Exotic Hadrons at LHCb

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M. Kreps on behalf of LHCb

DIS 2017, Birmingham, UK, 3-7 April, 2017

Physics Department

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Introduction

- In original Gell-Mann's paper, hadrons can be formed from more than quark-antiquark or three quarks
- Long standing puzzle where such combinations are
- Back in 2003 discovery of X(3872) renewed interest in this question
- Since then many states are seen in charmonium region
  - Too many to fit to charmonium spectrum
  - Some charged, so cannot be simple $c\bar{c}$
- Usual difficulty is to prove exotic nature and understand what it is

Volume 8, number 3 PHYSICS LETTERS 1 February 1964

A SCHEMATIC MODEL OF BARYONS AND MESONS *

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

We then refer to the members $u^{\frac{2}{3}}$, $d^{-\frac{1}{3}}$, and $s^{-\frac{1}{3}}$ of the triplet as "quarks" [6] q and the members of the anti-triplet as anti-quarks $\bar{q}$. Baryons can now be constructed from quarks by using the combinations (qqq), $(qqqq\bar{q})$, etc., while mesons are made out of $(q\bar{q})$, $(qq\bar{q}\bar{q})$, etc. It is assuming that the lowest

Pentaquark states

PRL 117, 082002
PRL 115, 072001

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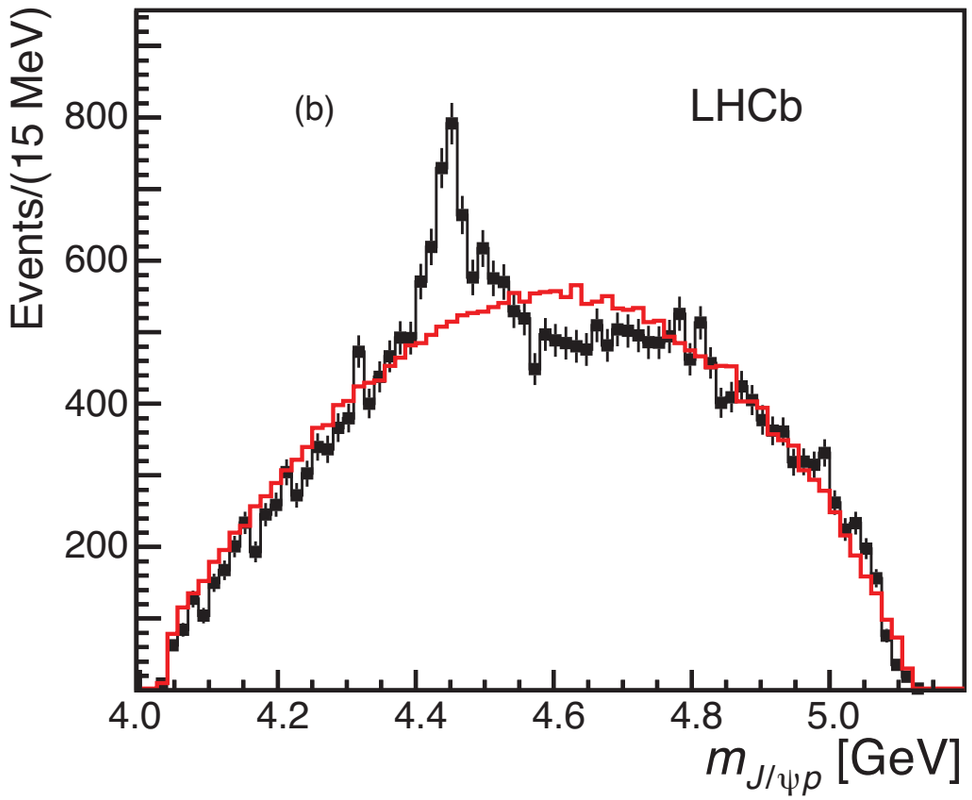
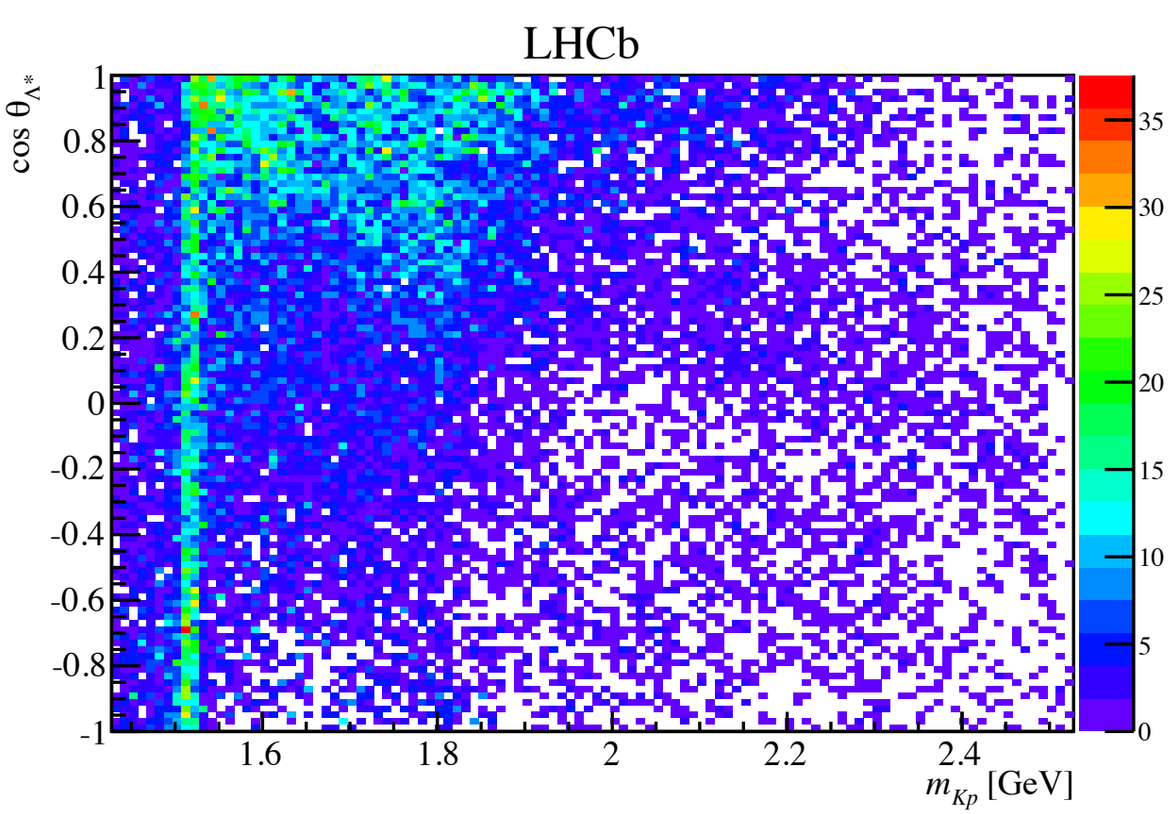
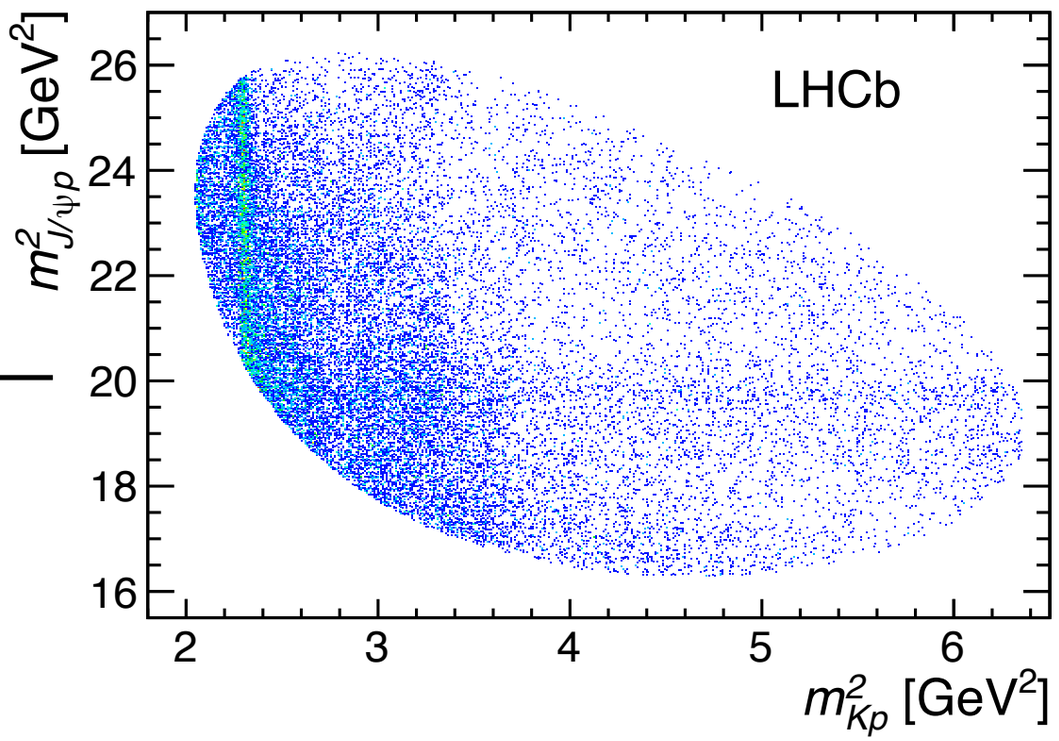
- In summer 2015 LHCb observed two pentaquark states in $\Lambda_b \rightarrow J/\psi pK$ decays
- Original analysis used amplitude fit
  - Sensitive, but depends on assumptions on resonances shapes
- Can do model independent test in the same decay







