Geant4 requirements from High Energy Physics (HEP)

J. Apostolakis, A. Dotti, A. Ribon
CERN PH/SFT

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Outline

We discuss first physics issues and then software ones. These are based on users' feedback, in various forms, but they are presented as we understand and interpret them. Eventual mistakes are due to us.

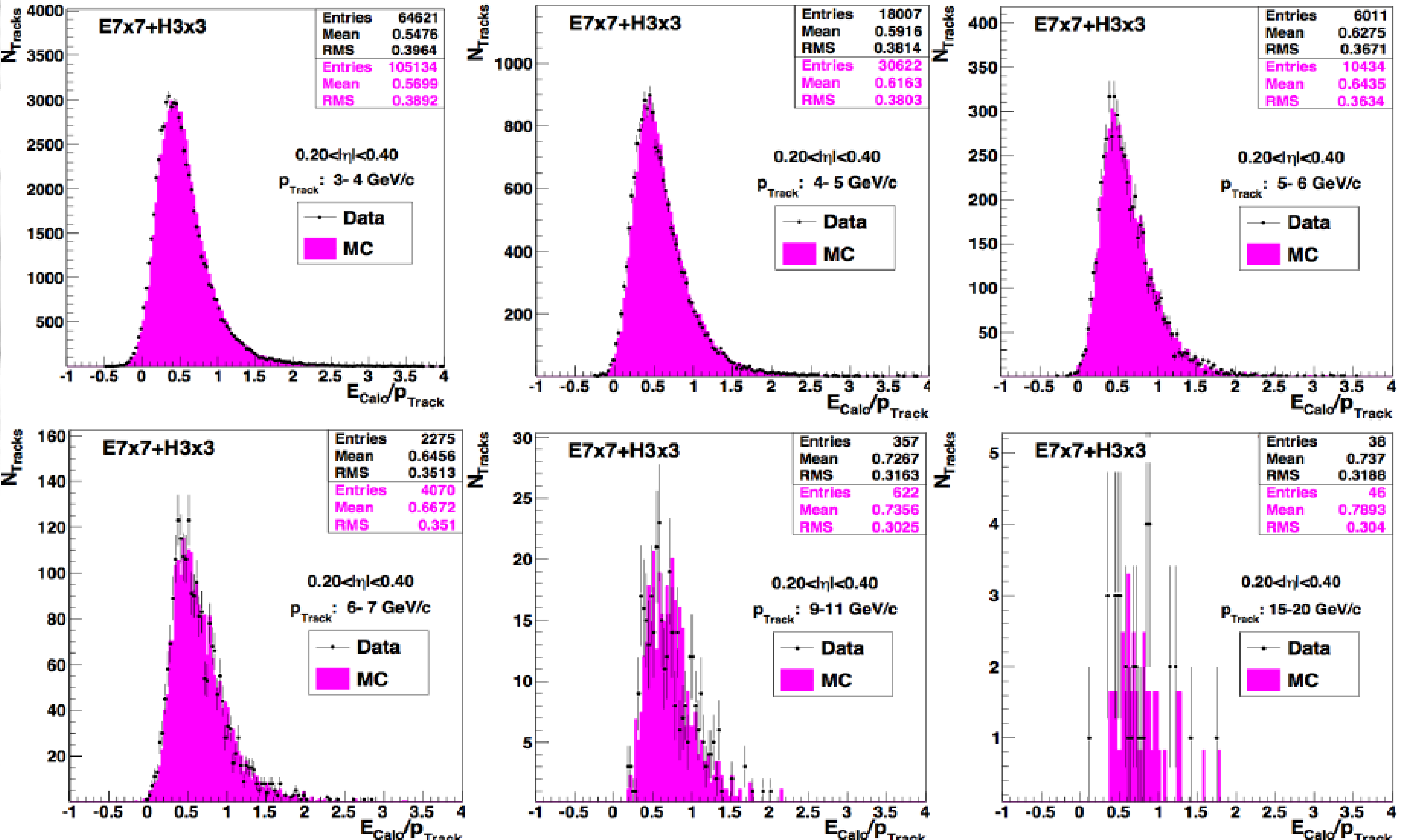
We have included several plots, but there will be not time to discuss most of them. For more information, please come to the parallel session 4A on physics validation.

