New results in Λ_b^0 baryon physics at CMS

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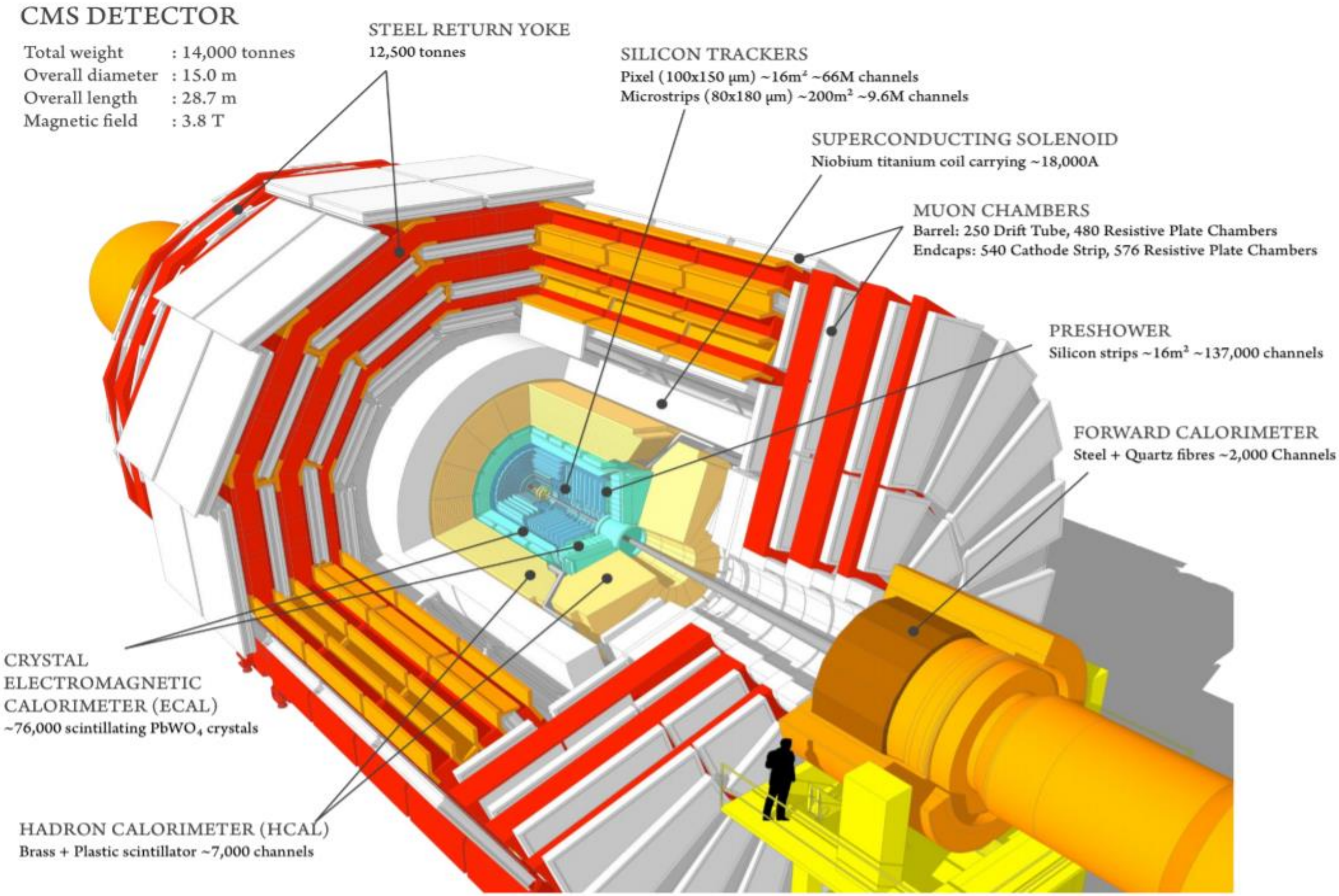
Outline

- CMS experiment
- Study of exited Λ_b^0 baryons in $\Lambda_b^0\pi^+\pi^-$ final state
- Observation of the $\Lambda_b^0 \rightarrow J/\psi\Lambda\phi$ decay
- Summary

CMS experiment

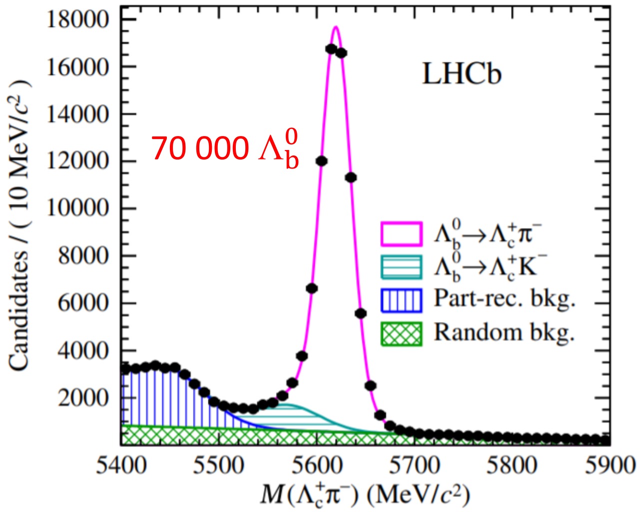


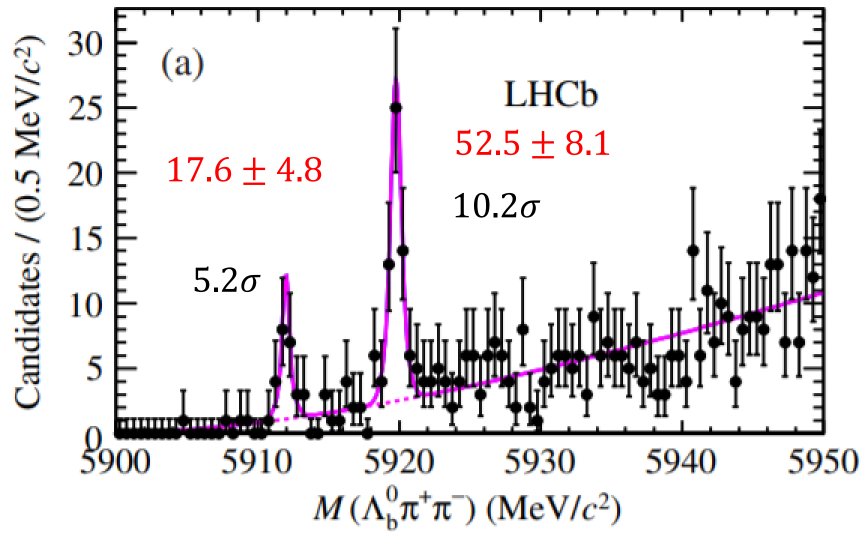
Study of excited Λ_b^0 states decaying to $\Lambda_b^0\pi^+\pi^-$ in proton-proton collisions at $\sqrt{s} = 13$ TeV

