IFAE

10th April 2019

New results of **pentaquark searches** in LHCb

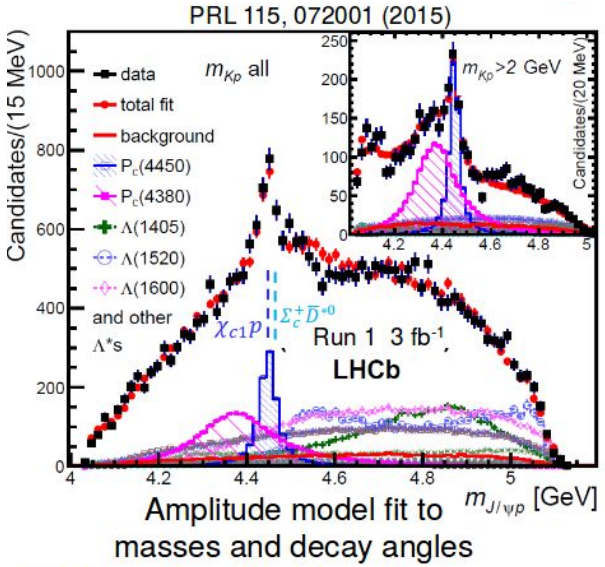
Elisabetta Spadaro Norella
on behalf of LHCb

Università di Milano
and INFN Milano

Pentaquark searches at LHCb

- $\Lambda_b \rightarrow J/\psi p K$ analysis:
  - In 2015 discovery of 2 states of $P_c^+ \rightarrow J/\psi p$ with Run1
  - TODAY: new results Run1 + Run2
- $B^0_{(s)} \rightarrow J/\psi p \bar{p}$ analysis:
  - First observation with 2011-2016 data accepted on PRL
  - Independent channel for pentaquarks in $J/\psi p$
    - Simple model with no other resonances like Λ^*

Run1



$\Lambda_b \to J/\psi p K$ Run1 + Run2 analysis

Talk at Moriond, 26/03

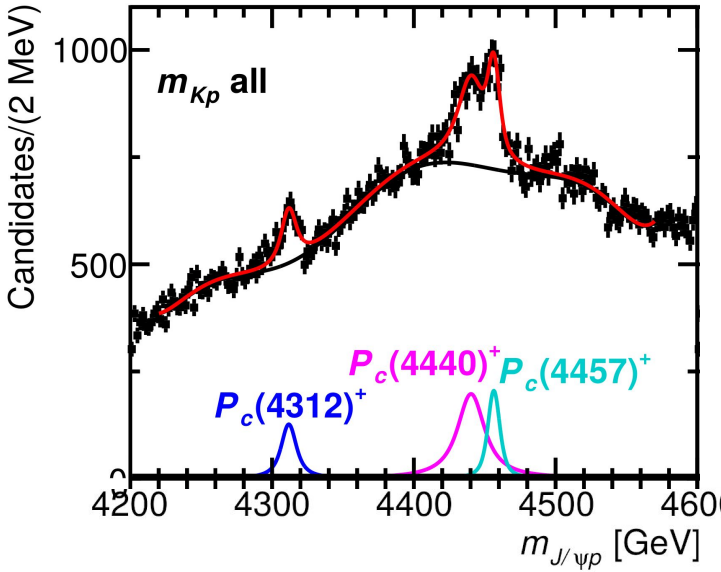
9x yield of 2015 analysis (~9 fb^{-1}) → 246k events

Fit to $m_{J/\psi p}$ invariant-mass distribution (full amplitude analysis in preparation)

→ 3 narrow peaks clearly visible

Nominal fit model:

- 3 BW + high-order polynomial bkg
  - New $P_c(4312)^+$!
  - Peak at 4450 MeV resolved in 2 narrower peaks
  - No sensitive to broad $P_c(4380)^+$



