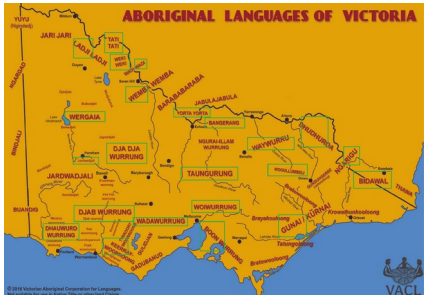
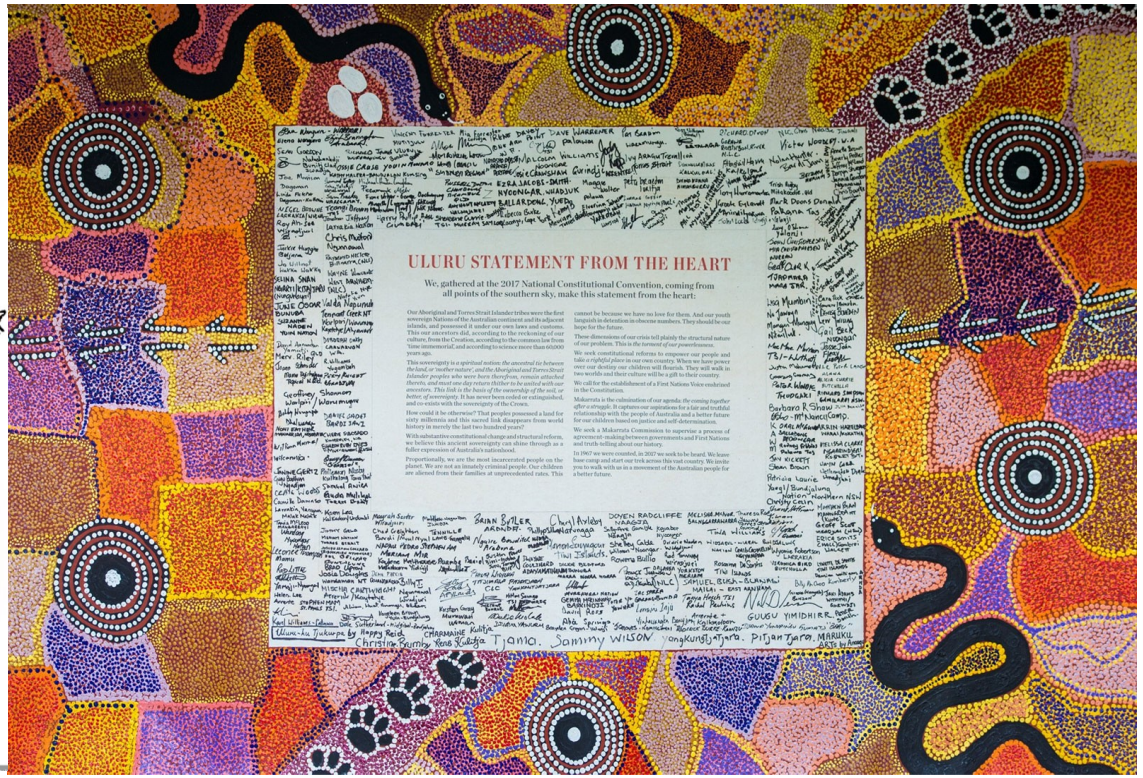
Acknowledgment of Country





[Cartoon from Simon Kneebone](#) [Uluru Statement from the Heart](#) [Treaty in Victoria](#) [First Peoples' Assembly](#)

Measuring Multi-Parton Interactions (MPI) with the LHCb Detector

Eliot Walton (she/her)

Monash Warwick Alliance Particle Physics Meeting 15 March 2023

Supervised by Ulrik Egede in collaboration with Tom Hadavizdeh and Matt Durham

Multi-Parton Interactions (MPI)

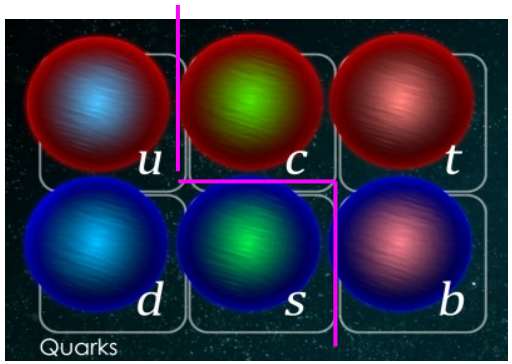
Multi-Parton Interactions are a ubiquitous feature of hadron collisions.

