Update on EvtGen
and related simulation developments

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SWIFTHEP Workshop
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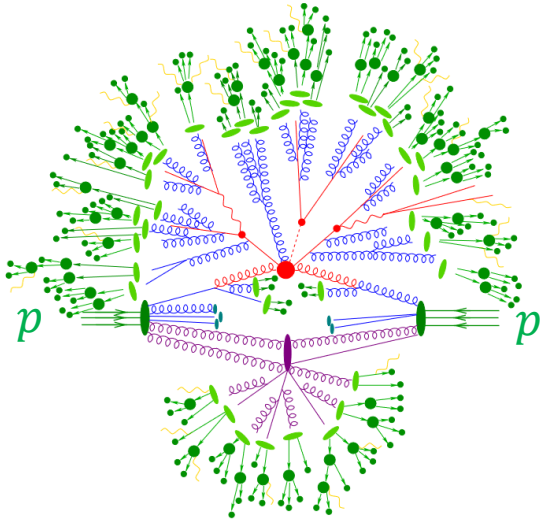
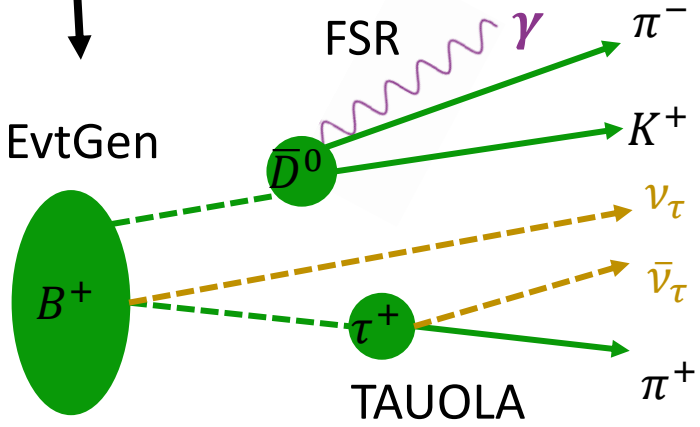
EvtGen in a nutshell

Simulation generator package specialised for decays of heavy particles containing b and c quarks.

Example collision simulated by PYTHIA8



- Contains 130 decay models for specific decays
- Maintains decay table with properties of $\sim 10^4$ explicit decays



External dependencies

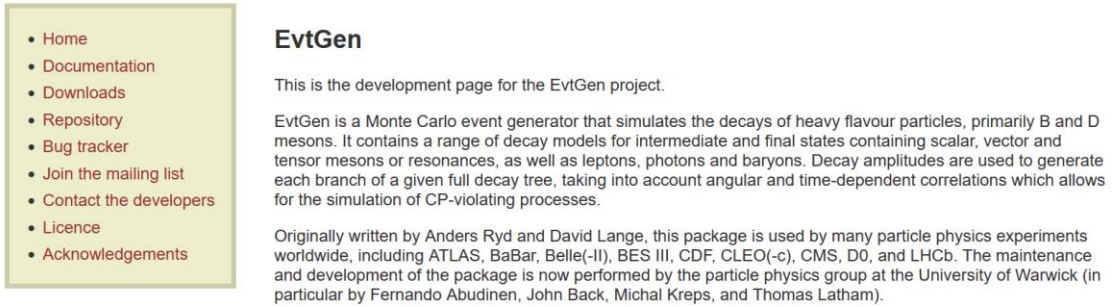
- Uses Pythia8 for decays of generic quark configurations
- Uses TAUOLA for decays of τ particles
- Relies on PHOTOS or PHOTONS++ for final-state photon radiation (FSR)

EvtGen status

- Developed in the 90's, stable over past 10 years
- Changes mostly additions of new models by different collaborators
- Maintained at Warwick since 2012 following merge of various experiment's forks by Anders Ryd
- Recently accomplished first **source-code modernisation** with help of research-software engineers at Warwick

⇒ Main goal of recent campaign: **enable thread safety**

https://evtgen.hepforge.org



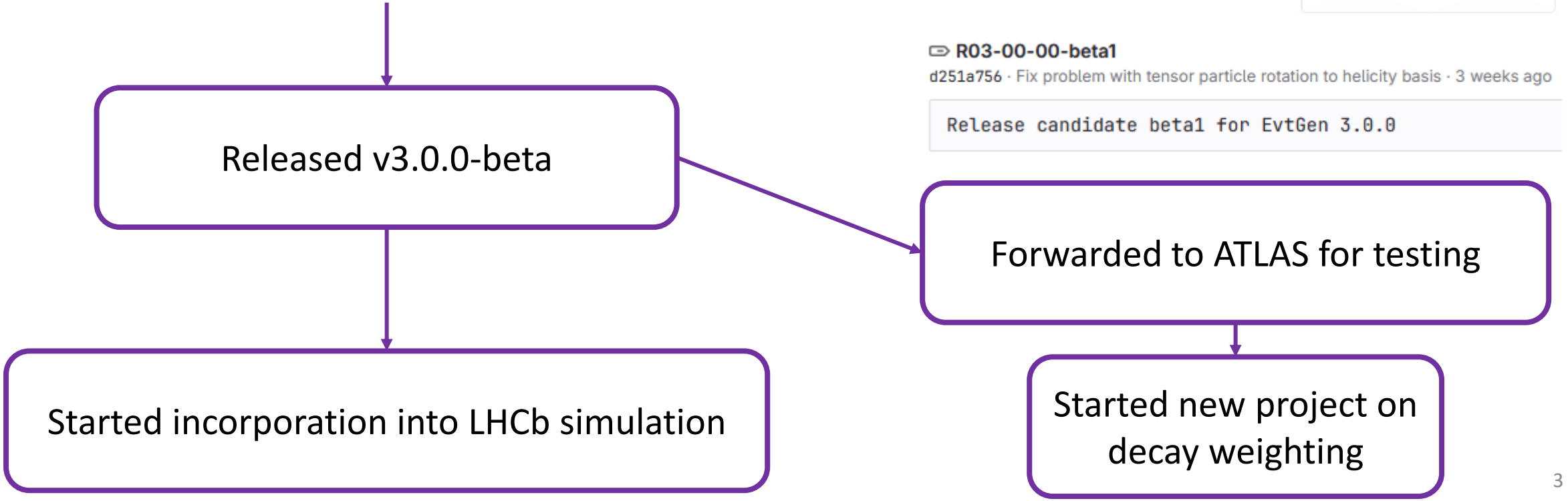
Mirror at https://gitlab.cern.ch/evtgen/evtgen
with continuous integration tests

Heather Ratcliffe
Chris Brady

Recent developments

- Propagated thread safety across the whole software framework
- Implemented multi-threading in testing framework
- Added tests for external dependencies
- Fixed bug with tensor particle rotation to helicity basis

Check it out!



