Validation

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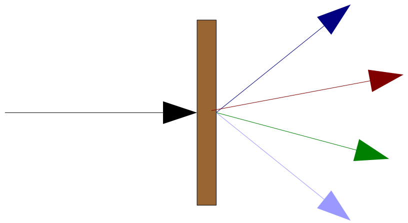
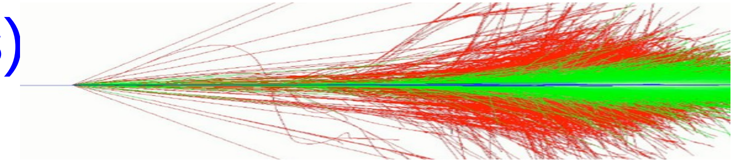
ESIPAP, Archamps, 8-9 February 2021

Validation & tuning of hadronic models

- The developers of the hadronic models are responsible of the tuning & validation of these models with thin-target (microscopic, single-interaction) measurements



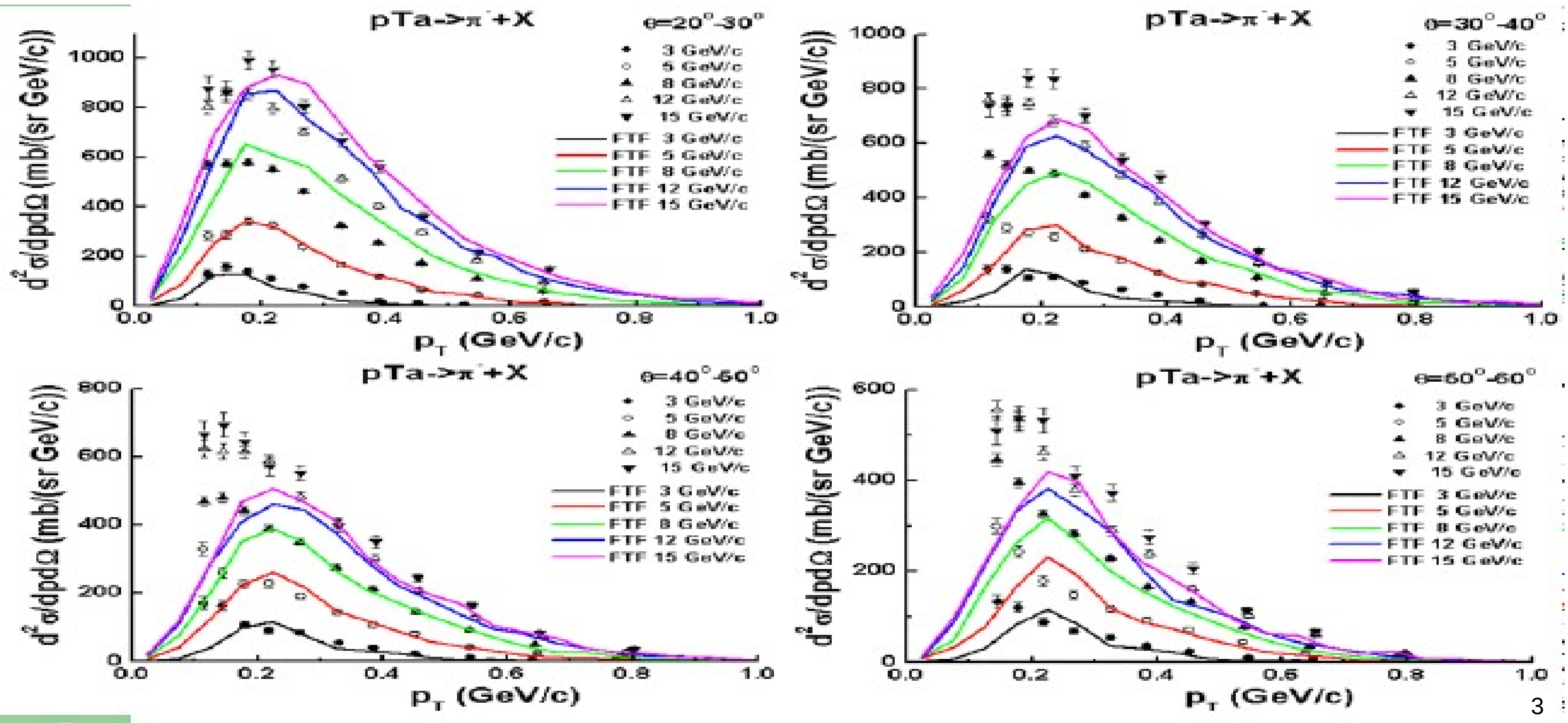
- Validation of complete physics configurations is performed by users mostly via measurements of hadronic showers in calorimeter test-beam setups (thick targets)