[PLB 803 (2020) 135345]

Exited Λ_b^0 baryons: history of studies

In 2012, LHCb Collaboration observed two narrow states in $\Lambda_b^0\pi^+\pi^-$ final state



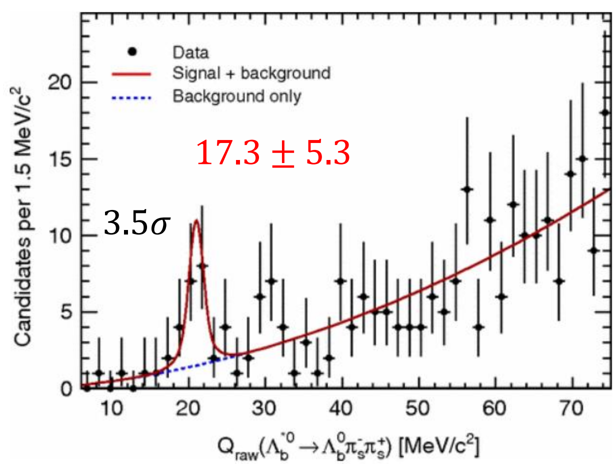


[PRL 109 (2012) 172003](#)

$$M_{\Lambda_b^{*0}(5912)} = 5911.97 \pm 0.12 \pm 0.02 \pm 0.66\ \mathrm{MeV}/c^2$$

$$M_{\Lambda_b^{*0}(5920)} = 5919.77 \pm 0.08 \pm 0.02 \pm 0.66\ \mathrm{MeV}/c^2$$

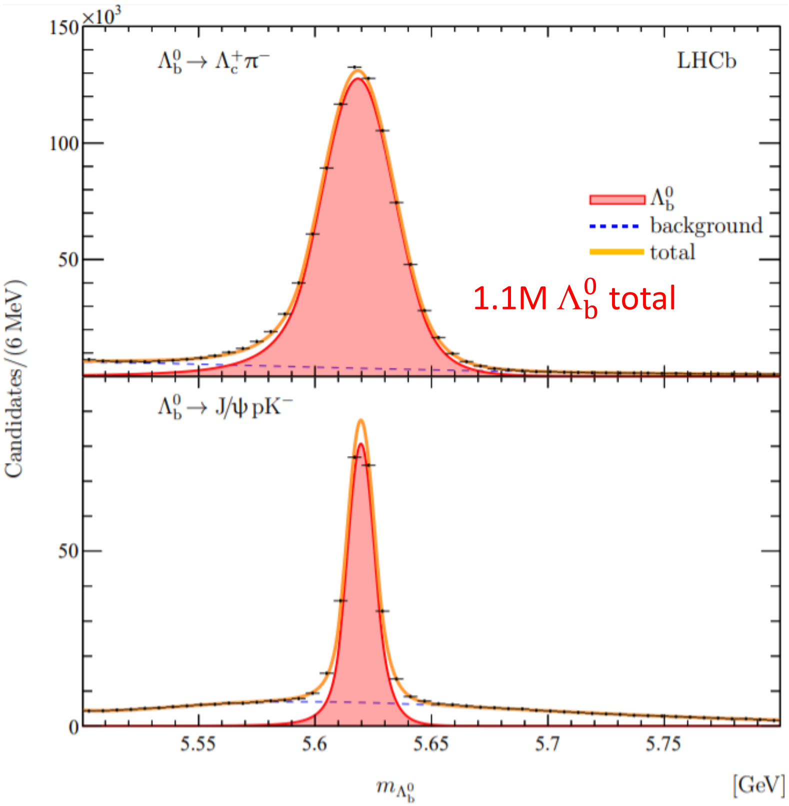
In 2013, CDF Collaboration confirmed only the heavier state with less significance

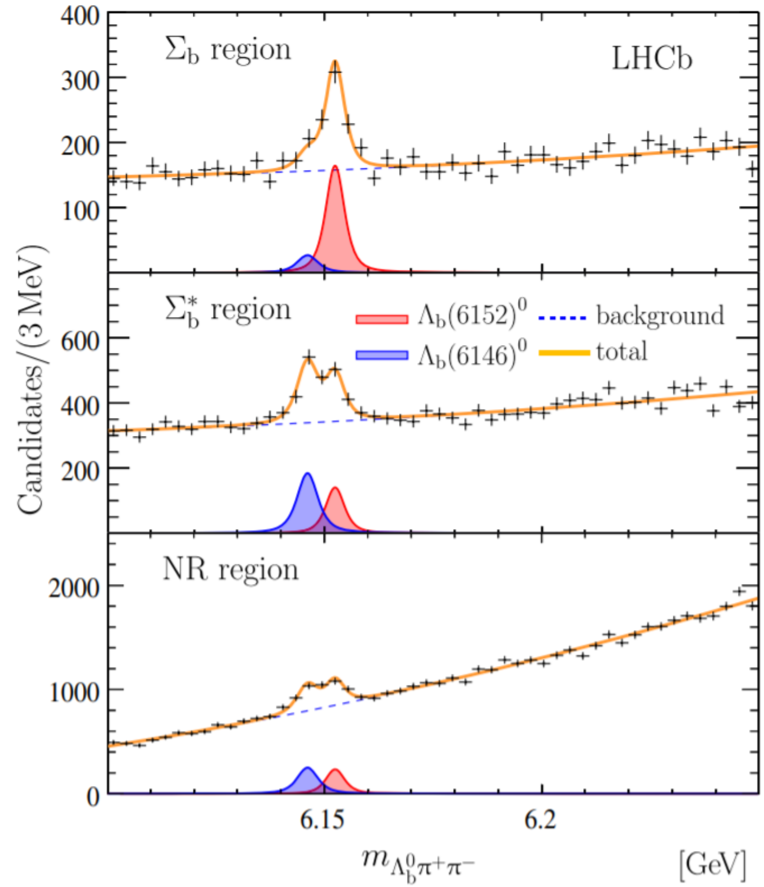


[PRD 88 (2013) 071101](#)

