Preliminary comparison between GEANT4, Fluka and the TileCal 2002 Test Beam data

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• integration of Fluka in the test beam Monte Carlo machinery
• Some details on the analysis
• Total energy distribution
  - 20 GeV
  - 50 GeV
• Shower shape (at 20 GeV)
  - lateral end longitudinal shape
  - longitudinal shape correlations
The 2002 Test Beam:

- 4 TileCal modules stacked together
- Projective particle beam
  - Electrons, pions, muons, and protons
  - Wide range of energies 2-350 GeV
• Be able to compare simulations results from Geant4 and FLUKA with data in the context of the ATLAS Tile 2002 test beam.

• To come up with a reusable machinery which is as much as possible application-independent:
  - In order to reduce implementation effort (and number of possible bugs) the maximum number of elements should be common to both G4 and FLUKA applications:
    ✓ common source of geometry
    ✓ same format of the simulation output allowing common digitization/analysis
  ✓ Main principles:
    ✓ Use GDML+FluGG+FLUKA to create FLUKA-hits with the material & geometry extracted from the G4 simulation of the TB.
    ✓ Re-use as much as possible the work done for the Geant4 and data comparison: re-create the same ntuples, use the same macros for the analysis.
FluGa Geant4 Geometry Interface
(FluGG) developed by P. Sala and S. Vanini
- allows running FLUKA with Geant4 geometry
  - FORTRAN - C++ interface allowing to 'plug' Geant4 geometry into FLUKA
- all the steering still done through FLUKA input cards
- all the output as in native FLUKA
  - configurable through input cards, based on FLUKA 'user routines'

- very useful tool, but a few things need to be added for the purpose of G4 - FLUKA validation:
  - Geometry is not always available in form of G4Classes (=> GDML)
  - Mimic of the G4 sensitive detectors
  - HitsManager
  - Root I/O hit persistency
GEANT4 SIMULATIONS AND FLUKA HIT ANALYSIS

- **G4 simulations:**
  - The geometry in use by the old Tile 2002 TB was ported (V. Tsulaia) to the ATHENA framework (ATLAS framework for event processing).
  - A G4Atlas application was assembled: the easiest way to use the latest G4 versions and (if needed) access to the digitization and reconstruction in use by the ATLAS exp.

- **Geometry exportation:**
  - Once the geometry is loaded into the Atlas G4 application it can be exported in xml format using the GDML writers. Fluka+Flugg can read the GDML geometry using the GDML readers.
  - Any mismatch in between the geometries used by G4 and FLUKA will be detected at the time the FLUKA hits are processed.
  - The read-out geometry (complex) implemented in the G4 SD is not exported.
    - The FLUKA-hits (pre/post step, PDG, energy, time) are read into the G4Atlas application and processed using the G4SD.
    - The process of FLUKA or G4 produces always the same TileHitVector container — we can use the same digitization, reconstruction and analysis

- **Analysis:**
  - Can be done at the step level, hit level or after digit+reconstruction
  - To reproduce the Tile2002 analysis a specific G4UserAction was created. It produces paw tuple information at the level of the energy-hit.

More information can be found in W. Pokorski and M. Gallas presentations at LCG Physics Validation Meeting 25 January 2006: [http://indico.cern.ch/conferenceDisplay.py?confId=a06408](http://indico.cern.ch/conferenceDisplay.py?confId=a06408)
**Monte Carlo Data**

- One position of the Tile calorimeter at $\eta = 0.35$
- The coordinate system has (0,0,0) at the center of the central barrel module 1, below we have the module 0 and on top two extended barrels.
- Particle gun:
  - PDGs: $+11, -211, +211, 2212, +13$
  - beam spot flat at -3000 mm ($z$ and $y$ in $[-16,9,16,9]$ mm)
  - beam smearing in theta and phi
  - constant energies: 20-350 Gev.

