Rare b →sll decays at 13 TeV by CMS Detector

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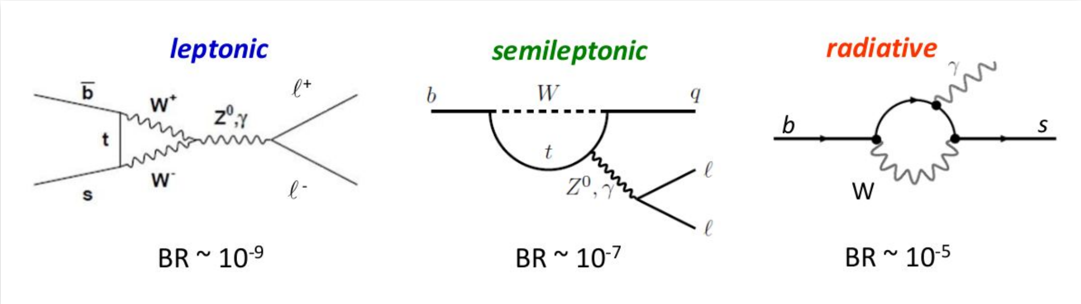
Outline

- Why look for rare B decays?
- Test of lepton flavor universality in $B^{\pm} \rightarrow K^{\pm}\mu^{+}\mu^{-}$ and $B^{\pm} \rightarrow K^{\pm}e^{+}e^{-}$ decays at 13 TeV
- Measurement of the $B^{0}_{s} \rightarrow J/\psi K^{0}_{S}$ effective lifetime at 13 TeV
- Angular analysis of $B^{0}_{s} \rightarrow \phi\mu^{+}\mu$ at 13 TeV
- Conclusion

Why look for rare decays of B mesons ?

- b → s,d quark transitions are Flavor Changing Neutral Currents (FCNCs), suppressed at tree level.
- In the Standard Model(SM) they only can occur through loops (penguin and box diagrams).
- Reveal the potential cracks in the SM, hinting at the existence of new physics (NP).
- Small SM branching fraction.



Observables/properties sensitive to new physics :

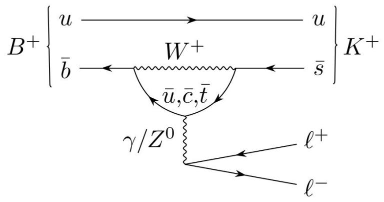
- Branching fractions
- Lepton flavor universality
- Lepton forward-backward asymmetry(A_{FB}), CP asymmetry (A_6) and much more!!

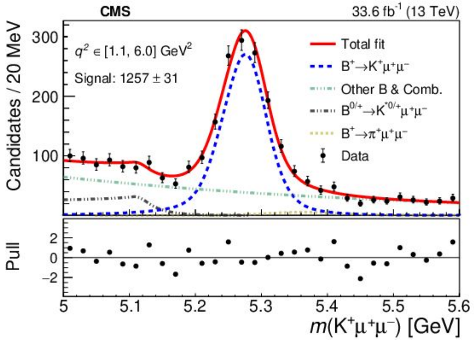
Test of lepton flavor universality in $B^\pm \to K^\pm\mu^+\mu^-$ and $B^\pm \to K^\pm e^+e^-$ decays

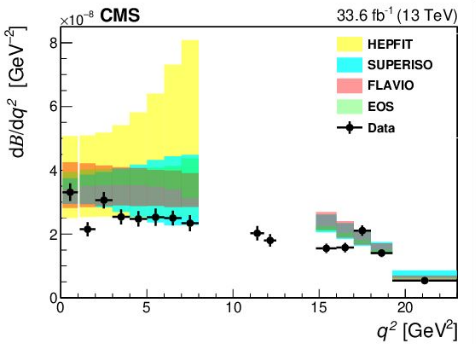
$\mathcal{B}(B^\pm \to K^\pm\mu^+\mu^-)$

- In SM the charged leptons ($e^\pm$, $\mu^\pm$, $\tau^\pm$) exhibit a similar behavior, commonly known as lepton flavor universality (LFU).
- Branching fractions of different lepton species could be modified differently by NP, thus resulting in LFUV.
- $B^\pm \to K^\pm l^+l^-$ decays provide an excellent environment to test LFU.
- The yield of $B^\pm \to K^\pm\mu^+\mu^-$ is 1267±55 in low q^2 region ($1.1 < q^2 < 6.0$ GeV^2/c^4) using 2018 dataset.
- The measured $\mathcal{B}(B^\pm \to K^\pm\mu^+\mu^-) = (12.42\pm0.68)\times10^{-8}$ in low q^2 bin and consistent with the present world average.

