

Tuesday,
September 23,
2025

Prediction

- The lowest 1^{-+} light tetraquark state is around 2 GeV, which is significantly far from the observed $\pi_1(1400)$, $\pi_1(1600)$ and $\eta_1(1855)$ state.
- The observed state $\pi_1(2015)$ is situated within the lowest 1^{-+} light tetraquark range. More experimental data and theoretical studies are essential for making unambiguous assignments.
- The lowest 1^{-+} charmoniumlike tetraquark state is around 4.3 GeV, might be observed in $\pi\chi_{c1}$, $\eta\chi_{c1}$, and γh_c decay processes.
- The lowest 1^{-+} fully-charmed tetraquark state is around 6.8 GeV, may be searched in $J/\psi h_c$ and, $\eta_c\chi_{c1}$ decay channels.

$$\pi^0 \quad I^G(J^{PC}) = 1^-(0^{-+})$$

$$\chi_{c1}(1P) \quad I^G(J^{PC}) = 0^+(1^{++})$$

$$\eta_c(1S) \quad I^G(J^{PC}) = 0^+(0^{-+})$$

$$J/\psi(1S) \quad I^G(J^{PC}) = 0^-(1^{--})$$

$$h_c(1P) \quad I^G(J^{PC}) = 0^-(1^{+-})$$

$$\begin{aligned}
 e^+e^- &\rightarrow \pi^+\pi^-\pi^0\chi_{c1} \\
 \chi_{c1} &\rightarrow \gamma J/\psi \\
 J/\psi &\rightarrow e^+e^- / \mu^+\mu^- \\
 \pi^0 &\rightarrow \gamma\gamma
 \end{aligned}$$

Final state: $\gamma\gamma\gamma\pi^+\pi^-e^+e^-$ or $\gamma\gamma\gamma\pi^+\pi^-\mu^+\mu^-$

BOSS version: 7.0.9

1) Charged tracks (MDC)

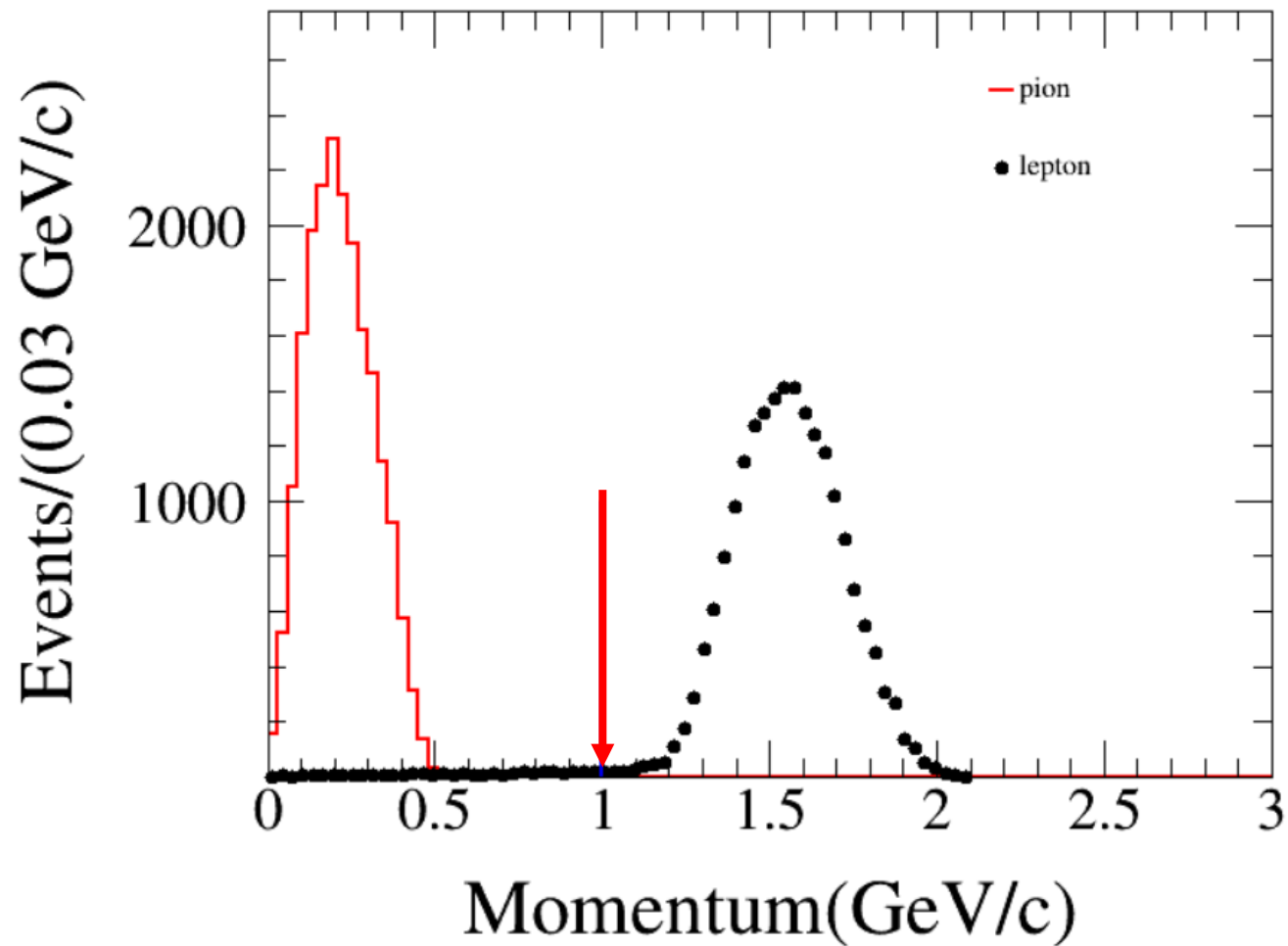
- $|\cos\theta| < 0.93$
- $R_{xy} < 1.0\text{ cm}, R_z < 10\text{ cm}$ (the beam line)
- $n_{\text{Good}} \geq 4$
- total charge is 0

Data sets

- Data : 2020 (@4640) run no. 63516-63715
- Inclusive MC : XYZ sample run no. 35227-36213 (@4600)

2) Neutral track

- $E_{\text{barrel}} > 25\text{ MeV}, |\cos\theta| < 0.8$
- $E_{\text{endcap}} > 50\text{ MeV}, 0.86 < |\cos\theta| < 0.92$
- EMC time $0 \leq t \leq 14$ (50 ns)
- the angle between the cluster and the nearest charged track < 10 degree
- $N_\gamma \geq 3$



Momentum distributions of π and leptons in the lab-frame generated from MC truth at CMS 4.260 GeV.

