Study of the J/ψ photoproduction at the STAR experiment

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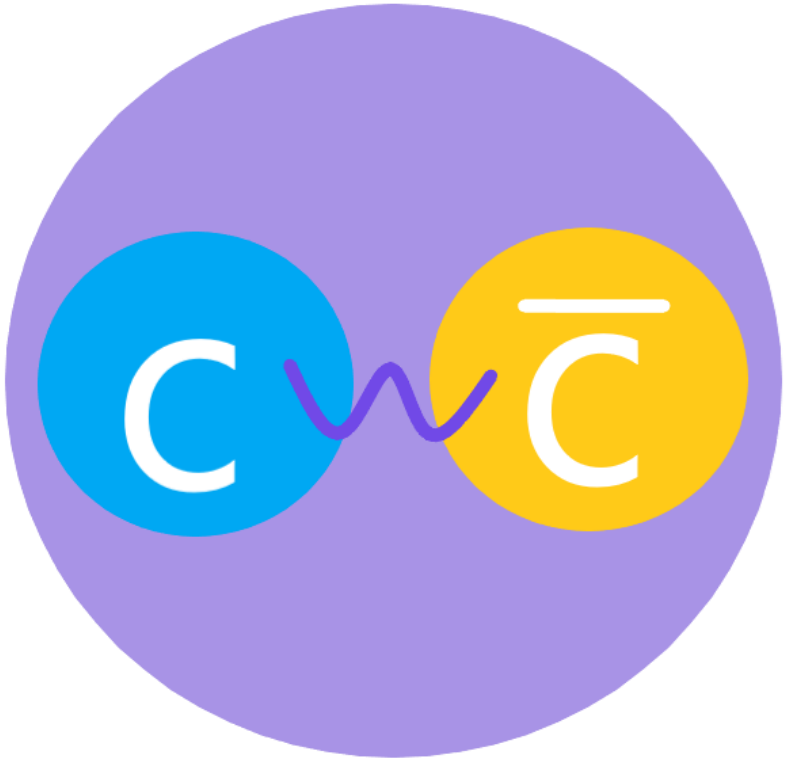
Research Project Defence

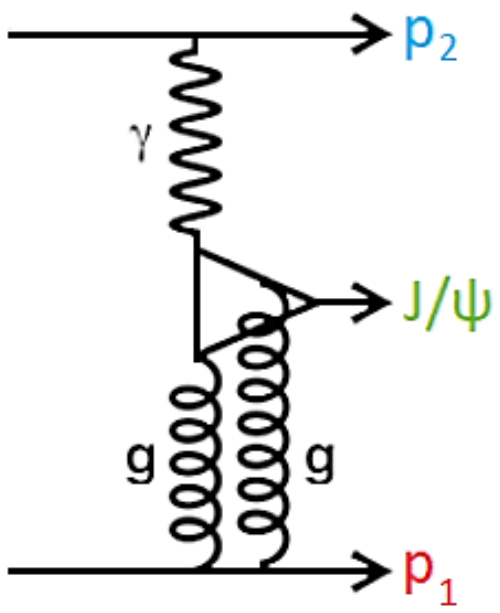
September 11, 2023



J/ψ

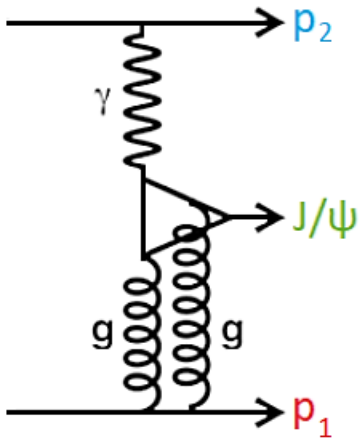
- c and anti-c
- vector meson – spin 1 and odd parity
- $m_{PDG} = 3.096 \pm 0.006$ GeV/c^2 (Taken from Ref. [1].)
- studied decay channel
  - J/ψ → gamma → e^+e^-
  - BR: (5.97 ± 0.03)% (Taken from Ref. [1].)

PHOTOPRODUCTION OF J/ψ



- UPC of protons at √s = 510 GeV
- Proton electromagnetic fields collide
  → Flux of photons (dipole model)
  → Fluctuate to a virtual hadronic state (dipole)
- Virtual $q\bar{q}$ pair scatters off proton
  → Emerges as real vector meson

DIFFRACTIVE PROCESS



TWO WAY OF PHOTON INTERACTIONS

- Hadronic processes – target disintegrates into new particles
- Diffractive interactions
  - Experimentally: the presence of the LRG and the presence of one or both incoming particles that remain intact after a collision and are detected by special forward detectors

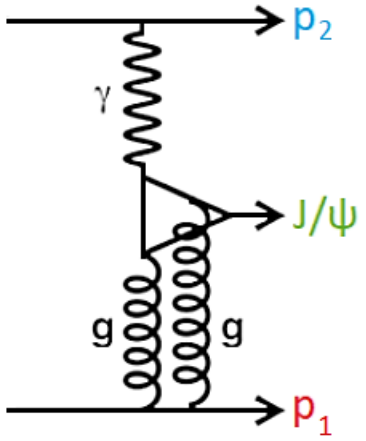
  - Good and Walker (1960): Collision at high energy in which no quantum numbers are exchanged between the colliding particles
  - Bjorken (1994): Diffractive reaction is characterized by a large, non-exponentially suppressed, rapidity gap in the final state

GOALS OF THE ANALYSIS

- J/ψ photoproduction in proton-proton collisions at √s = 510 GeV

A) CROSS SECTION

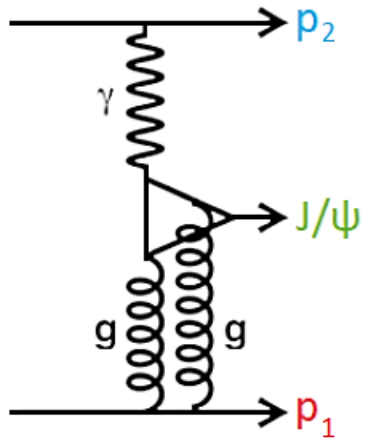
- Working towards the cross-section of J/ψ photoproduction as a function of transferred momentum |–t|



B) VIRTUAL PHOTON P_T

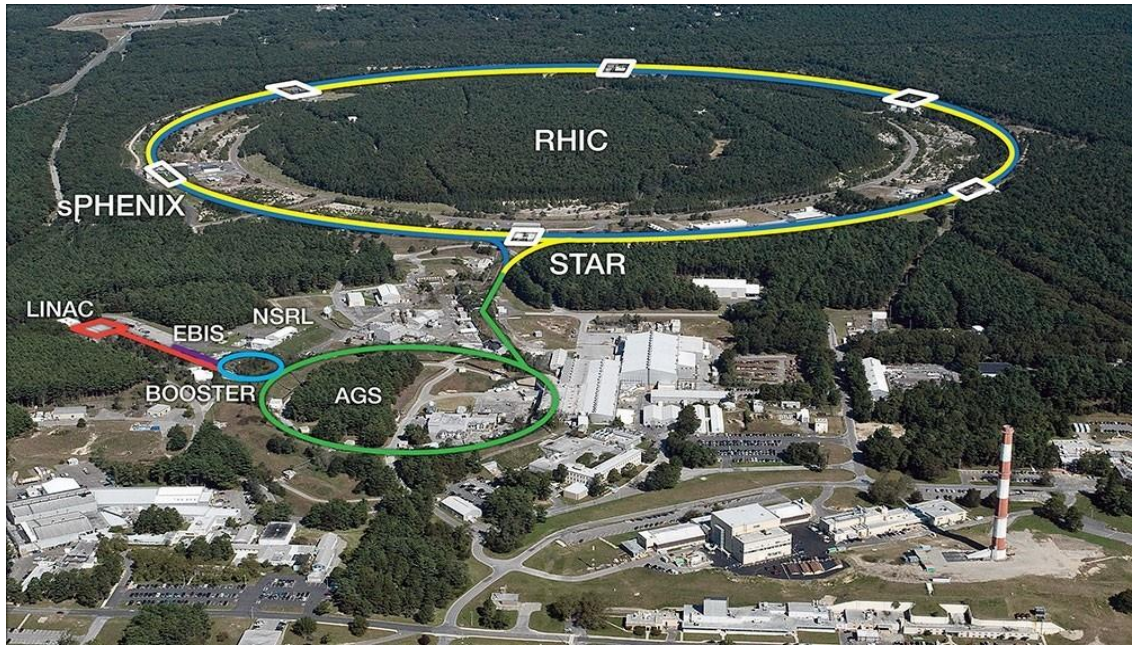
- The first analysis of this type with the possibility of measuring forward protons in Roman Pots
- Exclusive photoproduction process
- p_T of virtual photon: $-\mathbf{p}_{2,T} = (\mathbf{p}_{J/\psi} + \mathbf{p}_1)_T$

WHAT AND HOW DO WE MEASURE



- J/ψ → e^+e^- in central barrel
- One proton (high p_T) from Pomeron vertex in Roman Pots
- The other proton (low p_T) from photon vertex scatters at a small angle, not measured in Roman Pots

- STAR (the Solenoidal Tracker at RHIC)
  - One of two experiments at RHIC at the Brookhaven National Laboratory
  - Used subdetectors: TCP, BEMC, BBC, RP

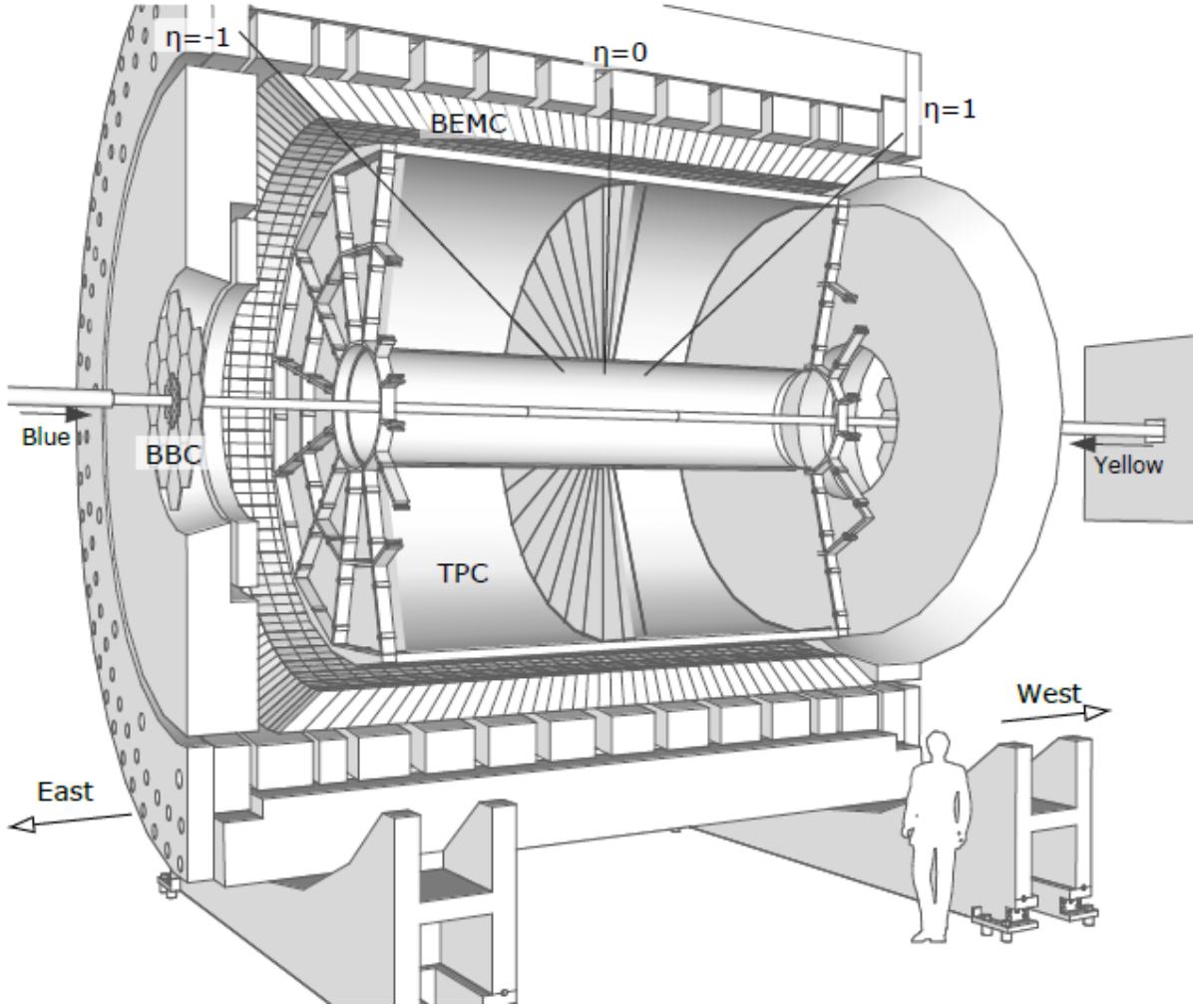


Schematic view of the RHIC accelerator complex with its pre-accelerators and the two currently running experiments STAR and sPHENIX. Taken from Ref. [2].

