Семинар
ОФВЭ ПИЯФ им. Б.П. Константинова НИЦ «Курчатовский Институт»

B-физика в эксперименте CMS

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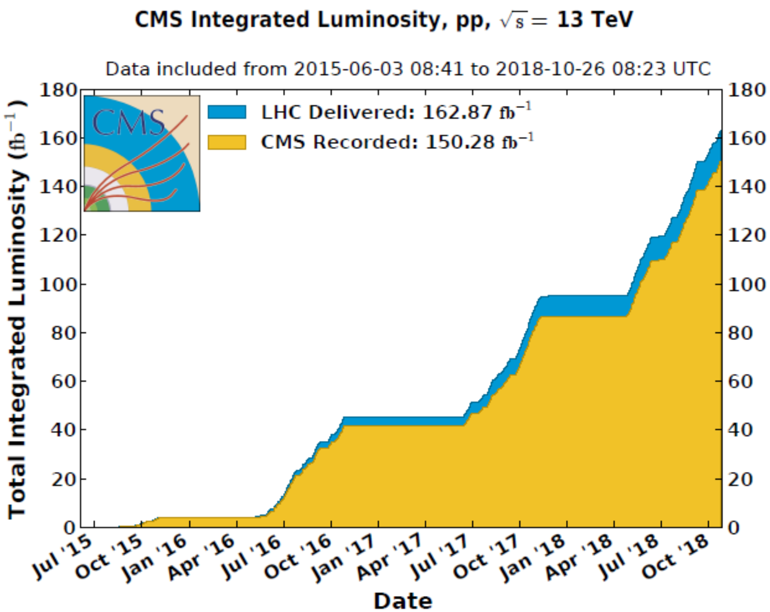
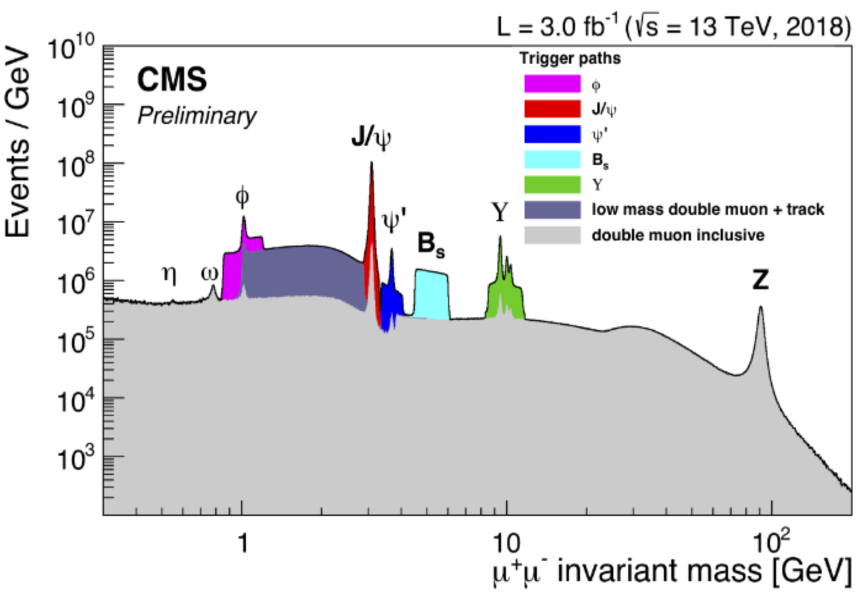
1. Введение
2. Результаты по классической спектроскопии b-адронов
3. Результаты по поиску многокварковых состояний, содержащих c- или b-кварки
4. Заключение и перспективы

Introduction



- 160 fb^{-1} has been delivered by the LHC in Run 2 (2015-2018) at $\sqrt{s}$=13 TeV.
- Very efficient data collection by CMS with improved track momentum resolution→ recorded over 140 fb^{-1} of physics-quality data.
- Ingenious trigger algorithms were developed for efficient online event selection.



CMS is contributing intensively into the heavy flavor

BPH: 58 papers published + 1 accepted + 1 submitted

Обзор тем, по которым идут исследования по B-физике в эксперименте CMS

Измерение сечений рождения
c- и b-адронов / измерение времен жизни и других
свойств b-адронов (тест предсказаний КХД моделей)

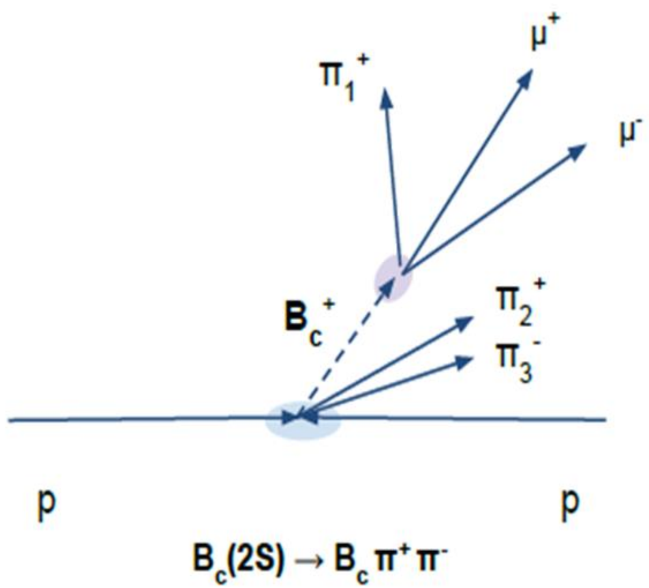
Поиск Новой Физики:
изучение процессов
$b \to s\ \mu^+\mu^-$ / $B_s \to \mu^+\mu^-$

Классическая спектроскопия b-адронов:
поиск новых уровней и изучение уже
открытых (проверка предсказаний КХД
моделей как шаг вперед к пониманию
природы сильного взаимодействия)

Поиск и изучение
многокварковых состояний,
содержащих c- и/или b-кварки:
в новых каналах распада
b-адронов и прямом рождении

Триггеры для записи событий с b-адронами

(1) Основная глобальная цель **L1 & HLT для B-физики**
– отобрать события, в которых есть
отлетевшие от первичной вершины J/ψ, ψ(2S) или Υ(1S, 2S, 3S) → μ+ μ-



(2) Есть и другие триггеры на B-физику
(например триггер, нацеленный на отбор FCNC распадов типа **b → s μ+μ-**),
но в этом докладе будут обсуждаться результаты, полученные на основе (1).

(3) Новый триггер на B-физику, **Bparking,** будет обсуждаться в конце доклада
в разделе Перспективы.

Классическая спектроскопия b-адронов

Избранные результаты!
Полный список работ –
http://cms-results.web.cern.ch/cms-results/public-results/publications/BPH/index.html

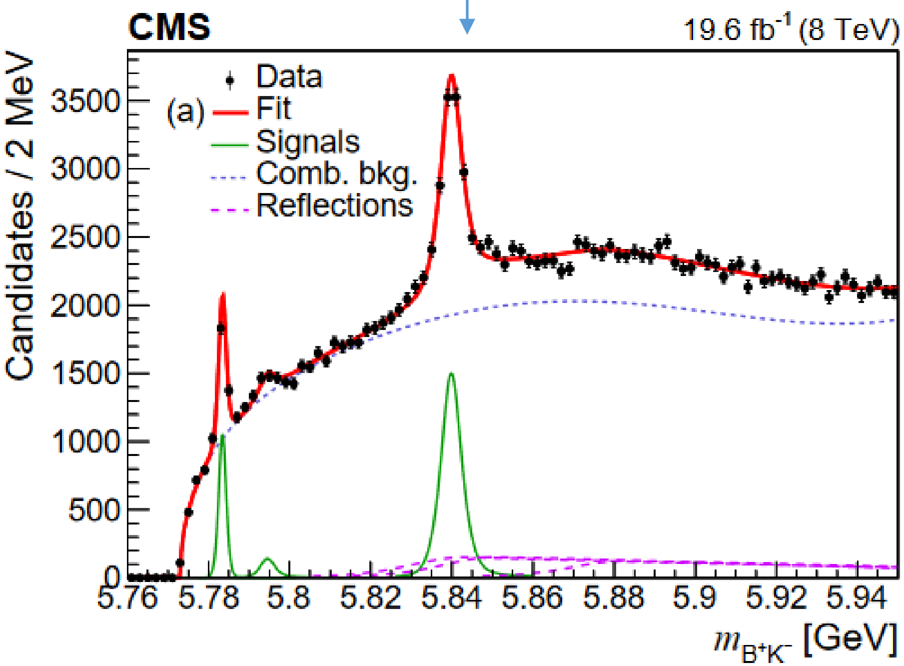
- Изучение P-волновых B_{s2}^*, B_{s1} и обнаружение $B_{s2}^*(5840)^0 \rightarrow B^0 K_s^0$
- Первое измерение отдельных уровней $\chi_{b1}(3P)$ и $\chi_{b2}(3P)$
- Обнаружение возбужденных состояний B_c^+ мезона: $B_c(2S)^+$ и $B_c^*(2S)^+$
- Обнаружение новых возбужденных состояний Λb бариона
- Обнаружение нового прелестного странного бариона $\Xi_b(6100)^+$

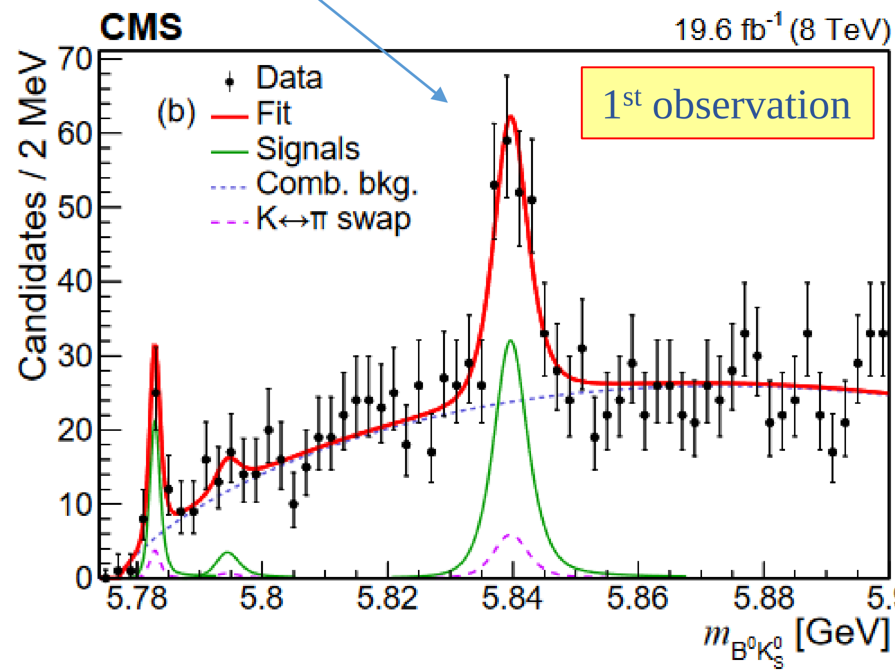
CMS: Studies of $B_{s2}^*(5840)^0$ and $B_{s1}(5830)^0$ decaying into B^+K^- and observation of $B_{s2}^*(5840)^0 \rightarrow B^0 K_s^0$

EPJC (2018) 78:939

$B_{s2}^*(5840)^0 \rightarrow B^+ K^-$

$B_{s2}^*(5840)^0 \rightarrow B^0 K_s^0$





First observation of the decay $B_{s2}^* \rightarrow B^0 K_S^0$

First evidence of the decay $B_{s1} \rightarrow B^{*0} K_S^0$

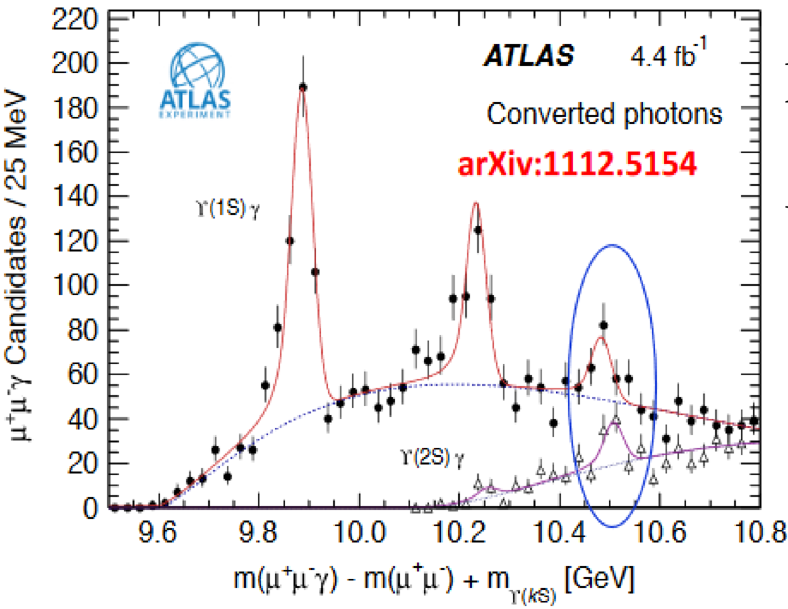
Masses, ΔM and ratios of σ∗Br measured.
Results are in agreement with existing measurements by CDF and LHCb

$$M_{B^0} - M_{B^+} = 0.57 \pm 0.49 \pm 0.10 \pm 0.02\,\text{MeV},$$
$$M_{B^{*0}} - M_{B^{*+}} = 0.91 \pm 0.24 \pm 0.09 \pm 0.02\,\text{MeV}.$$

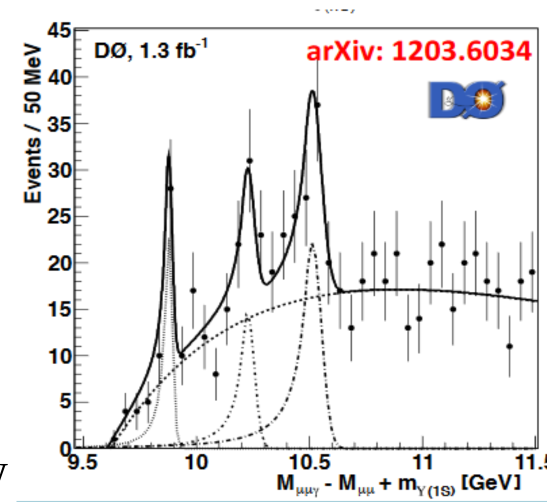
LHCb 2013: doi:10.1103/PhysRevLett.110.151803
CDF 2014: doi:10.1103/PhysRevD.90.012013

CMS: Observation of two resolved states $\chi_{b1,2}(3P)$

The history of the topic:

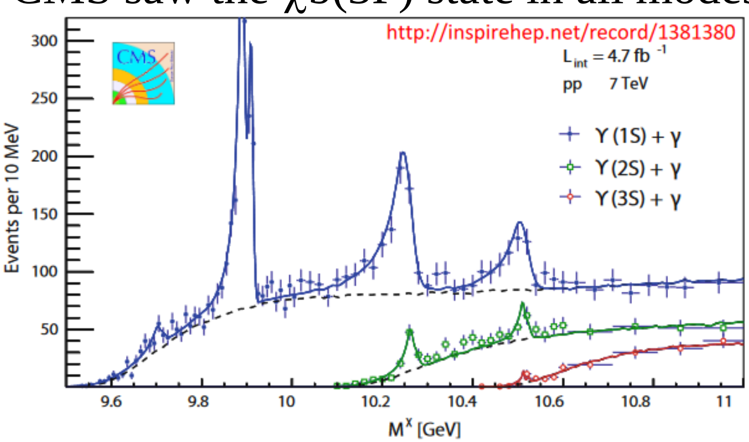


ATLAS observed the $\chi b(3P)$ state as a new Structure in $Y(1S)\ \gamma$ and $Y(2S)\ \gamma$ decays.

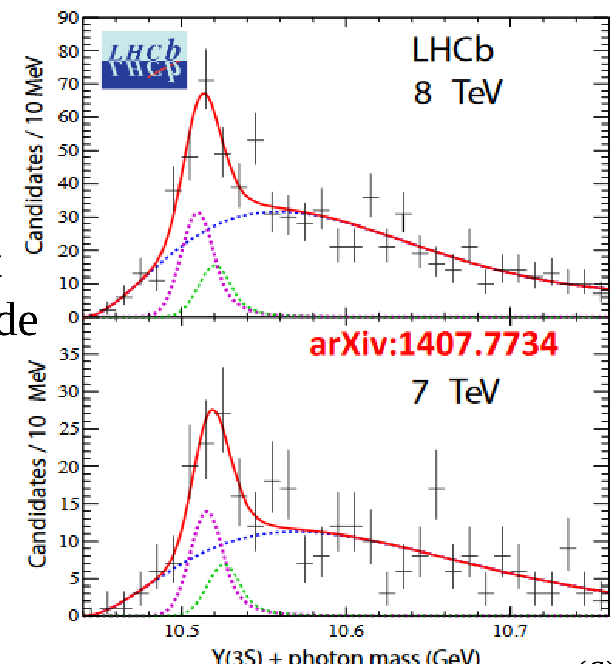


The D0 saw $\chi b(3P) \rightarrow Y(1S)\gamma$

CMS saw the $\chi b(3P)$ state in all modes



LHCb confirmed it in a new decay mode $Y(3S)\ \gamma$



CMS: Observation of two resolved states $\chi_{b1,2}(3P)$

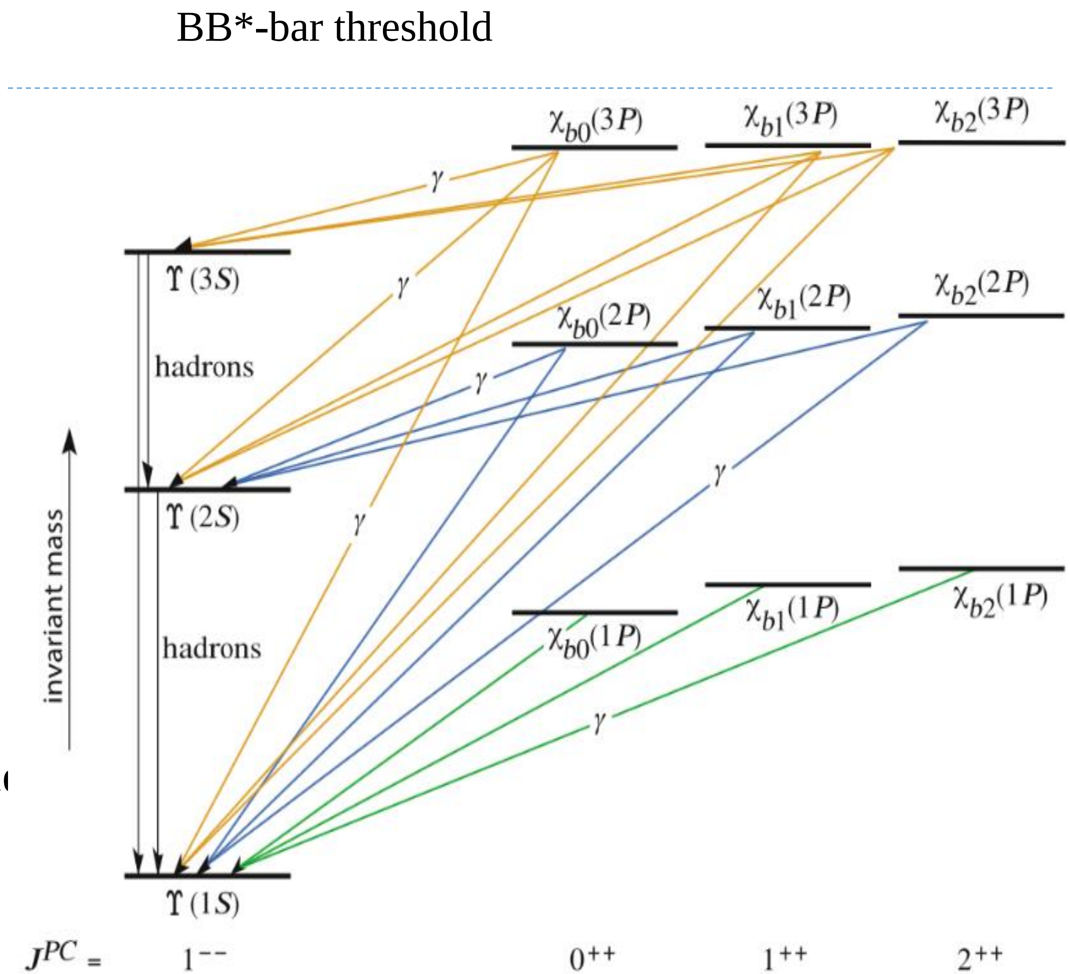
Motivation:

PRL 121 (2018) 092002

* The (bb-bar) family plays a special role in understanding how the strong force binds quarks.

• Measurements of the masses of the $\chi_{bJ}(3P)$ triplet states probe details of the bb-bar interaction and test theoretical treatments of the influence of open-beauty states on the bottomonium spectrum.

