IOP Institute of Physics

Exotic Hadron Spectroscopy 2019

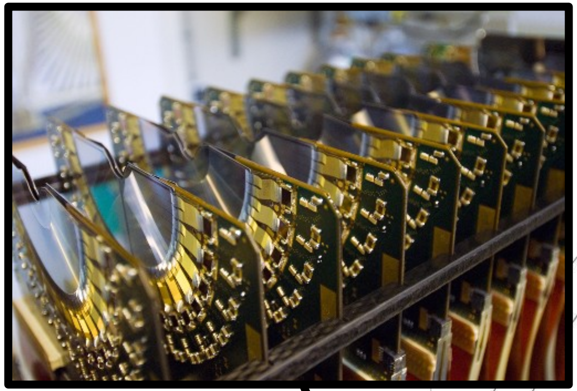
12–13 December 2019, King's Manor, York, UK

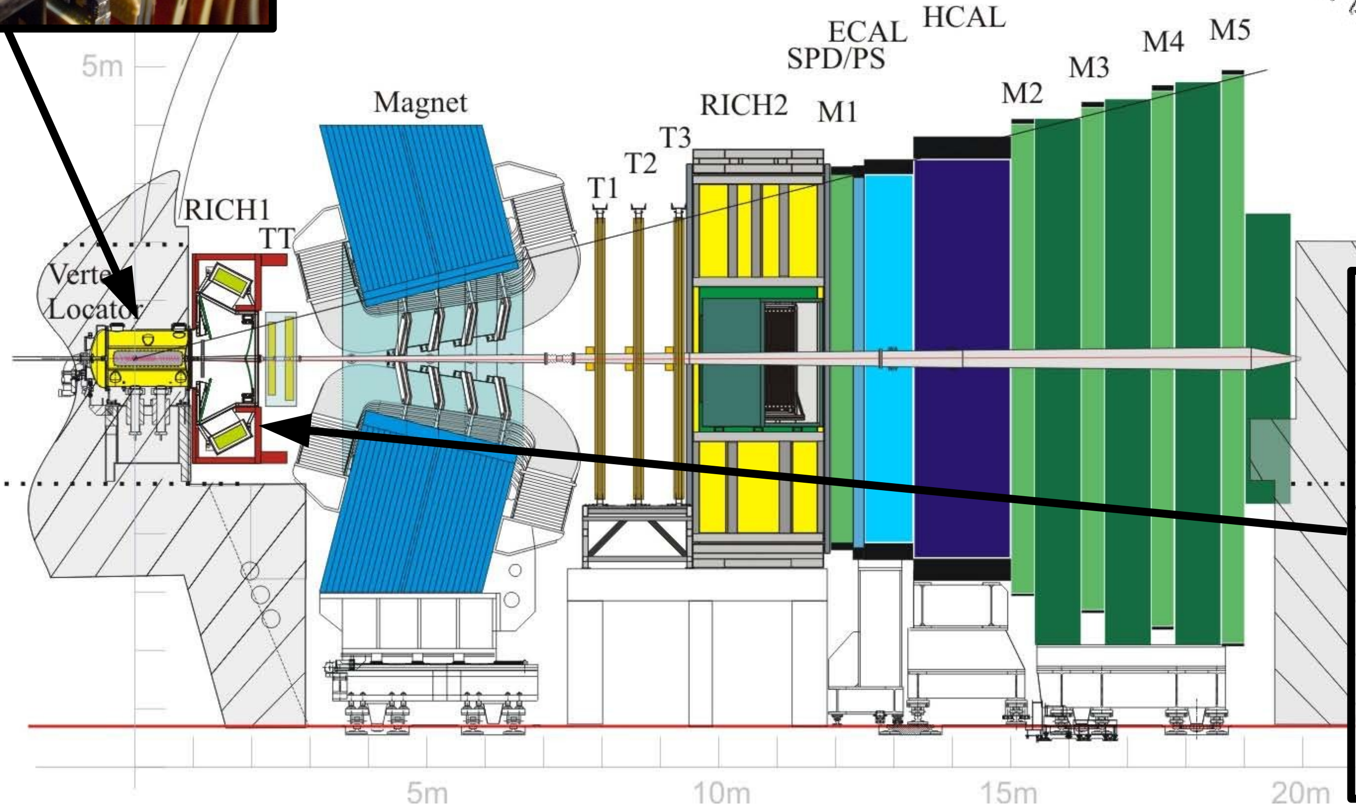
Overview of latest results on p-J/ψ pentaquarks

