X,Y,Z at Hadron Colliders

Wenbin Qian

LAPP, Annecy-le-vieux
IN2P3-CNRS et Université de Savoie

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X,Y,Z States

Recently, discoveries or evidences have been made in the well understood charmonium system and new resonance structures found are noted as *X, Y, Z* to indicate their unknown nature

- ☛ **Many models exist:**
  - ➢ **Tetra-quark: Tightly bound four quarks**
  - ➢ **Molecular state: Loosely bound mesons**
  - ➢ **Charmonium hybrids: charmonium states with an excited gluonic degree of freedom**
  - ➢ **Threshold effects**
- ☛ **Focus on current results of X(3872), X(4140), X(4300) and Z(4430) (better access through hadron machines, others see talk by R. Mizuk)**

State	m (MeV)	Γ (MeV)	J^{PC}	Process (mode)	Experiment (#σ)	Year	Status
X(3872)	3871.52±0.20	1.3±0.6	$1^{++}/2^{-+}$	$B \to K(\pi^+\pi^- J/\psi)$	Belle , BABAR	2003	OK
		(<2.2)		$p\bar{p} \to (\pi^+\pi^- J/\psi) + ...$	CDF, DØ		
				$B \to K(\omega J/\psi)$	Belle BABAR		
				$B \to K(D^{*0}\bar{D}^0)$	Belle, BABAR		
				$B \to K(\gamma J/\psi)$	Belle, BABAR		
				$B \to K(\gamma\psi(2S))$	BABAR, Belle		
$X(3915)$	3915.6 ± 3.1	28±10	$0/2^{?+}$	$B \to K(\omega J/\psi)$	Belle, BABAR	2004	OK
				$e^+e^- \to e^+e^-(\omega J/\psi)$	Belle		
X(3940)	3942^{+9}_{-8}	37^{+27}_{-17}	$?^{?+}$	$e^+e^- \to J/\psi(DD^*)$	Belle	2007	NC!
				$e^+e^- \to J/\psi\ (...)$	Belle		
$G(3900)$	3943 ± 21	52±11	1^{--}	$e^+e^- \to \gamma(D\bar{D})$	BABAR, Belle	2007	OK
$Y(4008)$	4008^{+121}_{-49}	226±97	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^- J/\psi)$	Belle	2007	NC!
$Z_1(4050)^+$	4051^{+24}_{-43}	82^{+51}_{-55}	?	$B \to K(\pi^+\chi_{c1}(1P))$	Belle	2008	NC!
X(4140)	4143.4 ± 3.0	15^{+11}_{-7}	$?^{?+}$	$B \to K(\phi J/\psi)$	CDF	2009	NC!
$X(4160)$	4156^{+29}_{-25}	139^{+113}_{-65}	$?^{?+}$	$e^+e^- \to J/\psi(D\bar{D}^*)$	Belle	2007	NC!
$Z_2(4250)^+$	4248^{+185}_{-45}	177^{+321}_{-72}	?	$B \to K(\pi^+\chi_{c1}(1P))$	Belle	2008	NC!
$Y(4260)$	4263 ± 5	108±14	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^- J/\psi)$	BABAR	2005	OK
					CLEO		
					Belle		
				$e^+e^- \to (\pi^+\pi^- J/\psi)$	CLEO		
				$e^+e^- \to (\pi^0\pi^0 J/\psi)$	CLEO		
X(4300)	$4274.4^{+8.4}_{-6.7}$	32^{+22}_{-15}	$?^{?+}$	$B \to K(\phi J/\psi)$	CDF	2010	NC!
$X(4350)$	$4350.6^{+4.6}_{-5.1}$	$13.3^{+18.4}_{-10.0}$	$0,2^{++}$	$e^+e^- \to e^+e^-(\phi J/\psi)$	Belle	2009	NC!
$Y(4360)$	4353 ± 11	96±42	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^- \psi(2S))$	BABAR, Belle	2007	OK
Z(4430)	4443^{+24}_{-18}	107^{+113}_{-71}	?	$B \to K(\pi^+\psi(2S))$	Belle	2007	NC!
$X(4630)$	4634^{+9}_{-11}	92^{+41}_{-32}	1^{--}	$e^+e^- \to \gamma(\Lambda_c^+\Lambda_c^-)$	Belle	2007	NC!
$Y(4660)$	4664±12	48±15	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^- \psi(2S))$	Belle	2007	NC!
Y_b(10888)	10888.4±3.0	$30.7^{+8.9}_{-7.7}$	1^{--}	$e^+e^- \to (\pi^+\pi^- \Upsilon(nS))$	Belle	2010	NC!

"Heavy quarkonium: progress, puzzles, and opportunities", arXiv:1010.5827

Exploring Nature of X(3872)

- Discovered in 2003 by Belle (PRL 91(2003) 262001), quickly confirmed by other experiments

- Information offered by B factories:

  - Evidence of $J/\psi\gamma$ by Belle (talk at 2010 QWG workshop) and Babar (PRD 74 (2006) 071101) : C = +1; radiative decay rates prefer 1^{++} vs 2^{-+}

  - Evidence (or not) of decay $\psi(2s)\gamma$ by Babar and Belle

  - Search for charged $X(3872)^{+}$ (PRD 85, 052004)

  - Search for C = -1 X(3872) partners ($J/\psi\eta$, $X_c\gamma$)

  - Mass and width measurements

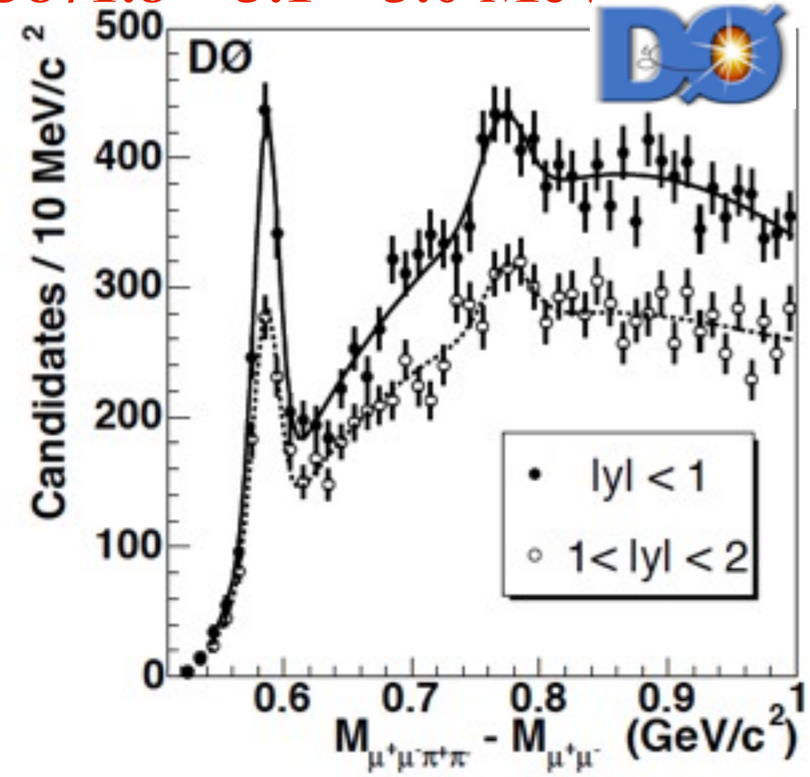
  - ......

- Three main directions to undercover its nature: mass measurement (vs $D^{*0}D^{0}$), cross section measurement, decay chain analysis (J^{PC})

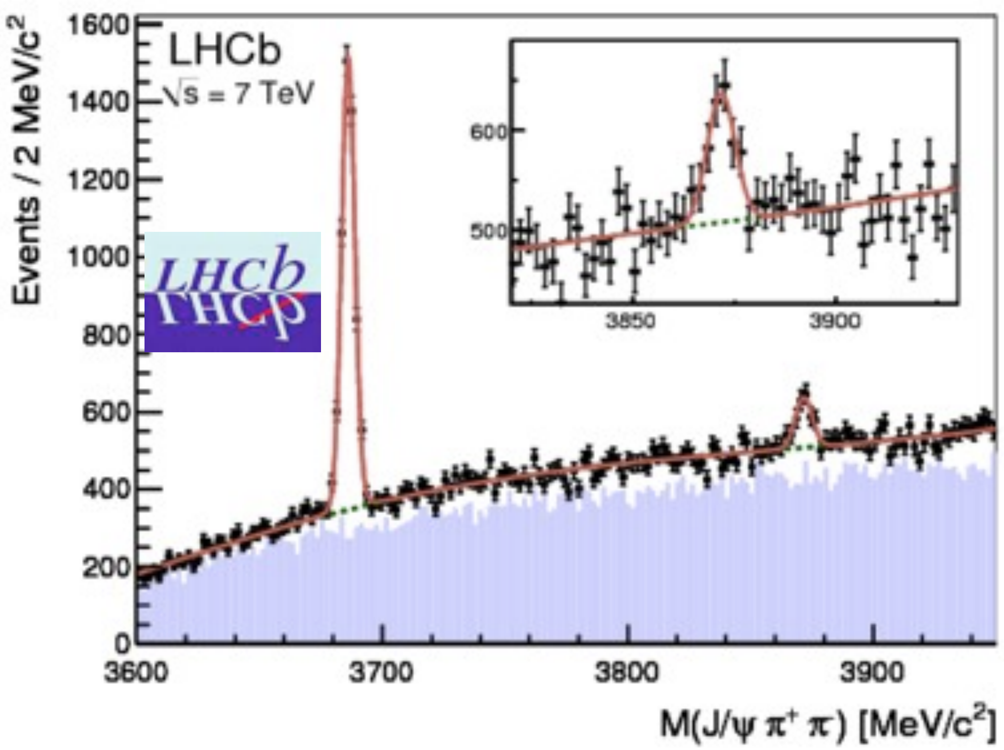
X(3872): Mass Measurement (1)

➢ In molecular state hypothesis, the mass should be below the $D^{*0}\overline{D^0}$ threshold

3871.8 ± 3.1 ± 3.0 MeV

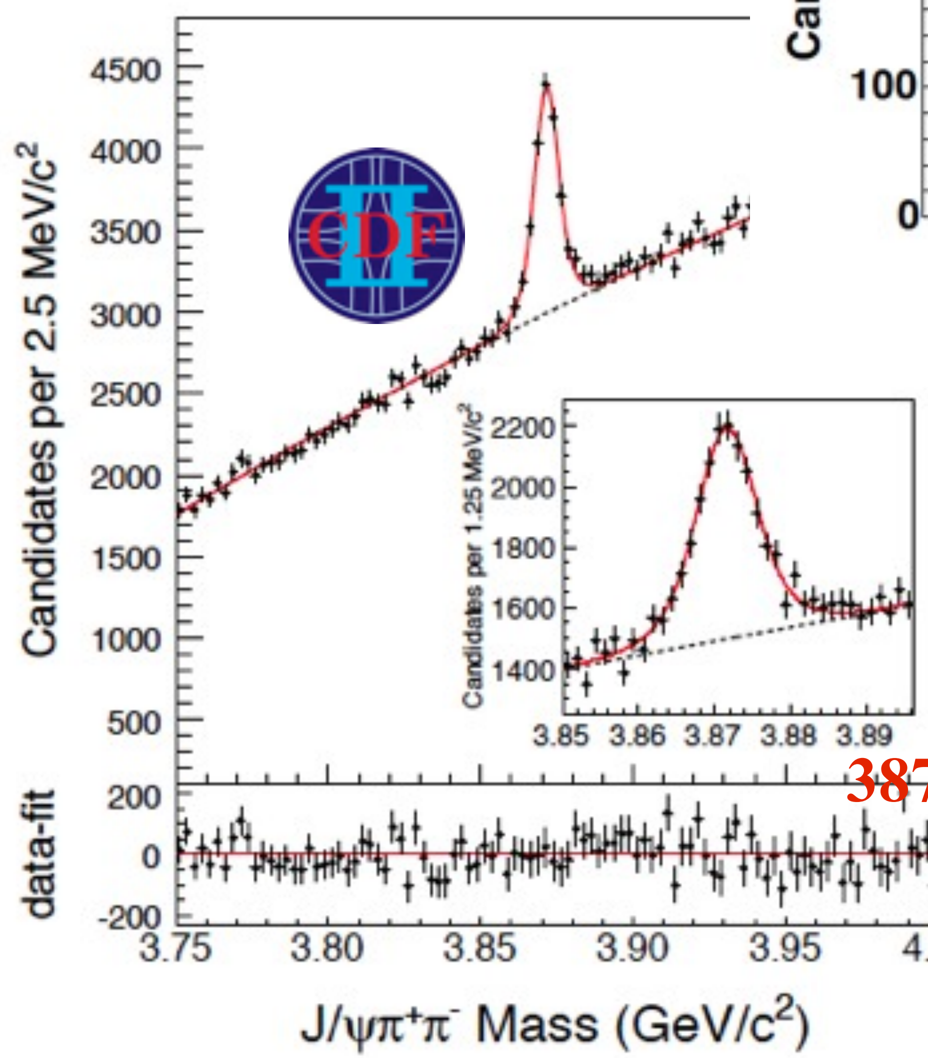


➢ Both CDF, D0 and LHCb (Belle, Babar) perform measurements on X(3872) mass using J/ψππ decay channel (with ψ(2s) for control particle)