Separation of π and leptons

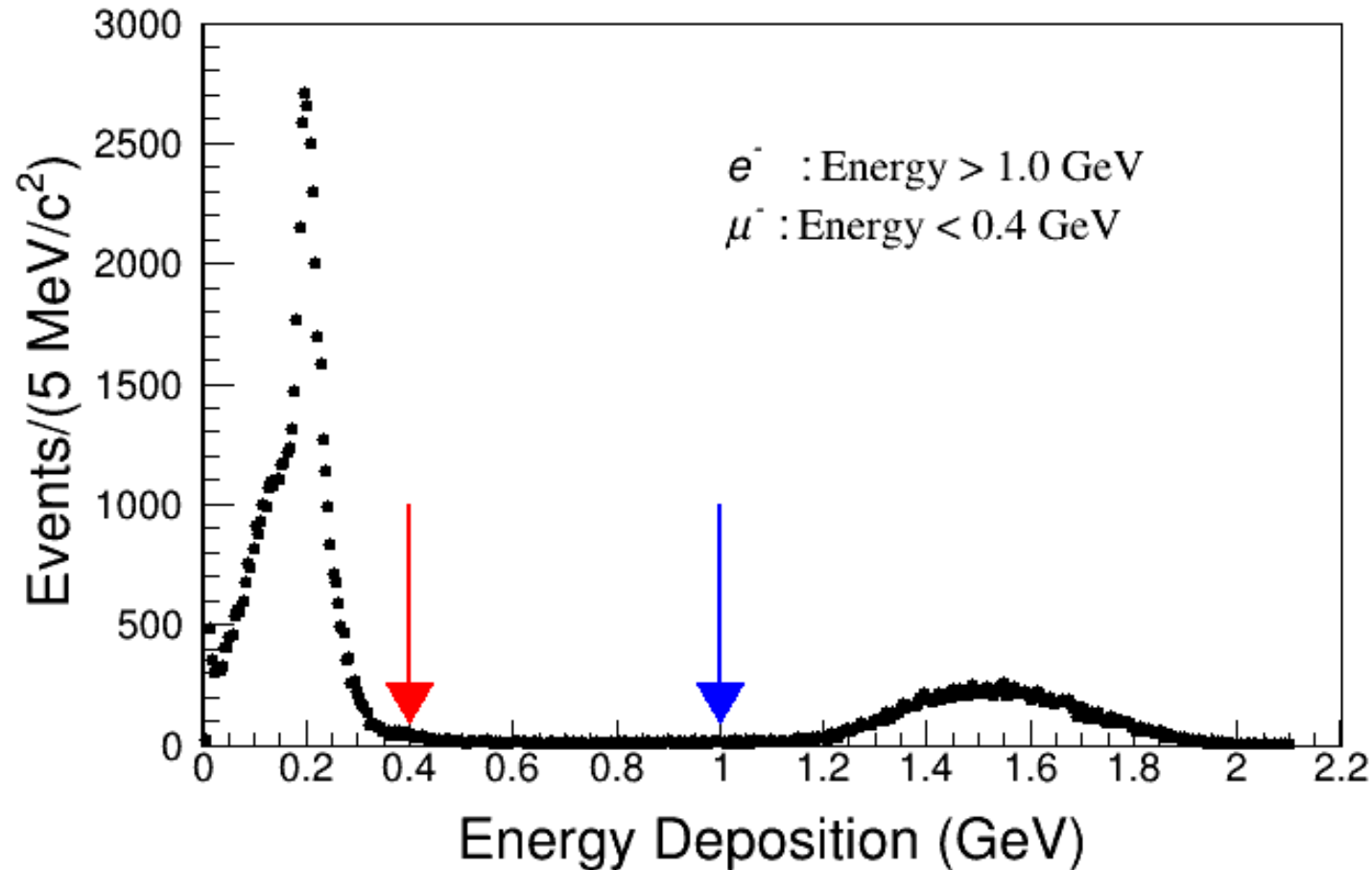
Leptons : Momentum > 1 GeV

$$(J/\psi \rightarrow e^+e^-/\mu^+\mu^-)$$

$\pi^\pm$: Momentum < 1 GeV

$$(e^+e^- \rightarrow \pi^+\pi^- \pi^0 \chi_{c1})$$

Separation of leptons



$$e^+e^- \rightarrow \pi^+\pi^-\pi^0\chi_{c1}$$

$$\chi_{c1} \rightarrow \gamma J/\psi$$

$$J/\psi \rightarrow e^+e^- / \mu^+\mu^-$$

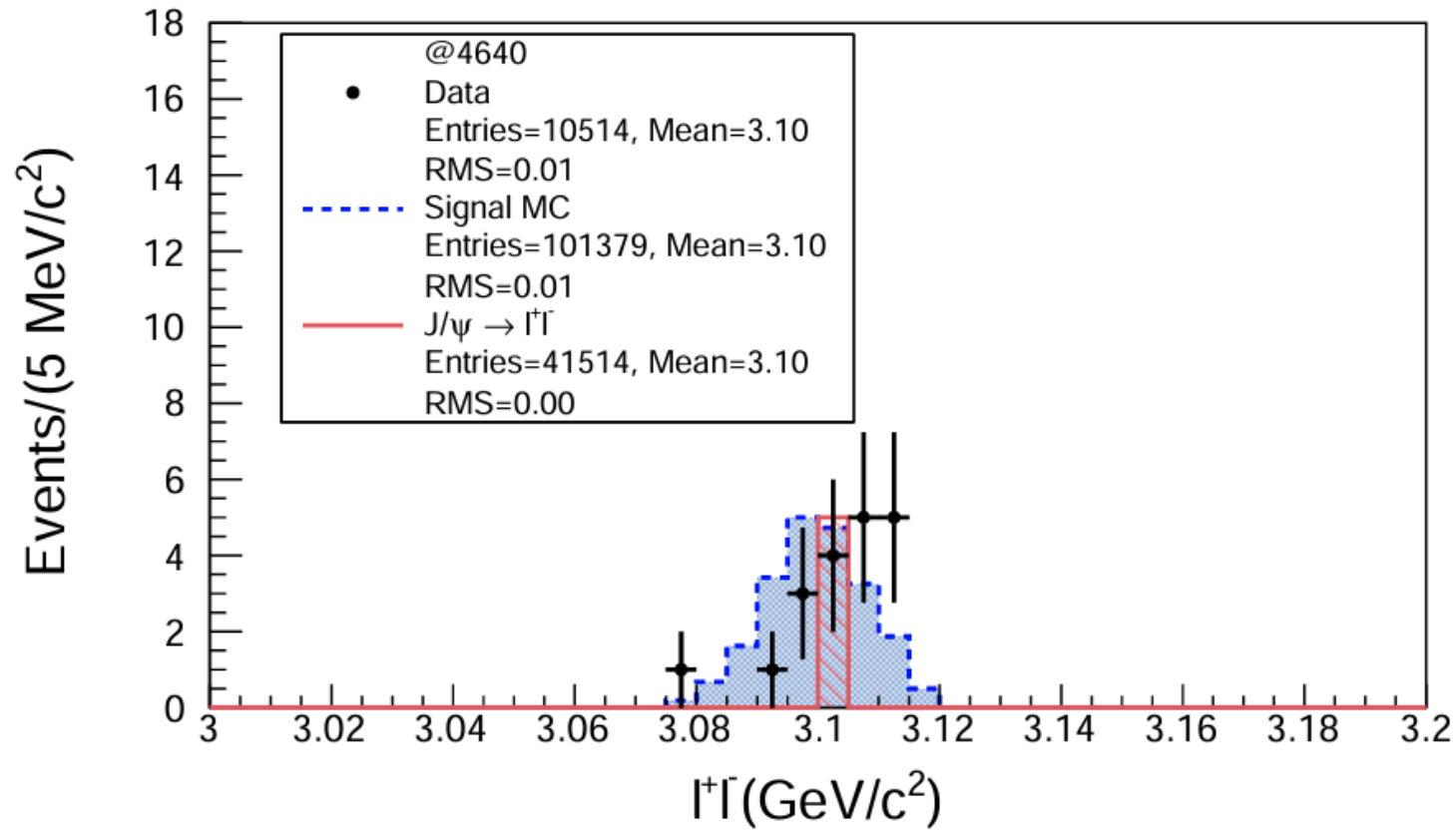
$$\pi^0 \rightarrow \gamma\gamma$$

Separate e/ μ

From EMC

e: $E_{deposit} > 1.0$ GeV

μ : $E_{deposit} < 0.4$ GeV



Additional cuts

1. $\chi^2 < 40$.
2. $|M_{l^+l^-} - 3.097| \leq 0.020$ GeV

Table 2: Decay branches of J/ψ .