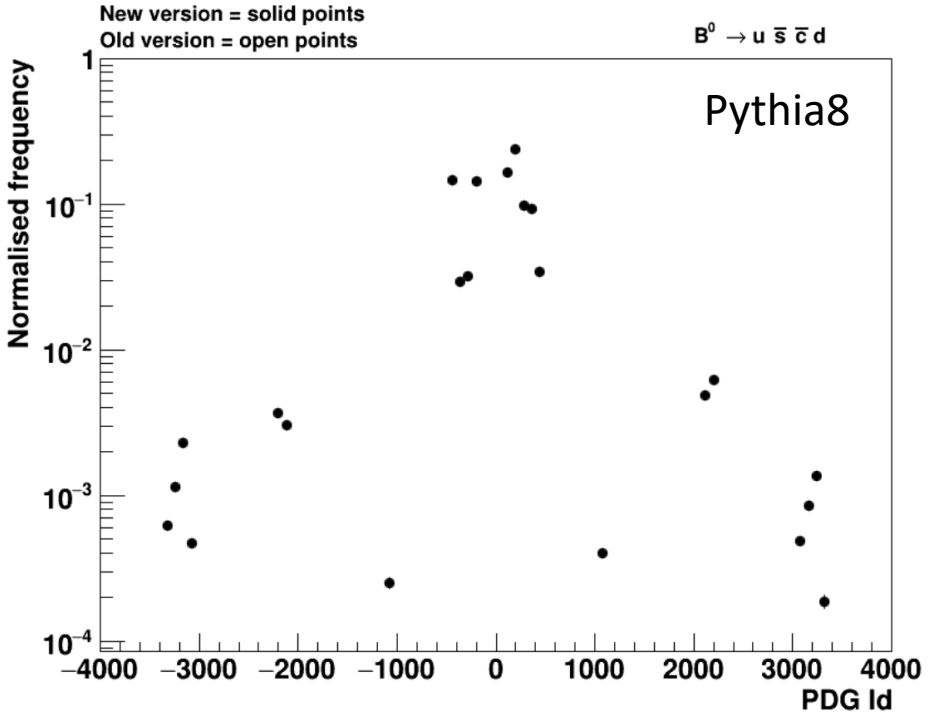
Validation

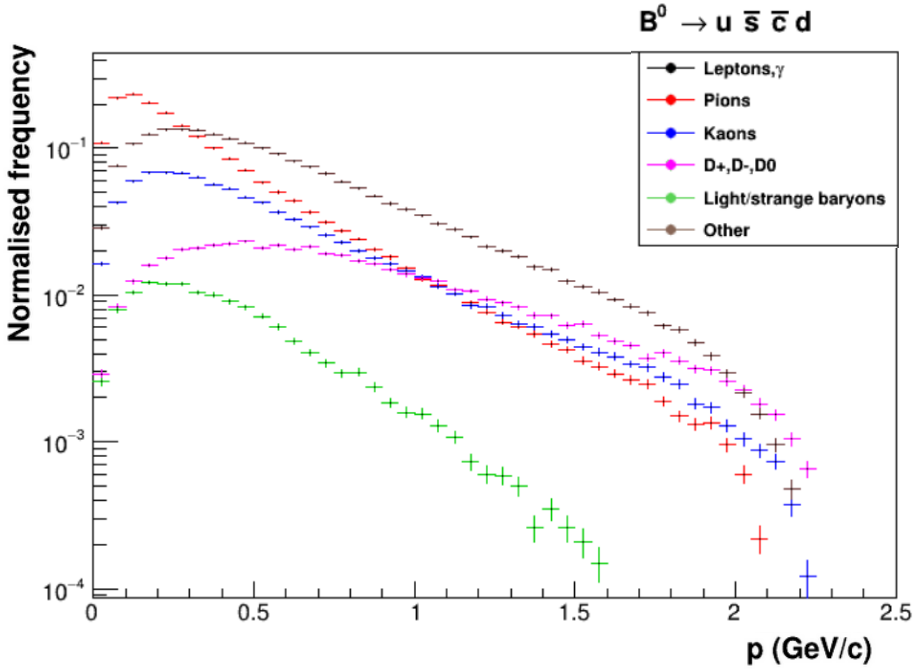
Simulation needs testing and validation after changes to ensure invariance of the physics models

- Implemented **testing framework** with common testing module and JSON configuration files
- Migrated all previous tests (covered only 40% of models) and added new ones to framework
- Tests cover all models and **external generators**
- Used for **continuous integration** in GitLab
- Implemented **multi-threaded testing**

