EvtGen and Pythia developments

EvtGen

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Pythia

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EvtGen status

- Generator package specialised for heavy-flavor hadron decays
  - Used as well inside simulation of b jets
- Contains about 130 decay models implementing specific dynamics of various decays
- Maintains detailed decay table with large number of explicit decays
  - Known decay branching fractions do not add up to 100%, remainder is filled up by generating quark configurations and passing those to Pythia8 for fragmentation
  - Fraction of decays passed to Pythia8 depends on particle (b-baryons rely more on Pythia8 than others)
- τ decays simulated using TAUOLA
- PHOTOS used for simulation of final-state radiation (FSR)
- Source code stable over past 10 years (most changes due to addition of new models)
- Recently went through some modernisation and cleanup

Plans for EvtGen

- Physics wise no plan for changes in near future
- Currently working on code consolidation
  - Unify coding style, C++ modernisation
  - Plan to decrease code duplication within decay models
  - Improve/Update documentation (Doxygen and paper/guide)
  - Implement common testing framework for validation
- Plan to make EvtGen thread safe
  - Event $\hat{=}$ particle whose decay is simulated (through full decay chain)
  - Main blockers are Tauola and Photos, which are not yet thread safe
  - Work on source-code redesign currently ongoing with help of computing engineers
  - Full adaptation might be challenging (core code adaptation should be doable)

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Issues with multithreading in EvtGen

- Structural limitations inside EvtGen for multithreading
  - Global instance of random number generator
  - Global instance of particle properties and decay table
- Limitations from dependences
  - TAUOLA
  - PHOTOS
- Needed structural changes identified and currently evaluating possible solutions
- Overcoming limitations from dependences are more challenging as they are external
  - TAUOLA and PHOTOS authors currently exploring ways to enable thread safety
  - Exploring use of Pythia8 as alternative to TAUOLA
  - Look for an alternative to PHOTOS (discussing about porting FSR simulation from other generators)

Pythia 8 for τ decays

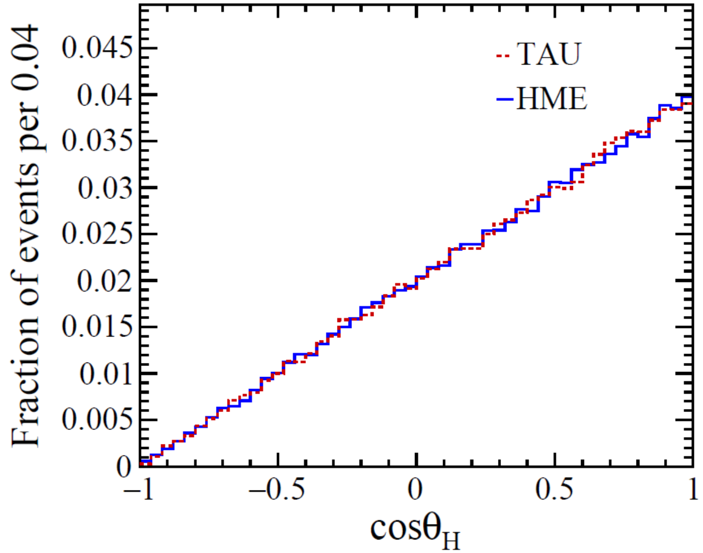
- In addition to multithreading limitations, spin-state information of τ not propagated between EvtGen and TAUOLA:
  - TAUOLA expects τ from W, Z, γ or H, not from B
  - needed for analyses sensitive to τ polarization

- Simulation of τ decays with spin-state propagation possible with PYTHIA8 using HME (helicity-matrix element) amplitude model.

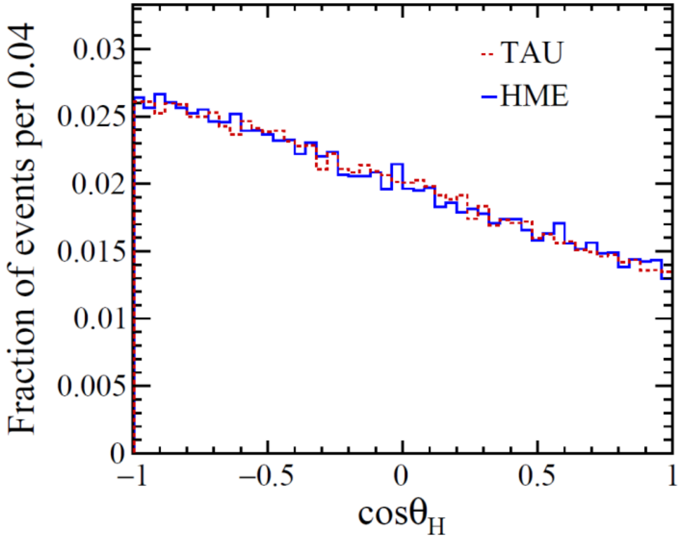
- Main EvtGen $\leftrightarrow$ Pythia interface ready

