

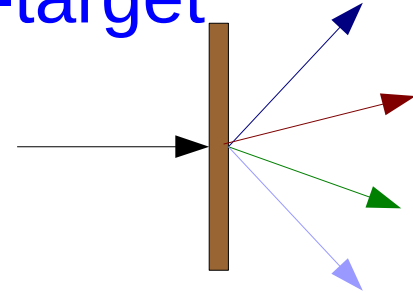
Validation

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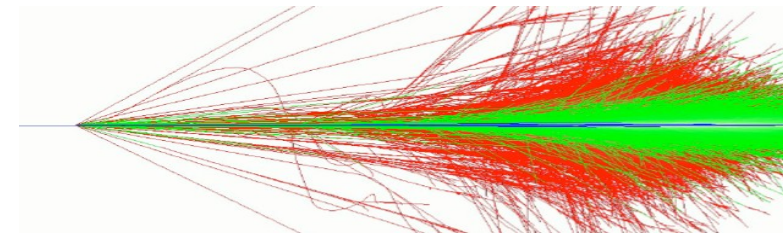


Validation & tuning of hadronic models

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



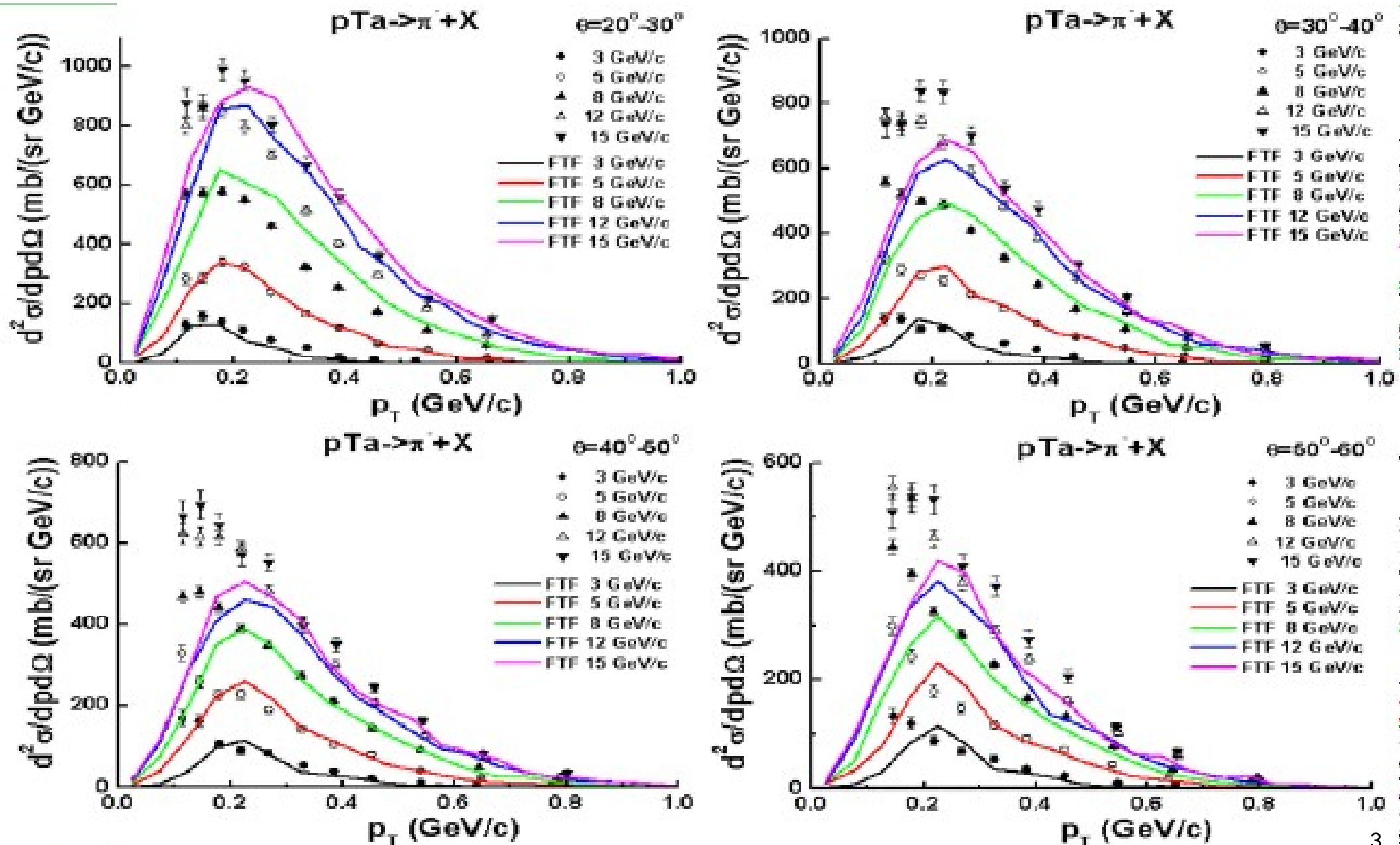
- Validation of complete physics configurations is performed by users mostly via measurements of **hadronic showers in calorimeter test-beam setups (thick targets)**



