New Hadronic Decays from LHCb

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On behalf of LHCb collaboration

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Content

Measurement of the ratio of branching fractions $\mathrm{B}(B_c^+ \to B_s^0 \pi^+) \,/\, \mathrm{B}(B_c^+ \to J/\psi\, \pi^+)$ [2210.12000]

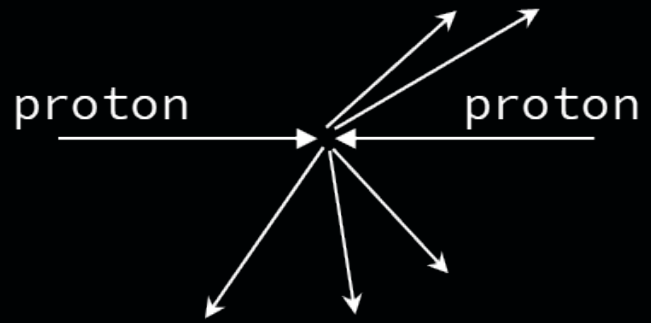
Search for prompt production of pentaquarks in open charm hadron final states [in preparation]

Observation of the $B_s^0 \to \chi_{c1}(3872)\, \pi^+\pi^-$ decay [2302.10629]

Observation of the $B^+ \to J/\psi\, \eta' K^+$ decay [2303.09443]

[detector, performance, event display]

The LHCb experiment

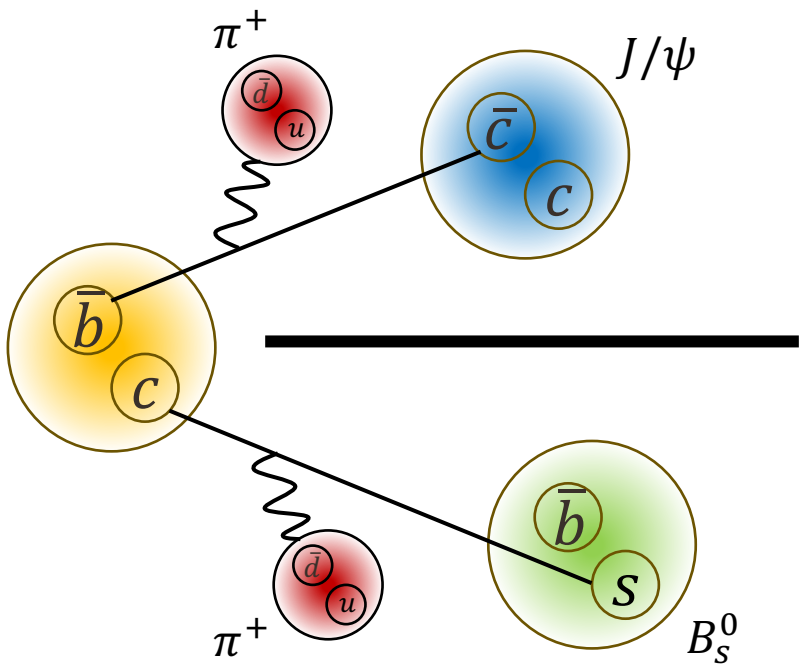


B_c^+ decays

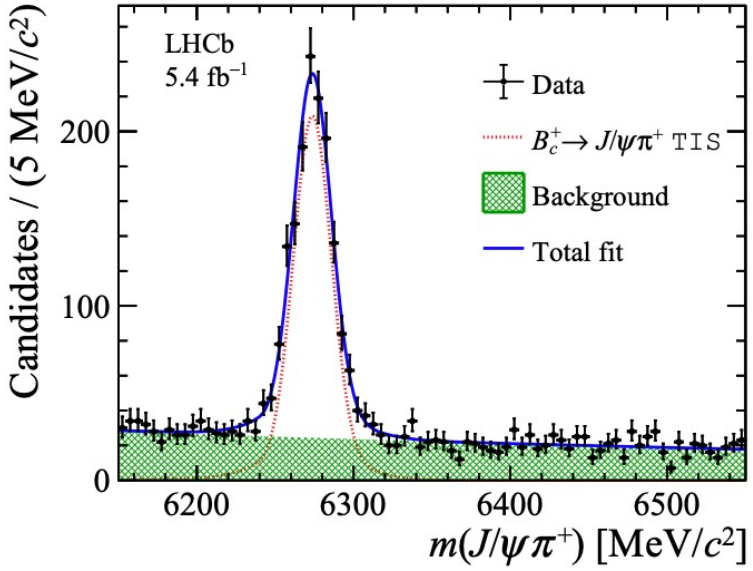

Rock garden, Chandigarh

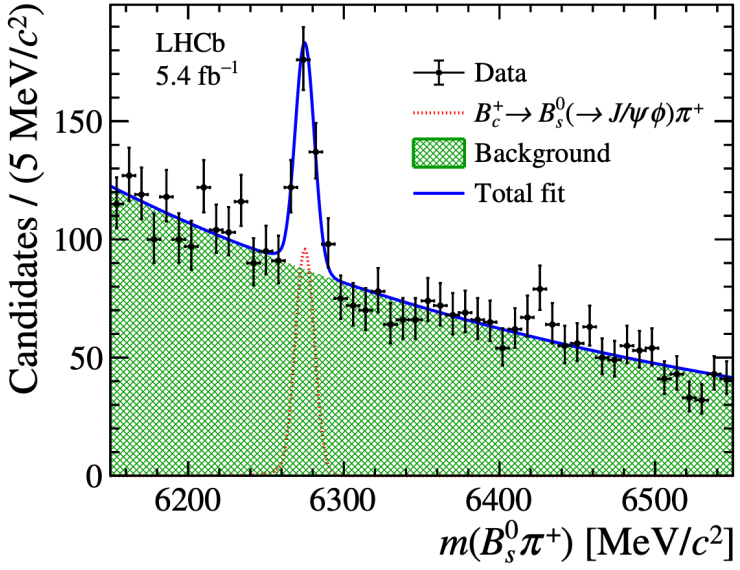
B_c^+ decays

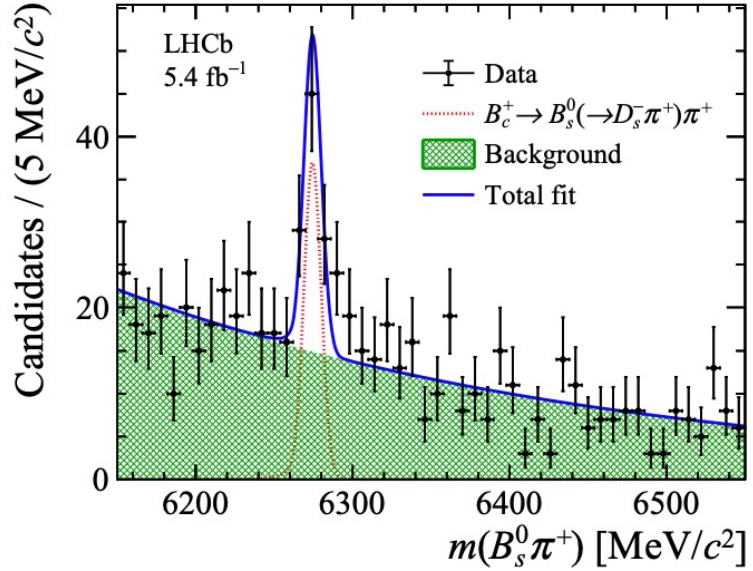
[LHCb, JHEP 07 (2023) 066]



- $\bar{b}$ **quark decays:** $\rightarrow J/\psi\pi^+$
- c **quark decays:** $\rightarrow B_s^0\pi^+$
  - $B_s^0 \rightarrow D_s^-\,\pi^+$ (bottom right)
  - $B_s^0 \rightarrow J/\psi\,\phi$ (bottom left)





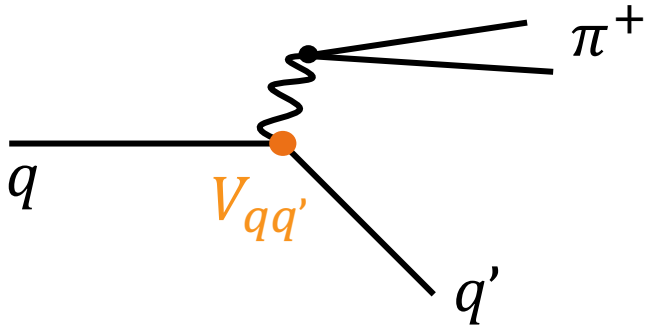


[LHCb, JHEP 07 (2023) 066]

Which heavy quark decays first

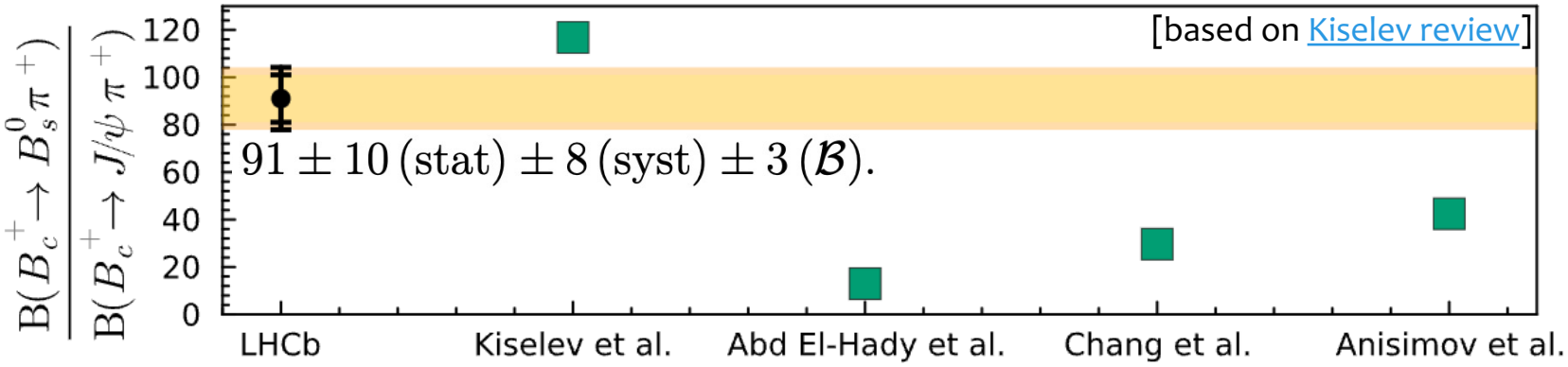
Standard weak decay, muon lifetime

- $\Gamma_{\mu\to e\bar{\nu}\nu} \sim m_\mu^5$ **(where m_μ^3 matrix element, m_μ^2 phase space)**



