Study of $\pi^+\pi^- D\bar{D}$ at BESIII

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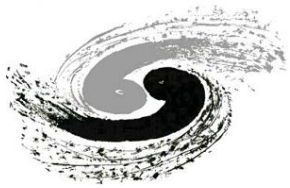
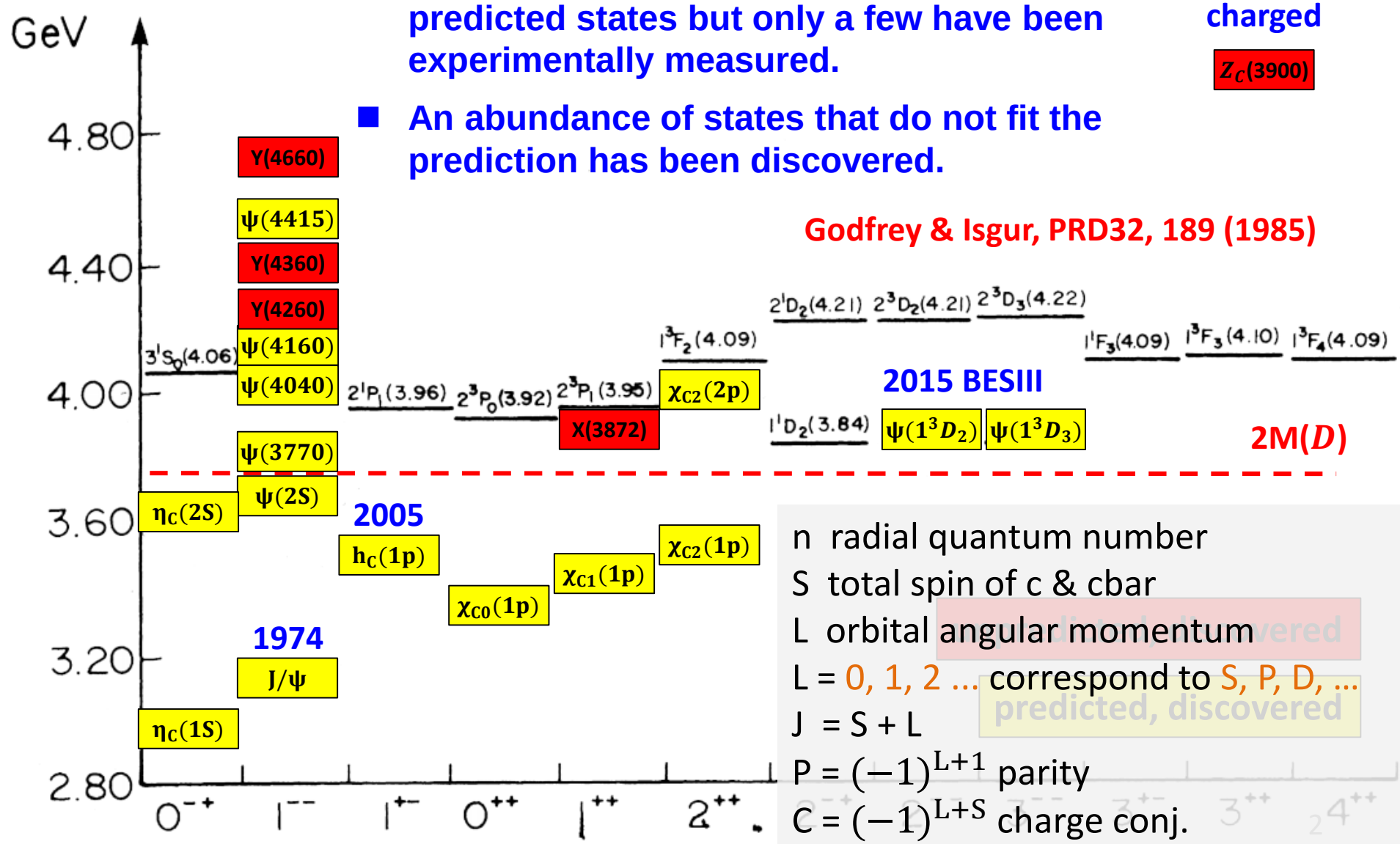


BESIII

Charmonium spectroscopy

- **Above the 2 M_D threshold there are many predicted states but only a few have been experimentally measured.**
- **An abundance of states that do not fit the prediction has been discovered.**



charged

$Z_C(3900)$

Godfrey & Isgur, PRD32, 189 (1985)

n radial quantum number

S total spin of c & cbar

L orbital angular momentum

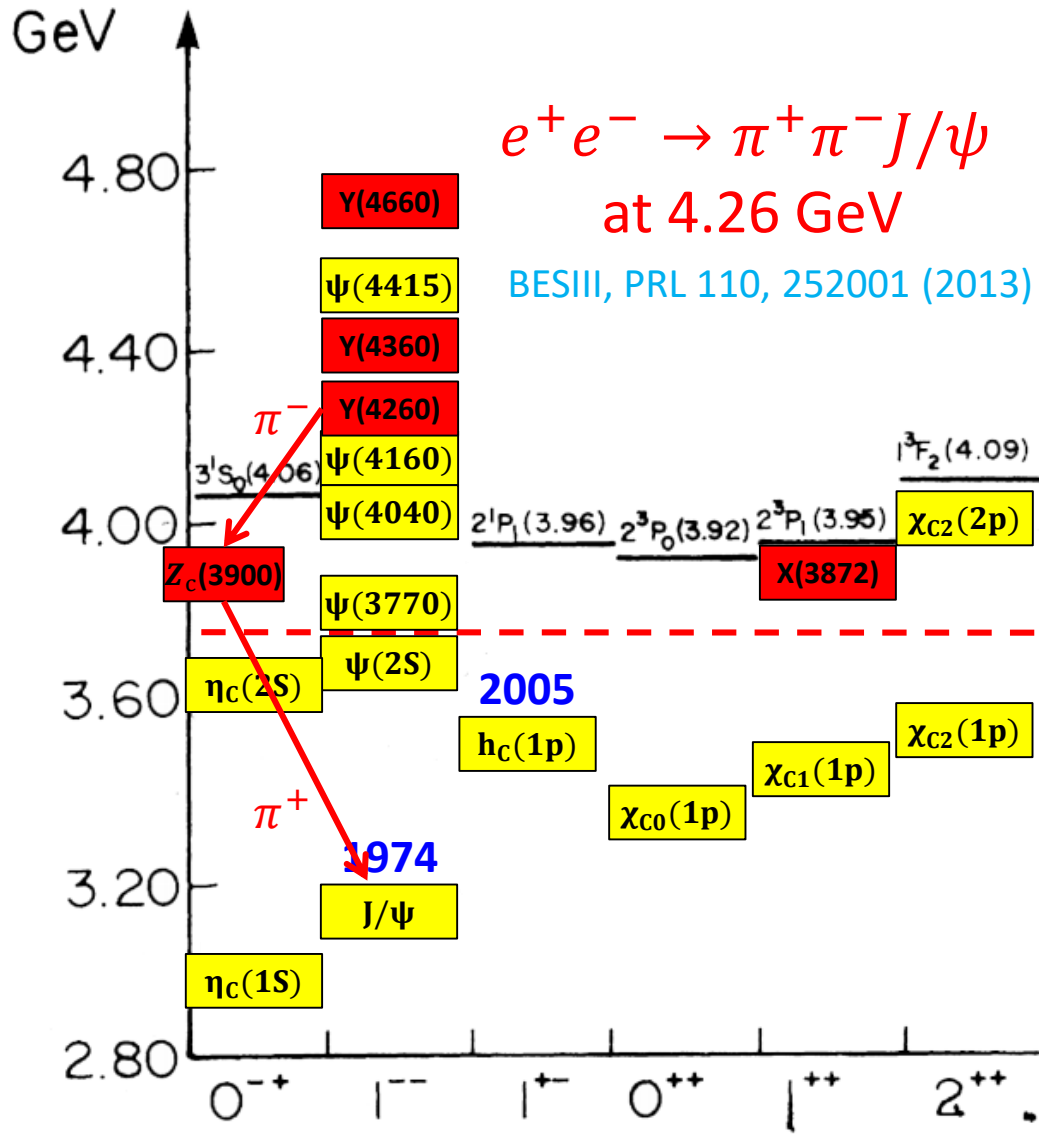
L = 0, 1, 2 ... correspond to S, P, D, ...

J = S + L

P = $(-1)^{L+1}$ parity

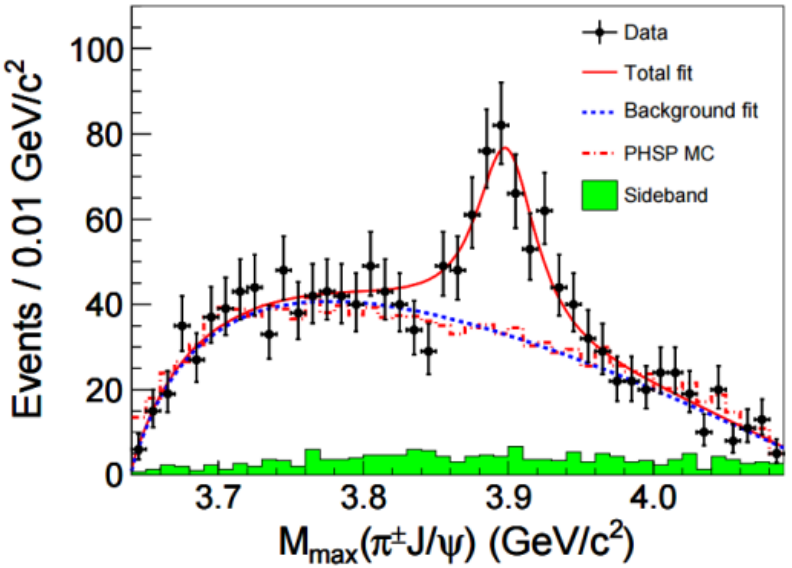
C = $(-1)^{L+S}$ charge conj.

Motivation



$e^+e^- \to \pi^+\pi^- J/\psi$ at 4.26 GeV

BESIII, PRL 110, 252001 (2013)



