Physics Validation

Detector Simulation Workshop
CERN, 6-7 October 2011

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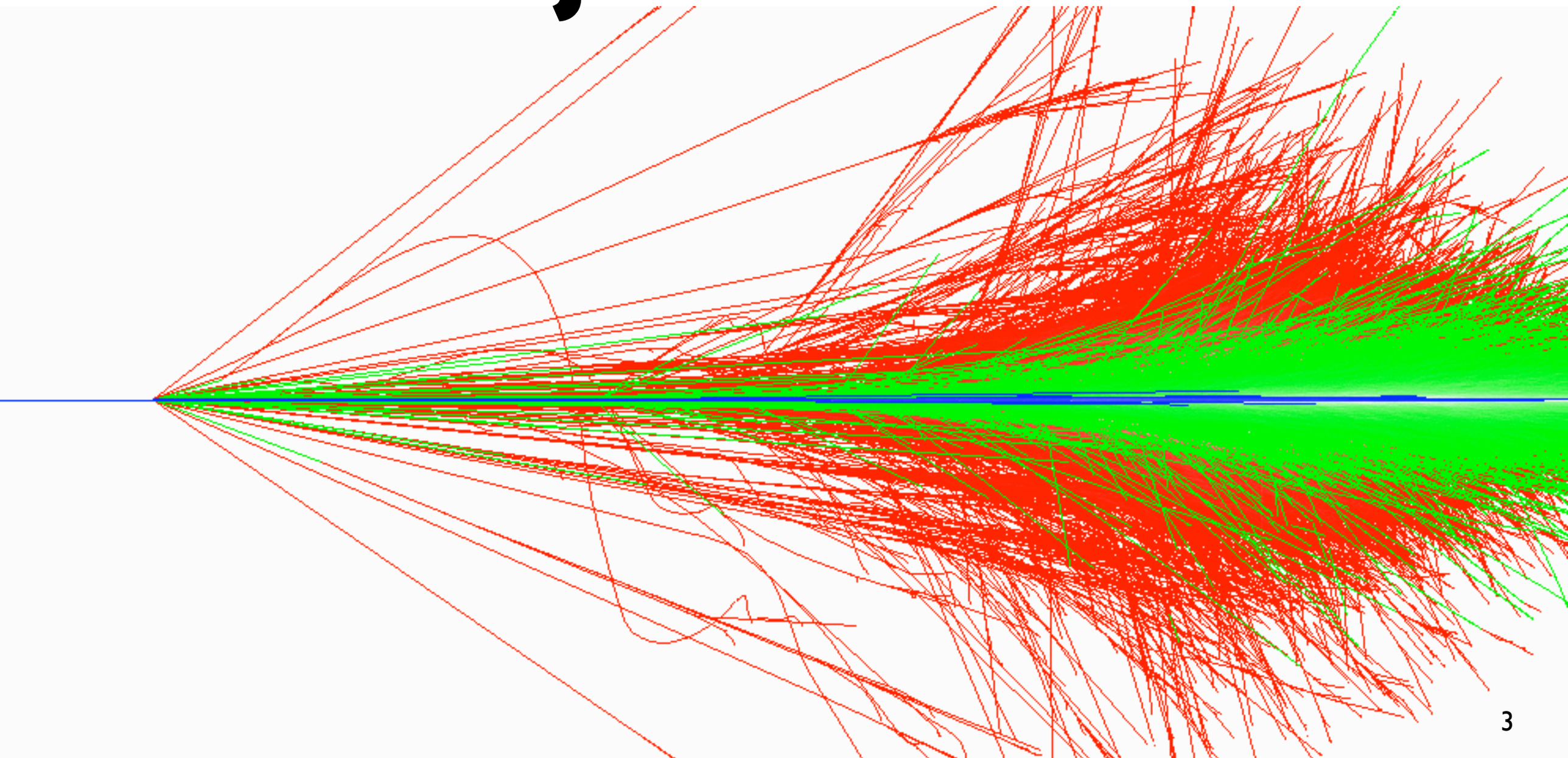
Outline

- **Introduction**: what is Physics Validation
- **Selection of results**
  - Test-beam comparison
  - Testing Suite
  - Thin-target
- **Future directions**

- Website: http://sftweb.cern.ch/validation
- Backup slides contain more details and plots

The Project Structure



Goal

- "[...] Provide **up-to-date comparison** between LHC data and detector simulation toolkits. [...] allow for an **in-depth improvement** of the simulation code [...]"

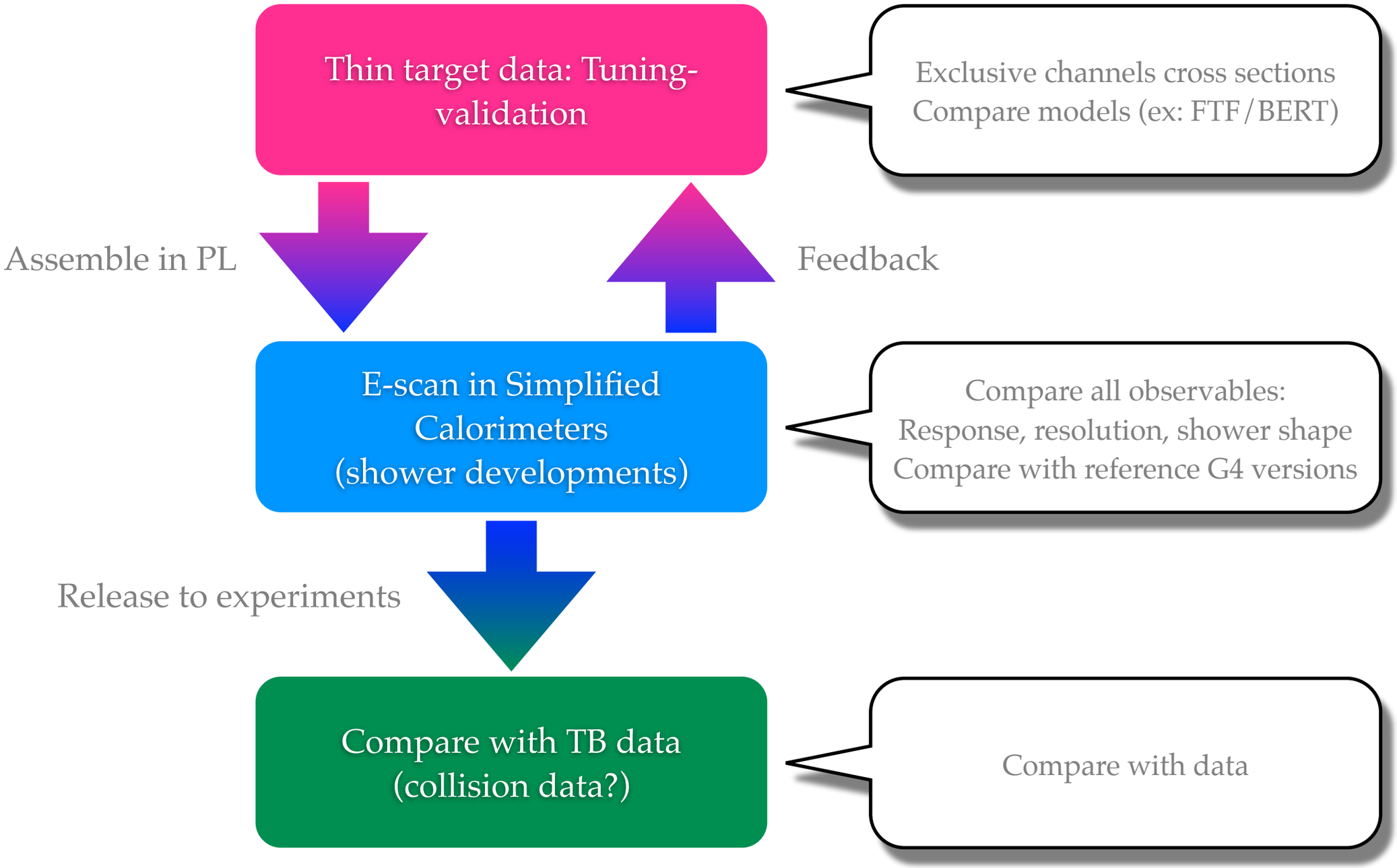
- Project started in 2004
  - **Requirements** on simulation softwares:
    - CERN-LCGAPP-2004-02
  - **Status of simulation** at the start of LHC:
    - CERN-LCGAPP-2010-02

Validation

- **Most stringent requirements** are set by calorimeters (see backup slides)
  - Hadronic showers area the most challenging
  - Typical observables:
    - **response** (e/π)
    - **resolution**
    - lateral and longitudinal **shower shapes**
- First source of validation are test-beam data
  - Simple environment: single particle of well defined energy

Activities

- **Developers**: thin-target data to tune models (see A. Ribon's talk),
- **Experiments**: validate physics list
- Total of 185 reports collected
  - **65% Hadronics physics** ; 20% EM ; 15% Miscellanea
  - **60% from experiments** ; 40% from developers
  - Validation Workshop (2006) https://indico.cern.ch/conferenceDisplay.py?confId=4532


Thin target data: Tuning-validation
Exclusive channels cross sections
Compare models (ex: FTF/BERT)
Assemble in PL
Feedback
E-scan in Simplified Calorimeters (shower developments)
Compare all observables:
Response, resolution, shower shape
Compare with reference G4 versions
Release to experiments
Compare with TB data (collision data?)
Compare with data

Selection of results

Here following top-down approach:
First what is closer to experiments, last thin-target

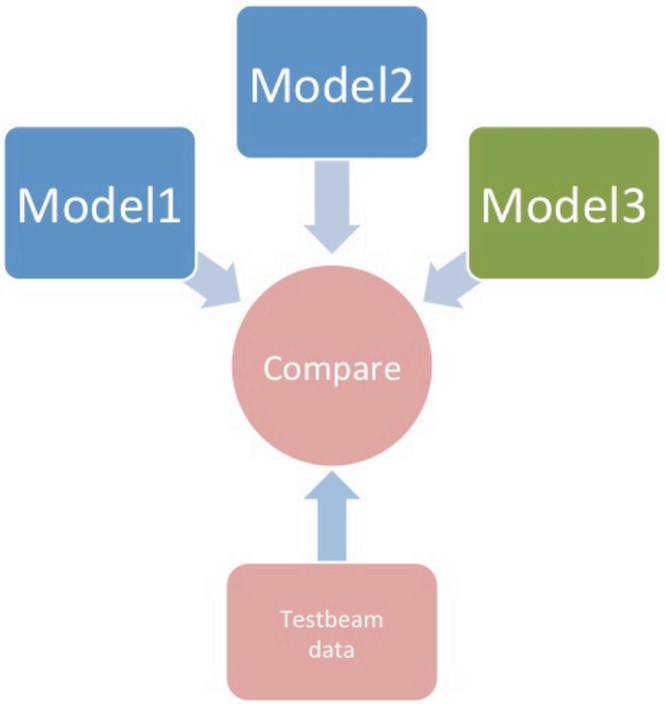
LHC Test-beam

Only few examples shown

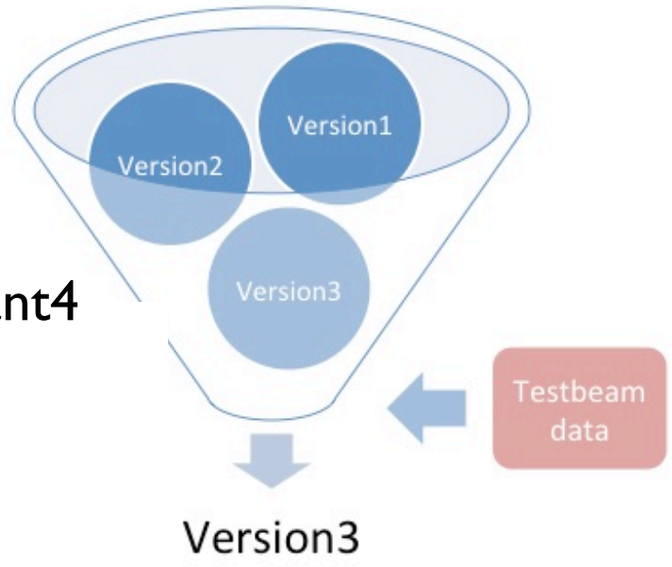
See yesterday presentations from experiments

Plots for all collected observables in backup

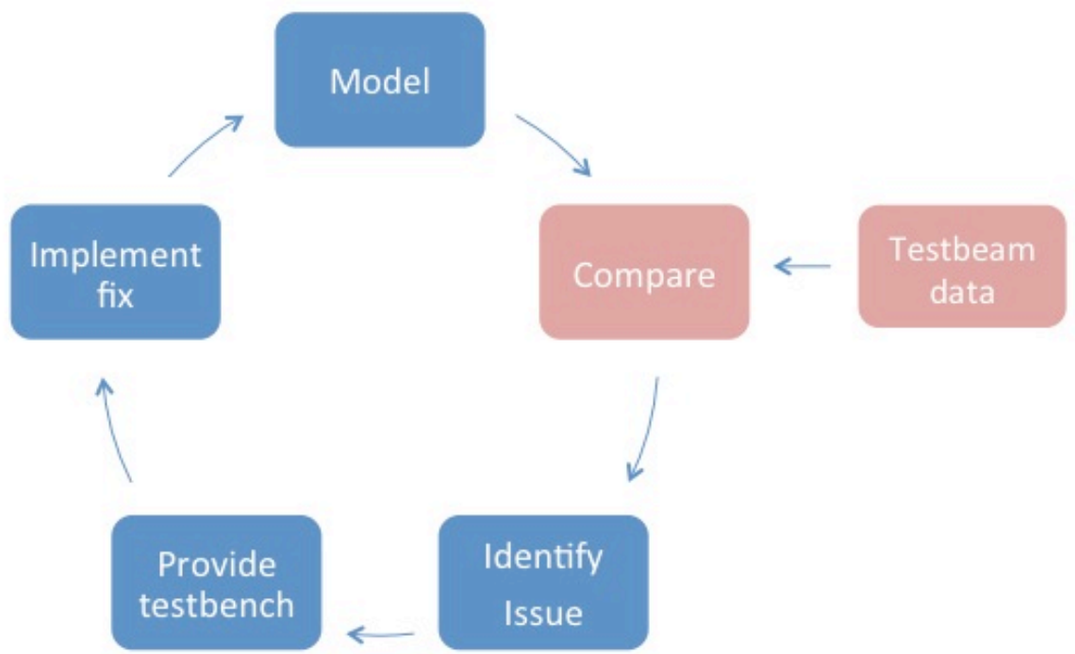
The three roles of test-beam



Compare models and identify best physics list for production



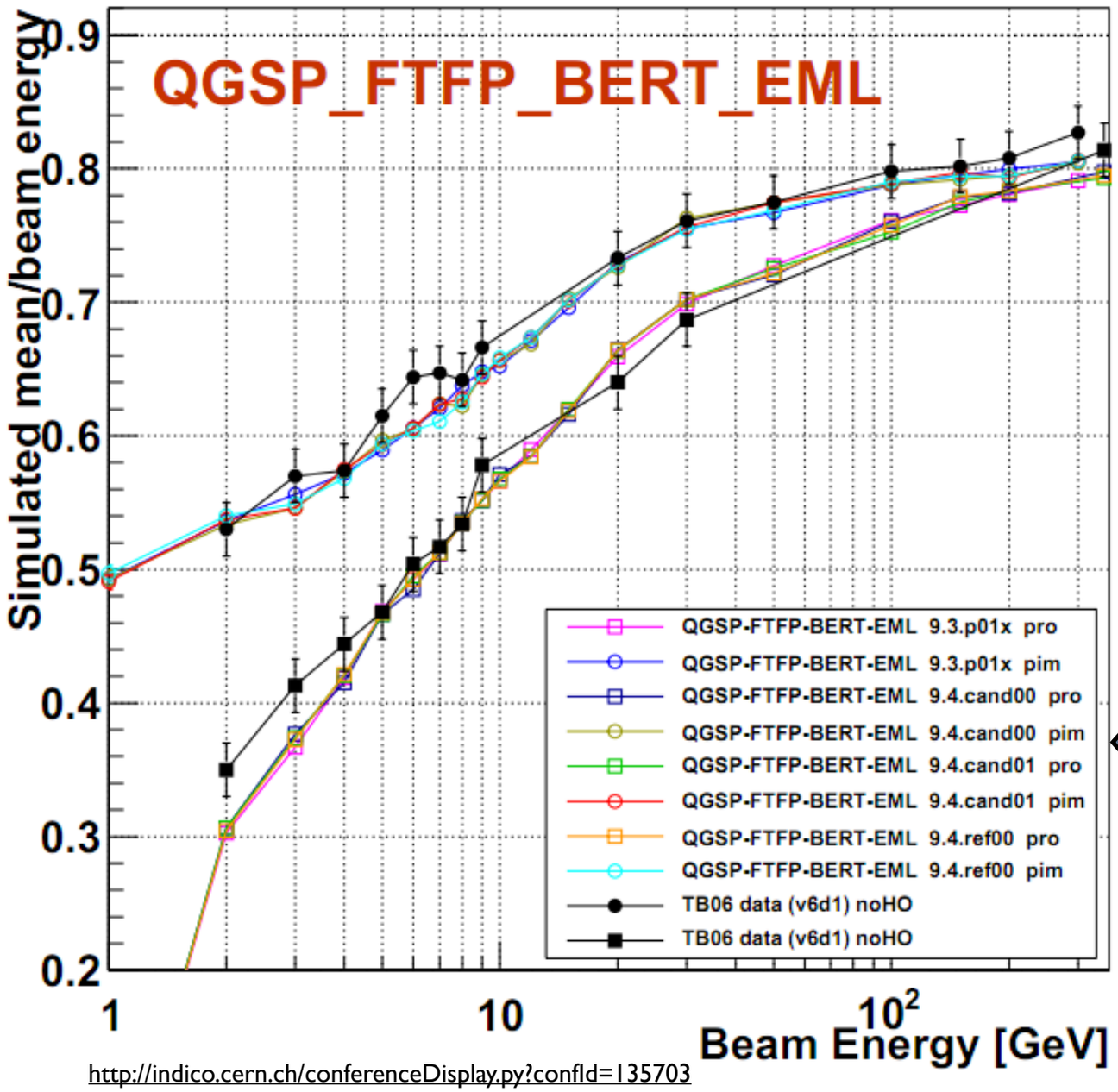
Monitor developments of Geant4



Identify issues, identify responsible models and provide test bench for fixes

Regression testing example

CMS combined TB



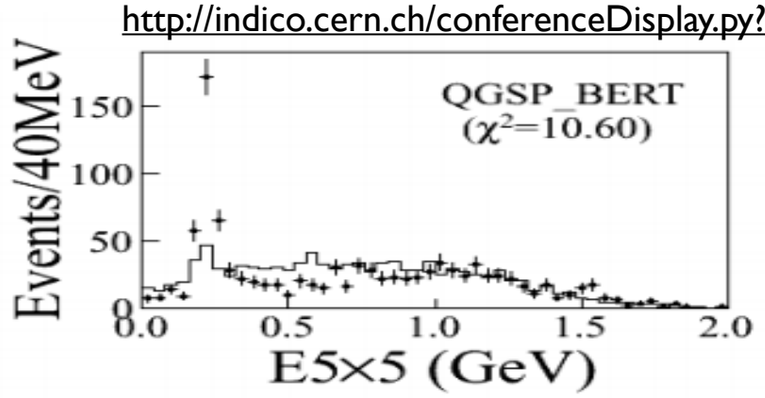
http://indico.cern.ch/conferenceDisplay.py?confId=135703

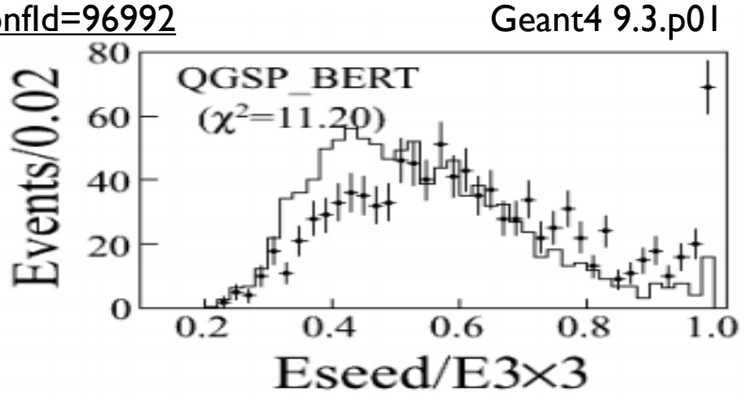
- **Detailed comparison** with pion and proton beams
- FTF based physics lists, best description of data
- **CMS strategy: tailor production physics list to experiments' need**

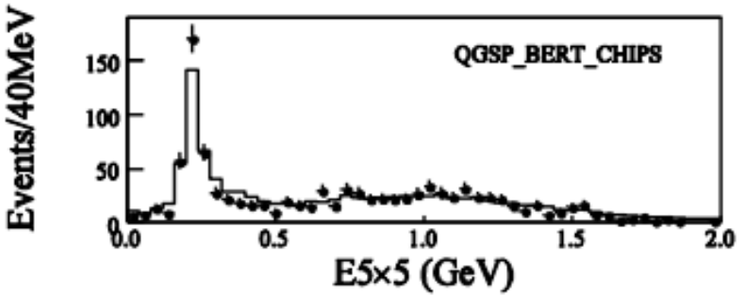
Monitor evolution of developments (monthly development release)

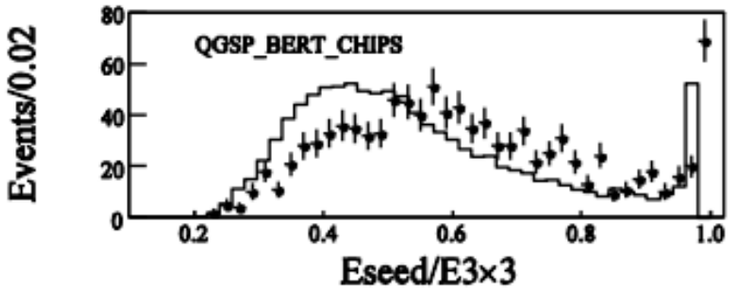
Anti-proton: BES III

http://indico.cern.ch/conferenceDisplay.py?confId=96992 Geant4 9.3.p01









- Clean anti-p sample for charmonium states decays
- Total energy in cluster
- Partial shower shape (core/halo)
- Note: short EM calorimeter, sensitive to cross-sections

