EvtGen and Pythia developments

EvtGen

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Pythia

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Recap on EvtGen status

- Generator package specialised for heavy-flavour 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 clean-up

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
- Currently making 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 is challenging (first core code adaptation almost finalized)

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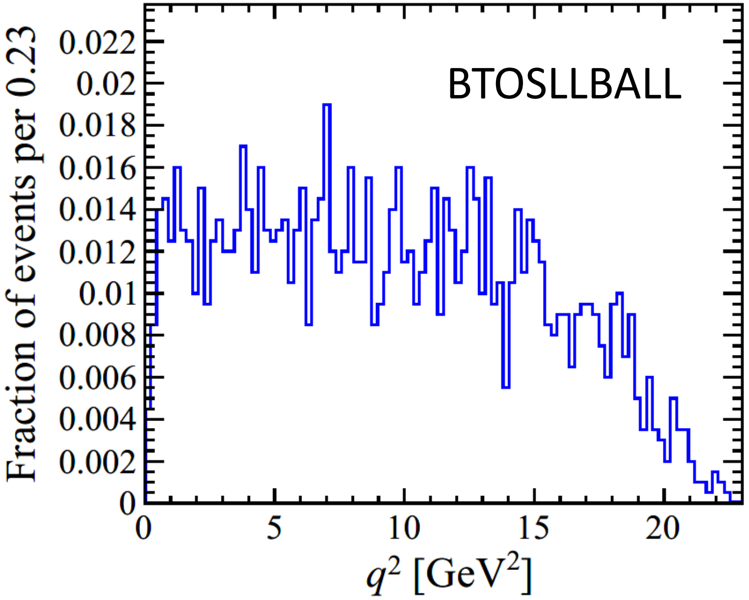
Testing framework

- Simulation needs testing and validation after structural changes due to code consolidation and implementation of thread-safety
- Tests (in different formats) existed only for about 40% of the 130 decay models
- Migrated all tests and added new ones to a common testing framework
  - $\Rightarrow$ With common testing module and configuration files
- Implemented automatic recognition of tests to be run depending on changes (still to be refined)

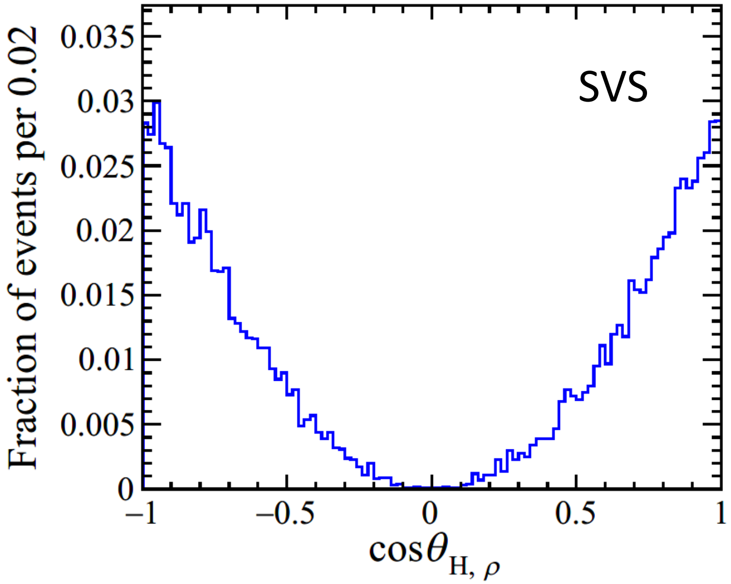
$\Rightarrow$ Finalized first working version with tests for all models

$\Rightarrow$ Will require to add new tests for each new model

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



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



Challenges for multithreading in EvtGen

- Internal: structural limitations for multithreading inside EvtGen
  - Global instance of random number generator
  - Global instance of particle properties and decay table

$\Rightarrow$ Needed structural changes identified and first combination of solutions found

- External: limitations from dependences
  - TAUOLA
  - PHOTOS

$\Rightarrow$ 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 (perhaps port FSR simulation from other generators)

