Updated LHCb measurements on pentaquark and tetraquark states

EPS-HEP 2017
Venice, Italy, July 5 - 12, 2017

Olaf Steinkamp
on behalf of the LHCb collaboration

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Winterthurerstrasse 190 CH-8057 Zürich
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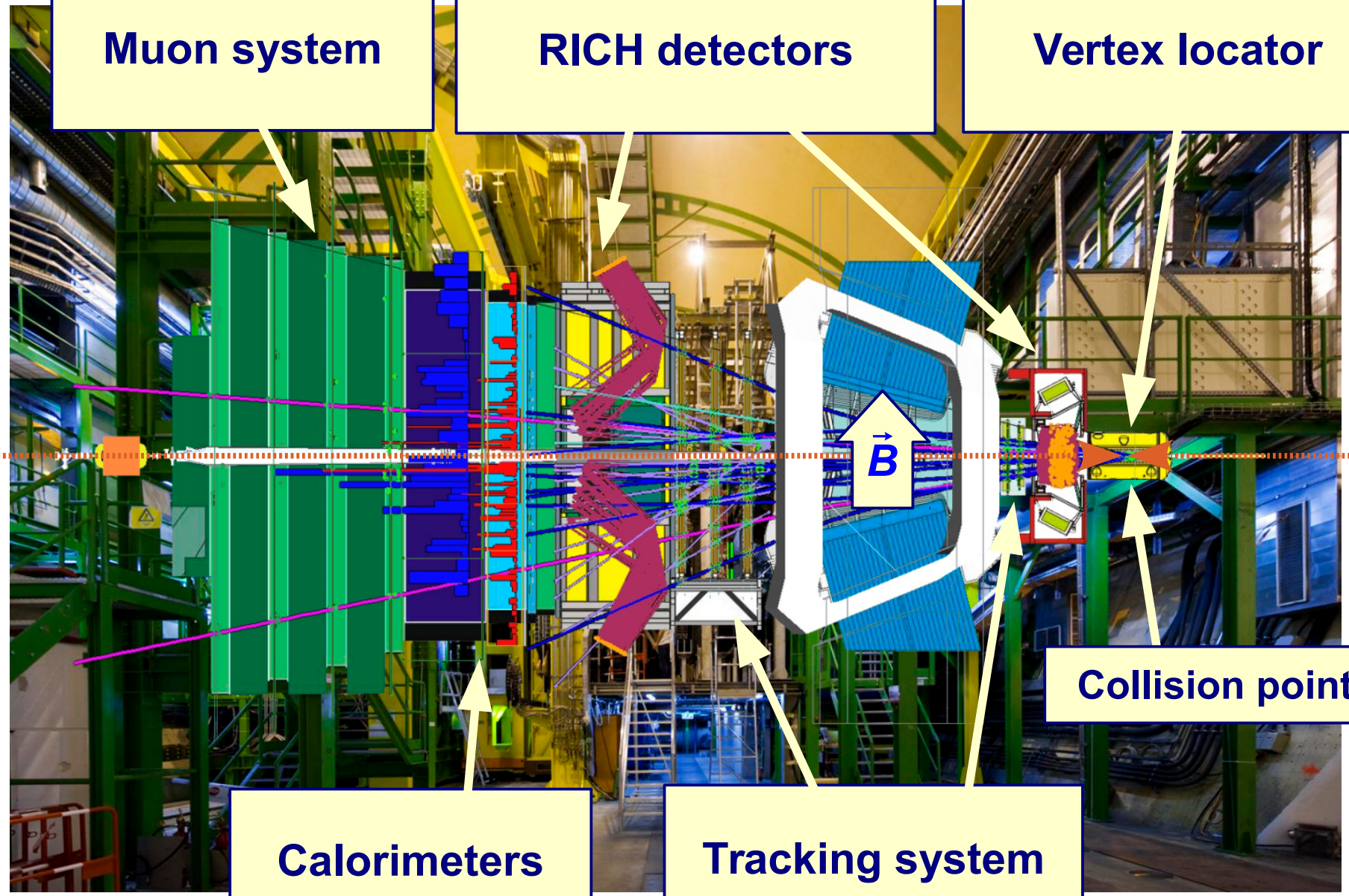
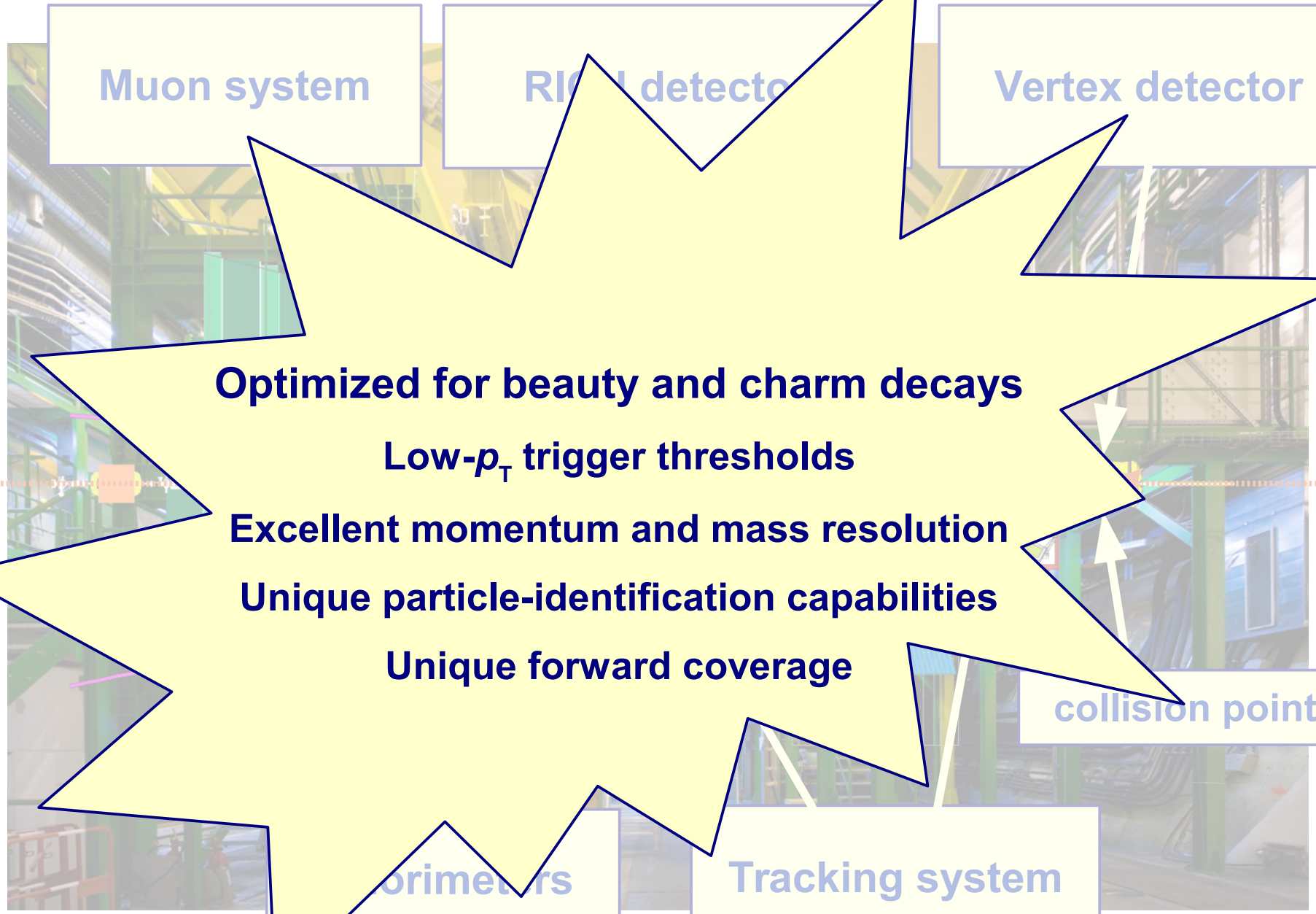
LHCb



[JINST 3 (2008) S08005]

LHCb



Optimized for beauty and charm decays

Low-p_T trigger thresholds

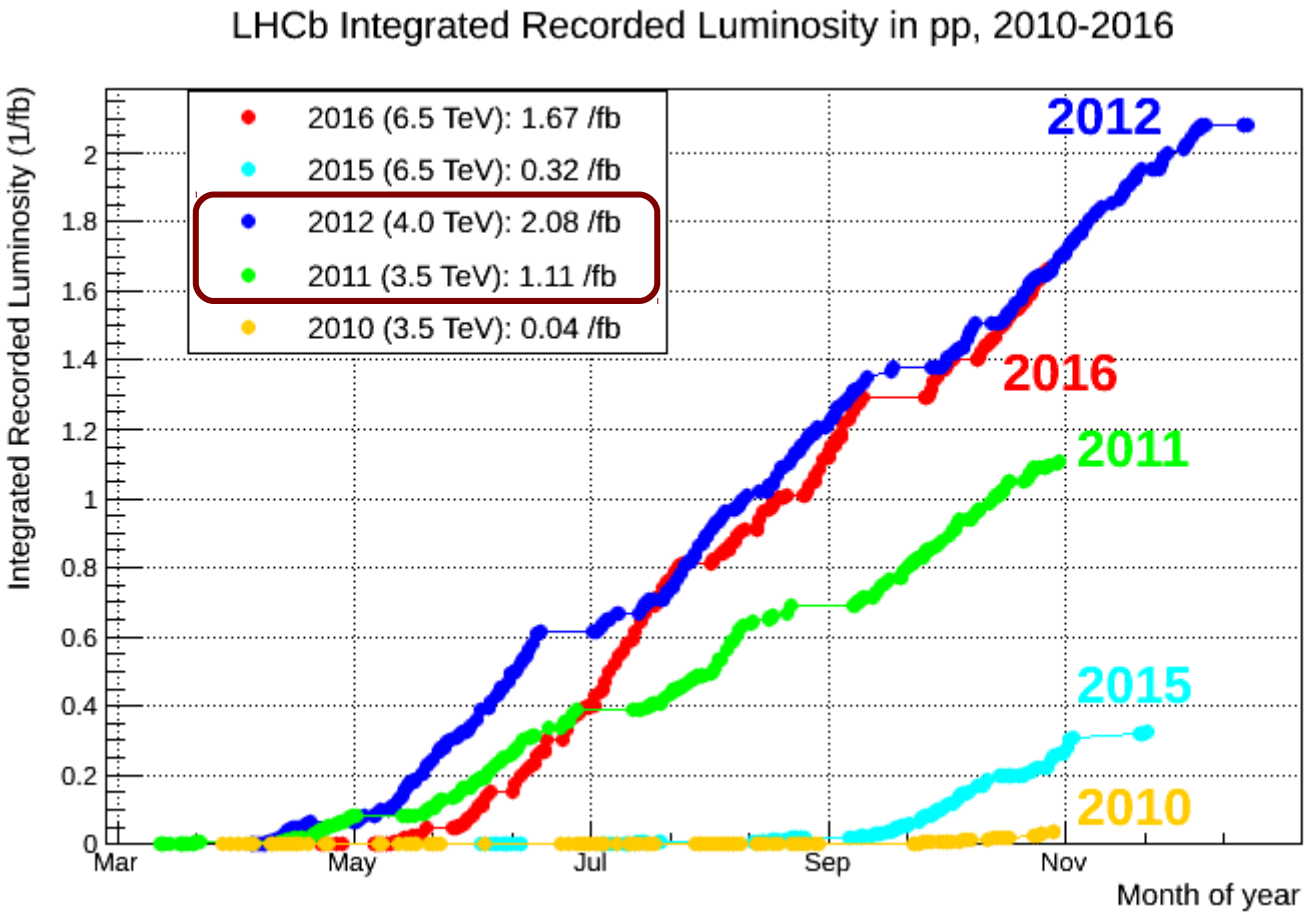
Excellent momentum and mass resolution

Unique particle-identification capabilities

Unique forward coverage

[JINST 3 (2008) S08005]

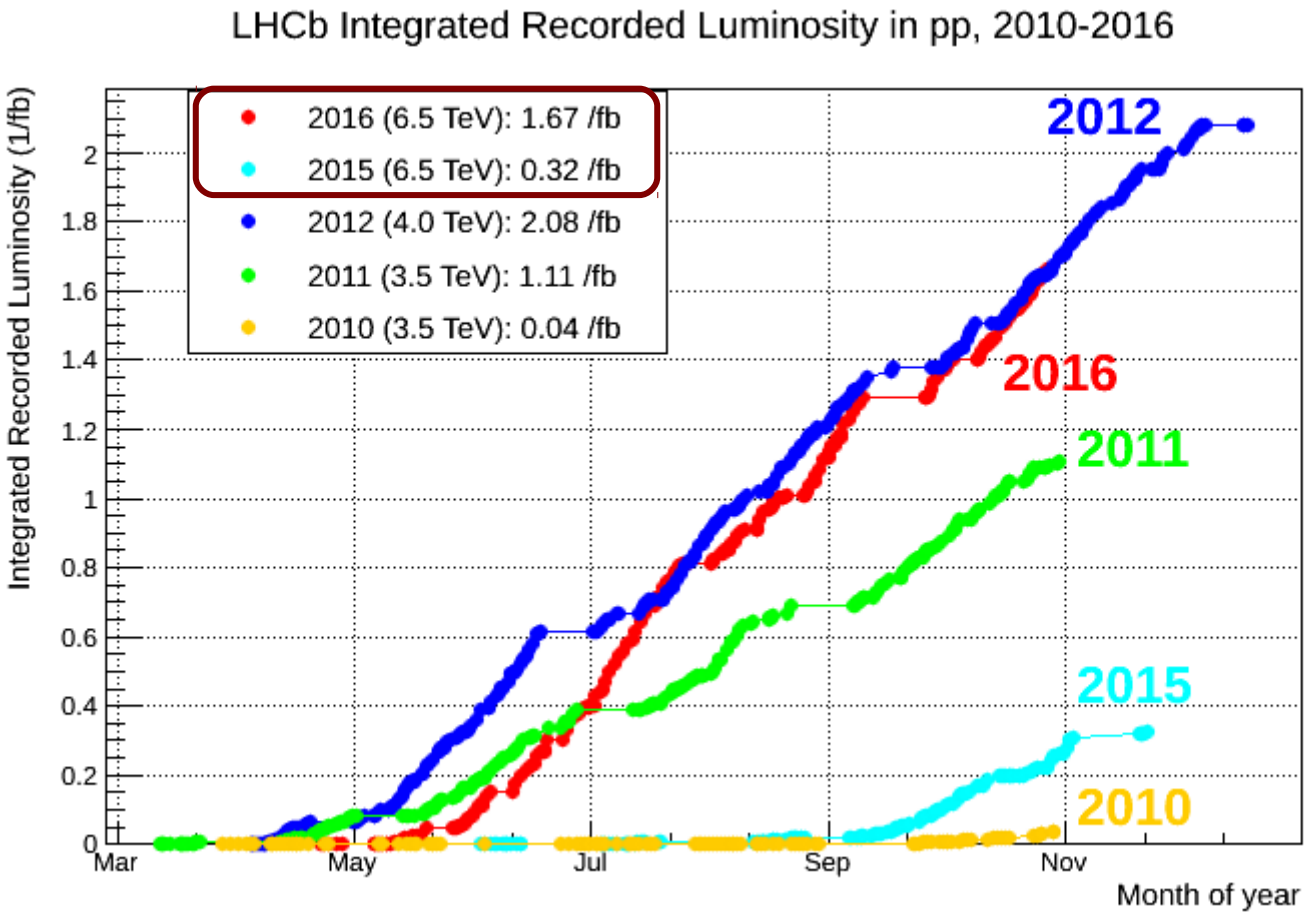
LHCb



Results presented here based on Run-I data:

