EvtGen status and news

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LHC Heavy-flavour WG topical meeting
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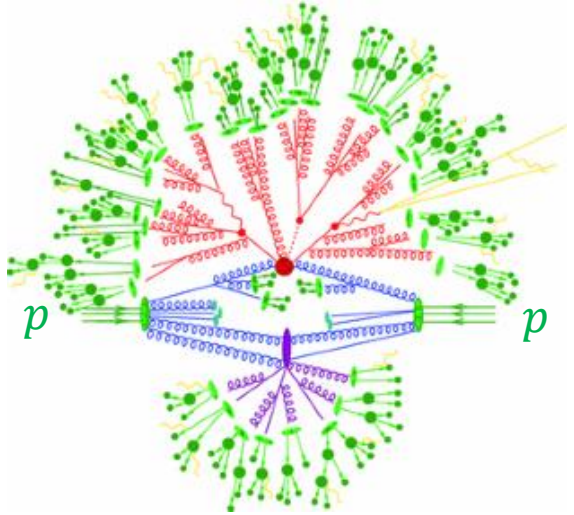
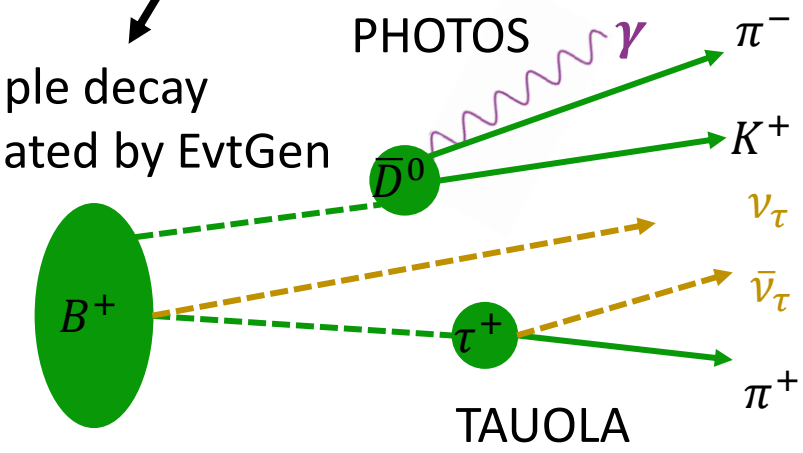
EvtGen generator

- 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 and plans

- Developed in the 90's, stable over past 10 years (changes mostly additions of new models)
- Physics wise no plan for changes in near future
- Major goal $\Rightarrow$ enable thread safety
- Code resides in HepForge with mirror in CERN gitlab

Recent developments

- Work on code modernisation, clean-up, removal of duplications, and documentation
- Implemented global testing framework for validation
- Fixing of broken models
- First full adaptation towards thread safety (further code redesign intended for the future)
- Studies of alternatives for τ simulation (to be continued)
- Added alternatives for FSR simulation (and further studies intended for the future)

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

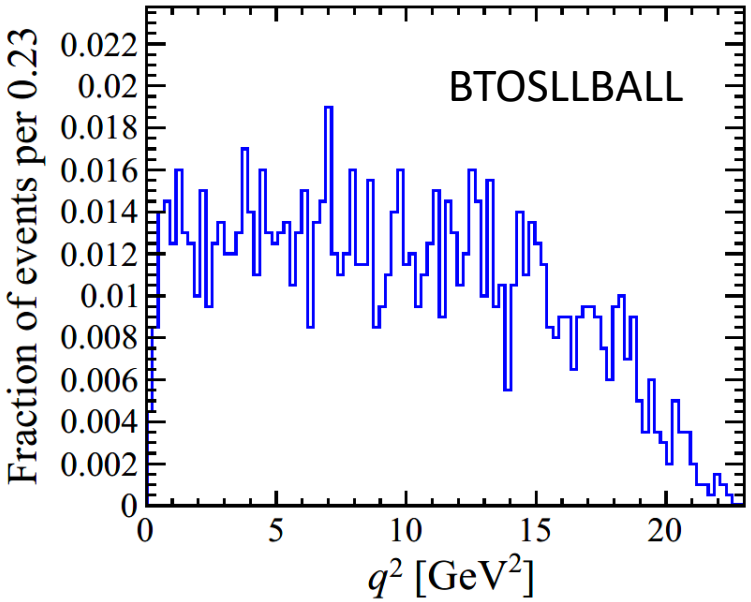
⇒ With common testing module and configuration JSON files