Physics requirements

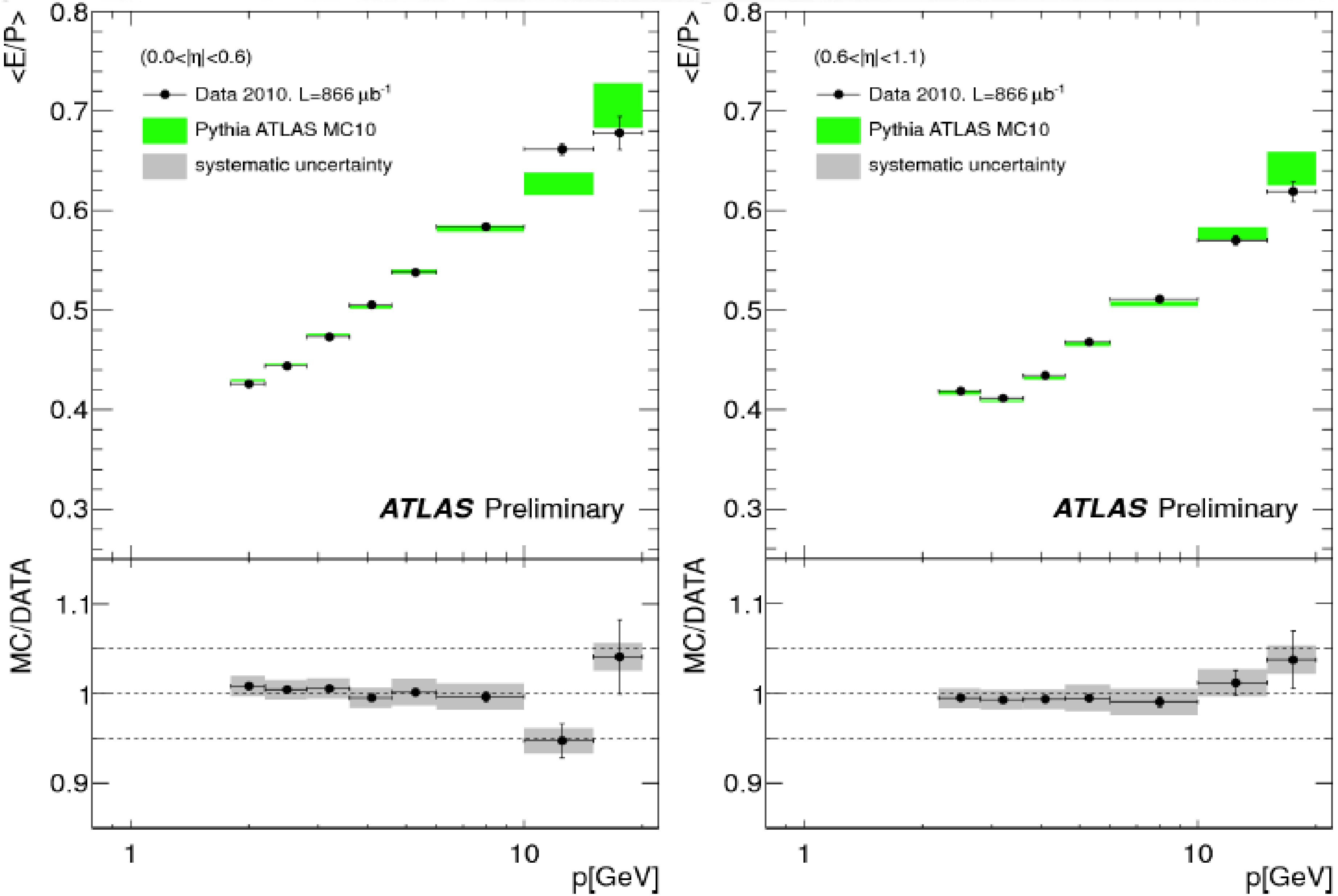
Energy response

- Very important for the jet energy scale
- Geant4 **QGSP_BERT**, **FTFP_BERT**, and **QGSP_FTFP_BERT** describe the energy response in calorimeters reasonably well, **within few %**
- For CMS, **QGSP_FTFP_BERT** (default in 2011) gives the best agreement with test-beam data, and it is smoother than QGSP_BERT (default until 2010)
- For ATLAS, **QGSP_BERT** (default) gives the best agreement with test-beam data, with **few % higher response** especially in the **TileCal** . Fritiof-based variants (QGSP_FTFP_BERT and FTFP_BERT) are smoother, but give an even higher response

