GEANT4 validation with HCAL TB2004 data

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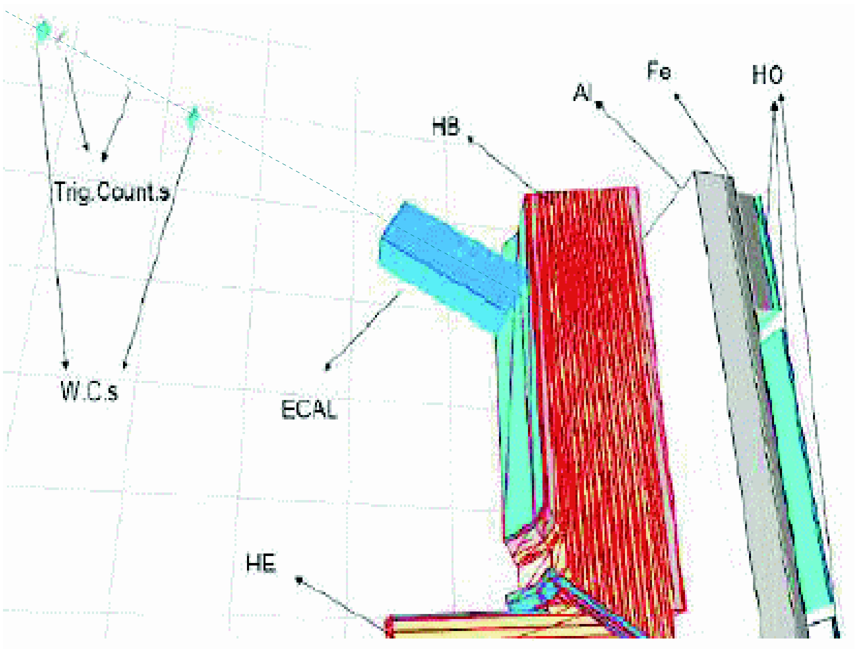
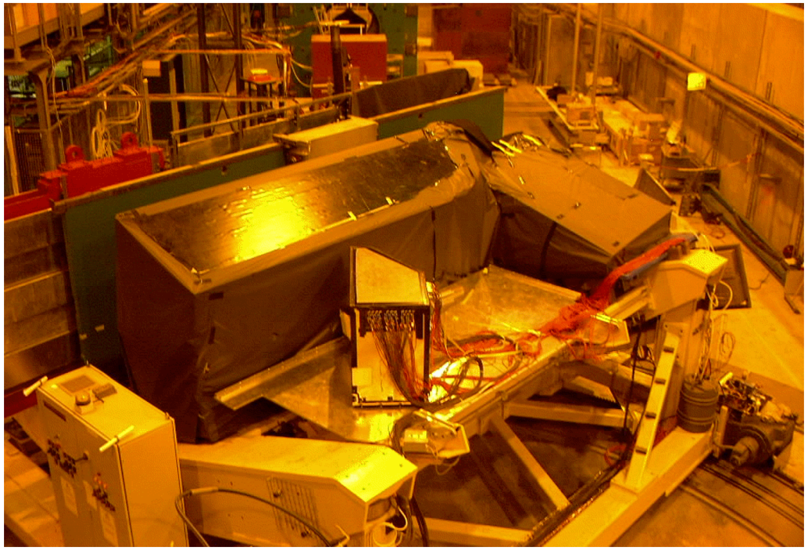
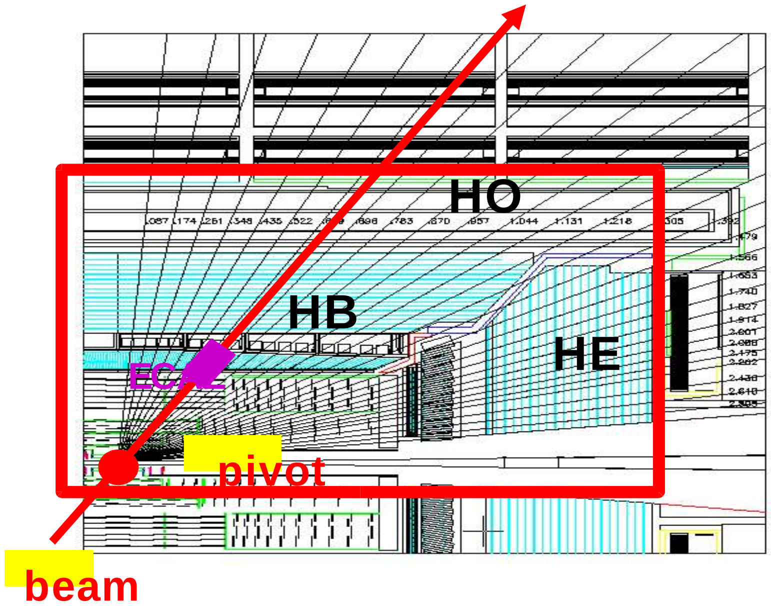
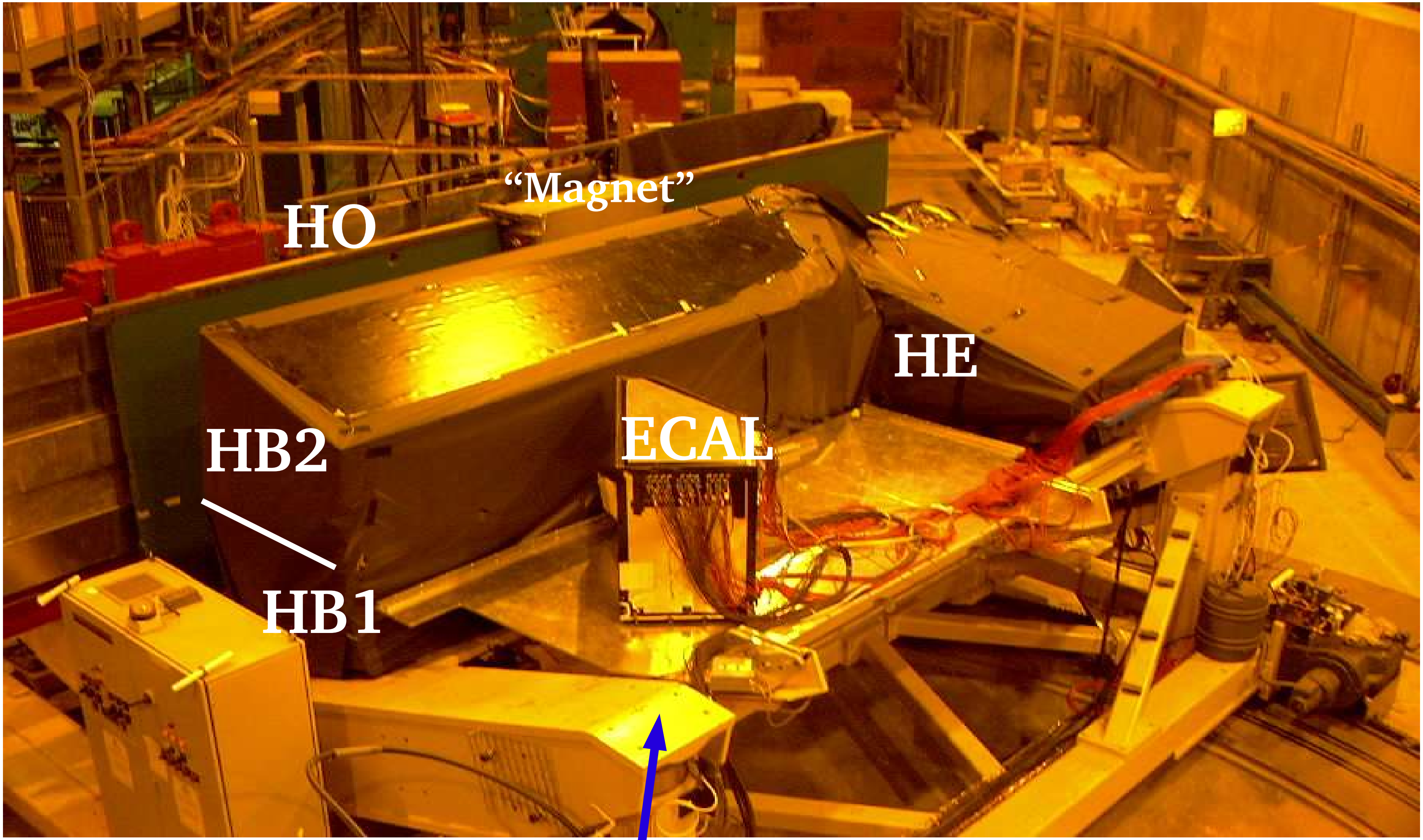




