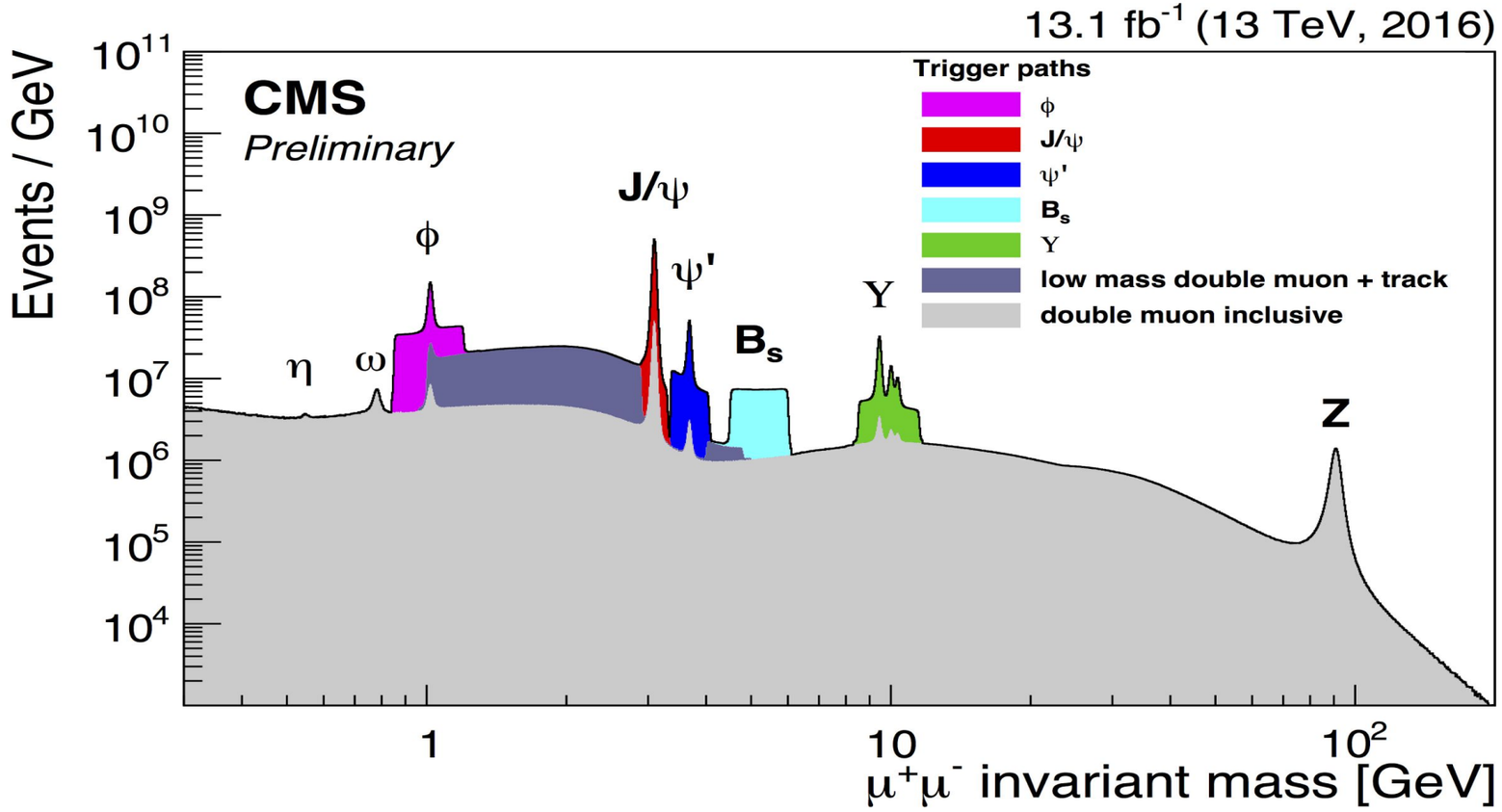

Heavy Flavor measurements and production studies at CMS

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For the CMS collaboration

DEPARTMENT OF PHYSICS , CINVESTAV-IPN, MEXICO

DPF2017, 31 Jul-4 Aug 2017, Fermilab.

Outline

- Motivation
- Experimental setup
- Overview of some results by CMS

  - Precision lifetime measurements of b hadrons reconstructed in final states with a J/ψ meson. 8 Tev
    CMS-PAS-BPH-13-008
  - Quarkonium production cross sections in pp collisions at √s = 13 TeV 13 Tev
    CMS-PAS-BPH-15-005

Motivation

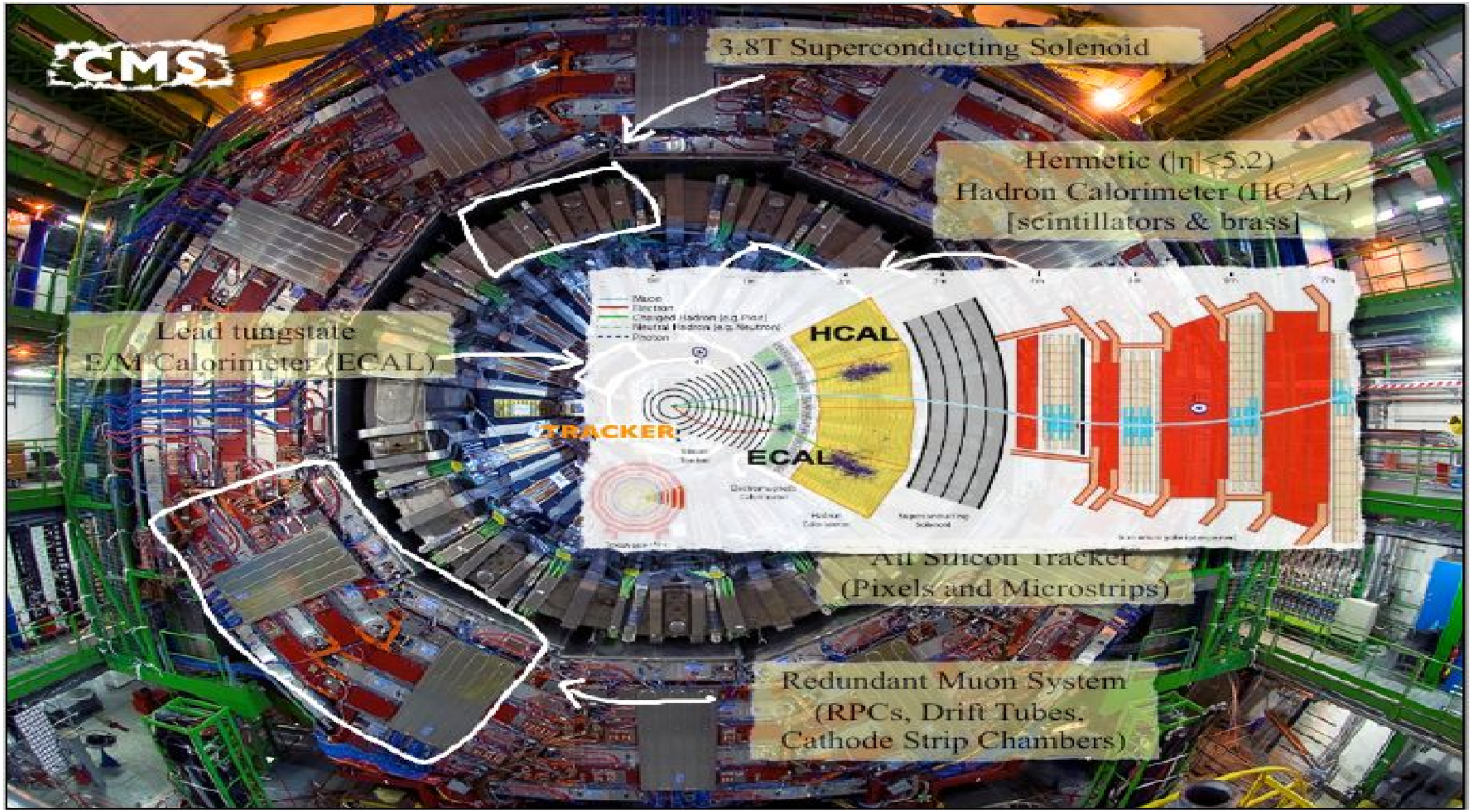
Quarkonium system can be used to test Quantum Chromodynamics (QCD) at all scales.

- Verification of NRQCD and effective field theory predictions.
- Advances in b/c-hadron spectroscopy.

Lifetime measurements play an important role in the study of non-perturbative aspects of QCD.

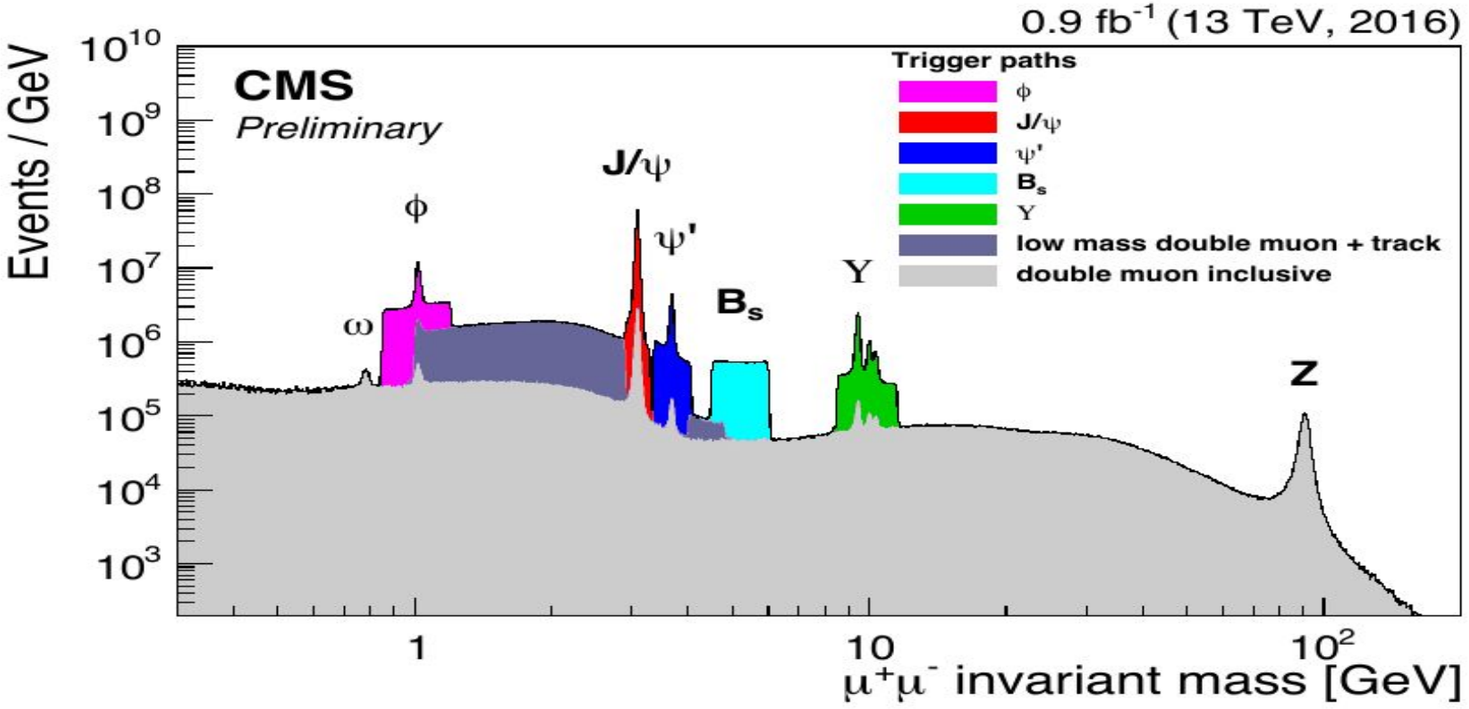
- Recent Bc lifetime measurements by the LHCb experiment are significantly larger than those measured at Tevatron.
- The issue of the Λ_b lifetime had not been solved.
- Understand the Bs $\rightarrow$J/Ψ $\pi\pi$ decay channel, which is a CP-odd eigenstate, is very important since it could be used to make CP-violation studies.