1 fb^{-1} at 7 TeV + 2 fb^{-1} at 8 TeV

LHCb



Run-II so far: 2 fb^{-1} at 13 TeV

$\sigma(pp \to b\bar{b})$: 300 μb @ 7 TeV → 500 μb @ 13 TeV

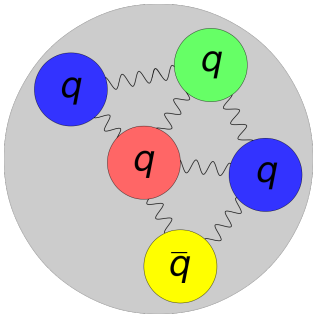
Improvements in trigger and selection efficiencies

[https://www.kickstarter.com/projects/239309591/pentaquark-a-solo-microgame-in-a-quantum-state]

Pentaquarks

Colour-neutral ($qqqq\bar{q}$) states

Consistent with QCD



A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN
California Institute of Technology, Pasadena, California

Received 4 January 1964

anti-triplet as anti-quarks $\bar{q}$. Baryons can now be constructed from quarks by using the combinations $(q\,q\,q)$, $(q\,q\,q\,q\,\bar{q})$, etc., while mesons are made out of $(q\,\bar{q})$, $(q\,q\,\bar{q}\,\bar{q})$, etc. It is assuming that the lowest

[Phys.Lett.8(1964)214]

Pentaquarks

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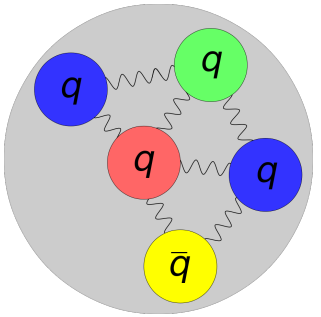
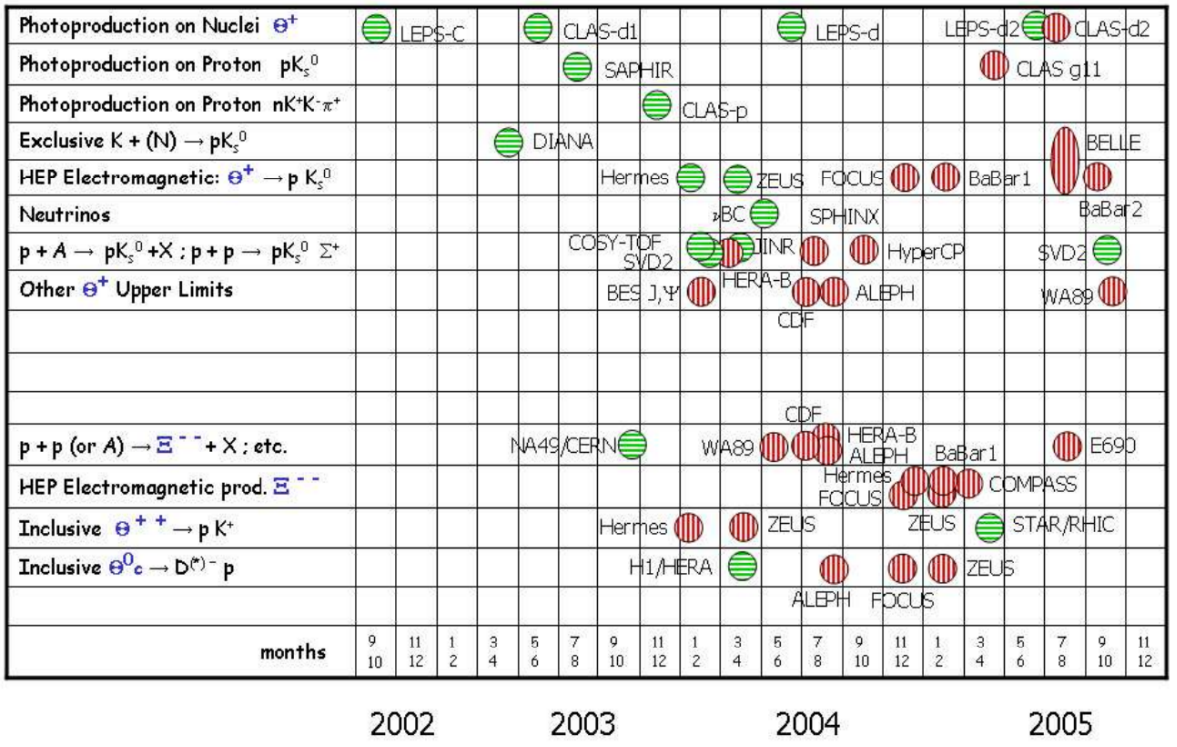
Consistent with QCD



… but seem to resist discovery,

e.g. history of the Θ(1540)⁺

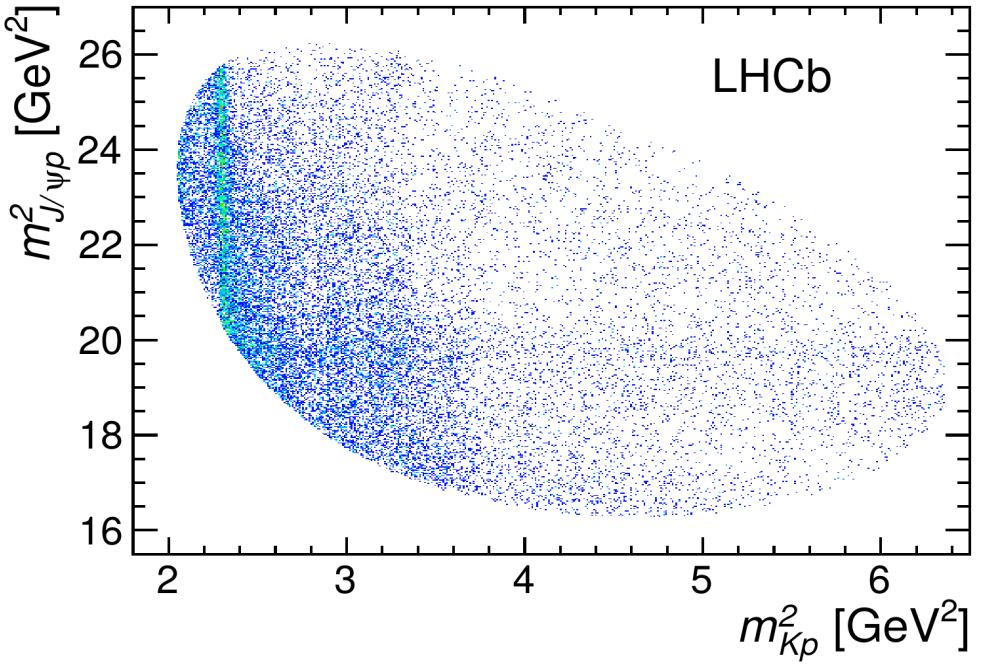


[AIP Conf.Proc. 842 (2006) 409]

$P_c(4380)^+$ and $P_c(4450)^+$

2015: LHCb observe two "Pentaquark-like" states studying $\Lambda_b^0 \to J/\psi\, p\, K^-$ decays

Unexpected structure in $J/\psi\, p$ invariant mass ($uudc\bar{c}$)



[PRL 115(2015)072001]

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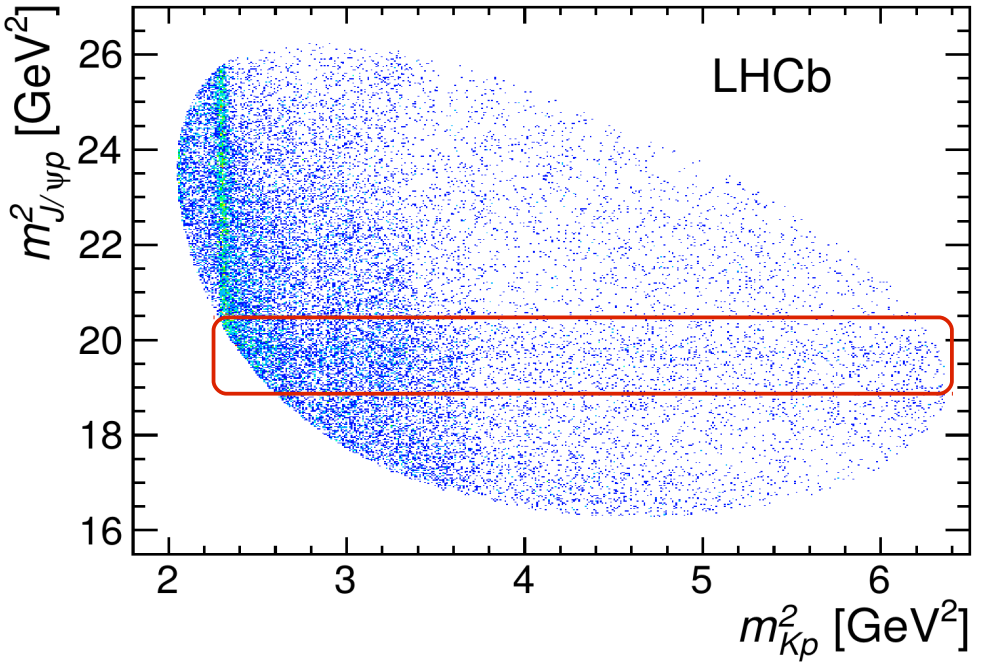

[PRL 115(2015)072001]

$P_c(4380)^+$ and $P_c(4450)^+$

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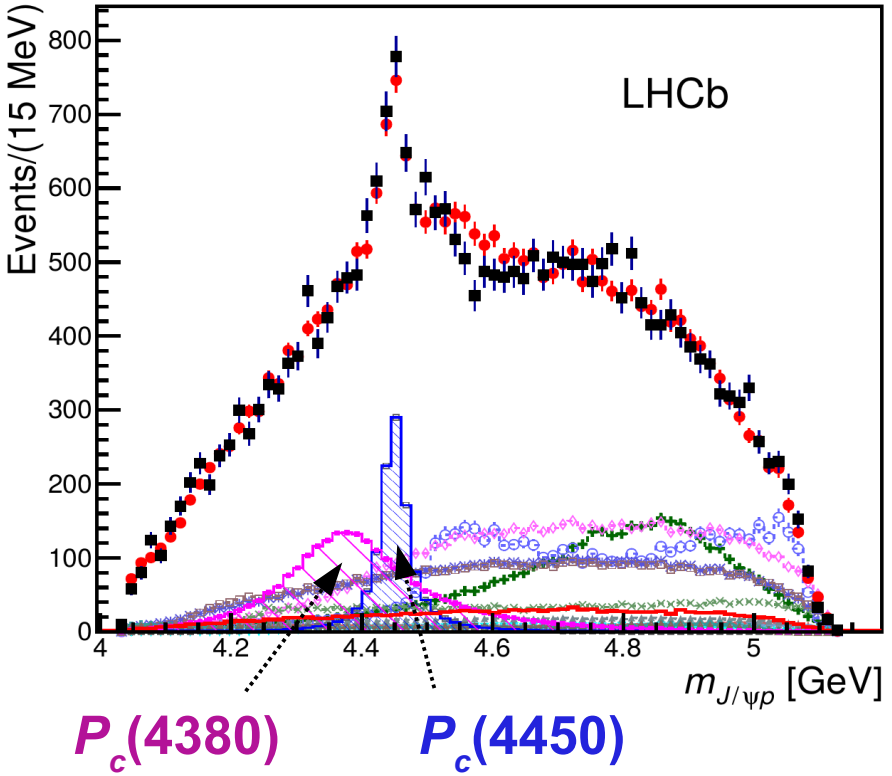
6-dim amplitude analysis:

need for two resonant $J/\psi\, p$ states

	σ	*M* (MeV)	Γ (MeV)
$P_c(4380)$	9	4380 ± 8 ± 29	205 ± 18 ± 86
$P_c(4450)$	12	4449.8 ± 1.7 ± 2.5	39 ± 5 ± 19

[PRL 115(2015)072001]



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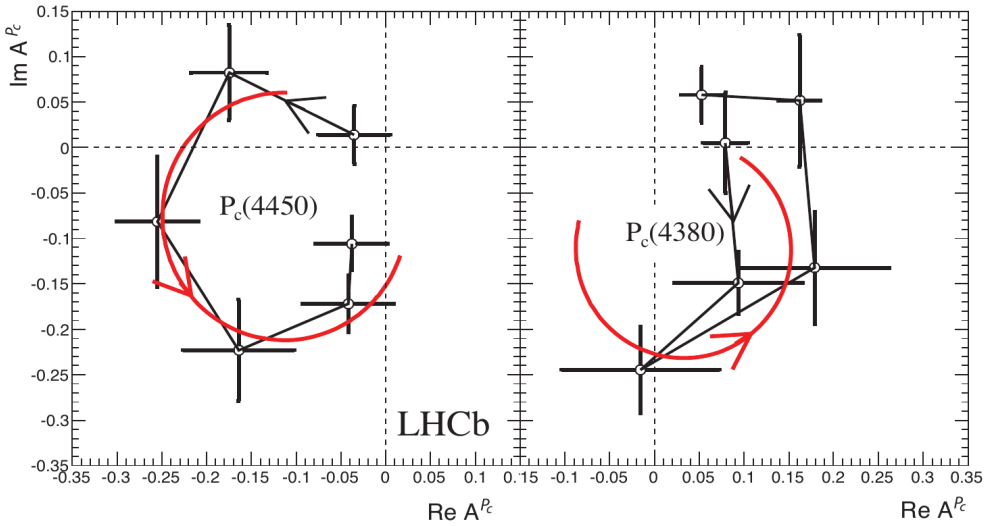


