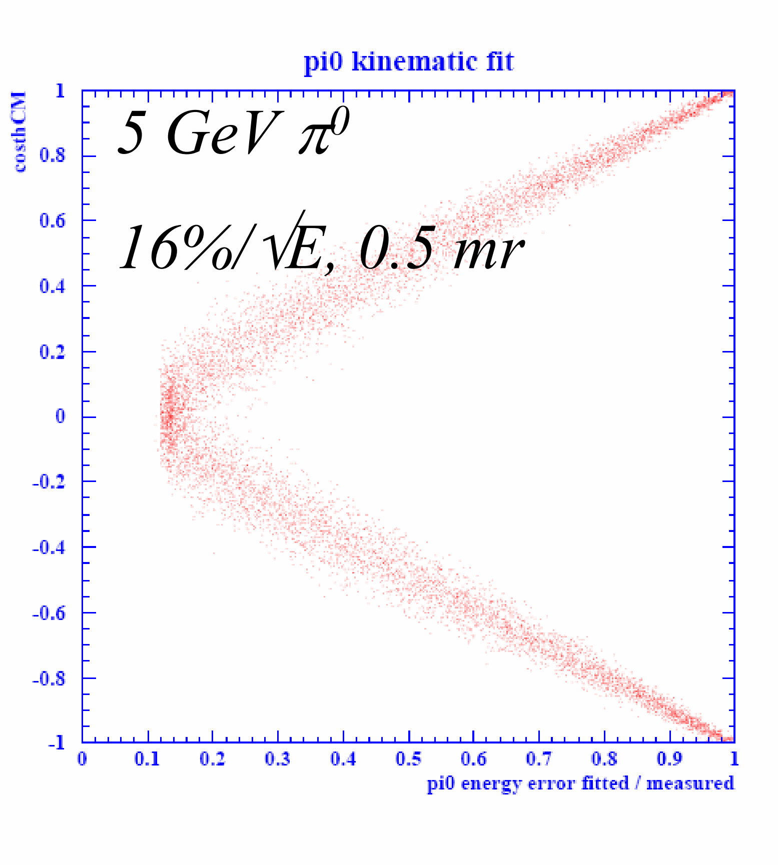
1 GeV photon, G4 study (GWW)



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*

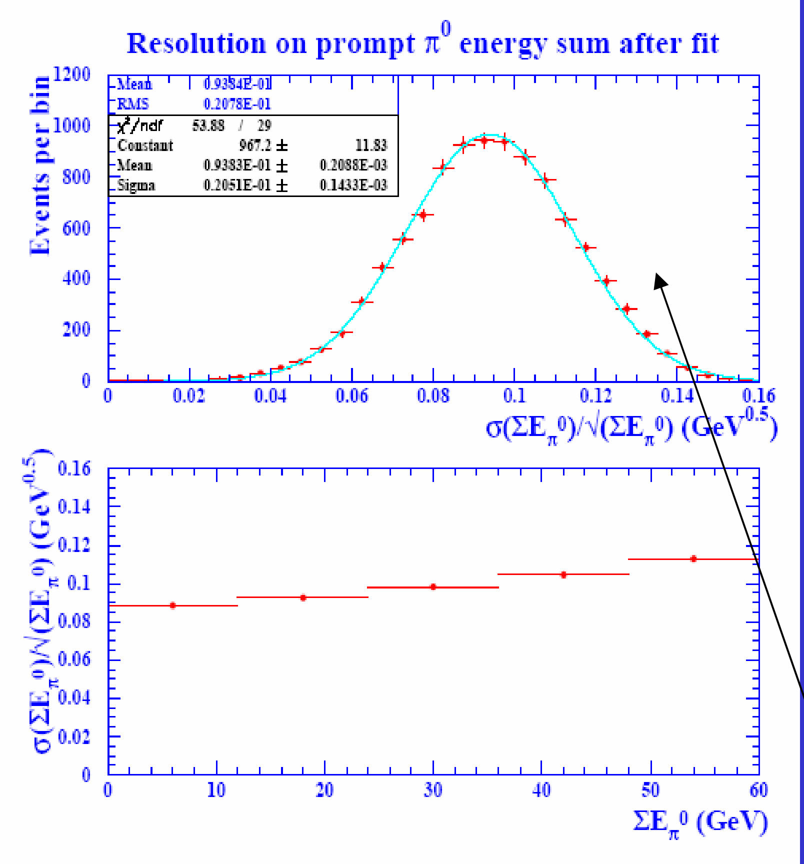
Practical Implementation for Hadronic Events

- 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 talks by P. Gris, C. Carloganu.

