Electroweak penguin decays to leptons at LHCb

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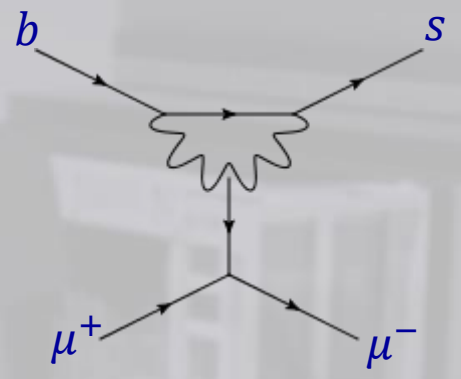
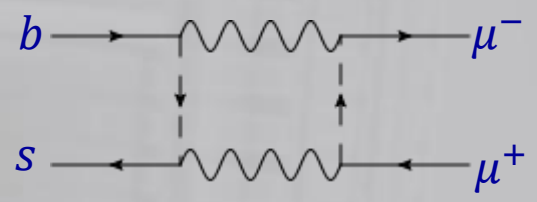
Overview:

- Reminders:
  - $B_s \to \mu^+\mu^-$ and $B_d \to \mu^+\mu^-$
  - Resonance observed in $B^+ \to K^+\mu^+\mu^-$ decays
  - $B^0 \to K^*\mu^+\mu^-$ and P_5'
- Hot off the press:
  - Angular analysis of charged and neutral $B \to K\mu\mu$ decays
  - $B^0 \to K^*\mu^+\mu^-$ isospin asymmetry and branching ratios
- Conclusions and looking forward

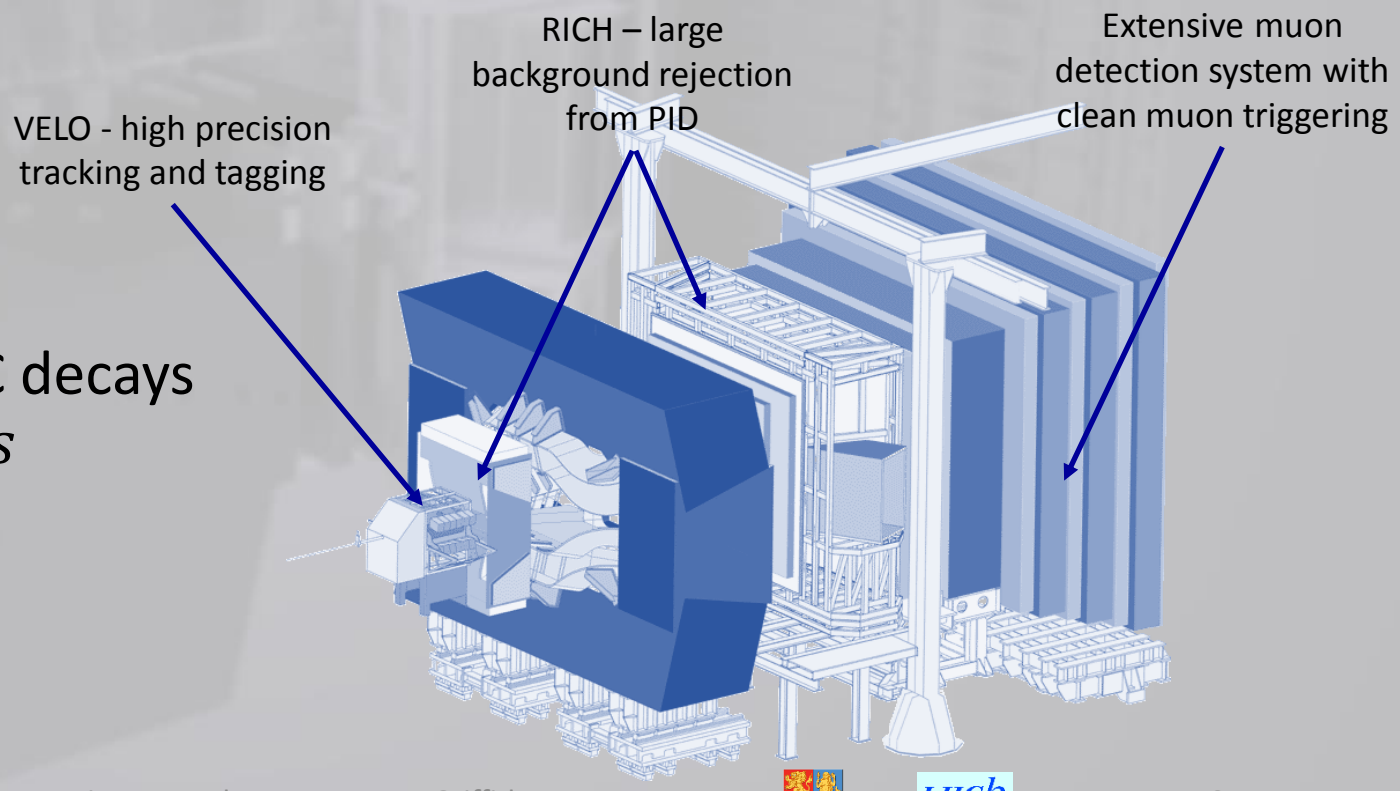
Rare Decays at LHCb

- FCNC's can occur through loops
  - Highly suppressed
  - Sensitive to new physics e.g additional diagrams from new BSM particles in loops
  - Numerous observables – many very sensitive to NP





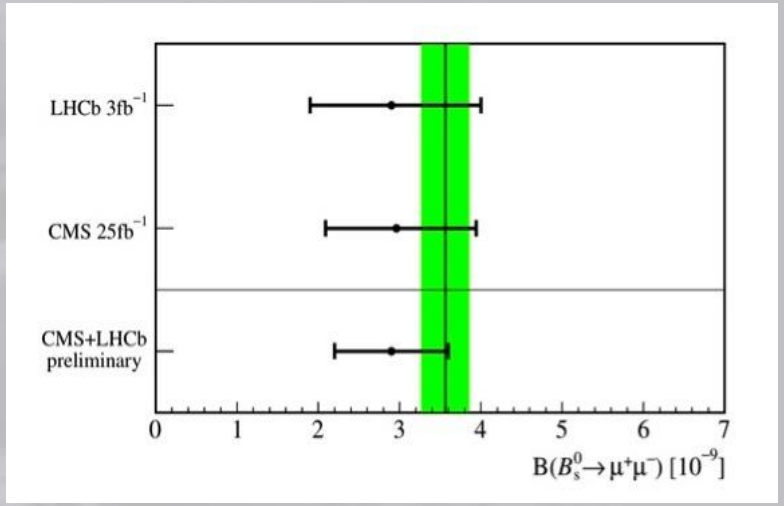
- LHCb ideal for studying rare FCNC decays of mesons and baryons, e.g $b \to s$
  - High resolution tracking
  - High performance PID
  - Muon signals 'clean' at LHCb



