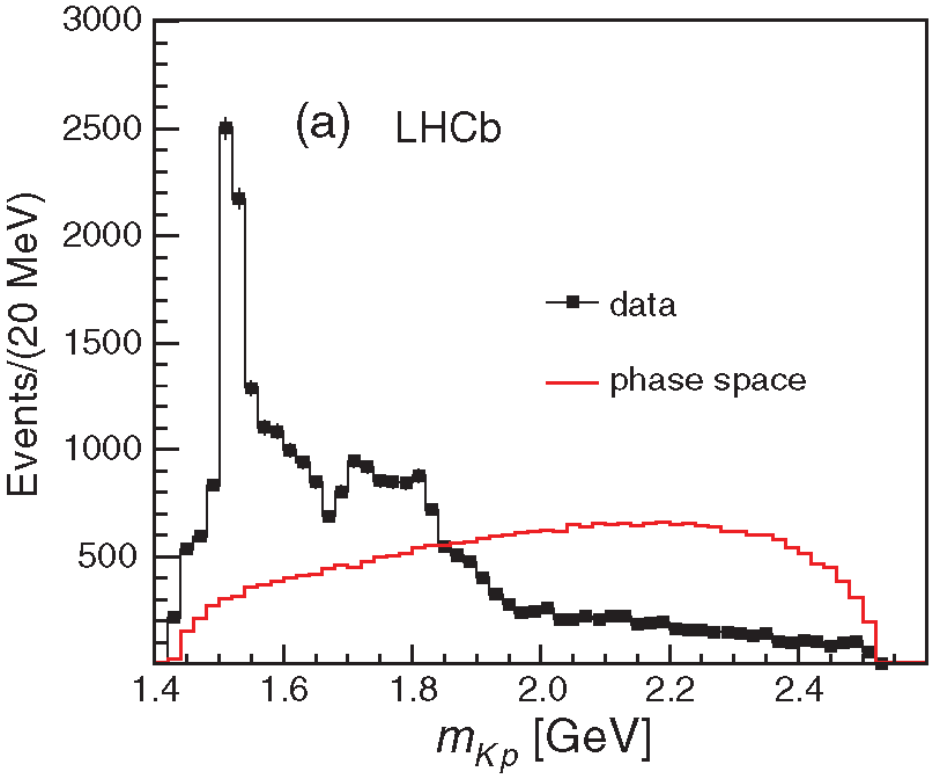
JÜLICH
FORSCHUNGSZENTRUM

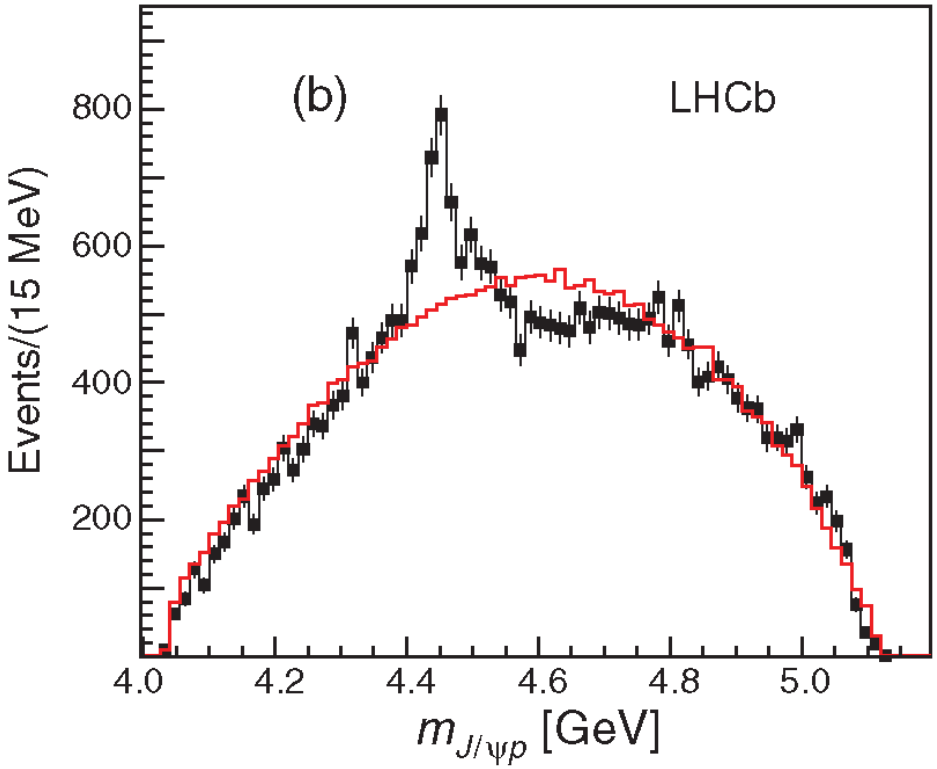
Can We See Hidden Charm Penta-quarks in the Reaction $pp \to pp\,J/\psi$?

Jun 25, 2019 | Albrecht Gillitzer

PANDA Collaboration Meeting 19/2, GSI Darmstadt

The LHCb Pentaquark seen in $\Lambda_b \to p\, J/\psi\, K^-$ decays



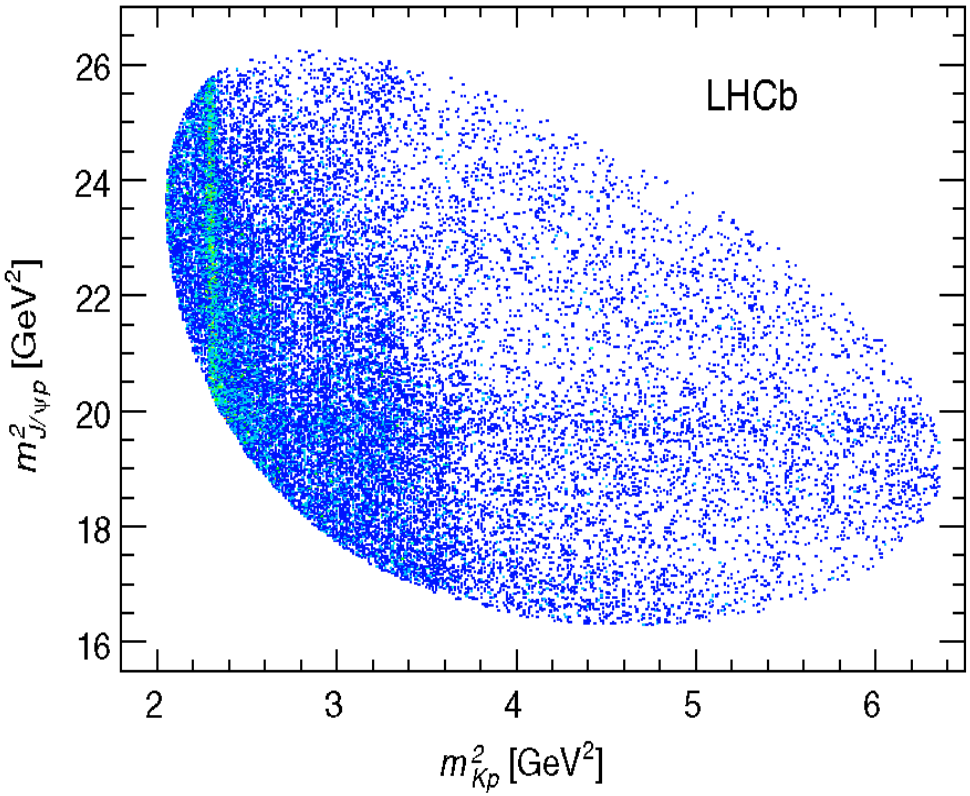


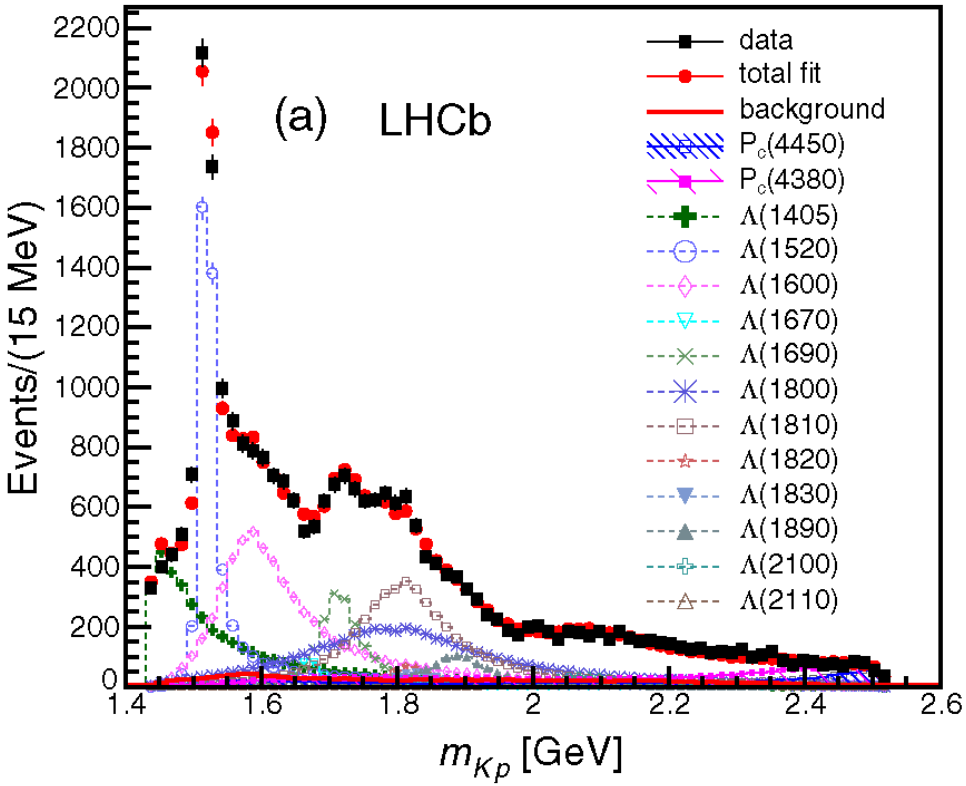
$P_c(4450)^+$:

- $M = 4449.8 \pm 1.7 \pm 2.5$ MeV
- $\Gamma = 39 \pm 5 \pm 19$ MeV
- $J^P = 5/2^+$ (or $5/2^-$ or $3/2^-$?)

R. Aaij *et al.*, PRL 115 (2015) 072001

The LHCb Pentaquark: Contribution of Λ^* States





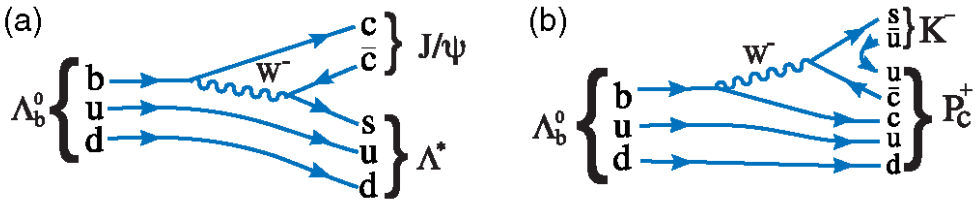


FIG. 1 (color online). Feynman diagrams for (a) $\Lambda_b^0 \to J/\psi\Lambda^*$ and (b) $\Lambda_b^0 \to P_c^+ K^-$ decay.

Λ^* resonances play a strong role

Λ^* spectrum not sufficiently known

R. Aaij *et al.*, PRL 115 (2015) 072001

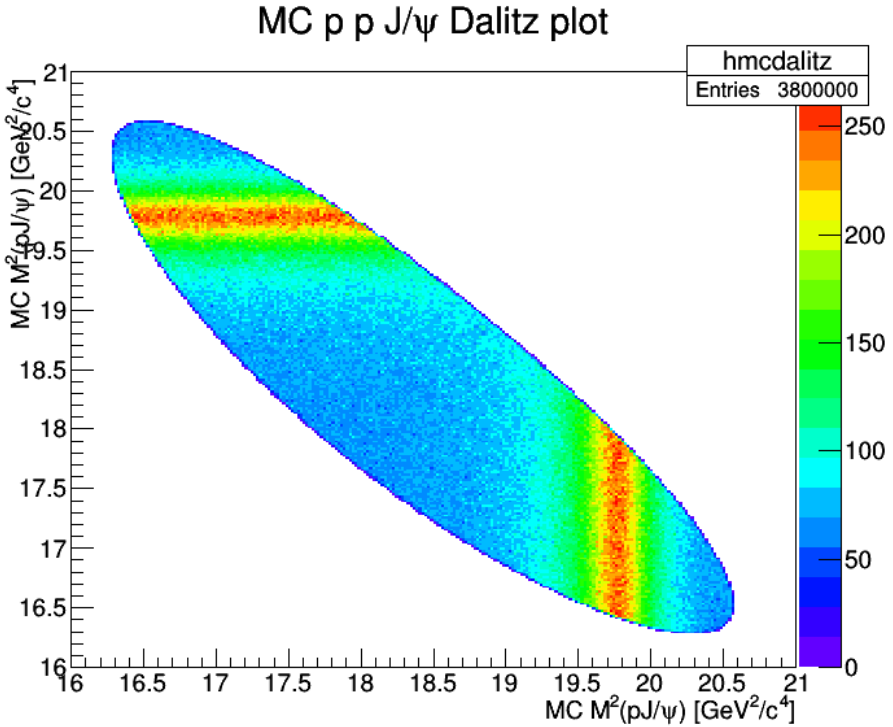
What can we do in PANDA?

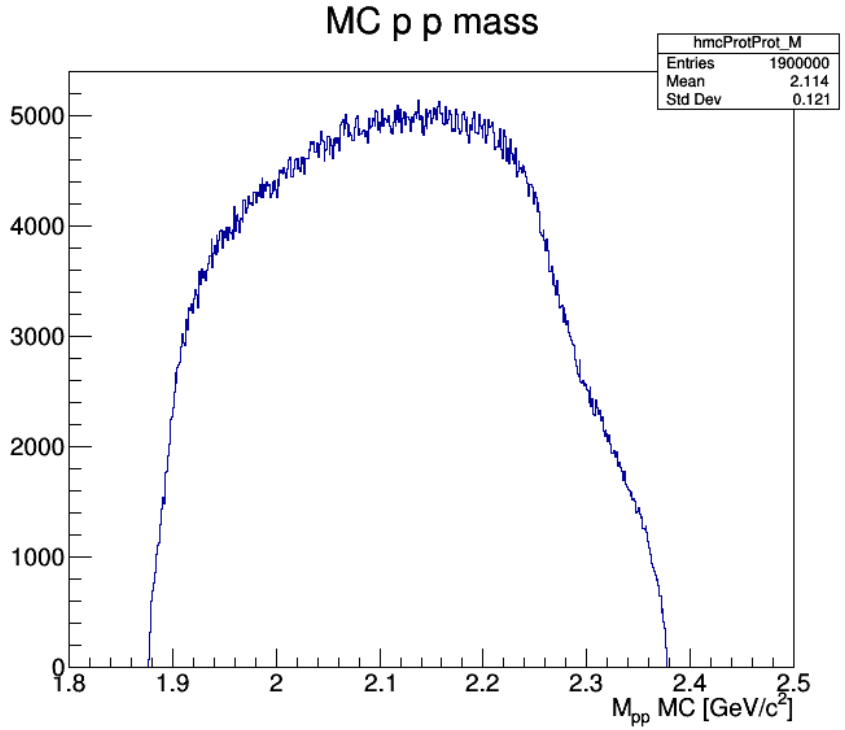
- We can already search for $P_c(4450)^+$ during commissioning with protons in $pp \to pp\,J/\psi$?
- Close to but still below the HESR kinematic limit (?)
- Different production mechanism, no contribution of Λ^* resonances
- Later on, if still interesting, it can of course also be done with antiprotons in $\bar{p}p \to \bar{p}p\,J/\psi$
- Search can be extended by including η_c in $pp \to pp\eta_c$

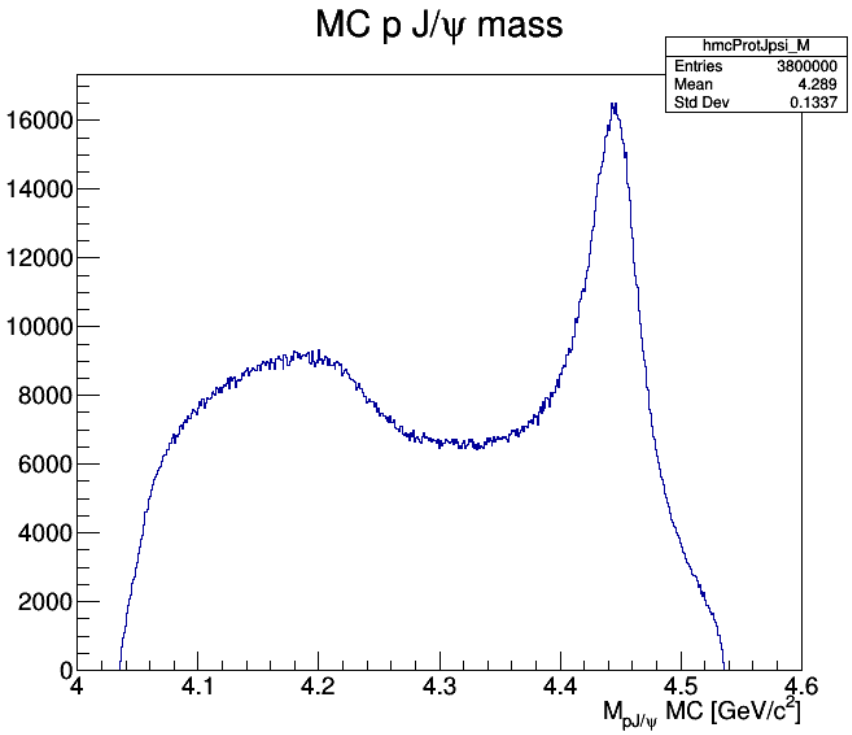
15 GeV/c $pp \to pp\,J/\psi$ Full PandaRoot Simulation

