LHCb Monte Carlo Overview

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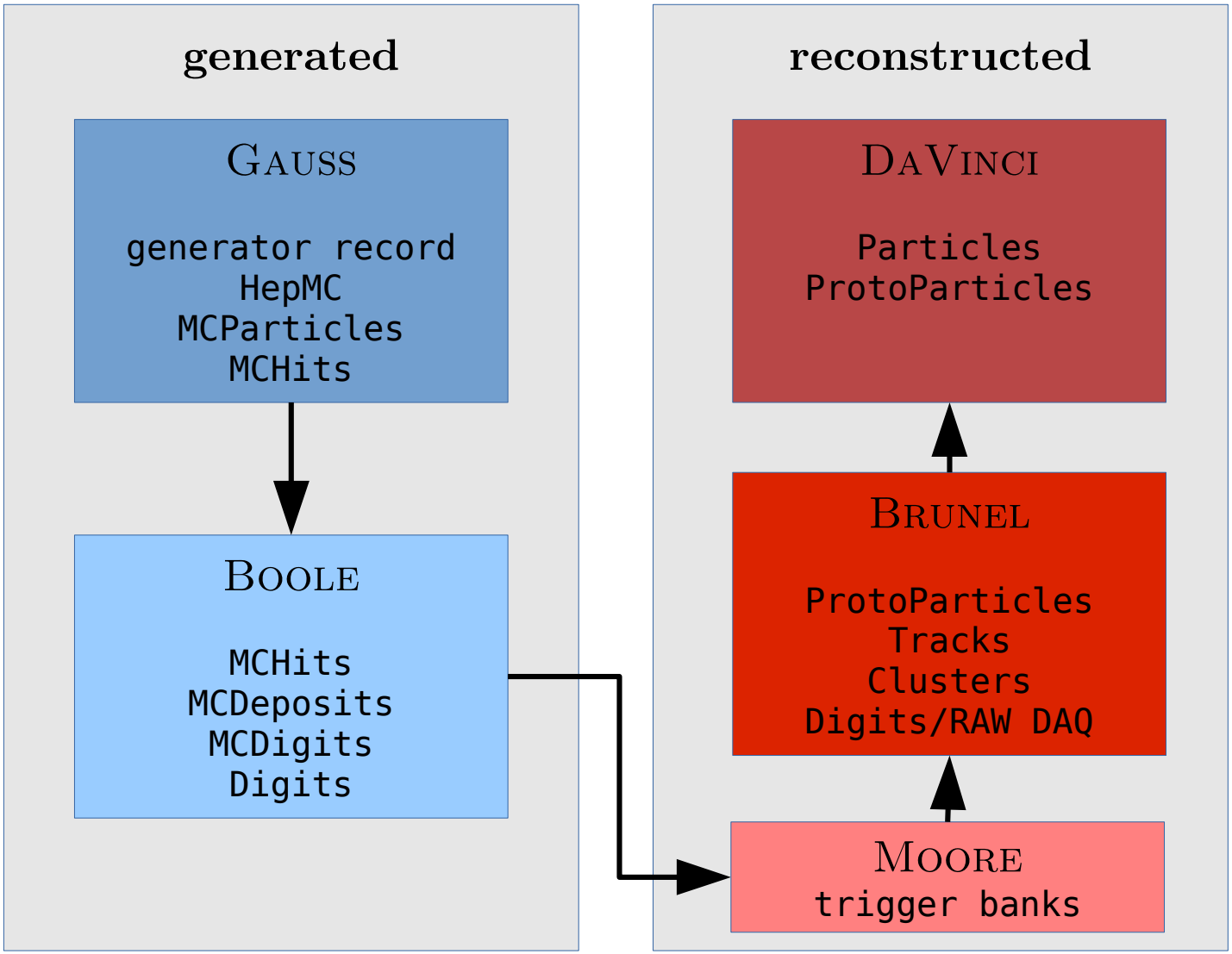
LHC Heavy Flavor Working Group

