Validation for Geant4.10.4 with CMS Collision Data

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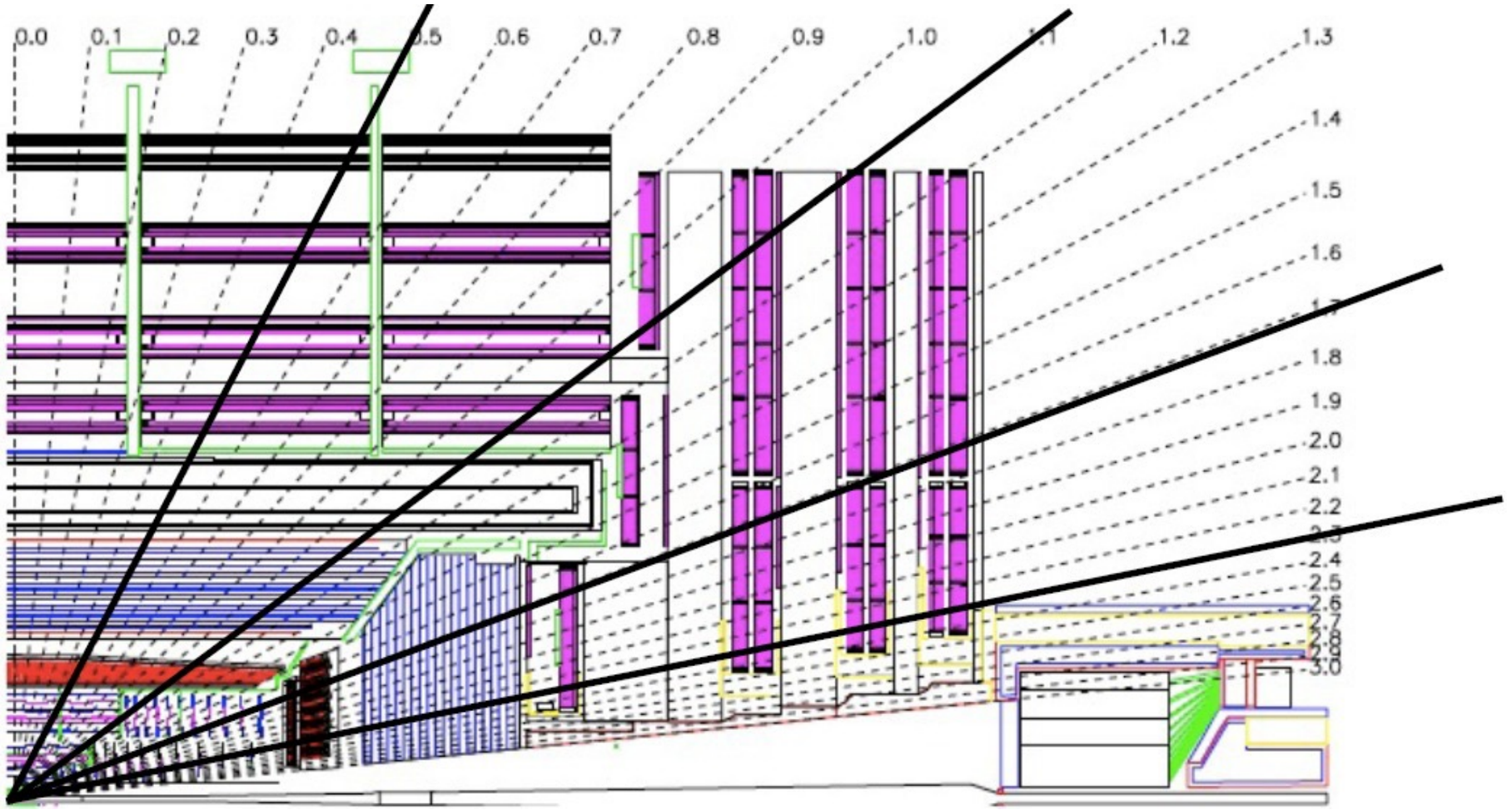
What is Done for Physics Validation

- Compare ratio of calorimeter energy measurement to beam or track momentum between data and MC. Data come from
  - test beam studies with identified particle type
  - isolated charged hadron sample in collision data
- Source of Data:
  - 2006 test beam set up in the SPS H2 beam line with HB prototype and one EB supermodule
  - Low luminosity runs taken during 2016B run period using Zero Bias and Minimum Bias triggers
- For Monte Carlo events are generated using FTFP_BERT_EMM Physics List for Geant4 versions 10.2.p02, 10.3.p03, 10.4.beta and 10.4:
  - Generate 50k events at each beam energy for the said type and for calibration generate 50k electron events in setups with and without EB
  - Generate 100k single particle event sample using a flat energy distribution between 1 and 20 GeV with a given admixture of pions, kaons and protons and anti-protons (as expected in minimum bias sample)