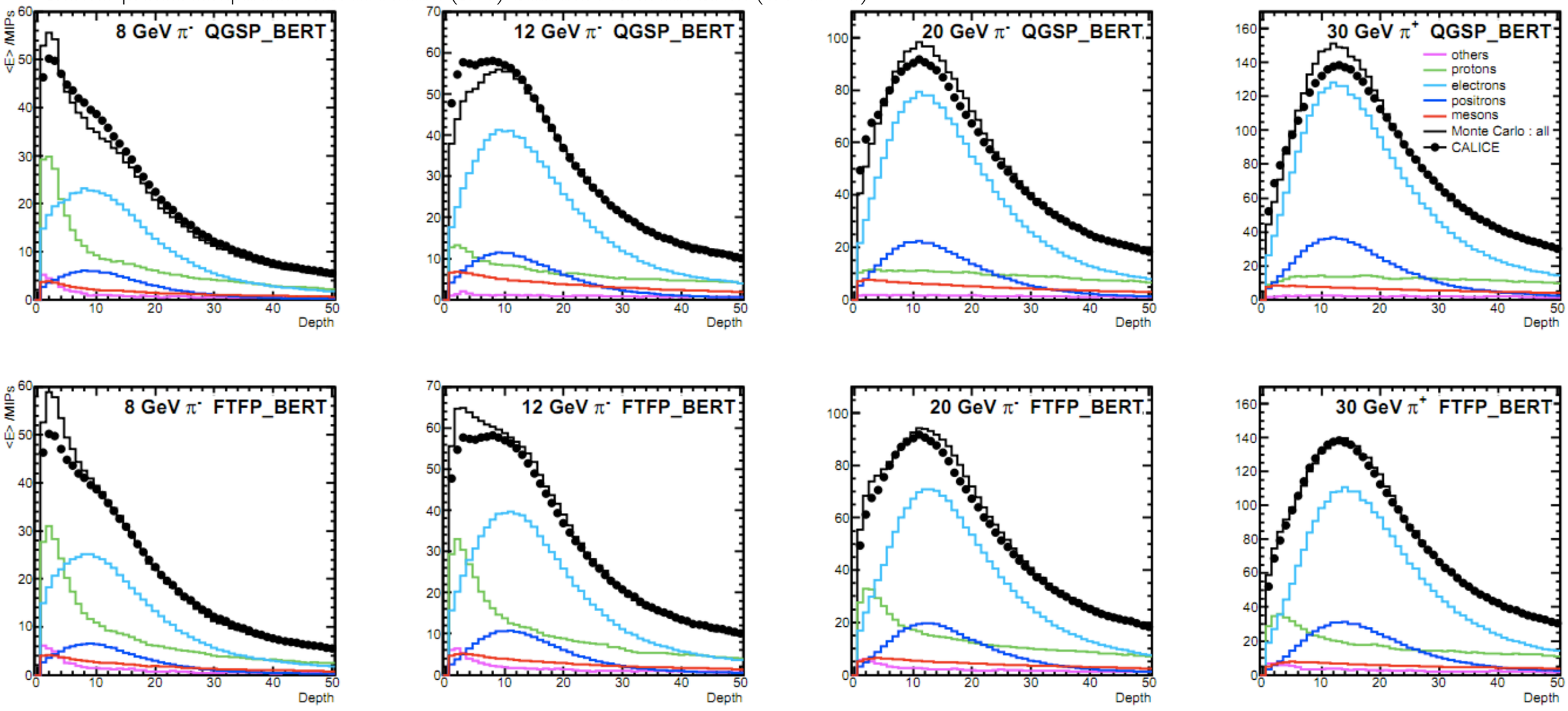
- Use of better cross-sections improves simulation of anti-proton
- **Results confirmed by LHC experiments**
- Similar improvements obtained for kaons
- Example of collaboration with non-LHC experiments

Shower Shapes

- High granular calorimeters CALICE
- Allow for unprecedent detail in resolving shower structure
- **Important feedback to improve shower shapes**

Shower profile: comparison with test-beam (SiW) data and MC break-down (G4 ver 9.3)

The CALICE collaboration *et al* 2010 *JINST* **5** P05007



Test-beam summary (G4 9.4.p01)

To be updated with this workshop feedback

	Response	**Resolution**	**Smoothness**	**Lateral Shape**	**Longitudinal Shape @10λ**	**Peculiarities, comments**
QGSP_BERT	+(1-3)%	-(5-10)%	Δ~5%@10GeV	π,p: -(10-20)%	π: -10% p: -20%	Extensive use of LHEP
FTFP_BERT **QGSP_FTFP_BERT**	**+(0-5)%** **(***)**	**-(3-7)%**	**Δ~0**	**π: -(10-20)%** **p: -(3-10)%**	**π: +10%** **p: +(10-20)%**	**anti-nucleons, hyperons via CHIPS(*), no LHEP**
CHIPS	+(5-10)%	-(10-20)%	Δ~0	π: -(3-10)% p: -(10-20)%	π: -10% p: -20%	anti-nucleons, hyperons, single model
FTF_BIC(**)	+(3-5)%	-(2-6)%	Several irregularities	-	π: +10%	Implements re-scattering at high E, Extensive use of LHEP

(*): Native FTF model under testing

(**): Much less tested at LHC

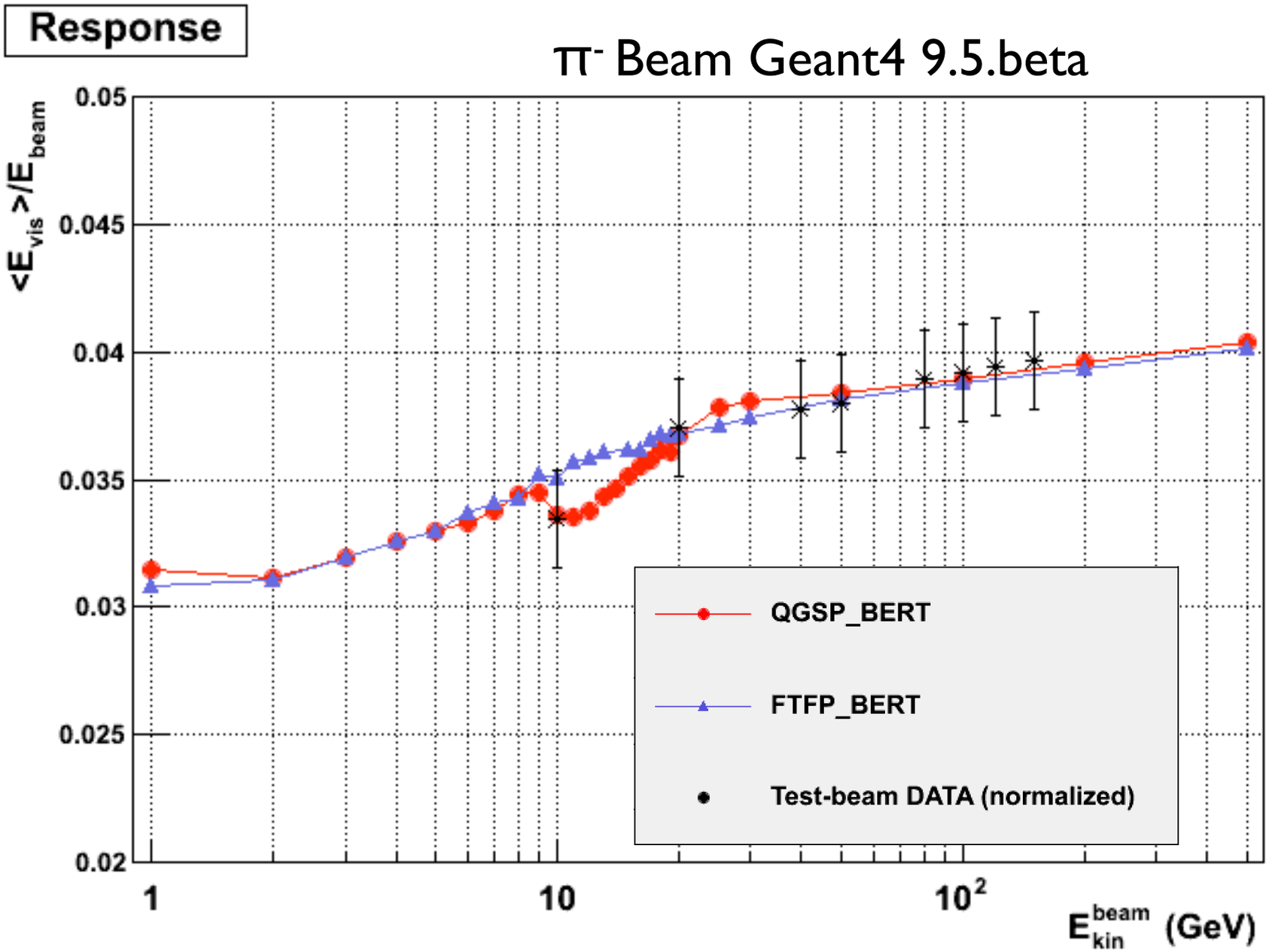
(***): Lower limit: CMS; Upper limit ATLAS

Geant4 Testing Suite

Simplified Calorimeter

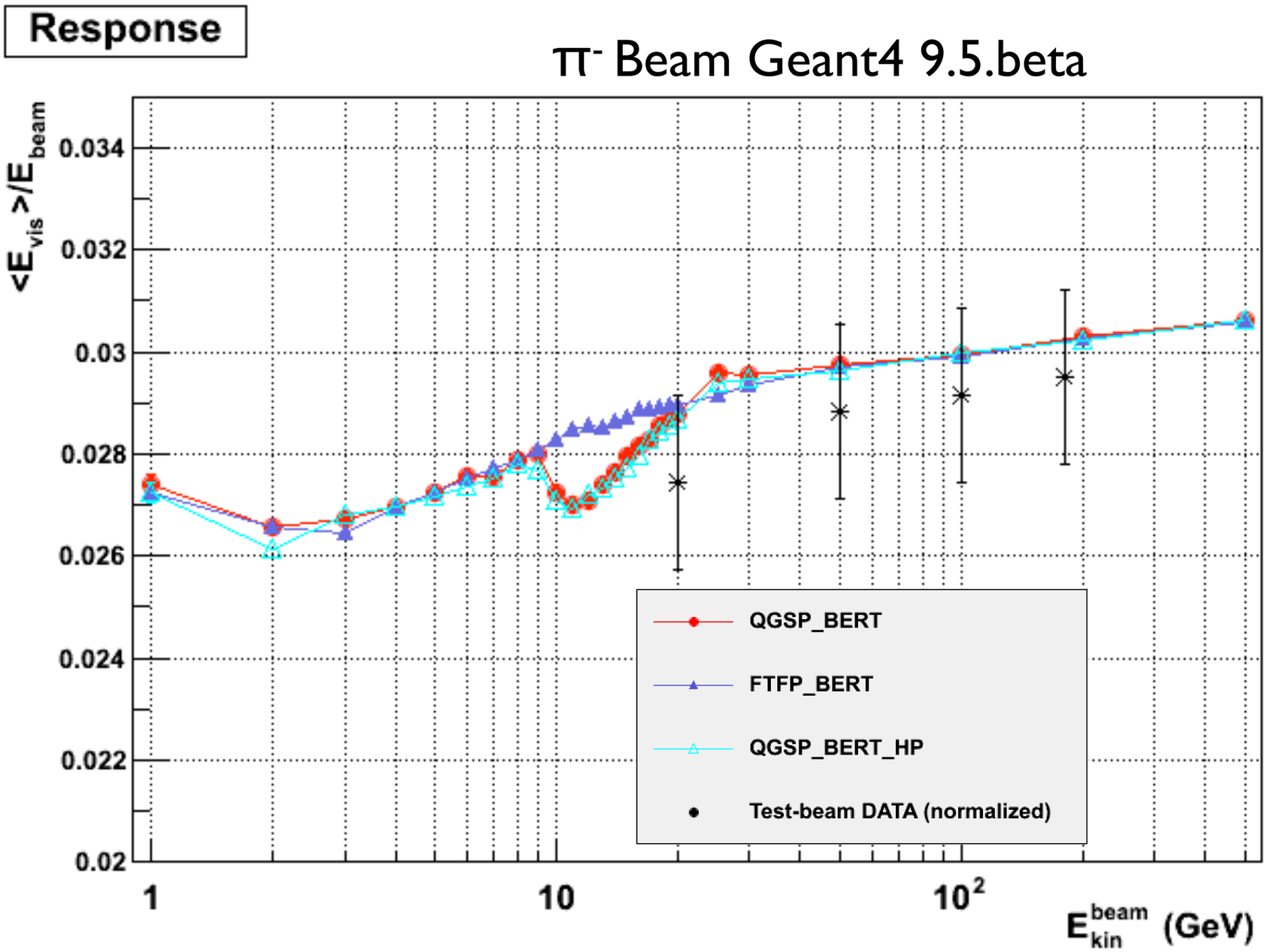
- **Frequent simulations to monitor developments**
  - Simplified geometry of:
    - LHCb, ATLAS, CMS calorimeters
    - Also: Zeus (compensating), CALICE (highly granular)
    - "Sandwich" geometry, no read-out effects
  - In two cases some comparison with data

Response: Cu/LAr



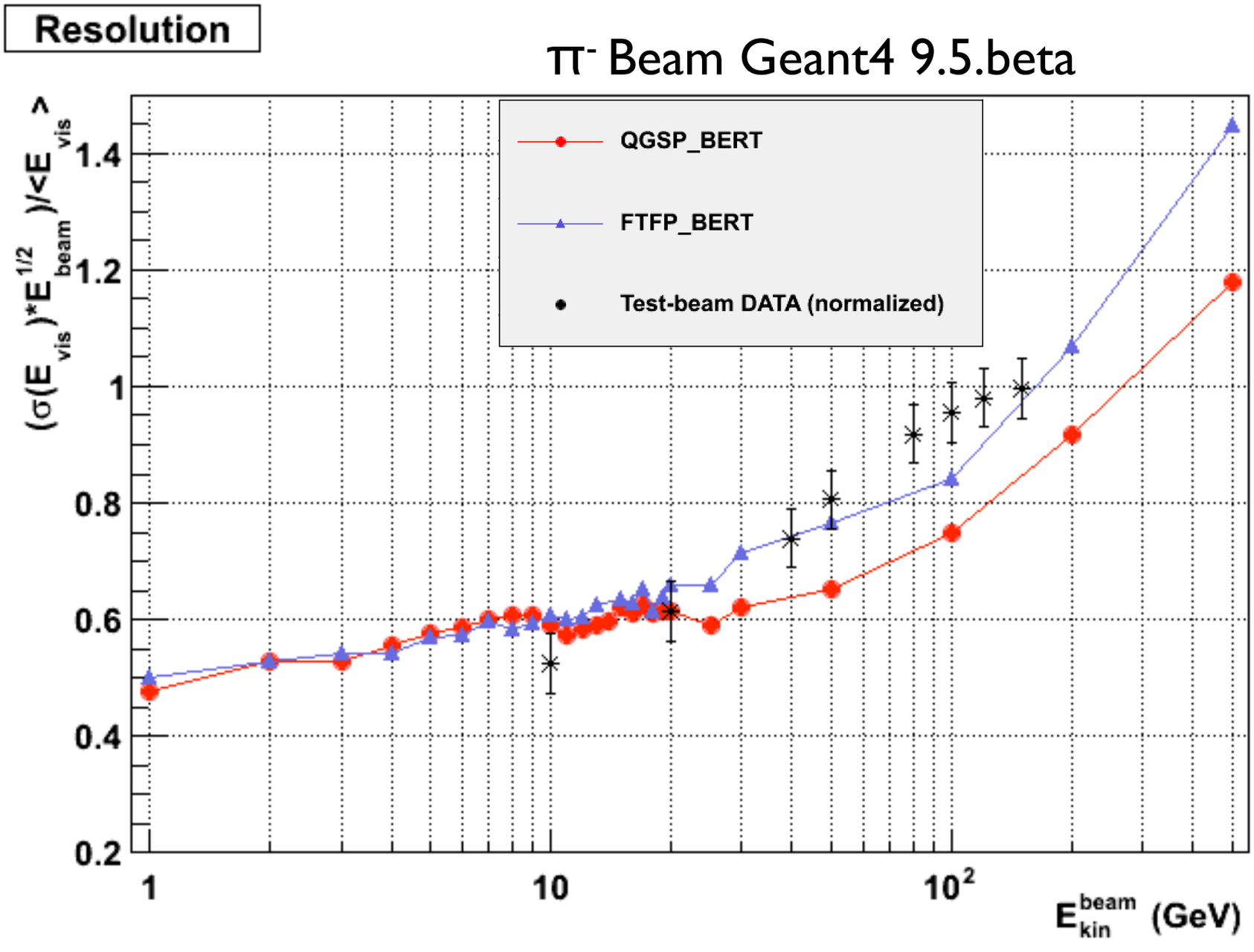
Data scaled:
$MC_{simple}/(c*Data)=MC_{full}/Data$

Response: Fe/Sci



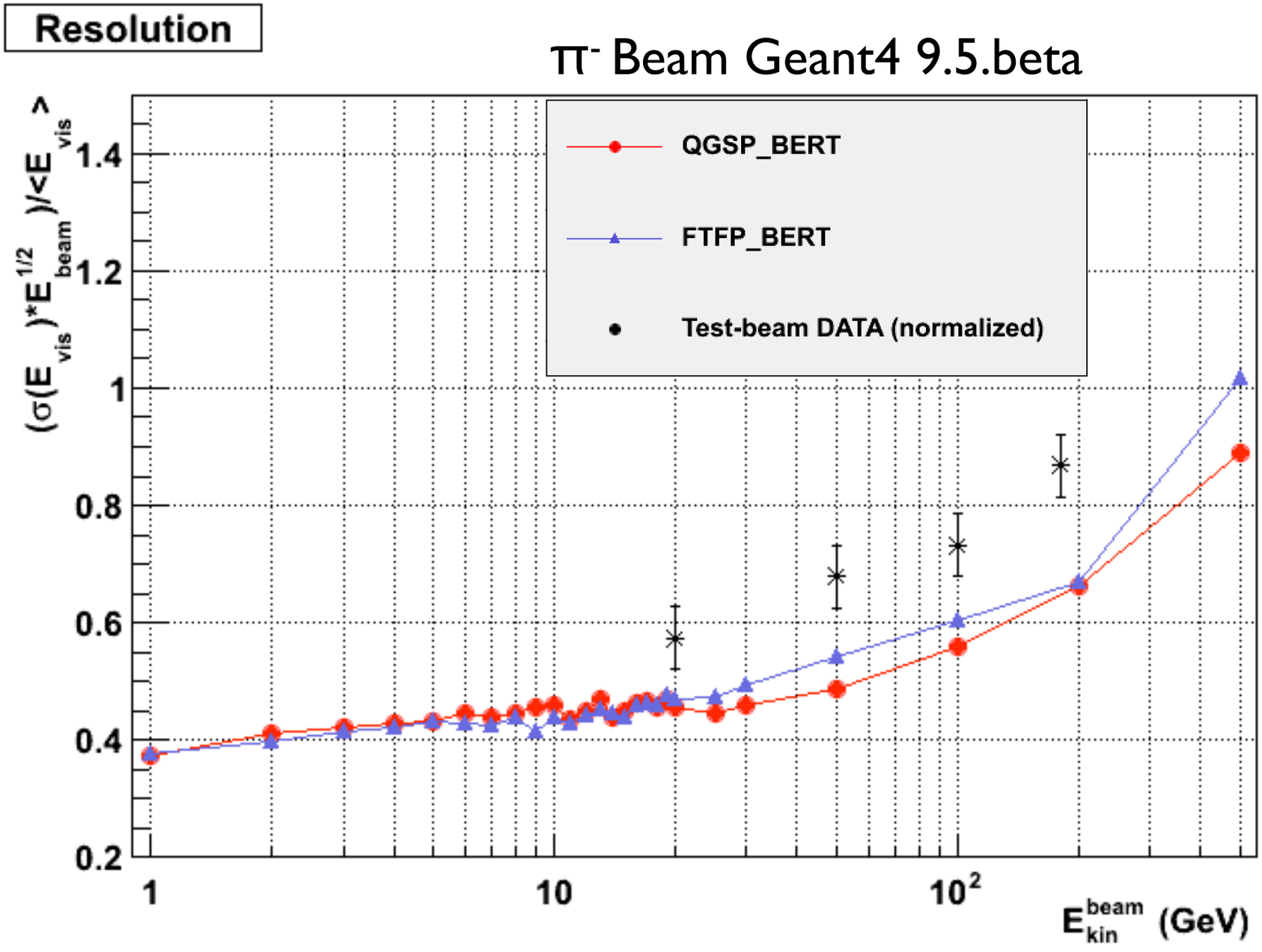
- Worse agreement
- Investigations ongoing:
  - Role of neutrons
  - Experimental effects (Birks' see later)

Resolution: Cu/LAr



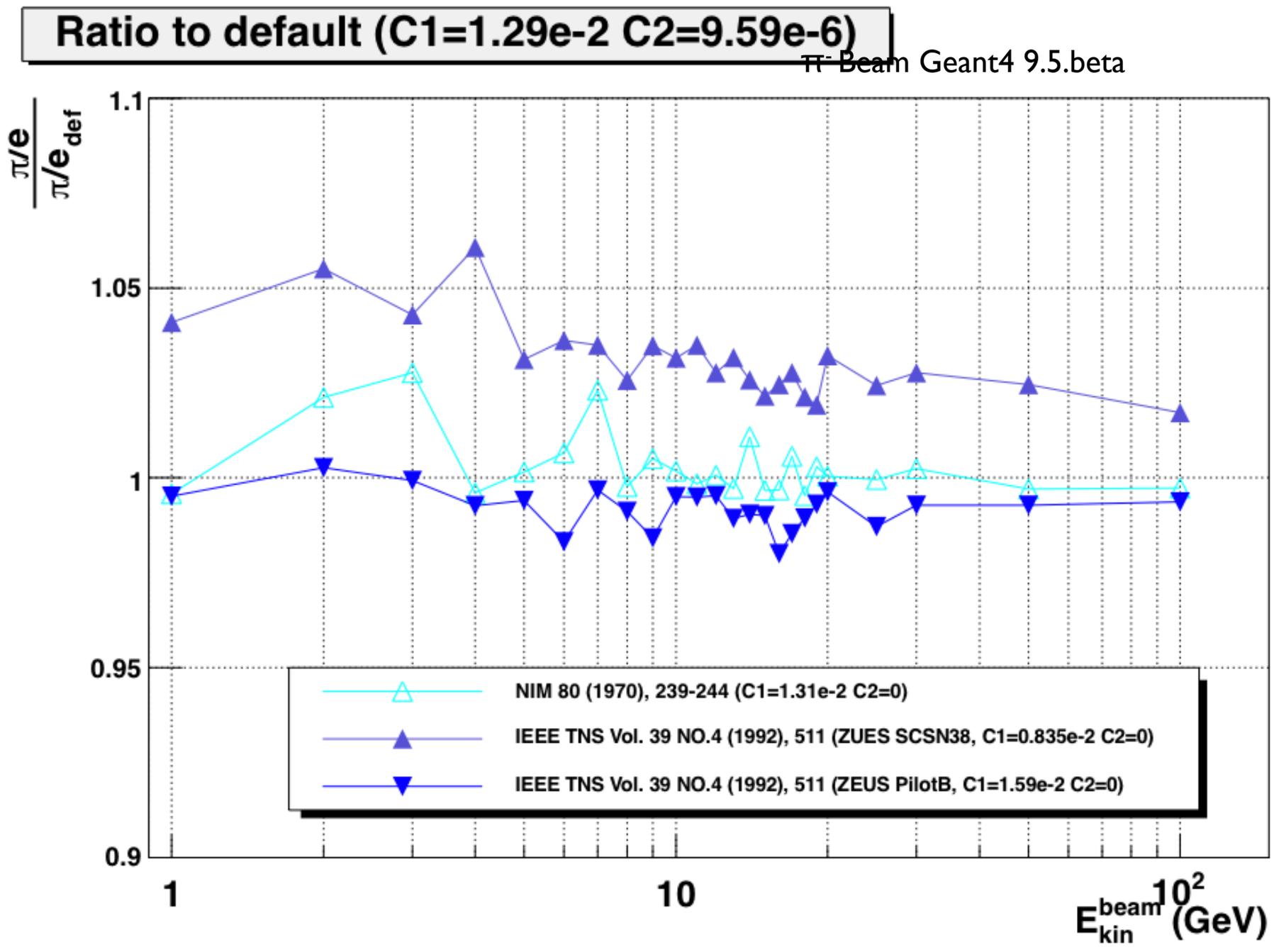
Note: no noise implemented in Geant4 simulation

