Non-universality in rare beauty decays?

Nikhef Jamboree

Mick Mulder

December 12, 2017

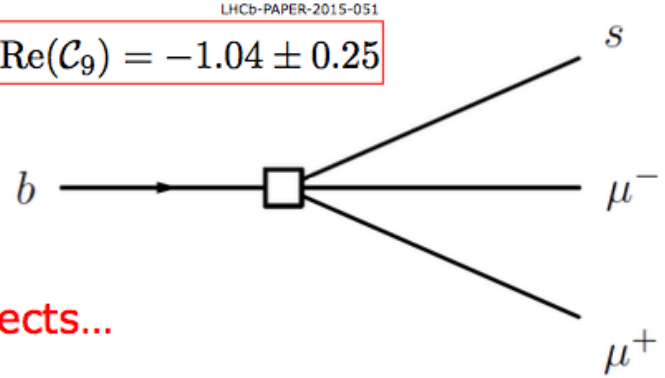
From the jamboree in 2015...

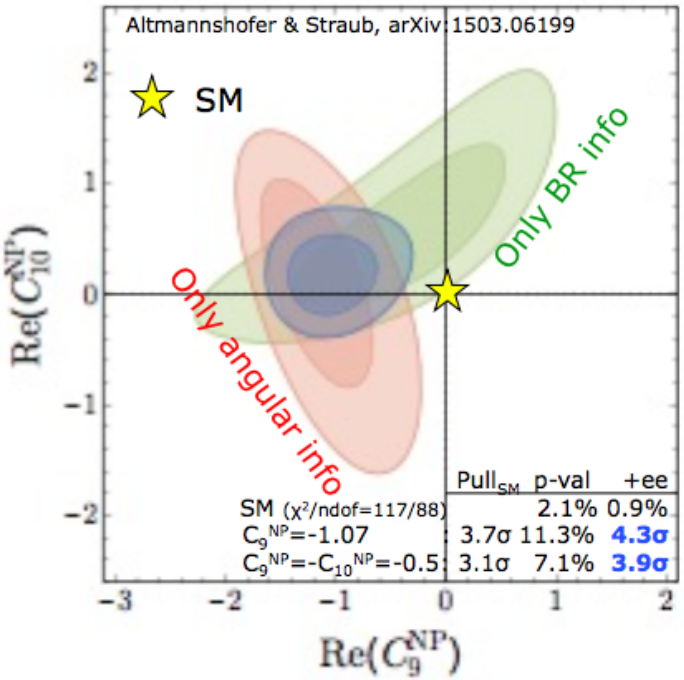
Theory: 1) Model independent fits

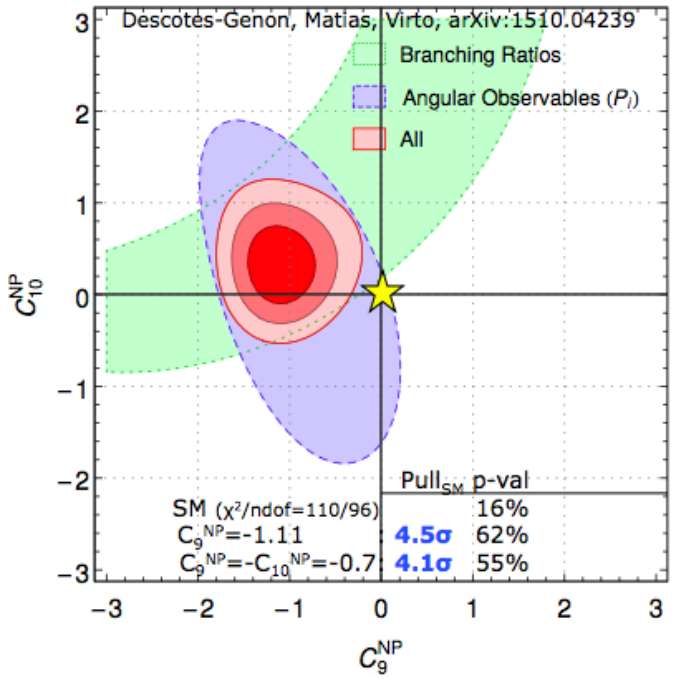
- C_9^{NP} deviates from 0 by >4σ
- Independent fits by more groups
  - C_9^{NP}=-1
  - C_9^{NP}=-C_{10}^{NP}
- Caveat: debate on charm-loop effects…

LHCb-PAPER-2015-051

$$\Delta \mathrm{Re}(\mathcal{C}_9) = -1.04 \pm 0.25$$







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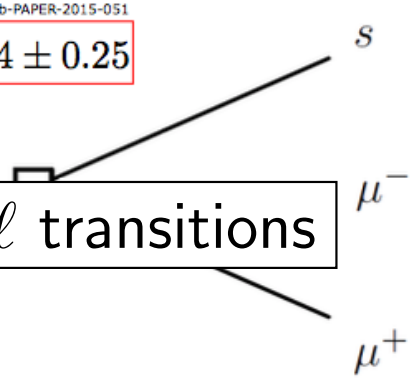

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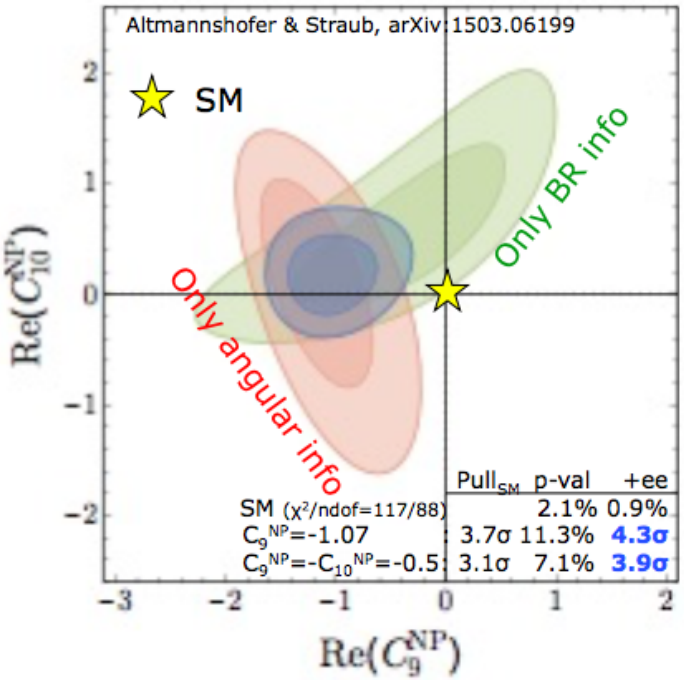

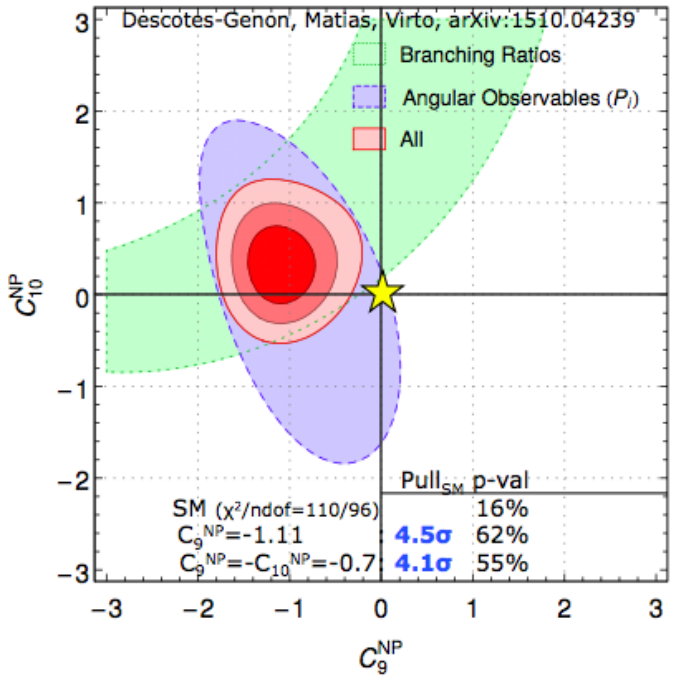

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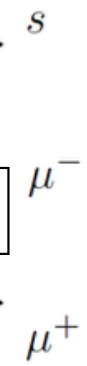

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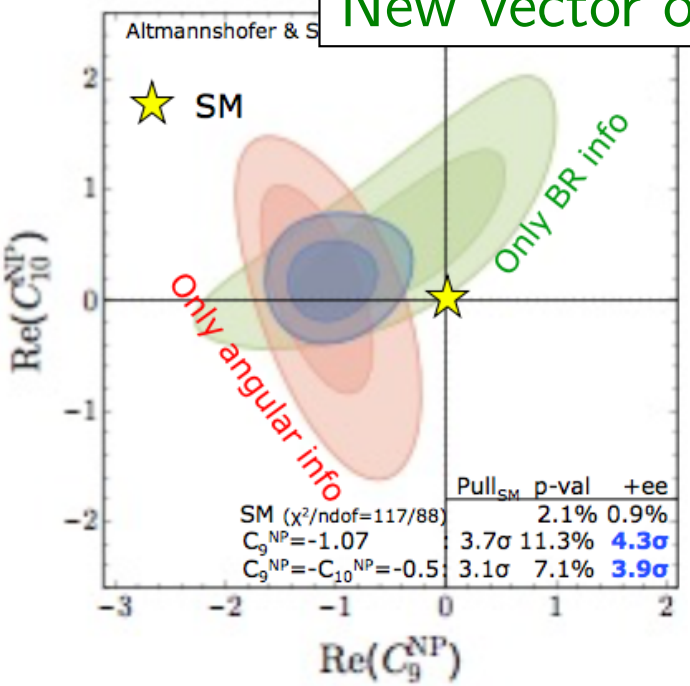

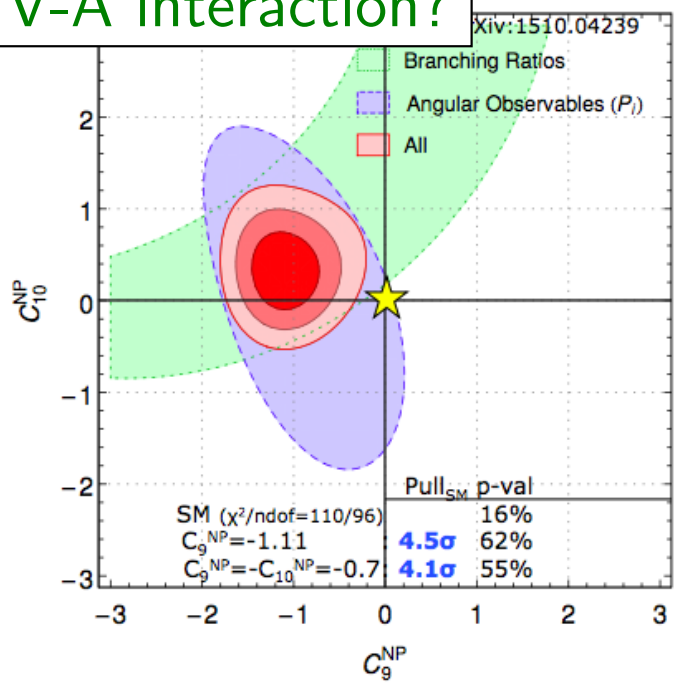

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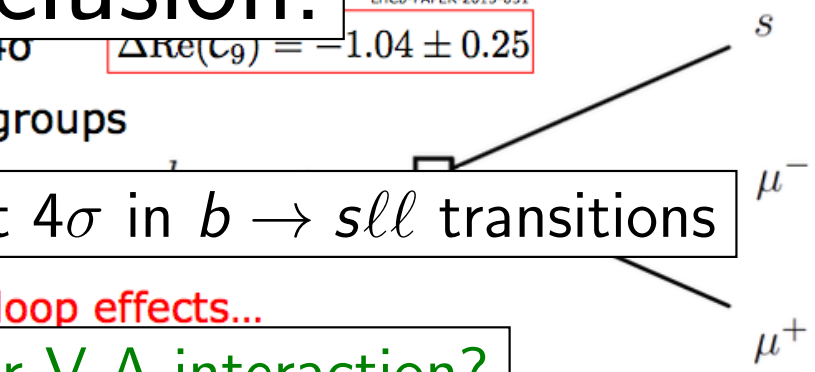

