

Overview of MC with LHCb

Philip Ilten
on behalf of LHCb

UNIVERSITY OF BIRMINGHAM

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17TH MCNET MEETING



Overview

- LHCb **designed** as dedicated B -physics experiment
- simulation framework built with this in mind
 - full modeling of decays, *e.g.* EVTGEN
 - complete detector description with GEANT4
 - well tuned underlying event for reliable soft physics
 - efficient use of minimum bias events for signal extraction
 - automated to handle \approx **5000** different signal decays
- 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
 - multiple general-purpose generators for hadronization, *etc.*



Event Anatomy

1) hard process

3) ISR

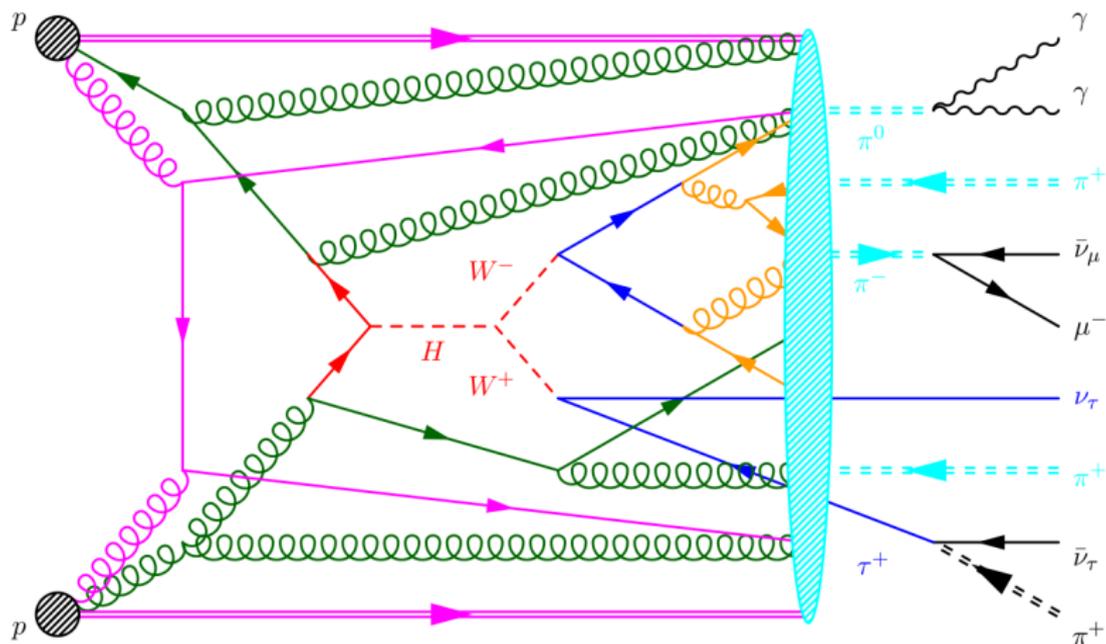
5) underlying event

7) particle decays

2) resonance decays

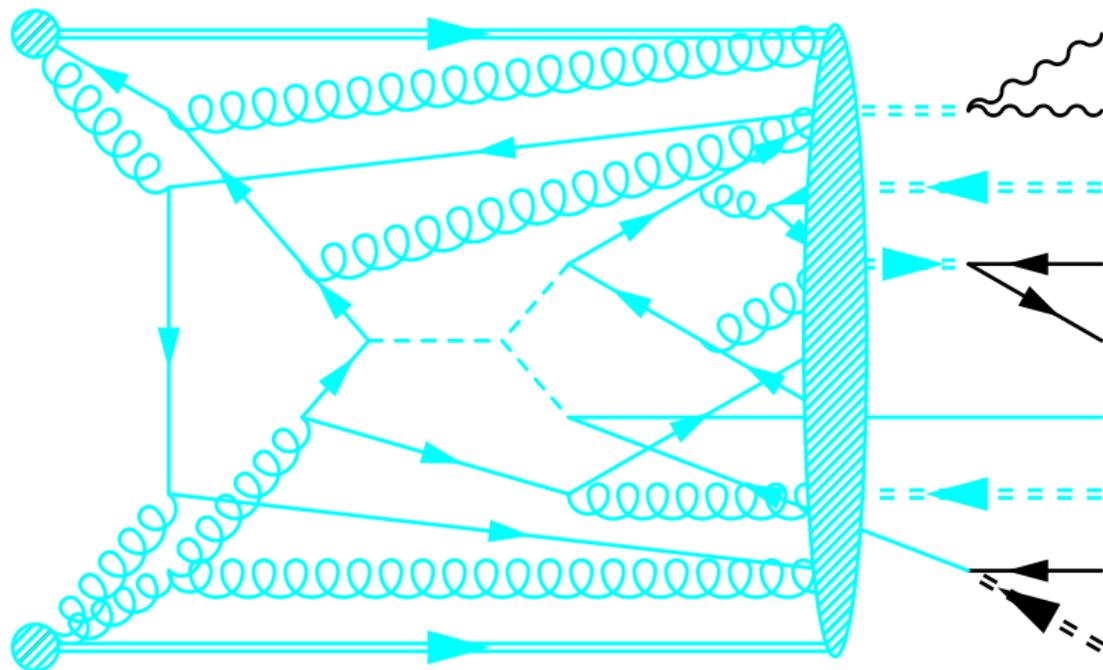
4) FSR

6) hadronisation

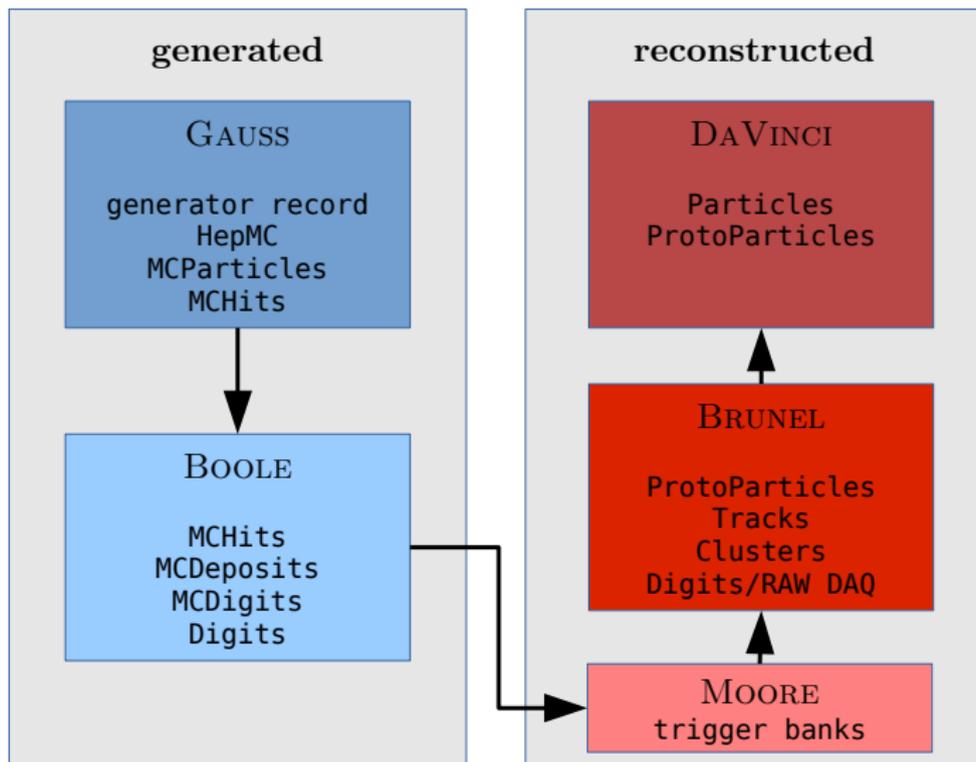


LHCb Event Anatomy

1) production 2) particle decays



LHCb Data Model



LHCb MC Requests

- 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

Request

Name: MC11a Model - HD - SplitOver - Trig and Strip Tagged
Type: Simulation State: New
Priority: 2b Author: gsoff
Inform also: List of DDAC users and/or mail addresses
MC Config: MC11a