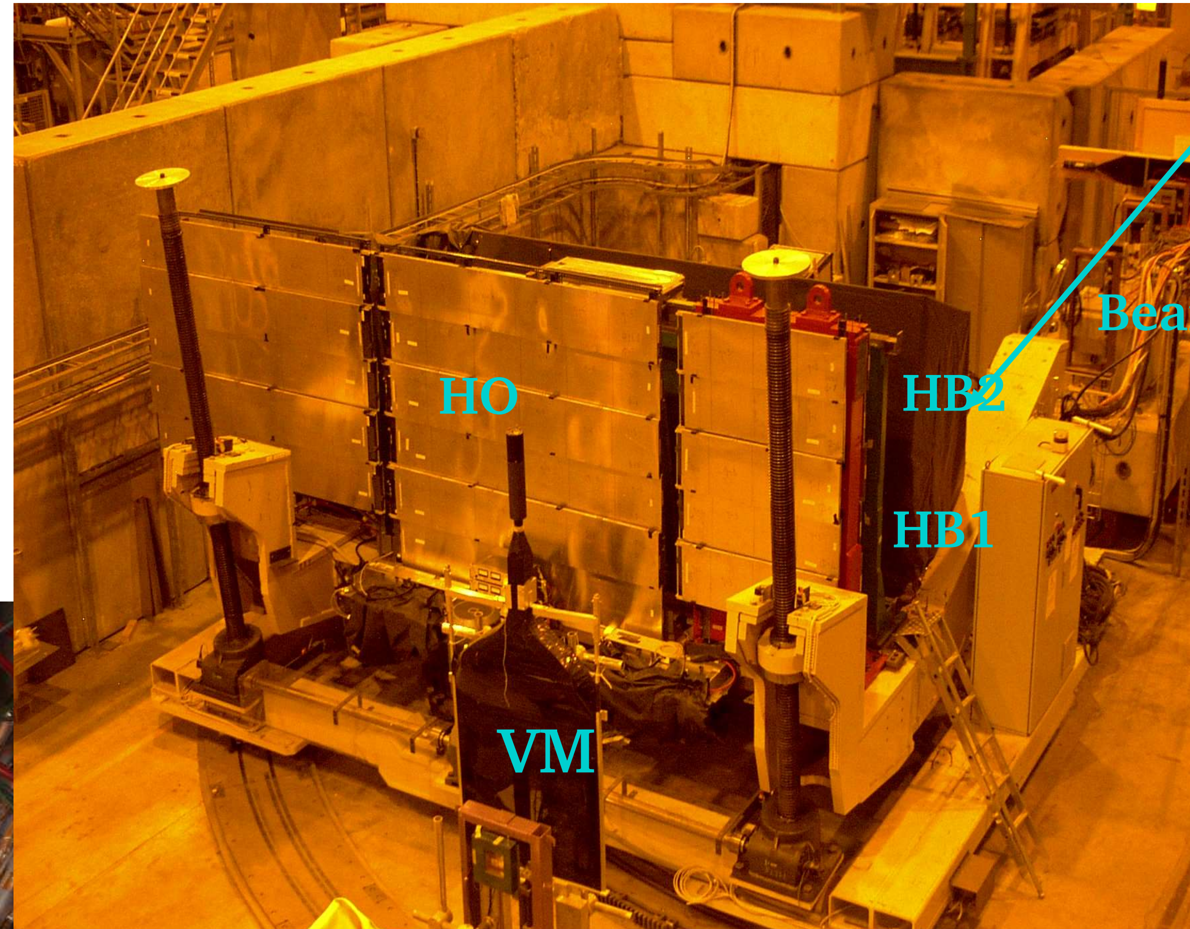
April 2006

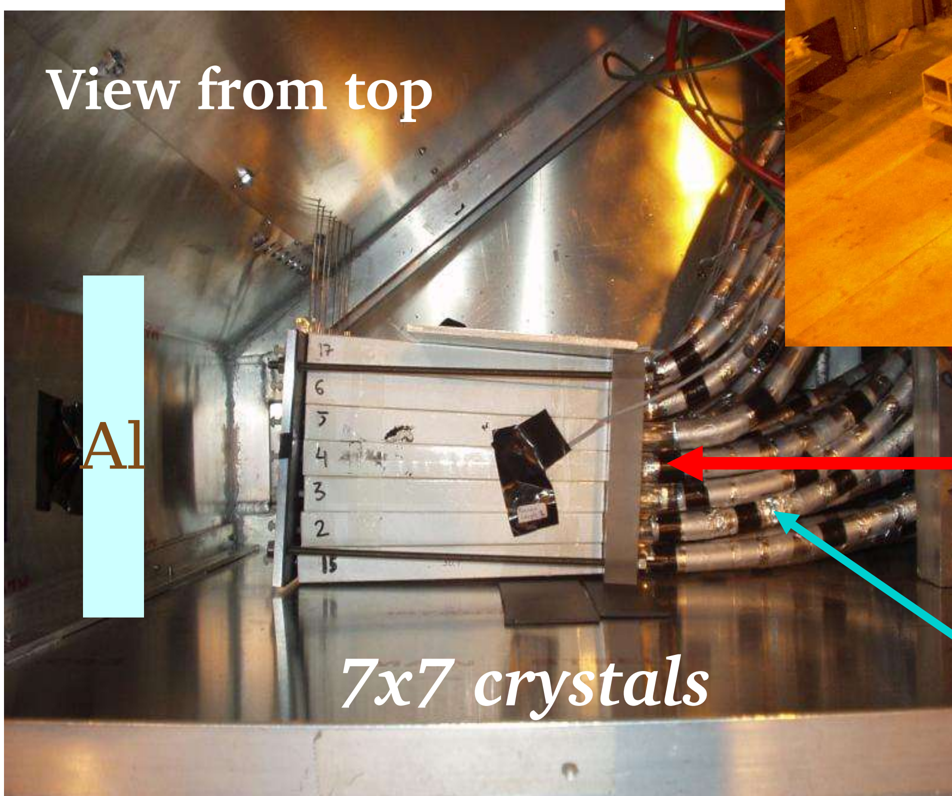


2 HB production wedges, 1 HE prototype wedge
HO layers on a movable table at CERN H2 beam line.



ECAL and HO



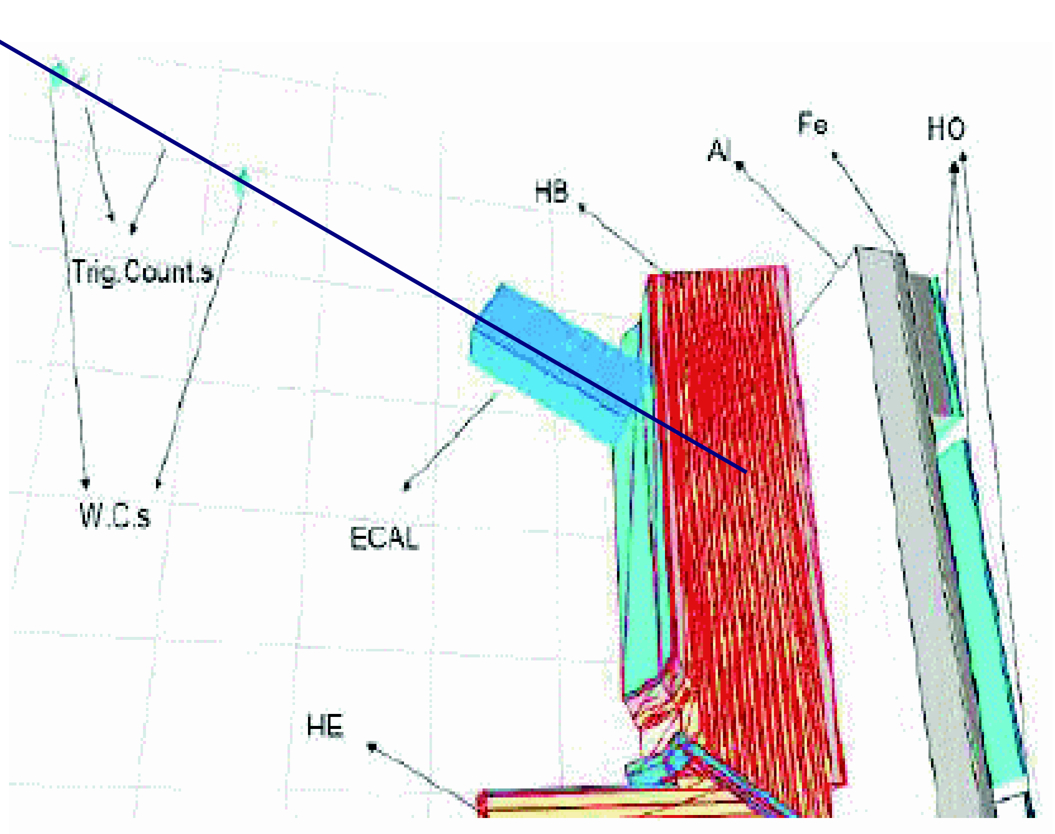


ECAL is readout by PMTs light guides are attached to the front face of the crystals

TB2004 simulation with GEANT4

Simulation of the HCAL TB2004 is done with OSCAR_3_7_0 package, which is based on Geant4.6.2.p02.
LHEP-3.7,QGSP-2.8,QGSC-2.9,FTFP-2.8

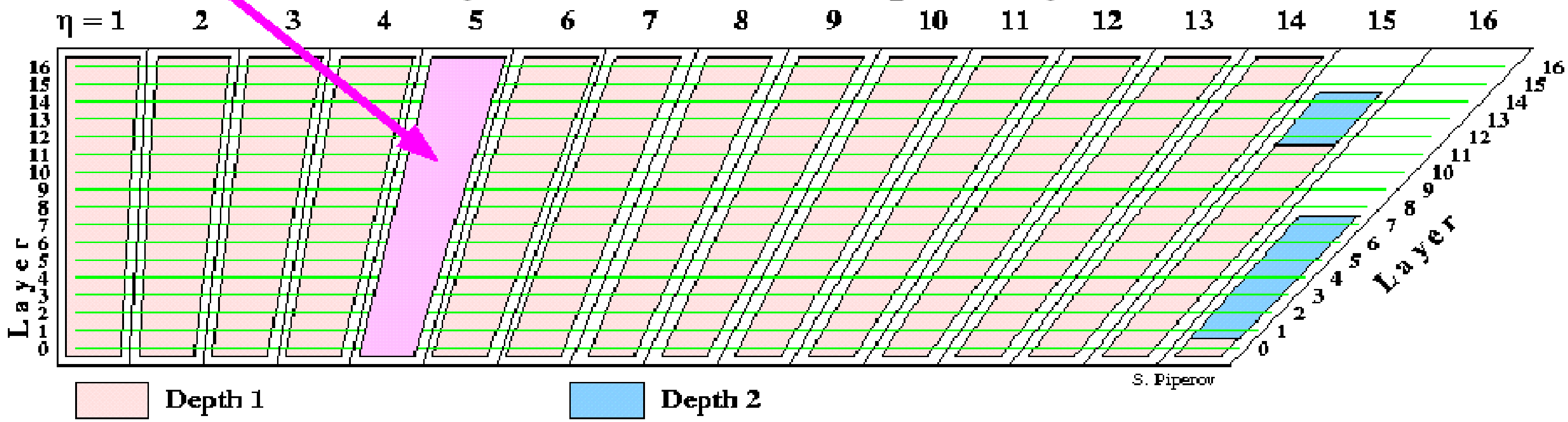
Setup doesn't work with OSCAR 5 – the new QGSP.



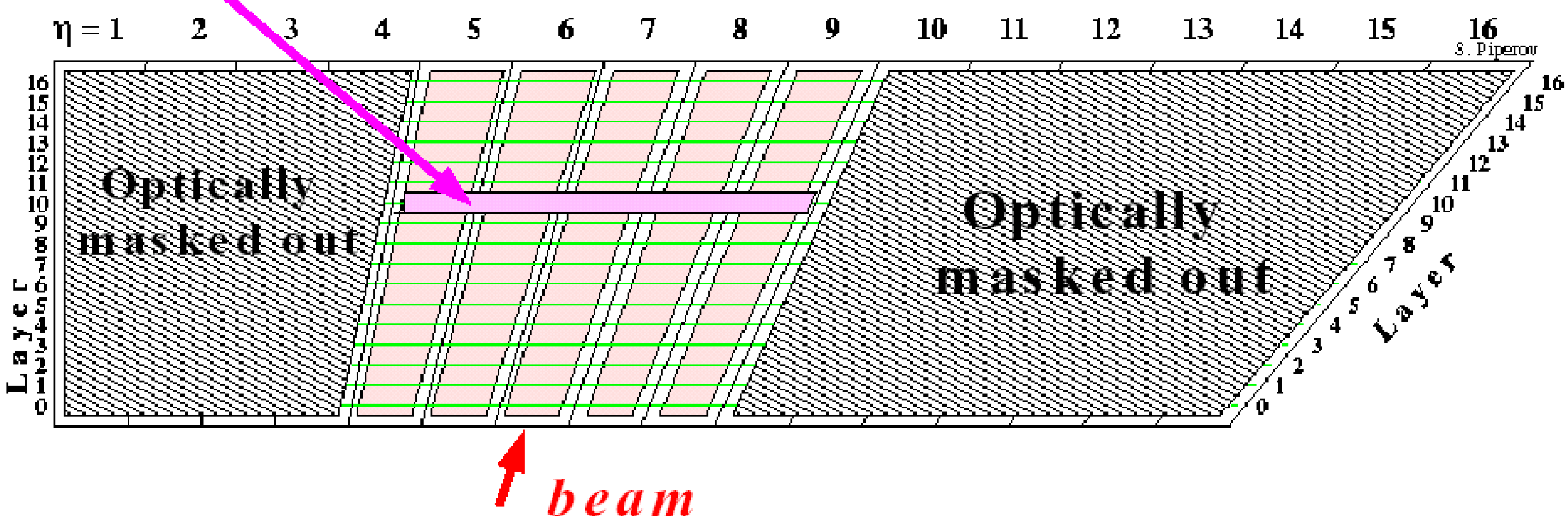
•Detailed HCAL geometry with HB1&HB2 read-out schema.
•ECAL – crystals, Al box and Al block behind ECAL.
•Beam line - trigger counters and wire chambers

HB readout scheme

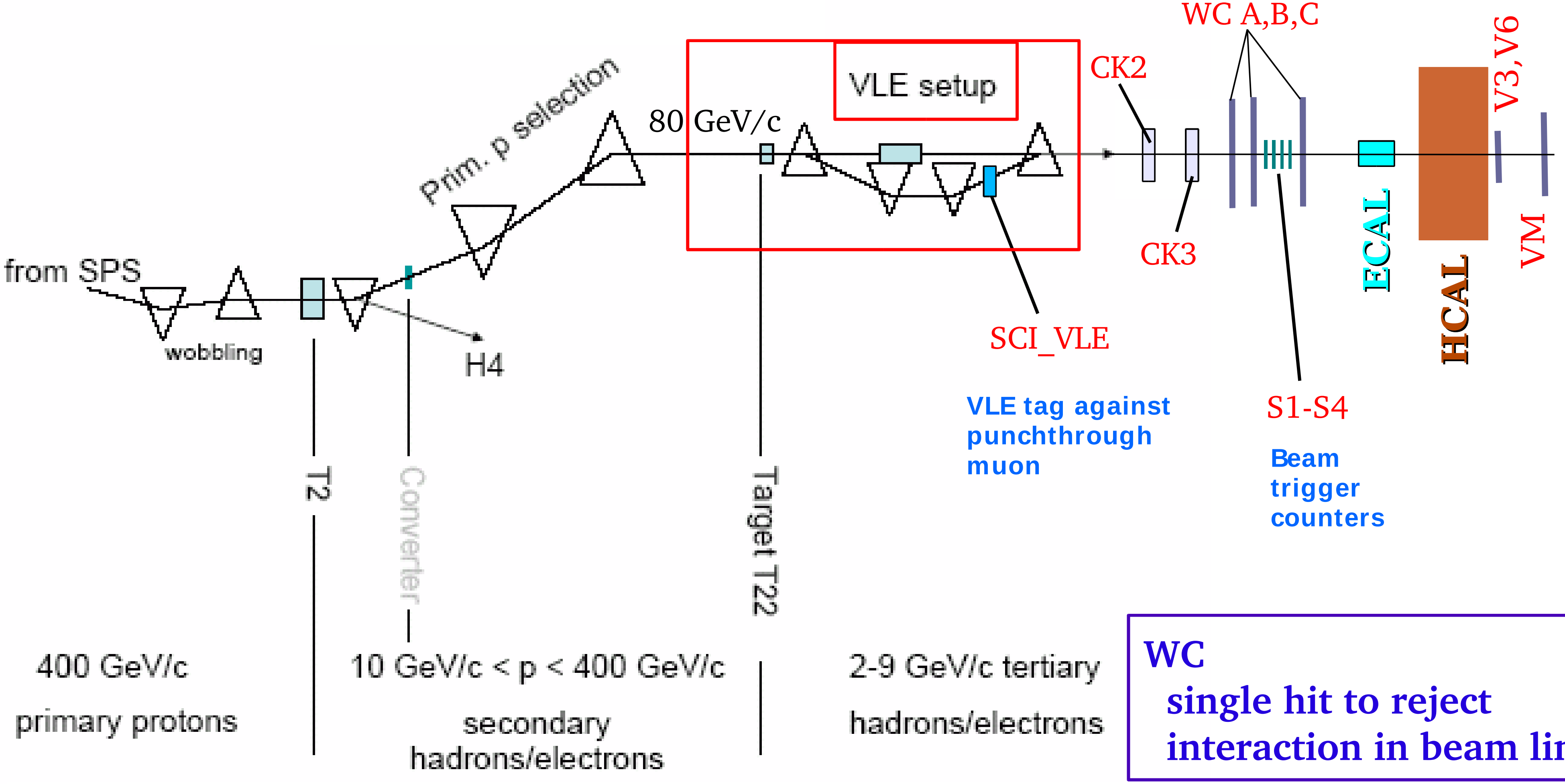
HB1: tower like – layers a summed optically