Pentaquark states

PRL 117, 082002

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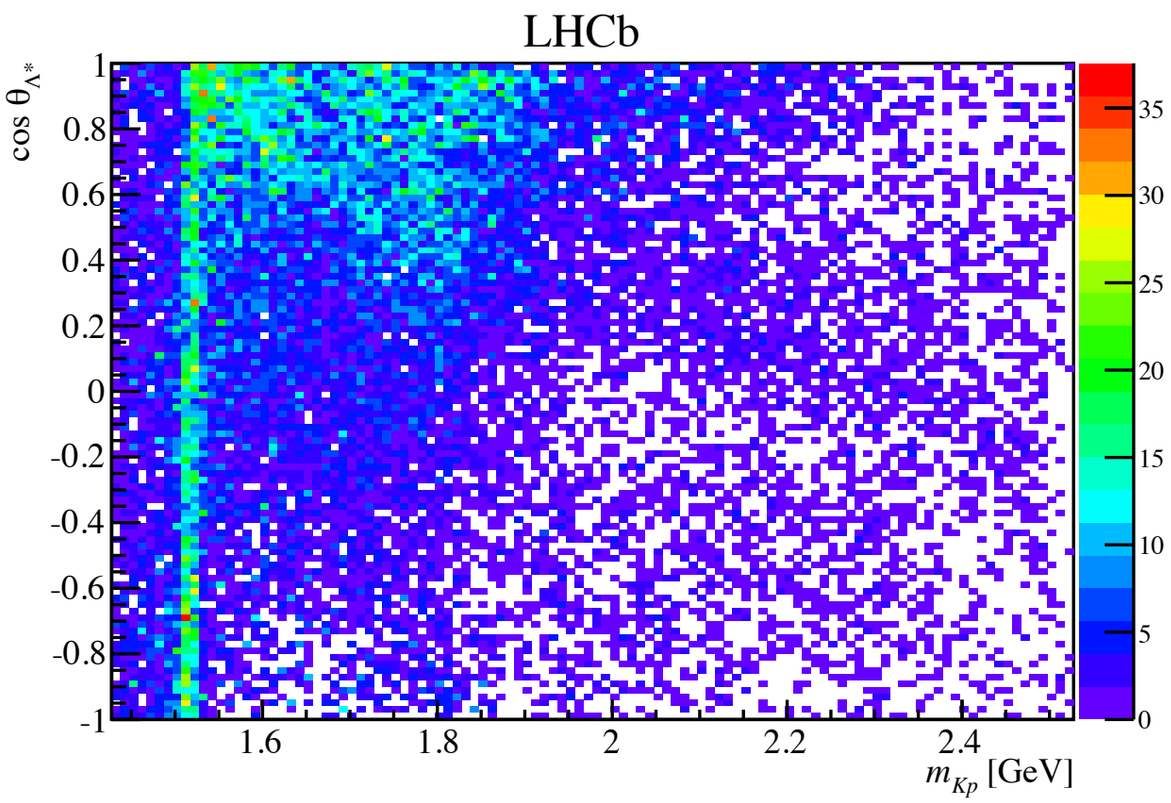
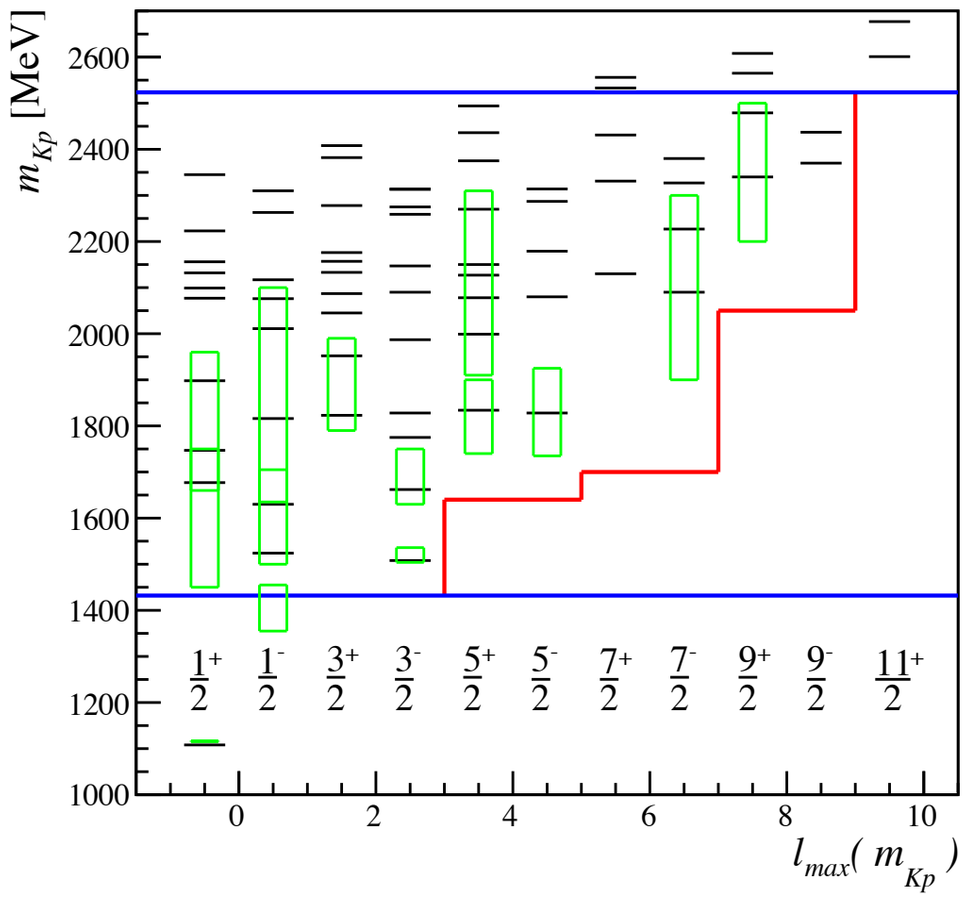
- Expand angular distribution in m(pK) bins in Legendre polynomials
- pK resonances will contribute to limited number of terms (up to 2×spin)
- On contrary pentaquark will be peaking in angular distribution and thus will contribute to much higher moments
- Remove terms above selected J_{max}
  - Dump pentaquark contribution
- Build model with pentaquark contribution suppressed