STAR DETECTORS

ELECTRON AND POSITRON PAIRS

- Time Projection Chamber
  - Detection and tracking
- Barrel Electromagnetic Calorimeter
  - Energy measurement



Cross-section of the STAR detector showing its beamline and subdetectors TPC, BEMC, BBC. Taken from Ref [3].

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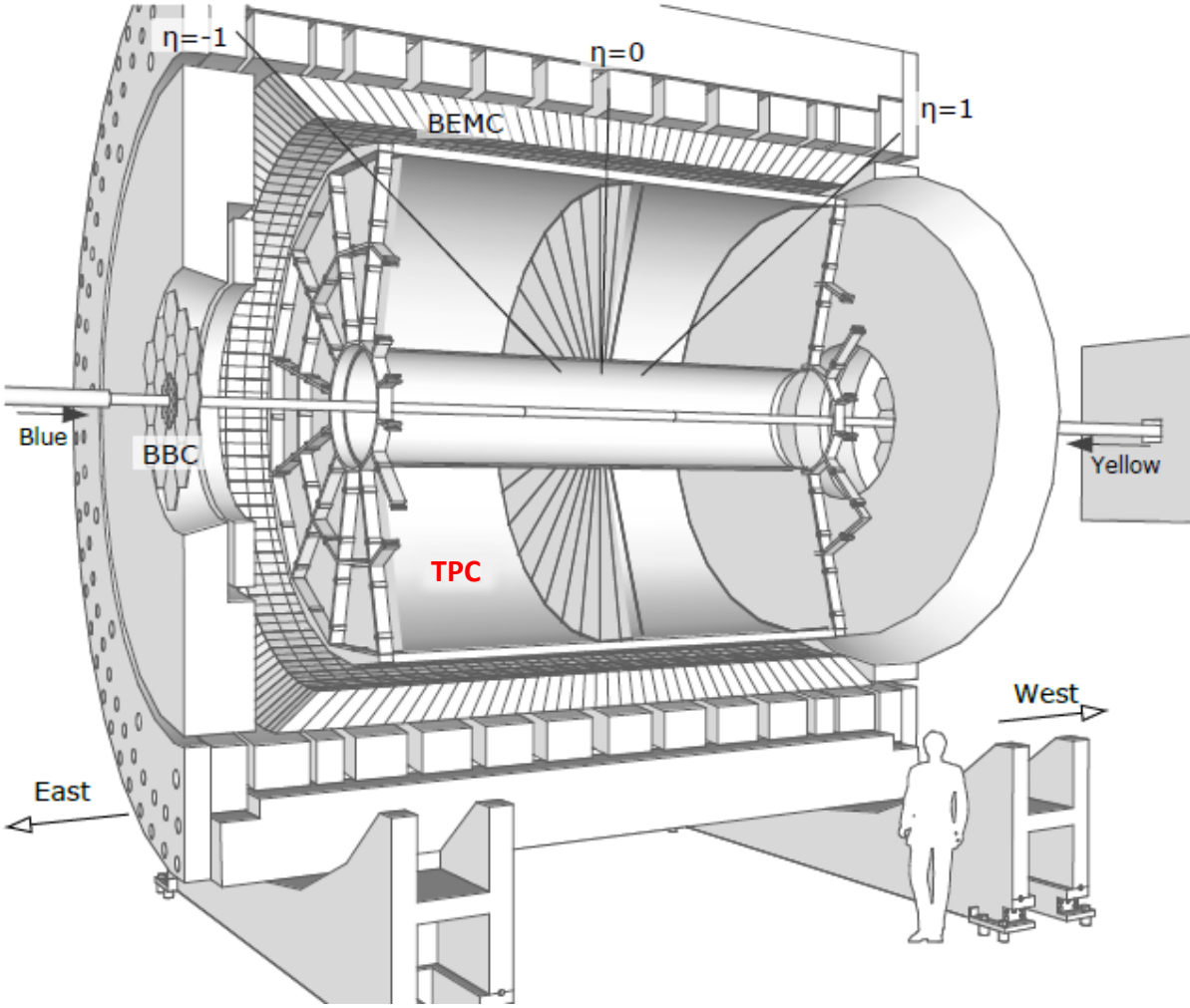

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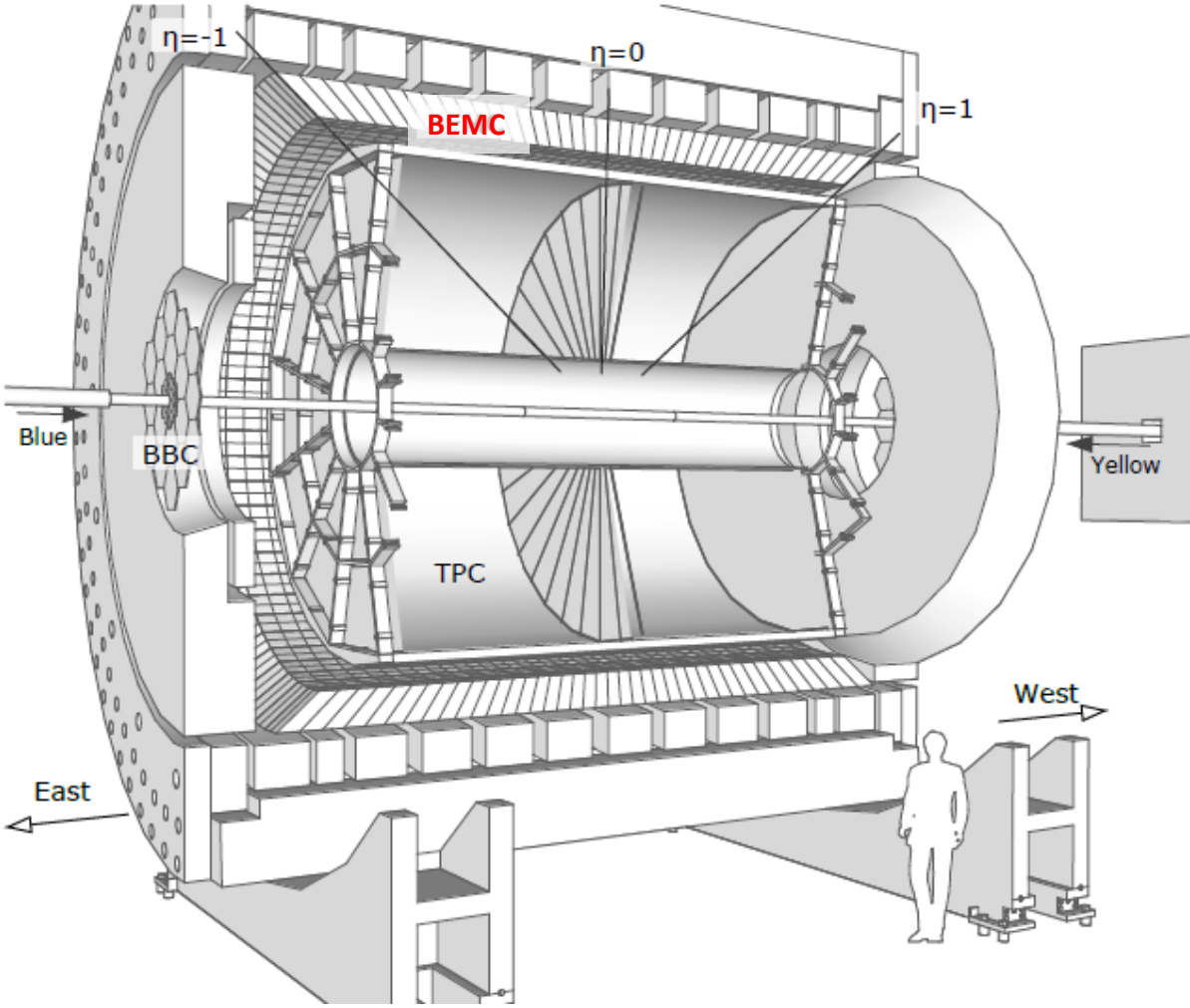

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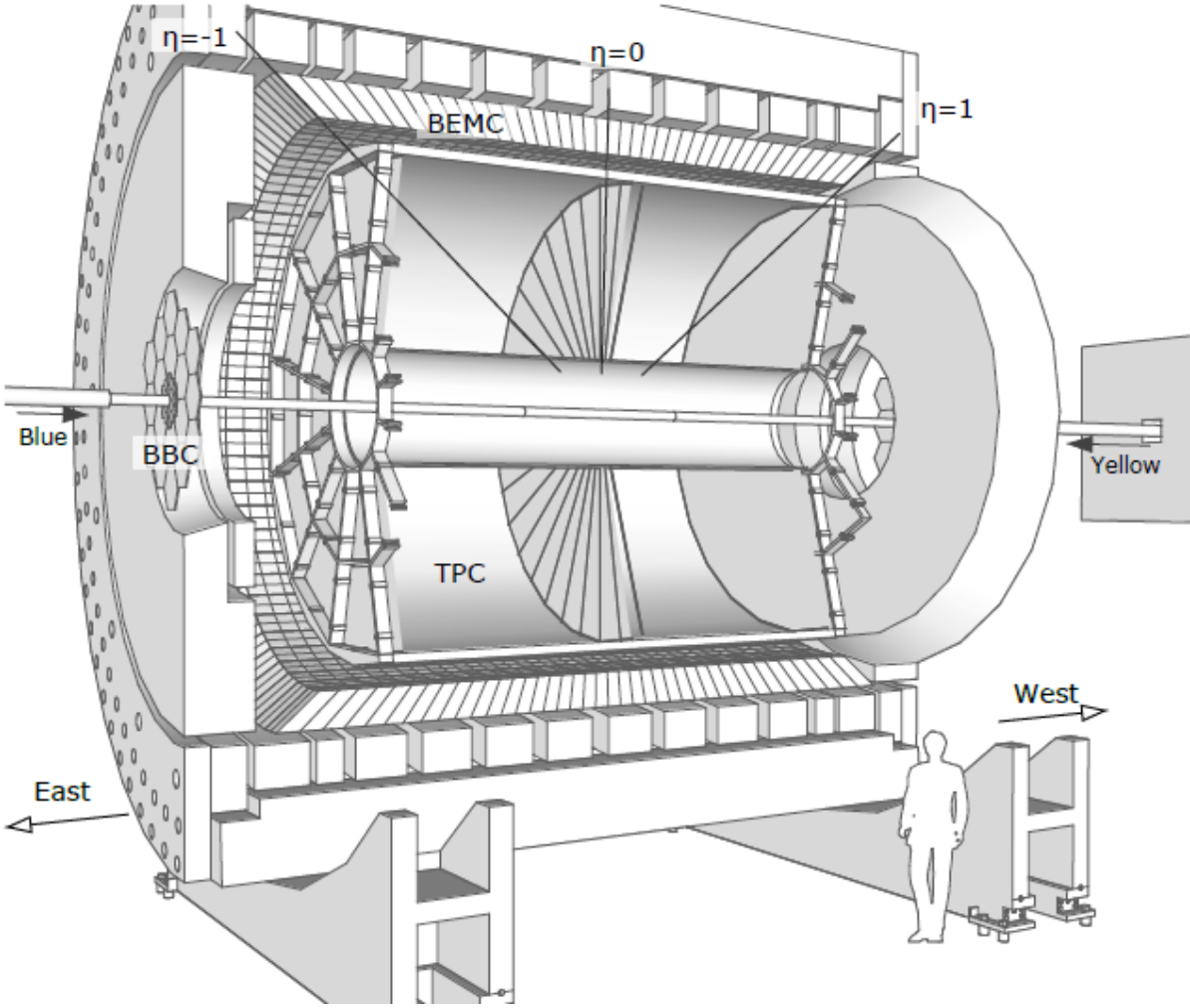
STAR DETECTORS