Energy Measurements



- Select good charged tracks using standard cuts
- Propagate them to calorimeter surface and select those which are well isolated from other charged or neutral particles in the calorimeter surface
- Measure energy by combining energy measurements from a matrix of NxN cells around the cell hit by the extrapolated track to the calorimeter surface in four regions (two in the barrel, one in the endcap and one in transition region)

Collision Data

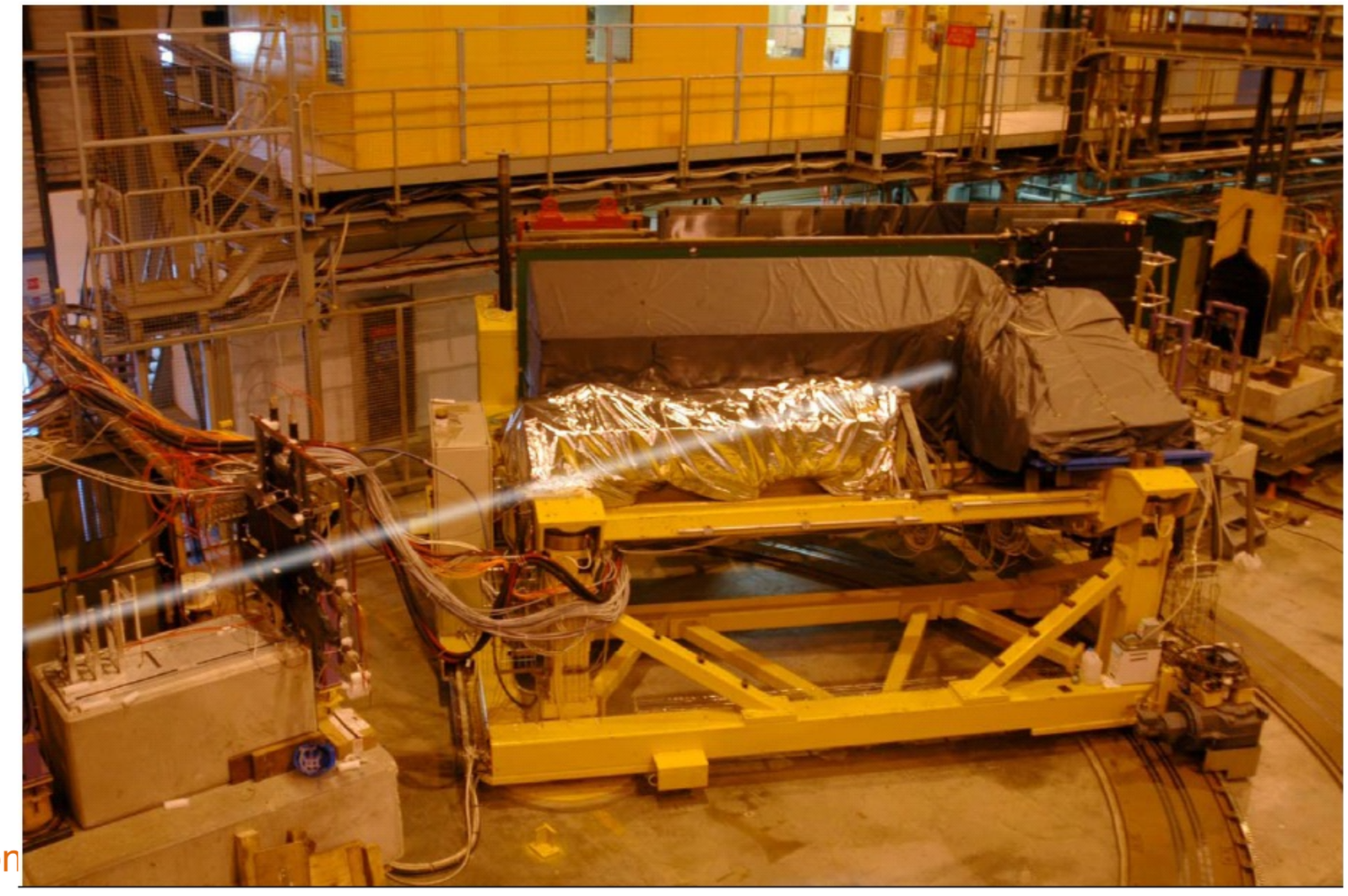
- Energy fraction in ECAL for narrow (7x7) or wide (11x11) matrix agrees reasonably between data and MC. Theres is some disagreement in the tail which could be partially due to limited statistics in the MC sample
- Fairly good agreement observed between data and MC for energy measured in the HCAL for narrow (3x3) as well as wide (5x5) matrix
- The level of disagreement in the combined signal between data and MC is between 2.0% to 5.5% for the Geant4 version 10.4 depending on the region of the detector

