G4 Validation using CMS HCAL Test Beam

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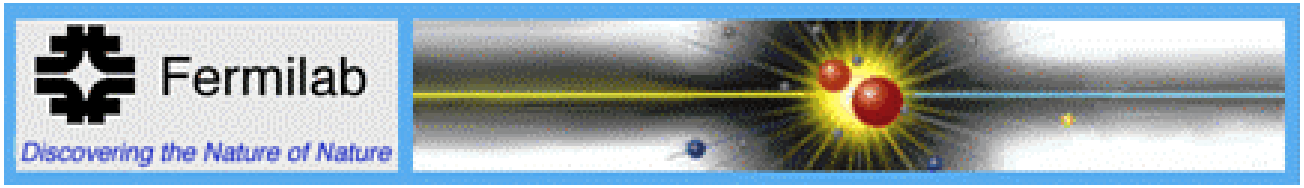
LCG validation meeting

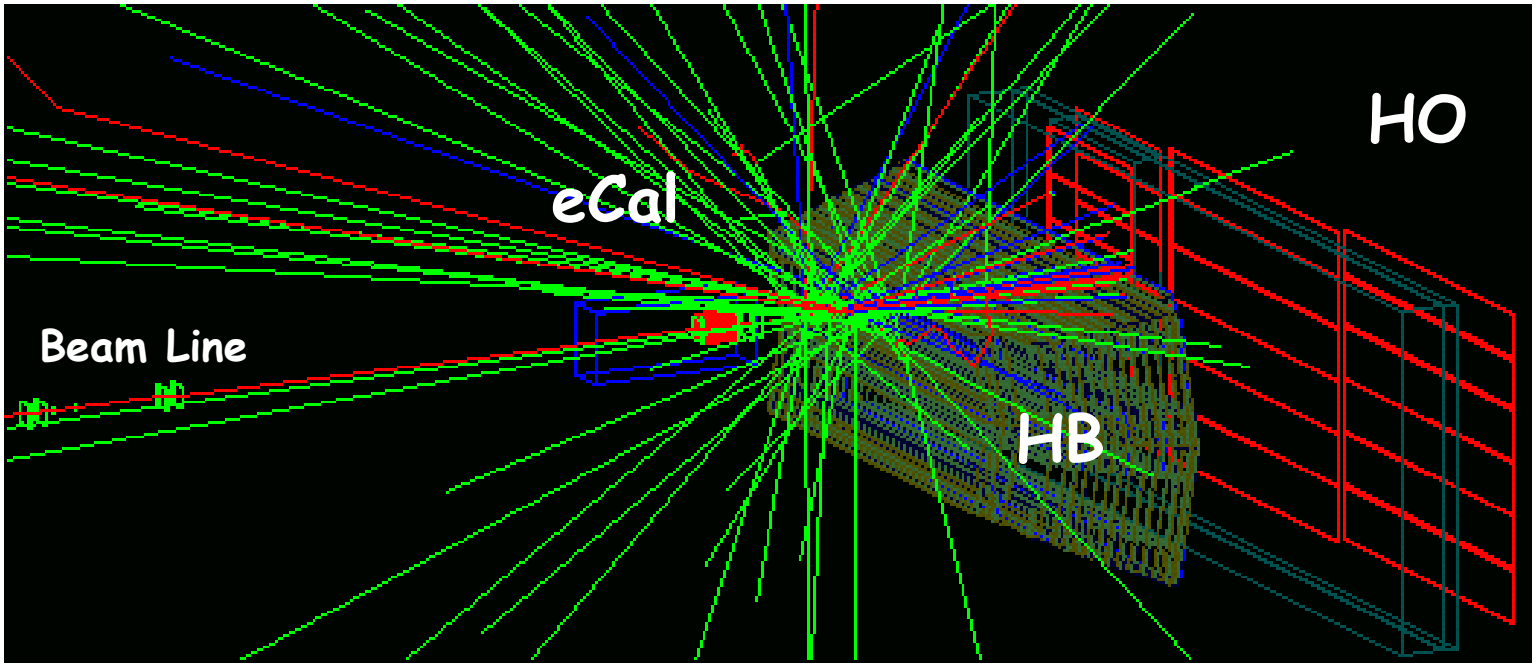


Motivation

- Validation of GEANT4-OSCAR
- Understanding of the successive Hcal test beam experiments (02,03,04)