Simulation Conditions (ID: 431283)

Description: Beam:3000GeV 2011-HagDown-Nu2-Slow-ErMC-Cuts
Beam: beta* = 3 m, angle = 0.520 mrad Magnetic field: -1
Beam energy: 3000 GeV Detector: 2011, Web Closed
Generator: Pythia Luminosity: pp collisions nu = 2, 5
G4 settings: LHEP and DM opt with no cuts appl

Processing Pass (Bin64/1716x407688377tagged/Recall3a/90striping17NoHuefficiencytagged)

Step 1 Sim04 with Nu+2.0 (with softener) - HD - MC11a - MC211-2012072117832(Sim04)
Options: SAPPKONV1GDP7F5GausBeam3000GeV+m180-MC11-m2-08m-pyS0K7L2SRD07/options
G/overType:py/BLPYTHANG07/options/Pythia.py/SAPPKONV1GDP7F5Gaus/G4P_LHEP_ErMCv2.0.py
Options format: null
DD08: MC211-20120727 Condition DB: MC211-20120727-cc-mc180 DDTag: null
Data: AppConf: app180/DecFiles v25r17 Runtime projects:
Viewer: V viewer-tes
Input file types: Output file types: S2M(X)

Step 2 Digi1 w softener - HD - MC11a - MC211-2012072117896(Digi1) Beam v25r1
Options: SAPPKONV1GDP7F5GausBeam3000GeV+m180-MC11-m2-08m-pyS0K7L2SRD07/options
G/overType:py/BLPYTHANG07/options/Pythia.py/SAPPKONV1GDP7F5Gaus/G4P_LHEP_ErMCv2.0.py
Options format: null
DD08: MC211-20120727 Condition DB: MC211-20120727-cc-mc180 DDTag: null
Data: AppConf: app180/DecFiles v25r17 Runtime projects:
Viewer: V viewer-tes
Input file types: S2M(X) Output file types: D2D2(X)

Step 3 Trigger - TK 048708037 Tagged - HD - MC211-2012072117896/Trigger407688377tagged

[Save without submission] [Submit to the production team] [Cancel]

Event

Type:
Number:
Comments:
10000000 - incl. D
Comment by 10000010 - incl. D=BasedElnVcc
10000020 - incl. D=BasedElnVcc
Model for MC 10000021 - incl. D=Based_L1EtrMC4Sp
Magnet down
run in Tagging 10000022 - incl. D=Based_L1EtrMC4Sp
For Gaus shp 10012004 - incl. D=DMuon_Bdhp_u3GeV
Comment by 10012005 - incl. D=DMuon_Bdhp_u3GeV
Use Struck RM 10012006 - incl. D=DMuon_OppositeSign_p3GeV/m4.7GeV
stripping line 10012007 - incl. D=DMuon_OppositeSign_p3GeV/m4.7GeV/m...
Comment by 10012008 - incl. D=DMuon_OppositeSign_p3GeV/m4.7GeV/m...
Modified to use latest Gaus v4r2 and DecFiles v25r4. Also insert MC Config to be MC11a.
Comment by 10022001_C_05_1025Electron
Comment by gsoff on Mar 16, 2012:
Modified to use latest DecFiles v25r5
Comment by gsoff on Jun 29, 2012:
Modified to use latest DecFiles v25r11
Comment by gsoff on Jul 20, 2012:
Modified to use latest Gaus v4r4 and DecFiles v25r12.
Comment by gsoff on Aug 08, 2012:
Modified to use latest database tags for 2011 in all steps (also pid file and some additional material) and latest DecFiles v25r13
Comment by gsoff on Sep 05, 2012:
Modified to use latest AppConf/33147 and DecFiles v25r14

