Full Simulation Results for CMS Calorimeters

Outline

- Validation using Test Beam Data
  - Electromagnetic Shower Shape
  - Hadronic Response, Shower Shape, ..
- Validation using Collision Data
  - Electromagnetic Showers
  - Jets and Missing Energy
  - Isolated Hadrons
- Summary

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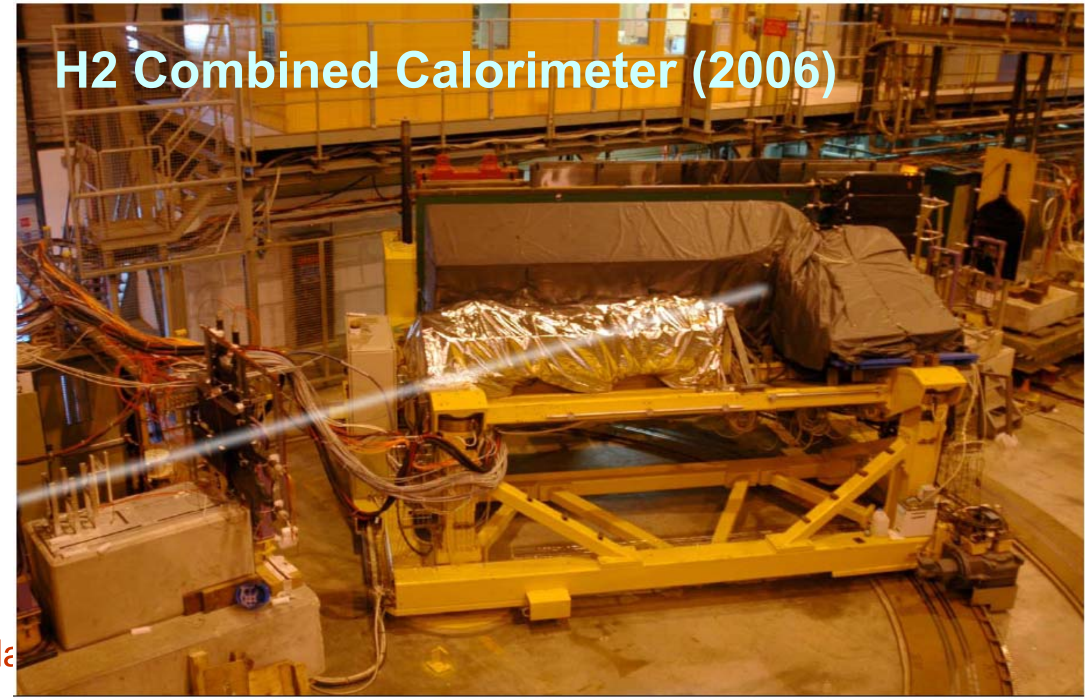
(On behalf of CMS collaboration)

LHC Detector Simulations
October 6, 2011

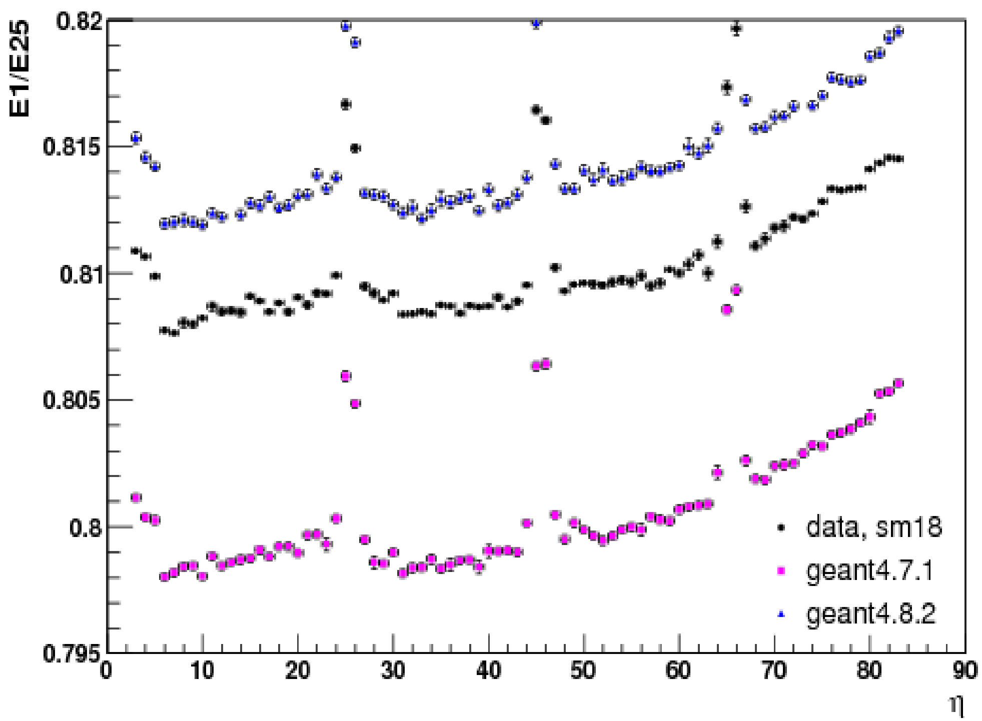
Test Beam Studies

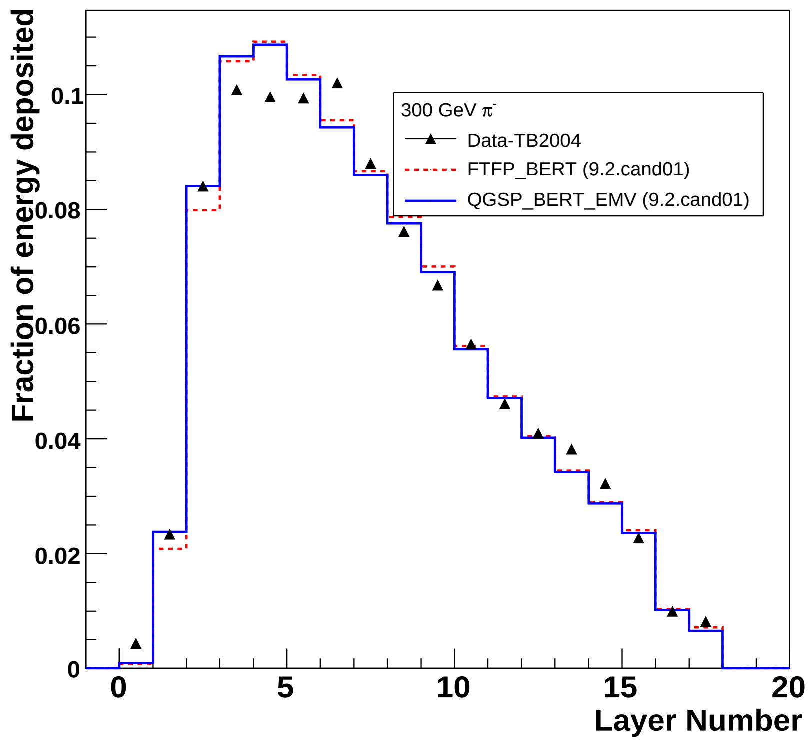
- CMS simulation is based on Geant4 and the current implementation is tuned to test beam data.
- Use electron beams at different energies in H4 test beam area to ECAL super-modules
  - Measure energy response, energy resolution, lateral shower profile, energy containment and leakage
- Use electron, muon and hadron beams at different energies in H2 test beam area to a combined calorimeter system
  - Measure energy response, energy resolution, shower shapes, energy sharing between ECAL and HCAL



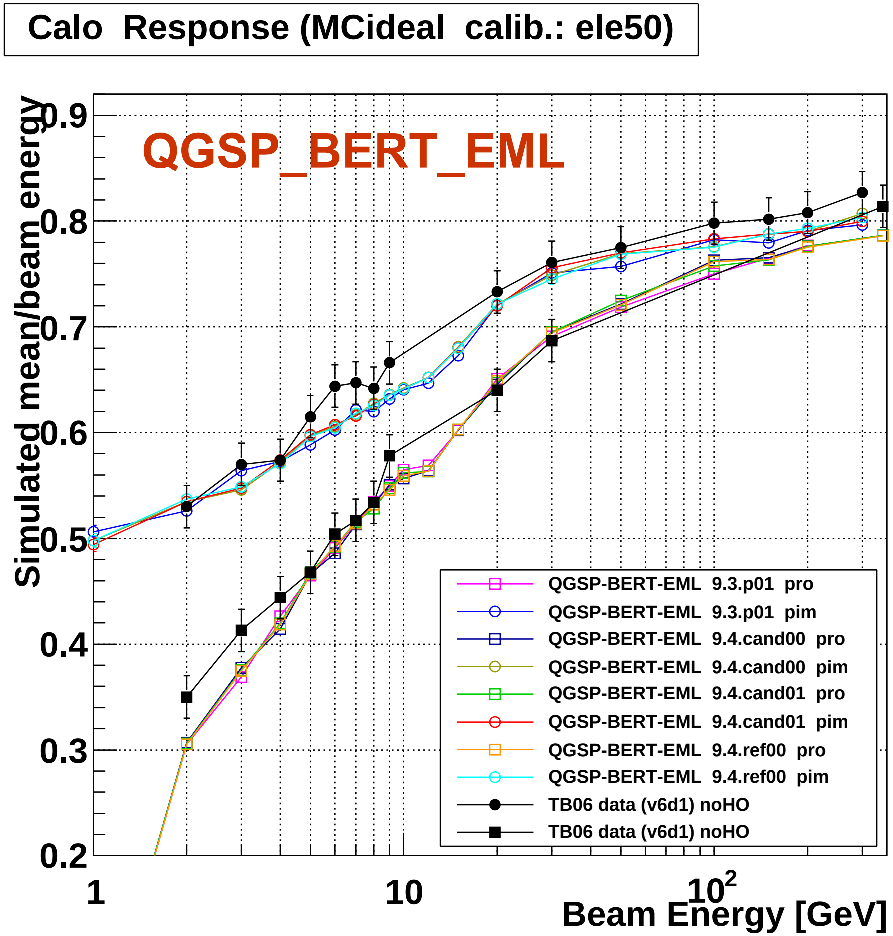
Results from Early Tuning

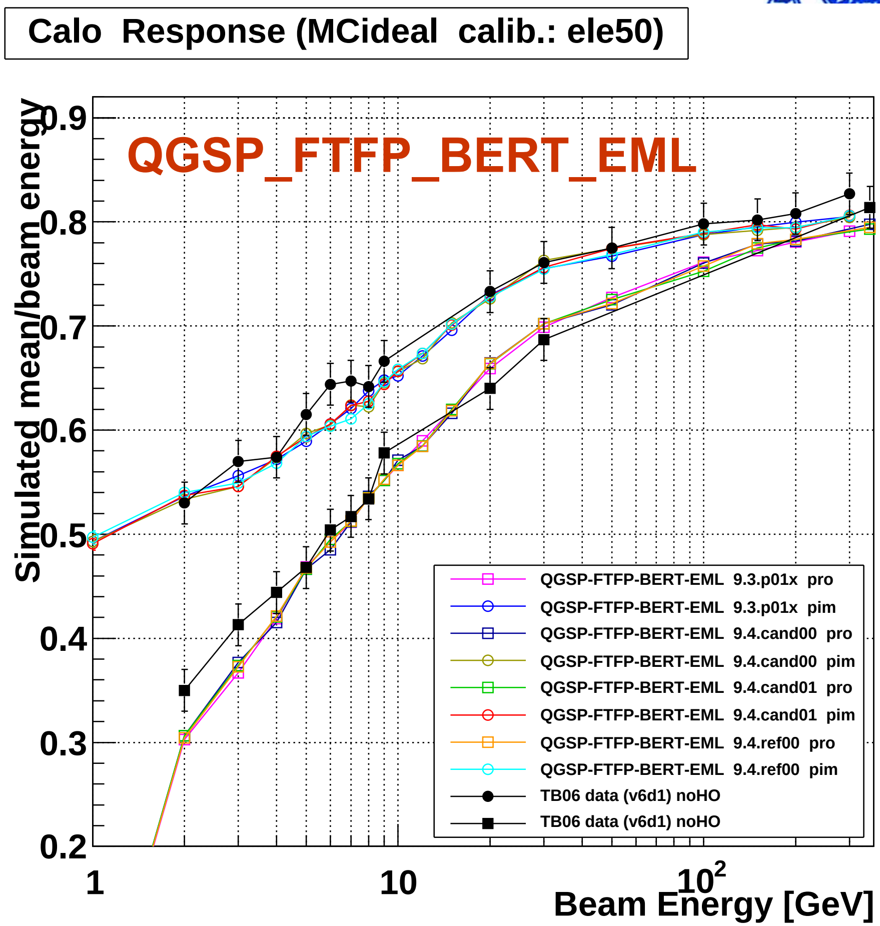
- Study lateral shower shape for electrons and tested to be agreeing with predictions of multiple scattering models after version 8.3
- Longitudinal profile for hadrons are in better agreement since CMS moves to use QGSP_BERT from QGSP



