# Overview of Belle II Event Generators

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LHC Heavy Flavor WG:
Simulation Techniques
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# Overview of Belle II Event Generators

| | |
|---|---|
| **AAFH** | Non-radiative two photon process |
| **BABAYAGA.NLO** | ee, μμ, γγ |
| **BBBREM** | Single Bremsstrahlung in eeγ |
| **BHWIDE** | ee (large angle) |
| **EKHARA** | Some two-photon channels |
| **EvtGen** | B, D and tau decay chains |
| **KKMC** | μμ, ττ, $q\bar{q}$, $\nu\bar{\nu}$ |
| **KORALW** | Radiative two-photon process |

| | |
|---|---|
| **MadGraph** | Direct production of New Physics |
| **PHOKHARA** | Low multiplicity final state |
| **PHOTOS** | Radiative corrections |
| **PYTHIA8.2** | Quark fragmentation & decays |
| **TAUOLA** | Tau decays |
| **TEEGG** | ee, single photon, single electron |
| **TREPS** | Two-photon processes |

# Current focus and development activities

Goal is to reduce the limitations of simulation samples and make it as close as to data. Validation and integration of new event generators.

- EvtGen updates to branching fractions (DECAY.DEC) with new inputs from PDG. Update EvtGen decay models and parameters.
- Improvement and tuning of PYTHIA
- Updates to low multiplicity generators
- Implementation of New Physics models

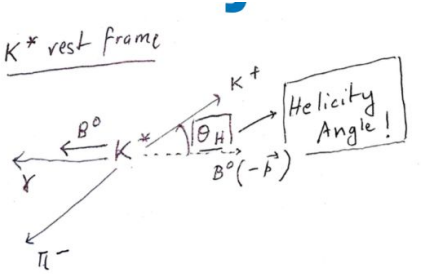
# EvtGen updates

(See Vidya Sagar’s slides)

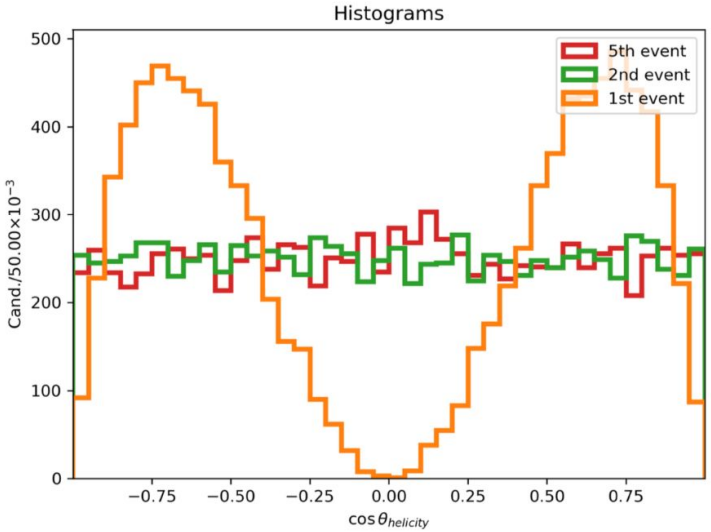
# EVTGEN scalar to tensor decay

Public scripts to reproduce this issue:
https://gitlab.desy.de/sayan97/evtgen_issue/

- Cosine Helicity distribution for Scalar to Tensor decay (e.g. $B^0 \to [K_2^* \to K\pi]\gamma$, $B^0 \to [\bar{D}_2^* \to \bar{D}\pi]\gamma$ using **HELAMP/ PARTWAVE** in **EvtGen** is incorrect when generating multiple events
- Issue may be due to **EvtEvalHelAmp** class
- Issue observed in EvtGen version 2.0.0, 2.1.1




```
…
EvtVector4R p_init( EvtPDL::getMass( B0 ), 0.0, 0.0, 0.0 );

EvtParticle* root_part =
EvtParticleFactory::particleFactory( B0, p_init );

root_part->setDiagonalSpinDensity();

myGenerator.generateDecay( root_part );

EvtParticle* kst = root_part->getDaug( 0 );
EvtParticle* k = kst->getDaug( 0 );

EvtVector4R p4b = root_part->getP4Lab();
EvtVector4R p4kst = kst->getP4Lab();
EvtVector4R p4k = k->getP4Lab();

ntuple.Fill(count , EvtDecayAngle( p4b, p4kst, p4k ) );
…
```