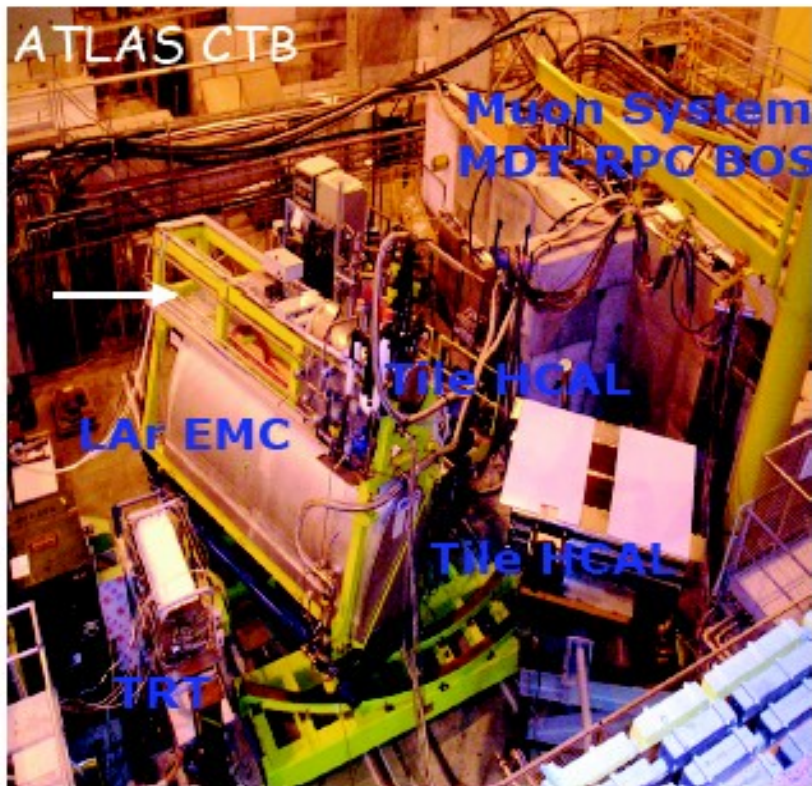
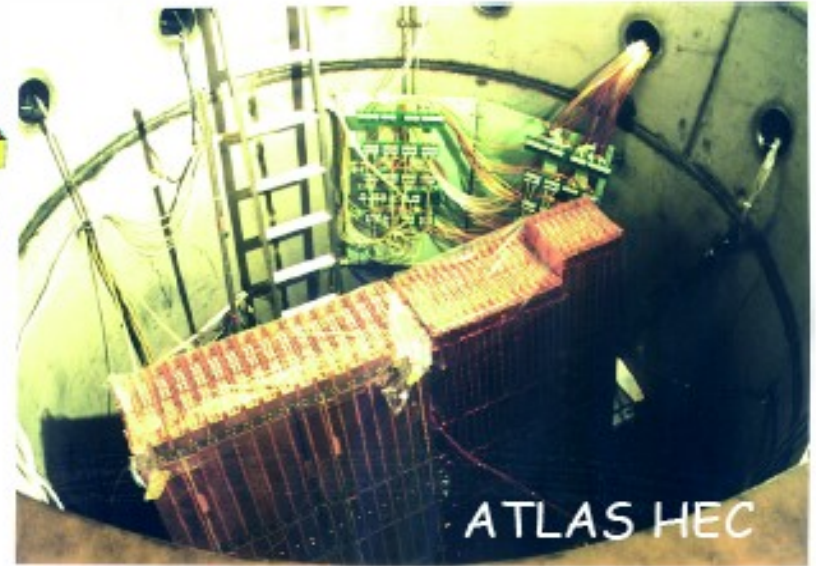
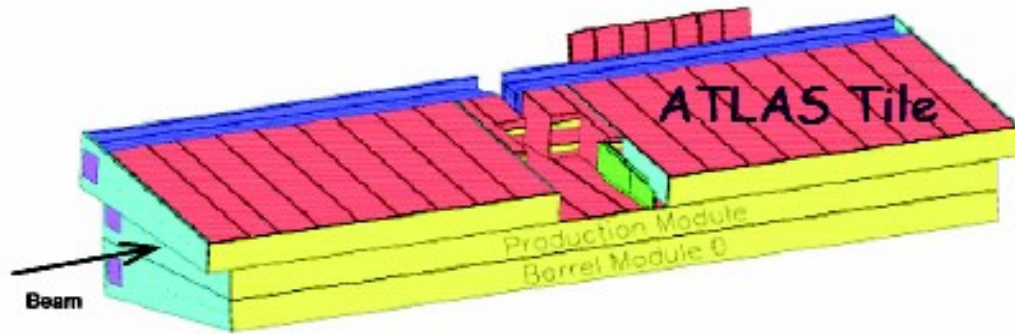
- The most important application of the hadronic models for collider experiments is the **simulation of jets**, which involves:
 1. the Monte Carlo event generator
 2. the convolution of the showers for each constituent hadron
 3. experiment specific: geometry & materials, digitization, etc.

