b Generator: Monash Group

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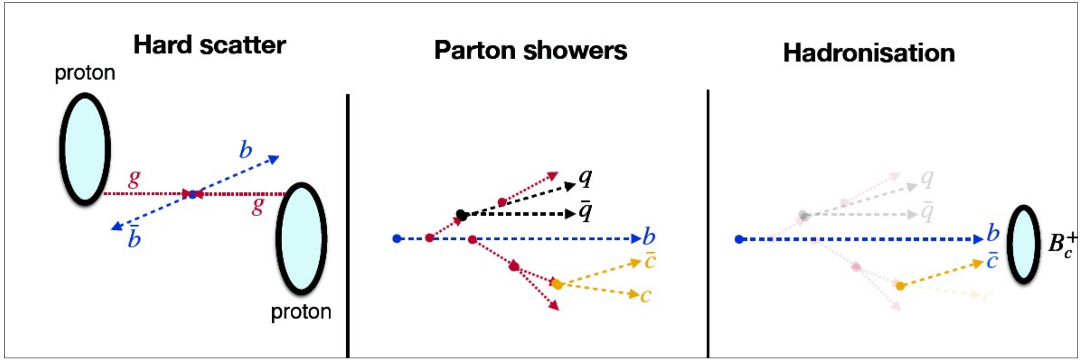
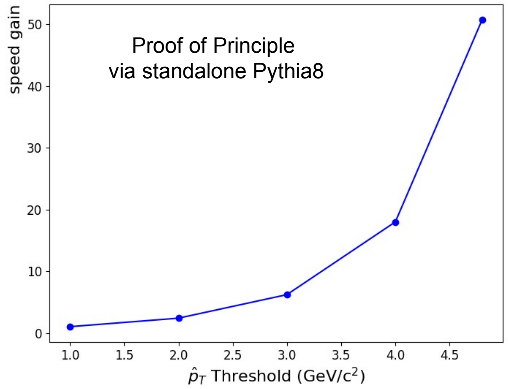
Outline

- Speed up LHCb simulations (merge request in progress)
- Doubly-heavy hadrons in Pythia8 (paper writing in progress)
- B enhancements
- Future plans

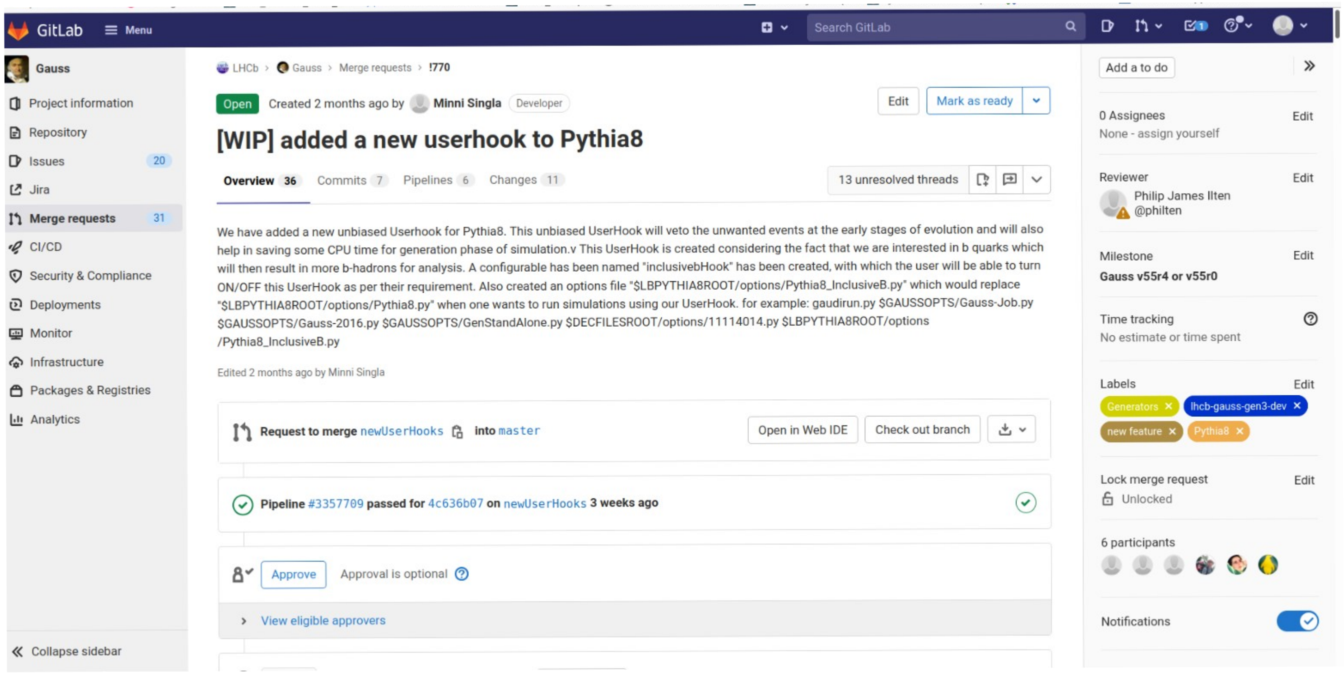
Speed up LHCb simulations

- We can make ***Generator phase*** of b-hadron production faster in LHCb simulation framework.
  - by using unbiased UserHooks in our Pythia8Production tool which will veto the unwanted events at the early stages of evolution
- this is most important in special studies where generator time dominates over Geant4 time.
- for example: in the production of multiple B's, B_c, Ξ_{cc}, Ω_{bb} etc.
- produced b-hadrons will still be unbiased





Request to add the userhook in LHCb simulation framework



Once the merge request is finalised, this will be the default method for B production in LHCb simulations