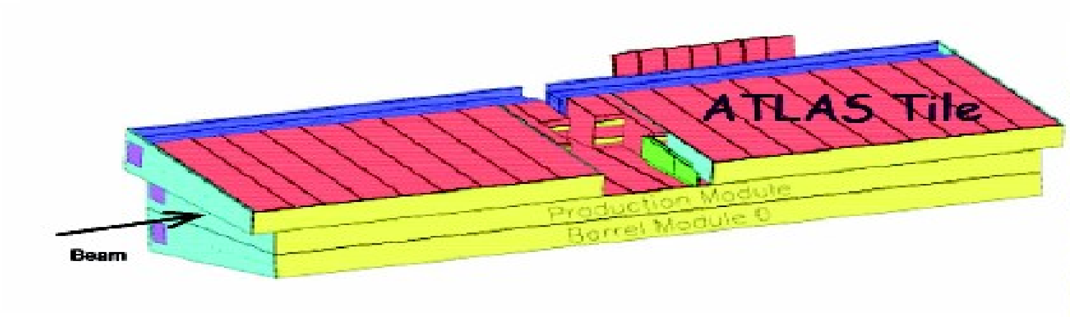
- The most important application of the hadronic models for collider experiments is the simulation of jets, which involves:
  1. the Monte Carlo event generator
  2. the convolution of the showers for each constituent hadron
  3. experiment specific: geometry & materials, digitization, *etc.*

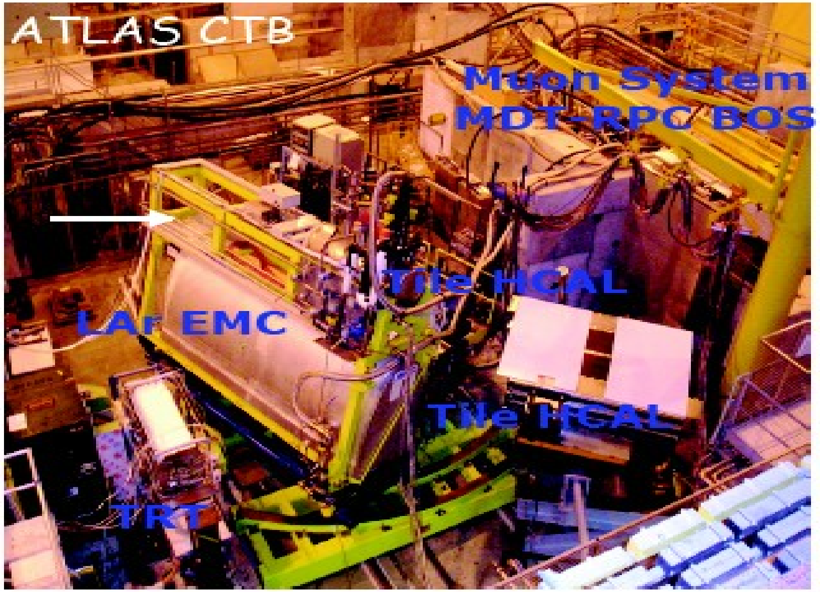
Model-level thin-target test

FTF validation, HARP-CDP data



LHC calorimeter test-beams





Calorimeter observables

- The simulation of hadronic showers can be validated with calorimeter test-beam set-ups, with pion and proton beams of various energies, considering the following observables:
  - Energy response: E_{rec} / E_{beam}
  - Energy resolution: $\Delta E_{rec} / E_{rec}$
  - Shower profile:
    - Longitudinal: $E_{rec}(z) / E_{rec}$
    - Lateral (transverse or radial): $E_{rec}(r) / E_{rec}$
- Note that we can test directly only single hadron showers in calorimeter test-beam set-ups, whereas for a collider experiment (e.g. ATLAS and CMS) jets are measured

A long journey...

