LHCb and Soft QCD

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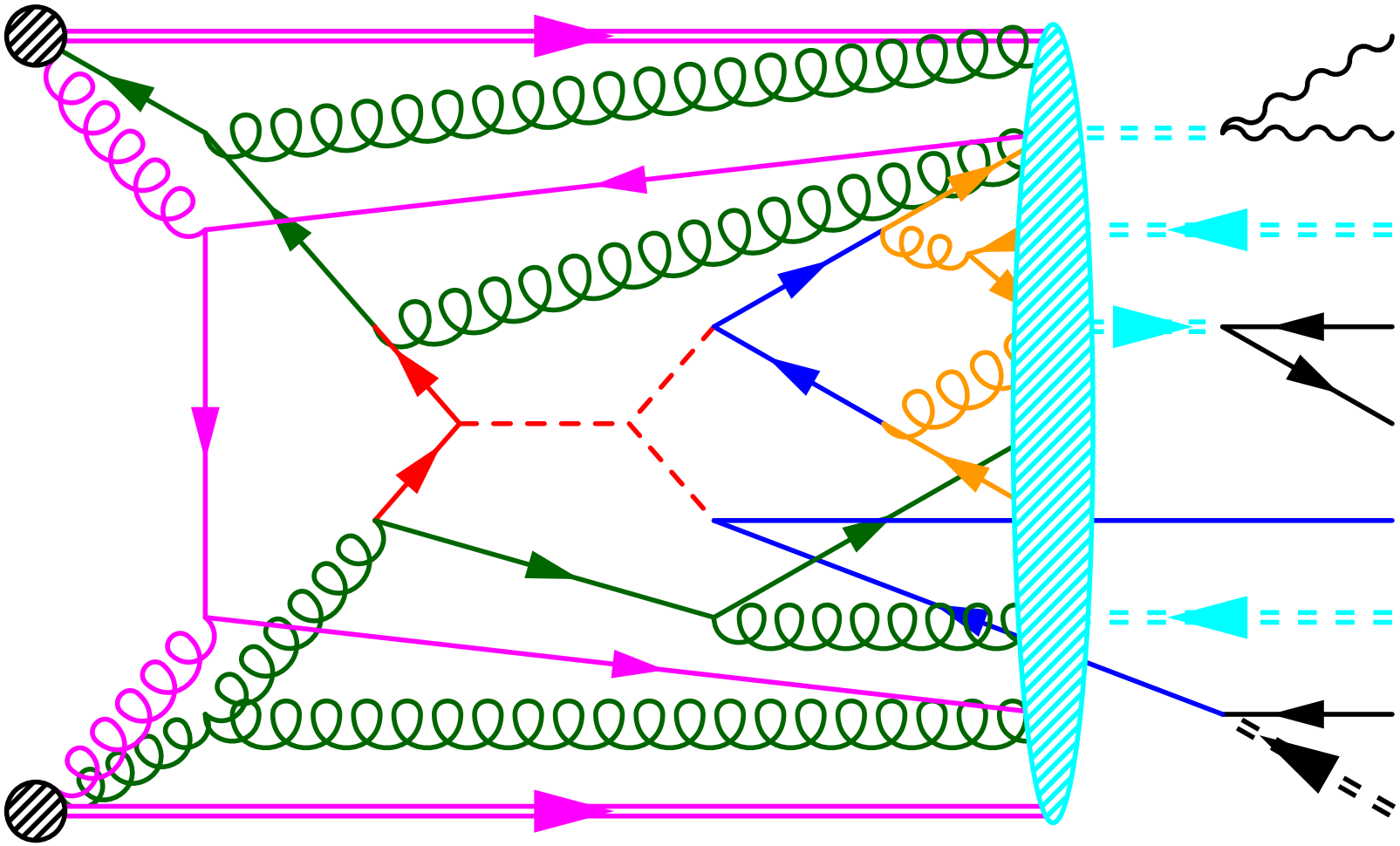
SnowMass EF05 Mini-Workshop

