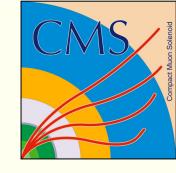


G4 validation with test beam data from LHC calorimetry (ATLAS and CMS)



P. Strizenec (*IEPSAS Kosice*) for ATLAS and CMS G4 validation groups

Based on:

- ATLAS Barrel TB 2002, 2004 (for details see: T. Carli, G4 review 16.4.2007;
 T. Carli, ATLAS simulation optimization 31.8.2007)
- ATLAS HEC TB (details in: A. Kiryunin & P. Strizenec, LCG physics validation 25.7.2007, some new results here)
- CMS H2 TB 2004, 2006 (details in S. Kunori et al., LCG physics validation 9.5.2007; S. Piperov, LCG physics validation 20.6.2007)
- CMS H4 TB 2006 (details in F. Cossuti et al., LCG physics validation 9.5.2007)
- thanks S. Banerjee for CMS summary material

Outline:

- short description of TB setups
- em physics results (only short examples)
- hadronic physics results
- conclusions & open questions

Detectors:



Muon spectrometer

4 super-conducting magnets: solenoid + 3 toroids

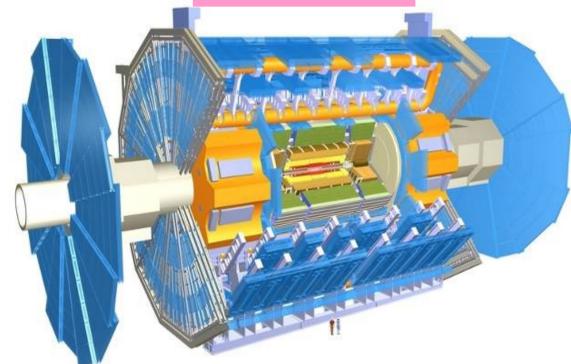
TileCal hadronic calorimeter

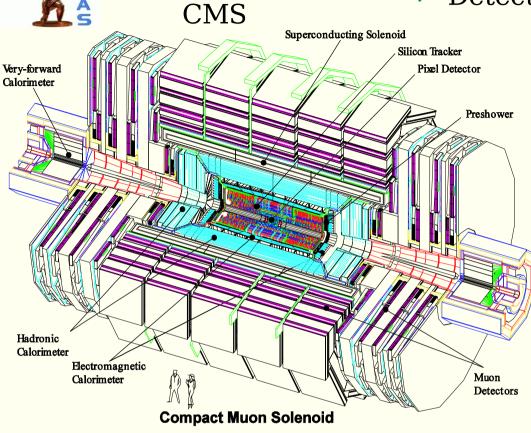
LAr calorimeters (EMC, HC)

Transition Radiation Tracker

Silicon tracker

Silicon Pixel detector

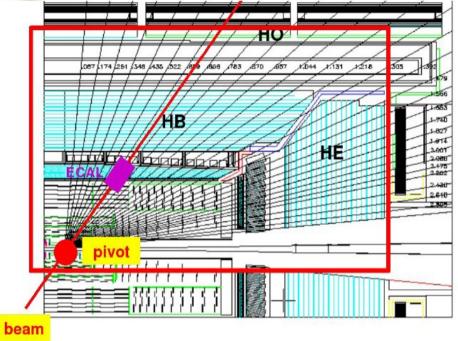




- ◆both are multi-purpose detectors, built on the LHC collider (proton-proton 7+7 TeV)
- primarily for detection of products of proton-proton collisions (ions possible)
- *searches for finalization of Standard Model, or physics beyond it

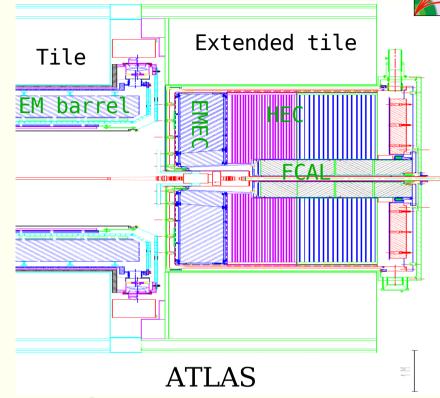


• Detectors:



CMS

- **◆** ECAL:
 - ◆ PbWO4 crystals (7x7 in 2004 and supermodule in 2006)
- **→** HCAL:
 - Brass/Scintillating tiles with wavelength shifter (production modules with final readout electronics). Special readout for longitudinal shower profile studies.
 - Forward region: Iron/quartz fibers



- ◆ LAr calos:
 - EM barrel (Pb accordeon) $|\eta|$ <1.475
 - ♦ EM Endcap (Pb Spanish fan) $1.4 < |\eta| < 3.2$
 - ♦ HAD Endcap (Cu) $1.5 < |\eta| < 3.2$
 - ♦ Forward (Cu, W) 3.2 < |η| < 4.9
- Had. barrel:
 - Scintillating tile / Fe

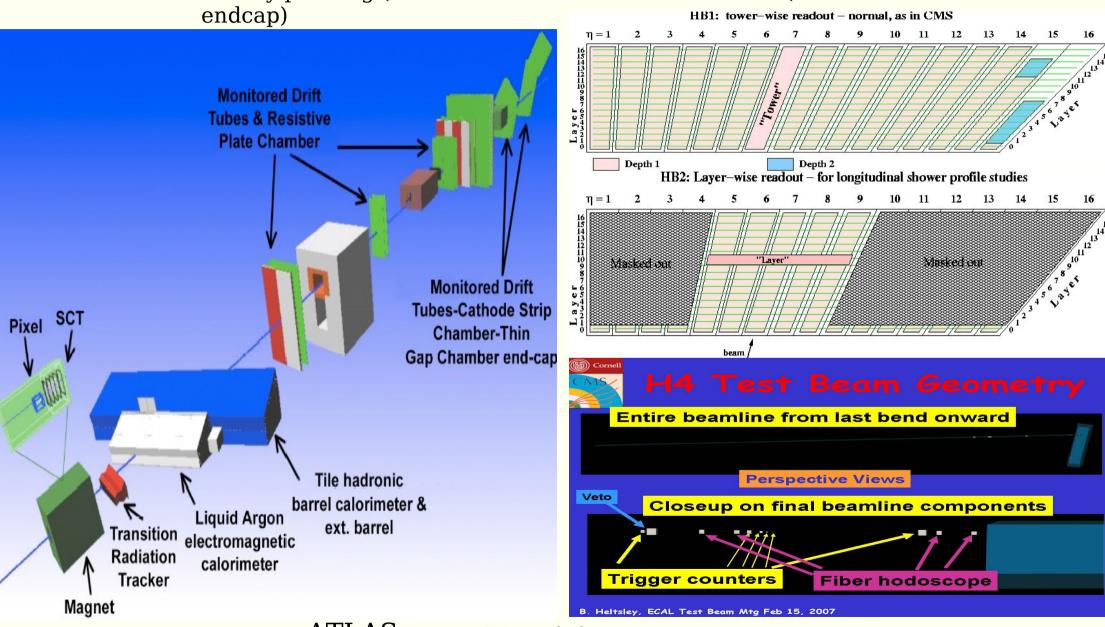




TB setups:

beam instrumentation properly described

ullet usually pointing (beam direction like in final detector (not in the ATLAS

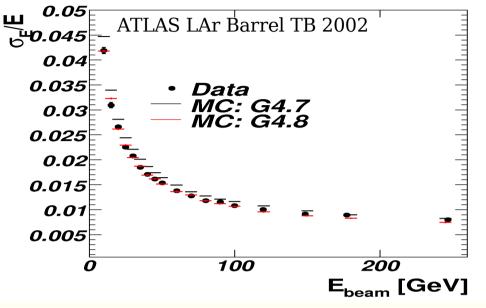


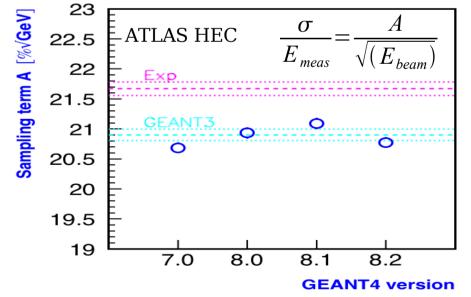
ATLAS

G4 workshop



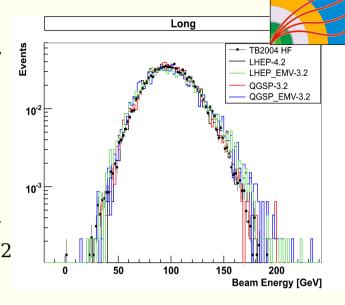


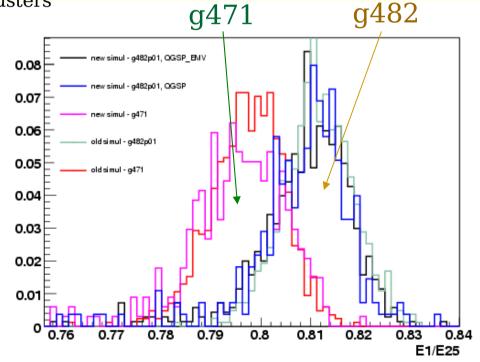




CMS HF 100 GeV e-, good agreement, used to calibrate response

CMS ECAL 50 GeV e-, G4.7.1 vs. G4.8.2 ratio of energies deposited in two clusters