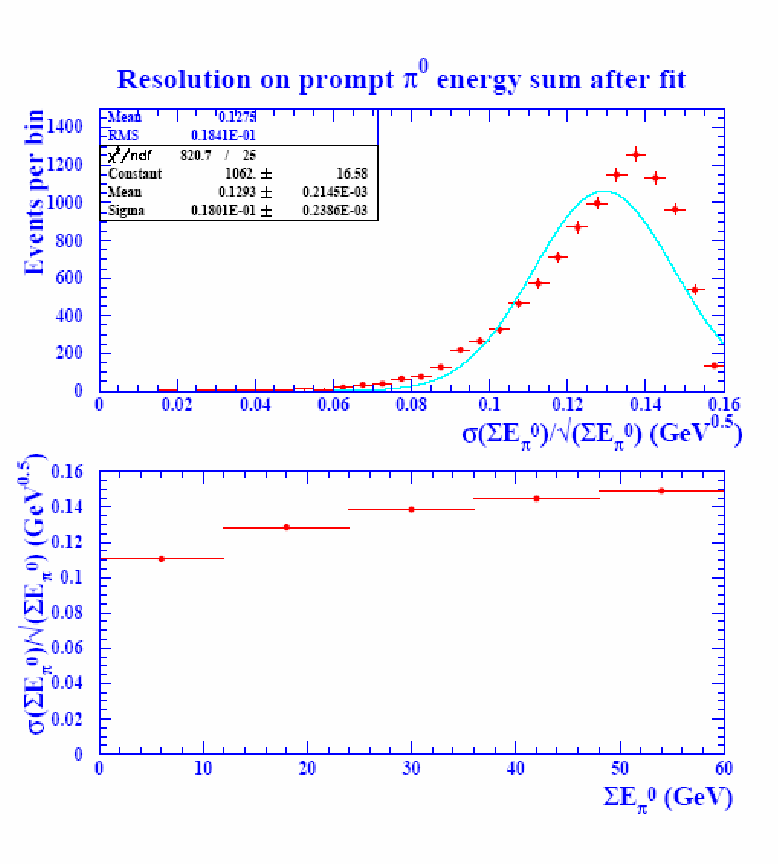
Applying mass-constraint to Z → hadrons

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

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



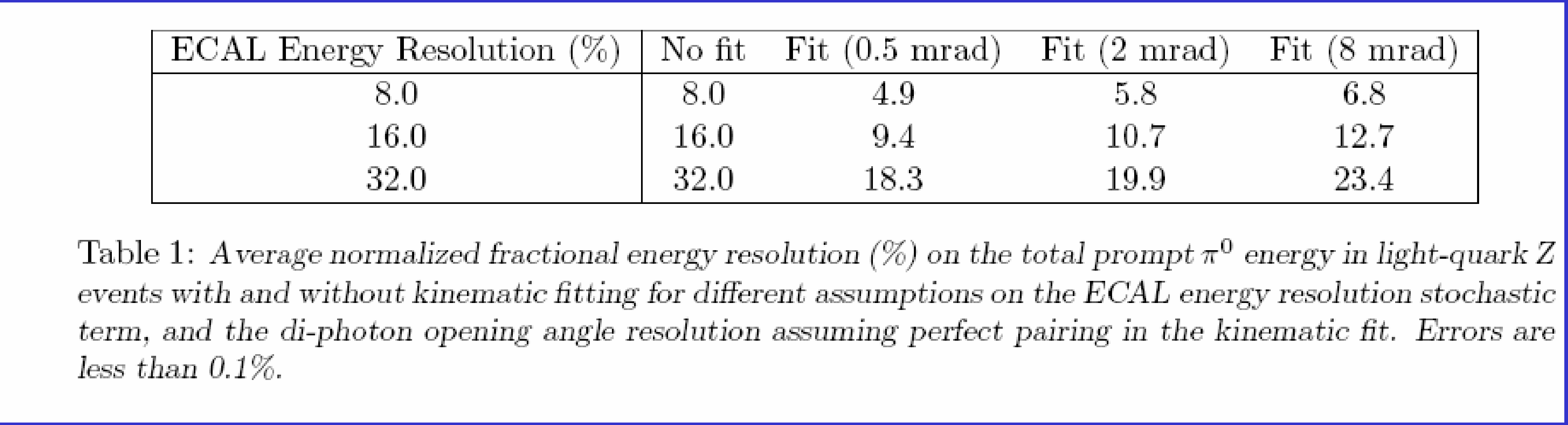
16%/√E, $\Delta\psi_{12}$=0.5mr



16%/√E, $\Delta\psi_{12}$=8mr

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

Summary on potential with perfect pairing



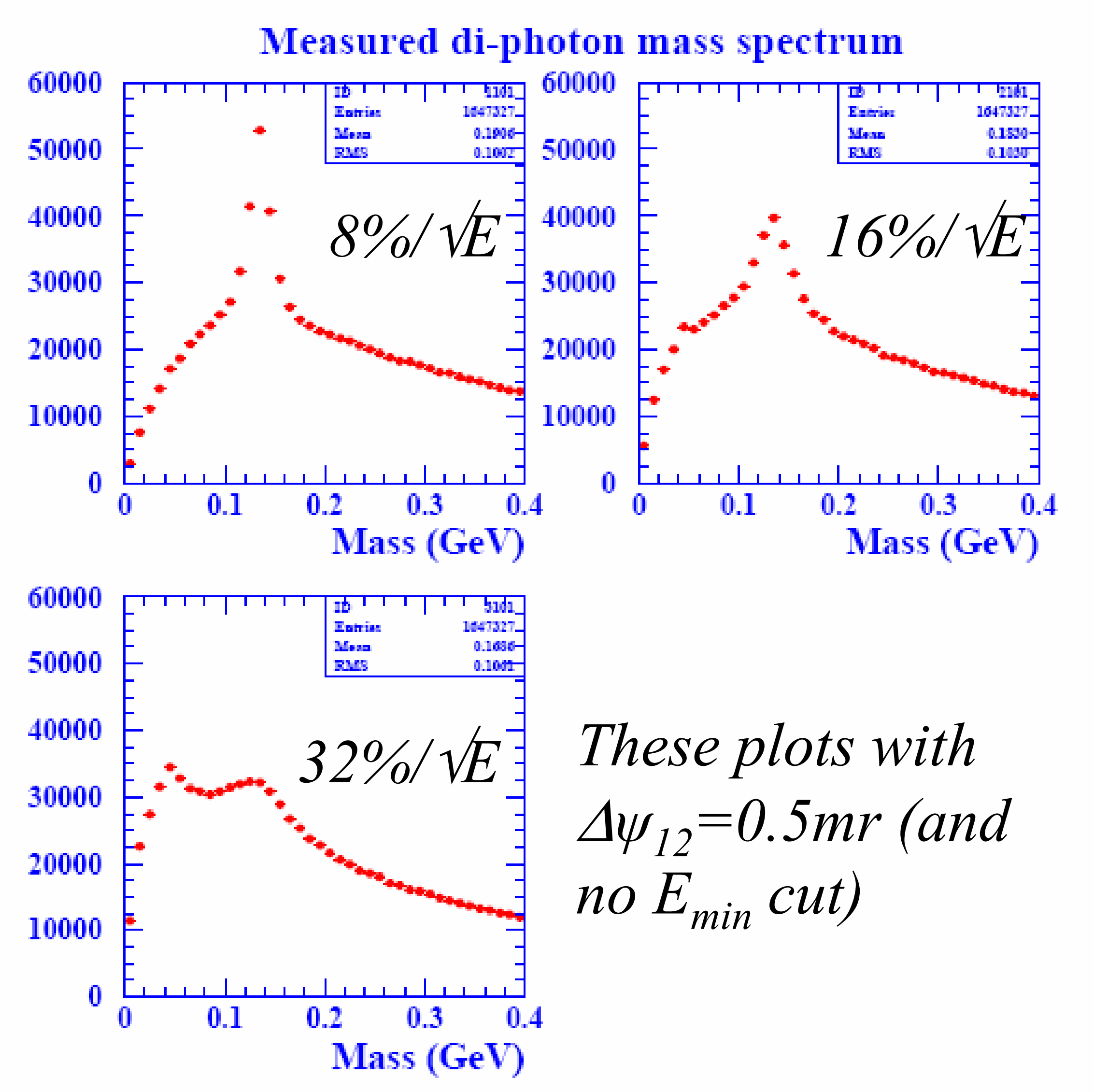
ECAL Energy Resolution (%)	No fit	Fit (0.5 mrad)	Fit (2 mrad)	Fit (8 mrad)
8.0	8.0	4.9	5.8	6.8
16.0	16.0	9.4	10.7	12.7
32.0	32.0	18.3	19.9	23.4

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)

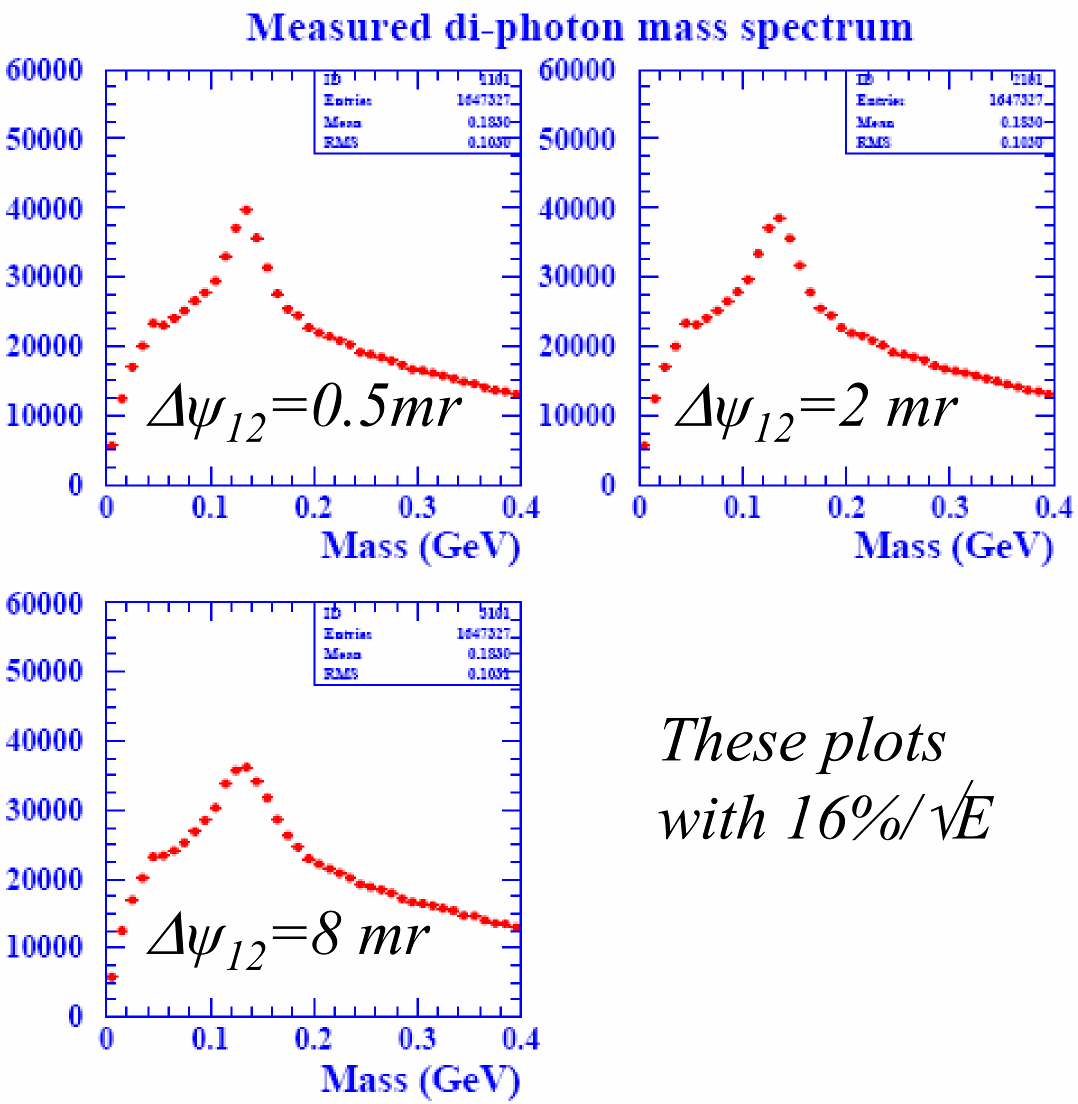
Include (vast) combinatorics

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



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

Same, but vary opening angle resolution



These plots with 16%/√E

Assignment Algorithm

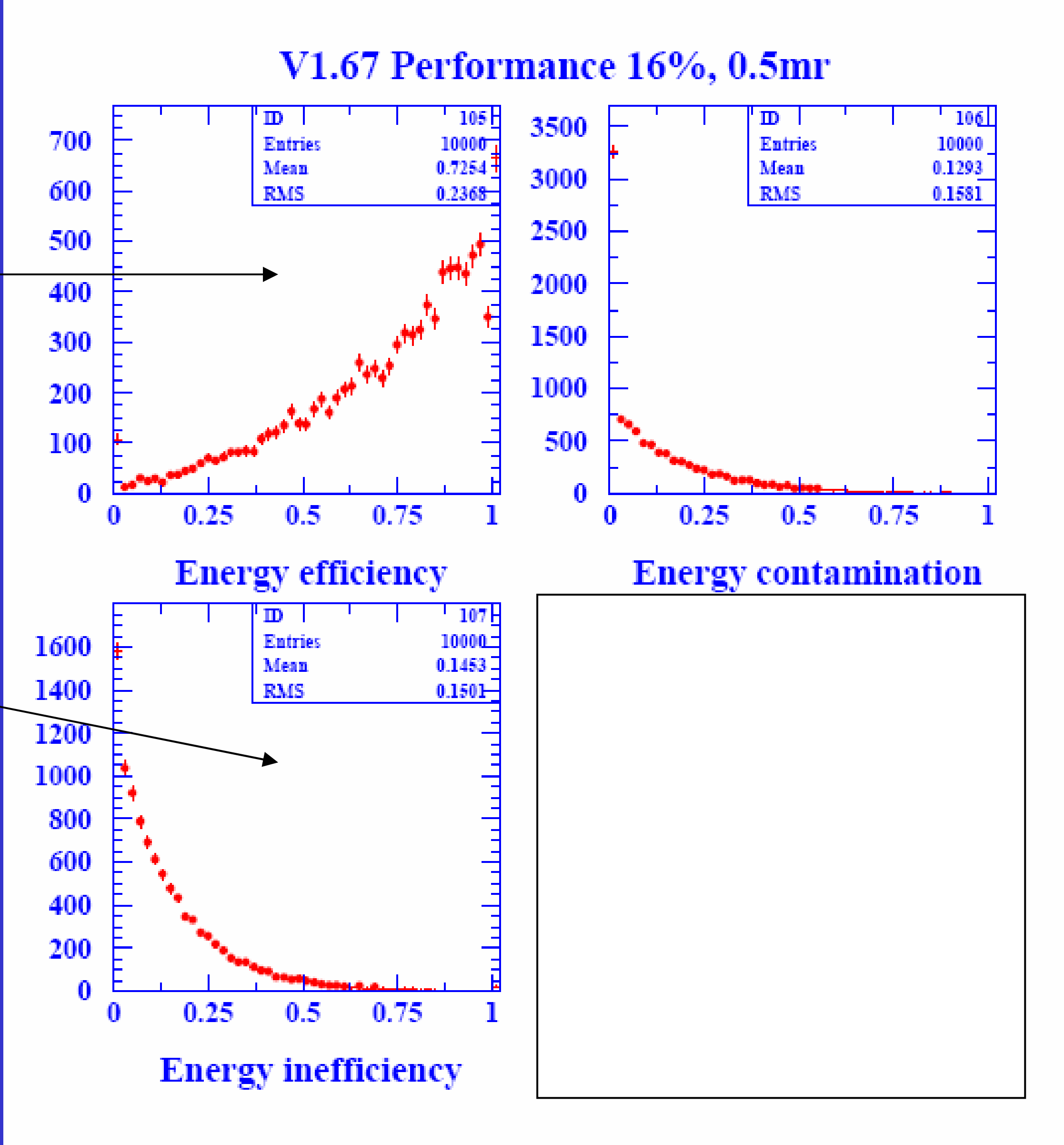
- Very basic so far. (Snap-shot)
- $E_\gamma > 0.1$ GeV
- $p_{fit} > 1\%$
- Form $\chi^2_{mass} = [(m - m(\pi^0))/0.007]^2 \rightarrow p_{mass}$
- Use a discriminant, $D = p_{fit}\, p_{mass}\, E_{\pi 0} / \sigma_m$
- Using energy sorted photons, assign photons to pairings if they have the highest D for 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}