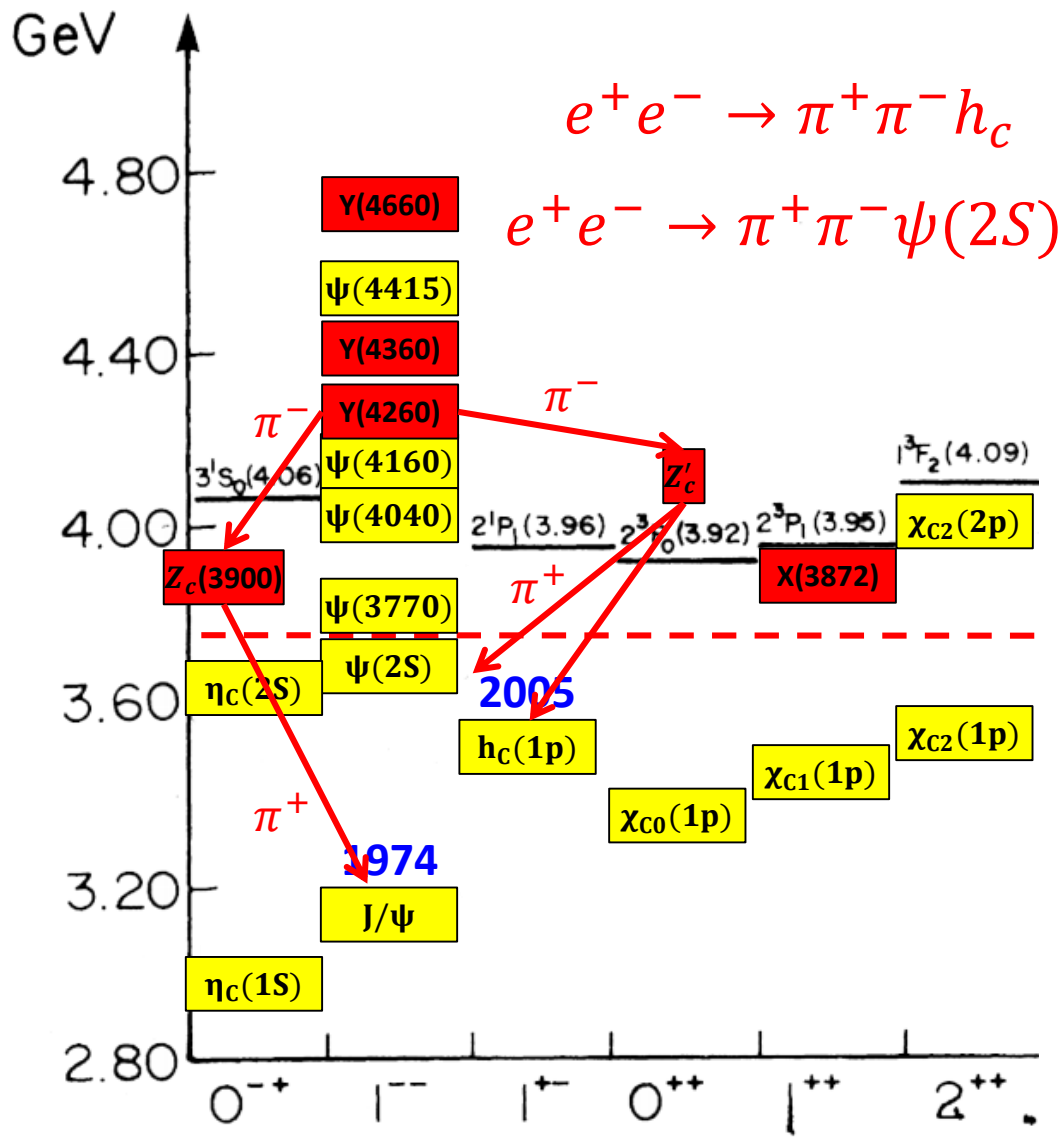
Charged charmonium-like structure

M = (3899.0 ± 3.6 ± 4.9) MeV/c^2
Γ = (46 ± 10 ± 20) MeV

Confirmed by Belle (PRL 110, 252002) and CLEOc (PLB 727, 366)

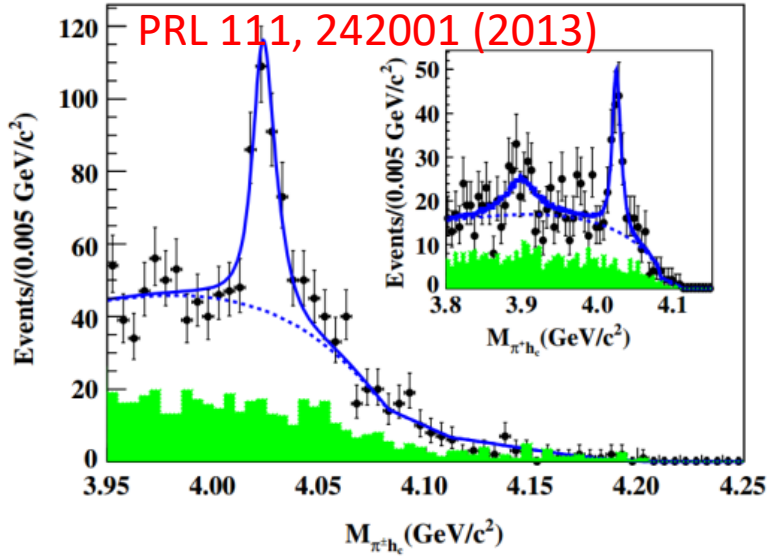
Close to DD∗ threshold
Interpretation?

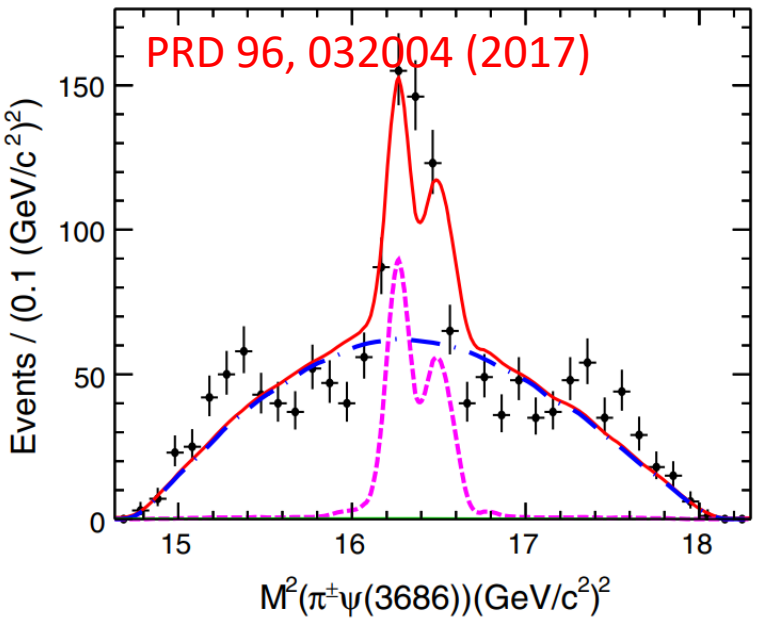
Motivation



$e^+e^- \to \pi^+\pi^- h_c$

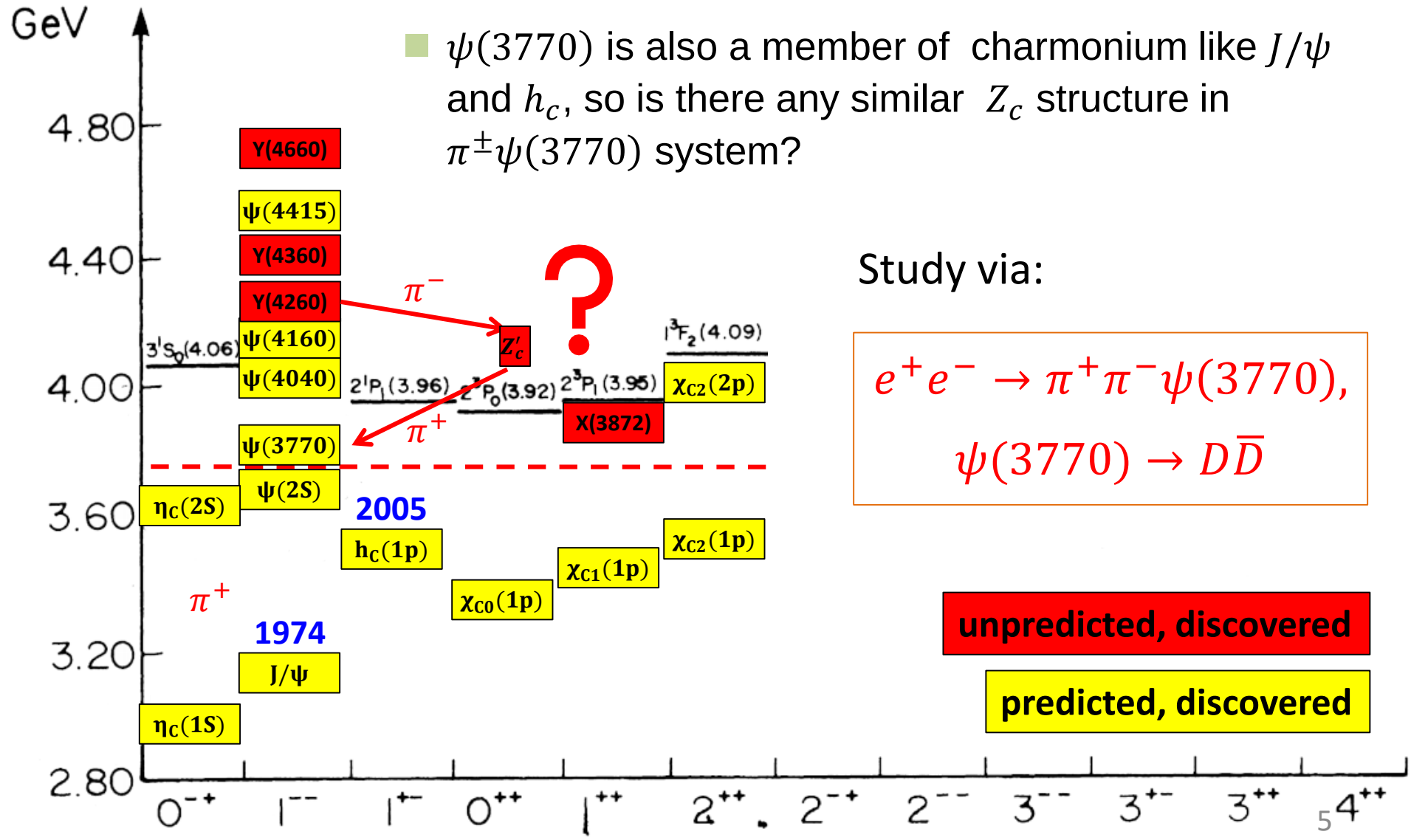
$e^+e^- \to \pi^+\pi^-\psi(2S)$





Motivation

- $\psi(3770)$ is also a member of charmonium like J/ψ and h_c, so is there any similar Z_c structure in $\pi^{\pm}\psi(3770)$ system?



Study via:

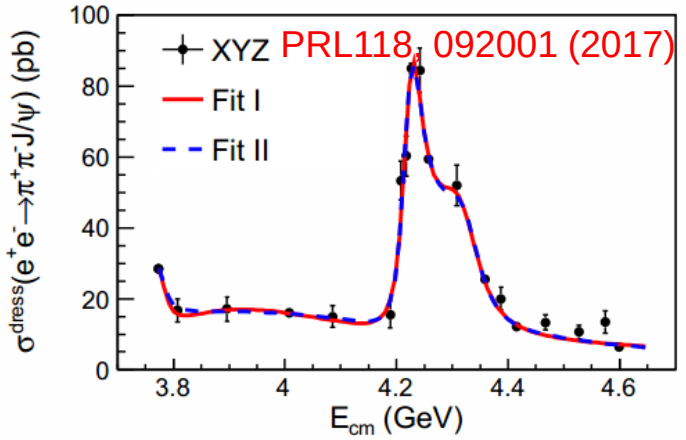
$$e^+e^- \to \pi^+\pi^-\psi(3770),$$
$$\psi(3770) \to D\bar{D}$$

