Feasibility Study of $Zc(3900)$ in $\bar{p}p$ with the PANDA Detector

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Intro

- The charmonium like state $Zc^{\pm}(3900)$ was observed by the BESIII [1] and Belle [2] collaborations in the $\pi^{\pm}J/\psi$ invariant mass spectrum of $e^+e^- \rightarrow \pi^+\pi^-$ at $\sqrt{s}$=4.26 GeV in 2013 and then confirmed by CLEO-c collaboration in the same process at s $\sqrt{s}$=4.17 GeV [3], which makes Zc(3900) the first confirmed charged charmonium like state.

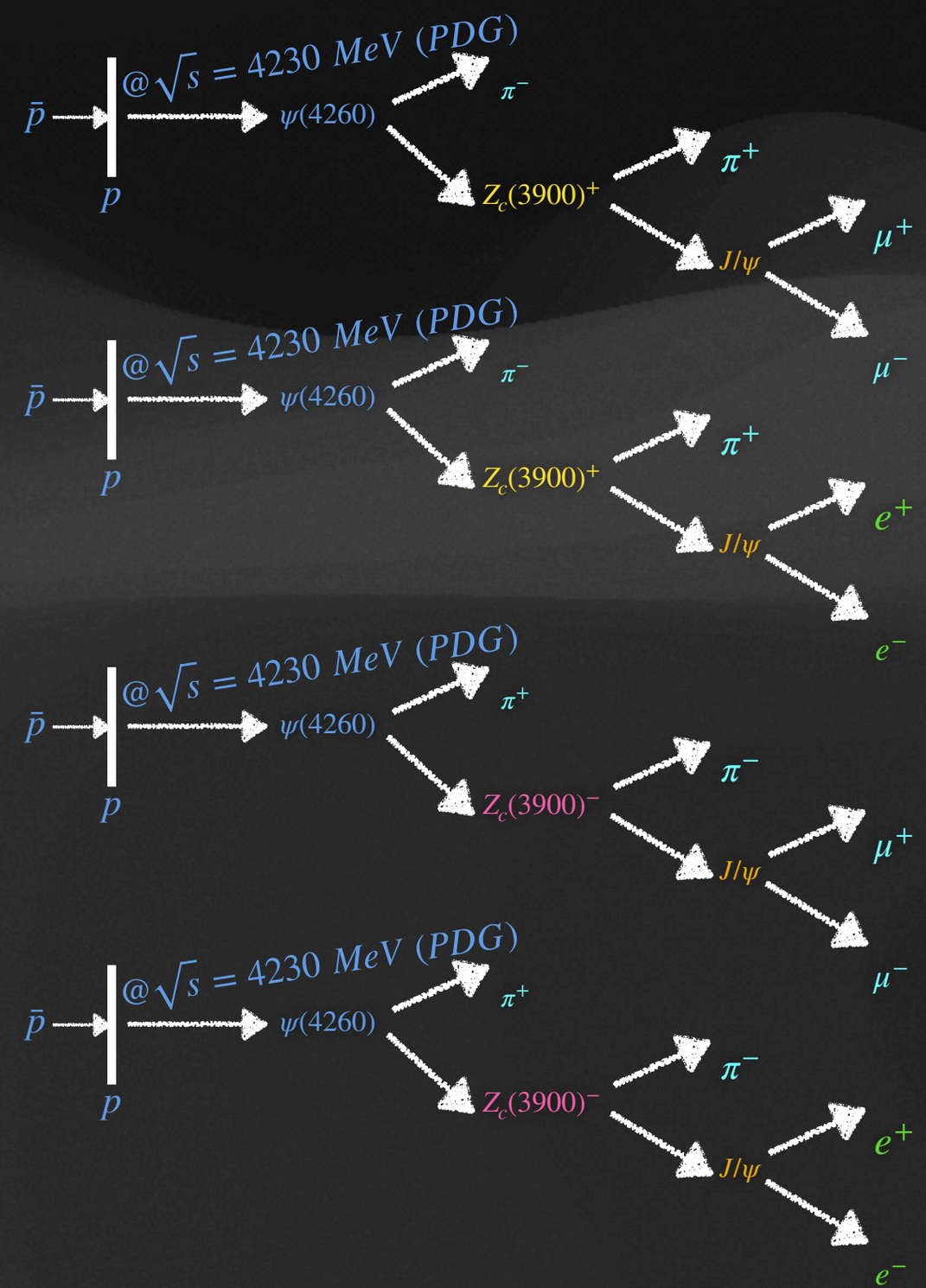
- [1] M. Ablikim et al. (BESIII Collaboration), Phys. Rev. Lett. 110, 252001 (2013).
- [2] Z. Q. Liu et al. (Belle Collaboration), Phys. Rev. Lett. 110, 252002 (2013); 111, 019901(E) (2013).
- [3] T. Xiao, S. Dobbs, A. Tomaradze, and K. K. Seth, Phys. Lett. B 727, 366 (2013).

Outline

- Zc(3900)
  - Event Generation
  - Reconstruction & Analysis
  - Background
- Summary

Event Generation

- 2 million events at each
- $P_{\bar{p}} = 8.5454$ GeV/c (at resonance of $\psi_{(4260)}$)
- assuming the branching ratio of 100% for $Zc(3900) \rightarrow \pi + J/\psi$
- Mass of $Zc(3900)^{\pm}$: $m_{Zc(3900)}$ = 3887.2 ± 2.3 [Mev/c²]
- Width: $\Gamma_{Zc(3900)}$ = 28.2 ± 2.6 [Mev/c²]



Reconstruction

Production and Reco:

- Simulation of transport through the detector
  - Production & Reco: Using PandaRoot dev: / FairSoft jun19p2 / FairRoot v18.2.1
  - Analysis: Using PandaRoot dev: / FairSoft apr22 / FairRoot v18.6.8
- Transport and reconstruction of particles is done with the PandaRoot framework
- Follow the decay tree
- Best PID algorithm is used (MuonBestPlus for μ^+,…)

Analysis

Reconst. Final States efficiencies

- Used decay pattern recognition and “best” particle identification (PID)
- Reconstructed FS: $\mu^-, \mu^+, \pi^-, \pi^+$
- Reconstruction efficiency for final state particles:

Parçacık türü	ε[%]
μ^+	95.47
μ^-	94.19
π^+	83.46
π^-	79.07

$\bar{p}p \to Zc(3900)^+\pi^-, (Zc(3900)^+ \to J/\psi\pi^+, (J/\psi \to \mu^+\mu^-))$

Parçacık türü	ε[%]
e^+	89.48
e^-	85.41
π^+	83.34
π^-	78.89

$\bar{p}p \to Zc(3900)^+\pi^-, (Zc(3900)^+ \to J/\psi\pi^+, (J/\psi \to e^+e^-))$

Parçacık türü	ε[%]
μ^+	96.61
μ^-	94.11
π^+	78.77
π^-	83.39

$\bar{p}p \to Zc(3900)^-\pi^+, (Zc(3900)^- \to J/\psi\pi^-, (J/\psi \to \mu^+\mu^-))$

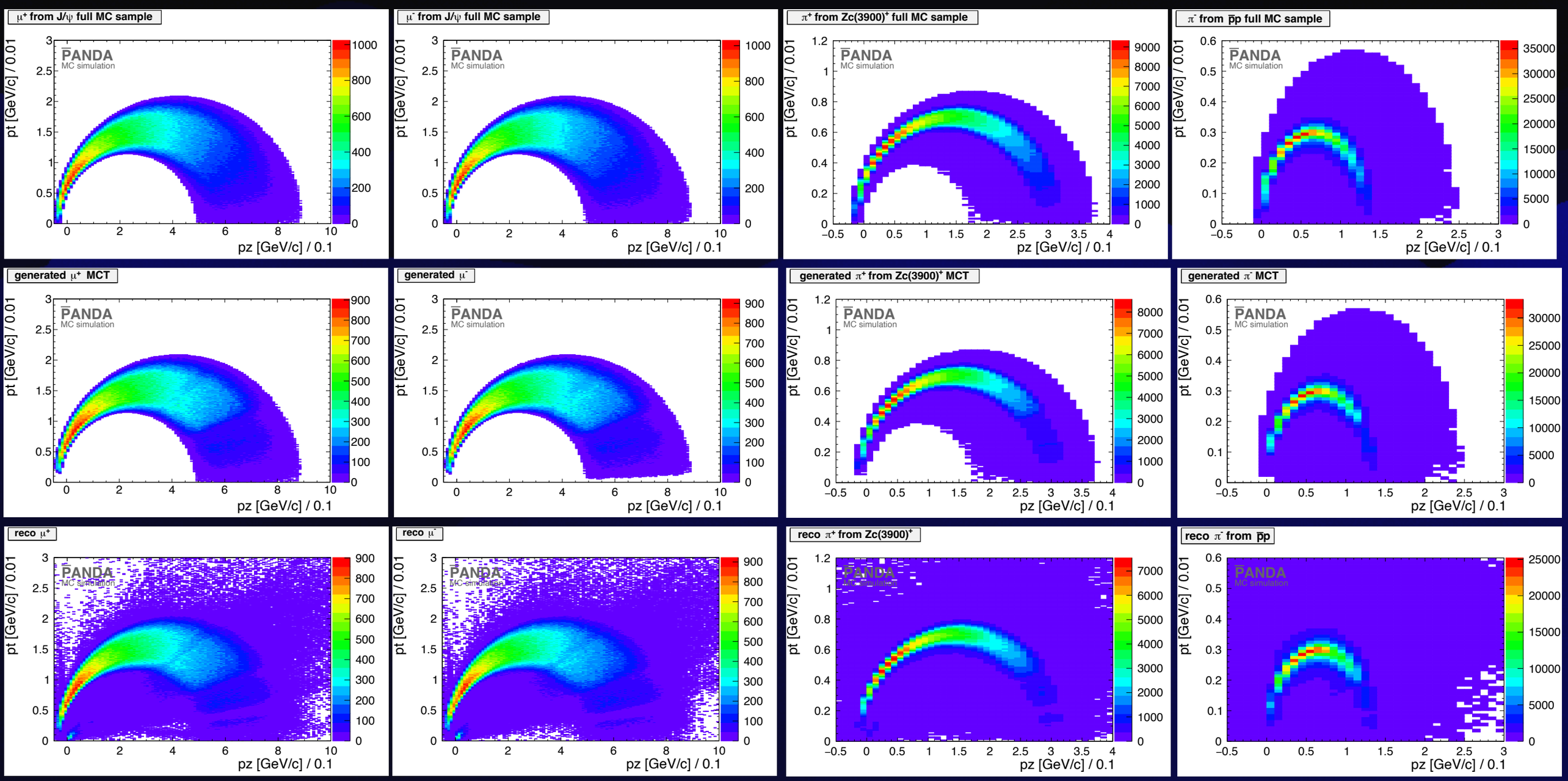
Parçacık türü	ε[%]
e^+	89.64
e^-	85.32
π^+	78.57
π^-	83.2

$\bar{p}p \to Zc(3900)^-\pi^+, (Zc(3900)^- \to J/\psi\pi^-, (J/\psi \to e^+e^-))$

Analysis

Reconstruction of FS: transverse vs. longitudinal Momentum Distributions

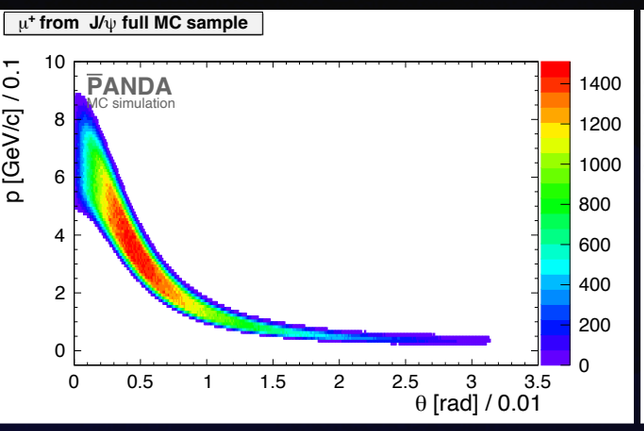
μ^+ μ^- π^+ π^-

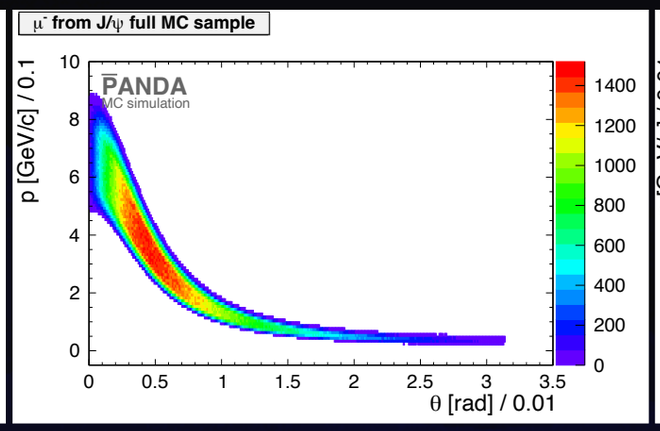


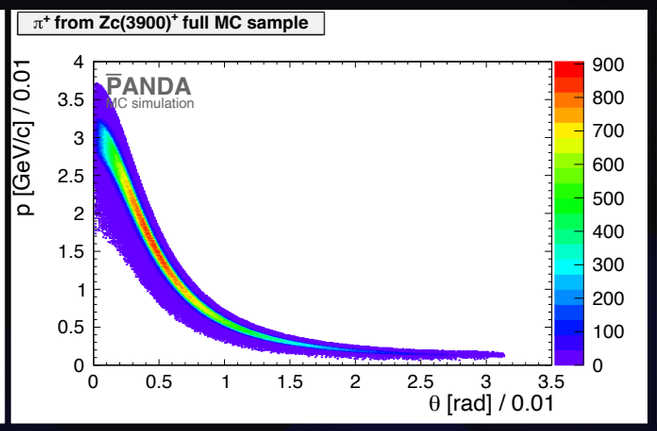
Analysis

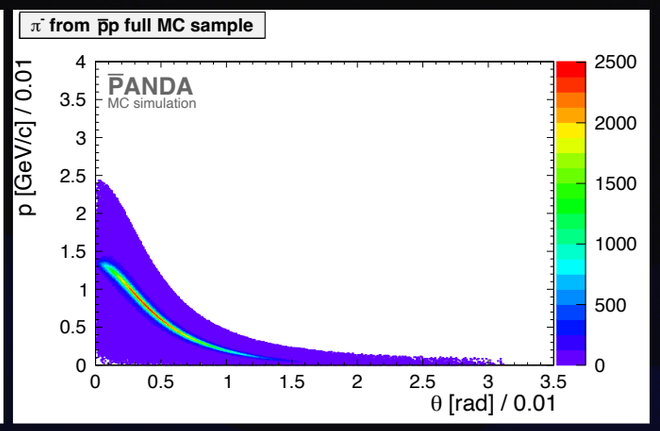
Reconstruction of FS: total momentum vs. Θ angle Distributions