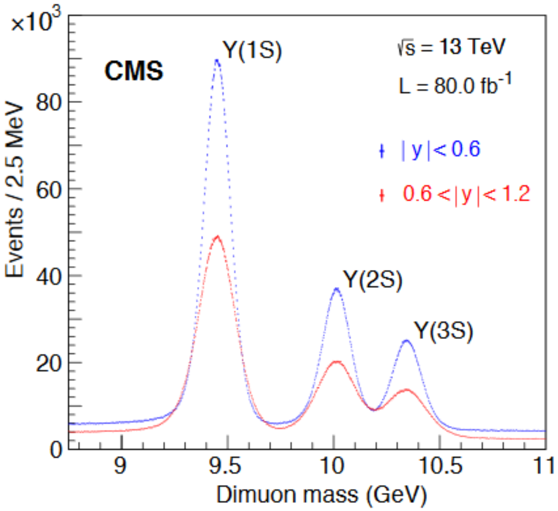
• The observation of a doublet structure in the 10.5 GeV peak should confirm the nature of the state and clarify the existence or absence of effects induc by the nearby open-beauty threshold.



Picture from : V. Knünz, Measurement of Quarkonium Polarization to Probe QCD - *DOI 10.1007/978-3-319-49935-2_2*

CMS: Observation of two resolved states $\chi_{b1,2}(3P)$

PRL 121 (2018) 092002



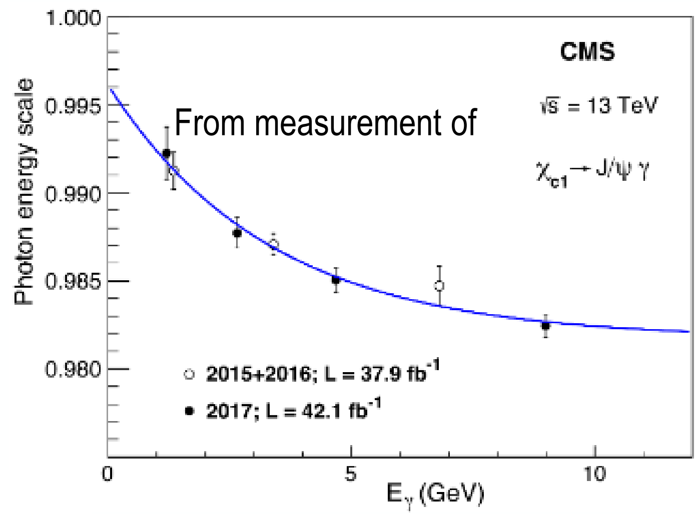
Upsilon(1,2,3S) sample

- Analyzing the full LHC Run 2 dataset (**13 TeV, 80 fb^{-1}**), CMS has **observed for the first time** the split in the **χ_{b1} (3P) - χ_{b2} (3P) doublet** and measured the masses of the two states

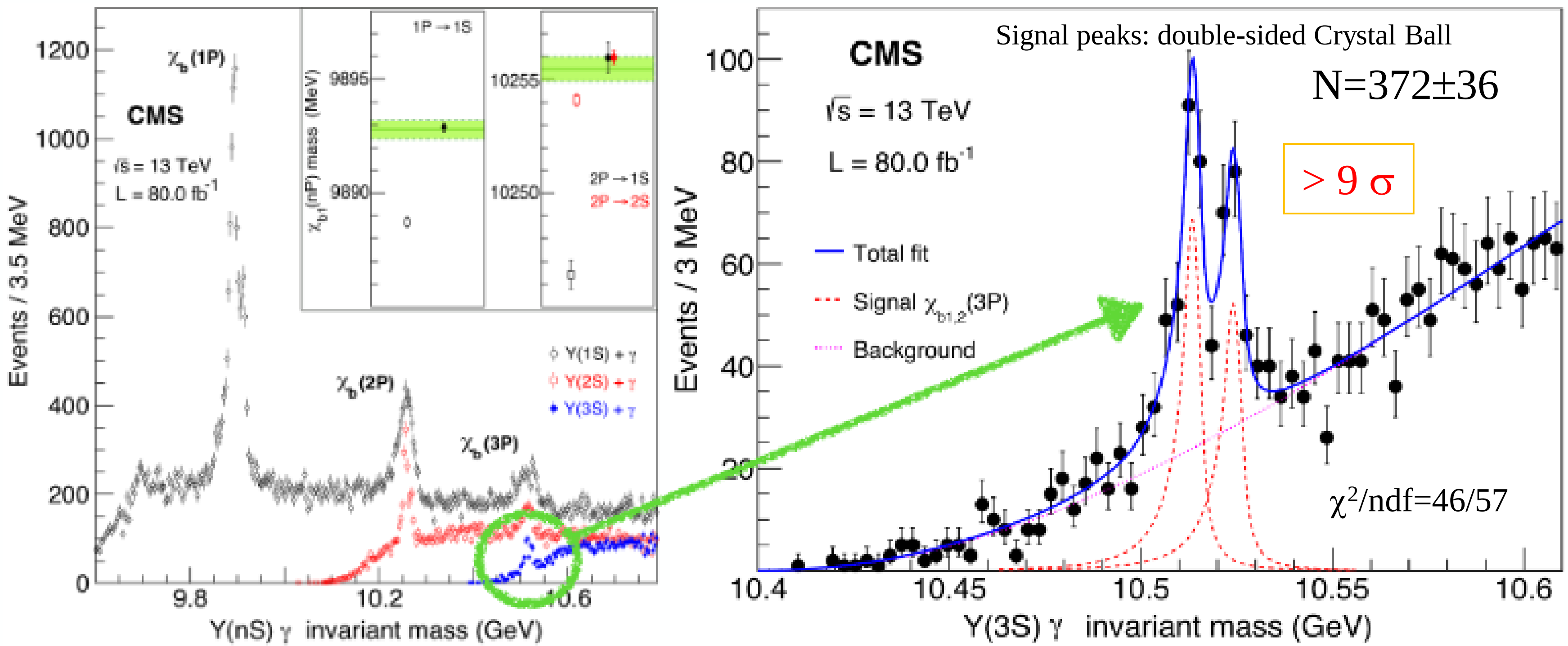
- **χ_b (3P)** is reconstructed in **Υ(3S) + γ** mode. The low energy **γ** is detected through **γ→e⁺e⁻** conversion inside the silicon tracker

- Photon energy scale is calibrated using high yield **χ_{c1} → J/ψ + γ** samples for high accuracy mass measurements

- Tested with **χ_b (1P, 2P)** states



CMS: Observation of two resolved states $\chi_{b1,2}(3P)$



PRL 121 (2018) 092002

M_1 = 10513.42 ± 0.41(stat) ± 0.18(syst) MeV

M_2 = 10524.02 ± 0.57(stat) ± 0.18(syst) MeV

ΔM = 10.6 ± 0.64(stat) ± 0.17(syst) MeV

This result strongly disfavours the breaking of the conventional pattern of splittings and supports the standard mass hierarchy.

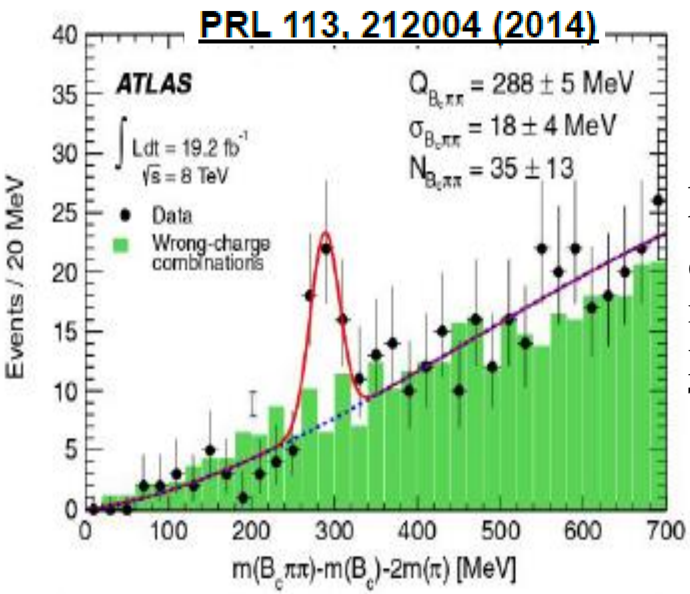
J=1,2 states well resolved for the first time

Significantly constrains theoretical predictions, which give mass splits in the range [-2, 18] GeV

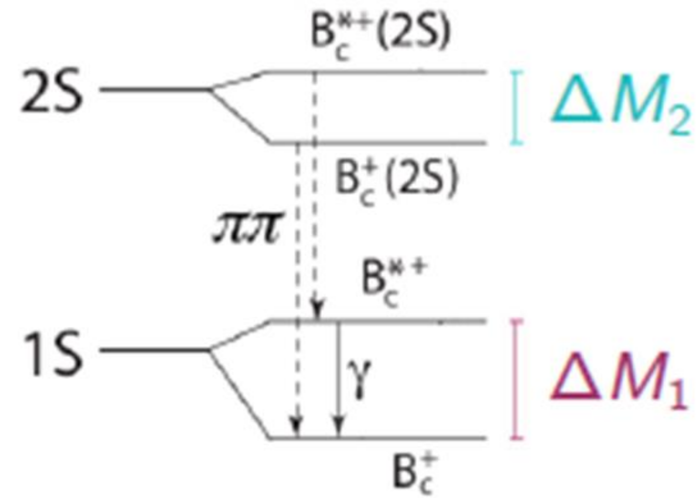
This measurement fills a gap in the spin-dependent bottomonium spectrum below the open-beauty threshold and should significantly contribute to an improved understanding of the non-perturbative spin-orbit interactions affecting quarkonium spectroscopy.

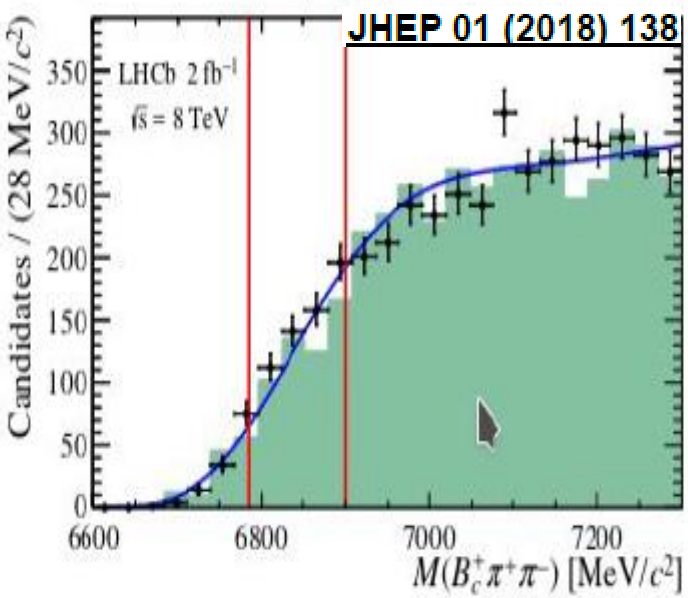
Excited B_c^+ states

The spectrum of B_c (bc) states will help to understand in a greater depth the dynamics of heavy-heavy quark systems



ATLAS reported the observation (5.4σ) of a new state with mass consistent with predictions for the Bc(2S)+. They used Run I data.





LHCb with 3325+-73 Bc+ (8 TeV data): "no significant signal is found"

[$M(B_c(1S)^*)$ - $M(B_c(1S))$] > [$M(B_c(2S)^*)$ - $M(B_c(2S))$]

$B_c(2S)^* \rightarrow B_c^* \pi^+ \pi^-$ followed by $B_c^* \rightarrow B_c \gamma_{lost}$

$B_c(2S) \rightarrow B_c \pi^+ \pi^-$

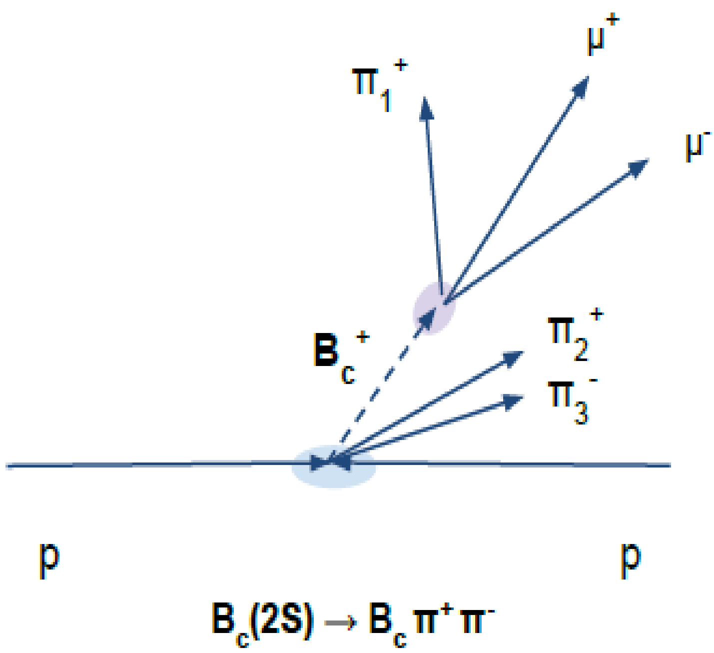
Two-peak structure with the $B_c(2S)^*$ peak at a mass shifted by

ΔM = [$M(B_c^*)$ - $M(B_c)$] - [$M(B_c(2S)^*)$ - $M(B_c(2S))$]

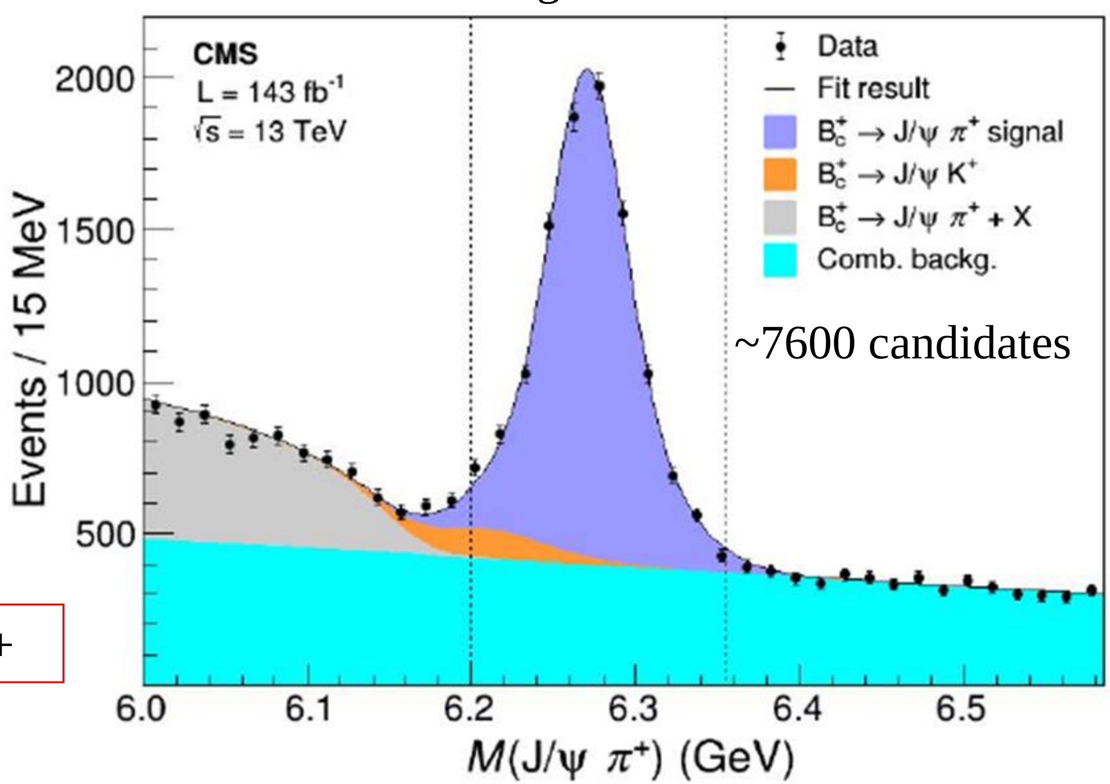
Theory predicts ~20 MeV

CMS: Selection of excited B_c^+ candidates

[Phys.Rev.Lett. 122 (2019) 132001]



Reconstructed ground state Bc+

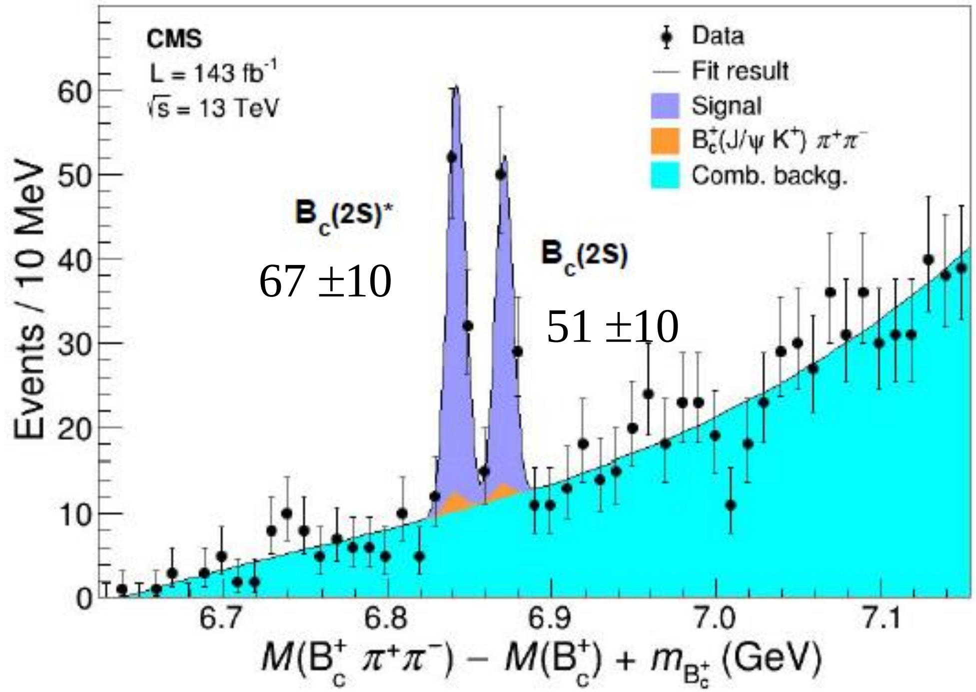


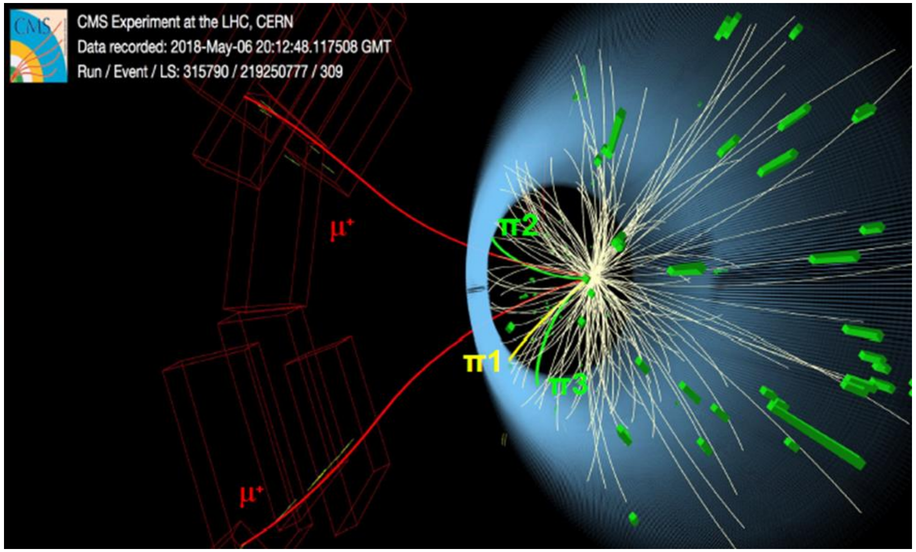
Full Run II data analysis, Bc+ → J/ψ π+

Selection:
Pt(pi1 –from Bc) >3.5 GeV;
Bc meson momentum (pt>15 GeV) should point to the PV in xy;
Pi2 (pt>0.8) and pi3 (pt>0.6) are tracks from PV which are combined with Bc+;
keep only one Bc+ pi2 pi3 combination with highest pt.