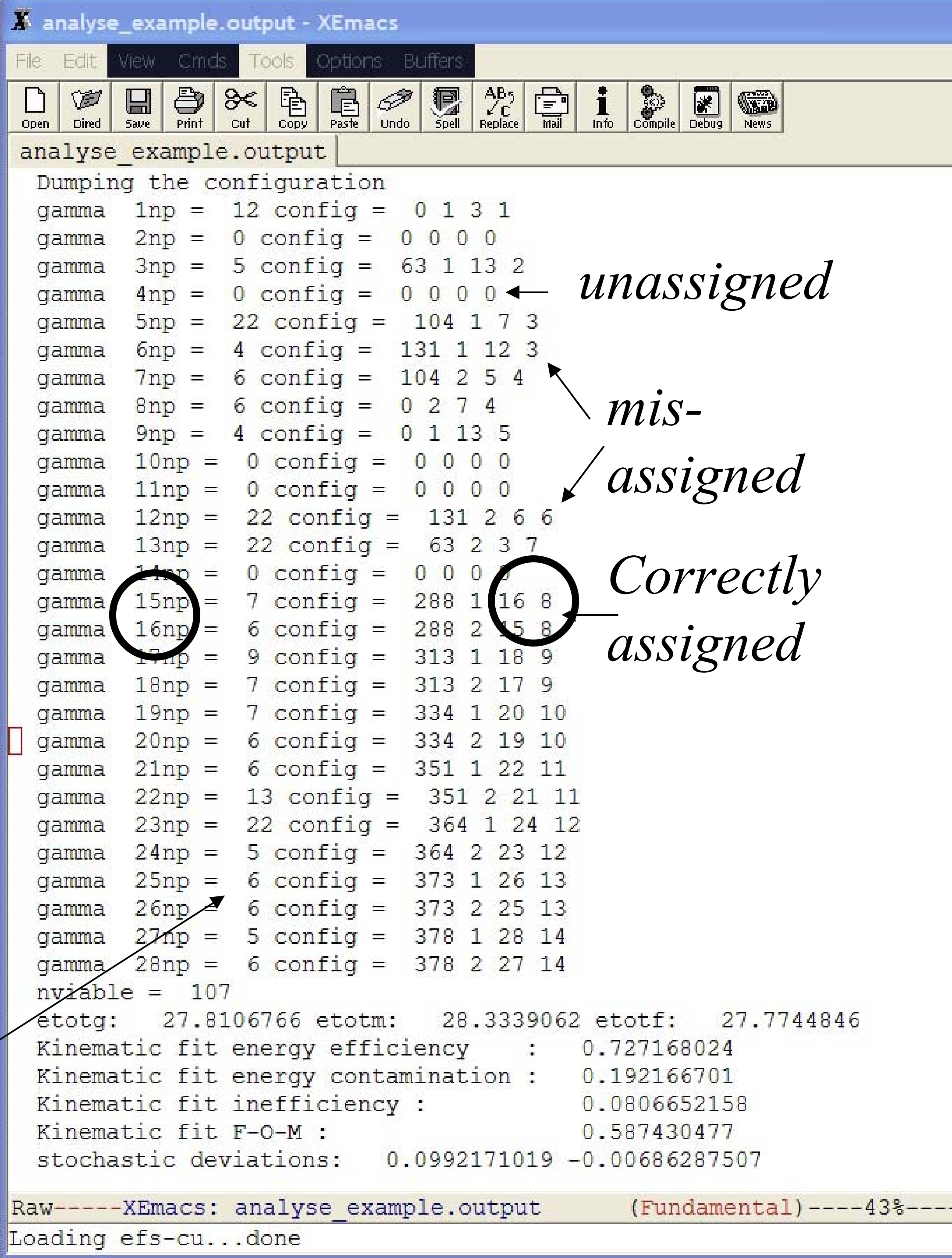
(example)

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 – 0.7%/√E



```
Dumping the configuration
gamma  1np =  12 config =  0 1 3 1
gamma  2np =  0 config =  0 0 0 0
gamma  3np =  5 config =  63 1 13 2
gamma  4np =  0 config =  0 0 0 0
gamma  5np =  22 config =  104 1 7 3
gamma  6np =  4 config =  131 1 12 3
gamma  7np =  6 config =  104 2 5 4
gamma  8np =  6 config =  0 2 7 4
gamma  9np =  4 config =  0 1 13 5
gamma  10np =  0 config =  0 0 0 0
gamma  11np =  0 config =  0 0 0 0
gamma  12np =  22 config =  131 2 6 6
gamma  13np =  22 config =  63 2 3 7
gamma  14np =  0 config =  0 0 0 0
gamma  15np =  7 config =  288 1 16 8
gamma  16np =  6 config =  288 2 15 8
gamma  17np =  9 config =  313 1 18 9
gamma  18np =  7 config =  313 2 17 9
gamma  19np =  7 config =  334 1 20 10
gamma  20np =  6 config =  334 2 19 10
gamma  21np =  6 config =  351 1 22 11
gamma  22np =  13 config =  351 2 21 11
gamma  23np =  22 config =  364 1 24 12
gamma  24np =  5 config =  364 2 23 12
gamma  25np =  6 config =  373 1 26 13
gamma  26np =  6 config =  373 2 25 13
gamma  27np =  5 config =  378 1 28 14
gamma  28np =  6 config =  378 2 27 14
nviable =   107
etotg:    27.8106766 etotm:   28.3339062 etotf:   27.7744846
Kinematic fit energy efficiency      :    0.727168024
Kinematic fit energy contamination :    0.192166701
Kinematic fit inefficiency :            0.0806652158
Kinematic fit F-O-M :                   0.587430477
stochastic deviations:   0.0992171019 -0.00686287507

Raw-----XEmacs: analyse_example.output      (Fundamental)----43%----
Loading efs-cu...done
```