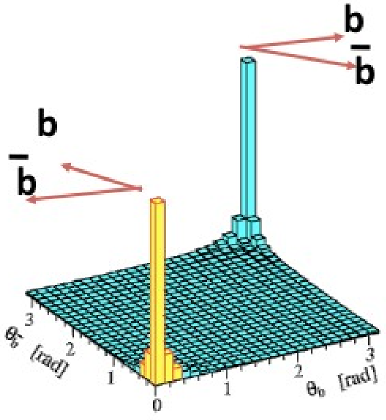
Tim Gershon
University of Warwick

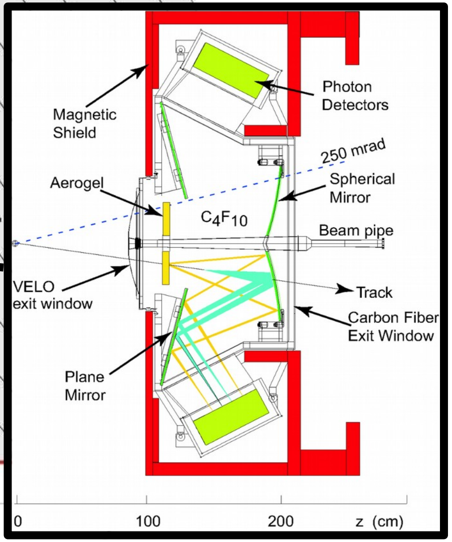
13 December 2019

LHCb detector







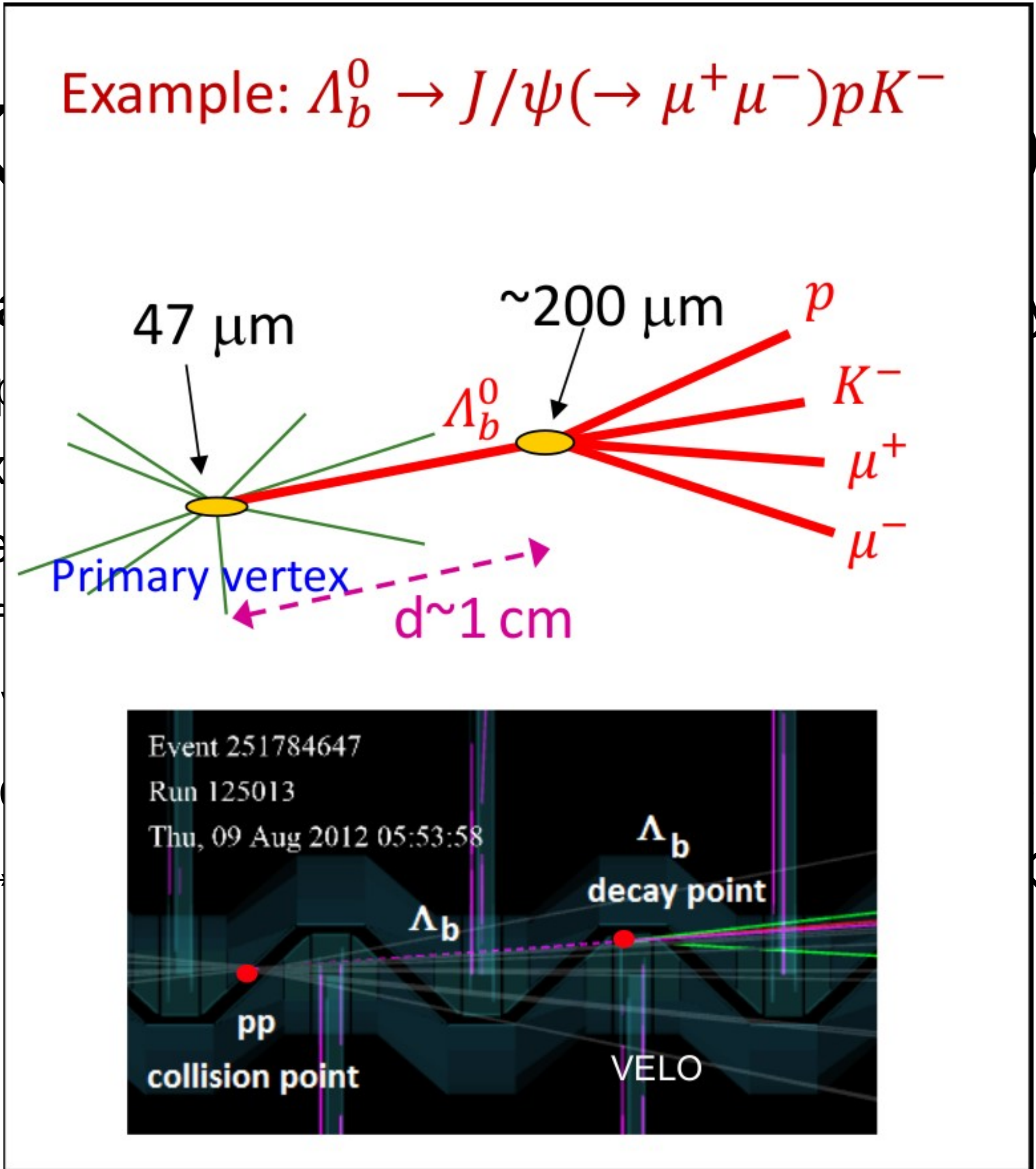


Key features of LHCb

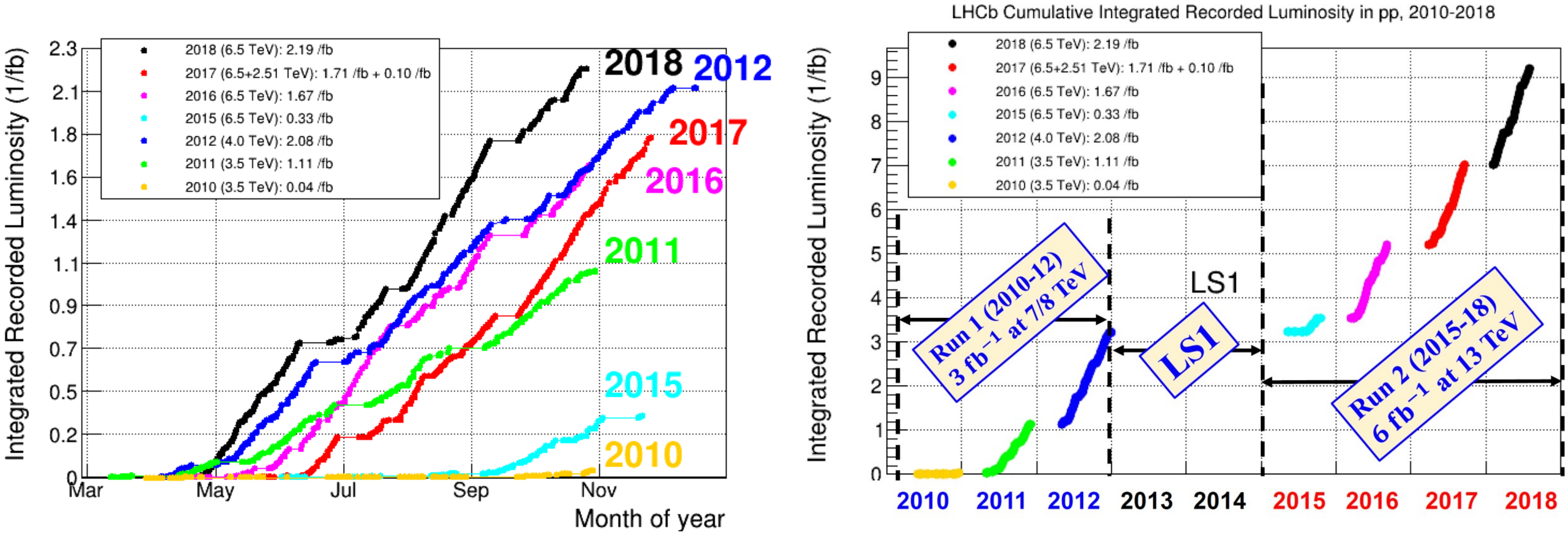
- Designed primarily to study CP violation and rare decays of b hadrons
  - Forward acceptance
  - Precise vertexing (distinguish displaced vertices)
  - Tracking system providing good momentum resolution
  - Particle identification to distinguish π/K/p
  - (quasi-)Inclusive trigger scheme
- Fortuitously, these features enable a broad physics programme
  - e.g. study $\Lambda_b \rightarrow J/\psi pK$ as a potential background to $B_s \rightarrow J/\psi KK$

K …)

- Designed prim… …ys of b hadrons
  - Forward accep…
  - Precise vertex…
  - Tracking syste…
  - Particle identif…
  - (quasi-)Inclusi…
- Fortuitously, th… …gramme
  - e.g. study $\Lambda_b \rightarrow$ … …K



LHCb data sample



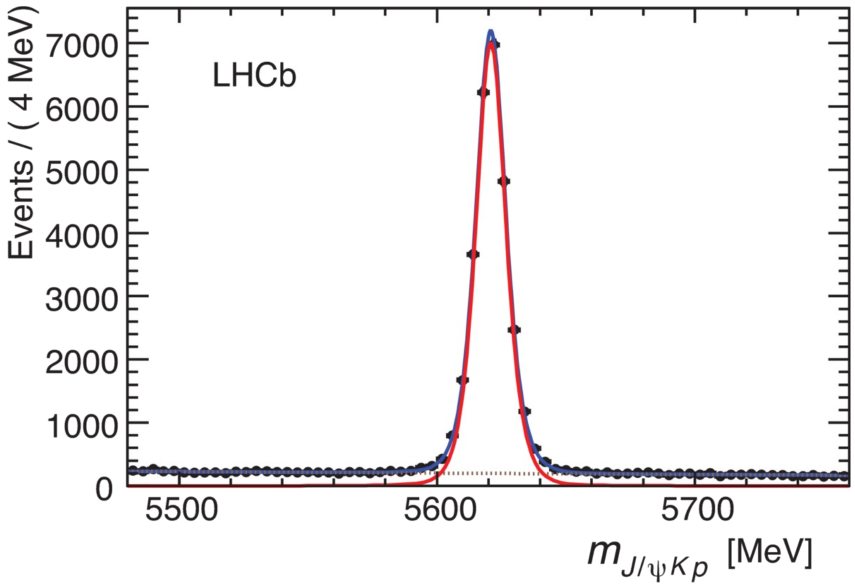
$\sigma(pp \to H_b X)$ = 72.0±0.3±6.8 μb (7 TeV), 144±1±21 μb (13 TeV)

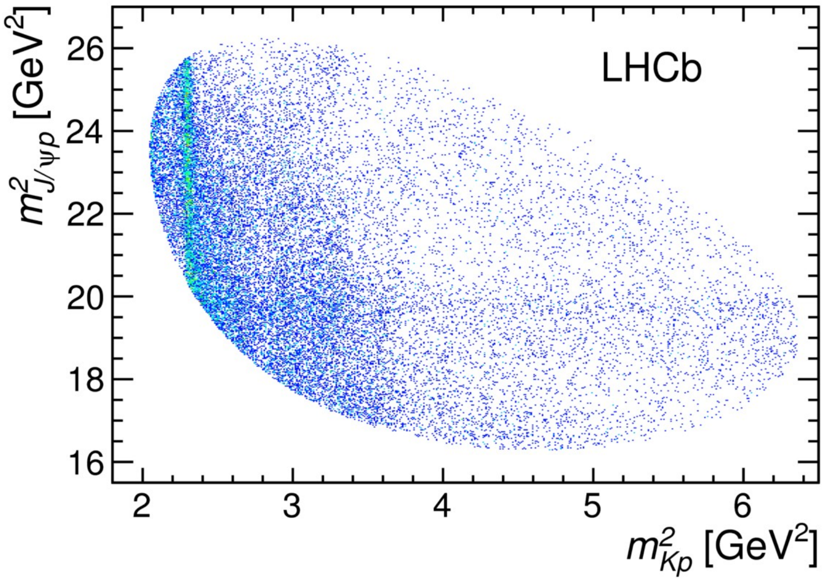
PRL 118 (2017) 052002, Erratum ibid. 119 (2017) 169901

$\Lambda_b \to J/\psi p K^-$

The first (2015) paper, based on Run 1 data (3/fb)

Phys. Rev. Lett. 115 (2015) 072001



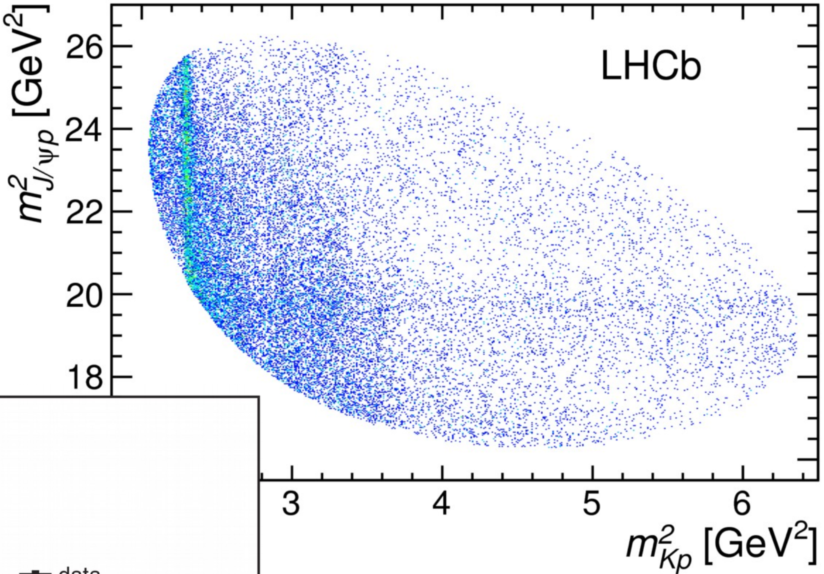


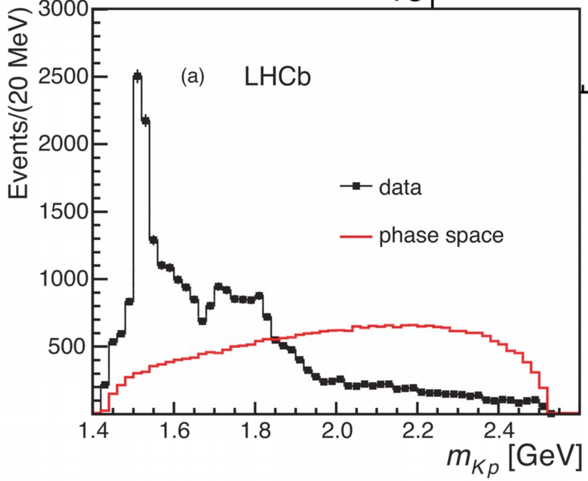
26 007±166 signal candidates (incl. 5.4% bkgs) in signal region

