Heavy Flavor measurements and production studies at CMS

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On behalf of the CMS collaboration
UNIVERSIDAD DE ANTIOQUIA, COLOMBIA

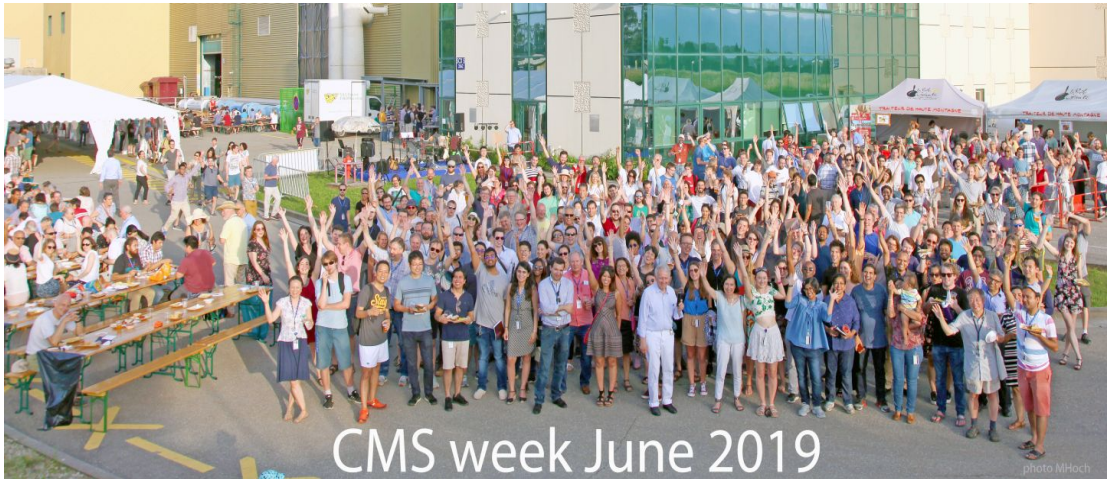
4th ComHEP: Colombian Meeting on High Energy physics
December 2 to 6, 2019, Barranquilla, Colombia.

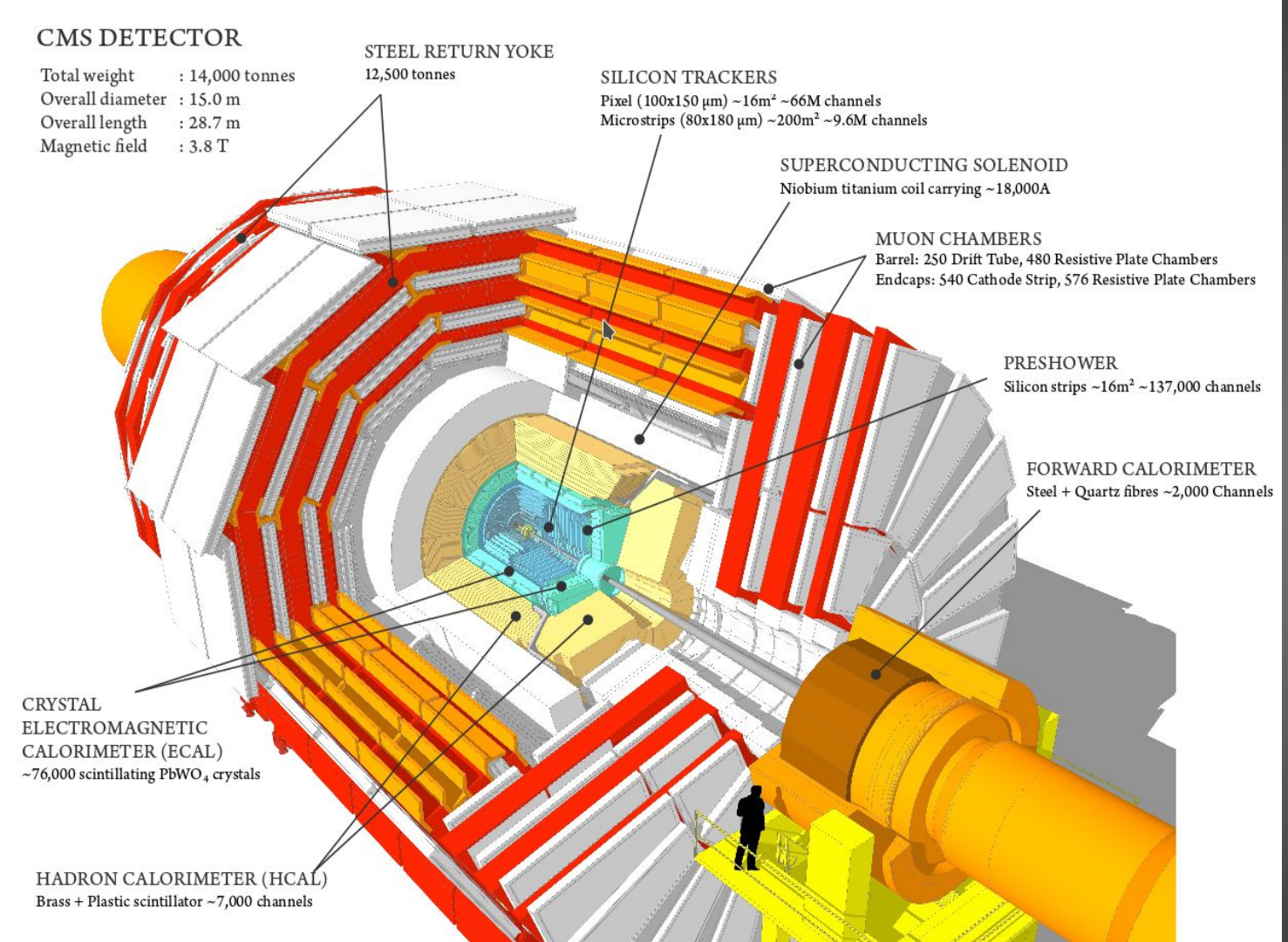
Outline

Recent physics results

- ★ **Observation of two excited Bc states and measurement of the Bc(2S) mass in pp collisions at $\sqrt{s}$ = 13 TeV. CMS-BPH-18-007.**
- ★ **Study of the $B \rightarrow J/\psi \Lambda p$ decay in proton-proton collisions at $\sqrt{s}$ = 8 TeV. CMS-PAS-BPH-18-005**
- ★ **Angular analysis of the decay $B^+ \rightarrow K^+ \mu^+ \mu^-$ in proton-proton collisions at $\sqrt{s}$= 8 TeV. CMS-BPH-15-001-003**
- ★ **Measurement of properties of $B_s \rightarrow \mu^+ \mu^-$ decays and search for $B^0 \rightarrow \mu^+ \mu^-$ with the CMS experiment. CMS-PAS-BPH-16-004**

CMS is a real global collaboration



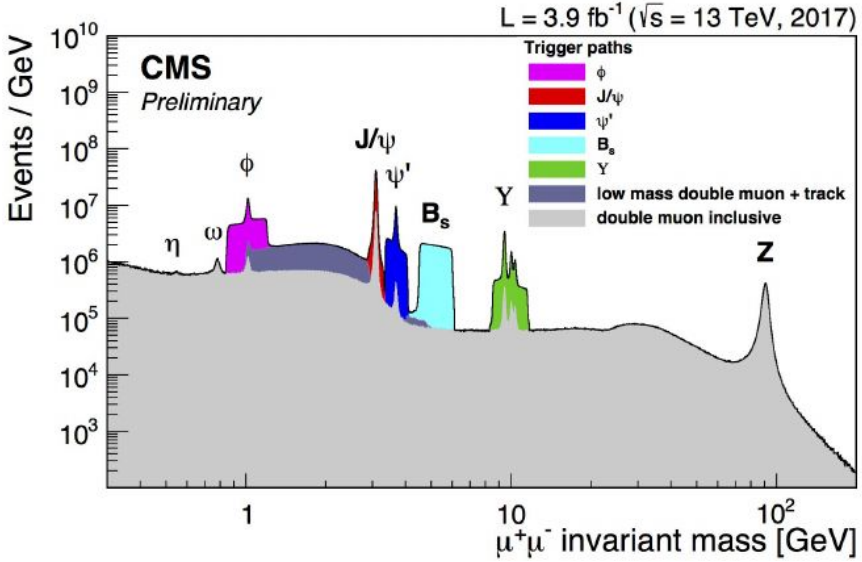


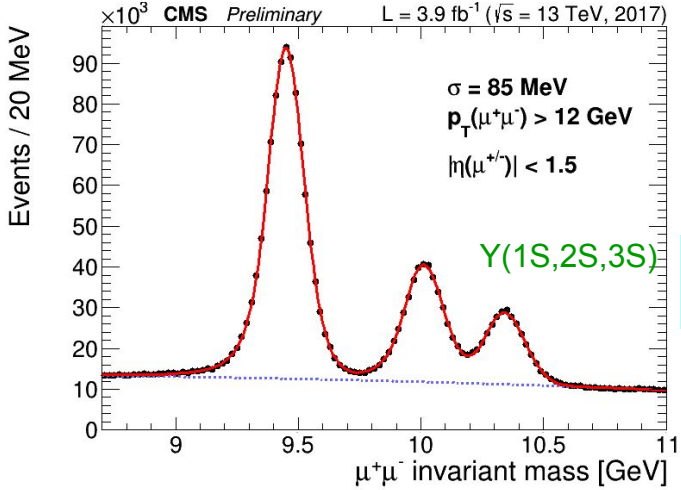
CMS status

The CMS detector Phase-1 upgrades started during the first Long Shutdown and continued during the Run 2 end of the year technical stops.

The Phase-1 upgrades are nearly complete.

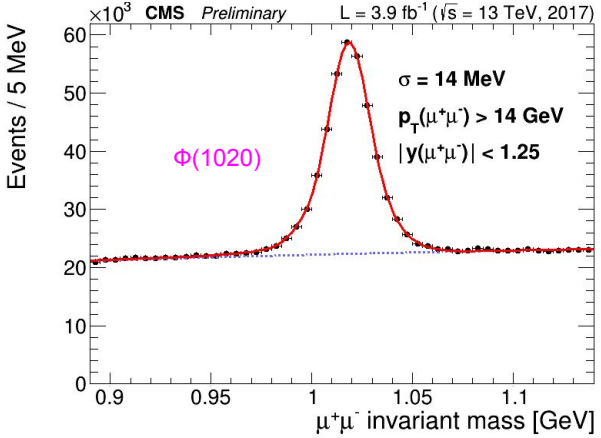
installation of the HCAL Barrel readout is the last step. CMS will complete the installation by the end of 2019.

