Hadron spectroscopy and exotic states at LHC

Results and prospects

A. Augusto Alves Jr.
on behalf of LHCb Collaboration
(Including results from CMS and ALICE collaborations.)

INFN sezione di Roma and Università di Roma "Sapienza"
aalvesju@cern.ch

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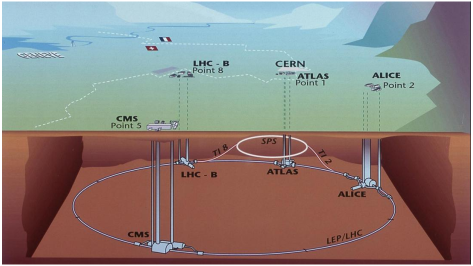
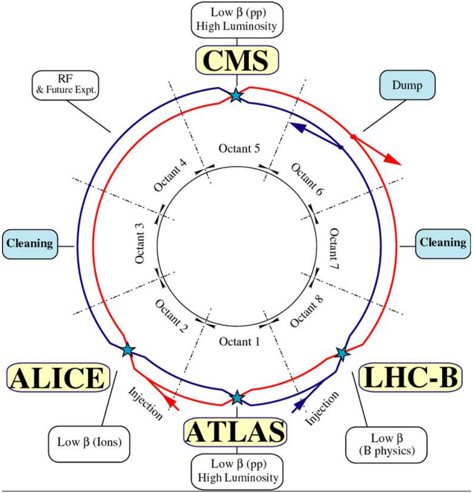
Outline

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





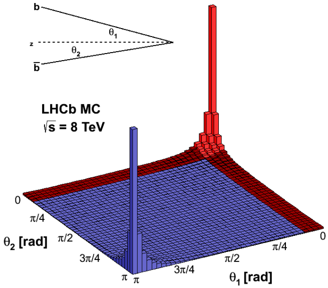
The LHC environment

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]

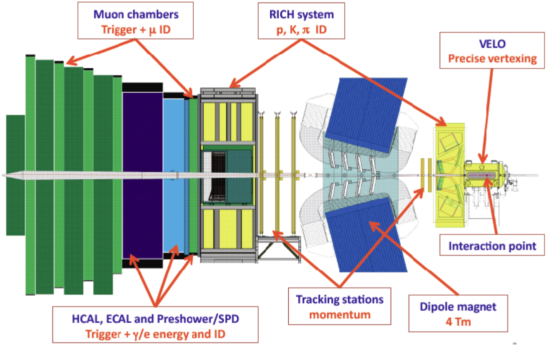
At the LHC energy, the $\mathrm{b\bar{b}}$ pairs are produced preferentially at forward (backward) directions.

- 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 $b\bar{b}$ 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.** $1 + 2\ \text{fb}^{-1}$ 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.

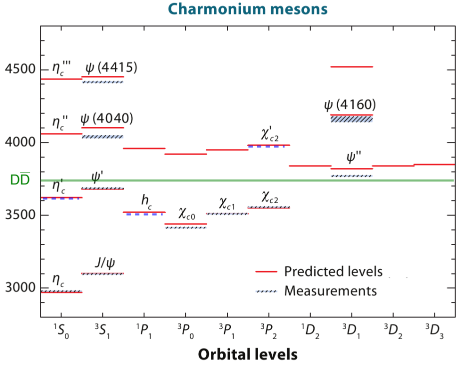
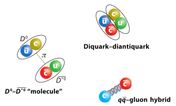


Figure from [Annu.Rev.Nucl. Part. Sci. 2008. 58:51–73]

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^+, $Z_c(3900)^+$...