arXiv:2401.07090







Measurement of $R(\mathrm{K})$

- $R(\mathrm{K})$ is measured in the low q^2 region of both the $B^+ \to K^+\mu^+\mu^-$ and $B^+ \to K^+e^+e^-$ channels, where

$$R(K) = \frac{B^+ \longrightarrow K^+\mu^+\mu^-}{B^+ \longrightarrow J/\psi(\mu^+\mu^-)K^+} \Big/ \frac{B^+ \longrightarrow K^+e^+e^-}{B^+ \longrightarrow J/\psi(e^+e^-)K^+}$$

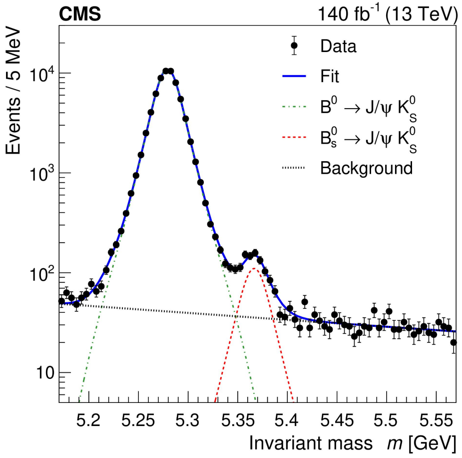
- The control modes $B^\pm \to J/\psi K^\pm$ with $J/\psi \to \mu\mu$ and $J/\psi \to ee$ help in significant cancellation of systematic uncertainties.
- *The measured* $\mathrm{R(K)} = 0.78^{+0.46}_{-0.23}\,(\mathrm{stat})^{+0.09}_{-0.05}\,(\mathrm{syst})$, which is in agreement with the standard model expectation $R(\mathrm{K}) \approx 1$.

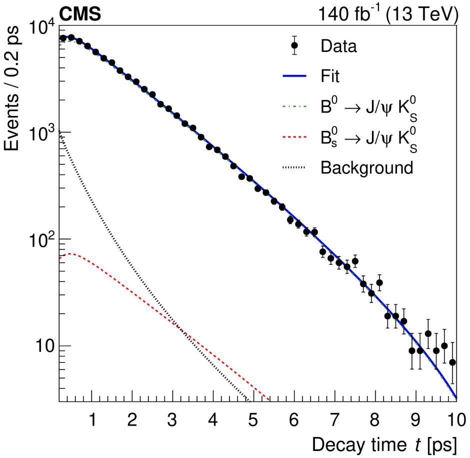
arXiv:2401.07090

Measurement of the $B^0_s \to J/\psi K^0_S$ effective lifetime

- B^0 – B^0_s oscillations provide a valuable tool in the study of *CP* violation.
- Phase φ_d arises from B^0 – B^0_s oscillations, is important in measuring CP violation.
- Φ_d can be determined well by studying the penguin contribution, which is $B_0^s \to J/\psi K^0_S$.
- Effective lifetime is determined by performing a 2D unbinned maximum likelihood fit to the B_0^s invariant mass and proper decay time distributions.
- Resulting effective lifetime is 1.59±0.07(stat)±0.03(syst) ps, which is the most precise measurement to date and agrees with SM.

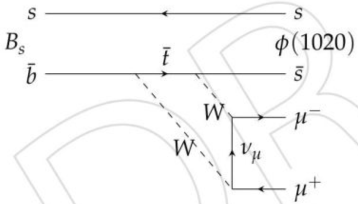
[arXiv:2407.13441](https://arxiv.org/abs/2407.13441)



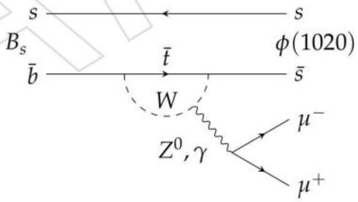


Angular Analysis of $B^0_s \to \phi\mu^+\mu$ at 13 TeV by CMS

- $B^0_s \to \phi\mu^+\mu$ is a FCNC process forbidden in SM at tree level.
- They proceed via electroweak penguin and box diagrams.
- Undiscovered particles may enter these diagrams and alter the decay amplitude.
- The analysis is based 137.5 fb^{-1} of integrated luminosity at com of $\sqrt{s}$ = 13 TeV.
- Aim to extract the set of angular parameters (CP averaged and CP asymmetries) for this decay as a function of the dimuon invariant mass squared (q^2) .

