EvtGen and Pythia developments

EvtGen

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Pythia

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SwiftHep workshop
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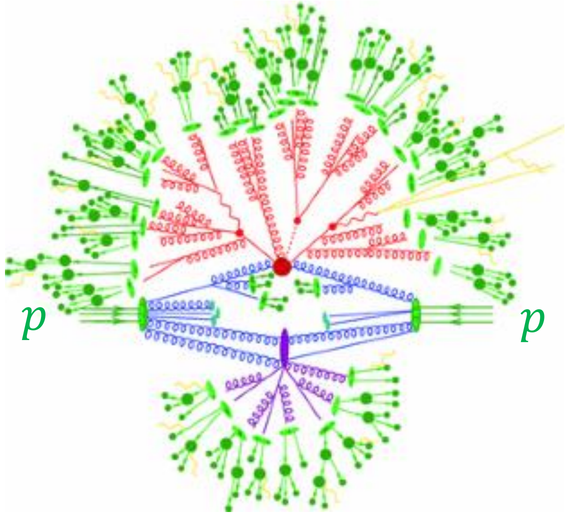
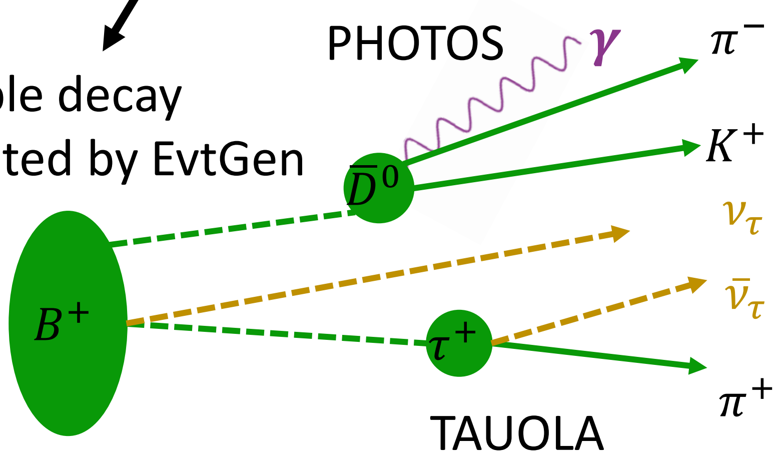
Recap on EvtGen

- EvtGen: 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
- Final-state radiation (FSR) simulated using PHOTOS

Example collision simulated by Pythia8



Example decay simulated by EvtGen



Status

- Developed in the 90’s, stable over past 10 years (changes mostly additions of new models)

Challenges for updates

- Various code styles across models (due to contributions from various authors)
- Several code duplications across models (often same kinematics but different form factors)
- Experiments (main users) need generators to be thread-safe as they are moving their simulation frameworks towards multithreading to exploit modern CPUs

Recent developments

- Work on modernisation and clean-up
- First adaptation of core code towards thread safety (with help of software engineers)
- Implemented global testing framework for validation
- Studies of alternatives for τ and FSR simulation New!

Heather Ratcliffe
Chris Brady

Plans

- 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)
  - Improve method to update decay table

- Continue work towards thread safety
  - On alternatives for external dependencies that are not yet thread safe (TAUOLA and PHOTOS)
  - Implementing full adaptation of internal code redesign

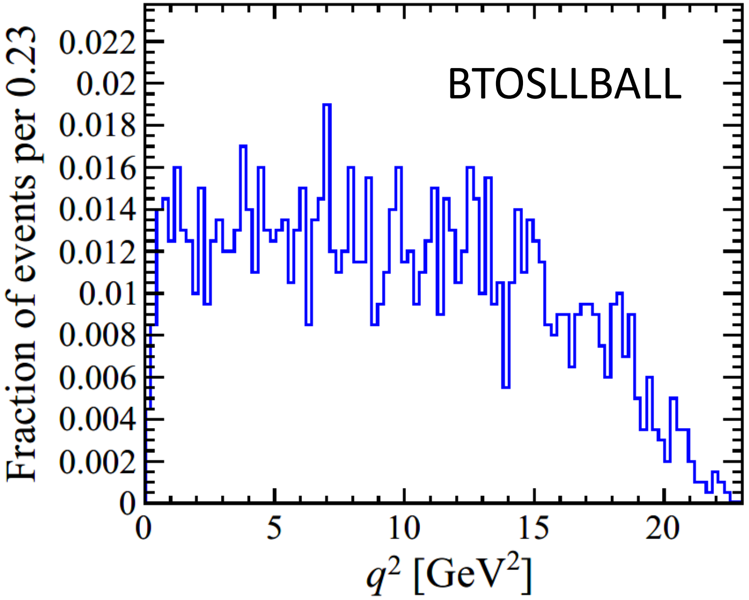
Testing framework

- 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
  - ⇒ With common testing module and configuration files
- Finalized first working version with tests for all models
- Some models support various configurations