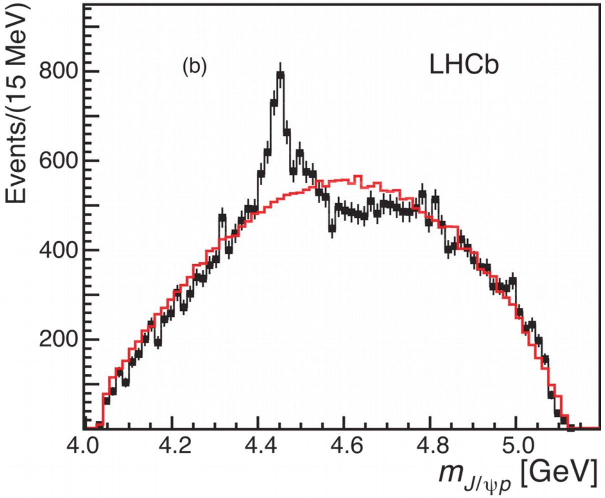
Phys. Rev. Lett. 115 (2015) 072001

$\Lambda_b \to J/\psi p K^-$

Structure in m(J/ψp) that cannot be explained by reflections from pK structures





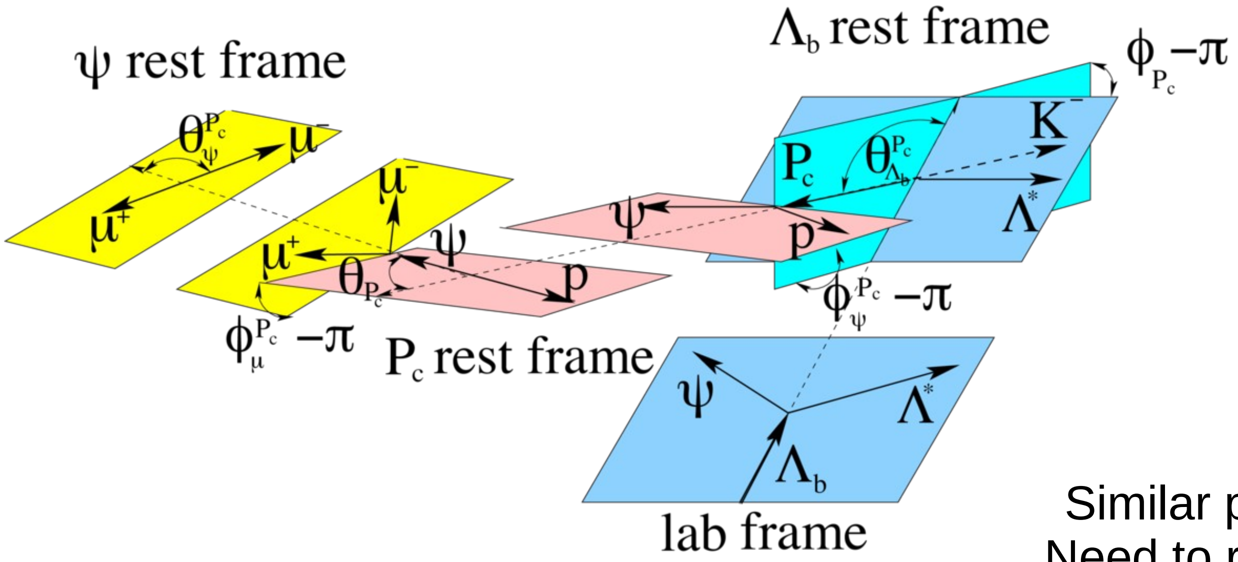


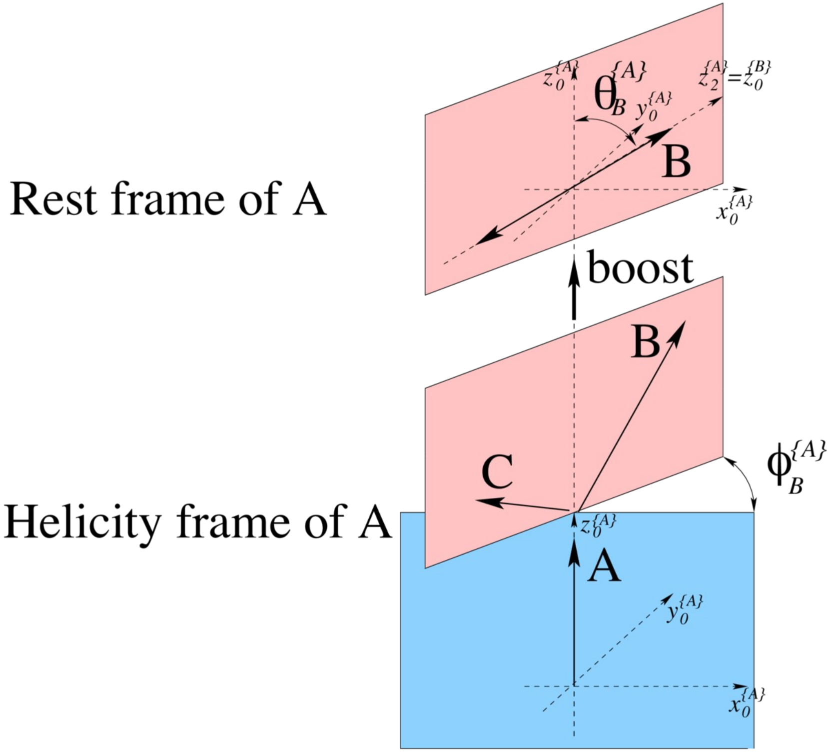
Phys. Rev. Lett. 115 (2015) 072001

Amplitude analysis

Paranoia due to previous pentaquark claims –
do the most complete & thorough analysis possible

Amplitude analysis accounting for small background contributions & efficiency variation across phase space
resolution effects ignored (no narrow structures)

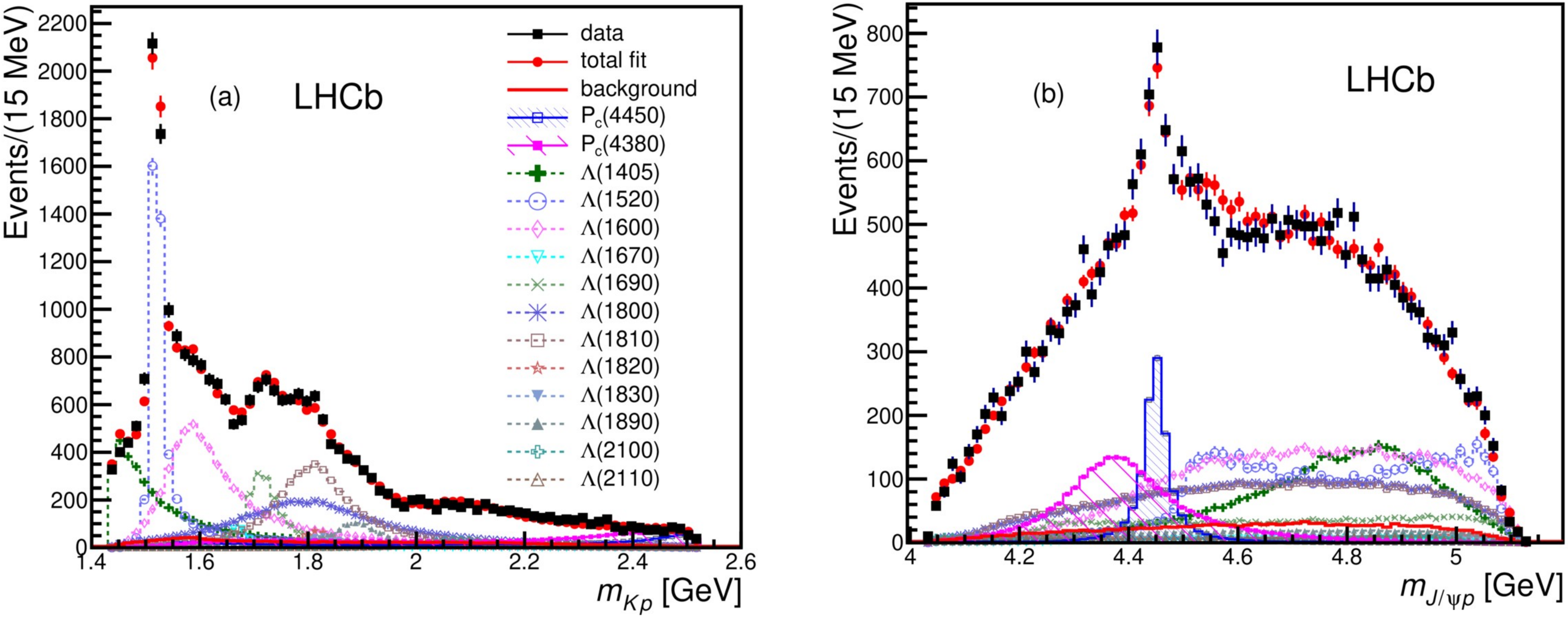




Similar pictures for other decay chains
Need to rotate correctly between frames

Phys. Rev. Lett. 115 (2015) 072001

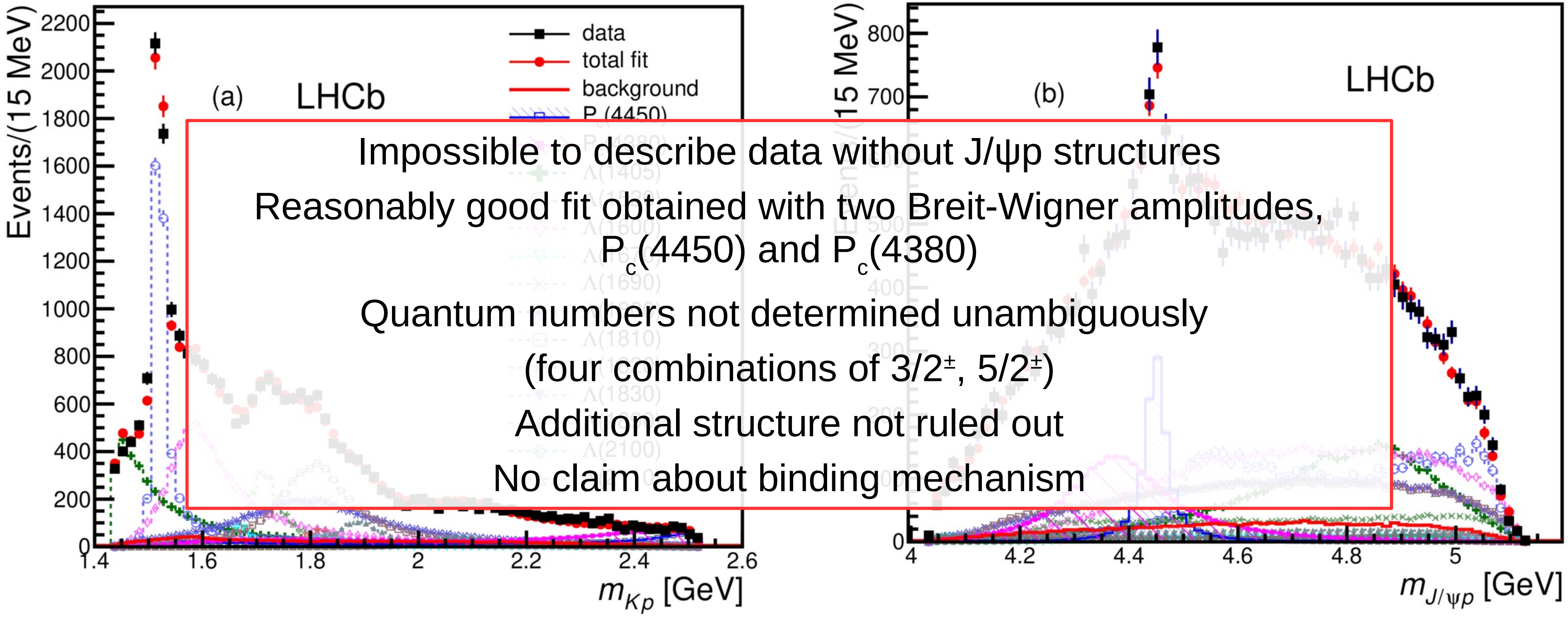
Results



“Reduced” Λ* model (“extended” Λ* model also considered)