Overview

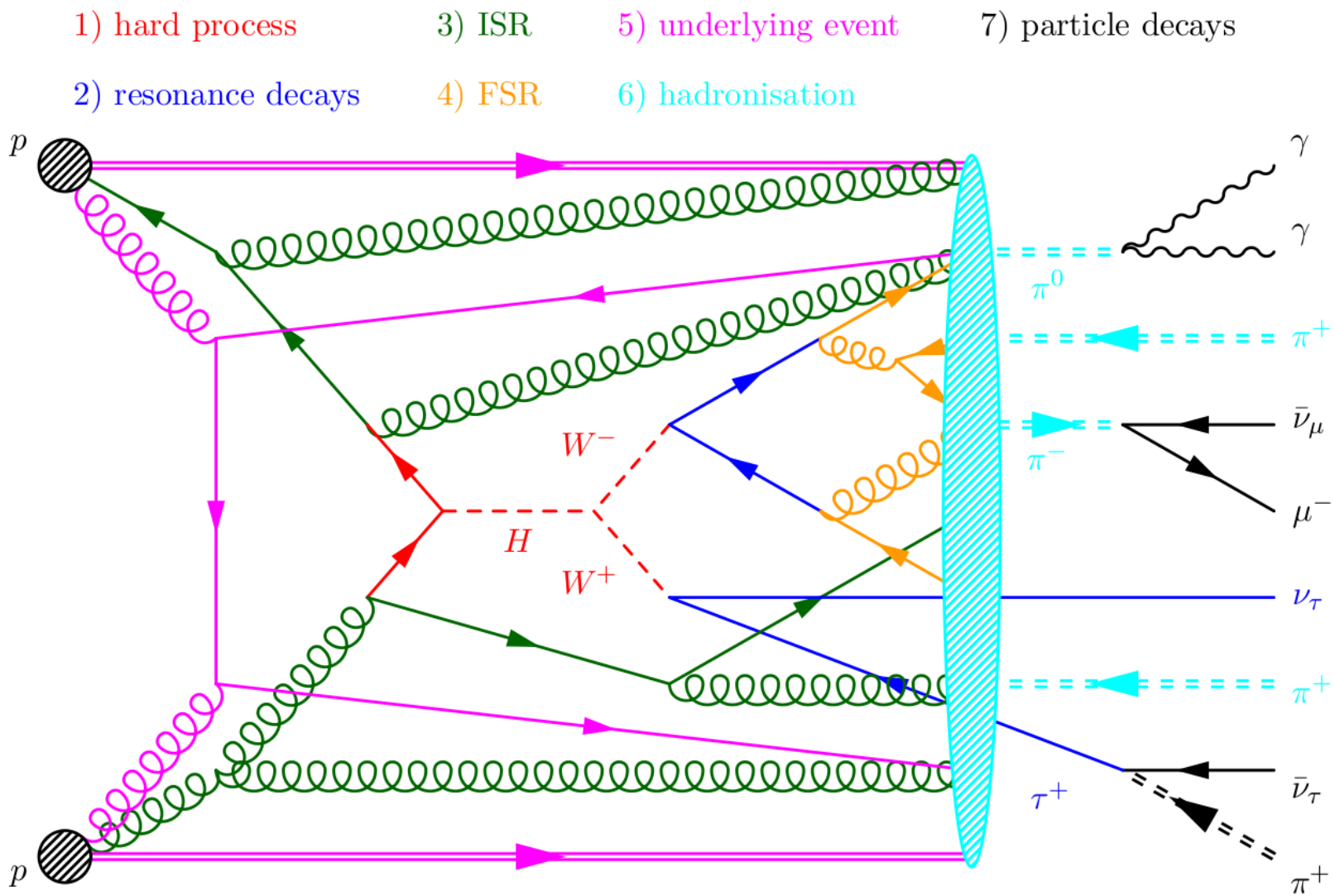
- LHCb **designed** as dedicated b-physics experiment
- simulation framework built with b-physics emphasis in mind
  - full modeling of decays, *e.g.* EvtGen
  - complete detector description with Geant4
  - automation to handle large number of signal decay requests
  - well tuned underlying event for reliable soft physics
  - efficient use of minimum bias events for signal extraction

