Calorimeter Simulations in the Context of the 4th Concept

ILC ALPCG07

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On Behalf of FNAL and INFN groups

Outlines

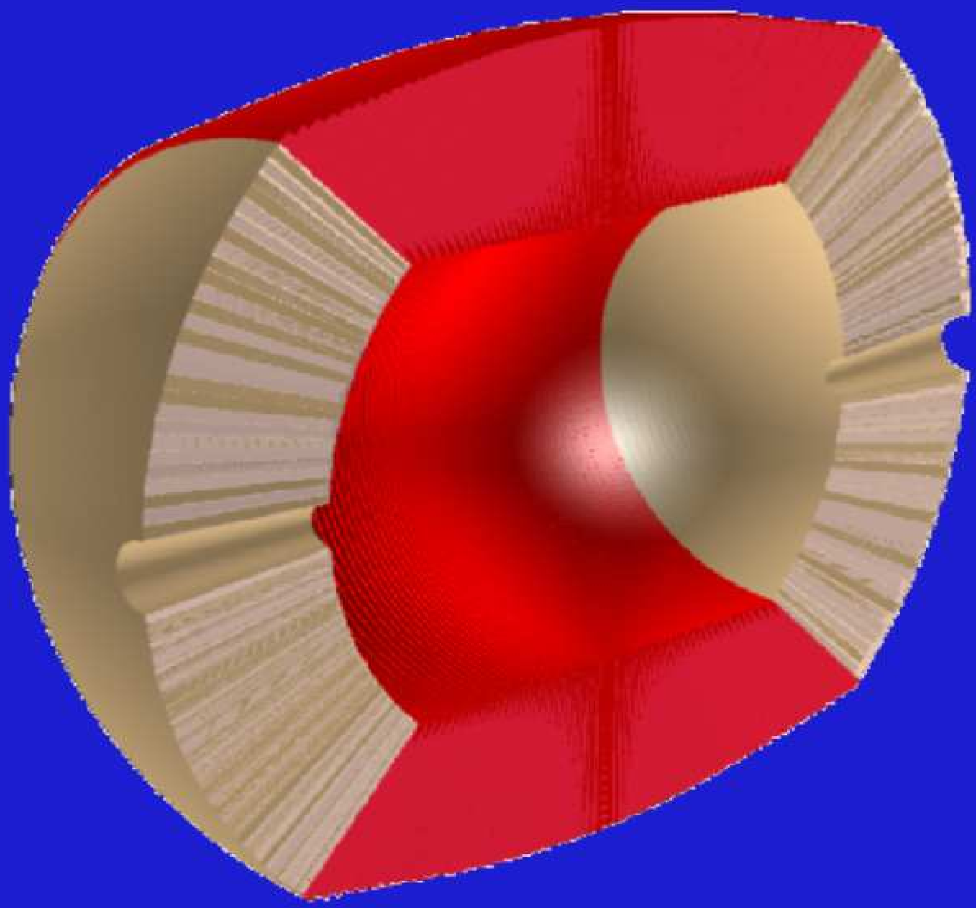
- Status of simulations of a Dual Readout Calorimeter
  - increased statistics
  - new studies
  - Improved pattern recognition/reconstruction
  - some bug fix
- Electromagnetic Calorimeter

The 4th Concept Hadronic Calorimeter (first version*)

- Cu + scintillating fibers + Ĉerenkov fibers
- ~1.5° aperture angle
- ~ 10 λ_{int} depth
- Azimuth coverage

  down to 3.8°
- Barrel: 13924 cells
- Endcaps: 6328 cells

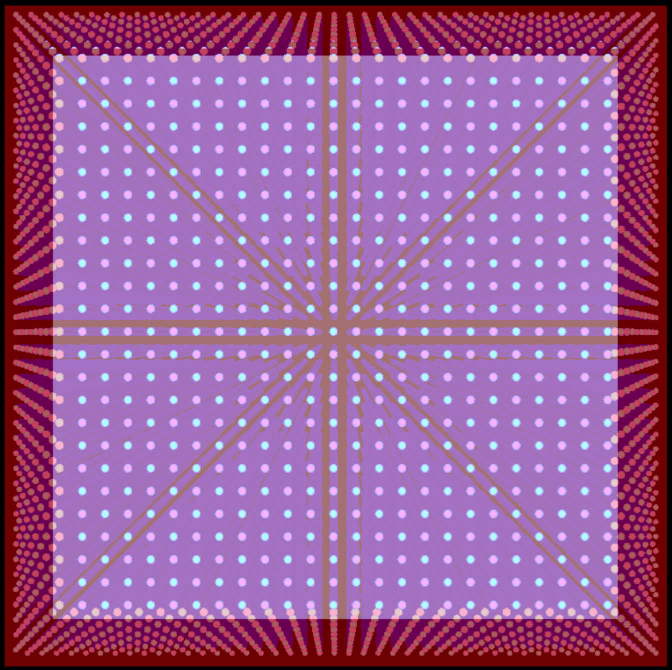
*In the present studies



Fully projective geometry

Hadronic Calorimeter Cells

Bottom view of single cell



Prospective view of clipped cell

300 μm radius

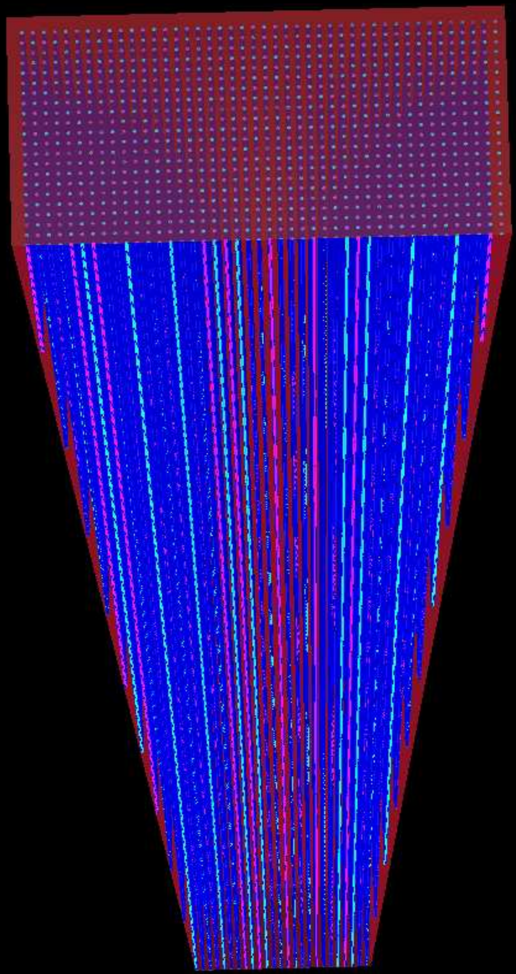
Plastic/Quartz fibers

Aperture Number=0.50

(C fibers)

Cell length: 150 cm

Top cell size:~ 8.8 × 8.8 cm^2



Bottom cell size: ~ 4.8 × 4.8 cm^2

Number of fibers inside each cell: 1980

equally subdivided between Scintillating and Cerenkov

Fiber stepping ~2 mm

Goal is $\sigma_E/E \approx 30\%-40\%/\sqrt{E}$

The two “keys” for the solution

Reduce the fluctuation that dominate the calorimeter performance

1. Fluctuation in the Electromagetic/Hadronic shower fraction, f_{em}
2. Fluctuation in visible energy (nuclear binding energy losses)

Have a jet-finder that handles successfully the energy/tracks outside the jets core

See A. Mazzacane talk on Wednsday

Reconstructed Energy

Total calorimeter energy: use two measured signals and two, energy-independent, calibration constants

$$E_{HCAL} = \frac{\eta_S \cdot E_S \cdot (\eta_C - 1) - \eta_C \cdot E_C \cdot (\eta_S - 1)}{\eta_C - \eta_S}$$

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$$\eta_c = \left(\frac{e}{h}\right)_C \quad \eta_S = \left(\frac{e}{h}\right)_S$$

From calibration

@ 1 Energy only

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Total calorimeter energy: use two measured signals and two, energy-independent, calibration constants

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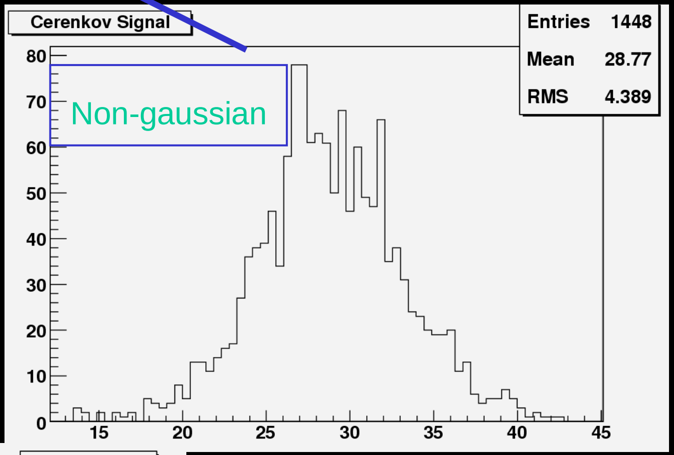

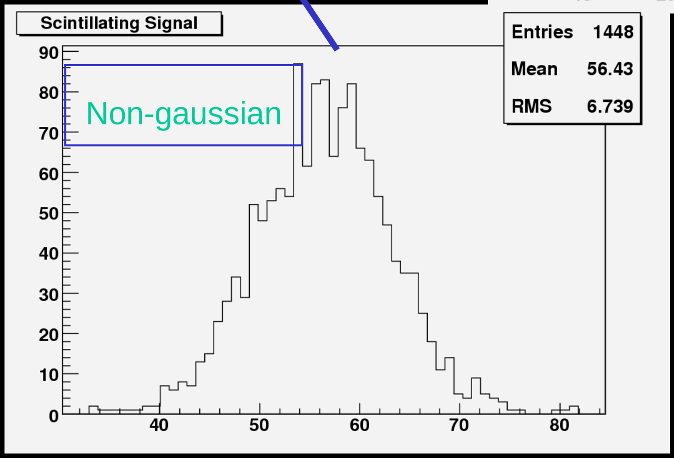

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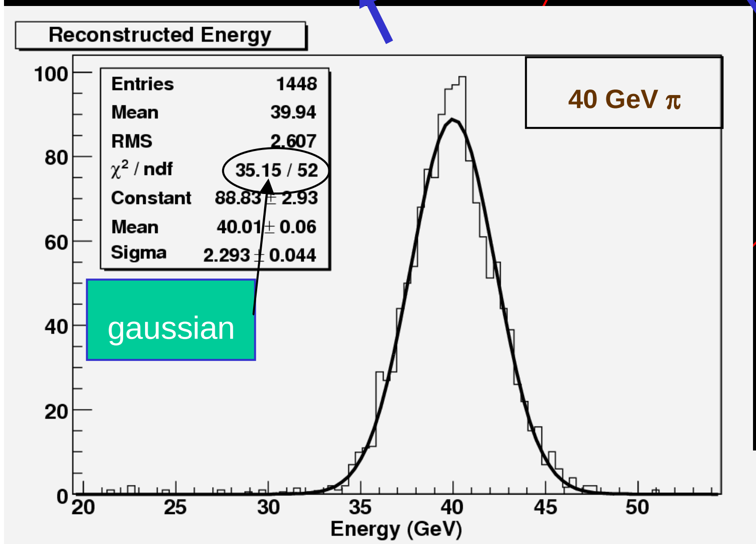
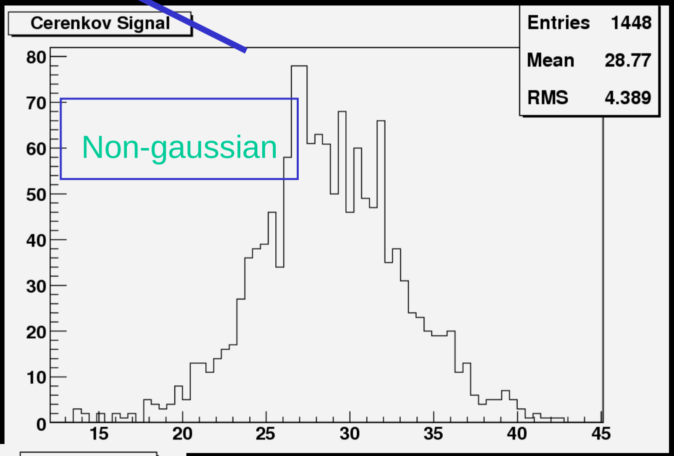
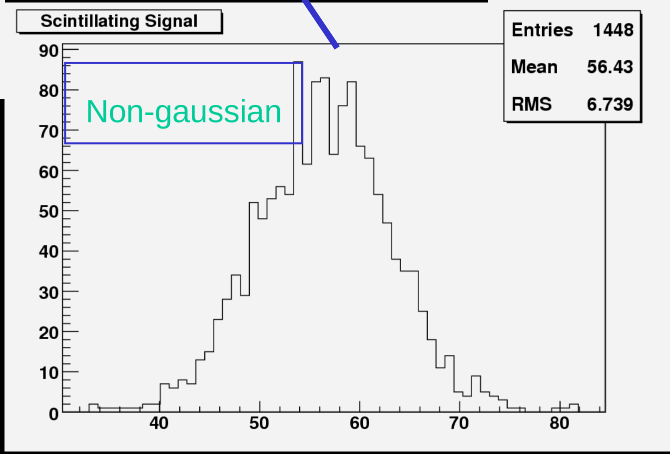






$$\eta_c = \left(\frac{e}{h}\right)_C \quad \eta_S = \left(\frac{e}{h}\right)_S$$

From calibration

@ 1 Energy only

Simulation Details

See my talk on Monday

At the tracking session

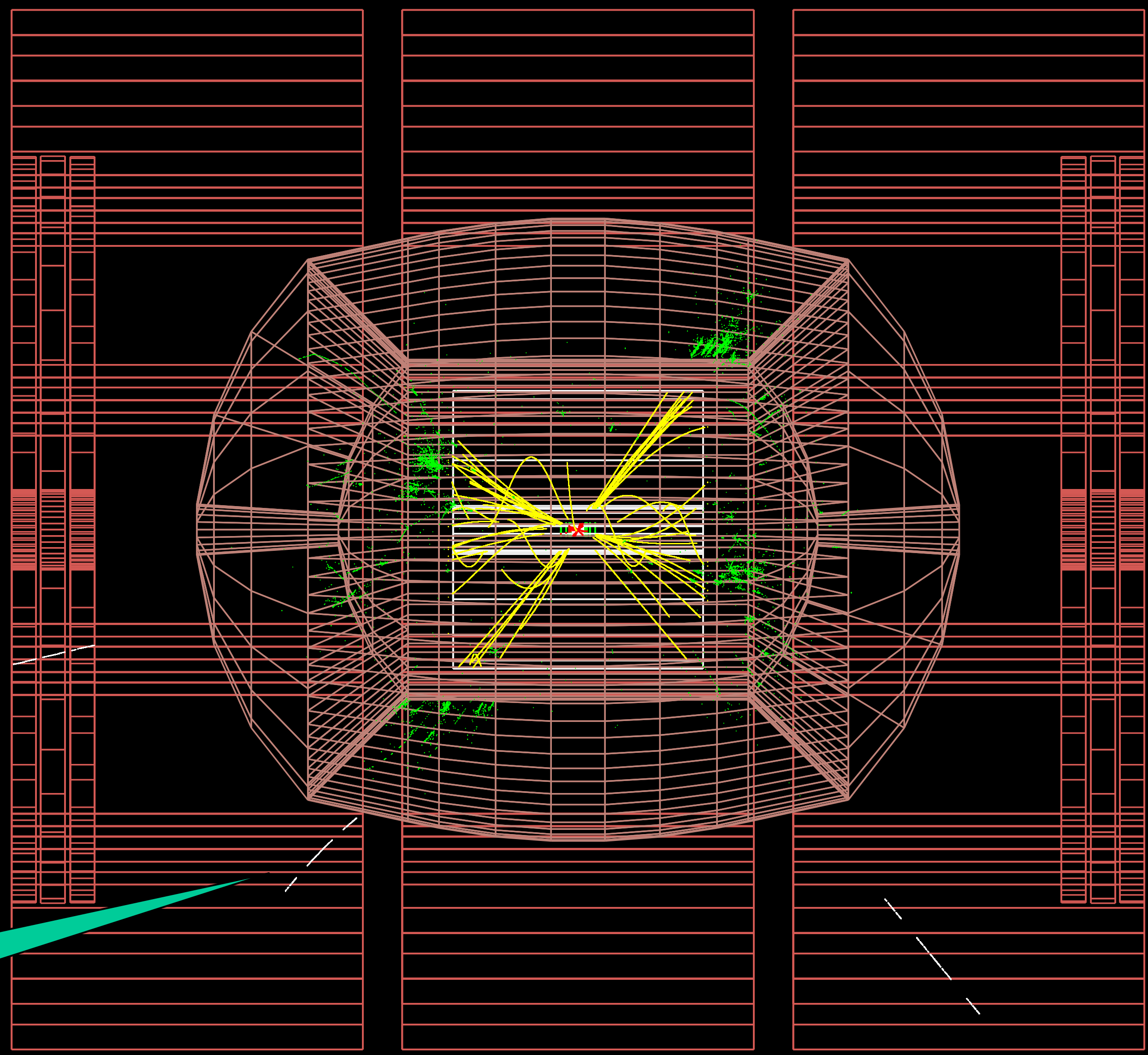
- ILCroot framework
- Full detector configuration (VXD, **TPC/SiT or DCH**, Calorimeter, Magnet)
- Pandora-Pythia,Whizard, Sherpa, CompHEP, GuineaPig to generate events
- Fluka to track particles in the detectors
- Scintillation and Cerenkov light handled with appropriate algorithms
- Full digitization/clusterization (noise, thresholds, etc.)
- Full pattern recognition
  - Clusterization = collection of nearby "digits"
  - Unfolding of overlapping showers through Minuit fit to shower shape
  - Durham for jet-finding/reconstruction

Event Display in ILCroot

$e^+e^- \rightarrow H^oH^oZ^o$

–> 4 jets 2 muons

ECM = 500 GeV



Low pt secondary muon

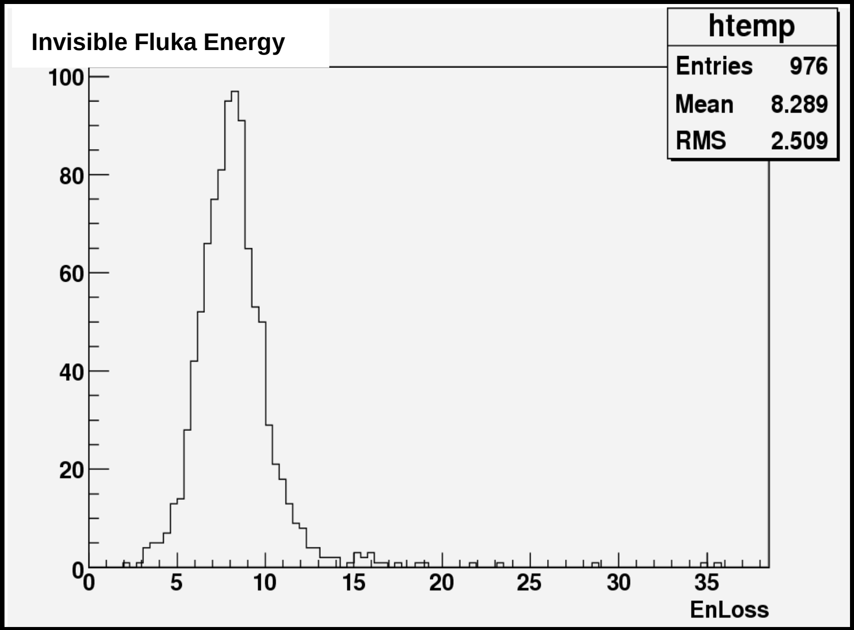
Understanding Fluka

- Total energy deposited in any volume (including Beam Pipe, Trackers, etc.)
- Total invisible energy
  - *"Energy of particles below threshold"*
  - *"Residual excitation energy"*
    - excitation energy which is left after evaporation of nuclei and not emitted as prompt gamma de-excitation (e.g., radioactive decay energy)
  - *"Energy escaping the system"* (i.e. Punch-through)
  - *"Discarded"* particles (i.e. neutrinos)
  - Energy of particles *out of time limit"*
  - *"Missing Energy"* (mostly endothermic nuclear reactions)