- Need to iron out a few details (helicity/spin basis, initialization)

$B^+ \rightarrow \tau^+(\rightarrow \pi^+\bar{\nu}_\tau)\,\nu_\tau$



$B^+ \rightarrow \tau^+\left(\rightarrow \mu^+\nu_\mu\bar{\nu}_\tau\right)\nu_\tau$



Testing framework

- Simulation needs testing and validation after structural changes due to code consolidation and implementation of thread-safety
- Tests (in different formats) exist only for about 40% of the 130 decay models
- Currently migrating all tests and adding new ones to a common testing framework
  - With common testing module and configuration files

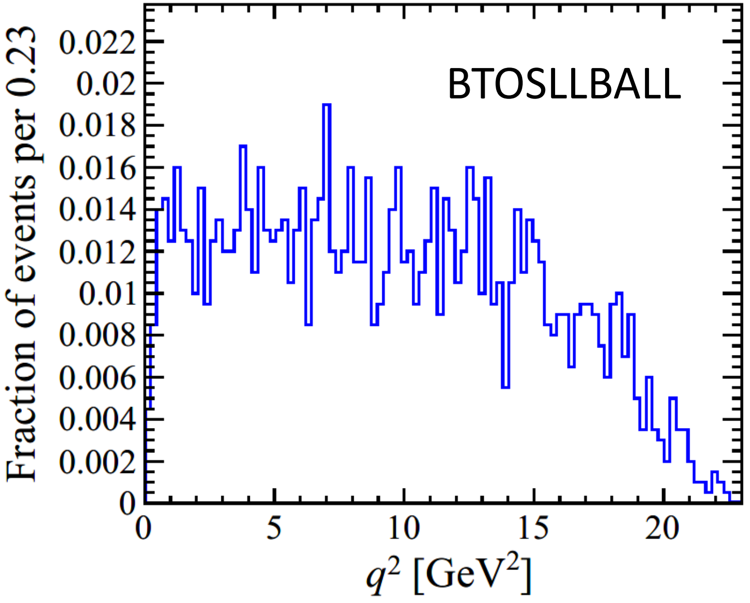
Plans:

⇒ Migrate/include tests for all decay models

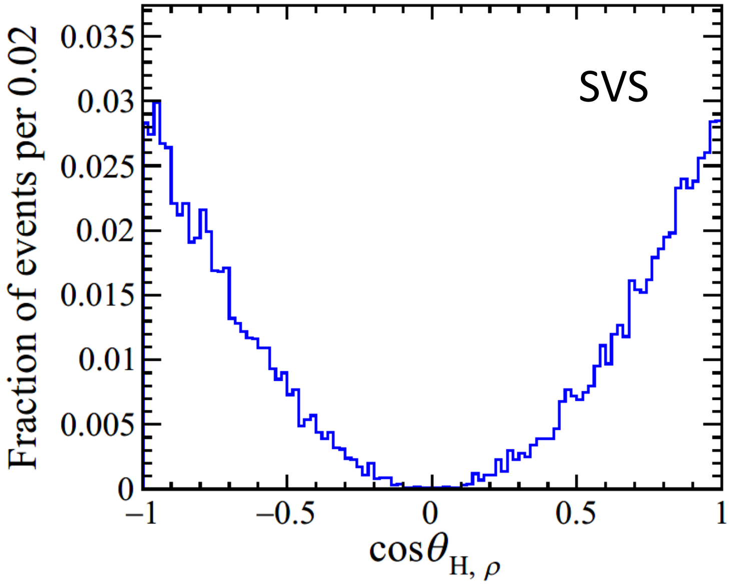
⇒ Implement automatic recognition of tests to be run depending on changes

⇒ Require to add new tests for each new model

$B^+ \to K^+\mu^+\mu^-$



$B^+ \to \overline{D}^0\rho^+(\to \pi^+\pi^0)$



Pythia status and plans

- General purpose generator for simulation of collision events of particles (electrons, protons, photons, heavy nuclei) at high-energies.
- Contains models for several aspects: hard/soft interactions, parton distributions, initial/final-state parton showers, multiparton interactions, fragmentation and decay.