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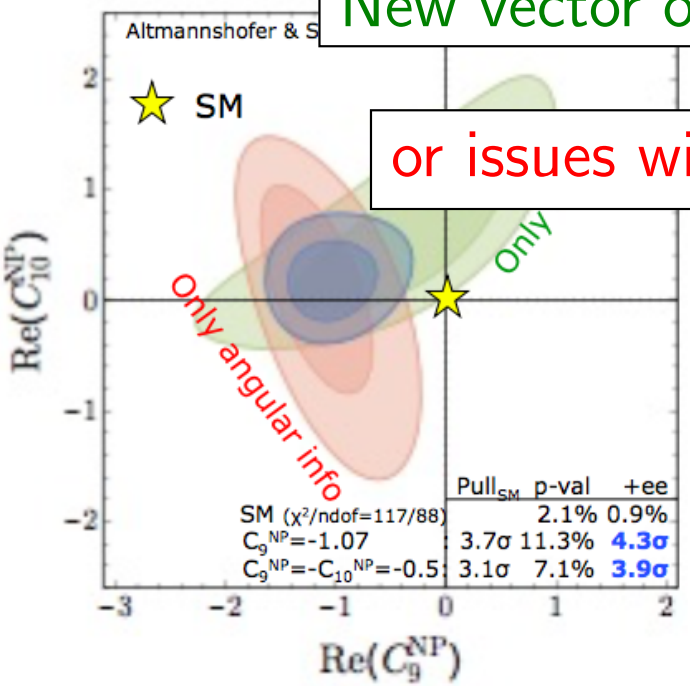

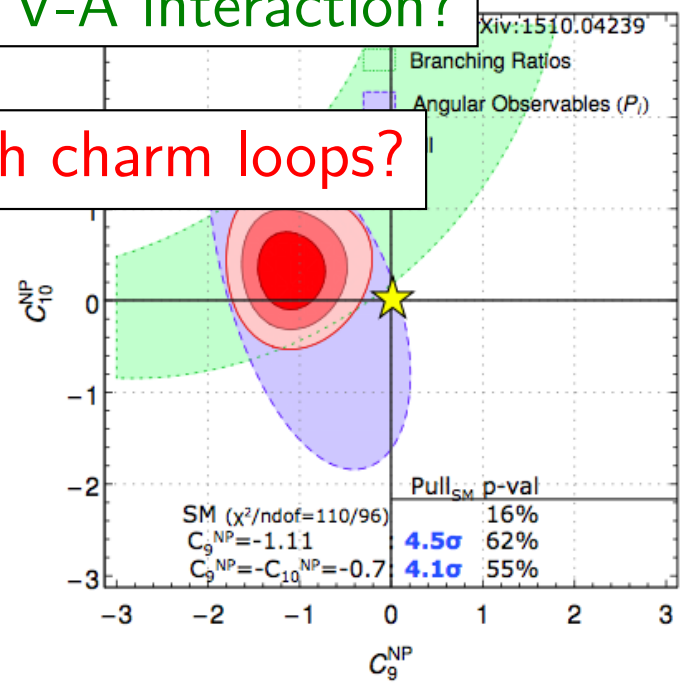

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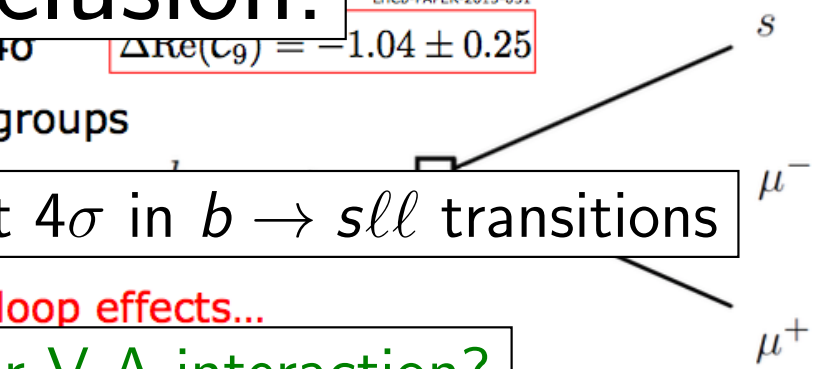

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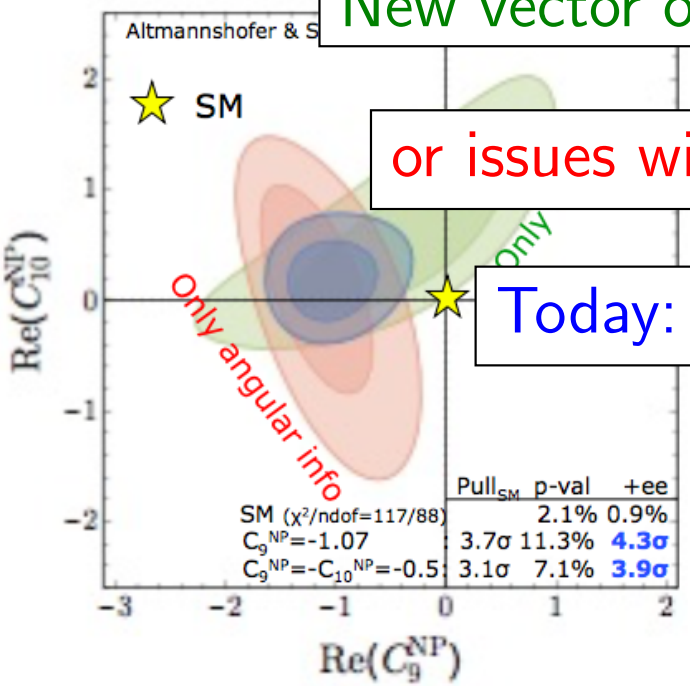
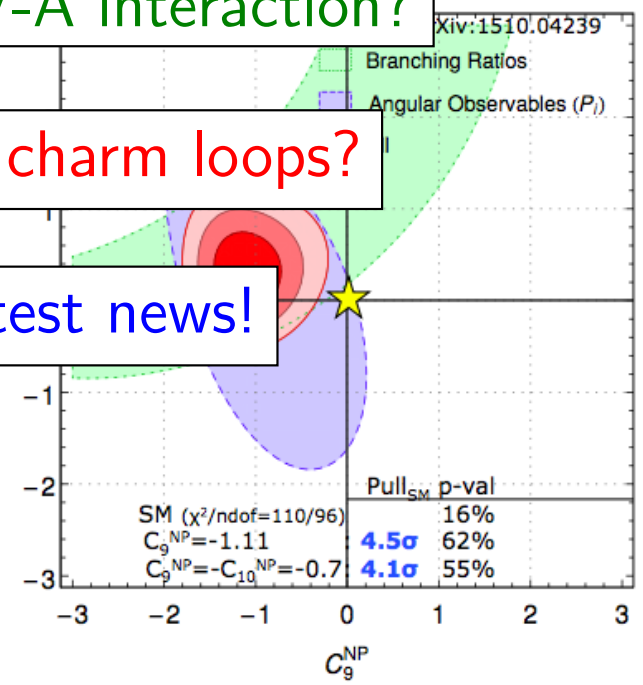
Today: latest news!





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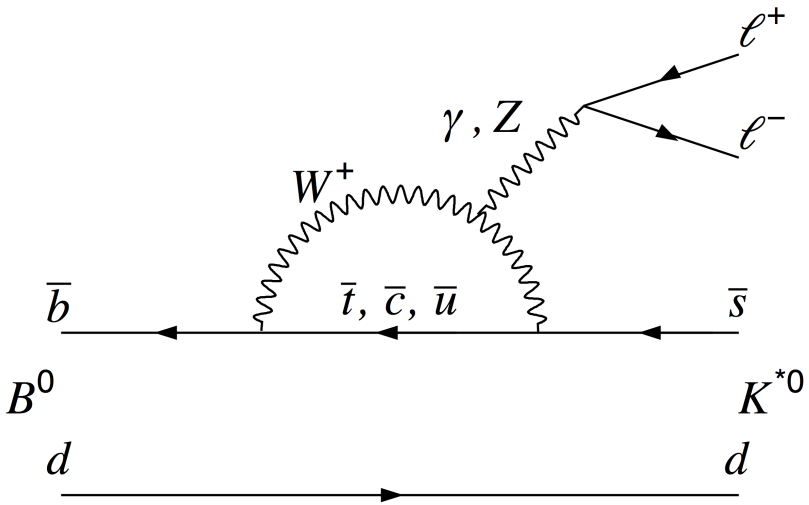

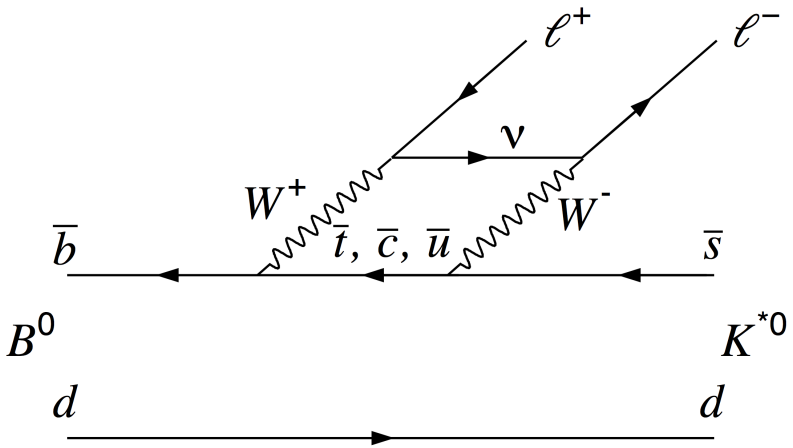

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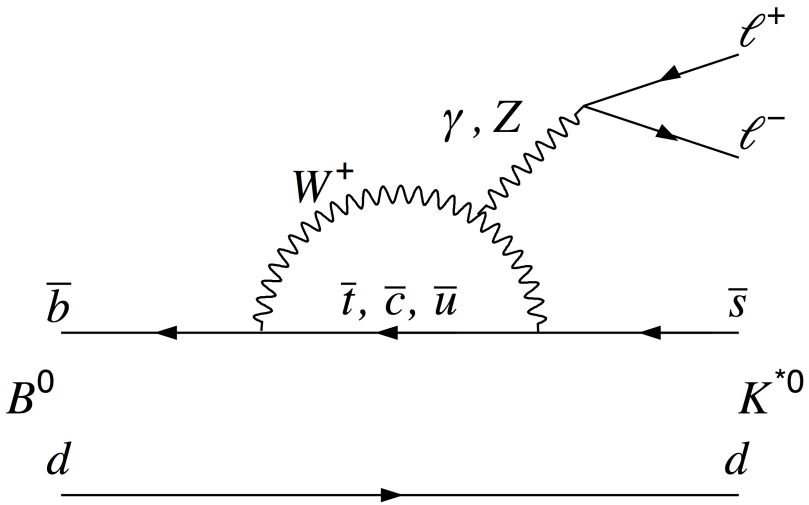