Look into Fluka manual for details

Almost never happen

Total Fluka Visible vs Invisible Energy



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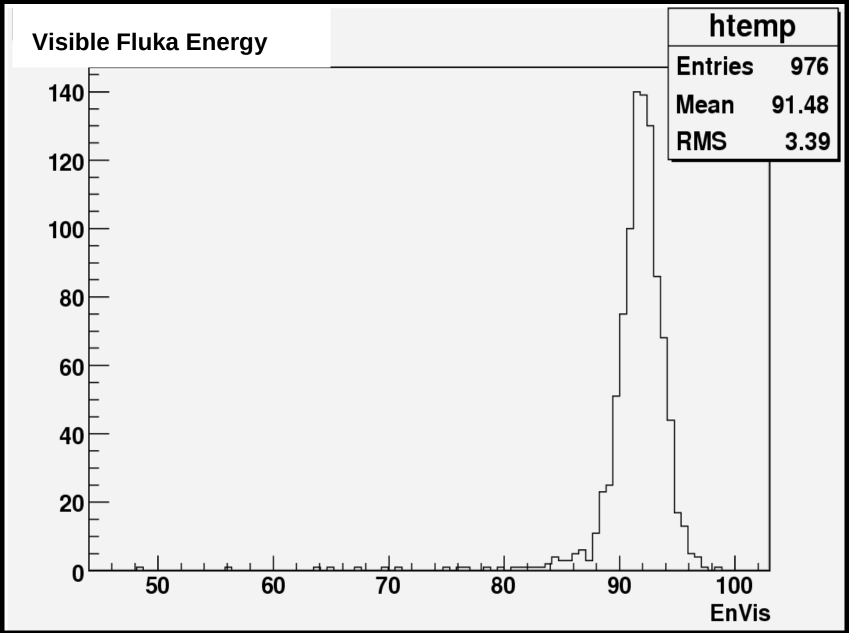

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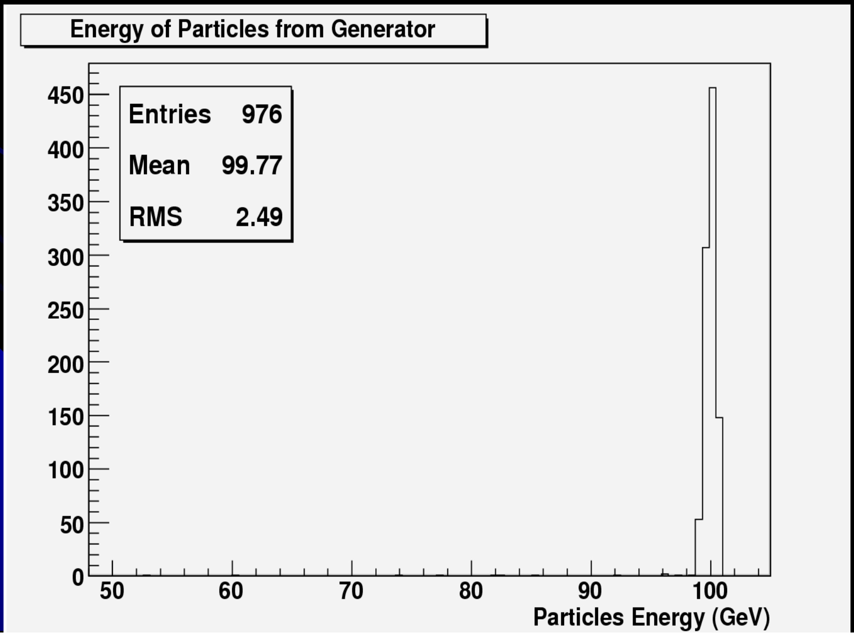
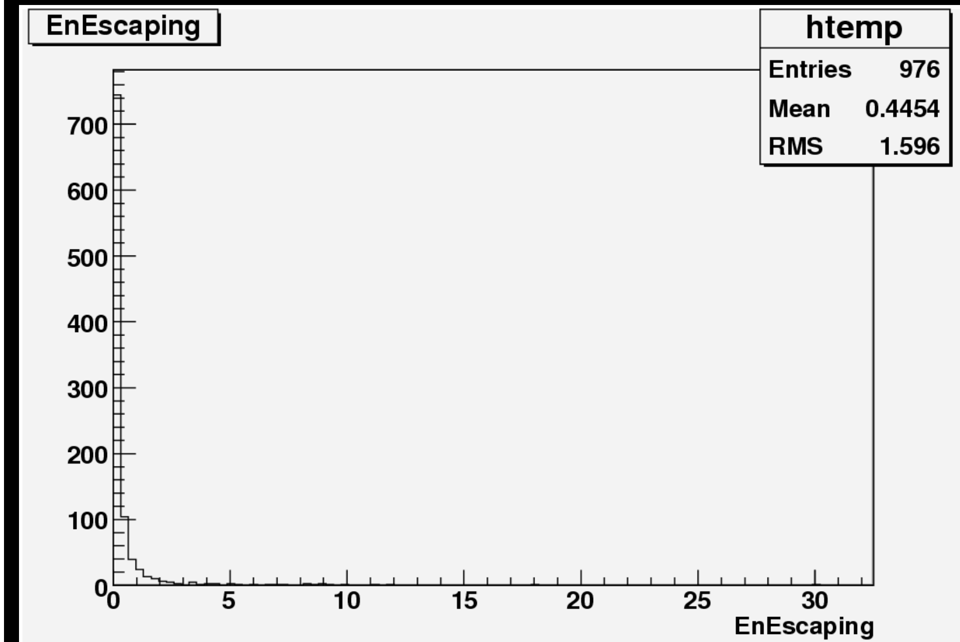


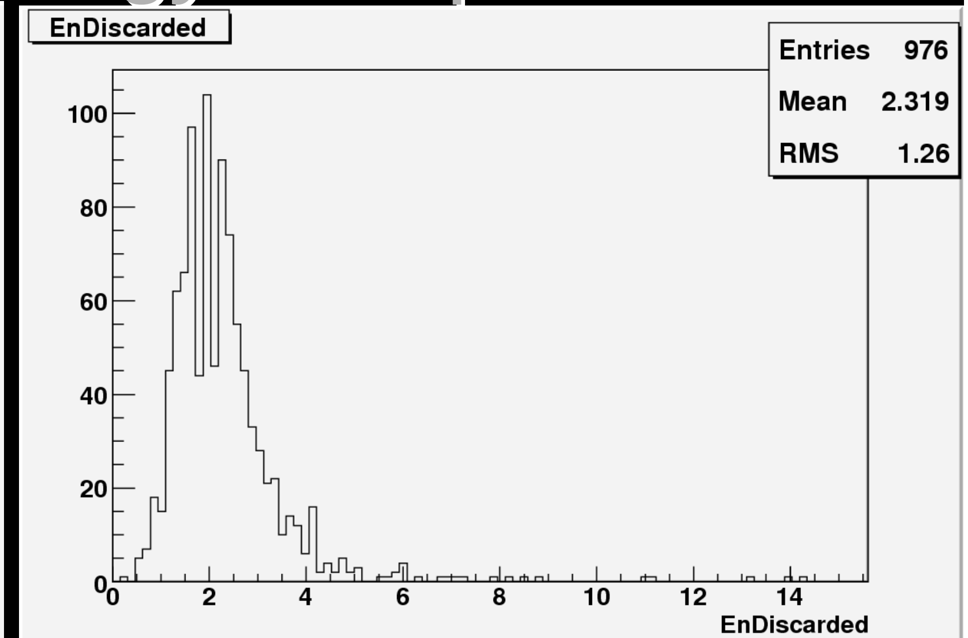
Di-jet events

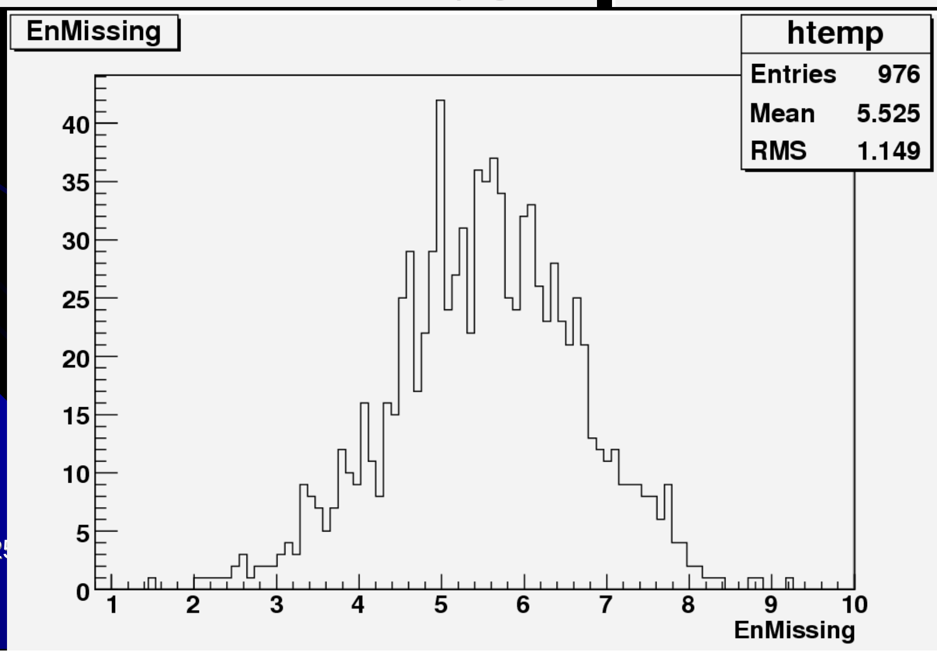
with

E_{cm} = 100 GeV

Fluka Invisible Energy Components







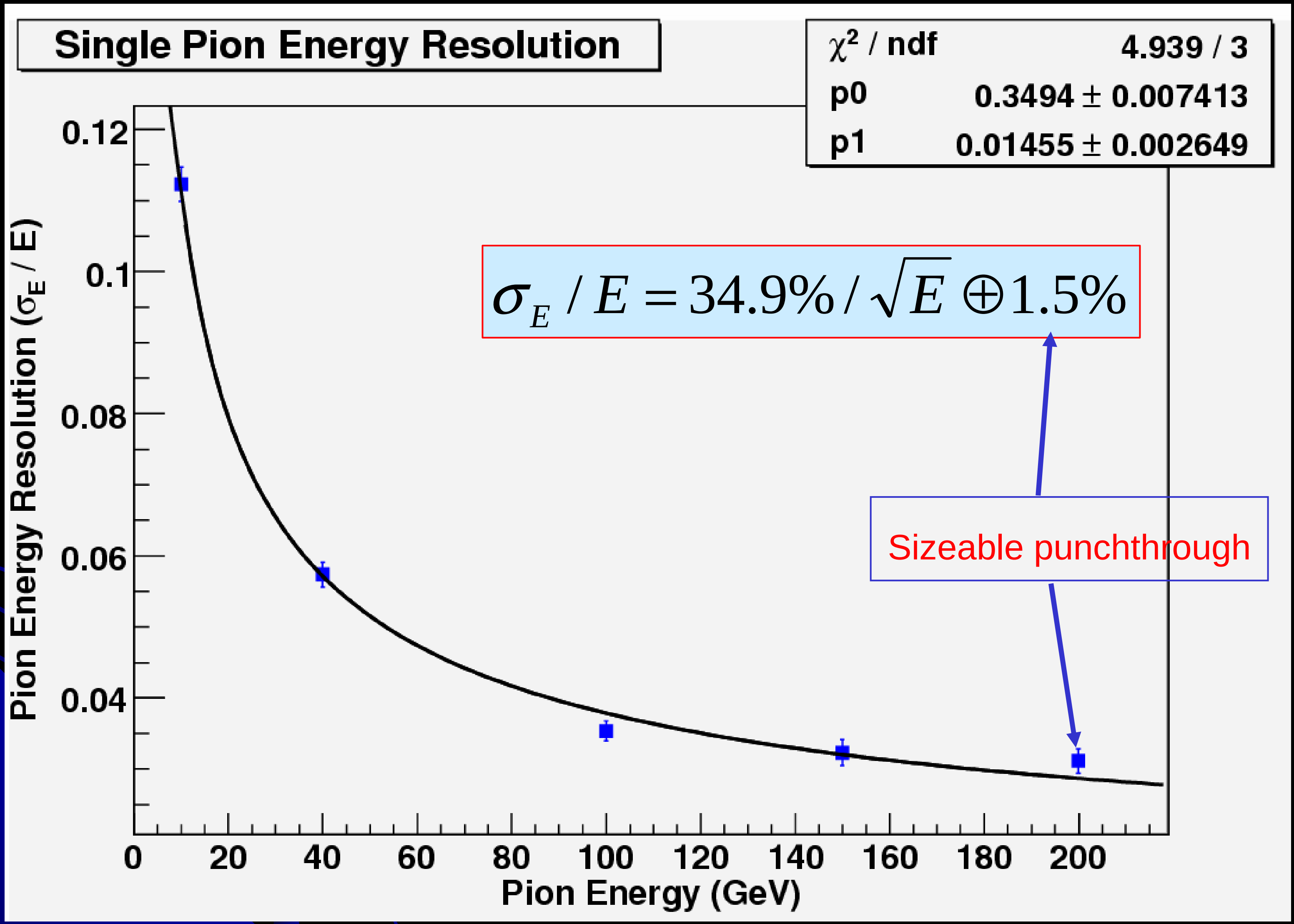
Di-jet events

with

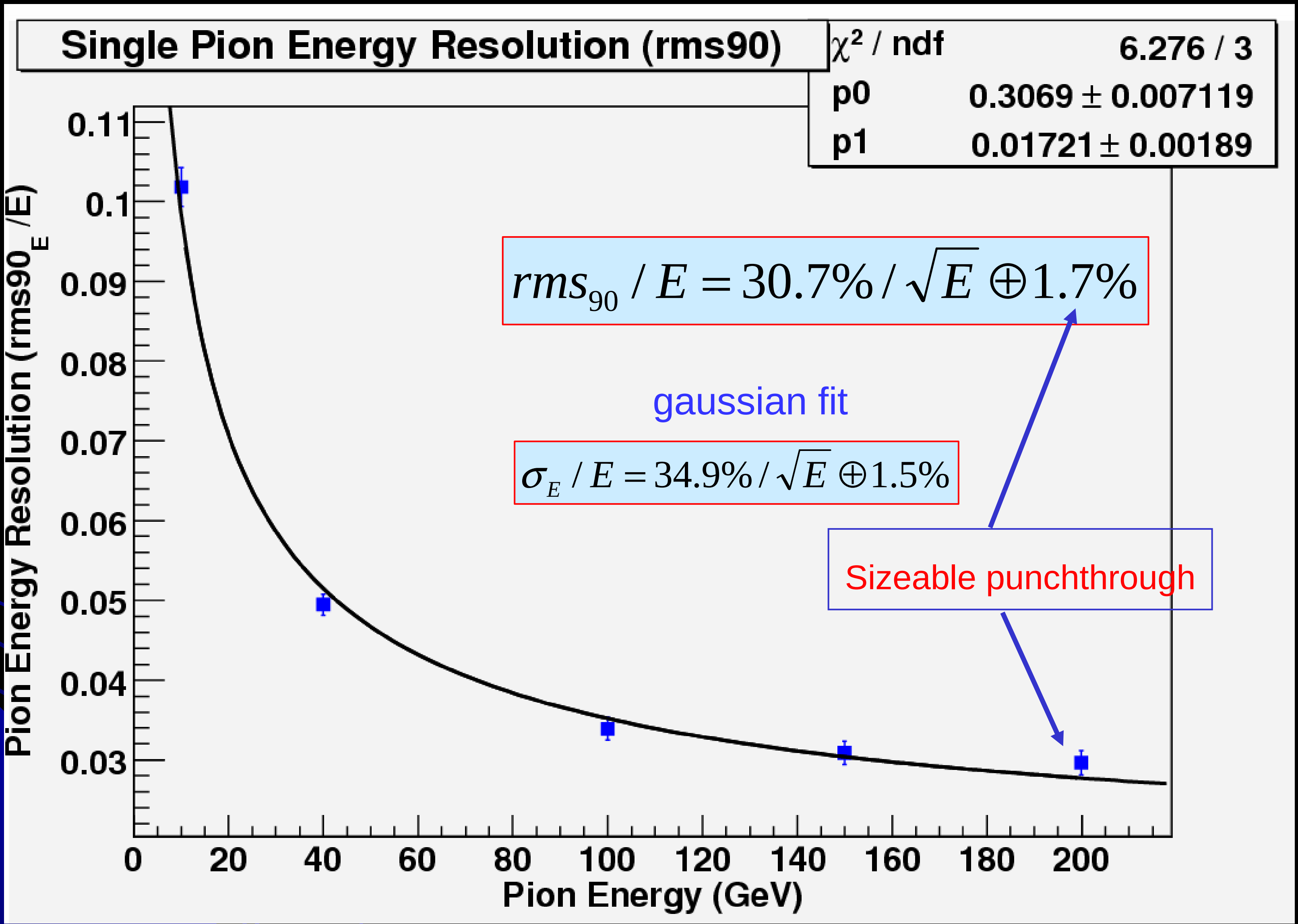
E_{cm} = 100 GeV

Single Particles Studies with Hadron Calorimeter

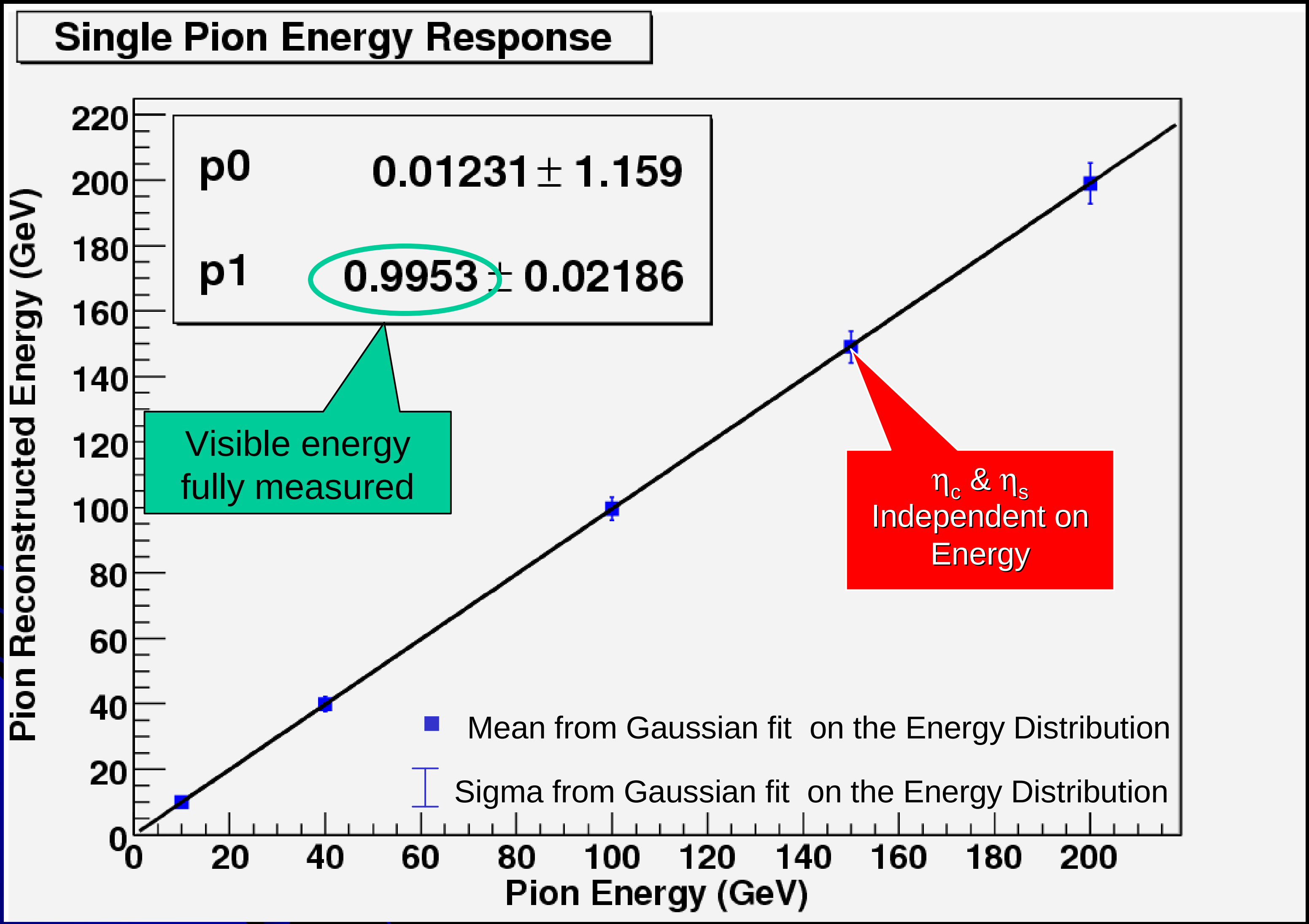
HCAL resolution with single π (using σ)