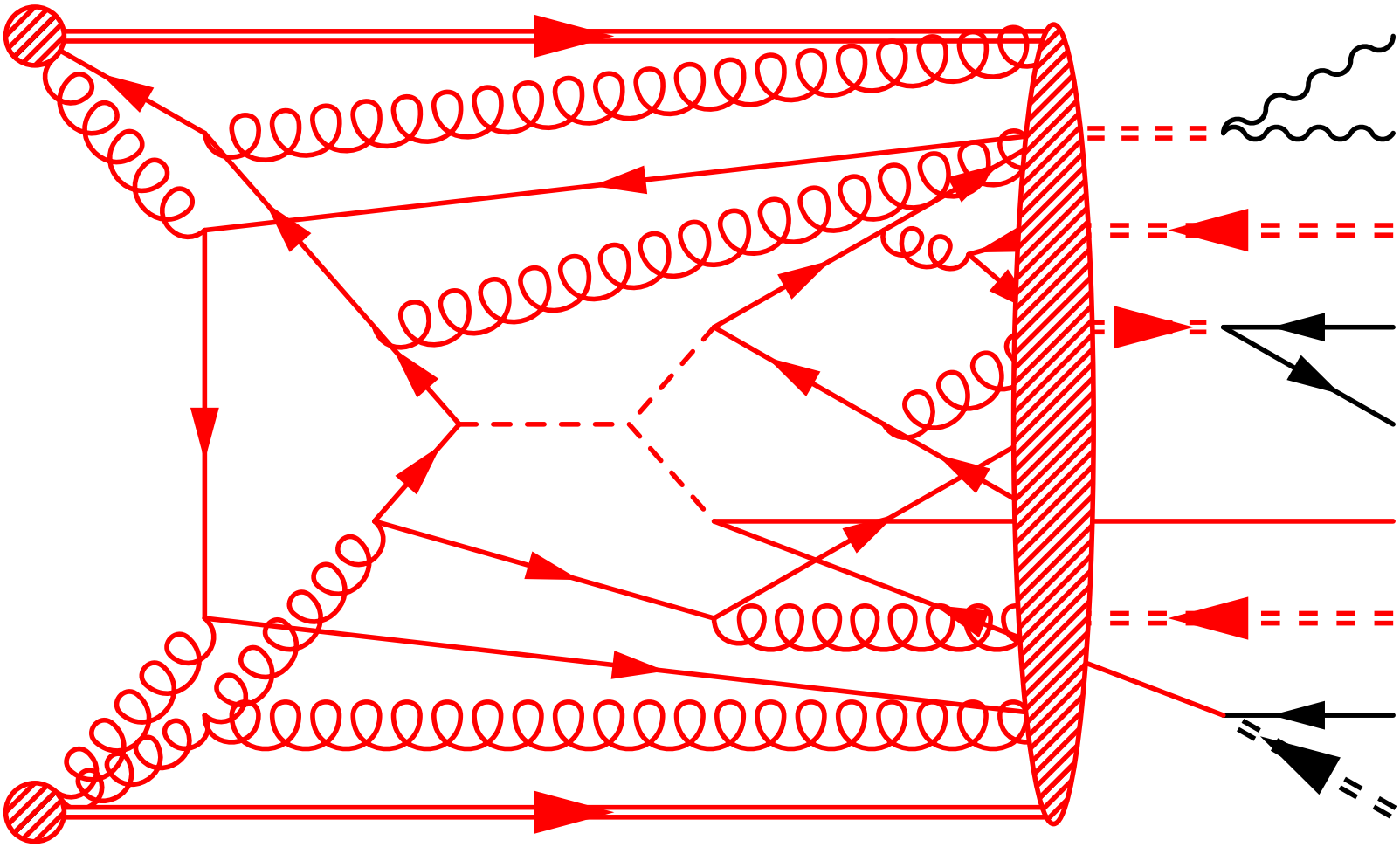
Event Anatomy

1) hard process
2) resonance decays
3) ISR
4) FSR
5) underlying event
6) hadronization
7) particle decays



LHCb Event Anatomy

1) production 2) particle decays



Overview

- LHCb **designed** as dedicated B-physics experiment
  - 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
  - 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.*

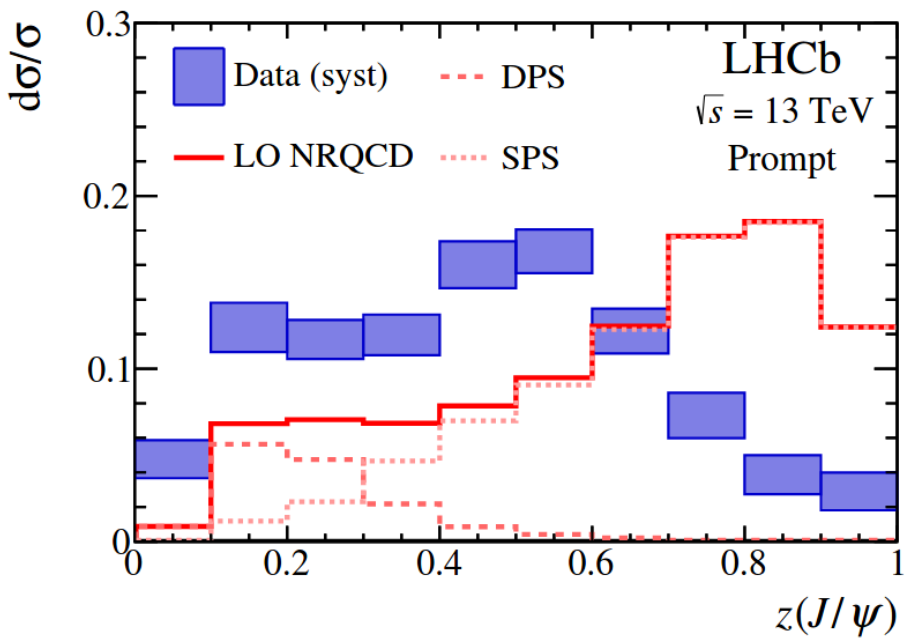
- $\approx$ **90% of LHCb simulation soft QCD**

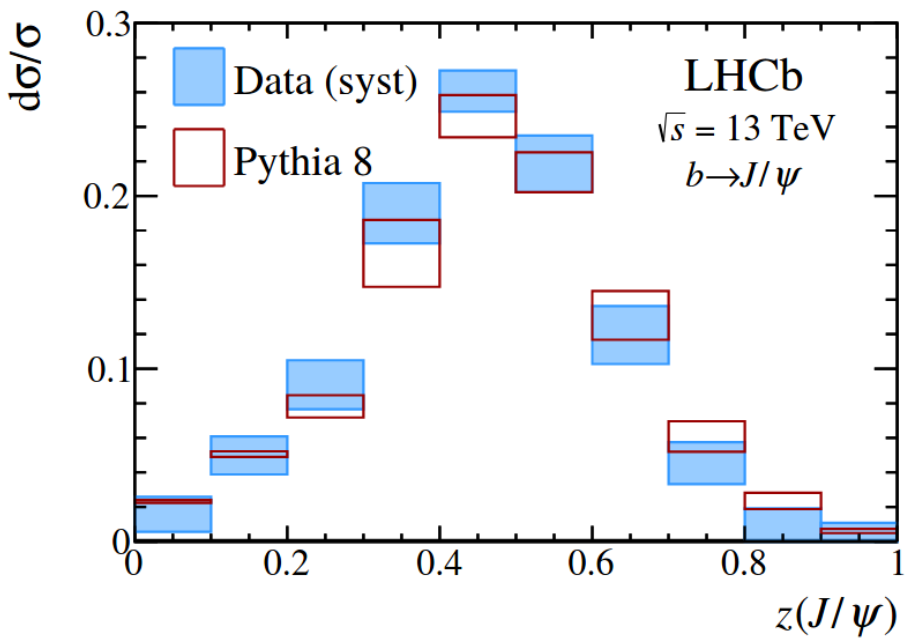
Systematics

- limiting systematics for Run 3 and beyond depend upon channel
- ϕ_s from $b \to c\bar{c}s$, $B_s \to \mu\mu$, $D^0 \to K^0_S\pi\pi$: not limited by systematics
- CKM γ tree level, charm asymmetries: detector asymmetries
- most limiting systematics from detector response
  - reconstruction asymmetries (charge-dependent)
  - particle identification
  - low(er) momentum tracks
  - neutral reconstruction
- these oftentimes depend on underlying Monte Carlo

Some Exceptions

- upcoming W mass measurements will be sensitive to non-perturbative components
- top analyses are still statistically limited
- some jet analyses are systematics limited

