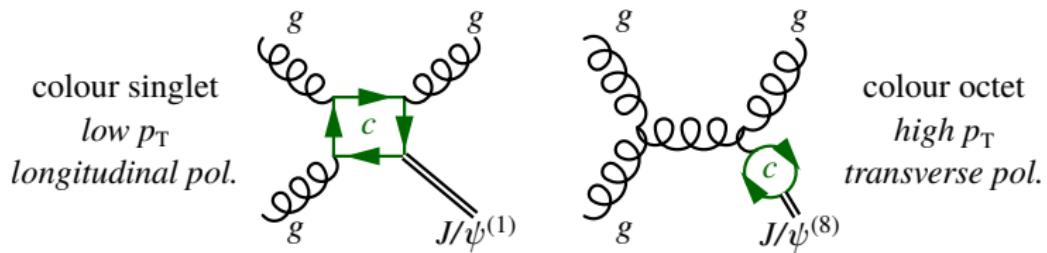


# Fragmentation of jets containing $J/\psi$ mesons in LHCb



Naomi Cooke on behalf of the LHCb collaboration

University of Birmingham  
LHC-EW WG: Jets and EW bosons

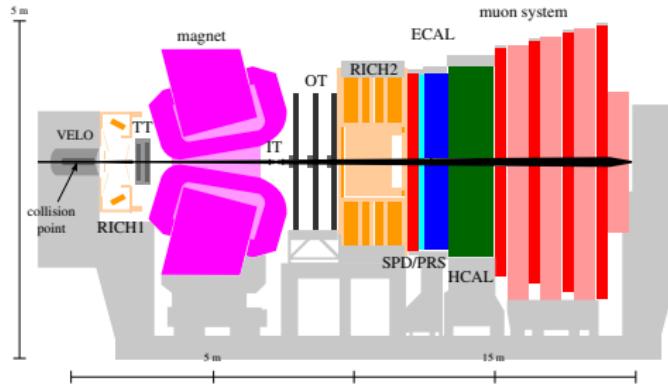
October 17, 2022

Today I will discuss:

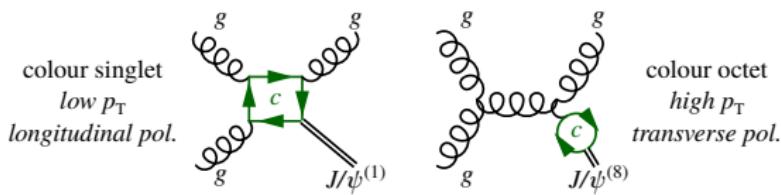
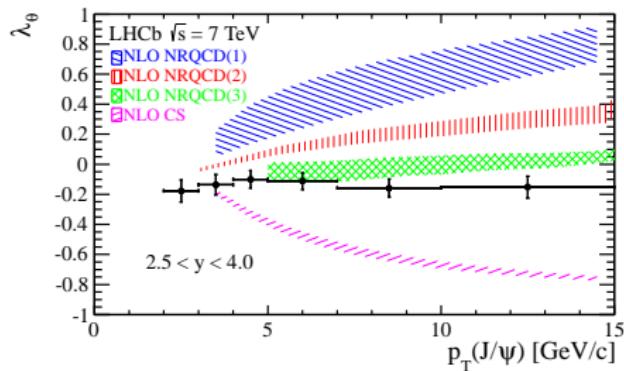
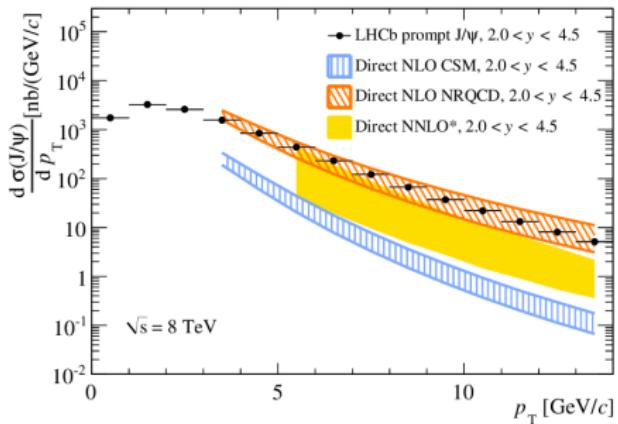
- Study of  $J/\psi$  production in jets
- Future measurements by LHCb
- Fragmentation contributions to Quarkonia production in Pythia 8