$P_c(4450)$ $P_c(4380)$

$P_c(4380)^+$ and $P_c(4450)^+$

2015: LHCb observe two "Pentaquark-like" states

studying $\Lambda_b^0 \to J/\psi\, p\, K^-$ decays

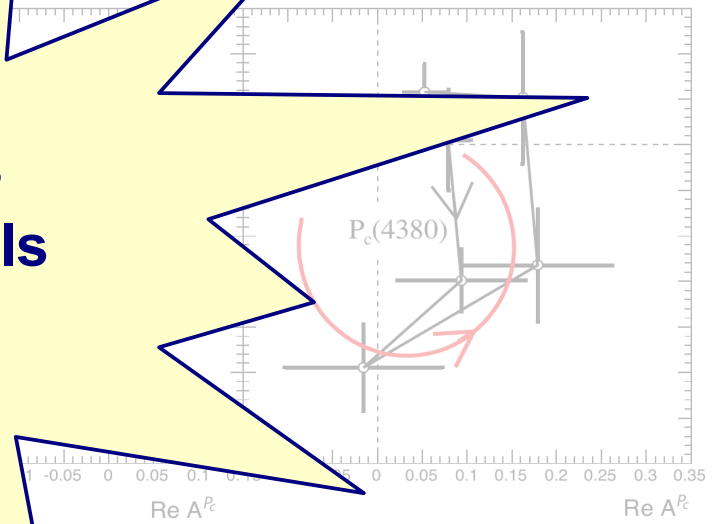
6-dim amplitu… analysis:

need for two res…

	σ	
$P_c(4380)^+$	…	
$P_c(4450)^+$	12	

Confirm these candidates
in other production channels

Search for additional
Pentaquark candidates



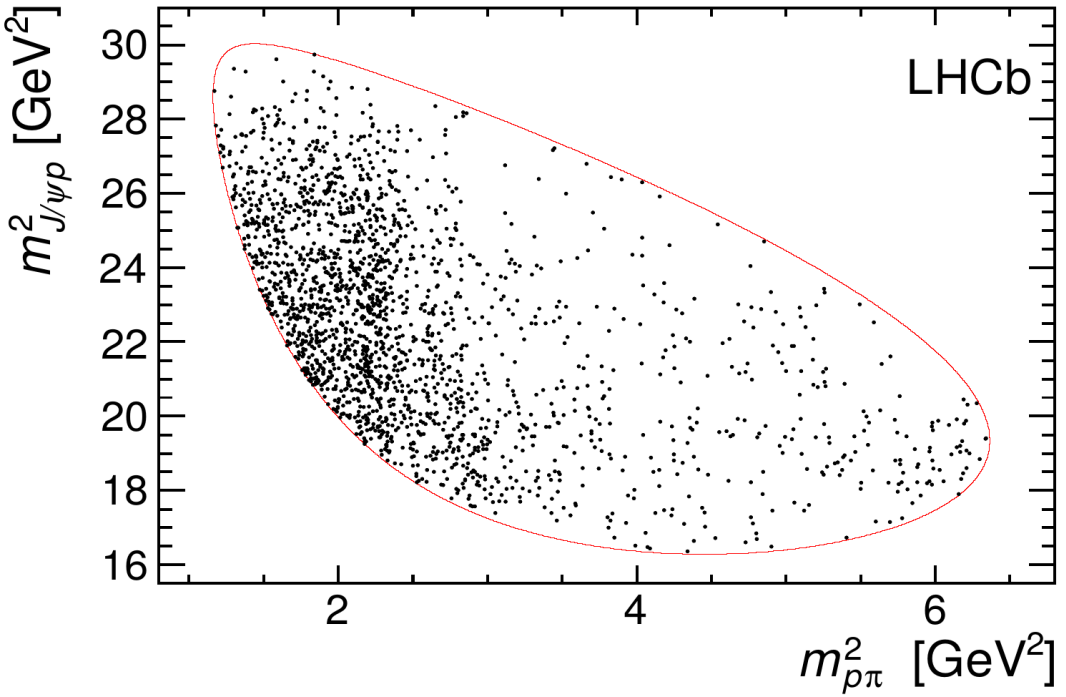
$\Lambda_b^0 \to J/\psi\, p\, \pi^-$

Search for these P_c states in $\Lambda_b^0 \to J/\psi\, p\, \pi^-$ decays

→ Test hypothesis of threshold effects

Higher backgrounds

Lower Branching Fraction
(Cabibbo suppressed)
→
≈ 15 times smaller statistics



[PRL 117(2016)082003]

$\Lambda_b^0 \to J/\psi\, p\, \pi^-$

Search for these P_c states in $\Lambda_b^0 \to J/\psi\, p\, \pi^-$ decays

→ Test hypothesis of threshold effects

More complicated dynamics:

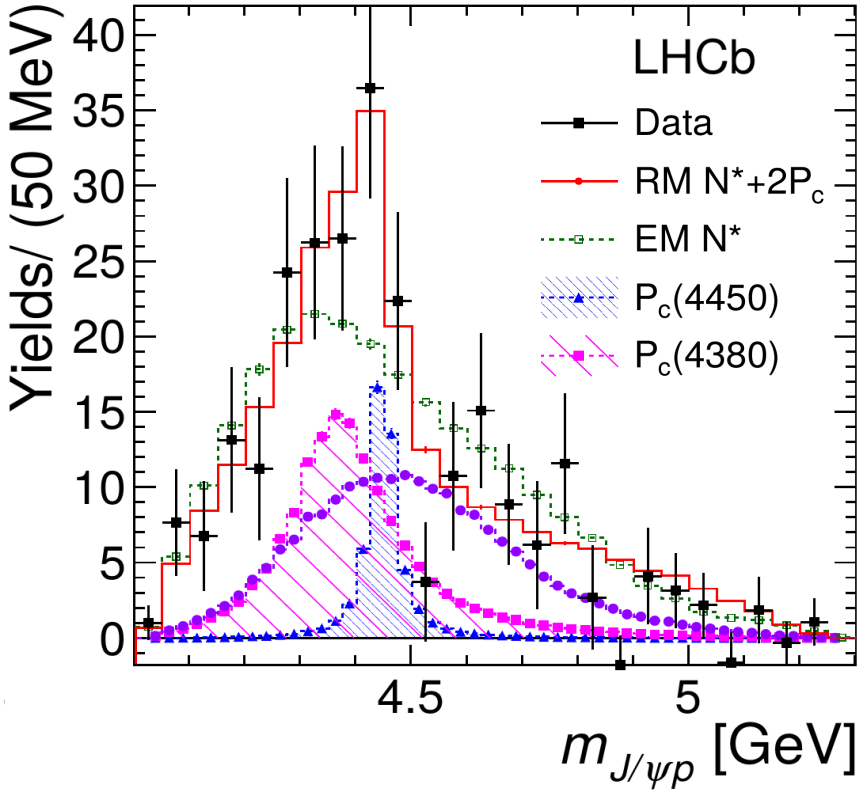
$N^* \to p\,\pi^-$

$P_c(4380)^+ \to J/\psi\, p$

$P_c(4450)^+ \to J/\psi\, p$

$Z_c(4200)^- \to J/\psi\, \pi^-$

[PRL 117(2016)082003]



(for $m_{p\pi} > 1.8$ GeV)

$\Lambda_b^0 \to J/\psi\, p\, \pi^-$

Search for these P_c states in $\Lambda_b^0 \to J/\psi\, p\, \pi^-$ decays

→ Test hypothesis of threshold effects

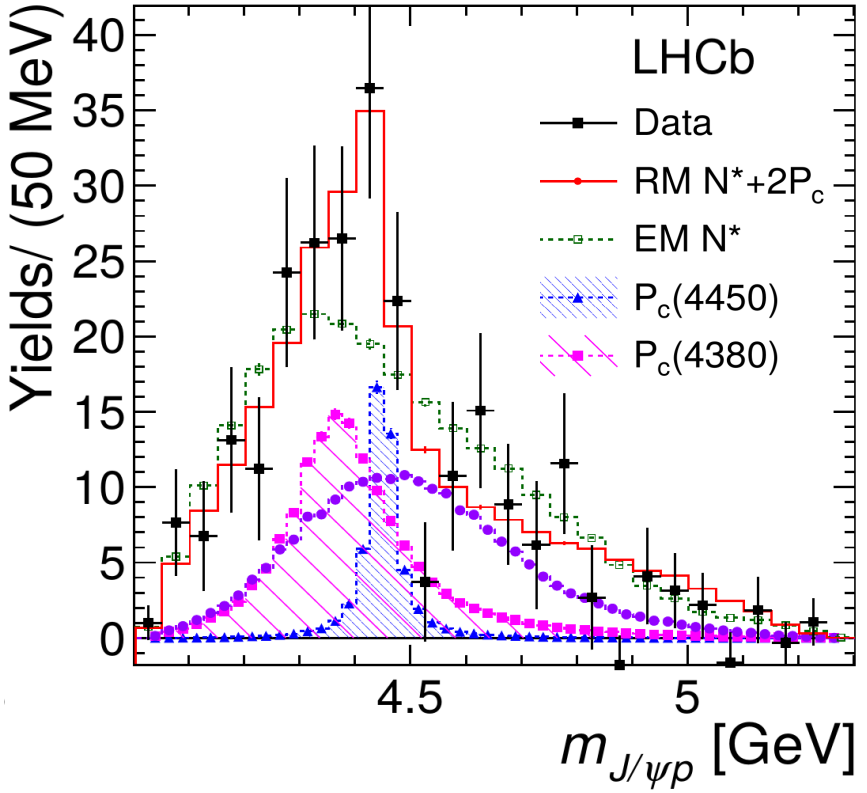
Angular analysis indicates need for "exotic" component:

3.3 σ for P_c^+ or Z_c^-

3.1 σ for P_c^+ if no Z_c^-

(including systematics)

[PRL 117(2016)082003]



(for $m_{p\pi}$ > 1.8 GeV)

$\Lambda_b^0 \to J/\psi\, p\, \pi^-$

Search for these P_c states in $\Lambda_b^0 \to J/\psi\, p\, \pi^-$ decays

→ Test hypothesis of threshold effects

Angular analysis indicates
need for "exotic" [illegible]onent

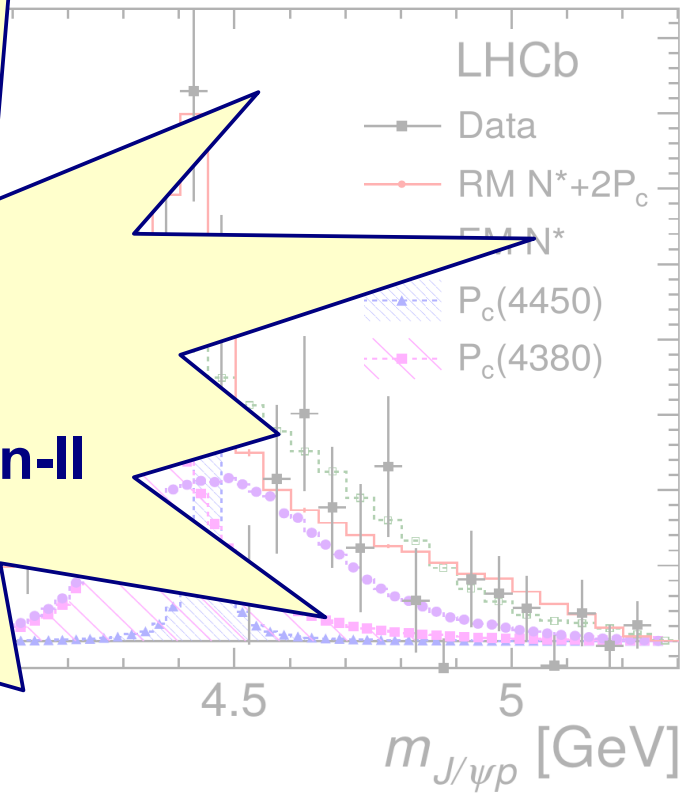
3.[illegible]

3.1 σ for [illegible]

(includin[illegible]

[PRL 117(2016)0[illegible]

… to be continued with larger data samples from Run-II



(for $m_{p\pi}$ > 1.8 GeV)

$\Lambda_b^0 \to \chi_{c(1,2)}\, p\, K^-$

Search for $P_c(4450)^+$ in $\Lambda_b^0 \to \chi_{c(1,2)}\, p\, K^-$ decays

→ Test hypothesis of re-scattering effect

[PRD92(2015)071502]

First step:
Observe the decay modes,
Measure Branching Fractions

$$\frac{BF(\Lambda_b^0 \to \chi_{c1}\, p\, K^-)}{BF(\Lambda_b^0 \to J/\psi\, p\, K^-)} =$$

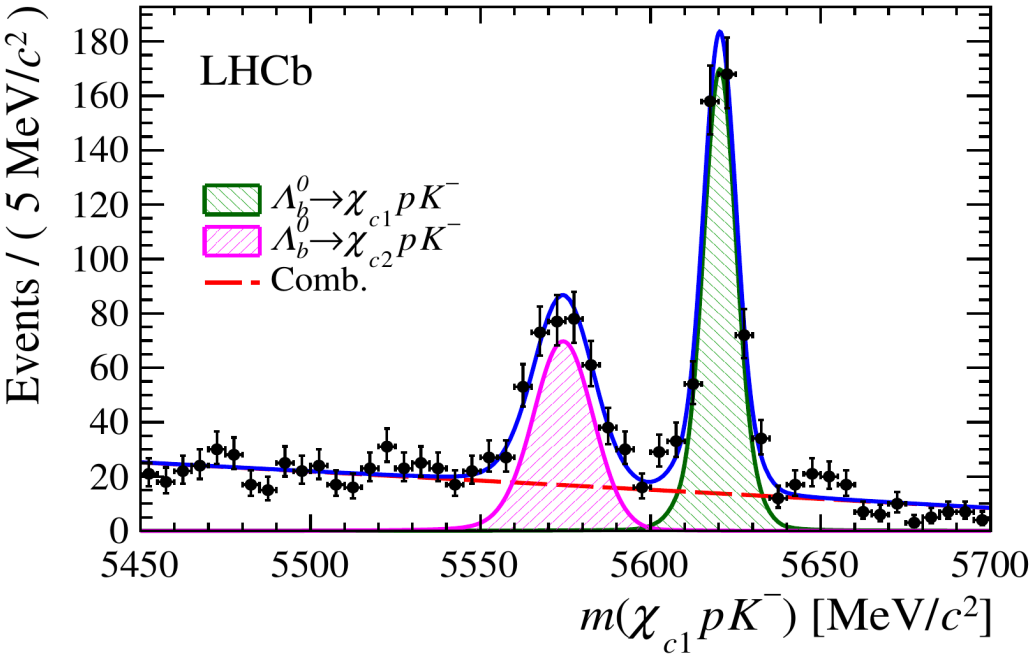
$$0.242 \pm 0.014 \pm 0.013 \pm 0.009$$

$$\frac{BF(\Lambda_b^0 \to \chi_{c2}\, p\, K^-)}{BF(\Lambda_b^0 \to J/\psi\, p\, K^-)} =$$

$$0.248 \pm 0.020 \pm 0.014 \pm 0.009$$

stat syst BFs

[arxiv:1704.07900]