$B_s \to \mu\mu$ and $B_d \to \mu\mu$ reminder

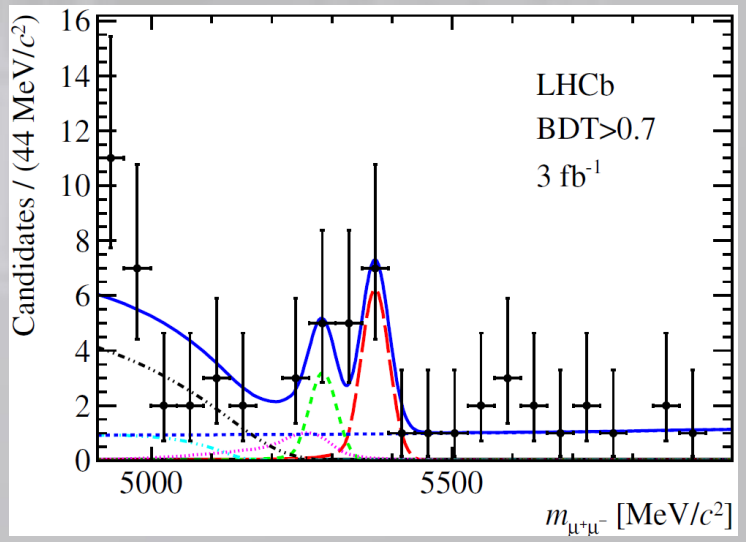
- Highly supressed from helicity and GIM
- Possible contributions from tree level BSM diagrams
  - Highly sensitive to new physics

- Branching fraction measured at both LHCb and CMS. Combined result highly constrains SUSY models.

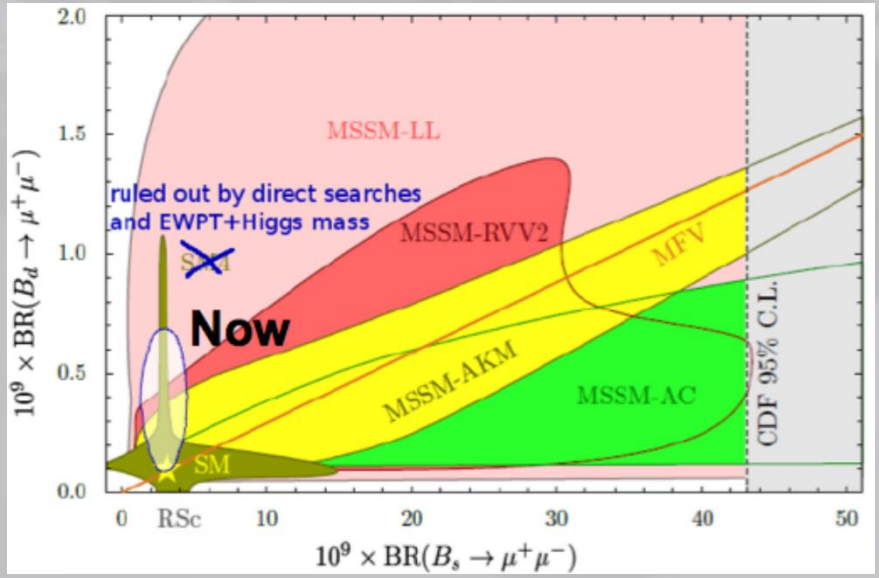


Combined LHCb and CMS results

Candidates for $B_s \to \mu\mu$ and $B_d \to \mu\mu$, LHCb



Allowed space for SUSY models in 2010 with CMS and LHCb constraints overlaid roughly in blue