Why LHCb?:

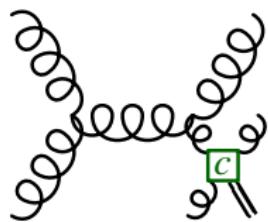
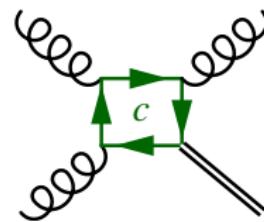
- Very good PID: Hadrons (RICH), di-muon masses (MUON)
- Probe unique phase space due to forward region
- Trigger: probe low momentum particles



- Hard production Non-Relativistic QCD (NRQCD) predicts:
  - Differential production cross section consistent with measurement.
  - $J/\psi$  produced largely isolated [JHEP 10 (2015) 172].
  - Large transverse polarisation [Eur. Phys. J. C 73, 2631 (2013)].



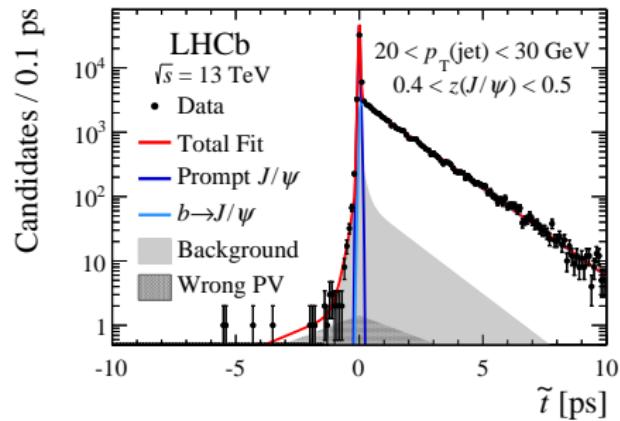
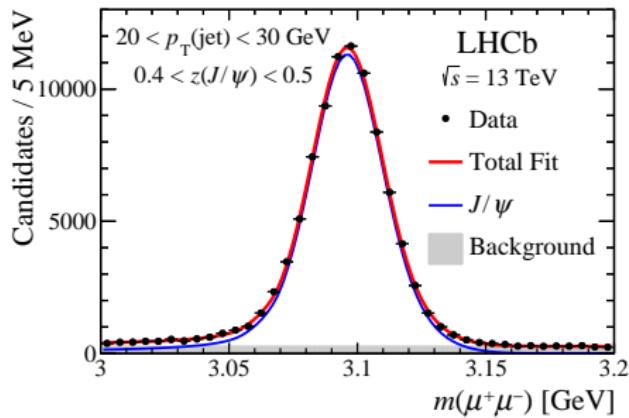
- Shower production analytic resummation NRQCD predicts:
  - Lack of polarisation.
  - $J/\psi$  rarely produced in isolation.
- Two quarkonia production mechanisms distinguishable by studying radiation associated with them  $\rightarrow$  jets.
- Instead of measuring cross section wrt  $p_T(J/\psi)$ , take into account surrounding radiation with  $z(J/\psi) \equiv p_T(J/\psi)/p_T(\text{jet})$ .