For quarks, $m_b^3 \gg m_c^3$. So, does b decay shortly? – no

$V_{bc}^2 \sim 10^{-3}$ **makes b-quark long-lived**

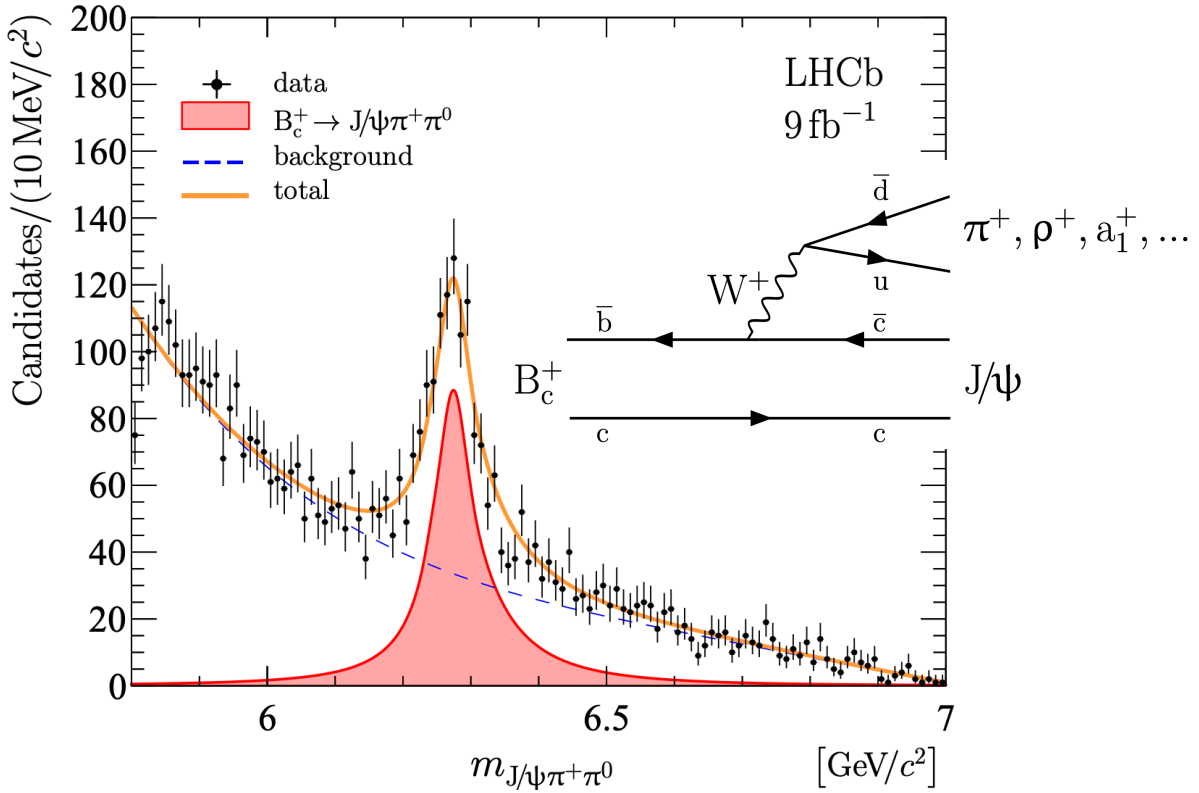


More on B_c^+

[LHCb-PAPER-2023-039]

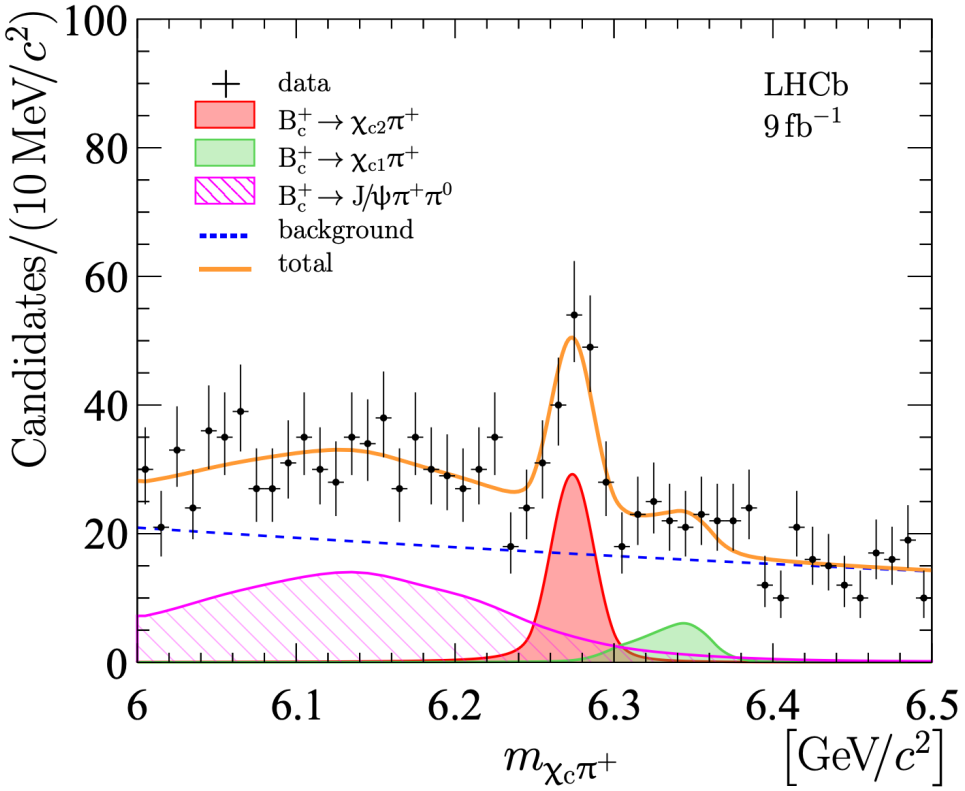
[LHCb-PAPER-2023-046]

$B_c^+ \to J/\psi\, \rho^+$



$$\frac{\mathcal{B}_{B_c^+\to J/\psi\pi^+\pi^0}}{\mathcal{B}_{B_c^+\to J/\psi\pi^+}} = 2.80 \pm 0.15 \pm 0.11 \pm 0.16\,,$$

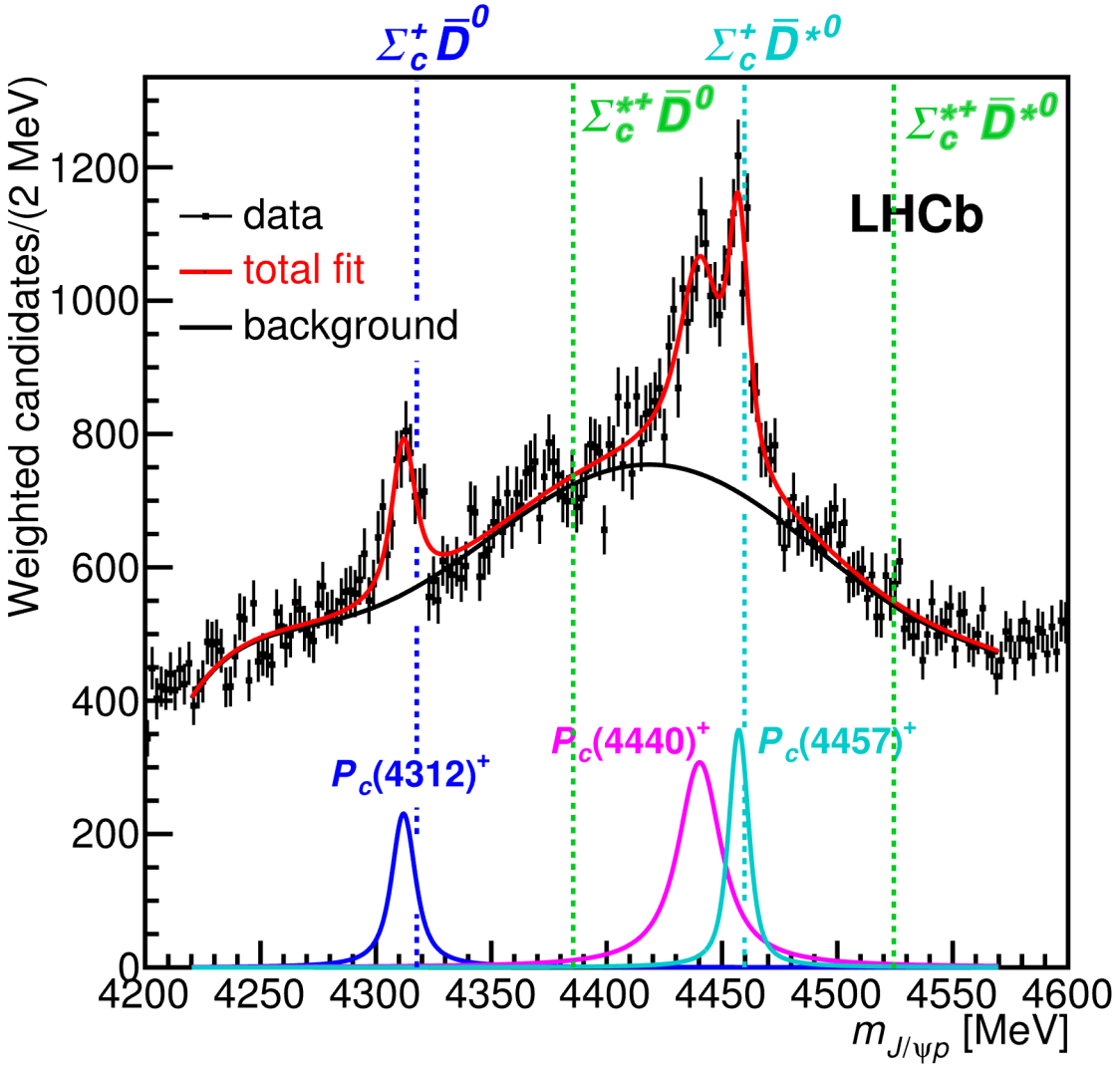
$B_c^+ \to \chi_c\, \pi^+$



$$\frac{\mathcal{B}_{B_c^+\to \chi_{c2}\pi^+}}{\mathcal{B}_{B_c^+\to J/\psi\pi^+}} = 0.37 \pm 0.06 \pm 0.02 \pm 0.01$$