Phys. Rev. Lett. 115 (2015) 072001

Results



Impossible to describe data without J/ψp structures

Reasonably good fit obtained with two Breit-Wigner amplitudes, $P_c(4450)$ and $P_c(4380)$

Quantum numbers not determined unambiguously

(four combinations of $3/2^{\pm}$, $5/2^{\pm}$)

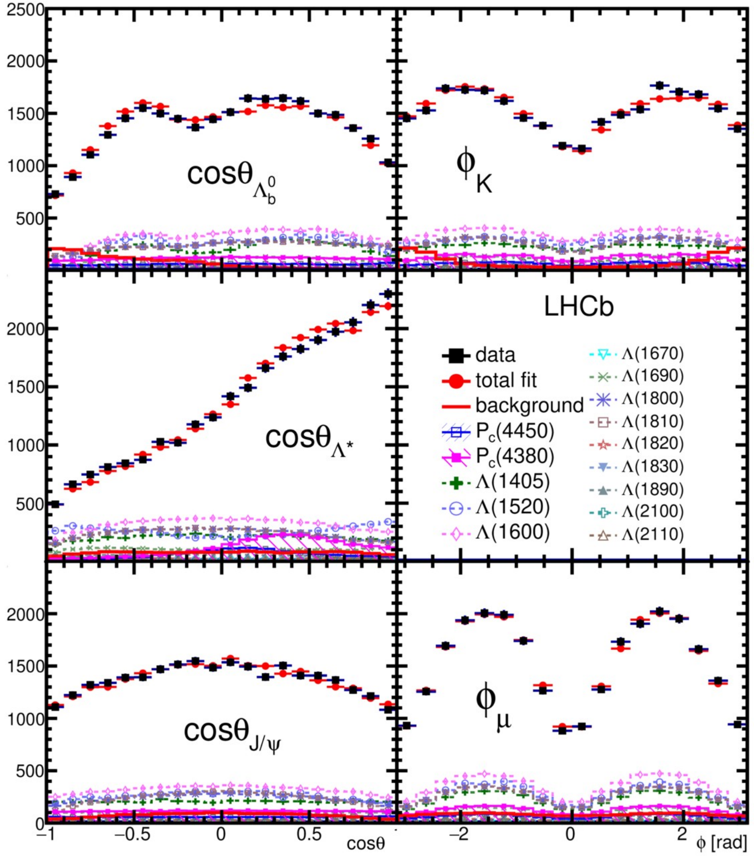
Additional structure not ruled out

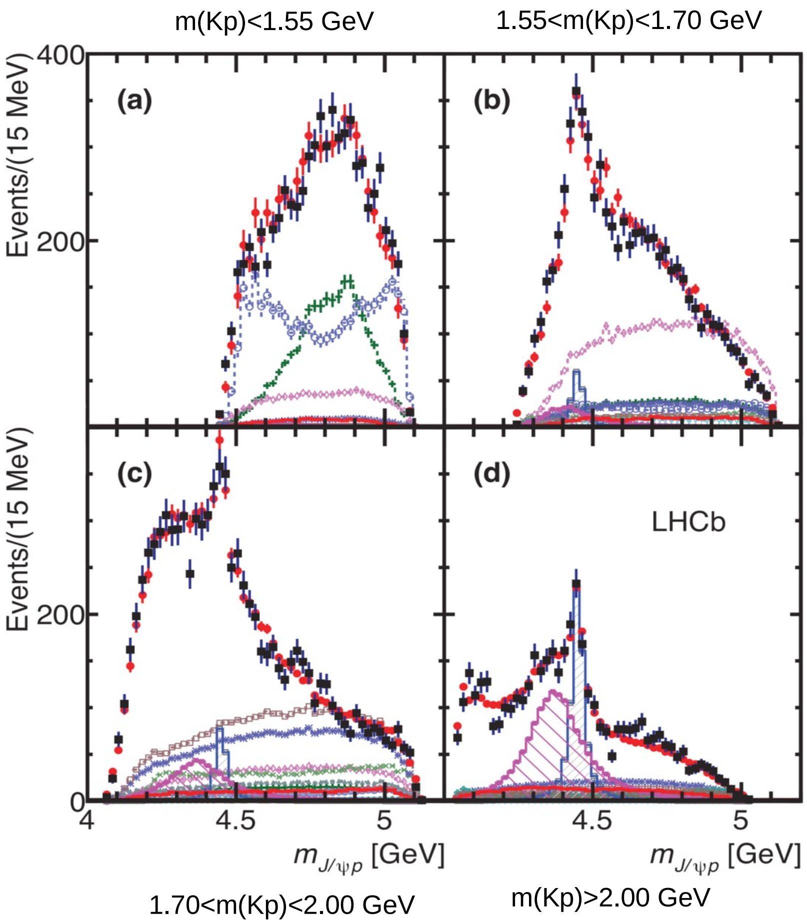
No claim about binding mechanism

“Reduced” Λ* model (“extended” Λ* model also considered)