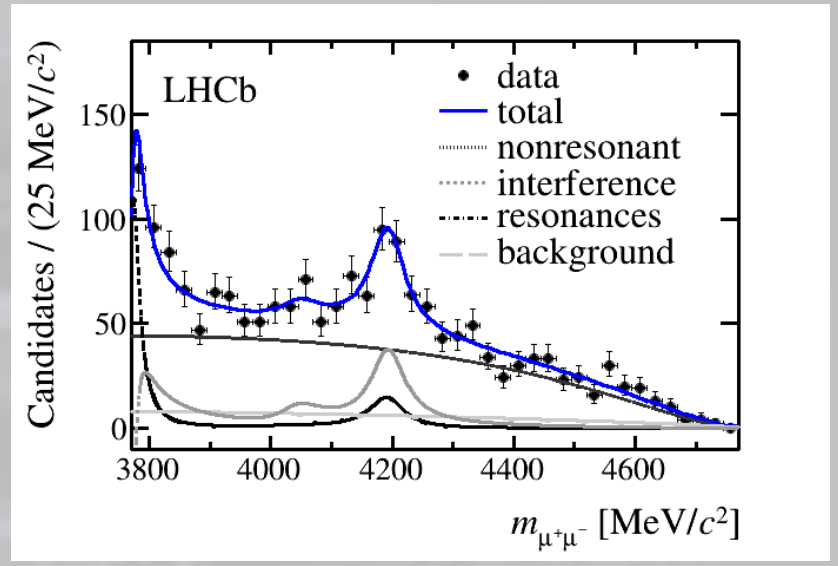
LHCb: arXiv:1307.5024

CMS: arXiv:1307.5025

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

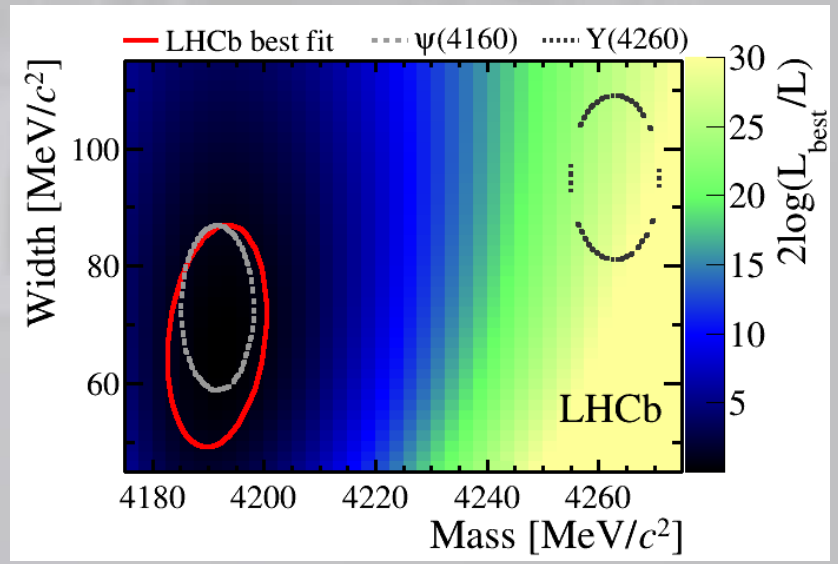
- Resonance observed in the dimuon system
- In region where K has low recoil to $\mu^+\mu^-$
- Corresponds to $\psi(4160)$
- $\mathcal{B}\,(\mathrm{B}^+ \to \psi(4160)K^+)$ probed

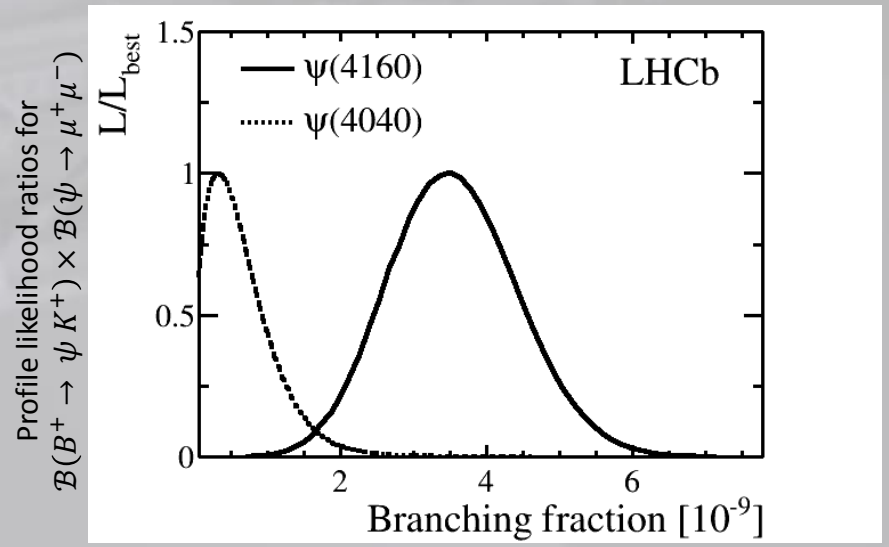
arXiv:1307.7595



Spectrum in high mass region of the dimuon system

Likelihood scan of resonance mass and width

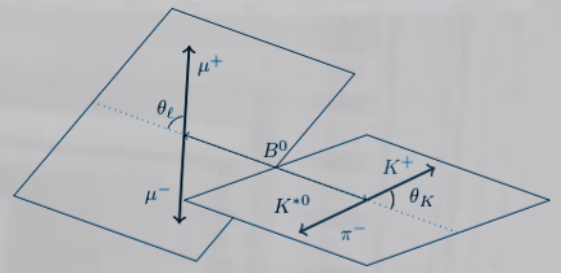




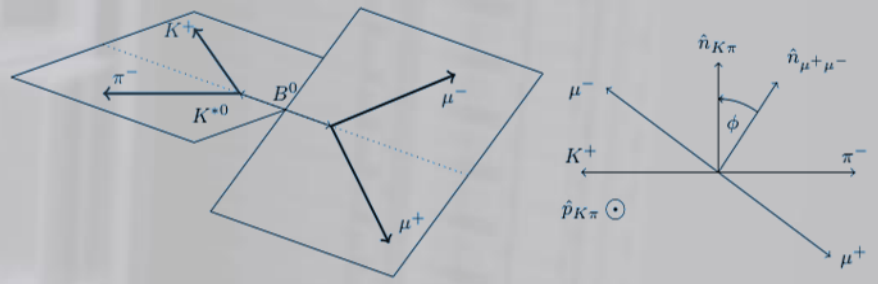
$B^0 \to K^* \mu^+ \mu^-$ angular analysis

- Looks at the differential angular distribution as functions of θ_l, θ_K, ϕ and q^2.
- Contains observables $P'_{4,5,7,8} = \frac{S_{j=4,5,7,8}}{\sqrt{F_L(1-F_L)}}$
- Reduced form-factor uncertainties in SM predictions

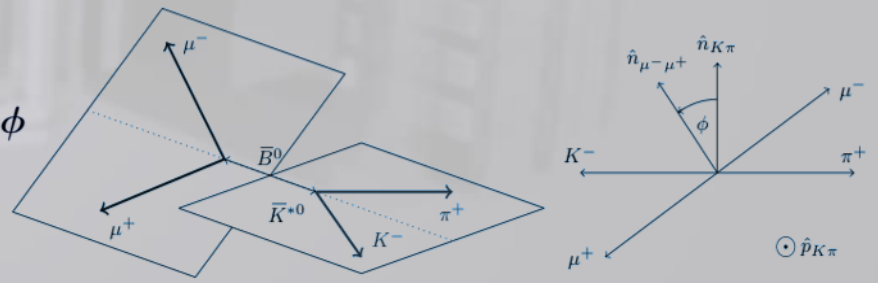
$$\frac{1}{d\Gamma/dq^2}\frac{d^4\Gamma}{d\cos\theta_\ell d\cos\theta_K d\phi dq^2} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos2\theta_\ell$$
$$- F_L\cos^2\theta_K\cos2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos2\phi + S_4\sin2\theta_K\sin2\theta_\ell\cos\phi$$
$$+ S_5\sin2\theta_K\sin\theta_\ell\cos\phi + S_6\sin^2\theta_K\cos\theta_\ell + S_7\sin2\theta_K\sin\theta_\ell\sin\phi$$
$$+ S_8\sin2\theta_K\sin2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin2\phi\Big],$$