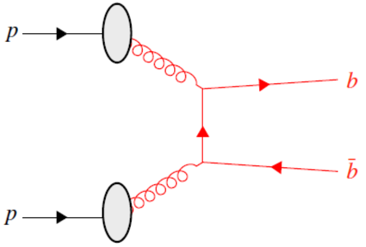
- The way to initiate the userhook is via using $LBPYTHIA8ROOT/options/Pythia8_InclusiveB.py options file in addition to all the other <options.py>
  - - For example: gaudirun.py $GAUSSOPTS/Gauss-Job.py $GAUSSOPTS/Gauss-2016.py $GAUSSOPTS/GenStandAlone.py $DECFILESROOT/options/11114014.py $LBPYTHIA8ROOT/options/Pythia8.py $LBPYTHIA8ROOT/options/Pythia8_InclusiveB.py

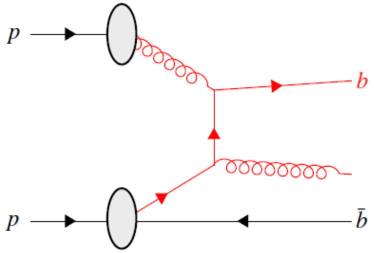
Heavy quark production in pp collision

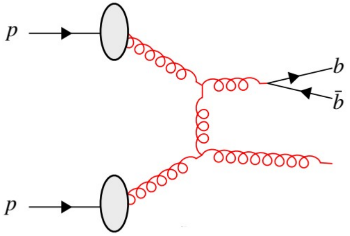
- **Pair Production**
- gg→QQbar, qqbar→QQbar
- B hadrons formed have strong tendency to be back-to-back in the transverse plane

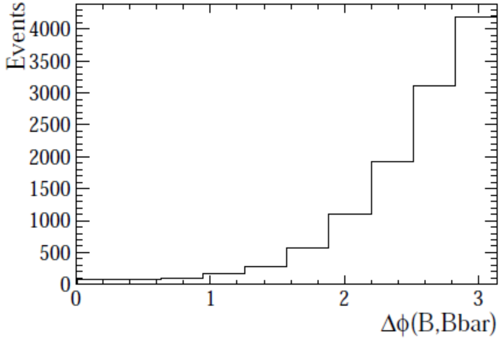
- **Flavor excitation:** Qg→Qg, Qq→Qq
- a virtual QQbar pair are produced in the proton
- one of them interacts with a q or g from the other proton.
- there is little to no correlation between the directions of the two heavy quarks in the transverse plane

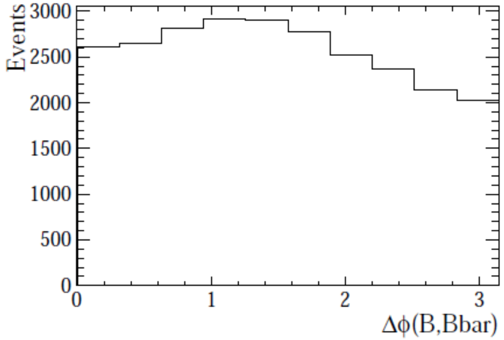
- **Gluon Splitting:** g→QQbar
- the gluon that produces the QQbar pair has a boost in transverse plane
- tend to have smaller angles between the two heavy hadrons

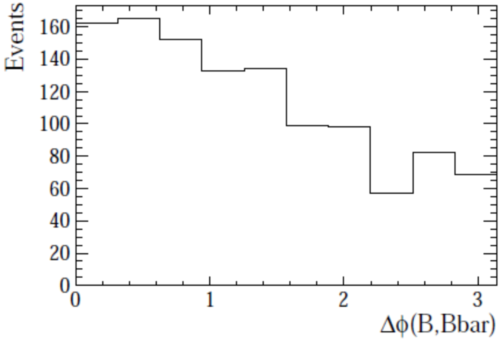






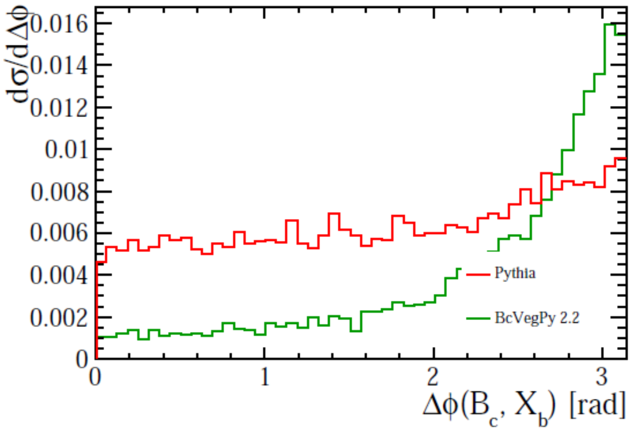


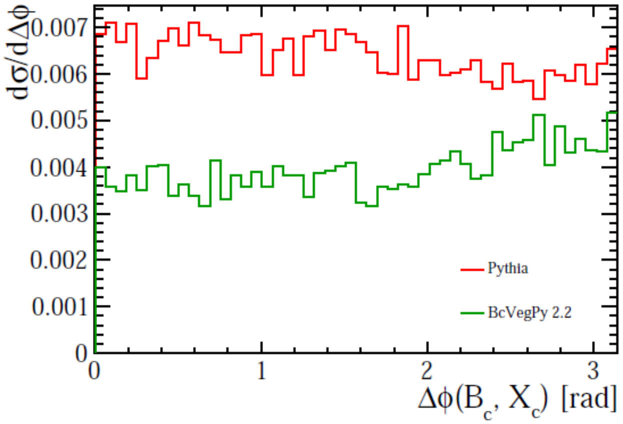




Double-heavy hadrons:: Pythia8 vs BcVegPy

- Currently Pythia8 isn't used to produce B_c or other double heavy hadrons at LHCb
- With the new samples we've created (using Userhooks) we are now able to compare of Pythia8 with the other dedicated generators like BcVegPy, GenXicc that have limitations in terms of the production processes.
- We are comparing the geometrical distribution of B_c mesons and the associated heavy hadrons as this can differentiate the production topologies.
- $\Delta\Phi$ is relative angles in the transverse plane between B_c and X_b / X_c hadron
- The sample produced by Pythia8 includes MPIs introducing the possibility of further production mechanisms for example double pair production, double flavor excitation
- As a result the distribution of events are more uniform in Pythia8.