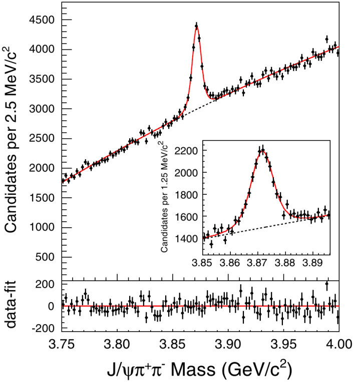
State	m (MeV)	Γ (MeV)	J^{PC}	Process (mode)
$X(3872)$	3871.52 ± 0.20	1.3 ± 0.6 (<2.2)	$1^{++}/2^{-+}$	$B\to K(\pi^+\pi^-J/\psi)$ $p\bar{p}\to(\pi^+\pi^-J/\psi)+...$ $B\to K(\omega J/\psi)$ $B\to K(D^{*0}\bar{D}^0)$ $B\to K(\gamma J/\psi)$ $B\to K(\gamma\psi(2S))$
$X(3915)$	3915.6 ± 3.1	28 ± 10	$0/2^{?+}$	$B\to K(\omega J/\psi)$ $e^+e^-\to e^+e^-(\omega J/\psi)$
$X(3940)$	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^{--}	$e^+e^-\to\gamma(\pi^+\pi^-J/\psi)$ $e^+e^-\to(\pi^+\pi^-J/\psi)$ $e^+e^-\to(\pi^0\pi^0J/\psi)$
$Y(4274)$	$4274.4^{+8.4}_{-6.7}$	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]

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

- 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 $\mathrm{X}(3872) \to J/\psi\pi^+\pi^-$ 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).

X(3872) production studies at LHCb

At LHCb, the 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)

X(3872) production studies at LHCb were performed:

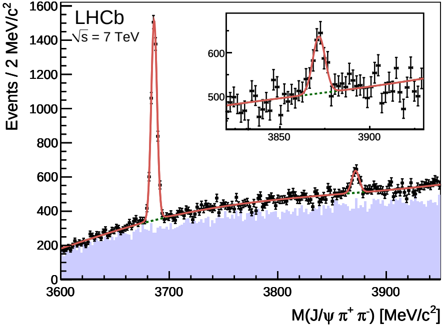
- Measuring the product of production cross-section multiplied by branching ratio to $X(3872) \to J/\psi\,\pi^+\pi^-$
- Assuming X(3872) as a 1^{++} state
- Performing an inclusive selection of $X(3872) \to J/\psi\,\pi^+\pi^-$ final state
- Fiducial range: $5 < p_T < 20$ GeV and $2.5 < y < 4.5$
- Efficiency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

X(3872) production studies at LHCb

Analysis performed on data sample with integrated luminosity of 34.7 pb^{-1} collected by the LHCb experiment in pp collisions at $\sqrt{s} = 7\,\mathrm{TeV}$ in 2010. [Eur. Phys. J. C. 72 (2012) 1972]

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

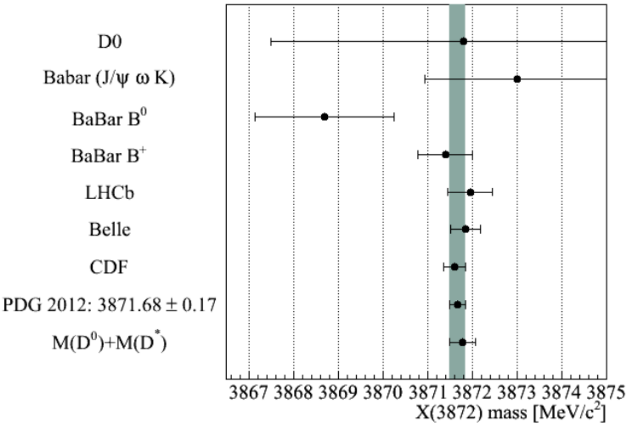
$$\mathrm{M}(X(3872)) = 3871.95 \pm 0.48(\mathrm{stat}) \pm 0.12(\mathrm{syst})\,\mathrm{MeV}/c^2$$