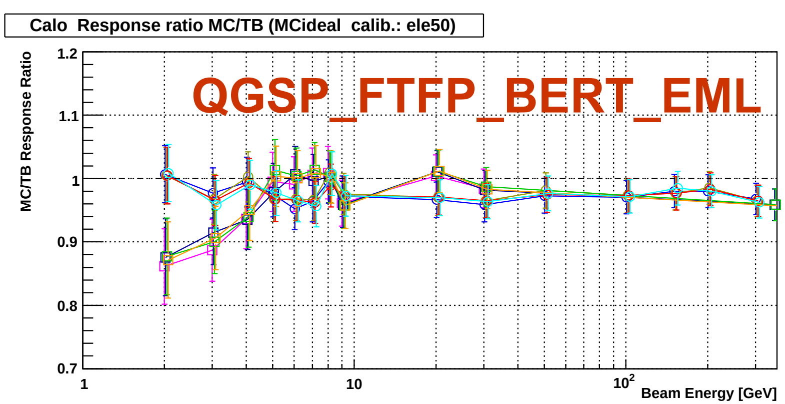


Calorimeter Response to Hadrons

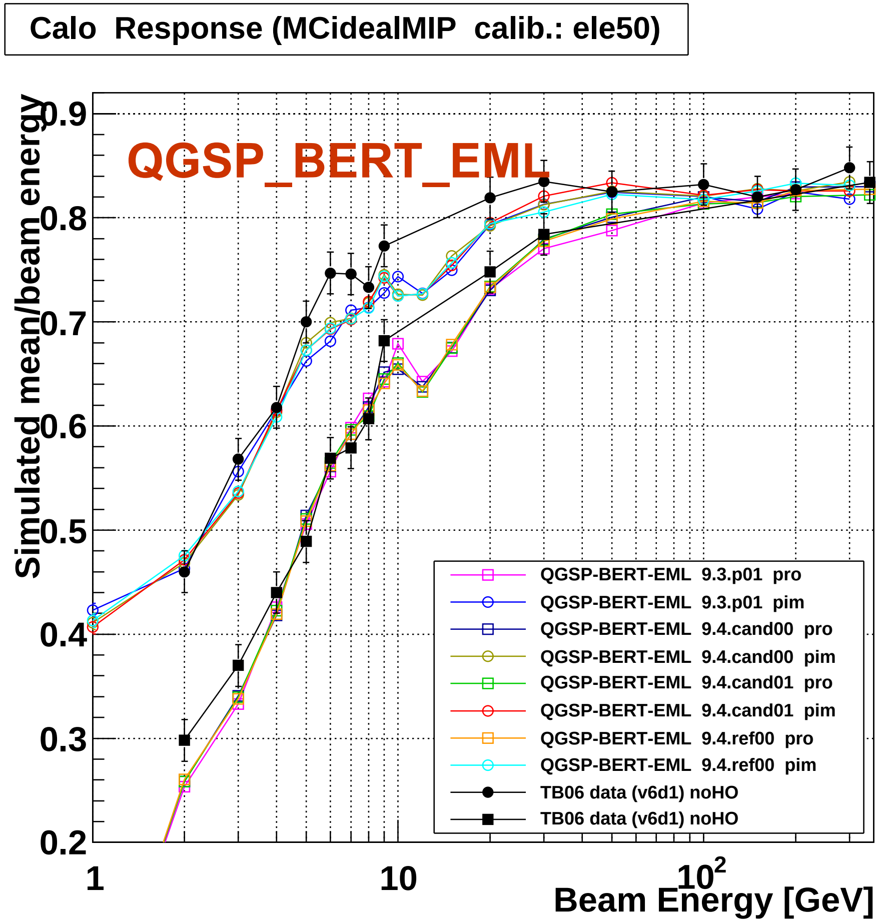


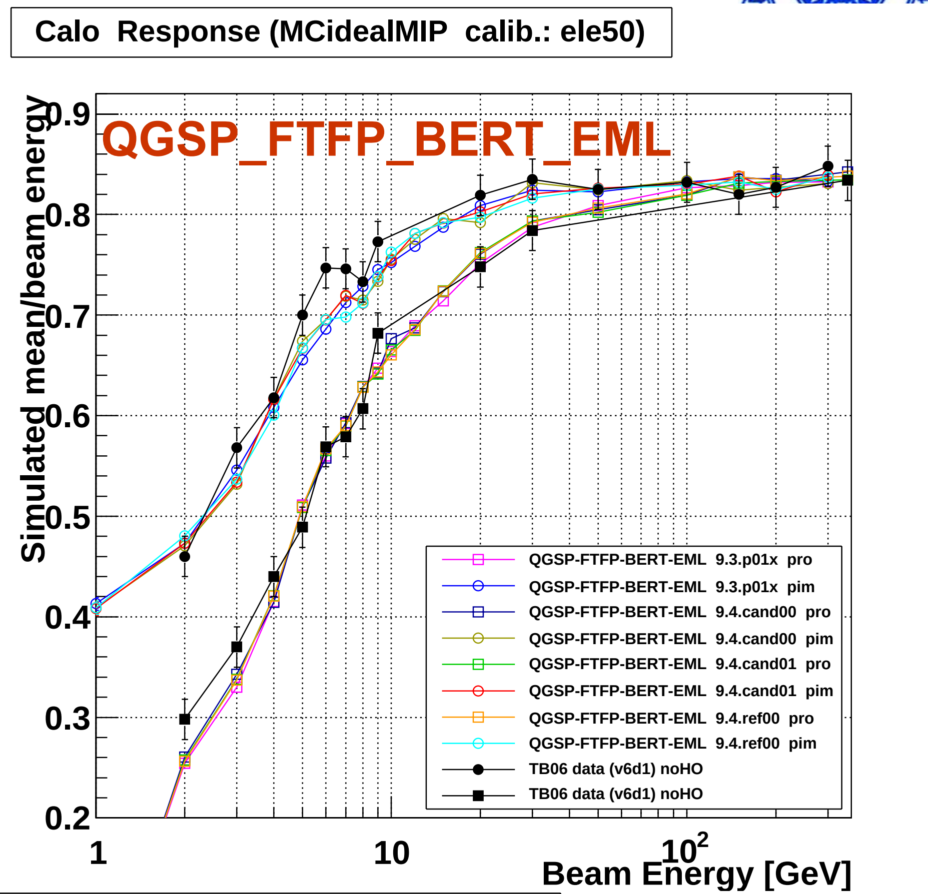


- Energy region between 10-20 GeV is smoother with the list QGSP_FTFP_BERT_EML
- Change default physics list for 2011 production

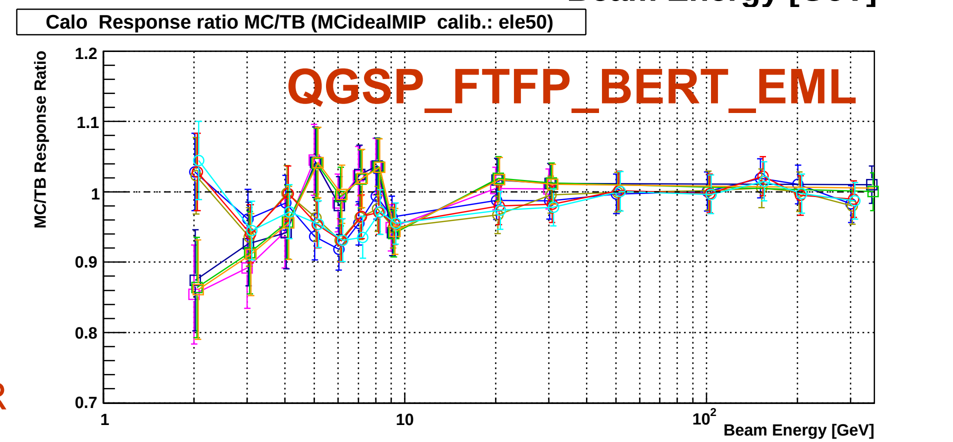


Response in the HCAL

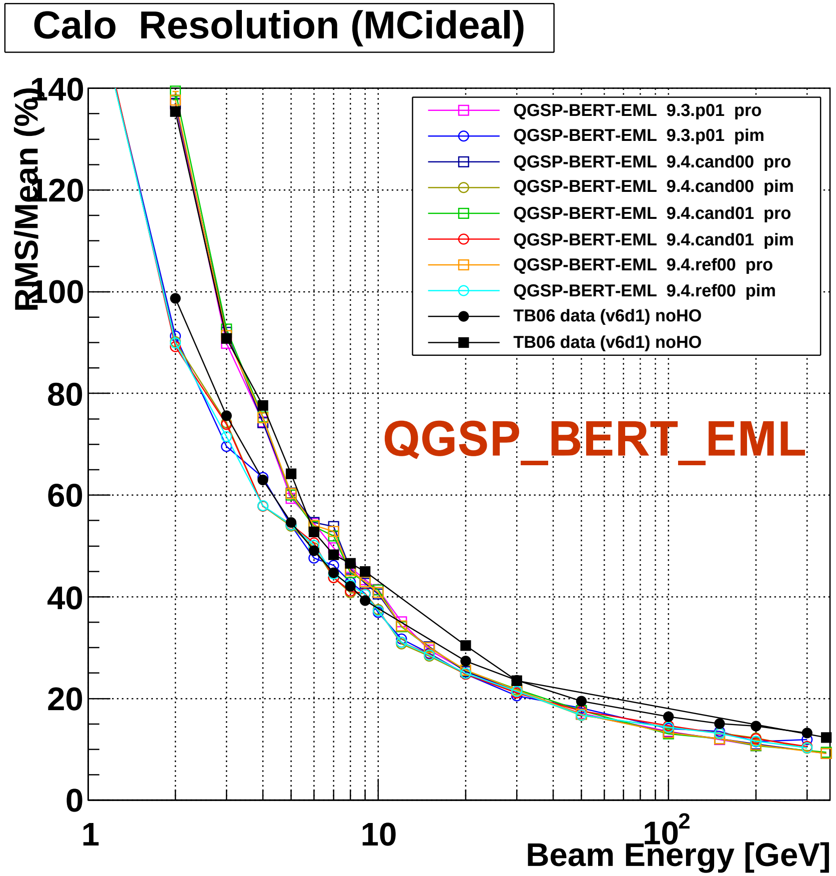


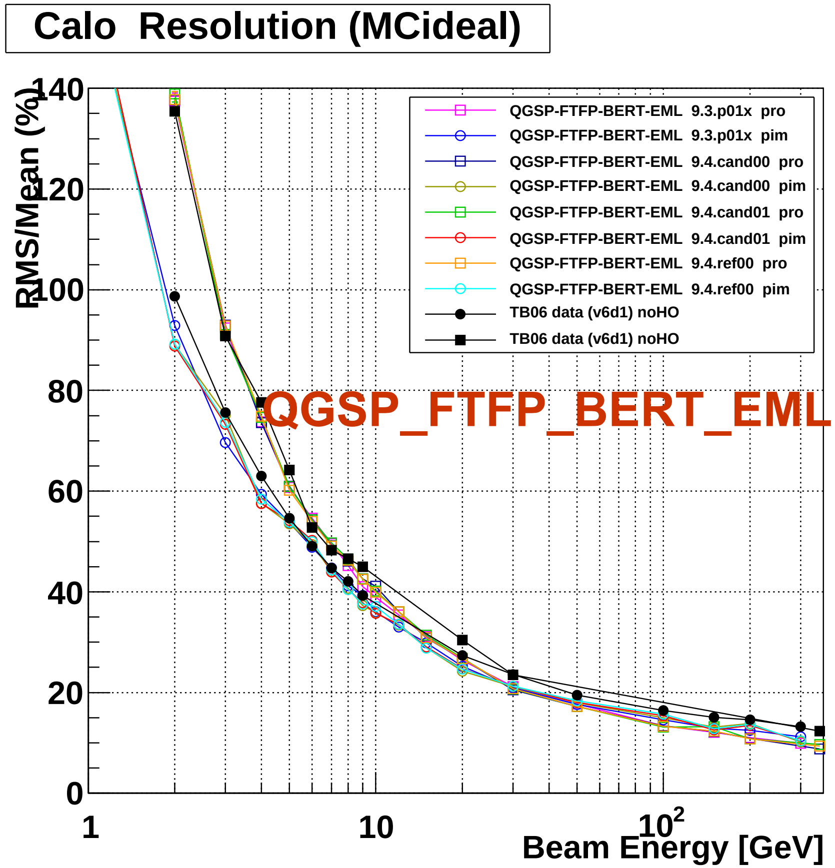


- Agreement is better with the new physics list: QGSP_FTFP_BERT_EML



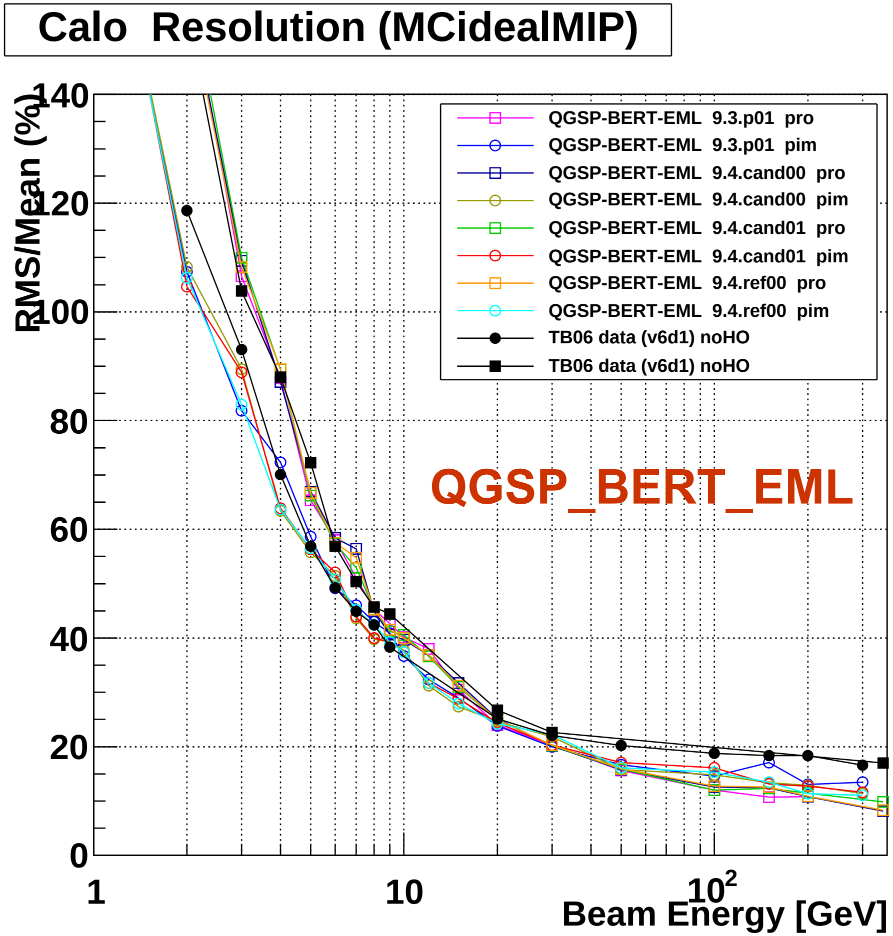
Calorimeter Energy Resolution

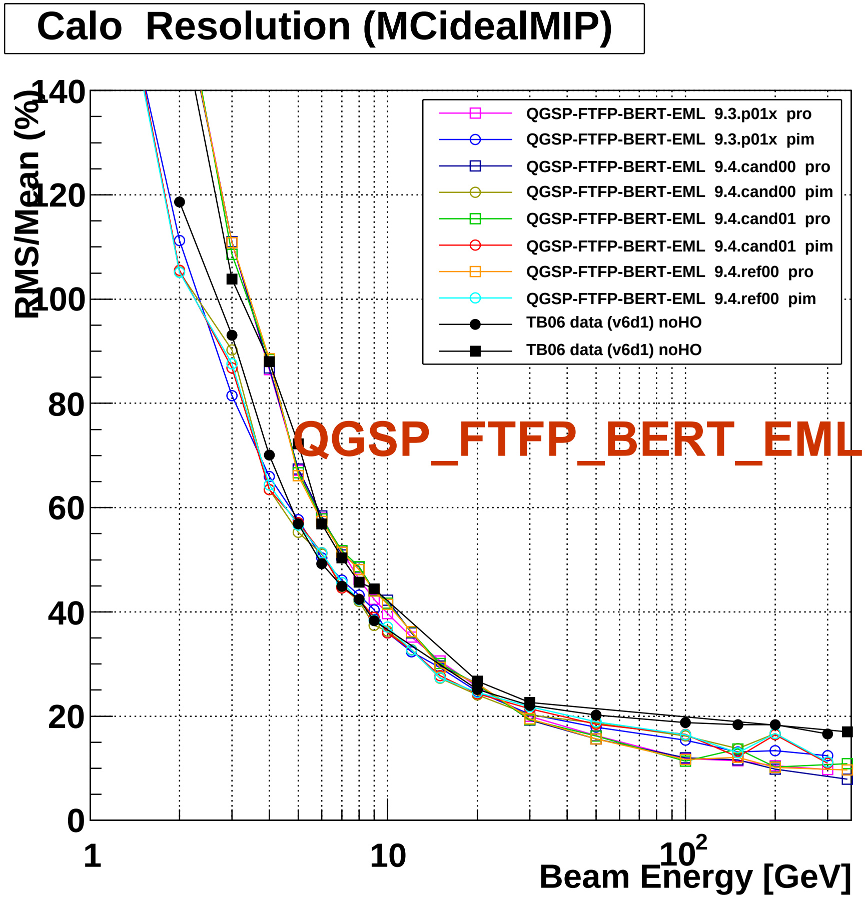




- Resolution is not affected by the choice of physics list
- Nor the version number

