New results in conventional and exotic spectroscopy at CMS

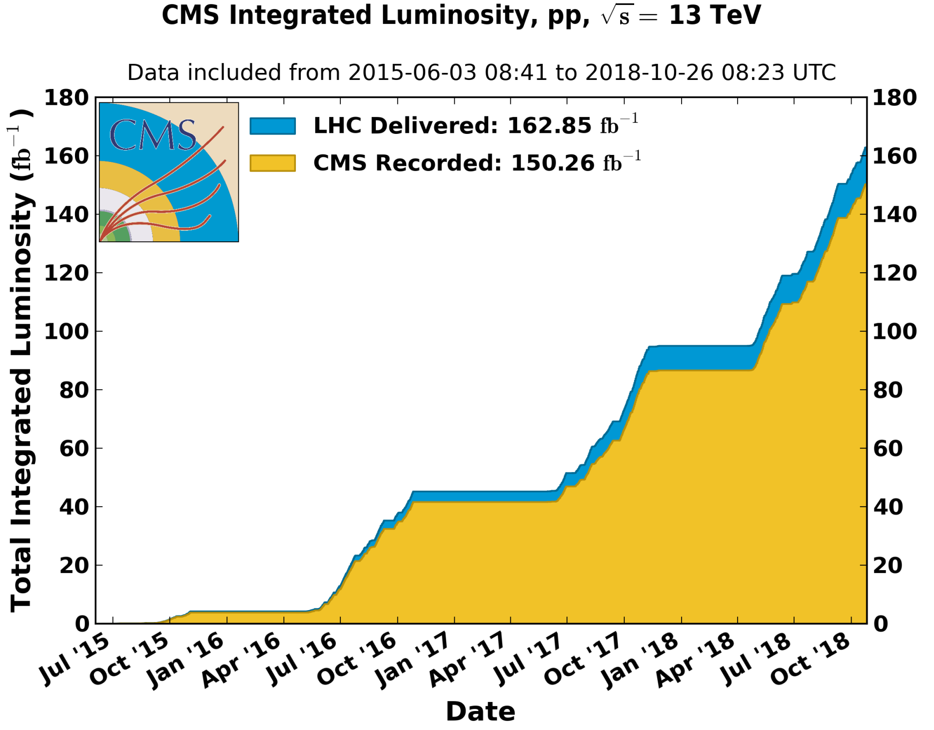
Adriano Di Florio
On Behalf of The CMS Collaboration

New results in conventional and exotic spectroscopy at CMS

- Search for exotic states in the $\Upsilon\mu^+\mu^-$ final state
- Study of the $B^+ \to J/\psi\ \bar{\Lambda}p$ decay
- (udb) spectroscopy: excited Λ_b^0 states
- (c$\bar{b}$) spectroscopy [not in this talk see Mastrapasquas's talk from yesterday]
- X(3872) in pp and heavy ion collisions [not in this talk see Fasanellas's talk just after this]

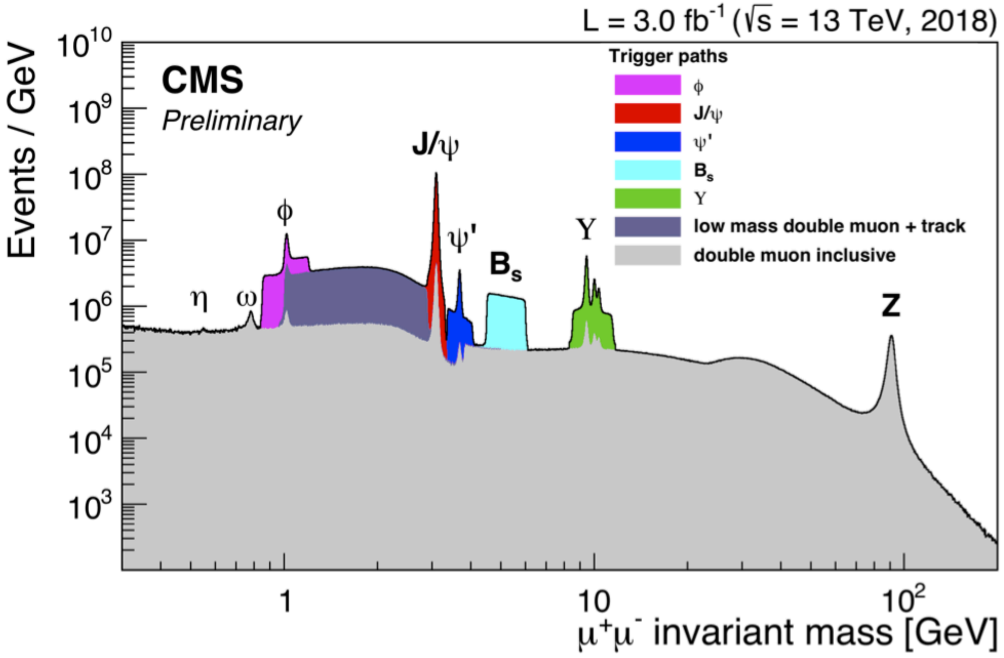
Compact Muon Solenoid

The CMS experiment has recorded 150 fb^{-1} at 13 TeV of data of which ~143 fb^{-1} have been certified for physics



Tracking system

- Good p_T **resolution** (down to $\Delta p_T/p_T \approx 0.01$ in barrel)
- Tracking efficiency >99% for central muons
- Good vertex reconstruction & impact parameter resolution O(μm)



Muon system

- Muon candidates reconstructed by matching muon segments and a silicon track in a large rapidity coverage ($|\eta|$<2.4)
- Good dimuon mass resolution ($|\eta|$ dependent):

$$\Delta M/M \sim 0.6 \div 1.5\% \longrightarrow \Delta M(J/\psi) \approx (20 \div 70) MeV$$

- Excellent muon-ID: $\varepsilon(\mu | \pi, K, p) \leq (0.1 \div 0.2)\%$

Search for exotic states decaying into $\Upsilon\mu^+\mu^-$

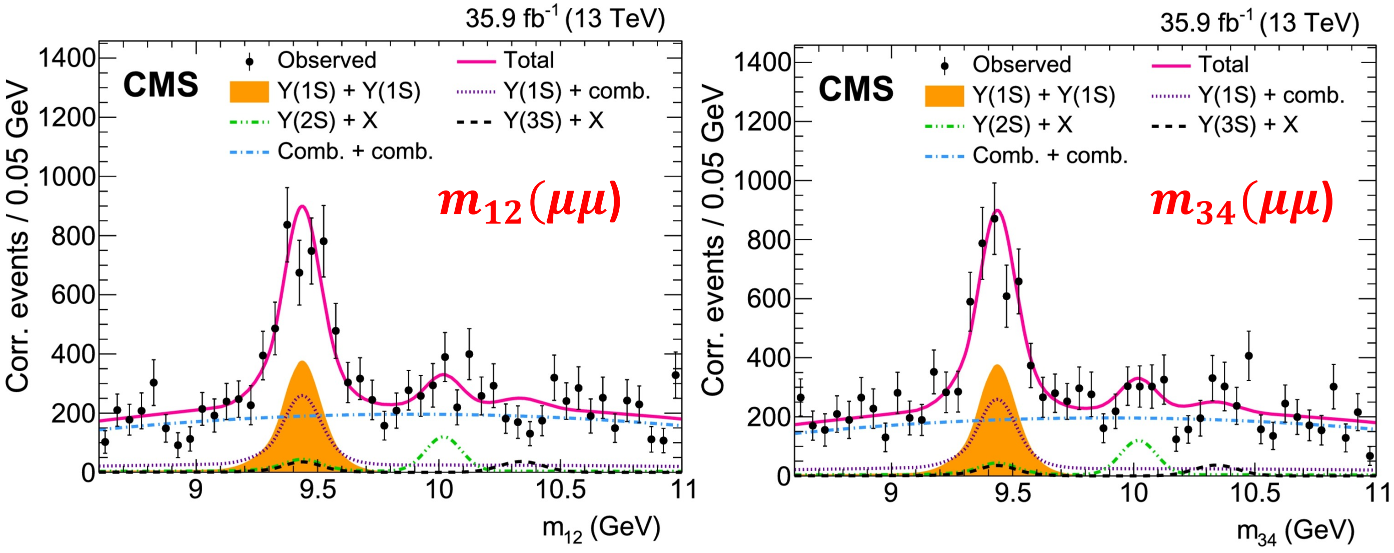
Phys. Lett. B 808 (2020) 135578

Searches for exotic resonances in $\Upsilon(1S)\mu\mu$

The existence of an heavy bottom tetraquark $[bb\bar{b}\bar{b}]$ is predicted by few theoretical models [1] [close to $2M(\eta_b)$ or $2M(\Upsilon(1S))$)

CMS presented a measurement of the $\Upsilon(1S)$ pair production cross section at $\sqrt{s} = 13$ TeV in PLB808(2020)135578 using 2016 pp collision data ($35.9 fb^{-1}$). This process may serve as a **standard reference** in a search for 4-quarks decaying to $\Upsilon(1S)\mu\mu$. Since the final state is the same and the event selection is similar.

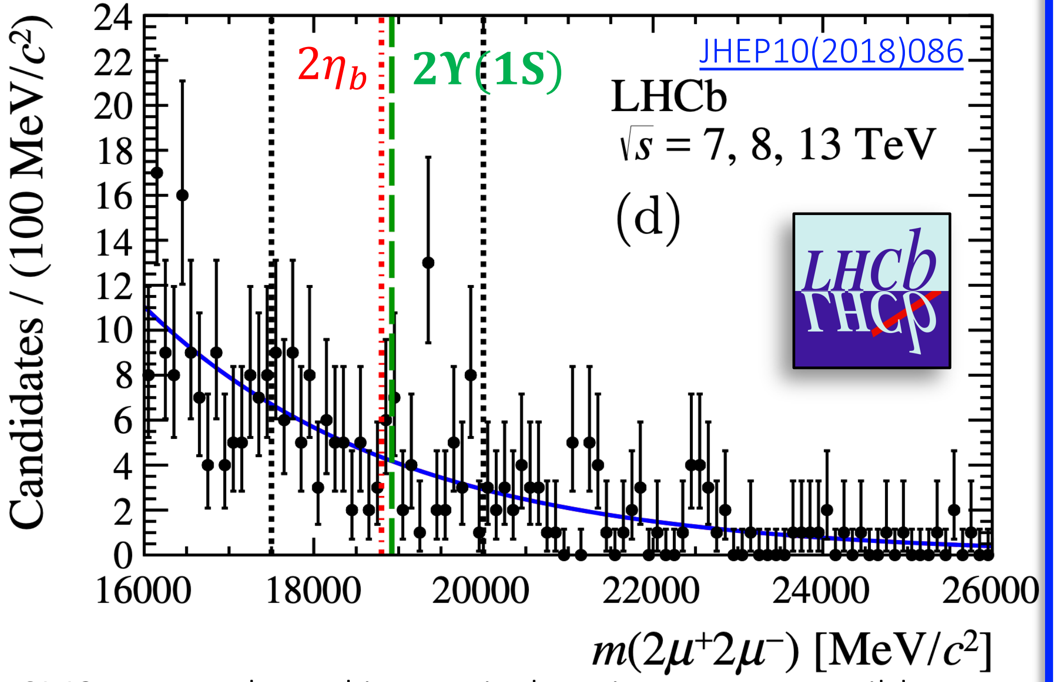
4μ events are selected with $p_T(\mu) > 2.5\text{GeV}$ and $P_{vtx}(4\mu) > 0.05$ and if any **OS** muon pair is **compatible with** J/ψ the event is discarded.



To improve the mass resolution, the mass difference is used:

$$\widetilde{m}_{4\mu} = m_{4\mu} - m_{\mu\mu} + m_{\Upsilon(1S)}$$

LHCb searched for $bb\bar{b}\bar{b}$ tetraquarks using data collected at $\sqrt{s} = 7; 8; 13$ TeV: no hint



CMS can probe a kinematical region not accessible at LHCb where **both** Υ can be reconstructed more efficiently

[1] Y.Chen *et al.*, PLB 705 (2013) 93 ; A.V. Berezhnoy *et al.*, PRD 86 (2012) 034004

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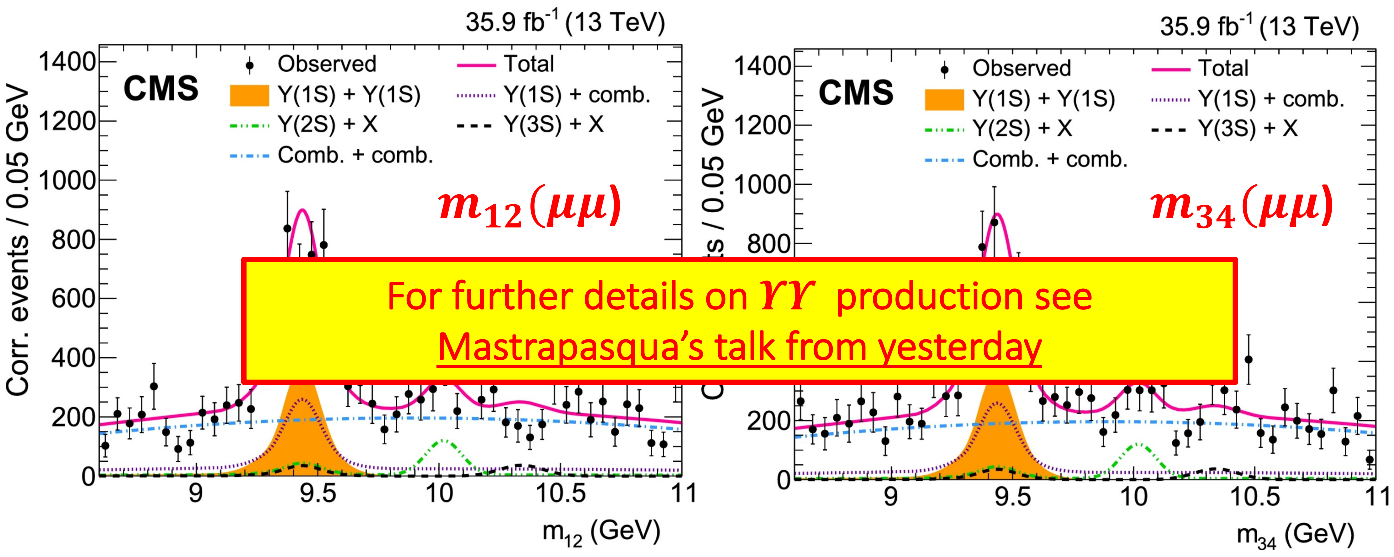

For further details on $\Upsilon\Upsilon$ production see Mastrapasqua's talk from yesterday

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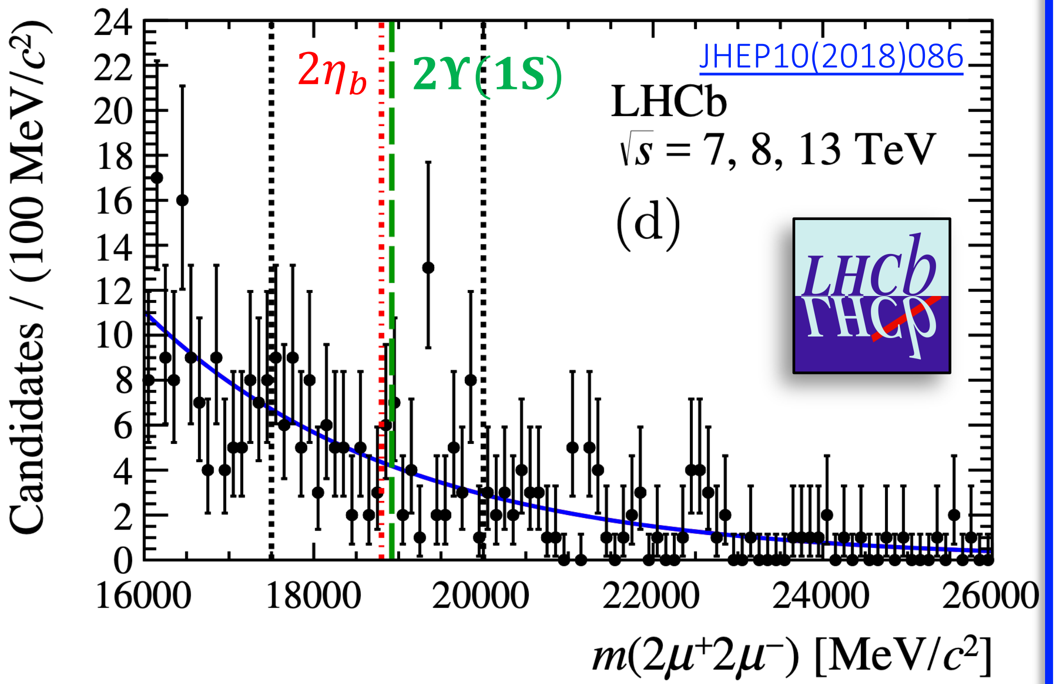