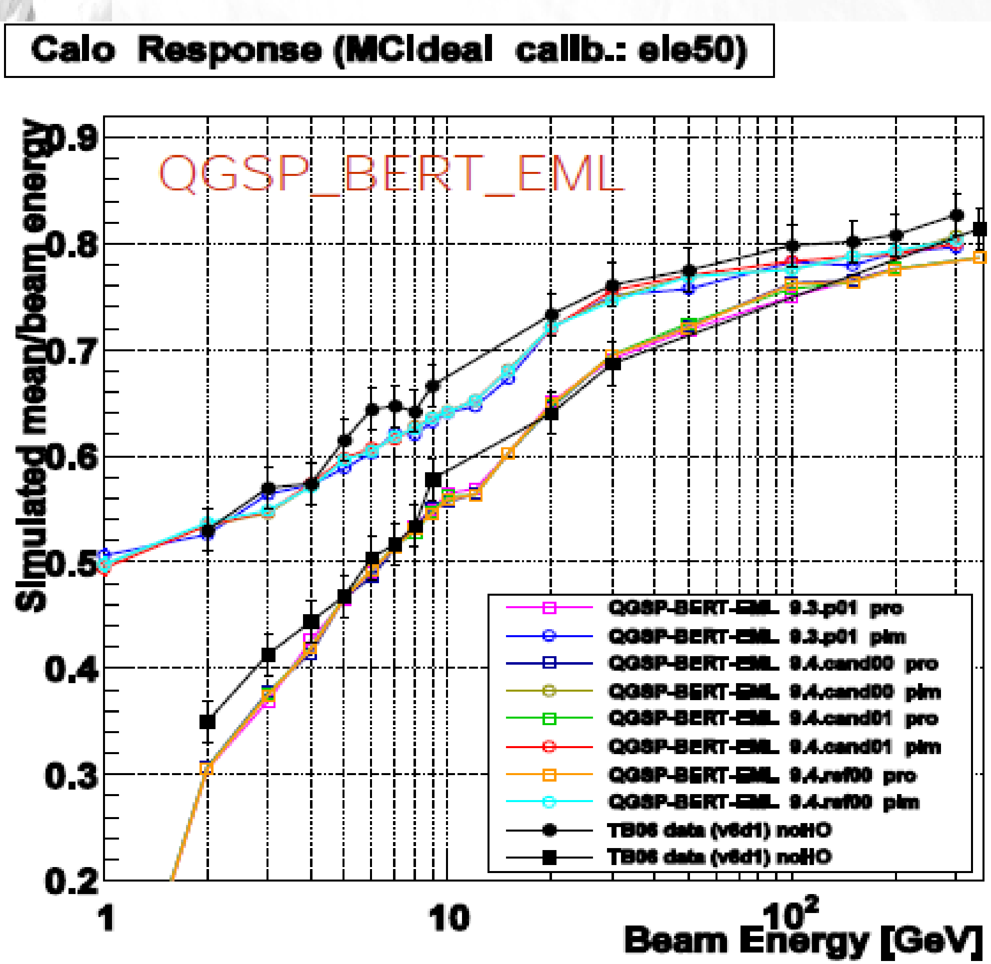
CMS E/p collision data

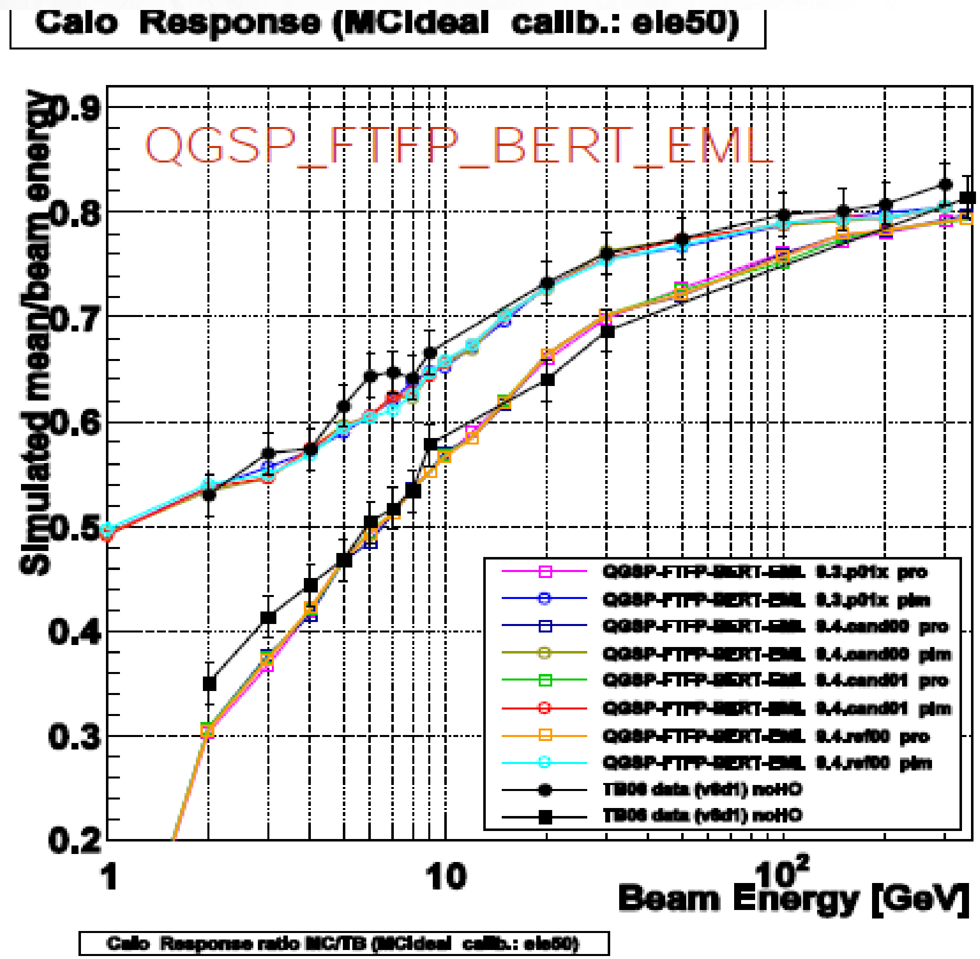


ATLAS E/p collision data

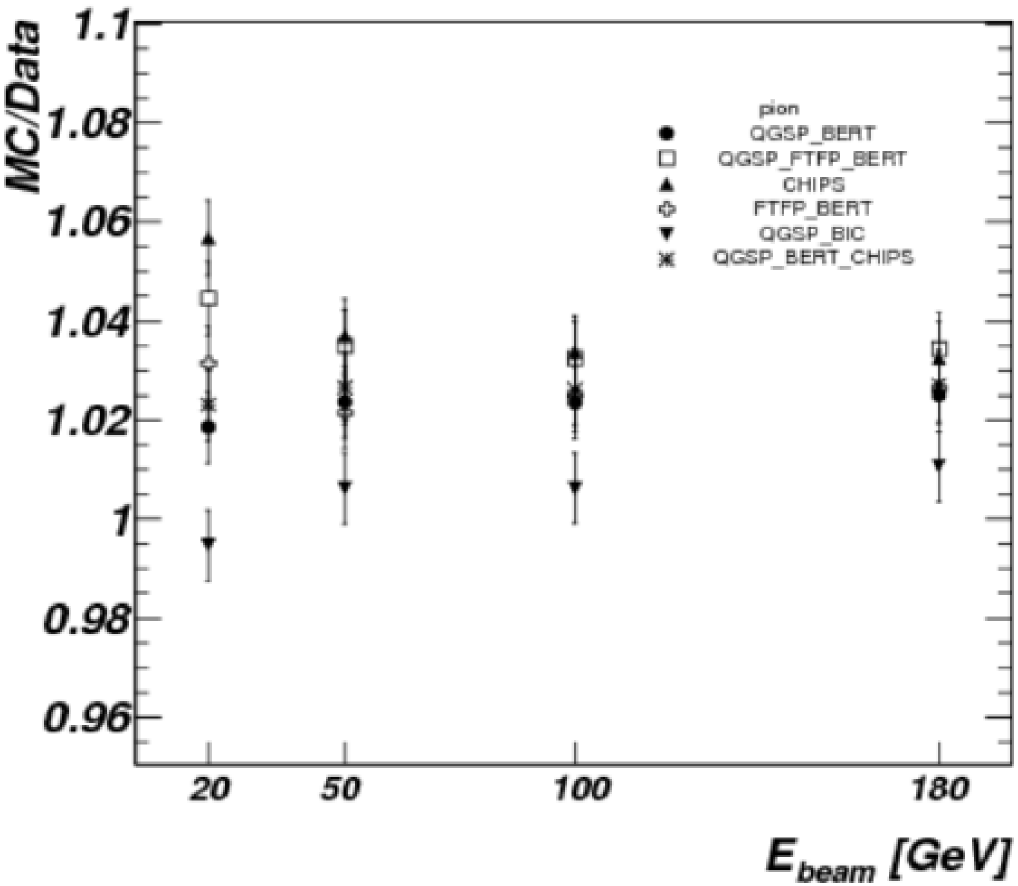


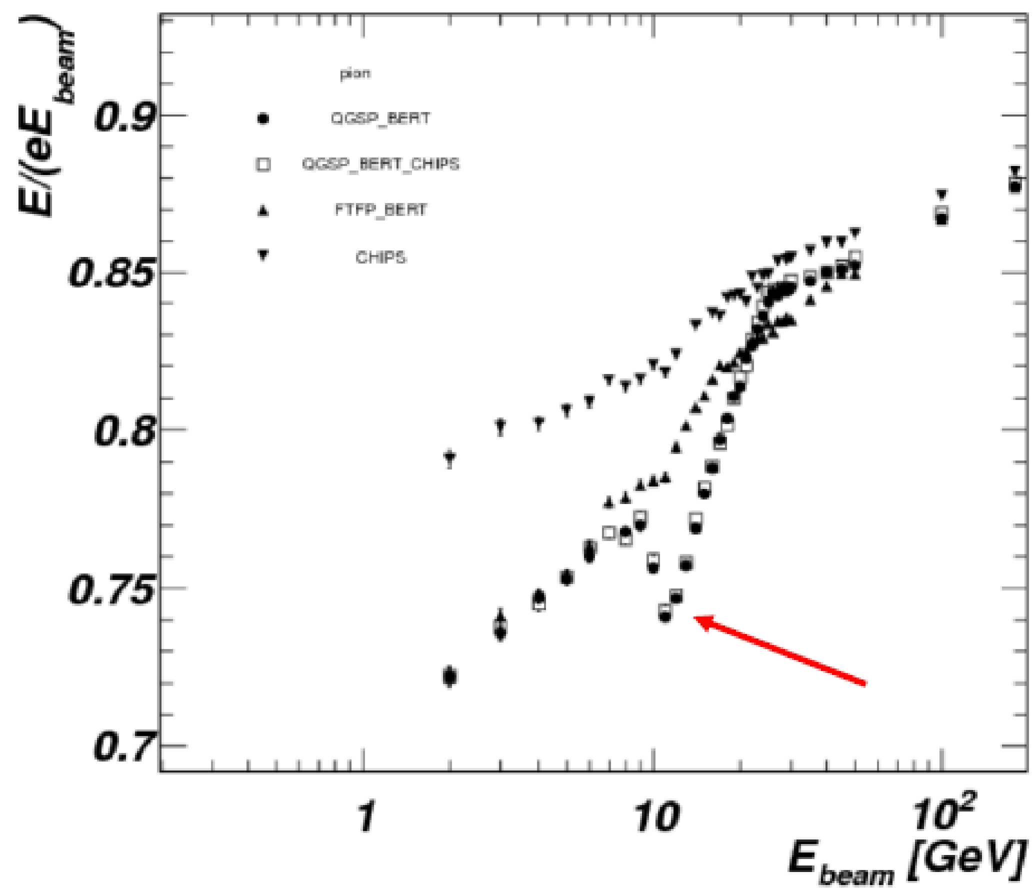
CMS combined test-beam G4 9.4





ATLAS TileCal test-beam energy response, G4 9.4

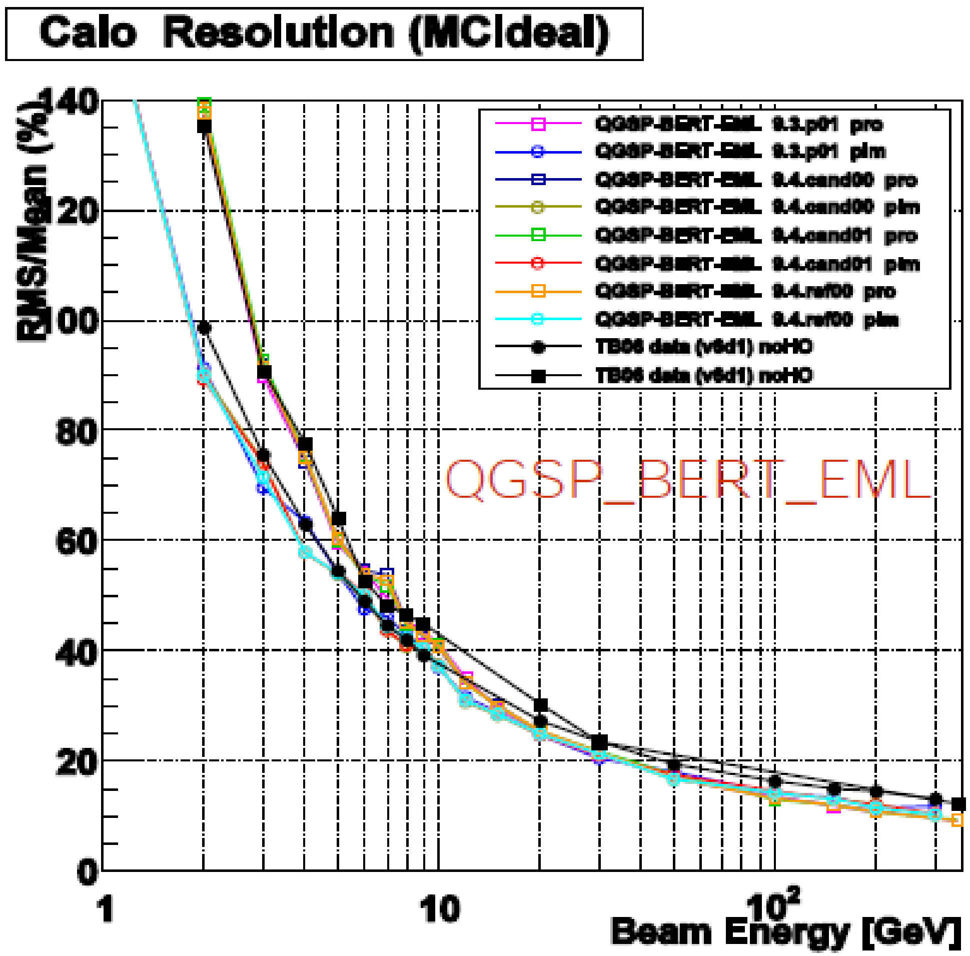


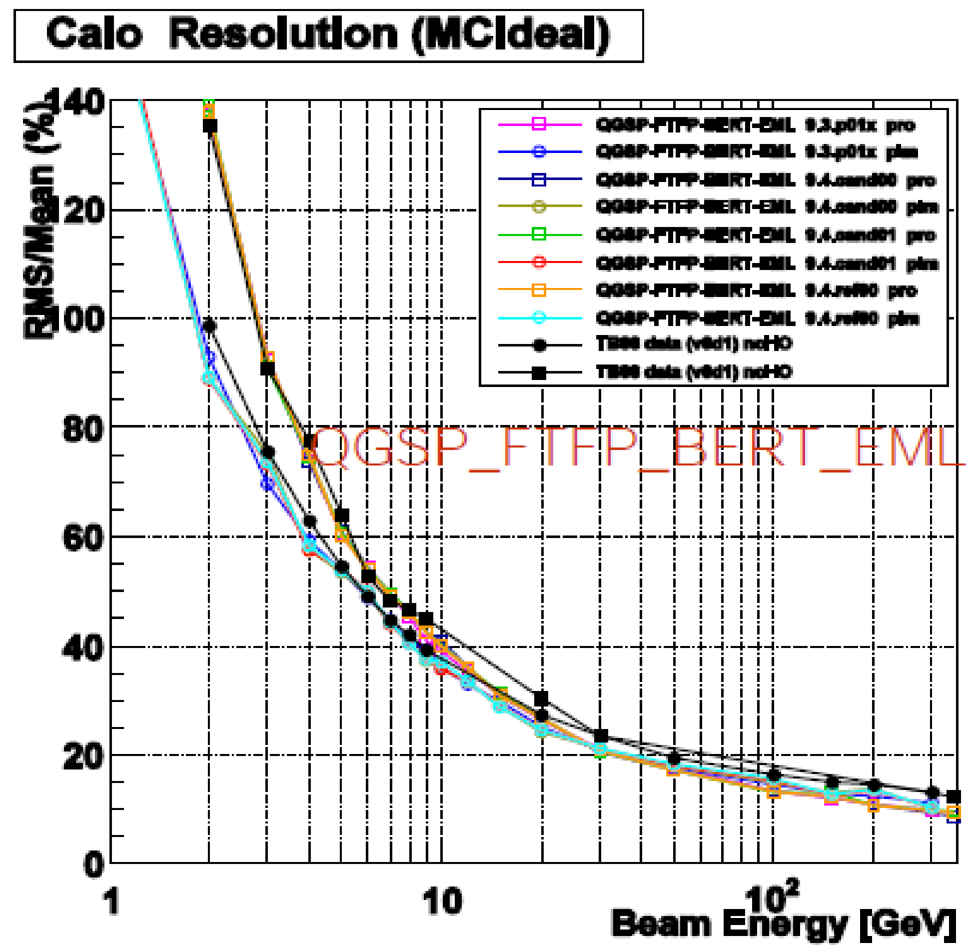


Energy resolution