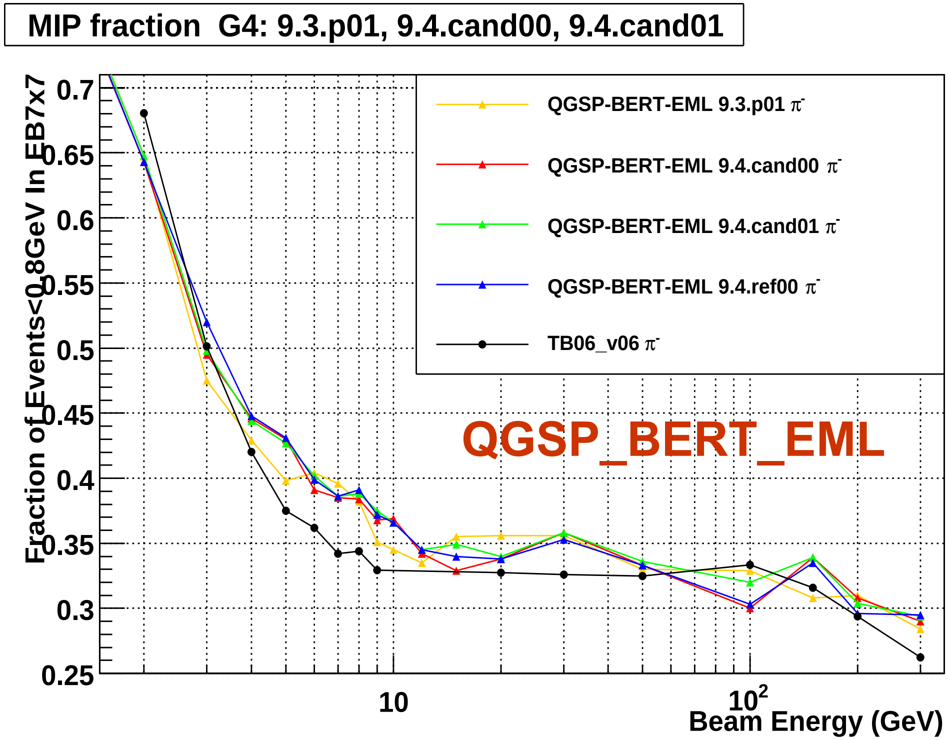
HCAL Energy Resolution

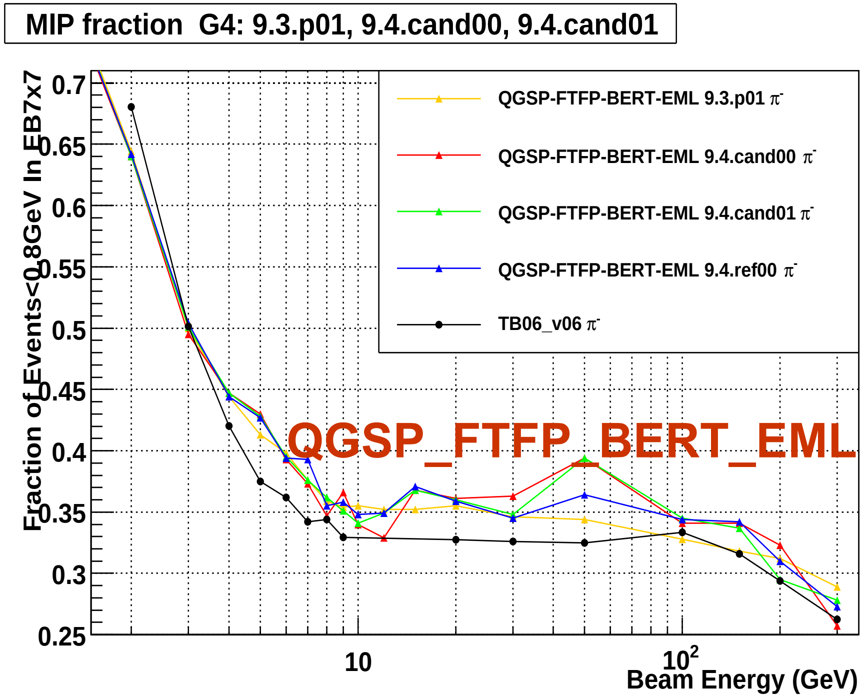




- Two lists give similar predictions and change from 9.3 to 9.4 does not change predictions significantly
- Geant4 gives too good resolution at high energies

MIP Fraction in the ECAL

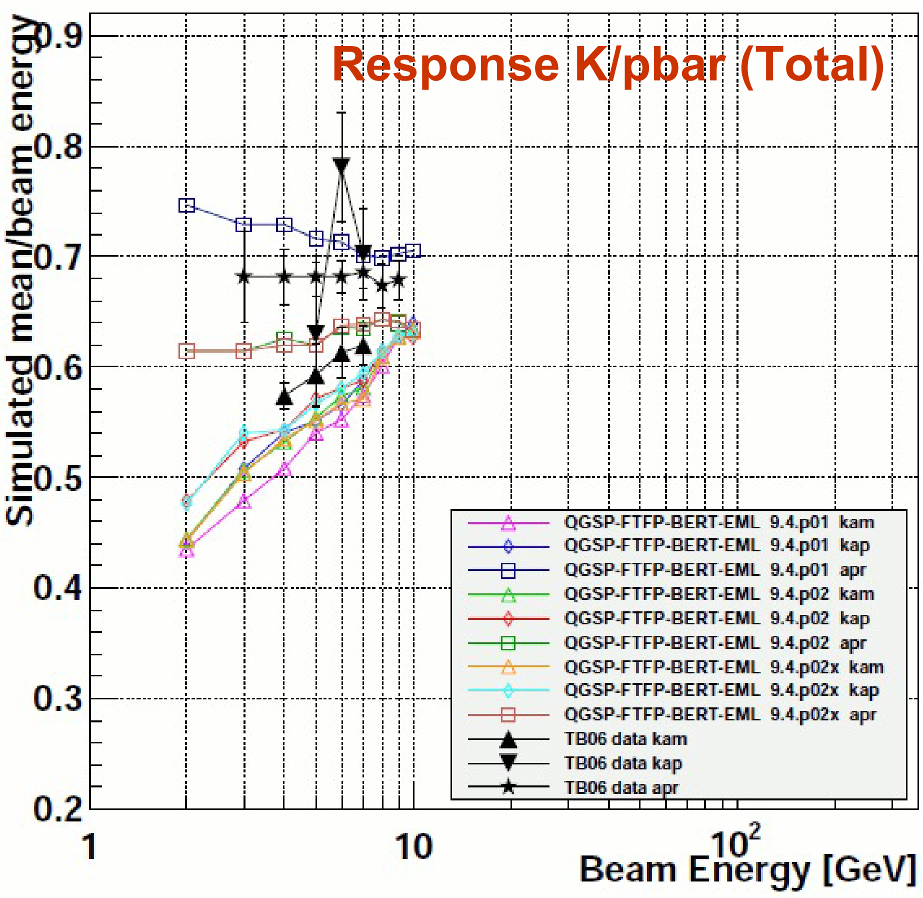


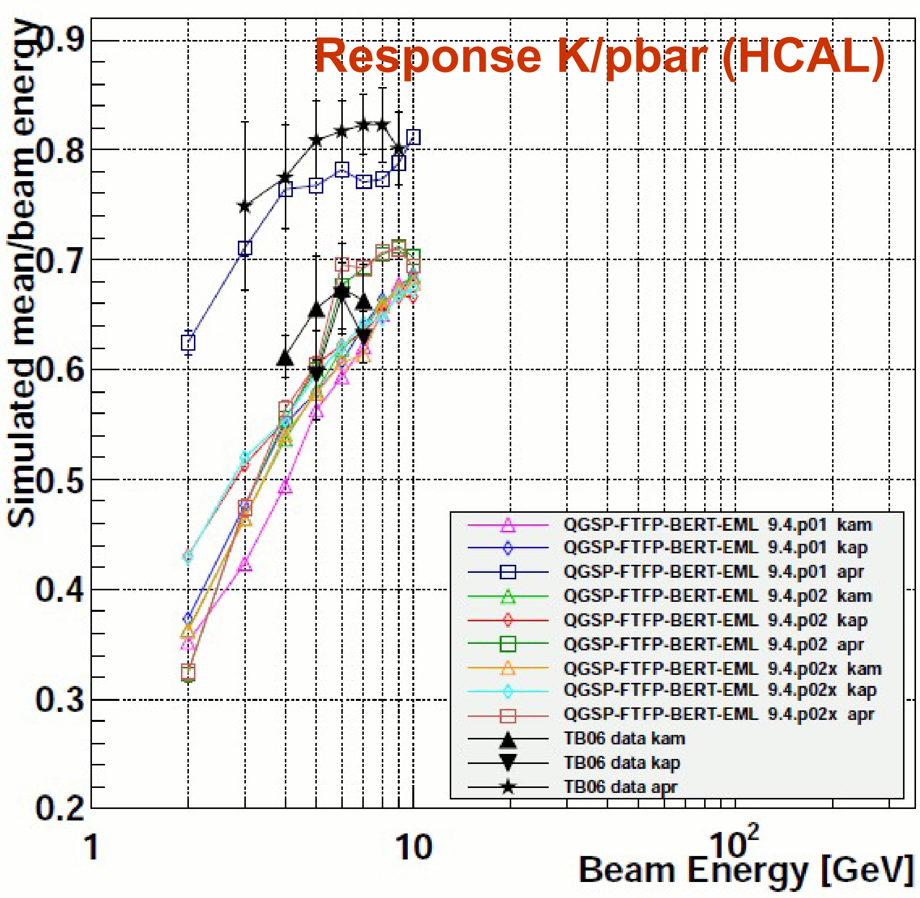


- Some strange structure observed around 50 GeV in the 2 candidate releases of 9.4 for QGSP_FTFP_BERT_EML which is not present in the release version
- Predictions are similar for the two physics lists

More Recent Validation

- Current issue is to improve predictions for kaons and anti-protons; smoothing the transition region
- Use of CHIPS for antiproton improves agreement. Have to look for new changes in the FTFP model

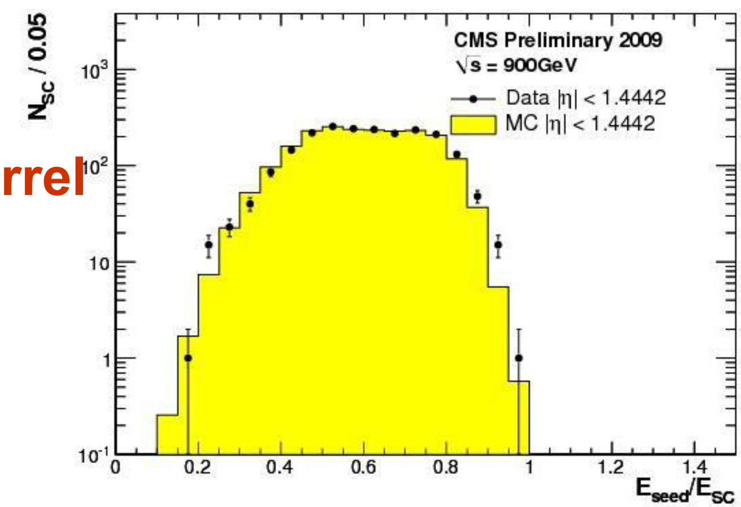




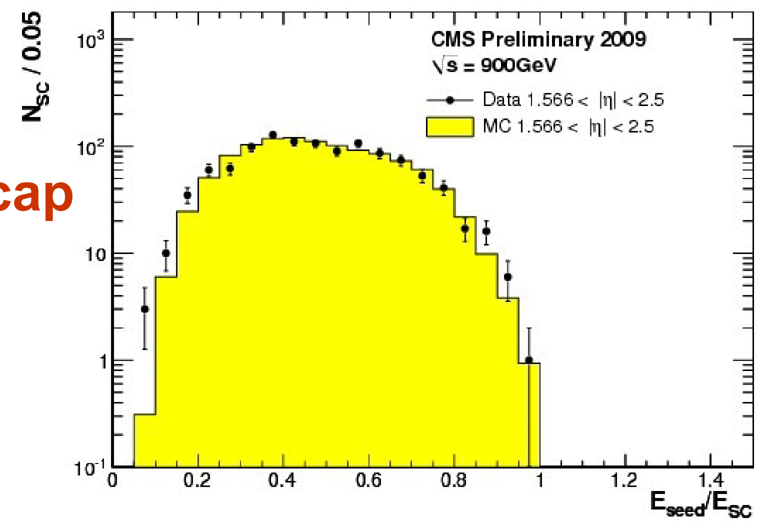
Validation using Collision Data

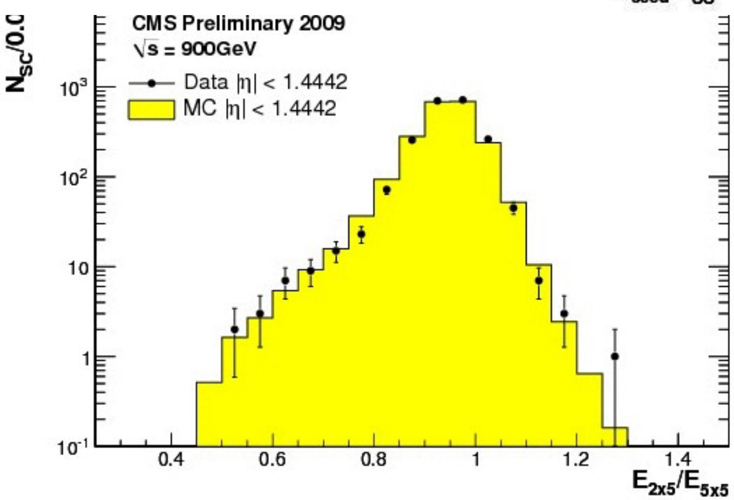
- LHC collision data are used in commissioning various components of the CMS detector. In that process try to focus on observables directly dependent on Geant4 shower code
- Look at the EM candidates and compare shower shape properties