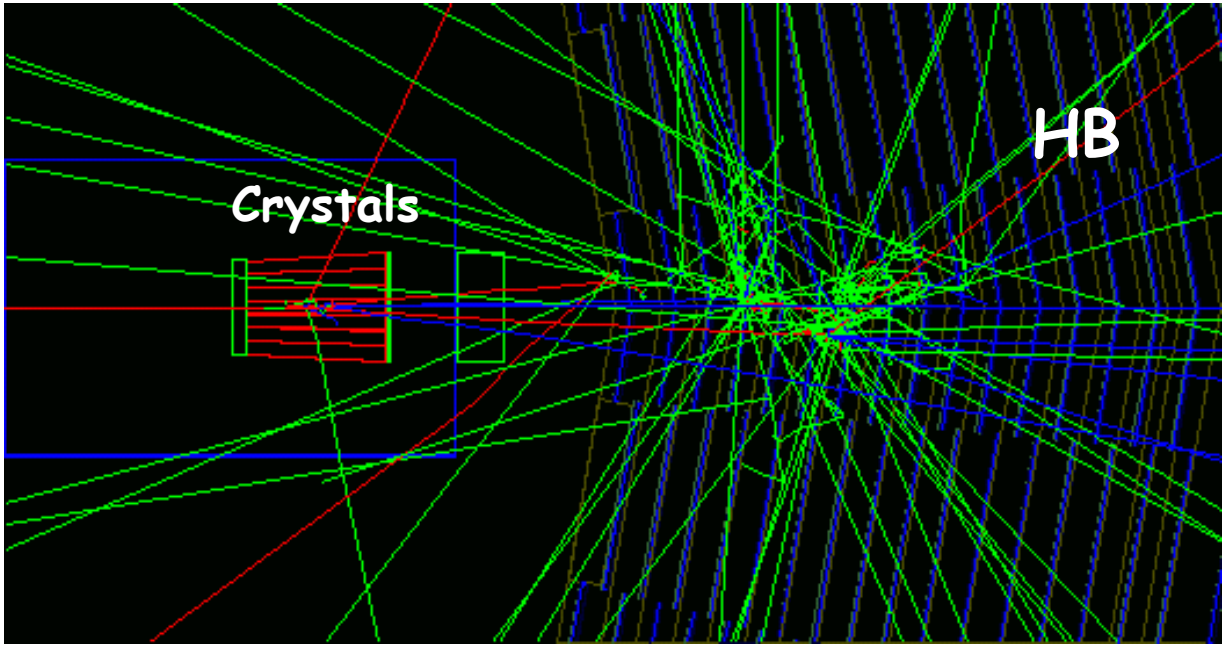
Use OSCAR_2_4_5 (G4.5.2), LHEP-3.6, QGSP-2.7
(HcalTB02 has been released as an OSCAR2 example)

- Beam Line System (trigger tiles & wire chambers)
- ECAL box (Crystal Matrix sub-system)
- HCAL Barrel
- HO
- Allow translation & rotation of both BL & ECAL box
- Root analysis package



Angle view of the full TB02 detector

100 GeV pion

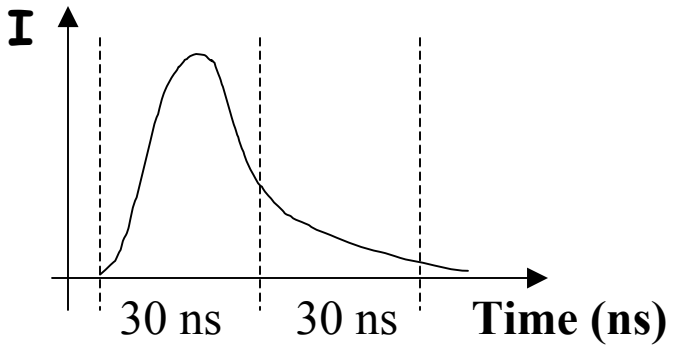


Side view of the eCal & HB sections of the TB02 detector

100 GeV pion

Readout (signal) Simulation

In principle, the pulse is integrated in two time slices:



But due to lack of clock synchronization, the position of the peak is not known with respect to time slices ⟶ the whole pulse, 4 time slices, is integrated in TB02 (time info lost)

• Calibration: Add up the scintillator energy in a ηxφ=5x5 super-tower (like in the TB experiment). Calibration factor is E_{ini}/E_{5x5} taken from 50 GeV π on tower (η,φ)=(9,4) in an HB only configuration.

50 GeV pions deposit 425 MeV in a 5x5 HCAL supertower about the (9,4) central: 0.85%

Calibration factor is: 117.7

•Response: with respect to 50 GeV for 20-300 GeV π (linerarity)

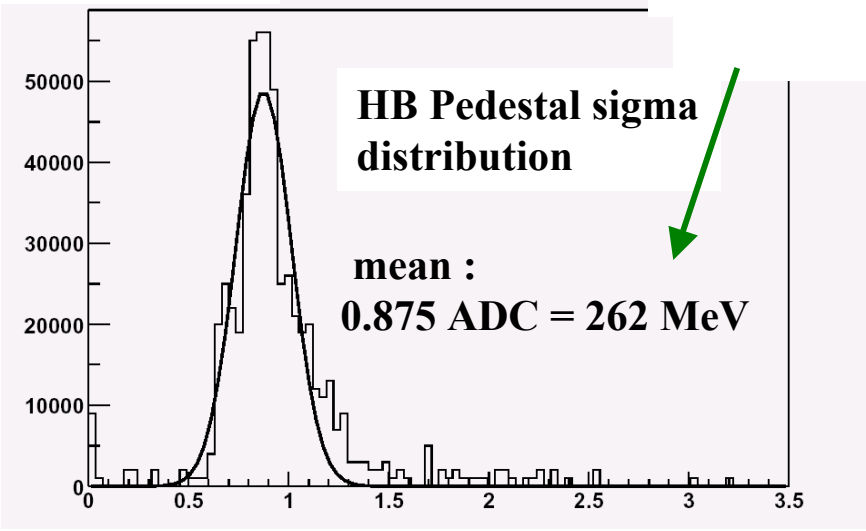
• Resolution: determine energy resolution as the width of the calibrated super-tower energy distribution.