Currently working on different aspects aimed at making simulation of b-hadron faster:

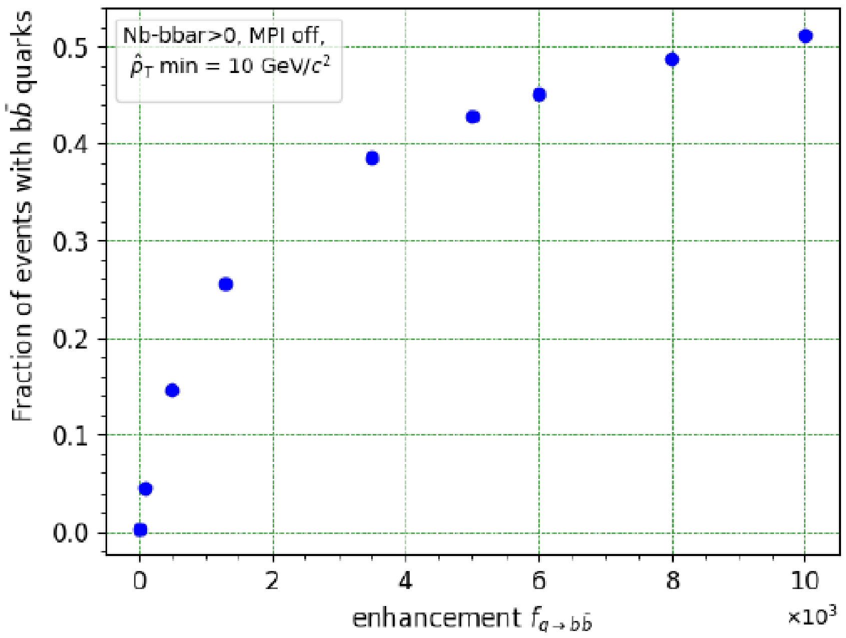
- B enhancement
- Doubly-heavy hadrons in Pythia

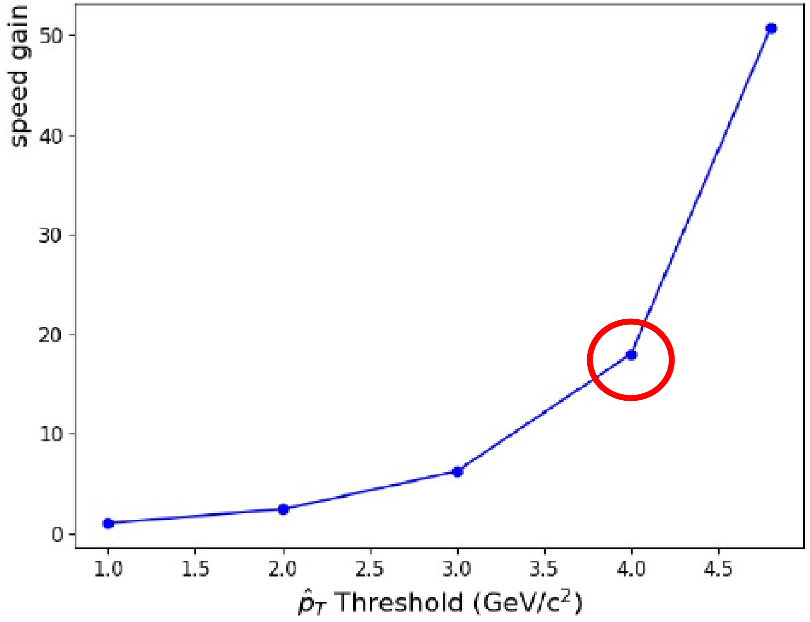
Plans for future developments:

- Forced hadronization
- Optimizing simulation with more than one heavy-quark pair

B enhancement

- Goal: make b-hadron production faster (in LHCb simulation)
- Particularly important for cases where generator consumes more CPU time than detector simulation
- Examples: production of $B_s, B_c, \Xi_{cc}, \Omega_{bb}$
- Produced b-hadrons should still be kinematically unbiased
- Module made flexible for user to enhance $g \to c\bar{c}, b\bar{b}$ splitting
- About to be ready to tested within LHCb simulation framework GAUSS