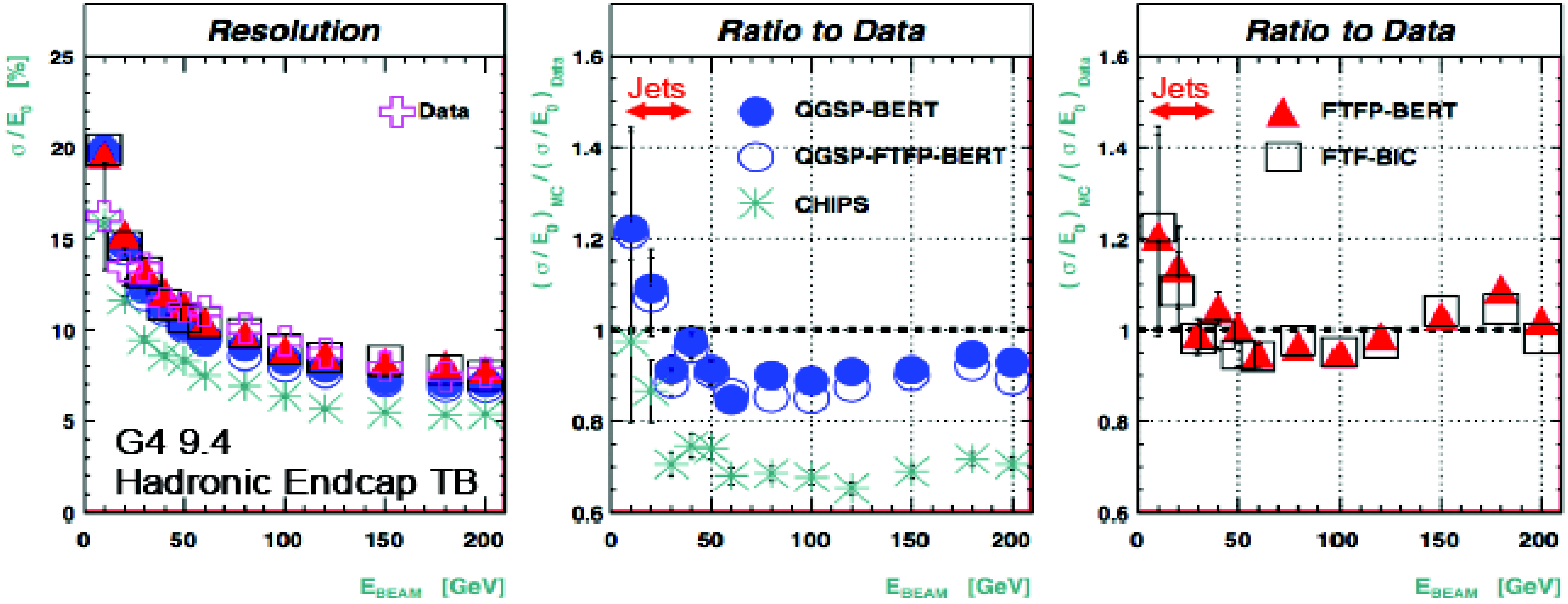
- Once you have collected data from a calorimeter test-beam set-up with hadron beams, there is a long work needed before drawing conclusions on the hadronic simulation :
  - Cleaning/selection cuts to have the purest possible sample
  - Model beam composition and spread
  - Check material composition, geometry, dead material
  - Model quenching effects (Birks' law), photo-statistics, *etc.*
  - Include noise, cross-talk, DAQ time-window, and digitization

To help on these steps:

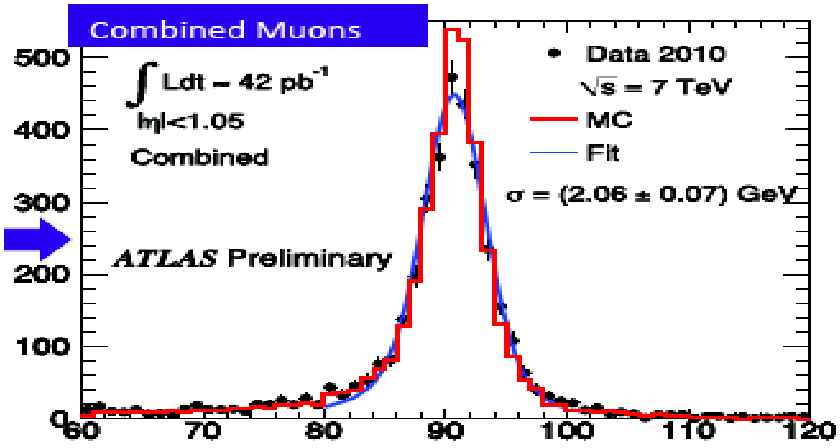
- Special triggers
- Muon beam
- Electron beam (also needed for the electromagnetic calibration)

Energy resolution

ATLAS HEC test-beam

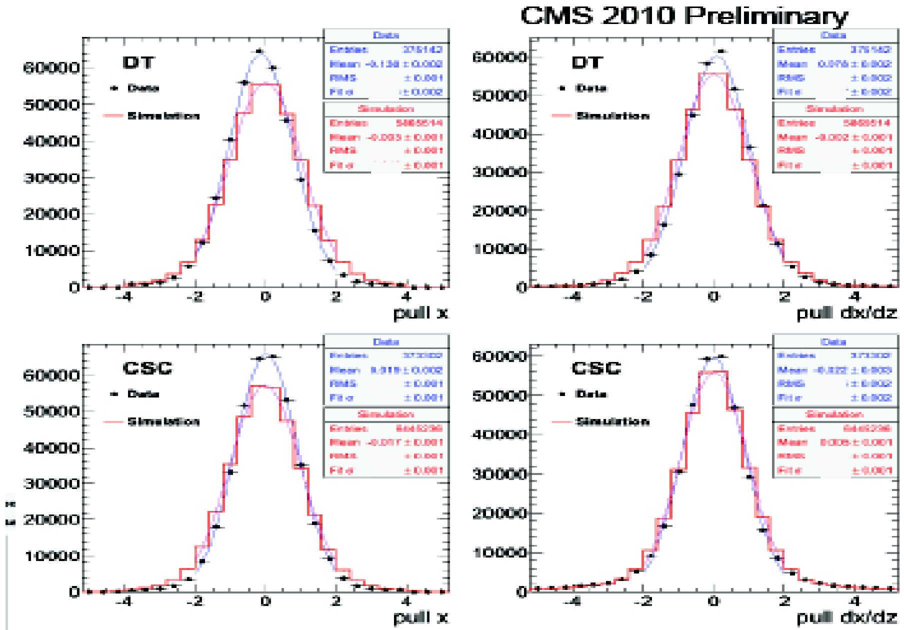


Muon simulation *vs.* p-p collision data



Z mass resolution of combined muons in the barrel, which require both an inner detector and muon spectrometer track

