Study of the J/ψ photoproduction with tagged forward proton in p+p collisions at $\sqrt{s} = 510$ GeV

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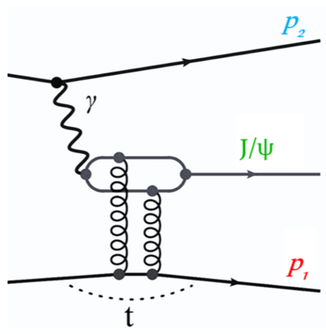
Abstract

We present the first measurement of the exclusive J/ψ photoproduction in proton-proton collisions at $\sqrt{s} = 510$ GeV by the STAR experiment. The unique Roman Pot detector system is utilized to measure forward-propagating protons from the diffractive interactions where one or both protons survive the collisions. This permits the calculation of missing transverse momentum in the collision. Conservation of transverse momentum governing the collision dynamics allows us to directly estimate the transverse momentum of the virtual photon of the interaction. The J/ψ is identified via its decay channel to electron-positron pair in the STAR central barrel detectors.

1. Introduction & Motivation

PHOTOPRODUCTION OF J/ψ IN p+p COLLISIONS

- $p + p \to p_1 + \mathrm{J}/\psi + p_2$
- $\mathrm{J}/\psi \to e^+ + e^-$ decay channel
- Interactions of proton's (p_1) electromagnetic fields, which are taken as fluxes of photons, with the other proton (p_2)
- Photons can fluctuate to a virtual hadronic state ($q\bar{q}$) which scatters of other proton and turns into a real vector meson (J/ψ)
- Interaction of $q\bar{q}$ pair with target proton through $\mathbb{P}$omeron exchange
- Diffractive process
  - Presence of one or both incoming particles that remain intact after a collision detected by special forward detectors - Roman Pots
  - Produced central system of particles X separated by large rapidity gaps (LRG) from the forward protons



GOALS OF THE ANALYSIS

- Cross-section of J/ψ photoproduction as a function of transferred momentum $|-t|$
- Possibility to have a precise measurement of p_{T} of the virtual photon thanks to the measurement of forward proton in Roman Pot detectors

2. STAR detectors

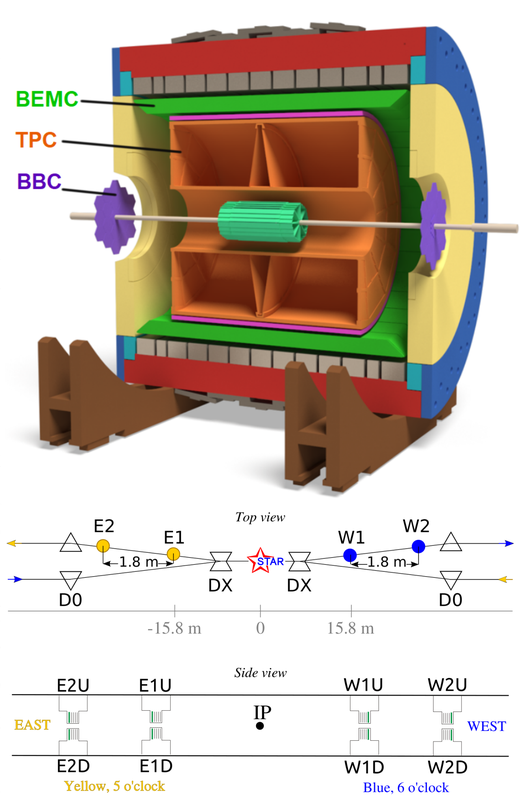
Electron and positron pairs

- **Time Projection Chamber (TPC):** Central gas filled cylinder used for trajectory reconstruction and particle identification with $\mathrm{d}E/\mathrm{d}x$ of charged particles. Pseudorapidity coverage $|\eta| < 1$
- **Barrel Electromagnetic Calorimeter (BEMC):** Located on the outer lateral area of TPC used for energy measurement of EM probes. Pseudorapidity coverage $|\eta| < 1$

Proton p_1 from $\mathbb{P}$ vertex (high p_{T})