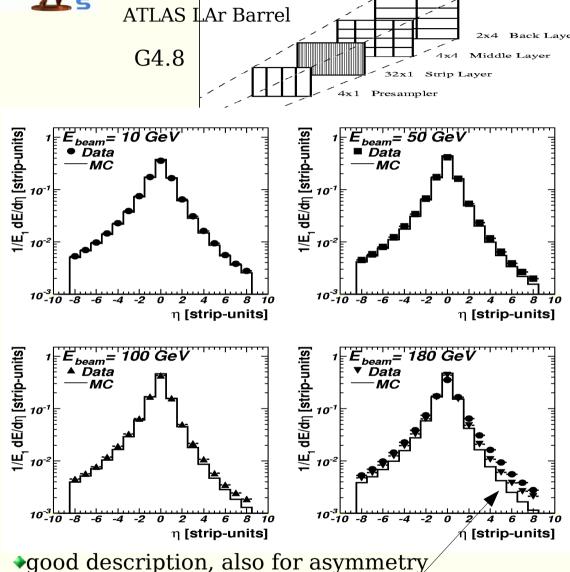


G4 validation with test beam data from LHC calorimetry (ATLAS and CMS)



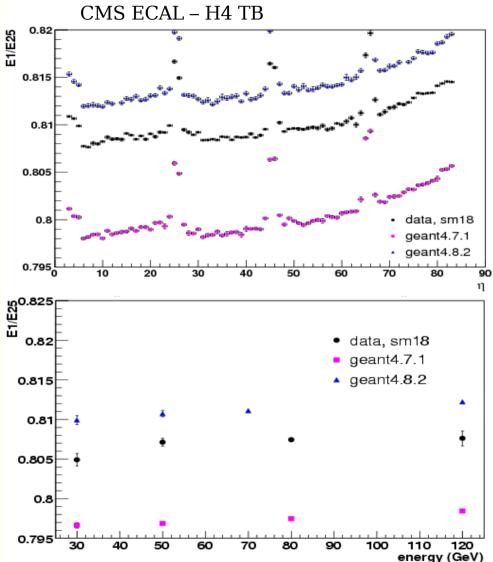
• Electron results (lateral profiles):





- problems in tails at large energy, (could be a detector effect xtalk?), might be a problem for particle ID in Atlas
- MC uncertainty shown, but not visible

 no dependence of the data-simulation offset on the energy
 G4 workshop



◆G4.8.2 closer to data



CMS

7

• Electron conclusions:

- good description of response and resolution of TB data with G4.8.2 for most of the tested setups
- SF agrees better with a first principle calculations now
- only for ATLAS HEC (Cu parallel plates) resolution is too optimistic
- the lateral profiles still shows some discrepancy (in all energies the same for CMS, but only for large energies in ATLAS LAr)
- the CPU penalty introduced with the new MS is partially recovering, for instance for ATLAS HEC simulations,
 - time ratio

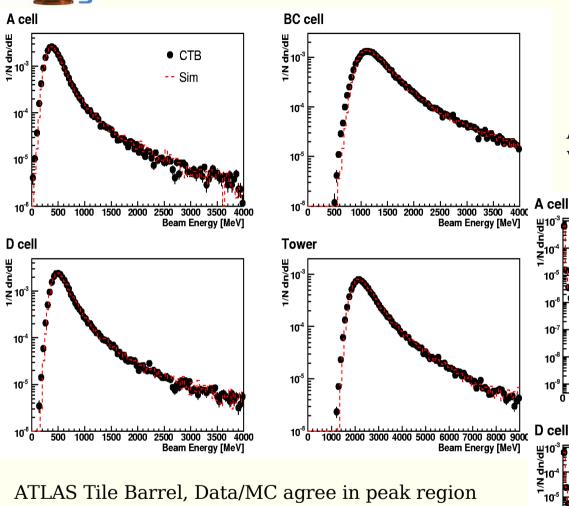
- G4.8.2p1 / G4.8.1.p2 = 0.91
- the preliminary time ratio G4.9.0 / G4.8.1p2 = 0.84





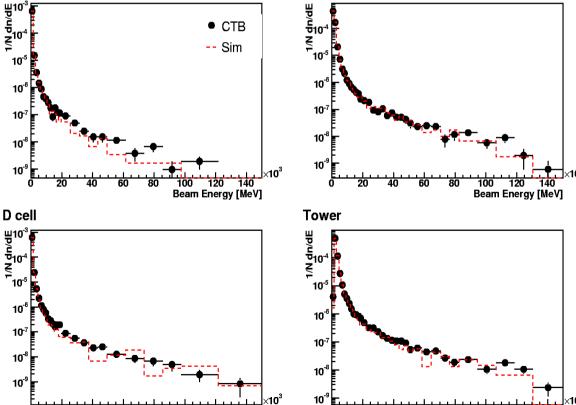


Beam Energy [MeV]



ATLAS Tile Barrel, catastrophic energy losses also well described in MC, 150 GeV beam

BC cell



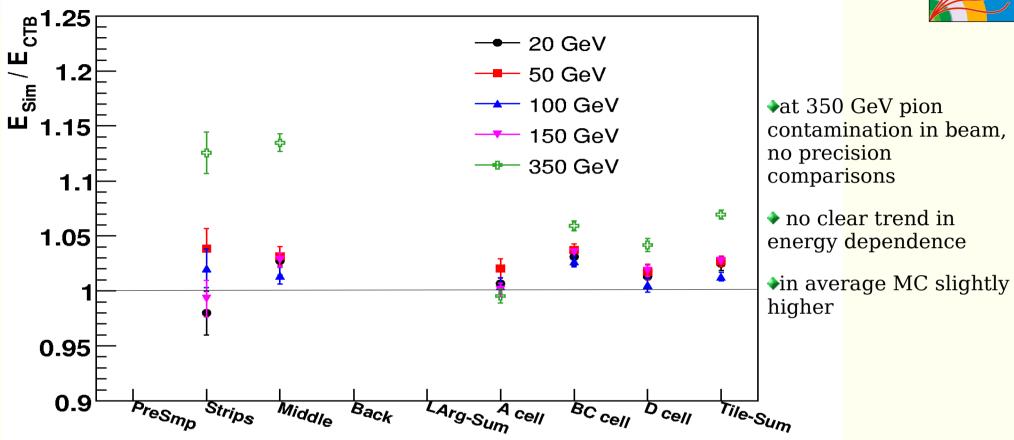
Beam Energy [MeV]

ATLAS Tile Barrel, Data/MC agree in peak region within 15%, data a bit wider, but this could be an instrumental effects. (dist. shifted to agree in peak)

G4.7





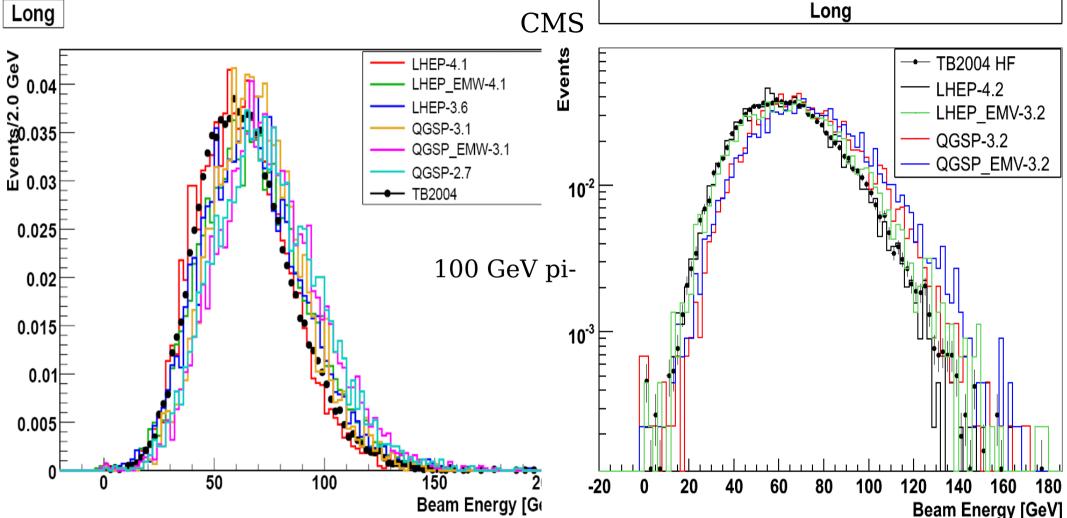


Muon conclusions:

- ◆ G4 describe the measured signal with 2% precision, with uncertainty ~ 1.5% - good quality of G4 (and also of understanding a detector)
- consistency between electron / muon energy deposits (em shower / ionization)



Hadronic results (energy distributions):