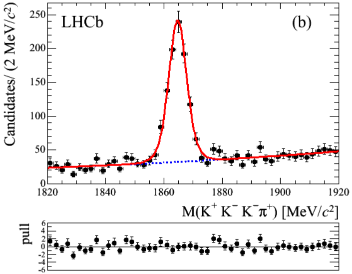
- 585 ± 74 X(3872) signal candidates
- Momentum scale calibration using $\mathrm{J}/\psi \to \mu^{+}\mu^{-}$.
- X(3872) peak fitted using a Voigt function with fixed width.
- Background studied from wrong-sign pions combinations and modeled by exponential function.
- Uncertainty dominated by statistics. 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: $E_{bind} = 0.16 \pm 0.26\ \mathrm{MeV}/c^2$



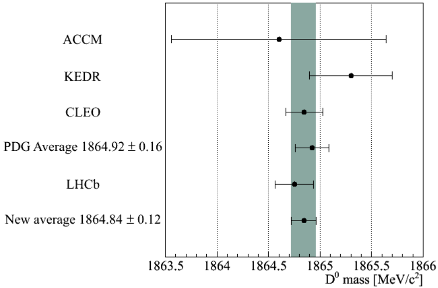
Precision D^0 mass measurement at LHCb



- arXiv:1304.6865
- 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

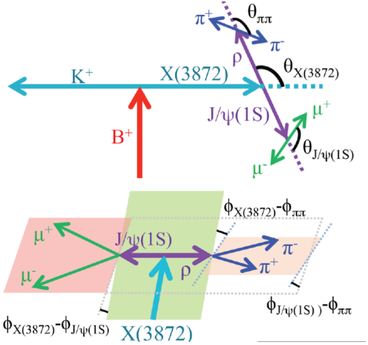
$$M(D^0) = 1864.75 \pm 0.15(\text{stat}) \pm 0.11(\text{syst})\ \text{MeV}/c^2$$

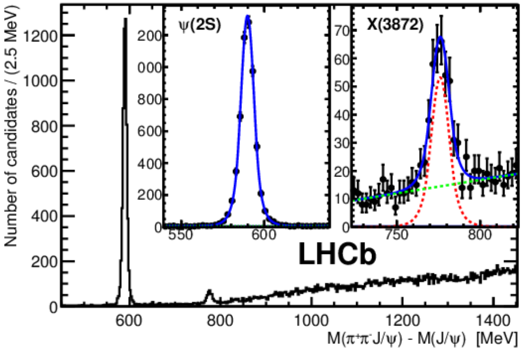
- This result reinforces that if $X(3872)$ is a $D^0\bar{D}^{0*}$ bound-state, it is loosely bound.
- Consistent with arxiv:1212.4191: $M(D^0) = 1864.851 \pm 0.020(\text{stat})$



X(3872) quantum numbers determination at LHCb

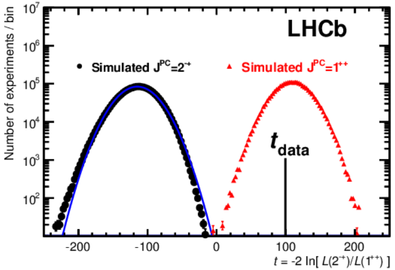
- Using the 1.0 fb^{-1} dataset recorded by LHCb in 2011
- 313 ± 26 $B^+ \to K^+ X(3872)$ with $X(3872) \to J/\psi \pi^+ \pi^-$.
- 5642 ± 76 $B^+ \to K^+ \psi(2S)$ with $\psi(2S) \to J/\psi \pi^+ \pi^-$.
- 5D analysis: all angular correlations used to measure $X(3872)$ J^{PC}

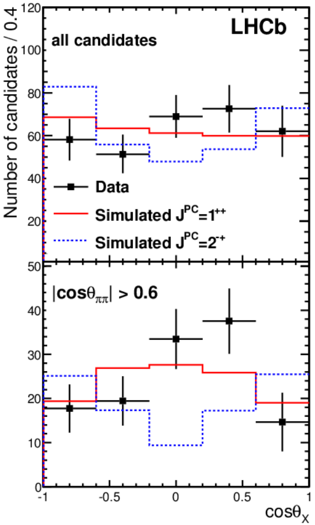




[arXiv:1302.6269]