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.

The simulation of jets involves:

1. the Monte Carlo Event Generator
2. the convolution of the showers for each constituent hadron

A long journey...

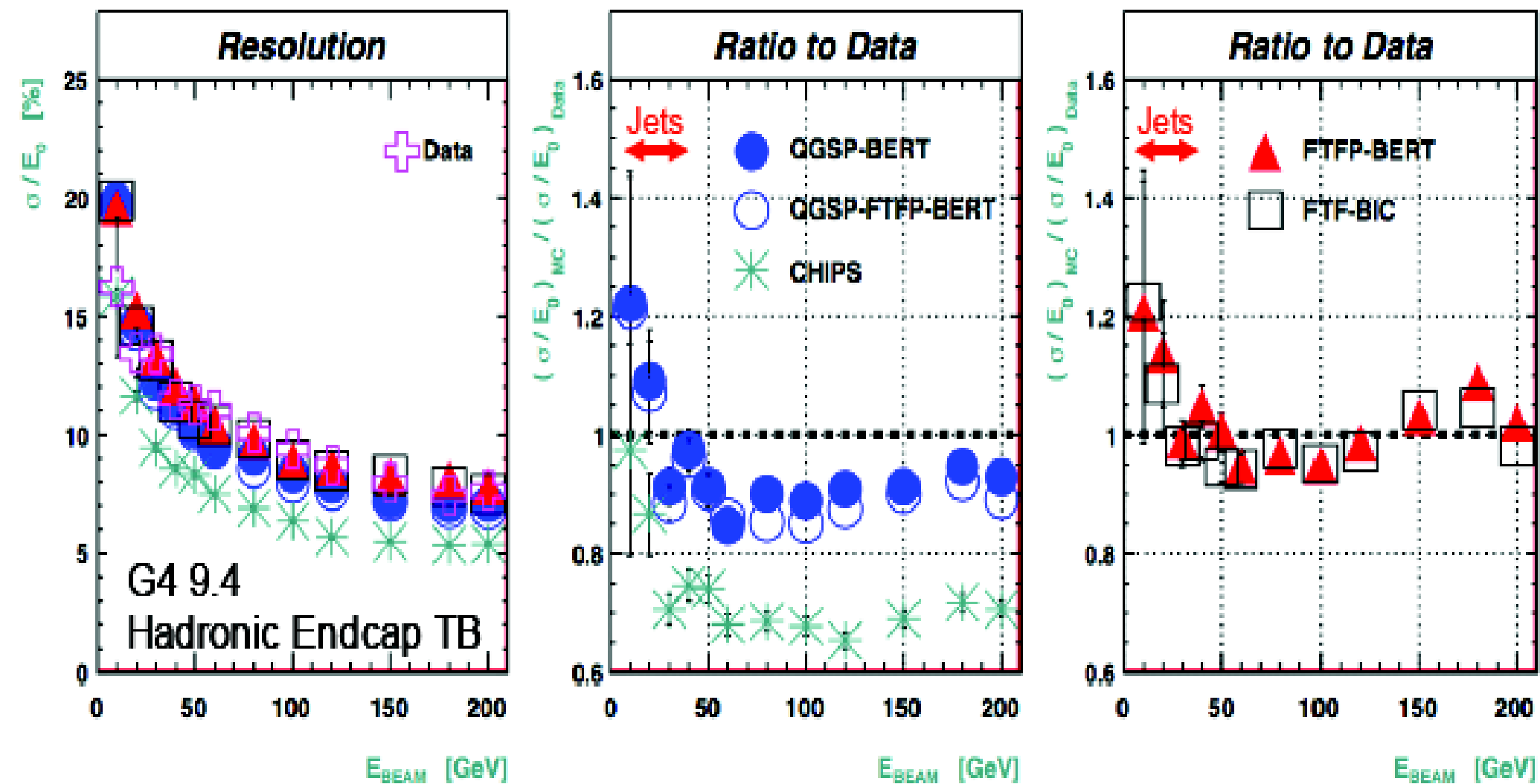
- Once you have collected data from a calorimeter test-beam set-up with hadron beams, there is a long work needed before drawing conclusions on the hadronic simulation:
 - Cleaning/selection cuts to have the purest possible sample
 - Model beam composition and spread
 - Check material composition, geometry,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