HF – quartz fibre calorimeter, sensitive to pi0 in hadronic shower

HF response calibrated with 100 GeV electrons, **G4.8.1p2** used, LHEP agree better with data

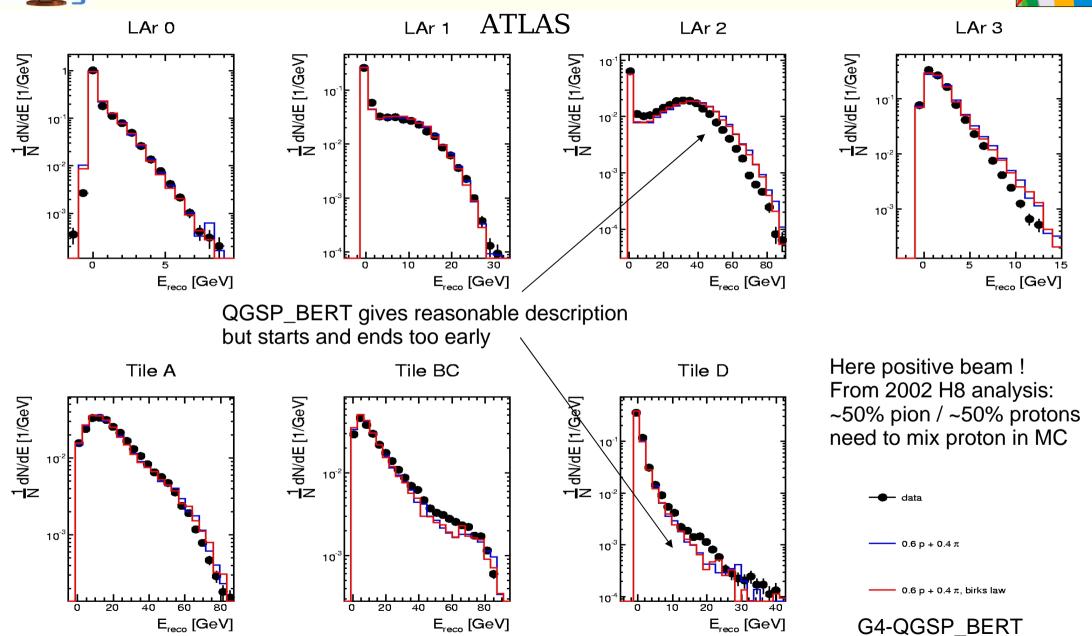
HF response calibrated with 100 GeV electrons, **G4.8.2p2** used, LHEP still better agree with data



Hadronic results (energy distributions):







With/without Birks law

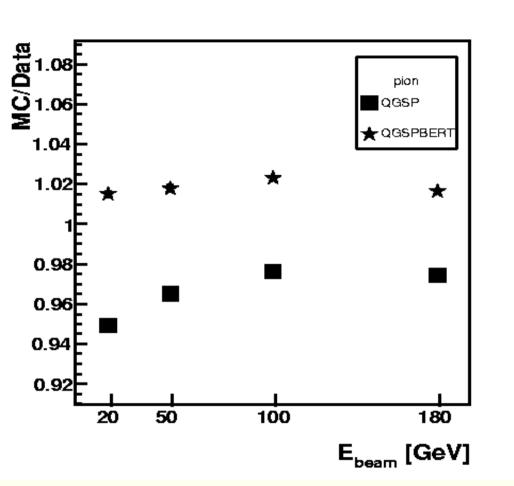
ATLAS Tile

G4.8.3

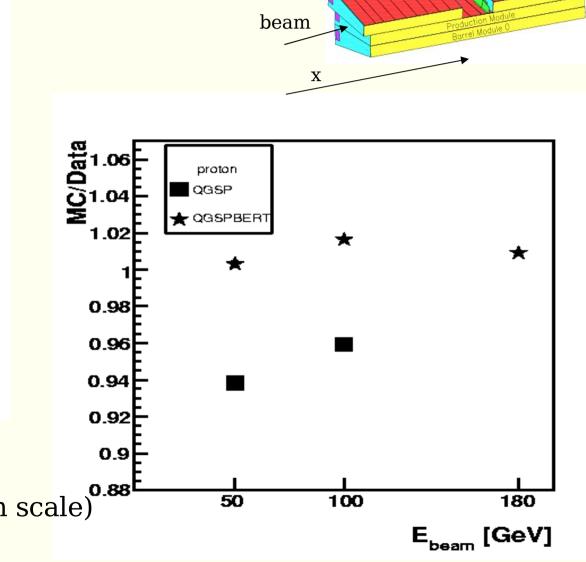








Pion linearity well described Absolute response within 2% (on em scale)

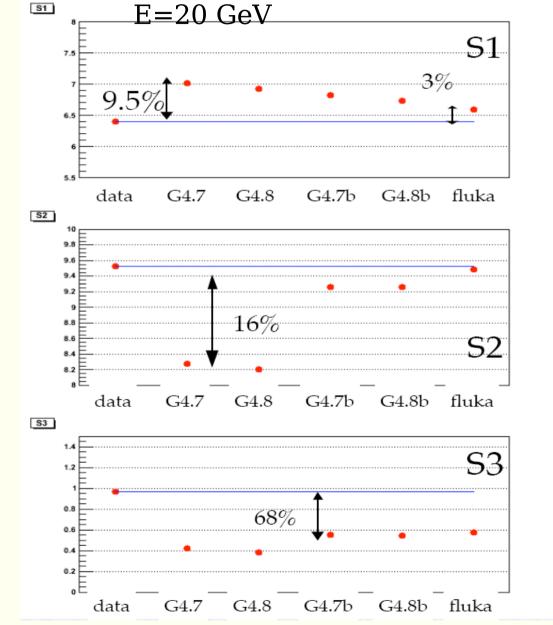




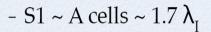
S1

Hadronic results (response):

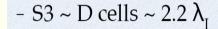
mean in layers

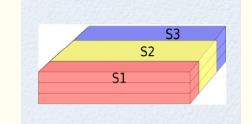


ATLAS Tile projective

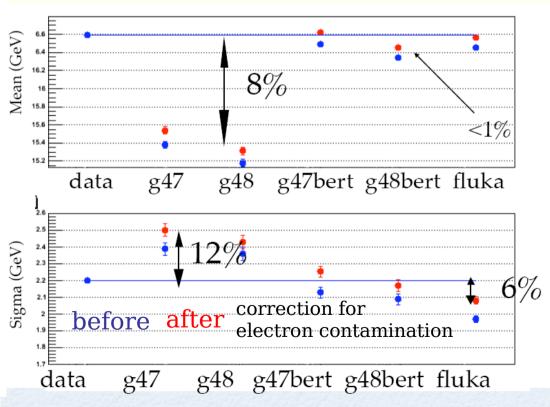


- S2 ~ BC cells ~
$$4.8 \lambda_{\rm r}$$





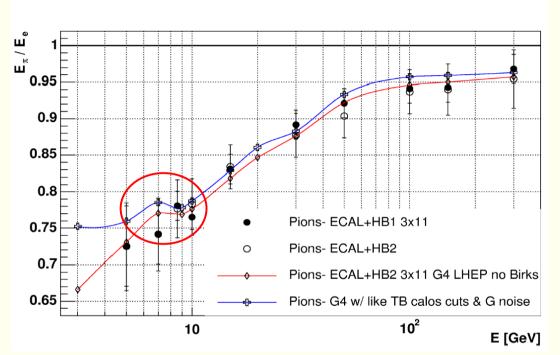
pion response:





Hadronic results (e/pi ratio):

pi/e TB HB2 vs G4 LHEP (no Birks law)

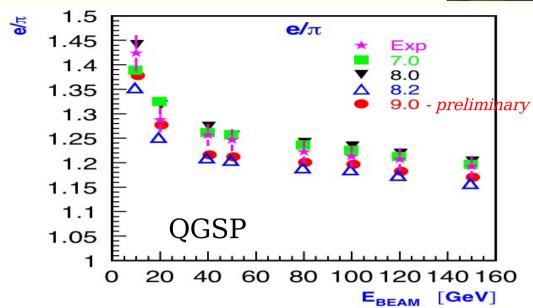


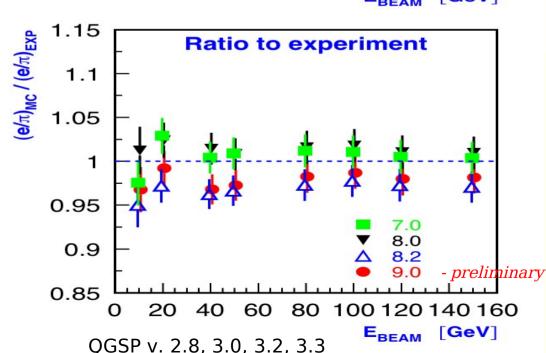
CMS

G4.6.2

LHEP - good agreement with data, except for p<10GeV.

