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# EvtGen: heavy flavour Event Generator

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on behalf of the Warwick EvtGen team

# Introduction

- Software tool to simulate B and D decays
  - Used by range of experiments (LHCb, ATLAS, CMS, Belle2, …)
  - 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)

# Decay generation

- Uses amplitudes, summing over helicity (projection of spin onto **p** direction) states to include full angular information
  $\Rightarrow$ spinor algebra (Jacob-Wick convention)
- Decay chain: sequence of sub-decays, e.g.
  $B \to D\ X, \quad D \to Y\ h, \quad X \to a\ b\ c$

- Generates kinematics for each sub-decay node

- Accept/reject decay probability *per node*:
  $\mathcal{P} = \Sigma_{\lambda\lambda'}\ \rho\ A_\lambda\ A_{\lambda'}{}^*$ = sum over all decay helicity states
  $\rho$ = forward/backward spin-density matrix containing correlated angular information from parent/sibling decays
  $\lambda$ = helicity states; $A_\lambda$ = 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

# Code Maintenance

- EvtGen master svn repository hosted at CERN
  - Current tagged version is 1.5.0 (released 21st Oct '15)
  - EvtGen "svn librarian" members have write access
  - Guest read access at 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++)
  - Critical bug fixes/collection of smaller changes ⇒ new tag every ~6 months
  - New versions announced via 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
  - Continually incorporating bug fixes/new models: LHCb ↔ master
    - There are some (minor) technical differences, but they use the same physics models

- Ask us questions using email: dev@evtgen.warwick.ac.uk
  - Bug fixes/new useful models from users are added to master repository
  - Warwick hosted web-page with news and some doc: http://evtgen.warwick.ac.uk

# Developments over past year

- New/updated physics models:
  - Complete mixing phenomenology of $B_s \rightarrow$ vector $\gamma$ (IFIC Valencia LHCb group)
  - $Ks^0 \rightarrow \pi^0\ \mu^+\ \mu^-$, 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. $B^- \rightarrow \mu^+\ \mu^-$ anti-$\nu_\mu\ \mu^-$ (N Nikitin)
  - Extended HQET form factors for semi-tauonic decays (B Hamilton, LHCb)

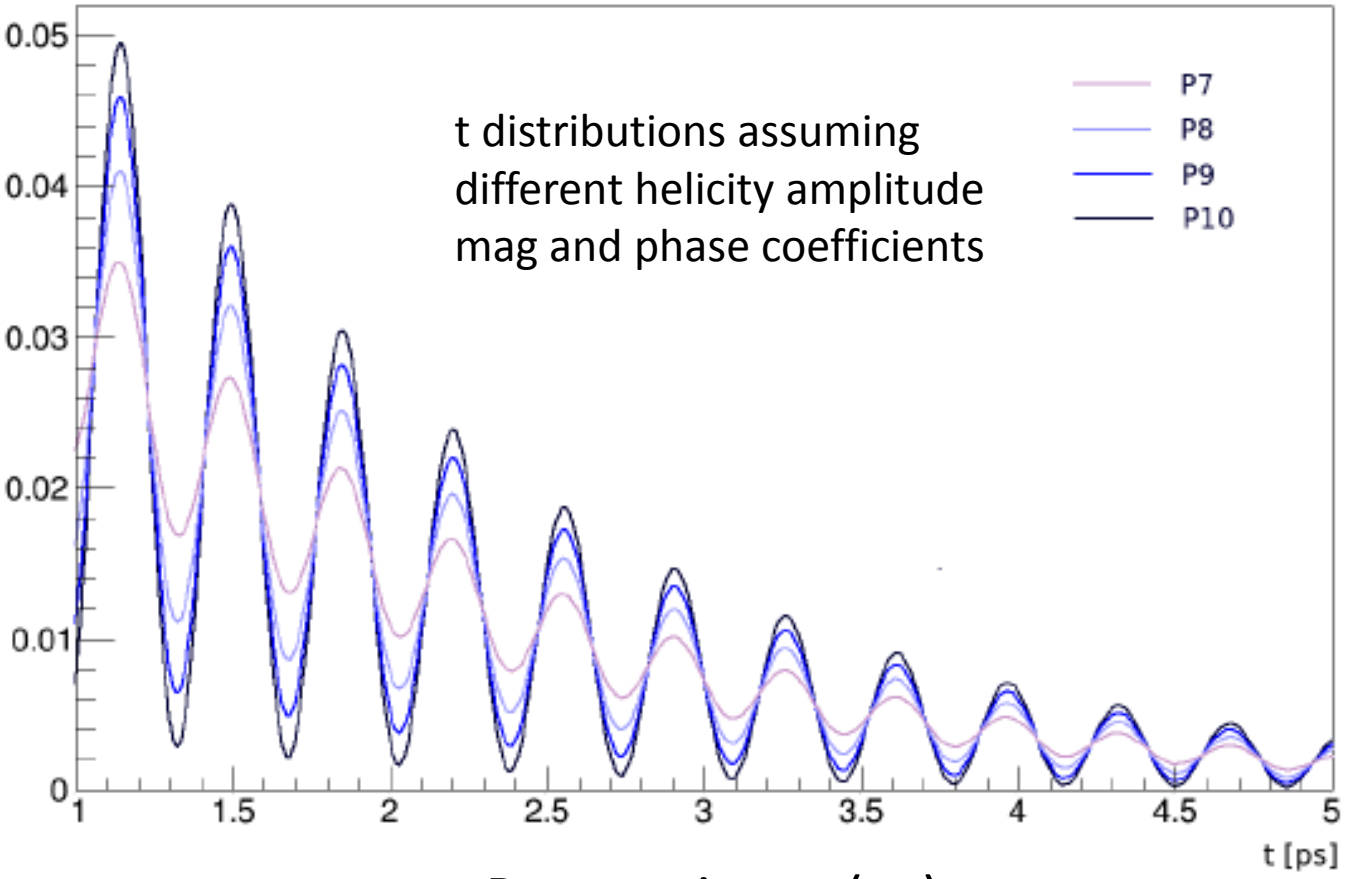
- Added Mersenne-Twister Random Number Generator (RNG)
  - Enabled if configure script detects c++11-feature compiler (e.g. gcc 4.7)
  - Stdlib RNG removed; resonance ordering affected generated phase space (!)
  - Simple RNG kept; no biases seen for kinematics (particle ordering)