Pentaquarks

Rock garden, Chandigarh



(1D) [LHCb, PRL 122 (2019) 22, 222001]

(AmAn) [LHCb, PRL 115 (2015), 072001]

Pentaquarks $P^+_{c\bar{c}}$ in $\Lambda_b^0 \to K^-(p\,J/\psi)$

Near threshold

$\Sigma_c^{(*)+}\bar{D}^{(*)0}$ / $\Sigma_c^{(*)++}D^{(*)-}$

Multiplicity matches threshold-states spin algebra

No observation in other final states so far

[naming scheme for hadrons, PDG2023]

New search of Pentaquarks in open-flavor decays

Pentaquark states seen in $J/\psi\, p$ must leave traces in

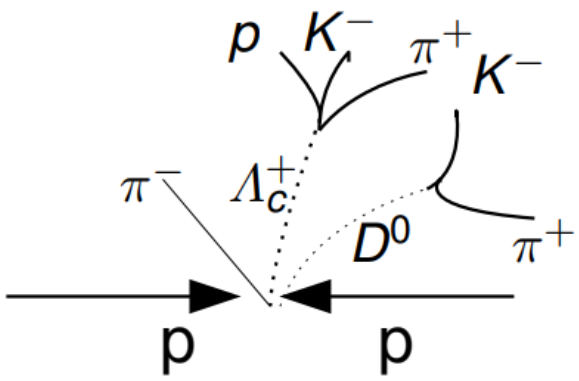
$$\Sigma_c^{(*)++} D^{(*)-}$$
$$\Sigma_c^{(*)+} \bar{D}^{(*)0}$$
$$\Sigma_c^{(*)+} D^{(*)-}$$
$$\Sigma_c^{(*)0} D^{(*)0}$$
$$\Lambda_c^+ D^{(*)-}$$
$$\Lambda_c^+ \bar{D}^{(*)0}$$

New search in prompt production is performed in many systems of

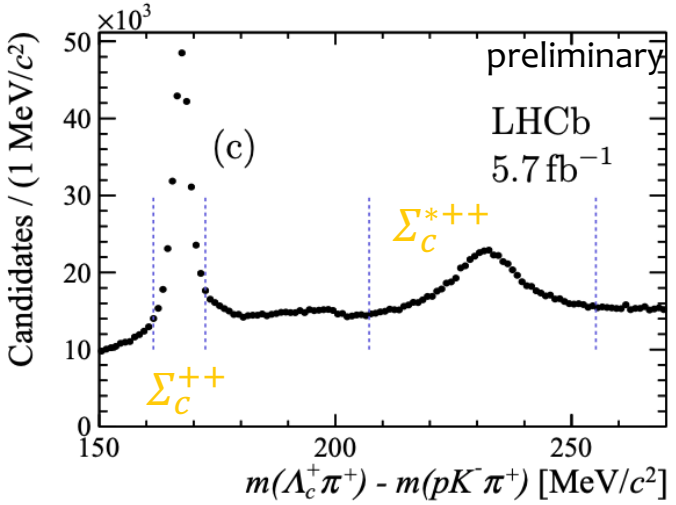
$$\Lambda_c^+ \bar{D}\, \pi^{\pm}$$

combinations

[LHCb-PAPER-2023-018, in preparation]



[courtesy G. Robertson (LHCb)]



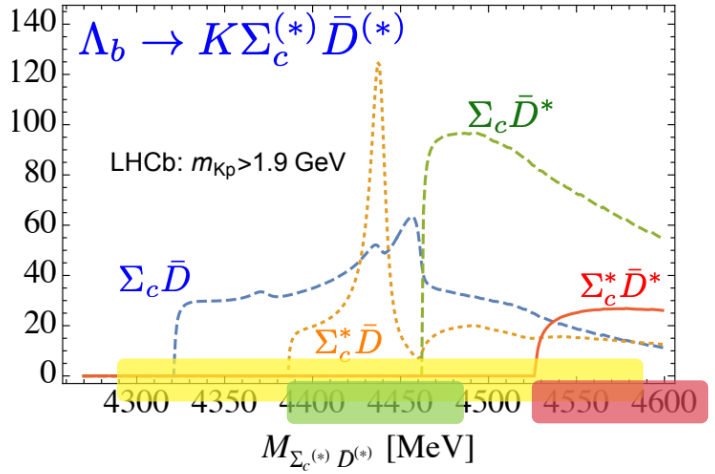
$\Sigma_c^{++}\bar{D}^0$ $\Sigma_c^0\bar{D}^0$	~~$\Sigma_c^{++}D^0$~~ ~~$\Sigma_c^0 D^0$~~	$\Sigma_c^{++}D^-$ $\Sigma_c^0 D^-$	~~$\Sigma_c^{++}D^+$~~ ~~$\Sigma_c^0 D^+$~~	~~$\Sigma_c^{++}D^{*-}$~~ ~~$\Sigma_c^0 D^{*-}$~~	~~$\Sigma_c^{++}D^{*+}$~~ ~~$\Sigma_c^0 D^{*+}$~~
$\Sigma_c^{*++}\bar{D}^0$ $\Sigma_c^{*0}\bar{D}^0$	$\Sigma_c^{*++}D^0$ $\Sigma_c^{*0}D^0$	$\Sigma_c^{*++}D^-$ $\Sigma_c^{*0}D^-$	$\Sigma_c^{*++}D^+$ $\Sigma_c^{*0}D^+$	$\Sigma_c^{*++}D^{*-}$ $\Sigma_c^{*0}D^{*-}$	~~$\Sigma_c^{*++}D^{*+}$~~ ~~$\Sigma_c^{*0}D^{*+}$~~
$\Lambda_c^+\bar{D}^0$	$\Lambda_c^+ D^0$	$\Lambda_c^+ D^-$	$\Lambda_c^+ D^+$	$\Lambda_c^+ D^{*-}$	$\Lambda_c^+ D^{*+}$
$\Lambda_c^+\bar{D}^0\pi^+$ $\Lambda_c^+\bar{D}^0\pi^-$	$\Lambda_c^+ D^0\pi^+$ $\Lambda_c^+ D^0\pi^-$	$\Lambda_c^+ D^-\pi^+$ $\Lambda_c^+ D^-\pi^-$	$\Lambda_c^+ D^+\pi^+$ $\Lambda_c^+ D^+\pi^-$	$\Lambda_c^+ D^{*-}\pi^+$ $\Lambda_c^+ D^{*-}\pi^-$	$\Lambda_c^+ D^{*+}\pi^+$ $\Lambda_c^+ D^{*+}\pi^-$

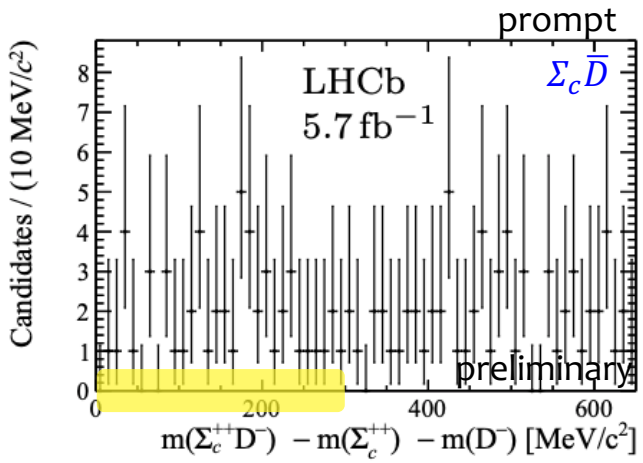
[X] : too small statistics for limit setting

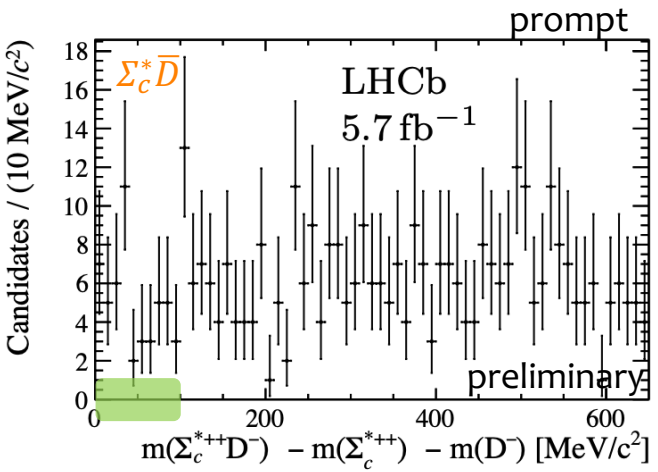
Search for pentaquarks: $\Sigma_c \bar{D}^{(*)}$

