Heavy Flavour at CMS

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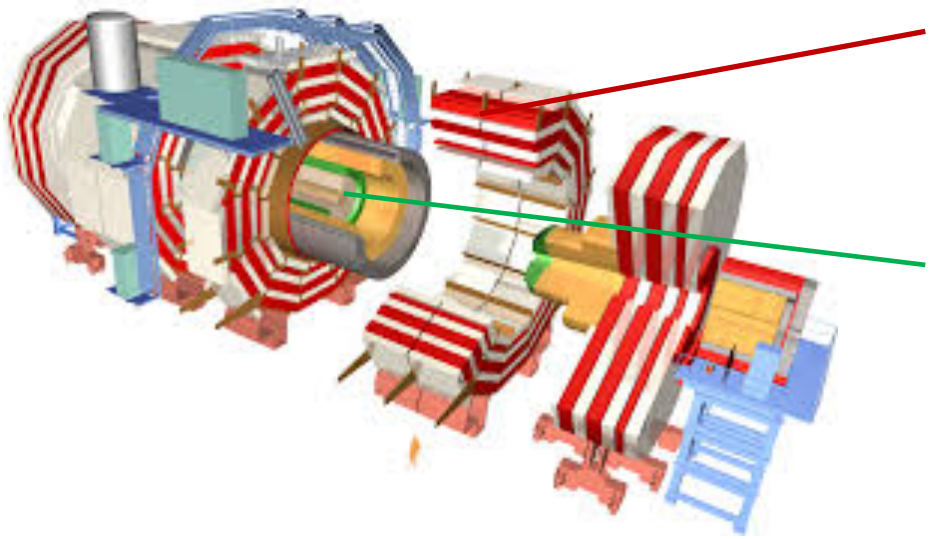
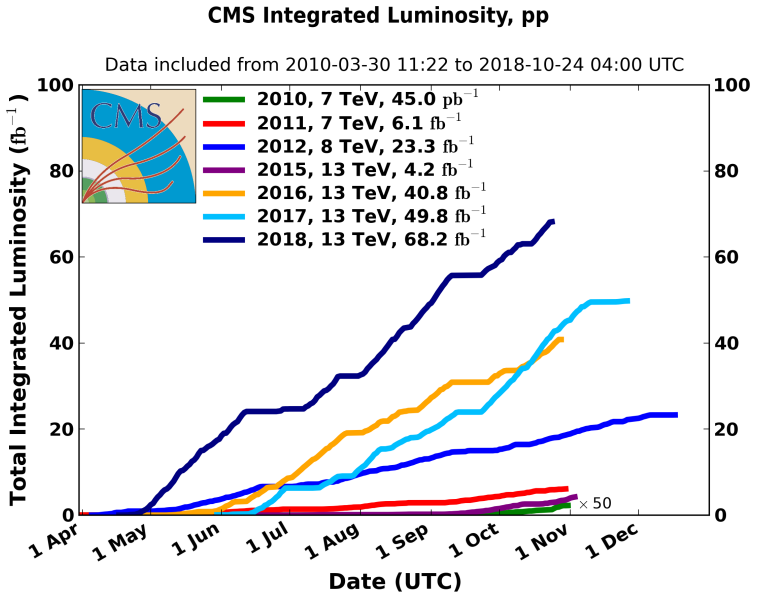
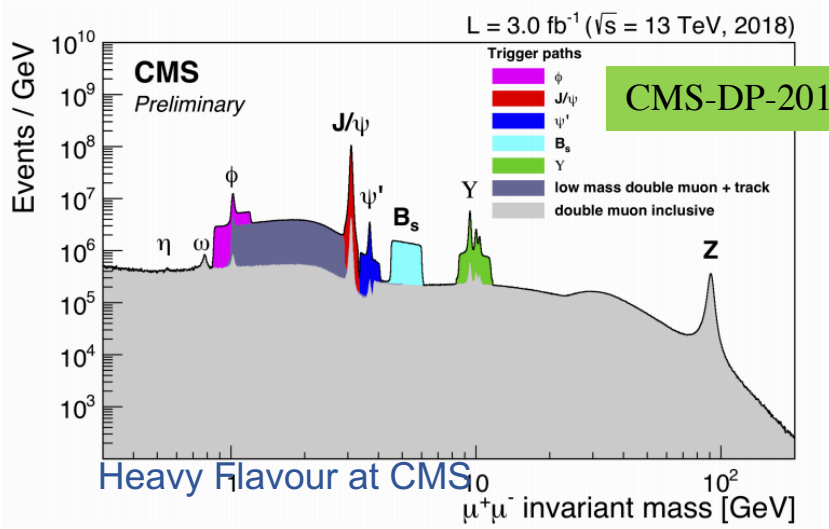
CMS for Heavy Flavour studies



- Muon tracking system consists of muon chamber and silicon tracker covers wide rapidity and p_T regions
- Thanks to the highly sensitive trackers, even low energy photons can be measured accurately using conversions
- Flexible trigger strategy provides a wide variety of study scopes including Higgs, SUSY, and b-physics