Resolution: Fe/Sci



Note: no noise implemented in Geant4 simulation

Scintillator based calorimeters

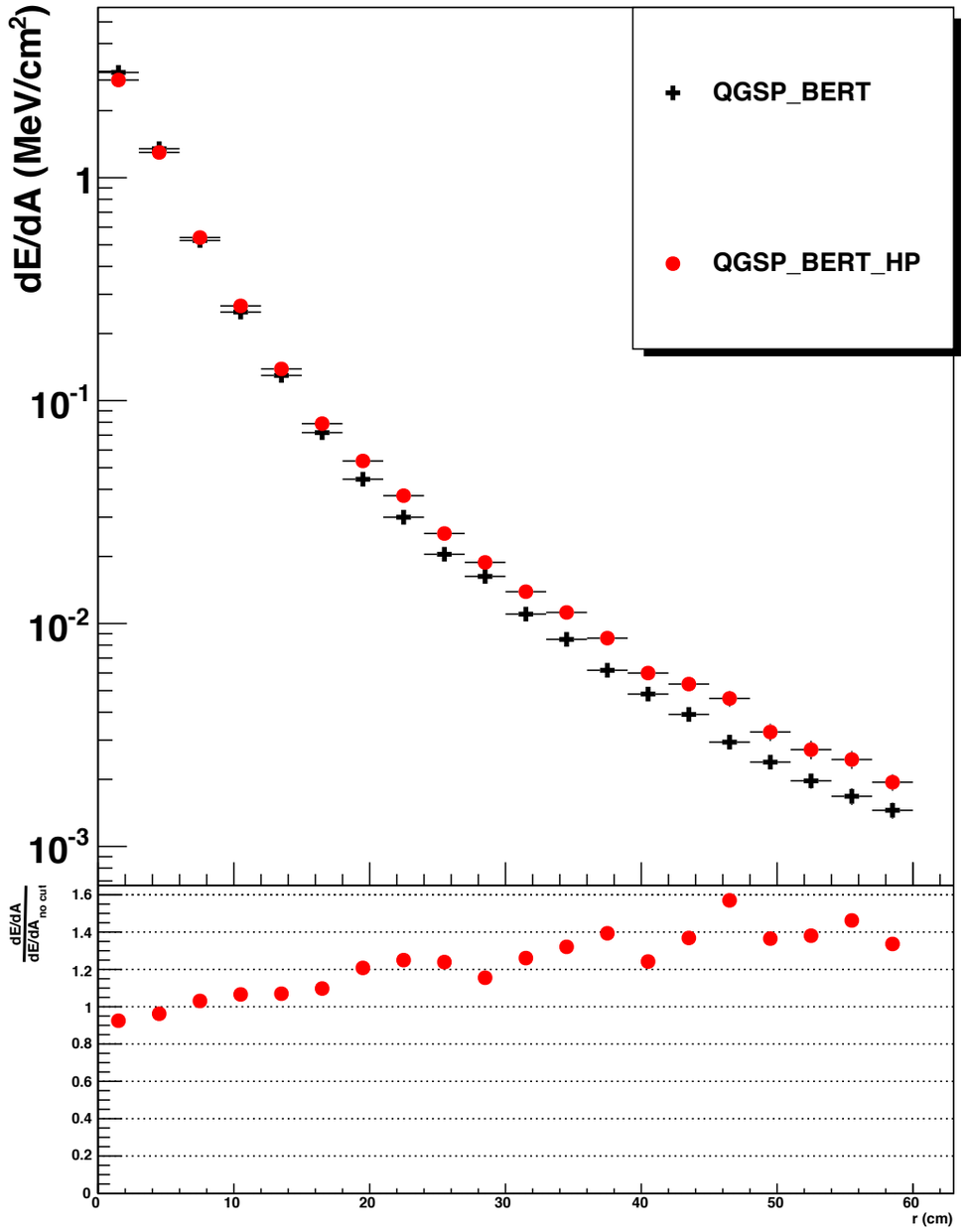


Max 4% differences depending on Birks' parameters choice

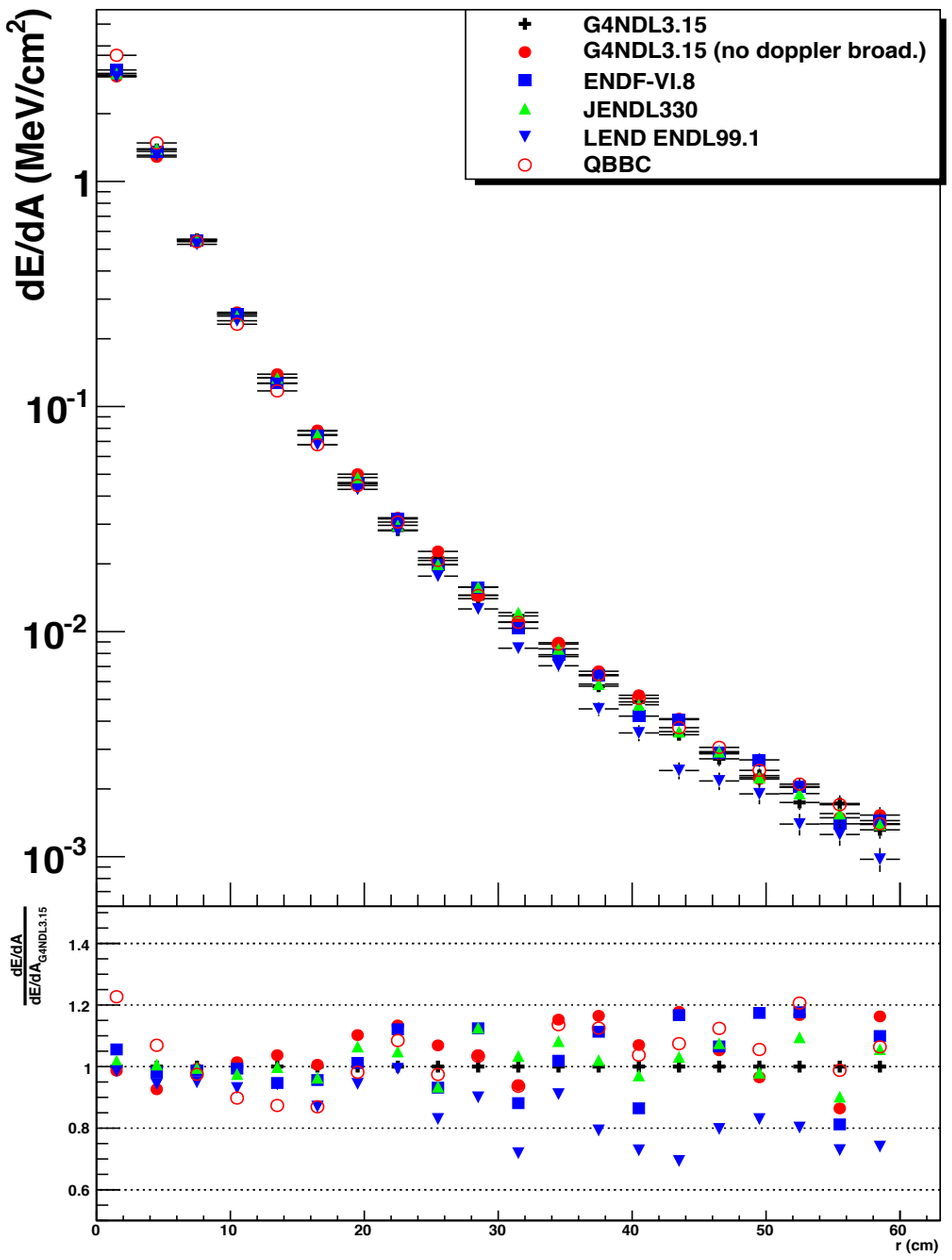
- **Similarly to noise simulation is responsibility of experiment's frameworks**
  - Using parametrizations from literature (need update to specific LHC scintillators?)
- **Are Birks' coefficients known for LHC experiments?**

Radial profile

Radial Profile π@8GeV: Pb/LAr



Radial Profile

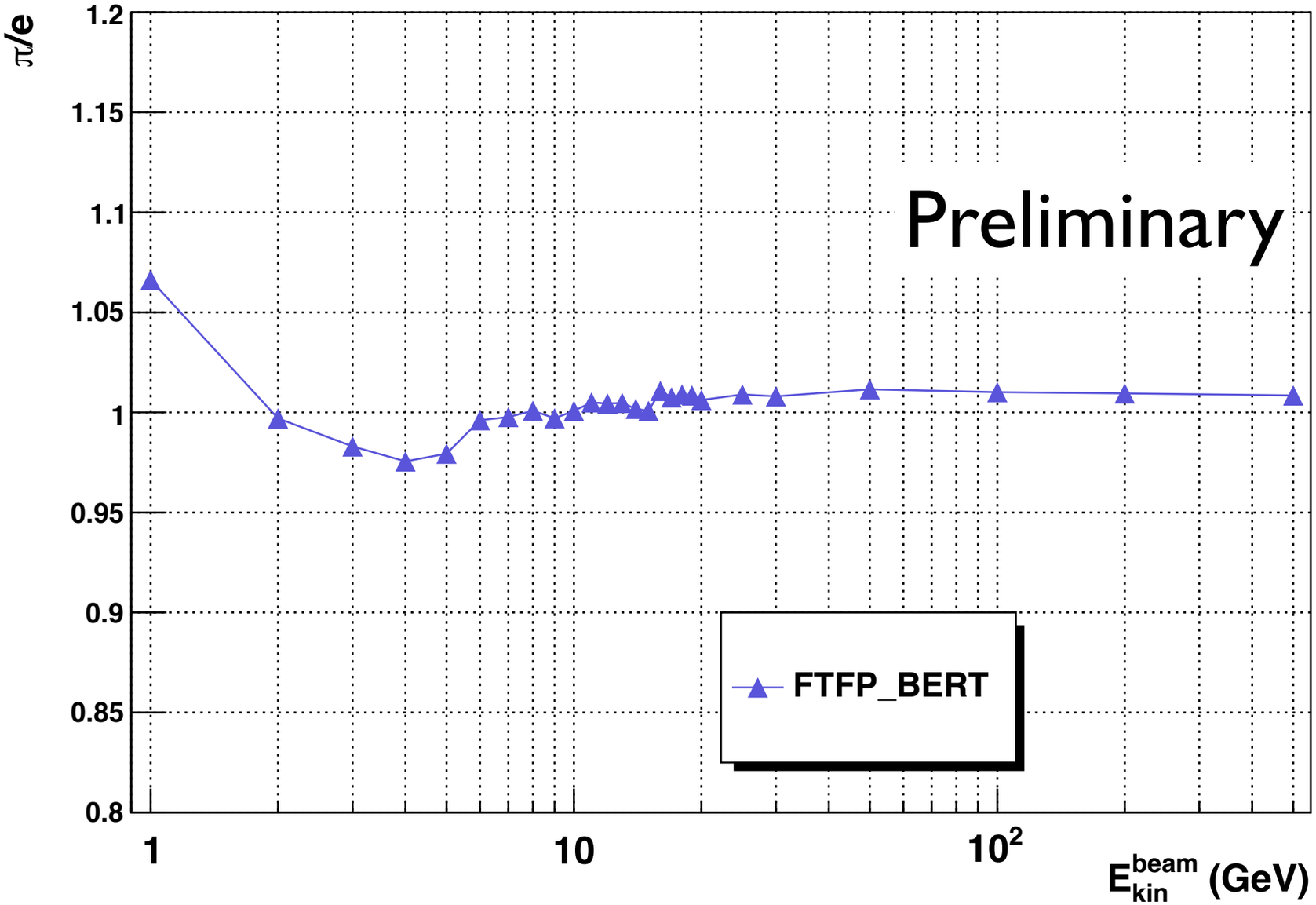


Low-E neutrons play important role for lateral profile

Challenging to compare with data: need CALICE

Compensating calorimeter

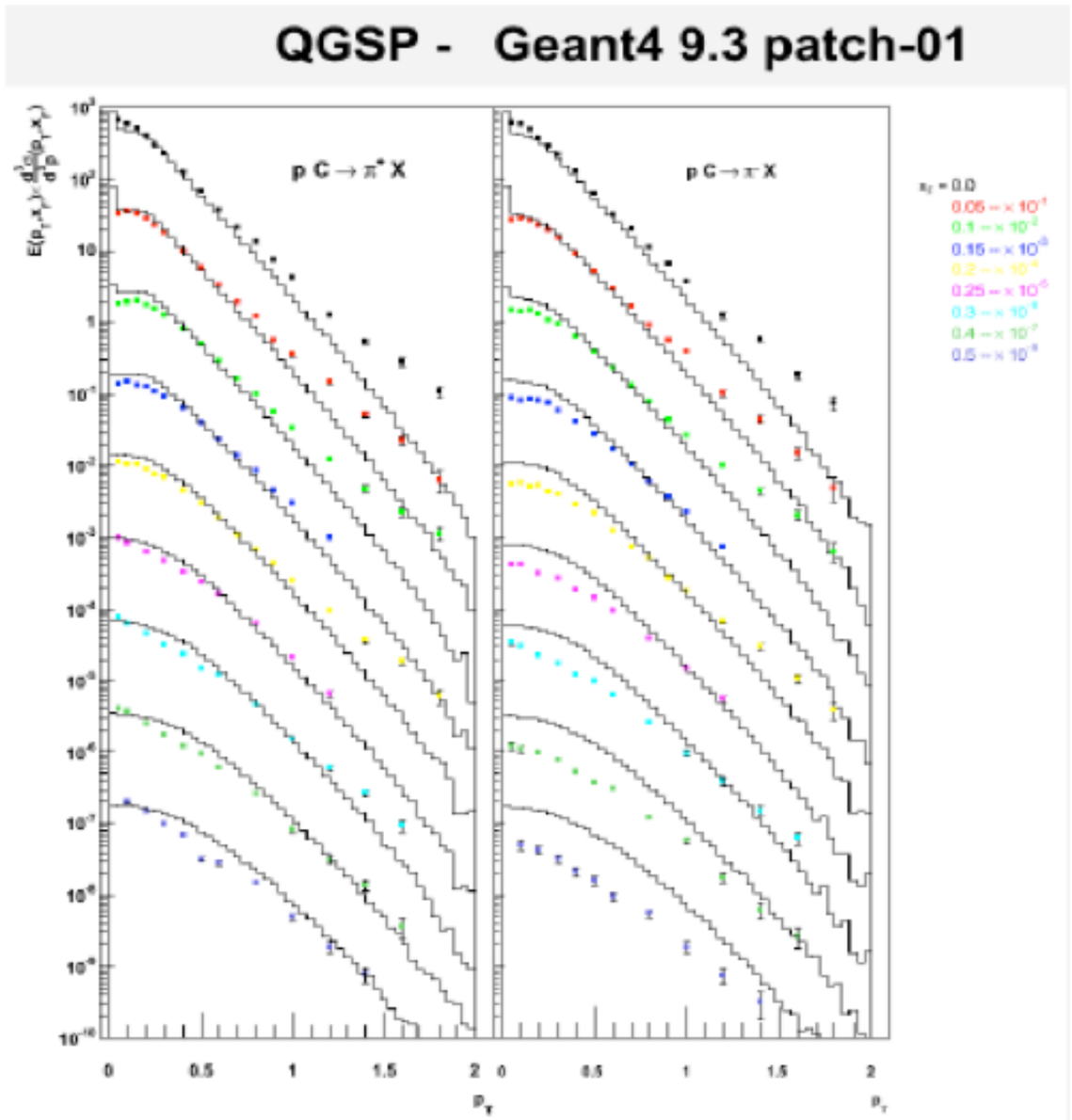
ZEUS Pb/Sci (NIM A262(1987) 229-242

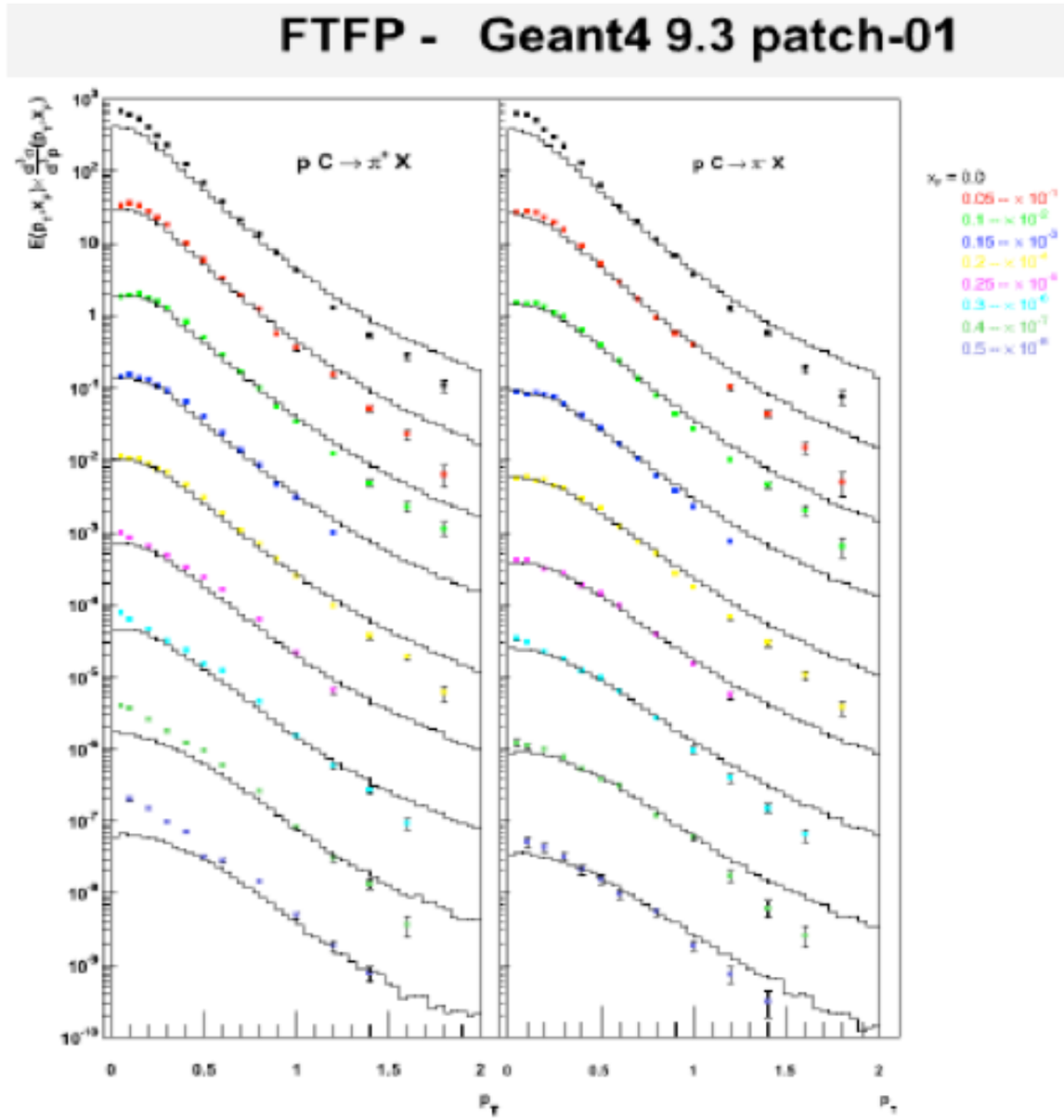


Thin Target Validation

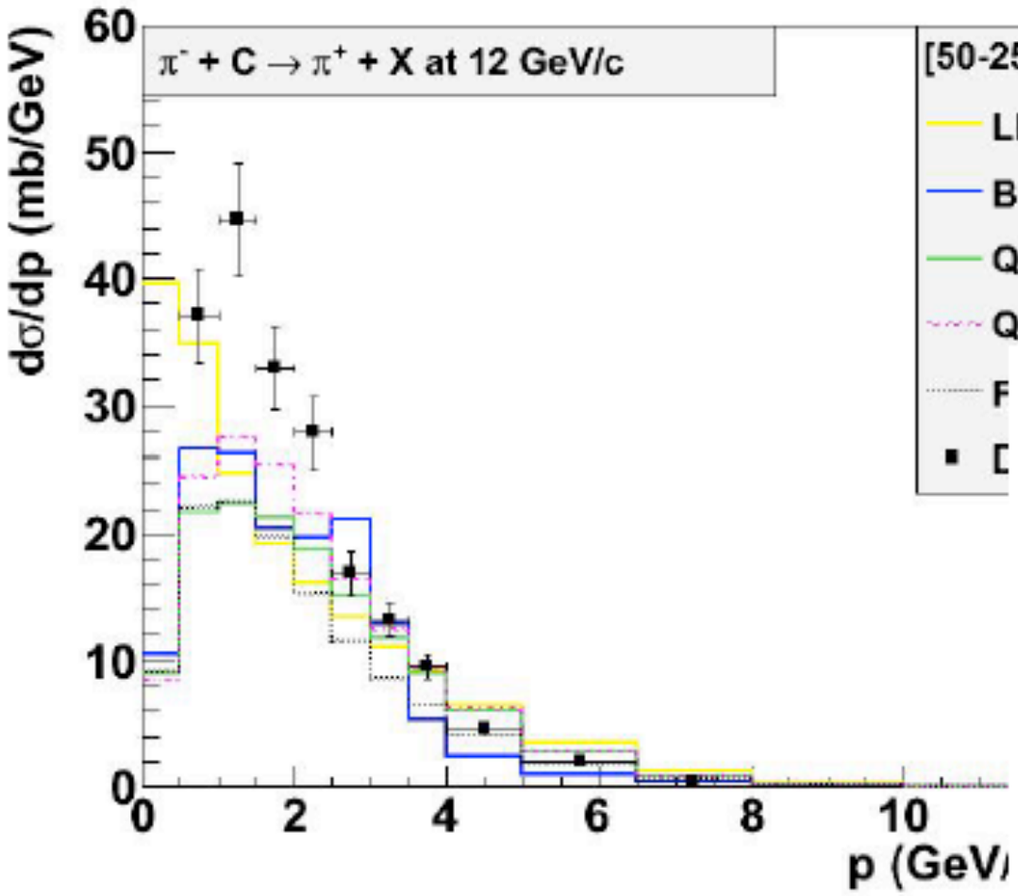
- **Thin-target data are used to:**
  - Tune models on single interactions (multiplicities, cross-sections, distributions)
  - Validate agains published and validated data
- Only few examples are possible here
  - Please refer to the backup slides for a compreensive list of benchmarks