- LHCb **expanded** its physics program considerably
- Monte Carlo needs have broadened
  - dedicated central exclusive production generators
  - inclusion of heavy ion models
  - control over matrix element matching and merging with showers
  - alternative general-purpose generators for hadronization, *etc.*

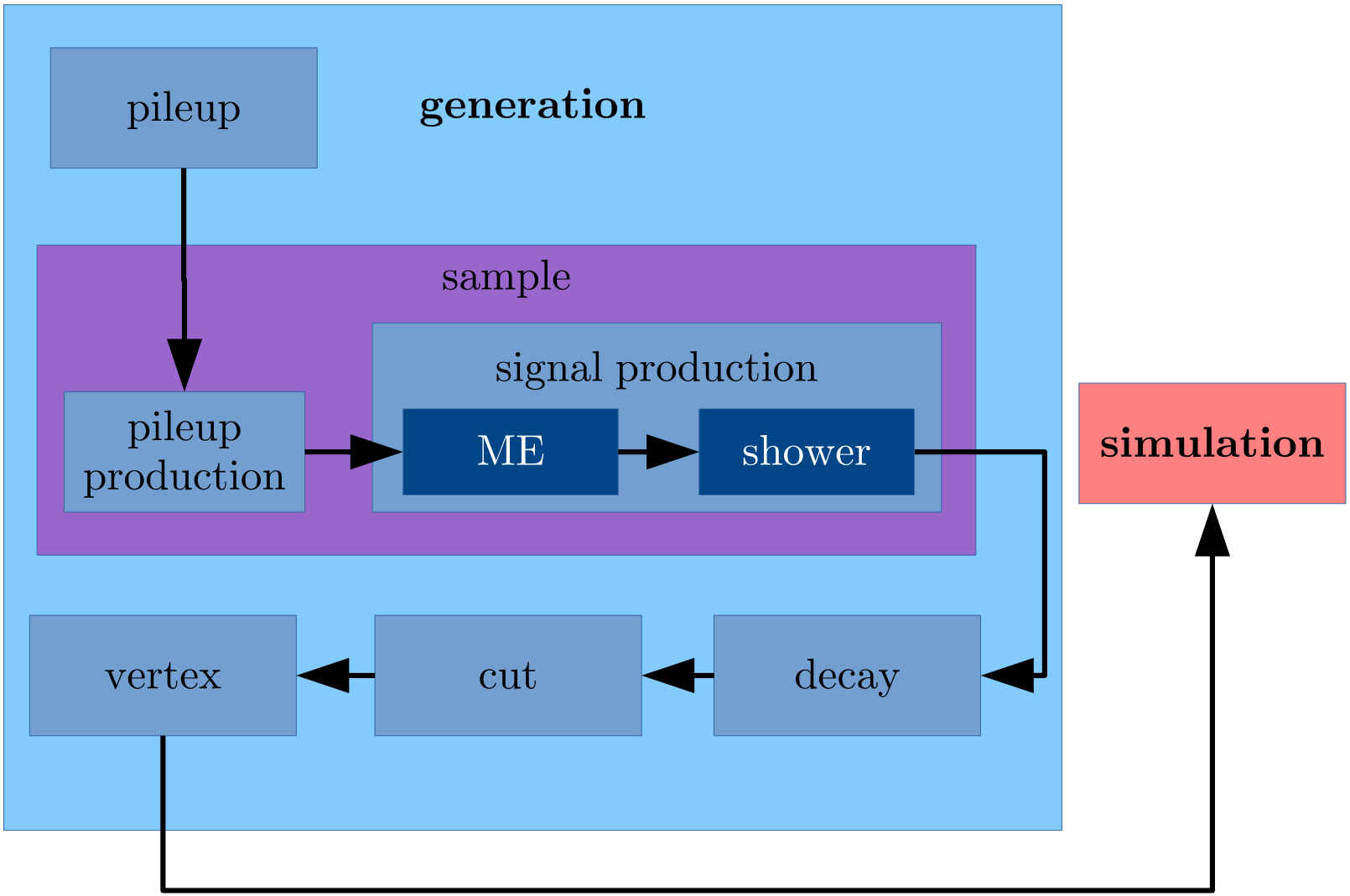
Data Model


generated
reconstructed
Gauss
generator record
HepMC
MCParticles
MCHits
DaVinci
Particles
ProtoParticles
Boole
MCHits
MCDeposits
MCDigits
Digits
Brunel
ProtoParticles
Tracks
Clusters
Digits/RAW DAQ
Moore
trigger banks

