Hadron spectroscopy and exotic states at LHCb

Results and prospects

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SAPIENZA
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Outline

1. The LHC accelerator and its detectors
2. Exotic states
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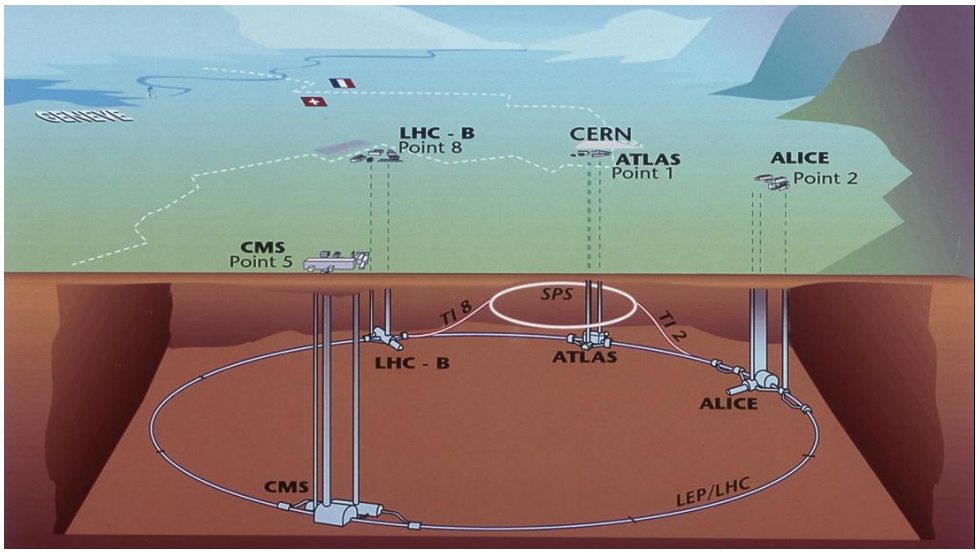
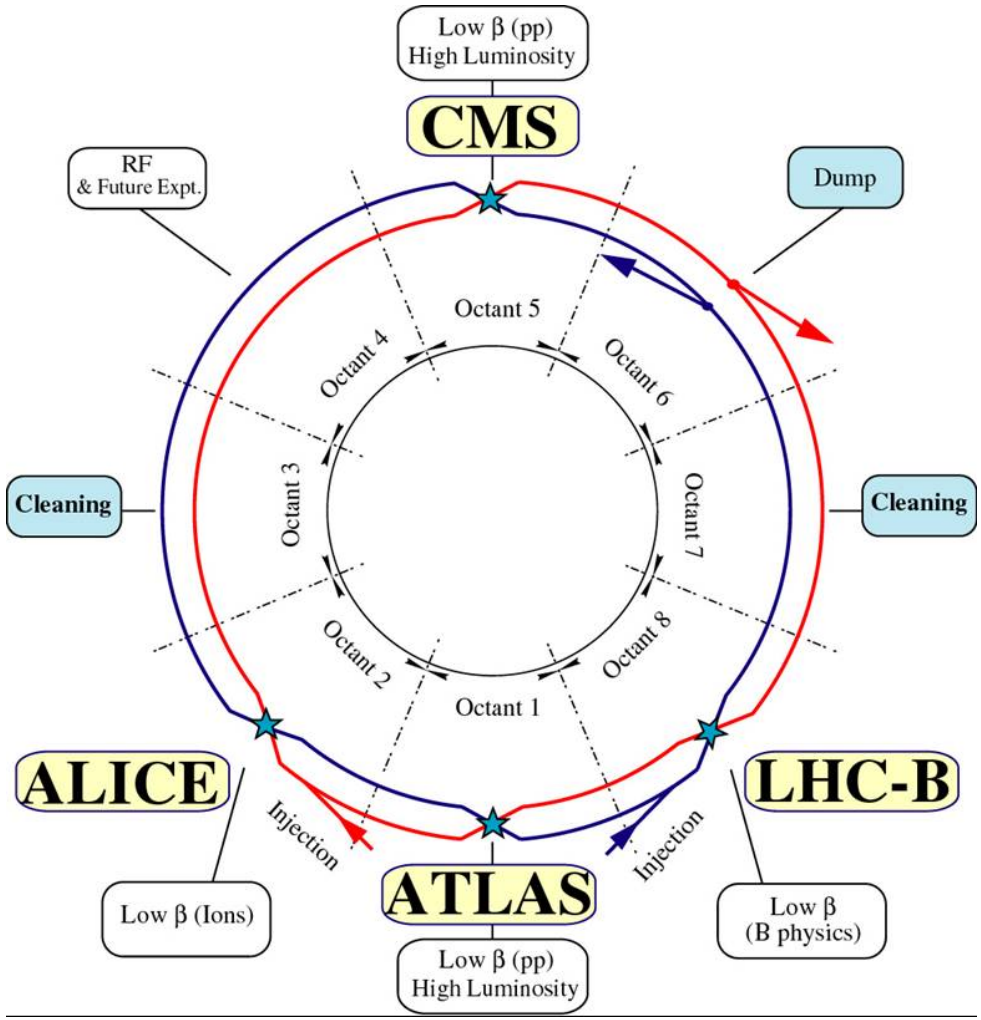
5. Results on $Z(4430)^{+}$
6. Light meson spectroscopy
7. Conclusions

The LHC accelerator and its detectors

The LHC is designed to collide two high luminosity and high energy beams of protons or heavy ions.

- Two general proposal high luminosity experiments: CMS and ATLAS
- One low luminosity experiment, dedicated to flavour physics experiment: LHCb
- Heavy-ion experiment: ALICE





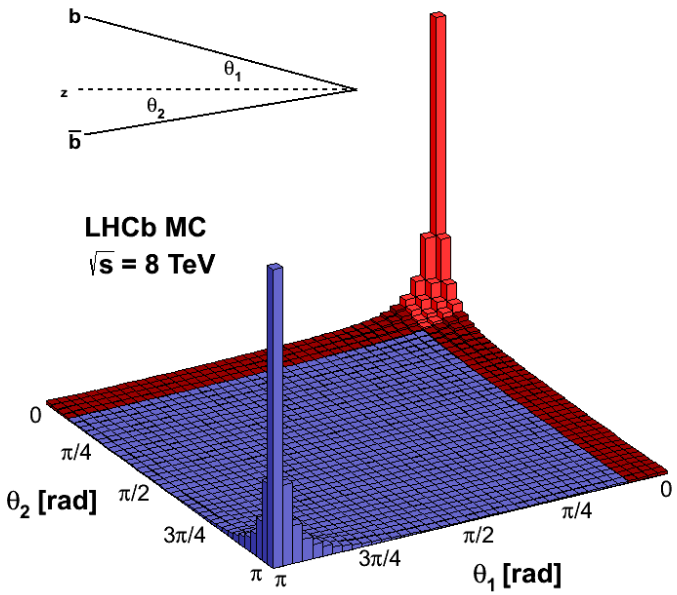
The LHC environment

During most of 2012 run, LHC collided protons at 8 TeV with an average instantaneous luminosity of $4 \times 10^{32} cm^{-2} s^{-1}$ and 20 MHz of bunch crossing. In these conditions:

- Inelastic cross section $\sim 60\,\mathrm{mb}$
- $\sigma(\mathrm{pp} \to \mathrm{b\bar{b}}X) = (284 \pm 20(\mathrm{stat}) \pm 49(\mathrm{syst}))\ \mu\mathrm{b}$ [PLB 694, 209]
- $\Longrightarrow$ $\sim 10^6$ $\mathrm{B\bar{B}}$ produced per second
- $\sigma(\mathrm{pp} \to \mathrm{c\bar{c}}X)$ is about 20 times higher. [Nucl.Phys. B871 (2013) 1-20]

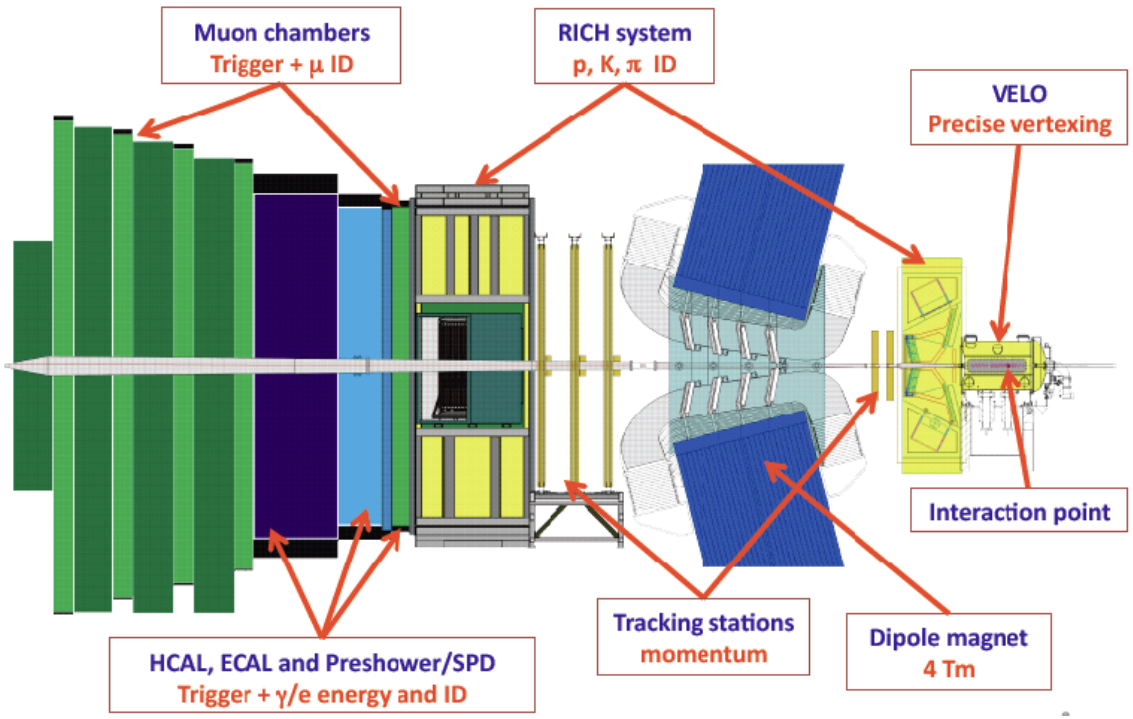
At the LHC energy, the $\mathrm{b\bar{b}}$ pairs are produced preferentially at forward (backward) directions.

- 4π acceptance design is not optimal
- Optimal solution is a forward detector: LHCb



The LHCb detector

LHCb experiment was designed to perform high precision flavor physics measurements at the LHC.



- **Single-arm design.** Covering the range $2 < \eta < 5$, LHCb can exploit the dominant heavy flavour production mechanism at the LHC and detects $\sim$ 40% of the $\mathrm{b\bar{b}}$ produced in foward region.
- **Good particle identification.** Excellent muon identification and good separation of π, K and p over (2 - 100) GeV.

- **Good vertexing and tracking.** Precise primary and secondary vertex reconstruction. Excellent momentum, IP and proper time resolution.
- **Dataset.** $1 + 2$ fb^{-1} aquired in 2011 + 2012 runs

Quarkonia status

In QCD-motivated models, quarkonia states are basically described as $q\bar{q}$ pairs bound by a short-distance potential approximately Coulombic (single-gluon exchange) plus a linearly increasing confining potential at large separations.

- All charmonium states bellow the $D\bar{D}$ mass threshold have been observed.
- Charmonium states above the $D\bar{D}$ or $D\bar{D}^*$ mass threshold can decay into $D\bar{D}$ and $D\bar{D}^*$ final states.
- Many predicted states still not observed.
- Similar situation in the Beauty sector.

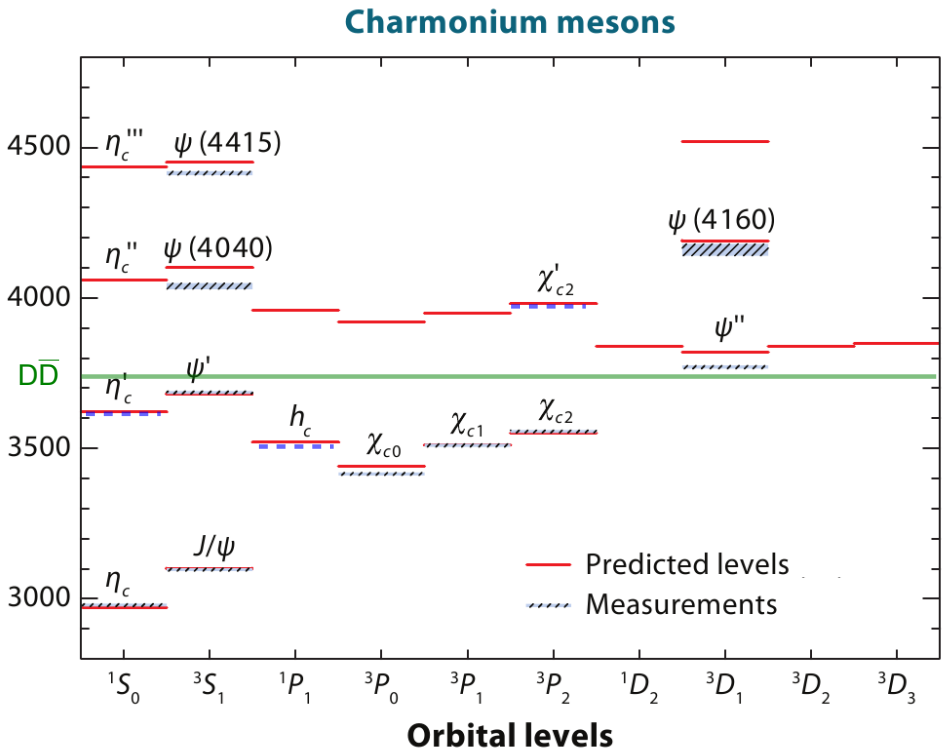


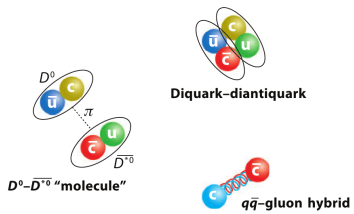
Figure from [Annu.Rev.Nucl. Part. Sci. 2008. 58:51–73]

XYZ states

Many new states have been observed at Charm-, B-factories and Tevatron

- Masses lying on the limits of the quarkonia spectrum
- Observed many different production mechanisms: ISR, e^+e^-, $\gamma\gamma$ and B decays.
- The measured masses does not correspond to the predicted values for conventional quarkonia.
- Properties does not fit very well to the quarkonia picture.