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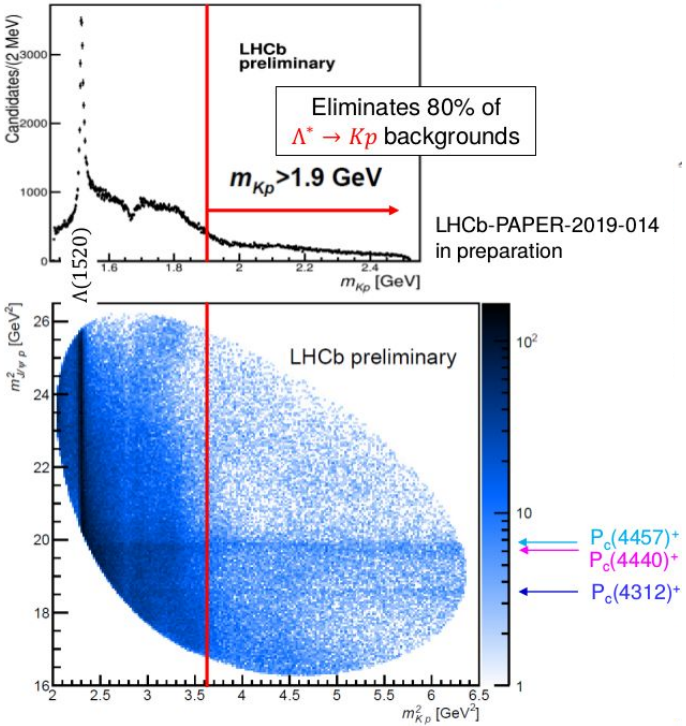
Λ* reflections?

To be confirmed by amplitude analysis



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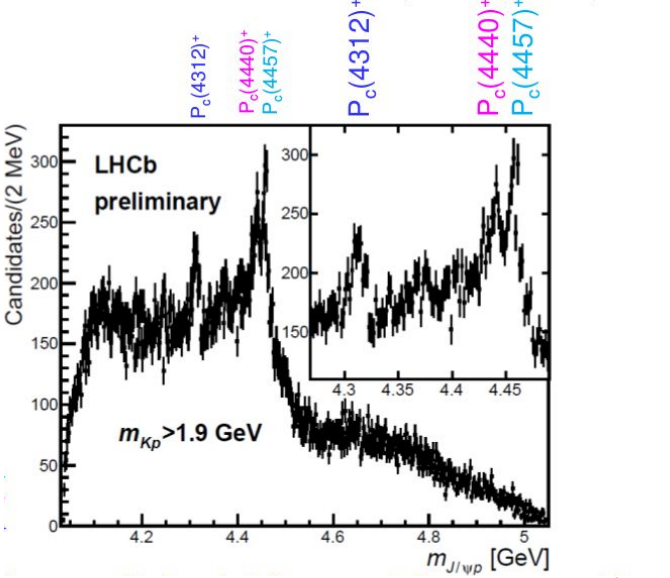
Mass resolution σ=2.3-2.7 (FWHM 5.4-6.4) MeV



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Fit $m_{J/\psi p}$ invariant mass

Different fits:

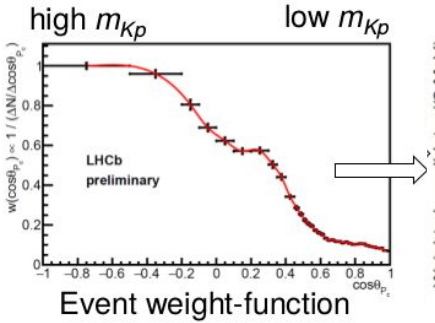
- Background parametrization
- Λ* composition:
  - Cut on m_{Kp}>1.9 GeV: Λ* in low region
  - Weighted on $\cos\theta_{Pc}$: Λ* for $\cos\theta_{Pc}$>0