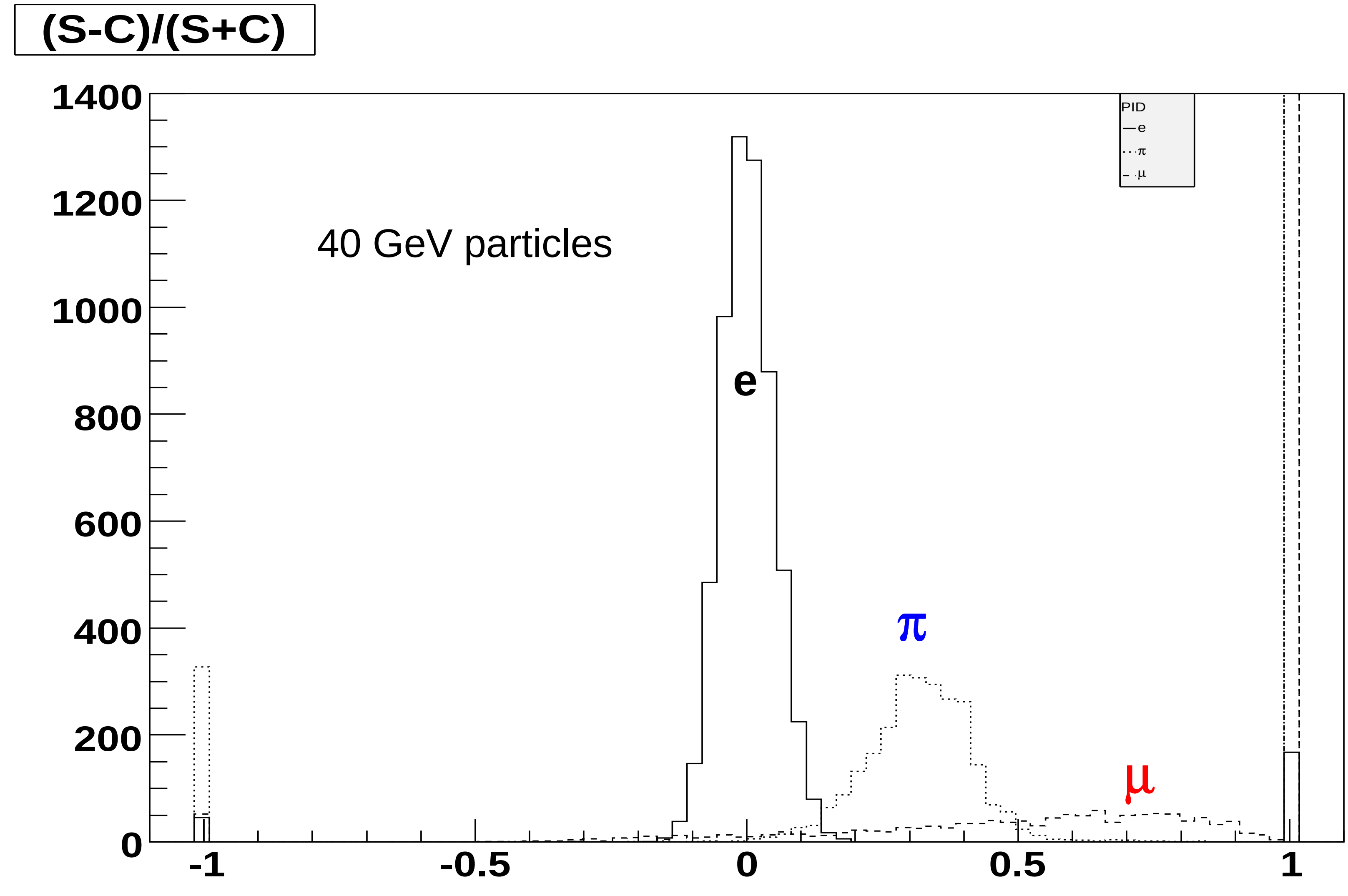
HCAL resolution with single π (using rms_{90})



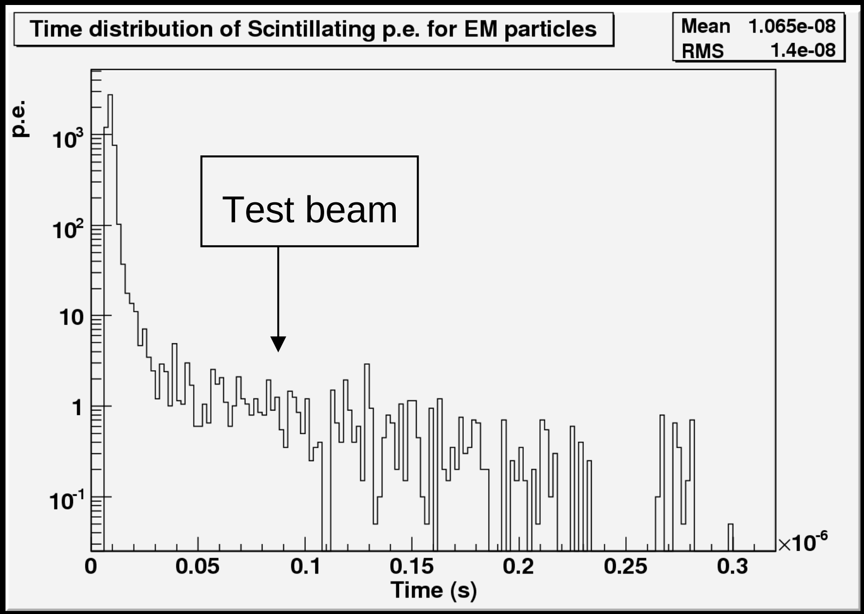
HCAL Response with single π (using σ)

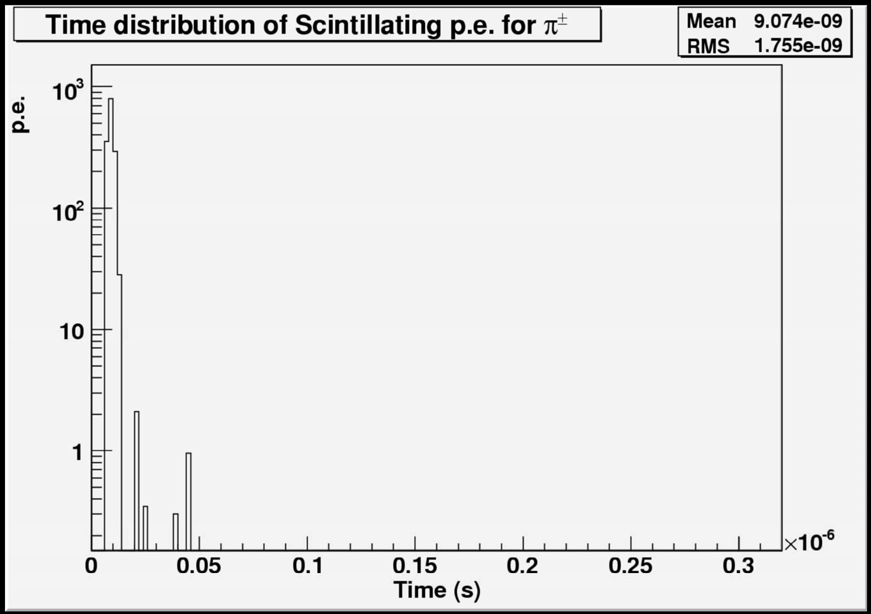


PID from HCAL

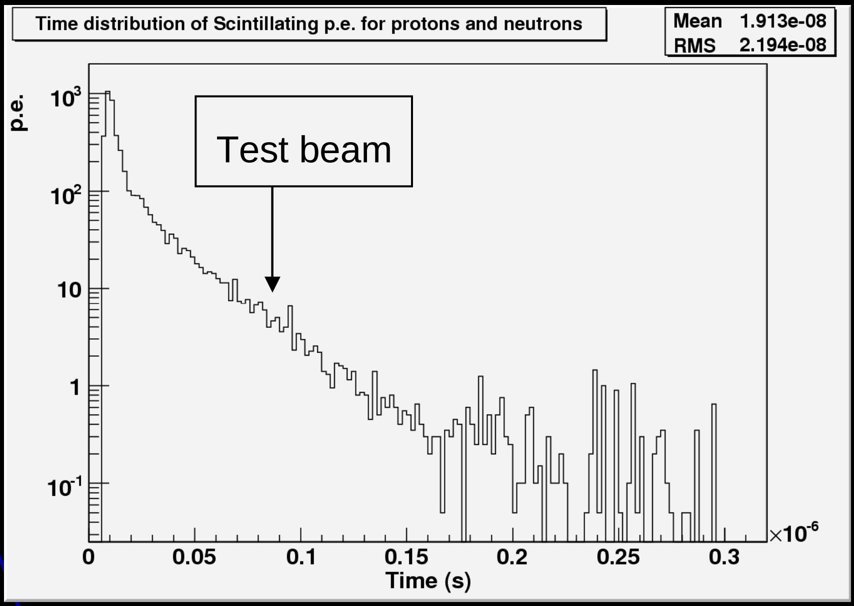


Time Spectrum of Scintillating Fibers

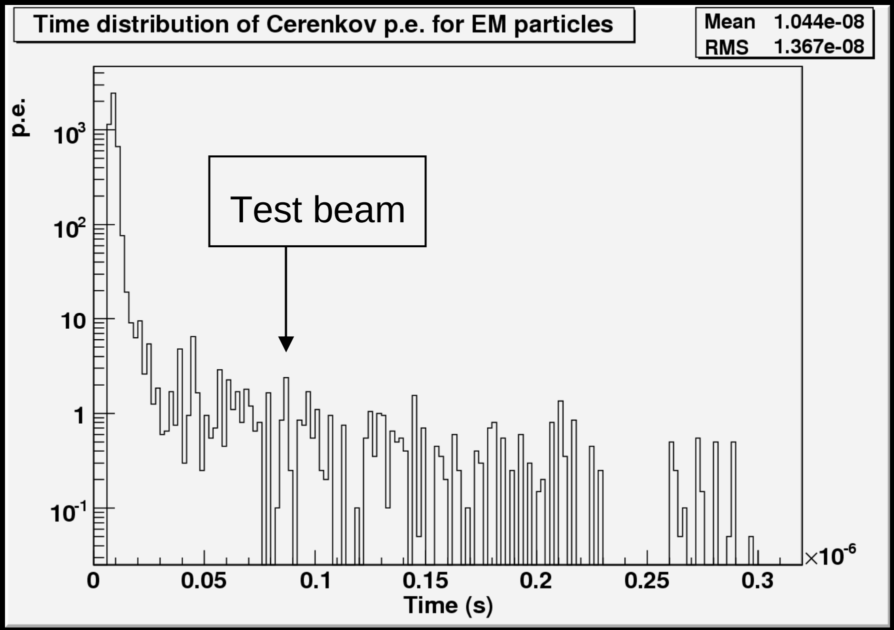


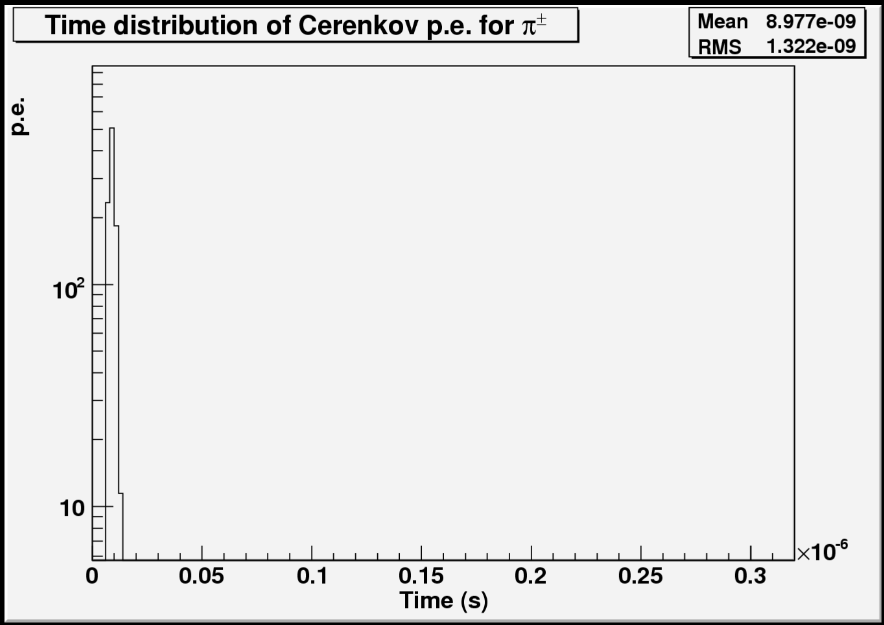


40 GeV π^-



Time Spectrum of Cerenkov Fibers





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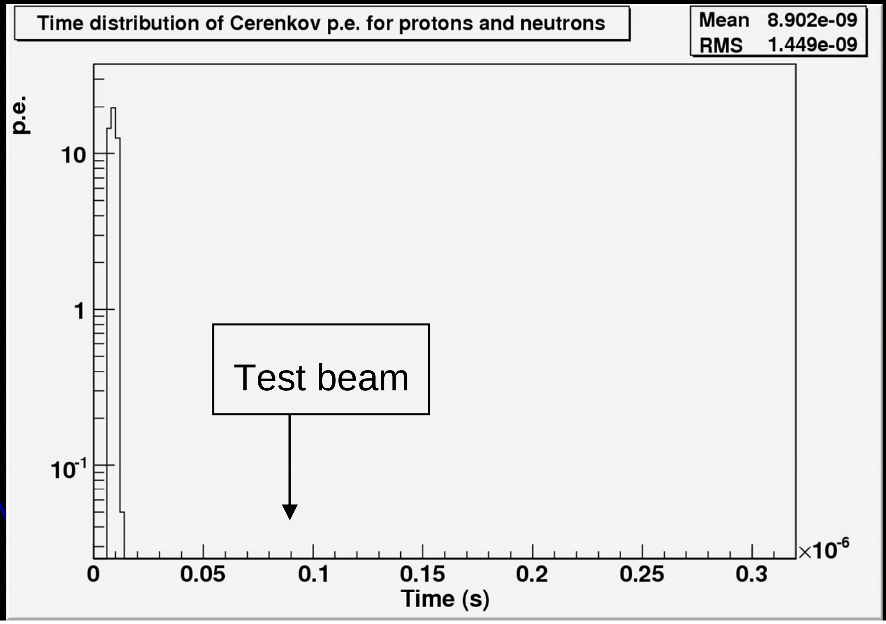


Di-jet Studies

with

Hadron Calorimeter

- See also the talk by A. Mazzacane on Wednsday

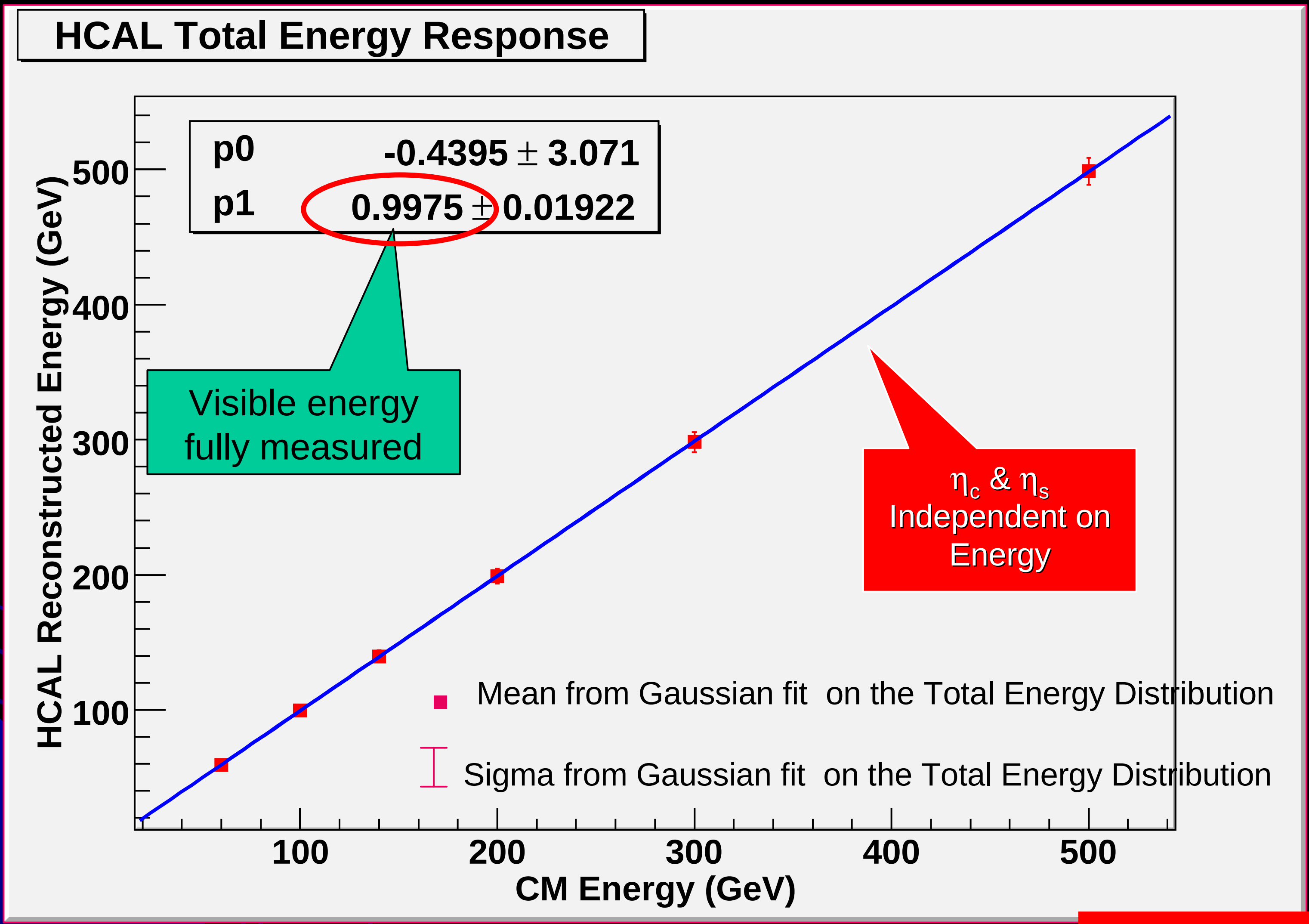
$e^+e^- \rightarrow qq$ (q=uds) @ 60, 100, 140, 200, 300, 500