All the three histograms should coincide

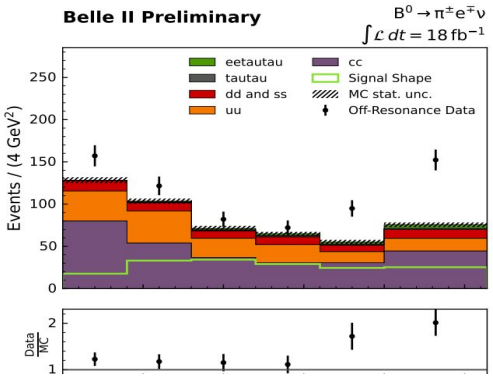
Unresolved issue at evtgen@projects.hepforge.org.
Looking forward to further discussion with EvtGen authors.

# PYTHIA tuning

# Why tune Pythia parameters?

$B \to \pi l \nu$ :

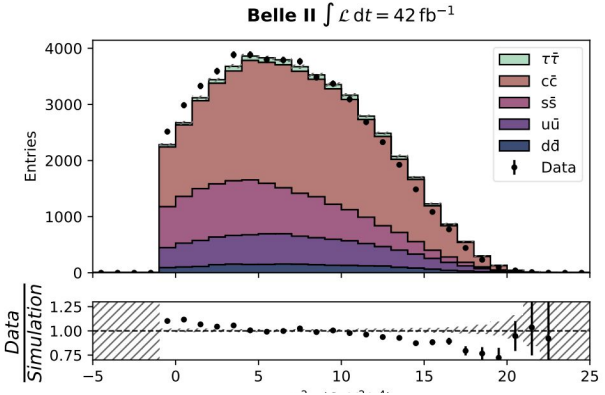
lumi-normalized

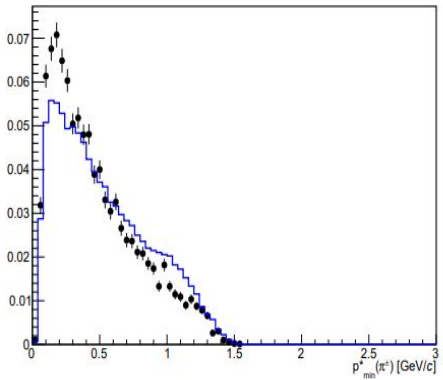


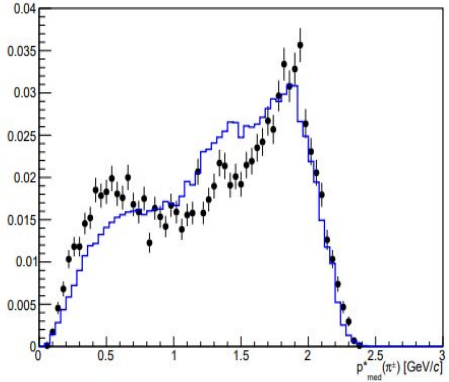

$B \to K \nu \nu$ :

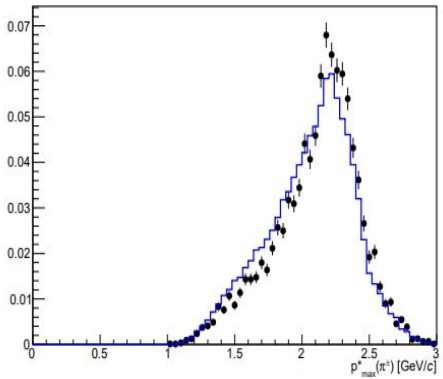
shape comparison

with factor of 1.3



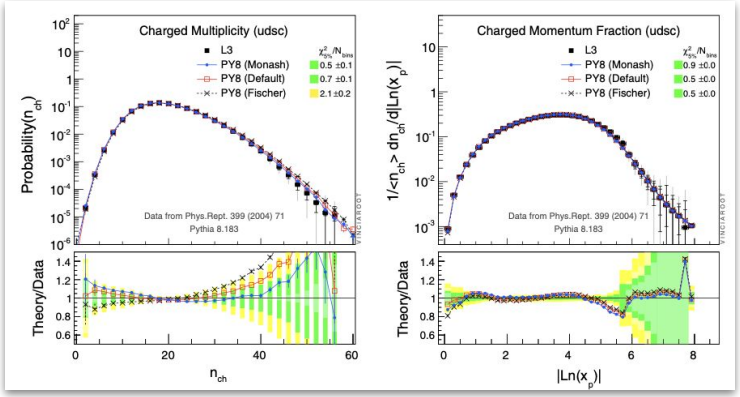




$\pi$ momenta distributions in $B^+ \to \rho^+ \rho^0$: (shape comparison)