Exited Λ_b^0 baryons: history of studies

In 2019, LHCb Collaboration observed two new exited states in $\Lambda_b^0\pi^+\pi^-$ final state in higher mass region





$$m_{\Lambda_b(6146)^0} = 6146.17 \pm 0.33 \text{ MeV},$$
$$m_{\Lambda_b(6152)^0} = 6152.51 \pm 0.26 \text{ MeV},$$
$$\Gamma_{\Lambda_b(6146)^0} = 2.9 \pm 1.3 \text{ MeV},$$
$$\Gamma_{\Lambda_b(6152)^0} = 2.1 \pm 0.8 \text{ MeV},$$

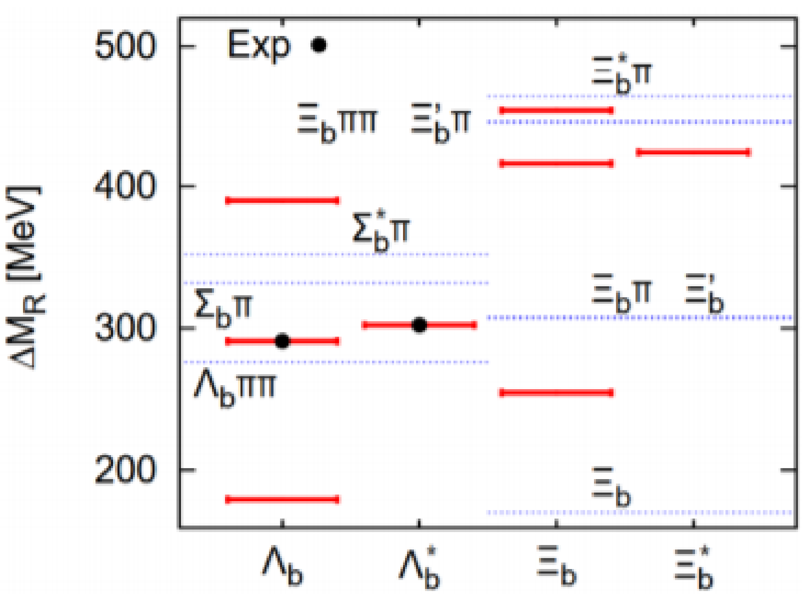
PRL 123 (2019) 152001

Possible interpretation –
a doublet of $\Lambda_b^0(1D)$ states

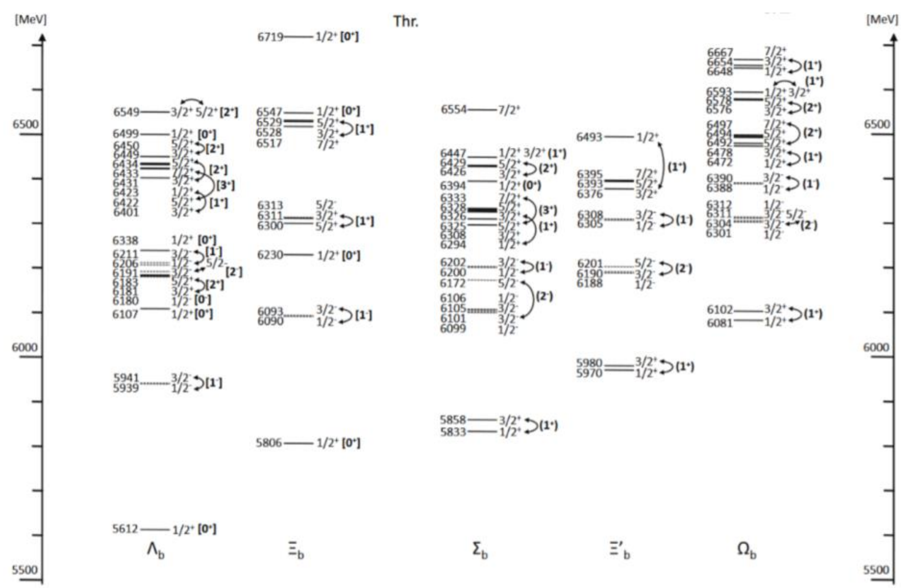
Exited Λ_b^0 baryons: theoretical background

There are many theoretical predictions of excited Λ_b^0 and Σ_b baryons, but the predicted masses are distributed in wide regions and do not point to any particular narrow window to search for a signal.
Some of them are in agreement with LHCb measurements, some do not. (Very often predictions don't have uncertainties, and it is hard to say if they are in agreement with a measurement)

