Status of EvtGen: general & LHCb

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on behalf of the EvtGen Warwick team & LHCb sim group
Introduction

• Software tool to simulate B and D decays
  – Used by range of experiments (ATLAS, Belle2, CMS, LHCb, ...)
  – Created by A Ryd and D Lange; now maintained by Warwick team

• Wide range of decay models
  – Amplitudes based on helicity formalism; CP violation (mixing)
  – Takes into account spin/angular correlations; coherent/incoherent production

• Sequential particle decays
  – Specified using text (or xml) decay files
  – Decay probabilities: accept/reject method for each node in decay chain
  – Kinematics generally assume resonances are relativistic BW
  – Dalitz plots use isobar model for BWs, not K-matrix

• External package features
  – HepMC: For writing events in HepMC format (mandatory)
  – Photos++: FSR $\gamma$ (optional)
  – Pythia8: Generic decays that have no specific EvtGen model (optional)
  – Tauola++: tau decays (optional)
Code Maintenance

• EvtGen master svn repository hosted at CERN
  – Current tagged version is 1.6.0 (released 1\textsuperscript{st} June 2016)
  – Guest read access at \url{http://svn.cern.ch/guest/evtgen}
  – Example build script, examples and validation code provided
  – Kept up-to-date with changes in external packages (e.g. Photos\textsuperscript{++})
  – Critical bug fixes/collection of smaller changes $\Rightarrow$ new tag every $\sim$6 months
  – New versions announced via \texttt{announce@evtgen.warwick.ac.uk} email list
    • Should contain MC contacts from all known experiments, as far as we know

• Dev team are LHCb collaboration members
  – LHCb uses its own version of EvtGen, manually “synched” with master repository, maintained by Warwick team
  – Continually incorporating bug fixes/new models: LHCb $\leftrightarrow$ master
    • There are some minor technical differences, but they use the same physics models

• Dev team email address: \texttt{dev@evtgen.warwick.ac.uk}
  – Bug fixes/new useful models from users are added to master repository
  – Warwick hosted web-page: \url{http://evtgen.warwick.ac.uk}
LHCb Integration

• EvtGen is a core part of the Gauss simulation software suite
  – Monte Carlo production for LHCb

• New models/bug fixes added after internal review process:
  – Presentation of decay model/bug fix (physics & code requirements) at Gauss simulation (vidyo) meetings
  – Code then added/changed in LHCb svn repository once approved
    • Progress tracked using Cern JIRA web-tracking tools
  – New/updated models ⇒ new Gauss release
  – New LHCb code then added to Warwick svn master version

• EvtGenExtras package used for models with external dependencies:
  – MINT, used for 4-body D decay modes
  – Gnu Scientific Library used for some $B \rightarrow K^\ast \ell\ell$ factorisation form factors
  – Models with MC biasing, e.g. flat angular distributions for $B \rightarrow h h \mu \mu$

• EvtGen also used for c-baryon, b-baryon and $B_c$ modes
  – phase-space generation only
Developments over past year

• New/updated physics models, mainly from LHCb:
  – Complete mixing phenomenology of $B_s \rightarrow$ vector $\gamma$ (IFIC Valencia LHCb group)
  – $K_s^0 \rightarrow \pi^0 \mu^+ \mu^-$, using JHEP08 (1998)004 (V Chobanova, DM Santos, J Dalseno; LHCb)
  – $B_c \rightarrow$ scalar $\ell \nu$, $B_c \rightarrow$ tensor $\ell \nu$ (J Wimberley, LHCb)
  – Updates for rare $\Lambda_b \rightarrow \Lambda^{(*)} \ell \ell$ (Warwick LHCb group)
  – $B \rightarrow 4$ leptons, e.g. $B^- \rightarrow \mu^+ \mu^- \text{anti-}\nu_\mu \mu^-$ (N Nikitin)
  – Extended HQET form factors for semi-tauonic decays (B Hamilton, LHCb)

• Added Mersenne-Twister Random Number Generator (RNG)
  – Enabled if configure script detects c++11-feature compiler (e.g. gcc 4.7)
  – Stdlib RNG removed; resonance ordering affected generated phase space (!)
  – Simple RNG kept; no biases seen for kinematics (particle ordering)

• Various issues resolved:
  – Bug fixes, mainly from LHCb “JIRA” web bug-tracking reports
  – Incorrect spinor algebra for $S_1 \rightarrow \frac{1}{2} S_2$, $\frac{1}{2} \rightarrow S_3 S_4$; EvtDiracParticle helicity rotations
  – Fixed some $b \rightarrow s \ell \ell$ form factor poles, particularly for $e^\pm$ modes (Warwick LHCb)
  – Photos++ changes in v3.60 caused problems for EvtGen (HepMC event issues)
    • Fixed in v3.61 after working closely with Photos developers ~2 weeks
\[ B_{(s)} \rightarrow V \gamma \]

*C Remon Alepuz et al, IFIC Valencia LHCb group*

- New EvtSVPHelICPMix model for mixing-induced CP violation from interfering time-dependent amplitudes