To help on these steps:

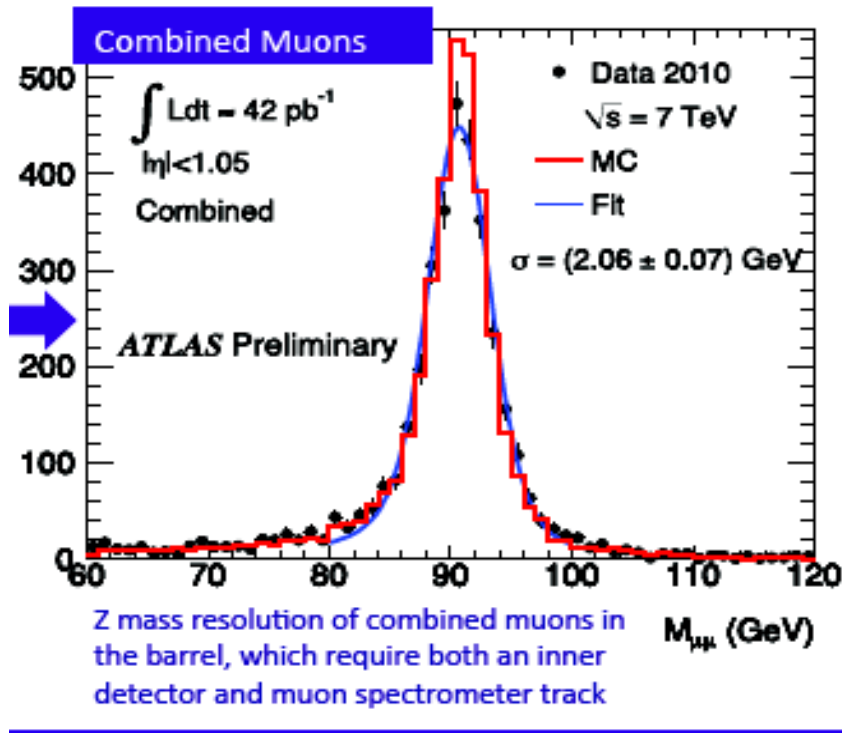
- Special triggers
- Muon beam
- Electron beam (also needed for the electromagnetic calibration)

