Search for $\chi_{c0,2}(2P)$ via $e^+e^- \to \gamma D\overline{D}$

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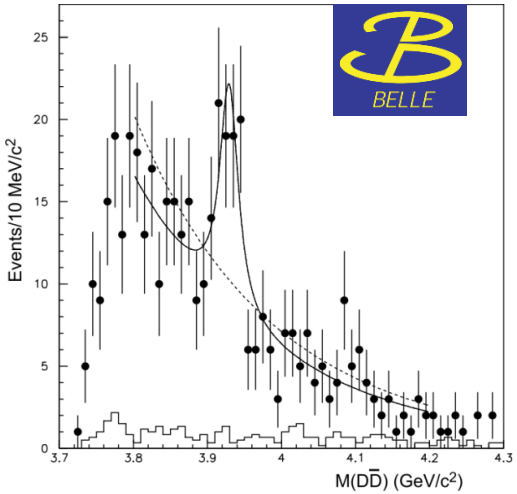
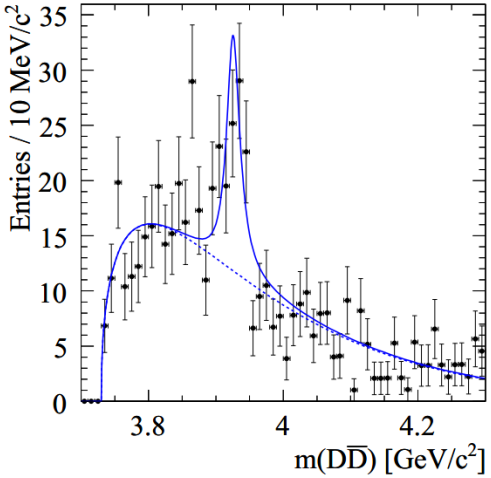
Outline

- Motivation
- Data set
- Event selection
- Cross section measurement
- Summary

Motivation

- $\chi_{c2}(2P)$ has been observed by Belle Collaboration on 2006 in $\gamma\gamma$ production of $D\overline{D}$ system. And conformed by BABAR Collaboration.





- $\chi_{c0,2}(2P)$ hasn't been observed by BESIII Collaboration.
- Article arXiv:1201.4155 point out that the E1 transition widths of $\psi(4040,4160) \to \gamma\chi'_{CJ}$ are model-insensitive and relatively large(tens to hundreds of keV), the corresponding branching ratios are of order $10^{-4} - 10^{-3}$. The BR of $\chi_{c0,2}(2P) \to D\overline{D}$ is predicted large[PRD 72, 054026 (2005)].
- So it is possible for us to search for $\chi'_{c0,2}$ at BESIII.

Software and D tag channels

✓ **Method** : Double Dtag, DTagAlg-00-01-05

✓ ***D* tag modes analyzed:**

Neutral Mode:

- $D^0 \to K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^+\pi^-, K^-\pi^+\pi^+\pi^-\pi^0.$
- $\bar{D}^0 \to K^+\pi^-, K^+\pi^-\pi^0, K^+\pi^-\pi^-\pi^+, K^+\pi^-\pi^-\pi^+\pi^0.$

Charged Mode:

- $D^+ \to K^-\pi^+\pi^+, K^-\pi^+\pi^+\pi^0, K_s^0\pi^+, K_s^0\pi^+\pi^0, K_s^0\pi^+\pi^-\pi^+.$
- $D^- \to K^+\pi^-\pi^-, K^+\pi^-\pi^-\pi^0, K_s^0\pi^-, K_s^0\pi^-\pi^0, K_s^0\pi^-\pi^+\pi^-.$

Data set

- ✓ **Boss Version and data:**
  - 4180 data at Boss 702p02

- ✓ **MC samples:**
  - **Inclusive MC:**
    - $e^+e^- \to$ Inclusive @ 4.18 GeV
  - **Exclusive MC**:
    - $e^+e^- \to \gamma\chi_{c2}(2P), \chi_{c2}(2P) \to D^0\overline{D}^0, D^+D^-$
    - $e^+e^- \to \gamma\chi_{c0}(2P), \chi_{c0}(2P) \to D^0\overline{D}^0, D^+D^-$
    - $e^+e^- \to \gamma D^0\overline{D}^0\ , \gamma D^+D^-$
    - $e^+e^- \to D^{*0}\overline{D}^0, D^{*+}D^-$
    - $e^+e^- \to D^{*0}\overline{D}^{*0}, D^{*+}\overline{D}^{*-}$
    - $e^+e^- \to \gamma D^0\overline{D}^{*0}$

Event selection

✓ **Charged tracks**

- |Rxy|<1cm,|Rz|<10cm ,|cos θ|<0.93

✓ **Good photon**

- E > 25 MeV for | cosθ| < 0.8 ; E > 50 MeV for 0.86<| cos θ |<0.92
- 0≤T≤14(1=50ns)

✓ **Particle identification**

- π:Prob(π)>Prob(K)
- K: Prob(K)>Prob(π)

✓ $\boldsymbol{D\bar{D}}$ **pair**

- Use the dtagtool to find double tag candidate with average mass closest to the PDG value of D mass in each mode. Mass window: |M($D/\bar{D}$) – m(D)| < 120 MeV.

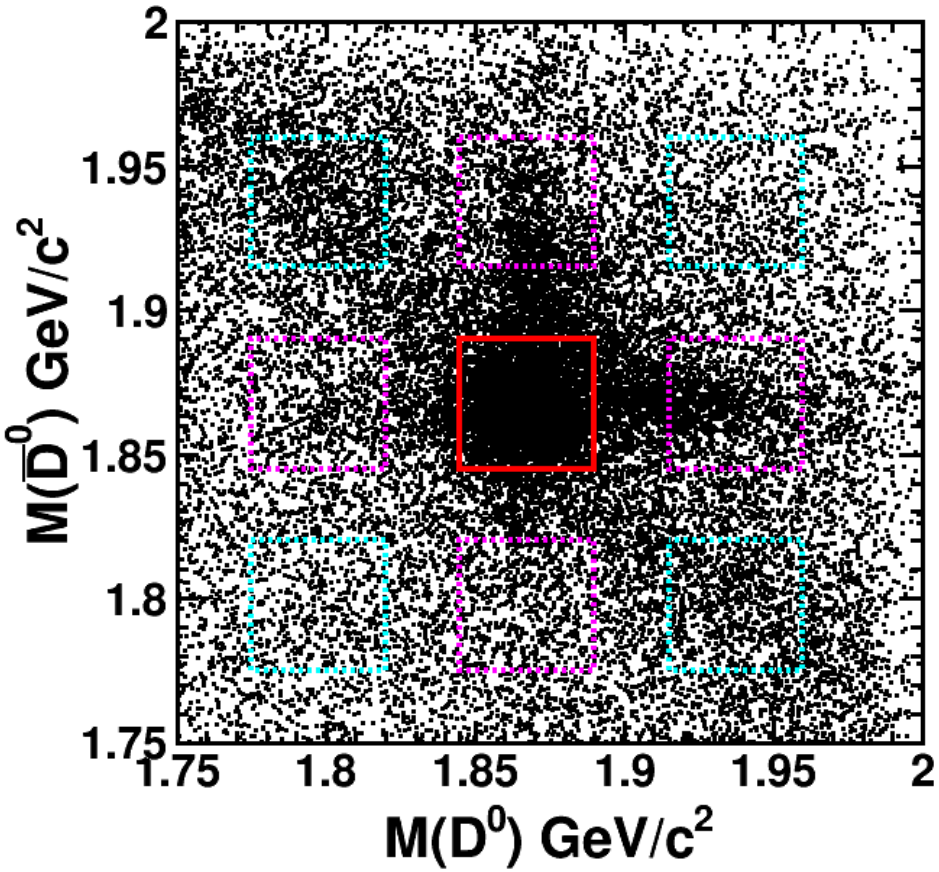
✓ **One $\boldsymbol{\gamma}$ out of $\boldsymbol{D\bar{D}}$ pair :**

✓ **Kinematic fit(4C/5C/6C)**

- In the mode contain π^0 and K_S^0, π^0 and K_S^0 mass constrain applied, and the mode with minimum χ^2 in each event is selected.