  ⇒ With possibility to use **std** or **tbb** thread models

Available also for users to facilitate testing/development





Implementation of multithreading

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

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

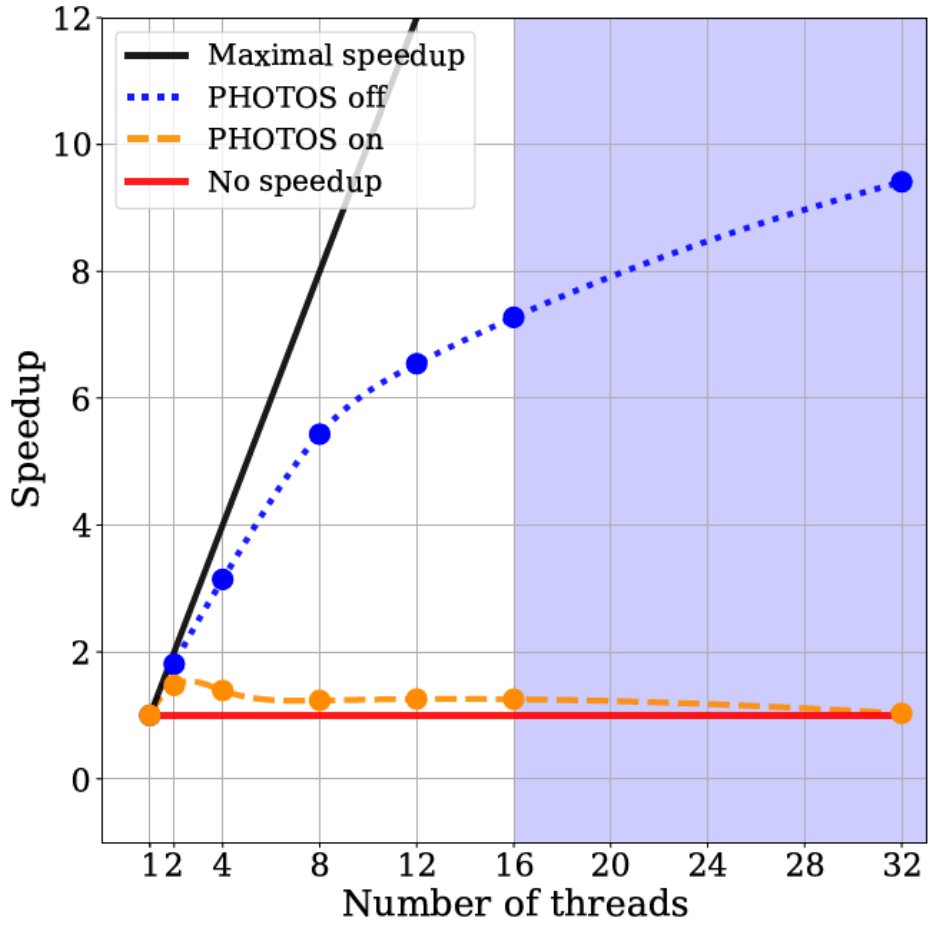
Current solution

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

⇒ Passes all tests

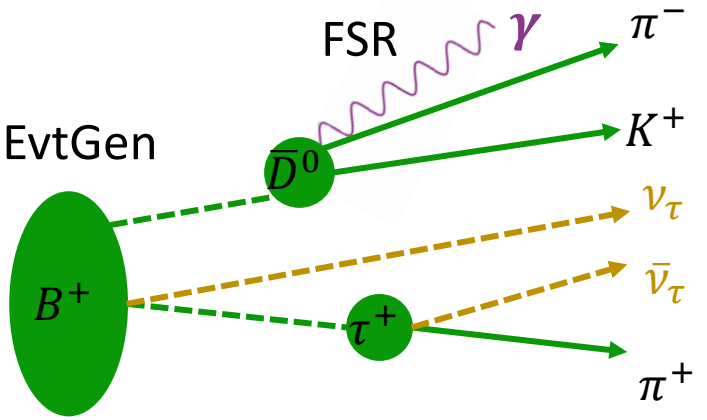
⇒ Performance limited by external dependencies

⇒ Study alternatives



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



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

Φ: Phase-space of photons

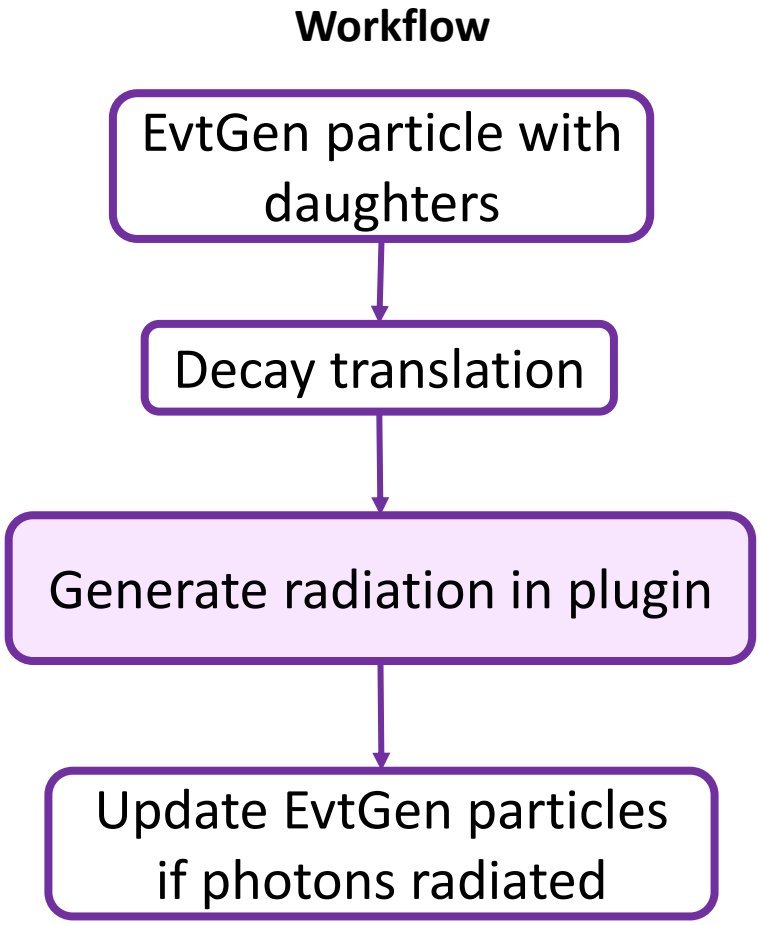
- Generators add photons (accept/reject) based on $f(\Phi)$
- Default generator is PHOTOS
- Recently included Sherpa's PHOTONS++ as alternative
- Currently developing Vincia (inside Pythia8) as alternative

```
Decay D0sig
  0.0390   K-   pi+   PHOTOS PHSP;
Enddecay
CDecay anti-D0sig
```

PHOTOS flag deprecated with FSR flag in EvtGen r3.X.X

Interfaces between EvtGen and Plugins

- Each decay-chain node translated
  - Into intermediate HepMC events (for PHOTOS)
  - Directly into Sherpa or Pythia objects (for Photons and Vincia)
- EvtGen random number propagated (full seed control)
- PHOTOS and Sherpa's PHOTONS++ not thread-safe yet ⇒ **mutex**
  - Need to mutex also HepMC translation (for PHOTOS)



Review (for Sherpa) by Marek Schönherr and Frank Krauss

Supporting Sherpa 2.2.15 and **new 3.x.x releases**

Challenges for interfacing

- Need to create full Pythia/Sherpa objects
- Several initialised objects are not used

  Example: Sherpa's initialisation takes as much time as $\sim 10^4$ decay events
- Need to control destruction of static instances

