

Search for $Z_c(3900)$ via Transformer

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- $Z_c(3900)$ decay chain
 $e^+e^- \rightarrow Z_c(3900)^\pm \pi^\mp$
 $Z_c(3900)^\pm \rightarrow J/\psi \pi^\pm$
 $J/\psi \rightarrow e^+e^-(\mu^+\mu^-)$

- Signal MC sample (BOSS 7.0.3)

decay tree	decay model
$e^+e^- \rightarrow Z_c(3900)^\pm \pi^\mp$	PHSP
$Z_c(3900)^\pm \rightarrow J/\psi \pi^\pm$	PHSP
$J/\psi \rightarrow e^+e^-(\mu^+\mu^-)$	VLL

- Data Sample (BOSS 7.0.3)

4.260 GeV Data at BESIII of 2013

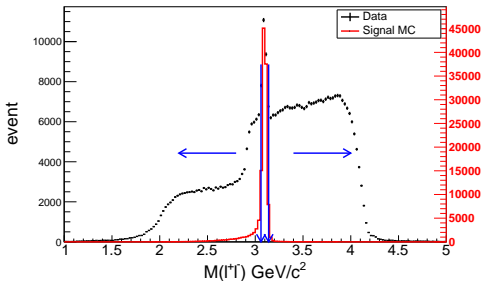
sample	luminance	center-mass energy	Run number
4260	$828.4 \pm 0.1 \pm 5.5$	$4257.97 \pm 0.04 \pm 0.66$	29677-30367 31561-31981

Preliminary Selection

- Good charged track selection
 - $|\cos\theta| < 0.93, |V_z| < 10\text{cm}, |V_r| < 1\text{cm}$
 - Four good tracks and zero net charge
- particle identification
 - $p > 1\text{ GeV}/c$ identified as lepton
 - $p < 1\text{ GeV}/c$ identified as π
 - The number of pions and that of leptons should be two in each event with zero net charge.
 - $E_{EMC} > 1.1\text{ GeV}$ identified as e
 - $E_{EMC} < 0.35\text{ GeV}$ identified as μ
- remove gamma-conversion background
 - $\cos(\pi^+\pi^-) < 0.98$
 - $\cos(\pi^\pm e^\mp) < 0.98$

Quantum Transformer

- Model : Transformer and Quantum Transformer
- Signal : Signal MC
- Background is form data :
 $M(I^+I^-) \in (0, 3.06) \cup (3.14, 5) \text{ GeV}/c^2$

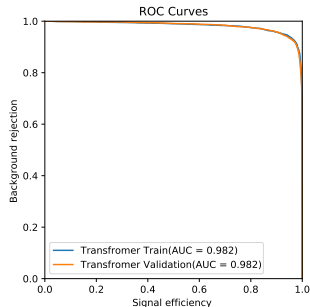
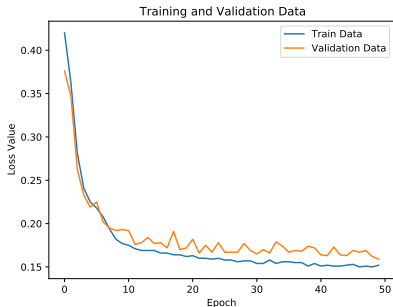


Train data set

- Data : 98577 event after preliminary cut
- Sideband data : 86609 event
- Signal : 124706 event
- Signal: background = 1:1
- Classical Transformer :
 - 20k events (10k for train, 10k for validation)
 - 50 epochs
- Quantum Transformer :
 - 20k events (10k for train , 10k for validation)
 - 8 epochs

Training Model

- Parameter Set: 26 variables
- 16 variables: four-momentum of 4 charge tracks
- 4 variables: momentum of 4 charge tracks
- 4 variables : angles between tracks
- 2 variables : $\text{Num}(\gamma)$, $\text{Emax}(\gamma)$