Recent results from CMS

Title	Publication
Measurement of production cross sections times branching fraction of $B_c^+ \to J/\psi\pi^+$ and $B^+ \to J/\psi K^+$ in pp collisions at $\sqrt{s} = 7$ TeV at CMS	CMS-PAS-BPH-13-002
Measurement of b hadron lifetime in pp collisions at $\sqrt{s} = 8$ TeV	EPJC 78 (2018) 457
Measurement of quarkonium production cross sections in pp collisons at $\sqrt{s} = 13$ TeV	PLB 780 (2018) 251
Measurement of the Λ_b polarization and angular parameters in $\Lambda_b \to J/\psi\Lambda$ decays from pp collisions at $\sqrt{s} = 7$ and 8 TeV	PRD 97 (2018) 072010
Search for the X(5568) state decaying into $B_S^0\pi^\pm$ in proton-proton collisions at $\sqrt{s} = 8$ TeV	PRL 120 (2018) 202005
Observation of the $B_{S2}^* \to B^0K_S^0$ decay and studies of excited B_S^0 mesons in proton-proton collisions at $\sqrt{s} = 8$ TeV	arXiv: 1809.03578, submitted to EPJC
Observation of the $Z \to \psi l^+ l^-$ decay in pp collisions at $\sqrt{s} = 13$ TeV	PRL 121 (2018) 141801
Observation of the $\chi_{b1}(3P)$ and $\chi_{b2}(3P)$ and measurement of their masses	PRL 12 (2018) 09002
Angular analysis of $B^+ \to K^+\mu^+\mu^-$ in proton-proton collisions at $\sqrt{s} = 8$ TeV	arXiv: 1806.00636, to appear in PRD
Measurement of angular parameters from the decay $B^0 \to K^{0*}\mu^+\mu^-$ in proton-proton collisions at $\sqrt{s} = 8$ TeV	PLB 781 (2018) 517

IHEP

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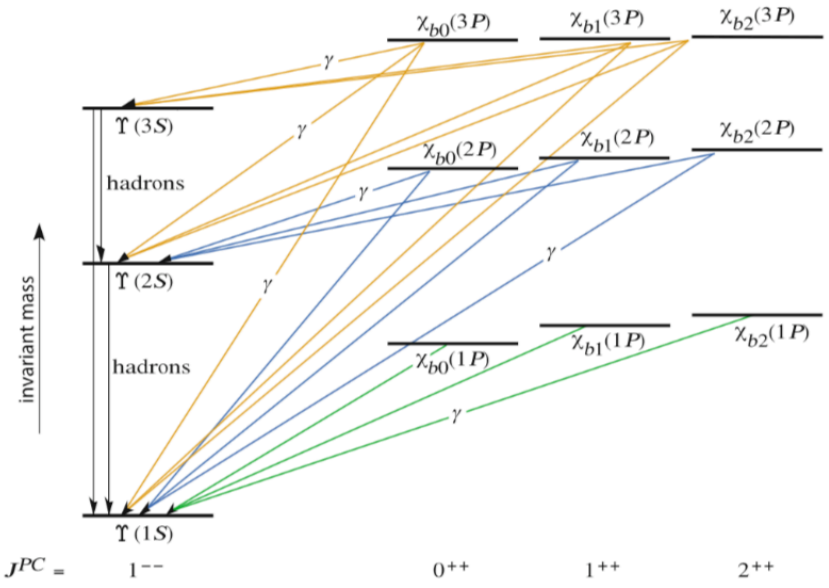
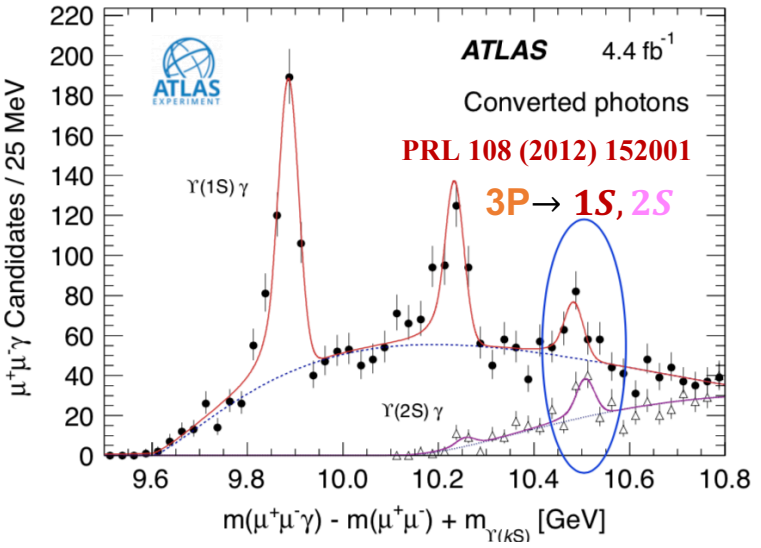
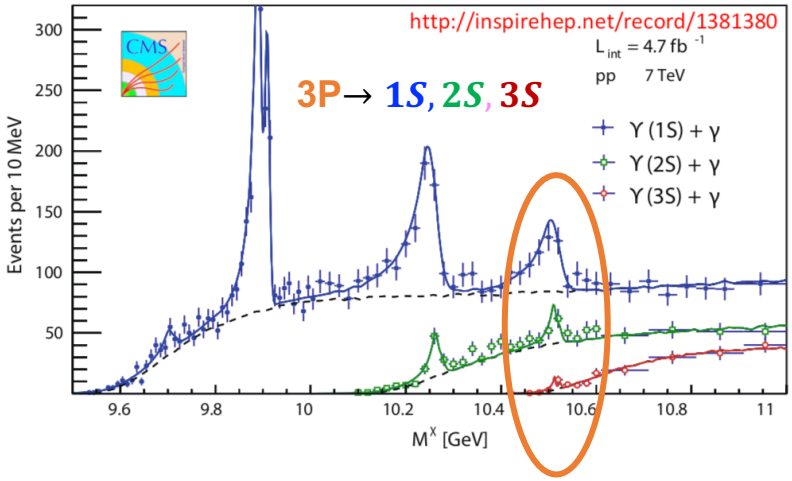
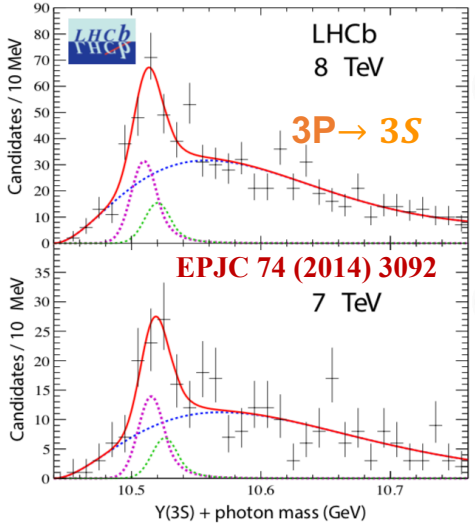
Observation of $\chi_{b1,2}(3P)$ mass split