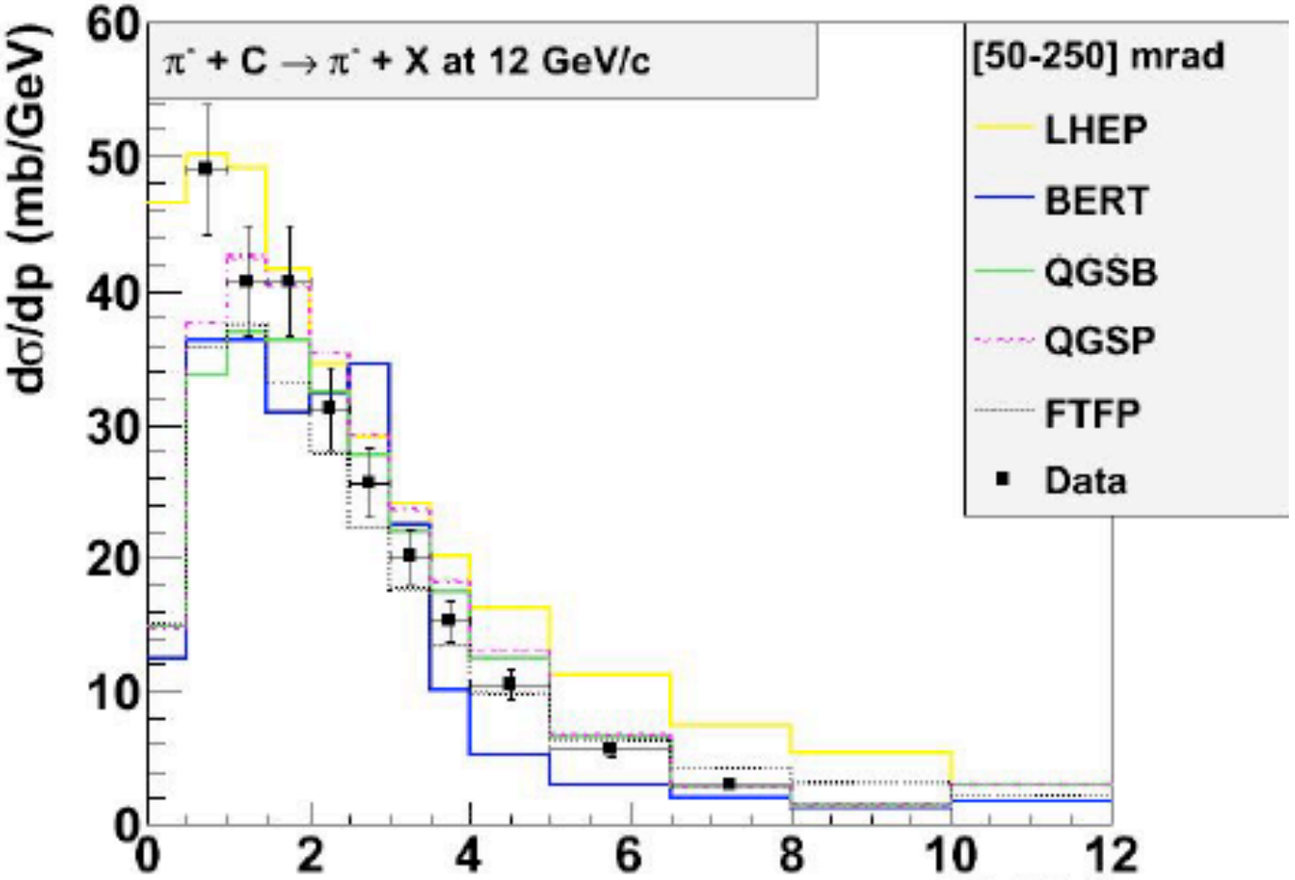
Example: p+C→$\pi^{\pm}$X p=158 GeV/c



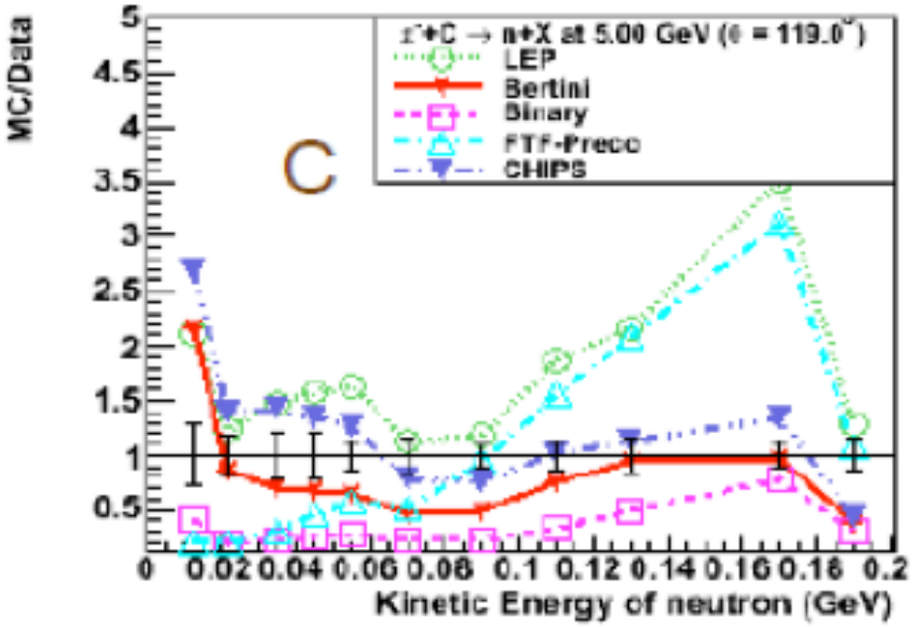


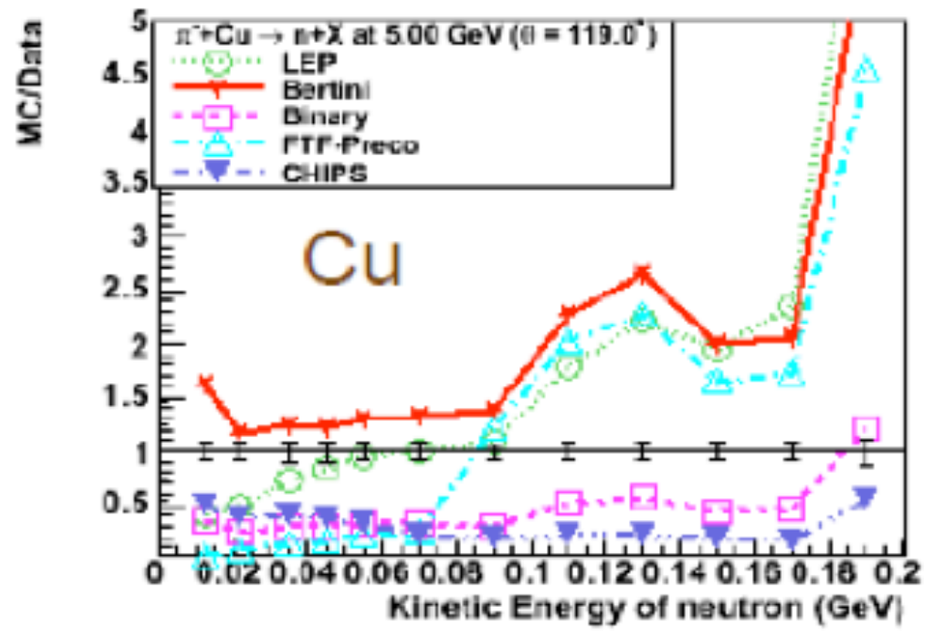
Example: $\pi^- + C \rightarrow \pi^{-+} X$, E_{kin}=12 GeV

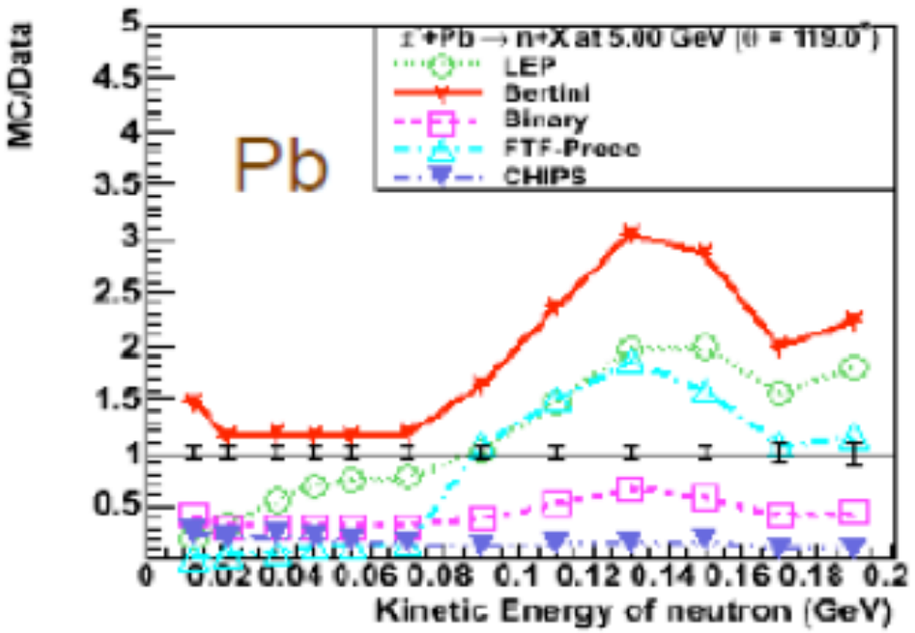


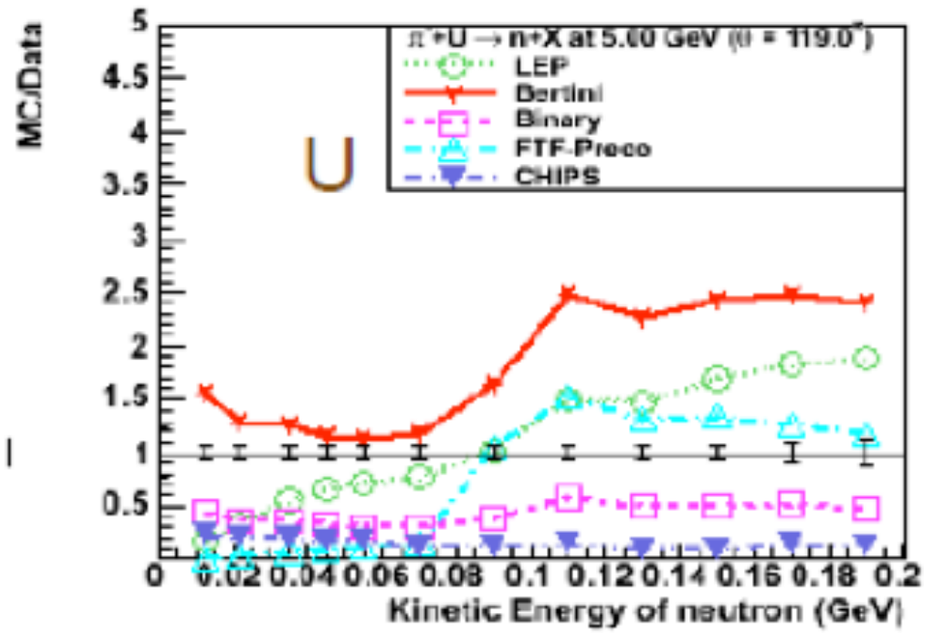


Example: $\pi^- + A \rightarrow n\ X$, E_{kin}=5 GeV, $\theta = 119^0$

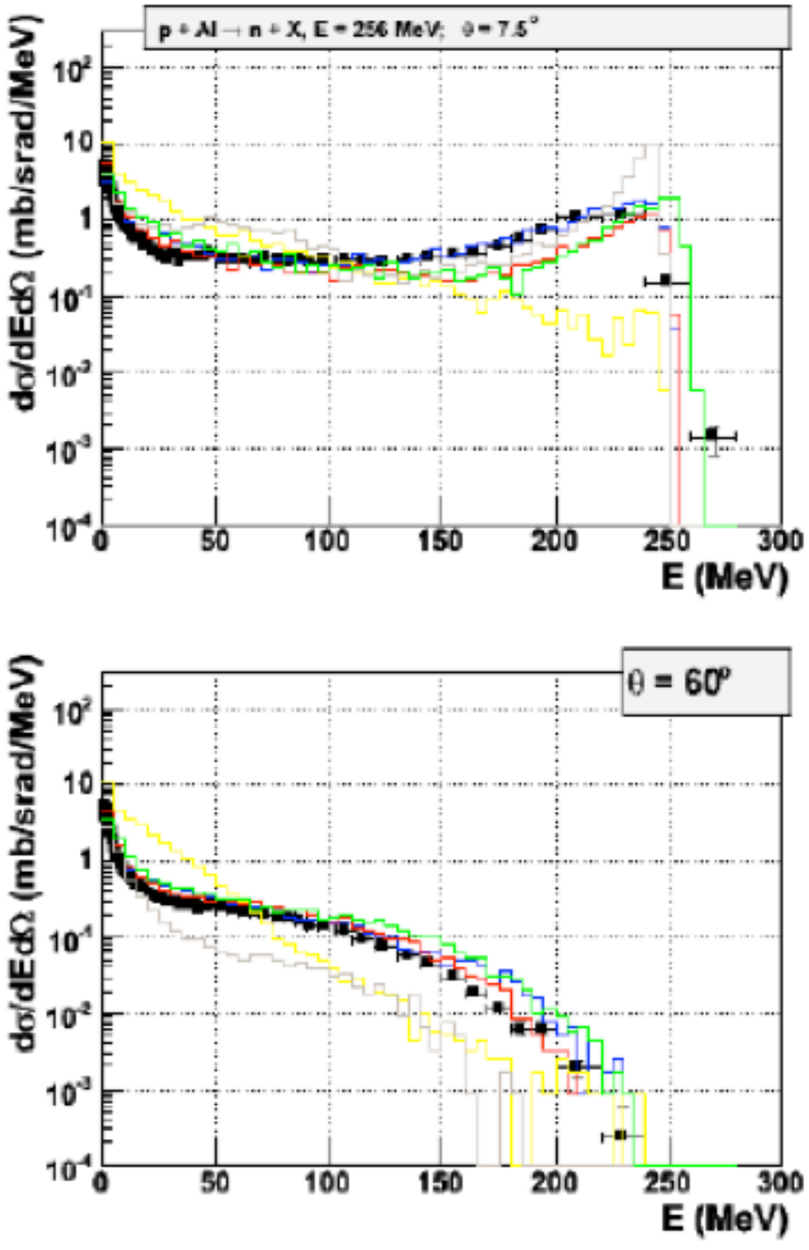








Al(p, n) 256 MeV


p + Al → n + X, E = 256 MeV; ϑ = 7.5°
θ = 30°
θ = 60°
θ = 150°
Data
BIC
BERT
LHEP
CHIPS
LIEGE
dσ/dEdΩ (mb/srad/MeV)
E (MeV)

Summarizing Results

Main Achievements

- **Bertini cascade**: improve response and lateral shower shape agreement
- **Improvement of quasi-elastic**: improve longitudinal shower shapes
- **Use of theory based models on all energy range**: remove model unphysical "transitions"
- **Improved cross-sections for anti-protons and kaons**: improve description in thin layers

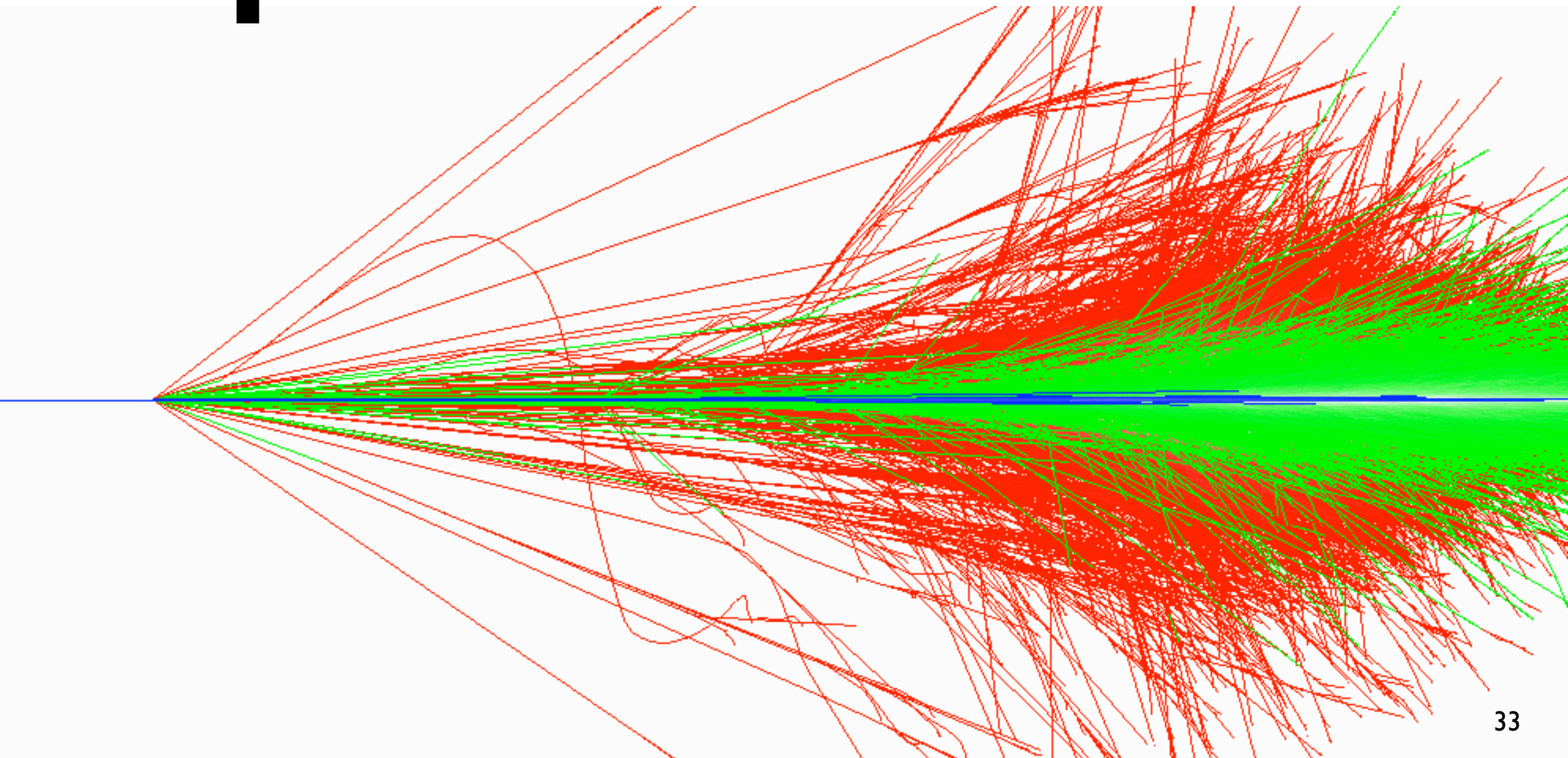
Issues that are being addressed

- Multiple Scattering in thin layers [#SIM-26]
- Kaon cross-sections [#SIM-31]
- EM lateral R90 [#SIM-50]
- Improved Bremsstrahlung model [#SIM-136]
- Diffraction [#SIM-1]
- Quasi-elastic [#SIM-111]
- Hadronic shower resolution [#SIM-79]
- Anti-protons simulation [#SIM-131]
- Ion-ion interactions [#SIM-72]
- Study cut-range dependency in TileCal calorimeter [#SIM-120]
- **π**0 production validation [#SIM-87]
- Hadronic lateral shower shapes [#SIM-77]

Some notes from yesterday

- **EM physics**, already precise simulation. We want to do better since issues <1% are still existing...
- **Need to better document/clarify** physics list content. What are the EM options? What is the content? Recipes for calibration.
- LHCb: **dE/dX in thin layers**. Is it ok?
- **Muons simulation at 1 TeV**. What is the status there? Seems ok to me, more quantitative? Use Z mass peak as a "candle" for muons simulation?
- **Cavern background** flux inside factor 2 (obtained now with FLUGG)
- **Optical photons.** Issue here is CPU, need to rely on models/ parametrizations. Not using G4 native for the moment
- Are **clustering algos** sensitive to shower shape? If yes how much?
- **All experiments need improved K, anti-p, Hyperons**
  - Technical requirement form CMS: separate CHIPS cross-sections (use them everywhere, model is slow)
  - Need data for K cross-sections, use LHCb, ALICE data themselves?