Progress on thread-safety

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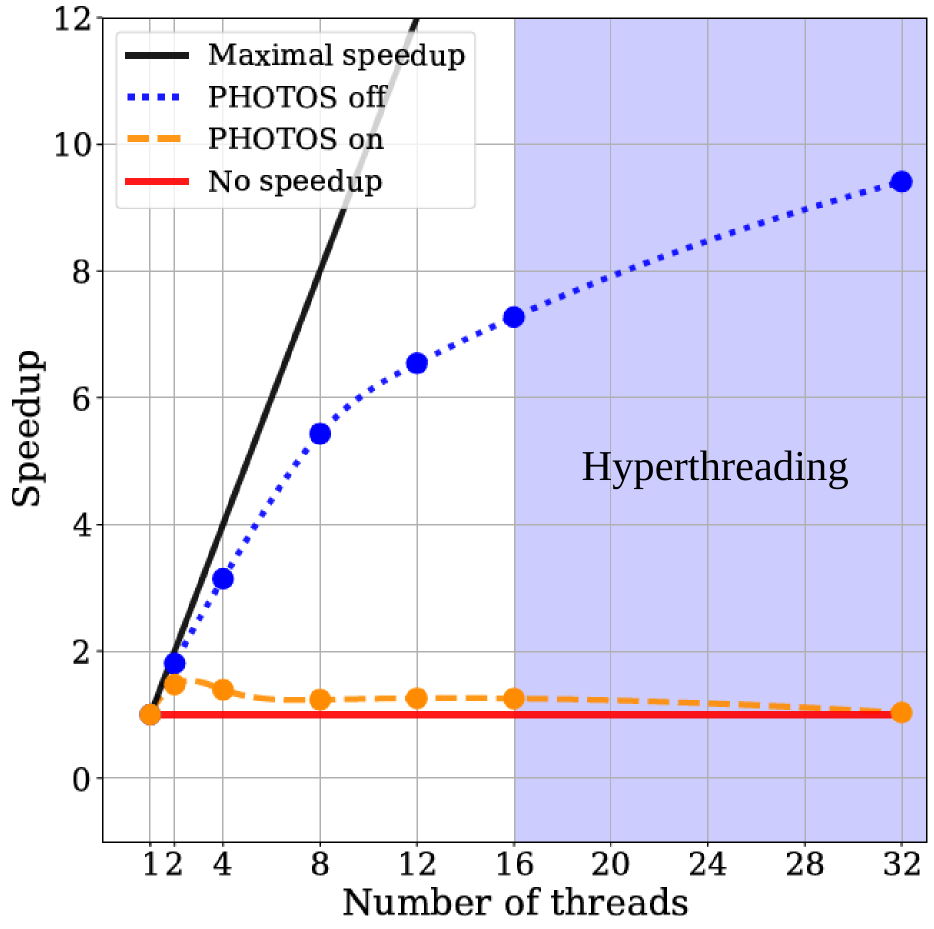
Set of solutions to reach thread-safety (preliminary):

- Converted **static** objects to **static const** where possible
- Global singleton objects made thread-local
- Serialized (mutexed) calls to PHOTOS and TAUOLA

⇒ Deeper structural changes needed to fully exploit multi-threading (plan to continue working on it)

⇒ Current preliminary status reached thread-safety, passing tests for all decay models