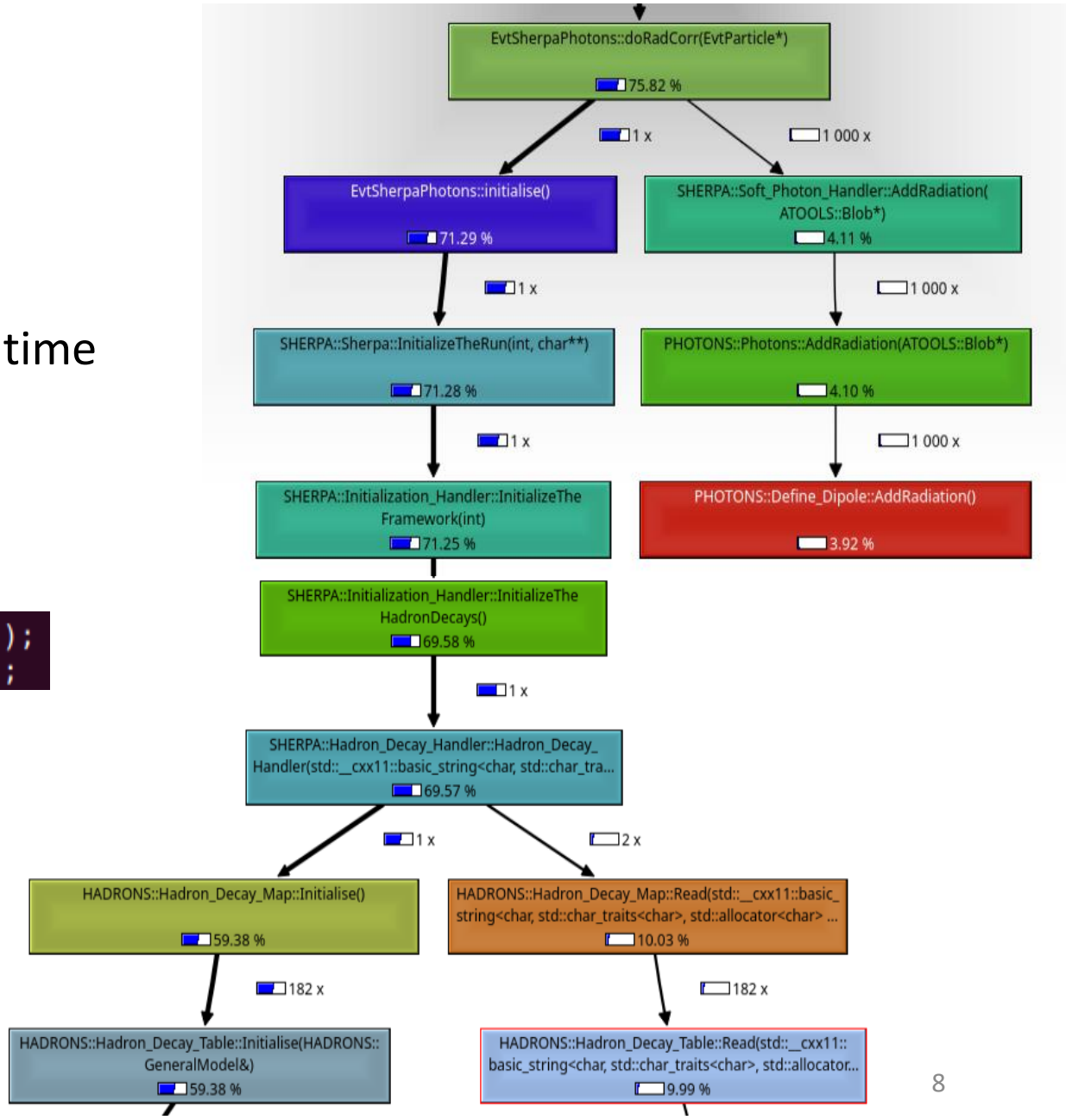
Users must call this function

```
EvtSherpaPhotons::finalise();
```