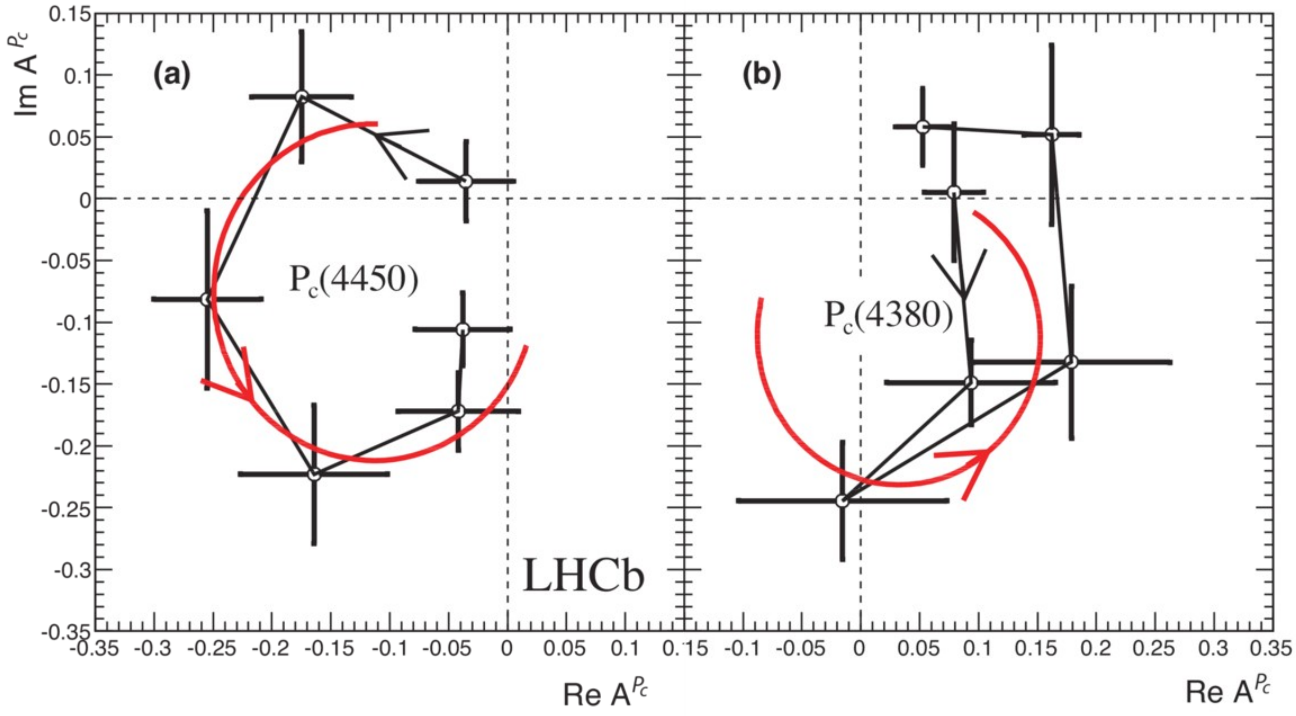
Phys. Rev. Lett. 115 (2015) 072001

Additional projections





Argand diagrams

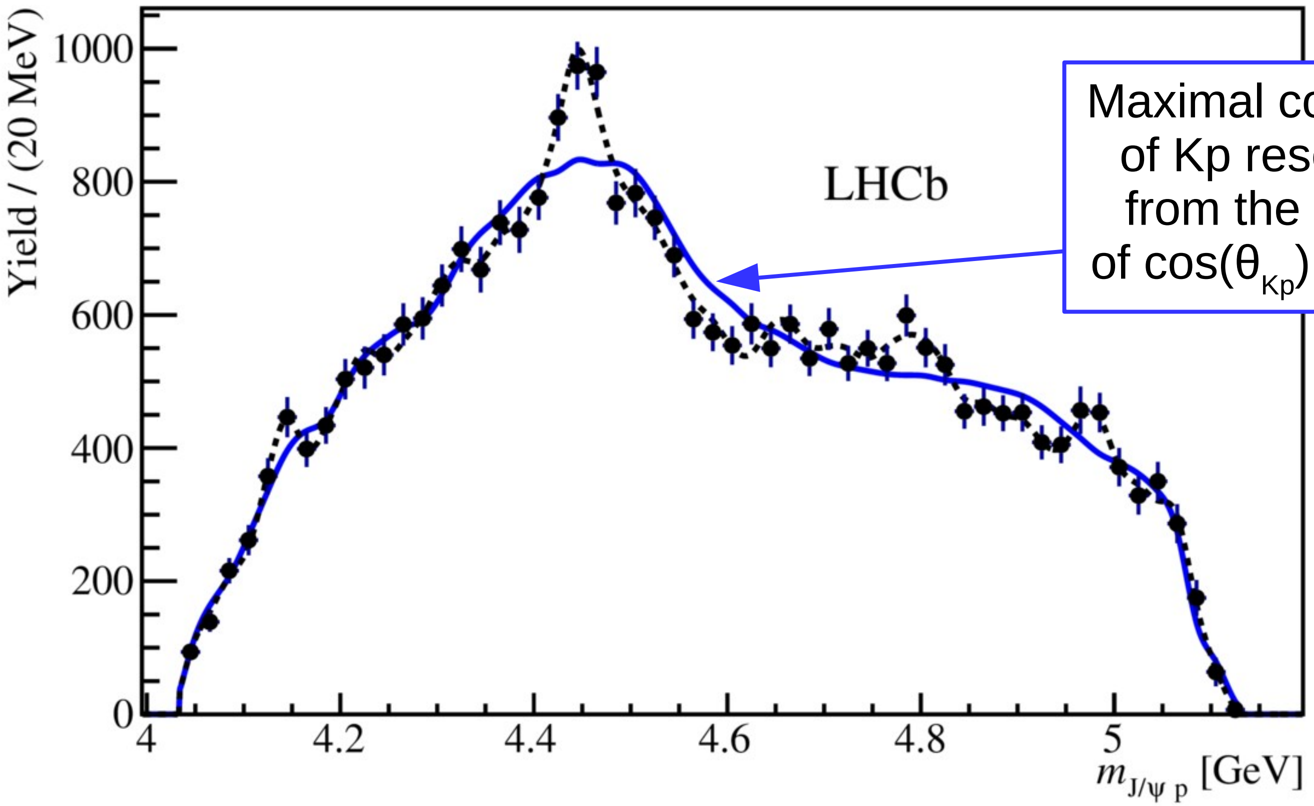


Statistically limited & inconclusive

Strongly model dependent (based on best model available at the time)

Phys. Rev. Lett. 117 (2016) 082002

Model-independent confirmation



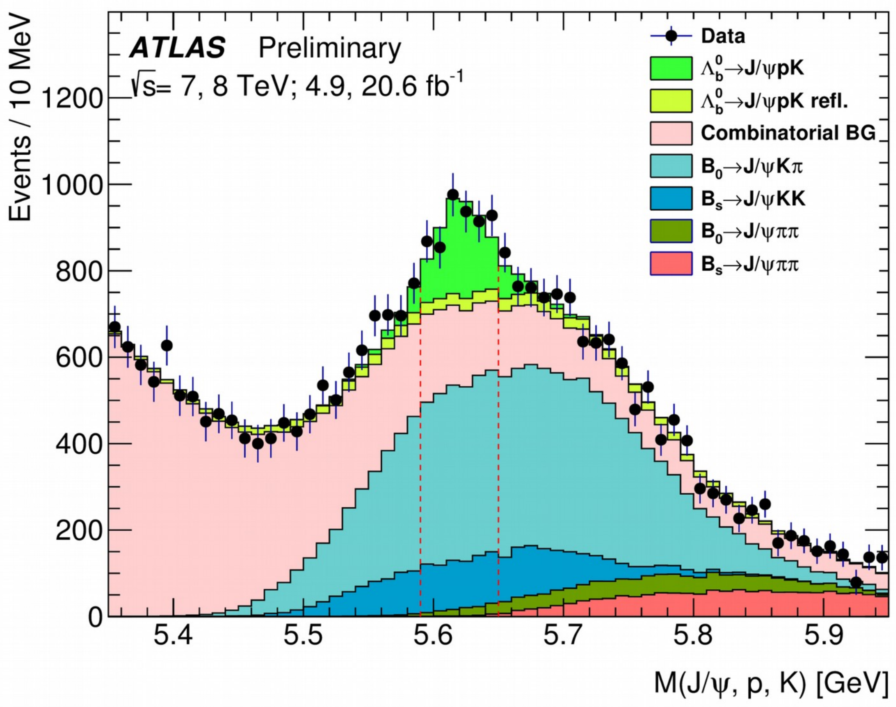
Maximal contribution of Kp resonances from the analysis of $\cos(\theta_{Kp})$ moments

Follow up studies

- Desire for observation of any new state to be confirmed by >1 experiment and in >1 decay mode
  - Other experiments:
    - Photoproduction (see talk by Peter Pauli), ATLAS (CMS?)
  - Other final states:
    - $\chi_{c1}p$ (work in progress on others, e.g. $\Lambda_c\overline{D}$)
- However, J/ψp final state is golden, especially for LHCb
    - J/ψp structures in other b hadron decay modes
    - Partner states, e.g. decaying to J/ψΛ
    - Update $\Lambda_b \rightarrow J/\psi p K^-$ with more data

ATLAS-CONF-2019-048

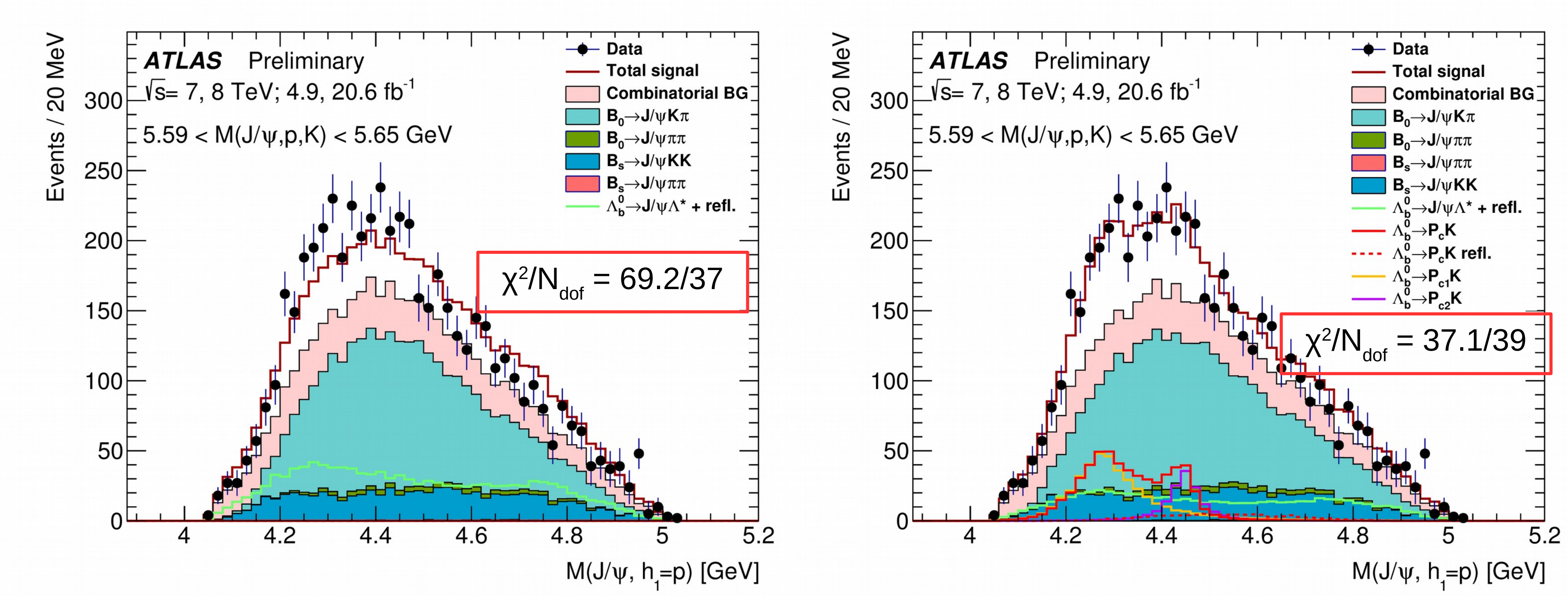
$\Lambda_b \to J/\psi p K^-$ by ATLAS



Difficult to separate signal from both

- combinatorial background
  - vertexing resolution not as good as LHCb
- misidentified $B \to J/\psi hh$ decays
  - lack of $\pi/K/p$ discrimination

