$B_s \to \mu\mu\gamma$ at LHCb - and elsewhere

GDR-Inf Workshop – 09/07/2019

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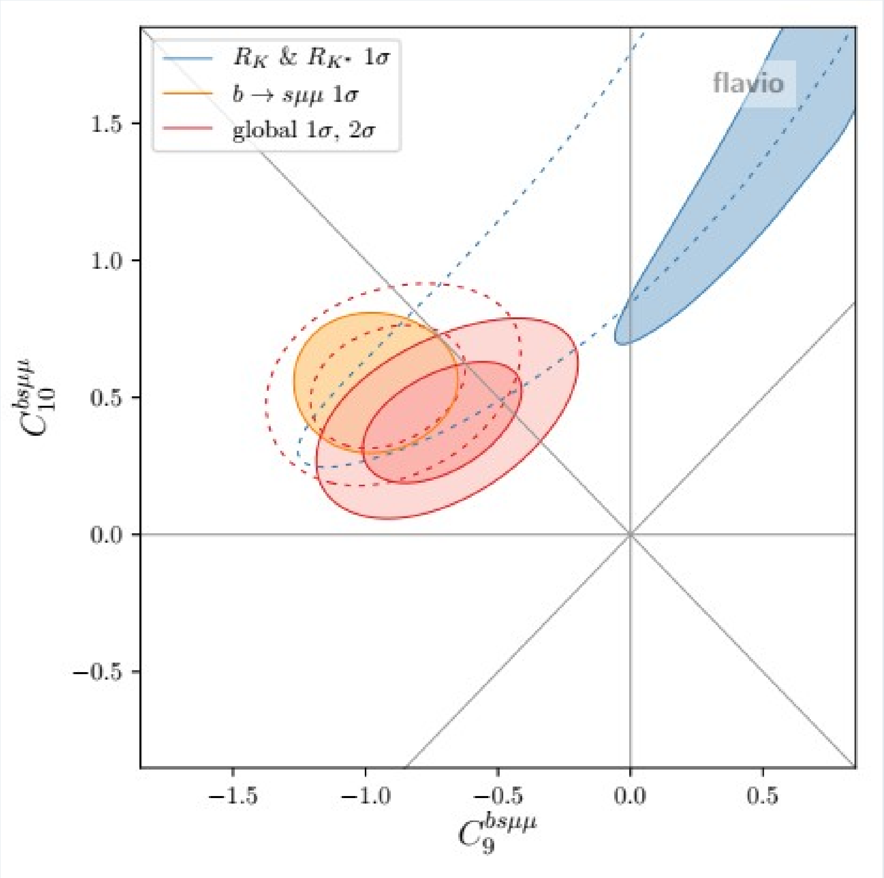
$b \to s\ell\ell$ anomalies

- Updates presented at Moriond 2019
  - R_K and $\Lambda_b \to \Lambda\mu\mu$ updates by LHCb
  - R_{K^*} measurement by Belle
  - $B_s \to \mu\mu$ measurement by Atlas
- The global picture didn't change much, but a lepton flavor universal contribution is now favored by the data