HB2: layer like – *longitudinal shower profile*



Beam line with particle identification



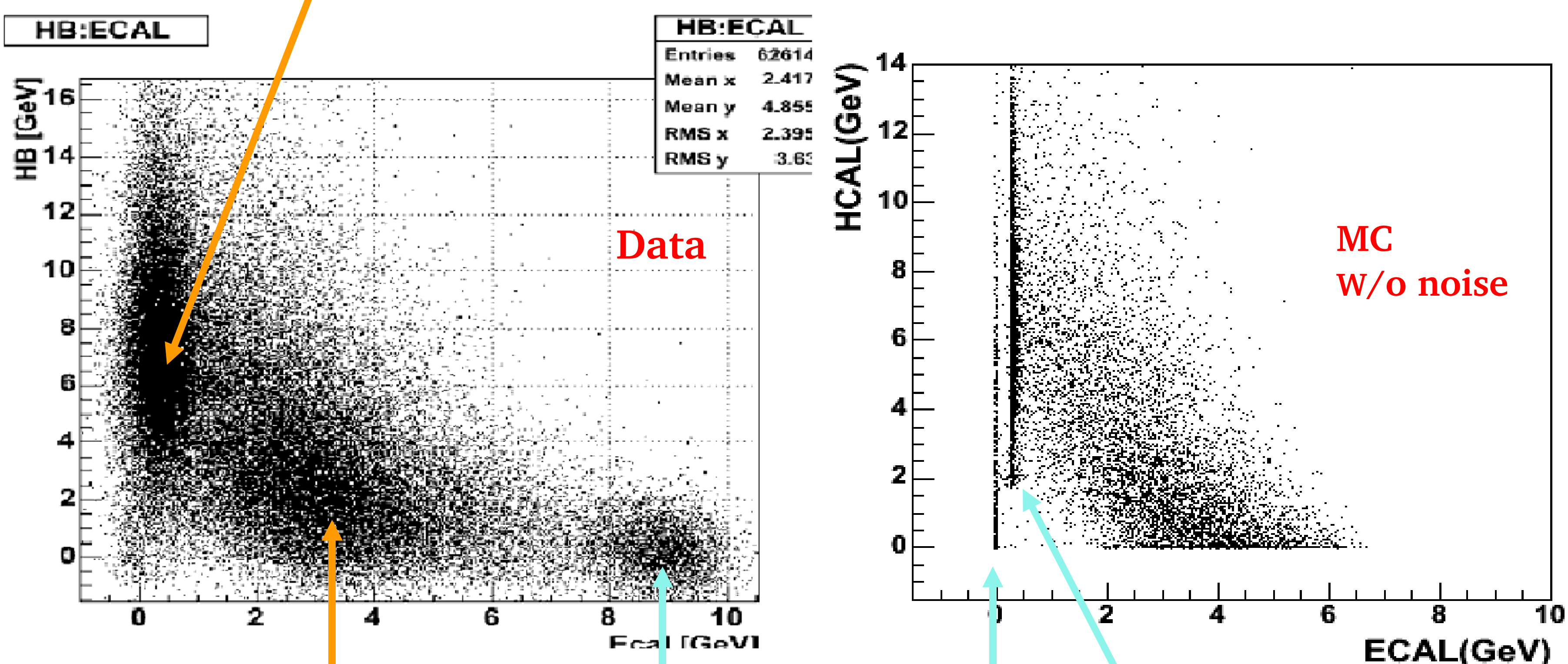
WC
single hit to reject
interaction in beam line

Available beam tunes:
- pions 2-300 GeV
- electrons 9-100 GeV
- muons 80/150 GeV

P-ID:
- CK2- electron
- CK3- pion / kaon / proton
- V3, V6, VM – muon

9 GeV pi+

mip in ECAL, i.e. no-interaction in ECAL



Interactions in ECAL

e^+

$\pi \to \mu \nu$ decays in beam line

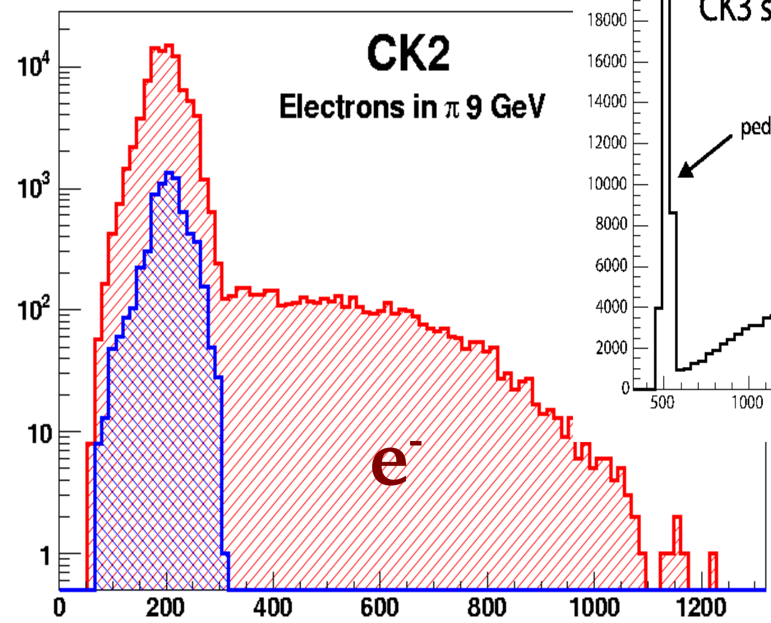
Interactions in beam line

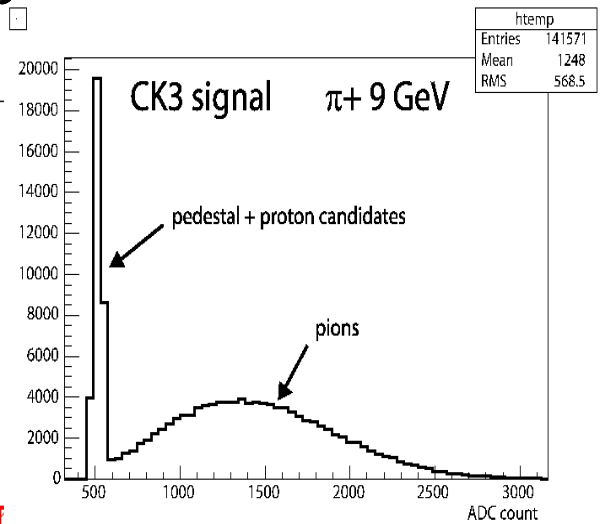
Need a lot of clean-up !

Beam cleaning strategy

Beam particle ID counters have efficiency constrain

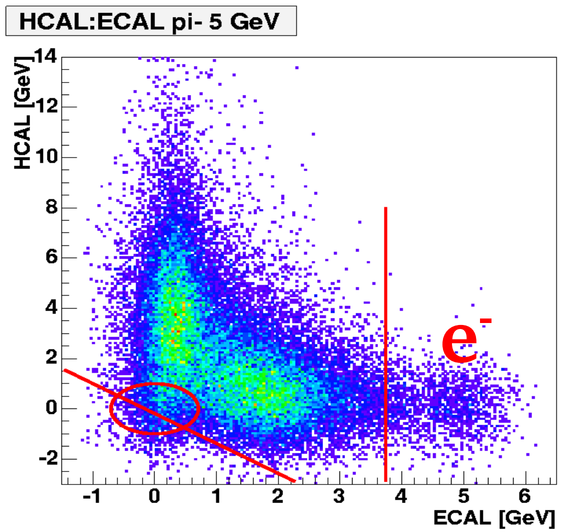
- Muon veto (VM,V3,V6)
- Electron ID(CK2):92%
- Protons,Kaons/Pions separation(CK3)
- VLE tag(SCI_VLE): VLE vs punch through muons

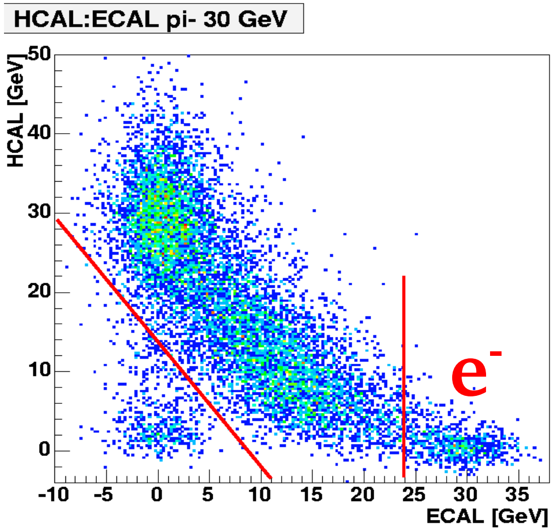




Calorimeter based cuts

- Electrons – clean ID
- Interaction in the beam line – source of systematics
- Muons form pions decay





Particle ID counters

Muon ID

* VM : large scintillators block – tags punch-true muons, placed behind HCAL
* VM3 : mounted on HB back at phi=3
* VM6 : mounted on HB back at phi=6

Electron ID

*CK2 : cerenkov counter – tags electrons
less then 92% efficiency. Used for 5-15 GeV beams.

Proton ID

*CK3 : cerenkov counter – tags protons and kaons at certain energy range:

P(pi,GeV)	P(mu,GeV)	P(p,GeV)	P(K,GeV)
3.5	***2.65***	***23.5***	***12.35***

less then 98% efficiency.

4.4% of pi-- 9GeV are “proton tagged”
19.7% of pi+ 9GeV are “proton tagged”

VLE ID

*SCI_VLE : scintillator at the VLE line – tags VLE beam particles.

Interaction at the beam line

*Wire Chambers: single hit requirement.

Beam content: Particle ID counters

Pi- tunes:

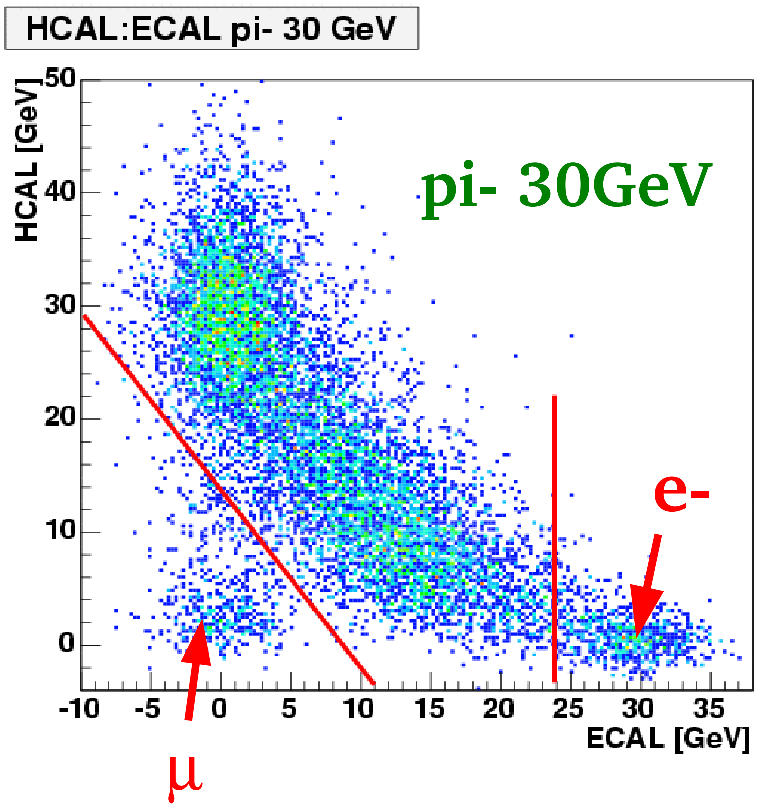
Energy [GeV]	tagged Muons	tagged electrons	No-e&No-mu	No-e&No-mu&WC-veto
15	10.8%	33.2%	56.0%	39.8%
10	6.9%	68.7%	24.4%	16.9%
9	1.4%	6.0%	62.0%	31.7%
7	3.5%	9.4%	60.3%	25.4%
5	5.4%	6.0%	53.3%	26.5%
3	28.9%	27.7%	24.3%	11.8%
2	85.2%	6.9%	2.2%	1.0%

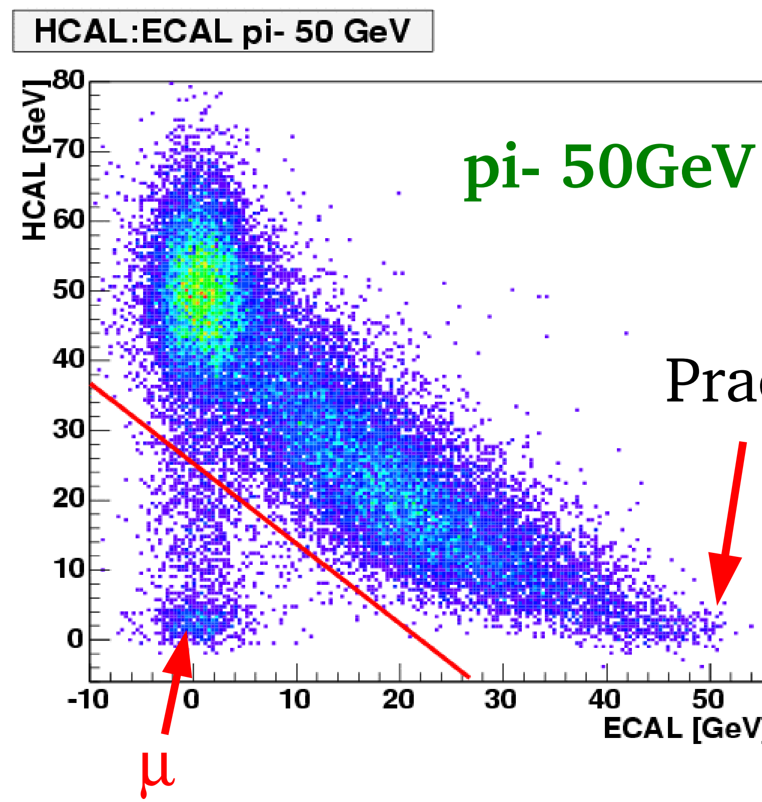
The particle Id counters are used for low energy beam tunes 2-15 GeV

- 2-9 GeV are produced by the VLE beam line setup.
- 10,15 GeV are the lower available energy from the high energy beam line setup.
- 30-300 GeV are using the calorimeter based cuts only.

