Study of $e^+e^- \to \pi^+\pi^-\gamma\chi_{c1,2}$ and try to determine $X(3823)'$s parameters

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Charmonium Group Meeting

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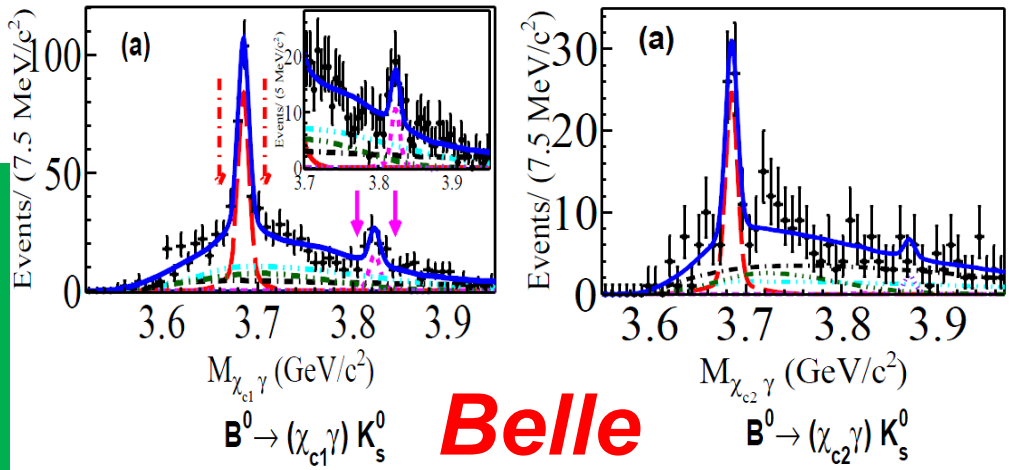
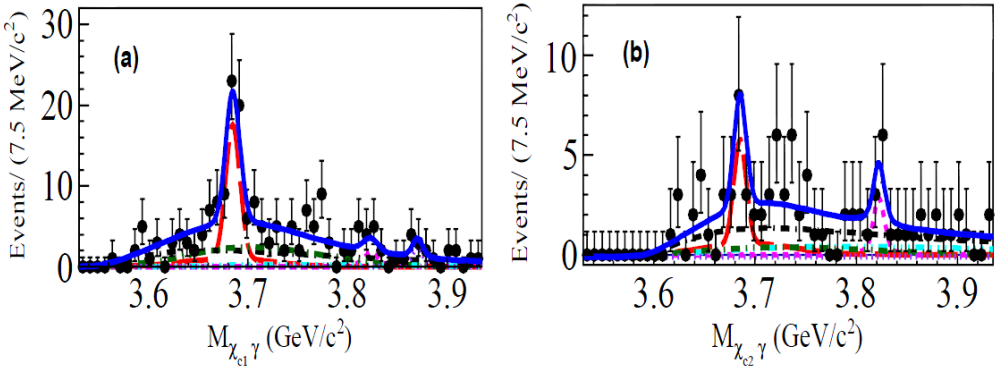
目录 Contents

Motivation

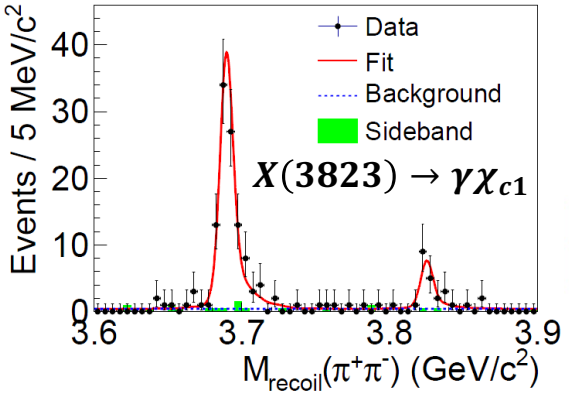
PRL111,032001(2013)