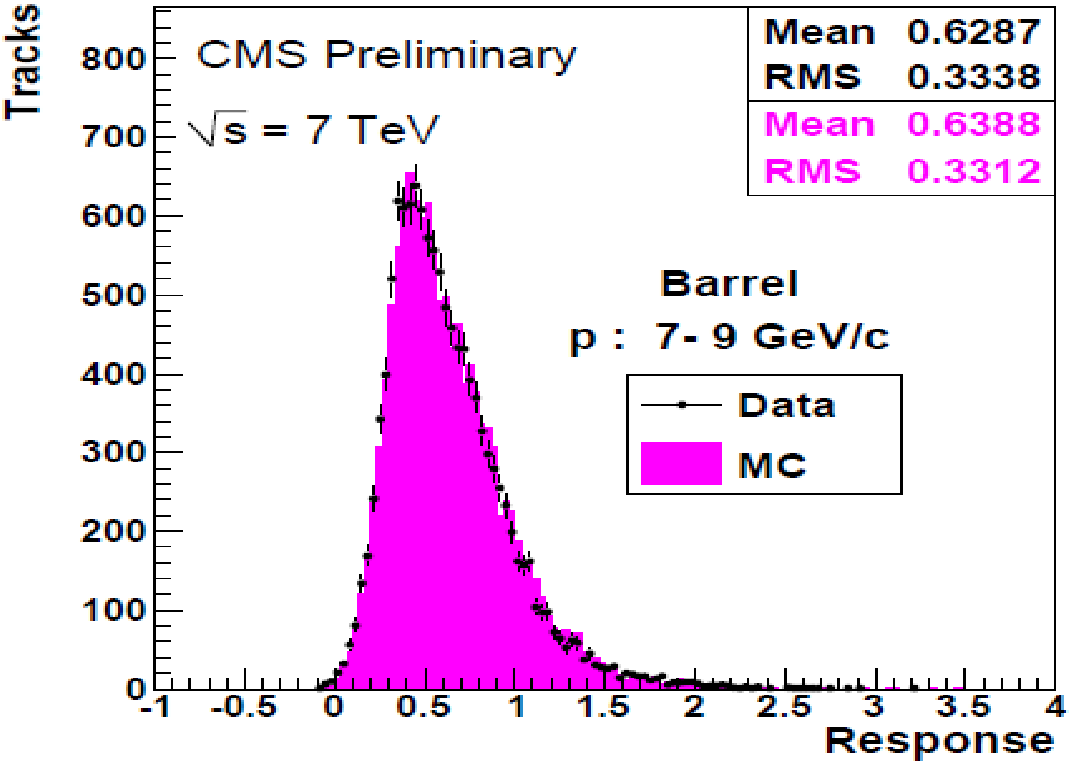
- Muon physics in G4 is extensively tested and validated in the energy range 10 GeV – 10 TeV

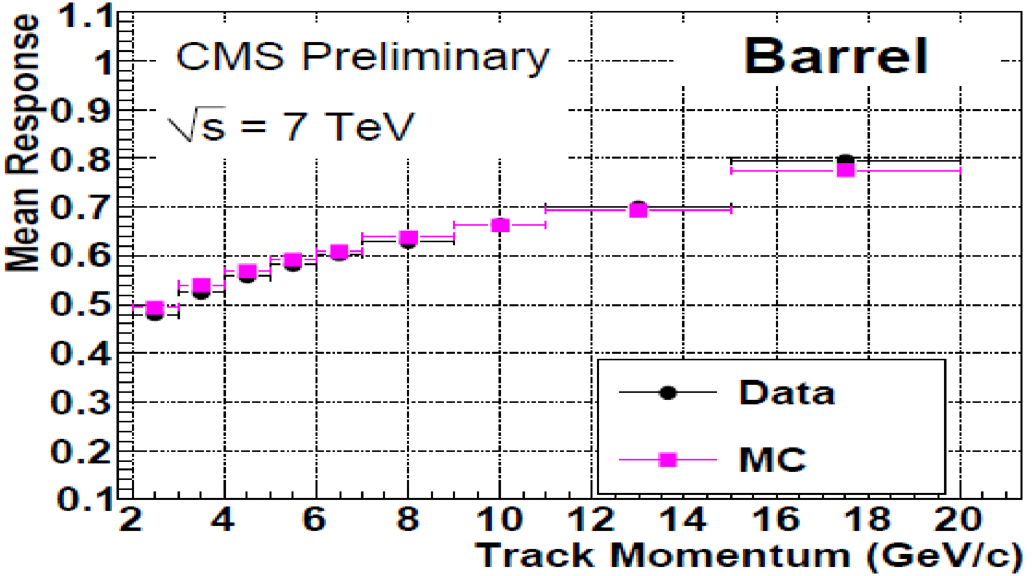


- Resolutions of extrapolations from central tracker to muon segments
  - checks proper implementation of material, multiple scattering through solenoid, absorber