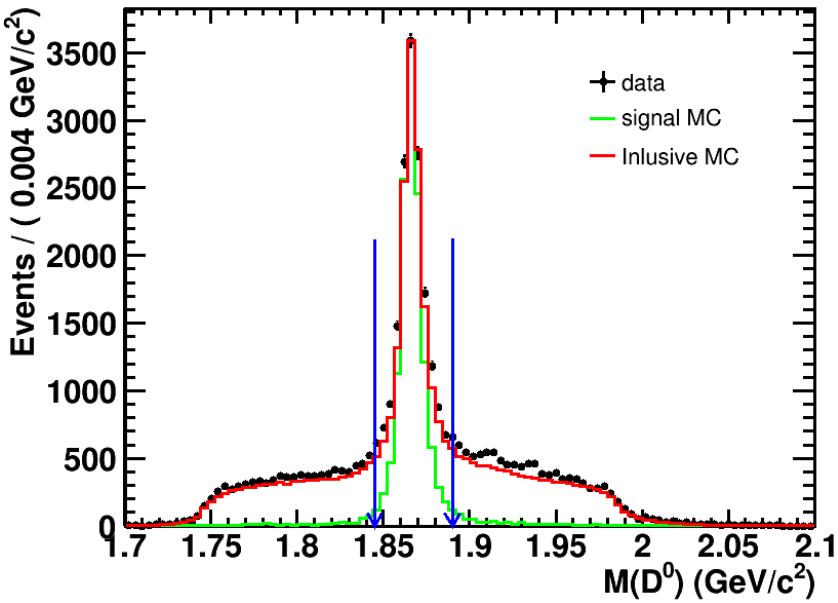
$$\chi_{c2}(2P) \to D^0\overline{D}^0$$

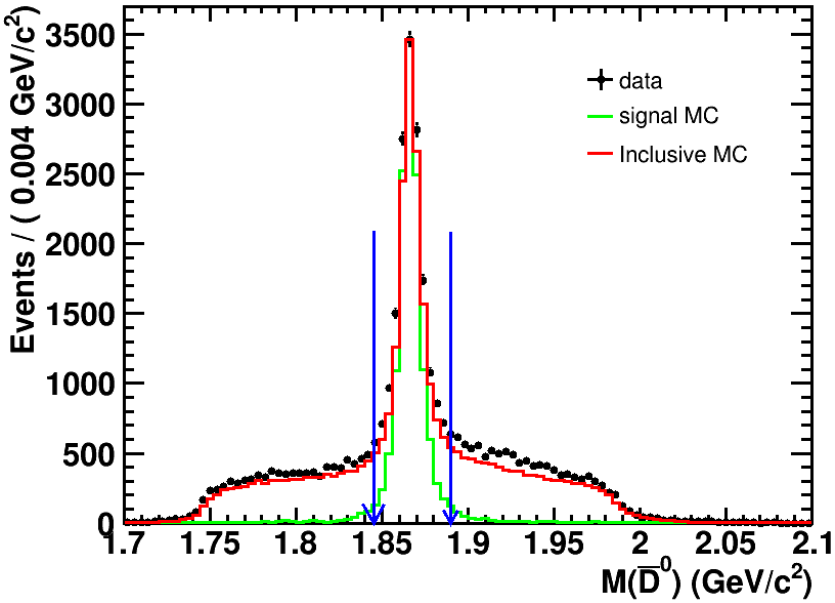
Scatter plot of M(D^0) and M($\overline{D}^0$) in data



- Red box is for the signal region, pink box and blue box are for sidebands region.

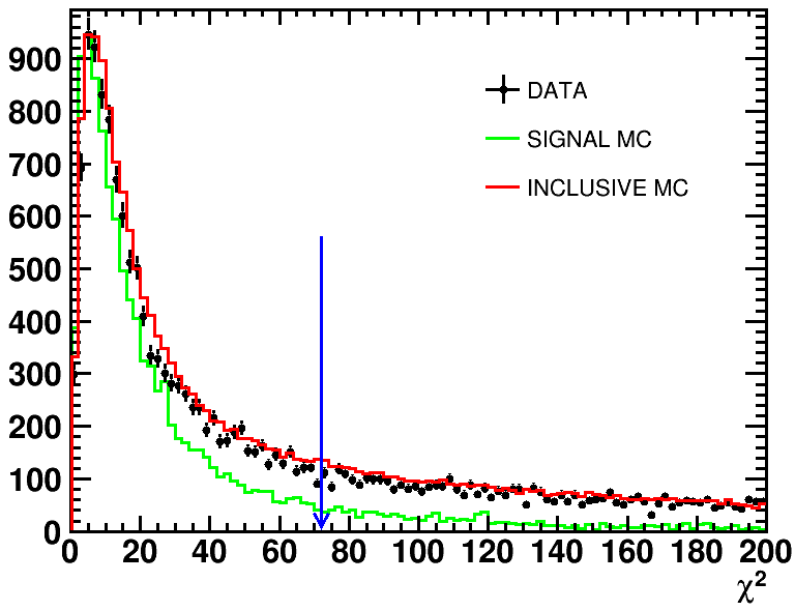
Invariant mass distribution of D^0 and $\overline{D}^0$

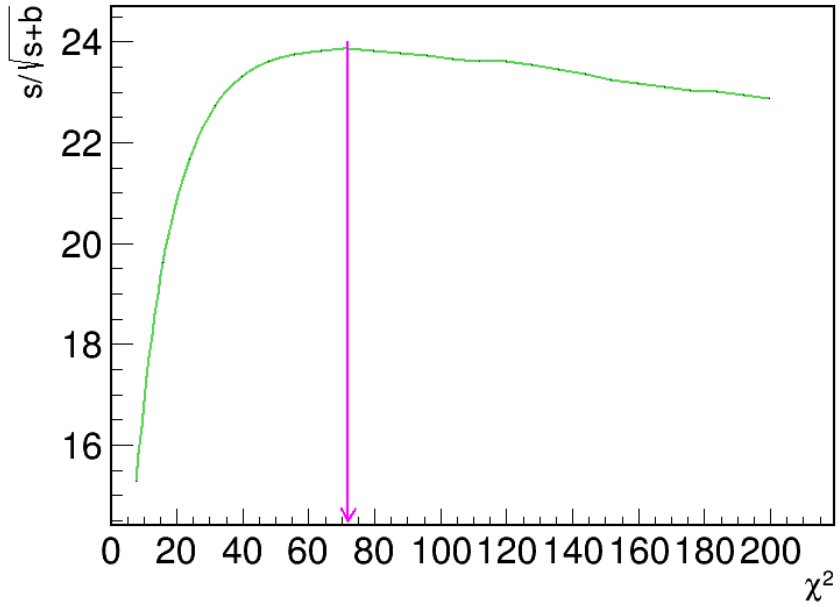




- 1.845 < M(D^0) < 1.89 GeV/c^2(left)
- 1.845 < M($\overline{D}^0$) < 1.89 GeV/c^2(right) to
- Reject non-DDbar background.