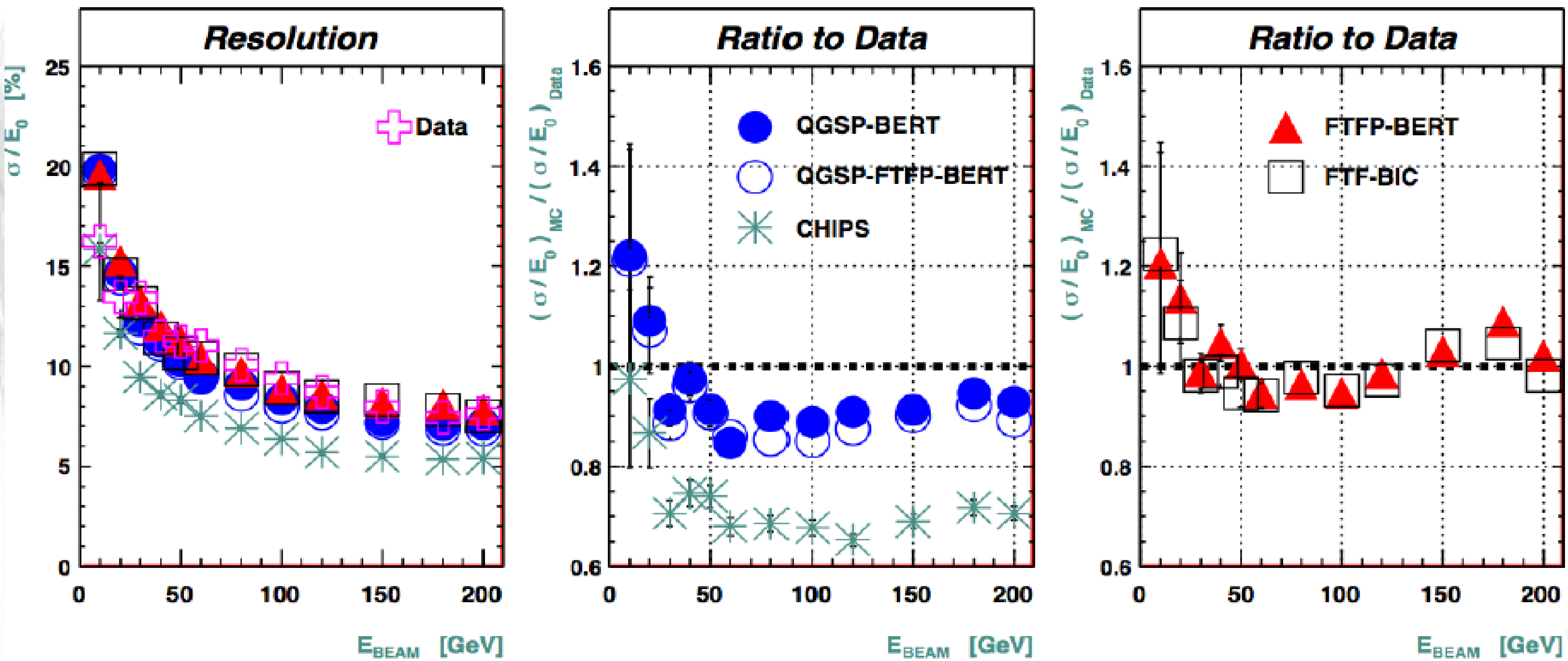
- Very important for di-jet invariant masses
- Geant4 physics lists of interest for LHC (QGSP_BERT, FTFP_BERT, QGSP_FTFP_BERT) are producing **too optimistic (narrower) energy resolutions**, by **~ 10%** with respect to test-beam data (both ATLAS and CMS)
- Recent versions of FTFP_BERT are producing energy resolutions in better agreement with ATLAS HEC (Cu-LAr) test beam...