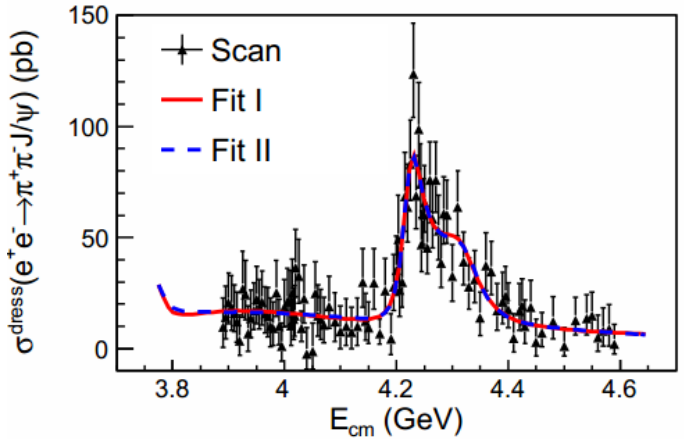
unpredicted, discovered

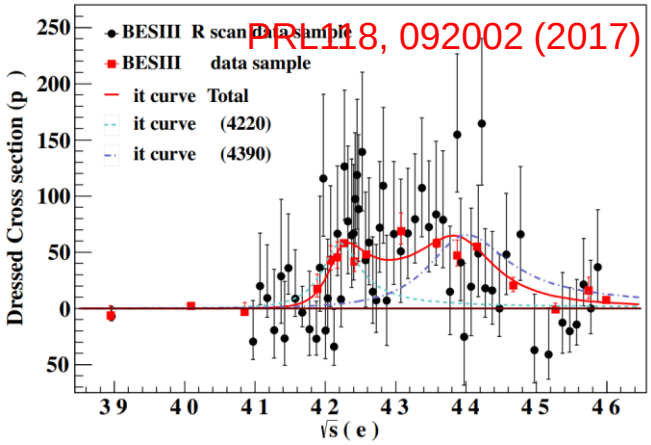
predicted, discovered

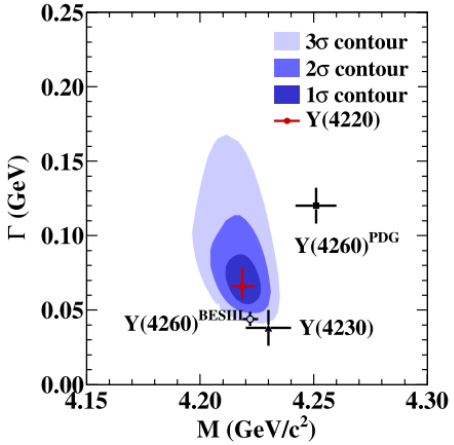
Motivation

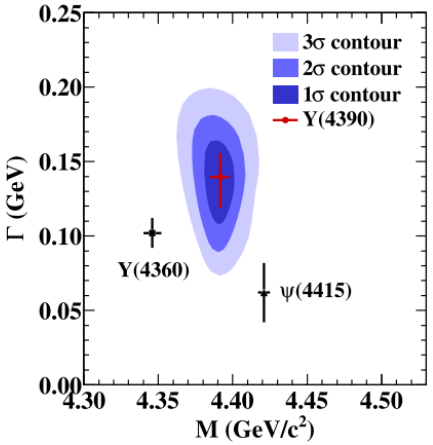
- Through precision measurement, BESIII observed Y(4220) and Y(4320) in the line-shape of $e^+e^- \to \pi^+\pi^- J/\psi$, Y(4220) and Y(4390) in the line-shape of $e^+e^- \to \pi^+\pi^- h_c$. Maybe similar Y states in the line-shape of $e^+e^- \to \pi^+\pi^-\ \psi(3770)$?







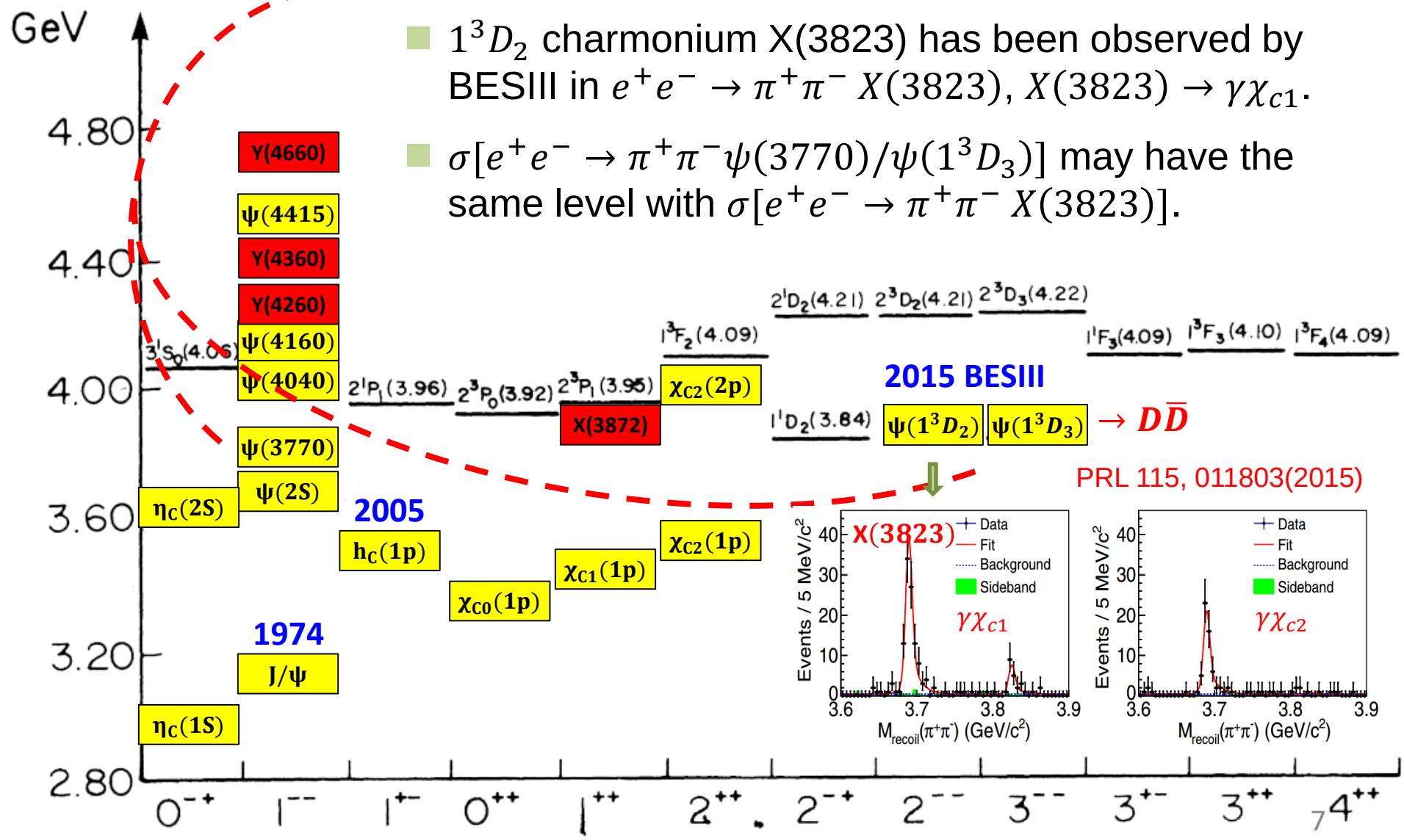




Motivation

D-wave triplet

- 1^3D_2 charmonium X(3823) has been observed by BESIII in $e^+e^- \to \pi^+\pi^- X(3823), X(3823) \to \gamma\chi_{c1}$.
- $\sigma[e^+e^- \to \pi^+\pi^-\psi(3770)/\psi(1^3D_3)]$ may have the same level with $\sigma[e^+e^- \to \pi^+\pi^- X(3823)]$.



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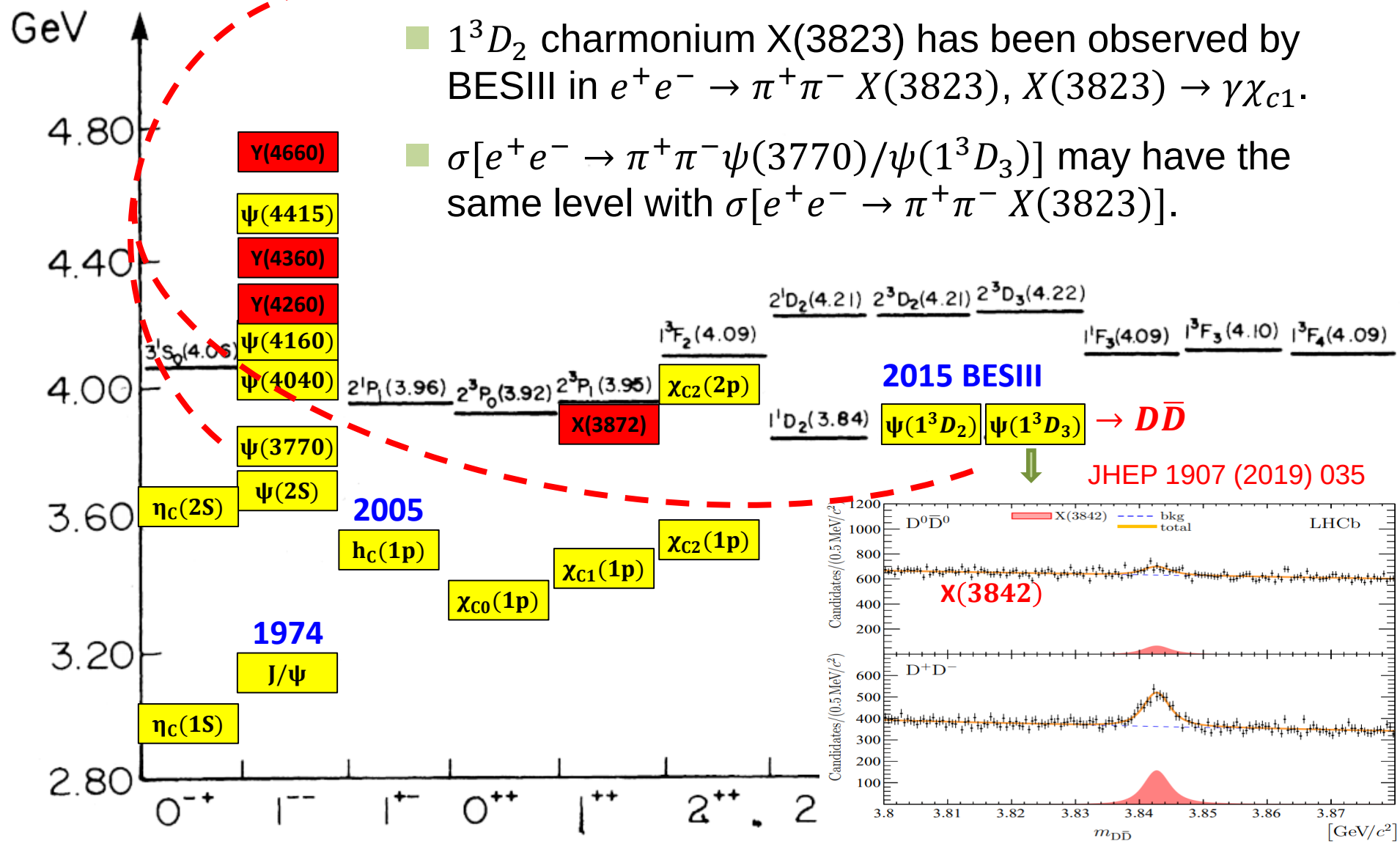
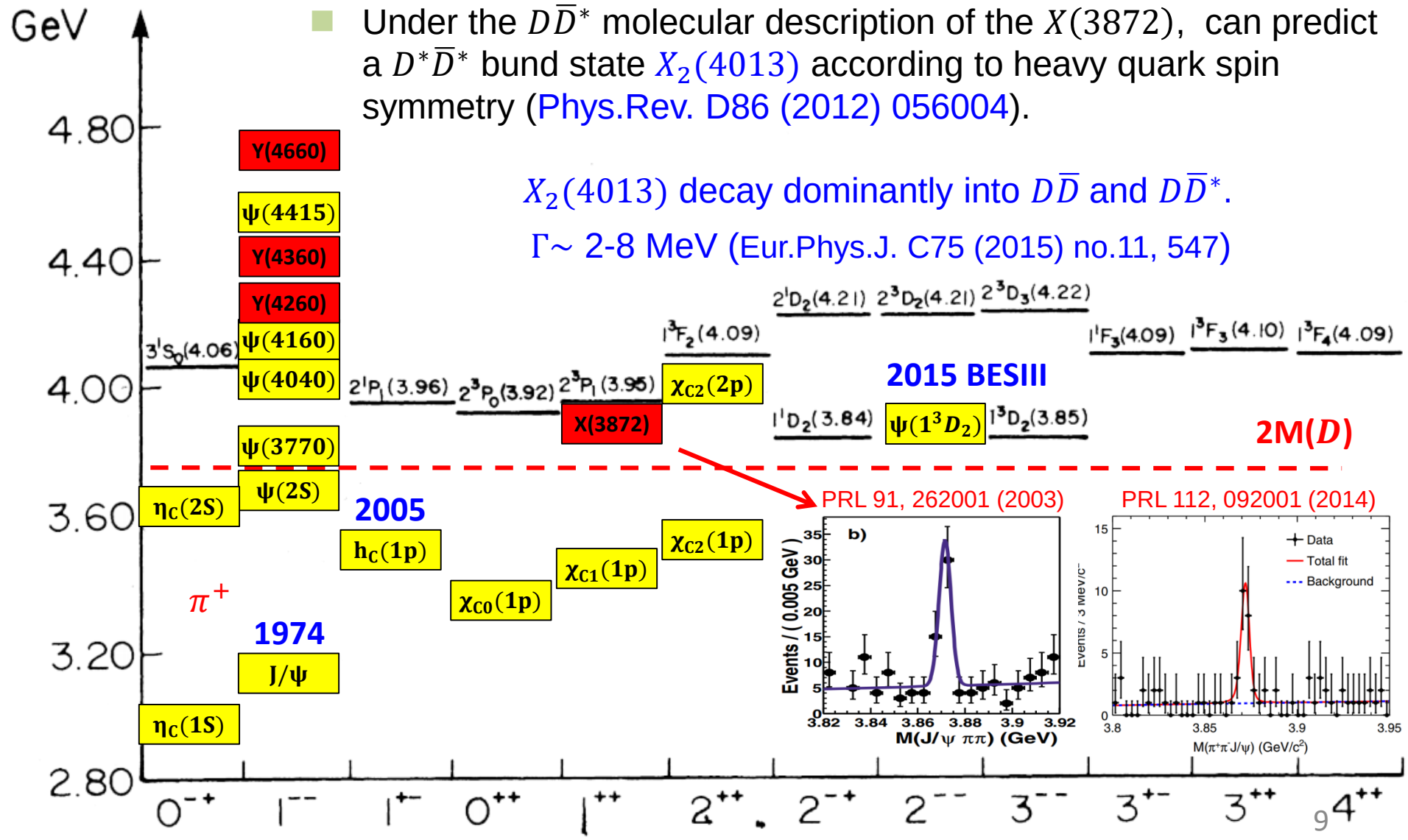