- Various issues resolved:
  - Bug fixes, mainly from LHCb "JIRA" web bug-tracking reports
  - Incorrect spinor algebra for $S_1 \rightarrow ½\ S_2$, $½ \rightarrow S_3\ S_4$; 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 EvtSVPHelCPMix model for mixing-induced CP violation from interfering time-dependent amplitudes




Proper time t (ps)

# Dirac particle helicity rotations

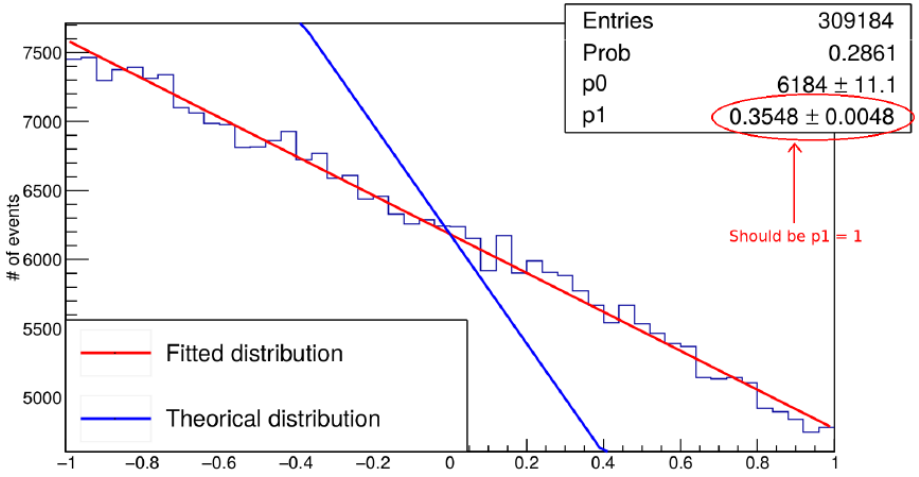
*L M Garcia Marcin et al, LHCb IFIC Valencia group*

- Wrong angular distribution for spin- ½ anti-particles appearing as both daughter and parent: $S_1 \rightarrow ½\ S_2$, $½ \rightarrow S_3\ S_4$