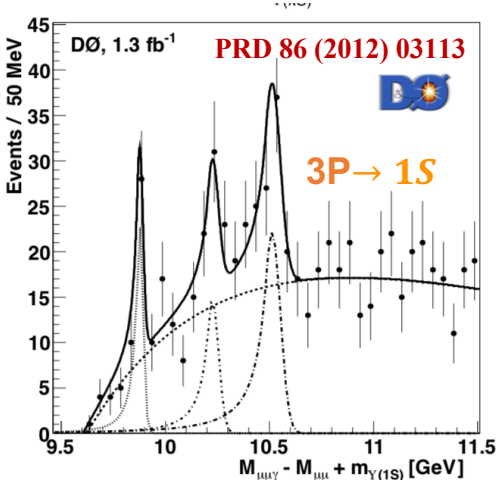
PRL 121 (2018) 092002











Observation of $\chi_{b1,2}(3P)$ mass split

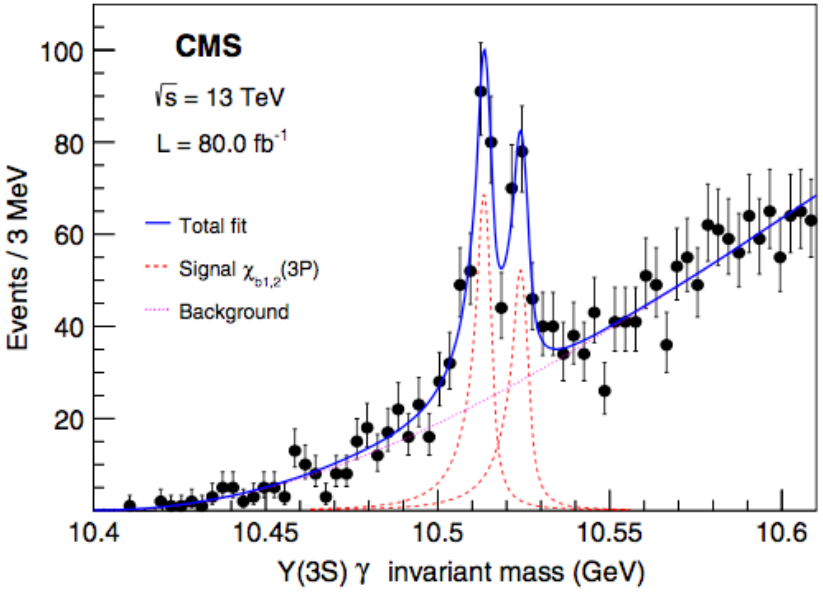
PRL 121 (2018) 092002

- **First observation** of resolved $\chi_{b1}(3P)$ and $\chi_{b2}(3P)$ states and their masses measurement through the decay channel

$$\chi_b(3P) \rightarrow \Upsilon(3S)\gamma$$

- Using pp data at **13 TeV** collected in **2015 + 2016 + 2017**, corresponding to integrated luminosities of 2.7, 35.2, and 42.1 fb^{-1} (**80 fb^{-1}** total)

- Extended unbinned maximum likelihood fit.
- The $\chi_{b1}(3P)$ and $\chi_{b2}(3P)$ signal peaks are modeled with a double-sides Crystal Ball, and the total yield is 372 $\pm$ 36.