Many theoretical interpretations in discussion:



- conventional quarkonia;
- tetra-quarks states;
- meson-molecules;
- hybrid mesons;
- threshold effects;

The table should be updated to include some new states: Z_b^+, $Z_c(3900)^+$...

State	m (MeV)	Γ (MeV)	J^{PC}	Process (mode)
$X(3872)$	3871.52 ± 0.20	1.3 ± 0.6 (<2.2)	$1^{++}/2^{-+}$	$B\to K(\pi^+\pi^- J/\psi)$ $p\bar{p}\to(\pi^+\pi^- J/\psi)+...$ $B\to K(\omega J/\psi)$ $B\to K(D^{*0}\bar{D}^0)$ $B\to K(\gamma J/\psi)$ $B\to K(\gamma\psi(2S))$
$X(3915)$	3915.6 ± 3.1	28 ± 10	$0/2^{?+}$	$B\to K(\omega J/\psi)$ $e^+e^-\to e^+e^-(\omega J/\psi)$
$X(3940)$	3942^{+9}_{-8}	37^{+27}_{-17}	$?^{?+}$	$e^+e^-\to J/\psi(D\bar{D}^*)$ $e^+e^-\to J/\psi$ (...)
$G(3900)$	3943 ± 21	52 ± 11	1^{--}	$e^+e^-\to\gamma(D\bar{D})$
$Y(4008)$	4008^{+121}_{-49}	226 ± 97	1^{--}	$e^+e^-\to\gamma(\pi^+\pi^- J/\psi)$
$Z_1(4050)^+$	4051^{+24}_{-43}	82^{+51}_{-55}	?	$B\to K(\pi^+\chi_{c1}(1P))$
$Y(4140)$	4143.4 ± 3.0	15^{+11}_{-7}	$?^{?+}$	$B\to K(\phi J/\psi)$
$X(4160)$	4156^{+29}_{-25}	139^{+113}_{-65}	$?^{?+}$	$e^+e^-\to J/\psi(D\bar{D}^*)$
$Z_2(4250)^+$	4248^{+185}_{-45}	177^{+321}_{-72}	?	$B\to K(\pi^+\chi_{c1}(1P))$
$Y(4260)$	4263 ± 5	108 ± 14	1^{--}	$e^+e^-\to\gamma(\pi^+\pi^- J/\psi)$ $e^+e^-\to(\pi^+\pi^- J/\psi)$ $e^+e^-\to(\pi^0\pi^0 J/\psi)$
$Y(4274)$	$4274.4^{+8.4}_{-6.7}$	32^{+22}_{-15}	$?^{?+}$	$B\to K(\phi J/\psi)$
$X(4350)$	$4350.6^{+4.6}_{-5.1}$	$13.3^{+18.4}_{-10.0}$	$0,2^{++}$	$e^+e^-\to e^+e^-(\phi J/\psi)$
$Y(4360)$	4353 ± 11	96 ± 42	1^{--}	$e^+e^-\to\gamma(\pi^+\pi^-\psi(2S))$
$Z(4430)^+$	4443^{+24}_{-18}	107^{+113}_{-71}	?	$B\to K(\pi^+\psi(2S))$
$X(4630)$	4634^{+9}_{-11}	92^{+41}_{-32}	1^{--}	$e^+e^-\to\gamma(\Lambda_c^+\Lambda_c^-)$
$Y(4660)$	4664 ± 12	48 ± 15	1^{--}	$e^+e^-\to\gamma(\pi^+\pi^-\psi(2S))$
$Y_b(10888)$	10888.4 ± 3.0	$30.7^{+8.9}_{-7.7}$	1^{--}	$e^+e^-\to(\pi^+\pi^-\Upsilon(nS))$

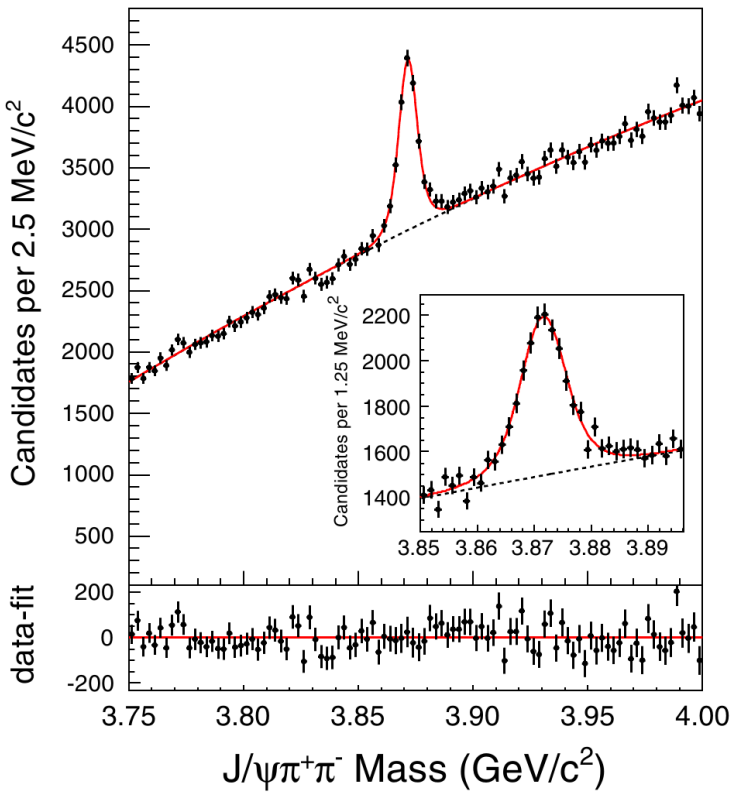
[Eur.Phys.J.C71:1534,2011]

X(3872)

The X(3872) exotic-meson was discovered in 2003 by the Belle collaboration in $\mathrm{B} \to \mathrm{KX(3872)}$ with $\mathrm{X(3872)} \to \mathrm{J}/\psi\pi^+\pi^-$.

- Its existence was immediately confirmed by BaBar,CDF, DØ collaborations.
- Quantum numbers previously constrained to 1^{++} or 2^{-+}. It were just measured by LHCb as 1^{++}.
- Clear signature on the $\mathrm{X(3872)} \to \mathrm{J}/\psi\pi^+\pi^-$ mode. $\pi^+\pi^-$ mass spectrum well studied.
- Mass known to 0.2 MeV and width < 1.2 MeV.

[PRL 103,152001 (2009)]



The nature of the X(3872) remains uncertain:

- Conventional charmonium $\chi_{c1}(2^3\mathrm{P}_1)$.(very unlikely)
- Mesonic molecular state: $D^{*0}\bar{D}^0$ bound state.
- Tetraquark (diquark-anti-diquark).

$\mathrm{X}(3872)$ production studies at LHCb

At LHCb, the $\mathrm{X}(3872)$ can be studied using:

- Prompt candidates: higher statistics but large combinatorial background.
- Candidates from B decays: lower statistics but more clear samples
- Both kinds of candidates (inclusive selection)

$\mathrm{X}(3872)$ production studies at LHCb were performed:

- Measuring the product of production cross-section multiplied by branching ratio to $\mathrm{X}(3872) \to \mathrm{J}/\psi\,\pi^+\pi^-$
- Assuming $\mathrm{X}(3872)$ as a 1^{++} state
- Performing an inclusive selection of $\mathrm{X}(3872) \to \mathrm{J}/\psi\,\pi^+\pi^-$ final state
- Fiducial range: $5 < p_{\mathrm{T}} < 20\ \mathrm{GeV}$ and $2.5 < \mathrm{y} < 4.5$
- Efficiency estimated from Monte Carlo

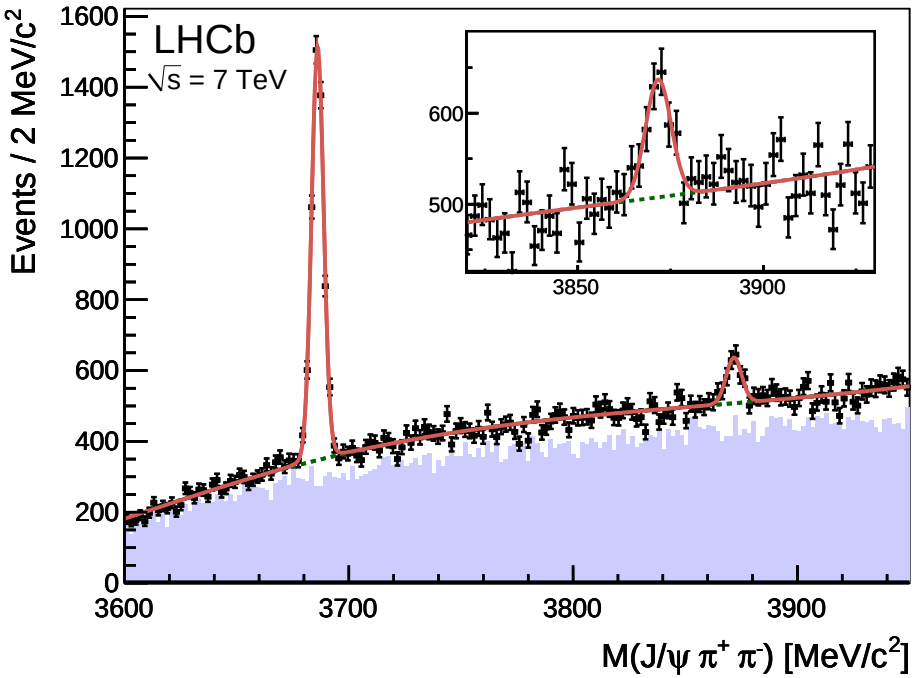
X(3872) production studies at LHCb

[Eur. Phys. J. C. 72 (2012) 1972]

Analysis performed on data sample with integrated luminosity of 34.7 pb^{-1} collected by the LHCb experiment in pp collisions at $\sqrt{s} = 7\ \text{TeV}$ in 2010.

$$\sigma(\text{pp} \to \text{X}(3872) + \cdots) \times \mathcal{B}(\text{X}(3872) \to \text{J}/\psi\,\pi^+\pi^-) = 5.4 \pm 1.3(\text{stat}) \pm 0.8(\text{syst})\,\text{nb}$$

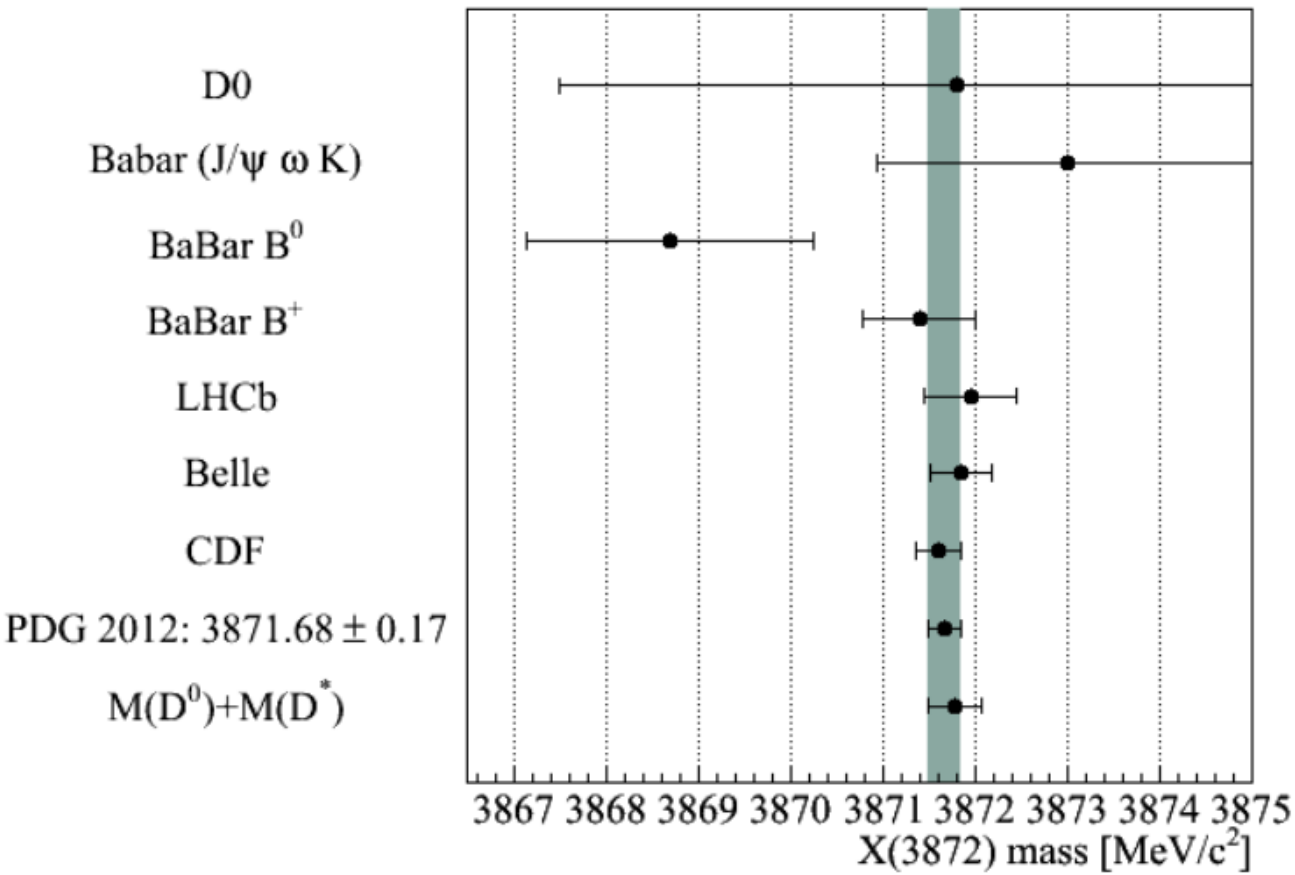
$$\text{M}(X(3872)) = 3871.95 \pm 0.48(\text{stat}) \pm 0.12(\text{syst})\,\text{MeV}/c^2$$