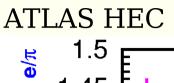
ATLAS HEC

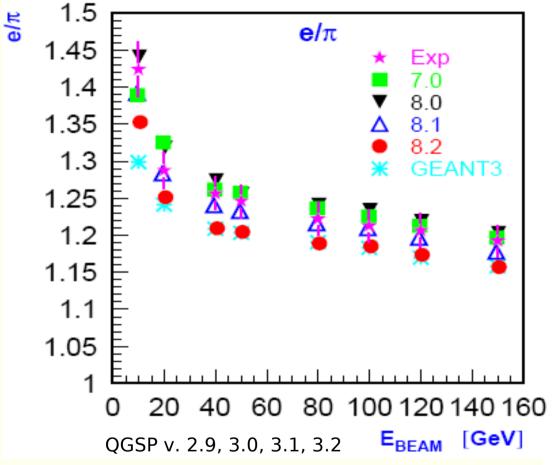


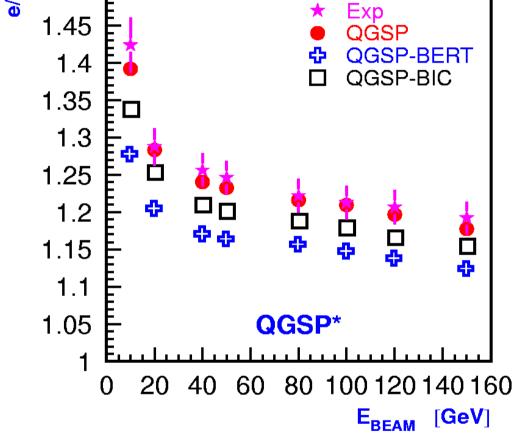




Hadronic results (e/pi ratio):







- ◆G481: pion response well described by QGSP, Bertini too high (resolution to good)
- ◆Shower shape too short in QGSP, good with Bertini
- ◆But why change 8.1->8.2 ? Only elastic scattering changed...
- ◆To be understood

- Adding cascade models response is increased by \sim 5% (effect can be partially recovered by introducing Birks law – next slide)
- Resolution becomes smaller and does not agree with data



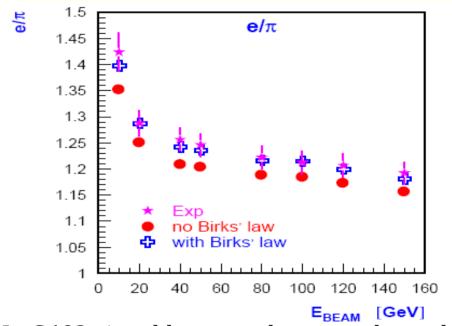
Birks law

CMS promps unry preduce

LAr recombination depends on particle energy loss

$$\frac{Q}{Q_0} = \frac{A}{1 + k dE/dx}$$

ATLAS HEC



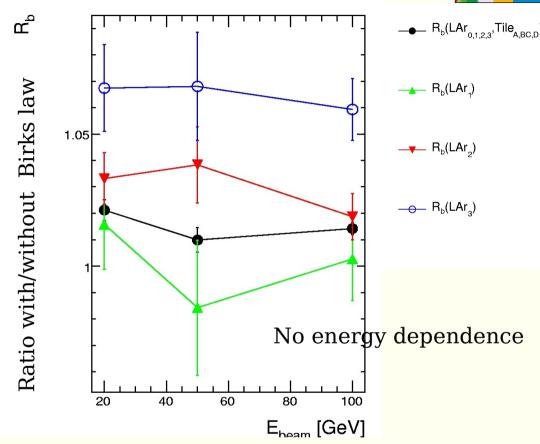
In G482 signal becomes larger and resolution smaller, not yet understood (only change in elastic scattering).

Shower shapes similar in G481 and G482

QGSP_G481 ~ QGSP_G482 + Birks (recover response, and partially resolution)

For QGSP_BERT therefore still discrepancy to data, no consistent picture

ATLAS LAr/Tile



LAr Barrel: effect few percent, shifts MC towards data



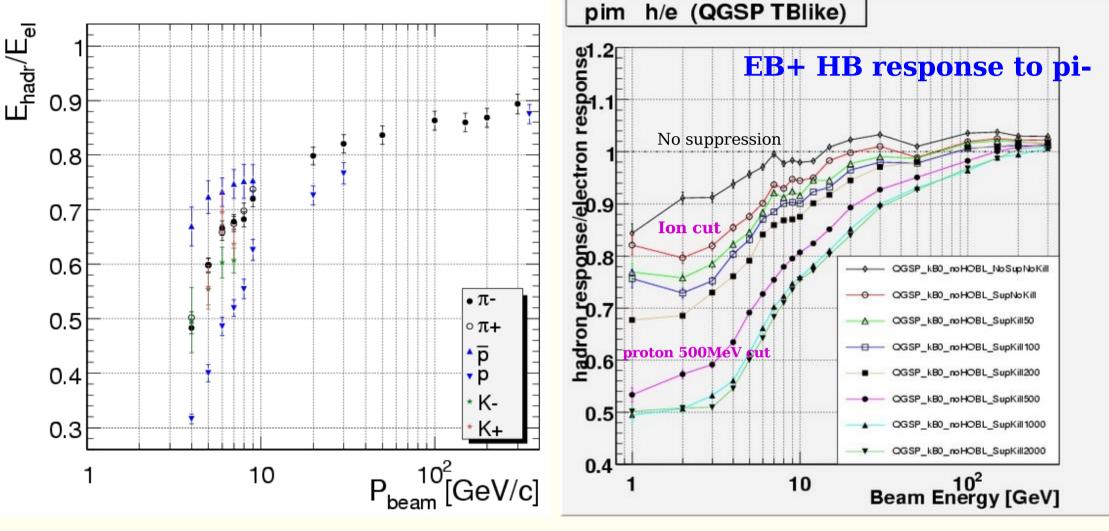


Hadronic results (had/e ratio):

CMS TB 2006

G4.8.1





example from TB2006 – suppressing slow and heavy particles helps to get better profile for had/e ratio.. Possible reason, see next page

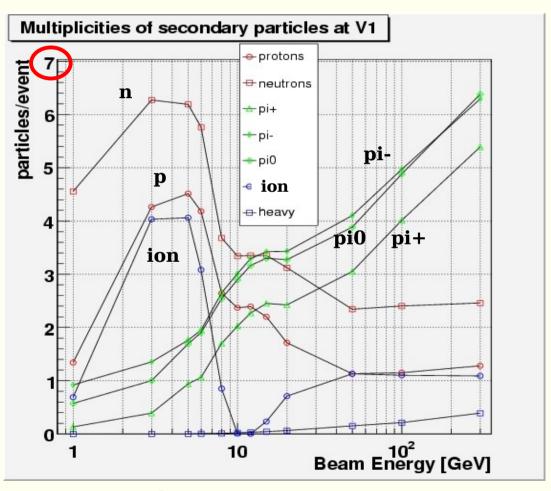


Hadronic results (had/e ratio): CMS TB 2006



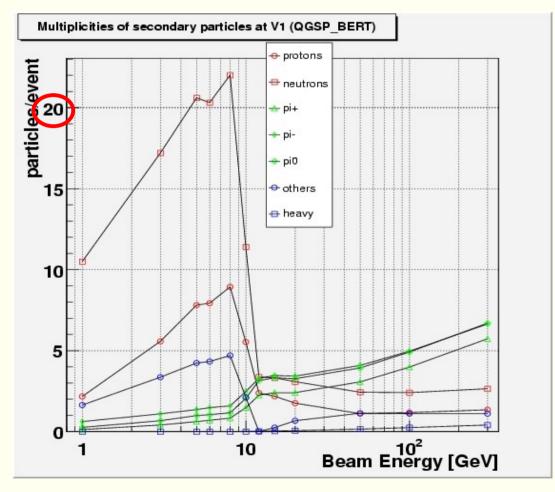
Multiplicity of Secondary Particles at First Interaction Point

QGSP



too much neutrons/protons/ions?

QGSP-BERT



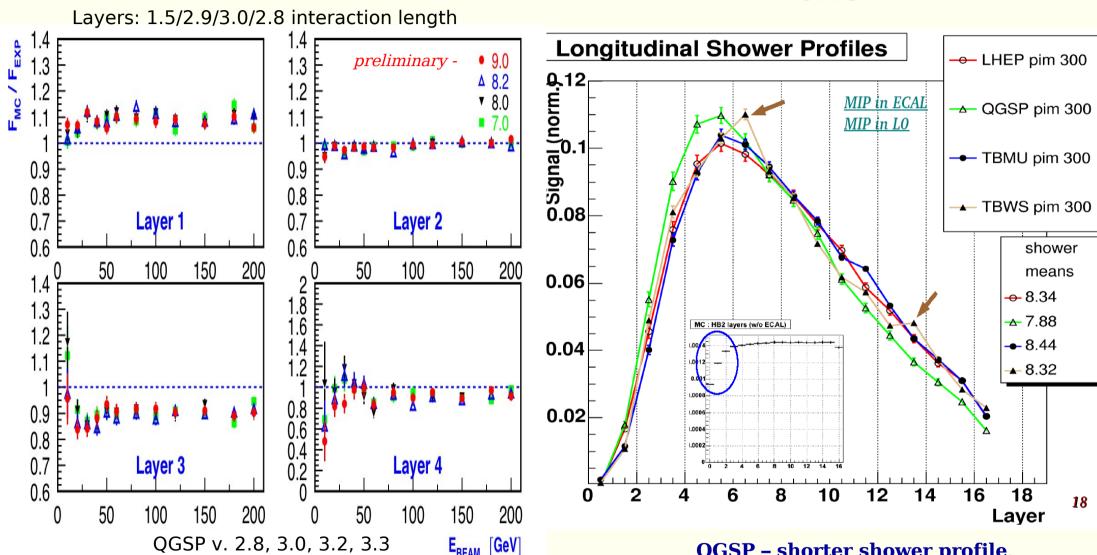
pion production not smooth at 10-20 GeV?