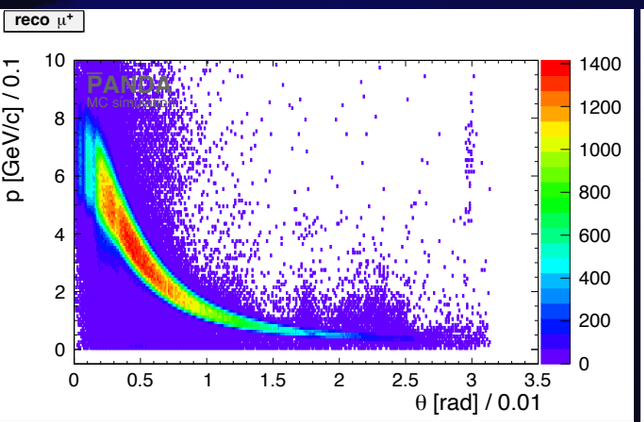
μ^+ μ^- π^+ π^-

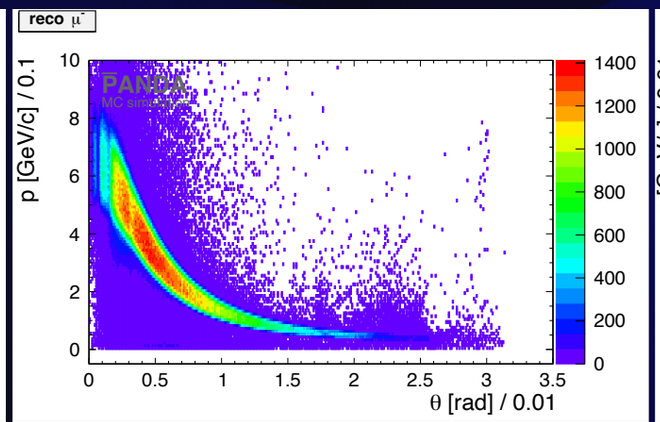


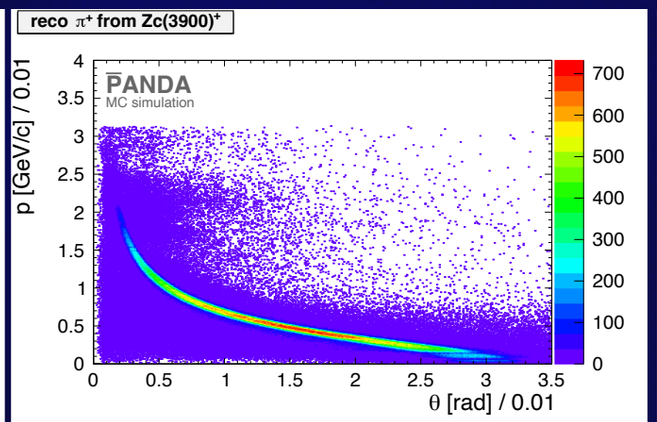


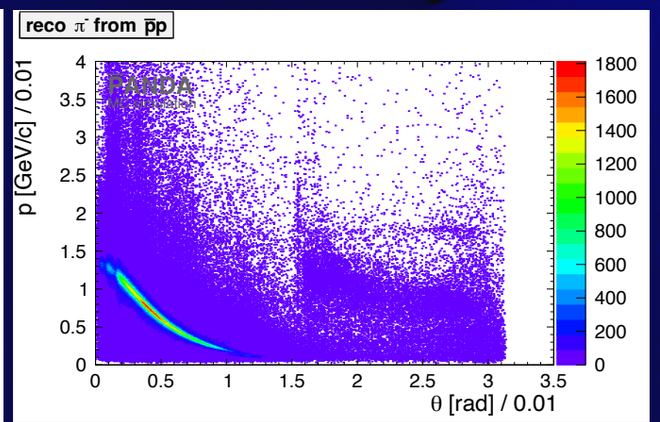








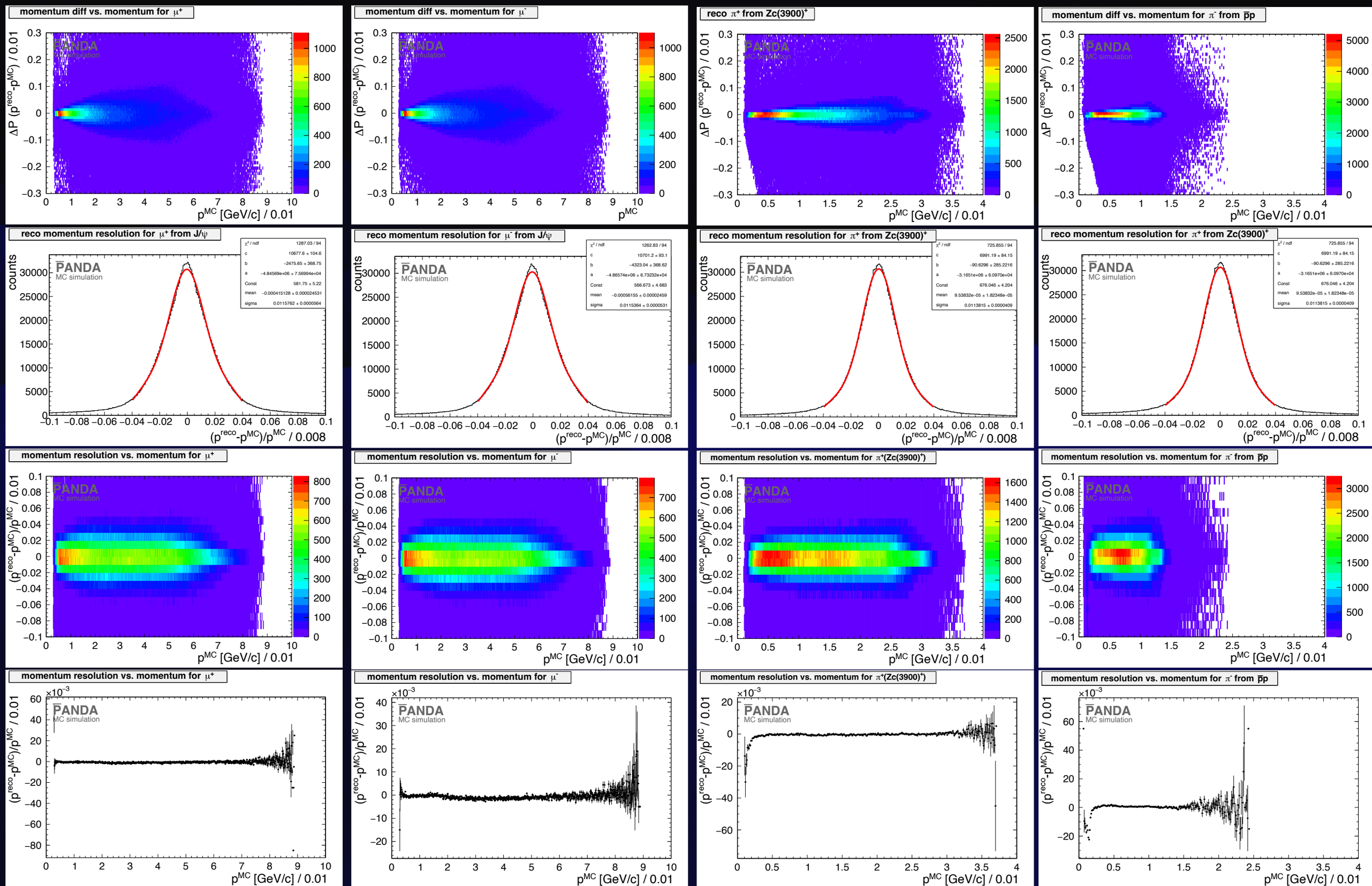




Analysis

Reconstruction of FS: Momentum Resolution

μ^+ | μ^- | π^+ | π^-



Analysis

Reconstructed FS: $\mu^-, \mu^+, \pi^-, \pi^+$

- Momentum Resolutions

Parçacık türü	*dp/p* [%]
μ^+	1.158
μ^-	1.154
π^+	1.138
π^-	1.136

$\bar{p}p \to Zc(3900)^+\pi^-, (Zc(3900)^+ \to J/\psi\pi^+, (J/\psi \to \mu^+\mu^-))$

Parçacık türü	*dp/p* [%]
e+	1.426
e-	1.403
π+	1.146
π-	1.134

$\bar{p}p \to Zc(3900)^+\pi^-, (Zc(3900)^+ \to J/\psi\pi^+, (J/\psi \to e^+e^-))$

Parçacık türü	*dp/p* [%]
μ+	1.167
μ-	1.155
π+	1.123
π-	1.152

$\bar{p}p \to Zc(3900)^-\pi^+, (Zc(3900)^- \to J/\psi\pi^-, (J/\psi \to \mu^+\mu^-))$

Parçacık türü	*dp/p* [%]
e+	1.447
e-	1.435
π+	1.121
π-	1.151

$\bar{p}p \to Zc(3900)^-\pi^+, (Zc(3900)^- \to J/\psi\pi^-, (J/\psi \to e^+e^-))$

Analysis

Reconstruction of Resonance State : J/ψ

- Invariant mass cut on $\mu^+\mu^-$ (e^+e^-) to select J/ψ cands $m_{J/\psi}$: (3.0969 ± 0.5) GeV/c^2
- Perform RhoDecayTreeFitter fit
- Select candidate with DecayTree fit prob > 0.01

Analysis

Resonance States: J/ψ

- Reconstructed: efficiency

Parçacık türü	ε[%]
J/Ψ	67.29

$\bar{p}p \to Zc(3900)^+\pi^-, (Zc(3900)^+ \to J/\psi\pi^+, (J/\psi \to \mu^+\mu^-))$

Parçacık türü	ε[%]
J/Ψ	30.44

$\bar{p}p \to Zc(3900)^+\pi^-, (Zc(3900)^+ \to J/\psi\pi^+, (J/\psi \to e^+e^-))$

Parçacık türü	ε[%]
J/Ψ	67.26

$\bar{p}p \to Zc(3900)^-\pi^+, (Zc(3900)^- \to J/\psi\pi^-, (J/\psi \to \mu^+\mu^-))$