- 50% resonant, 50% continuum
- LHCb central values for P_c^+
- $J/\psi \to e^+e^-$ (VLL)
- PHSP all other cases
- 1.9 M events
- Analysis
  - Decay Tree Fitter
  - Ideal PID (here)
  - Realistic PID (completed)
  - 10 M FTF background

```
noPhotos

Decay ppSystem
0.5 p+ p+ J/psi       PHSP;
0.5 p+ Pc(4450)+      PHSP;
Enddecay

Decay Pc(4450)+
0.5 p+ J/psi          PHSP;
Enddecay

Decay J/psi
1.0 e+ e-             VLL;
Enddecay

End
```

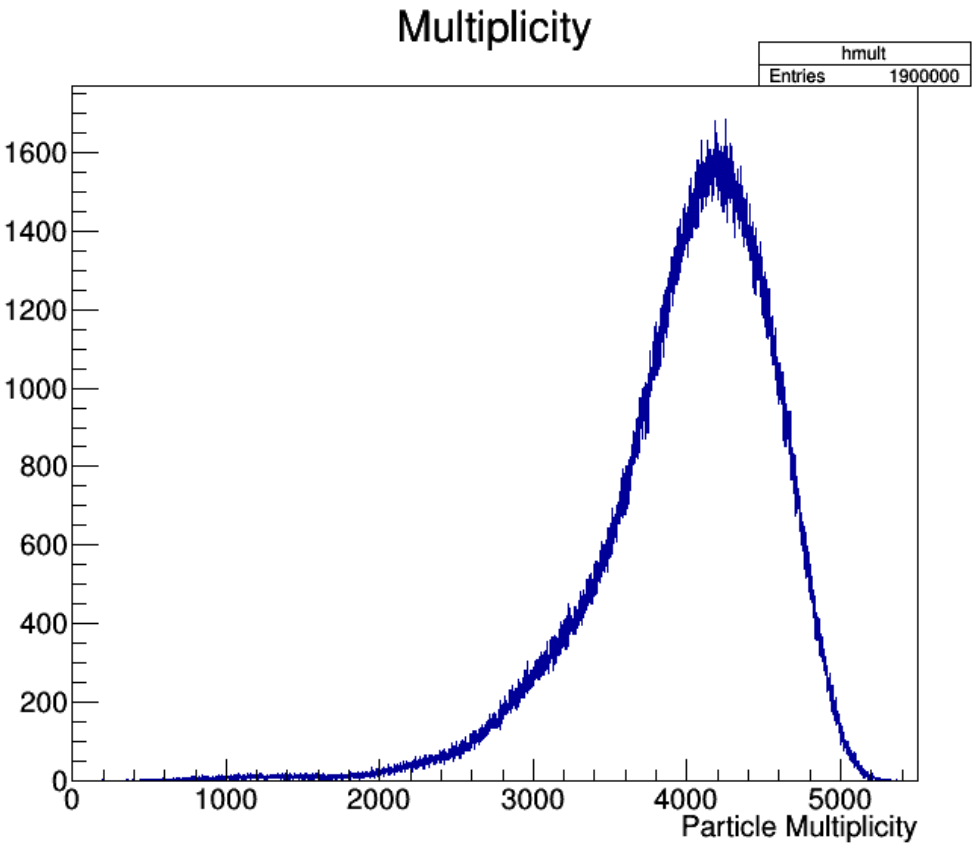


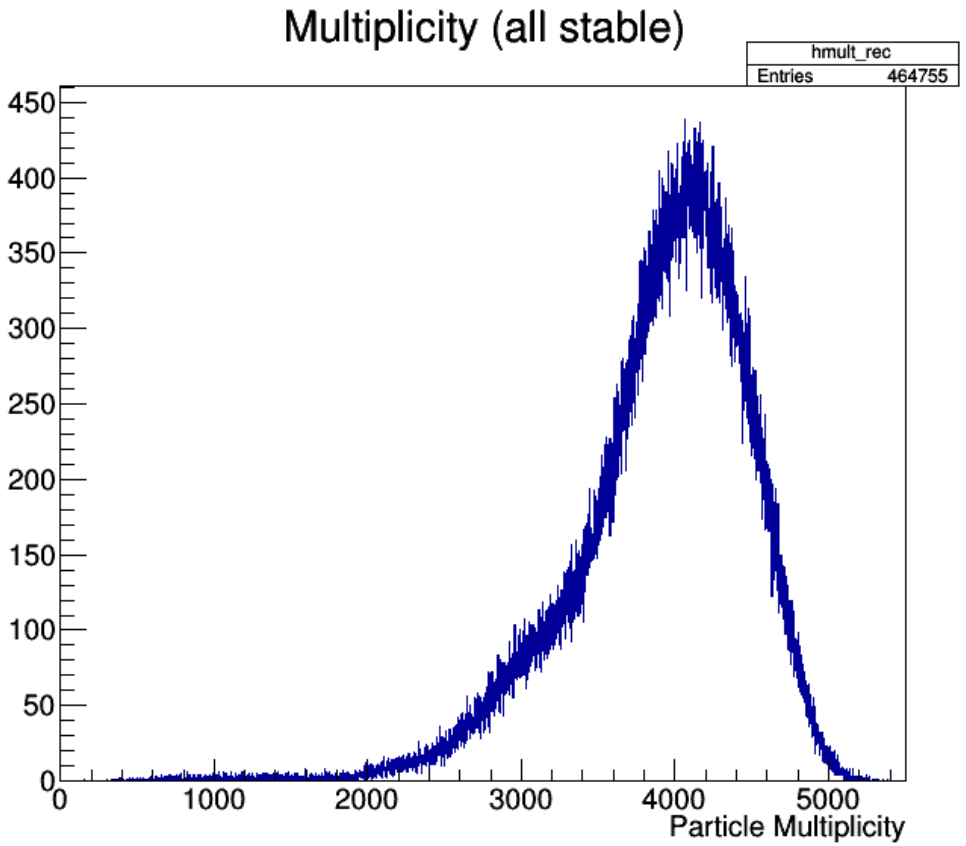




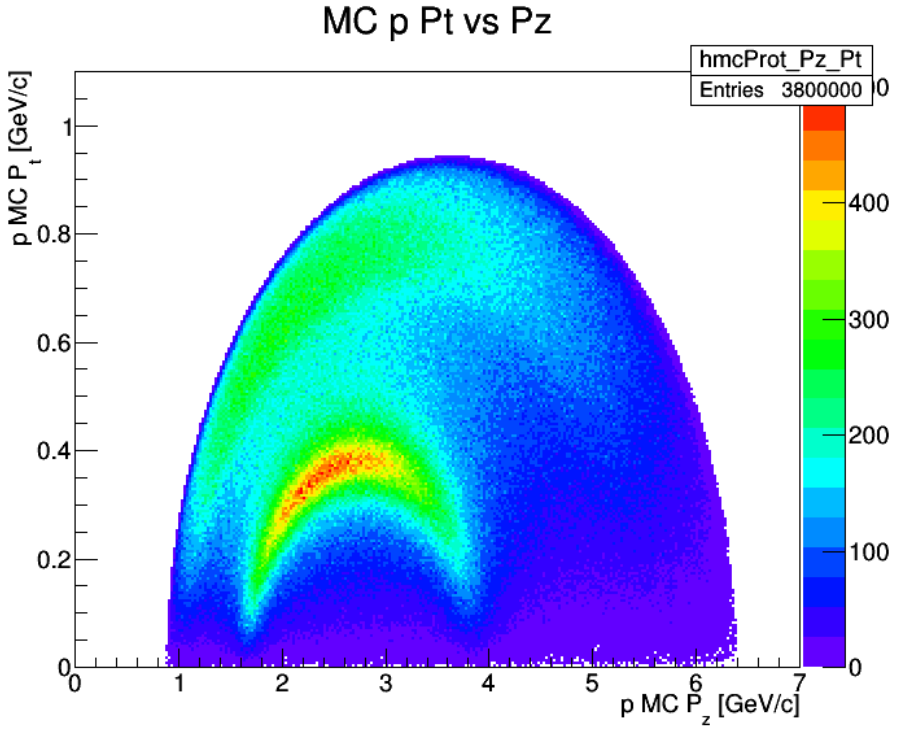
Generated events

High MC Track Multiplicity





- Many secondary particles at 15 GeV/c
- Also for reconstructable events (24.5%) → good pre-selection


MC p Pt vs Pz
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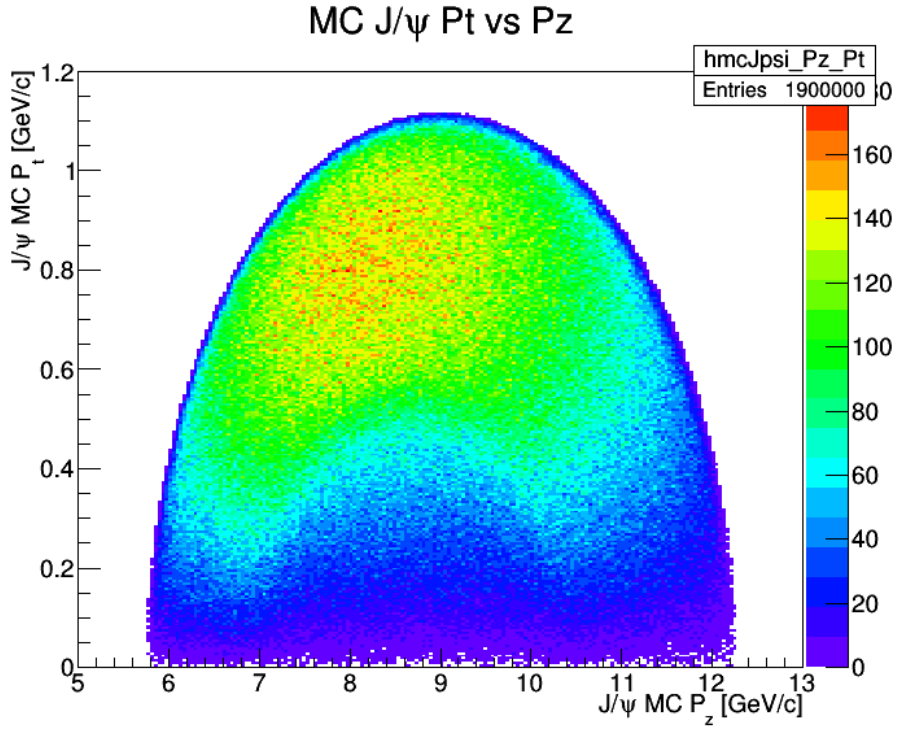
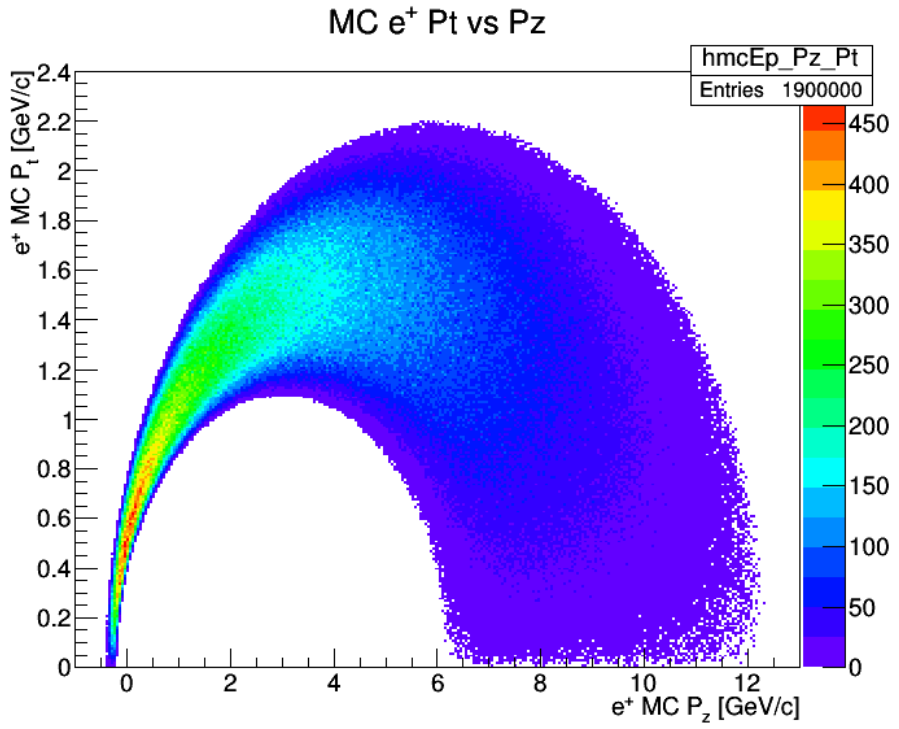
p MC P_t [GeV/c]
p MC P_z [GeV/c]


MC J/ψ Pt vs Pz
hmcJpsi_Pz_Pt
Entries 1900000
J/ψ MC P_t [GeV/c]
J/ψ MC P_z [GeV/c]


MC e+ Pt vs Pz
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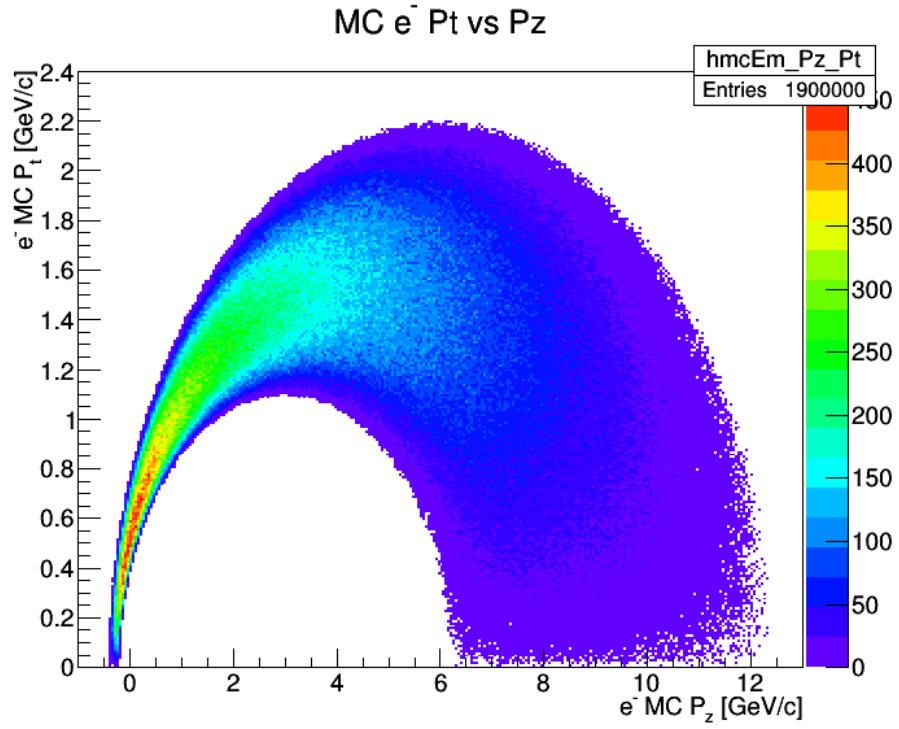
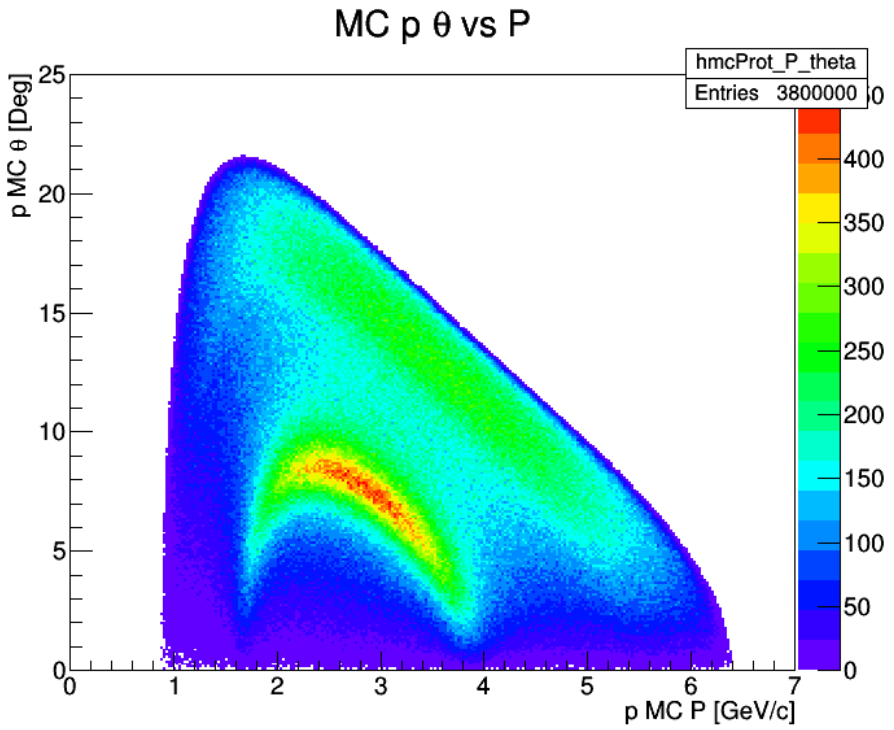
Entries 1900000
e+ MC P_t [GeV/c]
e+ MC P_z [GeV/c]