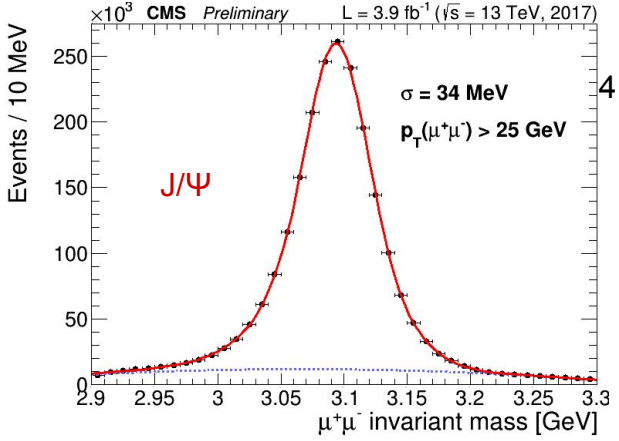


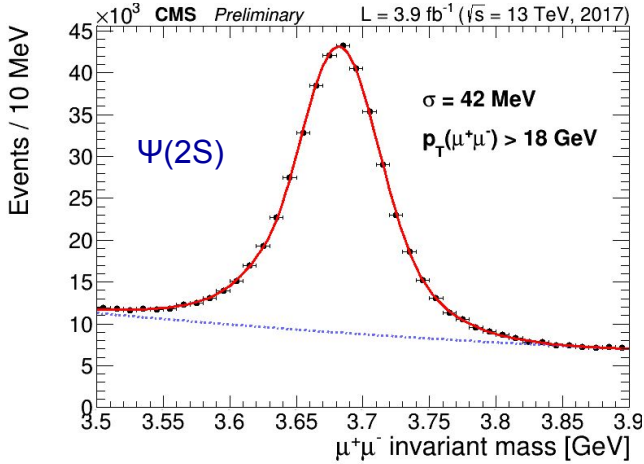


Experimental setup: dedicated HF triggers

Using 2017 data: CMS-DP-2017-029



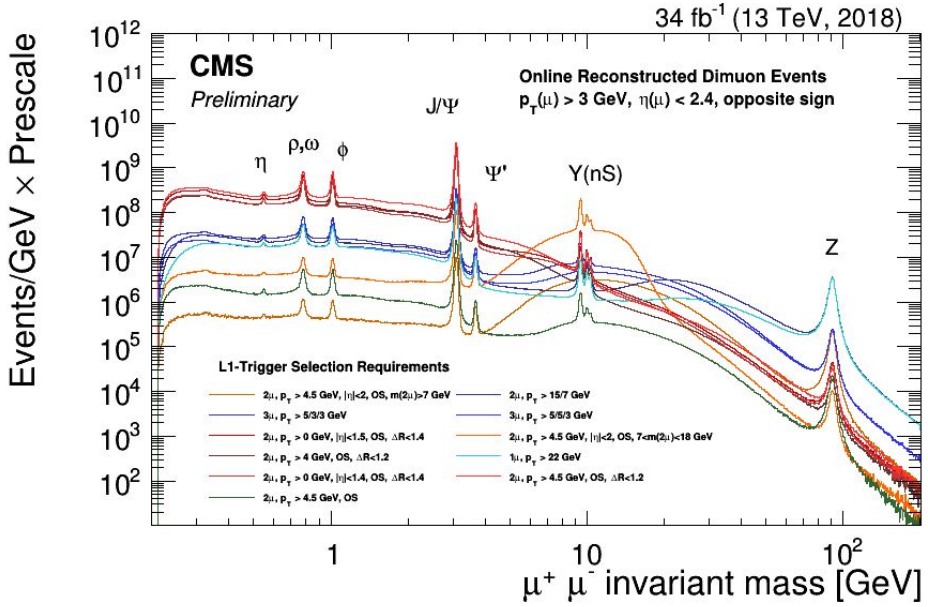




Run 2 data taking

CMS DP2018_055

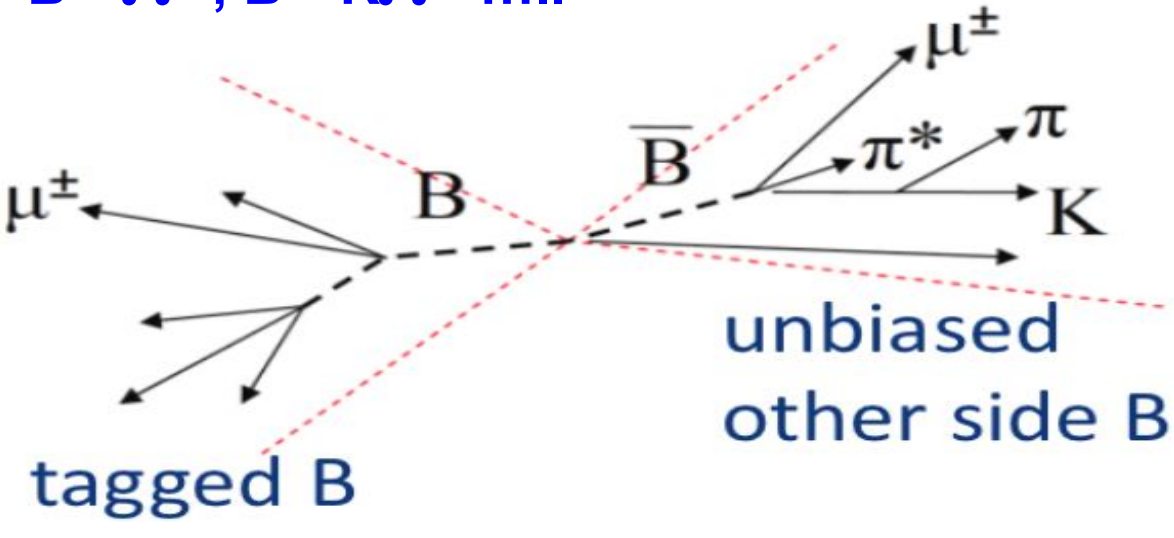
- Traditional trigger algorithms usually require high pt particles to reduce the event rate, and then read out the full event information.
- Need to reduce the event size to collect events at a higher rate.
- Reconstruct at the High Level Trigger (HLT) stage, drop RAW data and analyse using the HLT objects.
  - needs adequate calibration at the HLT level and validation against full reconstruction



B Parking in CMS

- **Motivation:** Study B anomalies. Can be used also for LLP search.
- **Goal:** Collect large (~10^{10} events) unbiased sample of B
- **Idea:** Triggering on muon from B (tag), to collect unbiased B on the other side (probe)

$B \to l^+ l^-$, $B \to K l^+ l^-$ .....



Reach so-far-unexplored territory with the help of scouting, parking and other novel techniques.

Recent Physics Results

(some kind of teasers and spoilers:
later in the coffee, we can continue the discussion)

PHYSICAL REVIEW LETTERS

moving physics forward

APS physics

Dear Sir or Madam,

We are pleased to inform you that the Letter

Observation of two excited B_c^+ states and measurement of the $B_c^+(2S)$ mass in pp collisions at $\sqrt{s} = 13$ TeV

A.M. Sirunyan *et al.* (CMS Collaboration)
Phys. Rev. Lett. **122**, 132001 (2019)

Published 2 April 2019

has been highlighted by the editors as an Editors' Suggestion. Publication of a Letter is already a considerable achievement, as *Physical Review Letters* accepts fewer than 1/4 of submissions, and is ranked first among physics and mathematics journals by the Google Scholar five-year h-index. A highlighted Letter has additional significance, because only about one Letter in six is highlighted as a Suggestion due to its particular importance, innovation, and broad appeal. Suggestions are downloaded twice as often as the average Letter, and are covered in the press substantially more often. If Suggestions were a separate publication, they would have an Impact Factor of 17. More information about our journal and its history can be found on our webpage prl.aps.org.

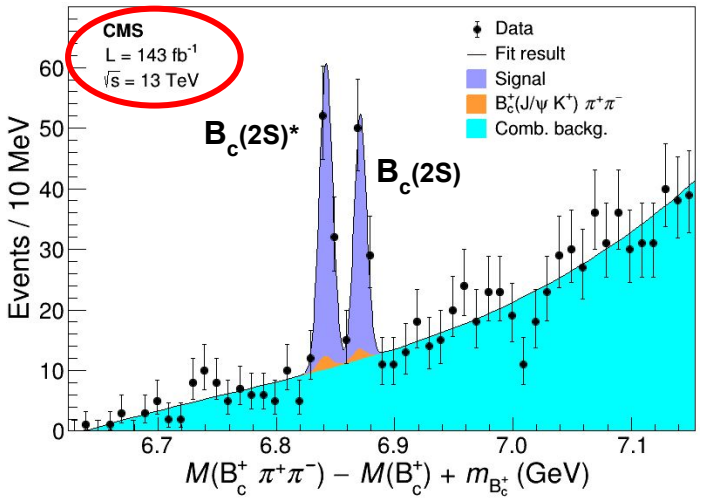
Yours sincerely,

Hugues Chaté
Editor
Physical Review Letters

Michael Thoennessen
Editor in Chief
Physical Review

First LHC full Run 2 paper

Observation of two excited B_c^+ states and measurement of the $B_c^+(2S)$ mass in pp collisions at $\sqrt{s}$ = 13 TeV



Phys. Rev. Lett. 122 (2019) 132001

Highlighted as an Editors' Suggestion
(as it happened last year for:
observations of Hbb and ttH)

Observation of two excited B_c states and measurement of the $B_c(2S)$ mass in pp collisions at $\sqrt{s}$ = 13 TeV

PRL 122 (2019) 132001

CMS Draft Analysis Note

The content of this note is intended for CMS internal use and distribution only

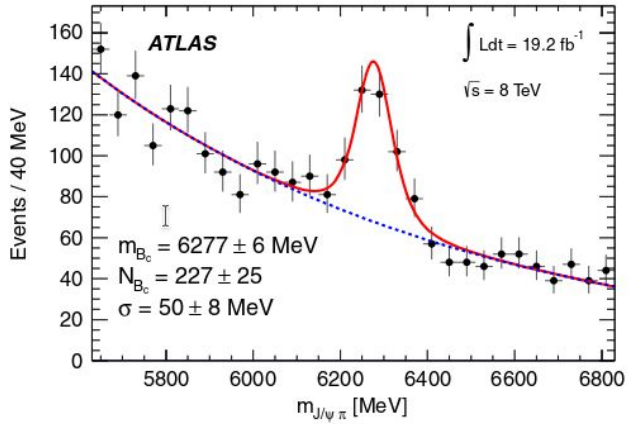
2019/02/12
Head Id:
Archive Id: 488878:488884
Archive Date: 2018/12/20
Archive Tag: trunk

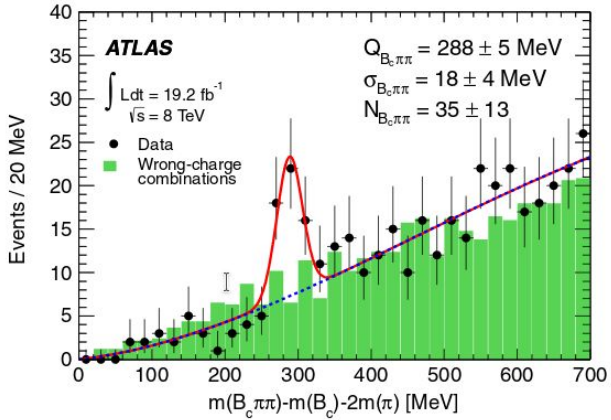
Study of excited B_c meson decays to $B_c\pi\pi$

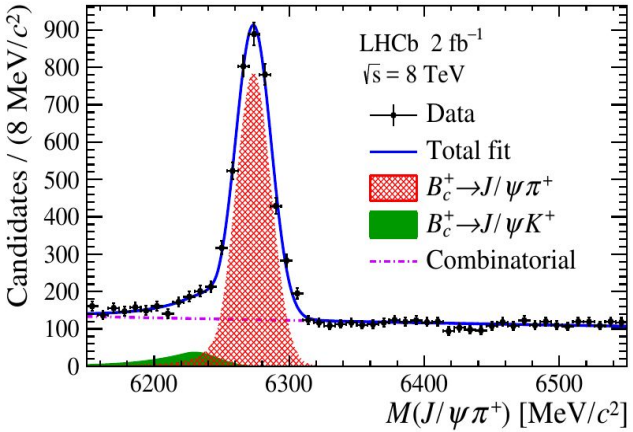
Jhovanny A. Mejia Guisao[1], Cesar A. Mondragón Herrera[2], Daniel A. Pérez Navarro[2], Alberto Sánchez Hernández[2], Wen-Liang Huang[3], and Francesco Fiori[4]

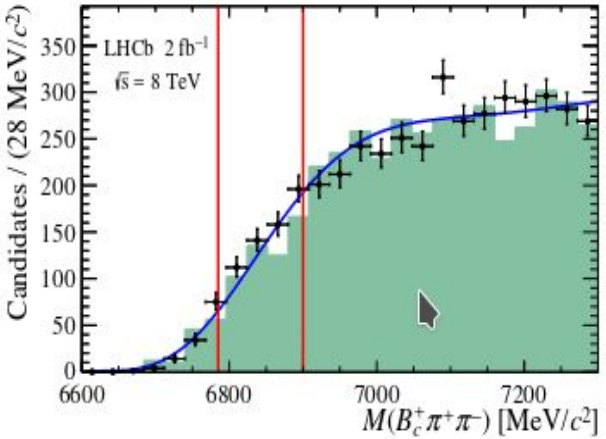
[1] Universidad de Antioquia, Medellin, Colombia
[2] CINVESTAV, Mexico City, Mexico
[3] National Taiwan University
[4] Università di Pisa and INFN Sezione di Pisa

Excitate B_c meson









PRL 113, 212004 (2014)

They report the observation of a new state whose mass is consistent with predictions for the $B_c(2S)$

The $B_c(2S)$ is reconstructed from the decay $B_c\pi\pi$ followed by $B_c \rightarrow J/\psi\pi$ with a local significance of 5.4 σ

JHEP 01 (2018) 138

With 3325 ± 73 B_c events :
"No significant signal is found" in the search for the excited states $B_c(2S)$ and $B_c(2S)^*$ in 8 TeV data

Reconstruction of the $B_c\pi\pi$

The $B_c(2S)^*$ decays to the B_c ground state through the emission of two pions and a soft photon (around 55 MeV in rest frame) :

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

Since the photon is not detected, we end up seeing

$$B_c(2S)^* \rightarrow B_c \pi^+ \pi^- \text{ plus "missing energy"}$$

Same final state as

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

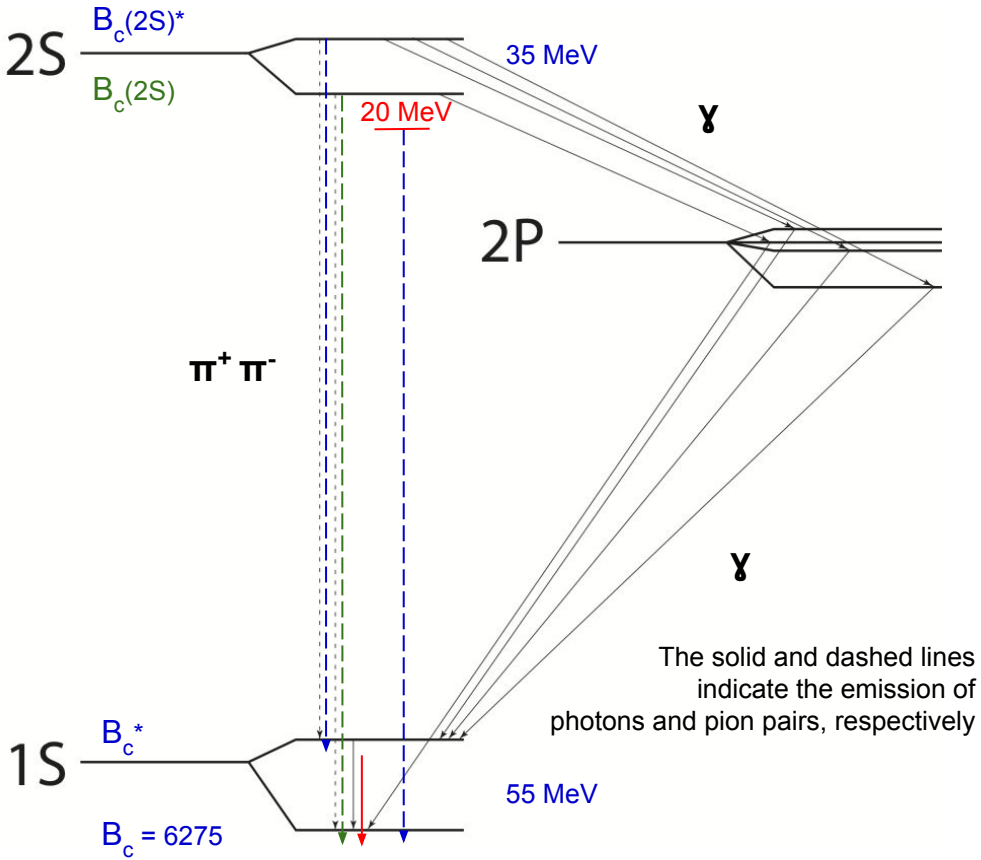
So, we see a two-peak structure in the $B_c \pi^+ \pi^-$ mass distribution, with the $B_c(2S)^*$ peak at a mass shifted by

$$\Delta M = [\, M(B_c^*) - M(B_c) \,] - [\, M(B_c(2S)^*) - M(B_c(2S)) \,]$$

which is predicted to be around 20 MeV.