CMS

Hadronic results (longitudinal profiles):

ATLAS HEC CMS



G4.9.0 should contain new quasi-elastic, and therefore have longer shower (seen in ATLAS Barrel). But not for copper calorimeter - study by A. Ribon

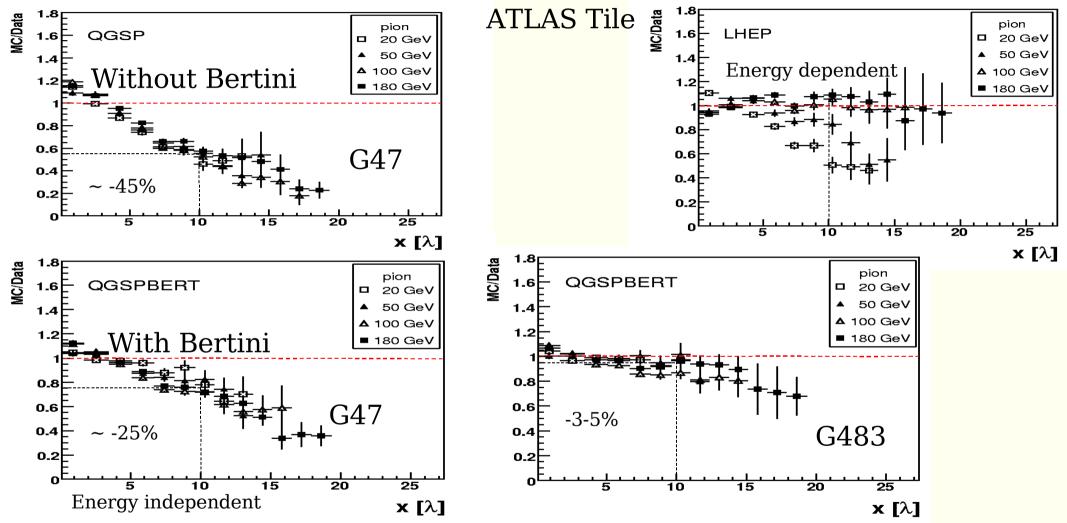
QGSP - shorter shower profile.



CMS

20

Hadronic results (longitudinal profiles):



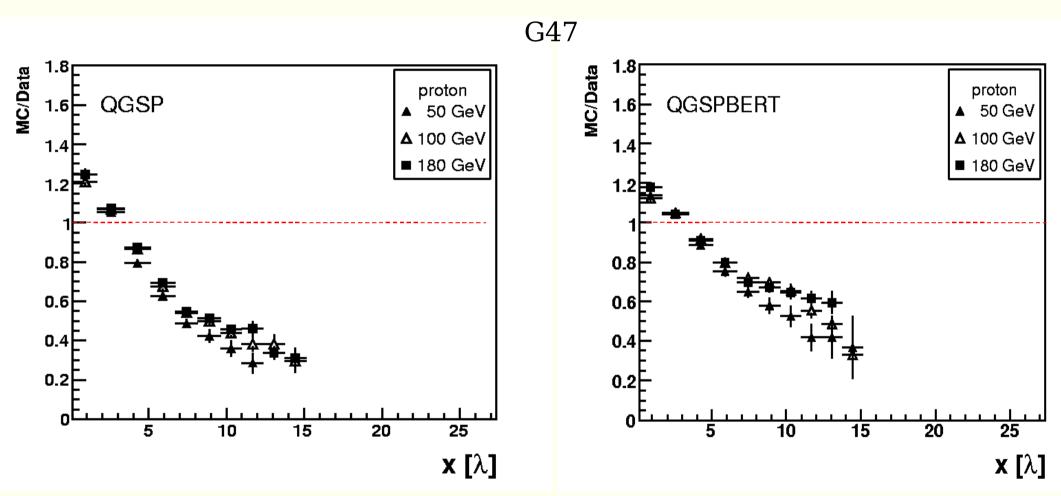
- *QGSP predicts too short showers, LHEP describes shower profile at high energies quite well.
- ◆G4.8.3 introduced new quasi-elastic scattering, seems to help here (but not with proton see next pages)
- ◆Nuclear cascade model make shower longer and better describe the data





Hadronic results (proton longitudinal profiles):

ATLAS Tile

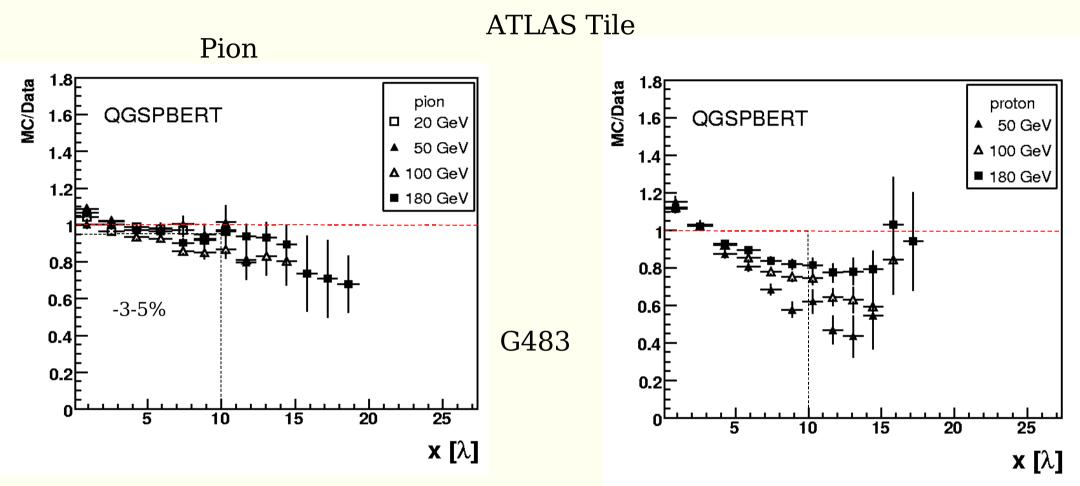


◆QGSP and Bertini similar behaviour like for pions - predicts too short showers, nuclear cascade improve a situation slightly



CMS

Hadronic results (longitudinal profiles):



- ◆Introducing new quasi-elastic scattering, seems to help much less for protons?
- Energy dependency for protons?



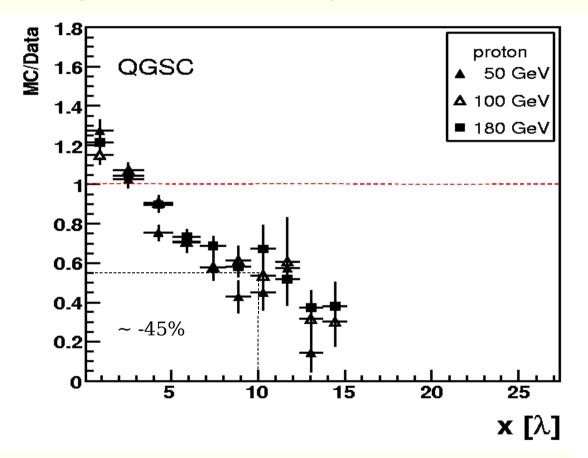
Hadronic results (longitudinal profiles):

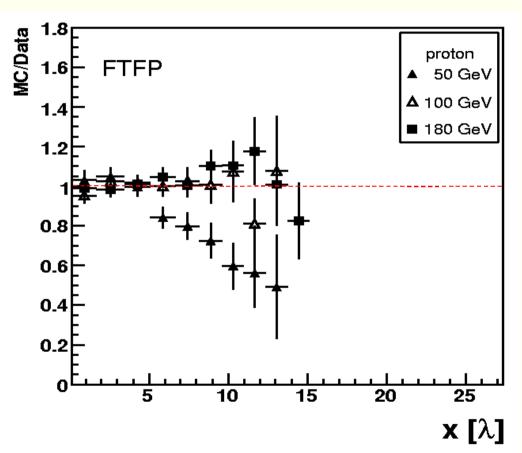


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ATLAS Tile

First glance to G49: (only 1k events available)

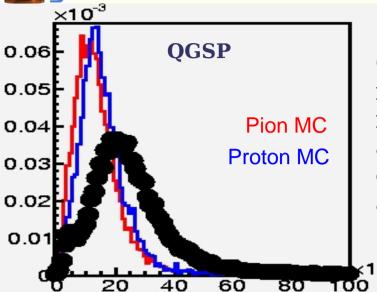




G49 ~ G483 (to be confirmed with more statistics) Some interesting new physics list appearing.