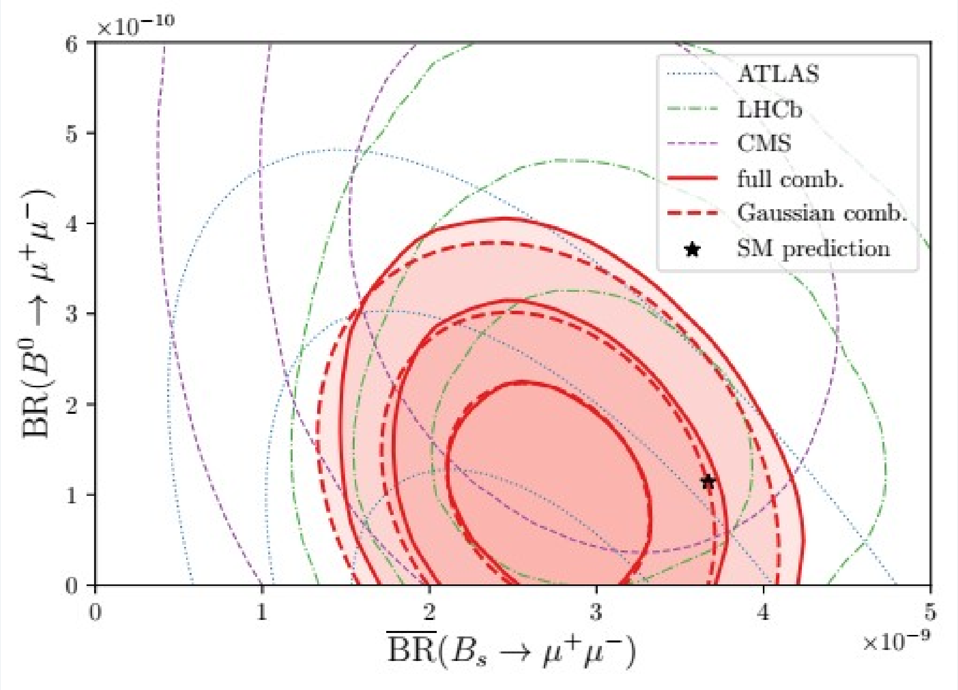


See also fits by other groups:
[Alguero, Capdevila, Crivellin, Descotes-Genon, Masjuan, Matias, Virto]
[Ciuchini, Coutinho, Fedele, Franco, Paul, Silvestrini, Valli]

[Aebischer, Altmannshofer, Guadagnoli, MR, Stangl, Straub]

$b \to s\ell\ell$ anomalies

- Combination of BR($B_{(s)} \to \mu\mu$) measured by different experiments already shows a ~2σ tension
- LHCb is working on the update of this measurement
- Belle II won't be able to measure $B \to \mu\mu$ due to too low statistics