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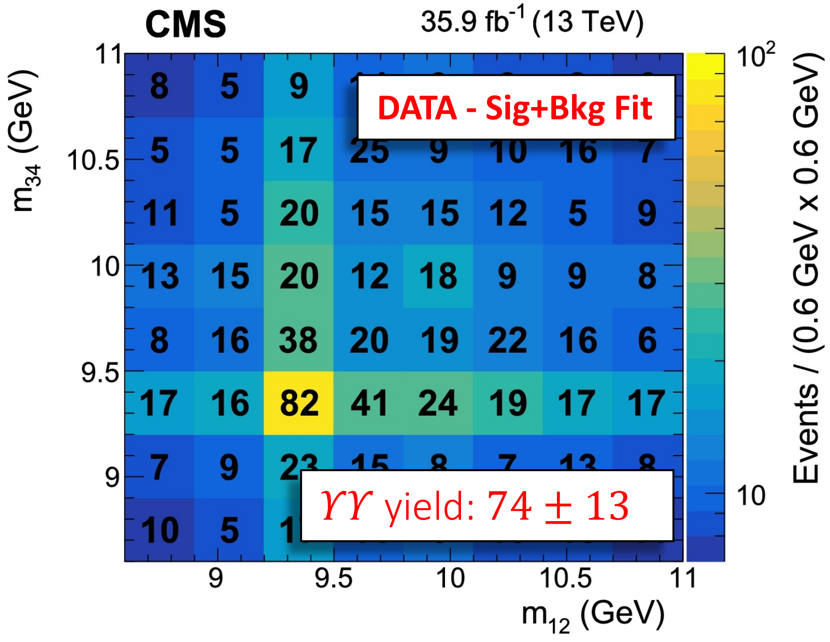
Background Sources for $\Upsilon(1S)\mu\mu$



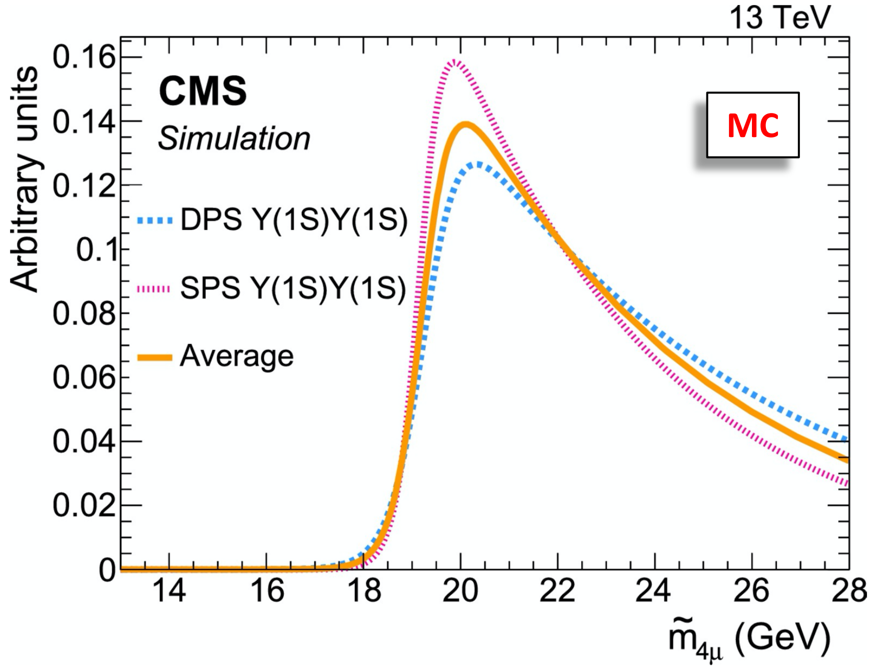
$\Upsilon\Upsilon$ Background

The **shape** is estimated from simulations averaging SPS and DPS contributions using

$$f_{DPS} = 0.39 \pm 0.14$$

estimated in the cross section measurement. The **yield** is extracted from data asking for the mass of a dimuon pair:

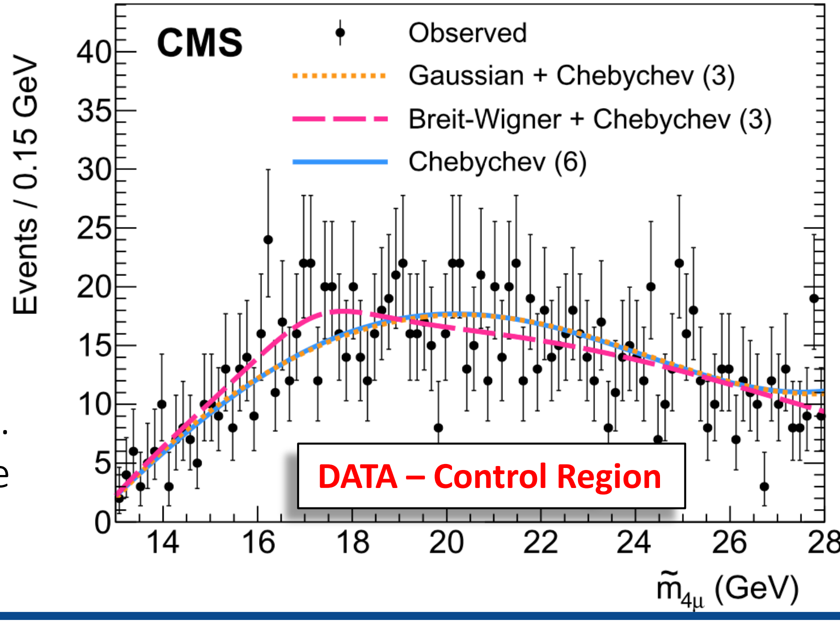
$$|m_{12/34} - \Upsilon(1S)| < 2\sigma$$



Combinatorial Background

Obtained fitting data in the signal region with three possible functions

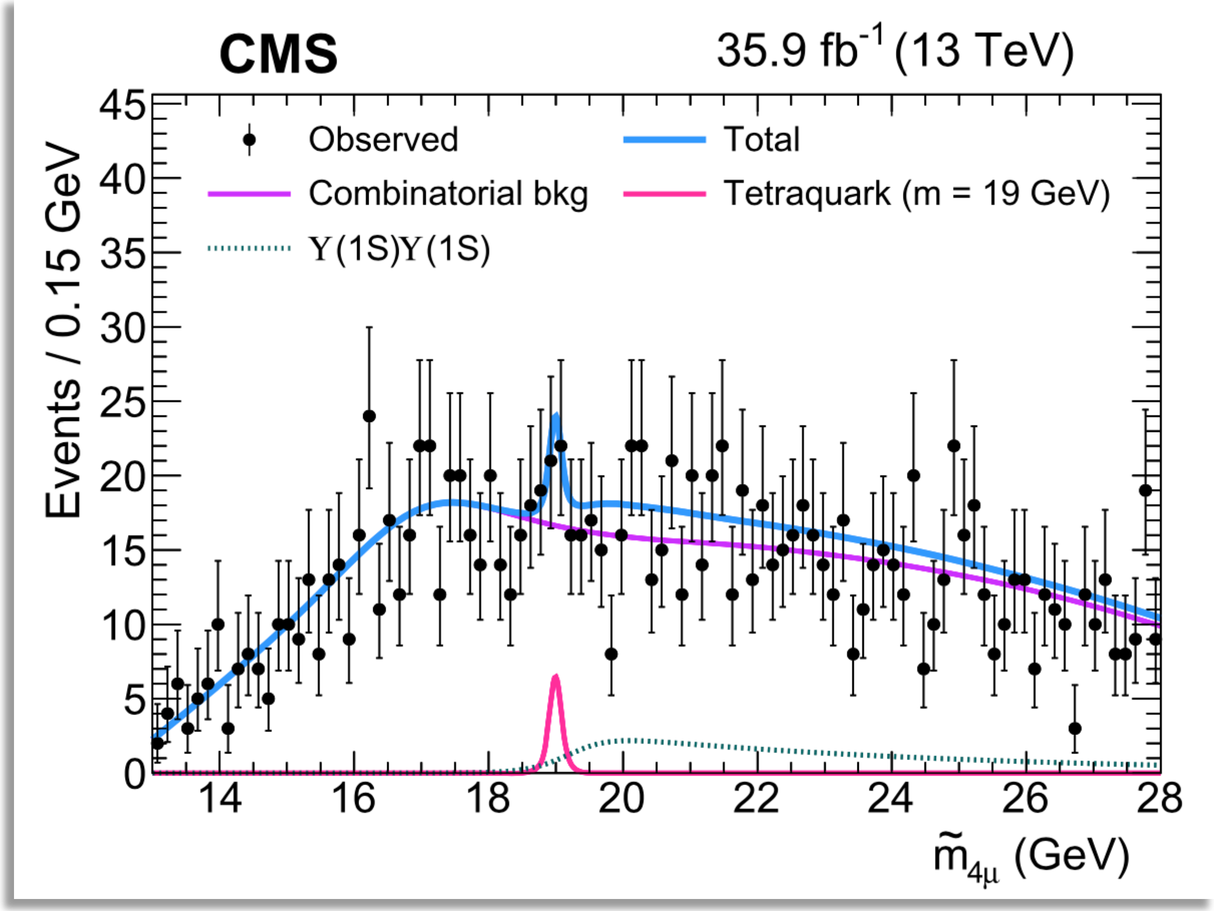
- Gaussian + 3rd Chebychev
- Breit-Wigner + 3rd Chebychev
- 6th Chebychev



which behaviour and χ^2_{fit} is checked in a control region where $10^{-10} < \chi^2_{4\text{vtx}} < 10^{-3}$. In the signal region the **parameters** and the **choice of the functional form** of the combinatoria background are **freely floating**.

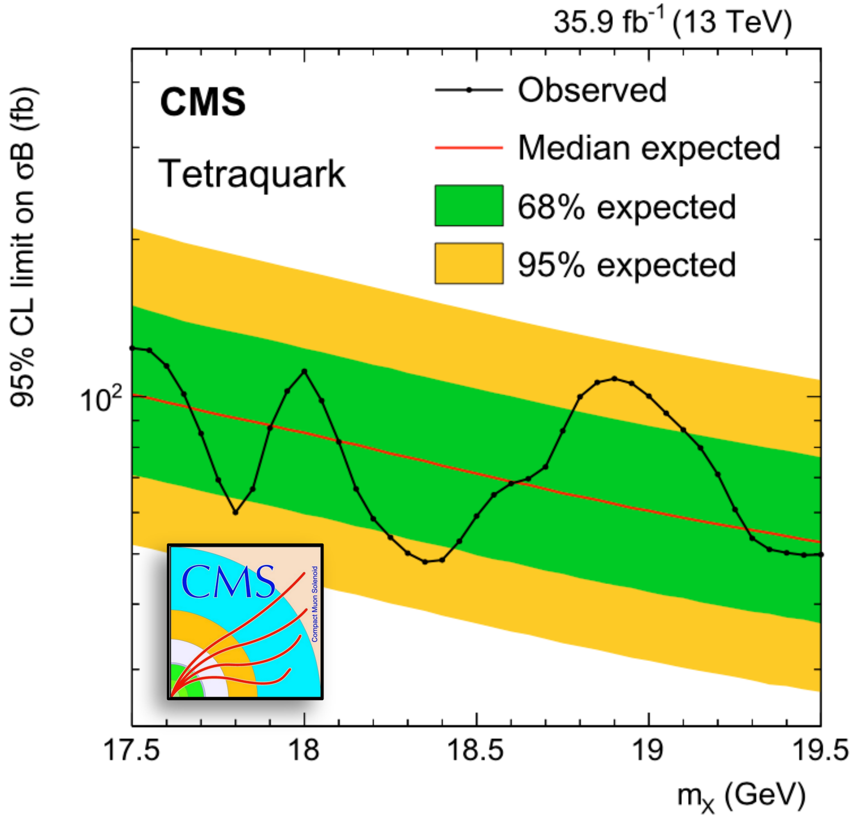
Tetraquark Searches

Observed distribution does not show any unexpected peak



The existence of an heavy bottom tetraquark is checked in a mass window between 17.5÷19.5 GeV (namely around 4 times the mass of the bottom quark). A mass-dependent **upper limit** is set on

$$\sigma_{pp\to X}\times\mathcal{B}(X\to\Upsilon(1S)\mu\mu\to 4\mu)$$

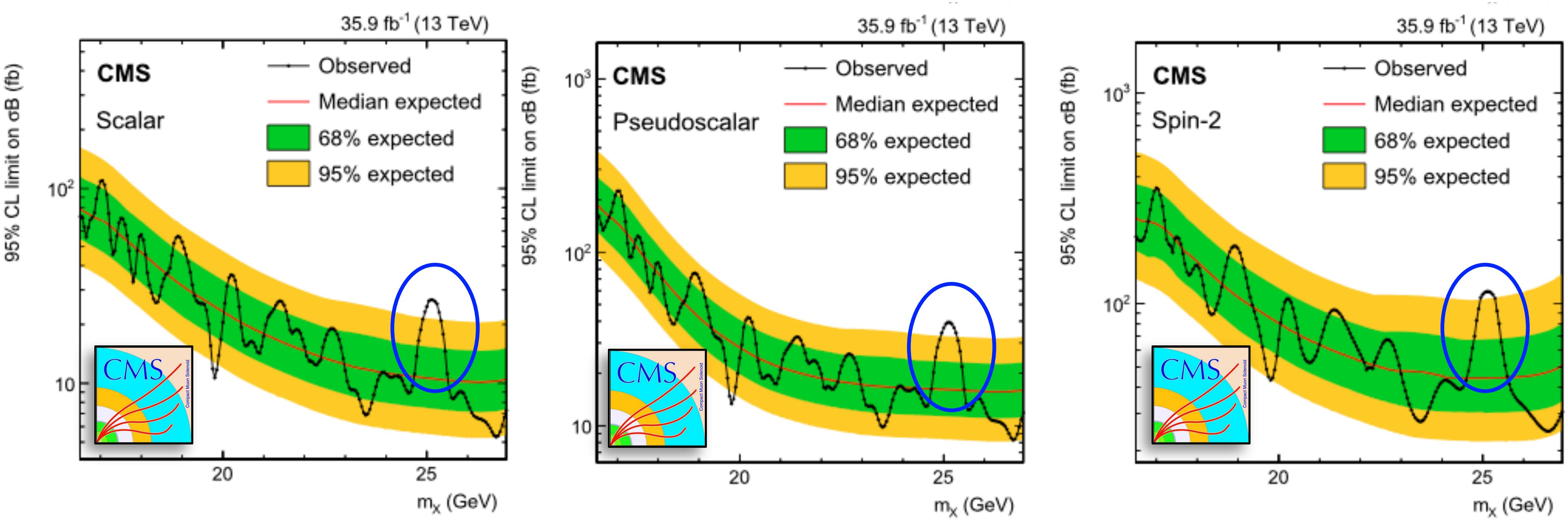


N.B. using the number of $\Upsilon(1S)\Upsilon(1S)$ events observed in data as a reference, a resonance with a mass at ~19GeV and having a similar production **cross-section**, $\boldsymbol{\mathcal{B}}\,(\rightarrow \mathbf{4\mu})$ and **kinematic distributions** as the $\Upsilon(1S)\Upsilon(1S)$ production, would produce ~100 candidates.

Generic Searches

A **generic search** for narrow resonances **(scalar, pseudoscalar, tensor produced in gluon fusion)** decaying to $\Upsilon(1S)\mu\mu$ is performed in an extended mass window $[16.5 \div 27.0\ \mathrm{GeV}]$ and is probed using the **JHUGEN** models.