One have to notice:

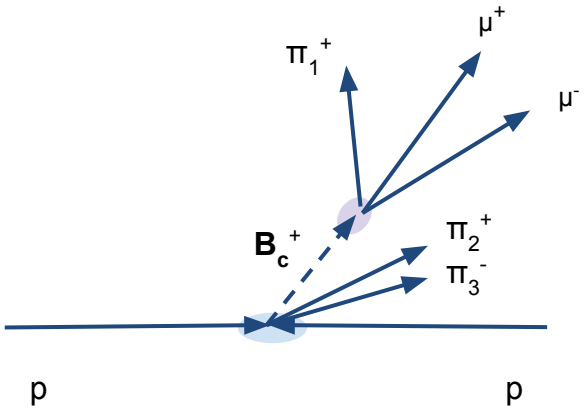
$$[\, M(B_c(1S)^*) - M(B_c(1S)) \,] > [\, M(B_c(2S)^*) - M(B_c(2S)) \,]$$



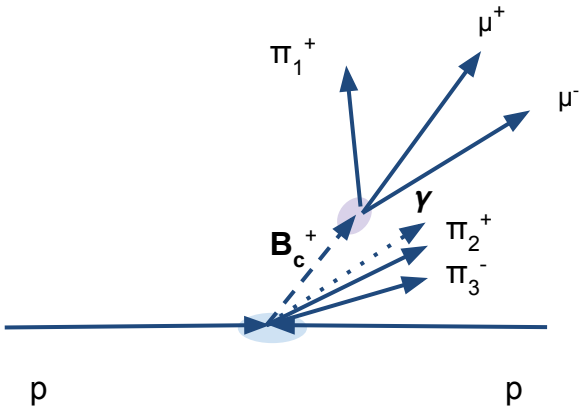
The solid and dashed lines indicate the emission of photons and pion pairs, respectively

Event selection criteria

- B_c meson momentum required to point to the PV in the *xy* plane
- The PV is re-fitted excluding the three B_c decay tracks (two muons and one pion (π_1))
- π_2 and π_3 are tracks in that PV, e.g. they are prompt tracks, which are combined with B_c
- tracks and muons satisfy high-quality requirements
- When multiple B_c π π candidates are found in the same event, we only keep the one with the highest pT value

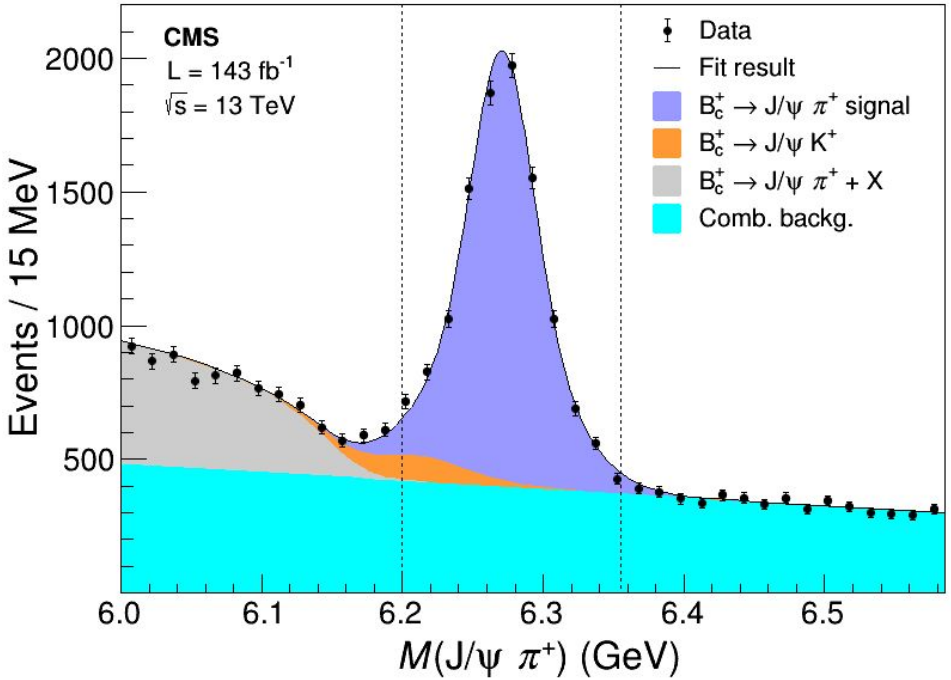


$B_c(2S) \rightarrow B_c \pi^+ \pi^-$



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

Reconstruction of B_c in data: 2015 + 2016 + 2017 + 2018



7629 ± 225 candidates

33.5 ± 2.5 MeV mass resolution

Fit details:

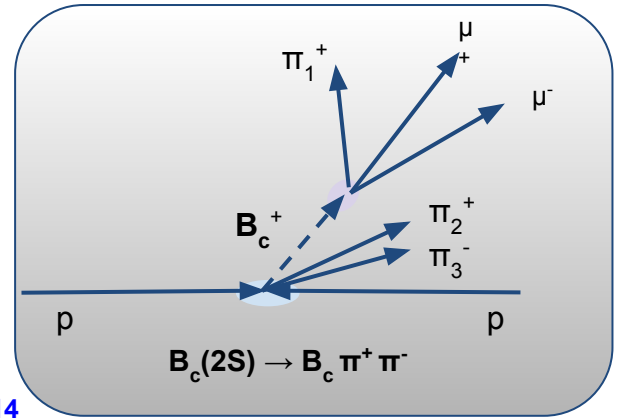
Unbinned ML; the signal is modeled using a double Gaussian with common mean and the background as a polynomial.
Additional background contributions from $B_c \to J/\psi\, K$ decay is modeled from the simulated sample,
while the partially reconstructed $B_c \to J/\psi\, \pi\, X$ decays are modeled with an ARGUS function convolved with a Gaussian.

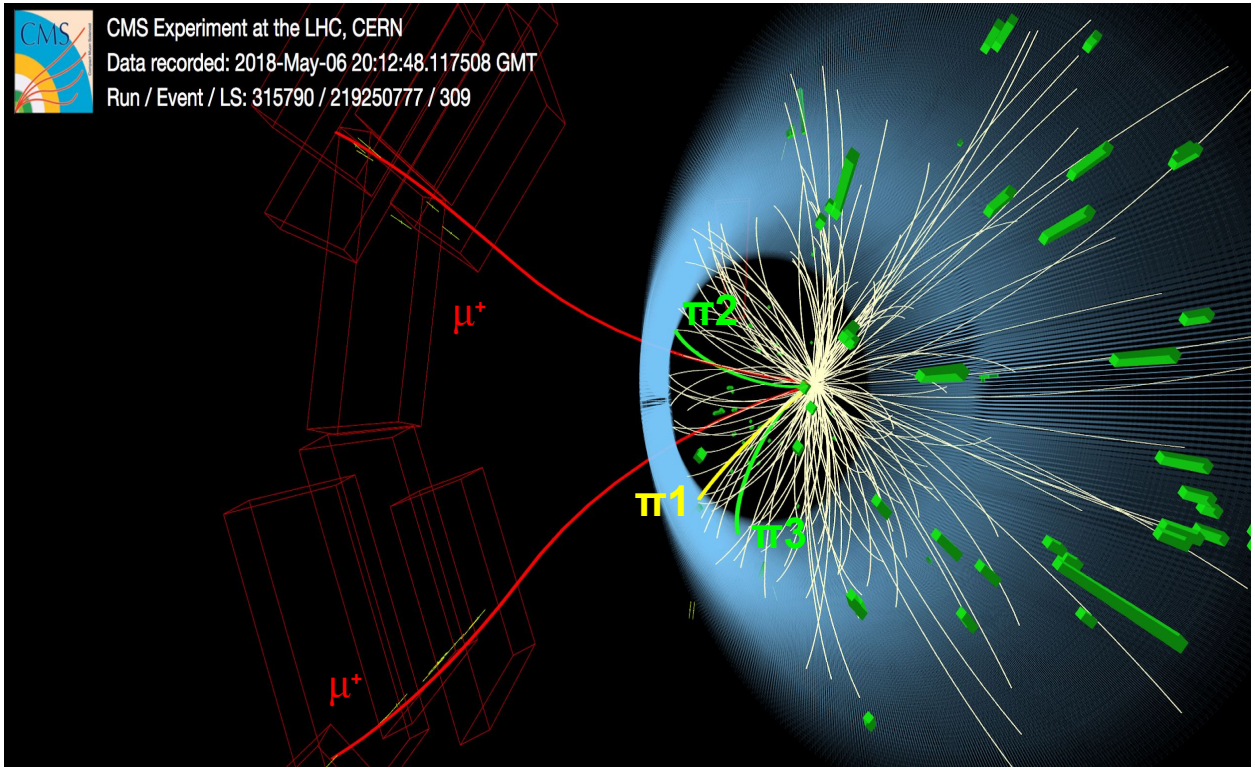
Event selection

kinematic requirements

$p_T(\pi_1) > 3.5$ GeV
B_c prob(vtx) > 0.1
$p_T(B_c) > 15$ GeV
B_c decay length > 0.01 cm

$6.2 < M(B_c) < 6.35$ GeV
$B_c \pi \pi$ prob(vtx) > 0.1
$p_T(\pi_2) > 0.8$, $p_T(\pi_3) > 0.6$ GeV



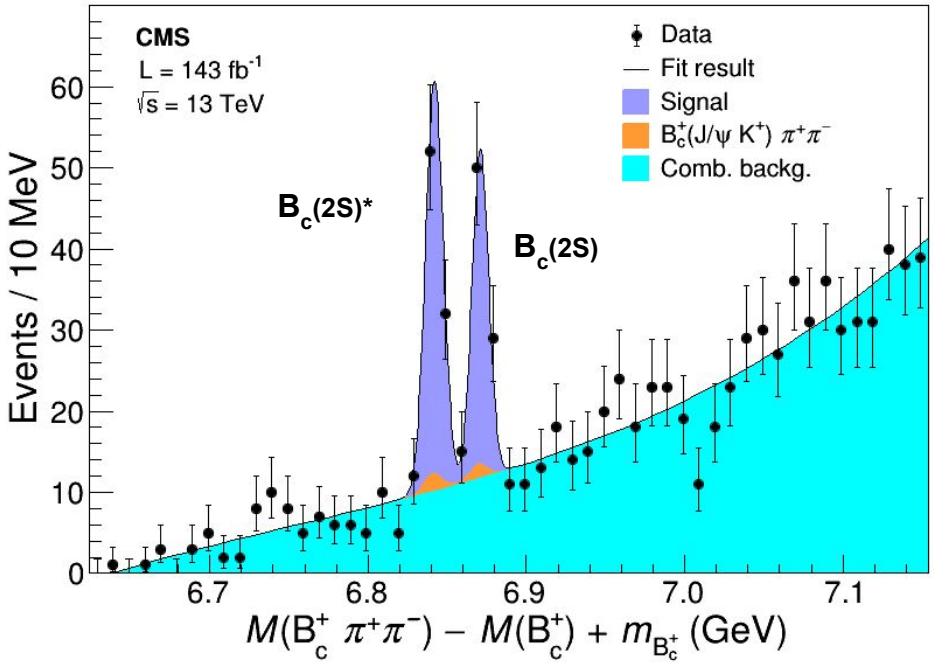


Event display of reconstructed candidate

Observation of the two-peak structure

The mass difference between the two states in the $B_c \pi^+\pi^-$ mass distribution is predicted to be $M(B_c(2S)) - \Delta M$, where

$$\Delta M = [\, M(B_c^{*}) - M(B_c)] - [\, M(B_c(2S)^{*}) - M(B_c(2S))] \quad \rightarrow \quad \sim 20 \text{ MeV}$$



Mass distribution fitted with Gaussian functions for the peaks and a 3rd order polynomial for the background.

Mass resolution agrees with MC expectations ~ 6 MeV

Two-peak structure observed (well resolved) :

$\Delta M = 29.1 \pm 1.5$ (stat) MeV

Local significance exceeding six σ for observing two peaks rather than one, evaluated through the ratio of likelihoods (including syst.). Each of them above five σ

Mass of $B_c(2S)$ measured to be:

$M(B_c(2S)) = 6871.0 \pm 1.2$ (stat) MeV

Natural widths : (50-90 keV predicted)

measurements consistent with zero, e.g. smaller than the resolution

Systematic uncertainty evaluation

The systematic uncertainties come from: $B_c(2S)$ fit modeling, J/ψ K uncertainties, partially reconstructed decays, and alignment of the detector.

Fit modeling:
alternative functions for the signal and the backgrounds
signal peaks: changed from two Gaussians to two Breit-Wigner functions
background: changed from a polynomial to a threshold function used in previous CMS analyses
observed differences in M and ΔM are quoted as systematic uncertainties: 0.8 and 0.7 MeV respectively

J/ψ K background contamination:
difference seen when its yield is varied by 10% (PDG BFs uncertainty): the difference is negligible

Alignment of the detector:
the possible misalignment of the detector biases the measured masses, however for studies with major detector changes (2016 vs 2017), was found to be negligible

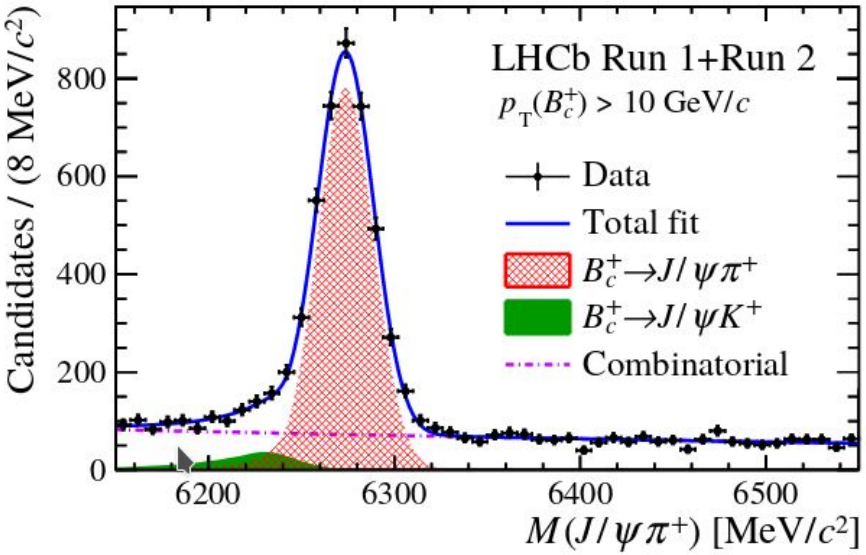
Partially-reconstructed decays:
the low-mass edge of the signal mass window was varied from 6.2 to 6.1 GeV, to increase (by 8%) this contamination;
the variations in the results are smaller than the uncorrelated stat. uncertainty: no systematic uncertainty is considered

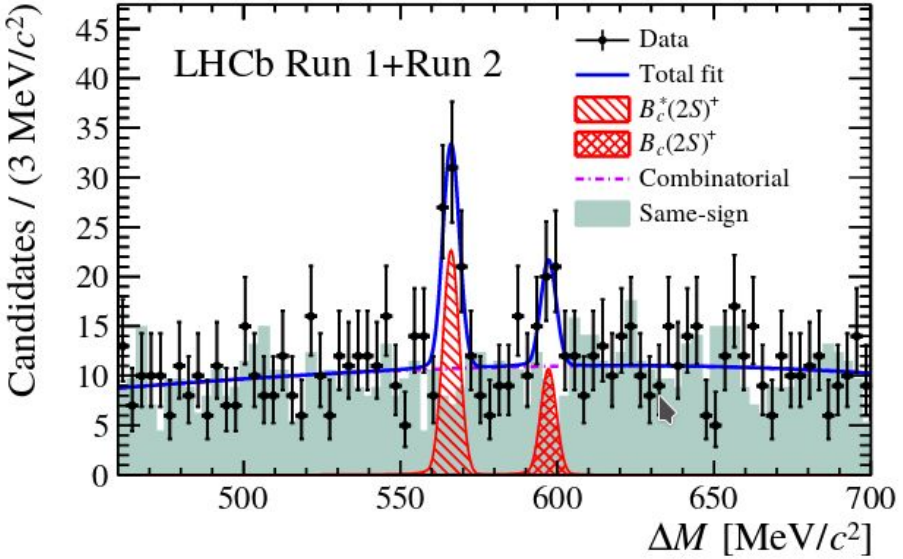
In summary, the total systematic uncertainty is 0.8 MeV for M and 0.7 MeV for ΔM,
fully determined by the choice of the fitting model for the signal peaks

Now LHCb has also confirmed the two peaks!