Conclusions
Input for discussion



New Requirements

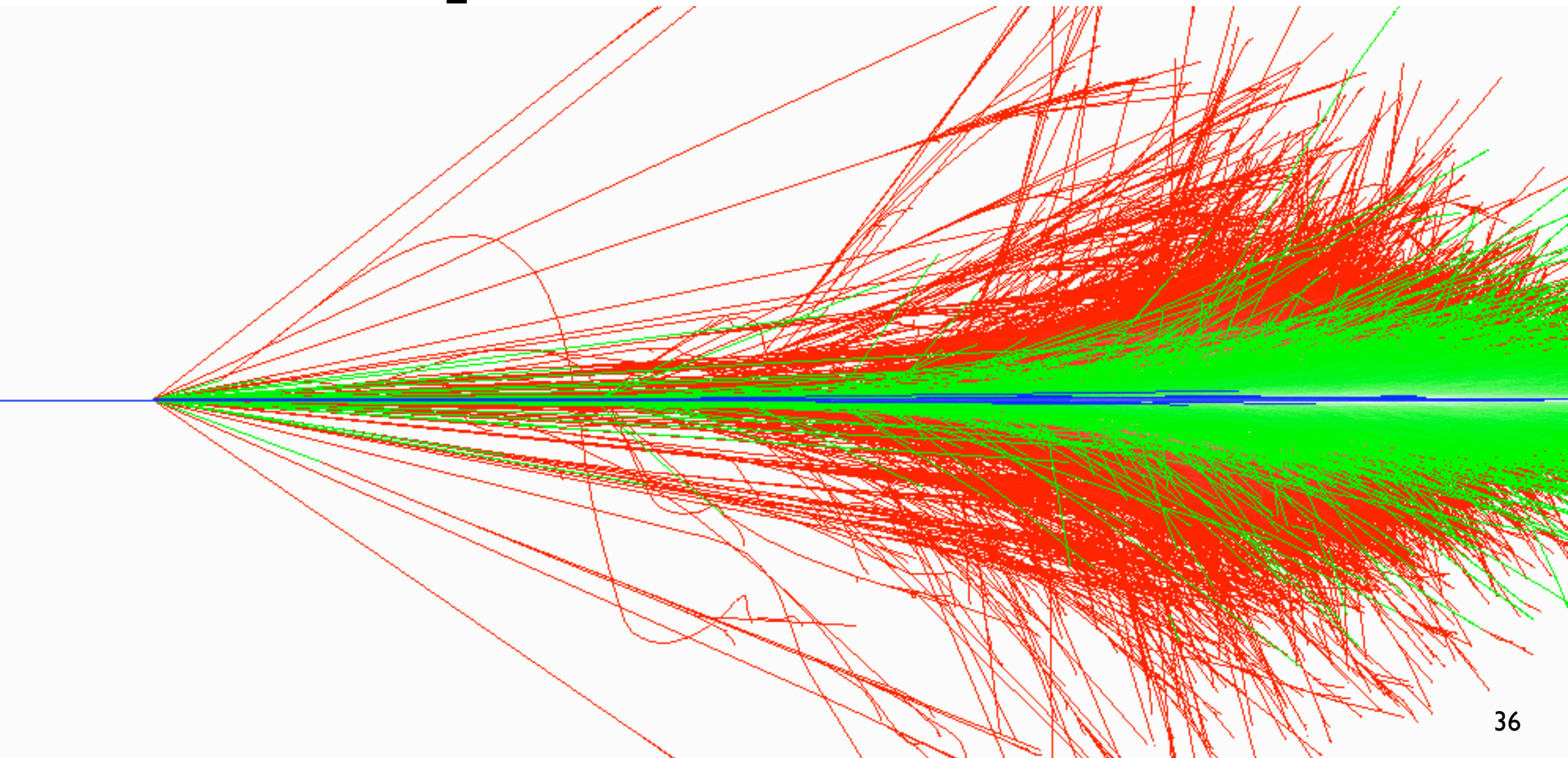
- Today we have the possibility to **extend and re-vitalize physics validation for LHC**

- How?
  - Refine / extend requirements for data-taking era
  - **Today start to collect these requirements**
    - Propose to create a note to be circulated by the end of the year

Proposed Actions

- **Include set of measurements from collision data to complete test-beams:**
  - low-E (from E/p measurements) single hadrons
  - isolated anti-protons, kaons
- **Need to keep alive test-beam data comparisons**
  - At least for major releases of simulation software
  - Extend simplified calorimeters test suite with additional data (in particular shower dimensions)

Backup slides



Requirements (CERN-LCGAPP-2004-02)

- EM showers (from $H \rightarrow \gamma\gamma$). Energy and position resolution; shower lateral and longitudinal profile; linearity ; from 100 MeV to TeV. **0.1-1%**
- Hadronic Showers. e/h ratio (for compositness searches). **few %**
- Hadronic Showers. Longitudinal shower (for punch-through). **No quantitative statement but "precise"**
- Pion resolution. **Should be covered by previous points**
- Muon Catastrophic energy losses (background muon chambers). **No quantitative statements.**
- Muon MSC (for CMS): **better than 10%**
- Cavern background: **in a factor 2 between FLUKA/G4**

More Test Beam data

Project Website section: https://sftweb.cern.ch/validation/plots

Repository for results

Included first round of results from ATLAS test-beam

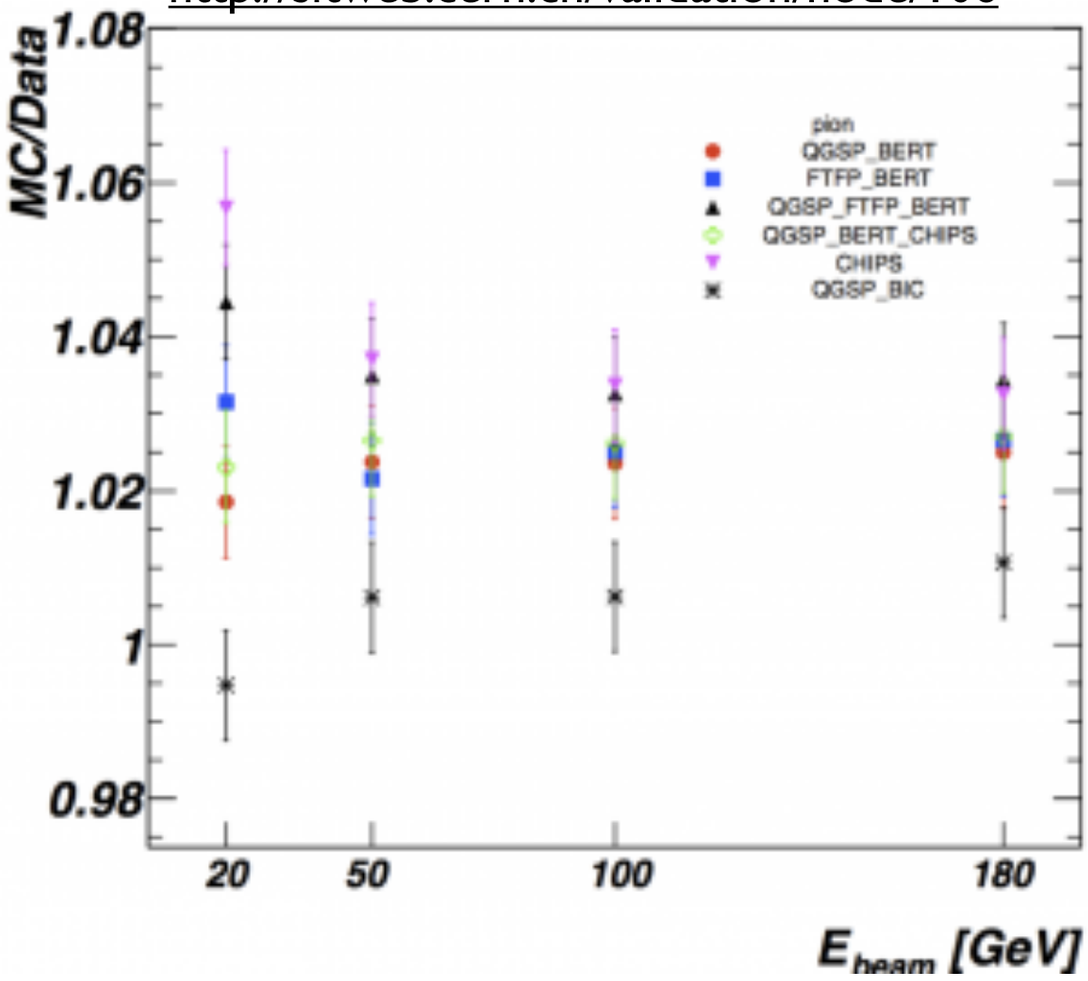
Need to add other experiments

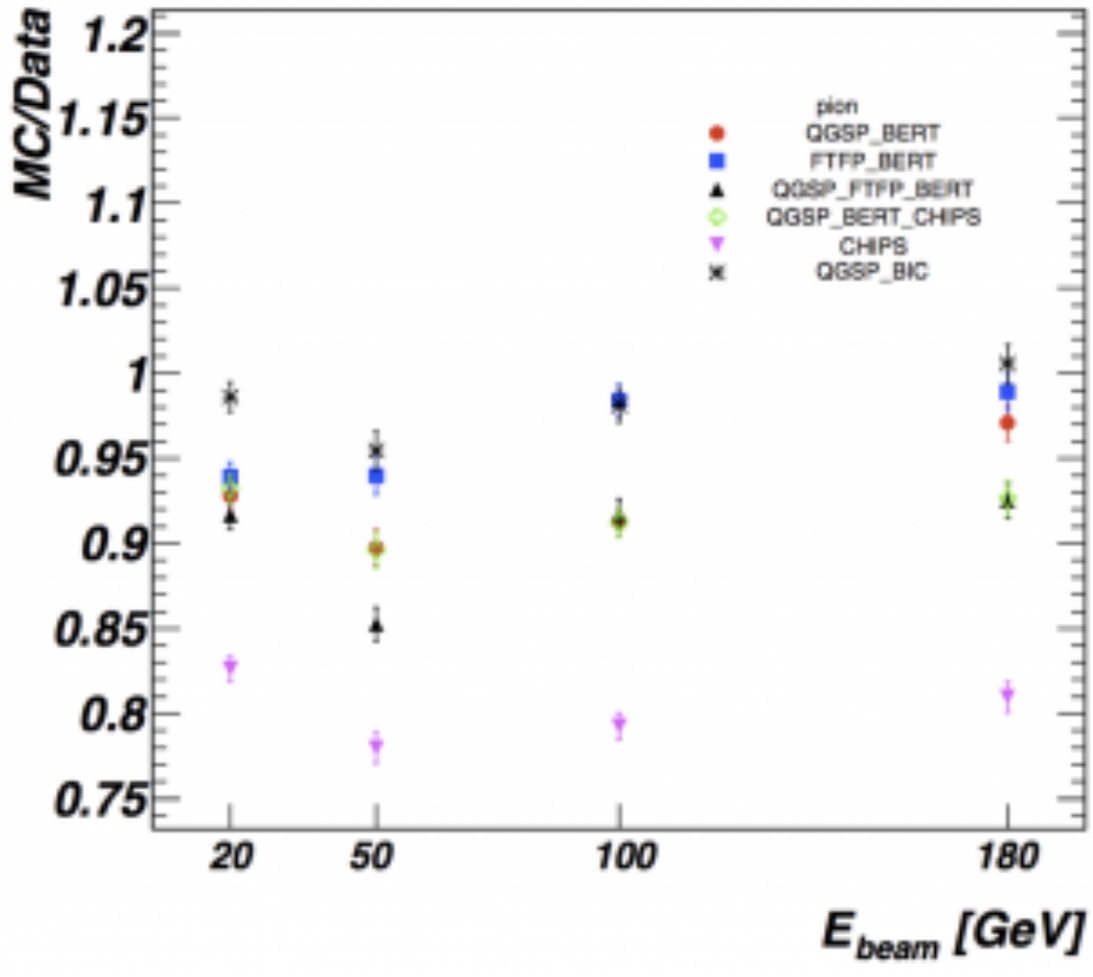
To be completed with collision data

Response

Pions in TileCal

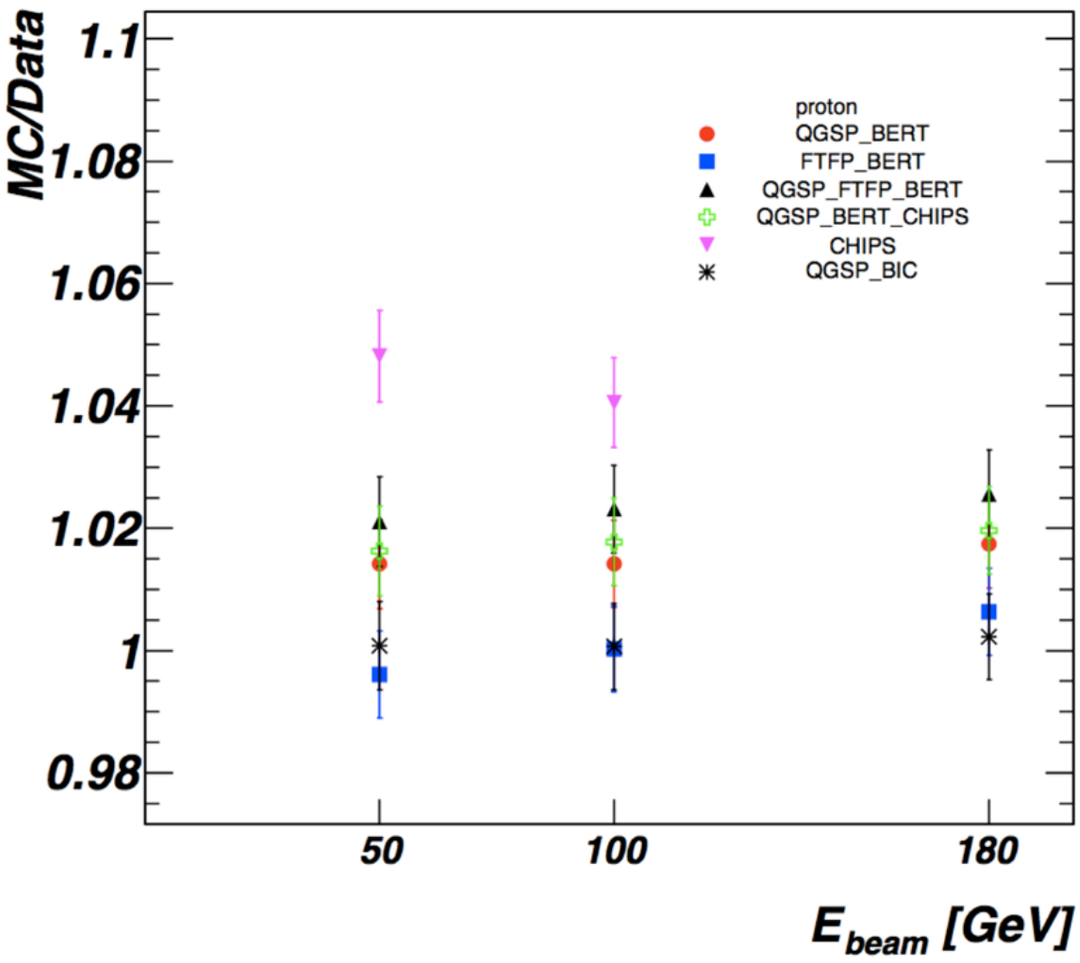
http://sftweb.cern.ch/validation/node/106

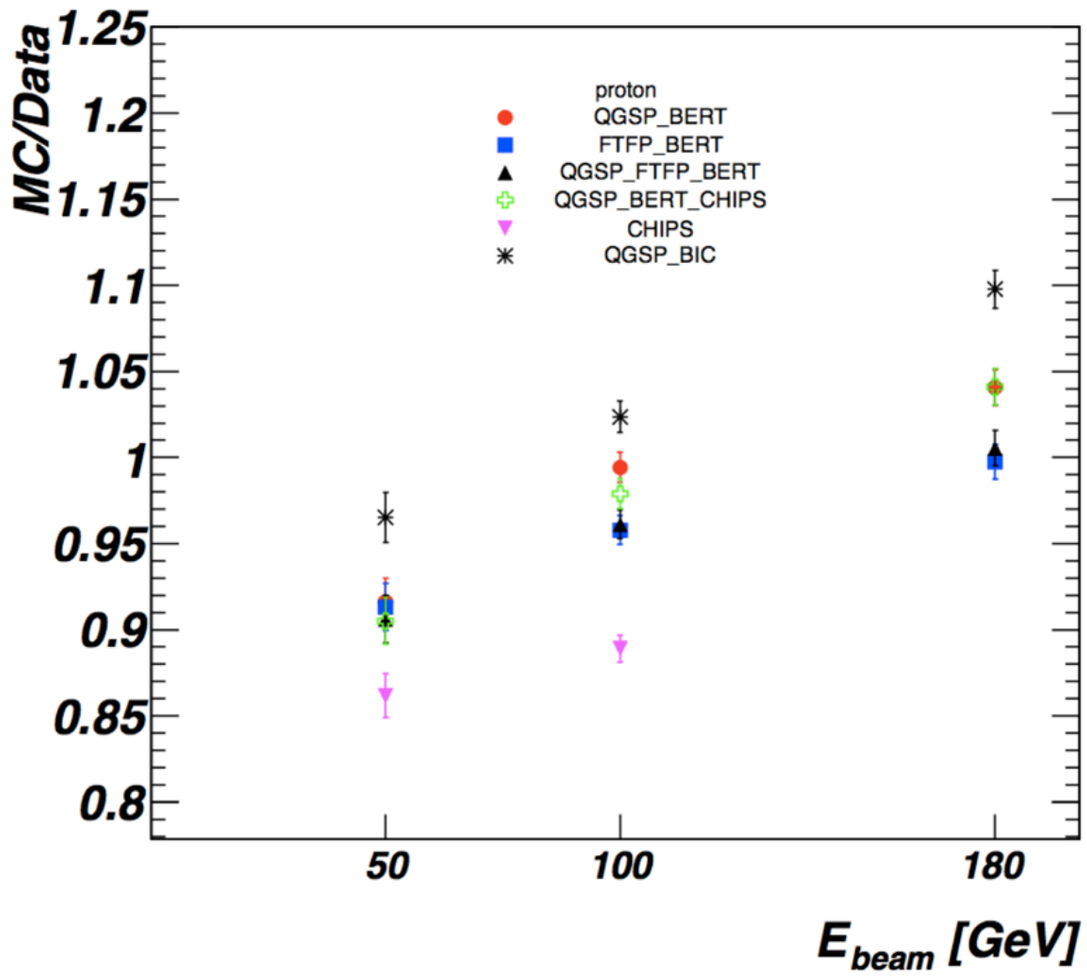




Protons in TileCal

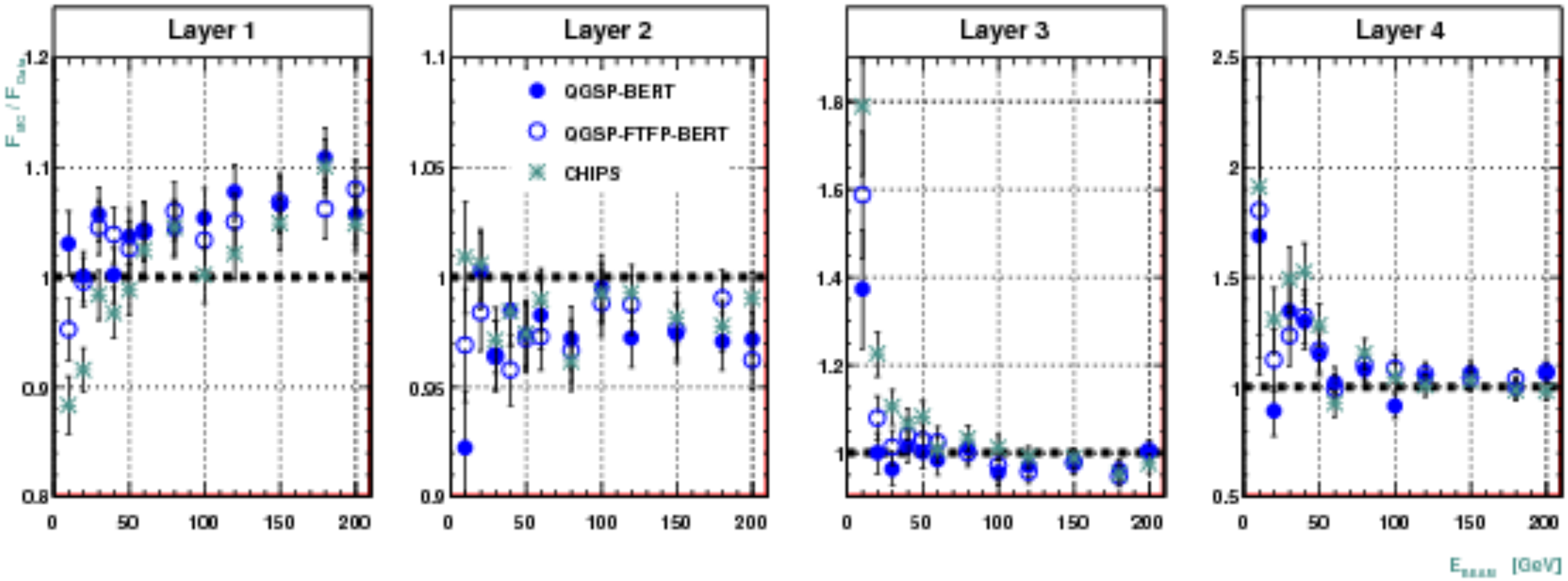
http://sftweb.cern.ch/validation/node/108