- Finalized first working version with tests for all models
- Some models support various configurations

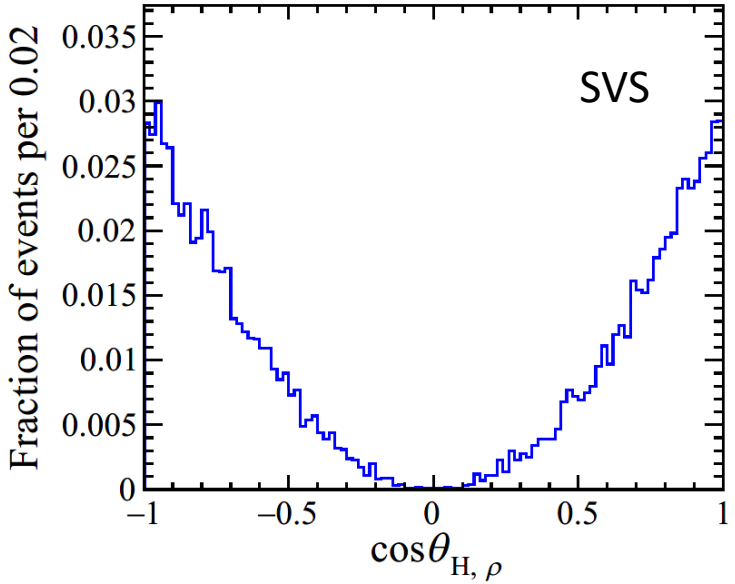
⇒ More tests needed to cover all configurations

⇒ Will require to add new tests for each new model

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



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



Implementation of multithreading

Challenges

- Internal: structural limitations
  - Global instance of random number generator
  - Global instance of particle properties and decay table
- External: limitations from dependences (look for alternatives) on TAUOLA and PHOTOS