Pentaquark states

PRL 117, 082002

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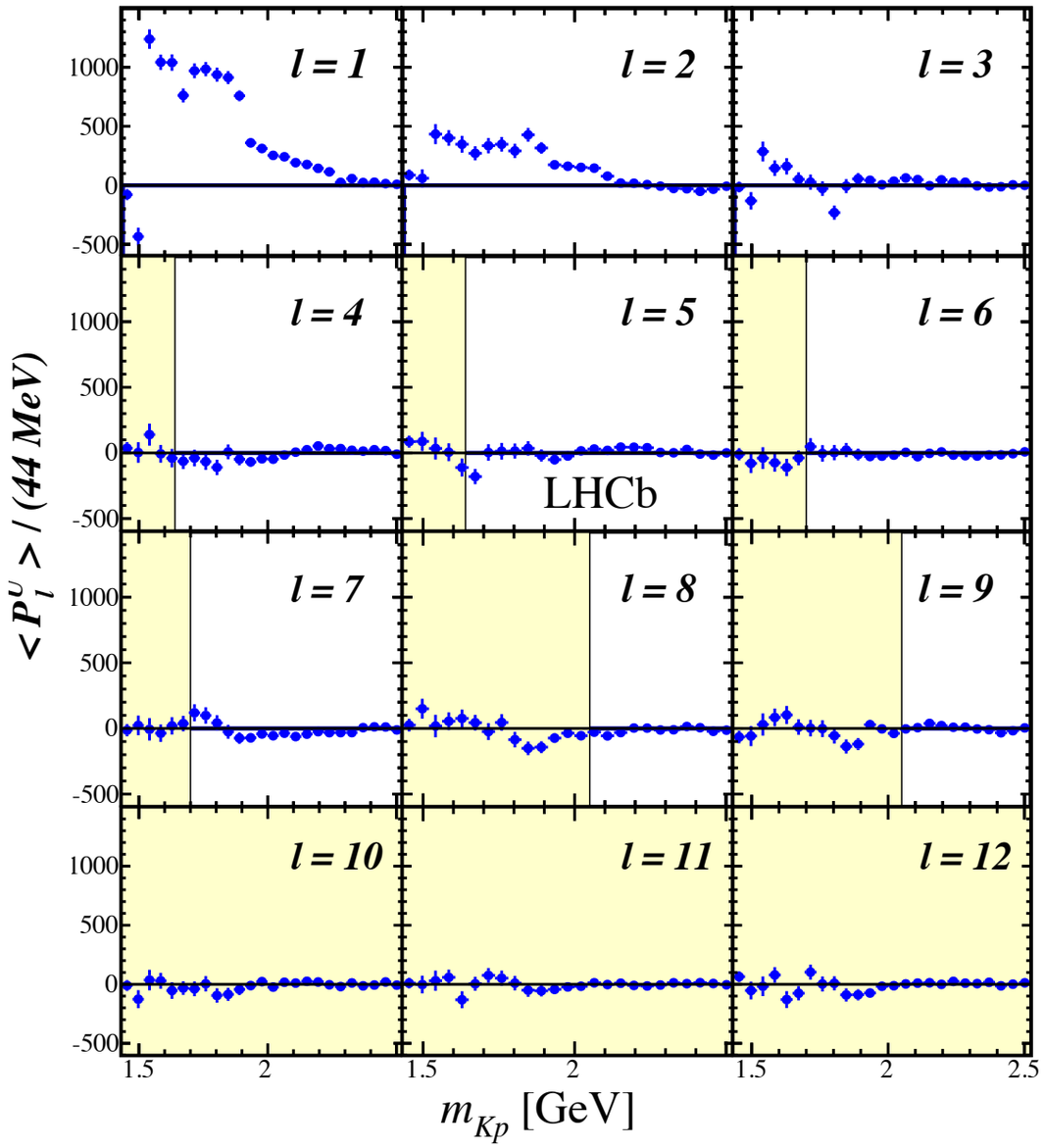
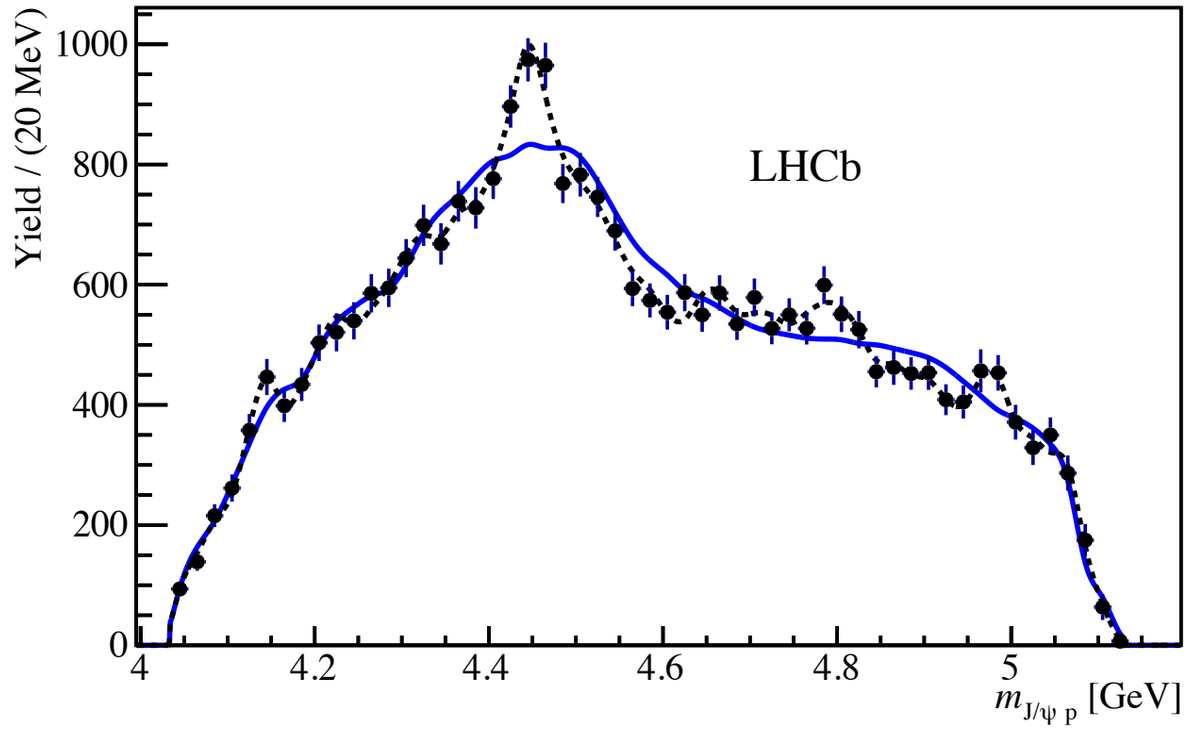
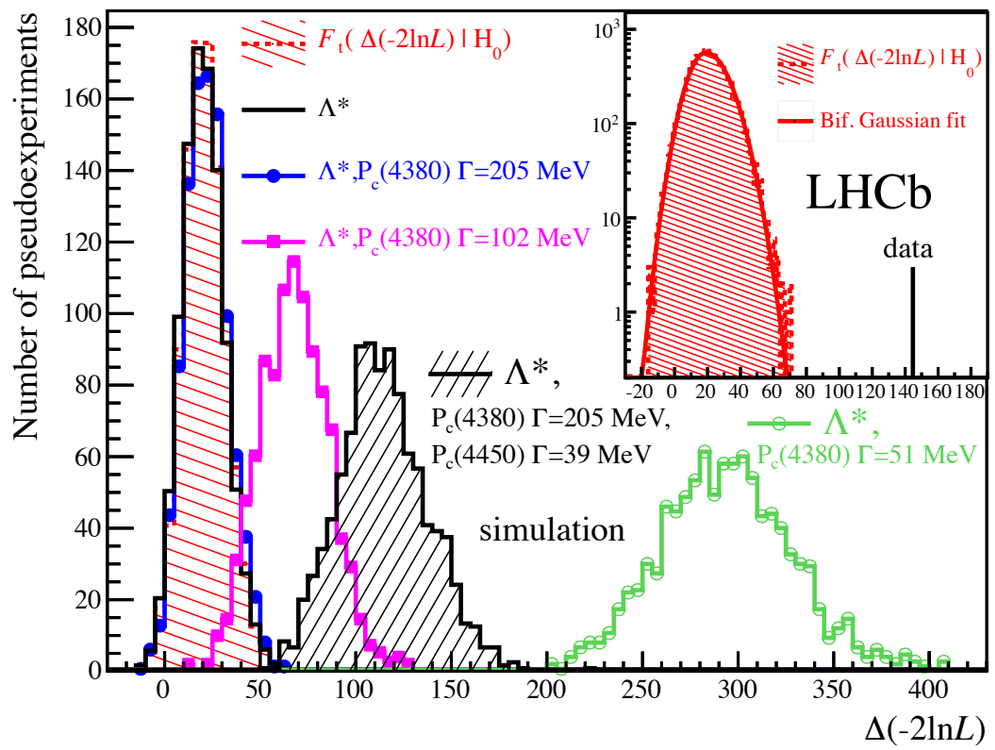




- Model independent analysis confirms pentaquark contributions
- Can quantify significance using pseudo-likelihood (>9σ)



Pentaquark states

PRL 117, 082003

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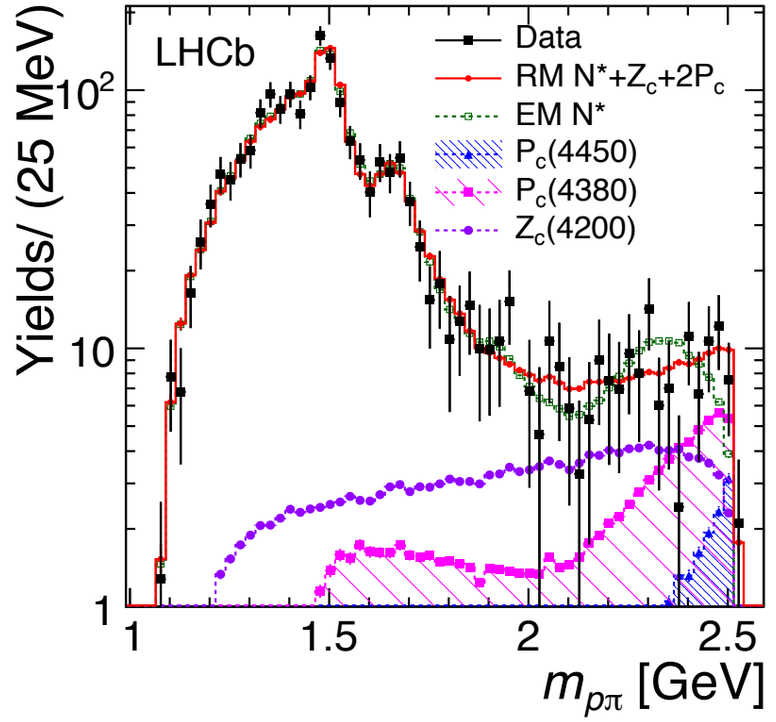
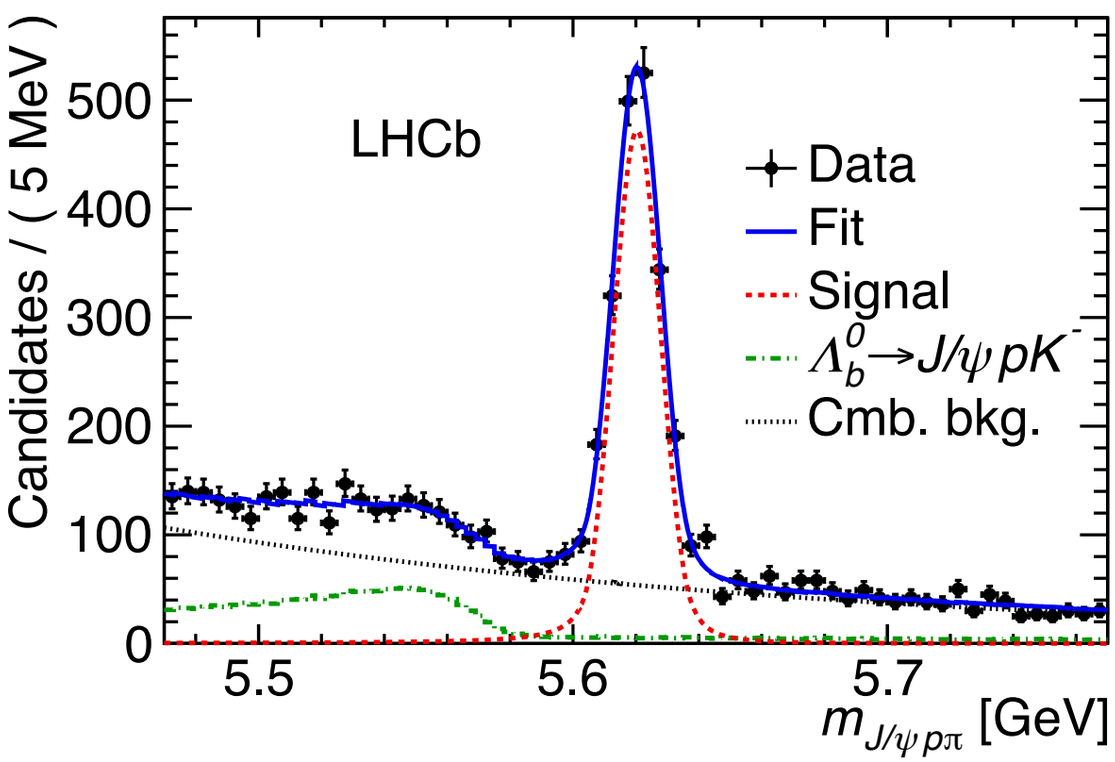
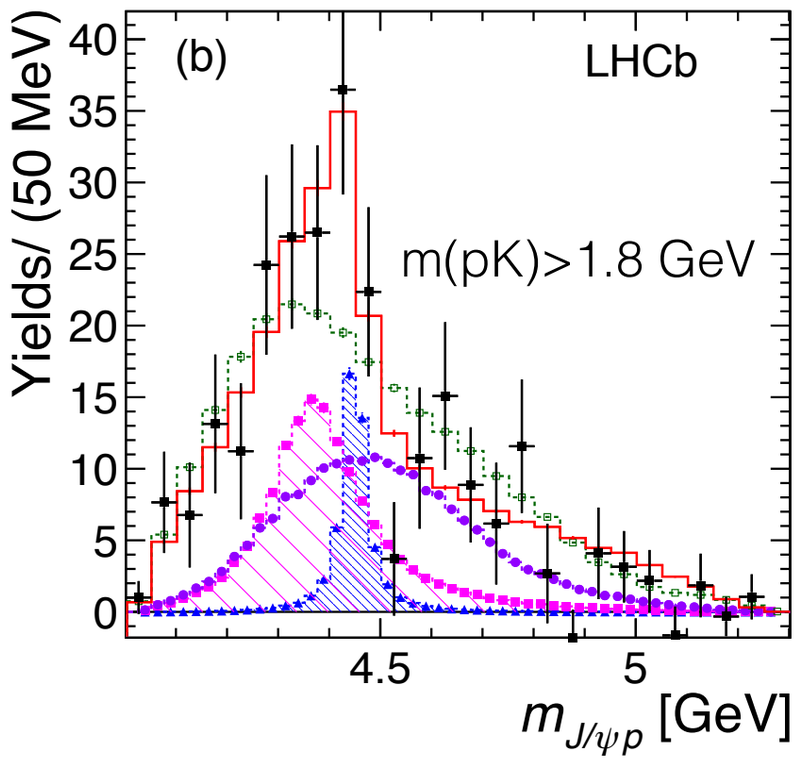
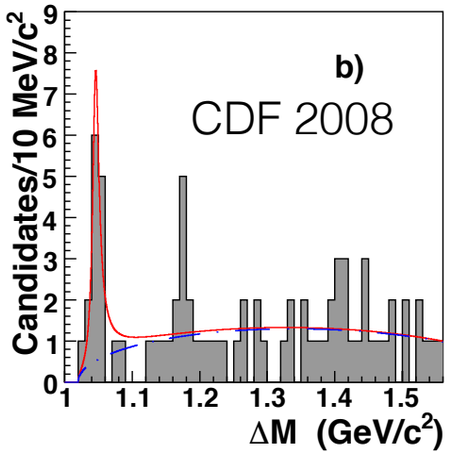
- Study Cabibbo suppressed $\Lambda_b \to J/\psi p \pi$ decays
- Statistics about factor 10 lower
- Possible $J/\psi\pi$ states in addition to $p\pi$ and $J/\psi p$
- Fit with two pentaquark and $Z_c(4200)$ about 3.1σ better than fit without exotic contributions
  - Without $Z_c(4200)$ in the fit, 3.3σ evidence for pentaquark states
- Consistent with $\Lambda_b \to J/\psi p K$ decays