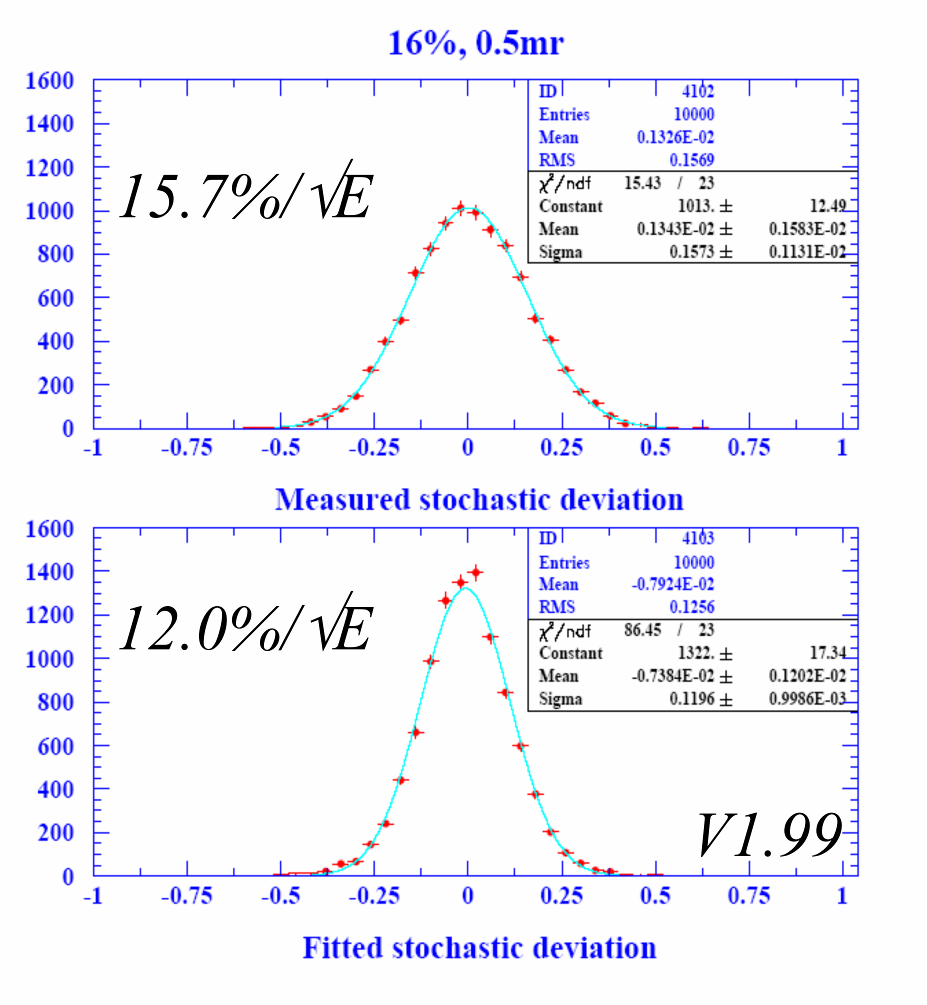
unassigned

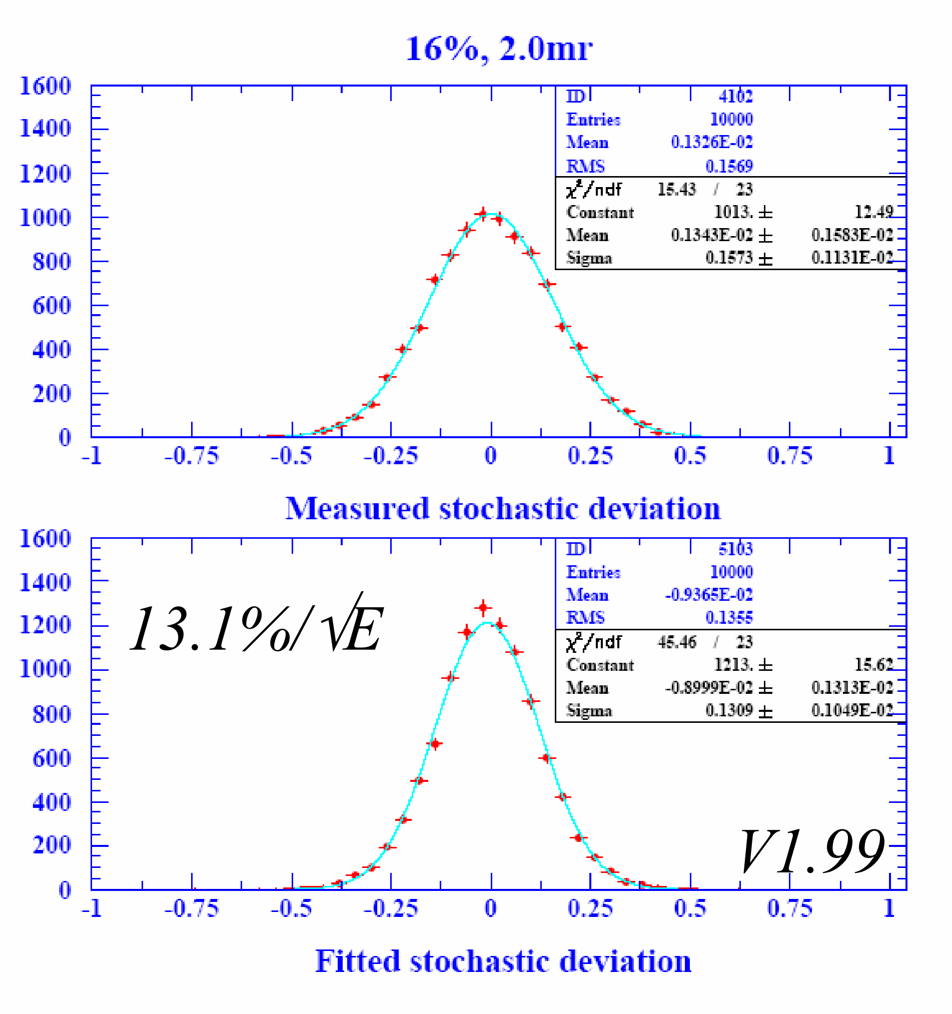
mis-assigned

Correctly assigned

Number of viable pairings for this photon

Updated Results (10k Z events)


16%, 0.5mr


16%, 2.0mr

I believe this may still be improved substantially

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

1. Perfect pairing

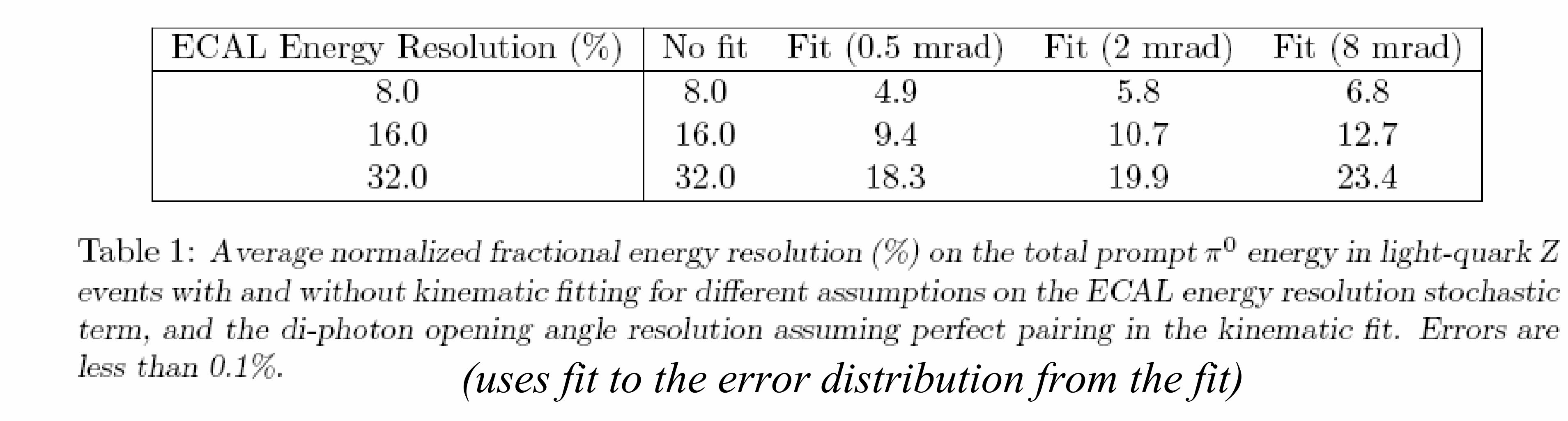


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Table 1: *Average normalized fractional energy resolution (%) on the total prompt π^0 energy in light-quark Z events with and without kinematic fitting for different assumptions on the ECAL energy resolution stochastic term, and the di-photon opening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

(uses fit to the error distribution from the fit)

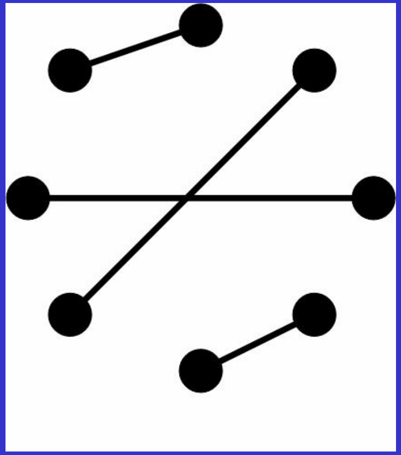
2. Assignment algorithm 1.99

Using fitted σ of deviation on same 10k events

7.9	*6.0*	*6.8*	*7.5*
15.7	***12.0***	*13.1*	*14.8*
31.0	*24.9*	*26.1*	*28.7*

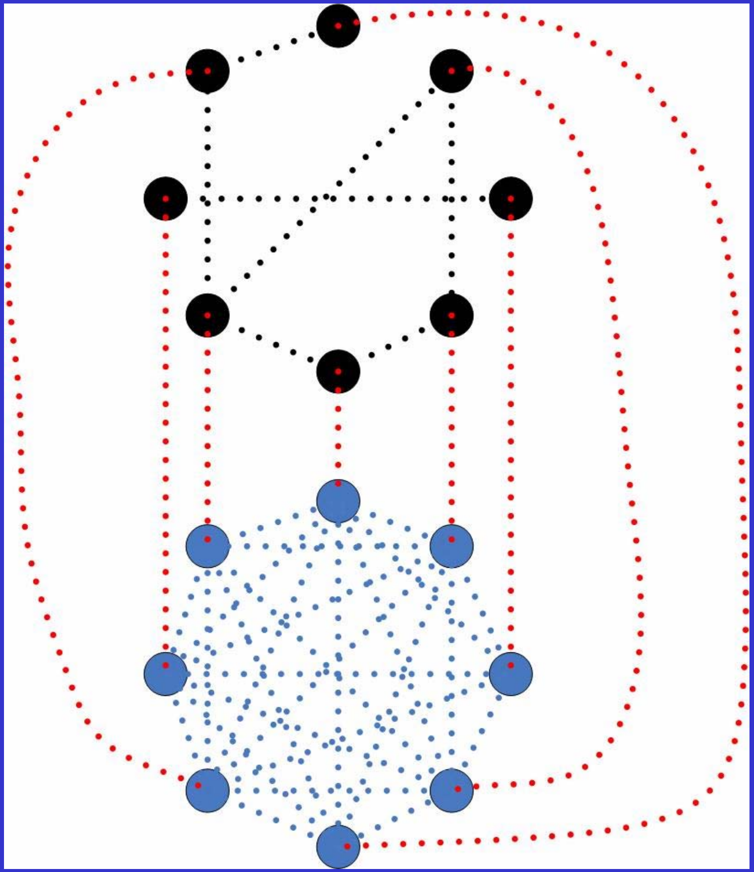
Recent Work on Global Assignment

- Consulted a mathematician specializing in combinatoric problems. (J. Martin, KU).
- A good framework appears to be as a matching problem.
- Classic assignment problem is an example of weighted bipartite matching. (eg. assign machines to workers)
- The π^0 problem on the other hand is in essence a "weighted non-bipartite matching problem"
- Edmonds "blossom" algorithm solves it in polynomial time.
  - Found a C implementation which works for very large N.
- Related to the traveling salesman problem.



