

Hadron particle detection (with the CMS detector)

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Sep.19, 2012, CERN

Outline

- Small introduction
- Hadron Calorimetry: Measuring the energy of a hadron
- CMS detector and its calorimetric systems
- TestBeam Measurements
- MonteCarlo Simulation and comparison to TestBeam

Before we start...

What do we know about matter?

Matter particles
All ordinary particles belong to this group

LEPTONS		QUARKS		
FIRST FAMILY	Electron Responsible for electricity and chemical reactions; it has a charge of -1	Electron neutrino Particle with no electric charge, and possibly no mass; billions fly through your body every second	Up Has an electric charge of plus two-thirds; protons contain two, neutrons contain one	Down Has an electric charge of minus one-third; protons contain one, neutrons contain two
SECOND FAMILY	Muon A heavier relative of the electron; it lives for two-millionths of a second	Muon neutrino Created along with muons when some particles decay	Charm A heavier relative of the up; found in 1974	Strange A heavier relative of the down; found in 1964
THIRD FAMILY	Tau Heavier still; it is extremely unstable. It was discovered in 1975	Tau neutrino not yet discovered but believed to exist	Top Heavier still	Bottom Heavier still; measuring bottom quarks is an important test of electroweak theory

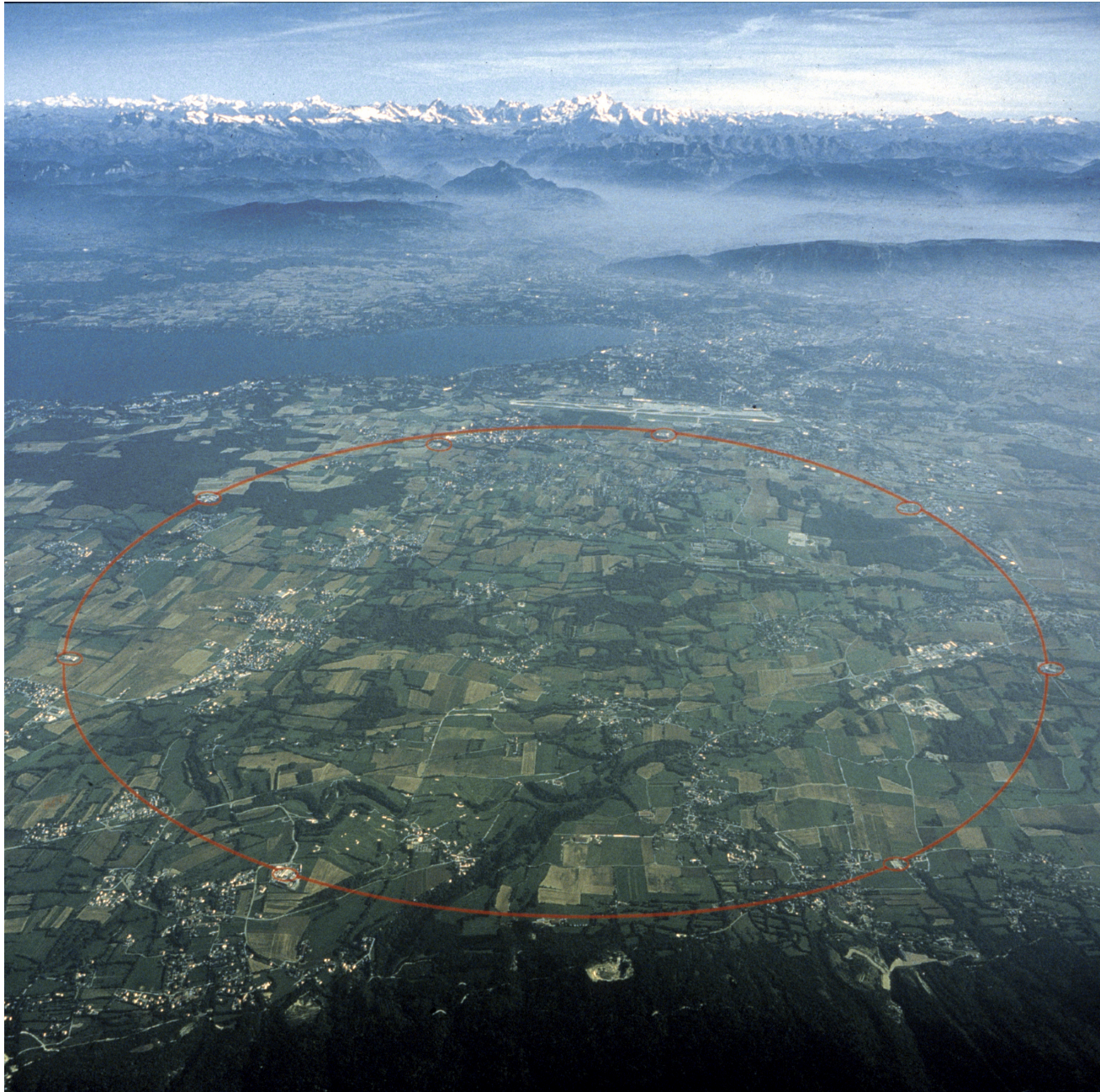
Force particles
These particles transmit the four fundamental forces of nature although gravitons have so far not been discovered

Gluons Carriers of the strong force between quarks Felt by: quarks The explosive release of nuclear energy is the result of the strong force	Photons Particles that make up light; they carry the electromagnetic force Felt by: quarks and charged leptons Electricity, magnetism and chemistry are all the results of electro-magnetic force	Intermediate vector bosons Carriers of the weak force Felt by: quarks and leptons Some forms of radio-activity are the result of the weak force	Gravitons Carriers of gravity Felt by: all particles with mass All the weight we experience is the result of the gravitational force
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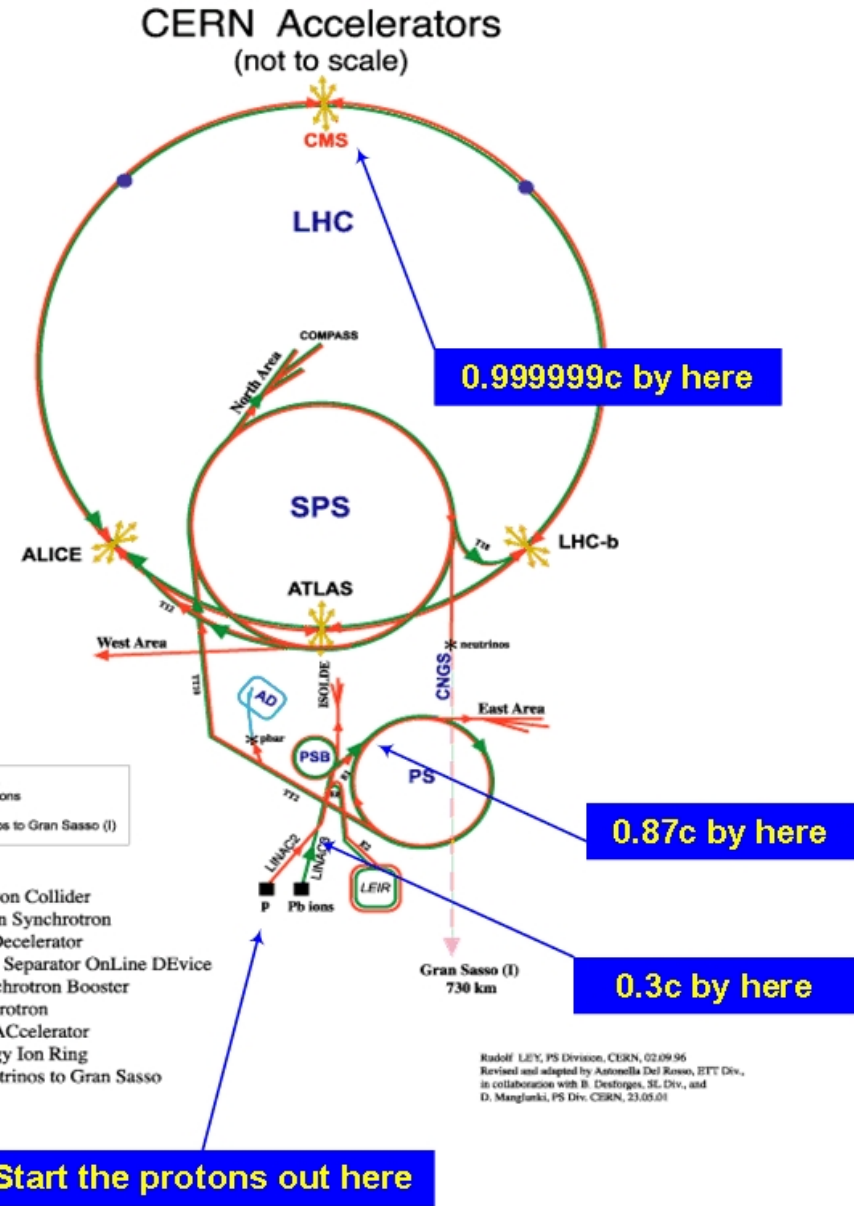
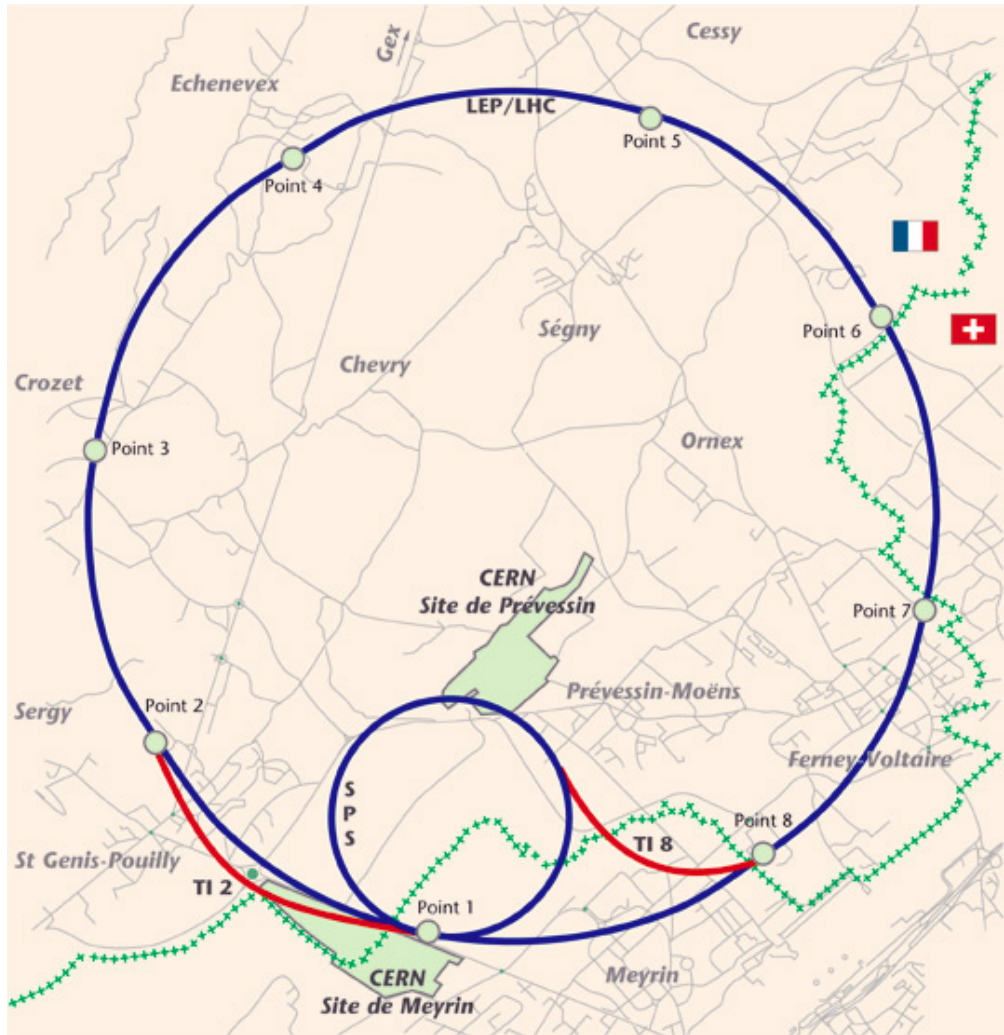
GRAPHICS: PETER CROWTHER