Upper limits range between $5 \div 380$ pb depending on the mass and signal model chosen. **The largest excess is observed around** $25.1\ \mathrm{GeV}$ **with a local statistical significance of** 2.4σ



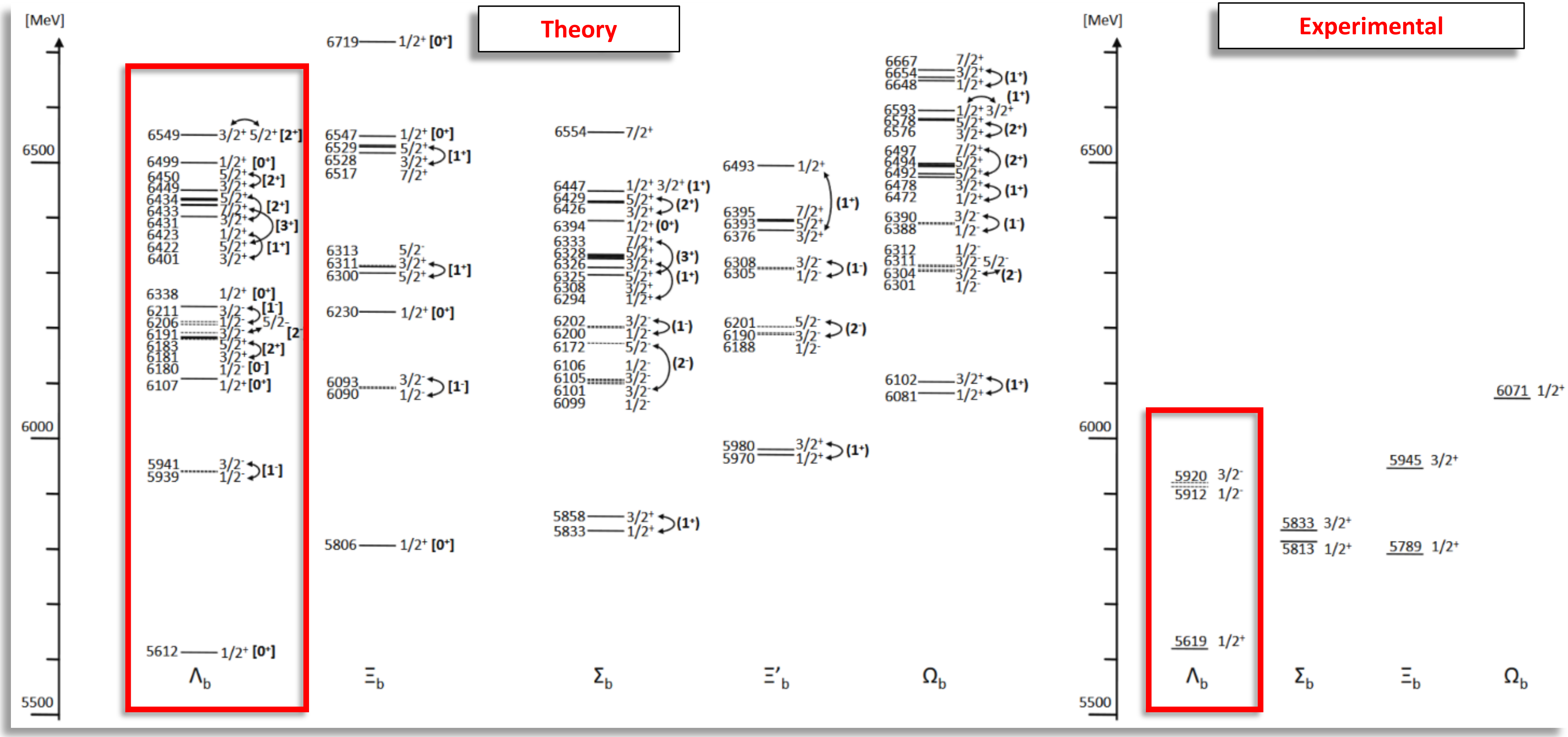
These searches should be performed again with full Run-II data

(udb) spectroscopy : excited Λ_b^0 states

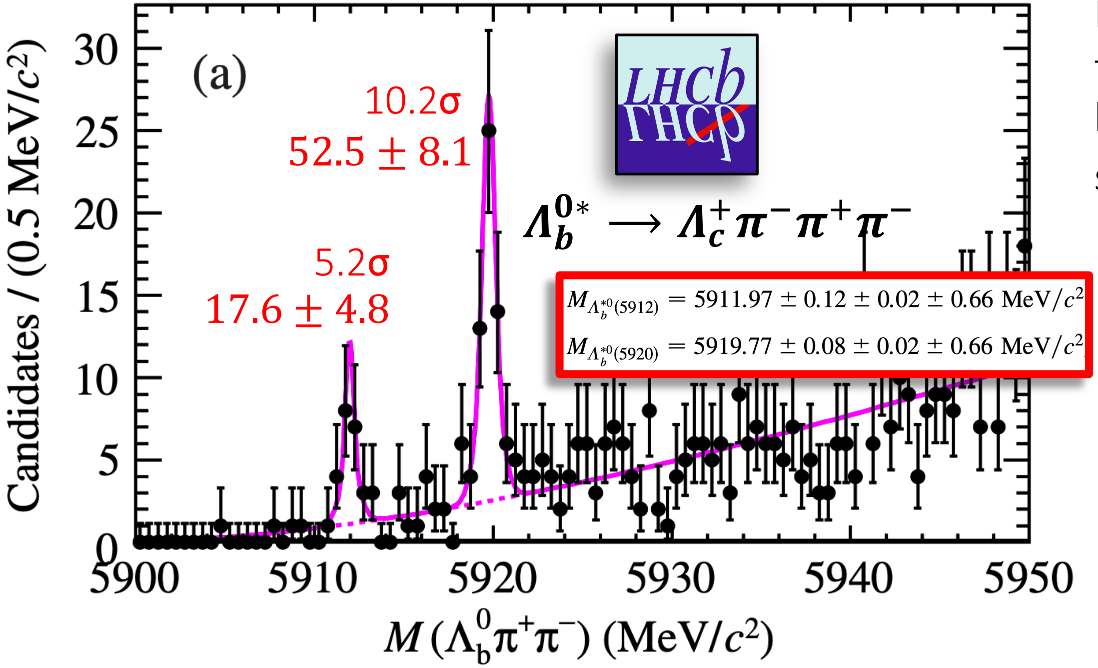
Phys. Lett. B 803 (2020) 135345

Introduction to Λ_b^0 excited states

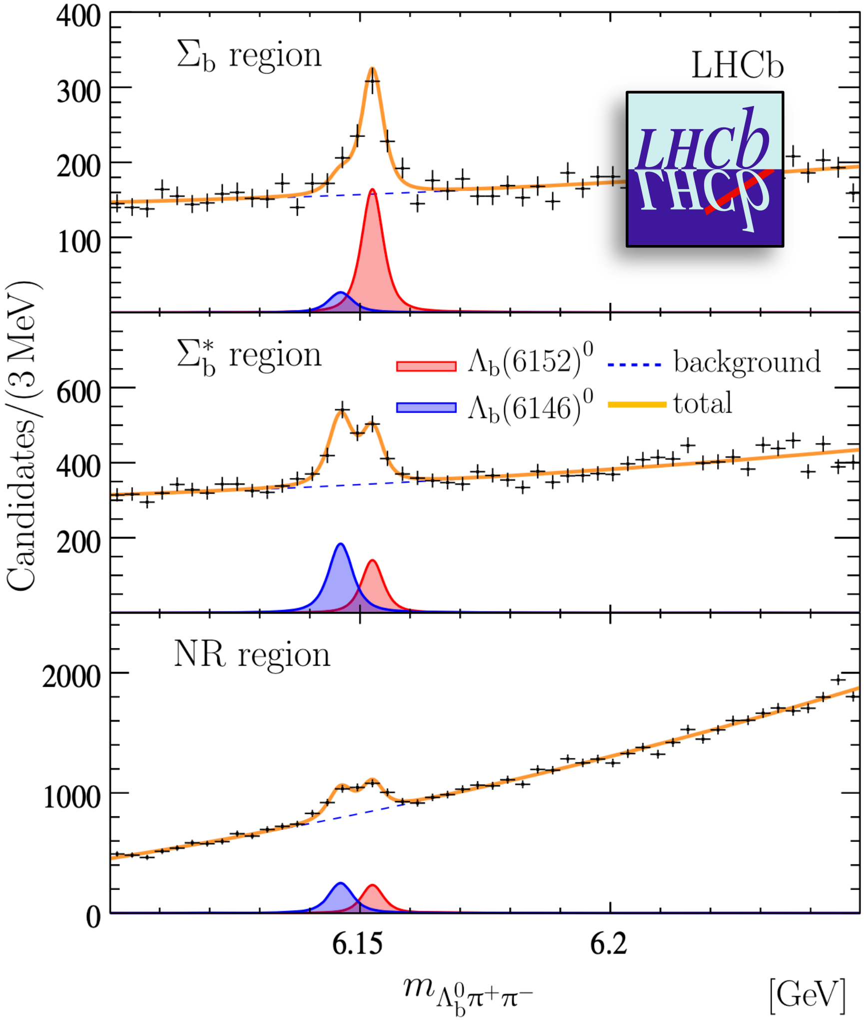
Studies of excited heavy baryon spectrum **are an important test** of Heavy Quark Effective Theory. There are **many theoretical predictions** of excited Λ_b and Σ_b states, but the predicted masses are spread in rather wide regions and **do not** point to **any narrow window** to search for a signal.



Introduction to Λ_b^0 excited states – LHCb first results



In PhysRevLett.109.172003 LHCb (2012)using $1fb^{-1}$ of 2011 data observed for the first time excited $\Lambda_b^{0*} \longrightarrow \Lambda_b^0\pi^+\pi^-$ using $\Lambda_b^0 \longrightarrow \Lambda_c^+\pi^-$ channel. Shortly later, in PhysRevD.88.071101 CDF (2013): confirmed **only the higher mass** state $\Lambda_b(5920)^0 \longrightarrow \Lambda_b^0\pi^+\pi^-$ with a significance of 3.5σ (see backup)



In 2019 in PRL 123 (2019) 152001 LHCb **using full Run-I+II dataset observed two new excited states decaying to $\Lambda_b^0\pi^+\pi^-$ final state:**

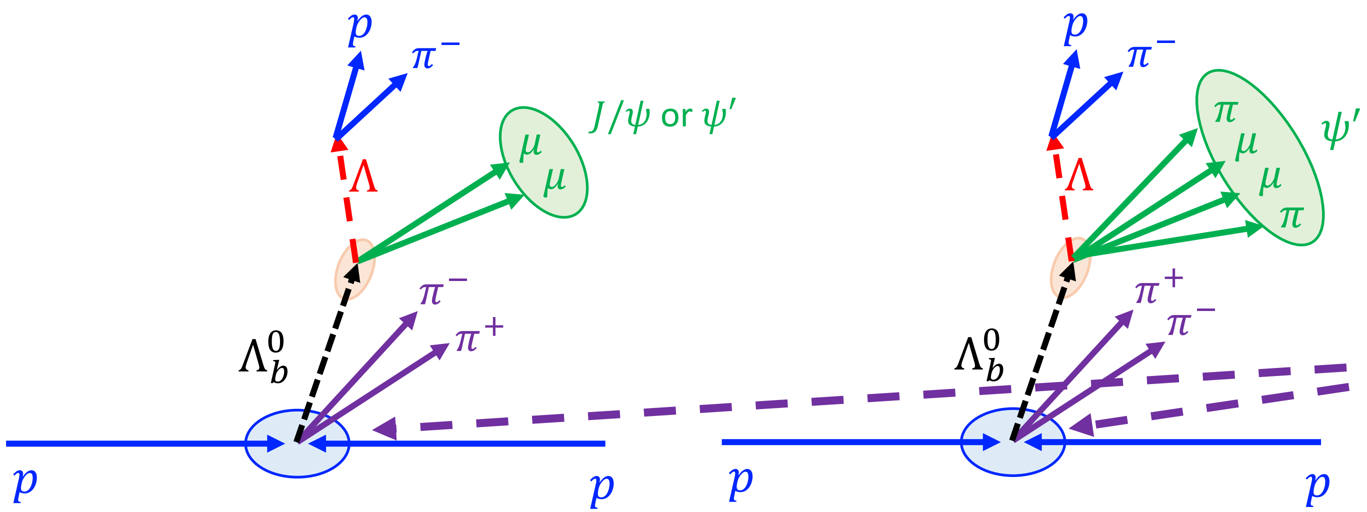
$\Lambda_b(6146)^0$ and $\Lambda_b(6152)^0$

using both channels $\boldsymbol{\Lambda_b^0 \longrightarrow \Lambda_c^+\pi^-}$ and $\boldsymbol{\Lambda_b^0 \longrightarrow J/\psi p K^-}$ with about $\boldsymbol{1.1M\ \Lambda_b^0}$ in total

In CMS **we cannot** use these most copious channels since **no dedicated trigger** (for $\boldsymbol{\Lambda_b^0 \longrightarrow \Lambda_c^+\pi^-}$) is possible: the backgrounds are too large due to the lack of hadronic PID

Λ_b^0 reconstruction at CMS

On the other hand we can easily use $\boldsymbol{\Lambda_b^0 \longrightarrow J/\psi\Lambda}$ and $\boldsymbol{\Lambda_b^0 \longrightarrow \psi(2S)\Lambda}$ with $\boldsymbol{\psi(2S)}$ decaying both in dimuon ($\longrightarrow \mu\mu$) channel and hadronic ($\longrightarrow J/\psi\pi^+\pi^-$) using a combination of various $\boldsymbol{J/\psi + X}$ and $\boldsymbol{\psi(2S) + X}$ triggers



Two additional OS prompt tracks (with pion mass hypothesis) are selected from the tracks forming the PV, chosen as the one with the smallest 3D pointing angle of the Λ_b^0 candidate.

Combinations with SS prompt pions are used as a control channel

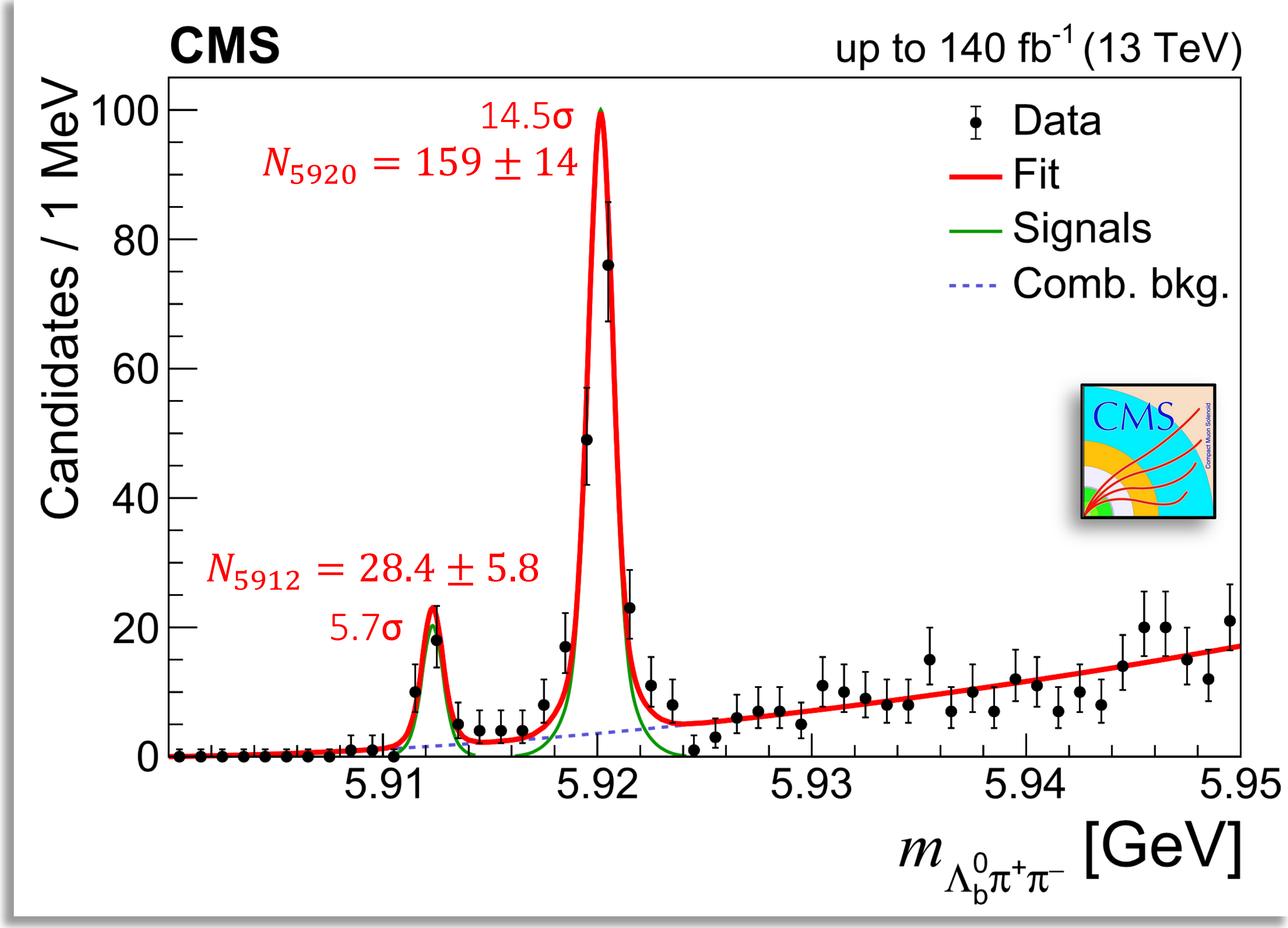
The analysis in has used **full RunII pp collision data** and has **been optimized differently**