Quarkonia production mechanisms

Aim is to study production mechanisms of quarkonia in Pythia8 to compare to distributions in data.

- Onia can be produced via following mechanisms:
  - **Hard process**
  - **MPI**
  - **Hard & MPI**
  - **Decay process** : for example a $X_{bb\ or}$ X_{cc} produced via any of the following mechanisms that then decays to quarkonia
    - Hard process
    - MPI
    - Hard & MPI
    - Shower
  - **Hadronisation**: where b and bbar (or c and cbar) combine to give quarkonia. The b-bbar (or c-cbar) here can then further come from one of the following processes
    - Hard process
      - Pair production
      - Flavour excitation
    - MPI
      - Pair Production
      - Flavour excitation
    - Hard & MPI
    - Shower

- Examples of most of these processes are on next slide

- Currently, Onia production is not available via the shower in Pythia8. This is something that Pythia8 authors are working on.

Upsilon (nS): preliminary results

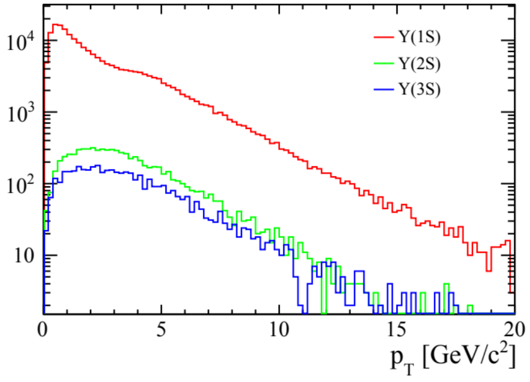
- sample size run ~25M events

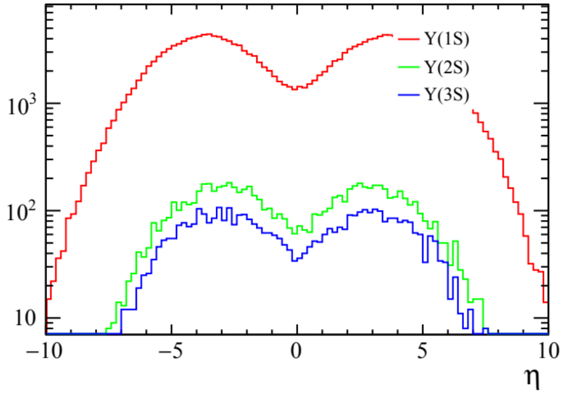
- production mechanism fraction in the table on right

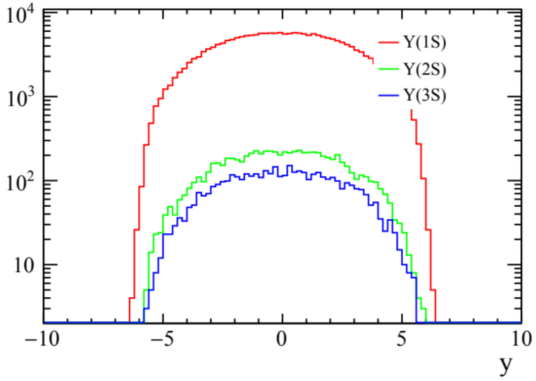
- eta (>2 & <5) cut applied.

	Y(1S)	Y(2S)	Y(3S)
Fraction produced	0.24%	0.01%	0.01%
Direct hard process	8.04%	56.43%	66.30%
Direct MPI	4.11%	27.33%	30.12%
Hard & MPI	-	-	-
Decay process	84.86%	16.24%	3.58%
- Hard	48.13%	10.19%	1.48%
- MPI	36.72%	6.04%	2.10%
- Shower	-	-	-
- Hard & MPI	0.003%	-	-
Hadronisation	2.99%	-	-
- Hard (PP, FE)	1.03%	-	-
- MPI	1.50%	-	-
- Shower	0.26%	-	-
- Hard & MPI	0.20%	-	-

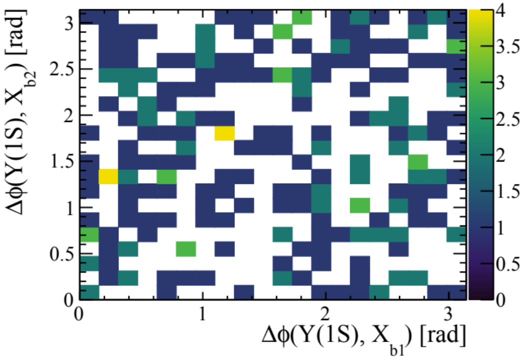
Upsilon(nS) kinematics







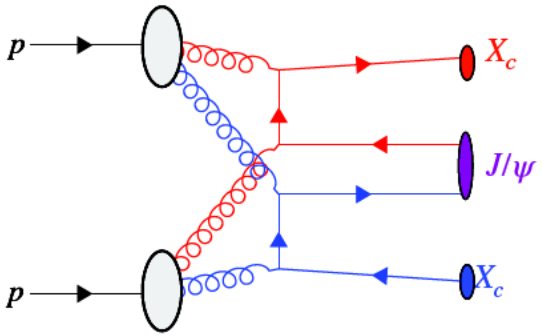
- The pT spectra, pseudo rapidity & rapidity distribution and relative angles in the transverse plane between Y(1S) and X_b hadron
- For ΔΦ the distribution of events in the 2D plane are more uniform as a result of the contributions from many different associated production mechanisms.