Event Anatomy



Gauss


pileup
generation
sample
signal production
pileup production
ME
shower
simulation
vertex
cut
decay

Tools

Beam, Vertex, and Pileup

- **beam tool** handles all beam related parameters, *except PDFs*
- **vertex tool** smears the vertex for each interaction
  - *beam spot*: sample position from 3D Gaussian distribution
  - *flat smear*, *smear from histogram*, *etc.*
- **pileup tool** controls number of interactions per event, n
  - *fixed luminosity*: sample n with $P(n,\nu) = \nu^n e^{-\nu}/n!$

$$\nu = \frac{\mathcal{L}\sigma}{f}$$

  - *variable luminosity*: same as fixed, but exponentially decrease ν

$$\nu = \frac{\mathcal{L}\sigma}{f}\frac{t_{\text{fill}}}{t_{\text{beam}}(1-e^{-t_{\text{fill}}/t_{\text{beam}}})}$$

  - *fixed interactions*: always generate the same n, typically 1
  - *rare process*: use *fixed luminosity* but return $n+1$

Sample Generation

- **sample generation tool** generates interactions for an event using production tool(s)
  - *minimum bias*: generates and accepts all minimum bias interactions
  - *inclusive*: minimum bias generation, but interactions are only accepted if requested particle types are produced, event flipped if signal $p_z < 0$
  - *plain signal*: like *inclusive* but decay particles heavier than the signal particle; continue until signal found and decay forced
  - *forced fragmentation*: generate signal decay and force fragmentation into this flavor
  - *repeated hadronization*: save event up to hadronization and re-hadronize until signal found
  - *special*: use signal configured production tool, *e.g.* $gg \to H \to b\bar{b}$ and separate minimum bias configured production tool to generate interactions

Production

- **production tool** produces single interactions from interface with an external generator
  - *multipurpose*: interfaces to generators that can produce full interactions, including underlying event, hard process, showers, and hadronization
    - Pythia 6, Pythia 8, Herwig++, Sherpa
  - *hard process*: only produces the hard process which must then be showered, hadronized, and integrated with underlying event
    - PowhegBox, GenXicc, BcVegPy, AlpGen, MadGraph
  - *parton shower*: takes an external hard process and showers, hadronizes, and include underlying event
    - Pythia 6, Pythia 8 . . . ideally all available multipurpose generators
  - *exclusive*: central exclusive production which only requires a hard process
    - SuperChic, LPair
  - *heavy ion*: interfaces to dedicated heavy ion generators
    - HiJing, CrMc

Decays and Cuts

- **decay tool** decays all remaining particles from the production tool, including requested signal
  - *EvtGen*: interface to the EvtGen package with support for τ decays via Tauola, FSR via Photos, and additional decays via Pythia 8
  - *multipurpose*: multipurpose generators can perform resonance decays from hard processes with correlated final states, *e.g.* $gg \to H \to \tau\tau$
- **cut tool** checks if a generated event satisfies requirements
  - *signal decay*: requirements applied only to signal particle and its subsequent decay, *e.g.* signal in LHCb acceptance, all signal decay products in LHCb acceptance, *etc.*
  - *full event*: requirements on full event, *e.g.* require at least two b-partons, arbitrary particle requirements, *etc.*

Production

Primary Generator

- Pythia 6 was primary production tool, migrated to Pythia 8
- not all needed final states produced from hadronization
- double heavy baryon production handled with GenXicc
  - arXiv:hep-ph/0702054, arXiv:1210.3458
  - produces $gg \to X\bar{Q}\bar{Q}$, $gQ \to X\bar{Q}$, and $QQ \to Xg$
  - interfaced with Pythia 6 and Pythia 8 showers
- S-wave and P-wave B_c states produced with BcVegPy
  - hep-ph/0309120, hep-ph/0504017, 1307.3344
  - produces $gg \to Xc\bar{c}$
  - also interfaced with Pythia 6 and Pythia 8 showers
- required excited onia production integrated into Pythia 8.185 and beyond