# Pythia tune

- Ongoing efforts to tune Pythia parameters by G. Karyan and H. Ghumaryan
- Peter Skands [Pythia's author and author of Monash 2013 tune] consulted
- New strategy:
  - Identify a set of distributions sensitive to Pythia parameters showing data-MC differences as tuning variables (flavor dependent)
  - Obtain detector unfolded distributions of tuning variables
  - Systematics from detector resolution & acceptance should be corrected
  - Detector-independent Pythia tuning




Open Access
Eur. Phys. J. C (2014) **74**: 3024
https://doi.org/10.1140/epjc/s10052-014-3024-y
*Special Article - Tools for Experiment and Theory*

**Tuning PYTHIA 8.1: the Monash 2013 tune**

P. Skands[1*], S. Carrazza[2] and J. Rojo[1,3]

# Low multiplicity generators

# TauolaBelle2: KKMC, Tauola & Photos(++)

Matrix element squared of $\tau^-$ decays can be written as $|\mathcal{M}|^2 = G + s^\mu \omega_\mu$,
where G is the spin-averaged part of the total width,
$s^\mu$ is polarization vector of $\tau$-lepton
and $\omega_\mu$ is the polarimeter vector encoding channel dependent phase space.
Matrix element squared of $e^-e^+ \to \tau^-\tau^+$ decays takes the form:
$|\mathcal{M}|^2 = |\mathcal{M}|^2_{\text{spin-av}} + \omega_\mu C^{\mu\nu} \bar{\omega}_\nu$
where $|\mathcal{M}|^2_{\text{spin-av}}$ is the spin-averaged part
and $C^{\mu\nu}$ is the spin-correlation matrix.
The event generator KKMC calculates the $|\mathcal{M}|^2_{\text{spin-av}}$ and $C^{\mu\nu}$,
whereas $\omega_\mu$ is done by **TAUOLA**.

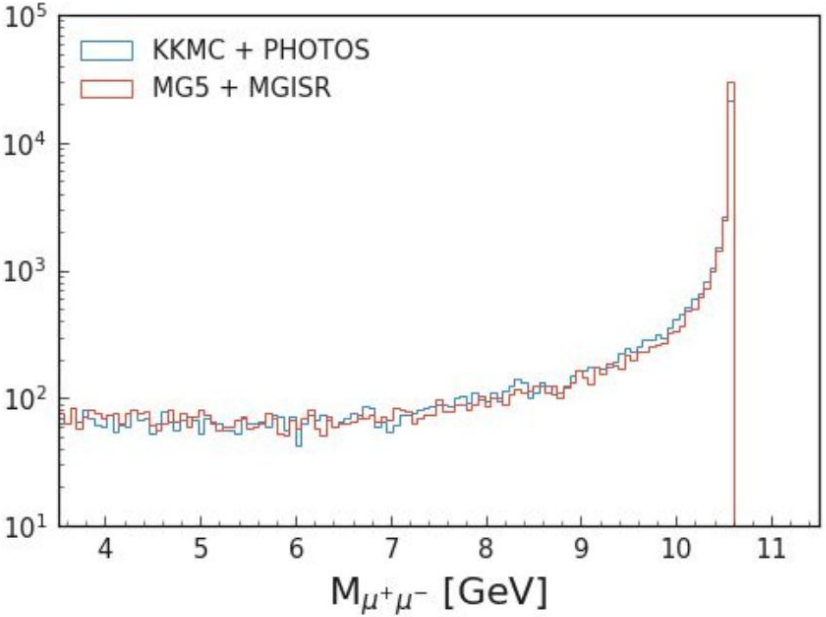
Main references:
KK2F [S.Jadach, B.F.L.Ward, Z.Was, Comput.Phys.Commun. 130 (2000) 260]
TAUOLA [S.Jadach, Z.Was, R.Decker, J.H.Kuhn, Comput.Phys.Commun. 76 (1993) 361]
PHOTOS [E.Barberio, Z.Was, Comput.Phys.Commun. 79 (1994) 291]