Isolated single hadron response: simulation *vs.* CMS p-p data

Agreement is better than ±3% between 2-20 GeV/c





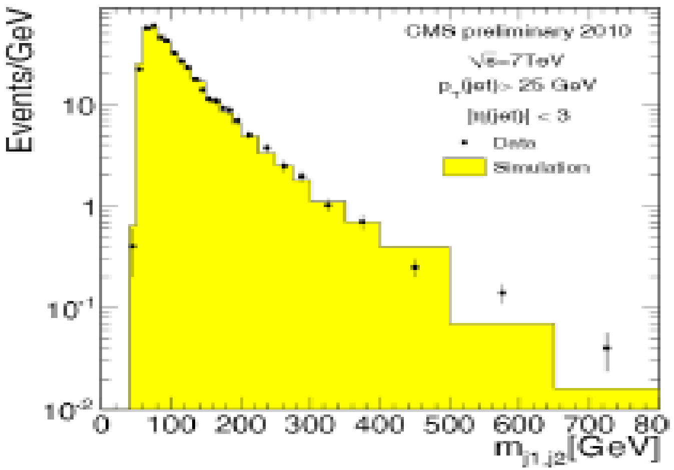
Di-jet invariant mass: simulation *vs.* CMS p-p data

Very good agreement between simulation and collision data!

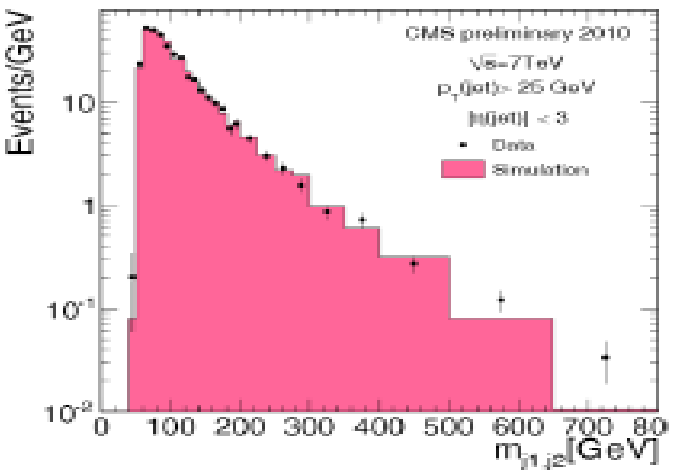
Three ingredients are convoluted in the simulation:

- Monte Carlo event generator: Pythia
- Detector simulation engine: Geant4
- Experiment-specific aspects: geometry/materials, digitization, calibration, reconstruction, *etc.*