MC e- Pt vs Pz
hmcEm_Pz_Pt
Entries 1900000
e- MC P_t [GeV/c]
e- MC P_z [GeV/c]


MC p θ vs P
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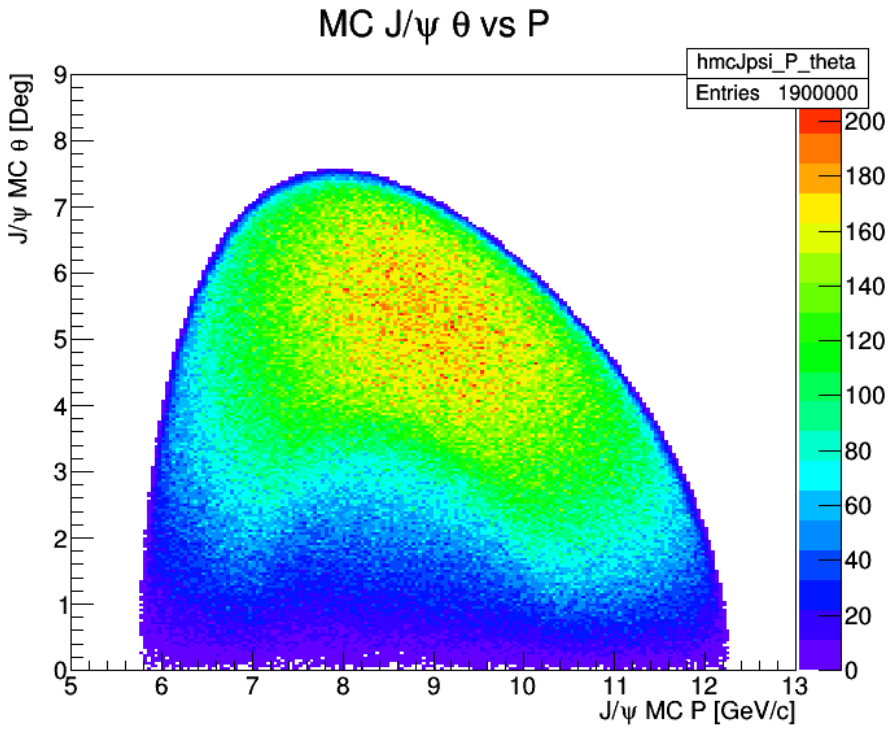
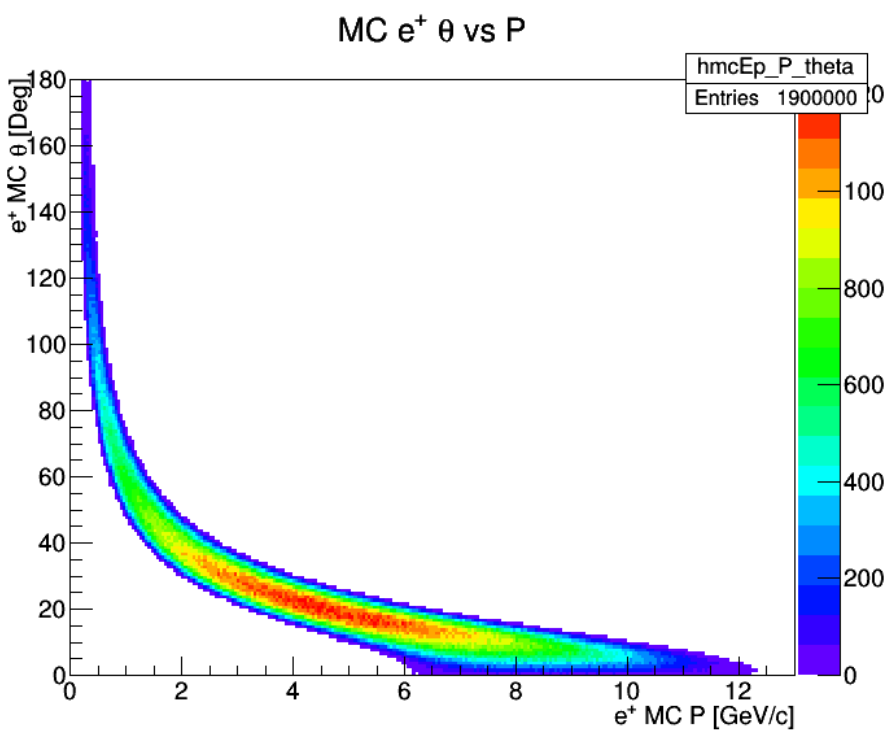
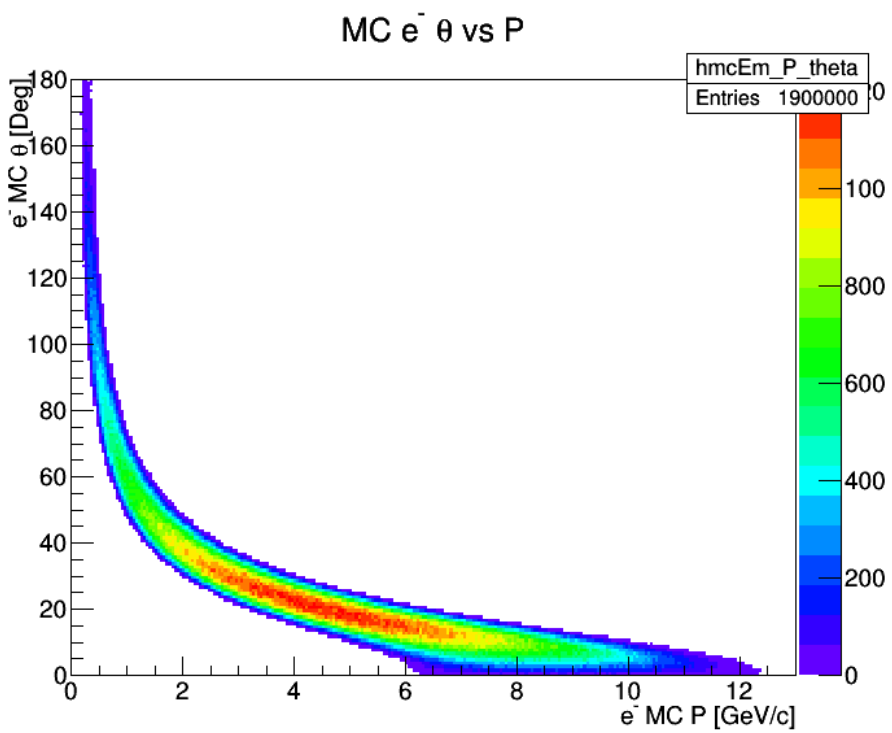
Entries 3800000
p MC θ [Deg]
p MC P [GeV/c]


MC J/ψ θ vs P
hmcJpsi_P_theta
Entries 1900000
J/ψ MC θ [Deg]
J/ψ MC P [GeV/c]


MC e+ θ vs P
hmcEp_P_theta
Entries 1900000
e+ MC θ [Deg]
e+ MC P [GeV/c]

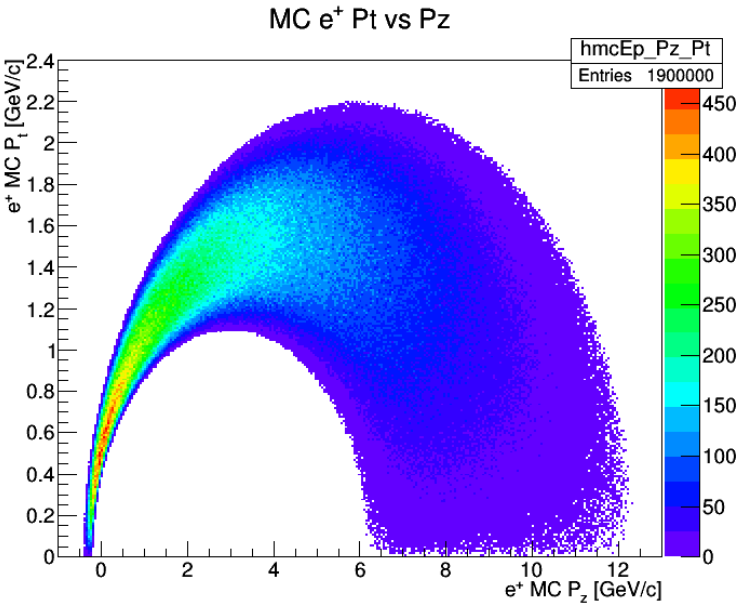

MC e- θ vs P
hmcEm_P_theta
Entries 1900000
e- MC θ [Deg]
e- MC P [GeV/c]

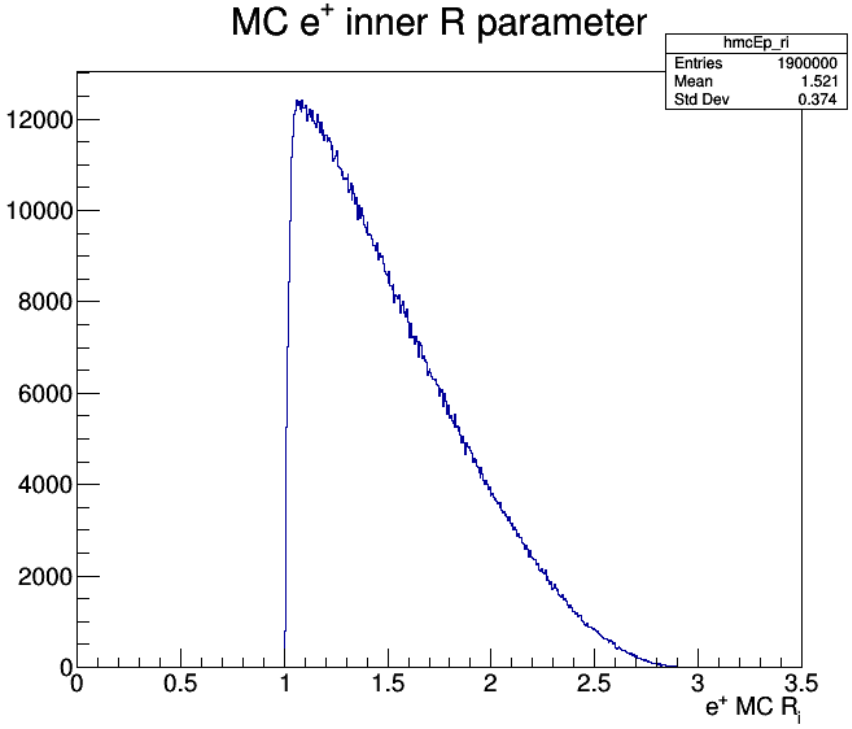
Preselection of p and e± Candidates

- Protons: $0.5\ \mathrm{GeV}/c < p < 8.0\ \mathrm{GeV}/c$ and $\theta < 30^o$
- Electrons: more complicated cut needed → use boundary of inner / outer ellipse to exclude empty region
- Ellipse: $\frac{(x-x_0)^2}{a^2} + \frac{y^2}{b^2} = 1$
- R parameter:

$$R_{i/o} = \sqrt{\left(\left(p_z - p_{i/o}\right)/a_{i/o}\right)^2 + p_t/b_{i/o}{}^2}$$

$$R_i > 0.9,\ R_o < 1.1$$

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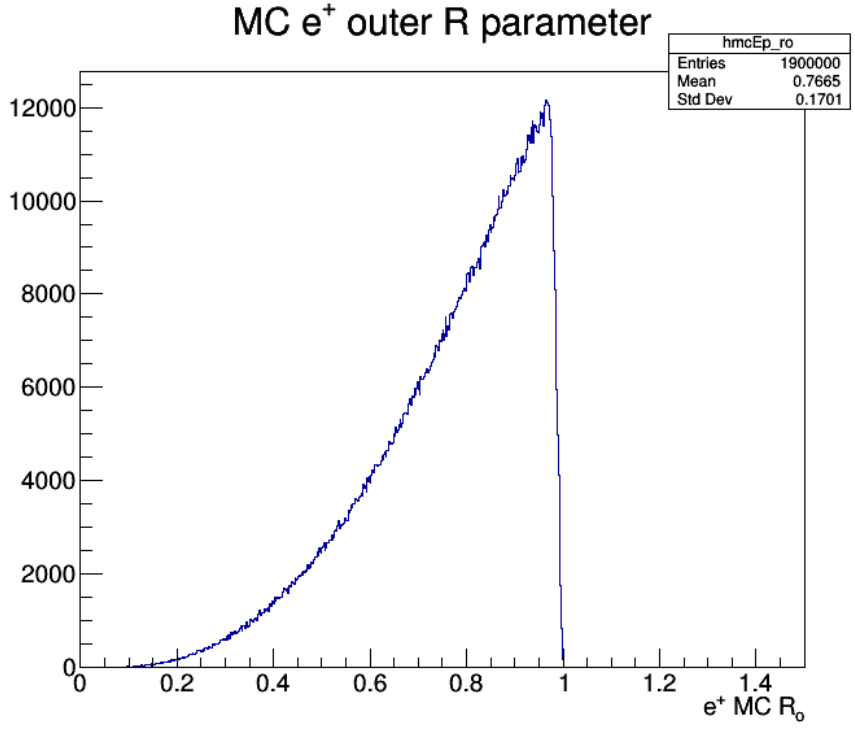
Std Dev 0.374
e+ MC Ri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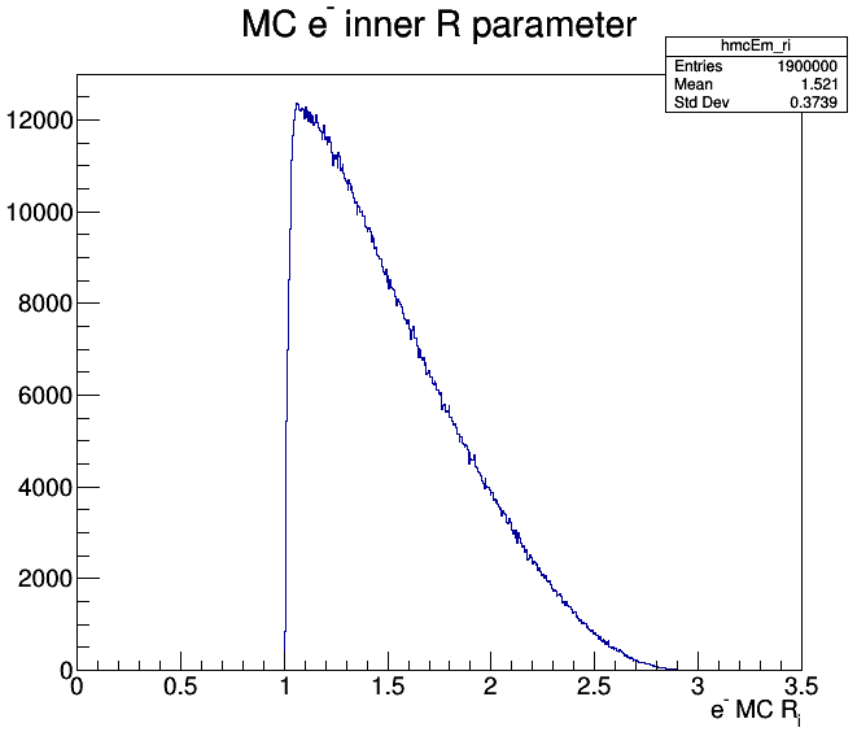
Std Dev 0.1701
e+ MC Ro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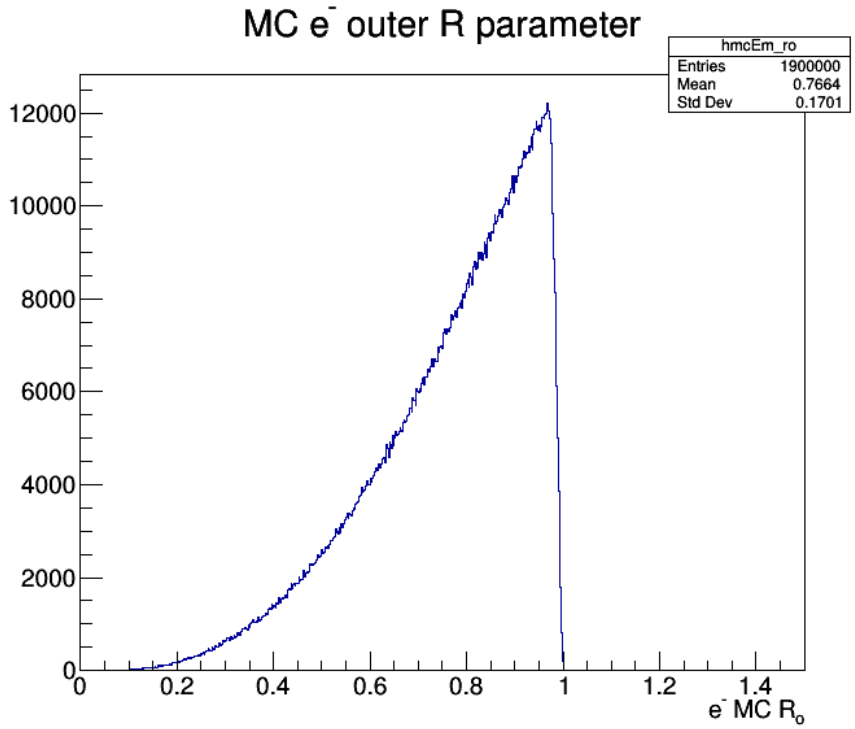
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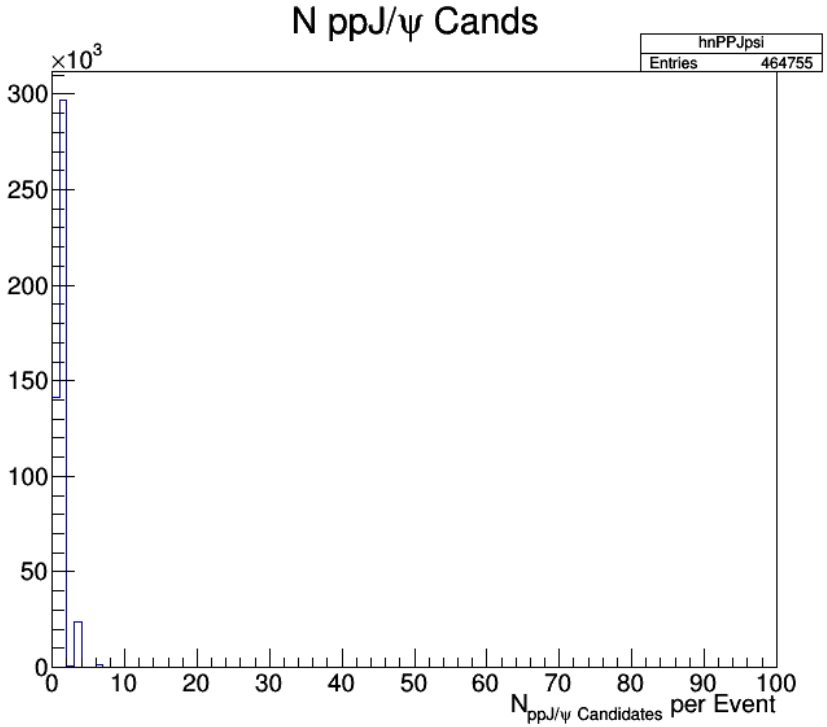
Std Dev 0.1701
e- MC Ro