PRD 87 (2013) 034032



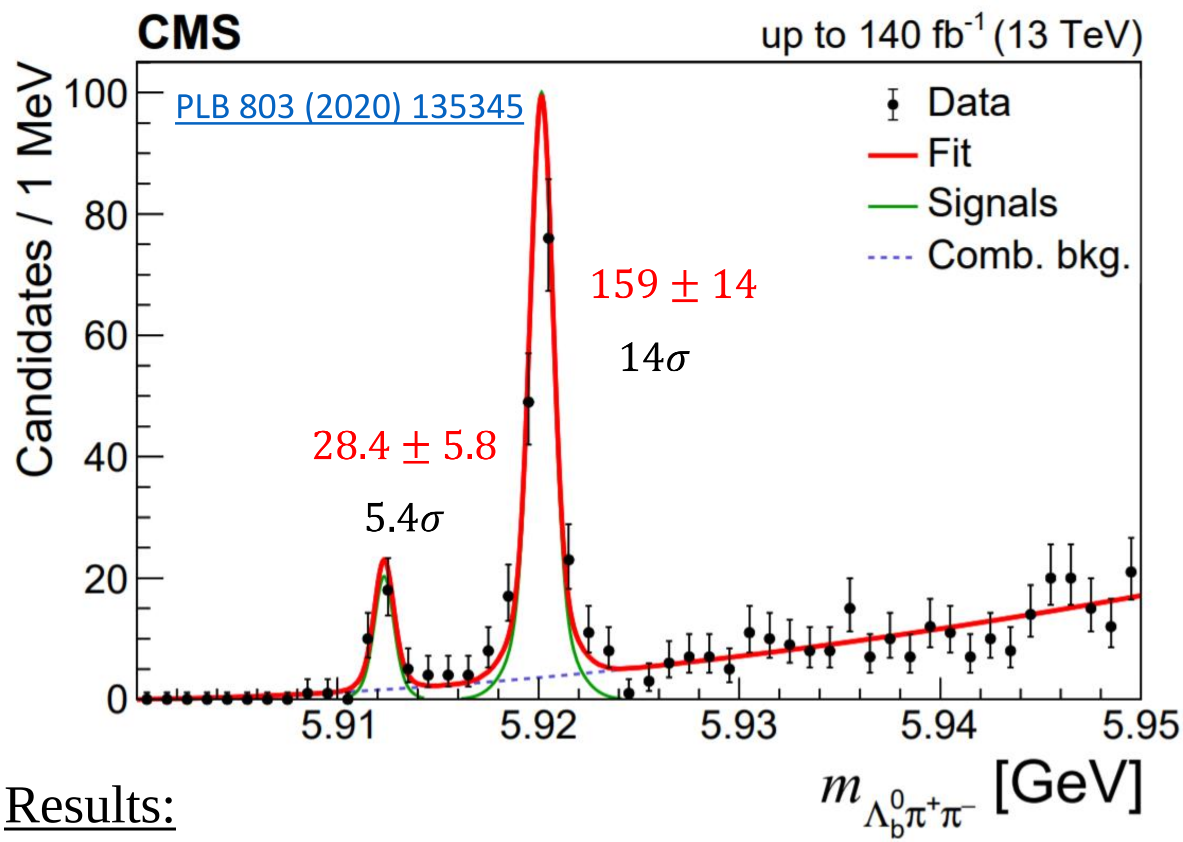
PRD 91 (2015) 034034



Near the threshold $\Lambda_b^0\pi^+\pi^-$ invariant mass distribution

Recently, CMS collaboration performed a study of excited Λ_b^0 baryons based on full Run II data, corresponding to integrated luminosity of 140 fb^{-1}

Since in CMS we cannot use $\Lambda_b^0 \to \Lambda_c^+\pi^-$ channel: no dedicated trigger, no hadron ID, we reconstruct Λ_b^0 baryons in $J/\psi\Lambda$ and $\psi(2S)\Lambda$ final states (~46k Λ_b^0).



2[nd] confirmation of $\Lambda_b^0(5920)$ state, first confirmation of $\Lambda_b^0(5912)$ state, mass measurements

- Signal: 2 DG*
- Background: $(x - x_0)^\alpha$

*DG – Double Gaussian, resolution function fixed from MC

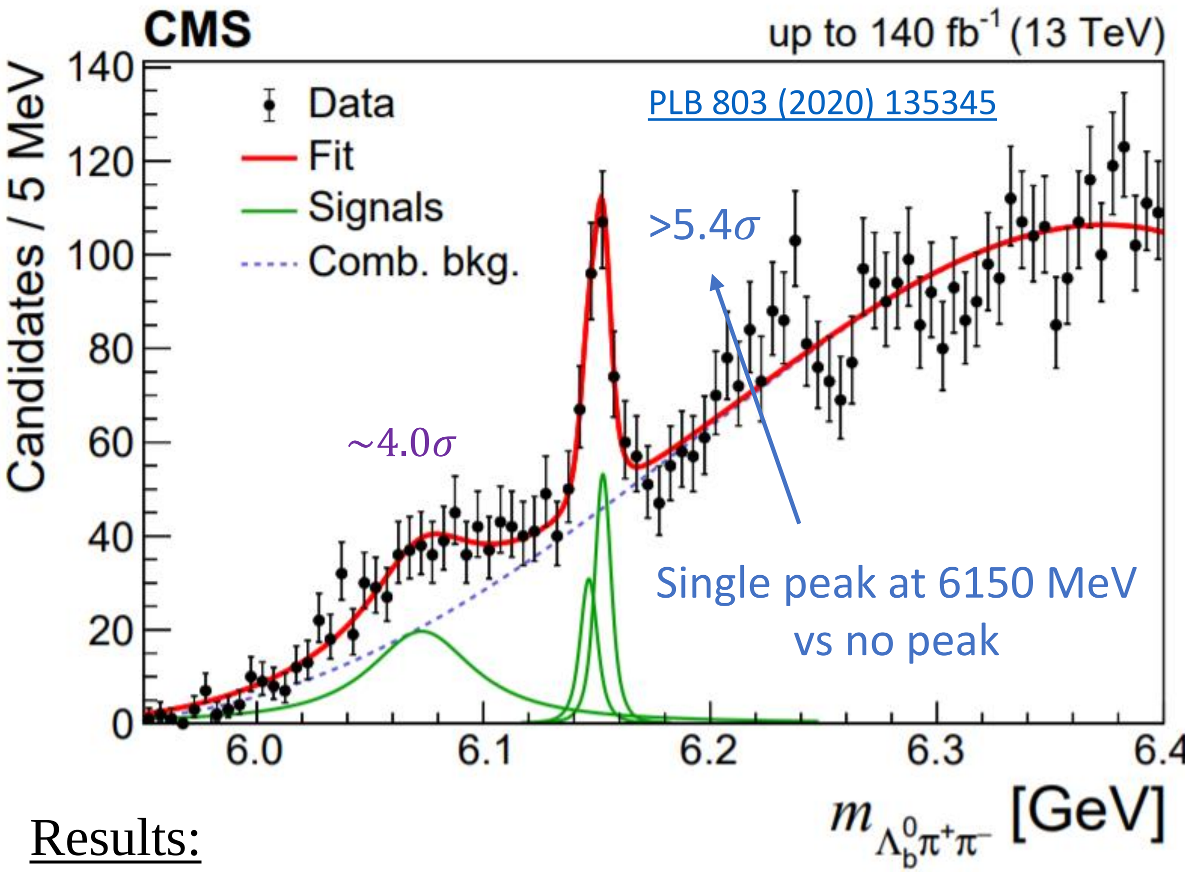
Results:

$M(\Lambda_b^0(5912)) = 5912.32 \pm 0.12 \pm 0.01 \pm 0.17$ MeV

$M\left(\Lambda_b^0(5920)\right) = 5920.16 \pm 0.07 \pm 0.01 \pm 0.17$ MeV

where the 3[rd] uncertainty is the uncertainty in the world-average Λ_b^0 mass value

High mass $\Lambda_b^0\pi^+\pi^-$ distribution



- For $\Lambda_b^0(6146)$: BW convolved with DG (Γ fixed to LHCb)
- For $\Lambda_b^0(6152)$: BW convolved with DG (Γ fixed to LHCb)
- For 6.0-6.1 excess: BW convolved with DG (Γ is free)
- Background: $(x - x_0)^\alpha * \mathrm{Pol1(x)}$

Results:

$\mathrm{N}\left(\Lambda_b^0(6146)\right) = 70 \pm 35$; $M\left(\Lambda_b^0(6146)\right) = 6146.5 \pm 1.9 \pm 0.8 \pm 0.2$ MeV

$\mathrm{N}\left(\Lambda_b^0(6152)\right) = 113 \pm 35$; $M\left(\Lambda_b^0(6152)\right) = 6152.7 \pm 1.1 \pm 0.4 \pm 0.2$ MeV

where the 3rd uncertainty is the uncertainty in the world-average Λ_b^0 mass value