Motivation

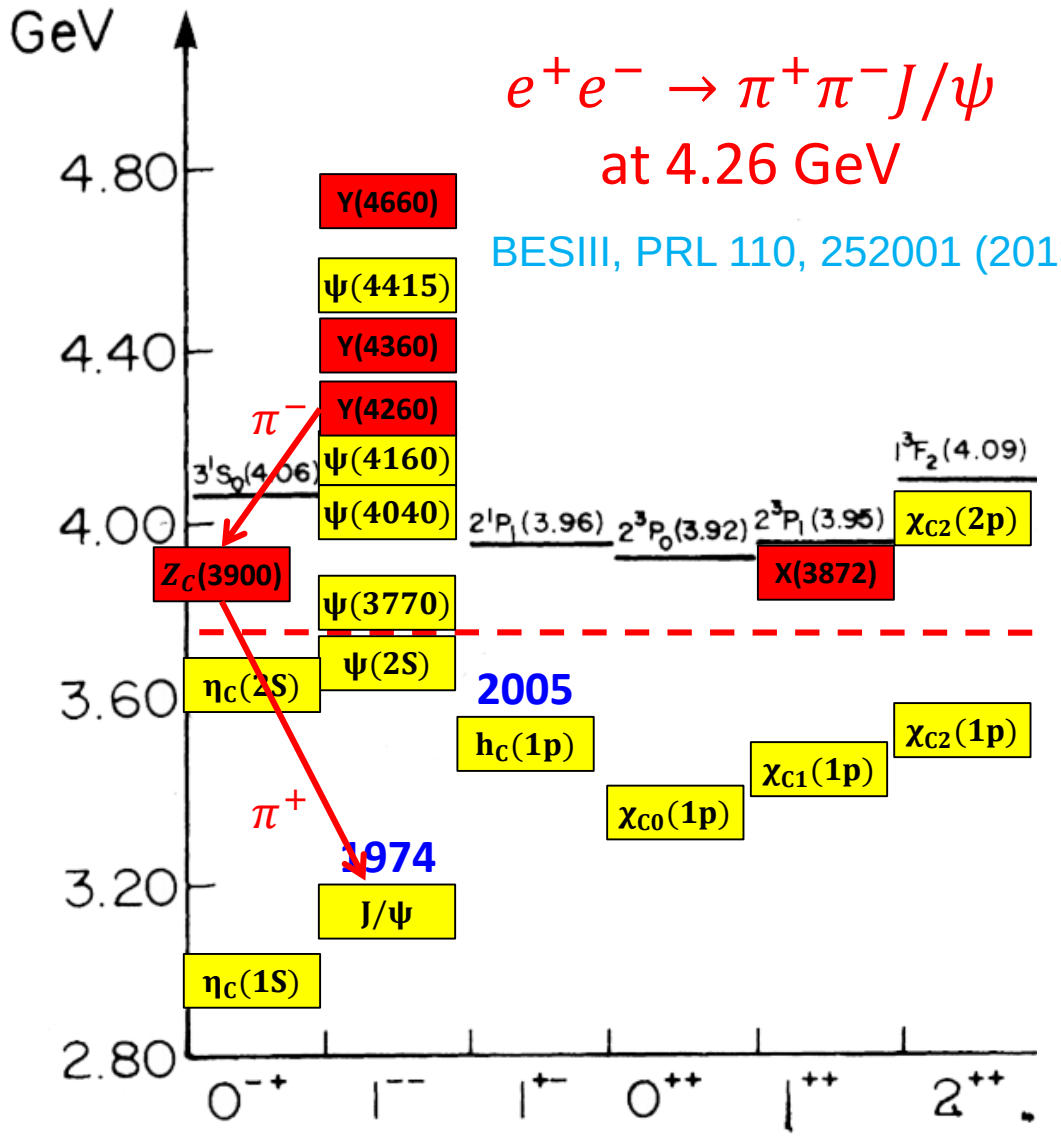
- $X(3872)$: First charmonium-like states been observed.
- Under the $D\bar{D}^*$ molecular description of the $X(3872)$, can predict a $D^*\bar{D}^*$ bund state $X_2(4013)$ according to heavy quark spin symmetry (Phys.Rev. D86 (2012) 056004).

$X_2(4013)$ decay dominantly into $D\bar{D}$ and $D\bar{D}^*$.

$\Gamma\sim$ 2-8 MeV (Eur.Phys.J. C75 (2015) no.11, 547)



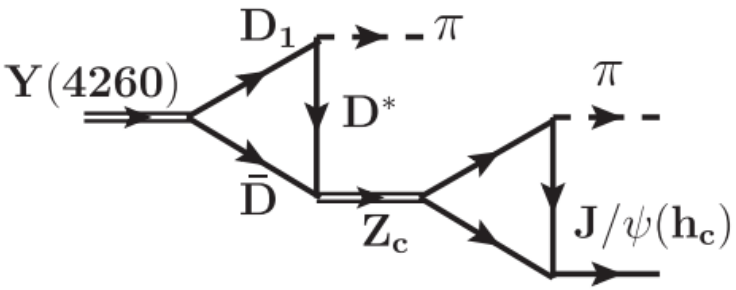
Motivation



$e^+e^- \to \pi^+\pi^- J/\psi$ at 4.26 GeV

BESIII, PRL 110, 252001 (2013)

PRL 111, 132003 (2013)



- Some theories suggest that the Y(4260) is a $\bar{D}D_1$ molecule.
- This interpretation can accommodate nearly all the present observations for Y(4260). Such as its absence in various open charm decay channels and the observation of $Z_c(3900)$ in $Y(4260) \to \pi^+\pi^- J/\psi$.

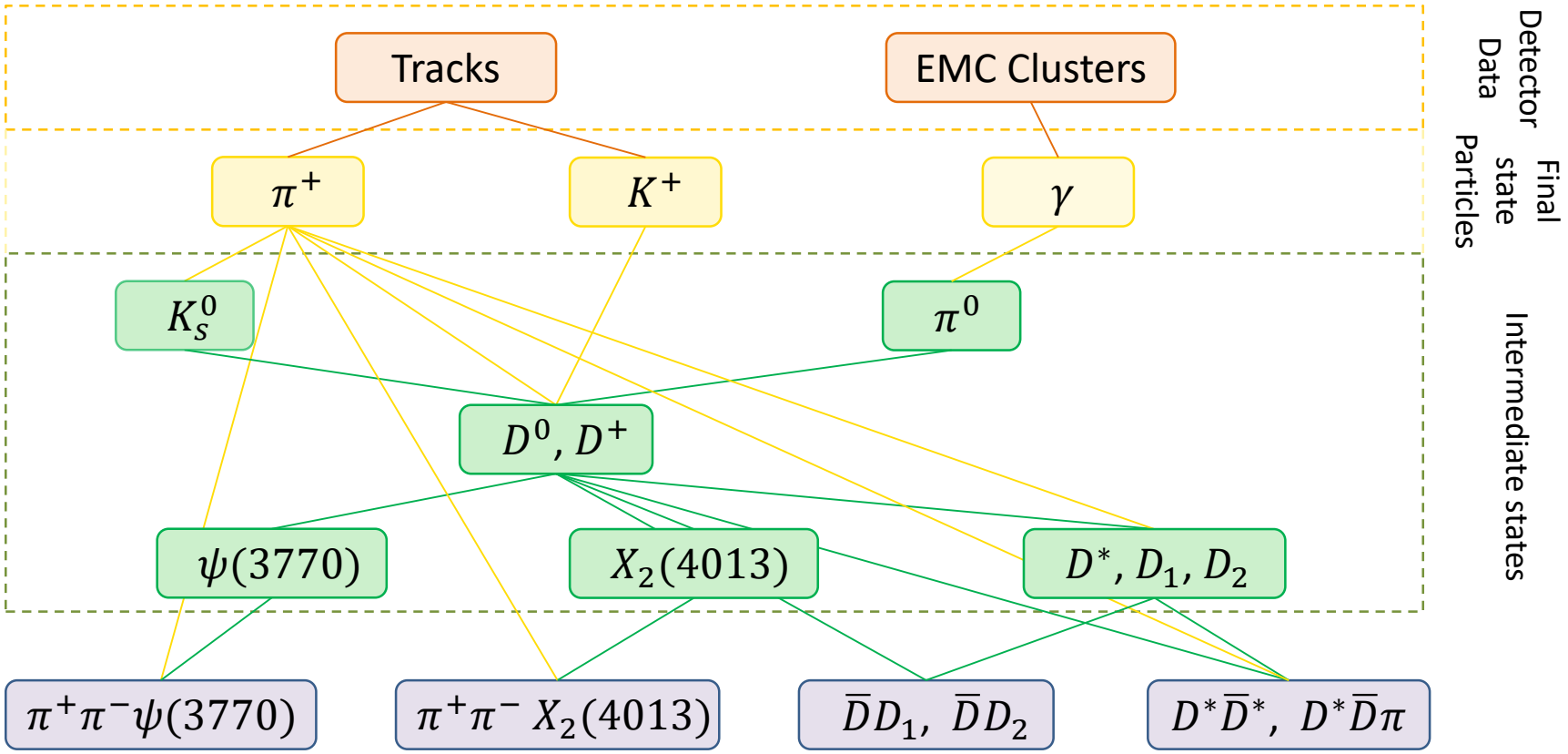
Analysis strategy

- Data samples:
  - 16 energy points from $\sqrt{s}$ = 4.09 to 4.60 GeV.
  - The total integrated luminosity is 5 fb^{-1} .
- Full reconstruction to suppress the backgrounds, tag D and $\bar{D}$, extra π^+ and π^-.
- Combine the final states $\pi^+\pi^- D\bar{D}$ to get the intermediate states.
  - $e^+e^- \to \pi^+\pi^-\psi(3770)/\psi(1^3D_3) \to \pi^+\pi^- D\bar{D}$
  - $e^+e^- \to \pi^+\pi^- X(4013) \to \pi^+\pi^- D\bar{D}$
  - $e^+e^- \to \bar{D}D_1 \to \pi^+\pi^- D\bar{D}$