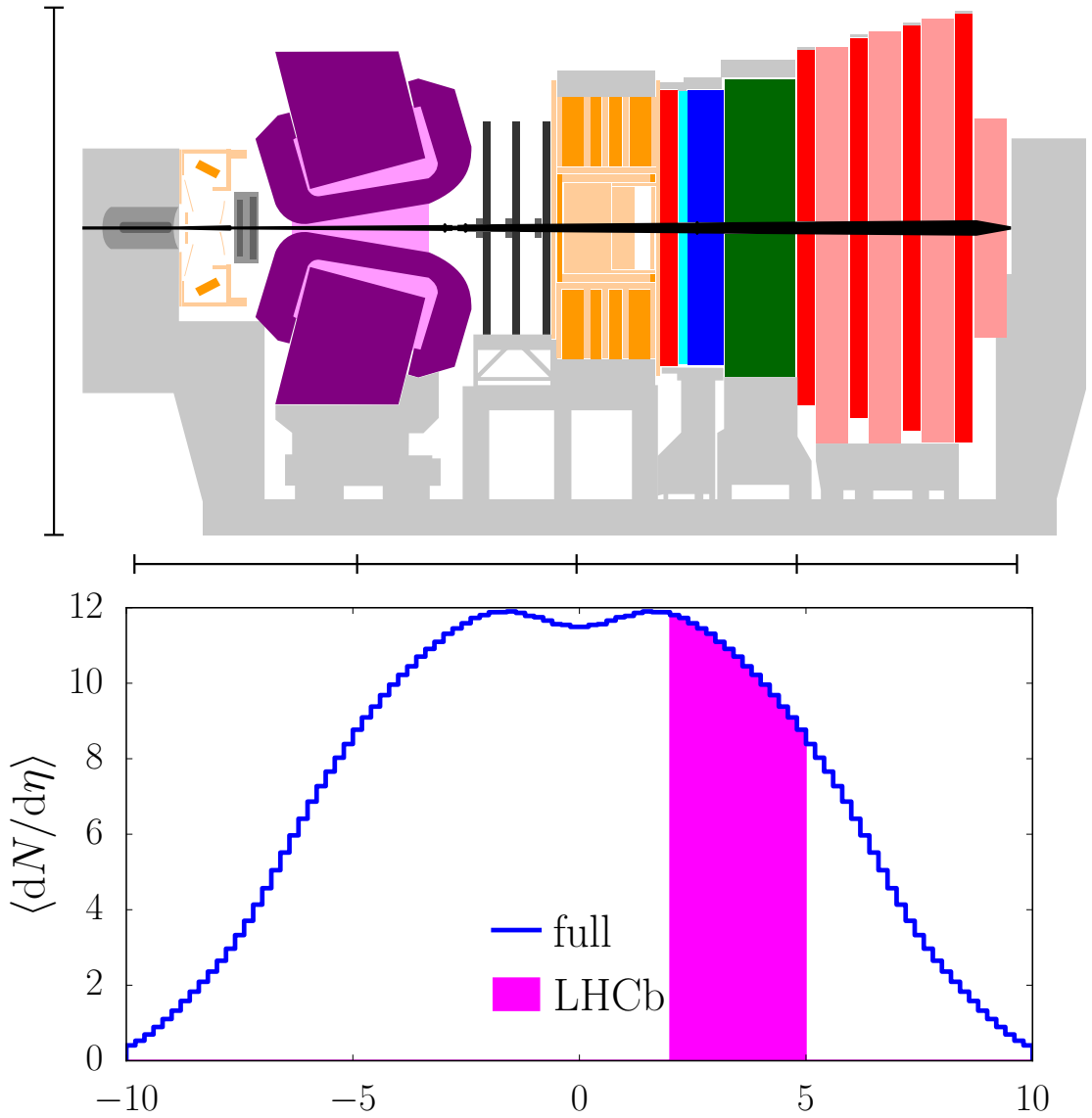




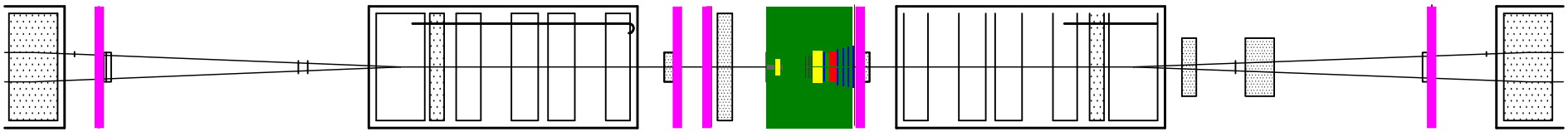
LHCb Tuning

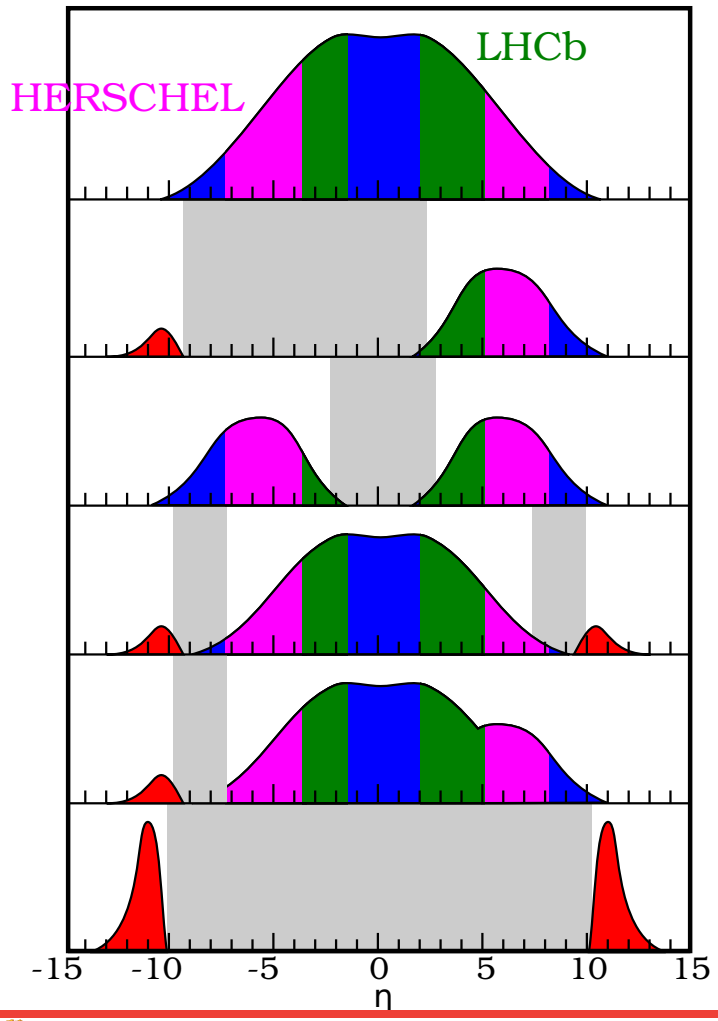
LHCb Acceptance

JINST 3 (2008) S08005

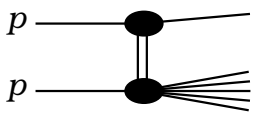


HERSCHEL Acceptance

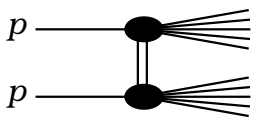




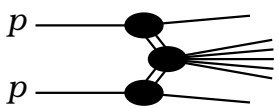
inelastic



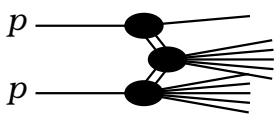
single diffraction



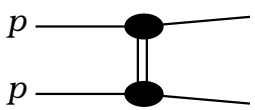
double diffraction



CEP elastic



CEP inelastic



elastic

Tuning Parameters

T. Sjöstrand

- hard process
  - PDFs, phase space cut-offs ($\hat{p}_\mathrm{T}$, $\hat{m}$), renormalisation scale, factorisation scale, SM parameters (CKM, $\alpha_s(M_Z)$, $\sin\theta_W$)
- parton showers
  - $\alpha_s(M_Z)$, scales, p_T damping, matching parameters, ordering method
- underlying event
