

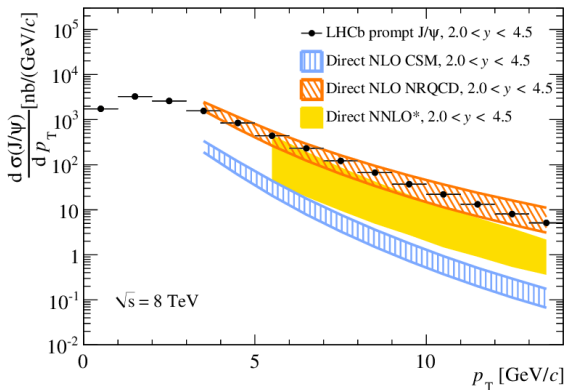
Quarkonia Showers in PYTHIA8



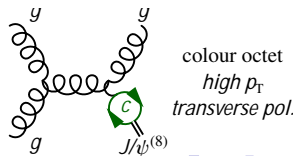
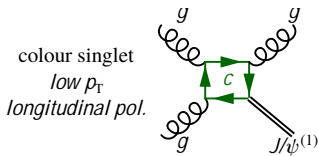
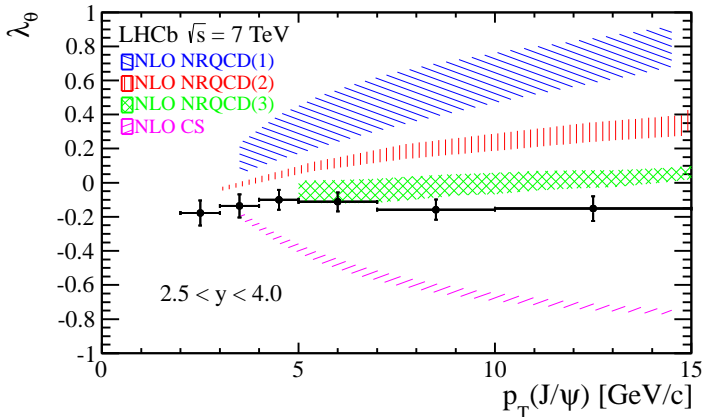
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University of Birmingham
IOP HEPP & APP Annual Conference 2022

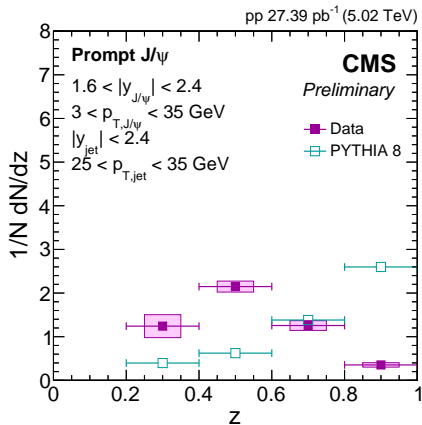
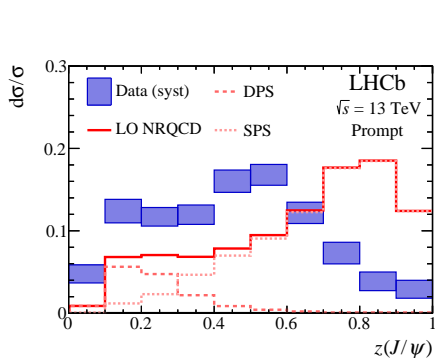
April 5th, 2022



- **Hard production Non-Relativistic QCD (NRQCD) predicts:**
 - Differential production cross section consistent with measurement.
 - J/ψ produced largely isolated.
 - Large transverse polarisation, minimal observed.