Observation of an excited Bc state

arXiv:1904.00081, **Phys. Rev. Lett. 122, 232001 (2019)**



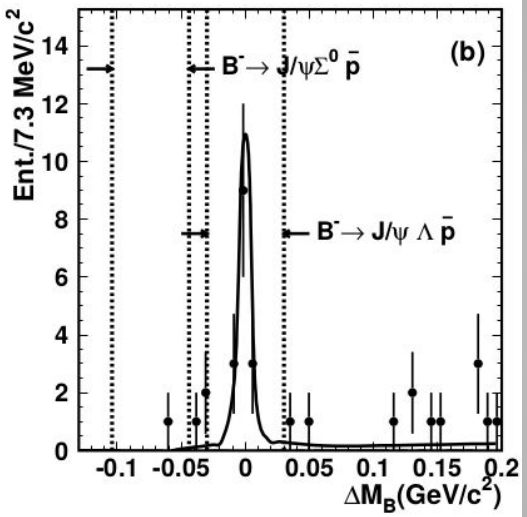


CMS-PAS-BPH-18-005:

Study of the $B \rightarrow J/\psi \Lambda p$ decay in proton-proton collisions at $\sqrt{s} = 8$ TeV.

First example of a B meson decay into baryons

Phys.Rev.D72:051105,2005

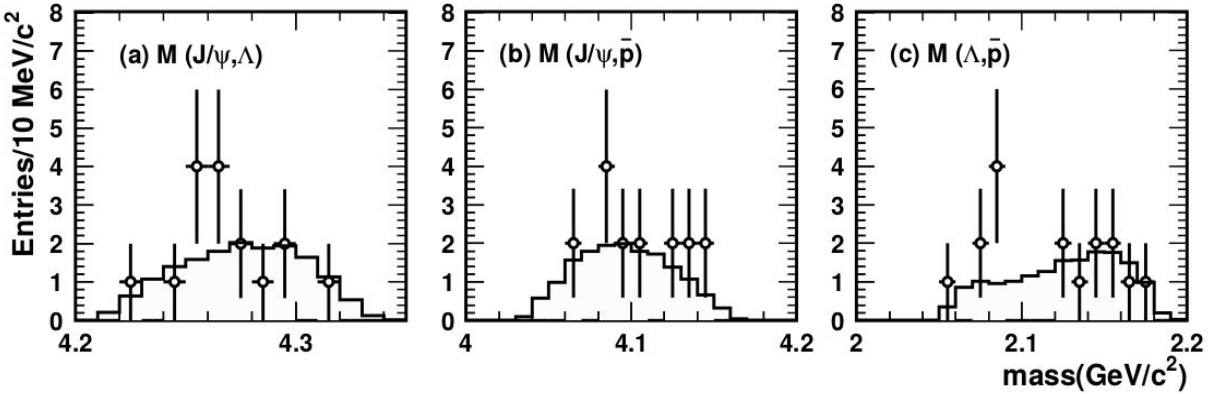


Observed in 2005 by Belle with very low yield (17.2 ± 4.1 events)

$\beta(B \rightarrow J/\psi \Lambda p) = (11.6 +/- 2.8^{+1.8}_{-2.3}) \times 10^{-6}$

Recently, the LHCb Collaboration reported the first observation of the baryonic Bc→J/ψppπ. 10.1103/PhysRevLett.113.152003

Motivation to study this decay is to search for new intermediate resonances in the **J/ψΛ, J/ψp and Λp** systems



Such a study in the Λb → J/ψpK decay resulted in the observation by the LHCb Collaboration of new multiquark states consistent with pentaquarks. 10.1103/PhysRevLett.115.072001, arXiv:1904.00081 (2019)

$B \rightarrow J/\psi \Lambda p$ production at CMS

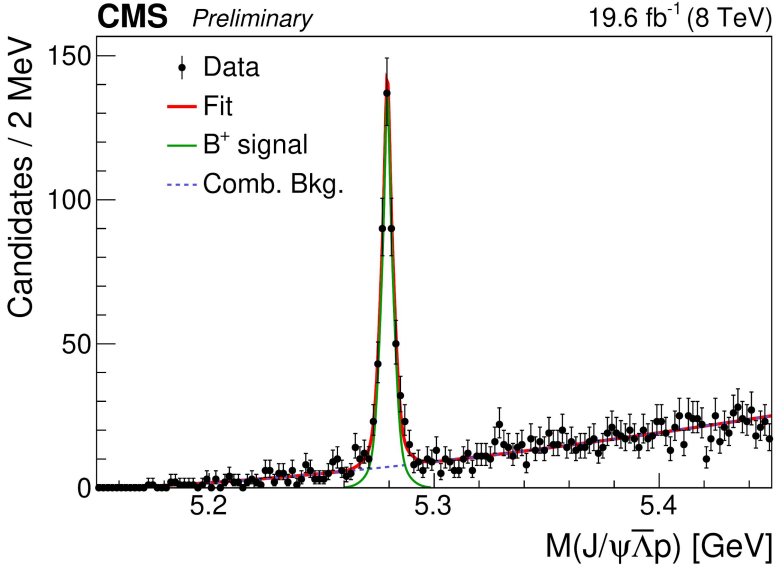
- Using data collected at 8 TeV, corresponding to an integrated luminosity of 19.6 fb^{-1}

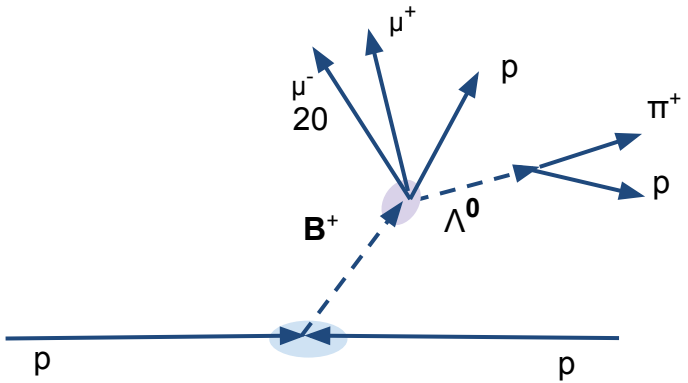
- The decay $B \rightarrow J/\psi K^{*}(K^{*} \rightarrow K_s^{0}\pi^{+})$ is chosen as the normalization channel, as it is measured with high precision and has a similar decay topology.

  The ratio of branching fractions is measured to be

  $(15.07 \pm 0.81 \text{ (stat)} \pm 0.40 \text{ (syst)} \pm 0.86(\beta)) \times 10^{-6}$

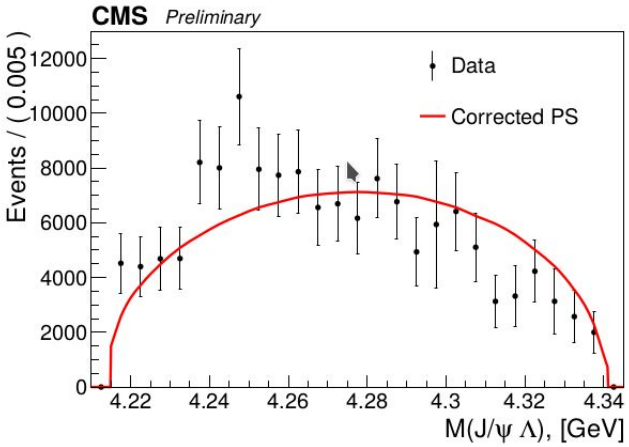
  This measurement is the most precise to date & consistent with previous Belle measurement

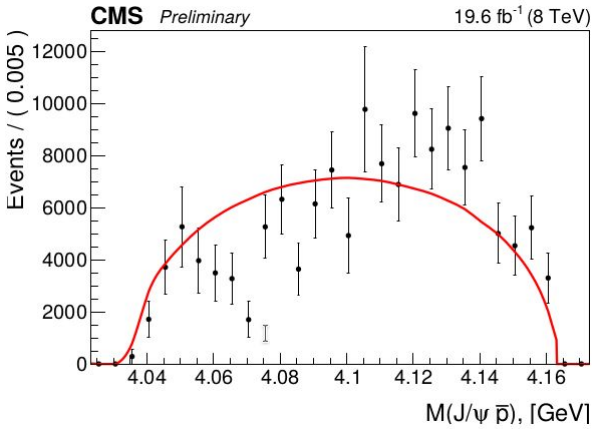


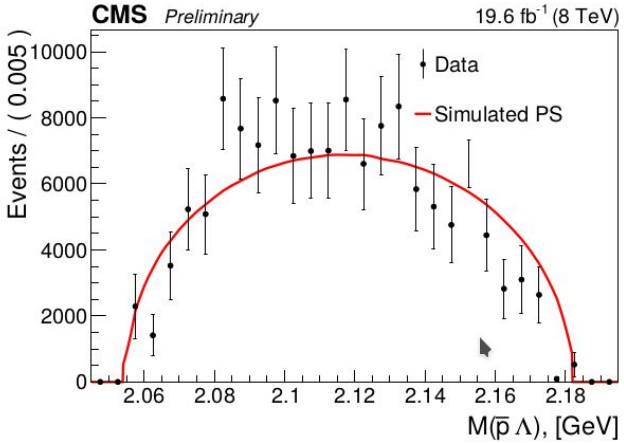


J/ψΛ, J/ψp and Λp systems

- Large signal yield allowed CMS to conduct a search for new exotic multiquark states in the two-body systems
- The three two-body systems show incompatibility with the phase space hypothesis







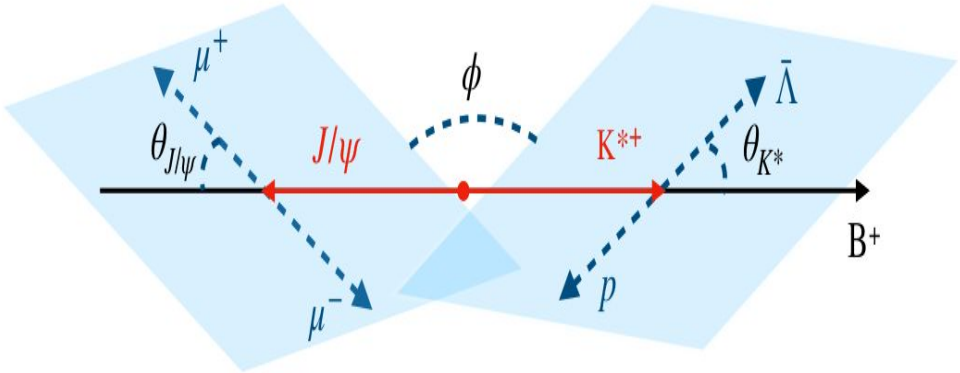
Model-independent approach: method of moments

- First introduced by the BaBar [PRD 79 112001(2009)] and later used by the LHCb [PRD 92,112009 (2015), PRL 117, 082002 (2016)].
- There are at least three known K^* resonances that can decay to Λp. So, these broad excited kaon states can contribute to the two-body invariant mass distributions.
- In each M(Λp) bin, the cos(θK^*) distribution can be expressed as an expansion in terms of Legendre polynomials:

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

cos (θK∗) helicity angle defined as the angle between Λ momentum and B+ momentum in the Λp rest frame

L_{max} equal to twice the spin of the highest-spin resonace can describe all the resonaces and their interferences. From table L_{max}= 2*4=8.