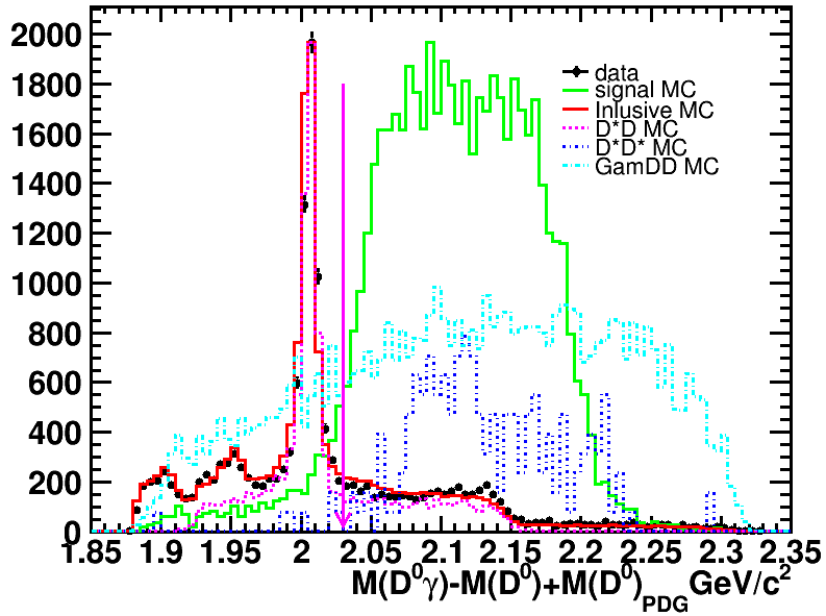
The χ^2 distribution requirement

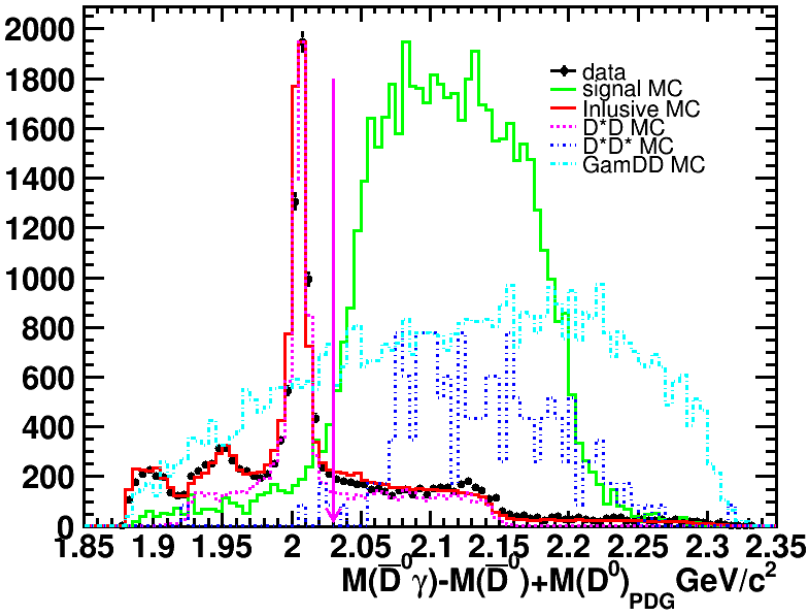




χ^2 distribution from kinematic fit: χ^2<72 .

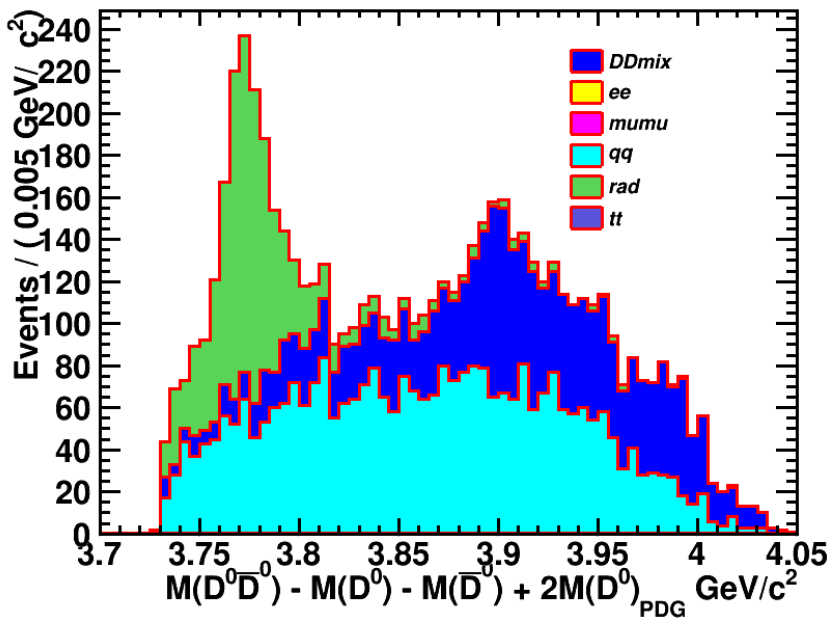
D^* background rejection

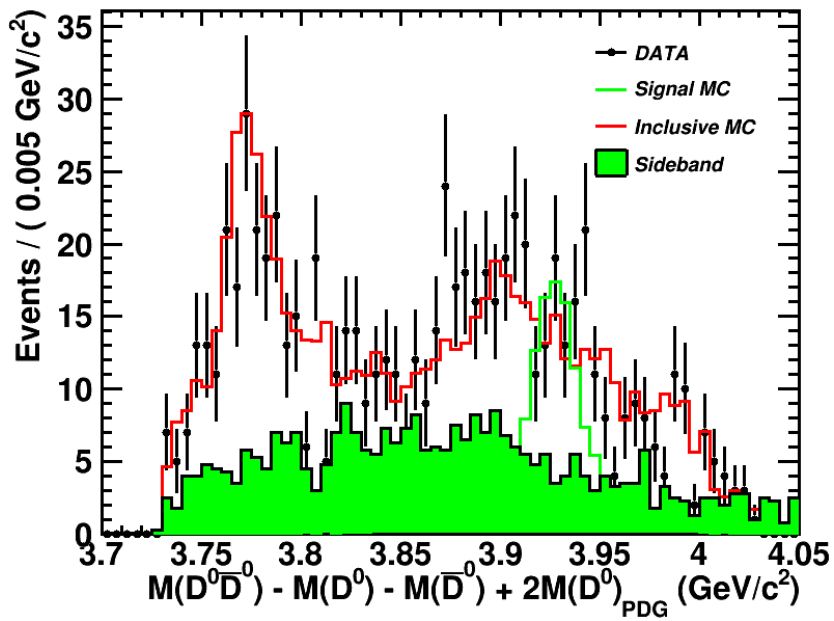




- Backgrounds from D*.
- $M(D^0\gamma) - M(D^0) + M(D^0)_{PDG} > 2.03 GeV/c^2$
- $M(\bar{D}^0\gamma) - M(\bar{D}^0) + M(\bar{D}^0)_{PDG} > 2.03 GeV/c^2$

$D^0\overline{D}^0$ invariant mass distribution



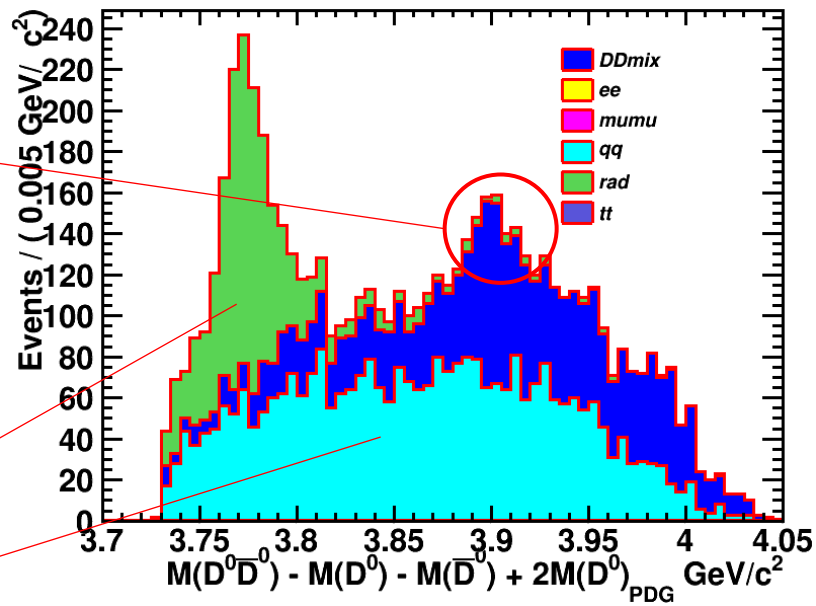


- Clear ISR $\psi(3770)$ signal, but no significant $\chi_{c0,2}(2P)$ signal.
- Many backgrounds from opencharm.

