CMS Flavor Highlights and Prospects

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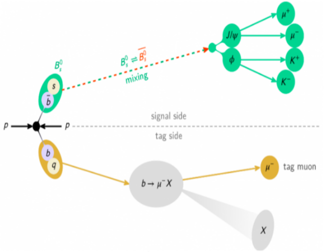
Outline of the talk

- CP violation in B_s decays
- Rare decays of B_s
- Search for lepton flavor violation
- New resonance searches (mesons and baryons)
- Conclusions

CP Violation in $B_s \to J/\psi\phi(1020)$

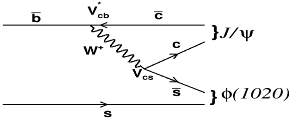
Talk by Giacomo Feldi in CP violation and Lifetime session 2 on Wed: 23/09



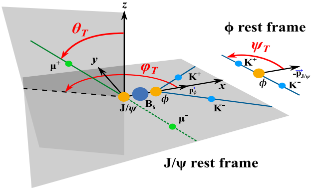
$$\phi_s \simeq -2\beta_s = -2arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right) = -36.96^{+0.72}_{-0.84} \text{ mrad.}$$

(PRD,84,033005,2011)

- **Trigger requires an extra Muon which increases tagging efficiency**
- ϕ_s coming from interference of decay and mixing: 1 phase $\Rightarrow$ golden decay mode

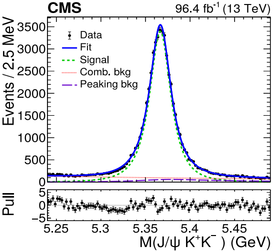


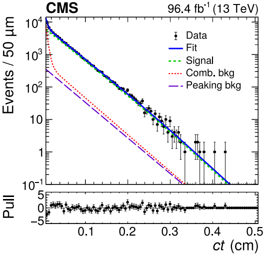
final state is not a single CP eigenstate

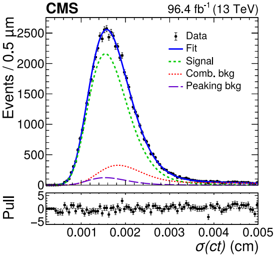


- Angular analysis to measure CP violation
- ψ_T: helicity angle of K^+ in the ϕ rest frame w.r.t. the negative flight direction of B_s^0
- θ_T: polar angle of the μ^+ in the J/ψ rest frame
- ϕ_T: azimuthal angle of the μ^+ in the J/ψ rest frame

Signal Extraction







- J/ψ and ϕ required to have a common vertex
- J/ψ mass is constrained to PDG value
- Peaking background from $B^0 \rightarrow J\psi K^* \rightarrow \mu^+\mu^- K^+\pi^-$
- 5-D fit to the data, 1-D projection are shown
- Opposite sign muon tag is used, Trigger requires an extra muon

Data sample	ϵ_{tag} (%)	ω_{tag} (%)	P_{tag}(%)
2017	45.7 $\pm$ 0.1	27.1 $\pm$ 0.1	9.6 $\pm$ 0.1
2018	50.9$\pm$ 0.1	27.3 $\pm$ 0.1	10.5 $\pm$ 0.1

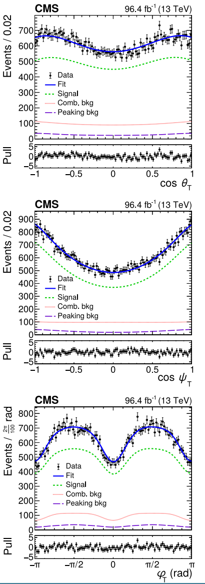
Extraction of fit parameters

Summary of fit results with uncertainties

Parameter	Fit value	Stat. uncer.	Syst. uncer.
ϕ_s [mrad]	-11	± 50	± 10
$\Delta\Gamma_s$ [ps^{-1}]	0.114	± 0.014	± 0.007
Δm_s [$\hbar$ ps^{-1}]	17.51	$^{+0.10}_{-0.09}$	± 0.03
$\lvert\lambda\rvert$	0.972	± 0.026	± 0.008
Γ_s [ps^{-1}]	0.6531	± 0.0042	± 0.0026
$\lvert A_0\rvert^2$	0.5350	± 0.0047	± 0.0049
$\lvert A_\perp\rvert^2$	0.2337	± 0.0063	± 0.0045
$\lvert A_S\rvert^2$	0.022	$^{+0.008}_{-0.007}$	± 0.016
$\delta_\parallel$ [rad]	3.18	± 0.12	± 0.03
$\delta_\perp$ [rad]	2.77	± 0.16	± 0.05
$\delta_{S\perp}$ [rad]	0.221	$^{+0.083}_{-0.070}$	± 0.048