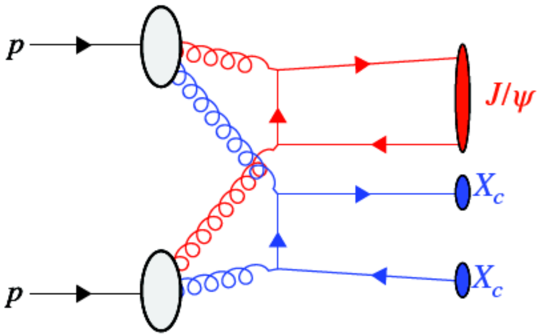
Charmonium studies (ncquark=4)

- Quarkonia can be formed from combinations of different parton interactions ('mixed') or from a single Parton interaction ('separate')

Mixed



Separate



Quarkonia in hard process must always be separate

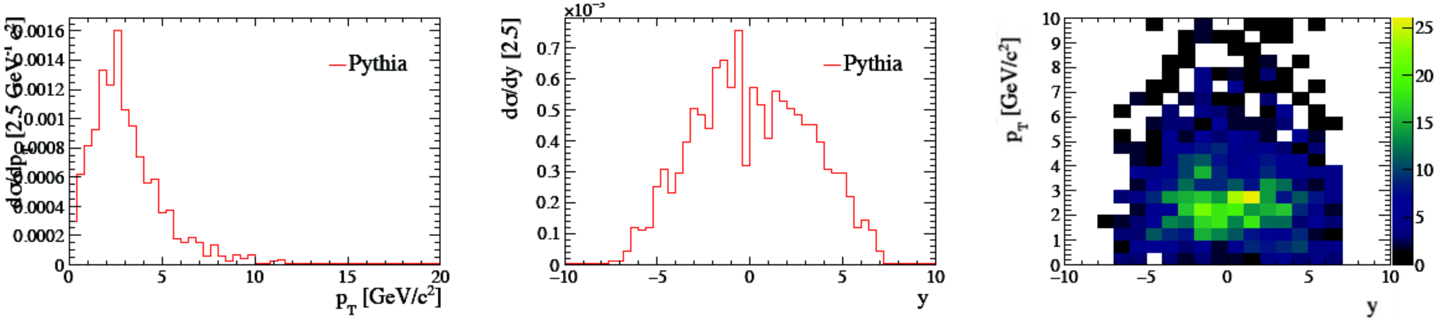
Therefore using quarkonia hard production must miss any contributions from MPI combinations

- For doubly-heavy baryons (Ξ_{cc}^{++} etc.) the diagrams can only be mixed as both quarks are particles or antiparticles

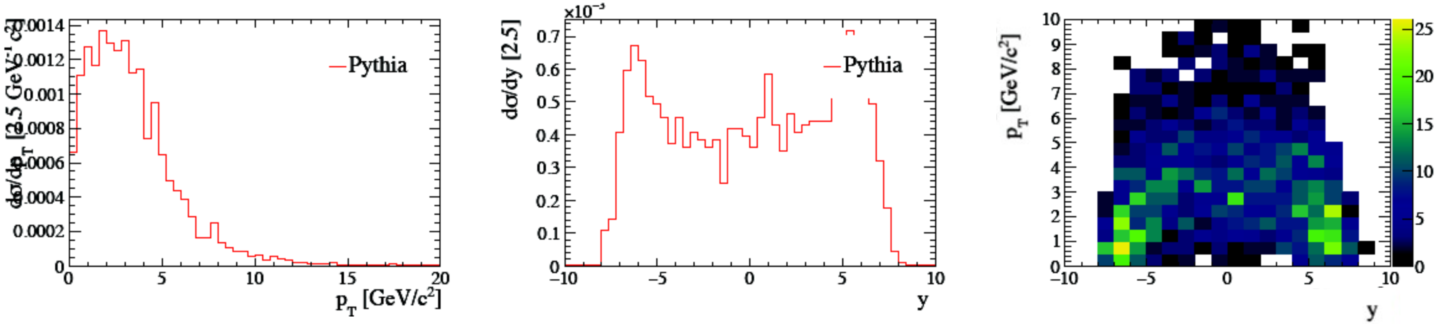
Charmonium kinematics

- Created sample of J/ψ Xc Xc and split up according to origin of the quarks that make up the J/ψ

Separate: $c\bar{c}$ in J/ψ come from the same $c\bar{c}$ pair



Mixed: $c\bar{c}$ in J/ψ come from different $c\bar{c}$ pairs



Work in progress

- writing a phenomenology paper on our studies for doubly heavy hadrons

- Proposing experimental measurements that could help differentiate the doubly-heavy hadron production mechanisms.
  - For example: reconstructing B_c candidates and associated singly-heavy hadrons at LHCb or elsewhere

Testing the role of multiparton interactions in doubly-heavy hadron production

Ulrik Egede, Tom Hadavizadeh, Minni Singla, Peter Skands

November 2021

Abstract

Abstract goes here.

1 Introduction

- Outline the what we're studying
  - What are doubly-heavy hadrons
  - Why do we want to study them
- How doubly heavy hadrons are currently simulated
  - Describe BcVegPy, GenXicc, Pythia (+others?)
  - Describe why the simulation can be slow, hence the need for dedicated generators
  - Outline assumptions made in stand-alone generators, i.e. single parton interaction
- Some sort of literature summary of B_c^+ production mechanisms [?].