Reconstruct $\chi_{c(1,2)} \to J/\psi\,\gamma$

Constrain $J/\psi\,\gamma$ mass to known χ_{c1} mass

$\Lambda_b^0 \to \chi_{c(1,2)} p K^-$

Search for $P_c(4450)^+$ in $\Lambda_b^0 \to \chi_{c(1,2)} p K^-$ decays

→ Test hypothesis of re-scattering effect

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First step:

Observe the decay modes,

Measure Branchi… …ction

$$\frac{BF(\Lambda_b^0 \to \chi_{c1} p K^-)}{BF(\Lambda_b^0 \to J/\psi p K^-)} = 0.242 \pm 0.0$$

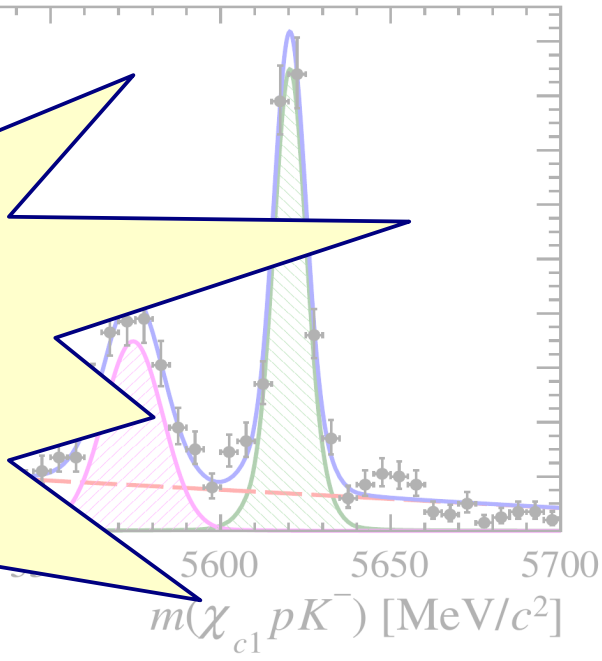
$$\frac{BF(\Lambda_b^0 \to \chi_{c2} p K^-)}{BF(\Lambda_b^0 \to J/\psi p K^-)} = 0.24$$

stat BFs

[arxiv:1704.07900]

Next:

Amplitude analysis



Reconstruct $\chi_{c(1,2)} \to J/\psi\gamma$

Constrain $J/\psi\gamma$ mass to known χ_{c1} mass

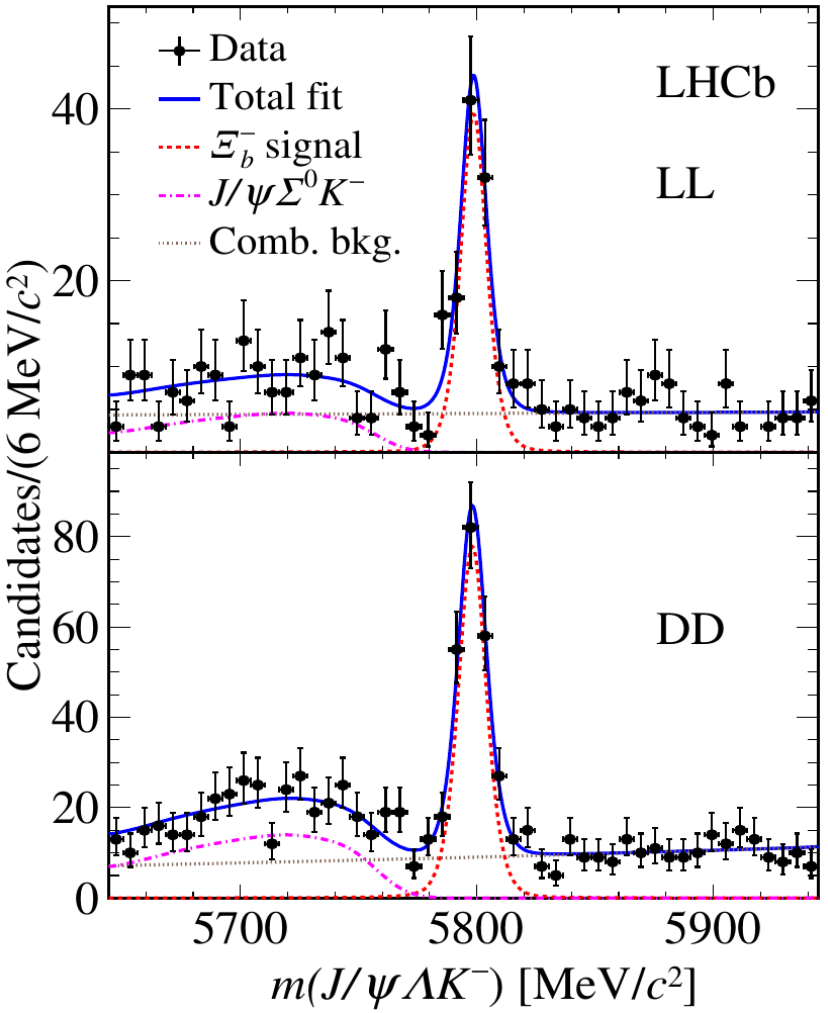
$\Xi_b^- \to J/\psi\,\Lambda\,K^-$

Search $\Xi_b^- \to J/\psi\,\Lambda\,K^-$ for possible ($udsc\bar{c}$) states

First step:
Observe the decay mode,
Measure Branching Fraction

$$\frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}} \times \frac{BF(\Xi_b^- \to J/\psi\,\Lambda\,K^-)}{BF(\Lambda_b^0 \to J/\psi\,\Lambda)} = (4.19 \pm 0.29 \pm 0.14) \times 10^{-2}$$

[arxiv:1701.05274]



$\Xi_b^- \to J/\psi\, \Lambda\, K^-$

Search $\Xi_b^- \to \boxed{J/\psi\, \Lambda}\, K^-$ for possible ($uds\bar{c}c$) states

First step:

Observe the decay mode

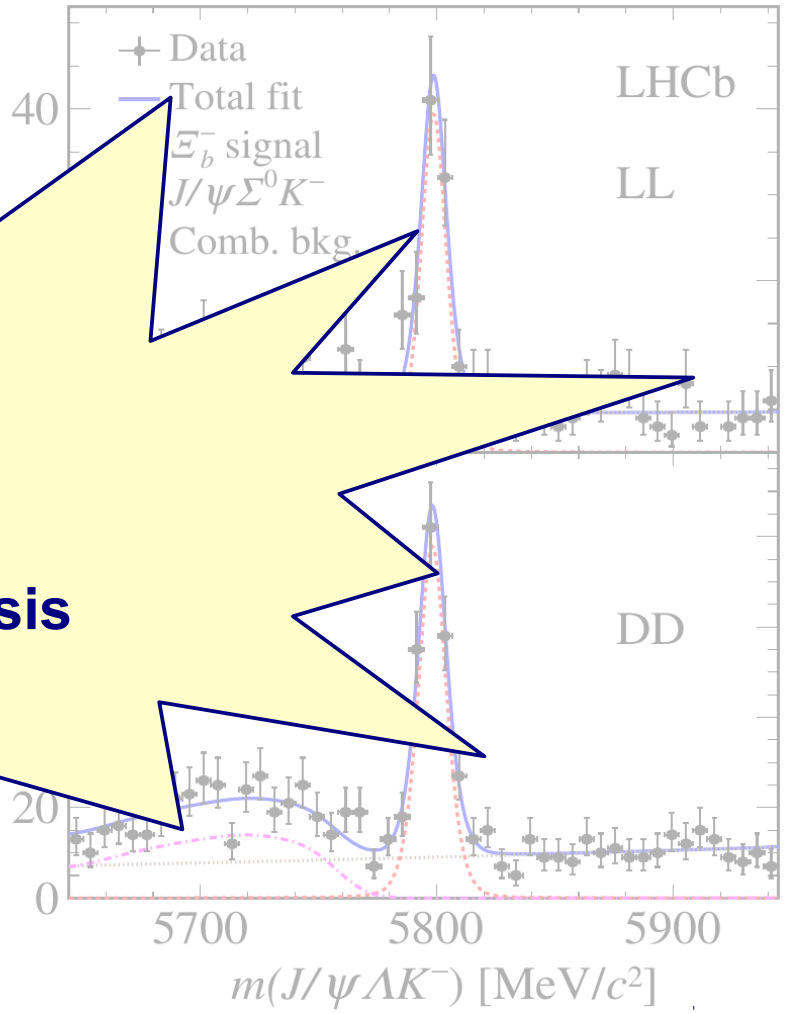
Measure Branc

$$\frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}} \times \frac{BF(\ldots}{BF(\Lambda\ldots}$$

[arXiv:1...

Next:

Amplitude analysis



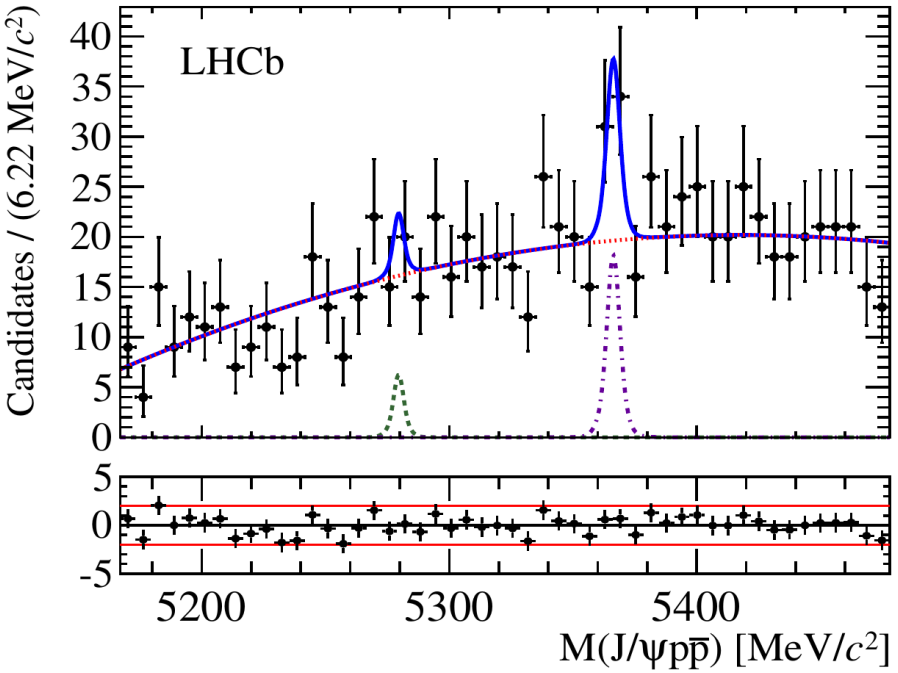
$B_{(s)}^{0} \to J/\psi\, p\, \bar{p}$

Search $B^0 / B_s^0 \to J/\psi\, p\, \bar{p}$ for ground-state P_c^+ states

So far only upper limits on BF from 2011 data set (1 fb^{-1})

$$BF(B^0 \to J/\psi\, p\, \bar{p}) < 6.0 \times 10^{-7}$$
$$BF(B_s^0 \to J/\psi\, p\, \bar{p}) < 5.3 \times 10^{-6}$$
@ 95 % C.L.

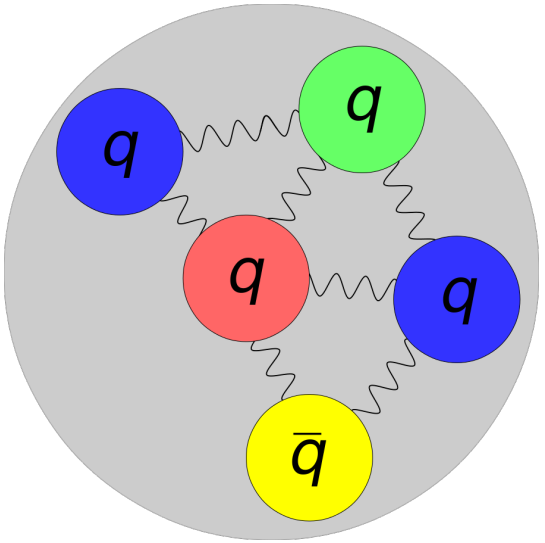
[JHEP 09(2013)006]



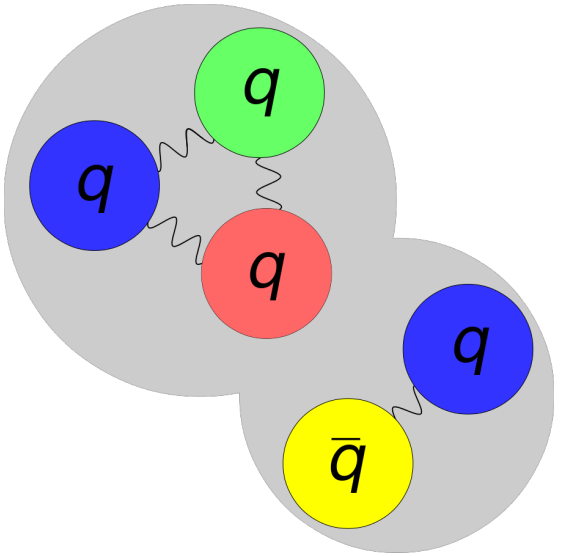
… analysis of full Run-I data set is underway

