Monte Carlo Simulations of Upsilon Meson Production

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Motivation

Upsilon mesons are a probe of quark-gluon plasma properties (QGP) created in heavy-ion collisions. The measured suppression of Upsilon yield in A+A over p+p is caused by:

- Debeye-like colour screening of diquark potential at high temperatures reached in QGP *[Phys. Rev. Lett.* ***109*** *(2012), 222301]*
- cold nuclear matter effects, such as shadowing, comover interaction or nuclear absorption *[Phys. Lett. B* ***503*** *(2001), 104-112]*
- feed-down contributions complicating the observed suppression pattern

In order to better understand the suppression of Υ mesons in QGP, it is essential to know their production mechanism, which consists of:

- hard scattering - $b\bar{b}$ production
- bound state formation - colour singlet, colour octet channels

Quarkonium production

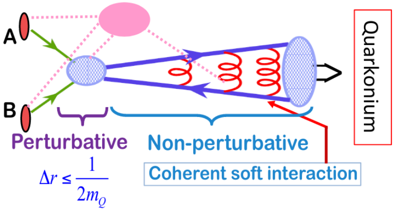
- Quarkonium production mechanism - hard scattering and non-perturbative hadronisation

- Several production models:
  - Colour singlet

    [Nuc. Phys. B 172, 425-434]
  - Colour octet

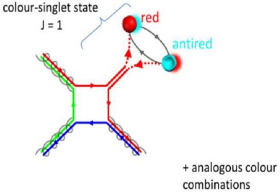
    [Phys. Rev. D 46, R3703(R)]
  - Colour evaporation

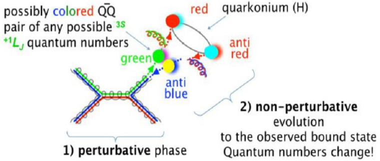
    [Phys. Lett. B 47 2, 217-221]



- Possible production in multiple parton interactions (MPIs)

  *[Phys. Lett. B **786** (2018), 87-93]*

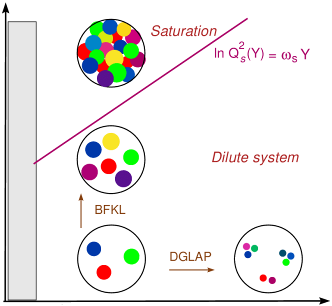




Υ multiplicity dependence

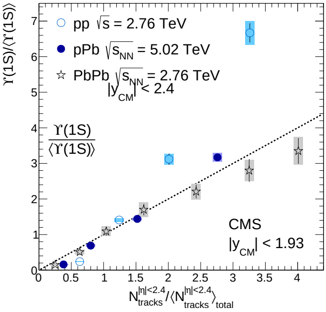
The multiplicity dependence of Υ production is sensitive to:

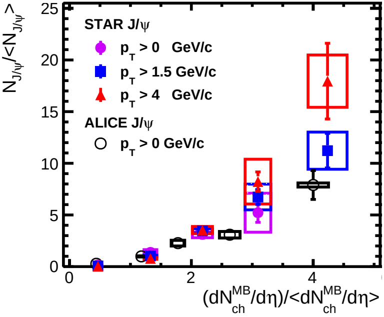
- interplay between soft and hard processes *[Phys. Rev. C **86**, 034903]*
  - Υ yield proportional to the number of MPIs
  - N_{ch} proportional to the energy density
- multiple parton interaction (MPI) influence



- possible parton saturation signatures (implemented in CGC/saturation based model) *[Eur. Phys. J. C **80**,560 (2020)]*
- string percolation model *[Phys. Rev. C **86**, 034903]*

Υ multiplicity dependence





- CMS (left): strong Υ production dependence on charged particle multiplicity in pp @ $\sqrt{s} = 2.76$ TeV
  *[JHEP **04** (2014), 103]*
- STAR (right): similar trend for J/Ψ in pp @ $\sqrt{s} = 200$ GeV
  *[Phys. Lett. B **786** (2018), 87-93]*

Normalised multiplicity dependence

Experimental observable $N_{\Upsilon}/\langle N_{\Upsilon}\rangle$ defined as:

$$N_{\Upsilon}/\langle N_{\Upsilon}\rangle = (N_{\mathrm{MB}}/N_{\mathrm{MB}}^{\mathrm{bin}})(N_{\Upsilon}^{\mathrm{bin}}/N_{\Upsilon}) \quad (1)$$

$N_{\mathrm{ch}}/\langle N_{\mathrm{ch}}\rangle$ ... self-normalised particle multiplicity

N_{Υ} ... total number of events containing Upsilon meson

$N_{\Upsilon}^{\mathrm{bin}}$ ... number of Upsilon events in corresponding multiplicity bin