CMS: Observation of two excited B_c^+ states and measurement of $B_c(2S)^+$ mass

[Phys.Rev.Lett. 122 (2019) 132001]

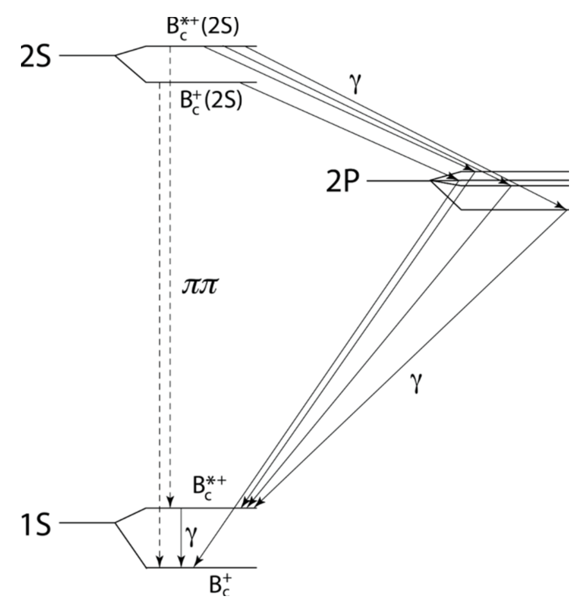




Mass resolution from MC ~ 6 MeV

Two-peak structure observed, well resolved:
$\Delta M = \Delta M1 - \Delta M2 = 29.1 \pm 1.5 \pm 0.7$ MeV,
each with > 5 σ significance

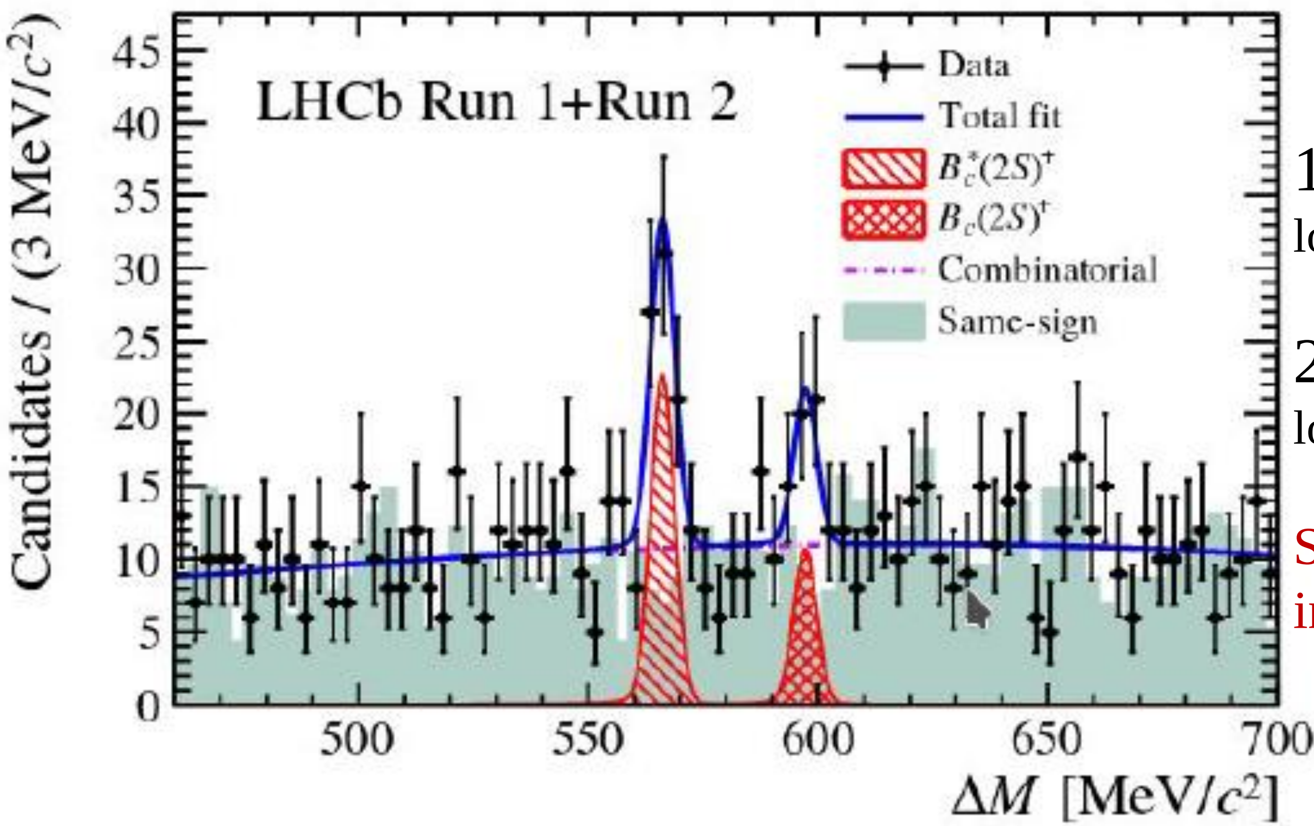
Mass of Bc+(2S):
$$6871.0 \pm 1.2(\text{stat}) \pm 0.8(\text{syst}) \pm 0.8(B_c^+)\ \text{MeV}$$



(12)

LHCb has confirmed the two-peaks-B_c*(2S) structure

PRL 122 (2019) 232001



1[st] peak:
local signif.=6.8σ, N=51±10

2[nd] peak:
local signif.=3.2σ, N=24±9

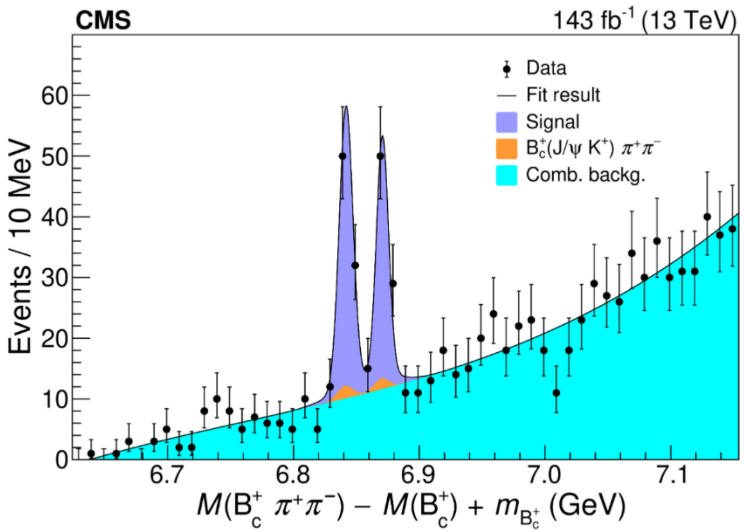
Smaller yields
in comparison with CMS.

The mass of Bc(2S)+ and ΔM are in agreement with CMS
and statistical errors are similar:

	$M(B_c(2S)^+)$, MeV	ΔM, MeV
CMS	$6871.0 \pm 1.2 \pm 0.8 \pm 0.8$	$29.1 \pm 1.5 \pm 0.7$
LHCb	$6872.1 \pm 1.3 \pm 0.1 \pm 0.8$	$31.0 \pm 1.4 \pm 0.0$

CMS: Measurement of Bc(2S) and Bc*(2S) cross-section ratios

[PRD 102 (2020) 092007]



$$R^+ \equiv \frac{\sigma(B_c(2S)^+)}{\sigma(B_c^+)} \mathcal{B}(B_c(2S)^+ \to B_c^+\pi^+\pi^-)$$

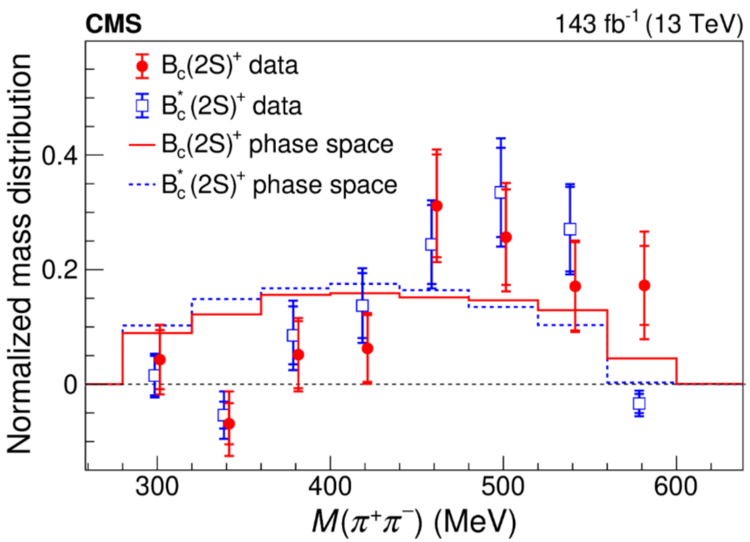
$$R^{*+} \equiv \frac{\sigma(B_c^*(2S)^+)}{\sigma(B_c^+)} \mathcal{B}(B_c^*(2S)^+ \to B_c^{*+}\pi^+\pi^-)$$

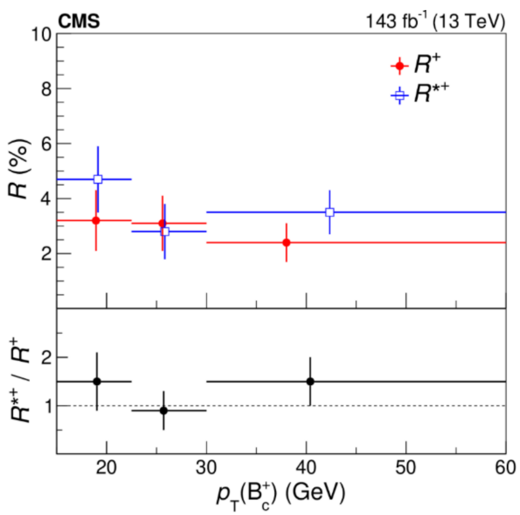
$$R^{*+}/R^+ = \frac{\sigma(B_c^*(2S)^+)}{\sigma(B_c(2S)^+)} \frac{\mathcal{B}(B_c^*(2S)^+ \to B_c^{*+}\pi^+\pi^-)}{\mathcal{B}(B_c(2S)^+ \to B_c^+\pi^+\pi^-)}$$

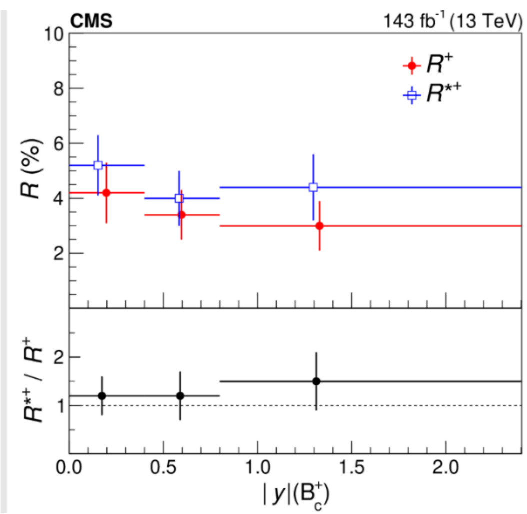
$$R^+ = (3.47 \pm 0.63\,(\text{stat}) \pm 0.33\,(\text{syst}))\%,$$

$$R^{*+} = (4.69 \pm 0.71\,(\text{stat}) \pm 0.56\,(\text{syst}))\%,$$

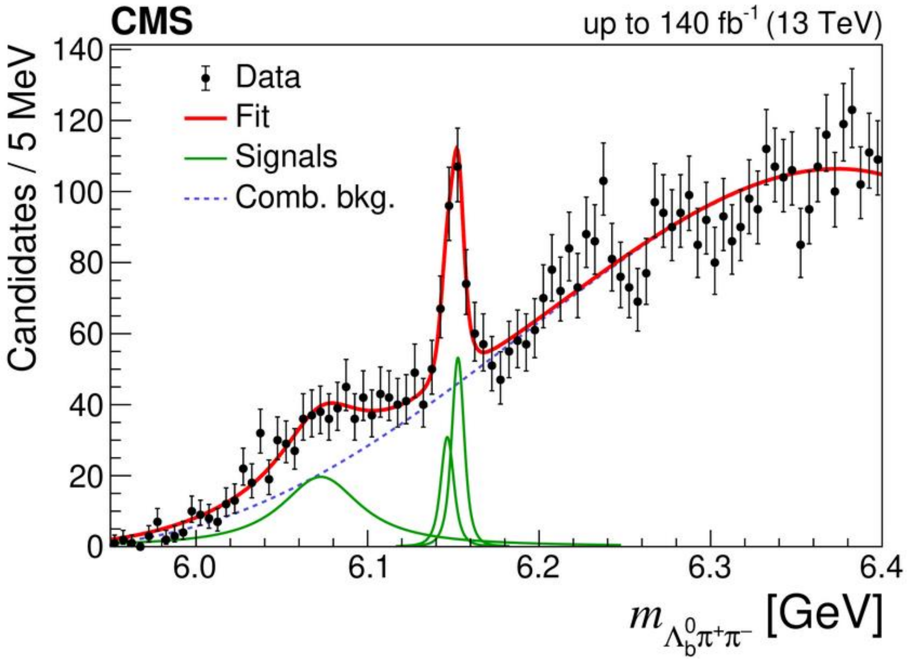
$$R^{*+}/R^+ = 1.35 \pm 0.32\,(\text{stat}) \pm 0.09\,(\text{syst}).$$







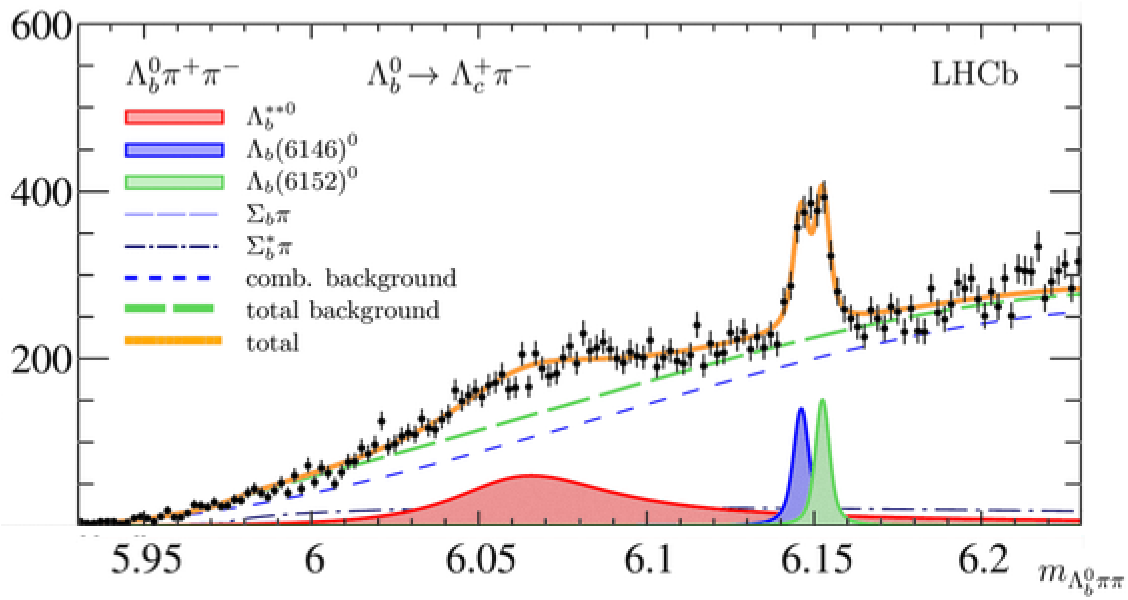
Beauty Baryons: Observation of 3 new excited Λb states



Phys. Lett. B 803 (2020) 135345

2020 hot beauty baryon topic:

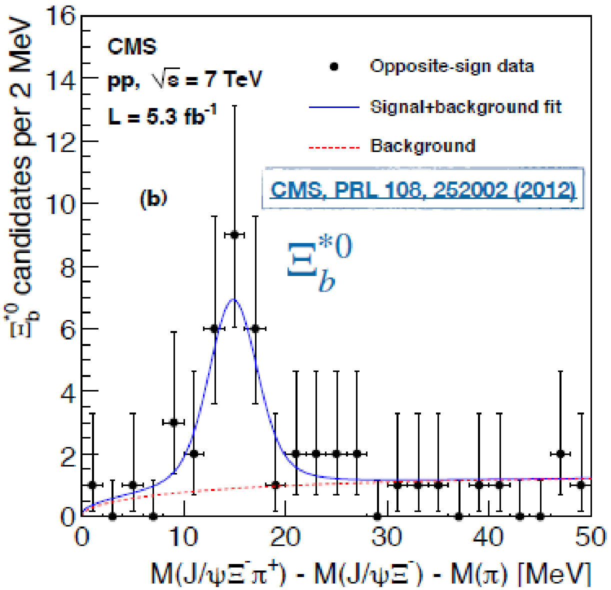
Observation by LHCb and CMS of 3 new excited Λ_b states, broad one is probably 2S state and two narrow are candidates for 1D doublet.

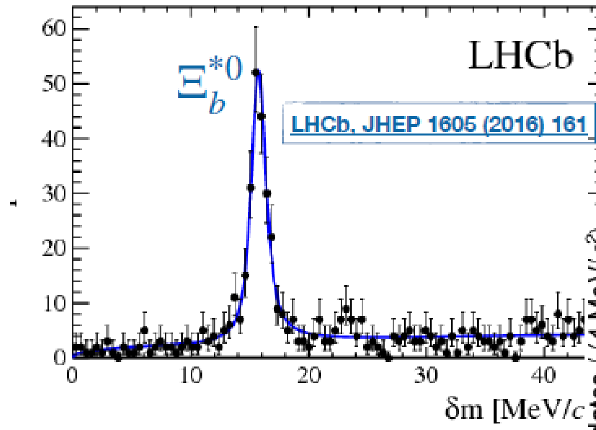


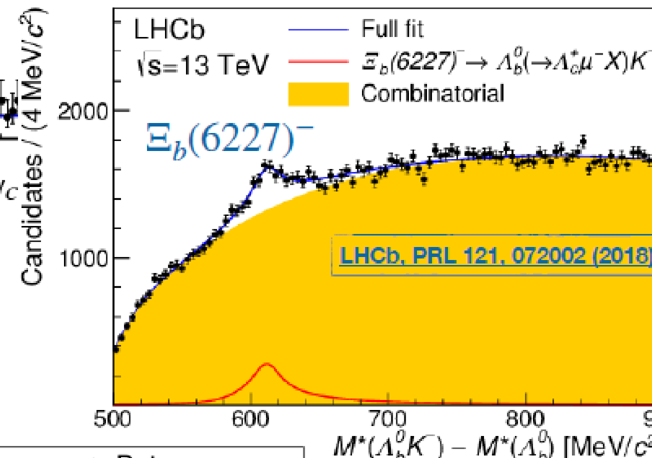
JHEP 06 (2020) 136

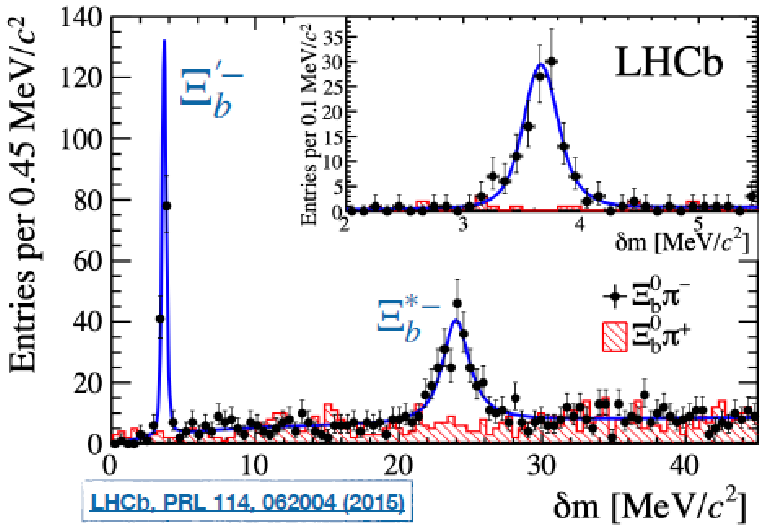
Параметры резонансов хорошо согласуются в обоих экспериментах

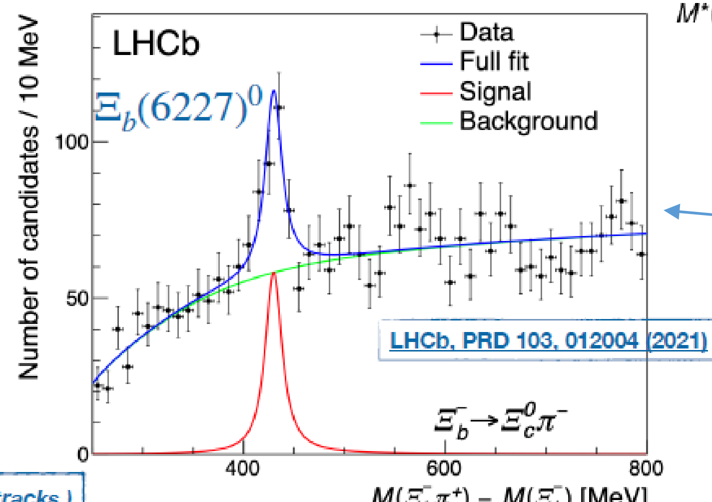
Спектроскопия прелестных странных возбужденных $\Xi_b^{-/0}$ барионов











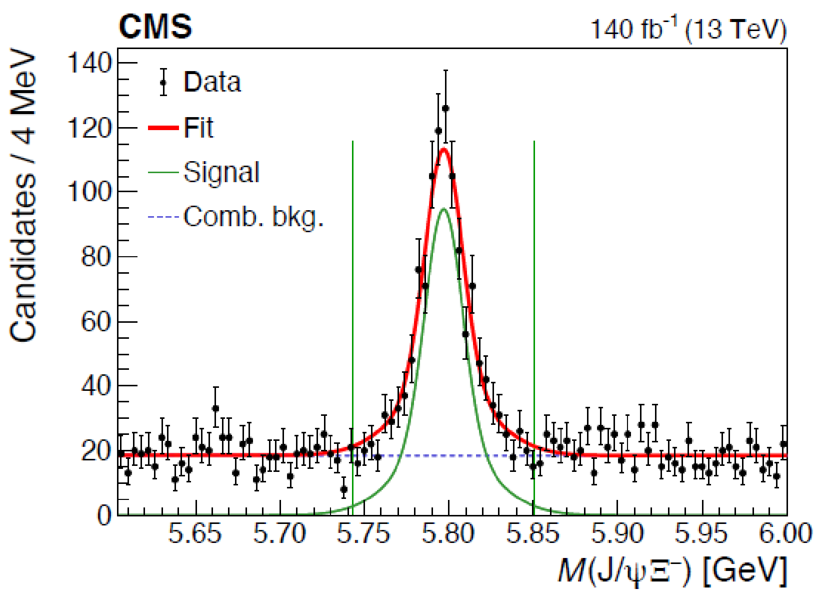
Isodoublet
$\Xi_b(6227)$
2S excitation?