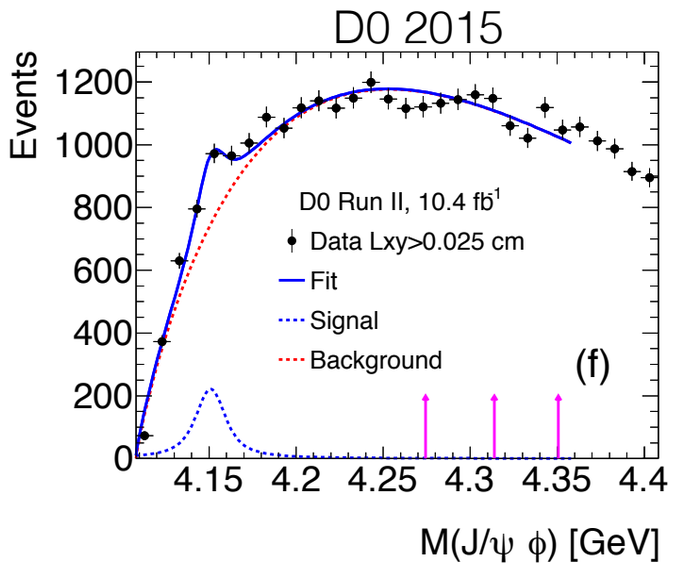


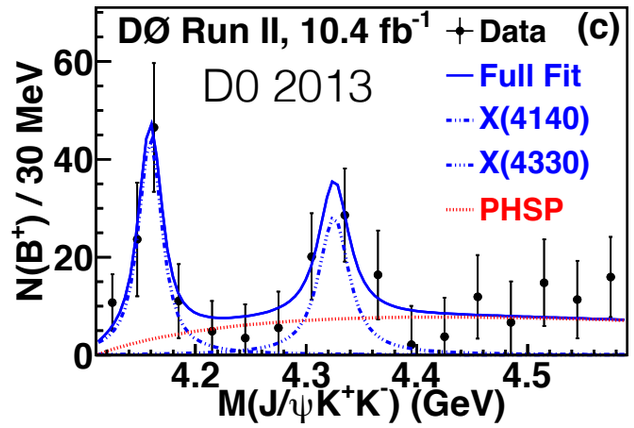


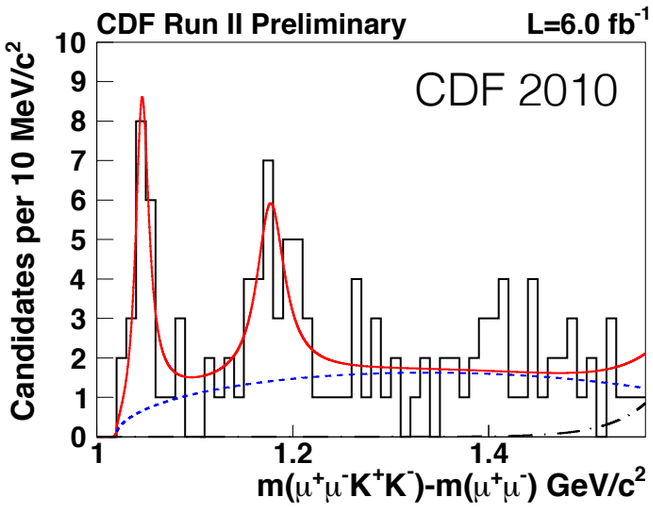


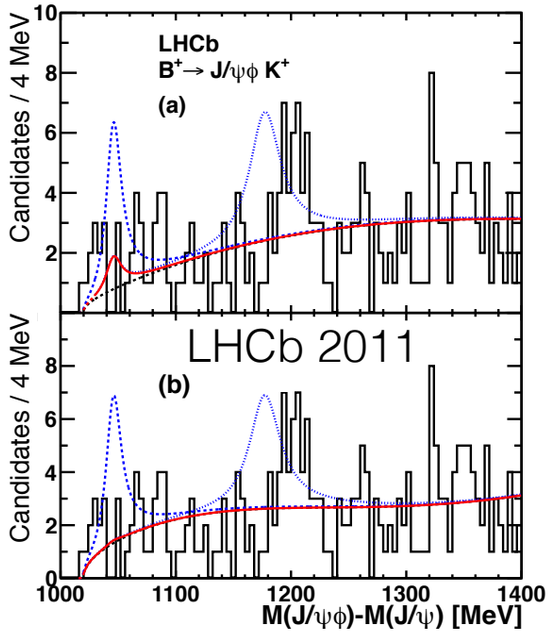
X(4140)→J/ψφ state

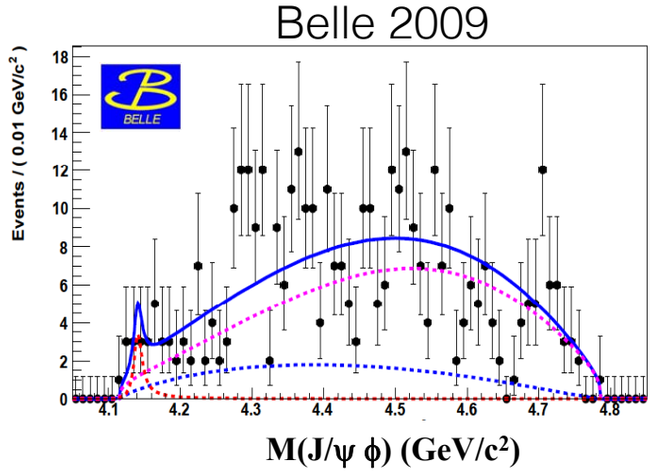


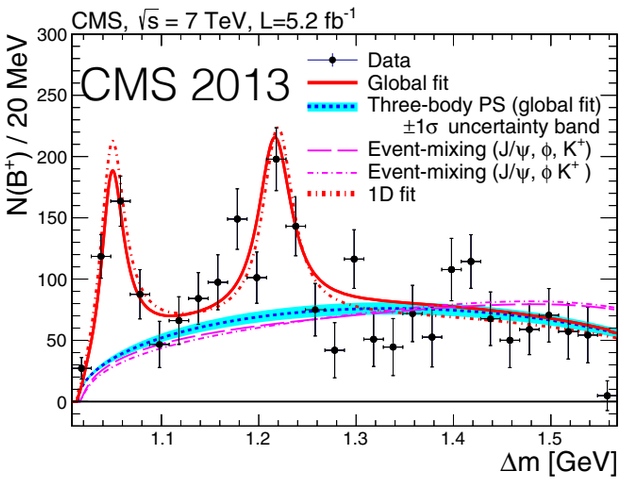


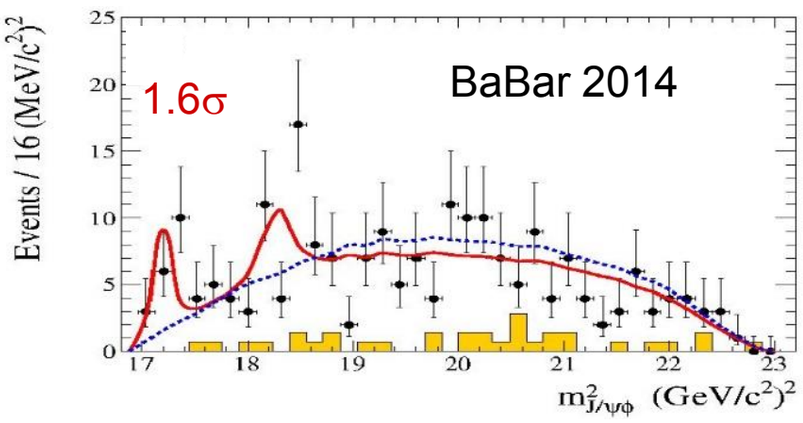












- X(4140)→J/ψφ claimed first by CDF in B⁺→J/ψφK
- Seen by some experiments, but not others
- Confusing situation