OSCAR2 TB02 Simulation: *Changes since last time (end of 2003) results*

OSCAR-2_4_5 with default cuts in range, LHEP-3.6 /QGSP-2.7 physics lists, XTALS+HB+HO

- Shoot on the *right tower (4,9)*
- HB Layer 1 energy modified to *weight* the same as layers 2-16
- HB Layer 1 thickness modified to match TB configuration (Max: 7.45 cm Min: 3.8 cm)

Noise in HB



- Noise constribution modified:

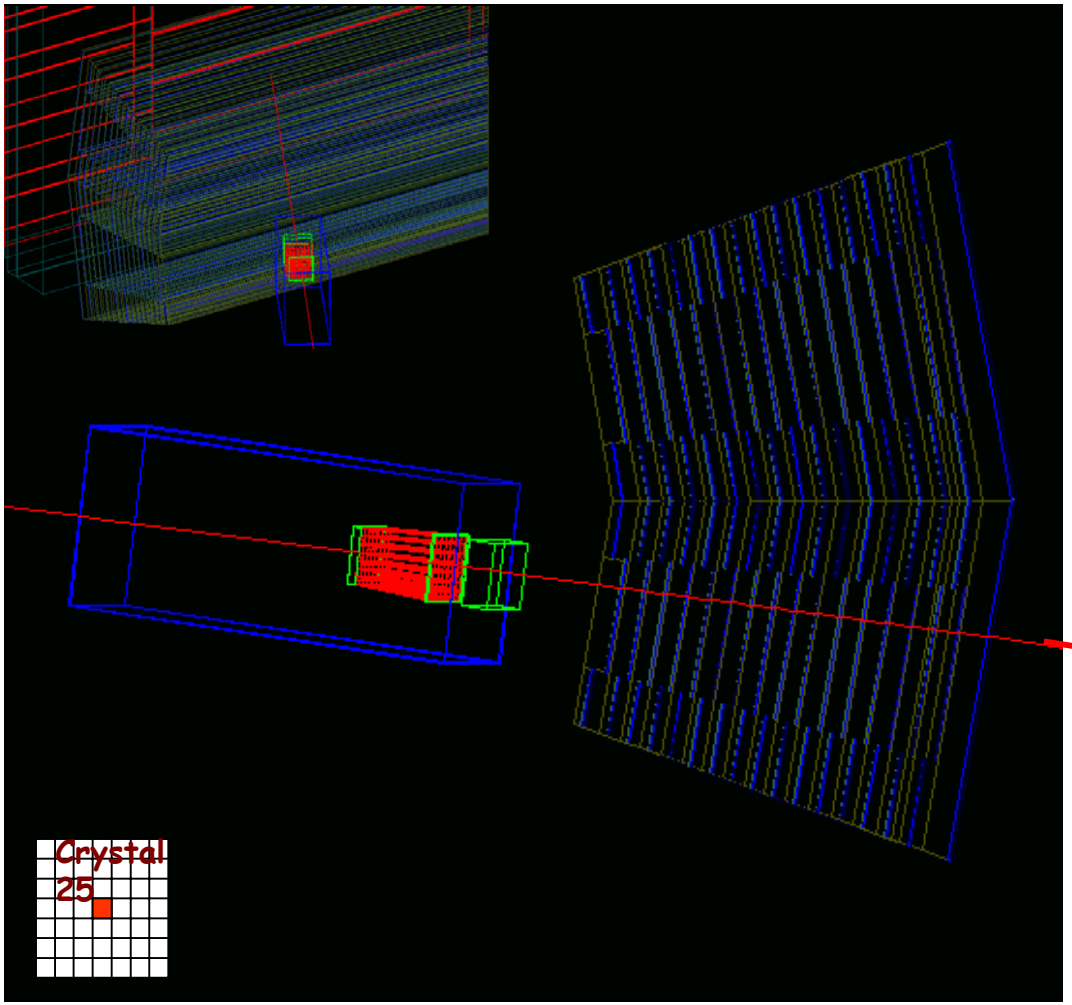
$E^{ECal}_{tower} \rightarrow E^{ECal}_{tower} + 115\ MeV * Rand$ ← Elect. Noise, pulse matching to measured electron resolution