Backgrounds analysis

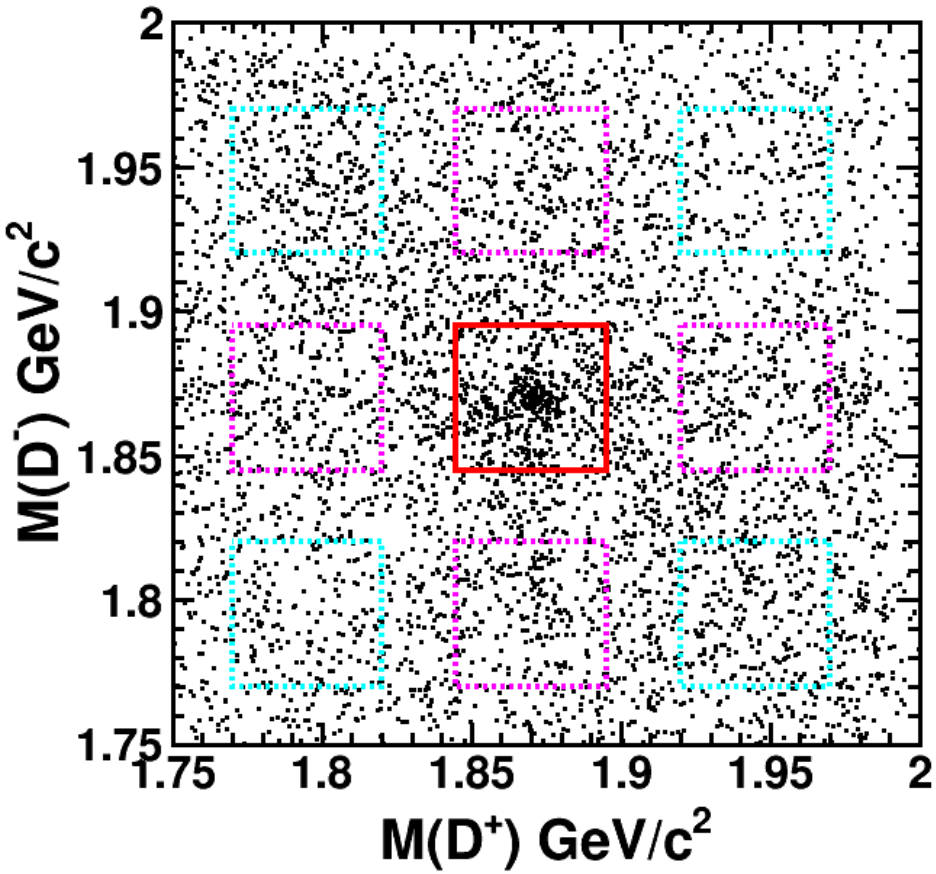
According to the analysis of inclusive MC, the main backgrounds are come from:

- $e^+e^- \to \bar{D}^0 D^{*0}$,
- $e^+e^- \to \bar{D}^{*0} D^{*0}$
- $e^+e^- \to \bar{D}^{*+} D^{*-}$,
- $e^+e^- \to \bar{D}^0 D^0$
- $e^+e^- \to D^- D^{*+}$,
- $e^+e^- \to \bar{D}^0 \pi^- D^{*+}$
- $e^+e^- \to \gamma \bar{D}^0 D^0$
- $e^+e^- \to \gamma \psi(3770)$
- $e^+e^- \to q\bar{q}$



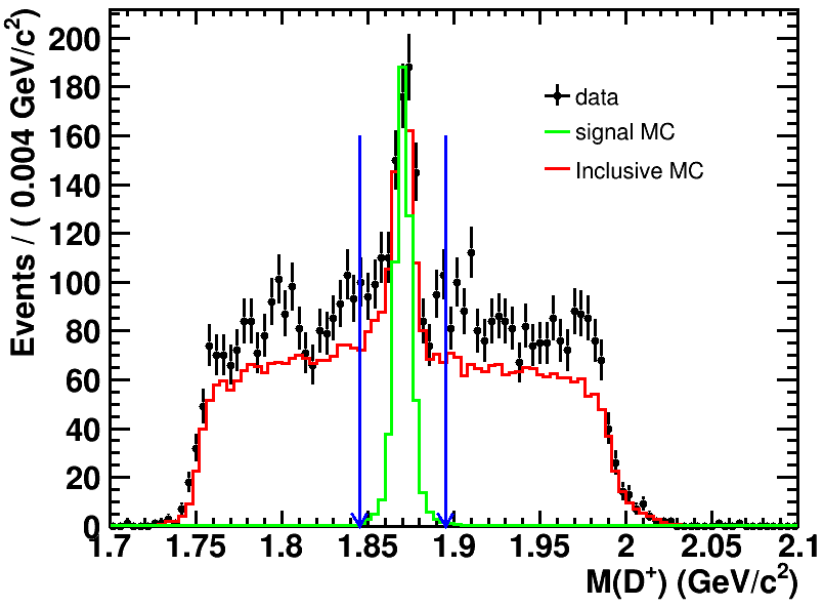
$$\chi_{c2}(2P) \to D^+D^-$$

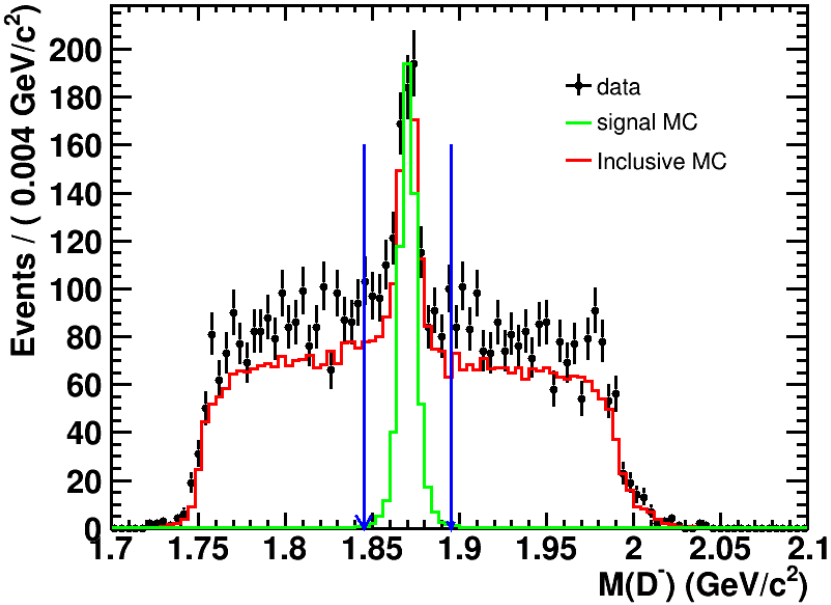
Scatter plot of M(D^+) and M(D^-) in data



- Red box is for the signal region, pink box and blue box are for sidebands region.

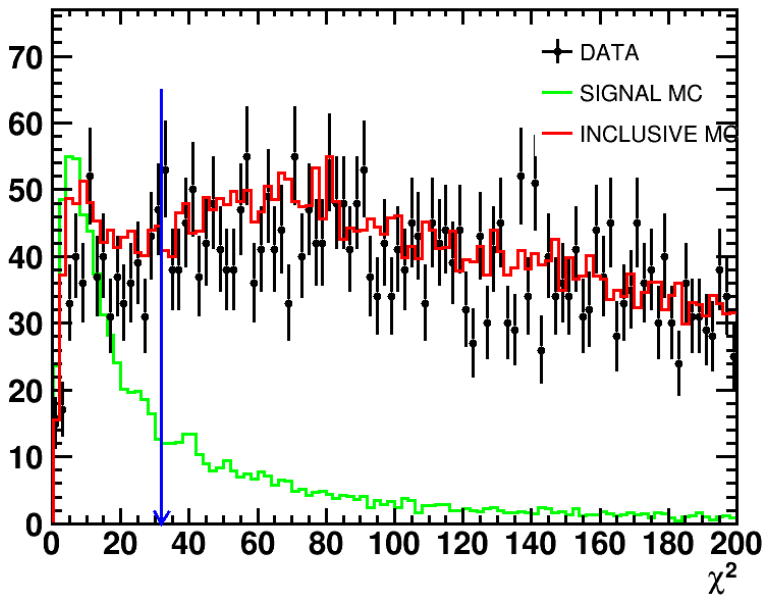
Invariant mass distribution of D^+ and D^-

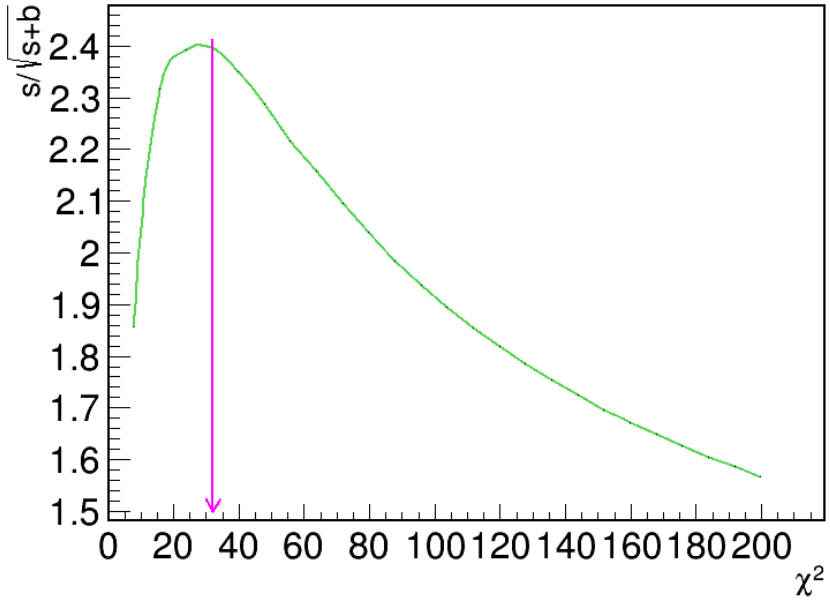




- 1.845 < M(D^+) < 1.895 GeV/c^2(left)
- 1.845 < M(D^-) < 1.895 GeV/c^2(right)
- Reject non-DDbar background.