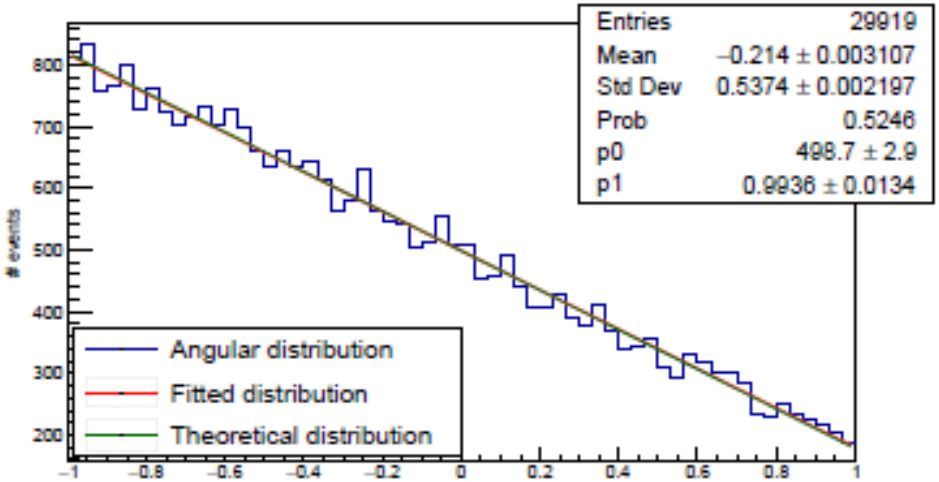
  $\mathcal{P}$=0 if anti-particle is at rest after rotation into helicity frame

- Corrected transformations of helicity rotation components
- Example: $\overline{\Lambda}_b \rightarrow \overline{\Lambda}\gamma$, $\overline{\Lambda}_b \rightarrow \overline{p}\ \pi^+$: $\Gamma(\Lambda_b) = (1 + 0.642\ \alpha_\gamma \cos\theta_\pi)$