3871.95 ± 0.48 ± 0.12 MeV

(stat) (syst)

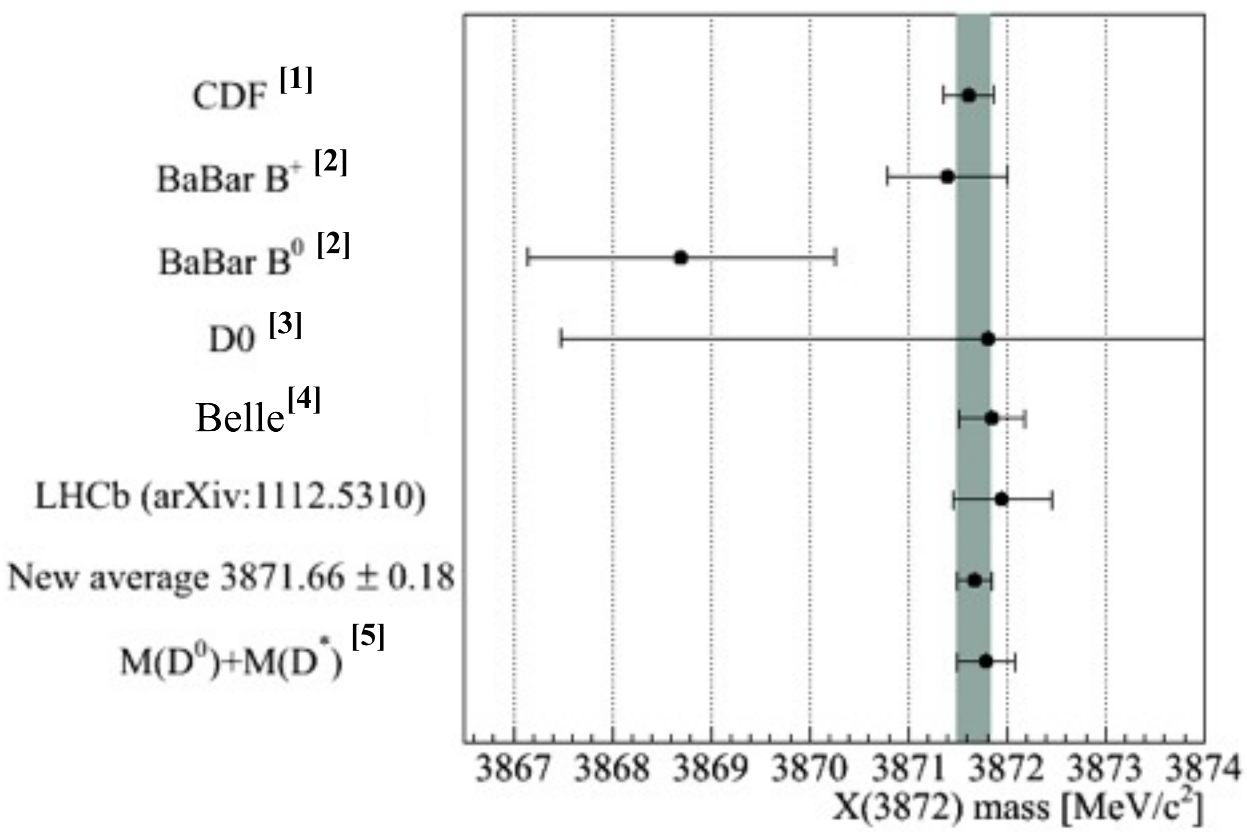


3871.61 ± 0.16 ± 0.19 MeV

[1] CDF Collaboration, Phys. Rev. Lett. 103 (2009) 152001
[2] D0 Collaboration, Phys. Rev. Lett. 93 (2004) 162002
[3] LHCb Collaboration, Eur. Phys. J. C. 72 (2012) 1972

X(3872): Mass Measurement (2)

- ➢ Current accuracy at similar level for CDF, Babar, Belle and LHCb
- ➢ "new average" : 3871.66 ± 0.18 MeV



➢More accuracy is desired to see if it is above, at, or below threshold (δm = -0.28±0.18(X(3872))±0.33(D^0) MeV)

➢ First measurement in LHCb with 37 pb^{-1} data; Further measurement with 1 fb^{-1} data ongoing to pin down the statistical error to ~0.12 MeV

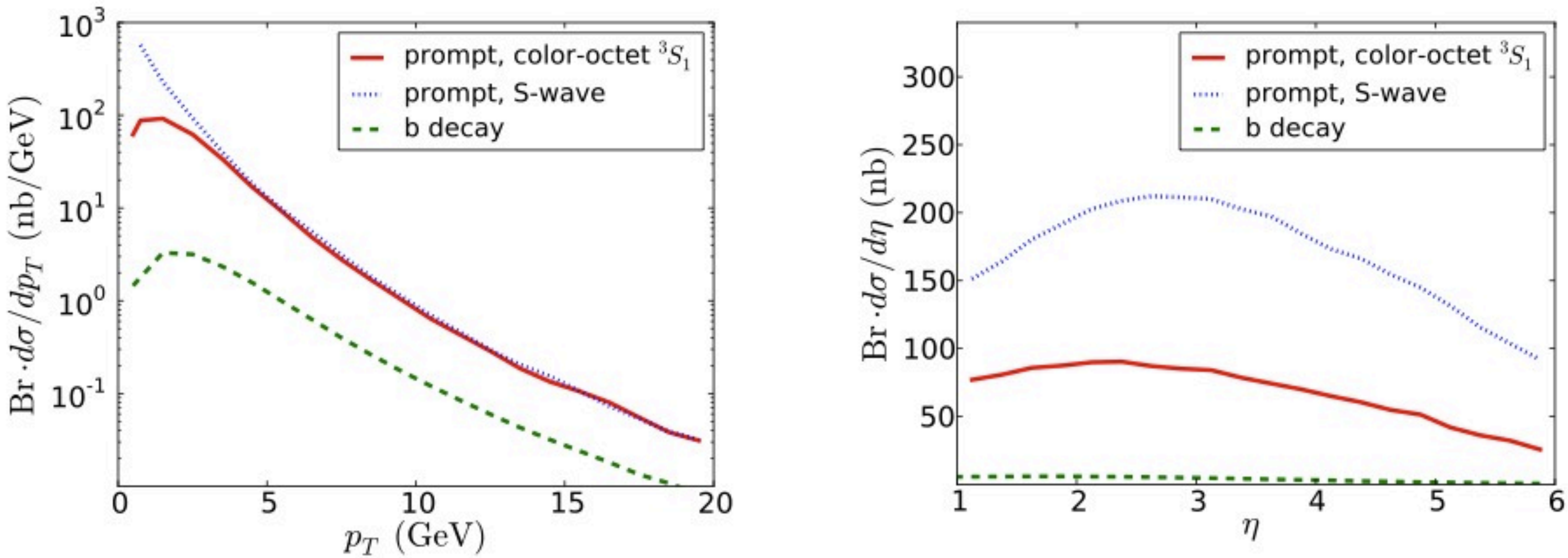
➢ More accuracy on M(D^0) and M(D^*) (M(D^*)- M(D^0) known ~0.07 MeV) also required; An update from LHCb (soon) will decrease error on average mass of M(D^0) from 0.16 MeV to 0.12 (×2) MeV

[1] CDF Collaboration, Phys. Rev. Lett. 103 (2009) 152001
[2] BABAR Collaboration, Phys. Rev. D77 (2008) 111101R
[3] D0 Collaboration, Phys. Rev. Lett. 93 (2004) 162002
[4] Belle Collaboration, Phys. Rev. D84 (2011) 052004R
[5] Particle Data Group, J. Phys. G37 (2010) 075021
[6] LHCb Collaboration, Eur. Phys. J. C. 72 (2012) 1972

X(3872) : Cross Section (1)

Cross section measurements also help in testing different models, calculations have been done for LHC using molecular nature and results from Tevatron

P. Artoisenet and E. Braaten; arXiv:0911.2016



- ➢ **The predictions in $\eta \in [2.5, 4.5]$ and $p_T \in [5, 20]$ GeV give**
  - ➢ **Prompt + *b* cross section: 13 ± 2.7 nb**
- ➢ **Using 35 pb^{-1} data, LHCb made an inclusive cross section measurement**

X(3872) : Cross Section (2)

➢ The measurement is done using:

$$\sigma_{X(3872)} \times \mathcal{BR}(X(3872) \to J/\psi\pi^+\pi^-) = \frac{N_{X(3872)}}{\epsilon_{\rm tot} \times \mathcal{L}_{\rm int} \times \mathcal{BR}(J/\psi \to \mu^+\mu^-)}$$

➢ $N_{x(3872)}$, the number of reconstructed $X(3872) \to J/\psi(\to\mu^+\mu^-)\pi^+\pi^-$

➢ $\mathscr{L}_{int}$ = 34.7 pb^{-1}, the integrated luminosity used

➢ ϵ_{tot}, the total reconstruction efficiency

➢ $\mathscr{B}r(J/\psi\to\mu^+\mu^-)$, the $J/\psi\to\mu^+\mu^-$ branching fraction

➢ We obtain the inclusive cross section in $\eta\in[2.5, 4.5]$ and $p_T\in[5, 20]$ GeV:

$$\sigma_{X(3872)} \times \mathcal{BR}(\mathrm{X(3872)} \to \mathrm{J}/\psi\pi^+\pi^-) = 4.7 \pm 1.1(\mathrm{stat}) \pm 0.7(\mathrm{syst})$$

➢ The measured value is 2.8σ smaller than the prediction in previous slide

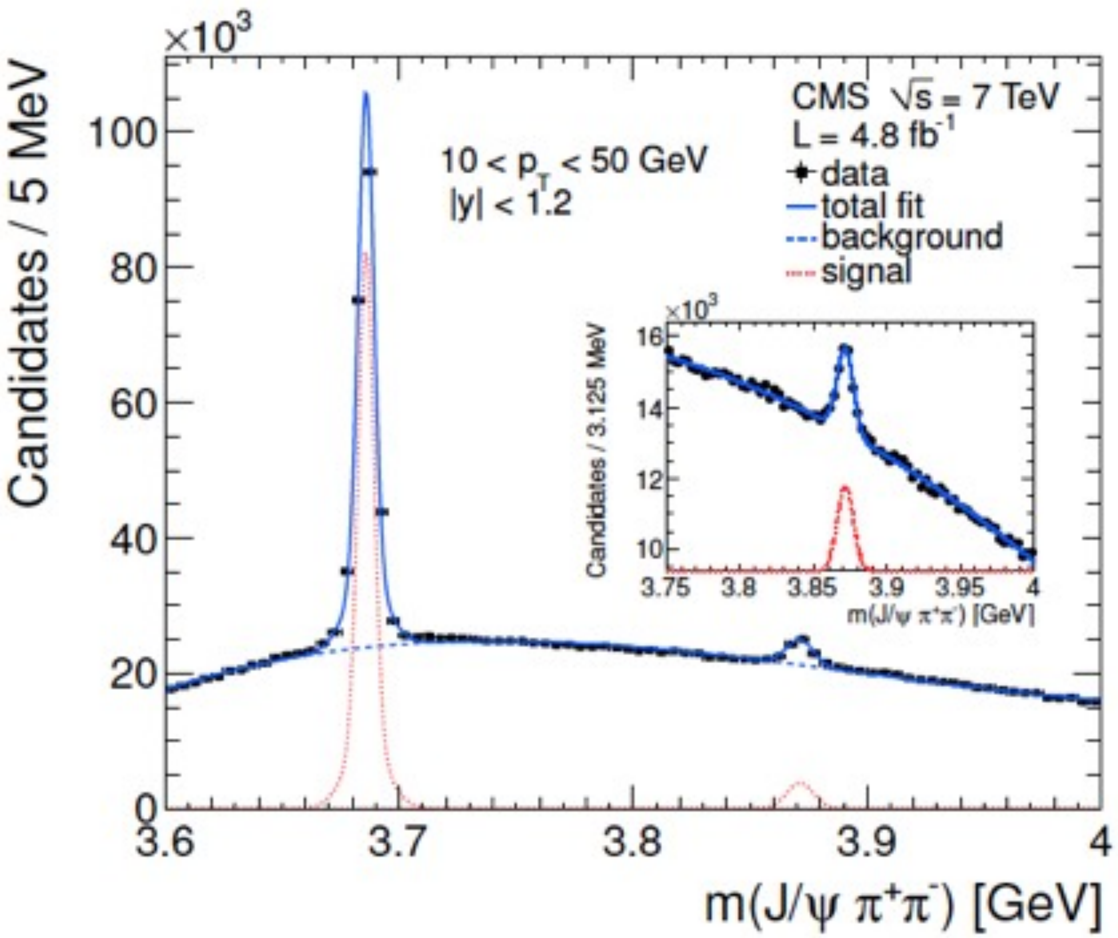
➢ Measurements with 1 fb^{-1} is ongoing and we will separate prompt and *b* component and measure it as a function of p_T and η