X(4140)→J/ψϕ state

PRD 95, 012002

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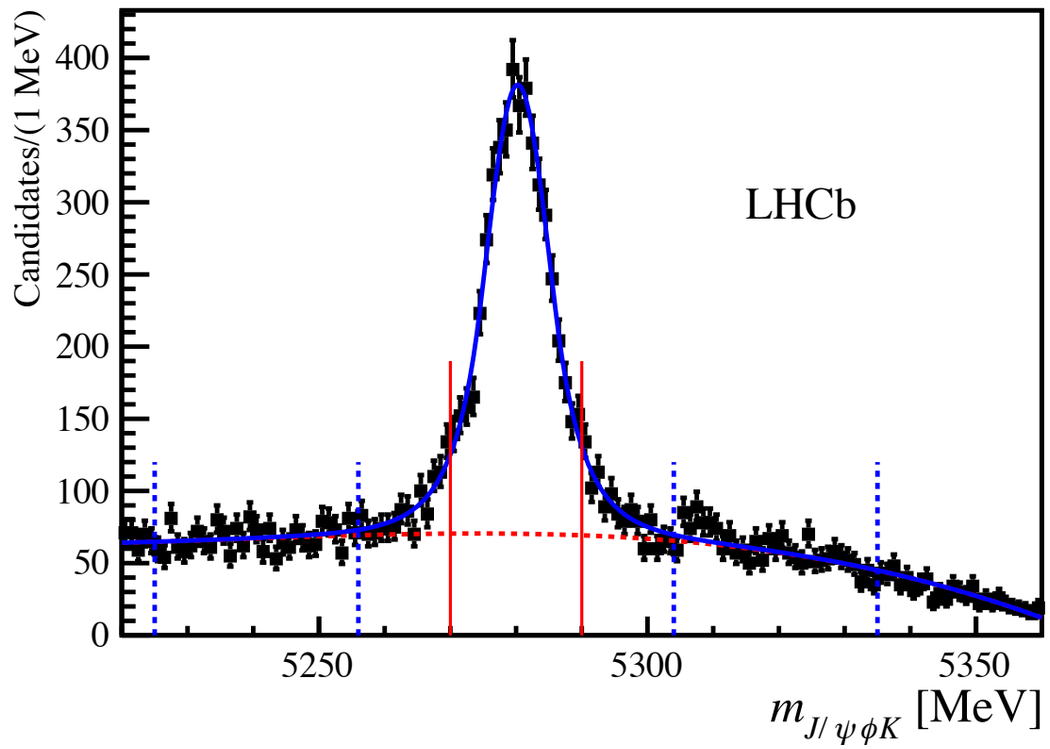
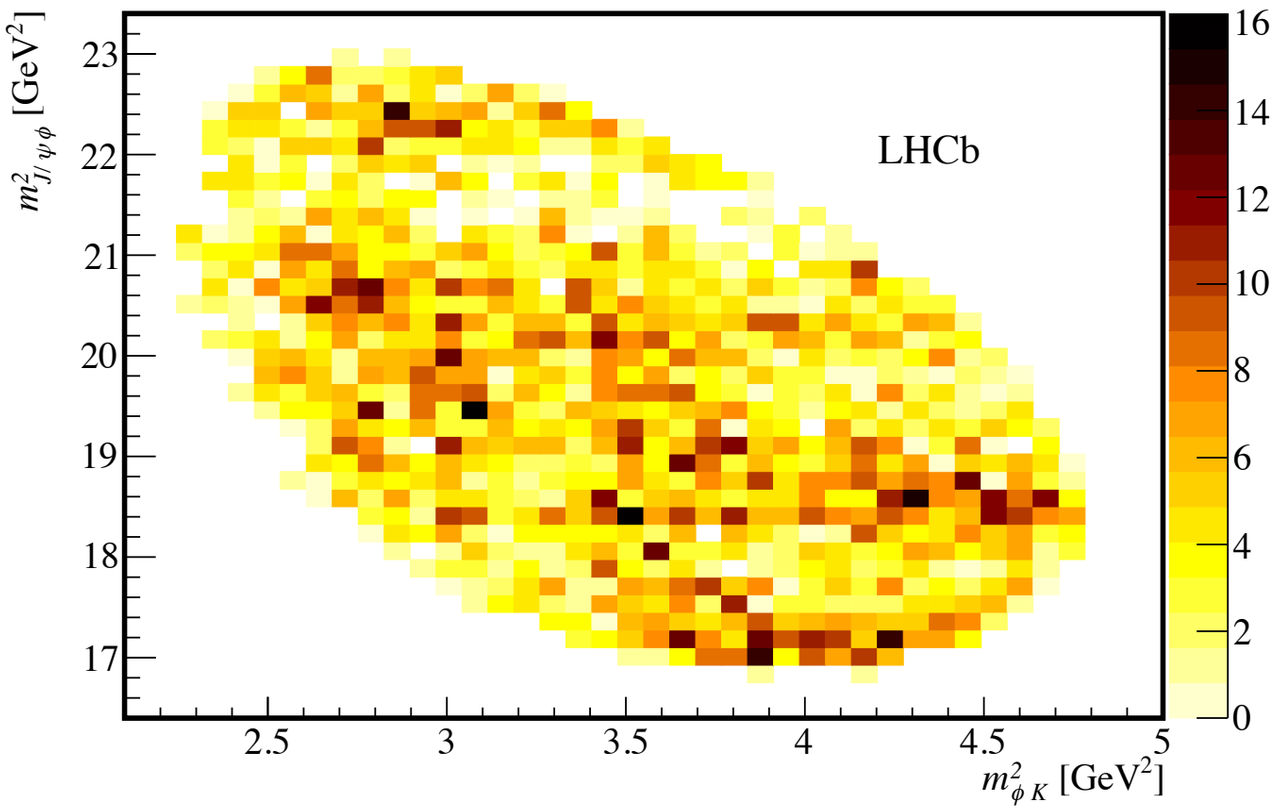
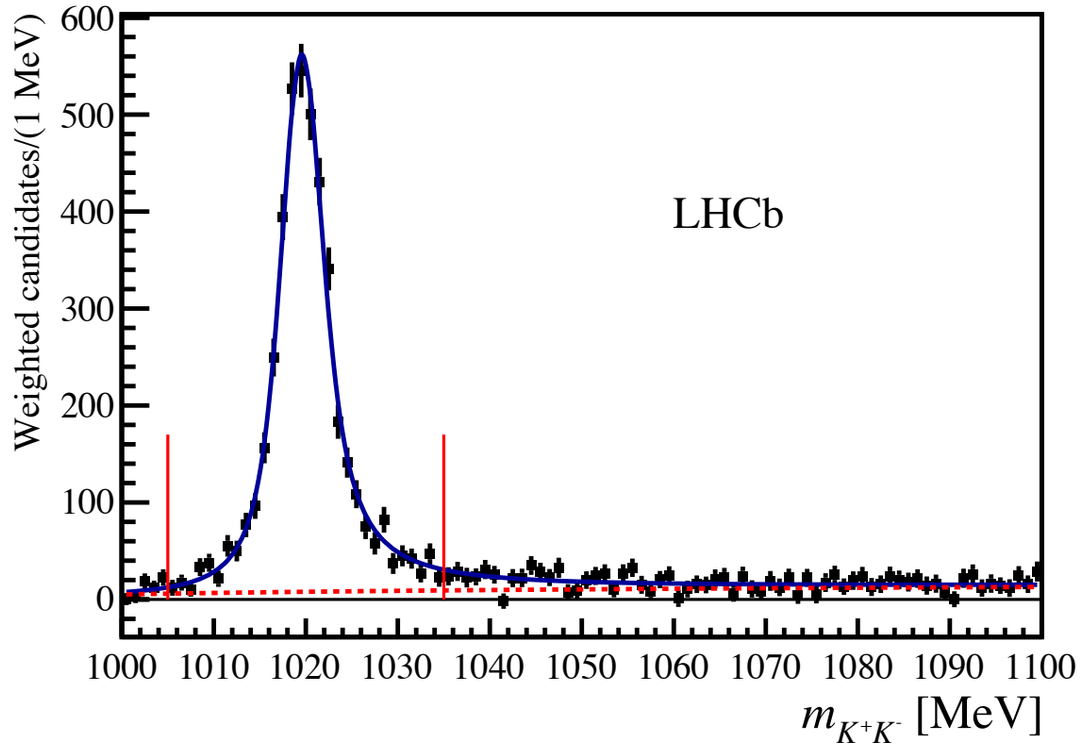
- LHCb performs amplitude analysis of $B^+ \to J/\psi\phi K$ decays
- Selection removes events when two KK combinations are consistent with ϕ
- Modelling becomes tricky as there is little information on $K^* \to \phi K$ resonances