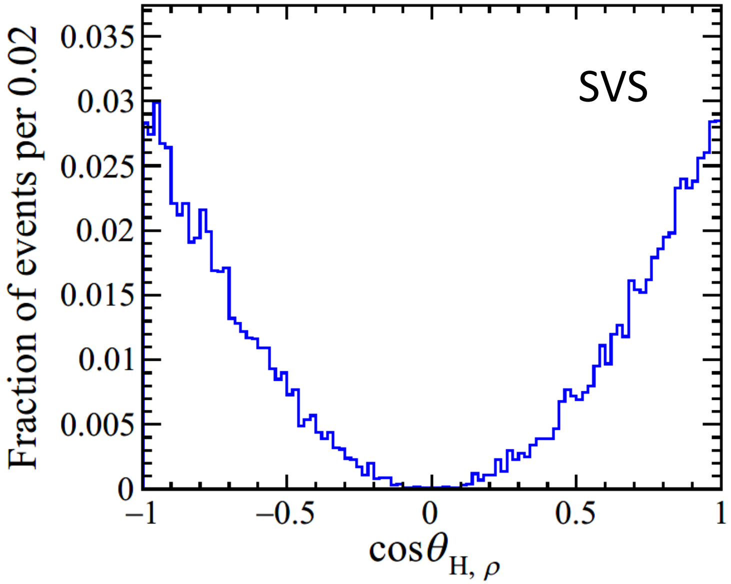
⇒ More tests needed to cover all configurations

⇒ Will require to add new tests for each new model

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



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

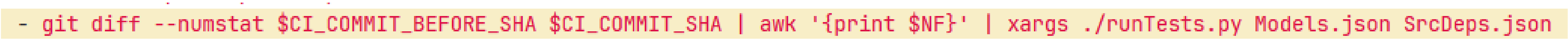


Testing framework

New!

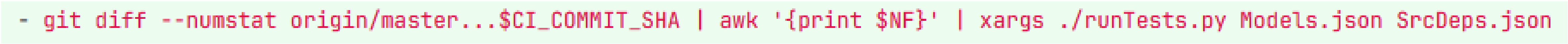
Implemented automatic recognition of tests to be run depending on changes

- Identify files modified in a commit
- If files associated with a model changed ⇒ run respective tests
- If framework files changed ⇒ run all tests
- Issue: Gitlab BEFORE_SHA variable not always set (for example when new branch created)



```
- git diff --numstat $CI_COMMIT_BEFORE_SHA $CI_COMMIT_SHA | awk '{print $NF}' | xargs ./runTests.py Models.json SrcDeps.json
```

⇒ Use as reference best common ancestor commit



```
- git diff --numstat origin/master...$CI_COMMIT_SHA | awk '{print $NF}' | xargs ./runTests.py Models.json SrcDeps.json
```

⇒ Output files for reference will be used as comparison

⇒ Still need to establish storage of reference files
(plan to use a separate GitLab project for storage)

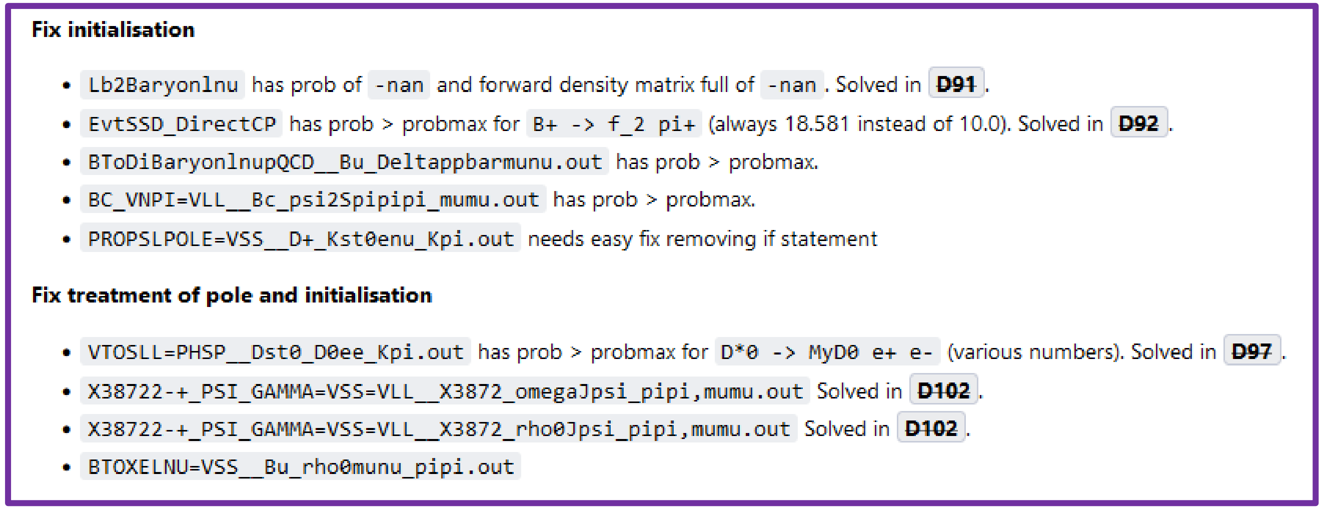
Fixing of broken modules

New!

