EXPLORING UPSILON PRODUCTION MECHANISM USING PYTHIA SIMULATION IN PROTON-PROTON

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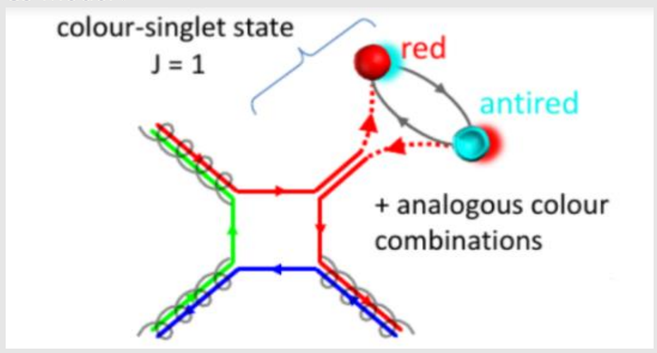
Abstract

The study focuses on understanding the production mechanism of quarkonium, specifically the Υ meson, in proton-proton (*pp*) collisions. While quarkonium can be produced in a Color Singlet (CS) state, the Color Octet (CO) channel and gluon emissions also play a role.
Upsilon-hadron correlations depend on the gluon emissions and can provide additional constraints on the production mechanism. This study uses the PYTHIA event generator to investigate the differences between the Upsilon-pion correlation produced in CS and CO channels. The simulation shows that Υ-pion correlations have an away-side peak at $\Delta\Phi = \pi$ and correlation is stronger for hight pion p_T .
It serves as a proof of principle for future analysis in the STAR experiment at RHIC in BNL.

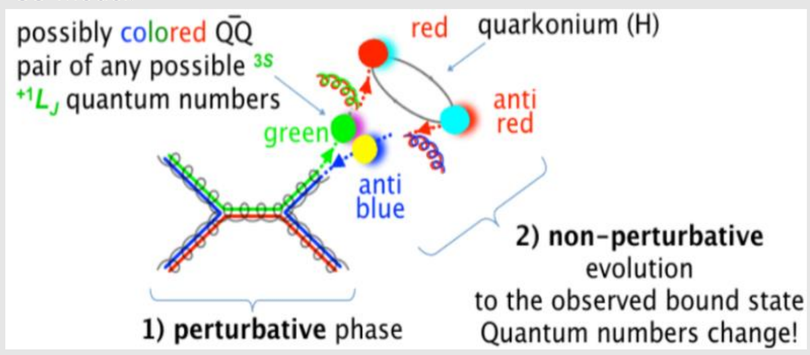
Motivation

CS Model :



- $Q\bar{Q}$ produced directly in a color neutral state in association with a gluon;
- calculations grossly under-predicted production cross section;
- predictions with higher-order corrections describe data better [1].

CO Model:



- $Q\bar{Q}$ can be produced in any colored or color-neutral state, with any quantum numbers $^{+1}L_J$;
- success in explaining the p_T spectra of quarkonia. Polarization prediction disagrees with experimental data [2].

➢ Hadronic activity directly around the heavy quarkonium has been suggested as an experimental observable to measure the radiation emitted off the colored heavy quark pair during production [3].

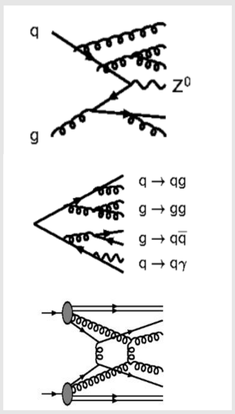
➢ Physics Goal: Investigate CS and CO Upsilon production mechanism by looking for Upsilon-hadron azimuthal correlations.

Methods

➢ PYTHIA [4] simulations of *p* + *p* events at 510 GeV using Heavy Flavor Tune and 13.6 TeV using Monash Tune;

➢ Physics processes ON:

- Initial-state parton showers (ISR):
- Final-state parton showers (FSR):
- Multiple parton–parton interactions(MPI):



➢ Hadron selection:

- Charged poins only;
- p_T > 0.2 GeV/c; $|\eta|$ < 1 or 2.4< η <4;

➢ Upsilon selection:

- directly produced Upsilon(1S) - no feed-down contribuion;
- dielectron decay (Υ (1S) → e^-e^+) only;

➢ Select Upsilon and Pion coming from the same event and calculate $\Delta\Phi = \varphi_\Upsilon - \varphi_\pi$

Predictions

➢ In *pp* collisions Drell – Yan (DY) production is accompanied by hadron production from fragments of the quark which radiated γ*.