X(4140)→J/ψϕ state

PRD 95, 012002

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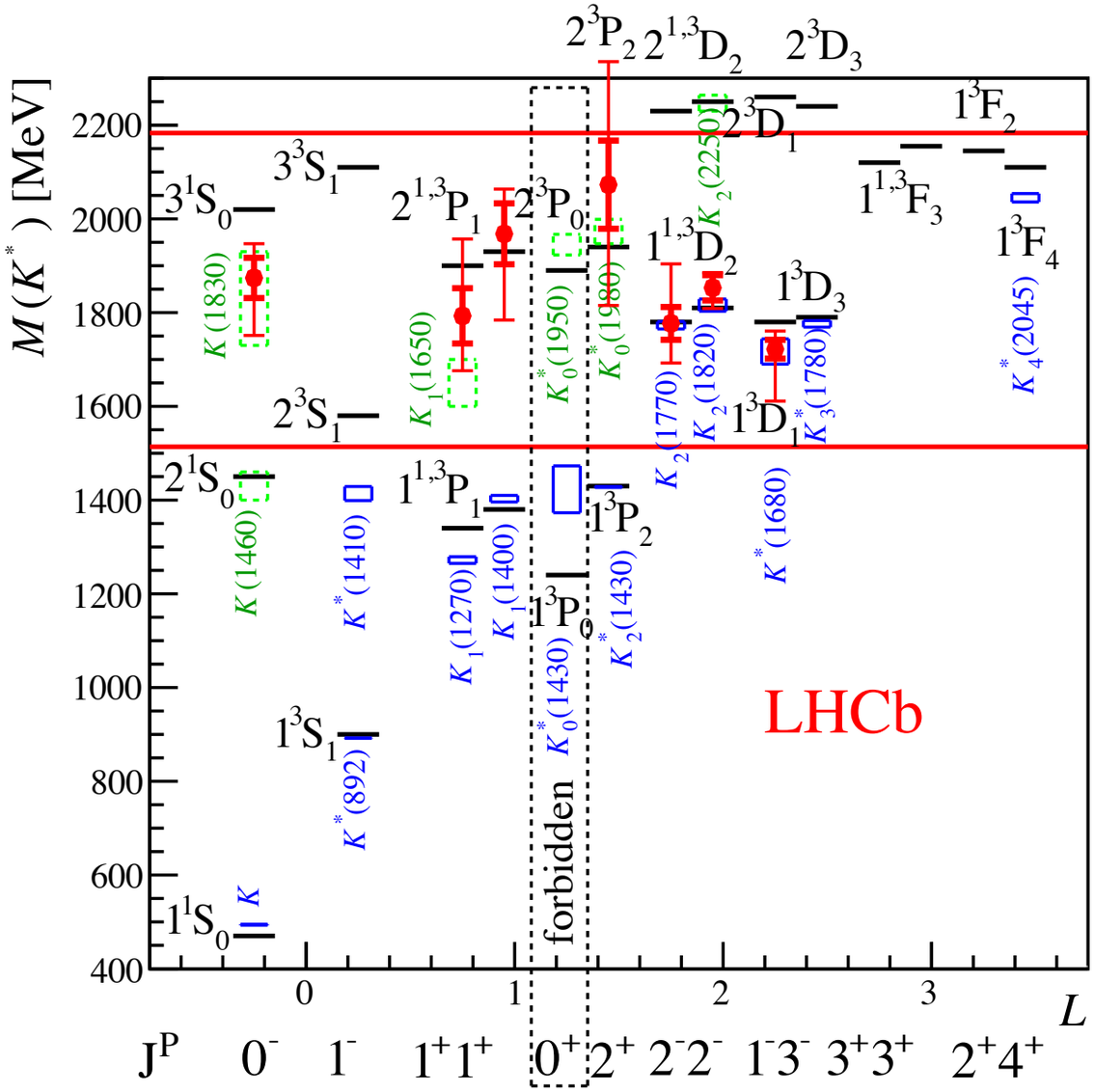

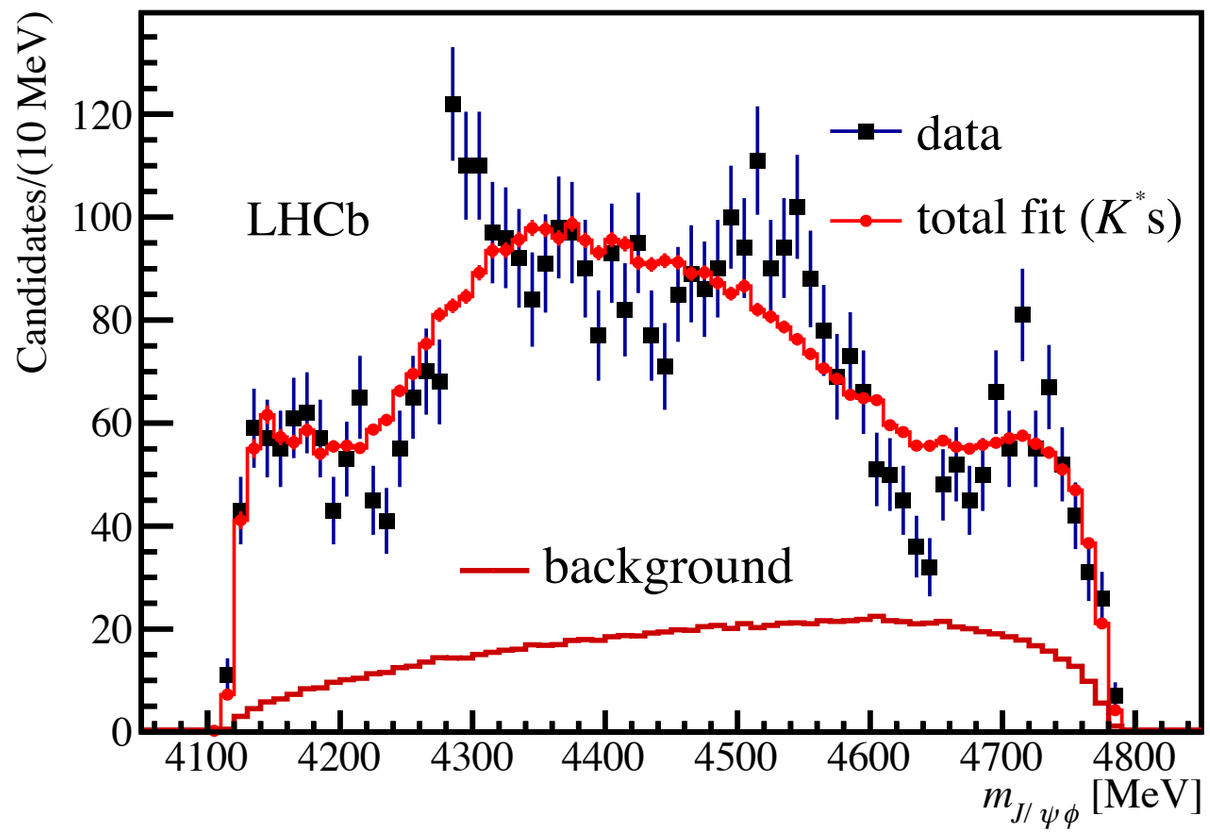

- Fit with ϕK resonances only could not describe data
- Adding more ϕK resonances does not improve description

X(4140)→J/ψϕ state

PRD 95, 012002

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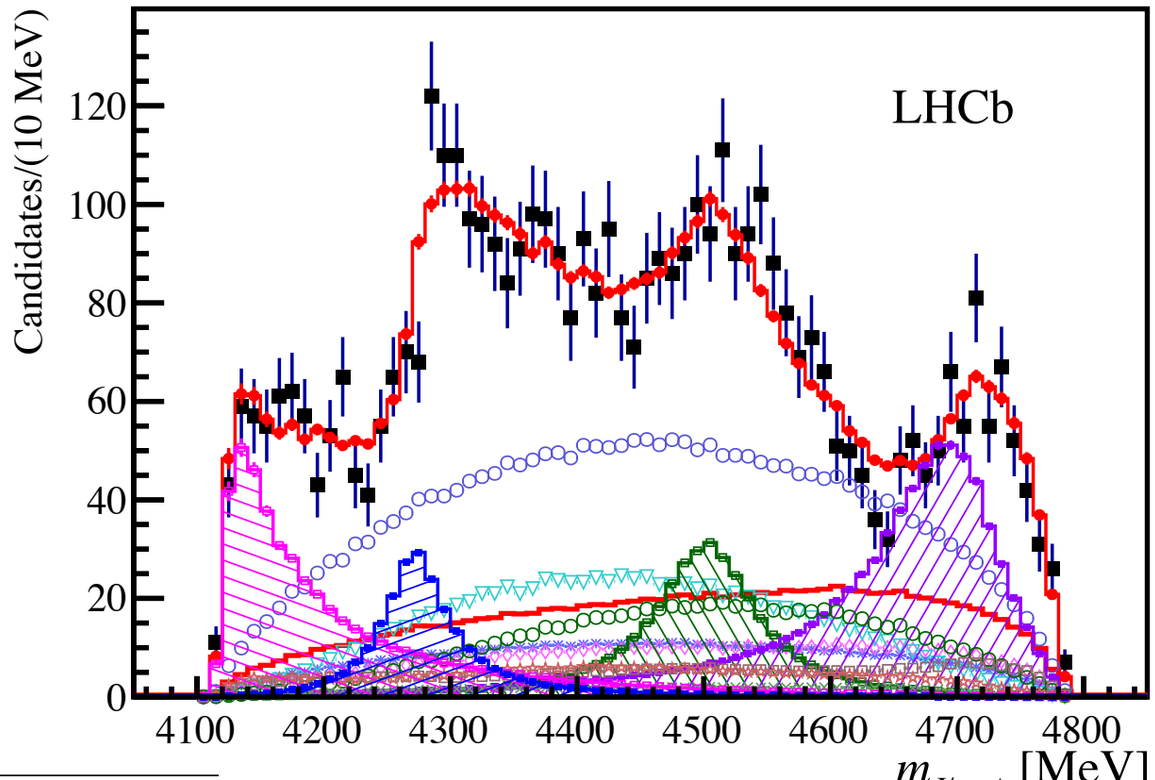
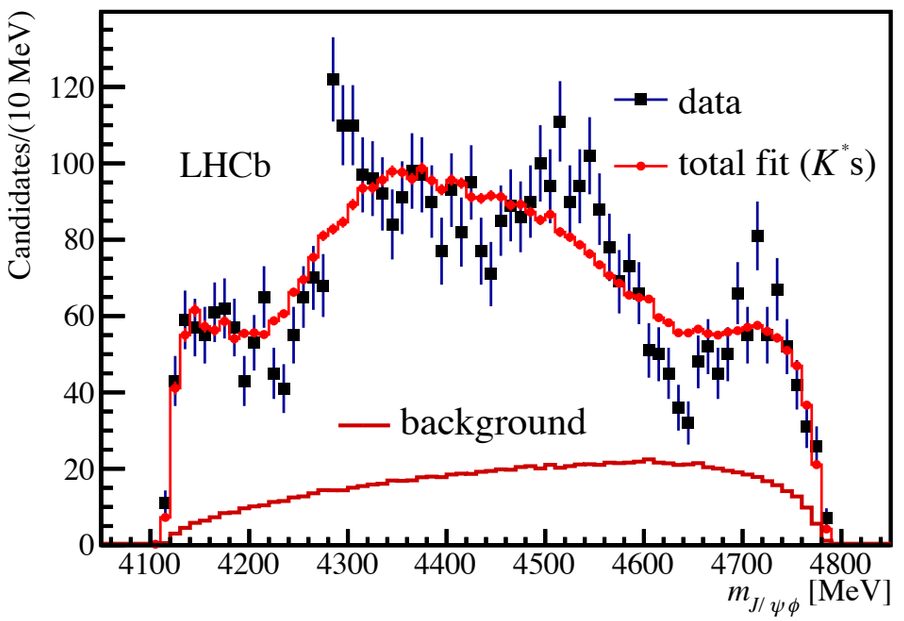
- Need 4 exotic contributions to describe data
- X(4140) possibly $D_sD_s^*$ cusp
- Some disagreement in parameters compared to previous experiments
  - Possibly due to missing interference effects in 1D fits