PROTONS

- Beam-Beam Counter
  - Measure the interaction vertex
  - MBT in pp collisions, LRG control
- Roman Pots
  - Detection, momentum reconstruction



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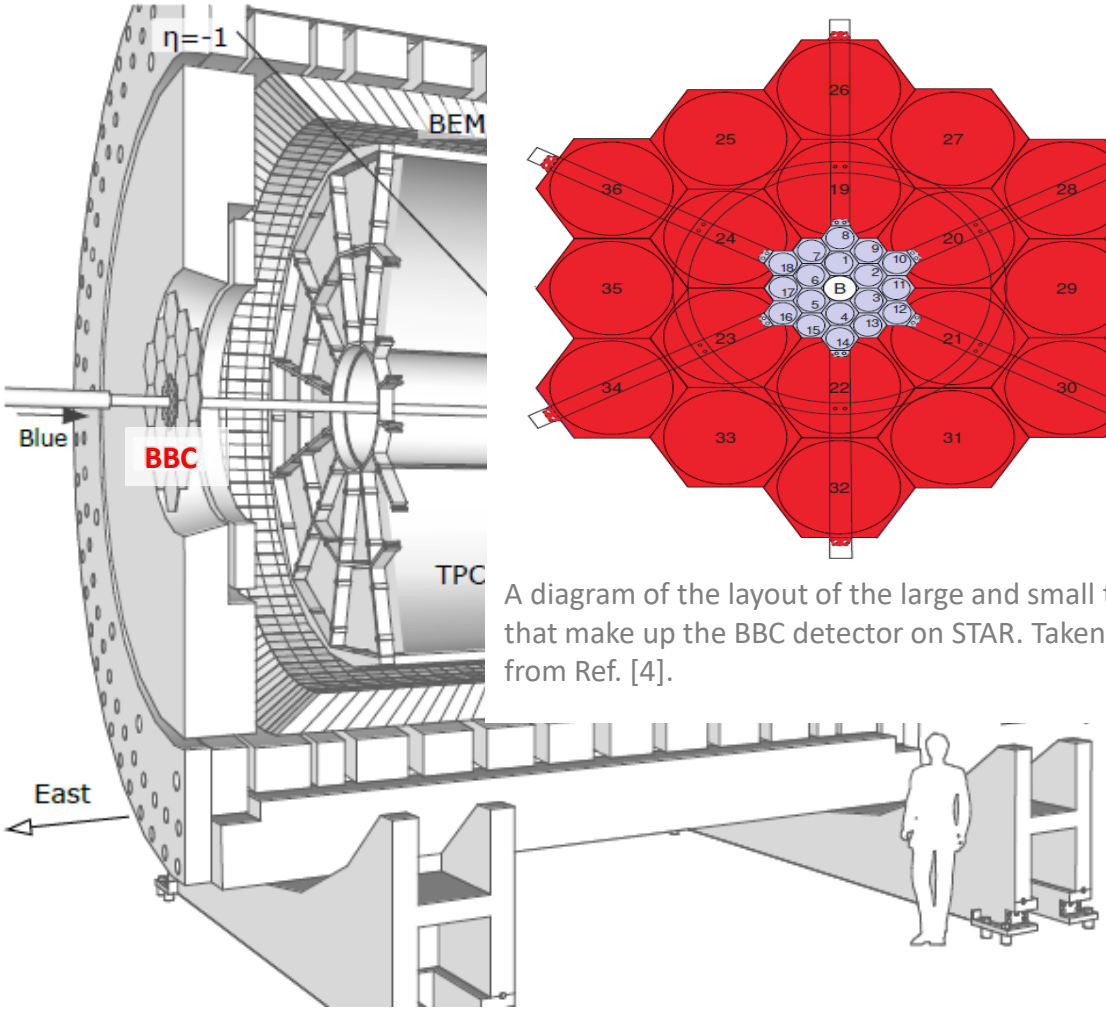


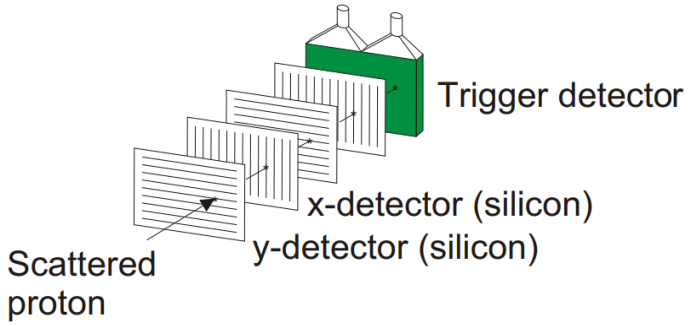
Cross-section of the STAR detector showing its beamline and subdetectors TPC, BEMC, BBC. Taken from Ref [3].

A diagram of the layout of the large and small tiles that make up the BBC detector on STAR. Taken from Ref. [4].

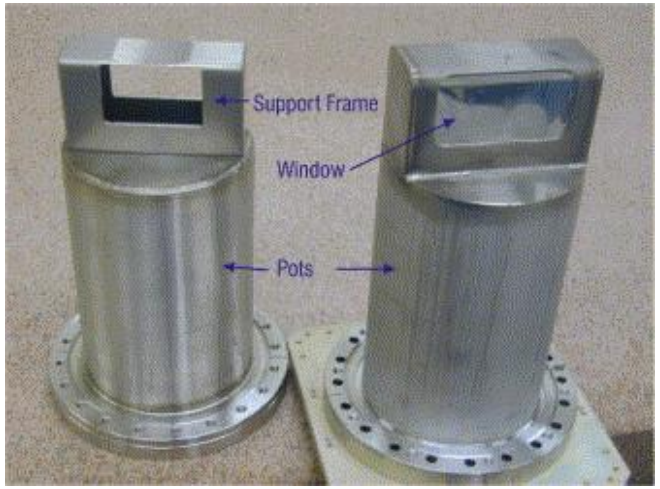
STAR DETECTORS

PROTONS

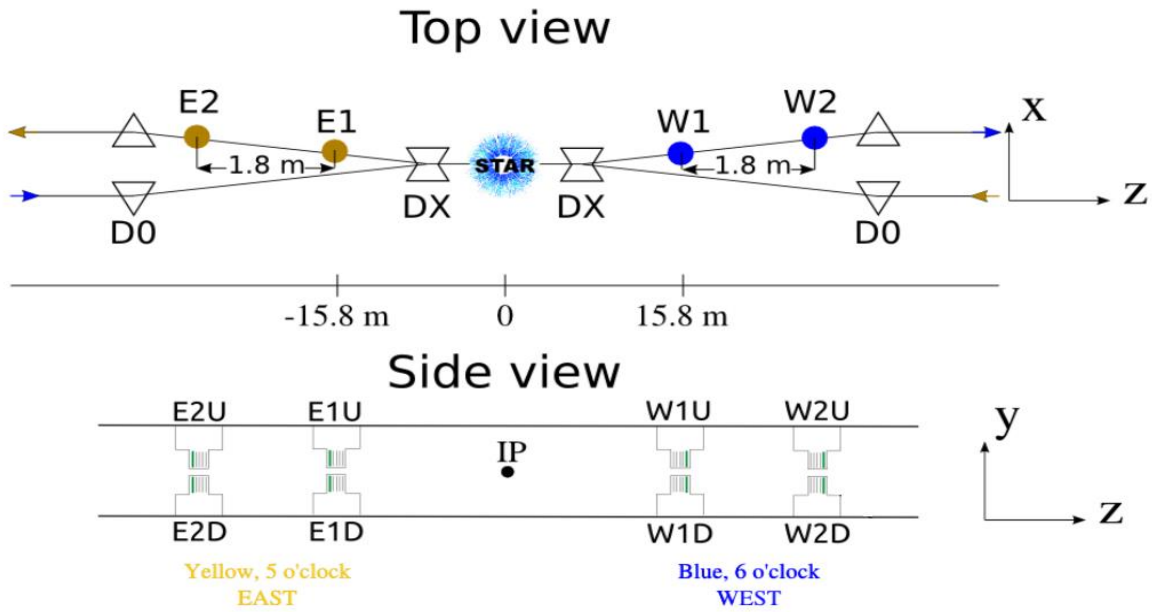
- Beam-Beam Counter
  - Measure the interaction vertex
  - MBT in pp collisions, LRG control
- Roman Pots
  - Detection, momentum reconstruction



Inside structure of the RP detector. Taken from Ref [7].



A Roman Pot vessel. Taken from Ref [6].



Layout of the experimental set-up. Top view on the upper plot and side view on the bottom plot. The central STAR detector in the middle and the four RP stations depicted as E1, E2, W1, W2. Dipole magnets depicted as DX and D0. Taken from Ref. [5].