Apply Model

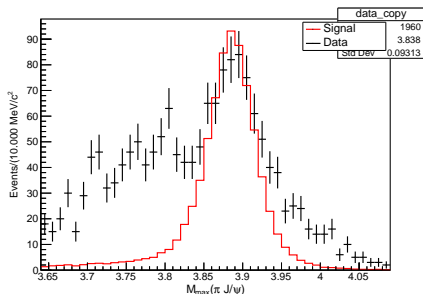
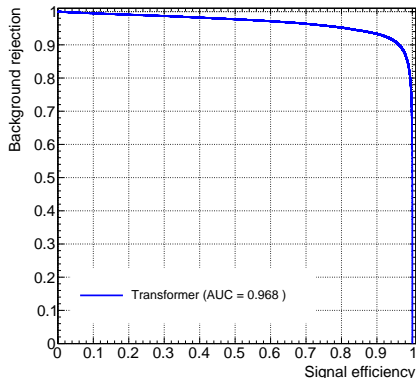
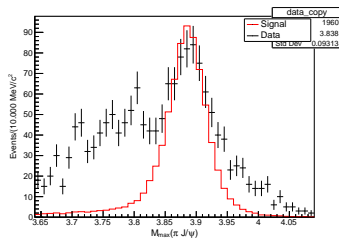
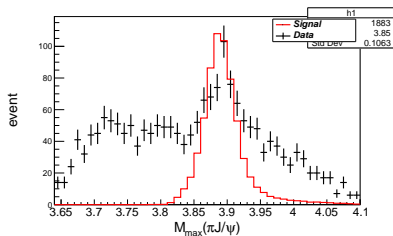


Fig : Apply the model to the real data and signal MC. ROC curve (left) and $M_{max}(\pi J/\psi)$ invariant mass distributions(right). In right panel, dots with error bars are data. The red curve is signal MC.

Apply Model



$$\epsilon = 231.63$$

$$\epsilon = 242.67$$

Fig: $M_{max}(\pi J/\psi)$ invariant mass distribution. The left plot shows the result using classical cuts, while the right plot displays the Transformer result .

$$\epsilon = \frac{s}{\sqrt{s+b}}$$

Here, s represents the number of events in the signal MC, while b represents the number of events in the data.

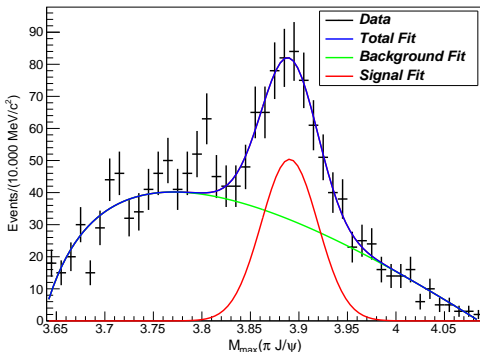
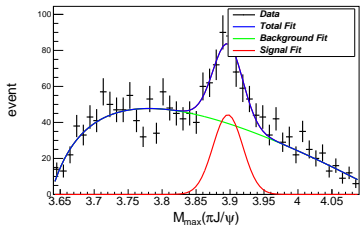
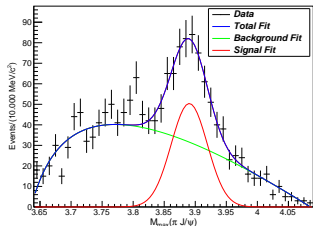


Fig : Fit to $M_{\max}(\pi J/\psi)$ invariant mass distributions with Gaussian resolution as signal function and $a/(x - 3.6)^b + c + dx$ background trem . Dots with error bars are data. The blue curve shows the total fit, the green curve shows the background fit, and the red curve shows the signal fit.



classical cut



Transformer

	classical cut	Transformer
Signal	243.2	367.6
Background	1526.9	1197.0
Total	1770.1	1546.7
$\epsilon = \frac{s}{\sqrt{s+b}}$	5.78	9.29

Here, s and b are obtained by fitting the data.