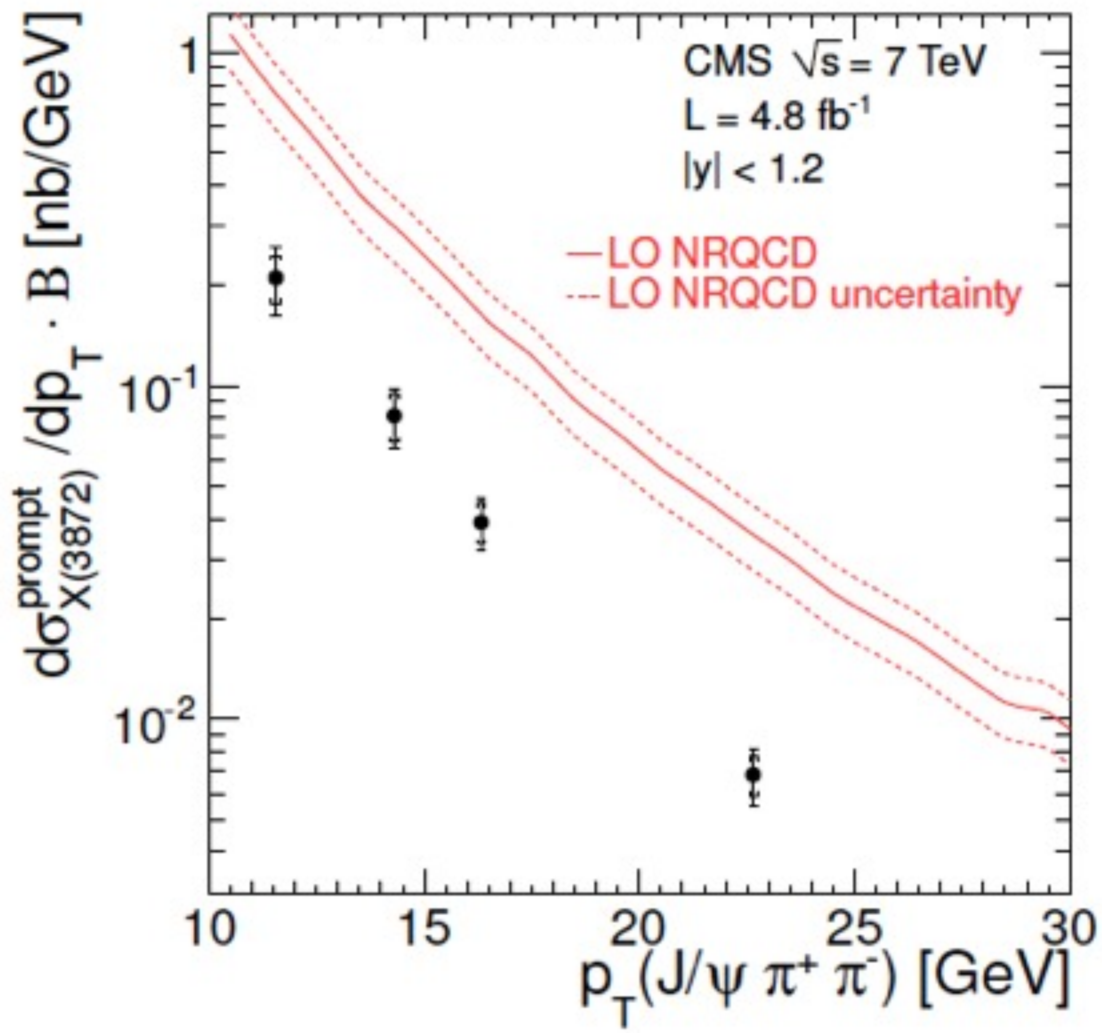
[1] LHCb Collaboration, Eur. Phys. J. C. 72 (2012) 1972

X(3872) : Cross Section (3)

➢ Using 4.8 fb^{-1} data, CMS performs a differential cross section (w.r.t ψ(2s)) measurement for prompt X(3872) in η∊[-1.2, 1.2] and p_T ∊[10, 50] GeV

➢ Prompt and detached components separated using lifetime-like distribution in x-y plane



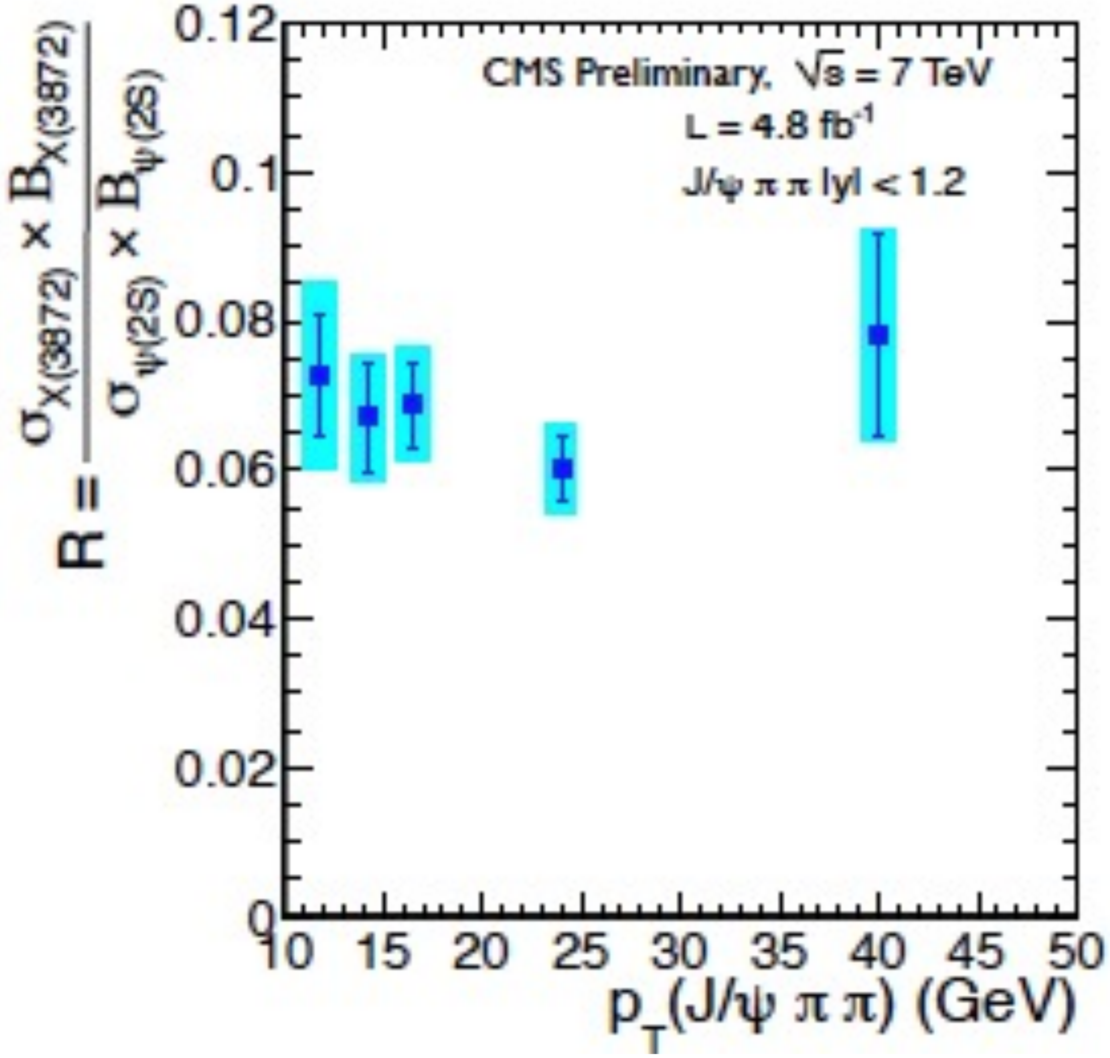


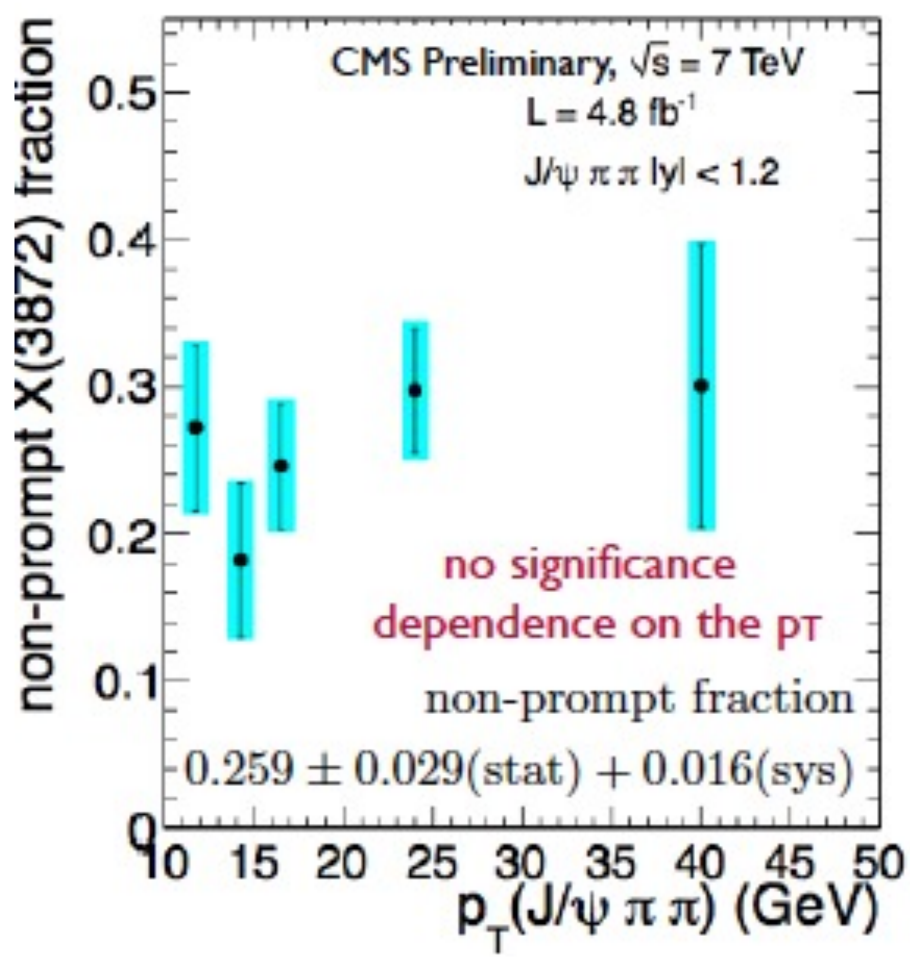
$$\sigma^{\mathrm{prompt}}(\mathrm{pp} \to \mathrm{X}(3872) + \mathrm{anything}) \cdot \mathcal{B}(\mathrm{X}(3872) \to \mathrm{J}/\psi\pi^+\pi^-) = 1.06 \pm 0.11\,(\mathrm{stat.}) \pm 0.15\,(\mathrm{syst.})\,\mathrm{nb}.$$

➢ NRQCD prediction: 4.01±0.88 nb (arXiv:0911.2016)

[1] CMS Collaboration, arXiv: 1302.3968

X(3872) : Cross Section (4)





$$R = \frac{\sigma(pp \to X(3872) + \text{anything}) \times B(X(3872) \to J/\psi\pi^+\pi^-)}{\sigma(pp \to \psi(2S) + \text{anything}) \times B(\psi(2S) \to J/\psi\pi^+\pi^-)}$$

$$R = 0.0662 \pm 0.0038(\text{stat}) \pm 0.0064(\text{syst})$$

Non-prompt fraction not dependent on p_T

Ratio to ψ(2s) not dependent on p_T

[1] CMS Collaboration, arXiv: 1302.3968

X(3872) : J^{PC} Determination (1)

Citation: J. Beringer *et al.* (Particle Data Group), PR D86, 010001 (2012) (URL: http://pdg.lbl.gov)

X(3872)

$$I^G(J^{PC}) = 0^?(?^{?+})$$

Seen by CHOI 03 in $B \to K\pi^+\pi^- J/\psi(1S)$ decays as a narrow peak in the invariant mass distribution of the $\pi^+\pi^- J/\psi(1S)$ final state,

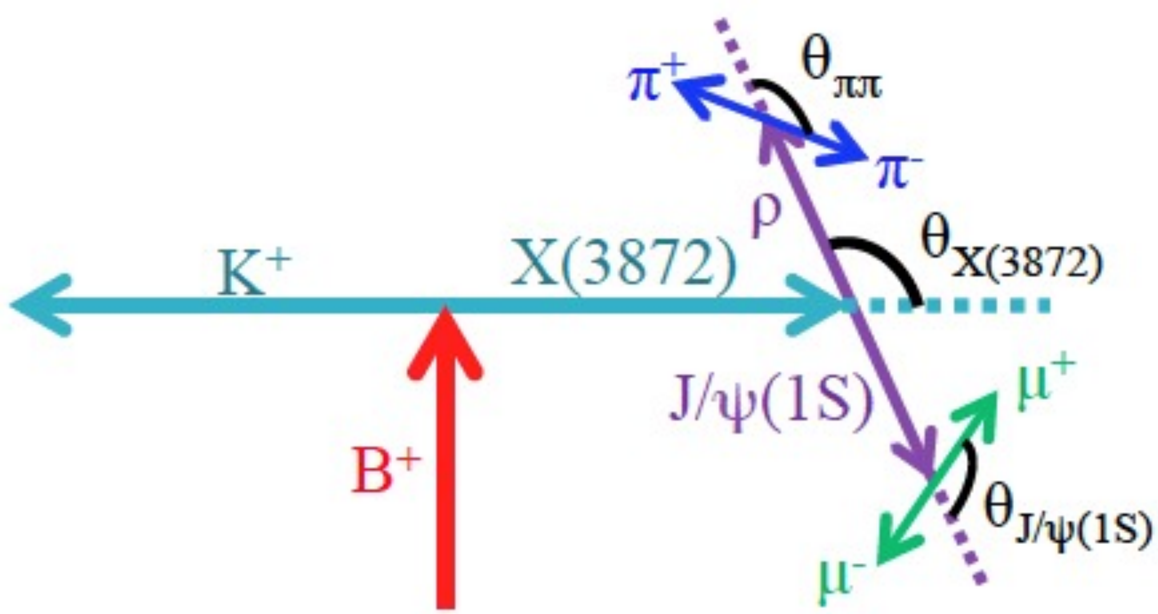
A helicity amplitude analysis of the $X(3872) \to J/\psi\pi^+\pi^-$ decay gives two possible J^{PC} assignments: $J^{PC} = 1^{++}$ and 2^{-+} (ABULENCIA 07E and CHOI 11).