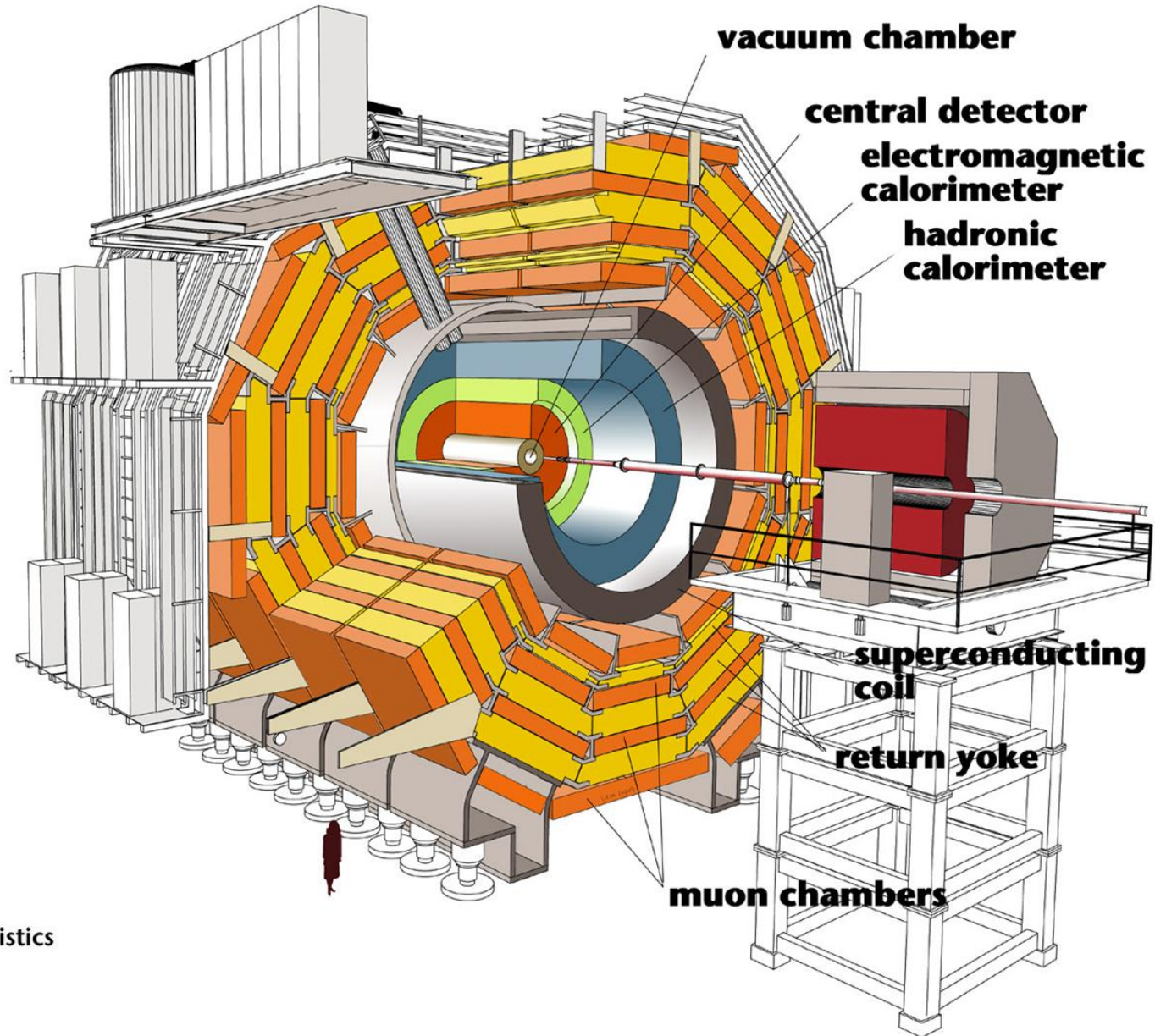
This is what we know about the particles that constitute our Universe. The only thing still missing WAS the Higgs-boson that gives mass to all the particles. Plus everything that we still don't know about...