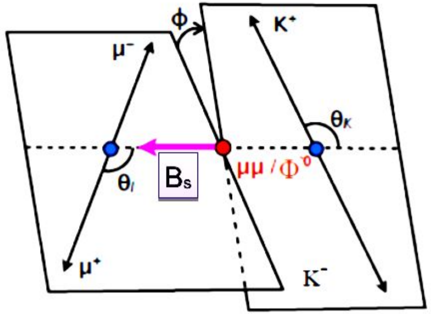


EW Box Diagram



EW Penguin Diagram

Illustration of the decay showing the angles θ_K, θ_L and ϕ :



- The angular differential decay rate for $B_s \to \phi\mu^+\mu^-$ is a function of q^2 , $\cos\theta_K$, $\cos\theta_L$, (Integrating out angle ϕ)

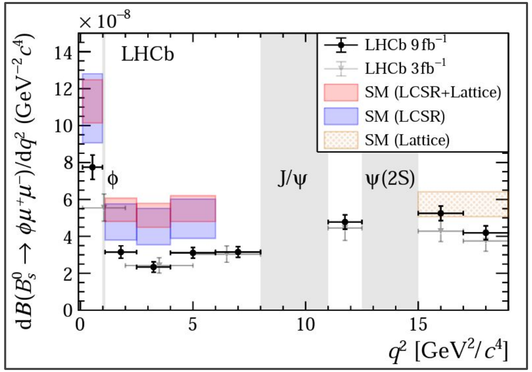
$$\frac{1}{d\Gamma/dq^2}\frac{d^2\Gamma}{d\cos\theta_k d\cos\theta_l} = \frac{9}{16}\Big(\frac{1}{2}(1-F_L)\cdot(1-\cos^2\theta_K)\cdot(1+\cos^2\theta_l) + 2F_L\cdot\cos^2\theta_K\cdot(1-\cos^2\theta_l) + A_6\cdot(1-\cos^2\theta_K)\cdot\cos\theta_l\Big)$$

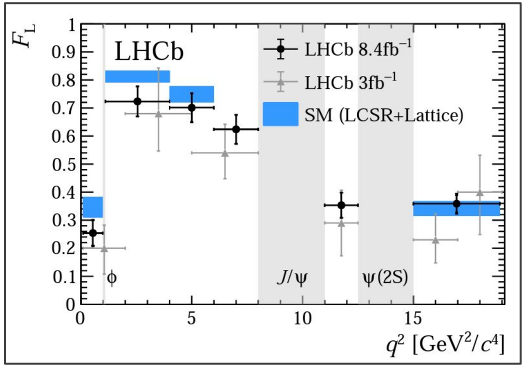
arXiv:2107.13428

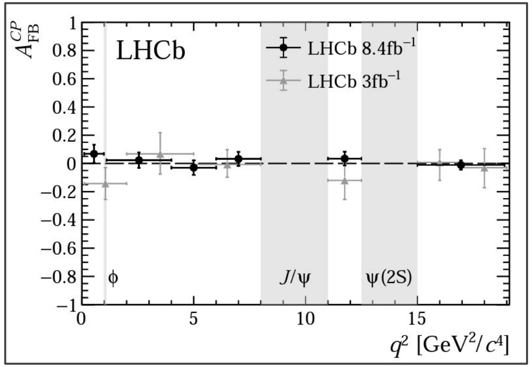
The angular observables **F_L is CP averaged**, and **A_6 is CP asymmetry.**

Previous Results

- CDF observed $B^0_s \to \phi\mu^+\mu$ in 2011 [PRL.106.161801]
- Angular analysis and differential branching fraction measurement performed by LHCb using 3fb^{-1} data in 2015 [JHEP09(2015)179]
- Branching fraction measurement by LHCb at 7,8 and 13 TeV using 1, 2 and 6 fb^{-1} respectively is 2021 [PRL.127.151801]
- Angular analysis performed by LHCb at 7,8 and 13 TeV using 3, 1.7 and 3.7 fb^{-1} respectively in 2021 [JHEP11(2021)043]