Theoretical prediction:arXiv:1912.07621

Parameter	Values
Δm_s $[\hbar ps^{-1}]$	18.77 ± 0.86
$\lvert\lambda\rvert$	1
$\Gamma_s ps^{-1}$	0.910 ± 0.013



Results

Results using 13 TeV data

ϕ_s = -11 $\pm$ 50 (stat.) $\pm$ 10 (syst.) mrad

$\Delta\Gamma_s$ = 0.114 $\pm$ 0.014 (stat.) $\pm$ 0.007 (syst.) ps^{-1}

Results using 13 TeV + 8 TeV data

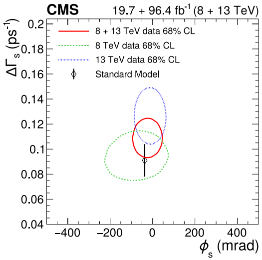
ϕ_s = -21 $\pm$ 45 mrad

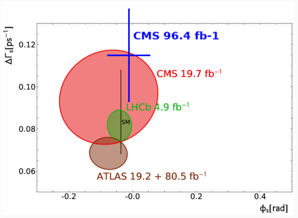
$\Delta\Gamma_s$ = 0.1073 $\pm$ 0.0097 ps^{-1}

Consistent with SM prediction

ϕ_s = $-36.96^{+0.72}_{-0.84}$ mrad

$\Delta\Gamma_s$ = 0.091 $\pm$ 0.013 ps^{-1}



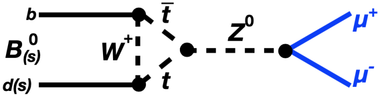


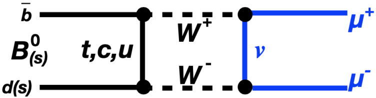
https://arxiv.org/abs/2007.02434 and submitted to PLB

Measurement of the $B_s^0/B^0 \to \mu^+\mu^-$

Talk by Chandiprasad Kar in Rare Decays session 2 on Tue: 22/09

- Rare $B^0 \to \mu^+\mu^-$ decays
  - Two branching fractions:
    $\mathcal{B}_{SM}(B_s^0 \to \mu^+\mu^-) = (3.57 \pm 0.17) \times 10^{-9}$
    $\mathcal{B}_{SM}(B^0 \to \mu^+\mu^-) = (1.06 \pm 0.09) \times 10^{-10}$
  - effective FCNC, helicity suppressed
    (but not in models with extended Higgs sectors)
  - $B^0 \to \mu^+\mu^-$ CKM suppressed $V_{ts}| > |V_{td}|$
  - $B_s0 \to \mu^+\mu^-$ decay-time integrated measurement because $\Delta\Gamma_s = \Gamma_s^L - \Gamma_s^H = 0.082 \pm 0.007\ ps^{-1}$

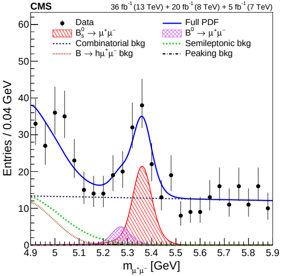




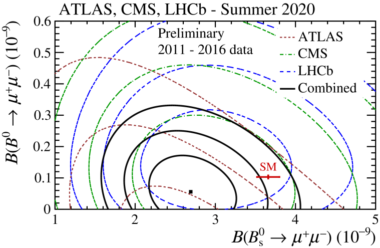
- SM prediction: $\mathcal{A}_{\Delta\Gamma}^{\mu^+\mu^-} = +1 \to \tau^{SM}_{\mu^+\mu^-}$
  (Only the heavy mass eigenstate decays to dimuons)
- $\mathcal{B}_{SM}(B_s^0 \to \mu^+\mu^-) = (3.0 \pm 0.6^{+0.3}_{-0.2}) \times 10^{-9}$
- LHCb: $\tau_{\mu^+\mu^-} = 2.04 \pm 0.44 \pm 0.05$ ps,