- 585 ± 74 $\text{X}(3872)$ signal candidates
- Momentum scale calibration using $\text{J}/\psi \to \mu^+\mu^-$.
- $\text{X}(3872)$ peak fitted using a Voigt function with fixed width.
- Background studied from wrong-sign pions combinations and modeled by exponential function.
- Uncertainty dominated by statistics. It will improve with 2011 dataset

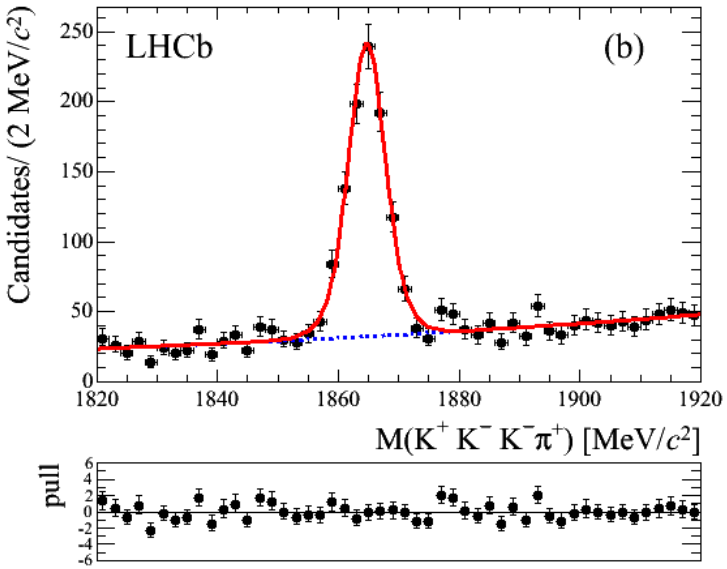
Status of X(3872) mass

- World average and $D^0\bar{D}^0*$-threshold are indistinguishable.
- Mass is a critical parameter for the $D^0\bar{D}^0*$-bound state hypotesis.
- Very low binding energy: $E_{bind} = 0.16 \pm 0.26\ \mathrm{MeV}/c^2$



Precision D^0 mass measurement at LHCb

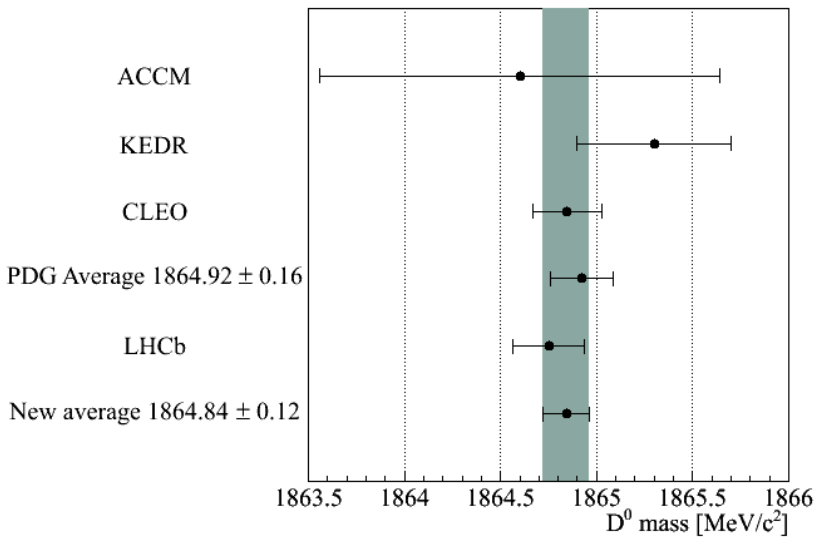
JHEP 1306 (2013) 065



- D^0 mass measurement using D produced in semileptonic B decays
- Using $D^0 \to K^+K^-K^+\pi^-$
- 846 ± 36 events, low Q, low systematics

$$M(D^0) = 1864.75 \pm 0.15(\text{stat}) \pm 0.11(\text{syst})\ \text{MeV}/c^2$$

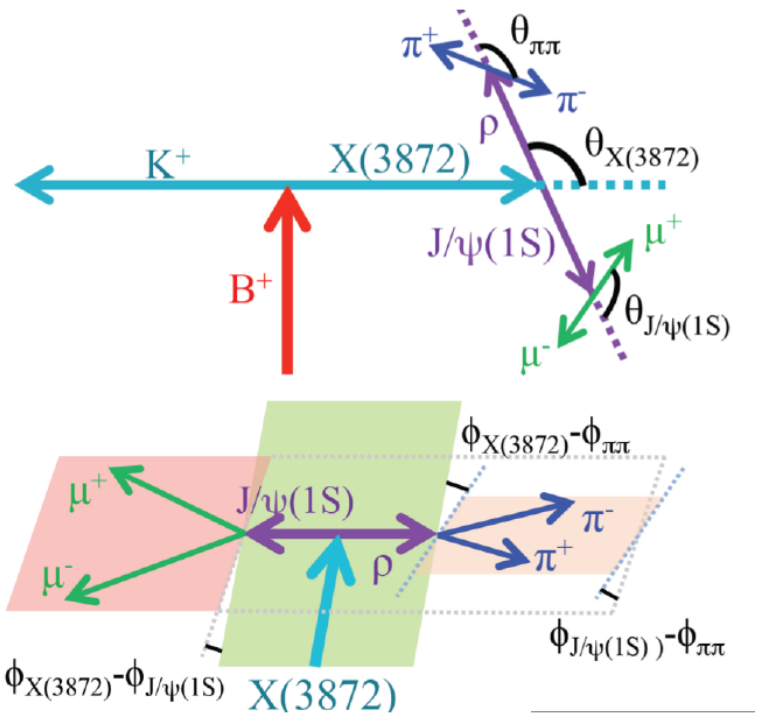
- This result reinforces that if $X(3872)$ is a $D^0\bar{D}^{0*}$ bound-state, it is loosely bound.
- Consistent with arxiv:1212.4191: $M(D^0) = 1864.851 \pm 0.020(\text{stat})$

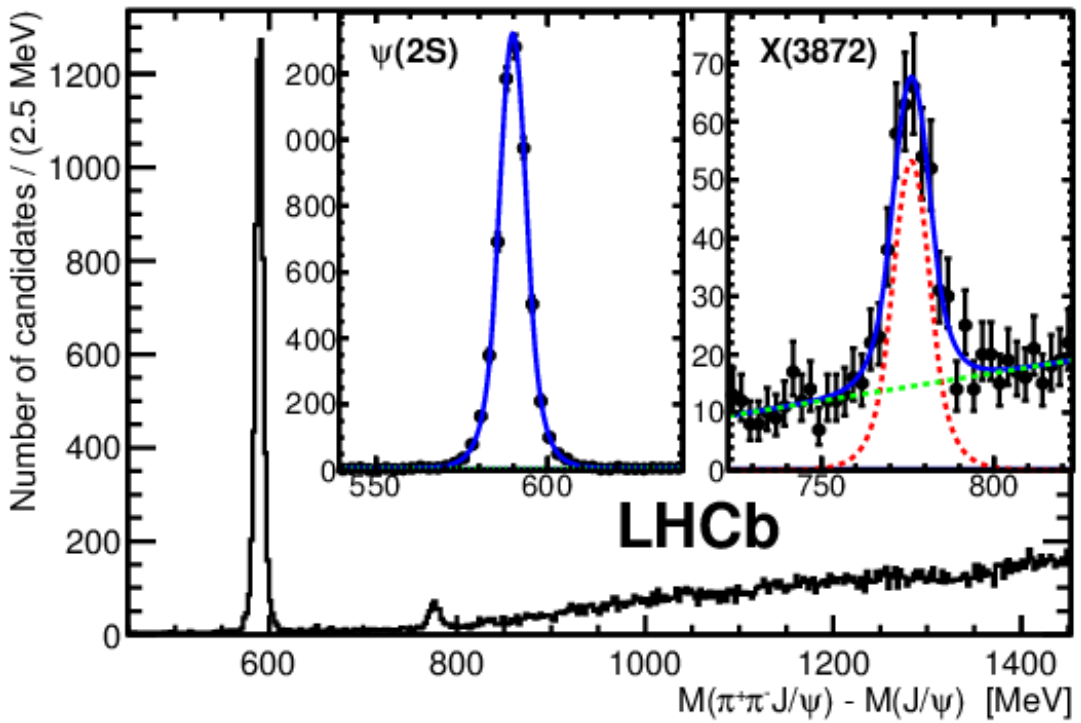


X(3872) quantum numbers determination

Phys. Rev. Lett. 110, 222001 (2013)

- Using the 1.0 fb^{-1} dataset recorded by LHCb in 2011
- 313 ± 26 $B^+ \to K^+X(3872)$ with $X(3872) \to J/\psi\pi^+\pi^-$.
- 5642 ± 76 $B^+ \to K^+\psi(2S)$ with $\psi(2S) \to J/\psi\pi^+\pi^-$.
- 5D analysis: all angular correlations used to measure X(3872) J^{PC}

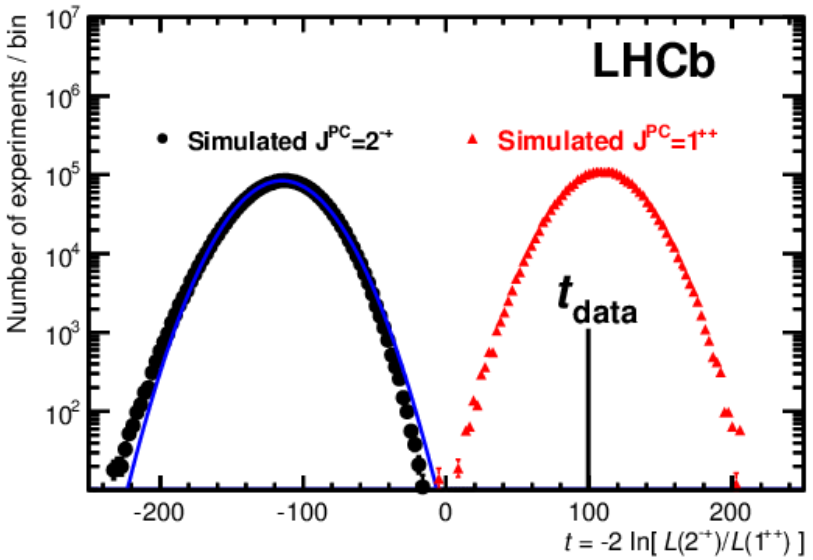


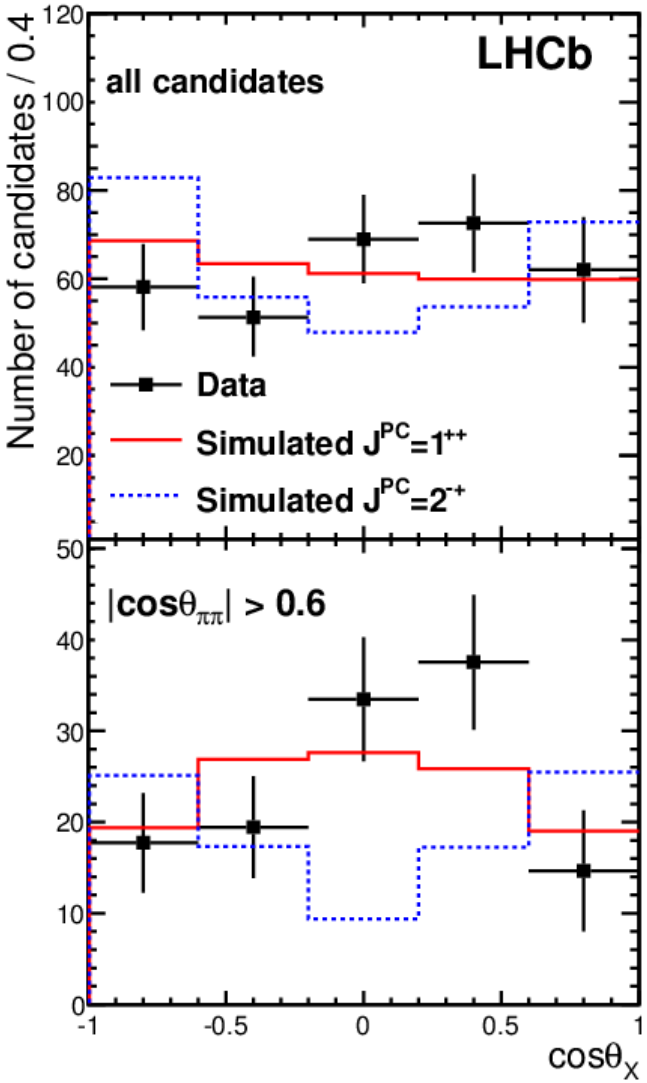


X(3872) quantum numbers determination

Phys. Rev. Lett. 110, 222001 (2013)

- Two X(3872) J^{PC} configurations are considered: 1^{++} and 2^{-+};
- Likelihood-ratio test, to discriminate between the assignments;
- Compare the results to simulated experiments;
- Data favour the 1^{++} over the 2^{-+} hypothesis at 8.4σ;