Given a set of photons (vertices in the graph), find the choice of connections (edges) with minimum total weight, yielding a "perfect matching".

Hadronic Event π^0's as a matching problem



Each black node is a resolved photon.

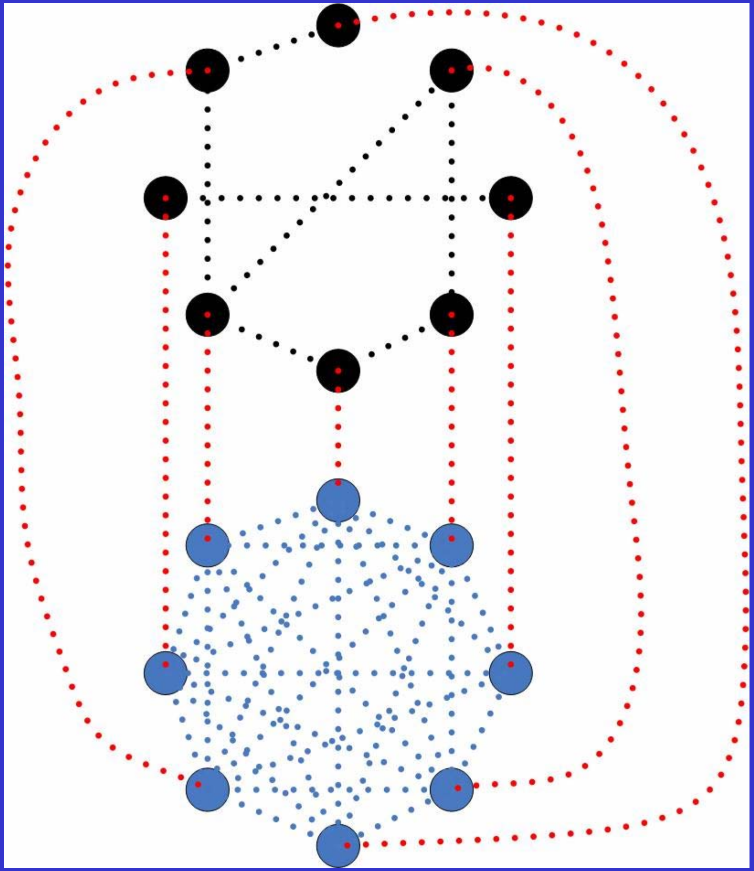
The black lines are viable π^0 kinematic fits with assigned weights, w_{ij},

Task is to find a metric to best characterize the likelihood of a particular match – and the penalty for non-assignment.

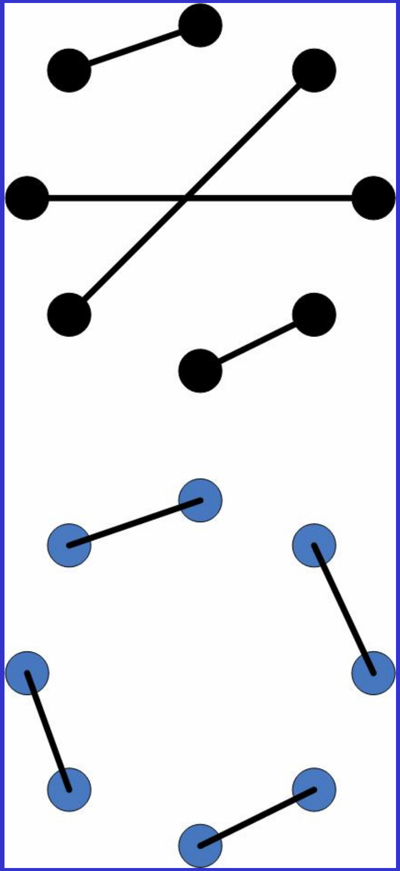
In order to deal with having an odd number of photons or photons that can not be matched have defined mirror-photons for each observed photon (the blue nodes).

The blue-lines are zero-weight mirror-photon/mirror-photon connections. The red lines are high-weight photon/mirror-photon connections to allow a "perfect-match" in cases where no KF is globally reasonable

Hadronic Event π^0's as a matching problem



Find matching where every "photon" is assigned, and minimizes the total edge weight.



Promising approach for visualizing the problem. Also need some measure of uniqueness (resolvability)

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.

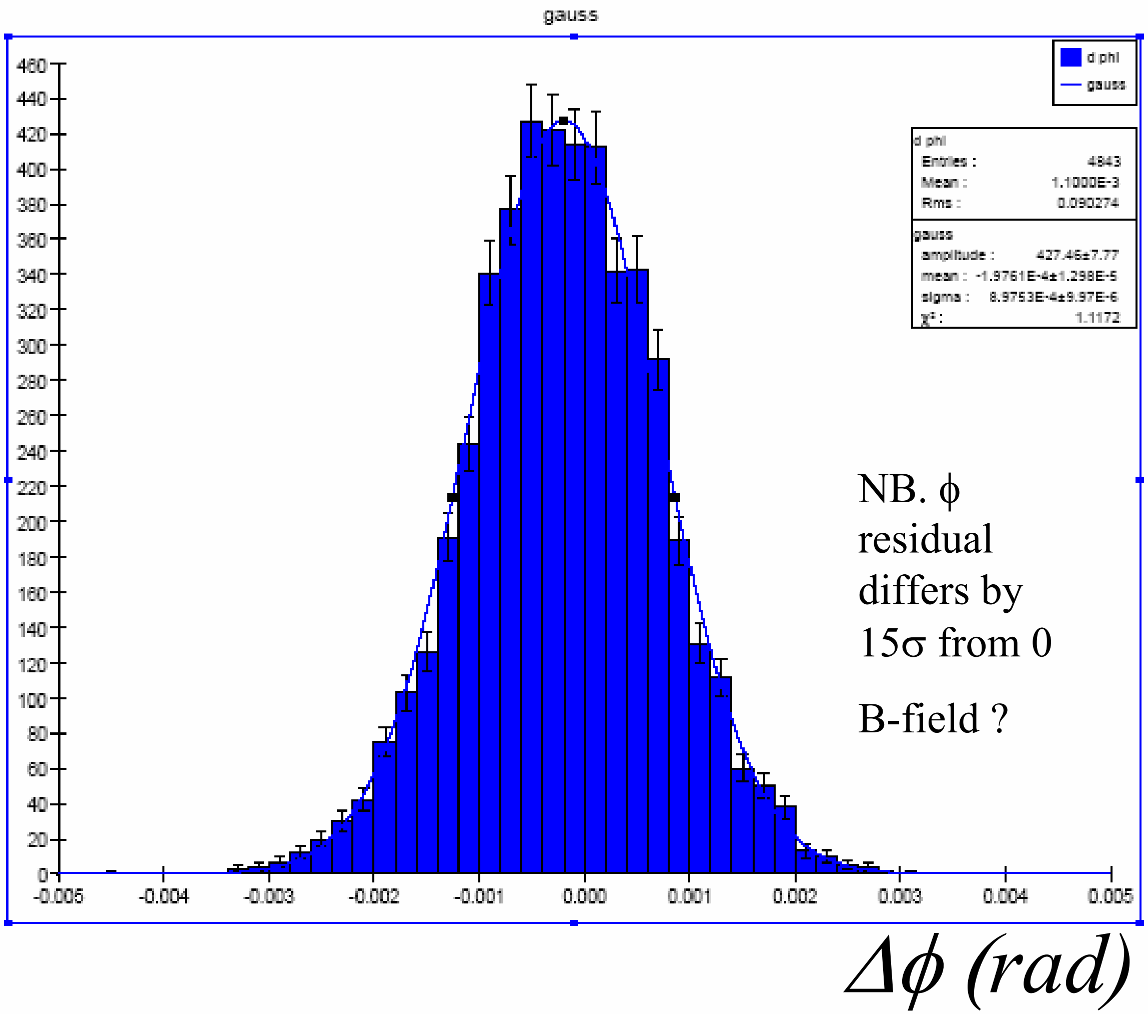
Backup Slides

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.