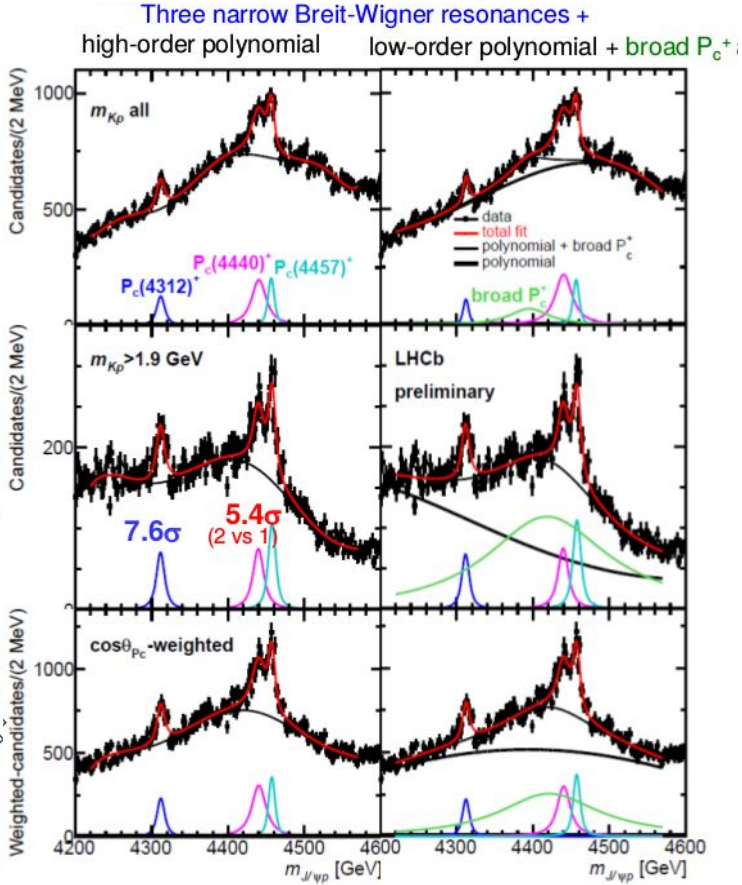
Other checks:

- fit with only $P_c(4312)$
- different selection
- toys for fitting approach using 6D amplitude model

Differences in Γ e M assigned as systematic uncertainties

The analysis is **not sensitive** to broad $J/\psi p$ contributions like $P_c(4380)^+$.





Fit results

Parameters: M, Γ e ***rate***

$$\mathcal{R} = \frac{\mathcal{B}(\Lambda_b^0 \to P_c^+ K^-)\mathcal{B}(P_c^+ K \to J/\psi p)}{\mathcal{B}(\Lambda_b^0 \to J/\psi p K^-)}$$

- Event-by-event efficiency parametrization ε → weights: 1/ε

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)	$0.53 \pm 0.16^{+0.15}_{-0.13}$

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Widths consistent with mass resolution

Theoretical interpretation

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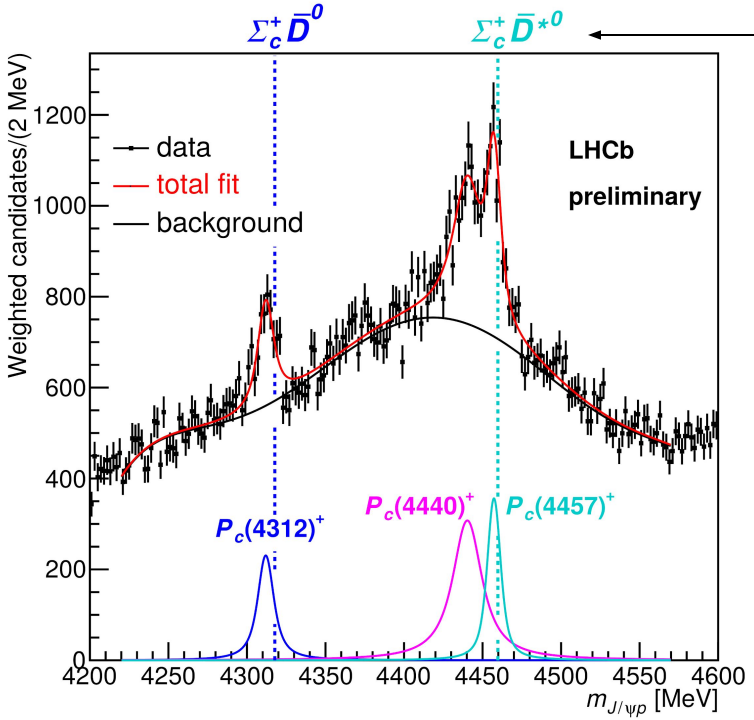
Near threshold masses and narrow resonances favor the hypothesis of molecules of baryon-meson