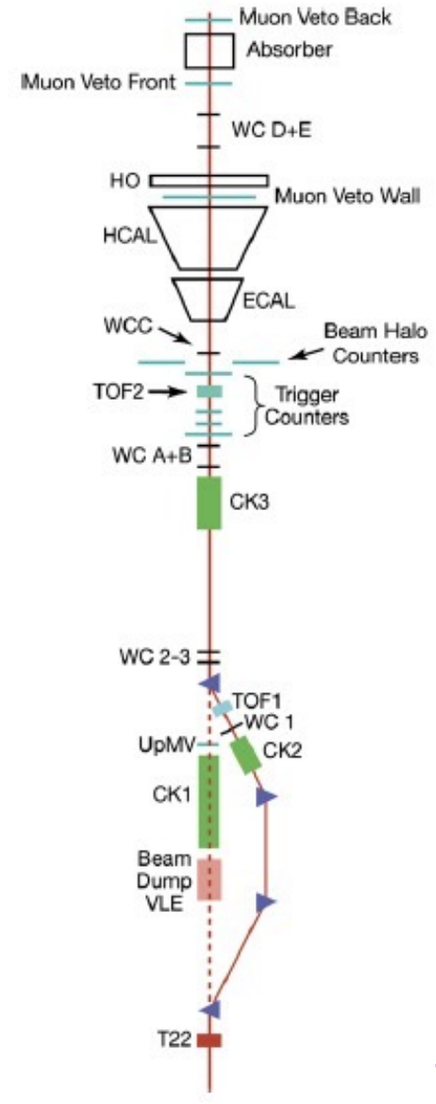
Mean level of disagreement between MC and data

	$(E_{7x7}+H_{3x3})/p$ 10.2.p02	$(E_{7x7}+H_{3x3})/p$ 10.4.beta	$(E_{7x7}+H_{3x3})/p$ 10.4	$(E_{11x11}+H_{5x5})/p$ 10.2.p02	$(E_{11x11}+H_{5x5})/p$ 10.4.beta	$(E_{11x11}+H_{5x5})/p$ 10.4
Barrel 1	(2.3±0.4)%	(1.9±0.4)%	(2.1±0.4)%	(2.6±0.4)%	(1.9±0.4)%	(2.7±0.4)%
Barrel 2	(3.6±0.4)%	(5.0±0.4)%	(3.6±0.4)%	(2.2±0.4)%	(2.6±0.4)%	(2.0±0.4)%
Transition	(4.9±0.5)%	(7.2±0.5)%	(5.5±0.5)%	(2.2±0.5)%	(4.8±0.5)%	(2.8±0.5)%
Endcap	(3.1±0.3)%	(5.9±0.5)%	(5.0±0.5)%	(1.5±0.5)%	(3.9±0.5)%	(3.0±0.5)%

2006 TestBeam Data

- The data correspond to single particle response due to well identified particles over a large momentum range (2 to 350 GeV)
- The results consist of the energy distributions for well identified particles at a fixed momentum
  - Particle identification is rather good for beam momenta at or below 9 GeV
- Use the setup described within CMSSW to simulate events with single particles.





