CMS HCAL Test Beam Results and Comparison with GEANT 4 Simulation

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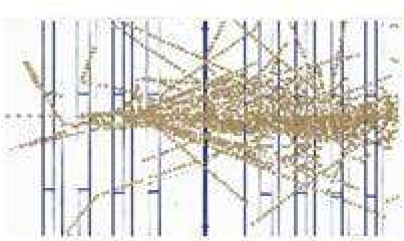
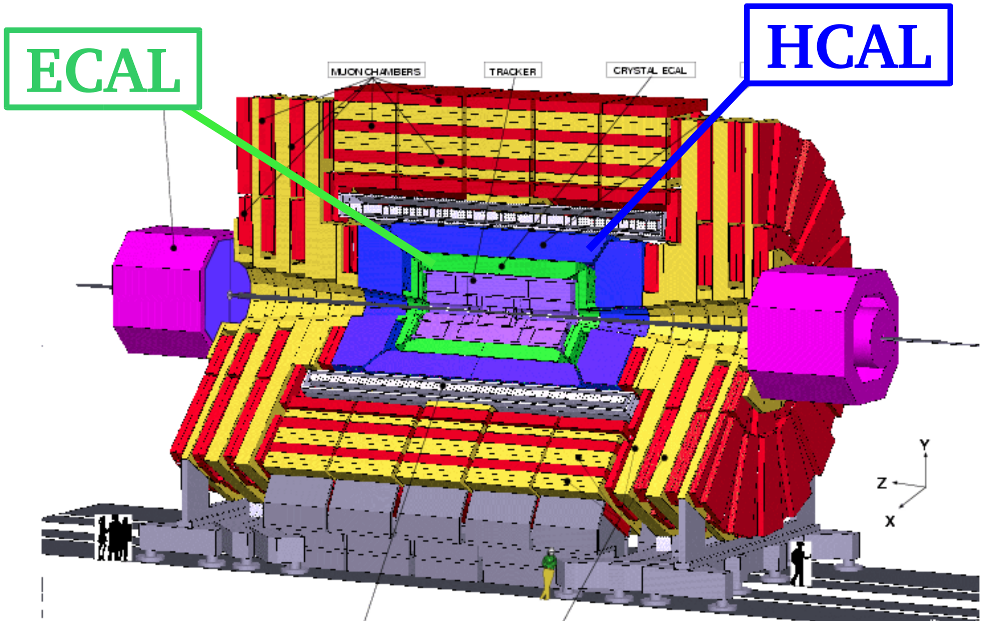
on behalf of the
CMS HCAL Collaboration



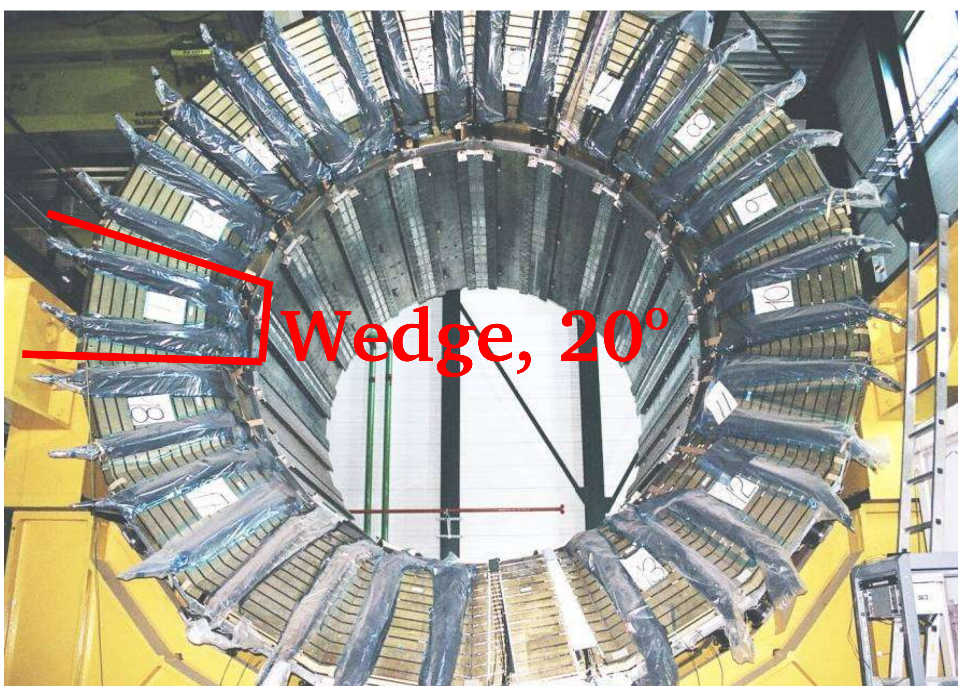
CALOR '06
Chicago June 5-9, 2006

CMS Calorimeter system

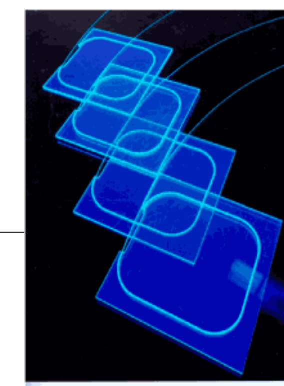


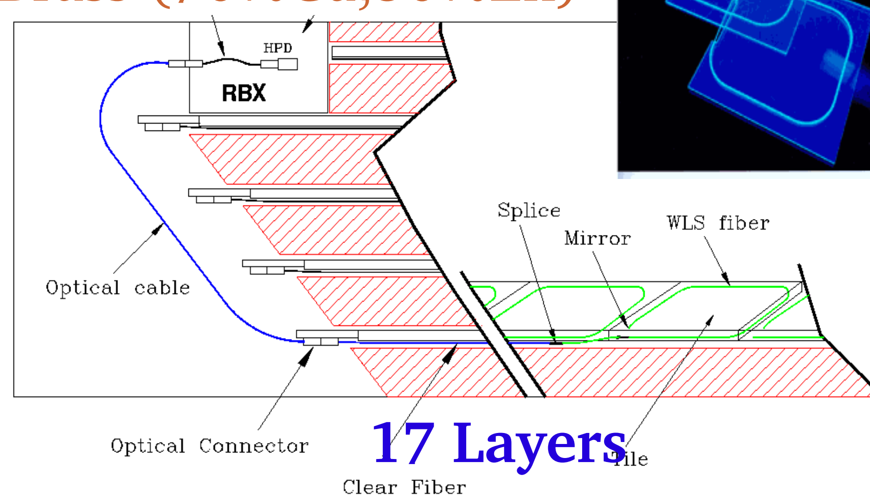
See Julie Whitmore's talk for details

ECAL:
$PbWO_4$
crystals



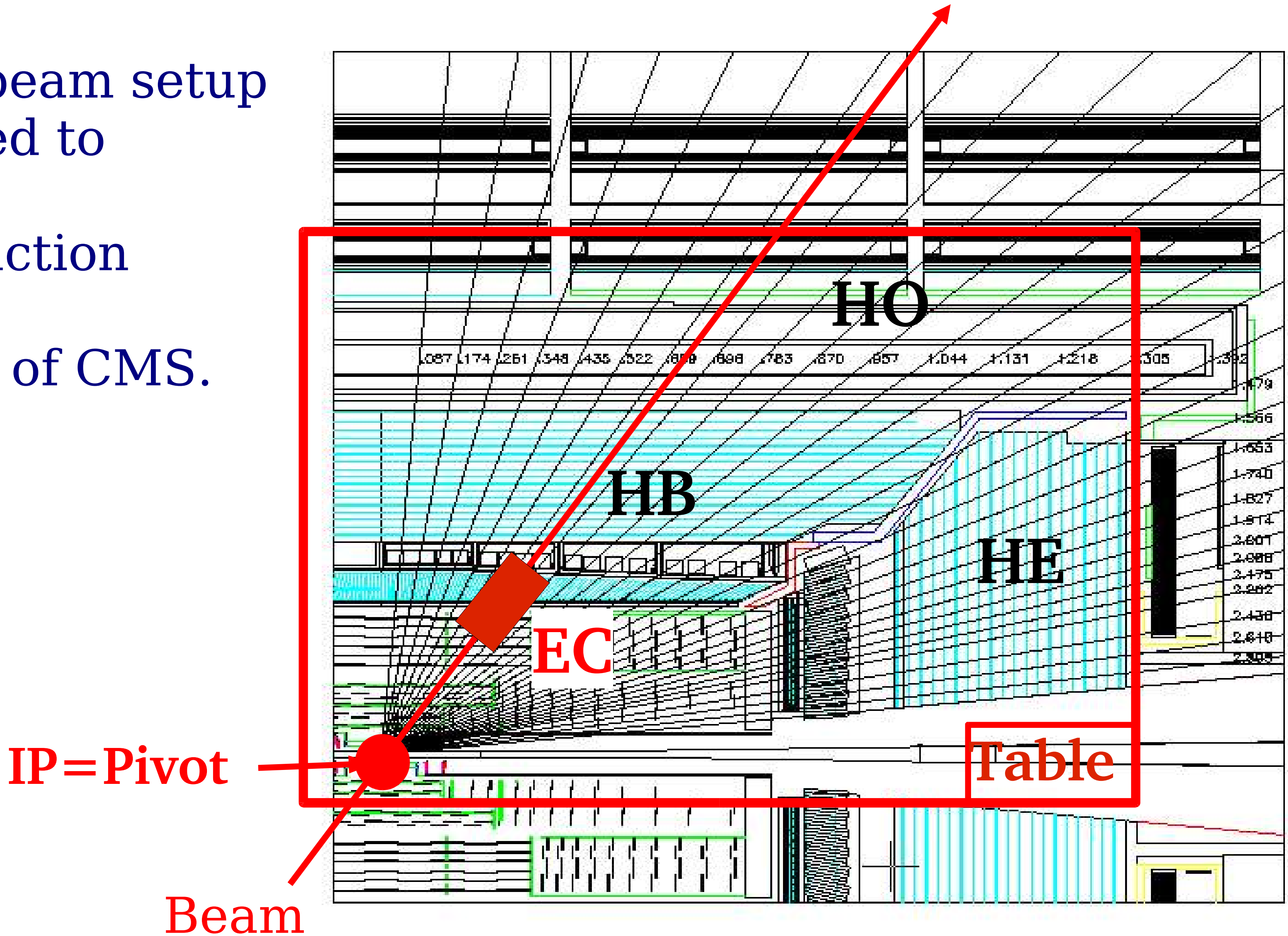
Sampling calorimeter
Scintillator
Brass (70%Cu,30%Zn)