rowNo	decay branch of J/ψ	iDcyBrP	nCase	nCCase
1	$J/\psi \rightarrow e^+e^-$	0	194	194
2	$J/\psi \rightarrow \mu^+\mu^-$	1	179	373
3	$J/\psi \rightarrow \pi^0\pi^+\pi^-\pi^+\pi^-$	3	40	413
4	$J/\psi \rightarrow \pi^+\pi^-\omega$	18	26	439
5	$J/\psi \rightarrow \pi^+\rho^-$	2	19	458
6	$J/\psi \rightarrow \rho^0a_2^0$	23	12	470
7	$J/\psi \rightarrow \pi^0\pi^+\pi^-$	28	12	482
8	$J/\psi \rightarrow \pi^-\rho^+$	14	10	492
9	$J/\psi \rightarrow p\bar{p}$	6	8	500
10	$J/\psi \rightarrow \omega f_2(1270)$	27	6	506

Run more data



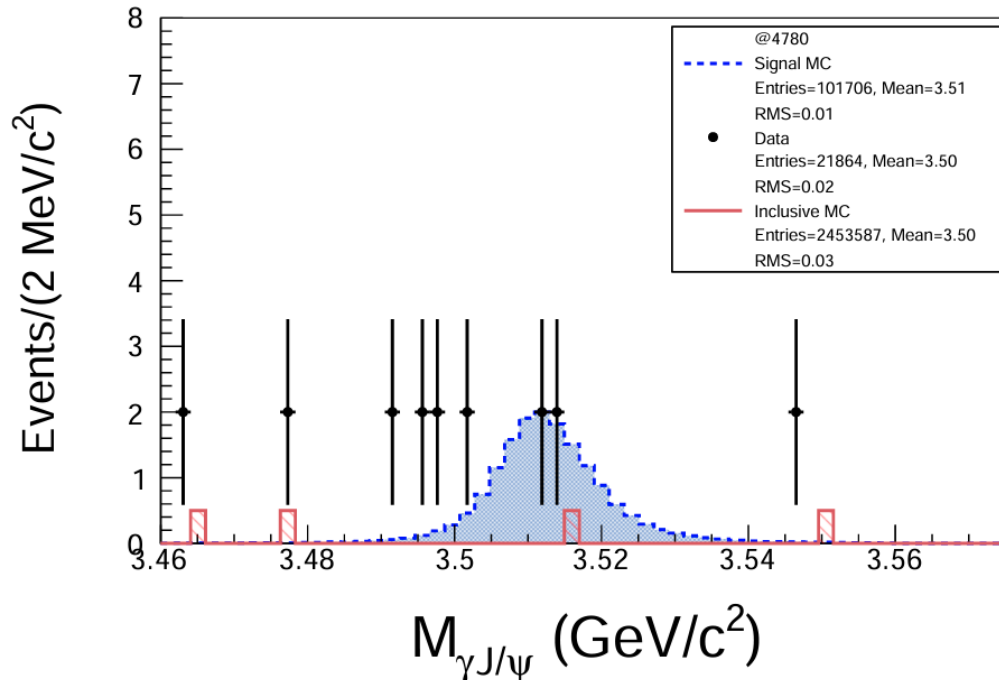
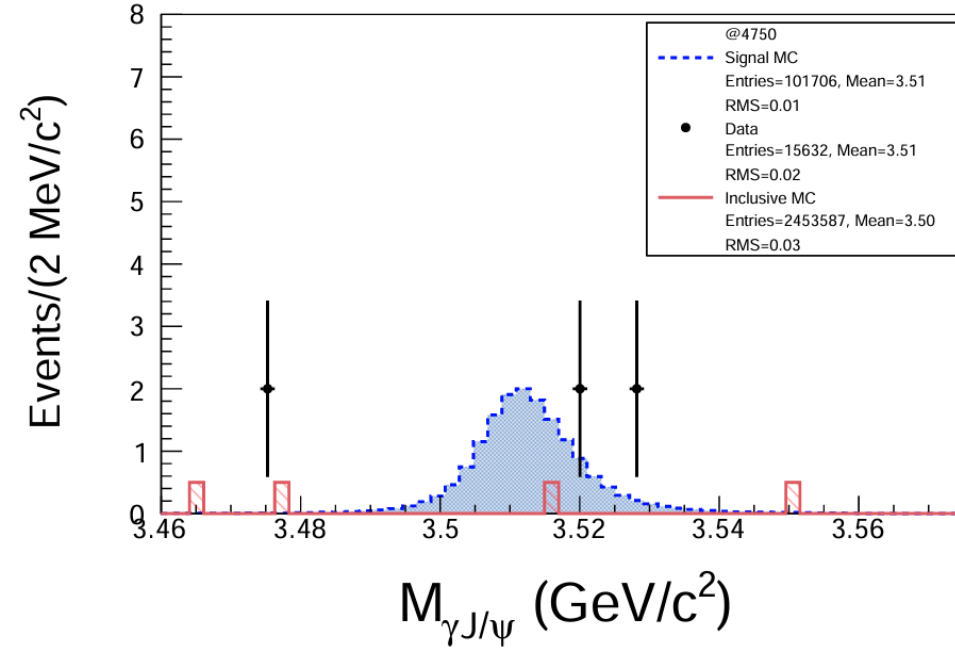
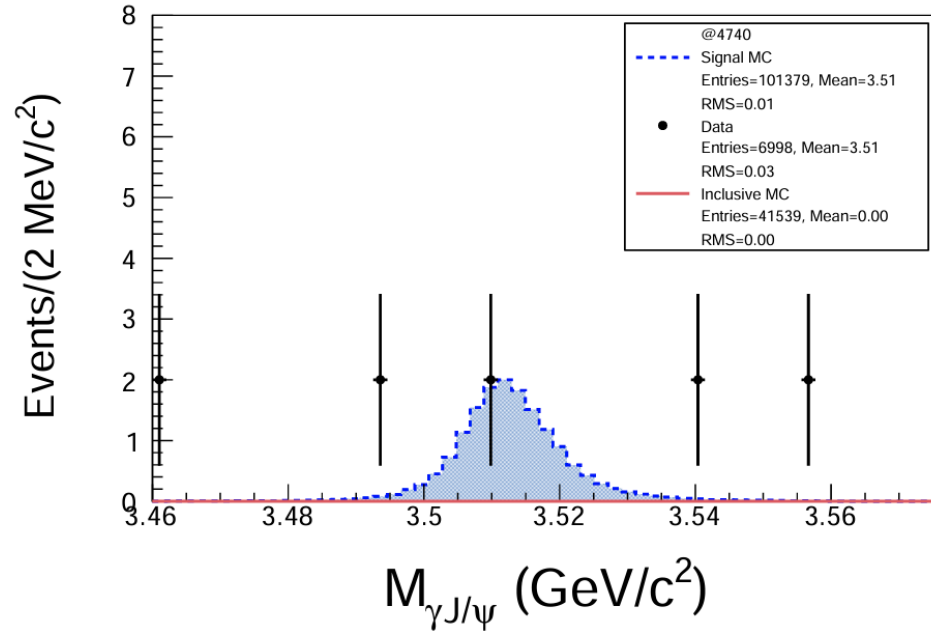
2021 4740--4946 (CPC46, No.11 (2022) 113003)