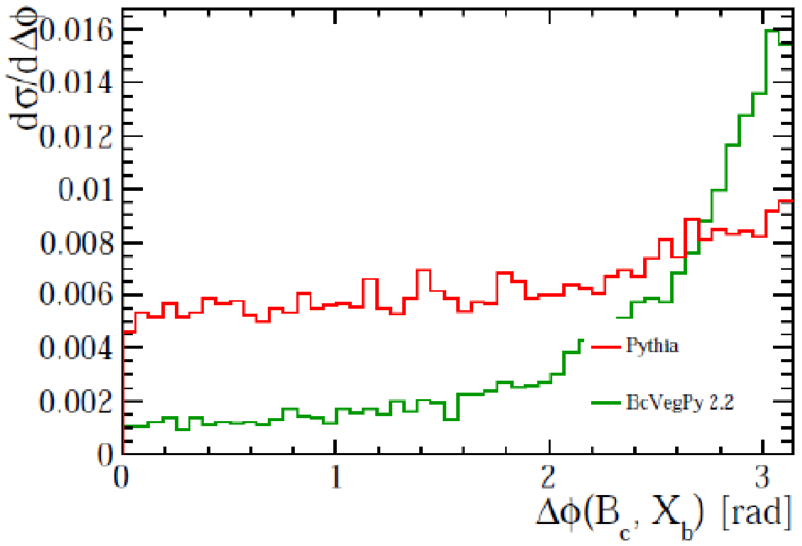


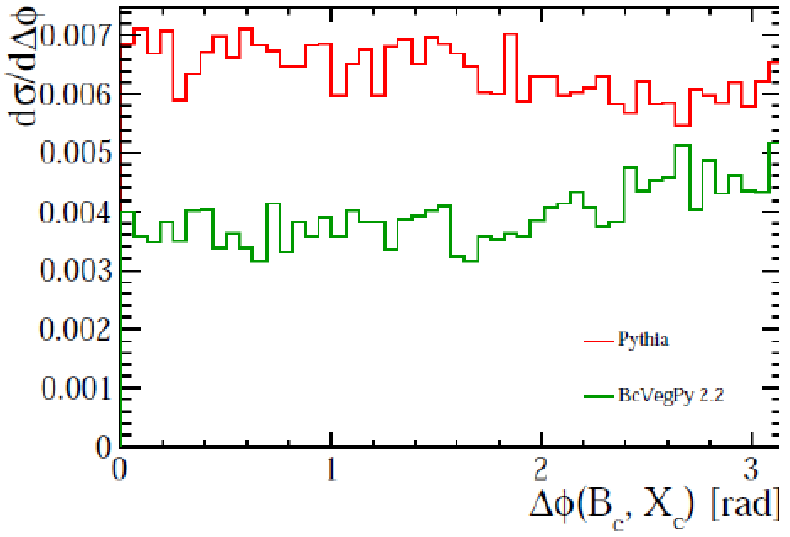
Proof of Principle via standalone Pythia

Double-heavy hadrons in Pythia

- Pythia currently not employed for B_c or other double heavy hadrons at LHCb
- Exploring ways to increase efficiency by vetoing events without desired heavy-quark composition at early simulation stage
- Possible vetoes based on presence of correctly colour-connected heavy quarks
- Currently comparing geometrical B_c distributions with dedicated generators like BcVegPy which currently has a limited list of supported production mechanisms
- $\Delta\phi$ sensitive to production mechanism
  $\Rightarrow$ More mechanisms available in Pythia 8 and thus more uniform distributions

$\Delta\phi$: angle between B_c and $X_{b(c)}$ hadron on transverse plane





Future plans

- Simulation with more than one heavy-quark pair
  - Currently investigating ways to improve efficiency of simulation for events with more than one heavy-quark pair produced in multiparton interactions
  - Aim to study production mechanisms of quarkonia and compare simulated kinematic distributions with data
- Forced hadronization
  - Implement forced hadronization rather than current repeated hadronization
  - Will make a considerable impact for events with baryons with multiple s like $\Omega_b(ssb)$
  - Less significant impact expected for $B^{\pm}, B^0$

Summary and outlook

EvtGen:

- Currently working on making EvtGen threadsafe

$\Rightarrow$ Full adaptation might be challenging but the plan is to first converge on core

$\Rightarrow$ Simulation of final-state radiation (currently using PHOTOS) also a major concern

$\Rightarrow$ Working on using Pythia8 as alternative to TAUOLA for τ simulation

$\Rightarrow$ Working on common testing framework for validation after changes

Pythia:

- Currently working in enhancement of b-hadron production to make simulation faster
- Exploring how to improve efficiency for events with multiple heavy quarks

$\Rightarrow$ Comparing simulated kinematic distributions with independent generators