→

```
m_photonsGen.reset();
m_sherpaGen.reset();
```

Currently discussing improvements with Sherpa authors

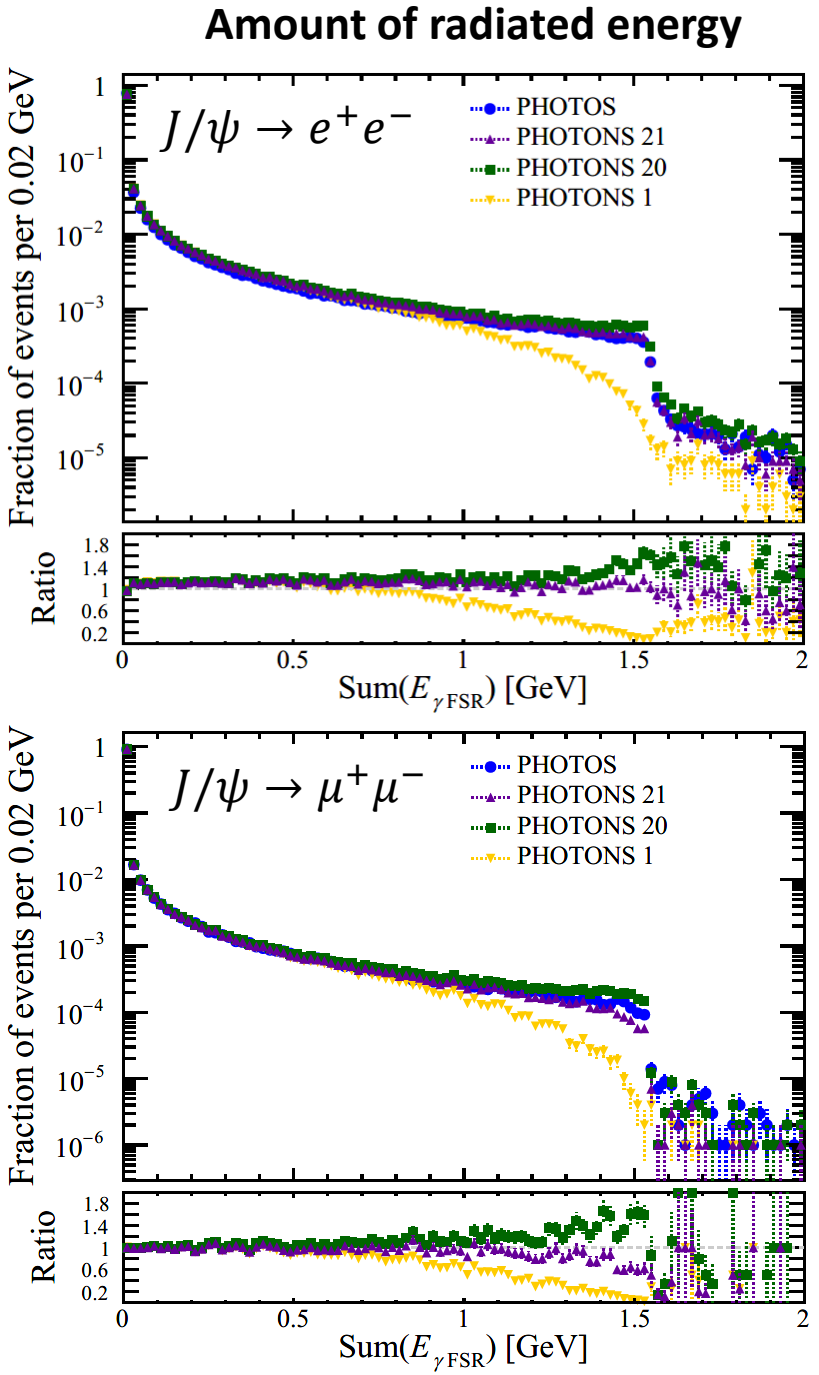


Sherpa's PHOTONS++ for FSR

- 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)
  - Approx. matrix-element corrections (mode 20) or
  - Exact matrix-element corrections (mode 21)
- With mode 1: fewer hard photons compared to PHOTOS (PHOTOS has matrix-element corrections implemented)
- With mode 2: generally good agreement with PHOTOS

⇒ Implemented switches for systematic studies

New in EvtGen R03-00-00-beta1!



Vincia QED shower for FSR

- Vincia parton shower evolution based on Antenna approximation (can be interleaved)
- Recently adapted to radiate off hadrons (previously supporting only leptons)
- Matrix-element corrections (MECs) in progress

⇒ Currently implementing and validating

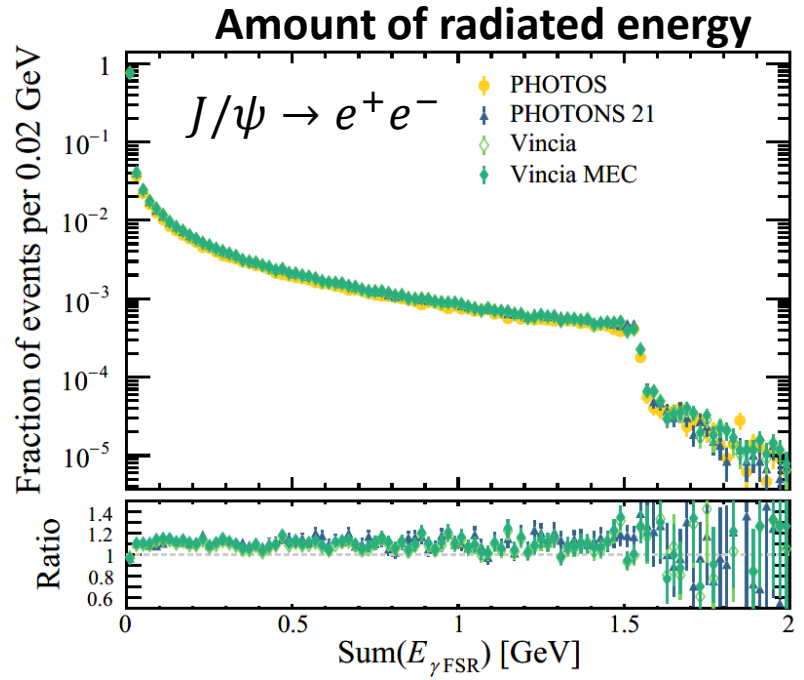
⇒ Preliminary results look promising

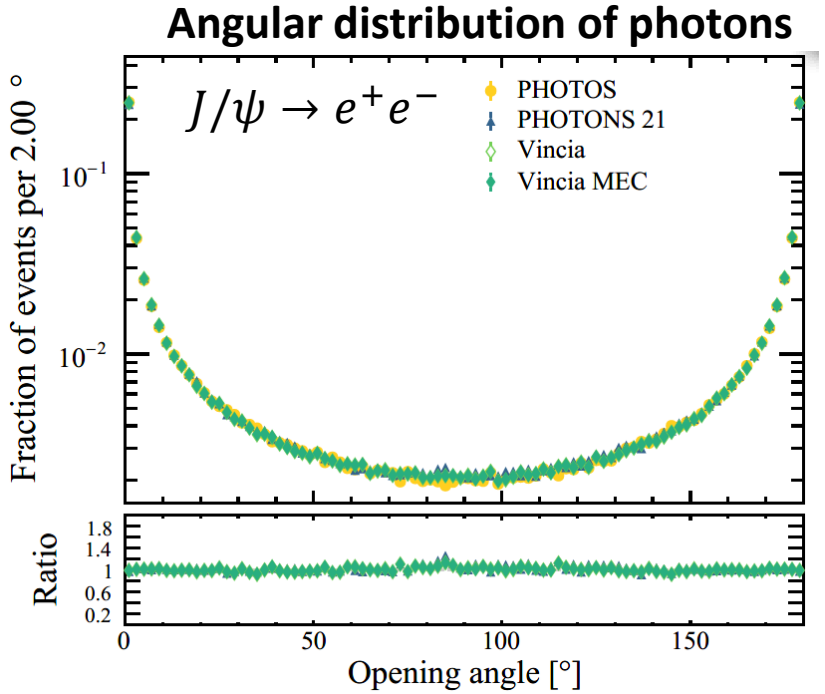
Technical aspects

- Vincia is embedded in Pythia8
- Algorithm implementation enables thread safety
- Developed EvtGen ↔ Vincia interface based on existing dependency with Pythia8

⇒ To be added to release (once in Pythia8 release)