Sample	Runno	Ecms(MeV)	luminosity(1/pb)	location
4740	65208-65307	4739.70+/-0.20+/-0.30	163.87+/-0.07+/-0.87	/besfs4/offline/data/707-1/xyz/round14/
4750	65322-65494	4750.05+/-0.12+/-0.29	366.55+/-0.10+/-1.94	/besfs4/offline/data/707-1/xyz/round14/
4780	65495-65645	4780.54+/-0.12+/-0.30	511.47+/-0.12+/-2.71	/besfs4/offline/data/707-1/xyz/round14/
4840	65647-65864	4843.07+/-0.20+/-0.31	525.16+/-0.12+/-2.78	/besfs4/offline/data/707-1/xyz/round14/
4914	65867-65935	4918.02+/-0.34+/-0.34	207.82+/-0.08+/-1.10	/besfs4/offline/data/707-1/xyz/round14/
4946	65938-66224	4950.93+/-0.36+/-0.38	159.28+/-0.07+/-0.84	/besfs4/offline/data/707-1/xyz/round14/

2020 4610--4700 MeV (CPC46, No.11 (2022) 113003)

Sample	Runno	Ecms(MeV)	luminosity(1/pb)	location
4610	64314-64360	4611.86+/-0.12+/-0.30	103.65+/-0.05+/-0.55	/besfs4/offline/data/706-1/xyz/round13/4612/dst
4620	63075-63515	4628.00+/-0.06+/-0.32	521.53+/-0.11+/-2.76	/besfs4/offline/data/706-1/xyz/round13/4620/dst
4640	63516-63715	4640.91+/-0.06+/-0.38	551.65+/-0.12+/-2.92	/besfs4/offline/data/706-1/xyz/round13/4640/dst
4660	63718-63852	4661.24+/-0.06+/-0.29	529.43+/-0.12+/-2.81	/besfs4/offline/data/706-1/xyz/round13/4660/dst
4680	63867-64015, 64365-65092 (TriggerExp.65078-)	4681.92+/-0.08+/-0.29	1667.39+/-0.21+/-8.84	/besfs4/offline/data/706-1/xyz/round13/4680/dst
4700	64028-64313	4698.82+/-0.10+/-0.36	535.54+/-0.12+/-2.84	/besfs4/offline/data/706-1/xyz/round13/4700/dst

Data in 2021 @4740 - 4946

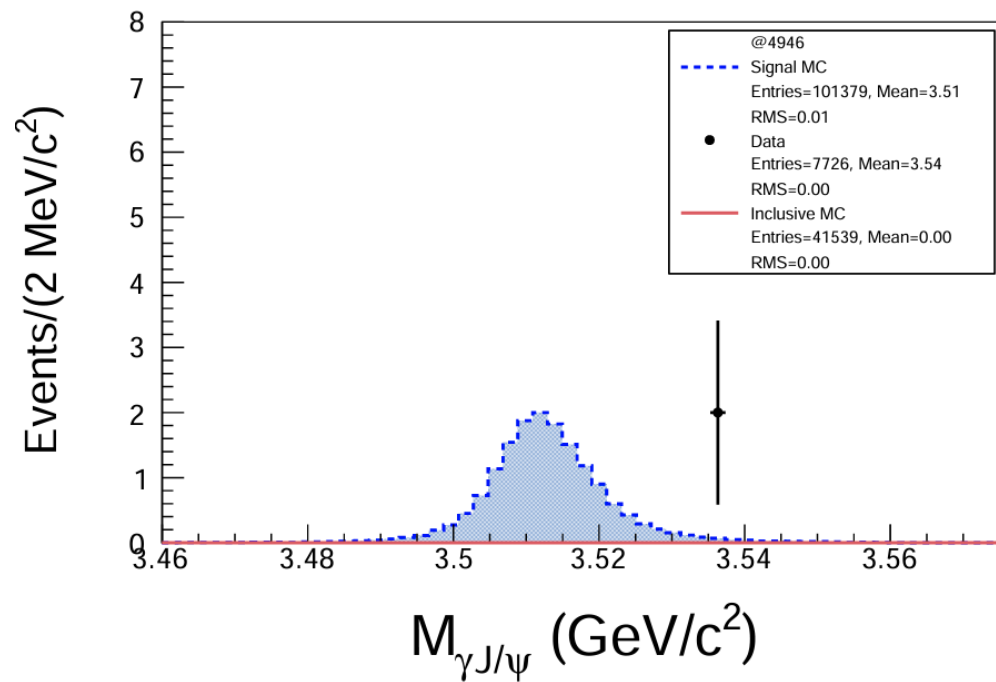
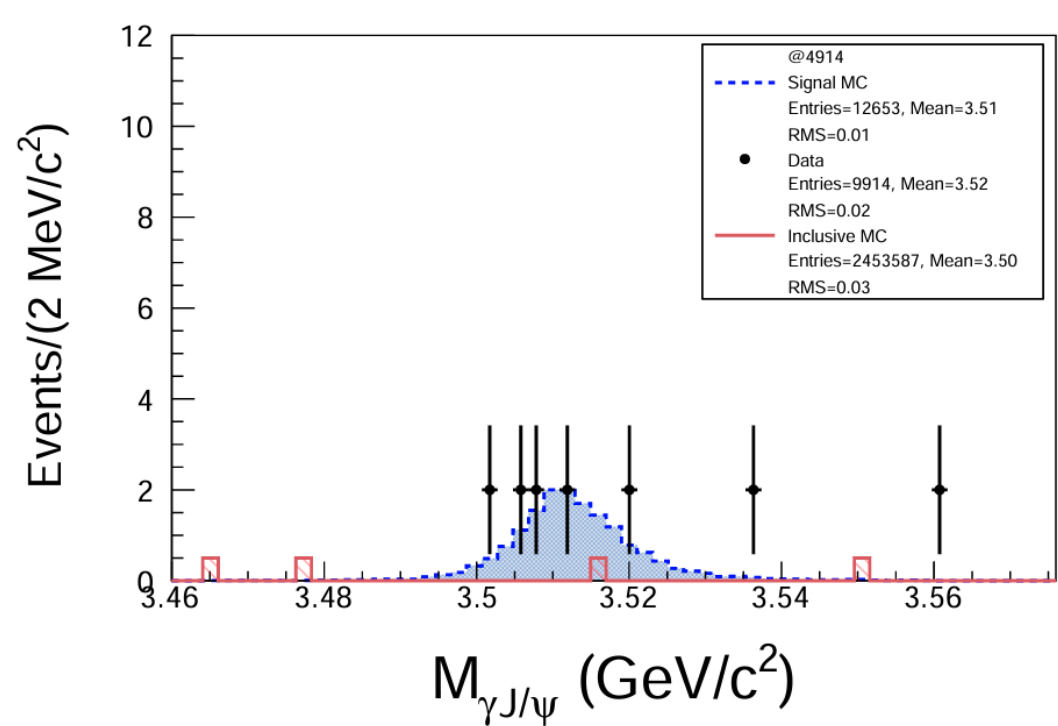
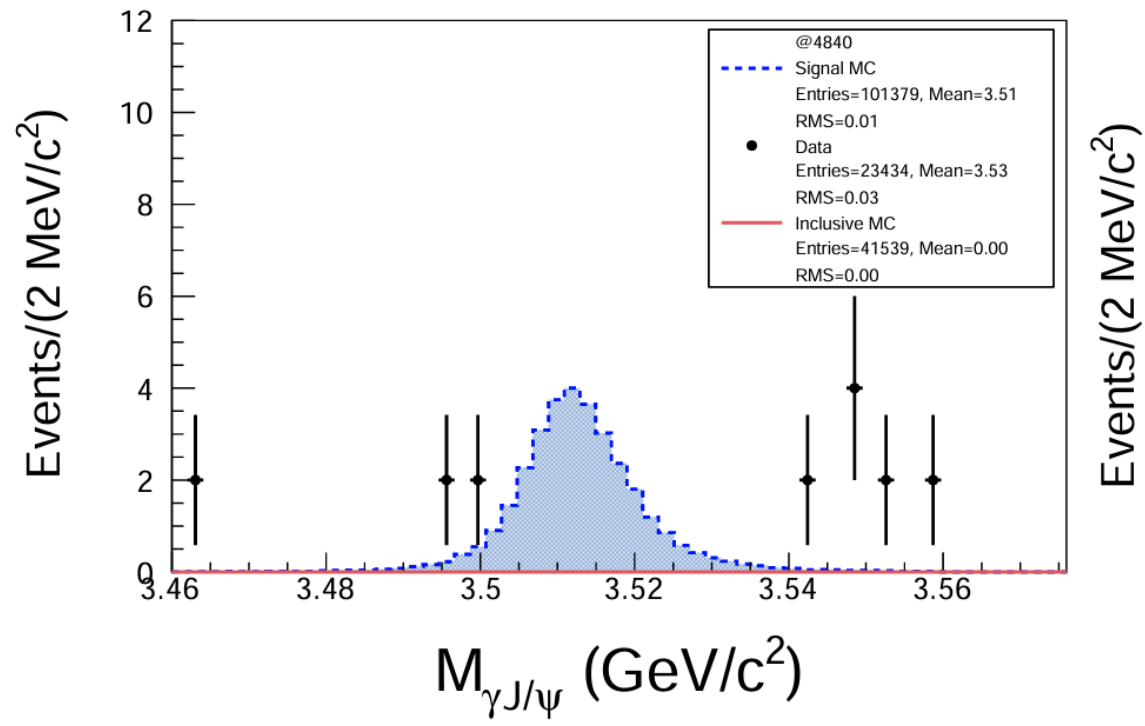