Hadrons are composite objects containing, valence quarks, sea quarks and gluons.

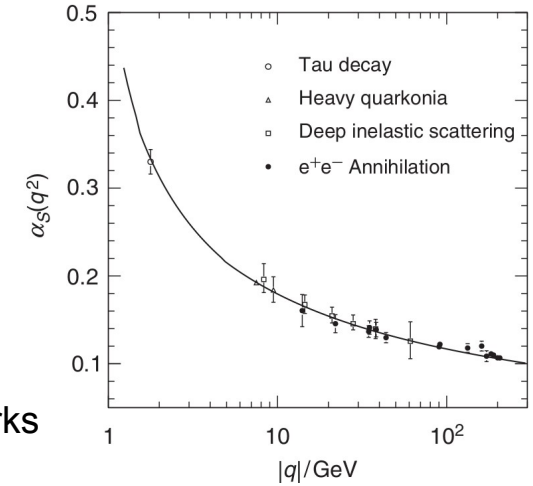
Any one of these may interact in a collision, there is nothing which prohibits more than one parton interacting.

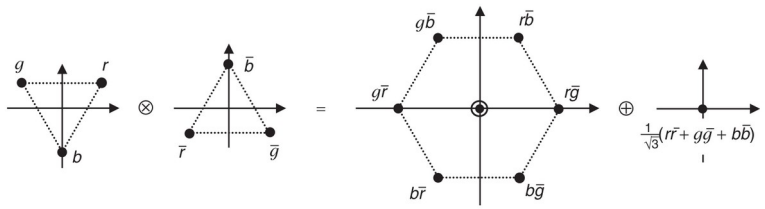
Often these interactions are low energy and therefore non-perturbative

Modeled using a combination pQCD such as parton-showers and semi-emprical models; folded into the generic “underlying event”.



Light Quarks Heavy Quarks

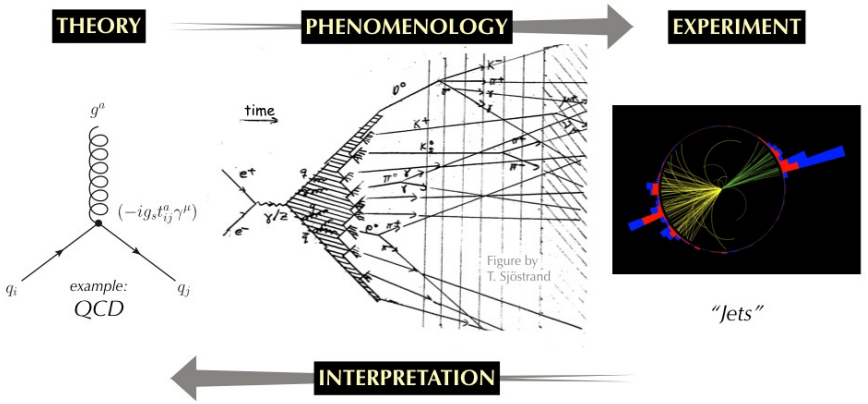




The Leading Colour Limit

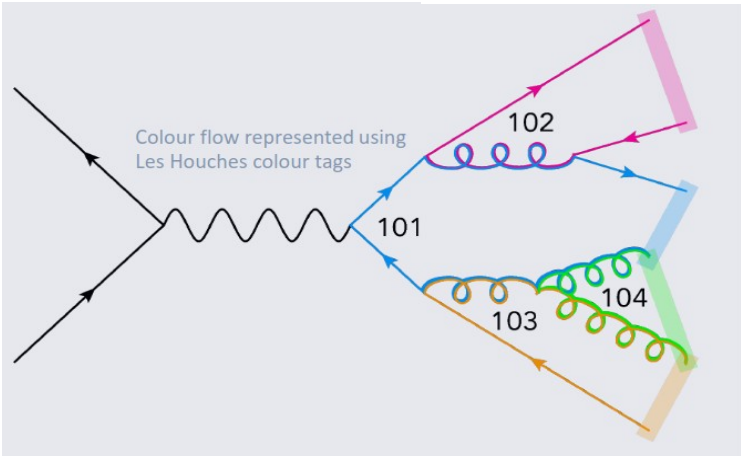
Monte Carlo (MC) event generators are the engines of theoretical particle physics