- at **low masses**, near threshold where **backgrounds** level is low
- at **high masses** where background is large

Near Threshold Low Mass Region

The mass difference variable **is used to cancel the resolution** in Λ_b^0 mass

$$m_{\Lambda_b^0\pi^+\pi^-} = M(\Lambda_b^0\pi^+\pi^-) - M(\Lambda_b^0) + \mathrm{M}^{\mathrm{PDG}}(\Lambda_b^0)$$



Signal(s)

$$g_1^1(\mu_1;\sigma_1^1) + g_2^1(\mu_1;\sigma_2^1)$$
$$g_1^2(\mu_2;\sigma_1^2) + g_2^2(\mu_2;\sigma_2^2)$$

σ_j^i fixed from MC $(\sigma_{eff}^1, \sigma_{eff}^2) \sim (0.6,0.8)\mathrm{MeV}$

Background

$$(x - x_0)^\beta$$

β free to float
x_0 fixed to mass threshold

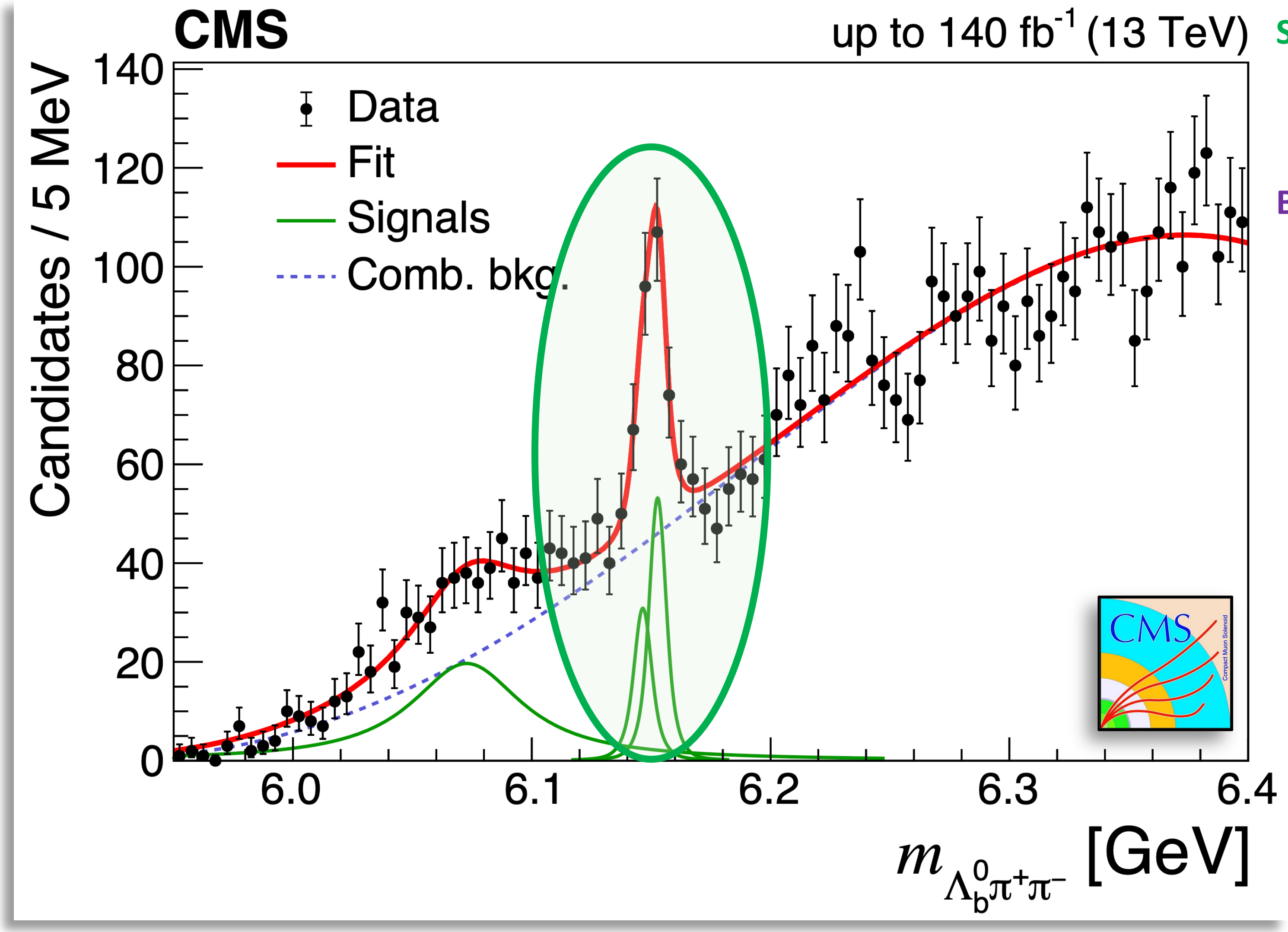
First confirmation of $\Lambda_b(5912)^0$ and confirmation of $\Lambda_b(5920)^0$

$$M(\Lambda_b(5912)^0) = [5912.32 \pm 0.12(stat) \pm 0.01(syst) \pm 0.17(m_{PDG}(\Lambda_b^0))]\mathrm{MeV}$$

$$M(\Lambda_b(5920)^0) = [5920.16 \pm 0.07(stat) \pm 0.01(syst) \pm 0.17(m_{PDG}(\Lambda_b^0))]\mathrm{MeV}$$

Consistent with those by LHCb/PDG and with similar precision

High Mass Region



Signal(s)

$B.W.(\Gamma) \otimes Two\ gaussian$

$\sigma_{eff} \sim 3.8$ MeV from MC
Γ fixed to LHCb ones

Background

$(x - \boldsymbol{x_0})^{\boldsymbol{\beta}} \cdot pol(1)$

$\boldsymbol{\beta}$ free to float
$\boldsymbol{x_0}$ fixed to mass threshold

First confirmation of $\boldsymbol{\Lambda_b\ (6146)^0}$ and $\boldsymbol{\Lambda_b\ (6152)^0}$

$$M(\Lambda_b(6146)^0) = [6146.5 \pm 1.9(stat) \pm 0.8(syst) \pm 0.2(m_{PDG}(\Lambda_b^0))]\mathrm{MeV}$$

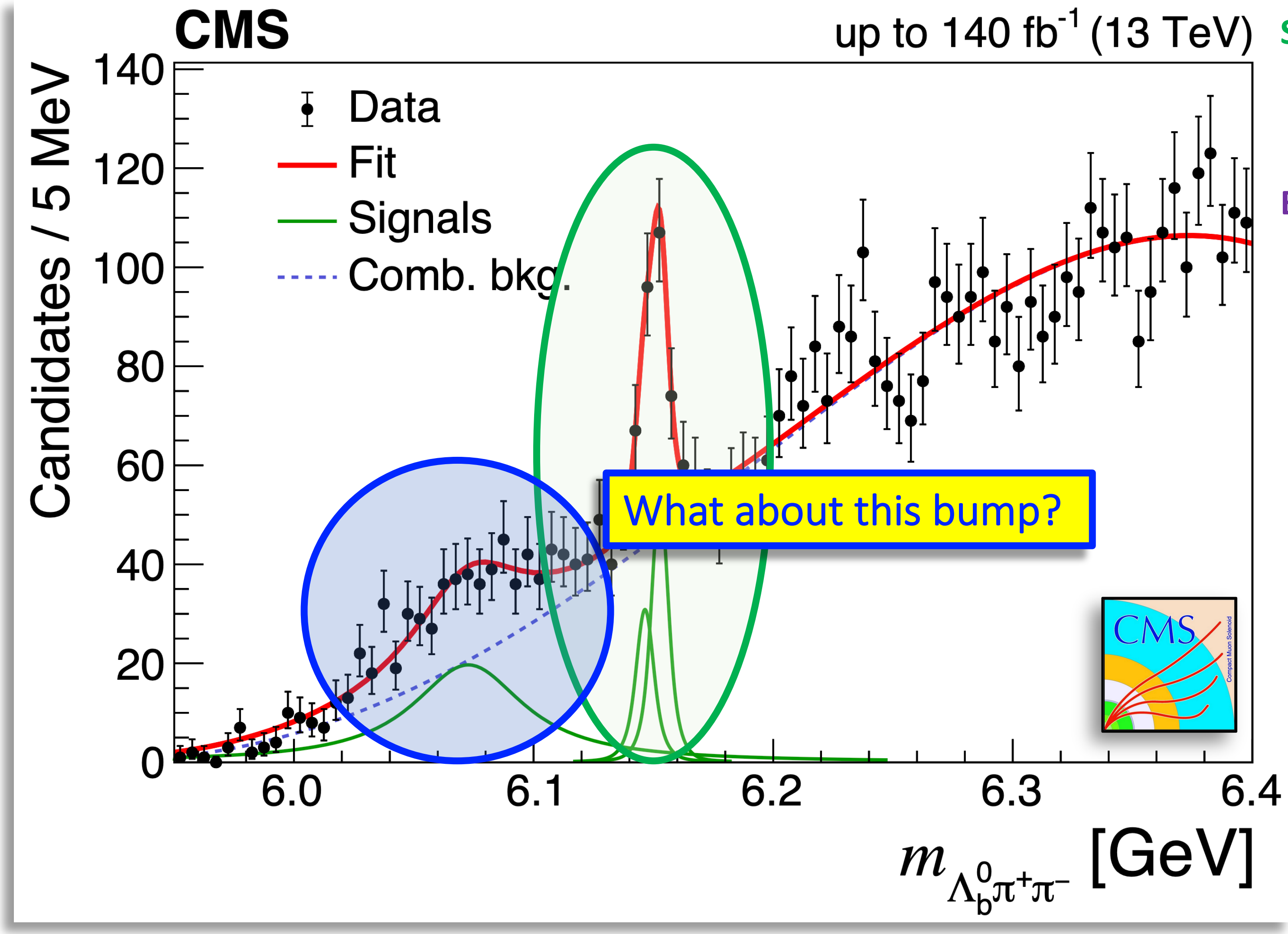
$$M(\Lambda_b(6152)^0) = [6152.7 \pm 1.1(stat) \pm 0.4(syst) \pm 0.2(m_{PDG}(\Lambda_b^0))]\mathrm{MeV}$$

... in agreement with LHCb values but not as precise as

N.B. Data are **consistent with a single peak** @6150MeV

- 1 Peak vs BKG only : $5.4 \div 6.5\sigma$ [depending on fit range and model for syst. evaluation]
- 2 Peaks vs 1 Peak : 0.4σ [not sensitive to splitting: **lower statistics & mass resolution**]

High Mass Region



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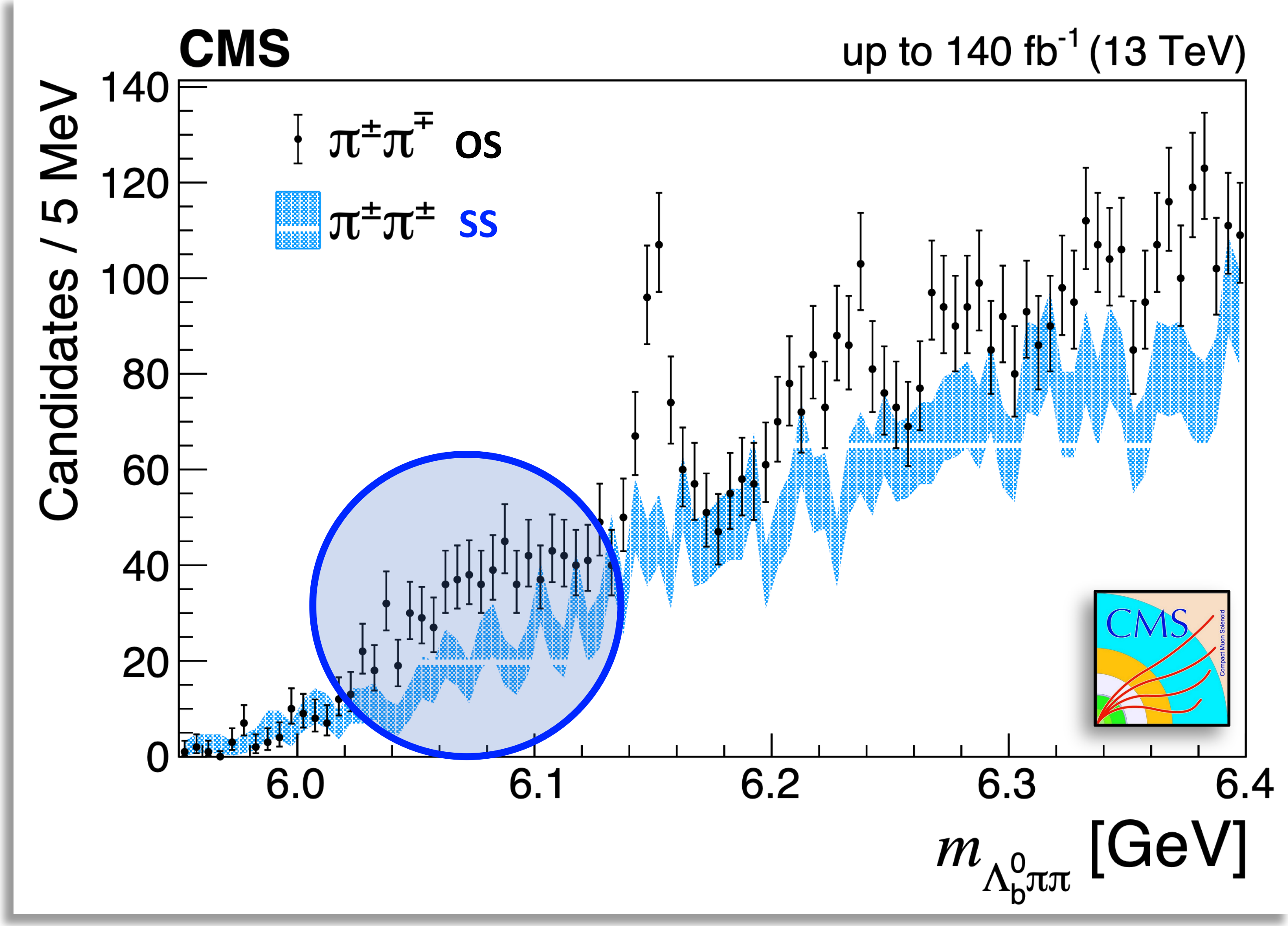
Same Sign $\pi^{\pm}\pi^{\pm}$ Distributions



The *bump* in the $\Lambda_b^0\pi^{\pm}\pi^{\mp}$ invariant mass spectrum is **not present in the same sign spectrum** $\Lambda_b^0\pi^{\pm}\pi^{\pm}$