Cannot reconstruct Ξ_b^0 at CMS (no hadron ID, hard to work with non-charged tracks)

Реконструкция основного состояния Ξ_b^-

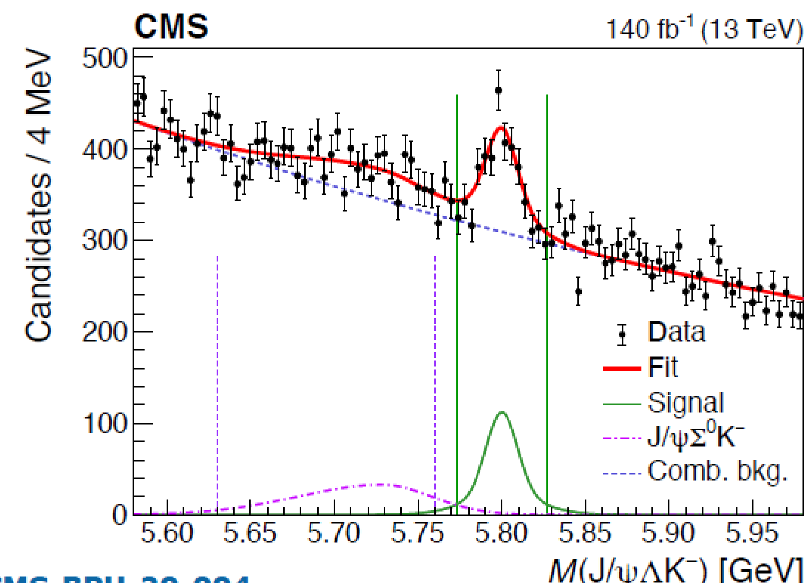
NEW

Use full Run-2 2016-2018 CMS data ($140\ fb^{-1}$, $\sqrt{s} = 13$ TeV) to search for a new $\Xi_b^{**-} \to \Xi_b^{*0}\pi^- \to \Xi_b^-\pi^+\pi^-$ resonance, basing on theoretical predictions and excited Ξ_c^{**} charm analogies



$N = 859 \pm 36$
$m = 5797.0 \pm 0.7$ MeV
$\sigma_{eff} = 19.0$ MeV (from MC)

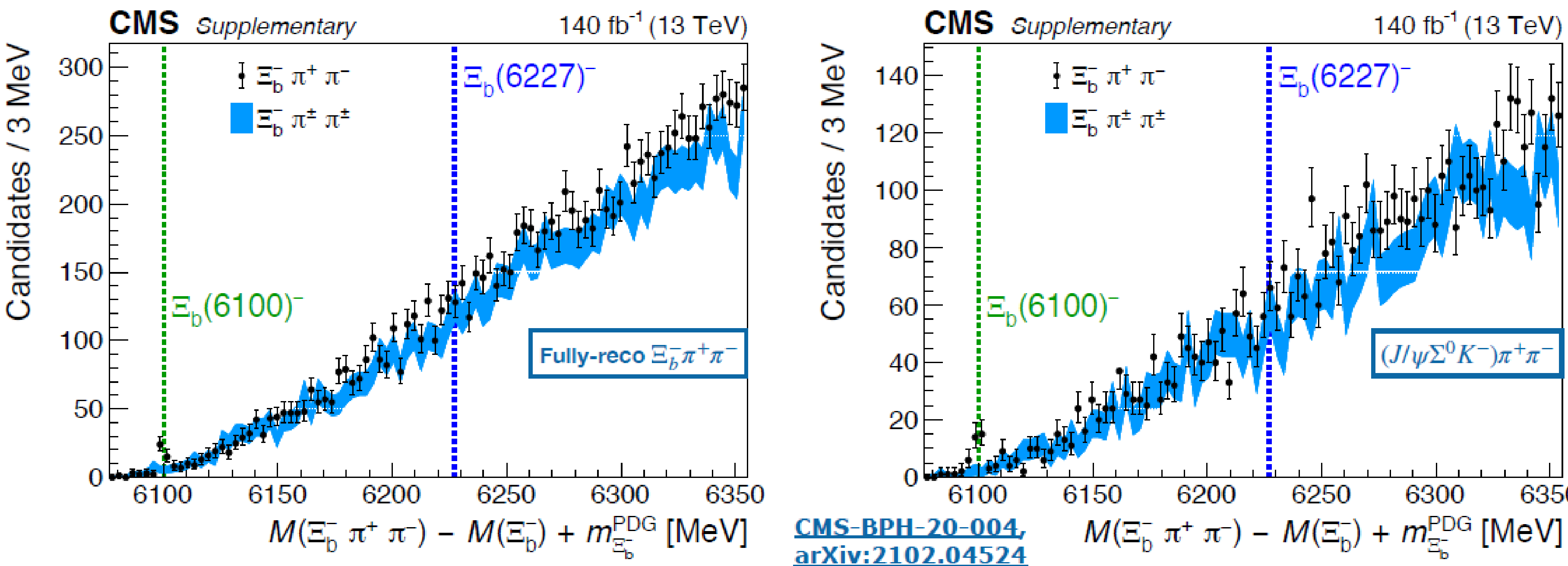
CMS-BPH-20-004, arXiv:2102.04524



$N = 815 \pm 74$
$m = 5800.1 \pm 1.2$ MeV
$\sigma_{eff} = 14.9$ MeV (from MC)
$N_{J/\psi\Sigma^0K^-} = 820 \pm 158$

Обнаружение нового прелестного странного возбужденного бариона $\Xi_b(6100)^-$

NEW

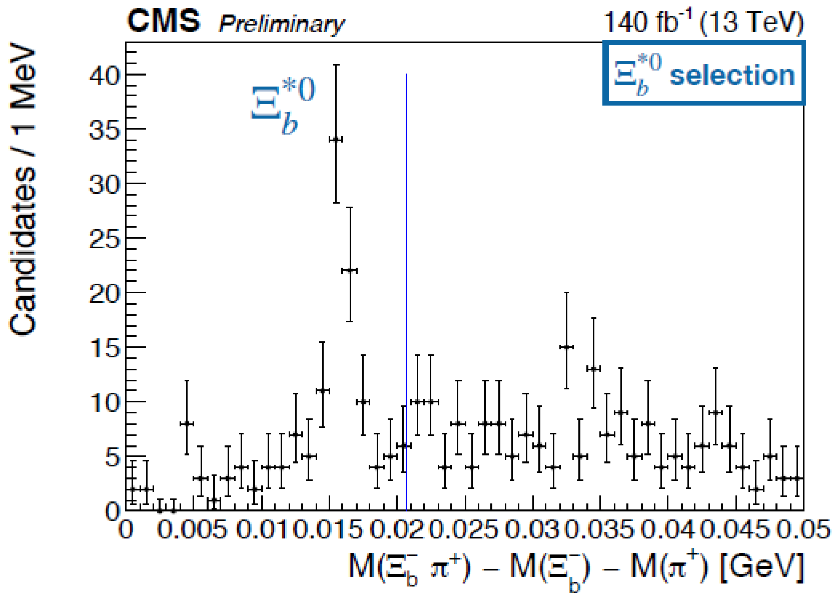


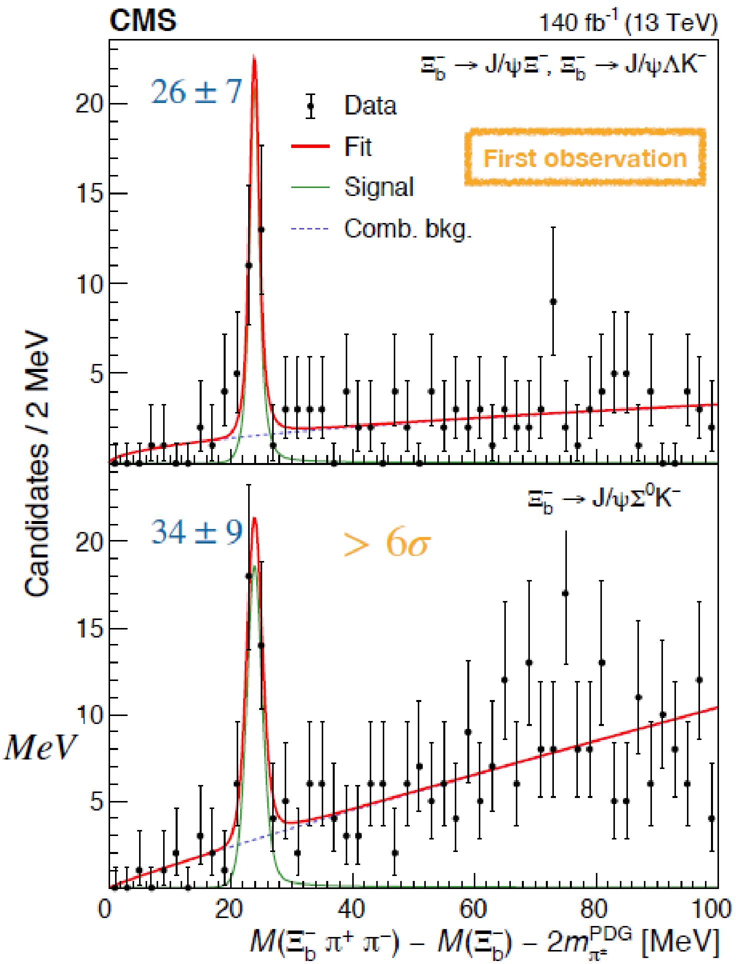
CMS-BPH-20-004, arXiv:2102.04524

- Invariant mass distribution of the selected $\Xi_b^- \pi\pi$ candidates with no requirements on the $\Xi_b^- \pi^+$ mass, for the opposite-sign (OS, circles) and same-sign (SS, band) events.

Узкий пик на пороге!

Обнаружение нового прелестного странного возбужденного бариона $\Xi_b(6100)^-$





arXiv:2102.04524

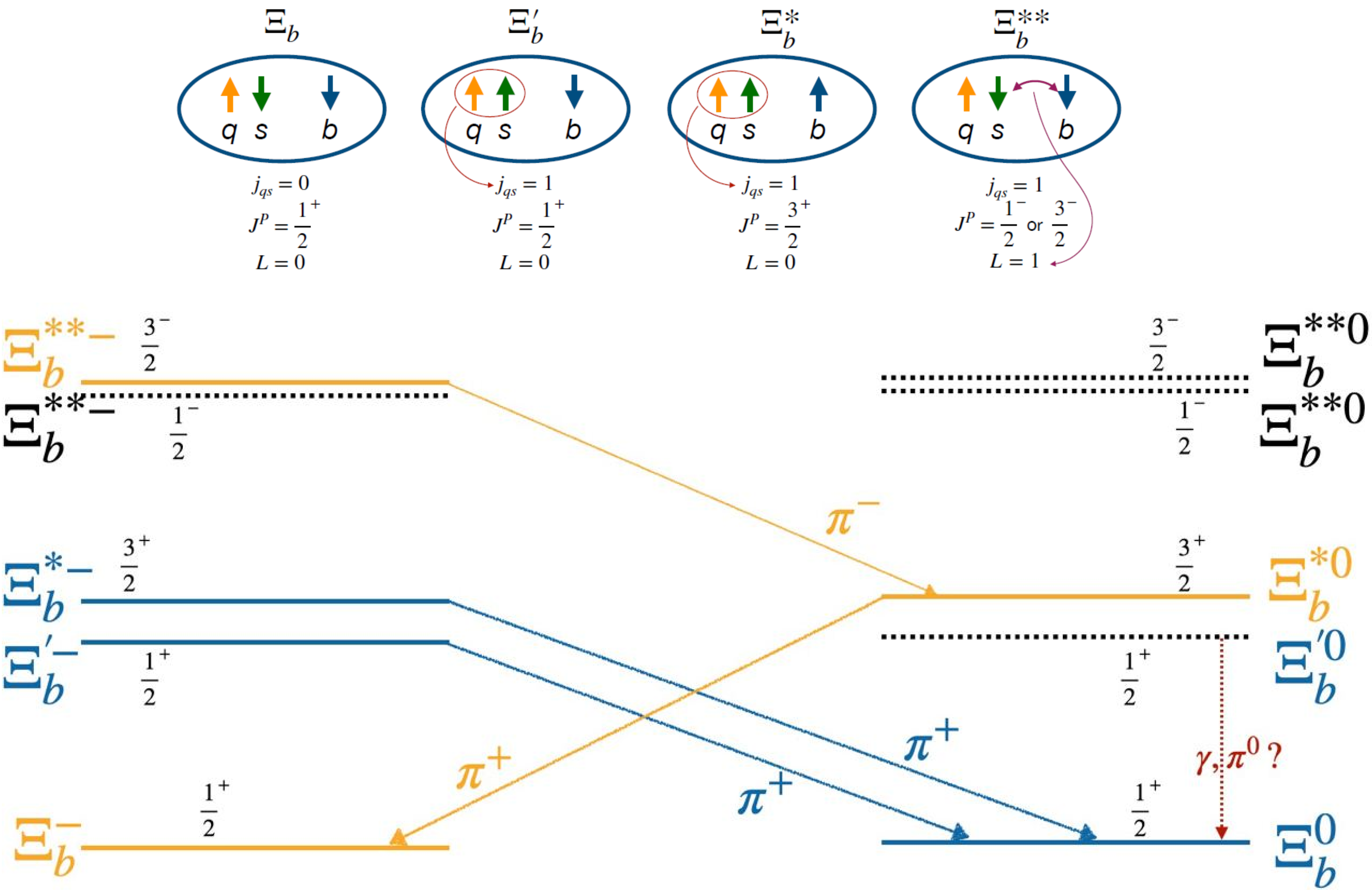
$$M(\Xi_b(6100)^-) - M(\Xi_b^-) - 2 \cdot m^{\mathrm{PDG}}(\pi^\pm) = 24.14 \pm 0.22 \pm 0.05\ MeV$$

$$M(\Xi_b(6100)^-) = 6100.3 \pm 0.2 \pm 0.1 \pm 0.6\ MeV$$

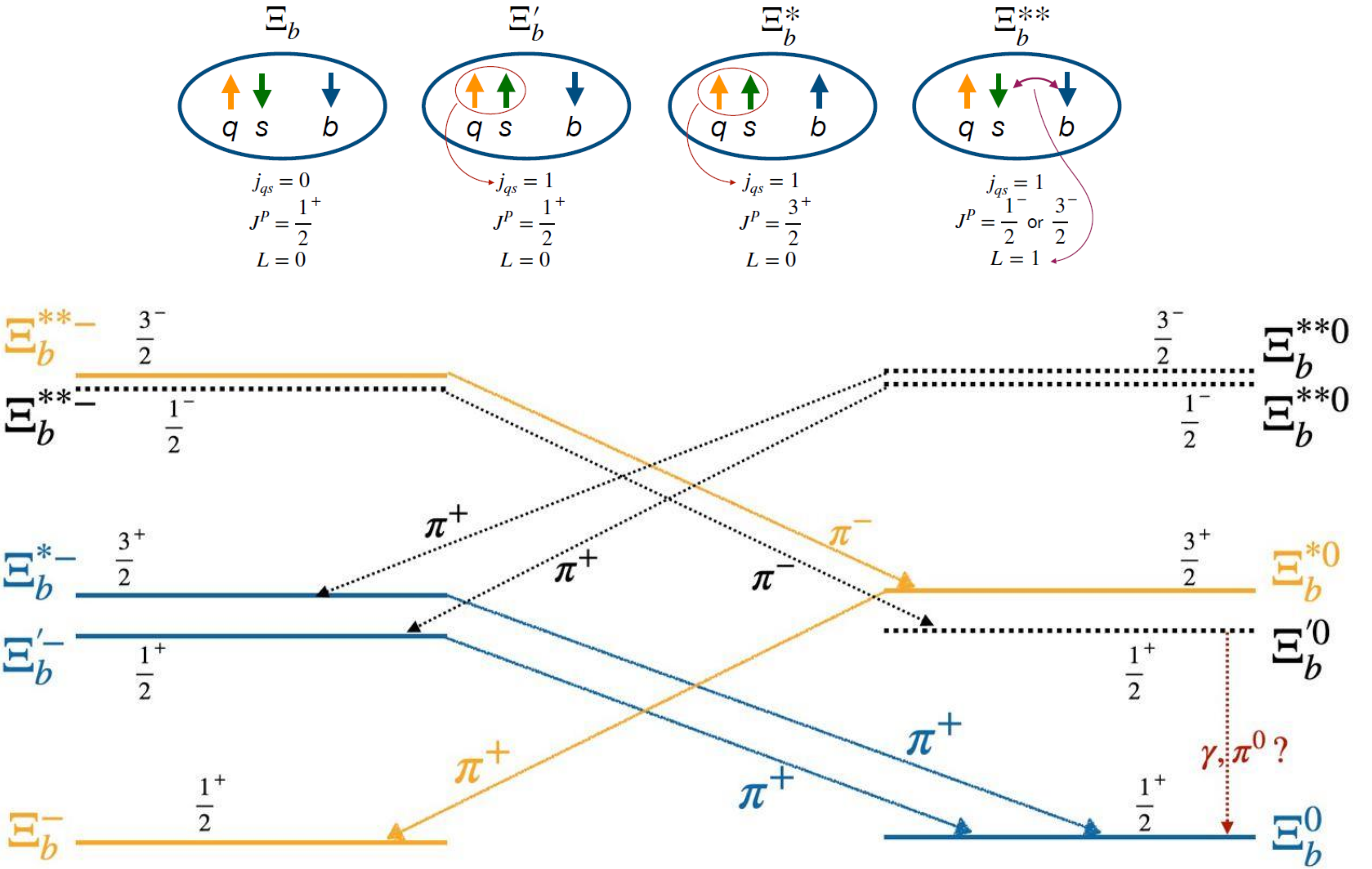
$$\Gamma(\Xi_b(6100^-) < 1.9\ MeV\ @95\ \%\ CL$$

CMS physics Briefing is available on the CMS website:
cern.ch/go/lVT7

Спектроскопия прелестных странных возбужденных $\Xi_b^{-/0}$ барионов



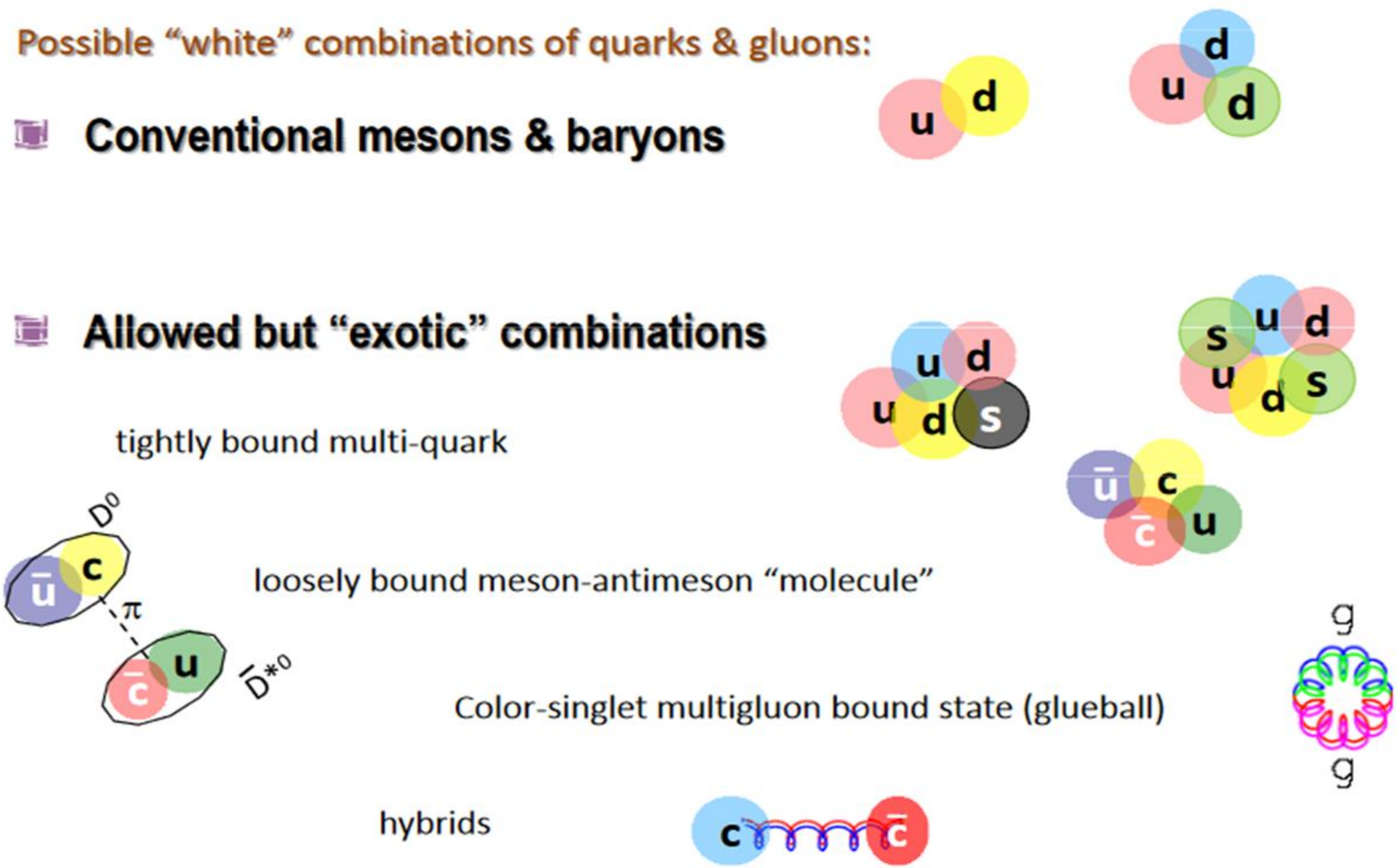
Спектроскопия прелестных странных возбужденных $\Xi_b^{-/0}$ барионов



В поисках многокварковых состояний

Hadrons: Conventional and Exotic

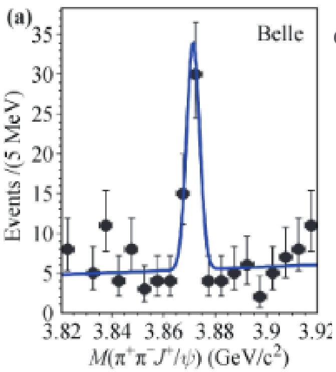
Are there any quark configurations other than mesons and baryons?
In theory such configurations are possible.
Which of them are realized in reality, in nature?