2 and 3 GeV are not used.

Calorimeter based cuts





Practically no e-
50-300GeV

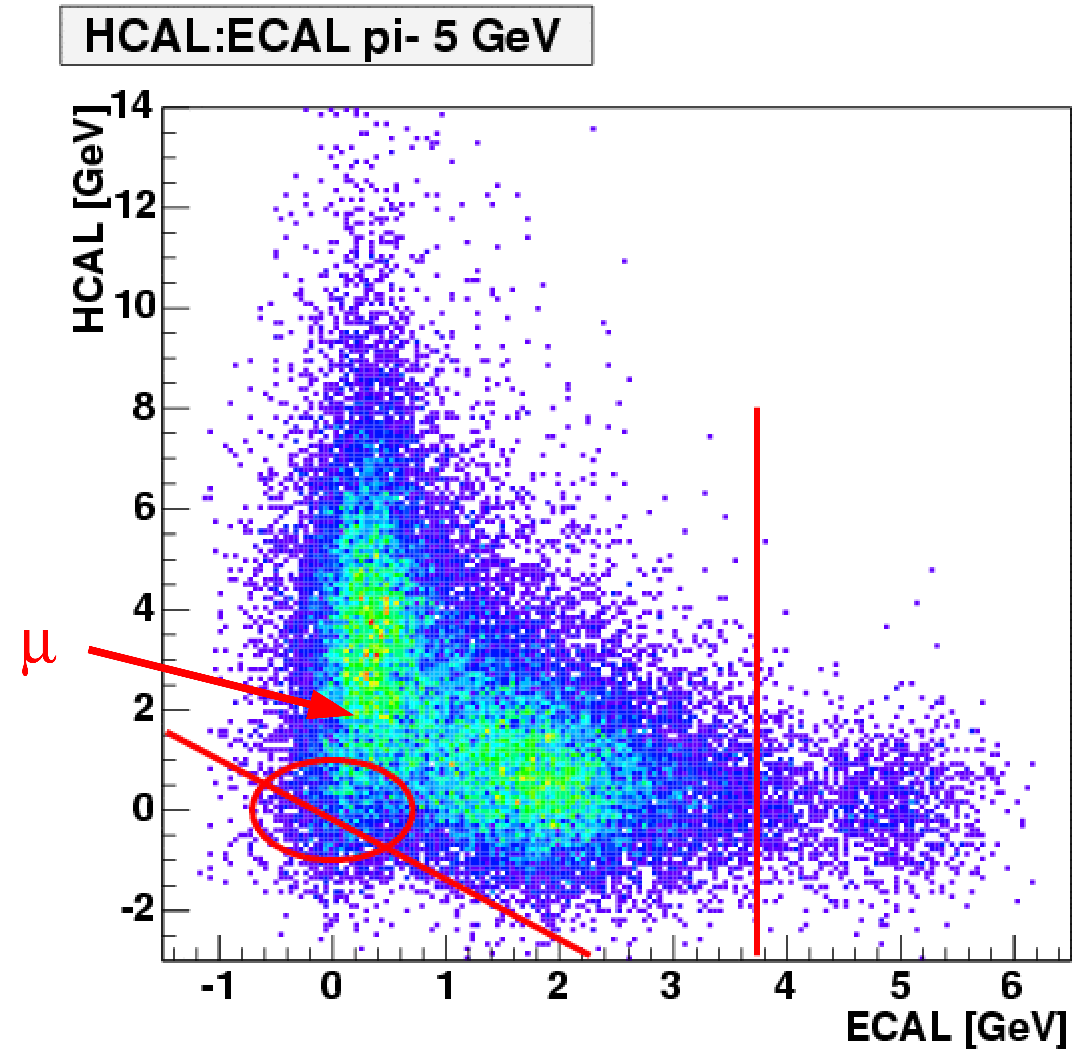
Energy [GeV]	$(E_{HCAL}/a + E_{ECAL}/b) > 1.$ a	b	$(E^2_{HCAL}/a + E^2_{ECAL}/b) > 1.$ a	b	$E_{ECAL} > c$ c
300	120.	120.	-	-	-
150	70.	60.	-	-	-
100	54.	46.	-	-	-
50	26.	22.	-	-	-
30	10.	7.	-	-	24
15	6.	2.5	-	-	12.5
10	3.	1.3	-	-	7.8
9	-	-	1.0	0.5	7.4
7	-	-	1.0	0.5	5.4
5	-	-	1.0	0.5	3.7

ECAL cut: removes electrons

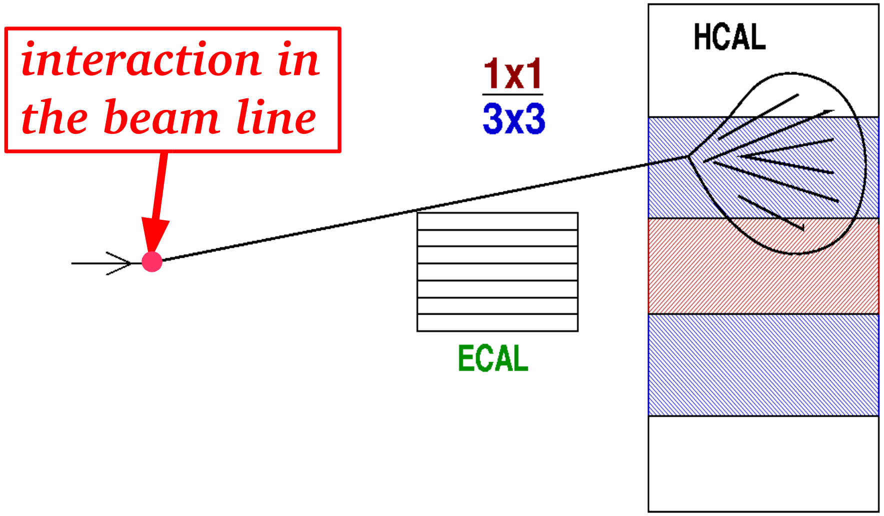
F(ECAL,HCAL): muons and interaction in the beam line.

Calorimeter based cuts

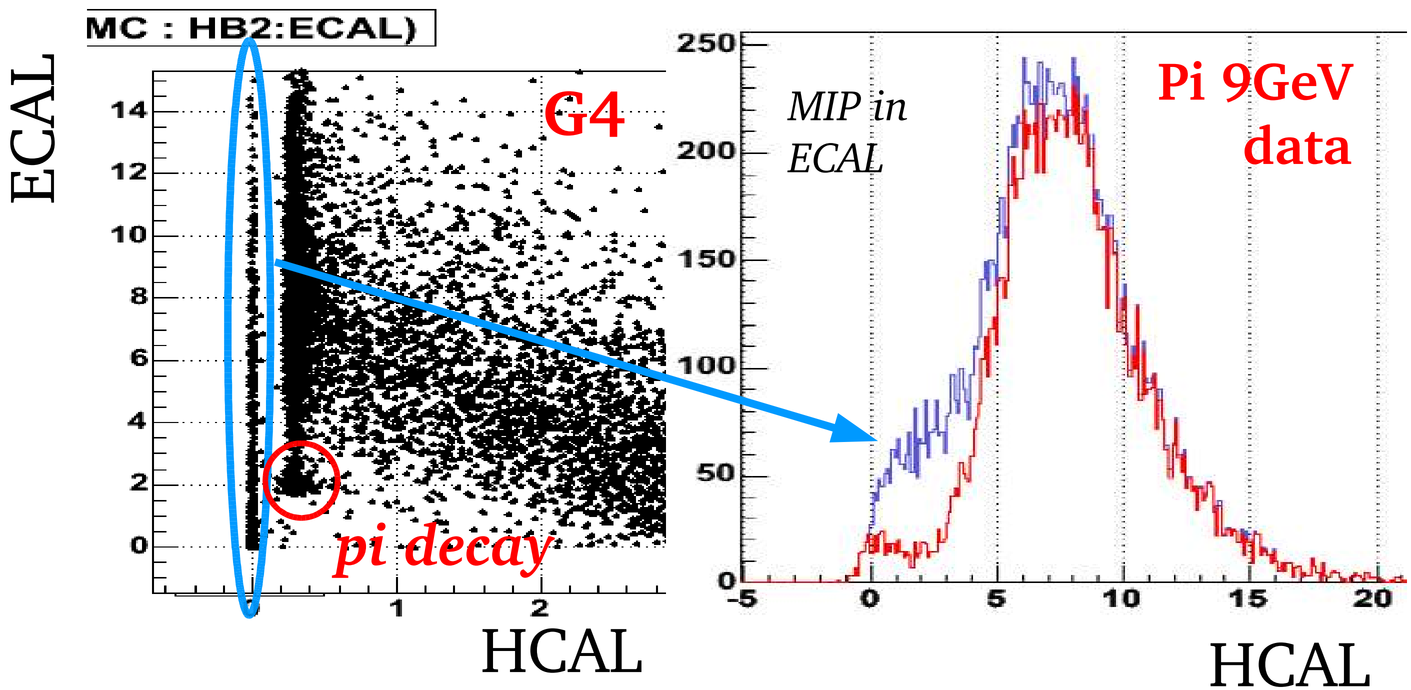
For very low energy F(ECAL,HCAL) cut is not very effective for rejection of the muon contamination in the beam . Also rejects only a fraction of the interaction in the beam line events.

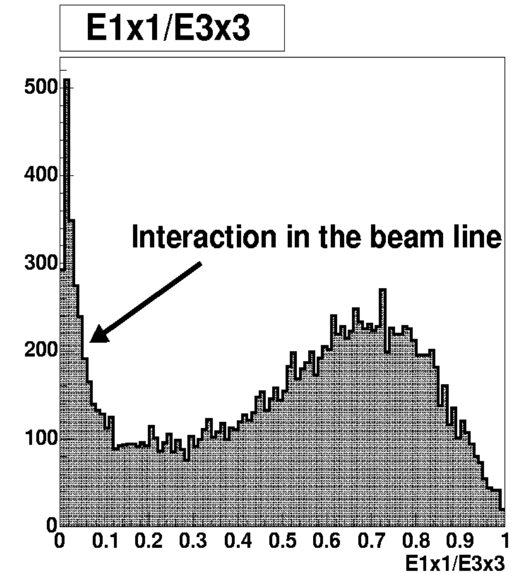


Interaction in the beam line

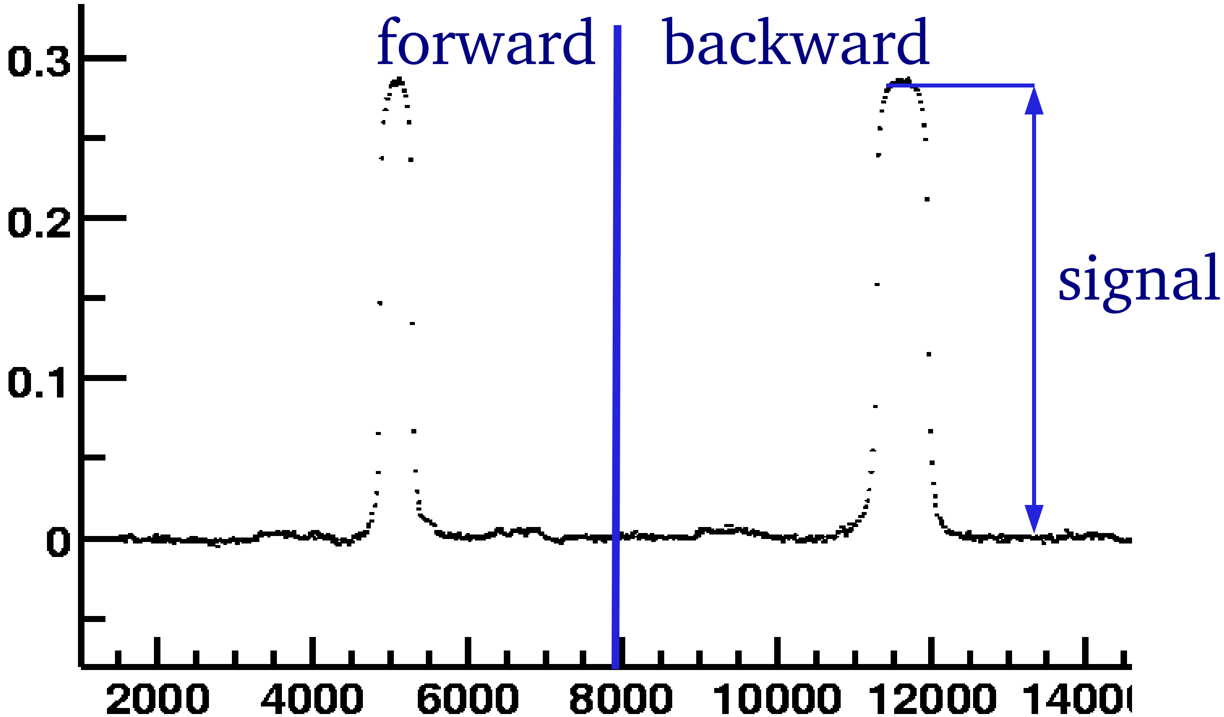


Energy deposition in 1x1 and 3x3 tower matrix is used to identify interaction in the beam line events.