1. Mass window

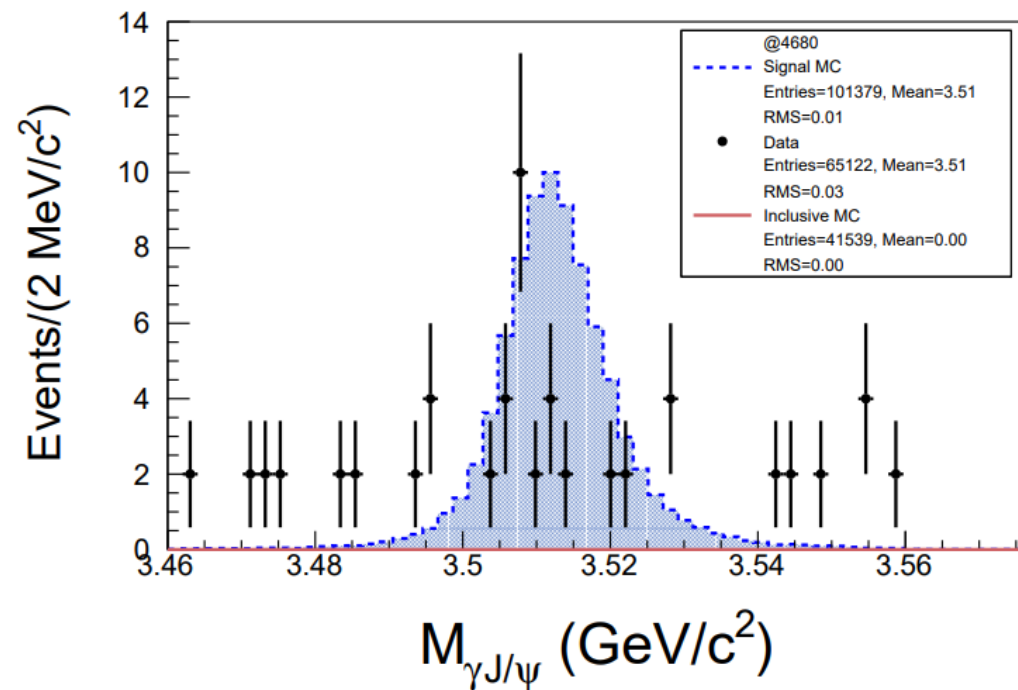
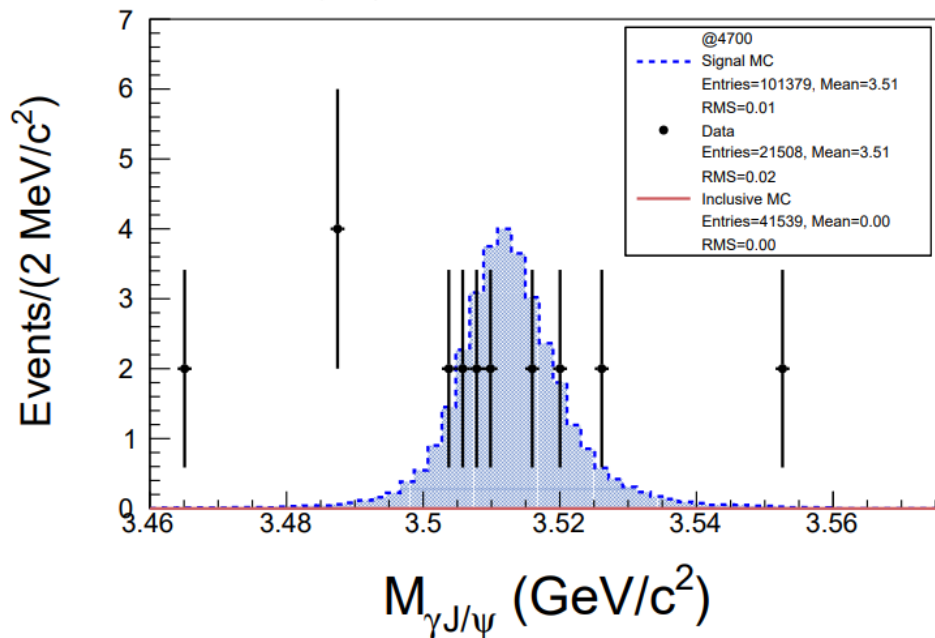
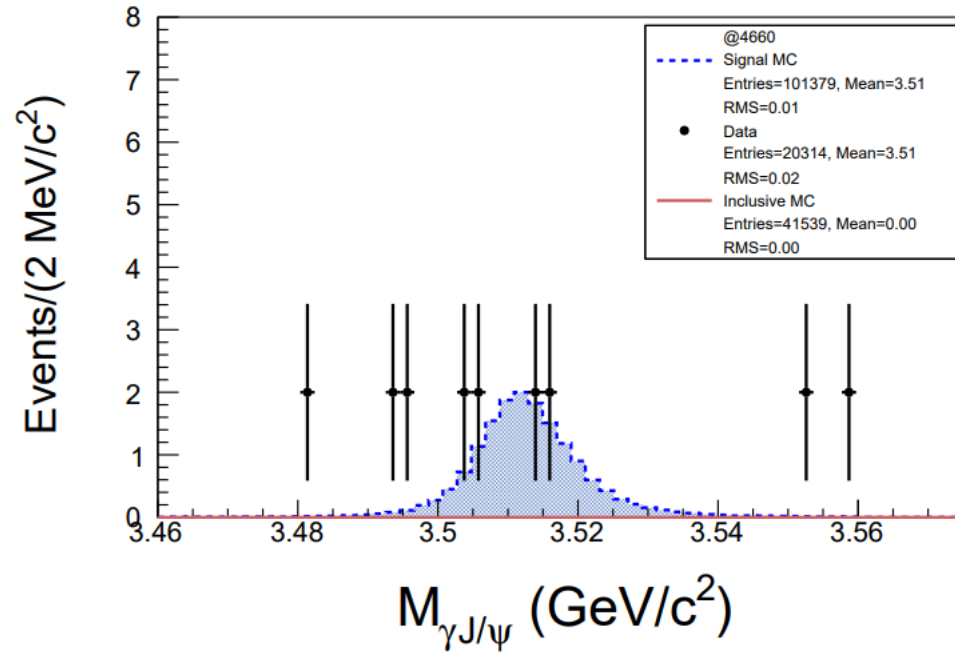
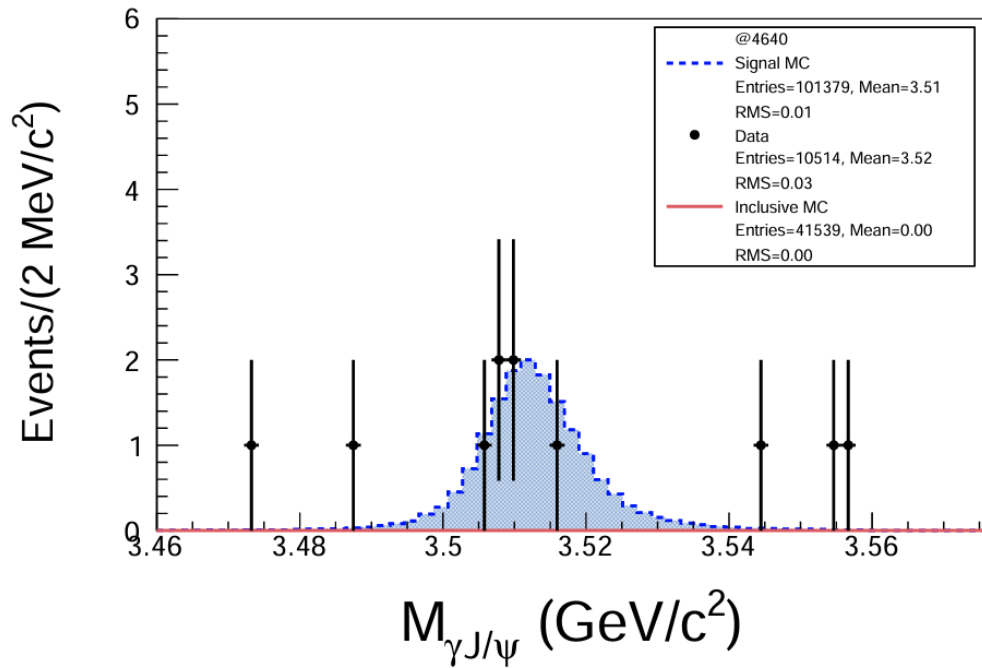
$$|M_{\gamma J/\psi} - 3.510| \leq 0.050 \text{ GeV}$$

Table 3: Decay branches of χ_{c1} .

