

Geant4 Workshop, Hebden Bridge, 14 September 2007

Hadronic Shower Shape studies in Geant4

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CERN PH/SFT

Outline

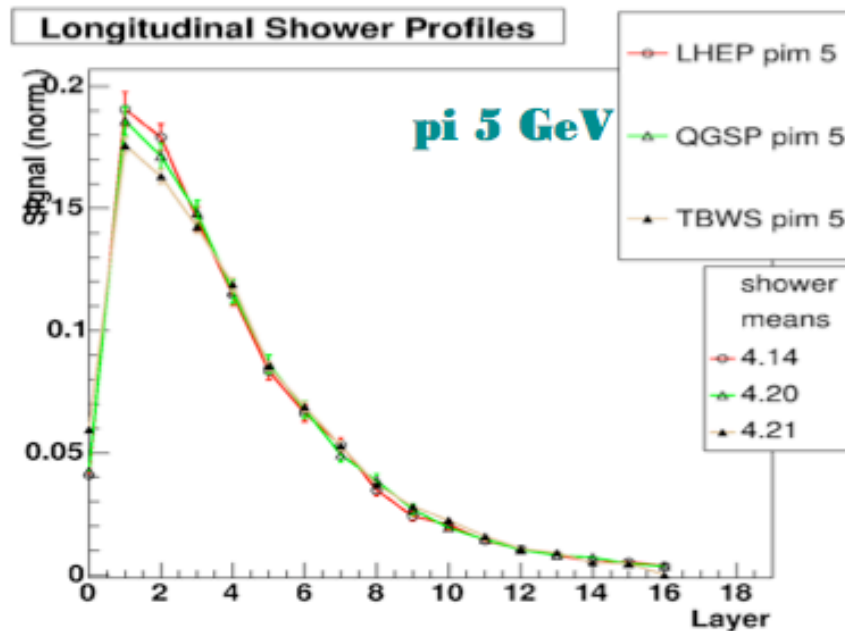
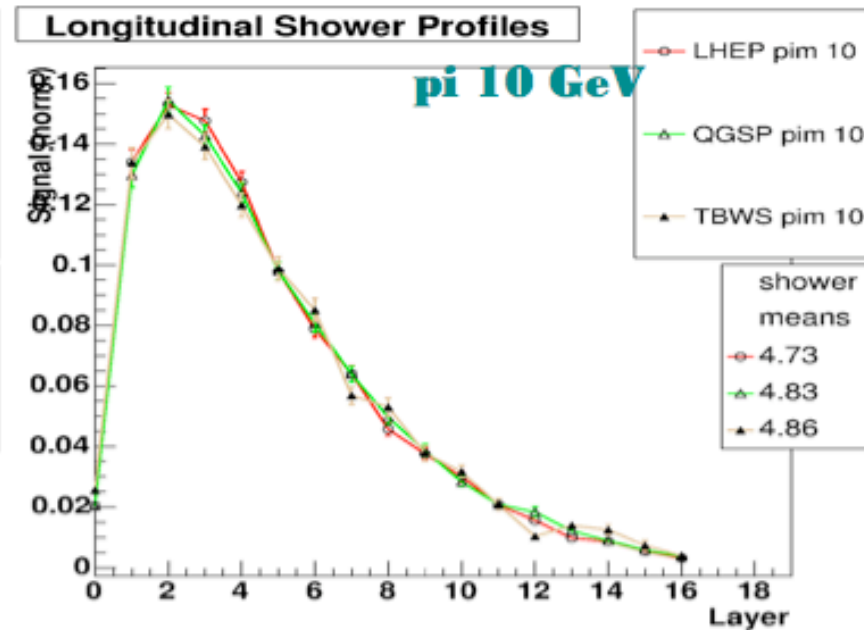
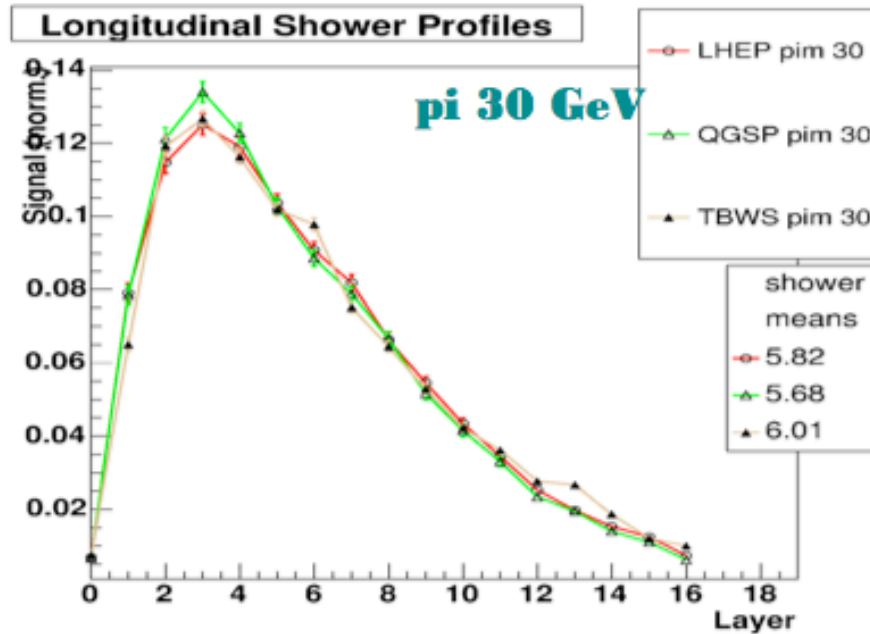
- ☐ Motivation
- ☐ Summary of the work done last year
- ☐ Some new results from the experiments
- ☐ Progress done this year
- ☐ Summary
- ☐ Outlook

Motivation

From comparisons between data from calorimeter test-beams of LHC experiments ([ATLAS HEC](#), [ATLAS TileCal](#), [CMS HCAL](#)) with Geant4 simulations with [LHEP](#) and [QGSP](#) Physics Lists, it has been concluded that:

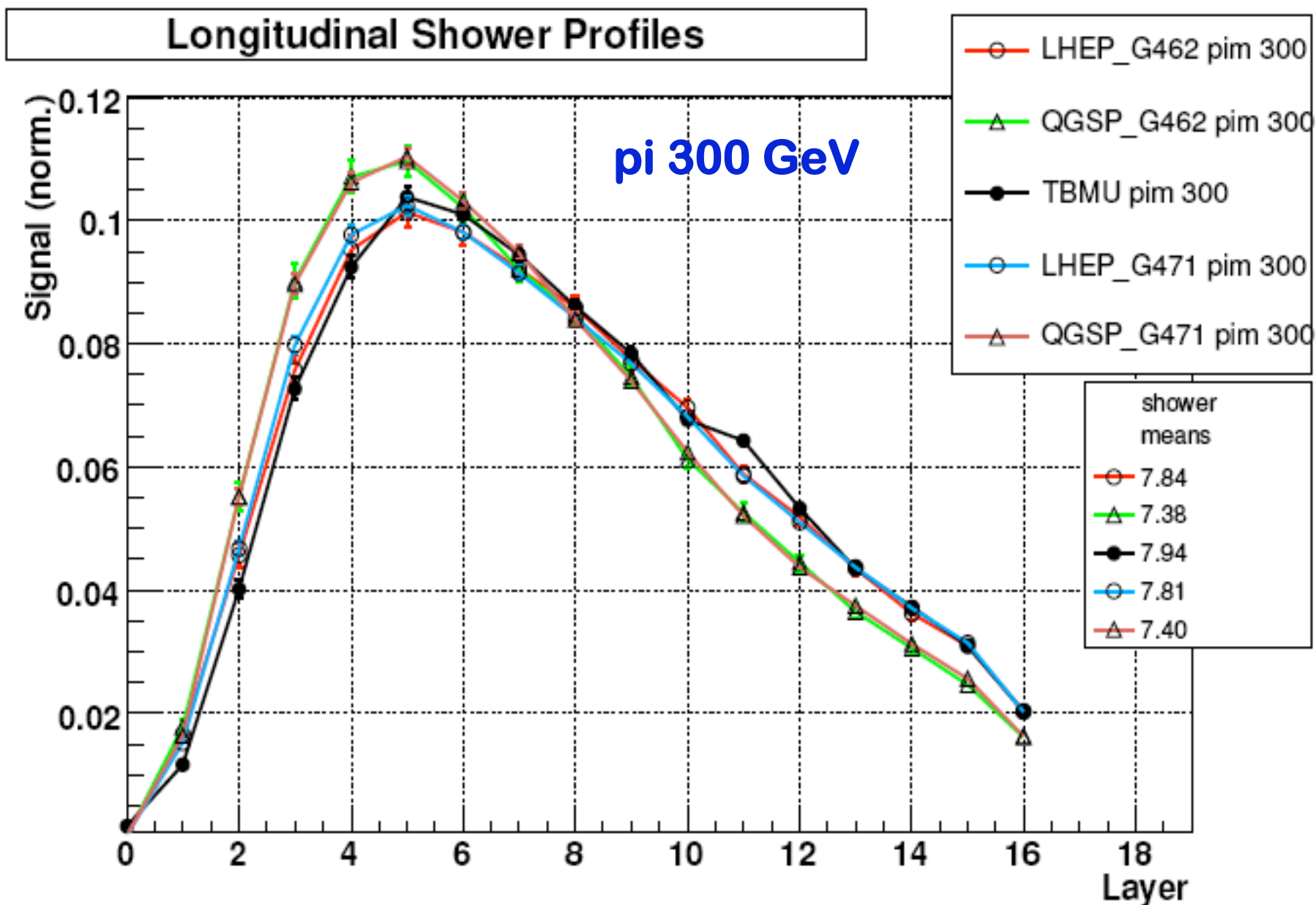
- σ_E/E is described well by LHEP and even better by QGSP;
- e/π is described very well by LHEP and even better by QGSP;
- **hadronic shower shapes** are **shorter** and **narrower** than data for QGSP, whereas LHEP looks better. QGSP and LHEP are similar at low and intermediate beam energies: good agreement with data for CMS, but not for ATLAS ! ?

CMS HCAL 2004 test-beam



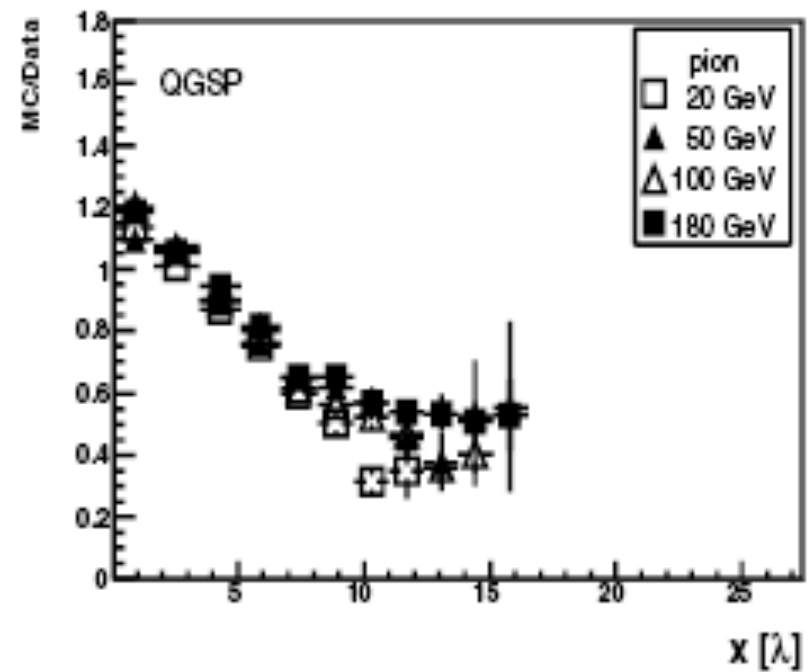
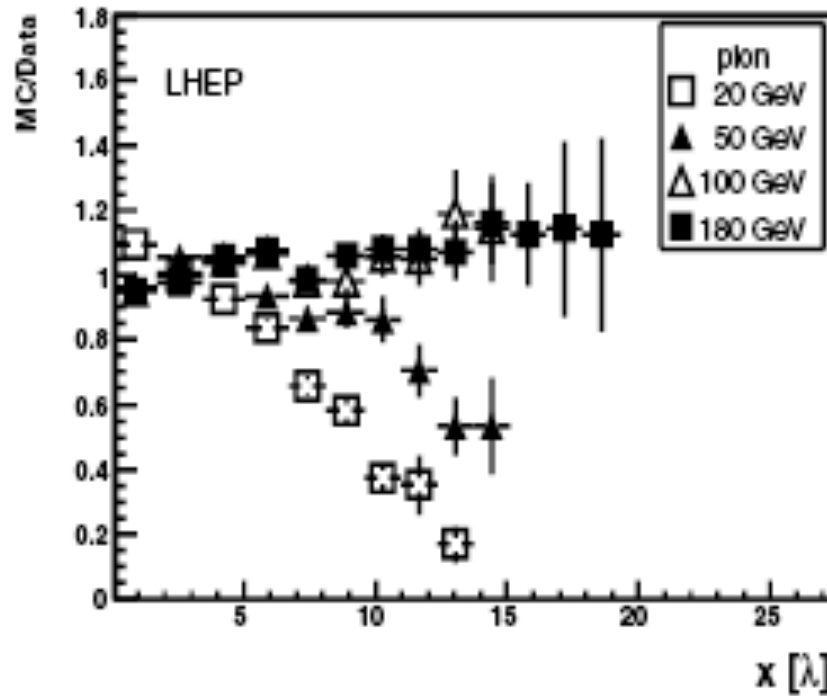
LHEP and QGSP show good agreement with test beam data at low and intermediate energies