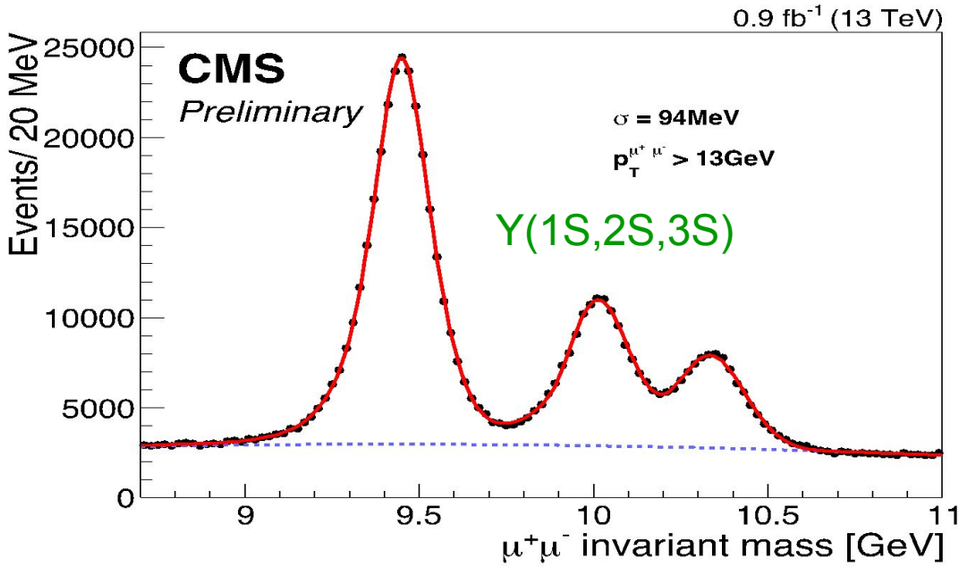
Experimental setup

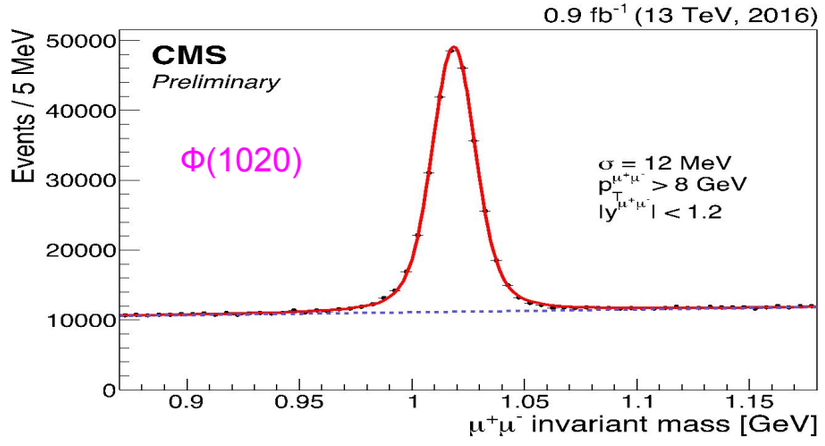


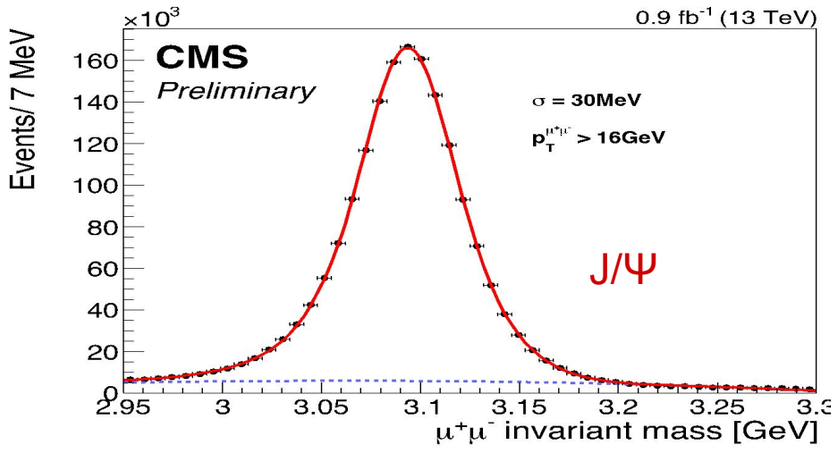
Compact Muon Solenoid: perfect detector for measuring muons

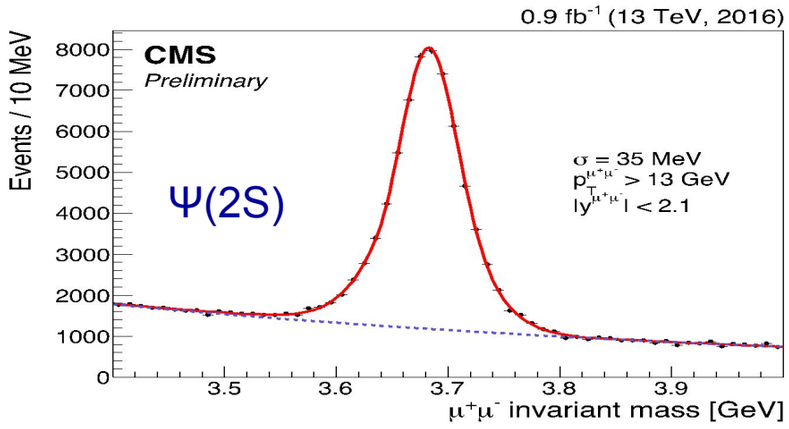
Experimental setup: dedicated HF triggers











[CMS-DP-2016-016]

Overview of the latest HF studies by CMS

- Measurement of the P1 and P5′ angular parameters of the decay B0→K*μ+μ− in proton-proton collisions at √s=8 TeV.
  CMS-PAS-BPH-15-008

- Precision lifetime measurements of b hadrons reconstructed in final states with a J/ψ meson. This talk
  CMS-PAS-BPH-13-008

- Observation of Y(1S) pair production at CMS.
  CMS-PAS-BPH-14-008

- Quarkonium production cross sections in pp collisions at √s = 13 TeV. This talk
  CMS-PAS-BPH-15-005

- Measurement of the total and differential inclusive B+ hadron cross sections in pp collisions at √s= 13 TeV.
  CMS-BPH-15-004

- Search for the X(5568) state in B0s pi+- decays.
  CMS-PAS-BPH-16-002

- Measurement of Lambdab polarization and the angular parameters of the decay Lambdab to J/psi Lambda.
  CMS-PAS-BPH-15-002

Quarkonium production

5 S-wave quarkonium states:

J/Ψ, Ψ(2S), Υ(1S,2S,3S)

Number of the prompt signal events: maximum likelihood fit, in a 2D bin, to mμμ spectra

$$BR(\mathrm{q\bar{q}} \to \mu^+\mu^-) \times \frac{d^2\sigma^{\mathrm{q\bar{q}}}}{dp_{\mathrm{T}}dy} = \frac{N^{\mathrm{q\bar{q}}}(p_{\mathrm{T}},y)}{\mathcal{L}\Delta y \Delta p_{\mathrm{T}}} \cdot \left\langle \frac{1}{\epsilon(p_{\mathrm{T}},y)\mathcal{A}(p_{\mathrm{T}},y)} \right\rangle$$

widths of the bin

average of the inverse acceptance times efficiency

$$\mathcal{A} = \frac{N^{gen}_{kin}(p_{\mathrm{T}},y)}{N^{gen}(p_{\mathrm{T}},y)}$$

From MC simulatin

$$\epsilon_{\mu\mu}(p_{\mathrm{T}},y) = \epsilon(p_{\mathrm{T}1},\eta_1) \cdot \epsilon(p_{\mathrm{T}2},\eta_2) \cdot \rho(p_{\mathrm{T}},y) \cdot \epsilon^2_{tk}$$

$\epsilon_{\mu\mu}$ Dimuon efficiency

ϵ Single-muon Tag&Prob

ρ Correlaction for μμ

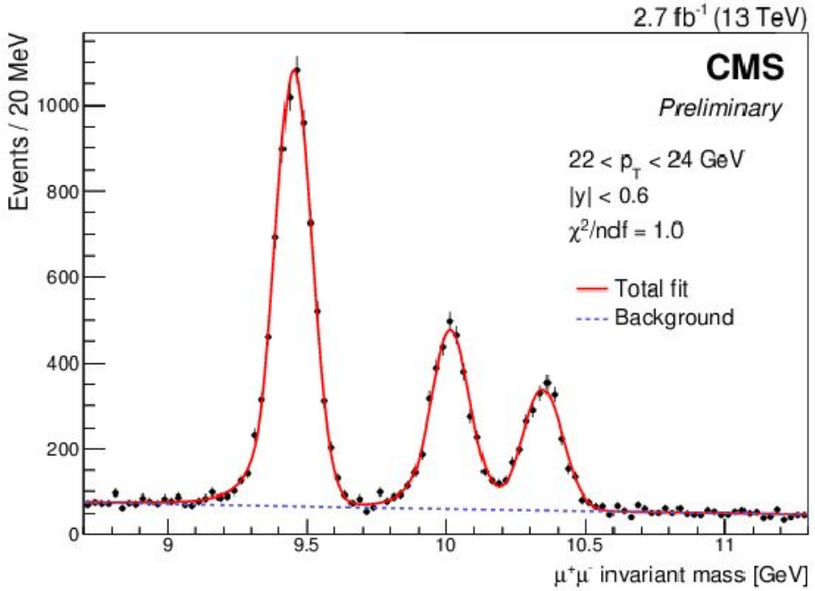
ϵ^2_{tk} Tracking efficiency

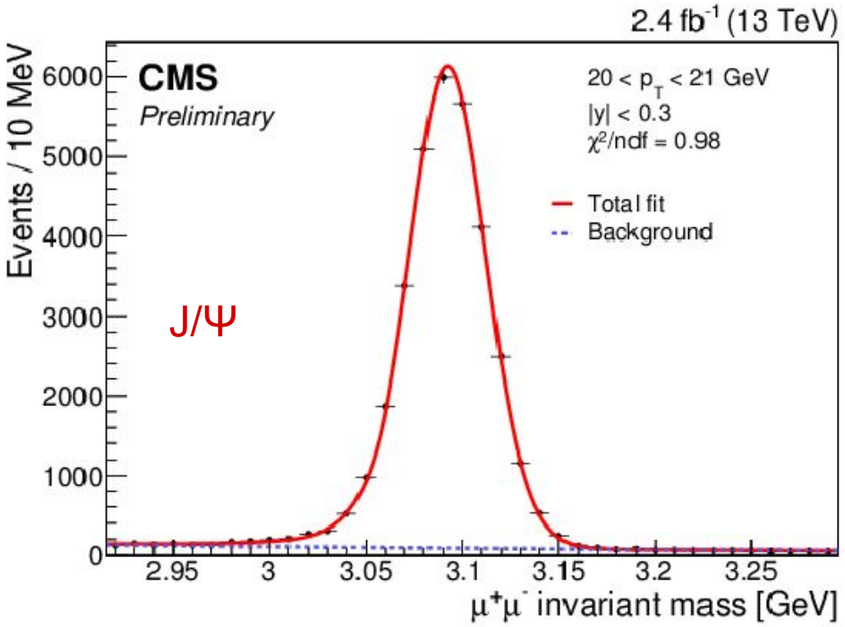
Yield: extracted from invariant mass of the Quarkonium candidate

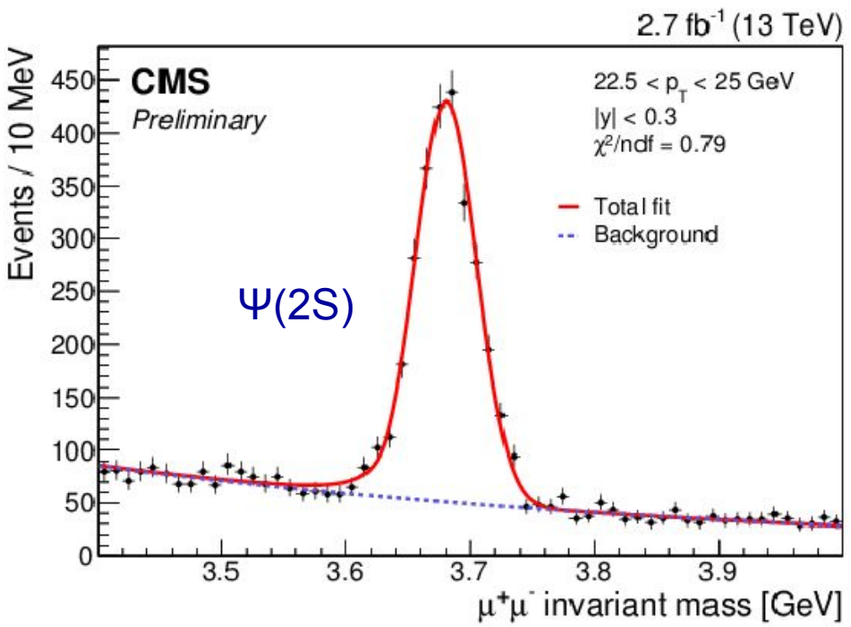
PDF signal shape:

- J/Ψ: Crystal Ball + Gaussian
- Ψ(2S): Crystal Ball
- Υ(1S,2S,3S) : Crystal Ball
-