$\alpha(\Lambda_b)$



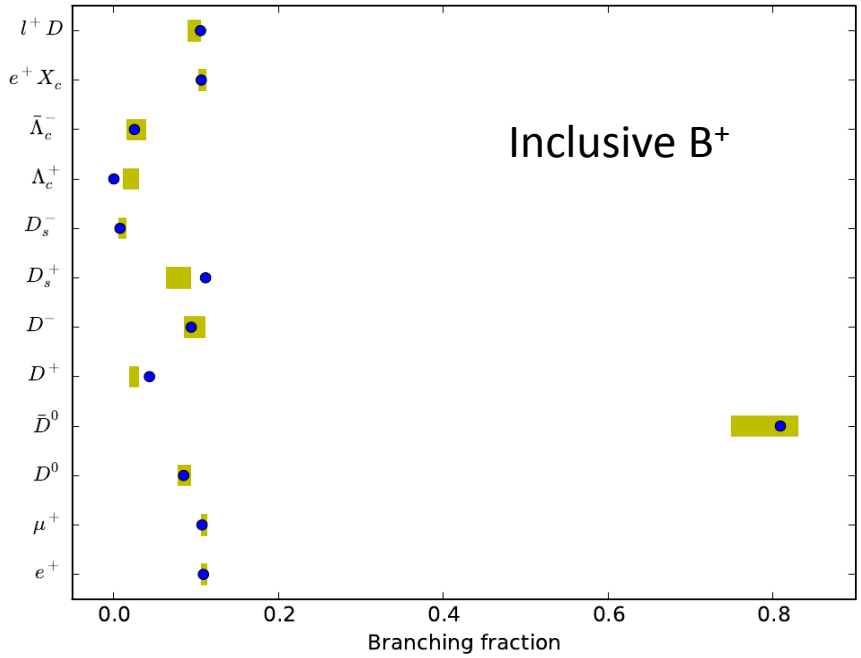

BEFORE: |Gradient| p1 = $|\alpha_\gamma|$ = 0.355 ≠ 1

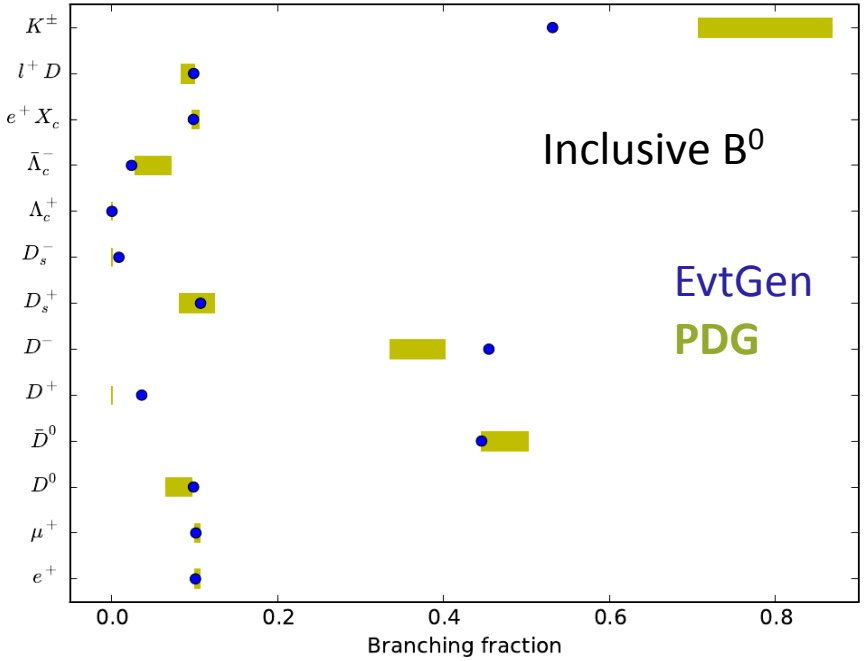



AFTER: |Gradient| = 1 as expected

# Particle Tuning

- DECAY.DEC updates in progress:
  - Full generic particle decay file using PDG BFs
  - Non-trivial issues using "automatic" tools
    - PDG sub-mode table indents inconsistent ⇒ double counting
    - Requires careful manual checking (reading original papers)
    - ΣExclusive = Inclusive not always the case (e.g. semileptonic decays)