CMS HCAL 2004 test-beam



ATLAS TileCal 2002 test-beam @90° incidence

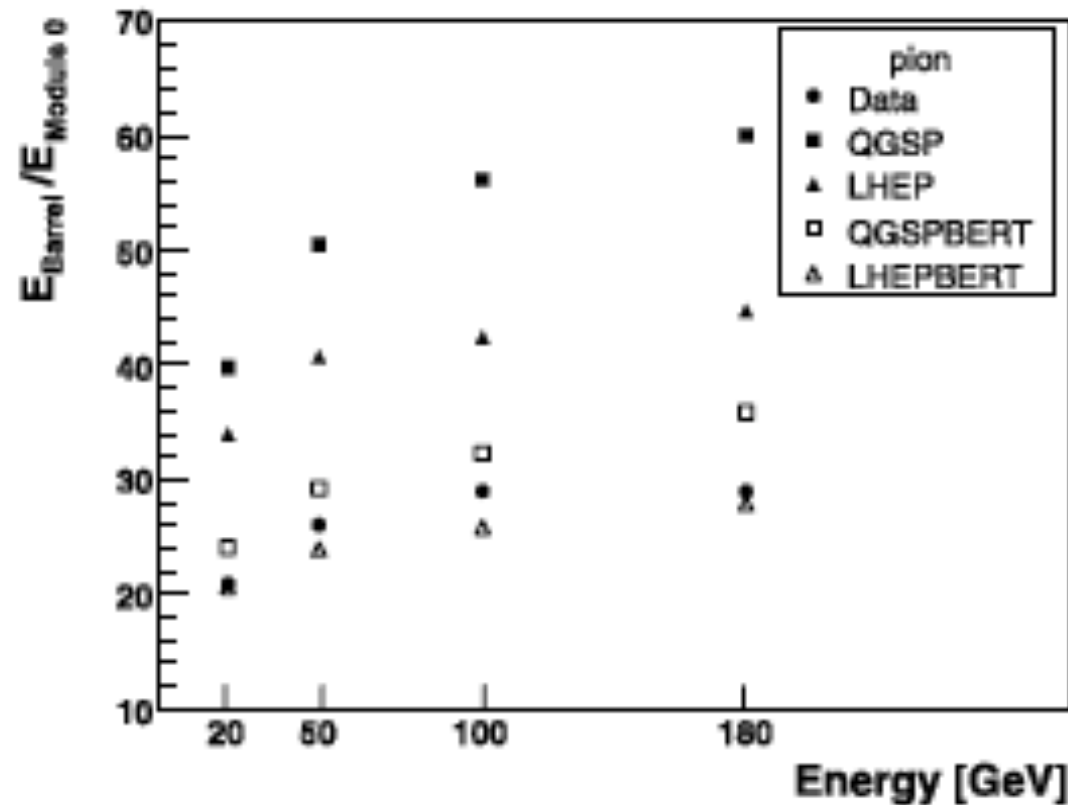
longitudinal profile



M.Simonyan, Physics Validation meeting 20-Sep-2006

ATLAS TileCal 2002 test-beam @90° incidence

lateral profile



M.Simonyan, Physics Validation meeting 20-Sep-2006

Summary from last year

- ❑ Written a note, [CERN-LCGAPP-2007-02](#), on the hadronic shower studies made in 2006.
- ❑ Cascade models (Bertini and Binary) improve the description of hadronic shower shapes: in particular, [QGSP_BERT](#) Physics List produces longer and wider showers than QGSP.
- ❑ Main two directions where improvements on hadronic shower shapes were expected:
 - **forward physics**
 - *replacement of LEP model below ~ 10 GeV*

New results

Comparisons of QGSP_BERT and QGSP_BIC Physics Lists with calorimeter test-beam data, especially for the energy response: E_{vis} , σ_E/E , e/π .

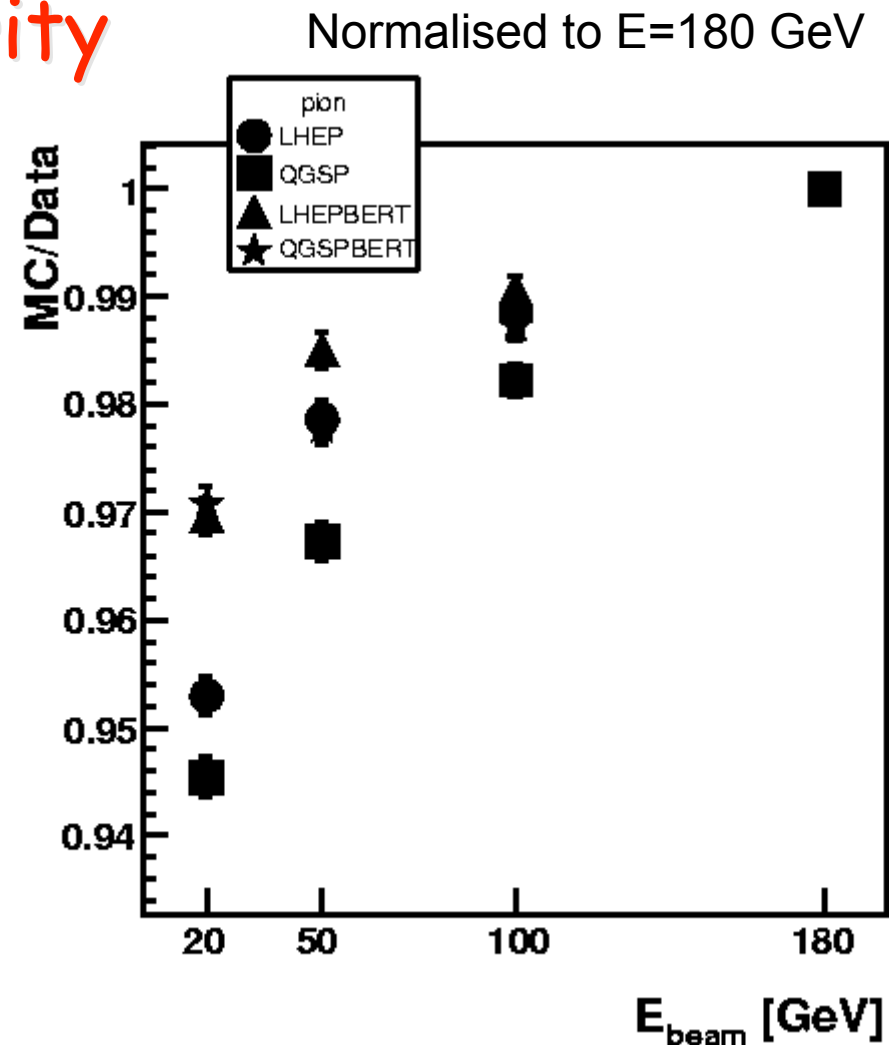
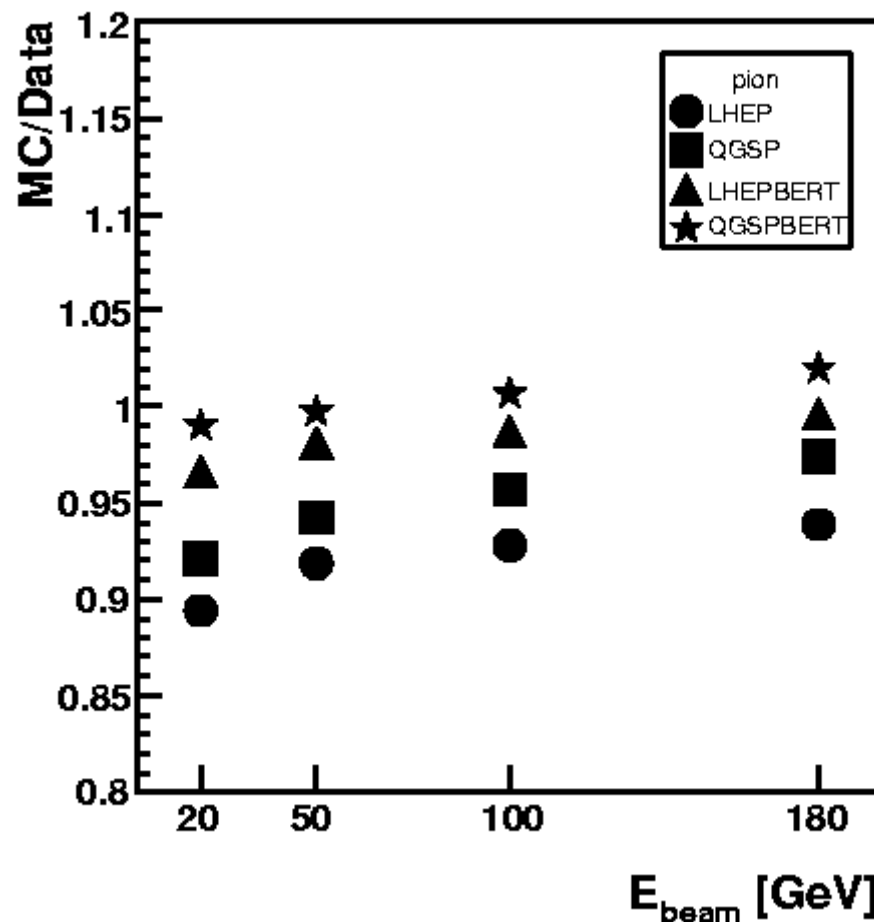
- For the visible energy
 $LHEP \leq QGSP \leq QGSP_BIC \leq QGSP_BERT$
- For the the energy resolution and the ratio e/π
 $LHEP \geq QGSP \geq QGSP_BIC \geq QGSP_BERT$

Which is closer to the data?

Different calorimeter test-beams give different answers...

Cascade models improve the hadronic shower shapes, but not always the energy response...

Pion Linearity

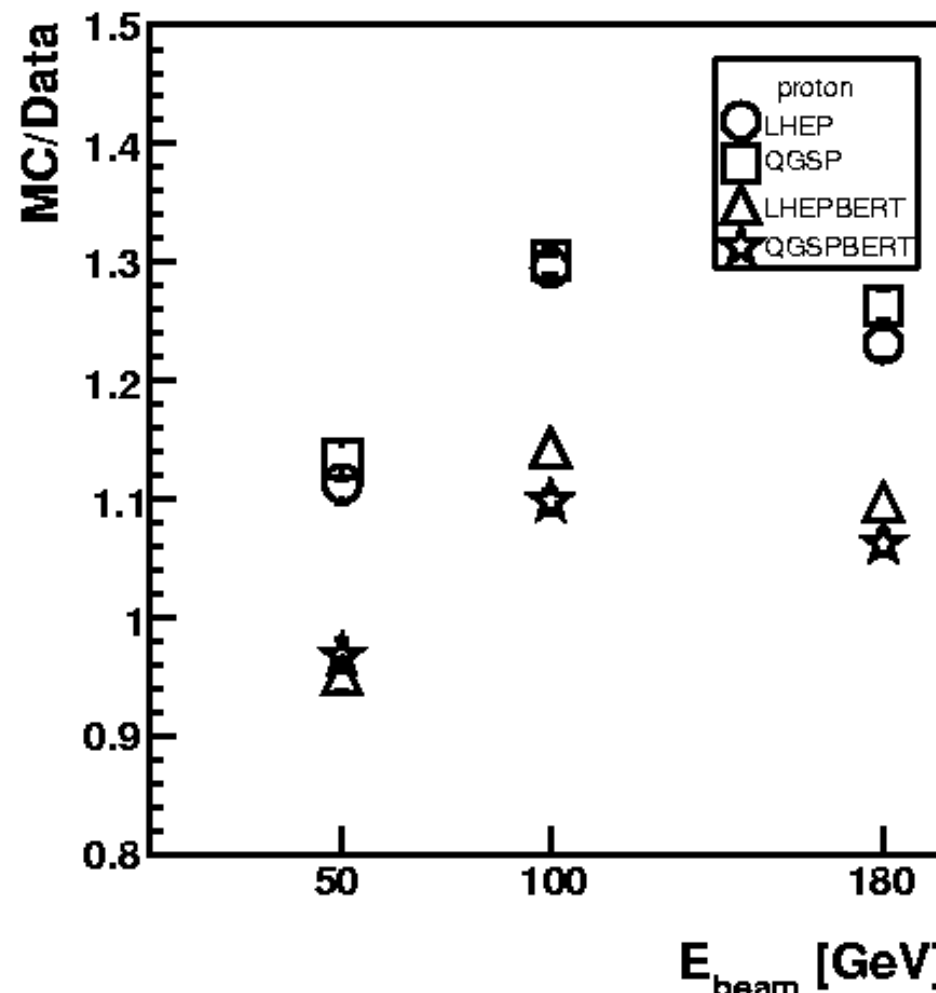
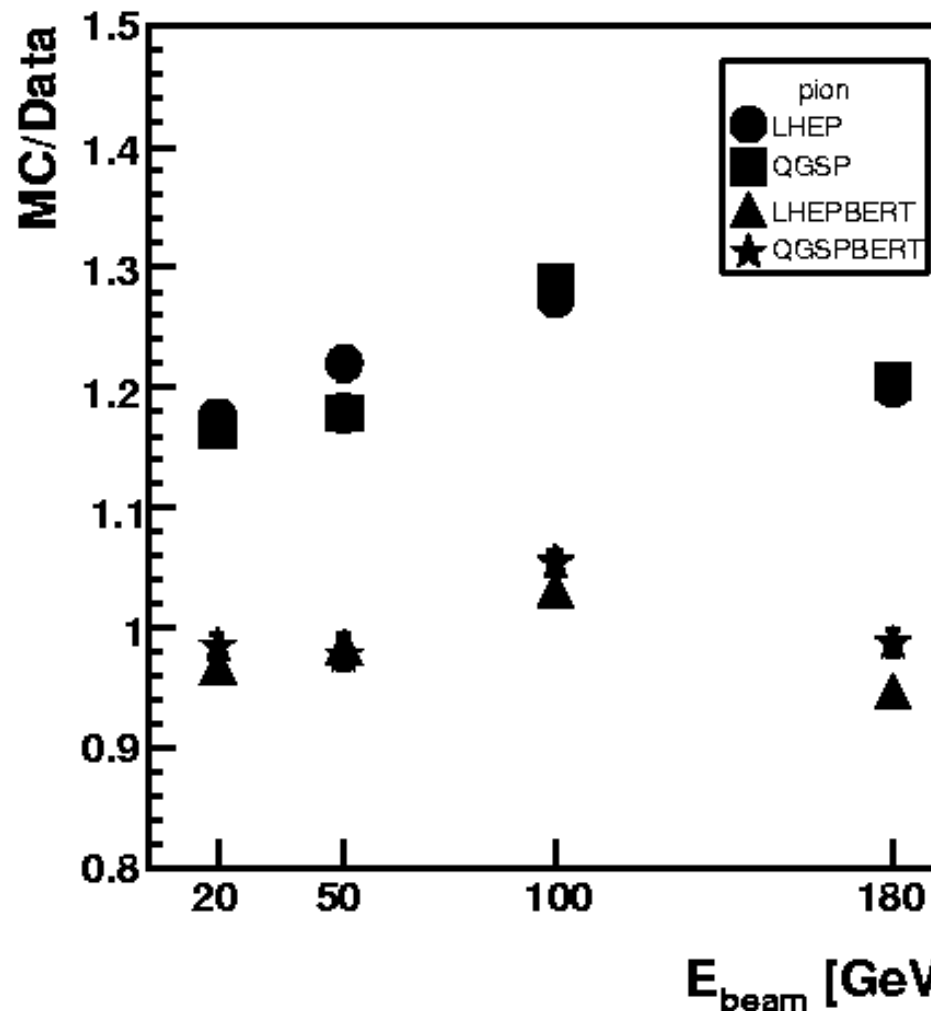