- 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;





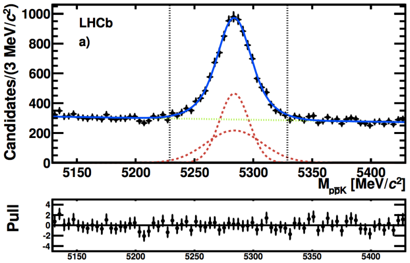
[arXiv:1302.6269]

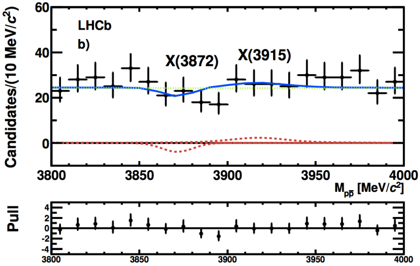
This result favours the interpretations of X(3872) as a exotic state.

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

- Search for $B \to K X(3872)$ with $X(3872) \to p\bar{p}$;
- 6951 ± 176 candidates of $B^+ \to K^+ p\bar{p}$
- $-9 \pm 8(\mathrm{stat}) \pm 2(\mathrm{syst})$ candidates of $X(3872) \to p\bar{p}$
- $13 \pm 17(\mathrm{stat}) \pm 5(\mathrm{syst})$ 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*

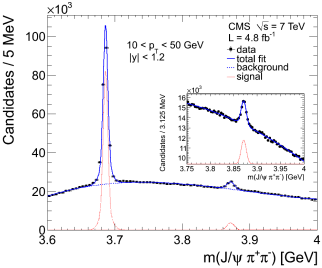
[arXiv:1303.7133]



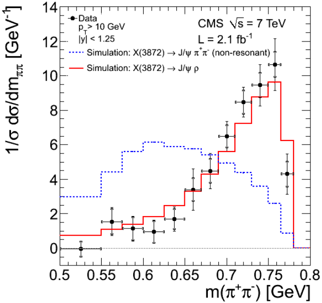


CMS collaboration performed detailed $X(3872)$ production studies using the decay mode $X(3872) \to J/\psi\,\pi^+\pi^-$, with $J/\psi \to \mu^+\mu^-$ and 4.1 fb^{-1} 7 TeV

- 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

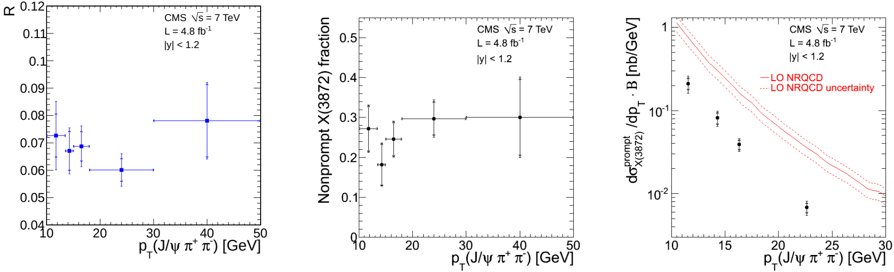


[arXiv:1302.3968]



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.

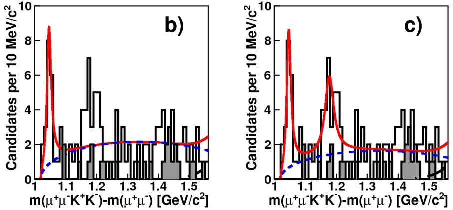


[arXiv:1302.3968]

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].