N_{MB} ... total number of minimum bias (MB) events

$N_{\mathrm{MB}}^{\mathrm{bin}}$ ... number of MB events in corresponding $N_{\mathrm{ch}}/\langle N_{\mathrm{ch}}\rangle$ bin

Mote Carlo event generator comparison

PYTHIA

- p_{T} ordered showers
- Lund string hadronisation
- direct Upsilon production (matrix elements for Bottomonia)

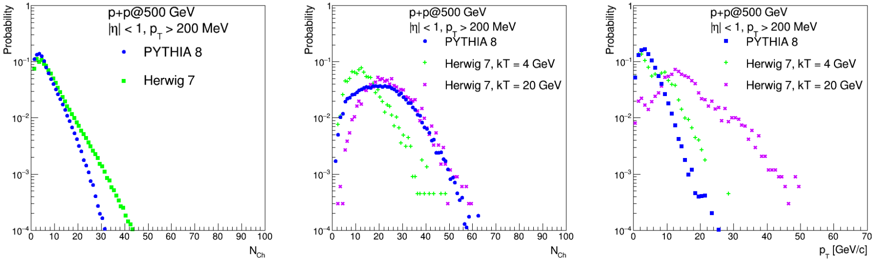
Herwig

- angular ordered showers
- cluster hadronisation
- Upsilon production during hadronisation ($b\bar{b}$ matrix element)

Simulation setup

- PYTHIA and Herwig simulations of pp collisions at 500 GeV
- Minimum bias: non-single-diffractive SoftQCD
- Track selection: $|\eta| < 1$, $p_{\mathrm{T}} > 0.2$ GeV/c, stable ($\tau > 10$ mm/c) (STAR acceptance)
- Upsilon selection: $p_{\mathrm{T}} > 0$ or 4 GeV/c, electron decay channel only, require both electrons within acceptance
- Directly produced Upsilon(1S) - no feed-down contribution
- Herwig production depends on b-parton $k_{\perp}$ cut (4 or 20 GeV/c) - lower values result in spoiling track multiplicity while improving the description of Upsilon p_{T} spectrum shape
- Comparison to STAR preliminary data *[J. Phys.: Conf. Ser. **1667** 012022]*

Spectra



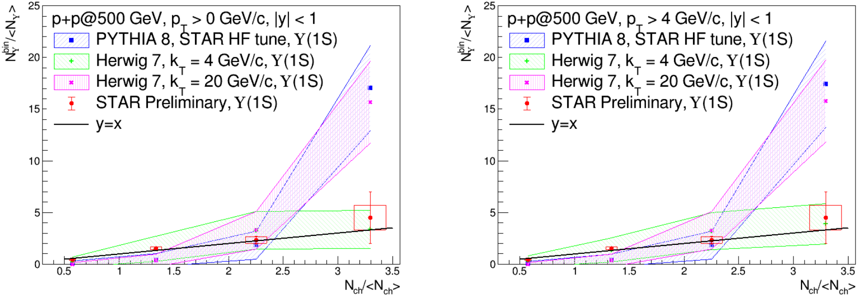
- multiplicity distributions for MB (left) and Upsilon(1S) (middle) events and p_T distributions for Upsilon events (right)
  - Upsilon N_{ch} spectra - PYTHIA and Herwig with $k_{\perp} = 20$ GeV/c have a similar shape
  - Upsilon p_{T} spectra - PYTHIA and Herwig with $k_{\perp} = 4$ GeV/c agree more closely

Results

- Normalised event multiplicity of Upsilon yield calculated using (1)

- $N_{\mathrm{ch}}/\left\langle N_{\mathrm{ch}}\right\rangle$ binning selected in order to match the binning of STAR preliminary data: 0-1, 1-2, 2-3, 3-8 and 8-100 (overflow bin)

Results



- Normalised Upsilon(1S) yield dependence on normalised multiplicity for PYTHIA and Herwig compared to STAR preliminary data
  [J. Phys.: Conf. Ser. ***1667*** *012022]*
  - left: p_{T} integrated
  - right: $p_{\mathrm{T}} > 4$ GeV/c
- Stronger than linear increase observed in model calculations

Conclusion

- The minimum bias spectra differ significantly for PYTHIA and Herwig at higher multiplicities
- Upsilon production in Herwig has limited validity
- Both PYTHIA and Herwig ($k_{\perp} = 20$ GeV/c) predict stronger than linear increase in normalised Upsilon yield in dependence on normalised multiplicity
- In comparison to STAR preliminary data both PYTHIA and Herwig ($k_{\perp} = 20$ GeV/c) predict higher values for larger multiplicities, while underestimating smaller multiplicity values
- The data suggests, that Upsilon mesons are produced in multi-parton collisions, due to stronger than linear increase predicted by PYTHIA and Herwig ($k_{\perp} = 20$ GeV/c) *[JHEP **09** (2015), 148]*

Acknowledgements

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