Bertini increases response, and improves the Data description for LHEP&QGSP
 QGSP a bit better than LHEP
 QGSPBERT and LHEPBERT within 3%

Pion and Proton Resolution

Pion

Proton

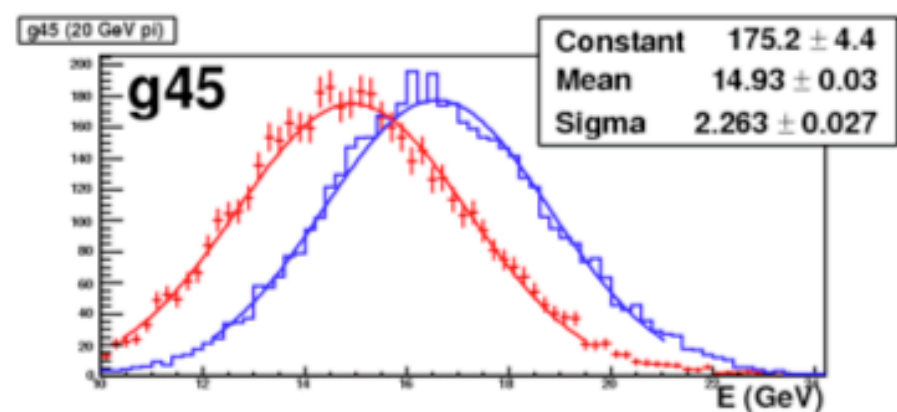
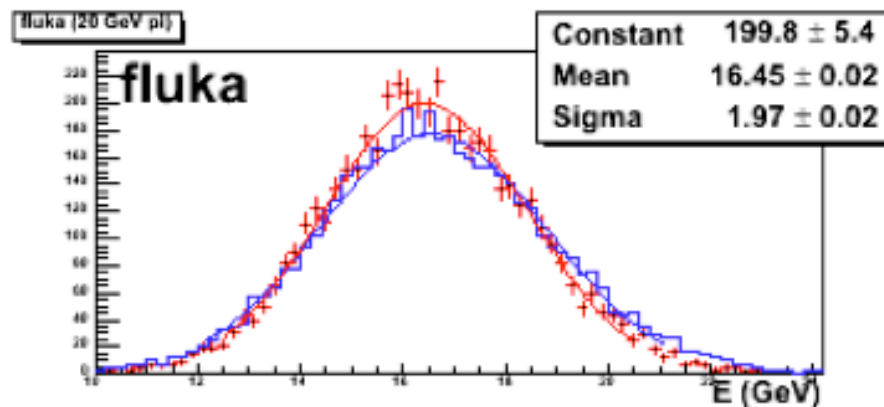
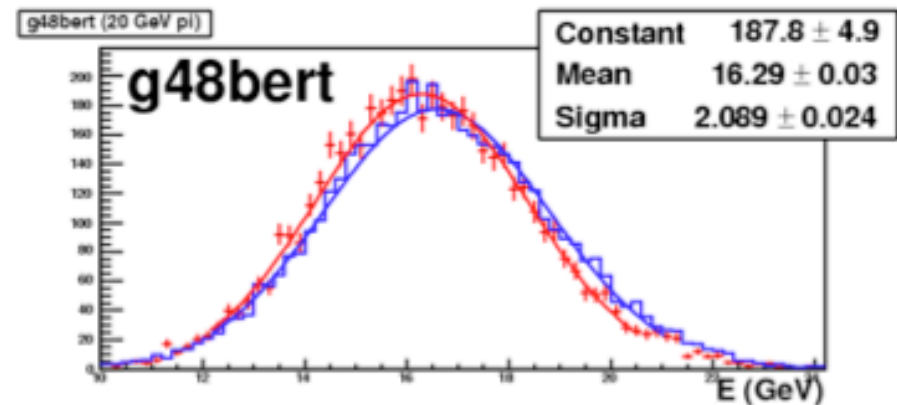
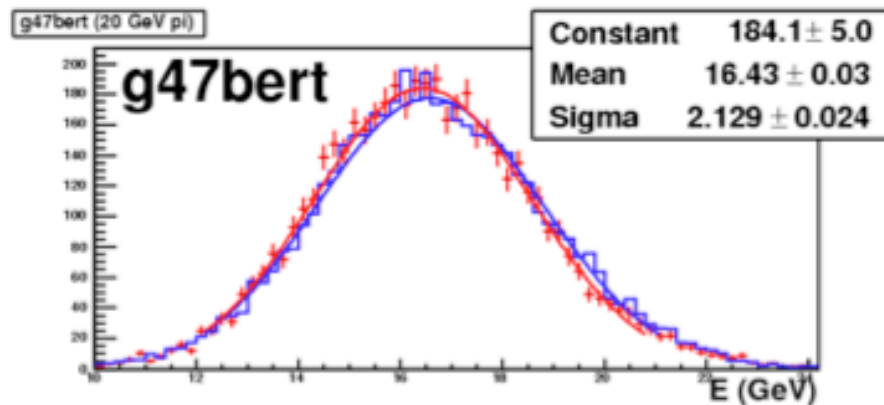
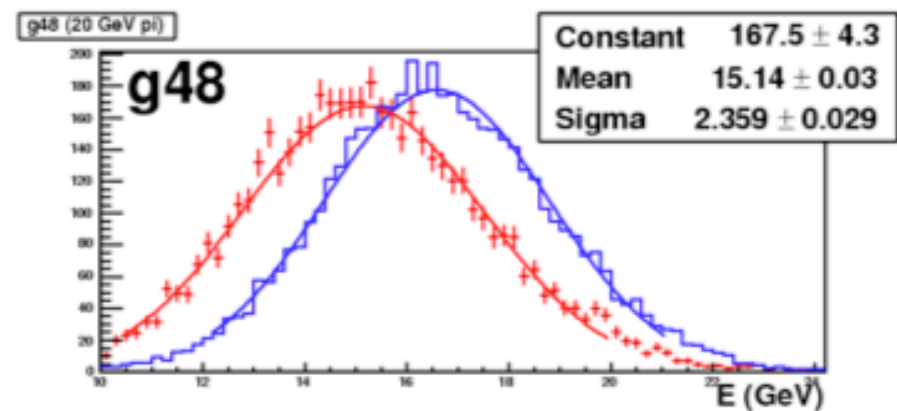
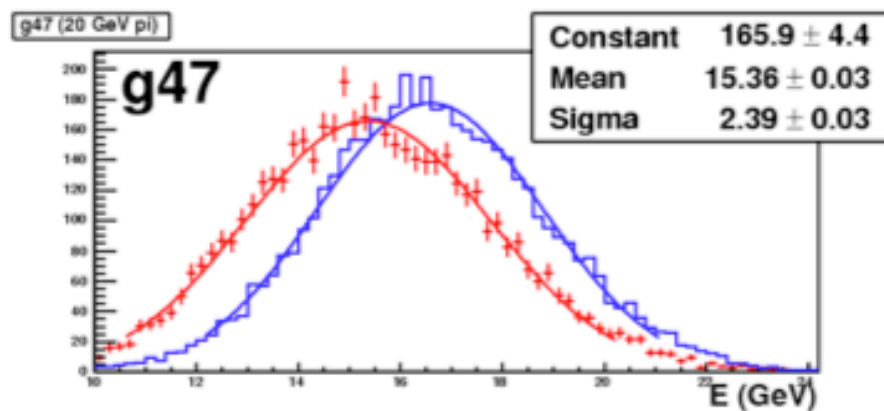


Resolution better described with Bertini (increased response \rightarrow better resolution)

MC/Data within 5% for pions and 10% for protons

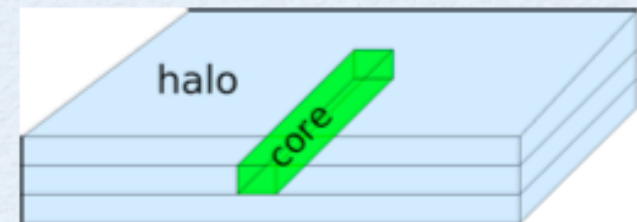
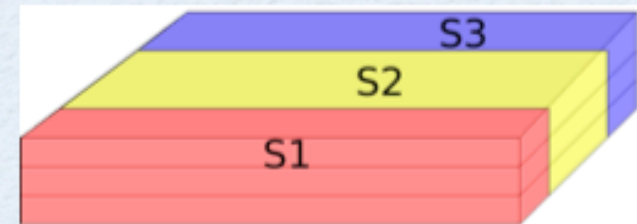
ATLAS Tile 2002, A.Dotti et. al, Physics Validation July 2007

20 GEV PIONS: TOTAL ENERGY

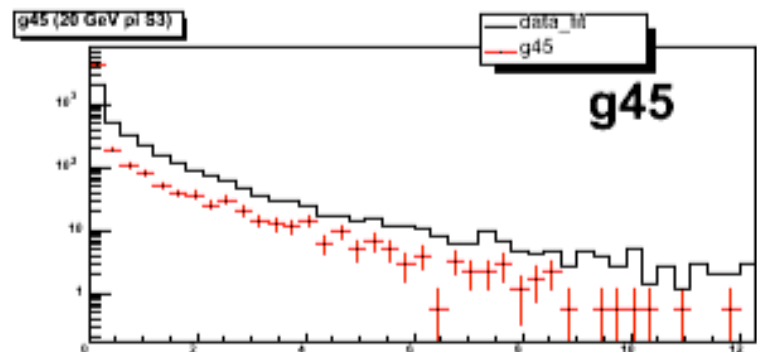
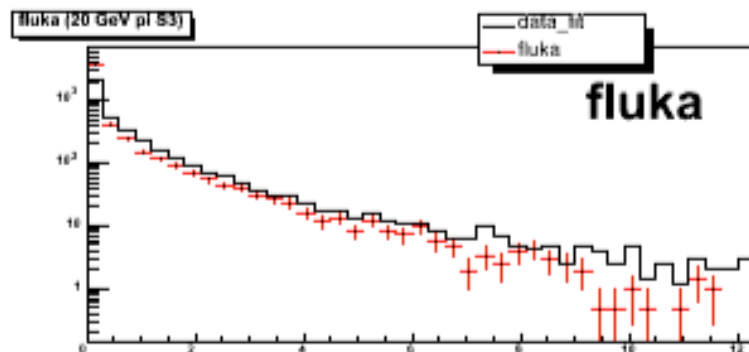
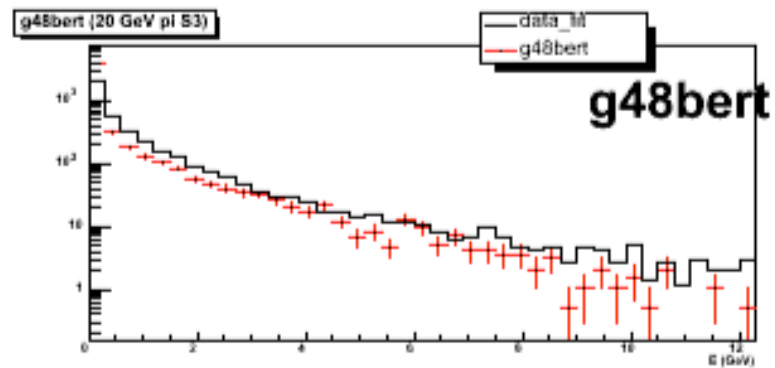
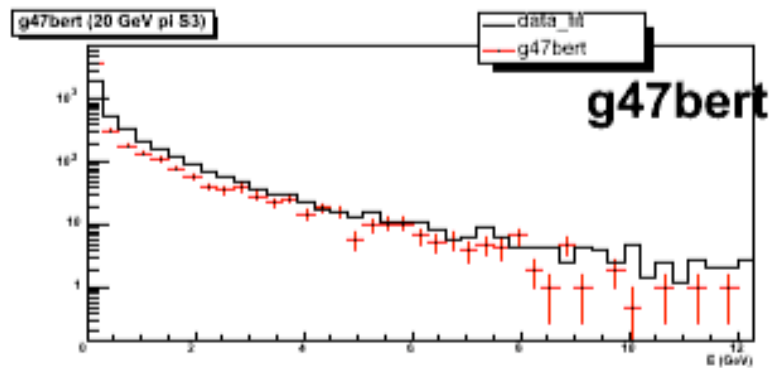
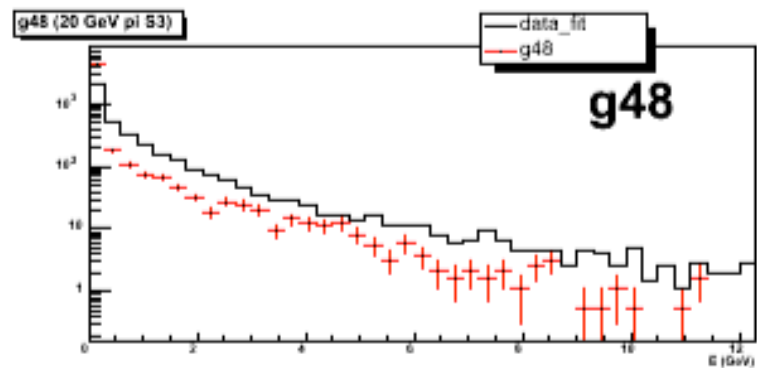
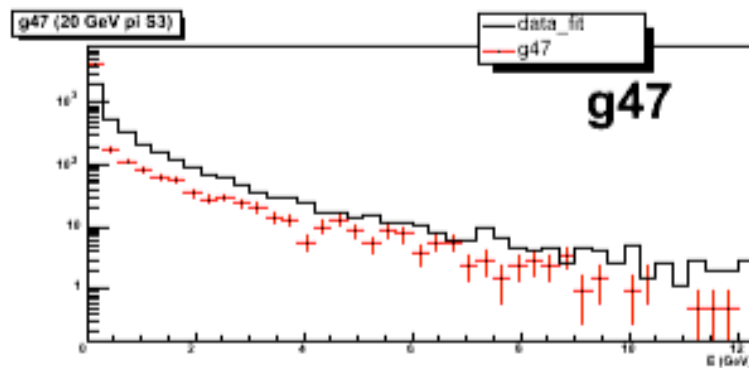