Energy resolution

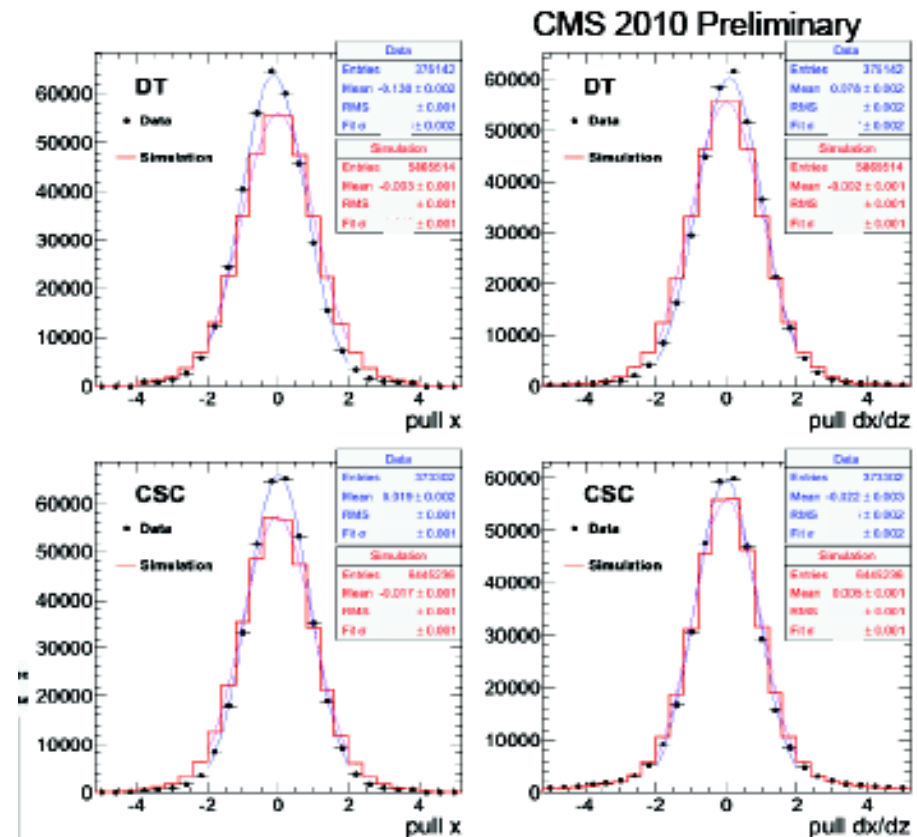
ATLAS HEC test-beam



Muon simulation vs. p-p collision data