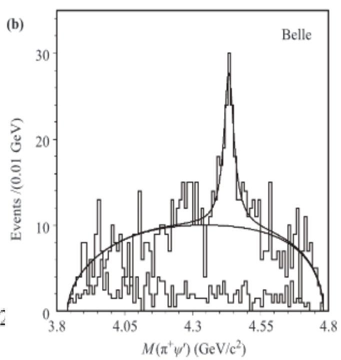


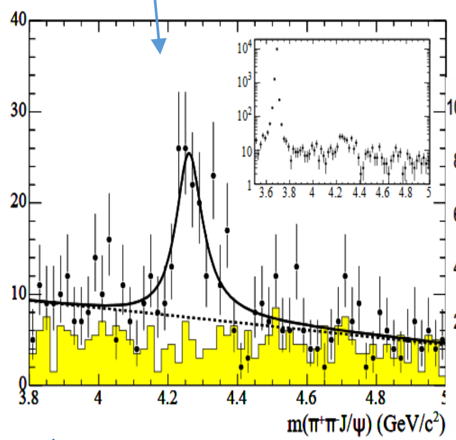
Exotic Hadrons: experimental results
and theoretical interpretation

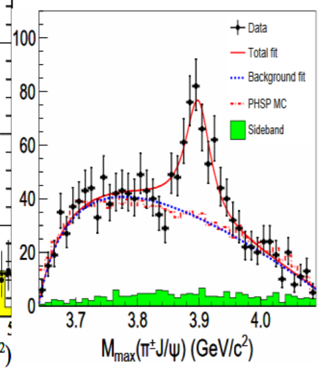
From 2003, thanks to B-factories Belle and BaBar (and then BES III and LHCb), the number of the candidates to exotic hadrons is growing continuously.
These are multiquark states. Some bright examples are
X(3872), Z(4430)+, from Belle, Y(4260) from BaBar, Z(3900)+ from BESIII /Belle

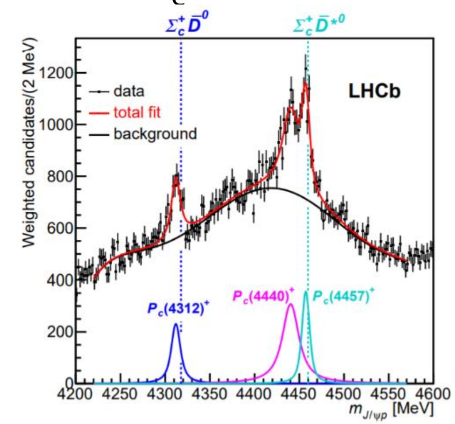
and P_c from LHCb.











This is a New Hadron Spectroscopy Era

Theoretical interpretation of all these exotic states still not clear.

Hadrocharmonium ?
Molecule ?
Rescattering
(threshold effect, cusp) ?
Tetraquark ?

→ **WE NEED MORE INFORMATION !**

Evidence for X(5568) → Bs π^+ by D0 Collaboration
→ search for this state in CMS.

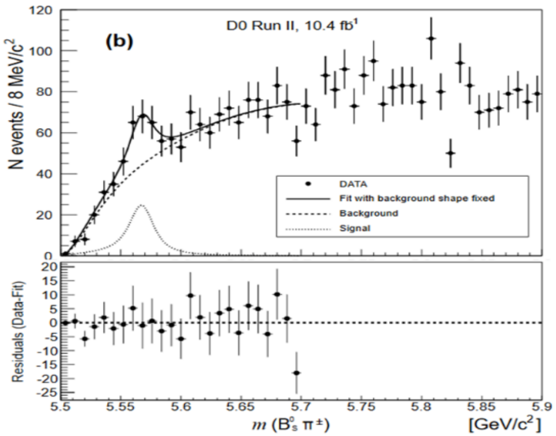
Поиск тетракварков, содержащих b-кварк

- Поиск X(5568) $\rightarrow$ Bs0 π+
- Поиск новых резонансов Xb $\rightarrow$ Y(1S) π+π-
- Поиск новых резонансов в системе Y(1S) μ+μ-

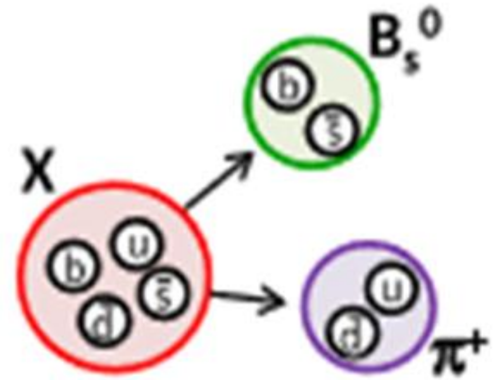
D0 Collaboration: Evidence for X(5568), new state decaying into Bs π+

Search for $X(5568)^+ \rightarrow B_s\,\pi^+$

PRL117. 022003(2016)



If confirmed, would be unique with 4 different flavours

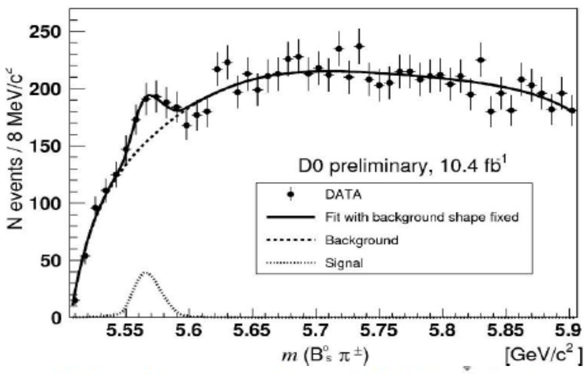


$$M = 5567.8 \pm 2.9^{+0.9}_{-1.9}\ \text{MeV},$$
$$\Gamma = 21.9 \pm 6.4^{+5.0}_{-2.5}\ \text{MeV},$$

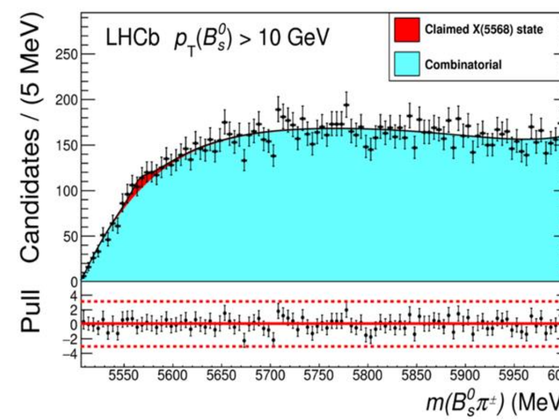
$$\rho_X^{D0} \equiv \frac{\sigma(p\bar{p} \to X + \text{anything}) \times \mathcal{B}(X \to B_s^0\pi)}{\sigma(p\bar{p} \to B_s^0 + \text{anything})} = (8.6 \pm 1.9 \pm 1.4)\%$$

Rather big number for the prompt production of 4-quark exotic state

D0 Conf. Note 6896



Similar results with $B_s^0 \to D_s \mu\nu$



PRL117. 152003(2016)

$$\rho_X^{\text{LHCb}}(p_T(B_s^0) > 5\,\text{GeV}) < 0.011\ (0.012)$$
$$\rho_X^{\text{LHCb}}(p_T(B_s^0) > 10\,\text{GeV}) < 0.021\ (0.024)$$
$$\rho_X^{\text{LHCb}}(p_T(B_s^0) > 15\,\text{GeV}) < 0.018\ (0.020)$$

Search for X(5568)+ in CMS is actual:

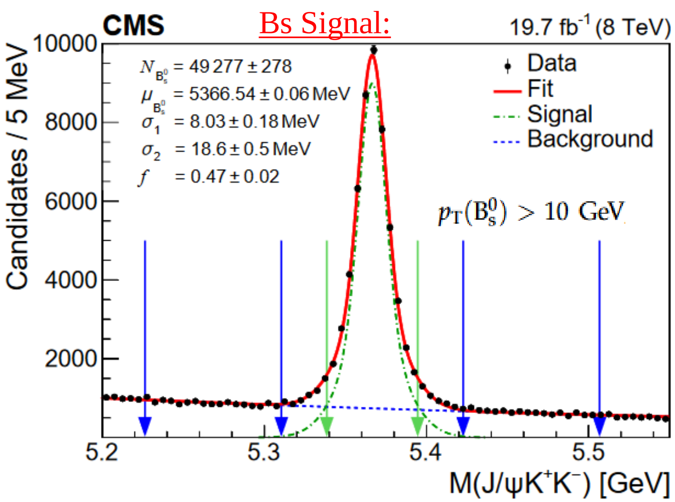
- Different η interval with LHCb,
- Beauty hadron production conditions are similar in D0 and CMS.

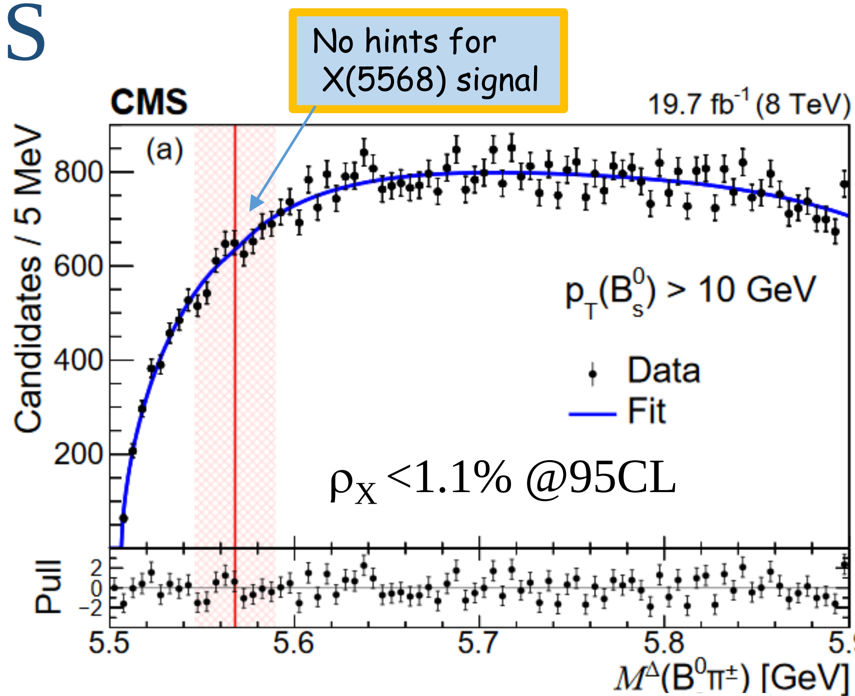
Search for X(5568) in CMS

$$\rho_X^{D0} \equiv \frac{\sigma(p\bar{p} \to X + \text{anything}) \times \mathcal{B}(X \to B_s^0 \pi)}{\sigma(p\bar{p} \to B_s^0 + \text{anything})} = (8.6 \pm 1.9 \pm 1.4)\%$$

CDF: A 95% C.L. upper limit of 6.7%

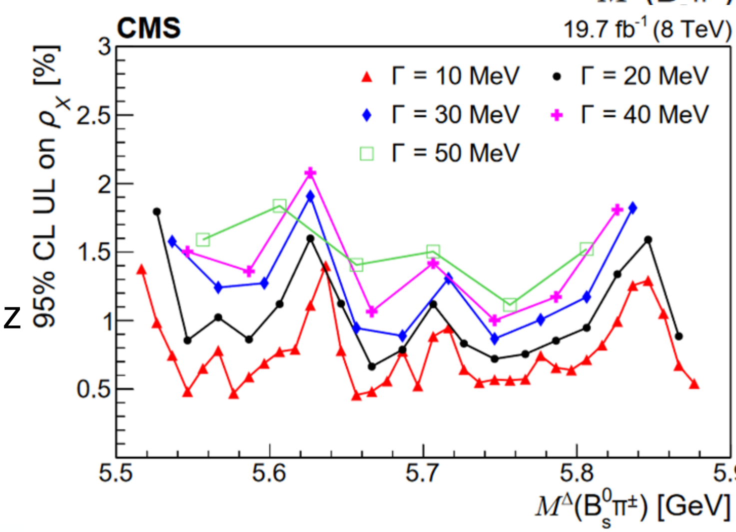
Phys.Rev.Lett. 120 (2018) no.20, 202006





PRL 120 (2018) 202005

By varying selection criteria, background parameteriz fit range and method of data description, the yield for X(5568) remains consistent with 0.



No evidence for X(5568) at the LHC

$\rho_X^{\text{ATLAS}} < 0.015$ at 95% CL for $p_T(B_s^0) > 10$ GeV

$\rho_X^{\text{ATLAS}} < 0.016$ at 95% CL for $p_T(B_s^0) > 15$ GeV

Phys.Rev.Lett. 120 (2018) no.20, 202007

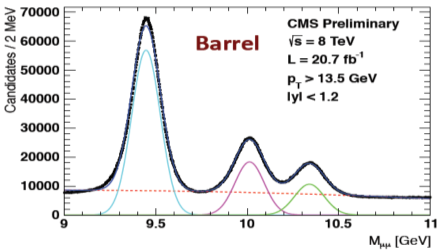
$\rho_X^{\text{CMS}} < 1.1\%$ at 95% CL for $p_T(B_s^0) > 10$ GeV

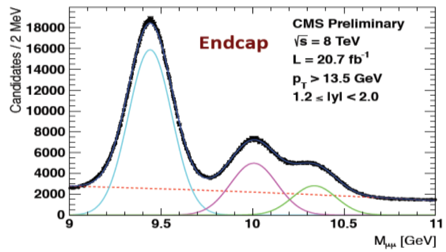
$\rho_X^{\text{CMS}} < 1.0\%$ at 95% CL for $p_T(B_s^0) > 15$ GeV

PLB 727 (2013) 57

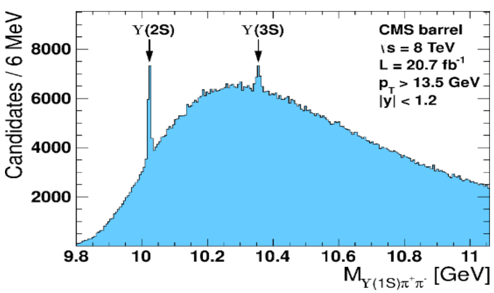
Search for exotic bottomonium states X_b decaying into $\Upsilon(1S)\ \pi^+\pi^-$

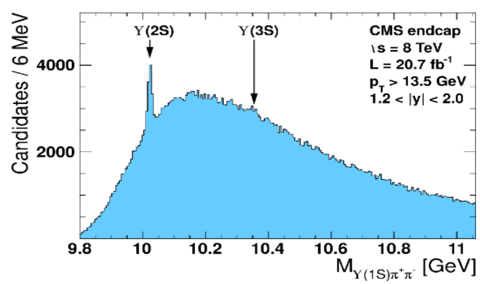
- The discovery of the X(3872) has prompted the search for a bottomonium counterpart $X_b \rightarrow \Upsilon(1S)\ \pi^+\pi^-$, according to HQS considerations - with mass close to the BB or BB* threshold, 10.562 and 10.604 GeV.
- It is expected that this X_b would be narrow, similar to X(3872), and has sizable Br.fr. to $\Upsilon(1S)\ \pi^+\pi^-$.





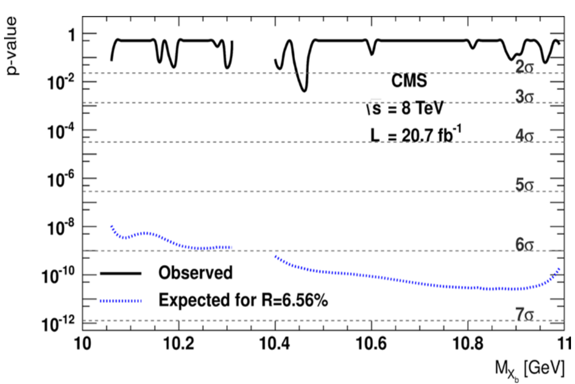
CMS has collected a large sample of $\Upsilon(nS) \rightarrow \mu^+\mu^-$ produced in pp collisions at 8TeV.
Separate barrel and endcap events to exploit better mass resolution and lower background in the barrel region.

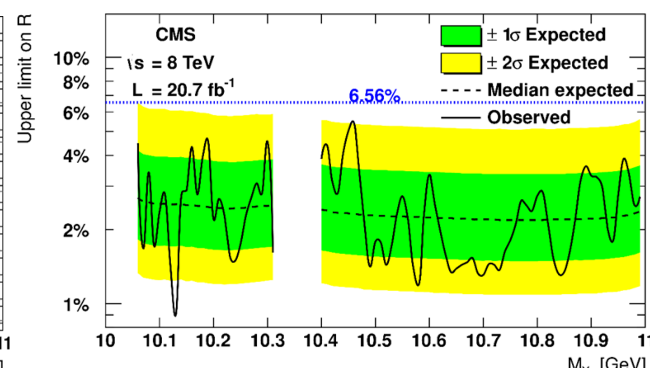




$p_T(\Upsilon(1S)\pi^+\pi^-) > 13.5$ GeV and $|y(\Upsilon(1S)\pi^+\pi^-)| < 2.0$

No structure found apart from Y(2S) and Y(3S)



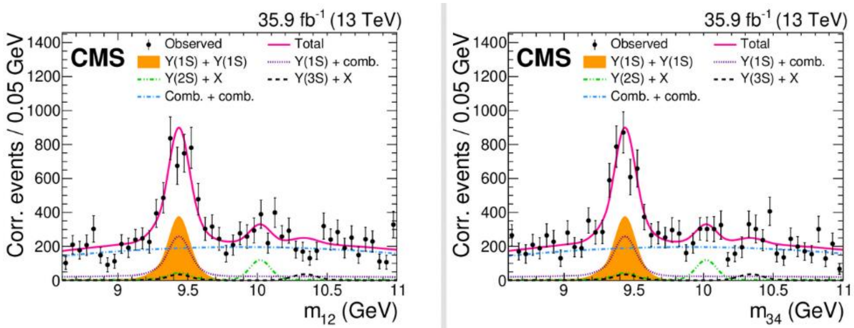


In analogy with the X(3872), expected signal significance > 5 σ if X_b(Br x cross-section)>6.5% of the corresponding product for $\Upsilon(2S) \rightarrow \Upsilon(1S)\ \pi^+\pi^-$ (R value)

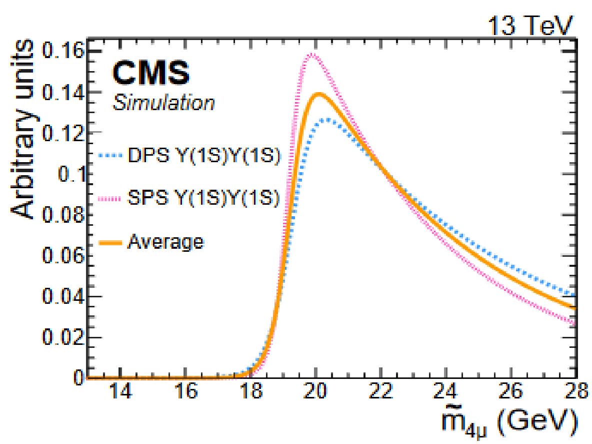
Measurement of the Υ(1S) pair production cross section and search for resonances decaying to Υ(1S)μ+μ− in proton-proton collisions at s√= 13 TeV

arXiv:2002.06393, submitted to PLB

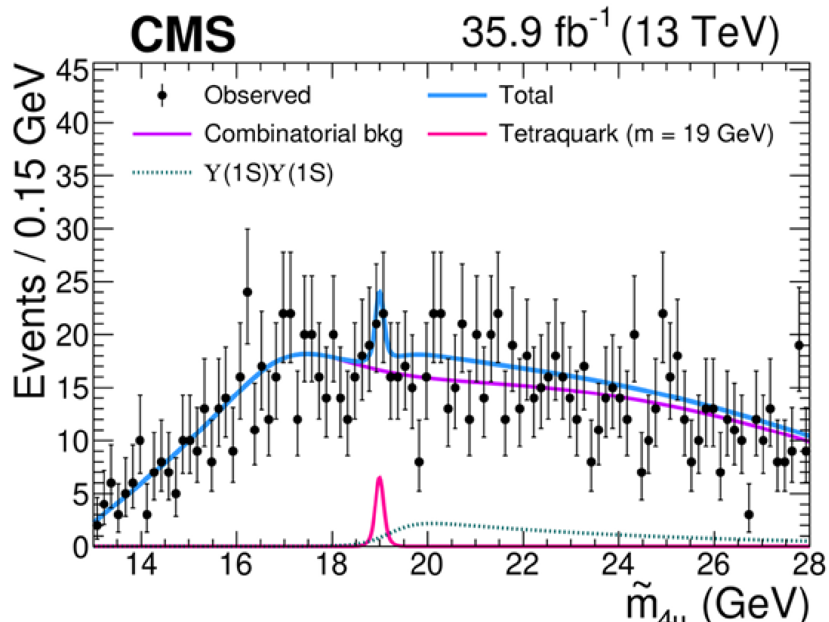
- Tetraquarks composed of 2 b quarks and 2 b anti-quarks could decay to a Υ(1S) + 2 leptons that possibly come from a Υ(1S) off-shell decay.
- Even with a small production cross section, it could result in a prominent signature at the LHC



The two projections and the results of the 2D fit to the muon pair invariant masses.