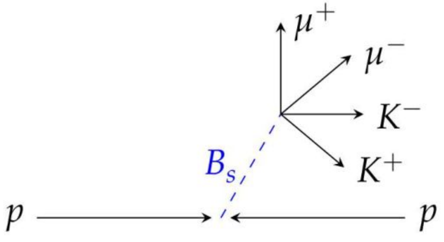






Signal Candidates Selections

- Events are selected by set of trigger paths, include two $\mu^{\pm}$ with p_T > 4 GeV and $|\eta|$ < 2.5
- φ mesons are reconstructed in the K^+K^- final state using two oppositely charged high-purity tracks.
- Each φ candidate is combined with $\mu^{\pm}$ in a fit to a common vertex to form a B^s_0 candidate.



Other Background Suppression:

- **Combinatorial background** : Suppressed by "**BDT**" algorithm
- **Resonance mode (J/Ψϕ,Ψ'ϕ) :** Suppressed by cuts [8-11] GeV/c^2 & [12.5-15] GeV/c^2 and anti-radiation veto
- **ϕ(1020) resonance** : Potential contamination is removed by a cut 1.01 GeV/c^2 < $m(K^+K^-)$ < 1.03 GeV/c^2
- **Peaking bkg** : Yield is constrained in the final fit
- Data with $q^2 \in$ [1.0, 18.9] GeV/c^2 are analysed in order to extract the signal parameters of interest (A_6, F_L)

Analysis Validations

- Selection and reconstruction can distort the angular and q^2 distributions observed in data.
- Effects are described by an angular efficiency $\boldsymbol{\varepsilon(\cos\theta_K, \cos\theta_l)}$,
    - ❑ Detector acceptance efficiency
    - ❑ Efficiency for reconstructing and selecting the signal candidates

- The efficiency modelling and the fitting procedures are validated with the following validations:
    - Closure test
    - High-statistics pure signal MC
    - Signal MC toys
    - Cocktail MC (data-like) toys
    - Control Channels $(B_s \rightarrow J/\Psi\phi, \Psi'\phi)$

Summary of $B^0_s \to \phi\mu^+\mu^-$ Angular Analysis by CMS

- Angular analysis is performed for the rare decay $B_s \to \phi\mu^+\mu^-$ on full Run 2 data at 137.5 fb^{-1} in different signal q^2 bins.
- Fits are performed on data with blinding the parameters of interests (POIs) (RooUnblindPrecision Class).
- All fits look reasonably good, and no abnormal distributions are found in data.
- Simulation studies with Run 2 sample is ongoing.