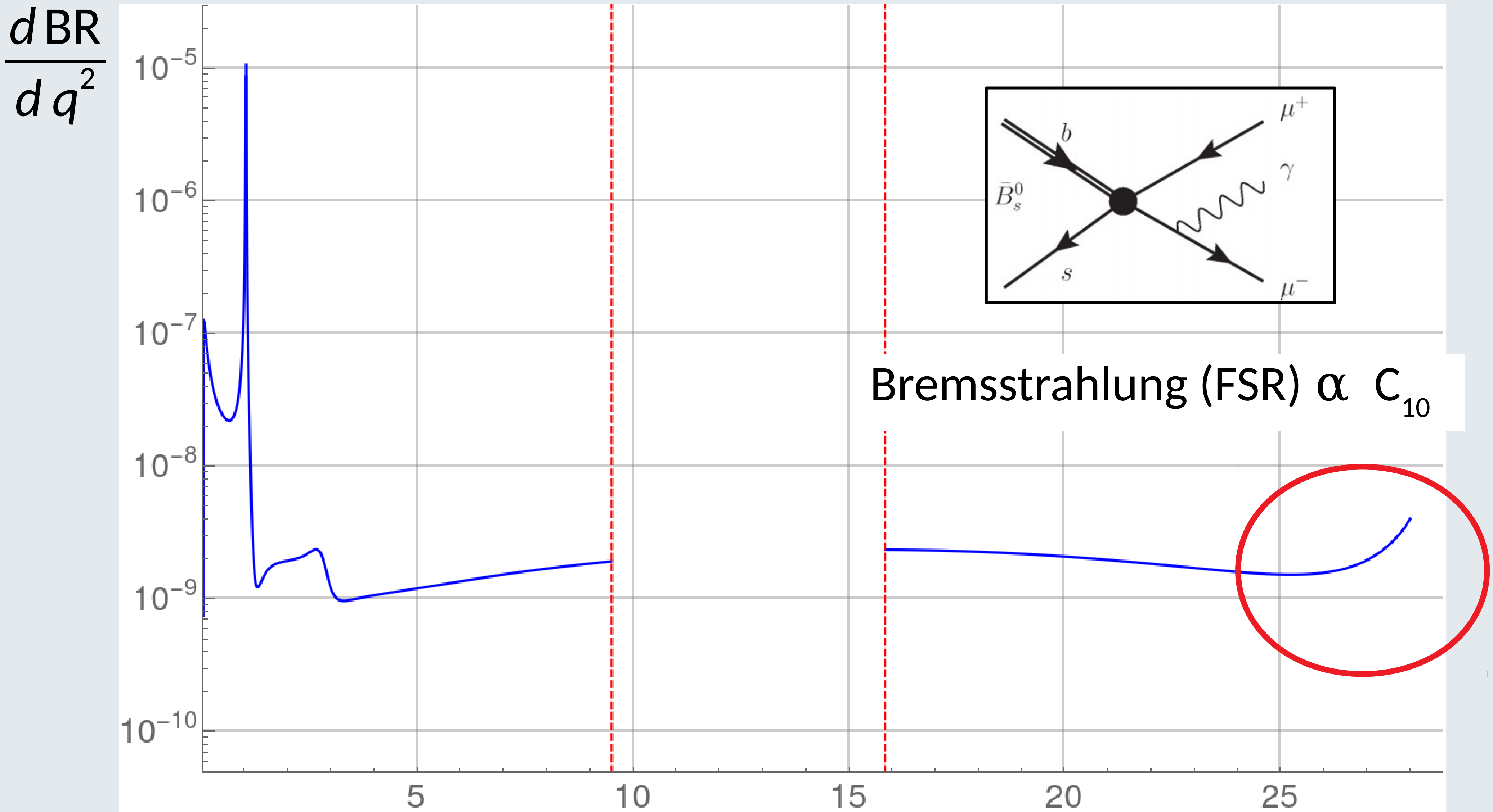


[Aebischer, Altmannshofer, Guadagnoli, MR, Stangl, Straub]

