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

Michaela Svěráková (for the STAR collaboration)
Faculty of Nuclear Sciences and Physical Engineering
Czech Technical University in Prague

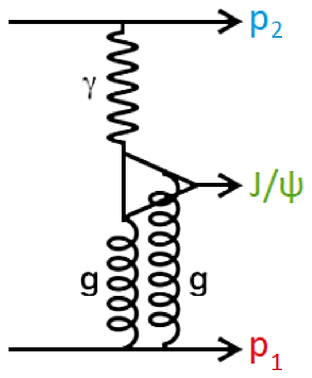
Abstract

We report the study of the photoproduction of J/ψ vector meson in proton-proton collisions at 510 GeV at the STAR experiment. This analysis utilizes the unique ability of the STAR experiment, which is the detection of forward-going protons using Roman Pot detectors. The J/ψ vector mesons are identified through decay into electron-positron pairs. The electron and positron tracks are detected in the Time Projection Chamber and Barrel Electromagnetic Calorimeter. Presented are the uncorrected invariant mass distribution of the electron-positron pairs after the subtraction of the like-sign combinatorial background and the calculated raw yield. Using the quantity of the missing transverse momentum, the calculation of which is based on the law of conservation of momentum in the collision, we investigate the possibility of determining the value of the transverse momentum of the virtual photon present in the photoproduction.

1. Introduction & motivation

PHOTOPRODUCTION OF J/ψ IN p+p COLLISIONS

- $p + p \rightarrow p_1 + \mathrm{J}/\psi + p_2$
- $\mathrm{J}/\psi \rightarrow e^+ + e^-$ 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 $IPomeron$ 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. Detectors of the STAR experiment

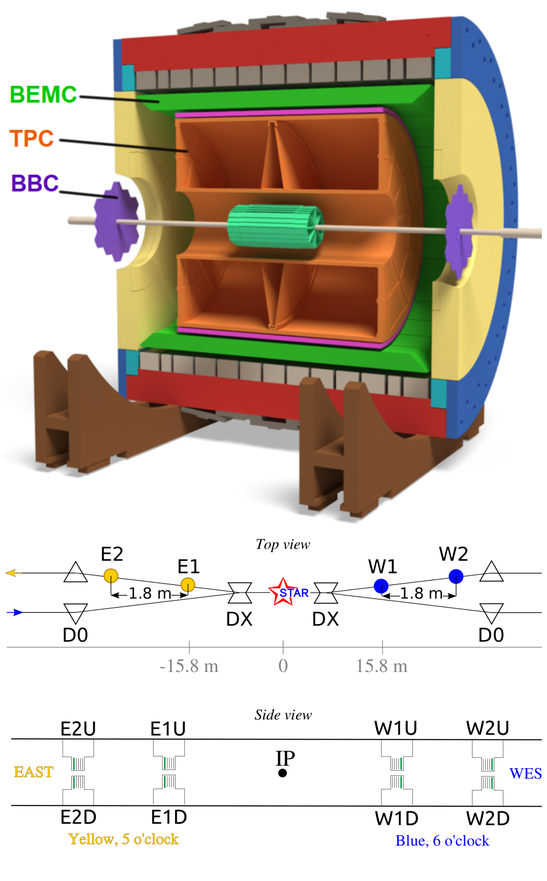
Electron and positron pairs

- **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 $IPomeron$ vertex (high p_{T})