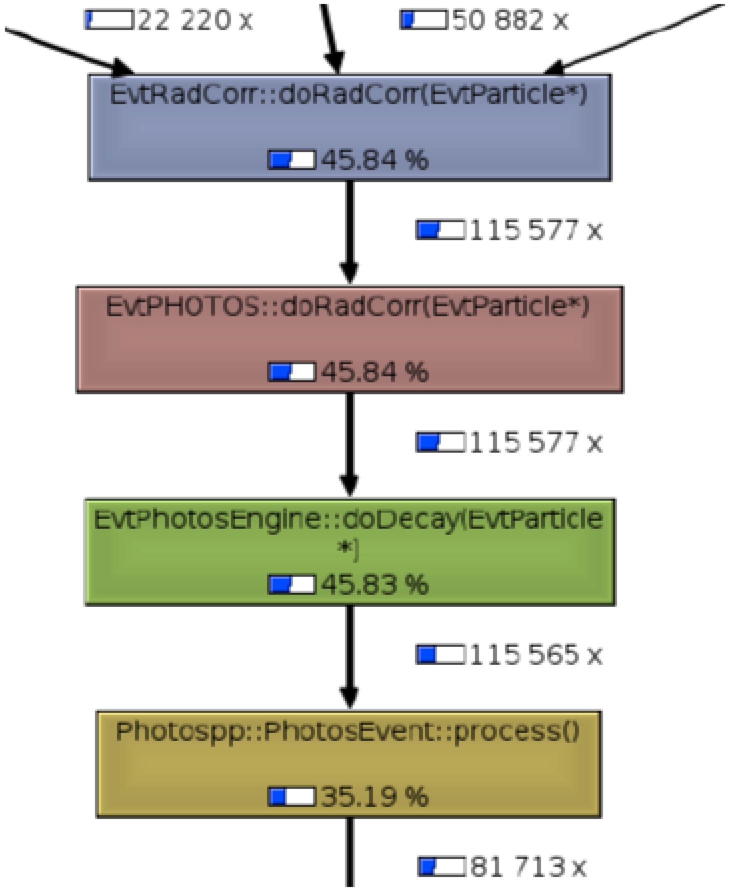
⇒ But performance limited by external dependencies



PHOTOS in EvtGen

- PHOTOS is commonly used in almost every decay
- Profiling shows a significant amount of CPU time consumption in PHOTOS itself
- Conversion EvtGen ↔ HepMC also significant
  - Similar conversion happens inside PHOTOS
  - Probably half of CPU time effectively spent on conversion
  - Need to try bypassing HepMC to estimate possible gain

⇒ Usually ~1/3 of EvtGen CPU time spent on FSR simulation



Pythia 8 for τ decays

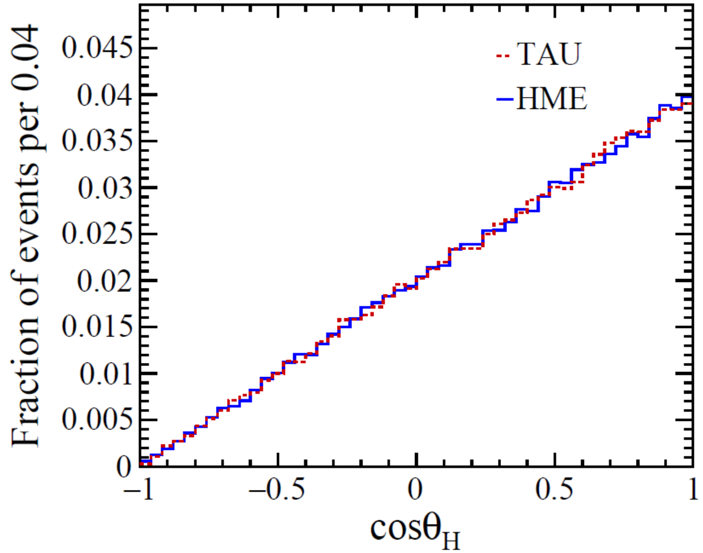
- In addition to multithreading limitations, spin-state information of τ not propagated between EvtGen and TAUOLA:
  - TAUOLA expects τ from W, Z, γ or H, not from B
  - needed for analyses sensitive to τ polarization

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

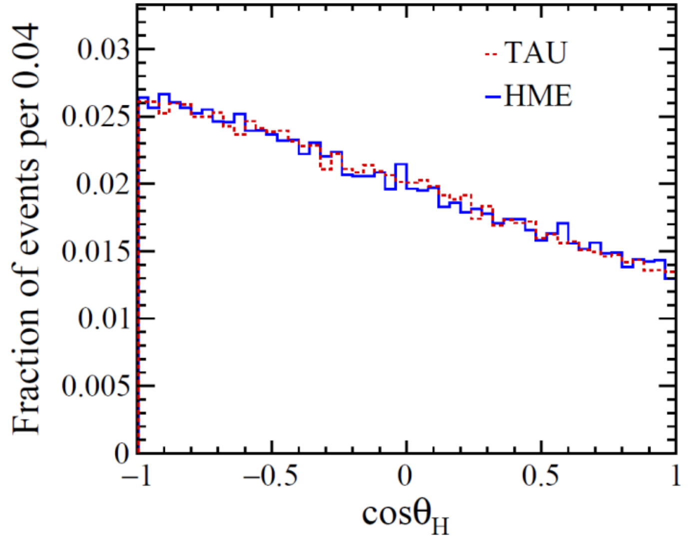
- Main EvtGen $\leftrightarrow$ Pythia interface ready