LONGITUDINAL AND LATERAL SEGMENTATION

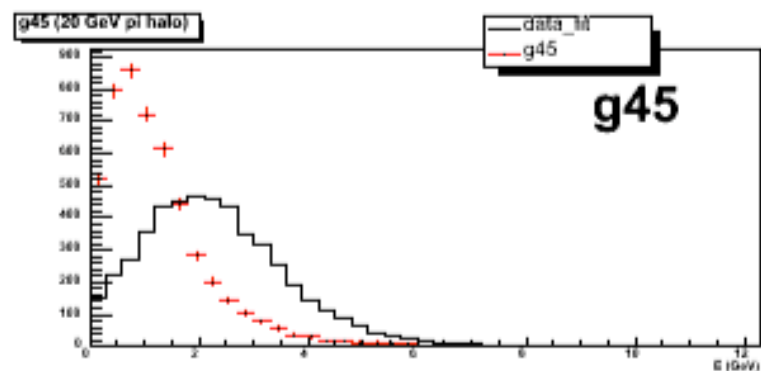
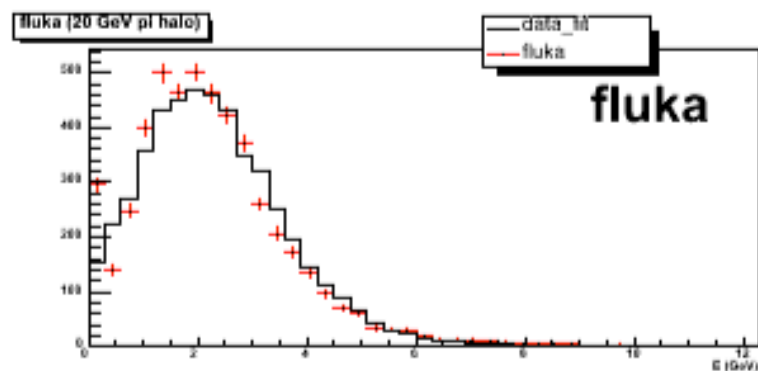
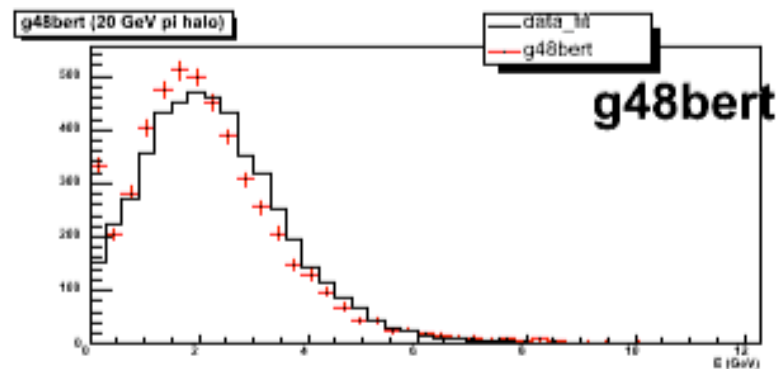
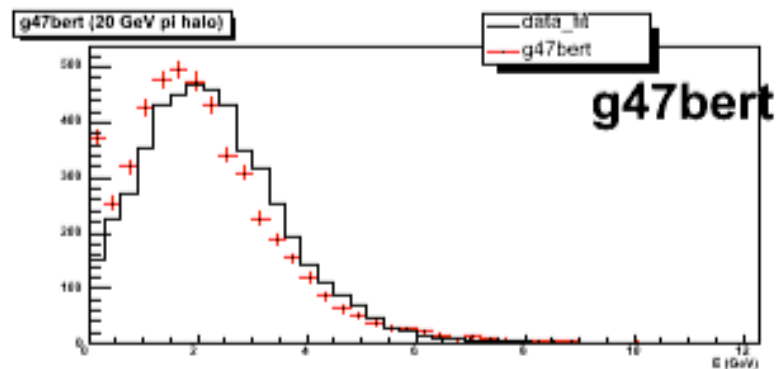
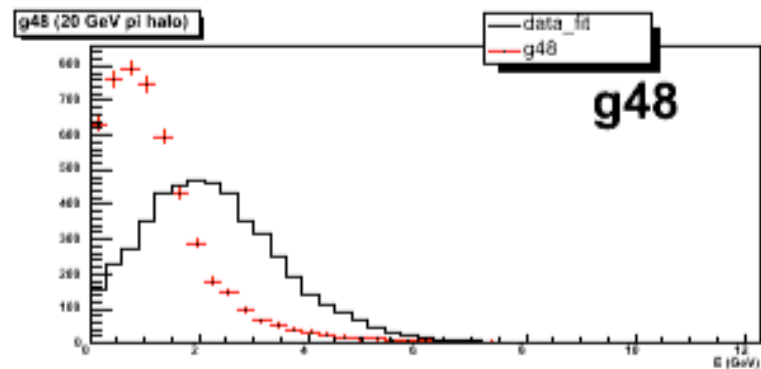
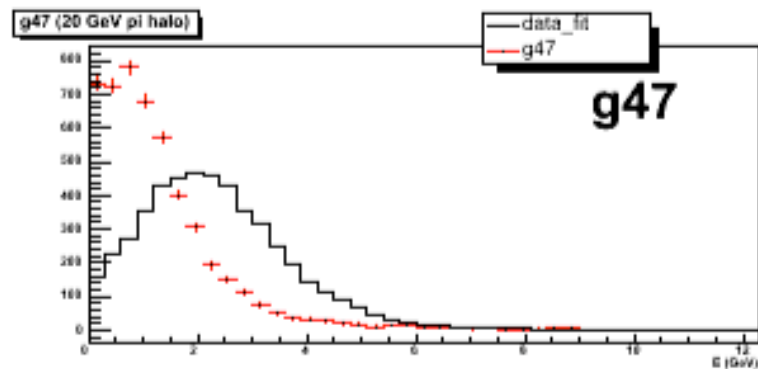
- TILECAL's longitudinal segments
 - S1 ~ A cells ~ $1.7 \lambda_I$
 - S2 ~ BC cells ~ $4.8 \lambda_I$
 - S3 ~ D cells ~ $2.2 \lambda_I$
- the core is defined as the projective tower crossed by the beam line ~ $25 \times 25 \times 150 \text{ cm}^3$
- the halo is the external volume



ENERGY IN SAMPLE 3



ENERGY RELEASE IN THE HALO



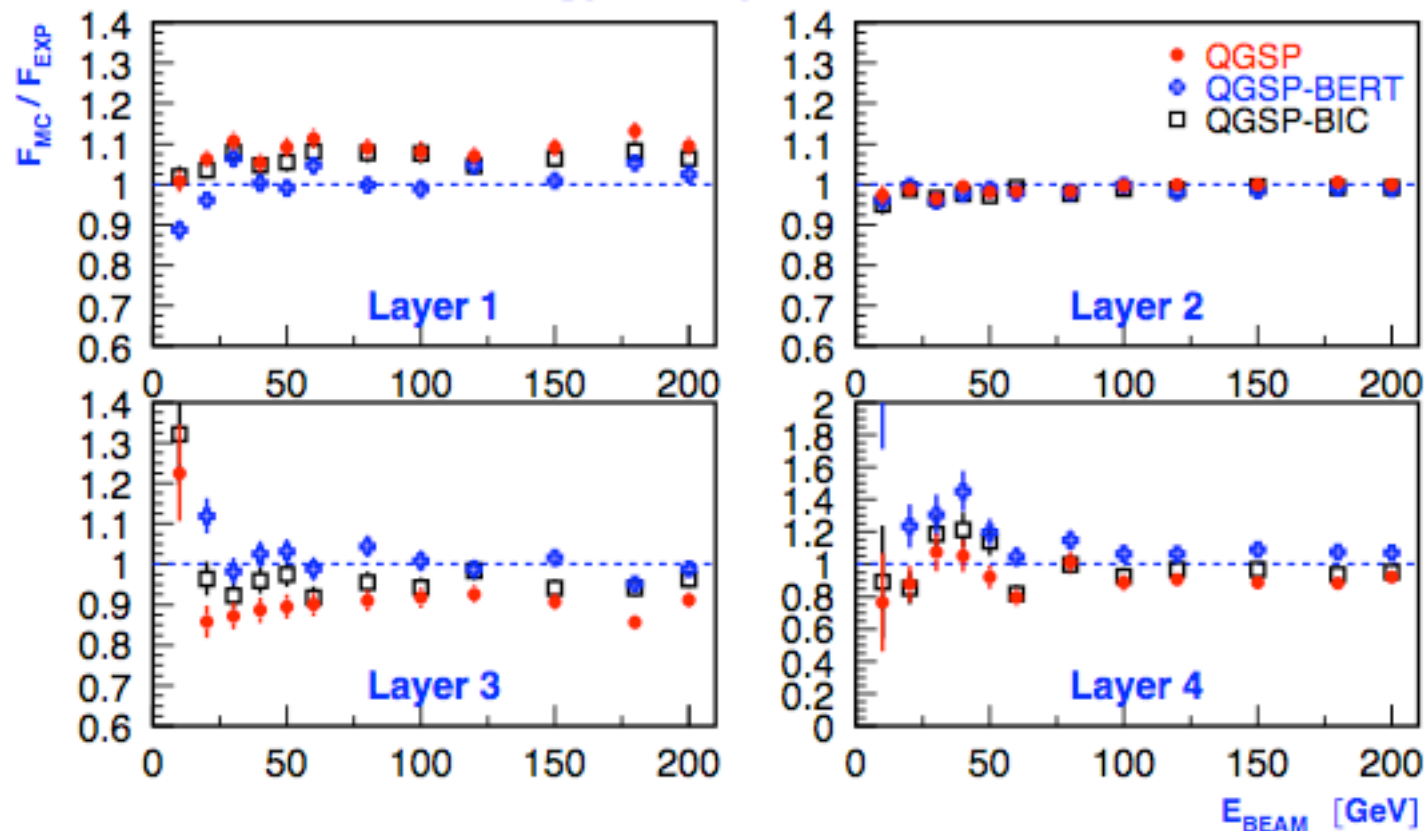
ATLAS HEC, A.Kiryunin & P.Strizenec, Physics Validation Feb 2007

LCG Physics Validation of LHC Simulations

February 28, 2007

Evaluation of physics lists with cascade models

Fraction of energy in layers: QGSP based lists



QGSP-BERT

good description of shower profiles (except low beam energies)