From A. Mazzacane talk

(rms$_{90}$: rms of central 90% of events)

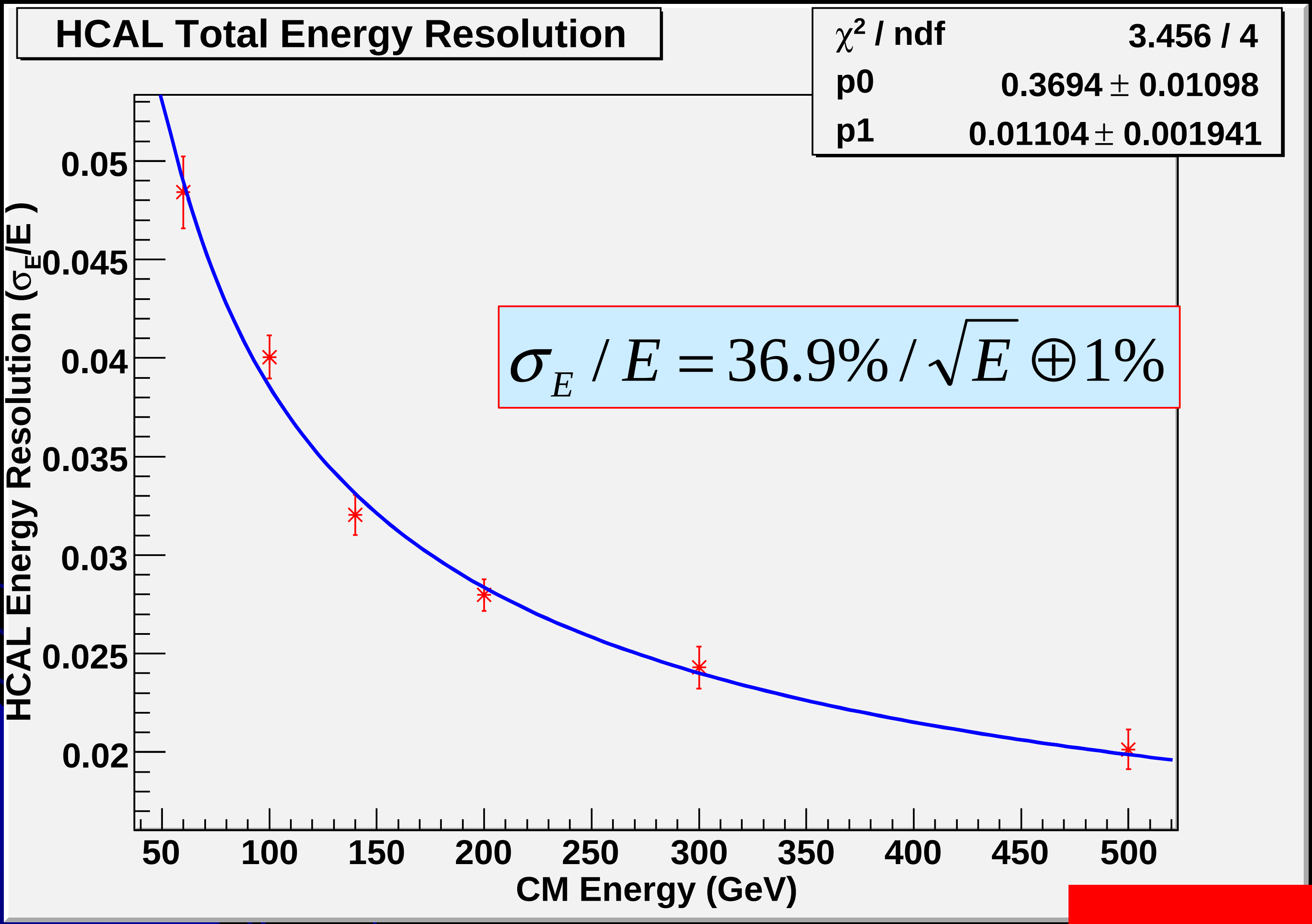
E_{CM}(GeV)	σ: $\sigma/E = \alpha/\sqrt{E}$	rms$_{90}$: $\sigma/E = \alpha/\sqrt{E}$
60	37.5	32.1
100	40.1	34.0
140	37.9	32.7
200	39.6	34.9
300	42.1	36.7
500	45.0	40.6

Energy Response



From A. Mazzacane talk

Total Energy Resolution (gaussian fit)



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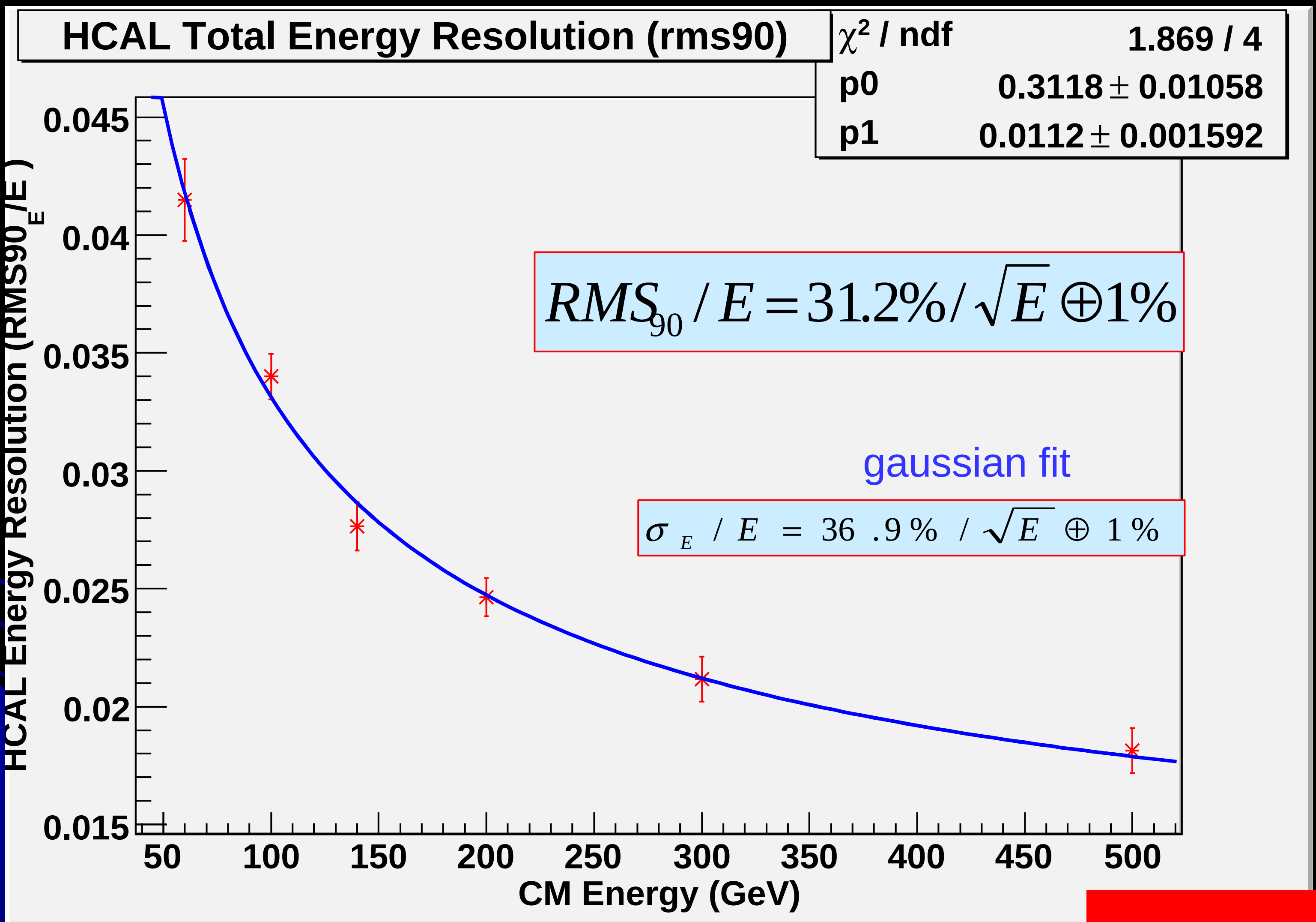
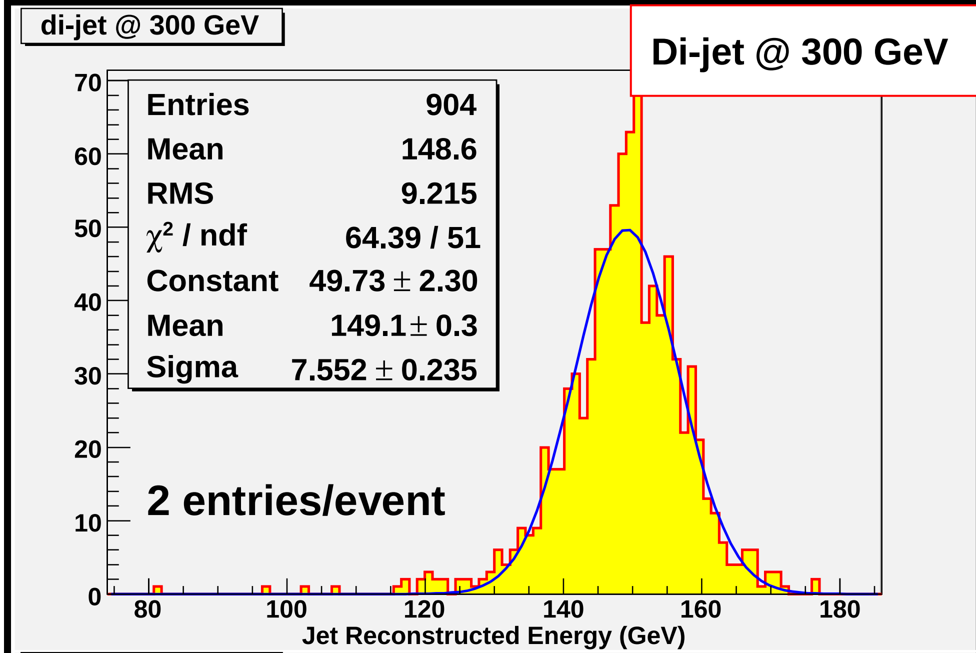


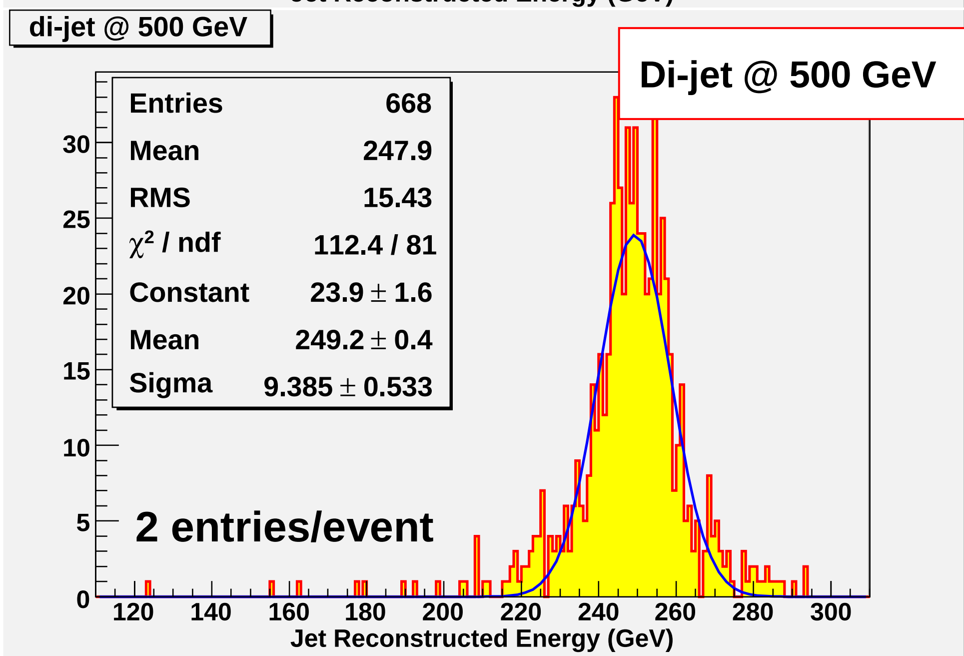
From A. Mazzacane talk

Jets Reconstruction Performance for di-jet events

- Use Durham jet finder
- Jet Energy reconstruction
- Energy Resolution

Di-jet events $e^+e^- \rightarrow qq$ (q=uds) @ 60, 100, 140, 200, 300, 500 GeV

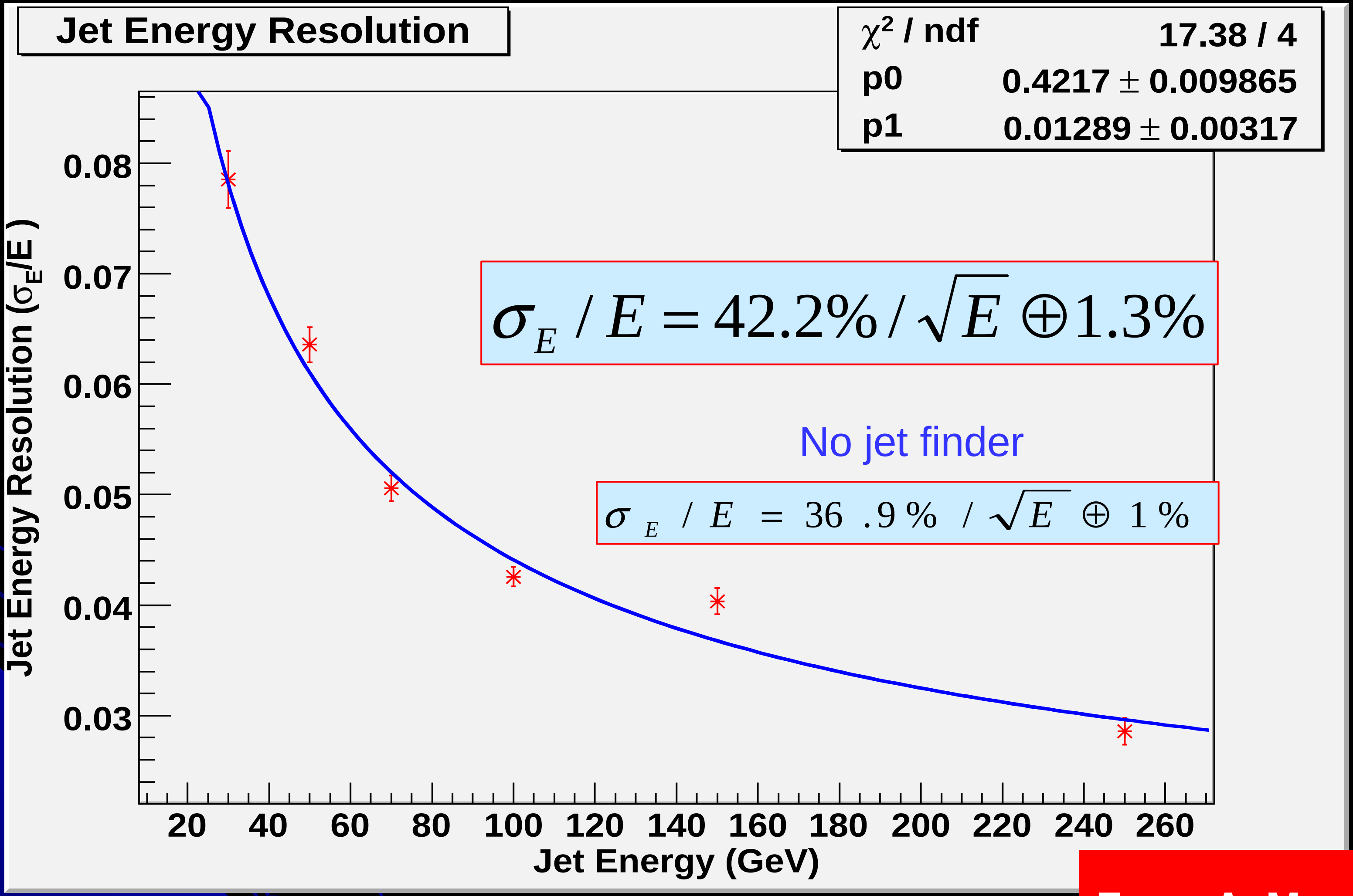




(rms90 : rms of central 90% of events)