Interaction point like geometry

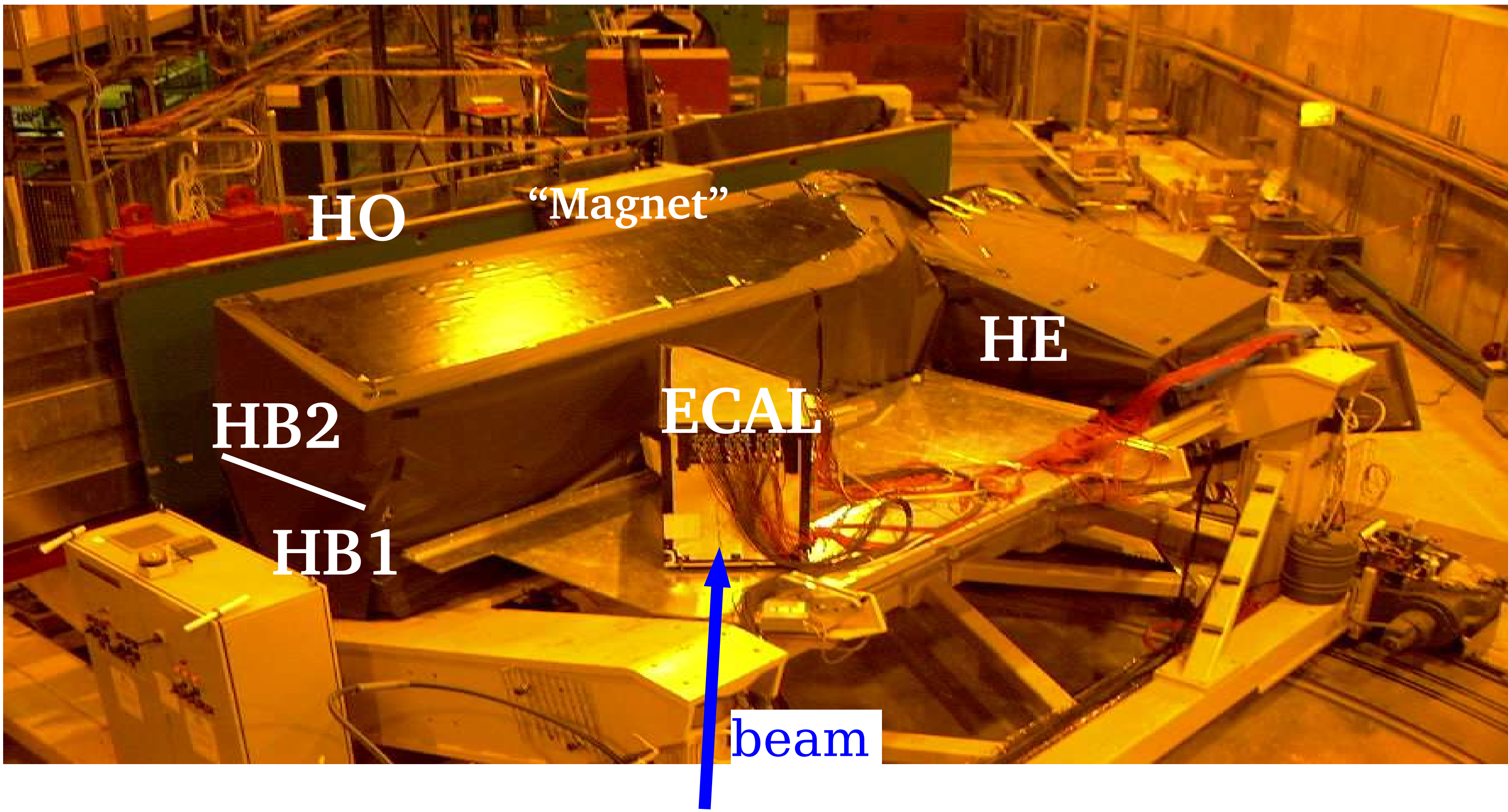
The test beam setup
is designed to
preserve
the interaction
point-like
geometry of CMS.