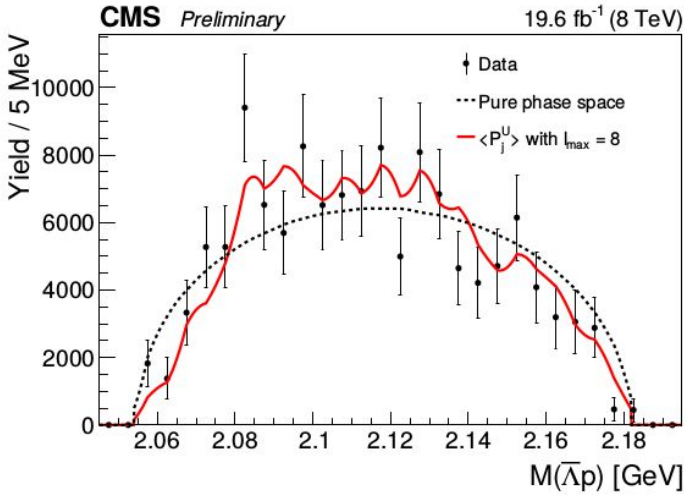
Resonance	Mass [MeV]	Natural width [MeV]	J^P
$K_4^*(2045)^+$	2045 ± 9	198 ± 30	4^+
$K_2^*(2250)^+$	2247 ± 17	180 ± 30	2^-
$K_3^*(2320)^+$	2324 ± 24	150 ± 30	3^+

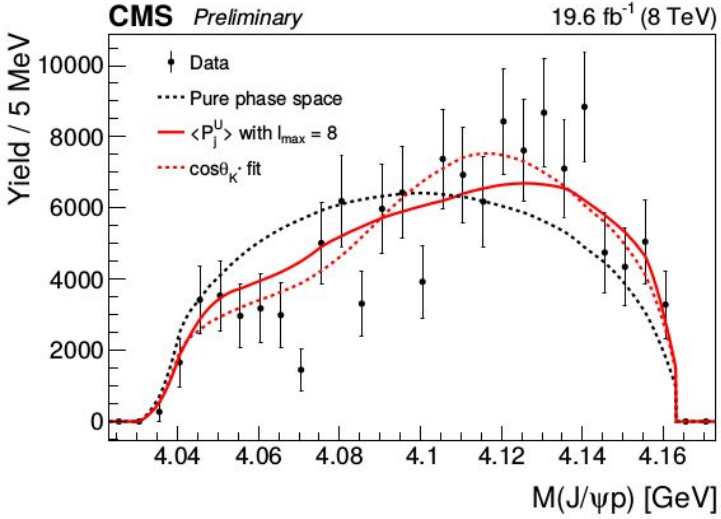
Simulation reweighting Results

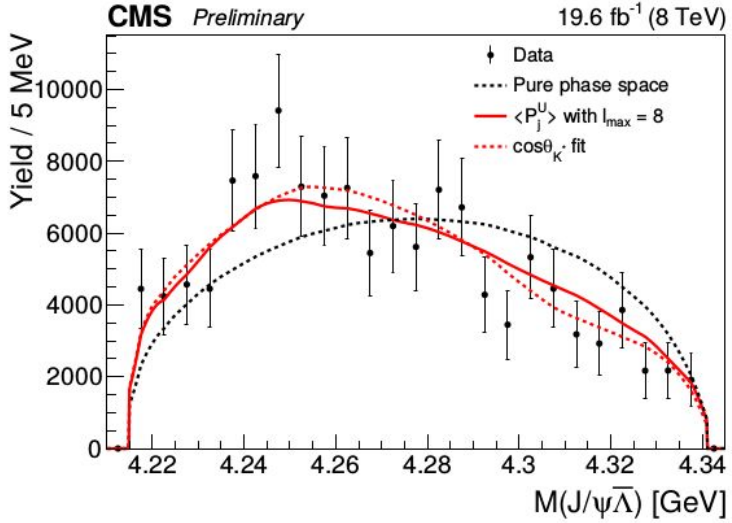
Simulation reweighting according to the observed angular structure in the Λp system.

It is evident that the description of the M(J/ψΛ) and M(J/ψp) data distributions is improved after accounting for the angular and invariant mass structure in the Λp system in simulation.

Compatibility with data eliminating the need for new resonances!







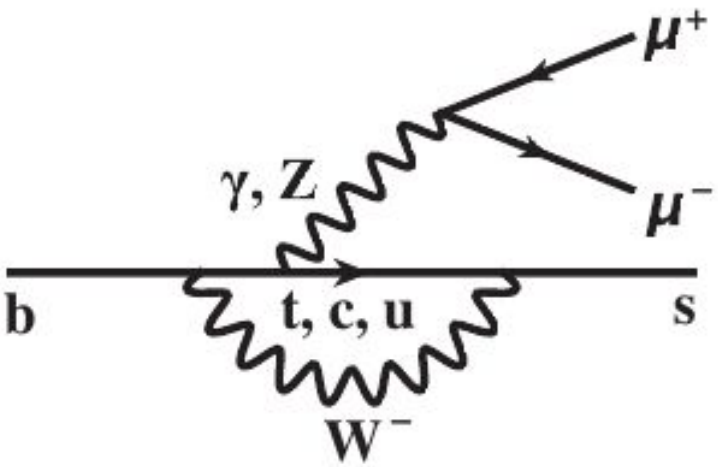
CMS-BPH-15-001-003

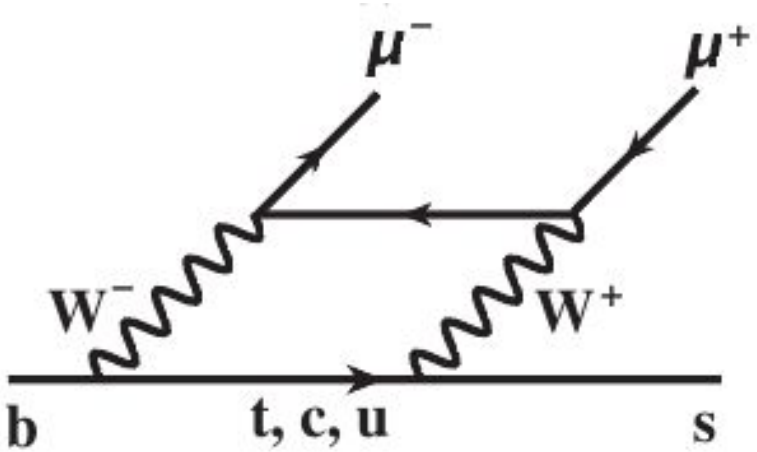
Angular analysis of the decay $B^+ \rightarrow K^+ \mu^+ \mu^-$ in proton-proton collisions at $\sqrt{s}$= 8 TeV.

Phys. Rev. D 98, 112011 (2018)

Angular analyses of $b \to s l^+ l^-$

The transitions of the type $b \to s l^+ l^-$ − is a flavor-changing neutral current (FCNC) process, with l denoting a charged lepton. In the SM, this type of transition is forbidden at tree level and occurs through higher-order processes via either electroweak Z/γ penguin diagrams or a W+W− box diagram. This makes the measurement of these rare FCNC decays more sensitive to possible physics phenomena beyond the SM.





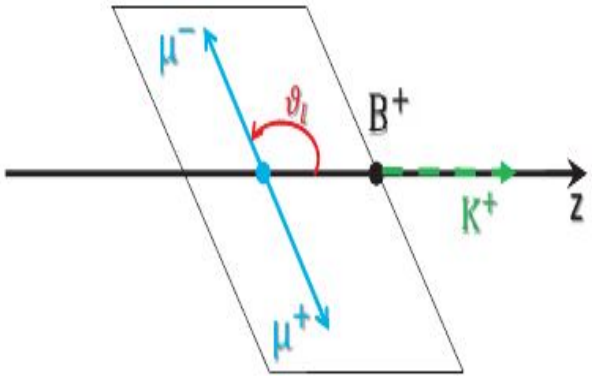
$B^+ \to K^+ \mu^+ \mu^-$ analysis

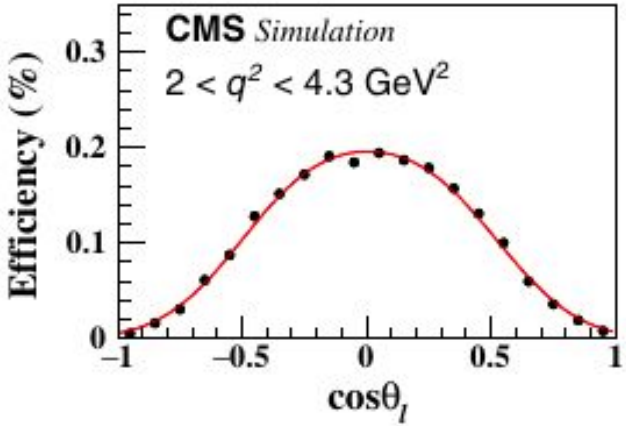
$$\text{pdf}(m, \cos\theta_\ell) = Y_S \cdot S(m) \cdot S(\cos\theta_\ell) \cdot \varepsilon(\cos\theta_\ell) + Y_B \cdot B(m) \cdot B(\cos\theta_\ell)$$

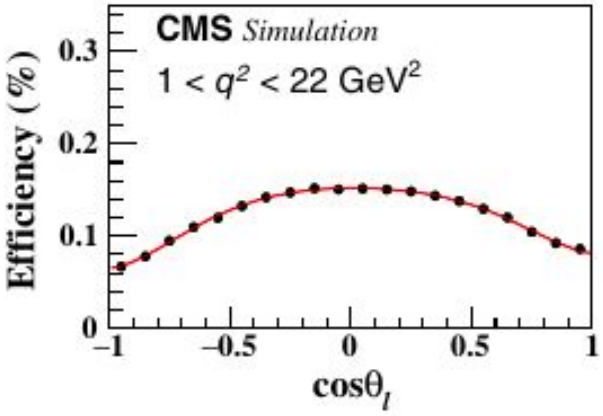
$$S(\cos\theta_\ell): \frac{1}{\Gamma}\frac{d\Gamma[B^+ \to K^+ \mu^+ \mu^-]}{d\cos\theta_l} = \frac{3}{4}(1 - F_H)(1 - \cos^2\theta_l) + \frac{1}{2}F_H + \mathcal{A}_{FB}\cos\theta_l$$

A_{FB}: $\mu^+\mu^-$ forward-backward asymmetry.

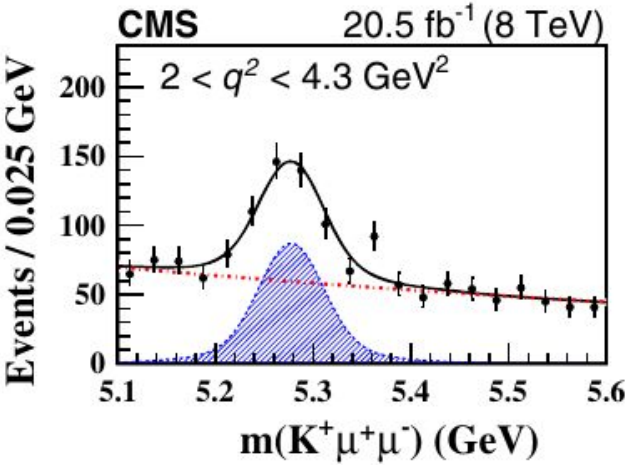
F_H: contribution from pseudoscalar, scalar and tensor amplitudes to the decay width Γ.