CMS combined test-beam: G4 9.4





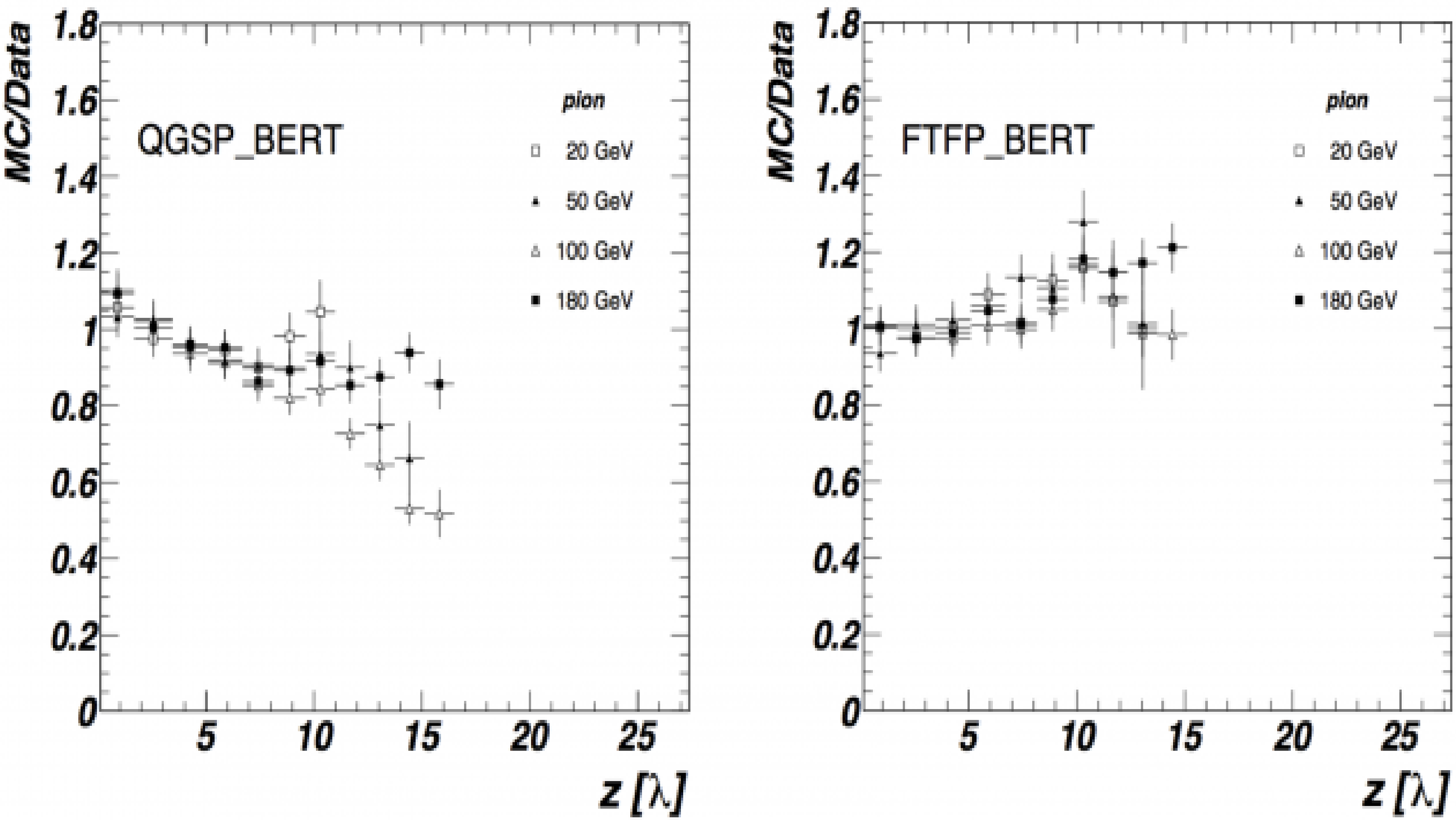
ATLAS HEC test-beam energy resolution, G4 9.4