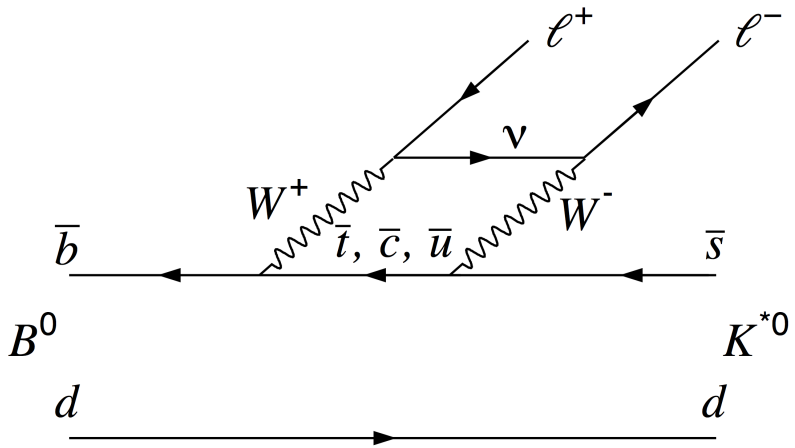

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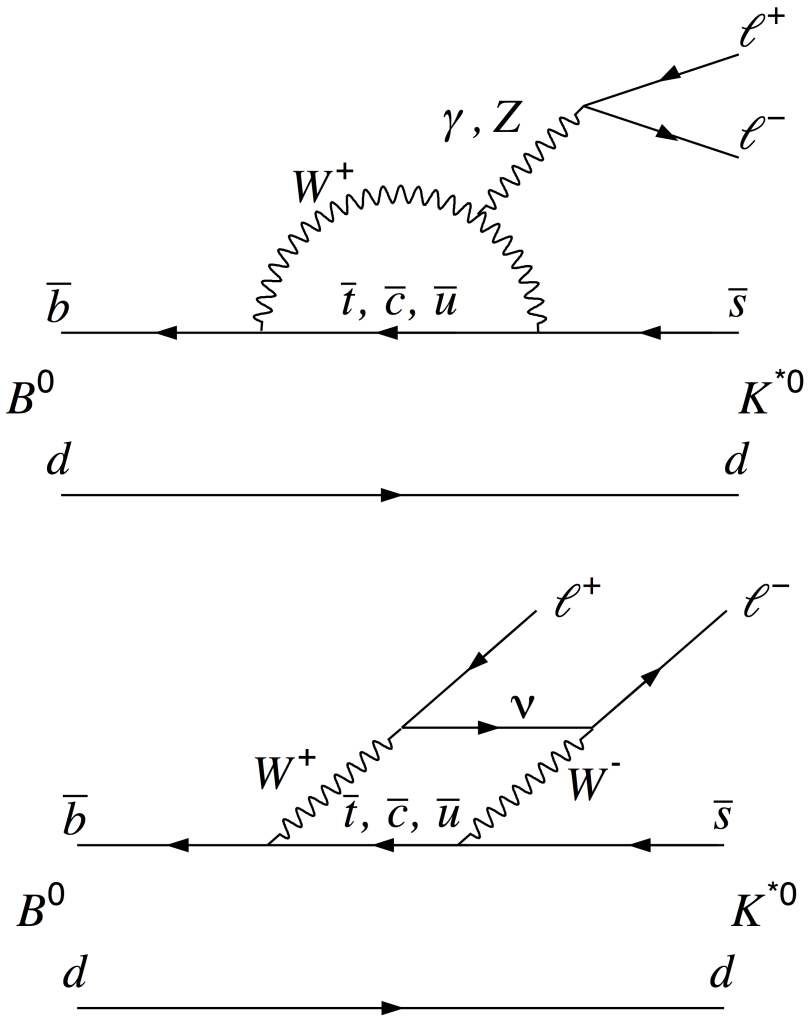
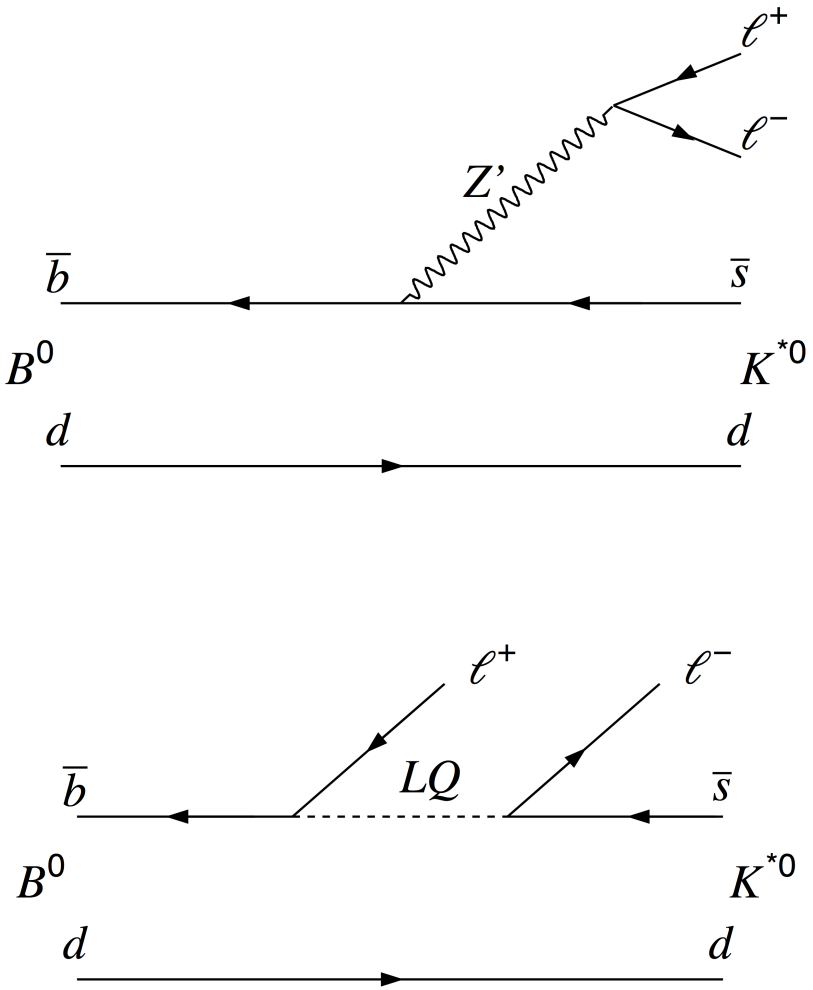
- The $b \to s\ell\ell$ transition goes via loop diagrams
- Very suppressed in the Standard Model!
- Sensitive to small New Physics contributions



Let's talk about penguins and boxes

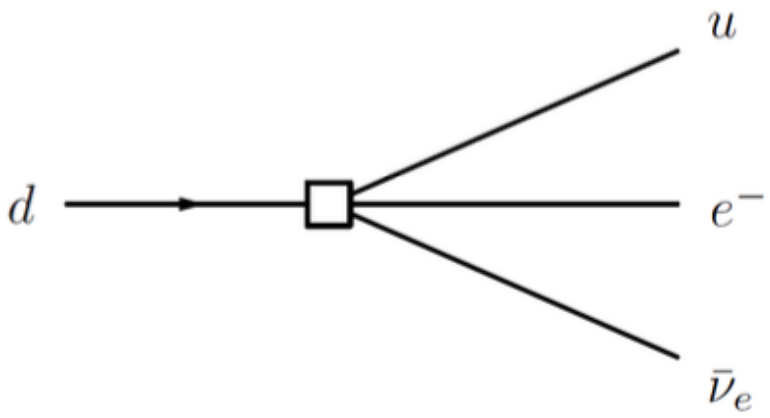
- The $b \to s\ell\ell$ transition goes via loop diagrams
- Very suppressed in the Standard Model!
- Sensitive to small New Physics contributions ($Z^{'}$, leptoquarks, ...)
- How to interpret measurements?

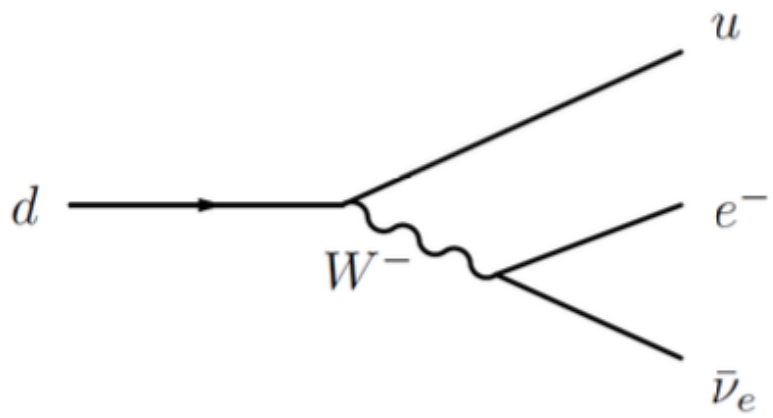


How to interpret $b \to s\ell\ell$ measurements

Effective Field Theory!

Most famous example: Fermi interaction





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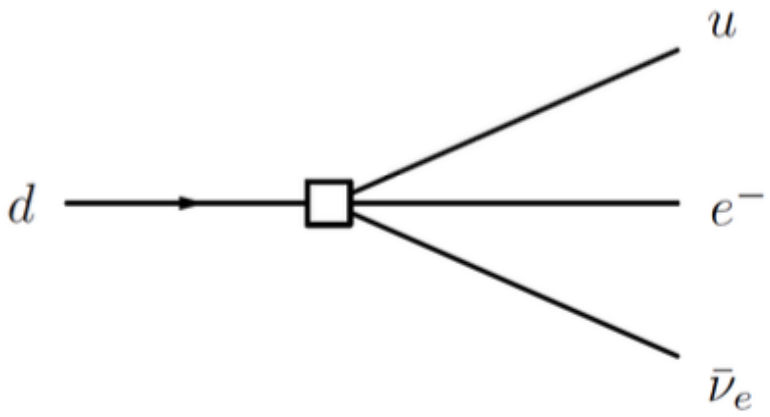
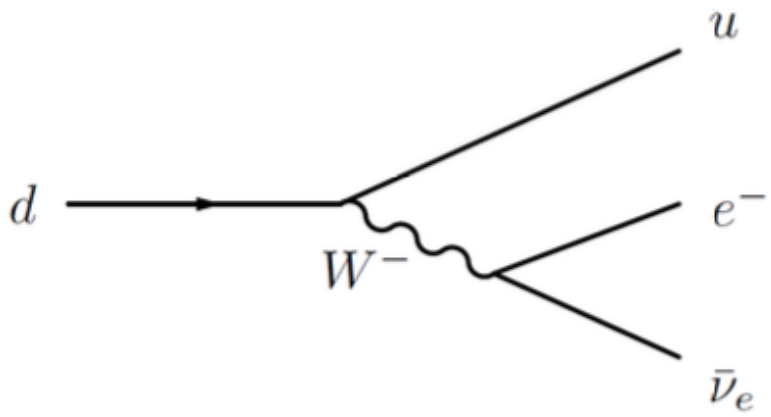
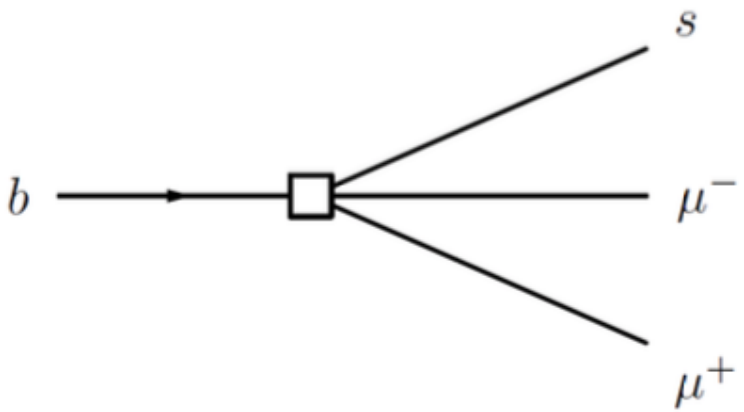
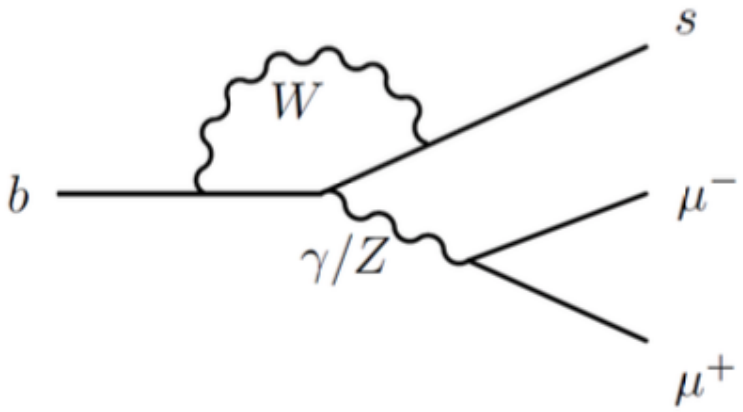




Similar approach for $b \to s\ell\ell$:

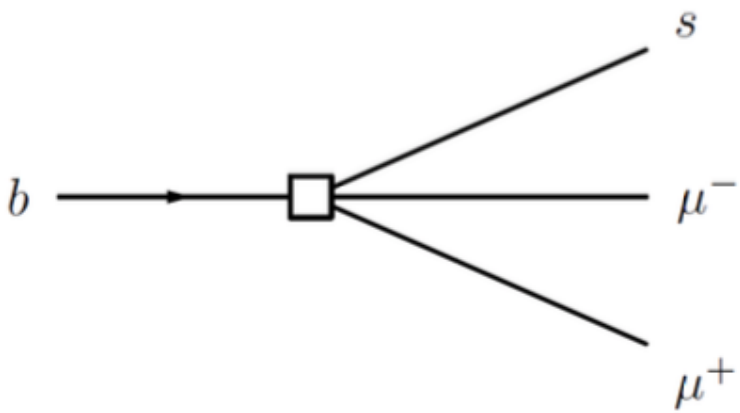


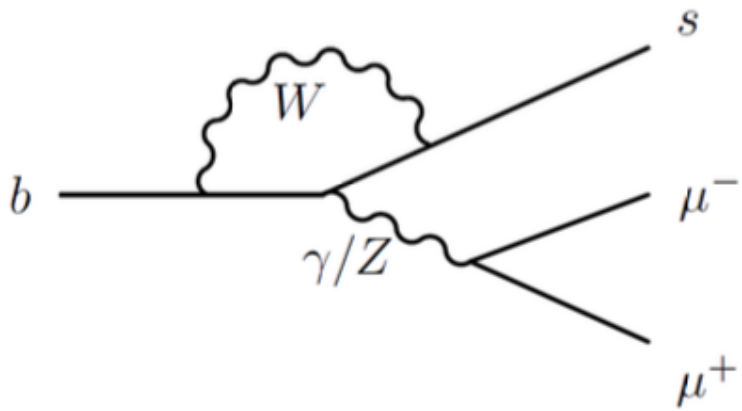


How to interpret $b \to s\ell\ell$ measurements

An EFT probes different couplings:

- Photon penguin (C_7)
- Vector (C_9)
- Axial vector (C_{10})
- Left-handed ($V - A = C_9 - C_{10}$)





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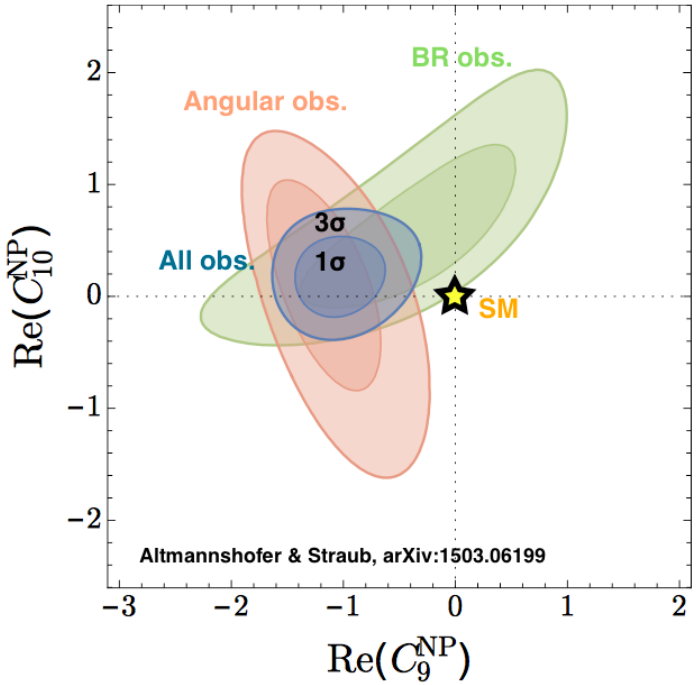
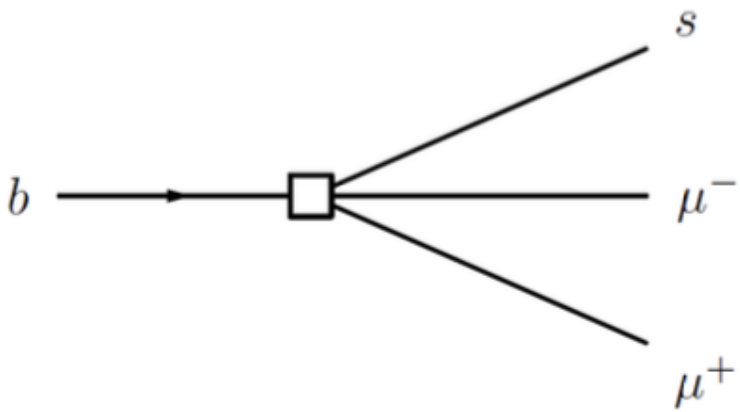
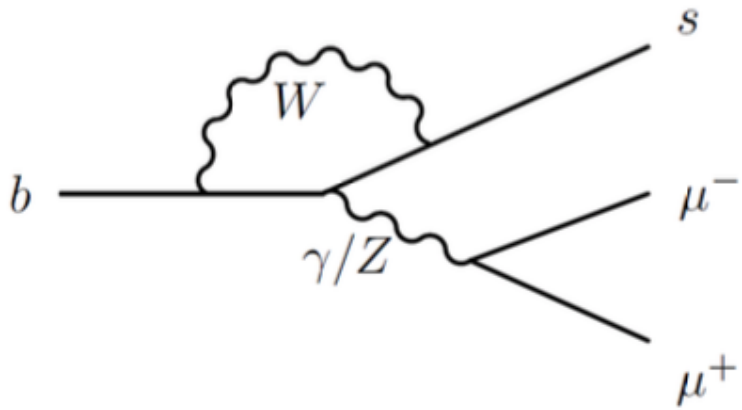
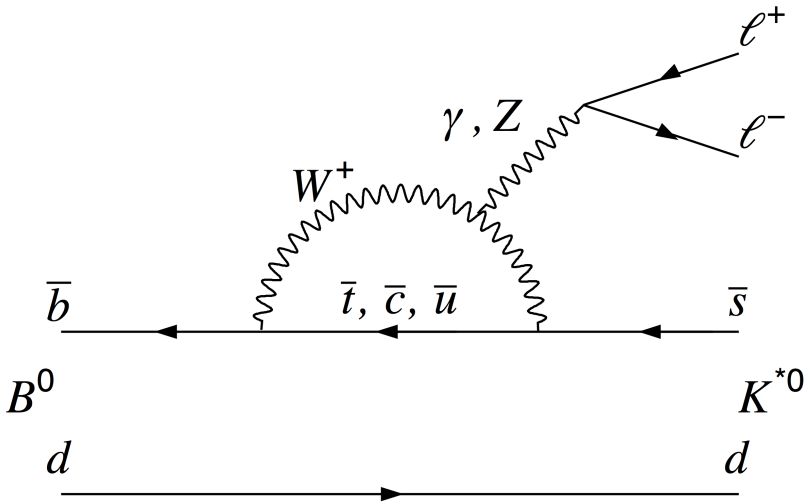




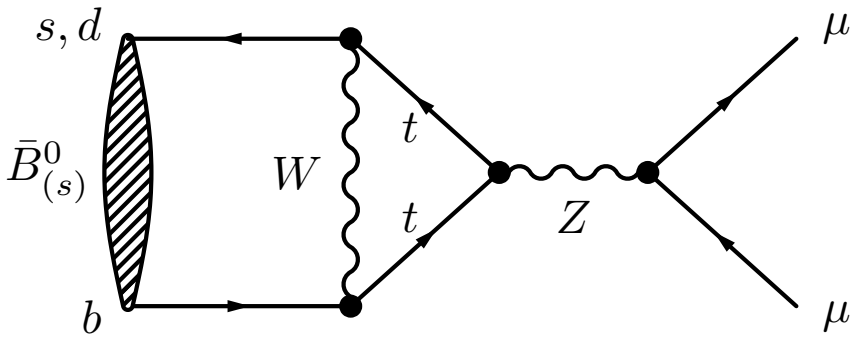


Two $b \to s\ell\ell$ decay types

Semi-leptonic decays
($X_b \to X_s \ell^+ \ell^-$)

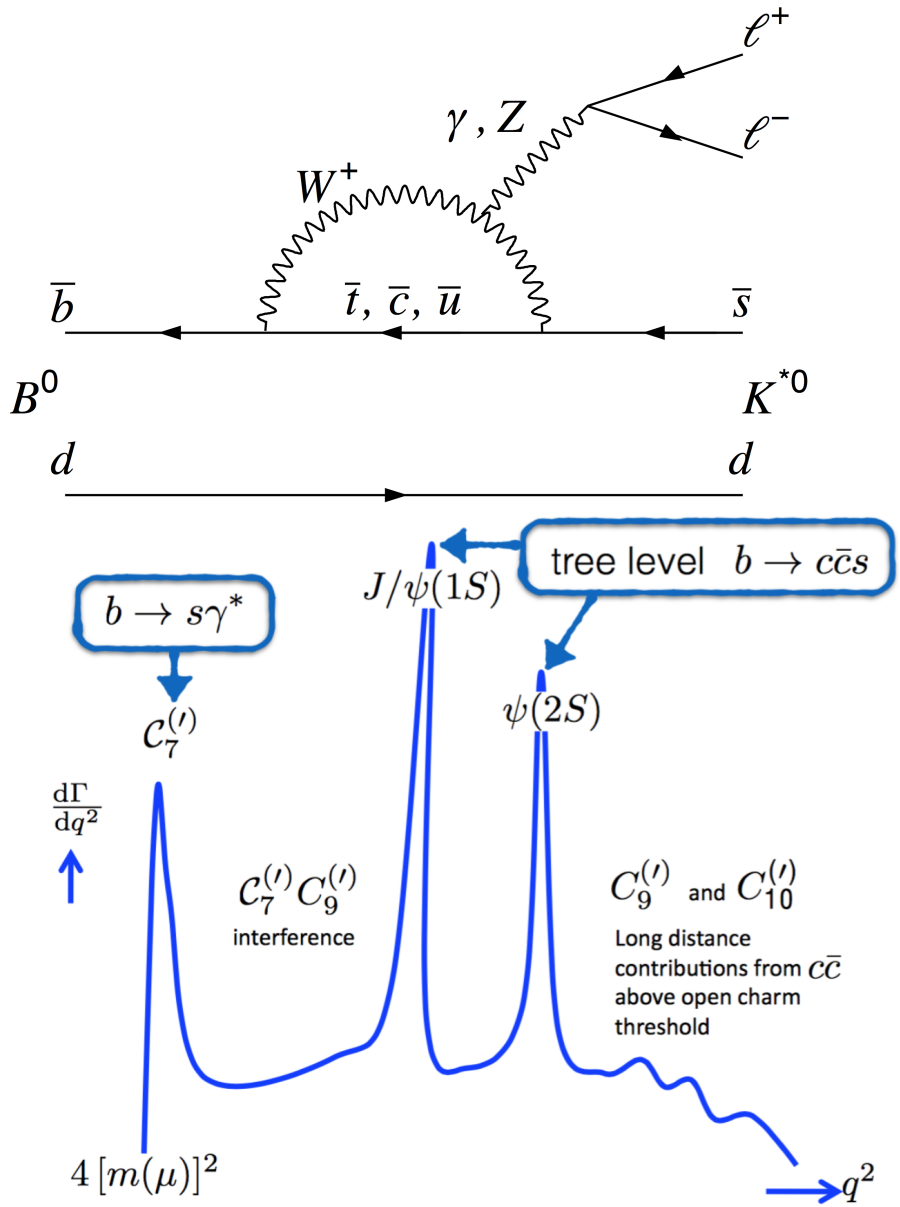


Leptonic decays ($B_s^0 \to \ell^+ \ell^-$)