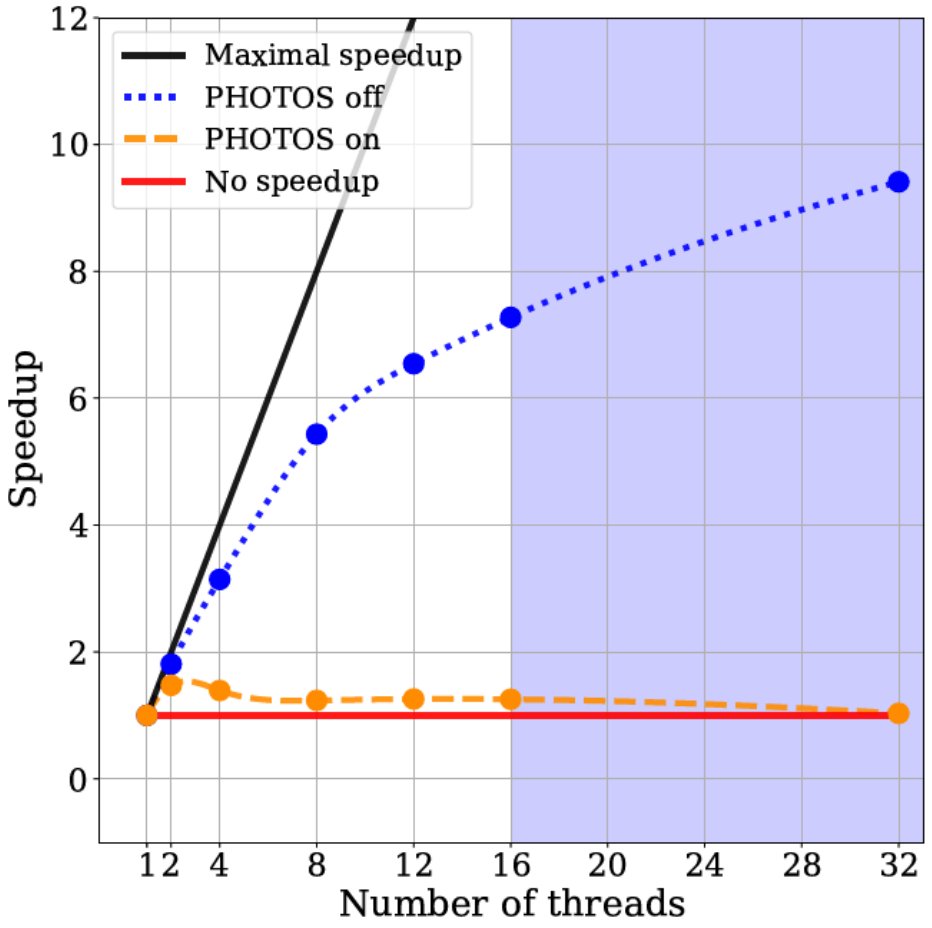
Preliminary solution

- Static objects made constant or thread-local
- Global singleton objects made thread-local
- Serialized (mutexed) calls to PHOTOS and TAUOLA

⇒ Deeper structural changes needed to fully exploit multi-threading

⇒ But performance limited by external dependencies

With help of research-software engineers:
Heather Ratcliffe, Chris Brady



Final-state radiation in EvtGen

- EvtGen relies on external specialised generators to add QED FSR corrections
- Generators generally treat the effect of FSR as a multiplicative correction to the decay rate

$$\mathrm{d}\Gamma^{\mathrm{radiative}} = \mathrm{d}\Gamma^{\mathrm{Born}}\, f(\Phi)\, \mathrm{d}\Phi$$

Φ: Phase-space of photons

- Decay tree is passed (node-by-node) to PHOTOS
- PHOTOS adds photons based on $f(\Phi)$ and event is retrieved
- Transference of events (back and forth) via HEPMC objects
- Recently studied and added alternatives to PHOTOS