**Geant4**

- Two versions:
  - geant4-07-patch-01 (25 Oct 2005)
  - geant4-08-01-patch-01 (27 Jul 2006)
- Two physics lists: QGSP, QGSP_BERT
- ATLAS standard cuts of 1mm.
- Birks' law implemented in the G4 sensitive detector.
- Time cut in the hit collection 200ns

**FLUKA**

- One version:
  - FLUKA-2006.3
- Configuration card: CALORIMEter
- Cuts suggested by Paola Sala (100kev for $e^+$ and 5 kev for gammas)
- Birks' law (quenching) implemented in FLUKA.
- Time cut in the hit collection 200ns
CALIBRATION

• Energy measured summing over 3 half-modules (-0.7 < \( \eta \) < 0)

• residual pedestal (small) subtracted from data

• data and MonteCarlo are both calibrated at nominal beam energy (20 GeV electrons)
CORRECTIONS

electronic noise is measured on data and a correspondent gaussian noise is added to the simulations to account for the effect of photostatics we also add a poissonian fluctuation to the MC (70.7 photoelectrons per GeV).
the total energy depends (~5%) on the impact point due to the periodic TileCal structure. Electron data and simulations are both corrected (pions do not suffer from this effect since their shower is larger)
PARTICLE SELECTION

• 20 GeV ($\pi^-$ run)
  - Cherenkov counter to separate e/\(\pi\) (4.9% residual electron contamination in pions)
  - anti-proton contamination is negligible
  - muon are easily removed (calorimetric cut)

• 50 GeV ($\pi^+$ run) preliminary results
  - Cherenkov used to identify protons
  - we use two variables related to the shower shape ($C_{\text{long}}$ and $C_{\text{tot}}$) to separate e/\(\pi\)
20 GeV ELECTRONS
Data MC simulation mean values at 20 GeV are fixed by the calibration

- MC Calib: 36.80
- Mean: 19.99 ± 0.02
- Sigma: 1.571 ± 0.018

- MC Calib: 33.07

- MC Calib: 34.03
- Mean: 19.95 ± 0.02
- Sigma: 1.427 ± 0.017
GEANT 4.8 has the better agreement with our data.

No residual pion contamination in electron run considered.

Statistical errors only.
20 GeV pions
20 GeV PIONS: TOTAL ENERGY

- **g47**
  - Constant: $165.9 \pm 4.4$
  - Mean: $15.36 \pm 0.03$
  - Sigma: $2.39 \pm 0.03$

- **g48**
  - Constant: $167.5 \pm 4.3$
  - Mean: $15.14 \pm 0.03$
  - Sigma: $2.359 \pm 0.029$

- **g47bert**
  - Constant: $184.1 \pm 5.0$
  - Mean: $16.43 \pm 0.03$
  - Sigma: $2.129 \pm 0.024$

- **g48bert**
  - Constant: $187.8 \pm 4.9$
  - Mean: $16.29 \pm 0.03$
  - Sigma: $2.089 \pm 0.024$

- **fluka**
  - Constant: $199.8 \pm 5.4$
  - Mean: $16.45 \pm 0.02$
  - Sigma: $1.97 \pm 0.02$

- **g45**
  - Constant: $175.2 \pm 4.4$
  - Mean: $14.93 \pm 0.03$
  - Sigma: $2.263 \pm 0.027$
we can study the residual contamination of electrons in pion beams using combination of calorimetric ($C_{\text{long}}$ and $C_{\text{tot}}$) and Cherenkov cuts

- Residual electrons in pion runs
  - using $C_{\text{long}}$ and $C_{\text{tot}}$: 2.7%
  - using Cherenkov gives: 4.9%
- At 20 GeV beam polarity is negative (very few anti-protons expected)
We study the effect of contamination on mean and sigma of the pion energy distribution adding the expected fraction of electrons to the correspondent pion sample.

Example: effect of a 10% electron contamination.
Electron contamination

Expected Residual Contamination

+0.7%

GEANT 4.7

No contamination

+4.7%
Comparison with the data

- Mean value is increased, we get a better MC/data agreement
- Sigma becomes larger, resulting in better or comparable agreement for GEANT+Bertini and Fluka

Before and after adding the electron contamination

<table>
<thead>
<tr>
<th></th>
<th>data</th>
<th>g47</th>
<th>g48</th>
<th>g47bert</th>
<th>g48bert</th>
<th>fluka</th>
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<tbody>
<tr>
<td>Mean (GeV)</td>
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<td>Sigma (GeV)</td>
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50 GeV Pions
(Preliminary Results)
EXPERIMENTAL ISSUES

- Cherenkov used to reject protons -> variables related to the shower shape are used to separate pions from positrons
  - mean value affected at 1% level
  - 5% uncertainty over the width
  - positron residual contamination (~2.7%)
- **Caveat**: the cut is not applied to MC (would induce a bias dependent on the how well the shape is reproduced, need a more detailed study)
50 GeV Pions