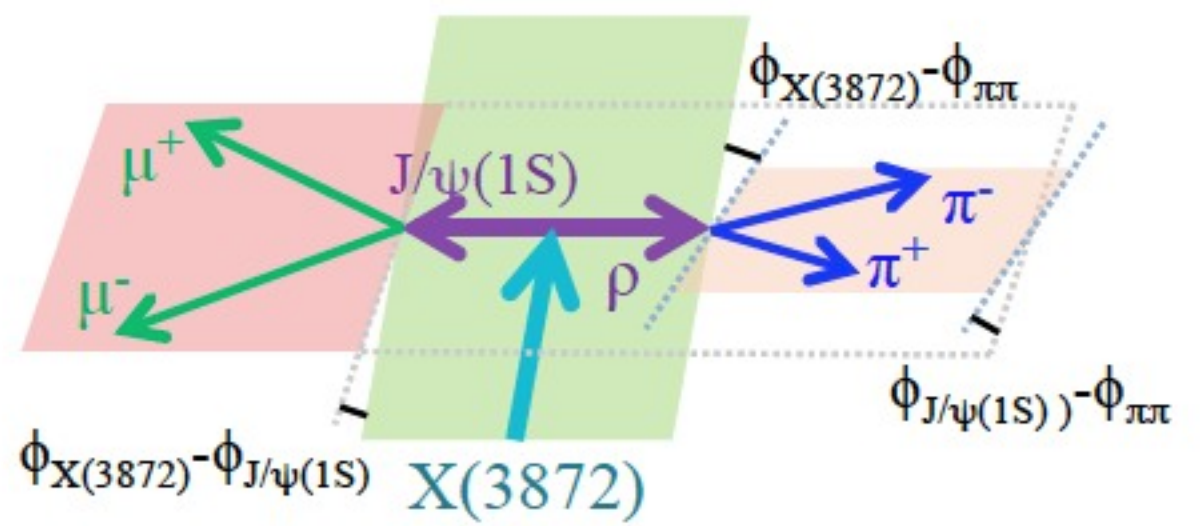
Unknown J^{PC} after 10 years of discovery

1^{++}: D^0D^{0*} molecule?

2^{-+}: $\eta_{c2}(1^1D_2)$?

➢ **Angular Analysis Needed ($X(3872)\to J/\psi\pi\pi$, ρ^0 dominated)**



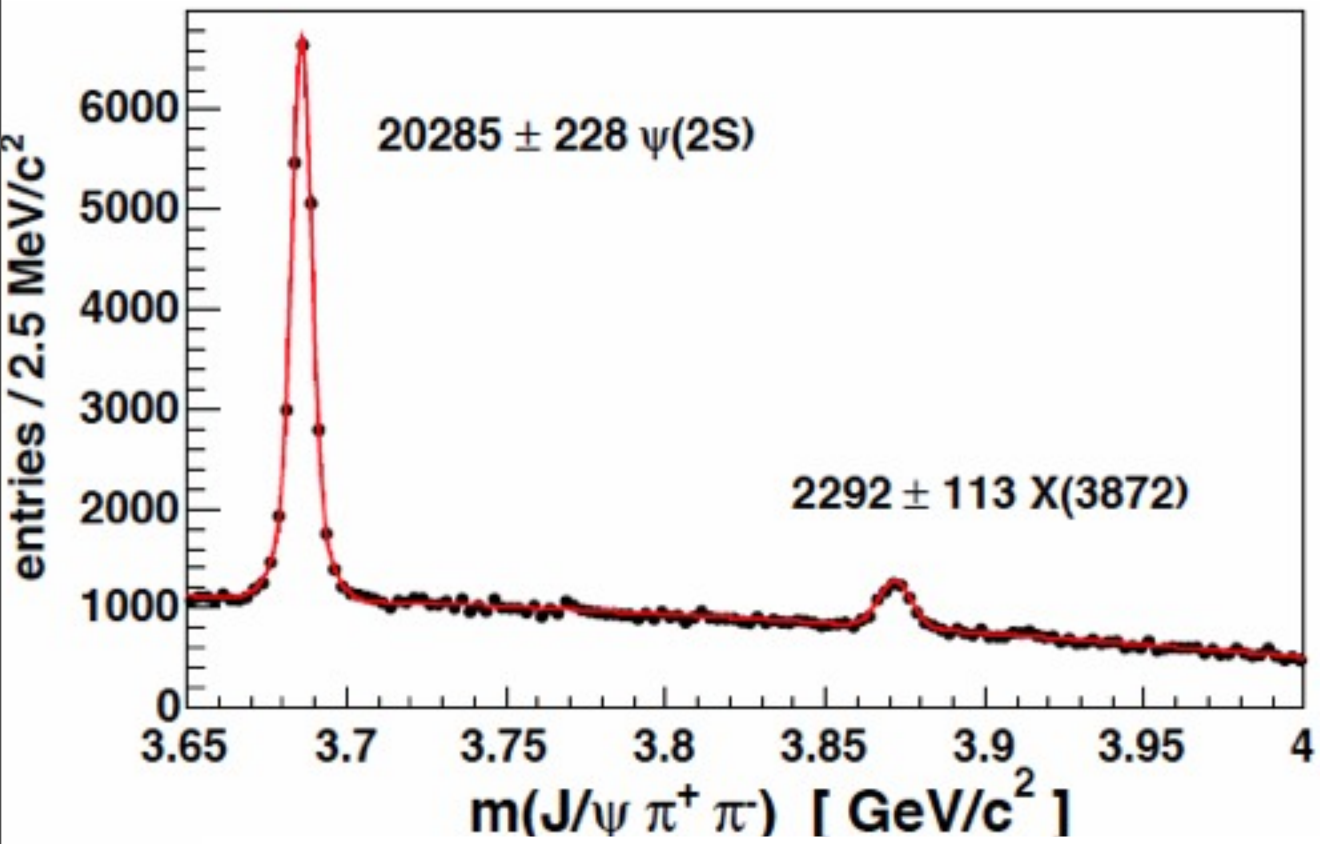


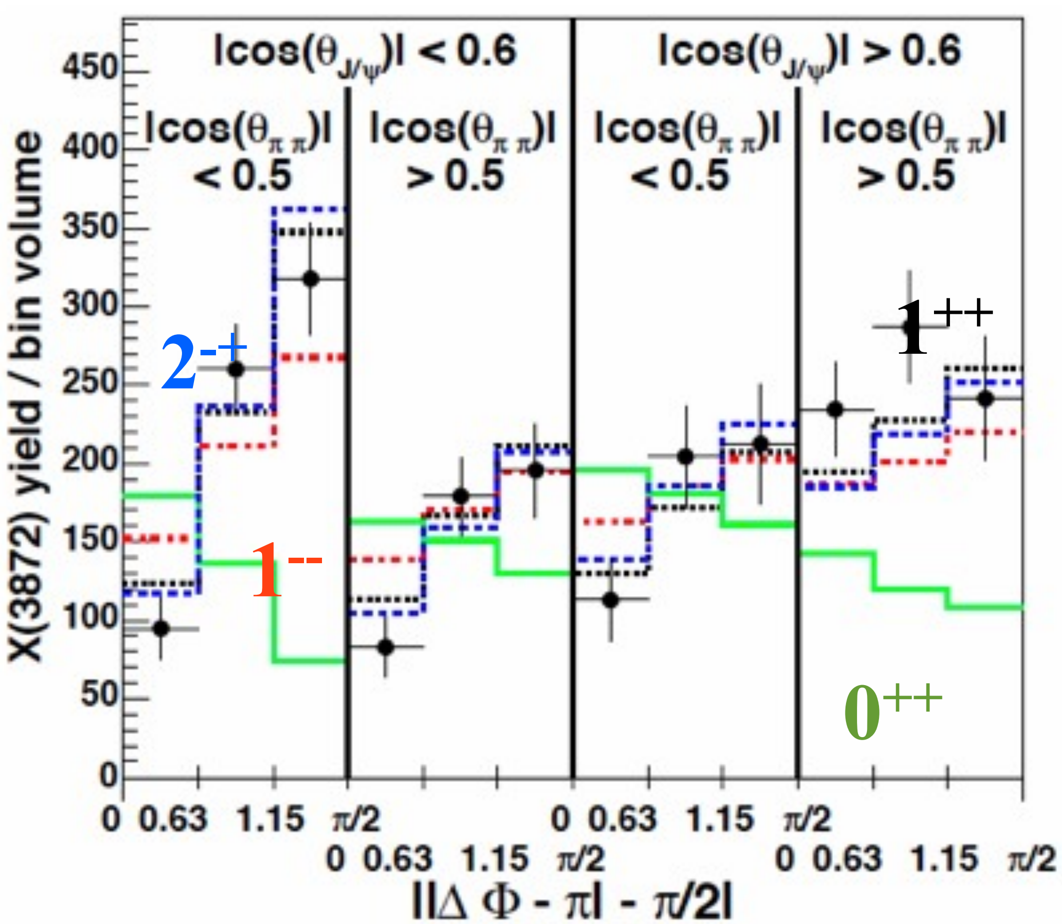
Full angular phase-space is 5D
In helicity formalism:
- 3 helicity angles: $\cos\theta_X, \cos\theta_{\pi\pi}, \cos\theta_{J/\psi}$
- 2 angles between decay planes: $\phi_{J/\psi}-\phi_{\pi\pi}, \phi_{J/\psi}-\phi_X$

inclusive production
Unpolarized →

J^{PC} info only in 3 angles:
$\cos\theta_X, \cos\theta_{\pi\pi}, \Delta\Phi=\phi_{J/\psi}-\phi_{\pi\pi}$

X(3872) : J^{PC} Determination (2)



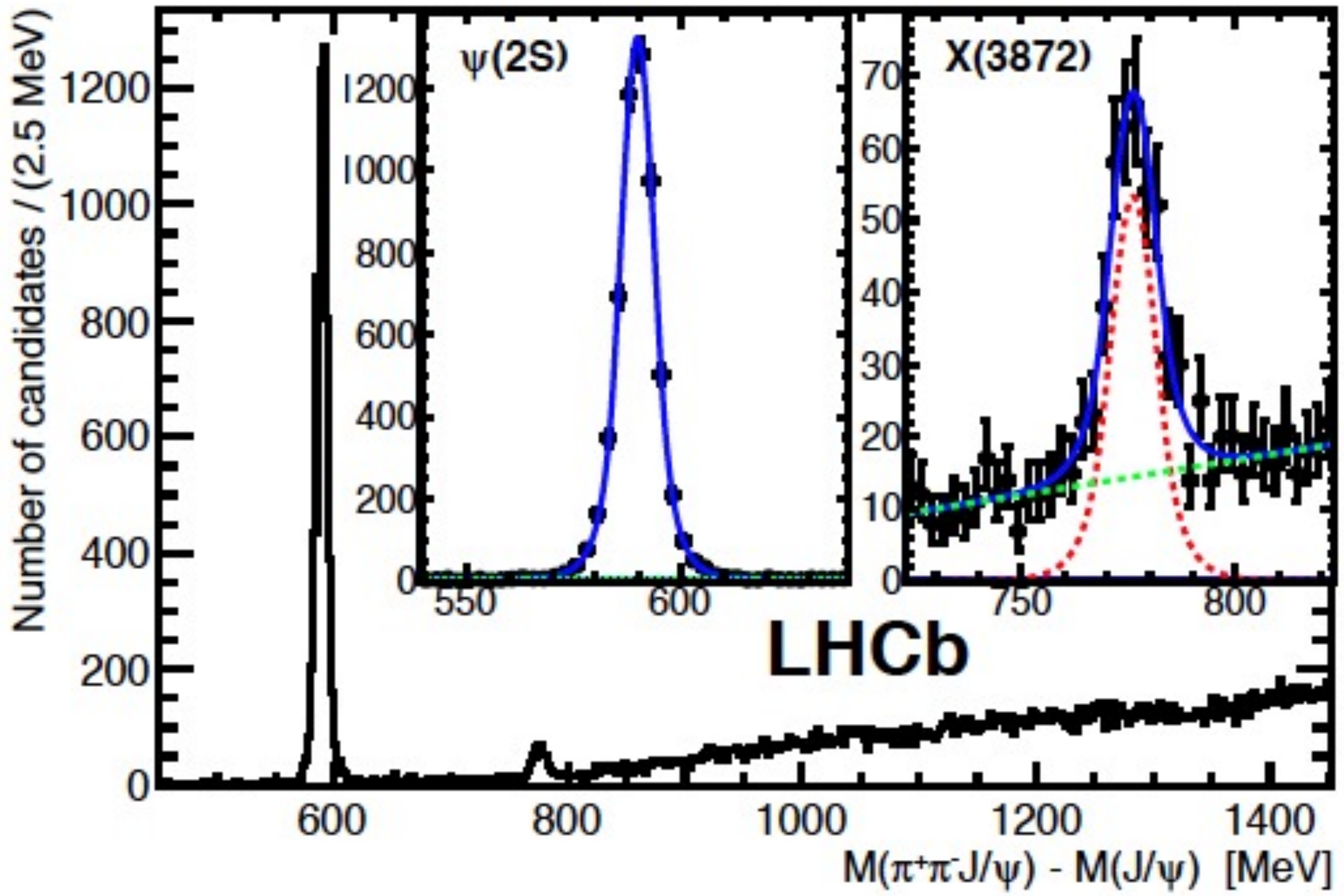


- Using 2292±113 **inclusively** produced X(3872), CDF performs angular analysis on J^{PC}
- All other spins up to 3 ruled out except 1^{++} and 2^{-+}
- **1D** analysis by Belle (173±16 events) in 2011 can't distinguish two states (another analysis by Babar using $B \to J/\psi\omega(3\pi)$ prefers 2^{-+})