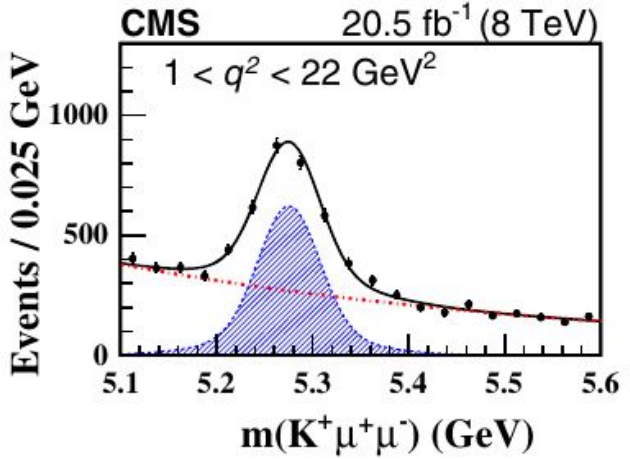


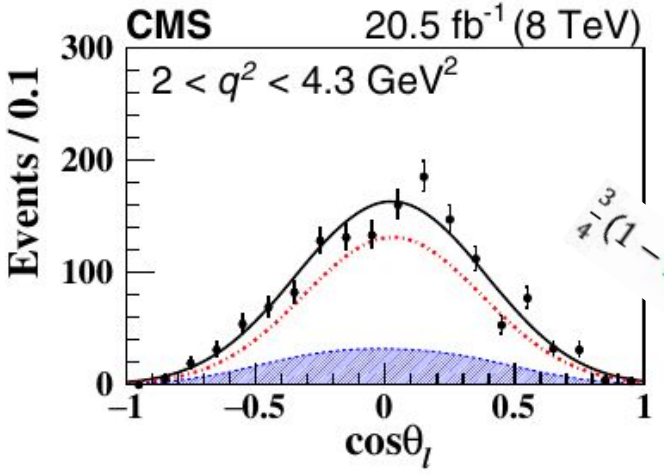




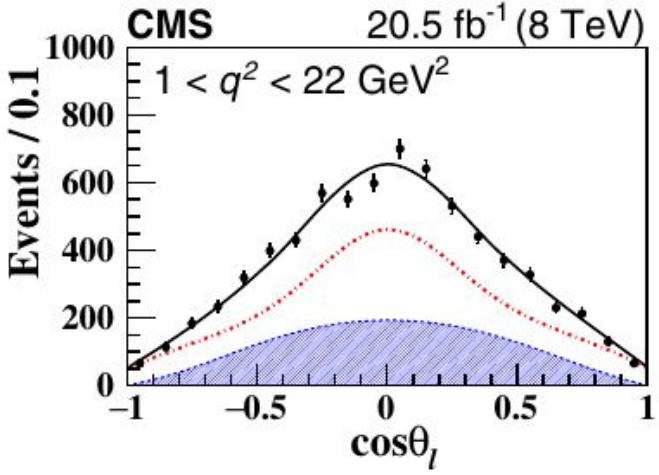
$B^+ \to K^+\mu^+\mu^-$ analysis





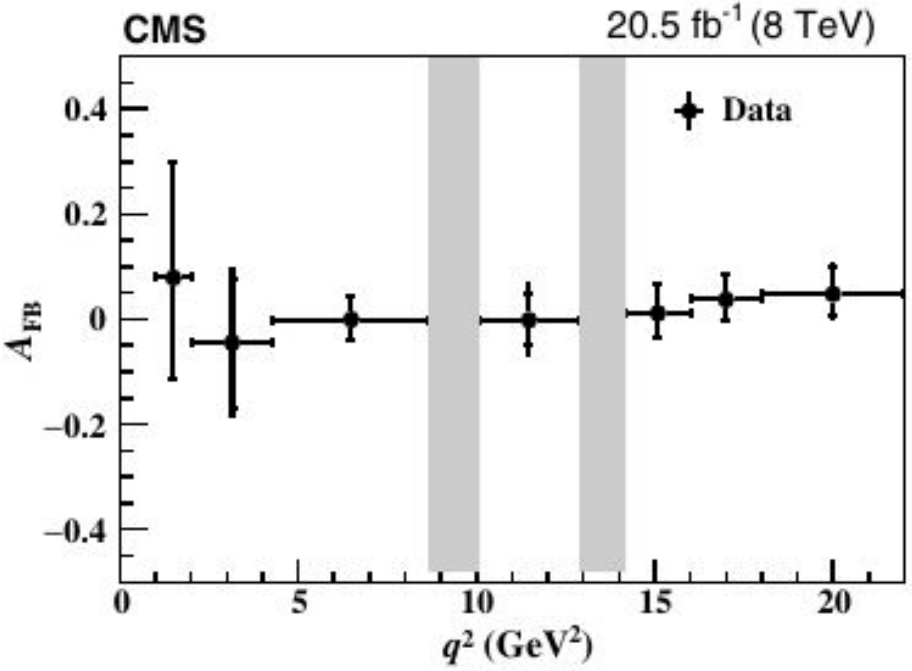


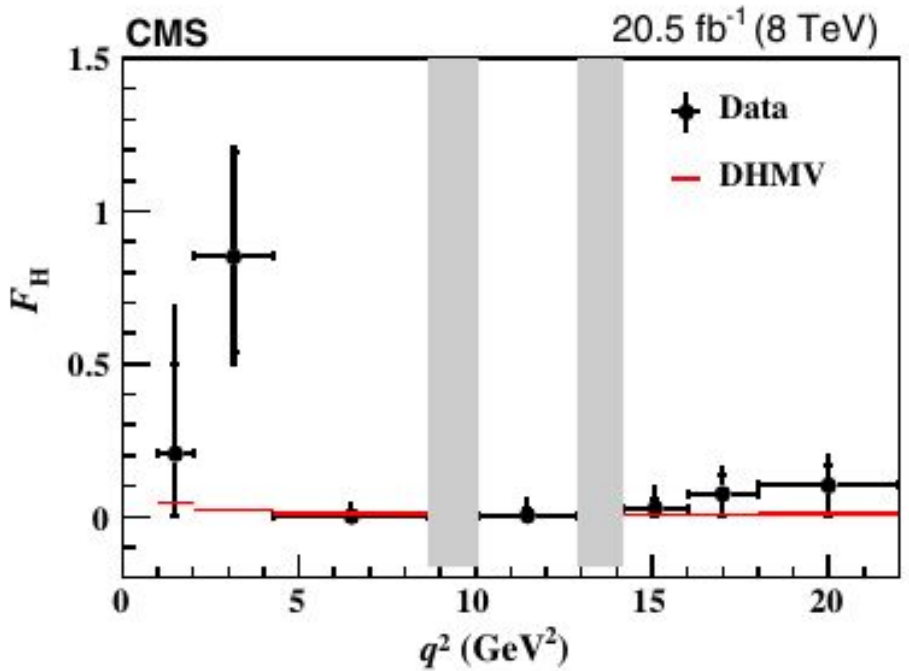
$$\frac{3}{4}(1-F_H)(1-\cos^2\theta_l)+\frac{1}{2}F_H+A_{FB}\cos\theta_l$$



double Gaussian with common mean.

$B^+ \rightarrow K^+ \mu^+ \mu^-$ analysis

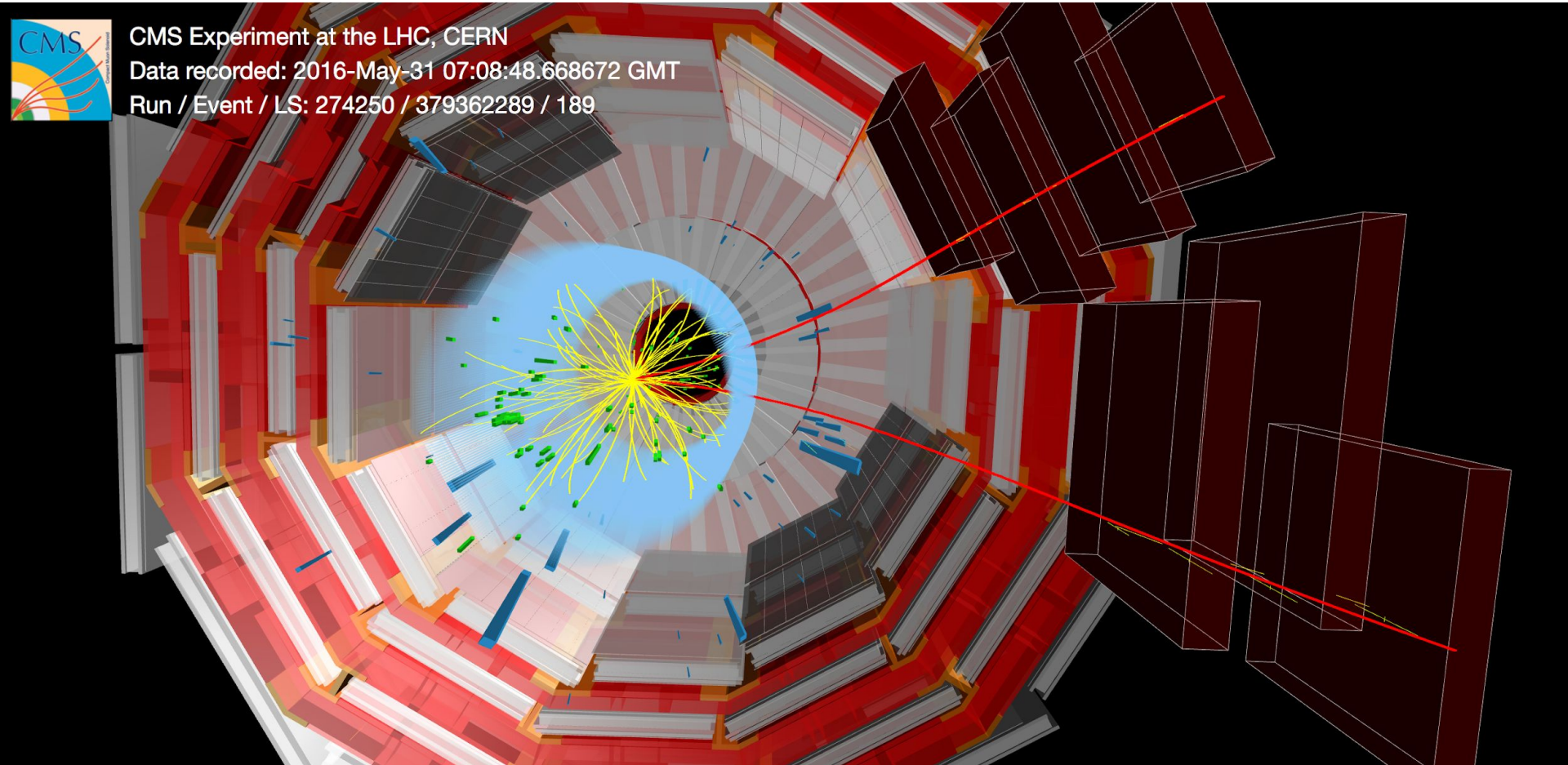




➔ The events are fit in seven q^2 bins from 1 to 22 GeV^2 , yielding 2286 signal events in total.

➔ Measured A_{FB} and F_H show good agreement with SM predictions within uncertainties. No indication of new physics

$B \rightarrow \mu^+\mu^-$



Measurement of properties of $B_s \to \mu^+\mu^-$ decays and search for $B^0 \to \mu^+\mu^-$ with the CMS experiment.

CMS-PAS-BPH-16-004

CMS Draft Analysis Note

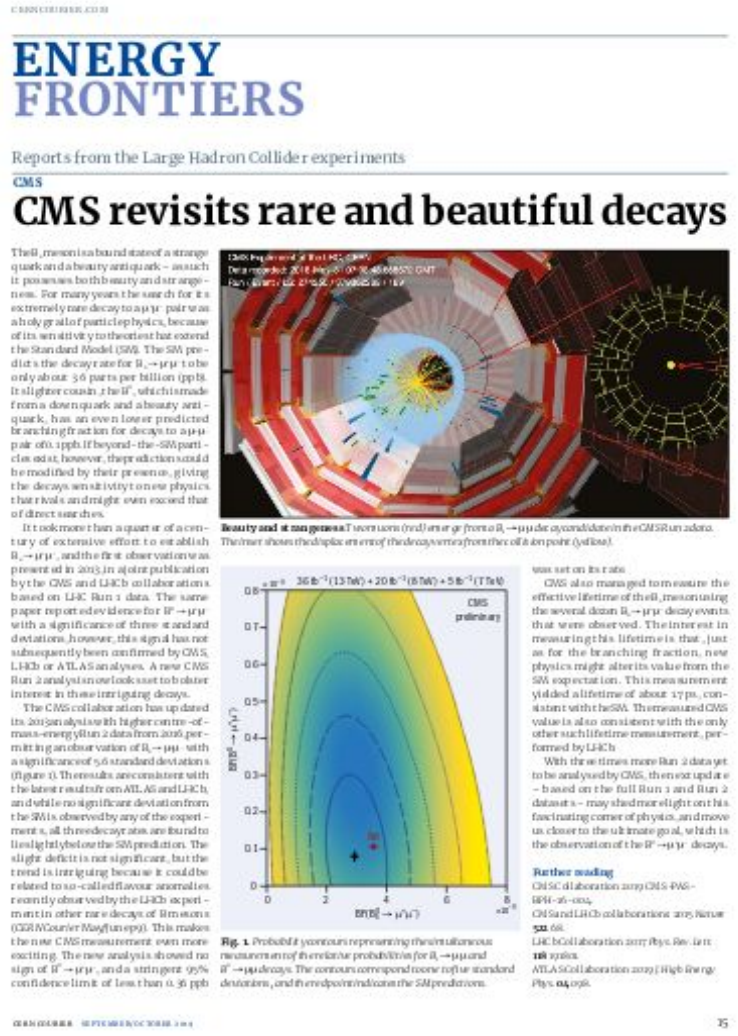
The content of this note is intended for CMS internal use and distribution only

2019/07/05
Archive Hash: 8619d76f-D
Archive Date: 2019/07/05

Measurement of $B_s^0 \to \mu^+\mu^-$ decays and search for $B^0 \to \mu^+\mu^-$ with the 2011, 2012, and 2016 dataset

D. Kotlinski[1], U. Langenegger[1], S. Wiederkehr[1], A. Starodumov[2], S. K. Swain[3], C. Kar[3], K.-F. Chen[4], Y.-T. Lai[4], and J. Mejia Guisao[5]

[1] Paul Scherrer Institute, Villigen, Switzerland
[2] ETH Zurich, Zurich, Switzerland
[3] National Institute of Science Education and Research, Bhubaneswar, India
[4] National Taiwan University, Taipei, Taiwan
[5] Universidad de Antioquia, Medellin, Colombia



ENERGY FRONTIERS

Reports from the Large Hadron Collider experiments

CMS

CMS revisits rare and beautiful decays

The B_s meson is a bound state of a strange quark and a beauty antiquark – as such it possesses both beauty and strangeness. For many years the search for its extremely rare decay to a $\mu\mu$ pair was a holy grail of particle physics, because of its sensitivity to theories that extend the Standard Model (SM). The SM predicts the decay rate for $B_s \to \mu\mu$ to be only about 3.6 parts per billion (ppb). Its slighter cousin, the B^0, which is made from a down quark and a beauty antiquark, has an even lower predicted branching fraction for decays to a $\mu\mu$ pair of 0.1 ppb. If beyond-the-SM particles exist, however, the prediction could be modified by their presence, giving the decays sensitivity to new physics that rivals and might even exceed that of direct searches.

It took more than a quarter of a century of extensive effort to establish $B_s \to \mu\mu$, and the first observation was presented in 2013 in a joint publication by the CMS and LHCb collaborations based on LHC Run 1 data. The same paper reported evidence for $B^0 \to \mu\mu$ with a significance of three standard deviations. However, this signal has not subsequently been confirmed by CMS, LHCb or ATLAS analyses. A new CMS Run 2 analysis is one to look out for to bolster interest in these intriguing decays.

The CMS collaboration has updated its 2013 analysis with higher centre-of-mass-energy Run 2 data from 2016, permitting an observation of $B_s \to \mu\mu$ with a significance of 5.6 standard deviations (figure 1). The results are consistent with the latest results from ATLAS and LHCb, and while no significant deviation from the SM is observed by any of the experiments, all three decay rates are found to lie slightly below the SM prediction. The slight deficit is not significant, but the trend is intriguing because it could be related to so-called flavour anomalies recently observed by the LHCb experiment in other rare decays of B mesons (CERN Courier May/Jun 2019). This makes the new CMS measurement even more exciting. The new analysis showed no sign of $B^0 \to \mu\mu$, and a stringent 95% confidence limit of less than 0.36 ppb was set on its rate.

CMS also managed to measure the effective lifetime of the B_s meson using the several dozen $B_s \to \mu\mu$ decay events that were observed. The interest in measuring this lifetime is that, just as for the branching fraction, new physics might alter its value from the SM expectation. This measurement yielded a lifetime of about 1.7 ps, consistent with the SM. The measured CMS value is also consistent with the only other such lifetime measurement, performed by LHCb.

With three times more Run 2 data yet to be analysed by CMS, the next update – based on the full Run 1 and Run 2 datasets – may shed more light on this fascinating corner of physics, and move us closer to the ultimate goal, which is the observation of the $B^0 \to \mu\mu$ decays.

Further reading

CMS Collaboration 2019 CMS-PAS-BPH-16-004.
CMS and LHCb collaborations 2015 *Nature* **522** 68.
LHCb Collaboration 2017 *Phys. Rev. Lett.* **118** 191801.
ATLAS Collaboration 2019 *J. High Energ. Phys.* **04** 098.