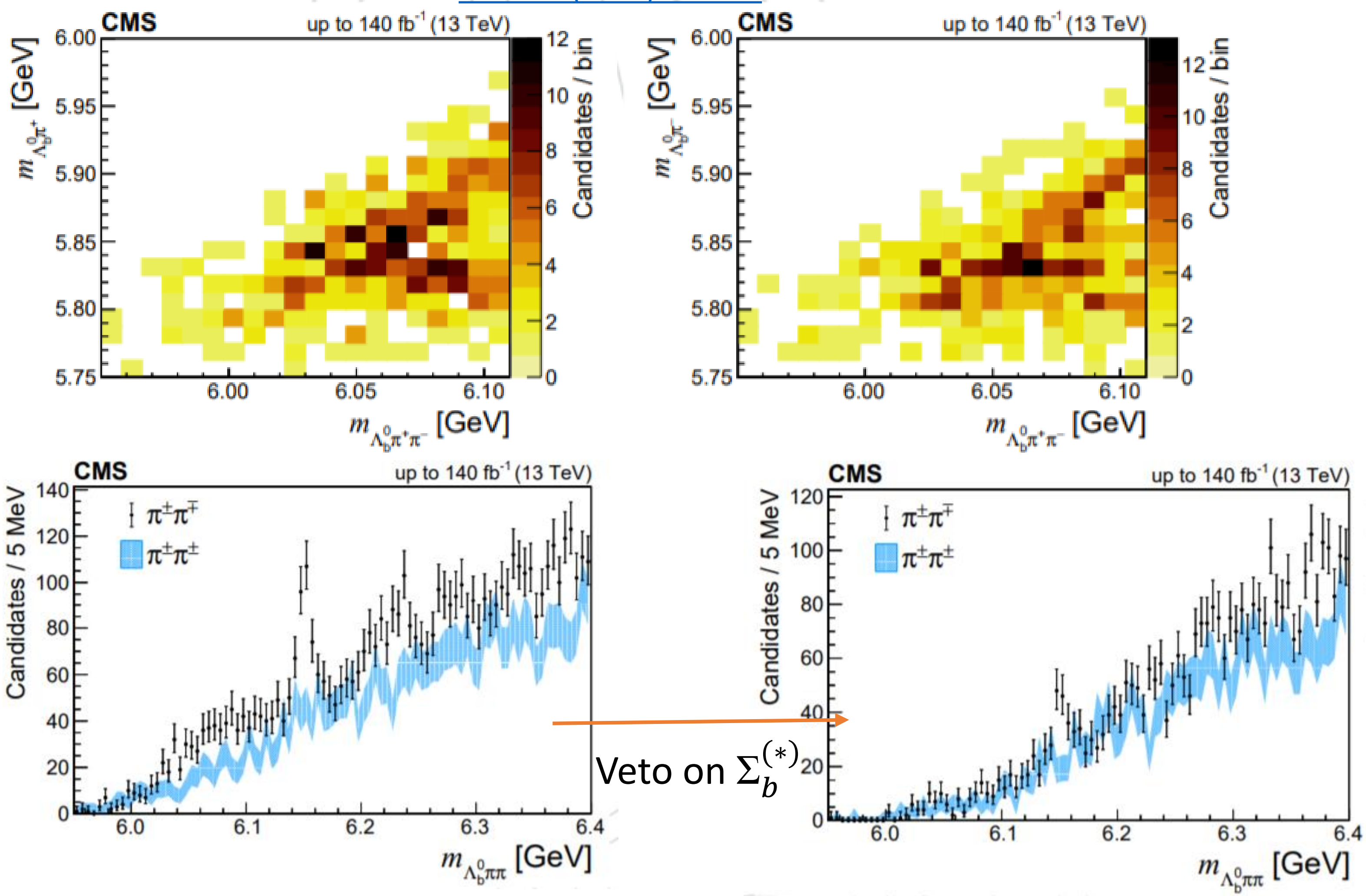
$\mathrm{N}(wide\ peak) = 301 \pm 72$; $M(wide\ peak) = 6073 \pm 5\ (stat.)$ MeV

$\Gamma(wide\ peak) = 55 \pm 11\ (stat.)$ MeV

Additional studies to understand the wide enhancement

- The nature of wide enhancement is still unclear
- The structure disappears in same-sign distribution
- Some correlation between the structure and $\Sigma_b^{(*)}$ is indicated

PLB 803 (2020) 135345



Exited Λ_b^0 baryons: results

- The study of excited Λ_b^0 states decaying to $\Lambda_b^0\pi^+\pi^-$ final state is performed using 2016-2018 data, the ground state is reconstructed in the following channels: $\Lambda_b^0 \to J/\psi\Lambda$ and $\Lambda_b^0 \to \psi(2S)\Lambda$
- CMS confirmed existence of $\Lambda_b^0(5912)$, $\Lambda_b^0(5920)$, $\Lambda_b^0(6146)$ and $\Lambda_b^0(6152)$ states, and the measured masses are in a good agreement with LHCb measurements

$$M(\Lambda_b^0(5912)) = 5912.32 \pm 0.12 \pm 0.01 \pm 0.17 \text{ MeV}$$
$$M\left(\Lambda_b^0(5920)\right) = 5920.16 \pm 0.07 \pm 0.01 \pm 0.17 \text{ MeV}$$
$$M\left(\Lambda_b^0(6146)\right) = 6146.5 \pm 1.9 \pm 0.8 \pm 0.2 \text{ MeV}$$
$$M\left(\Lambda_b^0(6152)\right) = 6152.7 \pm 1.1 \pm 0.4 \pm 0.2 \text{ MeV}$$

where the 3$^{\text{nd}}$ uncertainty is the uncertainty in the world-average Λ_b^0 mass value

- In addition, a broad structure is observed in mass region 6040 – 6100 MeV with a local significance ~4σ