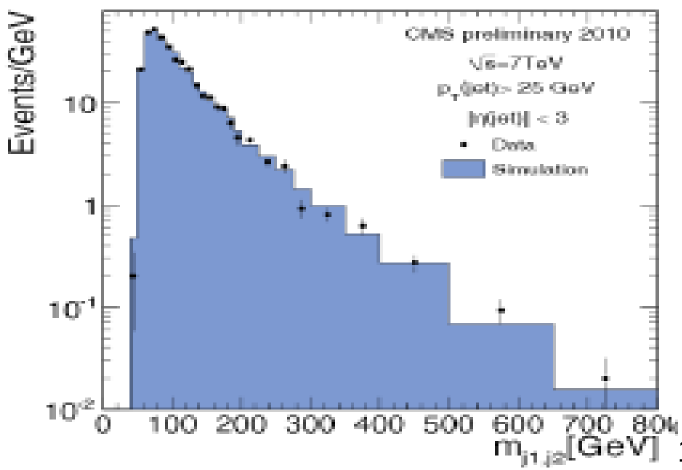
Calo jets



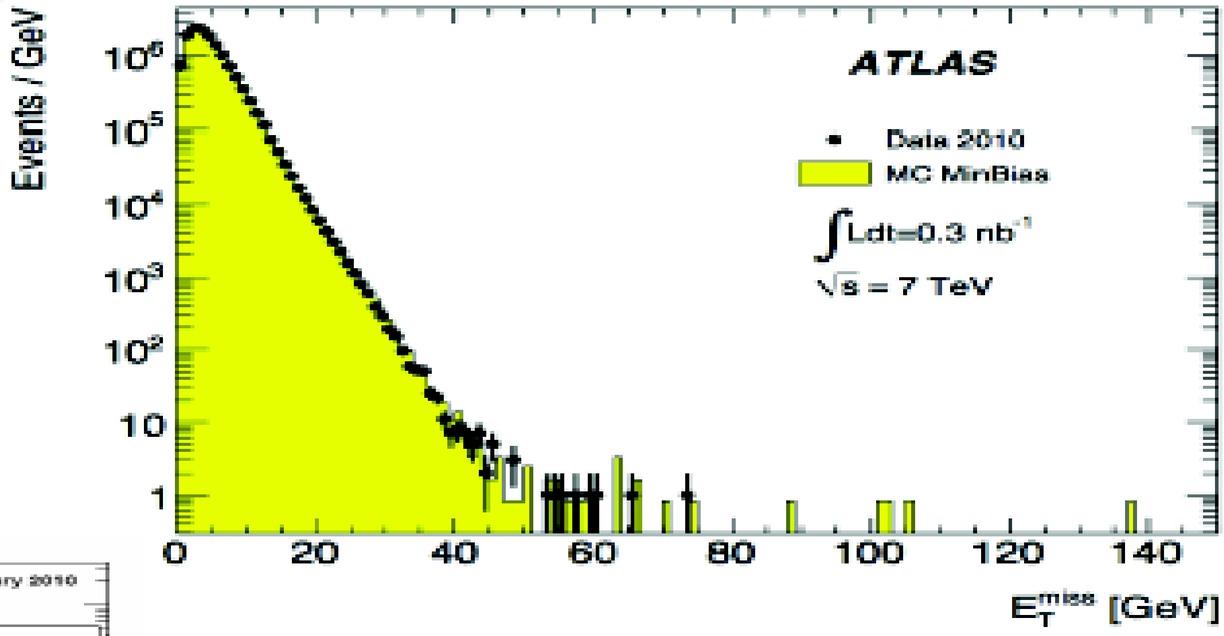
JPT jets

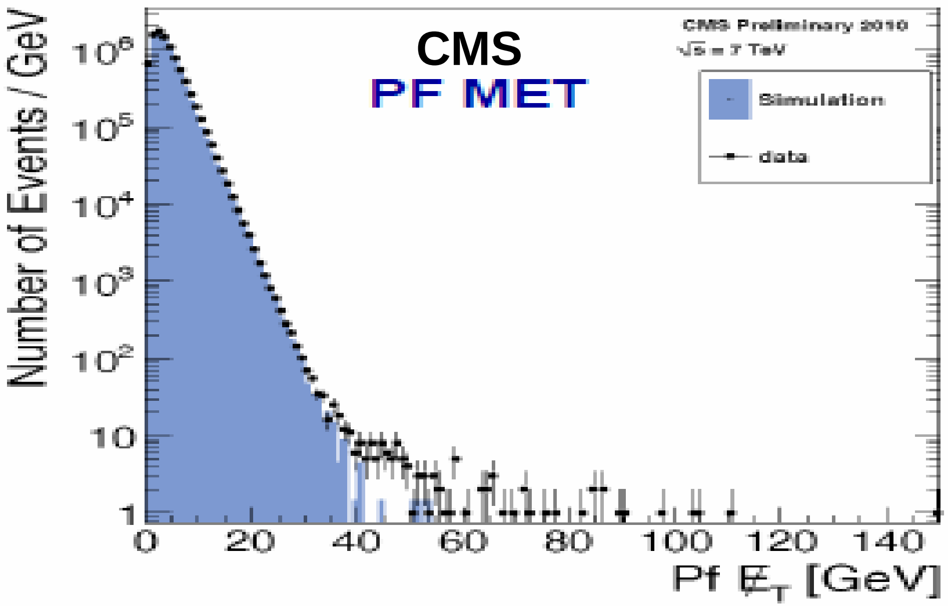


PF jets



Missing ET : simulation *vs.* collision data





Missing ET is a very complex (global) variable

Good agreement over 6 orders of magnitudes!