- Testing framework helped uncover issues in models
- Repairing broken models has taken large fraction of recent effort
- Needs understanding and familiarisation with underlying dynamics

⇒ Contacting authors when possible

- Some models turned out to be obsolete (plan to remove those)

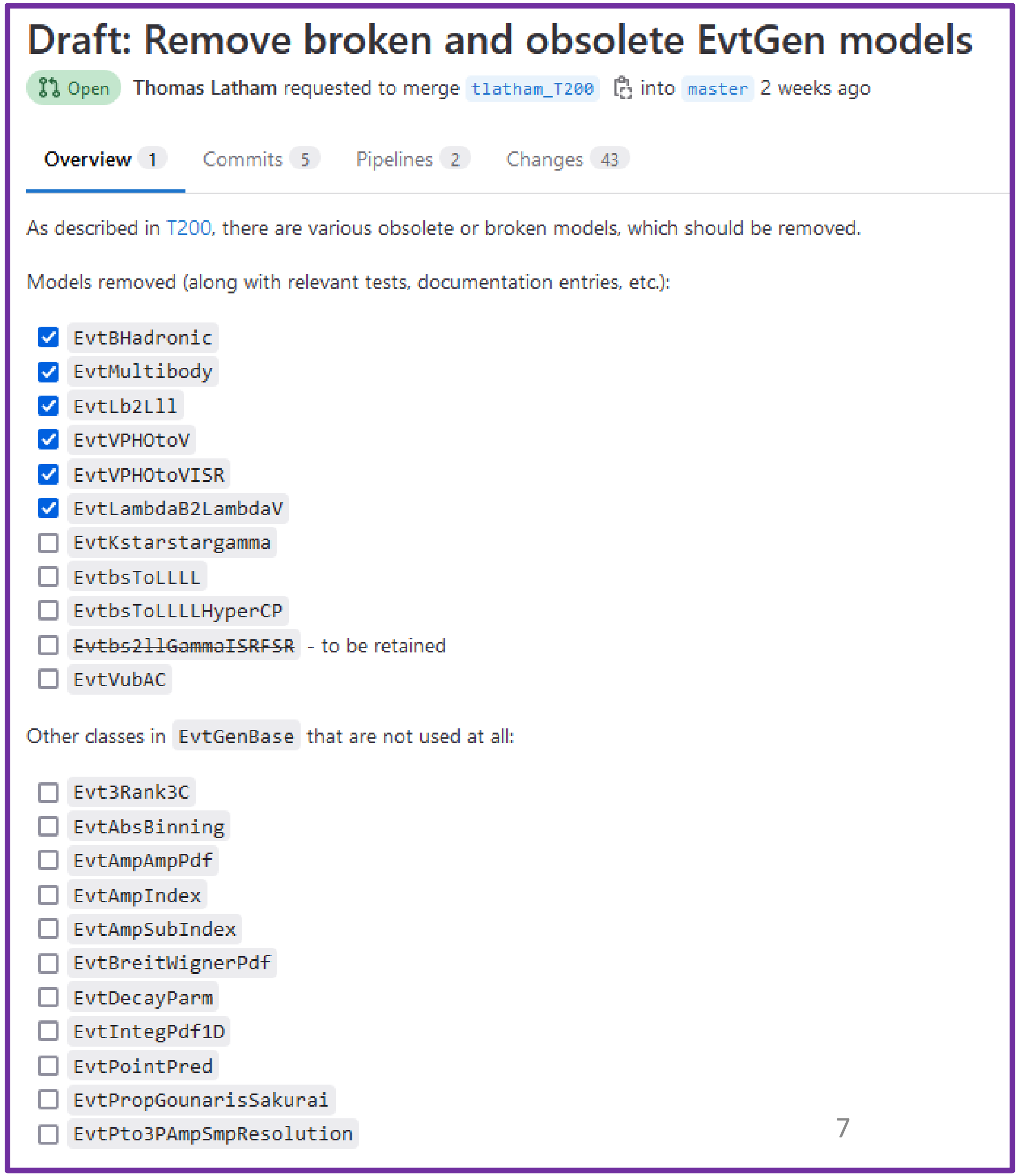


Fix initialisation

- `Lb2Baryonlnu` has prob of `-nan` and forward density matrix full of `-nan`. Solved in ~~D91~~.
- `EvtSSD_DirectCP` has prob > probmax for `B+ -> f_2 pi+` (always 18.581 instead of 10.0). Solved in ~~D92~~.
- `BToDiBaryonlnupQCD__Bu_Deltappbarmunu.out` has prob > probmax.
- `BC_VNPI=VLL__Bc_psi2Spipipi_mumu.out` has prob > probmax.
- `PROPSLPOLE=VSS__D+_Kst0enu_Kpi.out` needs easy fix removing if statement

Fix treatment of pole and initialisation

- `VTOSLL=PHSP__Dst0_D0ee_Kpi.out` has prob > probmax for `D*0 -> MyD0 e+ e-` (various numbers). Solved in ~~D97~~.
- `X38722-+_PSI_GAMMA=VSS=VLL__X3872_omegaJpsi_pipi,mumu.out` Solved in ~~D102~~.
- `X38722-+_PSI_GAMMA=VSS=VLL__X3872_rho0Jpsi_pipi,mumu.out` Solved in ~~D102~~.
- `BTOXELNU=VSS__Bu_rho0munu_pipi.out`



Draft: Remove broken and obsolete EvtGen models

Open Thomas Latham requested to merge `tlatham_T200` into `master` 2 weeks ago

As described in T200, there are various obsolete or broken models, which should be removed.