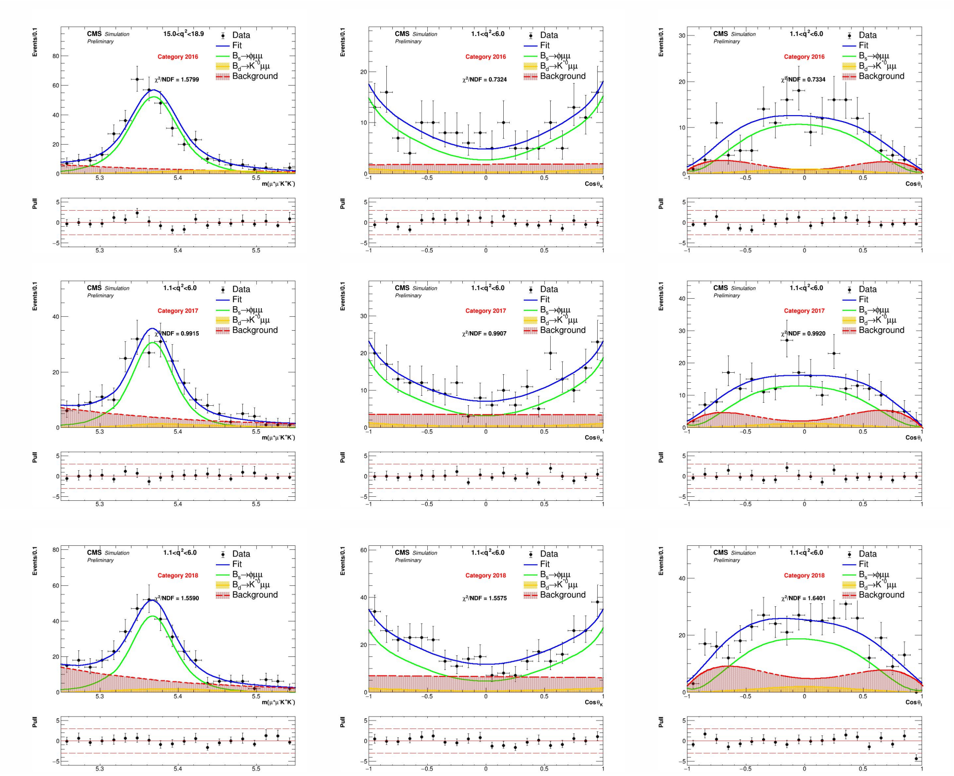
Conclusion

- Recents results on B decays at CMS at $\sqrt{s}$ = 13 TeV are discussed.
- R(K) measured in the range 1.1 < q^2 < 6.0 GeV^2 is found to be in agreement with SM.
- Measured effective lifetime of $B^0_s \rightarrow J/\psi K^0_S$ is the most precise result to date and can be used to constrain the parameters that govern mixing and CP violation in the B^0_s system.
- Angular analysis of $B^0_s \rightarrow \phi\mu^+\mu$ is studied as a function of q^2 at the integrated luminosity of 137.5 fb^{-1} of data with blinded POIs, at $\sqrt{s}$ = 13 TeV.

Thank you for your attention!

BackUp

Simultaneous 3D(mB_s, $cos\theta_K$, $cos\theta_l$) fits on data using blinding strategy



$1.1 < q^2 < 6.0$ GeV/c^2

- **RooUnblindPrecision** object is used for blinding the POIs (A_6, F_L).
- The uncertainty in the blind parameter is identical to that of the unblind parameter.

Signal PDF :

m(Kπμμ) :Double Crystal Ball distributions (DCB) with single mean

Angular Shape($cos\theta_K$, $cos\theta_L$) : Polynomials

Combinatorial Background PDF :

m(KKμμ) : Exponential function

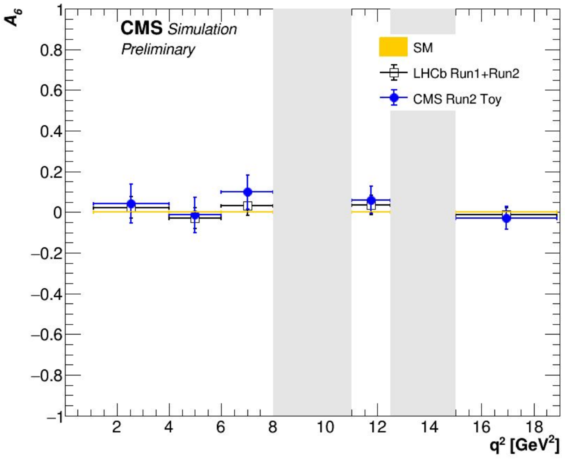
Angular Shape ($cos\theta_K$, $cos\theta_L$) : Polynomials

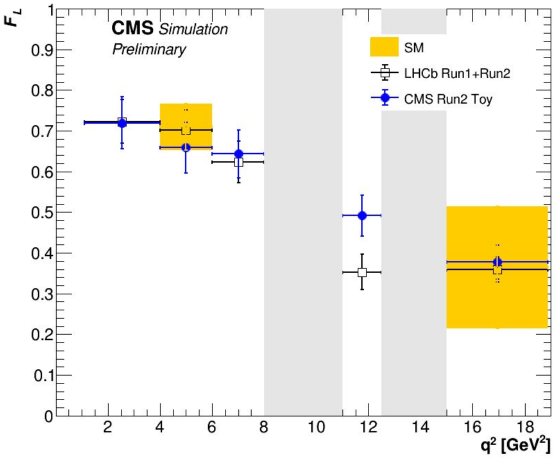
Peaking Background PDF :

m(KKμμ) : DCB with single mean

Angular Shape ($cos\theta_K$, $cos\theta_L$) : Polynomials and Gaussians

Angular Observables from Toy MC





The observables A_6, F_L from **Toy MC** show good agreement with the SM predictions and LHCb Run1 + Run2 results within the errors of the measurement.