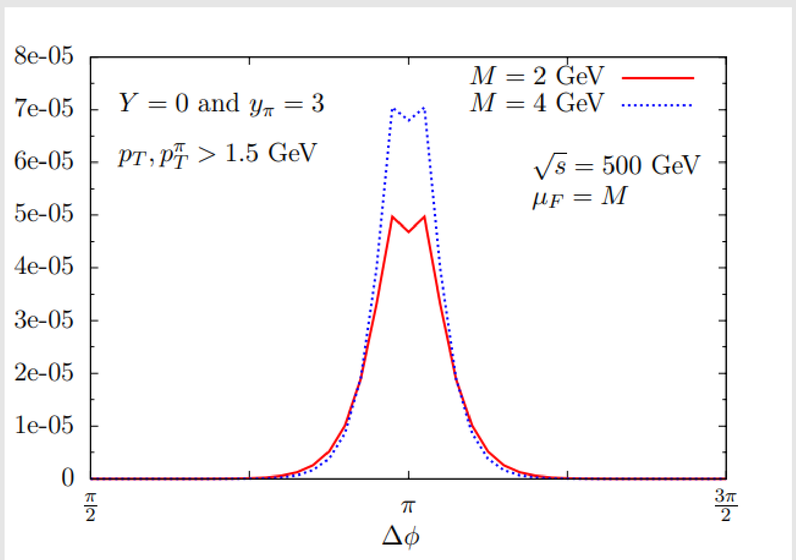


Fig.1. The correlation function C(Δφ) for the associated DY pair (γ → $l\bar{l}$) and pion production In pp collisions at √s = 500 GeV* [4].

➢ Away-side double-peak present in *pp* collisions of the photon (central) and pion (forward);

- The double-peak structure of *C(Δ→)* arises only for pions at large forward rapidities;
- The width of a double peak around Δφ ≃ π is strongly correlated with the magnitude of the saturation scale.

➢ Quarkonia production:
replacement of virtual photon with a gluon in dipole framework [5] →
a gluon from the projectile hadron can develop a fluctuation that contains a heavy quark pair.

➢ The double peak is expected also for Υ-hadron azimuthal correlation.

PYTHIA results

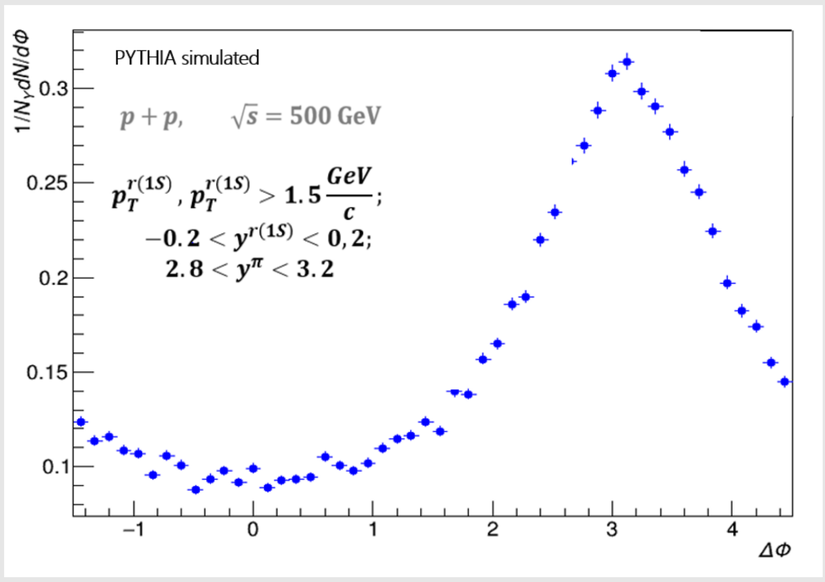


Fig.3. Υ (produced in CS via gg→ Υ(1S)g) and all pions correlations for different values of the Υ and pion rapidities.

➢ The double peak structure isn't observed.
➢ Probably reason: The double peak structure is particularly pronounced when the saturation scale takes on values comparable to the dilepton invariant mass. But PYTHIA does not implement this effect explicitly (only indirectly).