  - $\alpha_s(M_Z)$, hard processes, p_T damping, beam profile (shape, impact parameter), colour reconnection
- hadronisation
  - longitudinal momentum sharing, transverse width, flavor composition, vector to pseudo-scalar composition, baryon and meson production ratios

Observables

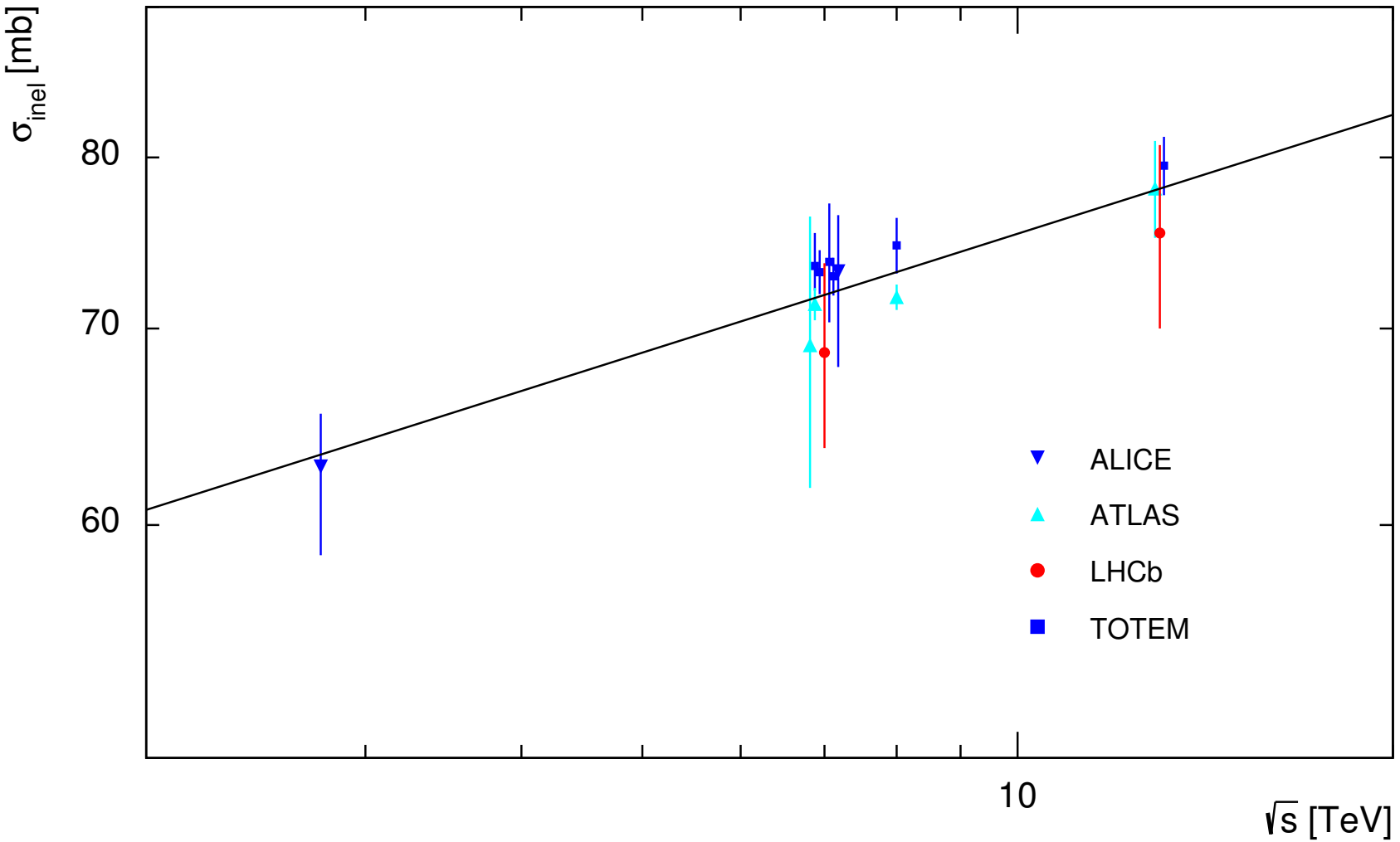
- test non-perturbative regimes of QCD
- tune multi purpose event generators
- look for new effects to refine models
- hard process
  - onia inclusive cross-sections
  - onia p_{T} distributions
- ISR
  - light jet thrust ($\alpha_s(M_Z)$)
  - p_{T} from $Z \to \mu\mu$ (primordial k_{T})
- FSR
  - similar to ISR
- underlying event
  - onia measurements
  - IR safe energy flow
- hadronisation
  - final state flavor composition
  - IR sensitive charge density and multiplicity
- particle decays
  - branching fractions
  - mass distributions, angular distributions, etc.