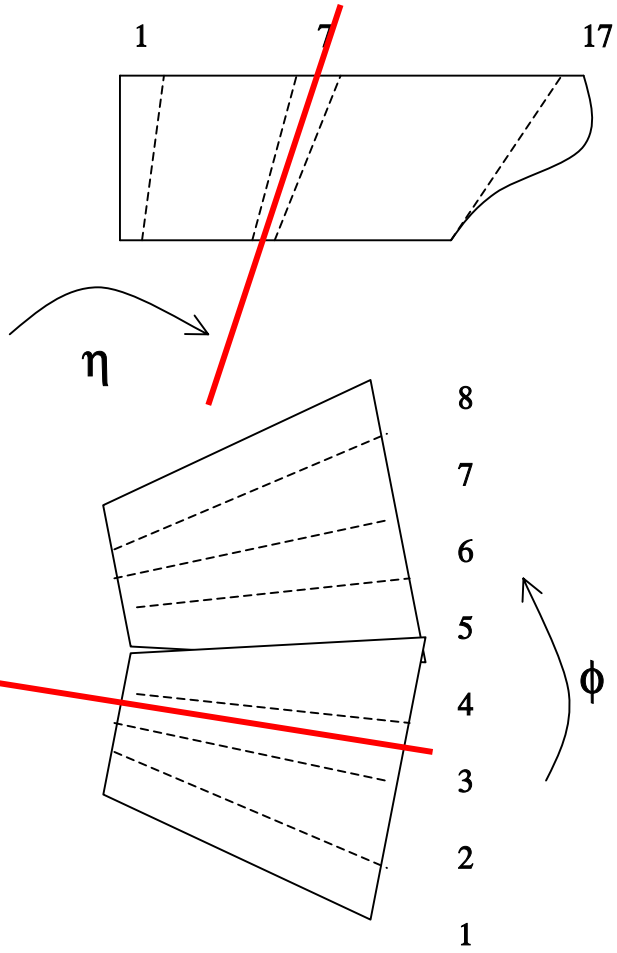
$E^{HB}_{scint} \rightarrow E^{HB}_{scint} + 0.1 * E^{HB}_{scint}\ MeV * Rand$ ← Long. Non-uniformity (?)

$E^{HB}_{tower} \rightarrow E^{HB}_{tower} + 524\ MeV * Rand$ ← Elect. Noise (4 time slices, *was 2 before*)

Performance Studies

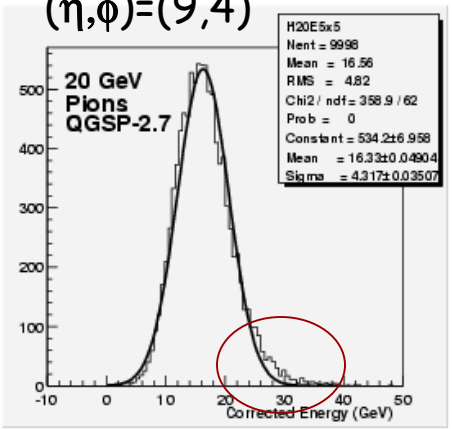
Based in a beam of π^- events onto crystal 25 (central) and the $(\eta,\phi)=(9,4)$ tower of the HB. Pion beams: 20, 30, 50, 100, 300 GeV.