Fritjof model very good at large energy, still bad at 50 GeV → would like to discuss with G4 experts

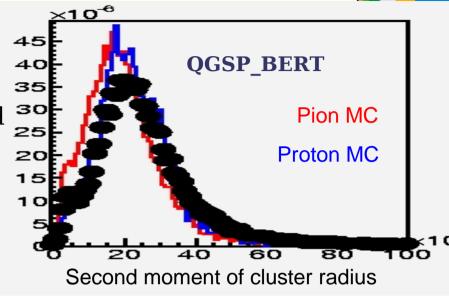


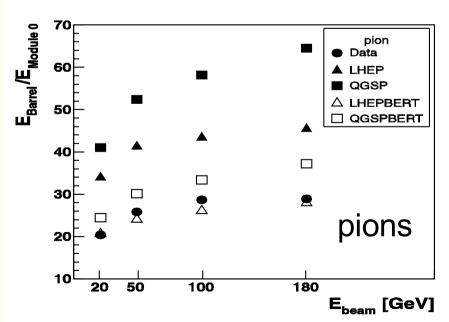


E=100 GeV
Good description, if pion/proton mix

in beam is considered and Bertini nucleon cascade model is assumed

ATLAS LAr/Tile G4.7

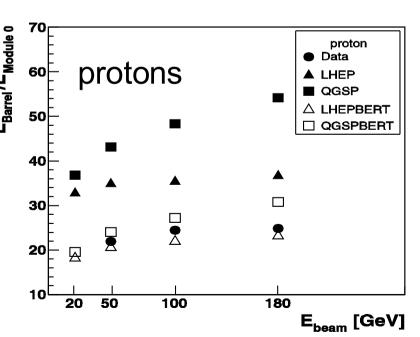




QGPS and LHEP predict too narrow showers.

ATLAS Tile

The description much improves with the Bertini model.



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G4 workshop



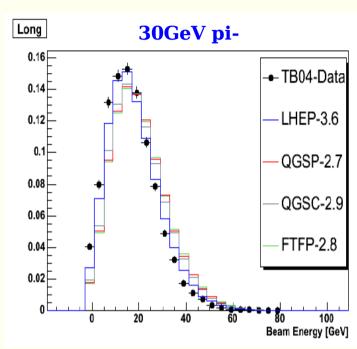


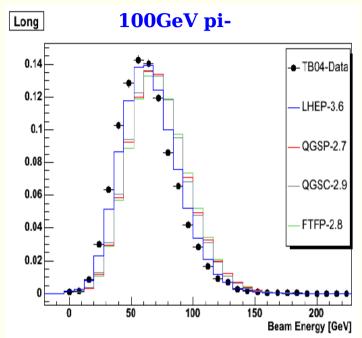


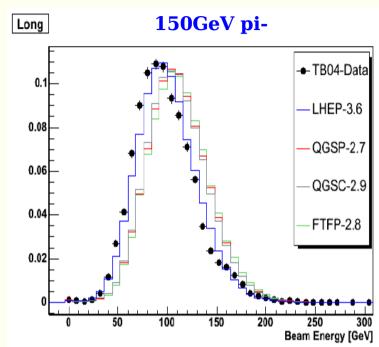
Hadronic results (energy resolution):

CMS

G4.7.0







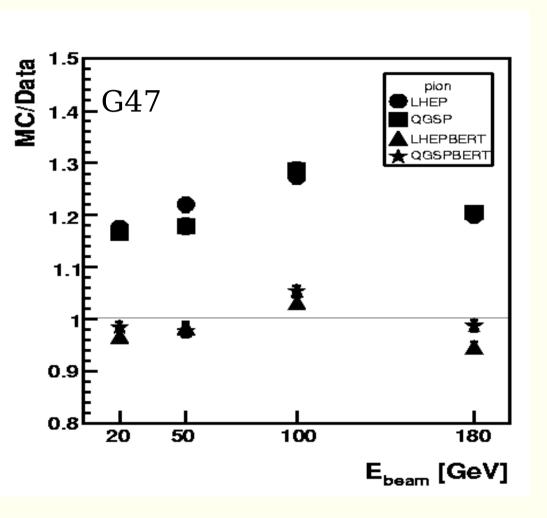
- ◆Resolution better described with LHEP
- ◆others too much pi0

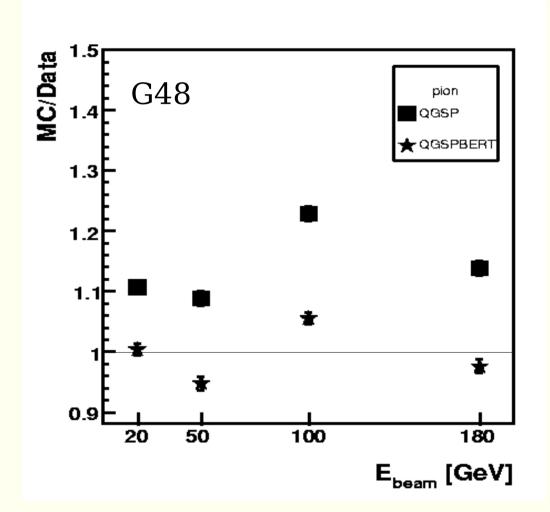


Hadronic results (energy resolution):



ATLAS Tile



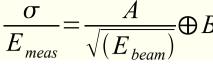


Resolution better described with Bertini in G47 and G483

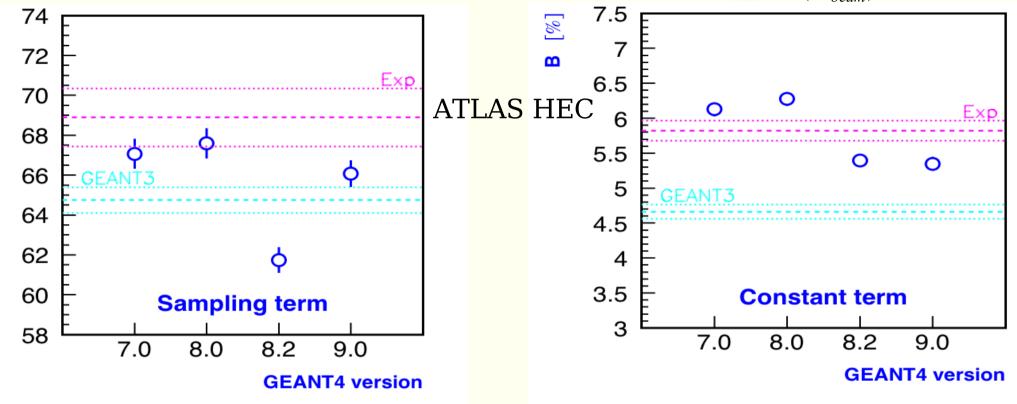


 $[\%\,\mathrm{GeV}^{1/2}]$

• Hadronic results (energy resolution):







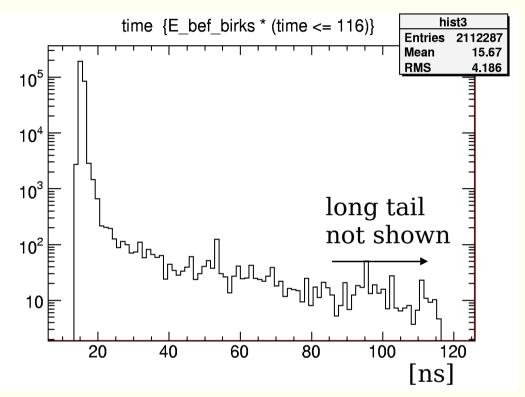
G4.9.0 results are preliminary, but clean recover of sampling term seen

Physics lists used: QGSP v. 2.8, 3.0, 3.2, 3.3

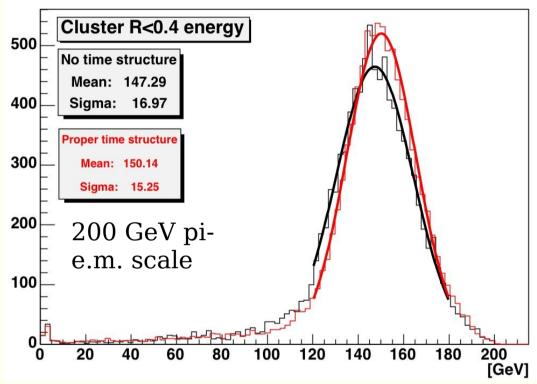


Hadronic results (time structure):

ATLAS LAr Barrel



ATLAS LAr Endcap



- ◆A lot of hits are out of time, but most of them have low energy
- ◆It was treated differently so far Tile used proper time structure LAr/Tile CTB not, LAr Endcap also not
- ◆Does G4 predict the correct time?