Together with Giacomo Morgante and Peter Skands @ Monash

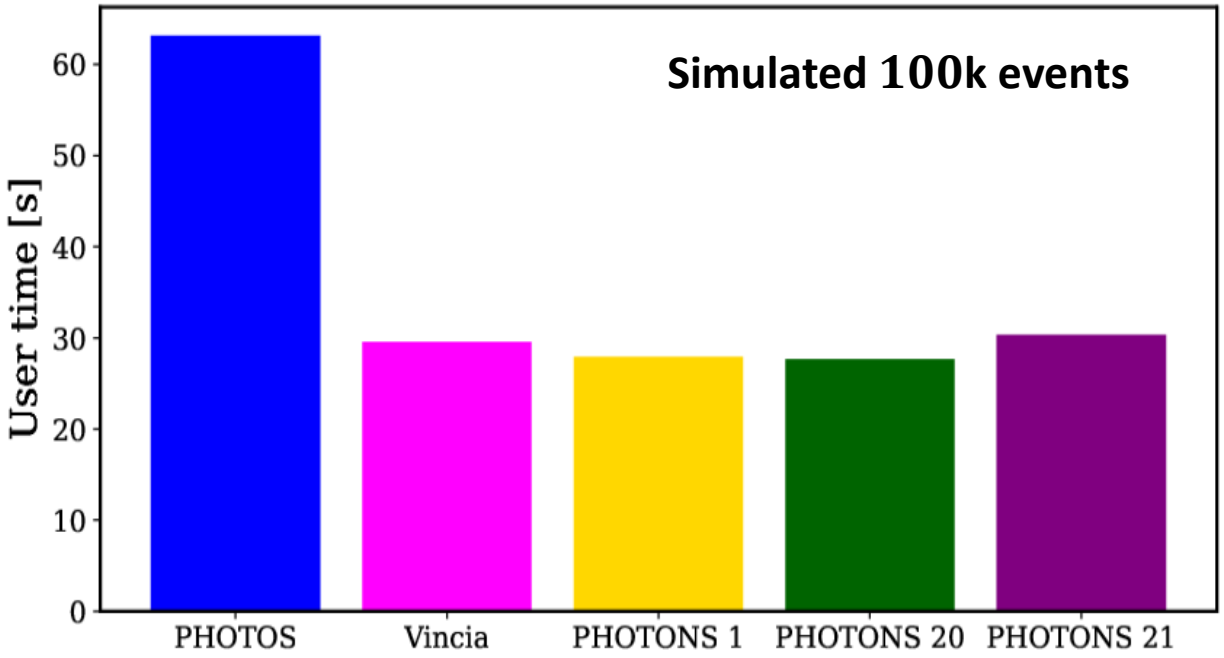




A word on timing

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

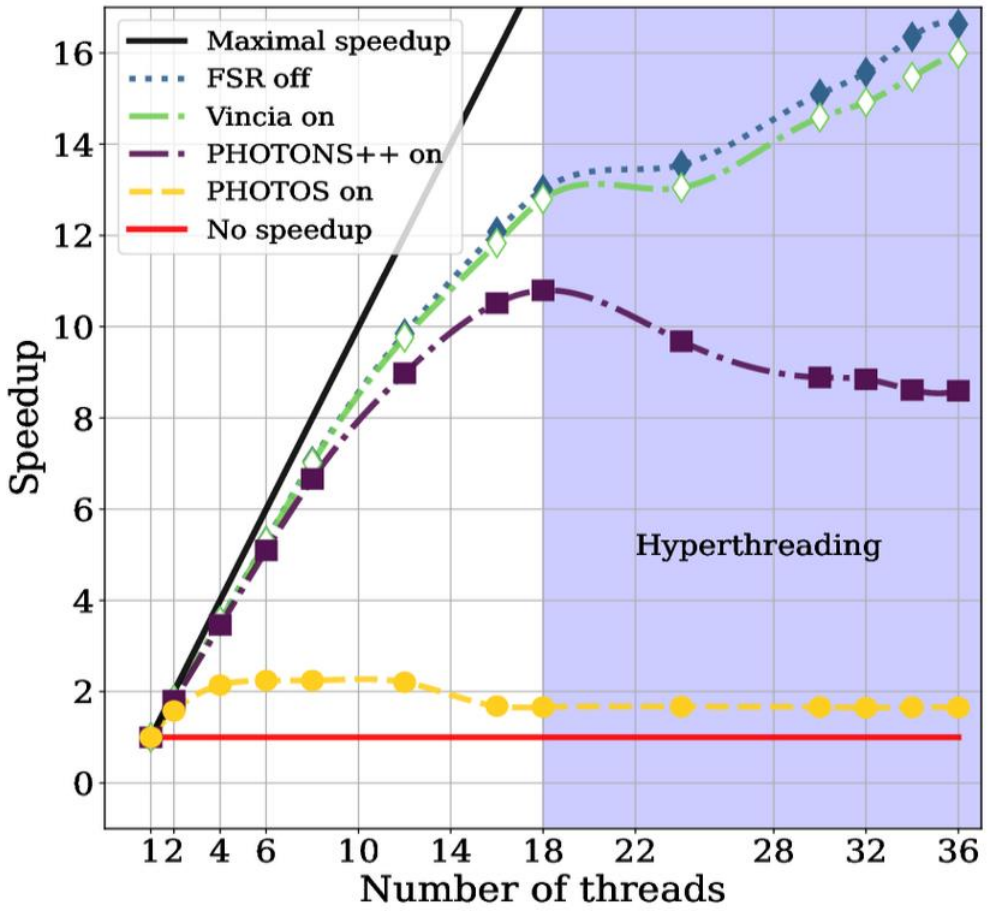
$\Rightarrow$ Benchmark for general use

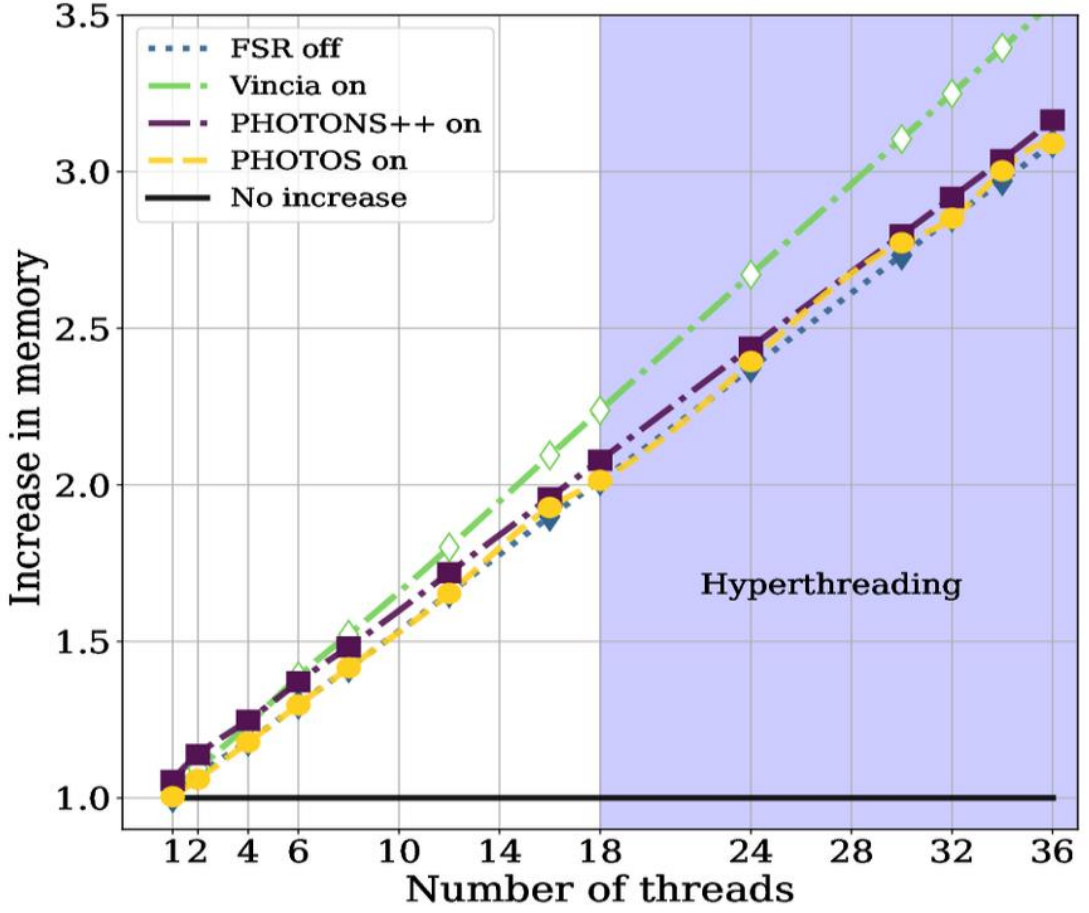


$\Rightarrow$ No large difference between PHOTONS options in generic case

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

Performance with multithreading





⇒ Better performance with new FSR alternatives

⇒ Deeper structural changes needed to fully exploit multithreading with increased memory sharing

MC tools workshop

Some of the topics discussed

- Evolution and update of **MC particle IDs**
- Challenges for **interfacing** between generators
  ⇒ Focus on final-state photon radiation
- Propagation of **spin-info** between generators
- Weighting to account for **decay table** variations

Started new project on decay weighting

https://conference.ippp.dur.ac.uk/event/1433

Decay Table variations

General decay table

- Ignores **uncertainties on branching fractions**
- Users can have **custom versions**
- Currently no support for **variations**

Idea: provide decay weights for systematic variations

Challenges

- Inconsistencies, PDG BFs not adding up to 1, theory uncertainties (form factors, etc)
- Calculate alternative amplitude for generated kinematic configuration
- Propagate alternative spin-density matrix through decay chain