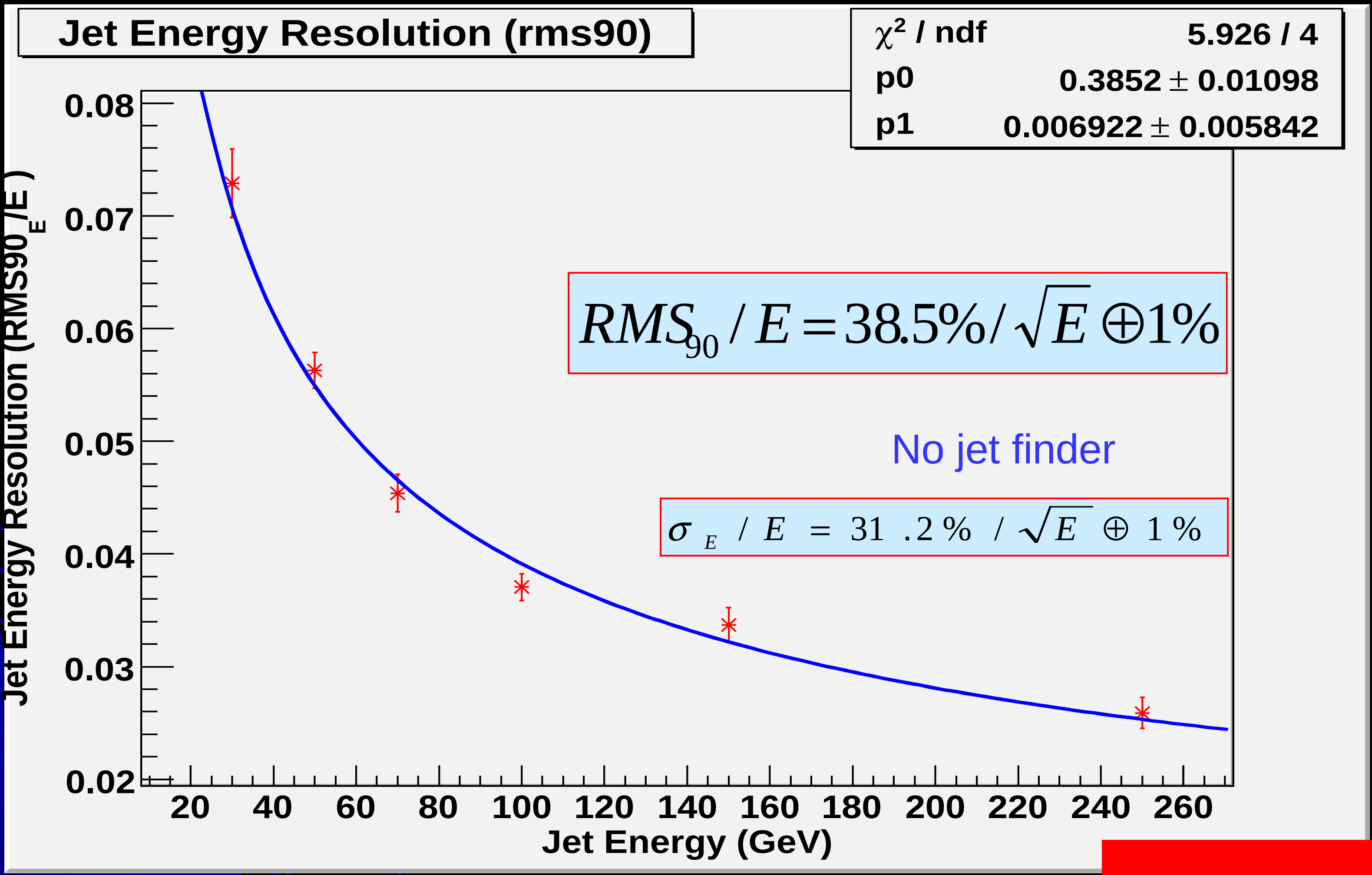
	σ	rms_{90}
E_{jet}(GeV)	$\sigma/E = \alpha/\sqrt{E}$	$\sigma/E = \alpha/\sqrt{E}$
30	43.0	39.9
50	45.0	39.8
70	42.3	38.0
100	42.6	37.1
150	49.4	41.3
250	45.2	41.0

Jet Energy Resolution (gaussian fit)



From A. Mazzacane talk

Jet Energy Resolution (rms$_{90}$)



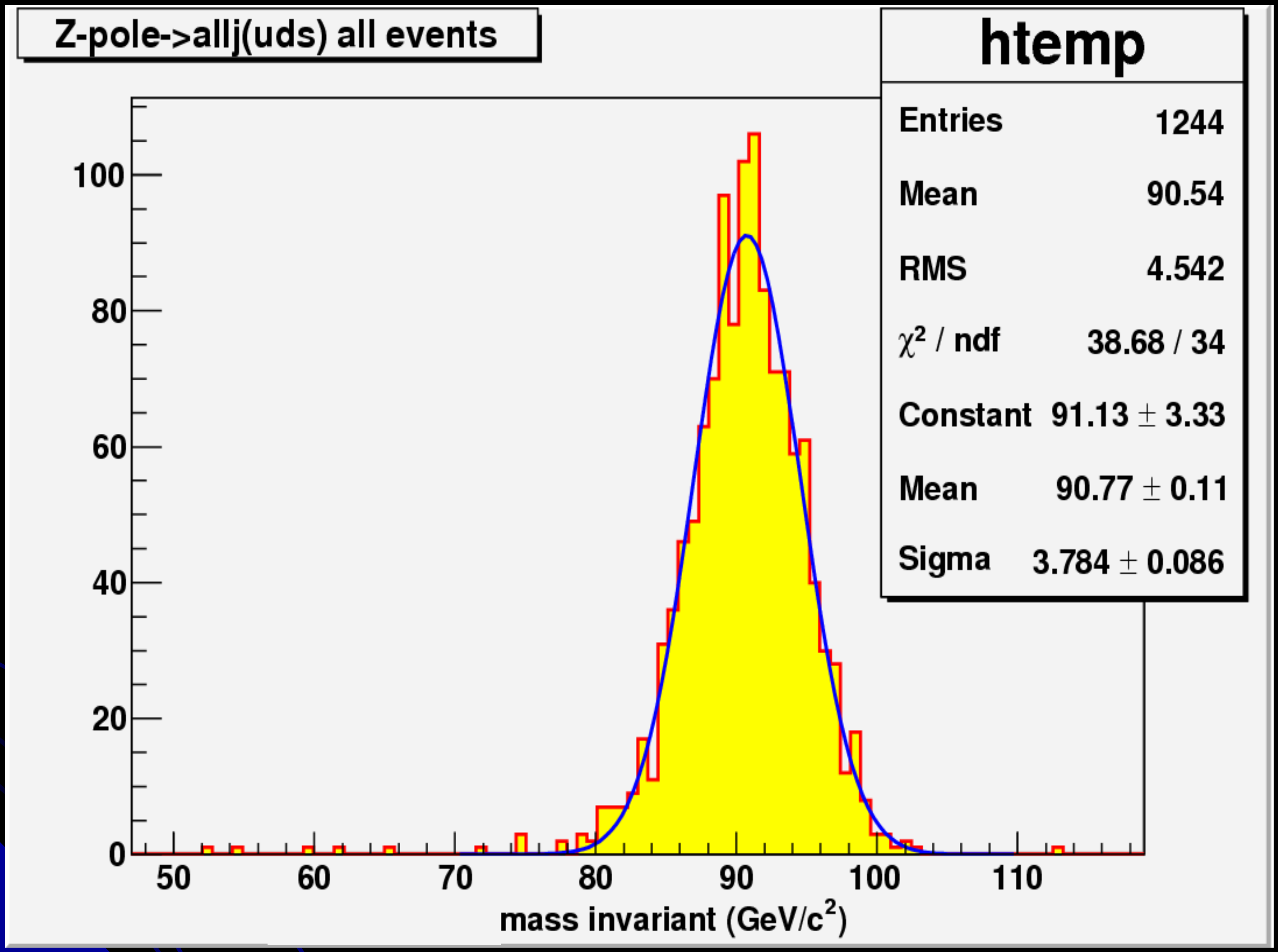
From A. Mazzacane talk

Z_o Pole Studies

Ecm = 91 GeV

Z_o Mass (with Gaussian fit)

39.7 %/sqrt(E)

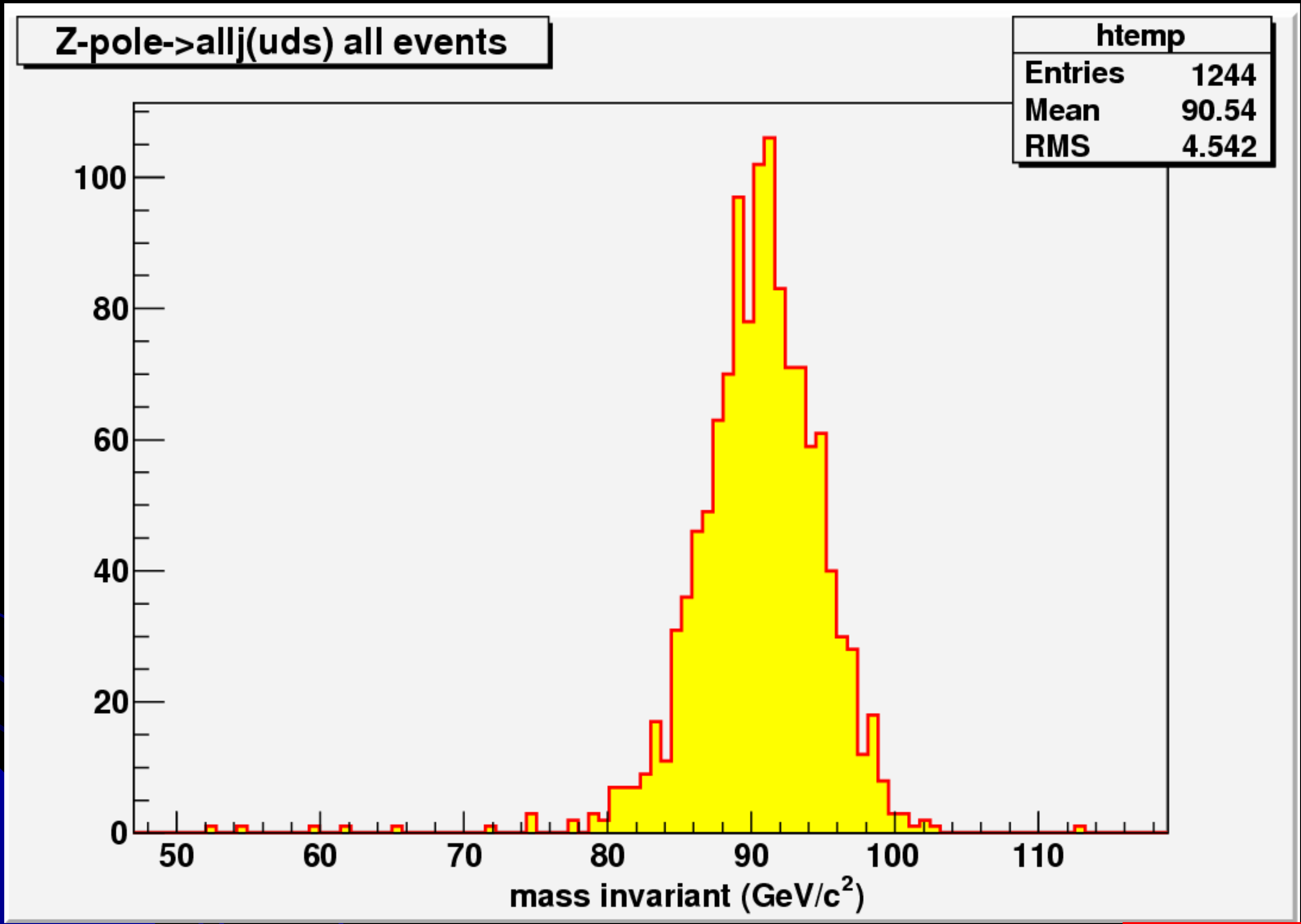


All events, no cuts

From A. Mazzacane talk

Z_o Mass (with RMS_{90})

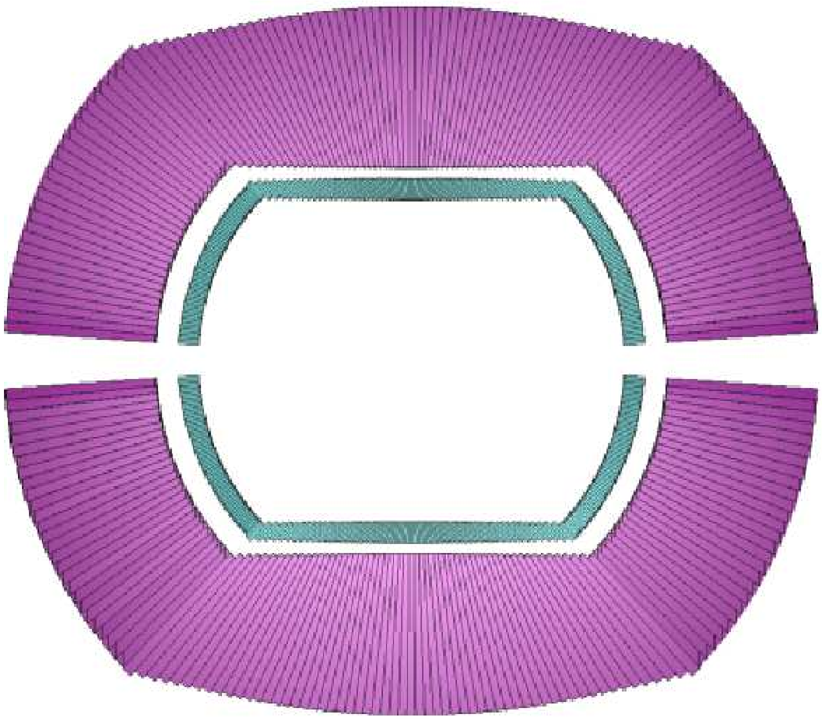
(rms_{90}: rms of central 90% of events) 32.8 %/sqrt(E)