PROPERTIES OF $B_s^0 \to \mu^+\mu^-$ DECAYS

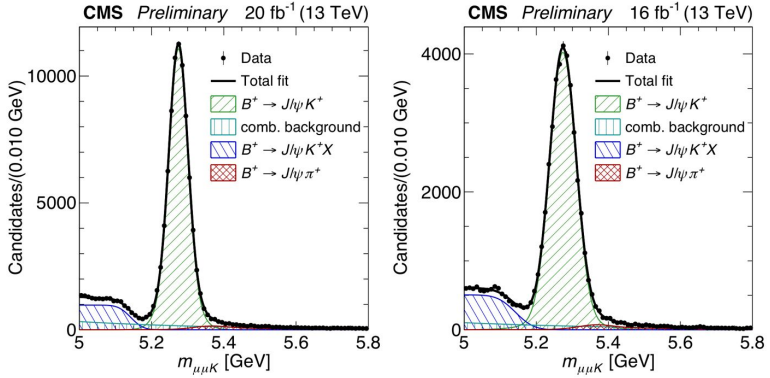
- Previous results from LHCb, ATLAS, CMS
- The $B_s \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ branching fractions: measure relative to $B^+ \to J/\psi\, K^+$ decays (with $J/\psi \to \mu^+\mu^-$)
  - Cancellation of many systematic uncertainties
  - Depends on the ratio of the fragmentation functions f_u/f_s
    - Use PDG value: $f_s/f_u = 0.252 \pm 0.012\,(\text{exp}) \pm 0.015$ (additional uncertainty assigned for p_t and energy dependence)

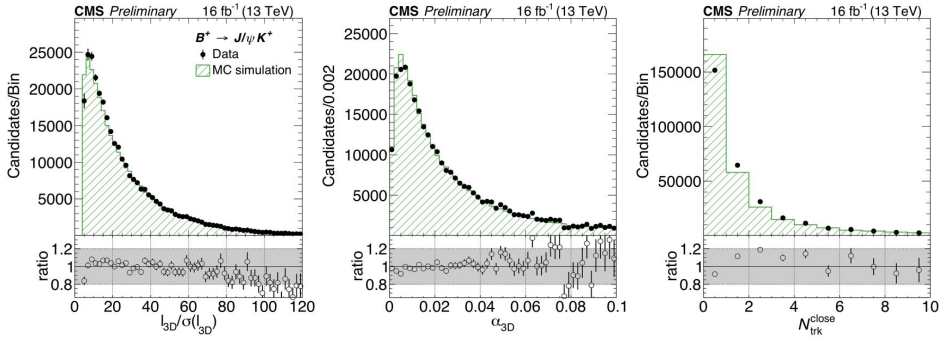
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \frac{N_S}{N_{obs}^{B^+}} \frac{f_u}{f_s} \frac{\varepsilon_{tot}^{B^+}}{\varepsilon_{tot}} \mathcal{B}(B^+ \to J/\psi K^+)\, \mathcal{B}(J/\psi \to \mu^+\mu^-)$$

- **Dataset: Run 1 (7, 8 TeV) + Run 2 (2016 13 TeV)**
- Dimuon selection optimized to reduce fake rates
- $B_s \to J/\psi\phi$ used in systematic studies

CMS-PAS-BPH-16-004

$B^+ \to J/\psi\, K^+$ Data/MC comparisons
Invariant-mass distributions for the μμK system (2016B)

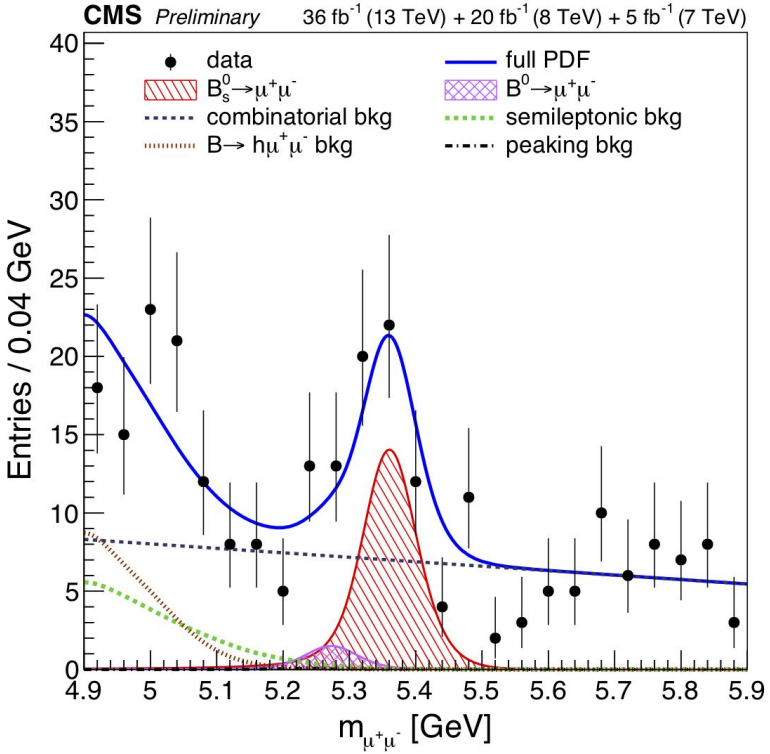




$B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ DECAYS

➔ The decay $B_s^0 \to \mu^+\mu^-$ is observed with a branching fraction of

- $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = [2.9^{0.7}_{0.6}(\text{exp}) \pm 0.2(f_s/f_u)] \times 10^{-9}$
  - Significance $B_s^0 \to \mu^+\mu^-$: **5.6 (6.5)** s.d. obs (exp)
- **No significant excess is observed for the decay $B^0 \to \mu^+\mu^-$,**
  - Upper limit $\mathcal{B}(B^0 \to \mu^+\mu^-) < 3.6 \times 10^{-10}$ at 95% confidence level
  - Previous CMS result: $\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.1 \times 10^{-9}$ **Phys. Rev. Lett. 111, 101804**
- **These results are consistent with standard model predictions**



CMS-PAS-BPH-16-004

$B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ DECAYS

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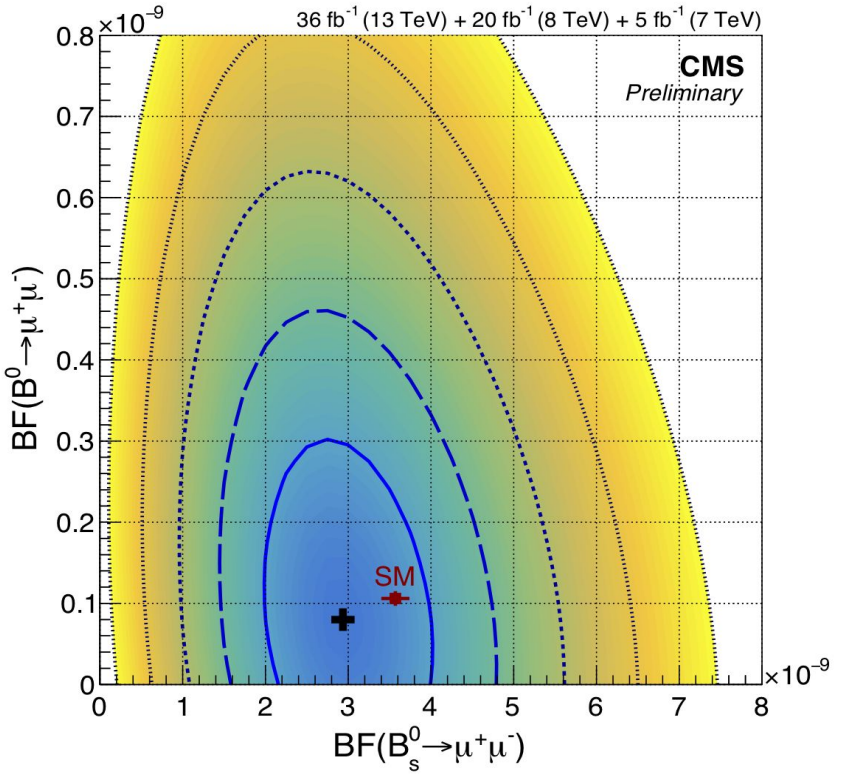


CMS-PAS-BPH-16-004

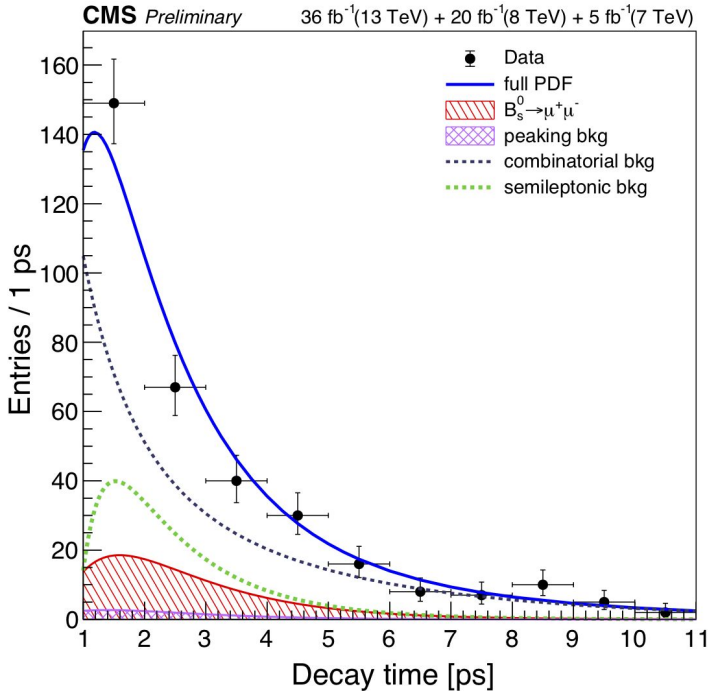
$B_s^0 \to \mu^+\mu^-$ EFFECTIVE LIFETIME

- $B_s^0 \to \mu^+\mu^-$ effective lifetime is determined using an 2D unbinned maximum likelihood fit to the dimuon invariant **mass** and proper **decay time** distributions:

$$\tau_{\mu^+\mu^-} = 1.7^{+0.61}_{-0.44}\ \text{ps}$$

The result is consistent with the SM expectations and with an earlier measurement from LHCb.

- Prospects for full Run 2 dataset:
  - **Resolve B^0 and enable precision comparisons to the SM for B_s^0**
  - **New physics could show up in the lifetime with improved precision.**



CMS-PAS-BPH-16-004

Summary

Considerable LHC data sets collected in Run 2 by CMS offers future opportunities in searches for new resonances .

For both experimentally and theoretically point of view, Heavy-flavor spectroscopy continues to be very fruitful.

Signals consistent with the $B_c(2S)$ and $B_c(2S)^*$ states have been separately observed for the first time by investigating the $B_c\pi\pi$ invariant mass spectrum measured by CMS.
The analysis is based on the full Run 2 data (13 TeV), corresponding to a total integrated luminosity of 143 fb-1

The ratio of branching fractions $\frac{\mathcal{B}(B^+ \to J/\psi \bar{\Lambda} p)}{\mathcal{B}(B^+ \to J/\psi K^{*+})}$ is measured. This measurement is the most precise to date. The study of two-body invariant mass distributions of the $B \to J/\psi \Lambda p$ decay products was performed. A model Independent approach was used to conclude that no new resonances are needed.

Angular analysis of the decay $B^+ \to K^+\mu^+\mu^-$ has been performed. The forward- backward asymmetry AFB of the muon system and the contribution FH of the pseudoscalar, scalar, and tensor amplitudes to the decay width are measured as a function of the dimuon mass squared. The results are consistent with previous measurements, and are also compatible with standard model predictions.

Summary

- $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ decays with Run 1 and 2016 data
  - update of branching fraction measurements

$$\overline{\mathcal{B}}(B_s^0 \to \mu^+\mu^-) = [2.9^{+0.7}_{-0.6}(\text{exp}) \pm 0.2(f_s/f_u)] \times 10^{-9}$$

$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 3.6 \times 10^{-10} \quad (95\%\text{CL})$$

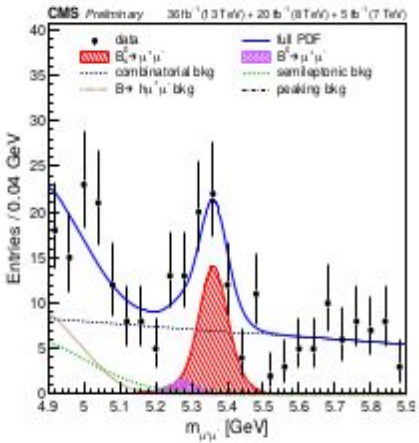
($B_s^0 \to \mu^+\mu^-$ significance: $5.6\,\sigma$ obs, $6.5\,\sigma$ exp, these results supersede PRL,111,101804)

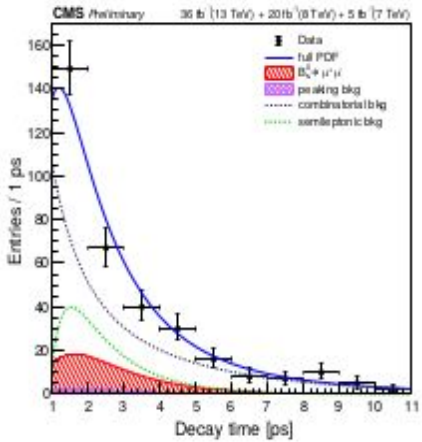
  - first $\tau_{\mu^+\mu^-}$ measurement of CMS

$$\tau_{\mu^+\mu^-} = 1.70^{+0.61}_{-0.44}\,\text{ps}$$

  - all results consistent with SM

Complete Run-2 analyses underway





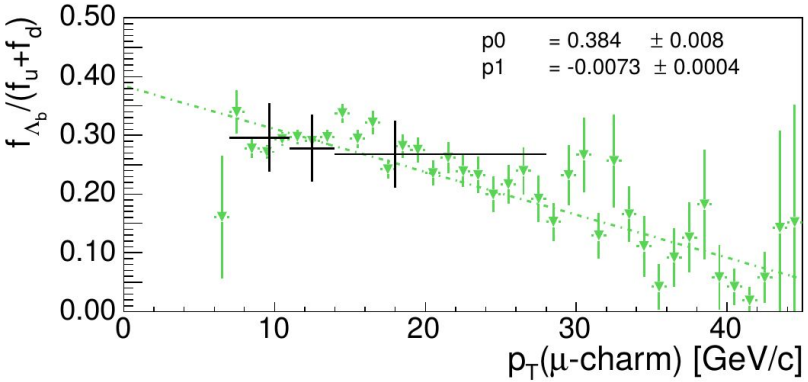
Thank you very much!!