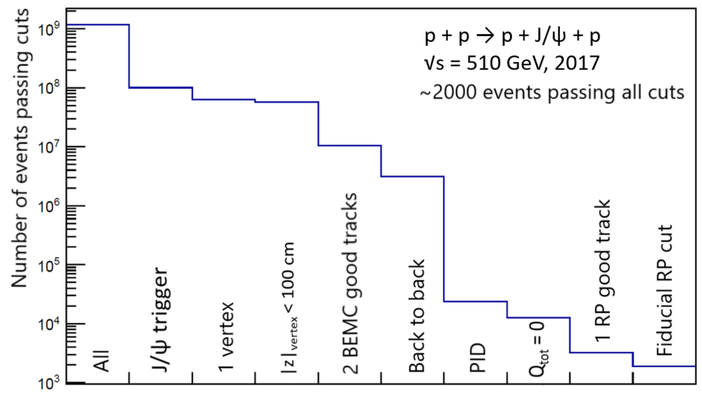
- **Beam Beam Counters (BBC):** Two plastic scintillation detectors placed at both ends of the TPC cylinder used to check the LRG. Pseudorapidity coverage $\eta : 2.1 - 5.0$
- **Roman Pot detector system (RP):** Four stations (E2, E1, W1, W2) each containing two Roman Pots with four silicon strip detectors and one plastic scintillator inside used to detect the forward protons and to reconstruct their momenta

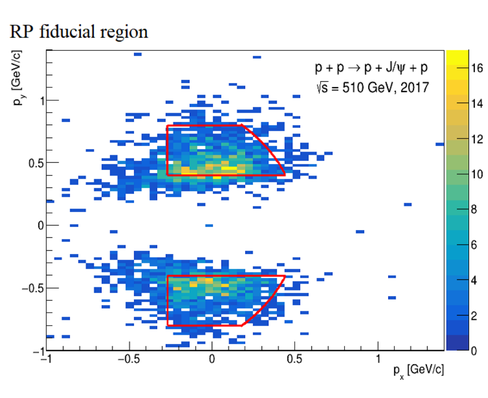
Proton p_2 from photon vertex (low p_{T}) scatters at a small angle, not measured in Roman Pots



3. Event selection

Data from proton-proton collisions at $\sqrt{s} = 510$ GeV from 2017 collected at the STAR experiment located at the Relativistic Heavy Ion Collider at the Brookhaven National Laboratory.



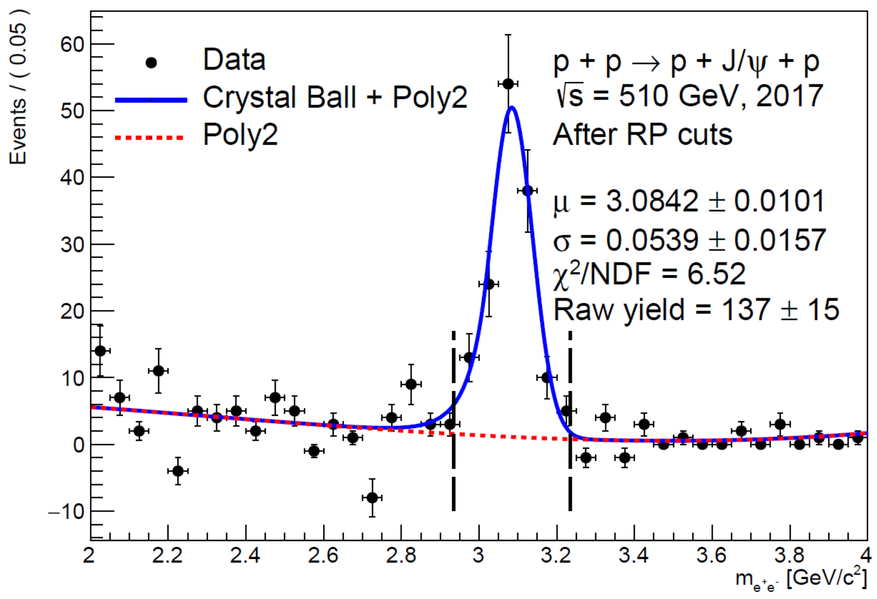


The order of the selection criteria is such that, after examining the trigger and vertex properties, the quality of the tracks in the central barrel is examined first, followed by electron/positron identification and cuts on the quality of tracks in Roman Pots.

