Correlation of Y meson production with the underlying event in pp collisions measured by the ATLAS experiment

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Introduction and Motivation

- There are many studies of small systems demonstrating QGP-like signatures that belong to soft physics, but there are not many measurements in hard probes.

- Previous study of long-range 2PC in Z-boson tagged pp collisions (Eur. Phys. J. C 80, 64 (2020)) → Hard + soft in pp collisions, comprehensive pileup technology developed

- Search for modification of the UE (soft) for different Upsilon states (hard) in pp collisions by measuring $n_{ch}, dn_{ch}/d\rho_T$ and $dn_{ch}/d\Delta\phi$, where $\Delta\phi = \phi^Y - \phi^h$

- CMS observed a decrease of the ratio of yields $Y(nS) / Y(1S)$ as a function of multiplicity and studied the effect in different sphericity intervals (JHEP04(2014)103, JHEP11 (2020) 001). It was suggested that the decrease in the ratios is an UE effect.
Analysis

- Full Run 2 13 TeV pp collisions data as sampled by ATLAS detector di-muon triggers
- \( Y \rightarrow \mu\mu \) events with \(|y^{\mu\mu}| < 1.6\).
- Charged particles: \(0.5 < p_T < 10\) GeV, and \(|\eta| < 2.5\)
- Analyze \( Y \) candidates in 5 mass regions, use fits to disentangle signal & background
- Extracting \( n_{ch} \) distributions for these 5 mass regions, one can see that the background in the ‘upper-mass’ and ‘lower-mass’ regions are quite similar in shape → sideband subtraction works well!
- Pileup is controlled
- \( n_{ch} \) distributions for \( Y \) states are different
Mean Values of $n_{ch}$ Distribution

Strong difference in the multiplicity of the UE for different $Y(nS)$ states is observed.

The effect is strongest at $p_T^{\mu\mu} = 0$ and diminishes with increasing $p_T^{\mu\mu}$, but still visible at 20-30 GeV.

Feed-down of $Y(nS)$ states, mass differences, systematic uncertainties cannot explain the effect.

At the lowest measured $p_T^{\mu\mu}$, for $Y(1S)$-$Y(2S)$ the difference is $3.6 \pm 0.4$ and for $Y(1S)$-$Y(3S)$ the difference is $4.9 \pm 1.1$. 
Kinematic Distributions of $Y(1S)$-$Y(nS)$

- **Subtracted $p_T$ distributions are consistent in shape with the UE and not jets.**

- Figure shows $p_T$ distributions of charged particles for $Y(1S)$ and subtracted distributions for $Y(1S)$-$Y(nS)$ for several $p_T^{\mu\mu}$ intervals. Markers – data, lines – Pythia.

- For $p_T^{\mu\mu} < 4$ GeV, the distribution resembles particles coming from the UE.

- For $p_T^{\mu\mu} < 30$ GeV, subtracted distributions are consistent in shape with $Y(1S)$ distribution measured in the lowest $p_T^{\mu\mu}$.

- Above 30 GeV, subtracted distributions gets harder, which is explained by feed-down decay processes.
Kinematic Distributions of Y(1S)-Y(nS)

- **Subtracted $\Delta \phi$ distributions resemble UE**

- Subtracted distributions start to display some non-uniformity in the interval $p_{T\mu\mu} \geq 12$ GeV.

- For Y(3S) at $p_{T\mu\mu} > 30$ GeV, peaks appear around $\Delta \phi = 0$ and $\Delta \phi = \pi$. Likely explained by feed-down decays (Y(nS)→Y(1S), $\chi_b$ (mP)→Y(nS))
  - Pythia shows effect of Y(nS)→Y(1S)
In Ref [arXiv:2203.11831v1], the transverse mass scaling of heavy mesons is studied using all available LHC data at $\sqrt{s} = 7, 8$ and $13$ TeV. Analysis reveals significant difference in the yield ratios of $Y(nS)/Y(1S)$ between expectations from $m_T$-scaling and the measurements. This difference has similar $p_T^{\mu\mu}$ shape as the difference in $\langle n_{ch} \rangle$ between $Y$-states measured by ATLAS, suggesting the possibility that these are two manifestations of the same physics mechanism.