(a) θ_K and θ_ℓ definitions for the B^0 decay



(b) ϕ definition for the B^0 decay



(c) ϕ definition for the $\bar{B}^0$ decay

$B^0 \to K^* \mu^+ \mu^-$ angular analysis

- Mostly consistent with SM predictions
- However, deviation seen in P_5' region
- Comparison with theory:

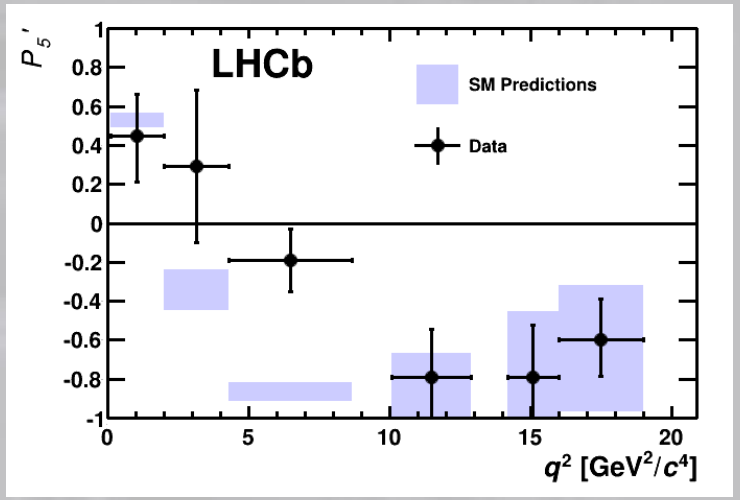
Descotes-Genon, et al arXiv:1303.5794

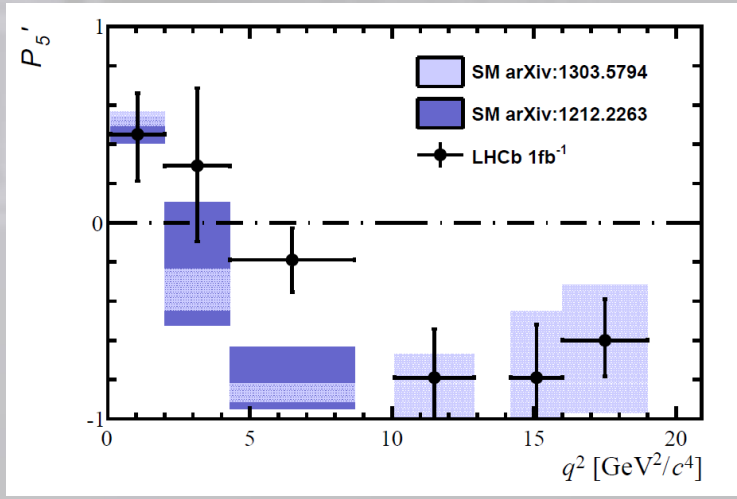
  - 3.7σ when looking at local discrepancy.
  - 0.5% chance of such discrepancy occurring in one of 24 bins.

Jäger et al arXiv:1212.2263

  - More conservative theoretical uncertainties calculations at low q^2
  - Significance reduced

arXiv:1308.1707





$B \to K\mu^+\mu^-$ angular analysis (B^+ and B^0)

- Differential branching fraction of charged and neutral $B \to K\mu\mu$ decays as function of the angle between one of the muons and the kaon in the dimuon rest frame

Contribution from (pseudo)scalar or tensor-like amplitudes
Small in SM

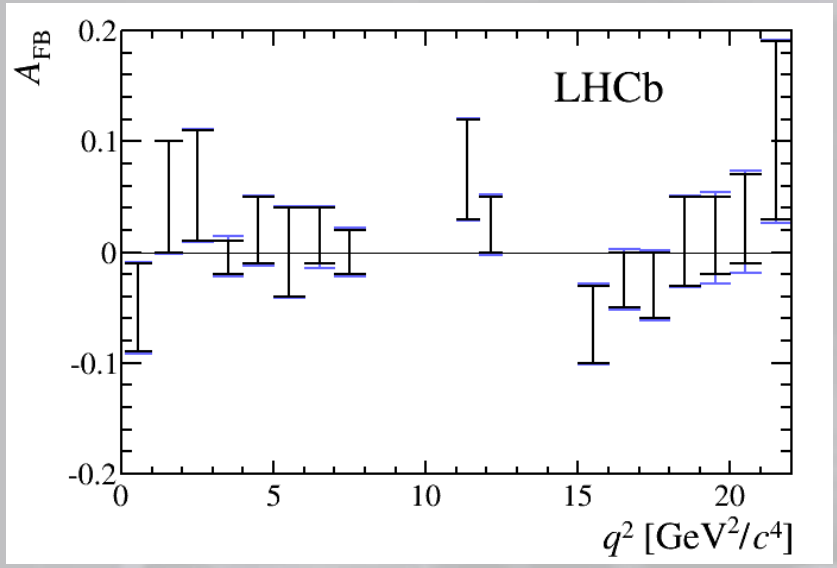
$$\frac{1}{\Gamma}\frac{d\Gamma}{dcos\theta_l} = \frac{3}{2}(1 - F_H)(1 - cos^2\theta_l) + \frac{1}{2}F_H + A_{FB}cos\theta_l F_H$$