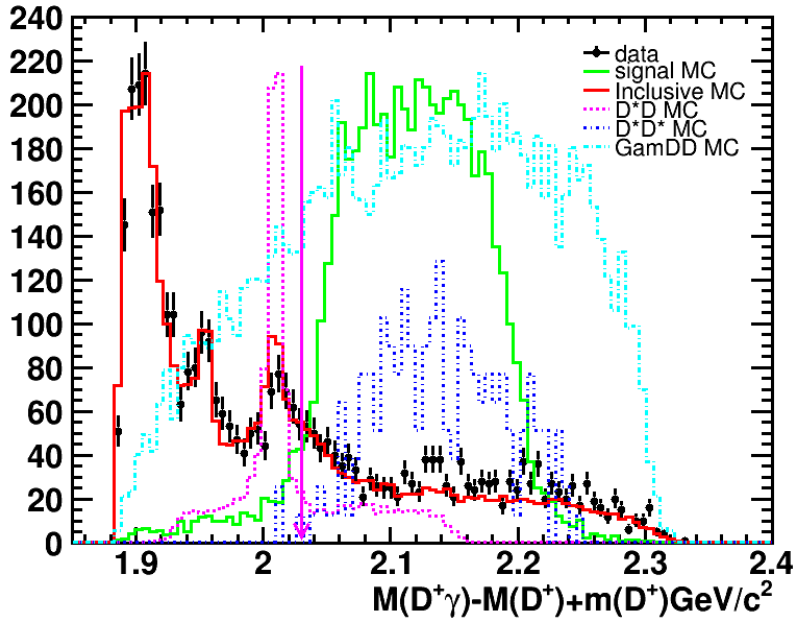
The χ^2 distribution requirement

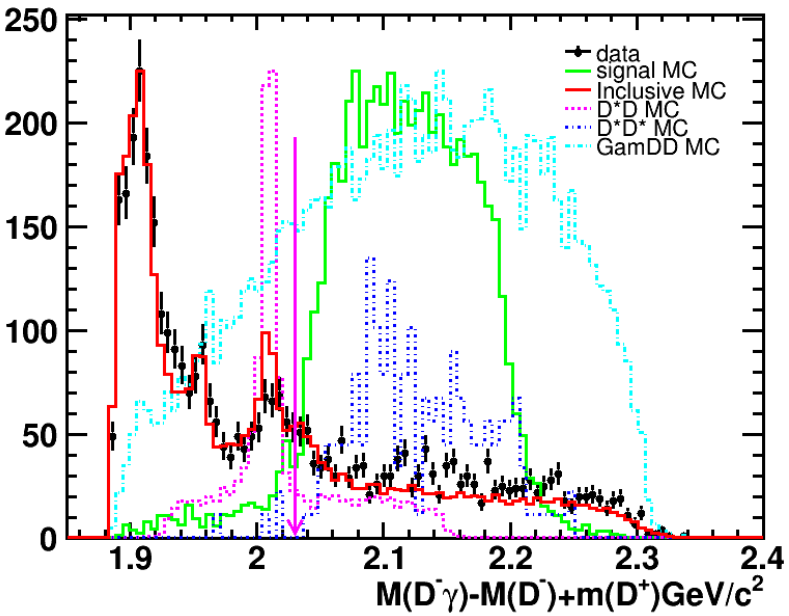




χ^2 distribution from kinematic fit: χ^2<32 .

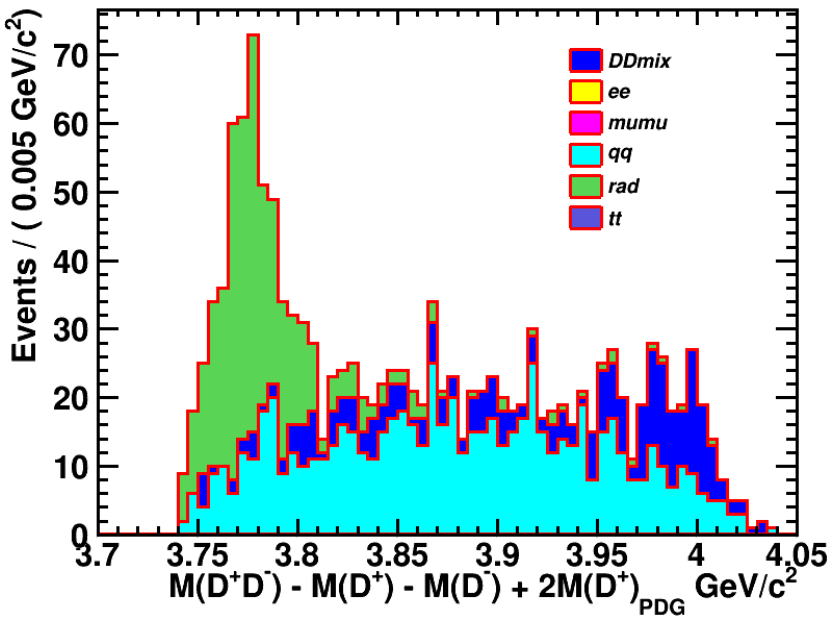
D^* background rejection

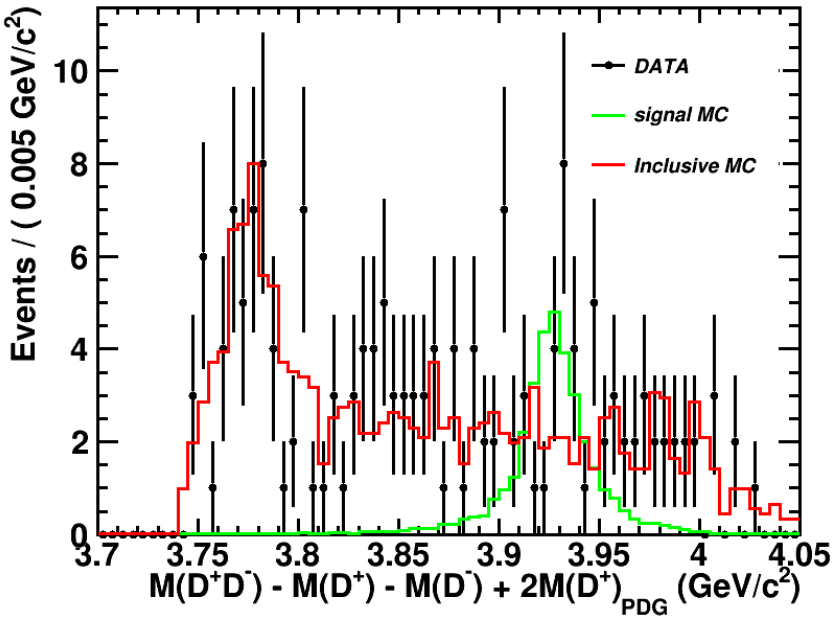




- Backgrounds from D*
- $M(D^+\gamma) - M(D^+) + M(D^+)_{PDG} > 2.03 GeV/c^2$
- $M(D^-\gamma) - M(D^-) + M(D^-)_{PDG} > 2.03 GeV/c^2$