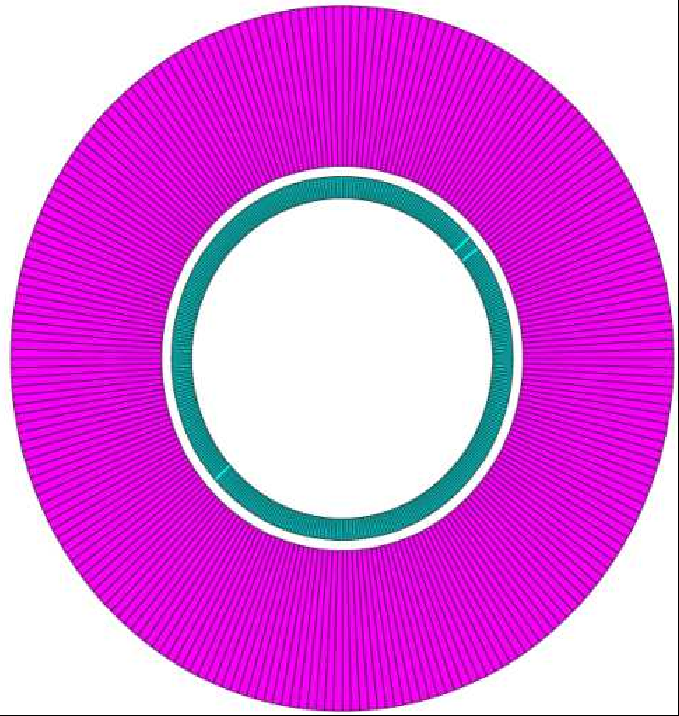


All events, no cuts

From A. Mazzacane talk

The 4th Concept Electromagnetic Calorimeter

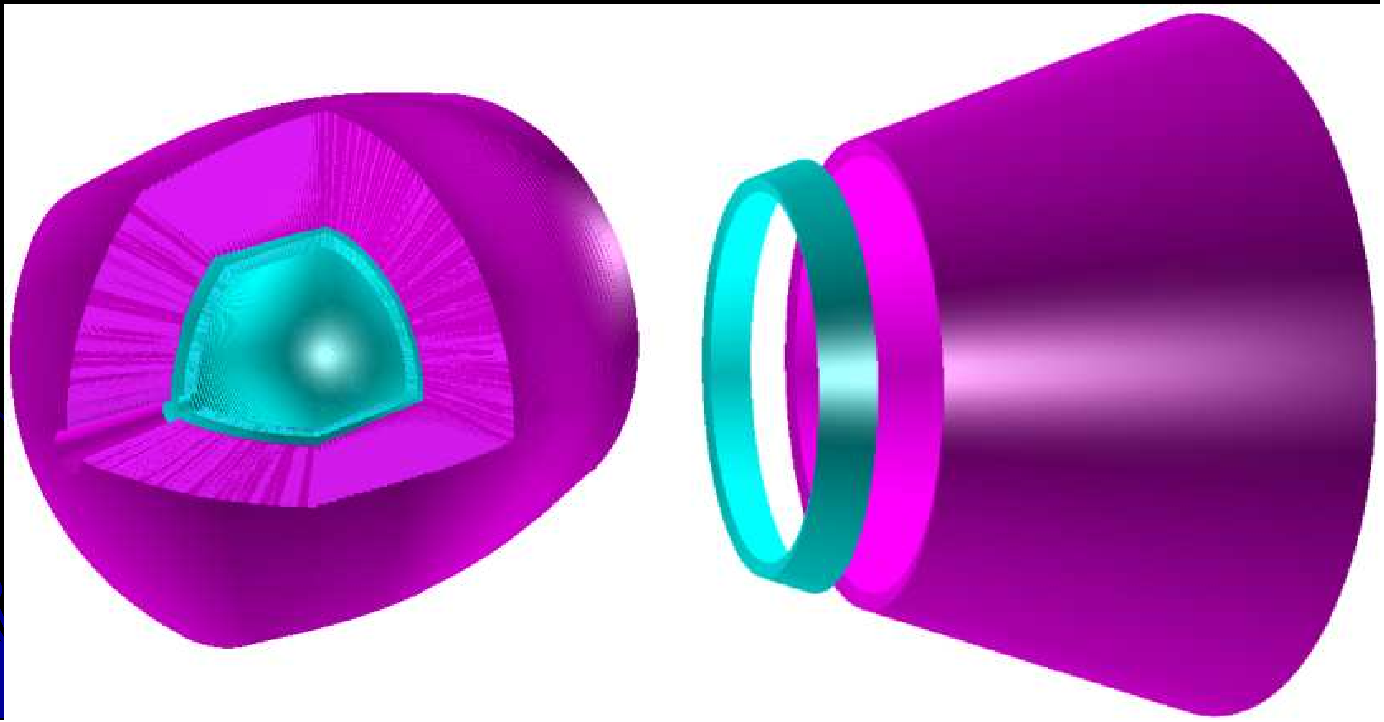




ECAL

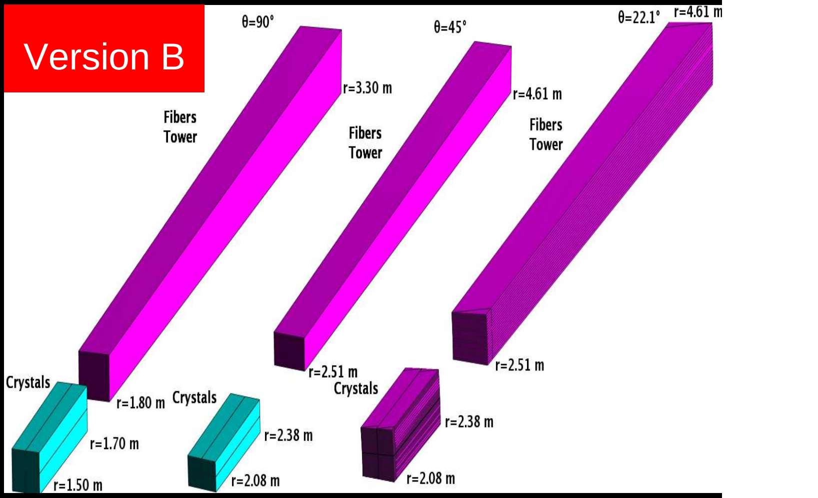
+

HCAL



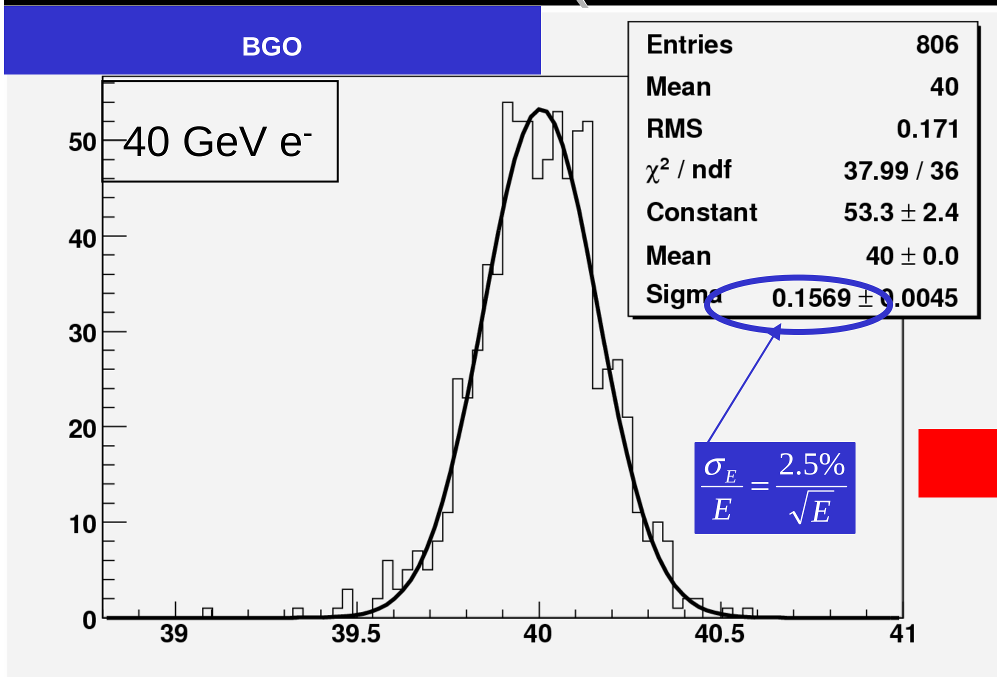
4th Concept Crystal Calorimeter

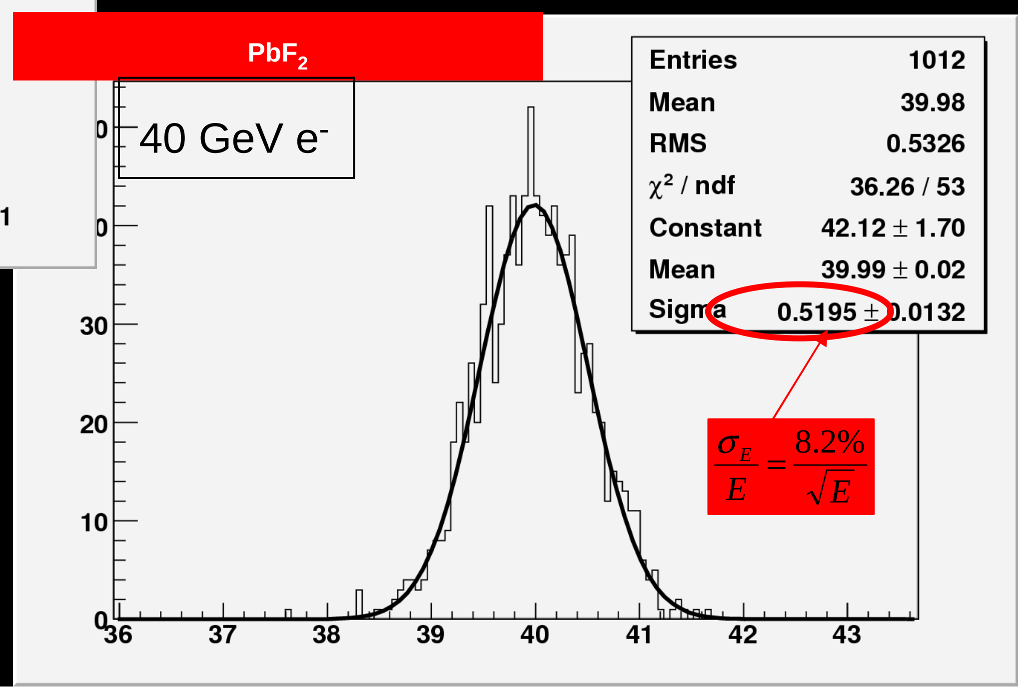
	Version A	Version B
Crystals	BGO (20 cm)	PbF_2 with 0.15% Gd doping 25 cm
Scintillation yield	5 pe/MeV	4.5 pe/MeV
Cerenkov yield	0.6 pe/MeV	1.4 pe/MeV
Dimensions	1 x 1 x 20 cm	2 x 2 x 25 cm
Rin, Rout cm	155,175	155, 180
material in front	5% X/Xo + tracking	None + tracking
Depth (X/X_o)	~ 17.9 X/X_o	~ 27.7 X/X_o
Depth (λ)	~0.88 λ	~1.25 λ
Granularity	~0.38°	~0.76°
Coverage in θ	3.4 °	3.4°
Total cell barrel	222784	55696
Total cell endcaps	2*50624	2*25312



E_S Distribution

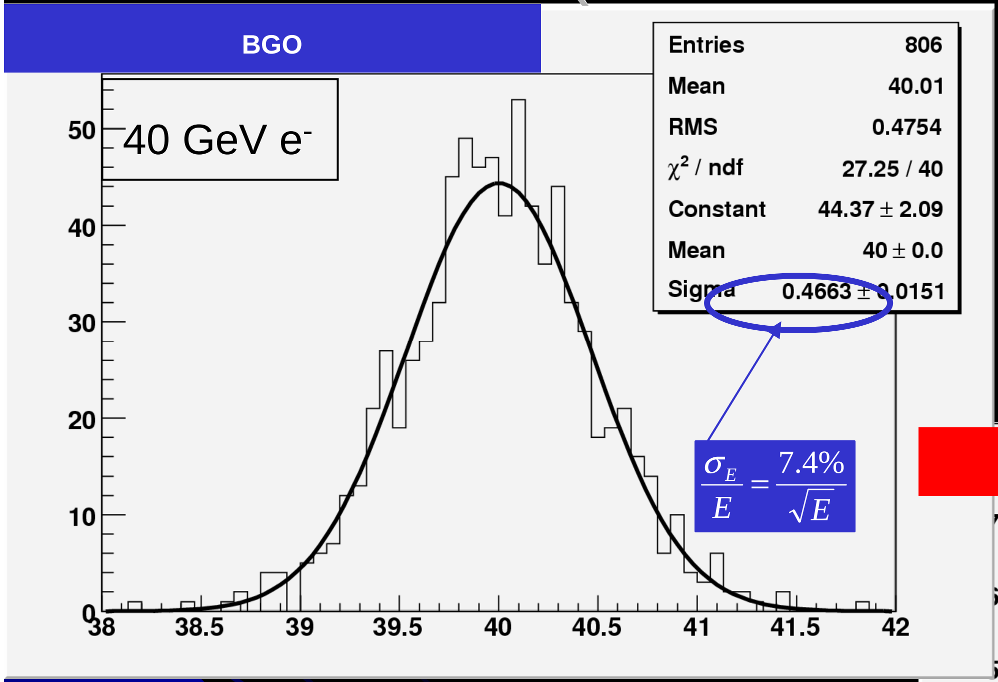
(for 50 cm long crystals)

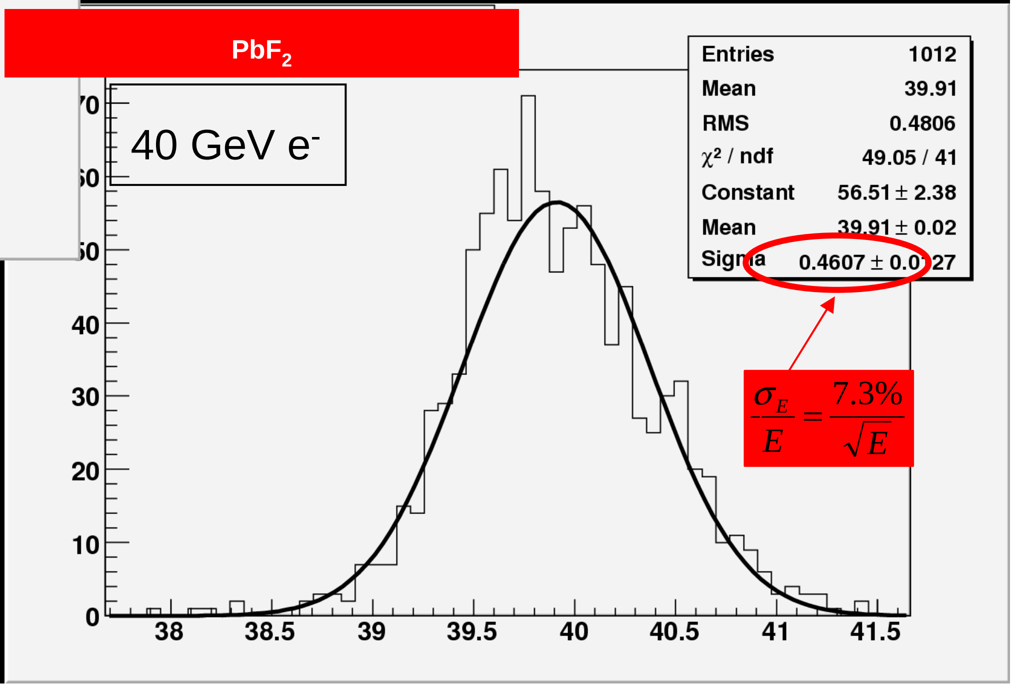




E_C Distribution

(for 50 cm long crystals)

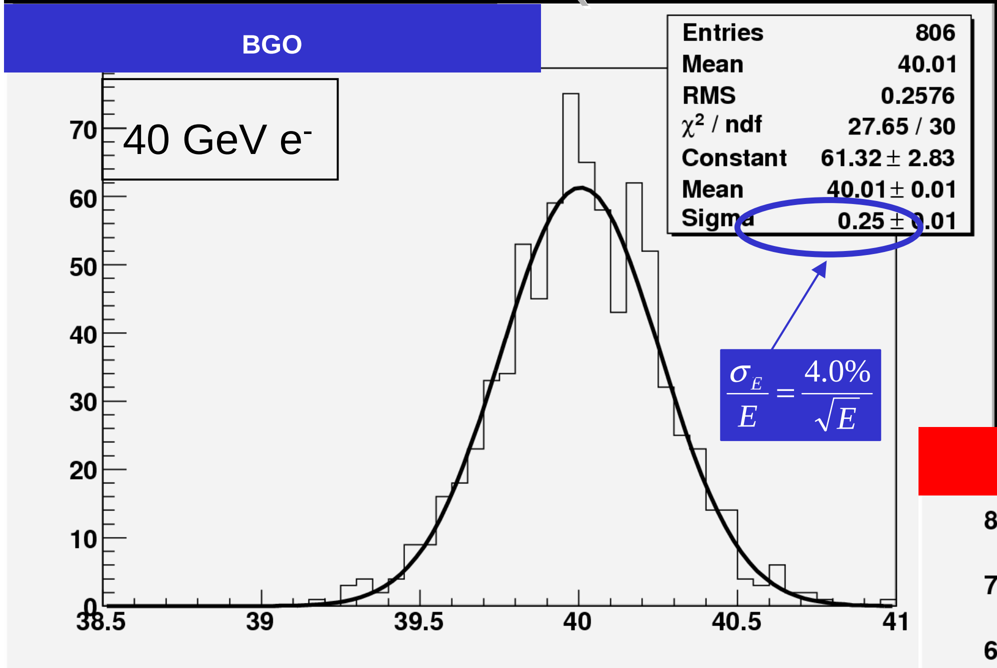


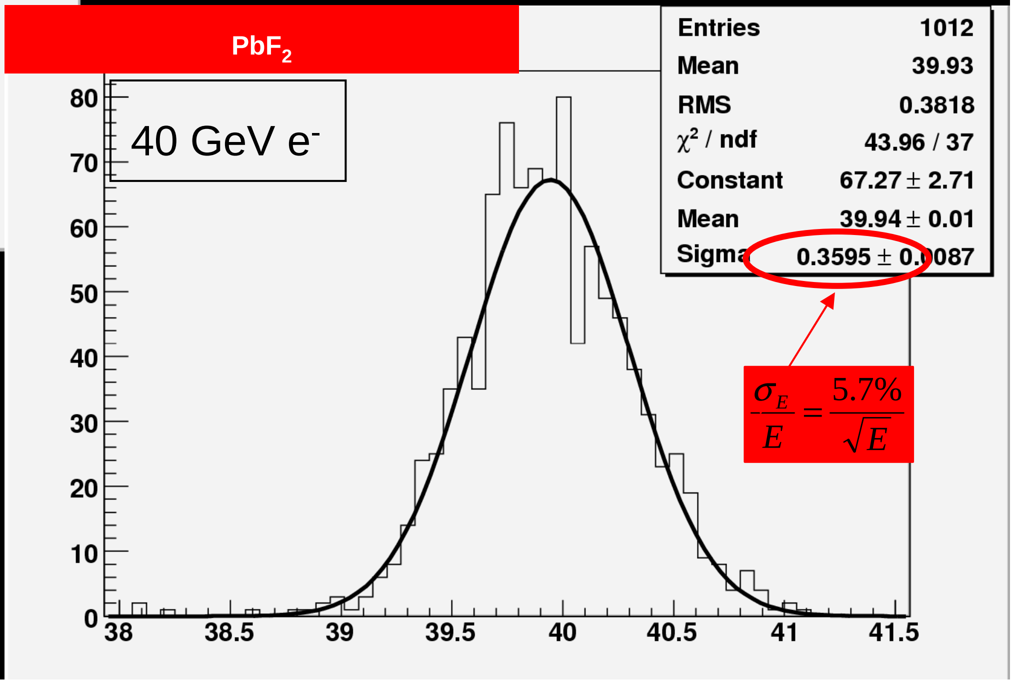


Combining E_S and E_C

(for 50 cm long crystals)

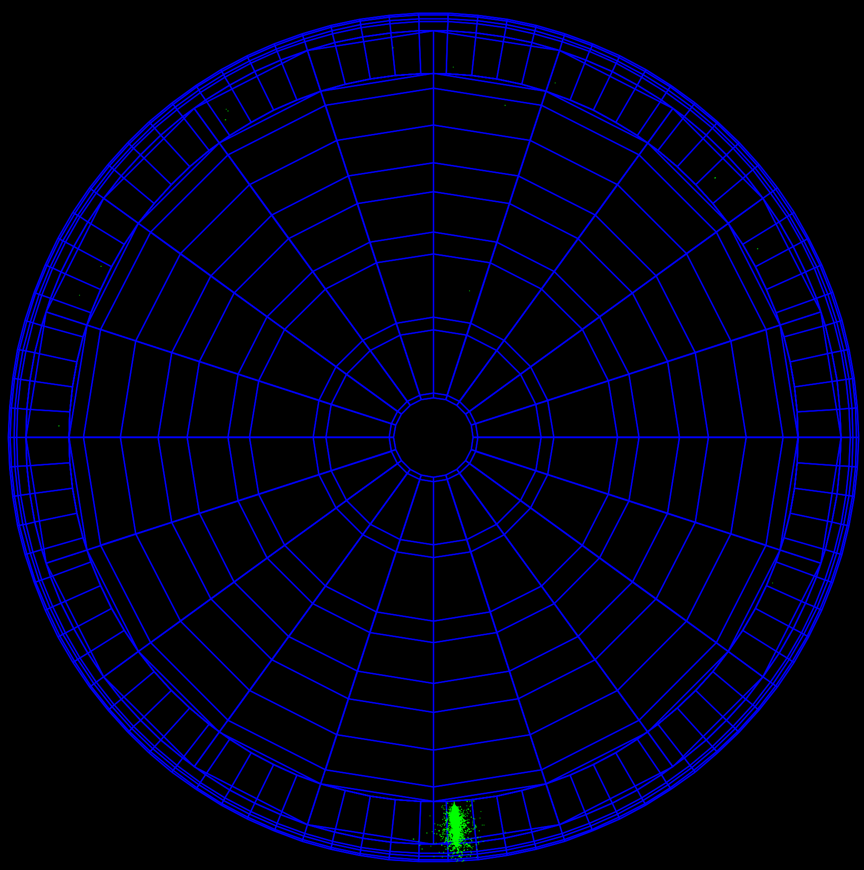
$$E_{ECAL} = \frac{\eta_S \cdot E_S \cdot (\eta_C - 1) - \eta_C \cdot E_C \cdot (\eta_S - 1)}{\eta_C - \eta_S}$$