- "Virtual" colliders which recreate collisions to make predictions
- Use pQCD where possible models otherwise
- All models are wrong but some are useful



Starting point for all MC event generators is the Leading Colour (LC) limit: $N_c \to \infty$

- Each colour is unique and matched to its anti-colour
- Expect corrections to be suppressed by $1/N_c^2 \sim 10\%$



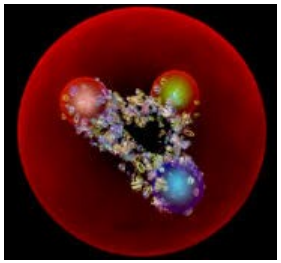
Colour Reconnection (CR)

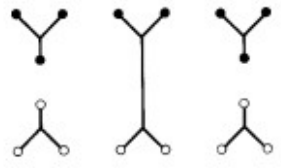
Colour Reconnections are a method to stochastically restore colour corrolations.

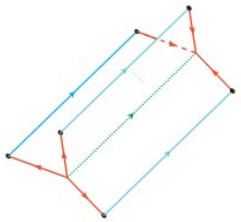
Approximates LC-partons as uncorrolated and uses SU(3) rules

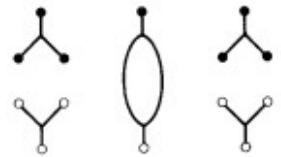
- $3 \otimes 3 = 8 \oplus 1$ anti-colour colour connections (gives dipole CR)

- $3 \otimes 3 = 6 \oplus 3$ colour-colour connections (gives junctions)

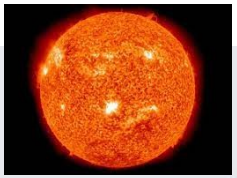


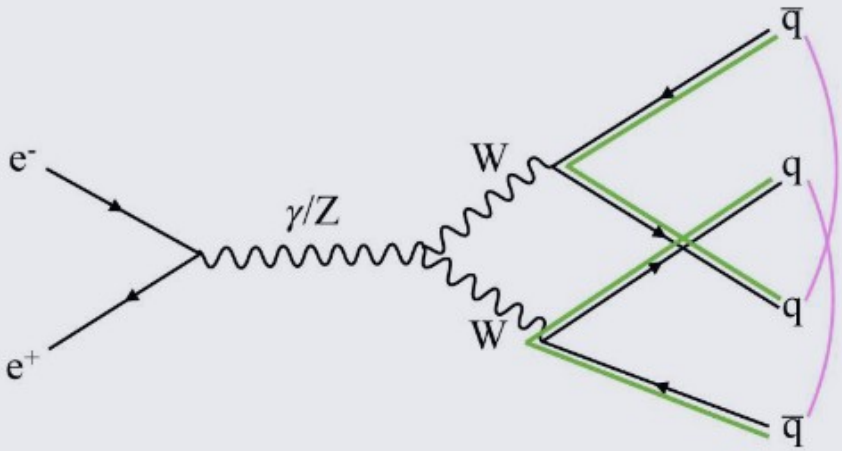






See Javira Altmann's talk here (last MWAPP meeting).





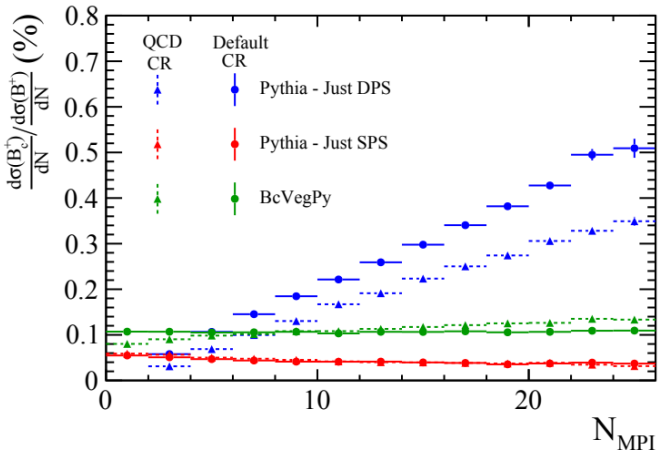
The Measurement $B_c^{\pm}$ / $B^{\pm}$ vs Multiplicity