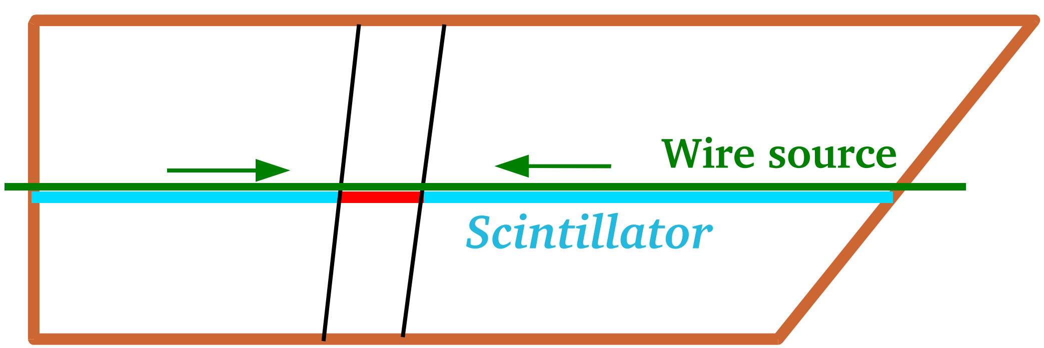




Calibration of the calorimeters

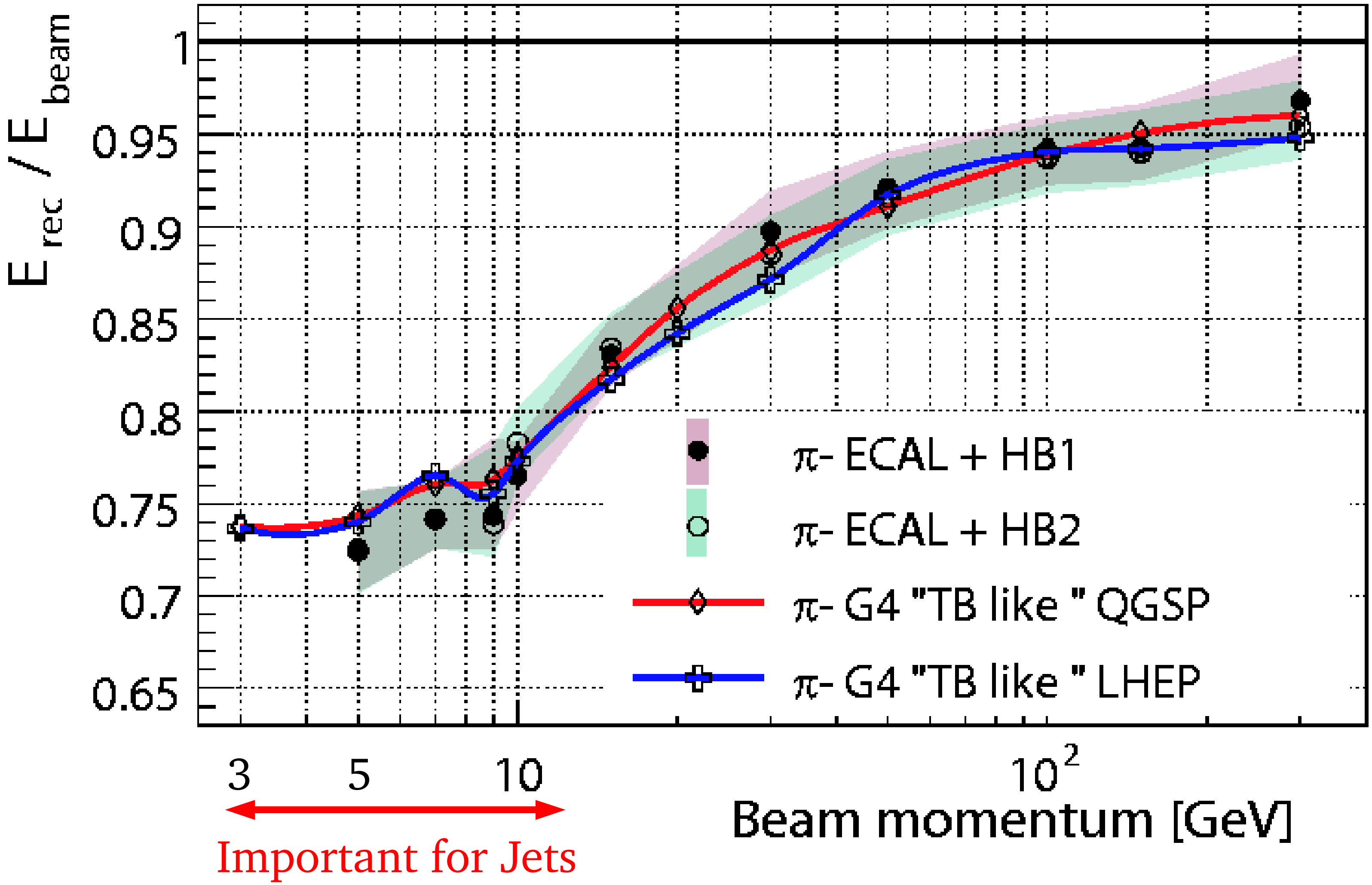


The uniformity calibration is done with Co^{60}, per-tower and per-layer with precision 3-4%



Energy scale:
ECAL: 100 GeV e-
HCAL: 50 GeV pi- with MIP in ECAL.

Calorimeter response to pions: ECAL+HCAL

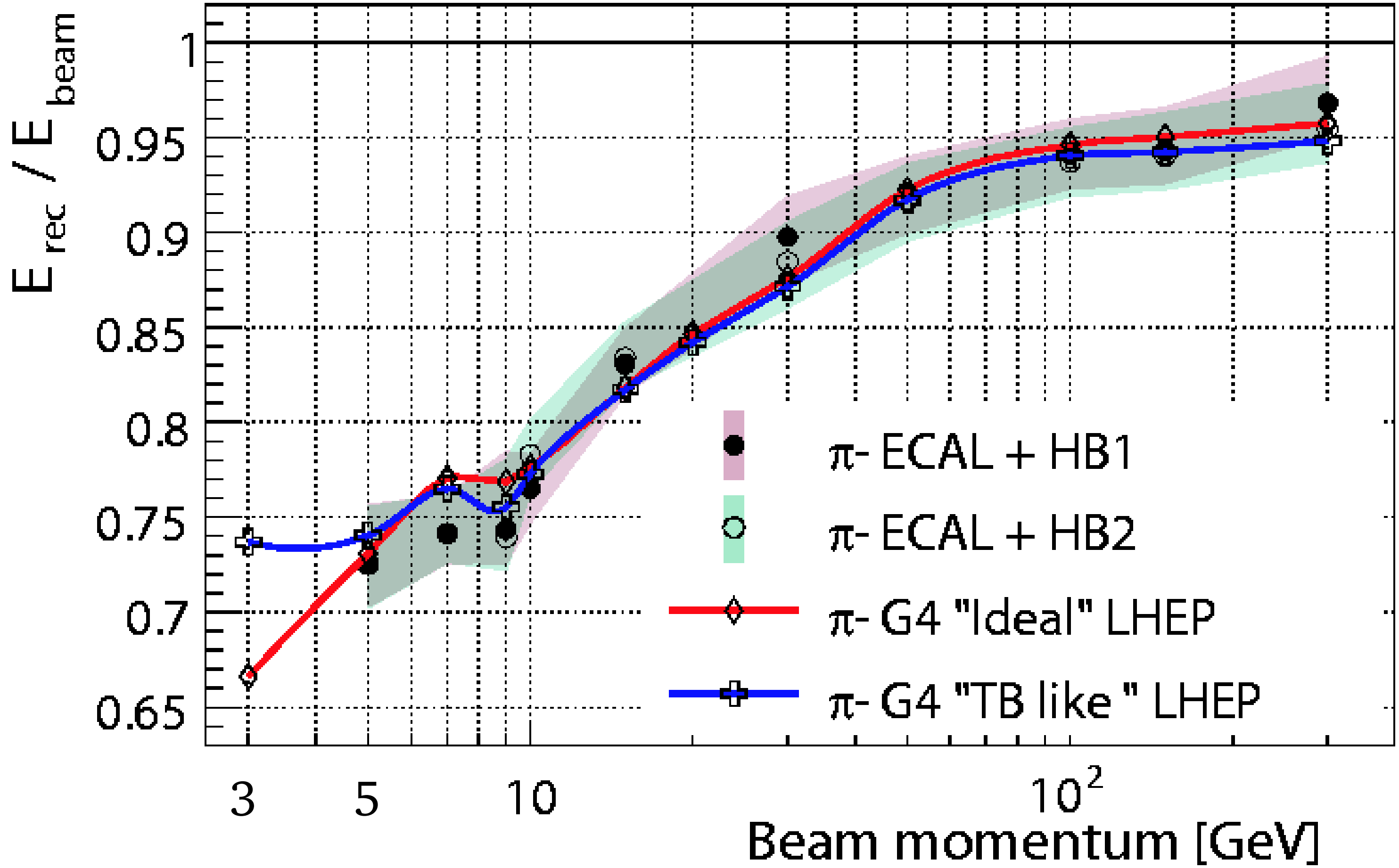


"TB like" G4 the same calorimeter based cuts like in the data cleaning

GEANT4: 7-10 GeV transition region from high to low energy parametrization.

Calorimeter response to pions: ECAL+HCAL (cont.)

Effect of the event selection



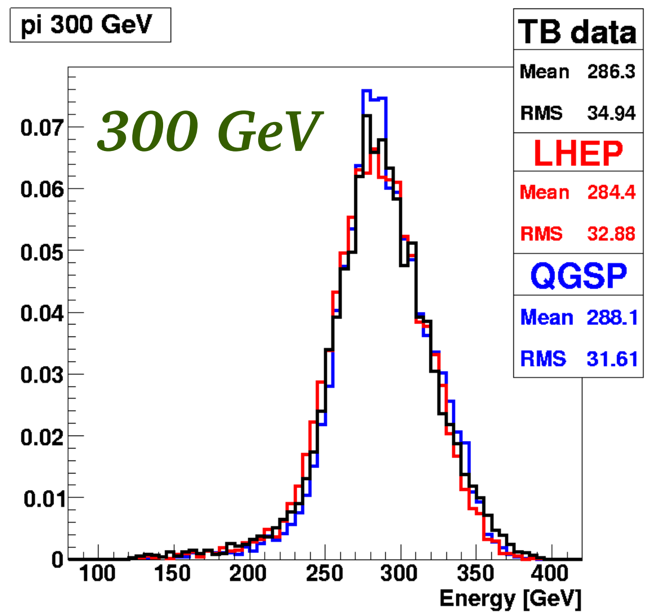
Effect of the interaction in the beam line and selection cuts:

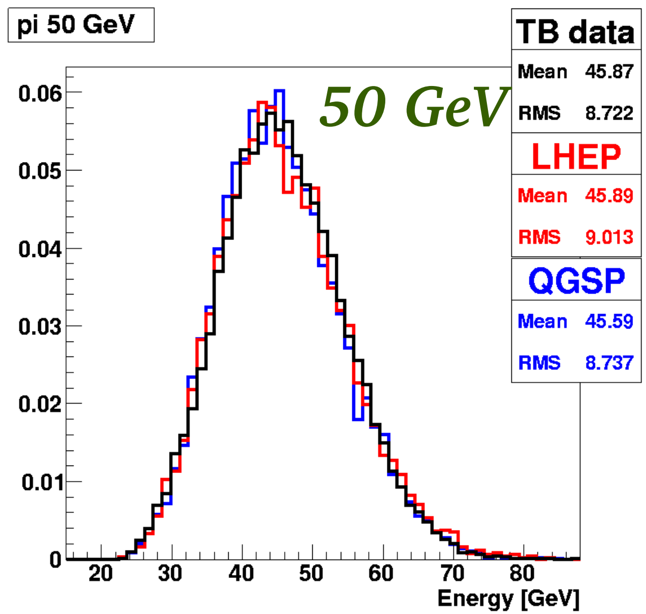
G4 “ideal” - no interaction in the beam line and calorimeter based cuts

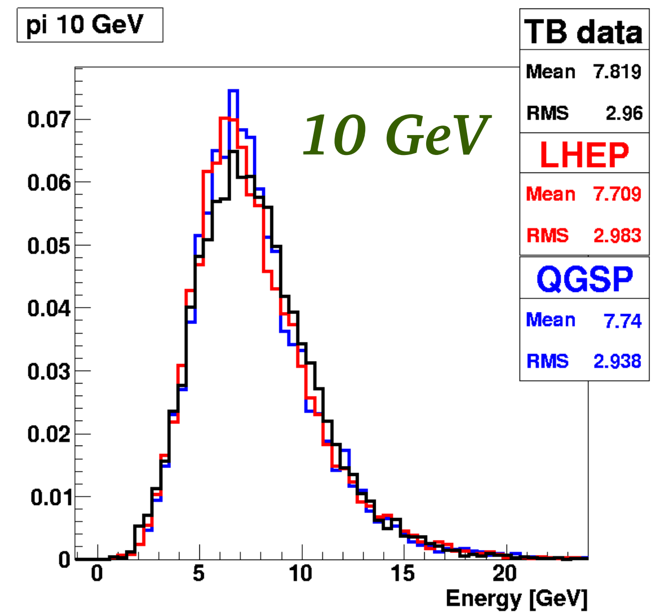
G4 “TB like” - data like event selection.