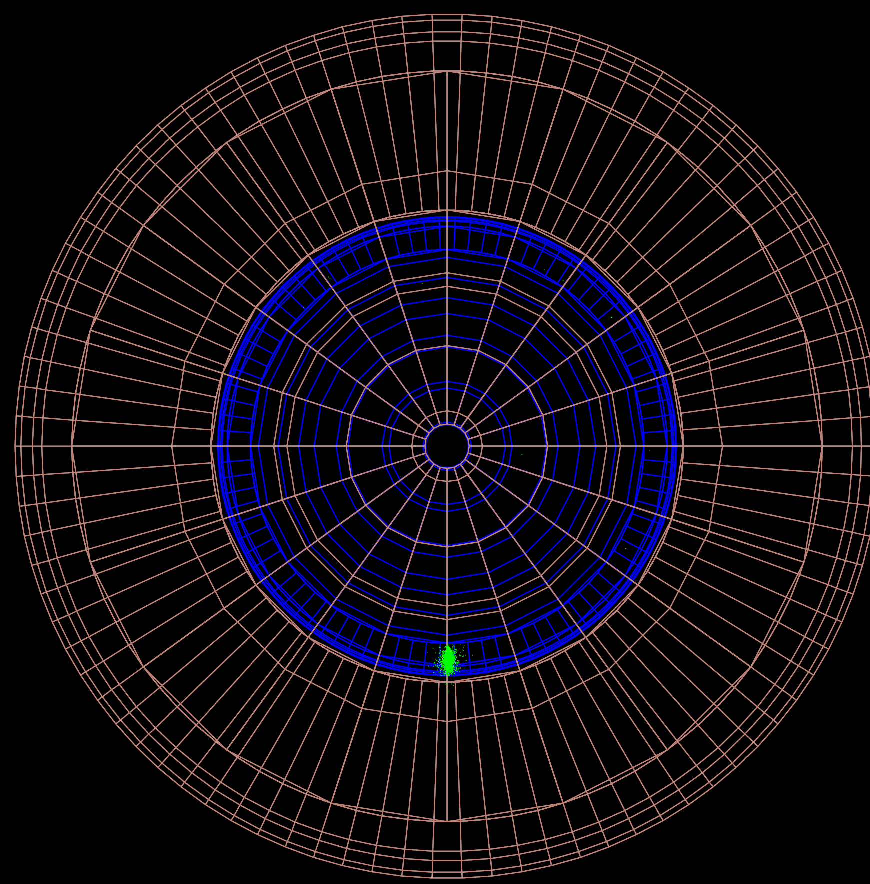




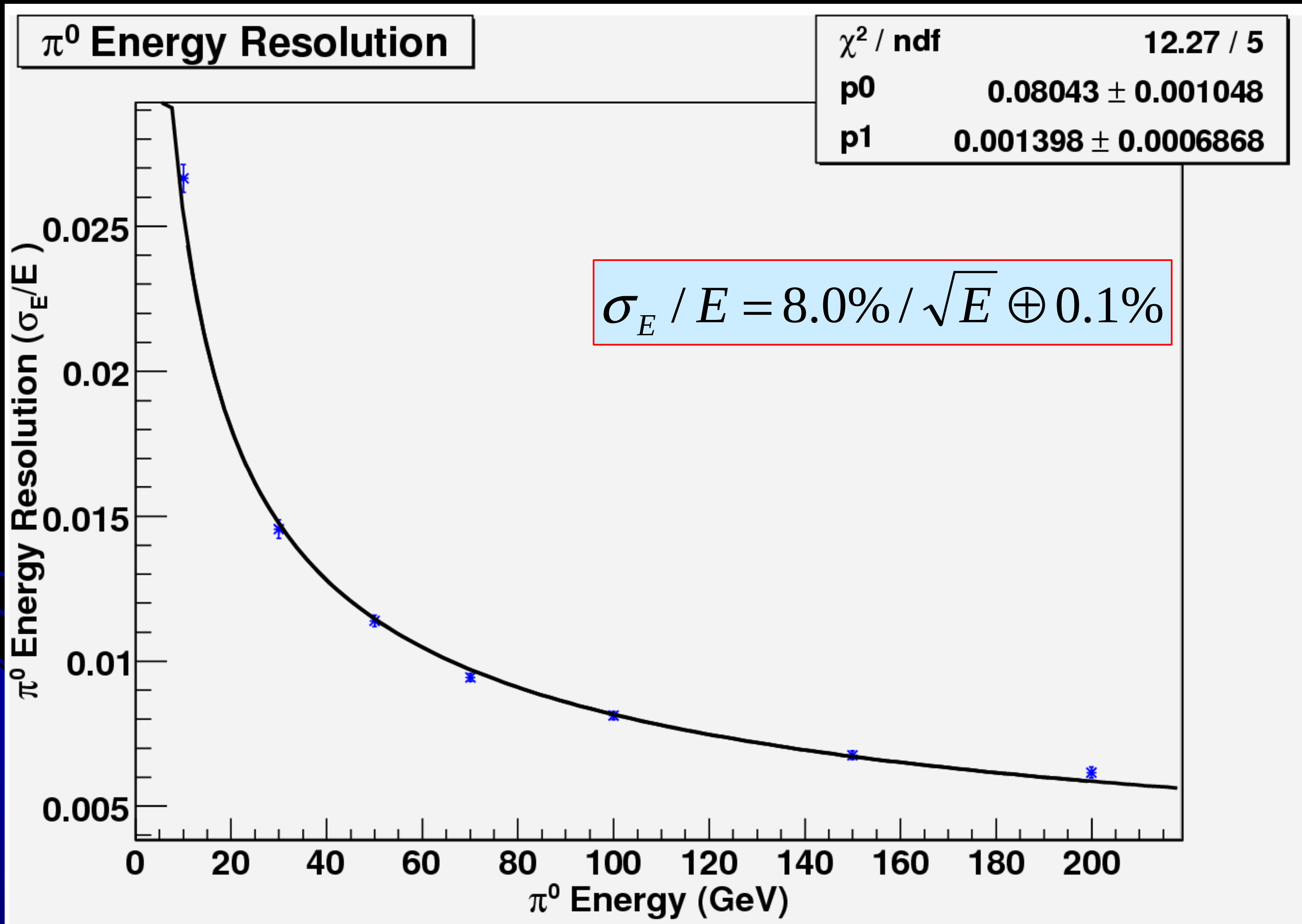
Recostruction in the Hadronic and Electromagnetic Calorimeters Combined

70 GeV π^o in ECAL+HCAL





Resolution for π^o in ECAL+HCAL



Performance Summary

Hadron Calorimeter (fibers)		
	σ_E/E	rms_{90}/E
Single hadron	$34.9\%/\sqrt{E} \oplus 1.5\%$	$30.7\%/\sqrt{E} \oplus 1.7\%$
Total visible di-jet	$36.9\%/\sqrt{E} \oplus 1.1\%$	$31.2\ \%/\sqrt{E} \oplus 1.1\%$
Single jet	$42.2\%/\sqrt{E} \oplus 1.2\%$	$38.5\%/\sqrt{E} \oplus 0.8\%$

Electromagnetic Calorimeter	
	σ_E/E
Single electron	4.0%-$5.7\%/\sqrt{E}$

Hadron + Electromagnetic Calorimeter	
	σ_E/E
Single π°	$8.0\%/\sqrt{E} \oplus 0.1\%$

What's Next

Entering Optimization Phase
New HCAL Layout*

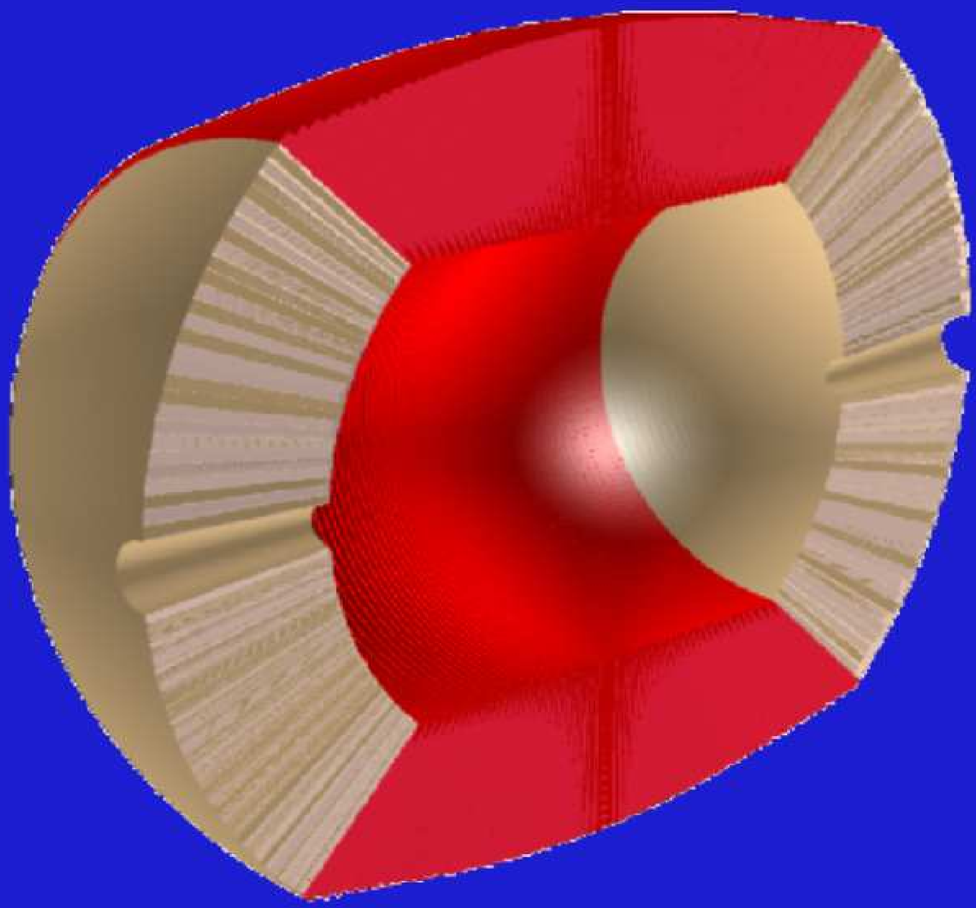
- Cu + scintillating fibers + Ĉerenkov fibers
- ~1.4° aperture angle
- Azimuth coverage

  down to 3.8°
- Barrel: 16384 cells
- Endcaps: 6084 cells

Changes from previos version

red color

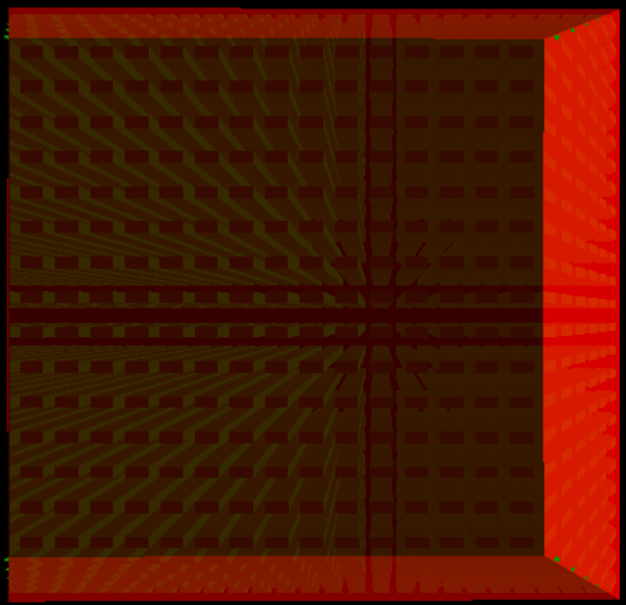
*Under development



Fully projective geometry

New Hadronic Calorimeter Cells

Bottom view of single cell

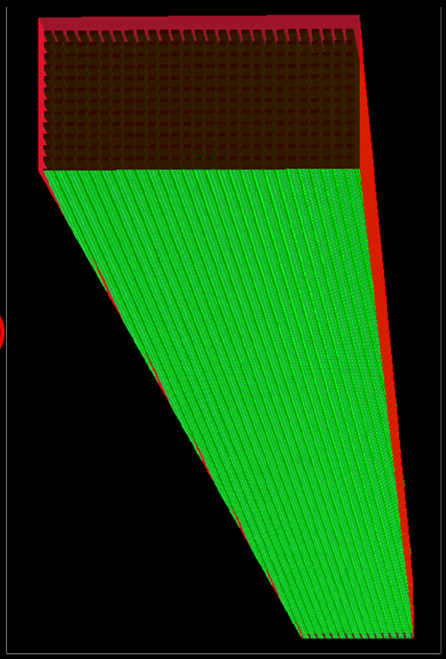


Prospective

view of

clipped cell

Top cell size:~ 8.1 × 8.1 cm^2



Square 1×1 mm^2

Plastic fibers (by St. Gobain)

Aperture Number=0.73

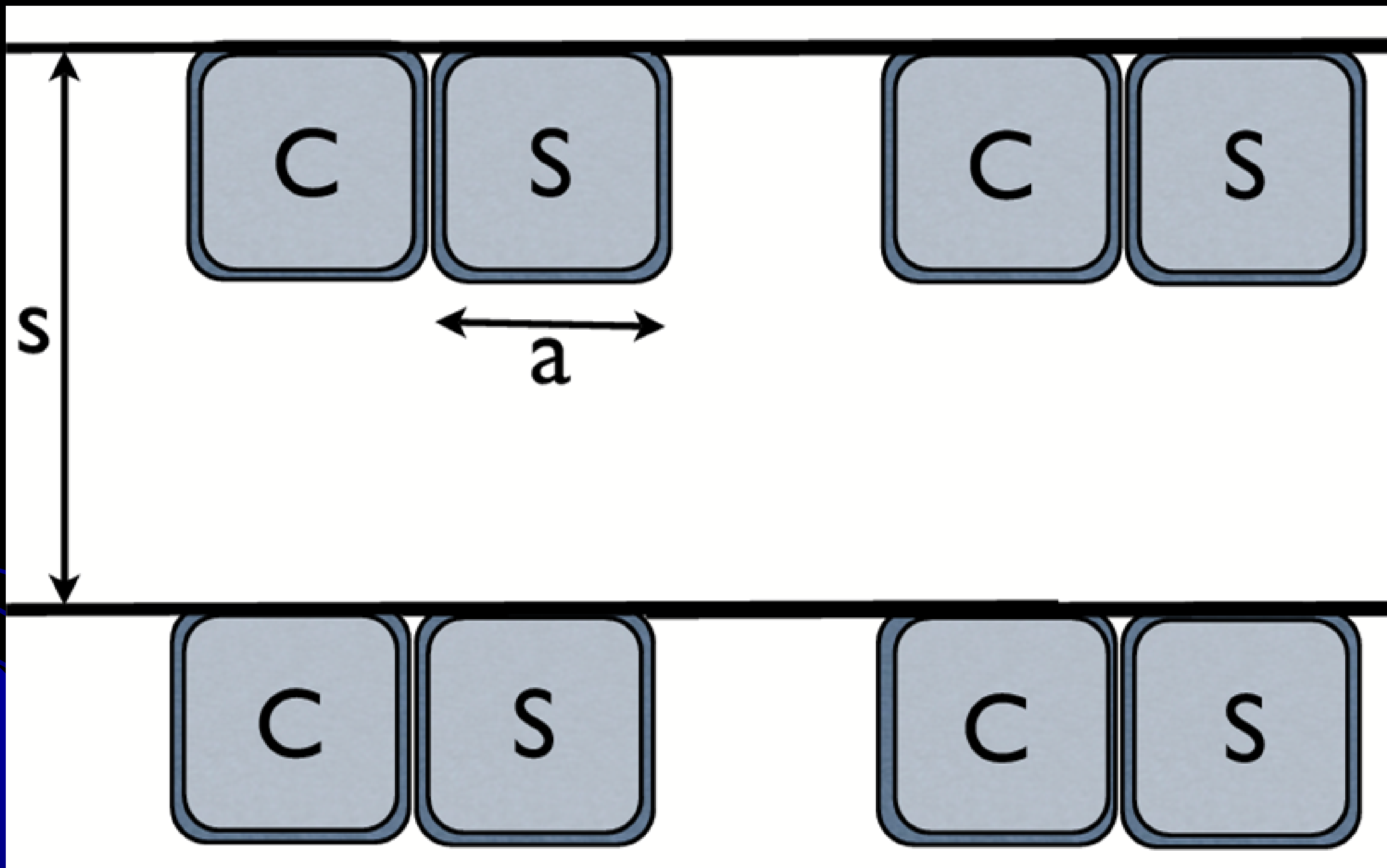
Cell length: 150 cm

Bottom cell size: ~ 4.4 × 4.4 cm^2

Number of fibers inside each cell:~1480

equally subdivided between Scintillating and Cerenkov

Fiber stepping ~3 mm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Summary

- Studies of a Calorimeter with Dual Readout are proceeding at full speed
- Montecarlo simulation **agrees very well with data** from DREAM test beam
- No equivalent comparison with experiment is still possible for the EM calorimeter
- Performance of Hadron Calorimeter indicates **it is well suited for single particle and jet reconstruction at ILC**:
- There is room to improve these resolutions

Backup slides

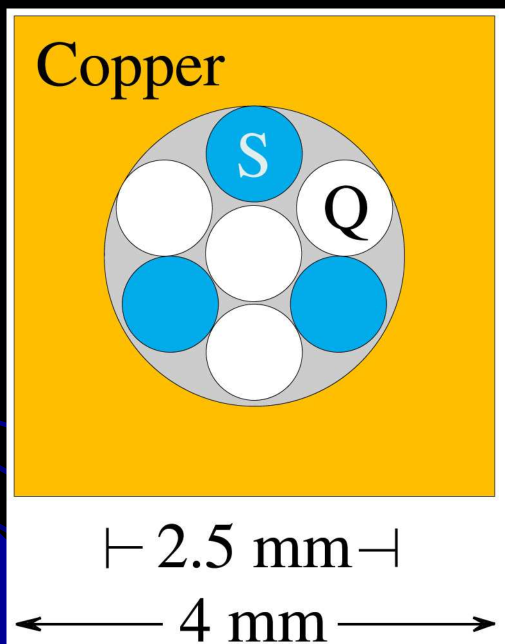
Dual Radout Technologies

- Sampling:
  - Fiber calorimeter (HCAL) + single crystal (ECAL)
- Total absorption:
  - Segmented crystals (HCAL &ECAL)

A6

Dual REAdout Module (DREAM)

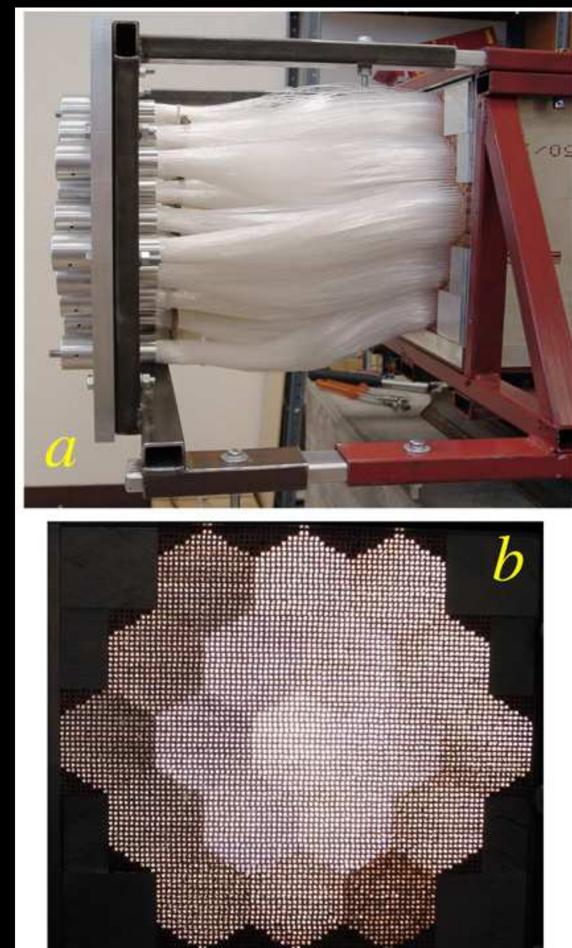
http://www.phys.ttu.edu/dream/



Unit cell

Back end of 2-meter deep module

Physical channel structure



Slide 51

A6 The technology has been proved at a test beam, but never in a real experiment.
Anna, 9/13/2007