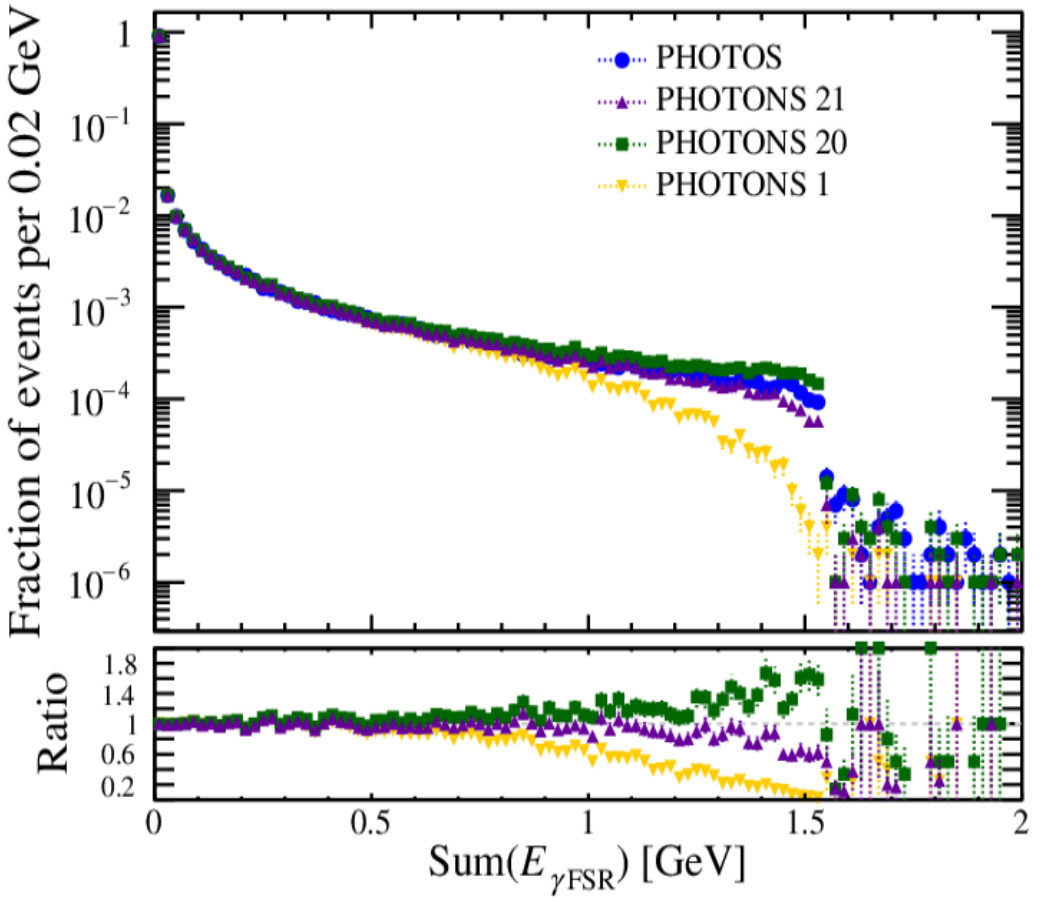
Sherpa's PHOTONS++ for FSR

- PHOTONS++ in Sherpa can simulate emission of soft photons based on YFS approximation (mode 1)
- If switched on also hard photons based on collinear approximation (mode 2), with
  - Approx. matrix-element corrections (mode 20) or
  - Exact matrix-element corrections (mode 21)
- Using option 1, observed fewer hard photons with respect to PHOTOS (note that PHOTOS has matrix-element corrections implemented)
- Generally good agreement with PHOTOS using options 20 and 21