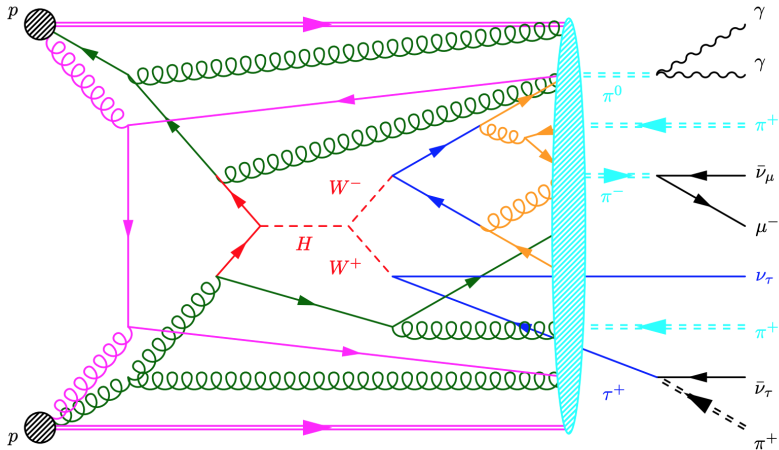


Instead of measuring the differential production cross section wrt $p_T(J/\psi)$, take into account surrounding radiation with $z \equiv p_T(J/\psi)/p_T(\text{jet})$.



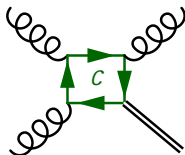
How does an MC generator work?

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

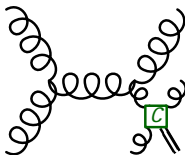


Courtesy of P. Ilten.

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



- Shower production** analytic resummation NRQCD predicts:
 - Lack of polarisation.
 - J/ψ rarely produced in isolation.
- Hence can incorporate quarkonia production within the parton shower!



- Aim to implement the following splittings into Pythia8:
 - $c \rightarrow \eta_c^{(1)} c$ (A)
 - $g \rightarrow \eta_c^{(1)} g$
 - $c \rightarrow \psi(nS)^{(1)} c$, $n = 1,2$ (A)
 - $g \rightarrow \psi(nS)^{(1)} gg$, $n = 1,2$ (A)
 - $c \rightarrow \chi_{ci}^{(1)} c$, $i = 0,1,2$
 - $g \rightarrow \chi_{ci}^{(1)} g$, $i = 0,1,2$
 - $g \rightarrow \psi(nS)^{(8)}$, $n = 1,2$ (A)
- Compare output with Ariadne (A) where possible. (Note: change in evolution variable etc.)
- Validate with LHCb and CMS data.

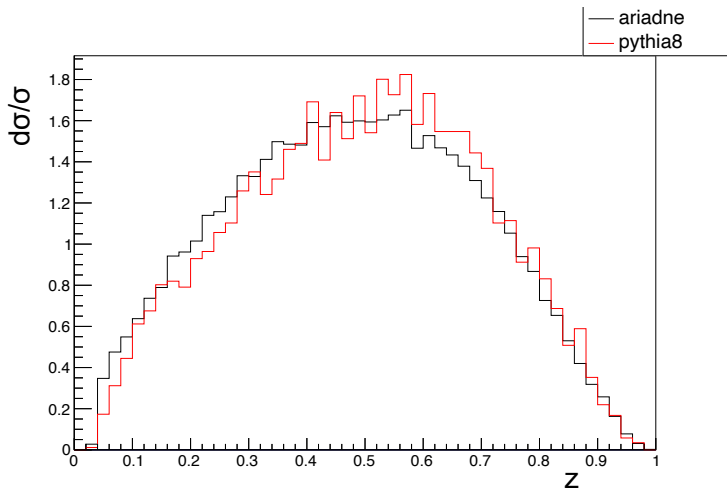
For example $c \rightarrow J/\psi^{(1)}$ c:

$$\frac{8\alpha_s^2 |R(0)|^2}{27\pi m_Q} \int_0^\infty ds \frac{1}{(s - m_Q^2)^4} \int_0^1 dz \theta \left(s - \frac{4m_Q^2}{z} - \frac{m_Q^2}{1-z} \right)$$

$$(s^2 - 2m_Q^2 s - 47m_Q^4) - z(s - m_Q^2)(s - 9m_Q^2) + 4 \frac{z(1-z)}{2-z} s(s - m_Q^2) - 4 \frac{8-7z-5z^2}{2-z} m_Q^2 (s - m_Q^2) + 12 \frac{z^2(1-z)}{(2-z)^2} (s - m_Q^2)^2$$

Need to translate to Pythia8 shower evolution variables, i.e. $\{s, z\} \rightarrow \{p_{T, \text{evol}}^2, z\}$, where $s = \frac{p_{T, \text{evol}}^2}{z(1-z)}$. Also, choose an overestimate to estimate the integral.

Tests produced without ISR and MPI initially. Define $z \equiv p_T(Q)/(s/2)$.