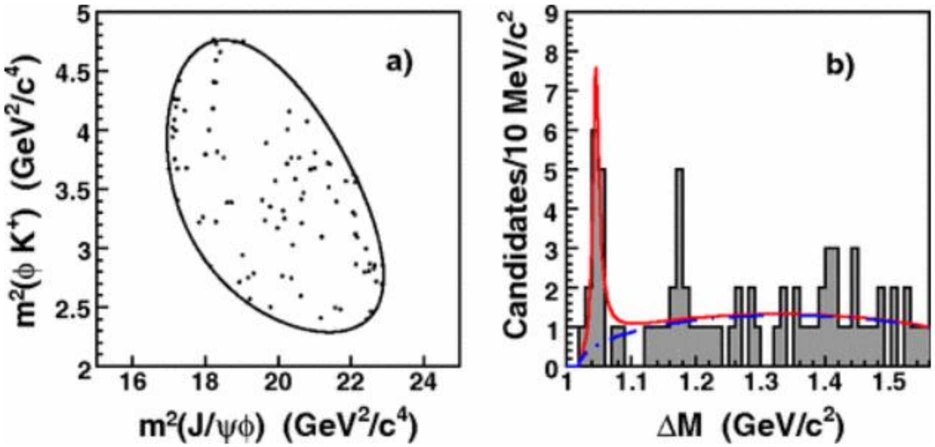
Observation of the $\Lambda_b^0 \to J/\psi\Lambda\phi$ decay in proton-proton at $\sqrt{s} = 13$ TeV

[PLB 802 (2020) 135203]

Observation of the $\Lambda_b^0 \rightarrow J/\psi\Lambda\phi$ decay

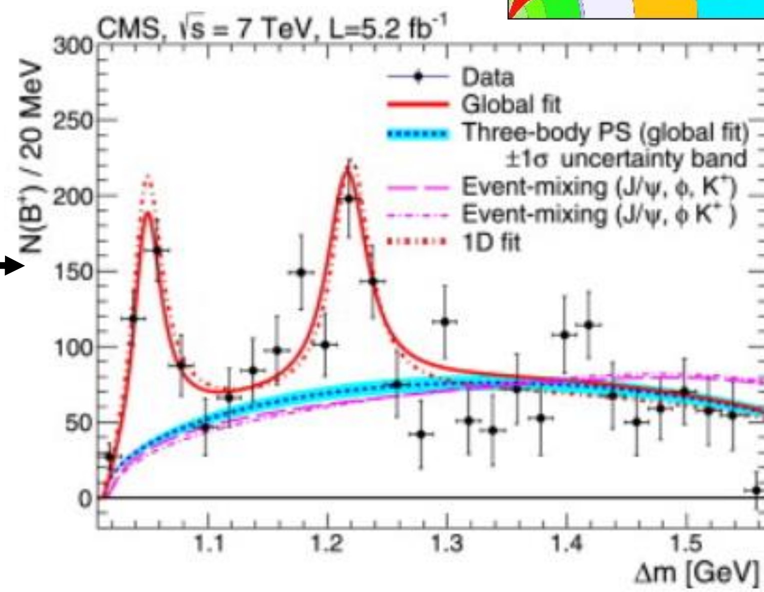
History of $B^+ \rightarrow J/\psi\phi K^+$ studies

PRL 102 (2009) 242002



In 2008 CDF Collaboration found an evidence of a narrow structure X(4140) near the $J/\psi\phi$ threshold in $B^+ \rightarrow J/\psi\phi K^+$ decays

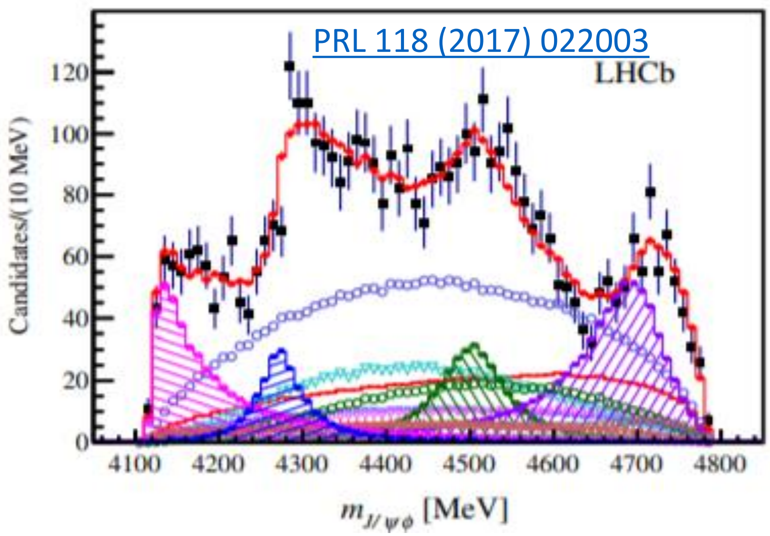
PLB 734 (2014) 261



Then, in 2014 CMS Collaboration presented observation of X(4140) and evidence of X(4274) in the same decay mode.

$$\Delta m = m(\mu^+\mu^- K^+ K^-) - m(\mu^+\mu^-)$$

PRL 118 (2017) 022003



Finally, in 2016 LHCb Collaboration performed full amplitude analysis and observed four exotic states: X(4140), X(4274), X(4500) and X(4700)