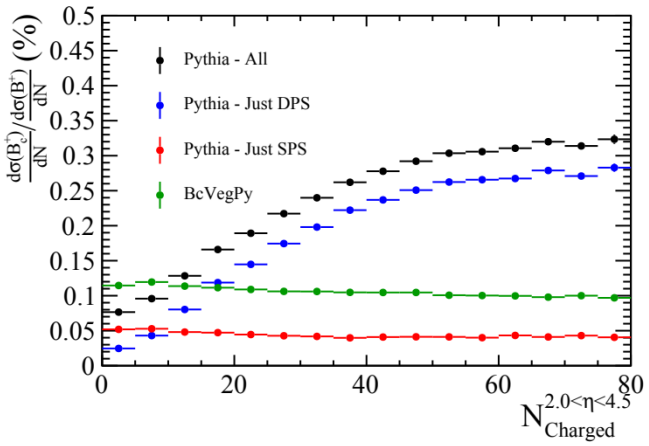
$B_c^{\pm}$ meson composed of a *b* quark and a *c* quark

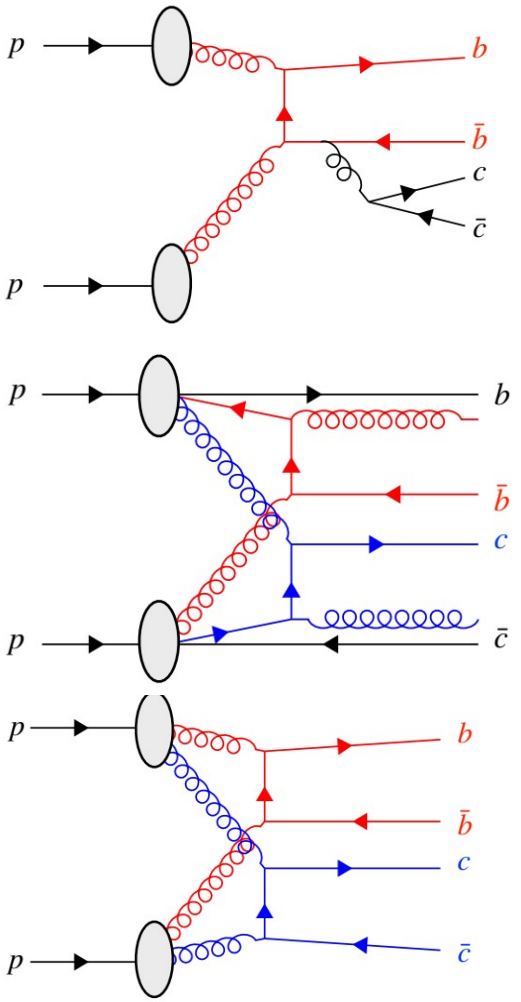
Production of a *cc* in *bb* fragmentation is heavily suppressed due to the *c* mass

Therefore formation of the $B_c^{\pm}$ should be sensitive to different formation and hadronisation mechanisms compared to the $B^{\pm}$

The particular formation mechanism probed using MC event generators is Double Parton Scattering (DPS) [https://arxiv.org/abs/2205.15681]