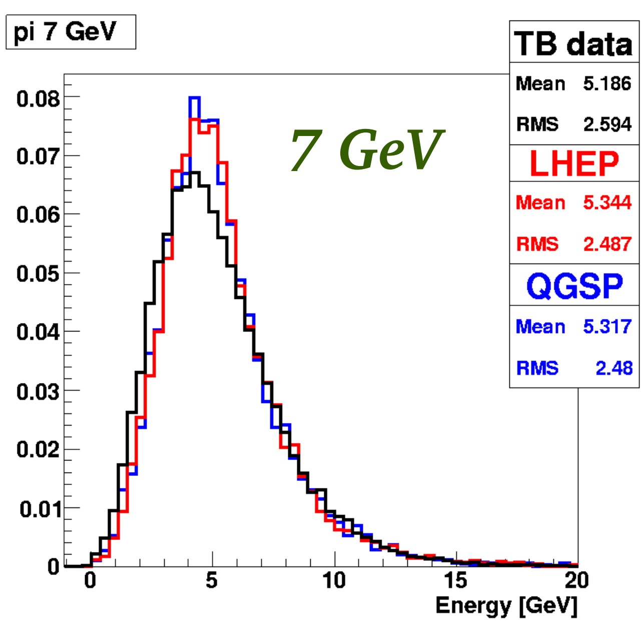
Limits on the lower end of the momentum range.

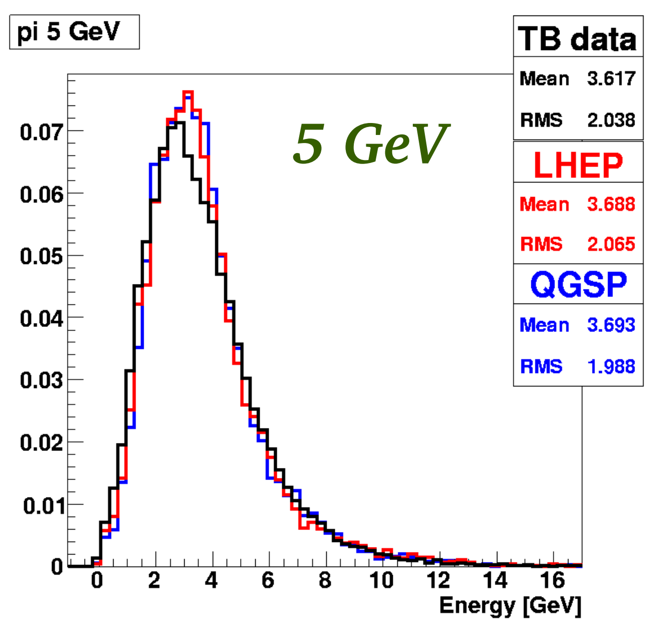
Energy spectrums: data vs GEANT4





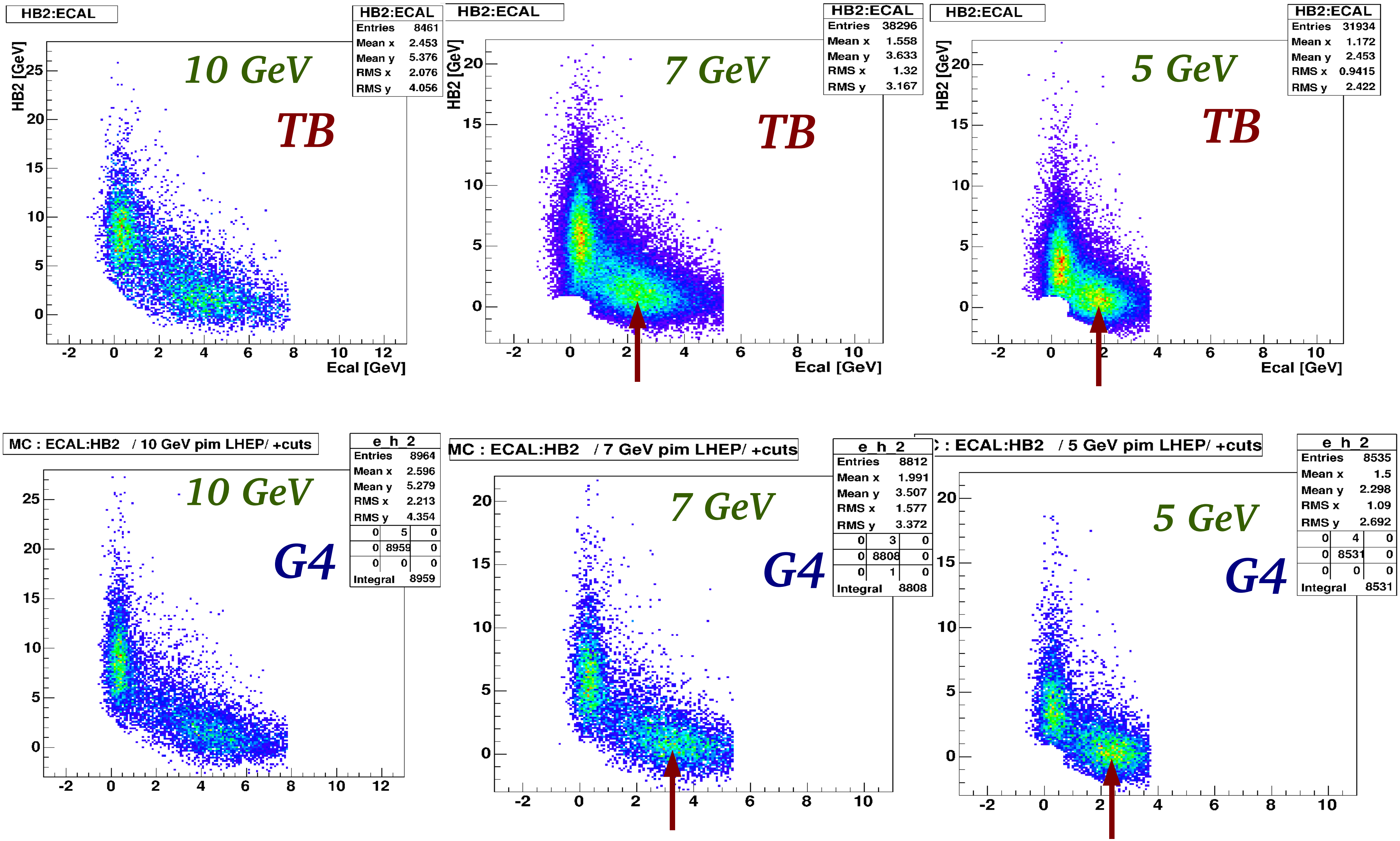






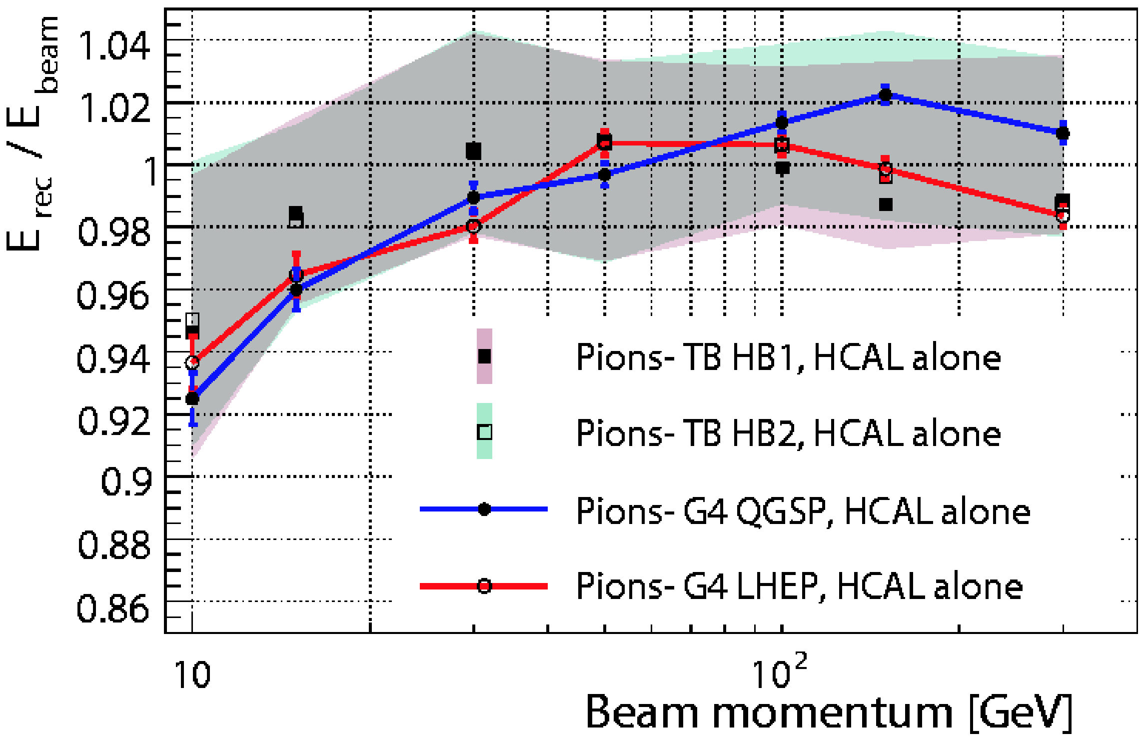
7-10 GeV is the transition region between low and high energy parametrization

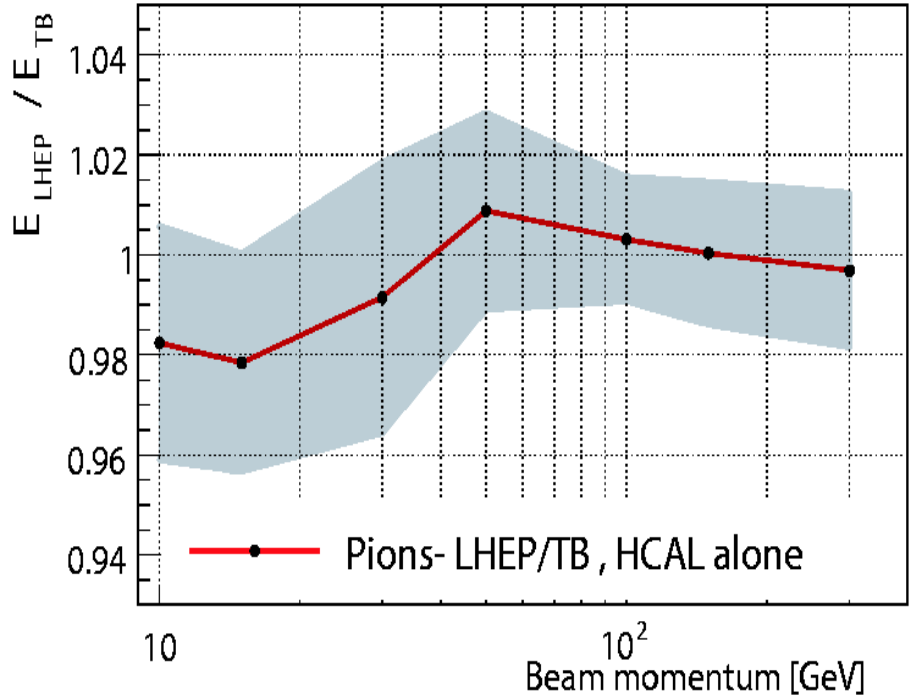
HCAL : ECAL energy deposition – Data vs GEANT4