N ppJ/ψ Cands
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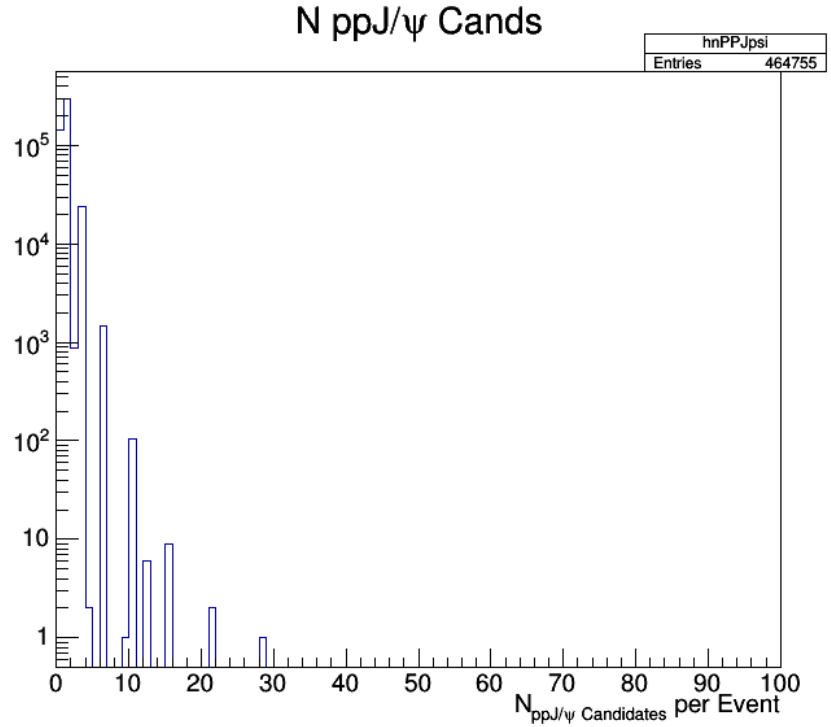
200
150
100
50
0
0 10 20 30 40 50 60 70 80 90 100
N ppJ/ψ Candidates per Event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10^2
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1
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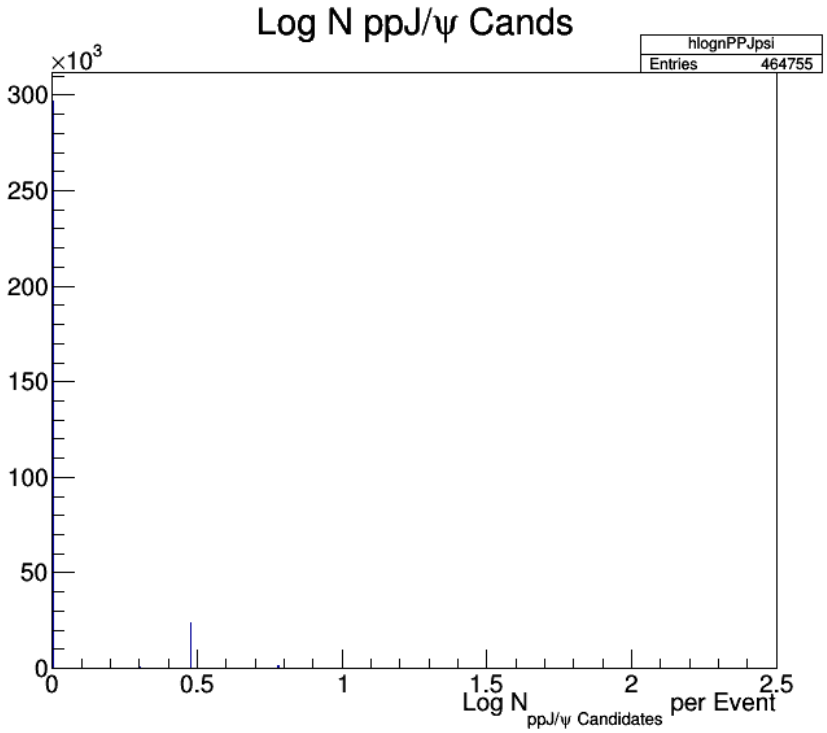
N ppJ/ψ Candidates per Event


Log N ppJ/ψ Cands
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×10^3
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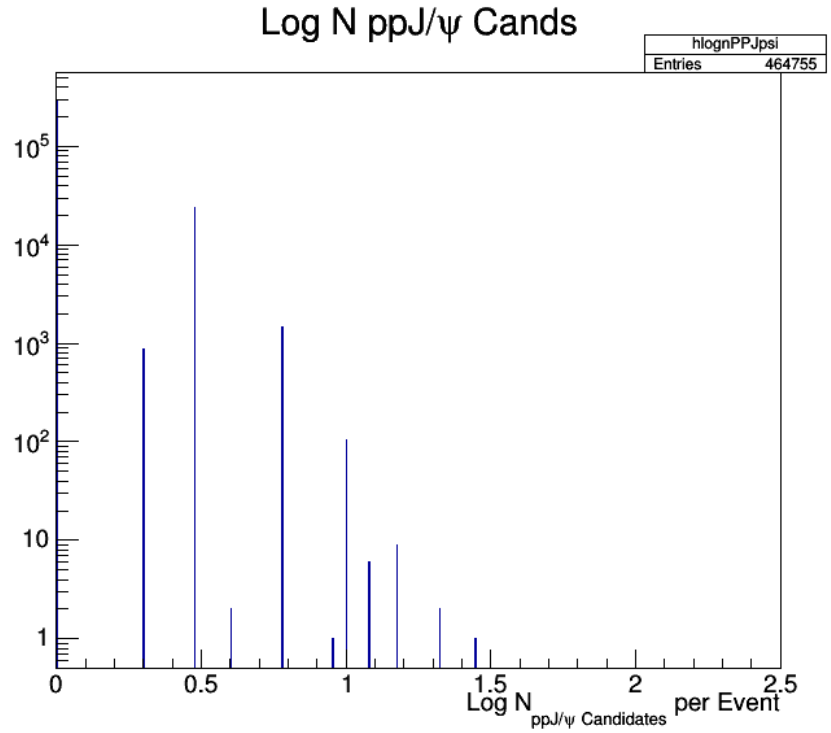
250
200
150
100
50
0
0 0.5 1 1.5 2 2.5
Log N ppJ/ψ Candidates per Event


Log N ppJ/ψ Cands
hlognPPJpsi
Entries 464755
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10^4
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10^2
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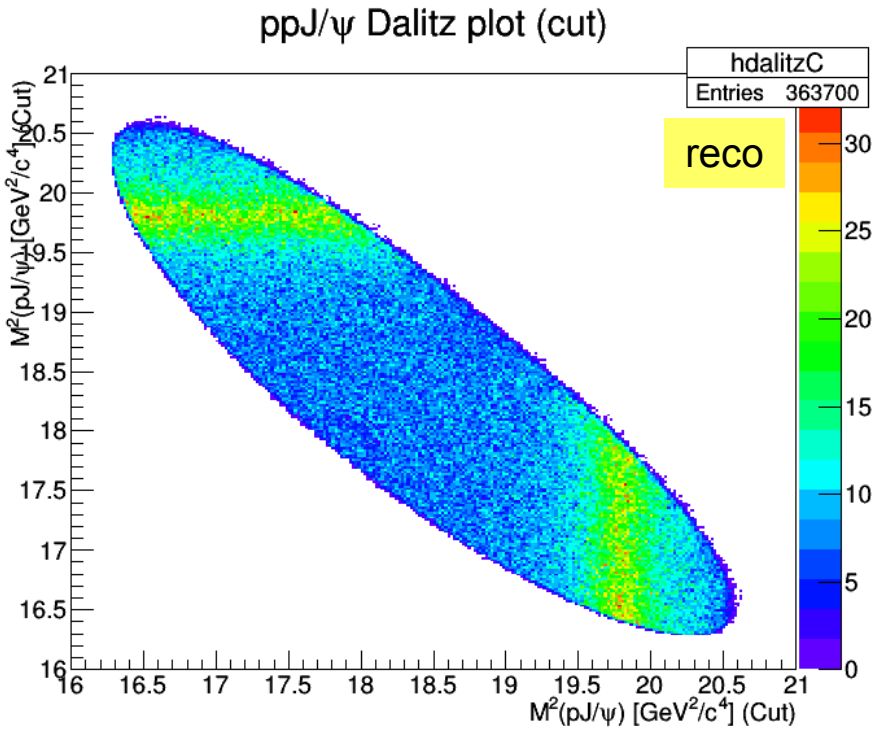
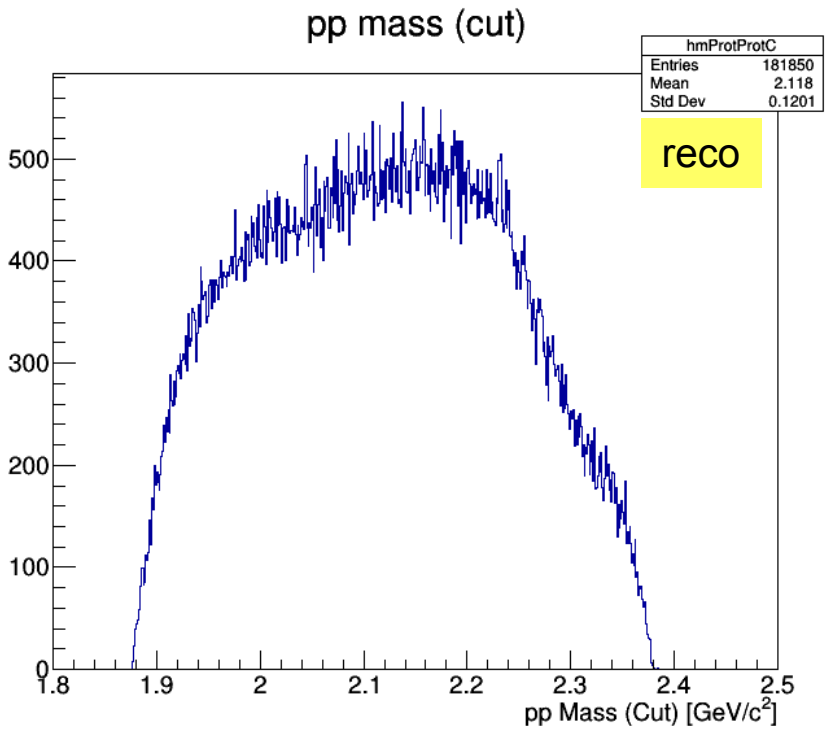
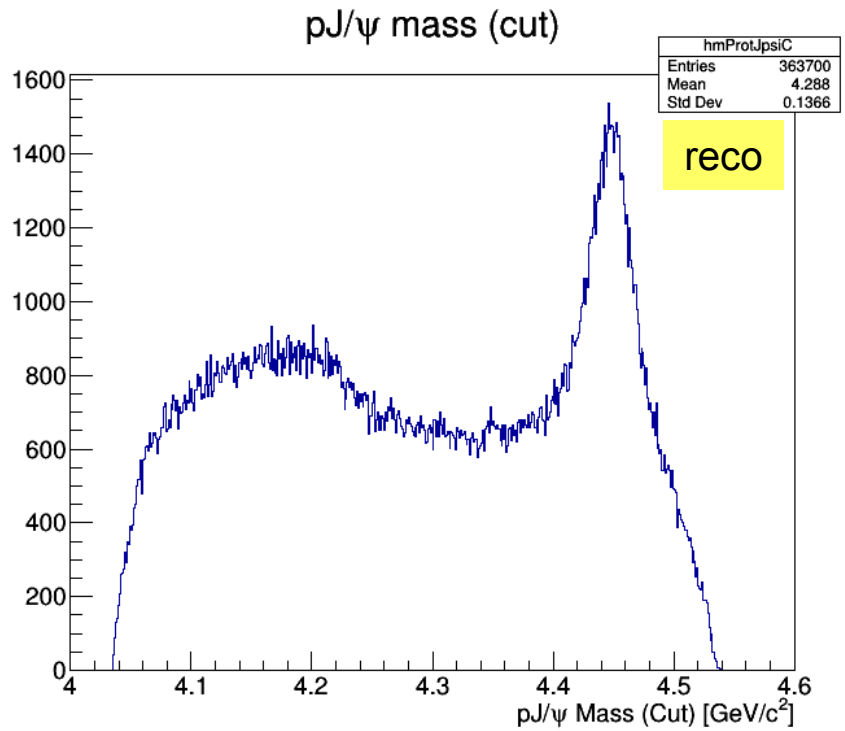
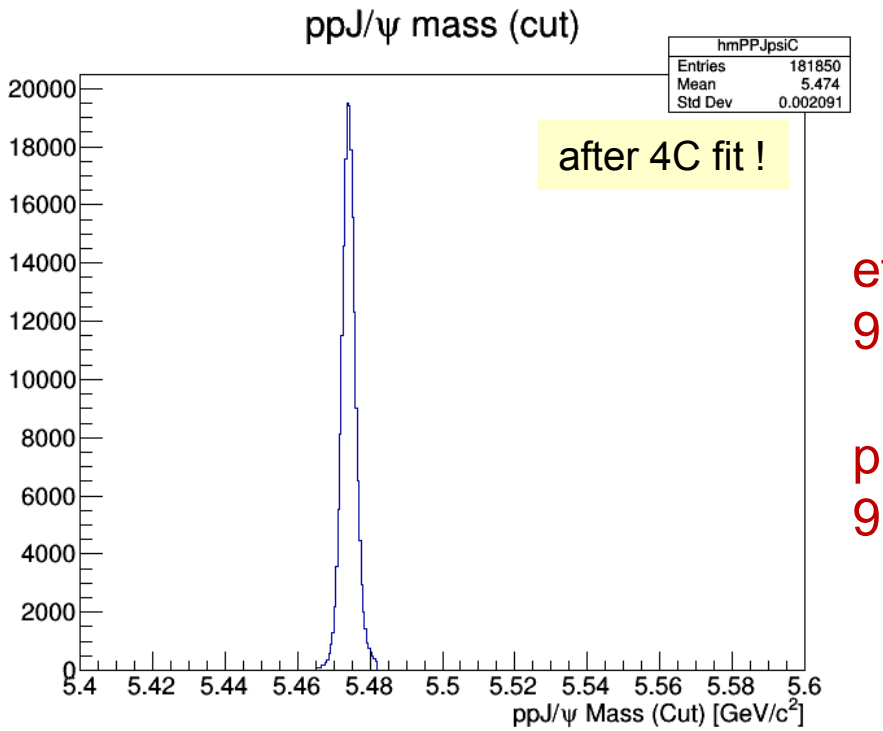
1
0 0.5 1 1.5 2 2.5
Log N ppJ/ψ Candidates per Event