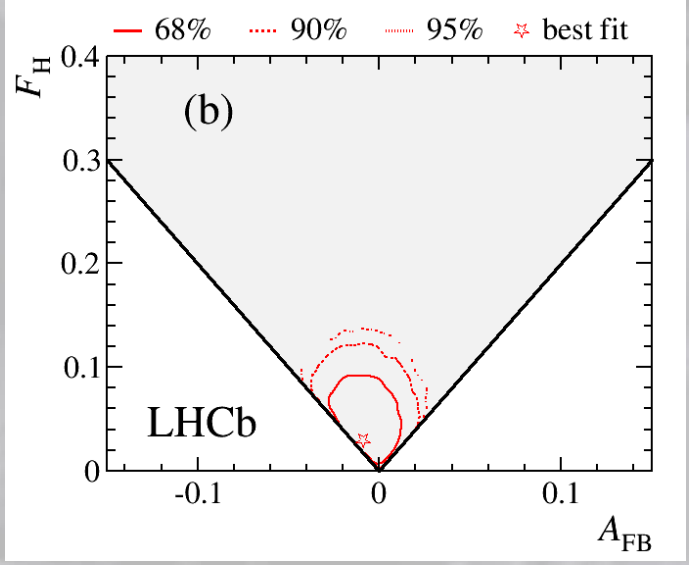
Forward-backward asymmetry. Zero up to tiny corrections in SM

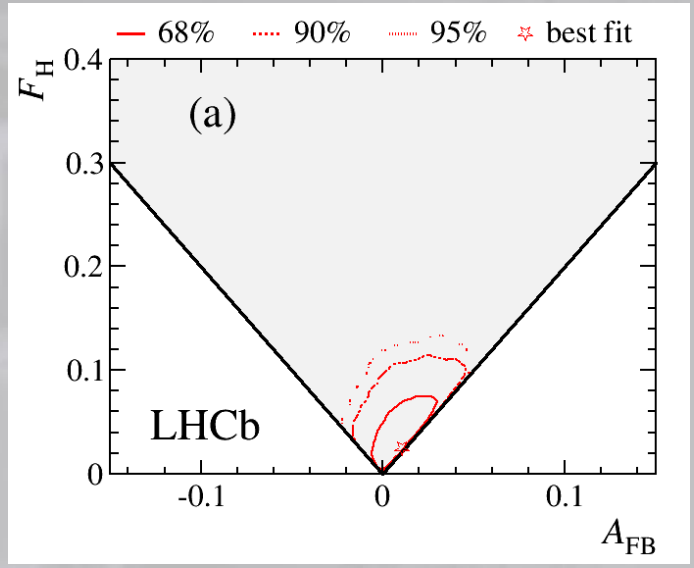
- NP models can give non-negligible values of F_H or A_{FB}

arXiv:1403.8045

$B \to K\mu^+\mu^-$ angular analysis (B^+ and B^0)

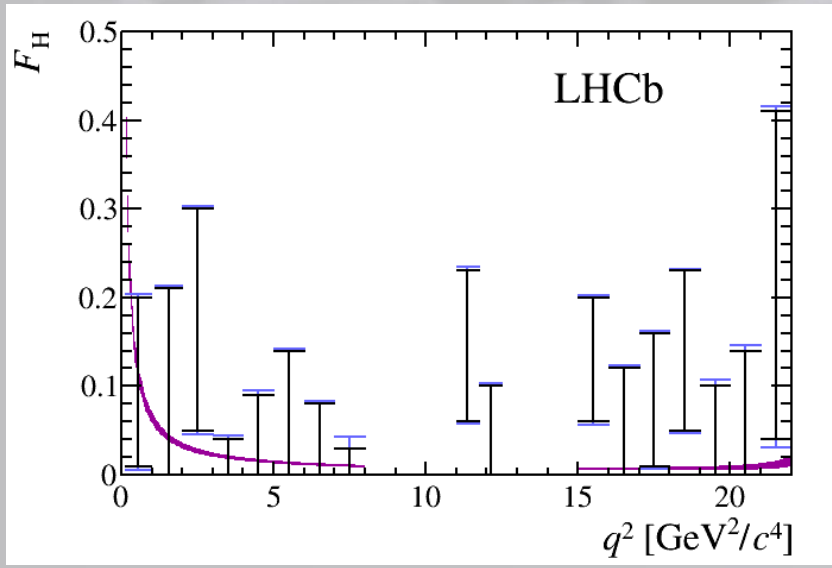






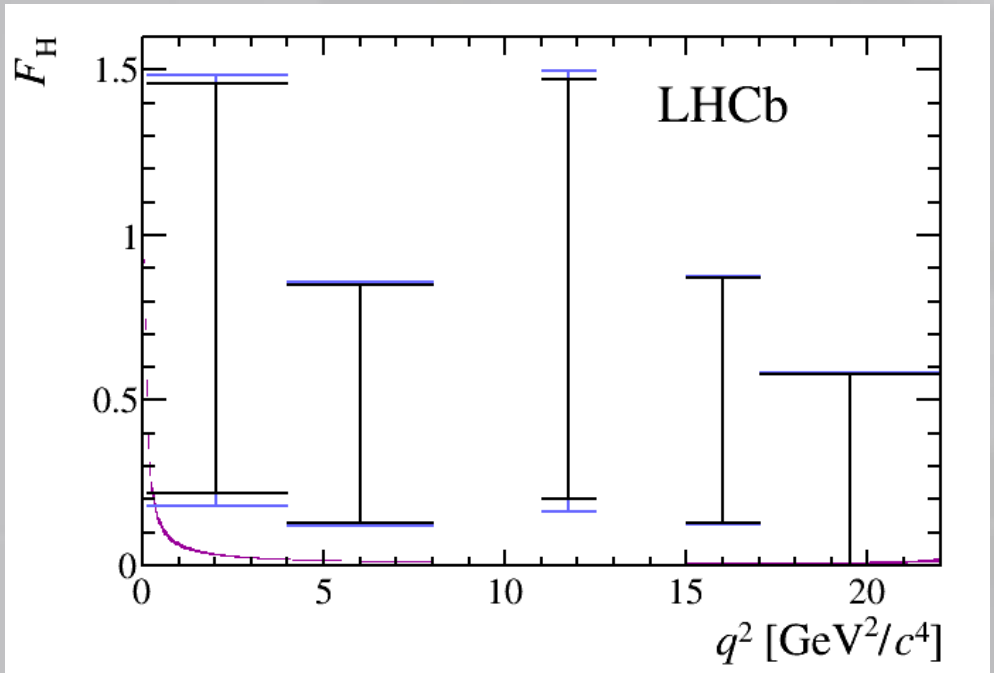
$1.1 < q^2 < 6.0\ GeV^2/c^4$

$15.0 < q^2 < 22.0\ GeV^2/c^4$



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

$B \to K\mu^+\mu^-$ angular analysis (B^+ and B^0)



$$B^0 \to K_s^0\mu^+\mu^-$$

- The most precise measurements to date
- Highly consistent with the SM
- Imposes much tighter constraints on tensor amplitudes
- Rules out cancellation effects for (pseudo)scalars in $B_s \to \mu\mu$ to explain results in non-SM case