Belle

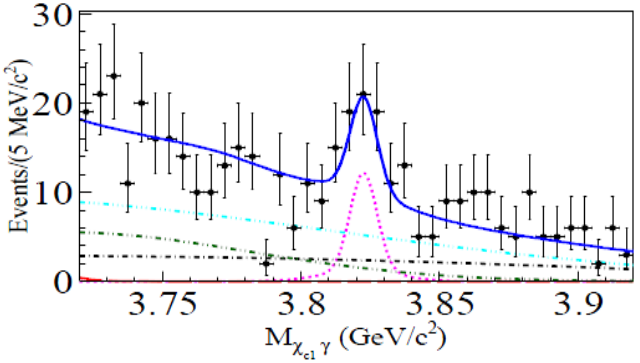


M=3821.7 ±1.3±0.7 MeV/c²



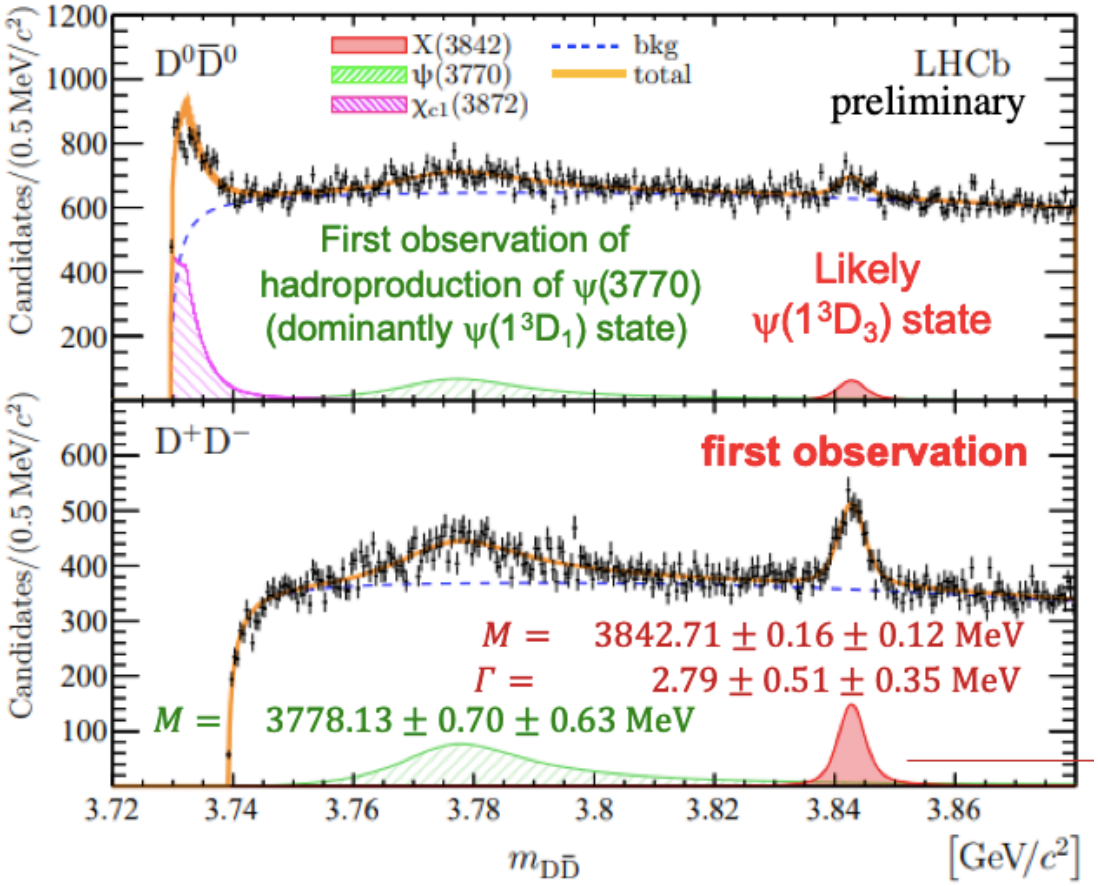
PRL115, 011803

BESIII



- Belle found an evidence of X(3823) ($\to \gamma\chi_{c1}$), afterwards BESIII observed the state with >5σ. It is likely a $\psi(1^3D_2)$, but no experimental evidence for its quantum number is reported up to now.
- We aim at determining Γ of X(3823), measuring cross sections, and also trying to check its quantum number.

Motivation



- Very lately, LHCb found a extremely narrow resonant structure X(3842) (→ $D\bar{D}$), likely $\psi(1^3D_3)$ state. According to the conservation of quantum numbers, X(3842) can also decay to $\gamma\chi_{c2}$. We search for it.

Data Set

Data sample	$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1})
4130	4.1300	400
4160	4.1600	400
4180	4.1783	3194.5
4190	4.1888	565.8
4200	4.1989	524.6
4210	4.2092	573.1
4220	4.2187	568.9
4230	4.2263	1100.9
4237	4.2357	530.6
4246	4.2428	537.4
4260	4.2580	828.4

In total: ~15 fb^{-1}

4270	4.2668	529.7
4280	4.2777	175.5
4290	4.2879	500
4315	4.3121	500
4340	4.3374	500
4360	4.3583	543.9
4380	4.3774	500
4400	4.3965	500
4420	4.4156	1090.7
4440	4.4362	570
4600	4.5995	586.9

Event selection criteria $e^+e^- \to \pi^+\pi^-\gamma\chi_{c1,2}(\to \gamma J/\psi)$

4C mixed with 1C

◆ Good Charged Tracks:

- $V_{xy} < 1.0\ cm$ && $|V_z| < 10.0\ cm$ (except for $\pi^{\pm}$ from K_S^0)
- $|\cos\theta| < 0.93$, Nchrg$\geq$3,
- Leptons: $P_l > 1$ GeV/c, N_l=2, $\sum_{i=1}^{N_l} C_i$=0; E_l<0.4 GeV for μ, E_l>1.0 GeV for e.
- Pions: P_{trk}<1 GeV/c,, if $N_\pi = 2$ && $\sum_{i=1}^{N_\pi} C_i$=0, 4C kmfit. method will be used; else if $N_{\pi^+} = 1$ || $N_{\pi^-} = 1$, 1C kmfit. method will be used.

◆ Good Photons:

- $E_\gamma \geq 25$ MeV for $|\cos\theta| < 0.8$
- $E_\gamma \geq 50$ MeV for $0.86 < |\cos\theta| < 0.92$
- $0 \leq \mathrm{TDC_{EMC}} \leq 14$ (50ns), $\theta(\gamma, \mathrm{Trk.}) > 10^\circ$
- $N_\gamma \geq 2$
- γ_H from $\chi_{c1,2}$ decay, γ_L from X decay

BOSS Version: 7.0.4

◆ Vertex Fit: official vertex fit for charged tracks

◆ Kinematic Fit: obtained with the least $\chi^2_{4C/1C}(\pi^+\pi^-\gamma\gamma l^+l^-)$

For 1C mode, missing a slow charged pion

Main Backgrounds

No.	BKG. Mode
1	$e^+e^- \to (n\gamma)l^+l^-, \gamma \to e^+e^- \dashrightarrow \pi^+\pi^-$
2	$e^+e^- \to \eta J/\psi, \eta \to \pi^+\pi^-\pi^0$
3	$e^+e^- \to \gamma\omega J/\psi, \omega \to \pi^+\pi^-\pi^0$
4	$e^+e^- \to \eta' J/\psi, \eta' \to \pi^+\pi^-\eta$
5	$e^+e^- \to (\gamma_{ISR})\, J/\psi\eta(\eta'), \eta(\eta') \to \gamma\pi^+\pi^-$
6	$e^+e^- \to \gamma_{ISR}\psi', \psi' \to \pi^+\pi^- J/\psi$
7	$e^+e^- \to \eta\psi', \psi' \to \pi^+\pi^- J/\psi, \eta \to \gamma\gamma$
8	$e^+e^- \to \gamma\gamma\psi', \psi' \to \pi^+\pi^- J/\psi$
9	

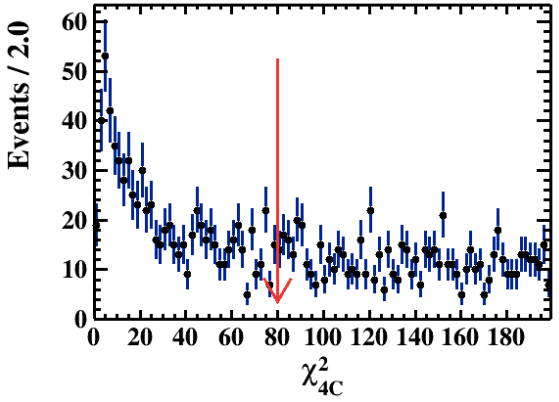
Preliminarily further selections for only 4C mode

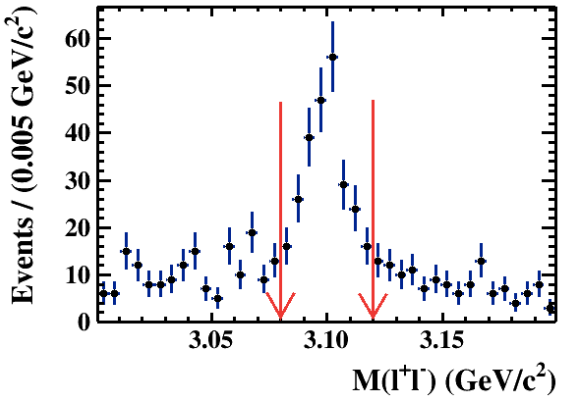
$\chi^2_{4C} < 80$

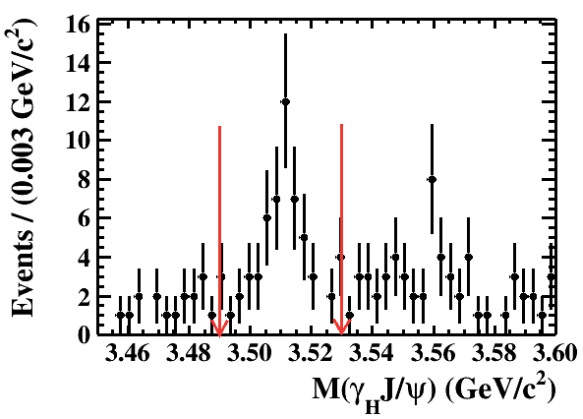
J/ψ signal region: $3.08 < M(\ell^+\ell^-) < 3.12$ GeV/c^2

