$B_s^0 \to \mu^+\mu^-\gamma$ from $B_s^0 \to \mu^+\mu^-$

Francesco Dettori

CERN European Organization for Nuclear Research

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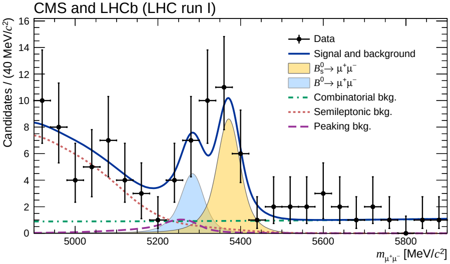
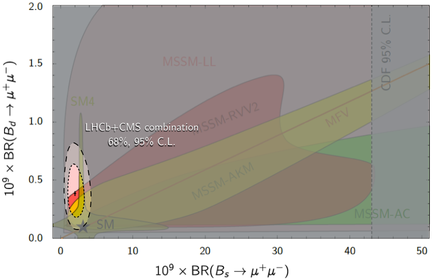
Based on: FD, D. Guadagnoli, M. Reboud - hep-ph/1610.00629

The discovery of $B_s^0 \to \mu^+\mu^-$ decays

- $B_s^0 \to \mu^+\mu^-$ golden channel for the search of NP in FCNC
- Strong limits on physics beyond the SM from combined LHC measurement
- Mainly sensitive to (pseudo)scalar contributions



[D. Straub http://arxiv.org/abs/1205.6094]

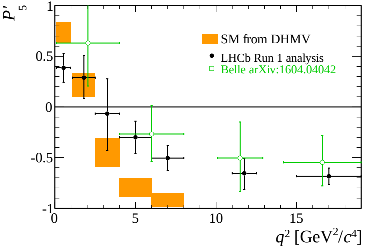


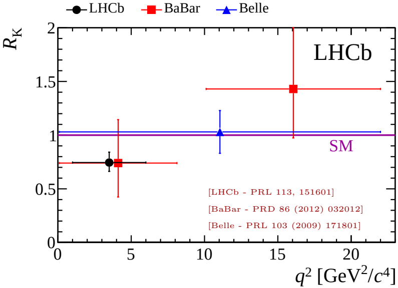
Published in Nature 522, 68-72

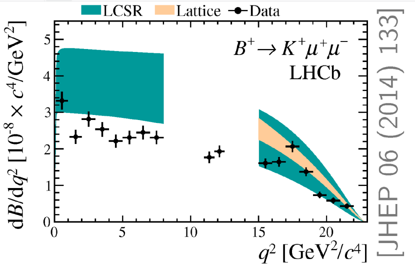
Status of flavour physics anomalies (1)

Several measurements showing discrepancies with respect to SM

- $B_d^0 \to K^* \mu^+ \mu^-$ angular distributions
- Low $b \to s\mu^+\mu^-$ branching fractions
- Hints of lepton non-universality in $B \to K\ell\ell$ and $B \to D\ell\nu$ decays
- Ratio of $B^0 \to \mu^+\mu^-$ / $B_s^0 \to \mu^+\mu^-$ branching fractions

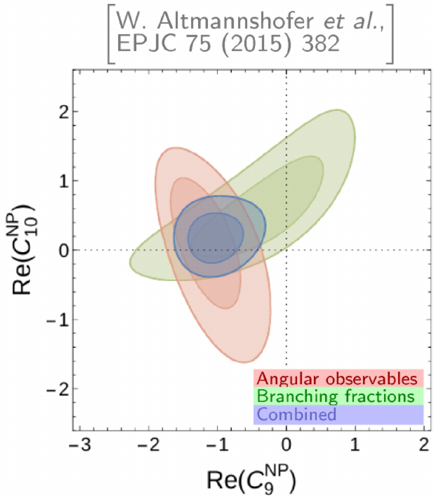






Status of flavour physics anomalies (2)

- All points to the presence of an additional interaction
- Several global fits to Wilson coefficients agree [Buttazzo et al - 1604.03940] [Bauer et al - PRL116,141802(2016)] [Crivellin et al - PRL114,151801(2015)] [Altmannshofer et al - PRD89(2014)095033]...
- Possible underestimated contributions from $c\bar{c}$ loops [Lyon et al - 1406.0566] [Altmannshofer et al -1503.06199] [Ciuchini et al - JHEP06(2016)116]
- Possible explanation is new high mass boson (Z')
- Can be **out of reach for direct production at LHC**
- Fundamental to be confirmed with Run II data