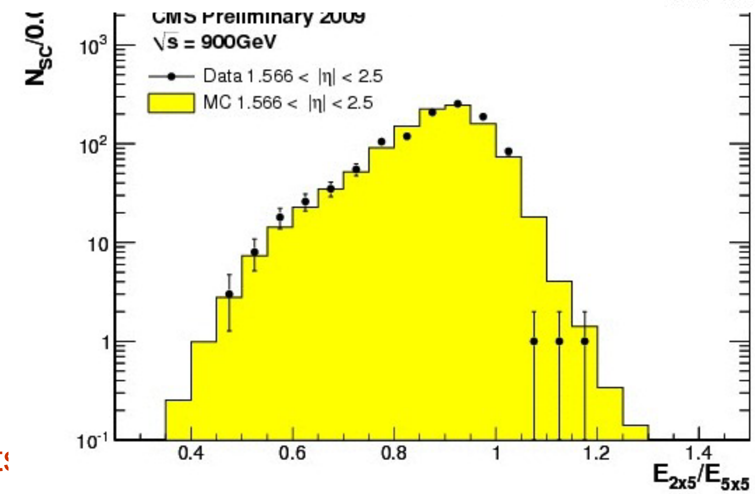
Barrel



Endcap

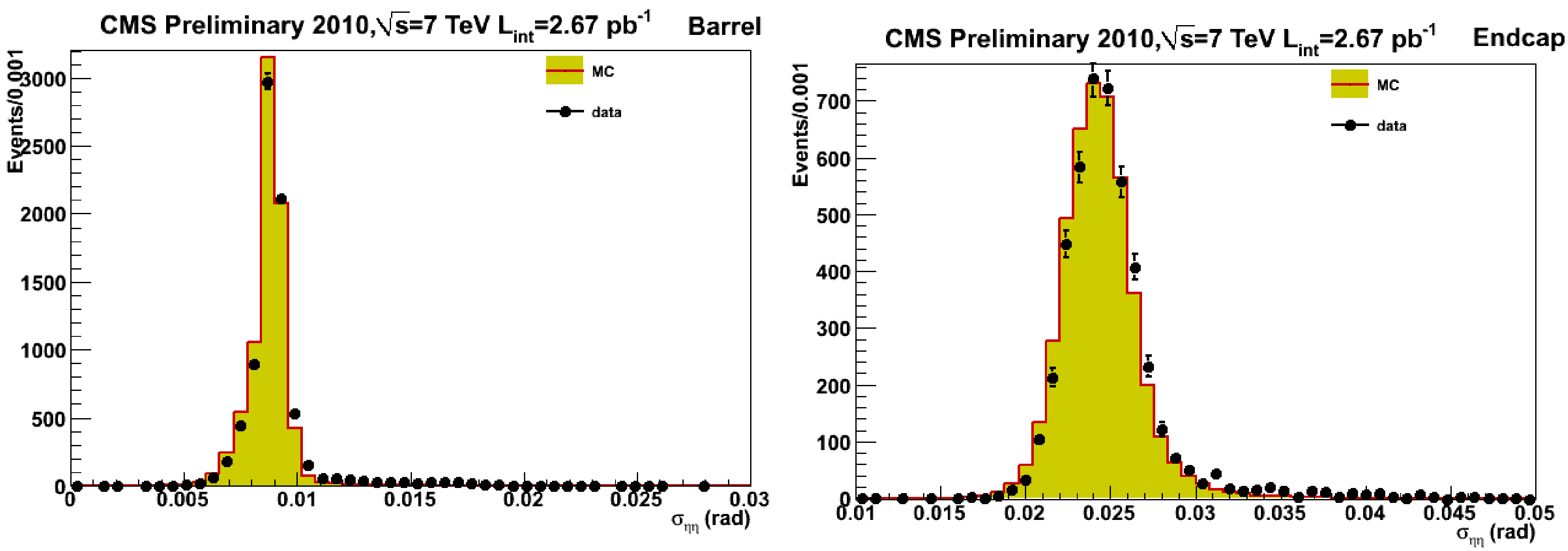




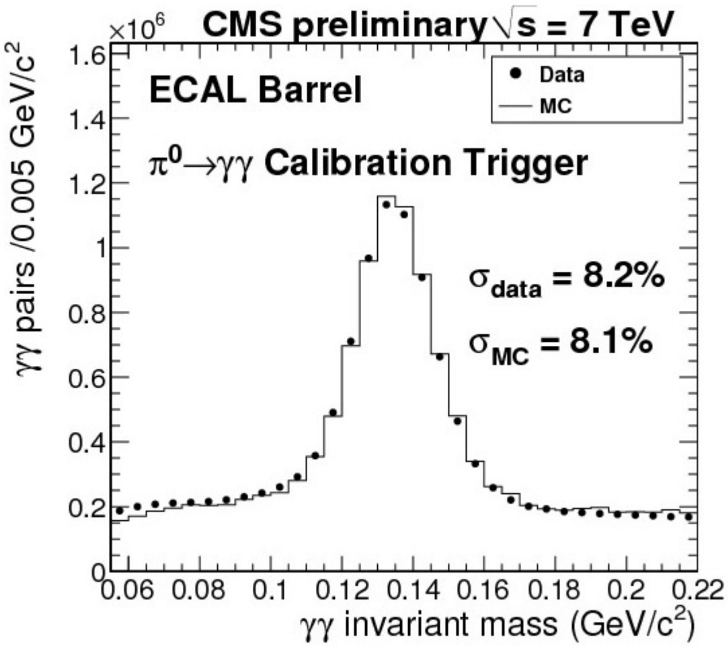


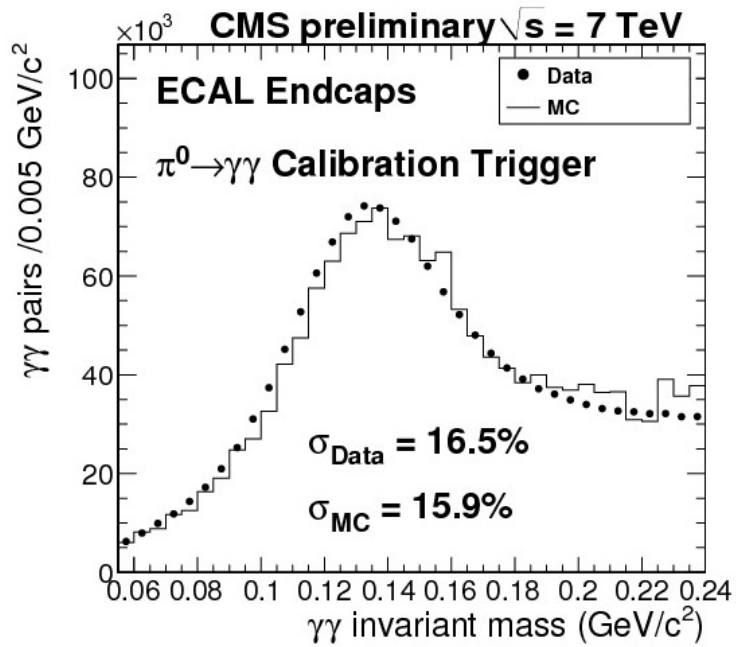
Shower Shape Variables

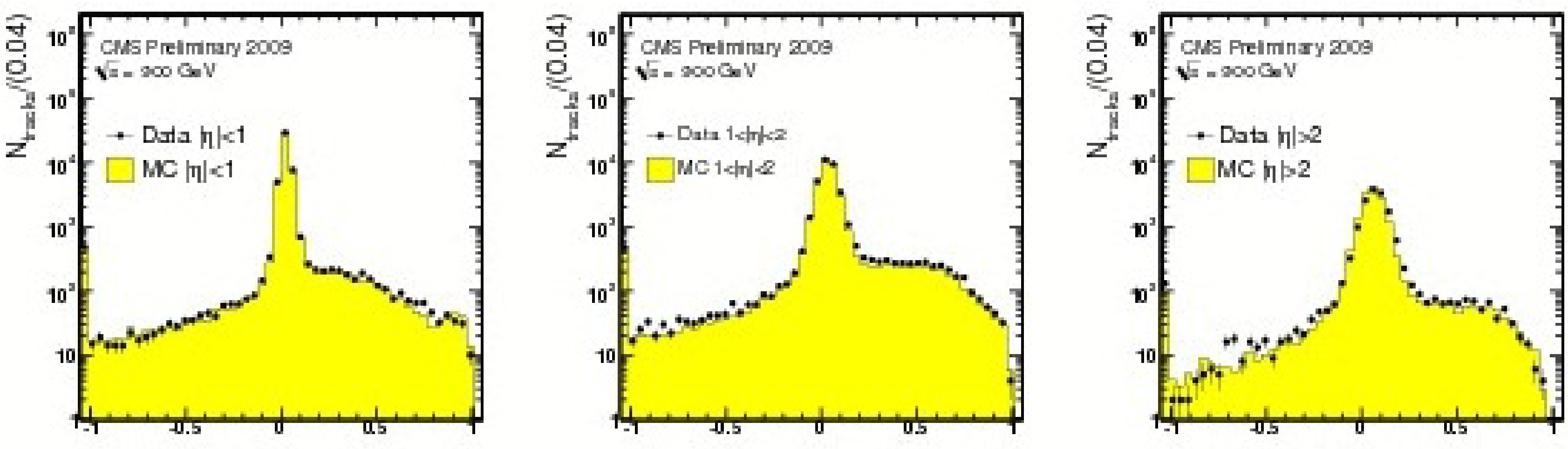
- Look at the width of showers due to electrons along the η direction for the barrel and the endcap
- For electrons, width along φ is wider due to B-field effects



Mass scale etc

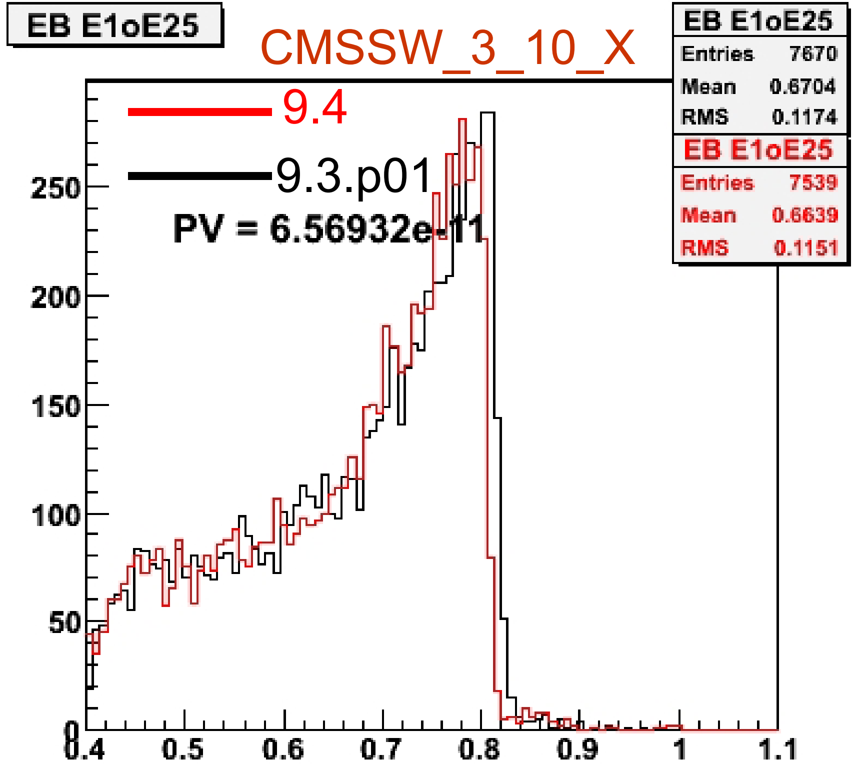


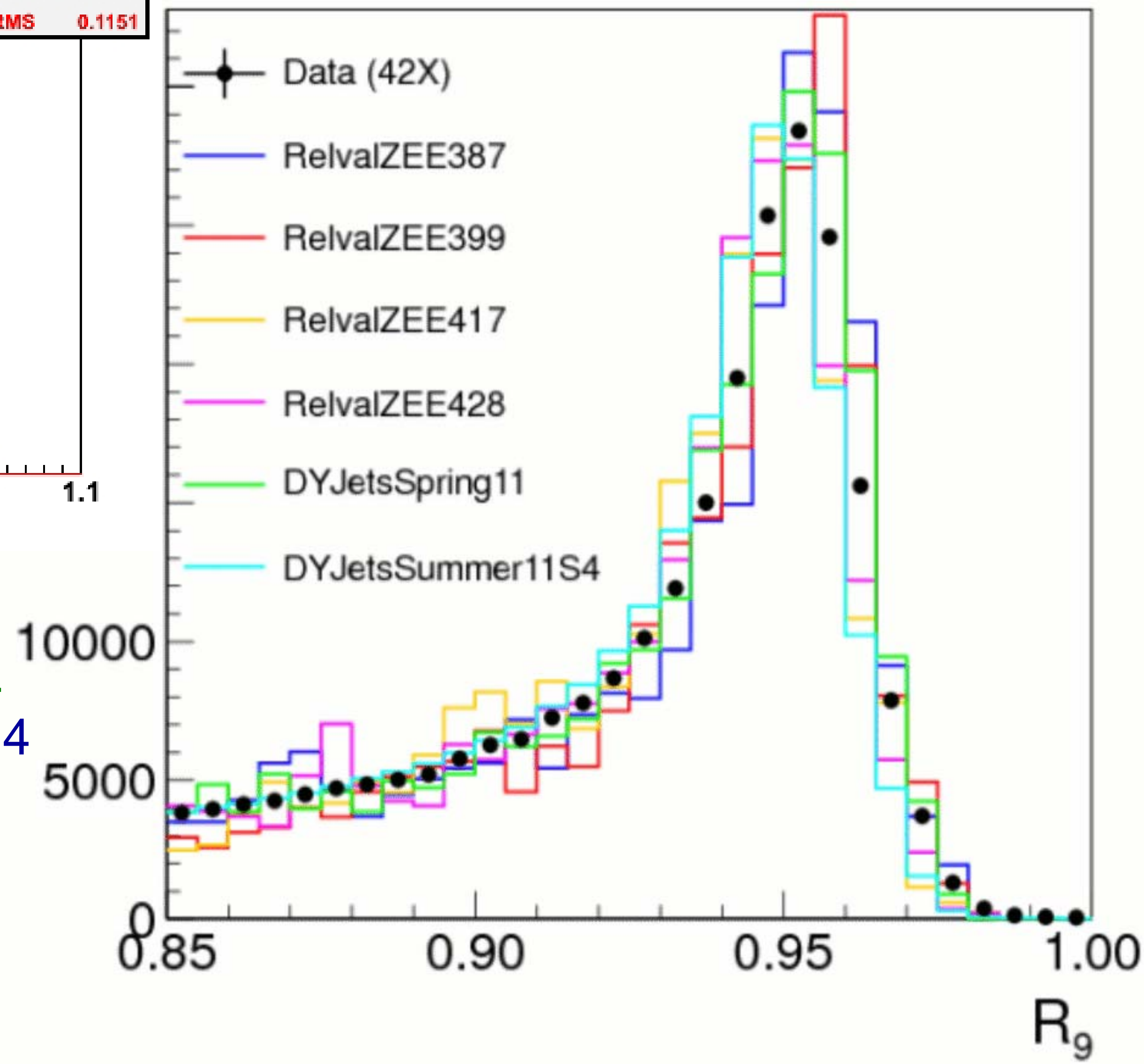




fBrem is the fractional energy loss in the tracker: useful to classify an electron candidate

A Recent Issue





- The lateral shower profile for photons (and $e^{\pm}$) is changing with the Geant4 version from 9.3.p01 to 9.4 to 9.4.p02. This is not yet understood and we need some help to get some of the key distributions agreeing better with the data.

Commissioning Jets & MET

- CMS uses 3 approaches for constructing jets and MET: use only calorimetric measurements, add tracking information, employ particle flow algorithm.
- Use tight p_T selection on jets to restrict data-MC comparisons in regions where Jets and MET are more reliable
- Use loose and uniform η range to make results with different Jet and MET reconstruction methods more coherent
- Events are selected using
  - At least one of the beam scintillator (BSC) MinBias trigger
  - Exclude events with any of the BSC beam halo triggers
  - Require BPTX bit 0
  - Remove scraping events
    - High-purity tracks fraction (>10 tracks) greater than 25%
  - Select events with good primary vertex
    - Vertex IsValid() true, vertex NDF >= 5 and vertex |z|<15 cm

Jet Selection

- Jets are reconstructed with the anti-k_T R=0.5 algorithm
- Corrections applied to all jet types (including JPT):
  - Relative (L2) correction which makes the jet response uniform in η, by calibrating, on average, to the response in the central region of the calorimeters (|η| < 1.3)
  - Absolute (L3) correction removes the p_T dependence of the jet response.
- Select dijet events back-to-back (in the transverse plane)
  - Remove noise
  - Reduce the effect of radiation

	Jet plots	MET plots
p_T(1st jet)	>25 GeV	>25 GeV
p_T(2nd jet)	>25 GeV	>10 GeV
Df= $\|f_{1st} - f_{2nd}\|$	> 2.1	
h	|h| < 3	

φ spectrum

Calo jets **JPT jets** **PF jets**

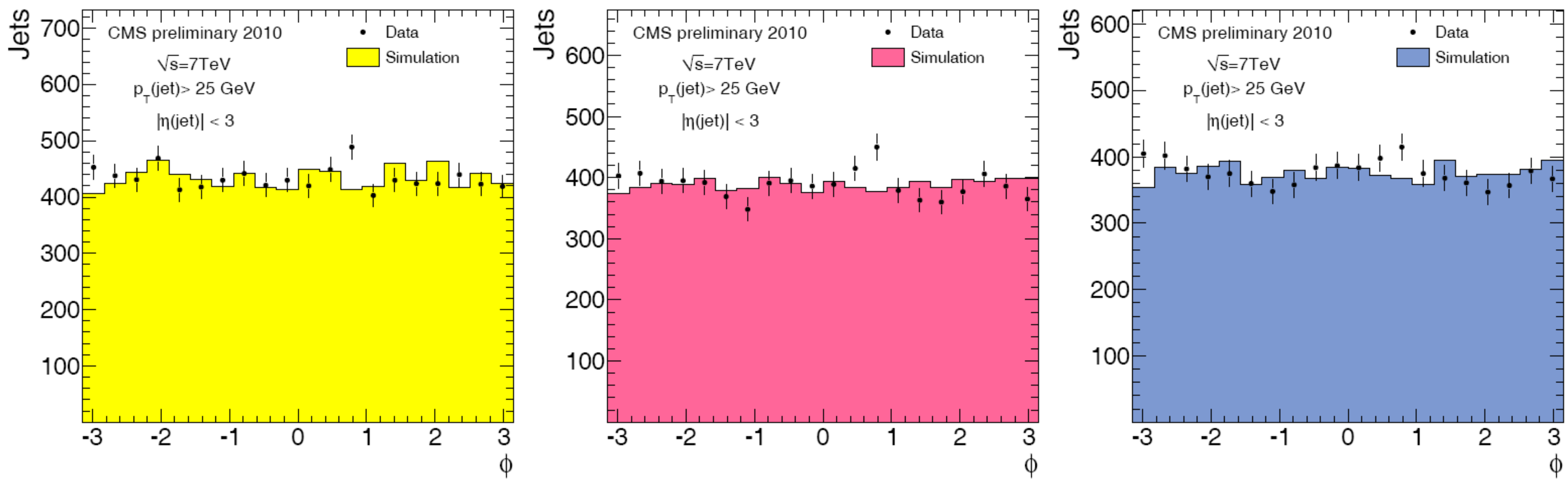


Figure: Data vs MC: Jet ϕ for dijet events: Calorimeter Jets, JPT jets, PFjets.