Models removed (along with relevant tests, documentation entries, etc.):

☑ `EvtBHadronic`
☑ `EvtMultibody`
☑ `EvtLb2Lll`
☑ `EvtVPHOtoV`
☑ `EvtVPHOtoVISR`
☑ `EvtLambdaB2LambdaV`
☐ `EvtKstarstargamma`
☐ `EvtbsToLLLL`
☐ `EvtbsToLLLLHyperCP`
☐ ~~`Evtbs2llGammaISRFSR`~~ - to be retained
☐ `EvtVubAC`

Other classes in `EvtGenBase` that are not used at all:

☐ `Evt3Rank3C`
☐ `EvtAbsBinning`
☐ `EvtAmpAmpPdf`
☐ `EvtAmpIndex`
☐ `EvtAmpSubIndex`
☐ `EvtBreitWignerPdf`
☐ `EvtDecayParm`
☐ `EvtIntegPdf1D`
☐ `EvtPointPred`
☐ `EvtPropGounarisSakurai`
☐ `EvtPto3PAmpSmpResolution`

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

⇒ Needed structural changes identified and first combination of solutions found

- External: limitations from dependences
  - TAUOLA
  - PHOTOS

⇒ 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
  - Exploring use of Vincia QED (Pythia8) shower and Sherpa’s PHOTONS++ as alternative to PHOTOS

New!

Progress on thread-safety

Heather Ratcliffe
Chris Brady

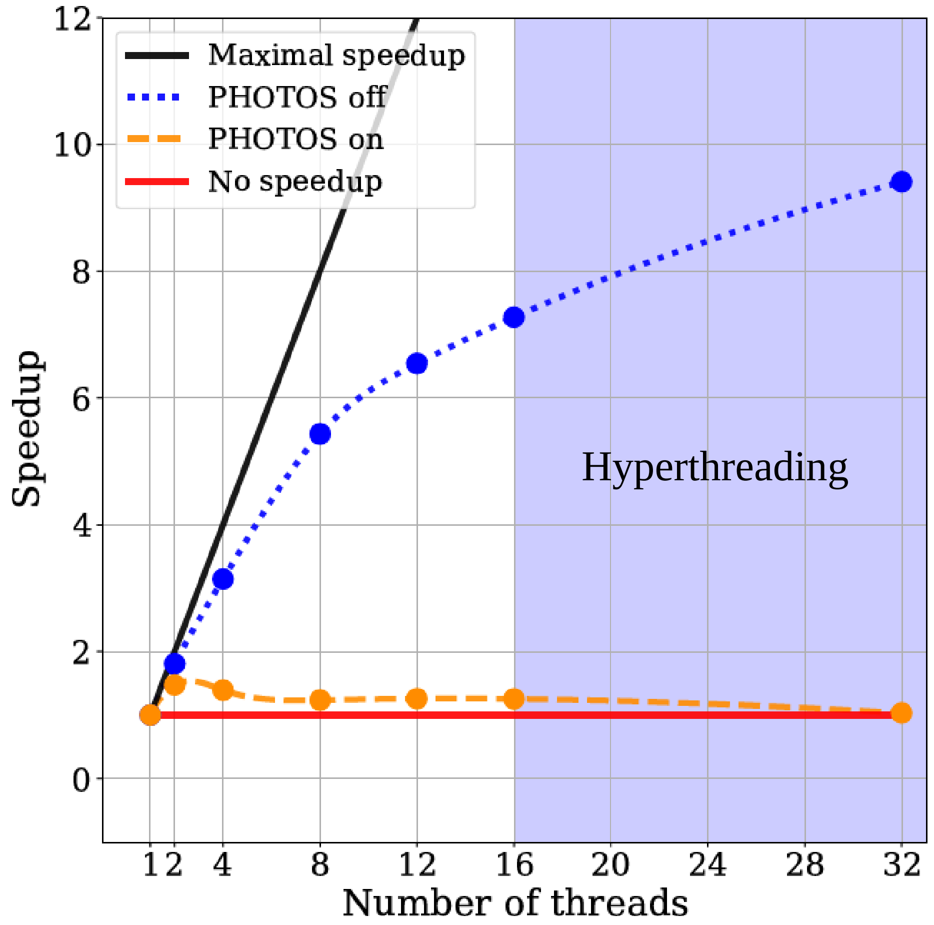
Set of solutions to reach thread-safety (preliminary):

- 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



Vincia QED shower for FSR

With help from Giacomo Morgante

- Recently started exploring Vincia's multipole QED shower for hadron decays
- Vincia is embedded in Pythia8
- Algorithm implementation enables thread safety
- Can simulate $\gamma \to e^+e^-$ splitting (if turned on)