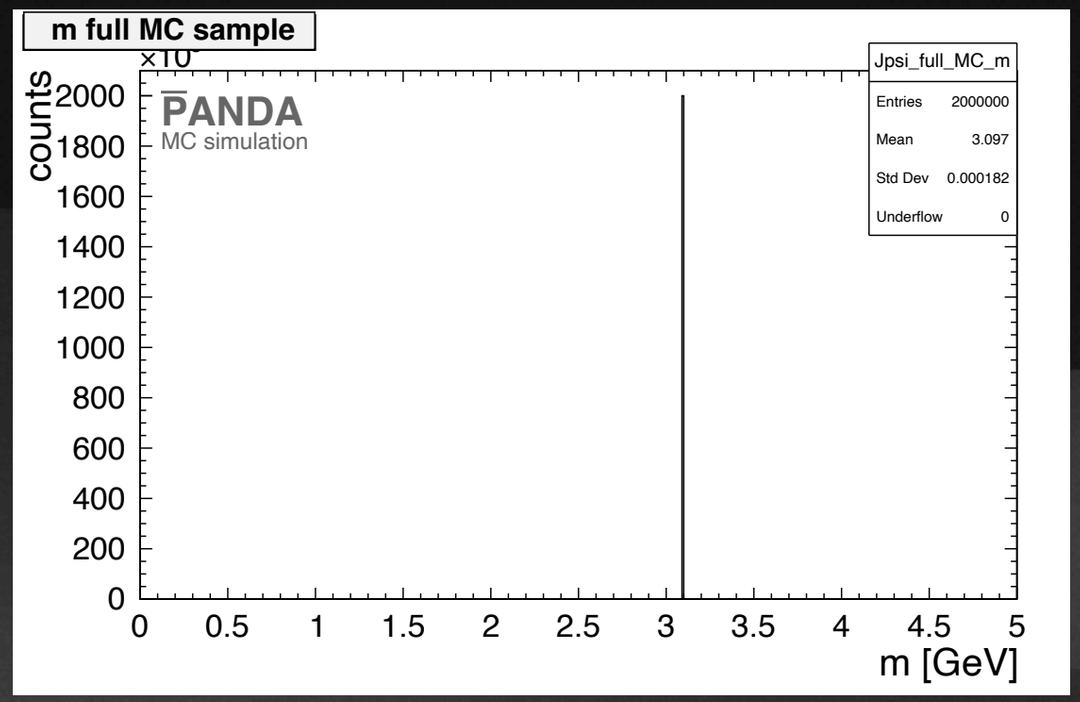
Parçacık türü	ε[%]
J/Ψ	30.47

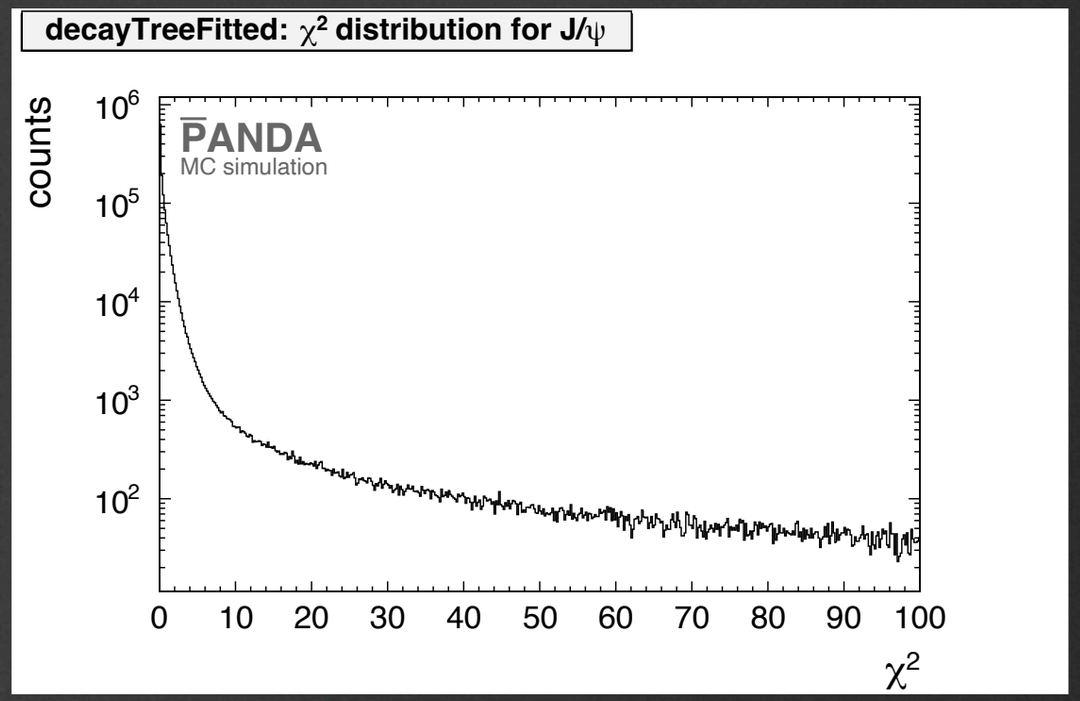
$\bar{p}p \to Zc(3900)^-\pi^+, (Zc(3900)^- \to J/\psi\pi^-, (J/\psi \to e^+e^-))$

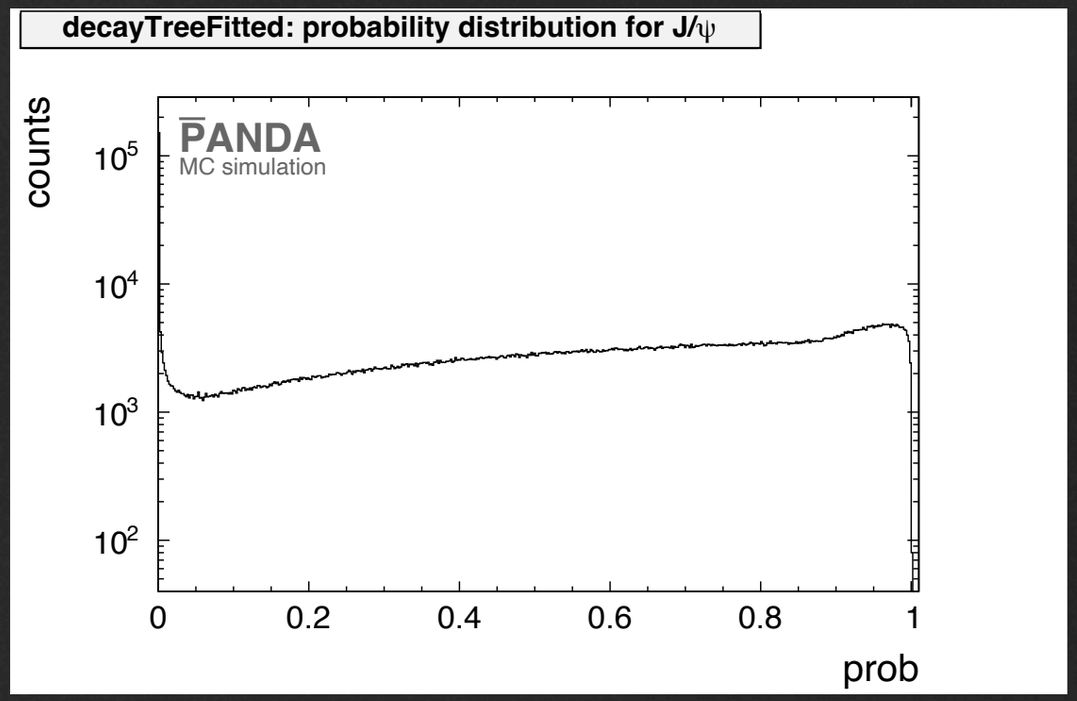
Analysis

Resonance States: J/ψ

- Reconstructed: m, chi2, prob



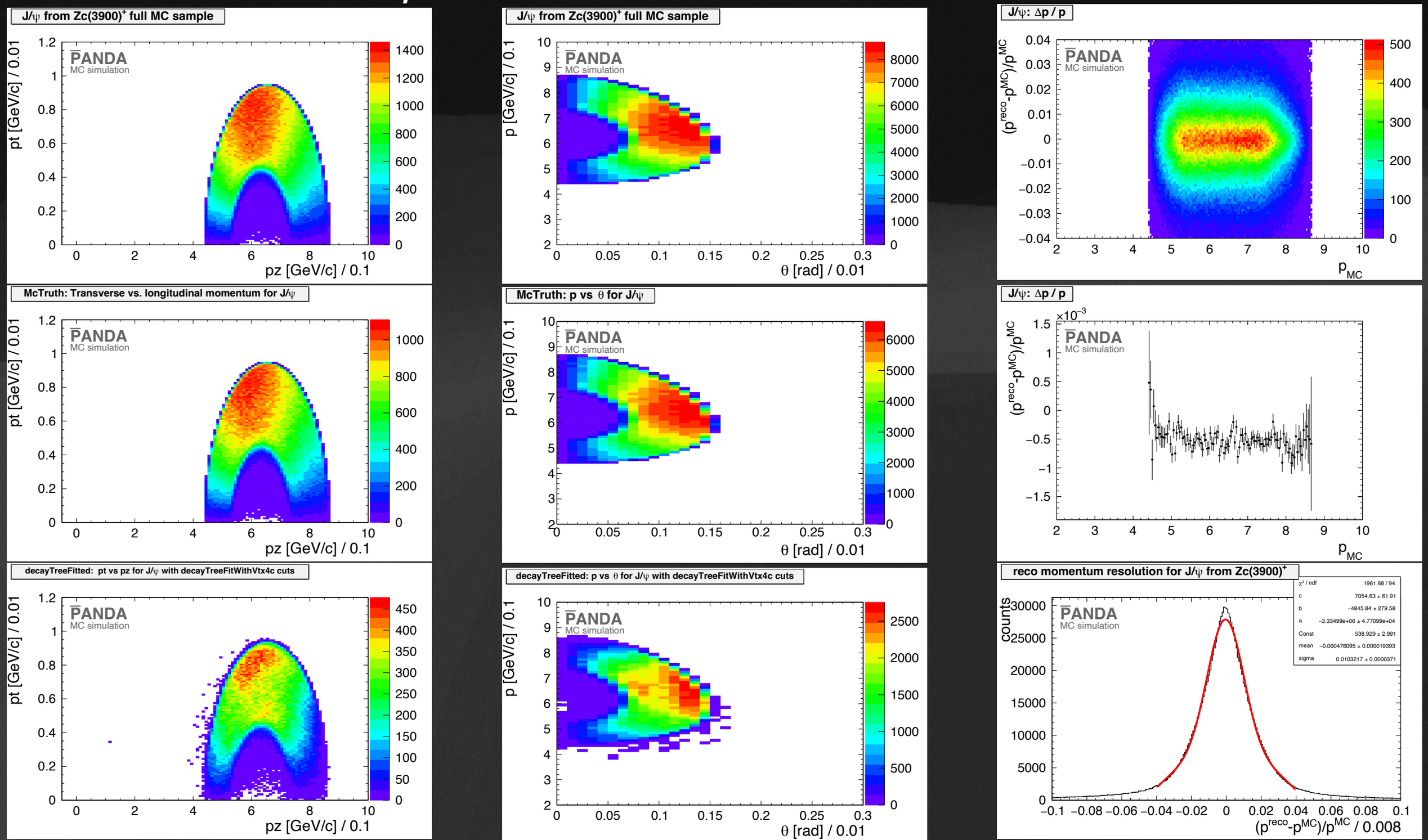




Analysis

Resonance States: Momentum Distributions

- Reconstructed: J/ψ



Analysis

Reconst. Resonance States: J/ψ

- Reconstructed: Momentum Resolution

Parçacık türü	d*p/p[%]*
J/Ψ	1.032

$\bar{p}p \rightarrow Zc(3900)^{+}\pi^{-}, (Zc(3900)^{+} \rightarrow J/\psi\pi^{+}, (J/\psi \rightarrow \mu^{+}\mu^{-}))$

Parçacık türü	*dp/p[%]*
J/Ψ	1.336

$\bar{p}p \rightarrow Zc(3900)^{+}\pi^{-}, (Zc(3900)^{+} \rightarrow J/\psi\pi^{+}, (J/\psi \rightarrow e^{+}e^{-}))$

Parçacık türü	*dp/p[%]*
J/Ψ	1028

$\bar{p}p \rightarrow Zc(3900)^{-}\pi^{+}, (Zc(3900)^{-} \rightarrow J/\psi\pi^{-}, (J/\psi \rightarrow \mu^{+}\mu^{-}))$

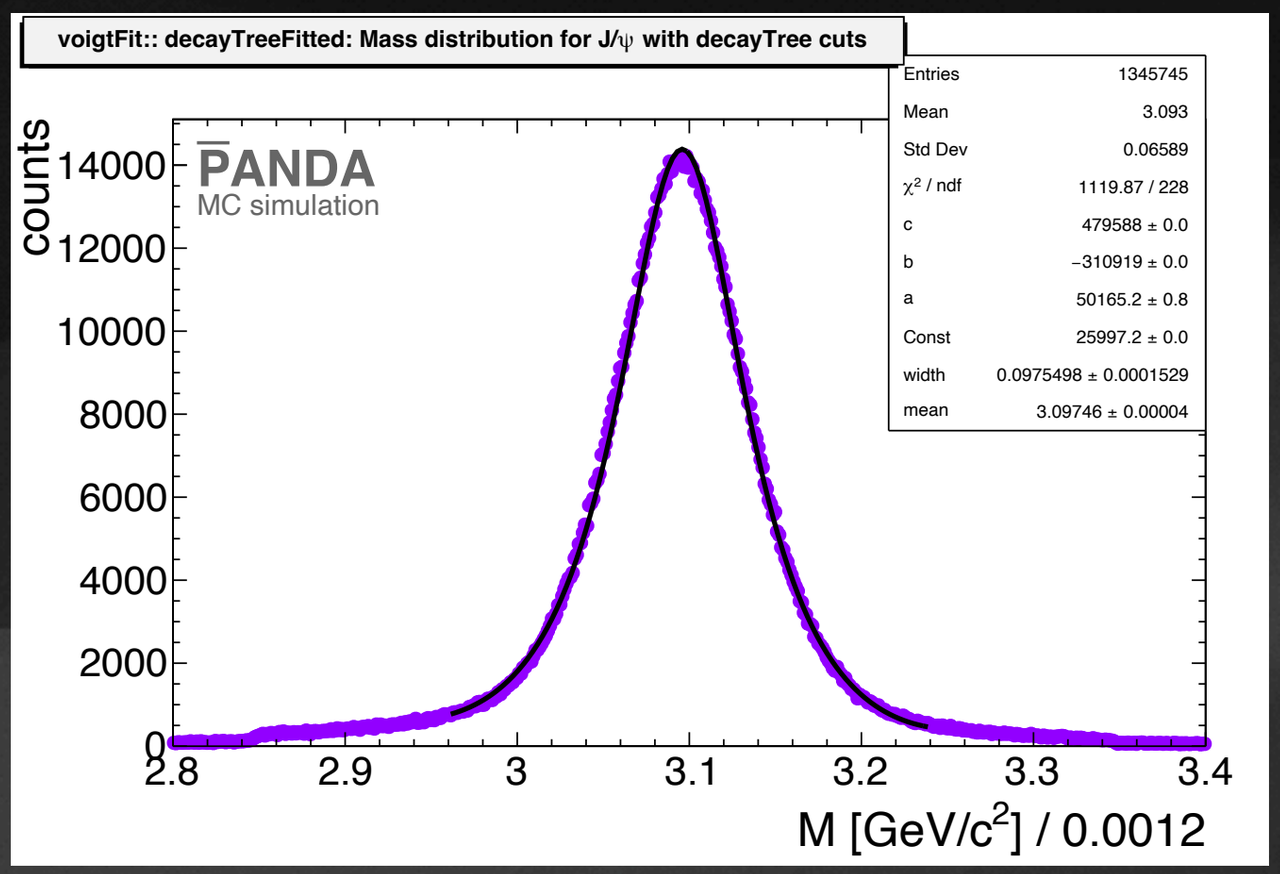
Parçacık türü	*dp/p[%]*
J/Ψ	1.365

$\bar{p}p \rightarrow Zc(3900)^{-}\pi^{+}, (Zc(3900)^{-} \rightarrow J/\psi\pi^{-}, (J/\psi \rightarrow e^{+}e^{-}))$