η spectrum

Calo jets **JPT jets** **PF jets**

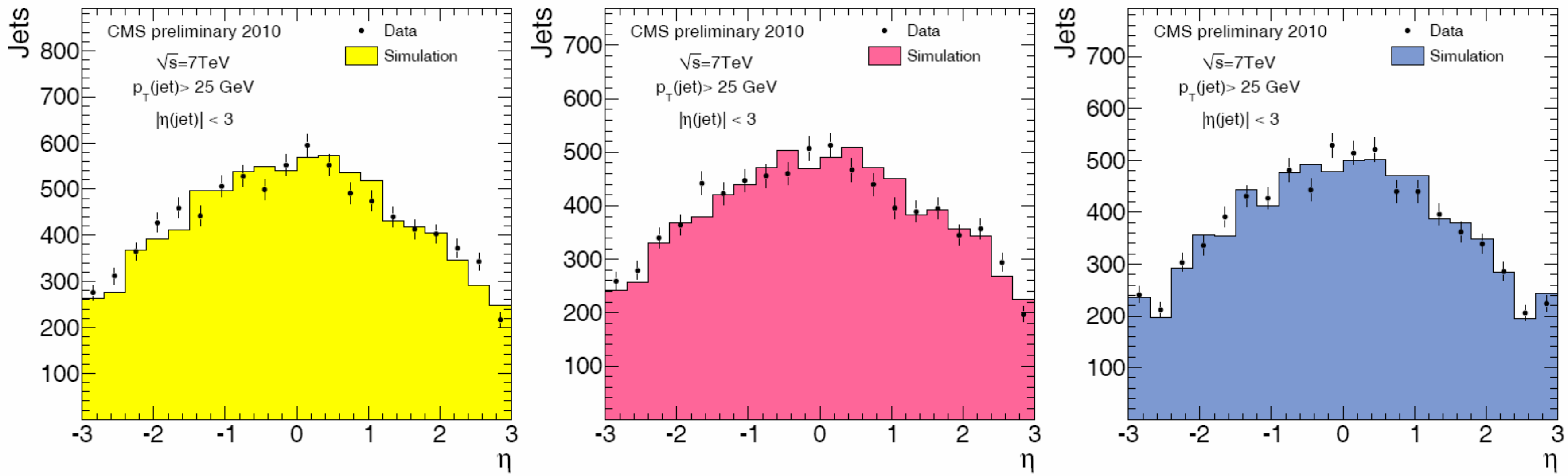
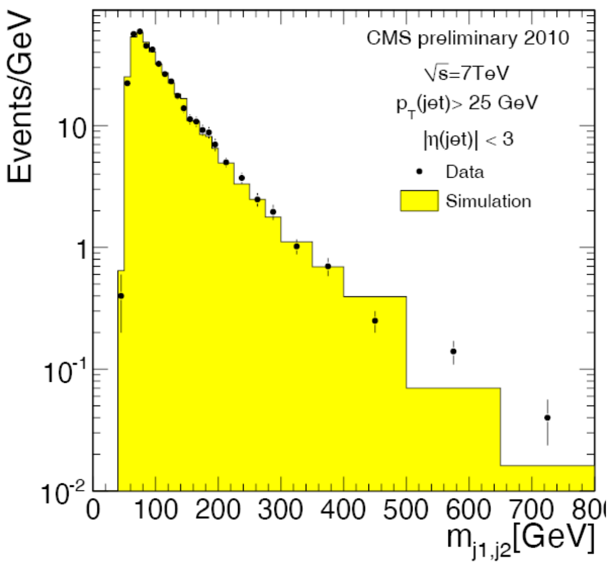


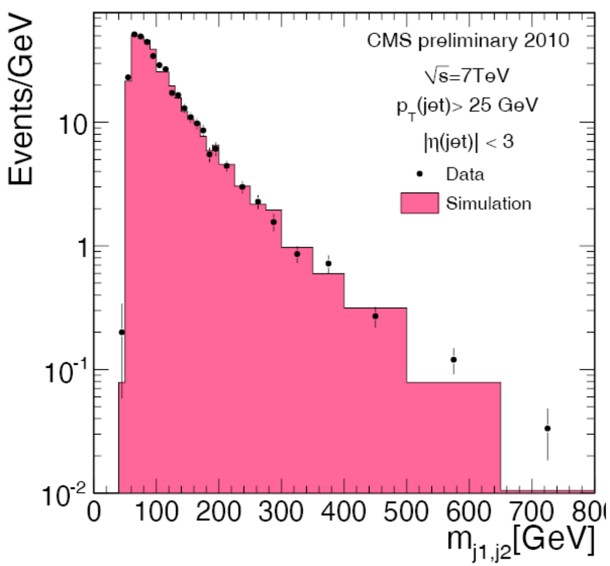
Figure: Data vs MC: Jet η for dijet events: Calorimeter Jets, JPT jets, PFjets.

Dijet Mass

Calo jets



JPT jets



PF jets

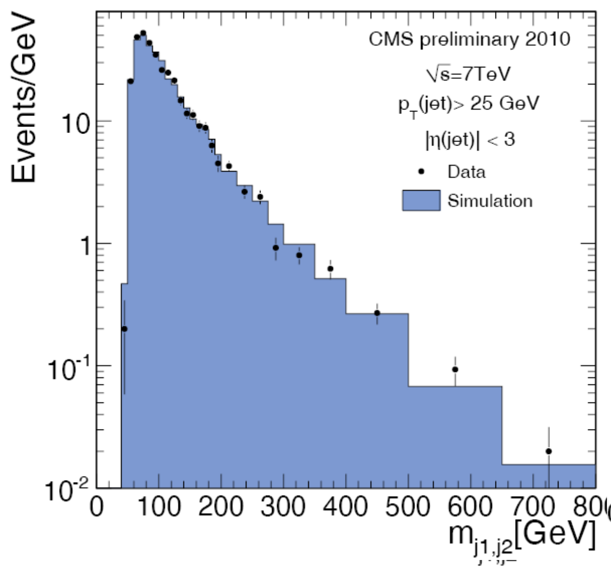
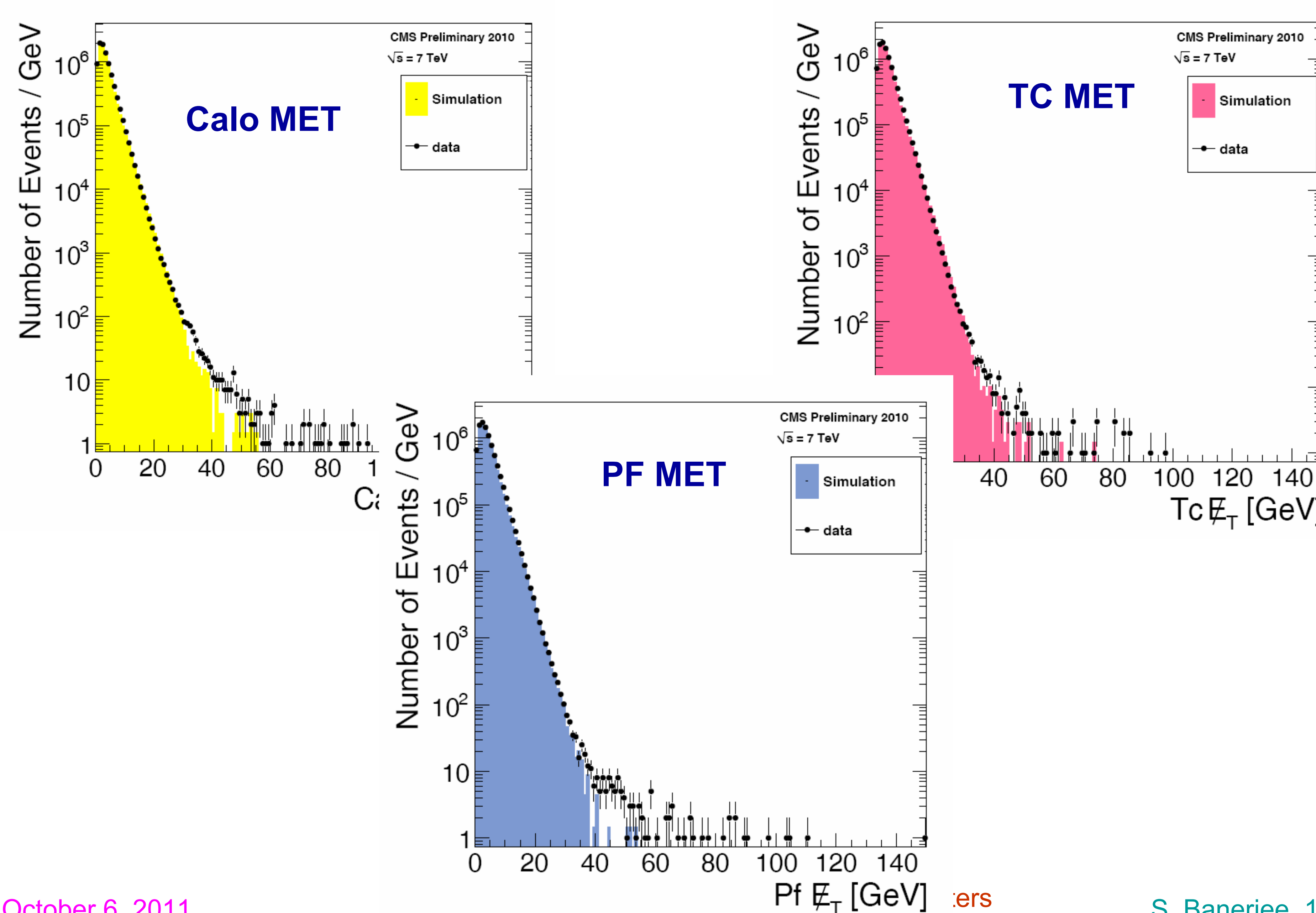
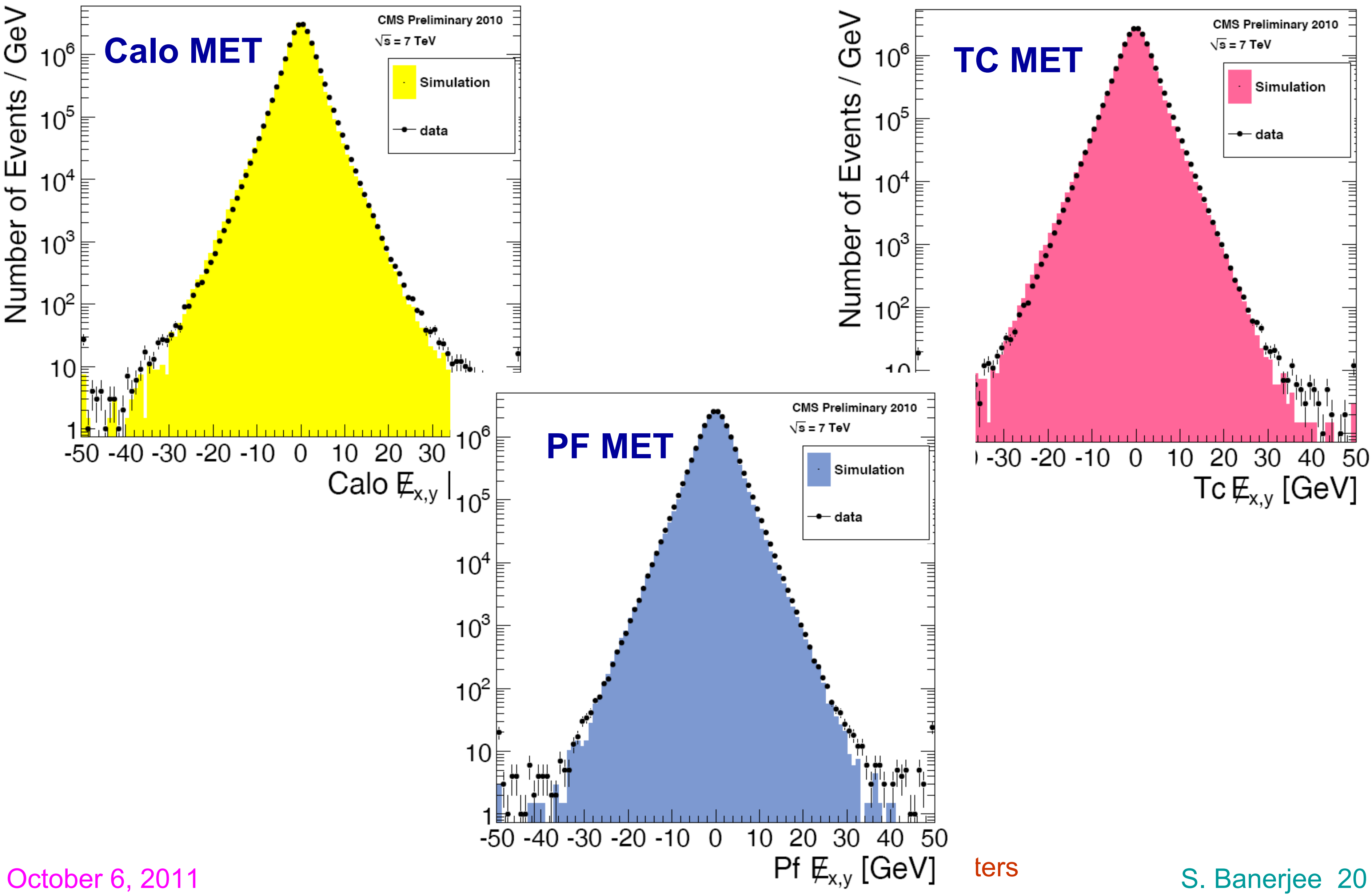


Figure: Data vs MC: Di jet mass $m_{j1,j2}$ for Calorimeter Jets, JPT jets, PFjets.