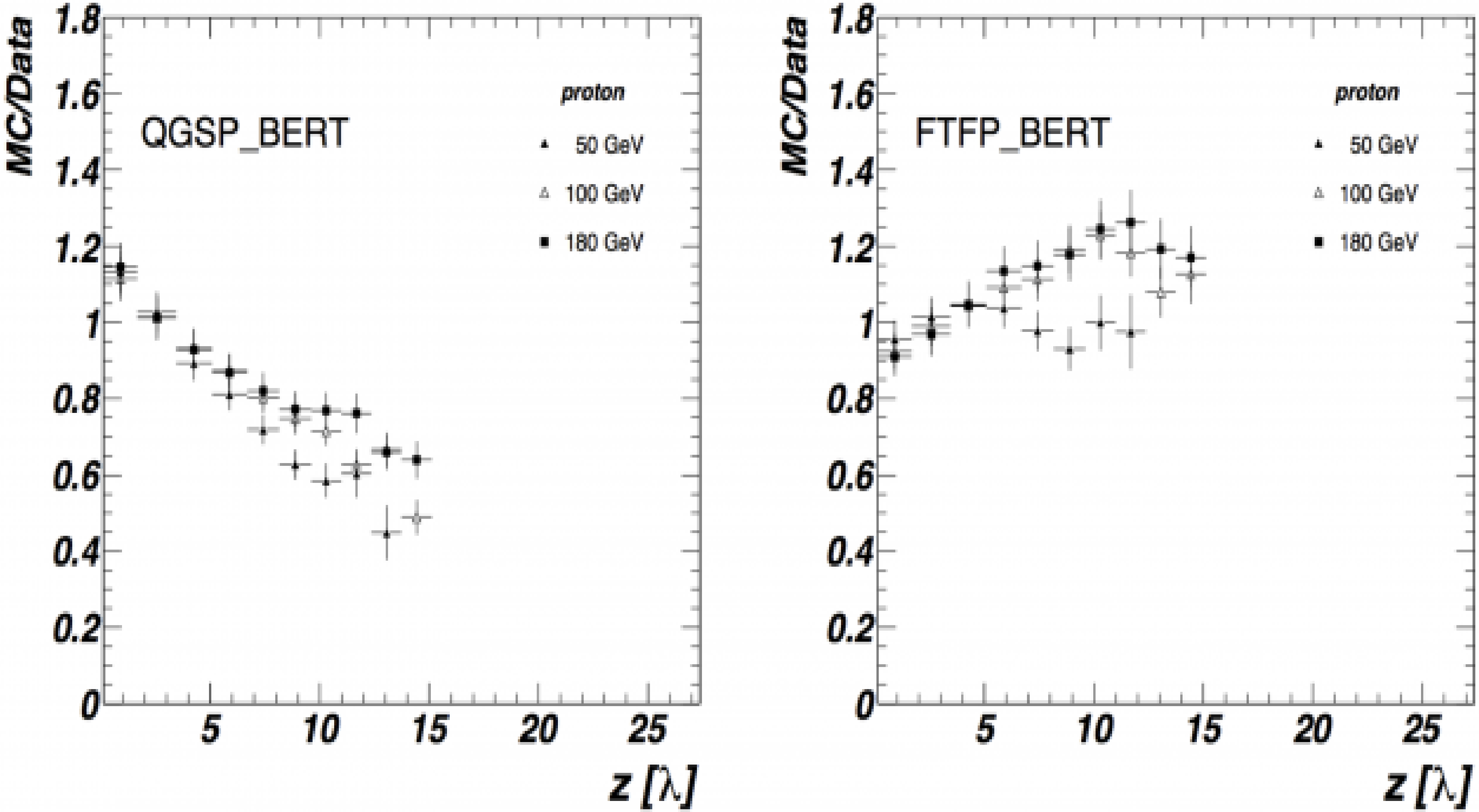
Longitudinal shower profile

- Important for jet corrections and particle identification
- QGSP_BERT longitudinal pion shower profiles are ~ **10% shorter** than test-beam data
- FTFP_BERT longitudinal pion shower profiles are ~ **10% longer** than test-beam data
- Proton shower longitudinal profiles are not so well simulated: QGSP_BERT is **shorter** by $\gtrsim$ **20%** , FTFP_BERT is **longer** by $\lesssim$ **20%** than test-beam data
- Progress in the past has been obtained thanks to better modeling of **quasi-elastic**. Further improvements on longitudinal shower profiles will likely need refinement in the **diffraction**, especially for QGS

ATLAS TileCal test-beam pion longitudinal shower profile, G4 9.4



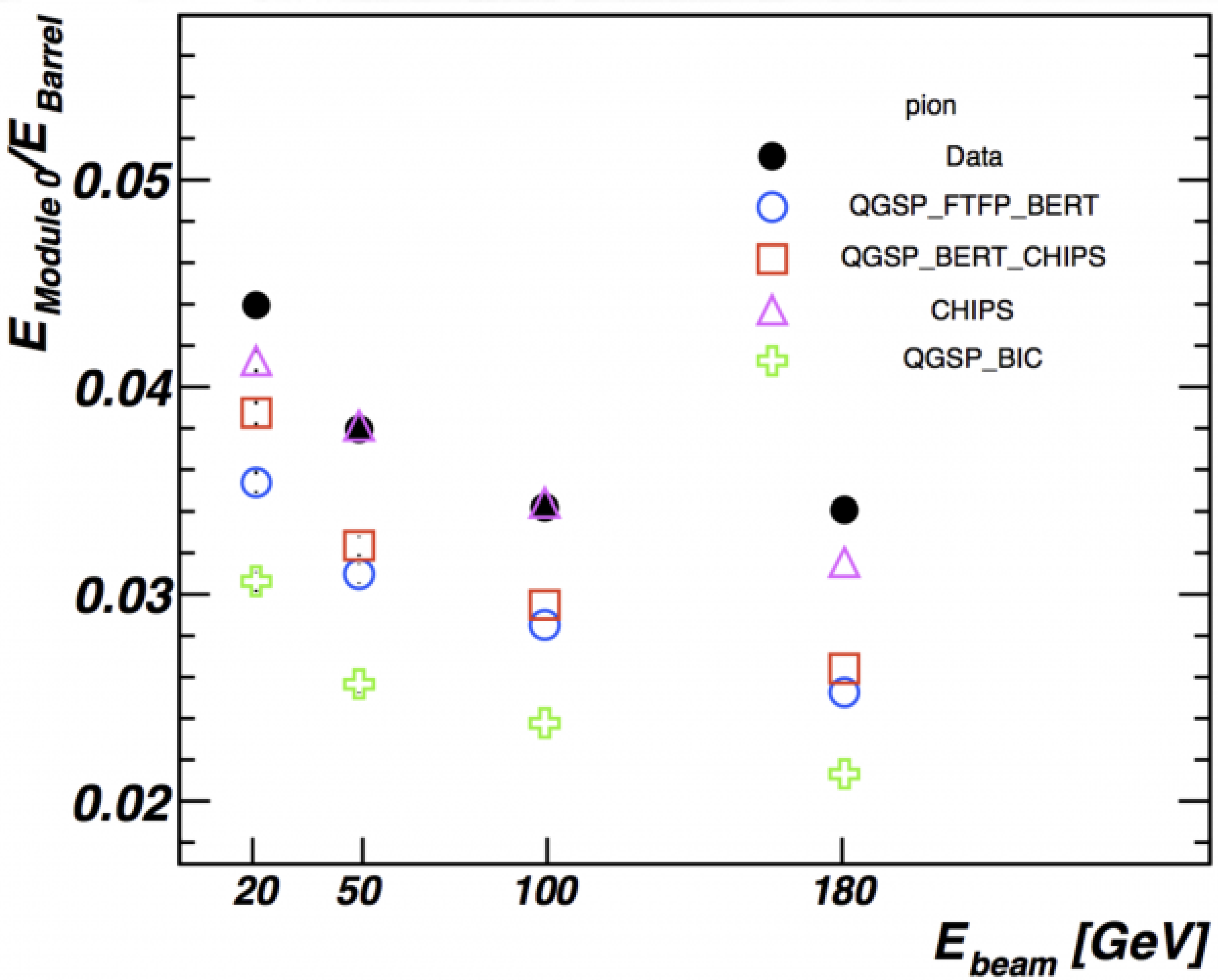
ATLAS TileCal test-beam proton longitudinal shower profile, G4 9.4