Contri-bution	sign. or Ref.	M_0 [MeV]	Γ_0 [MeV]	Fit results FF %
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	$4704\pm10\,^{+14}_{-24}$	$120\pm31\,^{+42}_{-33}$	$12\pm\ 5\,^{+\ 9}_{-\ 5}$



Observation of $\Xi_b \rightarrow J/\psi \Lambda K$

arXiv:1701.05274

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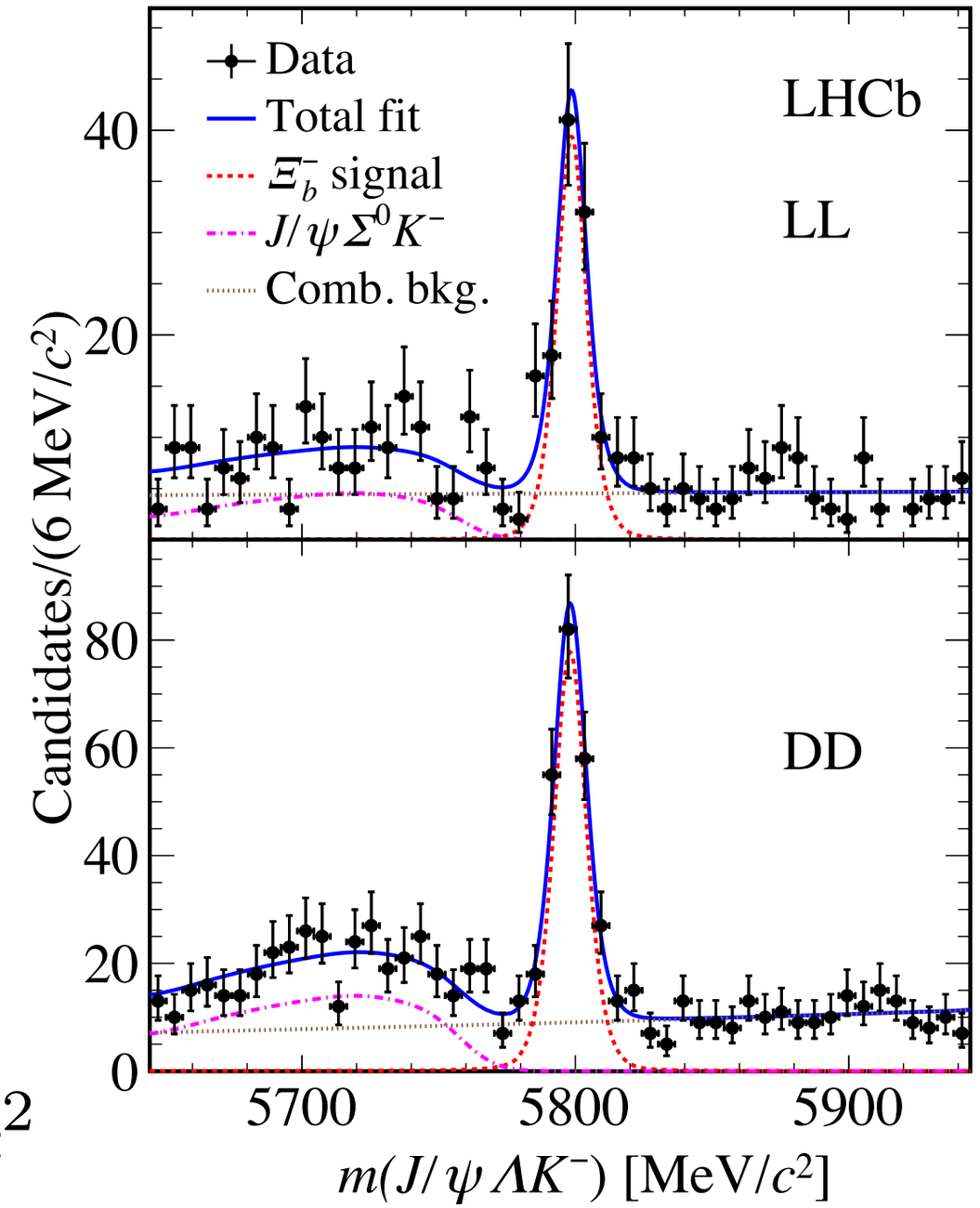
- With observation of pentaquark, quest for other such states
- It was suggested that J/ψΛ system could be place to observe strange pentaquark
- Search for large exclusive decay
  - Ultimately want amplitude analysis
- Decay $\Xi_b \rightarrow J/\psi \Lambda K$ observed
  - About 300 events in Run1
  - Significance of 21σ
- Can measure mass difference to Λ_b and combine with result from $\Xi_c \pi$

$$\delta M = 177.73 \pm 0.33 \pm 0.14 \text{ MeV}/c^2$$



Observation of $\Lambda_b \to \chi_{c(1,2)} pK$

LHCb-PAPER-2017-011 In preparation

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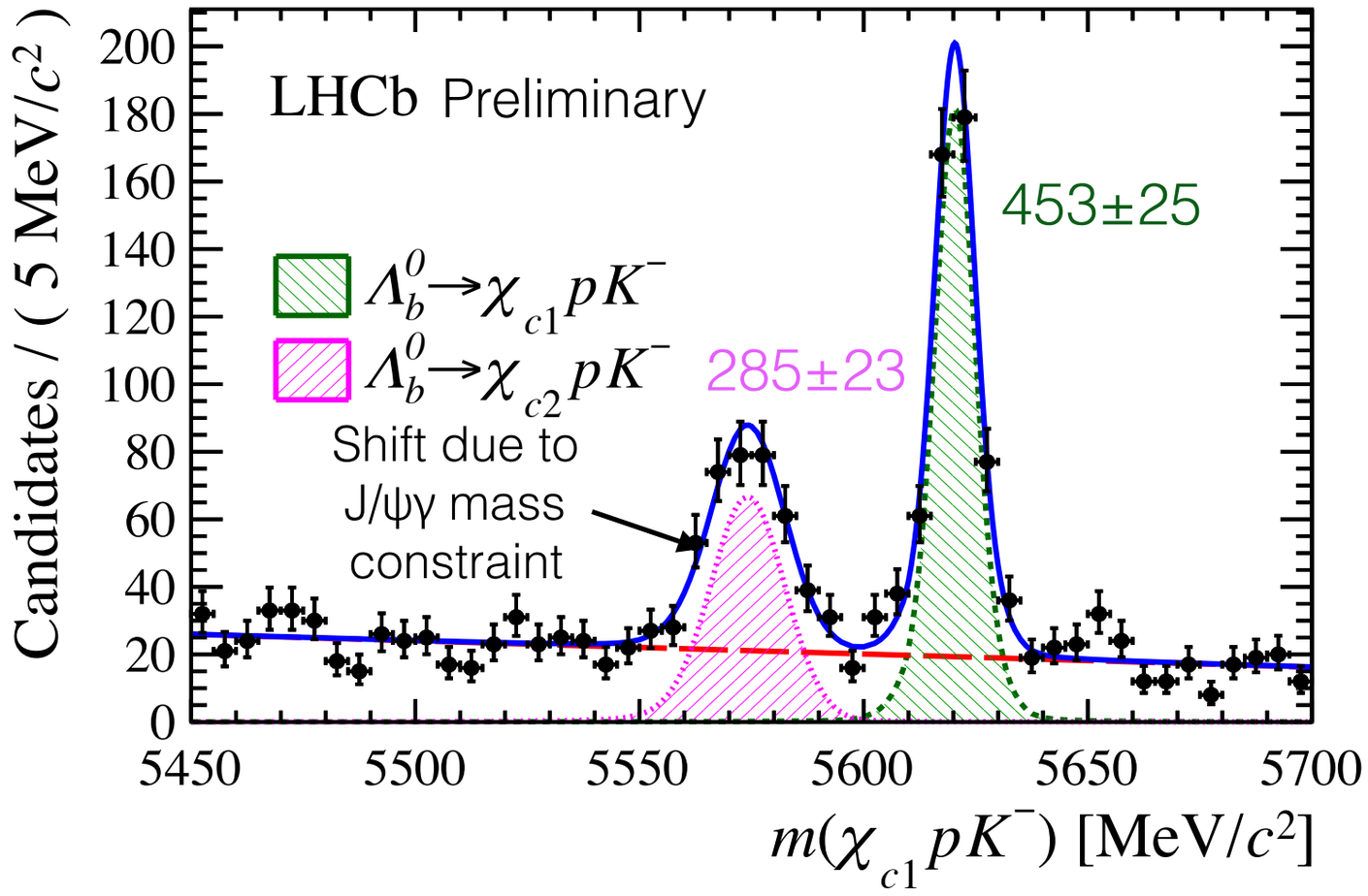
- In meson system charged states were seen in $\chi_c \pi$
- $P_c(4450)^+$ is close to $\chi_{c1} p$ threshold
- Information from $\chi_{c1} p$ can help to understand observed pentaquarks
- Search for decay $\Lambda_b \to \chi_{c(1,2)} pK$ decays