- LAr Endcap TB difference is ≈2% on scale and $\approx 1.3\%$ on resolution, both on e.m. scale
- LAr/Tile Barrel effect ≈1% on scale





Hadronic results, conclusions:

- ◆not so clear picture
- ◆response and resolution:
 - ◆ LHEP O.K. for CMS, in ATLAS only for HEC resolution
 - ◆ QGSP O.K. for response and resolution ATLAS HEC, but problems if adding Bertini
 - ◆ QGSP_BERT O.K. for ATLAS Tile, linearity excellent, only absolute energy too high ≈2%
- ◆shower profile:
 - QGSP starts and ends too early for all tested setups
 - ◆ LHEP O.K. for CMS and ATLAS Tile (some problems in energy behaviour), for ATLAS HEC at small energies rather close to QGSP, whereas at high energies it predicts a later start of the shower
 - ◆ LHEP below 10GeV problem in CMS (energy excess), too much slow protons/ions?





Hadronic results, conclusions:

- ◆shower profile (cont):
 - ◆Bertini model widens shower longitudinally and laterally:
 - ◆ for ATLAS setups better agreement with data (from 8.3 good agreement for ATLAS Tile)
 - ◆ improves the situation (for both pions and protons), new quasielastic scattering improves for pion, but not for proton ?
 - but HEC problems in response and resolution
- ◆CPU time is an issue starting from 8.1
- •first hints from 9.0 shows some improvements for CPU performance, to be tested in more details
- ◆Fritjof model looks good in 9.0 ATLAS Tile (small statistics so far available), to be studied further for other setups
- ◆how well the time structure of energy deposits is modelled?(Important for pile-up studies and proper digitization simulation)



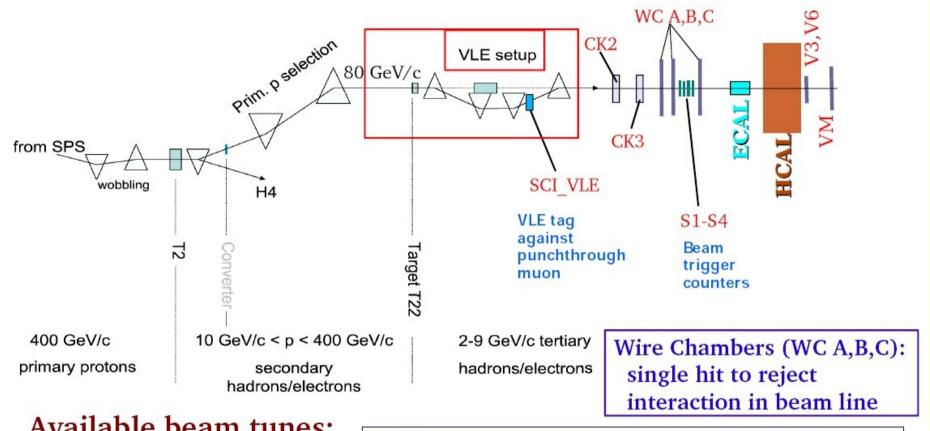


BACKUP SLIDES



CMS H2 beam line





Available beam tunes: pions 2-300 GeV muons 80/150 GeV electrons 9-100 GeV

P-ID:

Cerenkov counter (CK2) - electron Cerenkov counter (CK3) - pion / kaon / proton Scintillators (V3, V6, VM) - muon tagging

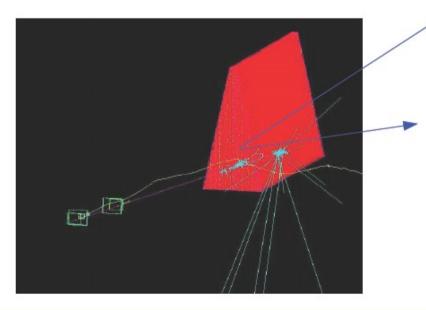


CMS

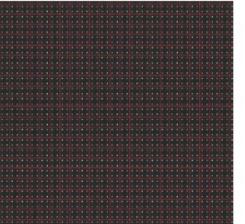


HF Test Beam Setup

One wedge and beam line elements.







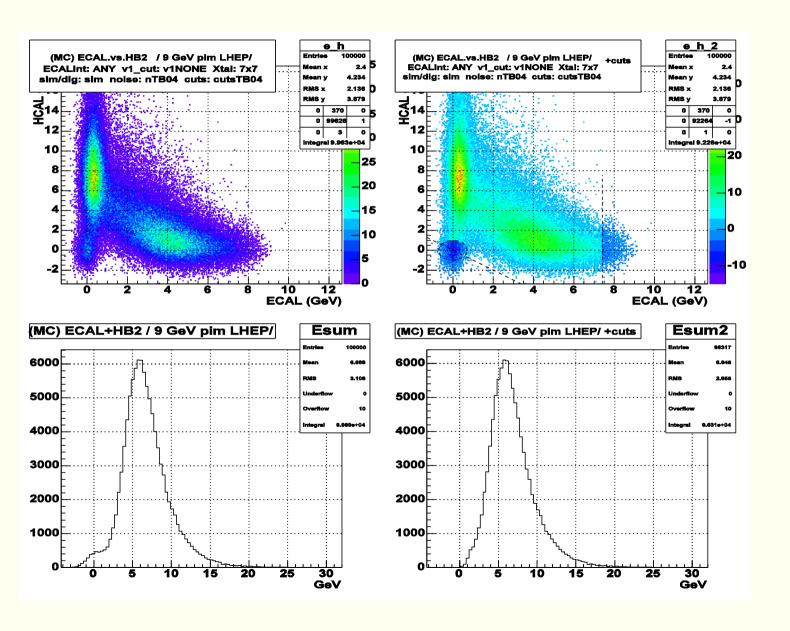
 $\begin{array}{l} 5~mm~x~5~mm~fiber\\ segmentation \end{array}$

... L S L S L S S L S L S L ...





CMS H2 beam line, cleaning of data

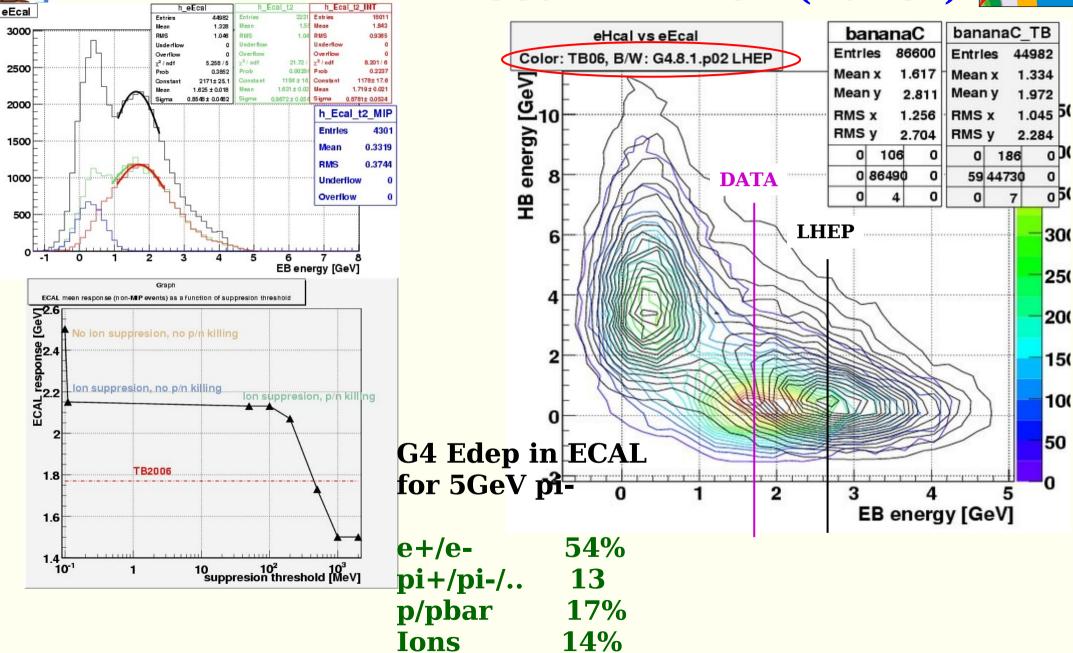


Calorimeter based cuts are necessary to clean up the beam interacted particles. These introduce systematic errors, but are the only way to enable comparison with TB data.