Pentaquarks

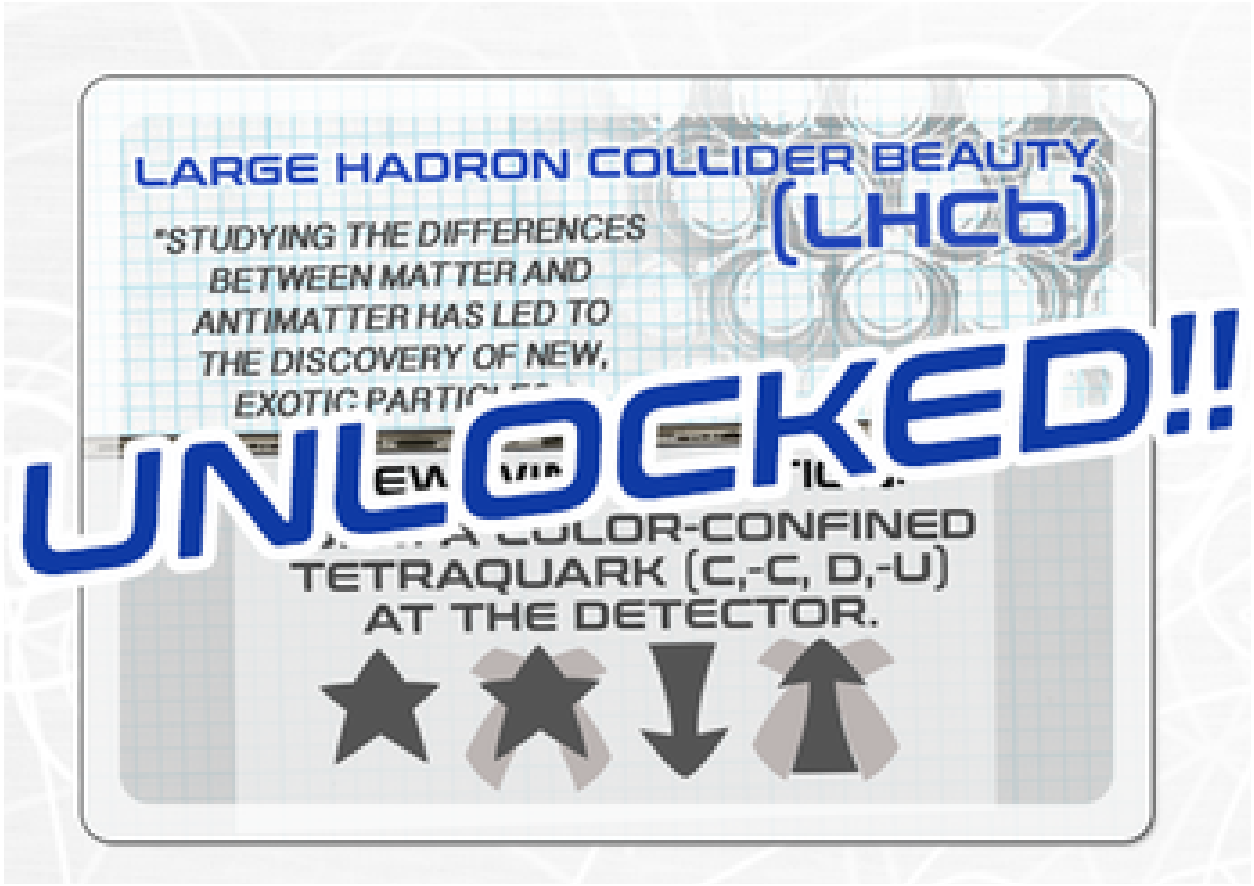
Searches in direct production
interesting to distinguish between



and



… but challenging:
large backgrounds,
unknown cross sections



THIS CARD CHANGES THE WIN CONDITION TO A TETRAQUARK!

[https://www.kickstarter.com/projects/239309591/pentaquark-a-solo-microgame-in-a-quantum-state]

$X(4140)^0$

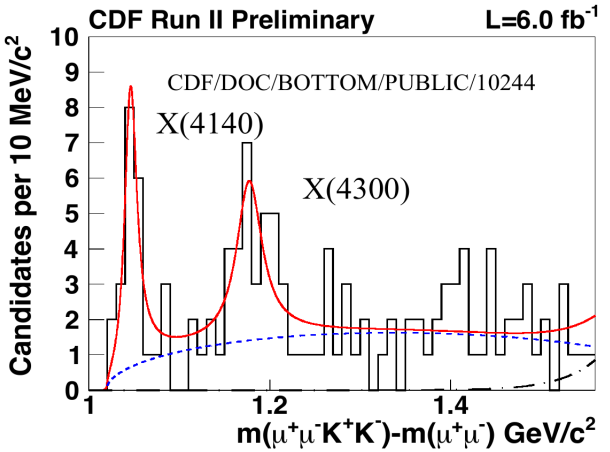
Narrow state in $B^+ \to J/\psi\,\phi\,K^+$ reported by CDF, DØ and CMS

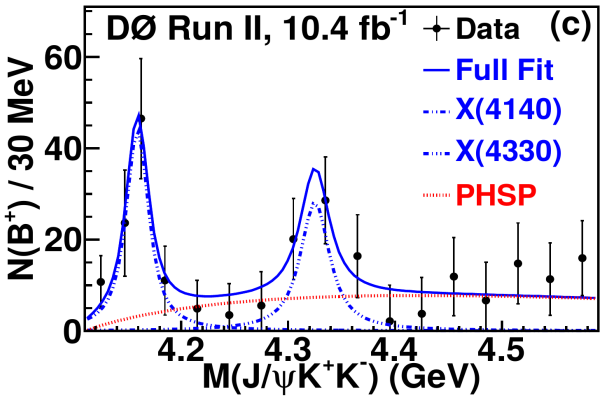
	σ	M (MeV)	Γ (MeV)
CDF	> 5	$4143.4^{+2.9}_{-3.0} \pm 0.6$	$15.3^{+10.4}_{-6.1} \pm 2.5$
DØ	3.1	$4159.0 \pm 4.3 \pm 6.6$	$19.9 \pm 12.6^{+3.0}_{-8.1}$
CMS	5	$4148.0 \pm 2.4 \pm 6.3$	$28^{+15}_{-11} \pm 19$

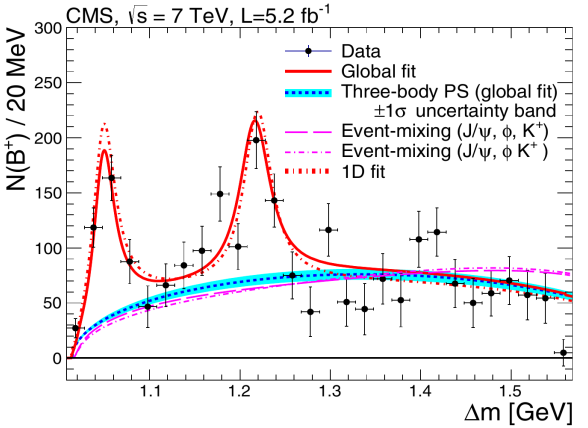
[PRL 102(2009)242002]
[PRD 89(2014)012004]
[PLB 734(2014)261]

… not seen by Belle

[arXiv:1011.3369] [PRL 104(2010)112004]







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[PRL 102(2009)242002]
[PRD 89(2014)012004]
[PLB 734(2014)261]

Various interpretations as:

Tetraquark

Molecule

Dynamically generated resonance

Coupled-channel effect

[see backup slide for references]

… not seen by Belle

[arXiv:1011.3369] [PRL 104(2010)112004]

$X(4140)^0$

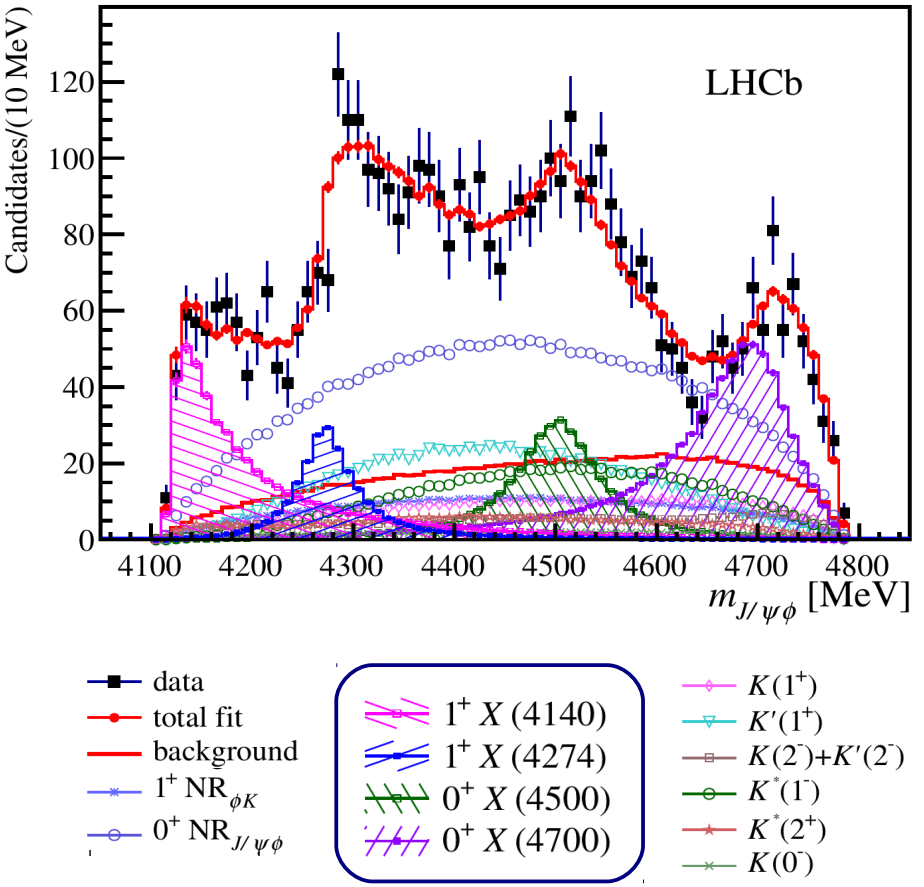
LHCb amplitude analysis of $B^+ \to J/\psi\,\phi\,K^+$

→ Find need for four new states

	σ	J^{PC}	M (MeV)	Γ (MeV)
$X(4140)$	8.4	1^{++}	$4160 \pm 4^{+5}_{-3}$	$83 \pm 21^{+21}_{-14}$
$X(4274)$	5.8	1^{++}	$4273 \pm 8^{+17}_{-4}$	$56 \pm 11^{+8}_{-11}$
$X(4500)$	6.1	0^{++}	$4506 \pm 11^{+12}_{-15}$	$92 \pm 21^{+21}_{-20}$
$X(4700)$	5.6	0^{++}	$4704 \pm 10^{+14}_{-24}$	$120 \pm 31^{+42}_{-33}$

[PRD 95(2017)012002]

[PRL 118(2017)022003]



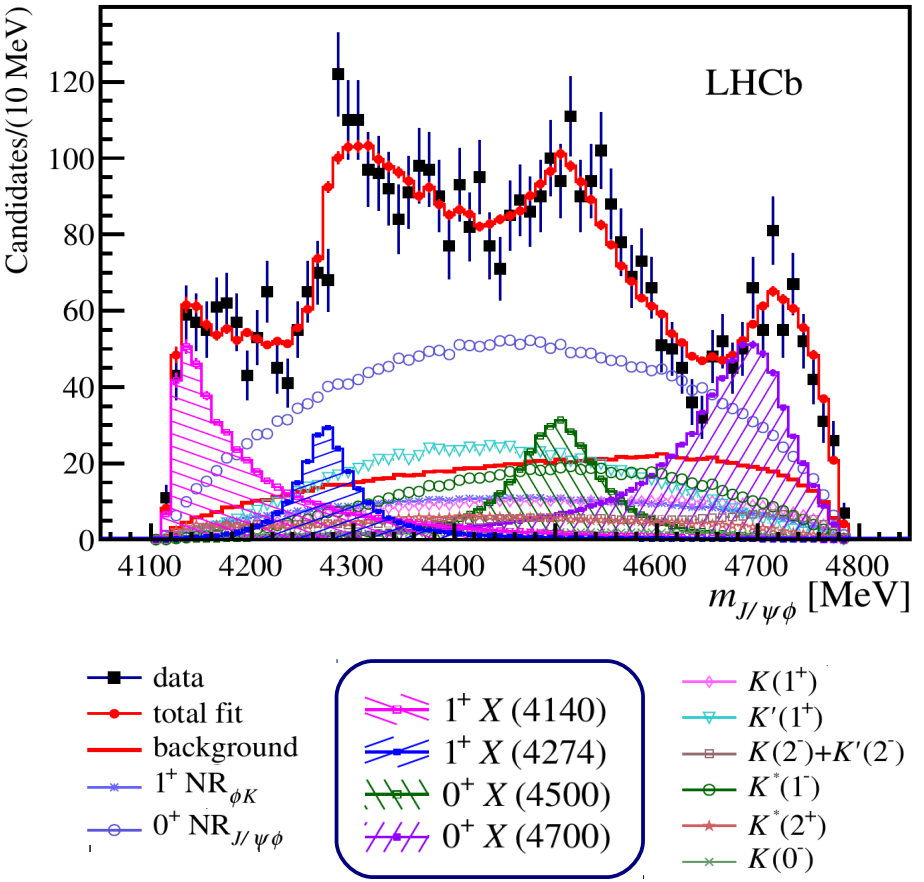
$X(4140)^0$

LHCb amplitude analysis of $B^+ \to J/\psi\,\phi\,K^+$

$X(4140)$: mass consistent with CDF/DØ/CMS, but width significantly larger

	σ	M (MeV)	Γ (MeV)
CDF	> 5	$4143.4^{+2.9}_{-3.0} \pm 0.6$	$15.3^{+10.4}_{-6.1} \pm 2.5$
DØ	3	$4159.0 \pm 4.3 \pm 6.6$	$19.9 \pm 12.6^{+3.0}_{-8.1}$
CMS	5	$4148.0 \pm 2.4 \pm 6.3$	$28^{+15}_{-11} \pm 19$
LHCb	8.4	$4160 \pm 4^{+5}_{-3}$	$83 \pm 21^{+21}_{-14}$

[PRL 102(2009)242002] [PRD 95(2017)012002]
[PRD 89(2014)012004] [PRL 118(2017)022003]
[PLB 734(2014)261]

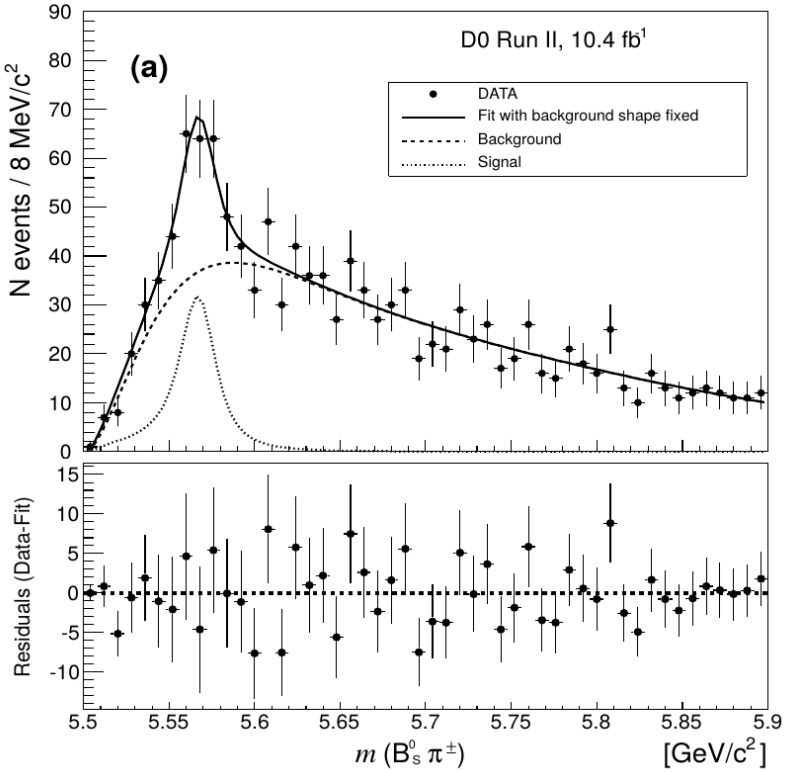


$Z(5568)^+$?