Upsilon-Hadron correlation

➢ Central - Central and Central-Forward correlations ⇒ measurable at STAR:

- *Central pseudorapidity range coverage:* $-1 < \eta < 1$;
- *Forward pseudorapidity range coverage:* $2.5 < \eta < 4$;
- *Pseudorapidities criteria have been applied to the e^+e^- pair.*

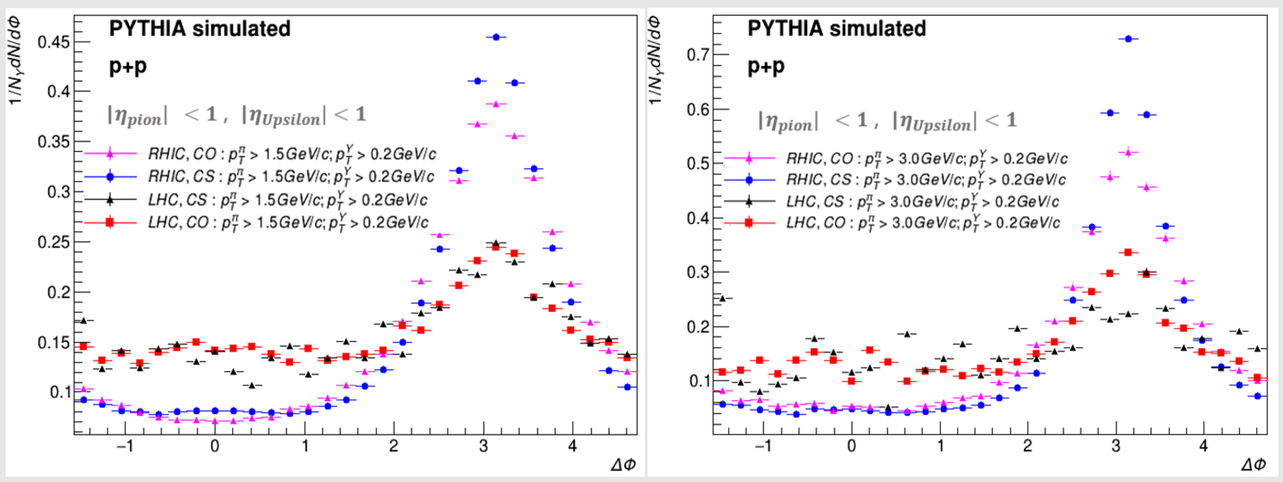


Fig.3. Υ + hadron azimuthal correlations for CS and CO production mechanism for central – central pseudorapidities at RHIC (√s = 510 GeV) and LHC (√s = 13.6 TeV) energies.

Fig.4. Υ + hadron azimuthal correlations for CS and CO production mechanism for central – forward pseudorapidities at RHIC (√s = 510 GeV) and LHC (√s = 13.6 TeV) energies.

➢ At RHIC energies, correlations are stronger for both CS and CO models;

➢ Increasing pions p_T influence the shape of the correlation by affecting the energy scale and momentum distribution of particles involved in the production process → differences in the observed correlations:
higher p_T → stronger correlation;

➢ Particles formed through the CS mechanism exhibit stronger correlations compared to the color octet CO mechanism;

➢ Differences between CO and CS models is smaller then for Central-Central case.

Conclusions

➢ The Υ + pion correlation is characterized by an away-side peak at $\Delta\Phi = \pi$.

➢ Upsilon – pion azimuthal correlations were obtained for the Υ particles generated via both the CS and CO production mechanisms at collision energies of √s = *510 GeV* and √s = *13.6 TeV*.

➢ Correlation increased for the color singlet scenario.

➢ A double-peak structure in the correlation has not been observed in the production of Υ particles via a color singlet state for pions located with forward pseudorapidities.

➢ The simulation results acquired will serve as a basis for comparison with the experimental data gathered from the STAR experiment conducted at the RHIC in BNL.

References

[1] Lansberg J.P., arXiv:0811.4005v1,. SLAC-PUB-13473
[2] CDF Collaboration, Phys. Rev. Lett. 99 (2007).
[3] Kraan, A. C., arXiv:0807.3123v1 [hep-ex], AIPConf.Proc.1038:45-54 (2008).
[4] E. Basso et al., PoS, EPS-HEP2015, 191 (2016).
[5] S. J. Brodsky, A. Hebecker and E. Quack, Phys. Rev. D 55, 2584 (1997).

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