J^{PC}	decay	LS	χ^2 (11 d.o.f.)	χ^2 prob.
1^{++}	$J/\psi\rho^0$	01	13.2	0.28
2^{-+}	$J/\psi\rho^0$	11,12	13.6	0.26
1^{--}	$J/\psi(\pi\pi)_S$	01	35.1	2.4×10^{-4}
2^{+-}	$J/\psi(\pi\pi)_S$	11	38.9	5.5×10^{-5}
1^{+-}	$J/\psi(\pi\pi)_S$	11	39.8	3.8×10^{-5}
2^{--}	$J/\psi(\pi\pi)_S$	21	39.8	3.8×10^{-5}
3^{+-}	$J/\psi(\pi\pi)_S$	31	39.8	3.8×10^{-5}
3^{--}	$J/\psi(\pi\pi)_S$	21	41.0	2.4×10^{-5}
2^{++}	$J/\psi\rho^0$	02	43.0	1.1×10^{-5}
1^{-+}	$J/\psi\rho^0$	10,11,12	45.4	4.1×10^{-6}
0^{-+}	$J/\psi\rho^0$	11	104	3.5×10^{-17}
0^{+-}	$J/\psi(\pi\pi)_S$	11	129	$\leq 1 \times 10^{-20}$
0^{++}	$J/\psi\rho^0$	00	163	$\leq 1 \times 10^{-20}$

[1] CDF Collaboration, Phys. Rev. Lett. 98 (2007), 132002, arXiv: hep-ex/0612053

X(3872) : J^{PC} Determination (3)



5642±76 **313±26**

➢ **LHCb joined with 313±26 X(3872) signals using 1fb^{-1} data**

➢ **A full 5D analysis performed**

➢ **Several analysis technics used and made it possible to distinguish the remaining two hypothesis**

➢ **ψ(2s) with known $J^{PC} = 1^{--}$ used as control (test) particle**

[1] LHCb Collaboration, arXiv: 1302.6269

X(3872) : J^{PC} Determination (4)

LHCb

➢ **Matrix elements for angular analysis**

$$|\mathcal{M}(\Omega|J_X)|^2 = \sum_{\Delta\lambda_\mu=-1,+1} \Big| \sum_{\lambda_{J/\psi},\lambda_{\pi\pi}=-1,0,+1} A_{\lambda_{J/\psi},\lambda_{\pi\pi}} \times D^{J_X}_{0,\lambda_{J/\psi}-\lambda_{\pi\pi}}(\phi_X,\theta_X,-\phi_X) \times D^1_{\lambda_{\pi\pi},0}(\phi_{\pi\pi},\theta_{\pi\pi},-\phi_{\pi\pi}) \times D^1_{\lambda_{J/\psi},\Delta\lambda_\mu}(\phi_{J/\psi},\theta_{J/\psi},-\phi_{J/\psi}) \Big|^2,$$

Different amplitude related by Clebsch-Gordan coefficients

$$A_{\lambda_{J/\psi},\lambda_{\pi\pi}} = \sum_L \sum_S B_{LS} \times \left(\begin{array}{cc|c} J_{J/\psi} & J_{\pi\pi} & S \\ \lambda_{J/\psi} & \lambda_{\pi\pi} & \lambda_{J/\psi}-\lambda_{\pi\pi} \end{array} \right) \times \left(\begin{array}{cc|c} L & S & J_X \\ 0 & \lambda_{J/\psi}-\lambda_{\pi\pi} & \lambda_{J/\psi}-\lambda_{\pi\pi} \end{array} \right)$$

As higher L is suppressed (L_{min} + 2, 4 ...), only L_{min} considered

$\rho^0(770)$: 1^{--} J/ψ: 1^{--}

J^{PC}	1^{++}	2^{-+}
L, S	L=0,S=1	L=1, S=1or 2

For J=1, 0 free parameter, J=2, 1 complex parameter: $\alpha = B_{11}/(B_{12}+B_{11})$

[1] LHCb Collaboration, arXiv: 1302.6269

X(3872) : J^{PC} Determination (5)

➢ A likelihood ratio test performed

$$t = -2\, s_w \sum_{i=1}^{N} w_i \ln \frac{P(\Omega_i \mid 2^{-+}, \alpha_{max})}{P(\Omega_i \mid 1^{++})}$$

P - PDF

$$\int P(\Omega \mid hyp)\, d\Omega = 1$$

➢ Background subtracted using sweight (ω_i)

➢ α_{max} maximizes the 2^{-+} likelihood $2\, s_w \sum_{i=1}^{N} w_i \ln P(\Omega_i \mid 2^{-+}, \alpha)$

α_{max}=(0.671±0.046, 0.280±0.046)

➢ s_w is a constant factor for correcting errors when using sweight to subtract background

$$s_w = \frac{\sum_{i=1}^{N} w_i}{\sum_{i=1}^{N} w_i^2}$$

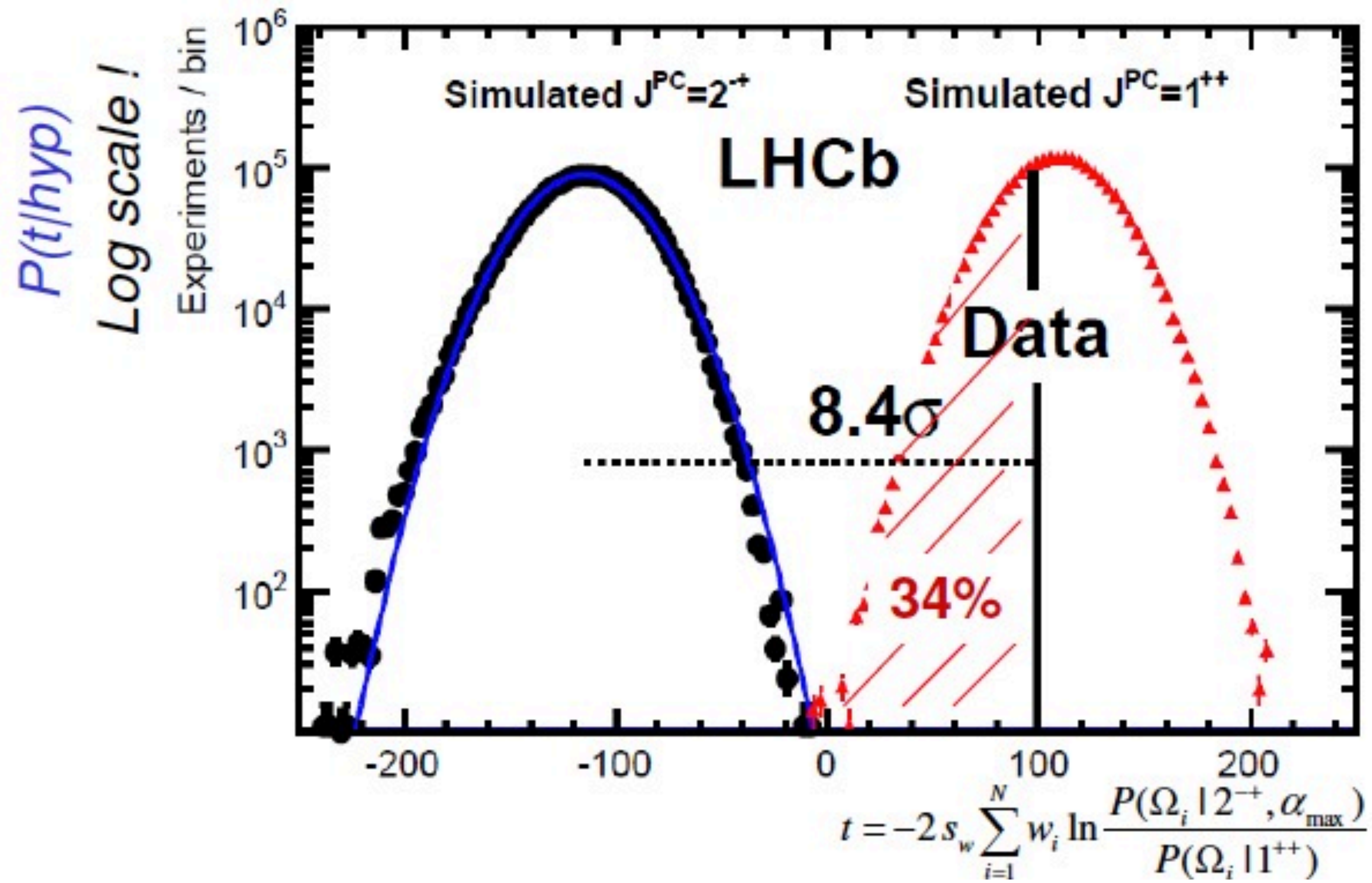
$$P(\Omega \mid hyp) = \varepsilon(\Omega \mid hyp) \left| M(\Omega \mid hyp) \right|^2 / I(hyp)$$

$$I(hyp) = \int \varepsilon(\Omega \mid hyp) \left| M(\Omega \mid hyp) \right|^2 d\Omega$$

➢ Efficiency depends little on hypothesis and can be factorized out with only dependence on its integration which can be obtained using simulated sample

[1] LHCb Collaboration, arXiv: 1302.6269

X(3872) : J^{PC} Determination (6)



2^{-+} ruled out by 8.4σ (Gaussian approximation)

> 5σ (direct from simulated number)

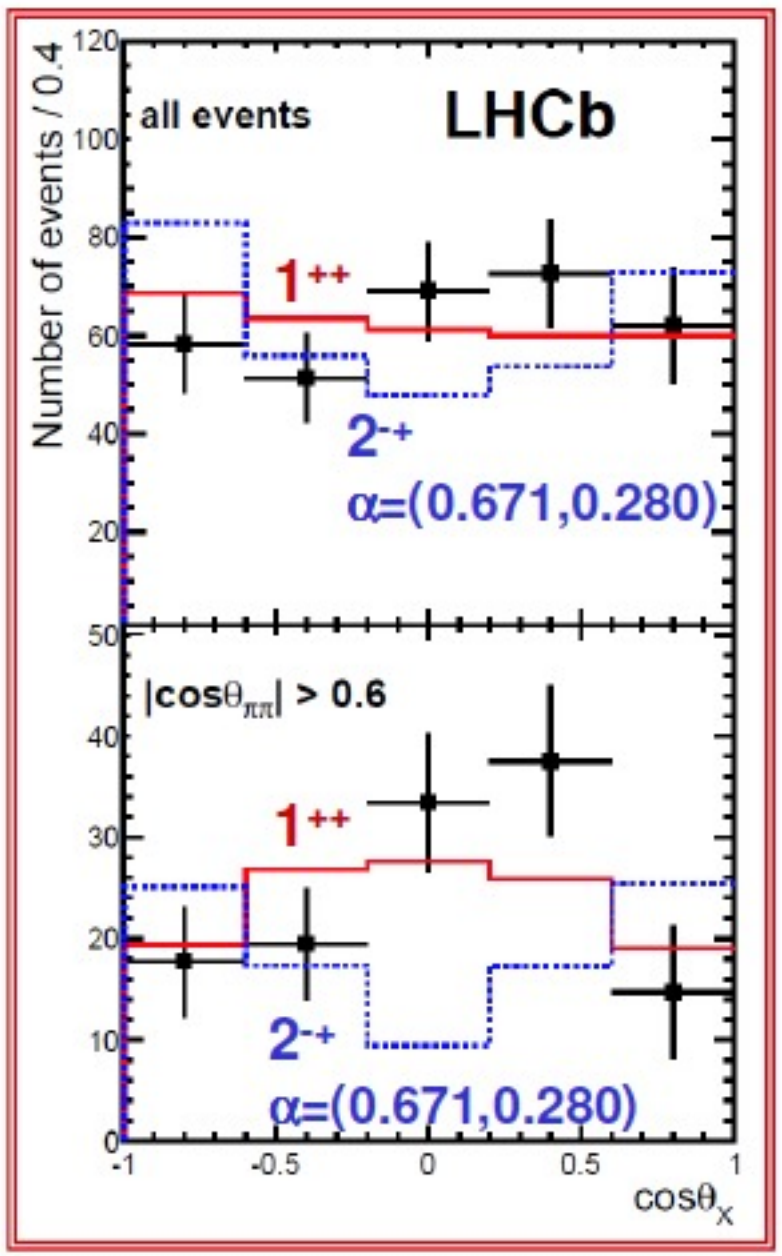
9.7σ (Wilks' theorem)