χ_{c1} signal region: $3.49 < M(\gamma_H J\psi) < 3.53$ GeV/c^2

χ_{c2} signal region: $3.536 < M(\gamma_H J\psi) < 3.576$ GeV/c^2







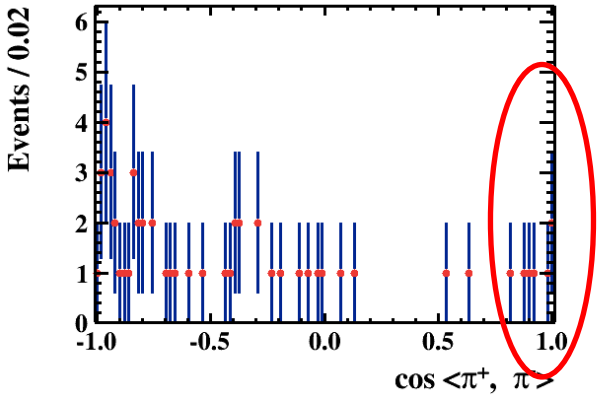
Taking data at 4.420 GeV for example

The selection criteria for 4C method is almost the same as Ref.[PRL **115**, 011803 (2015)].

BKGs. Ana. and Further Selections

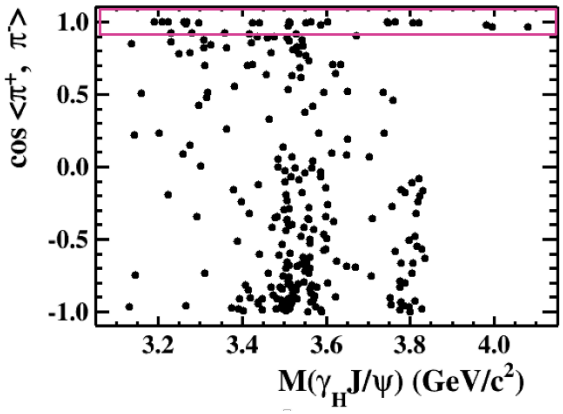
Study of the $\gamma - conversion$ BKG $e^+e^- \to (n\gamma)l^+l^-, \gamma \to e^+e^-$. And the e^+e^- pair is misidentified as a $\pi^+\pi^-$ pair.

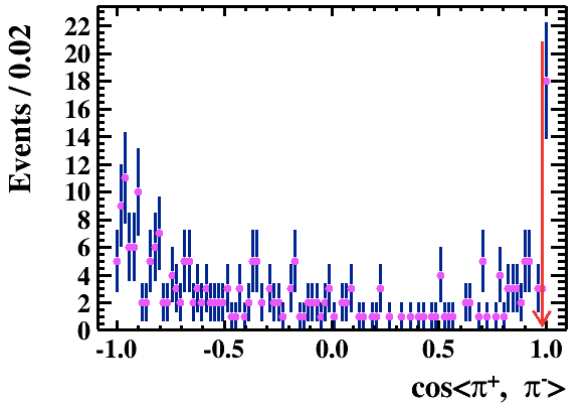
After the above preliminary requirements, no clear $\gamma-conversion$ BKG is found.



But if we check the scatter plot of $cos < \pi^+, \pi^- >$ versus $M(\gamma_H J/\psi)$, the $\gamma - conversion$ is actually significant.

Low statistics likes an umbrella of the backgrounds.



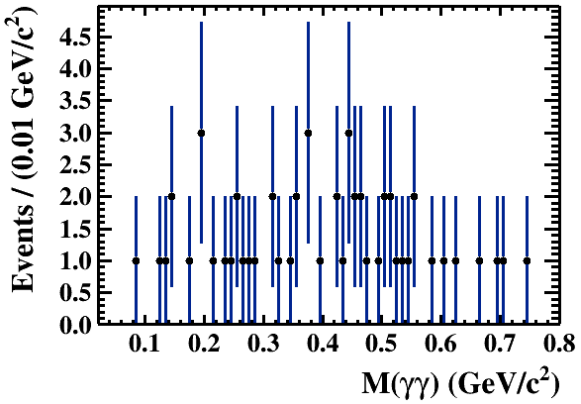


$\cos(\pi^+, \pi^-)$ < 0.98 is a good requirement and efficiency more than 99% (~99.3%).

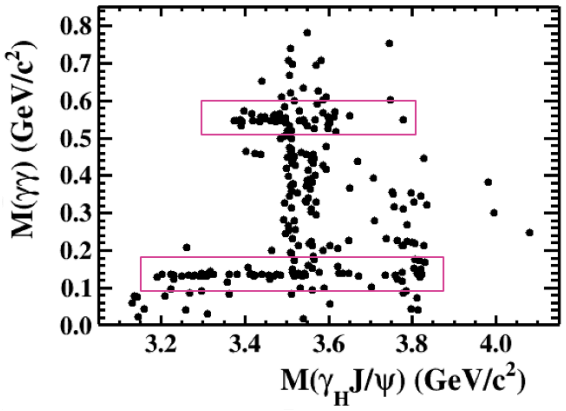
BKGs. Ana. and Further Selections

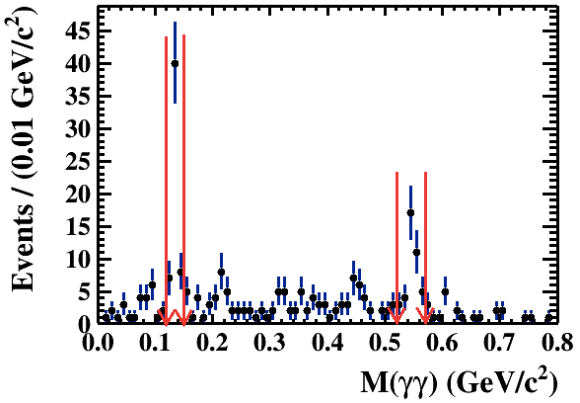
Study of the BKGs including $\pi^0/\eta \to \gamma\gamma$.

Requiring mass window of χ_{c1}, no clear π^0/η BKGs is in $M(\gamma\gamma)$.



But if no the χ_{c1} mass window is performed, the BKGs including $\pi^0/\eta \to \gamma\gamma$ emerged.