D^0channel	D^+channel
$K^-\pi^+$	$K^-\pi^+\pi^+$
$K^-\pi^+\pi^0$	$K^-\pi^+\pi^+\pi^0$
$K^-\pi^+\pi^+\pi^-$	$K_S^0\pi^+$
$K^-\pi^+\pi^+\pi^-\pi^0$	$K_S^0\pi^+\pi^0$
	$K_S^0\pi^+\pi^-\pi^+$

Analysis strategy

- The topology of $e^+e^- \to \pi^+\pi^- D\bar{D}$:



Event selection:

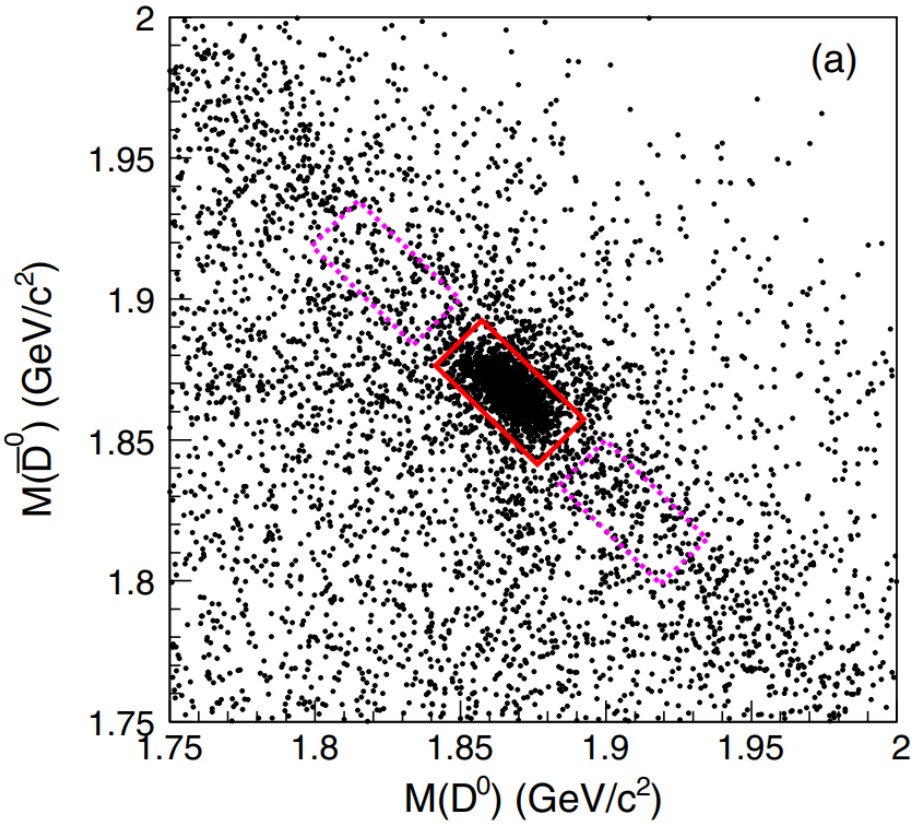
- ✓ **Charged tracks**
  - |Rxy|<1cm, |Rz|<10cm, |cos θ|<0.93
- ✓ **Good photon**
  - E > 25 MeV for | cosθ| < 0.8; E > 50 MeV for 0.86<| cos θ |<0.92
  - 0≤T≤14(1=50ns)
- ✓ **Particle identification**
  - π: Prob(π)>Prob(K)
  - K: Prob(K)>Prob(π)
- ✓ $\boldsymbol{D\bar{D}}$ **:**
  - Find D pair candidate with average mass closest to the PDG value of D mass in each mode.
- ✓ $\boldsymbol{\pi^+\pi^-}$ **out of** $\boldsymbol{D\bar{D}}$ **:**
  - $\mathrm{n}(\pi^+) = n(\pi^-) = 1$
- ✓ **Kinematic fit(4C/5C/6C)**
  - π^0 and K_S^0 mass constrain applied if needed, mode with minimum χ^2 in each event is selected.

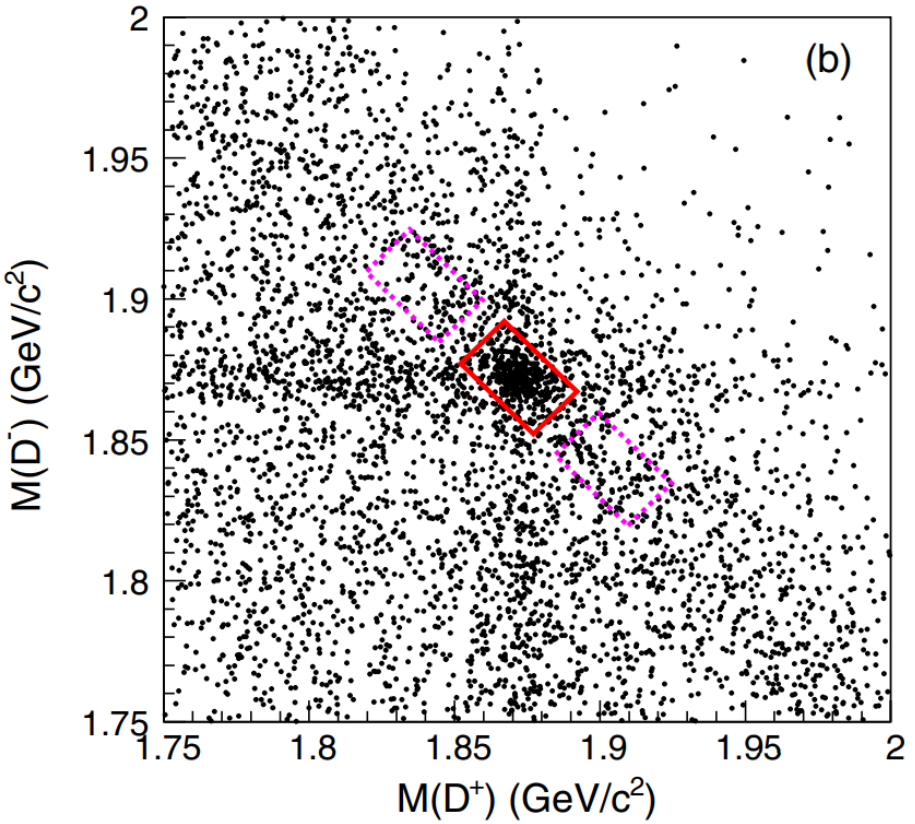
Event selection:

- Reject non-DDbar background,

Neutral mode: $-6 < \Delta\widehat{M} < 10\ \mathrm{MeV}, |\Delta M| < 35\ \mathrm{MeV}$

Charged mode: $-5 < \Delta\widehat{M} < 10\ \mathrm{MeV}, |\Delta M| < 25\ \mathrm{MeV}$

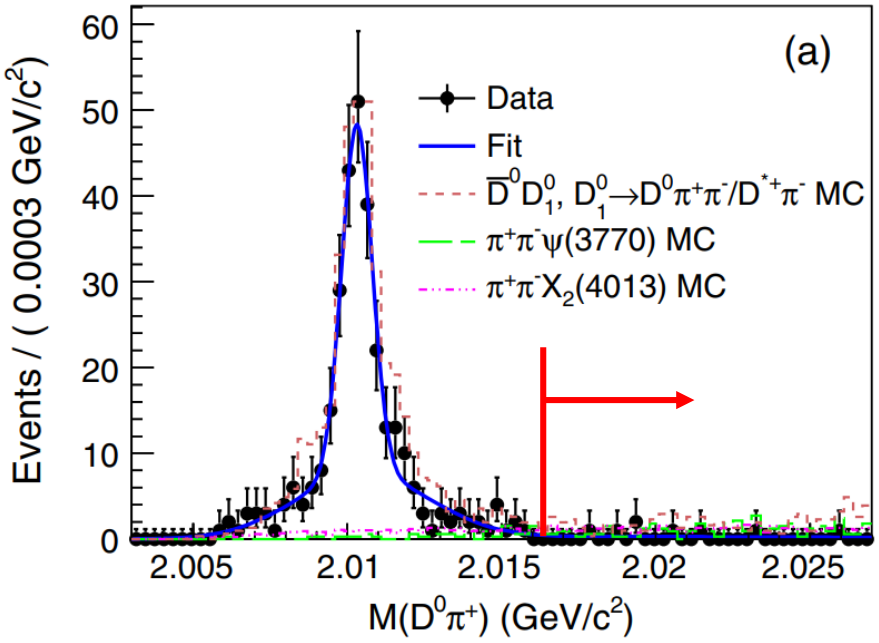


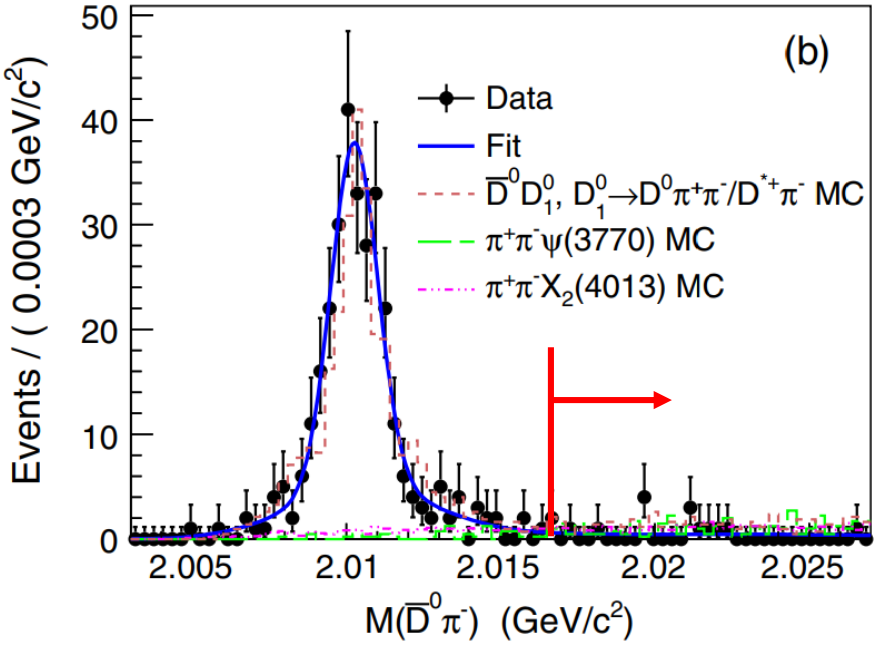


Event selection:

- For $\pi^+\pi^-\psi(3770)$, $\psi(3770) \to D^0\bar{D}^0$、 $\pi^+\pi^- X_2(4013)$, $X_2(4013) \to D^0\bar{D}^0$ and $\bar{D}^0 D_1^0$, $D_1^0 \to D^0\pi^+\pi^-$, reject the background contain D*:

$$M(D^0\pi^+) - M(D^0) + M(D^0)_{PDG} > 2.017\text{GeV}$$
$$M(\bar{D}^0\pi^-) - M(\bar{D}^0) + M(D^0)_{PDG} > 2.017\text{GeV}$$