Analysis

Reconst. Resonance States: J/ψ

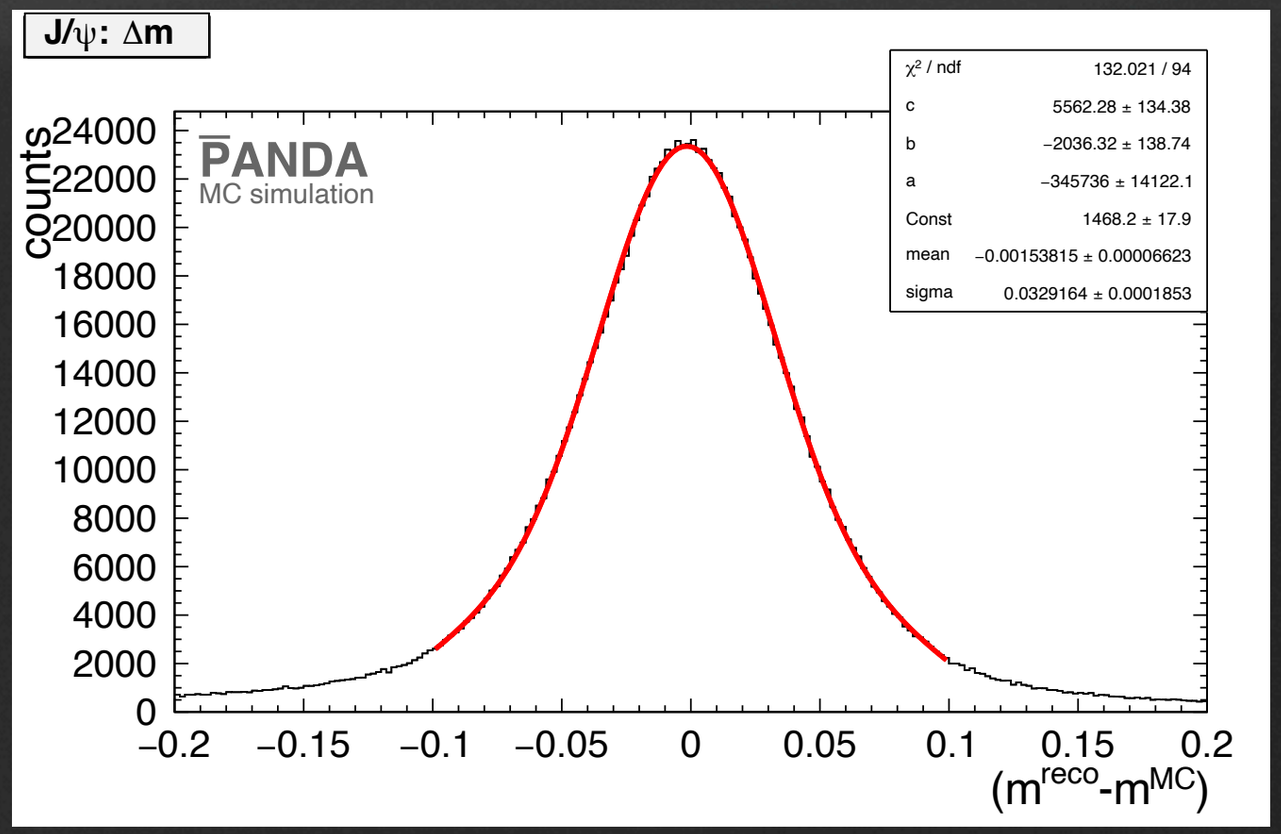
- Reconstructed: m, mDiff



VoigtFit:: quadratic Background + relativistic BW

$M_{J/\psi^{evt.pdl}}$: 3.09690 GeV/c²

$M_{J/\psi^{reco}}$: 3.09746 GeV/c²



Analysis

Reconst. Resonance States : Zc(3900)

- Combine J/ψ and π
- Mass cut with window $m_{Zc(3900)}$: [3.8872 ± 0.5] GeV/c^2
- Perform RhoDecayTreeFitter fit
- Select candidate with DecayTree fit prob > 0.01

Analysis

Reconst. Resonance States: $Zc(3900)$

- Reconstructed: efficiency

Parçacık türü	ε [%]
$Zc(3900)$	45.87

$\bar{p}p \to Zc(3900)^+\pi^-, (Zc(3900)^+ \to J/\psi\pi^+, (J/\psi \to \mu^+\mu^-))$

Parçacık türü	ε [%]
$Zc(3900)$	19.98

$\bar{p}p \to Zc(3900)^+\pi^-, (Zc(3900)^+ \to J/\psi\pi^+, (J/\psi \to e^+e^-))$

Parçacık türü	ε [%]
$Zc(3900)$	45.94

$\bar{p}p \to Zc(3900)^-\pi^+, (Zc(3900)^- \to J/\psi\pi^-, (J/\psi \to \mu^+\mu^-))$

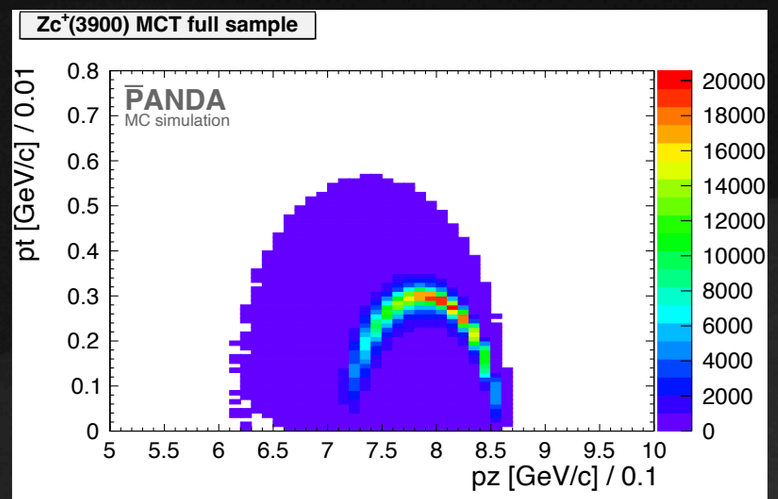
Parçacık türü	ε [%]
$Zc(3900)$	20.02

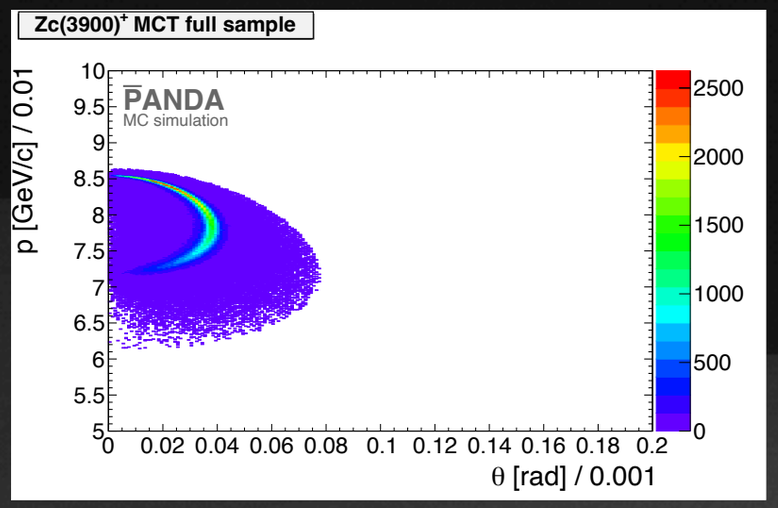
$\bar{p}p \to Zc(3900)^-\pi^+, (Zc(3900)^- \to J/\psi\pi^-, (J/\psi \to e^+e^-))$

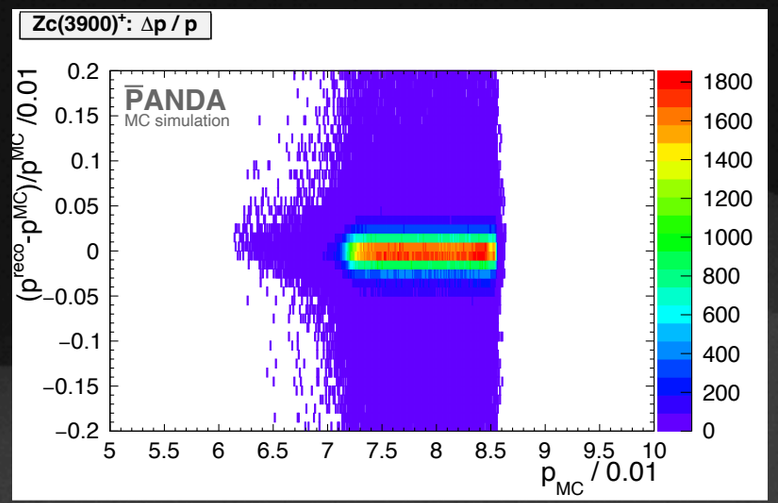
Analysis

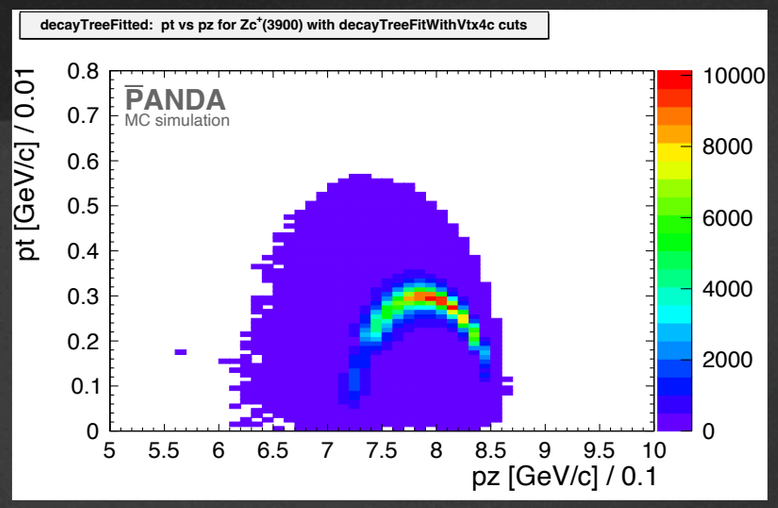
Reconst. Resonance States: $Zc(3900)$

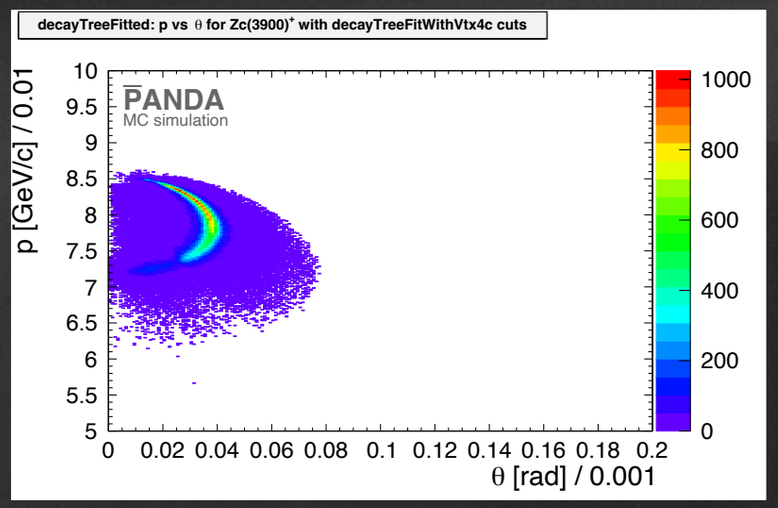
- Reconstructed: momentum distributions

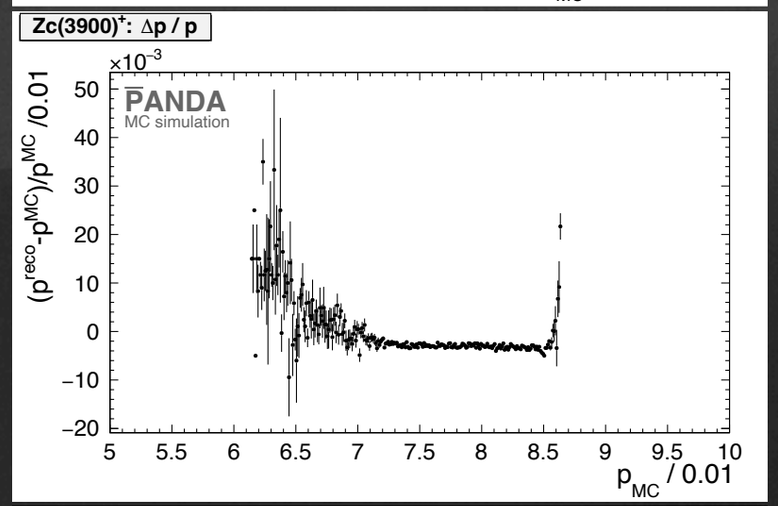


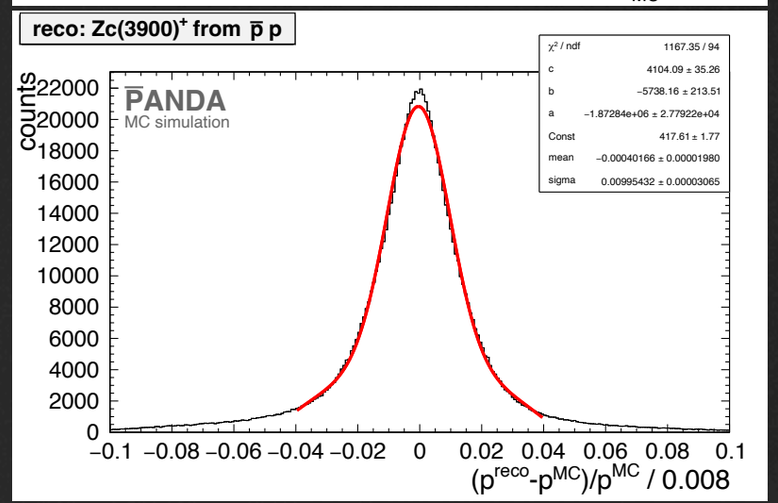












Analysis

Reconst. Resonance States: $Zc(3900)$

- Reconstructed: momentum resolutions

Parçacık türü	*dp/p* [%]
Zc(3900)	0.9954

$\bar{p}p \to Zc(3900)^+\pi^-, (Zc(3900)^+ \to J/\psi\pi^+, (J/\psi \to \mu^+\mu^-))$