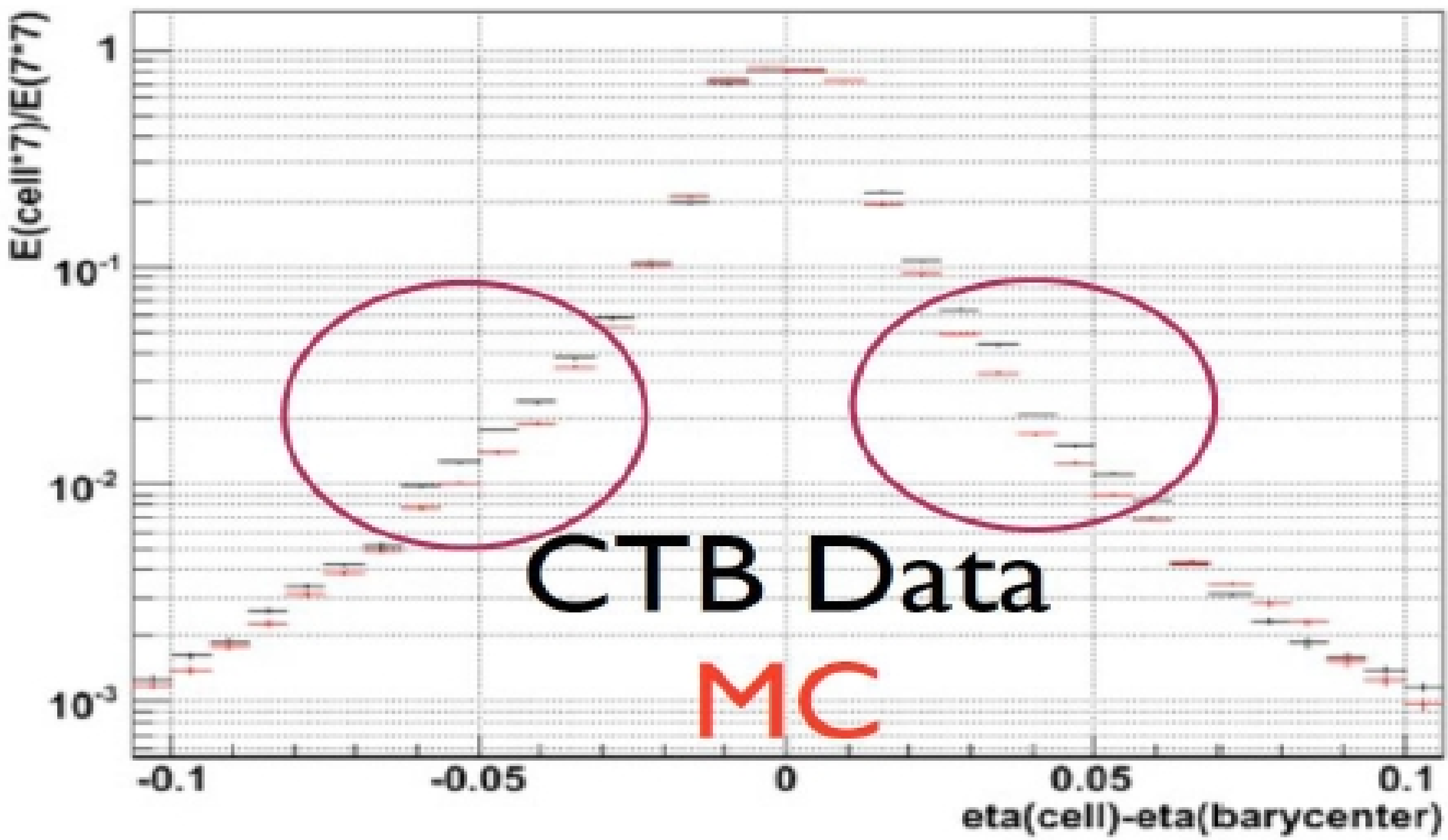
Lateral shower profile

- Relevant for isolation and separations between jets
- Results from LHC test-beam setup (ATLAS TileCal) and CALICE show that all Geant4 physics lists are producing pion and proton showers that are **narrower** than data by **10 ÷ 20 %**
- Improvements on this observable is very important for highly granular calorimeters under design for ILC, but likely not critical for the coarse LHC calorimeters
- Electromagnetic showers: CALICE and ATLAS have recently observed that Geant4 electromagnetic showers are a few % **narrower** than data. This is a critical issue (present also in Geant3). Work is undergoing to improve it, with already some partial promising results...

ATLAS TileCal test-beam pion lateral shower shape, G4 9.4



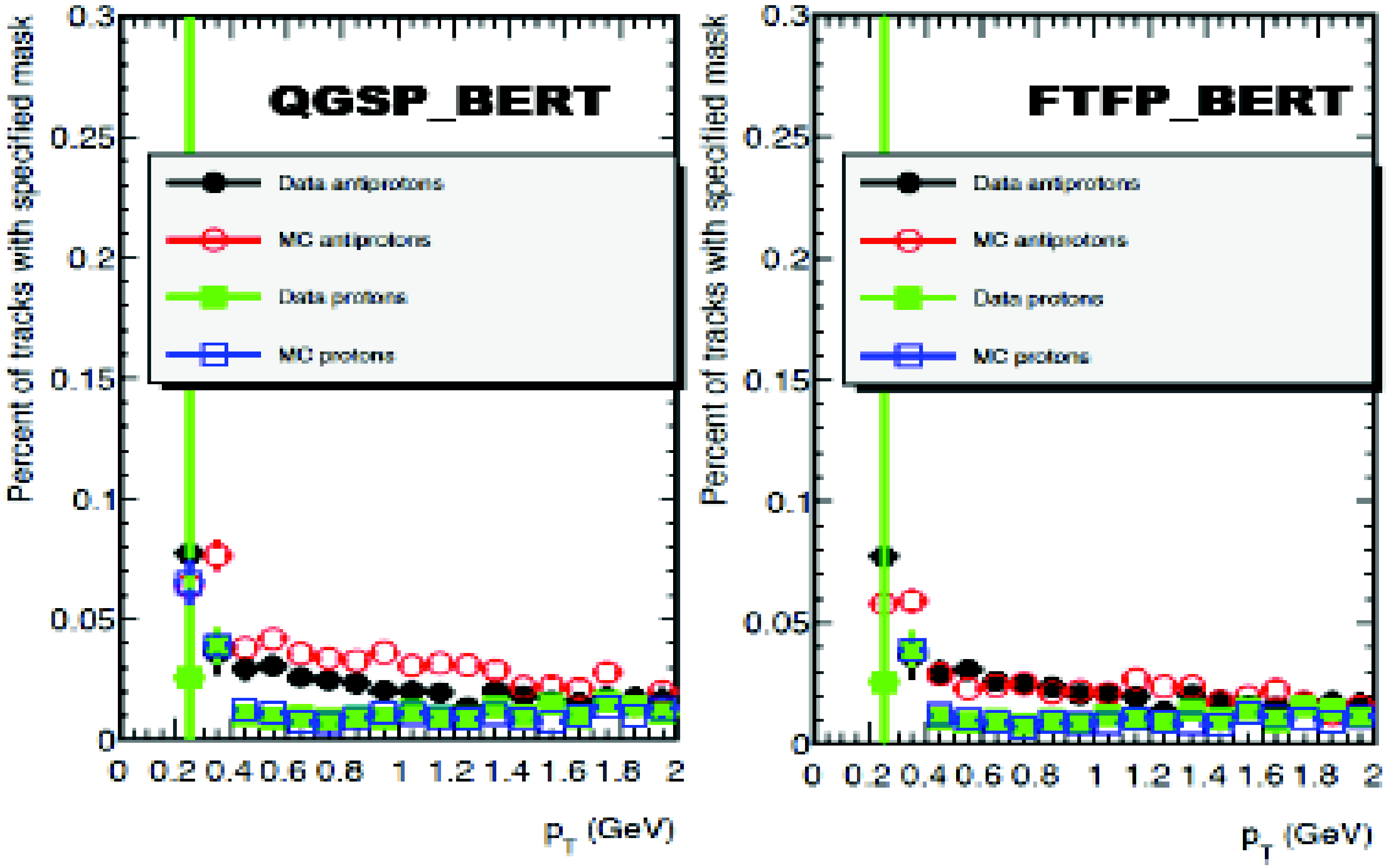
ATLAS EM lateral shape



Kaons and antiprotons

- Kaons and antiprotons are non negligible jet components
- For **LHCb**, the modeling of hadronics interactions (both cross section and final state) in thin layers is very important including Ks , Λ . The differences in interactions for particle and antiparticles, particularly for K± , are also vital
- Much less data available to test these particles
- For kaons, **CHIPS** provides the best current simulation in Geant4, available in QGSP_BERT_CHIPS and in all Fritiof-based physics lists (FTFP_BERT, QGSP_FTFP_BERT,...)
- For antiprotons, **Fritiof**-based physics lists provide the best simulation currently available in Geant4