The B → ℓℓγ decay

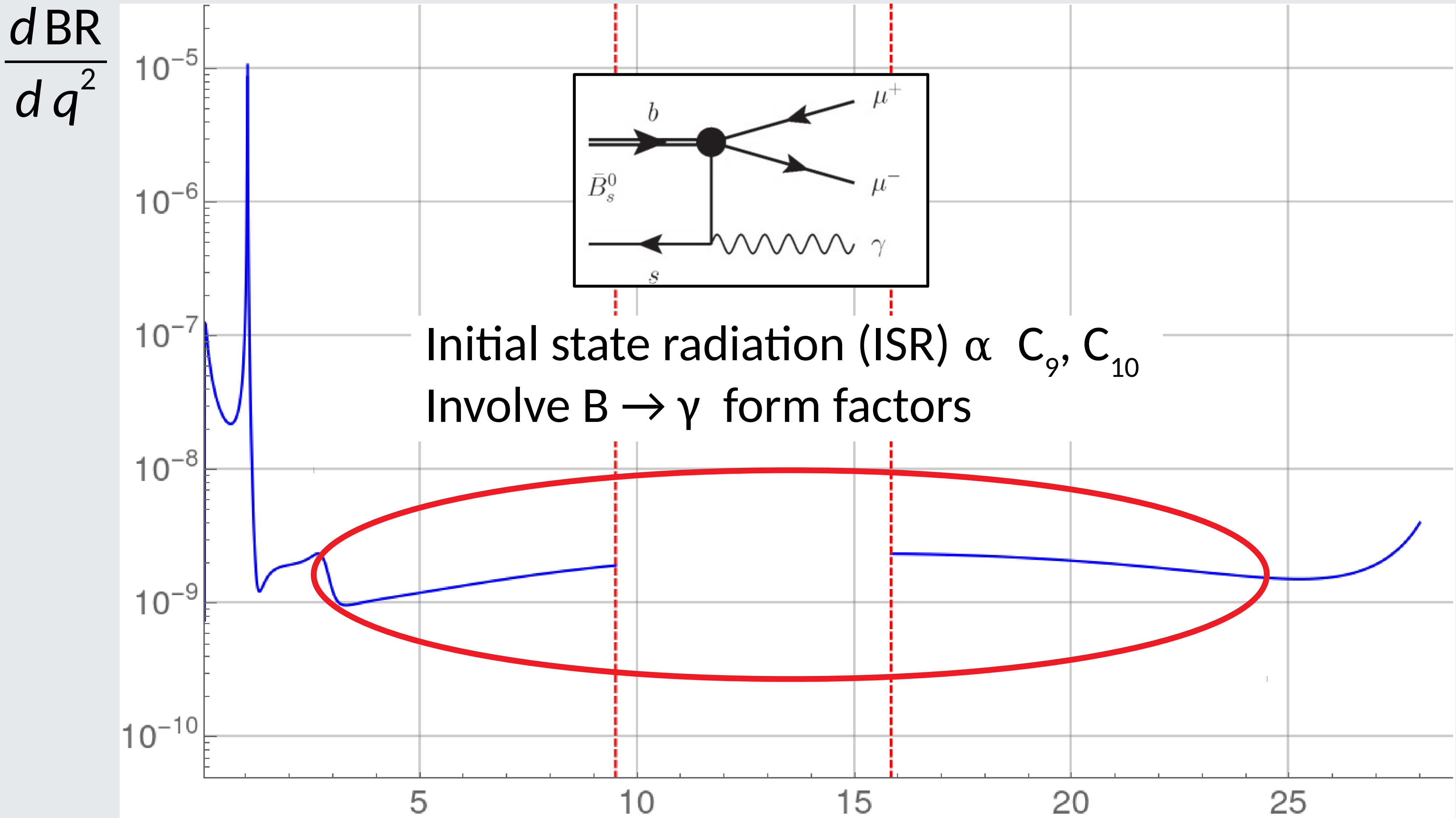
- The additional photon lifts **chiral suppression**:
  - $BR(B_s \to \mu\mu\,\gamma) \sim 10^{-8} \sim 10\, BR(B_s \to \mu\mu)$
  - $BR(B_s \to ee\,\gamma) \sim 10^{5}\, BR(B_s \to ee)$!
- Sensitivity to **C_7, C_9 and C_{10}** (and primed)
- **Not observed** so far: $B_d \to \mu\mu\gamma < 1.6\; 10^{-7}$ [BaBar, PRD-RC 77, 011104 (2008)]

$B_s \to \mu\mu\gamma$ in the SM



[Guadagnoli, MR, Zwicky]

$B_s \to \mu\mu\gamma$ in the SM



Initial state radiation (ISR) α C_9, C_{10}

Involve $B \to \gamma$ form factors

[Guadagnoli, MR, Zwicky]

q^2 [GeV^2]