$$z < 1$$

$$z \approx 1$$

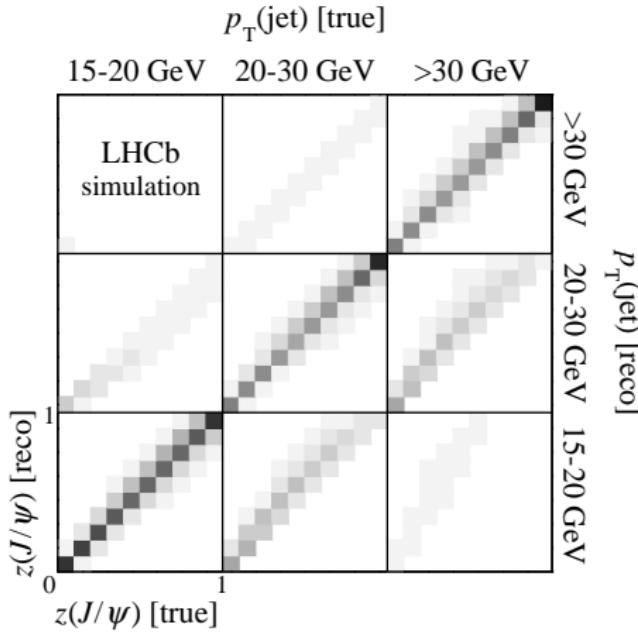
# Analysis procedure

Procedure [Phys. Rev. Lett. 118, 192001 (2017)]:

- Build  $J/\psi \rightarrow \mu^+\mu^-$  candidates in jets.
- Determine  $J/\psi$  signal yield with mass fits.
- Separate prompt (direct) from displaced (i.e. b decay) yields with pseudo-lifetime fits,  $t \equiv x_z - x_z(\text{PV})m_{J/\psi}/p_z$ .
- Efficiency corrected + Bayesian unfolded for jet energy resolution.

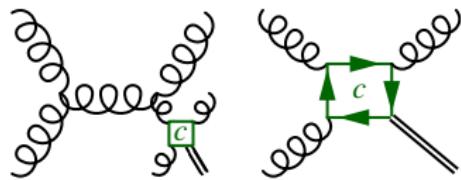
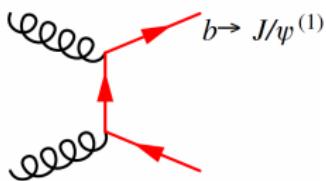
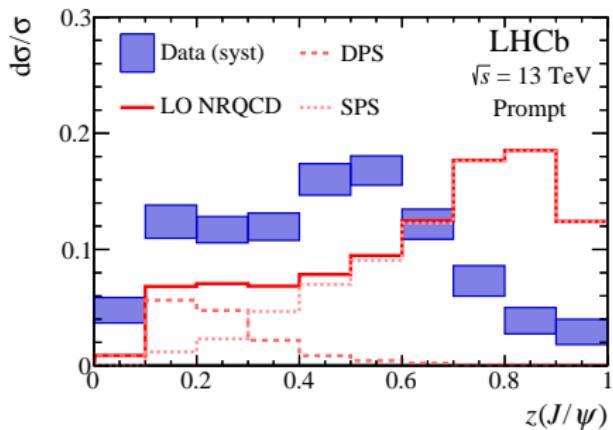
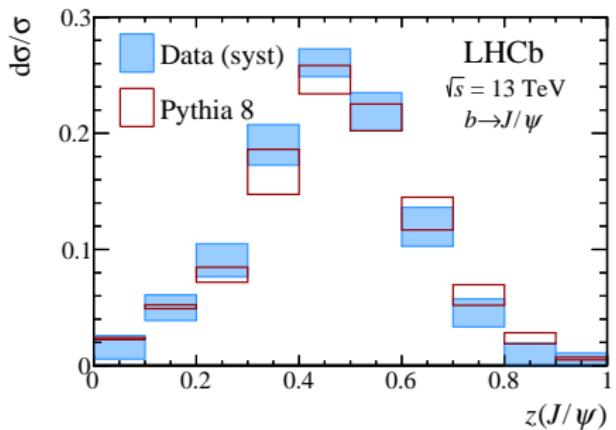


- Distributions are efficiency corrected.
- Unfolding  $p_T(\text{jet})$  from reconstruction to truth level is done to correct for jet energy resolution effects [Phys. Rev. Lett. 118, 192001 (2017)].