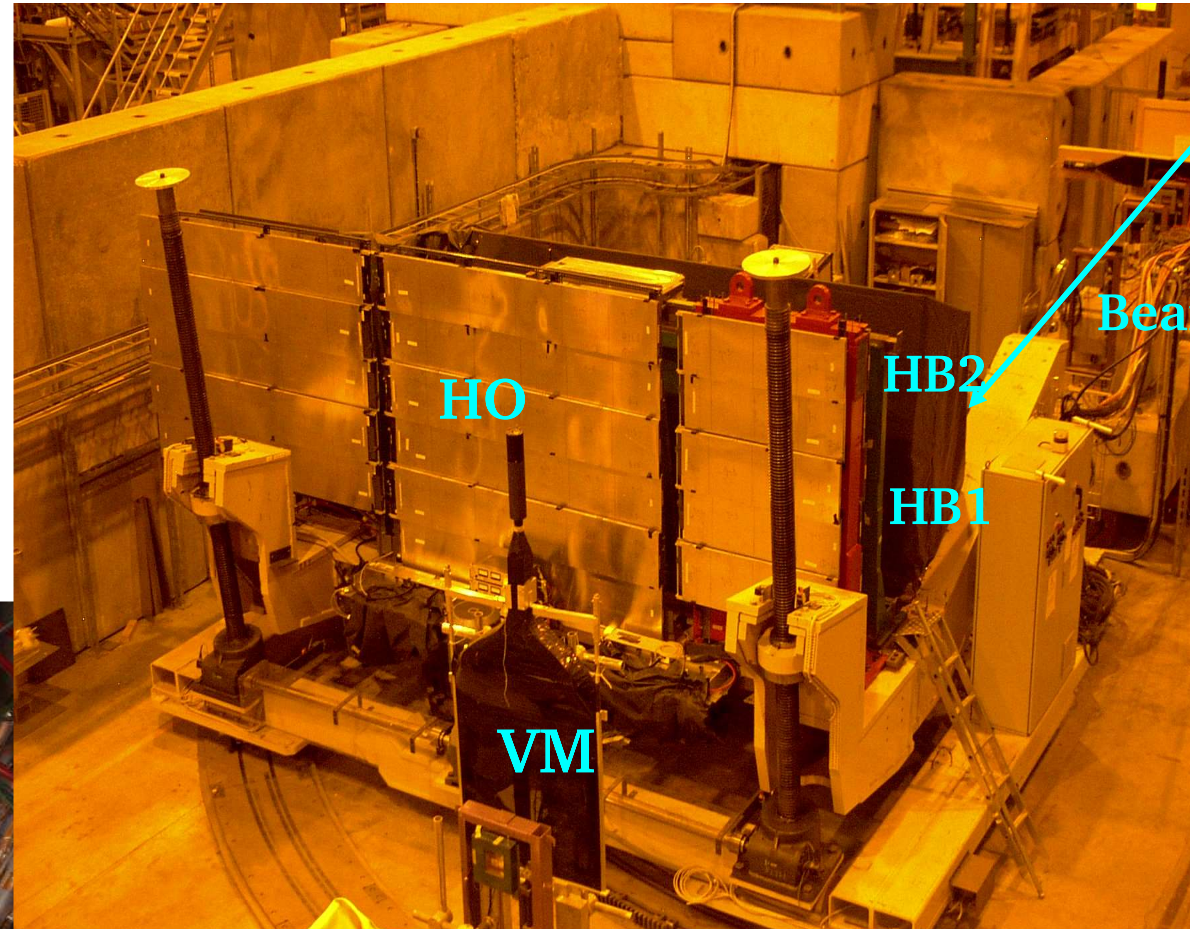
Test beam setup

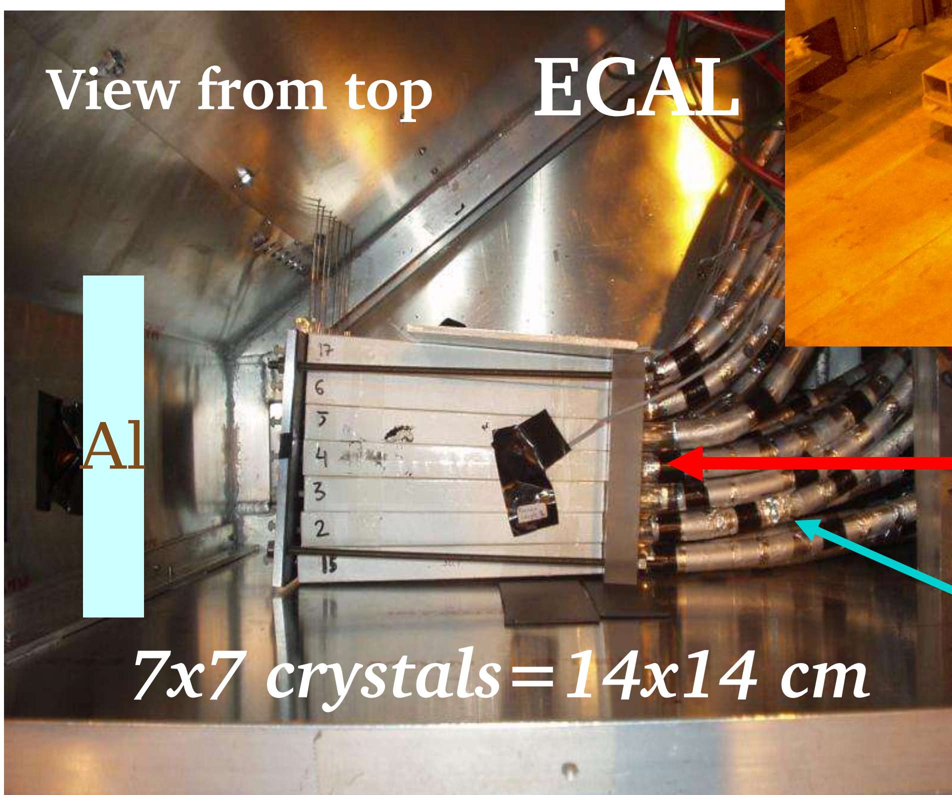
2 Hadron barrel wedges
1 Hadron endcap wedge
Hadron outer calorimeter

7x7 crystals ECAL
Material for Magnet
Movable table in η-ϕ plane



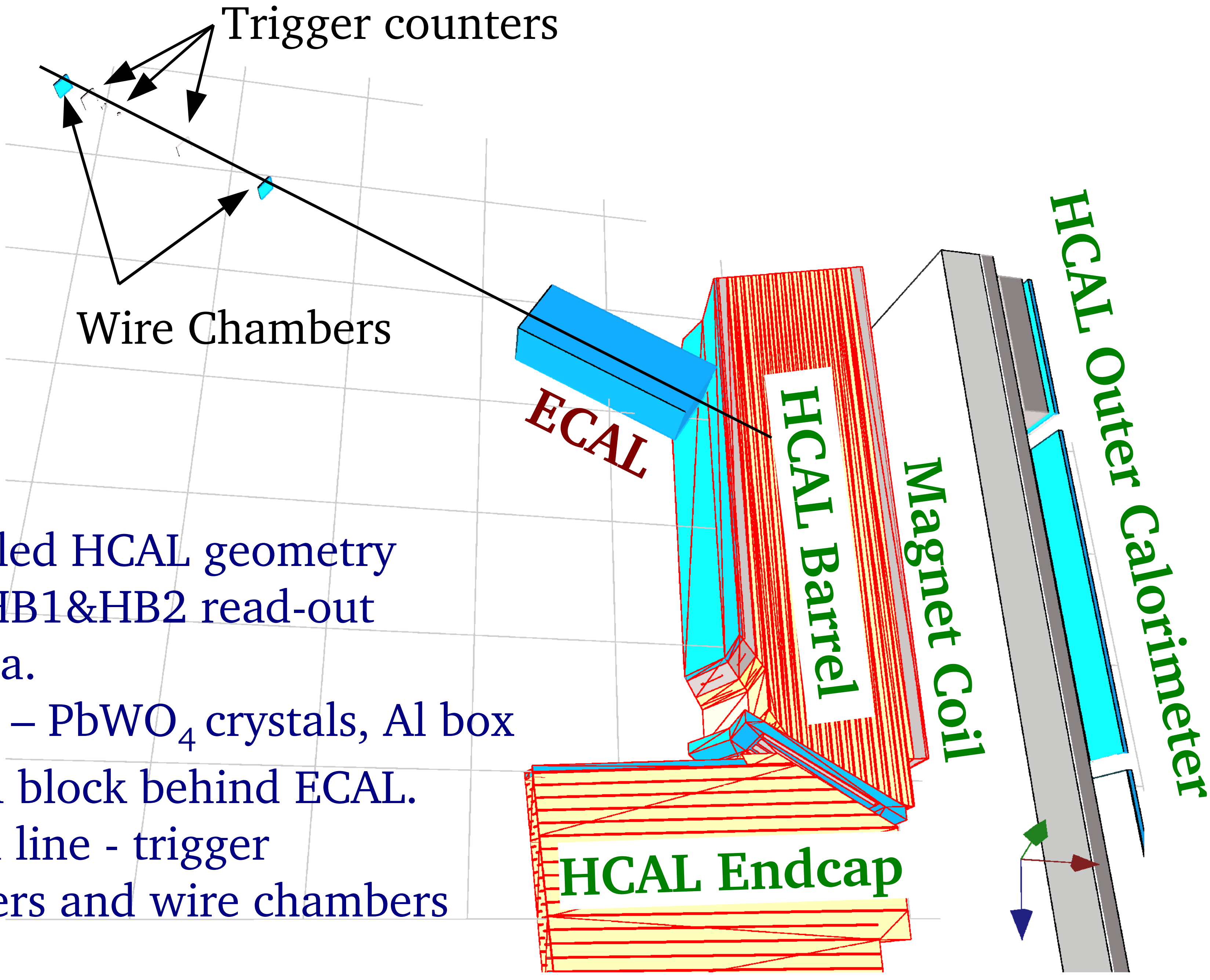
ECAL and HO





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

GEANT4 simulation



- Detailed HCAL geometry with HB1&HB2 read-out schema.
- ECAL – $PbWO_4$ crystals, Al box and Al block behind ECAL.
- Beam line - trigger counters and wire chambers

GEANT4 physics models validation

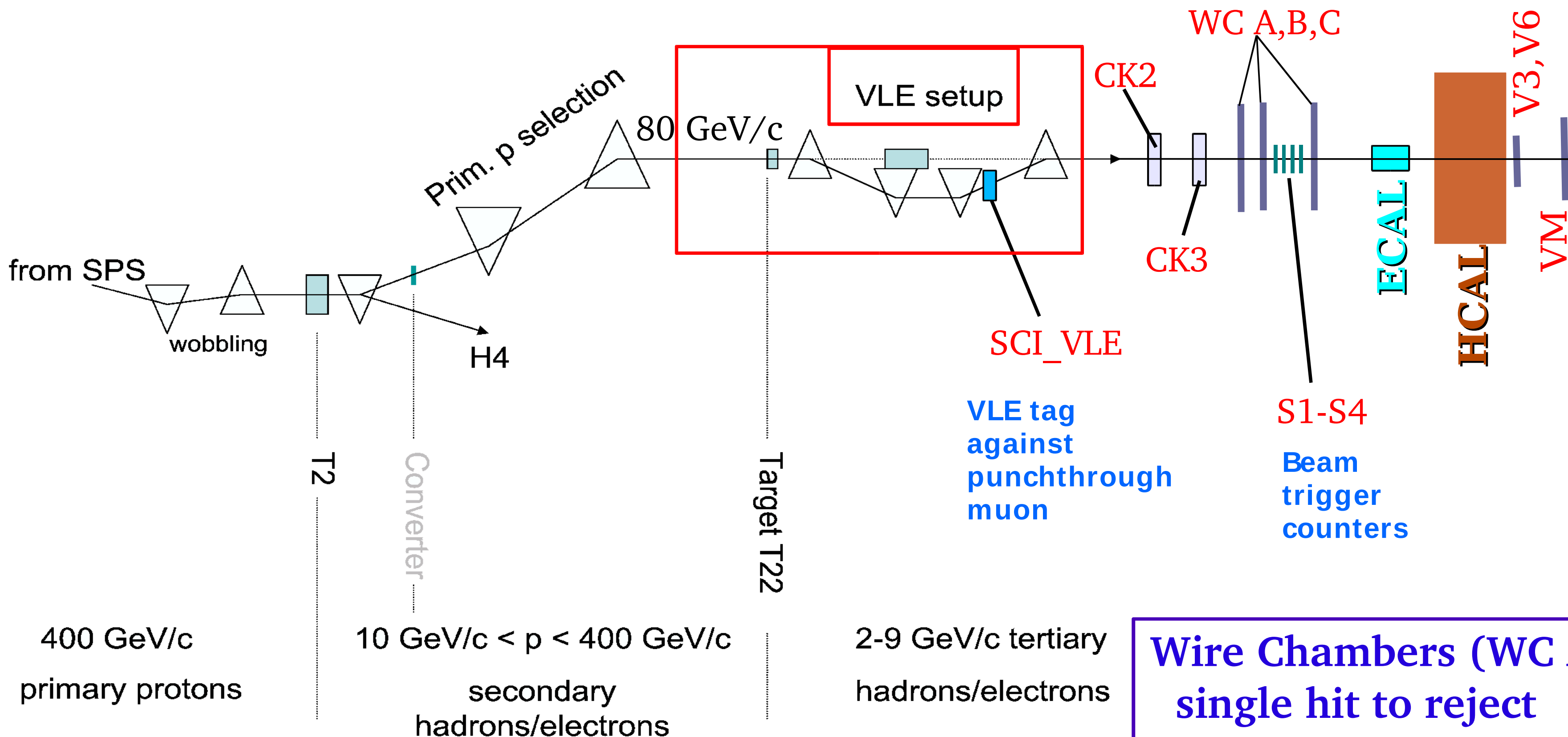
Physics lists tested against the test beam data :