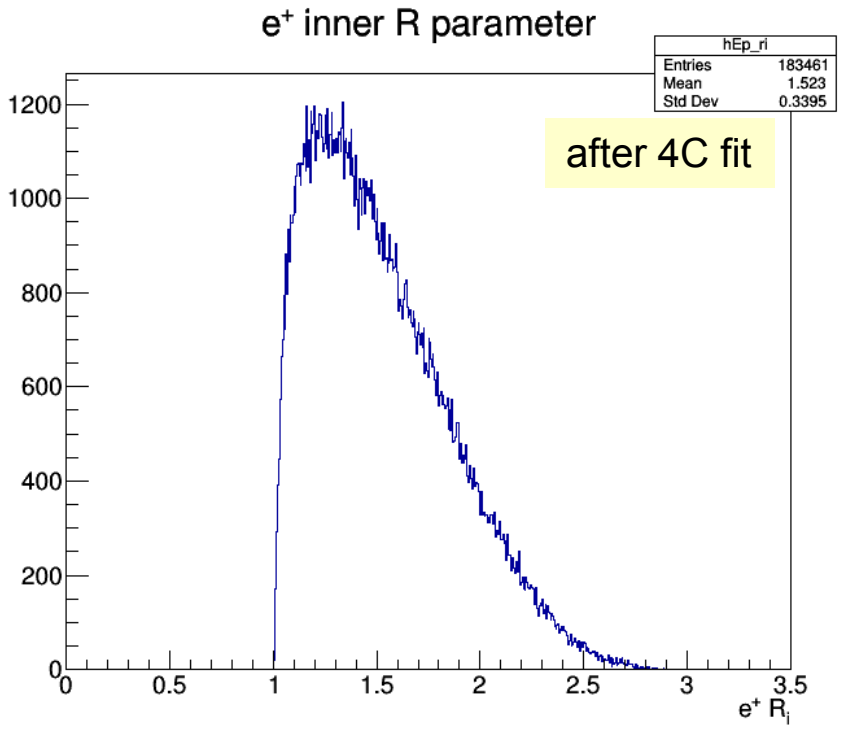






eff:
9.6%

purity:
98.0%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Entries 183461
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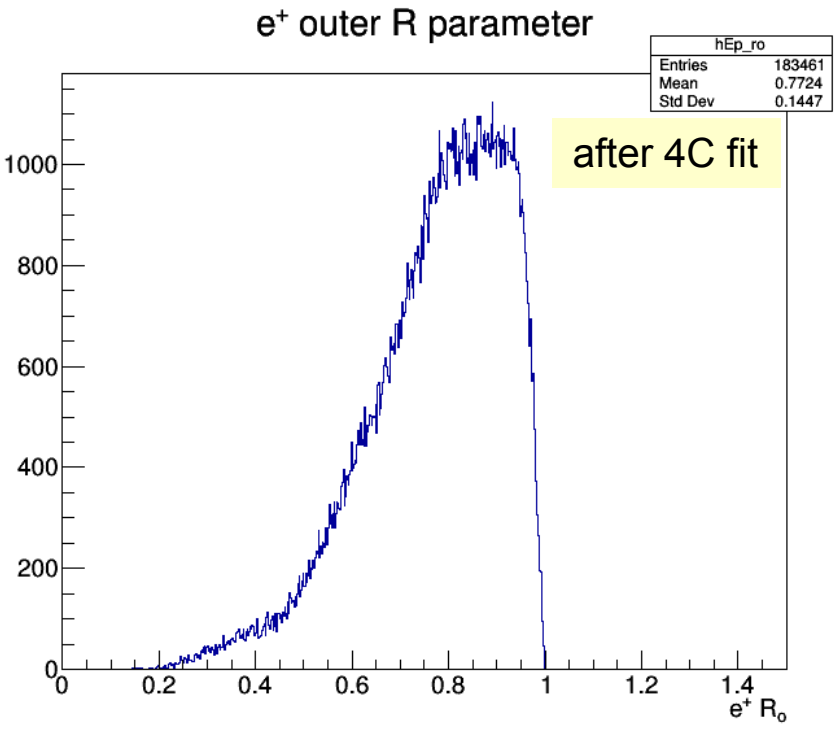
Std Dev 0.3395
after 4C fit
e+ Ri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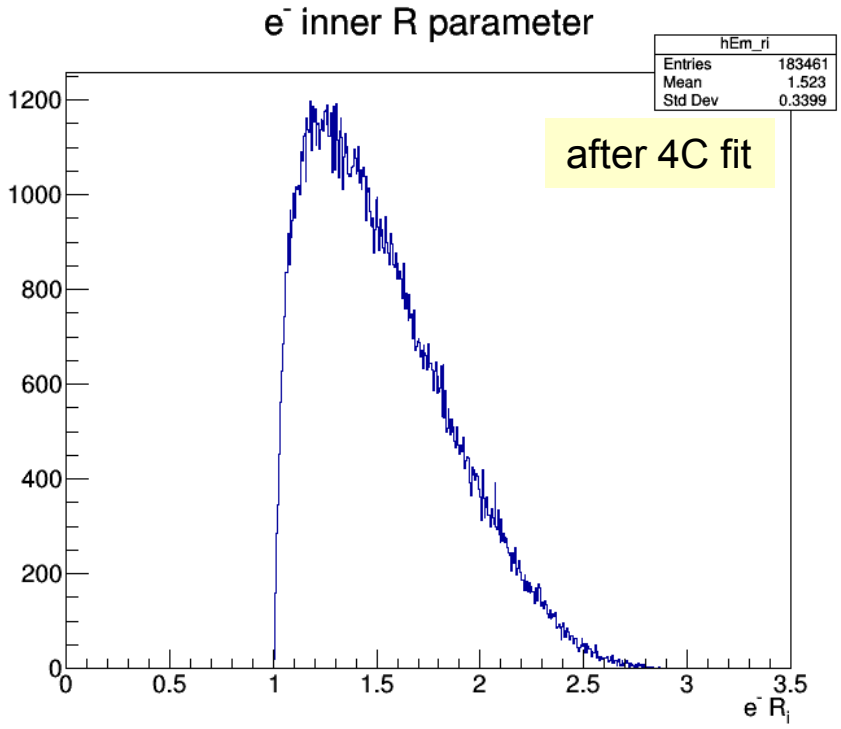
e+ Ro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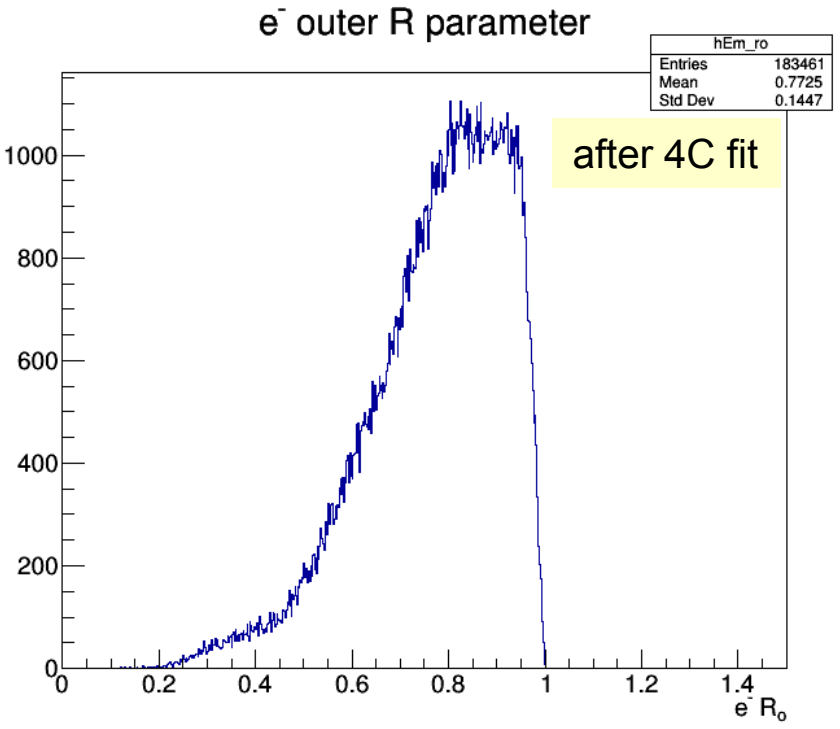
after 4C fit
e- Ri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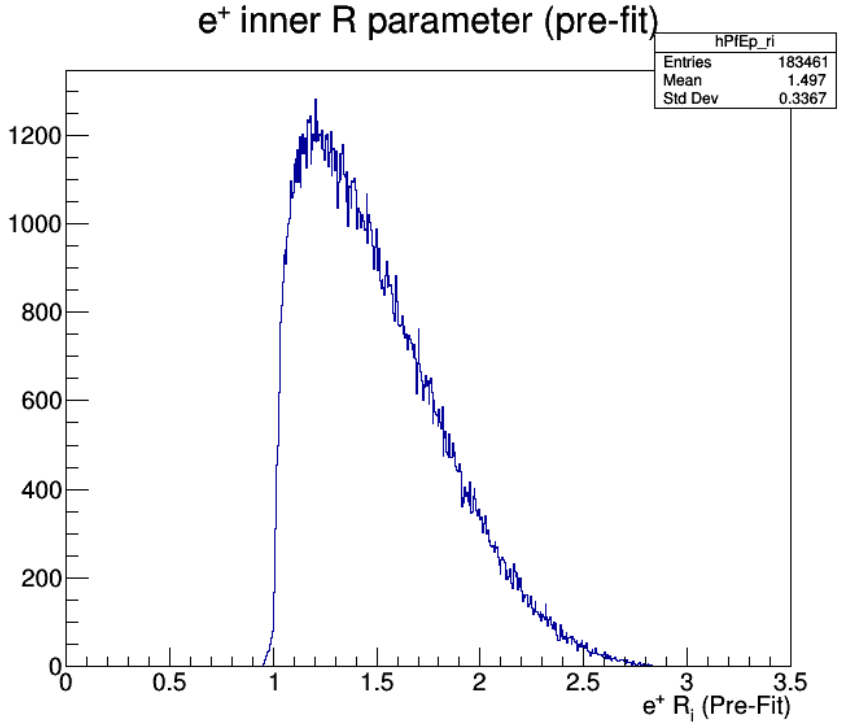
after 4C fit
e- Ro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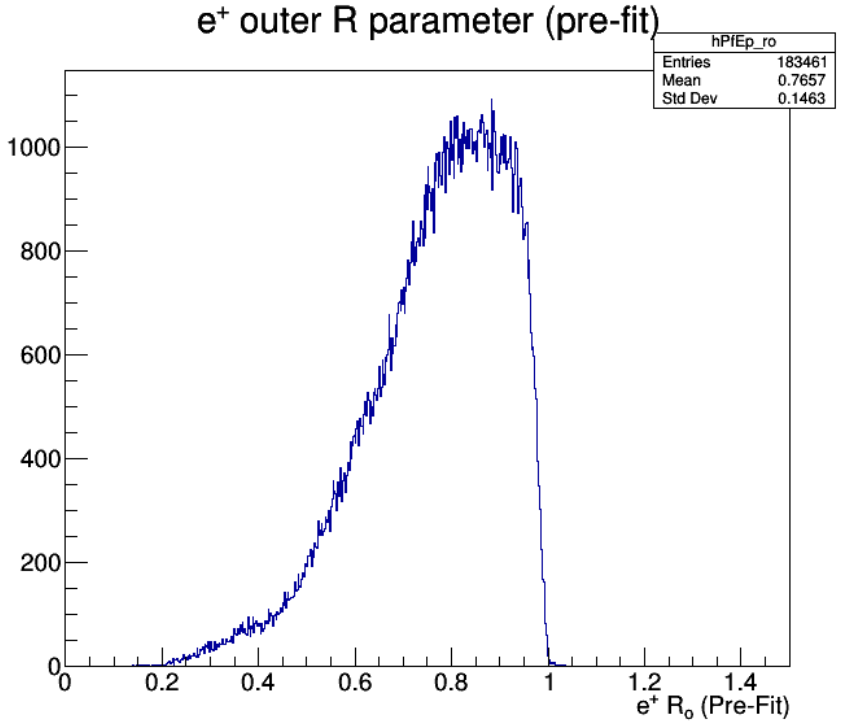
e+ Ri (Pre-Fit)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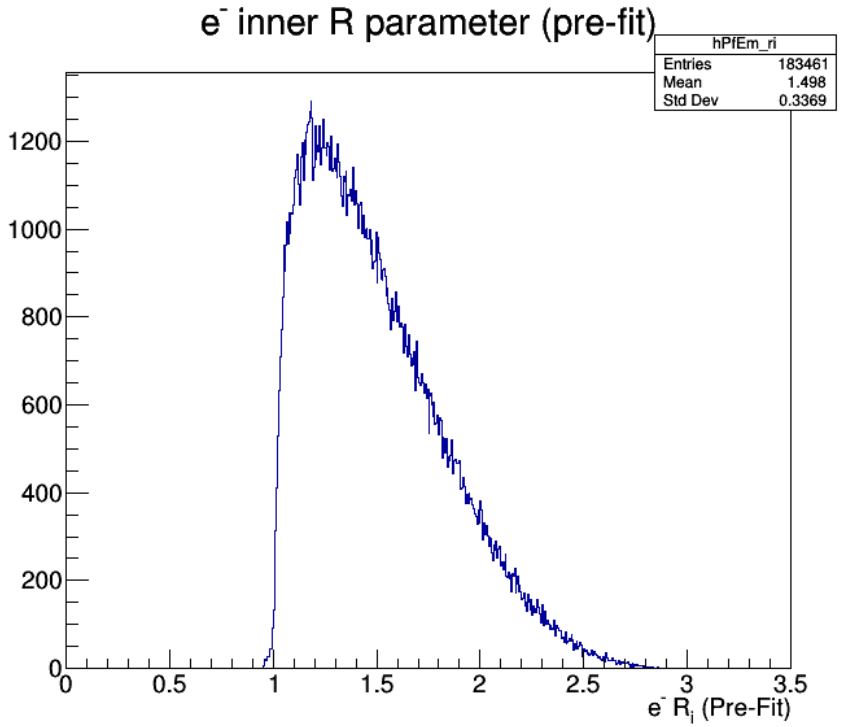
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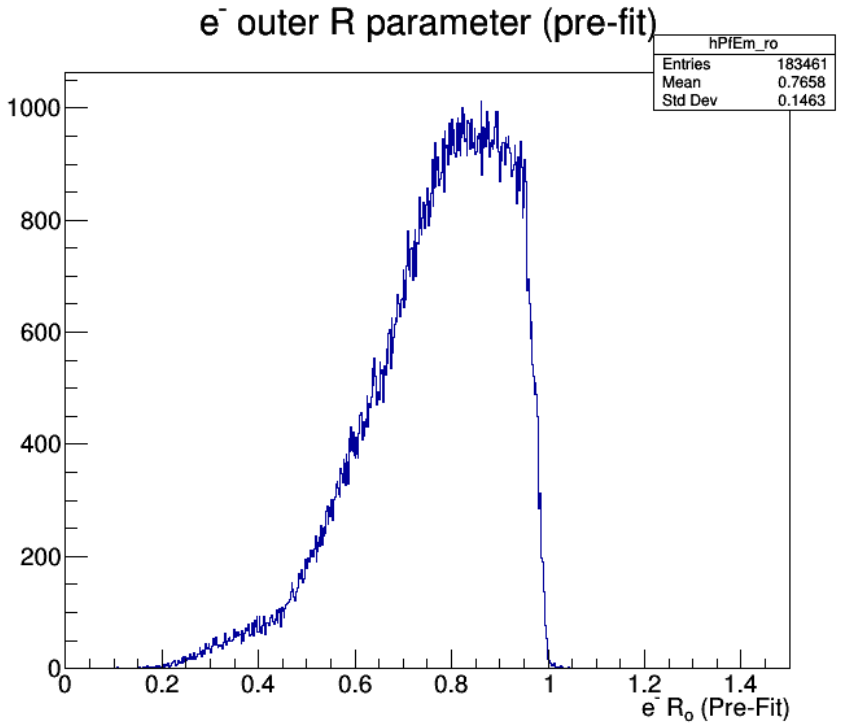
e- Ri (Pre-Fit)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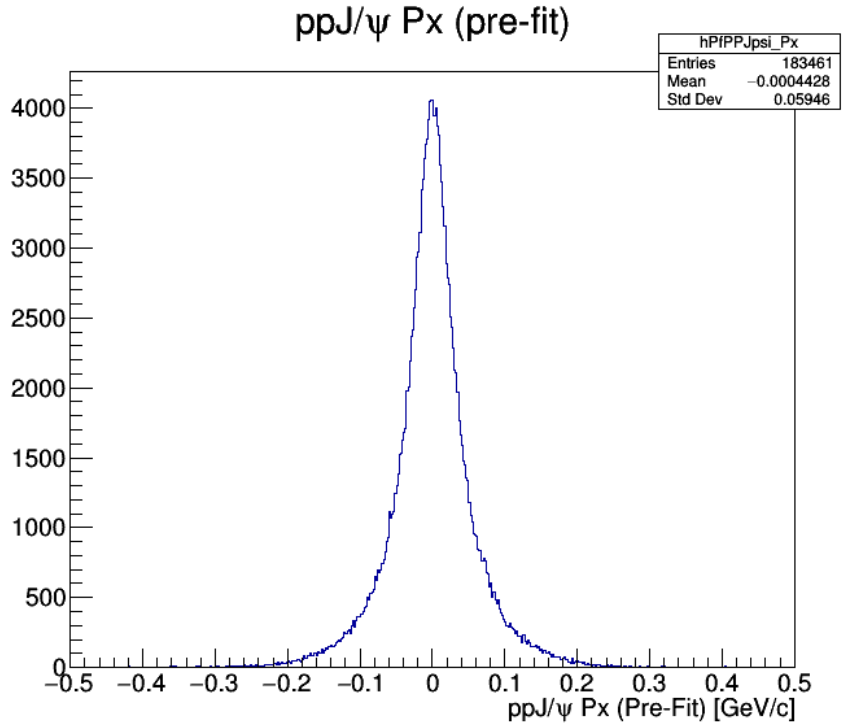
e- Ro (Pre-Fit)