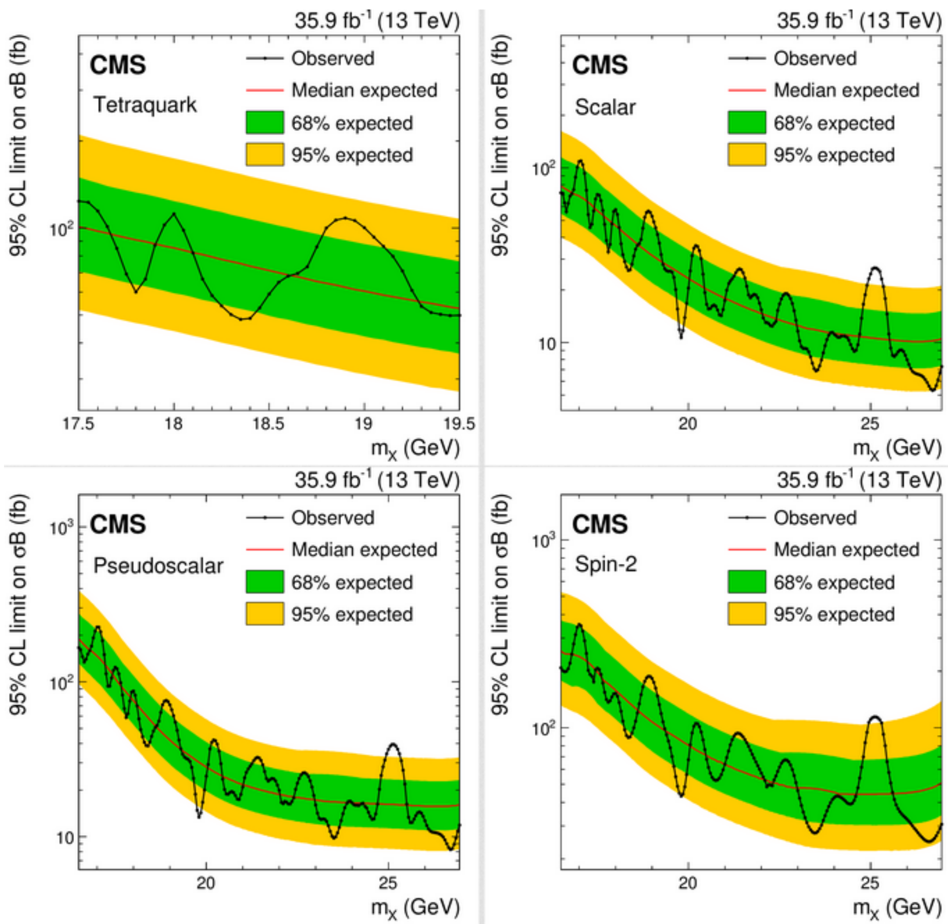
Distributions of $\tilde{m}_{4\mu}$ for simulated Υ(1S)Υ(1S) events.



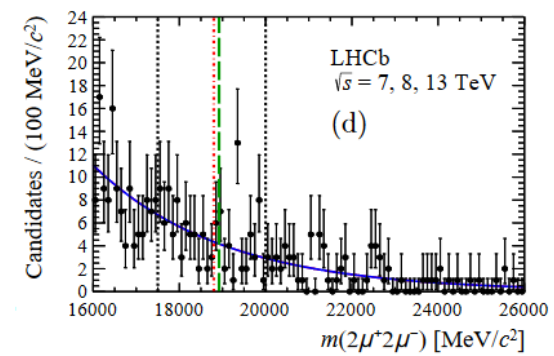
Measurement of the Υ(1S) pair production cross section and search for resonances decaying to Υ(1S)μ+μ− in proton-proton collisions at s√= 13 TeV

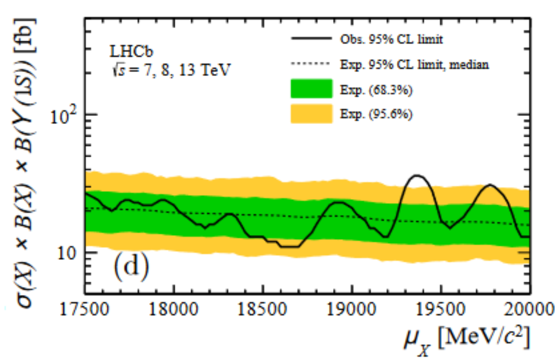
arXiv:2002.06393, submitted to PLB

UL's at 95% CL on the σxBr



LHCb results





Поиск очарованных пентакварков
в системах **$J/\psi\ \Lambda$** и **$J/\psi\ p$**
из барионного распада B^+ мезона

$B^+ \rightarrow J/\psi\ \Lambda\ p$

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

JHEP 12 (2019) 100

Motivation and experimental situation

$M(J/\psi\bar{\Lambda})$ and $M(J/\psi p)$ study

The study is motivated by the recent observation of P^+_c states by LHCb collaboration in $J/\psi p$ system. This decay provides a possibility to study both $J/\psi\Lambda$ and $J/\psi p$ systems.

New states are expected near threshold in The extended chromomagnetic model.

C. W. Xiao, J. Nieves, and E. Oset, "Prediction of hidden charm strange molecular baryon states with heavy quark spin symmetry",
Phys. Lett. B799 (2019) 135051

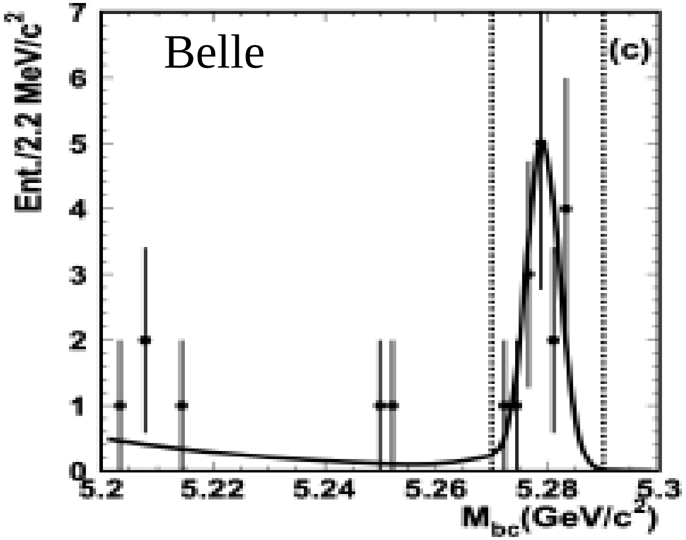
The existence of a molecular baryon decaying to $J/\psi\ \Lambda$ has been predicted

X.-Z. Weng, X.-L. Chen, W.-Z. Deng, and S.-L. Zhu,
"Hidden-charm pentaquarks and Pc states",Phys. Rev. D 100 (2019) 016014

Measurement of the $\mathscr{B}(B^+ \to J/\psi\bar{\Lambda}p)$

The only available measurement at the moment performed by Belle in 2005 with a large uncertainty Phys.Rev. D72:051105, 2005

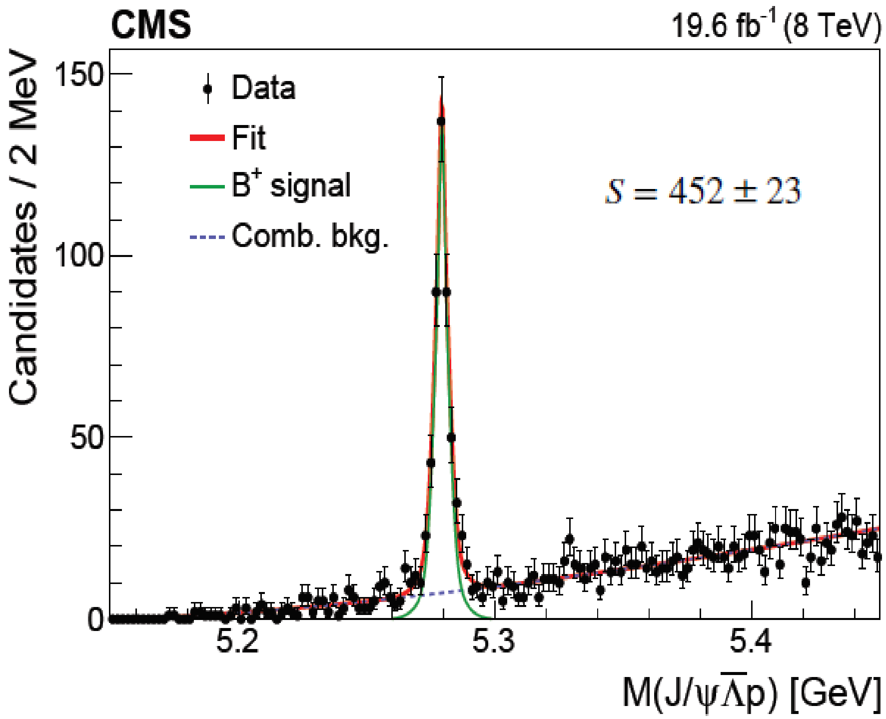
Br.fr.= $(11.6 \pm 2.8\ ^{+1.8}_{-2.3}) \times 10^{-6}$



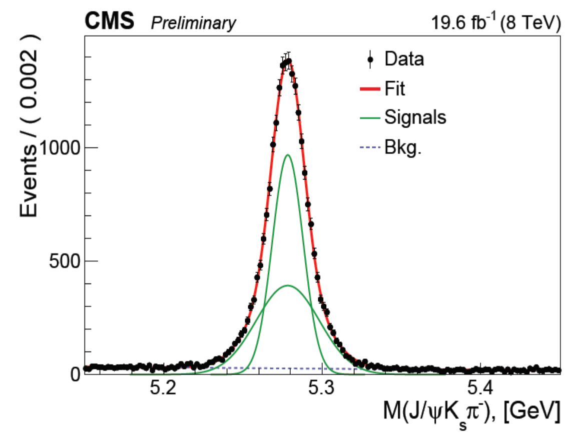
CMS: Study of $B^+ \to J/\psi \bar{\Lambda} p$

JHEP 12 (2019) 100

This study is based on 2012 8 TeV data (19.6 fb^{-1})



The B+ → J/ψ K*+ → J/ψ (K0s π+) was chosen as a normalization channel since it has the same decay topology and measured with high precision



$$\frac{\mathscr{B}(B^+ \to J/\psi\bar{\Lambda}p)}{\mathscr{B}(B^+ \to J/\psi K^{*+})} = (1.054 \pm 0.057(stat.) \pm 0.028(syst.) \pm 0.011(br.)) \times 10^{-2},$$

and using $\mathscr{B}(B^- \to J/\psi K^{*-}) = (1.43 \pm 0.08) \times 10^{-2}$

$$\mathscr{B}(B^+ \to J/\psi\bar{\Lambda}p) = (15.07 \pm 0.81(stat.) \pm 0.40(syst.) \pm 0.86(br.)) \times 10^{-6}$$

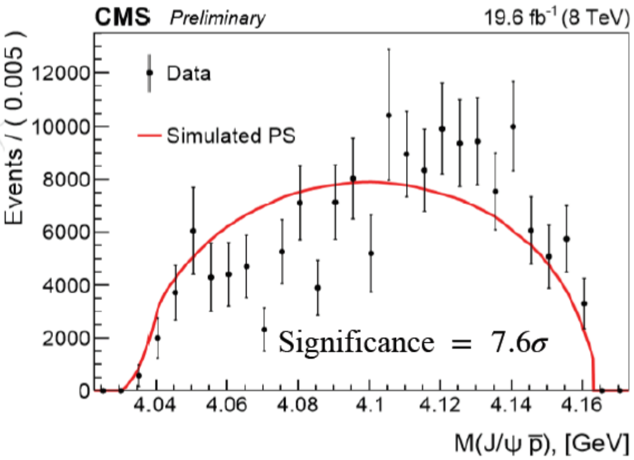
PDG mean value of $\mathscr{B}(B^+ \to J/\psi\bar{\Lambda}p) = (11.8 \pm 3.1) \times 10^{-6}$

The latest Belle measurement $\mathscr{B}(B^+ \to J/\psi\bar{\Lambda}p) = (11.7 \pm 2.8^{+1.8}_{-2.3}) \times 10^{-6}$

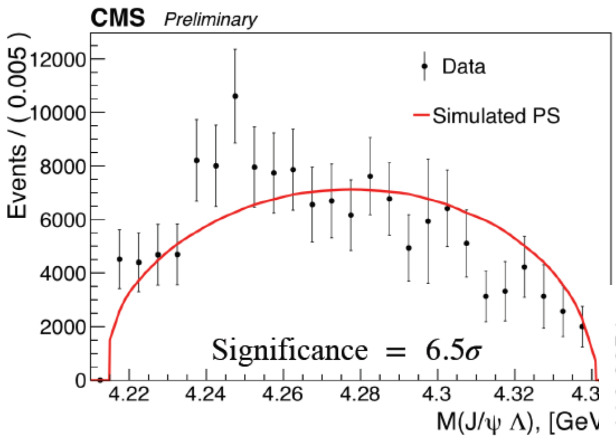
CMS: Study of $B^+ \to J/\psi \, \overline{\Lambda} \, p$

JHEP 12 (2019) 100

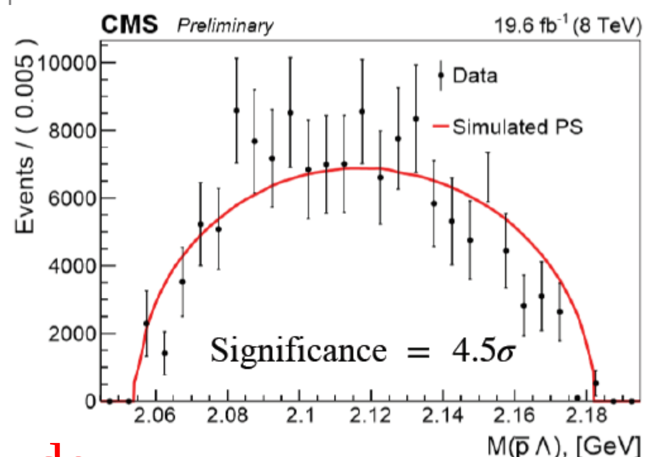
Comparison of phase space MC with efficiency corrected data



The significance of incompatibility with the phase space hypothesis is > 5.5σ for $J/\psi \, \Lambda$, > 6σ for $J/\psi \, p$ and > 3.4σ for $\Lambda \, p$ mass spectra, including systematics.



The significance of data incompatibility with data is calculated using likelihood ratio method



Before assuming new resonances, one should exclude another non-exotic scenarios

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

JHEP 12 (2019) 100

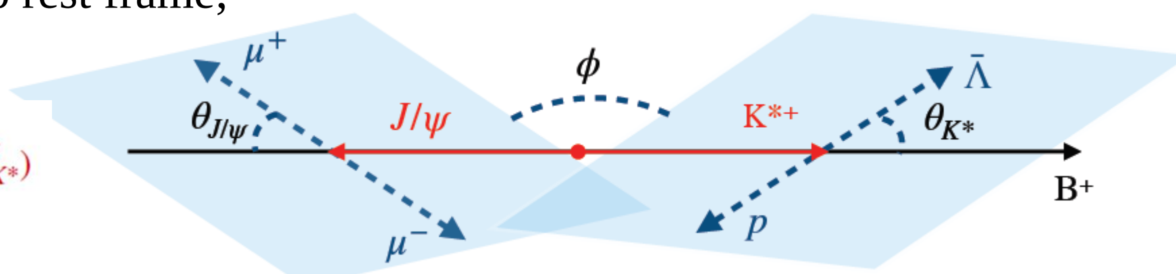
Model-independent approach: method of moments

- Introduced by BaBar [PRD 79 (2009) 112001] and then used by LHCb [PRD 92 (2015) 112009, PRL 117 (2016) 082002];
- There are 3 known K* resonances that can decay to Λp, so these K*'s can contribute to the 2-body invariant mass distributions;
- In each M(Λ p) bin, the $\cos(\theta_{K^*})$ distribution can be expressed as an expansion in terms of Legendre polinomials:

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

where θ_{K^*} is the helicity angle defined as the angle between Λ momentum and B+ momentum in the Λp rest frame;

$$w^i = 1 + \sum_{j=1}^{l_{max}} < P_j^N > P_j(cos\theta^i_{K^*})$$



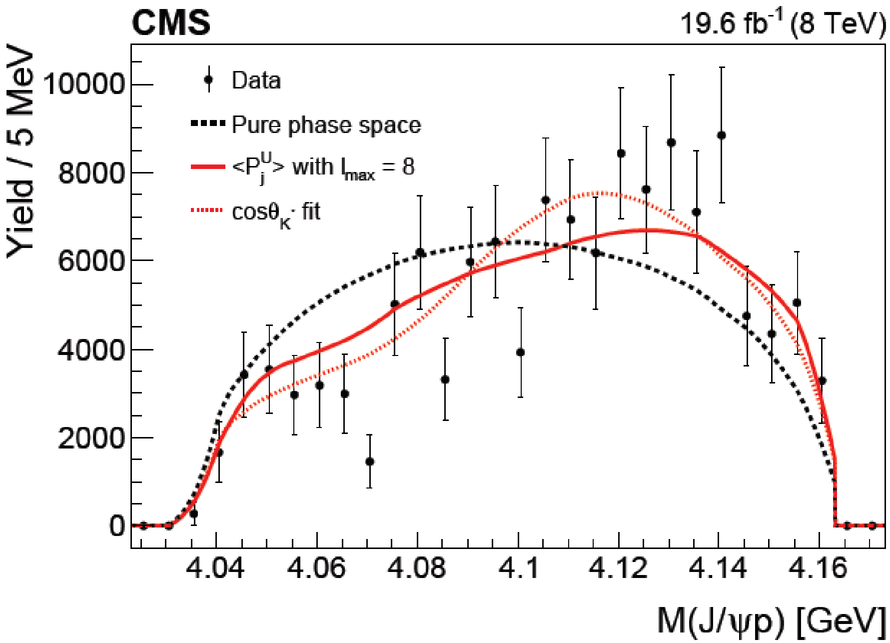
- For l_{max} = 2xJ, where J is the total spin of the highest-spin K*, one can take into account all these K* → Λp.
- From table l_{max} = 2x4=8.