Parçacık türü	*dp/p*[%]
Zc(3900)	1.299

$\bar{p}p \to Zc(3900)^+\pi^-, (Zc(3900)^+ \to J/\psi\pi^+, (J/\psi \to e^+e^-))$

Parçacık türü	*dp/p*[%]
Zc(3900)	0.9976

$\bar{p}p \to Zc(3900)^-\pi^+, (Zc(3900)^- \to J/\psi\pi^-, (J/\psi \to \mu^+\mu^-))$

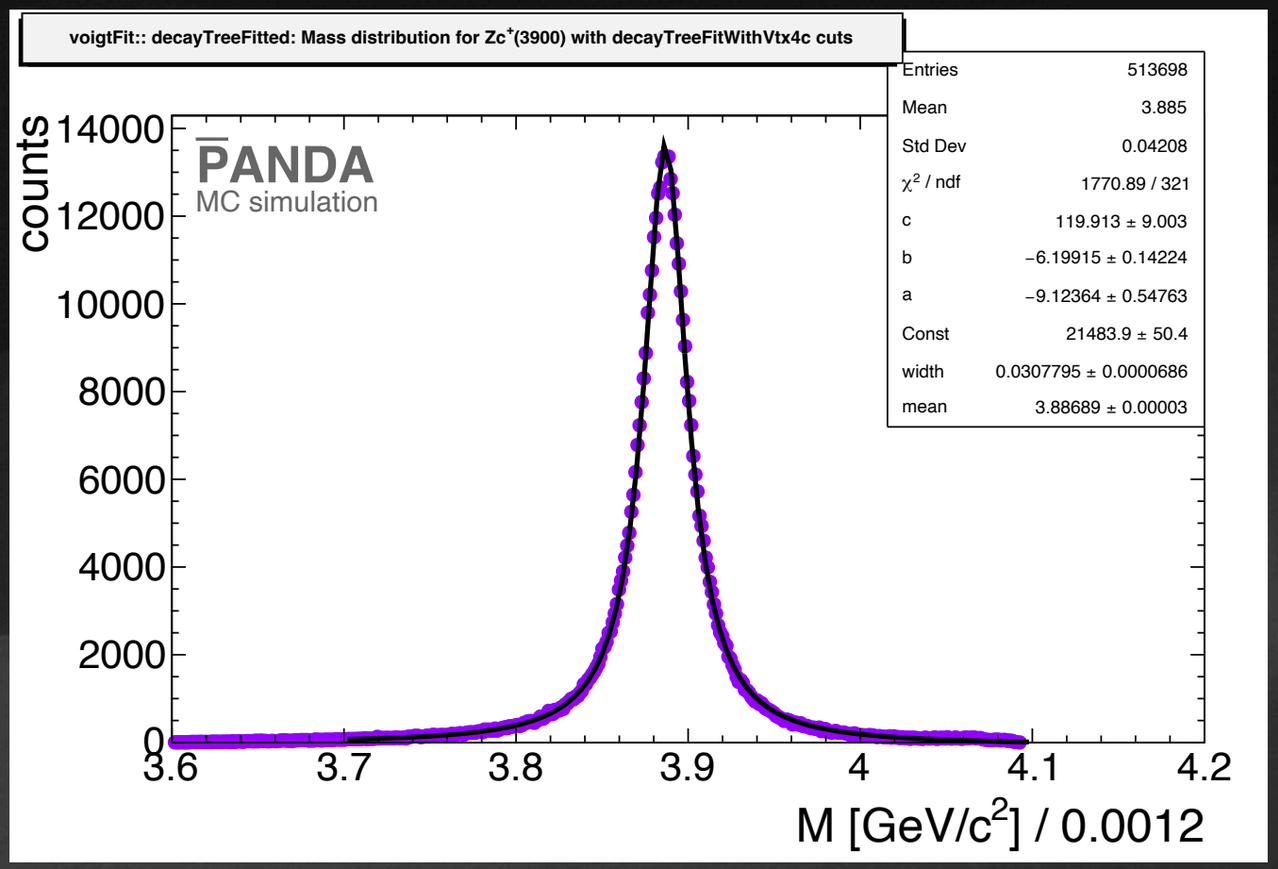
Parçacık türü	*dp/p* [%]
Zc(3900)	1.293

$\bar{p}p \to Zc(3900)^-\pi^+, (Zc(3900)^- \to J/\psi\pi^-, (J/\psi \to e^+e^-))$

Analysis

Reconst. Resonance States: $Zc(3900)$

- Reconstructed: m, mDiff



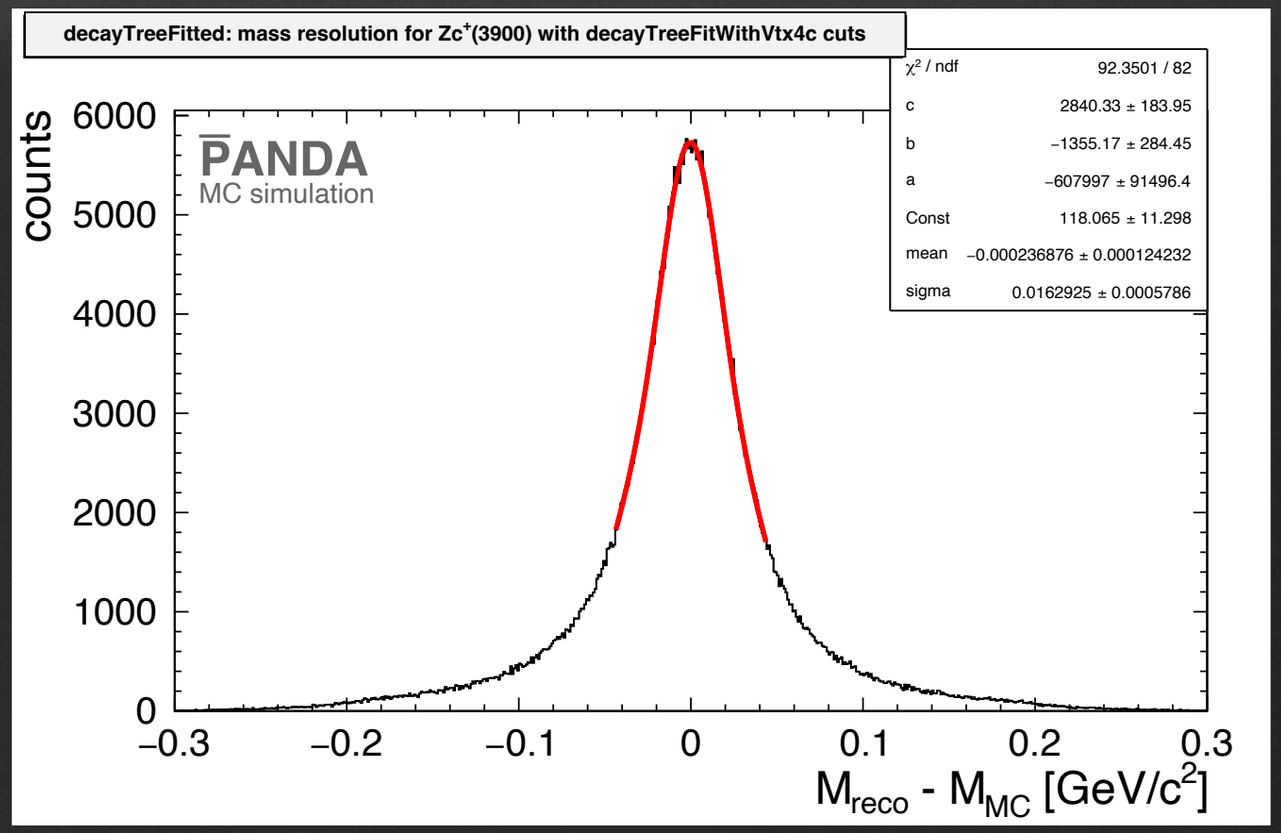
VoigtFit:: quadratic Background + relativistic BW

$M_{Zc(3900)^{evt.pdl}}$: [3.8872] GeV/c²

$\Gamma_{Zc(3900)^{evt.pdl}}$: [0.0282] GeV/c²

$M_{Zc(3900)^{reco}}$: [3.8869 ± 0.00003] GeV/c²

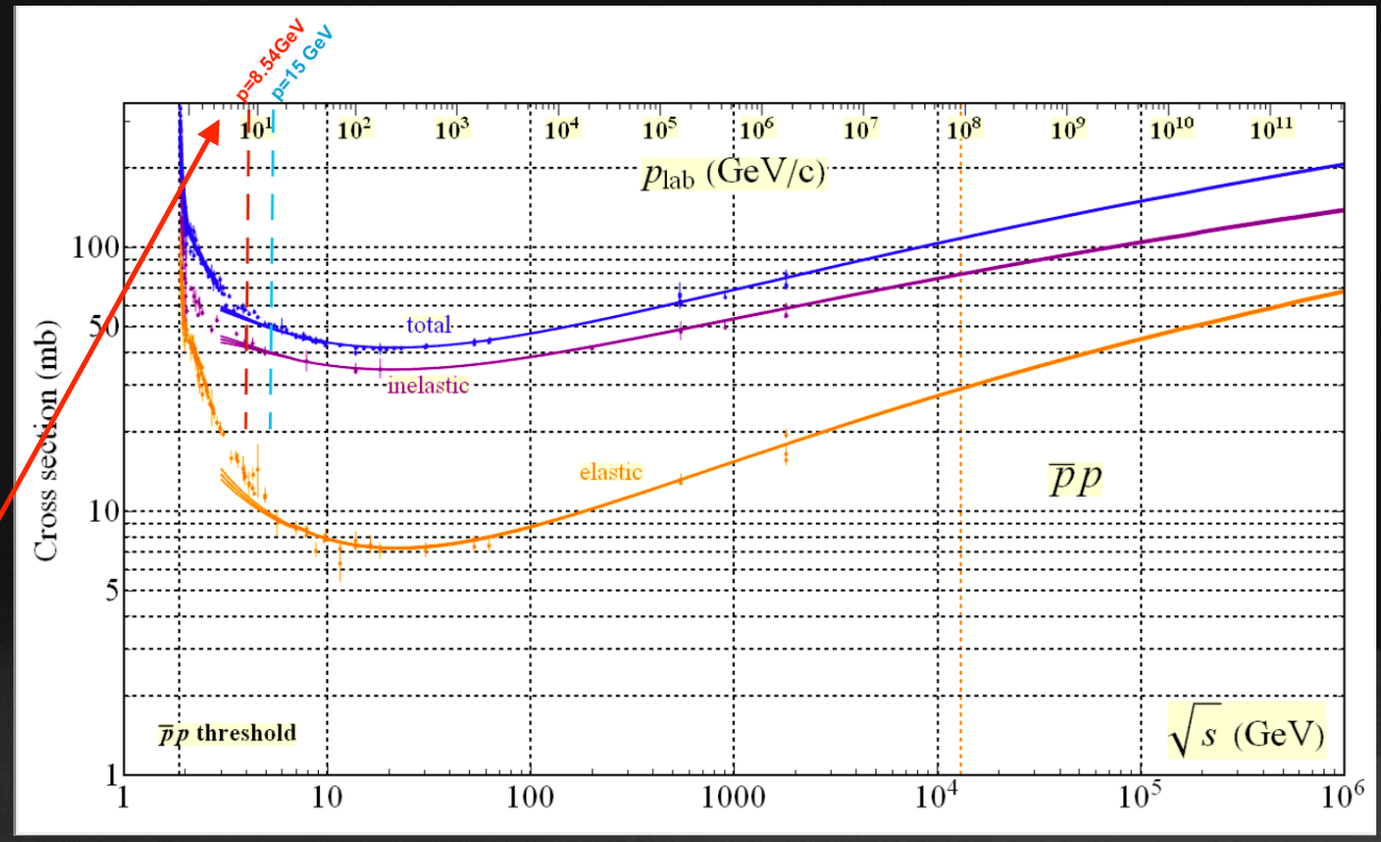
$\Gamma_{Zc(3900)^{reco}}$: [0.0308 ± 0.00007] GeV/c²



Analysis

Background

- 30 million events were generated with Dual Parton Model (DPM)
- Same analysis strategy applied to background events
  - no event out of 30 million survived after the applied cuts.
  - The non-observation of any background events corresponds to a 90% confidence upper limit of 2.3 events. (means reco eff, $\epsilon_{bkg} = 2.3 \cdot 10^{-8}$)
  - $\sigma_{sig} = [22.0 \pm 1.0]$ pb from Ref.[1]
  - at a beam momentum of 8.54 GeV/c, the inelastic cross section is $\sigma_{bkg} = 45$ mb Ref.[2].
  - The branching ratio of J/psi is set to 100% during event generation. To correct this value for the following calculations, the branching ratio $Br_{sig} = Br_{J/\psi} = 5.961$ for the J/psi decay in the decay tree is taken into account.