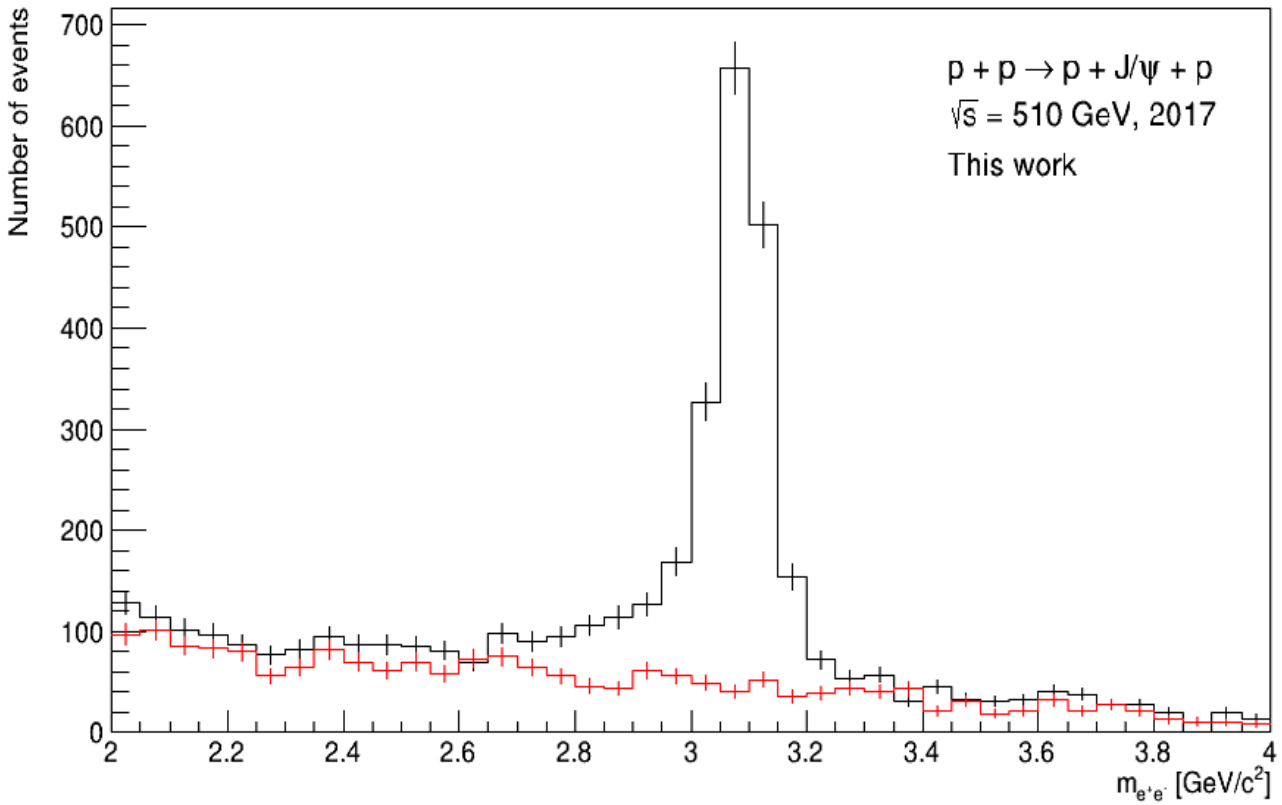
EVENT SELECTION

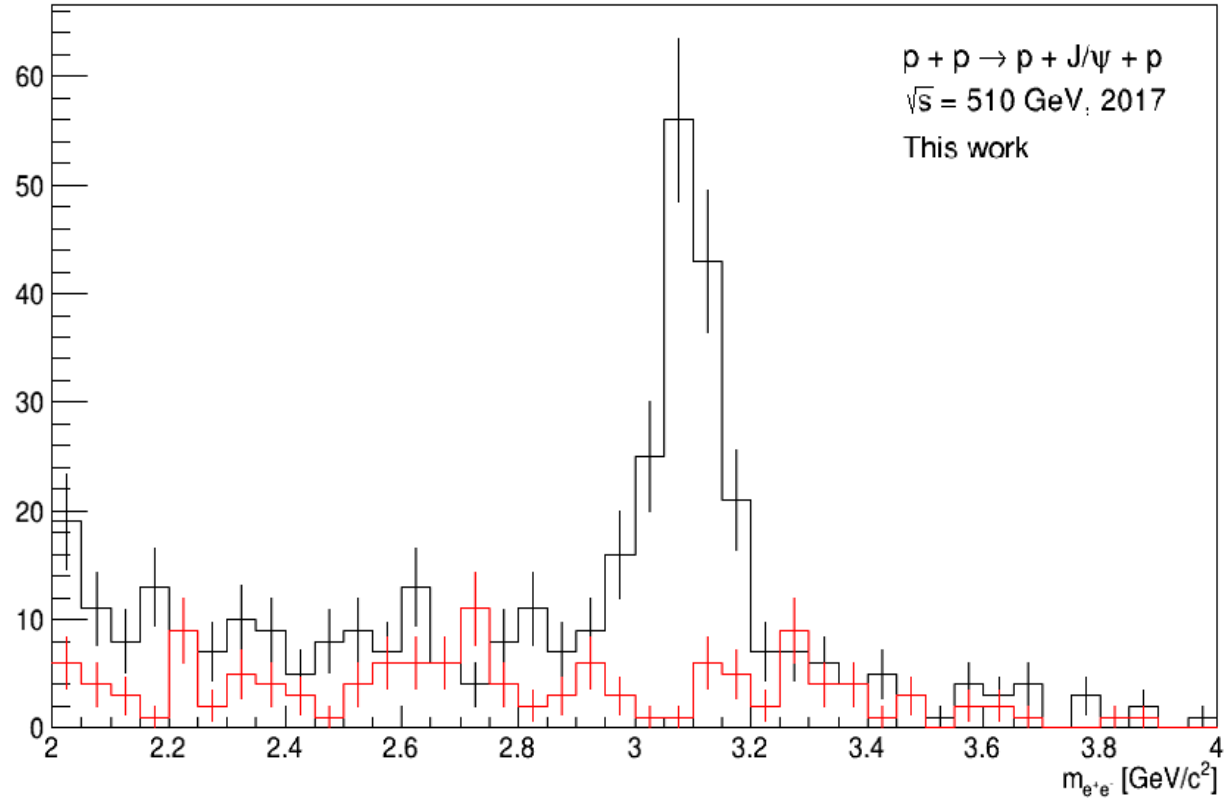
Data from *pp* collisions at √s = 510 GeV, 2017
After all cuts – 1904 events

- JPsi*HTTP trigger (100.22 mil events)
- Exactly 1 vertex
- Vertex |z| position < 100 cm
- Track selection
  - $|\eta_{BEMC}|$ of primary tracks < 1
  - |DCA(z)| < 1 cm & DCA(xy) < 1.5 cm
  - nHitsFit > 15
  - ndE/dx > 15
  - Exactly 2 tracks from the primary vertex with BEMC hits
- Back-to-back tracks in BEMC
  - $\Delta\phi_{BEMC}$ of segment numbers = 3
- The 2 tracks are e^+, e^-
  - Cut $\chi^2_{ee} = n\sigma_{e+}{}^2 + n\sigma_{e-}{}^2 < 3^2$
  - Additional cut $\chi^2_{KK} > 10$, $\chi^2_{\pi\pi} > 10$ and $\chi^2_{pp} > 10$ to remove background
- $Q_{tot} = 0$ (un/like sign division)
- Exactly 1 good track in RP
- Tracks in RP in fiducial region

  $(p_x + 0.6\ GeV/c)^2 + p_y{}^2 < 1.25\ GeV^2/c^2$
  $0.4\ GeV/c < |p_y| < 0.8\ GeV/c$
  $p_x > -0.27\ GeV/c$