- Need to iron out conversion of helicity/spin basis (and initialization)

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



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



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:

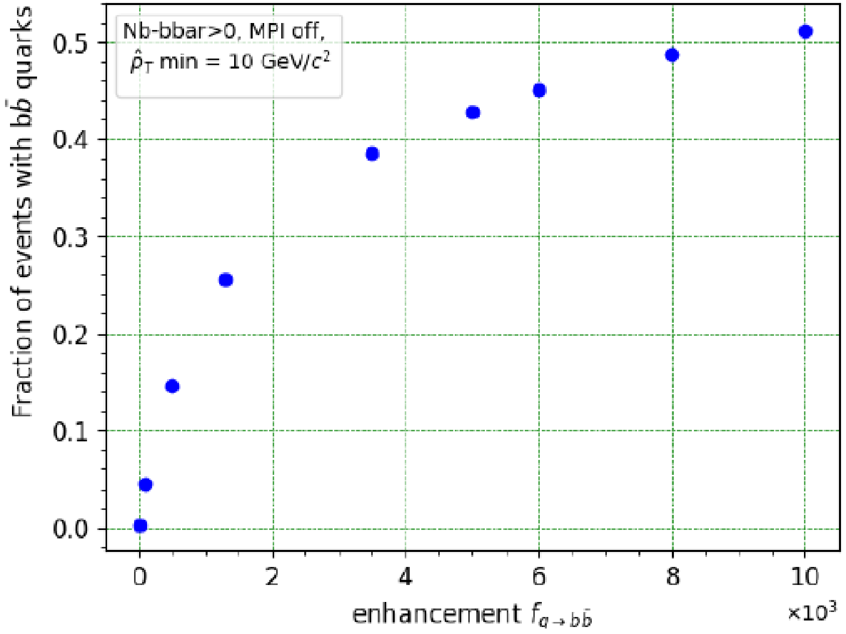
- B enhancement
- Doubly-heavy hadrons in Pythia

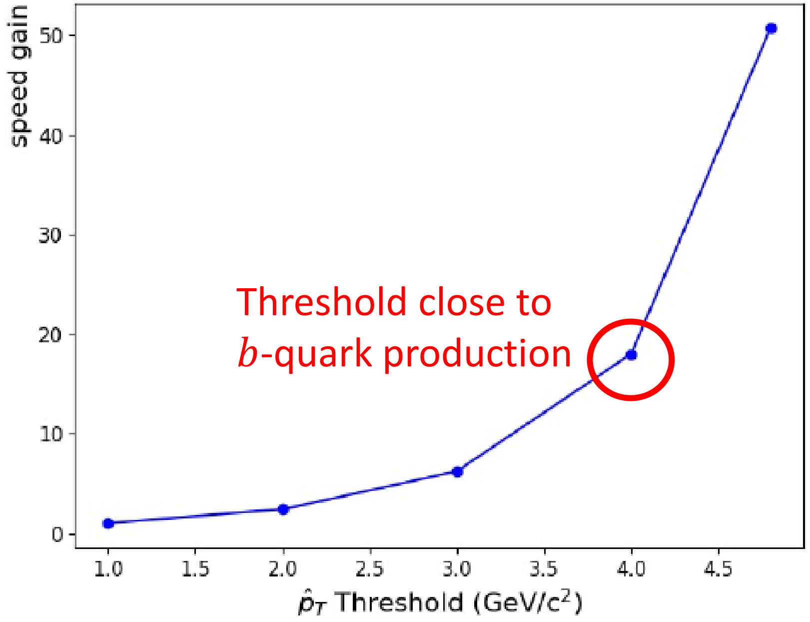
Plans for future developments:

- Forced hadronization
- Optimizing simulation for color-reconnection modes

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 $g \rightarrow c\bar{c}, b\bar{b}$ splitting
- About to be ready to tested within LHCb simulation framework GAUSS



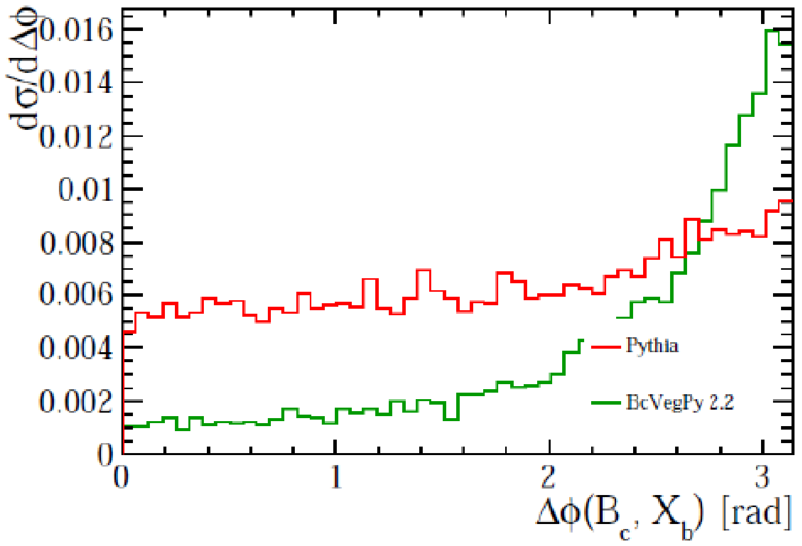


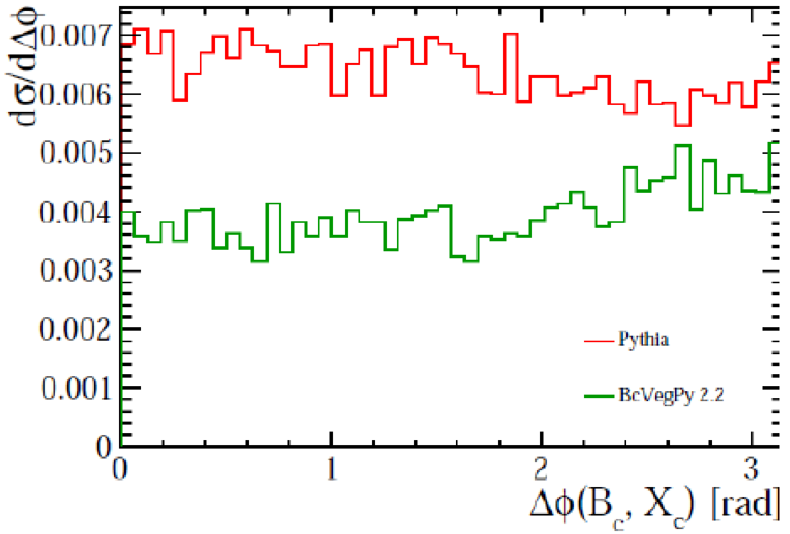
Proof of Principle via standalone Pythia