Assuming a single broad resonance X_b and using the same signal fit model as before:

$$M(X_b) = [6073 \pm 5(stat)]MeV$$

$$\Gamma(X_b) = [55 \pm 11(stat)]MeV$$

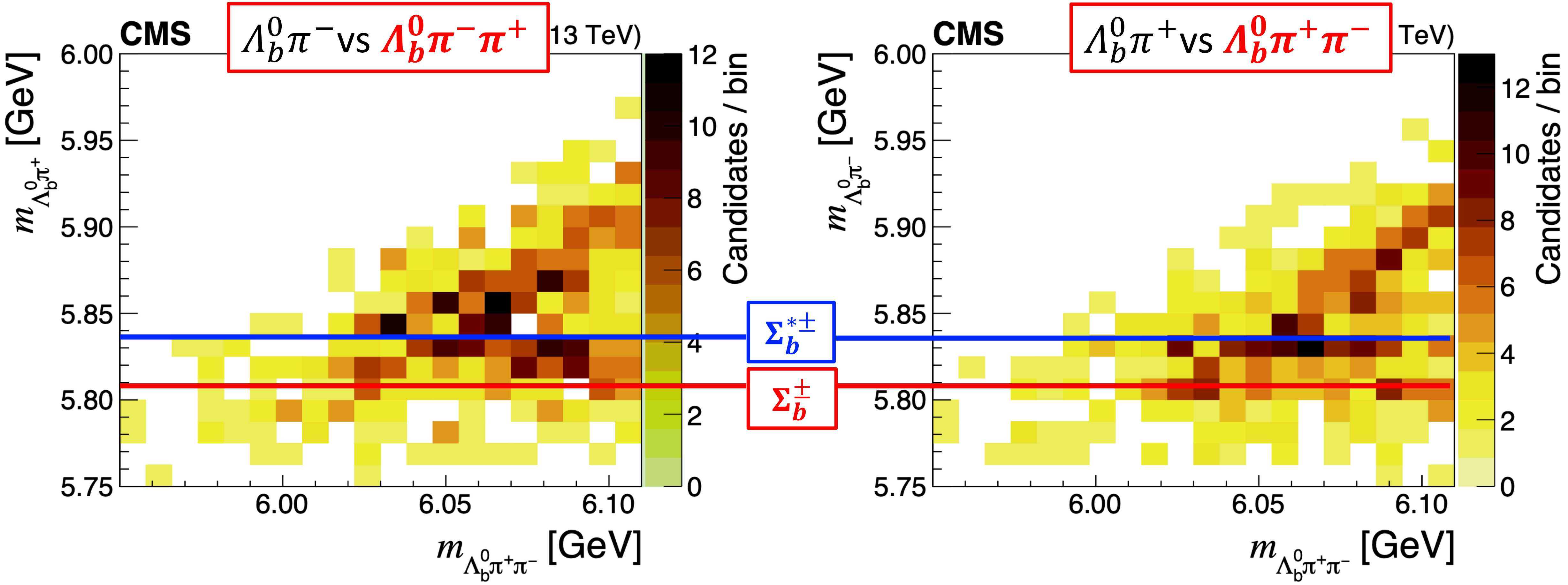
with **4σ** statistical significance

Various reflections have been thoroughly studied and **excluded** as the origin/nature of the bump. However it may be created by **partially reconstructed decays** of higher-mass states

The amount of data is too low to try a proper interpretation of the broad structure as it could **not necessarily** be a single state but - instead - a **superposition or several nearby broad states**.

$\Sigma_b^{(*)\pm}$ Contributions

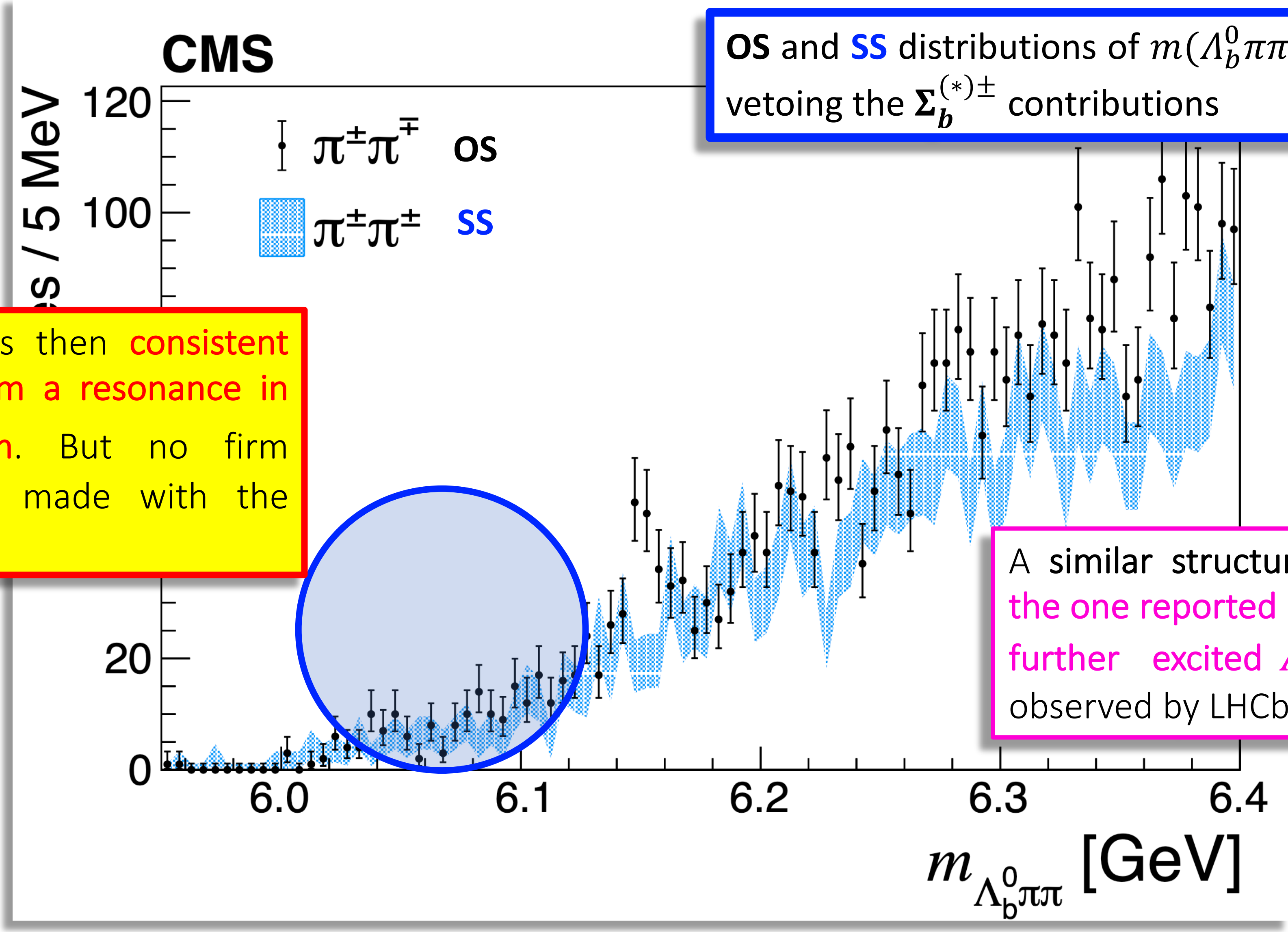
Inspecting the scatter plots $\Lambda_b^0\pi^\pm$ vs $\Lambda_b^0\pi^\pm\pi^\mp$ in the region of interest ($m_{\Lambda_b^0\pi^\pm\pi^\mp} < 6.11$ GeV)



Horizontal bands corresponding to the $\Sigma_b^{(*)\pm} \longrightarrow \Lambda_b^0\pi^\pm$ are visible and if we veto them …

$\Sigma_b^{(*)\pm}$ Veto

… we see that the «bump» **disappear**



OS and **SS** distributions of $m(\Lambda_b^0\pi\pi)$ vetoing the $\boldsymbol{\Sigma_b^{(*)\pm}}$ contributions

The **broad excess** is then consistent with originating from a resonance in the $\Sigma_b^{(*)\pm}\pi^\mp$ system. But no firm conclusion can be made with the present data.

A similar structure, consistent with the one reported here and possibly a further excited $\boldsymbol{\Lambda_b^0}$ state has been observed by LHCb (see backup).

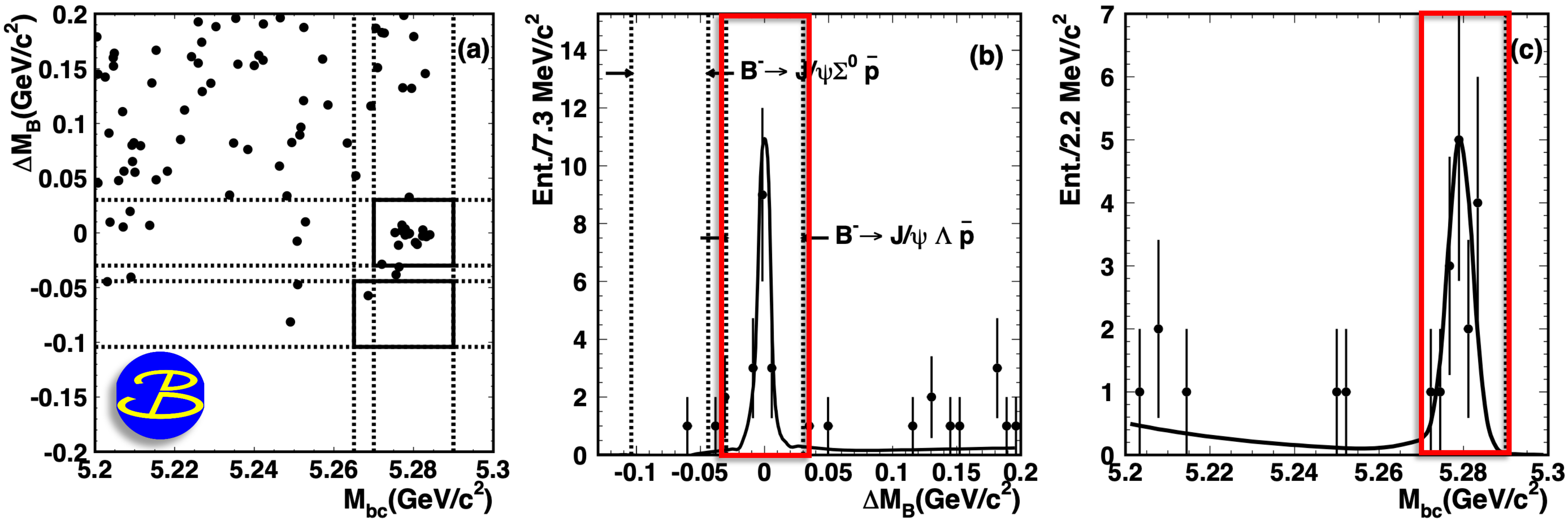
Study of the $B^+ \to J/\psi\, \bar{\Lambda} p$ decay

JHEP 12 (2019) 100

$B^{\pm}$

$B^+ \to J/\psi\ \bar{\Lambda} p$ decay

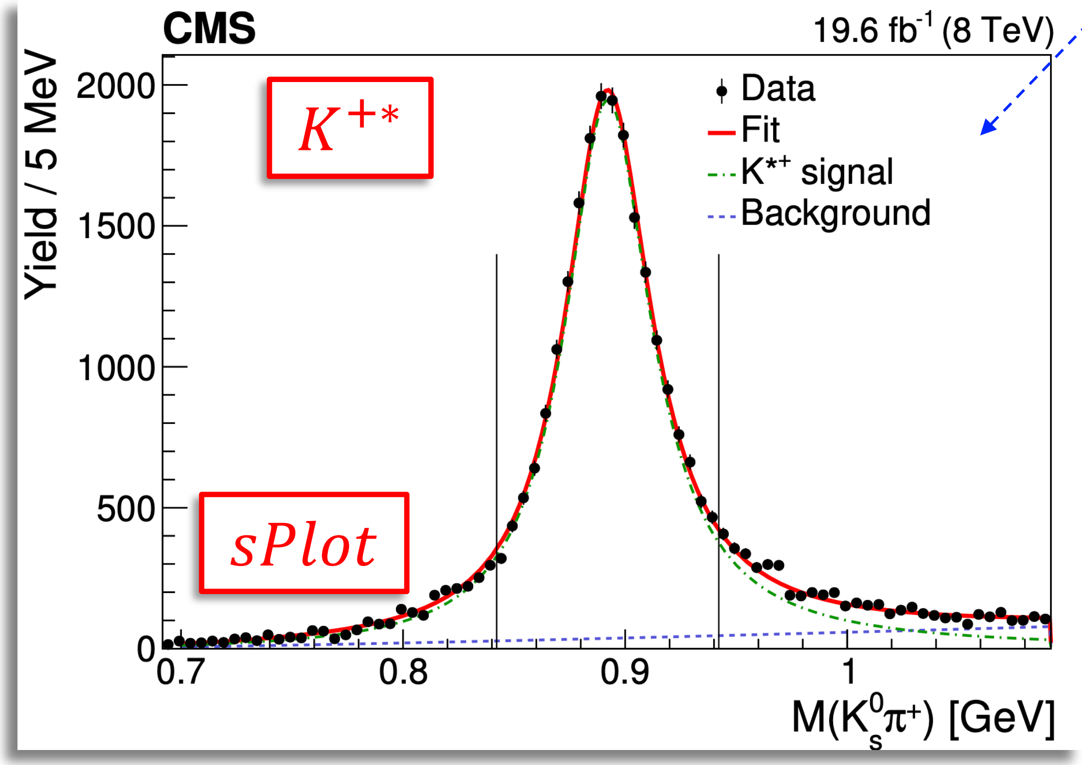
The $B^+ \to J/\psi\ \bar{\Lambda} p$ had been previously studied by Belle with 17 signal events in PhysRevD.72.051105



$B^+ \to J/\psi\bar{\Lambda}p$ decay

In JHEP12(2019)100 CMS studied $B^+ \to J/\psi\bar{\Lambda}p$ using 8 TeV **pp** collision data ($20fb^{-1}$) measuring its production properties and investigating the $J/\psi\bar{\Lambda}$, $J/\psi p$ and $p\bar{\Lambda}$ systems to search **for possible exotic hadron contributions** (such as pentaquarks similar to $P_c^+ \to J/\psi p$ in $\Lambda_b^0 \to J/\psi p B^-$). For the $\mathcal{B}$ measurement the channel $B^+ \to J/\psi K^{+*}$ with $K^{+*} \to K_s^0\pi^+$ and $K_s^0 \to \pi^+\pi^-$ acts as normalization channel (similar decay topology)

$$\frac{\mathcal{B}(B^+ \to J/\psi\bar{\Lambda}p)}{\mathcal{B}(B^+ \to J/\psi K^{*+})} = \frac{N(B^+ \to J/\psi\bar{\Lambda}p)\mathcal{B}(K^{*+} \to K_S^0\pi^+)\mathcal{B}(K_S^0 \to \pi^+\pi^-)\epsilon(B^+ \to J/\psi K^{*+})}{N(B^+ \to J/\psi K^{*+})\mathcal{B}(\bar{\Lambda} \to \bar{p}\pi^+)\epsilon(B^+ \to J/\psi\bar{\Lambda}p)}$$