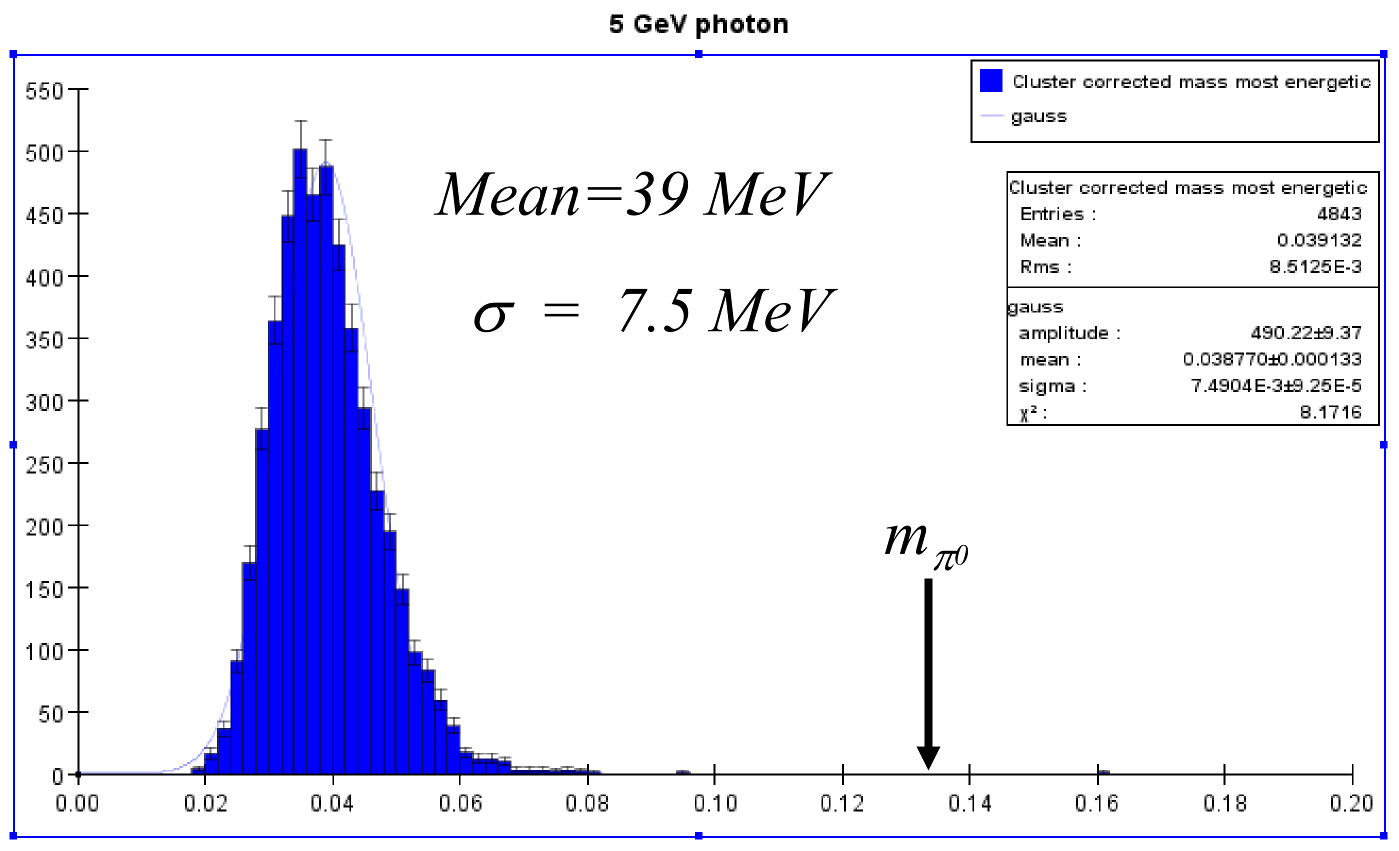


NB. ϕ residual differs by 15σ from 0

B-field ?

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

Cluster Mass for Photons



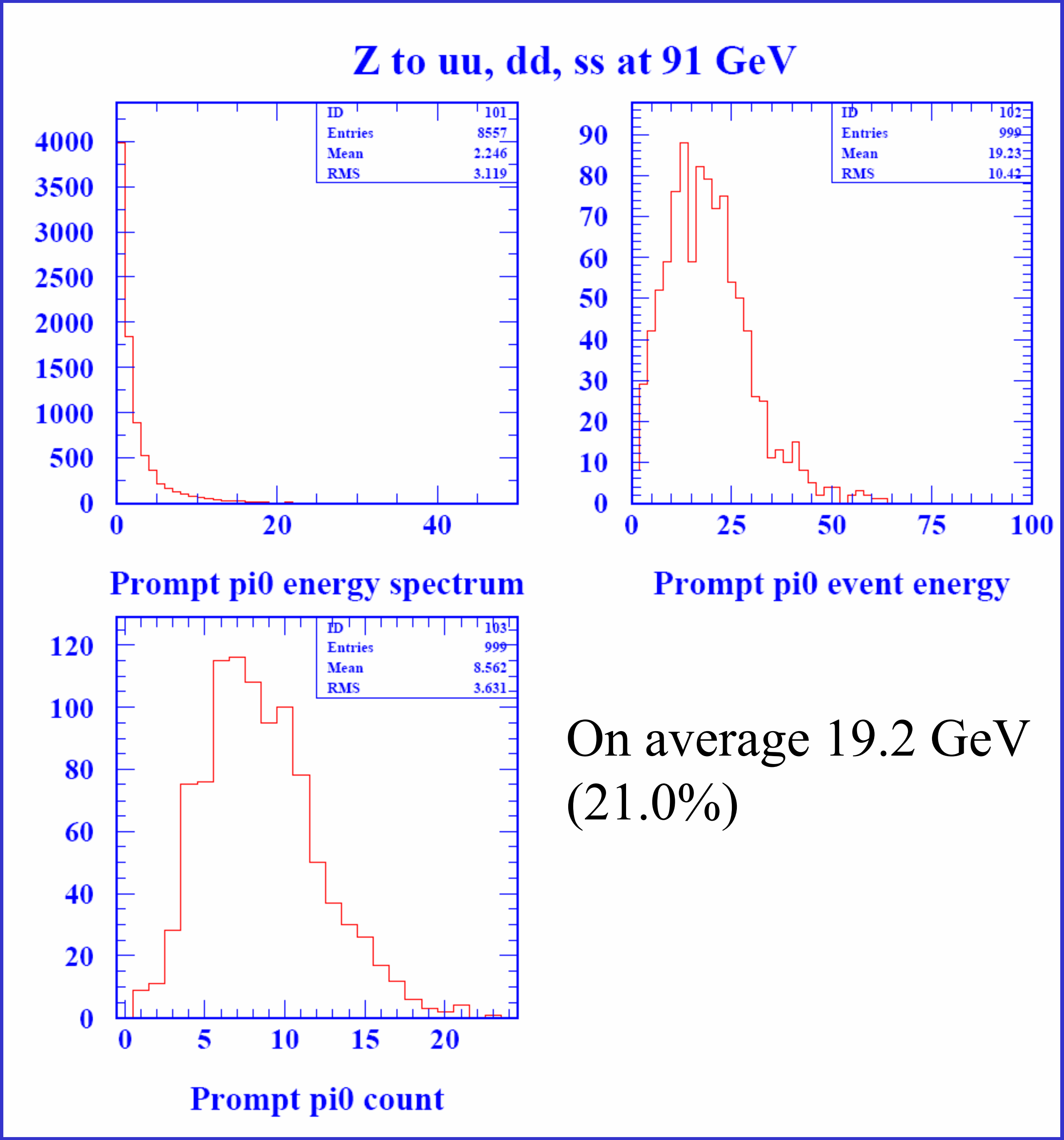
Cluster Mass (GeV)

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.

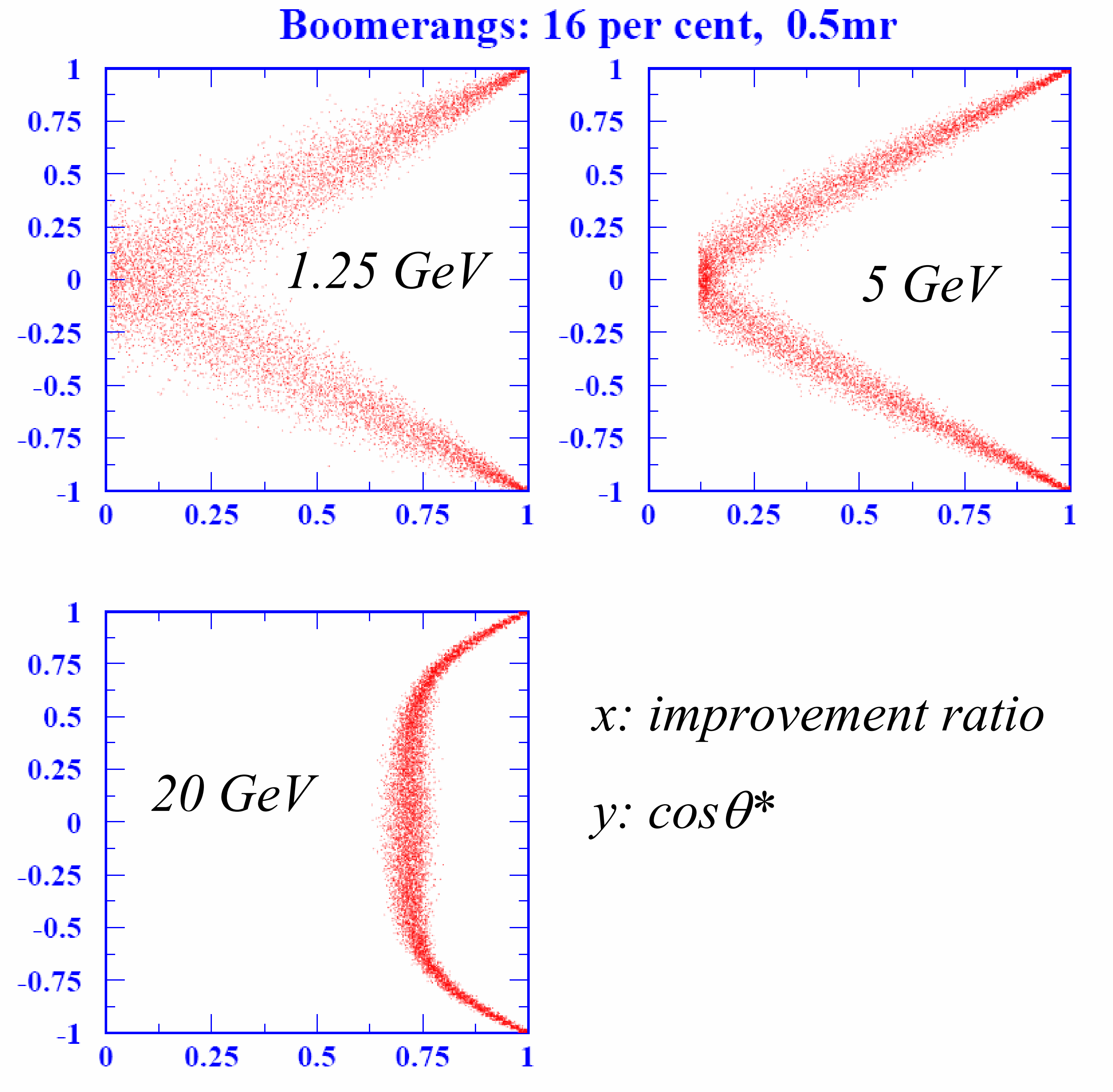
Performance depends on detector design (R, R_M, B, cell-size, …)



On average 19.2 GeV (21.0%)

NB generator has ISR and beamsstrahlung turned off.