1^{++} p-value: 34%

[1] LHCb Collaboration, arXiv: 1302.6269

X(3872) : J^{PC} Determination (7)

➢ **Distinguish by "eye"**

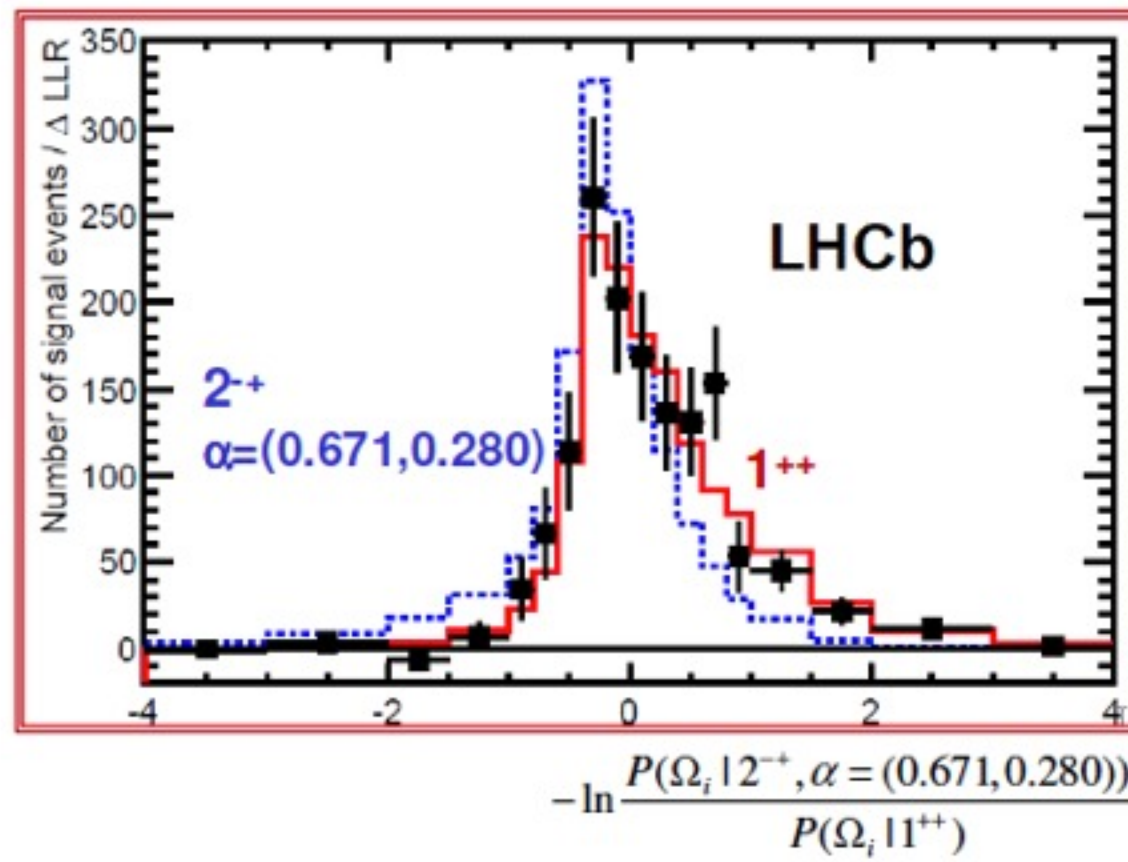


Hard if full events

Correlations
Angular analysis

Certain regions

Likelihood Distribution



Consistent with simulation

Distinguish between two J^{PC}

[1] LHCb Collaboration, arXiv: 1302.6269

Search for X(4140)+X(4300) (1)

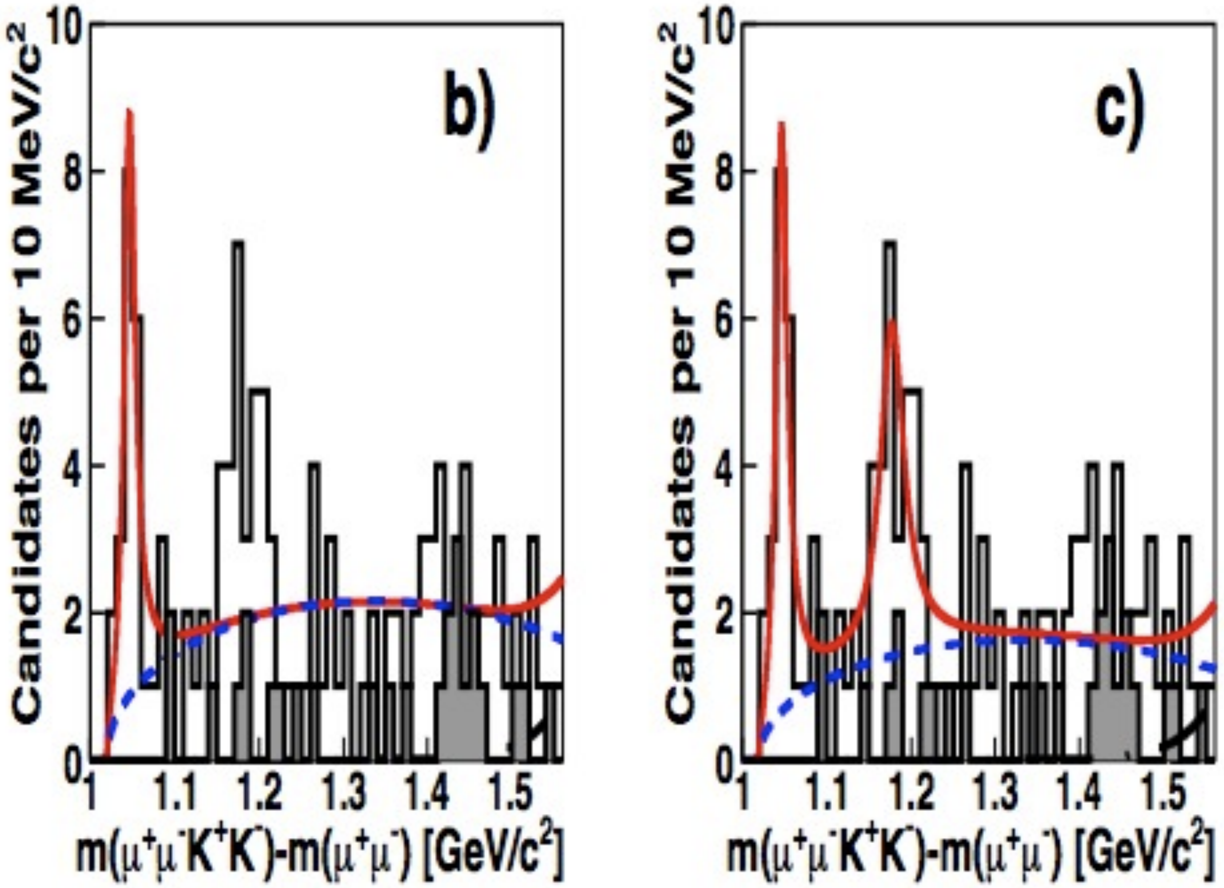
CDF observed a narrow structure *X(4140)→J/ψφ* (also named as *Y*(4140)) in *B→J/ψφK* decay with 6 fb^{-1} data

- **In CDF, 19±6(stat)±3(syst) resonance events within 115±12(stat) reconstructed *B→J/ψφK* events: 3.8σ significance and mass:**

$$M_{X(4140)} = 4143.4^{+2.9}_{-3.0}(stat) \pm 0.6(syst) MeV$$

- **CDF data also suggested a second state with 22±8 events, 3.1σ significance at higher mass:**

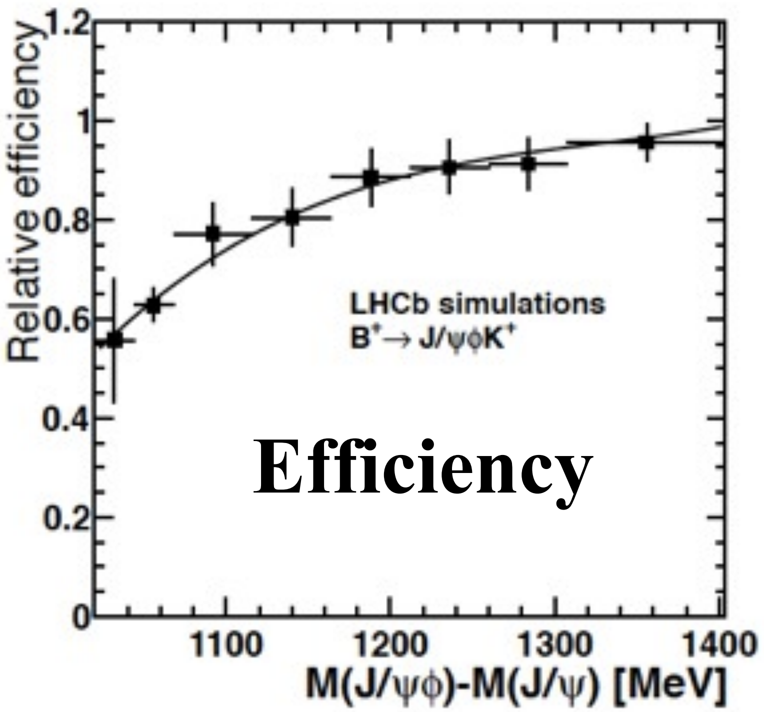
$$M = 4274.4^{+8.4}_{-6.7}(stat) \pm 1.9(syst) MeV$$



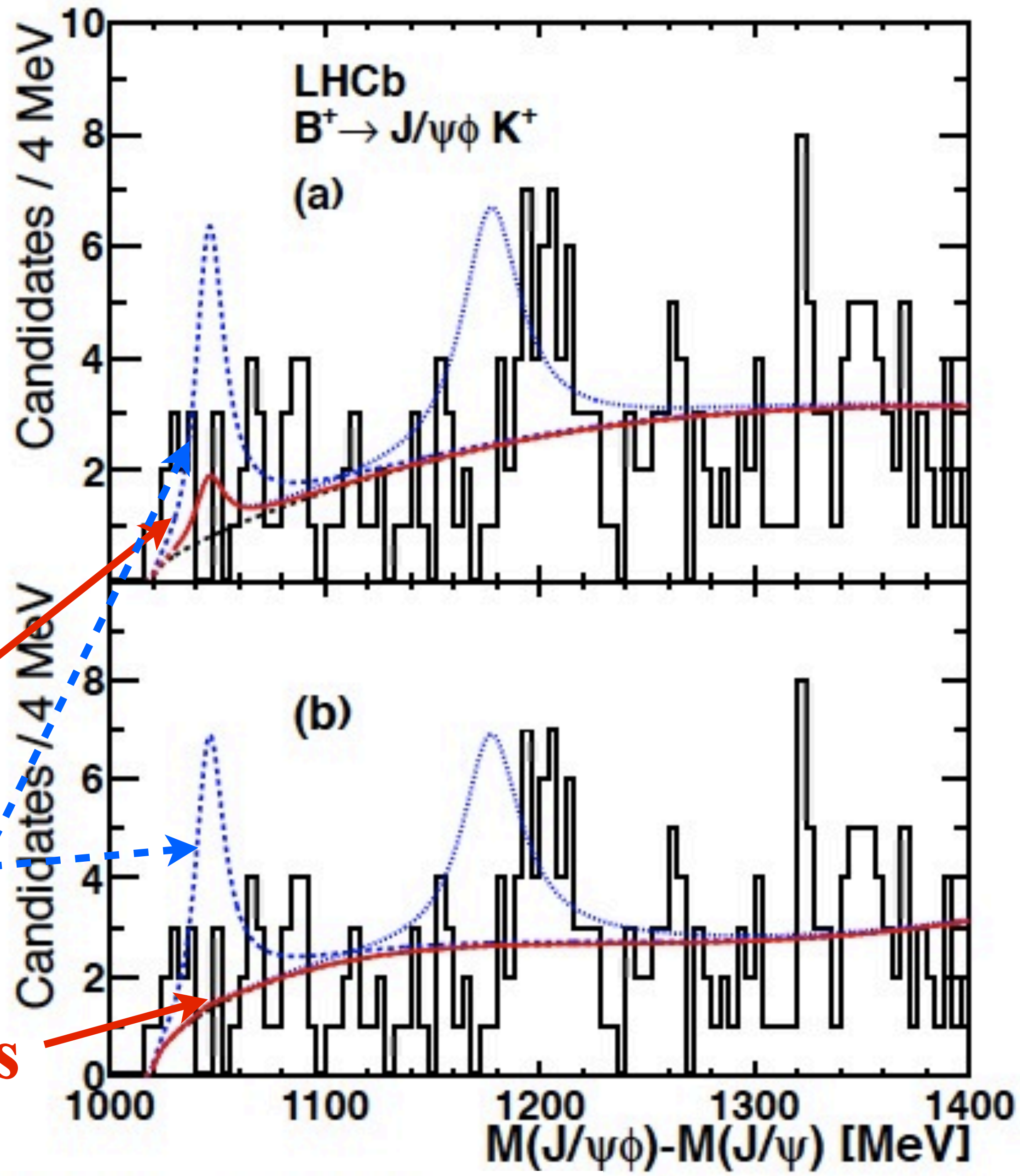
- **With 0.38 fb^{-1} of data, LHCb also performed a search using 346 ± 20 reconstructed B→J/ψφK**