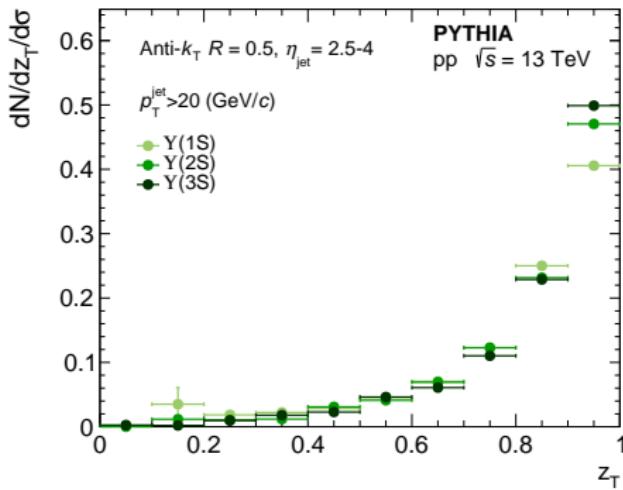
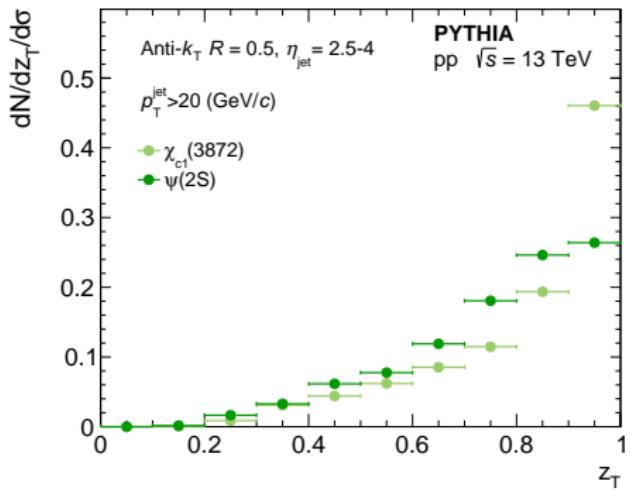


# $z(J/\psi)$ distributions

Measure  $d\sigma/\sigma$  versus  $z(J/\psi) \equiv p_T(J/\psi)/p_T(\text{jet})$ , to probe DPS. Prompt (direct from PV) and displaced (i.e. b decay) distributions measured [Phys. Rev. Lett. 118, 192001 (2017)].

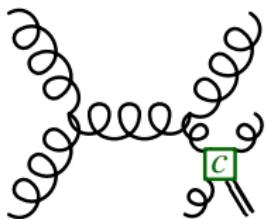


- Analyses for  $\psi(2S)$ ,  $\Upsilon(1S)$ ,  $\Upsilon(2S)$ ,  $\Upsilon(3S)$  and  $X(3872)$  are in progress.
- Predictions for the  $z$  distributions are shown below, where  $\Upsilon$ 's are predicted to be more isolated than  $\psi(2S)$  and  $X(3872)$ .

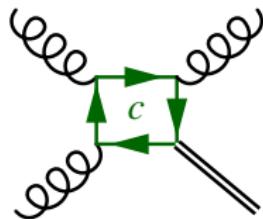


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- At the moment,  $J/\psi$ 's are only produced directly in the hard process, or in particle decays.



Shower production



Hard production

- Hence can incorporate quarkonia production within the parton shower!
- These splittings are being included into Pythia 8:

- $c \rightarrow \eta_c^{(1)} c$
- $g \rightarrow \eta_c^{(1)} g$
- $c \rightarrow \psi(nS)^{(1)} c, n = 1,2$
- $c \rightarrow \chi_{ci}^{(1)} c, i = 0,1,2$

- $g \rightarrow \chi_{ci}^{(1)} g, i = 0,1,2$
- $g \rightarrow \psi(nS)^{(8)}, n = 1,2$
- $g \rightarrow \psi(nS)^{(1)} gg, n = 1,2$

Study of  $J/\psi$  production in jets [[Phys. Rev. Lett. 118, 192001 \(2017\)](#)]:

- Displaced  $z(J/\psi)$  distribution described by PYTHIA8 predictions.
- Prompt  $z(J/\psi)$  distribution is less isolated than PYTHIA8 prediction.

Future analysis prospects:

- Analyses for  $\psi(2S)$ ,  $\Upsilon(1S)$ ,  $\Upsilon(2S)$ ,  $\Upsilon(3S)$  and  $X(3872)$  to be published soon.

Pythia 8 Simulation:

- New quarkonia splittings will be incorporated into the Pythia 8 parton shower.