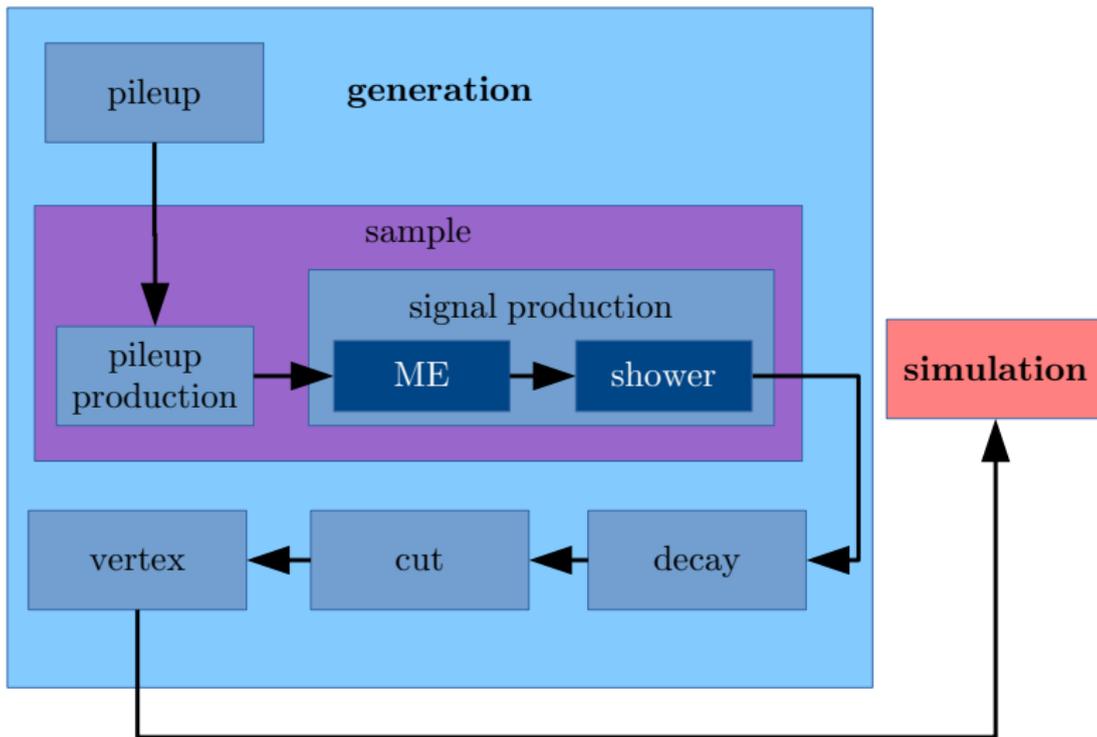
```
# EventType: GSDCTNXU
# Descriptor: {[[B0]nos -z mu+ mu- (K*(892)0
-z K+ pi-)]cc, ...}
# NickName: Bd.Kstmumu.phsp=DecProdCut,MomCut
# Cuts: DaughtersInLHCbAndWithMinP
# Documentation, PhysicsWG, Tested #
Responsible, Email, Date, CPUTime
Alias MyK*0 K*0
Alias Myanti-K*0 anti-K*0
ChargeConj Myanti-K*0 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
```



GAUSS Tools



GAUSS



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, decay particles heavier than the signal particle, accept if requested particle types are produced, flip event if signal $p_z < 0$
 - *plain signal*: like *inclusive* but force given signal decay
 - *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. $gg \rightarrow H \rightarrow b\bar{b}$, independent 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, and now PYTHIA 8



Decays and Cuts

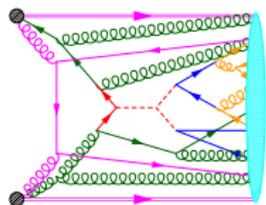
- **decay tool** decays all remaining particles from the production tool, including requested signal
 - *EvtGen*: interface to the EVTGEN package with support for τ decays via TAUOLA, FSR via PHOTOS, and additional decays via PYTHIA 8
 - *multipurpose*: multipurpose generators can perform resonance decays from hard processes with correlated final states, *e.g.* $gg \rightarrow H \rightarrow \tau\tau$
- **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