$B^0 \to K^* \mu^+ \mu^-$ isospin asymmetry

- Isospin asymmetry an ideal probe due to the cancellation of form-factor uncertainties

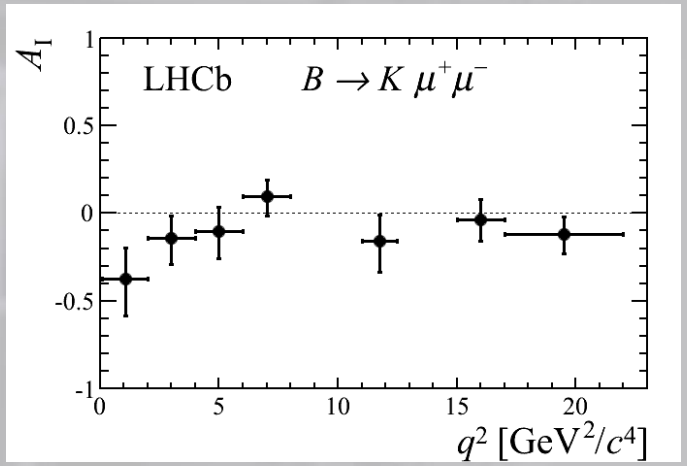
B^0/B^+ mean lifetime ratio

$$A_I = \frac{\Gamma(B^0 \to K^{(*)0}\mu^+\mu^-) - \Gamma(B^+ \to K^{(*)+}\mu^+\mu^-)}{\Gamma(B^0 \to K^{(*)0}\mu^+\mu^-) + \Gamma(B^+ \to K^{(*)+}\mu^+\mu^-)} = \frac{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) - \left(\frac{\tau_0}{\tau_+}\right) \cdot \mathcal{B}(B^+ \to K^{(*)+}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) + \left(\frac{\tau_0}{\tau_+}\right) \cdot \mathcal{B}(B^+ \to K^{(*)+}\mu^+\mu^-)}$$

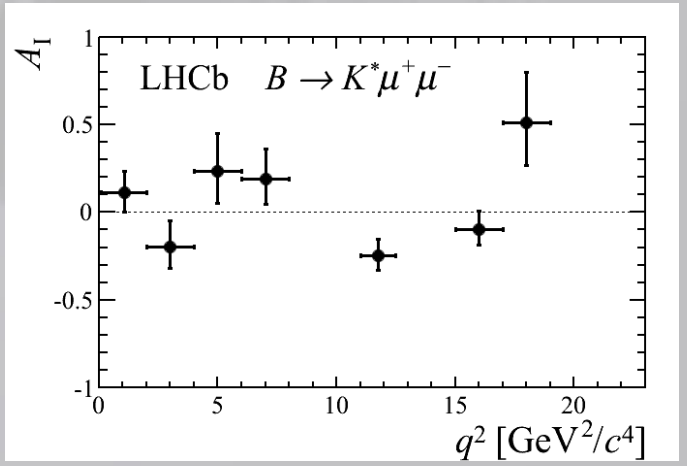
- In the SM A_I is small
  - $O(1\%)$ below J/ψ mass and even smaller above J/ψ mass
- Measured at BaBar and Belle
- Previous LHCb measurement on $1 fb^{-1}$ showed $> 4\sigma$ deviation from zero

$B^0 \to K^*\mu^+\mu^-$ isospin asymmetry

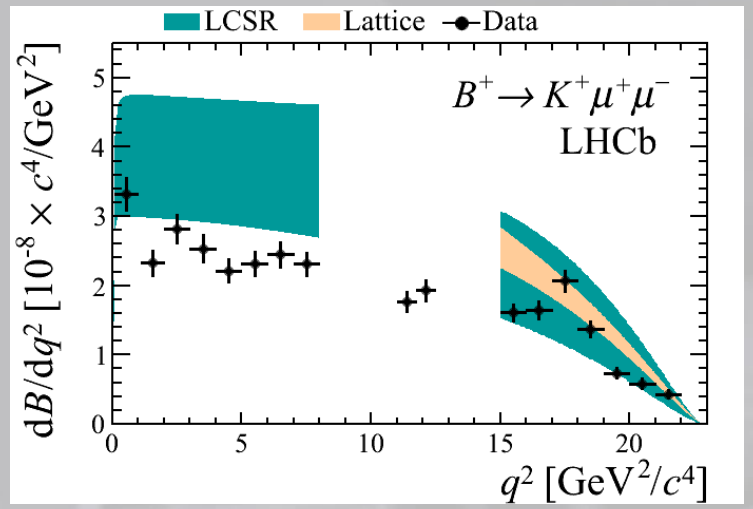
- With full LHCb data set, A_I more consistent with SM predictions (1.5σ)



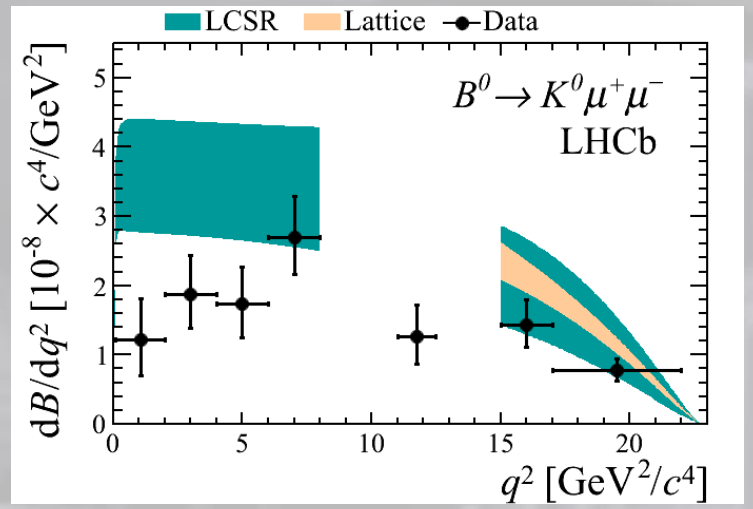
- What changed?
  - Assume isospin asymmetry in $B \to J/\psi K^*$ is 0
  - New reconstruction and event selection
  - Inclusion of 2012 data ($2fb^{-1}$)