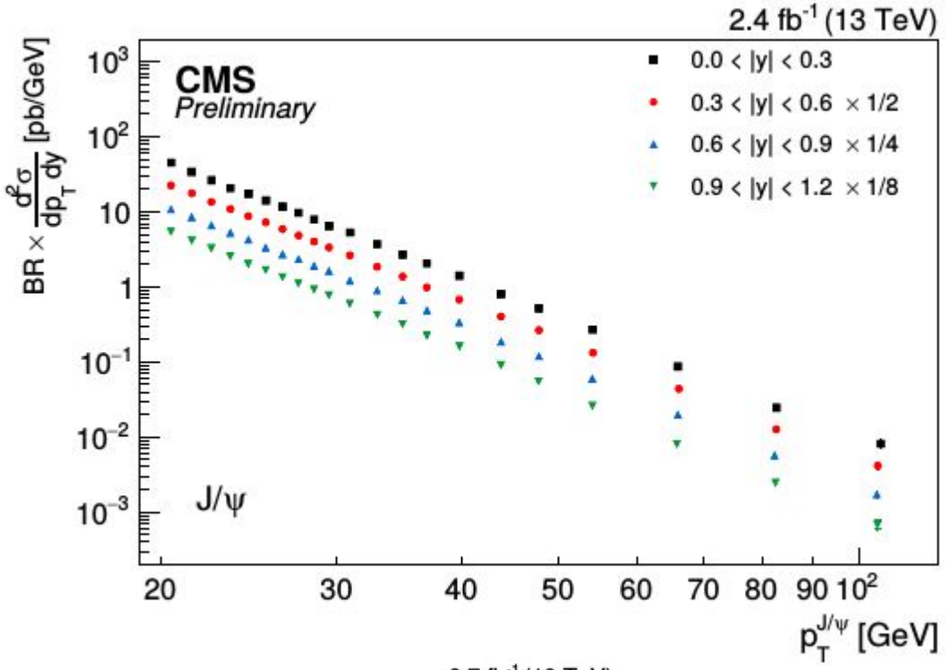
Background: exponential function

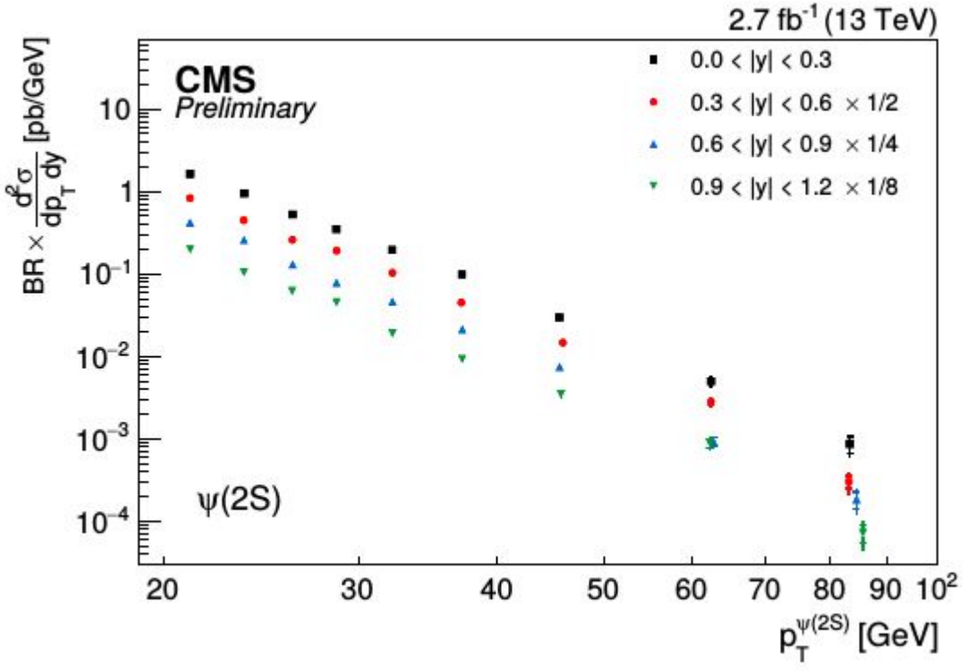


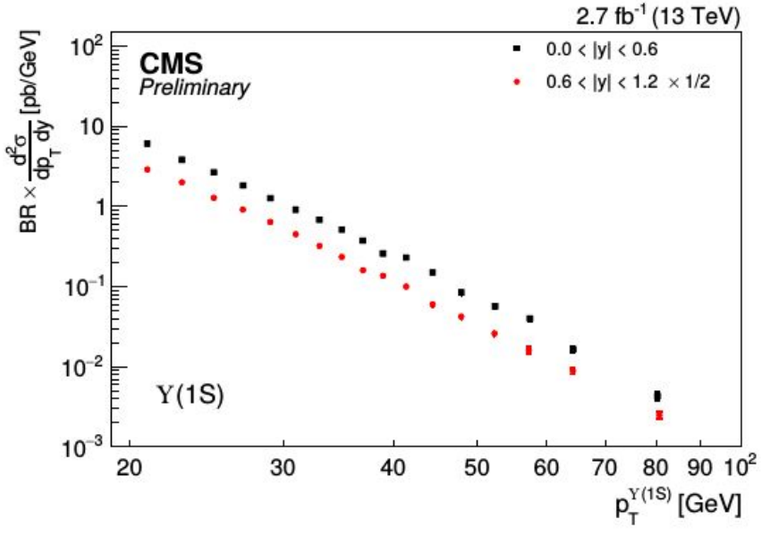


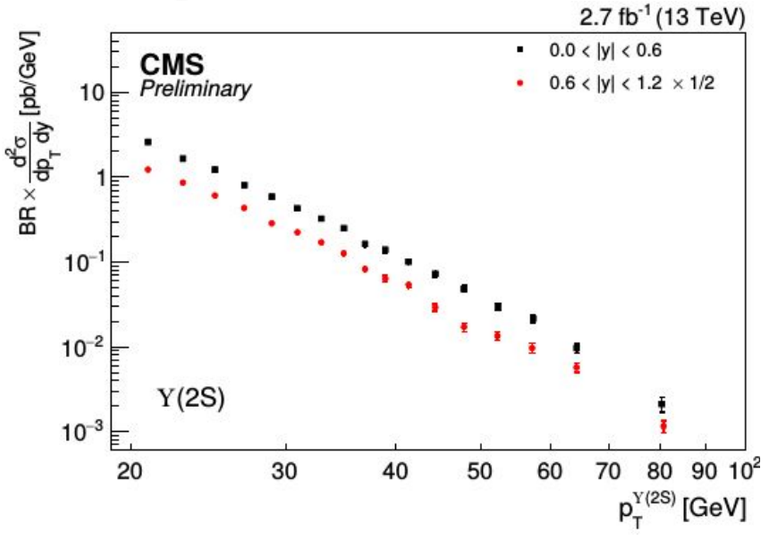


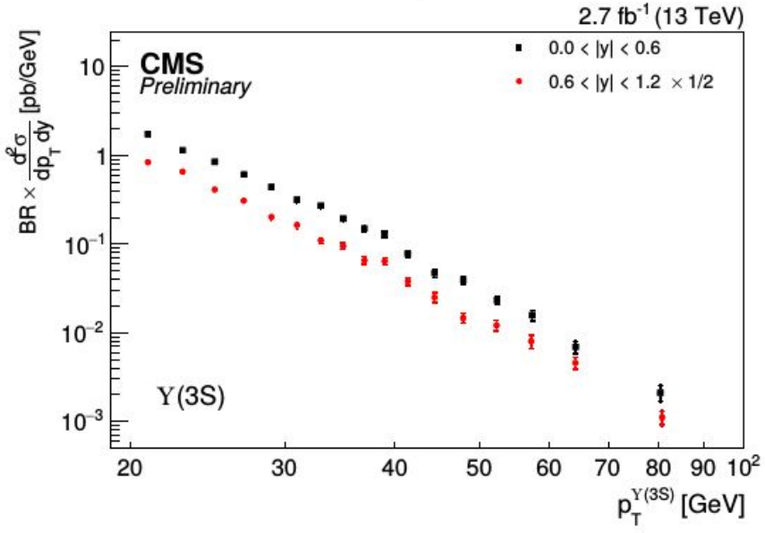
Cross sections results



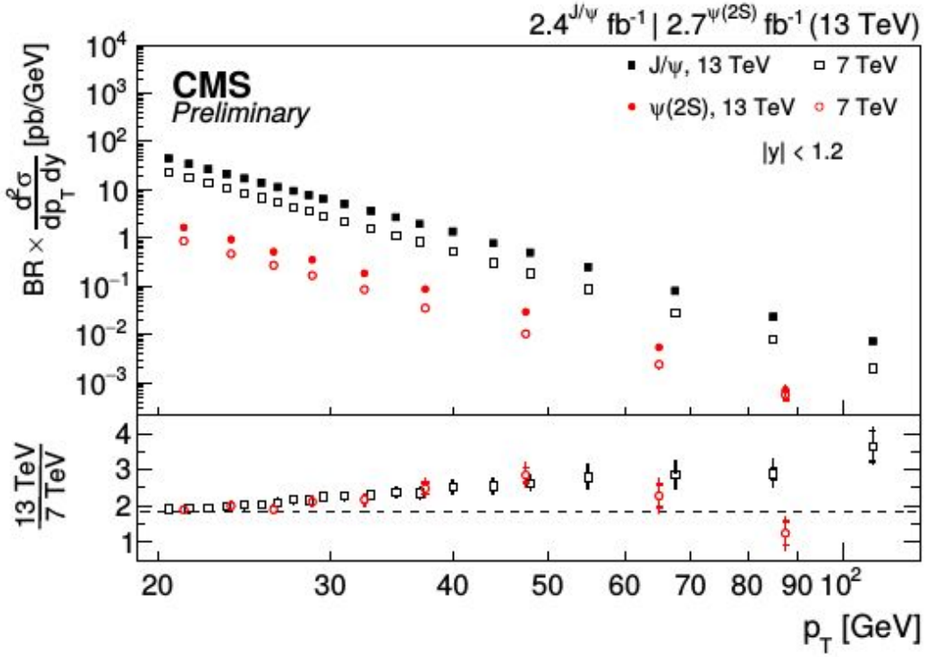