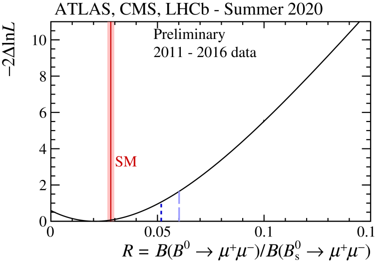
Results

published in JHEP04(2020)188



CMS-PAS-BPH-20-003





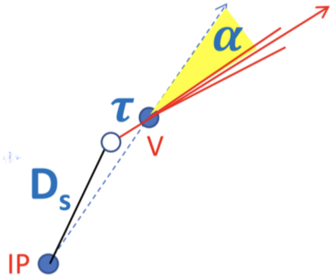
- Control samples: $B_s^0 \to J\psi(\mu^+\mu^-)\phi(K^+K^-)$ and $B^+ \to J\psi((\mu^+\mu^-)K^+$
- $\frac{f_s}{f_u} = 0.231 \pm 0.019$ (stat)
- $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = [2.9 \pm 0.7$ (exp) $\pm\ 0.2$ (frag)$] \times 10^{-9}$
- $\mathcal{B}(B^0 \to \mu^+\mu^-) < 3.6 \times 10^{-10}$ at 95 % CL
- Peaking background from $B^0 \to J\psi K^* \to \mu^+\mu^- K^+\pi^-$
- $\tau_{\mu^+\mu^-} = [1.70^{+0.60}_{-0.43}(stat) \pm 0.09(syst)]$ps

Measurements are consistent with SM

Lepton flavor violation in $\tau^+ \to \mu^+\mu^+\mu^-$

- Three generation of quarks and leptons
- Quarks and neutrinos change generation
- How about charged leptons?
- Many experiments are dedicated for this LFV measurements like Mu2e, COMET..
- Various models predict Br. $\sim 10^{-8}$

Talk by Chandiprasad Kar in Rare Decays session 2 on Tue: 22/09



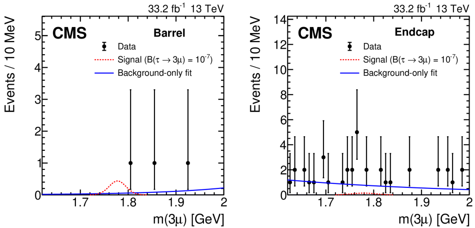
- World best limit: Belle $\sim 2.1 \times 10^{-8}$ at 90% CL (Phys. Lett. B 687 (2010) 139)

The present analysis has been performed combining τ's from W-boson and heavy mesons, B, D.

Results

submitted to JHEP/arXiv:2007.05658

$\tau \rightarrow \mu\mu\mu$ from W-boson decay

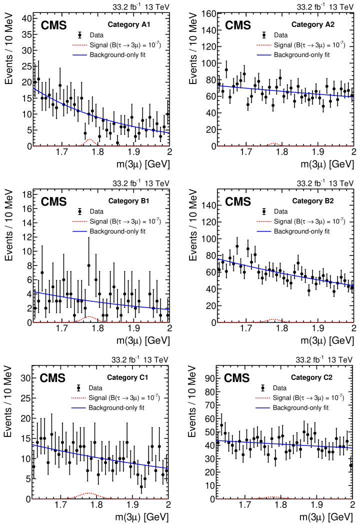


W $\rightarrow \tau$ decays:
$\mathcal{B}(\tau \rightarrow \mu\mu\mu) < 20 \times 10^{-8}$ 90% CL

Heavy mesons decays to τ decays:
$\mathcal{B}(\tau \rightarrow \mu\mu\mu) < 9.2 \times 10^{-8}$ 90% CL

Combined measurement:
$\mathcal{B}(\tau \rightarrow \mu\mu\mu) < 8.0 \times 10^{-8}$ 90 % CL