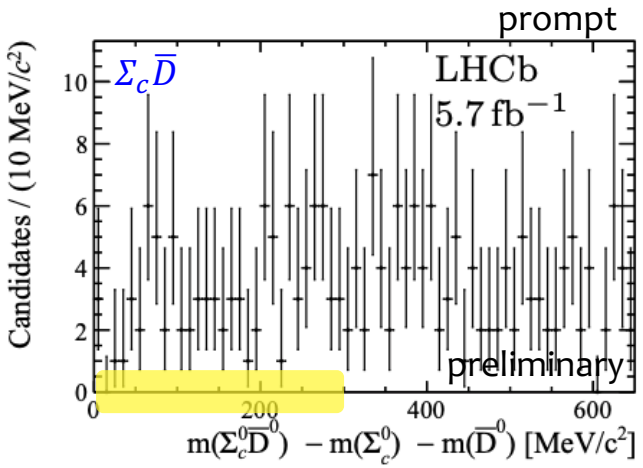
[LHCb-PAPER-2023-018, in preparation]

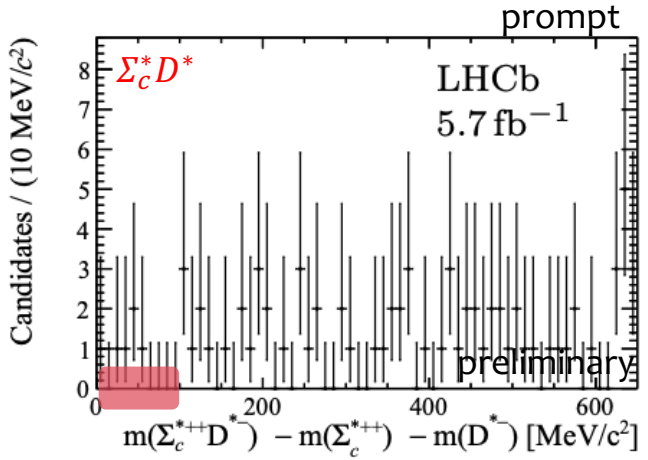
[Meng-Lin Du et al.]









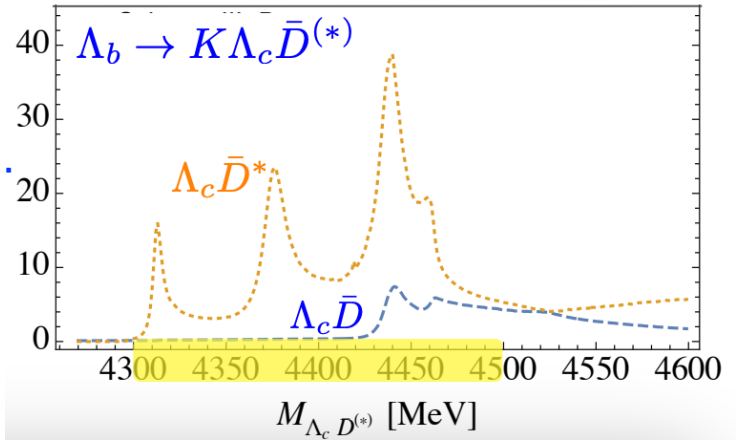


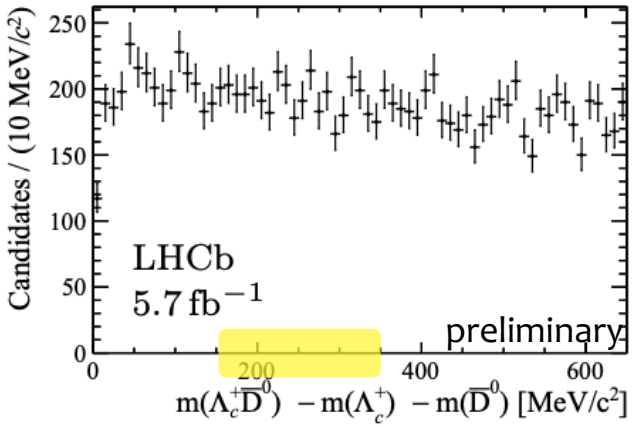
Statistically limited

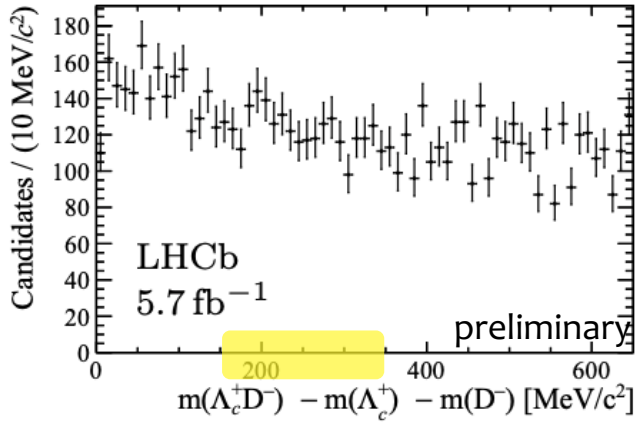
Search for pentaquarks: $\Lambda_c^+ \bar{D}$

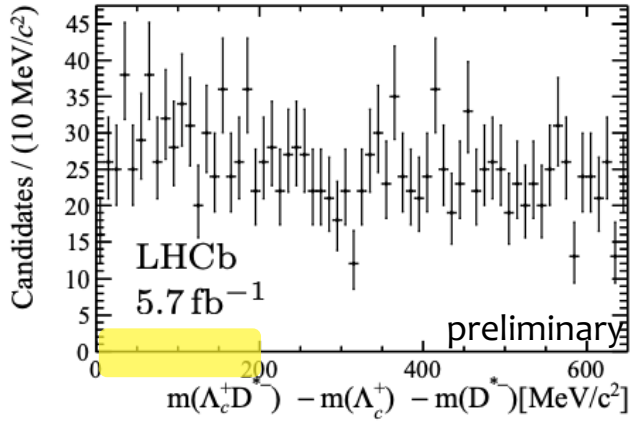
[LHCb-PAPER-2023-018, in preparation]

[Meng-Lin Du et al.]





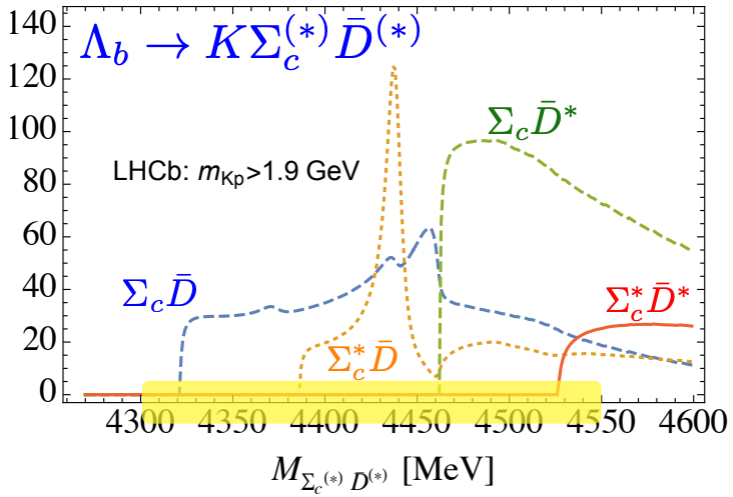




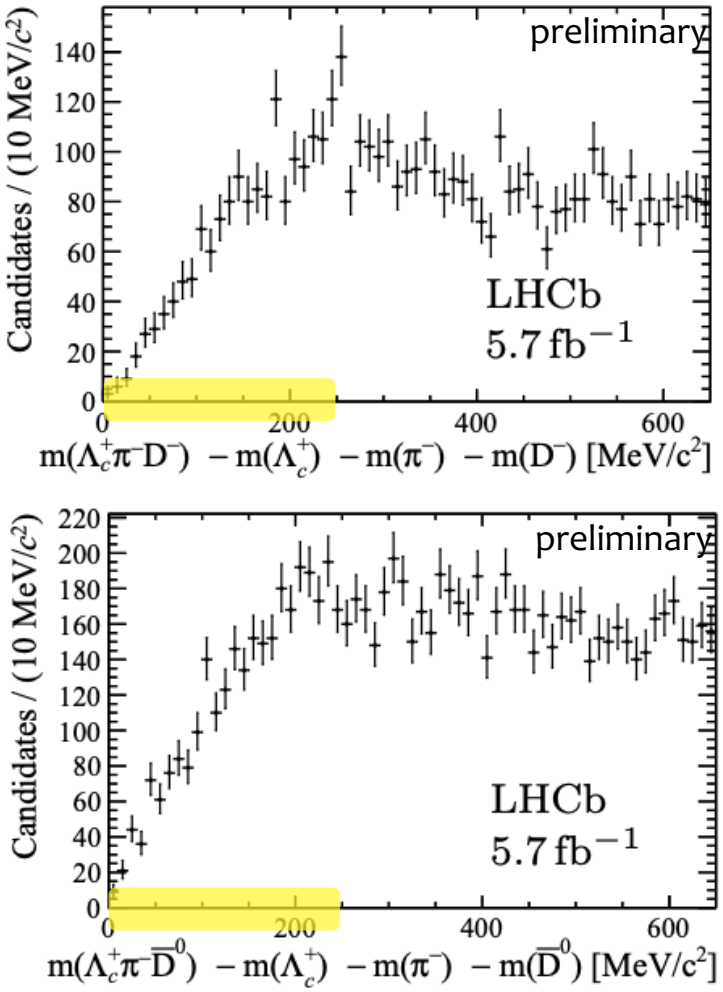
No obvious peaks

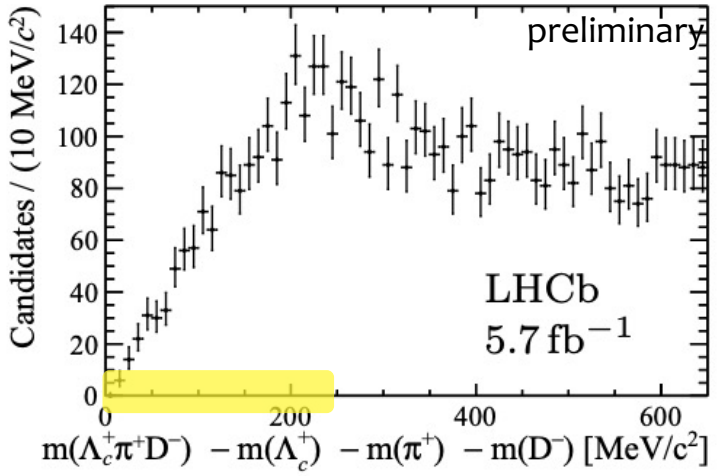
Search for pentaquarks: $\Lambda_c^+ \bar{D}\,\pi$

[LHCb-PAPER-2023-018, in preparation]



[Meng-Lin Du et al.]