DØ report significant peak in $B_s^0\pi^+$ mass with $B_s^0 \to J/\psi\,\phi$

$\rho_X = (8.6 \pm 1.9 \pm 1.4)\%$ of all B_s^0 from $Z(5568)^+$

[PRL 117(2016)022003]



$Z(5568)^+$?

DØ report significant peak in $B_s^0\pi^+$ mass with $B_s^0 \to J/\psi\,\phi$

$\rho_X = (8.6 \pm 1.9 \pm 1.4)\%$ of all B_s^0 from $Z(5568)^+$

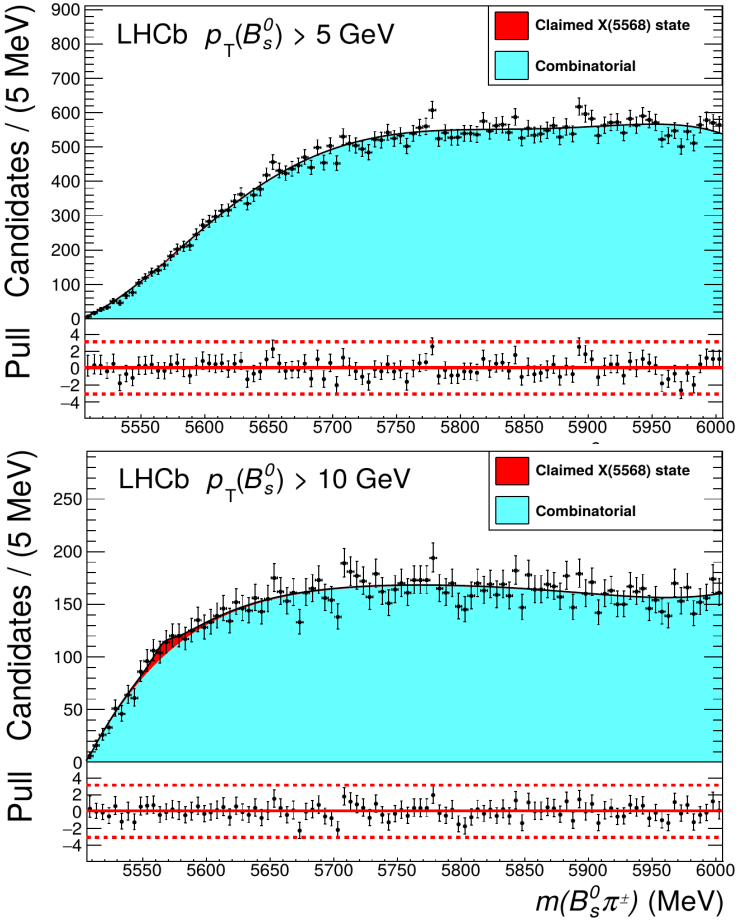
LHCb search in 122'000 $B_s^0\pi^+$ pairs

(20 × size of DØ sample)

No signal observed,

$\rho_X < 2.0\%$ at 95 % C.L.

[PRL 117(2016)152003]



Conclusions

Evidence for four exotic X^0 states

decaying to $J/\psi\,\phi$

DØ signal in $B_s^0\,\pi^+$ not confirmed

Observation of two pentaquark-like states

in $\Lambda_b^0 \to J/\psi\, p\, K^-$

Good prospect for searches in

$\Lambda_b^0 \to J/\psi\, p\, \pi^-$

$\Lambda_b^0 \to \chi_{c(1,2)}\, p\, K^-$

$\Xi_b^- \to J/\psi\, \Lambda\, K^-$

with the larger data samples from Run-II

Disclaimer

Teilchenphysik

Cern entdeckt ein neues Teilchen. Und jetzt?

Sein Name klingt kryptisch, niemand hatte es je gesehen, doch Physiker ahnten: Es muss es geben. Am Genfer Teilchenbeschleuniger wurde ein Xi cc++ entdeckt. Was ist das?

6. Juli 2017, 18:17 Uhr / Quelle: ZEIT ONLINE, dpa, dal / 135 Kommentare

Wie sicher ist die Entdeckung?

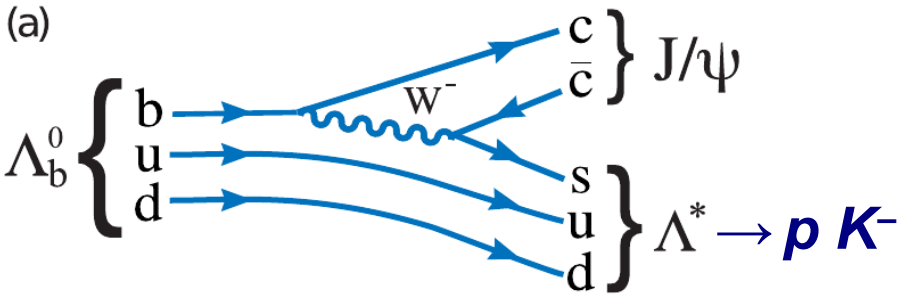
2015 hatte das Cern schon einmal die Entdeckung eines neuen Teilchens verkündet – damals ging es um ein sogenanntes Pentaquark. Diese stellte sich später jedoch als Messfehler heraus. Entsprechend vorsichtig sind die

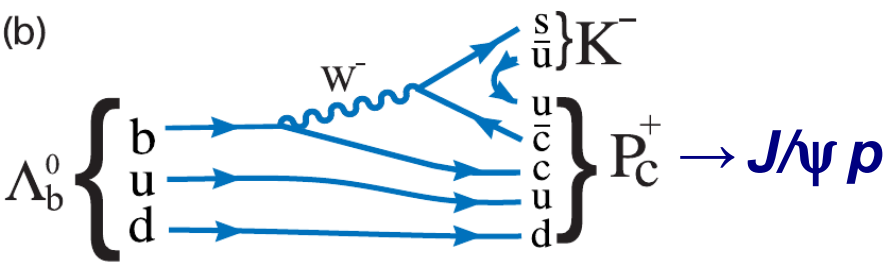
Disclaimer

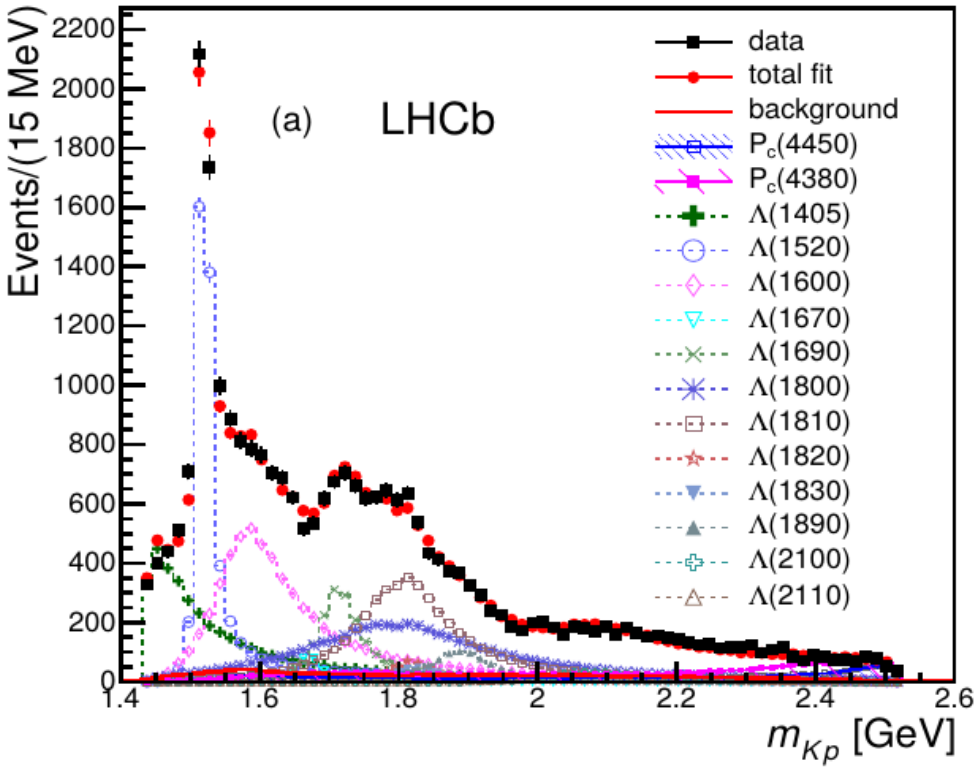
2015 hatte das Cern schon einmal die Entdeckung eines neuen Teilchens verkündet – damals ging es um ein sogenanntes Pentaquark. Diese stellte sich später jedoch als Messfehler heraus. Entsprechend vorsichtig sind die