⇒ Will enable user to switch between options for systematic studies

Amount of radiated energy

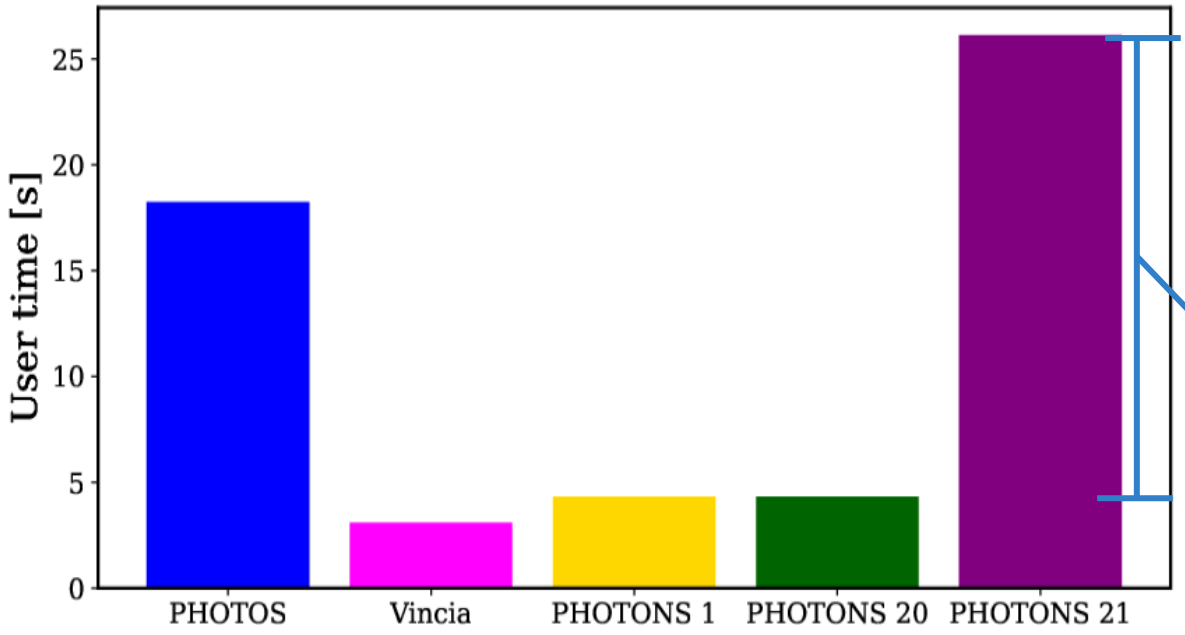
$J/\psi \to \mu^+\mu^-$

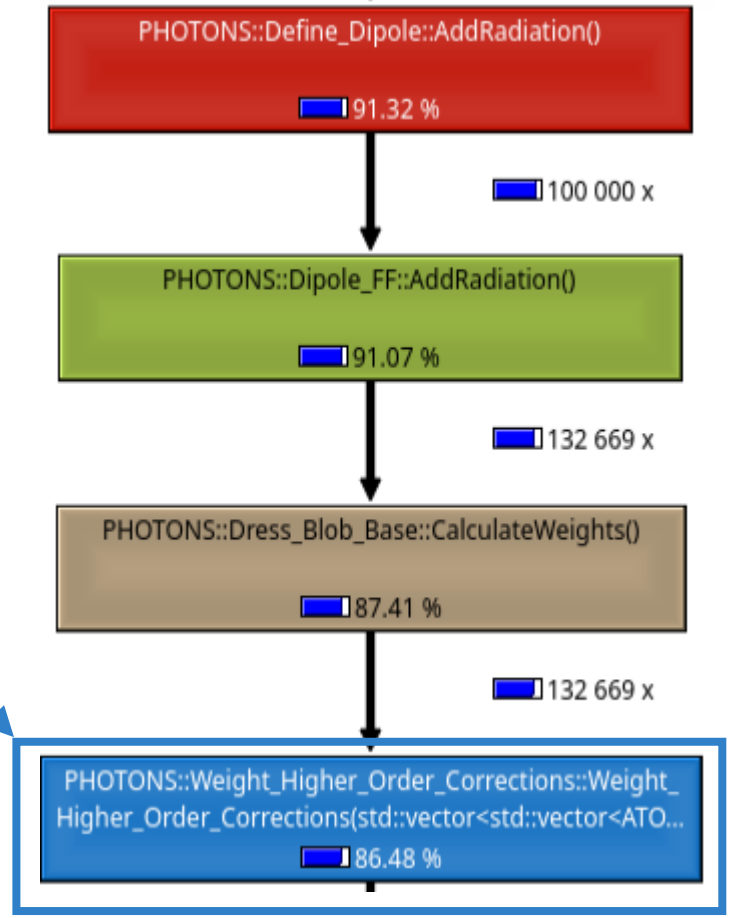


A word on timing

- Compare simulation time using $J/\psi \to e^+e^-$ decay as benchmark

⇒ Collinear singularities enhanced due to small electron mass





⇒ Largest consumption by exact matrix-element calculation

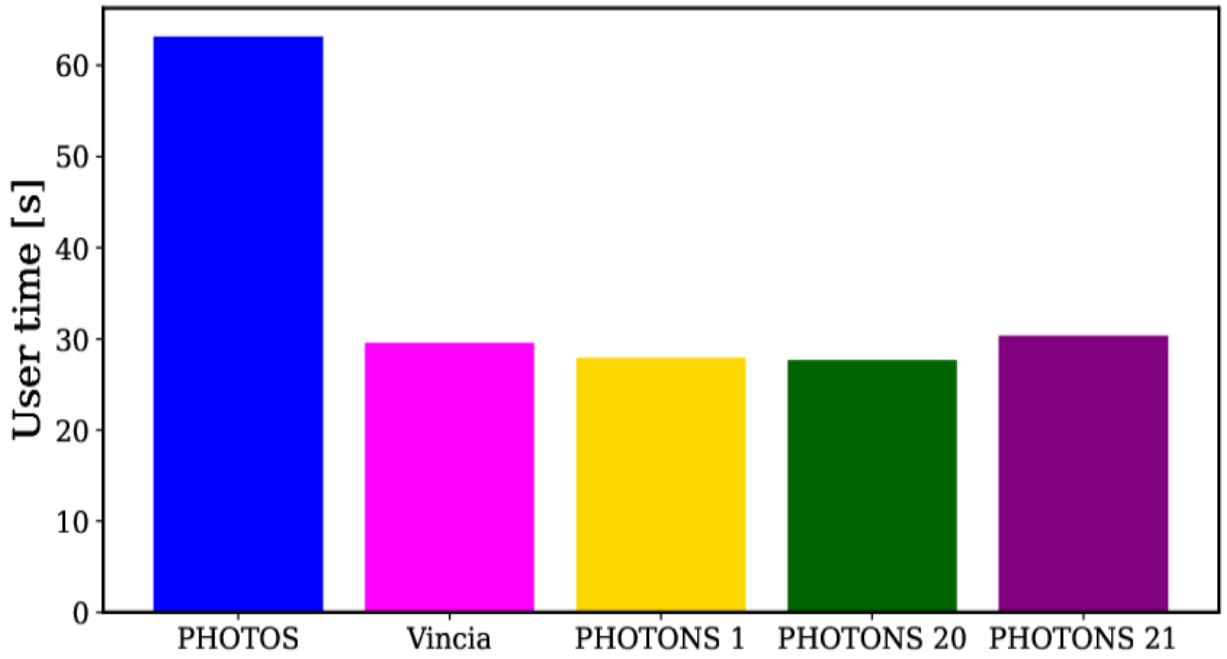
⇒ Good precision/time trade-off for option 20 (will use as default)