ppJ/ψ Px (pre-fit)
hPfPPJpsi_Px
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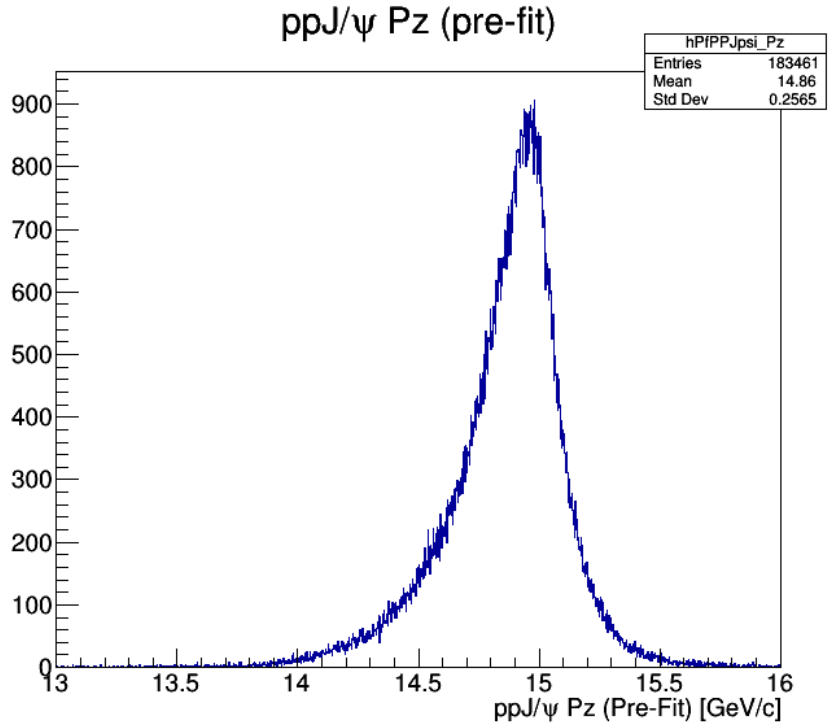
Std Dev 0.05946
ppJ/ψ Px (Pre-Fit) [GeV/c]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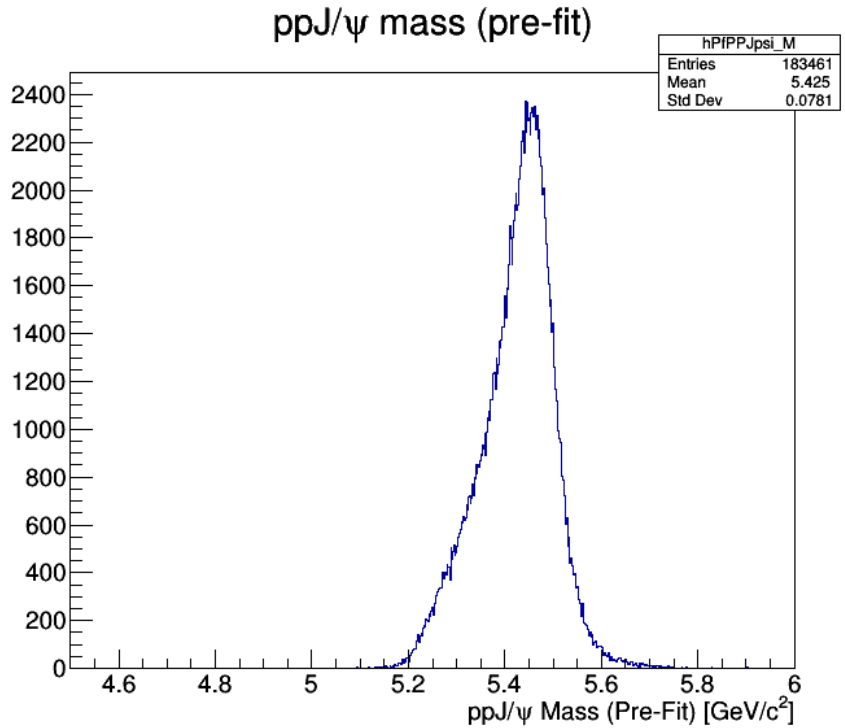
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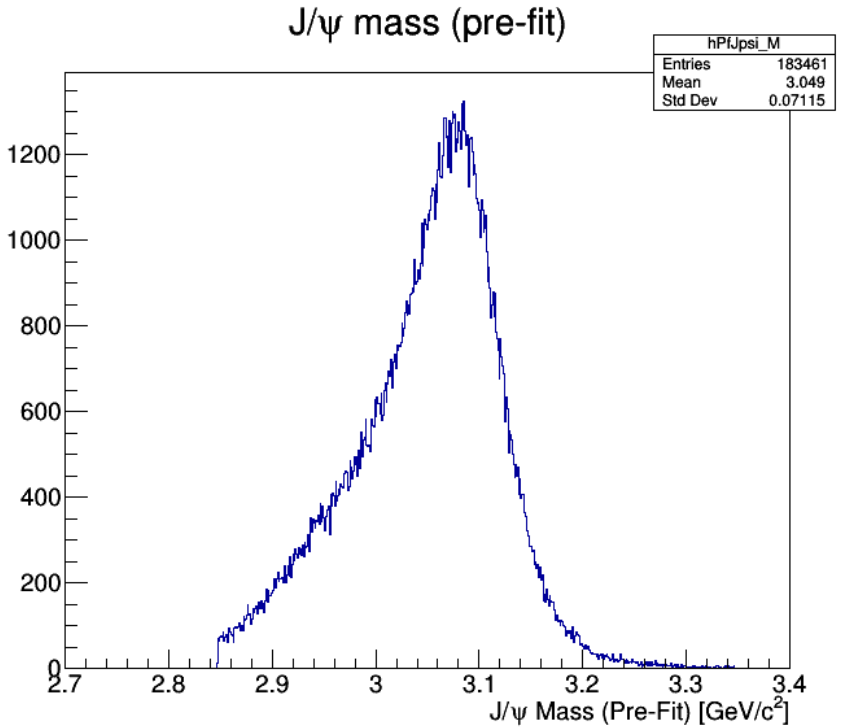
Std Dev 0.0781
ppJ/ψ Mass (Pre-Fit) [GeV/c²]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hPfJpsi_M
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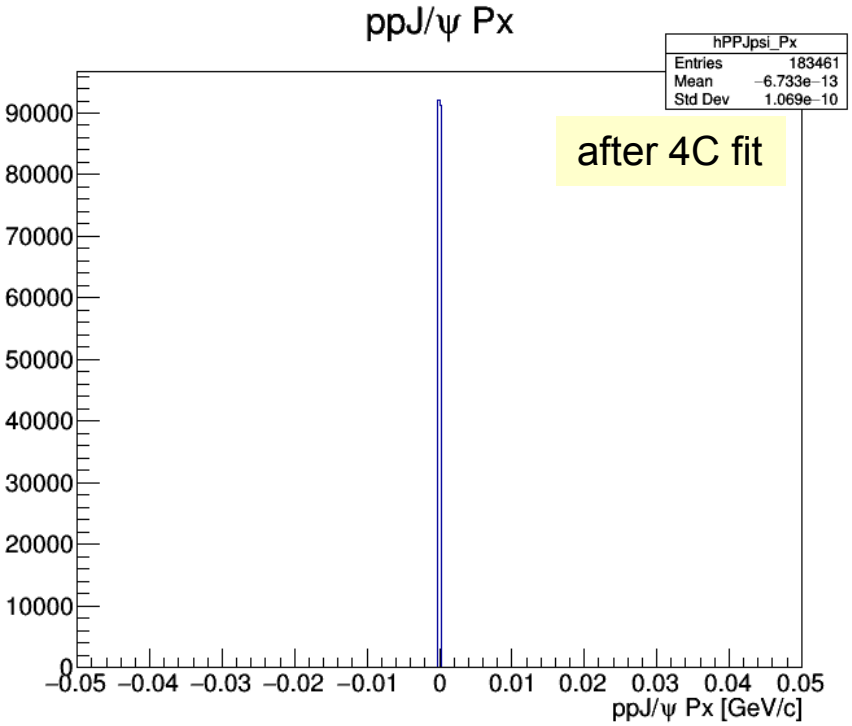
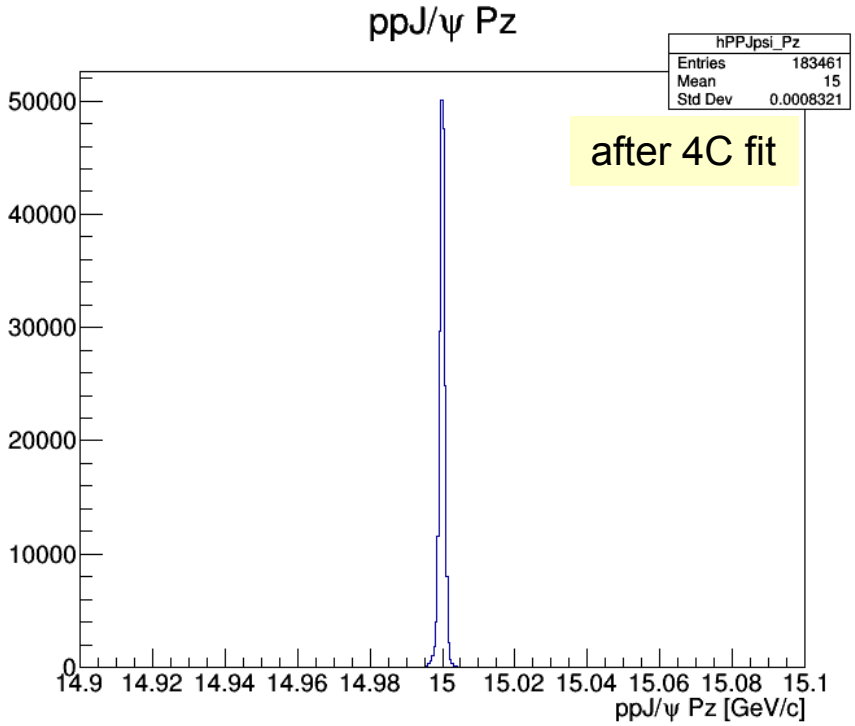
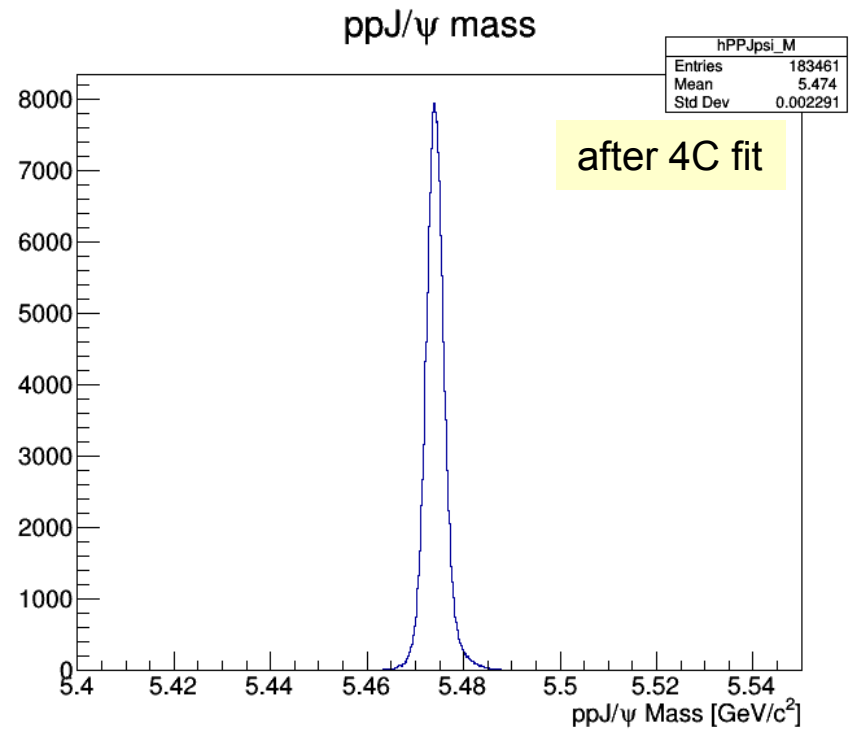
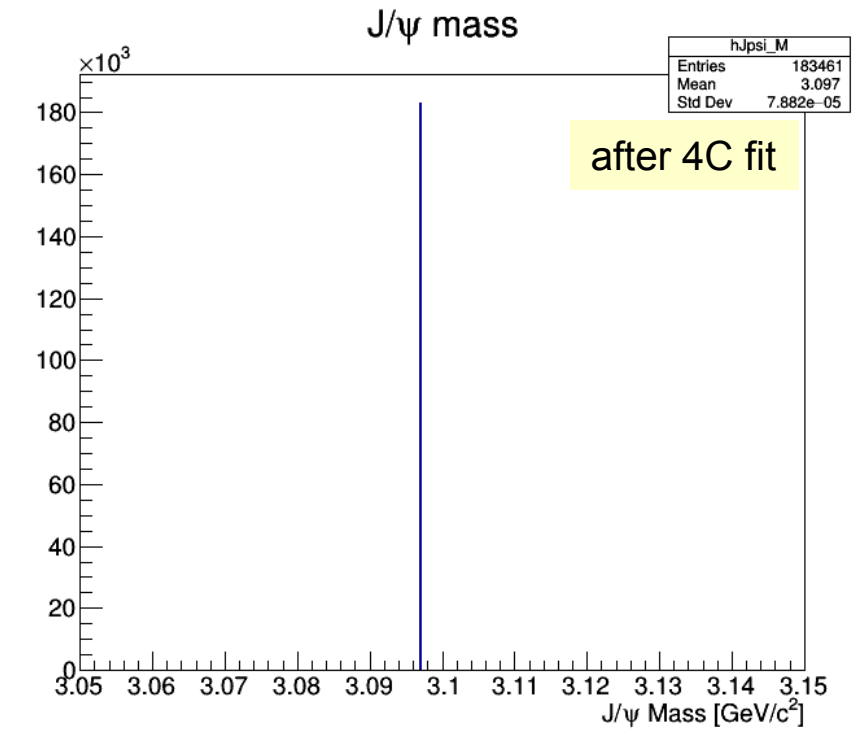
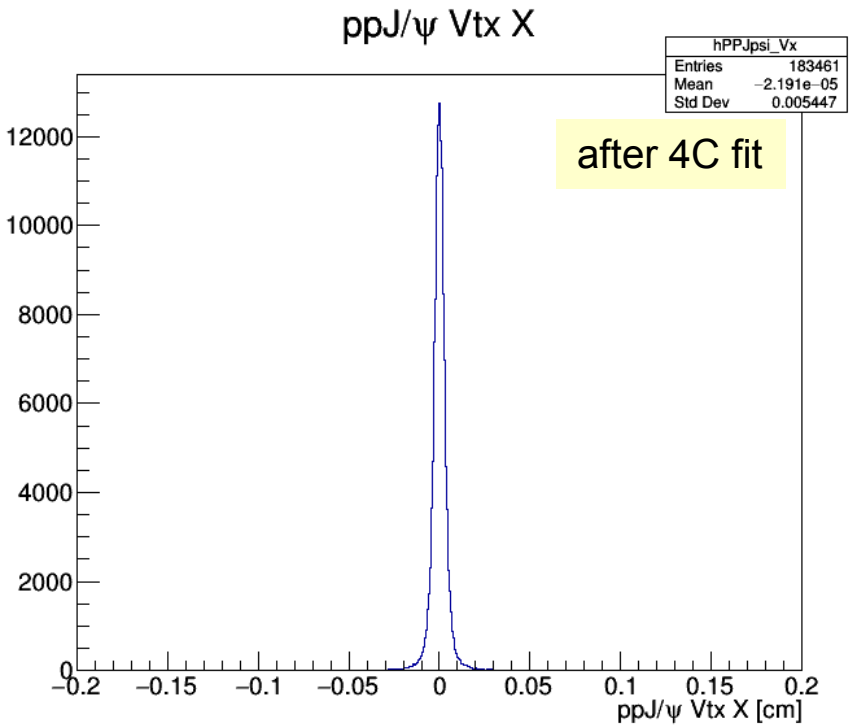
Std Dev 0.07115
J/ψ Mass (Pre-Fit) [GeV/c²]

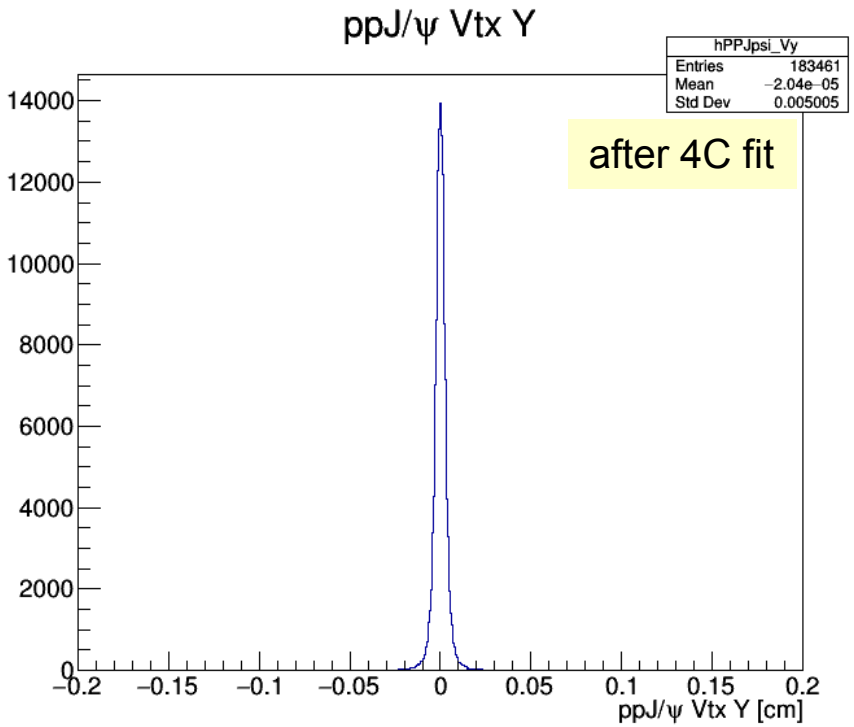

ppJ/ψ Px
hPPJpsi_Px
Entries 183461
Mean −6.733e−13
Std Dev 1.069e−10
after 4C fit
ppJ/ψ Px [GeV/c]