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

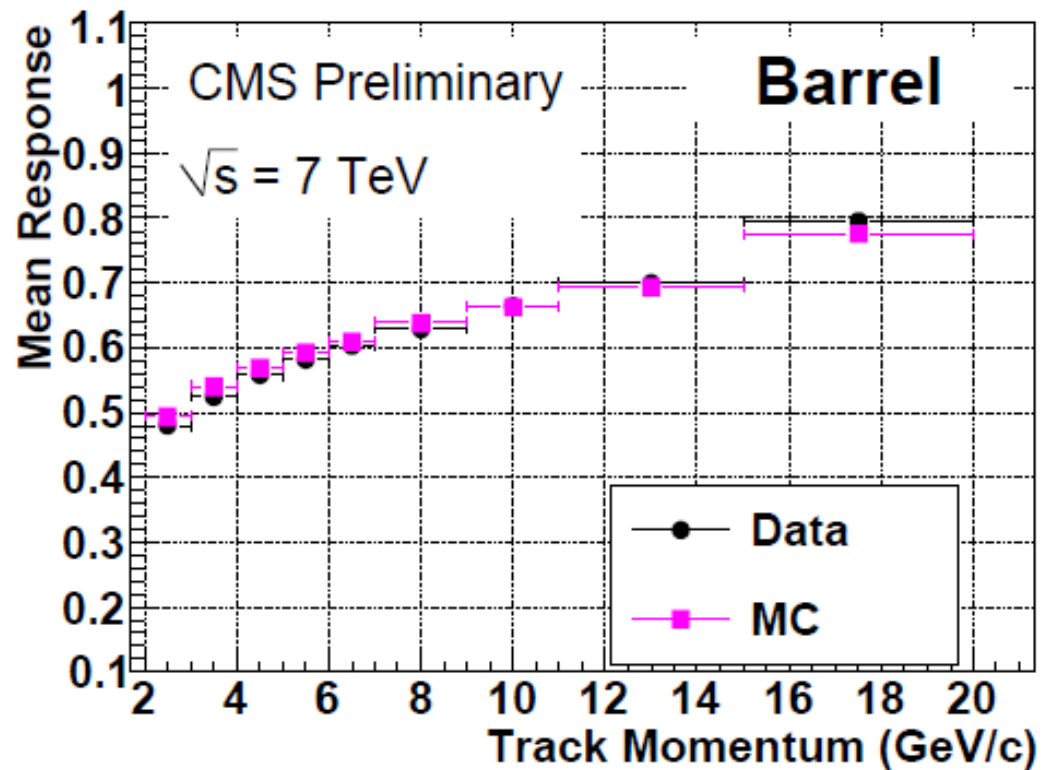
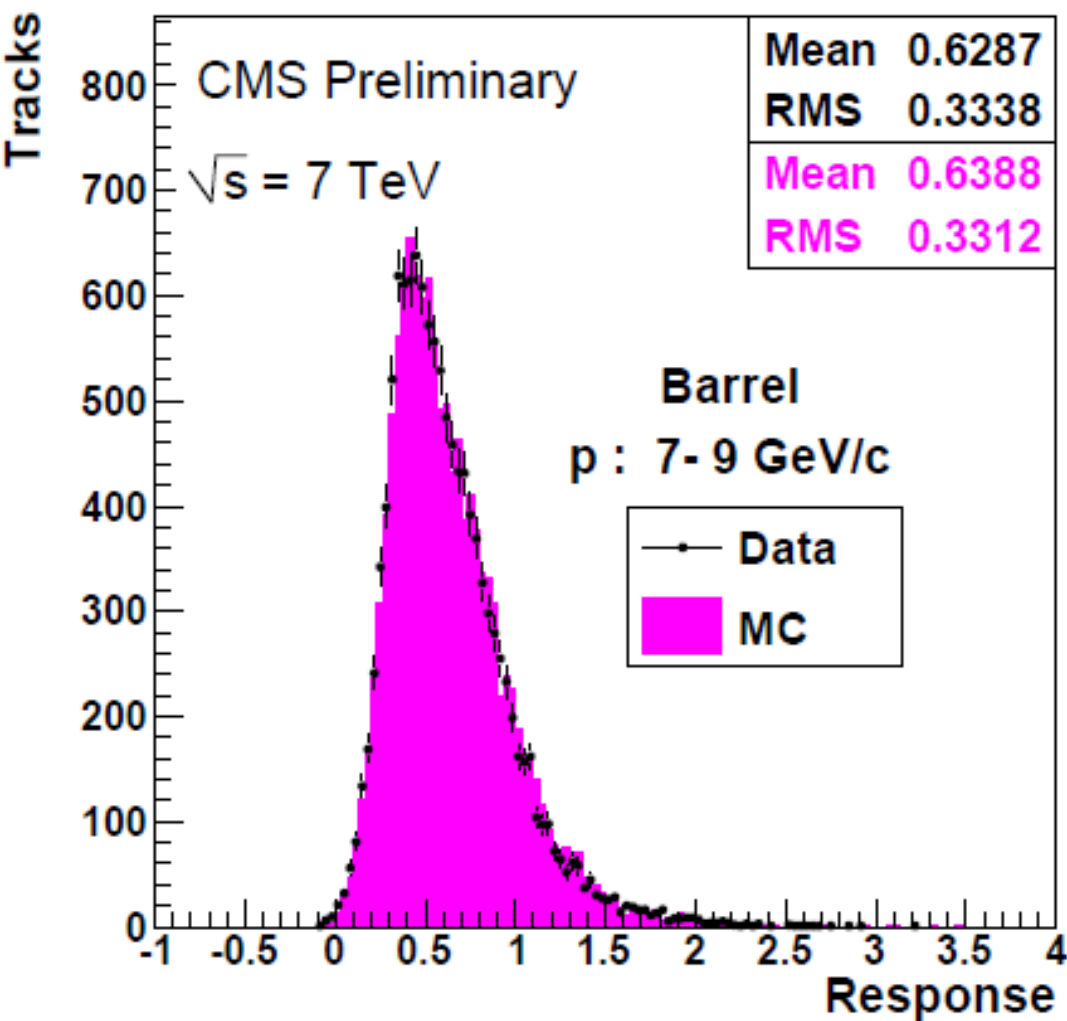