Example from general decay table

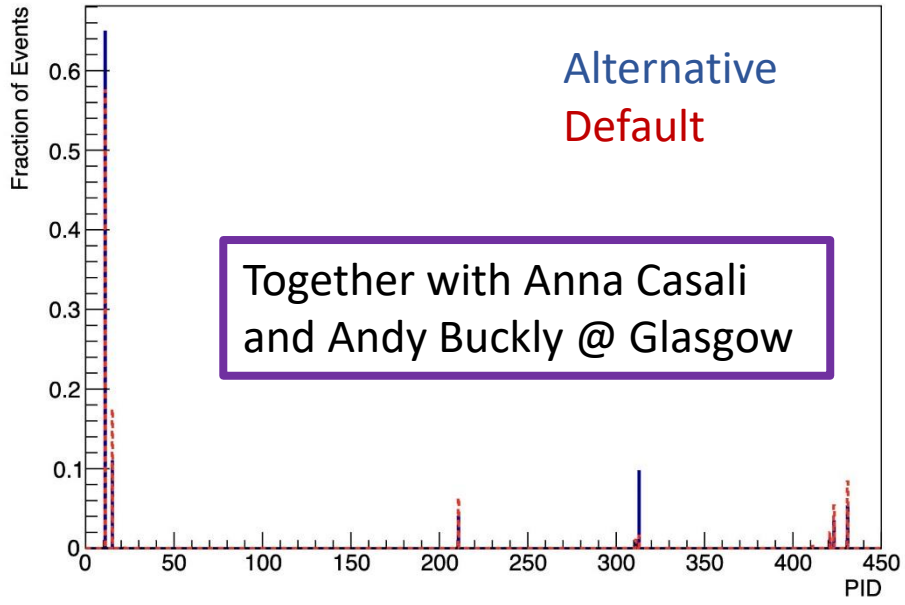
BFs

Models and configs

```
Decay anti-B0

#                    b -> c semileptonic
#
0.0493   D*+     e-      anti-nu_e      FSR  HQET2 1.207 0.920 1.406 0.853;
0.0219   D+      e-      anti-nu_e      FSR  HQET2 1.185 1.081;
0.0042   D_1+    e-    anti-nu_e        FSR  ISGW2;
0.0045   D_0*+   e-    anti-nu_e        FSR  ISGW2;
0.0046   D'_1+   e-    anti-nu_e        FSR  ISGW2;
0.0033   D_2*+   e-    anti-nu_e        FSR  ISGW2;
0.00045  D*+  pi0   e-    anti-nu_e      FSR  GOITY_ROBERTS;
0.00490  D*0   pi+  e-    anti-nu_e      FSR  GOITY_ROBERTS;
0.0015   D+   pi0   e-    anti-nu_e      FSR  GOITY_ROBERTS;
0.0043   D0   pi+   e-    anti-nu_e      FSR  GOITY_ROBERTS;
```

Simulation with two decay tables



Together with Anna Casali and Andy Buckly @ Glasgow

EvtGen releases

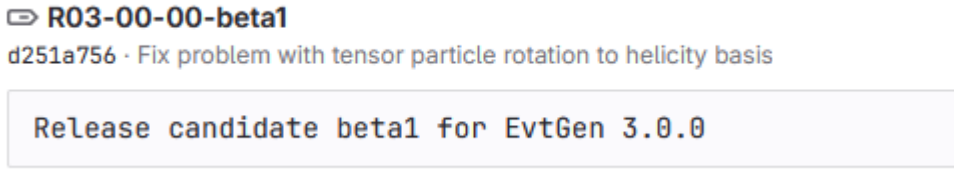
Release with latest subversion R02-02-03 (Sep 2024)

- Fixed RNG interface issue with Pythia8 310
- Fixed bug with tensor particle rotation to helicity basis

After the long campaign released R03-00-00-beta1 (Oct 2024) for users to test

- Implemented **thread safety**
- Implemented new **testing framework**
- Added Sherpa's PHOTONS++ as **FSR alternative**
- **Fixed** various **decay models** (removed obsolete ones)

Physics validation passed for all models with/without FSR when multithreading.