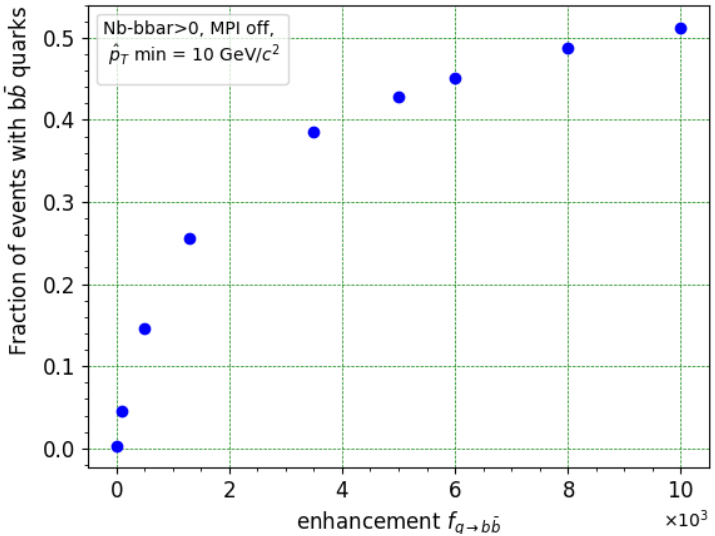
Unprecedented samples of doubly-heavy hadrons have been collected at the Large Hadron Collider and, through a study of their production mechanisms, pose a unique laboratory to examine the role of multi-parton interactions (MPIs) in hadron formation. Unlike singly-heavy hadrons, in which the heavy quark can hadronise with a light quark at lower hadronisation energy scales, the quarks in doubly-heavy hadrons are too massive to be produced this way at a significant rate and the hadrons must instead form from the coalescence of two heavy quarks produced at higher energy scales.

Samples of doubly-heavy hadrons can be simulated using Monte Carlo event generators such as Pythia [cite]. However, as these particles require the chance coalescence of two heavy particles into a bound state, their generation can be slow. Currently doubly-heavy mesons can be generated using dedicated generators, such as BcVegPy [cite] or GenXicc [cite], that perform fixed-order matrix-element calculations. These processes are then interfaced with event generators to simulate the rest of the event evolution and hadronisation.

1

b enhancements

- We are looking to enhance the g→b bbar and g→c cbar splittings in an unbiased way that can enhance production of the final state that we want
- We are considering changes to the core Pythia8 code for this as well.



Future Plans

- We also intend to study “Unbiased forced hadronisation” as a more efficient way to replace the current SignalRepeatedHadronisation at LHCb.

- for straight forward simulation of rarely produced b-baryons such as Ξ_b, Ω_b

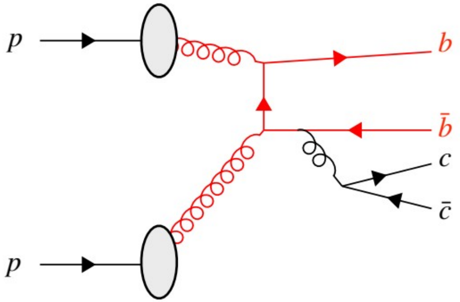
- New Monash-Warwick PhD student, **Eliot Walton**, will work on similar studies

in near future.

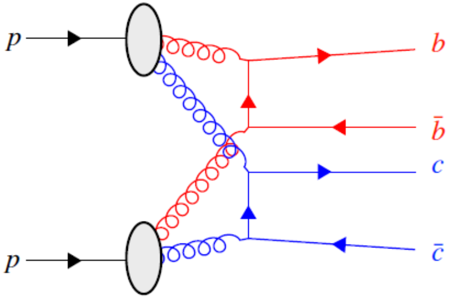
Thank you for your attention!

Back up

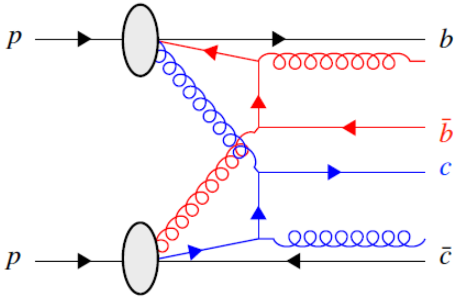
A few examples of Double-heavy hadrons production in pp collision