![Graph showing t distributions assuming different helicity amplitude mag and phase coefficients](image-url)
Wrong angular distribution for spin- \( \frac{1}{2} \) anti-particles appearing as both daughter and parent: \( S_1 \rightarrow \frac{1}{2} S_2, \frac{1}{2} \rightarrow S_3 S_4 \)

\( \mathcal{P} = 0 \) if anti-particle is at rest after rotation into helicity frame

Corrected transformations of helicity rotation components

Example: \( \Lambda_b \rightarrow \Lambda \gamma, \Lambda_b \rightarrow p\pi^+ : \Gamma(\Lambda_b) = (1 + 0.642 \alpha_\gamma \cos\theta_\pi) \alpha(\Lambda_b) \)

BEFORE: \(|\text{Gradient}| \ p_1 = |\alpha_\gamma| = 0.355 \neq 1 \)

AFTER: \(|\text{Gradient}| = 1 \) as expected
Particle Tuning

- DECAY.DEC: full generic particle decay file using PDG BFs
- Non-trivial issues when updating information using “automatic” tools
  - PDG sub-mode table indents inconsistent ⇒ double counting of BFs
  - Requires careful manual checking (reading original papers)
  - \( \Sigma \text{Exclusive} = \text{Inclusive} \) not always the case (e.g. semileptonic decays)

- Particle properties in evt.pdl (LHCb & v1.6.0) updated to PDG 2014
Inclusive charm BF tuning (Michal Kreps)
Implemented in LHCb and v1.6.0 DECAY.DEC (Pythia modes use Pythia8)
Future

• Updates in progress
  – DECAY.DEC: list of generic decays; consistency between inclusive/exclusive modes
    • “Recent” tuning only done for semileptonic B/D decays
  – Some more physics models, e.g. \( B \to u \ell \nu \) (LHCb), ...

• Will migrate general (Cern svn) repository to HepForge (git)
  – Integrated repository with web-tools, doxygen documentation
    • Tracking of bugs and new/requested features
  – Hope is that all experiments will eventually use this
  – Will use git and its code review tools
    • Experiments can “fork” code, add their changes, then we can add them to master version so that everyone else can benefit from fixes/additions

• Would like to remove remaining EvtGen Fortran code
  – Old CPV models involving \( B \to 3 \) pseudoscalars (e.g. \( 3 \pi \) with CKM \( \alpha \))
  – Fortran compiler is still required if you need Tauola++

• Lots of hardcoded physics parameters (mainly form factors)
  – Would be good to unify these, allow configuration via parameter files
  – Long term project, depends on interest from potential users
Open questions for discussion

• **Q1: Updates to DECAY.DEC from (latest) PDG tables**
  a) $\Sigma$ Exclusive modes $\neq$ Inclusive branching fractions (EvtGen rescales to 1.0 in such cases)
  b) Avoiding double-counting $\Rightarrow$ manual checking (slow process...reading papers)
  c) Try to combine update efforts with other MC generator groups (e.g. Pythia, Sherpa)

• **Q2: Tagging performance, generic decays**
  a) Generic $B \rightarrow D\pi/DK$ (BF~35%) decays use Pythia $\Rightarrow$ gives same $p$ distributions
  b) Quark content in Pythia modes last tuned during BaBar days (early 2000’s)
  c) Tuning study started by M Grosse & H Lacker few yrs ago, unknown if completed:
     see CERN EvtGen workshop Jan 2014: [https://indico.cern.ch/event/290370](https://indico.cern.ch/event/290370)

• **Q3: Baryonic B decays**
  Too few models in EvtGen. Can we improve this?

• **Q4: Improve testing and validation of existing models**
  a) Using existing models for new decay searches has revealed limitations/bugs
     e.g. LHCb extensions for semi-tauonic decays, spin-1/2 antiparticle decays
  b) Have experiments come across similar issues/problems?

• **Q5: Adding new models from theoretical predictions**
  EvtGen needs amplitudes in helicity formalism (spinors) $\Rightarrow$ angular distributions
Backup
EvtGen decay generation algorithm

- Uses amplitudes, summing over helicity (projection of spin onto $\mathbf{p}$ direction) states to include full angular information
  $\Rightarrow$ spinor algebra (Jacob-Wick convention)
- Decay chain: sequence of sub-decays, e.g.
  $B \rightarrow D X, \quad D \rightarrow Y h, \quad X \rightarrow a b c$
- Generates kinematics for each sub-decay node
- Accept/reject decay probability per node:
  $P = \sum_{\lambda, \lambda'} \rho \, A_\lambda \, A_{\lambda'}^* = \text{sum over all decay helicity states}$
  $\rho = \text{forward/backward spin-density matrix containing correlated angular information from parent/sibling decays}$
  $\lambda = \text{helicity states}; \, A_\lambda = \text{decay amplitude for state } \lambda$
- Each successful node decay is kept during decay cascade
  - Saves computational time for generating events
- Allows for different amplitude models for each node
  - Vector, scalar, tensor particles; form-factors; resonances