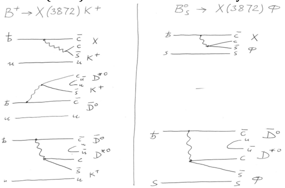
Will be performed using full RUN II data



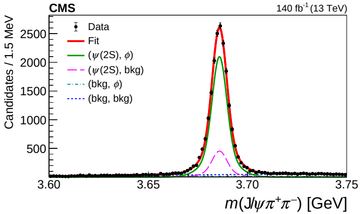
$\tau \rightarrow \mu\mu\mu$ from heavy mesons decay

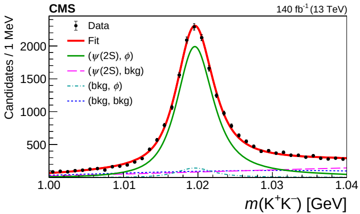
Observation of the $B_s^0 \to X(3872)\phi$ decay

X(3872) formation in b hadron decays



Talk by Daniela Fasanella in Spectroscopy session 1 on 23/09

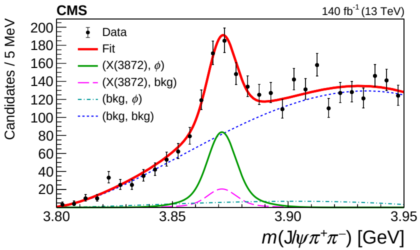




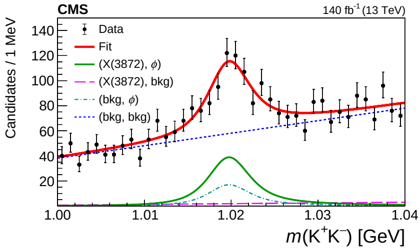
- X(3872) was observed in 2003 by Belle, but its nature is still unclear
- The decays of X(3872) in to $J/\psi\omega$ w.r.t $J\psi\rho$ violates isospin
- The X was never observed in B_s^0 decays

Measurement of its production in B_s^0 decays helps understanding the properties of X(3872), in particular dynamics of its formation in B hadron decays
$N(B \to \psi(2S)\phi) = 15\ 359 \pm 171$

Signal Extraction: 2D fit



Projections of the 2D fit

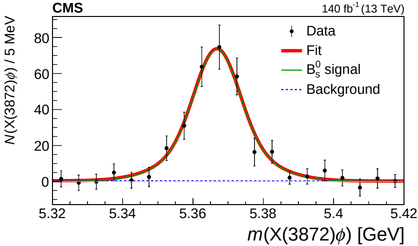


- Two-dimensional fit to m($J/\psi\pi\pi$) and m(KK)
- N(B $\rightarrow X(3872)\phi$) $= 299 \pm 39$
- Signal significance is more than 5σ, First Observation!

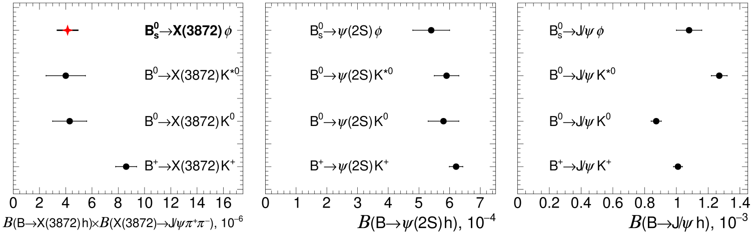
Results

- R = $\frac{\mathcal{B}(B_s^0 \to X(3872)\phi)}{\mathcal{B}(B_s^0 \to \psi(2S)\phi)}$ = (2.21 $\pm$ 0.29 (stat) $\pm$ 0.17 (syst))
- $\frac{\mathcal{B}(B_s^0 \to X(3872)\phi)}{\mathcal{B}(B^+ \to \psi(2S)K^+)}$ = 0.482 $\pm$ 0.063 (stat) $\pm$ 0.1037 (syst) $\pm$ 0.070 ($\mathcal{B}$)
- Major systematics come from signal and background modeling
- $\frac{\mathcal{B}(B_s^0 \to \psi(2S)\phi)}{\mathcal{B}(B^+ \to \psi(2S)K^+)}$ = 0.87 $\pm$ 0.10 (PDG)
- $\mathcal{B}(B^+ \to \psi(2S)K^+)$ is $\sim$ two times larger than $\mathcal{B}(B^0 \to X(3872)K^0)$
- This result further suggests that X(3872) is not behaving like a charmonium state