Pair Production & gluon splitting

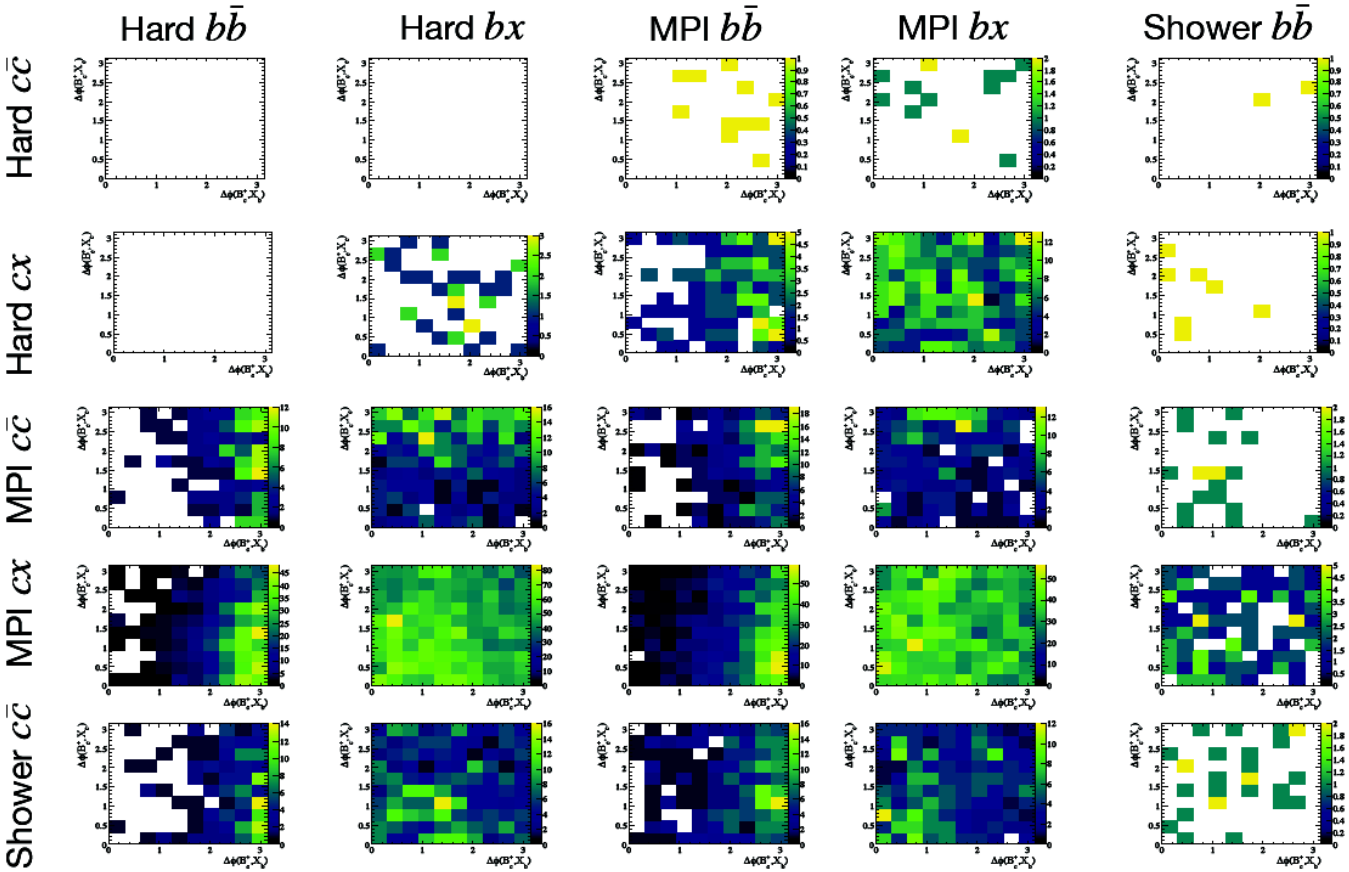


Double Pair Production



Double Flavor excitation

Double-heavy hadrons production in Pythia8 cont..



Upsilon Ancestors (a few examples)

*************Upsilon 3S Ancestors*************

no.	mom1	mom2	type	name	code	type
227	65		recoil	(Upsilon(3S))	-62	beam remnant
65	5		recoil	(Upsilon(3S))	-44	ISR
5	3	4	two mothers	(Upsilon(3S))	-23	hardest particles
3	62		normal	(g)	-21	hardest particles
4	63		normal	(g)	-21	hardest particles
62	70		normal	(s)	-41	ISR
63	226		recoil	(g)	-41	ISR
70	225		recoil	(s)	-41	ISR
226	2		normal	(g)	-61	beam remnant
225	1		normal	(s)	-61	beam remnant
2	0		system	(p+)	-12	beam particles
1	0		system	(p+)	-12	beam particles

Direct Hard process

*************Upsilon 1S Ancestors*************

no.	mom1	mom2	type	name	code	type
144	89		normal	(Upsilon)	-91	decay process
89	5		recoil	(Upsilon[3S1(8)])	-62	beam remnant
5	3	4	two mothers	(Upsilon[3S1(8)])	-23	hardest particles
3	87		recoil	(g)	-21	hardest particles
4	19		normal	(g)	-21	hardest particles
87	1		normal	(g)	-61	beam remnant
19	88		recoil	(g)	-41	ISR
1	0		system	(p+)	-12	beam particles
88	2		normal	(g)	-61	beam remnant
2	0		system	(p+)	-12	beam particles