$\Rightarrow$ Developed EvtGen $\leftrightarrow$ Vincia Interface based on existing dependency with Pythia8

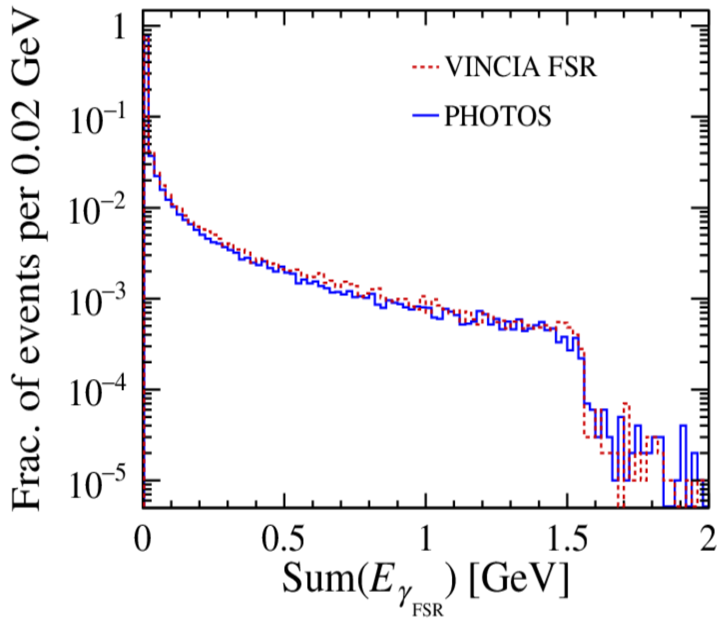
- Currently exploring as alternative to PHOTOS
- Matrix-element corrections (form factors, etc) not implemented yet

$\Rightarrow$ A lot of room for improvement and validation

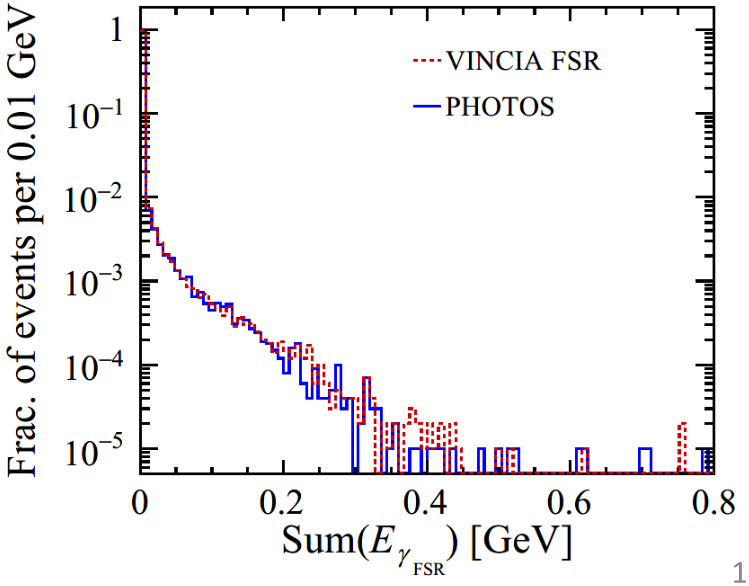
$\Rightarrow$ However, preliminary results look promising

New!

$J/\psi \to e^+e^-$



$\rho^0 \to \pi^+\pi^-$



Sherpa’s PHOTONS++ for FSR

New!

- PHOTONS++ in Sherpa can simulate emission of soft photons (to higher orders of perturbation theory)
- If switched on, also hard photons (to first order)
- Algorithm implementation enables thread safety