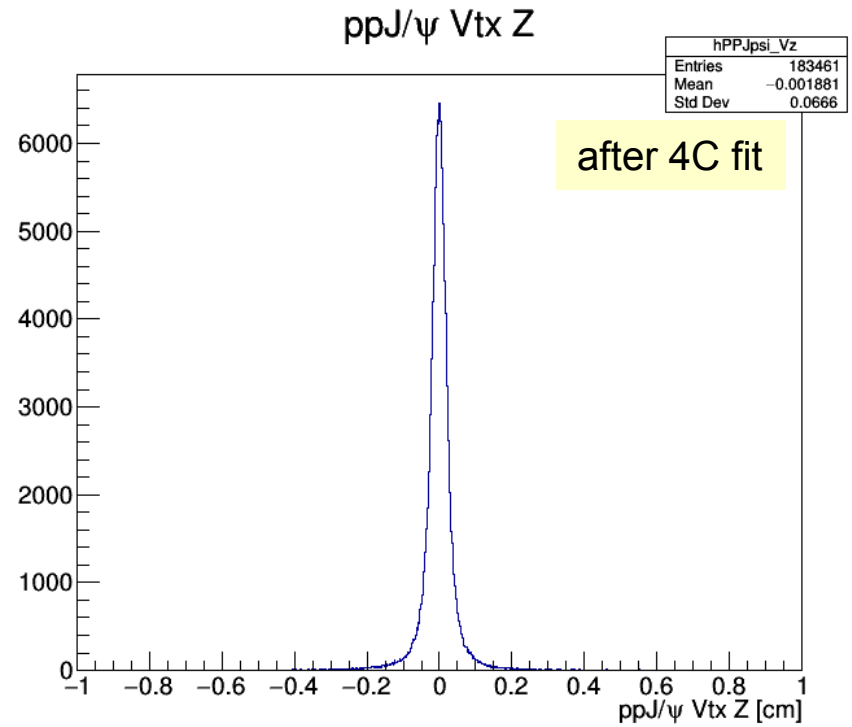

ppJ/ψ Pz
hPPJpsi_Pz
Entries 183461
Mean 15
Std Dev 0.0008321
after 4C fit
ppJ/ψ Pz [GeV/c]

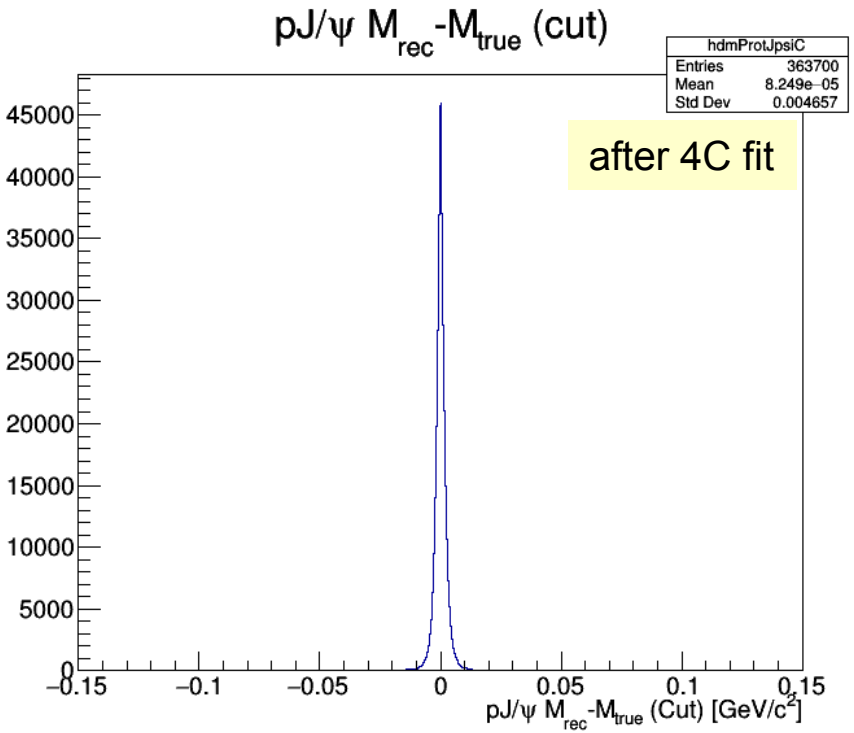

ppJ/ψ mass
hPPJpsi_M
Entries 183461
Mean 5.474
Std Dev 0.002291
after 4C fit
ppJ/ψ Mass [GeV/c²]

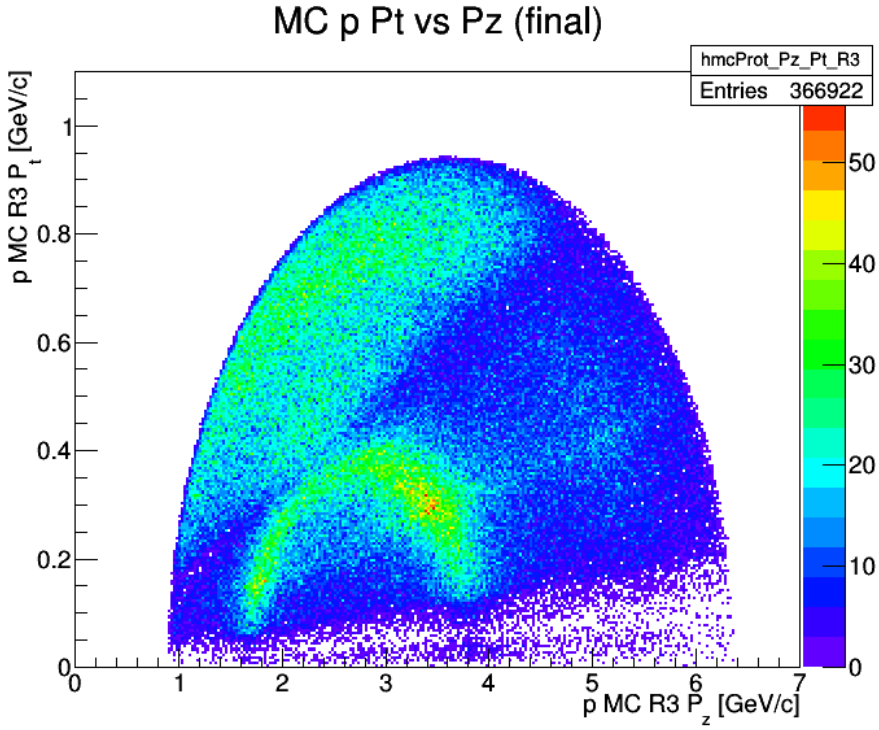

J/ψ mass
hJpsi_M
Entries 183461
Mean 3.097
Std Dev 7.882e−05
after 4C fit
J/ψ Mass [GeV/c²]

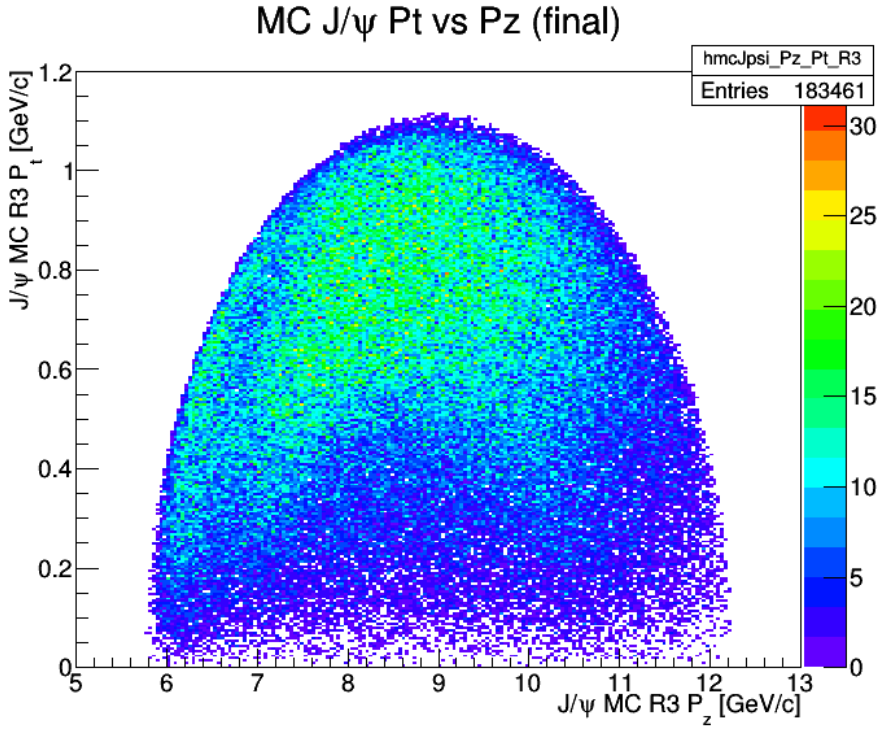

ppJ/ψ Vtx X
hPPJpsi_Vx
Entries 183461
Mean −2.191e−05
Std Dev 0.005447
after 4C fit
ppJ/ψ Vtx X [cm]

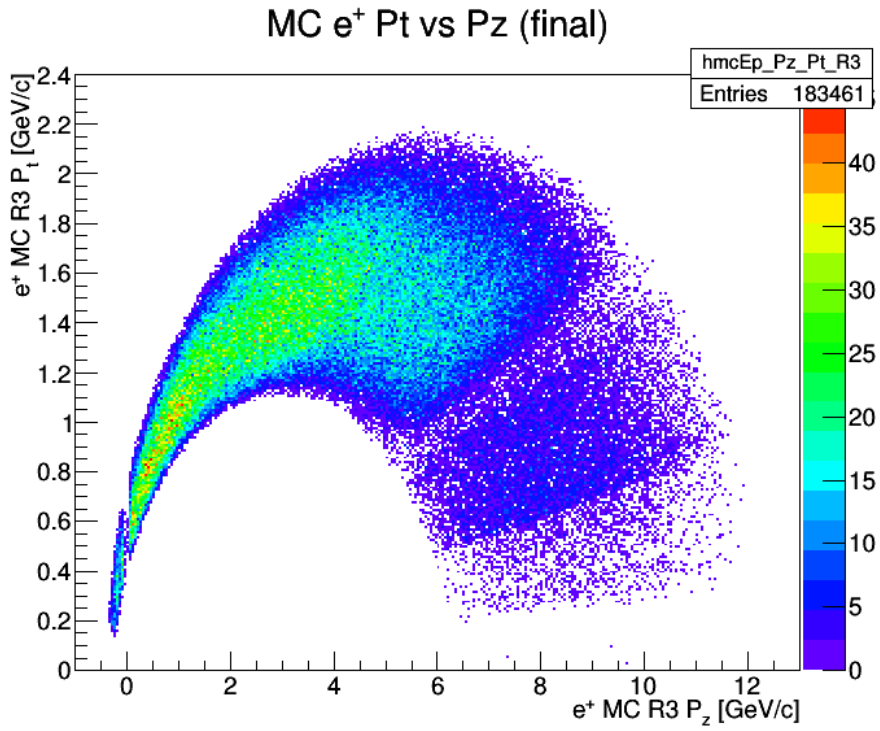

ppJ/ψ Vtx Y
hPPJpsi_Vy
Entries 183461
Mean −2.04e−05
Std Dev 0.005005
after 4C fit
ppJ/ψ Vtx Y [cm]

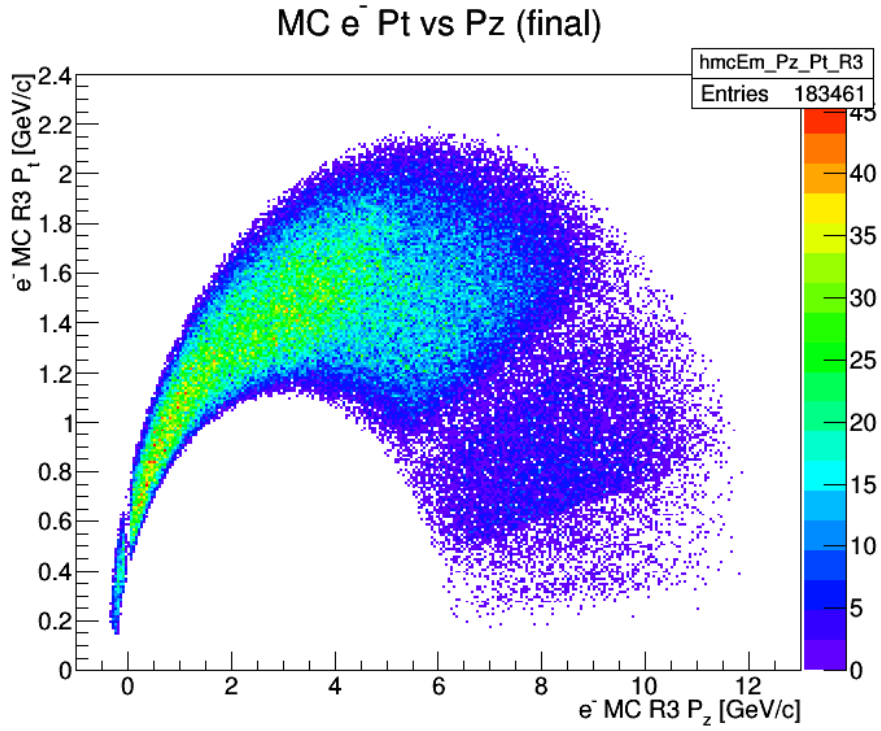

ppJ/ψ Vtx Z
hPPJpsi_Vz
Entries 183461
Mean −0.001881
Std Dev 0.0666
after 4C fit
ppJ/ψ Vtx Z [cm]

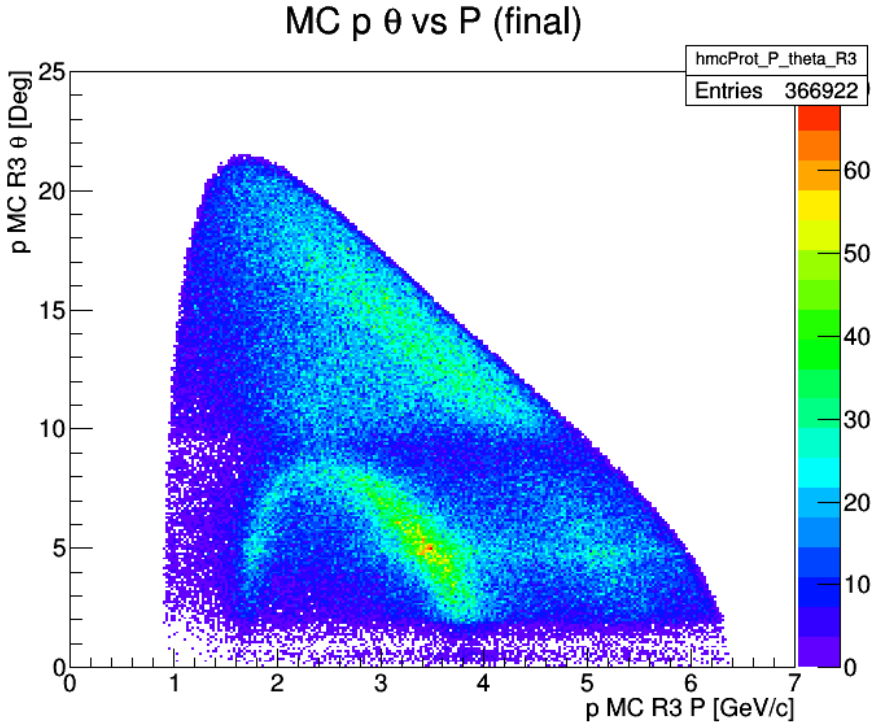

pJ/ψ M_rec-M_true (cut)
hdmProtJpsiC
Entries 363700
Mean 8.249e−05
Std Dev 0.004657
after 4C fit
pJ/ψ M_rec-M_true (Cut) [GeV/c²]