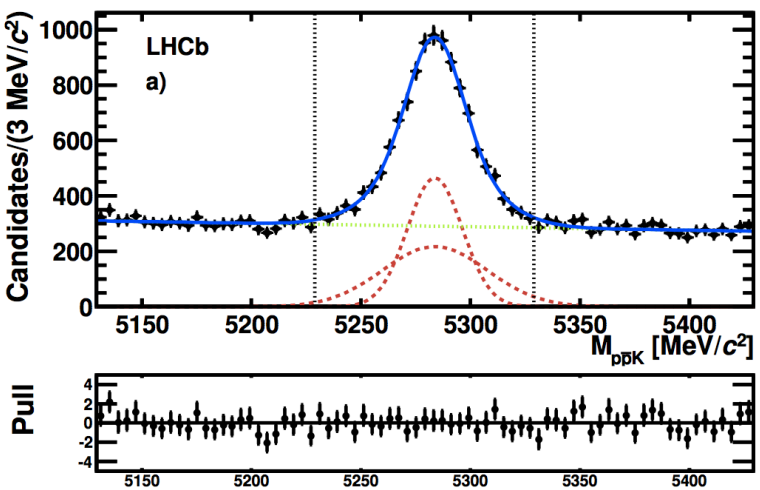


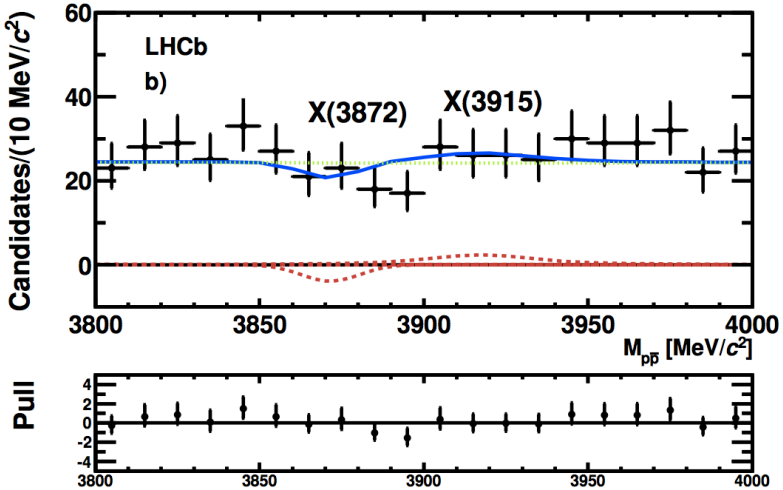
This result favours the interpretations of X(3872) as an exotic state.

Search for $X(3872)$ and $X(3915)$ in $B^+ \to K^+ p\bar{p}$

Eur.Phys.J. C73 (2013) 2462

- Search for $B \to KX(3872)$ with $X(3872) \to p\bar{p}$;
- 6951 ± 176 candidates of $B^+ \to K^+ p\bar{p}$
- $-9 \pm 8(\text{stat}) \pm 2(\text{syst})$ candidates of $X(3872) \to p\bar{p}$
- $13 \pm 17(\text{stat}) \pm 5(\text{syst})$ candidates of $X(3915) \to p\bar{p}$
- $\frac{\mathcal{B}(B^+ \to K^+ X(3872)) \times \mathcal{B}(X(3872) \to p\bar{p})}{\mathcal{B}(B^+ \to K^+ J/\psi) \times \mathcal{B}(J/\psi \to p\bar{p})} < 0.008 \,@\, 95\%\ CL$
- $\frac{\mathcal{B}(B^+ \to K^+ X(3872)) \times \mathcal{B}(X(3915) \to p\bar{p})}{\mathcal{B}(B^+ \to K^+ J/\psi) \times \mathcal{B}(J/\psi \to p\bar{p})} < 0.032 \,@\, 95\%\ CL$





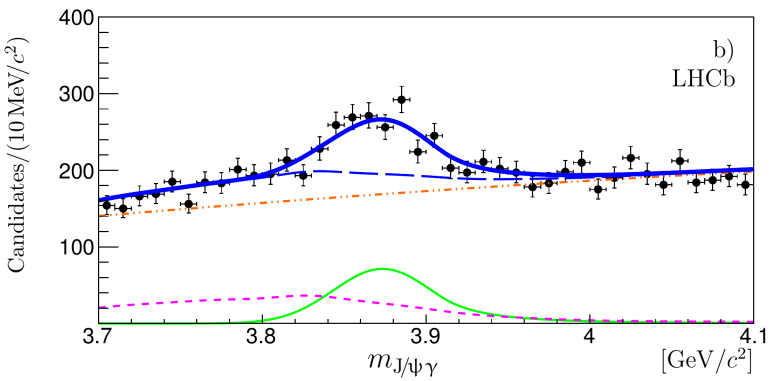
Evidence of $X(3872) \to \psi(2S)\gamma$

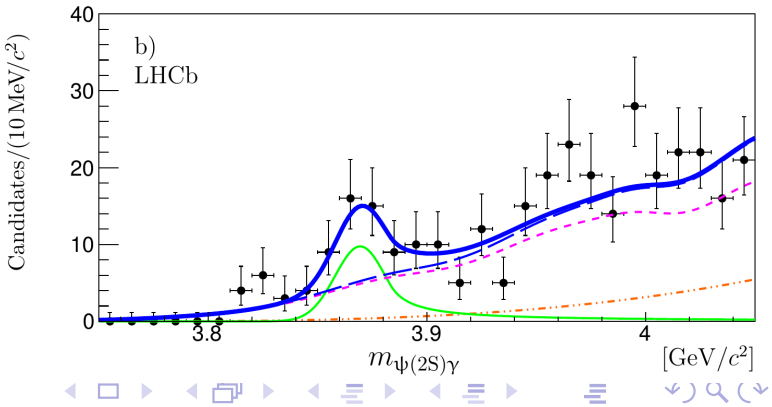
arXiv:1404.0275

Radiative decays of the $X(3872)$ provide a valuable opportunity to understand its nature.

- The $X(3872)$ C-parity has been determined studying the $X(3872) \to \gamma J/\psi$ decay.
- $R_{\psi\gamma} = \frac{\mathcal{B}(X(3872)\to\psi(2S)\gamma)}{\mathcal{B}(X(3872)\to J/\psi\,\gamma)}$ can give information about the internal structure of $X(3872)$.

- Analysis performed using 3 fb^{-1} collected in 2011 and 2012.
- Observed $4.4\,\sigma$ evidence of $X(3872) \to \psi(2S)\gamma$ in $B^+ \to K^+X(3872)$ decays.



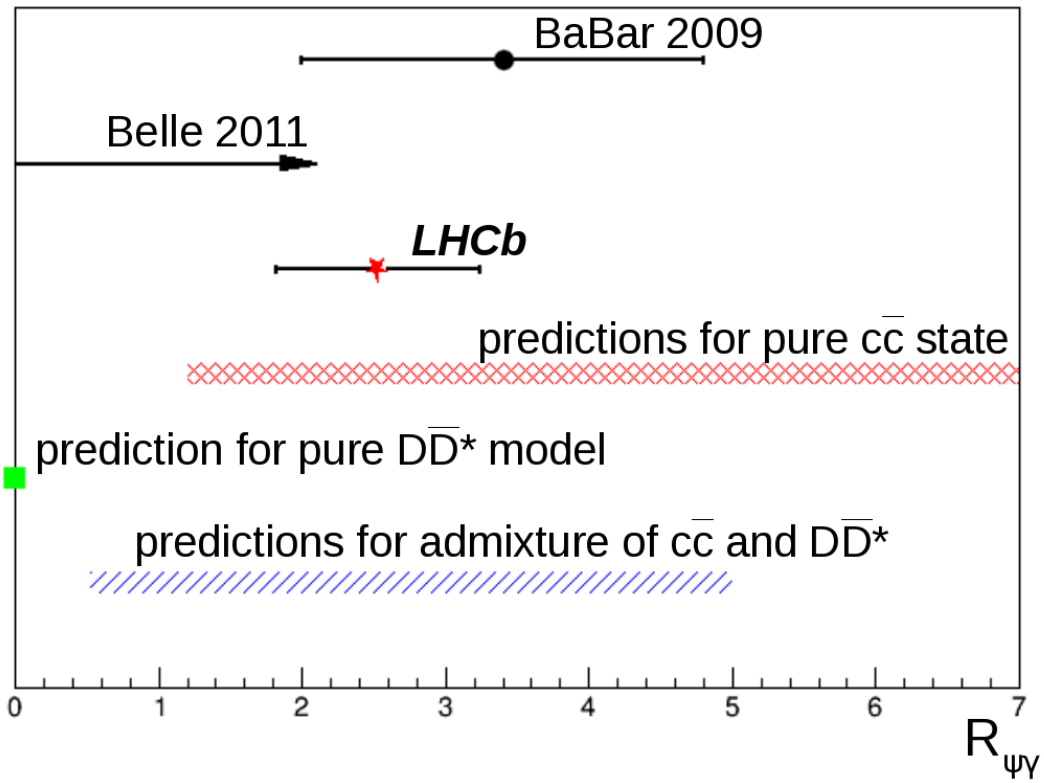


Parameter		Decay mode $X(3872) \to J/\psi\gamma$	$X(3872) \to \psi(2S)\gamma$
m_{B^+}	[MeV/c^2]	5277.7 ± 0.8	5281.9 ± 2.4
$m_{X(3872)}$	[MeV/c^2]	3873.4 ± 3.4	3869.5 ± 3.4
N_ψ		591 ± 48	36.4 ± 9.0

Evidence of $X(3872) \to \psi(2S)\gamma$

arXiv:1404.0275

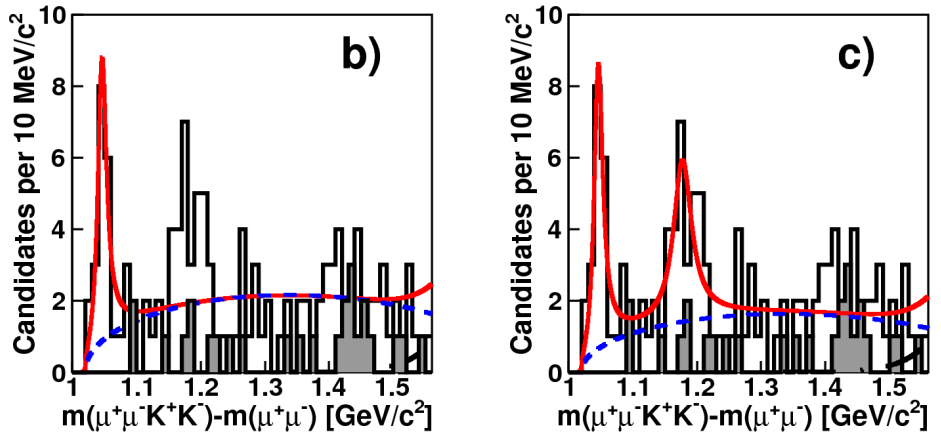
- $$R_{\psi\gamma} = \frac{\mathcal{B}(X(3872) \to \psi(2S)\gamma)}{\mathcal{B}(X(3872) \to J/\psi\,\gamma)} = 2.46 \pm 0.64 \pm 0.29$$
- These results disfavours $D^{*0}\bar{D}^{0}$ molecule hypothesis



The X(4140) and X(4274) candidates

Two exotic resonance candidates observed by CDF in $B^{\pm} \to J/\psi\,\phi K^{\pm}$ decays and decaying into $J/\psi\,\phi$.

[Ref. Phys.Rev.Lett. 102.242002, arXiv:1101.6058].



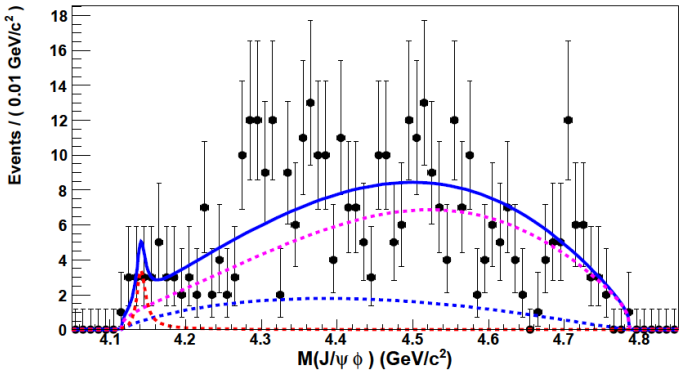
- 115 ± 12 candidates of $B^{\pm} \to J/\psi\,\phi K^{\pm}$
- X(4140) candidate with $M_{X(4140)} = 4143.4^{+2.9}_{-3.0} \pm 0.6\ \mathrm{MeV}/c^2$, $\Gamma_{X(4140)} = 15.3^{+10.4}_{-6.1} \pm 2.5\ \mathrm{MeV}/c^2$, with yield of 19 ± 6 and statistical significance of 5.0σ.
- Maybe a second state: $M_{X(4274)} = 4274.4^{+8.4}_{-6.4} \pm 1.9\,\mathrm{MeV}/c^2$, $\Gamma_{X(4274)} = 32.3^{+21.9}_{-15.3} \pm 7.6\,\mathrm{MeV}/c^2$, with yield of 22 ± 8 and statistical significance of 3.1σ.
- CDF results imply:

$$\mathcal{B}(B^+ \to X(4140)K^+) \times \mathcal{B}(X(4140) \to J/\psi\,\phi) = (5.2 \pm 1.7) \times 10^{-5}$$

The X(4140) and X(4274) candidates

Belle experiment also have searched for X(4140) and X(4274)

[see J. Brodzicka, Heavy flavour spectroscopy (LP09)]