$B_s^0 \to \mu^+\mu^-\gamma$

- $B_s^0 \to \mu^+\mu^-\gamma$ sensitive to $\mathcal{O}_{10}$ but also $\mathcal{O}_9$ and $\mathcal{O}_7$ †
- Increasing the number of observables sensitive to these operators is important to confirm or disprove flavour anomalies
- Sensitivity to $\mathcal{O}_7$ only for very low q^2 (ignored today)

† $B_s^0 \to \mu^+\mu^-\gamma$ studied in detail in: [Aliev et al. - PRD55(1997)7059] [Geng, et al. - PRD62 (2000) 074017] [Dincer, Sehgal - PLB521(2001)714] [Descotes-Genon, Sachrajda - PLB557(2003)213] [Kruger, Melikhov - PRD67(2003) 034002] [Melikhov, Nikitin - PRD70(2004)114028]

$B^0_{(s)} \to \ell^+\ell^-\gamma$ status

- $B^0_{(s)} \to \ell^+\ell^-\gamma$ in SM is about one order of magnitude larger than $B^0_{(s)} \to \ell^+\ell^-$

[Melikhov, Nikitin - PRD70(2004)114028]

m_ℓ	m_e			m_μ			m_τ		
E^γ_{min} (MeV)	20	50	80	20	50	80	20	50	80
$Br\left(B_d \to \ell^+\ell^-\gamma\right) \times 10^{10}$ [This work]	3.95	3.95	3.95	1.34	1.32	1.31	3,39	2.37	1.87
$Br\left(B_s \to \ell^+\ell^-\gamma\right) \times 10^{9}$ [This work]	24.6	24.6	24.6	18,9	18.8	18.8	11.6	8.10	6.42

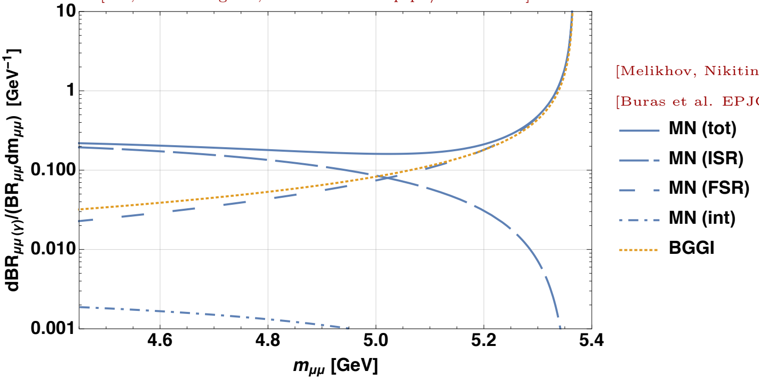
- No experimental result on $B^0_s \to \mu^+\mu^-\gamma$
- BaBar results on the B^0 modes [BaBar collaboration - PRD77(2008)011104]

$$\mathcal{B}(B^0 \to \mu^+\mu^-\gamma) < 1.5 \cdot 10^{-7}$$
$$\mathcal{B}(B^0 \to e^+e^-\gamma) < 1.2 \cdot 10^{-7}$$

- No results on the τ modes

$B_s^0 \to \mu^+\mu^-\gamma$ SM

[FD, D. Guadagnoli, M. Reboud - hep-ph/1610.00629]

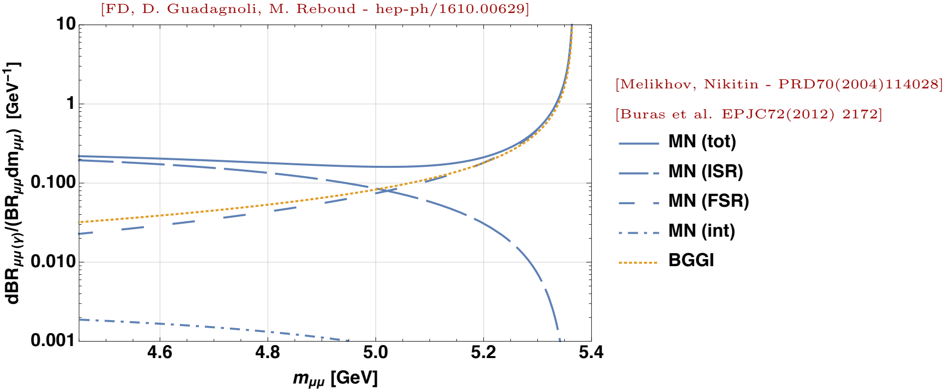


[Melikhov, Nikitin - PRD70(2004)114028]

[Buras et al. EPJC72(2012) 2172]

- Final state radiation (= soft bremsstrahlung)
- Initial state ratiation
- Interference