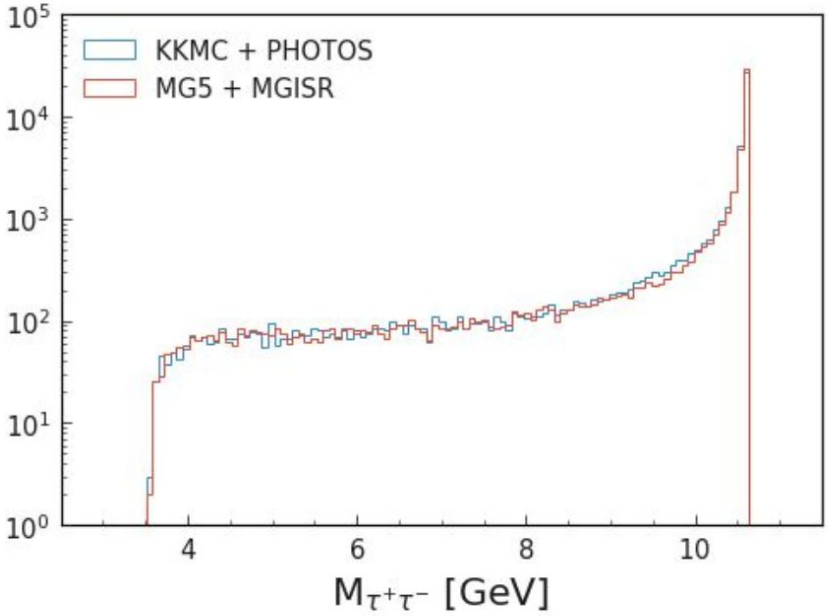
- **Photon radiation from tau production in $e^-e^+ \to \tau^-\tau^+(n\gamma)$ modeled by KKMC, while photon radiation in $\tau$ decays by PHOTOS. Also, $e^-e^+$ / $\mu^+\mu^-$ radiation by PHOTOS++.**
- 373 channels [including lepton flavor/lepton number/baryon number violating modes]
- 92 generic channels using PDG 2020 branching fractions, which add up to unity.
- Several new models for hadronic currents introduced [maintaining backward compatibility]
  - For $\tau^- \to \pi^-\pi^0\nu$, $\pi^-2\pi^0\nu$, $2\pi^-\pi^+\nu$, $\pi^-\pi^+K^-\nu$, $\pi^-\pi^0K^0\nu$, $\pi^-3\pi^0\nu$, $2\pi^-\pi^+\pi^0\nu$ decays
  - New parameterization of $\tau^- \to \pi^-4\pi^0\nu$ and $2\pi^-\pi^+2\pi^0\nu$ decays also added

# MadGraph and EKHARA updates

- MadGraph is currently the main generator for producing signal samples for Dark Sector signatures. MadGraph 3.4.0 available via external library includes ISR and beamstrahlung effects [+Python 3 support]
- LHEInput module could not boost MCParticles from CMS to LAB.
  New module: LHEInput → BoostMCParticles → SmearPrimaryVertex introduced to take beam properties directly from Conditions Database
  This new module can also be used with other generators providing LHEInput files.
- EKHARA is a generator for some specific two-photon processes:
  - $e^+e^- \to e^+e^-\pi^+\pi^-$ (EKHARA 1.X: arXiv/hep-ph/0510287)
  - $e^+e^- \to e^+e^-\pi^0$ (EKHARA 2.X: arXiv/1009.1881)
  - $e^+e^- \to e^+e^-\eta$, $e^+e^-\eta'$, $e^+e^-\chi_{c1}$ (EKHARA 3.0: arXiv/1805.07756)
  - C++ based user interface available around EKHARA 3.0

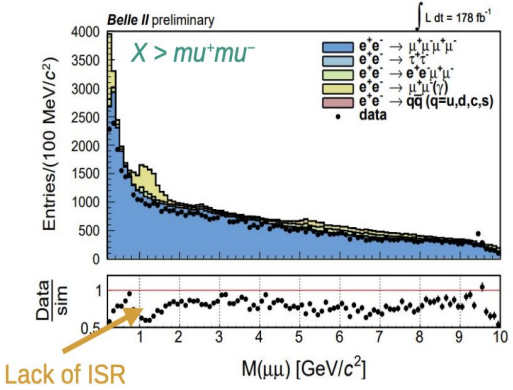
# ISR modeling in $e^+e^- \to \mu^+\mu^-\gamma$ and $e^+e^- \to \tau^+\tau^-\gamma$