SUMMARY

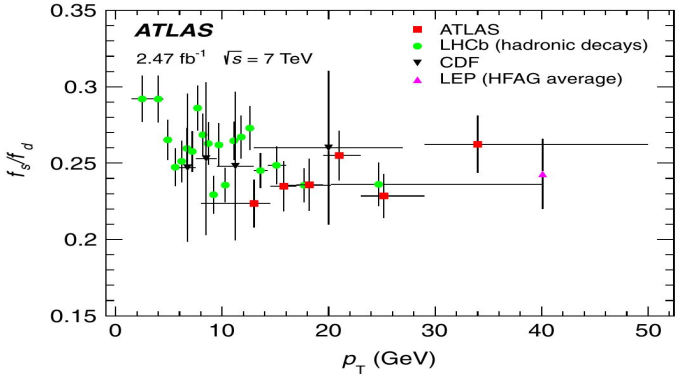
- **CMS is very busy during LS2!**
  - Vibrant **physics research** program exploiting Run 2 data
  - **Efficient technical program** completing Phase-1 upgrades, preparing for Run 3 (and HL-LHC)
- **CMS recently submitted its 900th scientific publication on results using LHC collision data.**
- Can expect many more results in the next months exploiting the full Run 2 dataset.

Motivation fs/fu. non-universality

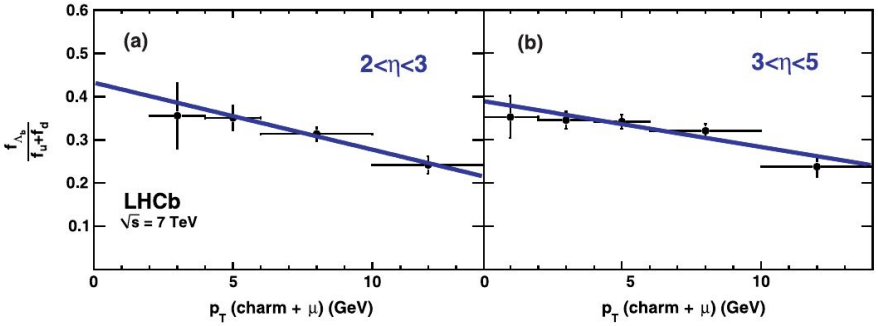
CDF: Phys. Rev. D77 , 072003 (2008)



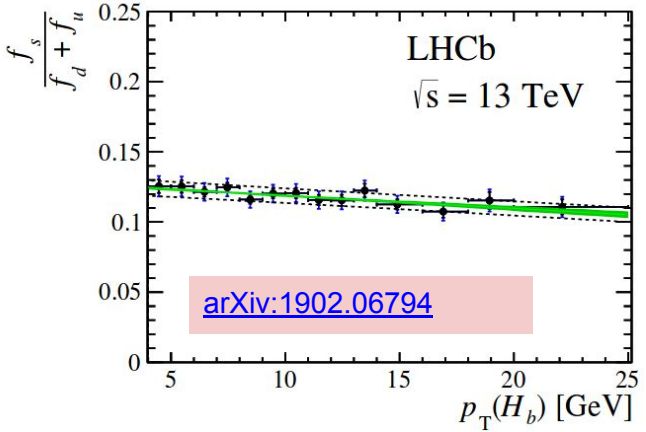
PRL 115, 262001 (2015)



PHYSICAL REVIEW D 85, 032008 (2012)

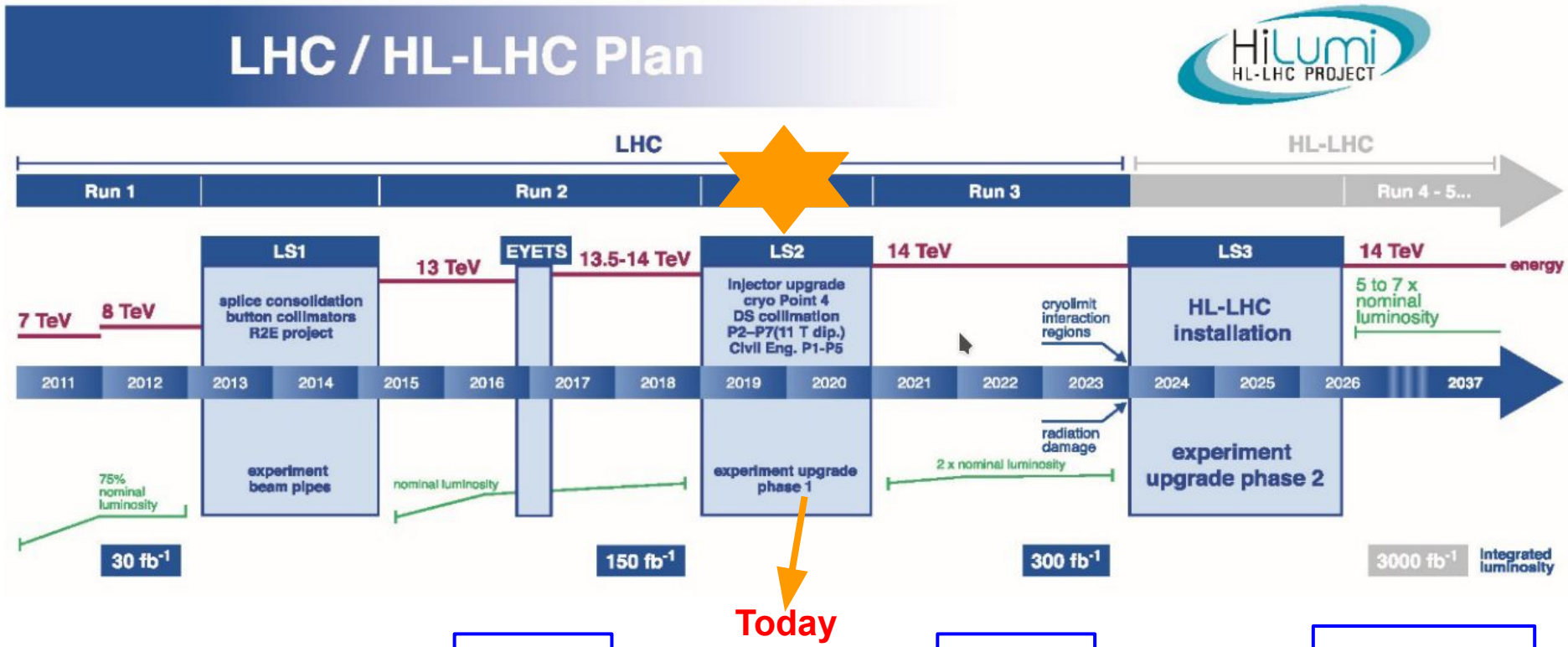


Phys. Rev. D 100, 031102 (2019)



arXiv:1902.06794

LHC TIMELINE

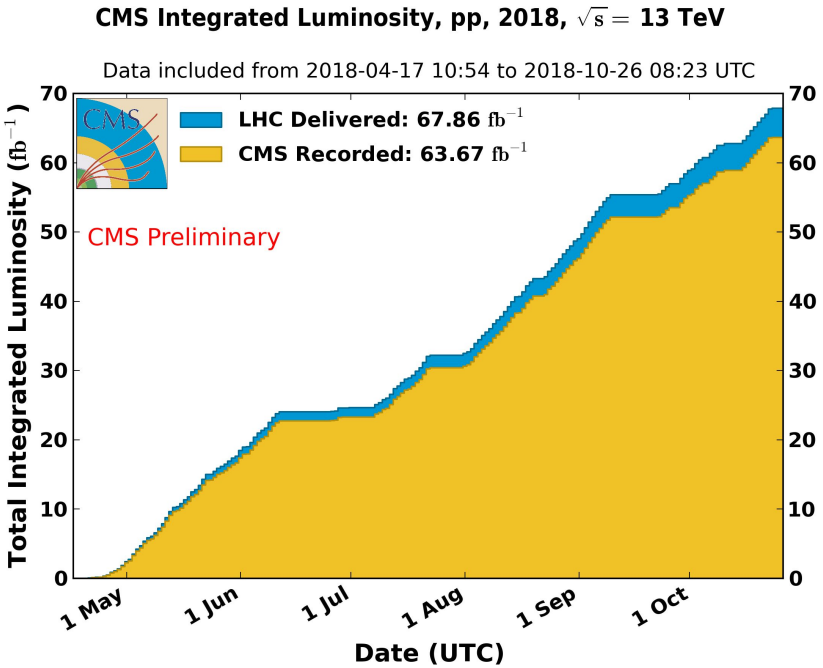


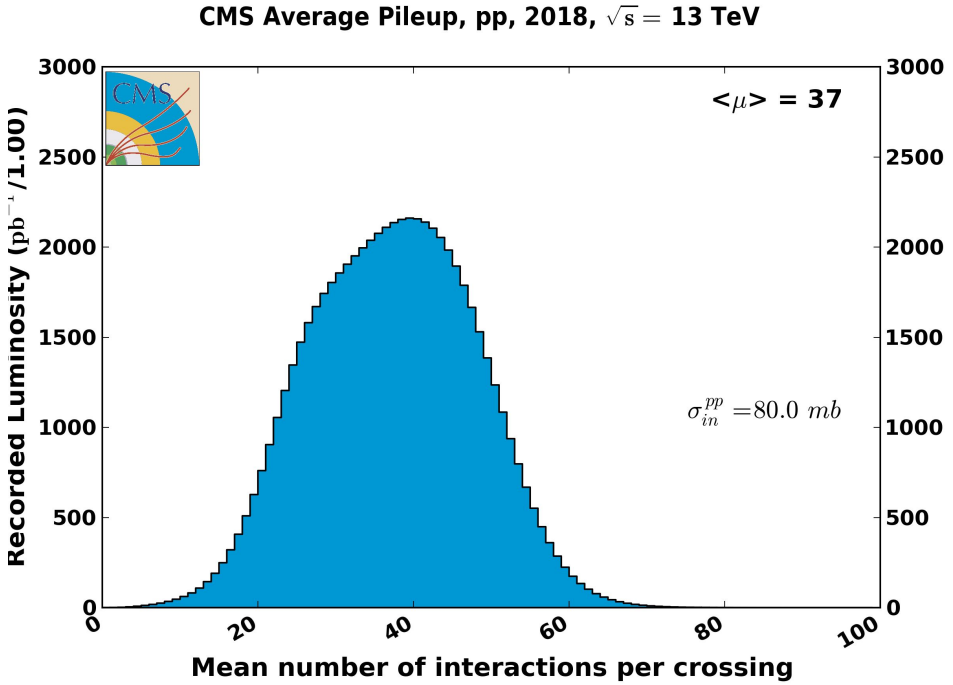
Run 2
<μ>~37

Run 2
<μ>~55

Run 4-5
<μ>~140-200

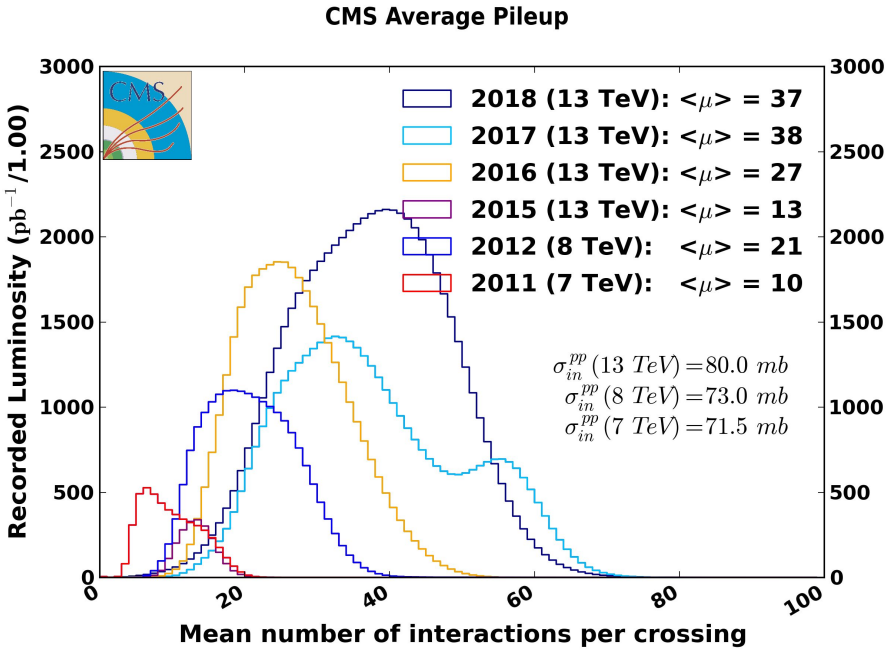
2018 run

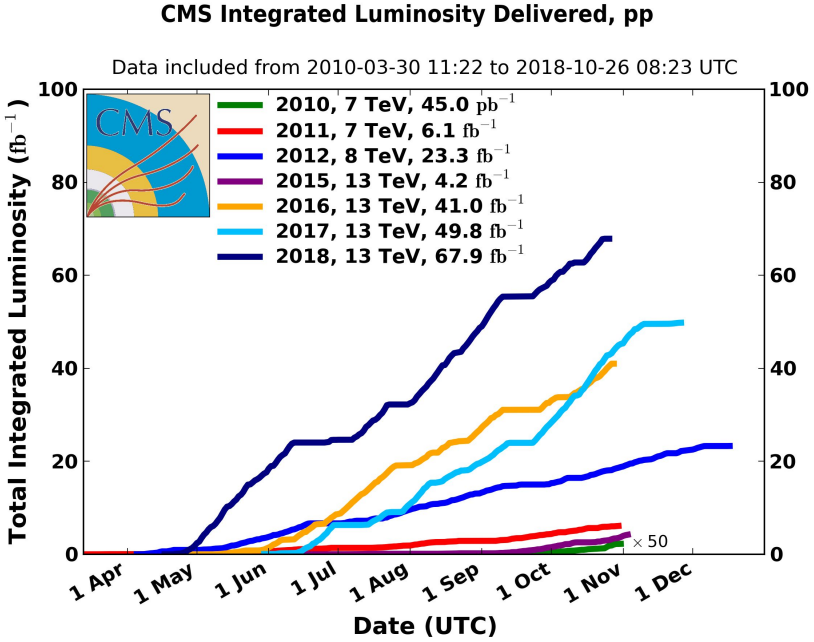




Exceeding the original integrated luminosity projections, 64 fb^{-1} has been delivered by the LHC in 2018.

Congratulations LHC, for a great performance!





	Int. Lumi	<μ>
7 TeV	6.1 fb^{-1}	10
8 TeV	23.3	21
13 TeV	163	37