$\Lambda_b \to J/\psi p K^-$ by ATLAS

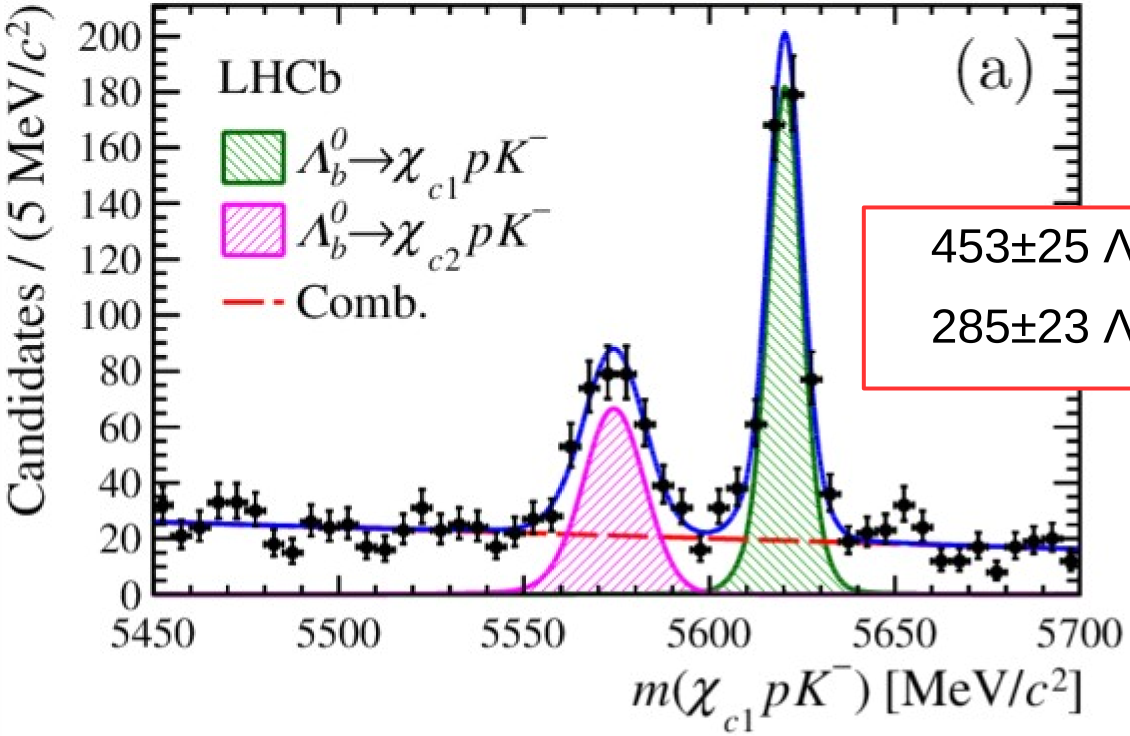


Comparison of 1D fits to m(J/ψp) (left) without and (right) with P_c states

Preference that P_c states should be included but not conclusive

Phys. Rev. Lett. 119 (2017) 062001

$\Lambda_b \to \chi_{c1} p K^-$



453±25 $\Lambda_b \to \chi_{c1} p K^-$ decays

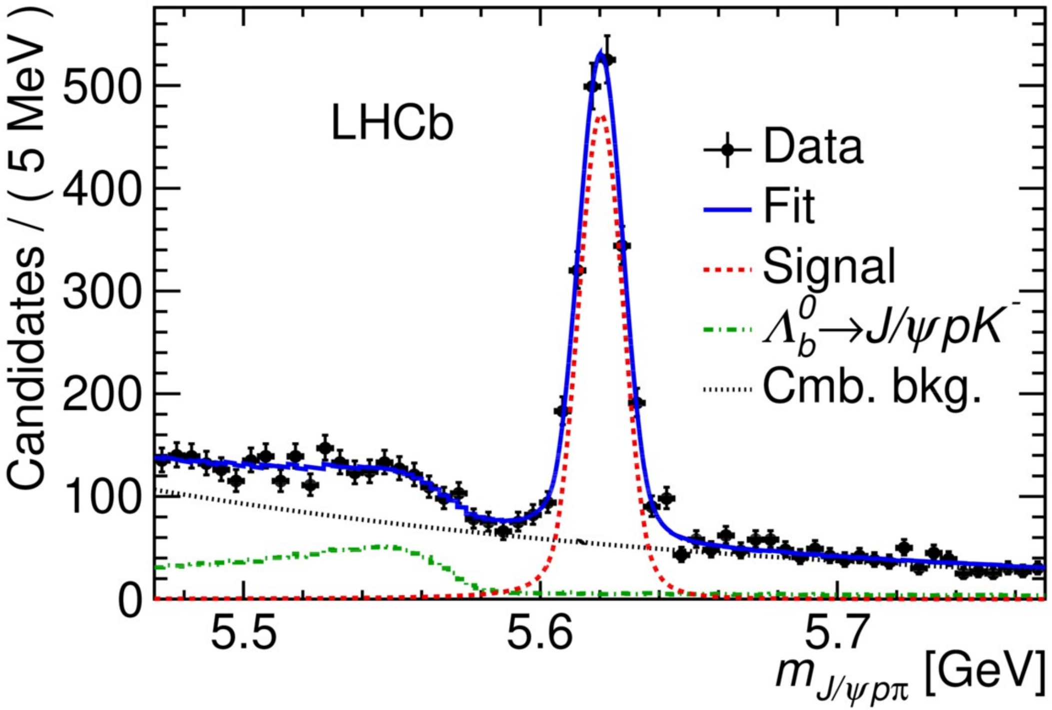
285±23 $\Lambda_b \to \chi_{c2} p K^-$ decays

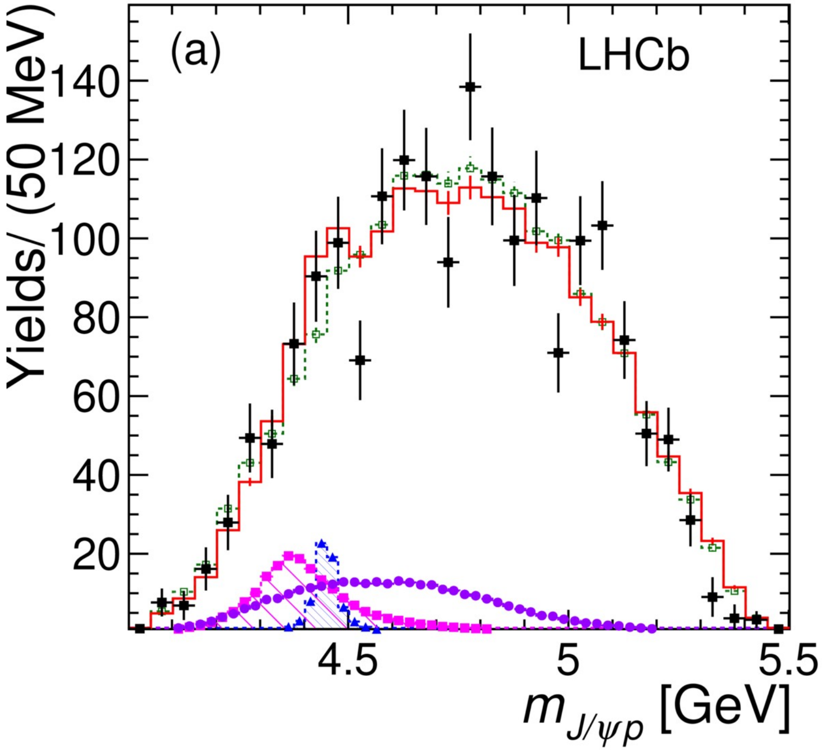
First observation with Run 1 data

Amplitude analysis should be possible with Run 1+2 statistics

Phys. Rev. Lett. 117 (2016) 082003

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





Analysis of Run 1 data, signal yield of 1885±50

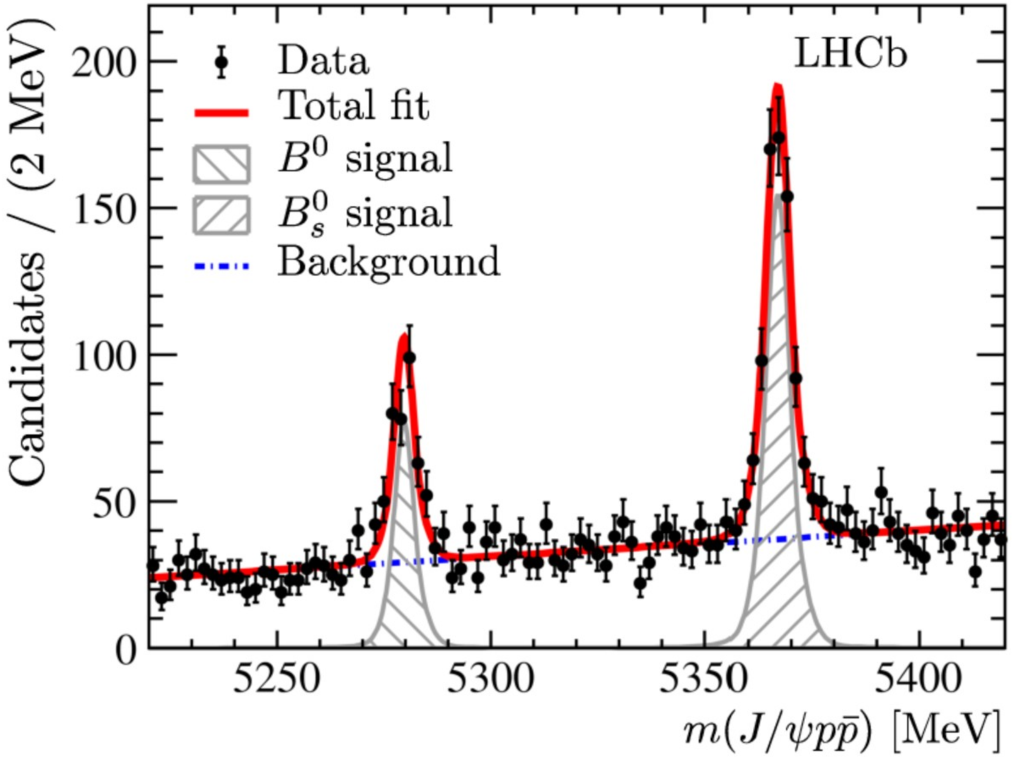
Evidence for exotic contributions, but could be P_c ($J/\psi p$) or Z_c ($J/\psi\pi$)

Phys. Rev. Lett. 122 (2019) 191804

$B_{(s)} \rightarrow J/\psi p\bar{p}$

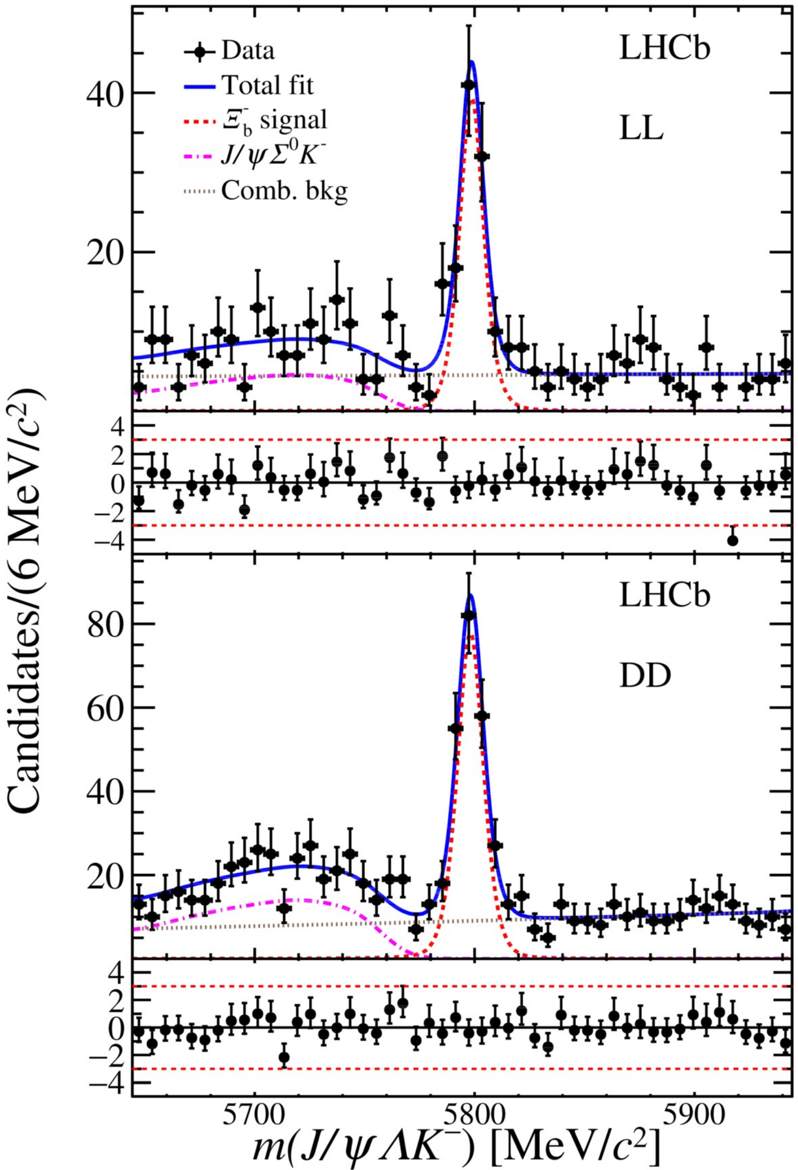
Analysis of Run 1 + some Run 2 data (5.2/fb)