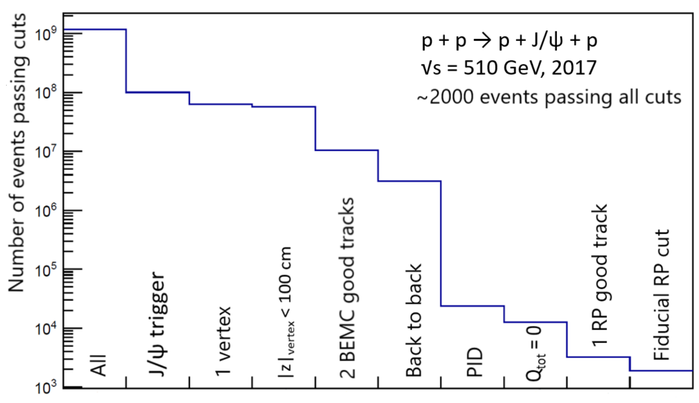
- **Beam Beam Counters (BBC):** Two plastic scintillation detectors placed at both ends of the TPC cylinder used to check the LRG. Pseudorapidity coverage $\eta : 2.1 - 5.0$
- **Roman Pot detector system (RP):** Four stations (E2, E1, W1, W2) each containing two Roman Pots with four silicon strip detectors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

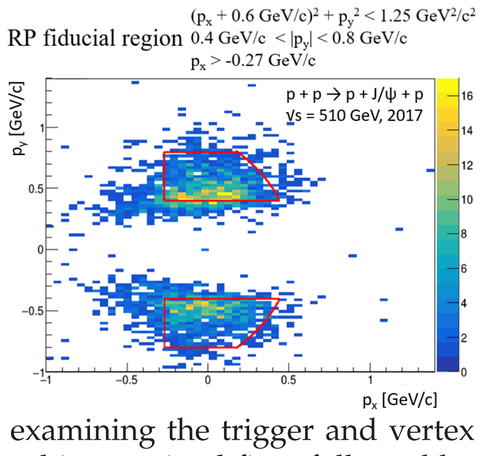
Proton p_2 from photon vertex (low p_{T}) scatters at a small angle, not measured in Roman Pots



3. Data & 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.



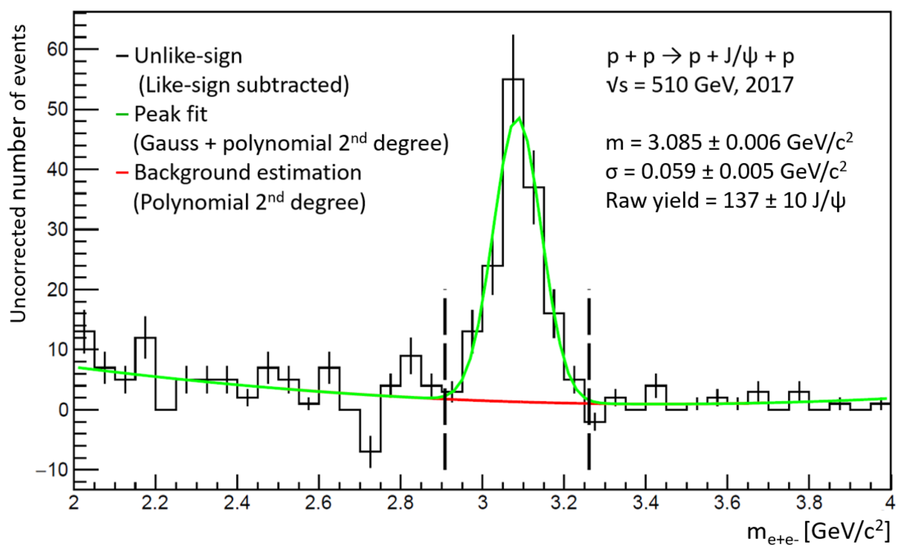


The order of the selection criteria is such that, after examining the trigger and vertex properties, the quality of the tracks in the central barrel is examined first, followed by electron/positron identification and cuts on the quality of tracks in Roman Pots.