QGSP-BIC

certain improvement w.r.t the standard QGSP

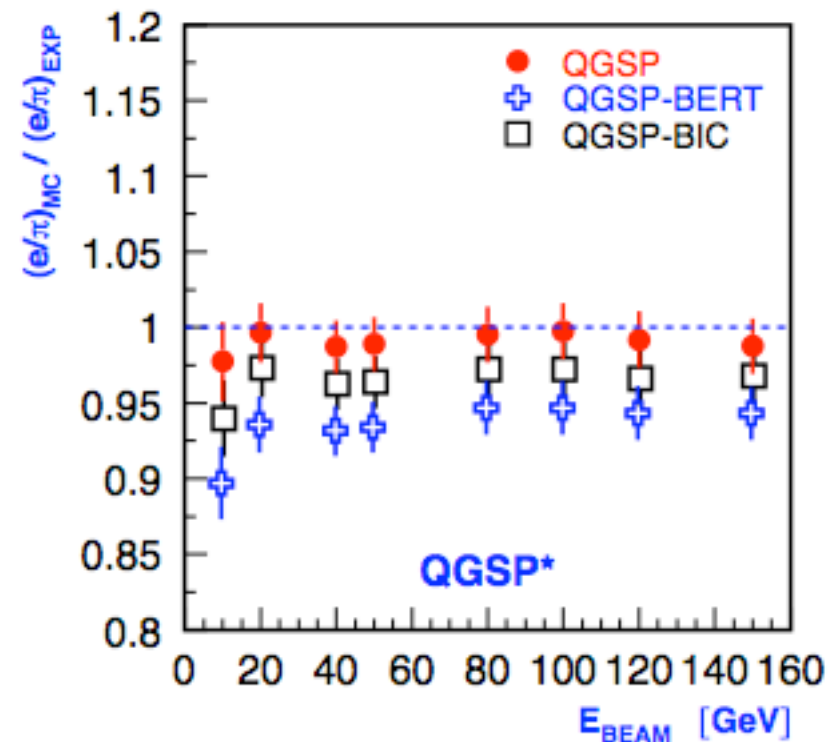
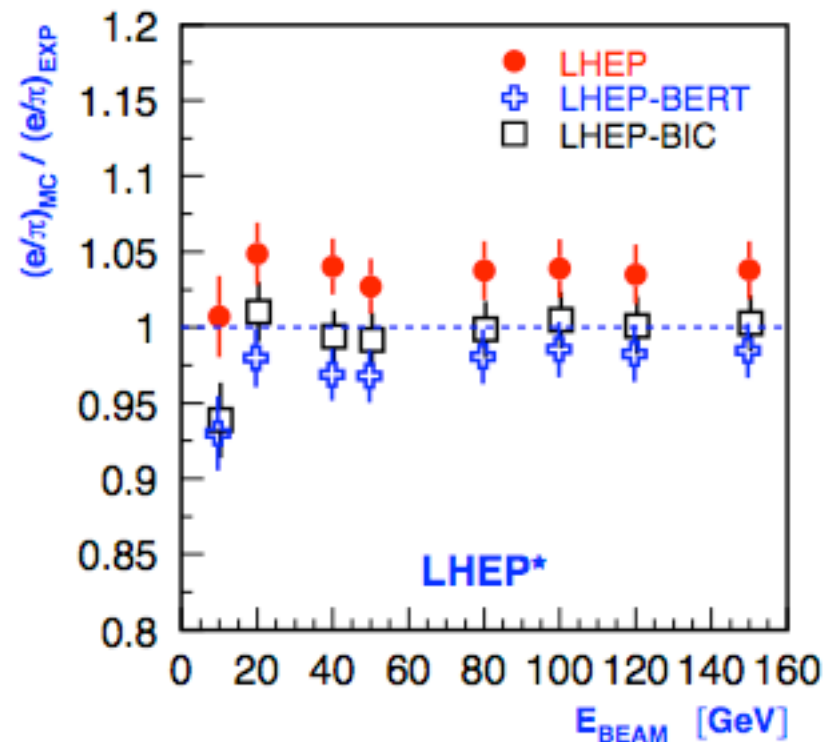
ATLAS HEC, A.Kiryunin & P.Strizenec, Physics Validation Feb 2007

LCG Physics Validation of LHC Simulations

February 28, 2007

Evaluation of physics lists with cascade models

Ratio e/π : comparison with experiment



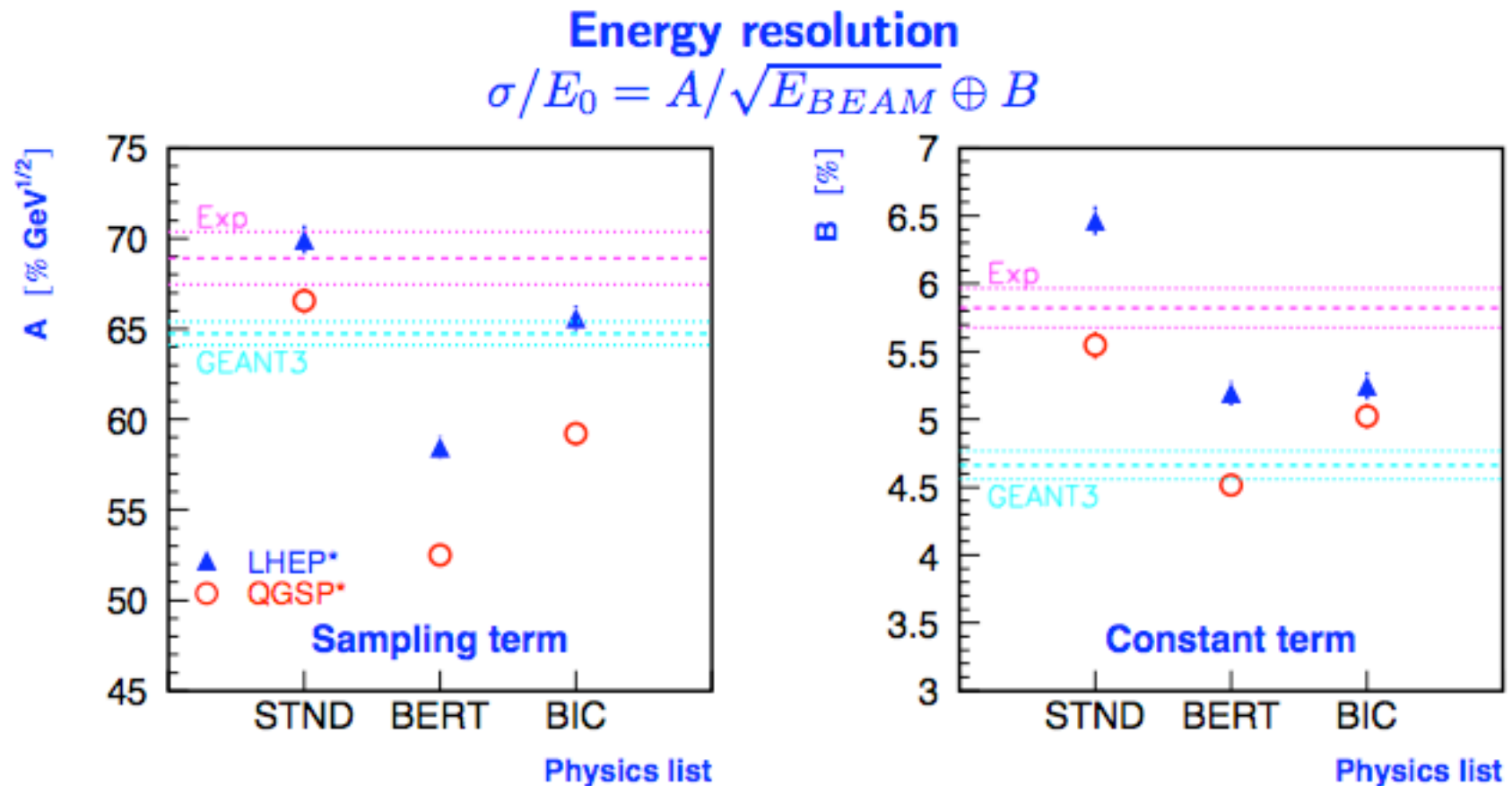
Lists with cascade models predict lower values of the e/π than standard lists
LHEP-BIC is in a good agreement with experiment

ATLAS HEC, A.Kiryunin & P.Strizenec, Physics Validation Feb 2007

LCG Physics Validation of LHC Simulations

February 28, 2007

Evaluation of physics lists with cascade models



Quasi-elastic & Fritiof model

Considering a 100 GeV π^- beam on a Iron-Scintillator sampling calorimeters (a kind of simplified version of the ATLAS TileCal calorimeter), we can look how the visible energy is distributed in four longitudinal quarters:

	G4 8.2.p01		G4 9.0	
	QGSP	FTFP	QGSP	FTFP
-----	-----	-----	-----	-----
f_{L1}	55.7%	56.5%	54.5%	52.2%
f_{L2}	33.6%	33.6%	34.0%	34.6%
f_{L3}	8.9%	8.2%	9.5%	10.6%
f_{L4}	1.8%	1.6%	2.0%	2.6%

The longitudinal shower shapes are longer in G4 9.0 because of the **quasi-elastic scattering**. Furthermore, **Fritiof model has been improved** (thanks to V.Uzhinskiy).

Diffraction

Last year, we tried to change by hand the relative fraction of diffractive events in QGS, without modifying the model:

`geant4/source/processes/hadronic/models/parton_string/qgsm/src/G4QGSParticipants.cc`

By increasing the diffractive component the longitudinal shower profile gets longer and a bit narrower. In particular, with a factor of 3, QGSP produces similar longitudinal shapes as LHEP.

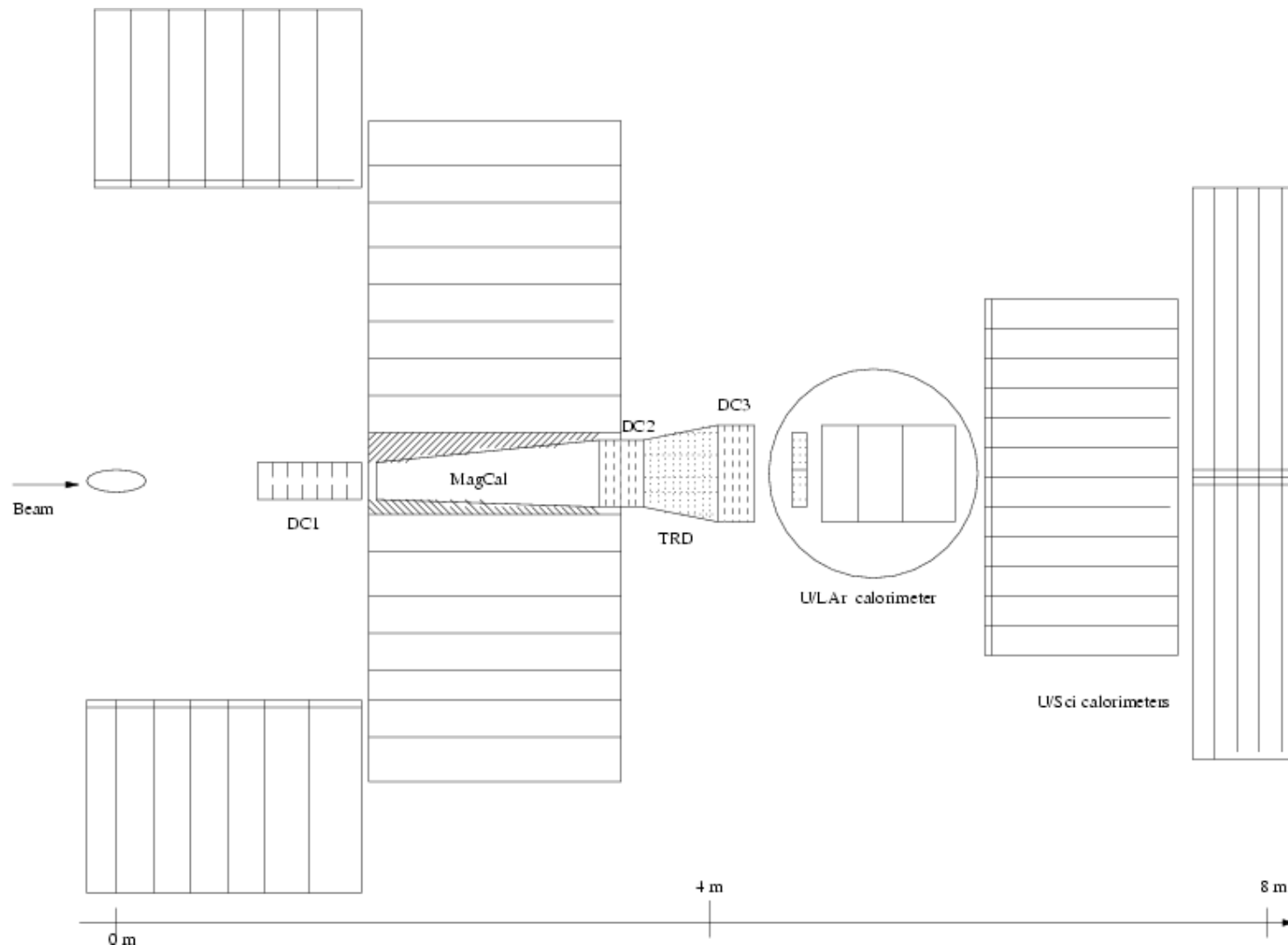
We have started recently to validate Geant4 diffraction using thin-target data.

Only one measurement is available for nucleon-nucleus target diffraction.

4th simple benchmark:

"Diffraction dissociation of nuclei in 450 GeV/c
proton-nucleus collisions"

Z.Phys.C 49 (1991) 355



Results

Data after selection: 2,605 events for Be;
464 events for Al;
1,425 events for W.

For the simulations, 10,000,000 generated events
(an "event" means a primary proton of 450 GeV/c).
After selection we are left with $O(10^4)$ events.