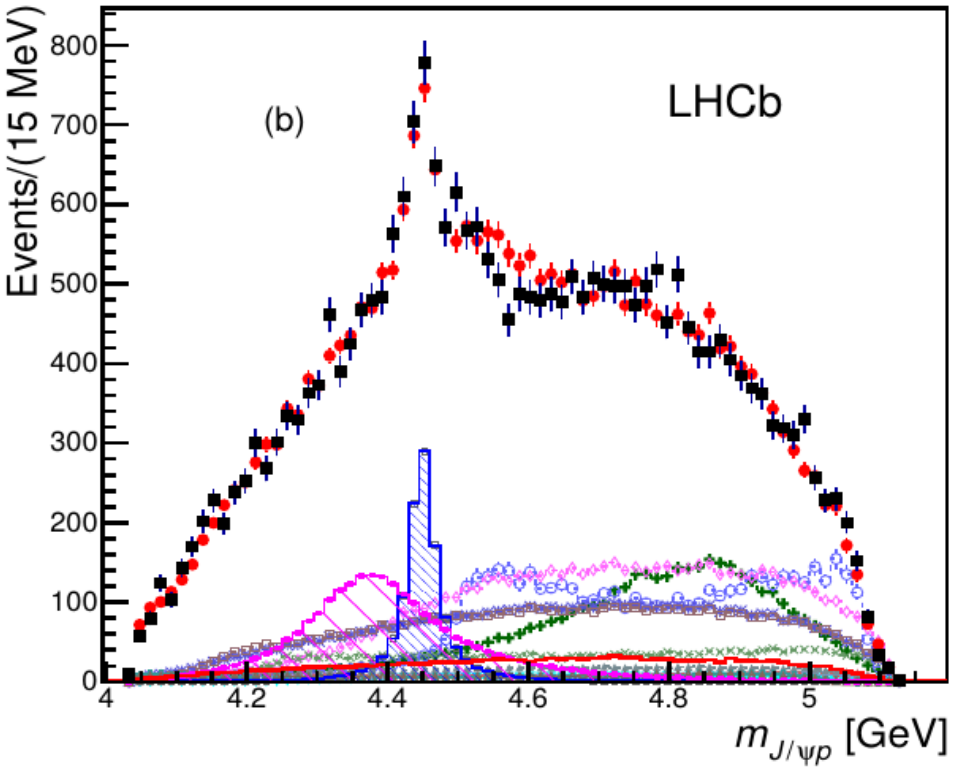
Backup

$P_c(4380)^+$ and $P_c(4450)^+$



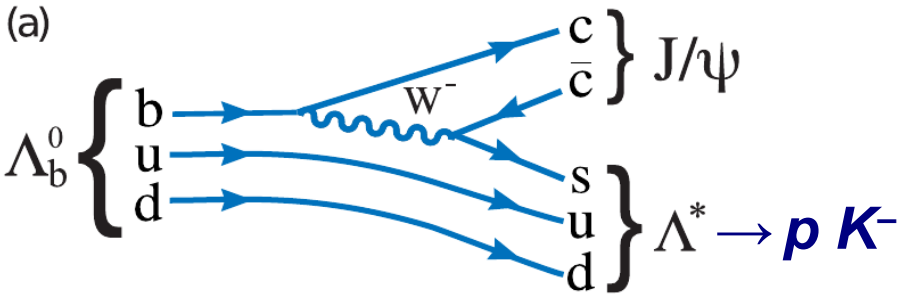


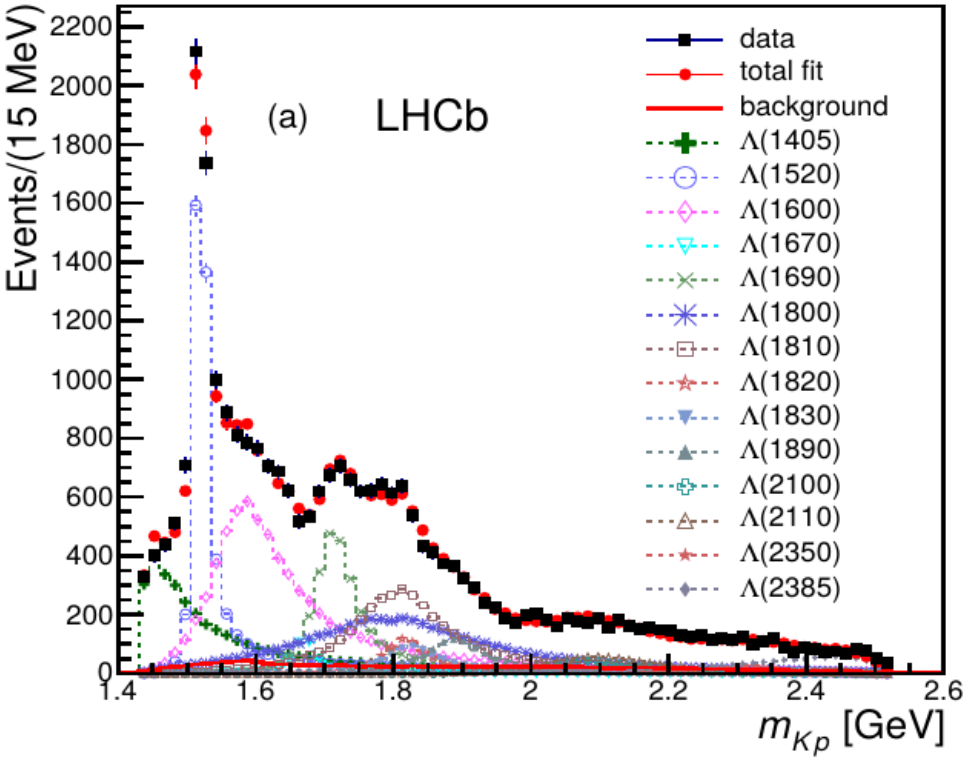


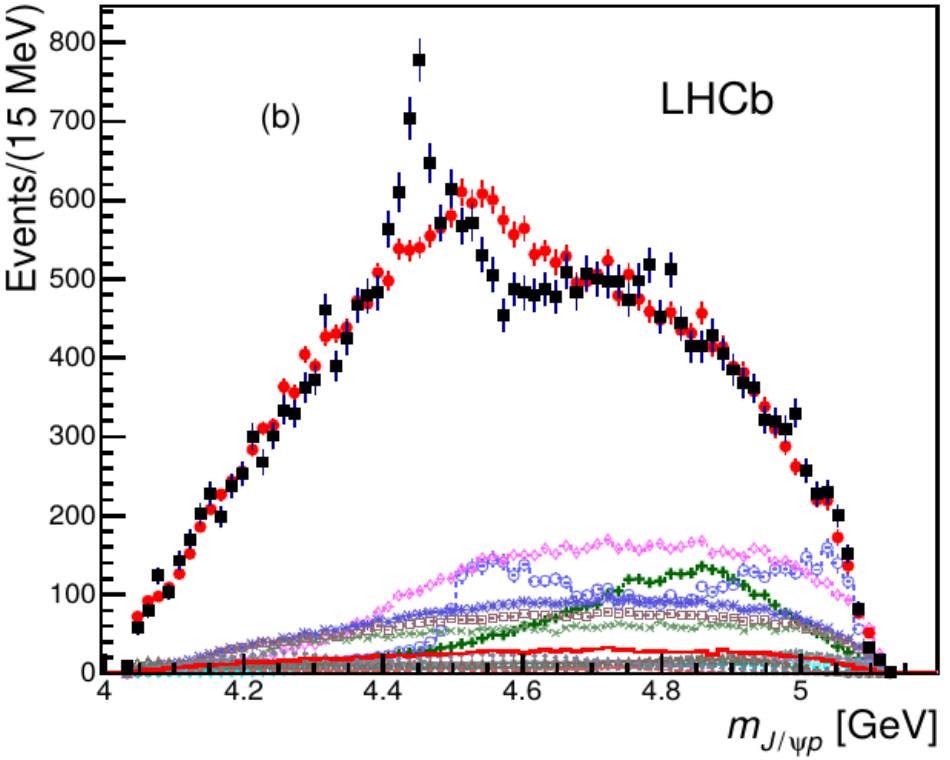


[PRL 115(2015)072001]

$P_c(4380)^+$ and $P_c(4450)^+$

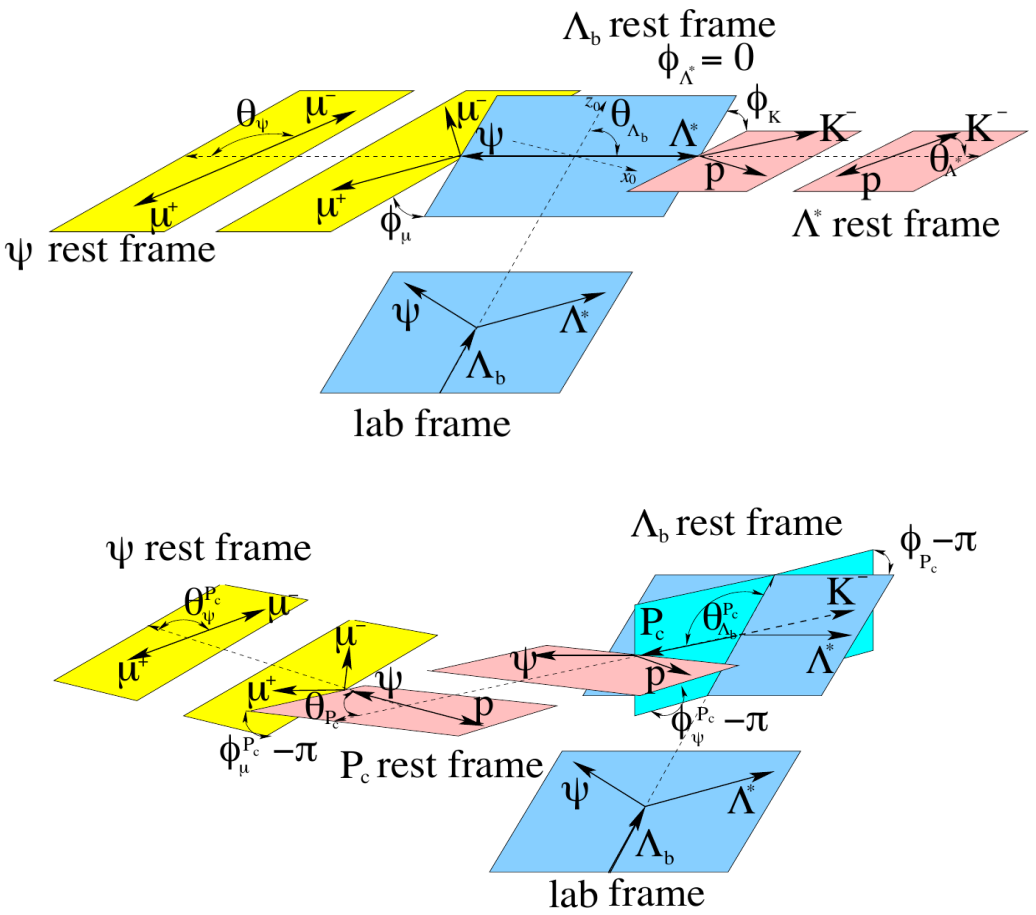


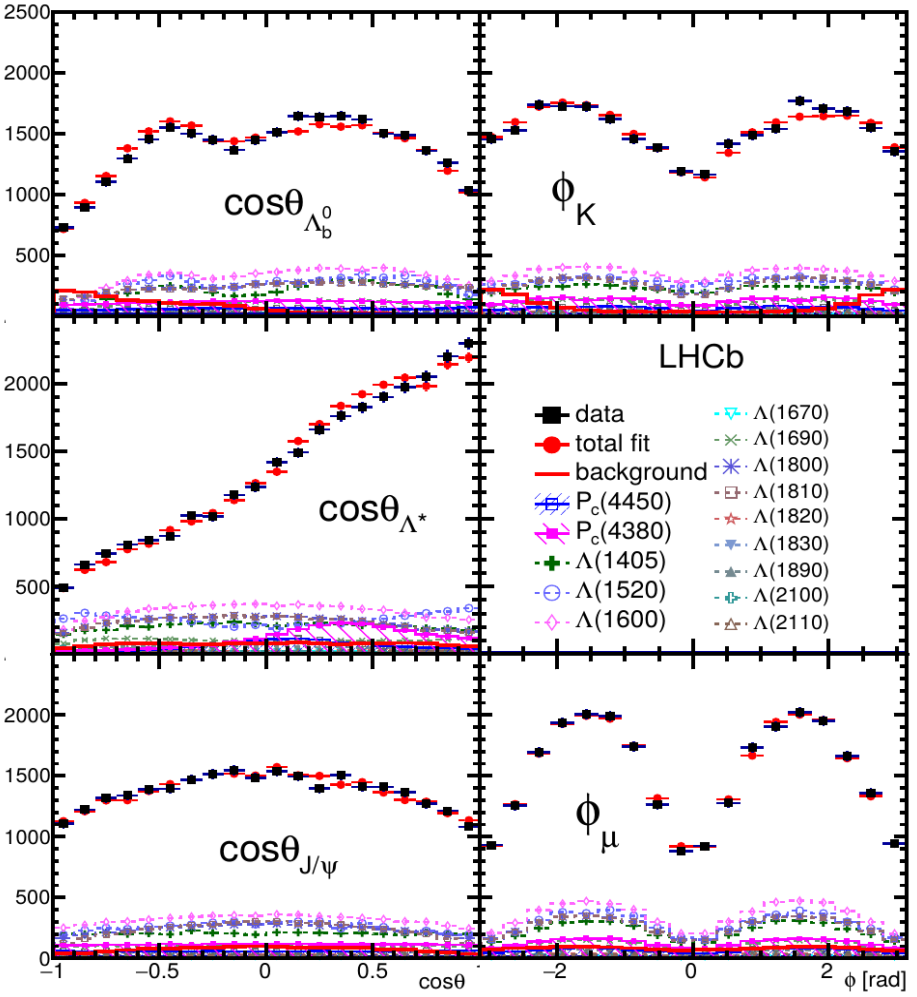




[PRL 115(2015)072001]

$P_c(4380)^+$ and $P_c(4450)^+$





[PRL 115(2015)072001]

$\Lambda_b^0 \to \chi_{c(1,2)}\, p\, K^-$

Search for $P_c(4450)^+$ in $\Lambda_b \to \chi_{c(1,2)}\, p\, K^-$ decays

→ Test hypothesis of re-scattering effect

[PRD92(2015)071502]

Side remark:

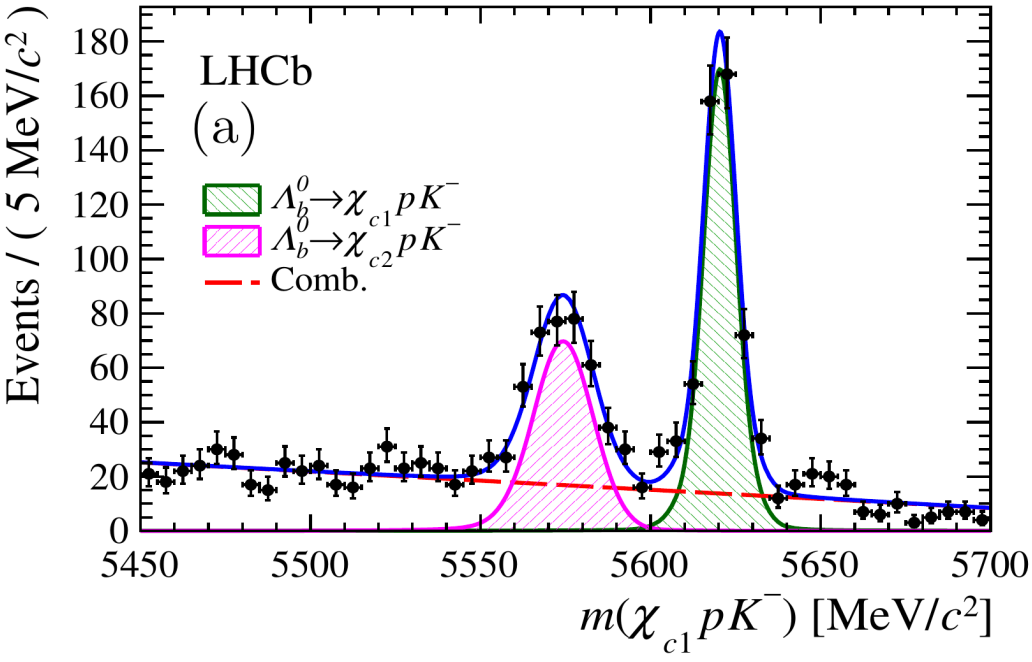
$$\frac{BF(\Lambda_b^0 \to \chi_{c2}\, p\, K^-)}{BF(\Lambda_b^0 \to \chi_{c1}\, p\, K^-)} = 1.02 \pm 0.11$$

[arxiv:1704.07900]

while

$$\frac{BF(B^0 \to \chi_{c2}\, K^*)}{BF(B^0 \to \chi_{c1}\, K^*)} = 0.17 \pm 0.05$$

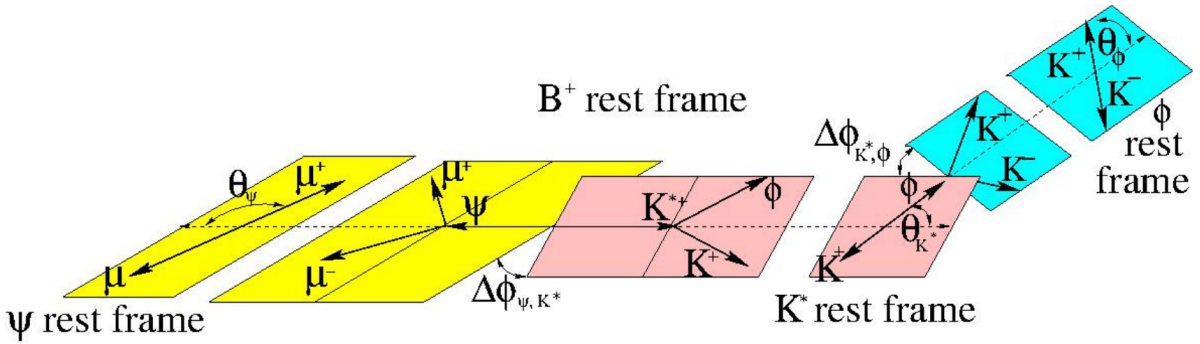
[NPB 874(2013)663]