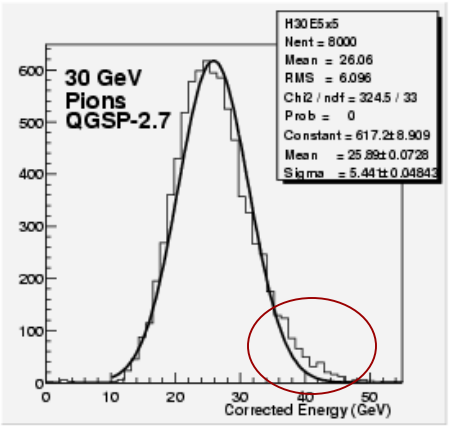


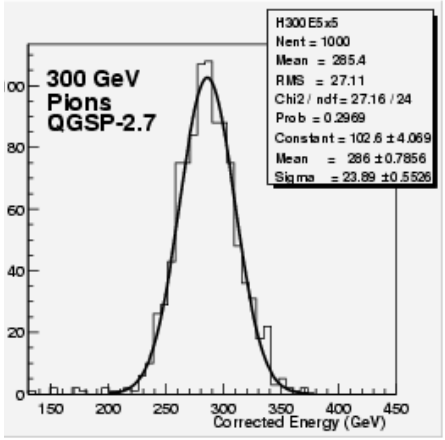


Response Functions

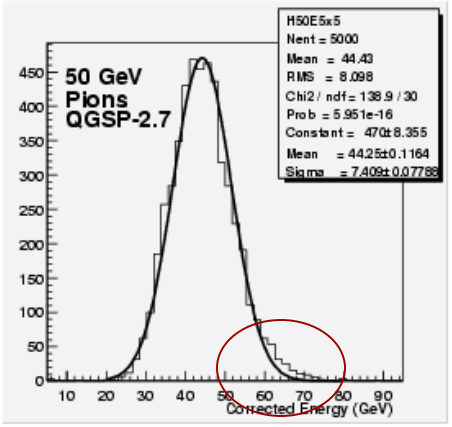
$(\eta,\phi)=(9,4)$

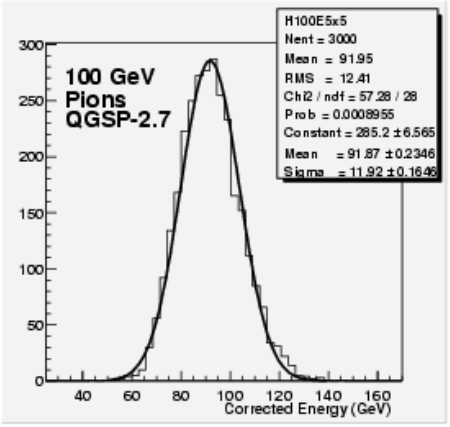






QGSP-2.7





Low energy π: long high energy tail, as expected from a non-compensating calorimeter (non-Gaussian behavior)

e/h (ECAL) = 1.6

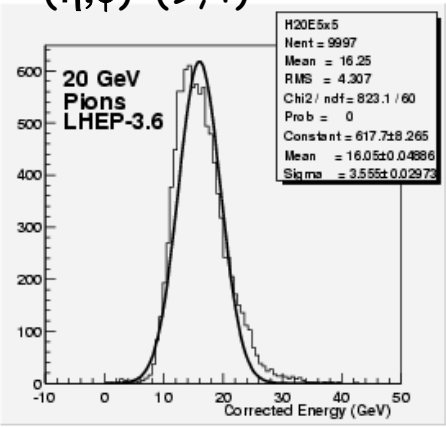
e/h (HCAL) = 1.39

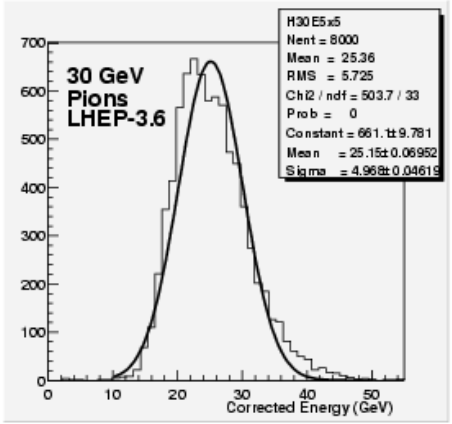
How do I define resolution?

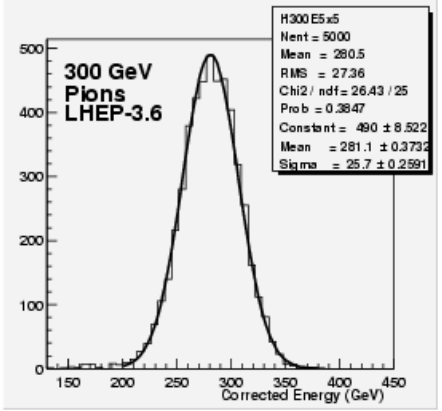
Initially, fit a Gaussian function to the distributions because that's what was done with the data.

Response Functions

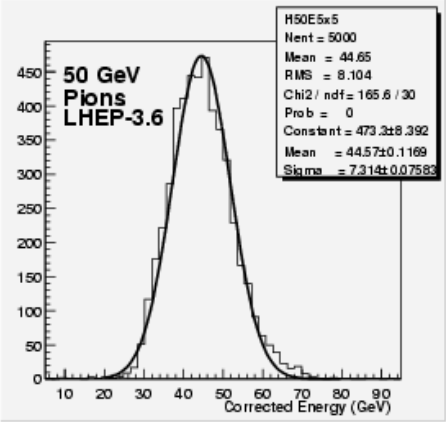
$(\eta,\phi)=(9,4)$

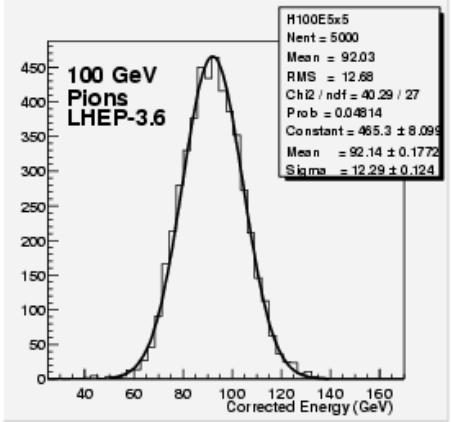






LHEP-3.6





Low energy π: long high energy tail,as expected from a non-compensating calorimeter (non-Gaussian behavior)

e/h (ECAL) = 1.6

e/h (HCAL) = 1.39

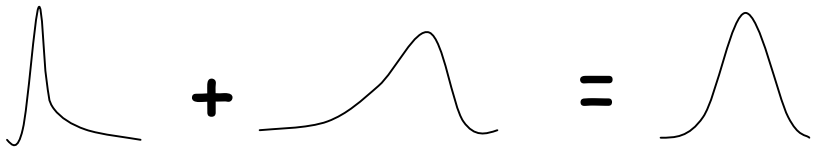
Plan to compare both Gaussian and RMS extracted resolutions in data and simulation – have only σ for now