Total Absorption Dual Readout Calorimeter

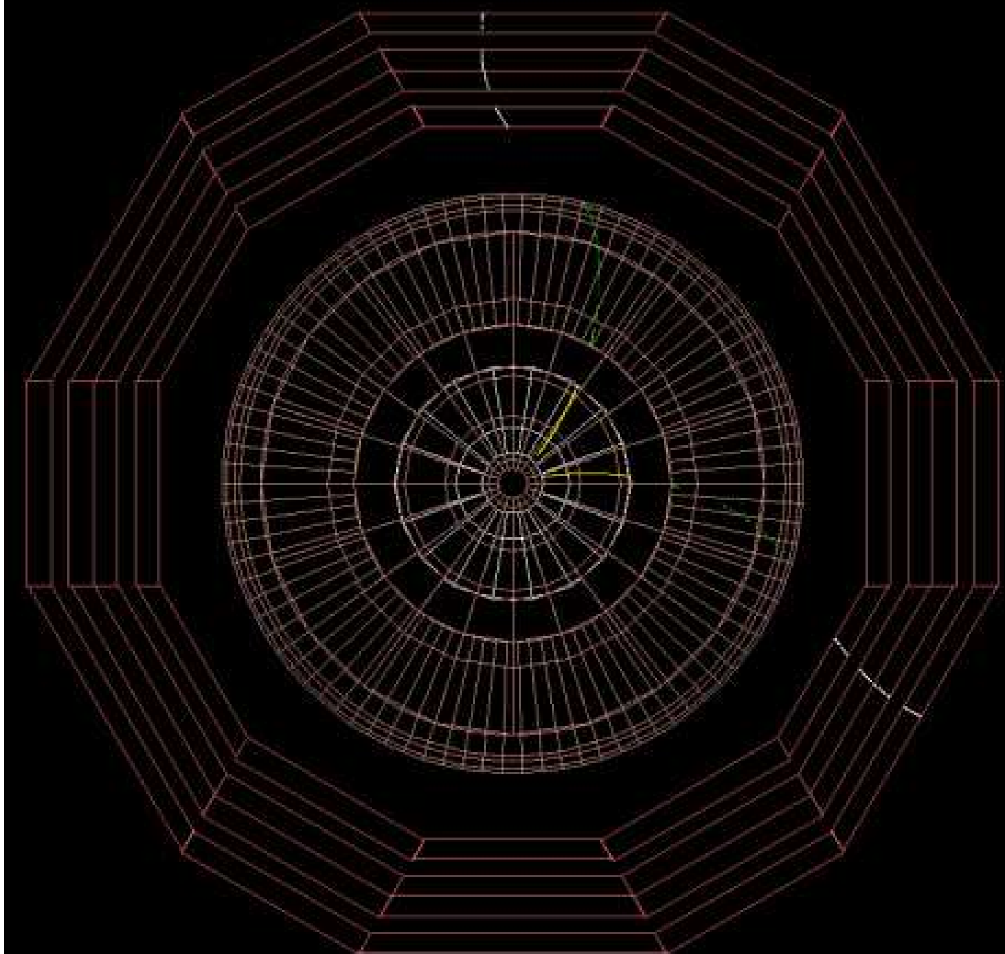
- Uniform, integrated (EM+HAD) calorimeter
- High density (~8g/cm3) ←→ 6-7 λ in a typical ILC calorimeter gap
- Linear response to hadrons and electrons (e/h=1)
- Excellent single particle and jet energy resolution (<25%/sqrt(E))
- Excellent electron/photon energy resolution
- Decoupled energy and spatial measurements of EM showers: three silicon pixel layers
- Total absorption calorimeter: minimal reliance on Monte Carlo modeling
- Longitudinal segmentation

Possible Calorimeter Design

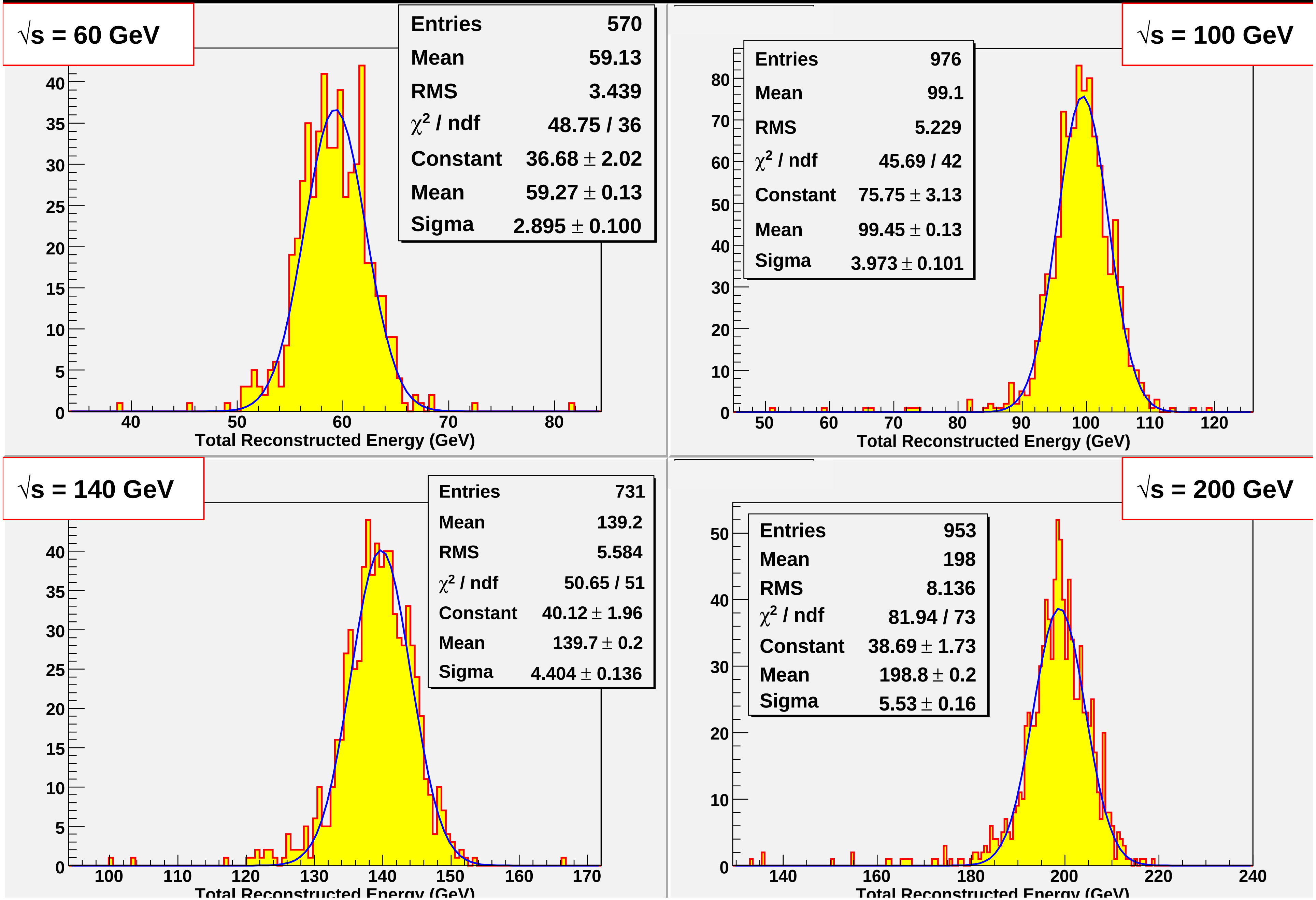
- Heavy crystals ($PbWO_4$, PbF_2 doped with scintillator) or scintillating glass transparent to Cherenkov
- Crystal sizes of the order of 2.5×5×5 cm in the EM 'section' to 10×5×5 cm in the HAD section
- All crystals read-out via silicon photodetectors (hermeticity)
- Crystals glued into full-depth towers

MUD and Calorimetry

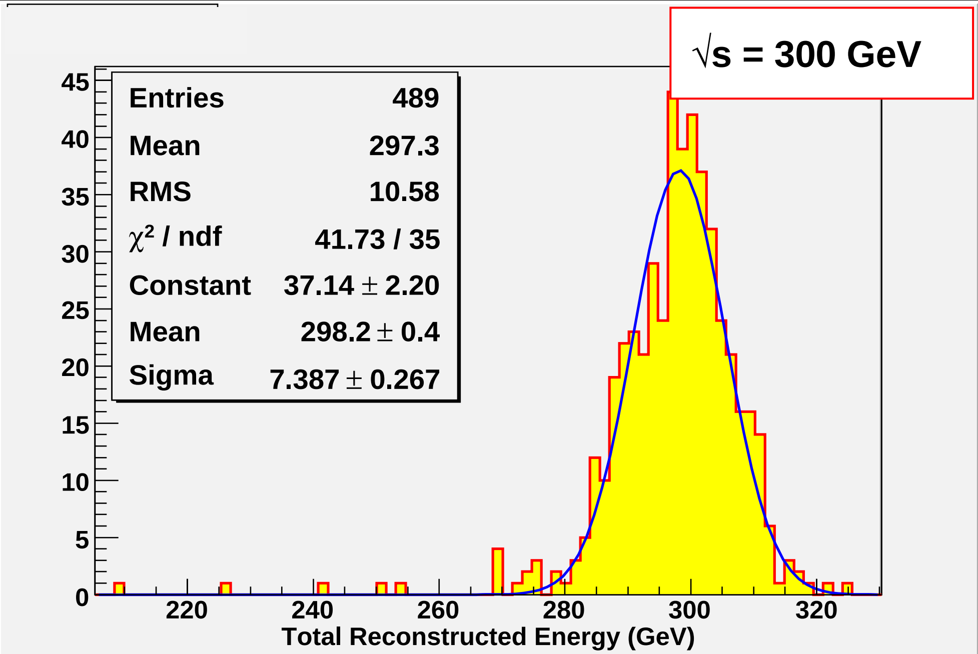
- Essential for jet reconstruction
  - Measure the momentum of hard particles escaping the calorimeter
  - Tail catcher for HCAL
- Provides continuous calibration via muon brehemstralung

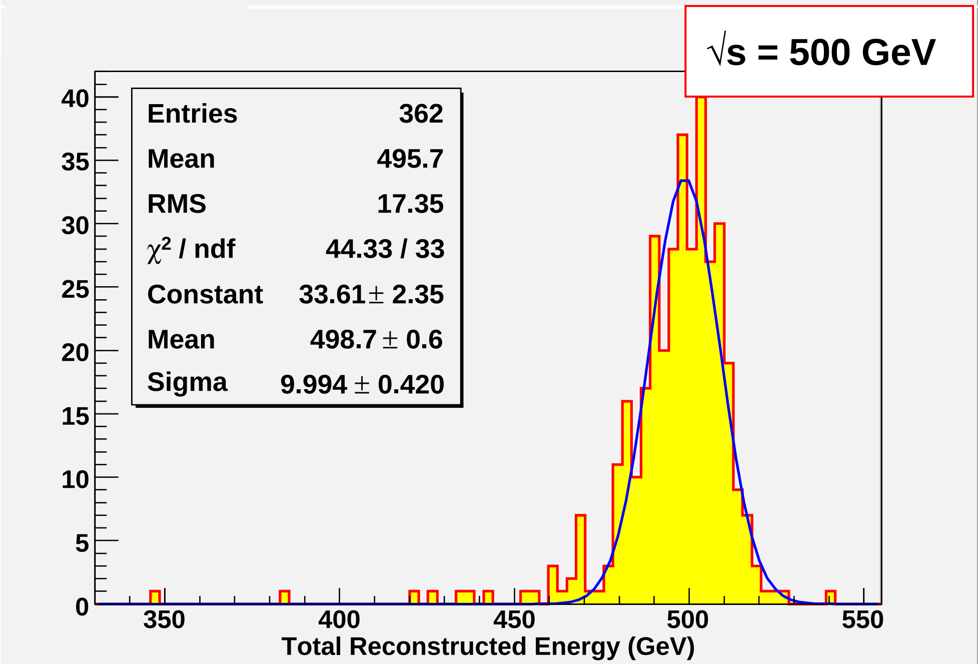


$e^+e^- \rightarrow qq$ (q=uds) @ 60, 100, 140, 200, 300, 500 GeV



$e^+e^- \rightarrow qq$ (q=uds) @ 60, 100, 140, 200, 300, 500 GeV

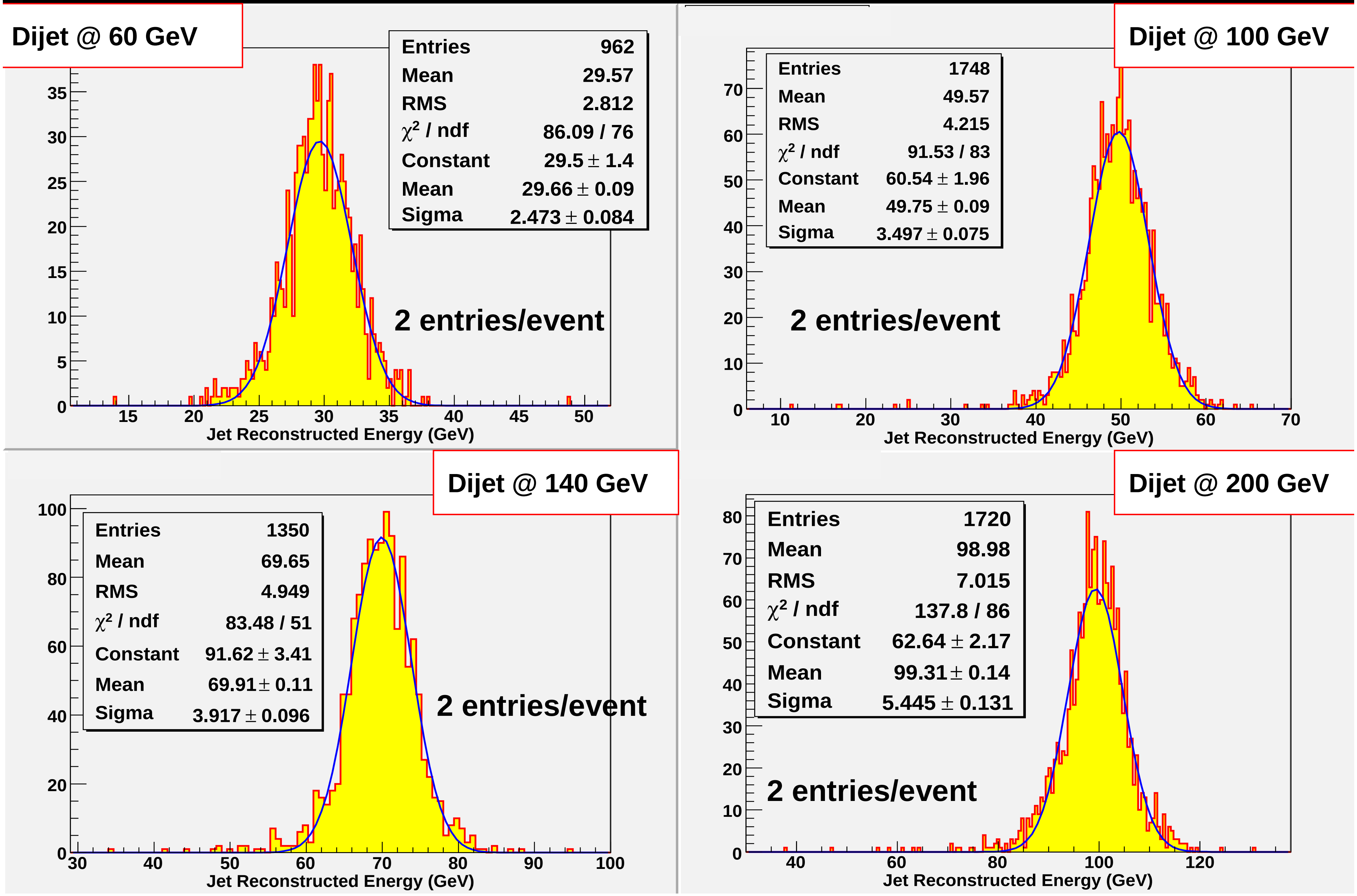




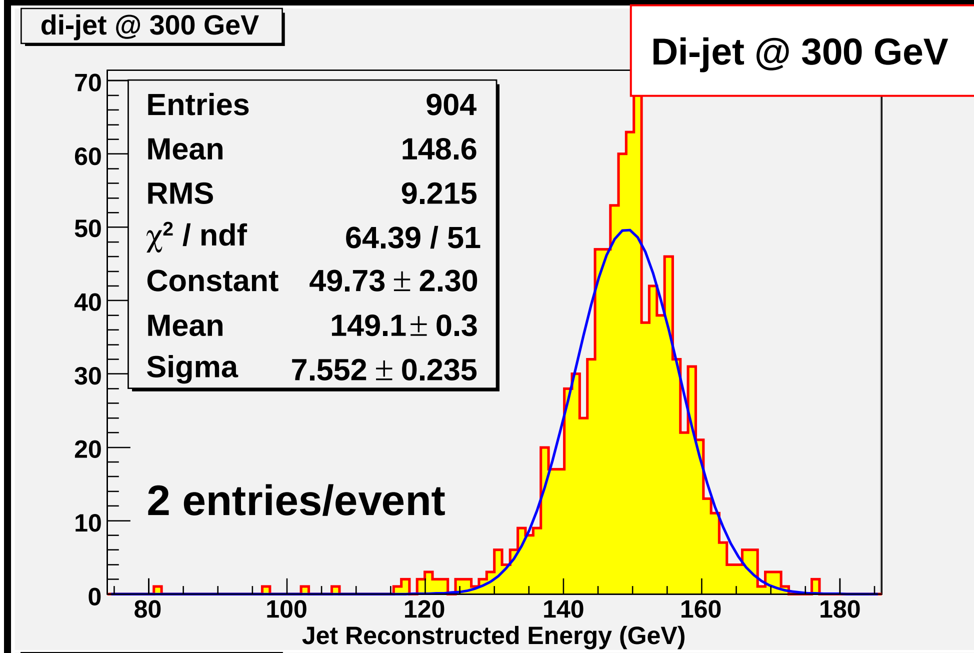
(rms_{90} : rms of central 90% of events)

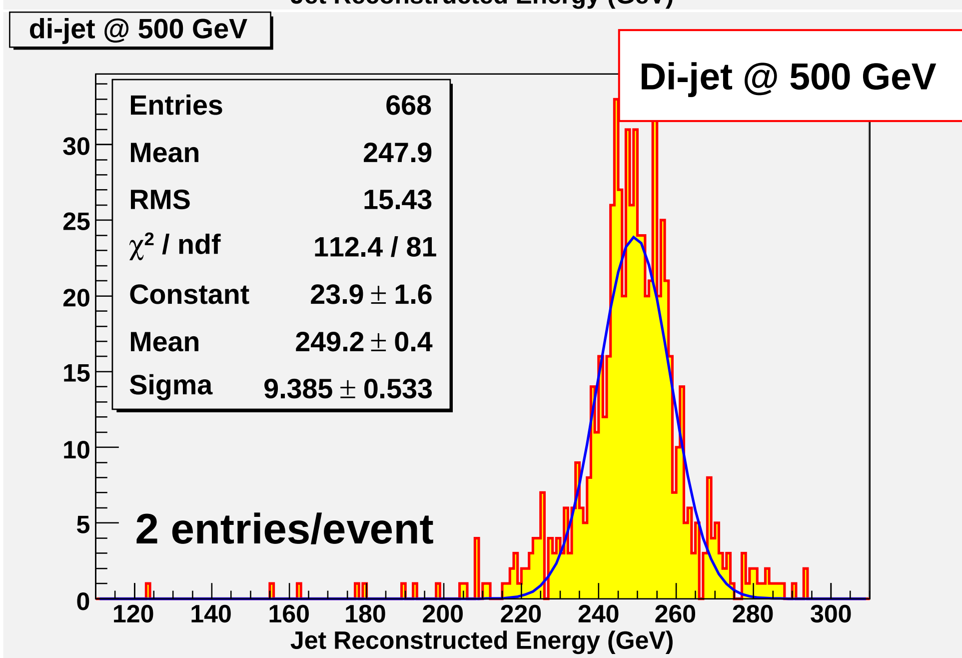
	σ	rms_{90}
E_{CM}(GeV)	$\sigma/E = \alpha/\sqrt{E}$	$\sigma/E = \alpha/\sqrt{E}$
60	37.5	32.1
100	40.1	34.0
140	37.9	32.7
200	39.6	34.9
300	42.1	36.7
500	45.0	40.6

Di-jet events $e^+e^- \rightarrow qq$ (q=uds) @ 60, 100, 140, 200, 300, 500 GeV



Di-jet events $e^+e^- \rightarrow qq$ (q=uds) @ 60, 100, 140, 200, 300, 500 GeV





(rms90 : rms of central 90% of events)

	σ	rms_{90}
E_{jet}(GeV)	$\sigma/E = \alpha/\sqrt{E}$	$\sigma/E = \alpha/\sqrt{E}$
30	43.0	39.9
50	45.0	39.8
70	42.3	38.0
100	42.6	37.1
150	49.4	41.3
250	45.2	41.0