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

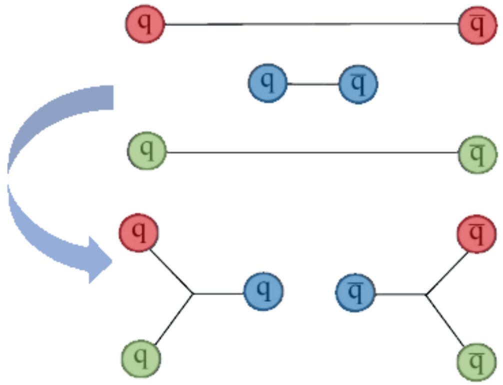


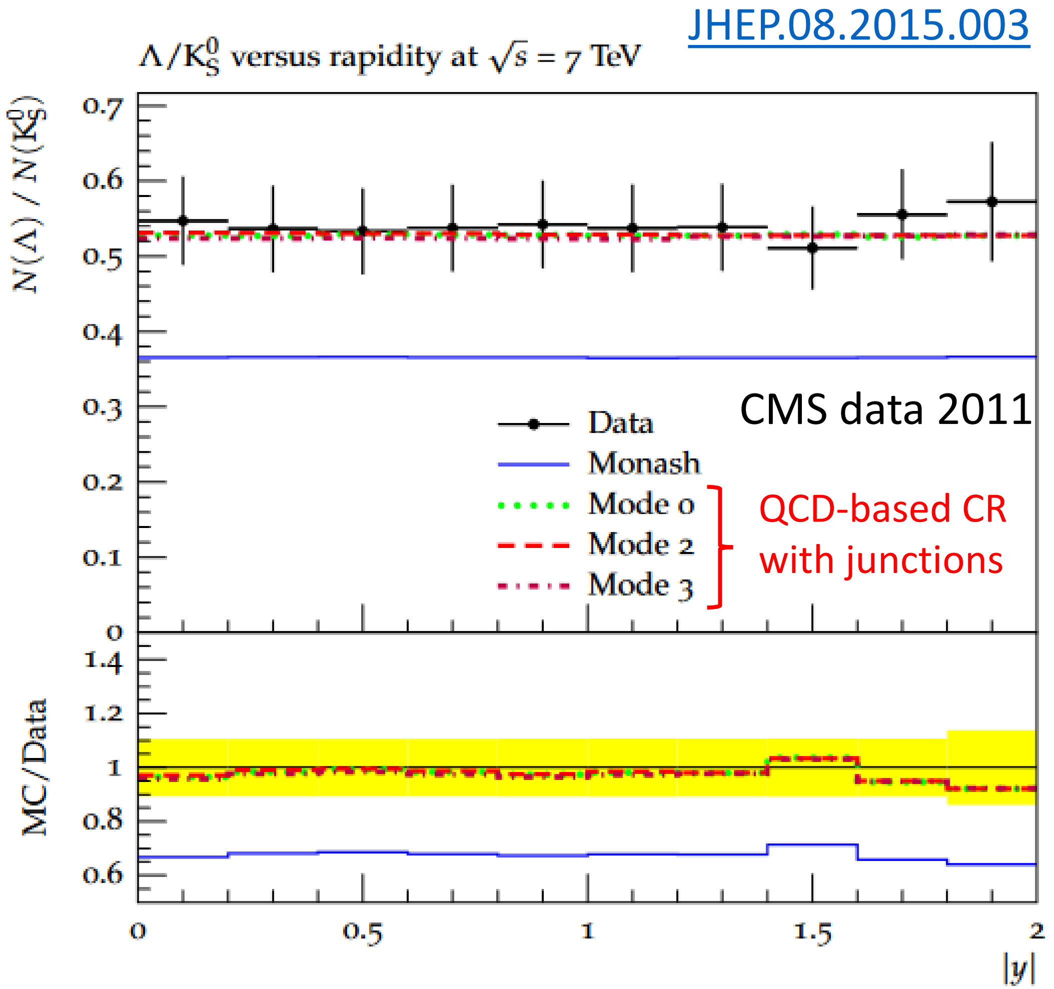


Improving color-reconnection models

- QCD-based color-reconnection models with junction agree well with collision data (without particular tuning)

CR junction: choose "shortest" string configuration





- However inefficient and CPU expensive
- Structural changes and efficient alternative algorithm for minimization identified (link)

⇒ Need to be implemented and tested, but promising for enhancement of baryon production

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 making EvtGen threadsafe

$\Rightarrow$ Finalized common testing framework for validation

$\Rightarrow$ Converged on preliminary set of solutions to enable thread-safety of generator (exploitation of multi-threading will require further structural changes)

$\Rightarrow$ Performance limited by external dependencies (especially PHOTOS)

$\Rightarrow$ τ decays: plan to iron out basis conversion for Pythia8 (interesting also for TAUOLA)

Pythia:

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

$\Rightarrow$ Plan to study production mechanisms and improve implementation of color-reconnection models