- **LHEP**: **L**EP/**HEP** *parametrized* models for inelastic scattering.
- **QGSP**: **Q**uark **G**luon **S**tring model for the "**P**unch-through" interactions.
- **QGSC**: **QGS**P + **C**hiral invariant phase-space decay.
- **FTFP**: diffractive string excitation similar to that in FRITOF and Lund

In this comparison is used Geant 4.6.2.p02
Parametrized: **LHEP-3.7**
Model based: **QGSP-2.8**

QGSC-2.9 *and* ***FTFP-2.8*** *produce very similar to QGSP-**2.8** results.*

Beam line with particle identification 2-300 GeV/c



Wire Chambers (WC A,B,C):
single hit to reject interaction in beam line

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

P-ID:
- **Cerenkov counter (CK2) - electron**
- **Cerenkov counter (CK3) - pion / kaon / proton**
- **Scintillators (V3, V6, VM) – muon tagging**

Beam contamination and cleaning

Beam contamination before the clean up:

P_{beam} [GeV]	mu [%]	el- [%]
300	0.7	0
150	2	0
100	2	0
50	2.5	0
30	3.5	7
15	11	35
10	7	70
9	1.5	6
7	3.5	10
5	5.5	6
3	30	30
2	85	7

VLE beam line

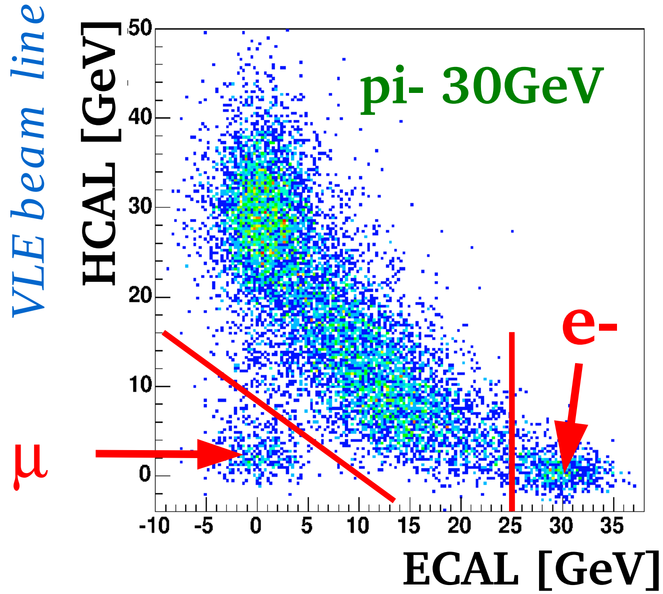
+ interaction in the beam line

2 and 3 GeV are not used

Beam cleaning:

- The particle Id counters are used for beam with momentum from 2 to 15 GeV
- Calorimeter based cuts: use the particle Id capabilities of the calorimeters.

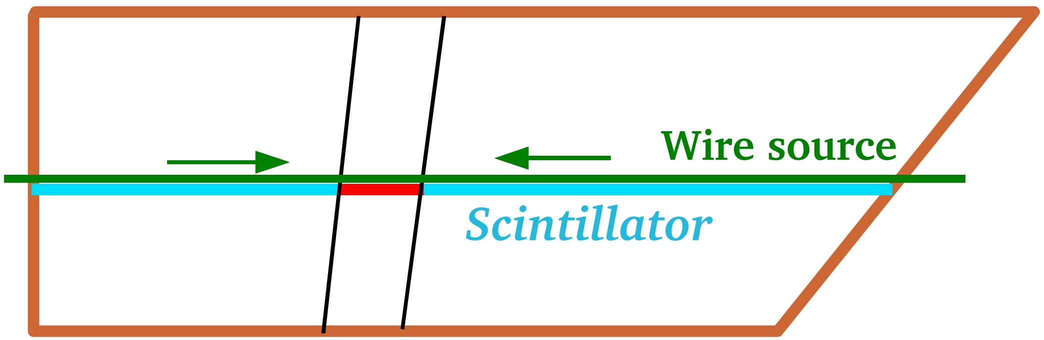
High energy muons a tagged by the muon veto counters with 99% efficiency. Low energy muons form pion decay are evaluated to be less then 1.5% for 9 GeV and below.



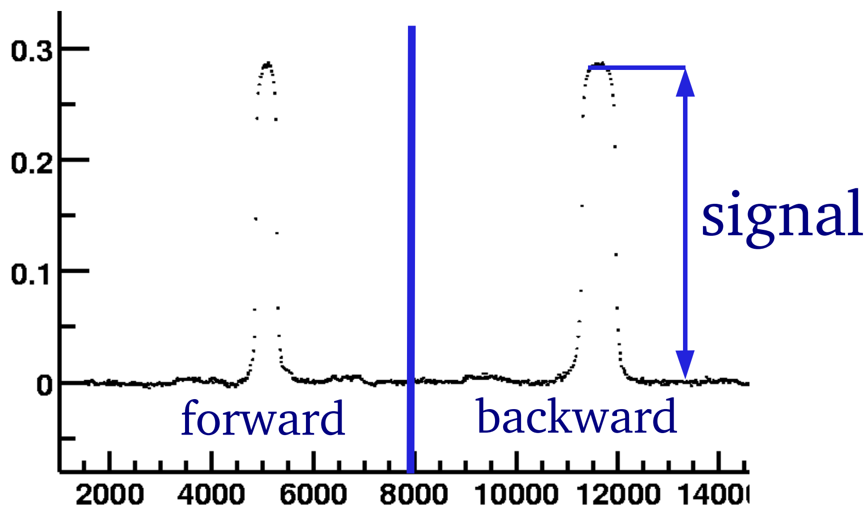
Electrons are clearly identify by ECAL/HCAL energy deposition.

Any remaining uncertainty in the beam contamination and interaction in the beam line is added to the systematics of the measurement.

Uniformity calibration and Energy Scale



See Mayda Velasco's talk



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

Reconstructed energy:

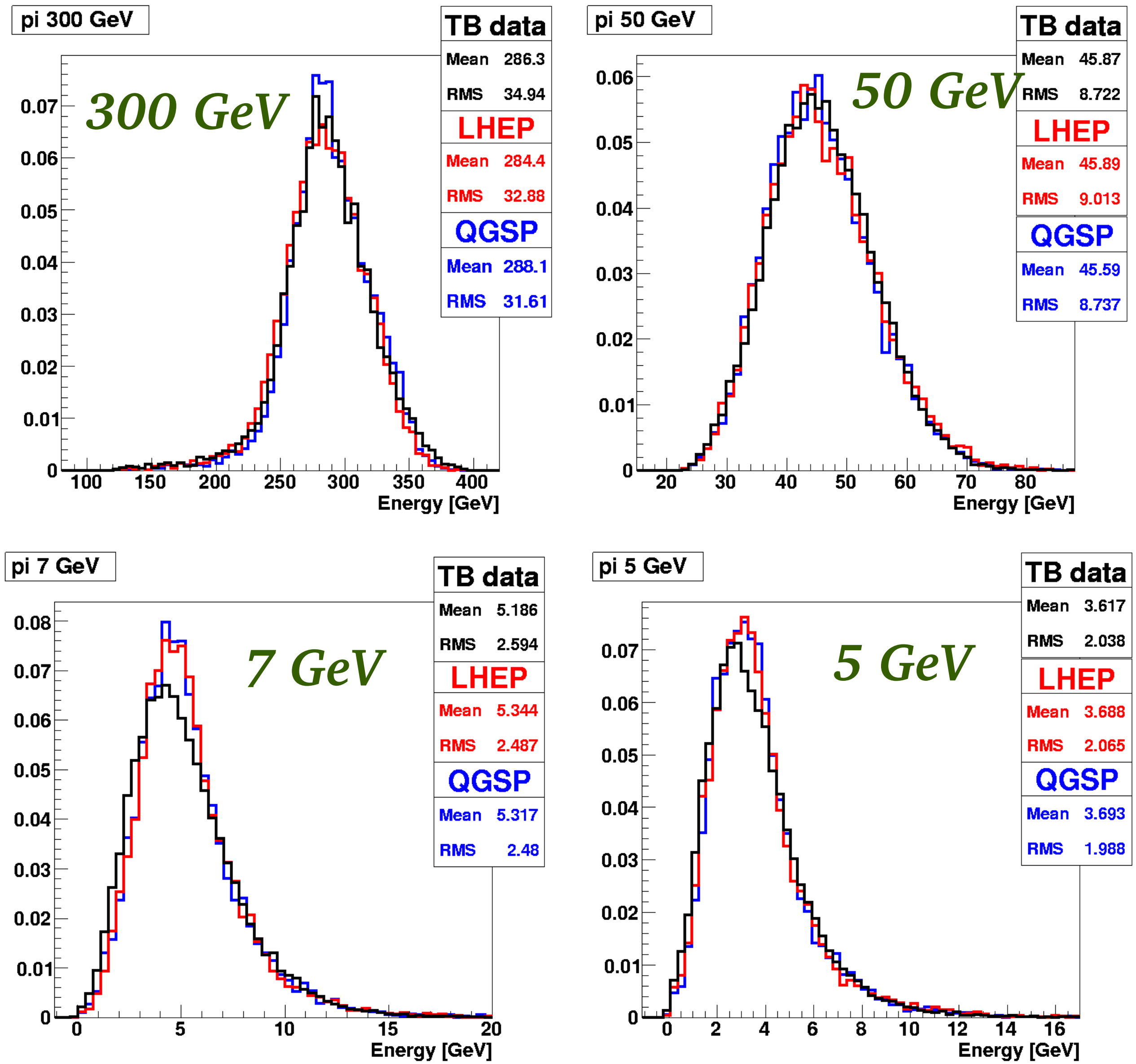
$$E_{rec} = a * E_{ECAL} + b * E_{HCAL}$$

Energy scale:

ECAL: 100 GeV e-

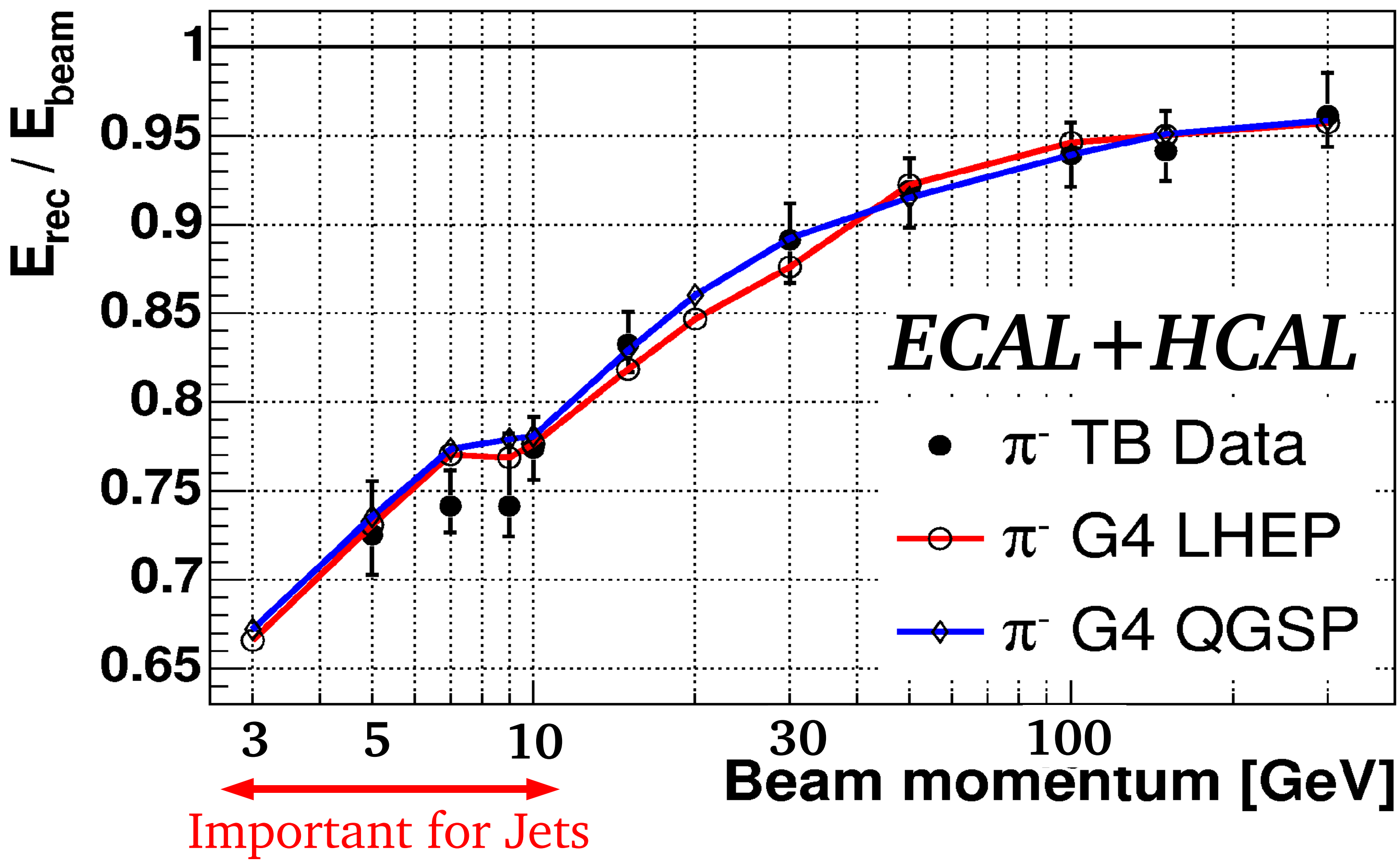
HCAL: 50 GeV pi- with MIP in ECAL.

Energy spectra ECAL+HCAL: data vs GEANT4



Good agreement between data and GEANT4 prediction.

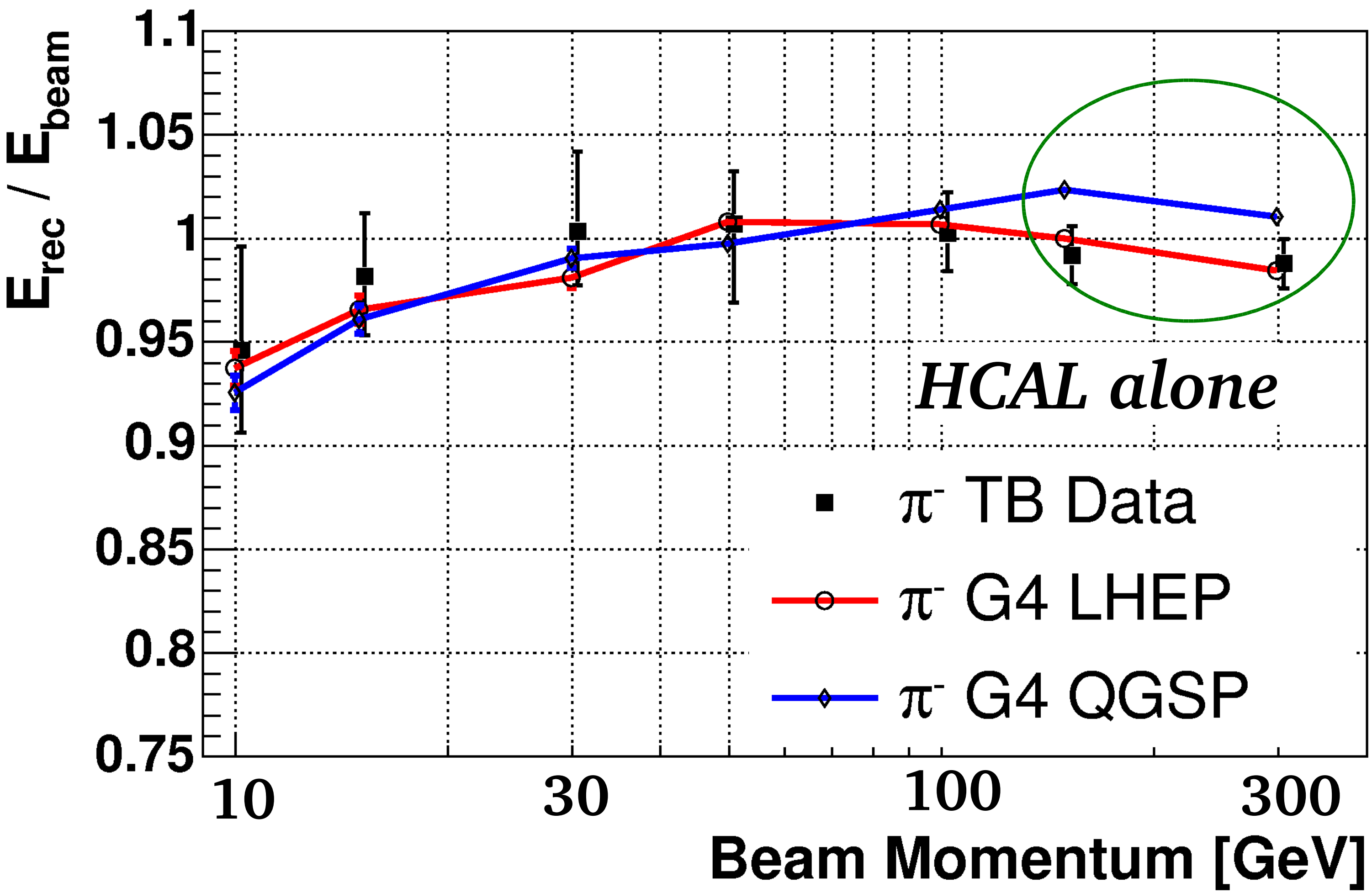
Calorimeter response to pions



GEANT4 models correctly the calorimeter response to pions in broad energy range. Correct representation of the single hadron response at low energy is important for simulation of the calorimeter response to jets.