LHCb Public Rivet Analyses

analysis	plugin	reference
inelastic cross-section	LHCB_2015_I1333223	JHEP 1502 (2015) 129
charge particle multiplicities and densities	LHCB_2014_I1281685	Eur. Phys. J. C 74 (2014) 2888
energy flow	LHCB_2013_I1208105	Eur. Phys. J. C 73 (2013) 2421
prompt charm cross-sections	LHCB_2013_I1218996	Nucl. Phys. B 871 (2013) 1-20
charged particle ratios	LHCB_2012_I1119400	Eur. Phys. J. C 72 (2012) 2168
V^0 ratios	LHCB_2011_I917009	Eur. Phys. J. C 72 (2012) 2168
inclusive ϕ cross-sections	LHCB_2011_I919315	Phys. Lett. B 703 (2011) 267-273
prompt K^0_S cross-sections	LHCB_2010_S8758301	Phys. Lett. B 693 (2010) 69-80
inclusive $b\bar{b}$ cross-sections	LHCB_2010_I867355	Phys. Lett. B 694 (2010) 209-216

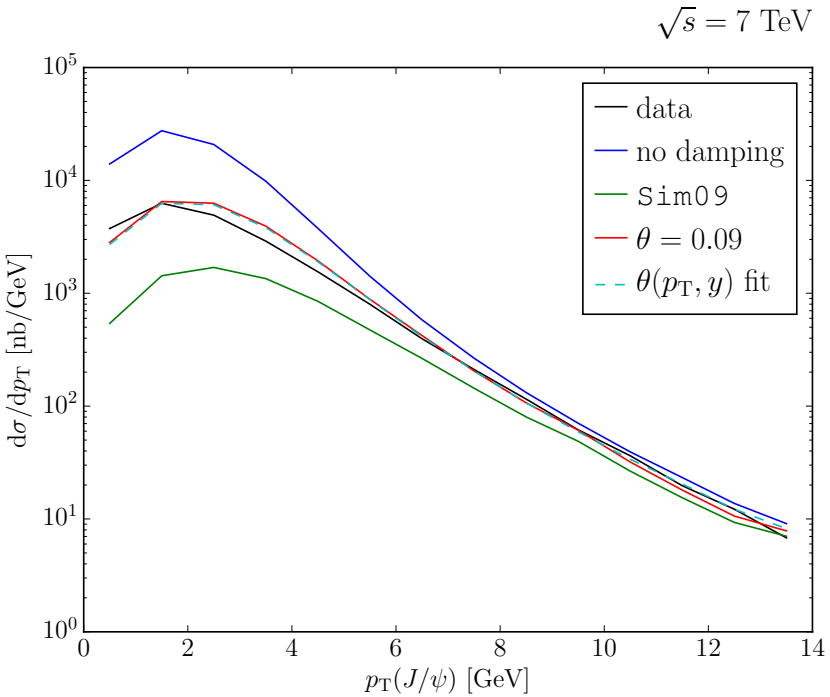
Inelastic Cross-Sections

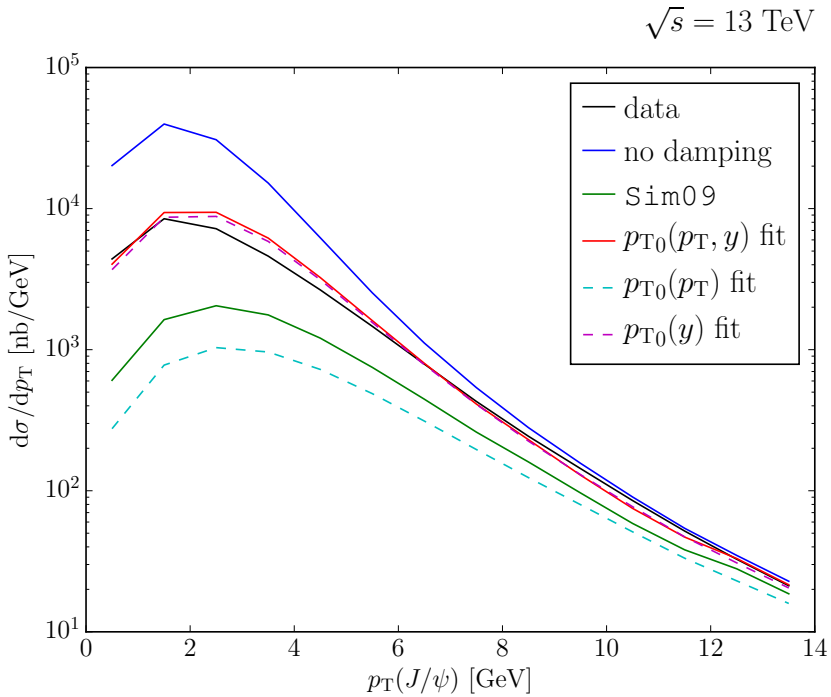
JHEP 06 (2018) 100



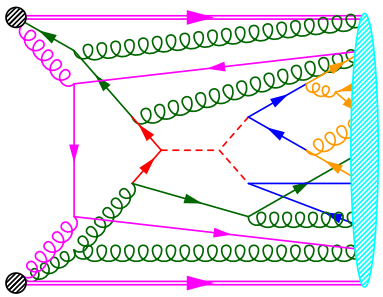
Quarkonia

$$\left(\frac{p_{\mathrm{T}}^4}{p_{\mathrm{T}0}^2 + p_{\mathrm{T}}^2}\right)\left(\frac{\alpha_s(p_{\mathrm{T}0}^2 + p_{\mathrm{T}}^2)^2}{\alpha_s(p_{\mathrm{T}}^2)}\right) \qquad p_{\mathrm{T}0}(\sqrt{s}) = p_{\mathrm{T}0}(E_0)\left(\frac{\sqrt{s}}{E_0}\right)^{\theta}$$