UNCORRECTED INVARIANT MASS

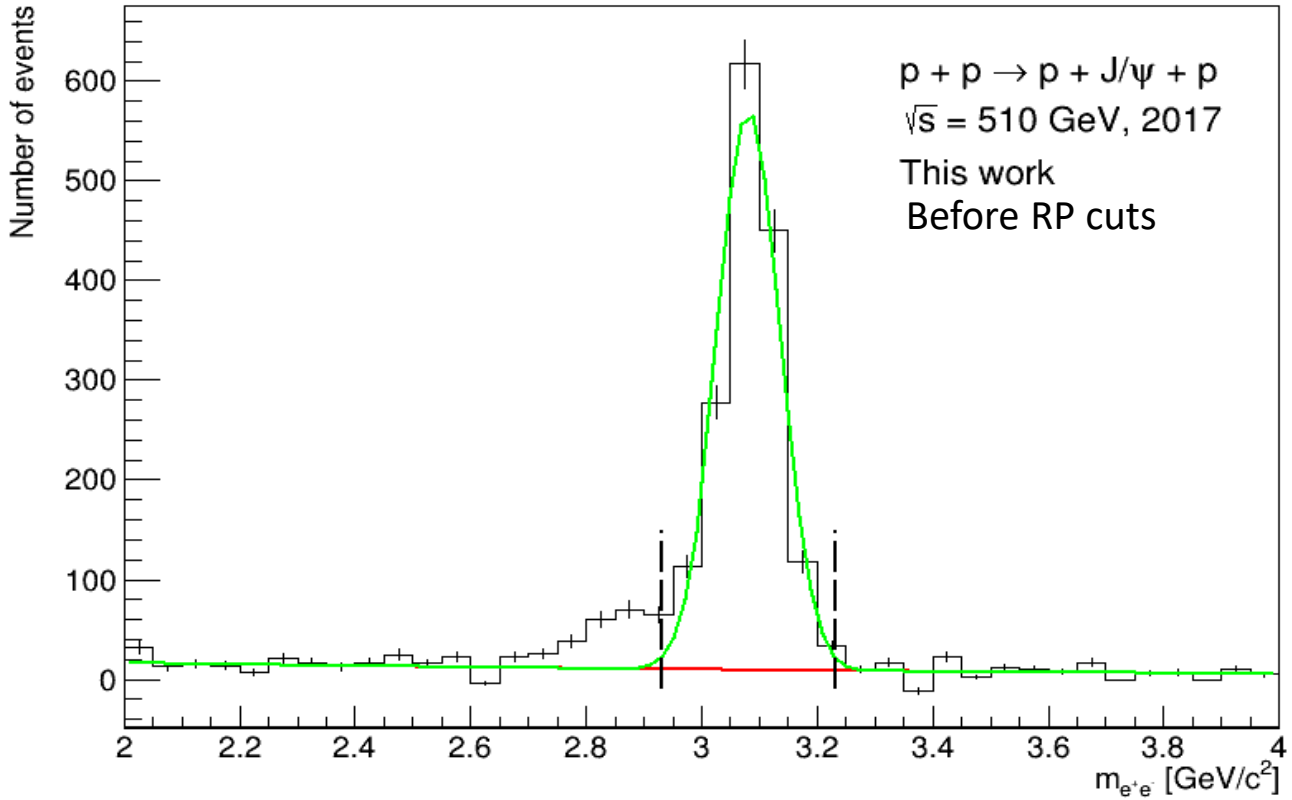


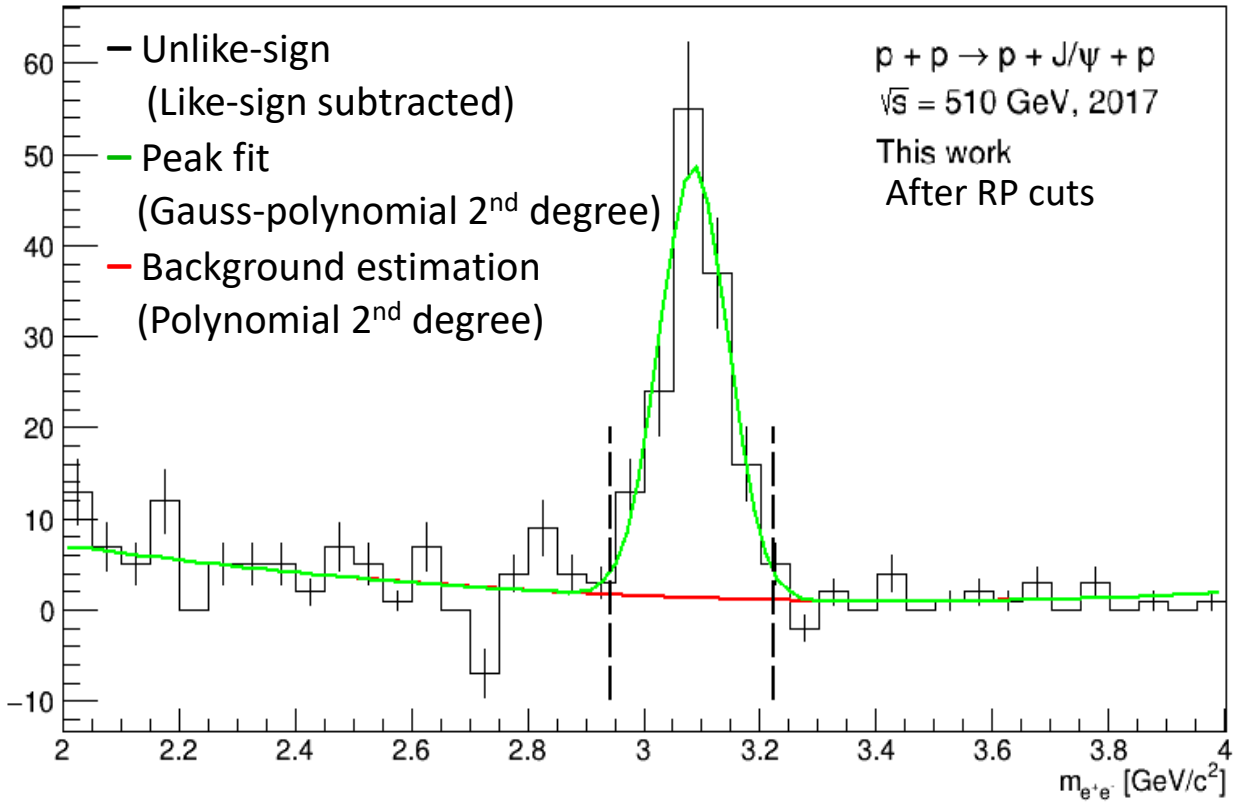


Before the RP cuts
- Unlike-sign combinations
- Like-sign combinations

After the RP cuts
- Unlike-sign combinations
- Like-sign combinations

UNCORRECTED INVARIANT MASS

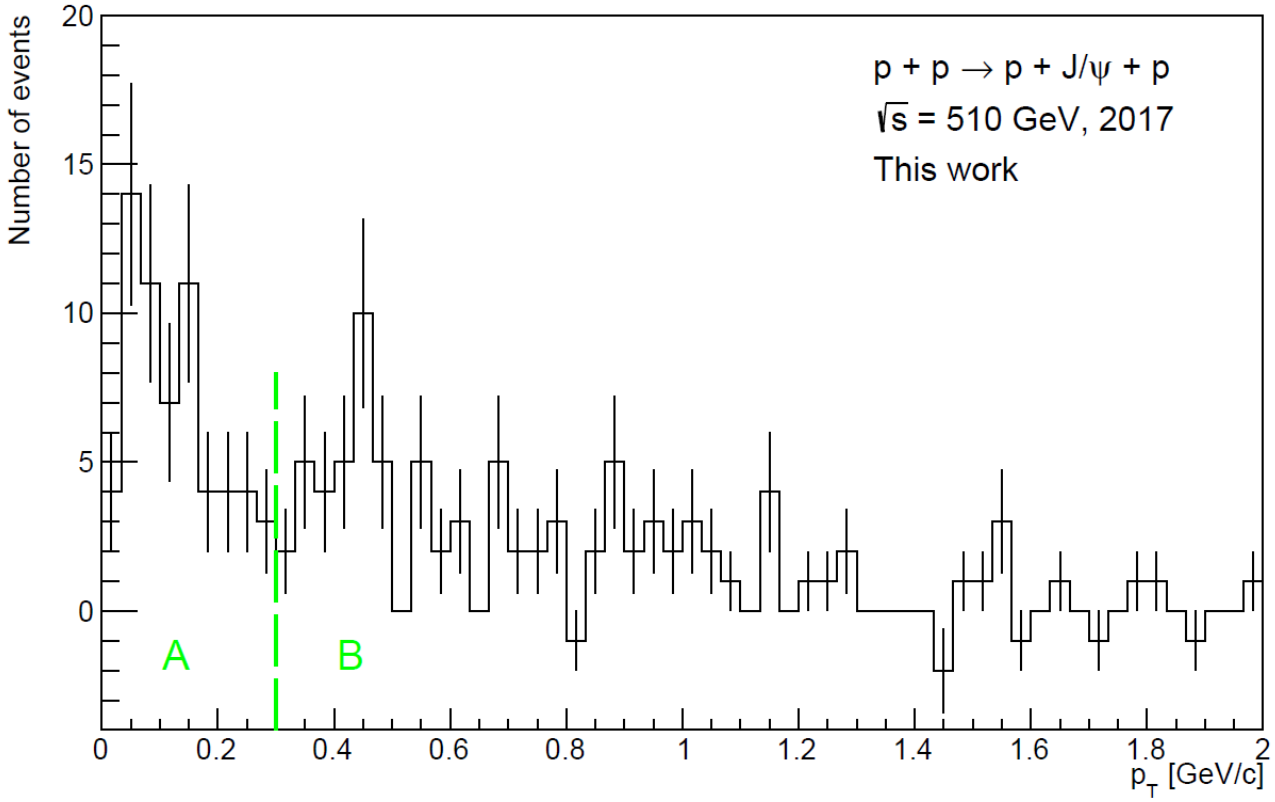


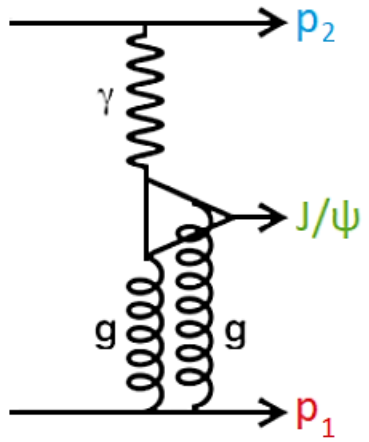


$m = 3.08 \pm 0.05$ GeV/c^2
$\sigma = 0.055 \pm 0.005$ GeV/c^2
Raw yield = 1528 J/ψ

$m = 3.085 \pm 0.006$ GeV/c^2
$\sigma = 0.059 \pm 0.005$ GeV/c^2
Raw yield = 137 J/ψ

MISSING P_T



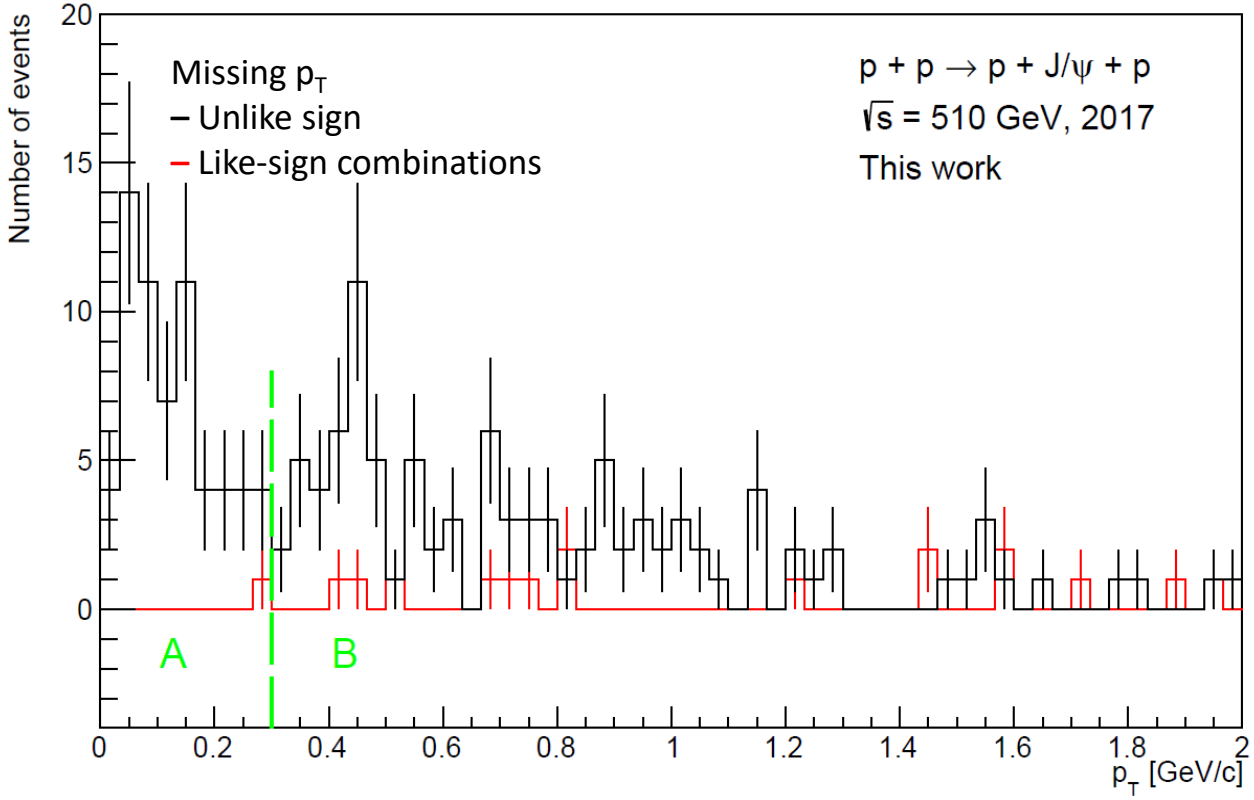


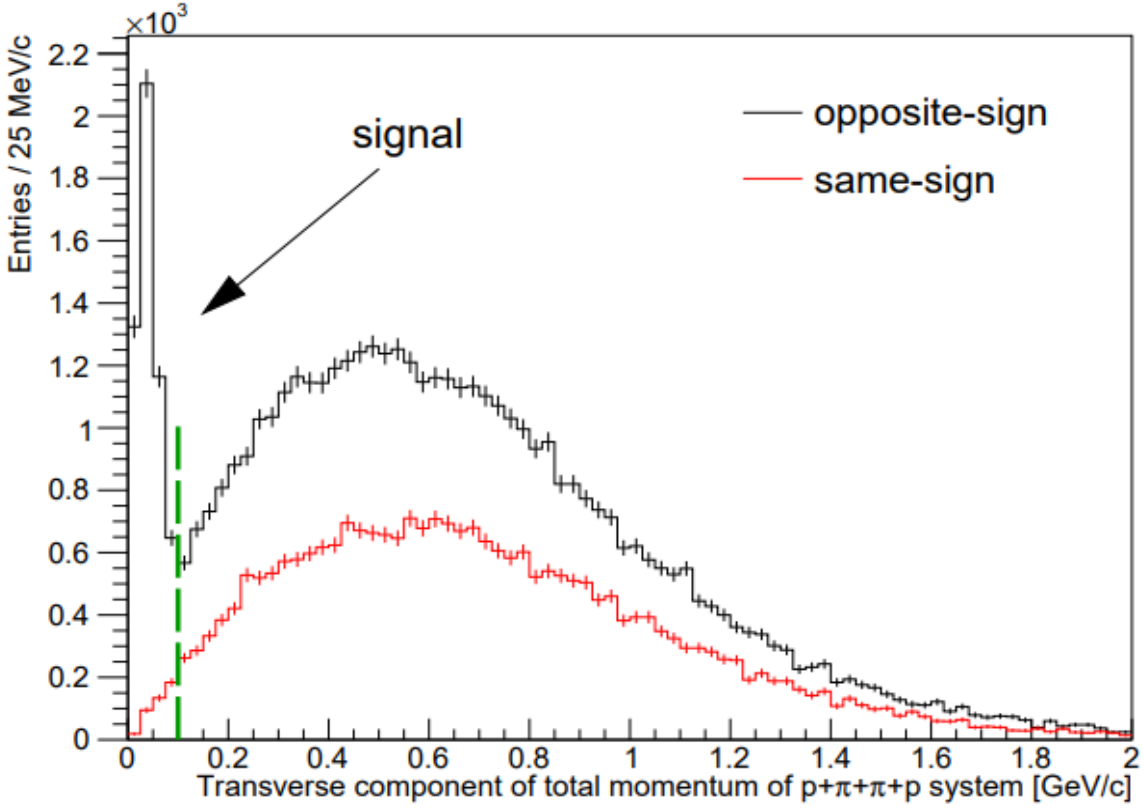
- Momentum conserved $(\mathbf{p}_1 + \mathbf{p}_2 + \mathbf{p}_{J/\psi})_T = 0$
- J/ψ and proton measured
- p_T of virtual photon is the missing p_T
- $-\mathbf{p}_{2,T} = (\mathbf{p}_1 + \mathbf{p}_{J/\psi})_T$

A: Peak at zero consistent with the exclusive process

B: Broad structure from 0.3 GeV is consistent with non-exclusive processes

MISSING P_T





Distribution shape comparable with measurement of central exclusive production at the STAR experiment in *pp* collisions at $\sqrt{s}$ = 200 GeV in 2015 despite smaller statistics

(Taken from Ref. [8].)

Thank you for your attention!