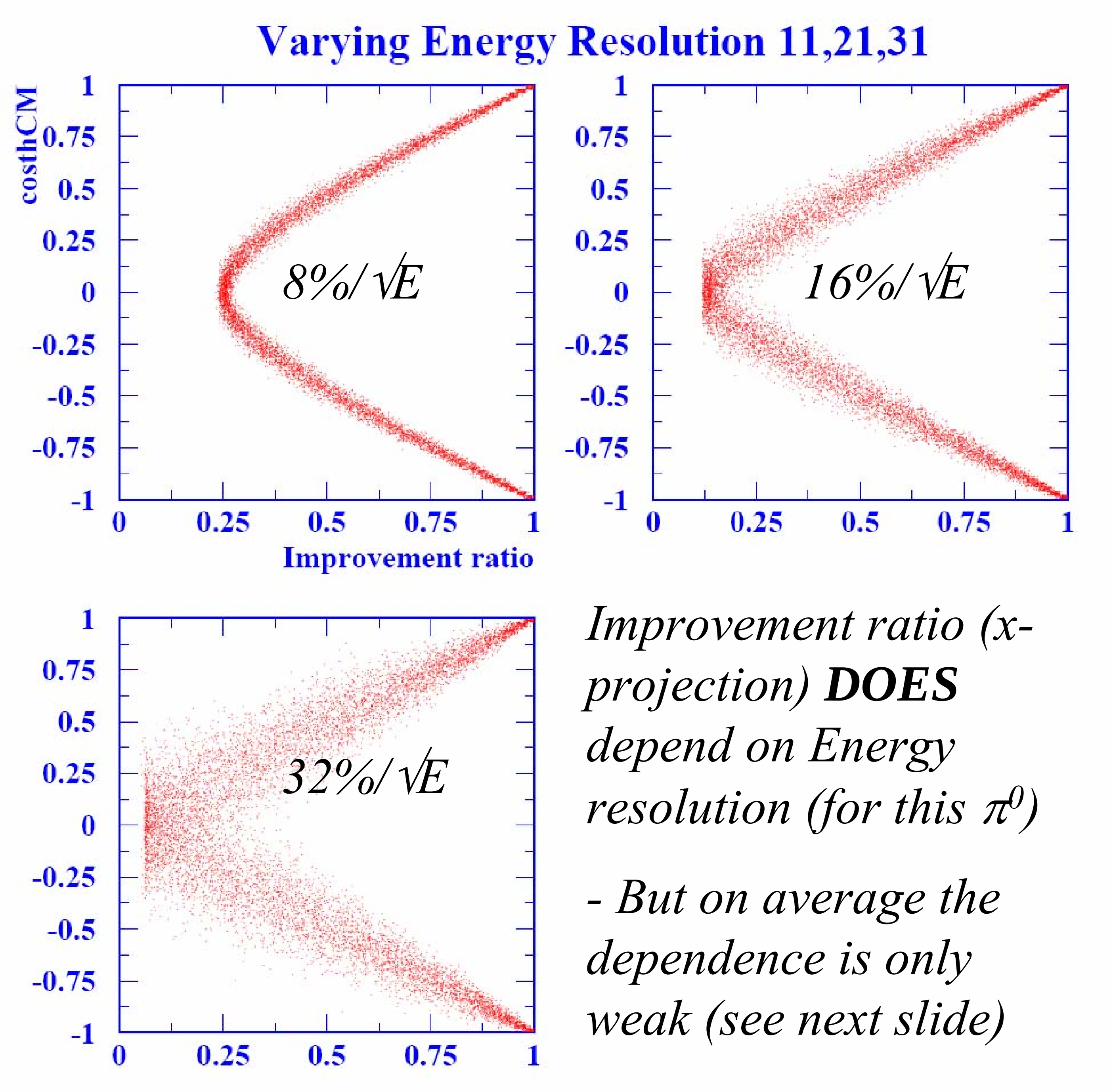
Dependence on π^0 energy



x: improvement ratio

y: $\cos\theta^*$

5 GeV π^0



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

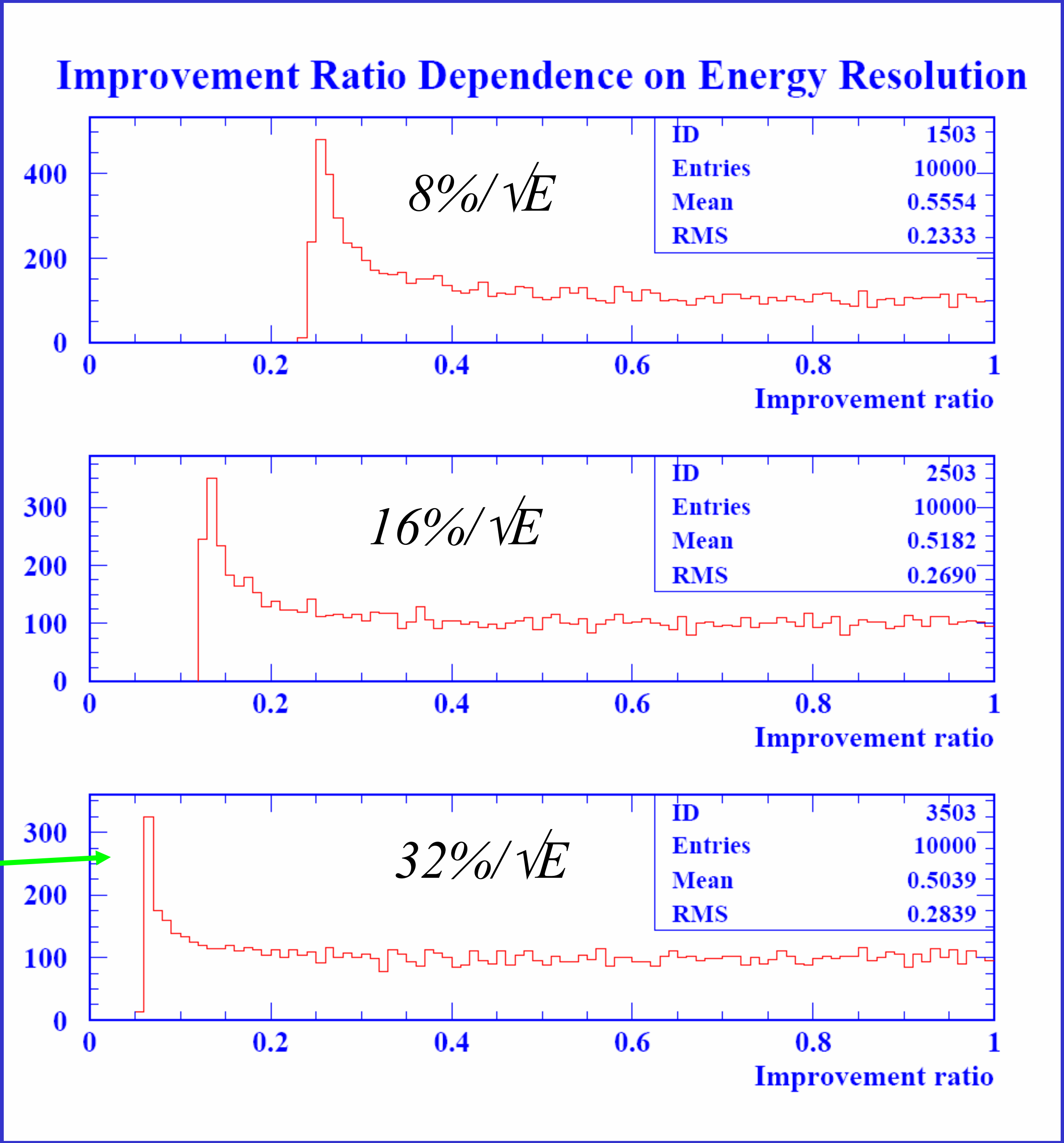
- But on average the dependence is only weak (see next slide)

This slide has been corrected from that presented at Vancouver

5 GeV π^0

Average improvement factor not highly dependent on energy resolution.