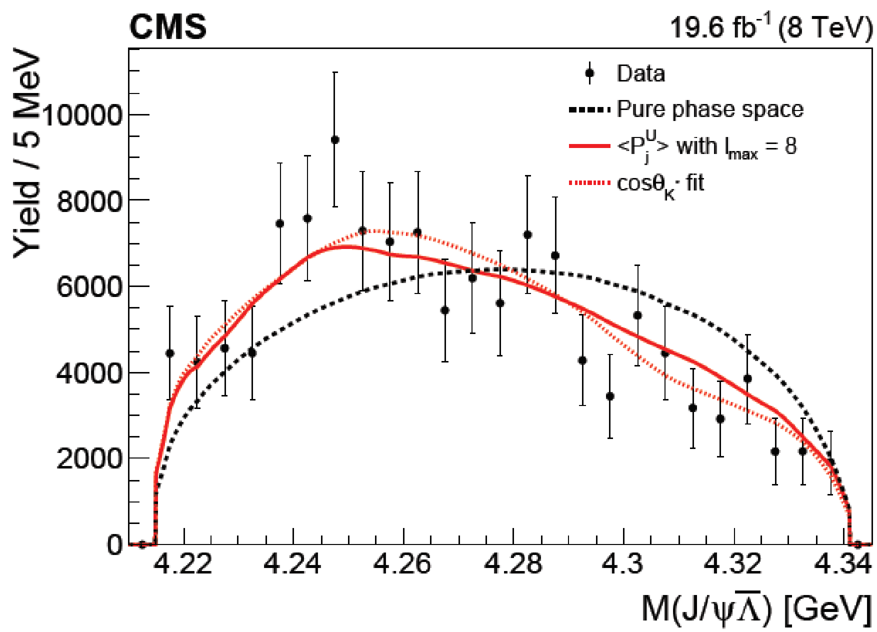
Resonance	Mass, MeV	Natural width, MeV	J^P
$K_4^*(2045)^+$	2045 ± 9	198 ± 30	4^+
$K_2^*(2250)^+$	2247 ± 17	180 ± 30	2^-
$K_3^*(2320)^+$	2324 ± 24	150 ± 30	3^+

CMS: Study of $B^+ \to J/\psi \bar{\Lambda} p$

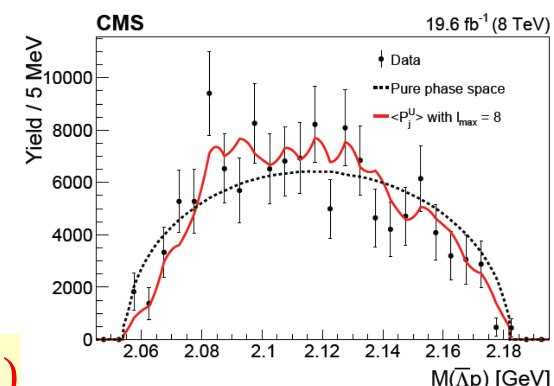
JHEP 12 (2019) 100

Simulation reweighting according to the observed structure in Λp





A model-independent approach that accounts for the contribution from known K*'s with spins up to 4 in the Λp system improves the agreement with data significantly!



Compatibility with data (incompatibility < 2.8 σ including syst.) eliminating the need for exotic resonances in this 3-body decay

Новые распады b-адронов как портал для поиска и изучения многокварковых состояний

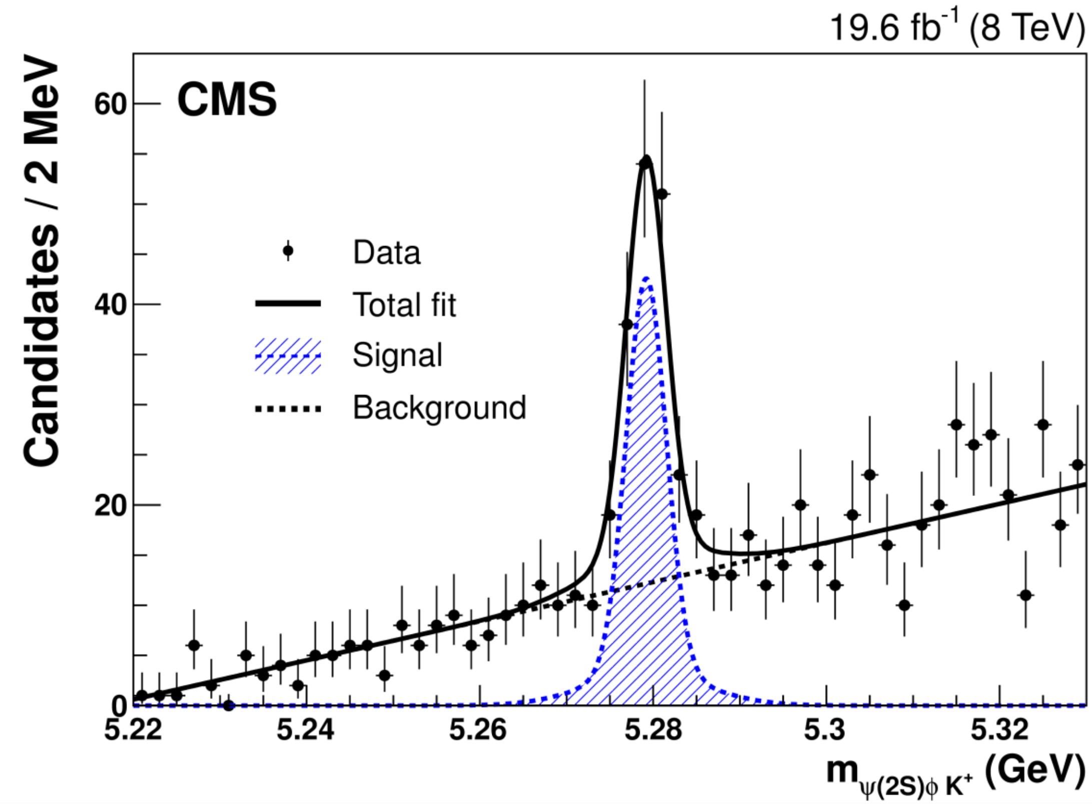
Observation of $B^+ \rightarrow \psi(2S)\,\phi\,K^+$

Phys. Lett. B 764 (2017) 66

By reconstructing the same decay with $\psi(2S)$ instead of J/ψ we observed a new B^+ decay channel

The relative branching fraction, using the mode $B^+ \rightarrow \psi(2S)\,K^+$ as normalization:

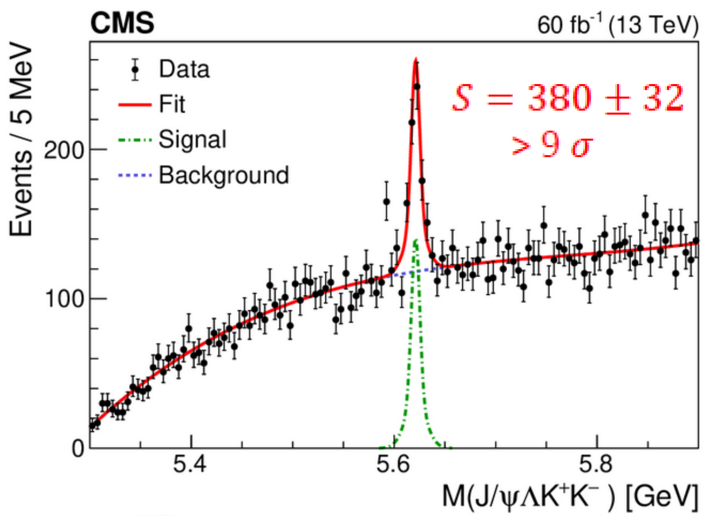
$$[\,4.0 \pm 0.4\,(\text{stat}) \pm 0.6\,(\text{syst}) \pm 0.2\,(\text{BF}(B^+ \rightarrow \psi(2S)\,K^+))\,] \times 10^{-6}$$

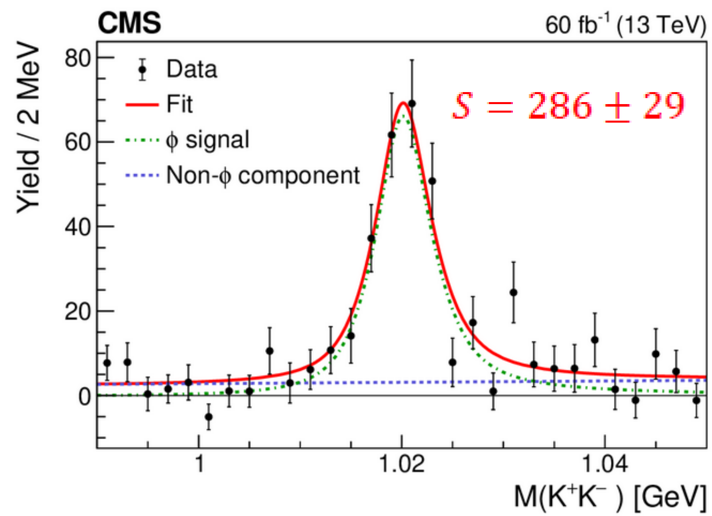


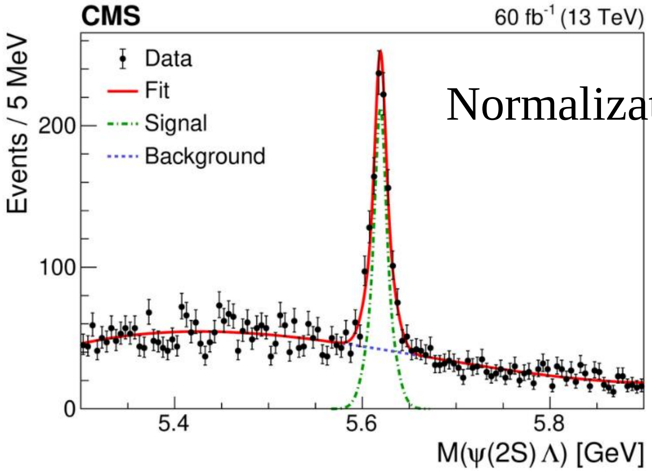
This is the first step towards the exploration of $\psi(2S)\,\phi$ system.

Observation of $\Lambda_b \rightarrow J/\psi\ \Lambda\ \phi$

Phys. Lett. B 802 (2020) 135203







Normalization mode

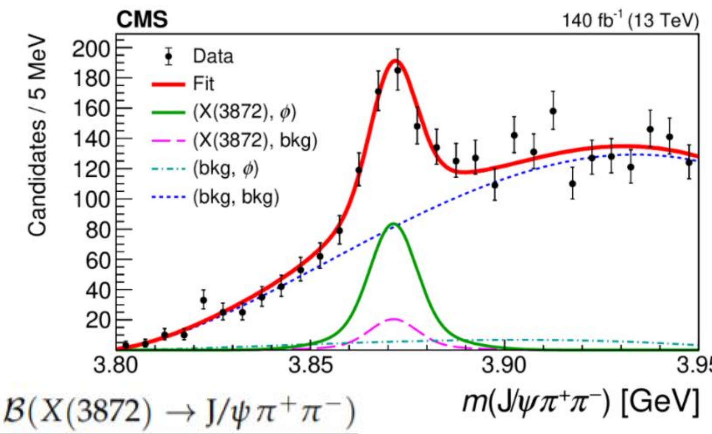
The study is based on 2018 13 TeV data ($60\ fb^{-1}$)

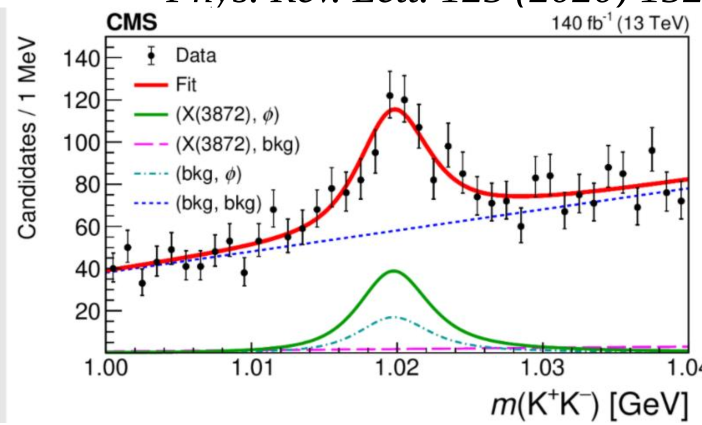
$$\frac{B\left(\Lambda_b^0 \rightarrow J/\psi\Lambda\varphi\right)}{B\left(\Lambda_b^0 \rightarrow \psi(2s)\Lambda\right)} = \left(8.26\ \pm 0.90\ (\text{stat.}) \pm 0.68(\text{syst.}) \pm 0.11(\text{br.})\right)\%$$

This new decay provides an opportunity to further explore the **$J/\psi\ \phi$ and $J/\psi\ \Lambda$** systems

Observation of $B_s^0 \to X(3872)\,\phi$

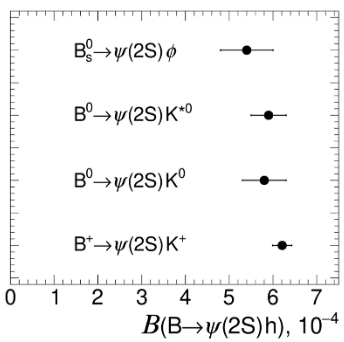
Phys. Rev. Lett. 125 (2020) 152001

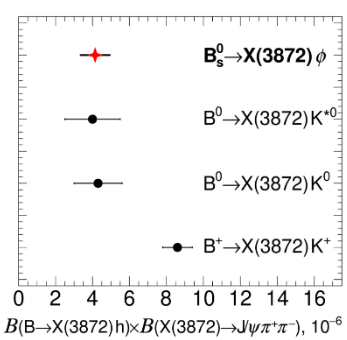




$$R \equiv \frac{\mathcal{B}(B_s^0 \to X(3872)\phi)\,\mathcal{B}(X(3872) \to J/\psi\,\pi^+\pi^-)}{\mathcal{B}(B_s^0 \to \psi(2S)\phi)\,\mathcal{B}(\psi(2S) \to J/\psi\,\pi^+\pi^-)}$$

$$R = (2.21 \pm 0.29\,(\text{stat}) \pm 0.17\,(\text{syst}))\%$$





X(3872) *formation in* ***B*** *decays is different from* ***psi(2S)*** *!*

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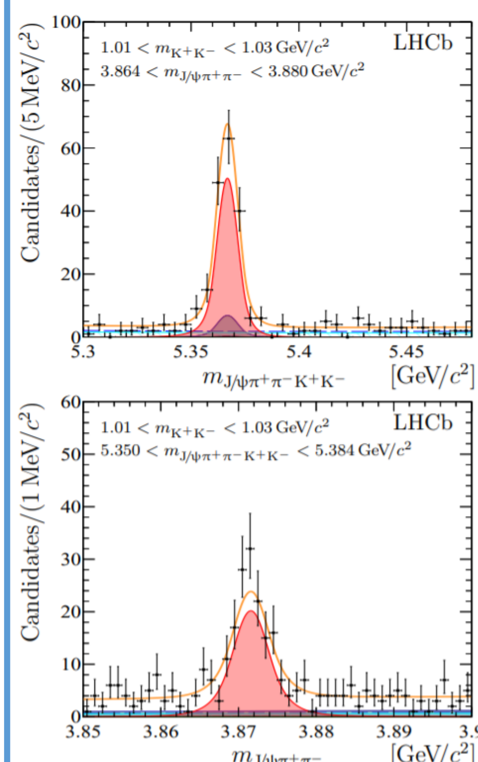
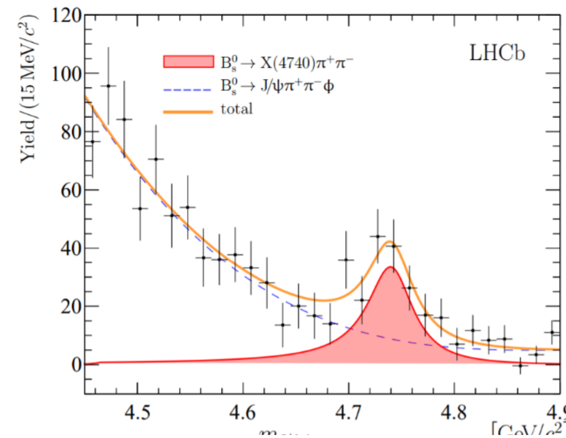


$$\mathcal{R}^{\chi_{c1}(3872)\phi}_{\psi(2S)\phi} = (2.42 \pm 0.23 \pm 0.07) \times 10^{-2}$$



$$m_{X(4740)} = 4741 \pm 6 \pm 6 \ \text{MeV}/c^2\,,$$
$$\Gamma_{X(4740)} = 53 \pm 15 \pm 11\ \text{MeV}\,.$$

Заключение

Although designed for high-pt physics, CMS is a very good apparatus for heavy flavor physics!

- Study of $B_{s(1,2)}^* \rightarrow B^+K^-$ and observation of $B_{s2}^*(5840) \rightarrow B^0 K^0_s$
- Observation of two resolved states $\chi_{b1,2}(3P)$:
  measurement of their masses and mass difference.
- Observation of two excited Bc+ states and measurement of Bc(2S)+ mass:
  first observation of two distinct states Bc(2S)+ and Bc(2S)*+
- Observation of new excited Λb states
- Observation of new beauty strange excited baryon $\Xi b(6100)^- \rightarrow \Xi b^- \pi^+\pi^-$

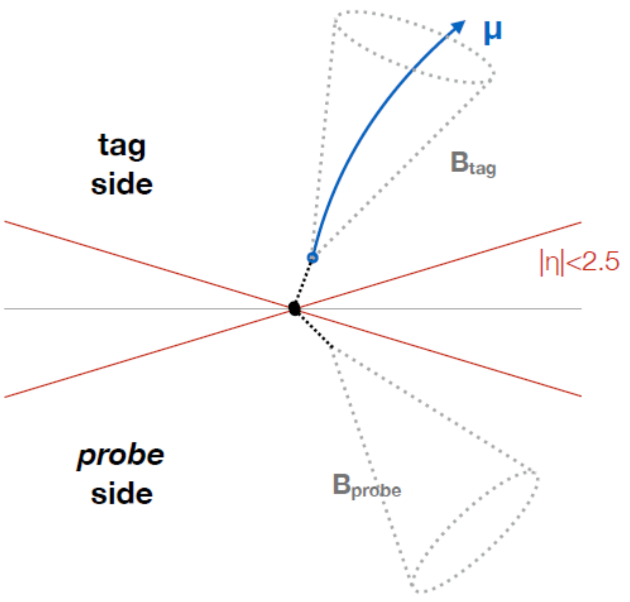
- Study of $B_s \pi^+$ spectrum and
  setting an UL on the production of X(5568)
- Search for the bottomonium partner of the X(3872)
  in $\Upsilon(1S)\pi^+\pi^-$ channel
- Search for resonances decaying to $\Upsilon(1S)\mu^+\mu^-$
- Study of $B^+ \rightarrow J/\psi \Lambda p$
- Observation of $B^+ \rightarrow \psi(2S) \phi K^+$ and $\Lambda_b \rightarrow J/\psi \Lambda \phi$
- Obsevration of $Bs \rightarrow X(3872) \phi$

Перспективы

Анализ данных BParking (2018):

Proposal to collect a generic sample of $\mathrm{O}(10^{10})$ B hadron decays designed to measure $\mathrm{R_K}$ and $\mathrm{R_{K^*}}$ in CMS using data parking in 2018

Mode	N_{2018}	f_B [17]	$\mathcal{B}$
Generic B hadrons			
B_d^0	4.99×10^9	0.4	1.0
$B^\pm$	4.99×10^9	0.4	1.0
B_s	1.56×10^9	0.1	1.0
b baryons	1.56×10^9	0.1	1.0
B_c	1.25×10^7	0.001	1.0
B hadrons total	1.25×10^{10}	1.0	1.0



Soon realized that the sample offers significantly more broad program with a potential to revolutionize the way we do B physics in CMS

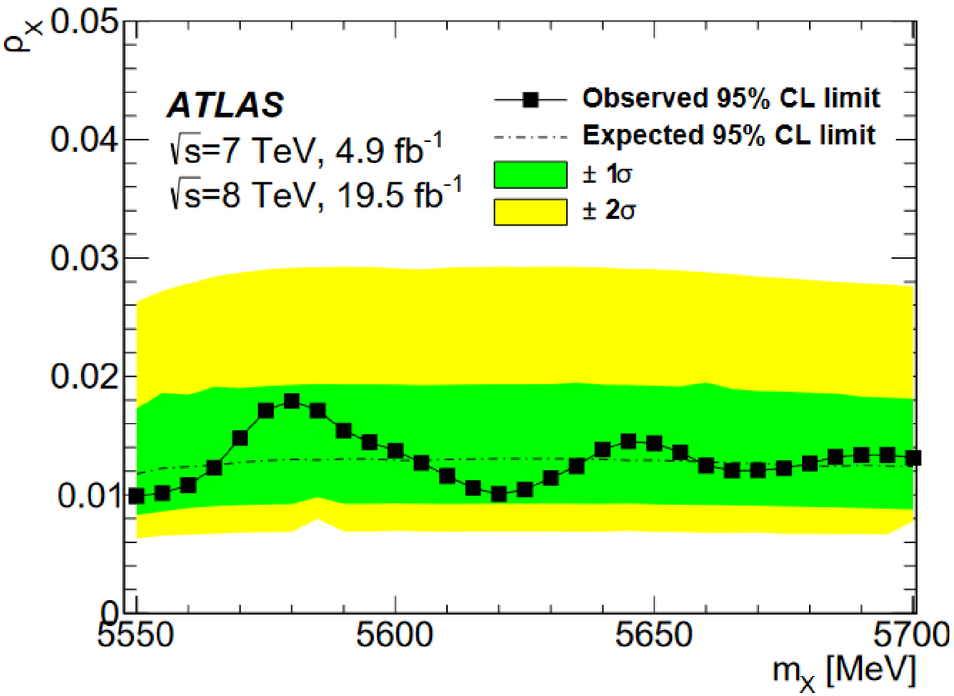
New results from CMS are expected soon.