SUMMARY

- Analysis of pp collisions at $\sqrt{s}$ = 510 GeV
- J/ψ photoproduction with tagged forward proton

- Applied cuts for background suppression
- J/ψ meson identified in the uncorrected invariant mass distribution
- Background consisting of like-sign pairs subtracted
- Raw yield of J/ψ calculated for data before and after RP cut
- First look at the p_T distribution of virtual photon, shape compared

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EVENT SELECTION BACKUP

- JPsi*HTTP trigger (100.22 mil events)
- Exactly 1 vertex
- Vertex |z| position < 100 cm
- Track selection
  - $|\eta_{BEMC}|$ of primary tracks < 1
  - |DCA(z)| < 1 cm & DCA(xy) < 1.5 cm
  - nHitsFit > 15
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  - Exactly 2 tracks from the primary vertex with BEMC hits
- Back-to-back tracks in BEMC
  - $\Delta\phi_{BEMC}$ of segment numbers = 3
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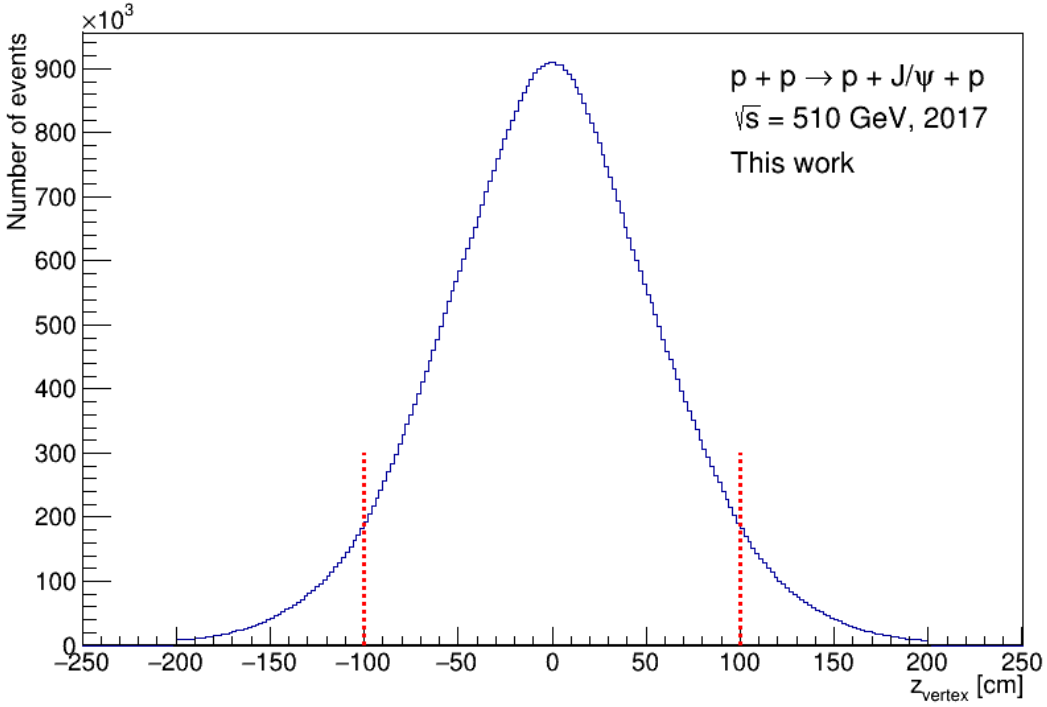

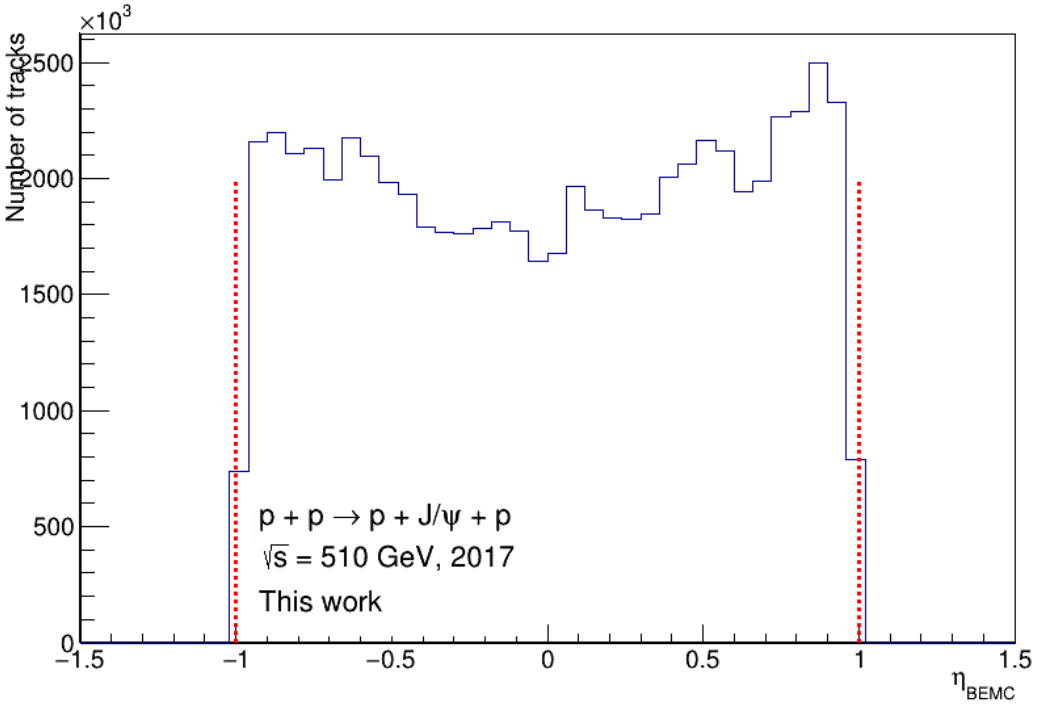

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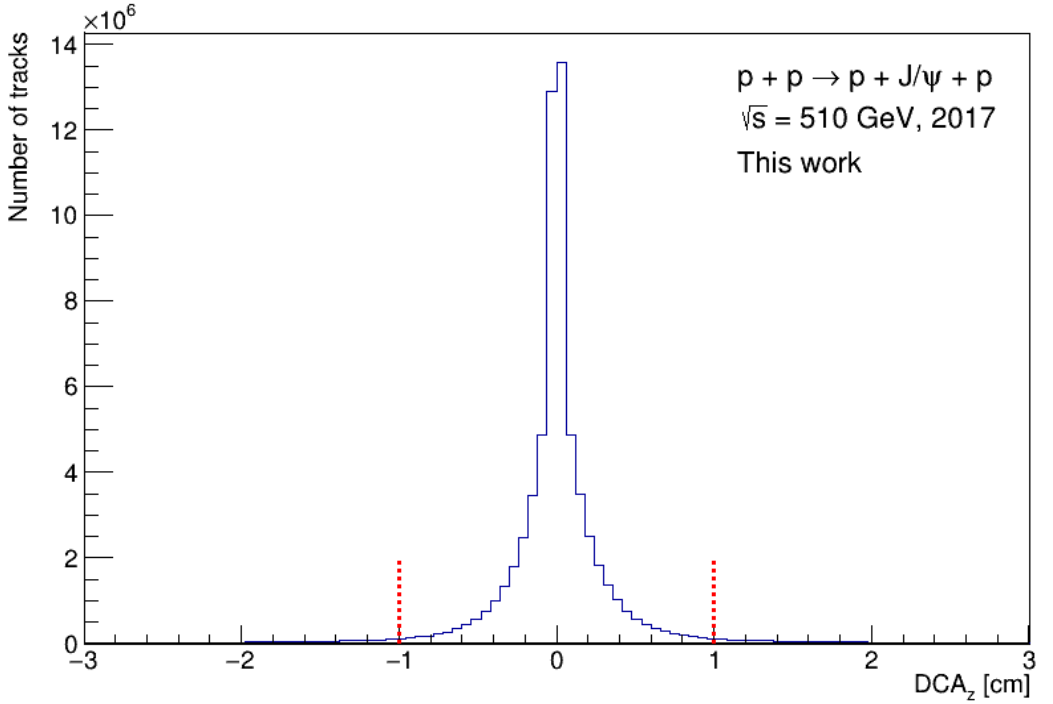

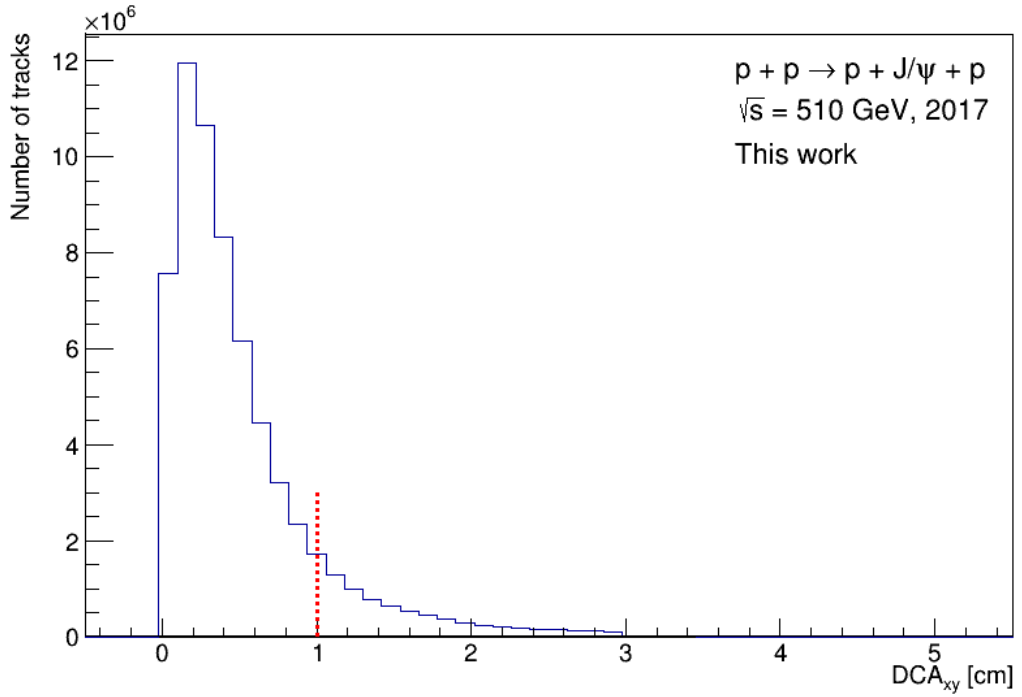

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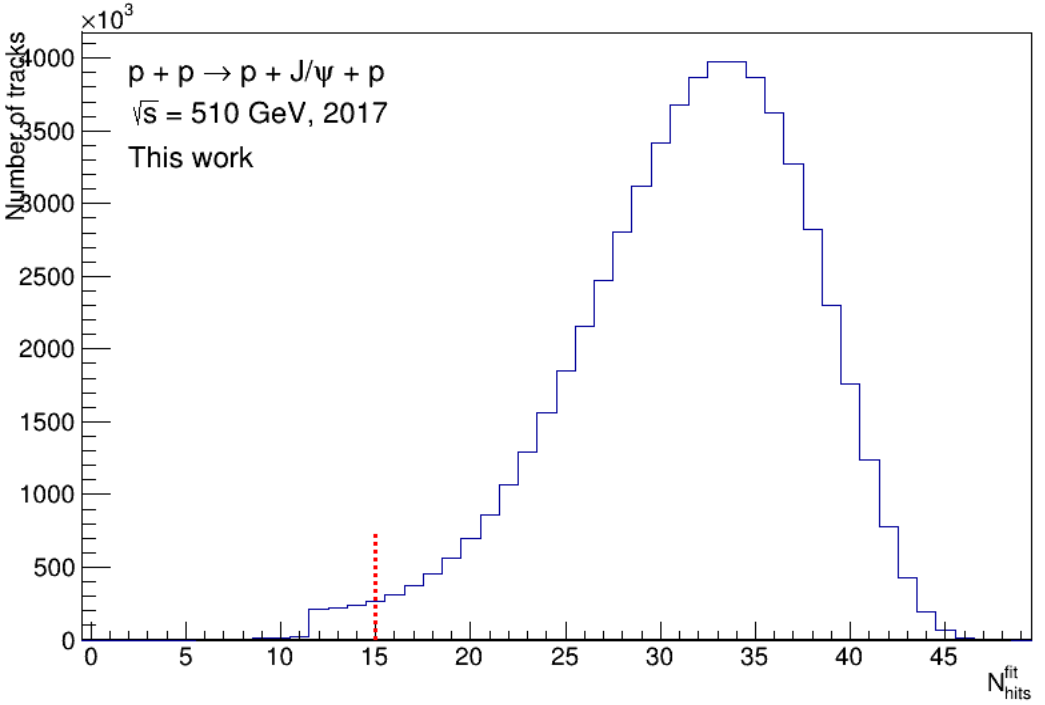