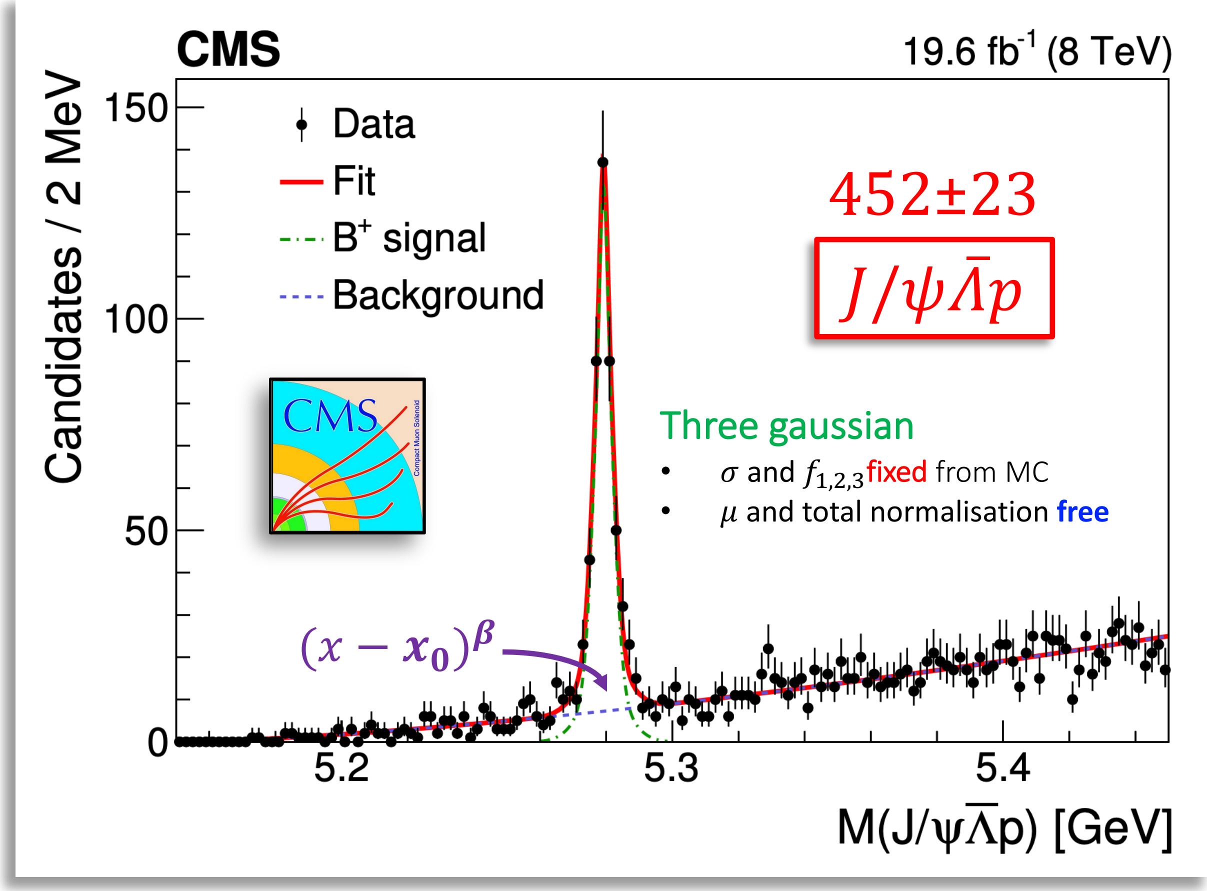


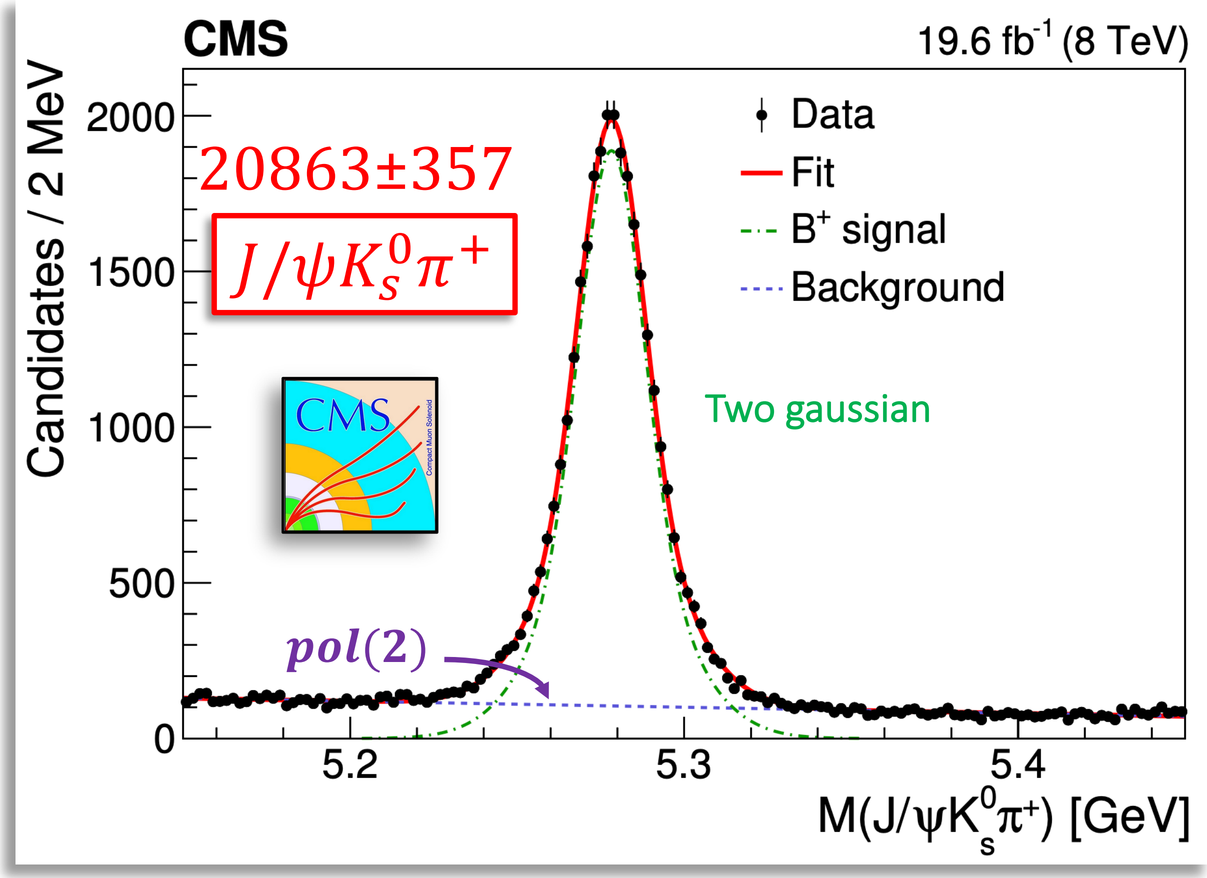
Event Selection

- $J/\psi \to \mu\mu$ *displaced* candidate selected at trigger level ($p_T(\mu) > 4\text{GeV}$ & $p_T(\mu\mu) > 6.9\text{GeV}$)
- $\bar{\Lambda} \to \bar{p}\pi^+$ displaced with $p_T(\bar{\Lambda}) > 1\text{GeV}$
- B^+candidate: $\mu\mu\bar{\Lambda}p$ vtx-fitting with $\text{M}(\mu\mu)$ constrained to J/ψ mass and $p(\bar{\Lambda})$ pointing to B^+ vertex
- B^+vertex: $L_{xy}/\sigma_{xy} > 3$, $\cos(\alpha_{B^+}) > 0.99$ and $P_{vtx} > 0.01$

Analogous selection for the normalization channel ($J/\psi K^{+*}$)

$\mathcal{B}$ calculation





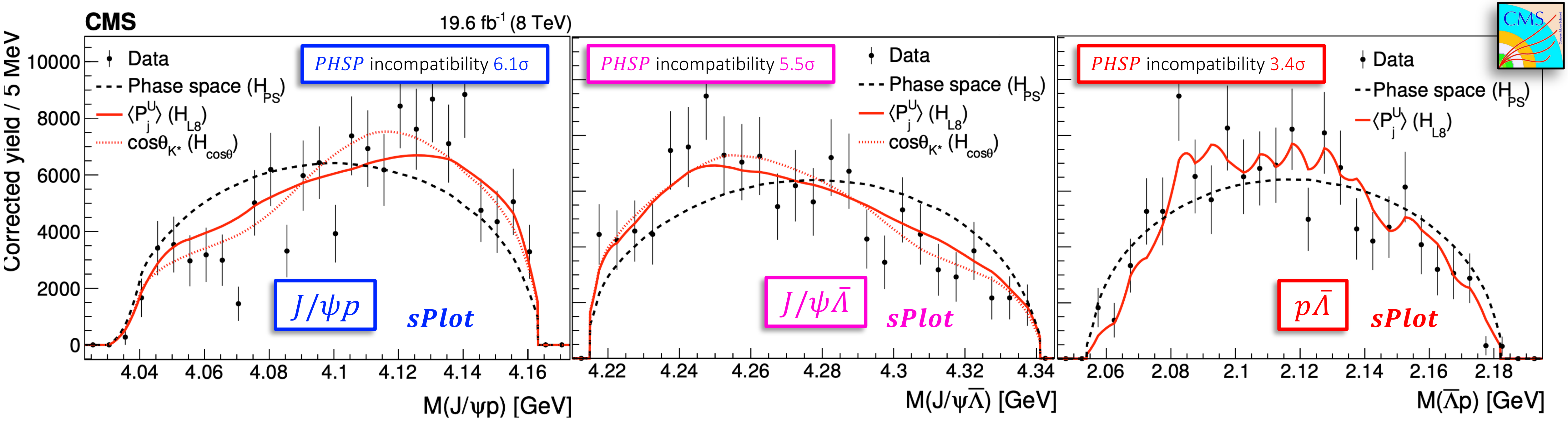
Using the world-average values for $\mathcal{B}(K^{+*}\to K_s^0\pi^+)$, $\mathcal{B}(K_s^0\to\pi^+\pi^-)$, $\mathcal{B}(\bar{\Lambda}\to\bar{p}\pi^+)$, $\mathcal{B}(B^+\to J/\psi K^{+*})$ we can calculate both

$$\mathcal{B}(\mathrm{B}^+\to \mathrm{J}/\psi\bar{\Lambda}\mathrm{p})/\mathcal{B}(\mathrm{B}^+\to \mathrm{J}/\psi \mathrm{K}^{*+}) = (1.054\pm0.057\,(\mathrm{stat})\pm0.035\,(\mathrm{syst})\pm0.011(\mathcal{B}))\%$$

$$\mathcal{B}(\mathrm{B}^+\to \mathrm{J}/\psi\bar{\Lambda}\mathrm{p}) = (15.1\pm0.8\,(\mathrm{stat})\pm0.5\,(\mathrm{syst})\pm0.9(\mathcal{B}))\times10^{-6}$$

This measurement is the most precise to date

Studing the two-body intermediate invariant masses $J/\psi\bar{\Lambda}$, $J/\psi p$ and $p\bar{\Lambda}$ we can compare it with the pure phase space decay hypothesis: none of the three mass spectra **can be adequately described** by **a pure three-body** nonresonant phase-space. Background subtraction is performed using the ***sPlot*** technique, with the invariant mass $m(J/\psi\bar{\Lambda}p)$ as the discriminating variable.



There are **at least three** known $K^*_{2,3,4}$ that can decay to $p\bar{\Lambda}$ **and interfere with the pure PHSP**

Resonance	Mass (MeV)	Natural width (MeV)	J^P
$K^*_4(2045)^+$	2045 ± 9	198 ± 30	4^+
$K^*_2(2250)^+$	2247 ± 17	180 ± 30	2^-
$K^*_3(2320)^+$	2324 ± 24	150 ± 30	3^+

To account for possible contributions from these resonances, we use a model-independent approach developed by BaBar in a search for the Z(4430) in $J/\psi\pi^+$ & $\psi(2S)\,\pi^+$ [Phys.Rev.D79:112001] and was later used by LHCb in a similar search for the Z(4430) [in $\psi(2S)\,\pi^+$ [Phys.Rev.D.92:112009]

MC Reweigthing: a Model-independent Approach

In bins of $M(p\bar{\Lambda})$ the angular distribution may be expanded in term of Legendre polynomials

$$\frac{\mathrm{d}N}{\mathrm{d}\cos\theta_{\mathrm{K}^*}} = \sum_{j=0}^{l_{\max}} \langle P_j^U \rangle P_j(\cos\theta_{\mathrm{K}^*}) \qquad l_{\max} = 8$$

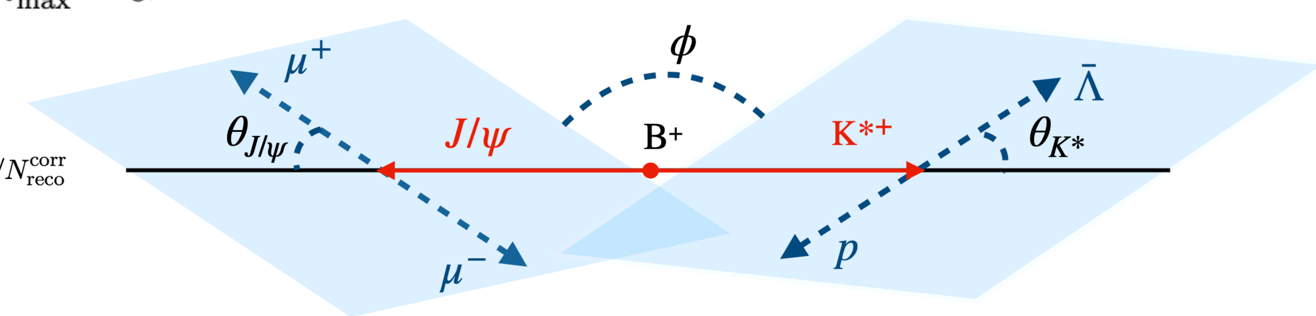
A **reweighting** of the simulated signal sample is performed (H_{L8}) using the weights →

$$w^i = 1 + \sum_{j=1}^{l_{\max}} \langle P_j^N \rangle P_j(\cos\theta_{\mathrm{K}^*})$$

$$\langle P_j^N \rangle = 2\langle P_j^U \rangle / N_{\mathrm{reco}}^{\mathrm{corr}}$$

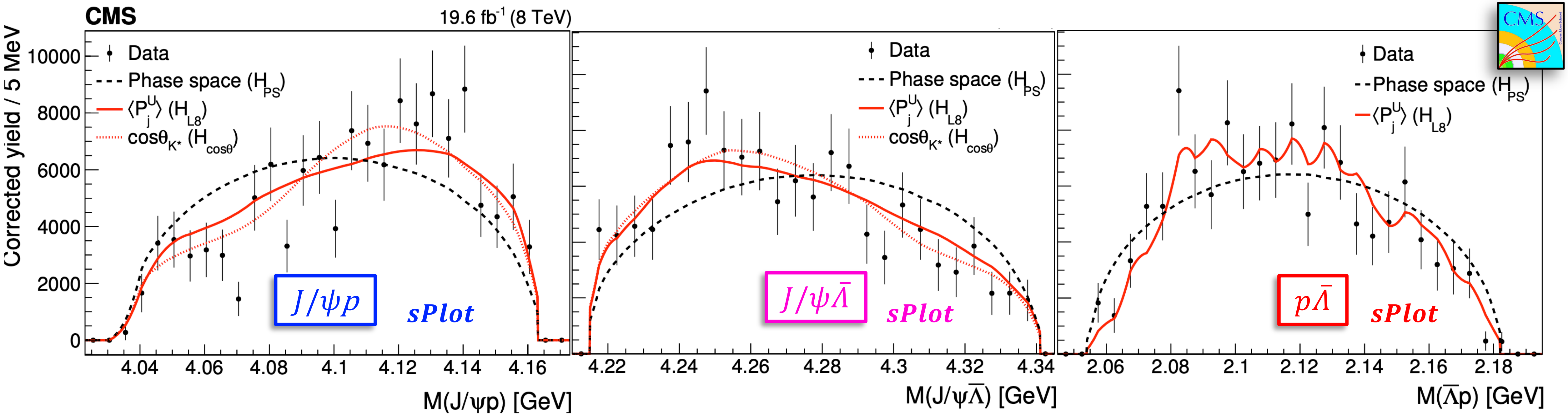
$$\langle P_j^U \rangle = \sum_{i=1}^{N_{\mathrm{reco}}} \frac{w_{\mathrm{sPlot}}^i}{\epsilon^i} P_j(\cos\theta_{\mathrm{K}^*})$$

Topology of the decay and terminology



In addition to this the pure phase space simulation may be **reweighted** to reproduce the $cos(\theta_{K^*})$ distribution in data (see backup) ($H_{cos\ \theta}$)

Accounting for $K^*_{2,3,4}$ resonances with spin up to 4 the incompatibility between efficiency-corrected data and reweighted MC drops down (at most) to 2.8σ: no need for extra exotic states to describe the observed data.



Summary

- No significant excess of events compatible with a narrow resonance has been observed in the window between **16.5** and **27** GeV within the $\Upsilon\mu^+\mu^-$ mass spectrum. To be performed with **full Run-II data**.

- The four excited $\boldsymbol{\Lambda_b^0}$ states observed by LHCb have been confirmed by investigating the $\boldsymbol{\Lambda_b^0\pi^\pm\pi^\mp}$ final state. A broad structure was also found **but its origin cannot be discerned** with the present data; a similar structure, consistent with the one reported here and possibly a further excited $\boldsymbol{\Lambda_b^0}$ state has been observed by LHCb (see backup).

- The $B^+ \to J/\psi\bar{\Lambda}p$ decay was studied. The intermediate $J/\psi\bar{\Lambda}$, $J/\psi p$ and $p\bar{\Lambda}$ systems have been investigated and the data are consistent with no exotic resonance decating to $J/\psi\bar{\Lambda}$ or $J/\psi p$

- … and stay tuned for next talk from Daniele Fasanella **about X(3872)** in pp and heavy ion collisions!