4. Results

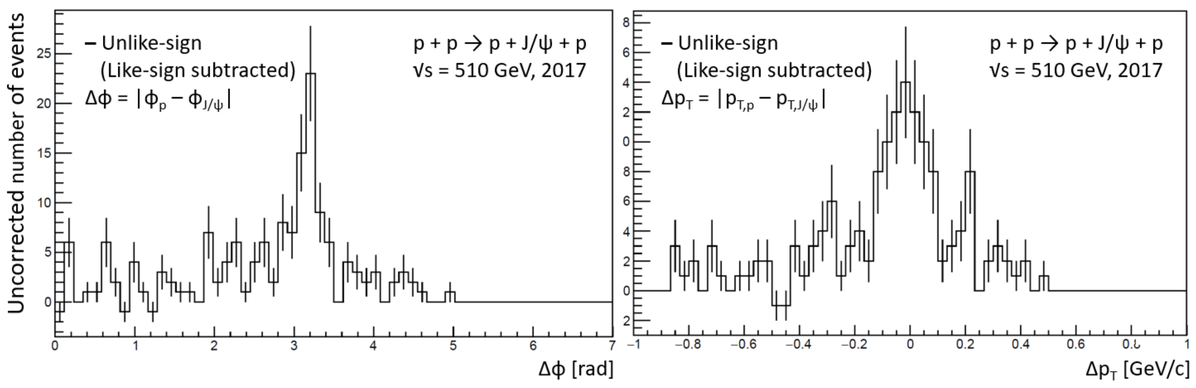
UNCORRECTED INVARIANT MASS AND RAW YIELD

- Prominent peak visible in the uncorrected invariant mass distribution
- Both fitting functions integrated to calculate the raw yield



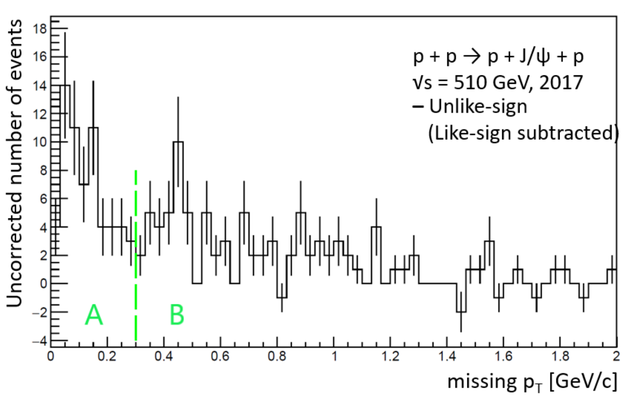
J/ψ - RP PROTON BALANCE

- Detected proton and reconstructed J/ψ should be back-to-back based on the kinematics of the final state. Expected $\Delta\phi = \left|\phi_{\mathrm{p}} - \phi_{\mathrm{J}/\psi}\right| = \pi$
- From the conservation of transverse momentum $\left(p_1 + p_2 + p_{\mathrm{J}/\psi}\right)_{\mathrm{T}} = 0$. 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 $\Delta p_{\mathrm{T}} = \left|p_{\mathrm{T,p}} - p_{\mathrm{T,J}/\psi}\right| = 0$



MISSING p_{T}

- Momentum conserved in a collision $\left(\mathbf{p_1} + \mathbf{p_2} + \mathbf{p_{\mathrm{J}/\psi}}\right)_{\mathrm{T}} = 0$
- J/ψ and proton measured
- p_{T} of the virtual photon is the missing p_{T}: $-p_{2,\mathrm{T}} = \left(p_1 + p_{\mathrm{J}/\psi}\right)_{\mathrm{T}}$
- **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

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 $IPomeron$ 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

Supported in part by U.S. DEPARTMENT OF ENERGY

The work was supported by the Grant Agency of the Czech Technical University in Prague, grant No. SGS22/174/OHK4/3T/14 and by the Ministry of Education, Youth and Sports of the Czech Republic through the project LM2023034 Brookhaven National Laboratory - the participation of the Czech Republic.

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

23rd ZIMANYI SCHOOL WINTER WORKSHOP ON HEAVY ION PHYSICS
December 4-8, 2023