⇒ Potential speedup using Vincia or PHOTONS by about factor 4

Another word on timing

- Compare simulation time when simulating generic $\Upsilon(4S) \rightarrow B\bar{B}$

$\Rightarrow$ Benchmark for general use

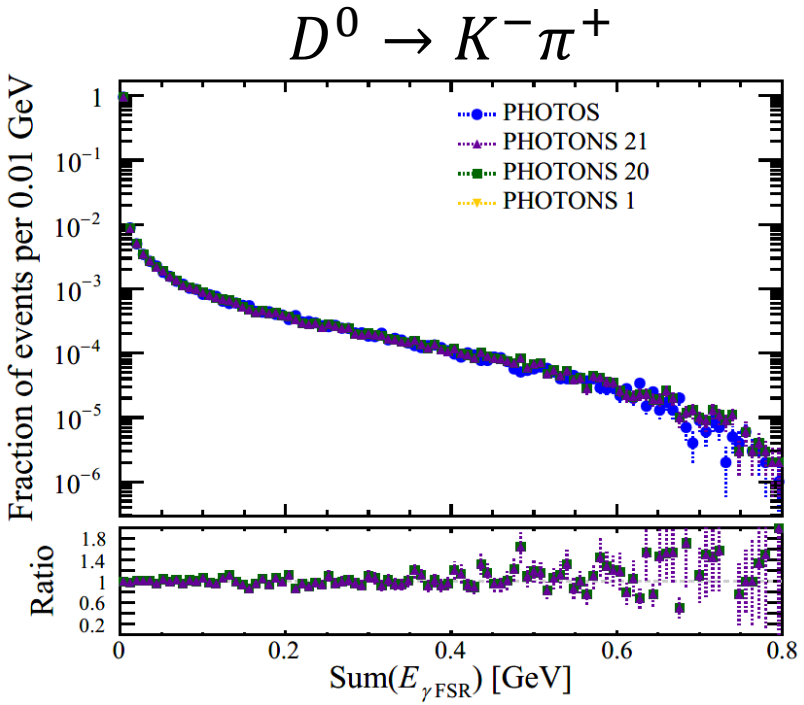


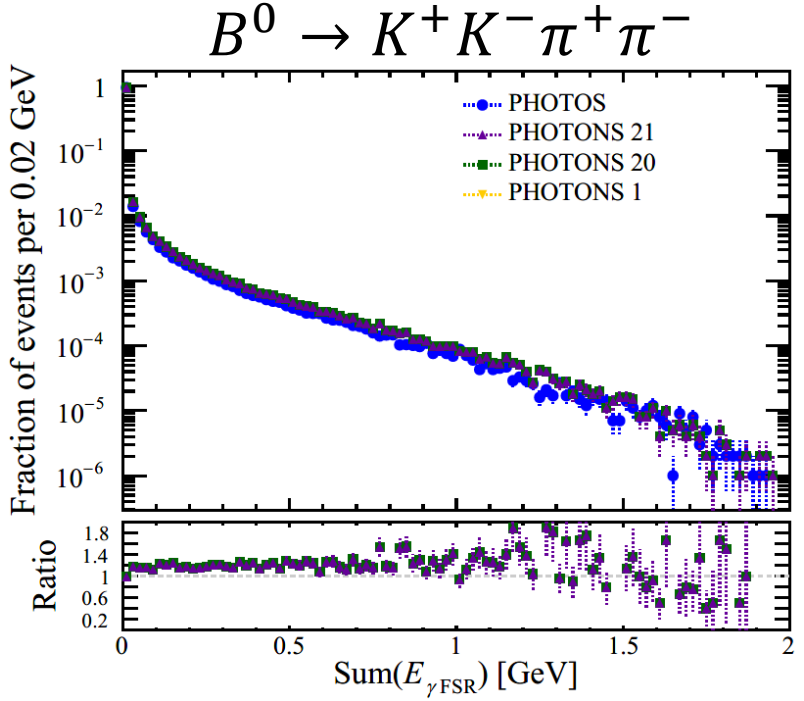
$\Rightarrow$ No large difference between PHOTONS options in generic case