It seems that vetoing π^0 and η is necessary as follows:

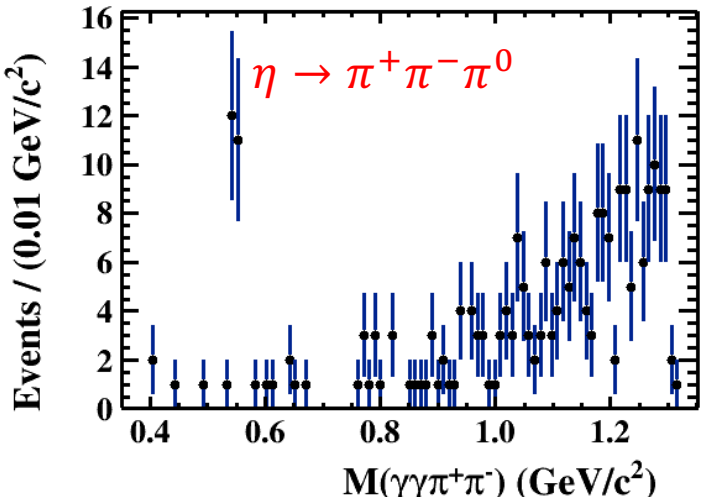
1. $M(\gamma\gamma)$ <0.12 || $M(\gamma\gamma)$ > 0.15 GeV/c²
2. $M(\gamma\gamma)$ <0.52 || $M(\gamma\gamma)$ >0.57 GeV/c²

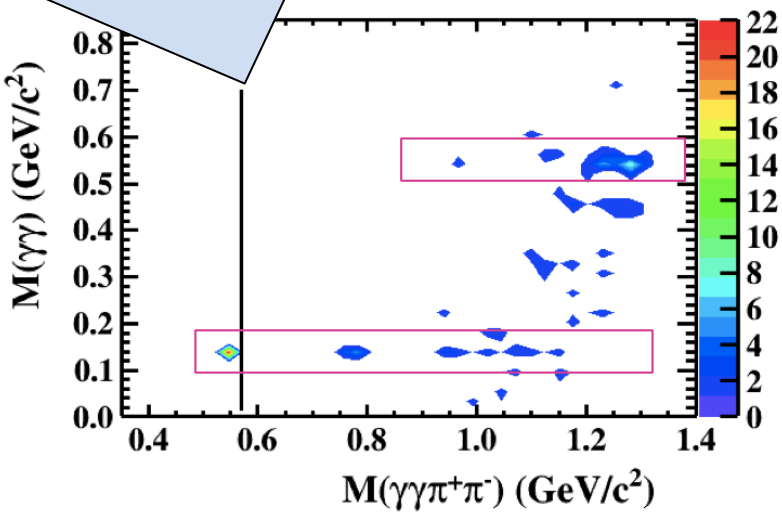
BKGs. Ana. and Further Selections

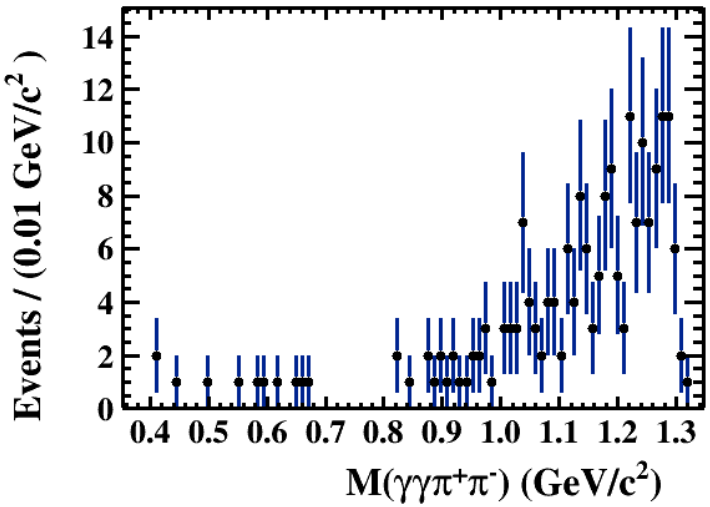
Also Study of the BKGs including $\pi^0/\eta \to \gamma\gamma$.

No χ_{c1} requirement here

$M(\gamma\gamma\pi^+\pi^-) > 0.57$ GeV/c² in the previous letter.







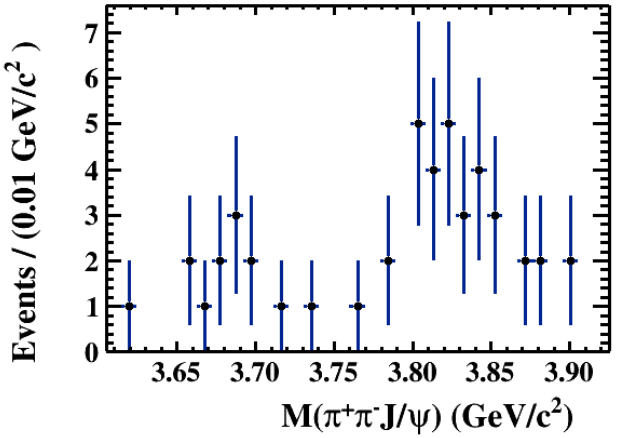
The requirements of vetoing π^0 and η looks better than that of $M(\gamma\gamma\pi^+\pi^-) > 0.57$ GeV/c² since it can exclude more BKGs.

However, the efficiency for using $M(\gamma\gamma\pi^+\pi^-) > 0.57$, which can exclude BKGs including $\eta \to \pi^0\pi^+\pi^-$, is more than 99.9%. (No eff. loss)

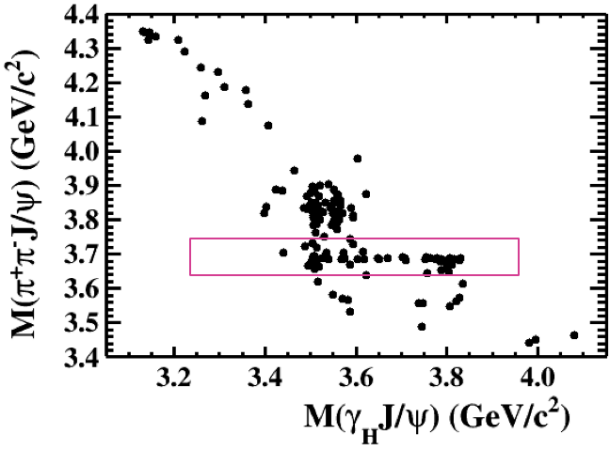
BKGs. Ana. and Further Selections

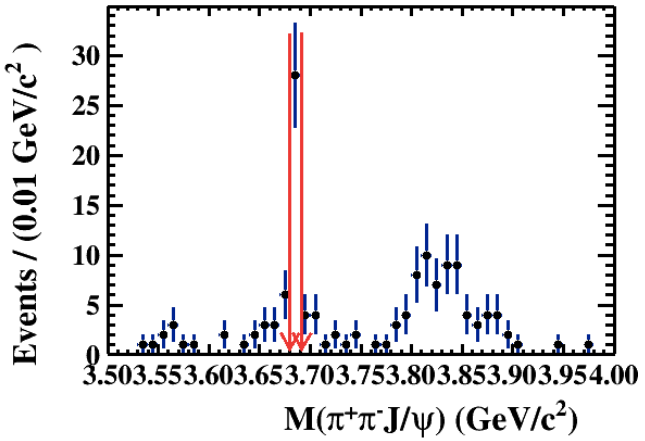
Study of the BKGs including $\psi(3686) \to \pi^+\pi^- J/\psi$.