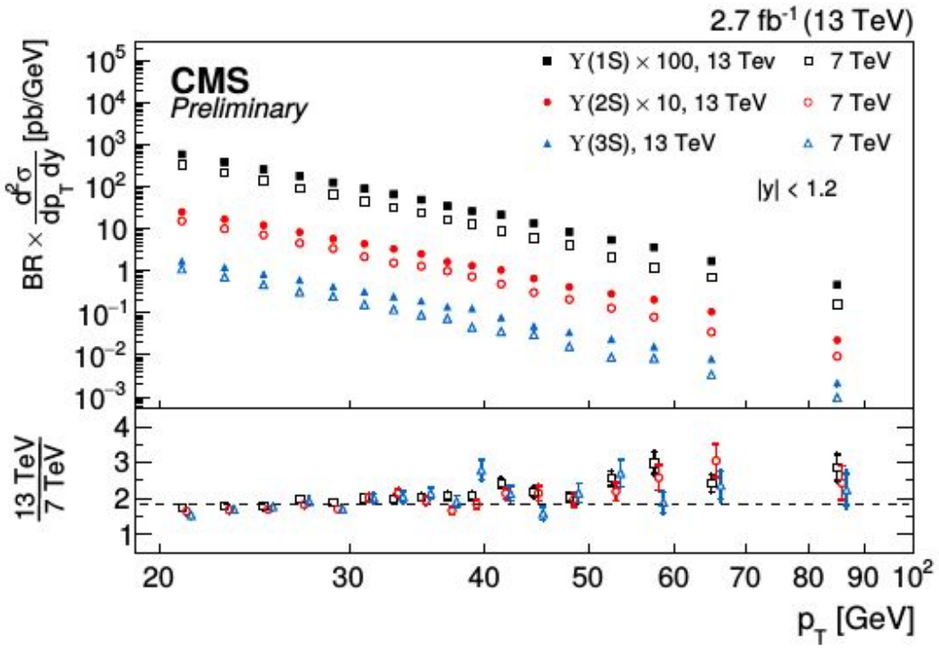




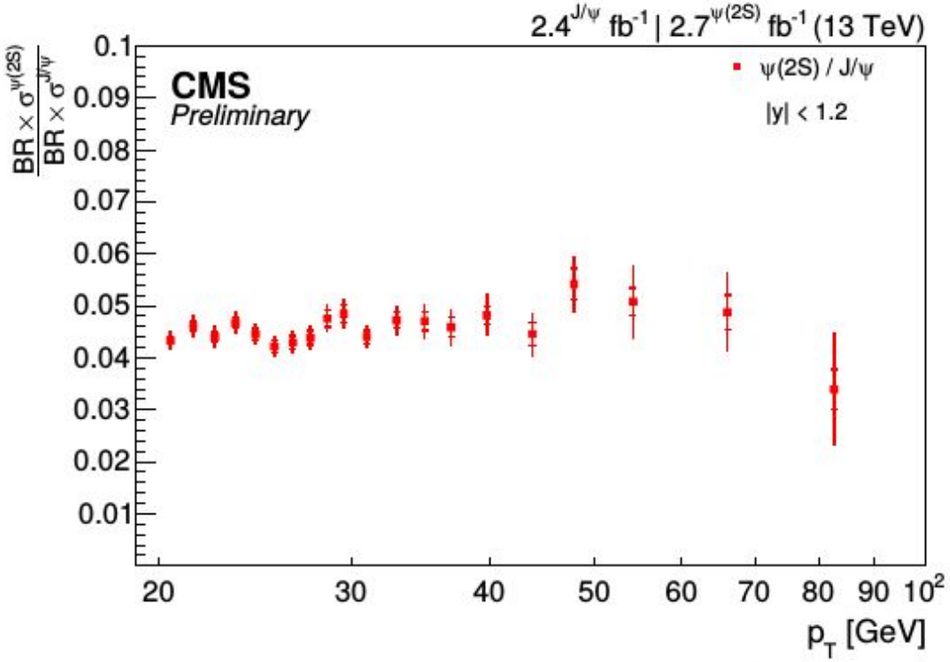


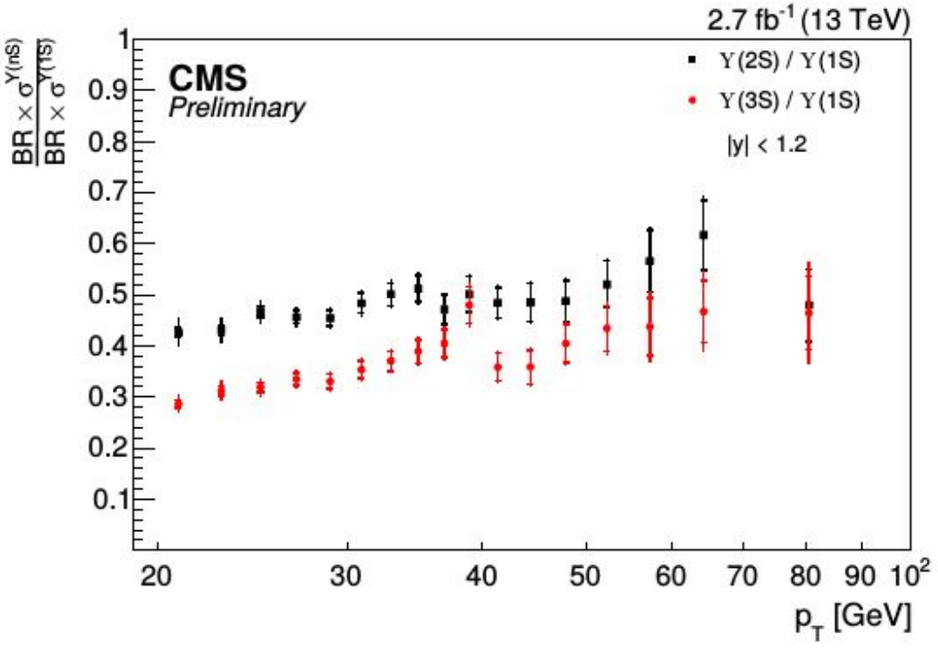
Comparison 13 Vs 7 Tev



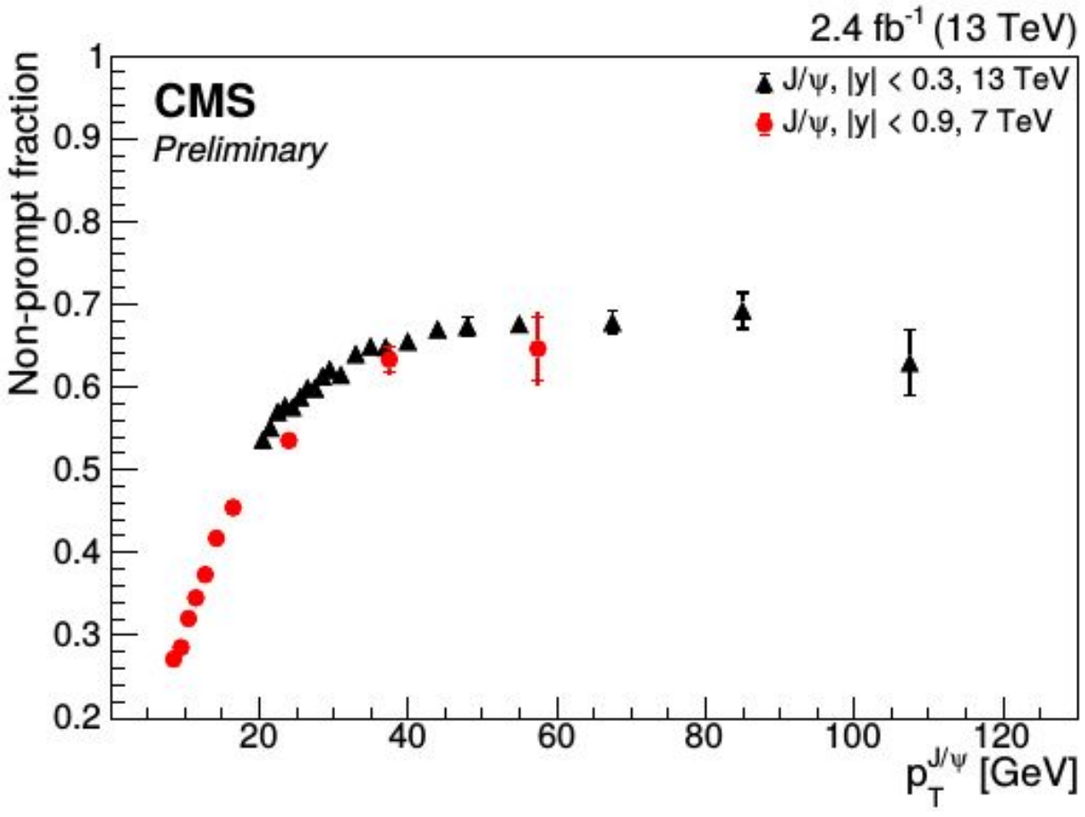


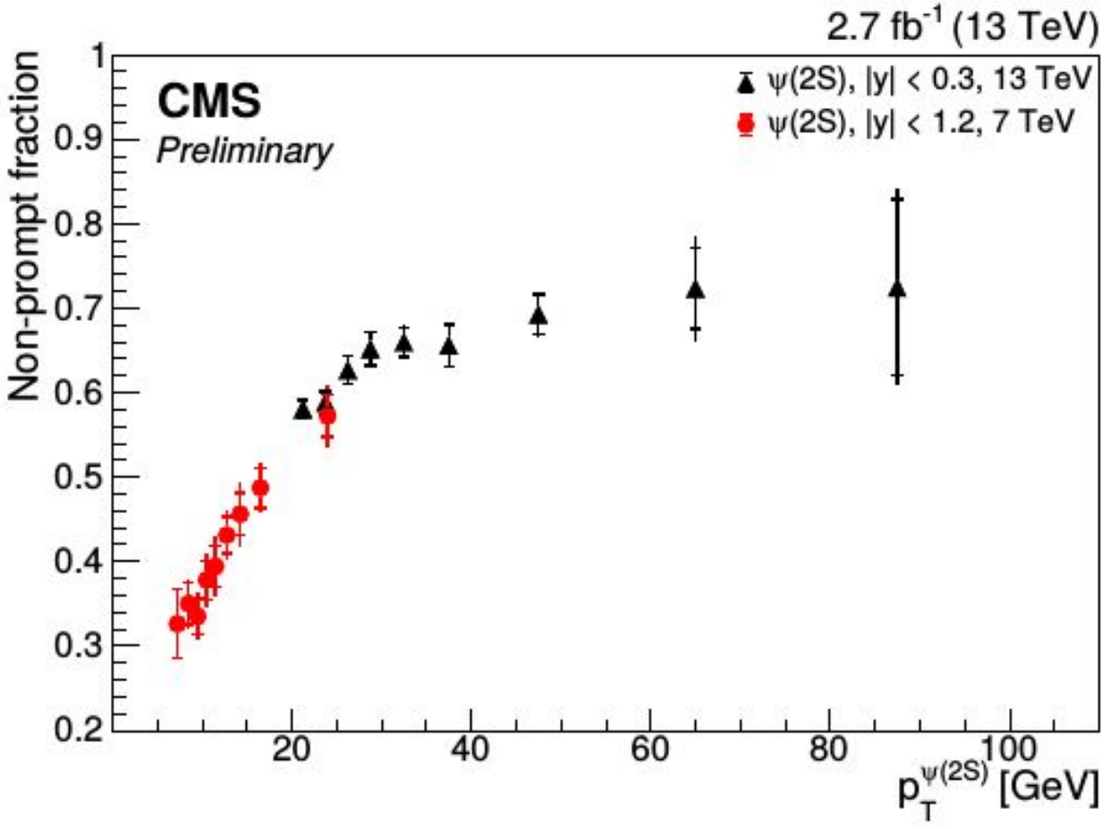
Radial excitations relative to ground states