Some discontinuity is observed at 7-10 GeV in the GEANT4 prediction.

HCAL alone response to pions

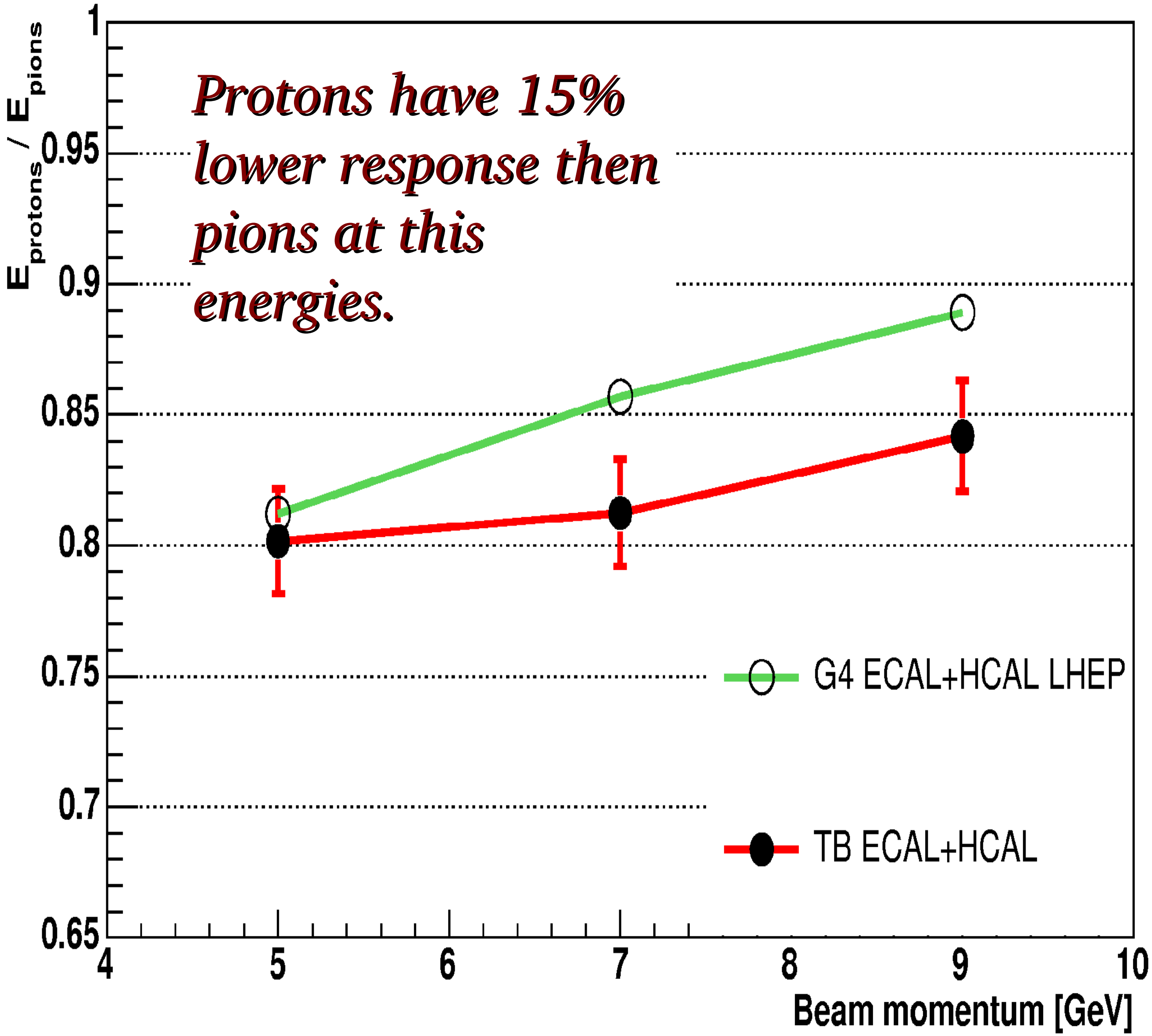


LHEP models better the high energy calorimeter response.

QGSP has less leakage on the back due to shorter shower.

HCAL alone: MIP in ECAL is required. HO is not used in this measurement to compensate the HB leakage on the back

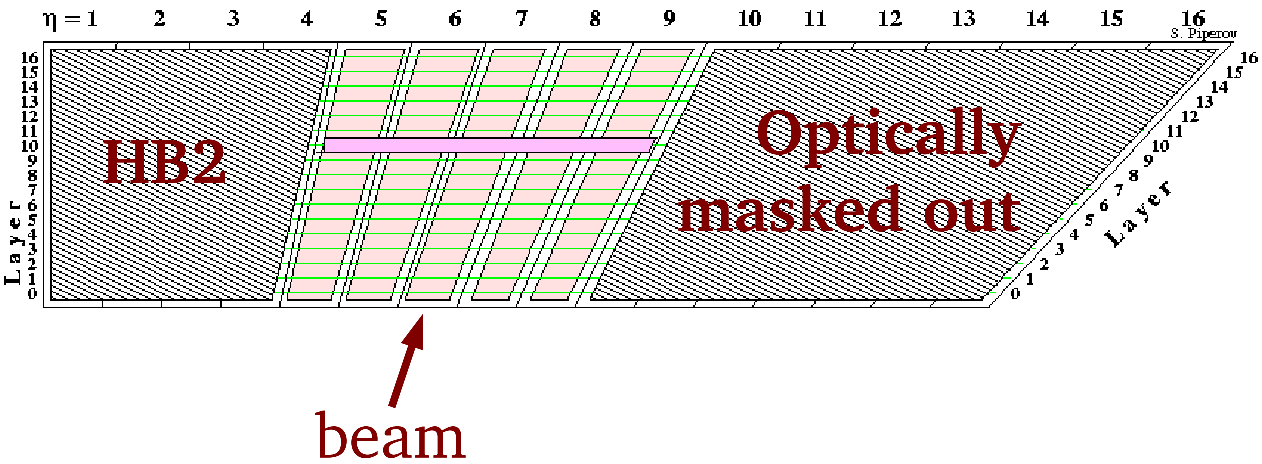
Proton over pion response ratio



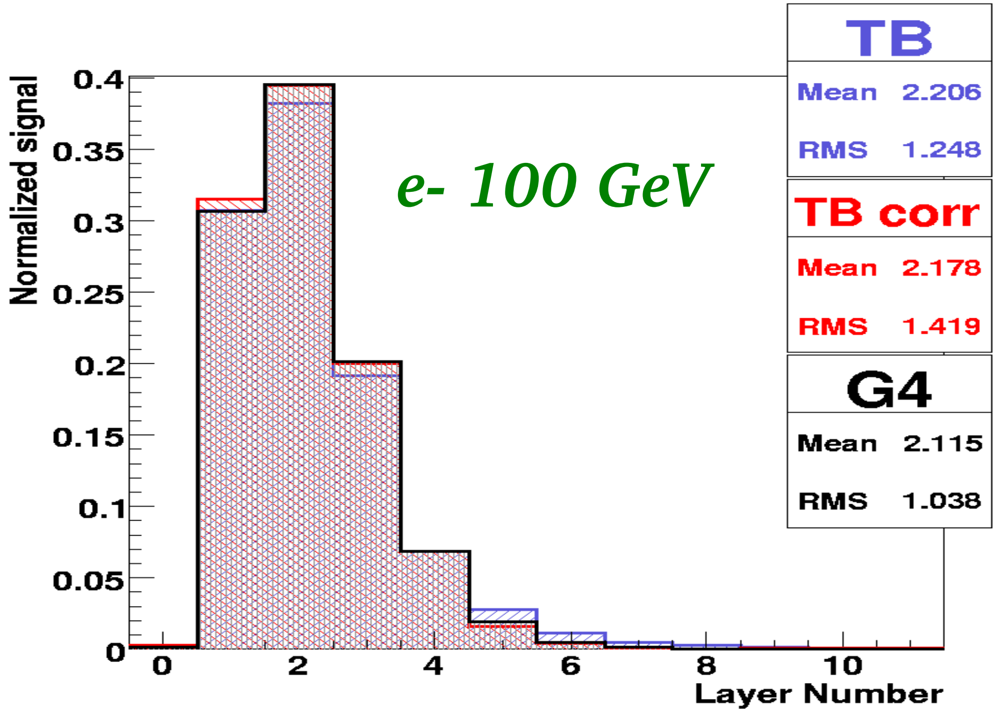
Significant difference in the calorimeter response to protons with respect to pions is observed in the data and is well represented in the GEANT4 simulation.