Requiring mass window of χ_{c1}, no clear $\psi(3686)$ BKGs is in $M(\pi^+\pi^- J/\psi)$.



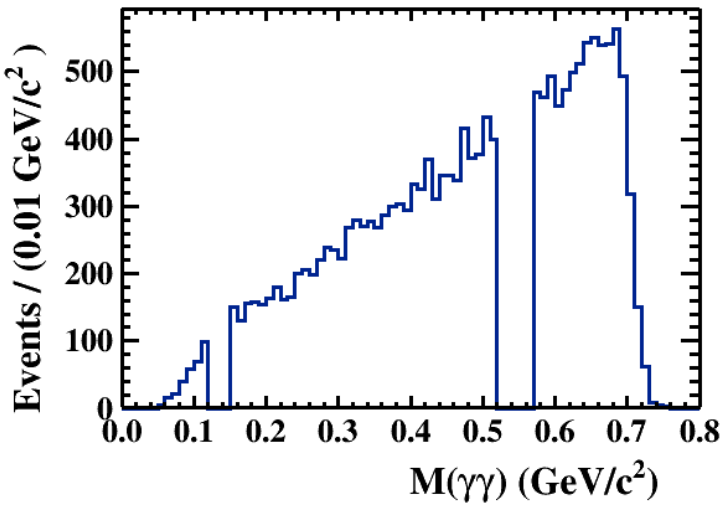
Removing the χ_{c1} mass window requirement as before….

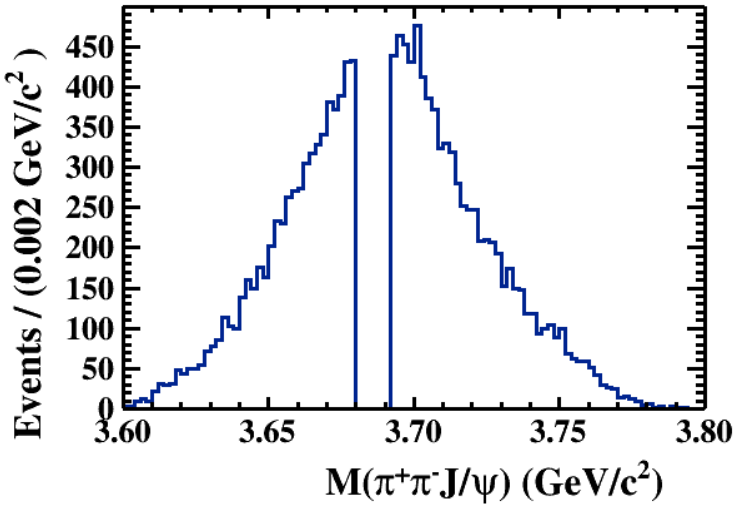




It is better to use the requirement of excluding $\psi(3686) \to \pi^+\pi^- J/\psi$ with $|M(\pi^+\pi^- J/\psi)$-3.686|<0.006 GeV/c².

Signal MC simulations at 4.420 GeV





Efficiency for only π^0 veto: 98.2%

Efficiency for only η veto: 88.9%

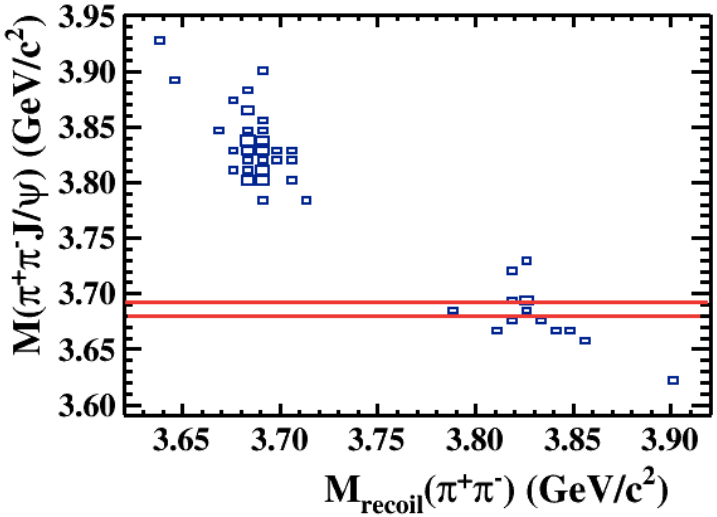
Efficiency for only $\psi(3686)$ veto: 85.1%

Low efficiency!

BKGs. Ana. and Further Selections

Search for optimized requirements for the $\psi(3686)$ BKGs removal.

Applying the requirements of $cos < \pi^+, \pi^- >$, χ^2_{4C}, J/ψ and χ_{c1} mass windows



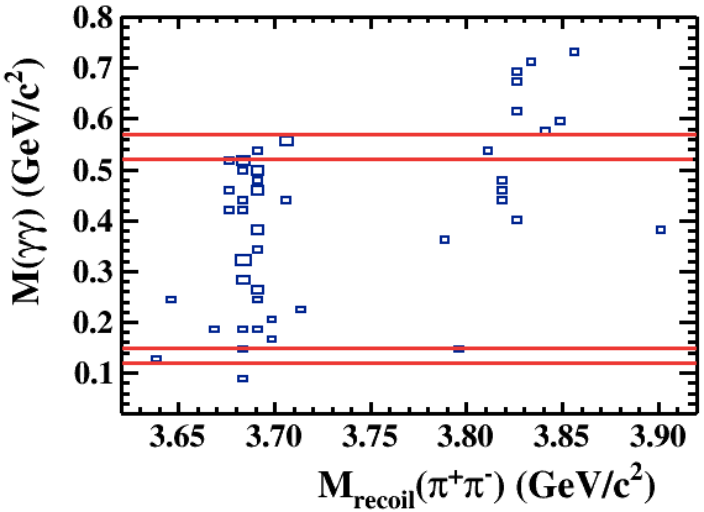
- The projection of the $\psi(3686)$-included BKGs on $M_{recoil}(\pi^+\pi^-)$ is just in a small range so that it is probably to form a peak in $M_{recoil}(\pi^+\pi^-)$.

- Therefore, the cut of $|M(\pi^+\pi^- J/\psi)$-3.686|<0.006 GeV/c^2 is necessary to exclude the possible peaking BKGs.

BKGs. Ana. and Further Selections

Search for optimized requirements for the $\pi^0/\eta \to \gamma\gamma$ BKGs removal.

Appling the requirements of $cos < \pi^+, \pi^- >$, χ^2_{4C}, J/ψ and χ_{c1} mass windows



- The projection of the π^0/η-included BKGs on $M_{recoil}(\pi^+\pi^-)$ is in a broad range so that it won't produce a peak in $M_{recoil}(\pi^+\pi^-)$.