LHC, CERN, Geneva



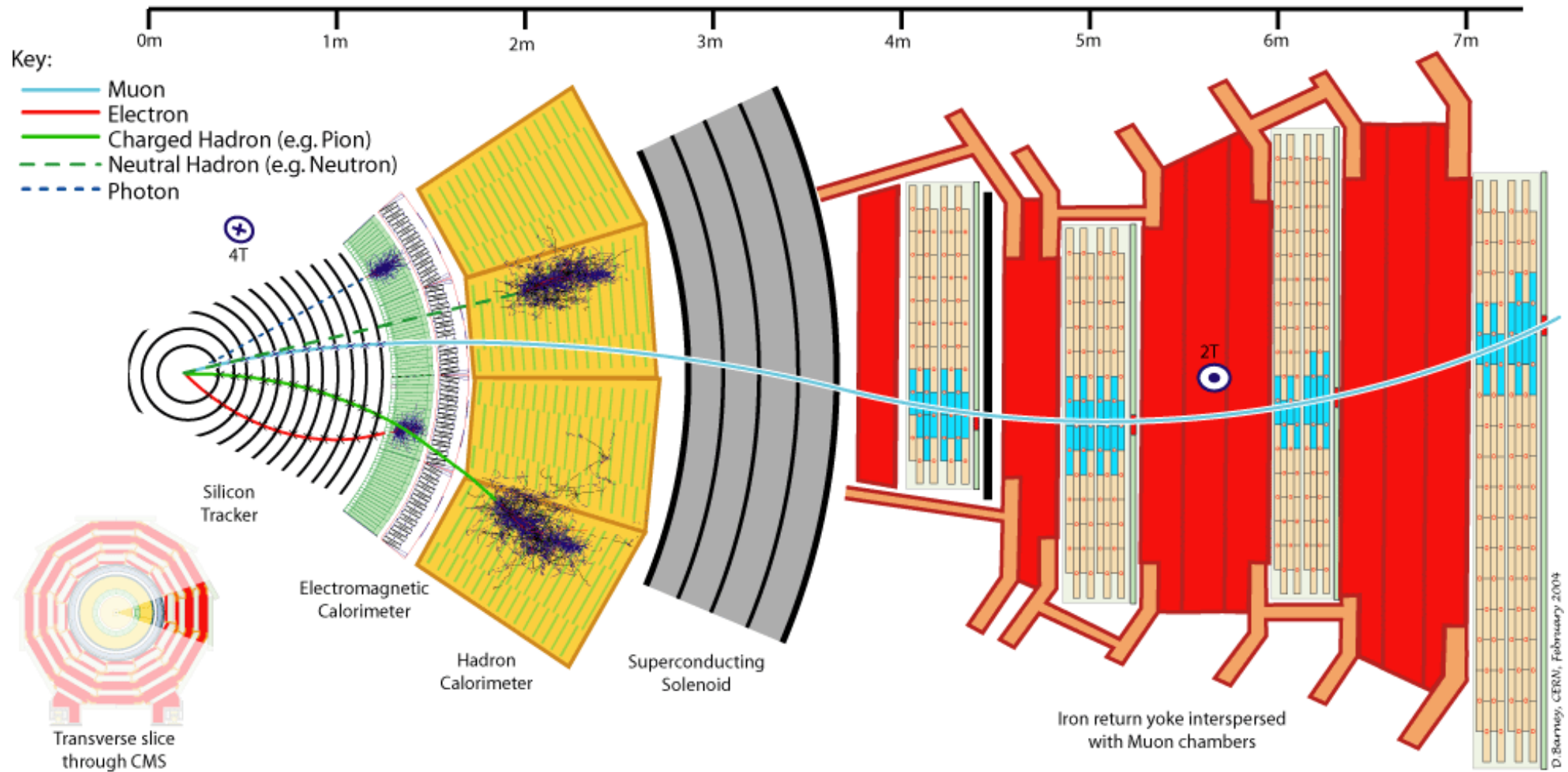
CERN and the Accelerators Complex





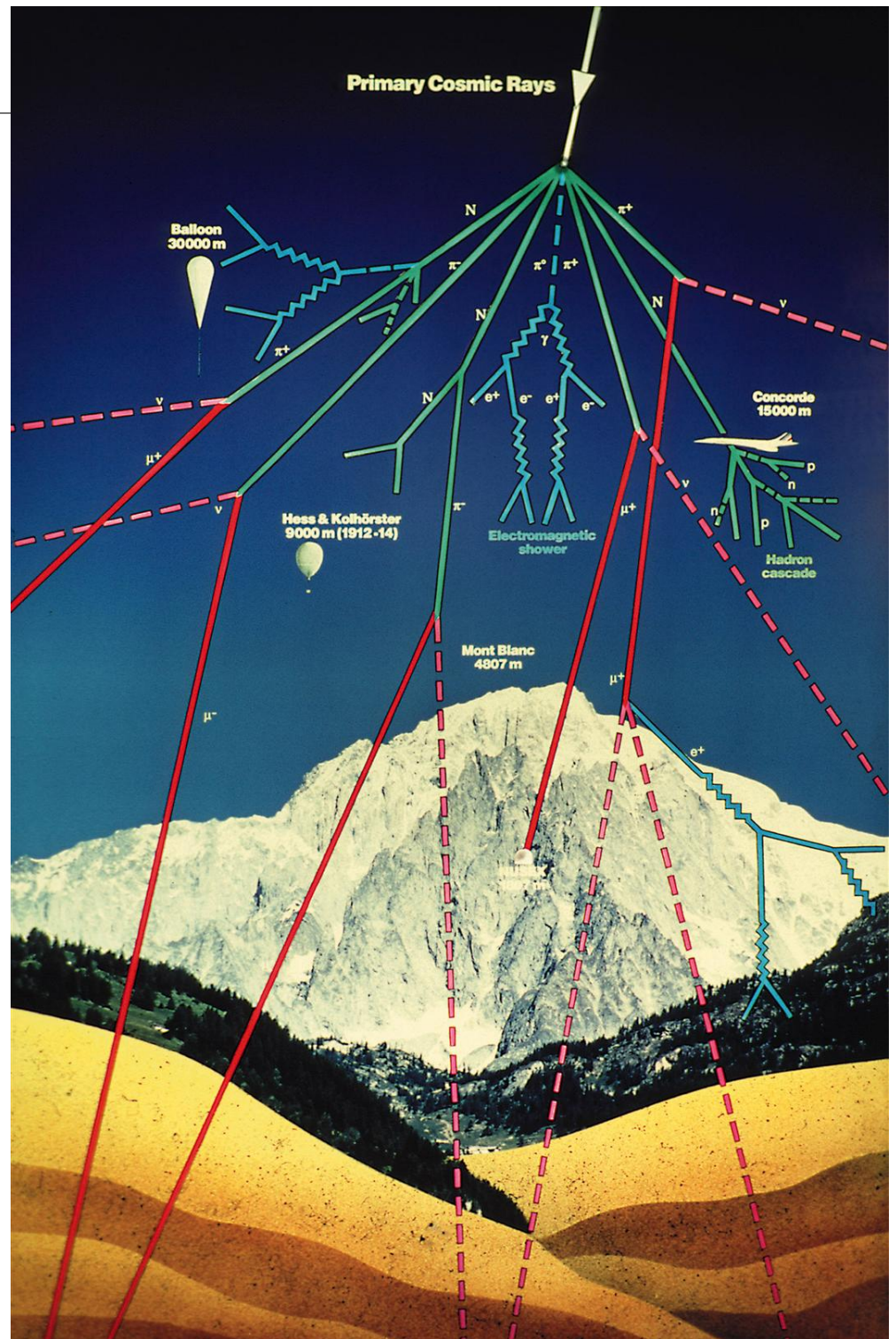
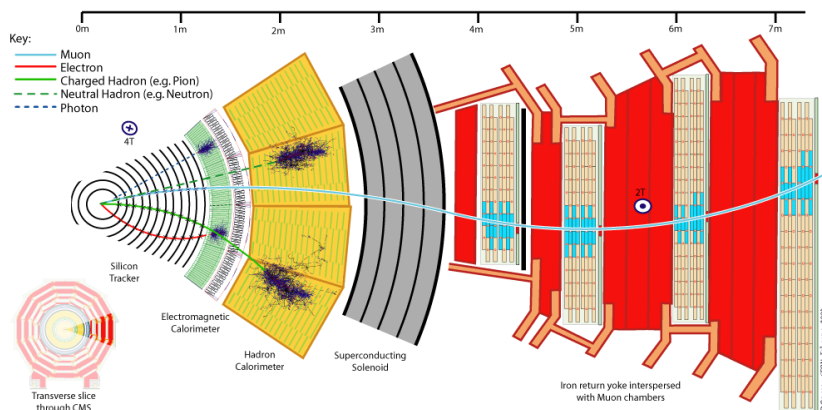
Detector characteristics

Width: 22m
Diameter: 15m
Weight: 14'500t



Atmospheric Showers

Something similar happens to the hadrons in the atmosphere above us:

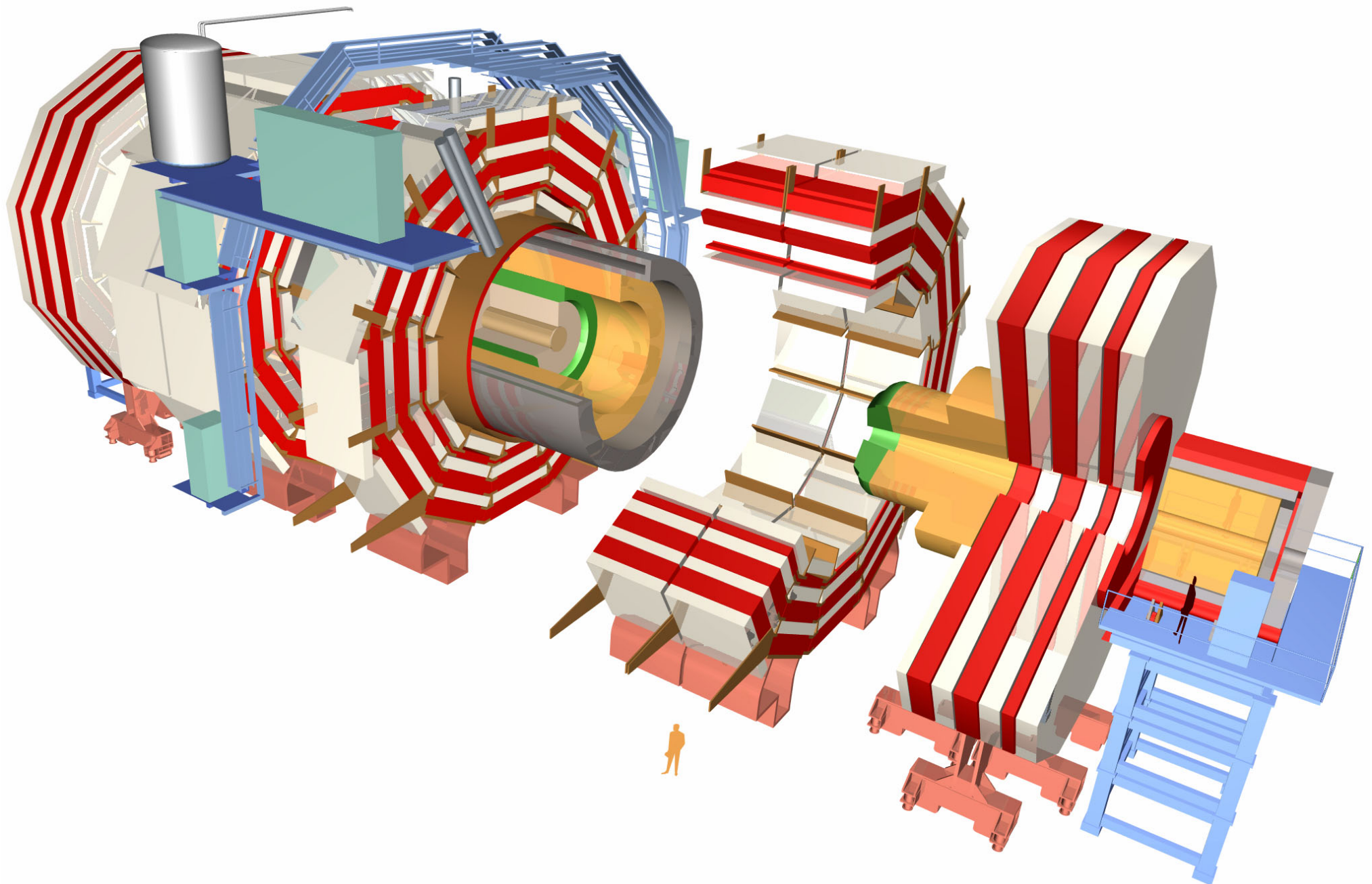


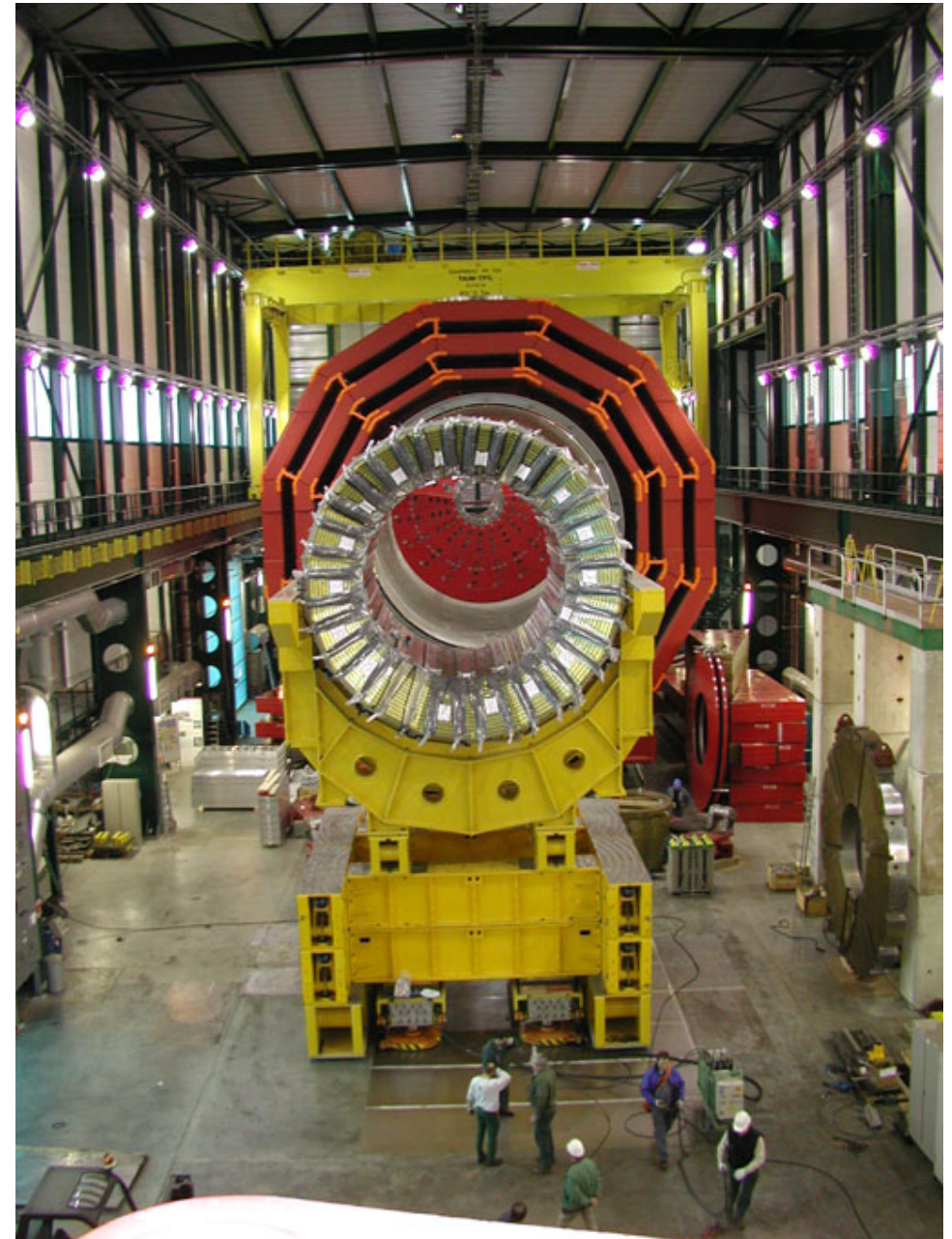
Function of Calorimeters:

- Measure the energy of a hadron (in most cases - jets of hadrons)
- Provide hermeticity, so that missing energy can be measured