TB02 Data Analysis: Linearity & σ_E/E

Measure (TB02) energy resolution and linearity for 20, 30, 50, 100, 300 GeV pions. Sources of systematic uncertainties:

- Backgrounds (muons, electrons) - large effect at low energy

  cuts in (E_{HCal},E_{ECal}) space: nominal, high, low.
- HCal calibration from 50 GeV MIP in ECAL - small
  - ECAL/HCAL energy "mix":
  - Background in 50 GeV distribution
  - $\Delta\langle\mu\rangle = \sigma/\sqrt{10{,}000} = \sigma/100$



$E_{HB} + E_{ECal} = E_{Tot}$

$E_{Tot} = f_{HB} * E_{HB} + f_{ECal} * E_{ECal}$

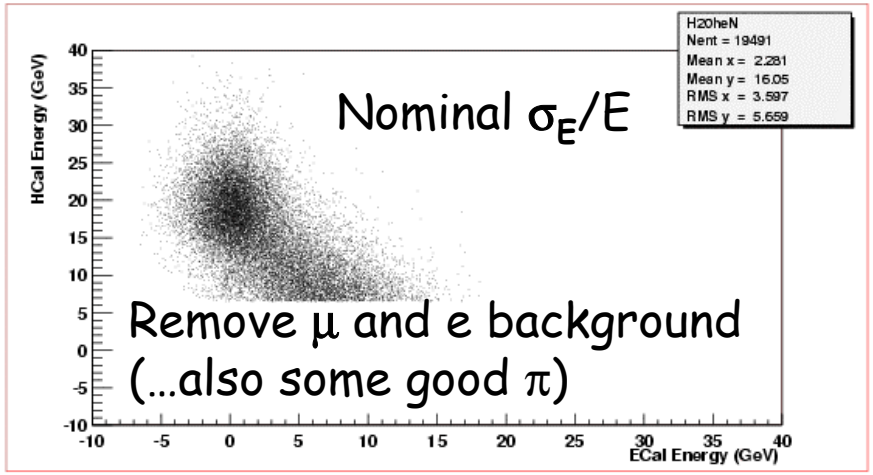
- Choice of HCal calibration point - It's not an uncertainty but part of the calorimeter tuning

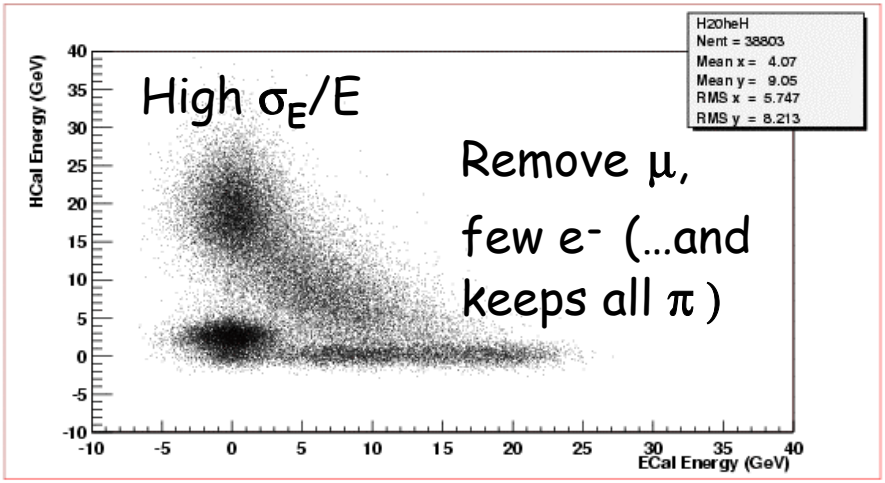
resolution depends on the calibration "point" due to HCal non-linearities

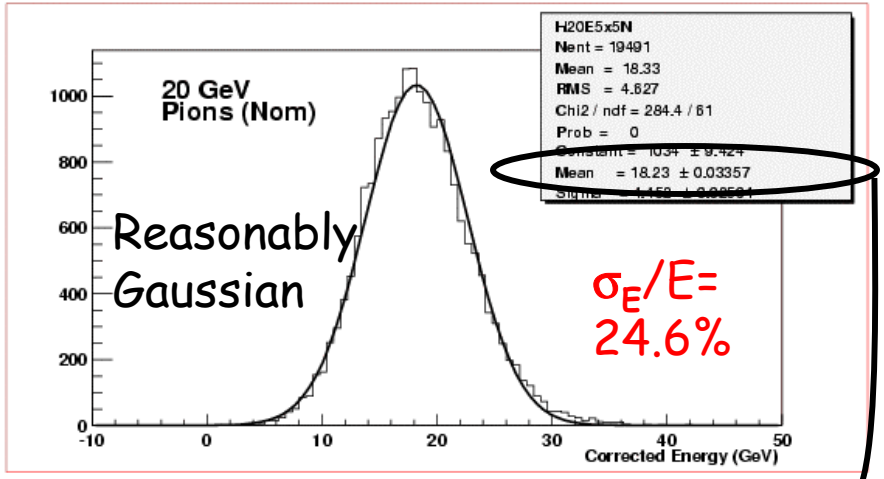
Bkgnd subtraction (20 GeV)