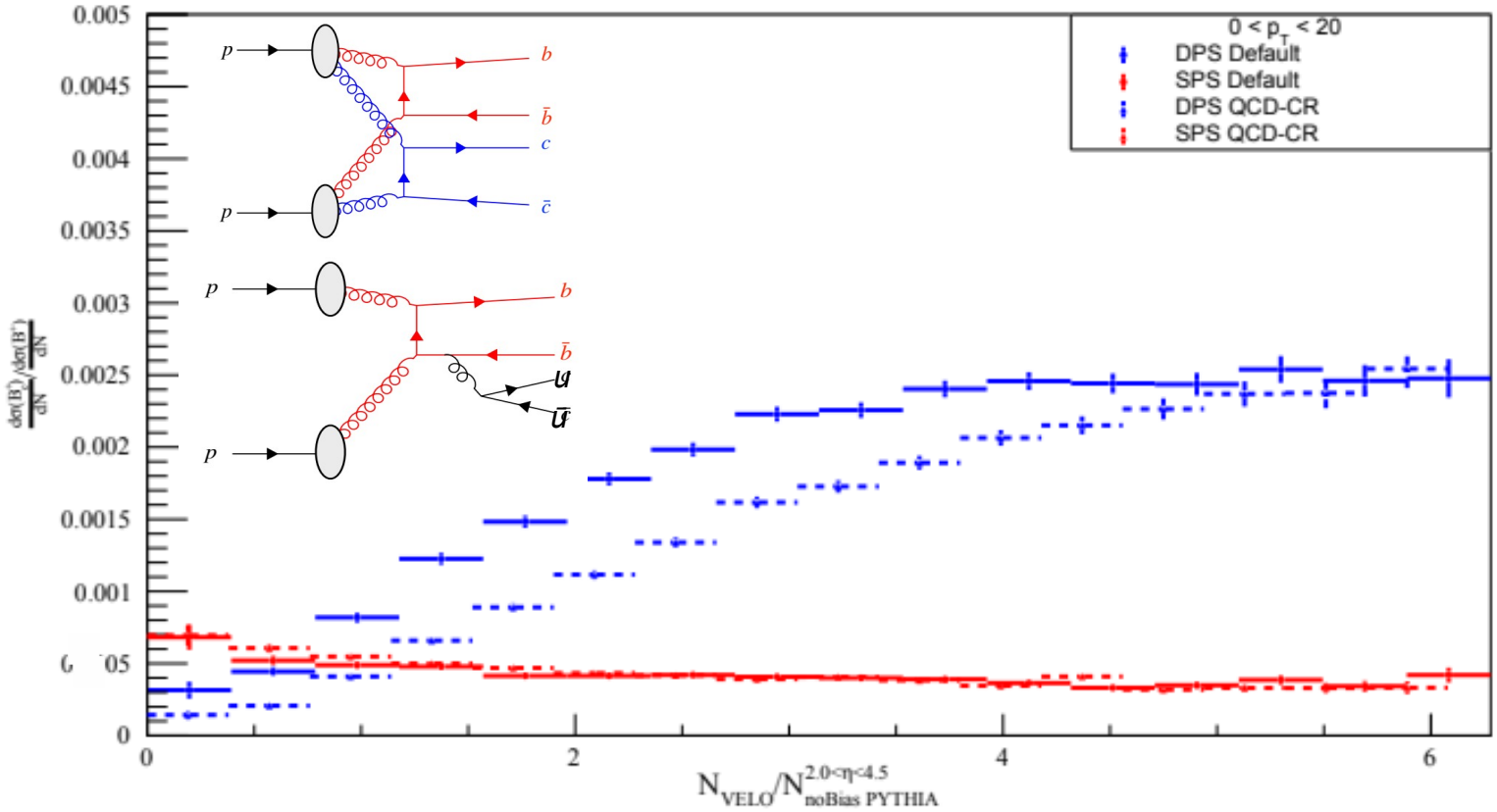




Sensitivity of $B_c^{\pm}$ / $B^{\pm}$ Slope to CR

Measurement of the $B_c^{\pm}$ cross section is sensitive to Colour Reconnection model

- more gentle slope with SU(3) CR : requires the b and c quark to be in a colour singlet ?



Event Selection

Stripping Line:

- FullDSTDiMuonJpsi2MuMuDetachedLine

Pions:

- TRCHI2DOF < 3
- PT > 1000*MeV
- P > 3000*MeV

J/psi:

- ADMASS('J/psi(1S)') < 50*MeV
- PT > 500*MeV

Bc:

- (ADOCA(1,2)<0.5*mm)
- in_range(5.0 GeV < M < 6.5 GeV)
- VFASPF(VCHI2/VDOF)<5

Comments:

- Selection is deliberately loose
- no PID variables used in the selection so that the same event selection can be used for:

$B_c^{\pm} \rightarrow J/\psi\, \pi^{\pm}$ and $B^{\pm} \rightarrow J/\psi\, K^{\pm}$

Comments:

- the $B^{\pm} \rightarrow J/\psi\, K^{\pm}$ mode is used in preference to the $B^{\pm} \rightarrow J/\psi\, \pi^{\pm}$ mode because of CKM suppression
- unlike standard multiplicity analyses nPV not restricted to 1.
- Use BDT for second stage of selection.