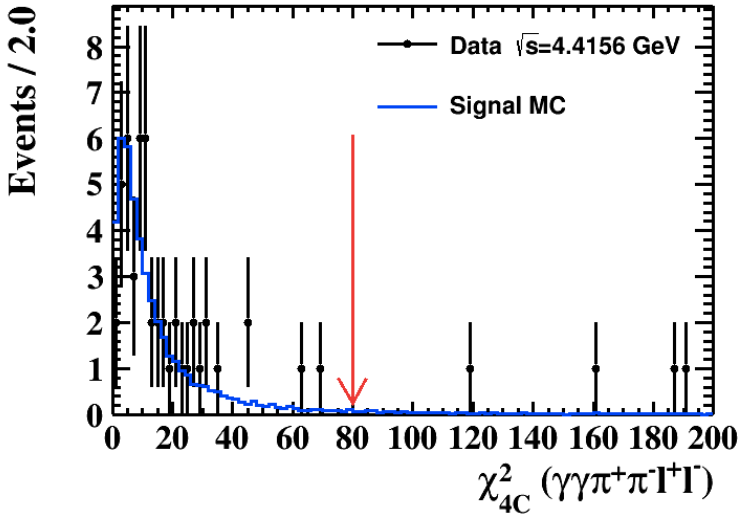
- According to our analysis, the main π^0/η-included BKGs are $e^+e^- \to (\eta, \gamma\omega, \eta')J/\psi$, with $\eta/\omega \to \pi^+\pi^-\pi^0$ and $\eta' \to \pi^+\pi^-\eta(\to \gamma\gamma)$. As we all known, the contributions of $(\gamma\omega, \eta')J/\psi$ events are much less than $\eta J/\psi$, so a polynomial term can describe them in the fit.

- For the BKG $e^+e^- \to \eta(\to \pi^+\pi^-\pi^0)J/\psi$, $M(\gamma\gamma\pi^+\pi^-) > 0.57$ is a good requirement due to the MC-simulated efficiency for this cut is more than 99.9%(no eff. loss).

Eventually further selections for 4C mode

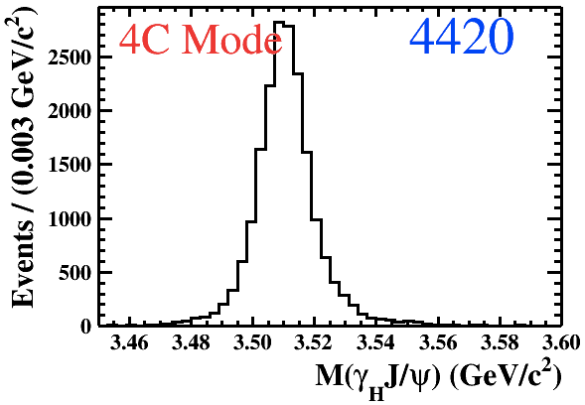
- J/ψ signal region: $3.08 < M(\ell^+\ell^-) < 3.12$ GeV/c^2
- χ_{c1} signal region: $3.49 < M(\gamma_H J\psi) < 3.53$ GeV/c^2
- Veto $\gamma - conserision$: $\cos(\pi^+, \pi^-) < 0.98$
- Veto $\psi(3686)$: $|M(\pi^+\pi^- J/\psi)\text{-}3.686| < 0.006$ GeV/c^2
- Veto $\eta \to \pi^+\pi^-\pi^0$: $M(\gamma\gamma\pi^+\pi^-) > 0.57$ GeV/c^2

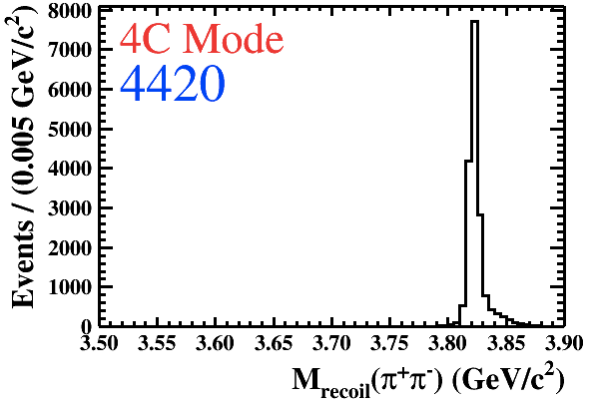
Applying the above requirements, to check the χ^2_{4C} distribution.

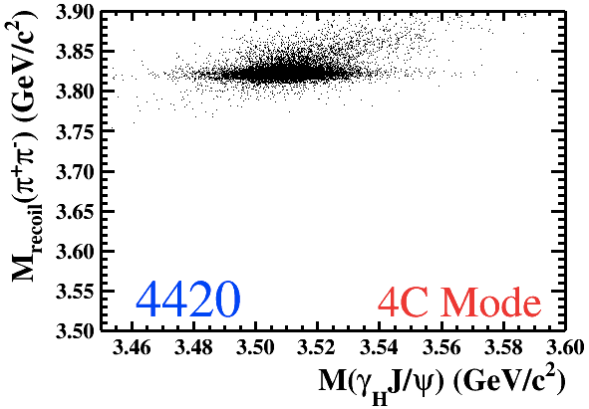


The requirement $\chi^2_{4C} < 80$ is appropriate, whose efficiency is 96.0% according to MC simulation.

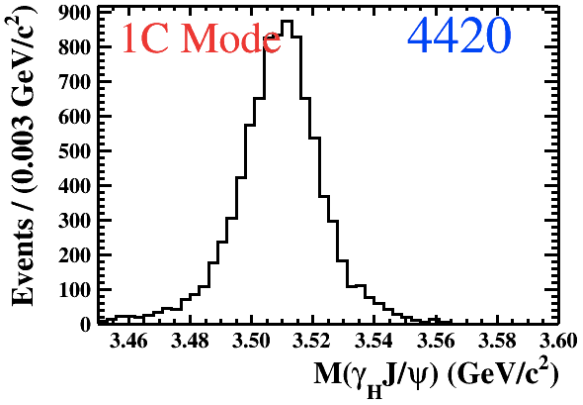
Signal MC simulation at 4.420 GeV

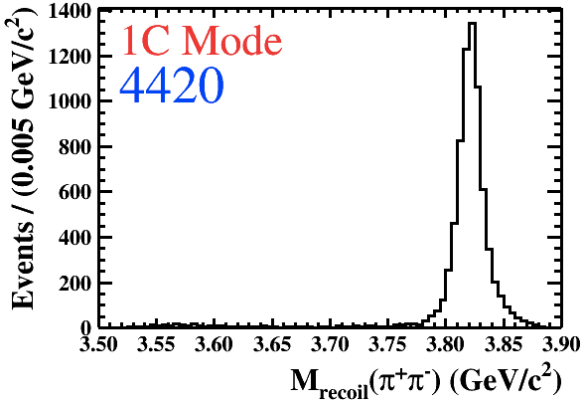


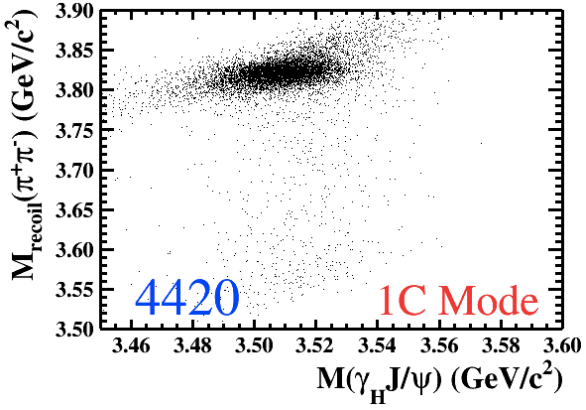




For the 1C mode, Just using the same requirements as the 4C mode.
We will analyze in detail the 1C mode later.