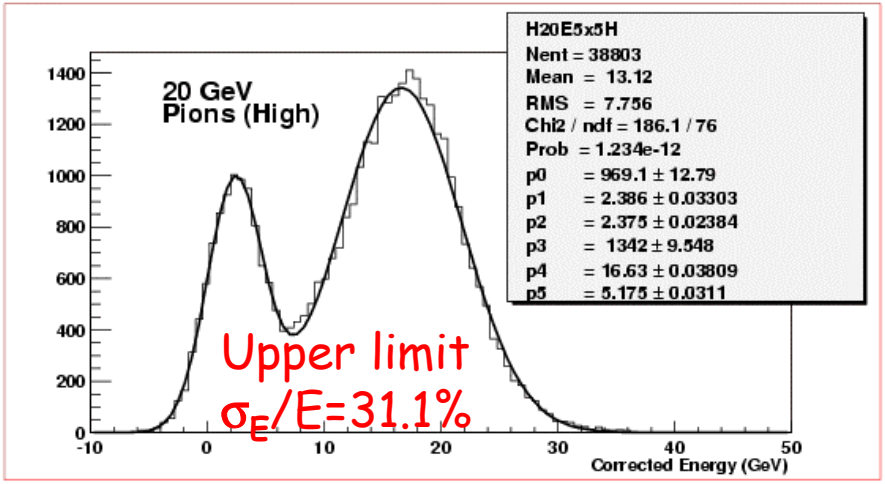
Cut: E_{HB}>6.5 GeV && (E_{HB} > -0.83*E_{em}+ 5.17)

No cuts: double Gaussian gives upper limit)





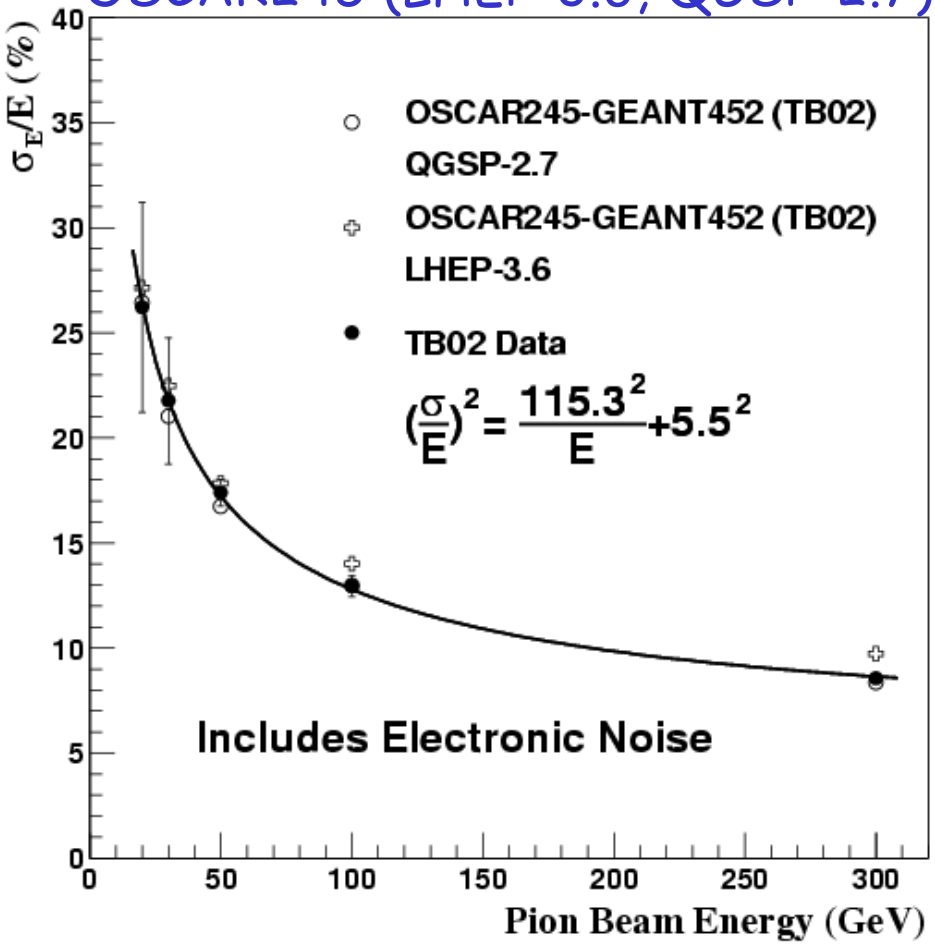




mean ~18.2 GeV

Pion Energy Resolution

OSCAR245 (LHEP-3.6, QGSP-2.7)



Syst.