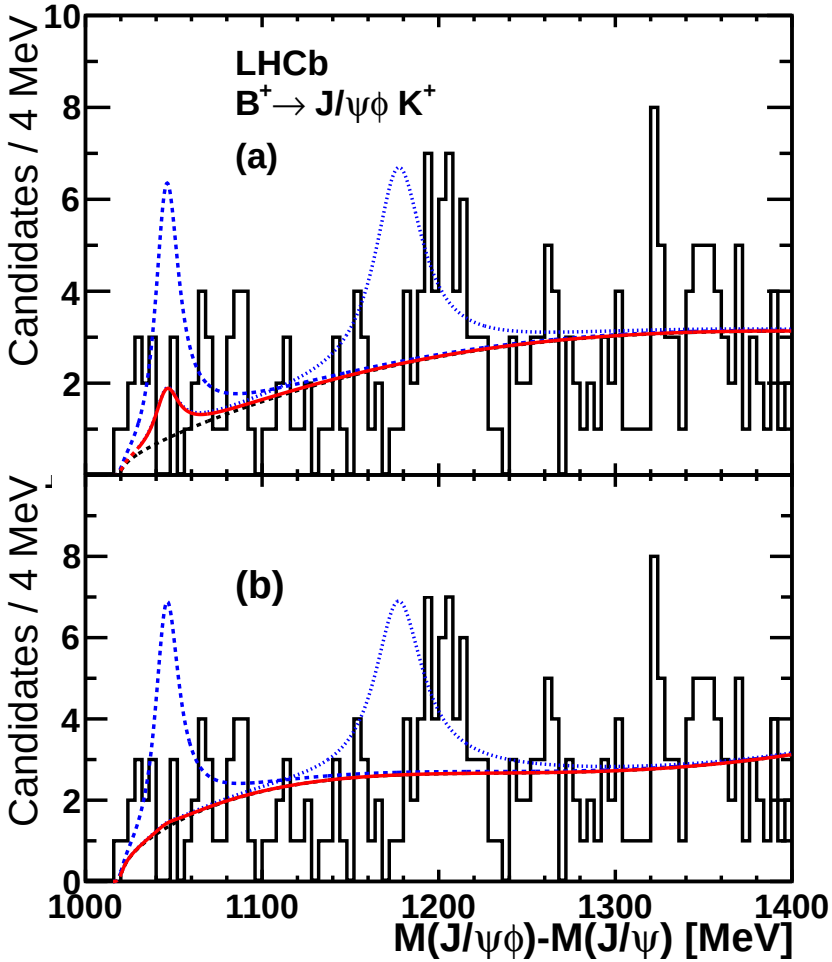
- Belle accumulated more events on $B^+ \to J/\psi\phi K^+$ than CDF but could not confirm or exclude the X(4140).
- Loss of efficiency near the threshold resulted in a lower sensitivity to X(4140) at Belle.
- $\mathcal{B}(B^+ \to X(4140)K^+) \times \mathcal{B}(X(4140) \to J/\psi\phi) < 6 \times 10^{-6}$

In summary:

- Charmonium states at this mass are expected to have much larger widths because of open flavour decay channels.
- Their decay rate into the $J/\psi\,\phi$ mode (so near the kinematic threshold) should be small and unobservable.
- Then, the observation by CDF has triggered much theoretical interest about the nature of this candidates.
- The existence of X(4140) and X(4274) candidates remains unconfirmed.

Search for $\mathrm{X}(4140)$ and $\mathrm{X}(4274)$

- The LHCb sensitivity to $\mathrm{X}(4140)$ signal is a factor two better than in CDF.
- According the CDF results, we should observe 35 ± 11 $\mathrm{X}(4140)$ signal candidates and 53 ± 19 $\mathrm{X}(4274)$ signal candidates.
- No narrow structure is observed near the threshold.
- The fit shown in (a) gives a $\mathrm{X}(4140)$ yield of 6.9 ± 4.9 events and a $\mathrm{X}(4274)$ yield of $3.4^{+6.5}_{-3.4}$ events.
- The fit shown in (b) gives a $\mathrm{X}(4140)$ yield of 0.6 events with a positive error of 7.1 events and zero signal $\mathrm{X}(4274)$ events with a positive error of 10.



- The solid red line represents the result of the fit to our data.
- The dashed blue line represents the the expected signal amplitude from the CDF results.
- The top and bottom plots background functions are: a) efficiency-corrected three-body phase-space; b) quadratic polynominal.

Results on $X(4140)$ and $X(4274)$ at LHCb

Phys. Rev. D 85,091103(R)(2012)

The results of the search for $X(4140)$ and $X(4274)$ at LHCb are the two following limits calculated at 90%CL:

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

LHCb(a)	LHCb(b)	CDF
< 0.07	< 0.04	$0.149 \pm 0.039 \pm 0.024$

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

LHCb	CDF (our estimate)
< 0.08	0.17 ± 0.06

In conclusion, LHCb performed the most sensitive search for the narrow $X(4140)$ and $X(4274)$ structures and:

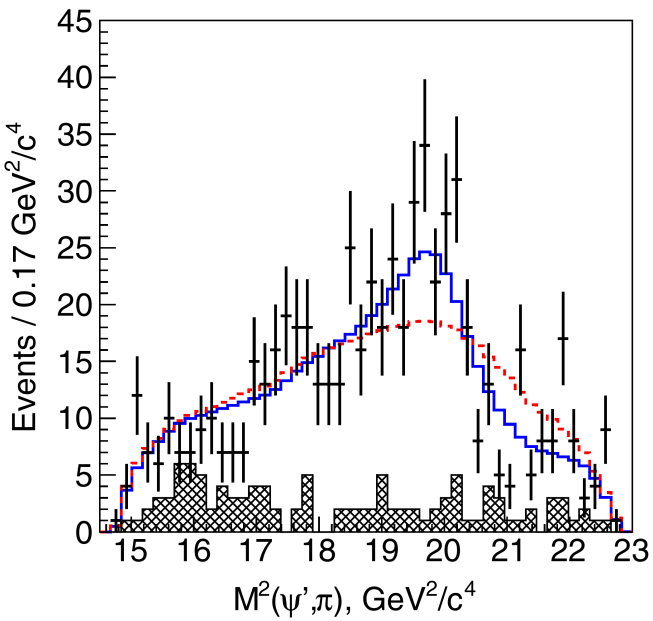
- Does not confirm the $X(4140)$ state previously reported by the CDF
- Does not observe any evidence of the $X(4274)$
- The LHCb results disagree at the 2.4σ level with the CDF measurement.

$Z(4430)^+$

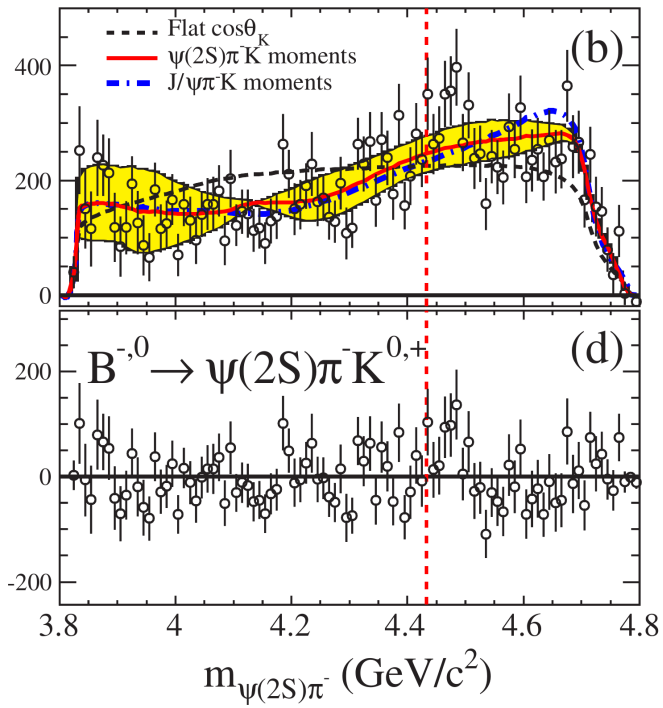
- Charged charmonium like state reported by Belle in $B^0 \to \psi(2S)K^+\pi^-$ decays [Phys.Rev.D88:074026]
- Searched and not confirmed or excluded by BaBar [Phys.Rev.D79:112001]
- Can not be explained as conventional object inside the Standard Model.
- Minimum quark content: $c\bar{c}u\bar{d}$
- No corresponding structure observed in $B^0 \to J/\psi K^+\pi^-$

$Z(4430)^+$ at Belle. $K^*(892)^0$ and $K_2^*(1432)$ vetoed.

With $Z(4430)^+$ and No $Z(4430)^+$



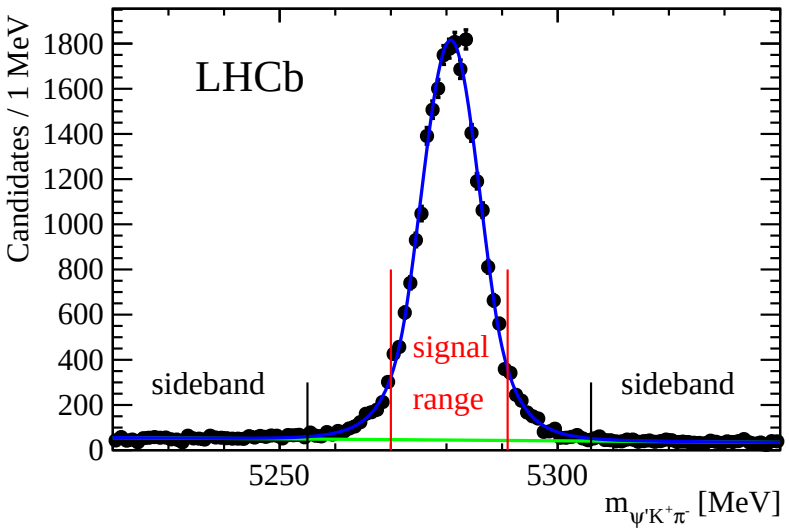
$Z(4430)^+$ at BaBar. Legendre polynomials approach.



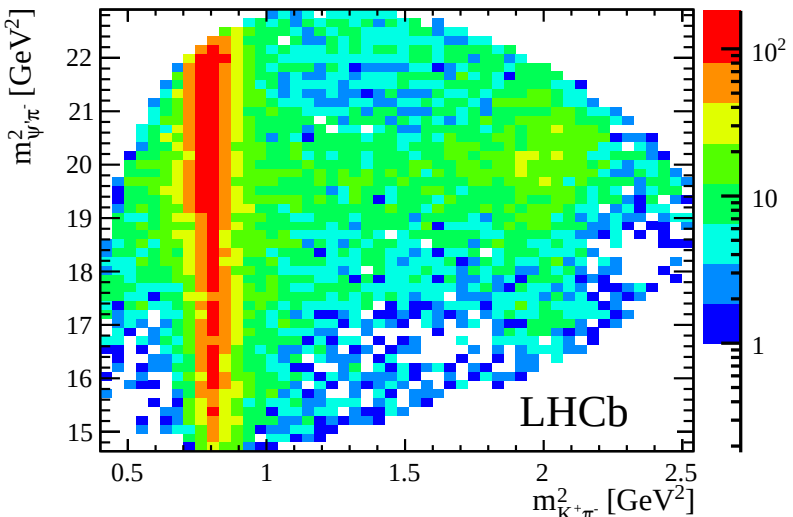
Confirmation of $Z(4430)^+$ at LHCb

arXiv:1404.1903

- Sample with >25.000 $\mathrm{B}^0 \to \mathrm{K}^+\pi^-\psi(2S)$ signal candidates,
- Analysis performed using two different approaches:
  - Model dependent. Four-dimensional amplitude fit.
  - Model independent. An analysis based on the Legendre polynomial moments extracted from the $\mathrm{K}\pi$ system
- Background from sidebands. Estimated 4% of combinatorial background in the signal region.
- Four-dimensional efficiency calculated using complete simulation of the detector



background subtracted Dalitz plot



$Z(4430)^+$: model independent analysis

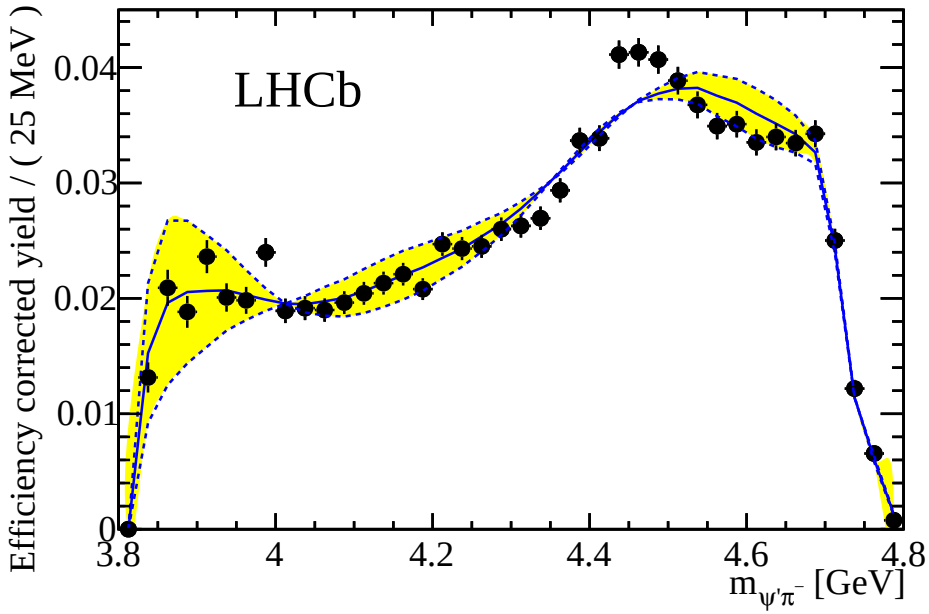
arXiv:1404.1903

The main goal is to check if the structures in the spectrum can be explained as reflections of the resonance activity in the $K\pi$ system.

- No assumptions on the K^* resonances. Only its maximum J is restricted.
- Angular structure of the $K\pi$ system is extracted using Legendre polynomial moments.
- The moments are used in toy Monte Carlo simulation to predict the expected spectrum.
- spectrum can not be explained in terms of moments corresponding to resonances with $J <= 2$.