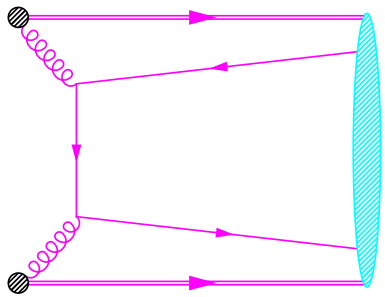


Generators in LHCb



general purpose

- Herwig++/7
- Pythia 6
- Pythia 8
- Sherpa



soft

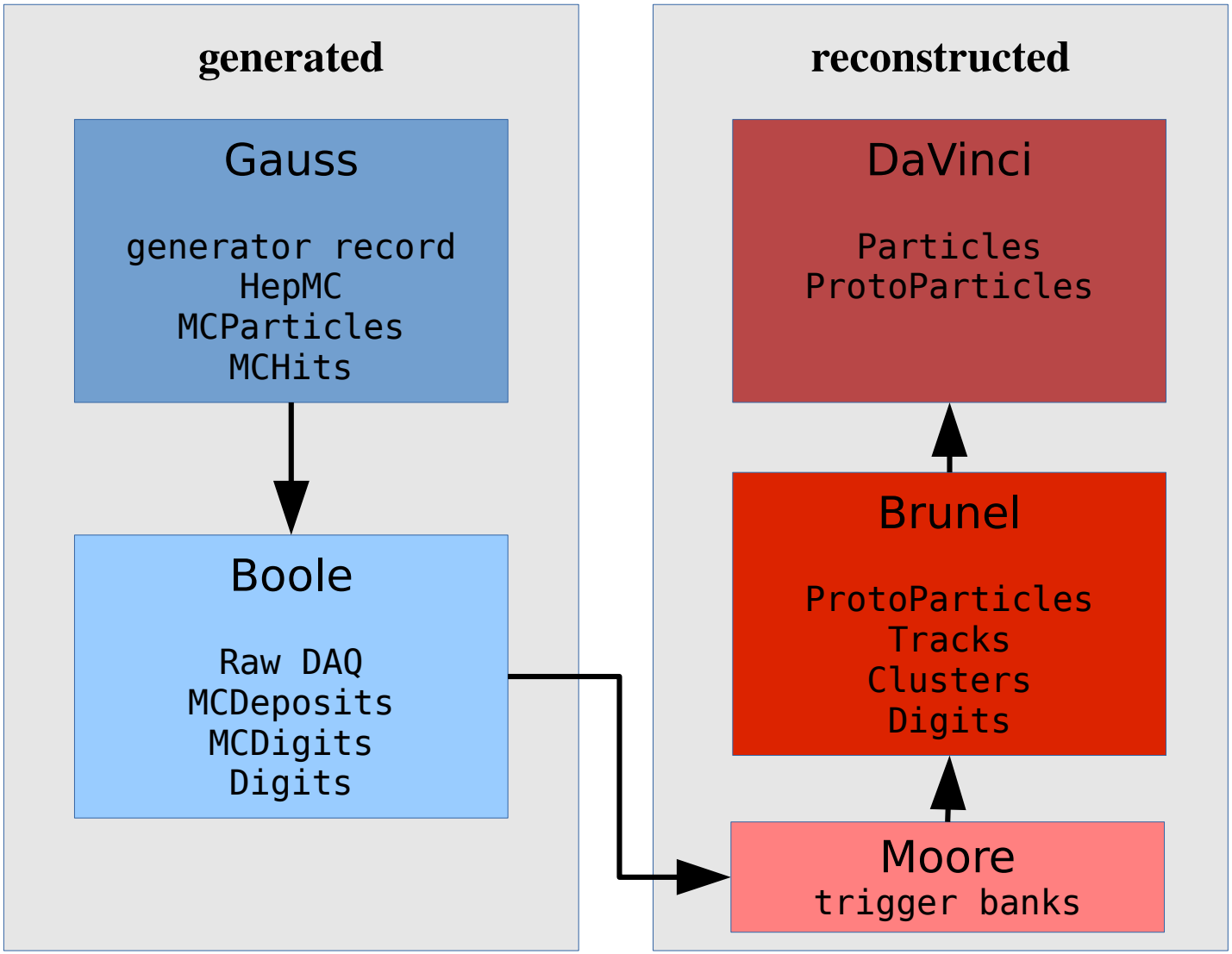
- CRMC
- HIJING

hard

- AlpGen
- BcVegPy
- LPair
- GenXicc
- aMC@NLO
- PowhegBox
- StarLight
- SuperChic 1/2