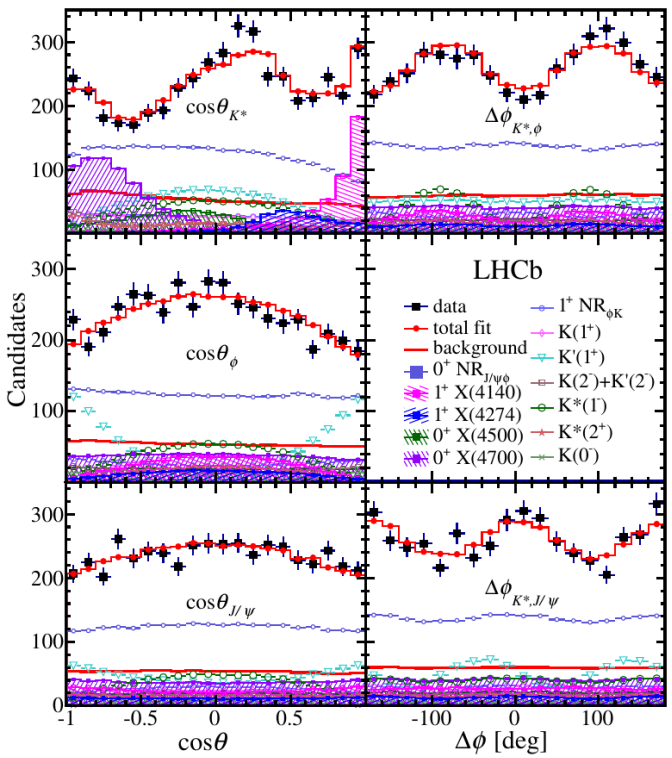


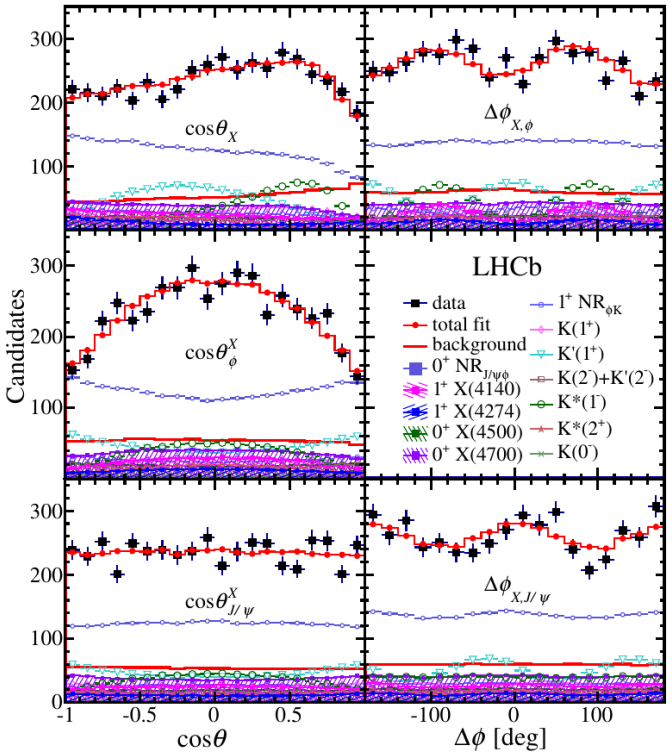
Reconstruct $\chi_{c(1,2)} \to J/\psi\,\gamma$

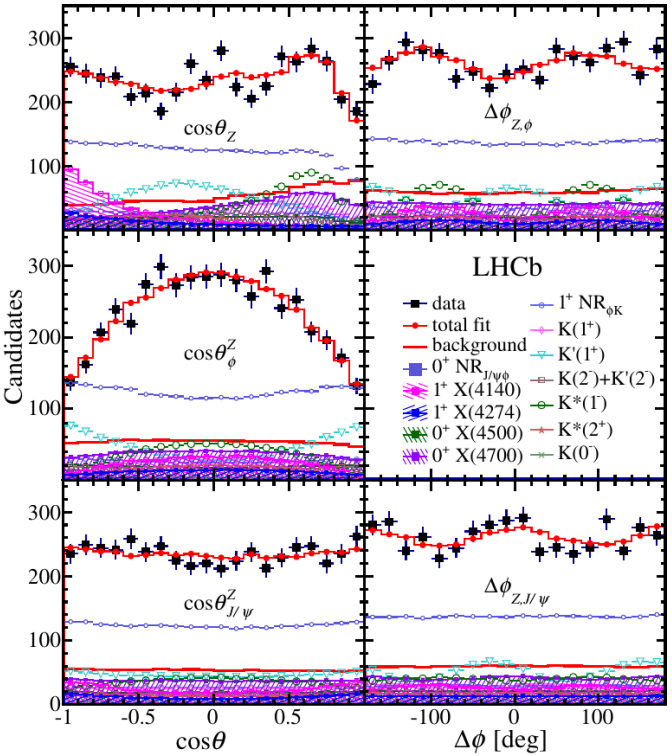
Constrain $J/\psi\,\gamma$ mass to known χ_{c1} mass

$X(4140)^0$







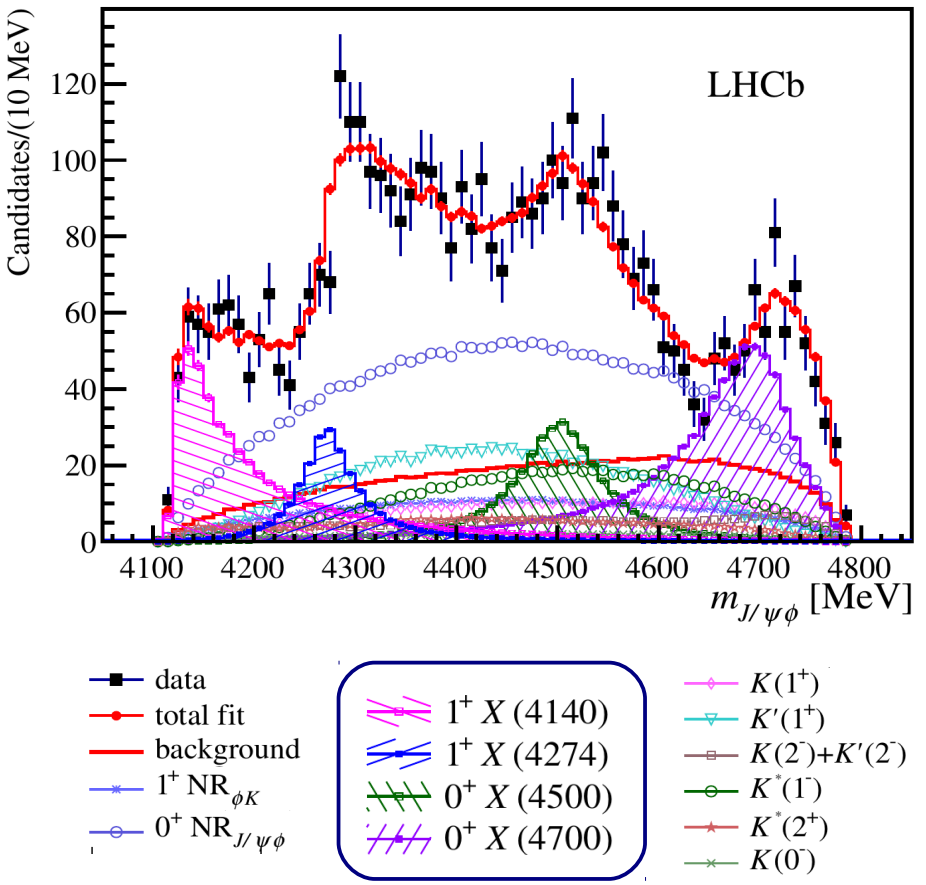


[PRD 95(2017)012002]

[PRL 118(2017)022003]

$X(4140)^0$

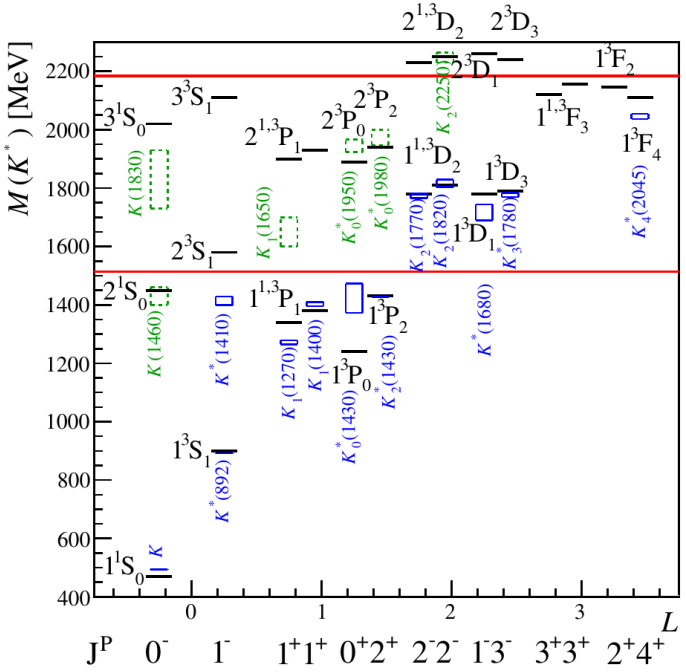
Contribution	sign. or Ref.	M_0 [MeV]	Γ_0 [MeV]	FF %	f_L	$f_\perp$
All $K(1^+)$	8.0σ			$42\pm 8^{+5}_{-9}$		
$NR_{\phi K}$				$16\pm13^{+35}_{-6}$	0.52 ± 0.29	0.21 ± 0.16
$K(1^+)$	7.6σ	$1793\pm59^{+153}_{-101}$	$365\pm157^{+138}_{-215}$	$12\pm10^{+17}_{-6}$	0.24 ± 0.21	0.37 ± 0.17
2^1P_1	[53]	1900				
$K_1(1650)$	[37]	1650 ± 50	150 ± 50			
$K'(1^+)$	1.9σ	$1968\pm65^{+70}_{-172}$	$396\pm170^{+174}_{-178}$	$23\pm20^{+31}_{-29}$	0.04 ± 0.08	0.49 ± 0.10
2^3P_1	[53]	1930				
All $K(2^-)$	5.6σ			$11\pm 3^{+2}_{-5}$		
$K(2^-)$	5.0σ	$1777\pm35^{+122}_{-77}$	$217\pm116^{+221}_{-154}$		0.64 ± 0.11	0.13 ± 0.13
1^1D_2	[53]	1780				
$K_2(1770)$	[37]	1773 ± 8	188 ± 14			
$K'(2^-)$	3.0σ	$1853\pm27^{+18}_{-35}$	$167\pm 58^{+83}_{-72}$		0.53 ± 0.14	0.04 ± 0.08
1^3D_2	[53]	1810				
$K_2(1820)$	[37]	1816 ± 13	276 ± 35			
$K^*(1^-)$	8.5σ	$1722\pm20^{+33}_{-109}$	$354\pm 75^{+140}_{-181}$	$6.7\pm1.9^{+3.2}_{-3.9}$	0.82 ± 0.04	0.03 ± 0.03
1^3D_1	[53]	1780				
$K^*(1680)$	[37]	1717 ± 27	322 ± 110			
$K^*(2^+)$	5.4σ	$2073\pm94^{+245}_{-240}$	$678\pm311^{+1153}_{-559}$	$2.9\pm0.8^{+1.7}_{-0.7}$	0.15 ± 0.06	0.79 ± 0.08
2^3P_2	[53]	1940				
$K_2^*(1980)$	[37]	1973 ± 26	373 ± 69			
$K(0^-)$	3.5σ	$1874\pm43^{+59}_{-115}$	$168\pm 90^{+280}_{-104}$	$2.6\pm1.1^{+2.3}_{-1.8}$	1.0	
3^1S_0	[53]	2020				
$K(1830)$	[37]	~ 1830	~ 250			
All $X(1^+)$				$16\pm3^{+6}_{-2}$		
$X(4140)$	8.4σ	$4146.5\pm4.5^{+4.6}_{-2.8}$	$83\pm21^{+21}_{-14}$	$13.0\pm3.2^{+4.8}_{-2.0}$		
ave.	Table 1	4147.1 ± 2.4	15.7 ± 6.3			
$X(4274)$	6.0σ	$4273.3\pm8.3^{+17.2}_{-3.6}$	$56\pm11^{+8}_{-11}$	$7.1\pm2.5^{+3.5}_{-2.4}$		
CDF	[29]	$4274.4^{+8.4}_{-6.7}\pm1.9$	$32^{+22}_{-15}\pm8$			
CMS	[25]	$4313.8\pm5.3\pm7.3$	$38^{+30}_{-15}\pm16$			
All $X(0^+)$				$28\pm 5\pm 7$		
$NR_{J/\psi\phi}$	6.4σ			$46\pm11^{+11}_{-21}$		
$X(4500)$	6.1σ	$4506\pm11^{+12}_{-15}$	$92\pm21^{+21}_{-20}$	$6.6\pm2.4^{+3.5}_{-2.3}$		
$X(4700)$	5.6σ	$4704\pm10^{+14}_{-24}$	$120\pm31^{+42}_{-33}$	$12\pm 5^{+9}_{-5}$		

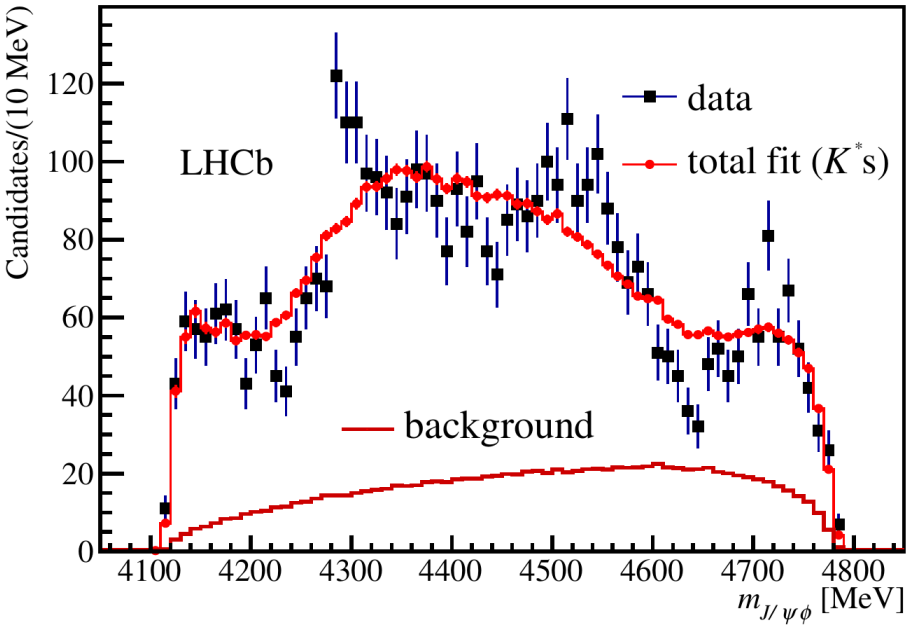


[PRD 95(2017)012002]

[PRL 118(2017)022003]

$X(4140)^0$





a nonresonant term plus candidates for two $2P_1$, two $1D_2$, and one of each of 1^3F_3, 1^3D_1, 3^3S_1, 3^1S_0, 2^3P_2, 1^3F_2, 1^3D_3 and 1^3F_4 states

[PRD 95(2017)012002]

[PRL 118(2017)022003]

$X(4140)^0$

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