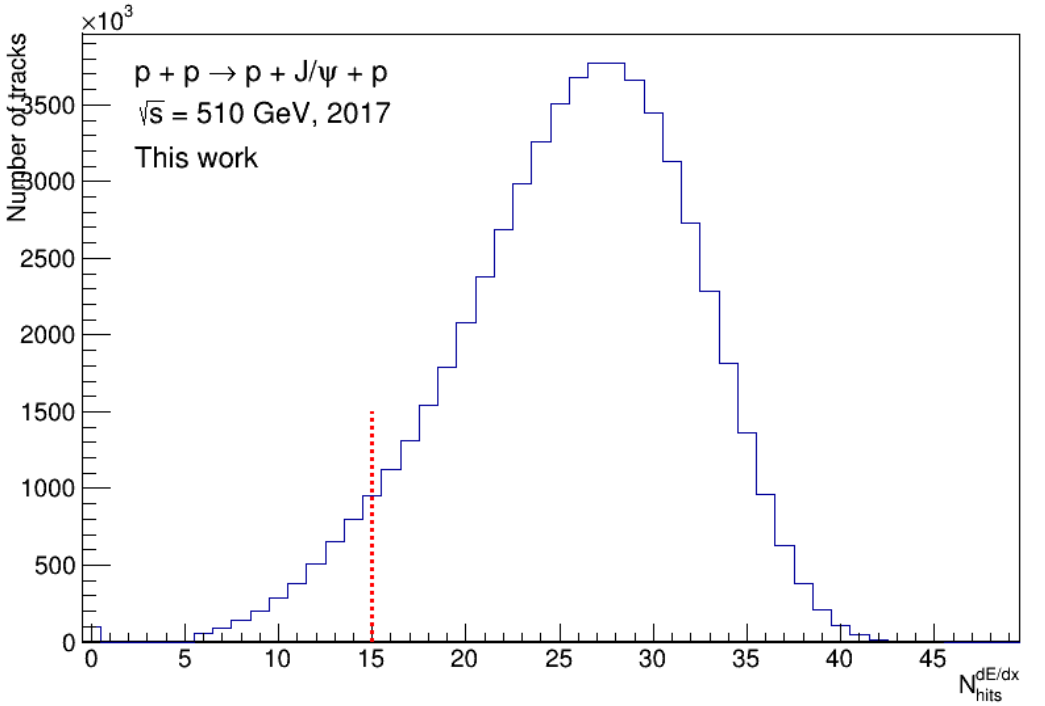

EVENT SELECTION BACKUP

- Back-to-back tracks in BEMC
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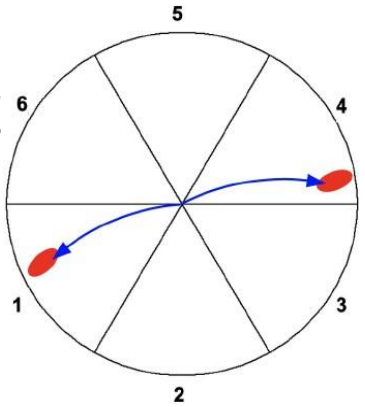

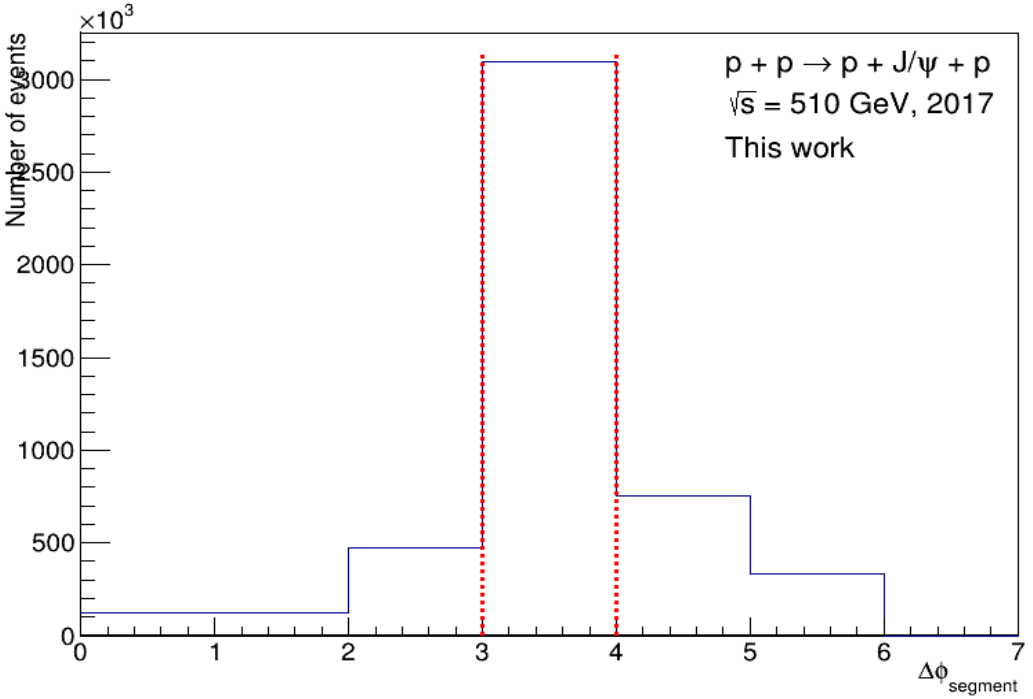

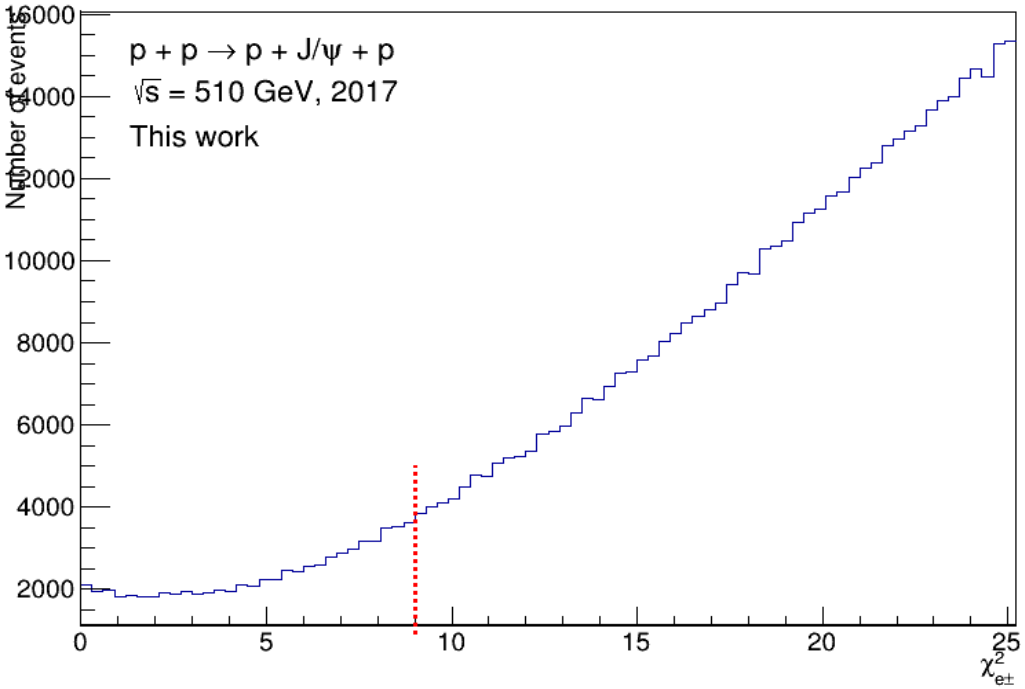

Michaela Sverakova (FNSPE, CTU)

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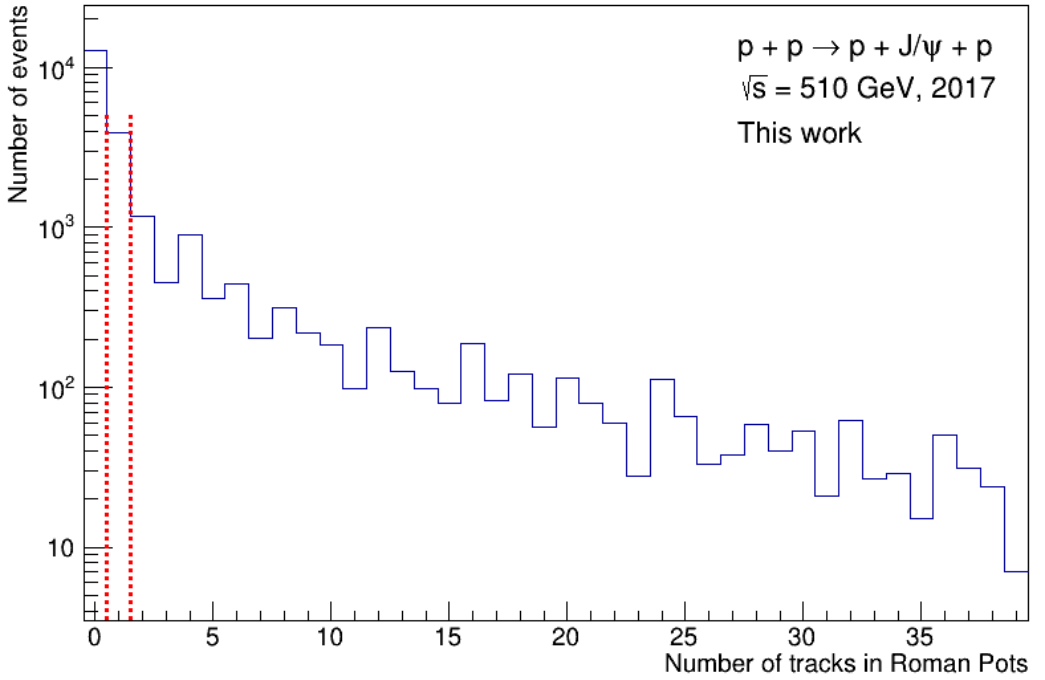
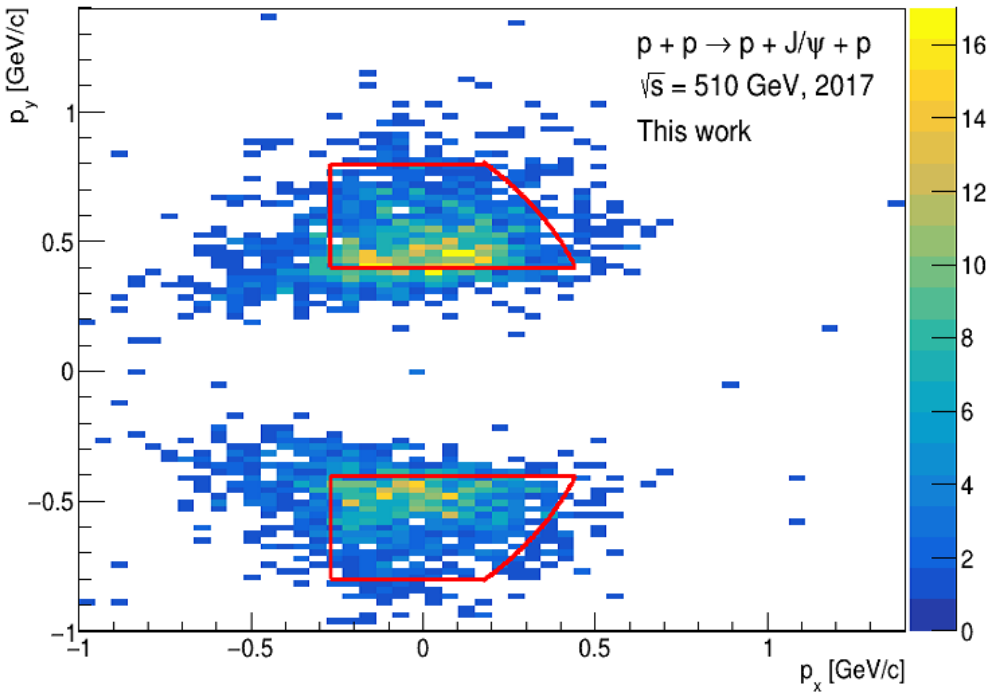