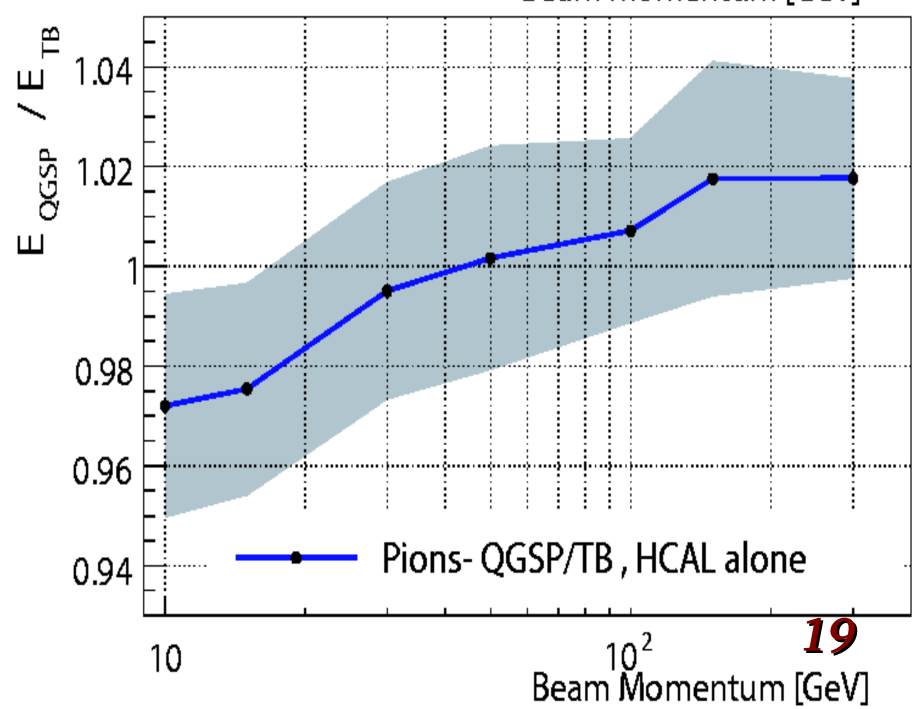
ECAL response is lower in GEANT4: geometry or physics or …?

Response to pions of HCAL alone





QGSP shows high response at high energies due to smaller leakage on the back of HCAL – shorter sower profile



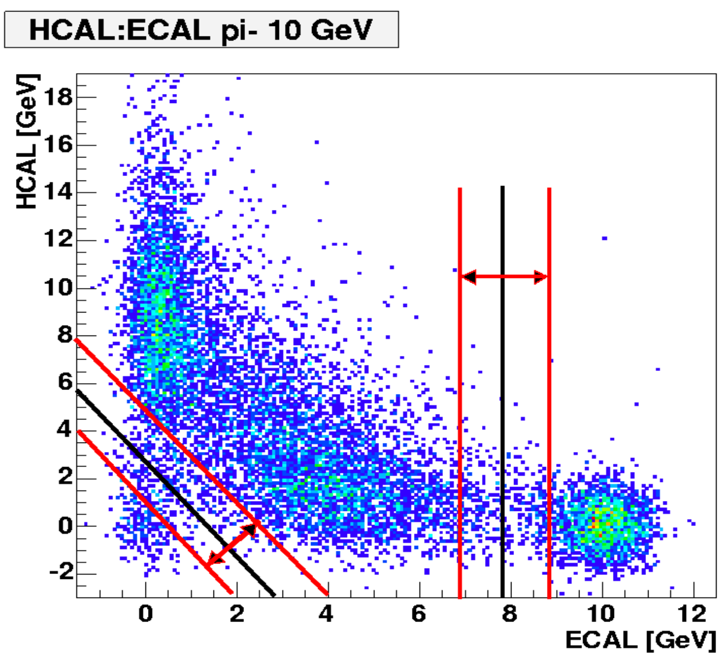
Uncertainties estimation

Source of uncertainties

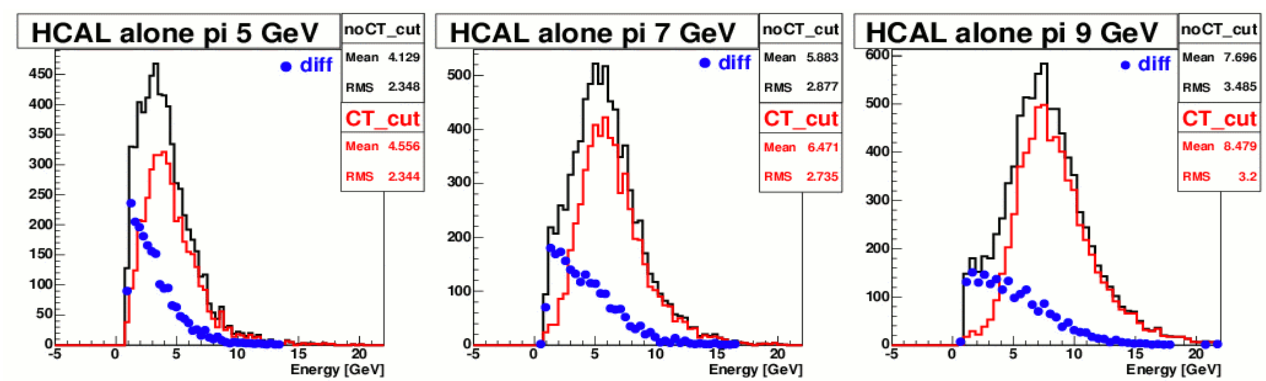
- Interaction in the beam line
- Pion decay
- Beam contamination
- Calorimeter based cuts
- Statistical error – small
- Energy calibration error – small
- Beam energy error - negligible

Energy scale HCAL: +0.25 -0.65%
bases on the MIP in ECAL value
Wire source: +- 1.6%

Fraction of the events with pion
in-fly decay is taken from GEANT



Interaction in the beam line



Beam Momentum [GeV]	ECAL+HCAL CT [GeV]	ECAL+HCAL noCT [GeV]	ECAL+HCAL CT-noCT [%]	HCAL-only CT [GeV]	HCAL-only noCT [GeV]	HCAL-only CT-noCT [%]
5	3.673	3.628	1.23	4.55	4.13	9.4
7	5.276	5.188	1.67	6.47	5.88	9.1
9	6.822	6.690	1.94	8.48	7.70	9.2

Uncertainties estimation (cont.)

ECAL+HCAL

P[GeV]	Stat	(0,0)cut	ECAL cut	Beam muons	pi decay	beam int.	All
300	+-0.12%	+1.9% -0.21%	-	-	-	-	+2.5% -1.8%
150	+-0.15%	+1.8% -0.43%	-	-	-	-	+2.4% -1.8%
100	+-0.17%	+0.9% -0.77%	-	-	-	-	+1.9% -1.9%
50	+-0.18%	+1.13% -1.51%	-	-	-	-	+2.0% -2.3%
30	+-0.28%	+1.54% -2.0%	+0.15% -0.04%	-	-	-	+2.3% -2.7%
15	+-0.27%	+1.37% -0.65%	+0.16% -0.08%	-	-	-	+2.2% -1.9%
10	+-0.42%	+1.53% -1.41%	+0.51% -0.13%	+0.05%	+0.19%	+0.39%	+2.3% -2.3%
9	+-0.25%	+1.2% -1.5%	+0.12% -0.09%	+0.01%	+0.98%	+1.94%	+5.5% -2.3%
7	+-0.25%	+0.95% -0.96%	+0.19% -0.19%	+0.00%	+0.69%	+1.67%	+2.7% -2.0%
5	+-0.33%	+3.6% -2.49%	+0.28% -0.28%	+0.00%	+0.12%	+1.23%	+4.2% -3.1%

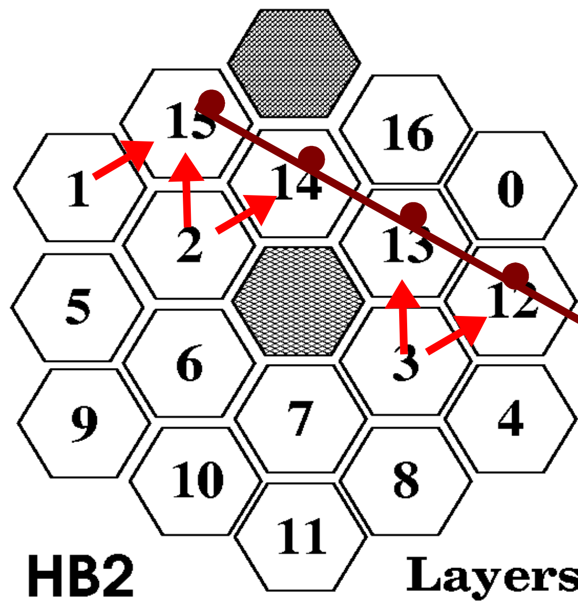
HCAL alone (MIP in ECAL)

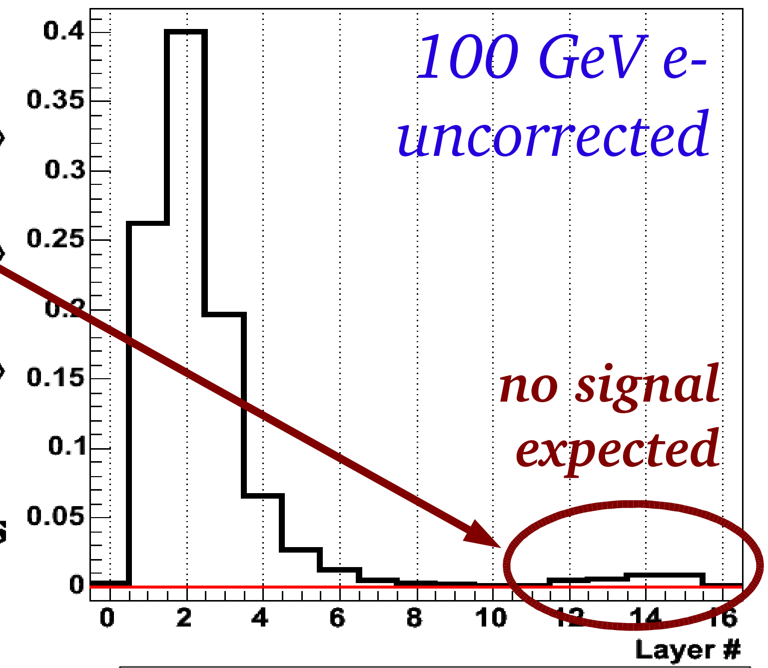
P[GeV]	Stat	(0,0)cut	Beam muons	pi decay	beam int.	All
300	+-0.39%	+4.7% -0.85%	-	-	-	+4.7% -0.94%
150	+-0.38%	+4.6% -1.3%	-	-	-	+4.6% -1.4%
100	+-0.39%	+3.2% -1.8%	-	-	-	+3.2% -1.8%
50	+-0.24%	+2.5% -3.8%	-	-	-	+2.5% -3.8%
30	+-0.48%	+3.8% -2.6%	-	-	-	+3.8% -2.6%
15	+-0.53%	+3.0% -2.9%	-	-	-	+3.1% -2.9%
10	+-0.82%	+3.9% -4.1%	+0.16 %	+1.15%	+3.2%	+5.3% -4.2%