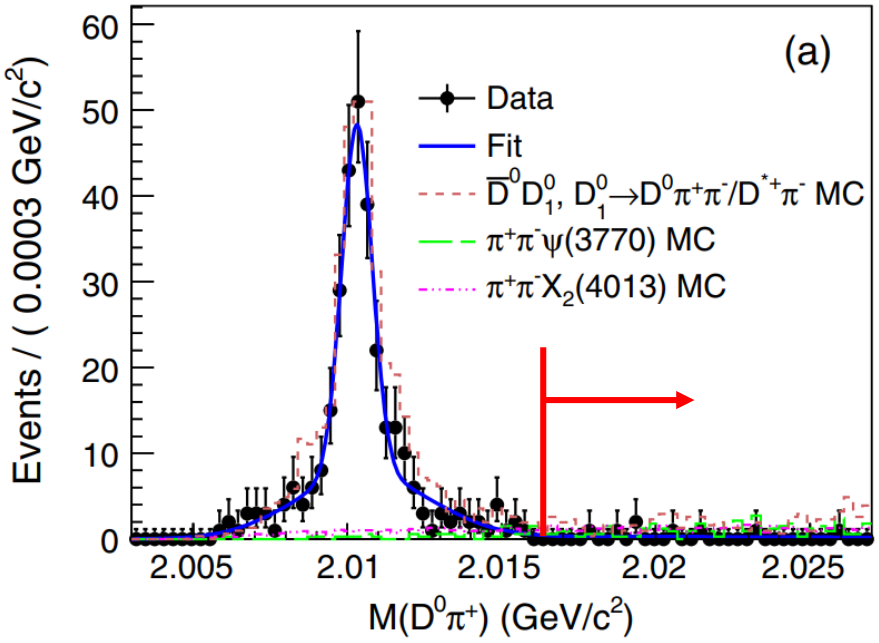


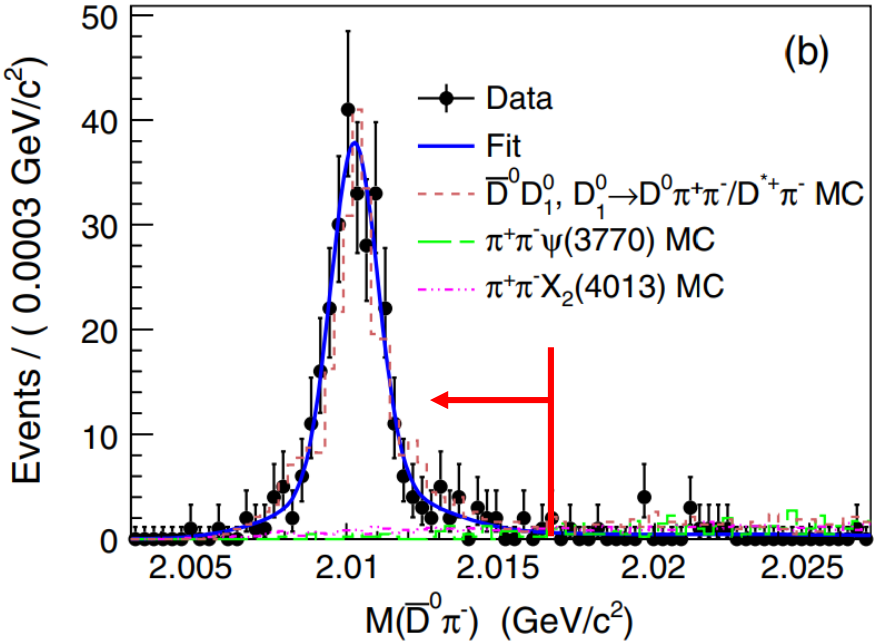


Event selection:

- For $e^+e^- \to \bar{D}^0 D_1^0$, $D_1^0 \to D^{*+}\pi^-$, keep one D^*:

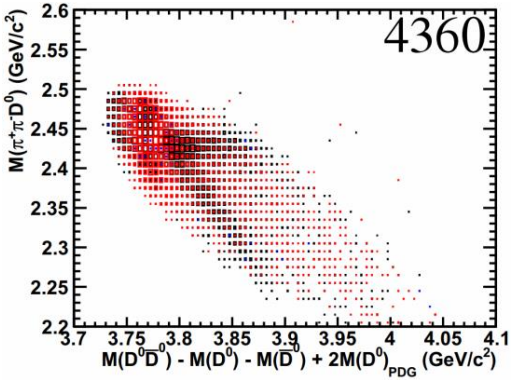
$$M(D^0\pi^+) - M(D^0) + M(D^0)_{PDG} > 2.017\text{GeV}$$
$$M(\bar{D}^0\pi^-) - M(\bar{D}^0) + M(D^0)_{PDG} < 2.017\text{GeV}$$

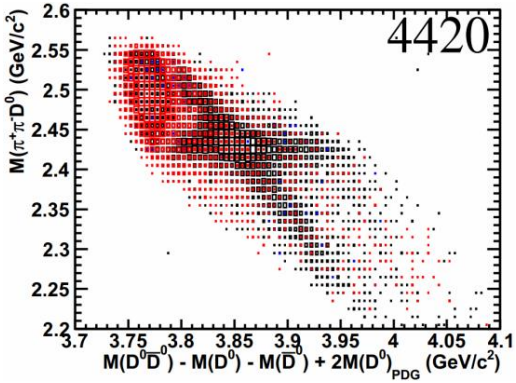


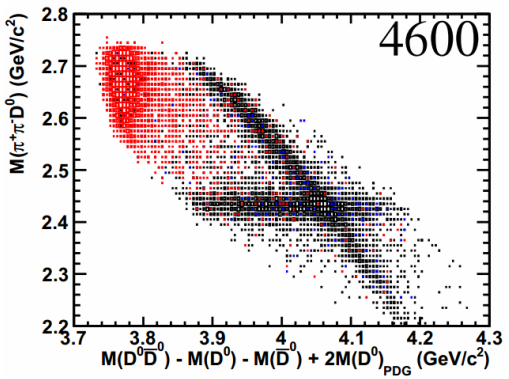


Event selection:

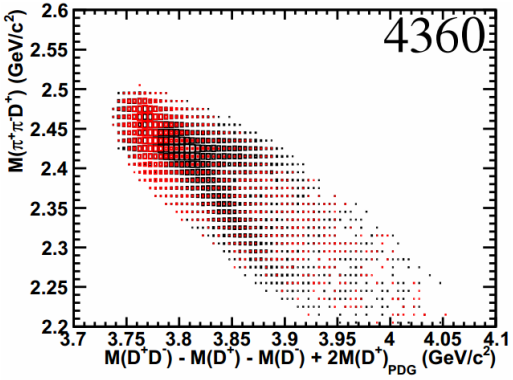
$D^0\bar{D}^0$

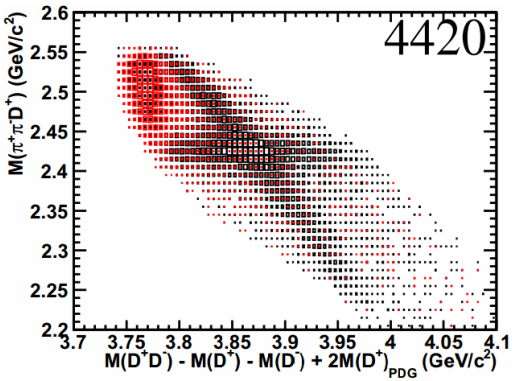


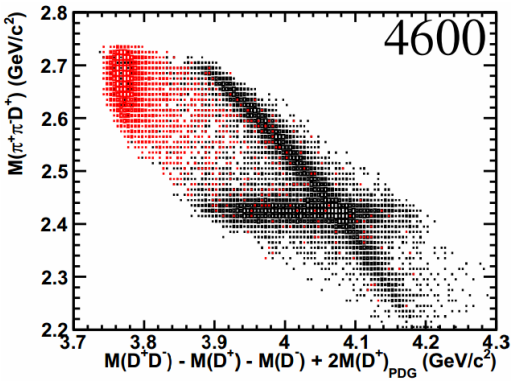




D^+D^-



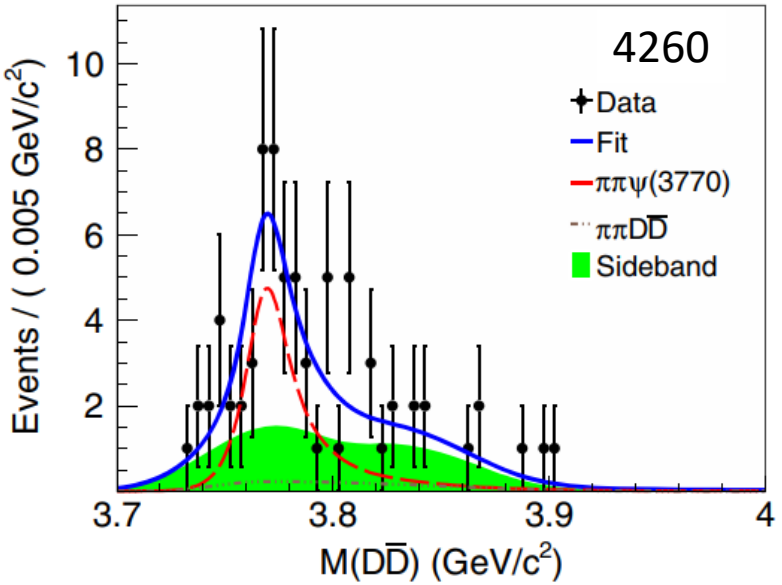


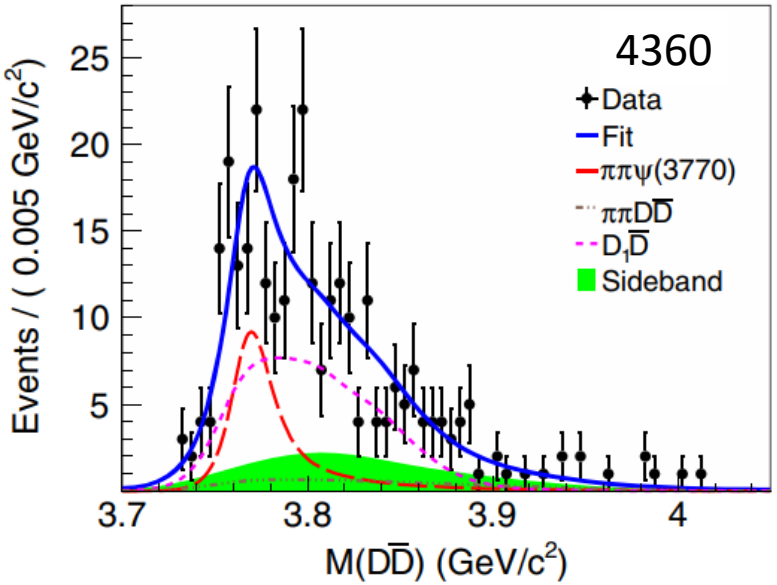


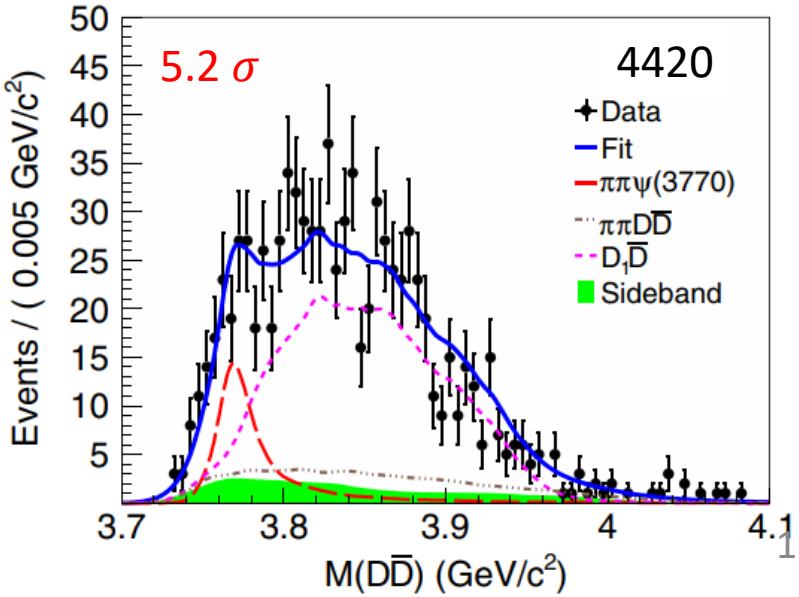
- At high energy region
  - For $e^+e^- \to \pi^+\pi^-\psi(3770)$, the $\bar{D}D_1$ backgrounds can be suppressed by: $M(D\pi^+\pi^-) > 2.45$ GeV
  - For $e^+e^- \to \bar{D}D_1$, the $\pi^+\pi^-\psi(3770)$ backgrounds can be suppressed by : $M(D^0\bar{D}^0) > 3.8$ GeV

$e^+e^- \to \pi^+\pi^-\psi(3770)$

- Clear $\psi(3770)$ signal in the invariant mass distribution of $D\bar{D}$.
- No $\psi(1^3D_3)$ signal.