Some peaking structures that might become pentaquarks with more statistics

[LHCb-PAPER-2023-034]

$\Lambda_c^+ D^0$ in b-decays

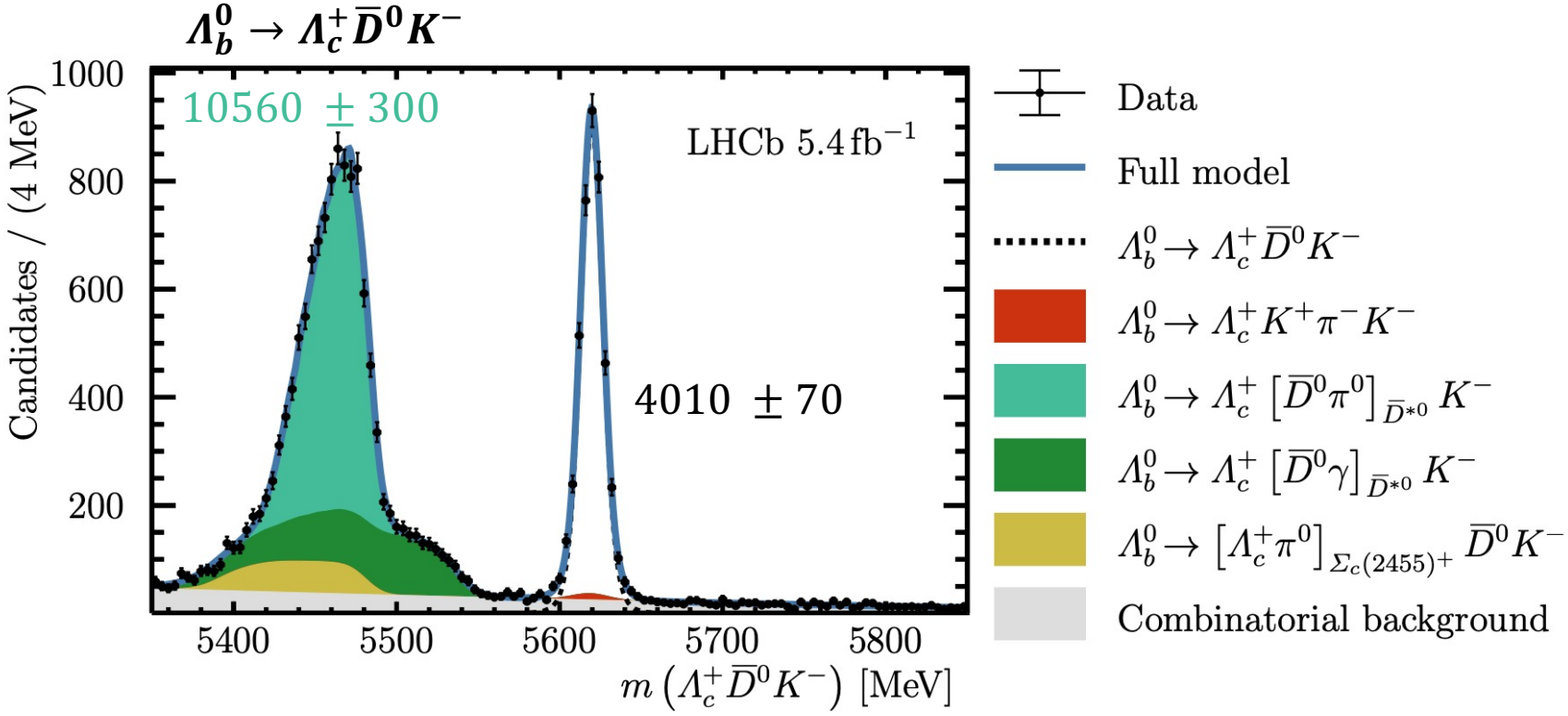
The decays $\Lambda_b^0 \to \Lambda_c^+ \bar{D}^0 K^-$ are observed.

Dalitz plot is populated by

- $D_s^{**-} (\to \bar{D}^0 K^-)$, and
- $\Xi_c^{**0} (\to \Lambda_c^+ K^-)$

states

Searches for pentaquark contributions are ongoing.

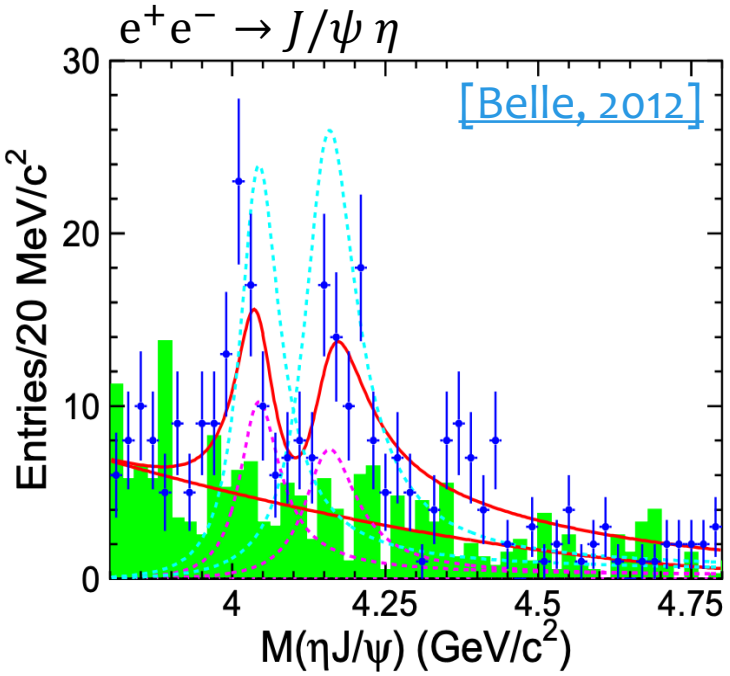


$J/\psi\ \eta'$

Rock garden, Chandigarh

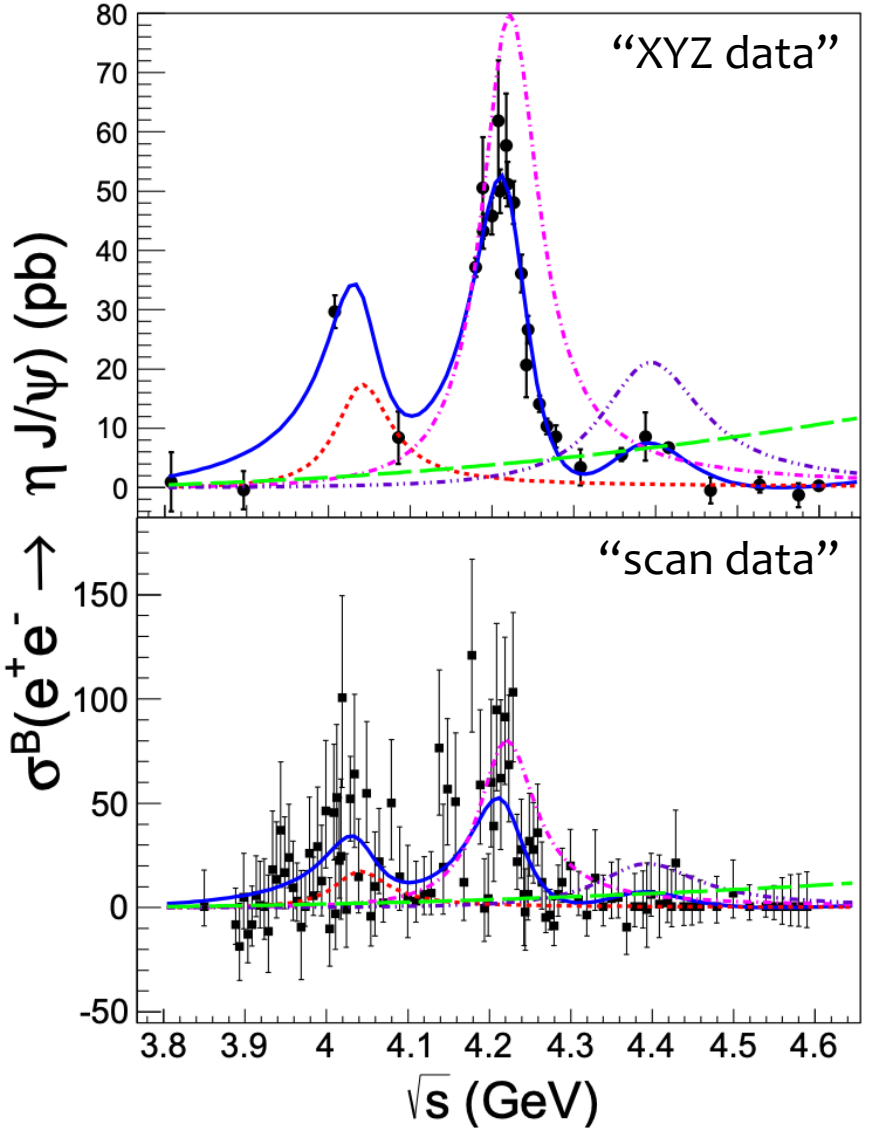
Studies of charmonium in $(J/\psi\,\eta)$