$M(\chi_{b1}(3P))$ = 10 513.42 $\pm$ 0.41 (stat) $\pm$ 0.18 (syst) MeV

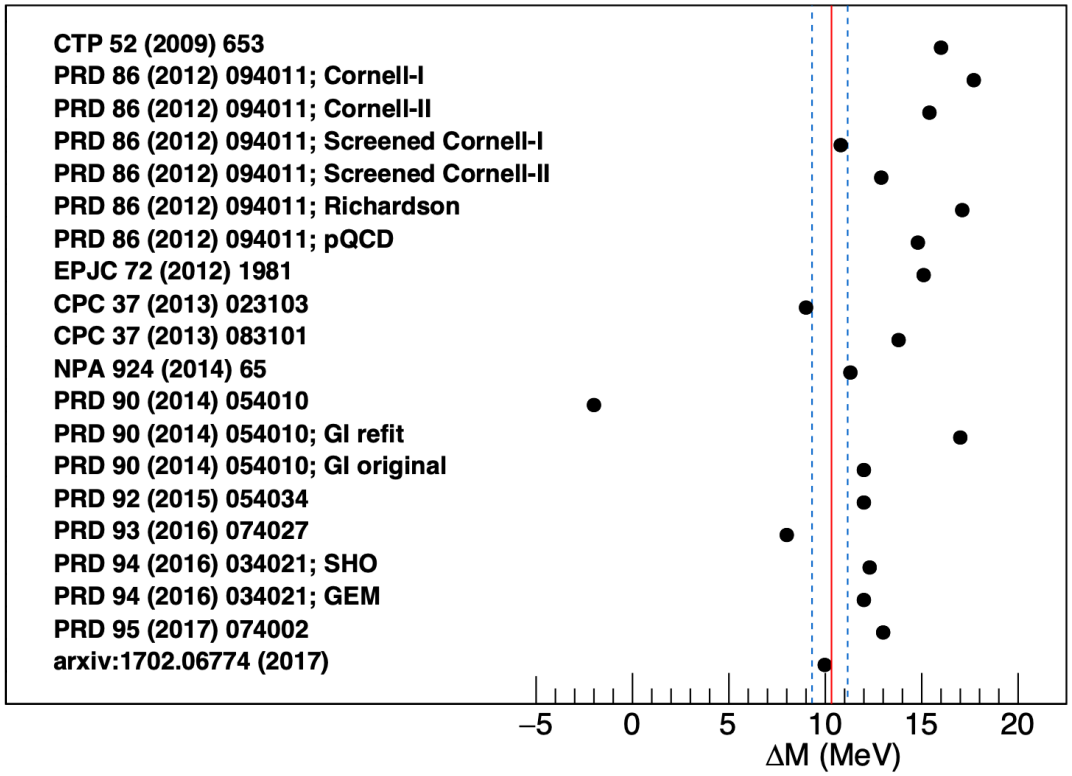
$M(\chi_{b2}(3P))$ = 10 524.02 $\pm$ 0.57 (stat) $\pm$ 0.18 (syst) MeV

Observation of $\chi_{b1,2}(3P)$ mass split

PRL 121 (2018) 092002

- Most of the theoretical predictions give a positive ΔM: $9 < \Delta M < 18$ **MeV**. The only exception give ΔM = **-2 MeV.**
- The measured mass difference between $\chi_{b2}(3P) - \chi_{b1}(3P)$ (in MeV):

$$\Delta M = 10.60 \pm 0.64\ (\text{stat}) \pm 0.17\ (\text{syst})$$



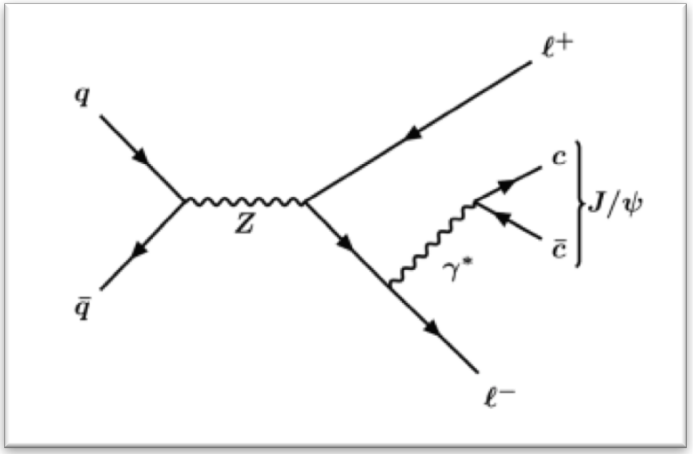
Observation of the $Z \to \psi l^+ l^-$ decay

PRL 121 (2018) 141801

- Only one exclusive leptonic decay channel $Z \to 4l$ has been observed apart from the common dilepton final states. Other searches (e.g. $Z \to \gamma ll$) only report upper limits so far.
- Theory estimates a branching fraction in the range of $(6.7 - 7.7) \times 10^{-7}$.
- Background for $H \to ZJ/\psi$ decays
- Very clean signature of 4 leptons:

  2 high-p_T leptons

  2 softer from the J/ψ



- First observation of **Z decaying to a J/ψ meson + a pair of leptons**

Observation of the $Z \to \psi l^+ l^-$ decay

PRL 121 (2018) 141801

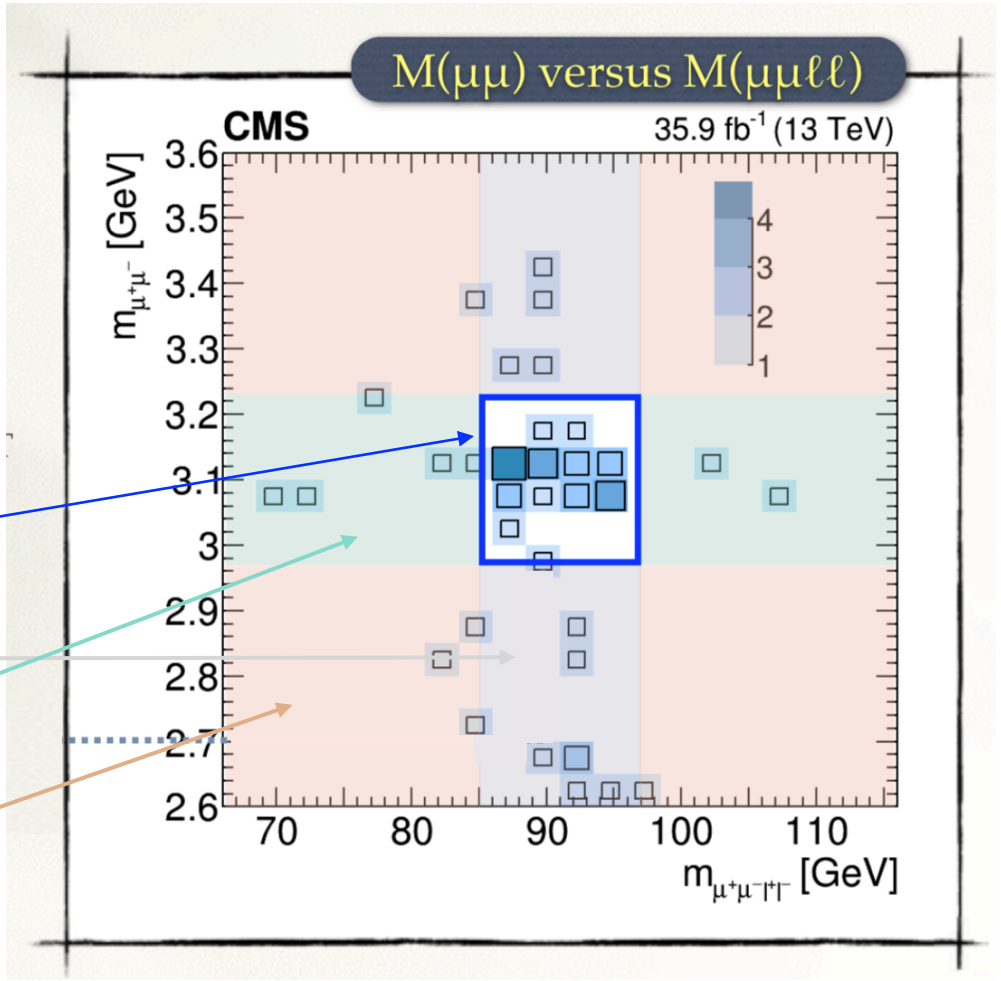
- **Full 2016 data of 35.9 fb^{-1} of 13 TeV** .
- Look for $Z \to J/\psi\mu^+\mu^-$ and $J/\psi e^+e^-$, with $J/\psi \to \mu^-\mu^+$.
- Four components are expected:

Z signal · J/ψ signal

Z signal · J/ψ background

Z background · J/ψ signal

Z background · J/ψ background



Observation of the $Z \to \psi l^+ l^-$ decay

PRL 121 (2018) 141801

- 2D unbinned extended maximum-likelihood fits to M($\mu\mu$) and M($\mu\mu ll$).

  Z signal: Breit-Wigner convoluted with a Gaussian

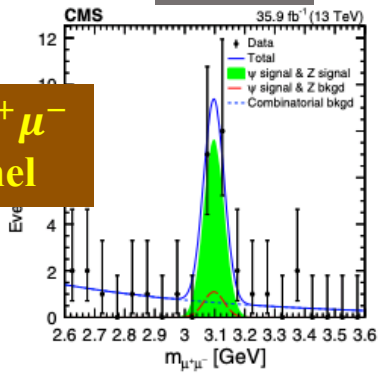
  J/ψ signal: single Gaussian

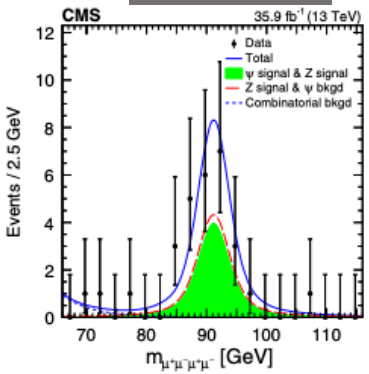
- Clean signal peaks. **5.7 σ**

- $\mathcal{R}_{J/\psi l^+ l^-} = \frac{\mathcal{B}(Z \to J/\psi l^+ l^-)}{\mathcal{B}(Z \to \mu^+\mu^-\mu^+\mu^-)}$ **= 0.67 $\pm$ 0.18 (stat) $\pm$ 0.05 (syst)**