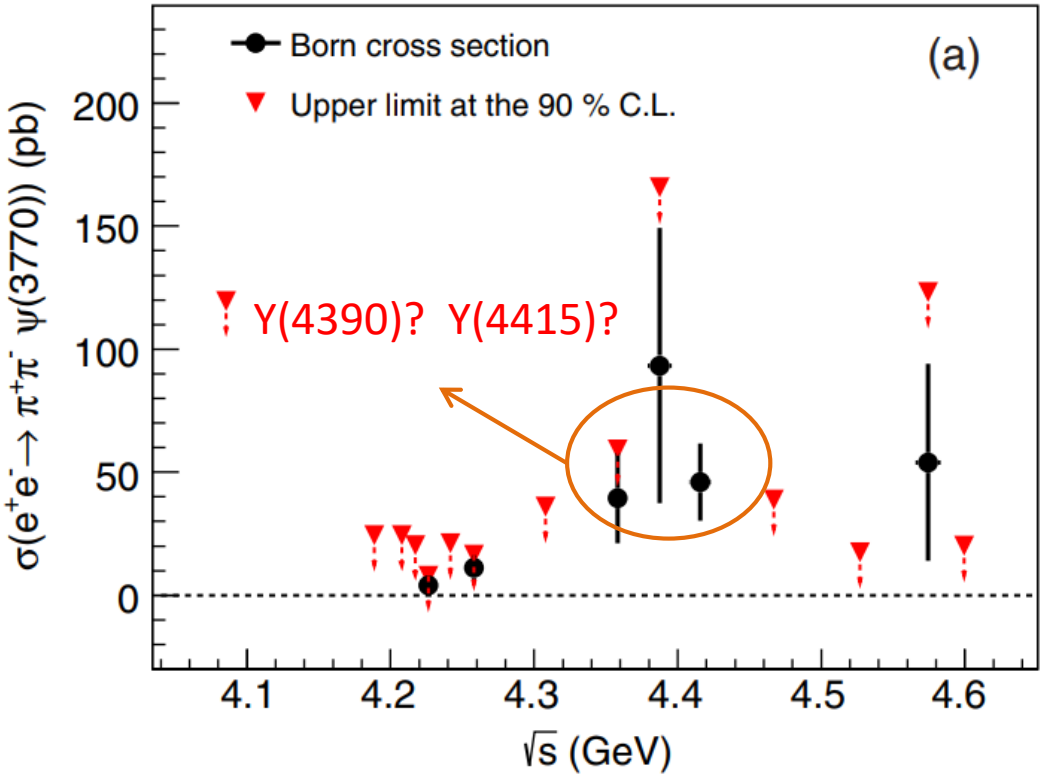




$e^+e^- \to \pi^+\pi^-\psi(3770)$

- Cross section measurement

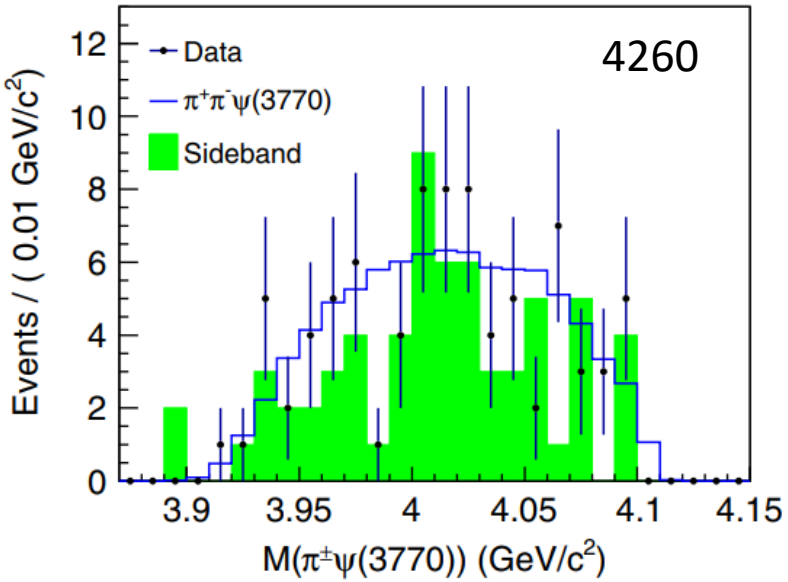
$$\sigma^B = \frac{N^{\rm obs}}{\mathcal{L}_{\rm int}(1+\delta^r)(1+\delta^v)(\mathcal{B}_{\psi(3770)\to D^0\bar{D}^0}\sum_{i,j}\epsilon_{i,j}\mathcal{B}_i\mathcal{B}_j + \mathcal{B}_{\psi(3770)\to D^+D^-}\sum_{k,l}\epsilon_{k,l}\mathcal{B}_k\mathcal{B}_l)}$$

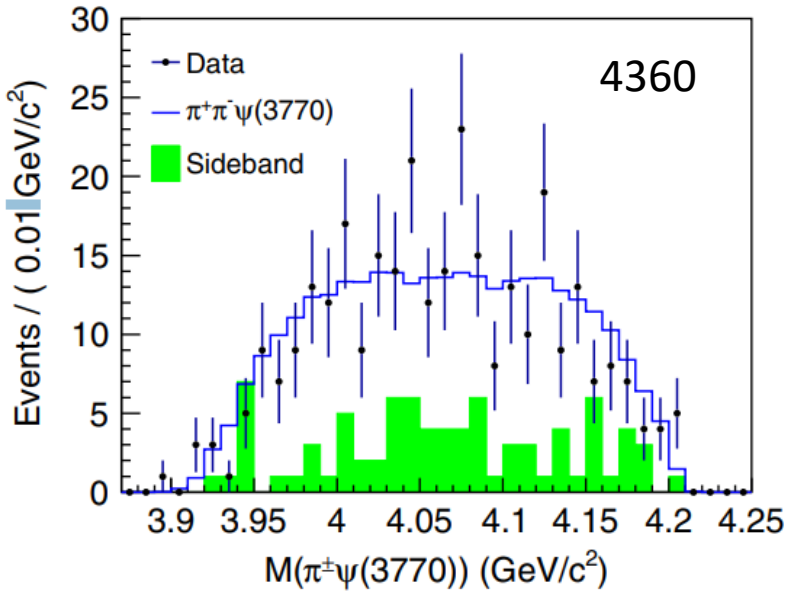


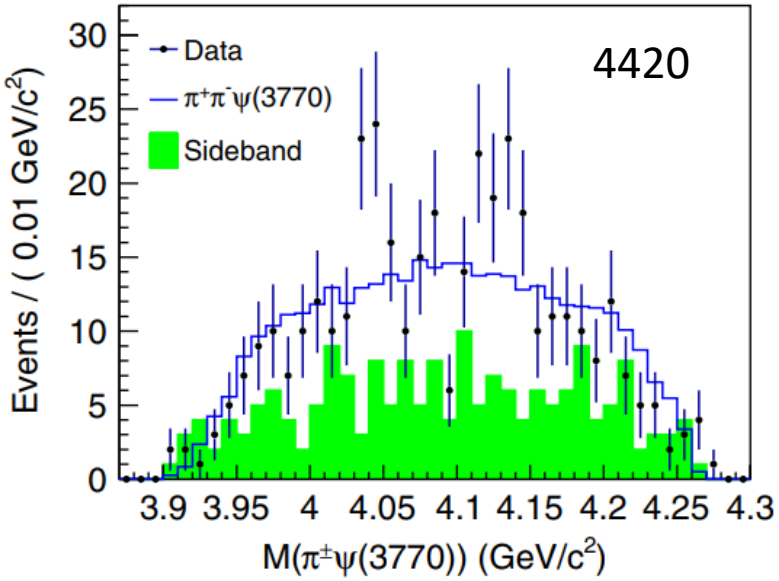
- Clear structure in the line-shape of $\pi^+\pi^-\psi(3770)$.

$e^+e^- \to \pi^+\pi^-\psi(3770)$

- No significant signal of Z_c was observed in the $\pi^{\pm}\psi(3770)$ system.
- But the date couldn't described well by pure $\pi^+\pi^-\psi(3770)$ and sidebands.

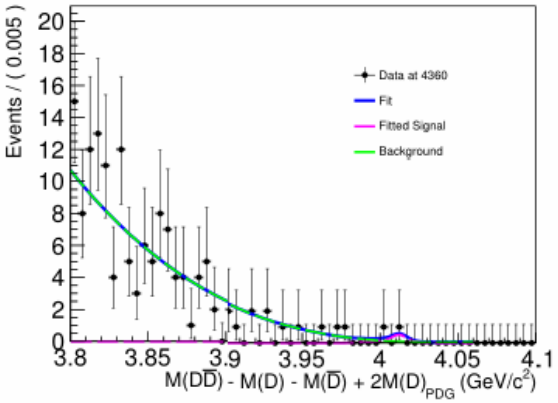


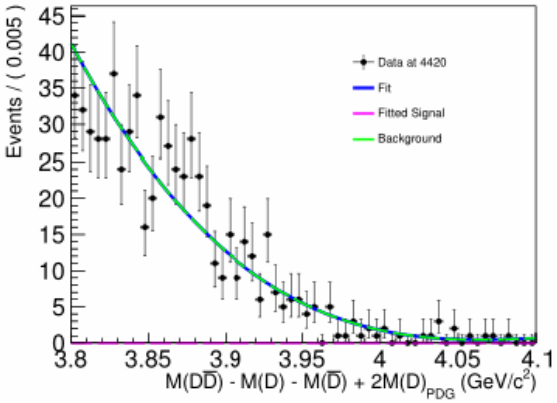


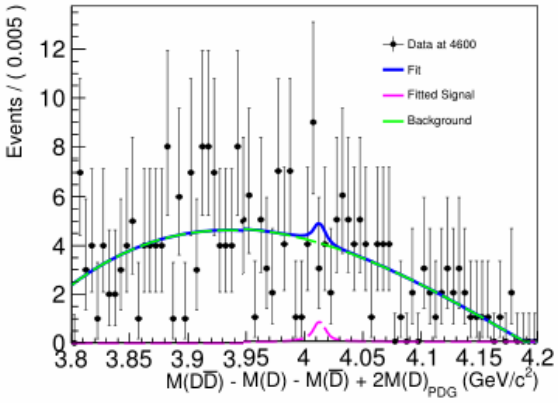


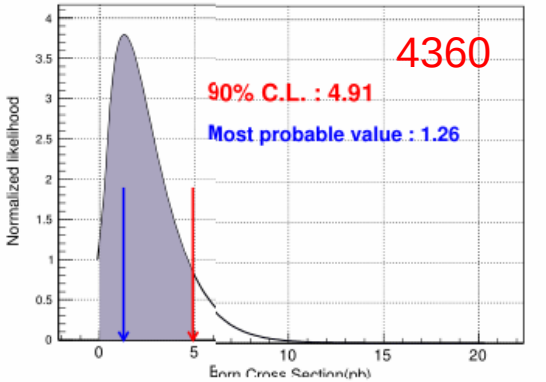
$e^+e^- \to \pi^+\pi^- X_2(4013)$

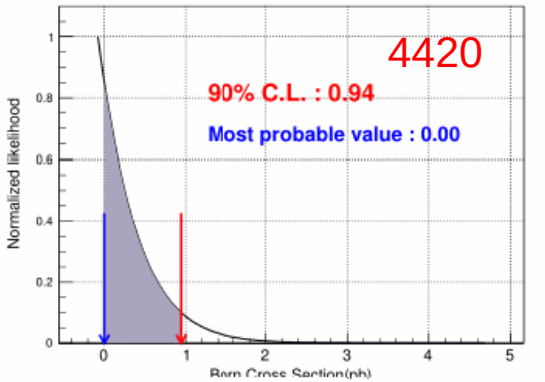
- No significant signal of $X_2(4013)$ was observed in the $D\bar{D}$ inviariant distribution.
- Maybe we can search for this process at higher energy region.
- Also we can search for $X_2(4013)$ via $e^+e^- \to \gamma X_2(4013)$.