[1] CDF Collaboration, arXiv:1101.6058

Search for X(4140)+X(4300) (2)



Efficiency



3-body phase space background

Parabolic × 3-body phase space background

7±5 events

Scaled from CDF: 35±9±6 events

0.6±7 events

$$\frac{\mathcal{B}(B^+ \to X(4140)K^+) \times \mathcal{B}(X(4140) \to J/\psi\,\phi))}{\mathcal{B}(B^+ \to J/\psi\,\phi K^+)} < 0.07.$$

$$\frac{\mathcal{B}(B^+ \to X(4274)K^+) \times \mathcal{B}(X(4274) \to J/\psi\,\phi)}{\mathcal{B}(B^+ \to J/\psi\,\phi K^+)} < 0.08$$

at 90% CL vs CDF:

2.4σ disagreement

0.149±0.039±0.024

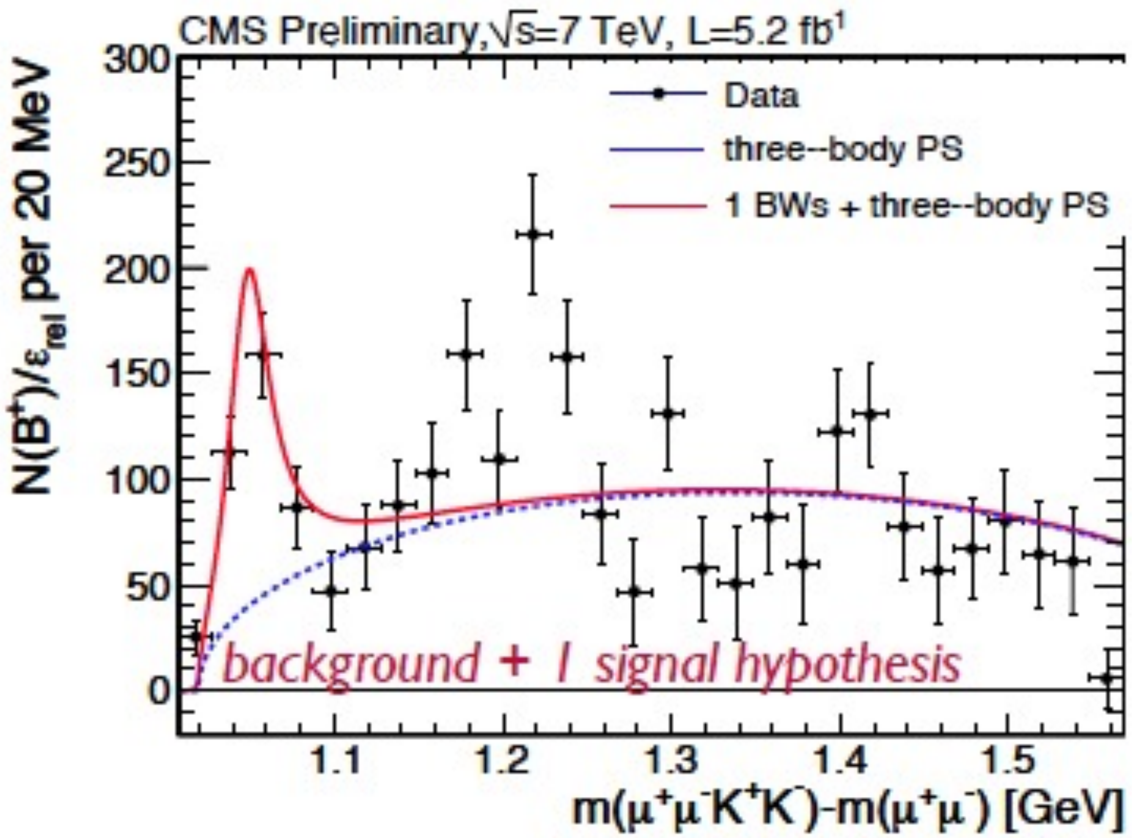
0.17±0.06 (stat.)

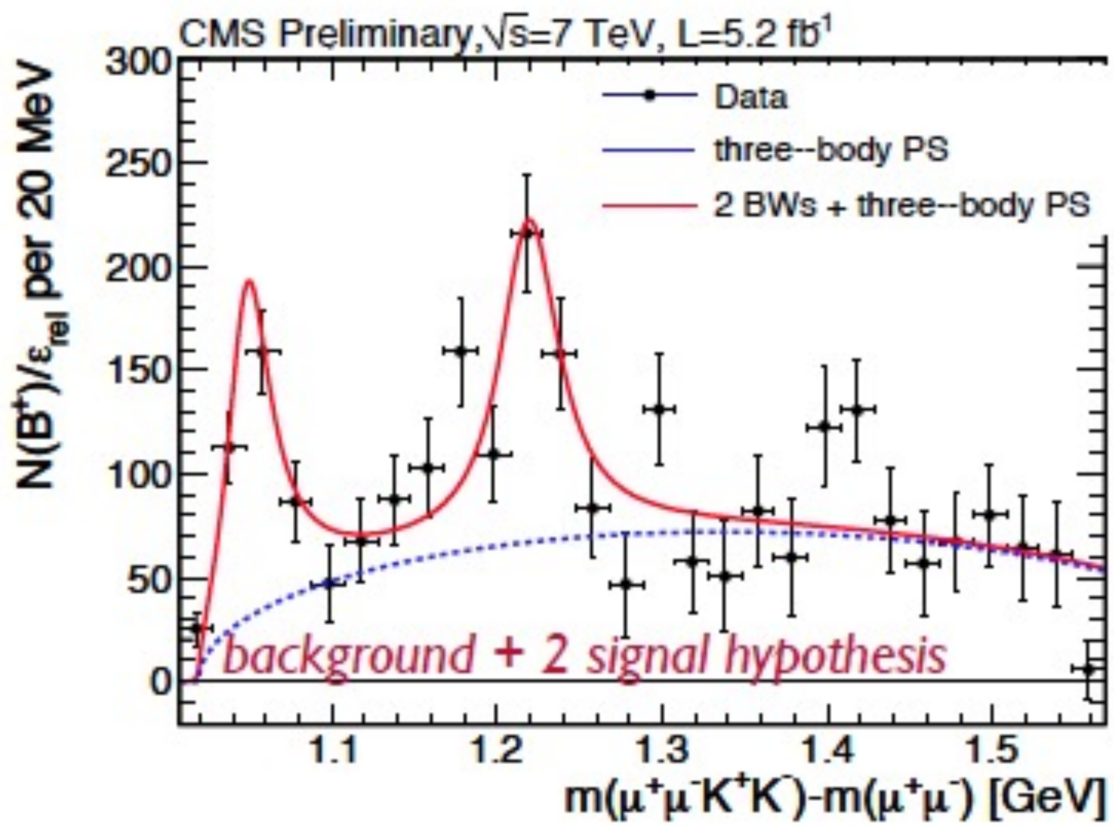
Not Confirmed

[1] LHCb Collaboration, Phys. Rev. D 85 (2012), 091103, arXiv: 1202.5087

Search for X(4140)+X(4300) (3)

➢ **Using 5.2 fb^{-1} of data, CMS joins with 2478 ± 162 reconstructed $B \to J/\psi\varphi K$**





	Mass (MeV)	Yields
First peak	1051.5±2.0	355 ± 46
Second peak	1220.0±3.0	445±83

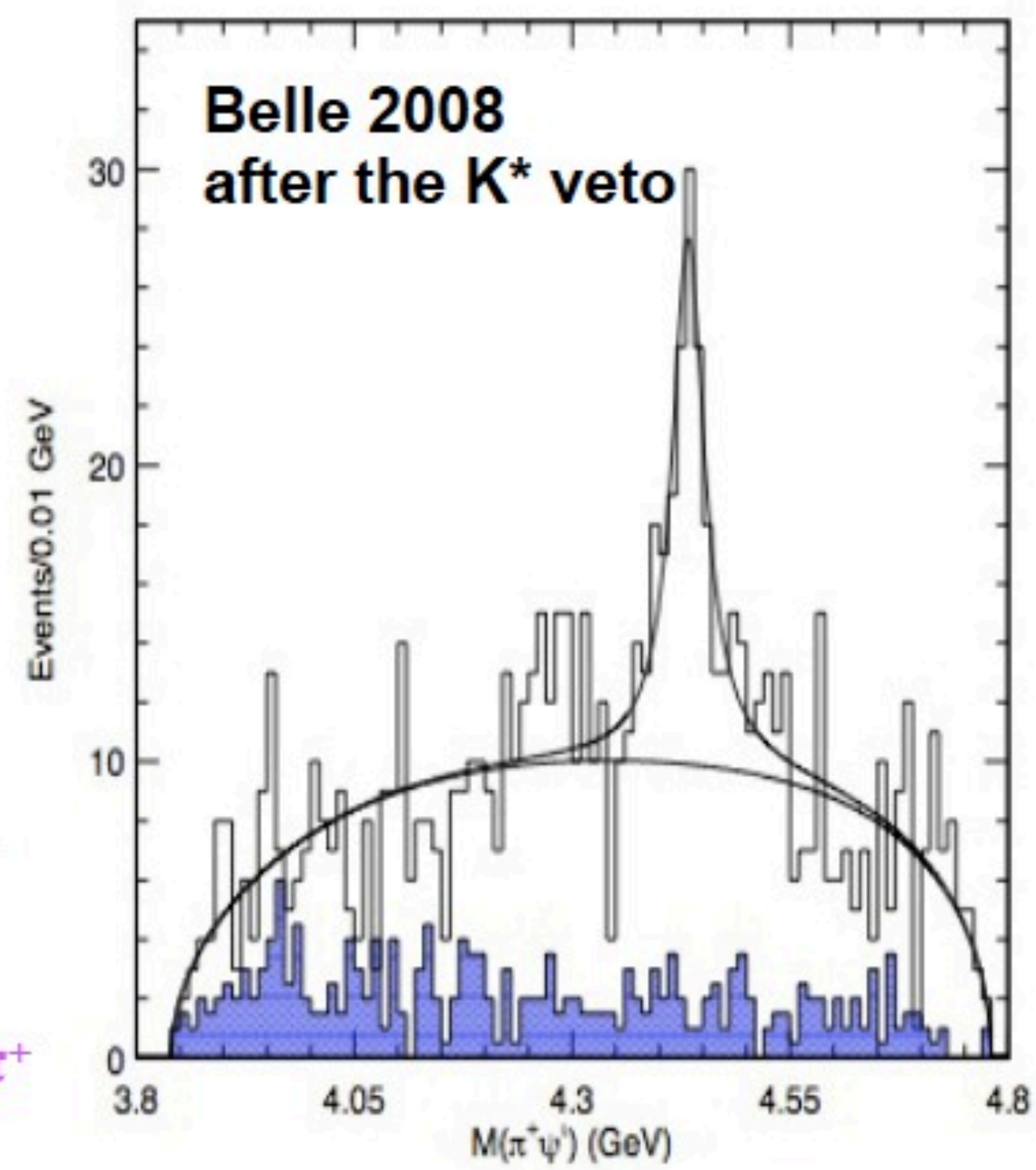
$M_1 = 4148.2 \pm 2.0 \pm 5.2$ MeV
$M_2 = 4316.7 \pm 3.0 \pm 10.0$ MeV
stat. sys.