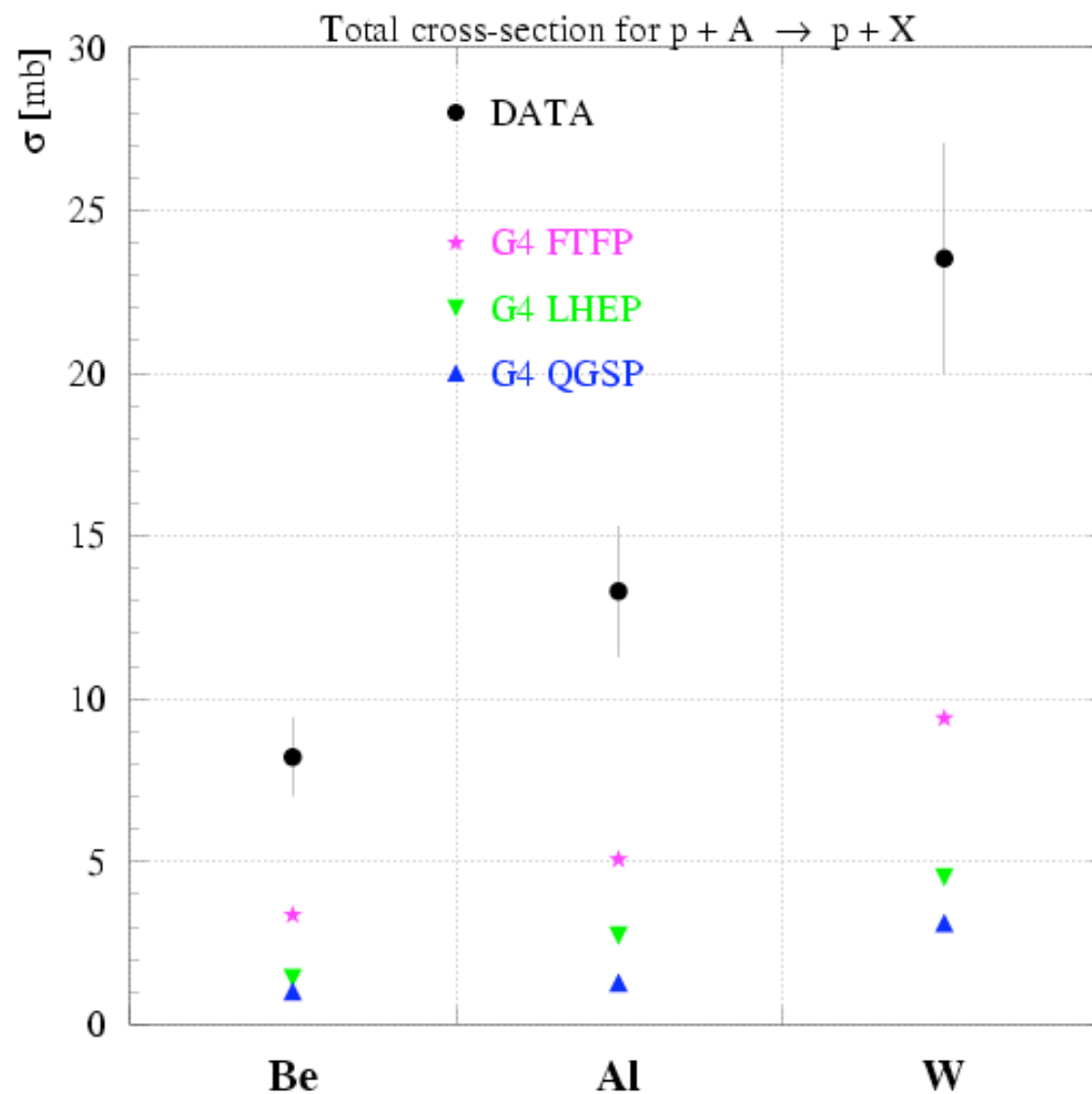
Total cross-sections in [mb] :

	Be	Al	W
DATA	8.21 ± 1.22	13.29 ± 2.01	23.52 ± 3.53
G4 FTFP	3.36 ± 0.03	5.06 ± 0.05	9.40 ± 0.12
G4 LHEP	1.43 ± 0.02	2.73 ± 0.04	4.52 ± 0.09
G4 QGSP	1.01 ± 0.01	1.27 ± 0.03	3.11 ± 0.07