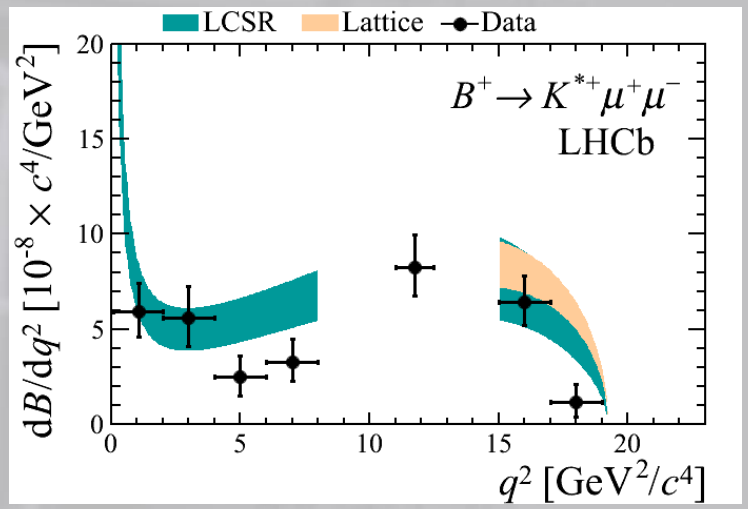
$B \to K^{(*)}\mu^+\mu^-$ branching fraction updates



$(4.29 \pm 0.07^{\dagger} \pm 0.21^{*}) \times 10^{-7}$



$(3.27 \pm 0.34^{\dagger} \pm 0.17^{*}) \times 10^{-7}$



$(9.24 \pm 0.93^{\dagger} \pm 0.67^{*}) \times 10^{-7}$

- $B^+ \to K^+\mu^+\mu^-$, $B^+ \to K^{*+}\mu^+\mu^-$ and $B^0 \to K^0\mu^+\mu^-$ BR's updated in isospin analysis.
- Results consistent yet all systematically lower than SM predictions
- LHCb measurements more precise than current world average