Fraction of J/ψ and ψ(2S) originating from b-hadrons





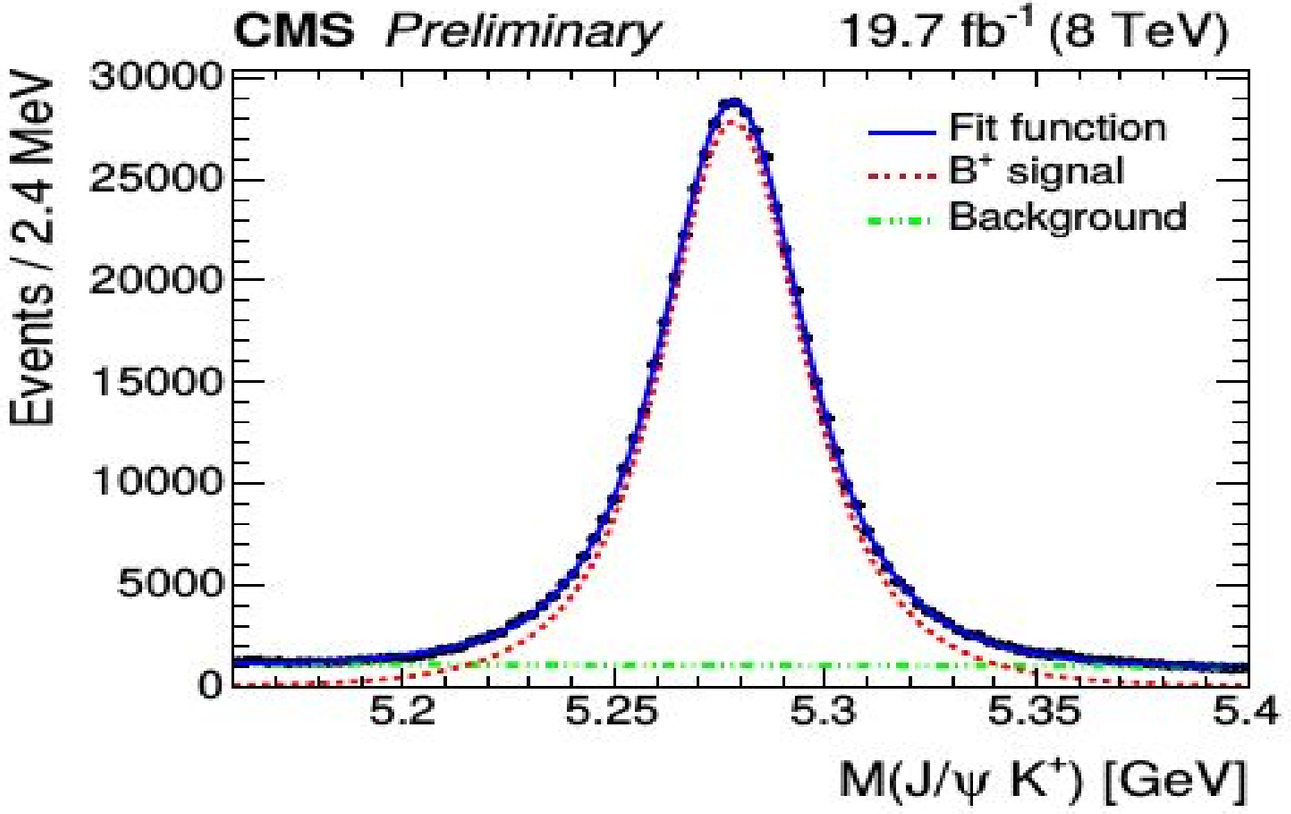
Lifetime measurements

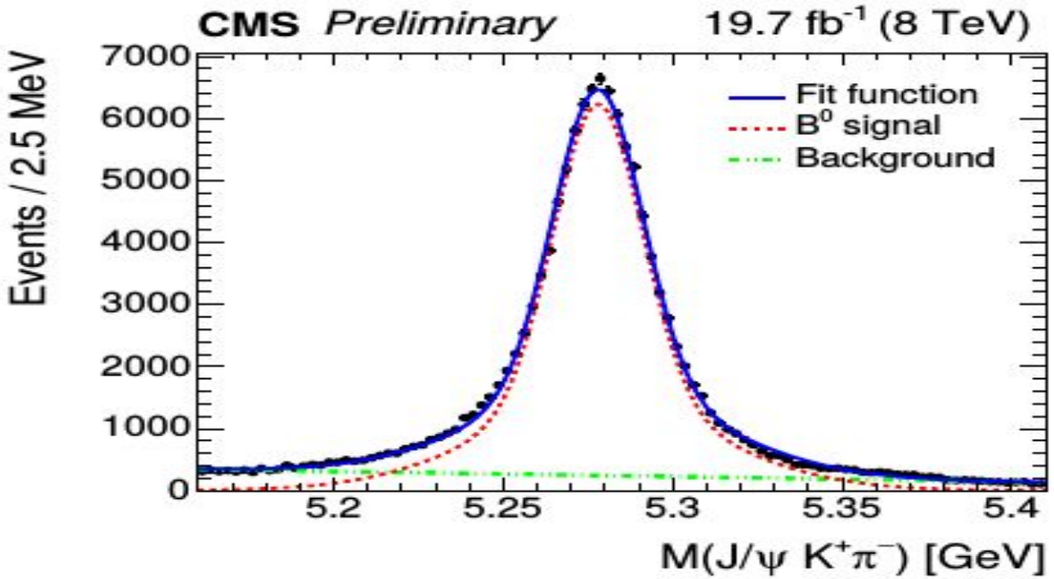
$B^+ \rightarrow J/\Psi\ K^+$

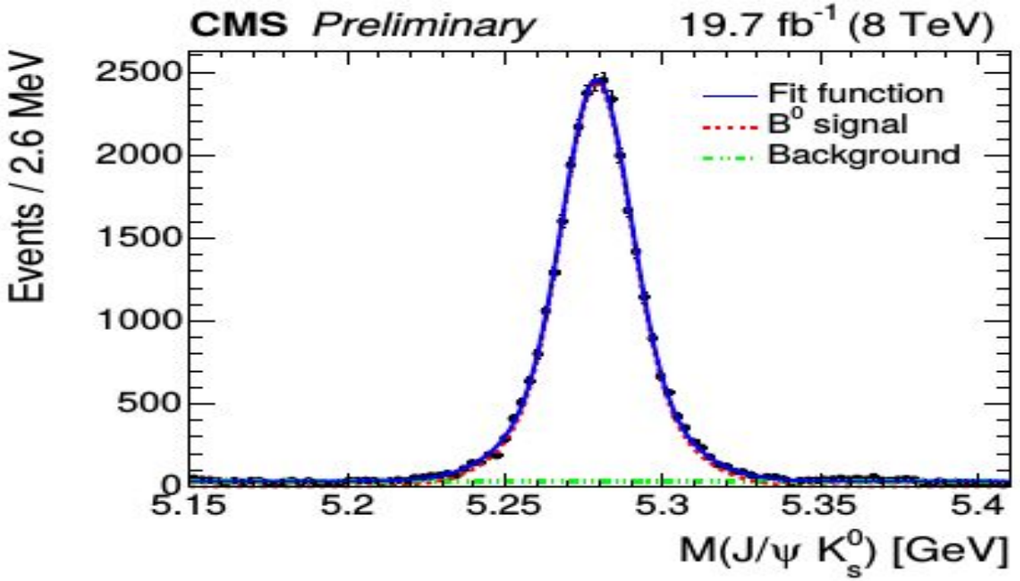
Reference channel

- Very well-known lifetime
- Calibration and specific systematic studies

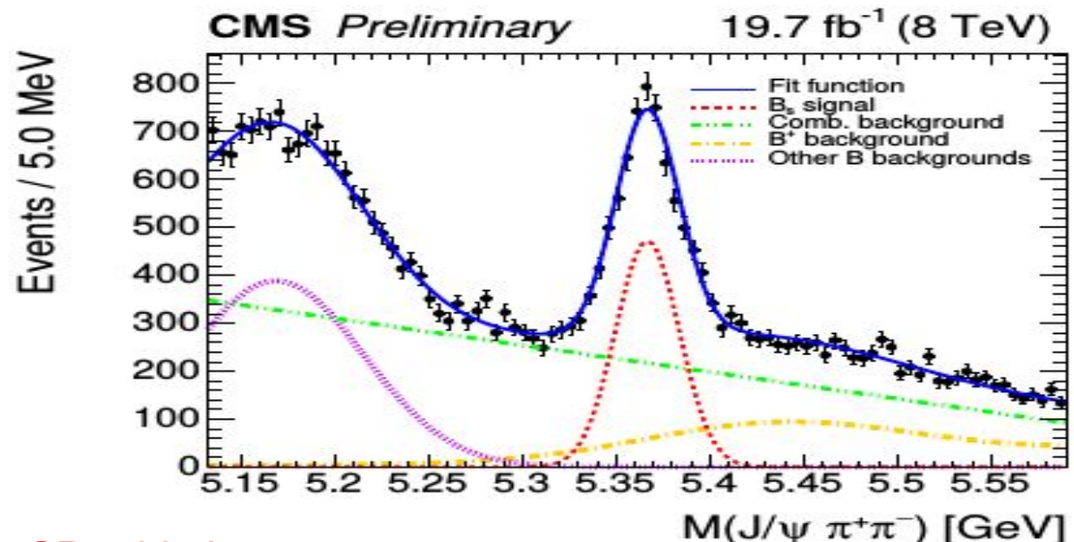
Contribution from partially reconstructed B mesons rejected by restricted mass window