Signal-to-Background ratio is defined as

$$\frac{S}{B} = \frac{\sigma_{sig} \cdot \epsilon_{sig} \cdot Br_{sig}}{\sigma_{bkg} \cdot \epsilon_{bkg}}$$

Signal significance is defined as

$$S_{sig} = \frac{N_{sig}}{\sqrt{N_{sig} \cdot + N_{bkg} \cdot F_{bkg}}}$$

Scaling factor is

$$F_{bkg} = \frac{N_{sig}^{gen} \cdot \sigma_{bkg}}{N_{bkg}^{gen} \cdot \sigma_{sig} \cdot Br_{sig}}$$

[1] M. Ablikim et al. (BESIII Collaboration). Phys. Rev. Lett. 119, 072001 (2017)
[2] https://pdg.lbl.gov/2022/hadronic-xsections/

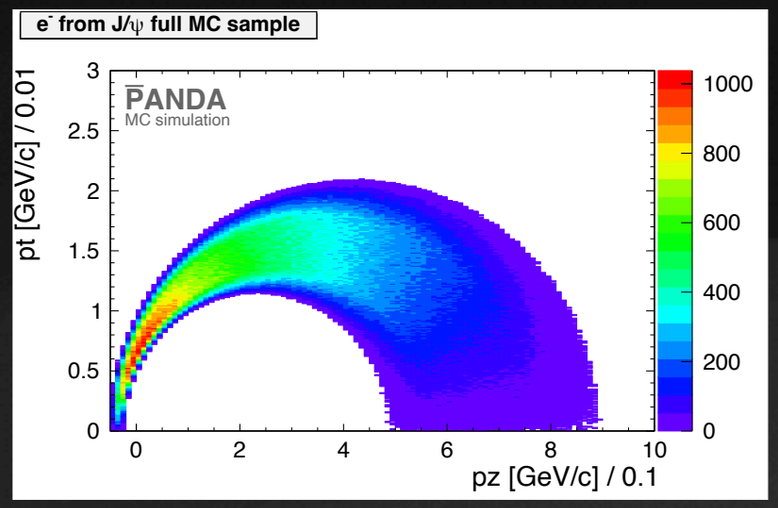
Summary

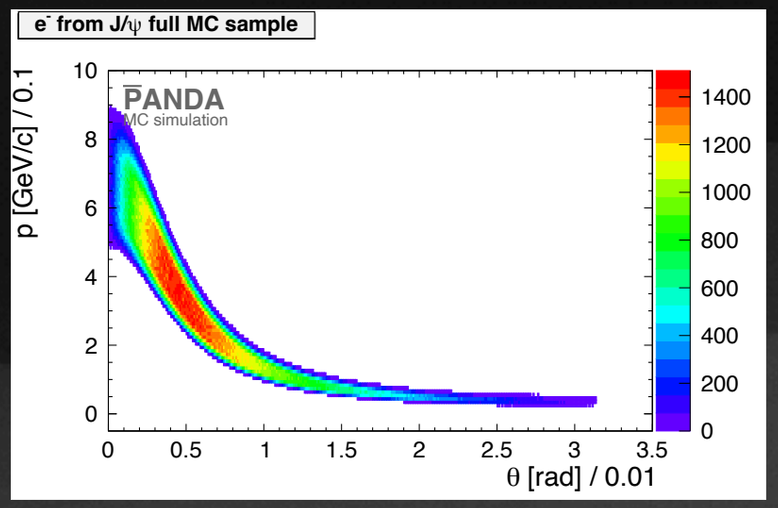
Particle type	ε_{reco} [%]	S / B x10^{-4}	S_{sig}
$Zc(3900)^+$ (from $\mu^+\mu^-$)	45.87	5.8	10.7391*
$Zc(3900)^+$ (from e^+e^-)	19.98	2.5	3.6877*
$Zc(3900)^-$ (from $\mu^+\mu^-$)	45.94	5.8	10.7035*
$Zc(3900)^-$ (from e^+e^-)	20.02	2.5	3.6905*
* assuming at least 1 background event			