D^+D^- invariant mass distribution





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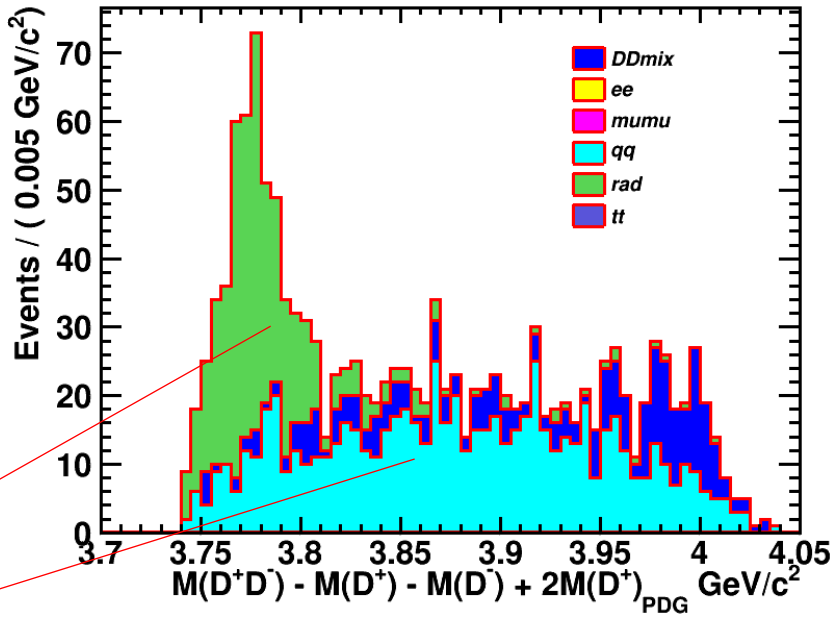
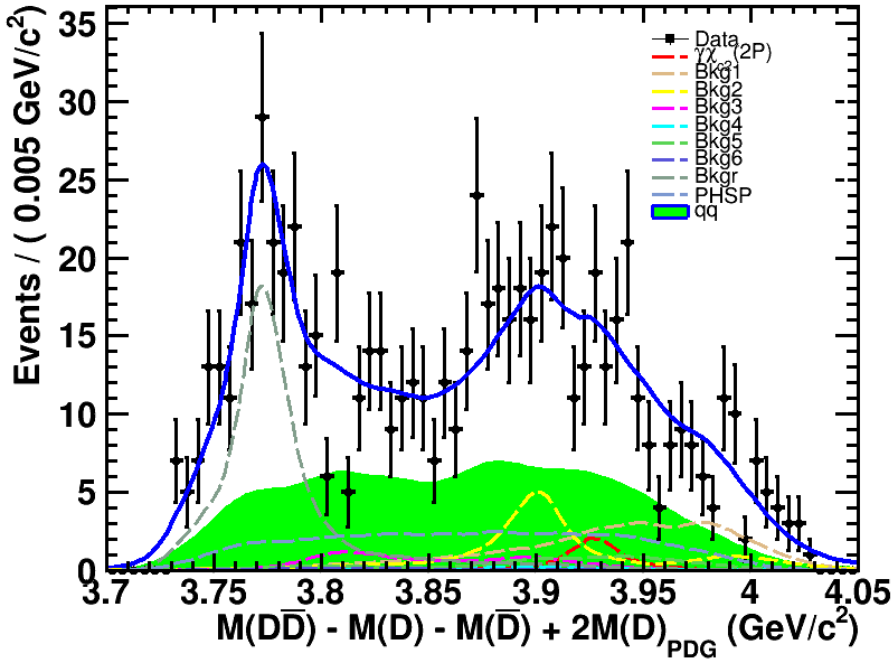
- $e^+e^- \to \bar{D}^{*-}D^{*+}$
- $e^+e^- \to D^-\pi^+D^{*0}$
- $e^+e^- \to D^-D^{*+}$
- $e^+e^- \to \bar{D}^0D^{*0}$,
- $e^+e^- \to \bar{D}^{*0}D^{*0}$
- $e^+e^- \to \gamma D^+D^-$
- $e^+e^- \to \gamma\psi(3770)$
- $e^+e^- \to q\bar{q}$



$\chi_{c2}(2P)$ signal extraction from M($D^0\overline{D}^0$)



N^{sig} = 14.97 $\pm$ 17.06
chisq/ndf = 1.03
S = 0.9σ

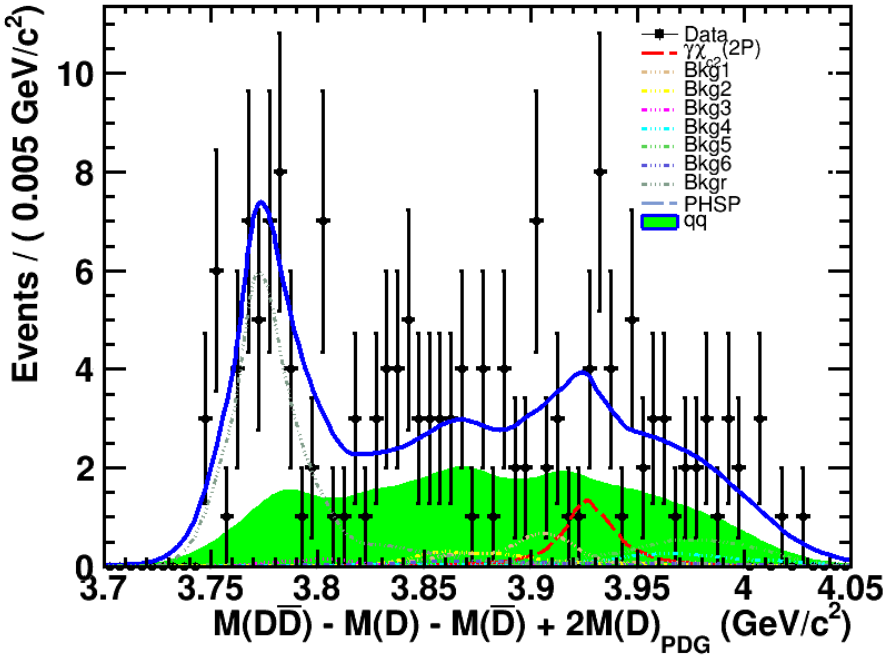
- Signal :

Signal MC shape, mass and width set at the PDG value

- Background:

MC shape of each backgrounds channel, Events number fix at that of equal luminosity

$\chi_{c2}(2P)$ signal extraction from M(D^+D^-)



N^{sig} = 6.14 $\pm$ 7.93
chisq/ndf = 1.03
S = 0.4σ

- Signal :

Signal MC shape, mass and width set at the PDG value

- Background:

MC shape of each backgrounds channel, Events number fix at that of equal luminosity

Cross section of $e^+e^- \to \gamma\chi_{c2}(2P)$

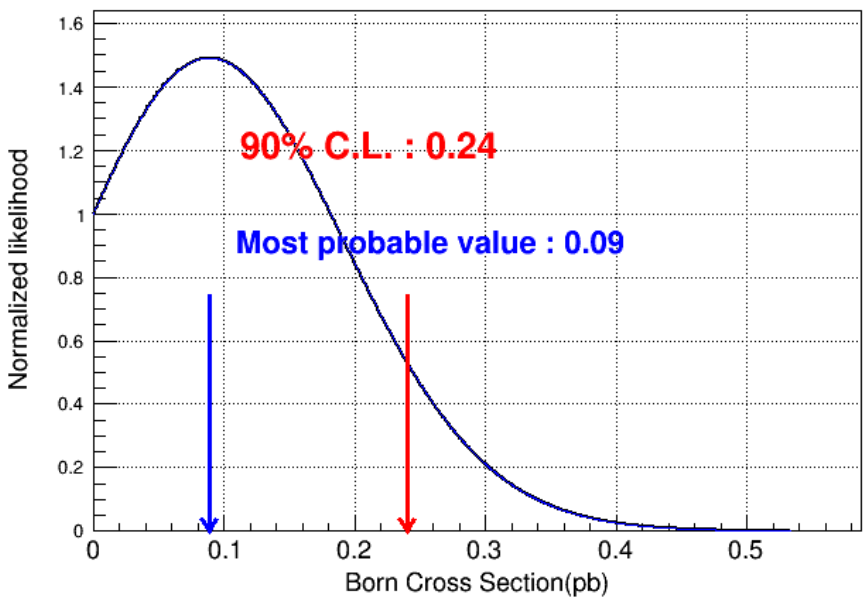
$$\boldsymbol{\sigma^B = \frac{N_n^{obs}}{\mathcal{L}_{int}(1+\delta^r)(1+\delta^v)\mathcal{B}_n \sum_{i,j} \epsilon_{i,j}\mathcal{B}_i\mathcal{B}_j}}$$