⇒ Can be explored as alternative to PHOTOS

- Recently started work on EvtGen ↔ Sherpa interface

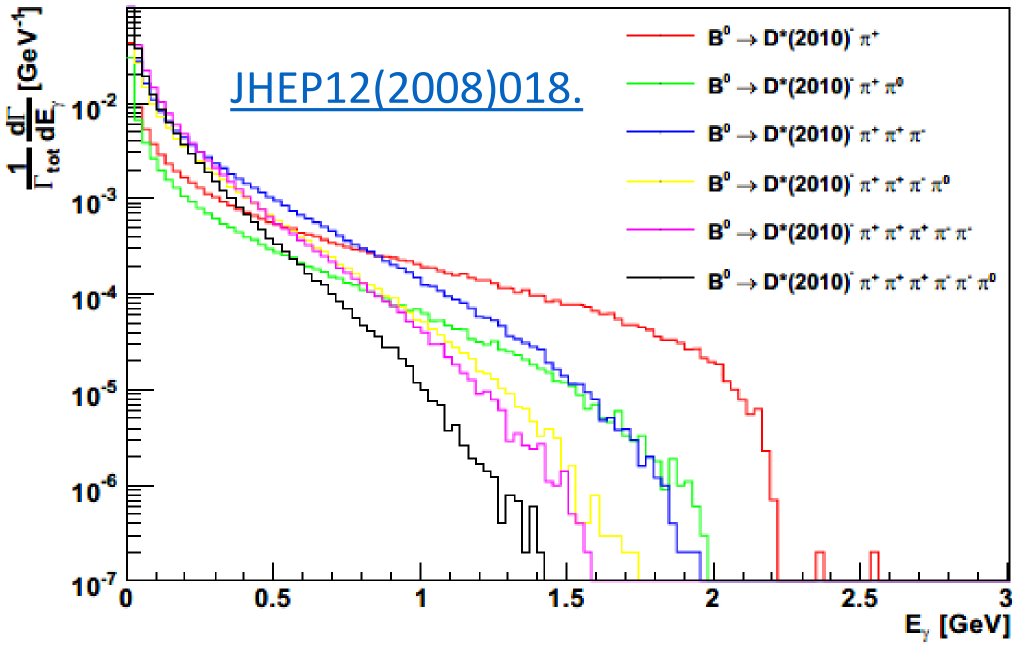
⇒ Skeleton for interface ready

⇒ Need to implement event translation and transfer (currently in contact with M. Schönherr and co.)

⇒ Requires tuning (for instance of cut-off energy)

⇒ And validation of physics output

Energy of radiated soft photon



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Pythia 8 for τ decays

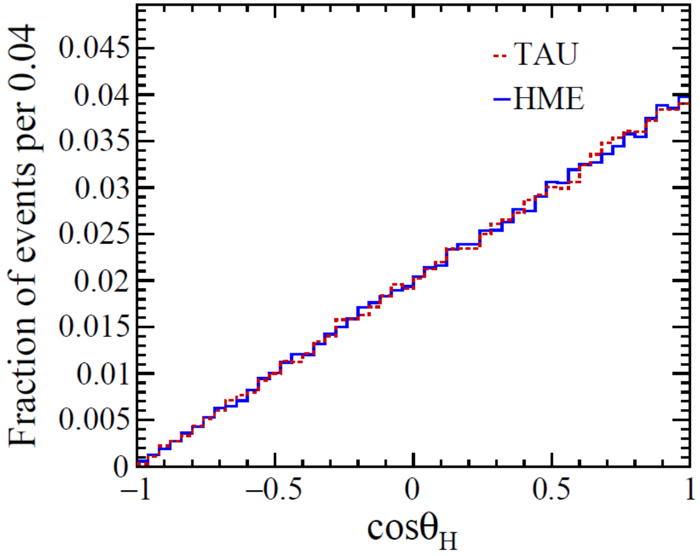
- In addition to multithreading limitations, spin-state information of τ not propagated between EvtGen and TAUOLA:
  - needed for analyses sensitive to τ polarization

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

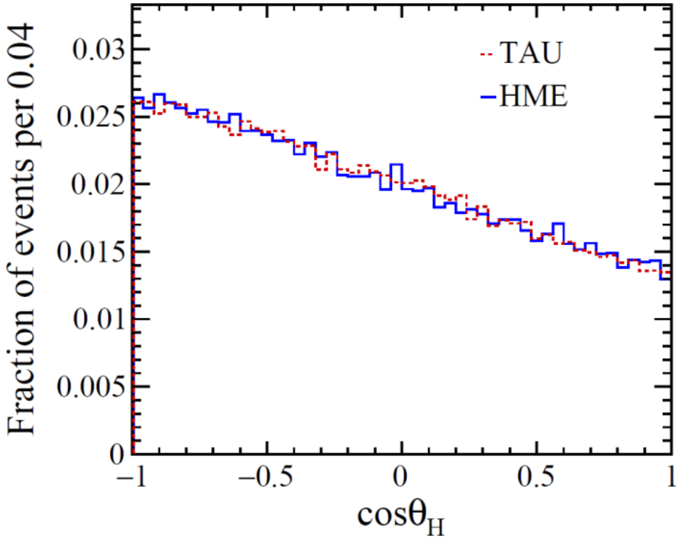
- Main EvtGen ↔ Pythia interface ready

- Generalization of conversion of helicity/spin basis (and initialization) not yet finalized (interesting also for interface with TAUOLA)

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



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



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

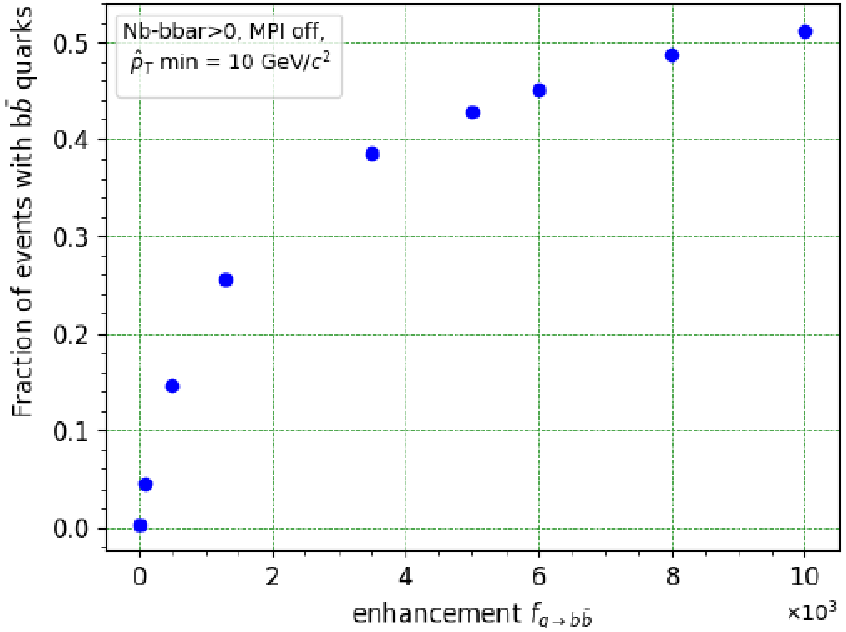
$\}$ Progress scarce due to person power, but plan to pick up next year