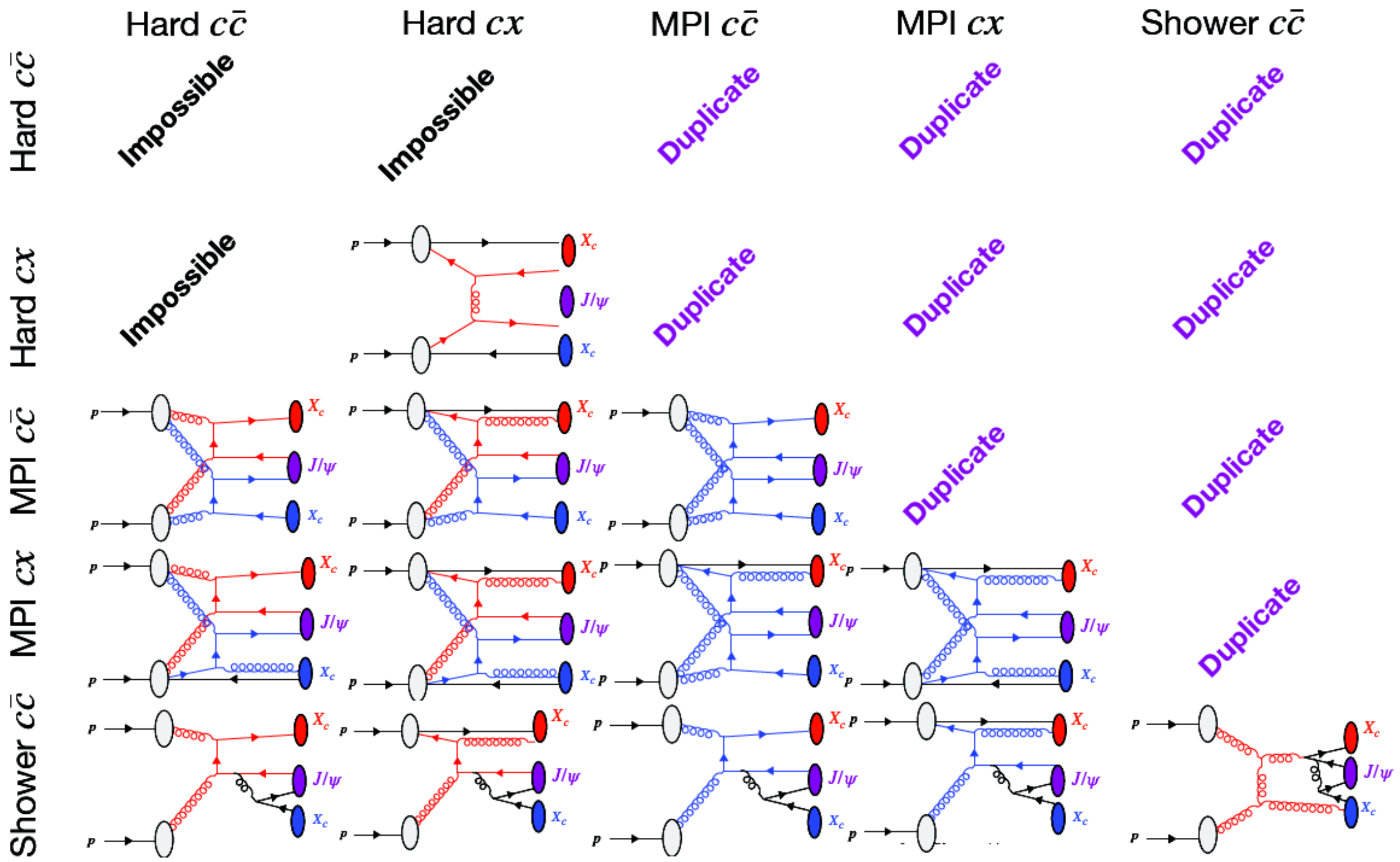
Decay: hard process

*************Upsilon1S Ancestors*************

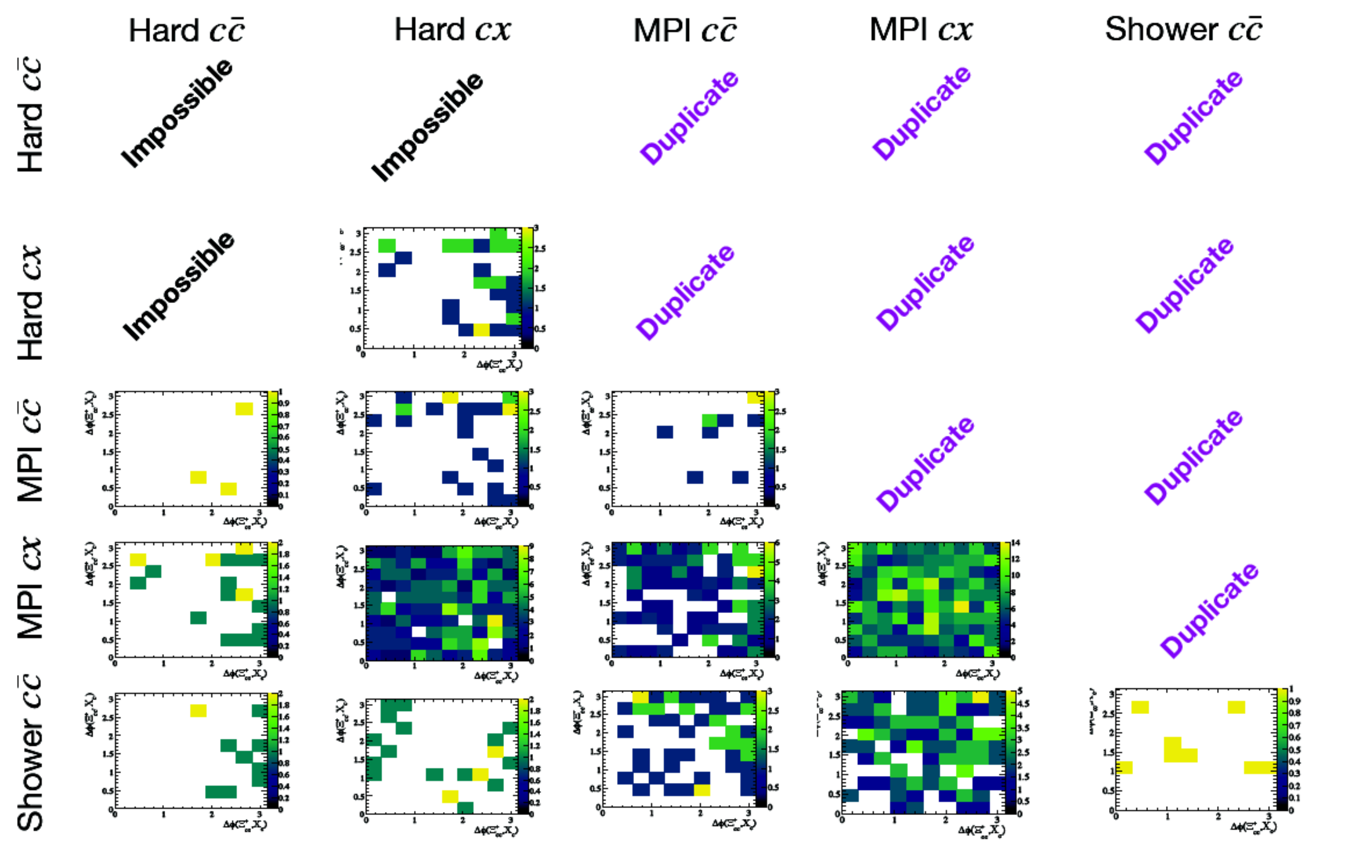
no.	mom1	mom2	type	name	code	type
80	78	79	two mothers	(Upsilon)	-81	hadronisation hadron
78	74		recoil	(b)	-71	hadronisation partons
79	51		recoil	(bbar)	-71	hadronisation partons
74	33		recoil	(b)	-62	beam remnant
51	42		recoil	(bbar)	-62	beam remnant
33	30	31	two mothers	(b)	-33	subprocess
42	29		normal	(bbar)	-43	ISR
30	71		recoil	(g)	-31	subprocess
31	72		recoil	(b)	-31	subprocess
29	10		normal	(bbar)	-43	ISR
71	1		normal	(g)	-61	beam remnant
72	2		normal	(b)	-61	beam remnant
10	7	8	two mothers	(bbar)	-33	subprocess
1	0		system	(p+)	-12	beam particles
2	0		system	(p+)	-12	beam particles
7	48		recoil	(g)	-31	subprocess
8	27		normal	(bbar)	-31	subprocess
48	1		normal	(g)	-61	beam remnant
27	40		normal	(bbar)	-41	ISR
1	0		system	(p+)	-12	beam particles
40	49		recoil	(bbar)	-41	ISR
49	2		normal	(bbar)	-61	beam remnant
2	0		system	(p+)	-12	beam particles