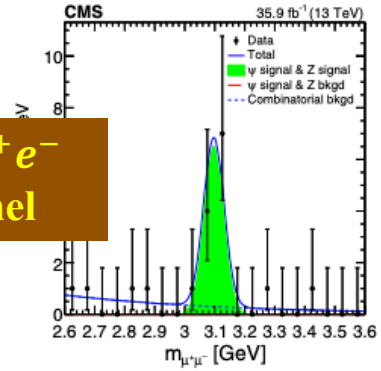
M($\mu\mu$) **M($\mu\mu$ll)**

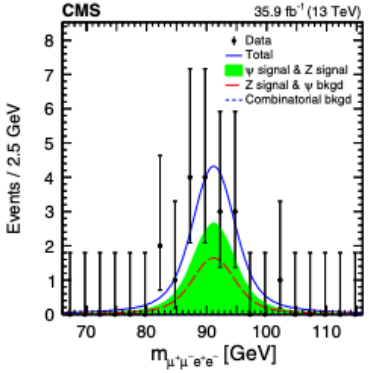
$J/\psi\mu^+\mu^-$ channel





$J/\psi e^+ e^-$ channel

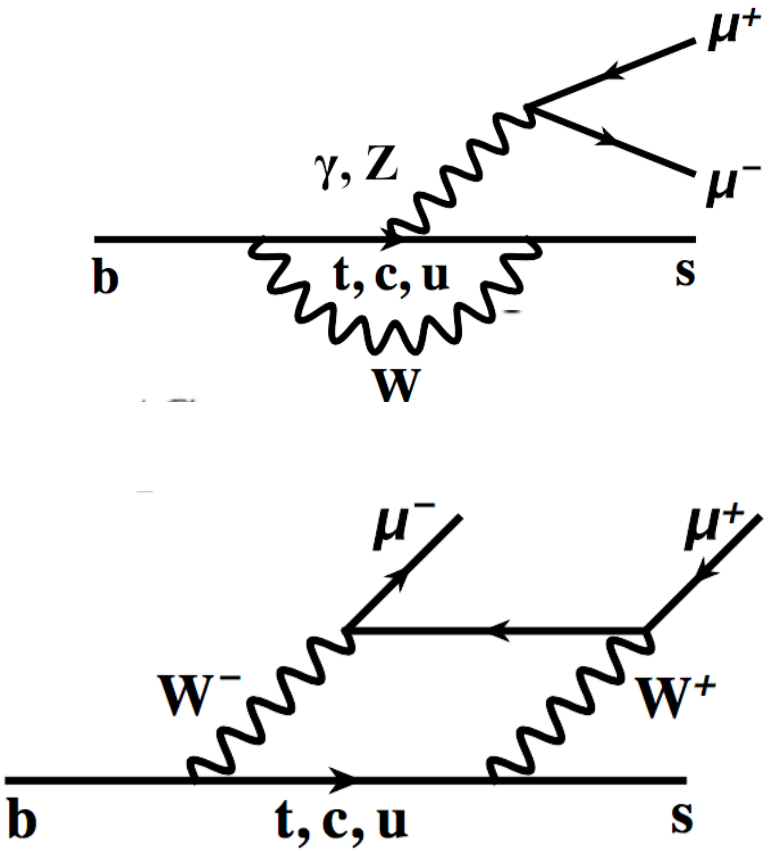




- Branching fraction of $(Z \to J/\psi l^+ l^-)$, $\mathcal{B}(Z \to J/\psi l^+ l^-) \sim 8 \times 10^{-7}$, is consistent with the prediction of SM.

Neutral current decays: the $b \to sll$

- $b \to sll$ is a FCNC transition, only possible at loop level in the SM.
- NP effects can contribute at the loop or tree level.
- Modifying **decay rates, angular distributions** etc.
- Study $b \to sll$ to search for new physics.



$B^0 \to K^{*0}\mu^+\mu^-$ angular observables

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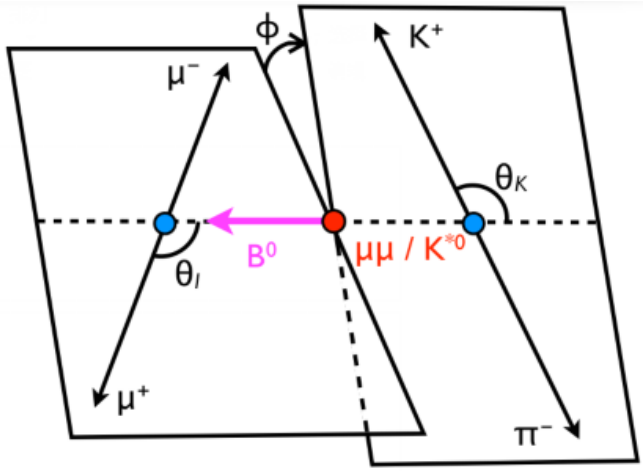
- Depends on q^2 and three decay angles
- Observables are sensitive to the Wilson coeffs.
- P_5' anomaly



$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta_l\mathrm{d}\cos\theta_K\mathrm{d}\phi} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_\mathrm{L})\sin^2\theta_K + F_\mathrm{L}\cos^2\theta_K + \frac{1}{4}(1-F_\mathrm{L})\sin^2\theta_K\cos 2\theta_l - F_\mathrm{L}\cos^2\theta_K\cos 2\theta_l + S_3\sin^2\theta_K\sin^2\theta_l\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_l\cos\phi + S_5\sin 2\theta_K\sin\theta_l\cos\phi + \frac{4}{3}A_{FB}\sin^2\theta_K\cos\theta_l + S_7\sin 2\theta_K\sin\theta_l\sin\phi + S_8\sin 2\theta_K\sin 2\theta_l\sin\phi + S_9\sin^2\theta_K\sin^2\theta_l\sin 2\phi\Big]$$

Decay rate parameterization:

JHEP 01 (2013) 048

For example: $P'_{i=4,5,6,8} = \dfrac{S_{j=4,5,7,8}}{\sqrt{F_L(1-F_L)}}$

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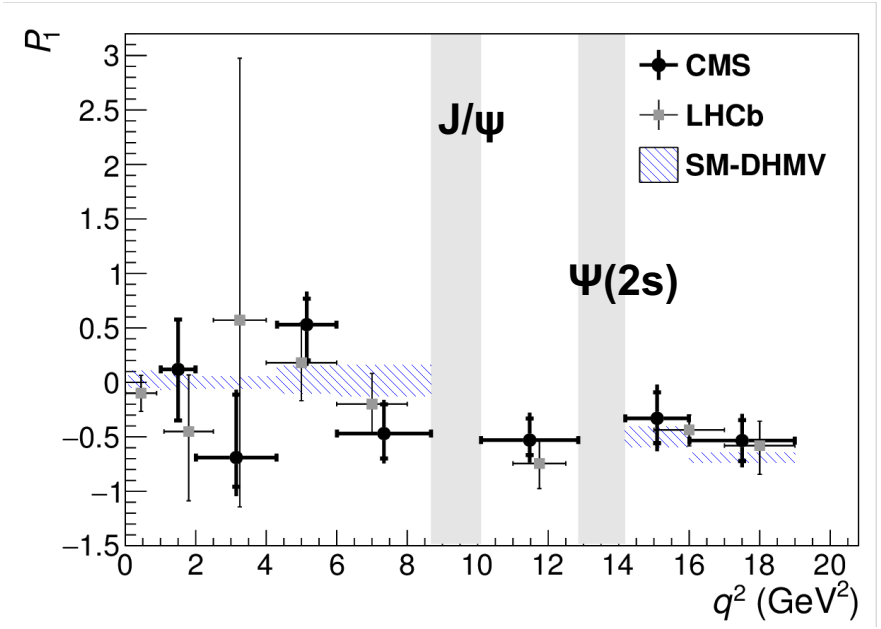
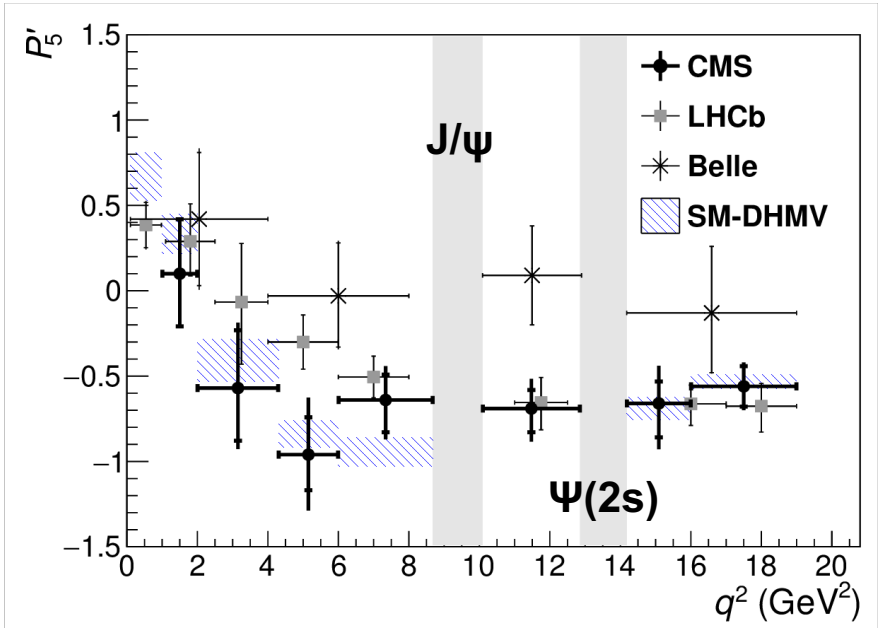
$B^0 \to K^{*0}\mu^+\mu^-$ angular observables





- **Using 20.5 fb^{-1} pp data taken in 2012.**
- The events are fit in seven q^2 bins from 1 to 19 GeV^2, yielding 1397 signal and 1794 background events in total.
- **CMS results are consistent with SM and previous measurements**

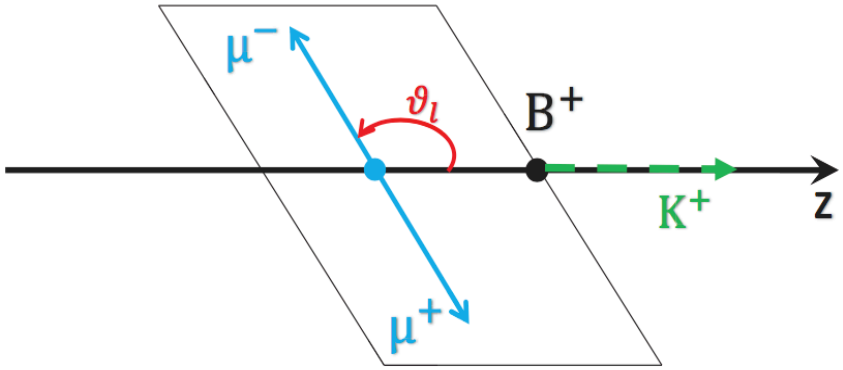
LHCb: *JHEP 02(2016) 104.*
SM-DHMV: *JHEP 01 (2013) 048, JHEP 05 (2013) 137*

Belle: *Phys. Rev. Lett. 118.111801(2017)*

arXiv 1806.00636 to appear in Phys. Rev. D

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

- The decay for the process $B^+ \to K^+\mu^+\mu^-$ can be described by $cos\theta_l$ and $q^2 = M^2_{\mu\mu}$
- Decay rate:



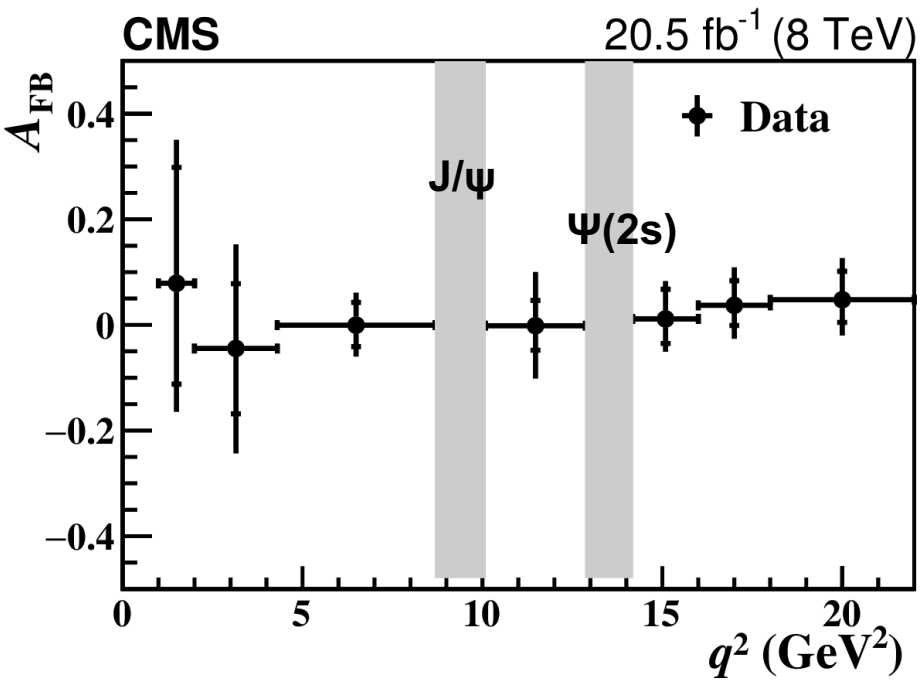
$$\frac{1}{\Gamma}\frac{d\Gamma[B^+\to K^+\mu^+\mu^-]}{d\cos\theta_l} = \frac{3}{4}(1-F_H)(1-\cos^2\theta_l) + \frac{1}{2}F_H + \mathcal{A}_{FB}\cos\theta_l$$

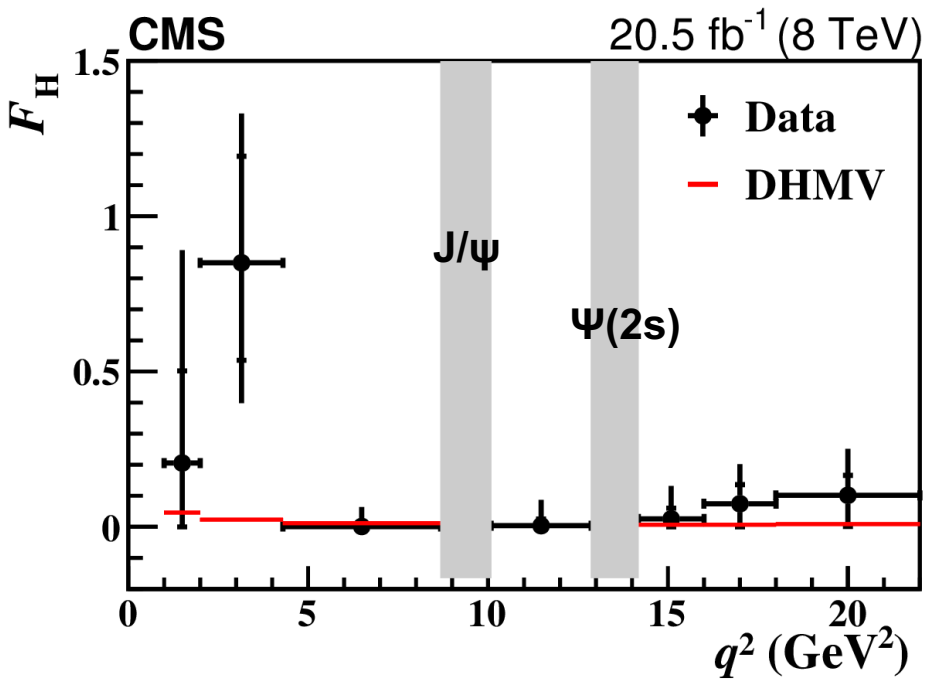
$$0 \le F_H \le 3, \quad |\mathcal{A}_{FB}| \le \min(1,\ F_H/2)$$

- F_H: a measure of the contribution from (pseudo) scalar and tensor amplitudes to the decay width
- A_{FB}: $\mu^+\mu^-$ forward-backward asymmetry

arXiv 1806.00636 to appear in Phys. Rev. D

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





- **Using 20.5 fb^{-1} pp data taken in 2012.**
- The events are fit in seven q^2 bins from 1 to 22 GeV^2, yielding 2286 signal events in total.
- **The measured A_{FB} and F_H show good agreement with the SM predictions within the uncertainty.**

Summary

- **CMS is producing high quality HF physics results**
  - Public:https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH
  - Observation of $\chi_{b1,2}(3P)$ masses split
  - First observation of $Z \to J/\psi ll$
  - Angular analyses of $B^0 \to K^{*0}\mu^+\mu^-$ and $B^+ \to K^+\mu^+\mu^-$: agree with SM predictions
- **Many new HF results are released.**
  - Excellent commissioning and performance
  - More to come from Run 2 data