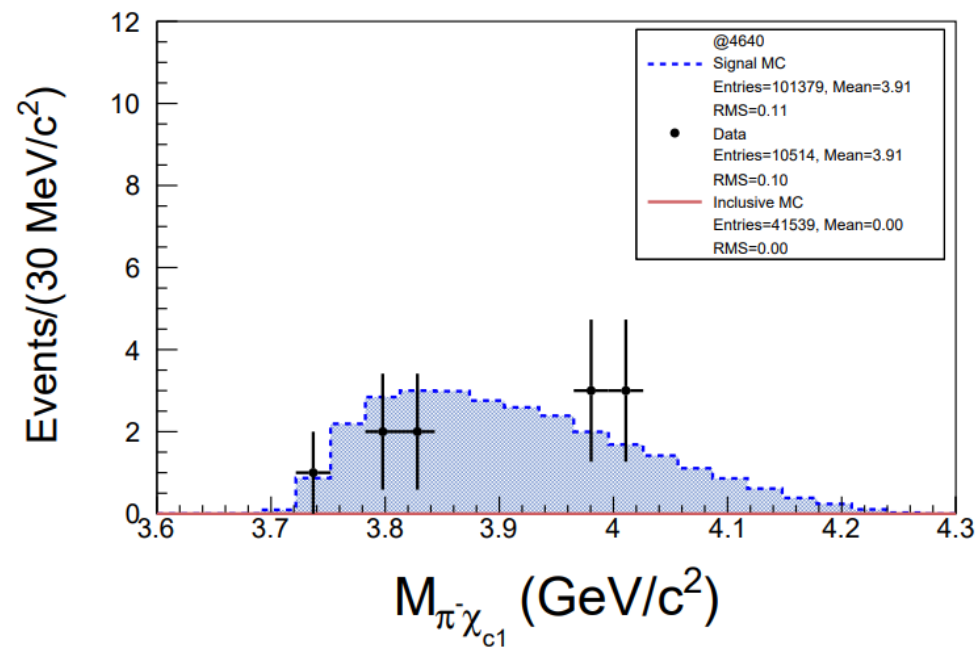
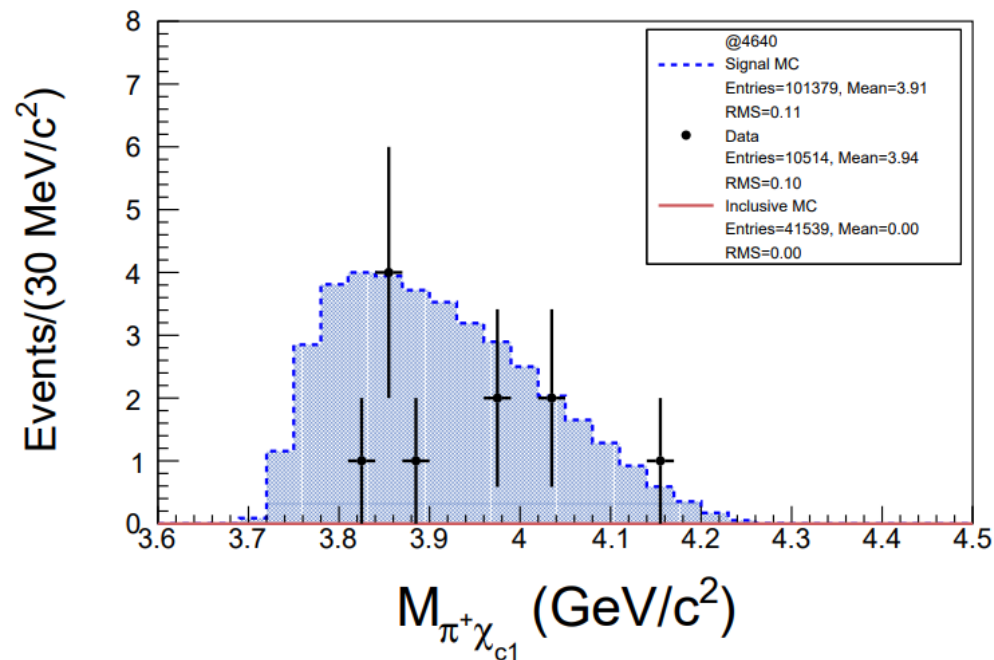
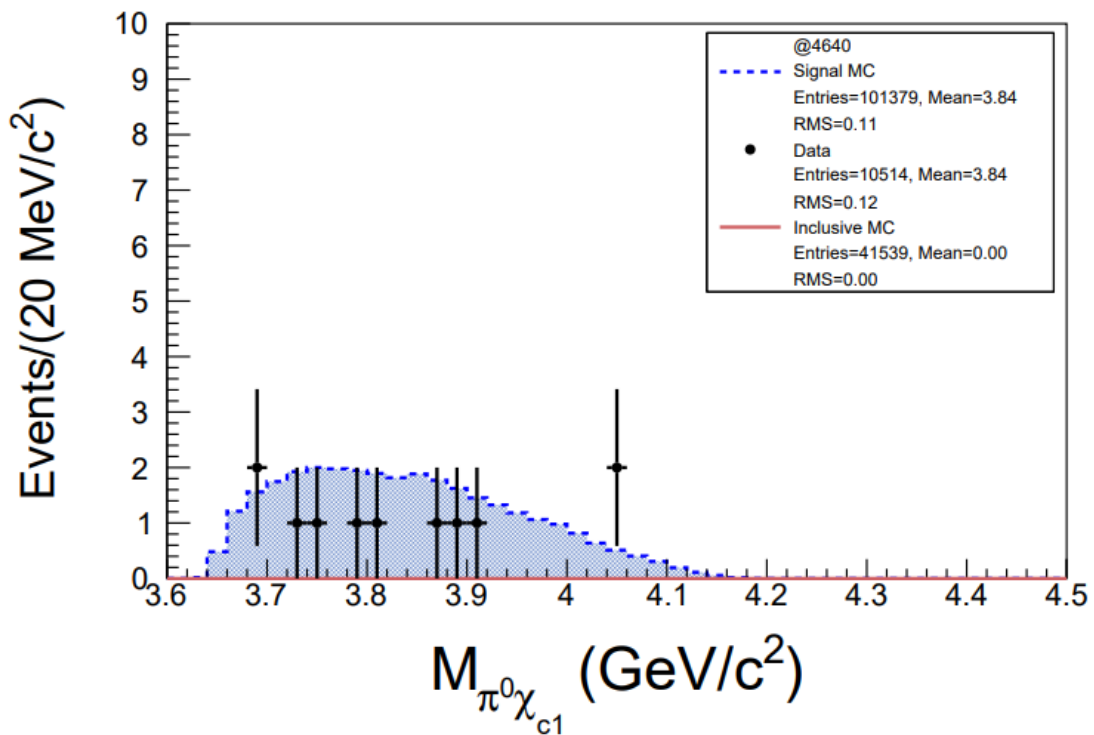
rowNo	decay branch of χ_{c1}	iDcyBrP	nCase	nCCase
1	$\chi_{c1} \rightarrow J/\psi \gamma$	1	7	7
2	$\chi_{c1} \rightarrow \rho^0 \pi^+ \pi^-$	2	4	11
3	$\chi_{c1} \rightarrow \pi^+ \pi^- \pi^+ \pi^-$	0	3	14
4	$\chi_{c1} \rightarrow \pi^+ \pi^- h_1(1170)$	3	2	16
5	$\chi_{c1} \rightarrow \pi^+ K^* K^{*-}$	6	2	18