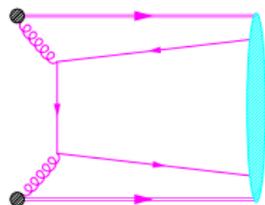


Production Generators



general purpose

- HERWIG++/7
- PYTHIA 6
- PYTHIA 8
- SHERPA



soft

- CRMC
- HIJING



hard

- ALPGEN
- BCVEGPy
- LPAIR
- GENXICC
- MADGRAPH
- POWHEGBOX
- STARLIGHT
- SUPERCHIC 1/2



Primary Generator

- PYTHIA 6 was originally 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](https://arxiv.org/abs/hep-ph/0702054), [arXiv:1210.3458](https://arxiv.org/abs/1210.3458)
 - produces $gg \rightarrow X\bar{Q}\bar{Q}$, $gQ \rightarrow X\bar{Q}$, and $QQ \rightarrow Xg$
 - interfaced with PYTHIA 6 and PYTHIA 8 showers
- S -wave and P -wave B_c states produced with BCVEGPY
 - [hep-ph/0309120](https://arxiv.org/abs/hep-ph/0309120), [hep-ph/0504017](https://arxiv.org/abs/hep-ph/0504017), [1307.3344](https://arxiv.org/abs/1307.3344)
 - produces $gg \rightarrow Xc\bar{c}$
 - also interfaced with PYTHIA 6 and PYTHIA 8 showers
- excited onia production integrated into PYTHIA 8.185 and beyond



Onia Production

- onia production modeled with NRQCD

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

- 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](https://arxiv.org/abs/hep-ph/0003142)
 - [arXiv:hep-ph/9807329](https://arxiv.org/abs/hep-ph/9807329) for $\langle \mathcal{O}^{Q\bar{Q}[^3D_J]}[^{2s+1}\ell_J] \rangle$
- non DPS double-onia production also available



Onia p_T Divergence

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

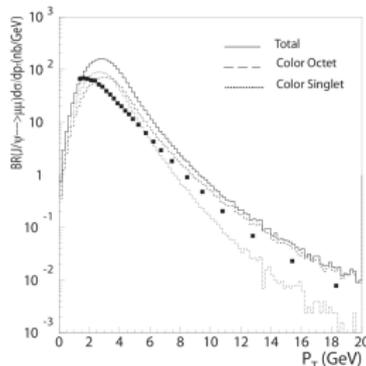
$$\left(\frac{p_T^4}{p_{T0}^2 + p_T^2} \right) \left(\frac{\alpha_s(p_{T0}^2 + p_T^2)^2}{\alpha_s(p_T^2)} \right)$$

- allow p_{T0} to be energy dependent

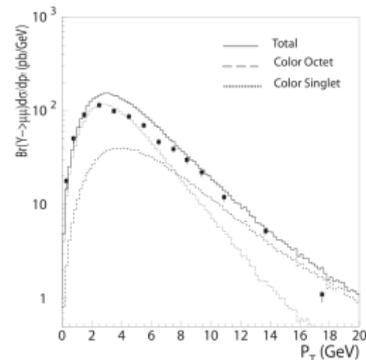
$$p_{T0}(\sqrt{s}) = p_{T0}(E_0) \left(\frac{\sqrt{s}}{E_0} \right)^\theta$$

- 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)
- PYTHIA 8 tune using Monash tune as starting point
 - 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
 - ATLAS and CMS K_S and Λ^0 measurements
 - LHCb, ATLAS, and CMS event multiplicity measurements used for underlying event
- new tune underway using 7 and 8 and 13 TeV datasets for the most recent version of PYTHIA 8



Conclusions



Outlook

- to cope with MC statistics needed for Run 3 options are under development, CPU and storage must be optimized
 - *filtered events* with fully reconstructed signals introduced, saves space but not time
 - *multiple trigger conditions* per event now stored, saves both time and space
 - *reddecay* signal multiple times and reuse fully simulated underlying event
 - *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



Requests

- interface through C++ (ideally no disk input/output)
 - event record input/output via HEPMC
 - particle properties can be easily and centrally set
 - random number generator can be externally provided
 - parts of generator can easily factorize
-
- faster is better ... already see non-negligible generator contribution
 - request specific particle species in final state

Thanks for all the incredible work
and support!