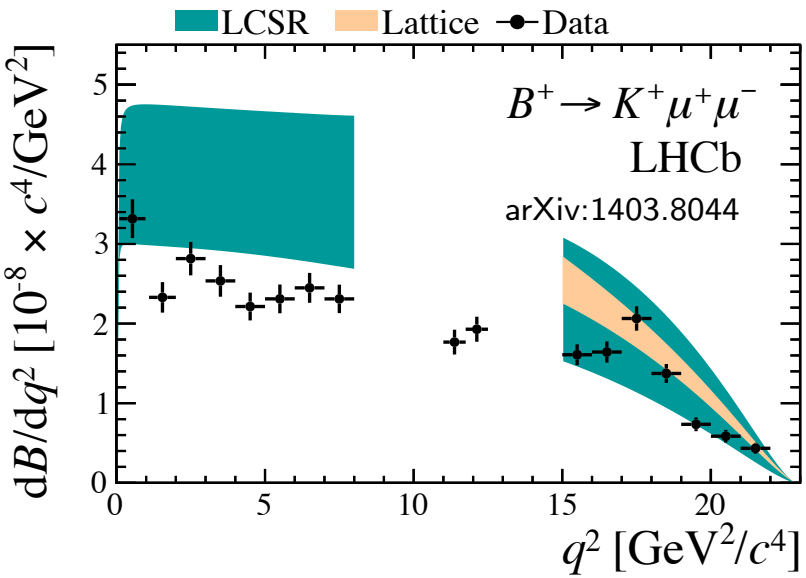


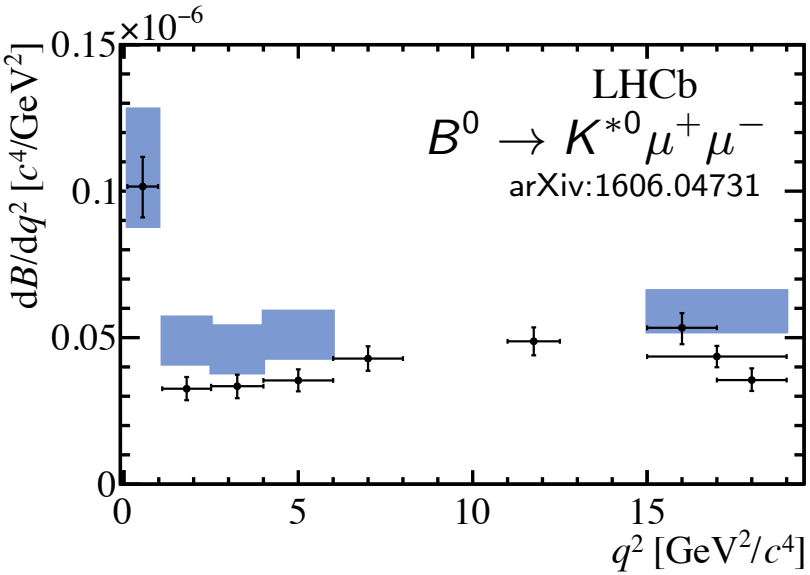
Semi-leptonic decays

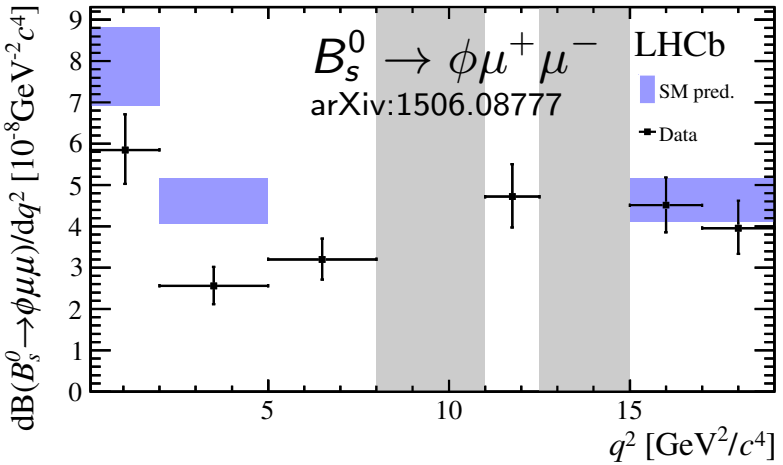
- Probes C_7, C_9 and C_{10}
- Three body decay: bins of $q^2_{\ell\ell}$
- Many final states
- QCD effects: form factors, charm resonances
- Three kinds of observables (from dirty to clean):
  - Branching fractions
  - Angular observables
  - Lepton universality

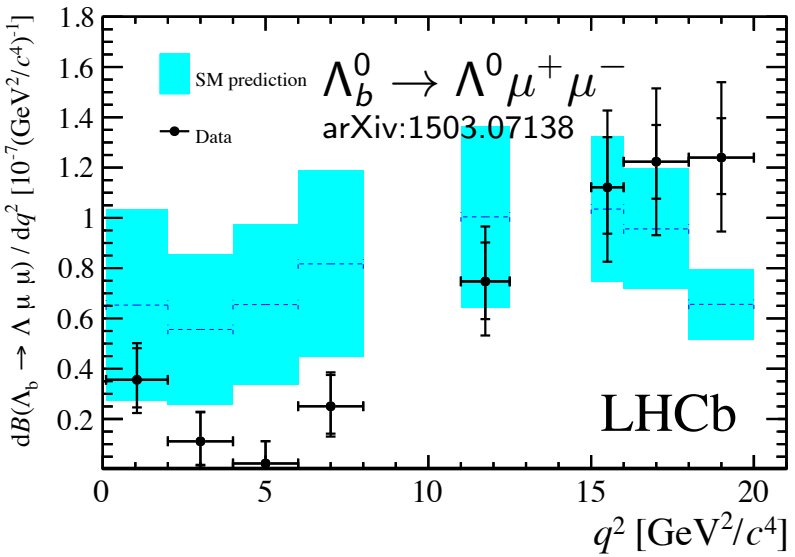


Semi-leptonic decays: branching fractions



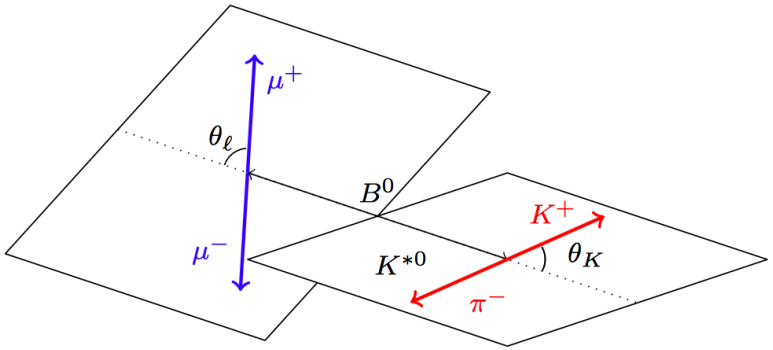






Semi-leptonic decays: angular observables

One example: $B^0 \to K^{*0}\mu^+\mu^-$ with full angular analysis
Ratios of observables with minimal dependence on form factors:



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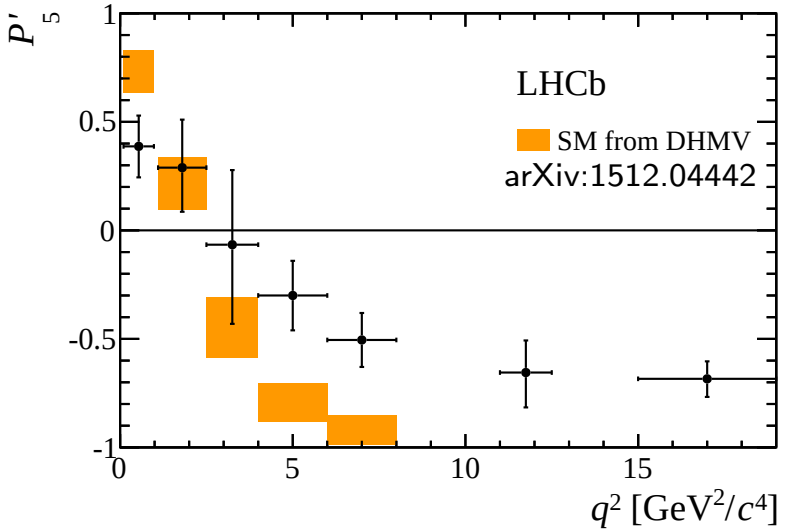

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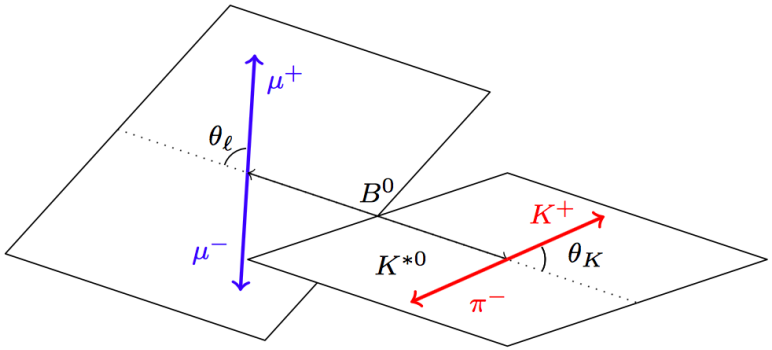

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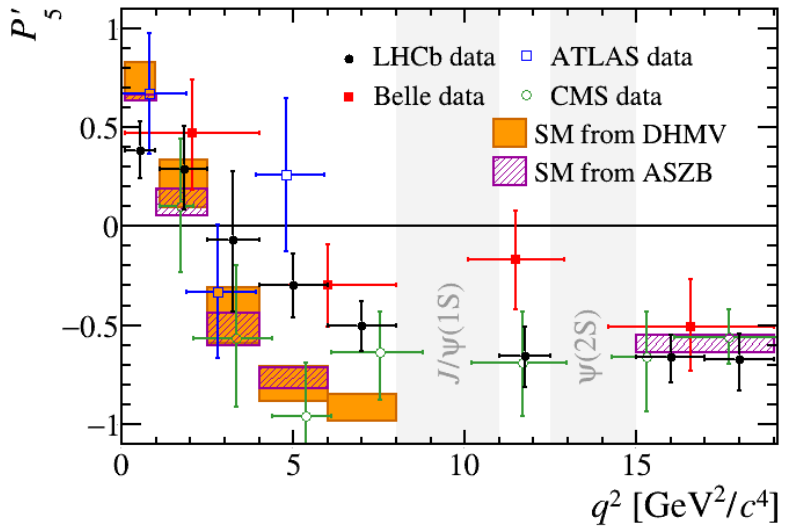
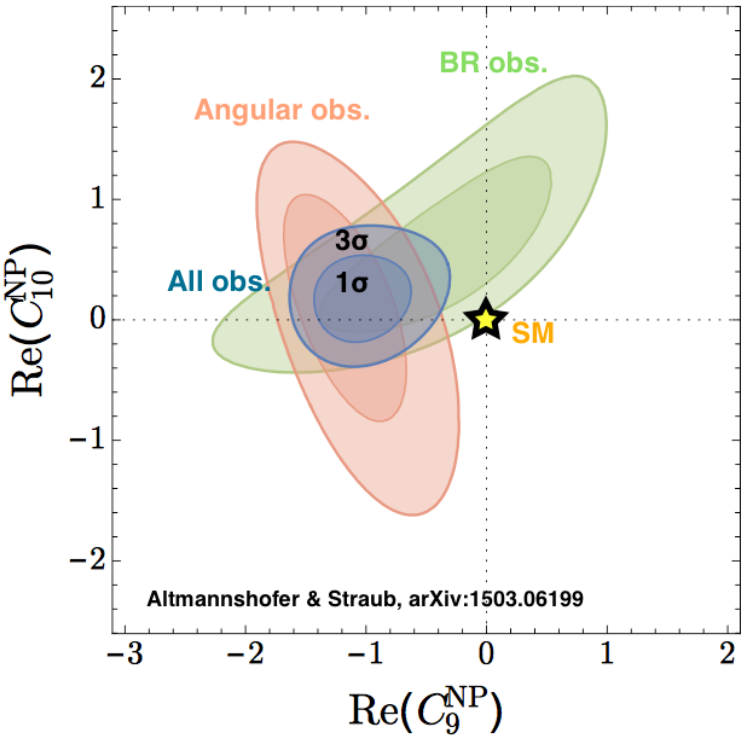


Contributions from charm loops?
New results from ATLAS, CMS, Belle: how do they compare?