LHCb Monte Carlo

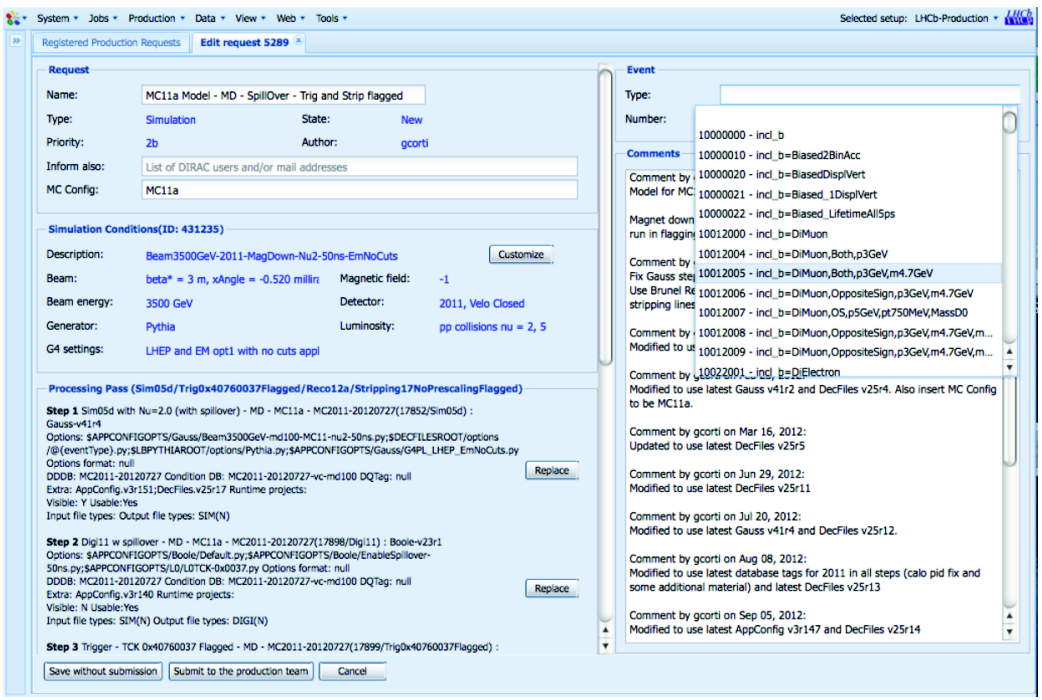
LHCb Processing and Data



LHCb MC Requests

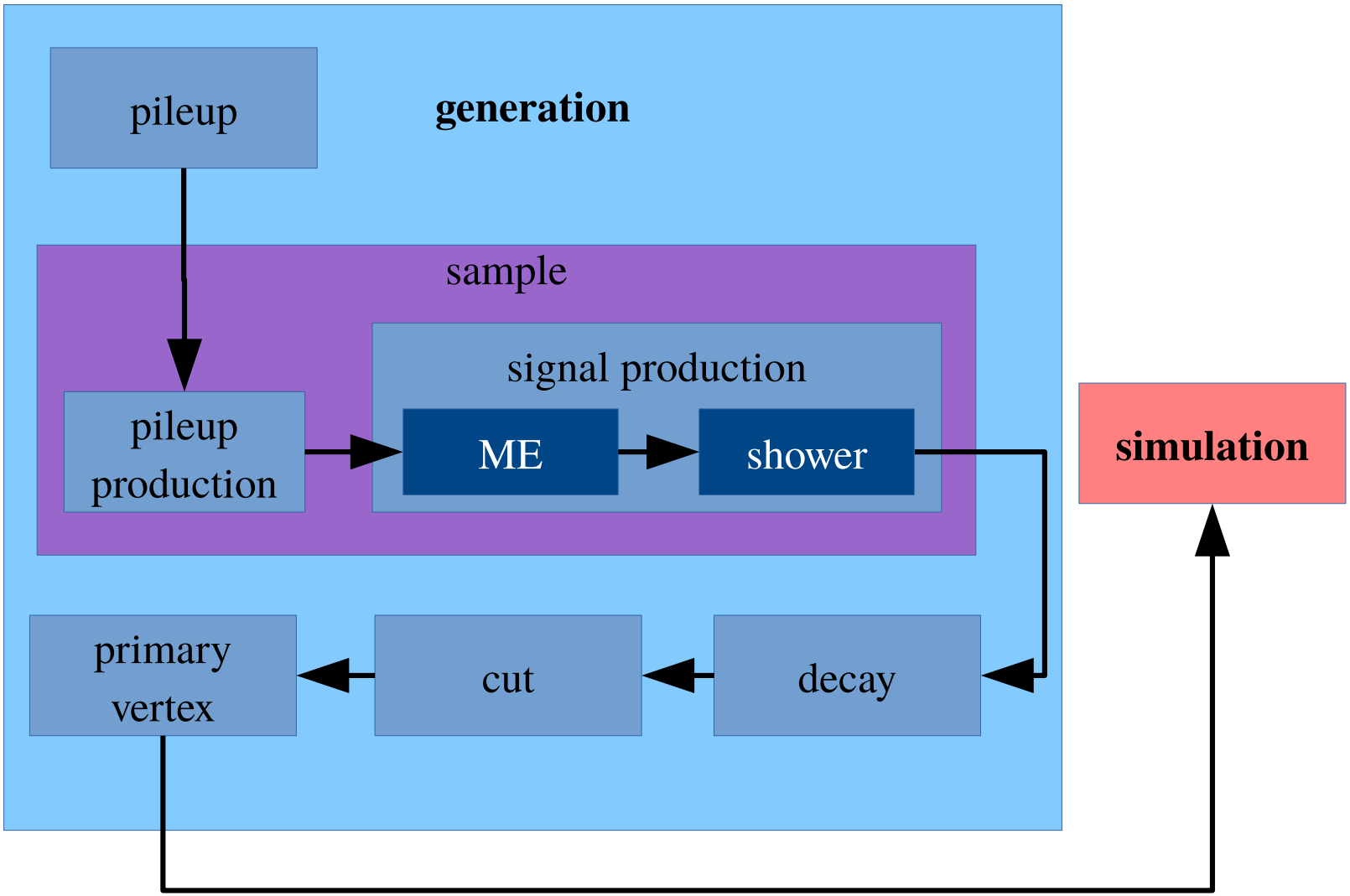
- all MC via central production
- every job selects a *model* and *event type*
- *decay file* provides the event type configuration