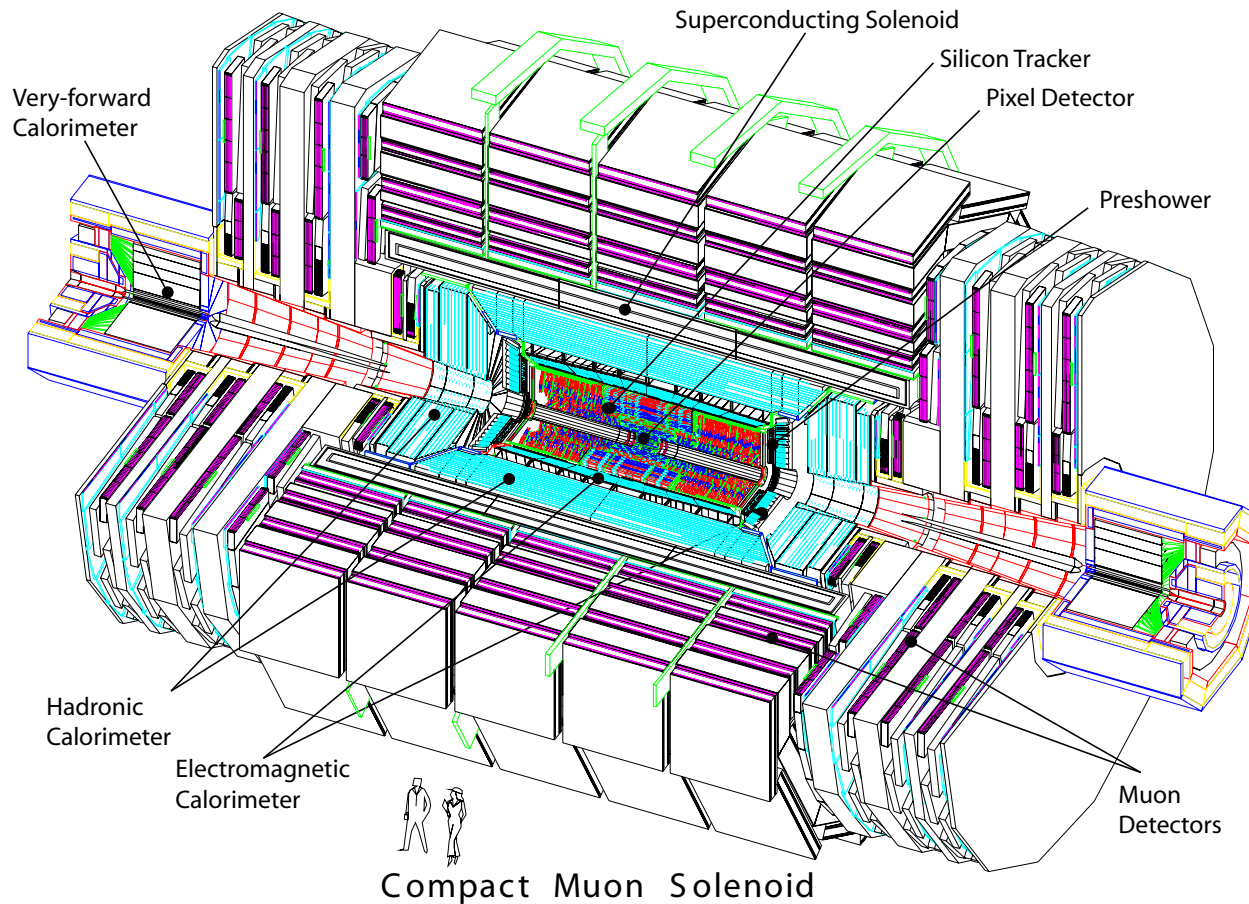
Depending on their function and application, calorimeters can be of various kinds:

- Homogeneous vs. Sampling (structure)
- Solid vs. Liquid (medium)
- Scintillating vs. Cherenkov (signal)
- Compensating vs. Non-compensating (performance)

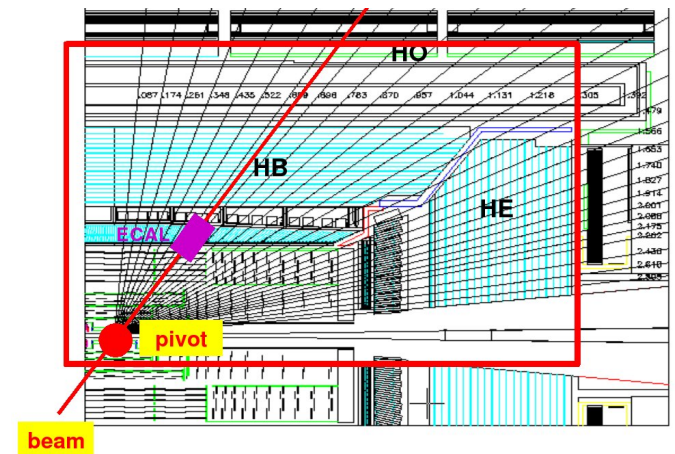








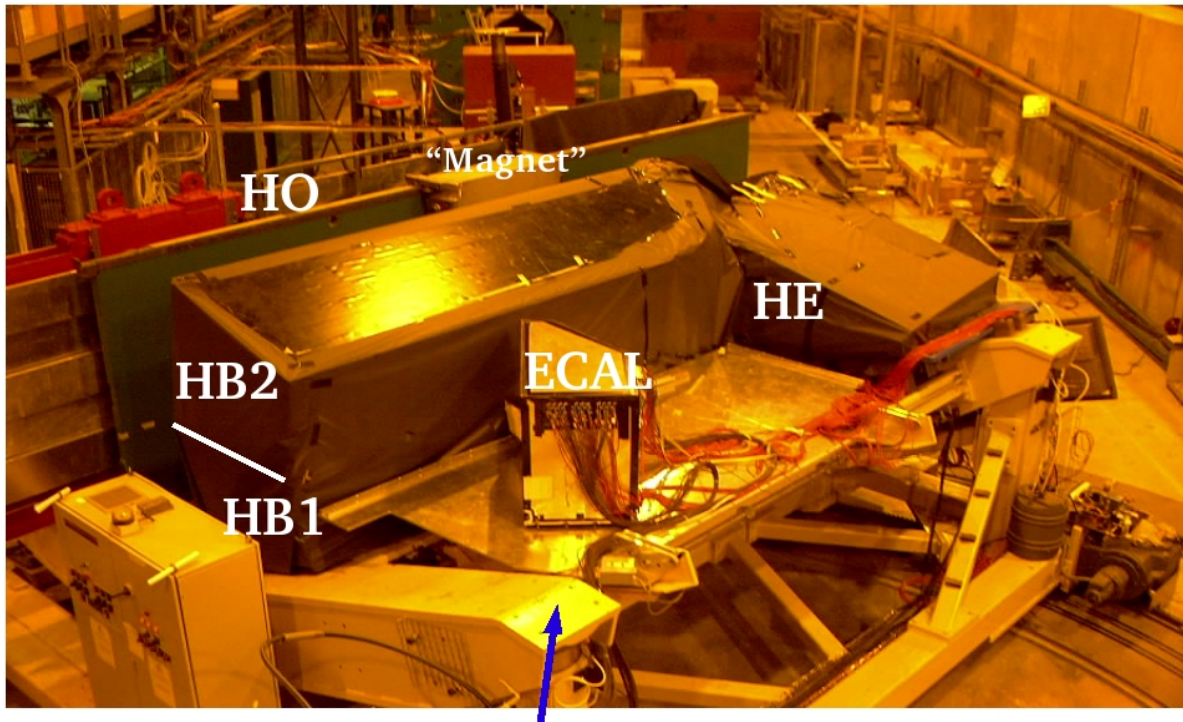
HCAL = Hadronic Calorimeter
 ECAL = Electromagnetic Calorimeter
 HB = HCAL Barrel
 HE = HCAL EndCap
 HO = HCAL Outer



Calorimetric systems present on the Testbeam 2004 table.

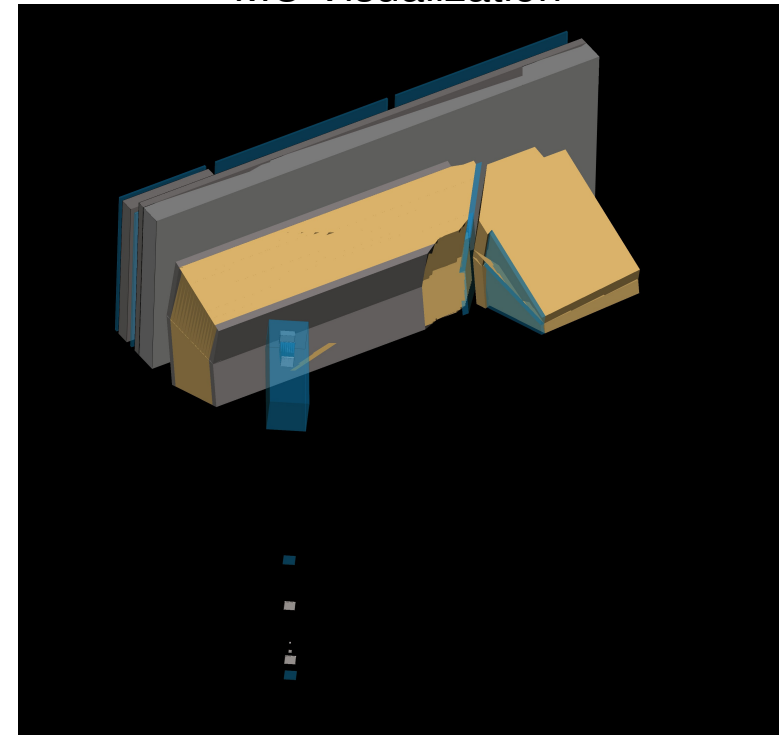
Pivot point corresponds to interaction point in CMS. ECAL is a matrix of 7x7 prototype crystals. HCAL Barrel modules are production wedges readout with real front-end electronics.

Photo of testbeam area



Beam from SPS.