Onia Production

- onia production modeled with NRQCD

$$\mathrm{d}\sigma(pp \to H + X) = \sum_{s,L,J} \mathrm{d}\hat{\sigma}(pp \to Q\bar{Q}[^{2s+1}L_J] + x)\langle \mathcal{O}^H[^{2s+1}L_J]\rangle$$

- color-singlet and color-octet production for any
  - $Q\bar{Q}[^3S_1]$ state
  - $Q\bar{Q}[^3P_J]$ state
  - $Q\bar{Q}[^3D_J]$ state
- any radial excitation allowed
- default production (easily changed) now includes J/ψ, $\psi(2S)$, $\chi_{cJ}(1P)$, $\psi(3770)$, Υ, $\Upsilon(2S)$, $\Upsilon(3S)$, $\Upsilon(4S)$, $\chi_{bJ}(1P)$
- long-distance matrix elements are taken from
  - arXiv:hep-ph/0003142
  - arXiv:hep-ph/9807329 for $\langle \mathcal{O}^{Q\bar{Q}[^3D_J]}[^{2s+1}\ell_J]\rangle$
- double-onia production underway

Onia p_{T} Divergence

- perturbative short-distance matrix elements, $\hat{\sigma}$, diverge at low p_{T}
  - smoothly re-weight

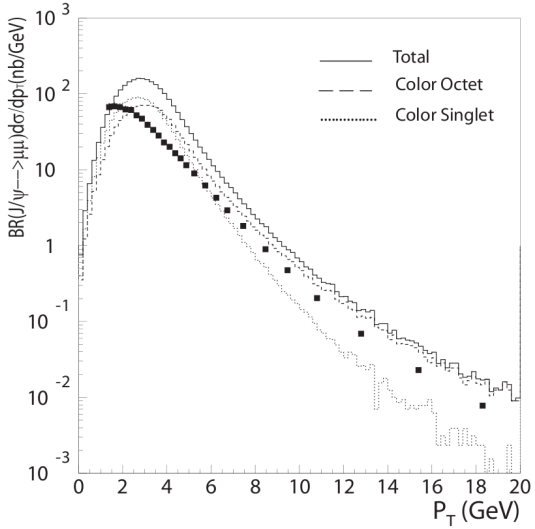
$$\left(\frac{p_{\mathrm{T}}^4}{p_{\mathrm{T}0}^2 + p_{\mathrm{T}}^2}\right)\left(\frac{\alpha_s(p_{\mathrm{T}0}^2 + p_{\mathrm{T}}^2)^2}{\alpha_s(p_{\mathrm{T}}^2)}\right)$$

  - allow $p_{\mathrm{T}0}$ to be energy dependent

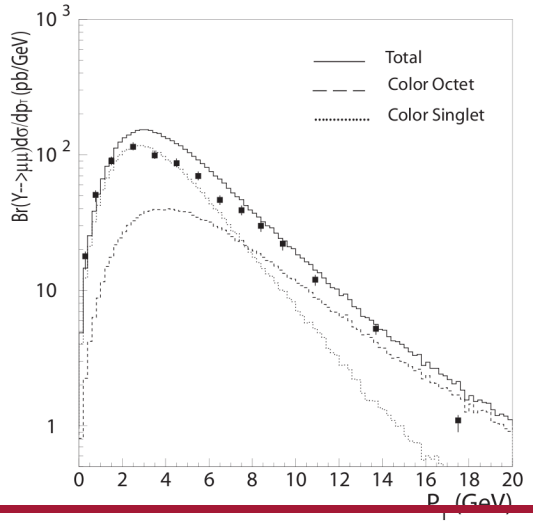
$$p_{\mathrm{T}0}(\sqrt{s}) = p_{\mathrm{T}0}(E_0)\left(\frac{\sqrt{s}}{E_0}\right)^{\theta}$$