Preliminary

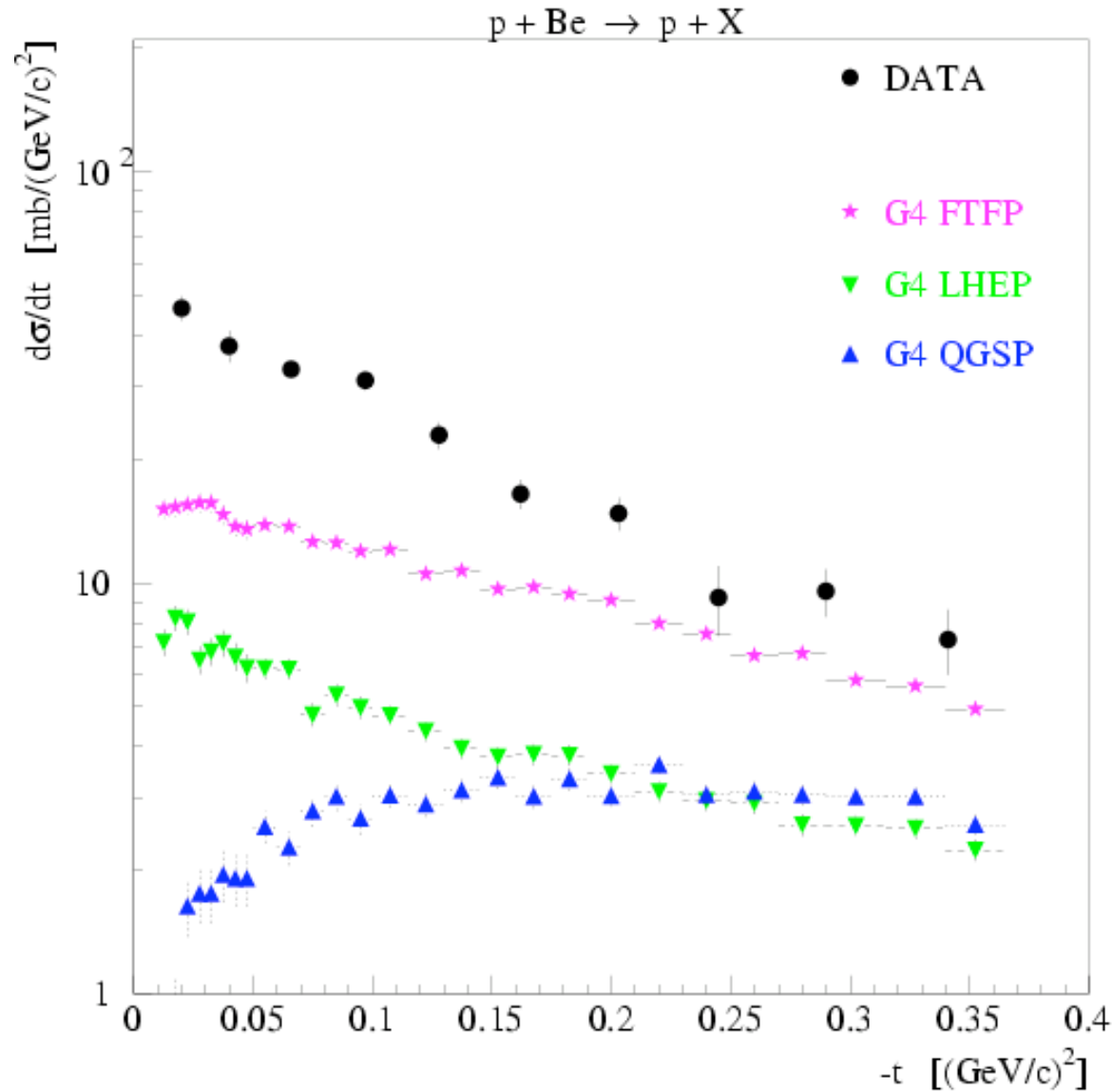
Preliminary

Total cross-sections



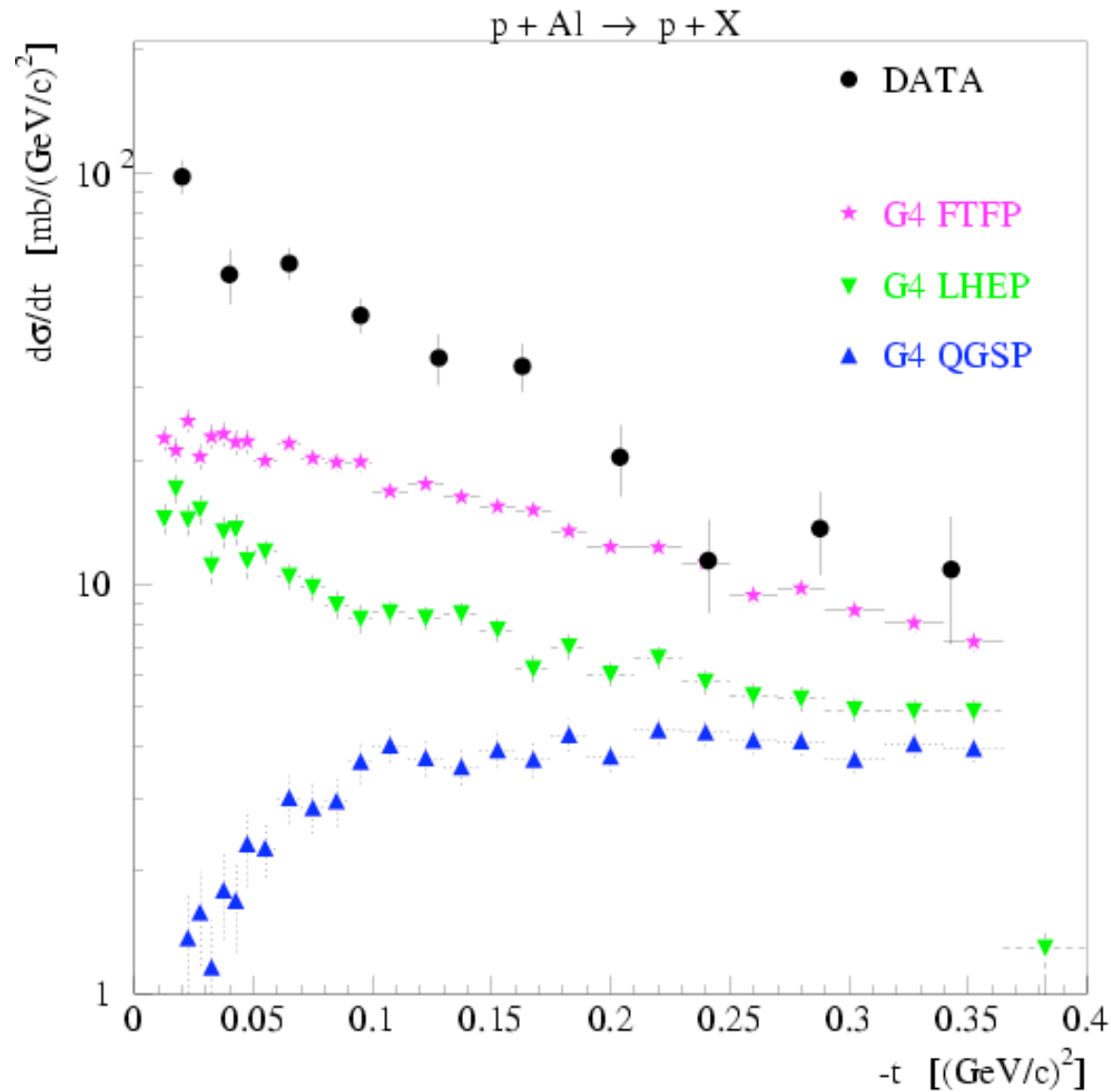
Preliminary

$$d\sigma (p + \text{Be} \rightarrow p + X) / dt$$



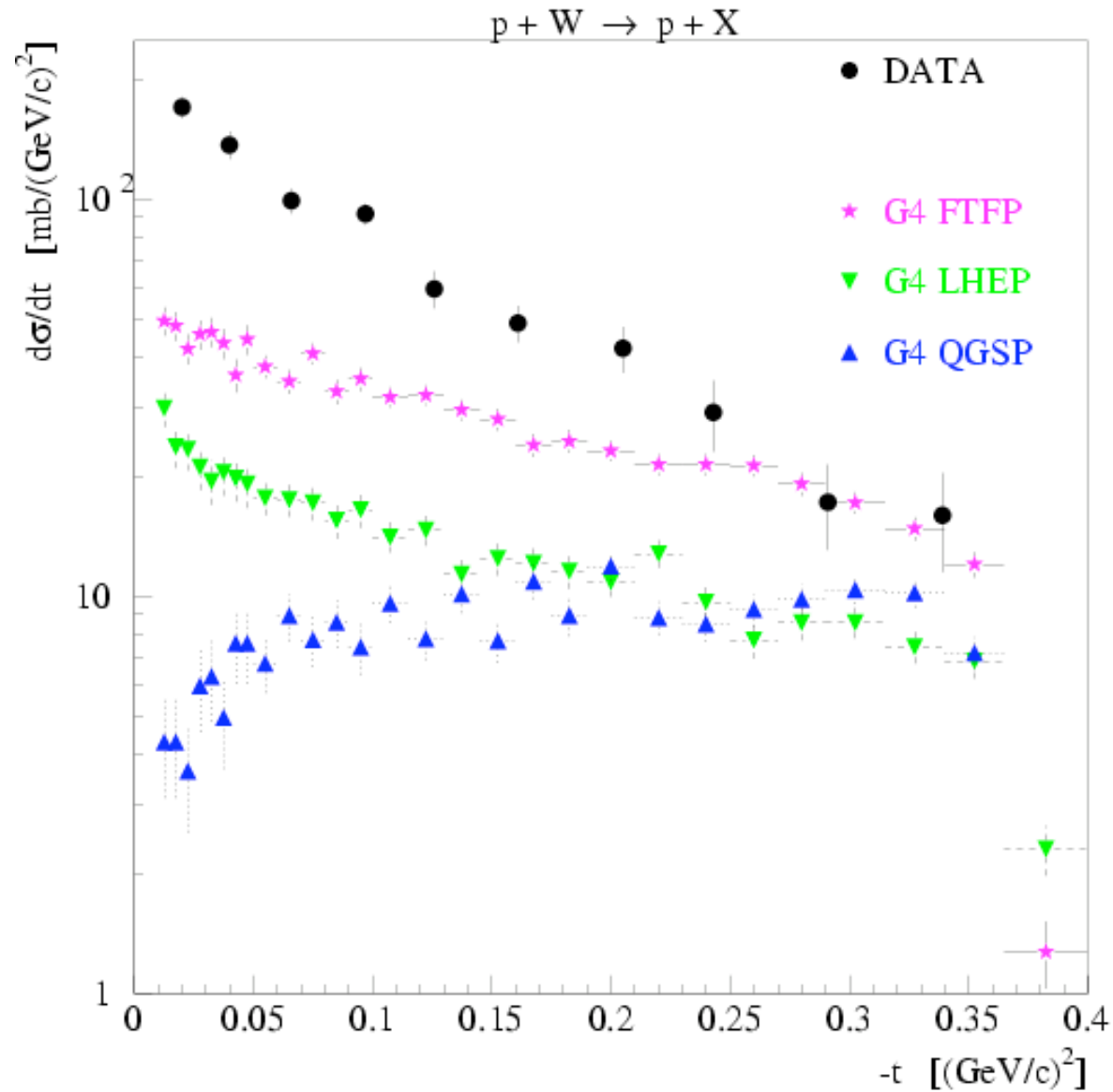
Preliminary

$$d\sigma (p + \text{Al} \rightarrow p + X) / dt$$



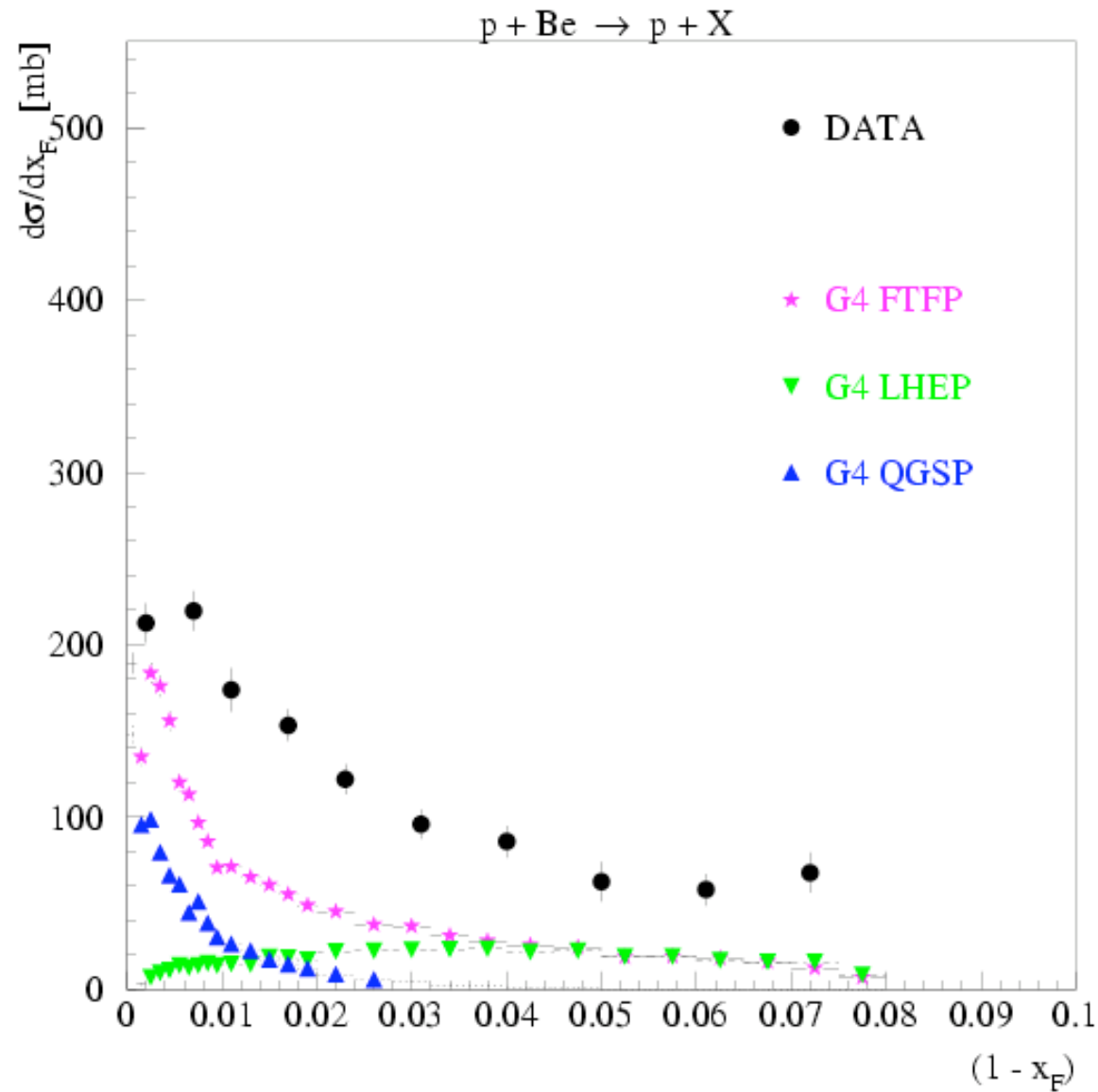
Preliminary

$$d\sigma (p + W \rightarrow p + X) / dt$$



Preliminary

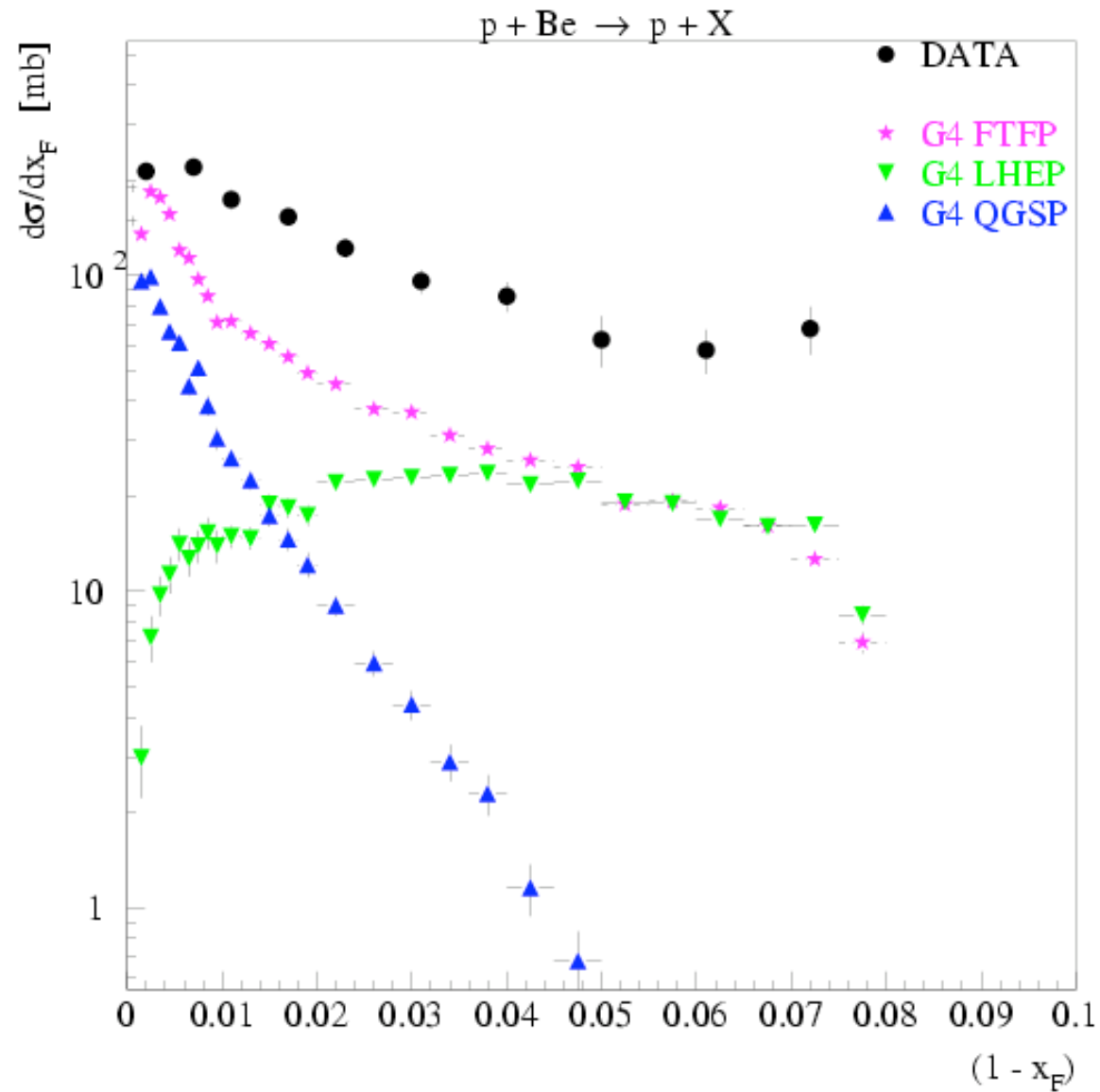
$$d\sigma (p + \text{Be} \rightarrow p + X) / d(1-x_F)$$



Preliminary

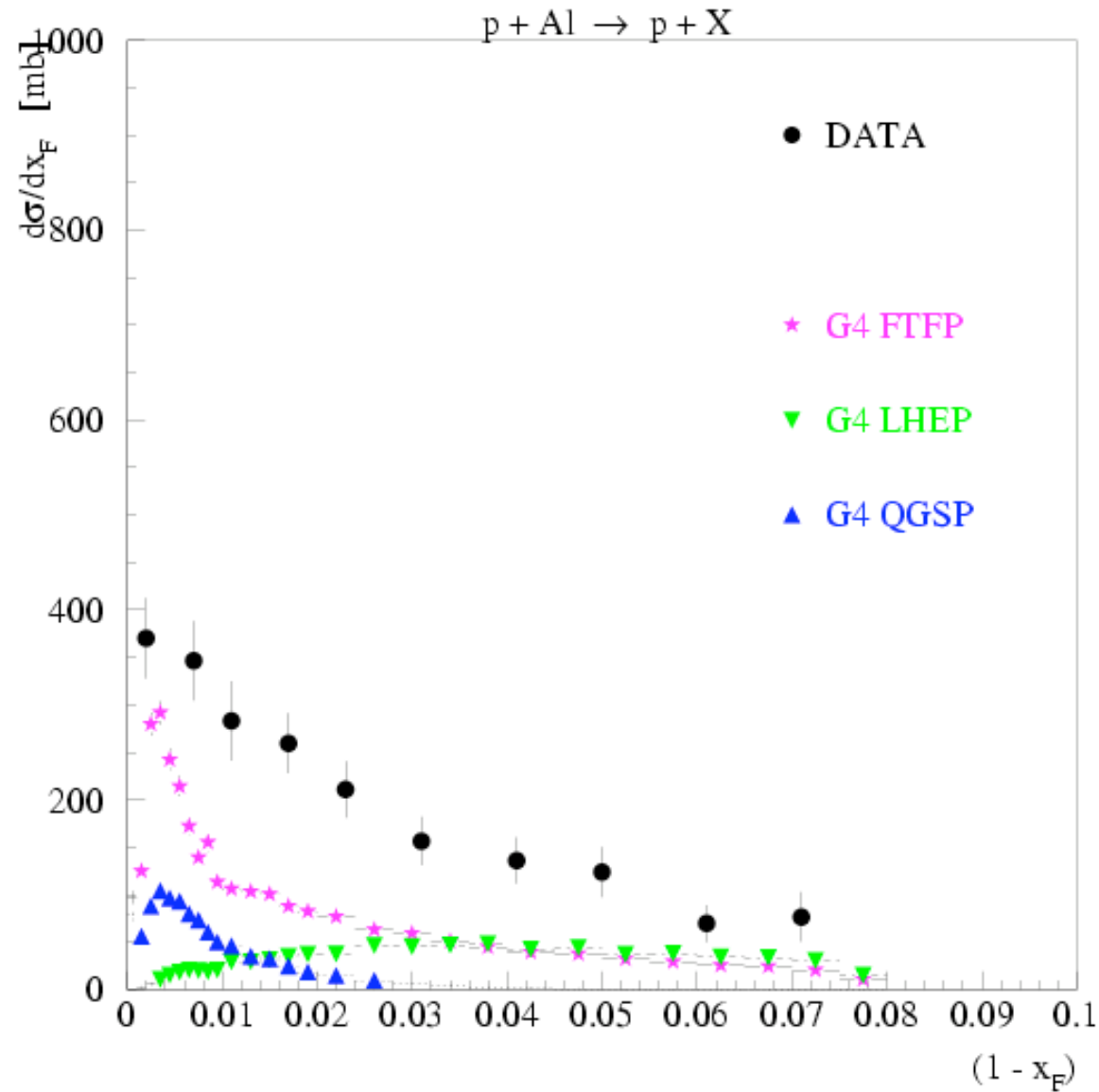
$$d\sigma (p + Be \rightarrow p + X) / d(1-x_F)$$