Only **below** this molecule threshold

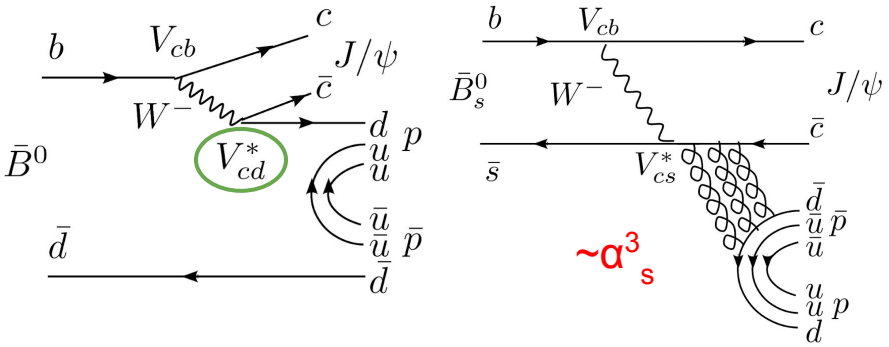
Two molecules: $\Sigma_c^+ D^0$, $\Sigma_c^+ D^{*0}$
→ 2 states with different spin

BUT neither pentaquark tight-structure nor triangle diagrams are excluded

→ Need an amplitude analysis for J^P quantum numbers

New pentaquark analysis: $B^0_{(s)} \rightarrow J/\psi p\bar{p}$ decay

- Candidate for pentaquark searches in $J/\psi p$ and $J/\psi \bar{p}$ and for glueball in pp system
- Both processes are suppressed due to Cabibbo and OZI suppression



- Limit on BR of B_s with no resonant structure:

$$\mathcal{B}(\bar{B}^0_s \rightarrow J/\psi p\bar{p}) \leq 10^{-9}$$

Eur. Phys. J. C75 (2015), no. 3 101

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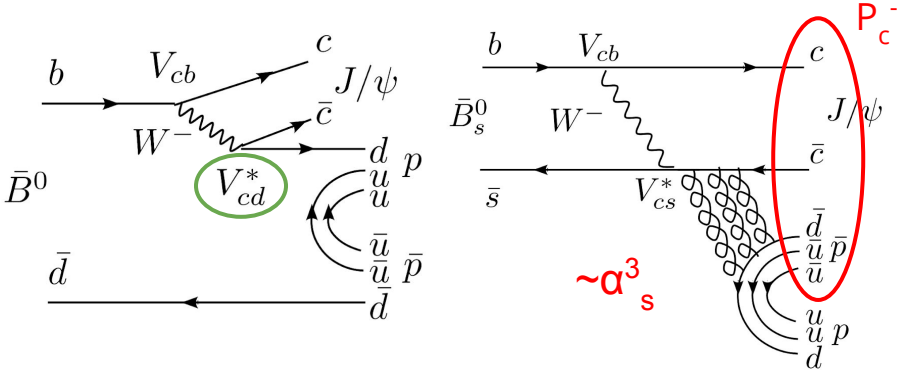