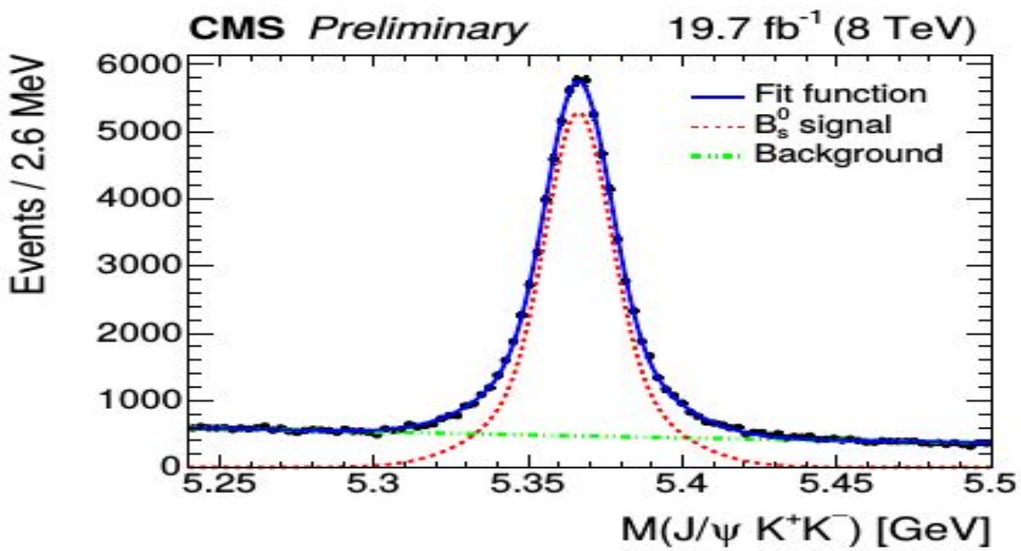






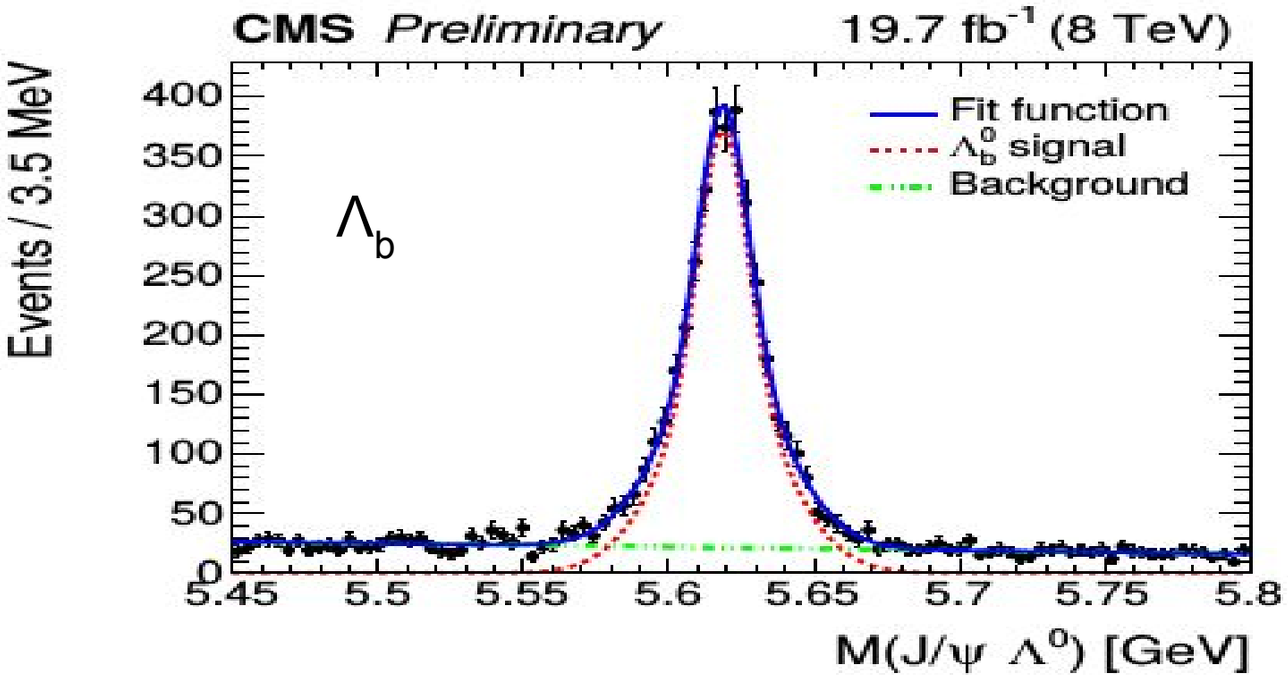
B^0

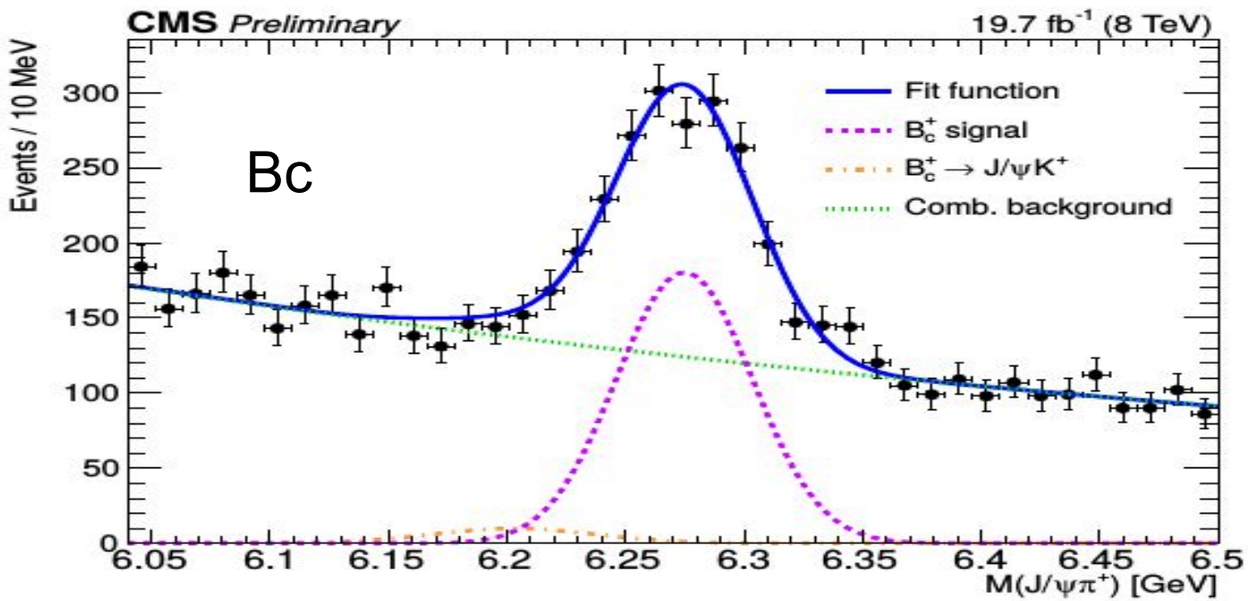


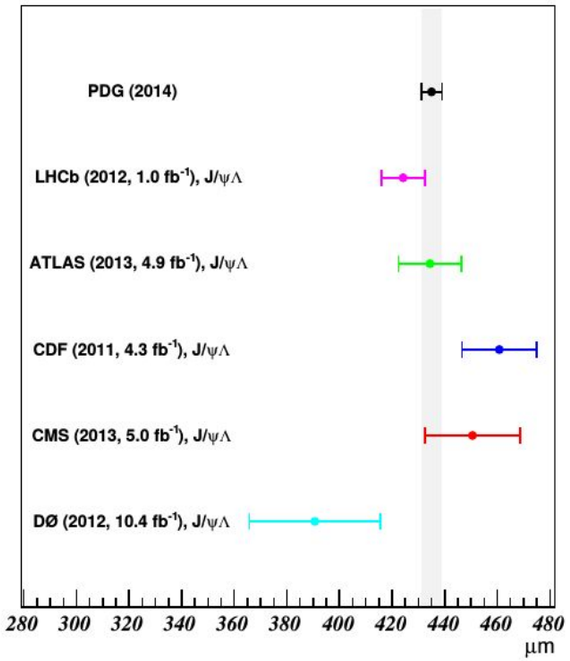


Bs

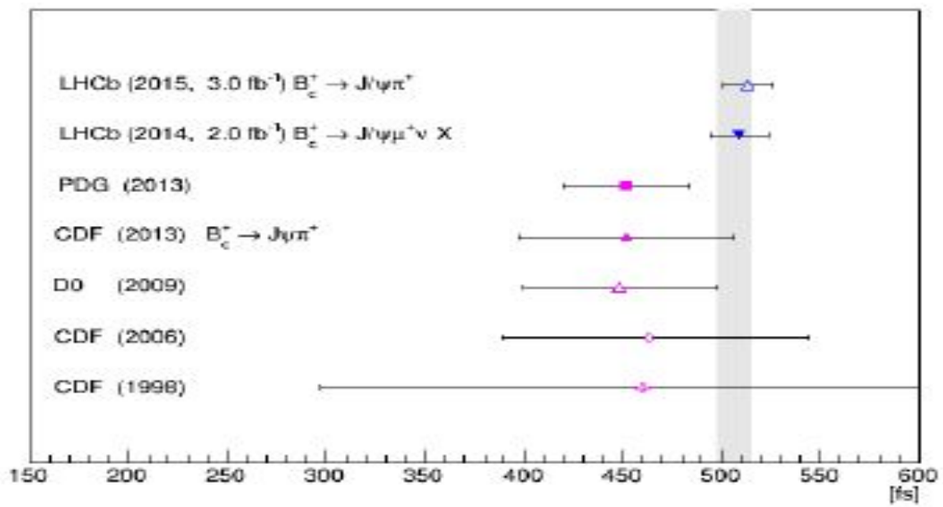
CP-odd eigenstate



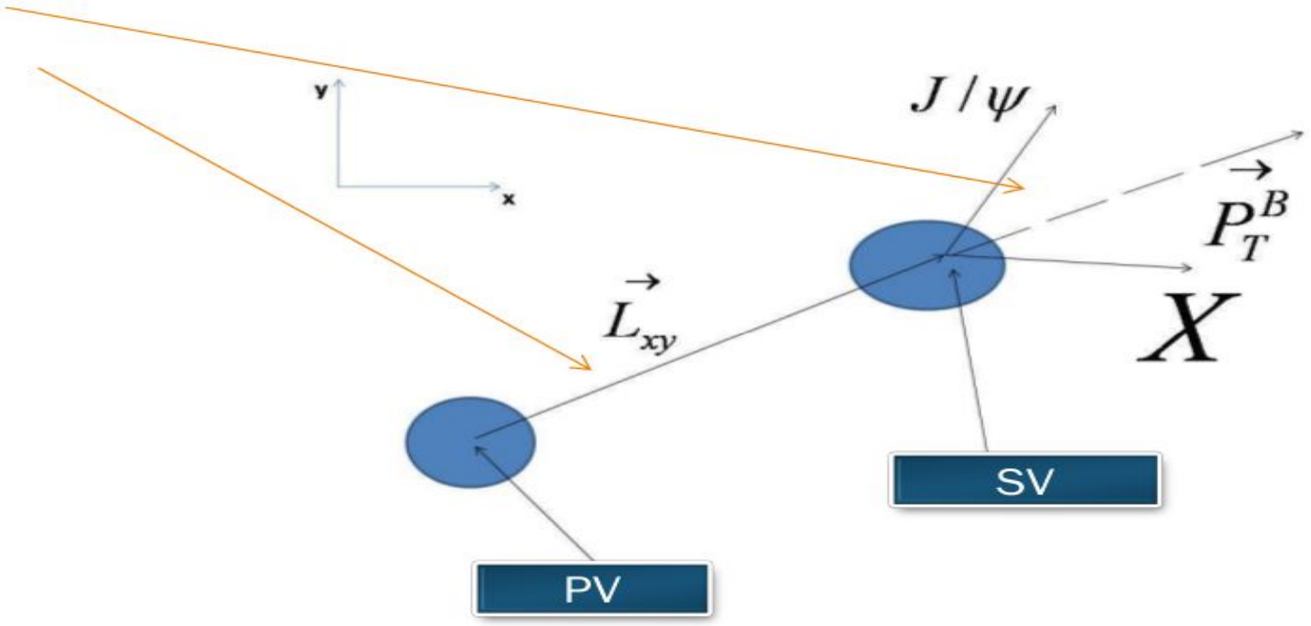




Previous Λ_b lifetime measurements have relatively wide ranges.



Discrepancy between LHCb and Tevatron experiments

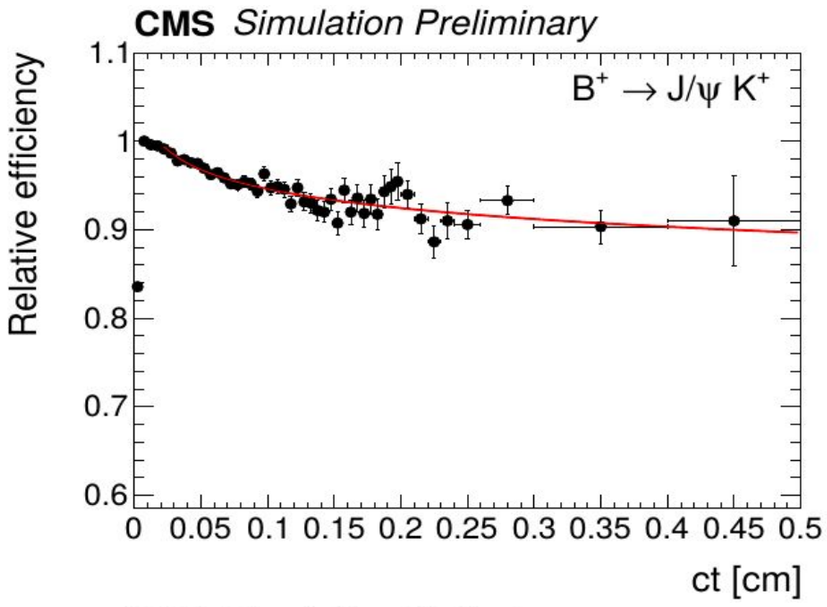


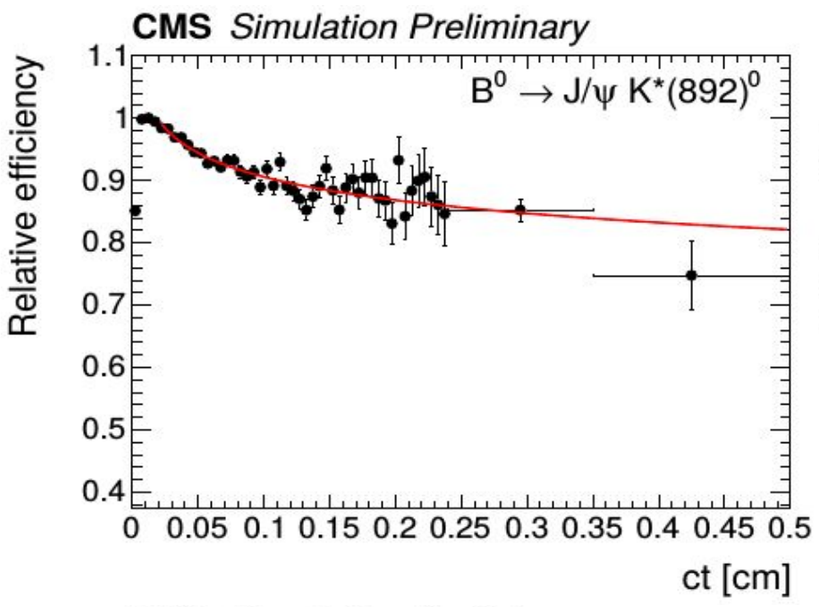
- Most of the lifetime measurements are based on the modeling of the ct, σ_{ct} and mass of the B hadrons.
- In the Bc Lifetime measurement a different approach (DeltaGamma) has been applied and it will be discussed later.
- Here L_{xy} is the distance of the flight of the B hadron in xy plane.

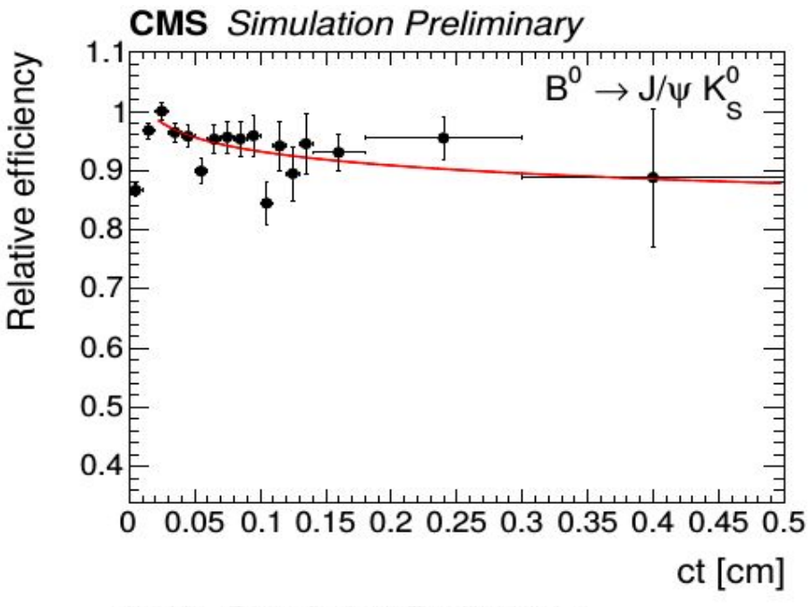
Efficiency correction is needed

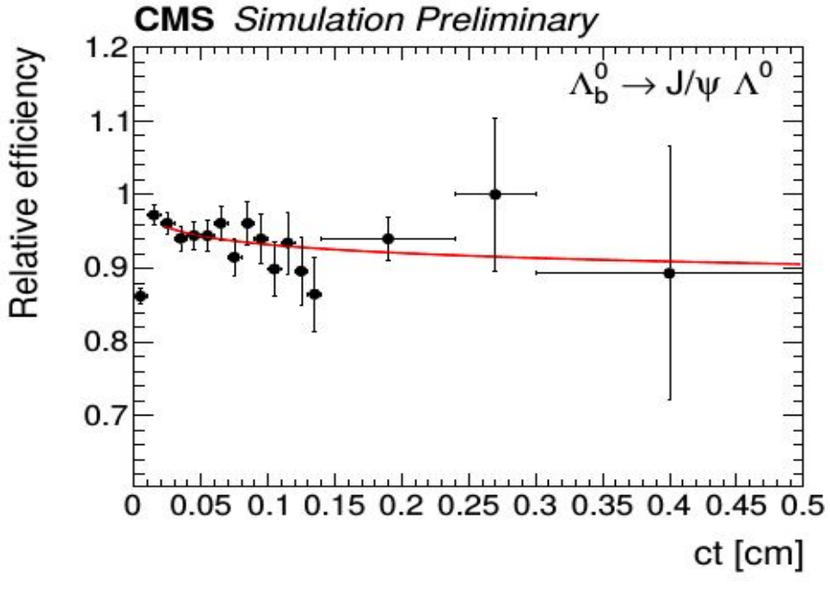
- Reconstruction and selection criteria generate the distortion
- Efficiency is taken from MC simulation
- The turn-on region is discarded selecting ct>200μm (100μm Bc)

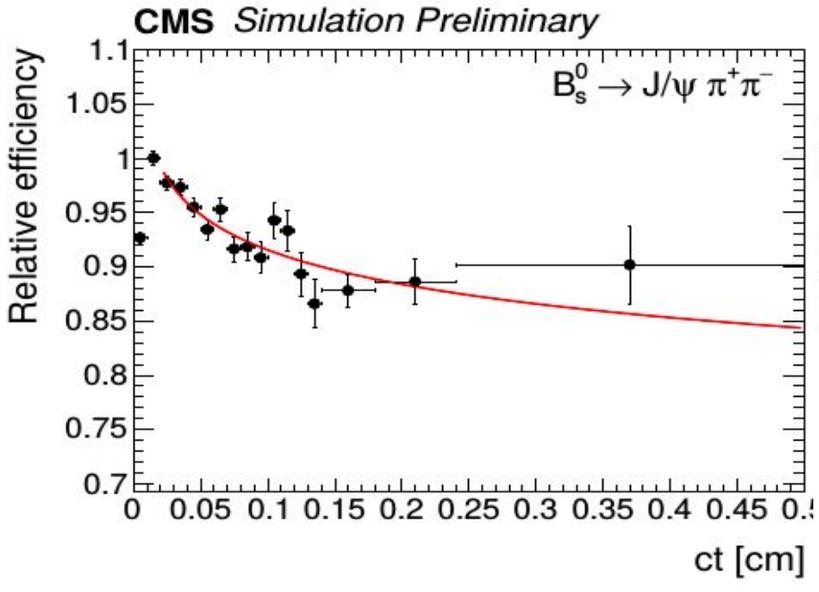
$$ct = \frac{L_{xy}}{(\beta\gamma)_T} = L_{xy}\frac{M}{p_T},$$