ATLAS hadronic interactions in the inner detector



Anti-baryons and anti-light-nuclei

- Interest from **ALICE** to have simulations of anti-baryons (n, p, Λ, Σ, Ξ, Ω) and anti light nuclei (d,t,3He,α) better than the rough model available in Geisha (i.e. LEP model in Geant4, used by all physics lists before G4 9.5.beta)
- V. Uzhinsky has implemented in Geant4, as a Fritiof extension, new processes (cross-sections and final states) for the hadronic interactions (elastic, quasi-elastic, and "deep inelastic") for these anti-particles, from 0 up to 1 TeV
- Available in Fritiof-based physics lists (e.g. FTFP_BERT) starting with version 9.5.beta .
  Under validation by ALICE

Multiple scattering

The **LHCb VELO** detector allows for very precise measurements of tracks and vertices

- Due to its highly non uniform and very special geometry (many thin planes) a very precise description of the multiple scattering is needed
- Discrepancy of IP vs Pt resolution between data and Geant4 have been observed:
  - Simple standalone studies show differences ranging from 4% to 8% when material is in a single thick volume or in many thin layer
- Therefore, LHCb would like to have an improved Geant4 simulation for multiple scattering for all particle types

High-energy ion-ion interactions

- **NA61** experiment (at CERN) needs Geant4 simulations of ion-ion interactions at high energies
- A new extended example, Hadr02, have been released which provides an interface to **DPMJET-II.5** . Also FTF and CHIPS ion/ion models are available in this example. NA61 is using this interface
- NA61 reported a problem in quasi-elastic events in p - C12 reaction at 30 GeV. This has been fixed. It remains to understand the difference between QGS and FTF quasi-elastic

CALICE wish list for G4

- Implement CALICE-like geometry in the check plots for new releases !!!
- Prepare for the imminent comparison Fe .vs. W with CALICE data
  - HP package, provisionally looks promising in CALICE at least for W
- Continue to improve CHIPS (fix cross section, lower visible energy, too long showers)
- Radial shower shape → indications from CALICE: too narrow in all lists

Time structure of hadron shower

CALICE is investigating the 4th dimension of the hadronic shower

Measured with a set of scintillator tiles with very high time resolution electronics installed behind the W-AHCAL (~5 λ_{int})

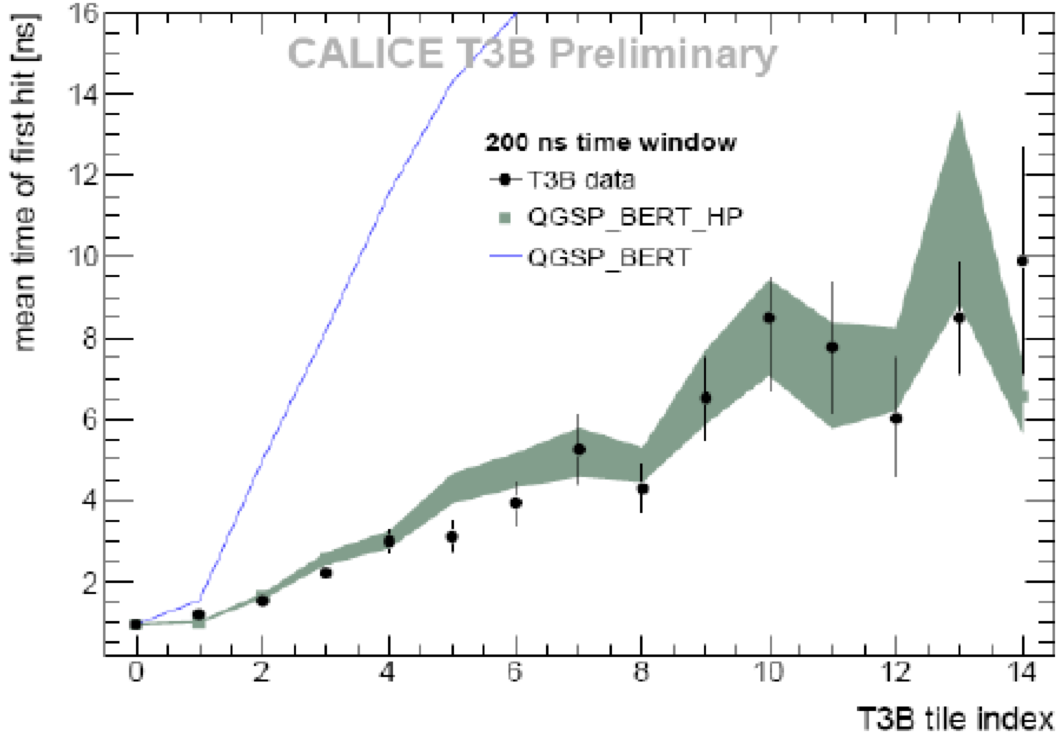


Figure 8. Mean time of first hit for 10 GeV π^- as a function of radial distance from the shower core (a tile index of 10 corresponds to approximately 30 cm). The data are compared with simulations using QGSP_BERT and QGSP_BERT_HP. The error bars and the width of the area in the case of QGSP_BERT_HP simulations show the statistical error, while for QGSP_BERT the errors are omitted for clarity.

- HP package needed to reproduce shower time structure in tungsten
- Does it also match the energy response and spatial profile? We will very soon be able to report on this.

Validation summary table for G4 9.4.p01

Table made by A. Dotti

	Response	Resolution	Smoothness	Lateral Shape	Longitudinal Shape @10λ	Notes
QGSP_BERT	+(1-3)%	-(10-5)%	Bad	-(20-10)%	π: -10% p: -20%	anti-nucleons, hyperons via LHEP
FTFP_BERT	+(3-5)%	-(7-3)%	Good	π: -(20-10)% p: -(10-3)%	π: +10% p: +(10-20)%	anti-nucleons, hyperons via CHIPS(*)
CHIPS	+(10-5)%	-(20-10)%	Very Good	π: -(10-3)% p: -(20-10)%	π: -10% p: -20%	native anti-nucleons, hyperons
FTF_BIC(**)	+(3-5)%	-(6-2)%	Bad	-	π: +10%	Implements re-scattering at high E

Software requirements

CPU and memory

- The CPU performance and memory usage of Geant4 applications are very important for the experiments that need to simulate billions of events
- The Geant4 team is **monitoring** regularly these quantities and trying to **improve** them
  - Improvements of the Bertini model (by M. Kelsey)
  - Studies to reduce the impact of HP neutrons
- On-going project in ATLAS for a seamless integration between **full** and **fast simulation**
- Growing interest (ATLAS and CMS) for running Geant4 simulations in **parallel** on multi-core CPUs

Stability

- Millions of events are regularly run by the Geant4 team to test new releases and reference tags. Thanks to this effort, Geant4 is very stable. However, few rare crashes or problems are reported from the experiments, which run billions of events in extremely complicated geometries
- Reproducibility of the random sequence is essential to be able to study rare problems and make the necessary code improvements. Non-reproducibility shows up sometimes
- Stuck particles (bouncing between volume boundaries) in Geant4 simulations have been reported. Under study
- FTF_BIC physics list is interesting for the rescattering but is not yet very stable

Summary & conclusions

- Up to now, overall satisfactory behavior of Geant4 simulations with respect to **LHC collision data**. **Test-beams data** are still providing more stringent validation for Geant4 simulations, especially for hadronic showers
- Need to keep a balance between **stability** and **new features/improvements** between Geant4 releases
- Focus on a **few physics lists**, relying on a **few key models**
- Energy response and energy resolution are the two most important observables for LHC physics, followed by longitudinal and lateral shower profiles. For ILC/CALICE the top observable is the lateral shower profile
- Growing attention to “other particles”, besides the traditional pions and protons

Thanks

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