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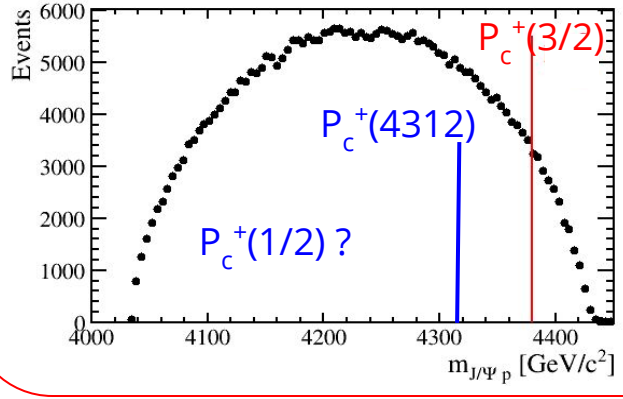
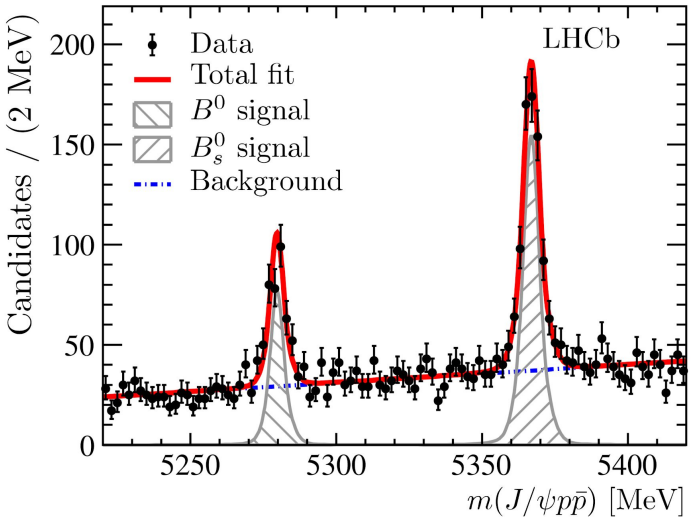
Pentaquarks allowed in B_s phase space



New pentaquark analysis: $B^0_{(s)} \to J/\psi p\bar{p}$ decay

First observation of $B^0_{(s)} \to J/\psi p\bar{p}$ decays with 2011-2016 data (5.2 fb^{-1}) arXiv:1902.05588



Mode	Yield
$B^0 \to J/\psi p\bar{p}$	256 ± 22
$B^0_s \to J/\psi p\bar{p}$	609 ± 31

$$\mathcal{B}(B^0 \to J/\psi p\bar{p}) = (4.51 \pm 0.40\ (\text{stat}) \pm 0.44\ (\text{syst})) \times 10^{-7},$$
$$\mathcal{B}(B^0_s \to J/\psi p\bar{p}) = (3.58 \pm 0.19\ (\text{stat}) \pm 0.33\ (\text{syst})) \times 10^{-6},$$

- BR of B_s: 2 order of magnitude higher than expected
- World's best single measurement of B_s and B^0 masses

m(Bs) = 5366.85 ± 0.19 ± 0.13 MeV
m(Bd) = 5279.74 ± 0.30 ± 0.10 MeV

- Amplitude analysis is ongoing with data till 2018 → around twice the statistics

Conclusions

- Very interesting results with Run1 + Run2 → 3 narrow peaks observed:
  - $P_c^+(4312)$, $P_c^+(4440)$ and $P_c^+(4457)$
- Amplitude analysis on this channel is ongoing to determine quantum numbers
- Analysis of $B^0_{(s)} \to J/\psi p\bar{p}$ can help distinguish among different models

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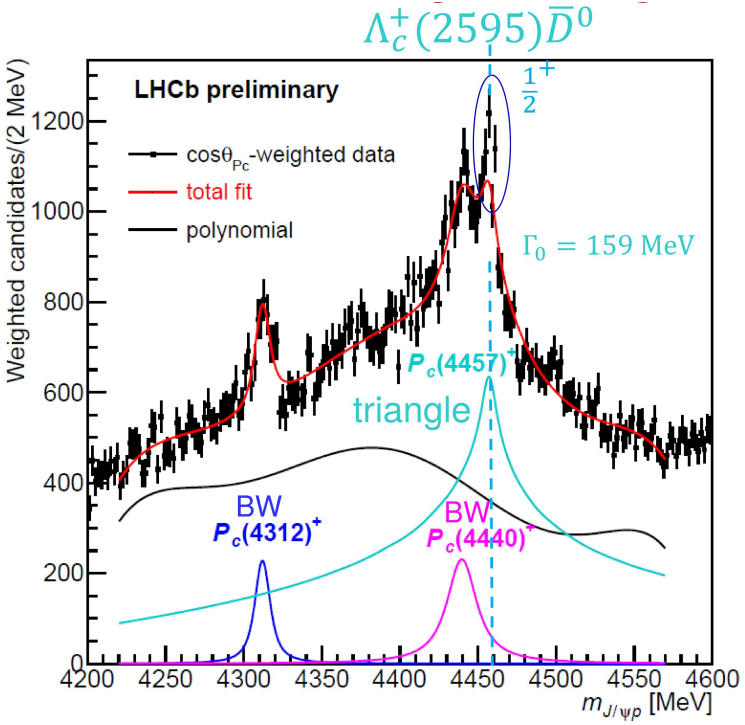
Grazie!