- LHCb-2007-042
- values set to MPI values

LHCb-2007-042



LHCb-2007-042

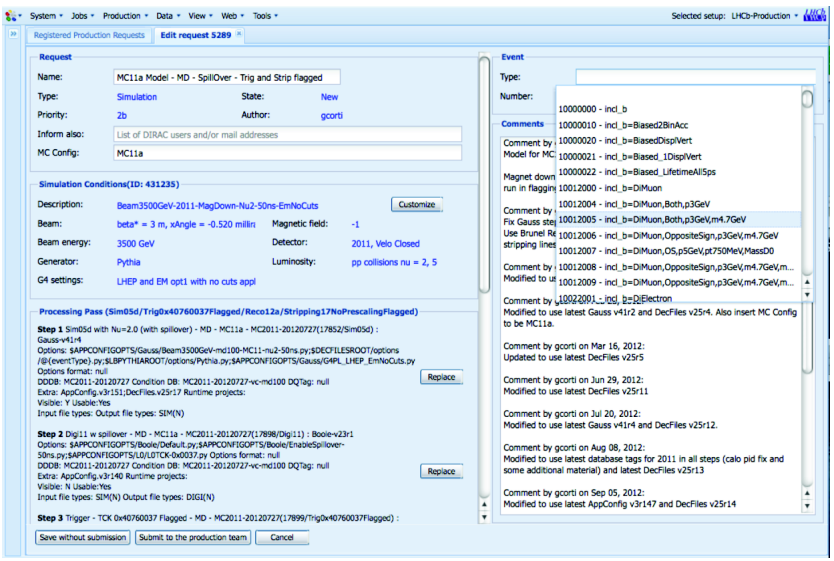


Tuning

- LHCb pre-LHC tune used for Pythia 6 10.1109/NSSMIC.2010.5873949 (does not include LHC data)
- tuning campaign underway for Pythia 8, using Monash tune until complete
  - based on CT09MCS PDF set
  - total cross-section measurements from LHCb, CMS, ATLAS, and TOTEM
  - rapidity gaps from ATLAS
  - flavor composition with LHC V^0, ϕ, and prompt hadron ratios
    - also utilize ATLAS and CMS K_S and Λ^0 measurements
  - LHCb, ATLAS, and CMS event multiplicity measurements used for underlying event
- tune will also be performed using 13 TeV dataset

Request Submission

- all MC via central production
- every job has *model* and *event type*
- *decay file* provides the event type configuration



`G`: general type and production scheme
`S`: initial state particles
`D`: features of decay
`C`: final charm hadrons and leptons
`T`: stable charged particles
`N`: neutrals
`X`: same `GSDCTN`, decay degeneracy
`U`: same `GSDCTNX`, model degeneracy

```
# EventType: GSDCTNXU
# Descriptor: {[[B0]nos -> mu+ mu- (K*(892)0
-> K+ pi-)]cc, ...}
# NickName: Bd_Kstmumu,phsp=DecProdCut,MomCut
# Cuts: DaughtersInLHCbAndWithMinP
# Documentation, PhysicsWG, Tested #
Responsible, Email, Date, CPUTime
Alias MyK*0 K*0
Alias Myanti-K*0 anti-K*0
ChargeConj Myanti-K*0 MyK*0
Decay B0sig
1.0 MyK*0 mu+ mu- PHSP;
Enddecay
CDecay anti-B0sig
Decay MyK*0
1.0 K+ pi- PHSP;
Enddecay
CDecay Myanti-K*0
End
```

Conclusions

Outlook

- options for upgrade MC computing model under development
  - both CPU and storage limits will require changes
- *filtered events* with fully reconstructed signals introduced, saves space but not time
- *multiple trigger conditions* per event now stored, saves both time and space
- *particle gun events* used to produce specific backgrounds and signals, but has limited use
- *fast MC* techniques such as detector geometry simplification and parametrization underway

- less b-physics oriented developments also underway
  - central exclusive production and heavy ion generators
  - full MadGraph/aMC@NLO + FxFx chain
  - gridpack deployment for NLO calculations