Geant4 hadronic and electromagnetic validation tests in LHCb

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Geant4 in LHCb

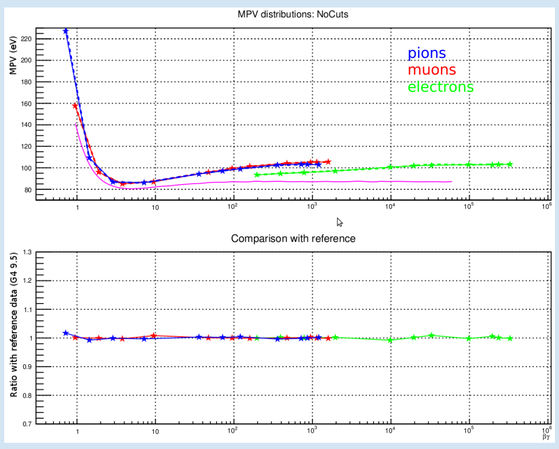
- LHCb uses GEANT4 to simulate the interactions of particles with the detector material and components.
- Simulation response can vary significantly due to modifications of material description, of detector geometry, or of the Geant4 toolkit
- Tools have been developed to study the effects of Geant4 modifications on the LHCb simulation framework (Gauss[1]) and on a stand-alone environments within the LHCb software infrastructure
- They have proven to be effective for investigating new and alternative models provided by Geant4, and also in identifying and fixing anomalous behaviours after changes

Electromagnetic Tests

- Within Gauss, tests are performed to measure energy deposition and photon emission (bremsstrahlung) in the silicon of the 'Vertex Locator' (VELO[2])
- Multiple scattering (MSc) tests also performed in GEANT4 using silicon planes with a VELO-like configuration
- Small discrepencies in the modelling of EM physics in the VELO can lead to large disagreements in, for example, track reconstruction compared to data
- Also analysed but not discussed here is energy resolution, shower profiles and sampling fraction using a simplified ECAL[3] of LHCb-like configuration in GEANT4
- During the recent move to GEANT4 v9.6, changes to the MSc modeling[4] were made. The effects of which can be seen in these tests

Deposited energy and photon emission in the VELO

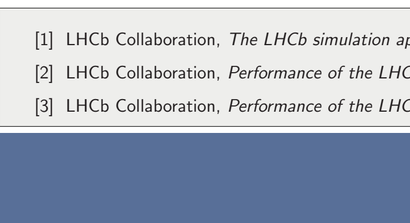
- Simulation of single particles (μ, **K**, π) at a range of discrete energies (0.1-100 $\mathbf{GeV}$) through the VELO



- Most probable values (MPV's) of muons, pions and electrons, for modified version of GEANT4 v9.6 physics list 'em_standard_opt1'
- Ratio of $\frac{dE}{dx}$ MPV's for modified 'em_standard_opt1' list (Geant4 9.6) and reference 'em_standard_opt1' list (Geant4 9.5)
- Comparison of the FWHM and MPV's of the $\frac{dE}{dx}$ distributions
- Using the same test scenarios, photons emitted by the simulated particles as they traverse the silicon show a $\sim$ **0.7%** shift in their mean energy between GEANT4 v9.5 and v9.6, likely due to changes to the MSc model

Scattering angle in silicon planes

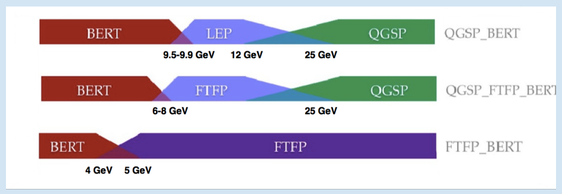
- Electrons fired through single 300μ**m** thick plane of silicon in GEANT4 (simplified model of VELO silicon) at range of energies to measure distribution of scattering angle θ



- MSc test ran with GEANT4 v9.5 and v9.6
- Changes made to MSc (UrbanMSC95) model in v9.6
- Testing GEANT4 v9.6 with old and new UrbanMSC95 model highlights change in behaviour.
- Recommendation from GEANT4 collaboration was to switch to UrbanMSC93 and WentzelVI

Hadronic Tests

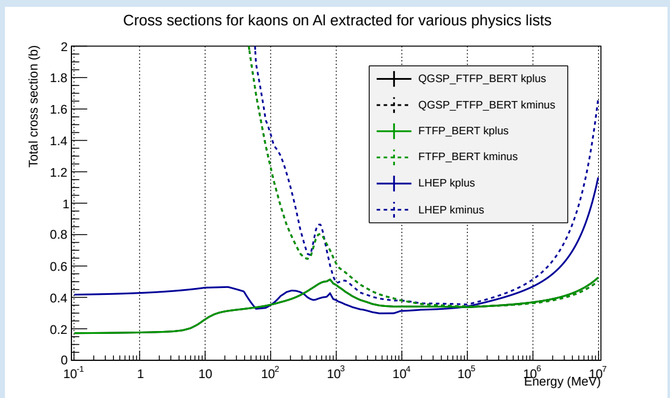
- Hadrons fired through layers of thin (**0.1 – 10mm**) materials, e.g. silicon, aluminium and beryllium
- Interaction cross-sections for hadrons and anti-hadrons in various materials are analysed in GEANT4
- Hadronic multiplicities are investigated within Gauss and also GEANT4 within the LHCb framework