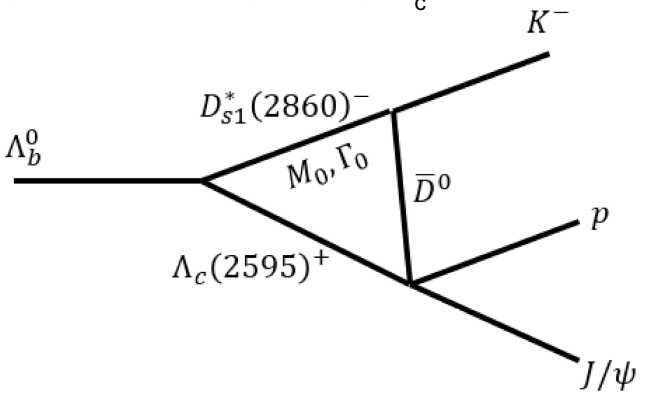
Funding from: Fond. Fratelli Confalonieri

BACKUP

Triangle diagrams



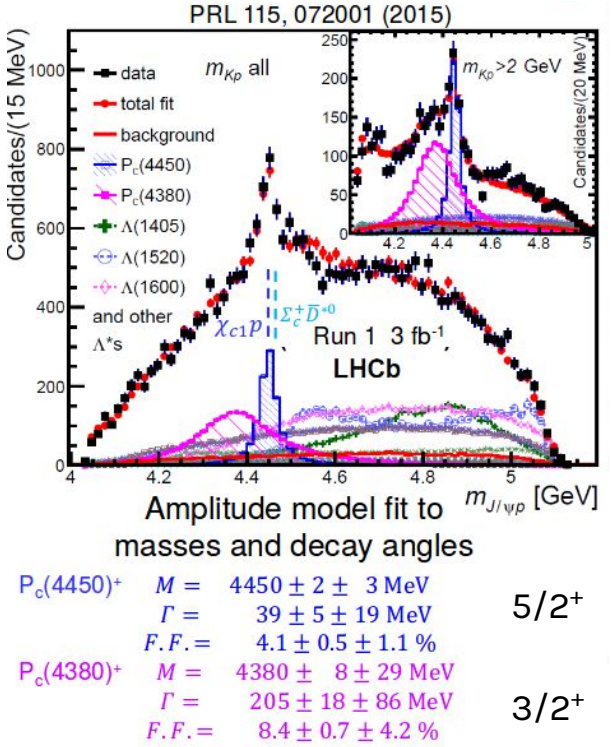
- $P_c(4312)^+$ and $P_c(4440)^+$ too far from threshold
- $P_c(4457)^+$: at the threshold of $\Lambda^+_c D^0$



- BUT to reproduce reasonable width for $D_{s1}^*(2860)$, the fit is not as good as with BW

Pentaquark analysis at LHCb

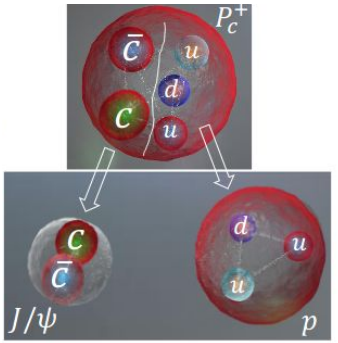
In 2015 LHCb discovered 2 states of $P_c^+ \rightarrow J/\psi p$ in $\Lambda_b \rightarrow J/\psi p K$ with 3 fb^{-1}