$\Rightarrow$ Potential speedup using Vincia or PHOTONS by about factor 2

News regarding FSR

- Sherpa's PHOTONS++ interface already in master branch and surely part of next release
- PHOTOS flag is deprecated by new general FSR flag
- User able to choose between PHOTOS (default) and Sherpa's PHOTONS++
- Generally very good agreement between generators
- User able to modify (previously hard coded) parameters of PHOTOS and PHOTONS++
- Exact details will follow with new release

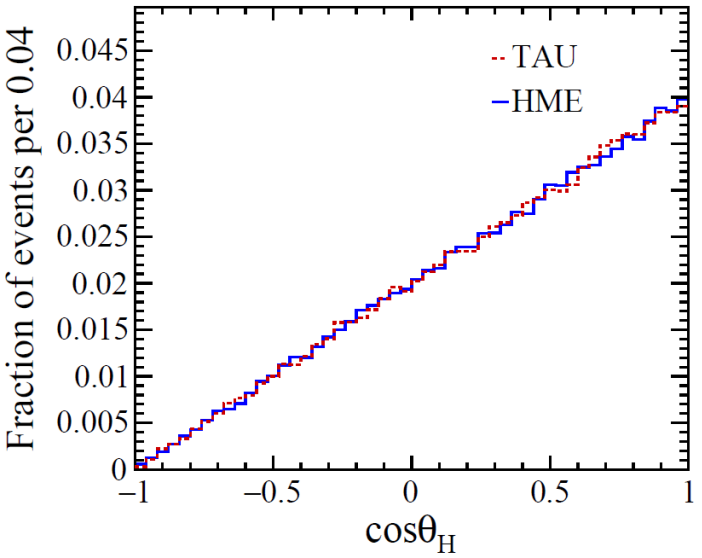




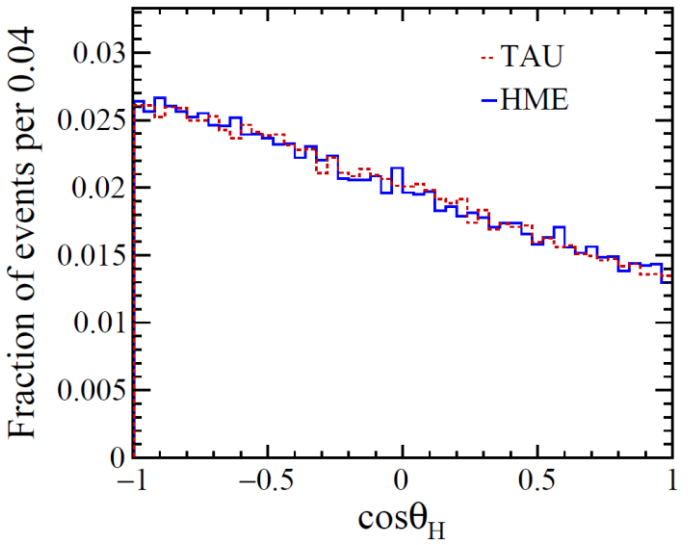
Plugins for τ decays

- EvtGen relies on TAUOLA for τ decays
- EvtGen $\leftrightarrow$ TAUOLA interface based on HEPMC
- Spin-state information of τ not propagated
  - TAUOLA reconstructs spin info from ancestors
  - 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
- Prototyped EvtGen $\leftrightarrow$ Pythia interface propagating spin-density matrix
- Generalisation of helicity/spin basis conversion has turned out challenging (but wish to continue work)

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



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



Summary and outlook

- Physics simulation inside EvtGen is kept invariant
- Implemented general testing framework
- Major modernisation and code clean-up campaign about to conclude

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

$\Rightarrow$ Performance limited by external dependencies

- Implemented new interface to Sherpa's PHOTONS++ as alternative for FSR
- τ decays: Propagation of spin-info across generators turned out challenging

$\Rightarrow$ Wish to continue in the future (help is welcome)

- Release 3.0.0 expected to come out by the end of summer 2024
- EvtGen paper being prepared (expected by early 2025)