- Resolutions of extrapolations from central tracker to muon segments

- checks proper implementation of material, multiple scattering through solenoid, absorber

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

Agreement is better than $\pm 3\%$ between 2-20 GeV/c



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

Very good agreement between simulation and collision data!

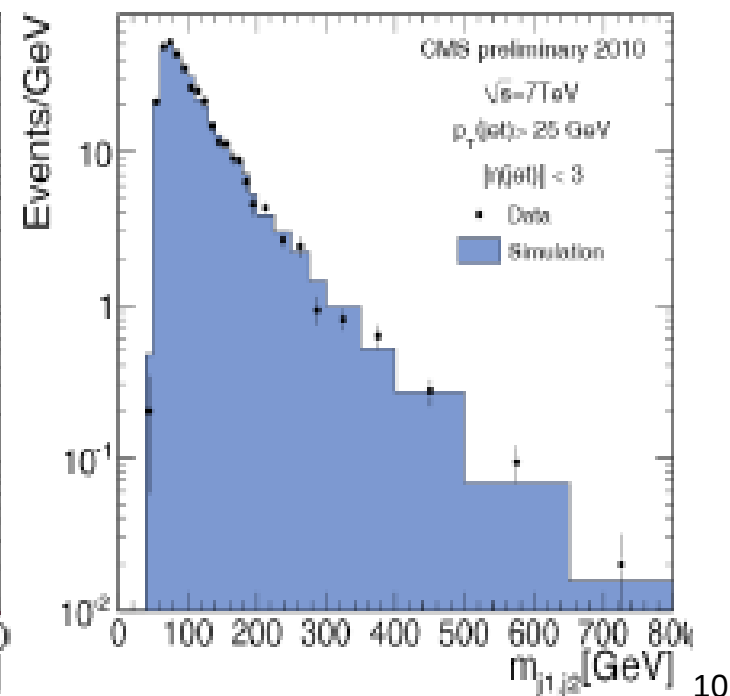
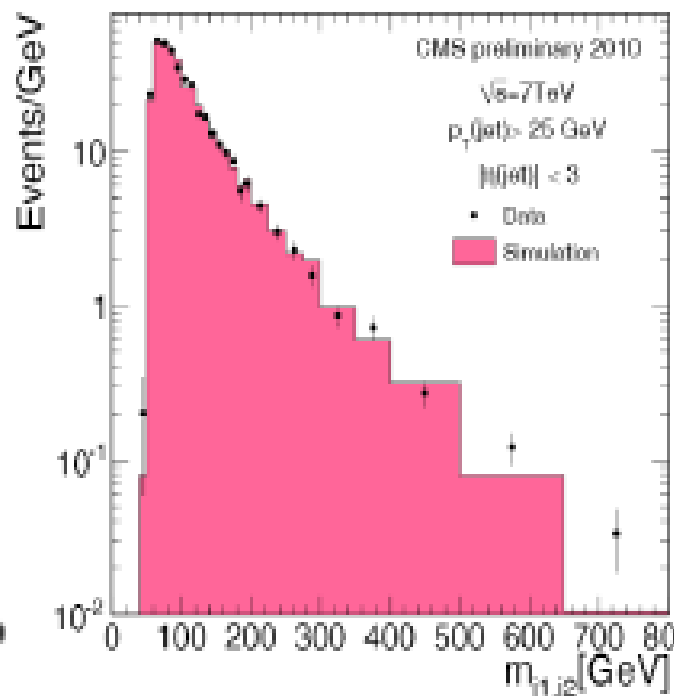
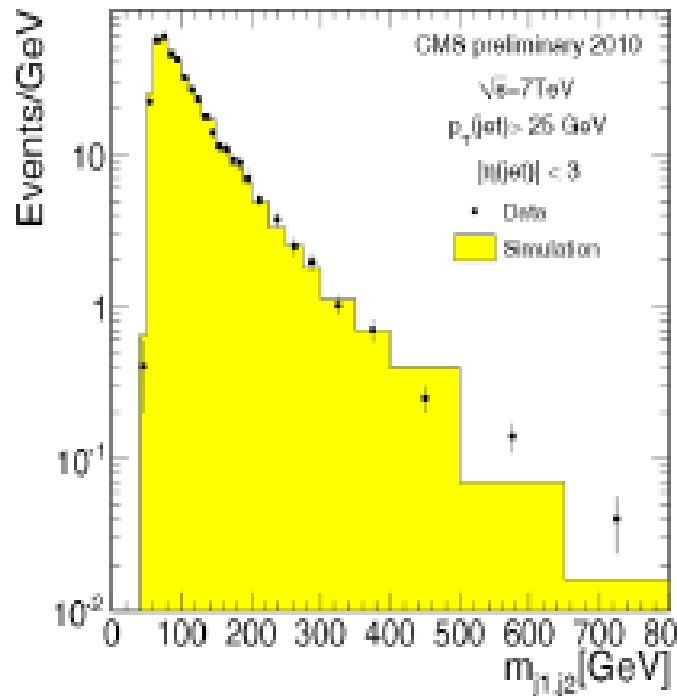
Three ingredients are convoluted in the simulation:

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

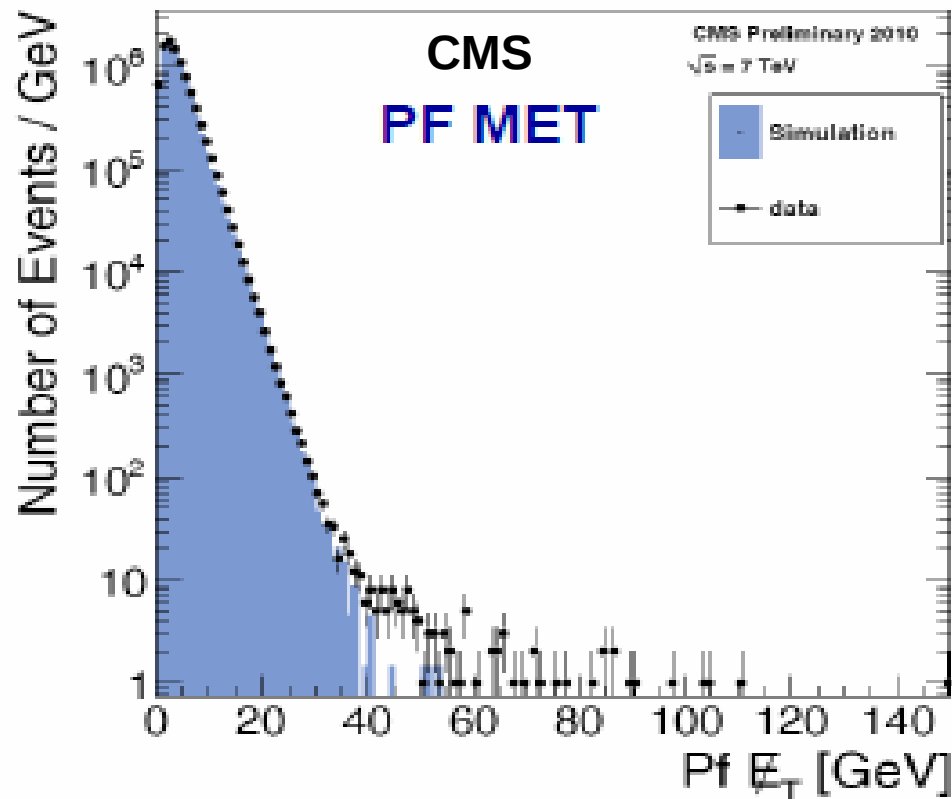
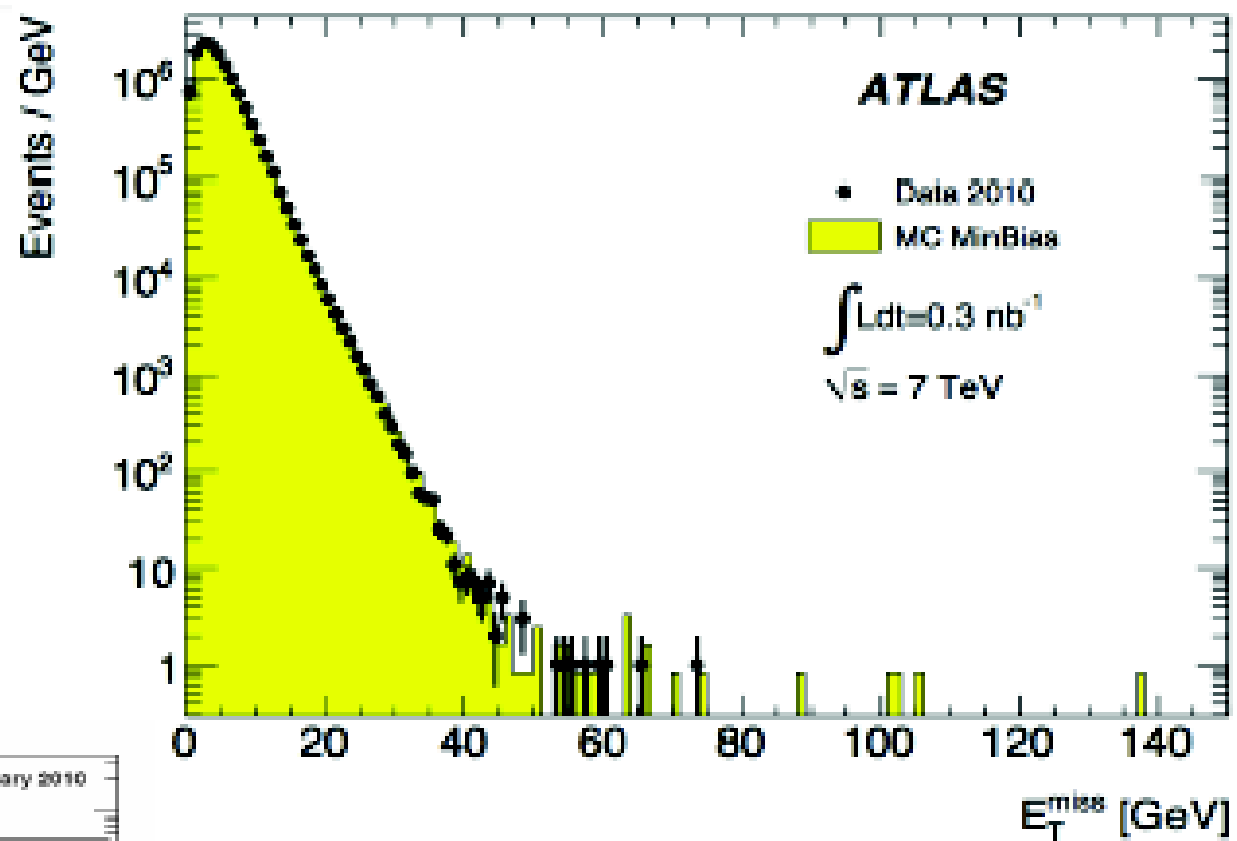
Calo jets

JPT jets

PF jets



Missing E_T : simulation vs. collision data



Missing E_T is a very complex
(global) variable

Good agreement over 6
orders of magnitudes!