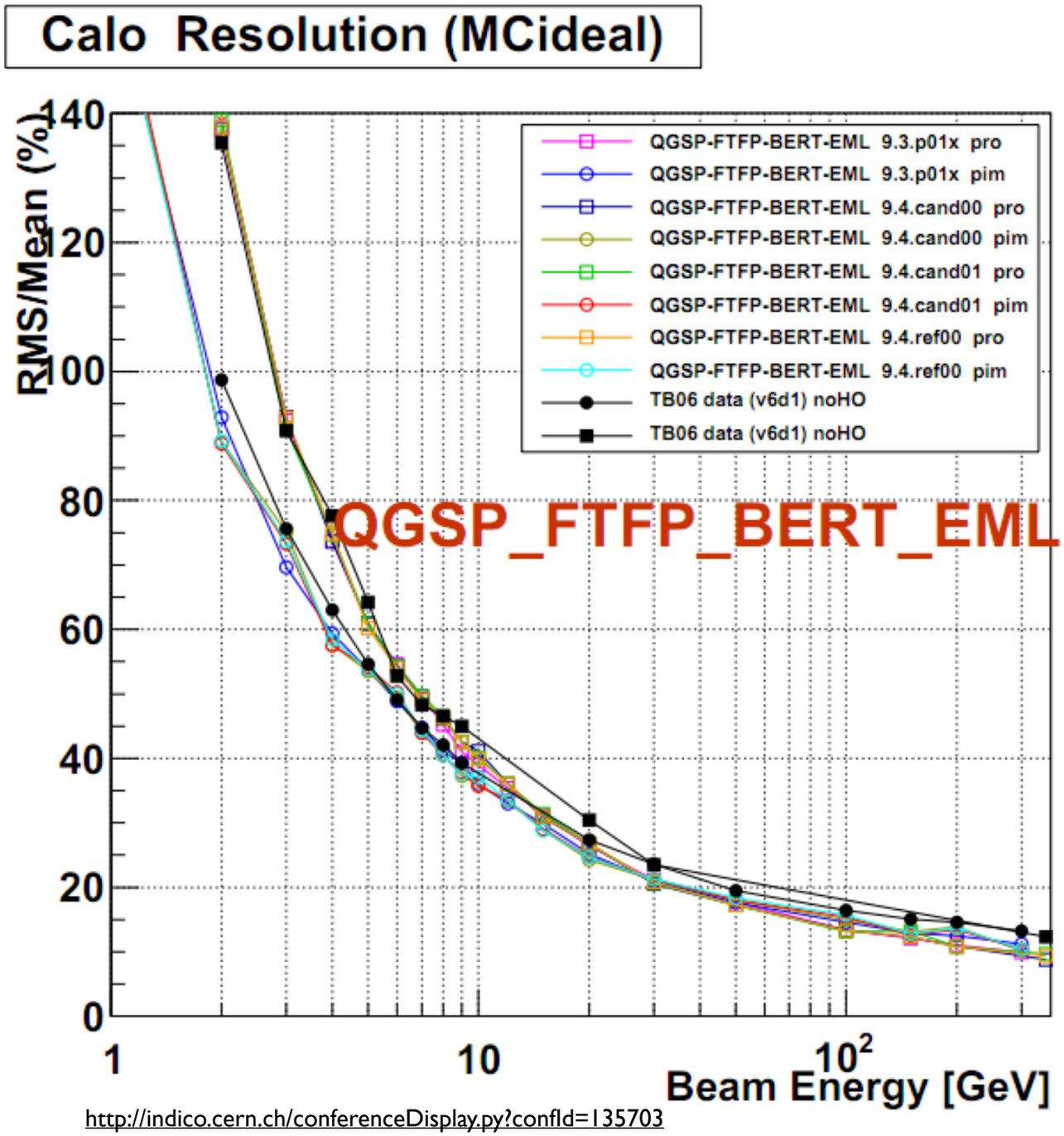
Protons in ATLAS HEC

http://sftweb.cern.ch/validation/node/100



Resolution

Resolution: CMS combined

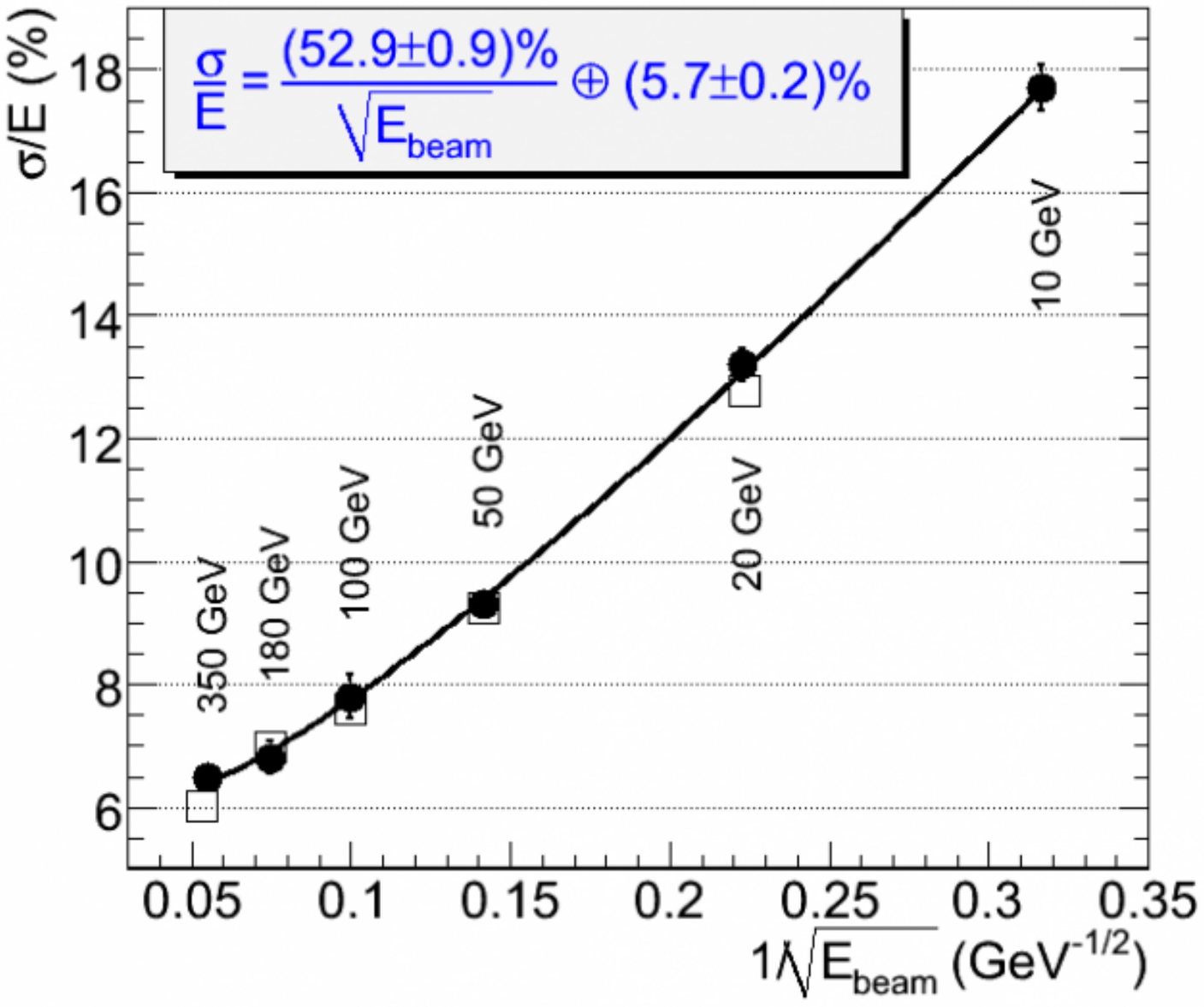


http://indico.cern.ch/conferenceDisplay.py?confId=135703

- **Detailed comparison** with pion and proton beams
- Monitor evolution of developments
- MC is too optimistic

Pions ATLAS TileCal

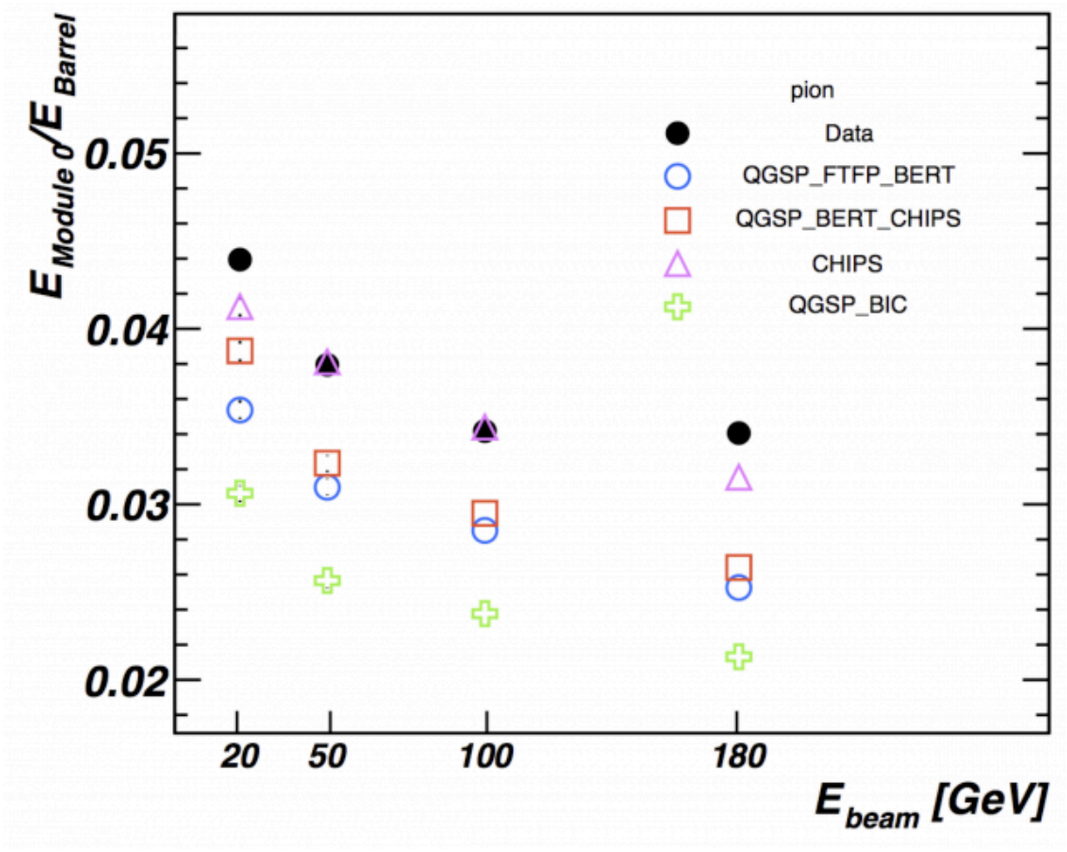
http://sftweb.cern.ch/validation/node/95

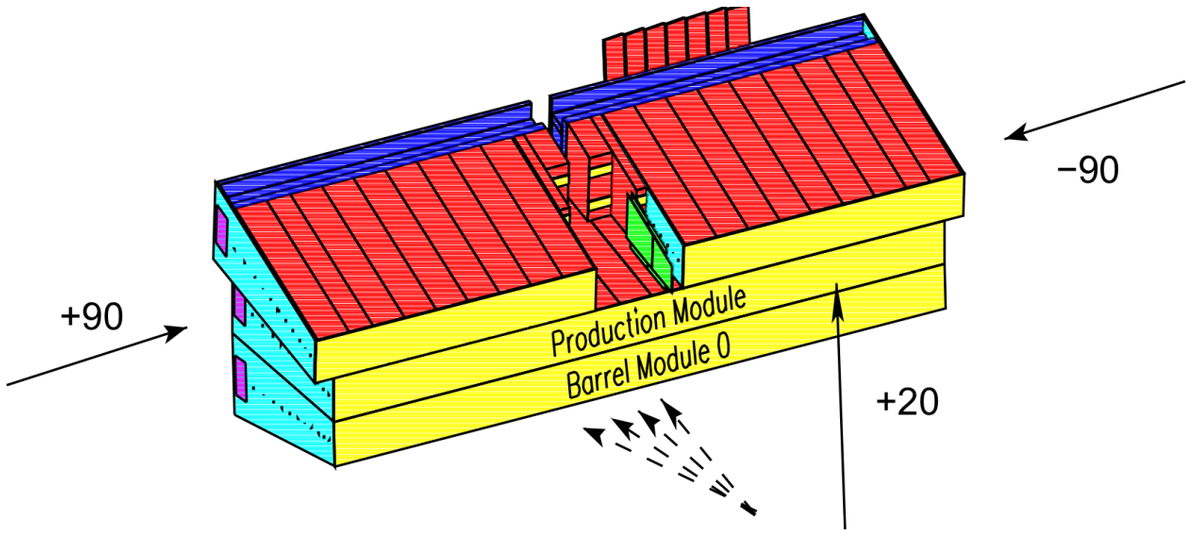


Shower Shapes

Lateral: ATLAS Tile

http://sftweb.cern.ch/validation/node/112

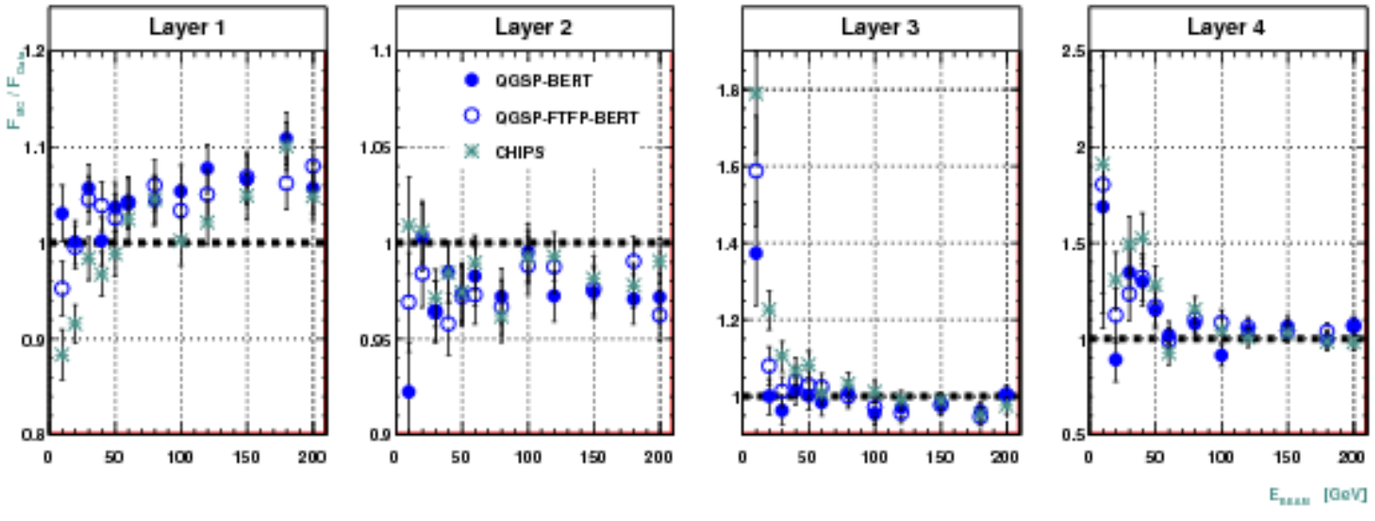




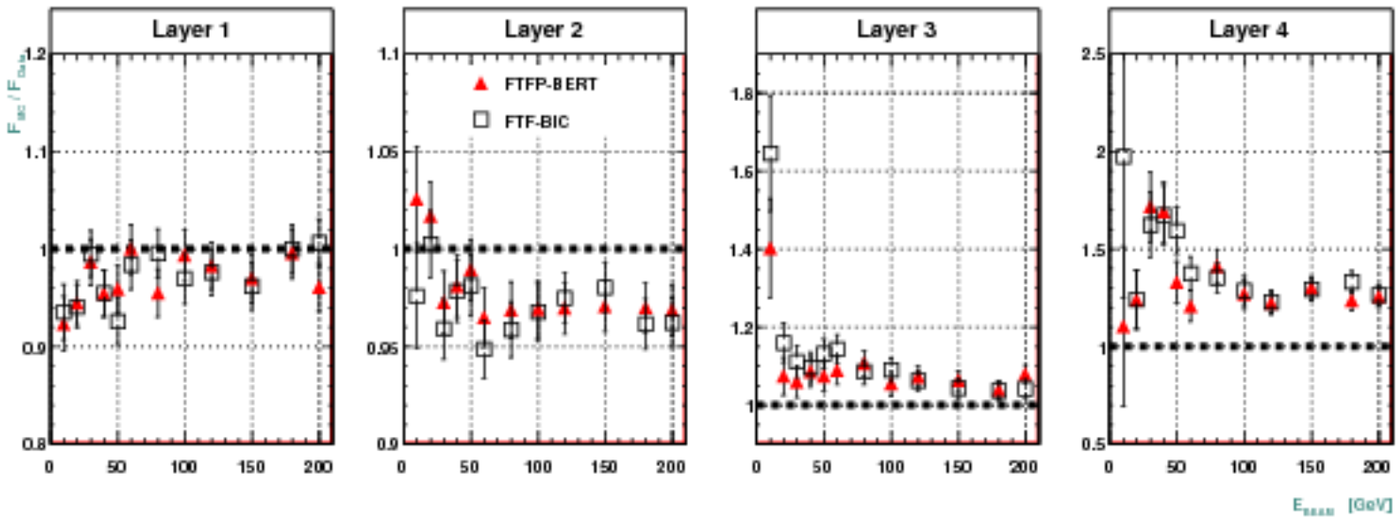
- Showers are too compact
- **Coarse granularity allows only for limited validation**
- Collaboration with high granular calorimeters is needed

Longitudinal ATLAS HEC

http://sftweb.cern.ch/validation/node/100

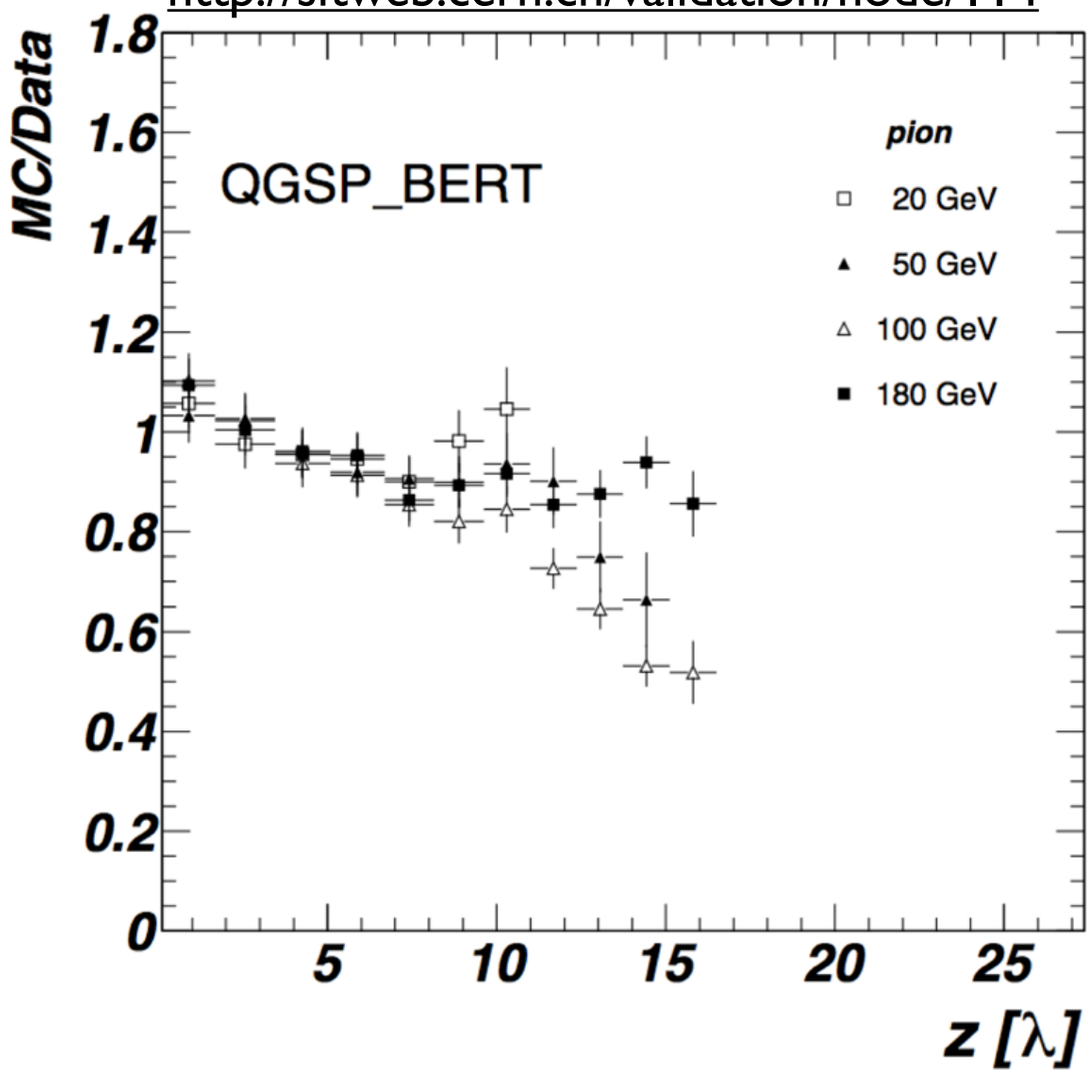


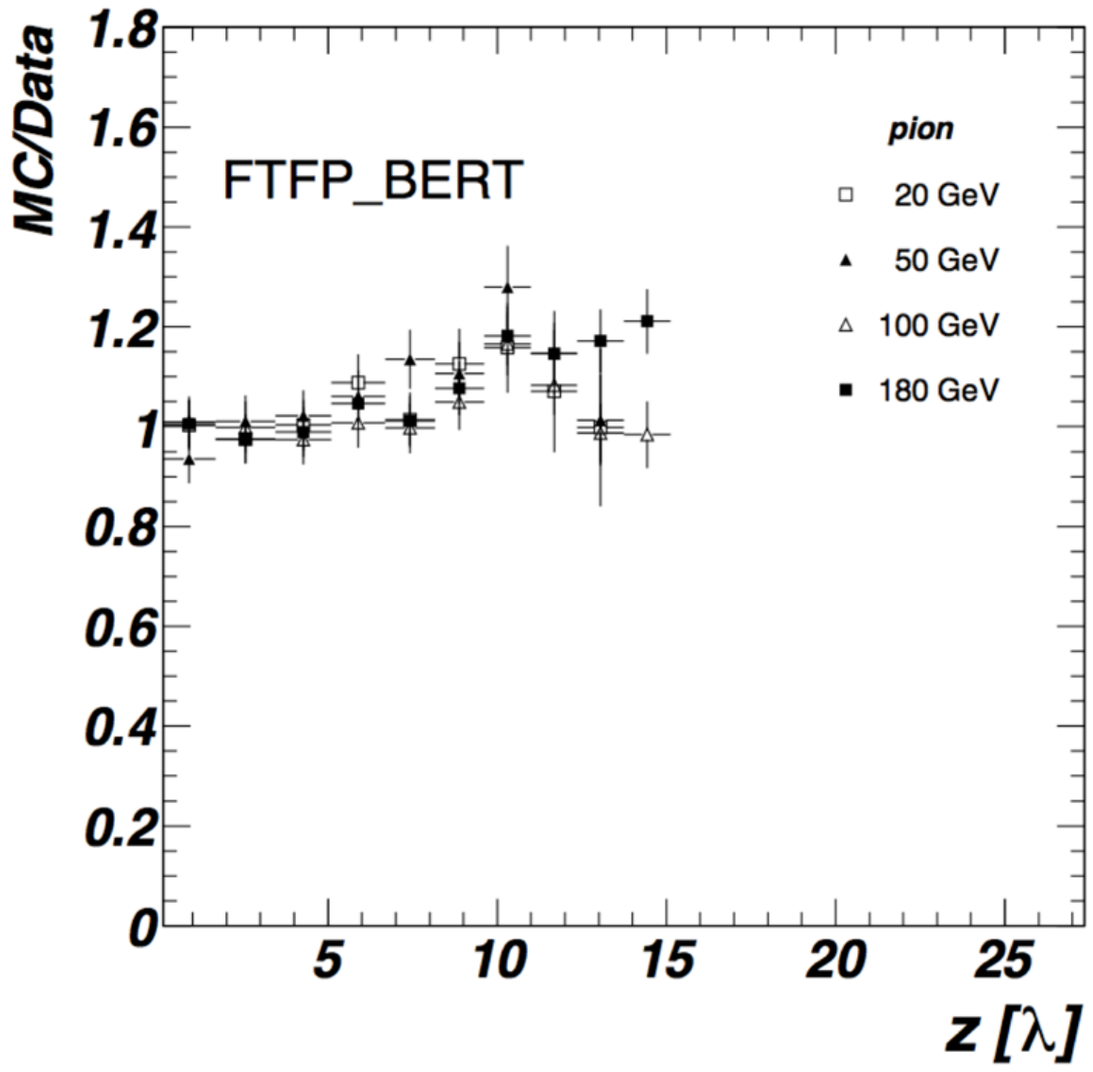
http://sftweb.cern.ch/validation/node/103