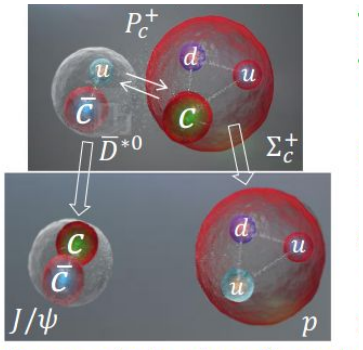


Theoretical interpretation:

- Tightly-bound pentaquark:
  - Wide states
  - bound energy ~ 400 MeV
  - Why is $P_c(4450)$ narrow? Higher value of L

- Loosely-bound state:
  - Narrow states
  - Molecule of baryon-meson: $\Sigma_c D^{*0}$ for $P_c(4450)$
  - Weak binding: masses below baryon-meson thresholds: Q ~ few MeV
  - Triangle diagrams with rescattering process $\chi_{c1}\, p$



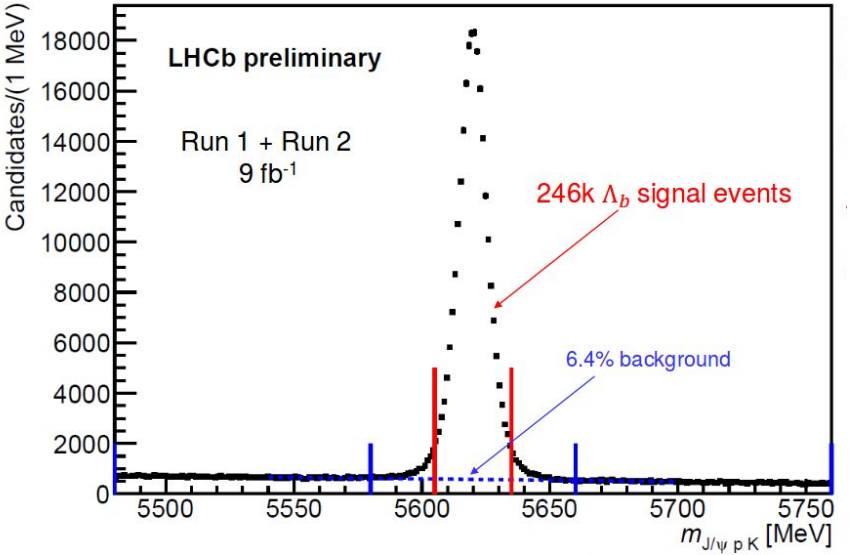


Dataset: Run1+Run2

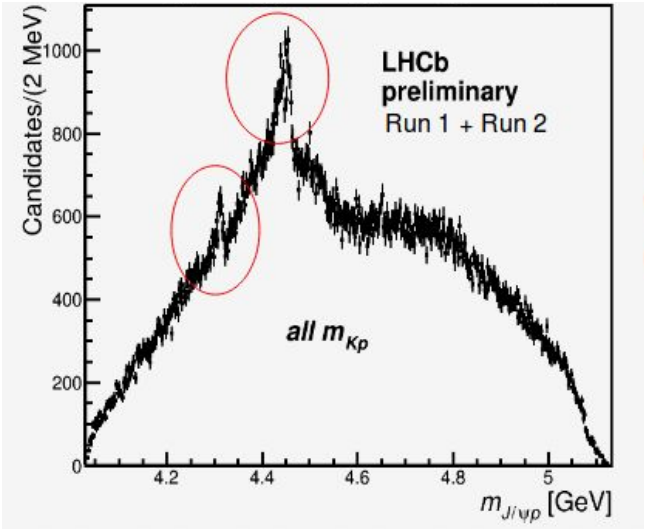
Talk at Moriond, 26/03

9x statistics than 2015 analysis

- Improvement in data selection with BDT
- luminosity x2 (9 fb^{-1})
- cross-section x2



New narrow peaks visible with fine binning:



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Significance: $\Delta\chi^2$ difference wrt null-hypothesis

- Best sensitivity with $\cos\theta_{Pc}$-weighted:
  - $P_c^+(4312)$: 8.5 σ → 8.2 σ with look-elsewhere effect
  - $P_c^+(4440)$ and $P_c^+(4457)$: 5.4 σ (6.2 σ) for m_{Kp}>1.9 GeV ($\cos\theta_{Pc}$-weighted)