- Each hadronic physics list is comprised of a series of models employed over specific energy ranges

Cross-sections in Geant4

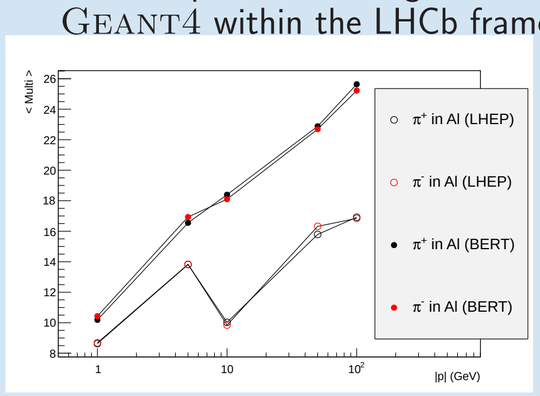
- Interaction probability extracted via $\mathbf{P_{int} = \frac{N_{int}}{N_{tot}}}$
- Cross-section for 'thin' layers: $\boldsymbol{\sigma_{int} = \frac{A}{\rho N_A \Delta x} \cdot P_{int}}$ where ρ is the material density, **A** is its mass number, $\mathbf{\Delta x}$ the thickness and $\mathbf{N_A}$ Avagadro's number



- Interaction cross-sections for **QGSP_BERT**, **FTFP_BERT** and **LHEP** hadronic physics lists compared, for both **K** and $\bar{\mathbf{K}}$ in a **10mm** beryllium target

Multiplicities from hadronic interactions

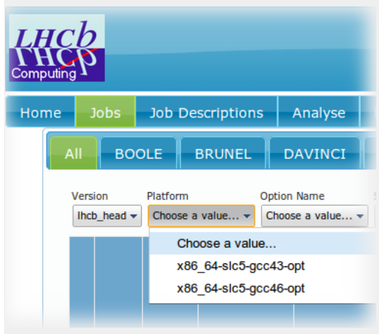
- **LHEP**, **FTFP_BERT** and **QGSP_BERT** hadronic physics lists compared
- Tests are performed within Gauss, but within a simple custom geometry of material planes, allowing direct comparison with tests in stand-alone GEANT4 within the LHCb framework



- ▷ Mean multiplicity generated in π^+/π^- collisions in 10mm Al as a function of the mother momentum
- ▷ In general, **FTFP_BERT** gives higher multiplicites, while **LHEP** shows unphysical discontinuities around the 5-10 $\mathbf{GeV}$ region
- ▷ LHEP not used in LHCb since 2010

- **FTFP_BERT** recommended by GEANT4
- **QGSP_BERT** also a viable alternative for calorimeters

Performance and regression testing with LHCbPR



- The goal is a systematic profiling of how changes in LHCb software framework affect results for test cases
- LHCbPR[5] is a Django-based web application to compare the results from simulation tests directly on the browser
- LHCbPR is still under development. Full implementation of these tests will allow scheduled, automatic validation of Gauss and GEANT4 within the LHCb software framework

Conclusions and future plans

- An expansive set of validation tests have been developed to periodically test GEANT4 at LHCb
- More tests to be implemented, such as Cherenkov tests
- When moving from GEANT4 v9.5 to 9.6 these tests proved to be key in validating the new software
- Behavioural changes, e.g. due to the modification of GEANT4's multiple scattering model detected independently in the relevant validation tests
- Implementing automation through the LHCbPR system to ensure the simulation software undergoes periodic validation and regression after changes to GEANT4, build system, etc.

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[1] LHCb Collaboration, *The LHCb simulation application, Gauss* LHCB-PROC-2011-006
[2] LHCb Collaboration, *Performance of the LHCb Vertex Locator* LHCB-DP-2014-001
[3] LHCb Collaboration, *Performance of the LHCb calorimeters* LHCB-DP-2013-003
V N Ivanchecnko et al, *Geant4 models for simulation of multiple scattering*, Journal of Physics Conference Series Volume 219, 2010
[5] Ben Courier et al. *Systematic profiling to monitor and specify the software refactoring process of the LHCb experiment* http://stacks.iop.org/1742-6596/513/i=5/a=052020