4. Results

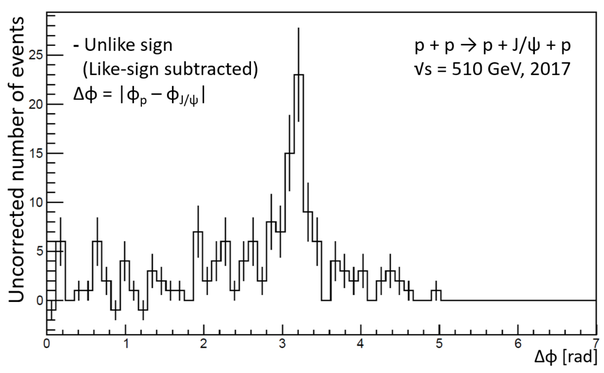
UNCORRECTED INVARIANT MASS AND RAW YIELD

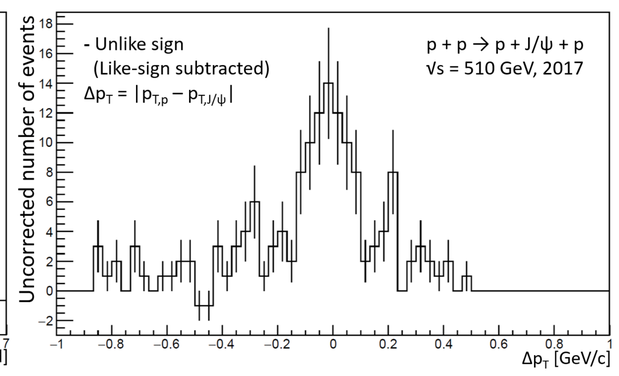
- Prominent peak visible in the uncorrected invariant mass distribution
- Signal is fitted with a crystal ball plus a second degree polynomial function (blue) and background with a second degree polynomial function (red).



J/ψ - RP PROTON BALANCE

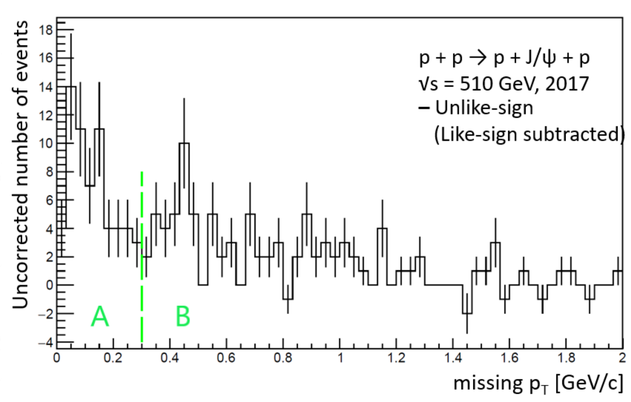
- Detected proton and reconstructed J/ψ should be back-to-back based on the kinematics of the final state. Expected $\Delta\phi = |\phi_{\mathrm{p}} - \phi_{\mathrm{J}/\psi}| = \pi$
- From the conservation of transverse momentum $(p_1 + p_2 + p_{\mathrm{J}/\psi})_{\mathrm{T}} = 0$. Small-$p_{\mathrm{T}}$ proton is believed to scatter at a small angle, hence p_{T} of the virtual photon is expected to be small. We take $p_{1,\mathrm{T}} \sim 0$ which gives $p_{2,\mathrm{T}} = -p_{\mathrm{J}/\psi}$. Expected $\Delta p_{\mathrm{T}} = |p_{\mathrm{T,p}} - p_{\mathrm{T,J}/\psi}| = 0$





MISSING p_{T}

- Momentum conserved in a collision $(\mathbf{p_1} + \mathbf{p_2} + \mathbf{p_{\mathrm{J}/\psi}})_{\mathrm{T}} = 0$
- J/ψ and proton measured
- p_{T} of the virtual photon is the missing p_{T}: $-p_{2,\mathrm{T}} = (p_1 + p_{\mathrm{J}/\psi})_{\mathrm{T}}$
- **A**: Peak at zero consistent with the exclusive process
- **B**: Broad structure from 0.3 GeV/c is consistent with non-exclusive processes



5. Summary & Outlook

We reported the first results of the analysis of the J/ψ photoproduction in p+p collisions at 510 GeV at the STAR experiment. They included the calculation of raw yield of J/ψ and the first look at the p_{T} distribution of virtual photon.

Next steps

- Investigation of the J/ψ contribution from χ_c since it is produced in Double $\mathbb{P}$ Exchange not the photoproduction channel
- Simulations with the Starlight generator and Starsim program in order to generate detector responses
- Extraction of efficiencies and resolutions from the simulations
- Cross check of selection variables between MC and data
- Study all further corrections needed to finalise the data for physics measurement

Acknowledgement

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The STAR Collaboration
https://drupal.star.bnl.gov/STAR/presentations