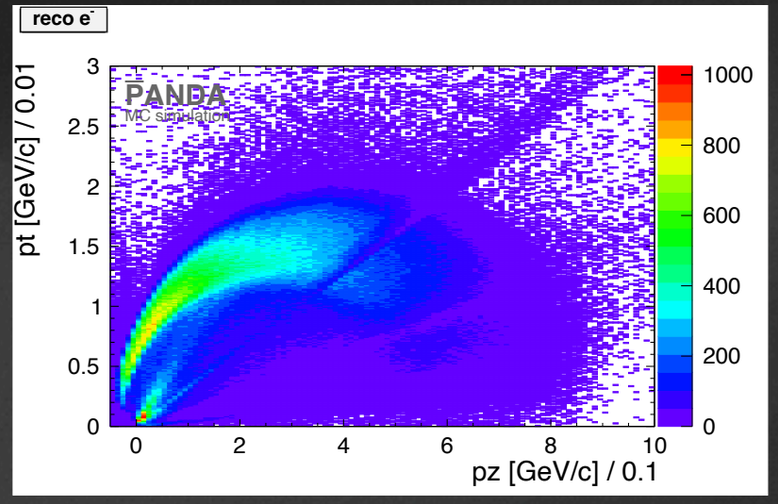
+

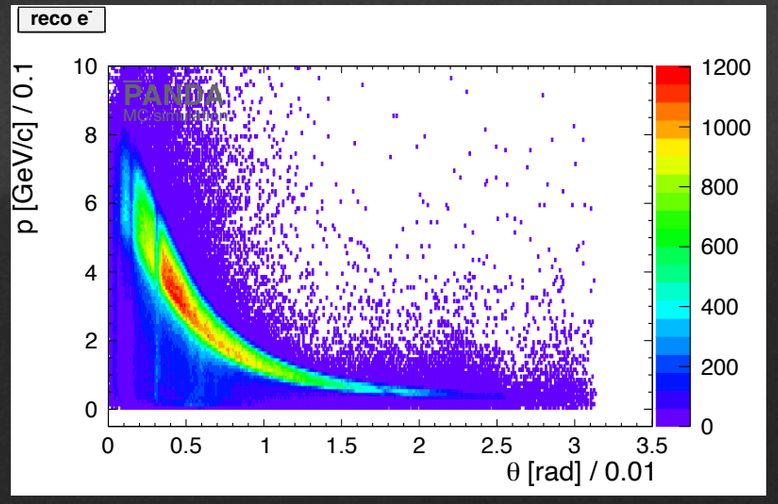
Backups

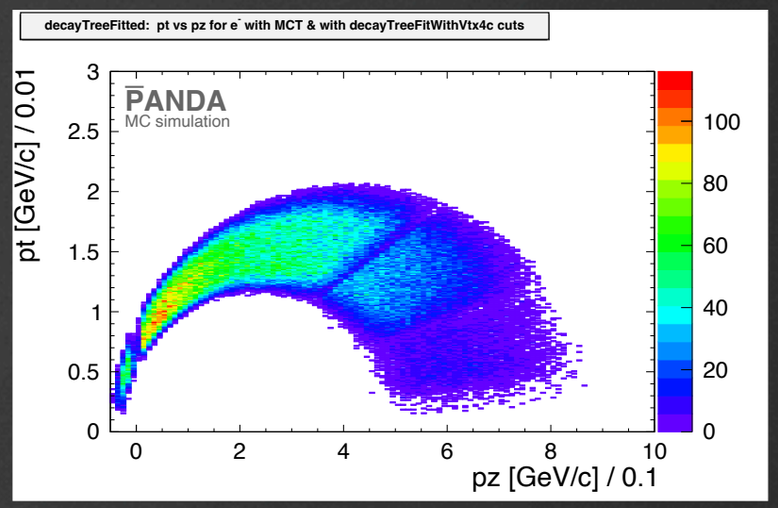
Electron channel : e^-

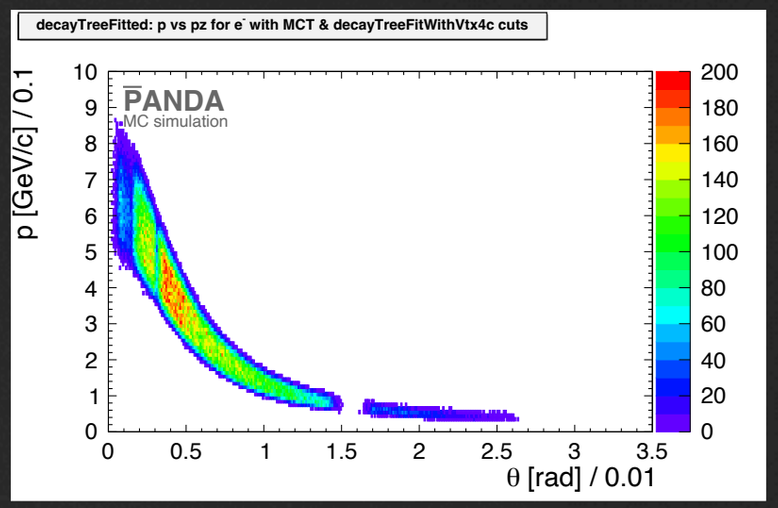






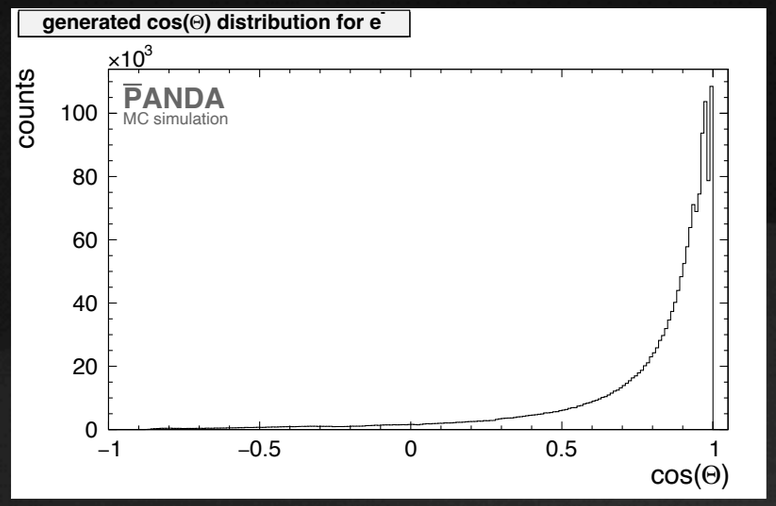


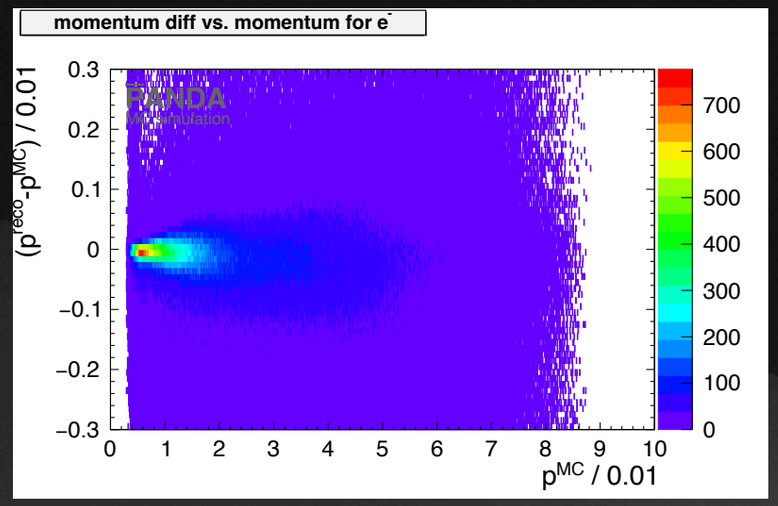


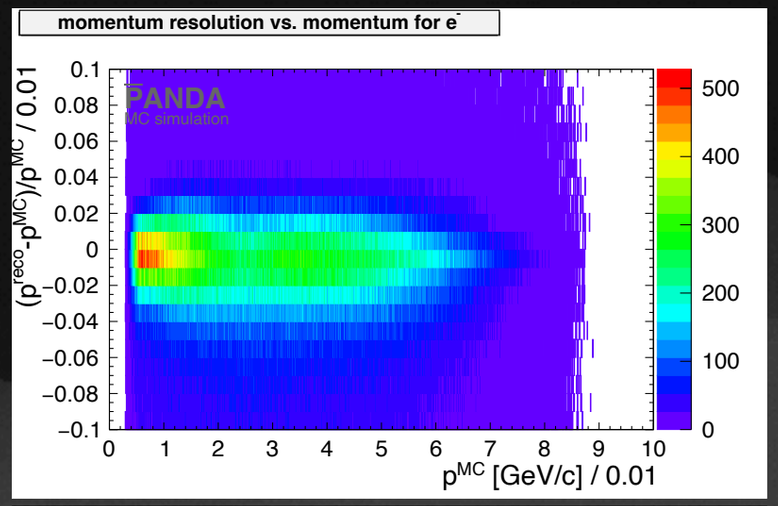


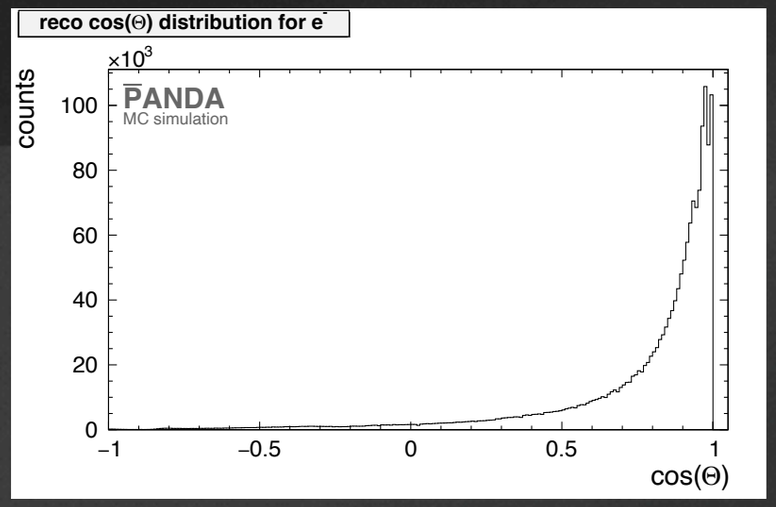
Backups

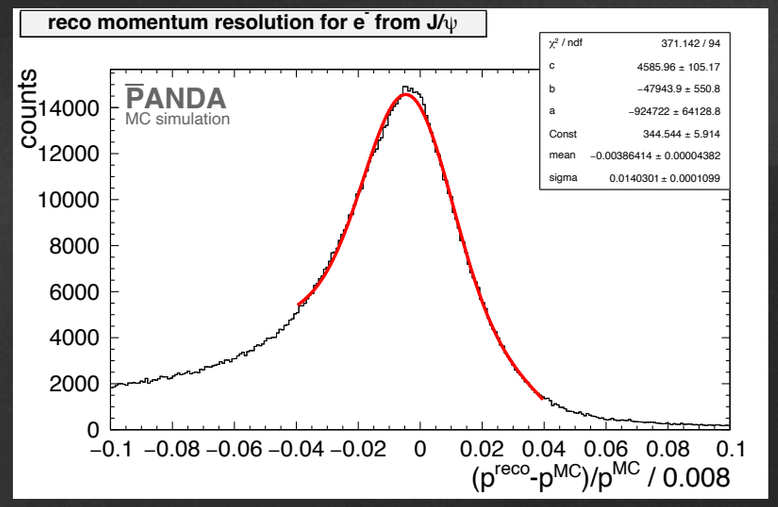
Electron channel : e^-

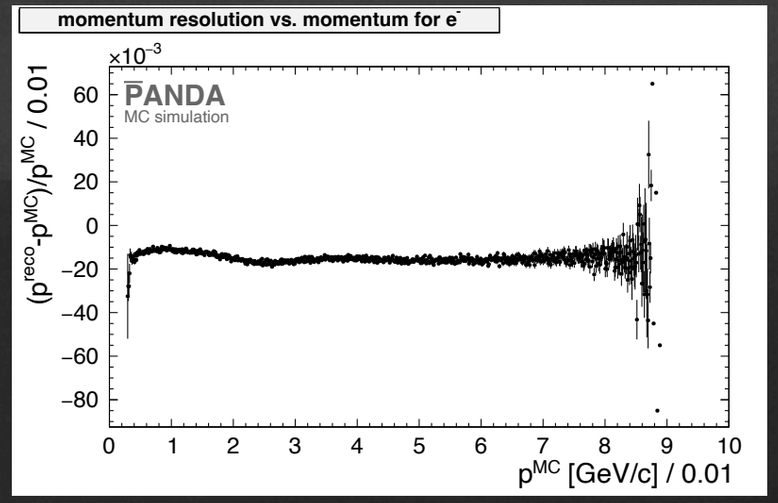






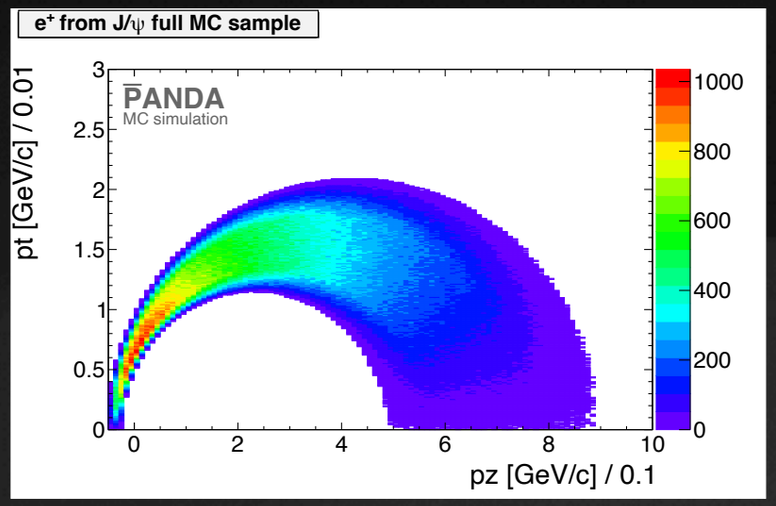


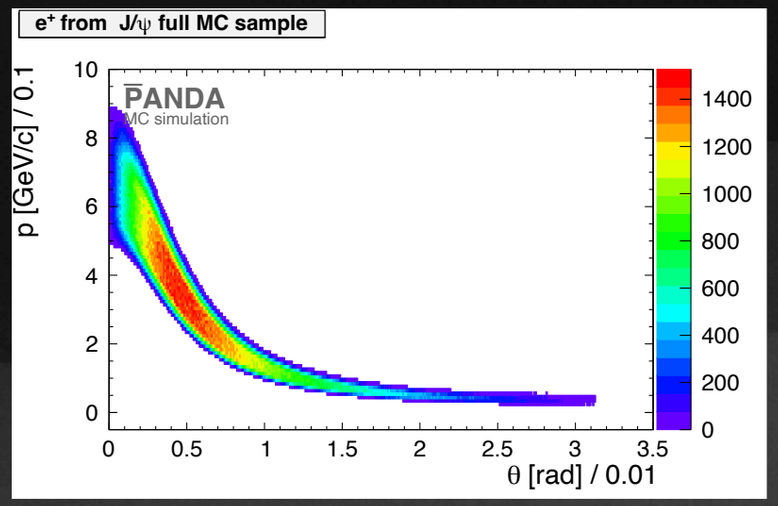


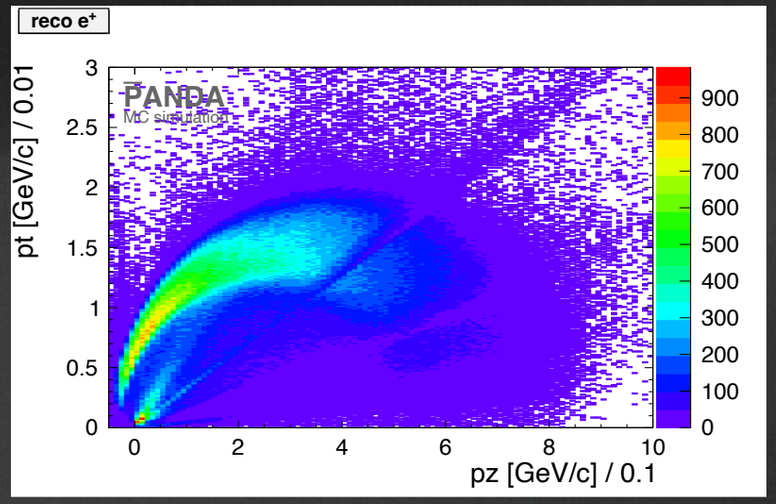


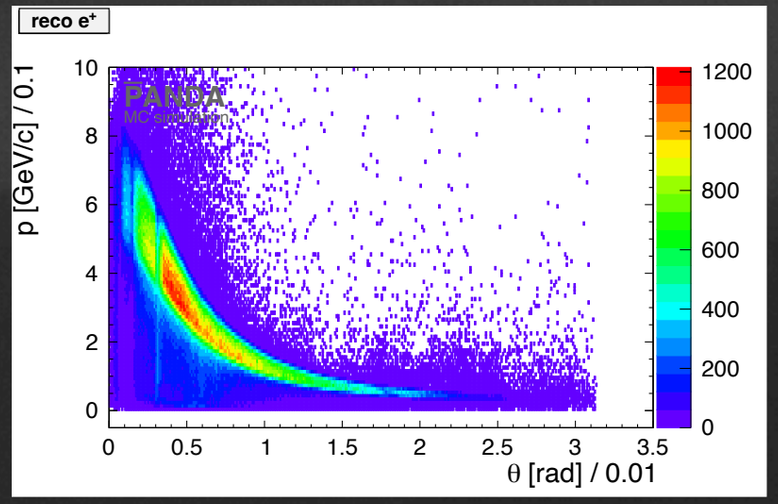
Backups

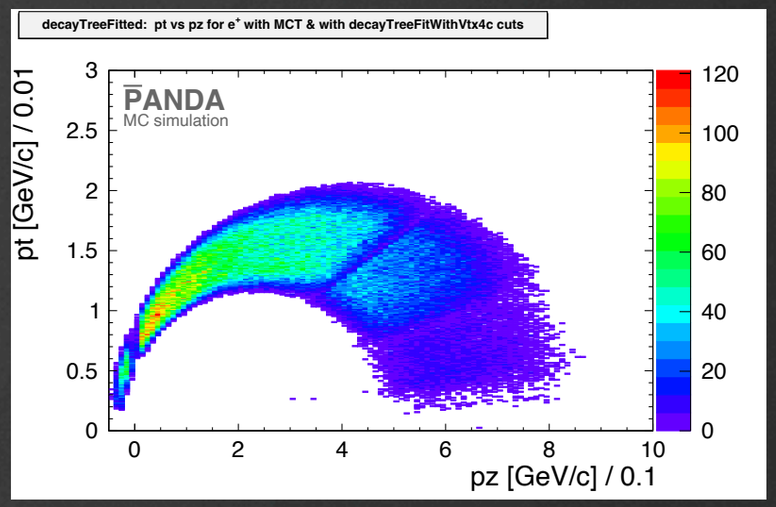