arXiv:2005.04764, accepted by PRL

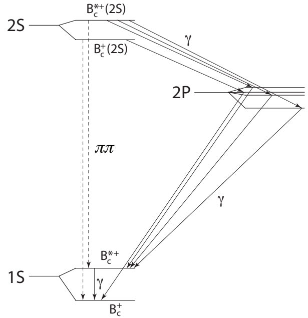


Comparison to other measurements



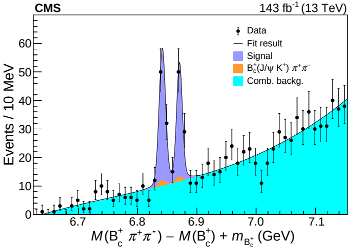
$B_c(2S)^+$ and $B_c^*(2S)$ cross-section Measurement

Talk by Adriano Di Florio in Spectroscopy session 1 on Tue: 23/09



Particle	Predicted M(MeV)
B_c	6247 - 6286
B_c^*	6308 - 6341
$B_c(2S)$	6835 - 6882
$B_c^*(2S)$	6881 - 6914

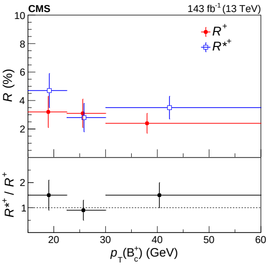
- $B_c(2S)^* \rightarrow B_c^*(B_c\gamma)\pi^+\pi^-$
- Since gamma is low energy, it is not detected $B_c^*(2S) \rightarrow B_c\pi^+\pi^-$ + missing energy
- $B_c(2S) \rightarrow B_c\pi^+\pi^-$

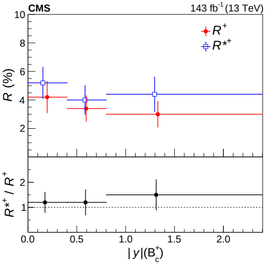


- So, We see a two peak structure in the $B_c\pi^+\pi^-$ mass distribution, with the $B_c^*(2S)$ peak at a mass shifted by $\Delta M = [M(B_c^* - M(B_c)] - M(B_c^*(2S)) - M(B_c(2S))]$
- $p_T(B_c^+) > 15$ GeV and $|y| < 2.4$
- Yield($B_c(2S)^+$)= 52 $\pm$ 9 ($> 5\sigma$)
- Yield($B_c(2S)^{*+}$)= 67$\pm$ 10 ($> 5\sigma$)

Results

arXiv:2008.08629, submitted to PRD



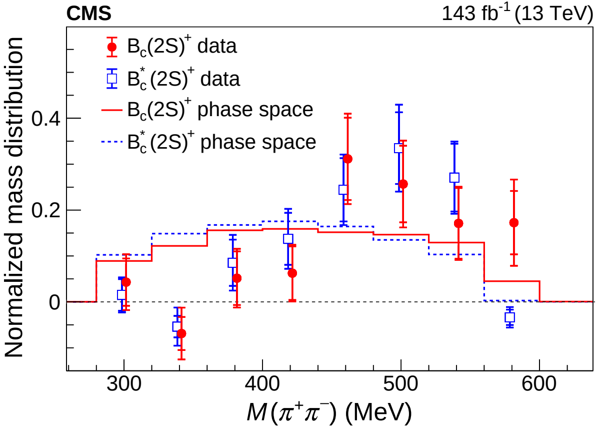


- $R^+ \equiv \frac{\sigma(B_c(2S)^+)}{\sigma(B_c^+)} \mathcal{B}(B_c(2S)^+ \to B_c^+\pi^+\pi^-) = \frac{N(B_c(2S)^+)}{N(B_c^+)} \frac{\epsilon(B_c^+)}{\epsilon(B_c(2S)^+)}$
- $R^{*+} \equiv \frac{\sigma(B_c^*(2S)^+)}{\sigma(B_c^+)} \mathcal{B}(B_c^*(2S)^+ \to B_c^{*+}\pi^+\pi^-) = \frac{N(B_c^*(2S)^+)}{N(B_c^+)} \frac{\epsilon(B_c^+)}{\epsilon(B_c^*(2S)^+)}$
- $\frac{R^{*+}}{R^+} = 1.35 \pm 0.32$ ($p_T(B_c^+)$ >15 GeV and $|y| < 2.4$)