Back Up

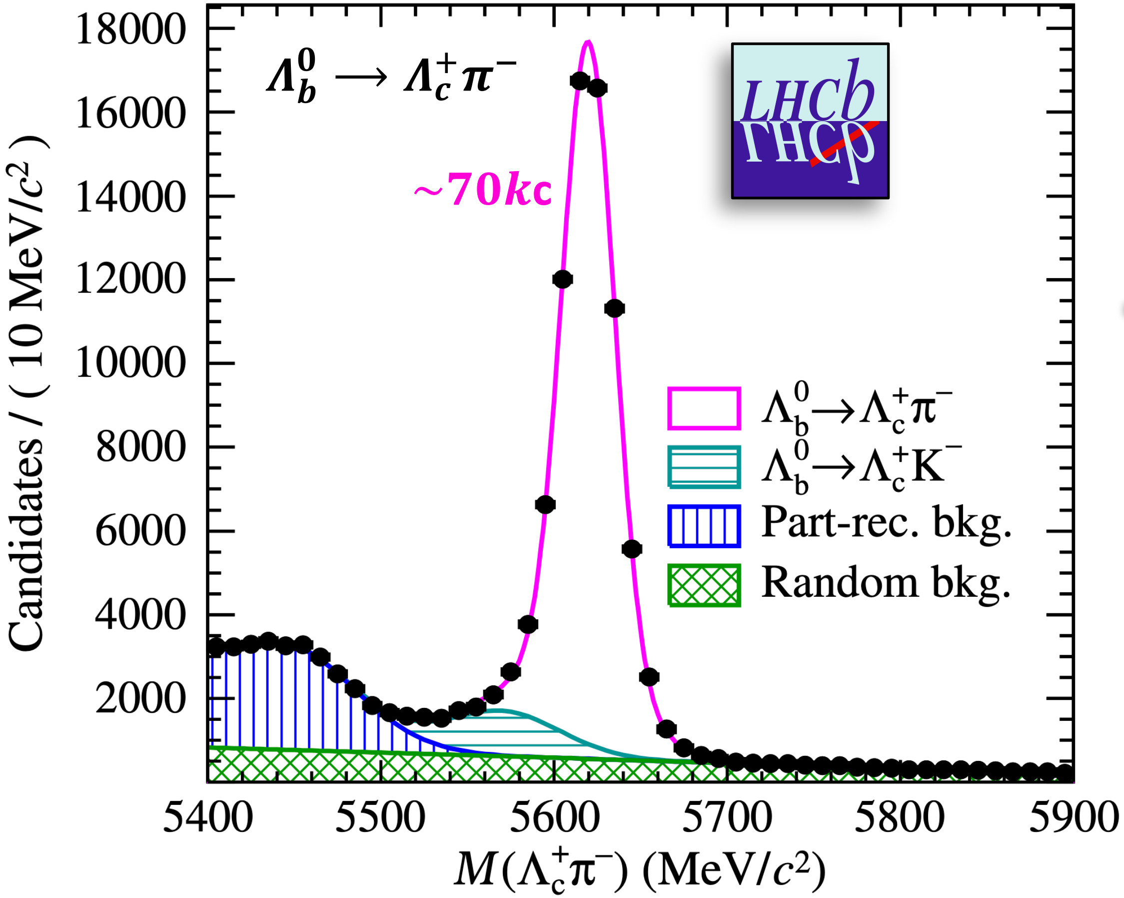
Systematic Uncertainties for Λ_b^0 excited states

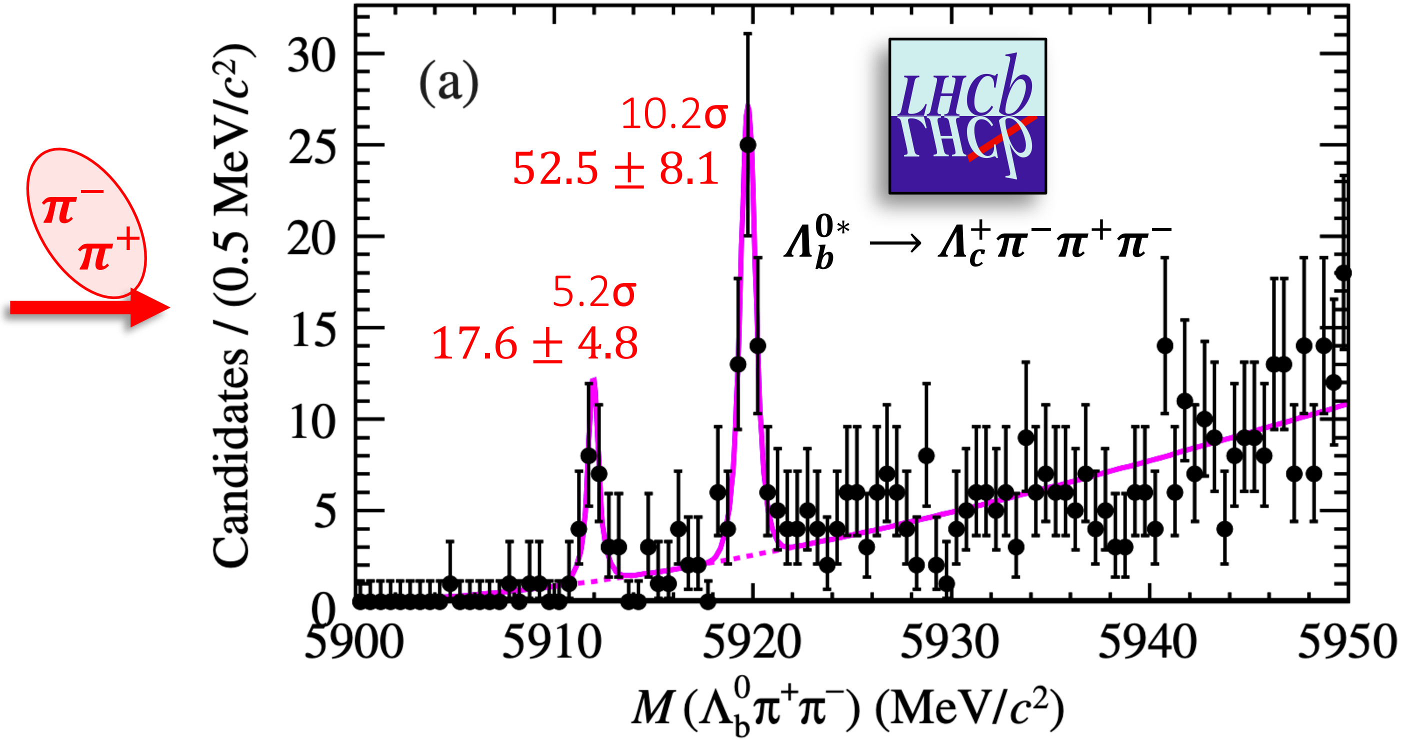
Source	$M(\Lambda_b(5912)^0)$	$M(\Lambda_b(5920)^0)$	$M(\Lambda_b(6146)^0)$	$M(\Lambda_b(6152)^0)$
Signal model	0.005	0.011	0.21	0.23
Background model	0.004	0	0.16	0.14
Inclusion of the wide bump region	—	—	0.35	0.14
Fit range	0	0	0.40	0.02
Mass resolution	0.007	0.001	0.01	0.09
Knowledge of Γ	—	—	0.43	0.26
Total	0.009	0.011	0.77	0.41

Introduction to Λ_b^0 excited states – LHCb first results

Studies of excited heavy baryon spectrum **are an important test** of Heavy Quark Effective Theory. There are **many theoretical predictions** of excited Λ_b and Σ_b states, but the predicted masses are spread in rather wide regions and **do not** point to **any narrow window** to search for a signal.

In PhysRevLett.109.172003 LHCb (2012)using $1fb^{-1}$ of 2011 data observed for the first time excited $\Lambda_b^{0*} \longrightarrow \Lambda_b^0\pi^+\pi^-$ using $\Lambda_b^0 \longrightarrow \Lambda_c^+\pi^-$ channel





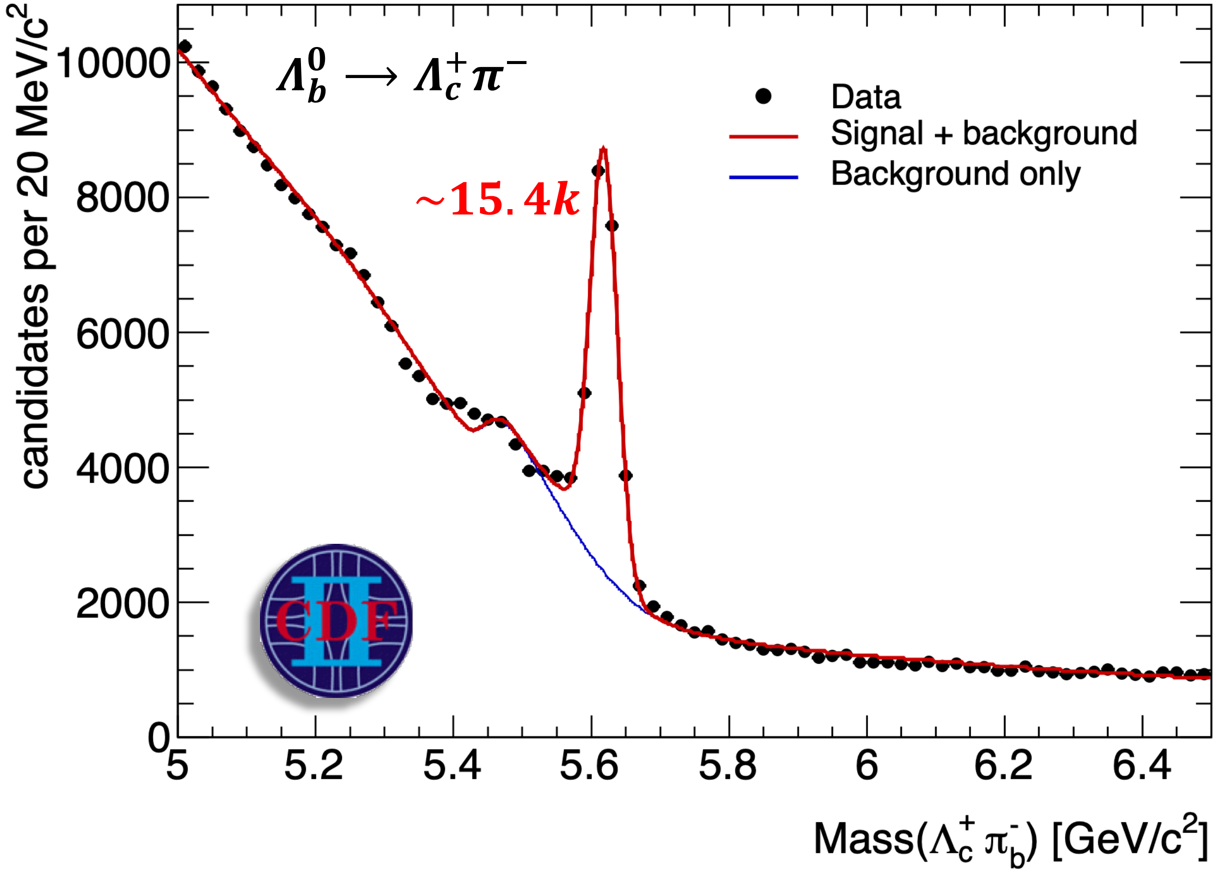
$$M_{\Lambda_b^{*0}(5912)} = 5911.97 \pm 0.12 \pm 0.02 \pm 0.66 \text{ MeV}/c^2$$

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

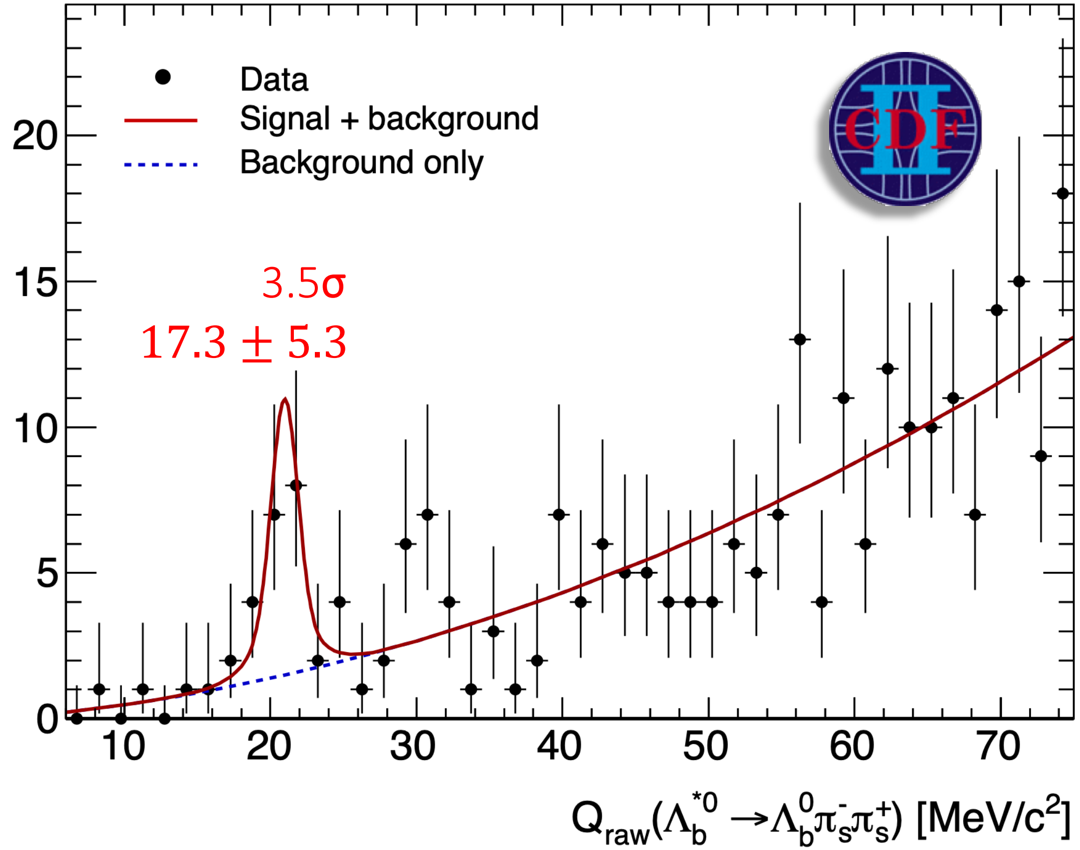
Introduction to Λ_b^0 excited states – CDF confirmations

Studies of excited heavy baryon spectrum **are an important test** of Heavy Quark Effective Theory. There are **many theoretical predictions** of excited Λ_b and Σ_b states, but the predicted masses are spread in rather wide regions and **do not** point to **any narrow window** to search for a signal.