➢ **The structure at 4148 MeV with significance >5σ consistent with a previous resonance structure by CDF**

➢ **Evidence for a second structure at 4317 MeV (4274 MeV for CDF)**

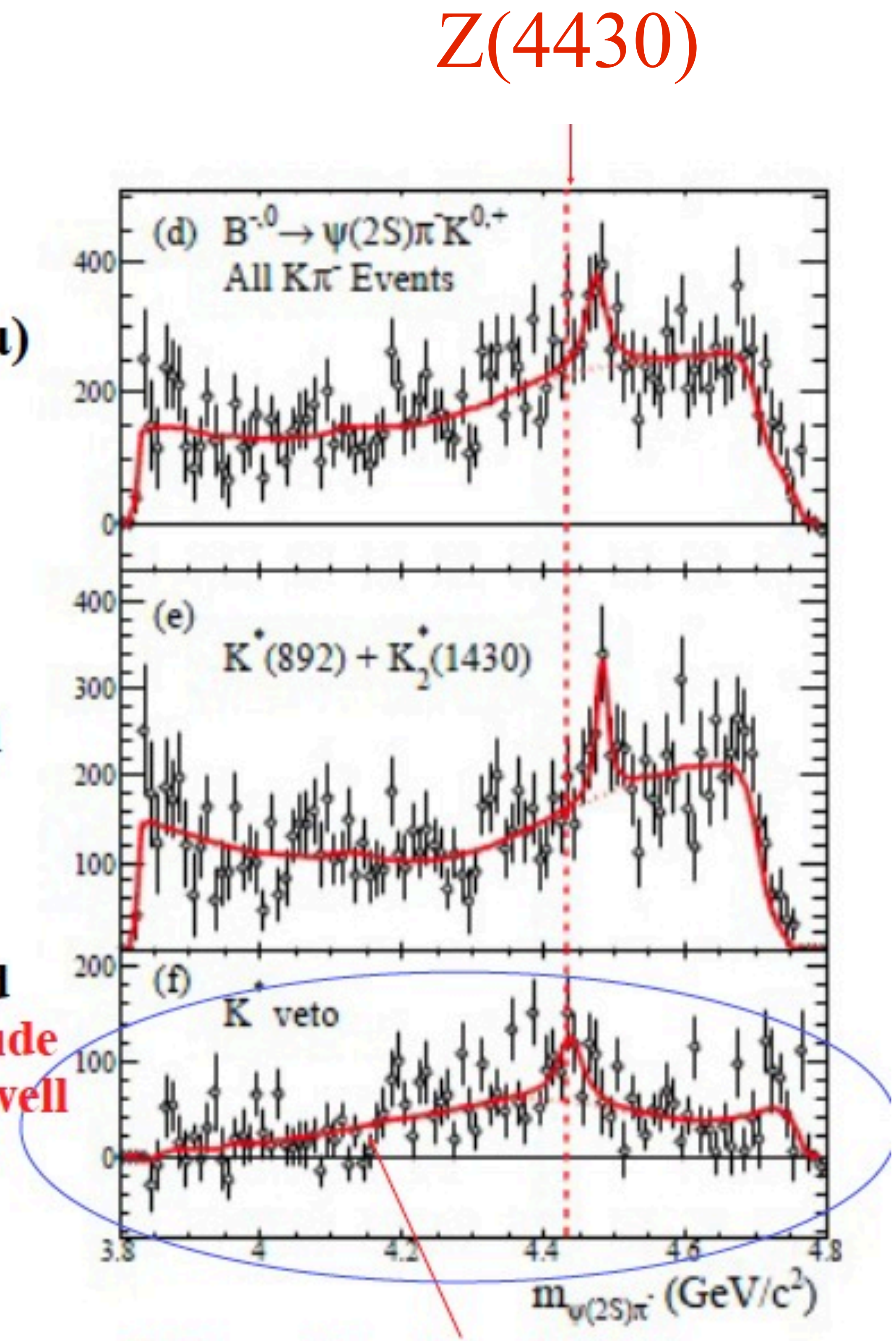
Search for Z(4430) (1)

- Claim of exotic $Z(4430)^+ \to \psi(2S)\pi^+$ resonance by Belle (minimal quark content $c\bar{c}u\bar{d}$ – "smoking gun" for existence of four-quark bound states)
- Four independent variables (4D) describing full kinematics of $B \to \psi(2S)K\pi$, $\psi(2S) \to \mu^+\mu^-$ decay (with additional assumptions also for $\psi(2S) \to \pi^+\pi^- J/\psi$, $J/\psi \to \mu^+\mu^-$)
- Belle PRL 100 (2008) 142001: 605 fb^{-1}
  - $B \to \psi(2S)K\pi$ (K^+ and K^0_s, $\psi(2S) \to l^+l^-$ or $\psi(2S) \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$, l=e or μ)
  - Simple-minded 1D analysis in $M(K\pi)$ and $M(\psi(2S)\pi)$:
    - veto K*(892),K*(1430) regions by cutting on $M(K\pi)$
    - 1D fit to $M(\psi(2S)\pi)$:
      - $$M = 4433 \pm 4(\text{stat}) \pm 2((syst))MeV$$
        $$\Gamma = 45^{+18}_{-13}(\text{stat})^{+30}_{-13}((syst)MeV$$
      - 121±20 Z events, 6.5σ evidence for $\psi(2S)\pi^+$ "resonance-like structure"



Search for Z(4430) (2)

- BaBar PRD 79 (2009) 112001: 413 fb^{-1}
  - $B \to \psi(2S) K\pi$ and $B \to J/\psi K\pi$ (K^+ and K^0_s, $\psi(2S) \to l^+l^-$ or $\psi(2S) \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$, l=e or μ)
  - Sophisticated 2D analysis in M(Kπ) vs $\cos\Theta_K$ (Θ_K-angle between K direction in Kπ rest frame and Kπ direction in the B rest frame):
    - 2D efficiency corrections
    - Fit M(Kπ) with known Kπ resonances (modified LASS parameterization for S-wave)
    - Determine $\cos\Theta_K$ moments vs M(Kπ)
    - Transform the above into reflections of the fitted Kπ structures in M(ψ(2S)π) [also M(J/ψπ)]. Conclude that their observed M(ψ(2S)π) and M(J/ψπ) data well described by the reflections of these Kπ structures.
    - When fitting $Z(4430)^+$ explicitly, set an upper limit which is consistent with the Belle's result
    - No evidence for $Z(4430)^+$ in the BaBar data, but also no disagreement with the Belle's claim

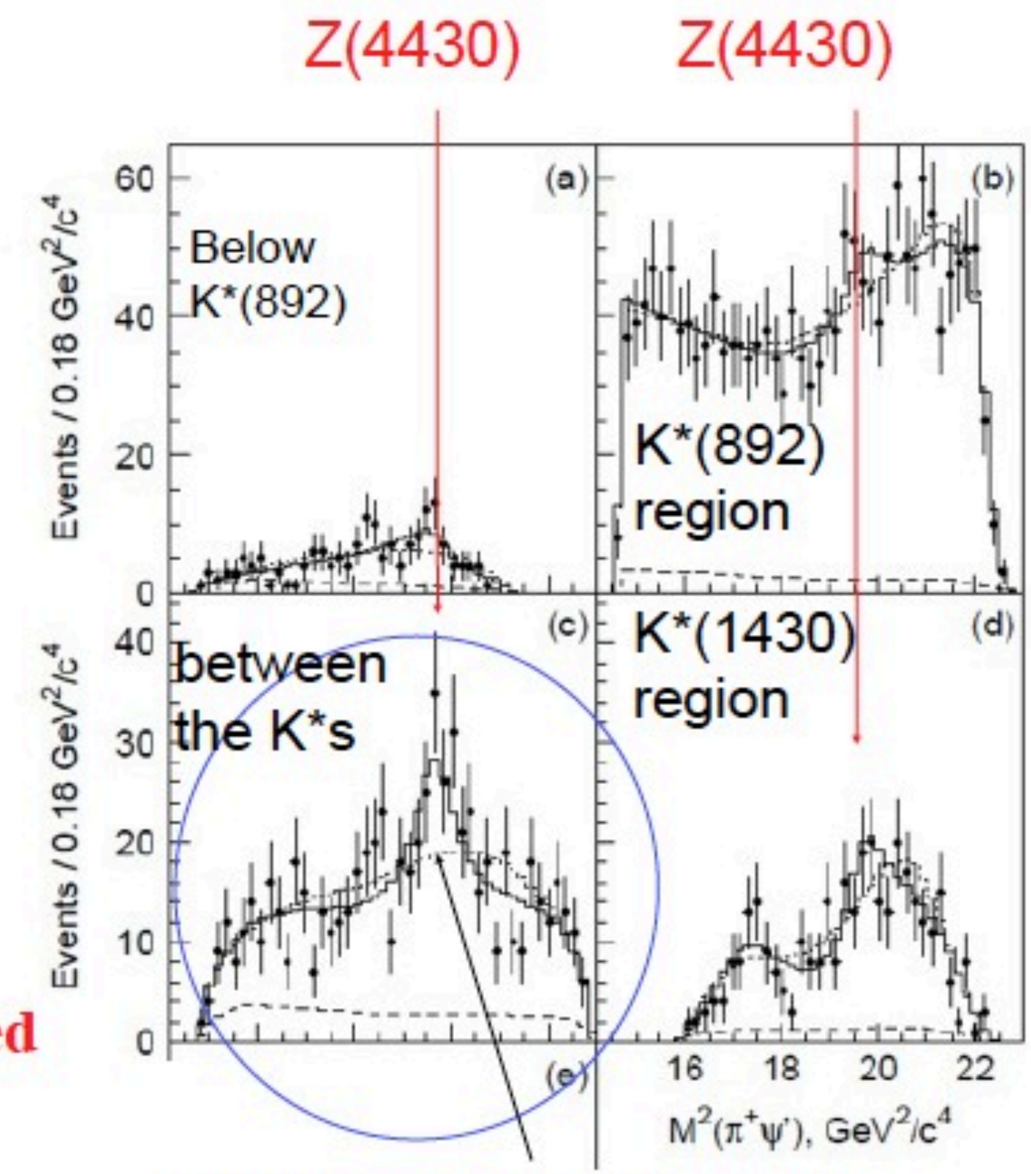


Background shapes determined by the Kπ reflections. Fit only background amplitude and relativistic S-wave BW line shape.

Search for Z(4430) (3)

- **Belle PRD 80 (2009) 031104: 605 fb^{-1}**
  - Reanalysis of B→ψ(2S)Kπ in response to implicit criticism contained in the BaBar paper
  - Sophisticated 2D analysis in M(Kπ) vs M(ψ(2S)π) ("Dalitz analysis"):
    - 2D efficiency corrections:
      - Still not bullet proof if efficiency not uniform in the other 2 degrees of freedom!
    - 2D fit of known Kπ resonances (Isobar model [i.e. explicit spin 0 resonances] for S-wave, LASS as cross-check) plus optionally Z(4430)
    - Conclude that their Dalitz plot not well described by the Kπ structures alone.
    - When fitting with Z(4430)$^+$ component:
      - $$M = 4443^{+15}_{-12}(\text{stat})^{+19}_{-13}((syst))MeV$$ $$\Gamma = 107^{+86}_{-43}(\text{stat})^{+74}_{-56}((syst)MeV$$
      - From change of the fit likelihood: 6.4σ evidence for exotic Z(4430)

      Changed in values and errors compared to their naïve approach in the 1st publication
  - No B→J/ψKπ results from Belle



Dotted curve – fit with the Kπ structures alone.

Search for Z(4430) (4)

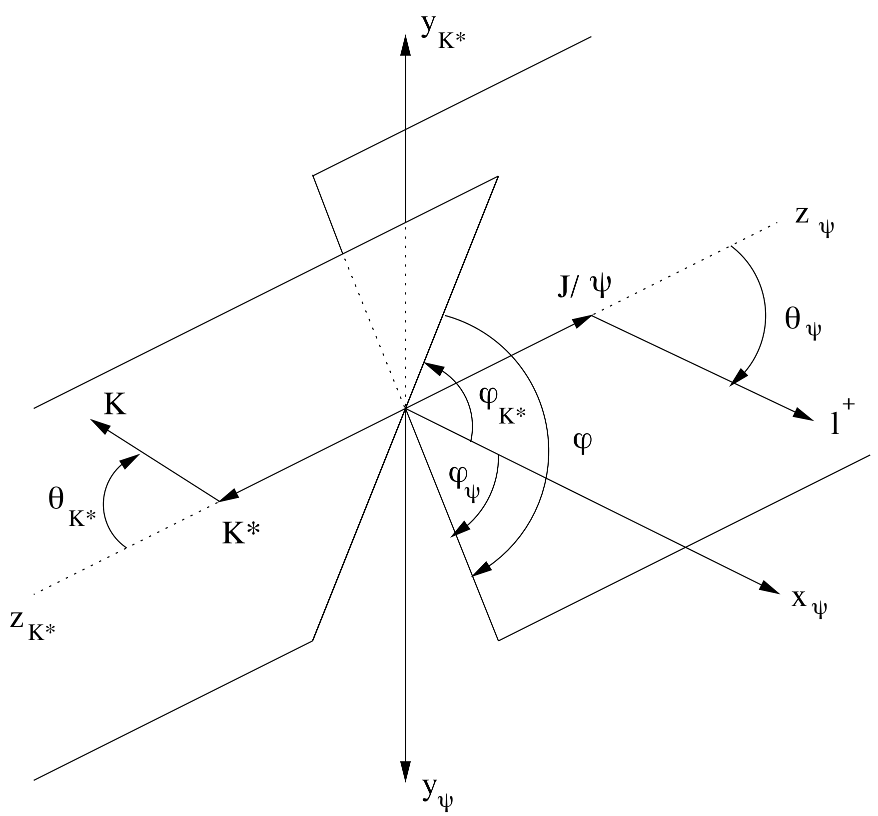
➢ **Z(4430)-like bump observed in $B \to \psi(2S) K\pi$ data, simple fit results in same mass as BELLE but larger width**

➢ **By now use full 2011 1 fb^{-1} data**

➢ **Four independent variables (4D) describing full kinematics of $B \to \psi(2S) K\pi$, $\psi(2S) \to \mu^+\mu^-$ decay**

➢ **One choice: $M(K\pi)$, $M(\psi(2S)\pi)$, $\cos(\theta_\psi)$, φ; 4D analysis**

➢ **Alternative approach using Babar's method also tried**



Conclusion

- ➢ **Rich programs for X, Y, Z physics at hadron colliders**

- ➢ **Still puzzle on nature of X(3872), but approaching closer with more properties explored**

  - ➢ **Better precision measurement on both X(3872) mass and D^0 mass**

  - ➢ **Production of X(3872) disagree with theoretical predictions using Molecular hypothesis with NRQCD**

  - ➢ **J^{PC} of X(3872) determined to b 1^{++}**

- ➢ **Puzzle on the existence of X(4140), X(4300) and Z(4430) still remains**

  - ➢ **Its existence should soon be answered with current data collected at LHC**

  - ➢ **Next will be on its properties**