PROCEEDINGS OF SCIENCE

Simulating fixed-target and heavy- ion collisions in LHCb

Benjamin Audurier for the LHCb collaboration[*†]
Universita degli studi di Cagliari, Cagliari, Italy
E-mail: benjamin.audurier@ca.infn.it

The LHCb experiment is a fully instrumented forward spectrometer designed for precision studies in the flavour sector of the Standard Model with proton-proton collisions at the LHC. As part of its expanding physics programme, LHCb collected data also during the LHC proton-nucleus collisions in 2013 and 2016 and during nucleus-nucleus collisions in 2015. These datasets provide access to unique kinematic coverage due to the forward detector layout of LHCb. Furthermore, in 2013 LHCb commissioned the internal gas target SMOG, becoming the only LHC experiment with a programme of fixed target physics. Each of these particular collision conditions required a different operational setup, as well as dedicated simulation productions based on heavy-ion Monte-Carlo event generators and interface extensions of the standard LHCb simulation framework. In these proceedings, we present the work done to implement such a variety of simulation productions for heavy-ion collisions, and to validate the produced samples. The future perspectives of the heavy-ion collision simulations at LHCb are also be discussed.

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1. Introducing the Gauss software

Since the past few years, the physic program of the LHCb experiment [1], initially dedicated to measurements and studies of B mesons physics, has been extended : it not only covers the domain of high-energy heavy-ions (HI) collisions but it also benefits from a unique fixed-target program with LHC beams, thanks to the internal gas target SMOG [2]. Therefore, a large variety of simulation conditions, combining the two different running (collider or fixed-target) modes and different projectile-target combinations at different colliding energy are required from the Monte Carlo (MC) framework in order to analyze this wide set of data.

Gauss [3] is the LHCb application dedicated to the event generation and the tracking of the produced particles in the simulated detector. Based on the Gaudi framework [4] and Geant4 [5, 6], it also encapsulates many generator packages from the physics community (e.g Pythia 8 [7] and EvtGen [8]). It is designed to be a highly modular framework with a set of adaptors and interfaces that shield users from generators and transport codes to different degrees.

Its structure can be divided in two independent phases (Figure 1): (i) in the event generation phase, particles are produced by a particle generator which may then be passed to EvtGen for further decays; (ii) in the detector simulation phase, the geometry and the alignment are loaded in Geant4 and particles are propagated through materials and energy deposits in sensitive material are recorded. As the second phase is shared by all the simulation types, only the first one needs to be adapted for fixed-target and HI analysis.

2. Configuring fixed-target and heavy-ion simulations

The Gauss generation phase is configured via Python files to set various conditions, i.e beam parameters or the number of pile-up interactions (See Ref. [9] for more details). On top of the commonly used settings, specific tools were developed for fixed-target mode. In addition, the EPOS generator [10] can be used either as a minimum bias (MB) event generator, or to embed signal processes Pythia events into an EPOS event for analysis involving heavy-flavour particles (not produced by EPOS)[1]. For example, to generate samples of signal $J/\psi \to \mu^+\mu^-$ events an EPOS MB event is generated for a given configuration (i.e fixed-target). Then a pp interaction

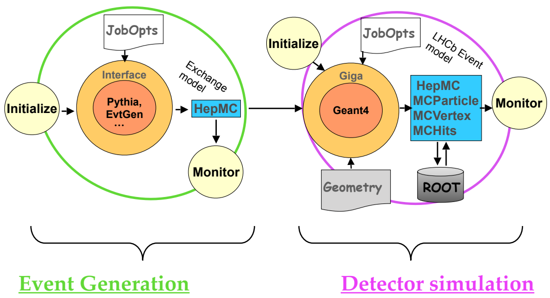

Figure 1: Schematic view of the Gauss framework structure.

[1]Even if such a procedure does not concerve energy, it is well suited for efficiency studies.

containing a J/ψ meson is generated with Pythia where all the particles but the J/ψ meson are removed and embedded in the EPOS event. The decay of the merged events is then handled with EvtGen. STARlight [11], a Monte Carlo simulation program for ultra-peripheral collisions (UPC) of relativistic ions, has also been incorporated into Gauss, with new features developed within LHCb propagated back to the project.

3. Data-simulation comparisons and future developments

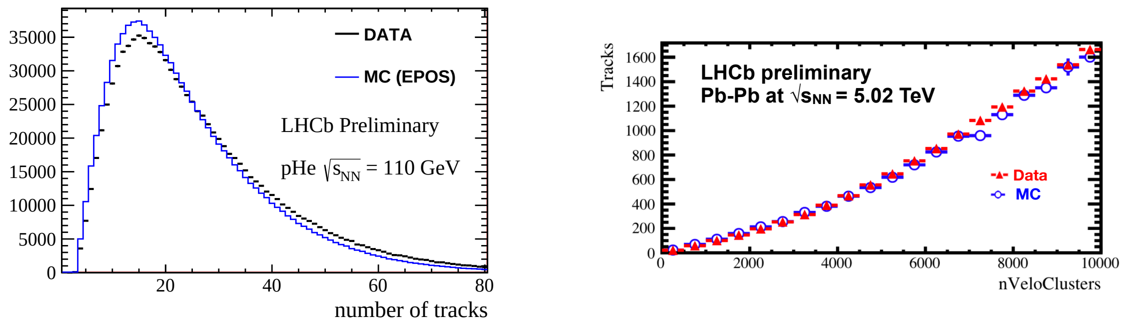

Figure 2: Comparison between minimum bias EPOS simulations and data. Left : number of tracks distribution in fixed-target pHe data at $\sqrt{s_{NN}} = 110$ GeV. Right : tracks multiplicity distribution versus the number of Velo clusters in Pb-Pb data at $\sqrt{s_{NN}} = 5.02$ TeV.

Results comparing data and MC simulations are shown in Figure 3. The EPOS generator reproduces track multiplicities for different types of tracks in fixed-target pHe data at $\sqrt{s_{NN}} = 110$ GeV [12]. A similar agreement between data and MC is found for the track multiplicity versus the Vertex Locator [13] occupancy in Pb-Pb data at $\sqrt{s_{NN}} = 5.02$ TeV. From those encouraging results in the low-occupancy regime, some development is foreseen at higher occupancy where simulations find difficulties to reproduce the data. Another future development is to adopt Pythia 8, which now includes HI production, for p-Pb simulations. Finally, works to correlate the simulated hard process (generated by Pythia) and underlying event activities (generated by EPOS) may help to reduce the remaining discrepancies between data and MC.

Recently, first results on the coherent J/ψ production in UPC were presented [14]. For these results, the STARlight generator implemented in Gauss was used to describe the various components contributing to the observed spectra of J/ψ mesons (Figure 3). Templates were obtained and allowed to determine the number of signal candidates, which will be used to compute the process cross-section in the final analysis.

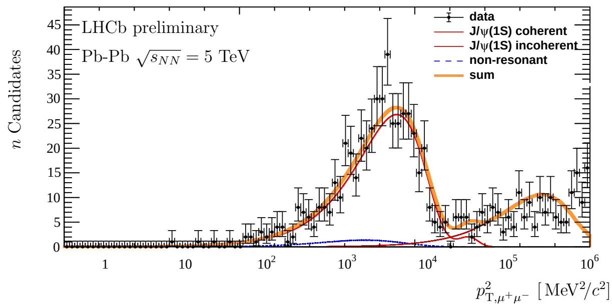

Figure 3: p_{T}^2 distribution of J/$\psi \to \mu^+\mu^-$ selected candidates measured by LHCb in ultra-peripheral Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV [14] fitted with templates for the different contributions.

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