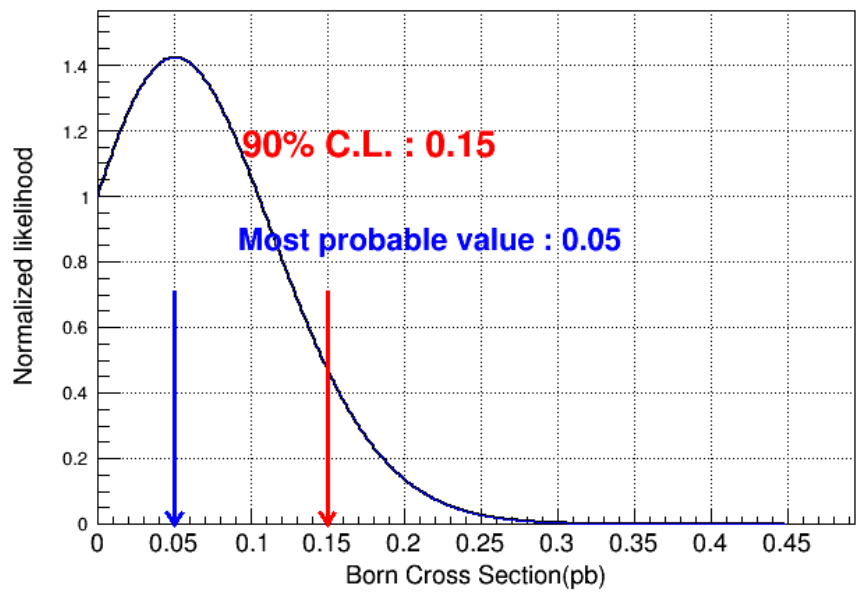
Mode	$\boldsymbol{N^{obs}}$	$\boldsymbol{\mathcal{L}_{int}}$	$\boldsymbol{1+\delta^r}$	$\boldsymbol{1+\delta^v}$	$\sum_{i,j}\epsilon_{i,j}\mathcal{B}_i\mathcal{B}_j$	σ(pb)*$\boldsymbol{\mathcal{B}_n}$
$D^0\overline{D}^0$	14.97±17.06	3189.0	0.750	1.056	0.0667	0.089± 0.101
D^+D^-	6.14±7.93	3189.0	0.750	1.056	0.0529	0.046±0.059

Upper limit of $e^+e^- \to \gamma\chi_{c2}(2P)$

The upper limit at 90% C.L. are estimate by:

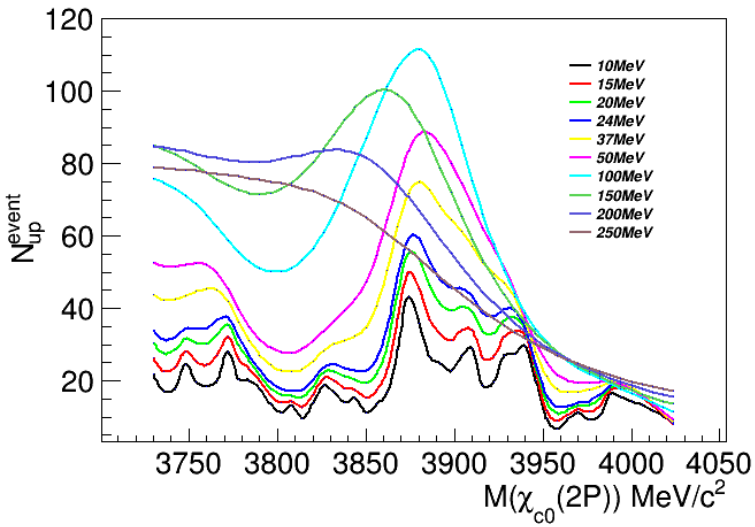
$$\frac{\int_0^{\sigma^{up}} L d\sigma}{\int_0^{\infty} L d\sigma} = 90\%$$

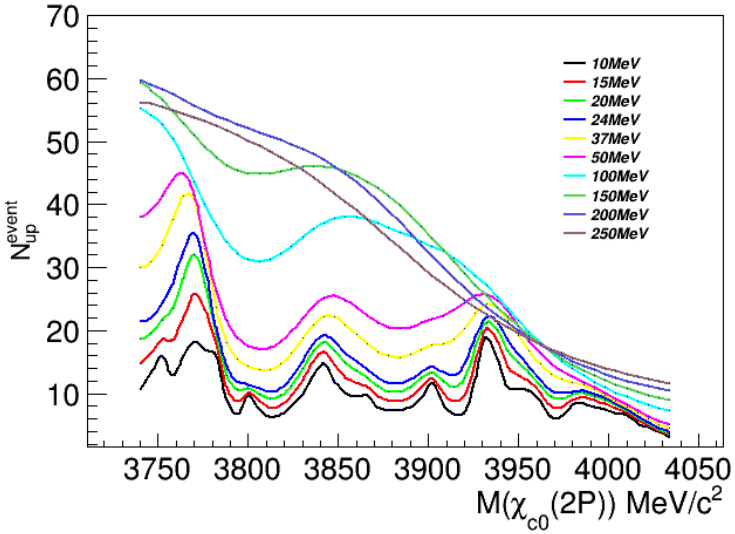




Upper limit of $e^+e^- \to \gamma\chi_{c0}(2P)$

- The resonance parameters of $\chi_{c0}(2P)$ haven't been determine now. We can try to determine the production cross section upper limit of $\chi_{c0}(2P)$ by assuming a series of its resonance parameters .
- Mass : 3730 - 4050MeV(50 points), width: 10 – 250MeV
- Signal: P*BW
- Backgrounds: MC shape of each backgrounds channel, Events number fix at that of equal luminosity .
- Upper limit of $\boldsymbol{N}^{sig}$:

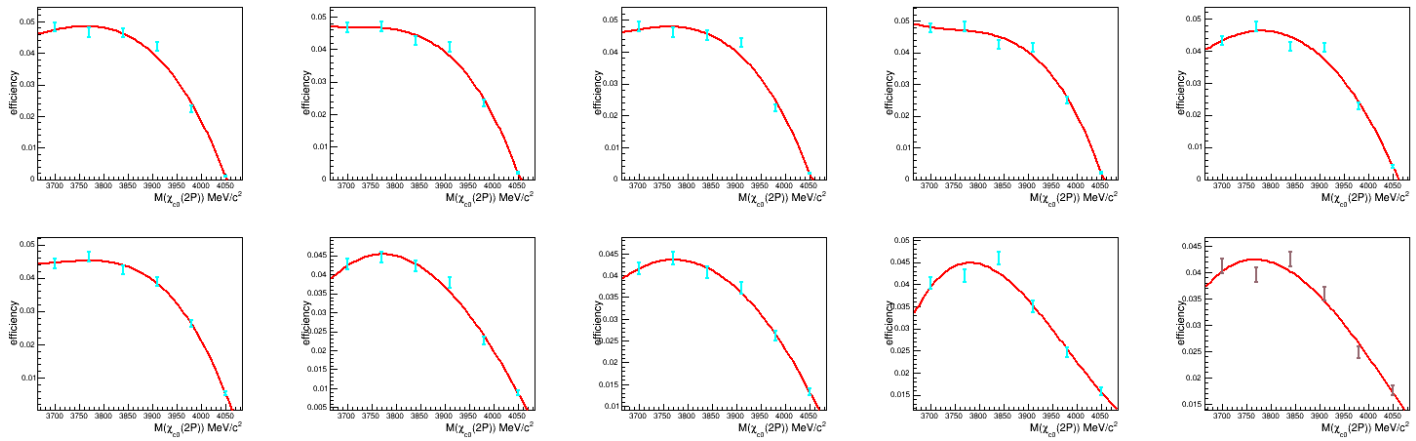




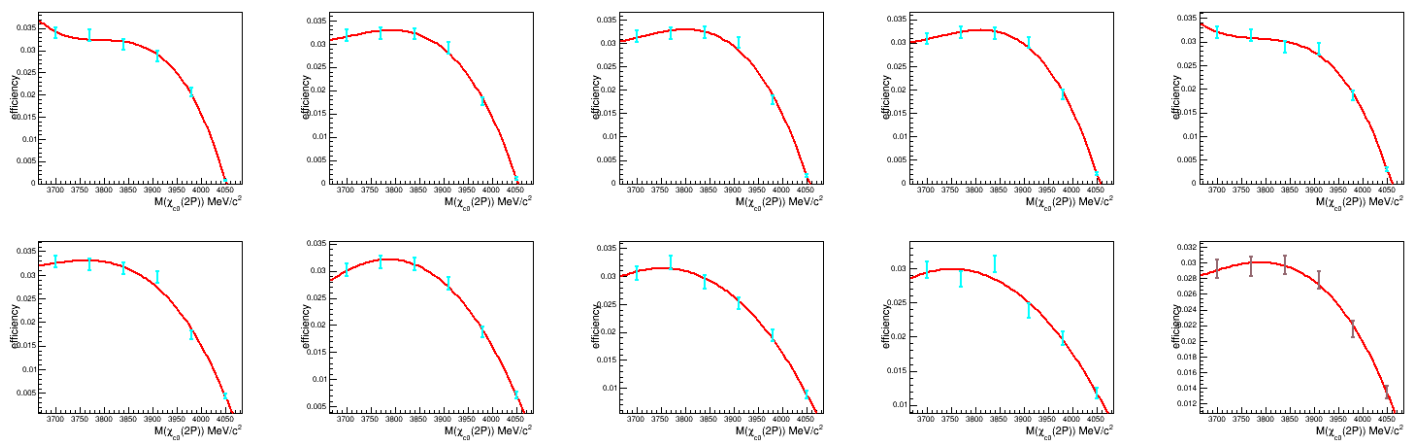
Efficiency

- Calculate the efficiency at the mass: 3730, 3770MeV, 3840MeV, 3910MeV, 3980MeV, 4050MeV of each width.
- Fit with 3rd polynomial.

$D^0\overline{D}^0$

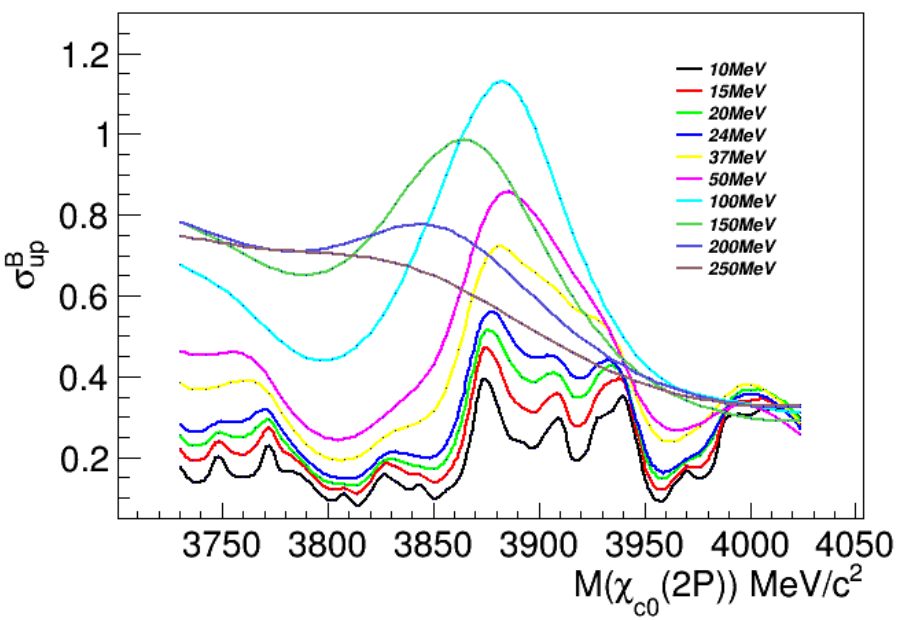


D^+D^-

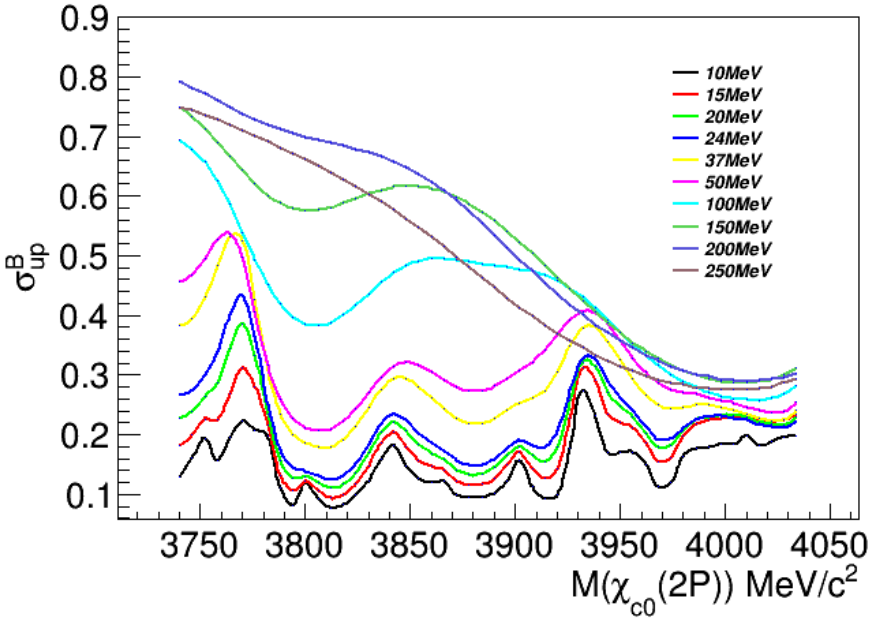


Upper limit of $e^+e^- \to \gamma\chi_{c0}(2P)$

The upper limit of the born cross-section of $e^+e^- \to \gamma\chi_{c0}(2P)$ times the branch ratio of $\chi_{c0}(2P) \to D\overline{D}$:



$D^0\overline{D}^0$



D^+D^-

System uncertainty estimation

- Luminosity : 1%
- Tracking and PID efficiency: 0.5%/track for PID and 1.0%/track for tracking respectively. From the results of the 2016 Winter Collaboration meeting reporters given by Jingwen Li (PID) and Xinyu Shan (tracking).
- Photon detection and π^0 reconstruction: 1.0% for each photon; 1.0% for each π^0 , from Luyu's reports.
- K_S^0 reconstruction: 4% for each K_S^0.
- kinematic fit: Track-parameter -corrected method.
- D mass region: Varying by $\pm$5MeV.
- Fitting range: Varying the limit of the fit range by $\pm$5MeV.
- Signal shape: Using the BW instead of signal MC to describe the signal.
- Backgrounds shape: We used 10X inclusive MC to describe the backgrounds and used another 10X inclusive MC to estimate the system uncertainty .

System uncertainty estimation

- ISR correction: We assume the $\gamma\chi_{c2}(2P)$ come from Y(4160), and varying the parameters of Y(4160) to estimate the system uncertainty .

Source	$D^0\overline{D}^0$(%)	D^+D^-(%)
Luminosity	1	1
Efficiency related	3.8	3.0
kinematic fit	1.1	1.0
D mass region	14.2	18.2
Fitting range	3.3	1.2
Signal shape	1.3	1.6
Background shape	3.9	1.5
ISR correction	0.5	0.5
Total	15.7	18.7

Summary

We perform an analysis of the $e^+e^- \to \gamma D\overline{D}$ at 4180 MeV to Search for $\chi_{c2}(2P)$ and $\chi_{c0}(2P)$. There is no significant signal $\chi_{c0,2}(2P)$ of in the invariant mass distribution of $D\overline{D}$. We give the production upper limit of $e^+e^- \to \gamma\chi_{c0,2}(2P) \to \gamma D\overline{D}$.

The reference arXiv: 1310.8597 predict that the $\sigma^{non-res}(e^+e^- \to \gamma\chi_{c2}(2P))$ ~ 0.24 pb, and theory predict that the $\sigma^{res}(e^+e^- \to \gamma\chi_{c2}(2P))$ ~ 5 pb near 4180 MeV. So our results are significantly smaller than the prediction.

Thanks for your attention!

Backup