Amplitude analysis may be possible with full Run 1+2



Signal yields of (B^0) 256±22 and 609±31 (B^0_s)

Small phase space ↔ precise B meson mass measurements



Phys. Lett. B772 (2017) 265

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

Analysis of Run 1 data

Sample separated by whether tracks from Λ decay leave hits in the VELO (LL) or not (DD)

Yields of 99±12 (LL) and 209±17 (DD)

Amplitude analysis may still be marginal with Run 1+2 data (but will be with LHCb Upgrade)

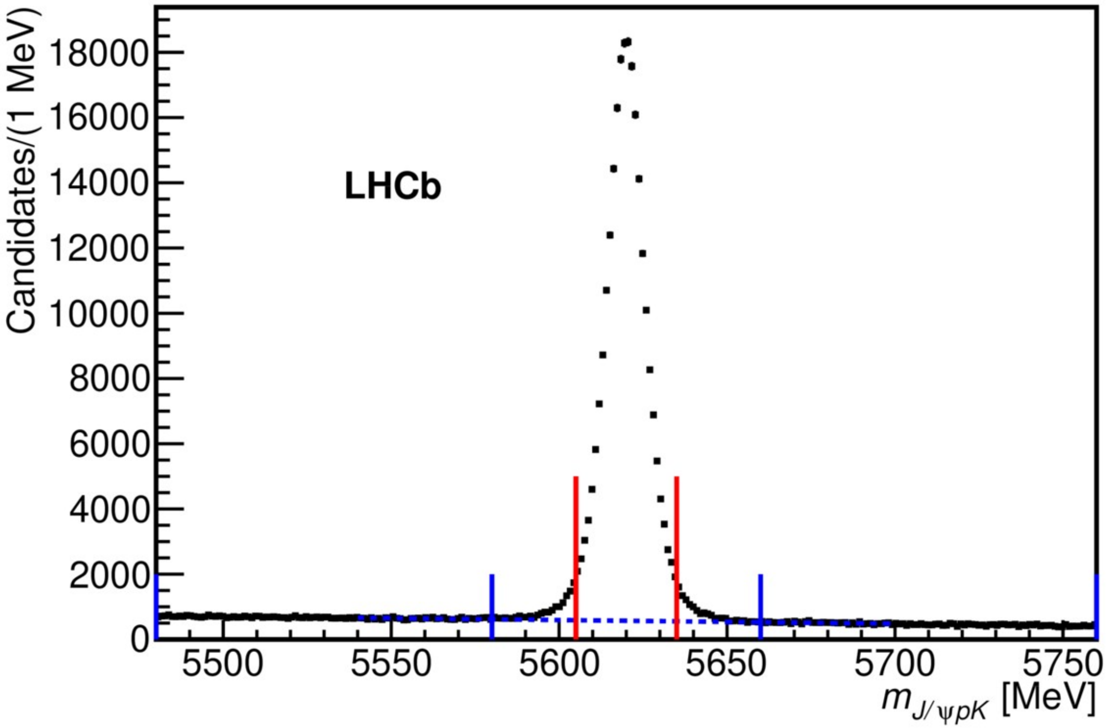
Phys. Rev. Lett. 122 (2019) 222001

$\Lambda_b \rightarrow J/\psi p K^-$

Update with full Run 1+2 data

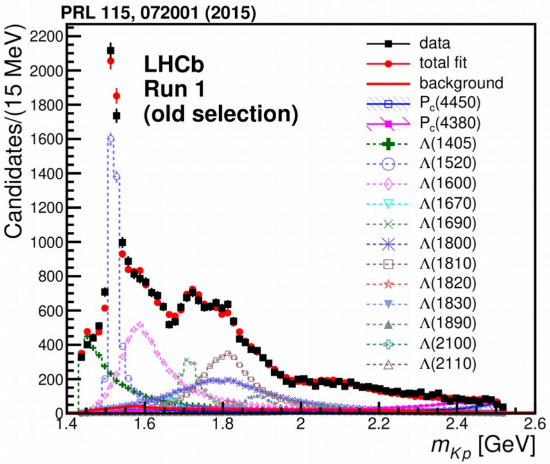
Improved selection

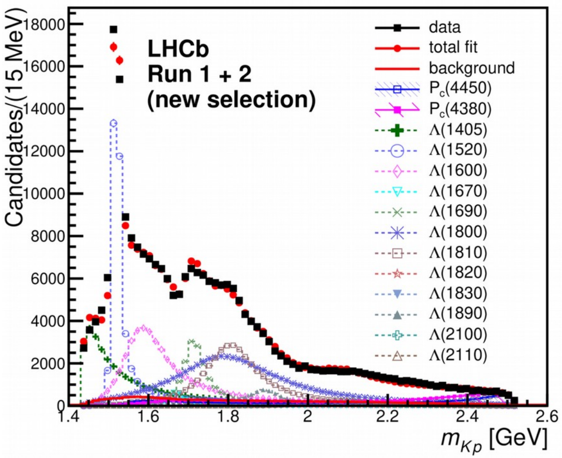
Signal yield of 246,000
(9 x Run 1 yield)
+ 6.4% background in signal region

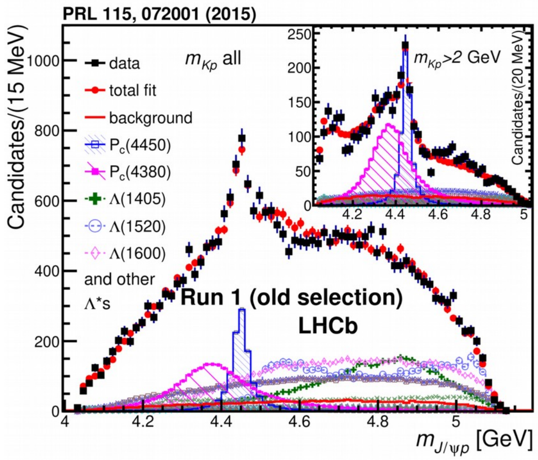


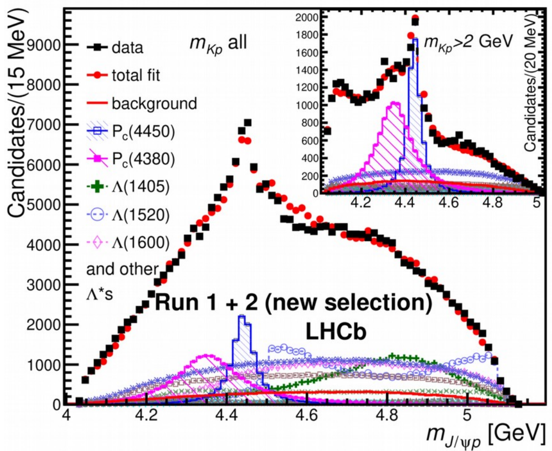
Phys. Rev. Lett. 122 (2019) 222001

$\Lambda_b \rightarrow J/\psi p K^-$









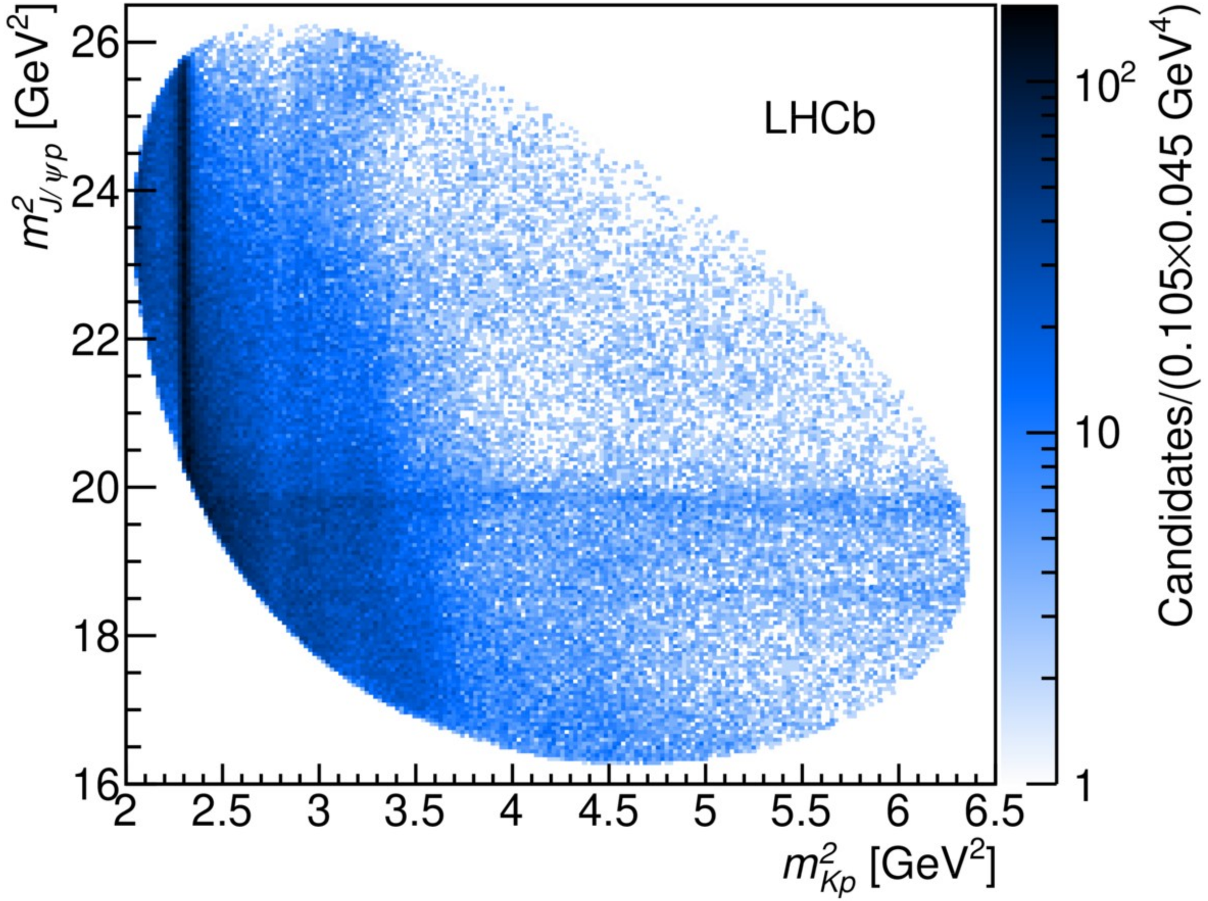
Previous and new data samples consistent