Check it out!

Plans for the future

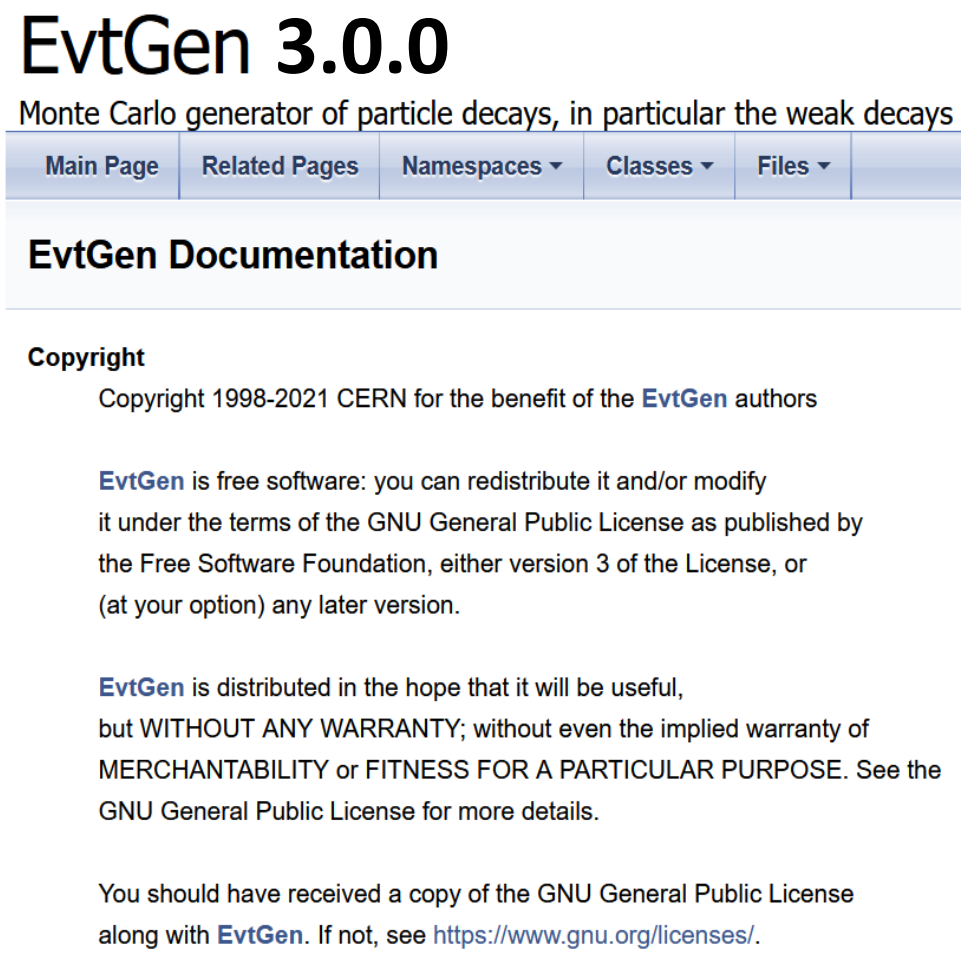
Immediate

- Include Belle II decay table
- Vincia for FSR
- Improve Doxygen documentation
- Prepare main Journal article

Long-term

- Add further models as requested by community
- Implement alternatives for τ particle simulation (fix spin propagation)
- Implement structural modifications to fully exploit multi-threading
- Provide event weights for alternative decay tables
- Interleave Vincia FSR with entire decay chain

https://evtgen.hepforge.org/doc/doxygen/test



EvtGen **3.0.0**

Monte Carlo generator of particle decays, in particular the weak decays

Main Page | Related Pages | Namespaces | Classes | Files

EvtGen Documentation

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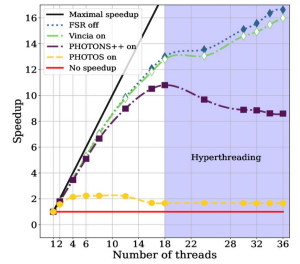
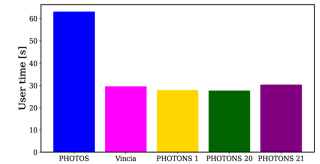
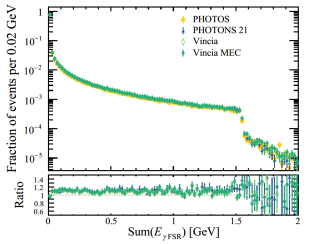
Many thanks to SWIFTHEP

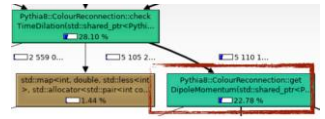
The SWIFTHEP project played a **crucial role**

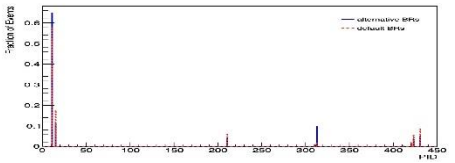
- Supporting two research-software engineers that worked actively on and provided guidance during the **modernisation campaign**
- Delivering the **first thread safe version of EvtGen**
- Fostering **collaborations across institutes**
  - Monash-Warwick (Vincia final-state radiation, Pythia colour reconnection)
  - Warwick-Durham (Sherpa final-state radiation)
  - Warwick-Glasgow (EvtGen decay weighting)
- Providing a **space to report and discuss progress**
- Fostering exchange of ideas ⇒ envisage **future projects**











Achievements making a significant impact on HEP community

Summary and outlook

- EvtGen — essential tool to study heavy-flavour particle decays in multiple experiments
- After long modernisation campaign ⇒ R03-00-00-beta1

⇒ New general **testing framework**

⇒ Implemented **thread safety**

(full exploitation of multi-threading will require further structural changes)

⇒ Performance limited by external dependencies

⇒ Implemented Sherpa's PHOTONS++ (and working on Vincia) as **alternative for FSR**

- Various projects for future developments (τ-spin propagation, structural modifications, …)

⇒ Started decay weight implementation

- Full release 3.0.0 expected by summer 2025 (and paper by year's end)

Stay tuned!

https://evtgen.hepforge.org

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