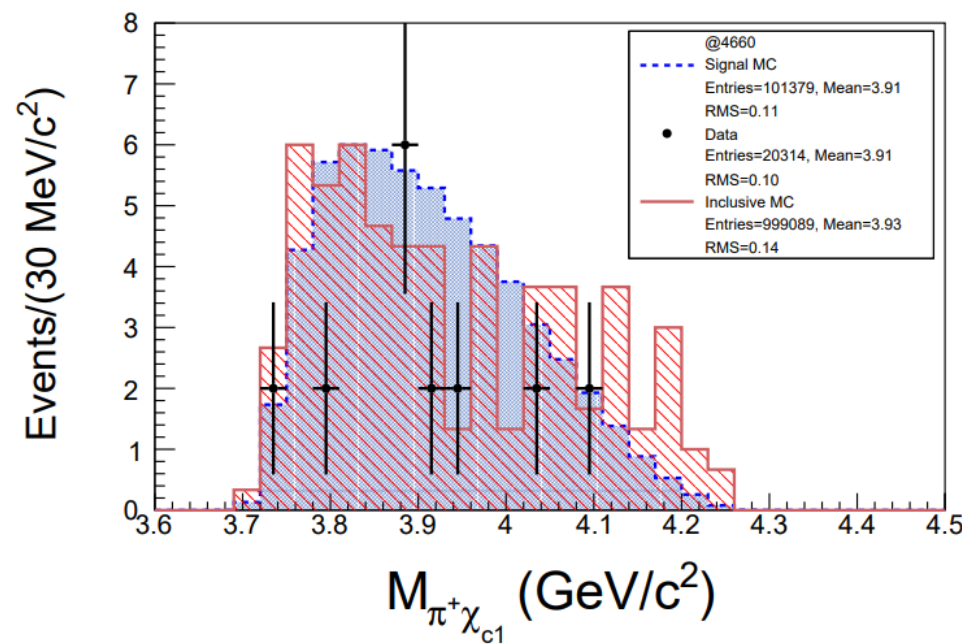
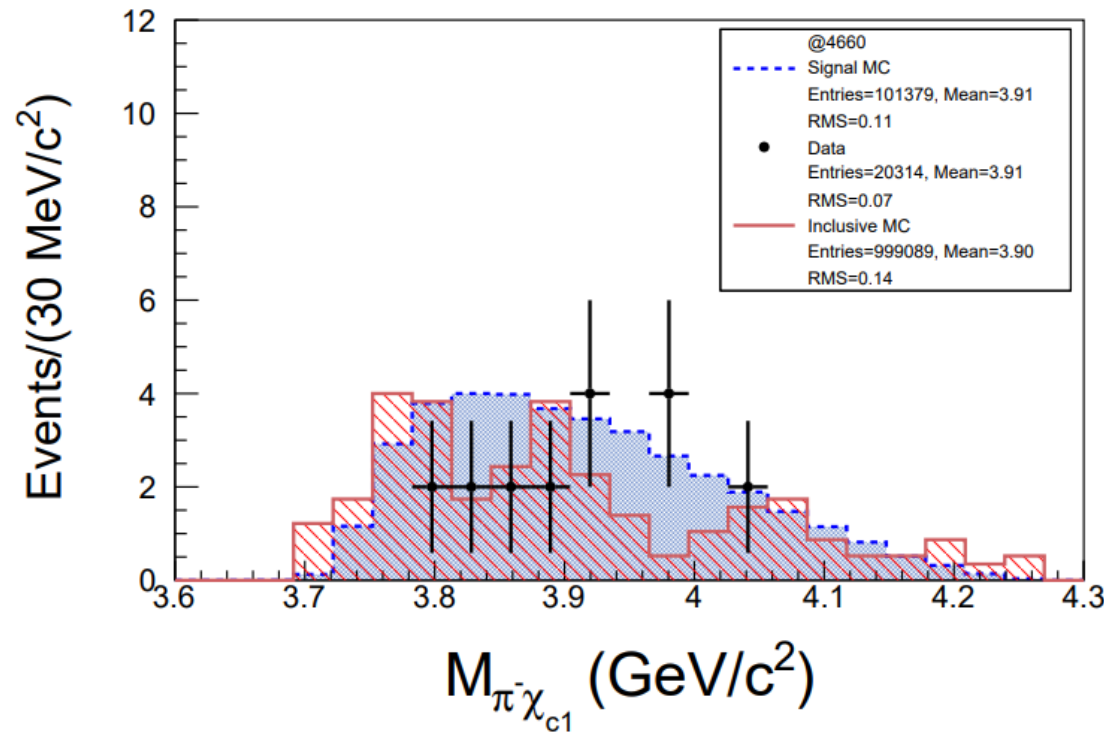
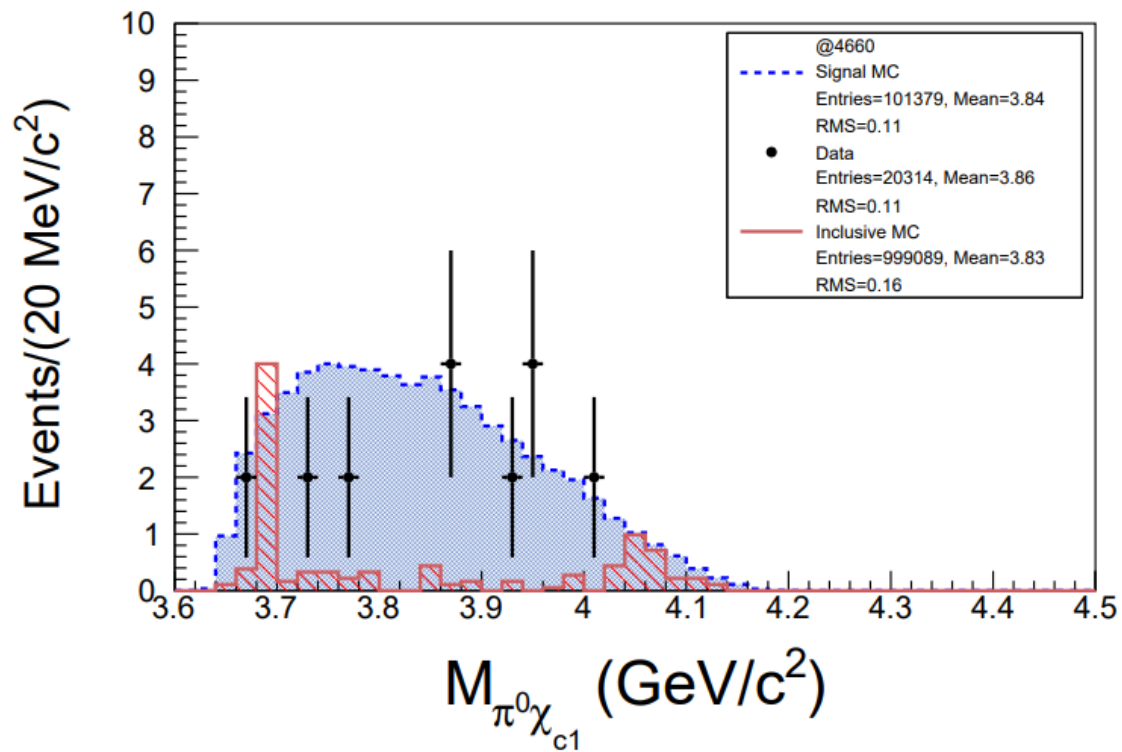
Data in 2020



Data in 2020 @4640



Data in 2020 @4660



Cut flow

```
total number:      100000
nGood>=4, nCharge==0: 65312 (%eff = 65.312%)
nGam>=3:           38922 (%eff = 38.922%)
pid:               15971 (%eff = 15.971%)
vertex fit:        15959 (%eff = 15.959%)
pi0 mw:            15720 (%eff = 15.72%)
kmfit:             6938  (%eff = 6.938%)
jpsi:              6269  (%eff = 6.269%)
chi:               6049  (%eff = 6.049%)
```

Next to do

1. Find $e^+e^- \rightarrow \omega\chi_{c1}, \omega \rightarrow \pi^0\pi^+\pi^-, \chi_{c1} \rightarrow J/\psi\gamma, J/\psi \rightarrow e^+e^-$
($e^+e^- \rightarrow e^+e^-\pi^0\pi^+\pi^-\gamma$)
 $e^+e^- \rightarrow \omega\chi_{c1}, \omega \rightarrow \pi^0\pi^+\pi^-, \chi_{c1} \rightarrow J/\psi\gamma, J/\psi \rightarrow \mu^+\mu^-$
($e^+e^- \rightarrow \mu^+\mu^-\pi^0\pi^+\pi^-\gamma$)
- ~~2. Perform χ_{c1} invariant mass distribution.~~
- ~~3. Study and suppress background.~~
- ~~4. Prepare .dst files for signal MC at $E_{cms} = 4.700$ GeV.~~

Mc 703



```
./create_datalist: line 8: data_datalist_703mc: command not found
Processed folder: 4200 - Found 26172 files
Processed folder: 4190 - Found 13543 files
Processed folder: 4220 - Found 8696 files
Processed folder: 4420 - Found 7466 files
Processed folder: 4210 - Found 7142 files
Processed folder: 4230 - Found 26991 files
Processed folder: 4360 - Found 5571 files
Processed folder: 4600 - Found 8344 files
Processed folder: 4270 - Found 30225 files
Processed folder: 4260 - Found 11958 files
Processed folder: 4246 - Found 13289 files
Processed folder: 4009 - Found 200 files
Processed folder: 4237 - Found 15767 files
Processed folder: doc - Found 0 files
Processed folder: 4280 - Found 3698 files
=====
List of .dst files saved to data_datalist_703mc
Total files found: 173615
```