Hadronisation: MPI process

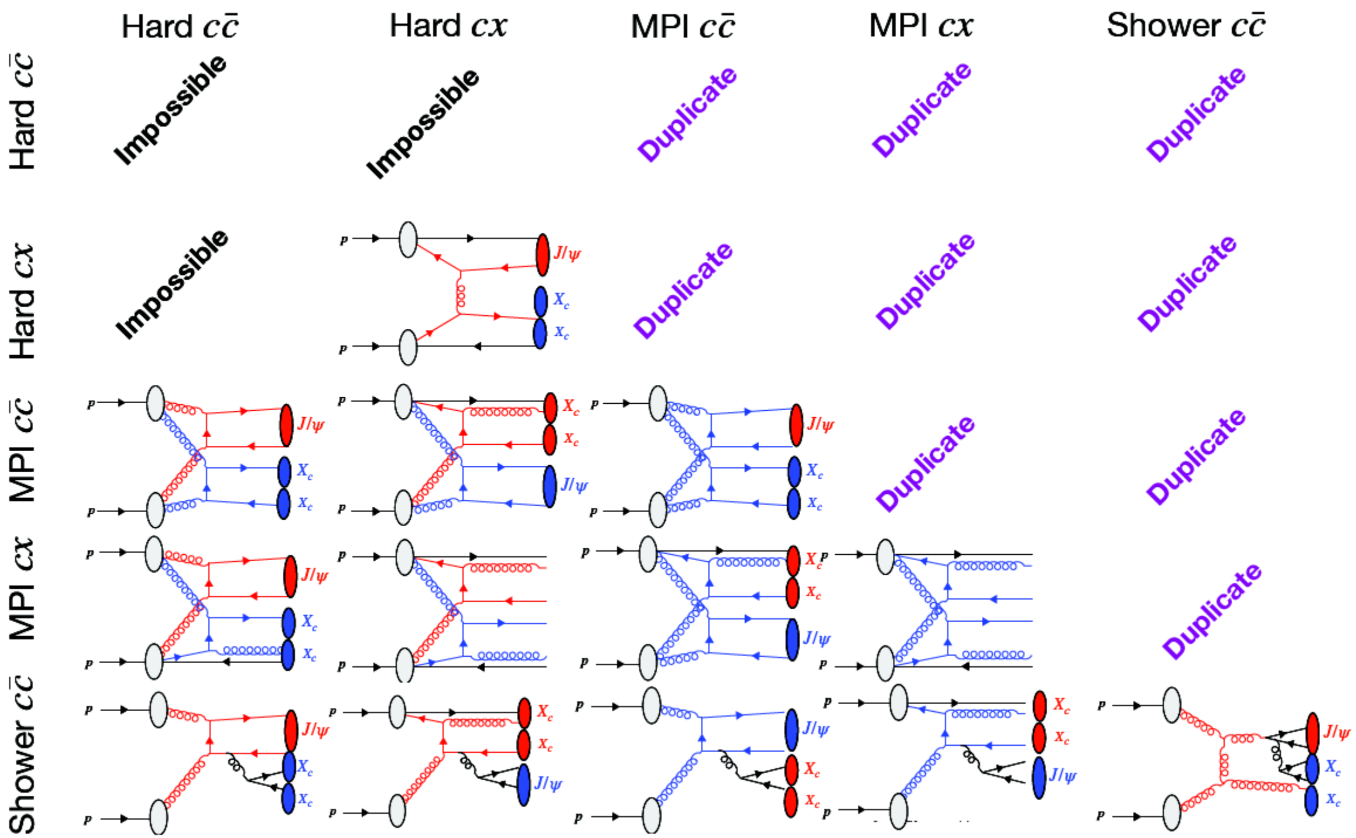
Quarkonia (mixed)



Quarkonia (mixed)



Quarkonia (separate)



Quarkonia (separate)