In PhysRevD.88.071101 CDF (2013): confirmed **only the higher mass state** $\Lambda_b\,(5920)^0 \longrightarrow \Lambda_b^0\pi^+\pi^-$ with a significance of **3.5σ**



π^-
π^+

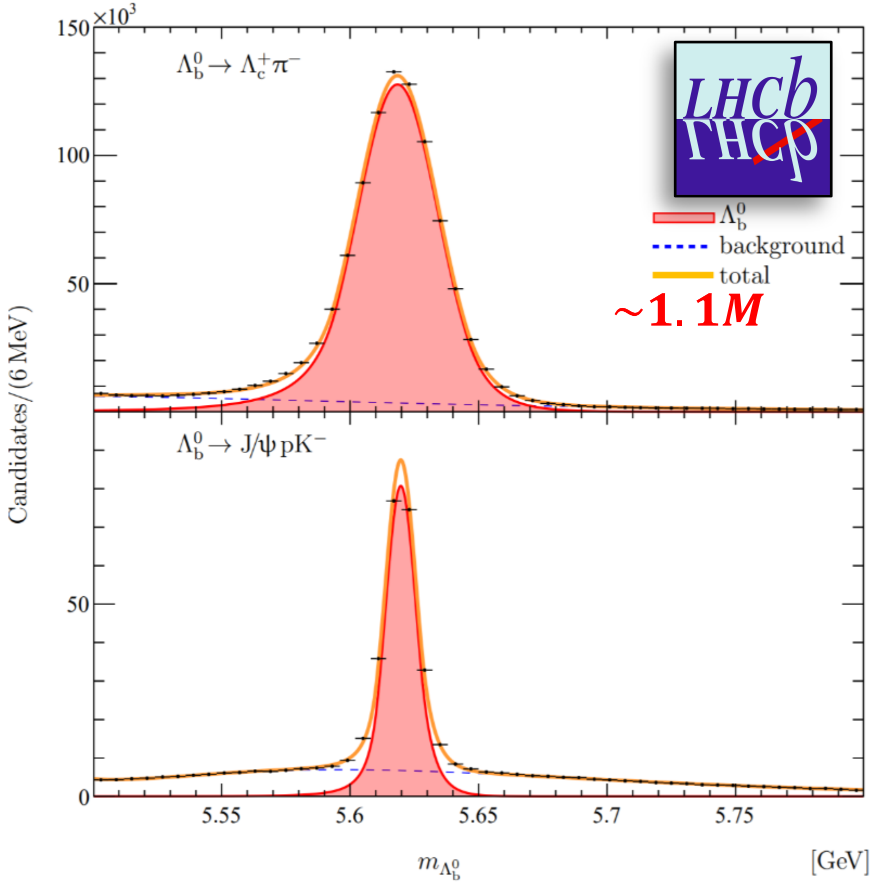


LHCb 2019: Two More States

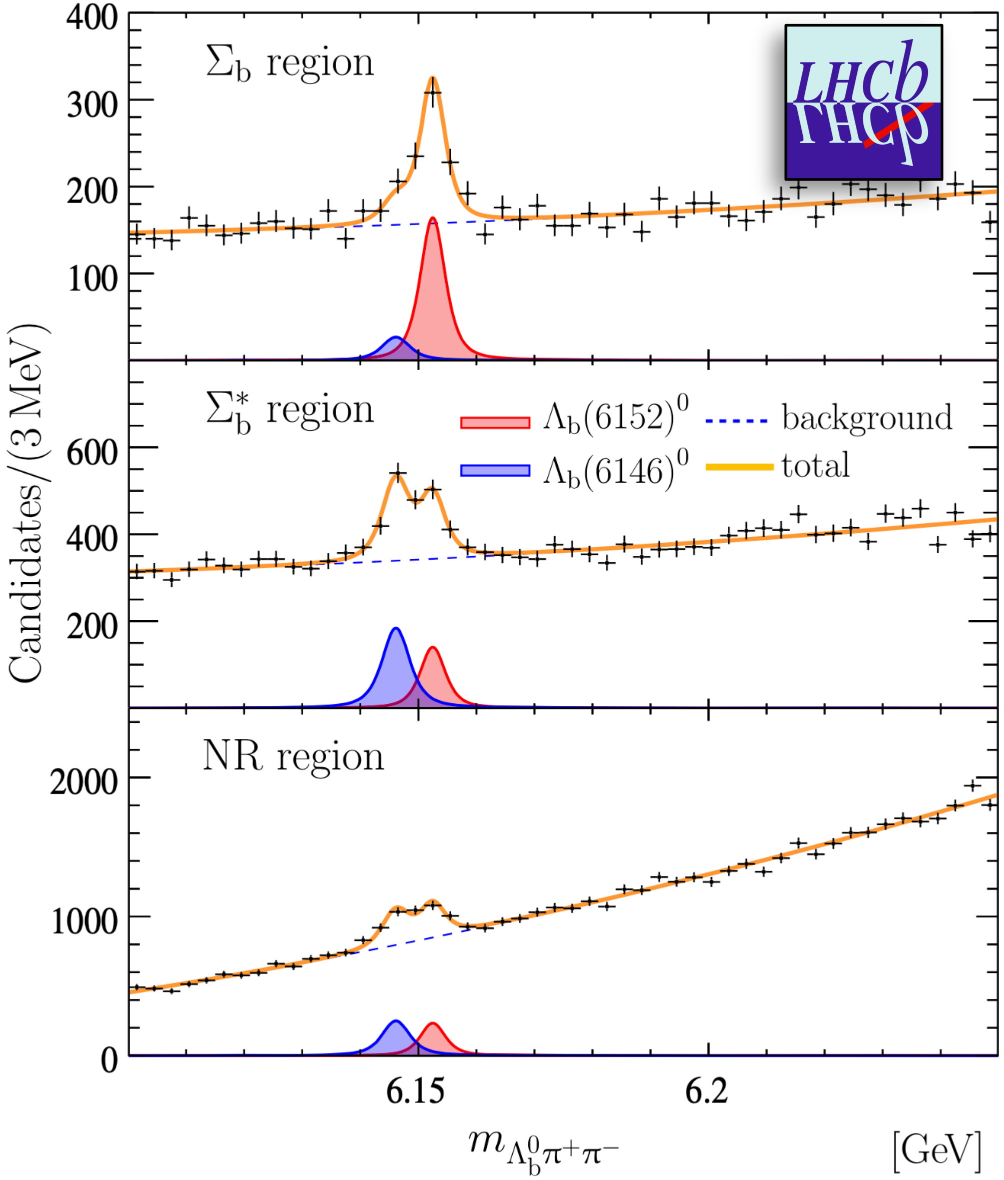
In 2019 in [PRL 123 (2019) 152001](#) LHCb **using full Run-I+II dataset observed two new excited states** decaying to $\Lambda_b^0\pi^+\pi^-$ final state:

$\Lambda_b\,(6146)^0$ and $\Lambda_b\,(6152)^0$

using both channels $\boldsymbol{\Lambda_b^0 \longrightarrow \Lambda_c^+\pi^-}$ and $\boldsymbol{\Lambda_b^0 \longrightarrow J/\psi p K^-}$ with about $\boldsymbol{1.1M}$ $\boldsymbol{\Lambda_b^0}$ in total

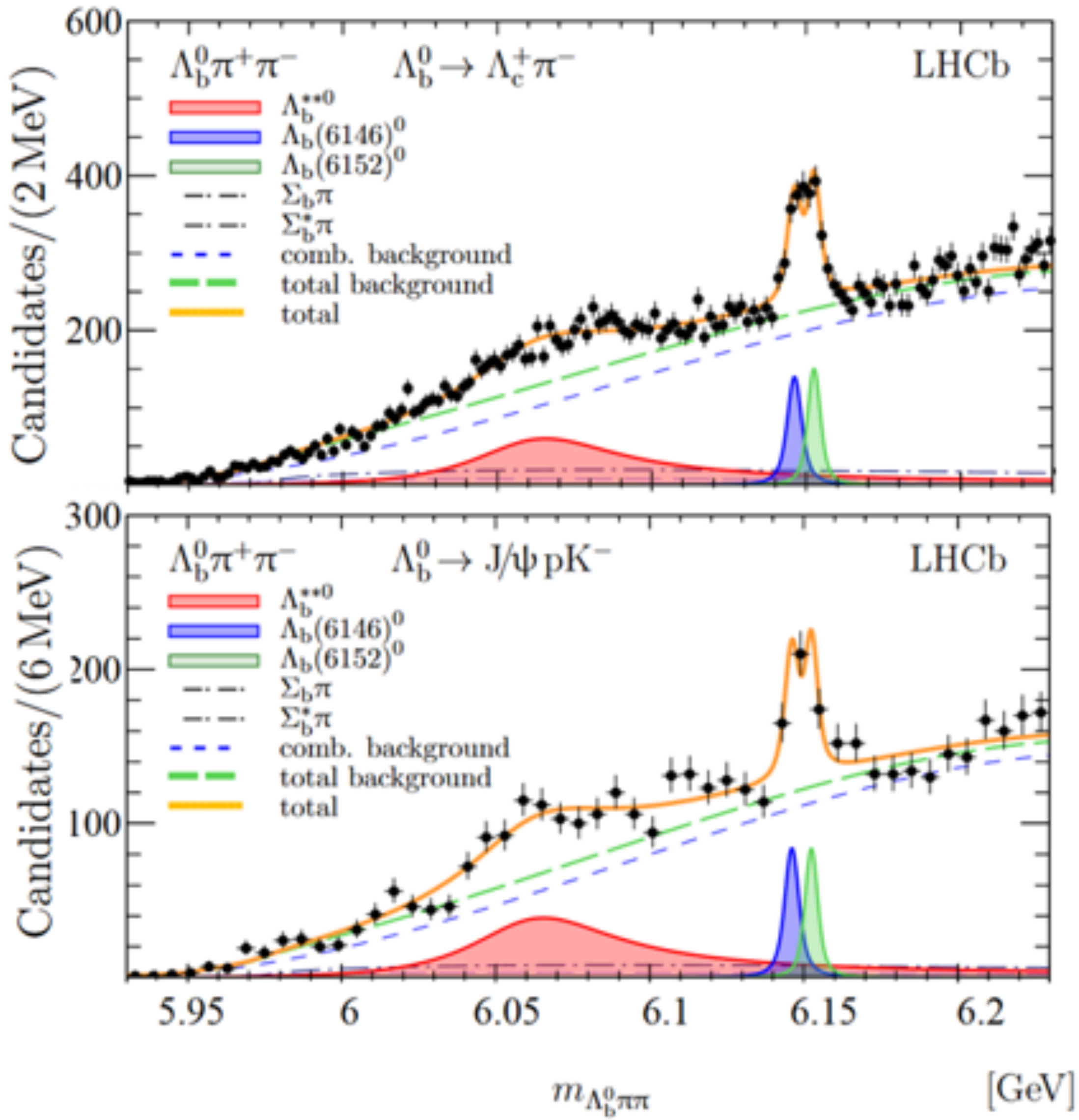


π^- π^+



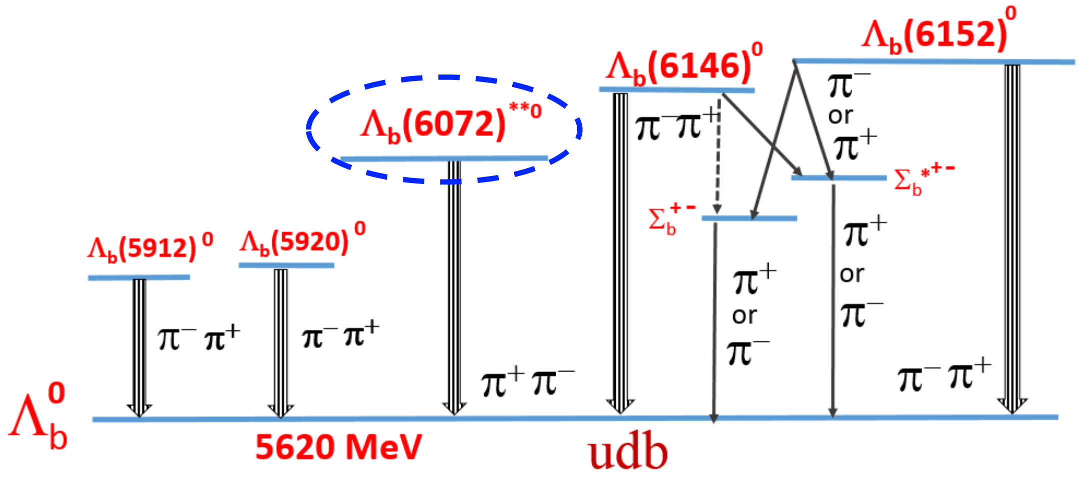
In CMS **we cannot** use these most copious channels since **no dedicated trigger** (for $\boldsymbol{\Lambda_b^0 \longrightarrow \Lambda_c^+\pi^-}$) were configured and the backgrounds are large due to the **lack of hadronic PID** (for both)

$\Lambda_b^0\pi^{\pm}\pi^{\mp}$ wide structure in LHCb



Later confirmed the wide structure in the $\Lambda_b^0\pi^{\pm}\pi^{\mp}$ spectrum and …

… possibly interpreted it as a further excited Λ_b^0 with mass and width compatible with expectations for the $\Lambda_b^0(2S)$ state



http://lhcb-public.web.cern.ch

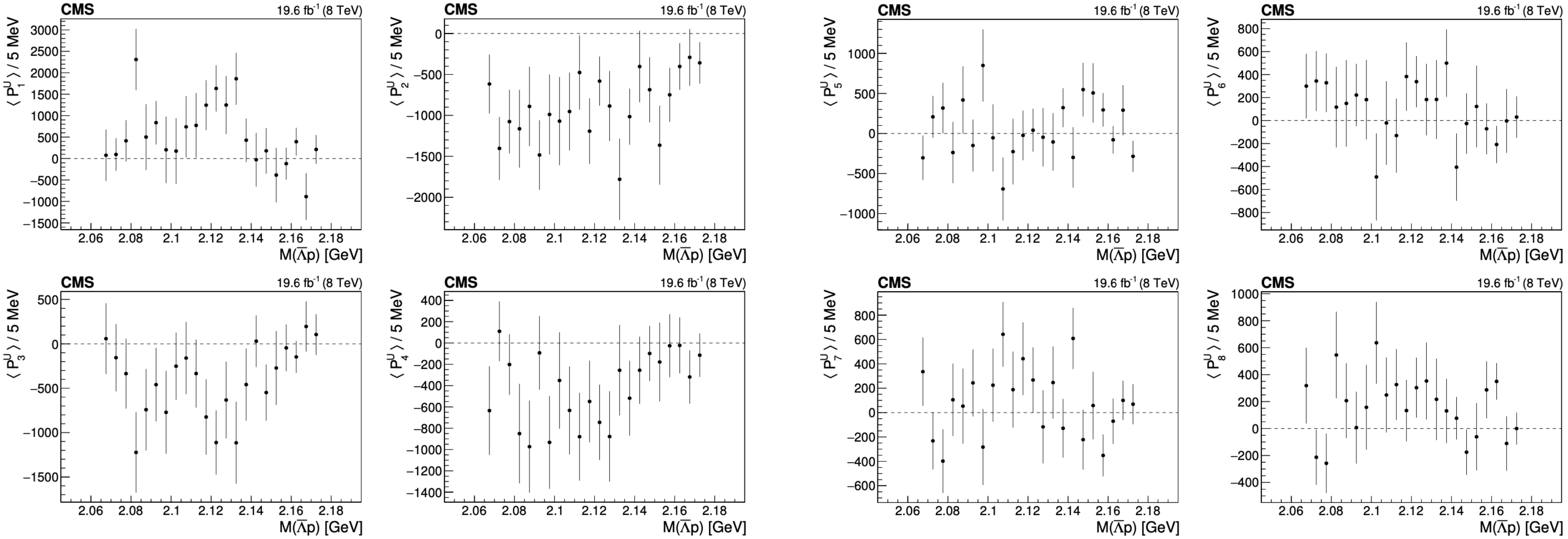
Systematics & efficiencies for $\mathcal{B}(B^+ \to J/\psi\bar{\Lambda}p)/\mathcal{B}(B^+ \to J/\psi K^{+*})$

$$\frac{\mathcal{B}(\mathrm{B}^+ \to \mathrm{J}/\psi\overline{\Lambda}\mathrm{p})}{\mathcal{B}(\mathrm{B}^+ \to \mathrm{J}/\psi\mathrm{K}^{*+})} = \frac{N(\mathrm{B}^+ \to \mathrm{J}/\psi\overline{\Lambda}\mathrm{p})\mathcal{B}(\mathrm{K}^{*+} \to \mathrm{K}^0_\mathrm{S}\pi^+)\mathcal{B}(\mathrm{K}^0_\mathrm{S} \to \pi^+\pi^-)\epsilon(\mathrm{B}^+ \to \mathrm{J}/\psi\mathrm{K}^{*+})}{N(\mathrm{B}^+ \to \mathrm{J}/\psi\mathrm{K}^{*+})\mathcal{B}(\overline{\Lambda} \to \overline{\mathrm{p}}\pi^+)\epsilon(\mathrm{B}^+ \to \mathrm{J}/\psi\overline{\Lambda}\mathrm{p})}$$

Source	Relative uncertainty (%)
Discrepancy between data and simulation	2.2
Background model in the $M(\mathrm{J}/\psi\overline{\Lambda}\mathrm{p})$ distribution	1.1
Background model in the $M(\mathrm{J}/\psi\mathrm{K}^0_\mathrm{S}\pi^+)$ distribution	0.1
Background model in the $M(\mathrm{K}^0_\mathrm{S}\pi^+)$ distribution	1.2
Signal model in the $M(\mathrm{J}/\psi\overline{\Lambda}\mathrm{p})$ distribution	0.9
Signal model in the $M(\mathrm{J}/\psi\mathrm{K}^0_\mathrm{S}\pi^+)$ distribution	0.6
Simulated sample event count	1.7
Total systematic uncertainty	3.3

$$\epsilon(\mathrm{B}^+ \to \mathrm{J}/\psi\mathrm{K}^{*+})/\epsilon(\mathrm{B}^+ \to \mathrm{J}/\psi\overline{\Lambda}\mathrm{p}) = 1.347 \pm 0.023,$$

First Eight Legendre Moments on $M(\Lambda p)$



Data-PHSP comparison on $cos(\theta_{K^*})$