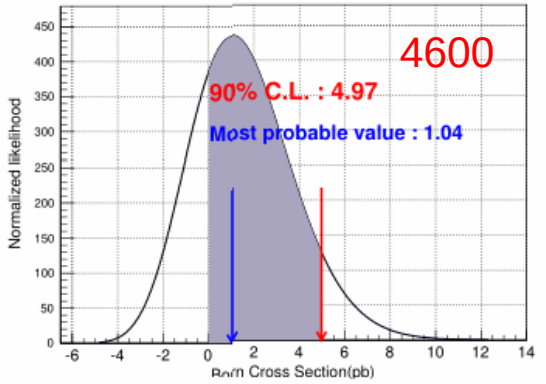








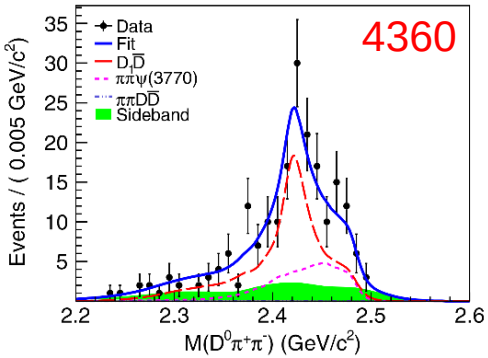


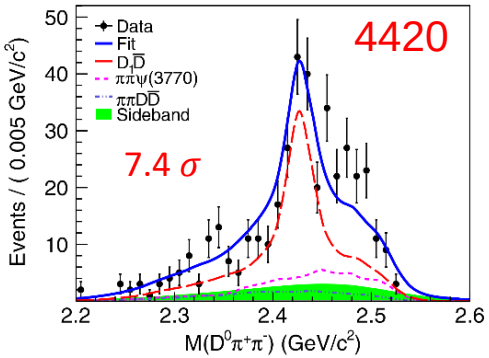


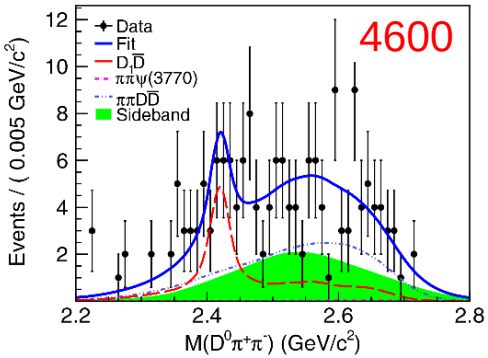
$e^+e^- \to \bar{D}D_1$

- Observed the process $e^+e^- \to \bar{D}^0 D_1(2420)^0$.

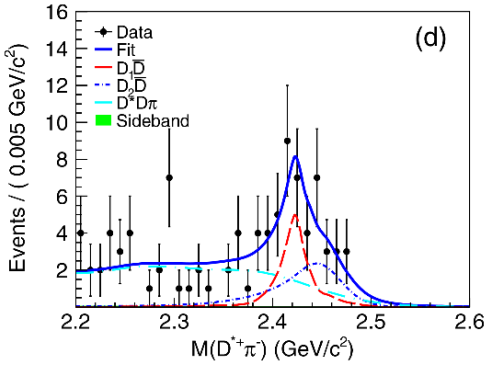
$D_1^0 \to D^0\pi^+\pi^-$

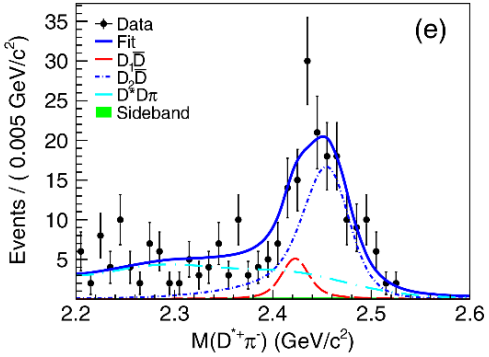


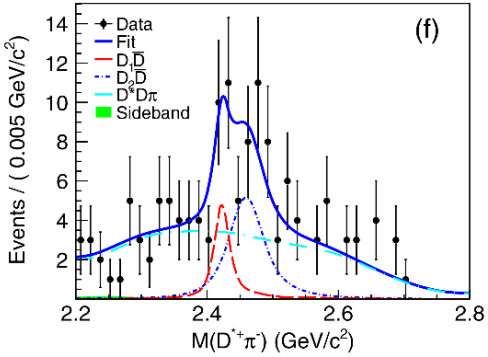




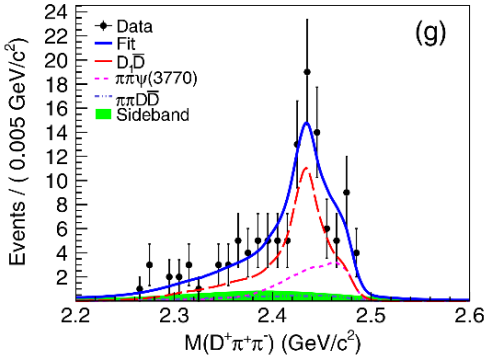
$D_1^0 \to D^{*+}\pi^-$

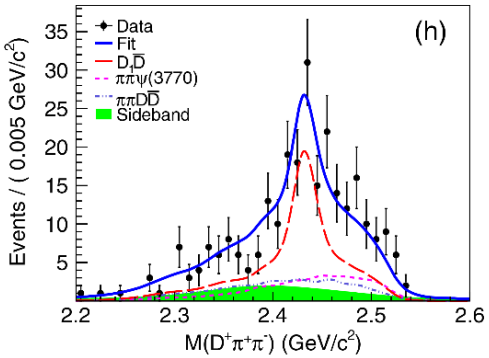


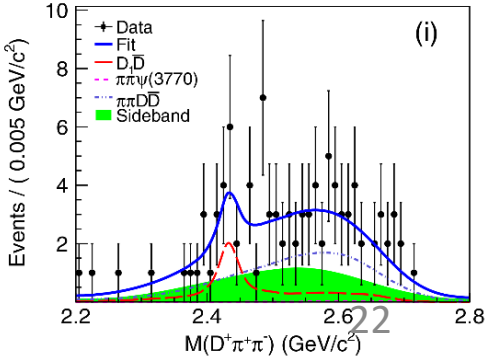




$D_1^+ \to D^+\pi^+\pi^-$



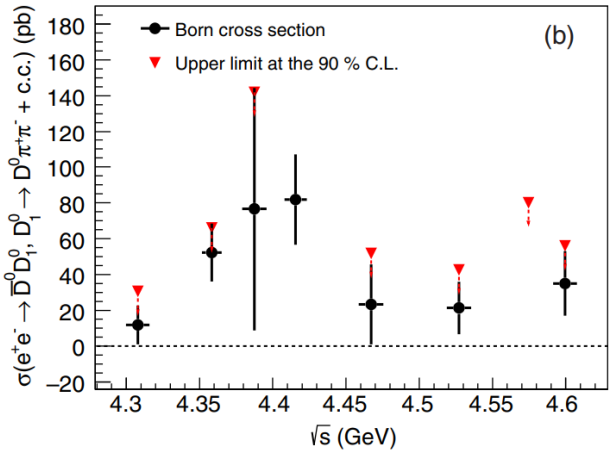




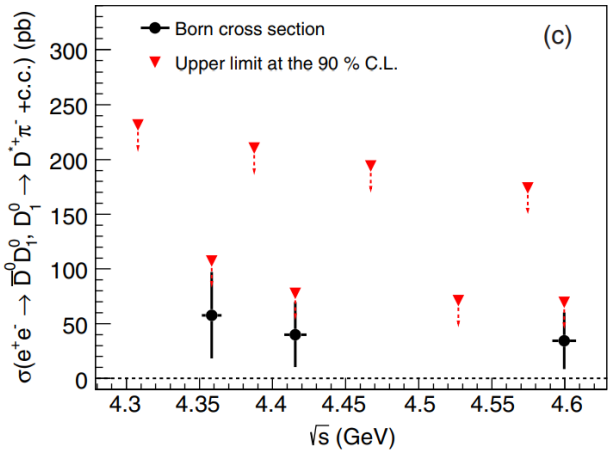
$e^+e^- \to \bar{D}D_1$

- Cross section measurement

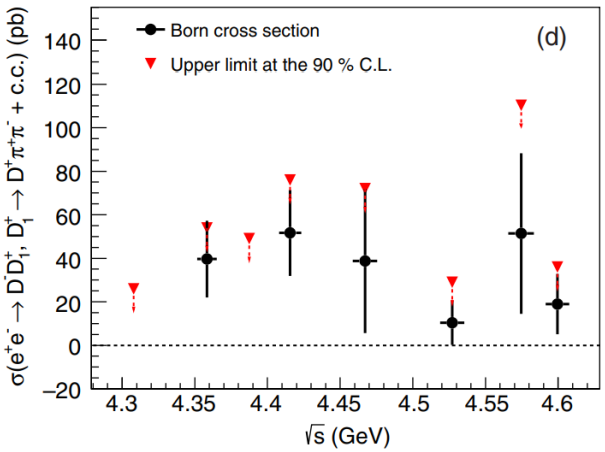
$$\sigma^B \times \mathcal{B}_{D_1(2420)\to X} = \frac{N^{\rm obs}}{\mathcal{L}_{\rm int}(1+\delta^r)(1+\delta^v)\sum_{i,j}\epsilon_{i,j}\mathcal{B}_i\mathcal{B}_j}$$



$D_1^0 \to D^0\pi^+\pi^-$



$D_1^0 \to D^{*+}\pi^-$



$D_1^+ \to D^+\pi^+\pi^-$

- Clear structure in the line-shape of $e^+e^- \to \bar{D}D_1$.

Summary

- The process $e^+e^- \to \pi^+\pi^-\psi(3770)$ was observed with significance 5.2 $\boldsymbol{\sigma}$.
- The process $e^+e^- \to \bar{D}D_1$ was observed with significance 7.4 $\boldsymbol{\sigma}$.
- No obvious Z_c signal was observed.
- No $\psi(1^3D_3)$ signal was observed.
- $X_2(4013)$ was searched via $e^+e^- \to \pi^+\pi^-X_2(4013)$, no obvious signal.

More data above 4.0 GeV at BESIII may help us to search for $\psi(1^3D_3)$ state, possible Z_c states in $\pi^\pm\psi(3770)$ system, possible Y states in the lines shape of $\pi^+\pi^-\psi(3770)$ and $\bar{D}D_1$.

Thanks for your attention.