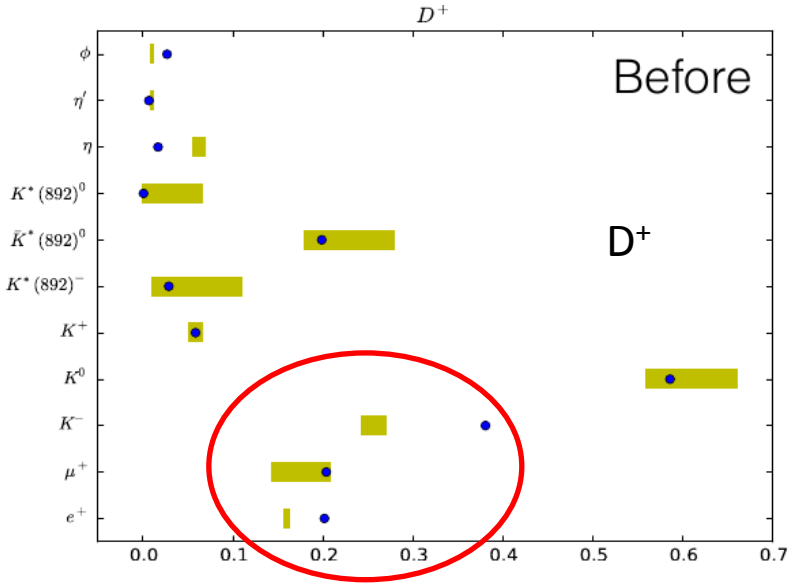


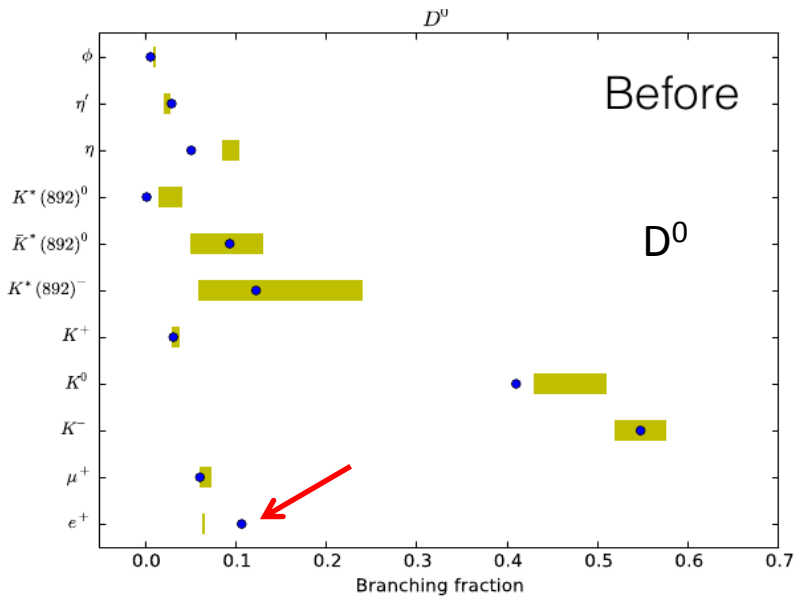



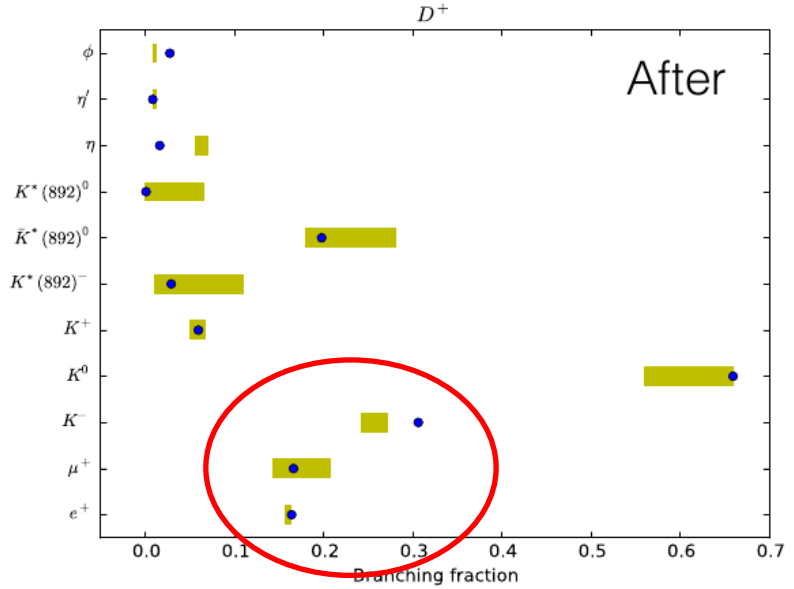

- Particle properties in evt.pdl
  - Updated within LHCb version, will add to master repository

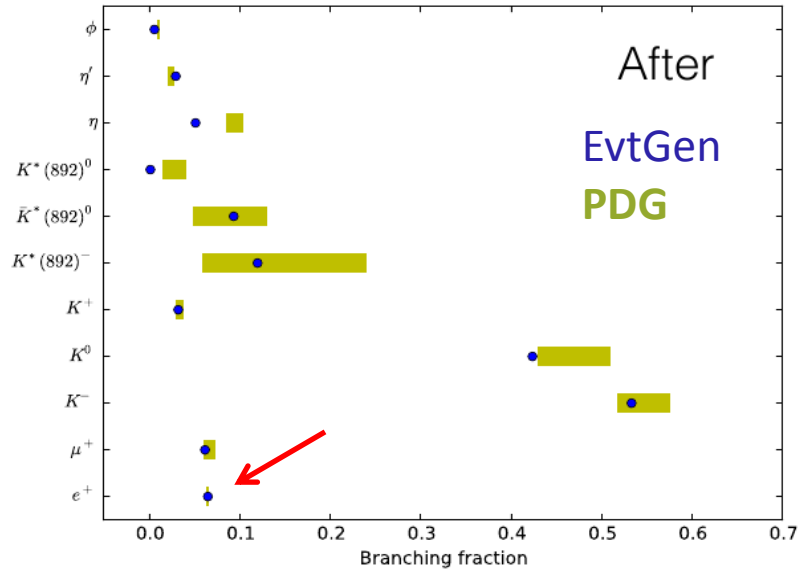
# Inclusive charm BF tuning

Implemented in LHCb DECAY.DEC (Michal Kreps); will add to repository



# Future

- Updates in progress
  - DECAY.DEC: list of generic decays; consistency between inclusive/exclusive modes
  - evt.pdl: particle property file
  - Adding new physics models (a few more expected from LHCb)

- Will migrate repository to HepForge
  - Well maintained infrastructure
  - Integrated repository with web-tools, doxygen documentation
    - Tracking of bugs and new/requested features
  - Hope is that all experiments will use this version
  - Expect to use **git** and its code review tools
    - Experiments can "fork" code, add their changes, then we can add them to master version

- Would like to remove remaining EvtGen Fortran code
  - Old CPV models involving B $\rightarrow$ 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

- Q1: Updates to DECAY.DEC from (latest) PDG tables
  - a) $\Sigma$ Exclusive modes > Inclusive branching fractions (EvtGen rescales to 1.0)
  - b) Avoiding double-counting $\Rightarrow$ manual checking (slow process…reading papers)
  - c) Should/can we combine update efforts with other MC generator groups?
- 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
- 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