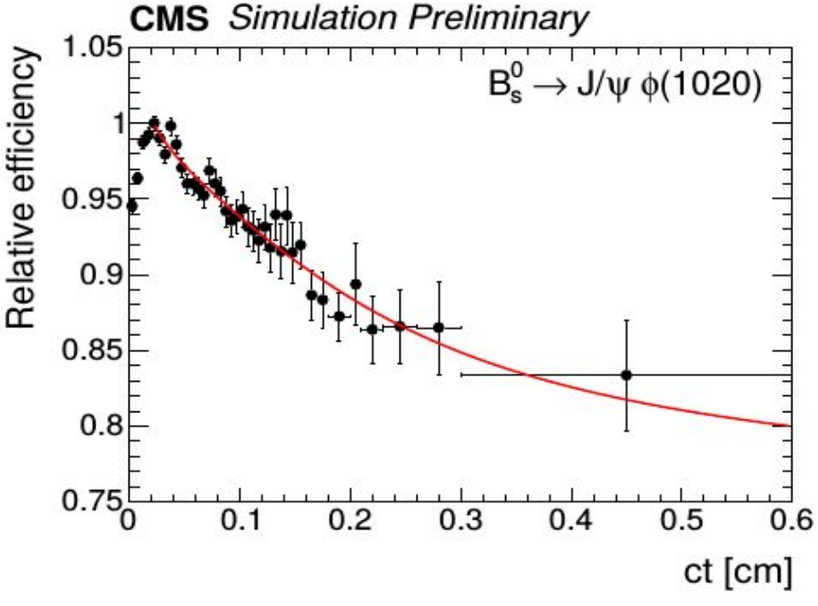




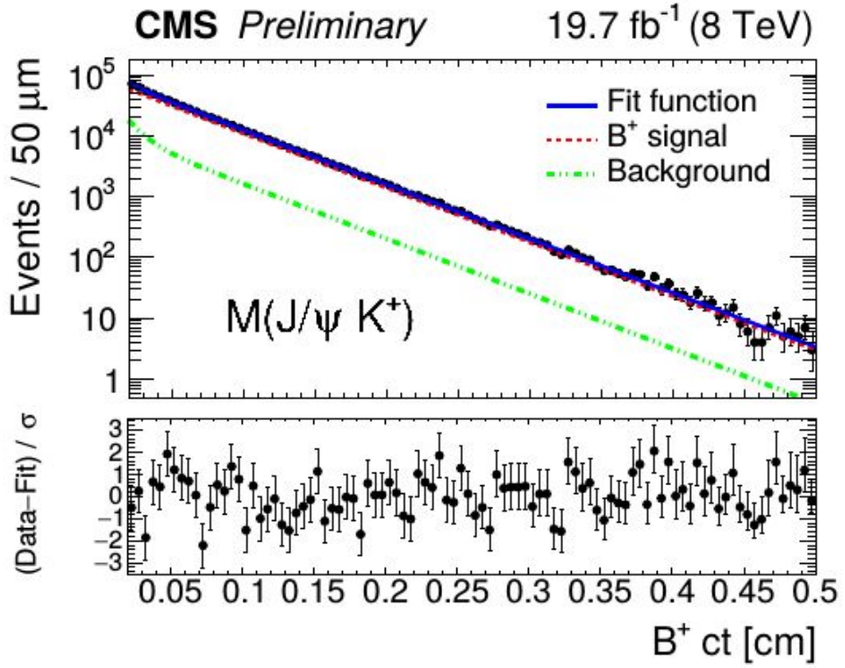


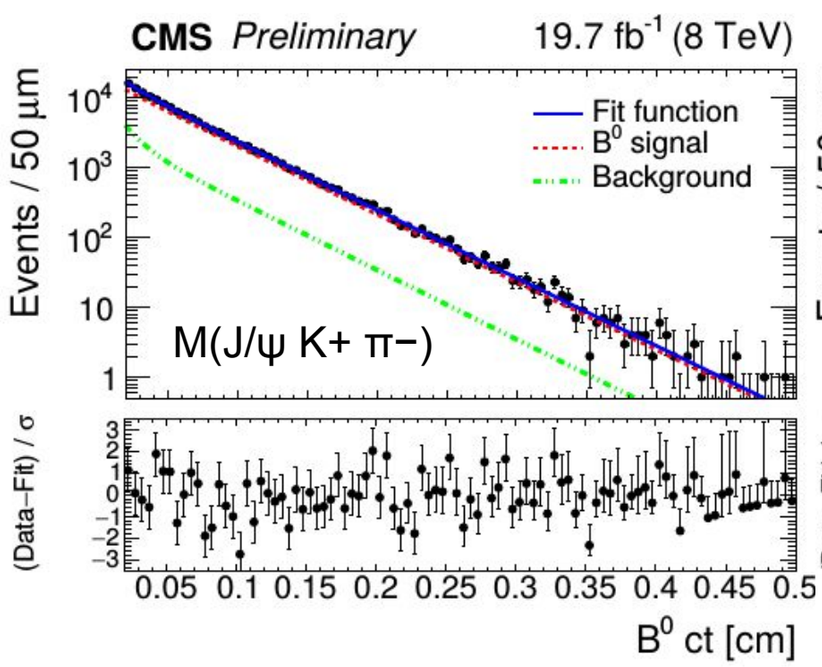


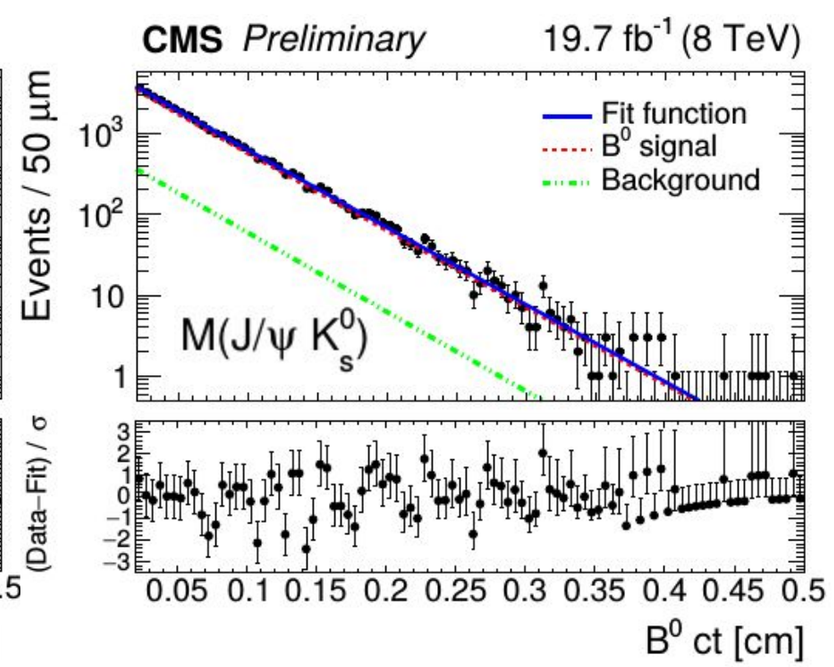


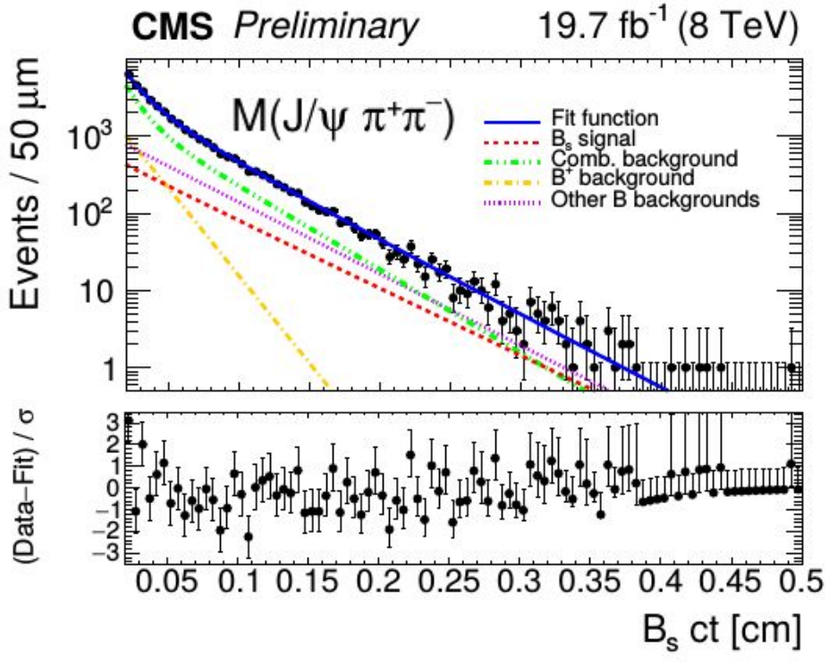


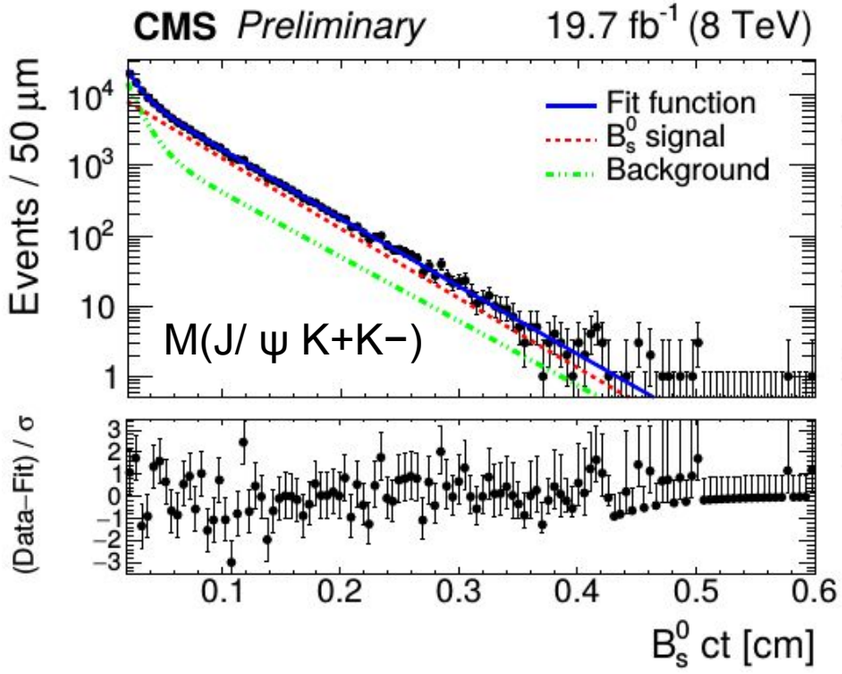
Efficiency is parameterized by an inverse power function, for ct>200μm











$$c\tau_{B^0} = 453.0 \pm 1.6 \pm 1.5\ \mu\text{m}\ (J/\psi K^*)$$

$$c\tau_{B^0} = 457.8 \pm 2.7 \pm 2.7\ \mu\text{m}\ (J/\psi K^0_s)$$

$$c\tau_{B^0_s} = 504.3 \pm 10.5 \pm 3.7\ \mu\text{m}\ (J/\psi\pi\pi)$$

$$c\tau_{B^0_s} = 443.9 \pm 2.0 \pm 1.2\ \mu\text{m}\ (\text{in } J/\psi\phi)$$

$$c\tau_{\Lambda_b} = 443.1 \pm 8.2 \pm 2.7\ \mu\text{m}.$$

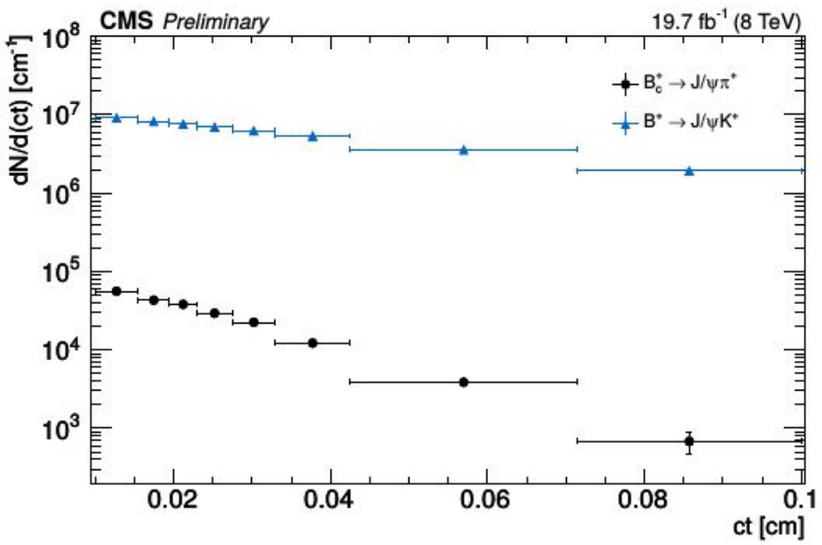
Bc Lifetime

The measurement of Bc lifetime is obtained using the difference between the total width of the Bc and B+ mesons in the decays Bc → J/ψπ + and B+→J/ψ K + (following LHCb approach)

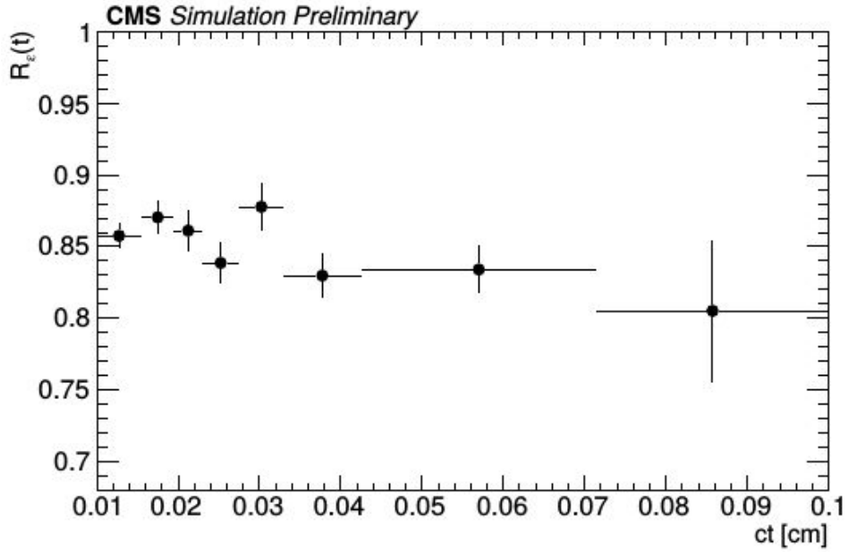
$$\frac{N_{B_c^+}(t)}{N_{B^+}(t)} = \mathcal{R}(t) = \frac{\epsilon_{B_c^+}(t) r(t) \otimes E_{B_c^+}(t)}{\epsilon_{B^+}(t) r(t) \otimes E_{B^+}(t)} = R_\epsilon(t) \exp(-\Delta\Gamma t)$$

$$\Delta\Gamma \equiv \Gamma_{B_c^+} - \Gamma_{B^+} = \frac{1}{\tau_{B_c^+}} - \frac{1}{\tau_{B^+}},$$