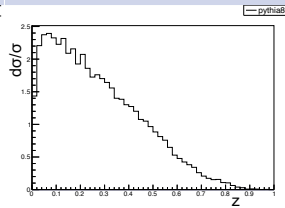
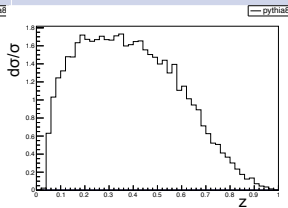
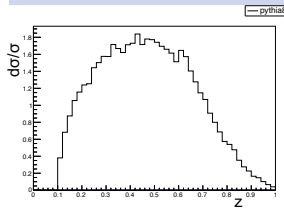


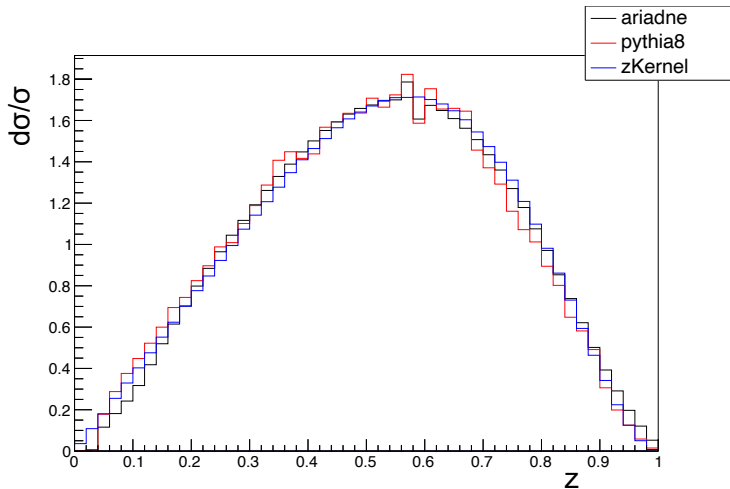
$$g \rightarrow \eta_c^{(1)} g$$

30 GeV

80 GeV

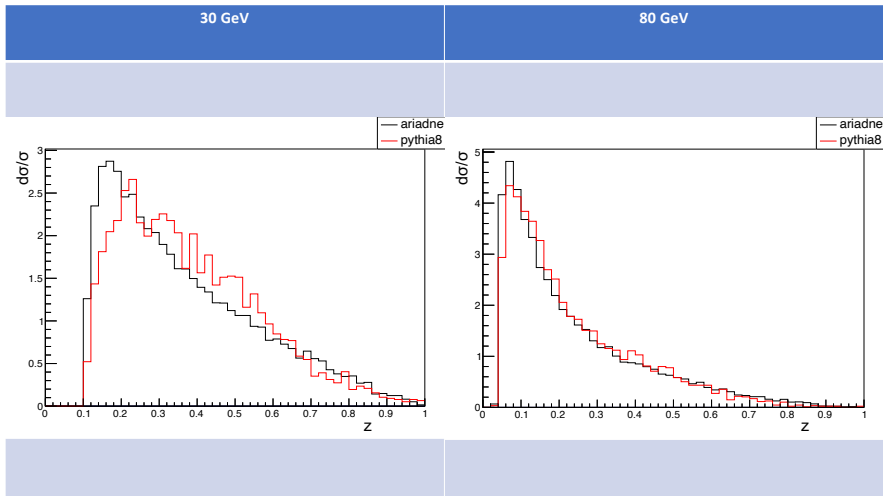
1000 GeV



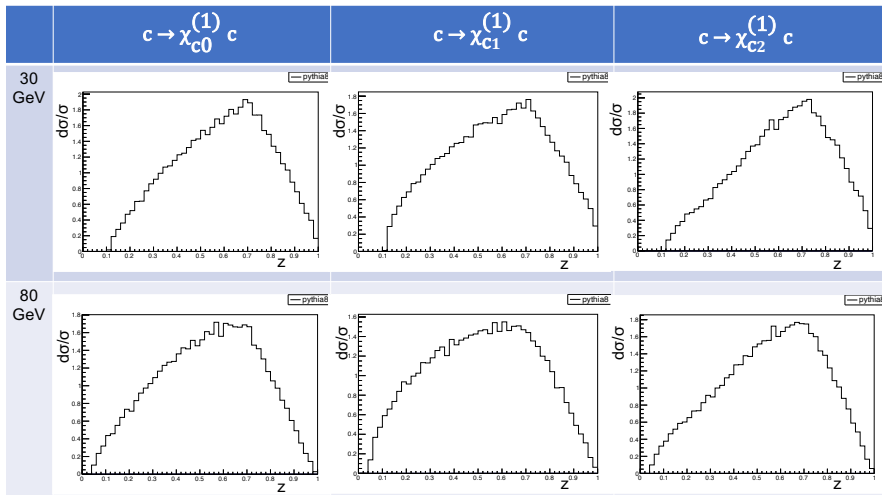


$$g \rightarrow J/\psi^{(1)} gg$$

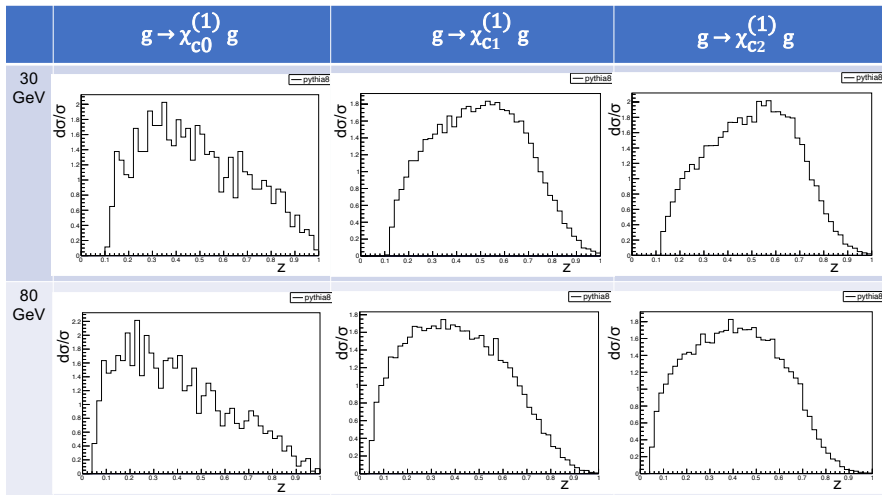
Due to di-gluon mass, translate variables from $\{r,y,z\} \rightarrow \{p_{T,evol}^2, m_{gg}^2, z\}$.



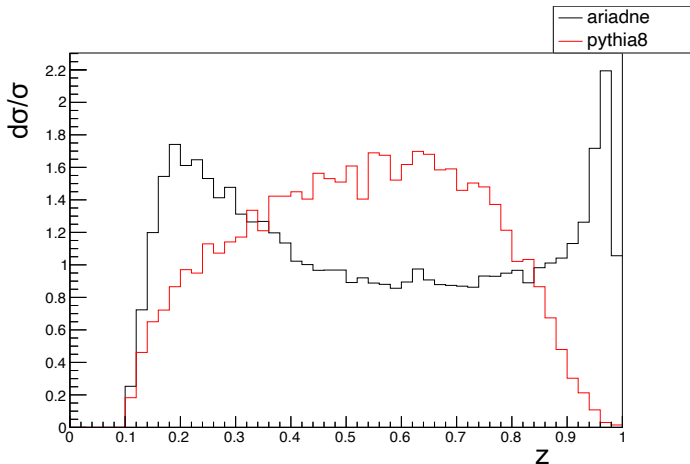
$$c \rightarrow \chi_{c_i}^{(1)} c$$



$$g \rightarrow \chi_{Ci}^{(1)} g$$



$$\frac{\pi \langle 0 | \mathcal{O}_8^\psi(^3S_1) | 0 \rangle}{24m_Q^3} \delta(1-z) \delta\left(1 - \frac{s}{M_\psi^2}\right)$$



Completed:

- Implemented the splittings: $x \rightarrow \eta_c^{(1)} x$, $x \rightarrow J/\psi^{(1)} x$, $g \rightarrow J/\psi^{(8)}$, $x \rightarrow \chi_{ci}^{(1)} x$.
- Interleaved the above splittings with ISR and MPI.
- Included all above in available splittings such as $g \rightarrow q\bar{q}/q \rightarrow qg/g \rightarrow gg$.

Work in progress:

- Include higher resonances + competition between them.
- Comparisons with data.

Future work:

- Matrix element correction.
- Matching + merging.