We will remeasure it this summer with improved particle Id.

Longitudinal shower profile measurement



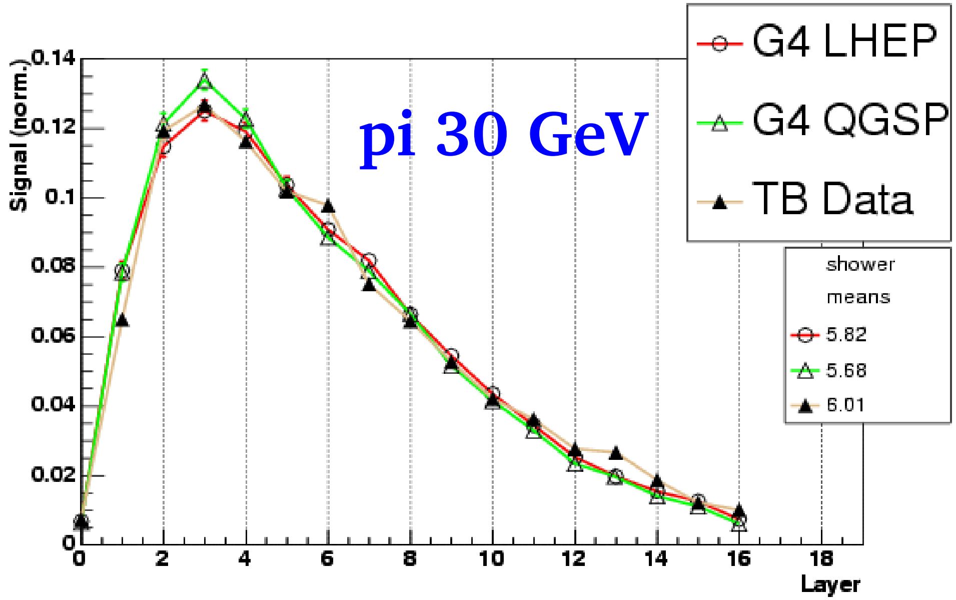
Modified read-out: redesigned optical decoding units to allow longitudinal shower measurement

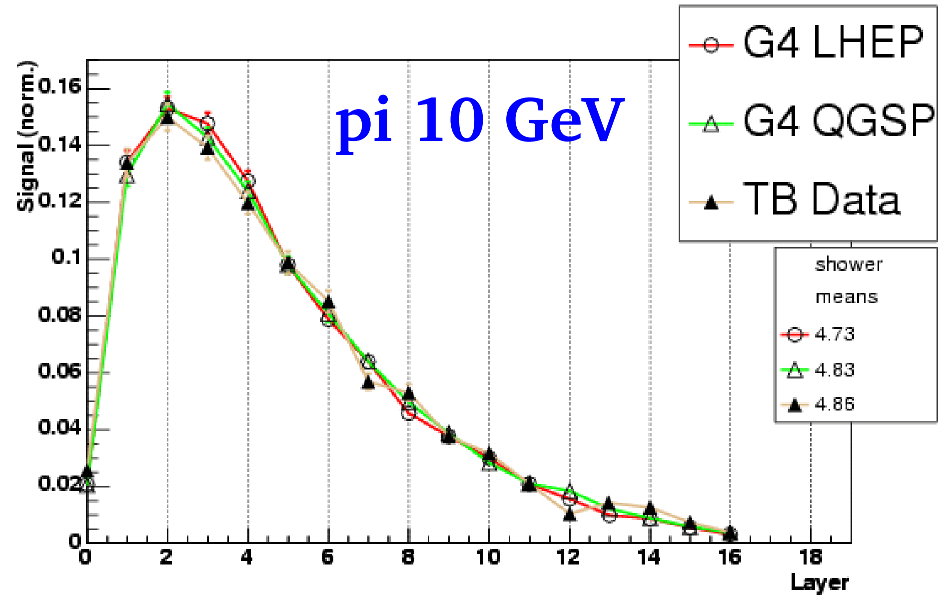


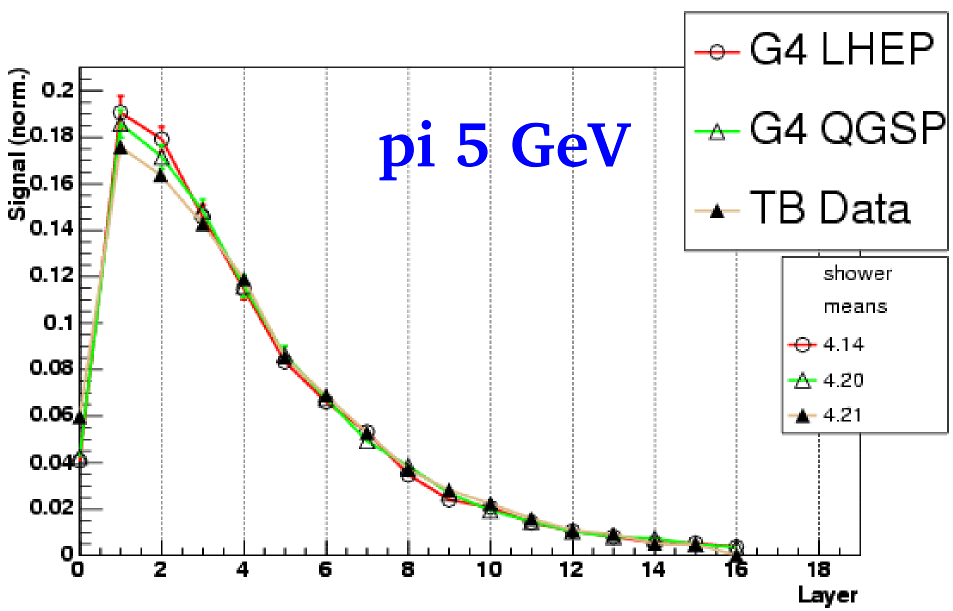
Electromagnetic shower profile in HCAL

Very good agreement between test beam data and GEANT4 prediction.

Longitudinal shower profile measurement (cont.)