efficiency *resolution*

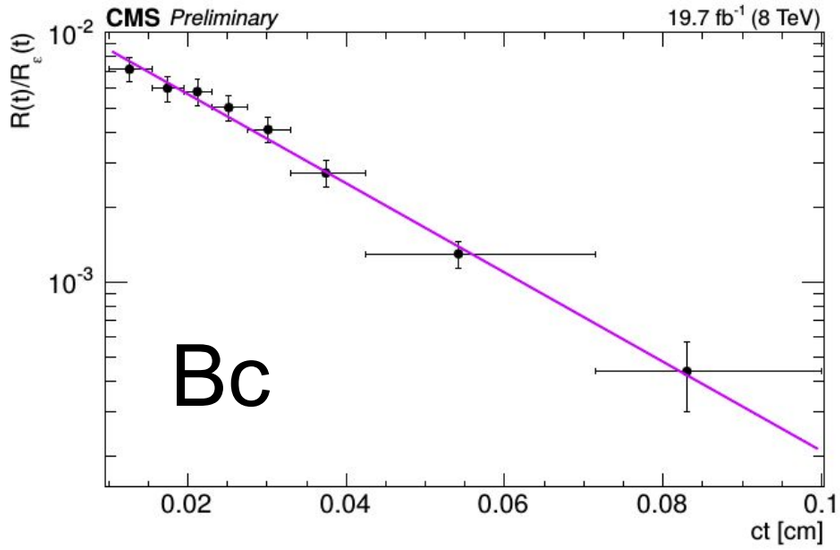


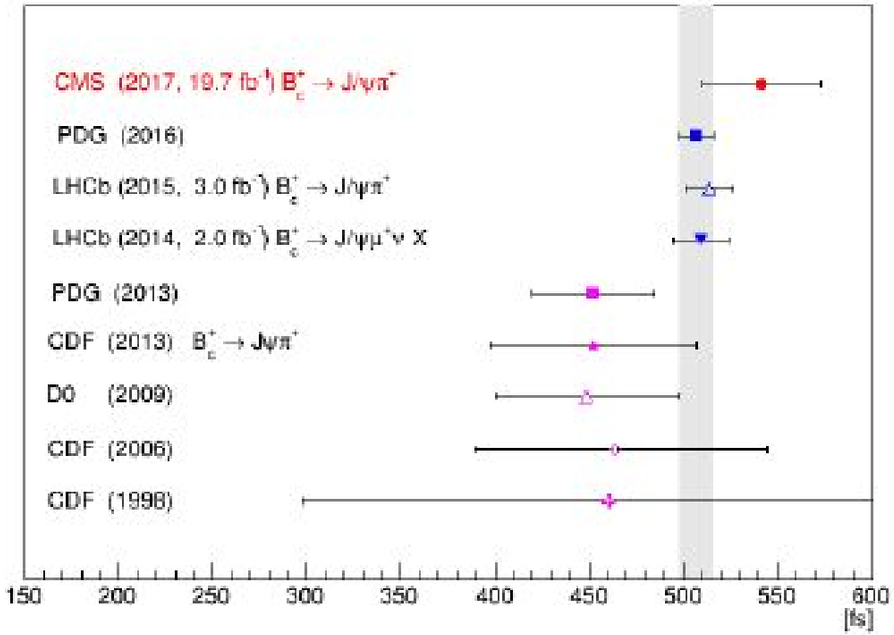
ct-distributions for Bc and B+ signals obtained from unbinned mass fits to the data split in ct regions



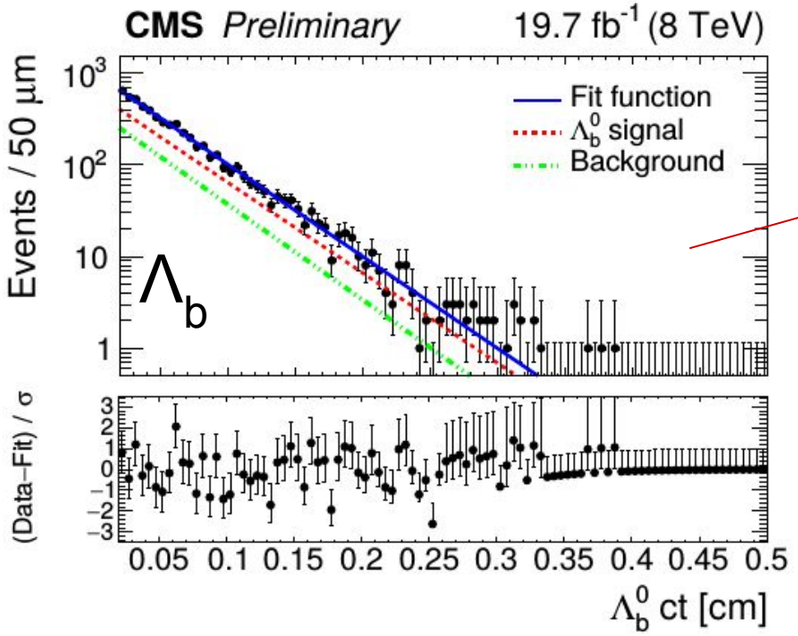
ratio of ct-efficiencies for Bc and B+ obtained from MC simulation

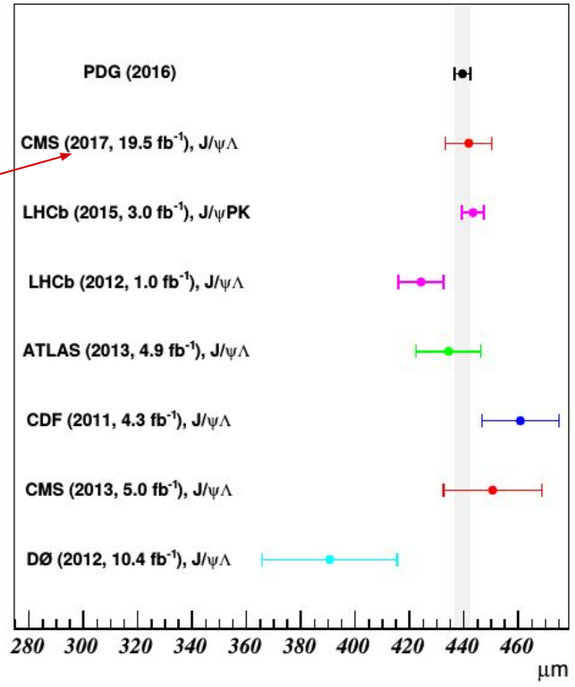
$$c\tau_{B_c^+} = 162.3 \pm 8.2\,(\text{stat}) \pm 4.7\,(\text{syst}) \pm 0.1\,(\tau_{B^+})\ \mu\text{m}$$





$$c\tau_{\Lambda_b^0} = 443.1 \pm 8.2\,(\text{stat}) \pm 2.7\,(\text{syst})\ \mu\text{m}.$$





Summary

Quarkonium production cross sections in pp collisions at $\sqrt{s}$ = 13 TeV

- These results shall contribute to consolidate the underlying hypotheses of NRQCD.
- Provide further input to constrain the parameters of the theory.
- Awaiting comparison to theoretical predictions.

Precision lifetime measurements of b hadrons reconstructed in final states with a J/ψ meson.

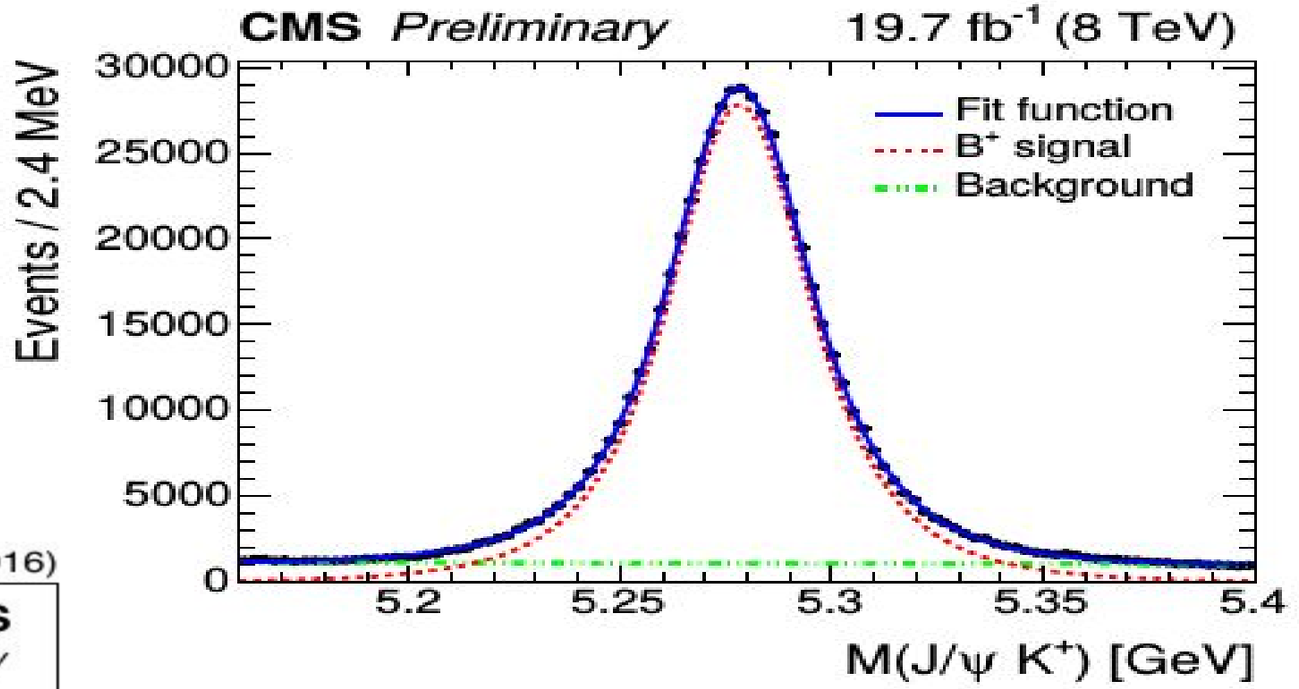
- All measured lifetimes are compatible with the current world-average values.
- The measurement of the Bc lifetime confirms a longer lifetime than found by the Tevatron experiments, in agreement with results from LHCb.
- The precision of the Λ_b lifetime measurement is also as good as all previous measurements in the $J/\psi\Lambda^0$ channel.
- CMS shows its capability to make precision time-dependent measurements, including CP-violation studies and effective lifetime measurements in rare decays.

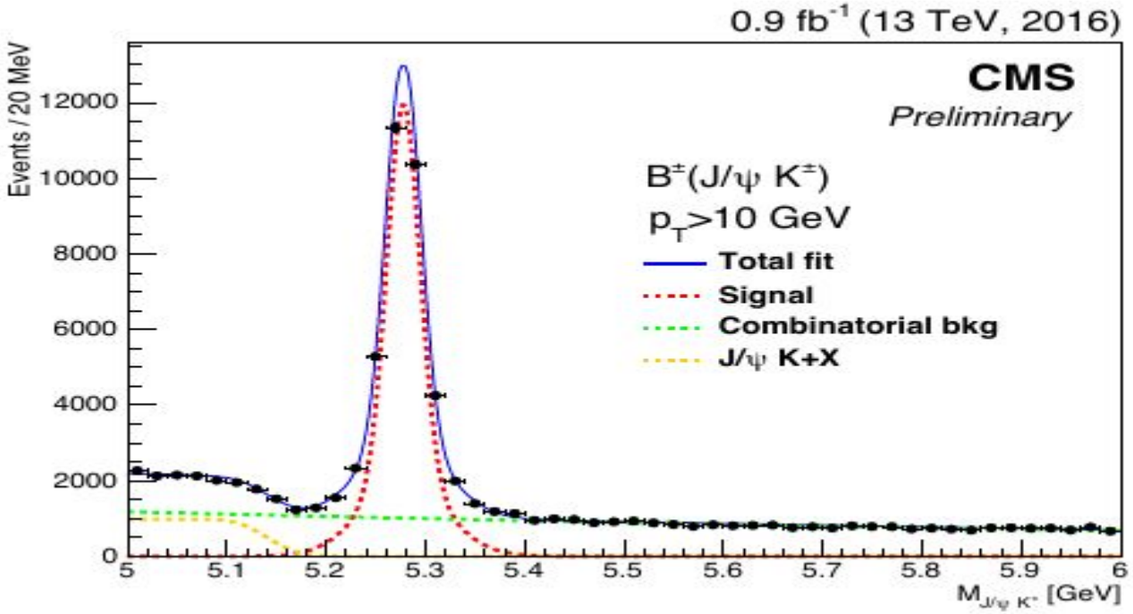
Thanks!

Lifetime measurements

$B^+ \rightarrow J/\Psi\ K^+$

- Reference channel
- Very well-known lifetime
-
- Calibration and specific systematic studies





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- Contribution from partially reconstructed B mesons rejected by restricted mass window

Source	Decay channel				
	$B^0 \to J/\psi K^*(892)^0$	$B^0 \to J/\psi K^0_S$	$B^0_s \to J/\psi \pi^+\pi^-$	$\Lambda^0_b \to J/\psi \Lambda^0$	$B^0_s \to J/\psi \phi$
PV selection	0.7	0.7	0.7	0.7	0.7
Detector alignment	0.3	0.7	0.3	0.7	0.3
ct resolution	0.0	0.1	0.1	0.2	0.1
MC finite size	1.1	2.4	2.0	2.3	0.6
Efficiency modelling	0.3	0.5	0.6	0.6	0.2
Absolute *ct* accuracy	0.2	0.2	0.2	0.2	0.2
Mass modelling	0.3	0.4	0.5	0.9	0.0
ct modelling	0.1	0.1	0.4	0.1	0.4
B^+ contamination	–	–	2.4	–	–
Mass window of the $\pi^+\pi^-$	–	–	1.5	–	–
$K^\pm\pi^\mp$ mass assumption	0.3	–	–	–	–
ct range	–	–	–	–	0.1
S-wave contamination	–	–	–	–	0.4
Total	1.5	2.7	3.7	2.7	1.2

Bc

Source	$\sigma_{\Delta\Gamma}$ [c/mm]	$\sigma_{c\tau_{B_c^+}}$ [μm]
PV choice	0.07	2.0
Fit model	0.12	3.7
ct binning	0.06	1.6
Simulation size	0.04	1.3
Misalignment	0.03	0.6
Total uncertainty	0.16	4.7

Finite size of the MC samples and efficiency determination are the dominant systematic sources