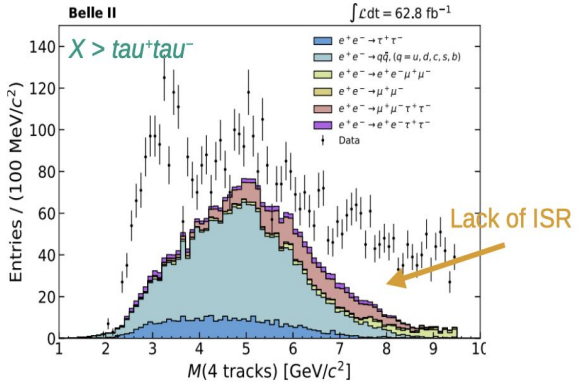


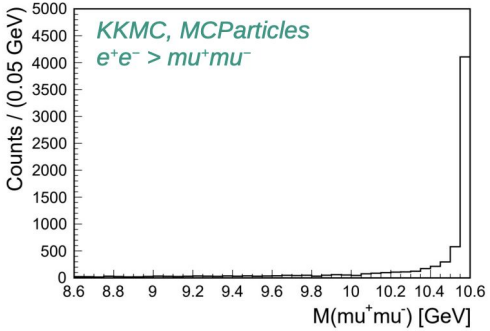

**Comparison between Madgraph and KKMC shows good agreement**

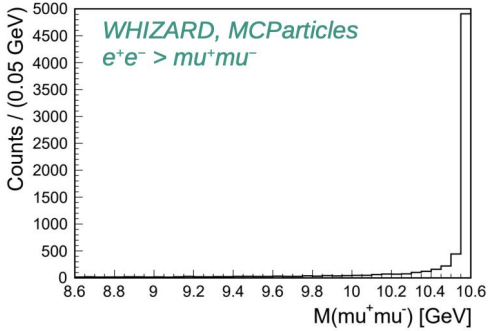
# WHIZARD generator




- AAFH used to generate 4-leptons final states; not including ISR/FSR effects
- WHIZARD can simulate ISR effects for dark sector, low multiplicity analyses
- WHIZARD available; stores events in LHEF files; import via LHEInput




Validation ongoing

# New event generators

# Several ongoing activities

- $B \to K\pi\pi\gamma$ event generator updates with many K-resonances including interference effects to measure photon polarization in b → sγ via decay angular distributions of K-resonances

Ongoing discussion between T.S.Lau and EvtGen authors

- New MC for b → s ℓ ℓ being developed with new vector amplitudes; ABSZ hadronic form factor; user can set non-zero complex Wilson coefficients for right-handed currents

$B \to K^*\ell^+\ell^-$ generator with new physics contributions

Alexei Sibidanov

University of Hawaii

Belle II Summer Workshop
12-16 June 2021

**Detecting lepton universality violation in angular distributions of $B \to K^*\ell^+\ell^-$ decays**

A. Sibidanov, T. E. Browder, S. Dubey, S. Kohani, R. Mandal, S. Sandilya, R. Sinha, S. E. Vahsen arXiv:2203.06827 **[hep-ph]**

- New BSM generator for $B^0 \to D^{*+}\ell^-\nu$

**Implications for the $\Delta A_{FB}$ anomaly in $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}$ using a new Monte Carlo Event Generator** arXiv:2206.11283 **[hep-ph]**

Bhubanjyoti Bhattacharya, Thomas E. Browder, Quinn Campagna, Alakabha Datta, Shawn Dubey, Lopamudra Mukherjee, Alexei Sibidanov Phys. Rev. D 107, 015011 (2023).

# Summary and Outlook

- Discussions with EvtGen, Pythia, KKMC authors

- Discussions on going with PDG, HFLAV and BESIII to synchronize branching fractions and decay model parameters in B, D and τ decays

- **Proper documentation (sphinx/confluence), maintain record of each modification via issues in gitlab for future references**

**Thanks for your attention and help us to improve our MC.**