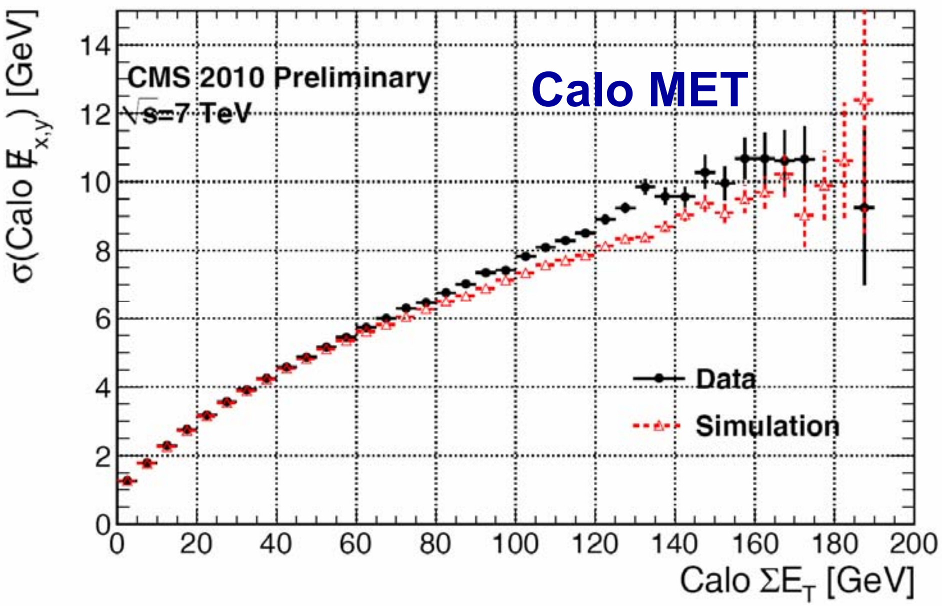
Inclusive MET

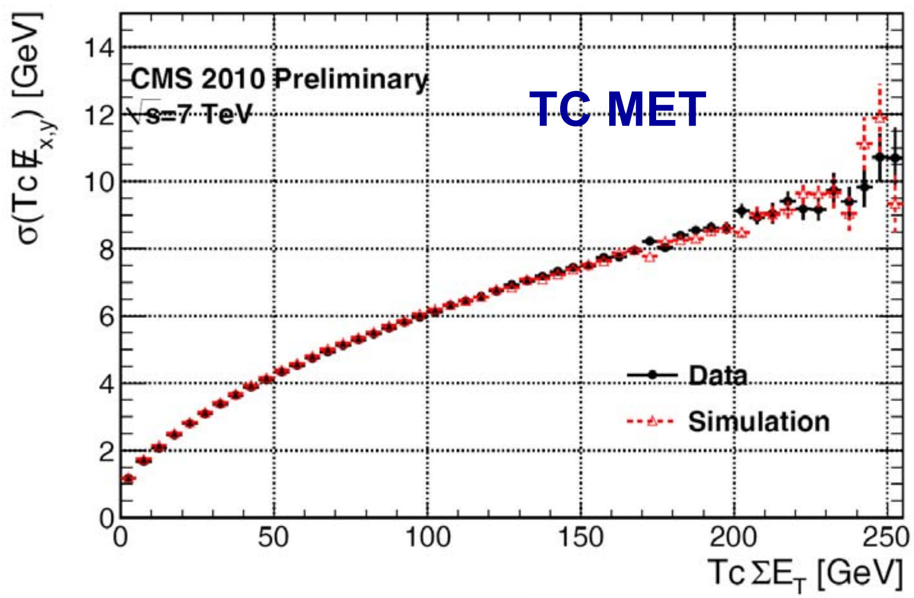


Inclusive $MET_{x,y}$

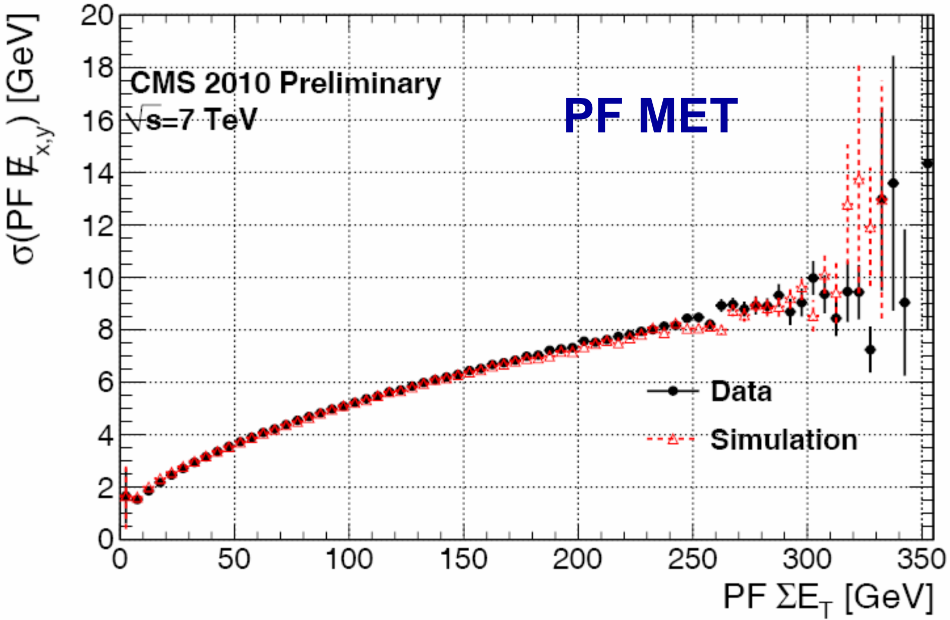


MET Resolution



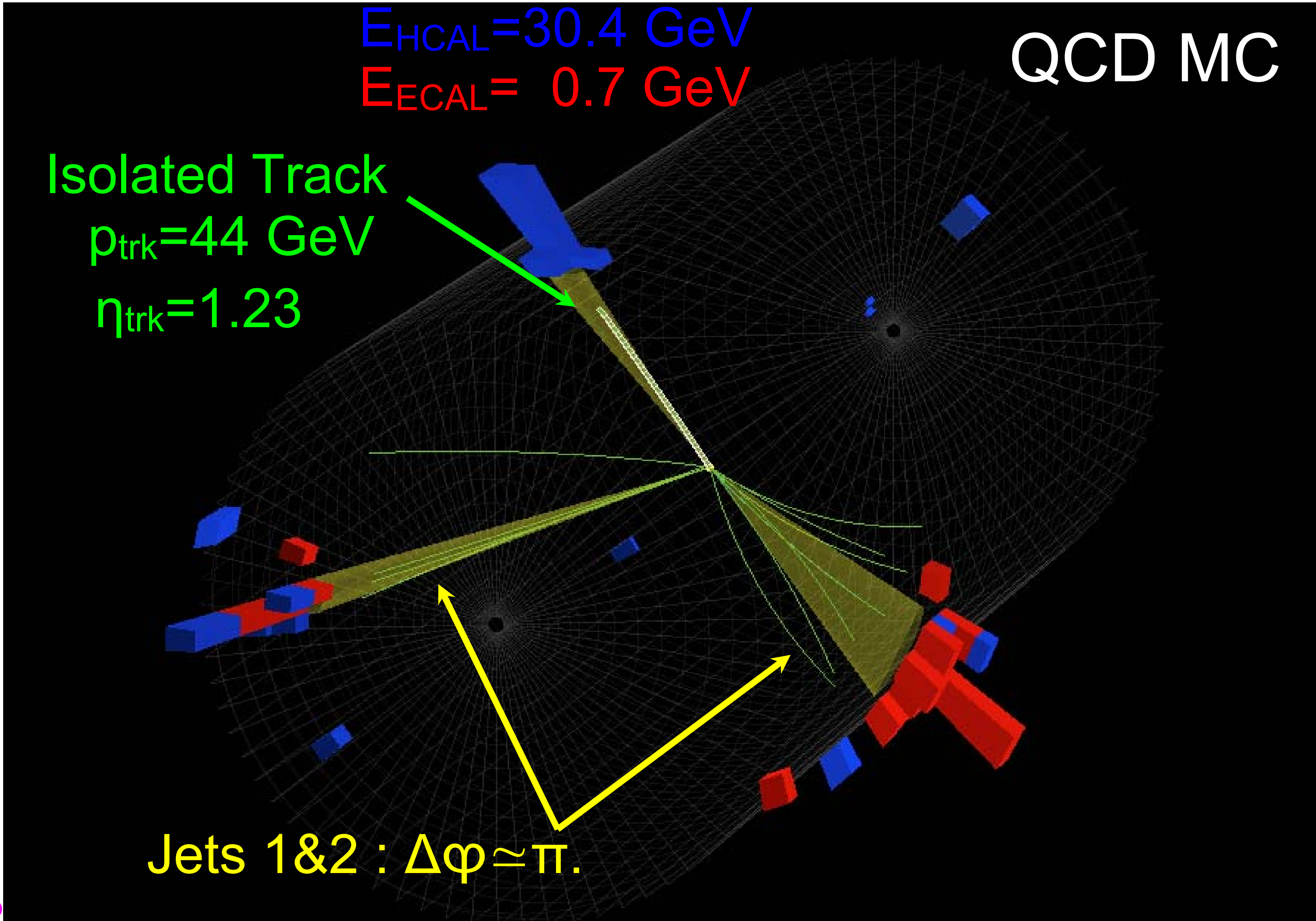


Variables in x and y axes are for uncorrected MET



Use of Isolated Charged Hadrons

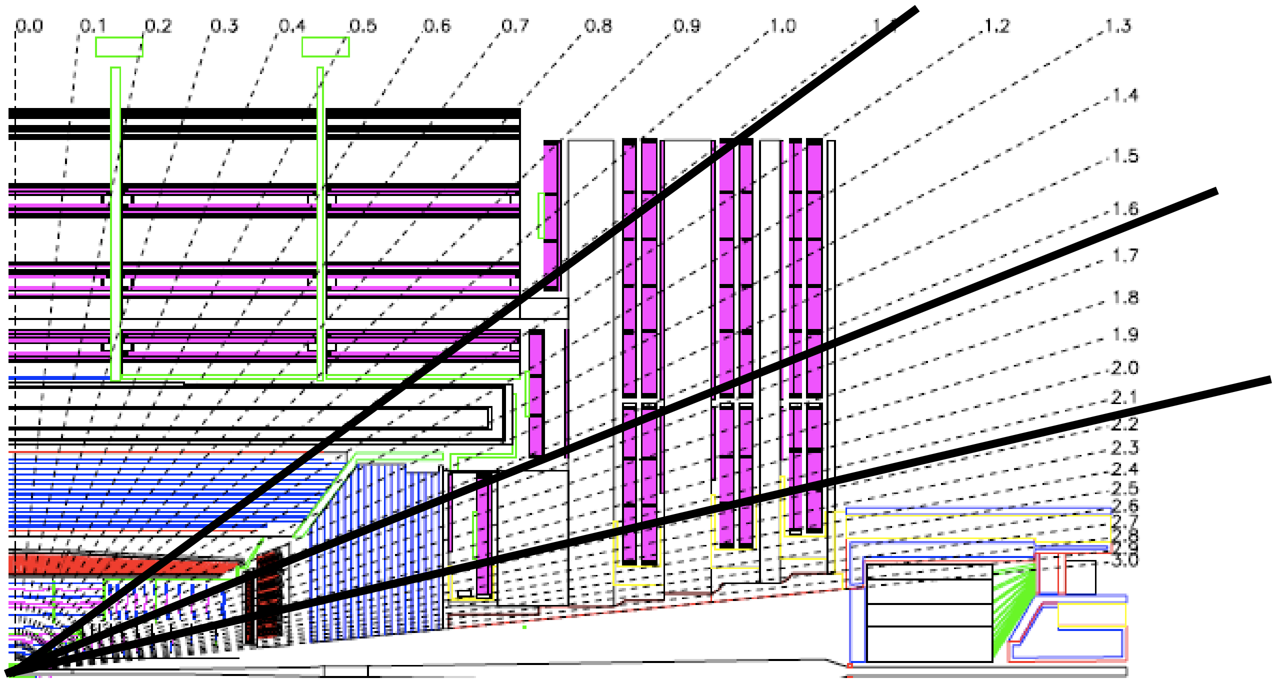
Use isolated charged particles from LHC collision data:



Analysis of Isolated Charged Tracks

- Select High purity tracks coming from the primary vertex and demand they are well measured:
  - Distance from primary vertex < 0.2 mm in *xy*-plane & along *z*
  - χ^2/d.o.f. < 5 & number of planes crossed ≥ 8
- Use missed hit information to reject interacting tracks in the tracker material or selection of long-lived particles
- To define the signal zone, propagate the track to the calorimeter surface (ECAL as well as HCAL) and use granularity of calorimeter → NxN matrix
  - Use test beam and simulation to decide signal zone size
  - Balance between containment and contamination
  - Final choice: 11x11 in ECAL and 3x3 in HCAL
- Demand the signal zone is isolated from other particles
  - Isolate from other charged particles by extrapolating all charged particles to ECAL/HCAL surface and see they are not within the isolation zone
  - Neutral isolation demanded by looking into energy deposit in an annulus region in ECAL (HCAL)

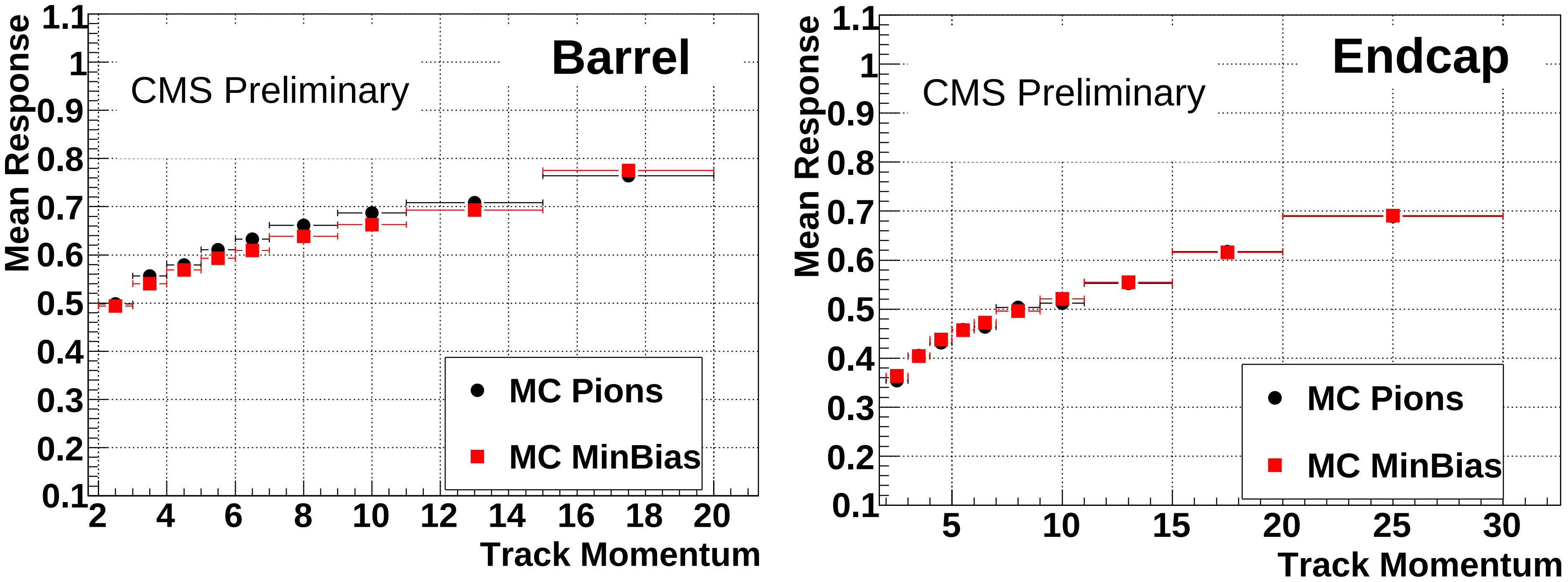
Measure as a Function of η



Divide the phase space in 3 angular regions:

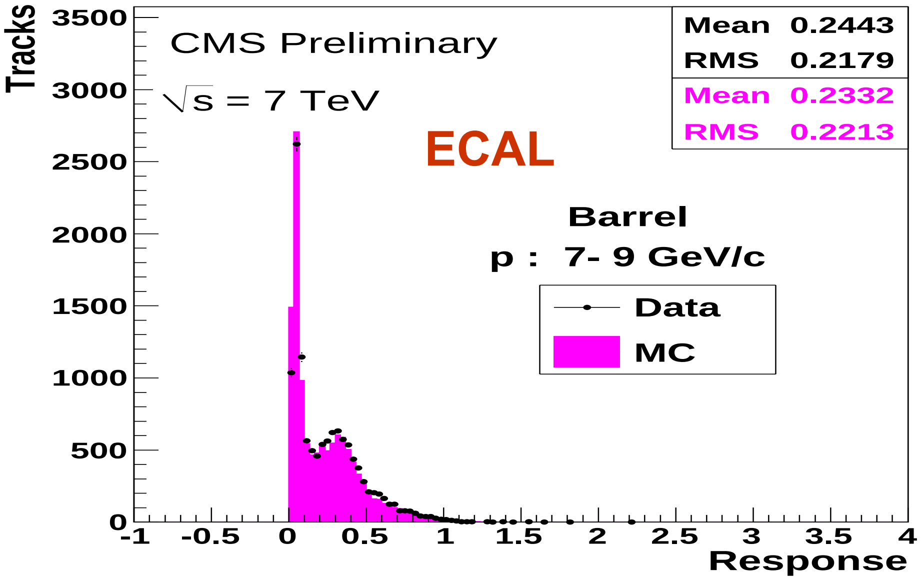
- $0.000 < |\eta| < 1.131$ (Barrel)
- $1.131 < |\eta| < 1.653$ (Transition)
- $1.653 < |\eta| < 2.172$ (Endcap)