`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

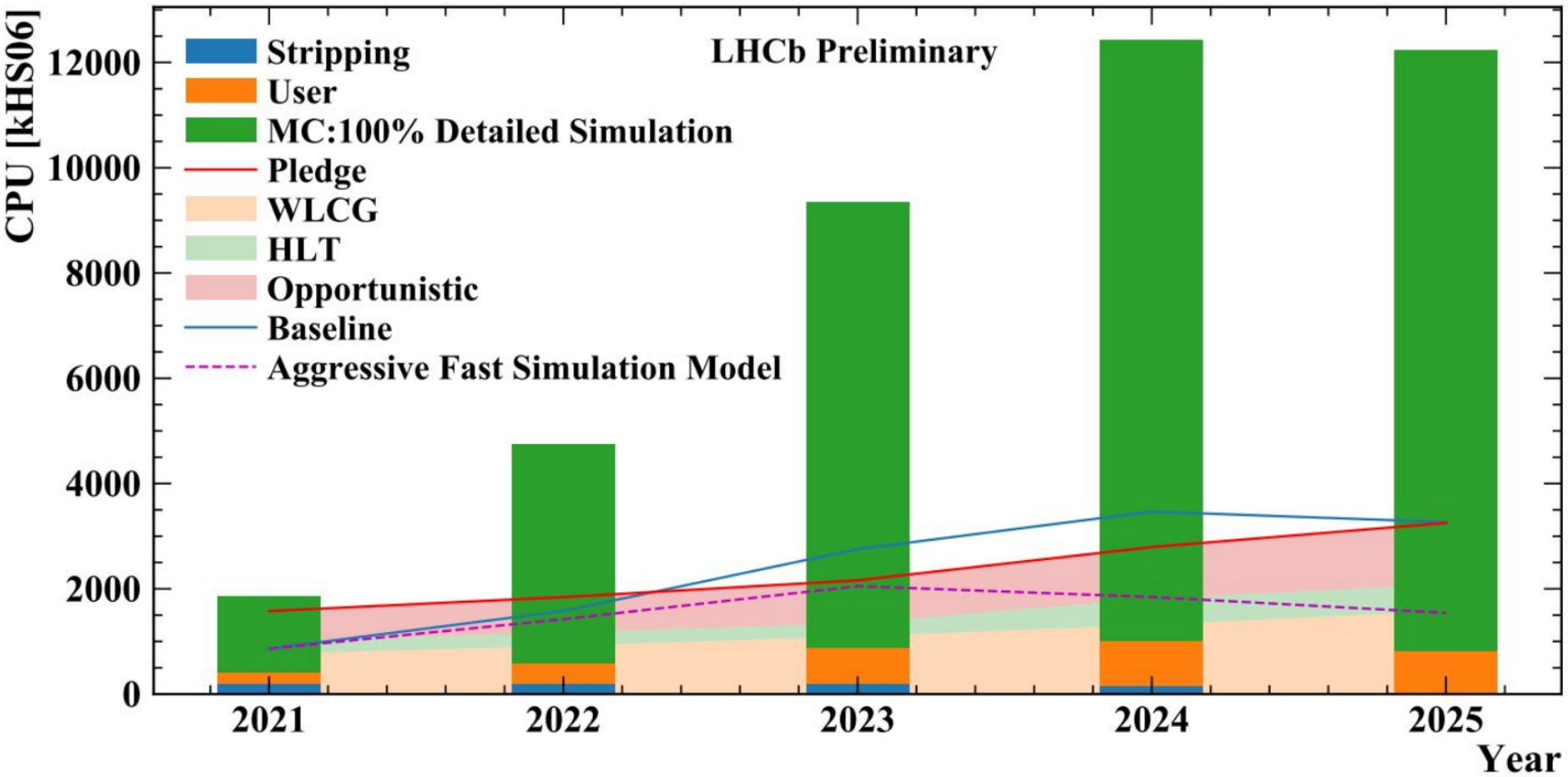



```
# EventType: GSDCTNXU
# Descriptor: {[[B0]nos -> mu+ mu- (K*(892)0
-> K+ pi-)]cc, ...}
# NickName: Bd_Kstmumu,phsp=DecProdCut,MomCut
# Cuts: DaughtersInLHCbAndWithMinP
# Documentation, PhysicsWG, Tested #
Responsible, Email, Date, CPUTime
Alias MyK*0 K*0
Alias Myanti-K*0 anti-K*0
ChargeConj Myanti-K*0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

Gauss


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

Simulation Bottleneck

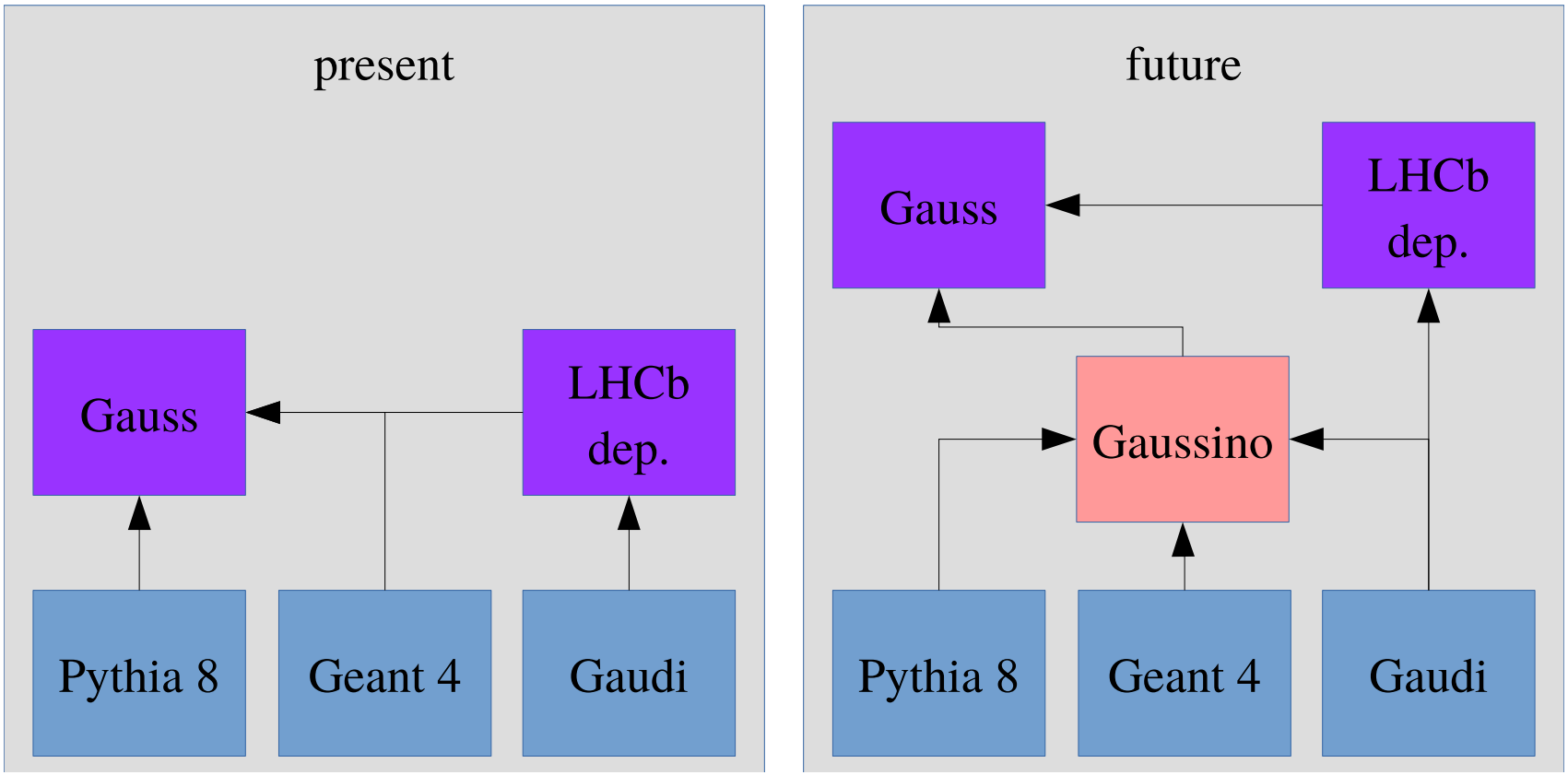


Generation Bottleneck

- simulation timing will match generation timing
- past:
  - *filtered events* with fully reconstructed signals introduced, saves space but not time
  - *multiple trigger conditions* per event now stored, saves both time and space
  - *redecay* signal multiple times and reuse fully simulated remaining event [arXiv:1810.10362]
  - *particle gun events* used to produce specific backgrounds and signals, but has limited use
- present:
  - fully multi-threaded environment
- future:
  - faster/biased soft QCD generation

Gaussino

- gitlab.cern.ch/Gaussino
- thread-safe generation
- Geant 4 MT that is integrated and working with Gaudi MT in Gaussino



Outlook

Final Thoughts

- LHCb is a non-standard LHC use case

- we have over **5000** different signal decays
- nearly **90%** of our simulation is soft QCD
- automation is critical

- in Run 3, we need to primarily use fast simulation
- generation for rare hadrons will become an issue