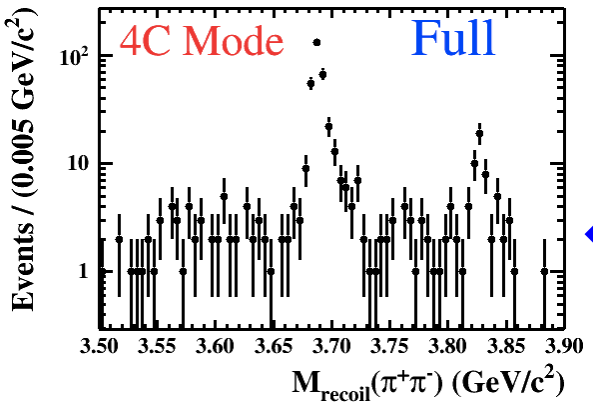


Efficiencies of signal MC simulations

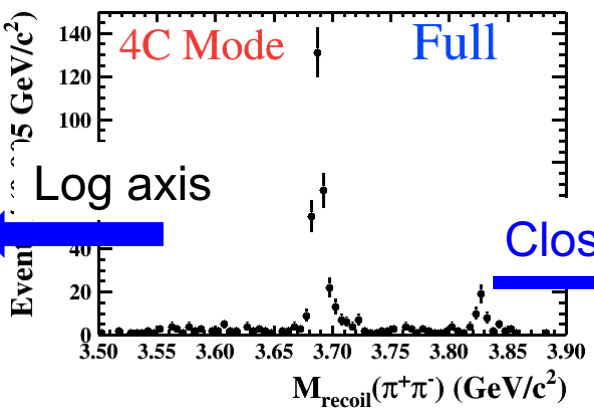
Data ID	ϵ_{4C} (%)	ϵ_{1C} (%)
4130	0.83	15.77
4180	11.46	17.71
4230	17.80	13.68
4260	18.93	12.38
4360	20.22	8.95
4420	18.73	7.45
4600	21.91	6.61

Adding the 1C mode should be helpful.