Charmonium states $\psi(4040)$, $\psi(4160)$, $\psi(4360)$, observed in $(J/\psi\,\eta)$ decays by Belle and BESIII



No evidence for $\psi(4260)$, $\psi(4415)$, $\psi(4430)$

[BESIII, 2020]



[LHCb-PAPER-2022-054]

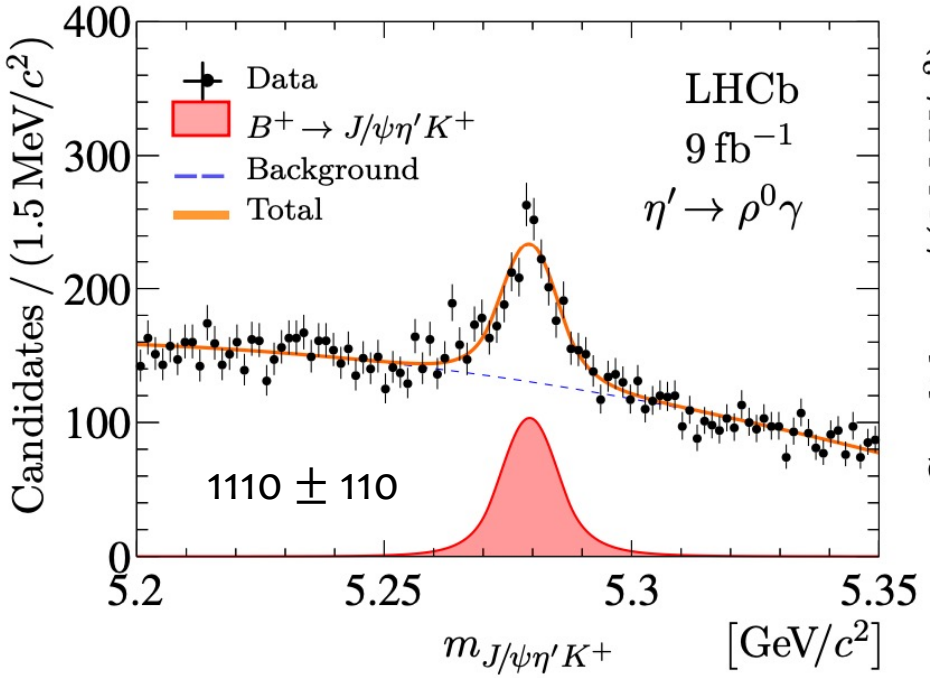
First look by LHCb

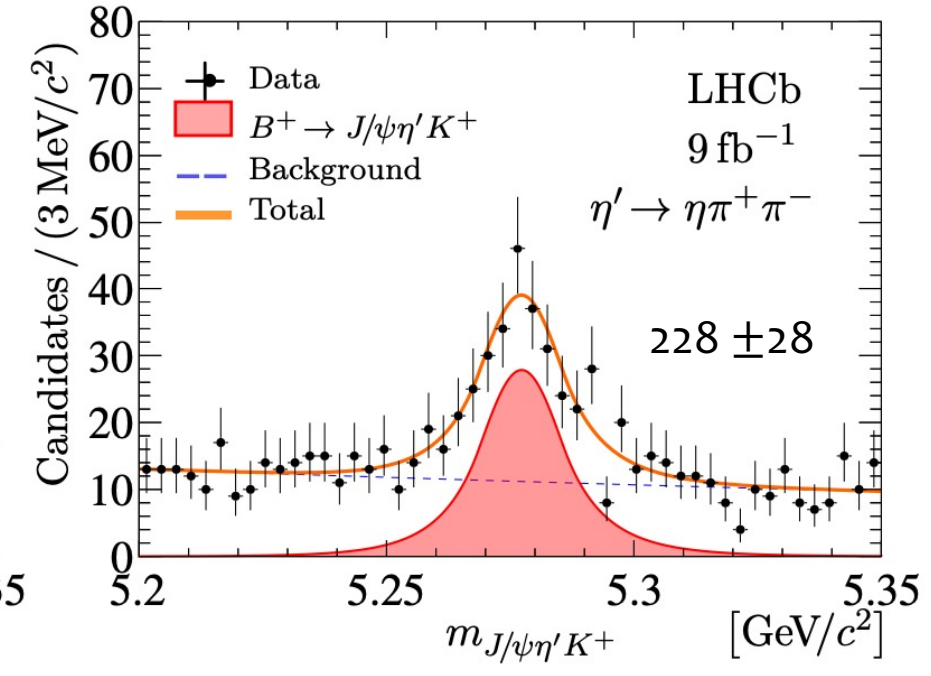
$B^+ \to J/\psi\, \eta' K^+$

with

$\eta' \to (\rho \to \pi^+\pi^-)\gamma$

$\eta' \to \pi^+\pi^-(\eta \to \gamma\gamma)$





First observation of the decay mode!

$$\frac{\mathcal{B}(B^+ \to J/\psi\eta' K^+)}{\mathcal{B}(B^+ \to \psi(2S)K^+)} = (4.91 \pm 0.47 \pm 0.29 \pm 0.07) \times 10^{-2},$$

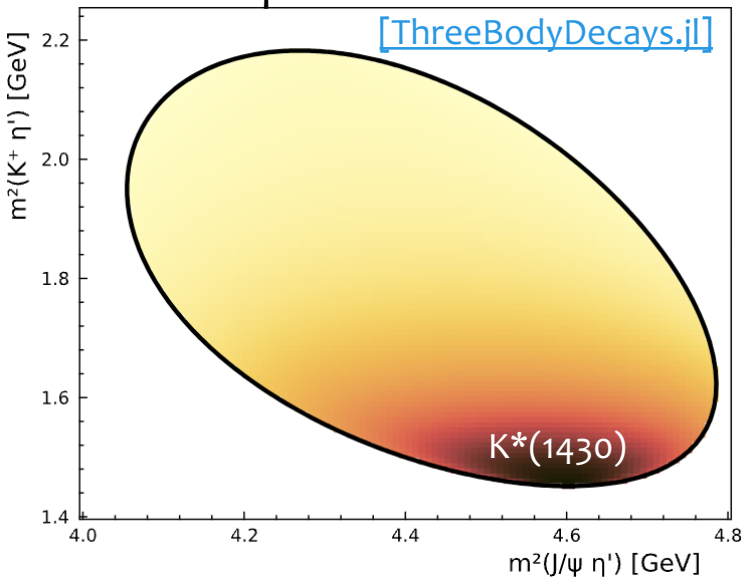
Projections $B^+ \to J/\psi\, \eta' K^+$

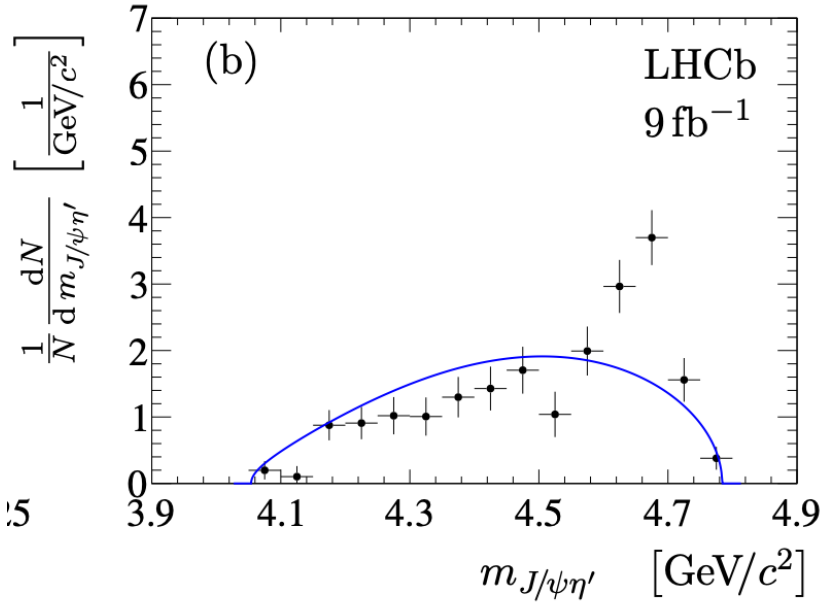
[LHCb 2023, JHEP 08 (2023) 174]

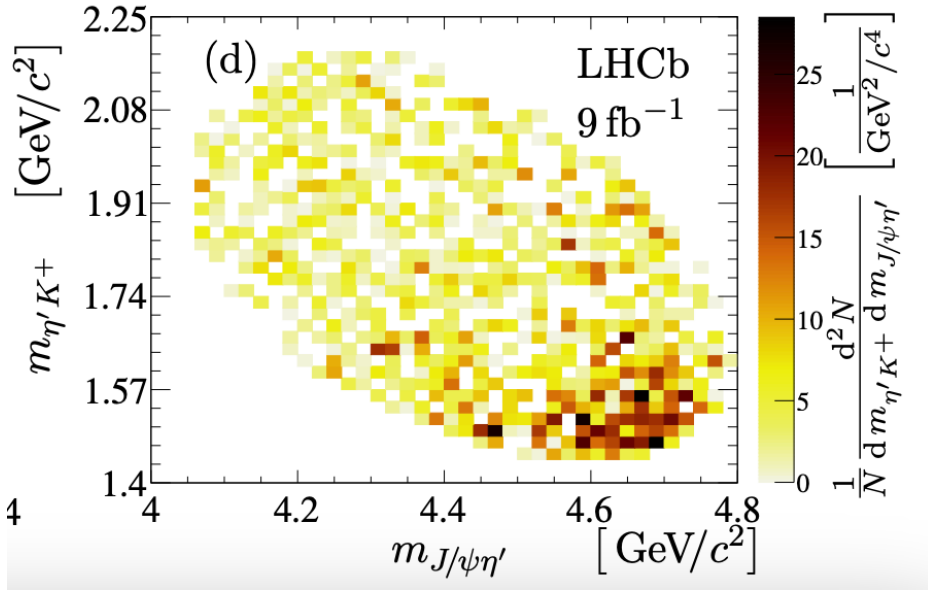
No significant contributions from charmonium or charmonium-like resonances.