Longitudinal TileCal

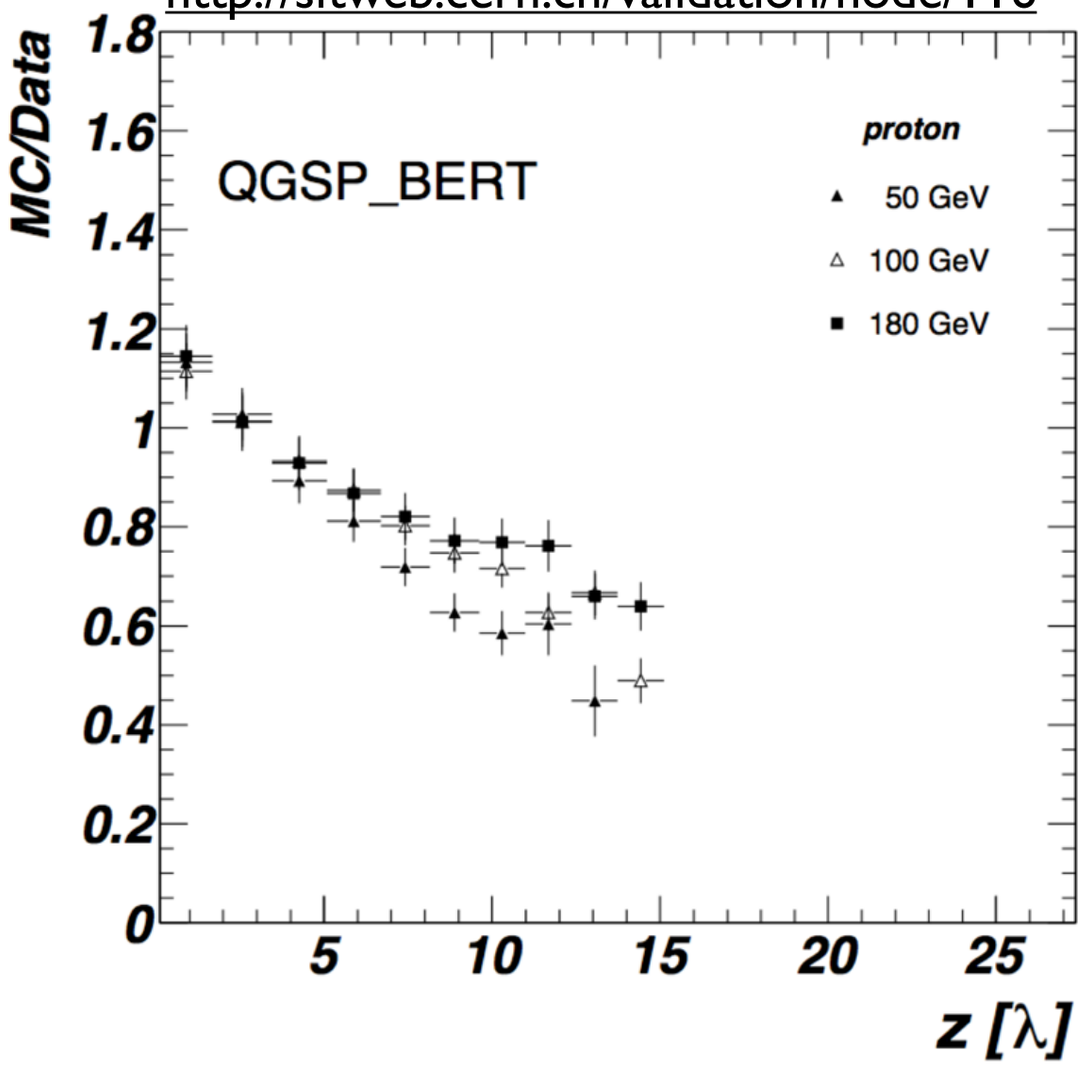
http://sftweb.cern.ch/validation/node/114

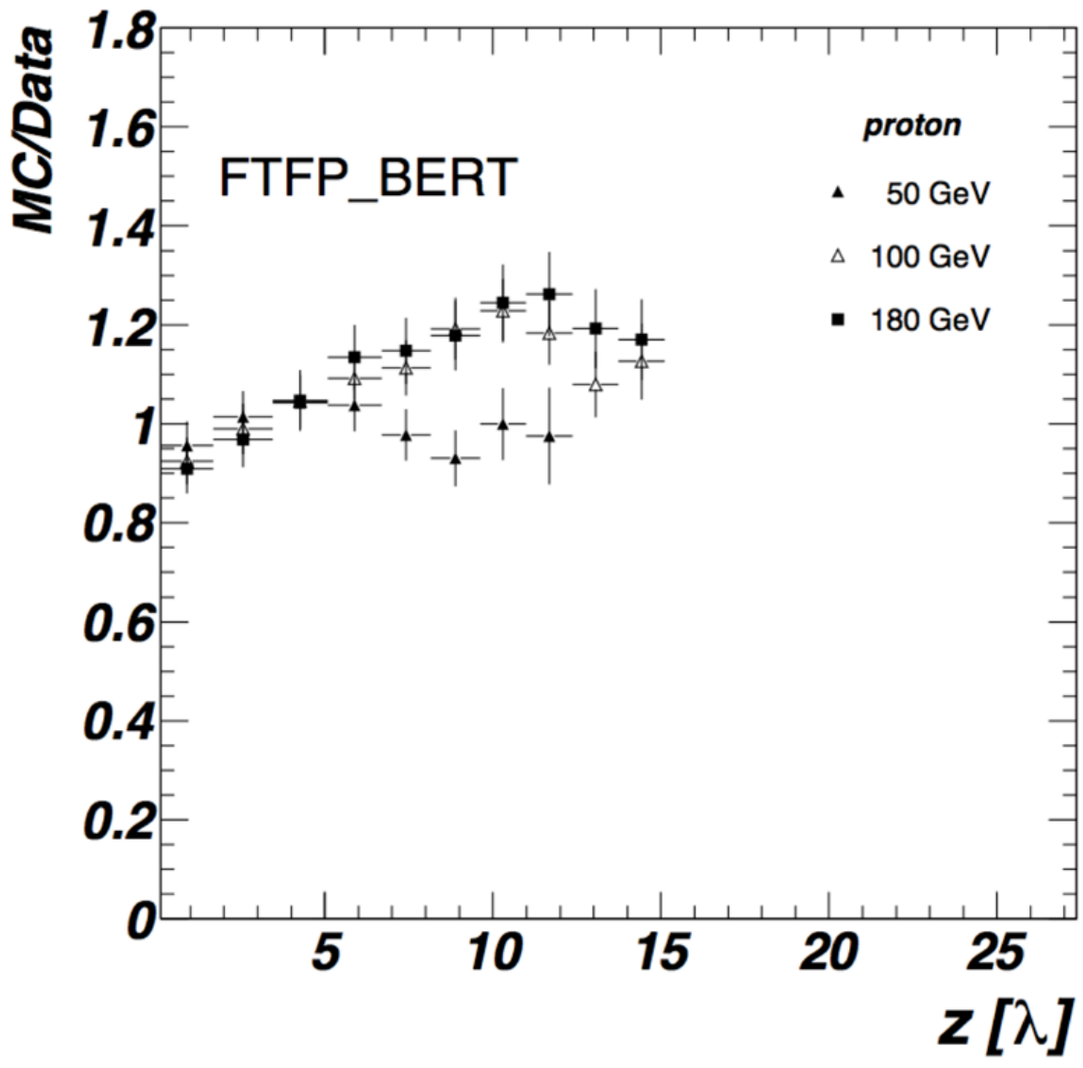




Longitudinal TileCal

http://sftweb.cern.ch/validation/node/116





Thin-Target Validation

- TEST30
  - **Double differential cross sections and integral plots**
  - About 85 settings (primary/energy/target)
  - EXFOR database
  - Targets Li, Be, C, Al, Si, Fe, Ni, Cu, In, Ta, W, Pb, Zr, Bi
  - **Energy 10-1500 MeV**
  - Reactions (p,n), (n,n), (n,p), and (p,p)
- TEST35 : HARP data
  - **Double differential cross sections**
  - About 210 settings
  - Targets Be, C, Al, Cu, Sn, Ta, Pb, N, O
  - **Energy 3-15 GeV**
  - Reactions (p,pi+/-), (pi+/-,pi+/-), (p,p), and (pi+/-,p)
- TEST30
  - IAEA : IAEA/ICTP **spallation benchmark**
  - Targets C, O, Al, Ni, Co, Fe, Cu, Y, Zr, Mo, Sn, Xe, Au, Bi, In, Pb, Ta, Th, U
  - **Energy 60-3000 MeV**
  - Reactions (p,p), (p,pi+/-), (p,d), (p,t), (p,3He), (p,4He), (p,n), (n,n), Ion(H,Iso)

- ITEP data (Y.D. Bayukov et.al.,)
  - **Inclusive p and n production**
  - 4-29 different angles in 8-9 kinetic energy bins
  - p/pi+/pi-
  - nucleus collisions
  - 12 targets from Be to U with **beam momenta of 1-9 GeV/c**
- BNL E-802 data (T. Abbott et al.)
  - **Inclusive pi+/-, K+/- and proton production**
  - **p beams at 14.6 GeV/c**
  - variety of nuclear targets (Be ... Au)
- MIPP data
  - **inclusive neutron production**
  - **p beams at 58, 59, 84 and 120 GeV/c**
  - targets: H, Be, C, Bi, U
- E597 data (J.J. Whitmore et al.)
  - **Pt and y distributions of pi+ and pi- produced**
  - **100 GeV/c beams of pi+, pi-, K+, p, pbar**
  - **320 GeV/c pi- beam**
  - targets: Mg, Ag, Au

- WA-069 data
  - **pi0 production**
  - **pi+/- beams at 140 GeV/c**
  - target: H
- NA49 data
  - **Inclusive pion production**
  - **proton beam at 158 GeV/c**
  - target: C
- NA22 data (N.M. Agababyan et al.)
  - **Inclusive pion production**
  - **pi+ and K+ beam at 250 GeV/c**
  - targets: Al, Au
- E592 data
  - **Inclusive production of pions, kaons, and protons**
  - **proton beam at 400 GeV/c**
  - targets: Li, Be, C, Al, Cu, Ta

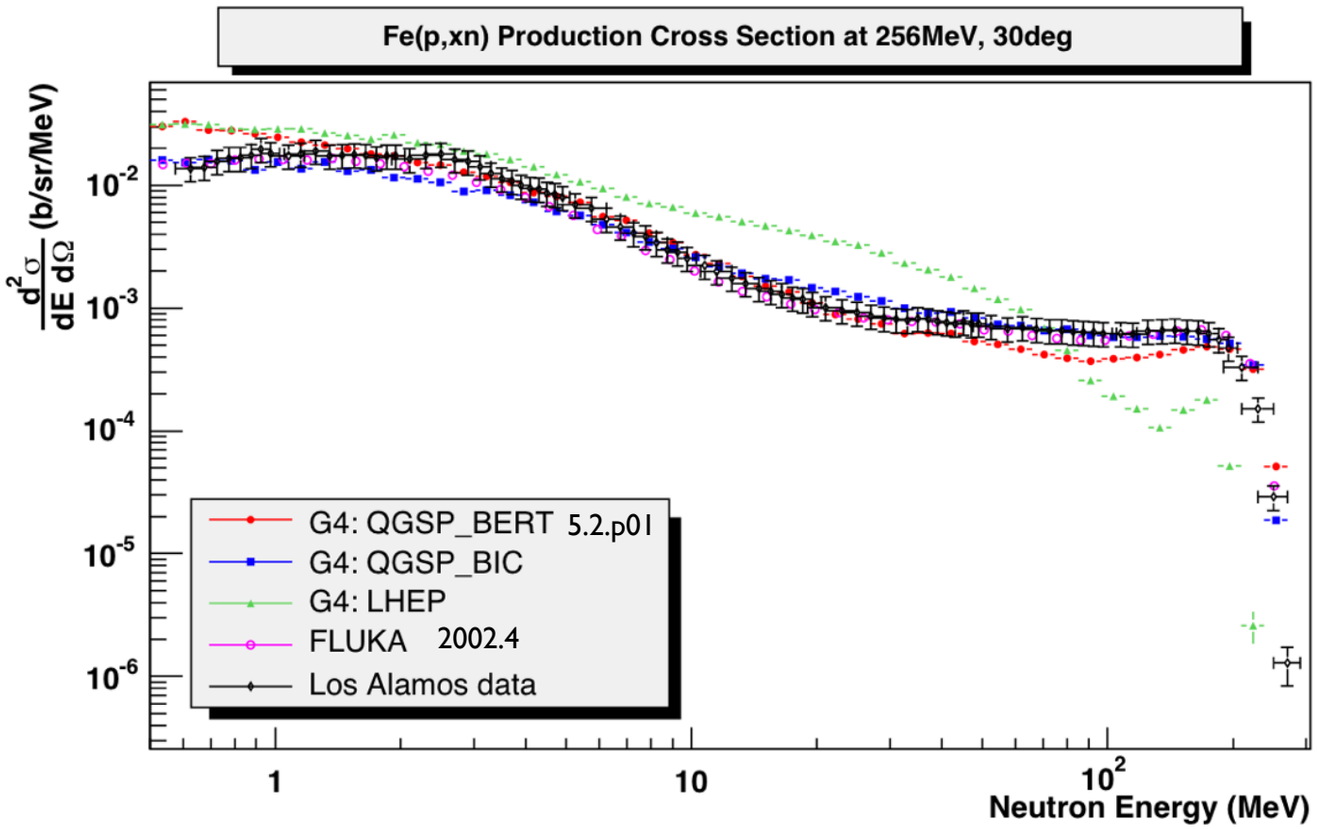
Additional material

- From the Geant4 main web page:
  - Results & Publications -> Validation and testing
- For electromagnetics :
  - Electromagnetic Physics -> Validation repository
- For hadronics :
  - Hadronic Physics -> Hadronic Validation Web Pages
- **New unified validation framework, under development**
- prototype with limited functionality available in:
- http://g4jsp.ifh.de:8080/G4HadronicValidation/

Simple Benchmarks

- **Verify simulation of well defined aspects of the simulation, important for LHC**
- Comparisons between published data and simulation (including FLUKA)
- Project started 2003
  - Now tests are performed routinely
  - Shown here mostly for historical reason
  - Some of them are part of "routine" Geant4 tests

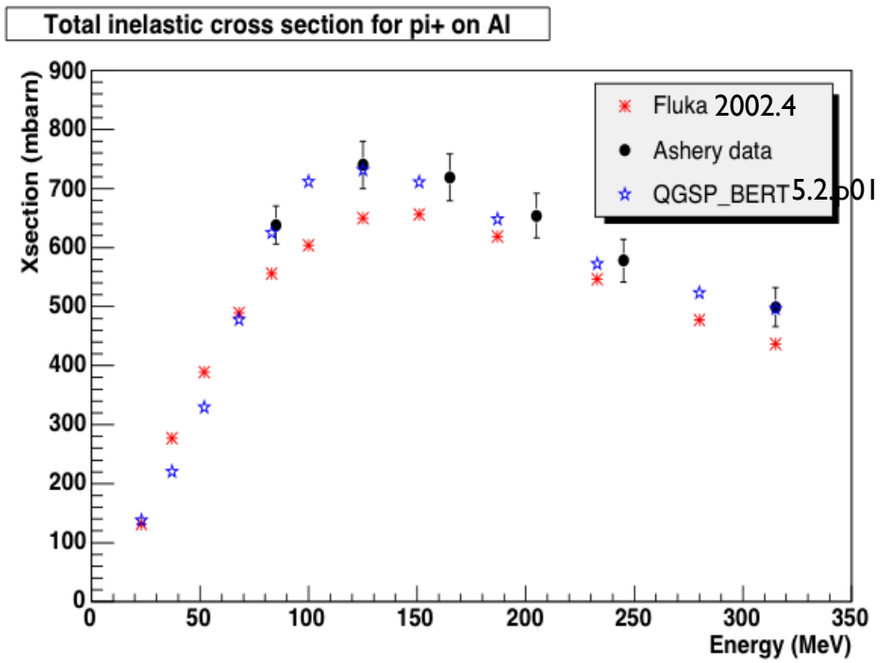
n Production

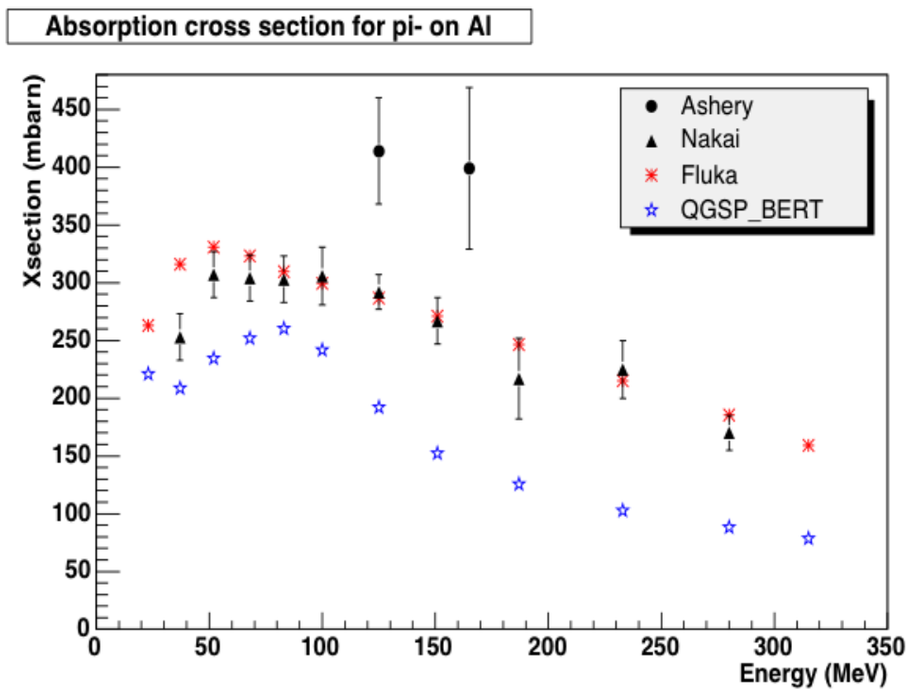


CERN-LCGAPP-2003-18

- Important benchmark for shower shapes, response in scintillators
- **Theory driven model show better agreement**
- Old result: to be updated

In flight π absorption

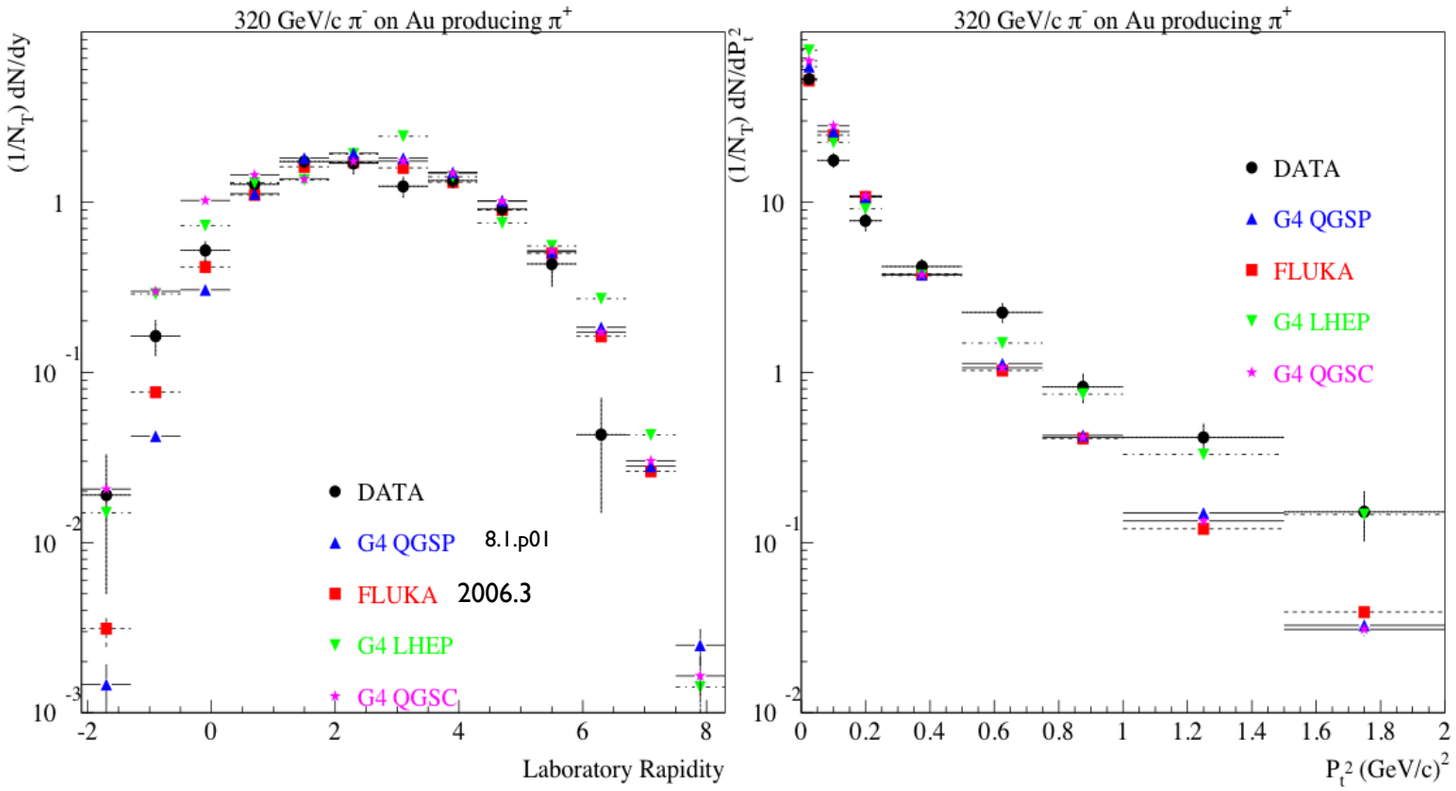




- Important benchmark for low energy component of shower
- **Total cross section well reproduced**
- Improvements for in-flight absorption needed