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5GeV Pi- in ECAL(PbWO4)

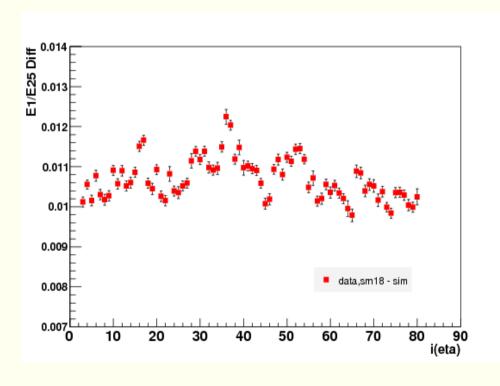


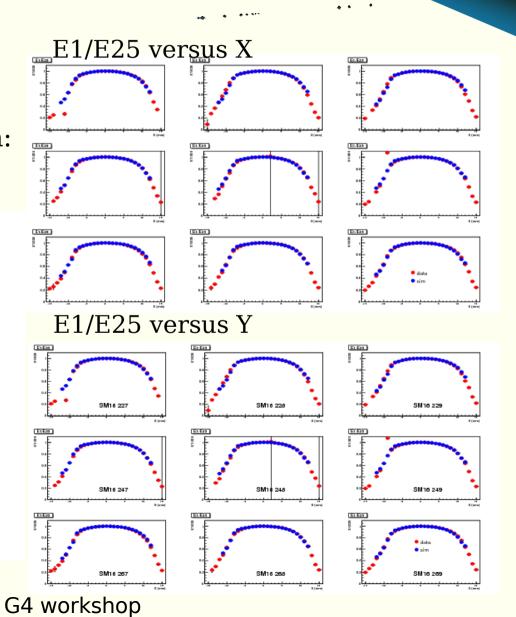
P. Strizenec, Hebden Bridge 13/09/07

G4 validation with test beam data from LHC calorimetry (ATLAS and CMS)

The CMS ECAL H4 testbeam simulation

data – simulation, difference in the containment vs eta: no evident trend is visible





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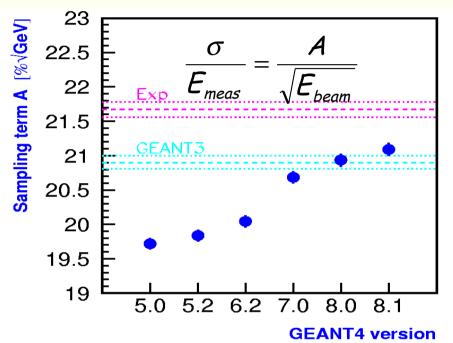


CMS

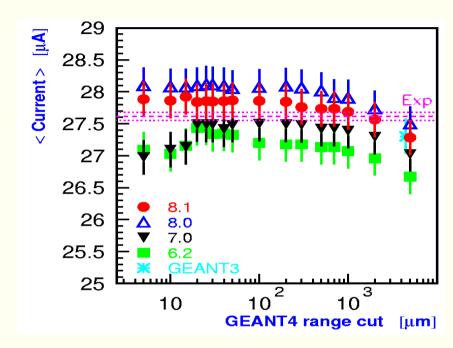
37

ATLAS HEC

Electron resolution



Electron signal in one cell



Performance of em physics in ATLAS:

- 1) larger visible energy, larger sampling fraction in agreement with first principle calculations
- 2) better description of resolution:
- 3) Consistency between electron and muon energy deposits (em shower/ionization)
- 4) no change in shower shapes observed so far
- 5) CPU increase 50-100%.

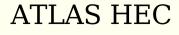
ATLAS Lar Barrel: good description of energy response, resolution longitudinal and radial profile using G4.8

ATLAS HEC: G4.8 improves over G4.7, resolution a bit too good in MC FCAL: sampling fractions and resolution in better agreement using G4.8

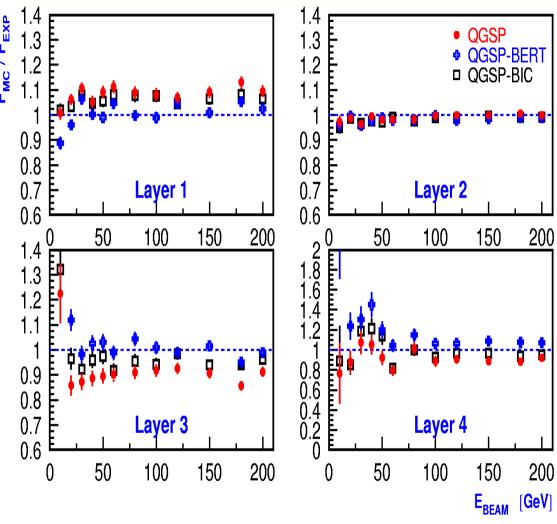




38

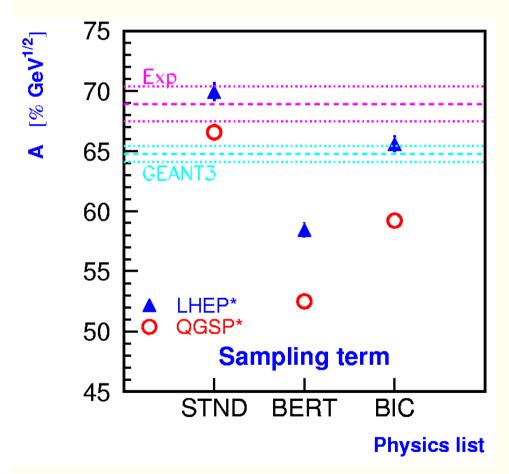






Adding nuclear cascade models gives good description of data.

Resolution

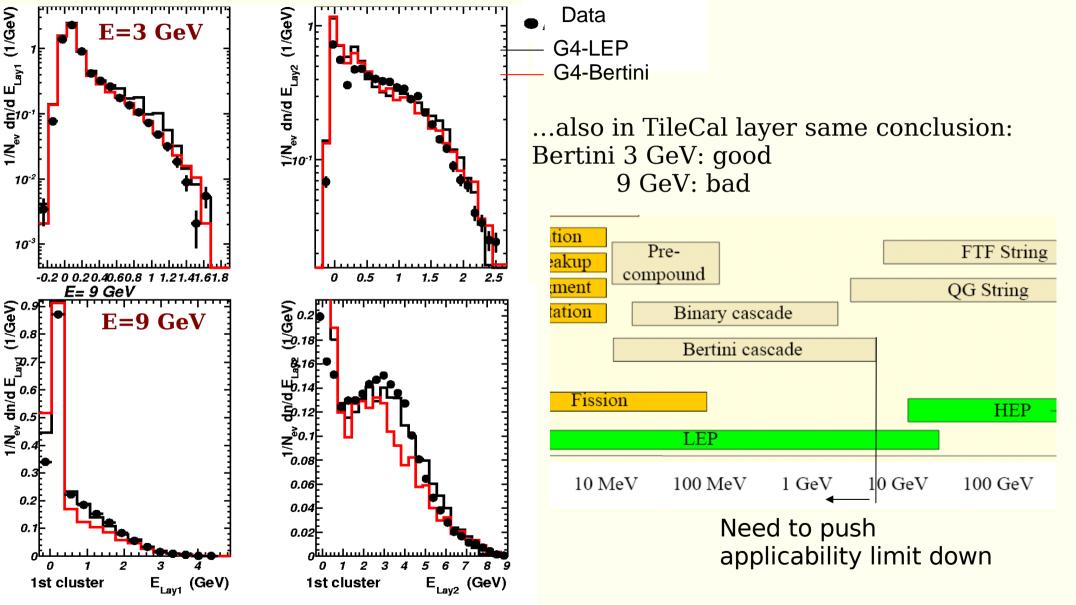






LAr/Tile Barrel CTB 2004: Pion Layer Energies



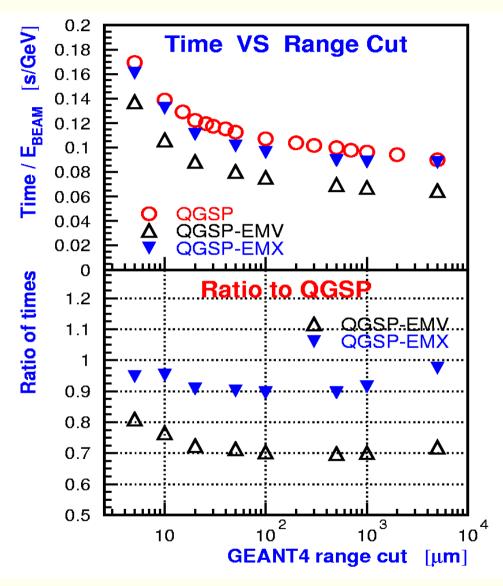


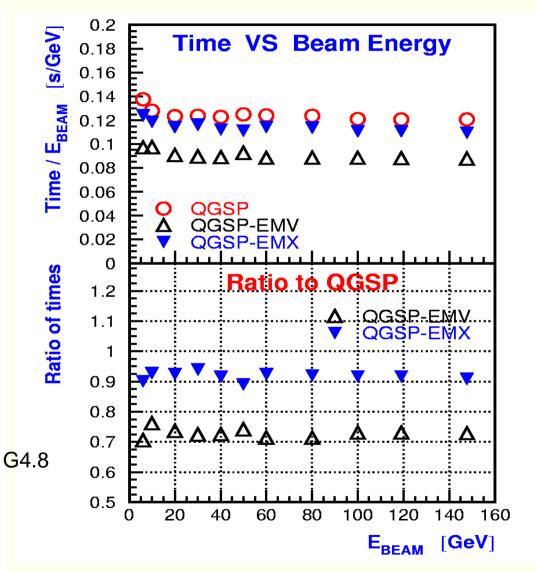




ATLAS HEC: Timing Performance











ATLAS HEC: Timing Performance