Global fits

Resulting Moriond 2017 update of global fit:

2015 (arXiv:1503.06199):



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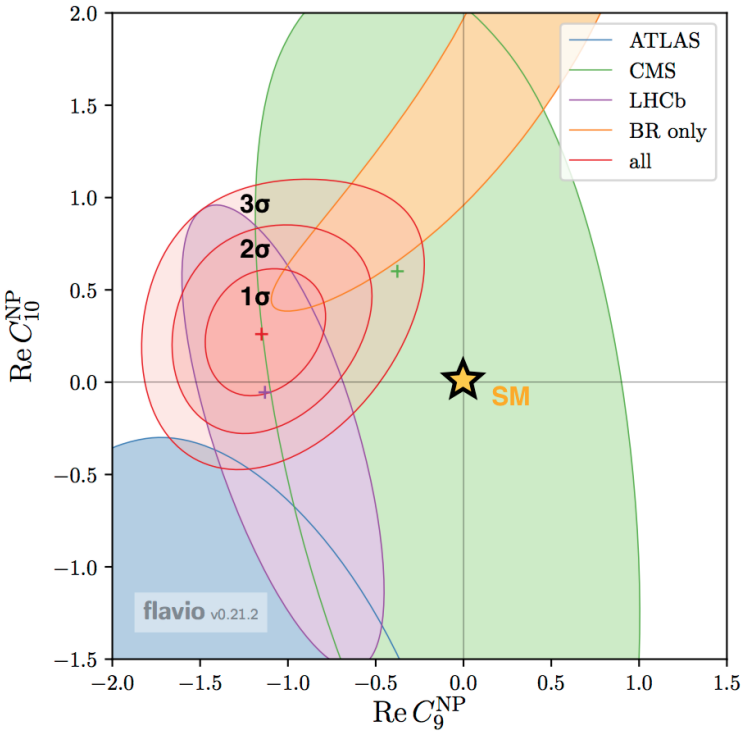

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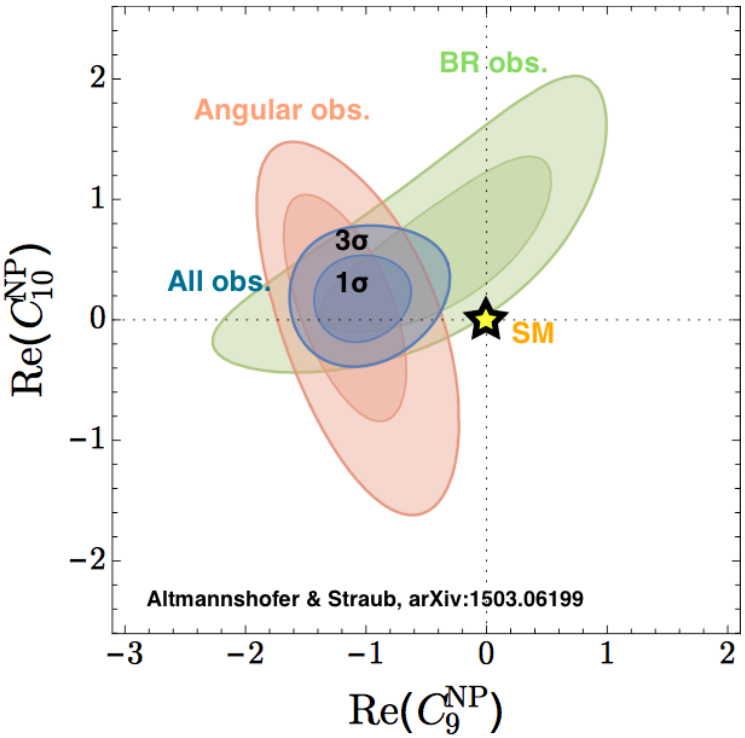

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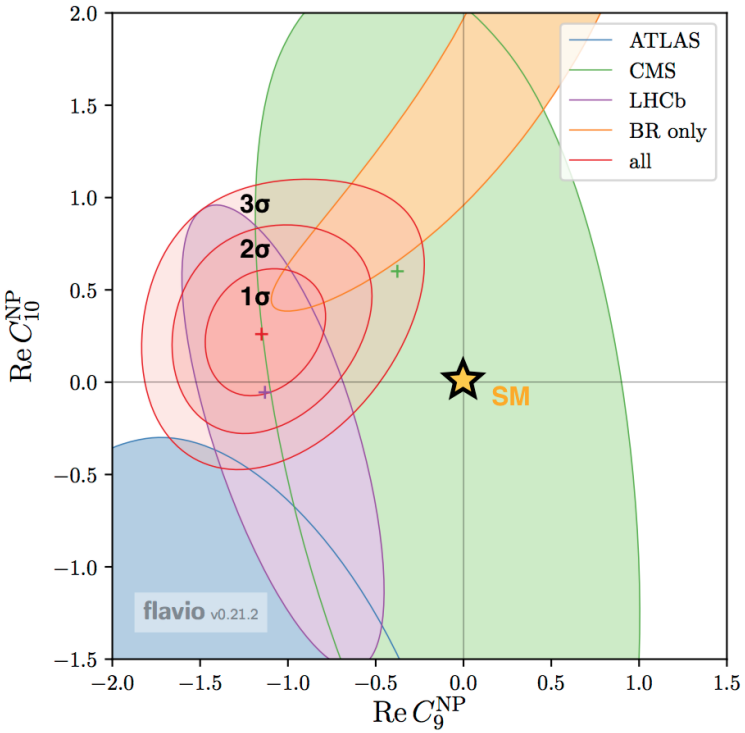


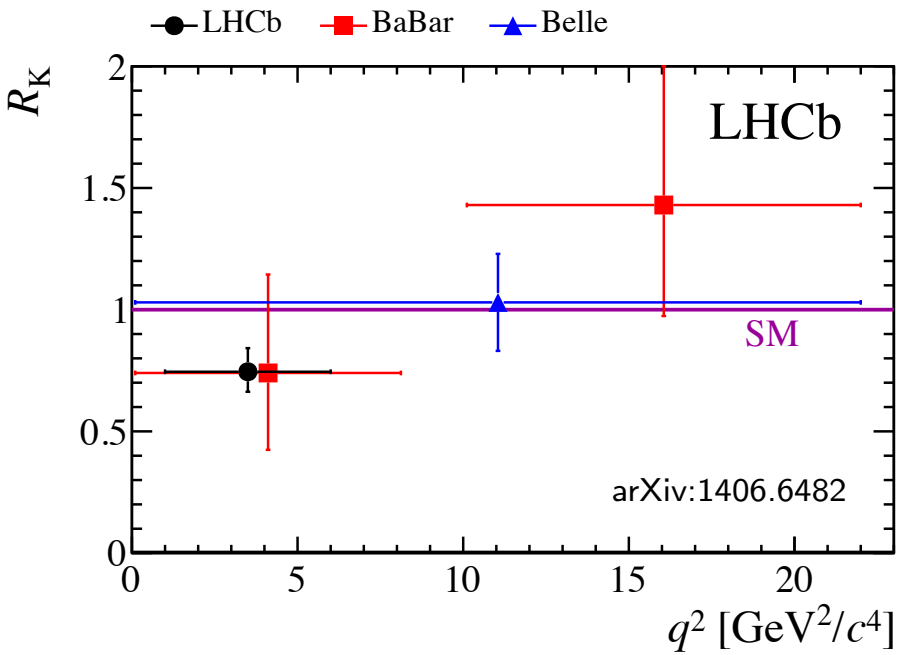
New measurements didn't change the picture

So where are the new LHCb results?

Semi-leptonic decays: lepton non-universality

$$R_K = \frac{\mathcal{B}(B^+ \to K^+ \mu^+ \mu^-)}{\mathcal{B}(B^+ \to K^+ e^+ e^-)}, R_{K^{*0}} = \frac{\mathcal{B}(B^0 \to K^{*0} \mu^+ \mu^-)}{\mathcal{B}(B^0 \to K^{*0} e^+ e^-)} \sim 1 \text{ in SM}$$

From 2014 (2.6σ):



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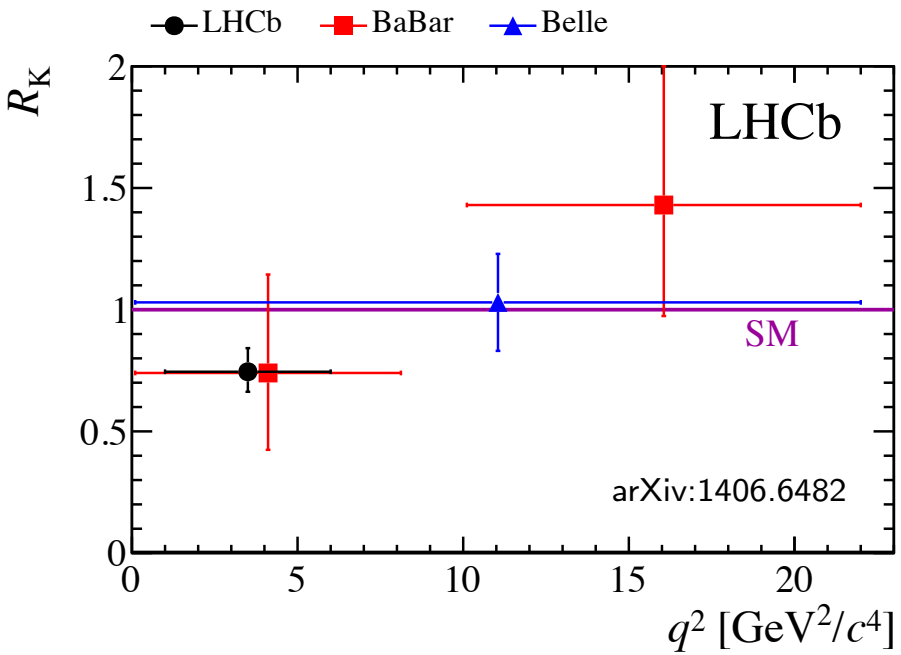
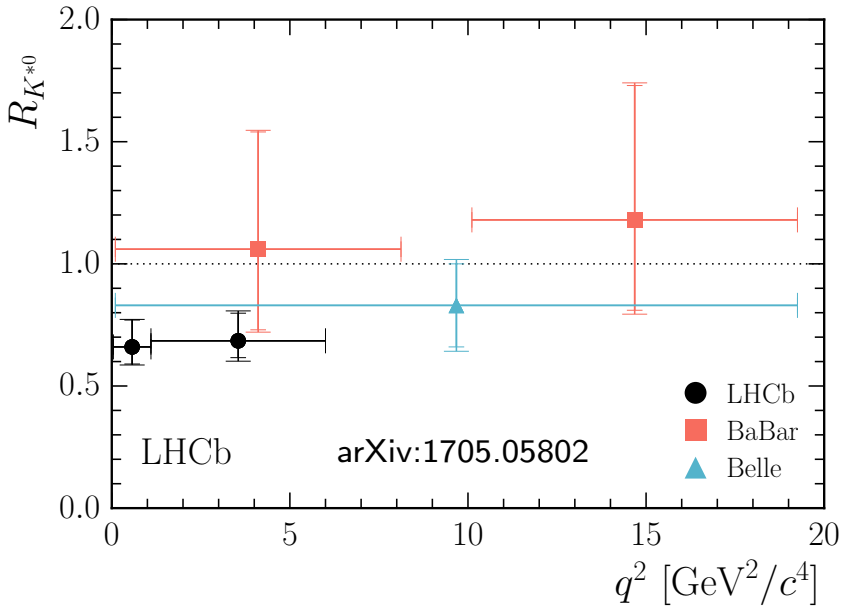


From April this year!
(2 bins with 2.2, 2.5σ resp.)