Amplitude fit is necessary for:

- Determine the K^* resonant structure of the $K\pi$ system.
- Determine the $Z(4430)^+$ parameters (mass, width, spin etc).



$Z(4430)^+$: amplitude fit

arXiv:1404.1903

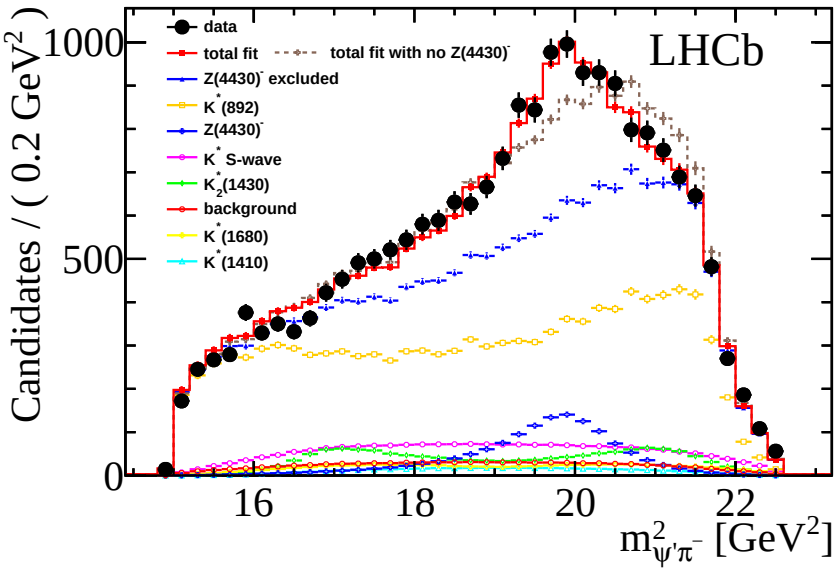
- Fitted parameters:

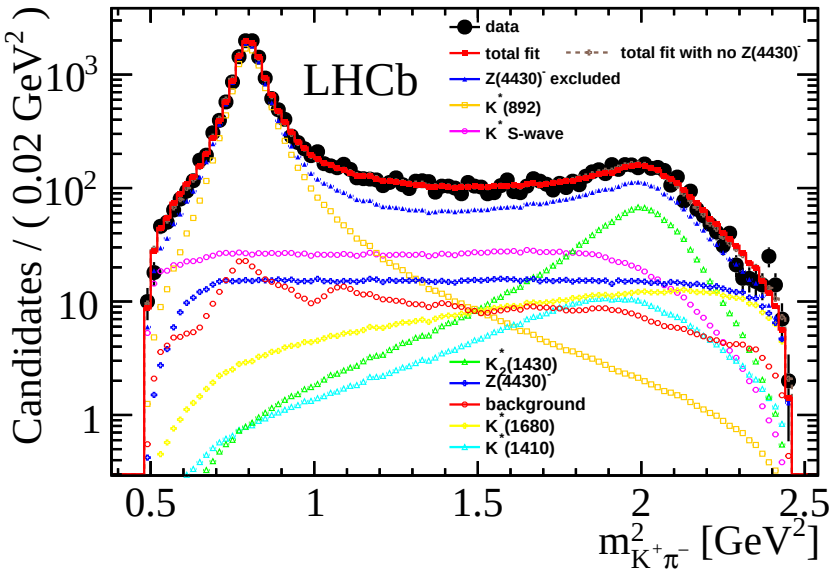
$$M_{Z(4430)^+} = 4475 \pm 7^{+15}_{-25}\,\mathrm{MeV}/c^2, \Gamma_{Z(4430)^+} = 172 \pm 13^{+37}_{-34}\,\mathrm{MeV}/c^2$$

$$f_{Z(4430)^+} = (5.9 \pm 0.9^{+1.5}_{-3.3})\%$$

.

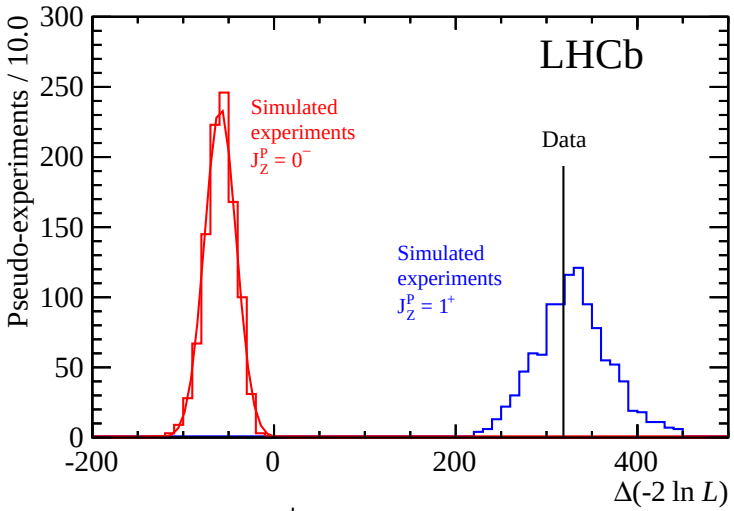
- Significance: $\Delta(-2lnL) > 13.9\sigma$





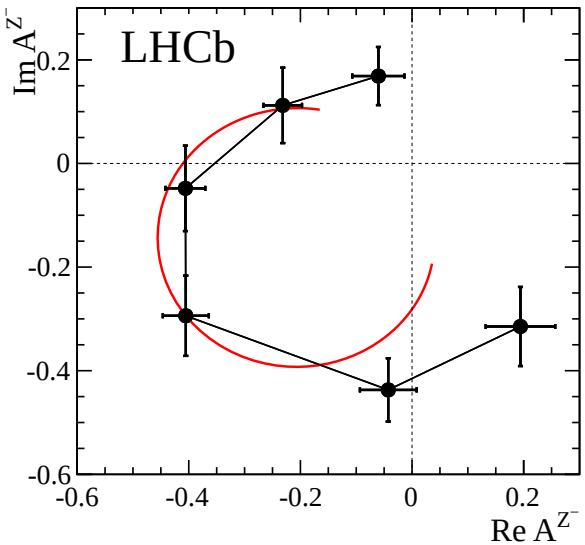
$Z(4430)^+$: resonance character and spin determination

arXiv:1404.1903



- $J^P = 1^+$ assignment favoured.
- Other J^P assignments are rulled out with large significance: $> 9\sigma$

- $Z(4430)^+$ amplitude is described by 6 independent complex numbers instead of a Breit-Wigner
- Observe a fast change of phase crossing maximum of magnitude.
- Expected behaviour for a resonance.



Spectroscopy in light quark sector: $\mathrm{B}^0 \to \mathrm{J}/\psi\,\pi^+\pi^-$

- The substructure of mesons belonging to the scalar nonet is controversial.
- Many possibilities: $\mathrm{q\bar{q}}$, $\mathrm{q\bar{q}q\bar{q}}$, mixtures etc.
- $\mathrm{q\bar{q}}$ case:

$$\begin{aligned} |f_0(980)\rangle &= \cos\varphi_m|s\bar{s}\rangle + \sin\varphi_m|n\bar{n}\rangle \\ |f_0(500)\rangle &= -\sin\varphi_m|s\bar{s}\rangle + \cos\varphi_m|n\bar{n}\rangle, \\ \text{where } |n\bar{n}\rangle &\equiv \frac{1}{\sqrt{2}}\left(|u\bar{u}\rangle + |d\bar{d}\rangle\right). \end{aligned}$$

- $\mathrm{q\bar{q}q\bar{q}}$ case:

$$\begin{aligned} |f_0(980)\rangle &= \frac{1}{\sqrt{2}}\left(|[su][\bar{s}\,\bar{u}]\rangle + |[sd][\bar{s}\bar{d}]\rangle\right) \\ |f_0(500)\rangle &= |[ud][\bar{u}\bar{d}]\rangle. \end{aligned}$$

- Observable of interest for both cases:

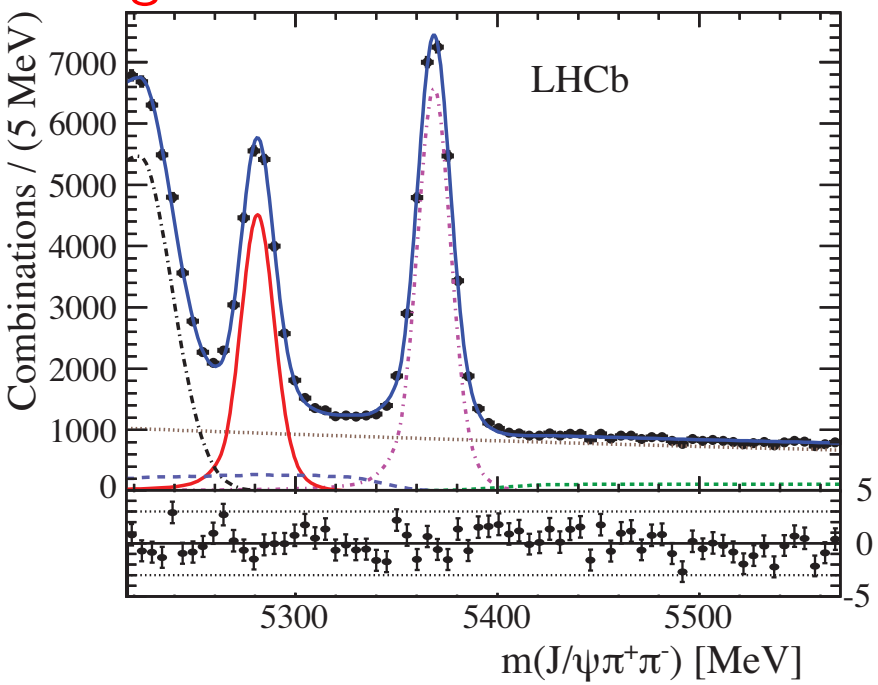
$$\tan^2\varphi_m \equiv r_\sigma^f = \frac{\mathcal{B}\left(\overline{B}^0 \to J/\psi\, f_0(980)\right)}{\mathcal{B}\left(\overline{B}^0 \to J/\psi\, f_0(500)\right)}\frac{\Phi(500)}{\Phi(980)}$$

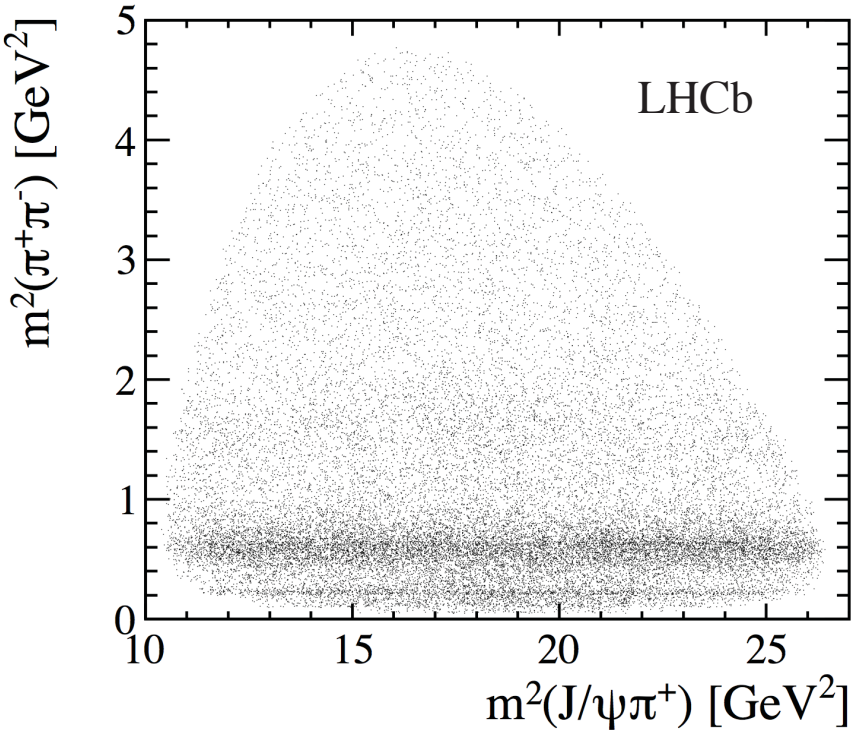
- Prediction for tetraquark states: $r_\sigma^f = 1/2$ [PRL 111, 062001 (2013)]

Amplitude analysis of $B^0 \to J/\psi \pi^+\pi^-$

- Approach similar to the analysis: 4D matrix element describing π^+ π^- resonances;
- No evidence of $J/\psi \pi^+$ resonances
- 19,000 B^0 signal candidates
- Background modelled from sidebands

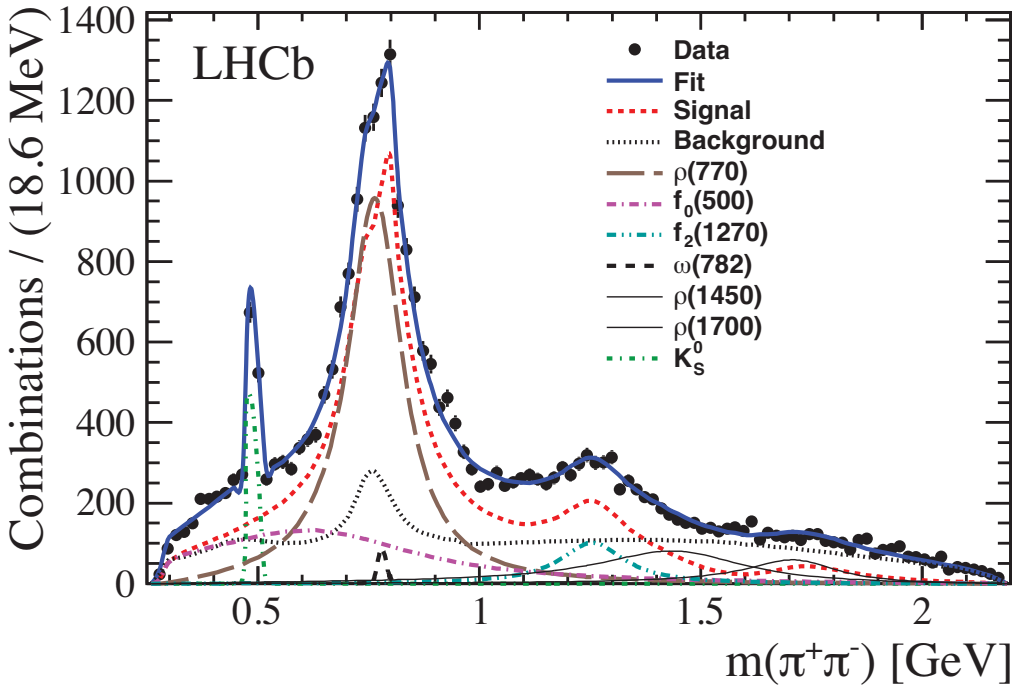
Signal B^0 candidates in red.