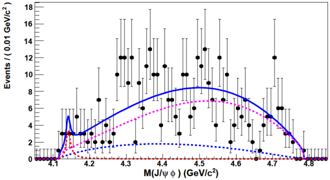
- 115 ± 12 candidates of $B^{\pm} \to J/\psi\,\phi K^{\pm}$
- X(4140) candidate with $M_{X(4140)} = 4143.4^{+2.9}_{-3.0} \pm 0.6\ \mathrm{MeV}/c^2$, $\Gamma_{X(4140)} = 15.3^{+10.4}_{-6.1} \pm 2.5\ \mathrm{MeV}/c^2$, with yield of 19 ± 6 and statistical significance of 5.0σ.
- Maybe a second state: $M_{X(4274)}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



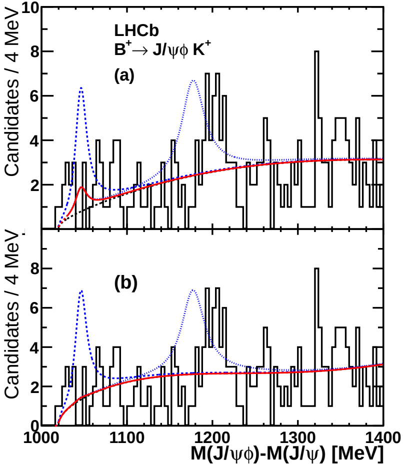
- Belle accumulated more events on $B^+ \to J/\psi\phi K^+$ than CDF but could not confirm or exclude the X(4140).
- Loss of efficiency near the threshold resulted in a lower sensitivity to X(4140) at Belle.
- $\mathcal{B}(B^+ \to X(4140)K^+) \times \mathcal{B}(X(4140) \to J/\psi\phi) < 6 \times 10^{-6}$

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 X(4140) and X(4274) at LHCb

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

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

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

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

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

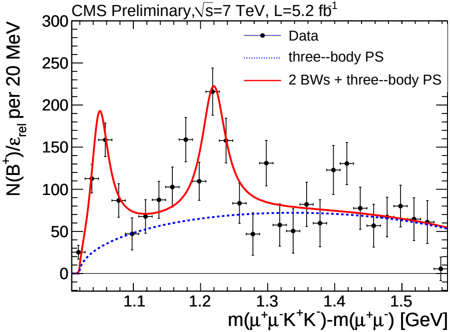
LHCb	CDF (our estimate)
< 0.08	0.17 ± 0.06

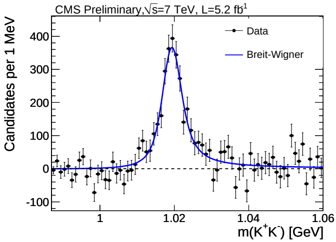
In conclusion, LHCb performed the most sensitive search for the narrow $\mathrm{X}(4140)$ and $\mathrm{X}(4274)$ structures and:

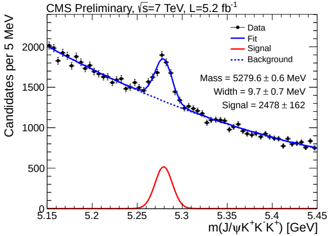
- Does not confirm the $\mathrm{X}(4140)$ state previously reported by the CDF
- Does not observe any evidence of the $\mathrm{X}(4274)$
- The LHCb results disagree at the 2.4σ level with the CDF measurement.
- Ref: Phys. Rev. D 85,091103(R)(2012)

Search for structures in the J/ψ ϕ spectrum at CMS

- Search for structures in the $J/\psi\,\phi$ spectrum in $B^{\pm} \to J/\psi\,\phi K^{\pm}$ decays
- Using 5.2 fb^{-1} dataset recorded by CMS in pp collisions at $\sqrt{s} = 7$ TeV
- $J/\psi\,\phi$-spectrum is modeled by two S-wave relativistic Breit-Wigner over a three-body phase-space non-resonant component.
- $m_1 = 4148.2 \pm 2.0(\mathrm{stat}) \pm 4.6(\mathrm{syst})\ \mathrm{MeV}/c^2$ and significance exceeding $5\,\sigma$
- $m_2 = 4316.7 \pm 3.0(\mathrm{stat}) \pm 7.3(\mathrm{syst})\ \mathrm{MeV}/c^2$.