**g47**
- Constant: $218.5 \pm 6.0$
- Mean: $40.36 \pm 0.05$
- Sigma: $4.664 \pm 0.051$

**g48**
- Constant: $211.8 \pm 5.8$
- Mean: $40.15 \pm 0.05$
- Sigma: $4.614 \pm 0.053$

**g47bert**
- Constant: $241.1 \pm 6.6$
- Mean: $42.58 \pm 0.05$
- Sigma: $4 \pm 0.0$

**g48bert**
- Constant: $248.3 \pm 6.8$
- Mean: $42.36 \pm 0.05$
- Sigma: $3.904 \pm 0.044$

**fluka**
- Constant: $275.8 \pm 5.4$
- Mean: $42.25 \pm 0.06$
- Sigma: $3.457 \pm 0.054$

**g45**
- Constant: $206.2 \pm 6.1$
- Mean: $39.67 \pm 0.05$
- Sigma: $4.615 \pm 0.052$

(preliminary results)
50 GeV pions mean and sigma

- the mean values for G4 + Bertini and Fluka are in agreement with our data within 2%

NB: cuts applied to data only. No contaminations included yet in MC

(preliminary results)
Preliminary studies on the proton contaminations

If the residual proton contamination is <5%, the effect can be safely neglected at this level of analysis.

Cherenkov pedestal well separated from signal. Proton residual (after Cher cuts) contamination neglected.
In addition, the effect of the calorimetric cut still needs to be understood in detail.
THE SHOWER SHAPE

($E = 20 \text{ GeV}$)
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 ~25x25x150 cm$^3$
• the halo is the external volume
Electron contamination has been included in MC simulations (4.9%).

To get rid of residual muons and out-of-axis events an energy release of at least 5 GeV is requested in the central tower.
LONGITUDINAL SHOWER SHAPE
ENERGY IN SAMPLE 1
ENERGY IN SAMPLE 2
ENERGY IN SAMPLE 3

- g47 (20 GeV pi S3)
  - data_fit
  - g47

- g48 (20 GeV pi S3)
  - data_fit
  - g48

- g47bert (20 GeV pi S3)
  - data_fit
  - g47bert

- g48bert (20 GeV pi S3)
  - data_fit
  - g48bert

- fluka (20 GeV pi S3)
  - data_fit
  - fluka

- g45 (20 GeV pi S3)
  - data_fit
  - g45
The longitudinal shower shape (20 GeV pion)

- All simulations give more energy in the first sample
- The tendency is reversed in Sample 2 and 3
- Fluka and G4+Bertini give reasonable agreement at this level of the analysis
- Fluka is the closest to data
LATERAL SHOWER SHAPE
ENERGY RELEASE IN THE CORE

Energy release distribution for different simulations:
- g47
- g47bert
- fluka
- g45
- g48
- g48bert
ENERGY RELEASE IN THE HALO
• GEANT with the Bertini list and Fluka are closer to the data
• GEANT without Bertini has significantly less energy in the shower halo
CONCLUSIONS
CONCLUSIONS

- GEANT4 QGSP has a lower energy response and the resulting shower shape is shorter and narrower than the data
  - GEANT4 needs Bertini to reproduce the characteristics of hadronic shower
- Overall acceptable agreement between data GEANT+Bertini and Fluka
- For 50 GeV need to take into account correct beam residual contaminations and effect of calorimetric cuts to improve comparison
- Big improvement on both simulation accuracy and on understanding of the data with respect to previous studies
Open issues and work in progress

- better control of contaminations and calorimetric cuts to extend the analysis on the total energy distributions at $E_{\text{beam}} = 100, 180, 350$ GeV
- expand our work on the shower shapes to higher energies.
BACKUP SLIDE
ELECTRON CUTS

• we use two variables related to the shower shape ($C_{\text{long}}$ and $C_{\text{tot}}$) to get rid of the residual electrons

\[
C_{\text{long}} = \sum_i \sum_{j=1}^2 \frac{E_{ij}}{E_{\text{beam}}}
\]

\[
C_{\text{tot}} = \frac{1}{\sum c E_c^\alpha} \sqrt{\sum_c \left( \frac{E_c^\alpha - \sum_c E_c^\alpha/N_{\text{cell}}}{N_{\text{cell}}} \right)^2}
\]