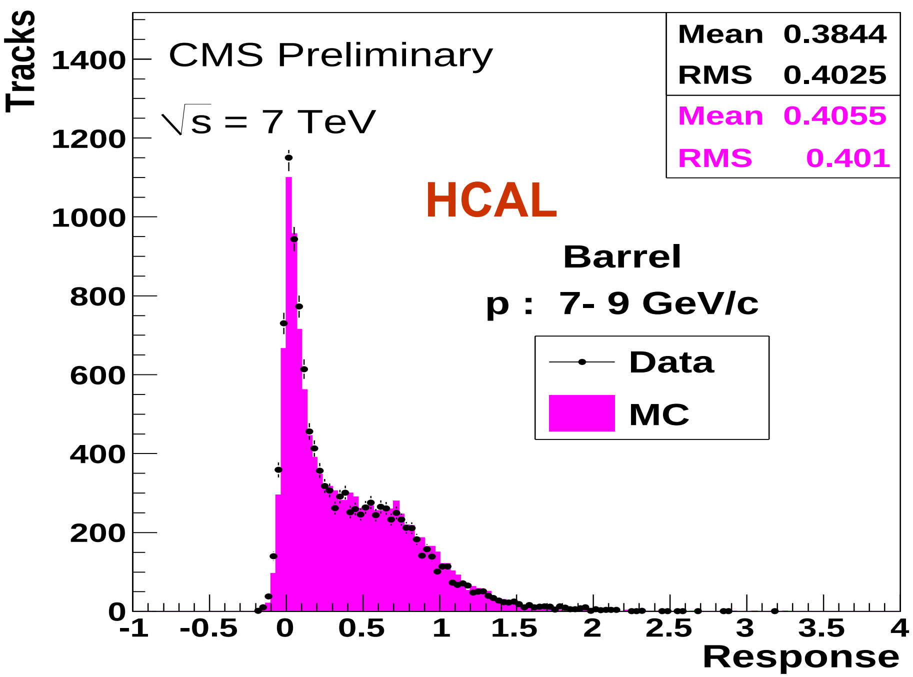
Closure Test

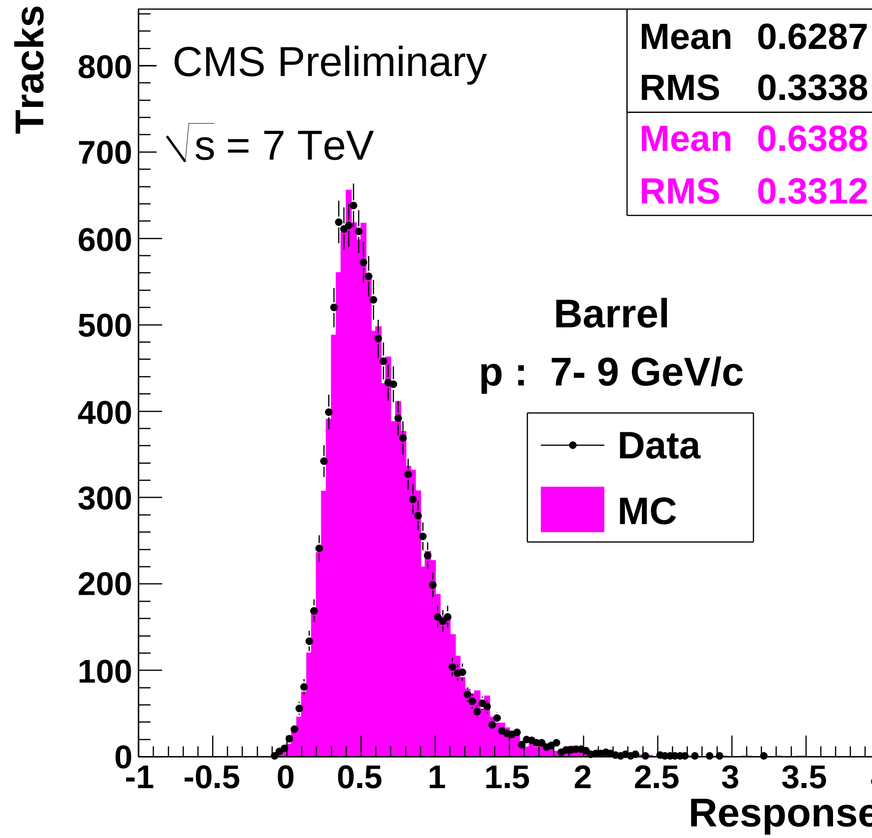


- Check isolation criteria by repeating the same measurements with minimum-bias and single particle Monte Carlo
- Very similar measurements observed – justifies choice of signal and isolation zones

Barrel Region (I)

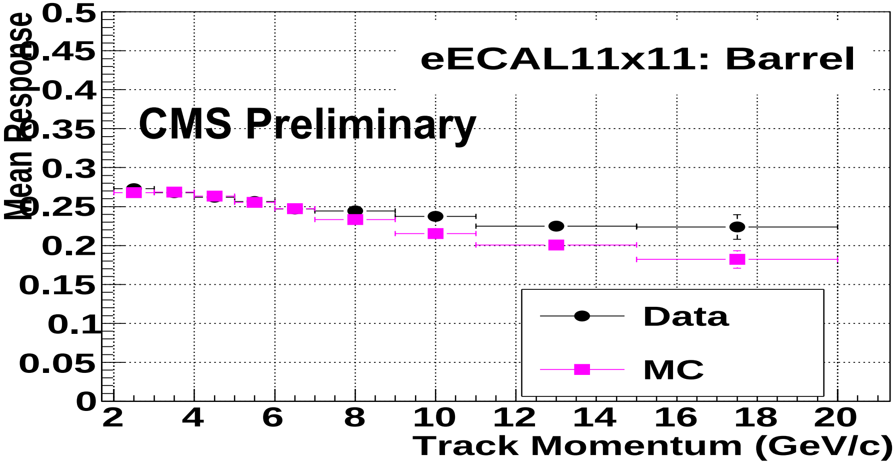


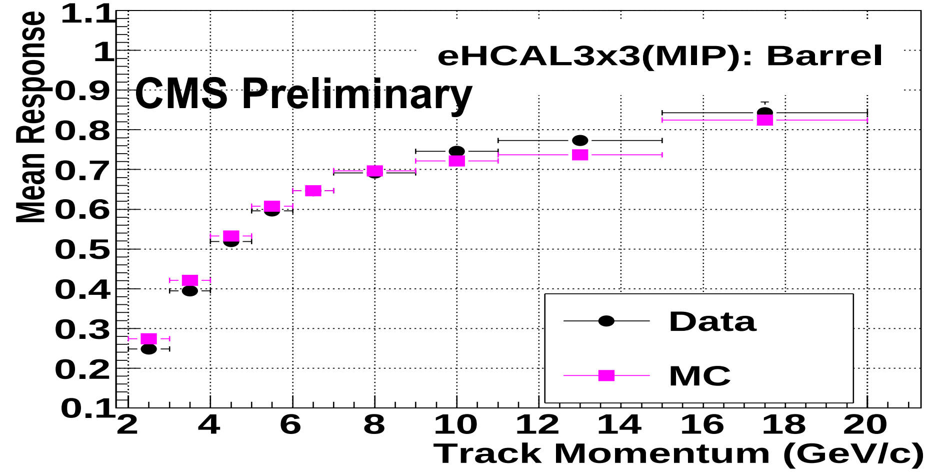


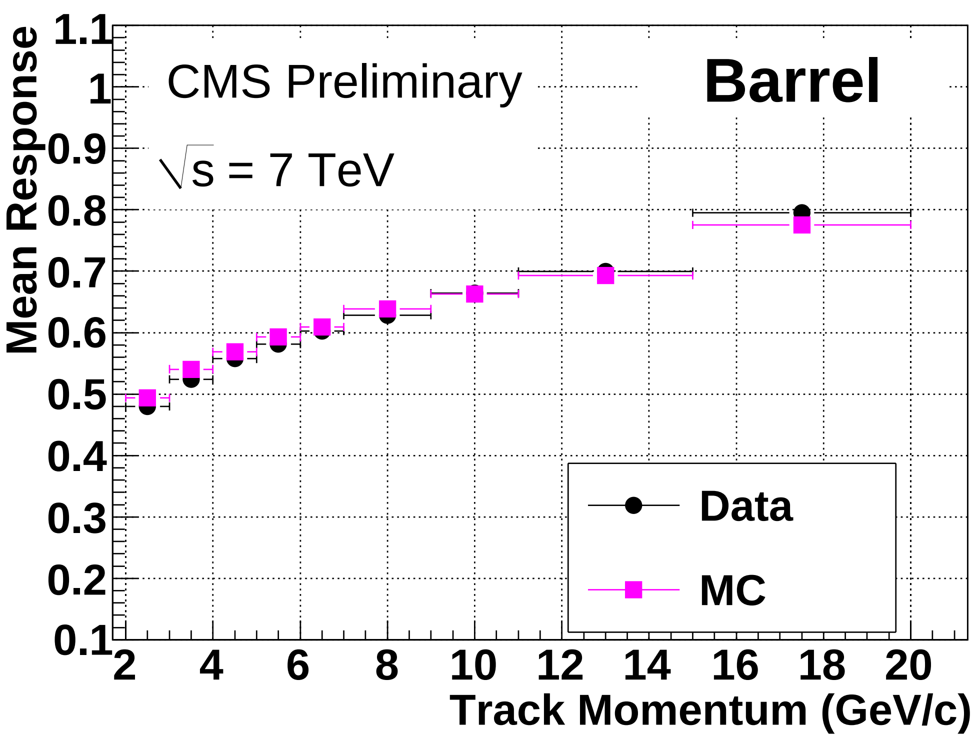


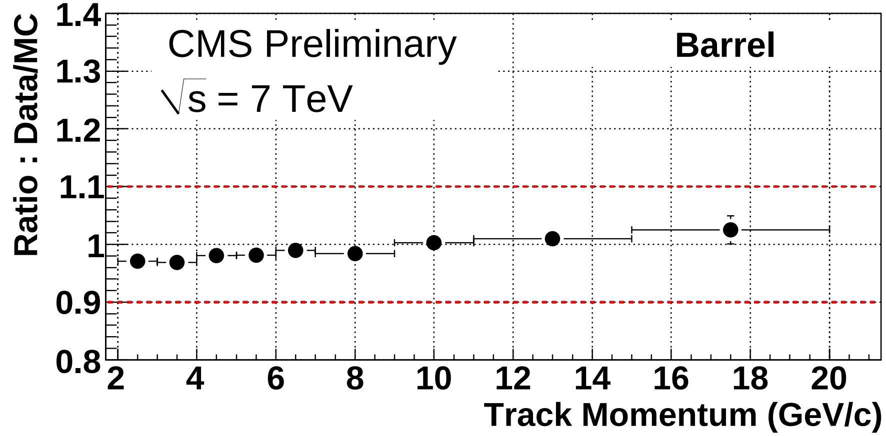
- Overall agreement is quite reasonable: small difference in individual contributions

Barrel Region (II)



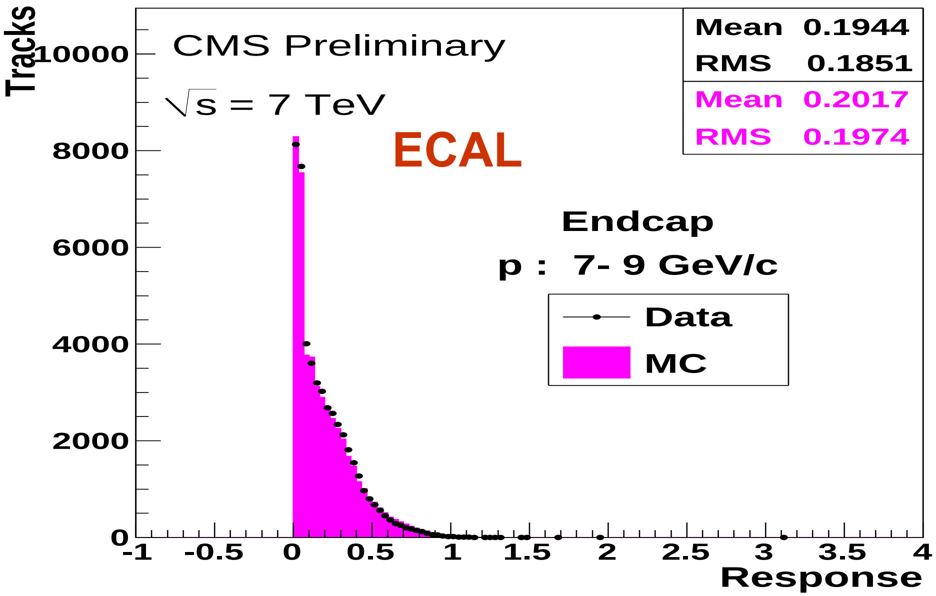


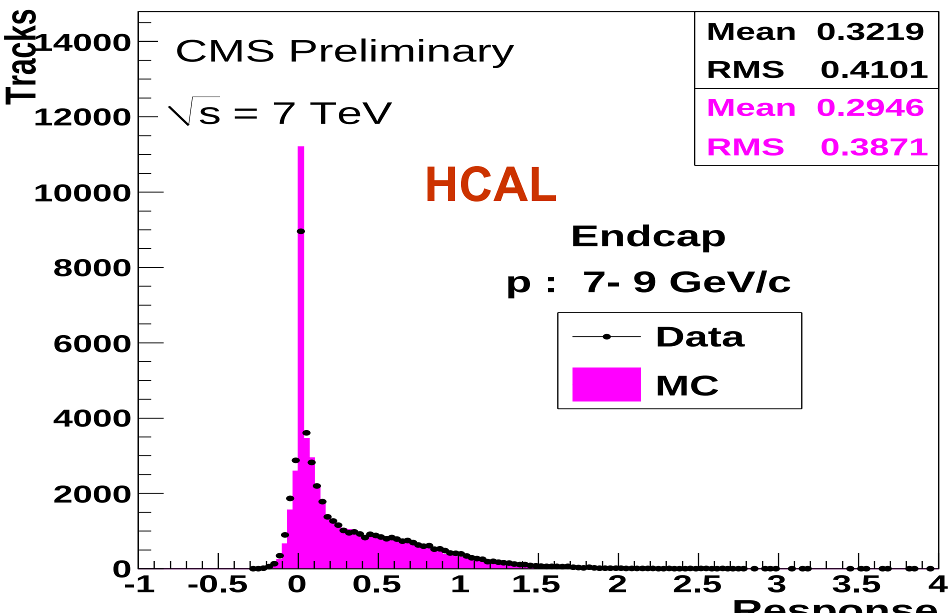


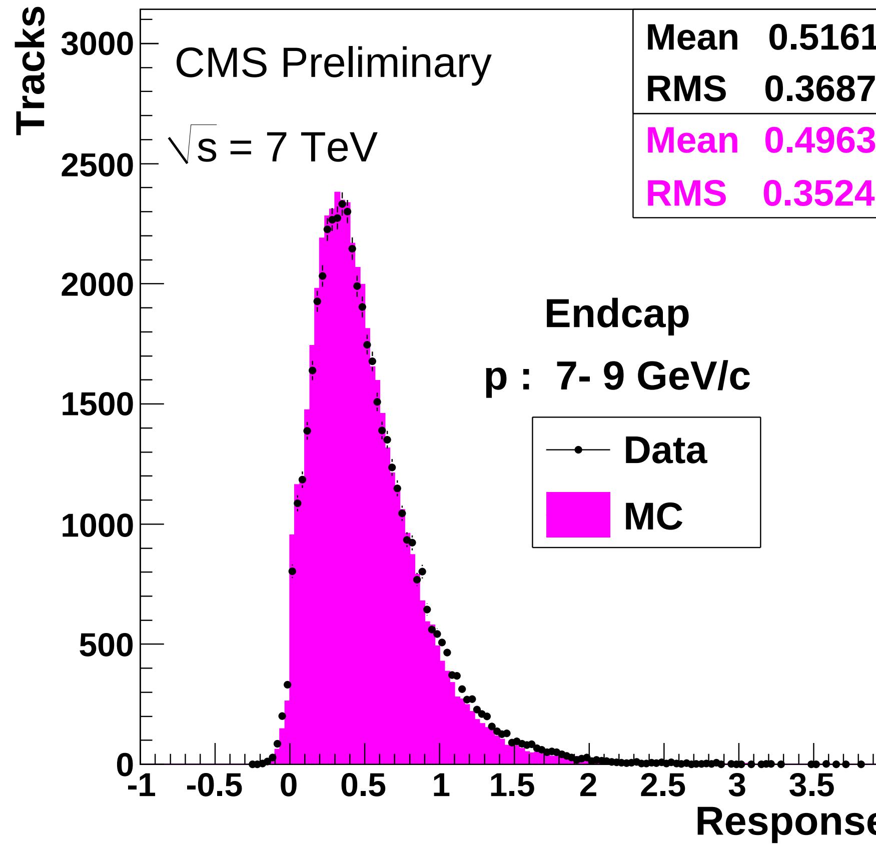


- Data/MC agreement is better than ±3% between 2-20 GeV/c

Endcap Region (I)