CERN-LCGAPP-2004-11

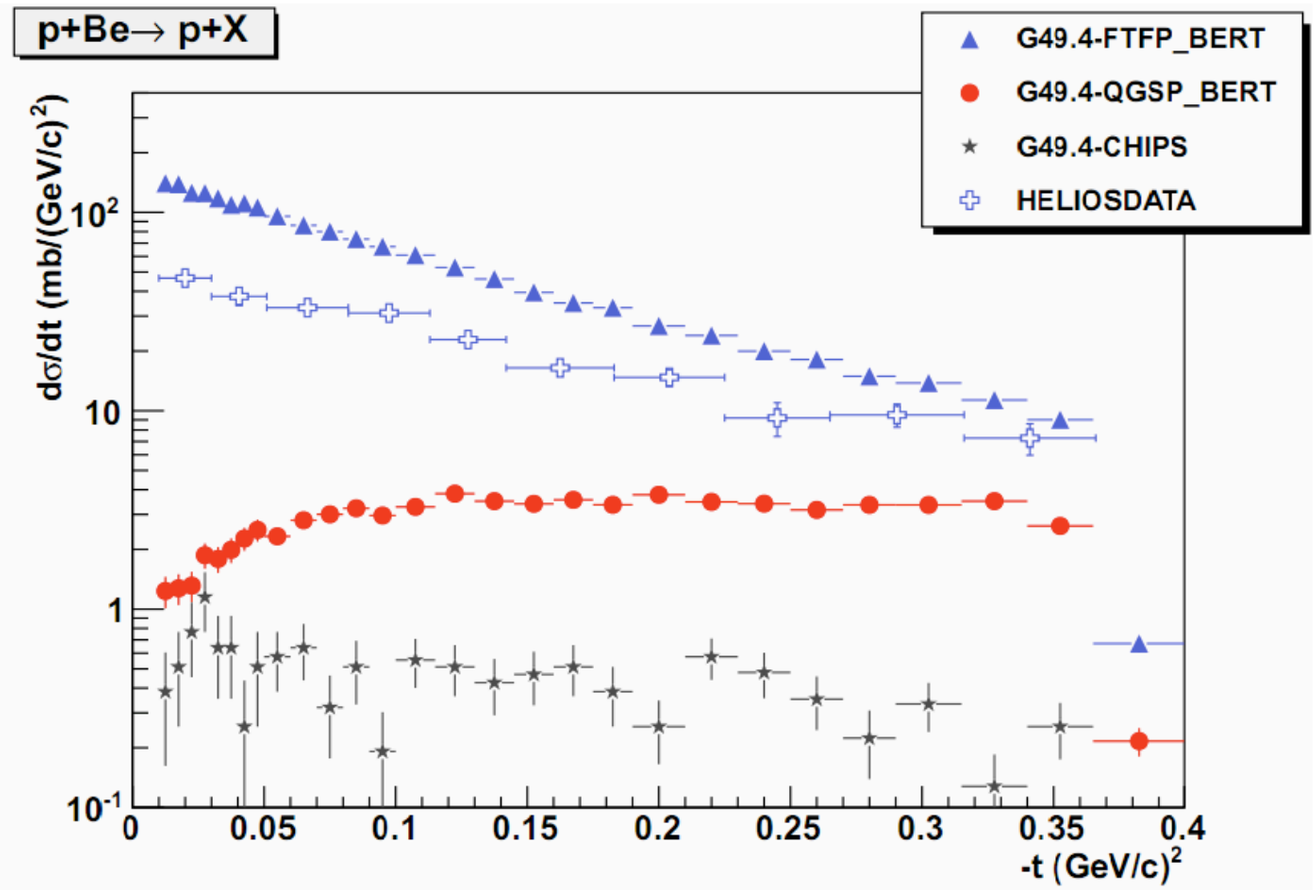
Pion production at High Energy



CERN-LCGAPP-2007-01

- Important benchmark for response in calorimeters
- **General good agreement**
- Old result: to be updated

Target diffraction



- Process plays a role in description of longitudinal development
- **Only FTF model can reproduce experimental shape**

- Cross sections are not well reproduced
  - **However process is only 4-10% of total inelastic cross-section**

CERN-LCGAPP-2011-02

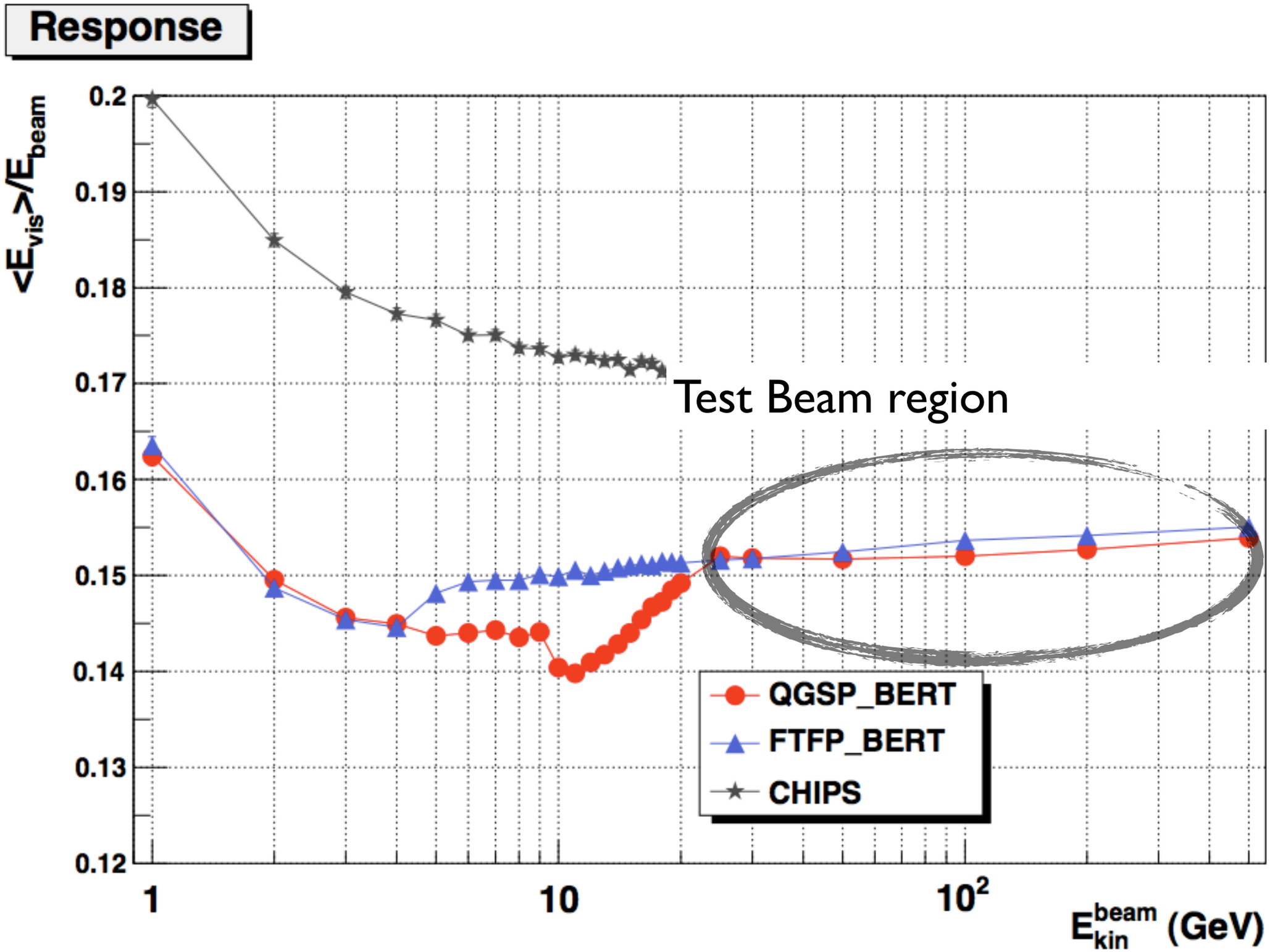
Test-beam: Comments

Why we still need TB

- Test-beam data provide a very clean environment to compare with simulations
- We want to validate simulations for hadronic physics at the level of 1%
- Experimental error must be much smaller then this
  - Already extremely challenging with test-beam data (see plots shown here)

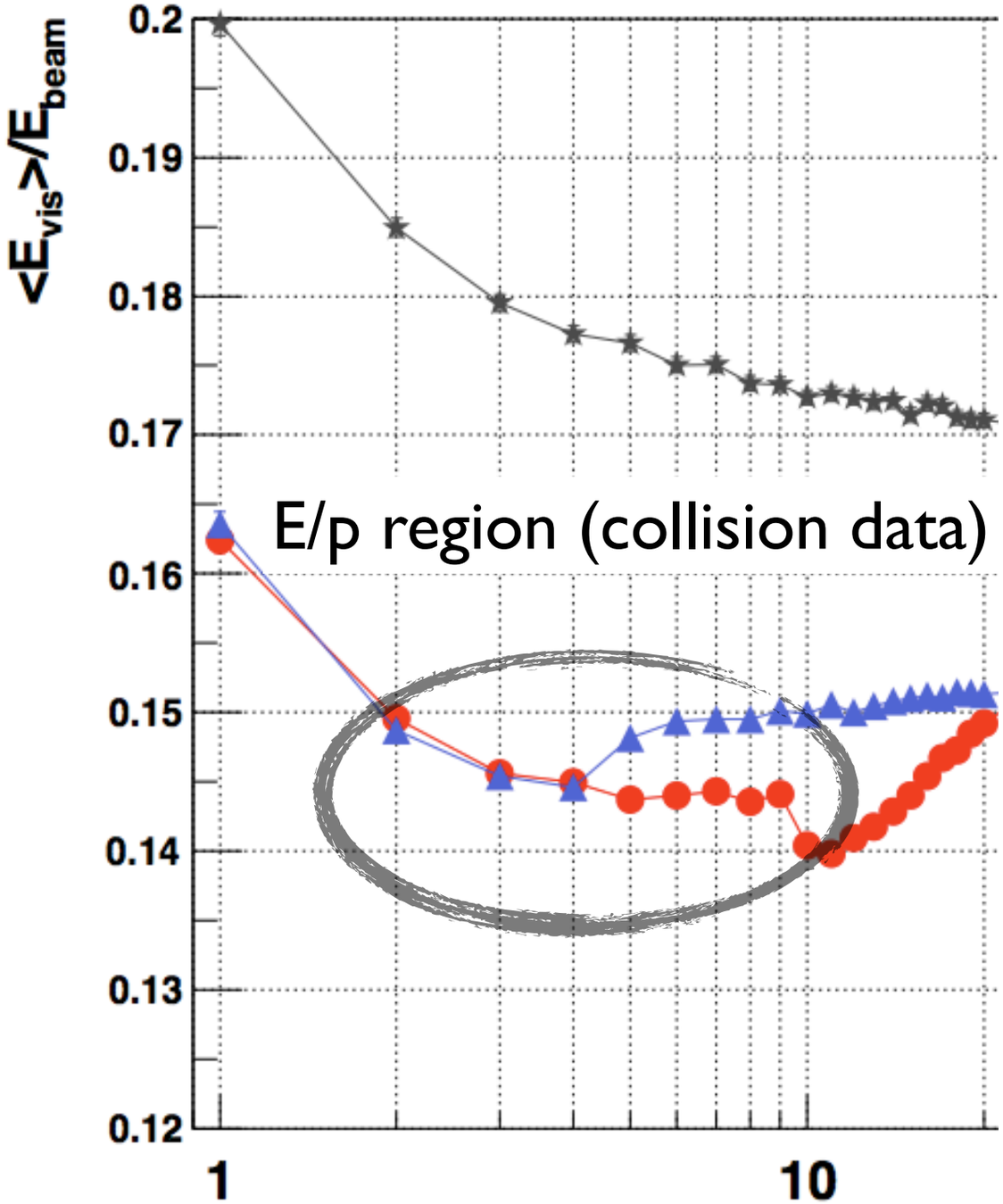
- Can collision data help?
  - Measurements are much more difficult
  - Different analysis can cover some regions of energy spectra

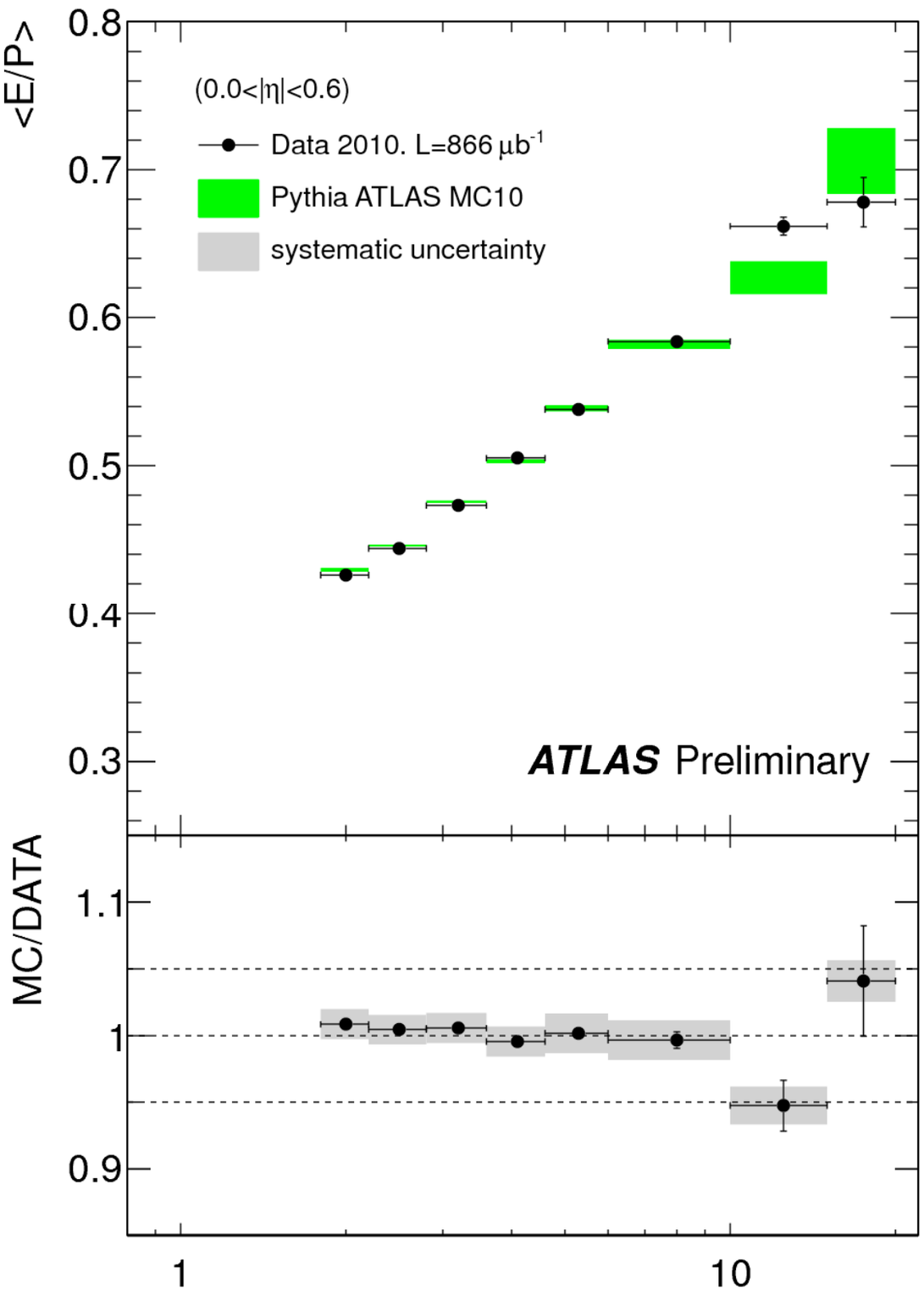
Data to use?


Response
$<E_{vis}>/E_{beam}$
0.2
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
1
10
10^2
E_{kin}^{beam} (GeV)
Test Beam region
QGSP_BERT
FTFP_BERT
CHIPS

Data to use?

Response





Website

Physics Validation Project

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News and announcements

2011-09-22
LPCC Detector Simulation Workshop at CERN (6-7 October 2011)

2011-05-16
New report available: Geant4 simulation of target-diffraction process

2011-05-04
First plots added

2011-04-14
Next LCG Physics Validation Meeting: April 27, 2011 at 15:00 (CERN Time)

2011-04-12
Web-site online

- **FLUKA**
- **Geant4**
- **Geant3**
- **ALICE**
- **ATLAS**

Our goal is to provide up-to-date comparison between LHC data and detector simulation toolkits. The detailed study of simulation results will allow for an in-depth improvement of the simulation code used by LHC experiments.

LCG Physics Validation Meeting

We regularly meet few times per year to discuss the status of simulation for experiments and any other subject. Presentation from experiments, developers and experts are shown at the **LCG Physics Validation for LHC Simulations** meetings.

Read more

General Information

This website contains useful links and information on the activities of the physics validation project. As an activity of the simulation project area we deal with the simulation of the LHC experiments.

Read more

LPCC Detector Simulation Workshop at CERN (6-7 October 2011)

LPCC (LHC Physics Center at CERN) is organizing a 2 days workshop on the Simulation of LHC detectors.

Read more

Results

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Search this site:

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News and announcements

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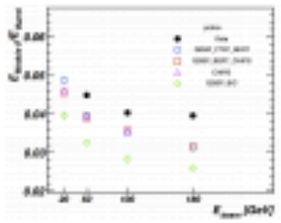
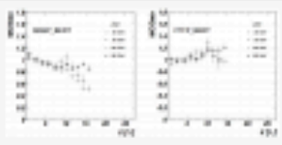
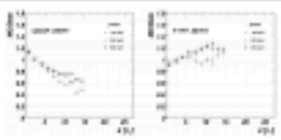
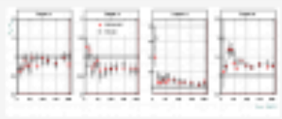
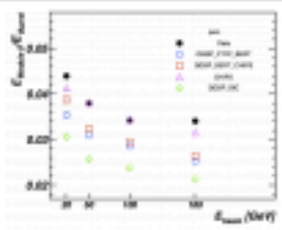
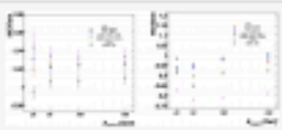
Result Plots

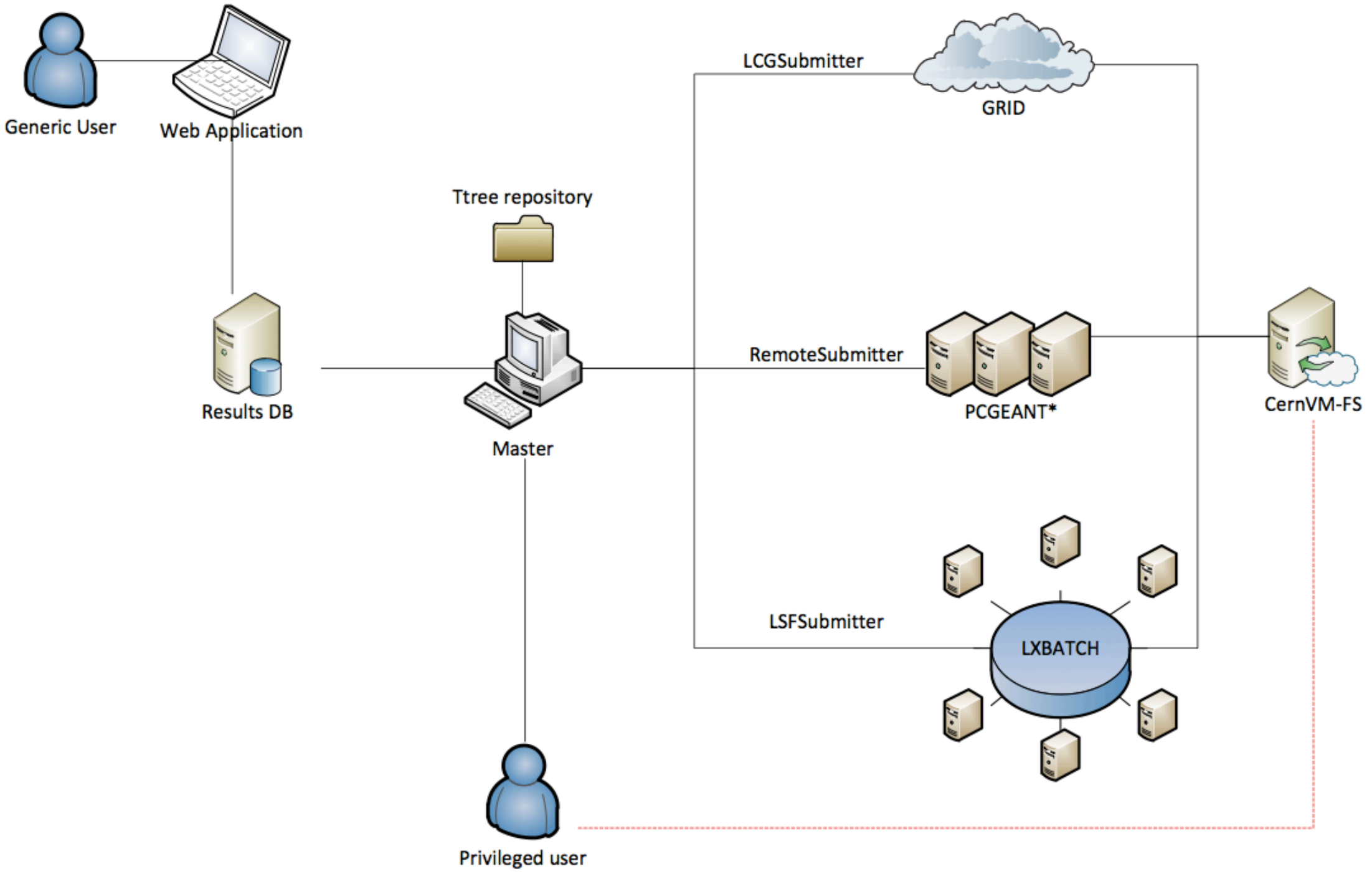
Plot	Title	Description	All terms
	Proton simulation comparison with ATLAS Fe/Scintillator hadronic calorimeter: lateral shower shape ratios	TileCal standalone lateral shower...	ATLAS, Protons, ShowerShapes, TileCal
	Charged pion simulation comparison with ATLAS Fe/Scintillator hadronic calorimeter: longitudinal shower shape ratios	TileCal standalone lateral...	ATLAS, Pions, ShowerShapes, TileCal
	Proton simulation comparison with ATLAS Fe/Scintillator hadronic calorimeter: longitudinal shower shape ratios	TileCal standalone...	ATLAS, Protons, ShowerShapes, TileCal
	Charged pion simulation validation with ATLAS Cu/liquid Argon hadronic calorimeter: shower shapes (II)	Pion shower shapes. MC/Data Ratio of...	ATLAS, AtlasHEC, Pions, ShowerShapes
	Charged pion simulation comparison with ATLAS Fe/Scintillator hadronic calorimeter: lateral shower shape ratios	TileCal standalone lateral shower...	ATLAS, Pions, ShowerShapes, TileCal
	Charged pion simulation comparison with ATLAS Fe/Scintillator hadronic calorimeter: response and resolution ratios	TileCal standalone response (...	ATLAS, Pions, Resolution, Response, TileCal

SimplifiedCalorimeter

Technical details are available at:
http://indico.cern.ch/conferenceDisplay.py?confId=156538

Validation Components

- **Geant4 Application** performing simulation
  - Output ROOT trees and histograms
- **Python Application** performing analysis, writing results in DB and producing plots
- **DIANE application**
  - Jobs running on distributed resources (batch and GRID)
- **CernVM FileSystem** used for software distribution
- **DRUPAL web application** to show results


Generic User
Web Application
Results DB
Ttree repository
Master
Privileged user
LCGSubmitter
GRID
RemoteSubmitter
PCGEANT*
CernVM-FS
LSFSubmitter
LXBATCH

- Each reference tag is validated with SimplifiedCalorimeter
- A total of ~9 millions events is produced with E from 1 GeV to 500 GeV
- Resources usage:
  - 300 CPU produce results in ~1 week (need the GRID)
  - Data 200GB of ROOT files
  - Few MB in DataBase