$B_s^0 \to \mu^+\mu^-\gamma$ SM

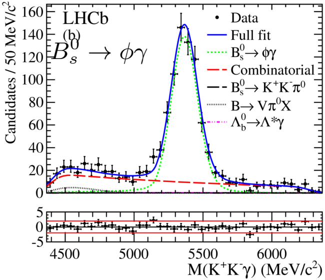


- Interference between ISR and FSR is below 1% of the total spectrum
- Negligible: $B_s^0 \to \mu^+\mu^- + (n\gamma)$ and $B_s^0 \to \mu^+\mu^-\gamma$ can be considered separate processes
- This holds also for beyond the SM: in particular shifts of C_9 and C_{10} of opposite sign diminish the interference

$B_s^0 \to \mu^+\mu^-\gamma$ direct measurement

- Direct measurement of radiative decays is experimentally challenging
  - ⋆ Much lower reconstruction efficiency due to the additional photon
  - ⋆ Energy share makes the two muons softer (hence smaller efficiency)
  - ⋆ Worse mass resultion: higher background
  - ⋆ Particularly true for hadron colliders due to the harsh environment
- Nevertheless they can be done if the branching fraction is “large” $B \to \phi\gamma$, $B \to K^*\gamma$ etc...
- $B_s^0 \to \mu^+\mu^-\gamma$ has the additional difficulty that is also very rare

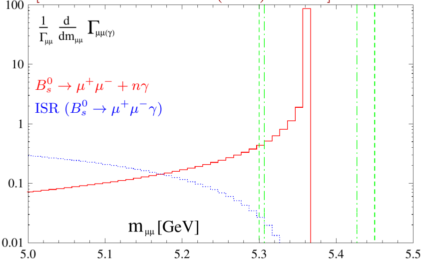
[LHCb - NuclPhysB867(2013) 1]



Final State Radiation

- The radiative tail of the $B_s^0 \to \mu^+\mu^-$ $(+n\gamma)$ decay is experimentally indistinguishable from the $B_s^0 \to \mu^+\mu^-$ itself
- The radiative tail is included up to a certain cut in dimuon mass correspondent to a certain photon energy
- The theoretical branching fraction is resummed to all orders in α_{em}

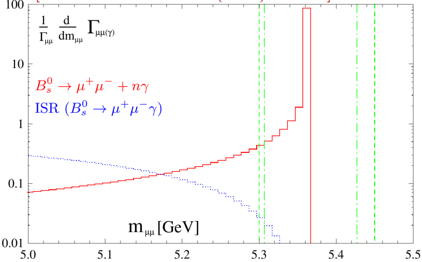
[Bobeth et al. PRL112(2014)101801]



Final State Radiation (2)

- To compare theory and experiment to search for new physics this has to be taken into account
- Experimentally it is done by using PHOTOS in MC simulations to generate $n\gamma$ from the final state
- This folds the final state contribution into the efficiency and is naturally taken into account
- Technically it is just a modification of the pdf used in the final fits

[Bobeth et al. PRL112(2014)101801]



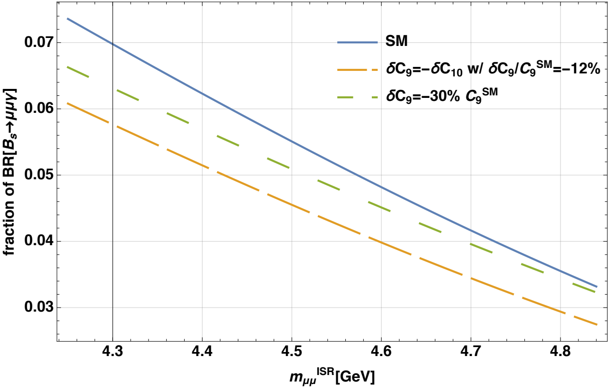
Method description

- $B_s^0 \to \mu^+\mu^-\gamma$ is itself a contamination (background) for the $B_s^0 \to \mu^+\mu^-$
- Contribution in the signal region is negligible
- Given the invariant mass distribution it is typically “absorbed” in the rest of the backgrounds:
  - Combinatorial background (typically a free exponential)
  - Partially reconstructed B decays (Constrained, but with large uncertainties)
- One can reverse the argument: if the background description has not required $B_s^0 \to \mu^+\mu^-\gamma$ so far, this must be limited to small branching fractions
- Even more: **we can exploit the “shoulder” of the dimuon invariant mass distribution to search for $B_s^0 \to \mu^+\mu^-\gamma$ decays**