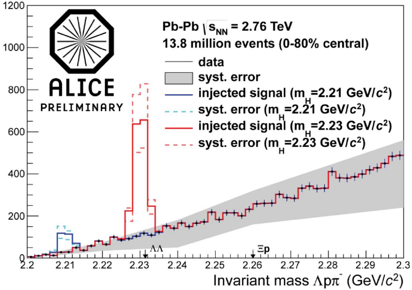


[see talk by Elif Aslı Yetkin, HCP2012 Kyoto, Japan]

Search for H-dibaryon at Alice

- Hypothetical bound state of uuddss ($\Lambda\Lambda$)
- Measurable decay modes: $\mathrm{H}^0 \to \Lambda\Lambda$ (up the $\Lambda\Lambda$ threshold) and $\mathrm{H}^0 \to \pi p \Lambda$ (bellow the $\Lambda\Lambda$ threshold)
- First predicted in a bag model calculation [PRL 38, 195 & 617 (1977)].
- Also suggested by recent lattice calculations [PRL 106,162001 (2011)] [PRL 106, 162002 (2011)]
- Upper limits recently setted by Belle: arXiv:1302.4028

- No signal observed. Upper limits:
- Strongly bound: $dN/dy \leq 8.4 \times 10^{-4}$ (99% CL)
- Lightly bound: $dN/dy \leq 2 \times 10^{-4}$ (99% CL)
- Thermal model prediction is $dN/dy = 3.1 \times 10^{-3}$
- Nucl. Phys. A, Vol 904-905, 547c-550c, 2013

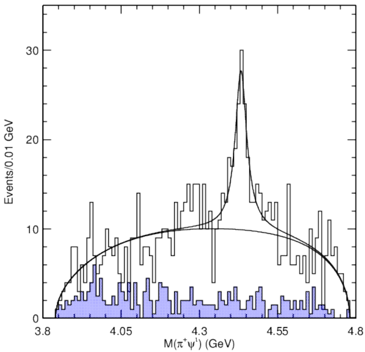


Thermal model would need to be wrong by a factor 10. On the other hand, the model describes the hypertriton yields measured with STAR correctly [PLB 697,203 (2011)] and [PRC 84, 054916 (2011)]

Prospects for $Z(4430)^+$ at LHCb

- Charged charmonium like state reported by Belle in $B^+ \to \psi(2S) K^+ \pi^-$ decays
  [Phys.Rev.Lett.100:142001,2008, Phys.Rev.D80:031104,2009]
- Searched and not confirmed by BaBar[Phys.Rev.D79:112001,2009]
- If confirmed it will be the strongest tetraquark candidate.
- No structure reported in the $B^+ \to J/\psi K^+ \pi^-$

$Z(4430)^+$ signal from Belle with 6.5 σ



Studies in progress at LHCb using the full 2011 + 2012 dataset

- Analysing both $B^+ \to J/\psi K^+ \pi^-$ and $B^+ \to \psi(2S) \to K^+ \pi^-$ modes.
- High statistics: expected more candidates of $B^+ \to J/\psi K^+ \pi^-$ and $B^+ \to \psi(2S) K^+ \pi^-$ than Belle and BaBar together.

Summary and perspectives

$\mathrm{X}(3872)$

- LHCb has measured the mass and production cross section in the range: $5 < p_{\mathrm{T}} < 20\ \mathrm{GeV}$ and $2.5 < y < 4.5$ using 2010;
- CMS performed detailed production studies using 4.8 fb^{-1} from the 2011 dataset;
- 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.
- Structures near $\mathrm{J}/\psi\,\phi$-threshold reported by CMS.
- Working in progress at LHCb and CMS to update the analysis using 2011 + 2012 dataset.

It is important that LHC experiments take advantage of their copious statistics to perform a full amplitude analysis on these decays. This seems to be the only way to understand the nature of these structures.