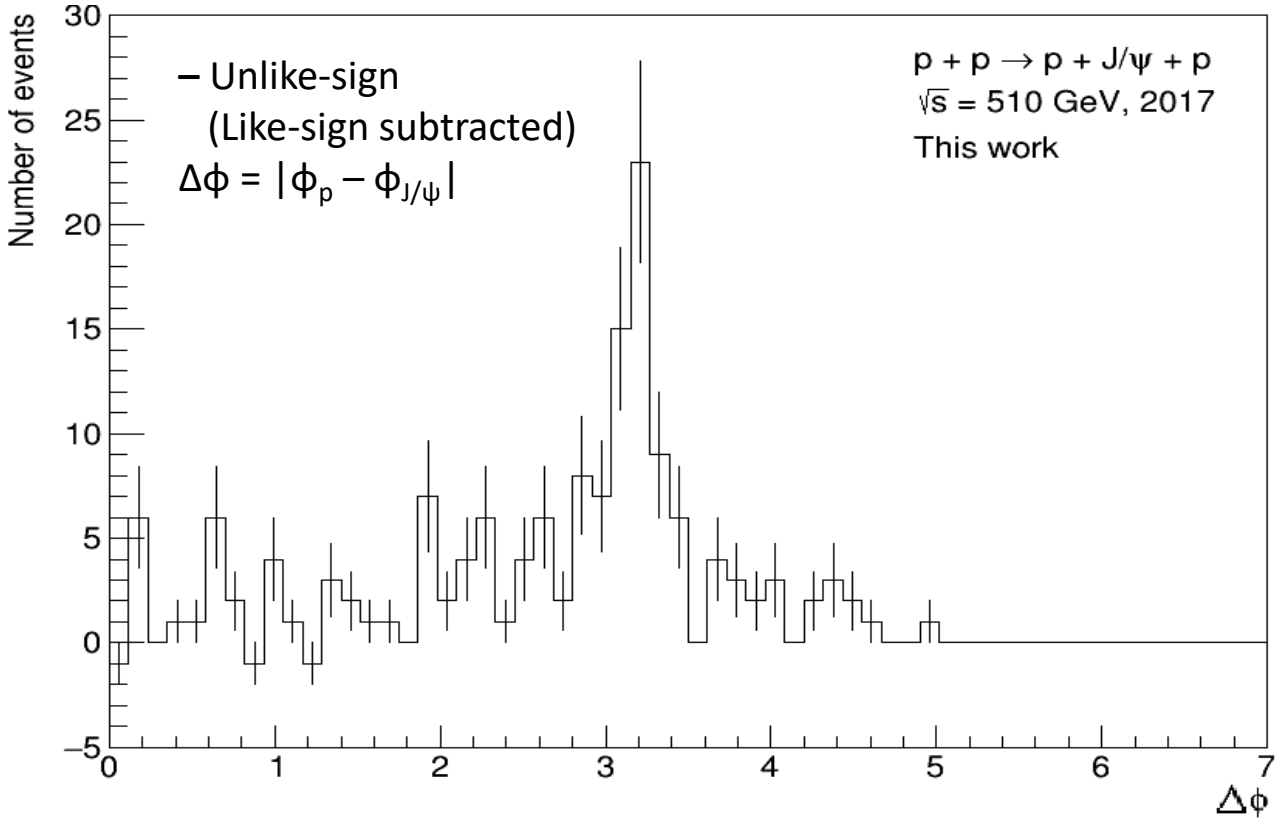


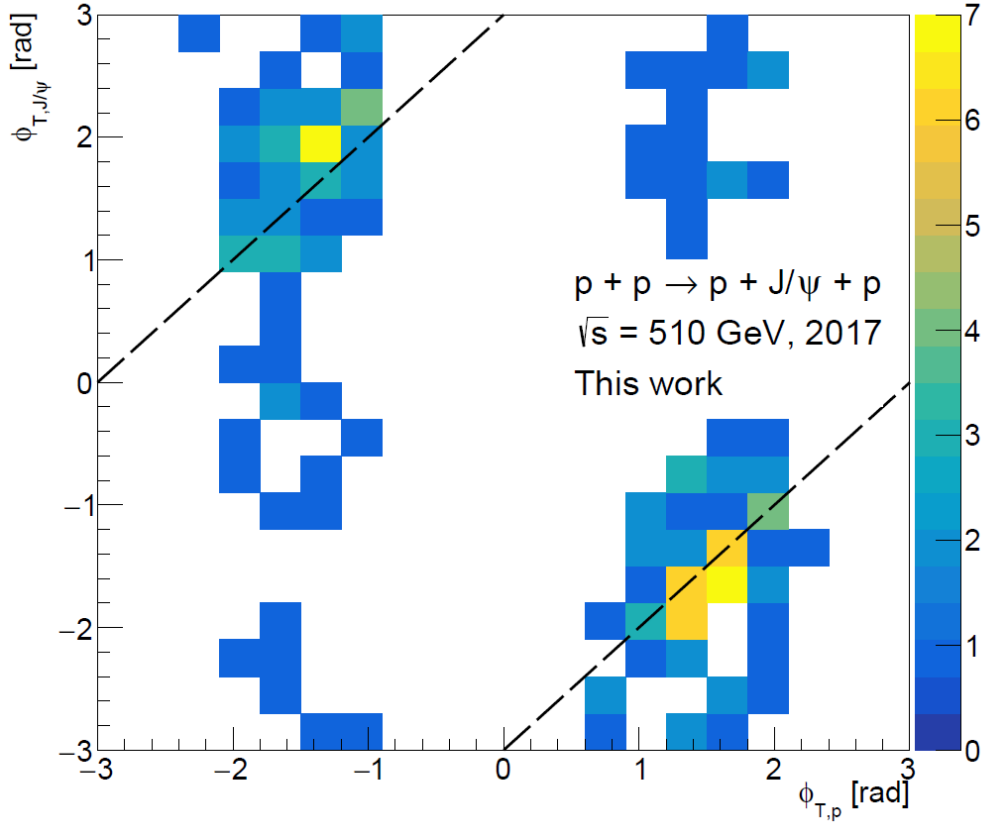
CHECK FOR J/ψ-RP proton balance

- Interest of this analysis to check the balance between the forward proton and the reconstructed J/ψ in the central barrel
- We look for the balance in the azimuthal angle and transverse momentum
- All plots in this section
  - after RP cuts, only for mass-candidates reconstructed J/ψ

  (±3σ region based on fit result)

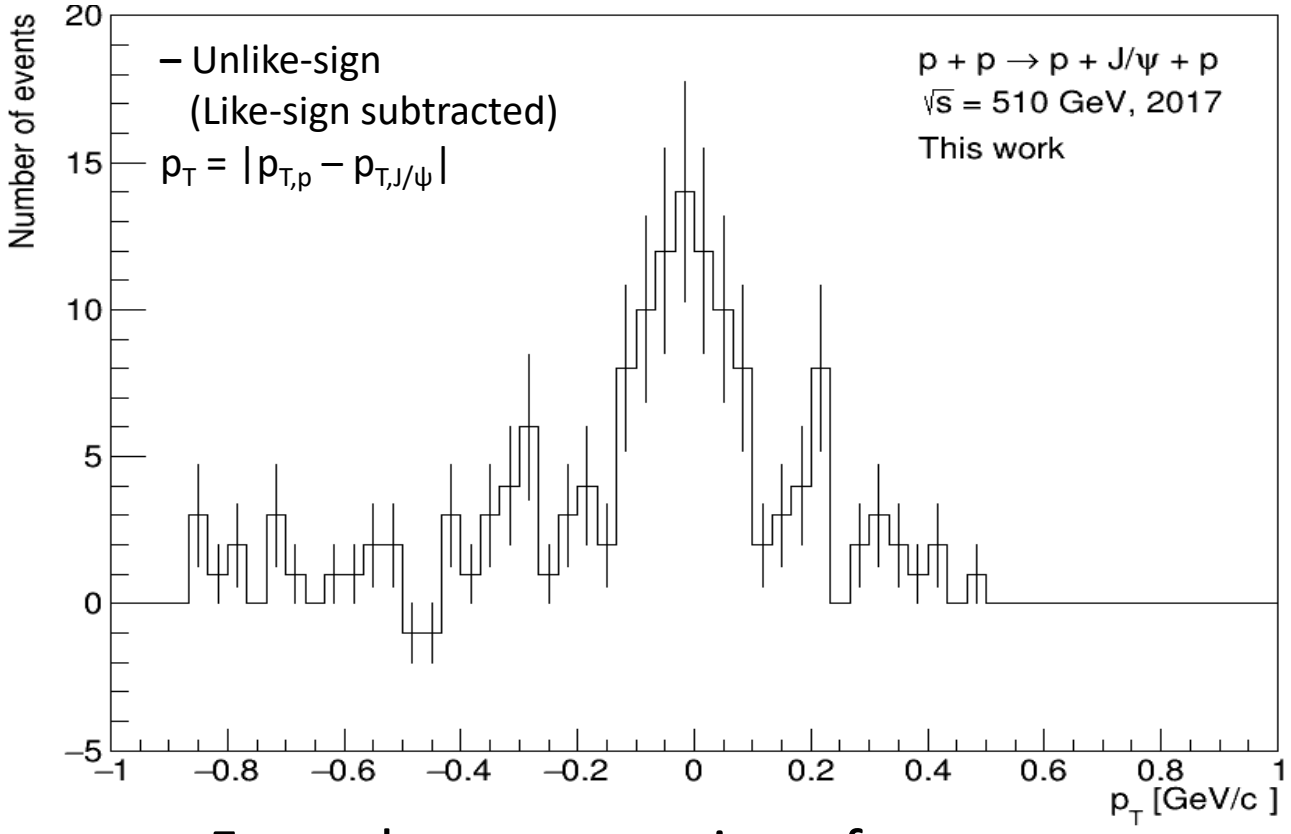
J/ψ-RP proton balance: azimuthal angle

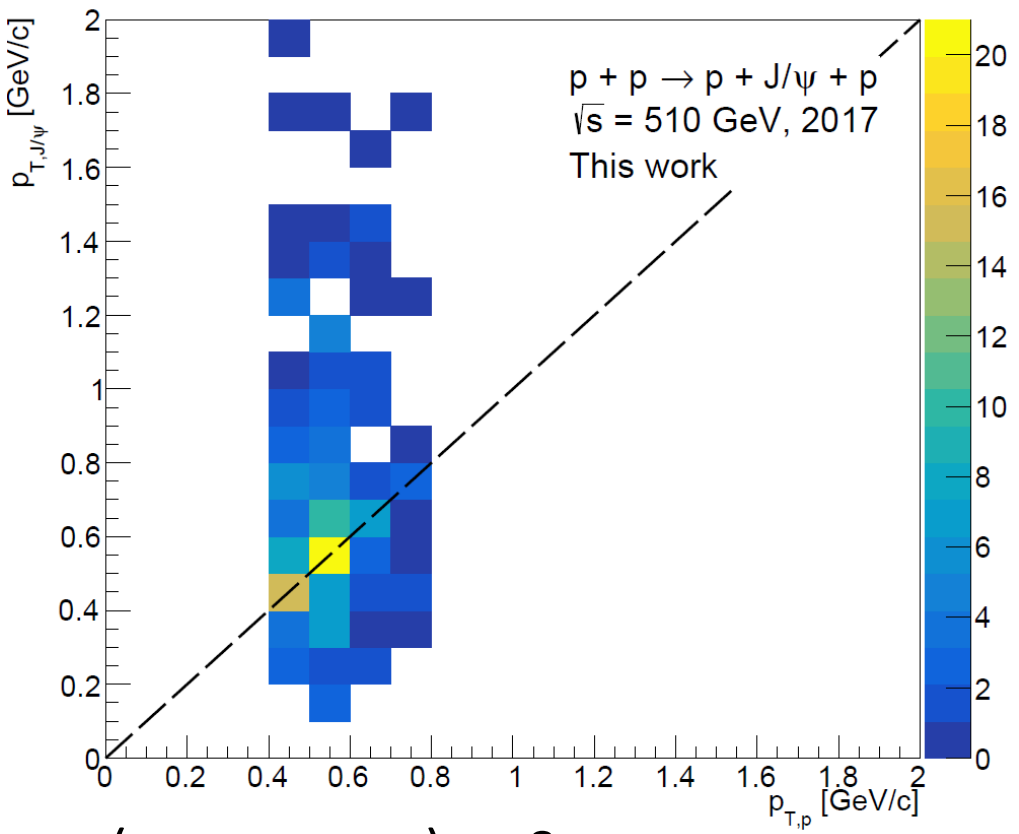




- Detected proton and reconstructed J/ψ should be back-to-back
- Based on the kinematics of the collision

J/ψ-RP proton balance: p_T





- From the conservation of transverse momentum $(p_1 + p_2 + p_{J/\psi})_T = 0$
- Small-p_T proton scatters at a small angle -> p_T of the virtual photon is small
- We take $p_{1,T} \sim 0$ which gives $p_{2,T} = -p_{J/\psi}$