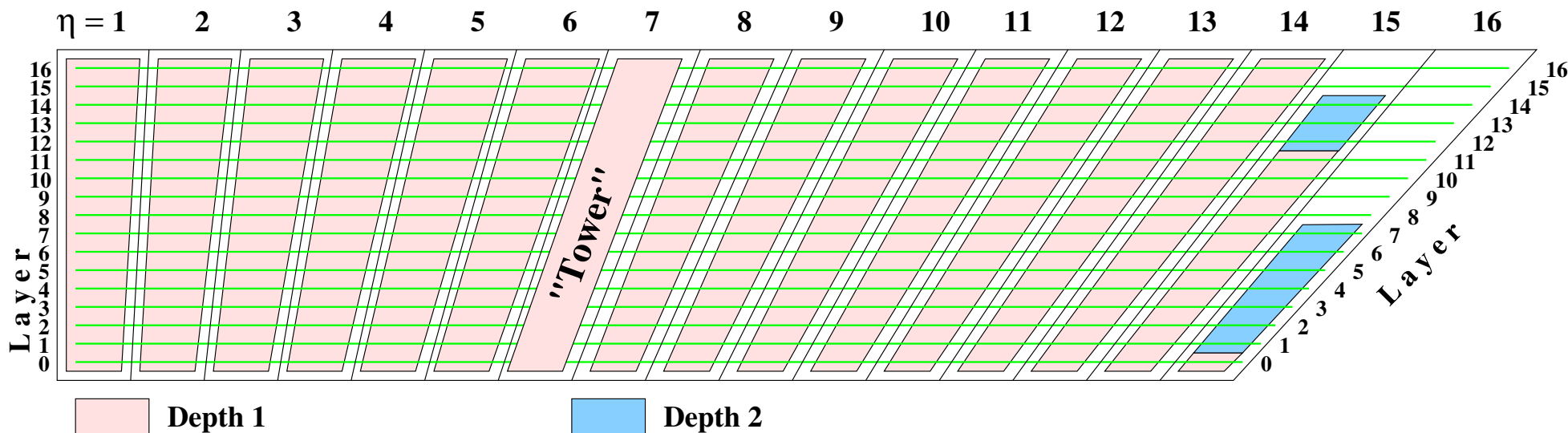
MC Visualization



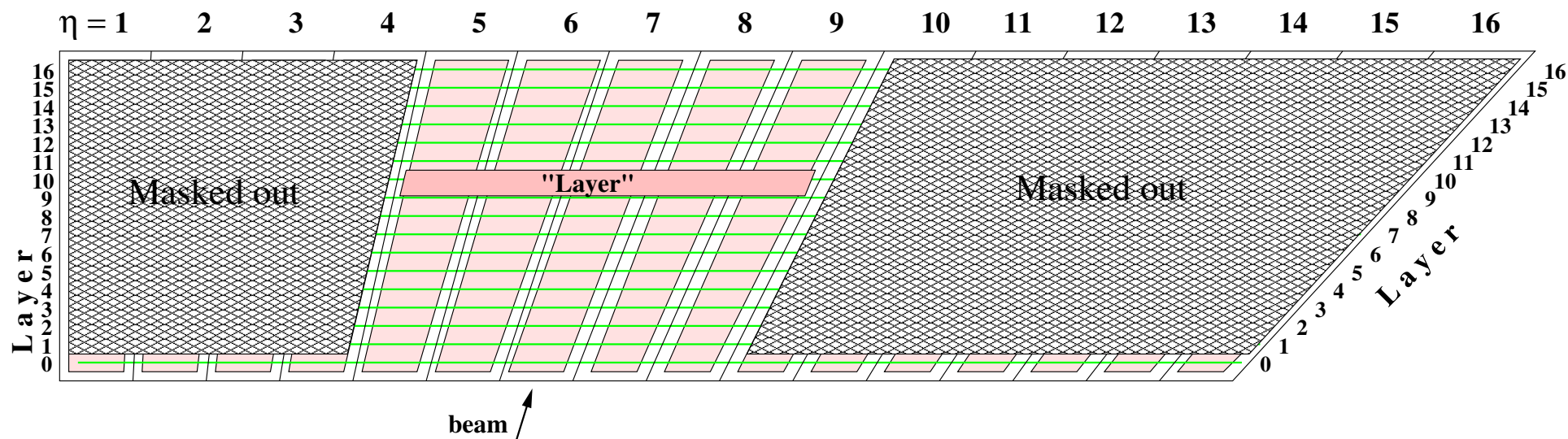
Moving table allows beam to be sent into arbitrary eta/phi tower of HCAL.
ECAL crystals always stay in the beam.

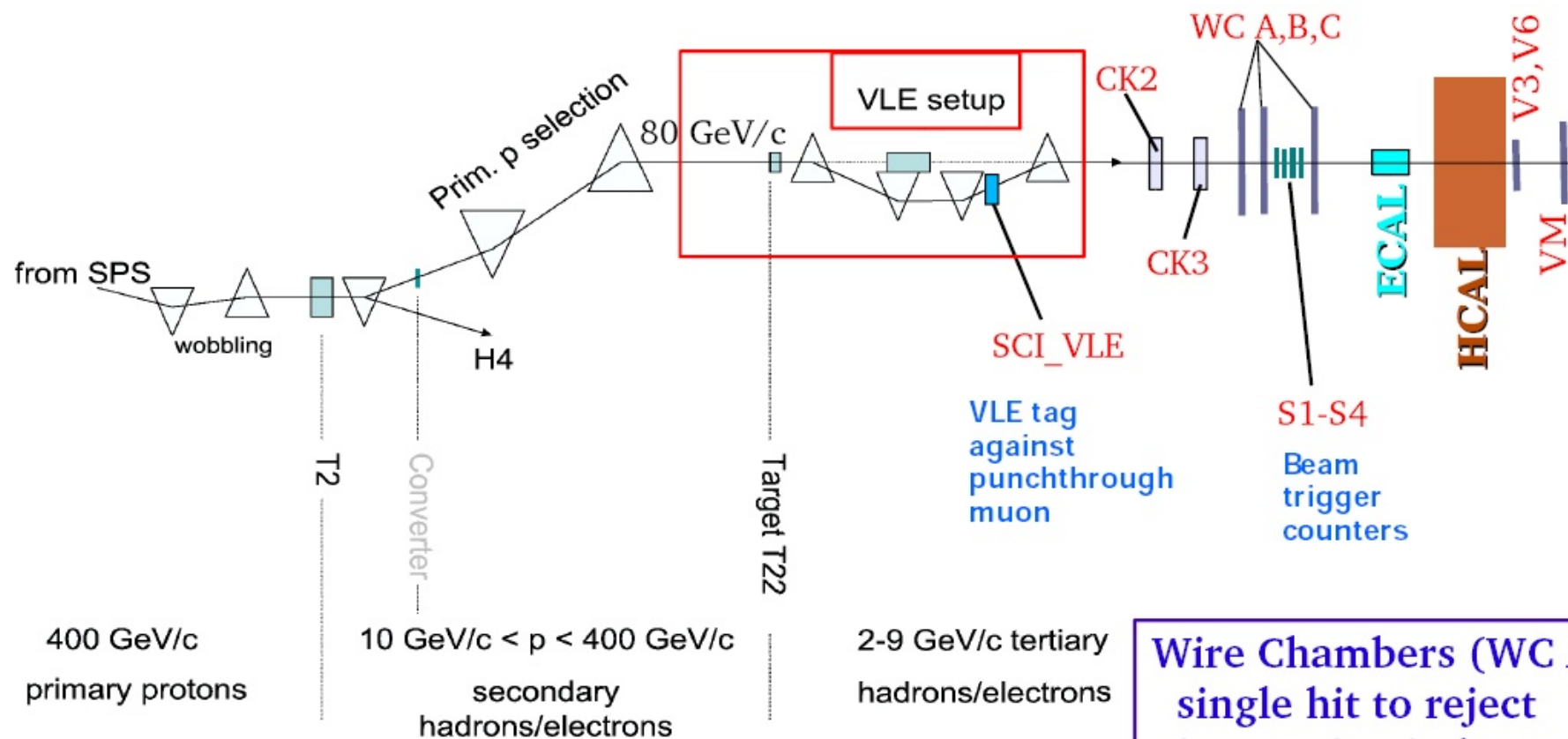


HB1: tower-wise readout – normal, as in CMS



HB2: Layer-wise readout – for longitudinal shower profile studies



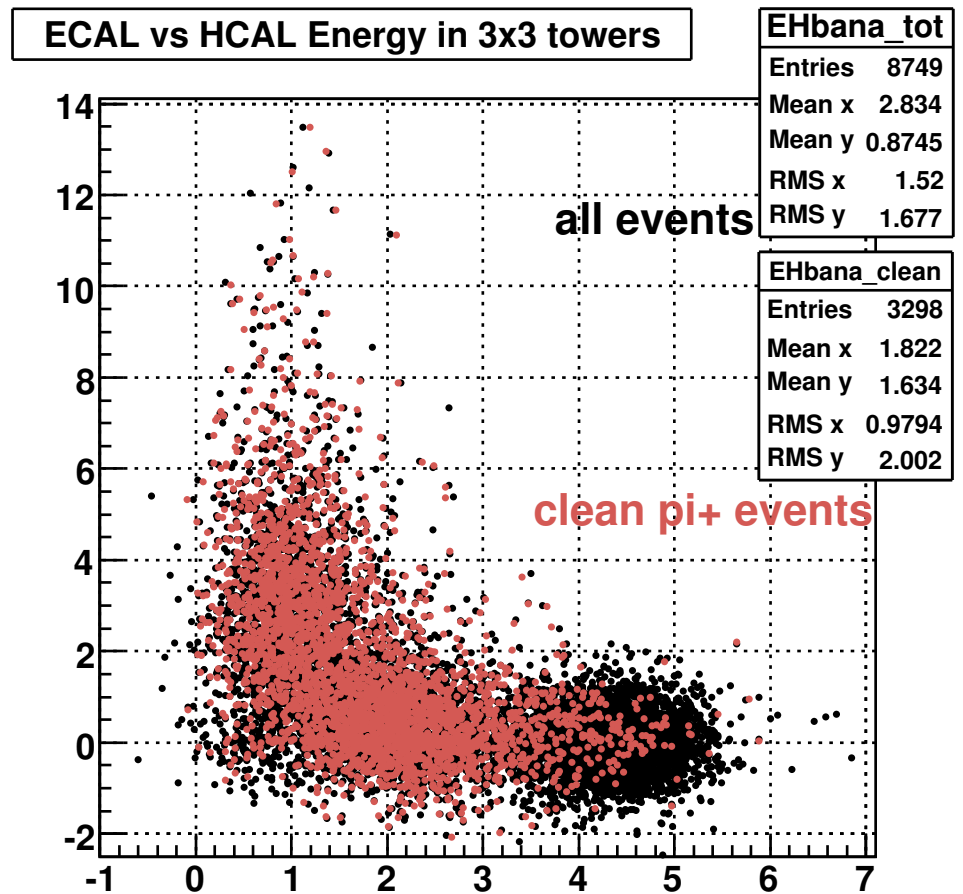
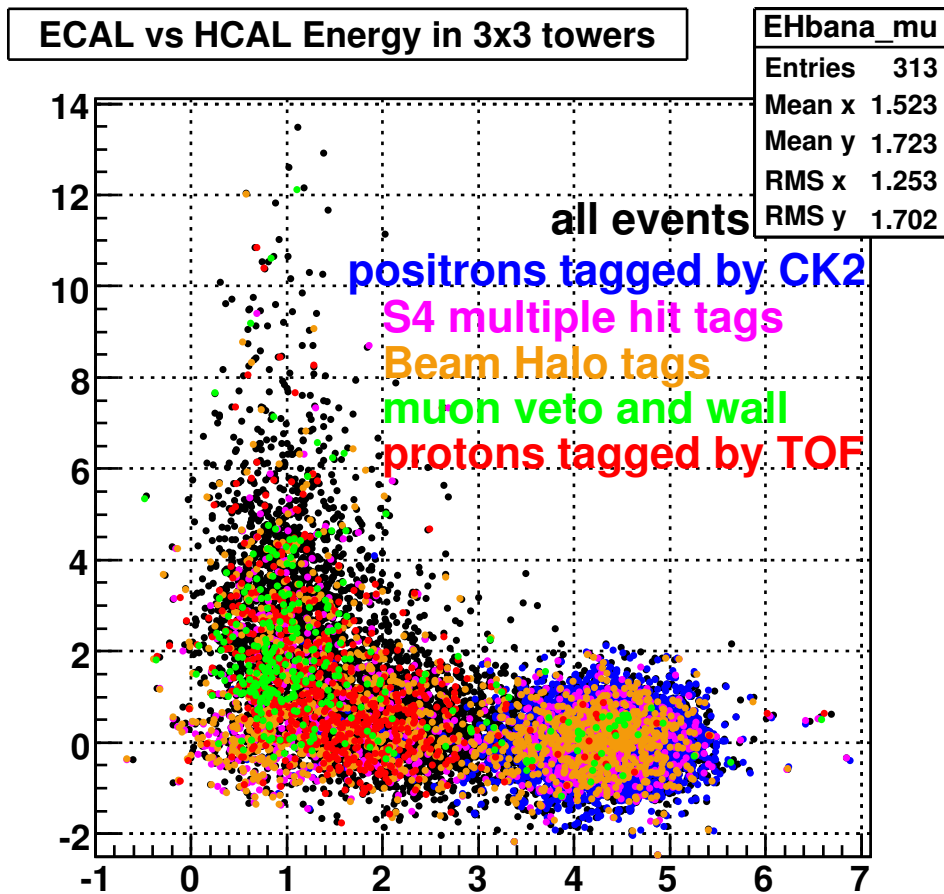