- Measured BF $\mathcal{B}\left(\Lambda_b^0 \to \chi_{c1} p K^-\right) = (7.3 \pm 0.4 \pm 0.4 \pm 0.6^{+1.0}_{-0.7}) \times 10^{-5}$

$\mathcal{B}\left(\Lambda_b^0 \to \chi_{c2} p K^-\right) = (7.4 \pm 0.6 \pm 0.4 \pm 0.6^{+1.1}_{-0.7}) \times 10^{-5}$

- Improve Λ_b mass (combined with other LHCb measurements)

$$M(\Lambda_b) = 5619.62 \pm 0.16 \pm 0.13 \text{ MeV}/c^2$$

Structure in $B_s\pi$ spectrum?

PRL 117, 152003

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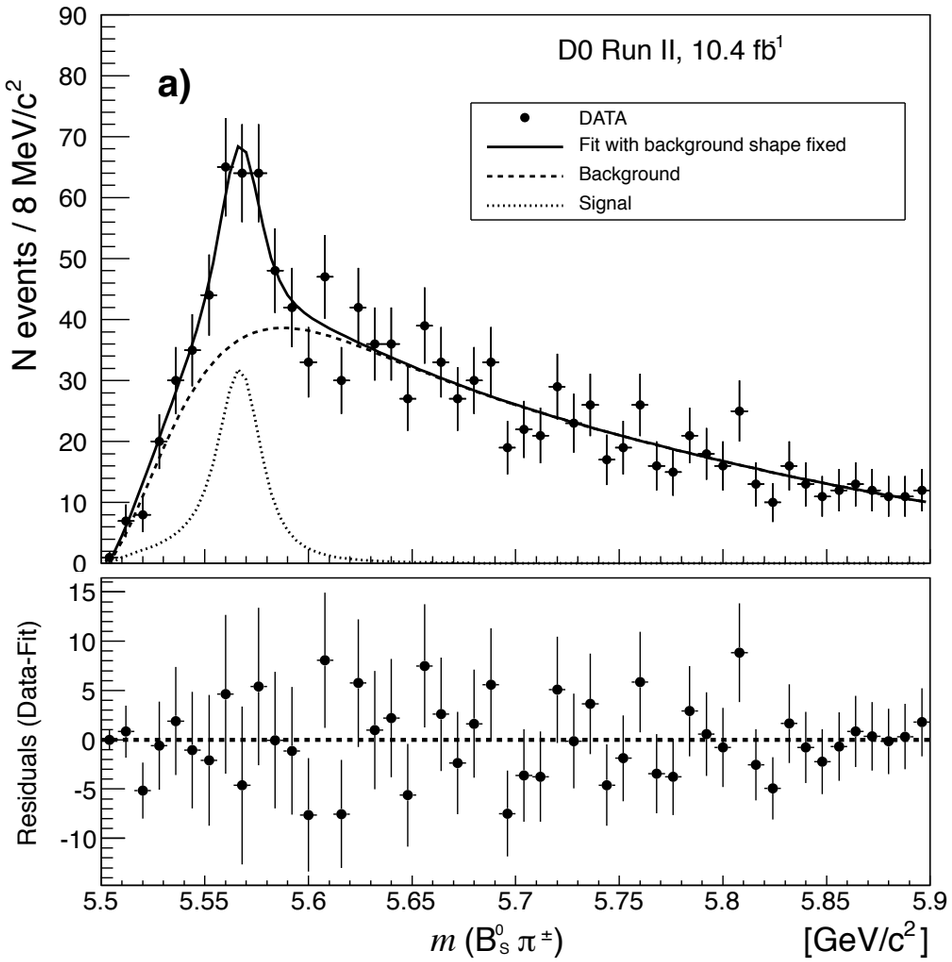
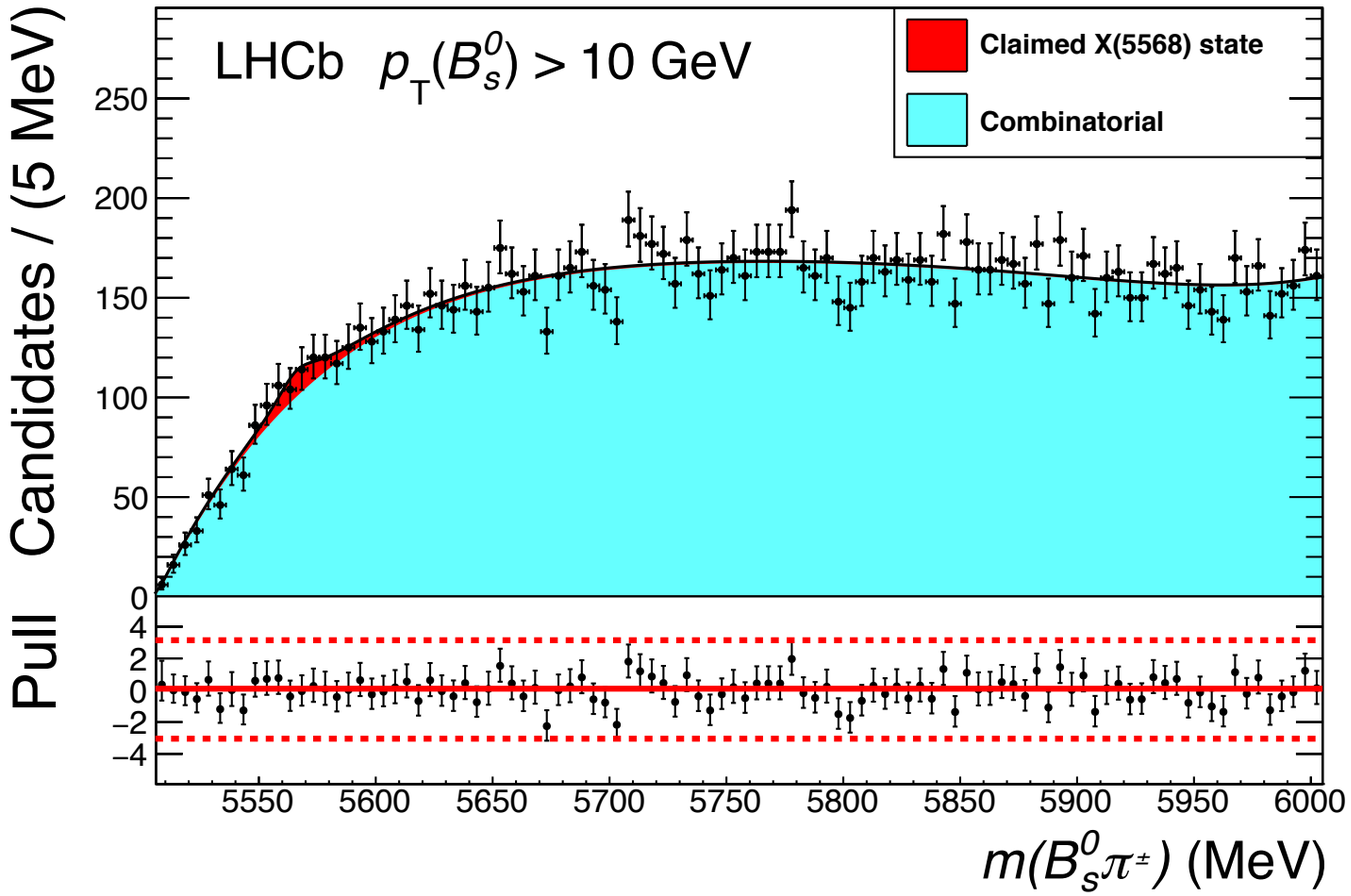
- D0 collaboration claimed state decaying to $B_s\pi^+$
- LHCb has large data sample to check it
  - 112600 B_s events (LHCb) vs. 5582 (D0)
- No state seen in place of D0 state





Conclusions

- LHCb has now large samples of b-hadron decays
- Several possible exotic hadrons could be studied in amplitude analysis
- Amplitude analysis allows to determine quantum numbers
- In past year we followed on pentaquarks observation
  - Clear evidence for states in model independent way
  - Decay $\Lambda_b \to J/\psi p \pi$ consistent with $\Lambda_b \to J/\psi p K$
  - Observed few other decays we can use for further searches of pentaquarks
- Cleared up some confusion with X(4140) state
  - Amplitude analysis prefers up to 4 exotic states
- We have Run2 data waiting to be exploited
  - Adds about factor of 2 in statistics right now