(some discrepancies between data and model more evident in larger sample)

Mass resolution is 2-3 MeV, while binning is 15 MeV

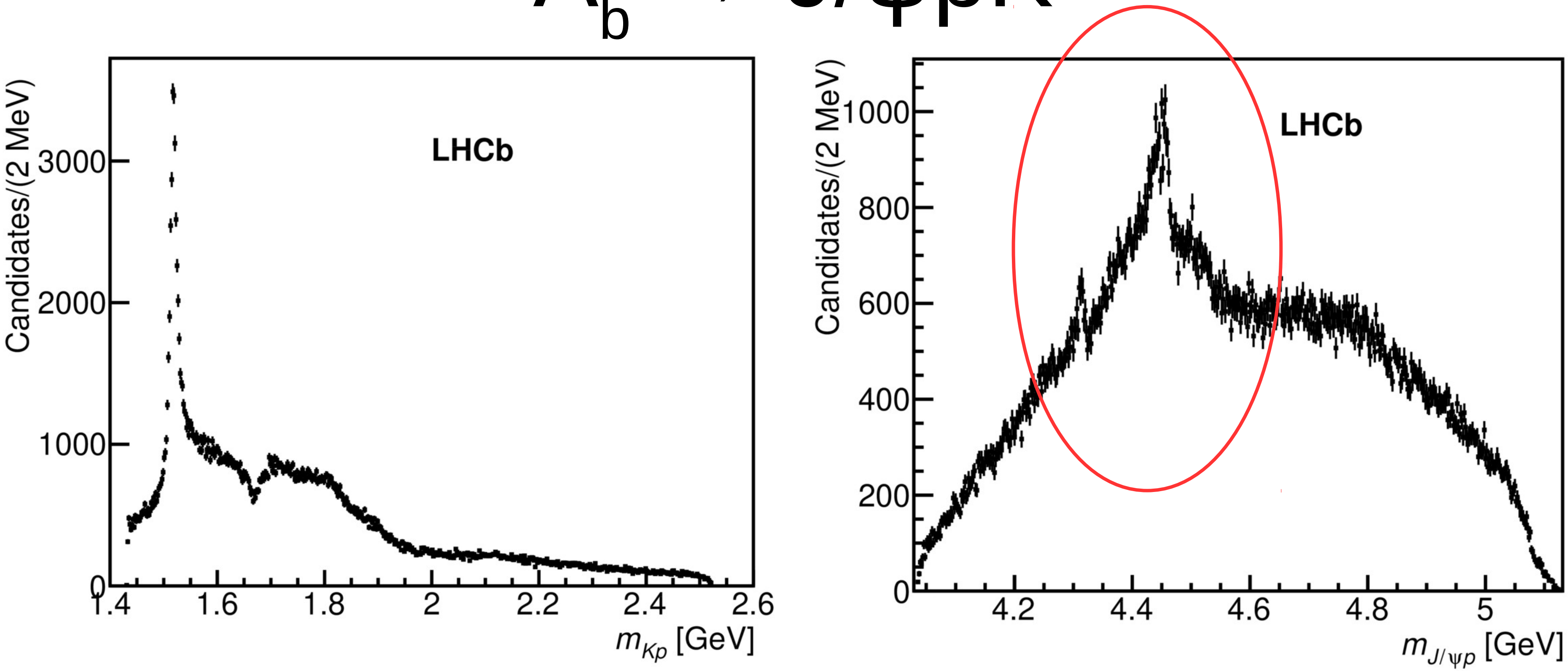
Phys. Rev. Lett. 122 (2019) 222001

$\Lambda_b \to J/\psi p K^-$



Phys. Rev. Lett. 122 (2019) 222001

$\Lambda_b \to J/\psi p K^-$



New, narrow structures emerge in larger sample

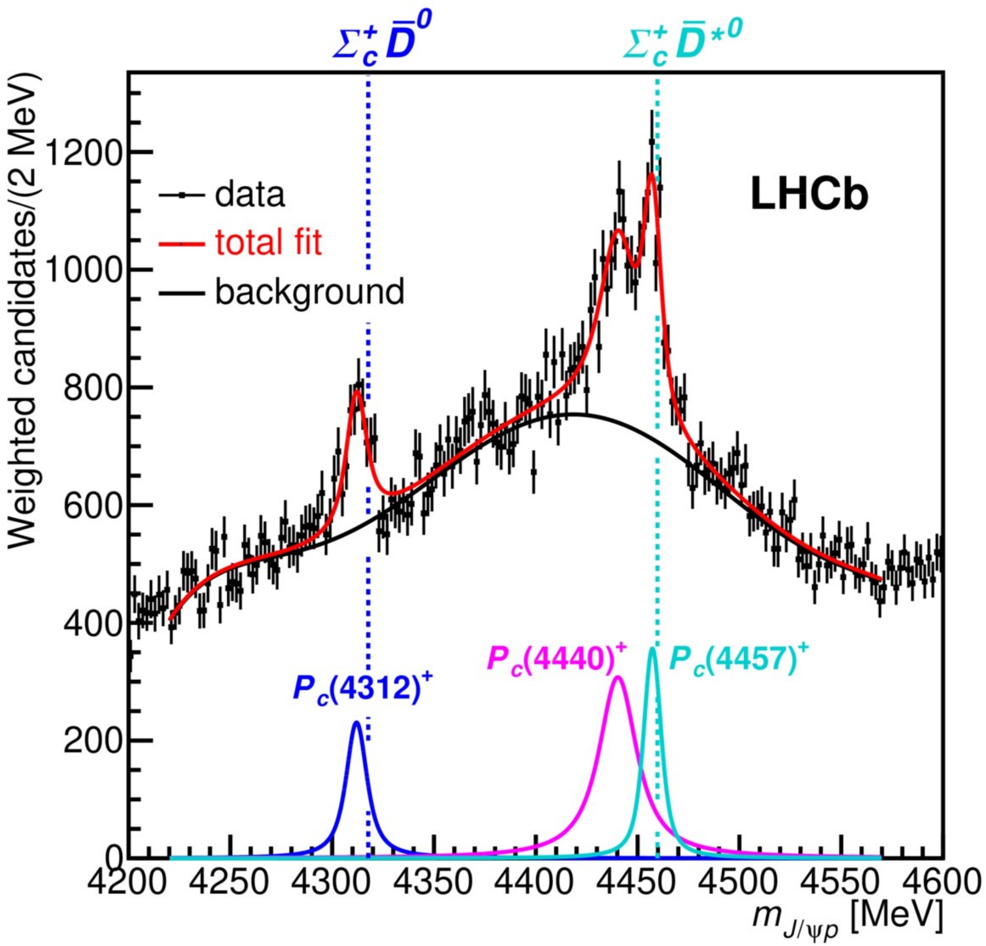
Good: can do simplified (1D) analysis

Bad: can no longer ignore resolution effects

(amplitude analysis becomes much more CPU-intensive)

Phys. Rev. Lett. 122 (2019) 222001

$\Lambda_b \rightarrow J/\psi p K^-$



Example 1D fit (one of many, all consistent)

- Data weighted as function of $\cos(\theta_{Pc})$ to enhance/suppress P_c/Λ^* contributions
- Polynomial background model
- 3 Breit-Wigner structures convolved with resolution function

This approach can robustly determine mass and width, but not J^P, of narrow states

Cannot determine properties of broad states
(need to wait for amplitude analysis, sorry)

Striking proximity to $\Sigma_c\bar{D}^{(*)}$ thresholds

Phys. Rev. Lett. 122 (2019) 222001

$\Lambda_b \rightarrow J/\psi p K^-$

State	M [MeV]	Γ [MeV]	(95% CL)	$\mathcal{R}$ [%]
$P_c(4312)^+$	$4311.9 \pm 0.7^{+6.8}_{-0.6}$	$9.8 \pm 2.7^{+\ 3.7}_{-\ 4.5}$	(< 27)	$0.30 \pm 0.07^{+0.34}_{-0.09}$
$P_c(4440)^+$	$4440.3 \pm 1.3^{+4.1}_{-4.7}$	$20.6 \pm 4.9^{+\ 8.7}_{-10.1}$	(< 49)	$1.11 \pm 0.33^{+0.22}_{-0.10}$
$P_c(4457)^+$	$4457.3 \pm 0.6^{+4.1}_{-1.7}$	$6.4 \pm 2.0^{+\ 5.7}_{-\ 1.9}$	(< 20)	$0.53 \pm 0.16^{+0.15}_{-0.13}$

Significances of all three states >5σ

Measurements of masses, widths, and relative production rates

N.B. $B(\Lambda_b \rightarrow J/\psi p K^-) = (3.17 \pm 0.04 \pm 0.07 \pm 0.34^{+0.45}_{-0.28}) \times 10^{-4}$ Chin.Phys. C40 (2016) 011001

Main systematic uncertainties from background & signal modelling (e.g. interference effects)

No results on J^P or on properties of broad states!

Summary

- LHCb detector provides exceptional sensitivity for hadron spectroscopy
  - many spectacular discoveries, in particular the charmonium pentaquarks
- $\Lambda_b \to J/\psi p K^-$ is a true golden channel
  - studies of other channels require more statistics, but exciting prospects for results with full Run 1+2 sample
  - data sample will increase again with LHCb Upgrade in Run 3 (2021-4)
  - long-term prospects also excellent with LHCb Upgrade II
- Ongoing discussion on interpretation and best models with which to fit data
  - amplitude analyses of increasing complexity, pushing at many boundaries