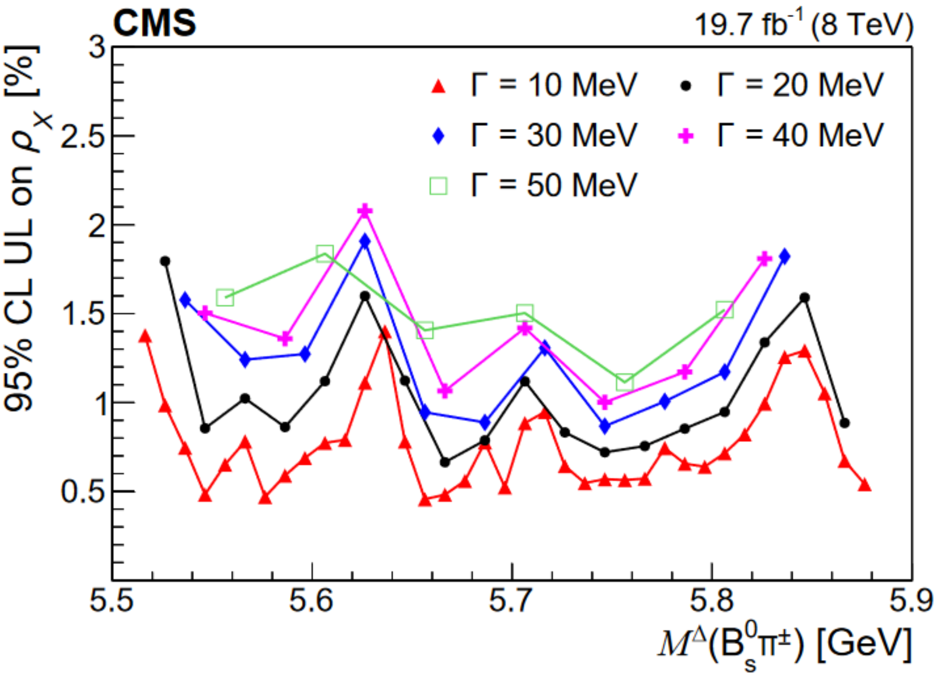
Backup slides

Search for X(5568) in ATLAS and CMS: **results**

By varying selection criteria, background parameterization, fit range and method of data description, the yield for X(5568) remains consistent with 0 ➞

No evidence of X(5568) at the LHC





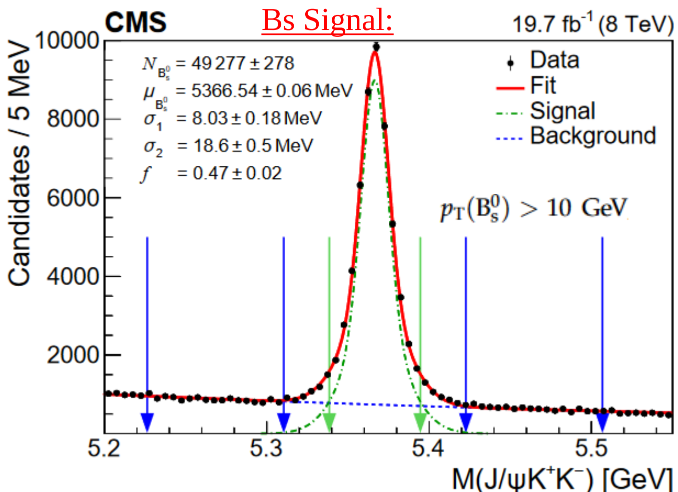
$\rho_X^{\mathrm{ATLAS}} < 0.015$ at 95% CL for $p_{\mathrm{T}}(\mathrm{B_s^0}) > 10$ GeV

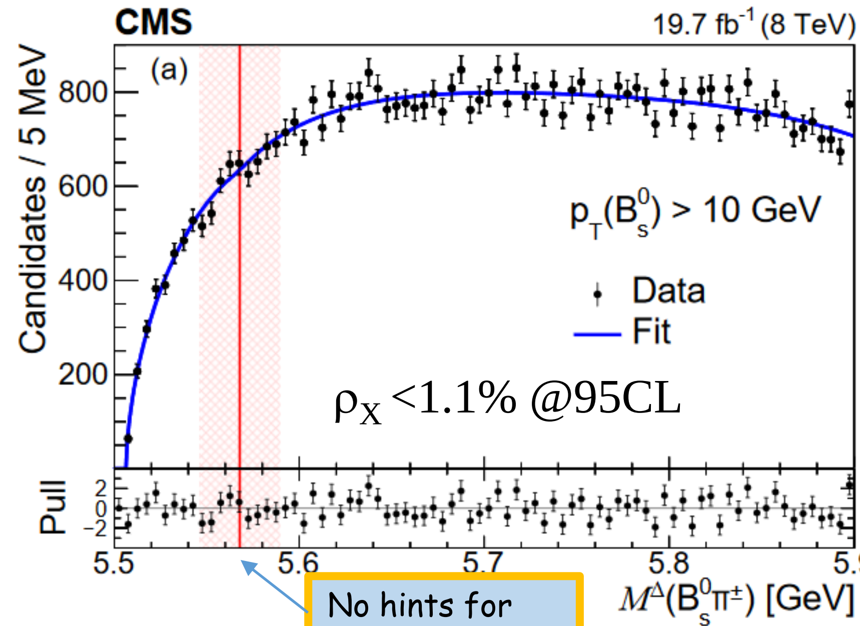
$\rho_X^{\mathrm{ATLAS}} < 0.016$ at 95% CL for $p_{\mathrm{T}}(\mathrm{B_s^0}) > 15$ GeV

$\rho_X^{\mathrm{CMS}} < 1.1\%$ at 95% CL for $p_{\mathrm{T}}(\mathrm{B_s^0}) > 10$ GeV

$\rho_X^{\mathrm{CMS}} < 1.0\%$ at 95% CL for $p_{\mathrm{T}}(\mathrm{B_s^0}) > 15$ GeV

Search for X(5568) in ATLAS and CMS



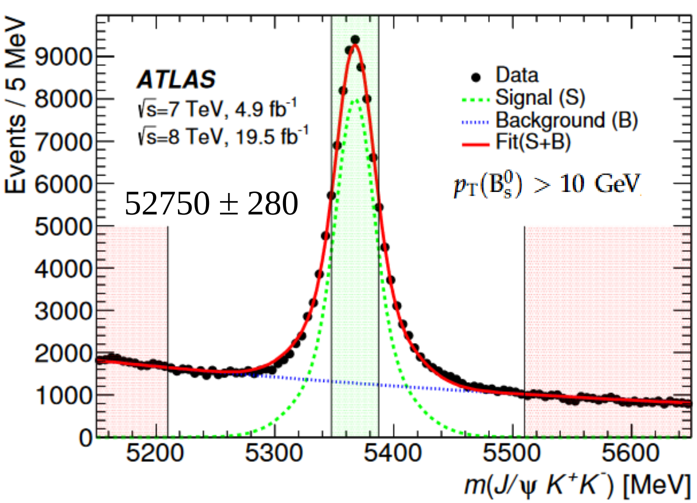


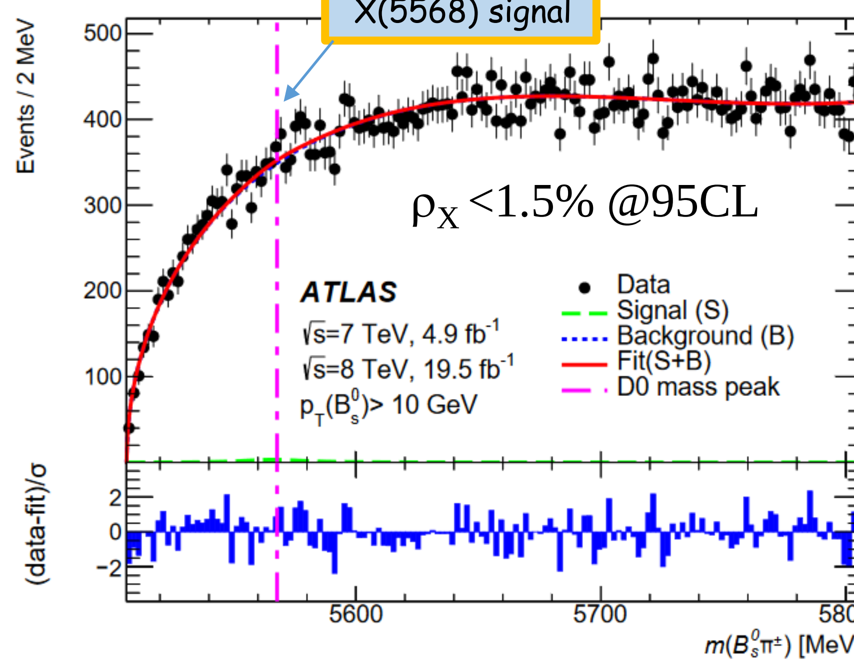
PRL 120 (2018) 202005

Comparison of Bs statistics

Factor **1.16** larger in CMS and **1.24** in ATLAS than LHCb reconstructed in the same momentum interval and for both ATLAS and CMS more than **9** larger than D0 sample.

No hints for X(5568) signal



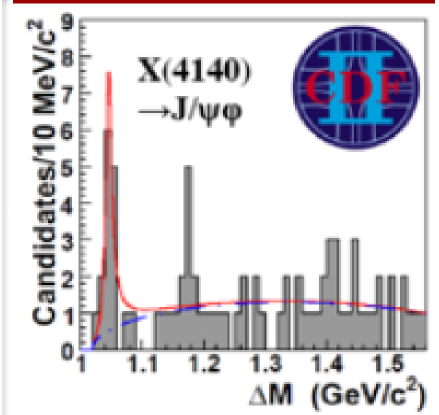


PRL 120 (2018) 202007

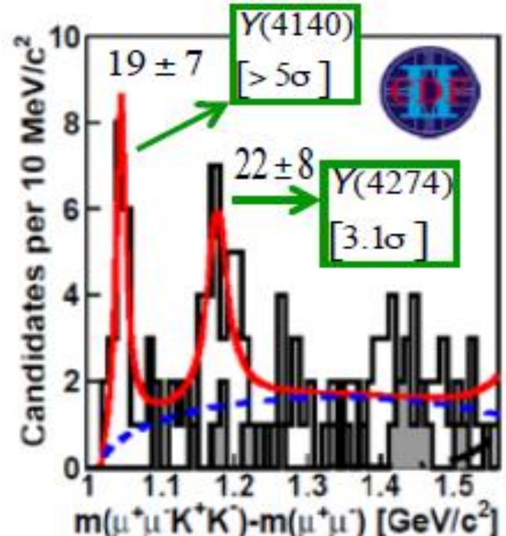
Confirmation of X(4140) → J/ψ ϕ

CDF (2009) reported evidence (@3.8σ) for … narrow peak in $J/\psi\varphi$ mass spectrum, close to the kinematical threshold, in decays $B^{\pm} \rightarrow J/\psi\ \phi\ K^{\pm}$

[PRL 102 (2009) 242002]



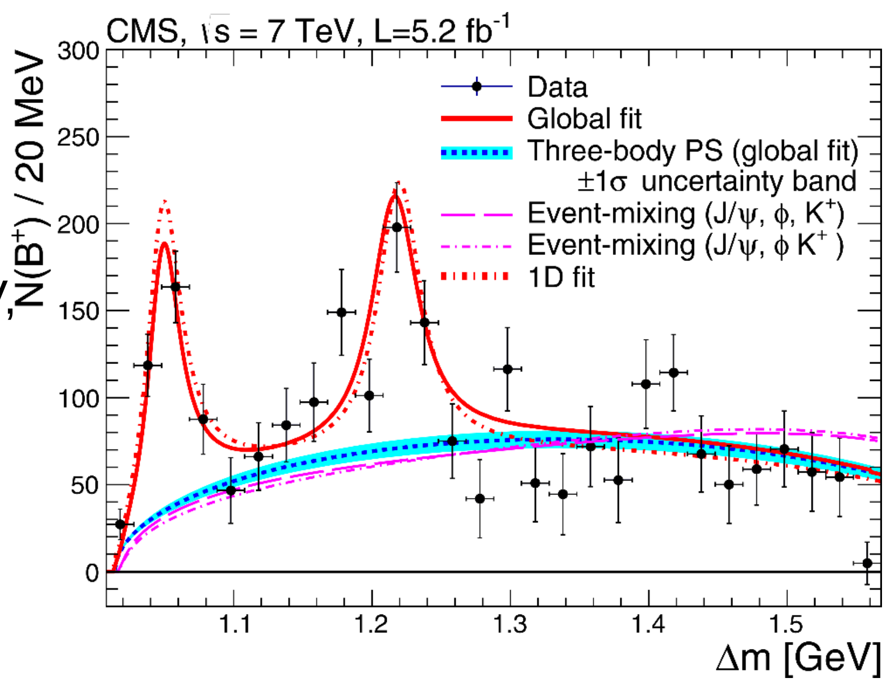
CDF (2011) presents update analysis with larger dataset,($6.0 fb^{-1}$ vs $2.7 fb^{-1}$)observing



[arXiv:1101.6058 (2011)]

- Peaking structure at the threshold and another peak in the Δm from B+ → J/ψ ϕ K+ decay (after background subtraction)
- Yield: 310+-70, M=4148.0+-2.4+-6.3 MeV, Γ=28+15-11+-19 MeV, signif.>5σ →

Consistent with the Y(4140) from CDF !
(first significant confirmation)



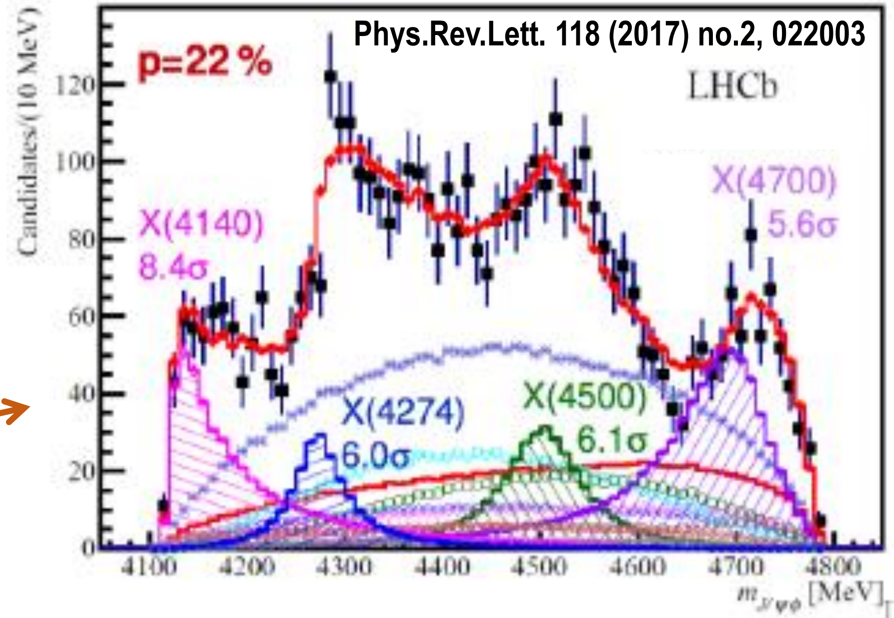
PLB 734 (2014) 261

Belle and BaBar searched for and didn't find that signal in the same B+ decay.

Study of the J/ψ ϕ system

LHCb has looked at these places:

- No signals were observed (2012) in a 346+-20 B+ sample;
- The measured UL implied a 2.4sigma tension with CDF;
- 4 resonance-like structures recently were established in the 6D AA analysis with a 4289+-151 B+ sample



Comparison of resonance parameters:

X(4140)	Yield	Mass, MeV	Width, MeV
CMS	310 ± 70	4148.0 ± 2.4 ± 6.3	38+30-15 ± 16
LHCb		4146.5±4.5+4.6-2.8	83±21+21-14

X(4274)	Yields	Mass, MeV	Width, MeV
CMS	418 ± 170	4313.8 ± 5.3 ± 7.3	38+30-15 ± 16
LHCb		4273.3±8.3+17.2-3.6	56.2±10.9+8.4-11.1

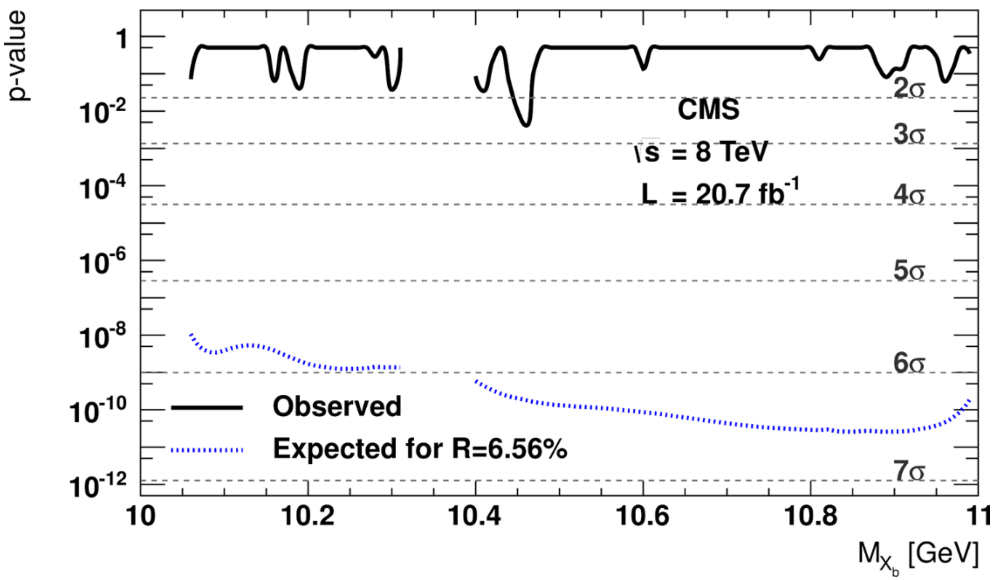
Several interpretations for the X(4140) have been proposed: Ds+*Ds-* molecule, cscs tetraquark, threshold kinematic effect, hybrid charmonium, weak transition with Ds+Ds- rescattering.

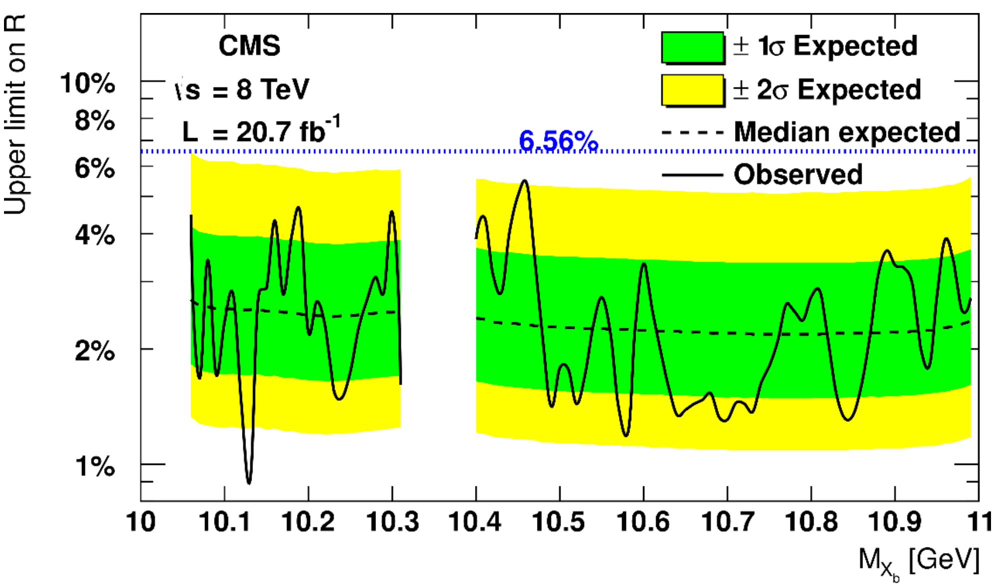
Recently, the D0 Collaboration has published the first evidence for the prompt production of the X(4140) PRL 115 (2015) 232001

→ It's interesting to perform the same search at LHC

Mass scan for $X_b \rightarrow \Upsilon(1S)\,\pi^+\pi^-$

PLB 727 (2013) 57





In analogy with the X(3872), expected signal significance > 5 σ if X_b(Br x cross-section)>6.5% of the corresponding product for $\Upsilon(2S) \rightarrow \Upsilon(1S)\,\pi^+\pi^-$ (R value)

Local p-values calculated using asymptotic approach and combining results of fits to the barrel and endcap regions.

Systematic uncertainties implemented as nuisance parameters.

The smallest local p-value is 0.004 at 10.46 GeV, corresponding to a stat. signif. of 2.6 σ, which is reduced to 0.8 σ when LEE is taken into account.

No significant excess is observed.
95% CL UL on the R varies from 0.9% to 5.4%.