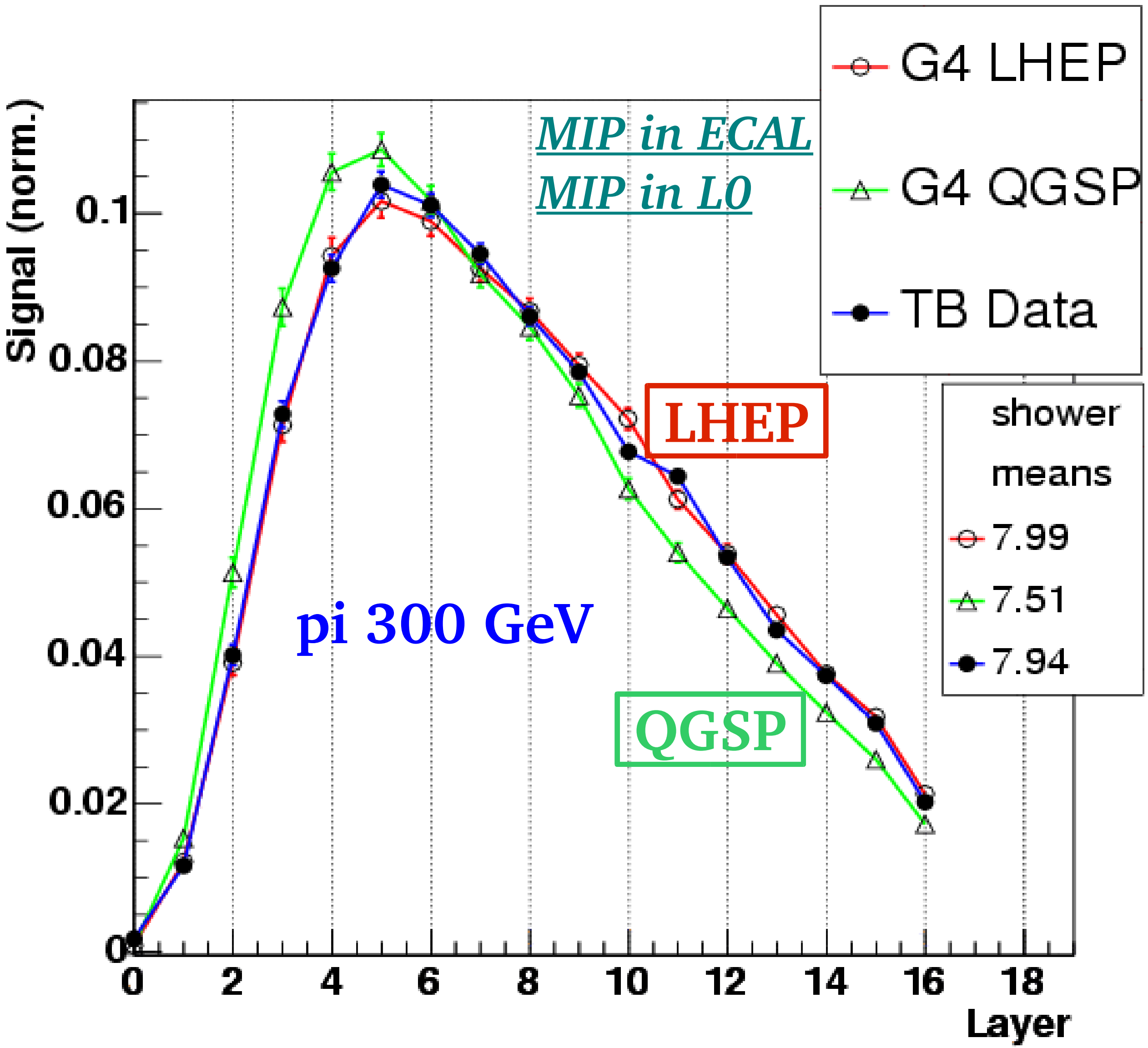






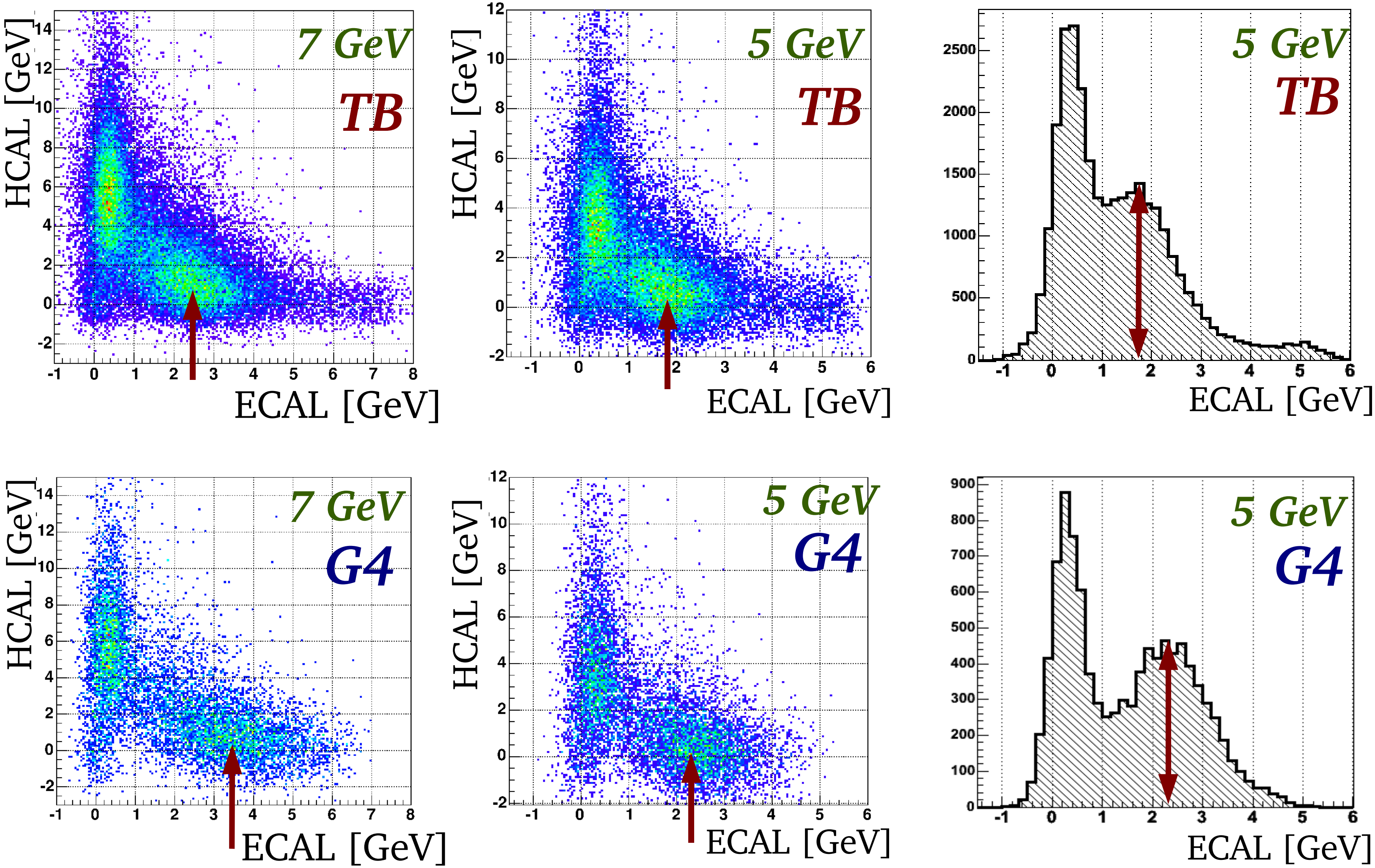
LHEP and QGSP show good agreement with test beam data at low and intermediate energies.

Longitudinal shower profile measurement (cont.)



QGSP physics list has shorter shower profile for incident particles with high momentum.

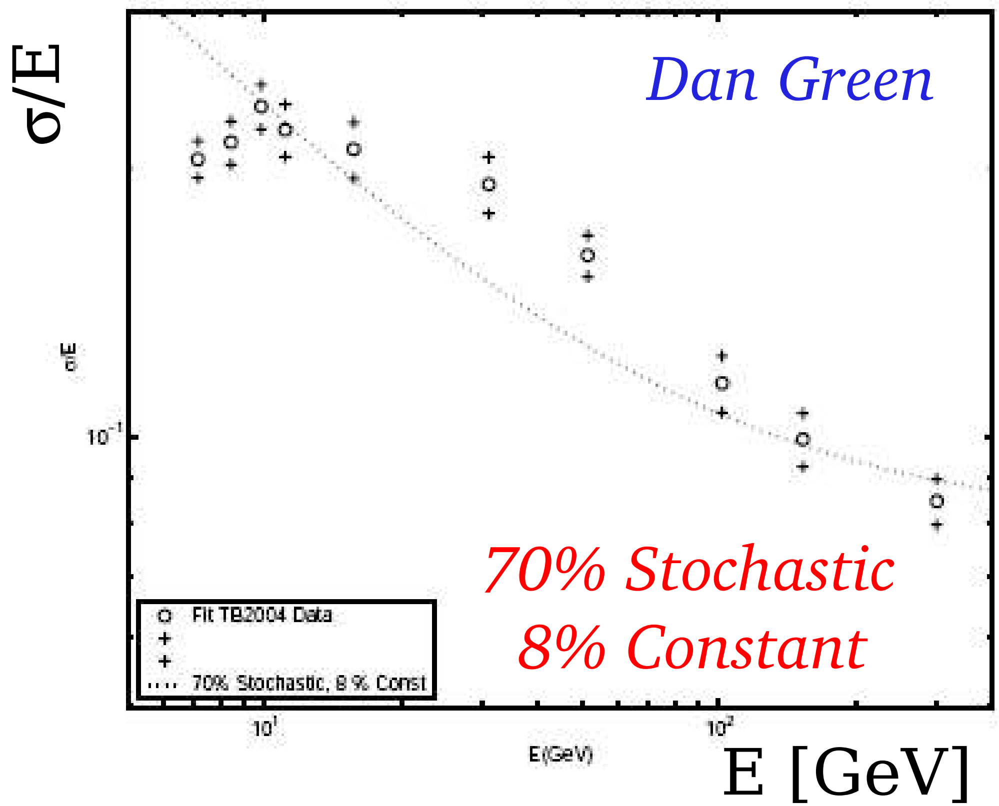
HCAL - ECAL response to very low energy pion beam



ECAL response is higher in GEANT4 at low energy: geometry or physics or …?

Cluster-based response compensation

Fractional energy resolution for pions.



Uses test beam data to fit the intrinsic electron to hadron response (e/h) and the average neutral fraction f_0 of the ECAL and HCAL as a function of the raw total calorimeter energy, E + H.

Conclusions and Outlook

- Calorimeter response for momentum range 5-300 GeV/c was measured with test beam in 2004.

- GEANT4 is in good overall agreement with the data
- LHEP shows best agreement

- We observed small discrepancy in the following quantities :
  1) Longitudinal shower shape for 150-300 GeV/c pions, modeled by QGSP physics list
  2) Discontinuity in the calorimeter response in 7-10 GeV/c range
  3) ECAL response to very low energy pion beam is higher in the GEANT4 simulation .

- *We plan to repeat the measurements this summer with ECAL production super-module and improved particle Id.*