Sensitivity

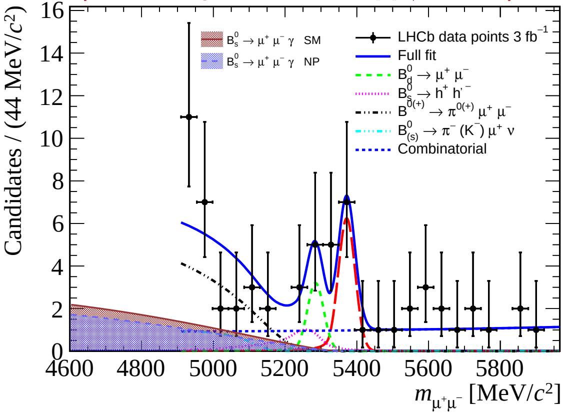
- Fraction of the $B_s^0 \to \mu^+\mu^-\gamma$ spectrum as a function of the dimuon mass lower boundary
- About 4.8% for $m_{\mu\mu} > 4.6$ GeV
- Significant changes with possible NP values of Wilson coefficients

[FD, D. Guadagnoli, M. Reboud - hep-ph/1610.00629]



Comparing $B_s^0 \to \mu^+\mu^-\gamma$ to a $B_s^0 \to \mu^+\mu^-$ search data

[FD, D. Guadagnoli, M. Reboud - hep-ph/1610.00629]



Data from LHCb Run I measurement

[PRL111(2013)101805]

Assumptions

- Used single event sensitivity to translated branching fraction into yield
- Assumed same efficiency as $B_s^0 \to \mu^+\mu^-$:
  true by definition at the end-point, but will fade down far from it

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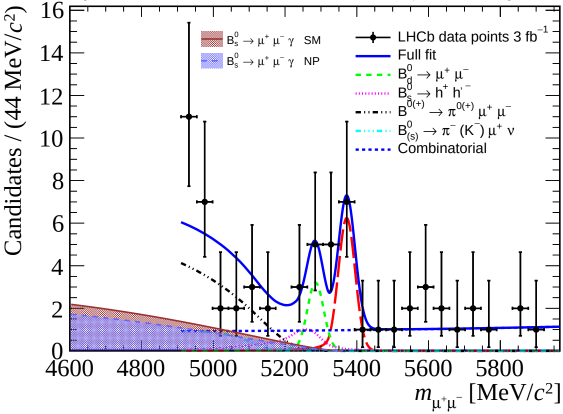

Data from LHCb Run I measurement

[PRL111(2013)101805]

- LHCb just an example, procedure can be applied to all experiments
- Important to constrain the partially reconstructed backgrounds even more

Further remarks

- Method applicable to any $M \to \ell\ell\gamma$ decay
  - ⋆ more sensitive for muons and electrons
  - ⋆ theoretical uncertainties might dominate (e.g. $D^0 \to \mu^+\mu^-\gamma$)
- Method applicable to any $M \to \mu^+\mu^- X$ but..
  - ⋆ the higher M_X the less some (experimental) assumptions are valid
  - ⋆ Backgrounds might be too large / unconstrained

Experimental remarks (a biased view)

While the method is generic I have a biased view...

- I have no doubt this can be applied to LHCb but it requires effort:
  - ⋆ Detailed estimate of $B_s^0 \to \mu^+\mu^-\gamma$ efficiency vs $m_{\mu\mu}$ and correspondent integrated efficiency for different models
  - ⋆ Precise control of backgrounds from $B \to X\mu\mu$ and others with particle mis-identification which are now too low in mass for $B_s^0 \to \mu^+\mu^-$ searches
- ATLAS and CMS are in a different position
  - ⋆ Have on their side the much larger statistics
  - ⋆ Worse dimuon mass resolution (from 25 MeV of LHCb to 30 up to 100 in the GPDs depending on cathegory) can increase the cross-feed with $B_s^0 \to \mu^+\mu^-$
  - ⋆ Difficult to control other B backgrounds without correctly reconstructed proxies, but they have great MC productions
  - ⋆ Lack of personpower (?): maybe not, we have seen that $B_s^0 \to \mu^+\mu^-$ attracted a lot of resources
- Belle II
  - ⋆ As soon as data taking starts we will have a new player in town, but mostly on $B_d - B^+$
  - ⋆ Low background
  - ⋆ Full reconstruction might also be feasible ($B_d^0 \to \mu^+\mu^-\gamma$)

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Conclusions

- $B_s^0 \to \mu^+\mu^-\gamma$ provides complementary sensitivity to $\mathcal{C}_9$ and$\mathcal{C}_{10}$
- Direct measurement might be experimentally far
- Proposed alternative method for search that can arguably provide first mesurements of $B_s^0 \to \mu^+\mu^-\gamma$
- Run II LHC mesurements might already give interesting limits or maybe more...

Backup