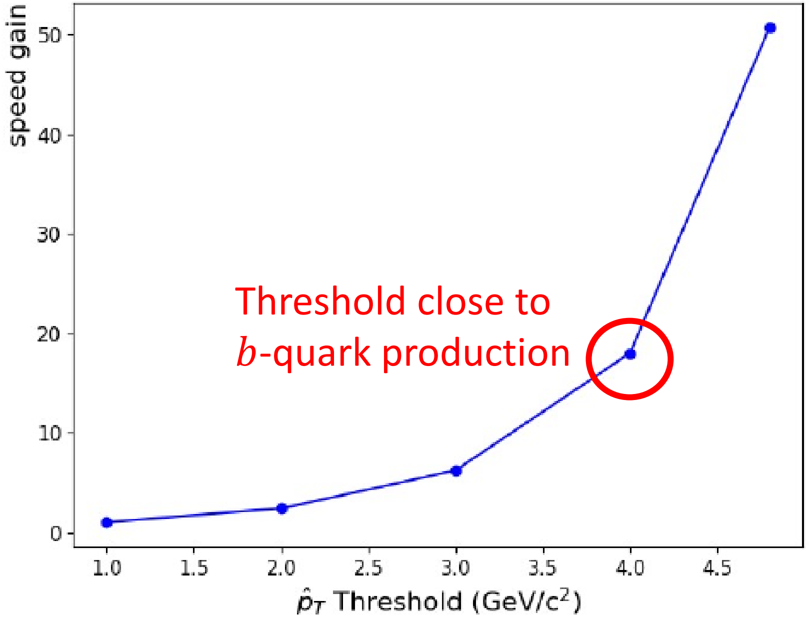
Plans for future developments:

- Forced hadronization
- Optimizing simulation for colour-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 $g \to c\bar{c}, b\bar{b}$ splitting
- About to be ready to tested within LHCb simulation framework GAUSS





Threshold close to b-quark production

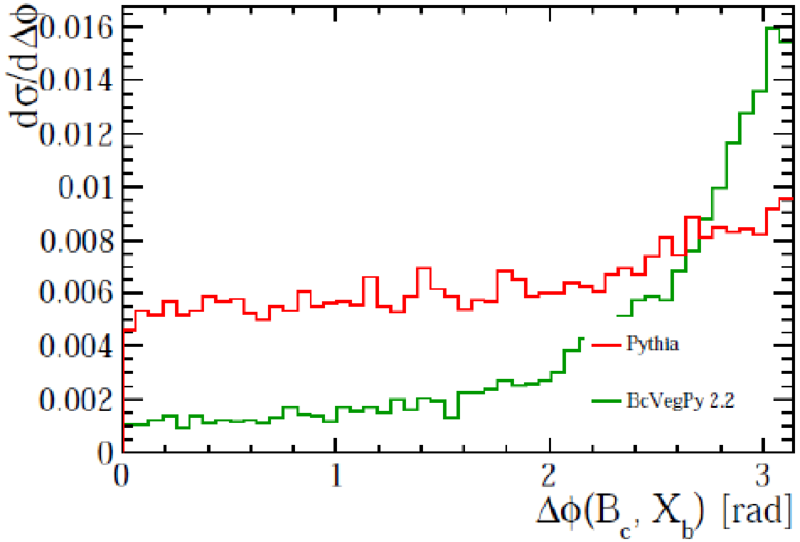
Proof of Principle via standalone Pythia