Observation of the $\Lambda_b^0 \to J/\psi\Lambda\phi$ decay

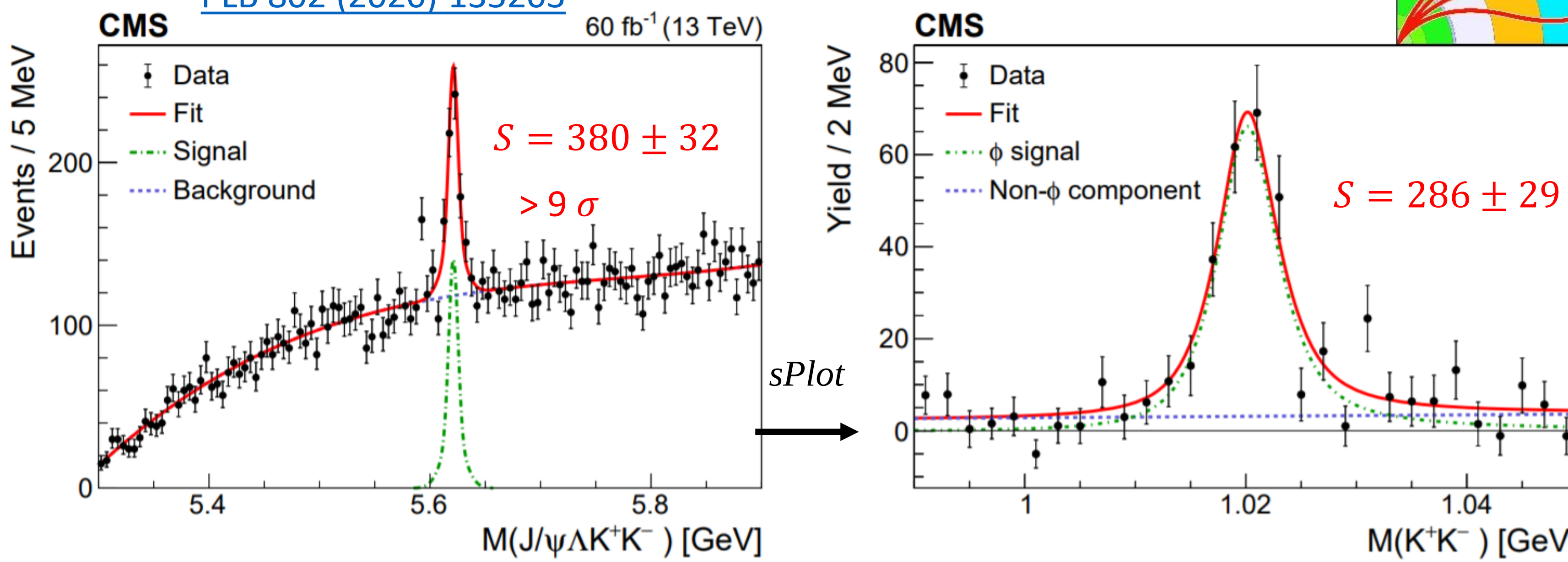
Motivation

- Better understanding final-state strong interactions in b baryons
- The $\Lambda_b^0 \to J/\psi\Lambda\phi$ decay is baryonic analogue of the $B^+ \to J/\psi\phi K^+$ decay and detailed studies of the $J/\psi\phi$ spectrum produced in baryonic decays may provide an important test for the production of observed exotic states
- Also, this decay provides an opportunity to investigate $J/\psi\Lambda$ mass spectrum too, once a sufficient number of signal events is accumulated

Observation of the $\Lambda_b^0 \to J/\psi \Lambda \phi$ decay

The study is based on 2018 13 TeV data (60 fb^{-1})

PLB 802 (2020) 135203

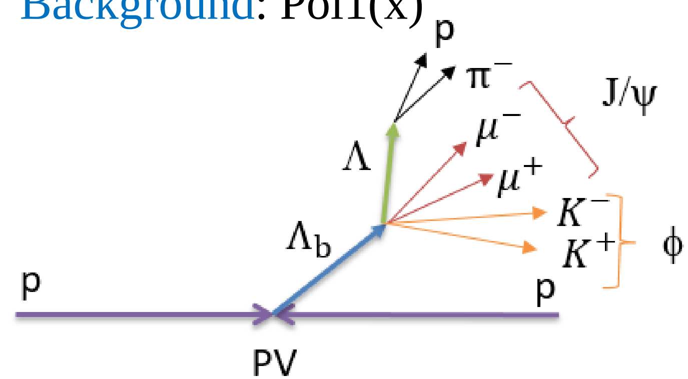


- Signal: DG
- Background: Pol3(x)

- Signal: BW convolved with DG (Γ fixed to PDG)
- Background: Pol1(x)

Unbinned maximum likelihood fit is applied to $J/\psi \Lambda K^+K^-$ invariant mass distribution. Then, *sPlot* technique is used to obtain $M(K^+K^-)$ distribution from signal component. Finally, the $\Lambda_b^0 \to J/\psi \Lambda \phi$ yield is obtained from fit of background-subtracted $M(K^+K^-)$ distribution.

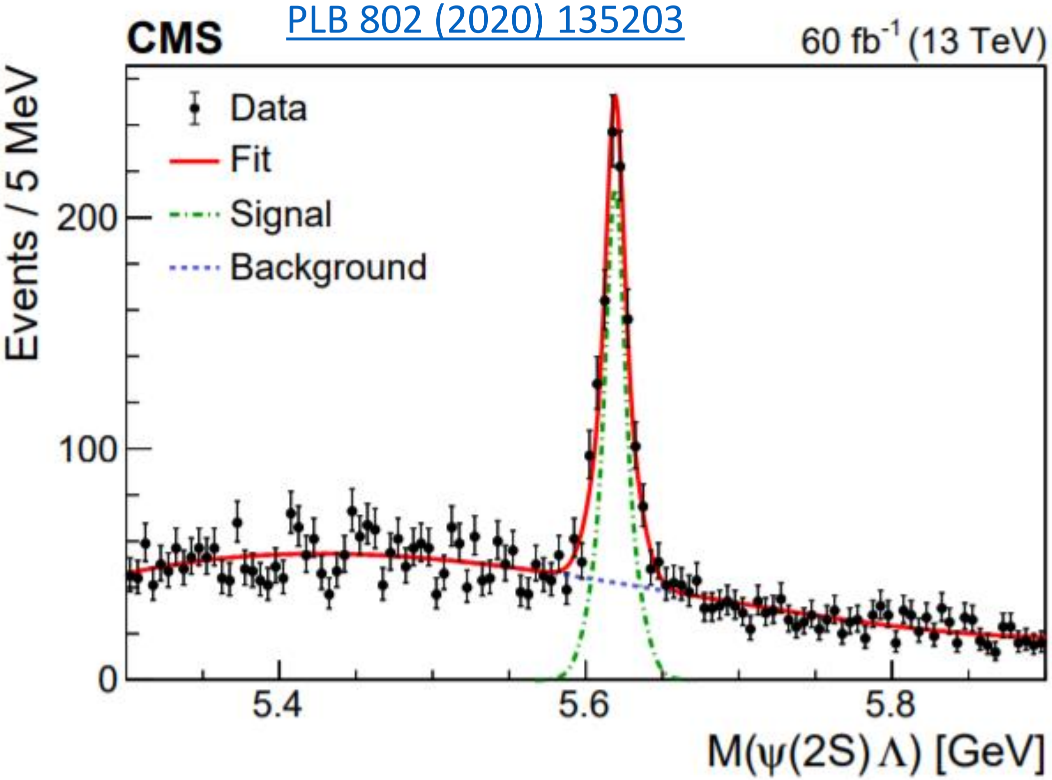
Given the current statistics it is still not possible to investigate the $J/\psi\phi$ and $J/\psi\Lambda$ spectra yet



Topology of the $\Lambda_b^0 \to J/\psi \Lambda \phi$ decay

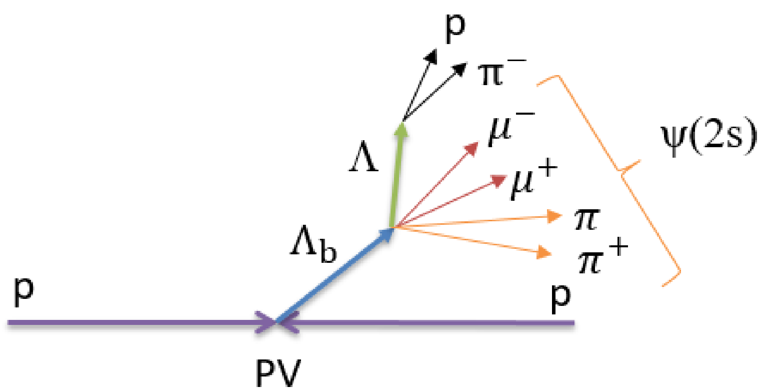
Observation of the $\Lambda_b^0 \to J/\psi\Lambda\phi$ decay