Available beam tunes:
 pions 2-300 GeV
 muons 80/150 GeV
 electrons 9-100 GeV

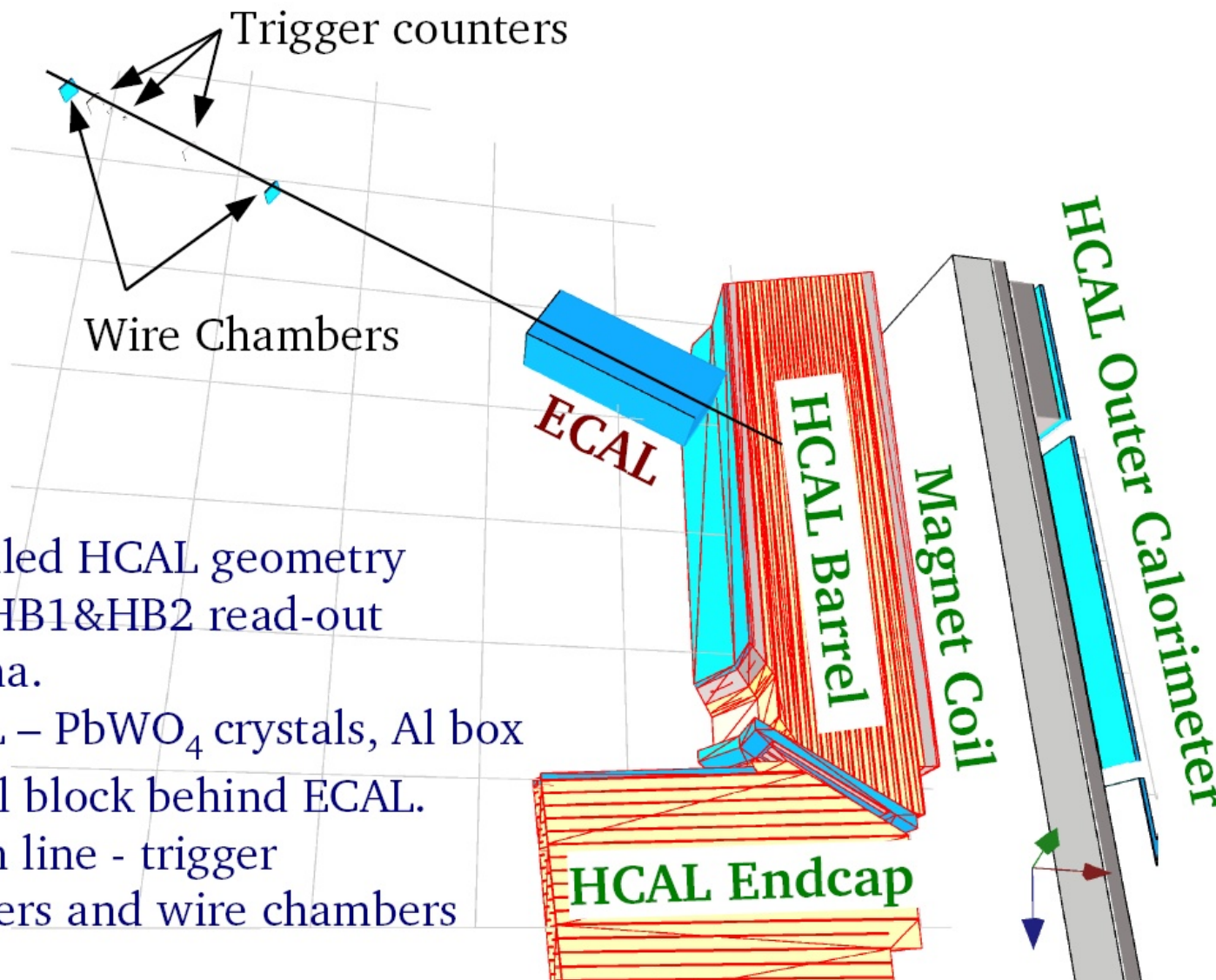
P-ID:

Cerenkov counter (CK2) - electron
 Cerenkov counter (CK3) - pion / kaon / proton
 Scintillators (V3, V6, VM) - muon tagging

Example of beam clean-up possible in the Test-Beam
Run#29665: 5GeV pi+

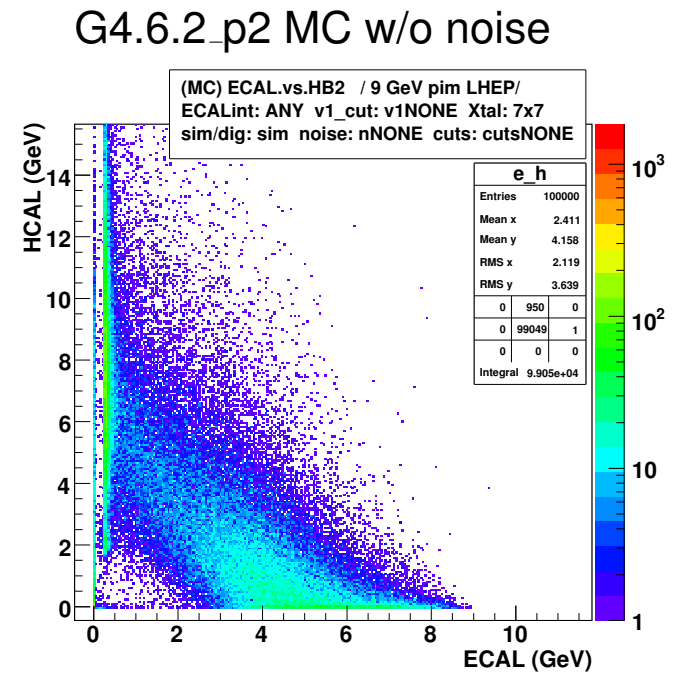
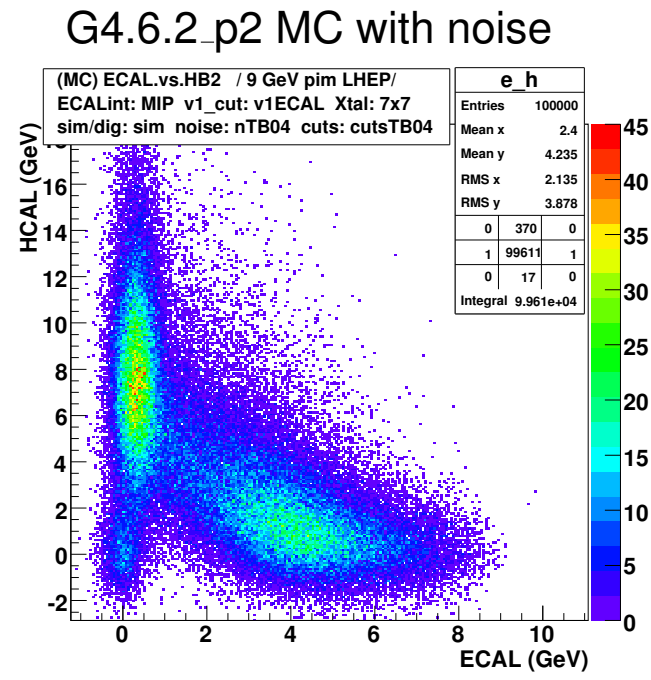
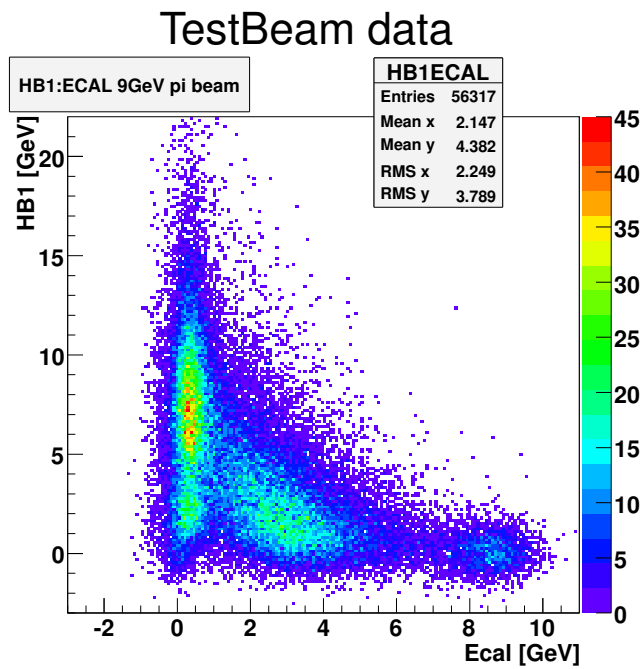