† *statistical uncertainty* $*$ *systematic uncertainty*

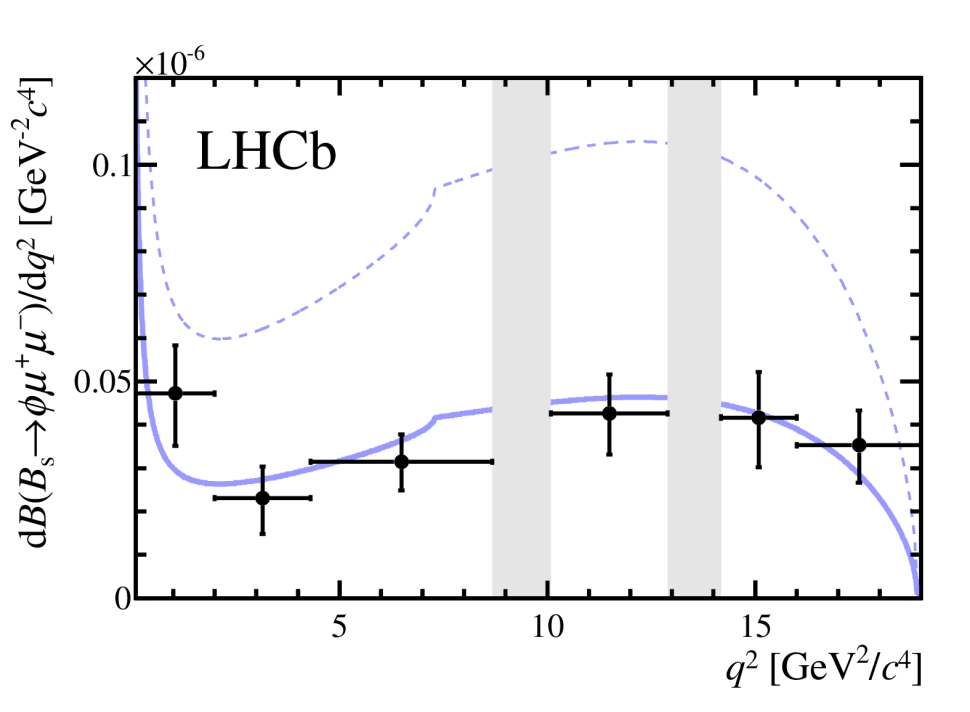
arXiv:1403.8044

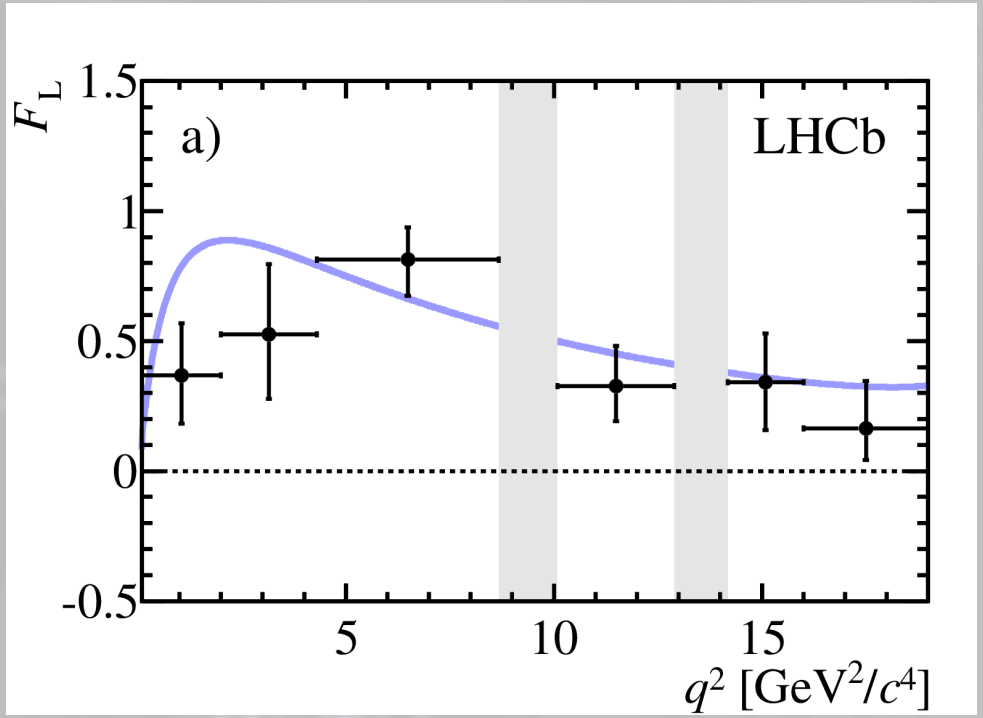
Conclusions

- Some very recent and interesting results from rare B decays to leptons
  - Measurements of F_H, A_{FB} impose tight constraints on new physics
  - Branching fraction results on $B \to K\mu^+\mu^-$ like decays more precise than world average and largely consistent with SM
  - Still some interesting anomalies to be investigated
- Several analyses of new b-hadron channels in the pipeline
- Some analyses with interesting results from previous year still to be updated to current full dataset – (stay tuned!)

Backup Slides

$B^0 \to \phi\mu^+\mu^-$ BR and angular analysis





- Interesting counterpart to $B^0 \to K^*\mu^+\mu^-$ due to narrow ϕ peak.
- Results from $1fb^{-1}$ consistent with SM across all obervables
- Imposes much tighter constraints on tensor amplitudes
- Being updated to $3fb^{-1}$

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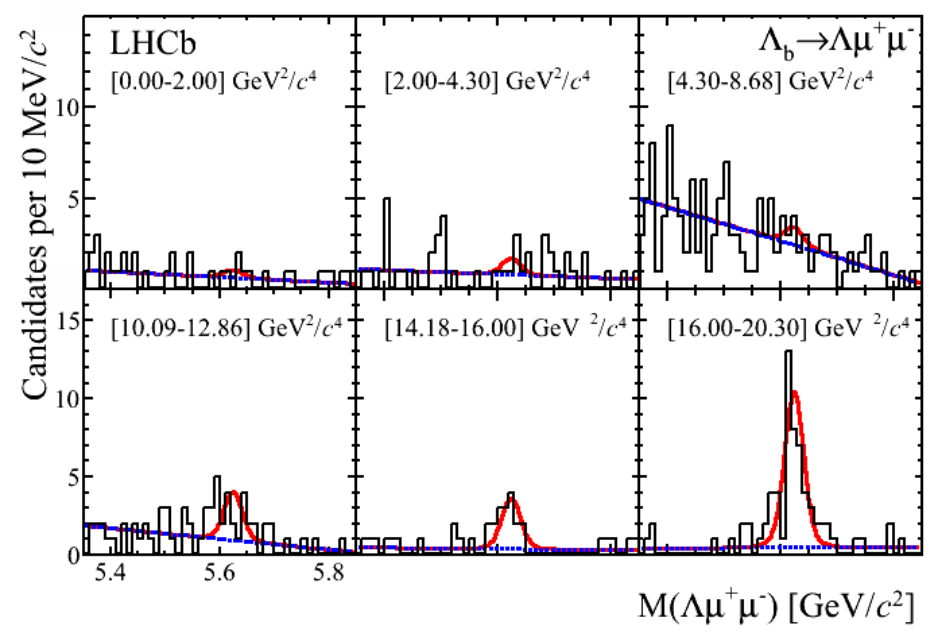
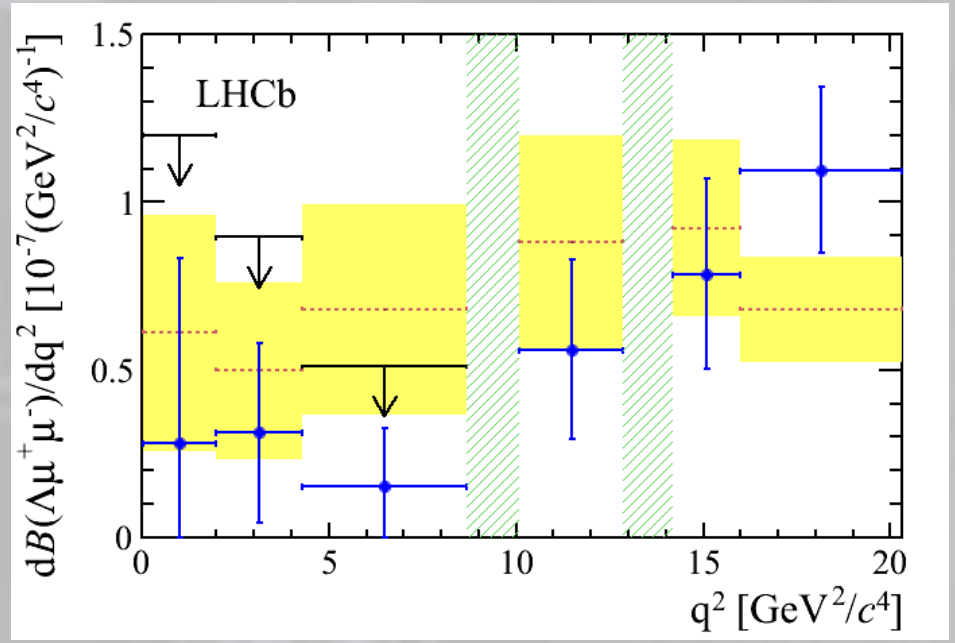
$\Lambda_b^0 \to \Lambda\,\mu^+\mu^-$ Branching ratio measurement





- Good cross-check for $B \to K\mu\mu$ channels
- Added interest due to non-zero spin
- No signal observed at low q^2 but results consistent with SM
- Being updated to $3fb^{-1}$ with angular analysis
- Also investigating $\Lambda_b^0 \to \Lambda^*(\to pK)\mu^+\mu^-$

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