Log scale



Preliminary

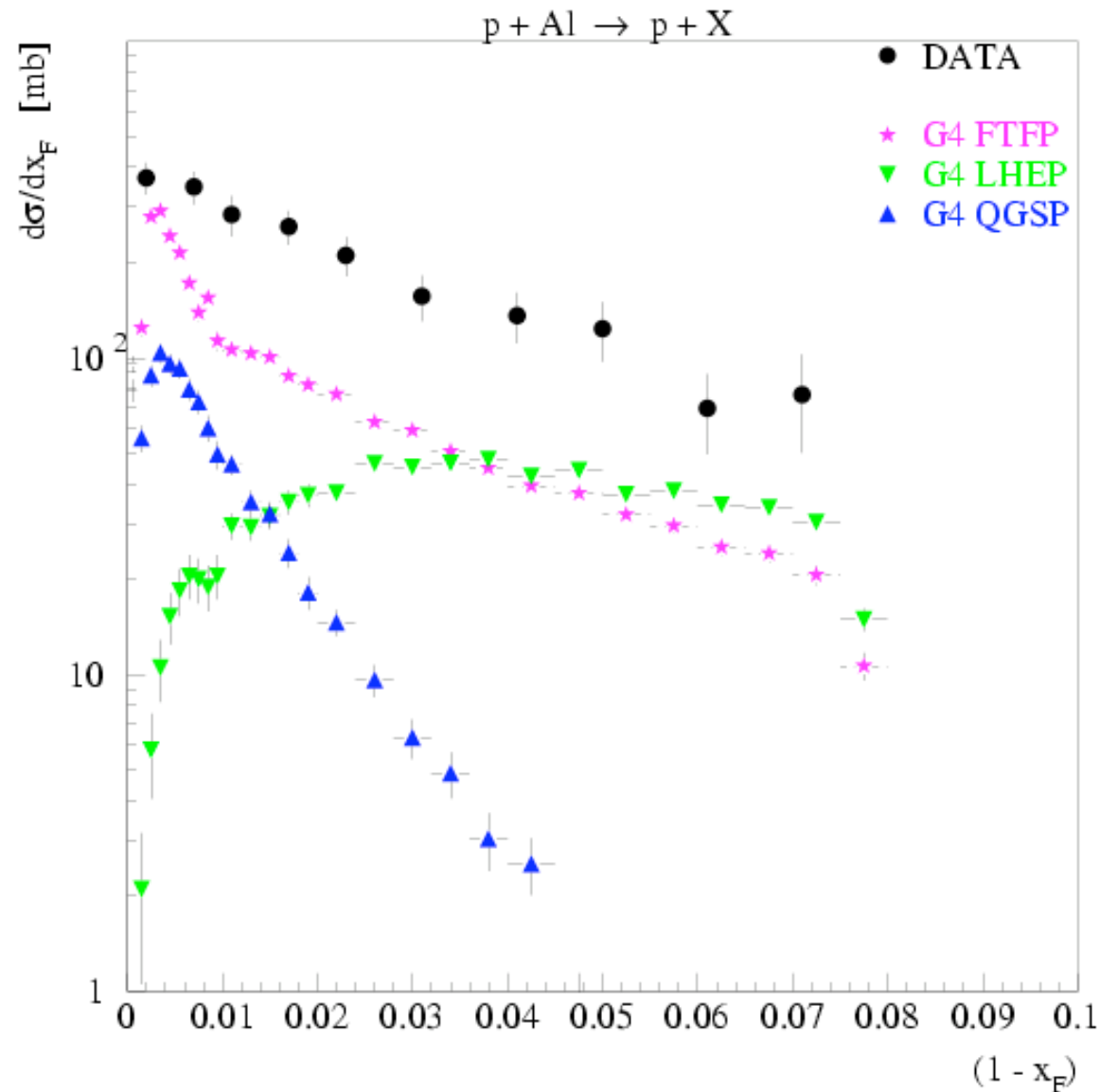
$$d\sigma (p + \text{Al} \rightarrow p + X) / d(1-x_F)$$



Preliminary

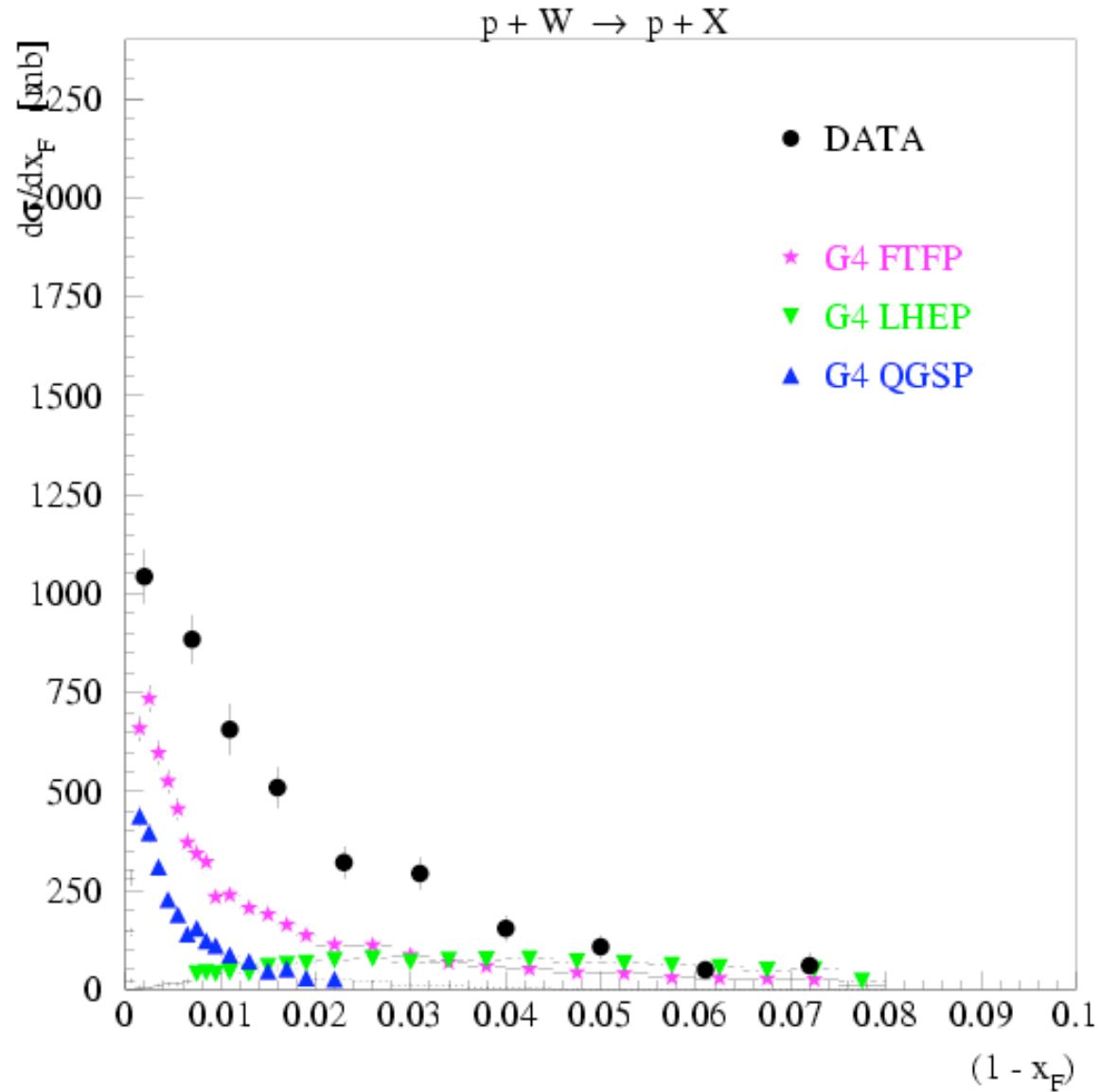
$$d\sigma (p + \text{Al} \rightarrow p + X) / d(1-x_F)$$

Log scale



Preliminary

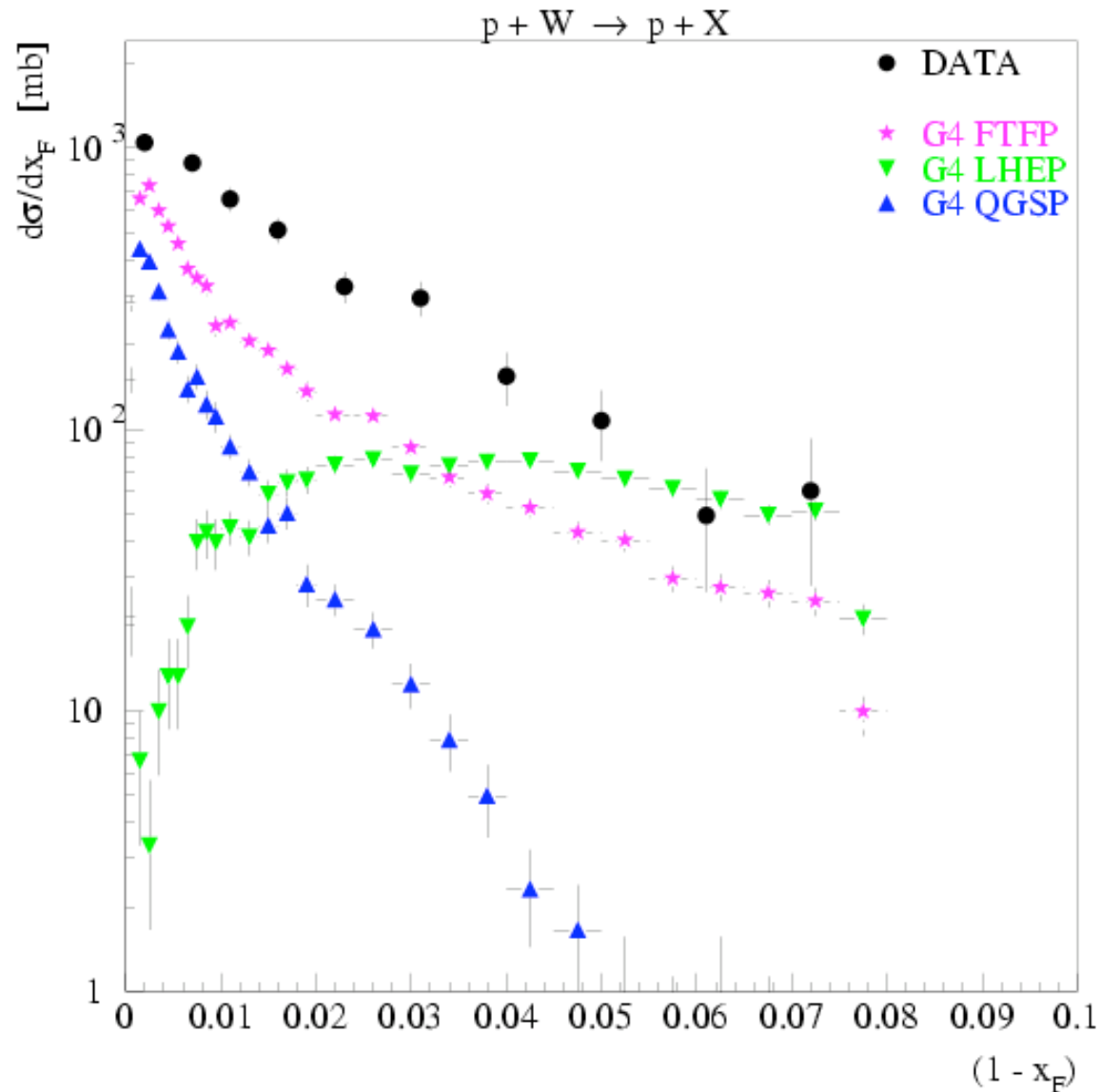
$$d\sigma (p + W \rightarrow p + X) / d(1-x_F)$$



Preliminary

$$d\sigma (p + W \rightarrow p + X) / d(1-x_F)$$

Log scale



Preliminary conclusions on diffraction

- First look at the data, neglecting the acceptance correction for the simulation
- **FTFP** is lower by a factor of ~ 2.5 but it has reasonable spectra in $-t$, $(1 - X_F)$
- **LHEP** is lower by a factor of ~ 5 and has a wrong $(1 - X_F)$ spectrum
- **QGSP** is lower by a factor of ~ 8 and has a wrong $-t$ spectrum
- Improvement of the **QGS** (and, to a less extend, **FTF**) **diffraction** is clearly needed!
As a positive consequence, this will produce hadronic shower significantly longer...

Summary

- ❑ Written a report to summarize our studies on hadronic showers up to February 2007. We plan to update it next year.
- ❑ **Cascade models** (Bertini, Binary) improve the hadronic shower shapes; but the energy response increases while the width decreases...
- ❑ **Quasi-elastic** scattering has been included in QGS- and FTF-Physics Lists, with some improvement on the longitudinal shower shape.
- ❑ **Fritiof** model has been revised, with significant improvement on the longitudinal shower shape.
- ❑ **Diffraction**, which is important for hadronic shower shapes, is significantly underestimated.

Outlook

- ❑ Continue validation of **forward physics** (Alberto)
- ❑ Improve **diffraction** (Mikhail, ...)
- ❑ Further improvement of **Fritiof** (V.Uzhinsky)
- ❑ Continue revision of **cross-sections** (V.Grichine)
- ❑ Study **energy response & resolution** of Bertini and Binary cascade models (Alberto, ...)
- ❑ Continue to **validate & investigate & improve all G4 hadronic physics** (Gunter, V.Ivantchenko, Alex, John,...)
- ❑ ... *(suggestions are welcome!)*

We made recently some improvements on the simulation of hadronic showers in Geant4...

but further work and progress are still needed!