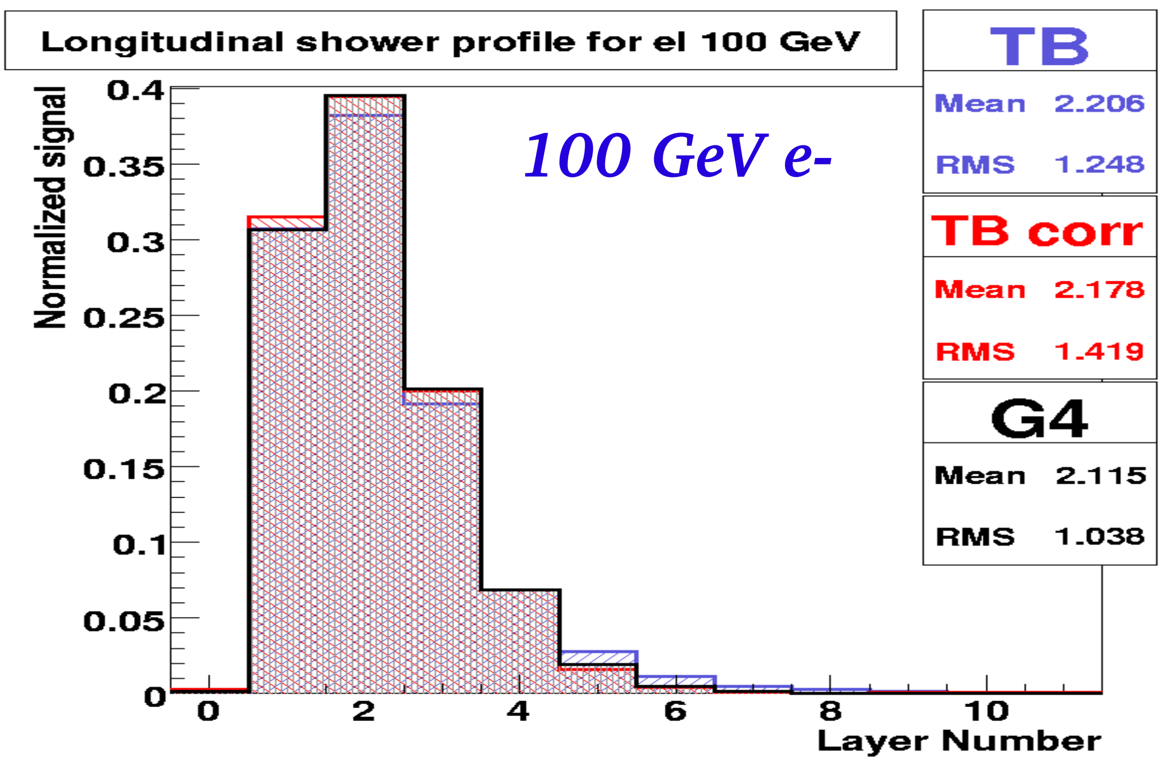
Longitudinal Shower Profile

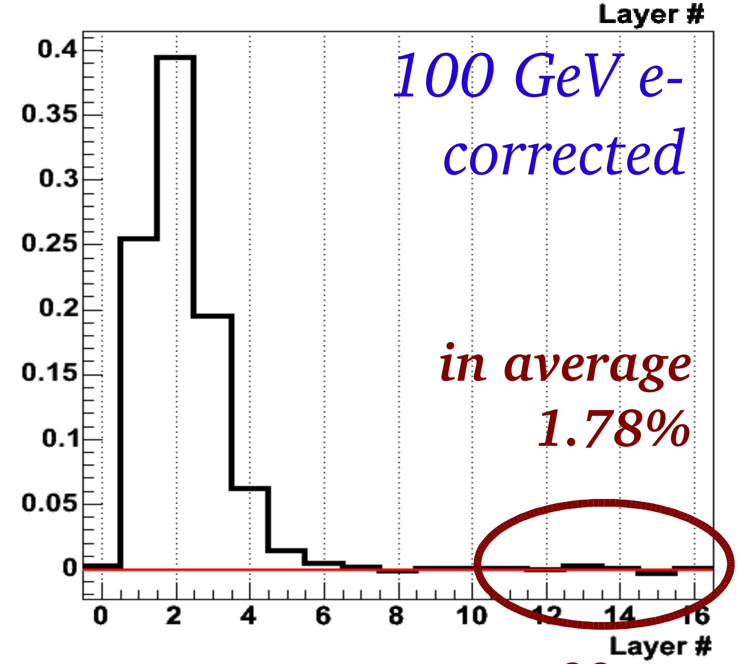
In HPD cross-talk without magnetic field

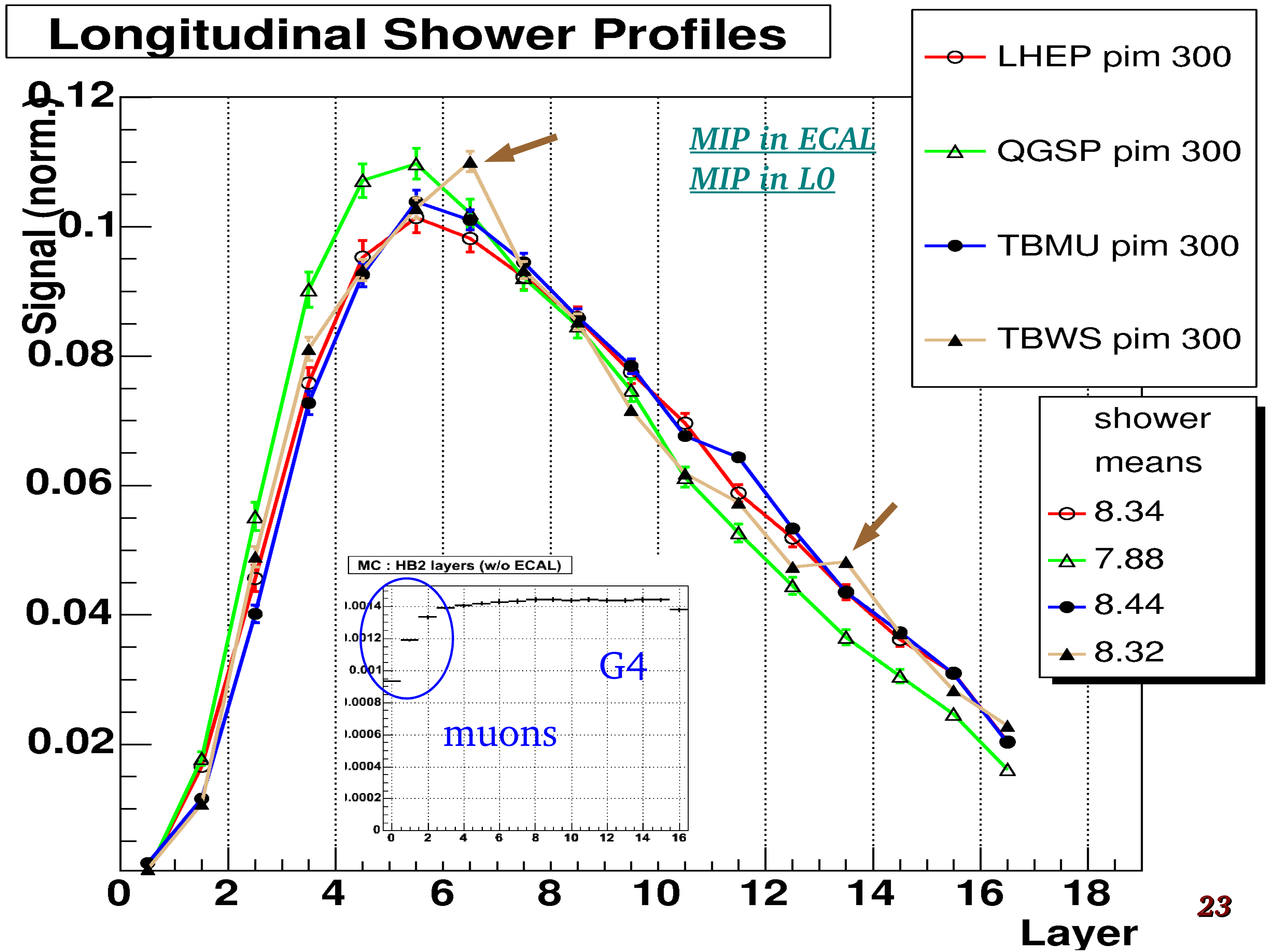
In the test beam environment there is no magnetic field to compensate the cross-talk – correction is necessary.





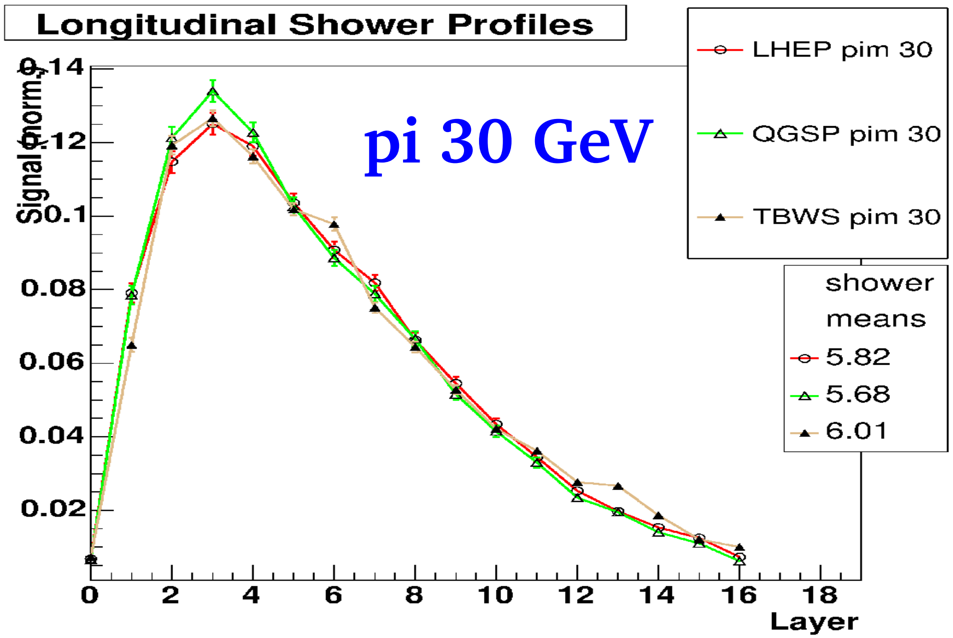


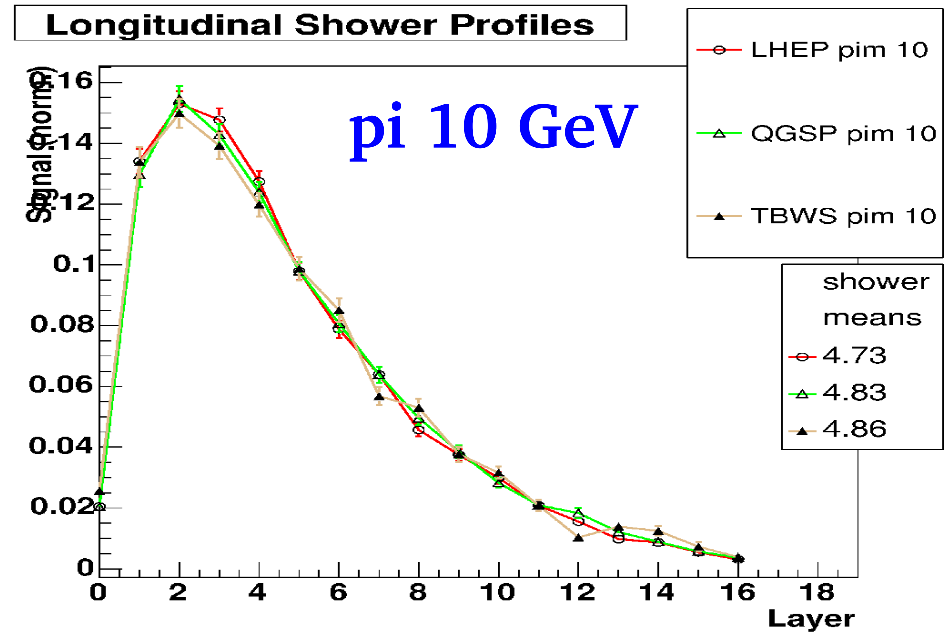


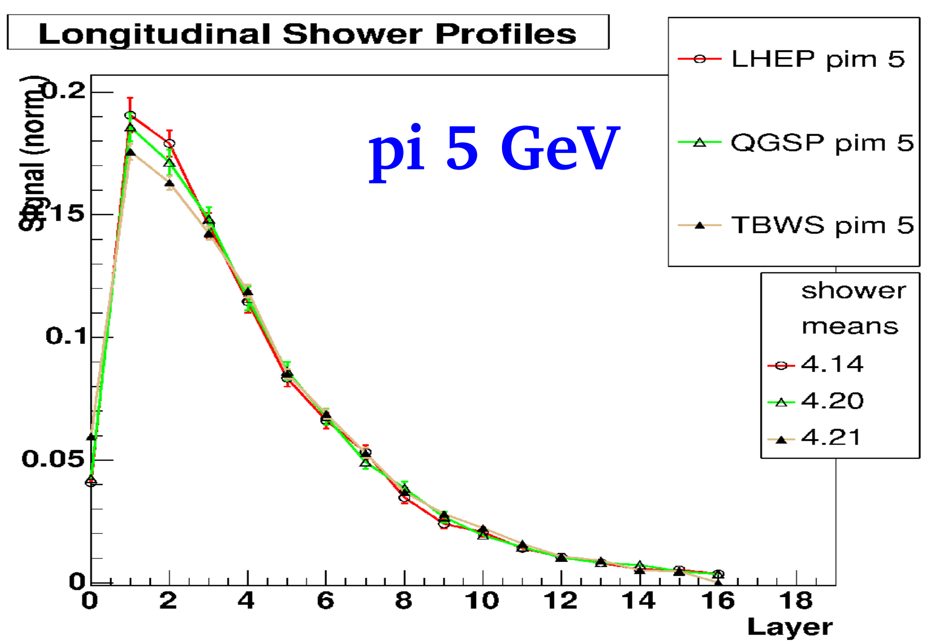


Longitudinal Shower Profiles
Signal (norm.)
Layer
MIP in ECAL
MIP in L0
LHEP pim 300
QGSP pim 300
TBMU pim 300
TBWS pim 300
shower means
8.34
7.88
8.44
8.32
MC : HB2 layers (w/o ECAL)
G4
muons

Longitudinal shower profiles (cont.)







LHEP and QGSP show good agreement with test beam data at low and intermediate energies

Conclusions and Outlook

- Monte Carlo prediction agree well with the HCAL TB2004 data.

- LHEP seems to model shower profile better than QGSP(2.8) for energies above 150 GeV (TB2004 simulation doesn't work with OSCAR 5.0.0)

- The ECAL response to pions is higher in the simulation for 7GeV and below.

- There will be another test beam this summer. Better particle ID and tagging of the interaction in the beam line events are designed. Real ECAL super-module will be used.