All simulations done with Geant4 toolkit

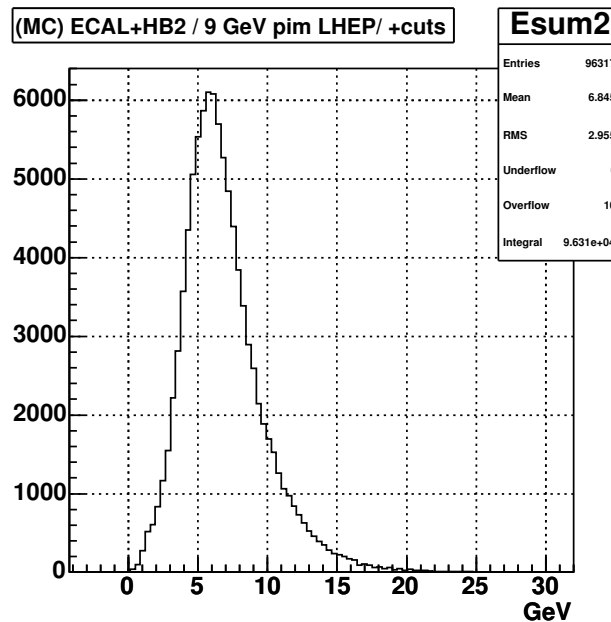
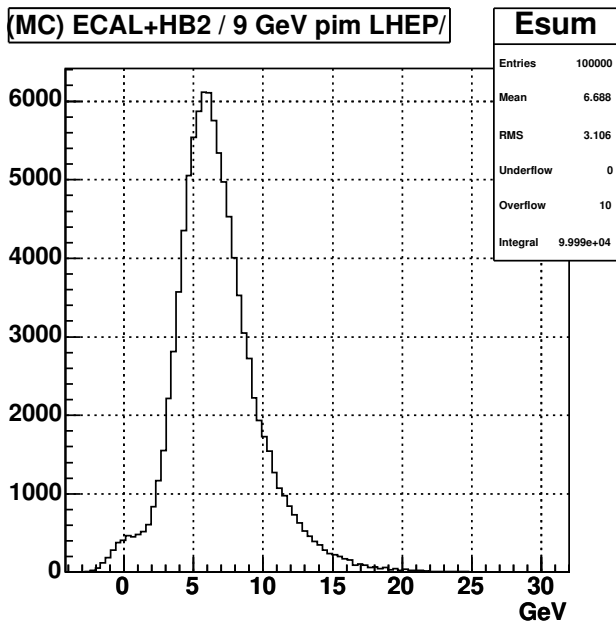
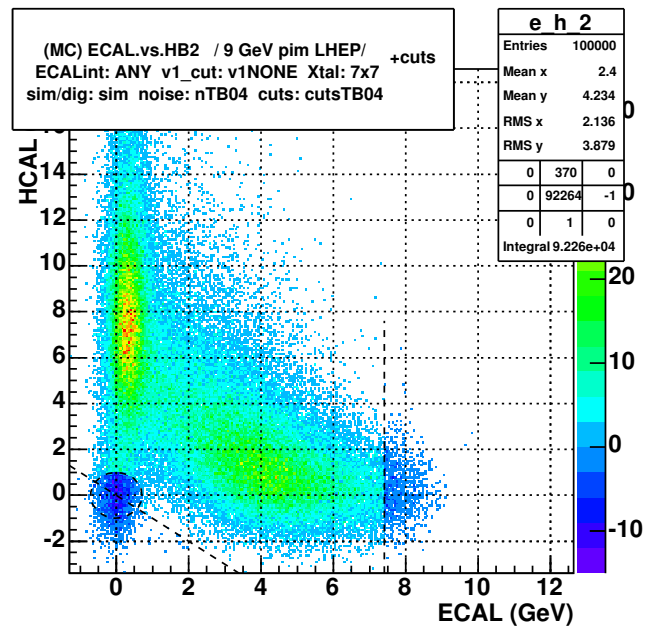
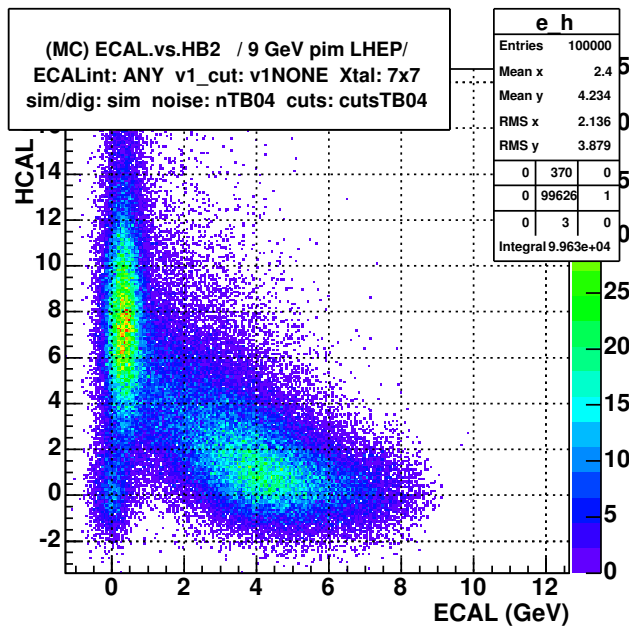


- Detailed HCAL geometry with HB1&HB2 read-out schema.
- ECAL – PbWO_4 crystals, Al box and Al block behind ECAL.
- Beam line - trigger counters and wire chambers

HCAL signal vs. ECAL signal - the "banana" plot

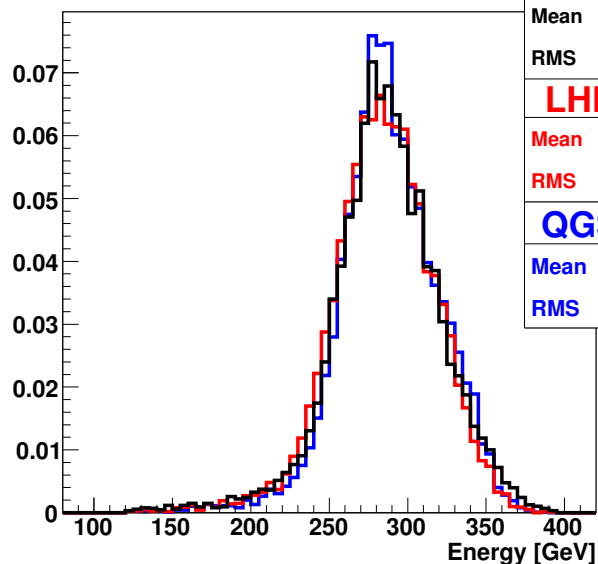


- electron contamination in pion beam
- interactions in beamline
- muons from pion decay



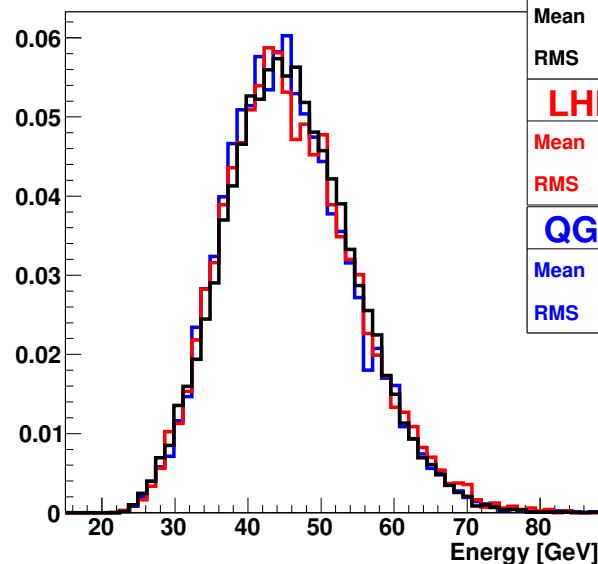
Calorimeter-based cuts are necessary to clean up the beam-interacted particles. These introduce systematic errors, but are the only way to enable comparison with the TB data.

pi 300 GeV



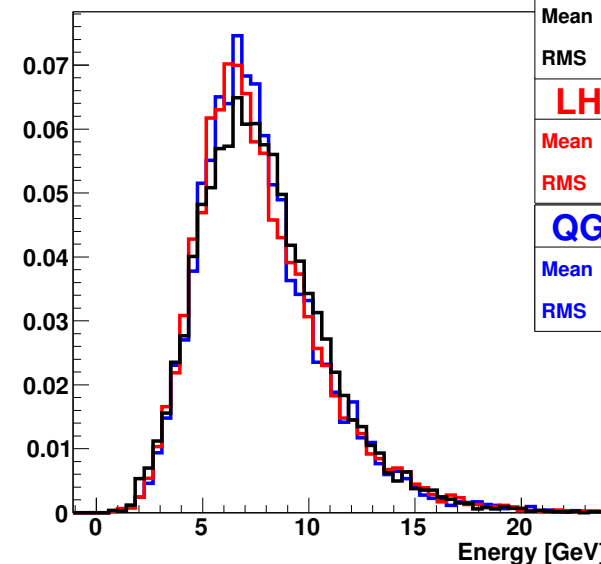
TB data	
Mean	286.3
RMS	34.94
LHEP	
Mean	284.4
RMS	32.88
QGSP	
Mean	288.1
RMS	31.61

pi 50 GeV



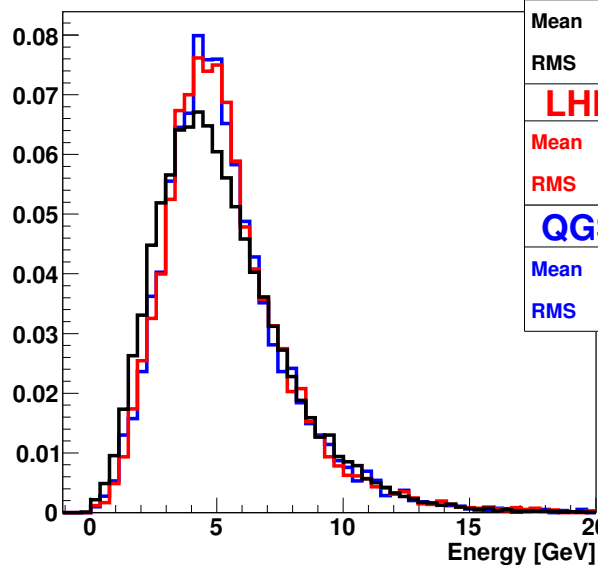
TB data	
Mean	45.87
RMS	8.722
LHEP	
Mean	45.89
RMS	9.013
QGSP	
Mean	45.59
RMS	8.737

pi 10 GeV



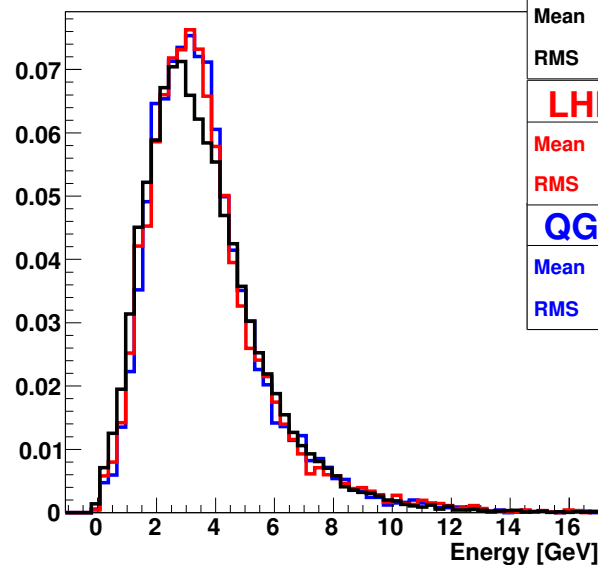
TB data	
Mean	7.819
RMS	2.96
LHEP	
Mean	7.709
RMS	2.983
QGSP	
Mean	7.74
RMS	2.938

pi 7 GeV



TB data	
Mean	5.186
RMS	2.594
LHEP	
Mean	5.344
RMS	2.487
QGSP	
Mean	5.317
RMS	2.48