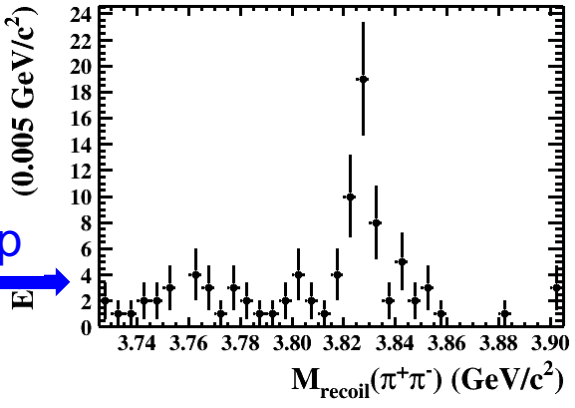
Summary for X(3823) in mixed 4C-1C mode

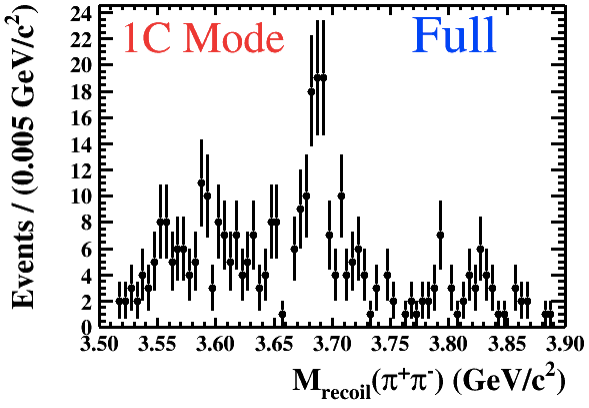


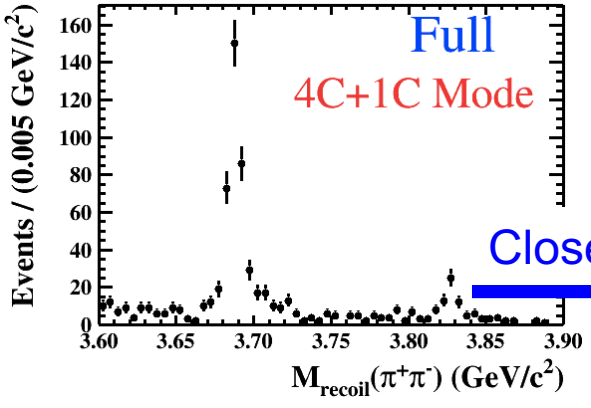
Log axis



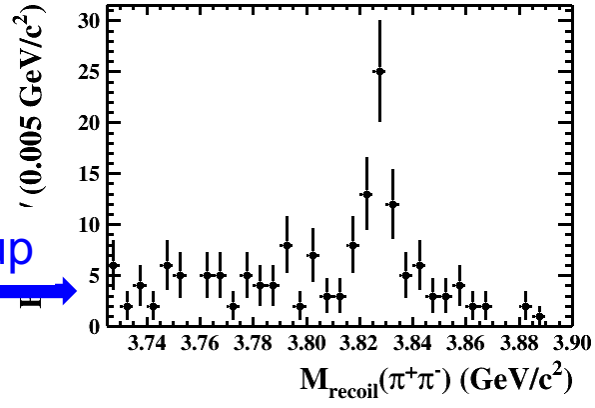
Close-up



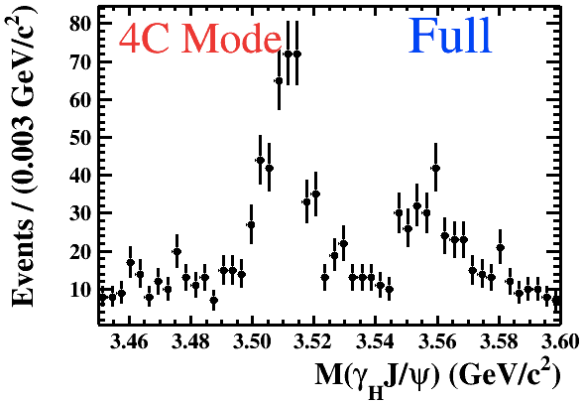


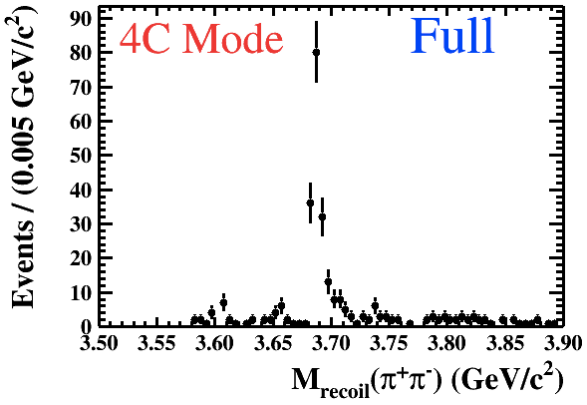


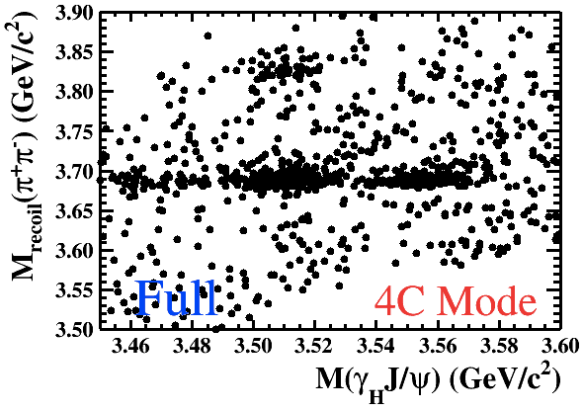
Close-up

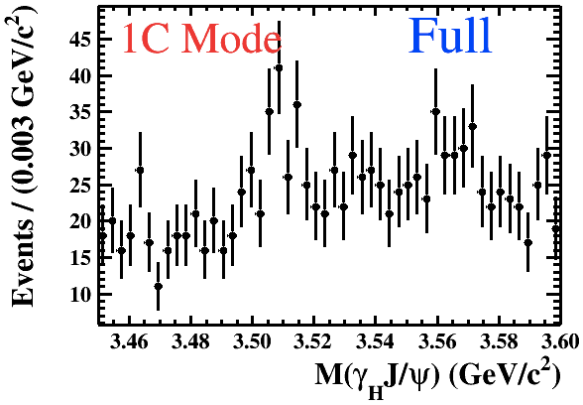


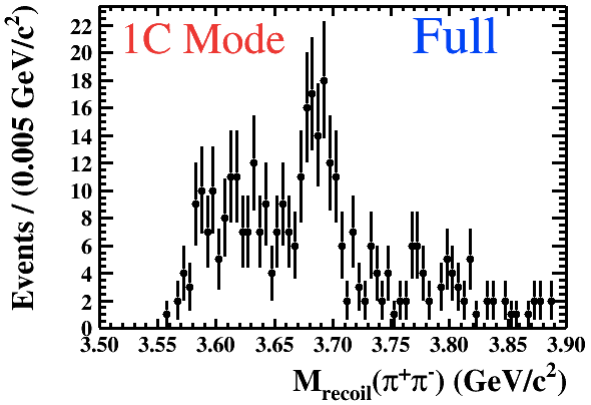
Summary for $X(\gamma\chi_{c2})$ in mixed 4C-1C mode

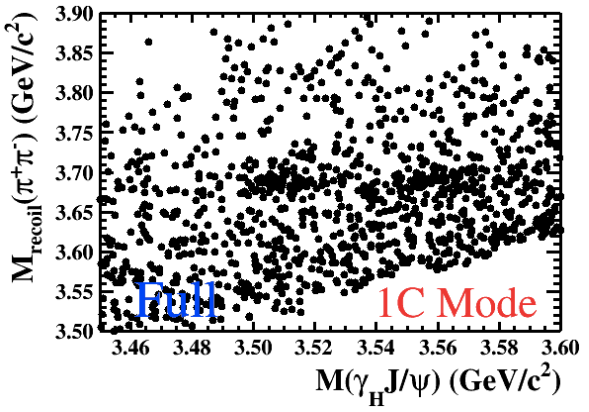






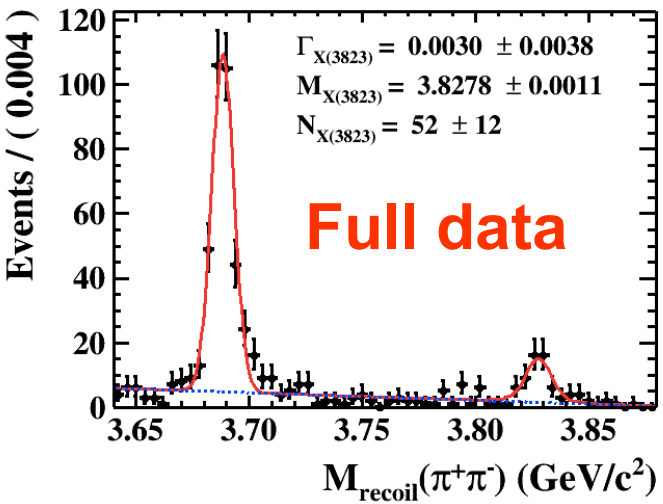






More detailed BKGs analysis for the 1C mode is needed to depress the BKGs.

Unbinned simultaneous fit for only 4C mode

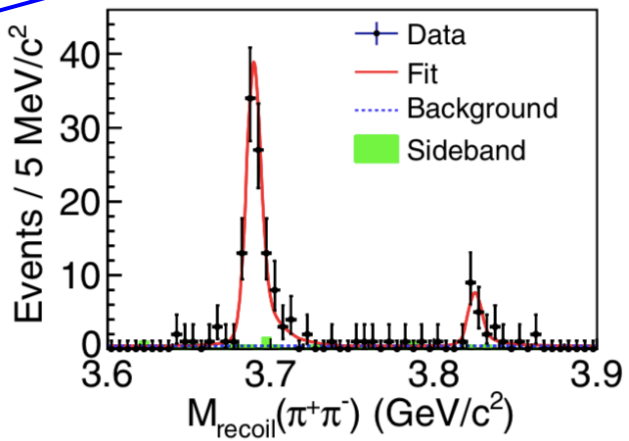


Preliminary result

$$\Gamma_{X(3823)} = 0.0030 \pm 0.0038$$
$$M_{X(3823)} = 3.8278 \pm 0.0011$$
$$N_{X(3823)} = 52 \pm 12$$

- **Signal PDF for** $X(3823)$: **BW**⊗Gauss ($\psi(3686)$ resolution)
- **Signal PDF for** $\psi(3686)$: Single Gaussian
- **BKG:** **1st-order chev. Poly.**

PRL115, 011803 (2015)



Next to do

- Further study the BKGs in the 1C mode
- Measure the product cross sections $e^+e^- \to \pi^+\pi^- X(3823)$ and the upper limit for $e^+e^- \to \pi^+\pi^- X(3842)$.
- Try to determine the J^P of X(3823) if possible.

THANK YOU FOR YOUR ATTENTION!