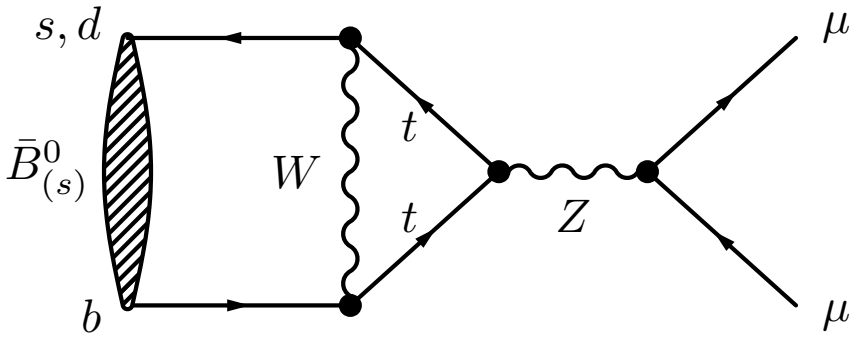


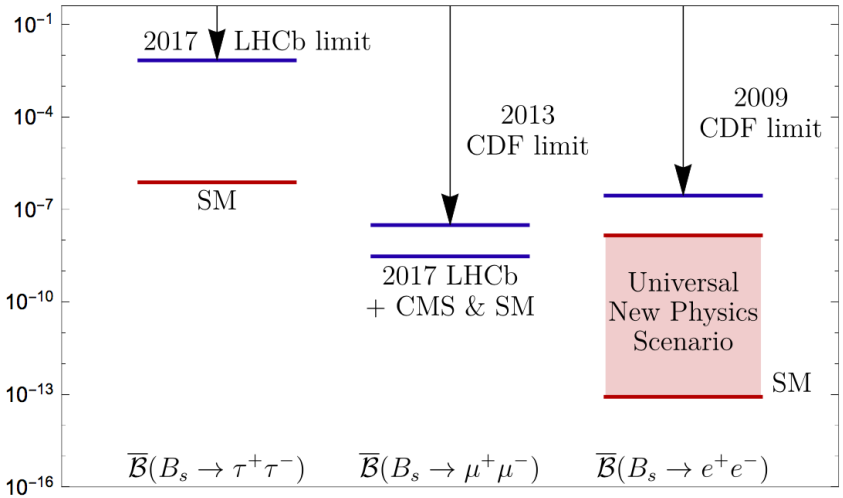
Deviation at 3.5-4σ level in these two measurements alone!

Leptonic decays

- Probes C10 in SM
- Theoretically clean
- Sensitive to (pseudo-)scalars
- Helicity suppressed ($\sim m_\ell^2/m_B^2$)

- Interesting papers by Fleischer et al. (1703.10160, 1709.04735)
- First limit on $B_s^0 \to \tau^+\tau^- (< 6.8 \times 10^{-3})$ by LHCb (Kristof de Bruyn)

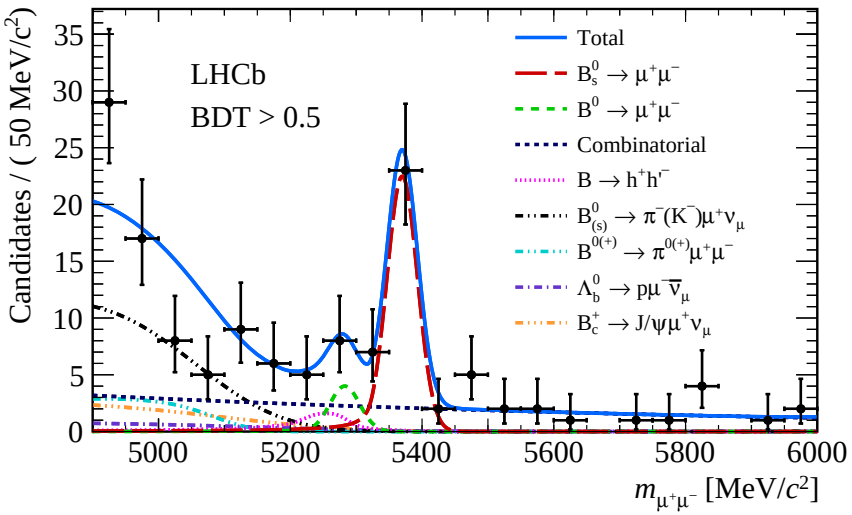




(N.B. picture assumes lepton flavour universality $\to$ NP in $B_s^0 \to \tau^+\tau^-$ small)

Leptonic decays: $B_s^0 \to \mu^+\mu^-$

- As promised last year by Flavio:



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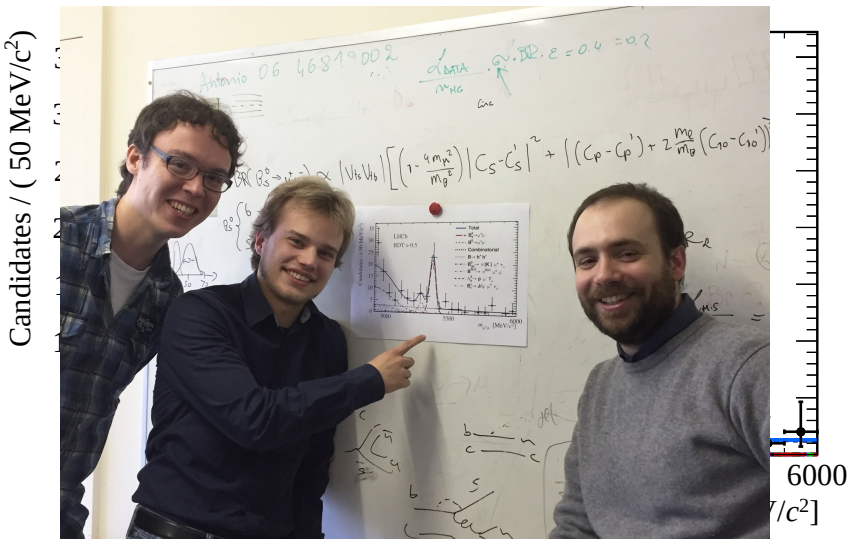
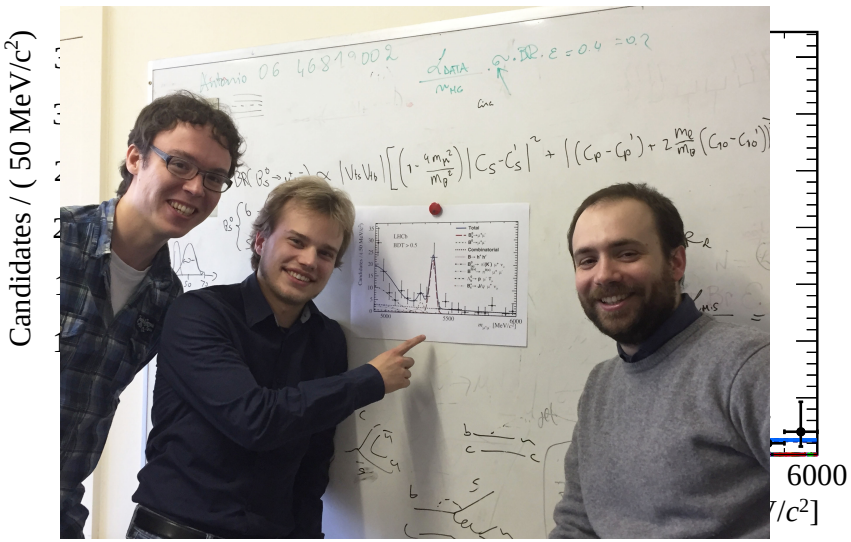
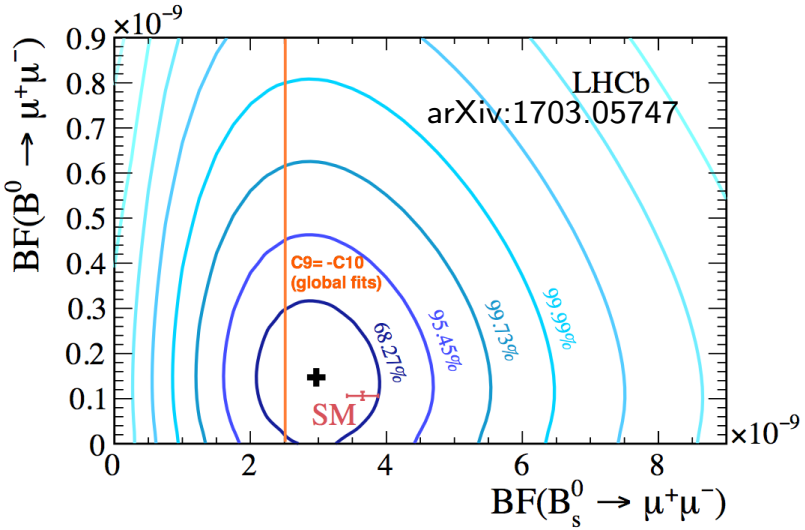


Leptonic decays: $B_s^0 \to \mu^+\mu^-$

- As promised last year by Flavio: **single experiment observation**!
- $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.0 \pm 0.6(\text{stat.})^{+0.3}_{-0.2}(\text{syst.})) \times 10^{-9}$
- **Strongest limit** on $\mathcal{B}(B^0 \to \mu^+\mu^-) < 3.4 \times 10^{-10}$ at 95% CL





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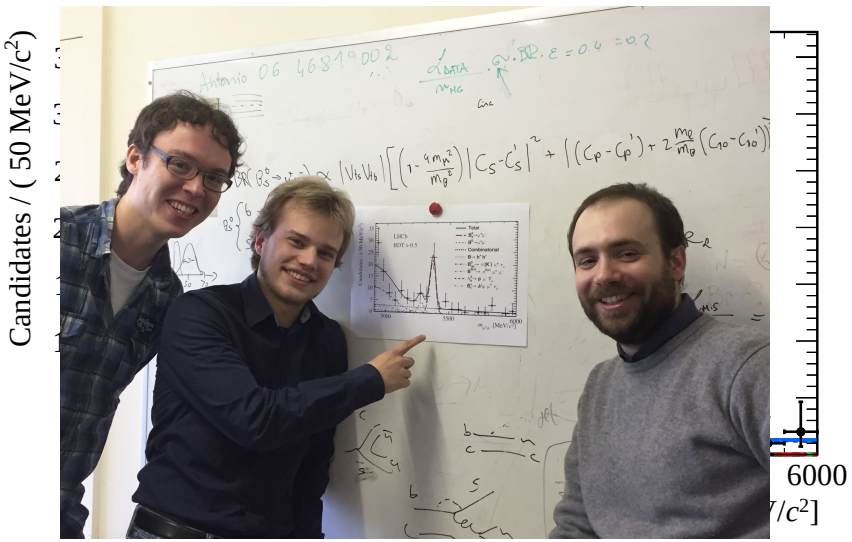
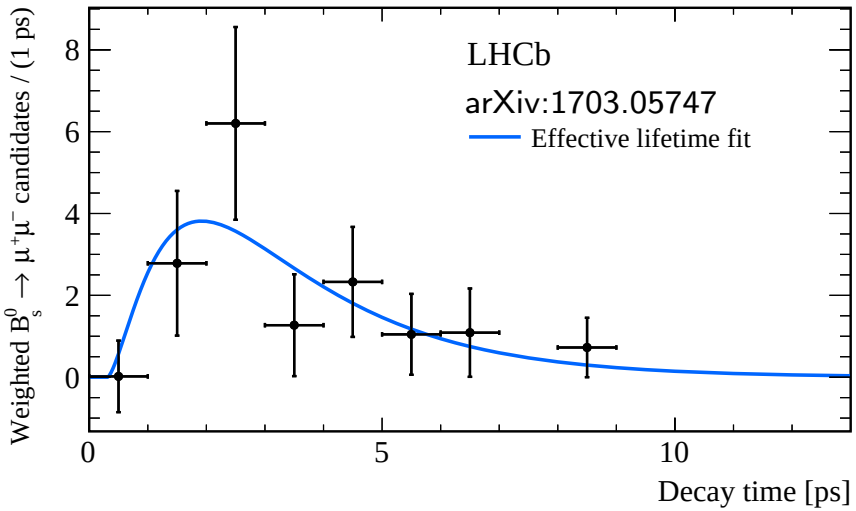
- **Strongest limit** on $\mathcal{B}(B^0 \to \mu^+\mu^-) < 3.4 \times 10^{-10}$ at 95% CL
- **New: effective lifetime** (as proposed by Fleischer et al.):
  $\tau(B_s^0 \to \mu^+\mu^-) = 2.04 \pm 0.44 \pm 0.05$ ps ($\tau_{\text{SM}} = 1.60$ ps)