PLB 802 (2020) 135203



- Signal: DG
- Background: Pol3(x)

The $\Lambda_b^0 \to \psi(2S)\Lambda \to J/\psi\pi^+\pi^-\Lambda$ decay was chosen as a normalization channel since it has the same decay topology



The branching fraction ratio is measured to be :

$$\frac{B(\Lambda_b^0 \to J/\psi\Lambda\phi)}{B(\Lambda_b^0 \to \psi(2S)\Lambda)} = \frac{N(\Lambda_b^0 \to J/\psi\Lambda\phi)\,\epsilon(\Lambda_b^0 \to \psi(2S)\Lambda)\,B(\psi(2S) \to J/\psi\pi^+\pi^-)}{N(\Lambda_b^0 \to \psi(2S)\Lambda)\,\epsilon(\Lambda_b^0 \to J/\psi\Lambda\phi)\,B(\phi \to K^+K^-)} =$$
$$= (8.26 \pm 0.90\,(\text{stat.}) \pm 0.68(\text{syst.}) \pm 0.11(\text{br.}))\%$$

Summary

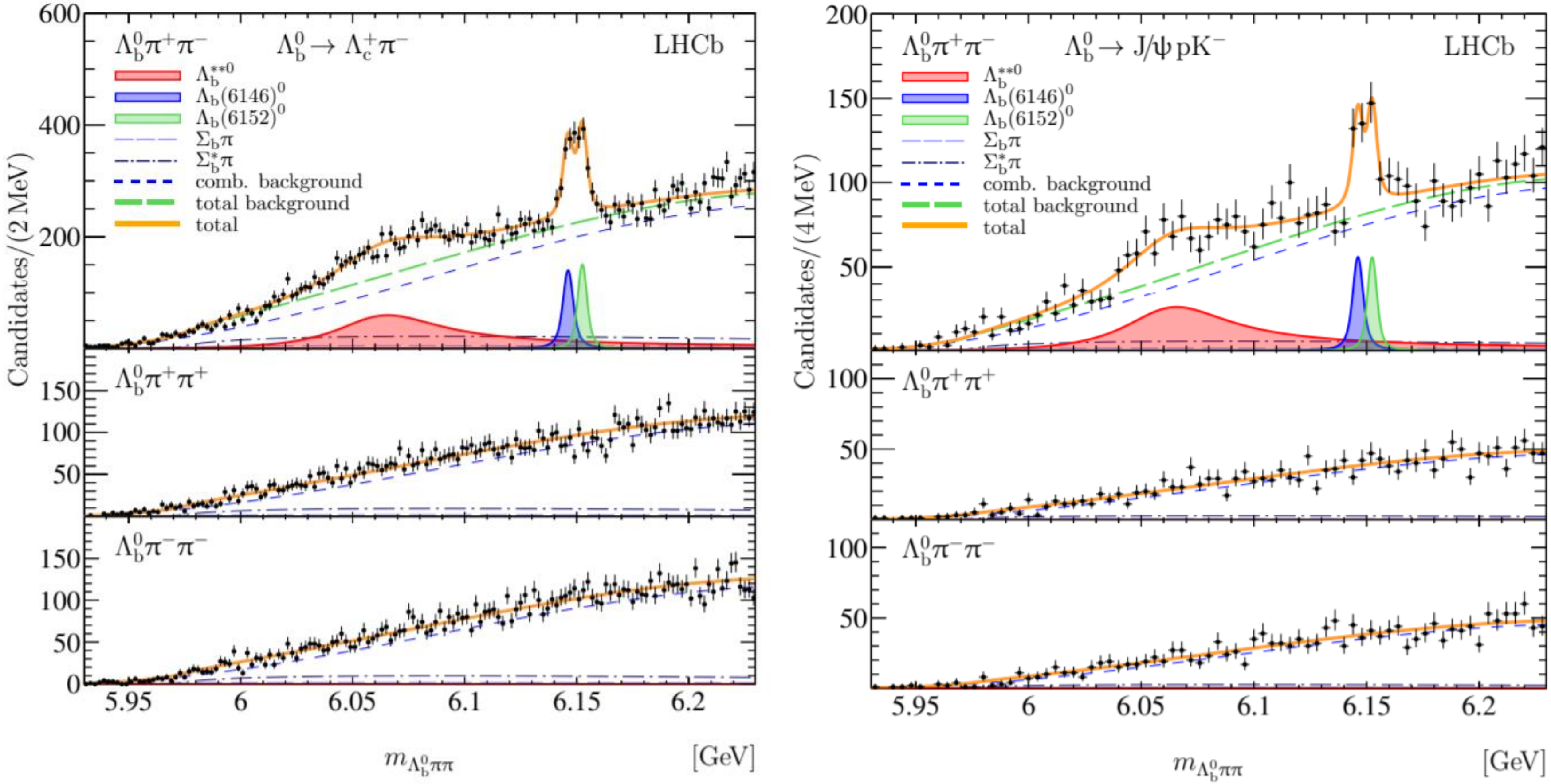
- Excited Λ_b^0 states are studied in the $\Lambda_b^0\pi^+\pi^-$ mass spectrum
  - ✓ Existence of four states, $\Lambda_b^0(5912)$, $\Lambda_b^0(5920)$, $\Lambda_b^0(6146)$ and $\Lambda_b^0(6152)$ is confirmed, and mass measurements are performed
  - ✓ A broad excess of events is observed in the region 6040-6100 MeV, we need more data for understanding the nature
  - ✓Recently, LHCb confirmed existing of the broad structure with more statistical power
- Observation of $\Lambda_b^0 \rightarrow J/\psi\Lambda\phi$ decay
  - ✓ Measurement of $B(\Lambda_b^0 \rightarrow J/\psi\Lambda\phi)/B(\Lambda_b^0 \rightarrow \psi(2S)\Lambda)$

Thank you for attention!

Backup slides

LHCb result on the broad excess

JHEP 136 (2020) 10.1007



$m = 6072.3\ \pm 2.9 \pm 0.6 \pm 0.2$ MeV

$\Gamma = 72 \pm 11 \pm 2$ MeV

Results are in a good agreement with CMS