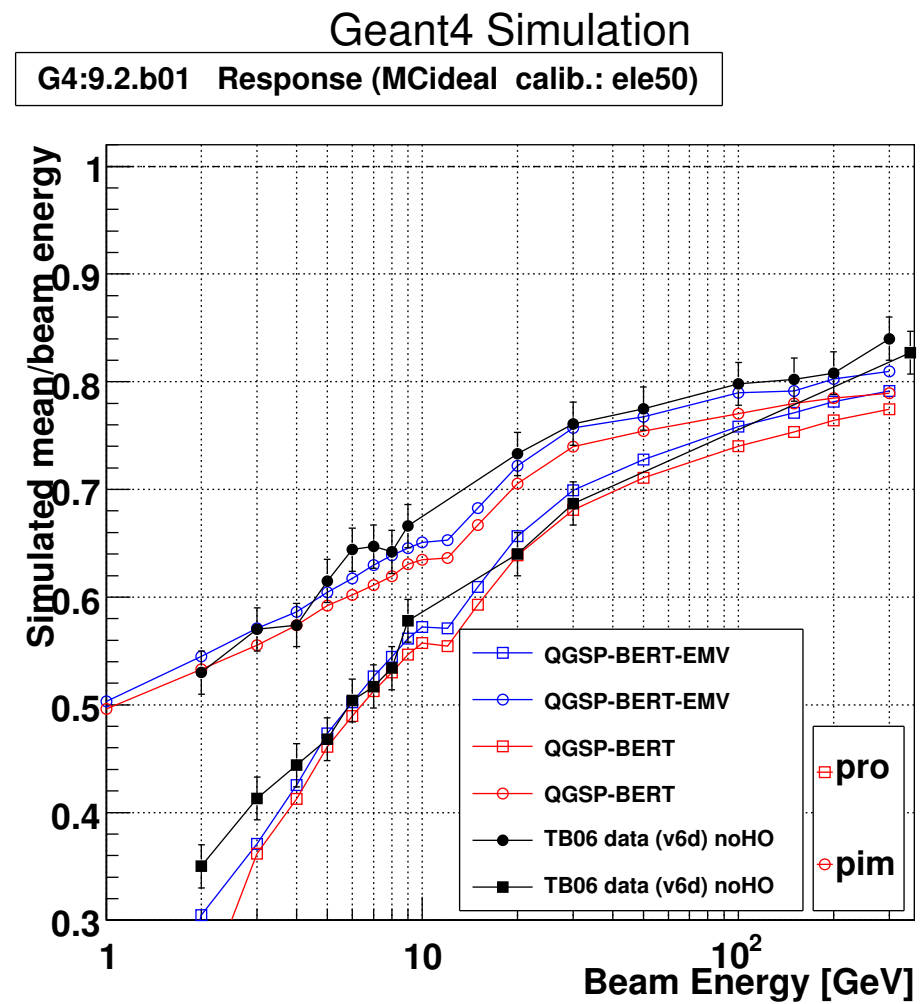
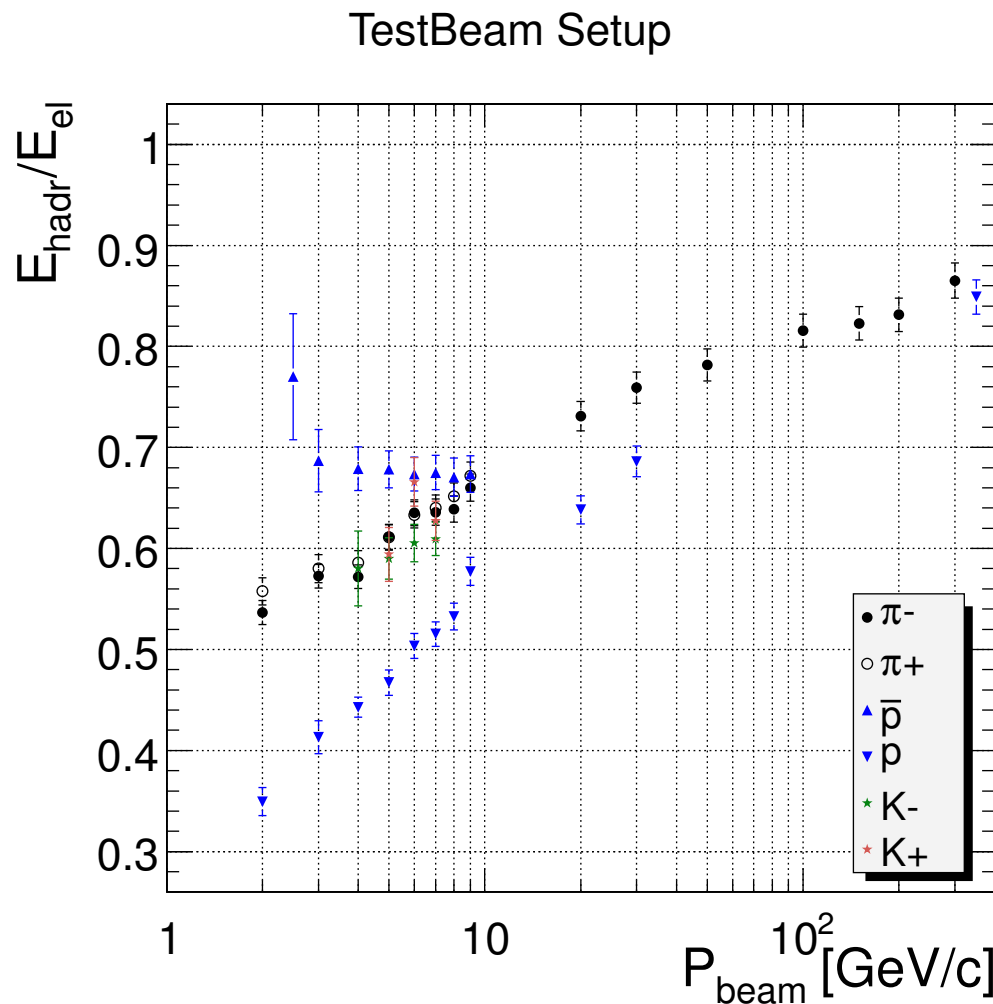
pi 5 GeV

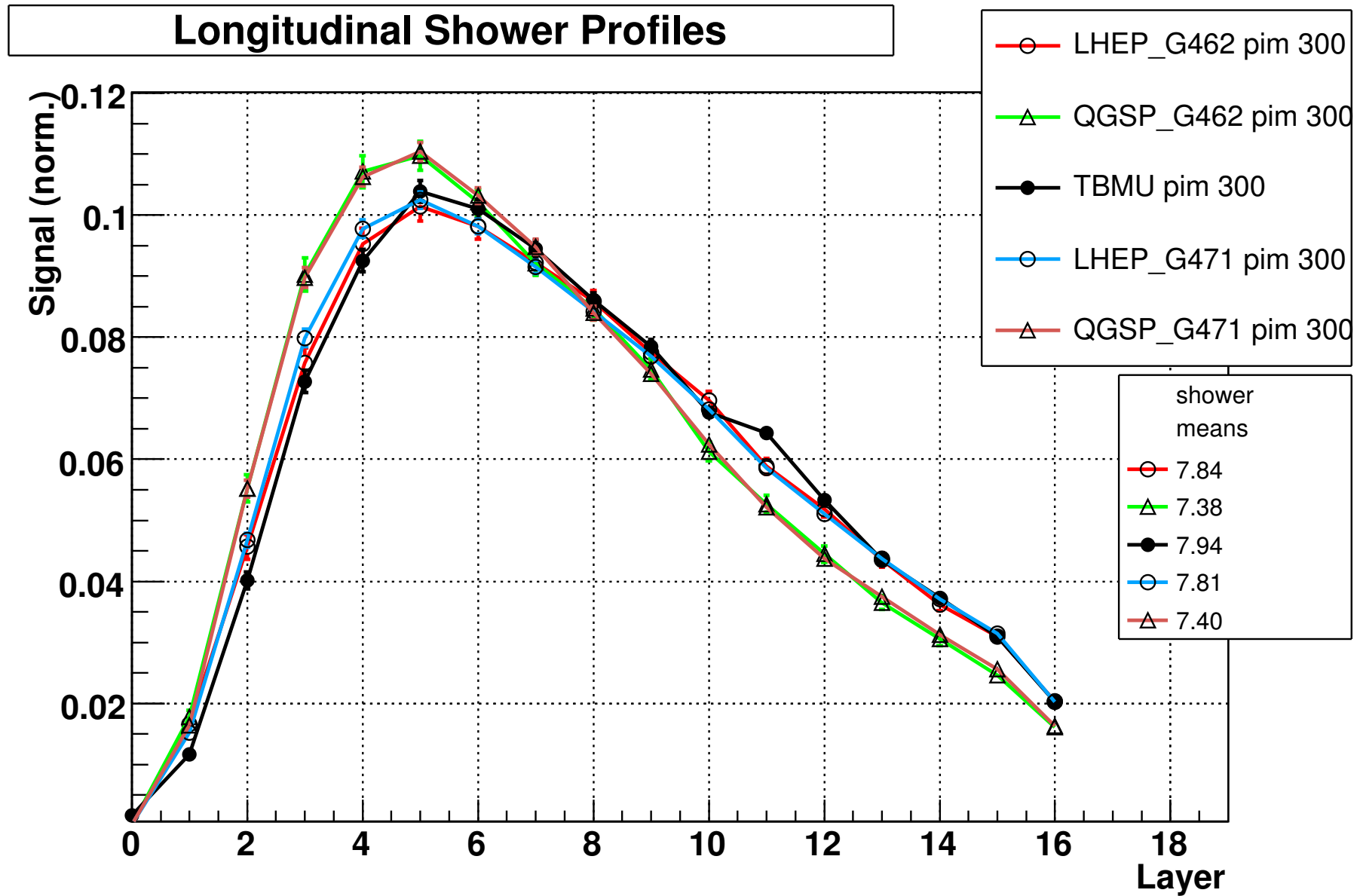


TB data	
Mean	3.617
RMS	2.038
LHEP	
Mean	3.688
RMS	2.065
QGSP	
Mean	3.693
RMS	1.988

Good agreement with data.

Comparison of Test-Beam data and Geant4 Linearity of Response





Summary

- Calorimeters play a crucial role in detecting hadrons
- They can be of various kinds, depending on their application
- Their MonteCarlo simulation is very expensive in terms of CPU power
- CMS calorimeters have been studied in TestBeams in great detail before installing them in the experiment