Data

E	σ_E/E(%)	stat	bkgnd	calib
20.	26.22	0.15	5.00	0.1
30.	21.76	0.12	3.00	0.2
50.	17.40	0.10	0.60	0.2
100.	12.95	0.07	0.40	0.3
300.	8.55	0.05	0.00	0.3

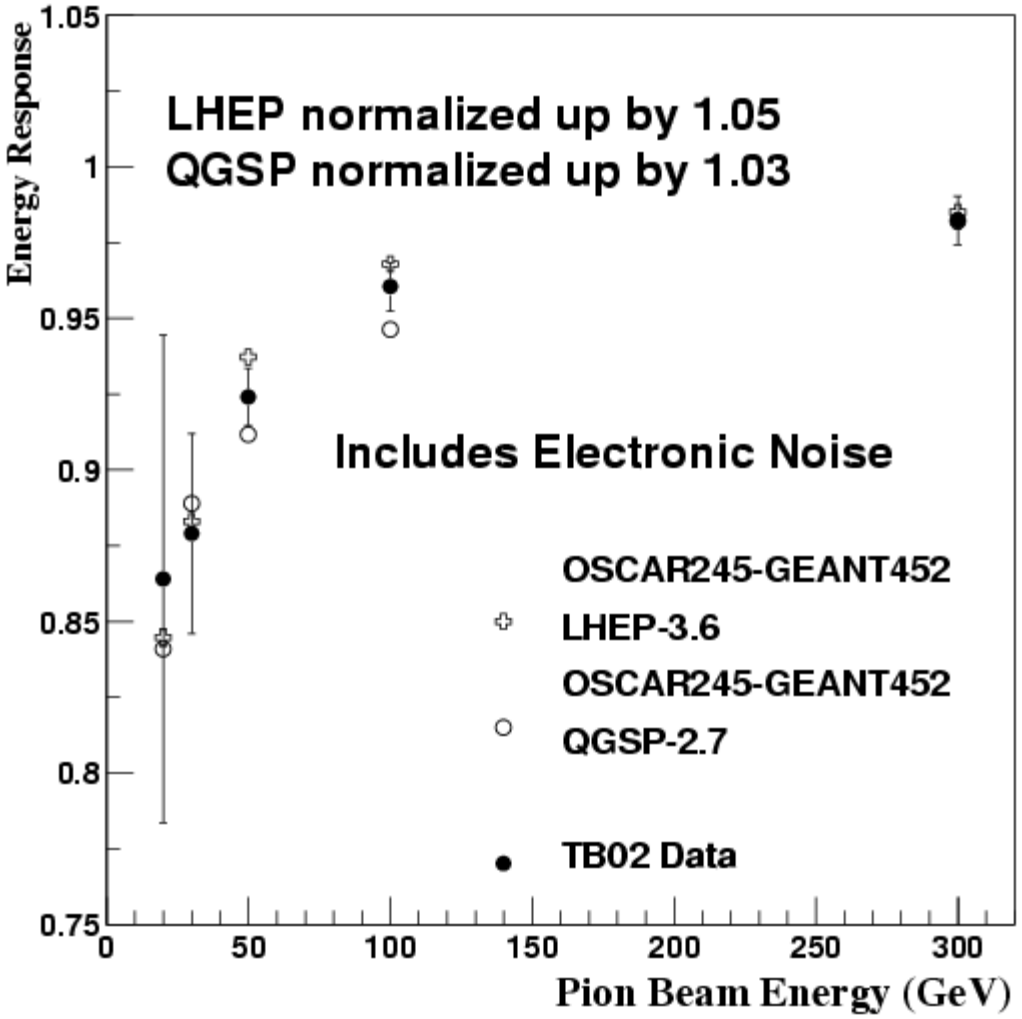
Syst. Errors 100% correlated in Energy, uncorrelated with each other (added in quadrature)

Excellent agreement in resolution

(LHEP a little higher than QGSP)

Pion Energy Linearity

OSCAR245 (LHEP-3.6, QGSP-2.7)



Syst.

Data

E	σ_E/E	stat	bkgnd	calib
20.	0.8640	0.0015	0.0800	0.008
30.	0.8790	0.0010	0.0320	0.008
50.	0.9240	0.0010	0.0050	0.008
100.	0.9604	0.0007	0.0003	0.008
300.	0.9823	0.0004	0.0003	0.008

Syst. Errors 100% correlated in Energy, uncorrelated with each other (added in quadrature)

Excellent agreement in linearity

(LHEP/QGSP grows a little faster/slower than data)

Conclusions

- Simulation now runs under OSCAR245, it is part of the official release, and includes more accurate electronics noise, layer 1 thickness & energy weight, more modern physics lists.

- Data analysis includes systematic uncertainties to allow validation.

Validation studies (resolutions, linearity) using LHEP-3.6 & QGSP-2.7 (TB02-OSCAR245) are completed.

Longitudinal and transverse profiles will soon be generated for comparison with the upcoming HCAL TB 2004 experiment (longitudinal profiles and as low as 2 GeV pions).

Still need to take a look at σ versus RMS resolutions and tune a $\chi 2$ test analysis package (for when we have low energy pions and smaller systematic uncertainties).