Energy Distributions

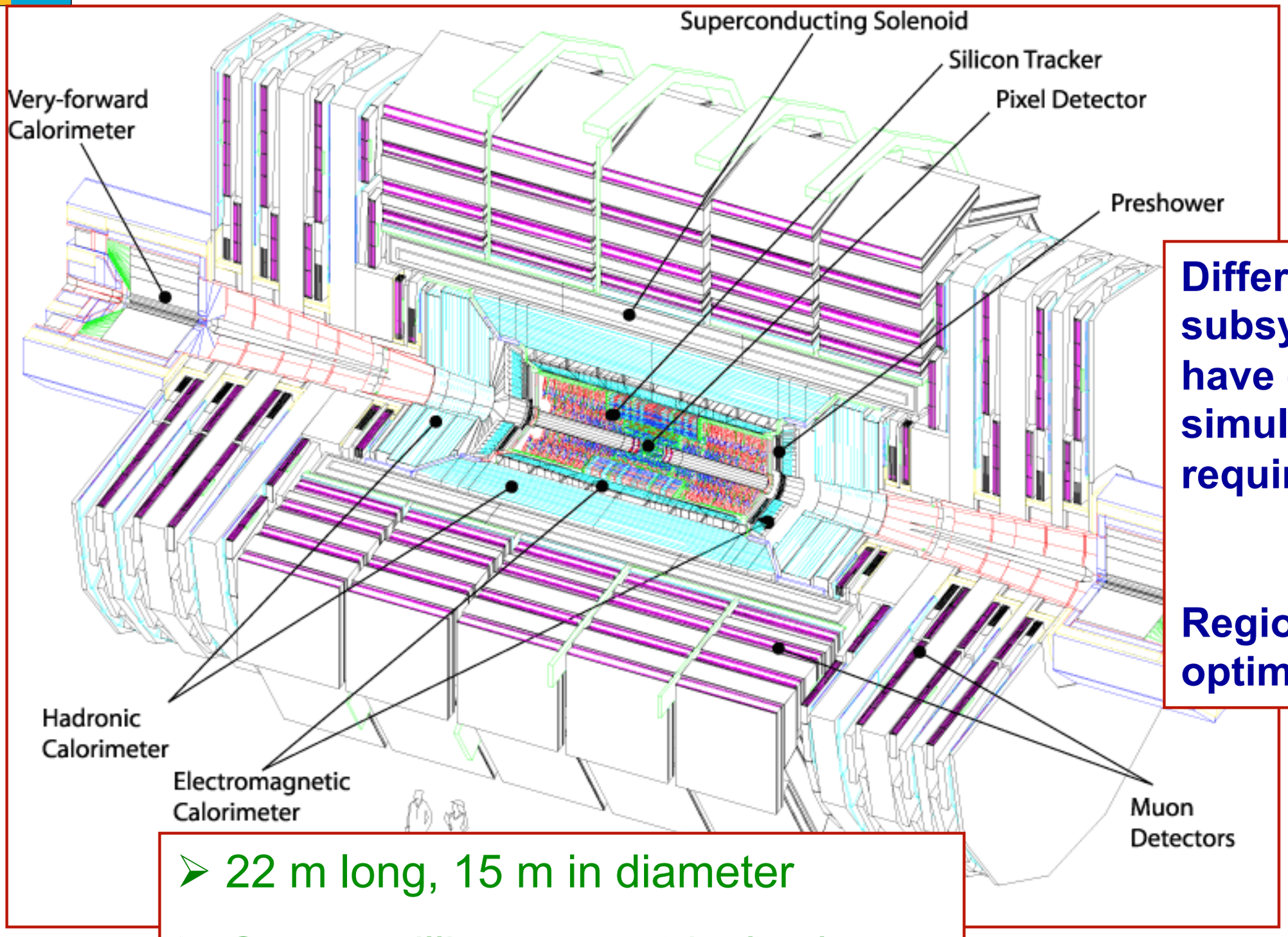
- Particle identification has been very good for the low energy data (with beam momentum below 10 GeV/c)
- Energy calibration for ECAL as well as HCAL is done in the MC sample in the same way as in the data (using 50 GeV/c electrons in setups with and without the ECAL super module)
- Measured energy spectrum in the calorimeter is compared between data and MC
  - Total energy measured for negative pion beams of 4 GeV/c and 6 GeV/c show that the data have a longer tail than the MC (mean level of disagreement could be as high as 20%)
  - Similar observation is observed for positive pions as well
  - Energy distribution for protons at 3 GeV/c and 7 GeV/c show that all four Monte Carlo versions provide a decent description of the data (the level of agreement is better than in the case of pions)

Summary

- Predictions from the physics list FTFP_BERT_EMM from Geant4 versions 10.2.p02, 10.3.p03, 10.4.beta and 10.4 are compared with the data as well as the Geant4 version in the current CMSSW release
- The level of agreement between data and Monte Carlo for the version 10.4 of Geant4 is quite good for collision data and similar to earlier comparisons for test beam data (pion data show slightly wider energy distributions than MC predictions)
- Geant4.10.4 is an acceptable candidate as the simulation engine for CMS full simulation

Additional Slides

CMS Detector



Different subsystems have different simulation requirements

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Region based optimization

- 22 m long, 15 m in diameter
- Over a million geometrical volumes
- Many complex shapes

Selection of Isolated Tracks

- Select good charged tracks
  - $p_T > 1$ GeV
  - Chi-square/d.o.f. < 5
  - # of layers crossed > 8
  - Fractional error on p < 0.1
  - No missed hits in inner/outer layers
  - originates close to primary vertex (< 0.2 mm in x-y and r-z planes)
  - reach the HCAL surface
- Impose isolation of these charged particles
  - propagate track to calorimeter surface and study momentum of tracks (selected with looser criteria) reaching ECAL (HCAL) within a matrix of 31x31 (7x7) around the impact point of the selected track
  - study energy deposited in an annular region in ECAL (HCAL) between 15x15 and 11x11 (7x7 and 5x5) matrices for neutral isolation
- Final cuts
  - No tracks in the isolation region
  - Energy cut of 2 GeV for neutral isolation