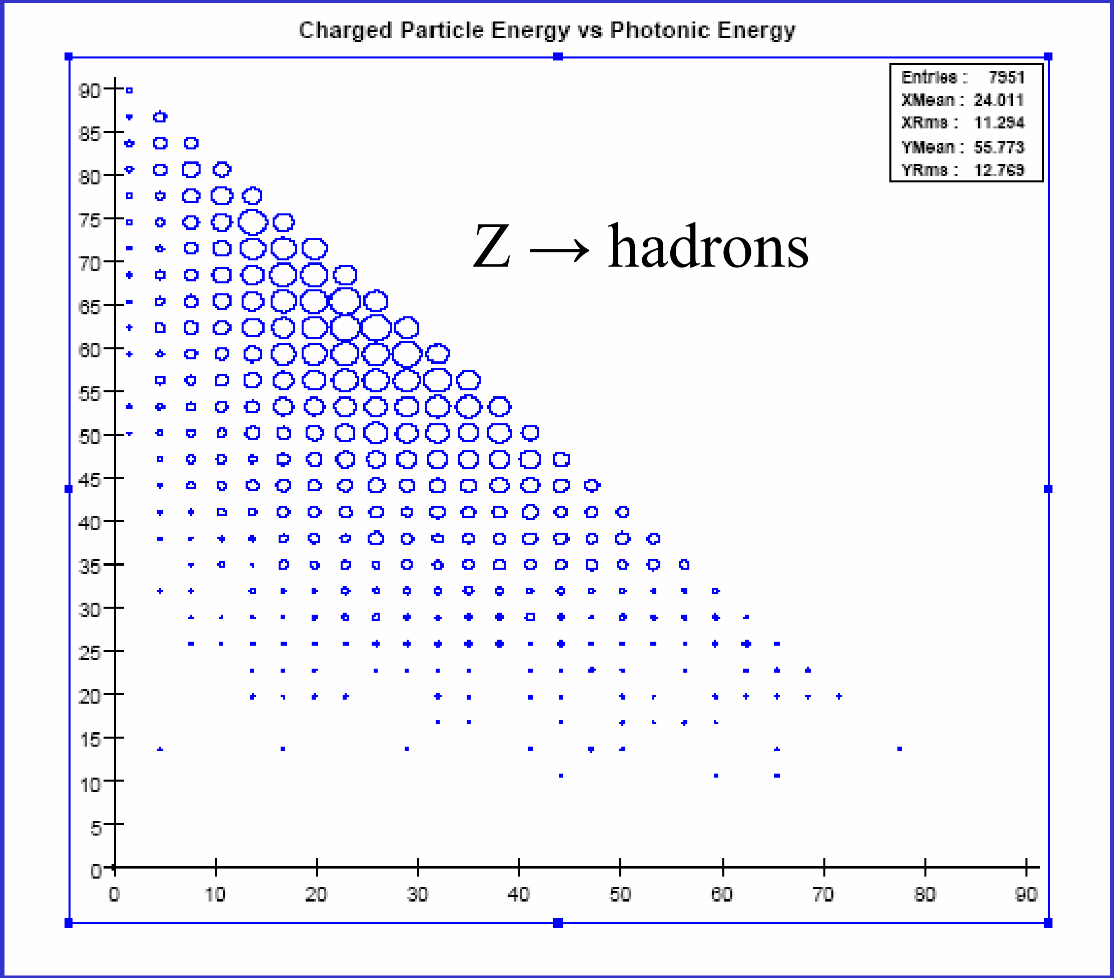
BUT the maximum possible improvements increase as the energy resolution is degraded.



PFA "Dalitz" Plot

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

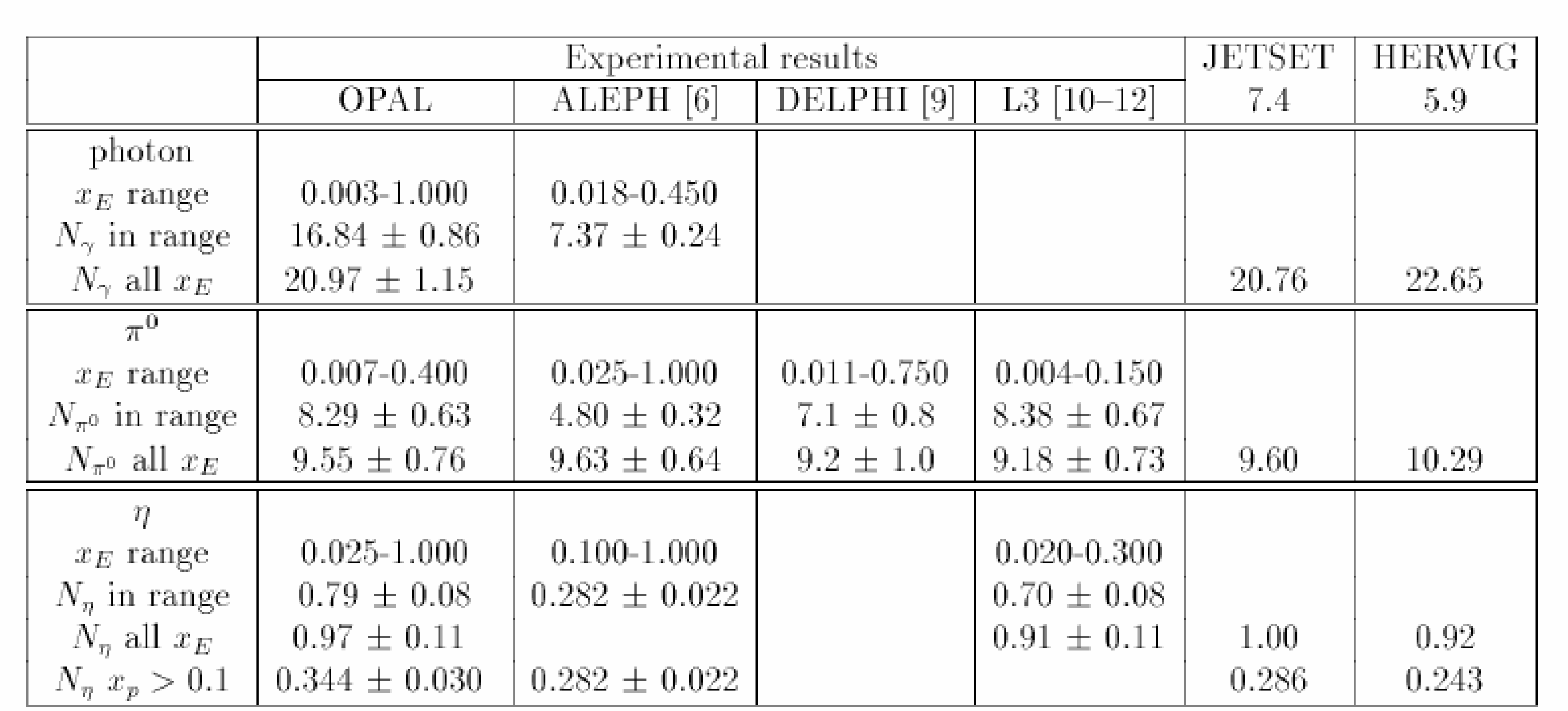
"On Evaluating the Calorimetry Performance of Detector Design Concepts", for an alternative detector-based view of what we need to be doing.



Z → hadrons

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:

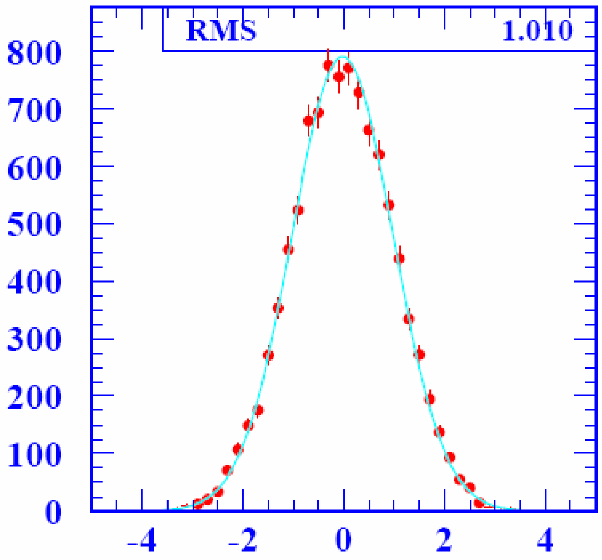
  E_1 (Energy of photon 1)
  E_2 (Energy of photon 2)
  ψ_{12} (3-d opening angle of photons 1 and 2)

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

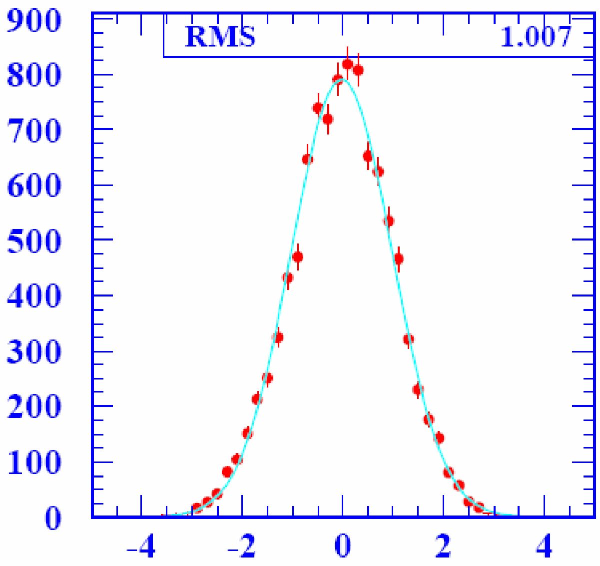
    (assumes individual γ's are completely resolved and measured independently)
  - and the constraint equation

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

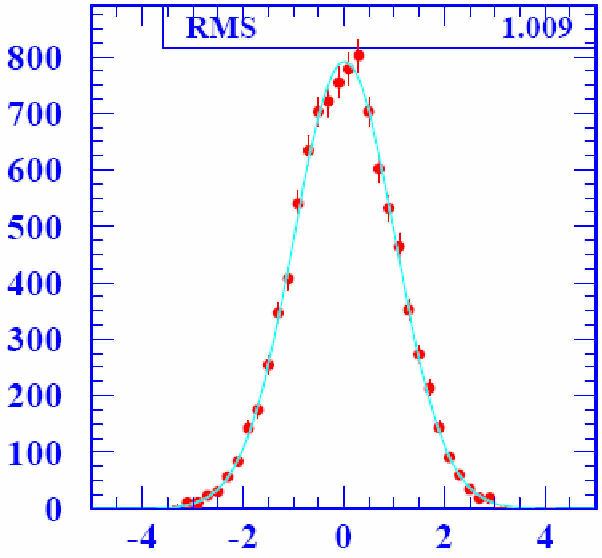
Pull distributions



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