	R^+	R^{*+}	R^{*+}/R^+
$J/\psi\pi^+\pi^-$ fit model	5.5	5.5	–
$B_c^+\pi^+\pi^-$ fit model	5.9	2.9	2.9
Efficiencies: statistical uncertainty	1.1	1.0	1.4
Efficiencies: spread among years	1.8	1.6	0.9
Efficiencies: pion tracking	4.2	4.2	–
Decay kinematics	1.5	6.9	4.2
Helicity angle	1.0	6.0	3.5
Total	9.5	12.0	6.4

No dependency on p_T and absolute rapidity

Di-pion Mass Measurement



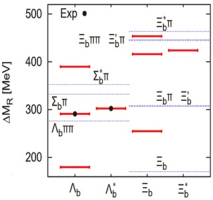
- Different from phase space

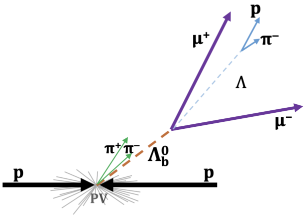
https://arxiv.org/abs/2005.04764, submitted to PRD

Excited Λ_b^0 baryons

Λ_b is constructed using $J/\psi(\mu^+\mu^-)\Lambda(p\pi)$, $\psi(2S)\Lambda$, ($\psi(2S) \to \mu^+\mu^-$ and $\psi(2S) \to J\psi\pi^+\pi^-$)

Talk by Vincenzo Mastrapasqua in HF Production and Heavy Ions parallel session on 22/09

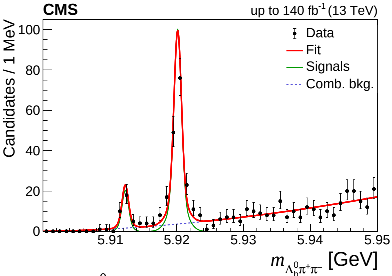




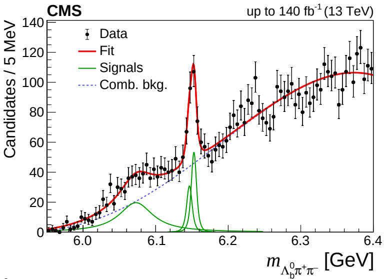
- Many theoretical predictions of excited Λ_b and Σ_b
- some agree with LHCb measurements
- In CMS, we can not use Λ_c^+ due to large background (no hadron ID)
- $\Lambda_b^0 \to \psi\Lambda$ ($\mu^+\mu^- + \Lambda \to p\pi^-$ displaced vertex)
- Additional two prompt pions from PV

Results

Talk by Adriano Di Florio in Spectroscopy session 1 on 23/09



Physics Letters B Volume 803, 10 April 2020, 135345



$M(\Lambda_b(5912)^0) = 5912.32 \pm 0.12 \pm 0.01 \pm 0.17$ MeV $\quad M(\Lambda_b(6146)^0) = 6146.5.32 \pm 1.9 \pm 0.8 \pm 0.2$ MeV

$M(\Lambda_b(5920)^0) = 5920.16 \pm 0.07 \pm 0.01 \pm 0.17$ MeV $\quad M(\Lambda_b(6152)^0) = 6152.7 \pm 1.1 \pm 0.4 \pm 0.2$ MeV

- Systematics uncertainty dominated by signal and background model and mass resolution
- Broad peak at 6073 $\pm$ 5 MeV, signal yield is 301 $\pm$ 71 ($\sim 4\sigma$) (confirmed by LHCb)
- More data will allow to explain the nature of the broad peak
- Results confirm LHCb observation of the four excited narrow states

Conclusions

- Excellent opportunity for wide spectrum of flavor physics measurements that are challenging and complementary to other experiments
- More data will improve the measurements
- No signature of physics beyond SM
- Stay tuned for more measurements using more data
- More detailed talks on the CMS measurements are in parallel sessions