Amplitude analysis of $B^0 \to J/\psi \pi^+\pi^-$

R	$\mathcal{B}(\overline{B}^0 \to J/\psi R, R \to \pi^+\pi^-)$
$\rho(770)$	$(2.50 \pm 0.10^{+0.18}_{-0.15}) \times 10^{-5}$
$f_0(500)$	$(8.8 \pm 0.5^{+1.1}_{-1.5}) \times 10^{-6}$
$f_2(1270)$	$(3.0 \pm 0.3^{+0.2}_{-0.3}) \times 10^{-6}$
$\omega(782)$	$(2.7^{+0.8+0.7}_{-0.6-0.5}) \times 10^{-7}$
$\rho(1450)$	$(4.6 \pm 1.1 \pm 1.9) \times 10^{-6}$
$\rho(1700)$	$(2.0 \pm 0.5 \pm 1.2) \times 10^{-6}$



- Best fit model shows does not require $f_0(980)$ component.
- Upper limit on the $f_0(500) - f_0(980)$ mixing angle.
- Different from tetraquark prediction (1/2) by 8σ

$$\tan^2 \varphi_m \equiv r_\sigma^f = \left(1.1^{+1.2+6.0}_{-0.7-0.7}\right) \times 10^{-2} < 0.098 \quad \text{at } 90\% \text{ C.L}$$

Many other results in b and c spectroscopy

Access:

http://lhcbproject.web.cern.ch/lhcbproject/CDS/cgi-bin/index.php

LHCb Papers

N°	Title	Journal	Code	Submit Date	Lead Group
185	Measurement of the Ξ_b^- and Ω_b^- baryon lifetimes	()	LHCB-PAPER-2014-010	07 May 2014	B2CC
184	Measurement of the resonant and CP components in $\overline{B}^0 \to J/\psi\pi^+\pi^-$ decays	()	LHCB-PAPER-2014-012	05 May 2014	B2CC
183	Observation of the resonant character of the $Z(4430)^-$ state	()	LHCB-PAPER-2014-014	07 Apr 2014	B&Q
182	Evidence for the decay $B_c^+ \to J/\psi 3\pi^+ 2\pi^-$	()	LHCB-PAPER-2014-009	1 Apr 2014	B&Q
181	Evidence for the decay $X(3872) \to \psi(2S)\gamma$	()	LHCB-PAPER-2014-008	1 Apr 2014	B&Q
180	Angular analysis of charged and neutral $B \to K\mu^+\mu^-$ decays	()	LHCB-PAPER-2014-007	31 Mar 2014	RD
179	Differential branching fractions and isospin asymmetries of $B \to K^{(*)}\mu^+\mu^+$ decays	()	LHCB-PAPER-2014-006	31 Mar 2014	RD
178	Study of beauty hadron decays into pairs of charm hadrons	()	LHCB-PAPER-2014-002	14 Mar 2014	B2OC
177	Measurement of polarization amplitudes and CP asymmetries in $B^0 \to \phi K^*(892)^0$	()	LHCB-PAPER-2014-005	12 Mar 2014	BNoC

Summary and perspectives

$\mathrm{X}(3872)$

- LHCb has measured the mass and production cross section in the range: $5 < p_{\mathrm{T}} < 20$ GeV and $2.5 < \mathrm{y} < 4.5$ using 2010;
- LHCb measured the $\mathrm{X}(3872)$ quantum numbers.
- We need to know with higher precision the D^0 and masses in order to check if $\mathrm{X}(3872)$ mass is up or bellow the $\mathrm{D}^0\mathrm{D}^*$ mass threshold.
- Charmonium interpretation strongly disfavored.

$\mathrm{X}(4140)$ and $\mathrm{X}(4274)$

- Not confirmed by LHCb.
- Working in progress at LHCb to update the analysis using 2011 + 2012 dataset.

$Z(4430)^+$

- Existence confirmation with $> 13.0\sigma$
- Quantum numbers determination $J^P = 1^+$
- Resonant behaviour observed.

Light quark spectroscopy using $\mathrm{B}^0 \to \mathrm{J}/\psi\,\pi^+\pi^-$

- No evidence for $f_0(980)$ resonance production

$f_0(980)$ as a tetraquark state ruled out at $8\,\sigma$

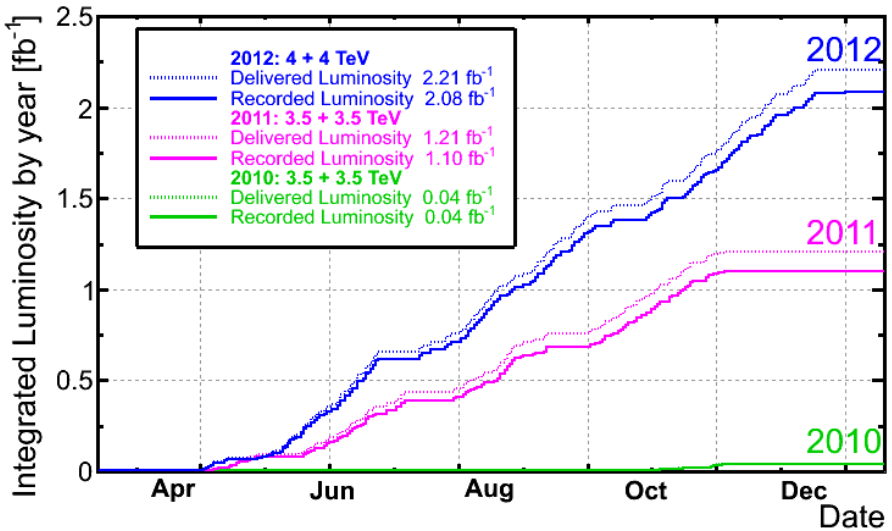
Thanks!

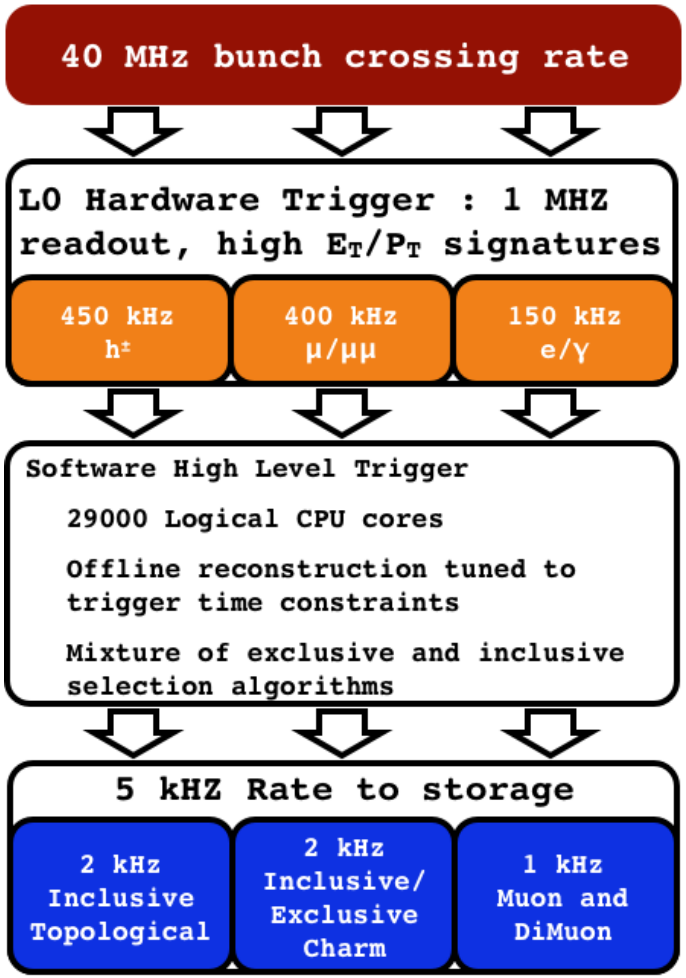
Backup

The LHCb trigger and dataset

Running conditions in most of 2012

- LHC: 20 MHz bunch crossing
- Luminosity: $4.0 \times 10^{32} cm^{-2} s^{-1}$, using luminosity leveling
- Visible interactions rate: 12.0 - 14.0 MHz
- L0 output rate: 950 kHz
- HLT output rate:4.5 kHz
- Event size: 60 kB





37 pb^{-1} **acquired in 2010**

1 fb^{-1} **acquired in 2011**

2 fb^{-1} **acquired in 2012**

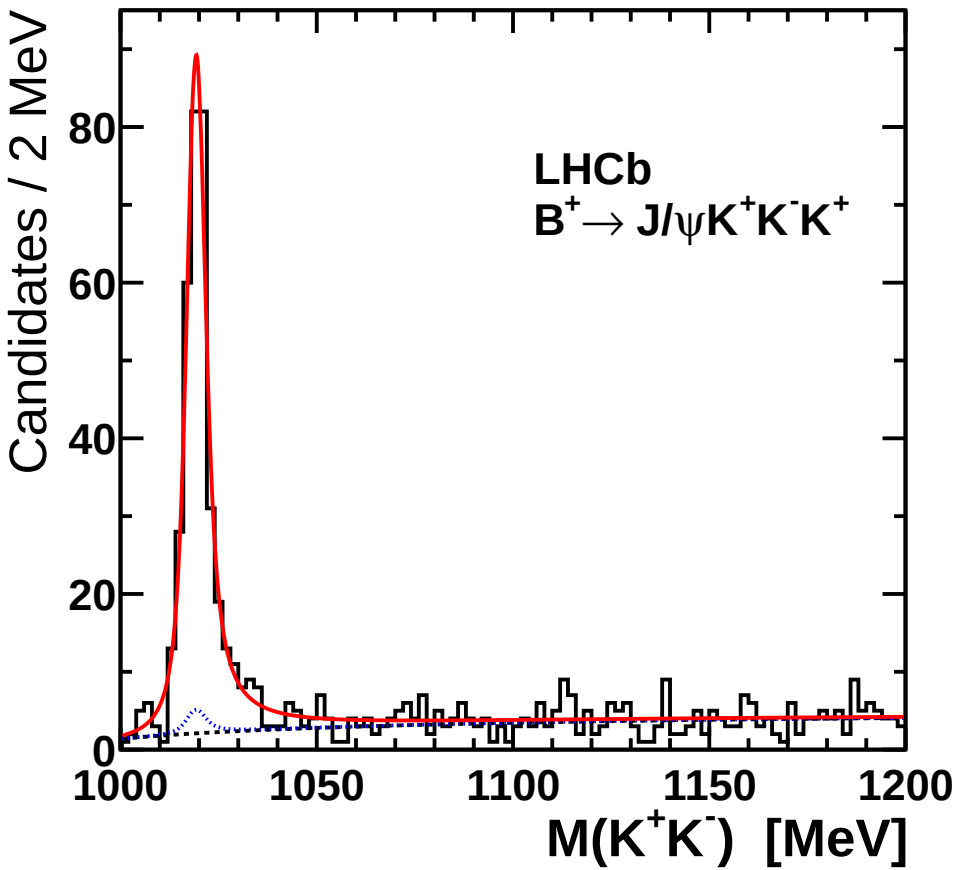
X(3872) mass measurement at LHCb: uncertainties

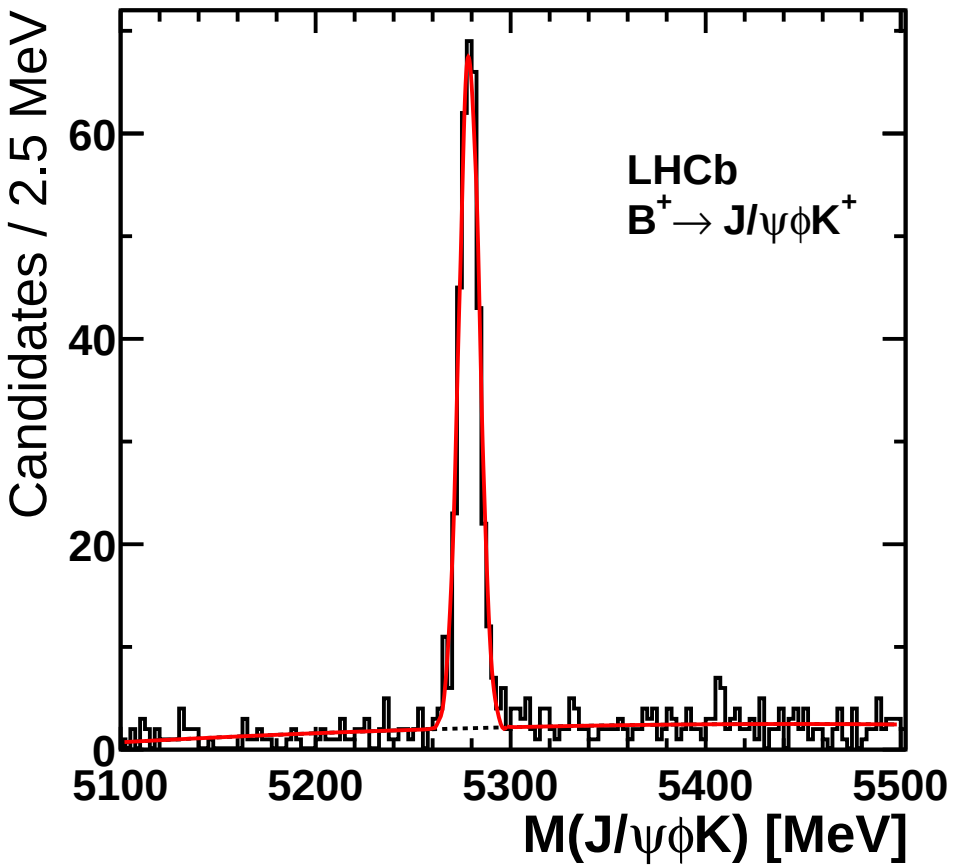
Source of uncertainty	$\Delta\sigma/\sigma$ [%]
$X(3872)$ polarization	2.1
$X(3872)$ decay model	1.0
$X(3872)$ decay width	5.0
Mass resolution	5.8
Background model	6.4
Tracking efficiency	7.4
Track χ^2 cut	2.0
Vertex χ^2 cut	3.0
Muon trigger efficiency	2.9
Global event cuts	3.0
Muon identification	1.1
Integrated luminosity	3.5
$J/\psi \to \mu^+\mu^-$ branching fraction	1.0
Total	14.3