Dominated by K* resonances

An example







$B_s^0 \to \chi_{c1}(3872)\,\pi^+\pi^-$

Rock garden, Chandigarh

$\chi_{c1}(3872)$ in B decays

Puzzle with isospin ratio
$B^0 \to \chi_{c1}(3872) K^0$
$B^+ \to \chi_{c1}(3872) K^+$

~1 (naively)

$$\frac{\mathcal{B}(\mathrm{B_s^0} \to X(3872)\phi)}{\mathcal{B}(\mathrm{B^0} \to X(3872)\mathrm{K^0})} \overset{\chi_{c1} \to J/\psi\,\pi^+\pi^-}{=} 0.96 \pm 0.31$$ Using [CMS 2021] + [PDG]

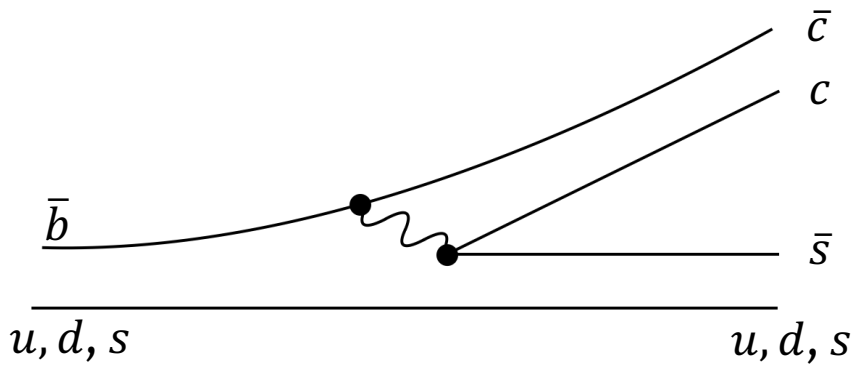
$$\frac{\mathcal{B}(\mathrm{B_s^0} \to X(3872)\phi)}{\mathcal{B}(\mathrm{B^+} \to X(3872)\mathrm{K^+})} \overset{\chi_{c1} \to J/\psi\,\pi^+\pi^-}{=} 0.482 \pm 0.063\,(\mathrm{stat}) \pm 0.037\,(\mathrm{syst}) \pm 0.070\,(\mathcal{B}).$$ [CMS 2021]

$$\frac{\mathcal{B}(B^0 \to K^0 X(3872))}{\mathcal{B}(B^+ \to K^+ X(3872))} \overset{\chi_{c1} \to J/\psi\,\pi^+\pi^-}{=} 0.50 \pm 0.14\ (\mathrm{stat}) \pm 0.04\ (\mathrm{syst})$$ [Belle 2011]

$$\frac{\mathcal{B}(B^0 \to X(3872)K^0)}{\mathcal{B}(B^+ \to X(3872)K^+)} \overset{\chi_{c1} \to \bar{D}^0 D^{*0}}{=} 1.34^{+0.47}_{-0.40}(\mathrm{stat})^{+0.10}_{-0.12}(\mathrm{syst}),$$ [Belle 2023]

To understand better the production,
$B_s^0 \to \chi_{c1}(3872)\ (K^+K^-)_\phi$

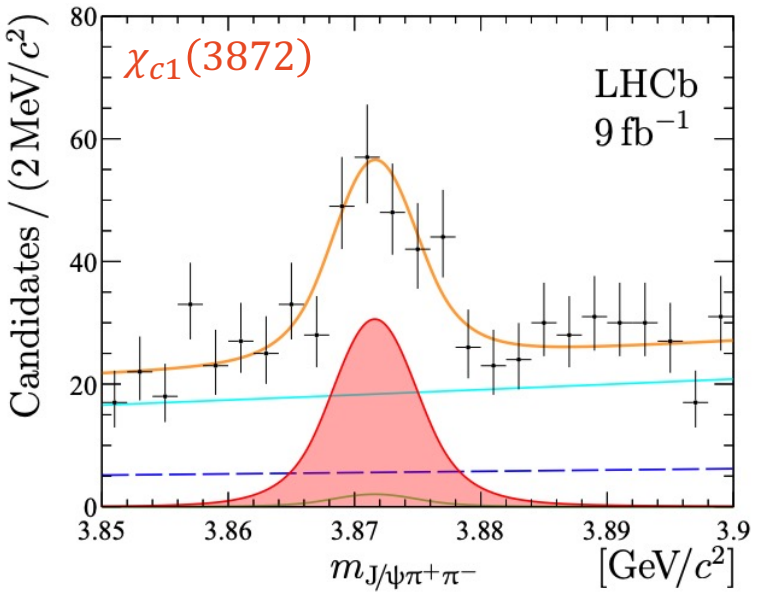
we look at the $\chi_{c1}(3872)$ production current with $\pi^+\pi^-$
$B_s^0 \to \chi_{c1}(3872)\,\pi^+\pi^-$

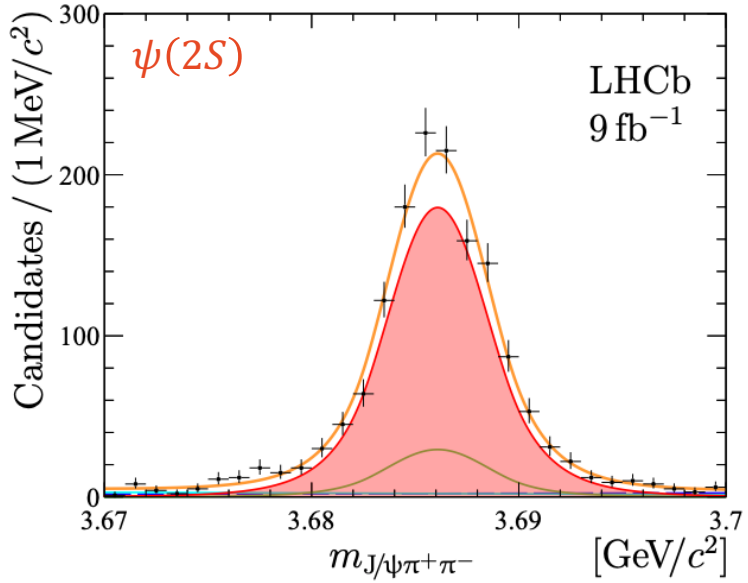


[LHCb-PAPER-2023-015]

$B_s^0 \to \chi_{c1}(3872)\pi^+\pi^-$

- **First observation**
- $\chi_{c1}(3872) \to J/\psi\,\pi^+\pi^-$ **is considered**
- $\psi(2S) \to J/\psi\,\pi^+\pi^-$ **is a reference**





$$\frac{\mathrm{B}(B_s^0 \to \chi_{c1}(3872)\pi^+\pi^-) \times \mathrm{B}(\chi_{c1}(3872) \to J/\psi\,\pi^+\pi^-)}{\mathrm{B}(B_s^0 \to \psi(2S)\pi^+\pi^-) \times \mathrm{B}(\psi(2S) \to J/\psi\,\pi^+\pi^-)} = 6.8 \pm 1.1 \pm 0.2\ \%$$ [this study]

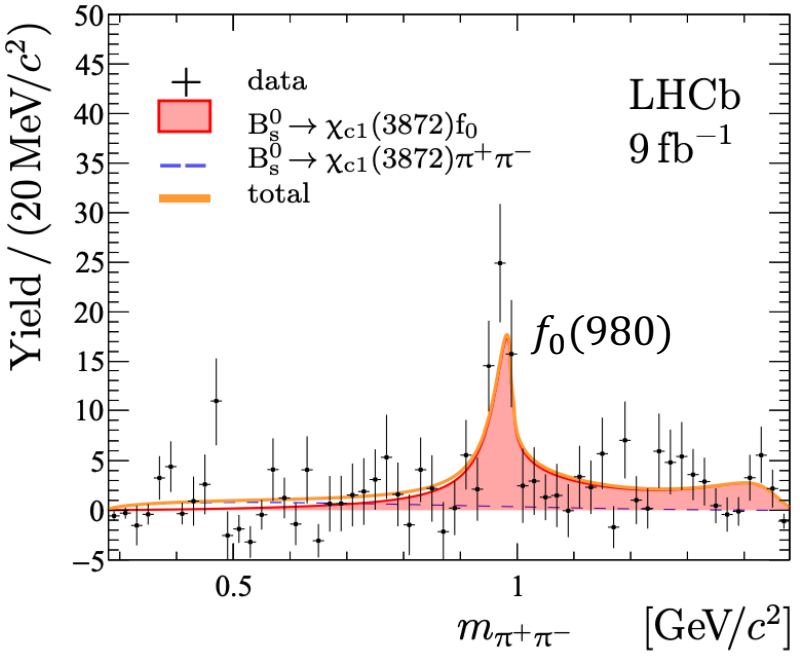
$$\frac{\mathrm{B}(B_s^0 \to \chi_{c1}(3872)\varphi) \times \mathrm{B}(\chi_{c1}(3872) \to J/\psi\,\pi^+\pi^-)}{\mathrm{B}(B_s^0 \to \psi(2S)\varphi) \times \mathrm{B}(\psi(2S) \to J/\psi\,\pi^+\pi^-)} = 2.21 \pm 0.29 \pm 0.17\ \%$$ [CMS 2021]

[LHCb-PAPER-2023-015]