Measurement in Progress

Expect the measurement to be published by September

- 3 months to finish the work (April - May)
- 3 months for internal review (July – August)
- 1 month for journal review (August - September)

References

[1]. Acknowledgment of Country. Sources:

Cartoon from Simon Kneebone Uluru Statement from the Heart Treaty in Victoria First Peoples' Assembly

[2]. "Visual Representation of SU(3)" from M. Thomson, *Modern Particle Physics*, Cambridge University Press, 2013

[3]. "Particles of the Standard Model of particle physics". Image: Daniel Dominguez/CERN. https://home.cern/science/physics/standard-model Accessed 13/2/2023.

[4]. "World average of α_s" from M. Thomson, *Modern Particle Physics*, Cambridge University Press, 2013

[5]. "Sketch of Particle Phenomenology", figure by T. Sjöstrand, reproduced from P. Skands. https://skands.physics.monash.edu/research/ Accessed 13/2/2023.

[6]. J. Altmann "The Leading Colour Limit" and "Colour Reconnection Topologies" from *Production of heavy flavour baryons in event generators (specifically Pythia)*, presented on 25/10/2022. https://indico.cern.ch/event/1213707/contributions/5106685/attachments/2534610/4361806/Heavy%20baryon%20production.pdf

[7]. "Proton animation", ID: CERN-FOOTAGE-2015-005-001 created on 2015-02-13 https://home.cern/tags/animation. Accessed 13/2/2023.

References

[8]. G.C. Rossi, *A unified QCD-string description of ordinary hadrons and multi-quark states* presented on 13/12/2022. https://indico.cern.ch/event/1184070/.

[9]. ThomasVogel. “Waterdrop. Water Drop Leaf Environmental Conservation Balance Green Nature stock photo”. Accessed 13/2/2023. https://www.istockphoto.com/photo/waterdrop-water-drop-leaf-environmental-conservation-balance-green-nature-gm157429894-10083565

.

[10]. NASA/SDO/AIA, “Sun Blasts a M6.6 Flare”, from *National Geographic.* https://education.nationalgeographic.org/resource/sun. Accessed 13/2/2023.

[11]. U. Egede *et al*., The role of multi-parton interactions in doubly-heavy hadron production, 2022. doi: 10.48550/ARXIV.2205.15681.

[12]. annief, “shh” posted by taloringer. https://cheezburger.com/9088389376. Accessed 13/2/2023.

[13]. C. Ratti, F. Geurts, R. Rapp and R. Bellwied, “Banner” in *Quark Matter 2023.* *https://indico.cern.ch/event/1139644/*. Accessed 13/2/2023.

Back Up: Possible Trigger List

Possible trigger list courtesy of Dr Tom Hadavizdeh

Trigger line	2011 and 2012	2016	2017 and 2018
L0MuonDecision_TOS	✓	✓	✓
L0DiMuonDecision_TOS	✓	✓	✓
Hlt1TrackMuonDecision_TOS	✓	✓	✓
Hlt1TrackAllL0Decision_TOS	✓		
Hlt1TrackMVADecision_TOS		✓	✓
Hlt1TwoTrackMVADecision_TOS		✓	✓
Hlt2Topo{2,3,4}BodyDecision_TOS		✓	✓
Hlt2TopoMu{2,3,4}BodyDecision_TOS		✓	✓
Hlt2Topo{2,3,4}BodyBBDTDecision_TOS	✓		
Hlt2TopoMu{2,3,4}BodyBBDTDecision_TOS	✓		
Hlt2SingleMuonDecision_TOS	✓		
Hlt2DiMuonDetachedDecision_TOS	✓		✓

Table 4: Trigger lines required in different data taking periods. For each trigger level the requirement is the logical OR of the listed lines.