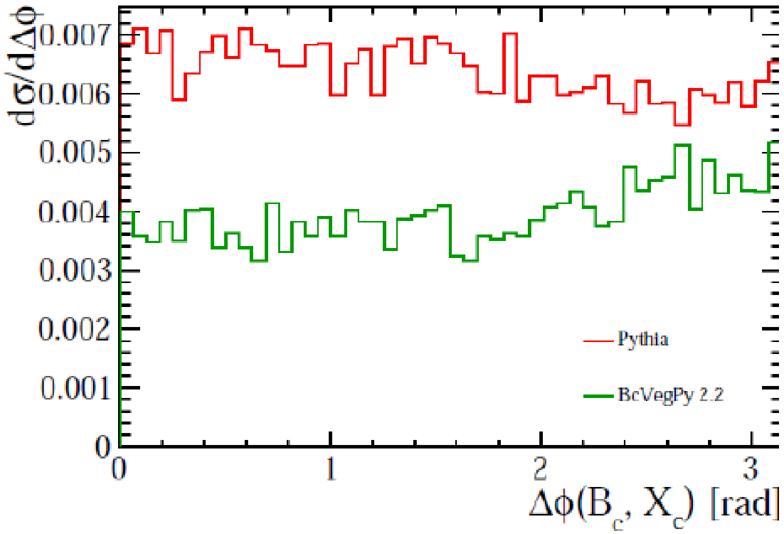
Double-heavy hadrons in Pythia

- 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

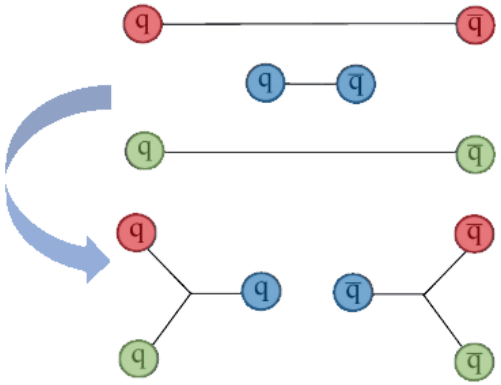




Improving colour-reconnection models

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

CR junction: choose “shortest” string configuration



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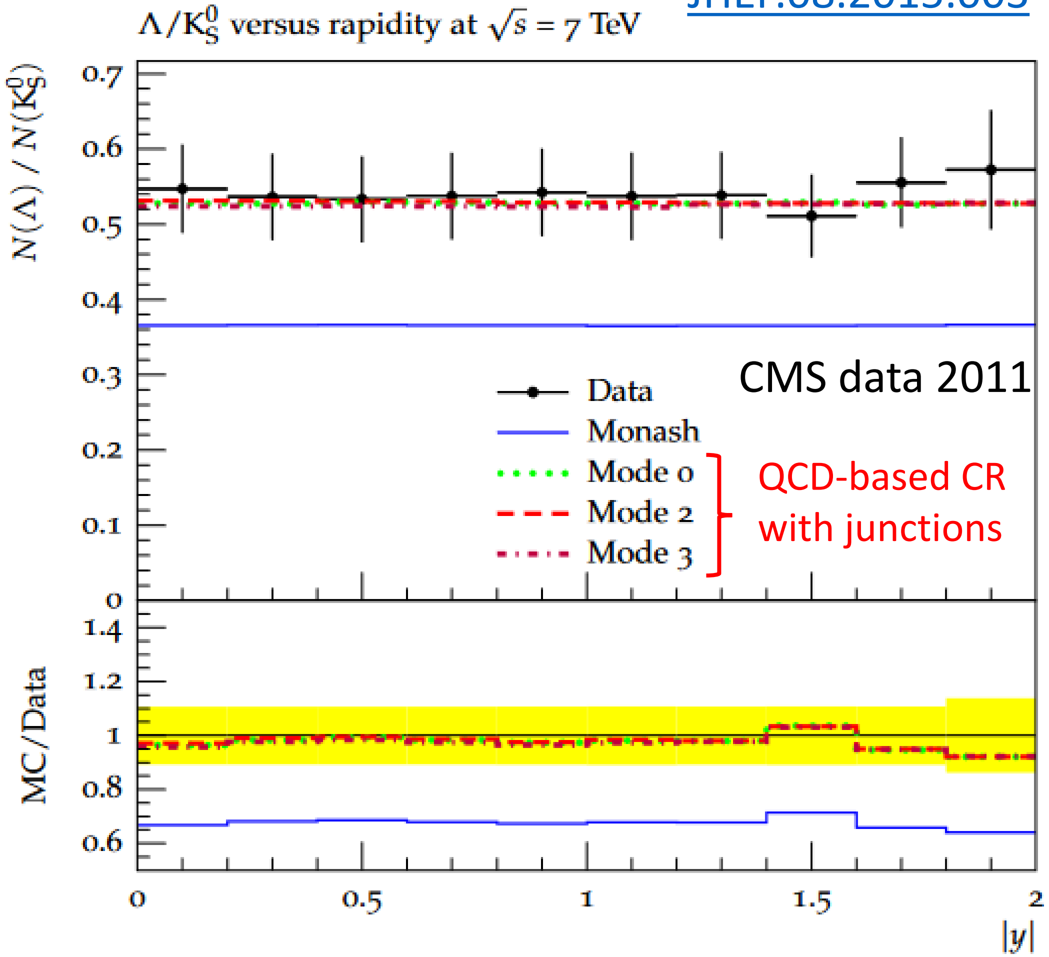

- However inefficient and CPU expensive
- Structural changes and efficient alternative algorithm for minimization identified (link)

⇒ 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:

- Continue work towards thread safety

⇒ Finalized common testing framework for validation

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

⇒ Performance limited by external dependencies

⇒ Started exploring Vincia QED and Sherpa’s PHOTONS++ as alternatives for FSR

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

Pythia:

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

⇒ Plan to study production mechanisms and improve implementation of colour-reconnection models