Electron channel : e^+

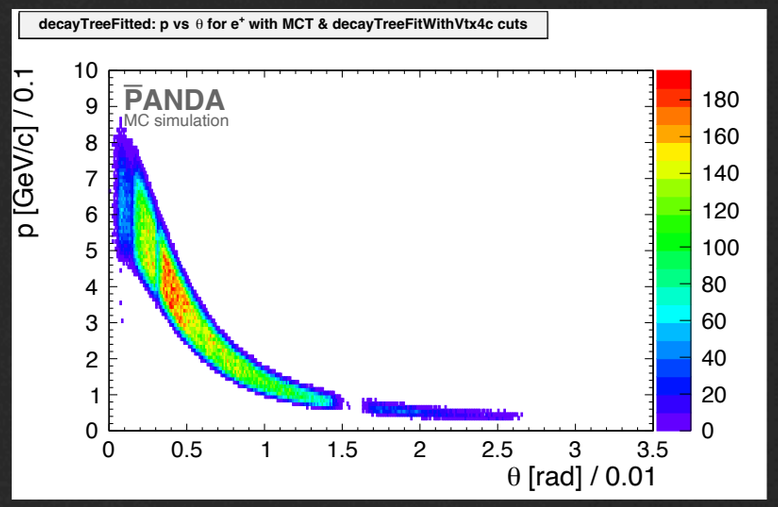






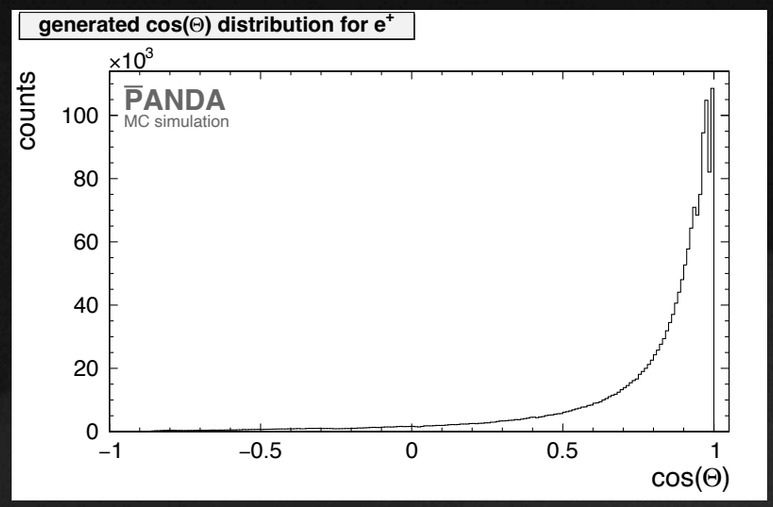


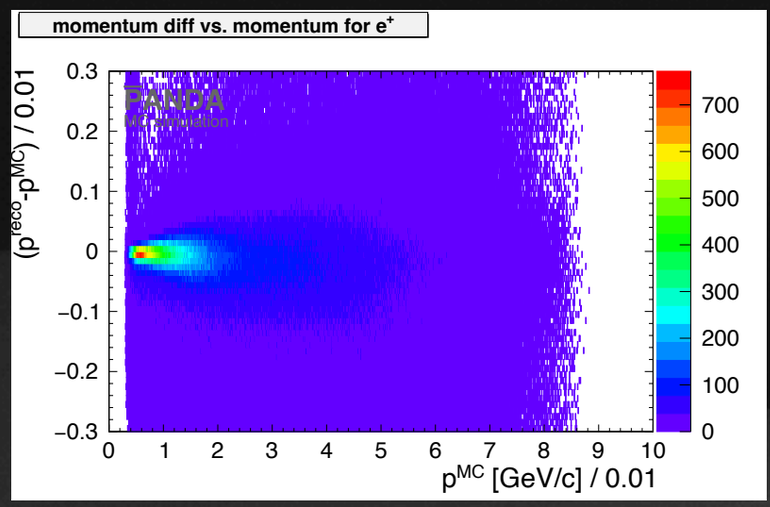


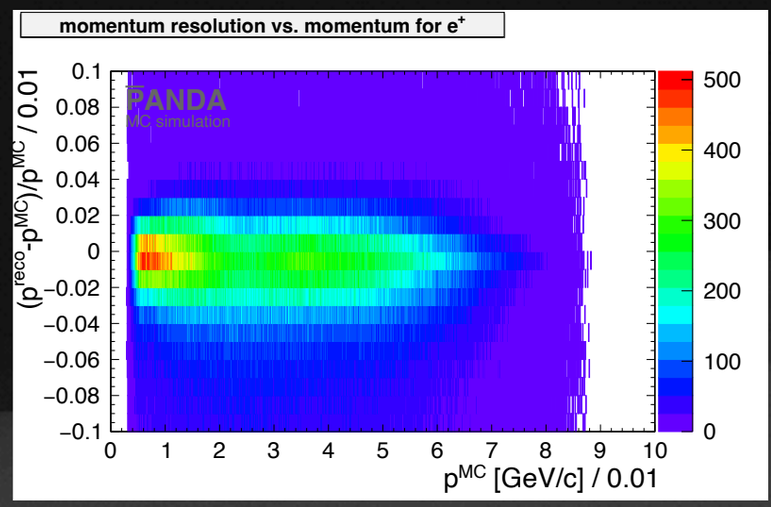


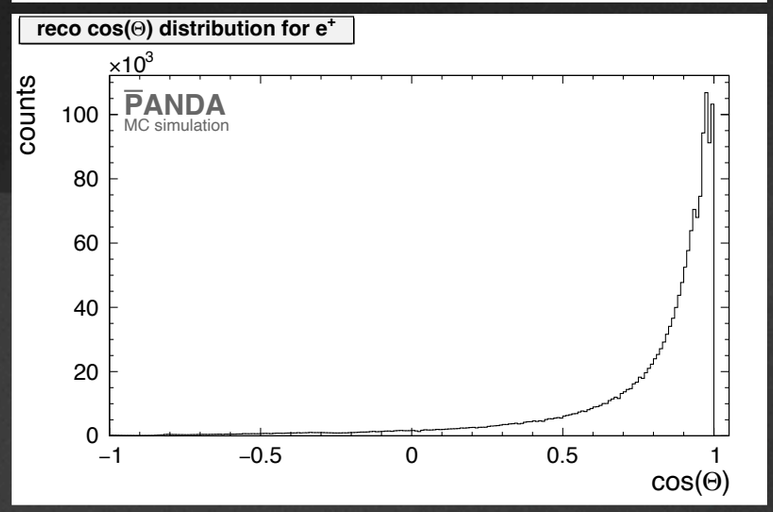
Backups

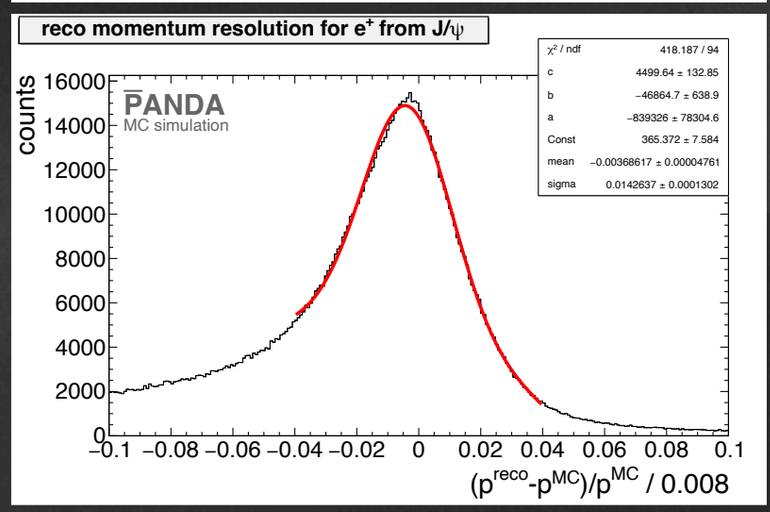
Electron channel : e^+

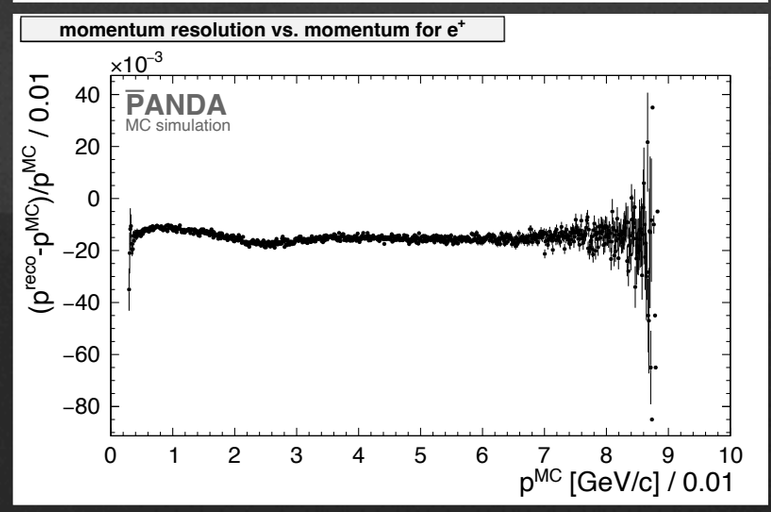






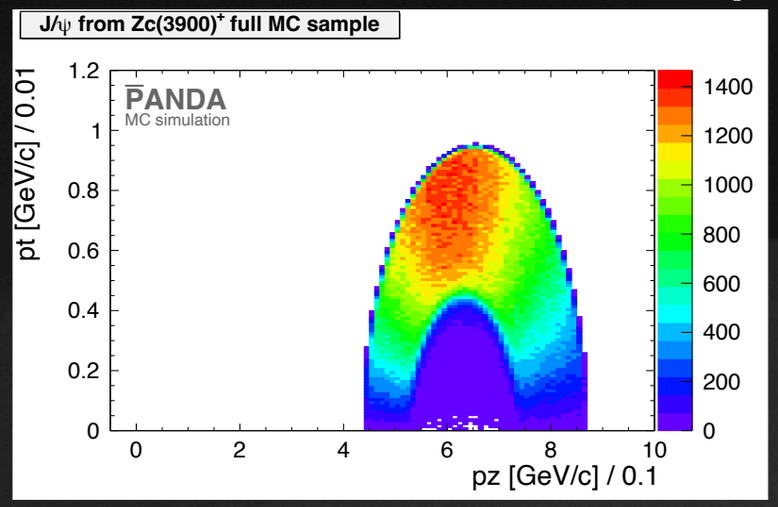


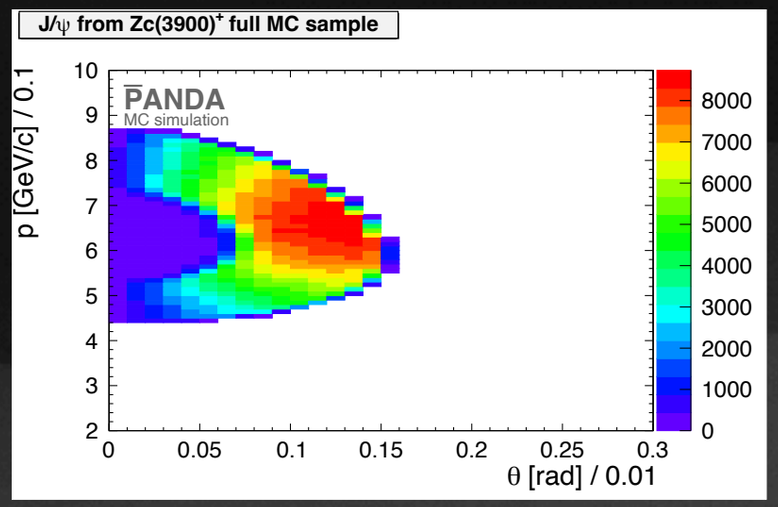


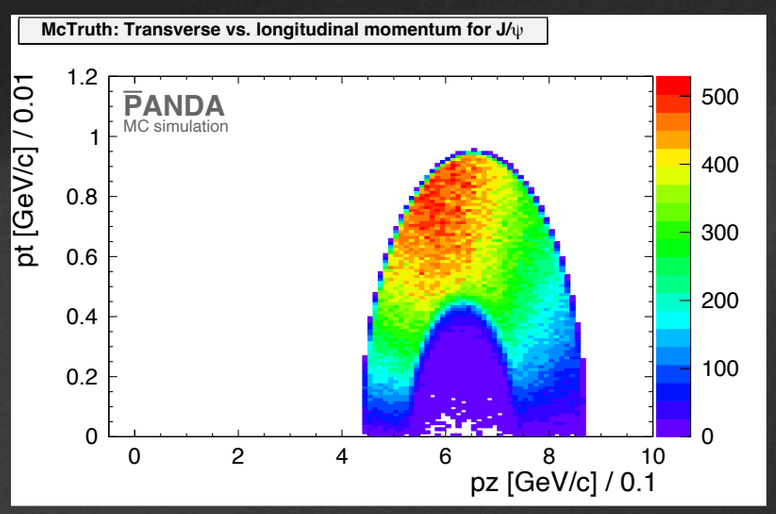


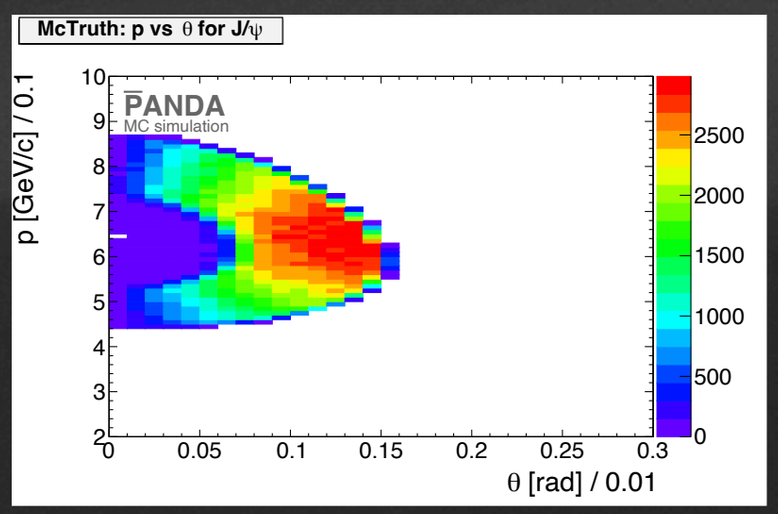
Backups

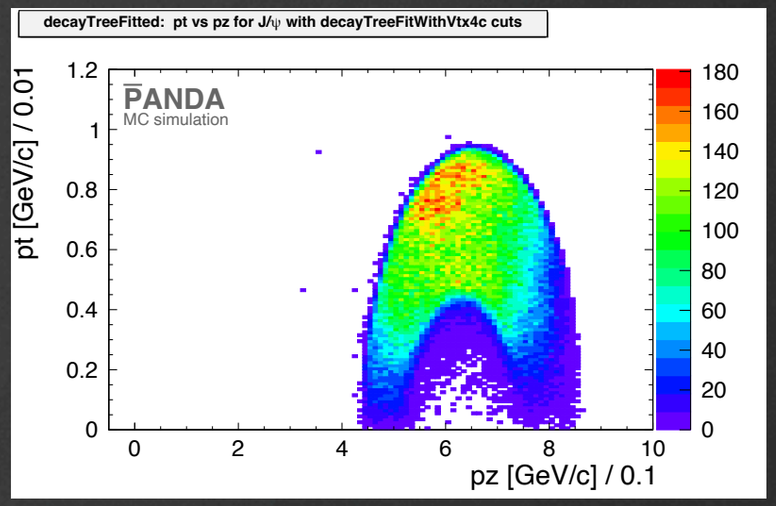
Electron channel : J/ψ

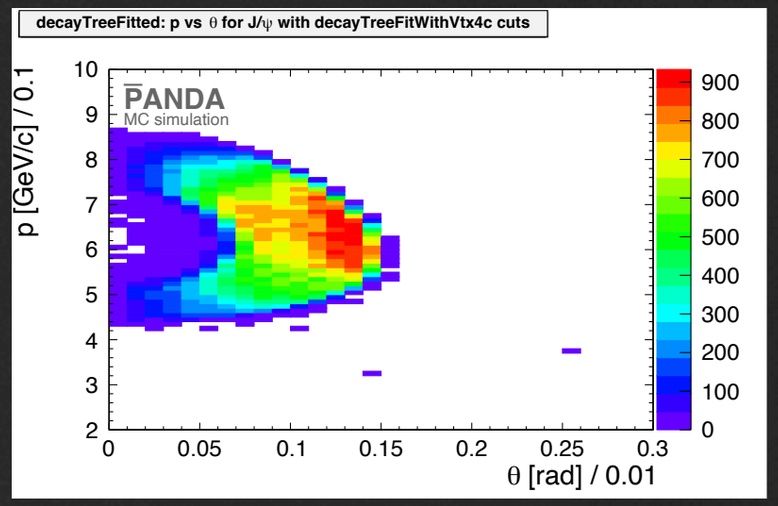












Backups

Electron channel : J/ψ