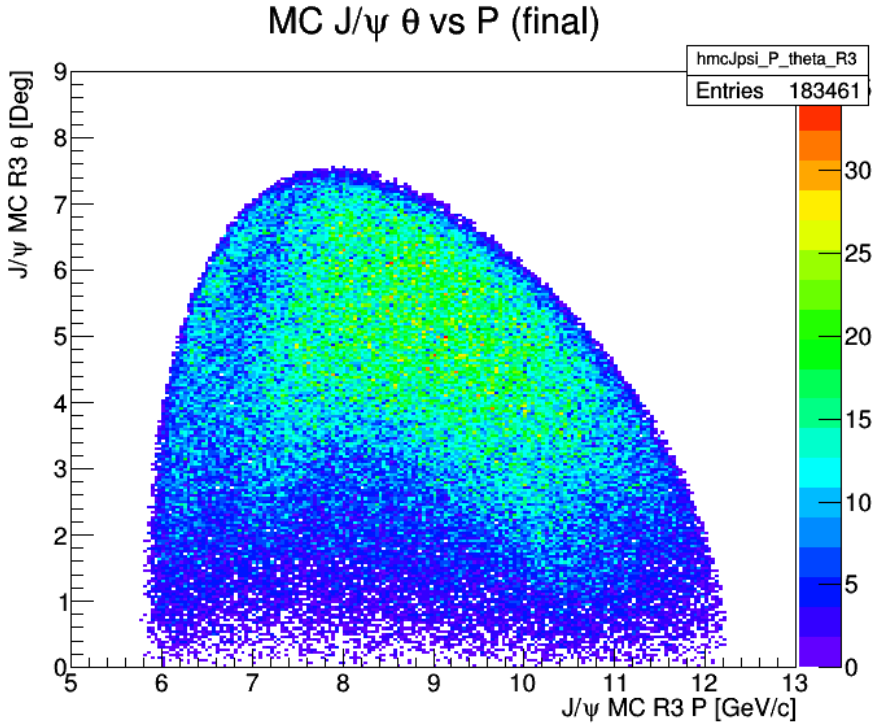

MC p Pt vs Pz (final)
hmcProt_Pz_Pt_R3
Entries 366922
p MC R3 P_t [GeV/c]
p MC R3 P_z [GeV/c]

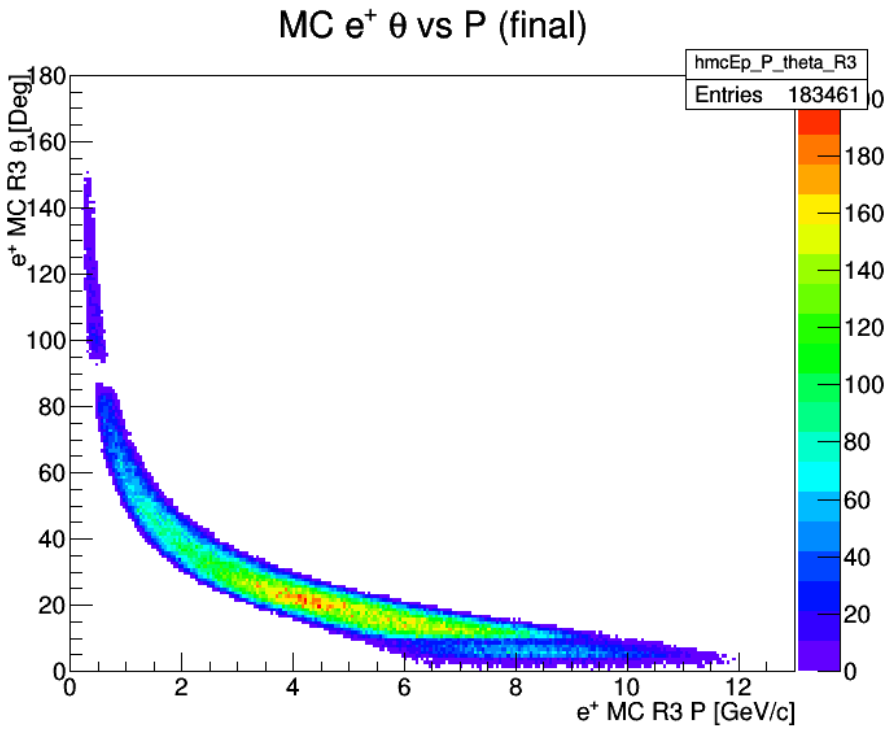

MC J/ψ Pt vs Pz (final)
hmcJpsi_Pz_Pt_R3
Entries 183461
J/ψ MC R3 P_t [GeV/c]
J/ψ MC R3 P_z [GeV/c]

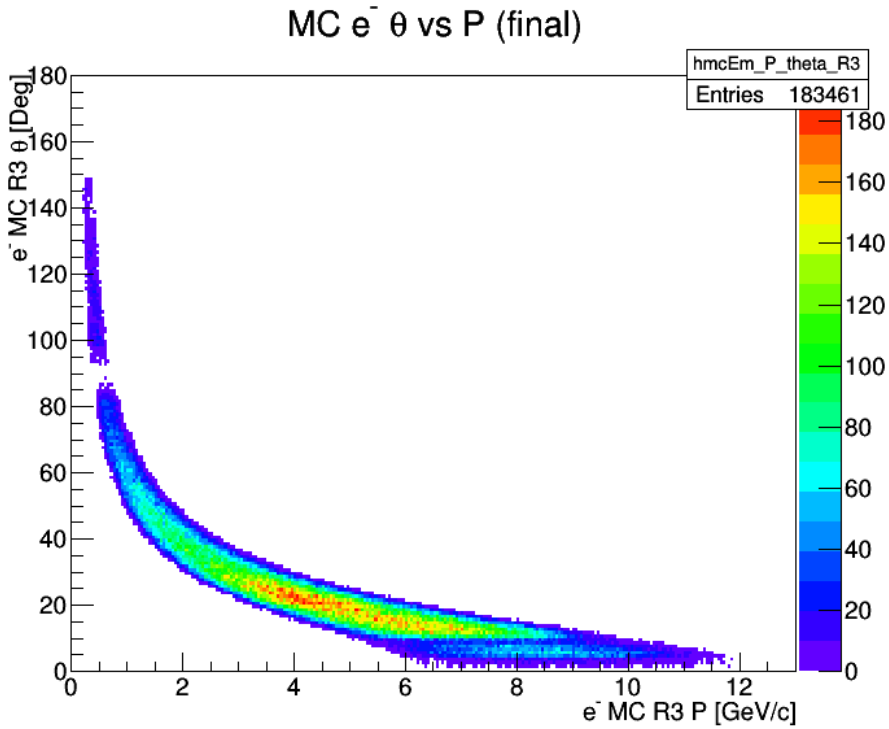

MC e+ Pt vs Pz (final)
hmcEp_Pz_Pt_R3
Entries 183461
e+ MC R3 P_t [GeV/c]
e+ MC R3 P_z [GeV/c]


MC e- Pt vs Pz (final)
hmcEm_Pz_Pt_R3
Entries 183461
e- MC R3 P_t [GeV/c]
e- MC R3 P_z [GeV/c]


MC p θ vs P (final)
hmcProt_P_theta_R3
Entries 366922
p MC R3 θ [Deg]
p MC R3 P [GeV/c]

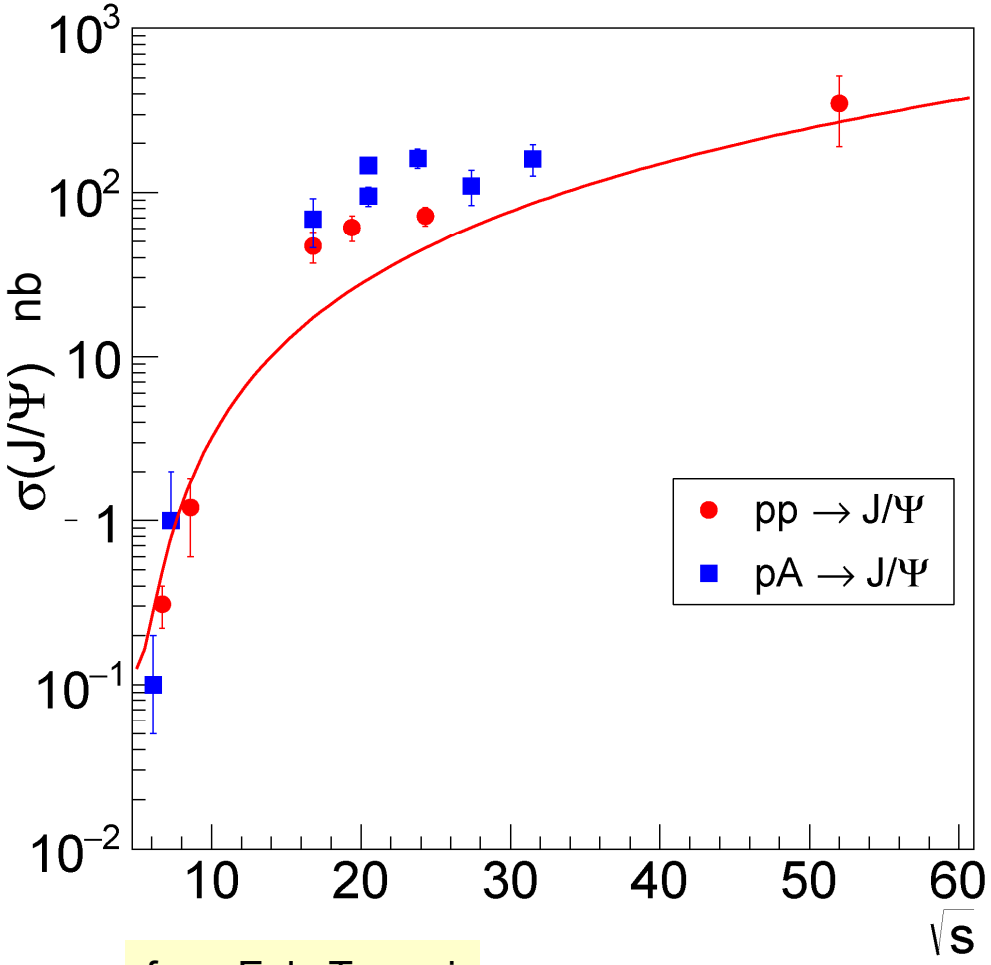

MC J/ψ θ vs P (final)
hmcJpsi_P_theta_R3
Entries 183461
J/ψ MC R3 θ [Deg]
J/ψ MC R3 P [GeV/c]


MC e+ θ vs P (final)
hmcEp_P_theta_R3
Entries 183461
e+ MC R3 θ [Deg]
e+ MC R3 P [GeV/c]

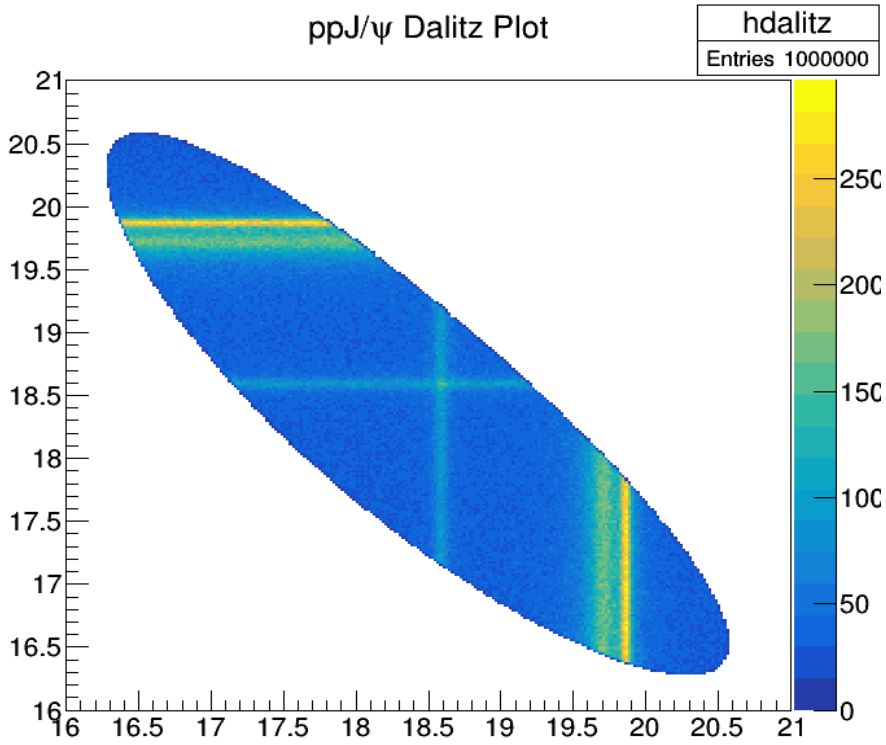

MC e- θ vs P (final)
hmcEm_P_theta_R3
Entries 183461
e- MC R3 θ [Deg]
e- MC R3 P [GeV/c]

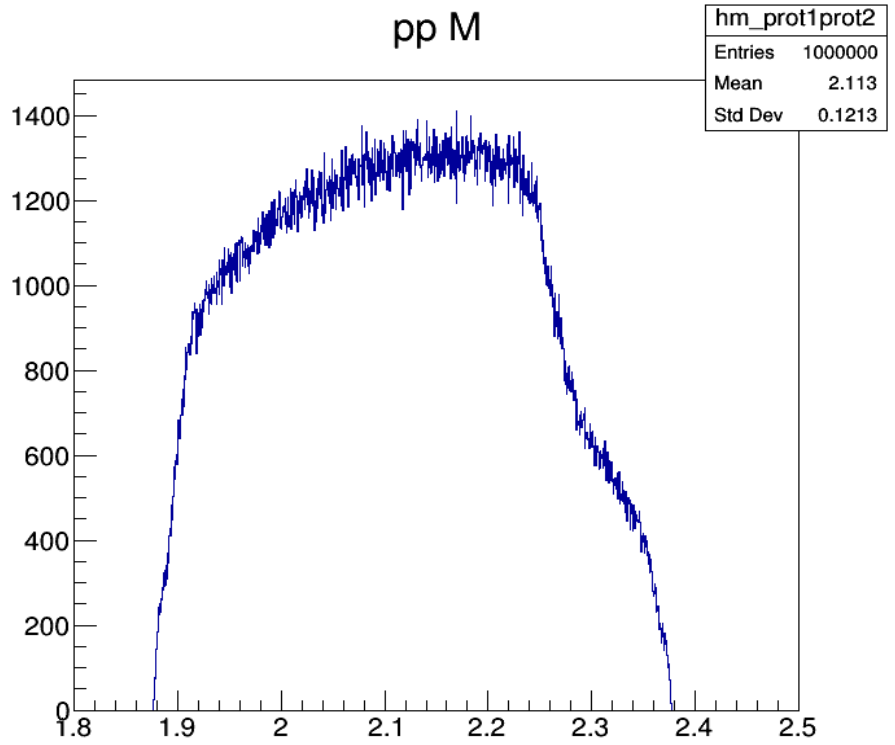
The $pp \to pp\,J/\psi$ Cross Section

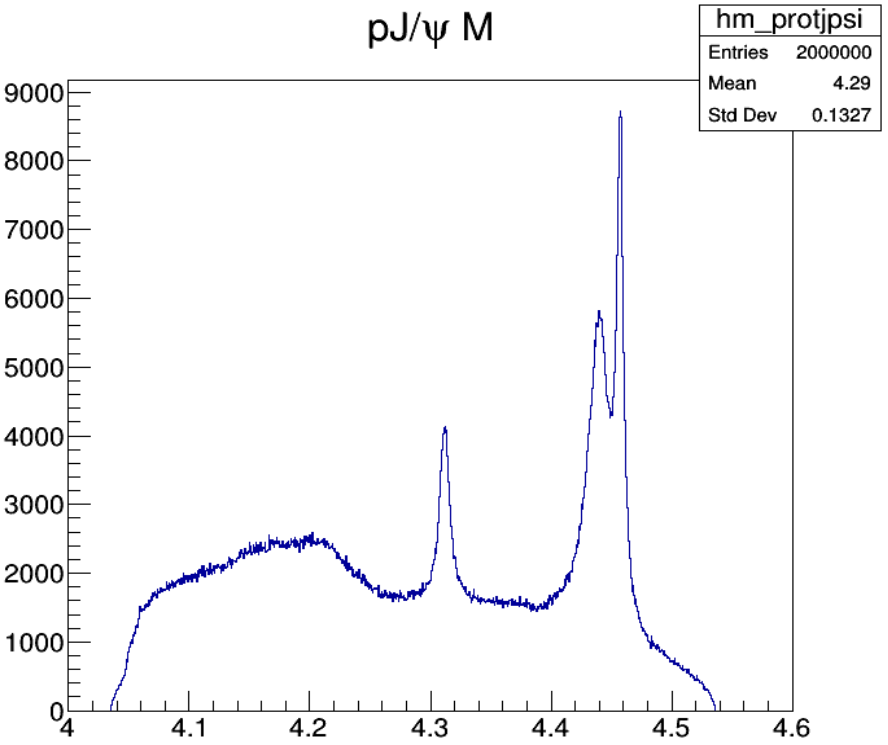
- no data very close to threshold
- cross section will be small
- no case for initial commissioning
- should add e^+e^- and $\mu^+\mu^-$ decay data
- $\sigma = 0.1$ nb, full L, 2 months → ~1200 $pp\,J/\psi$ events reconstr.



from Egle Tomasi







New LHCb data arXiv:1904.03947

3 states $P_c(4312)^+$, $P_c(4440)^+$, $P_c(4457)^+$

Generated events

Simulation started

Conclusion & Outlook

- 1.9 M events $pp \to pp\,J/\psi \to ppe^+e^-$ including $P_c(4450)^+$ simulated and analyzed with treefitter & ideal PID
- 9.6% reco efficiency, 98.0% purity
- issues: composite candidate mass constraint, P4 constraint, PID
- to do:
  - open PID
  - updated P_c resonance parameters
  - S/B with hadronic background (FTF)
  - up-to-date PandaRoot version
  - $J/\psi \to \mu^+\mu^-$ decay channel