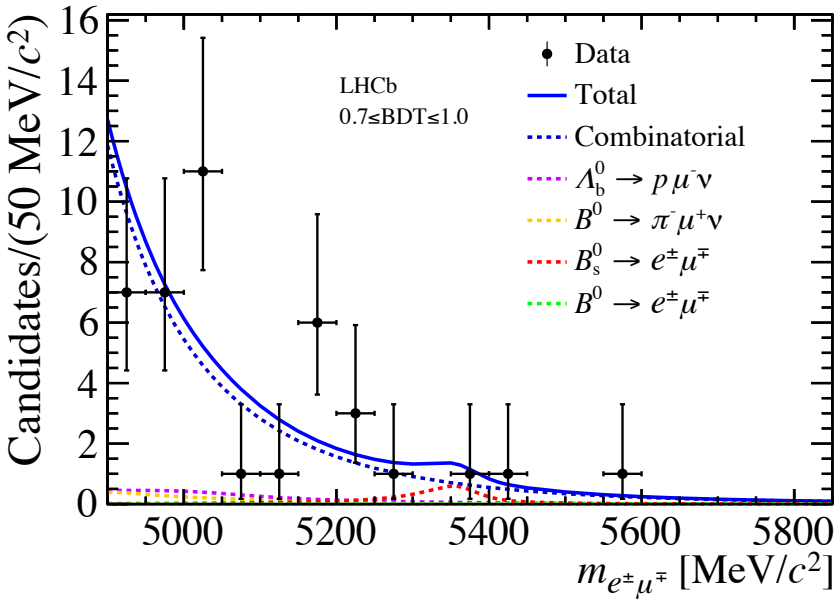
$B^0_{(s)} \to \mu^+\mu^-$ is consistent w. SM, but **statistics limited!**

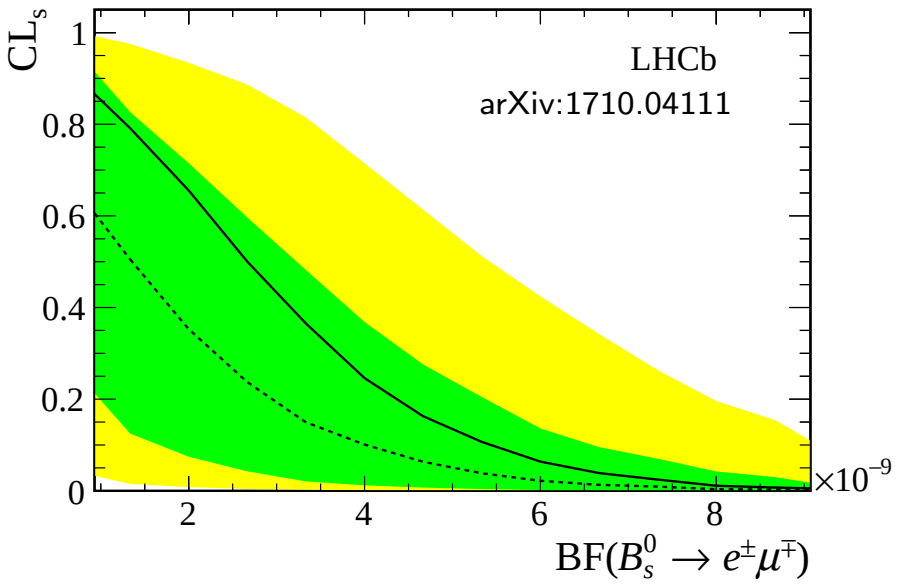




A LFV intermezzo

- Flavio and Maarten: $B^0_{(s)} \to e^{\pm}\mu^{\mp}$
- In case of lepton non-universality, lepton flavour violation is expected
- Previous LHCb limit improved by factor ~ 2.5
- $\mathcal{B}(B^0_s \to e^{\pm}\mu^{\mp}) < 6.3 \times 10^{-9}$ at 95% CL
- $\mathcal{B}(B^0 \to e^{\pm}\mu^{\mp}) < 1.3 \times 10^{-9}$ at 95% CL
- **LHCb LFV programme ongoing!**

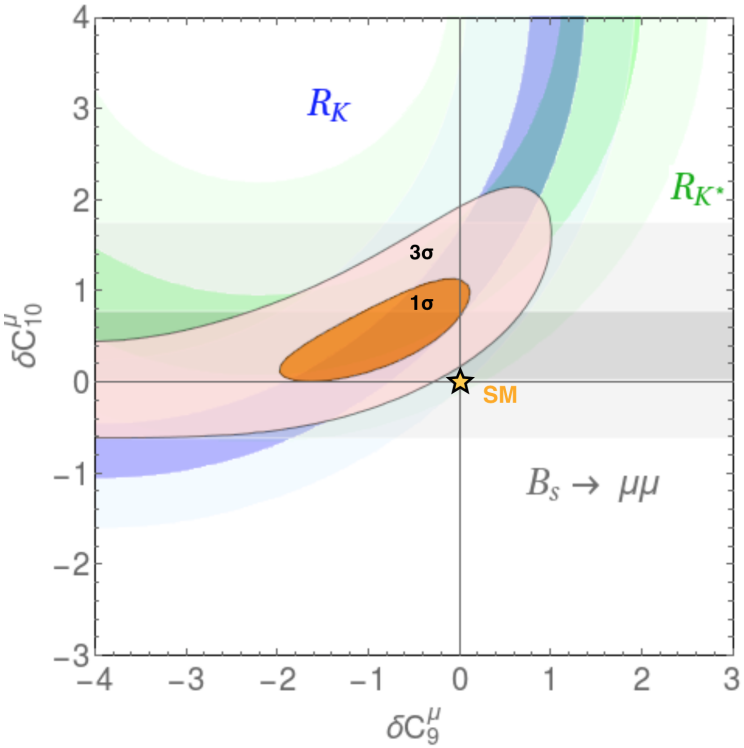




Global fits

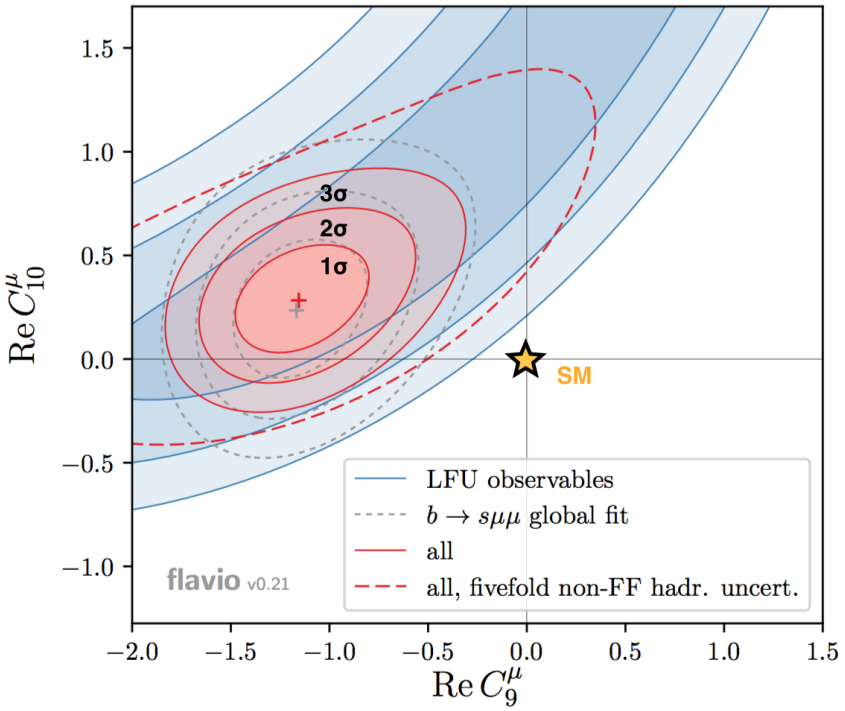
Revisit the global fit by including R_K and $R_{K^{*0}}$:

Clean observables (3.5-4σ)



(arXiv:1704.05446)

All observables (4-6σ)

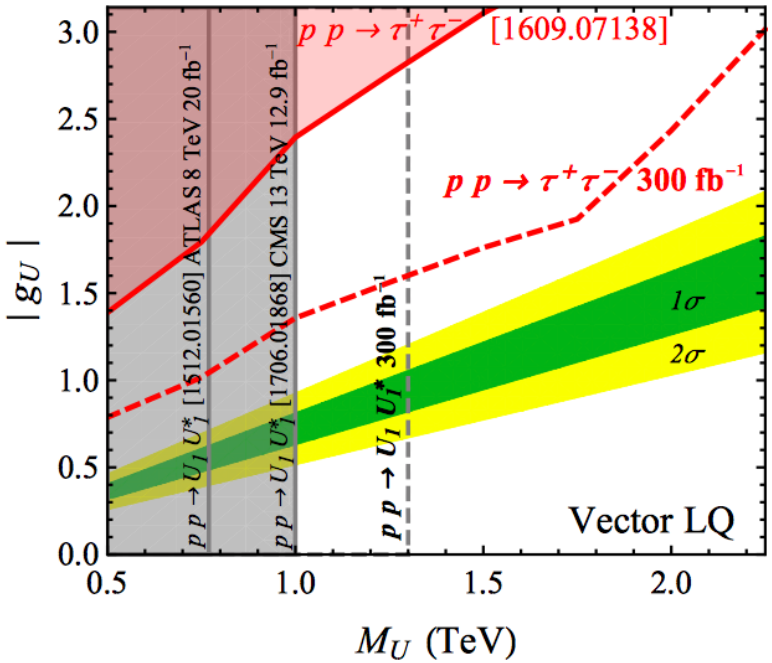


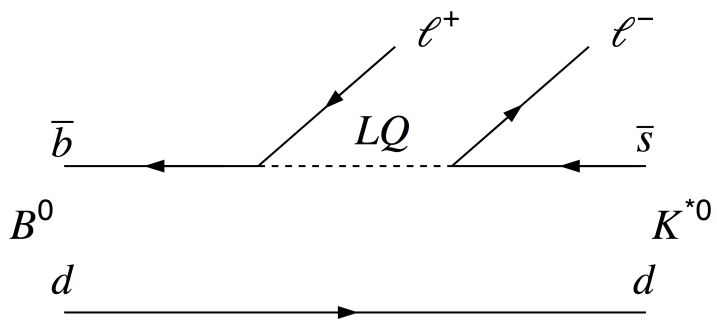
(arXiv:1704.05435)

A consistent picture from clean and dirty observables!

Possible models

- Many papers discussing $R_K^{(*0)}$, sometimes with $R(D^{(*)})$
- Main explanations:
  - Leptoquark(s)
  - $Z^{'}$ and $W^{'}$
- **My favorite model: vector leptoquarks!** (arXiv:1706.07808)
- Couples mainly to 3rd generation, so main signatures:
  - 100x enhancement of $b \to s\tau\tau$, for example $B_s^0 \to \tau^+\tau^-$
  - high p_T: $pp \to \tau^+\tau^-$ or direct leptoquark searches ($t\bar{t}\nu\nu$)





Conclusions

- **Rare beauty decays are sensitive to NP**
- Current measurements point to one place (not SM!)
  - Leptoquark(s) ?
  - $Z^{'}$ and $W^{'}$?
- **LHCb is investigating!**
  - Run 1 + Run 2 data ($\sim 3\times$ Run 1!)
  - New decay modes ($R_\phi, R_\Lambda, B^0_{(s)} \to e^+e^-, ...$)
  - LFV programme ($\Lambda^0_b \to \Lambda^0 e^\pm \mu^\mp, B^0_{(s)} \to \tau\mu, ...$)
- **Significant contribution from Nikhef** in LHCb and theory
- **Exciting times in b physics!**

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- **Exciting times in b physics!**

Thanks for your attention!

Backup slides

Backups are often required

Outlook

Plans for next half year from sure, to likely, to possible:

- Search for $B_s^0 \to K^{*0}\mu^+\mu^-$ (which is $b \to d\ell\ell$)
- Angular analysis of $\Lambda_b^0 \to \Lambda^0\mu^+\mu^-$
- Search for $B^+ \to K^+e^\pm\mu^\mp$
- Search for $B^0_{(s)} \to \tau^\pm\mu^\mp$
- R_K
- Angular analysis (absolute + LFU) of $B^0 \to K^{*0}e^+e^-$

Wide range of measurements!