$Z(4430)^{+}$

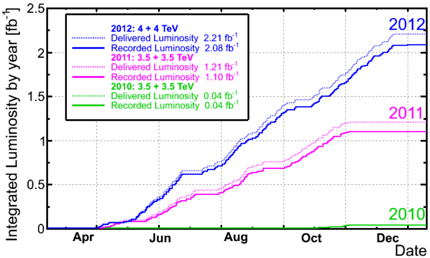
- Work in progress at LHCb.

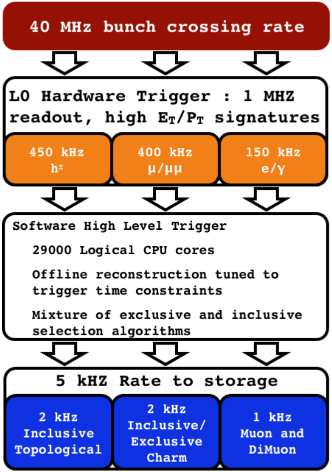
Thanks!

Backup

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

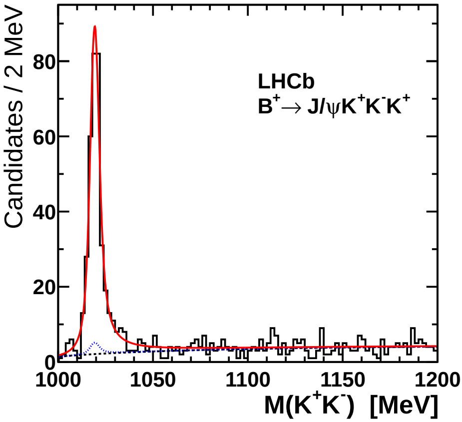
2 fb^{-1} acquired in 2012

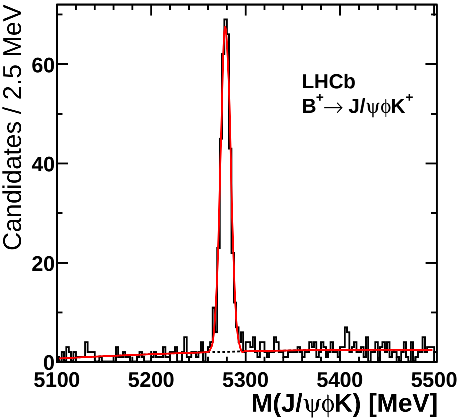
X(3872) mass measurement at LHCb: uncertainties

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

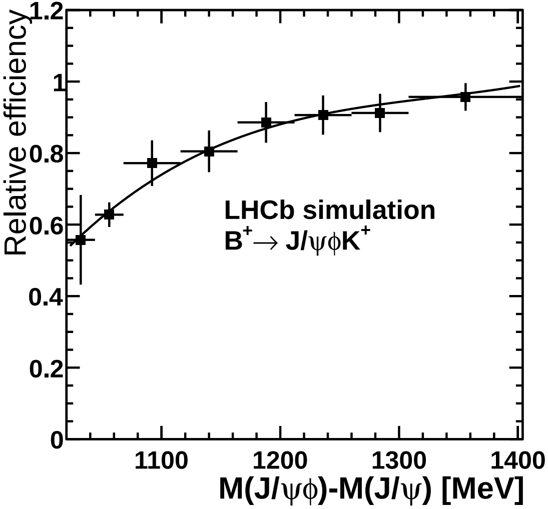
Category	Source of uncertainty	Δm [MeV/c^2]	
		$\psi(2S)$	$X(3872$
Mass fitting	Natural width	–	0.01
	Radiative tail	0.02	0.02
	Resolution	–	0.01
	Background model	0.02	0.02
Momentum calibration	Average momentum scale	0.08	0.10
	η dependence of momentum scale	0.02	0.03
Detector description	Energy loss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

- LHCb searched for X(4140) and 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 $B^{\pm} \to J/\psi\, \phi K^{\pm}$ events





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



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)