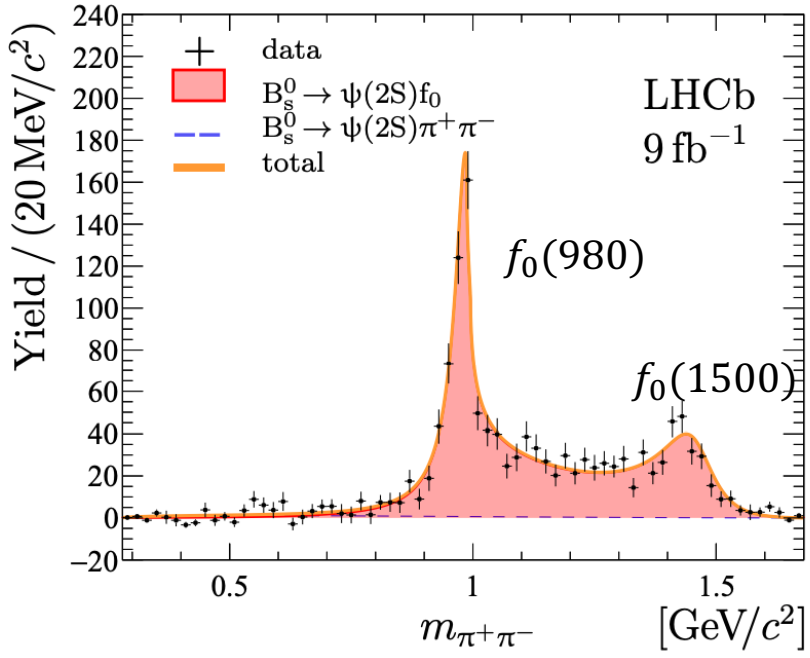
$B_s^0 \to \chi_{c1}(3872)\pi^+\pi^-$

$s\bar{s}$ drives the production current

The spectrum is consistent with strange-dominated f_0 resonances



$B_s^0 \to \psi(2S)\pi^+\pi^-$



Ramping up with Run-III

[LHCb Upgrade]

Vertex detector is successfully reinstalled

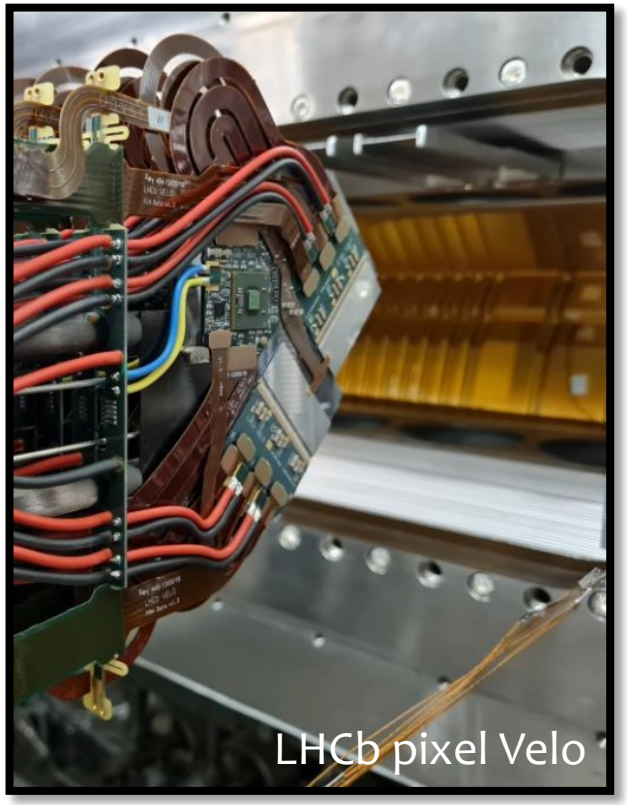
Downstream tracker is replaced

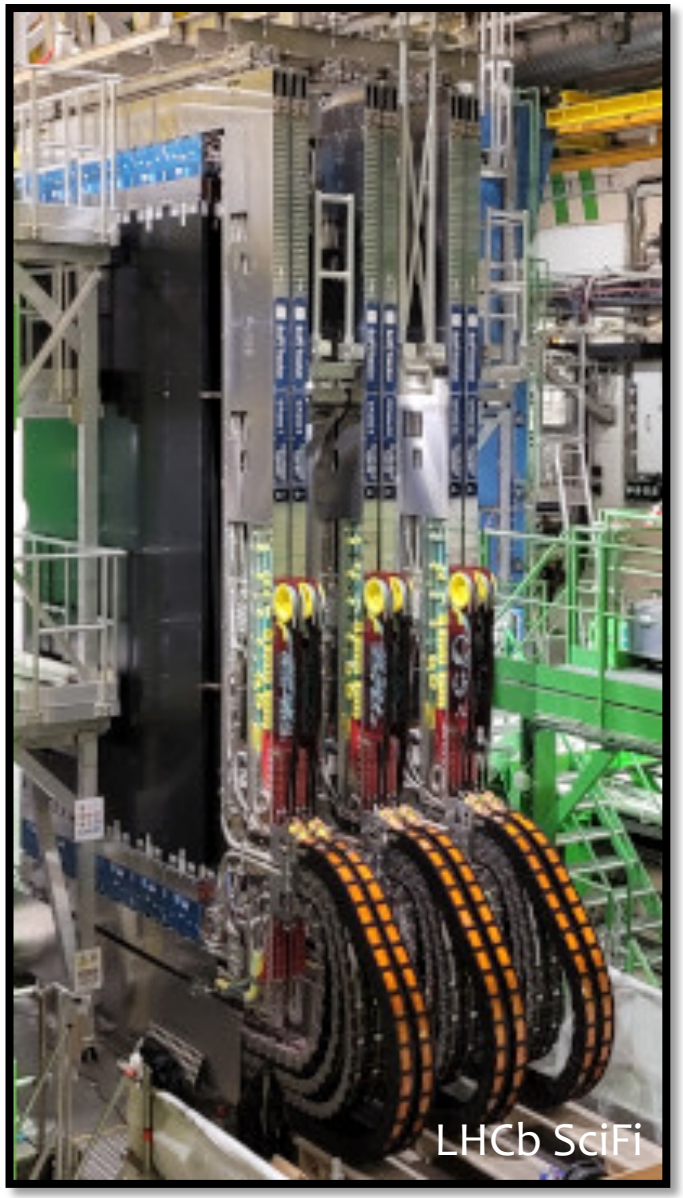
No calorimeter trigger (L0)

Schedule:

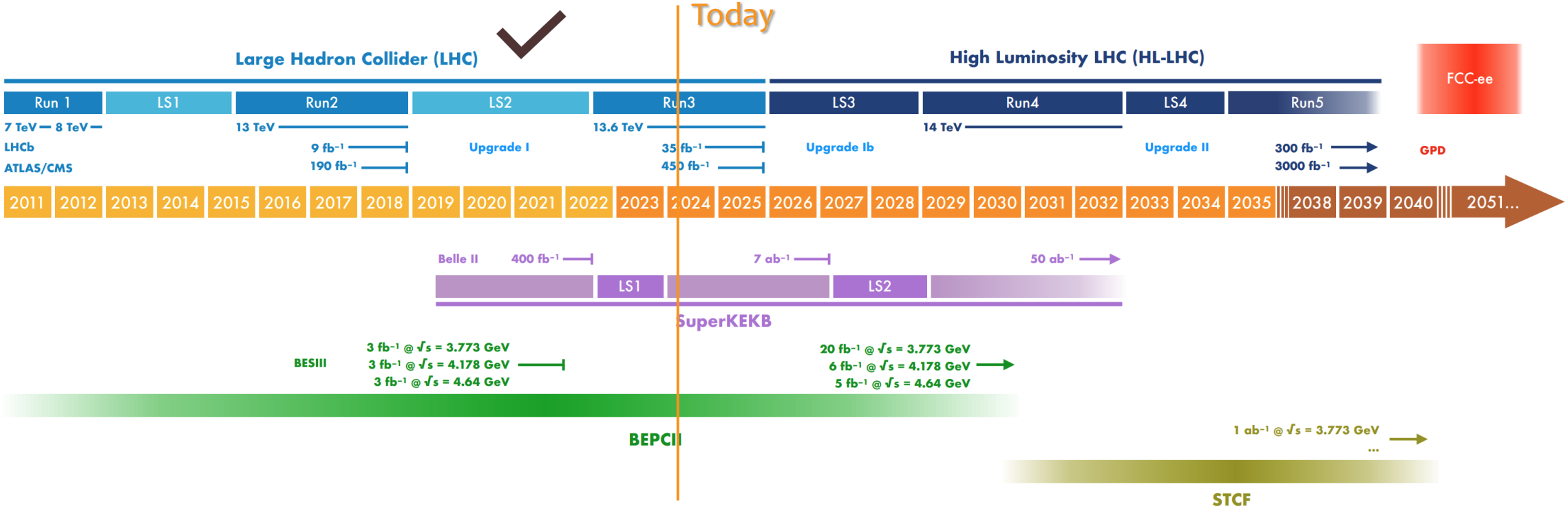
- 6 March: cavern closed
- 11 March: first circulating beam
- 3 April: first stable beams
- 12-25 April: intensity ramp up
- 25 April: start luminosity production

Goal: 120 days (2024) + 140 days (2025)


LHCb pixel Velo


LHCb SciFi

[W. Altmannshofer, F. Archilli, 2206.11331]



Future runs of LHCb

~~Conclusion.~~ Quiz

- **Which quark in B_c^+ decays faster?**

- $B_s^0 \to J/\psi\, 4\pi$ **which charmonium dominates** $J/\psi\, \pi^+\pi^-$ **spectrum?**

- **Give an order of magnitude** $(10^{-2}, 10^{-3}, 10^{-4})$

$$\frac{\mathcal{B}(B^+ \to J/\psi \eta' K^+)}{\mathcal{B}(B^+ \to \psi(2S) K^+)}$$