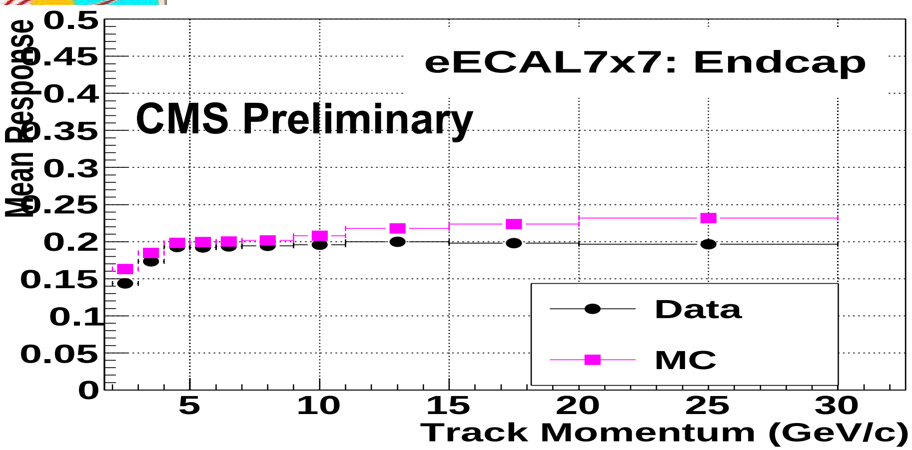


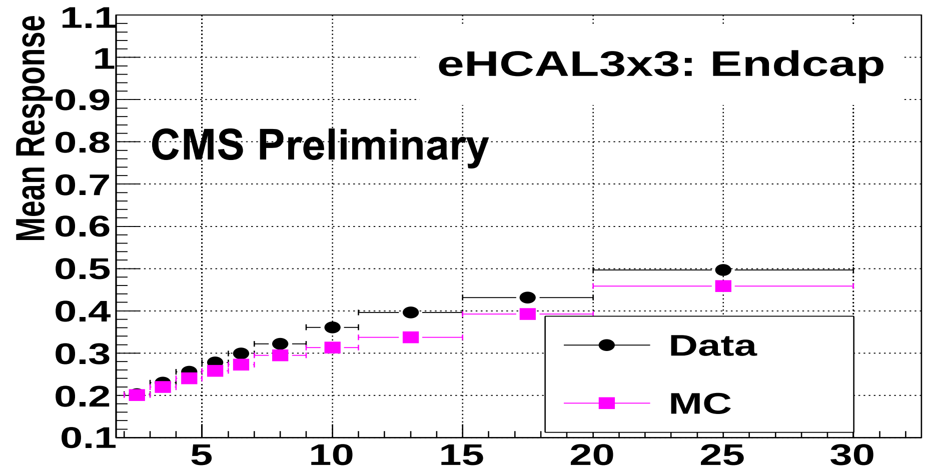


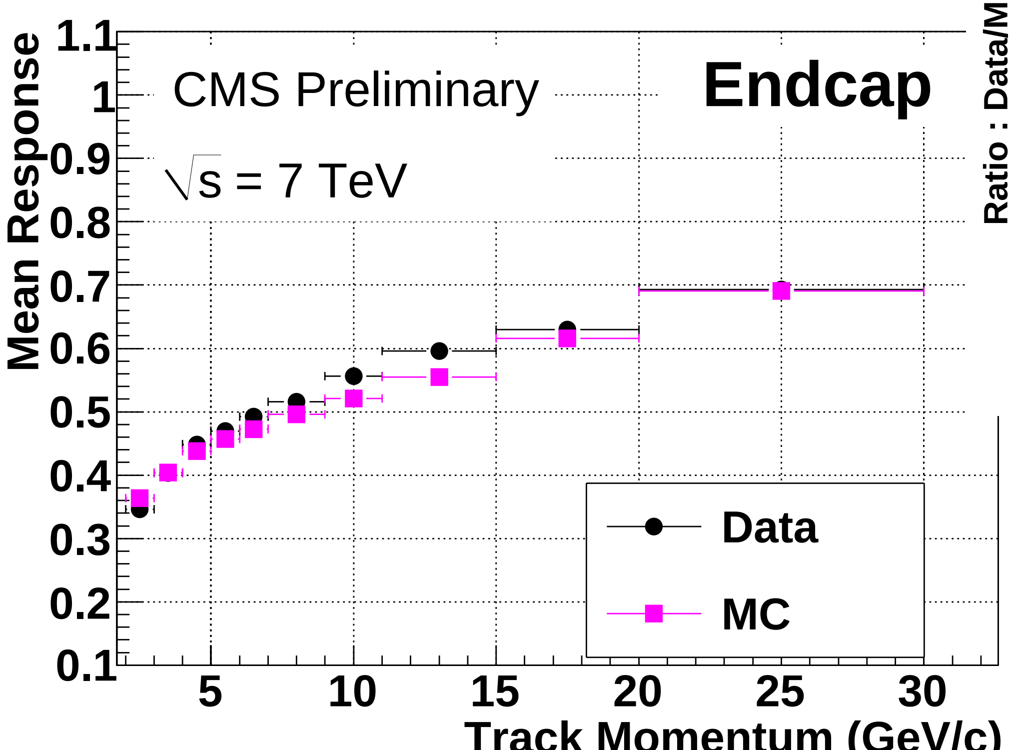


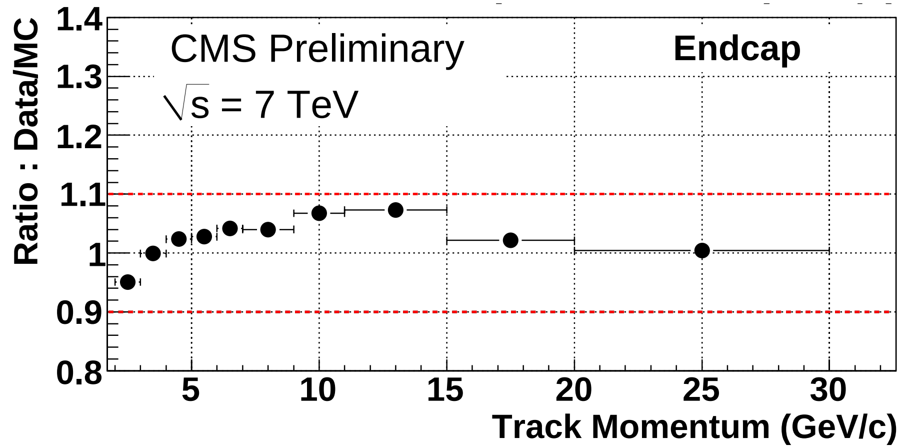
- Data give somewhat larger response in HCAL – but overall response still within 5%

Endcap Region (II)









- Agreement in overall response is still within ±5% - trying to understand the source of discrepancy

Summary

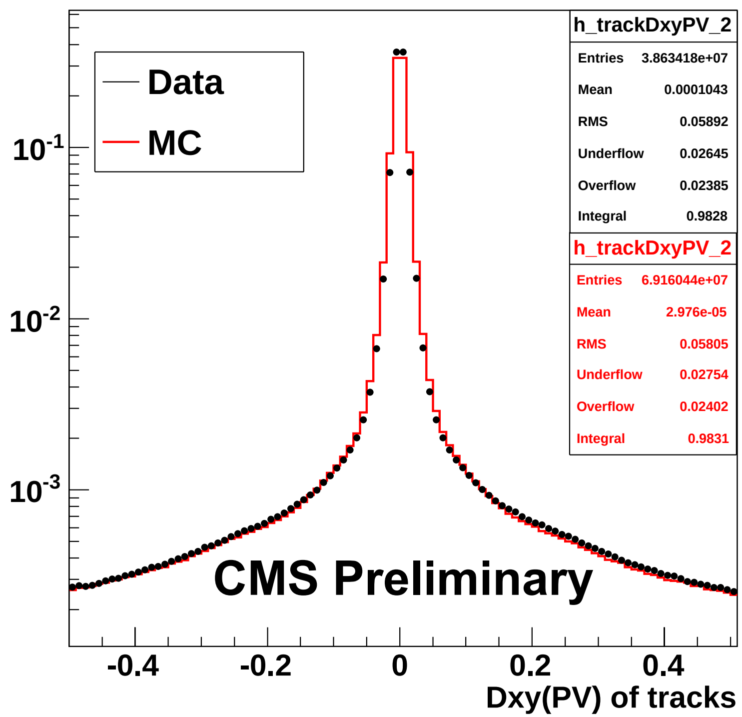
- CMS has been validating the physics models inside Geant4 using its test beam as well as collision data.
- Several physics lists inside the most recent version of Geant4 provide good agreement of the energy response, resolution of $\pi^{\pm}$ and protons. More work is needed to improve the physics for $K^{\pm}$, anti-protons & hyperons.
- Electromagnetic physics in Geant4 give a good description of shower shapes for electron and photon candidates in the collision data.
- However there is some issue in understanding MS models during the transition of Geant4 release. May need a better tuning soon.
- Isolated charged particles are used to measure calorimeter response of hadrons as a function of particle energy. These are used to compare data with Monte Carlo predictions.
- There is an impressive agreement between Geant4 predictions and data in the barrel region. The agreement worsens in the endcap region. Still energy resolution is an issue to be understood better.

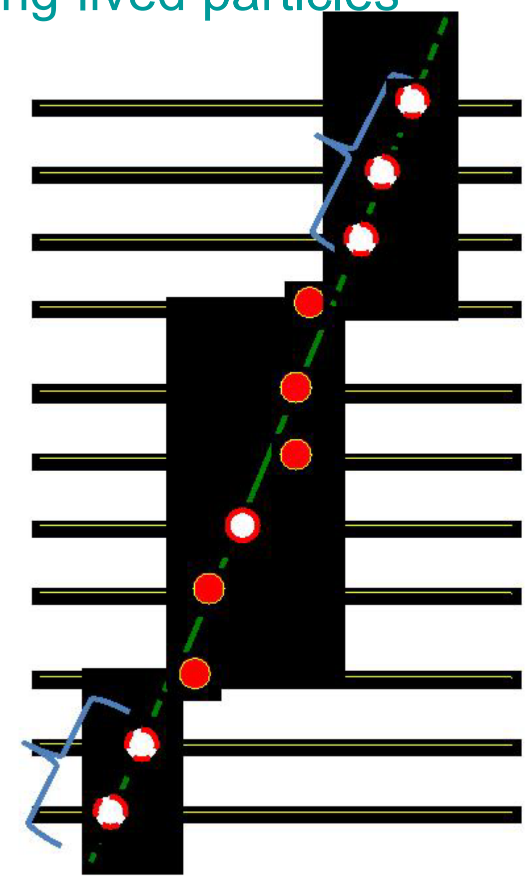
Backup Slides

Track Selection

- Use High purity tracks coming from the primary vertex:
  - Distance from primary vertex < 0.2 mm in *xy*-plane & along *z*
- Well measured tracks
  - χ^2/d.o.f. < 5
  - Number of planes crossed ≥ 8

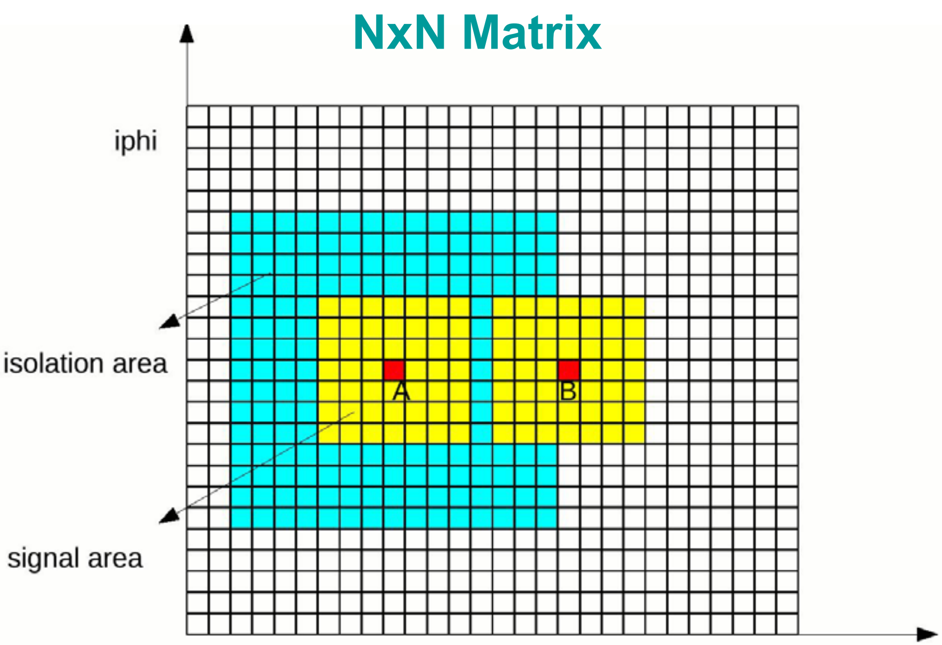
Use of missed hit information is important for rejection of interacting tracks in the tracker material or selection of long-lived particles

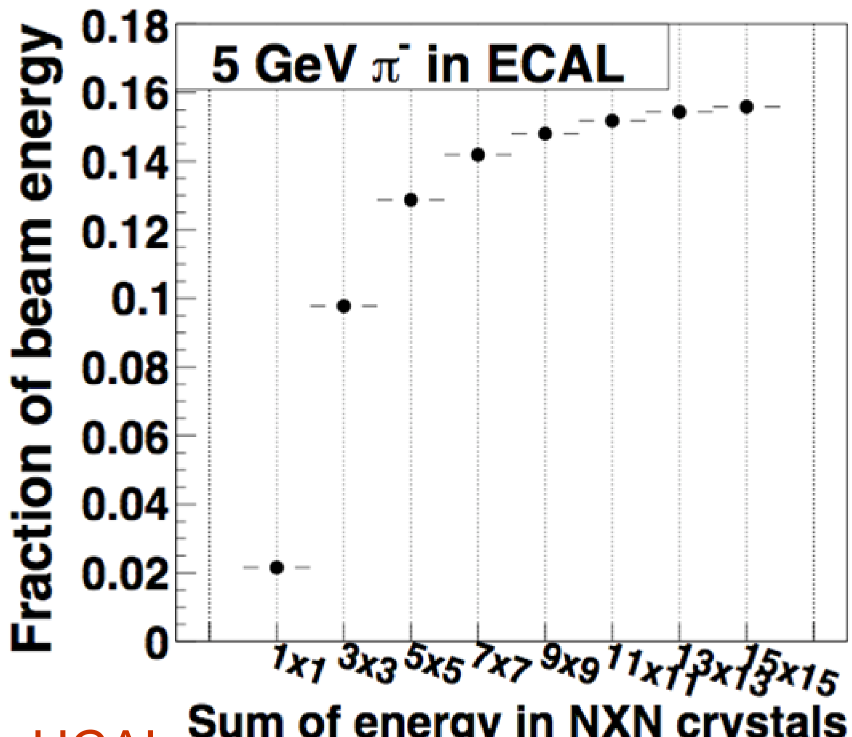




Signal Zone

- Propagate the track to the calorimeter surface (ECAL as well as HCAL)
- Use granularity of calorimeter → NxN matrix
- Use test beam and simulation to decide signal zone size
- Balance between containment and contamination





Final choice: 11x11 in ECAL and 3x3 in HCAL

Isolation Criteria

- Isolate from other charged particles by extrapolating all charged particles to ECAL/HCAL surface and see they are not within the isolation zone
- Neutral isolation demanded by looking into energy deposit in an annulus region in ECAL (HCAL)