Category	Source of uncertainty	Δm [MeV/c^2]	
		$\psi(2S)$	$X(3872$
Mass fitting	Natural width	–	0.01
	Radiative tail	0.02	0.02
	Resolution	–	0.01
	Background model	0.02	0.02
Momentum calibration	Average momentum scale	0.08	0.10
	η dependence of momentum scale	0.02	0.03
Detector description	Energy loss correction	0.05	0.05
Detector alignment	Track slopes	0.01	0.01
Total		0.10	0.12

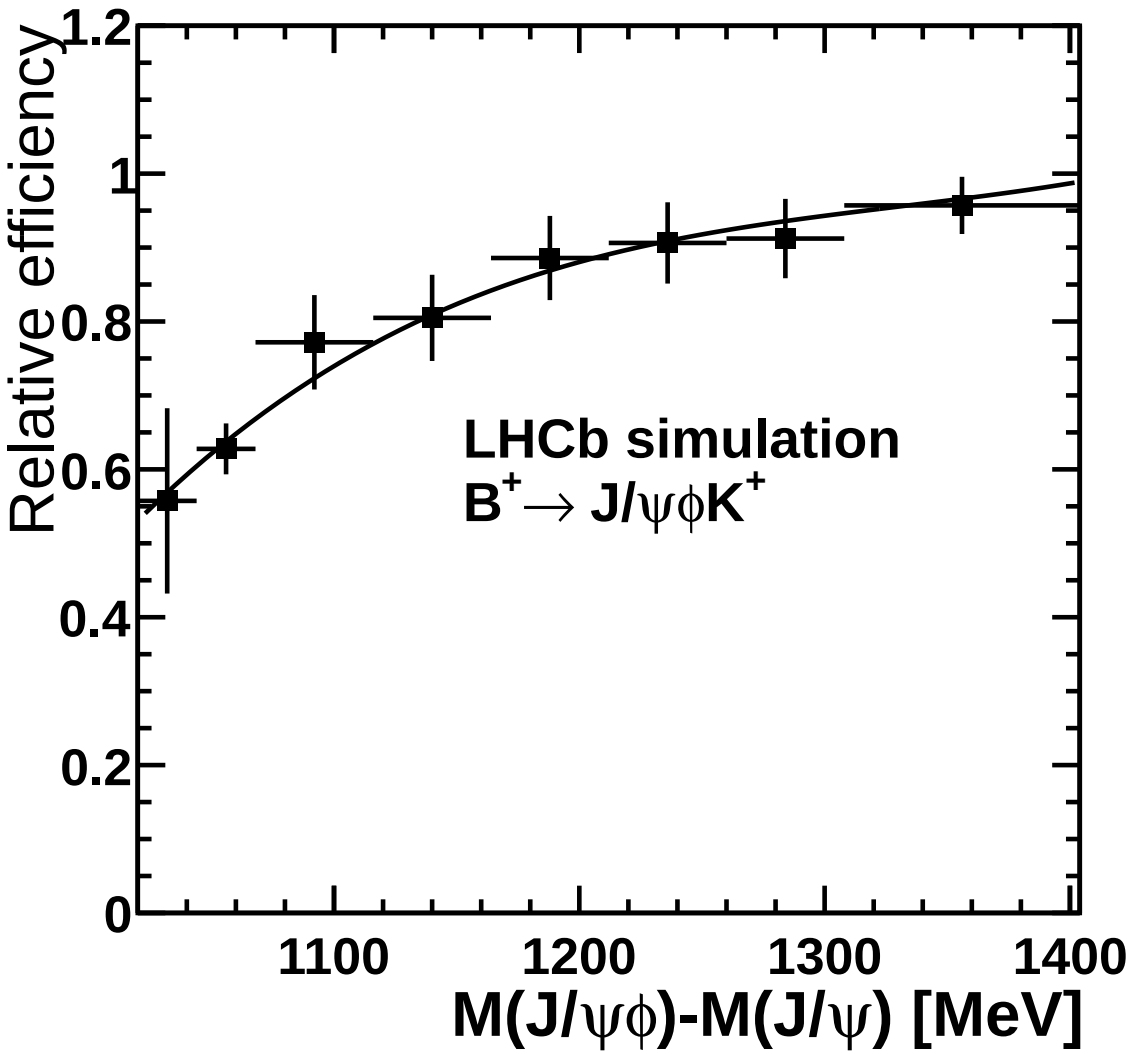
Search for $\mathrm{X}(4140)$ and $\mathrm{X}(4274)$ at LHCb

- LHCb searched for $\mathrm{X}(4140)$ and $\mathrm{X}(4274)$ in a sample with 0.376 fb^{-1} of 2011 dataset [Ref. Phys. Rev. D 85, 091103(R) (2012)].
- Background subtracted sample with 382 ± 22 $\mathrm{B}^{\pm} \to \mathrm{J}/\psi\,\phi\mathrm{K}^{\pm}$ events





Search for X(4140) and X(4274) at LHCb:efficiency



X(3872) quantum numbers: previous measurements

CDF

- Sample dominated by prompt $\mathrm{X}(3872)$
- 3D analysis: fit to $\pi^+\pi^-$ and J/ψ helicity angles and te angle between the $\pi^+\pi^-$ and J/ψ decay planes
- $\mathrm{X}(3872)$ J^{PC} constrained to 1^{++} or 2^{-+}
- Phys.Rev.Lett.98:132002 (2007)

BaBar

- Observed 34 ± 7 $\mathrm{X}(3872) \to \omega \mathrm{J}/\psi$
- Study of $\omega \to \pi^-\pi^+\pi^0$ mass distribution favoured 2^{-+}, but 1^{++} was not ruled out.
- arXiv:1005.5190, Phys. Rev. D 82, 011101(R) (2010)

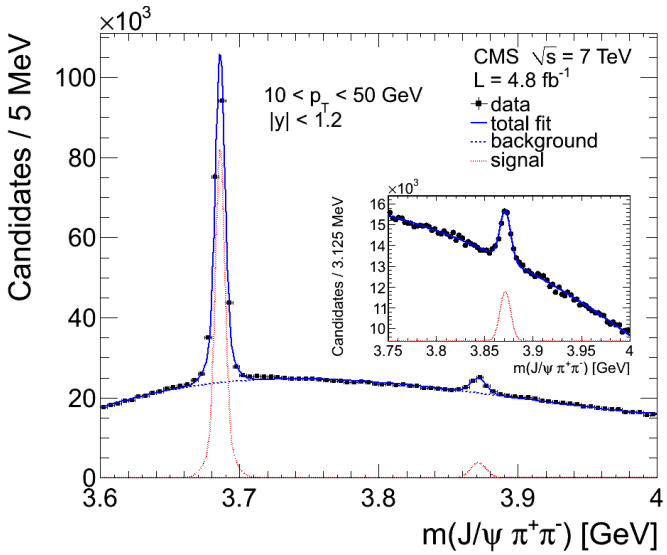
Belle

- Observed 173 ± 16 $\mathrm{B} \to \mathrm{X}(3872)\mathrm{K}$, with $\mathrm{X}(3872) \to \mathrm{J}/\psi\pi^+\pi^-$ and $\mathrm{J}/\psi \to \mu^+\mu^-$
- By studying one-dimensional distributions in three different angles, Belle concluded that their data were equally well described by the 1^{++} and 2^{-+} hypotheses.
- arXiv:1107.0163, Phys. Rev. D 84, 052004 (2011)

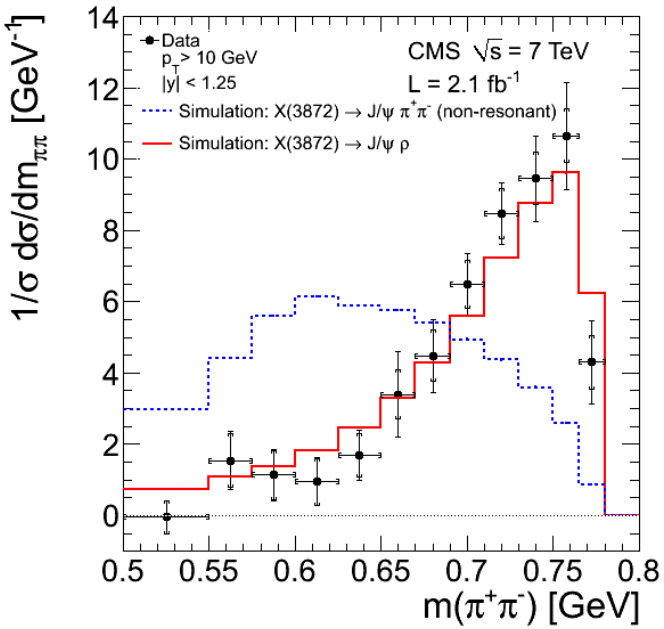
X(3872) production studies at CMS

CMS collaboration performed detailed X(3872) production studies using the decay mode $X(3872) \to J/\psi \pi^+\pi^-$, with $J/\psi \to \mu^+\mu^-$ and 4.1 fb^{-1} 7 TeV

- Measurements are performed in the range $10 < p_{T\,X(3872)} < 50$ GeV and rapidity $|y| < 1.2$.
- Detailed study of the dipion mass showing the decay proceeds dominantly through a intermediate ρ

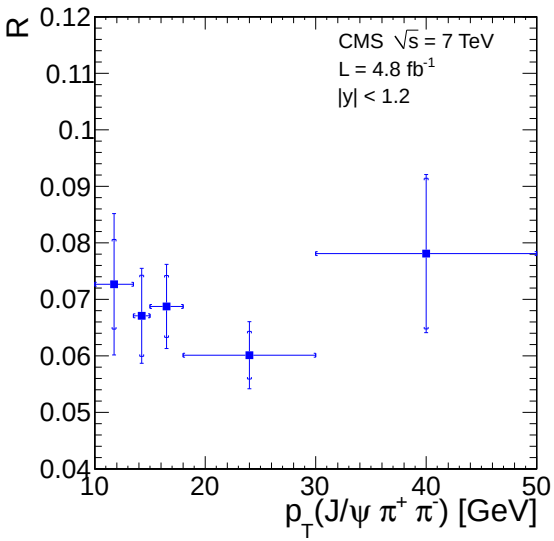


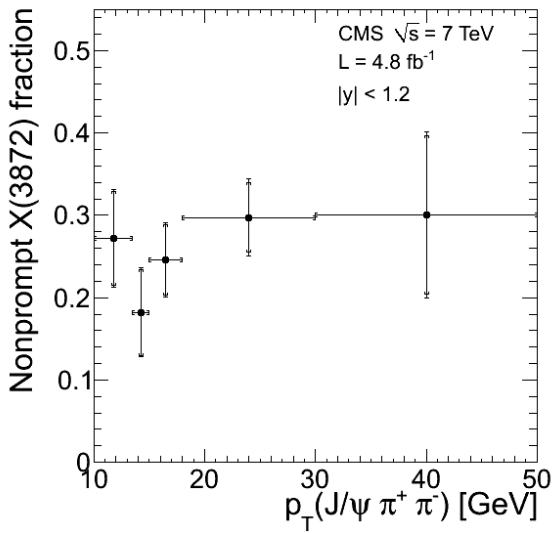
[arXiv:1302.3968]

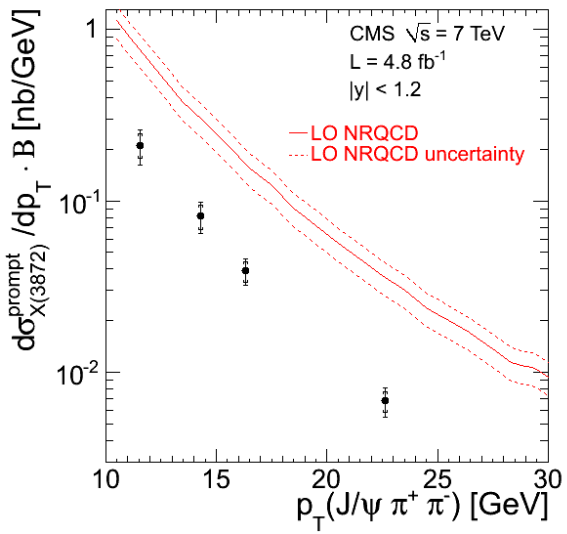


X(3872) production studies at CMS

- Ratio of the X(3872) and $\psi(2S)$ cross sections times their branching fractions into $J/\psi\pi^+\pi^-$ measured in function of p_T.
- Fraction of X(3872) originating from B decays.
- Prompt X(3872) differential cross section times branching fraction into $J/\psi\pi^+\pi^-$ and comparison with theory prediction.







[arXiv:1302.3968]

$J/\psi\ \pi^+$ mass in $B^0 \to J/\psi \pi^+\pi^-$