B → γ form factors

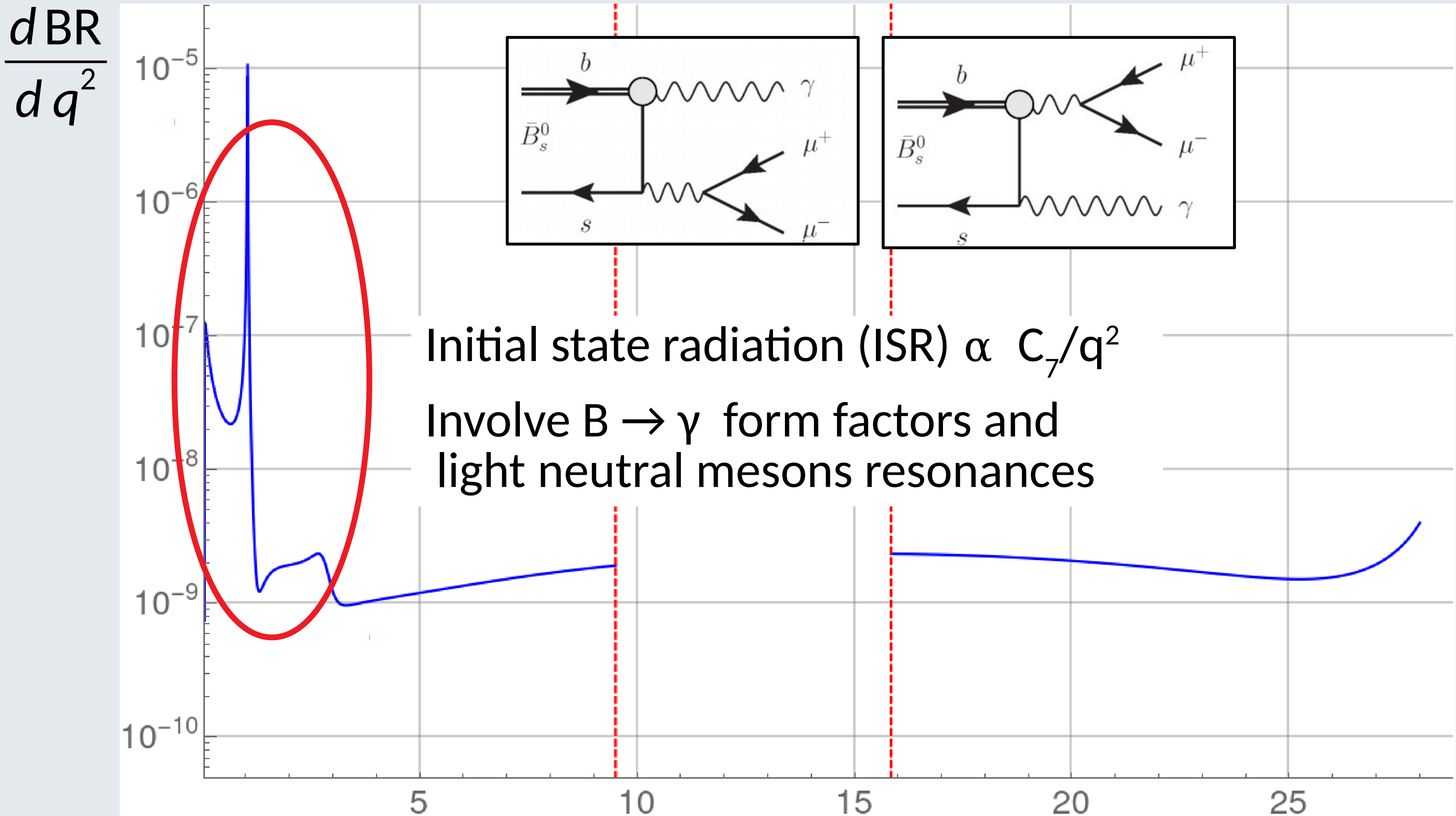
- **Idea 1**: Assume a single pole distribution in the entire q^2 range [Kruger, Melikhov, '03]:

$$F_i(q^2) = \beta_i \frac{f_B M_B}{\Delta_i + E_\gamma} \qquad E_\gamma = \frac{M_B}{2}\left(1 - \frac{q^2}{M_B^2}\right)$$

- **Idea 2**: Use $B \to K^*$ form factors [e.g. Bharucha, Straub, Zwicky]

- Solution (not down yet): Use **light-cone sum rules** at low q^2 and **lattice** at high q^2 and extrapolate to the full range
  - Proof of concept of radiative leptonic calculation on lattice [1907.00279]

$B_s \to \mu\mu\gamma$ in the SM



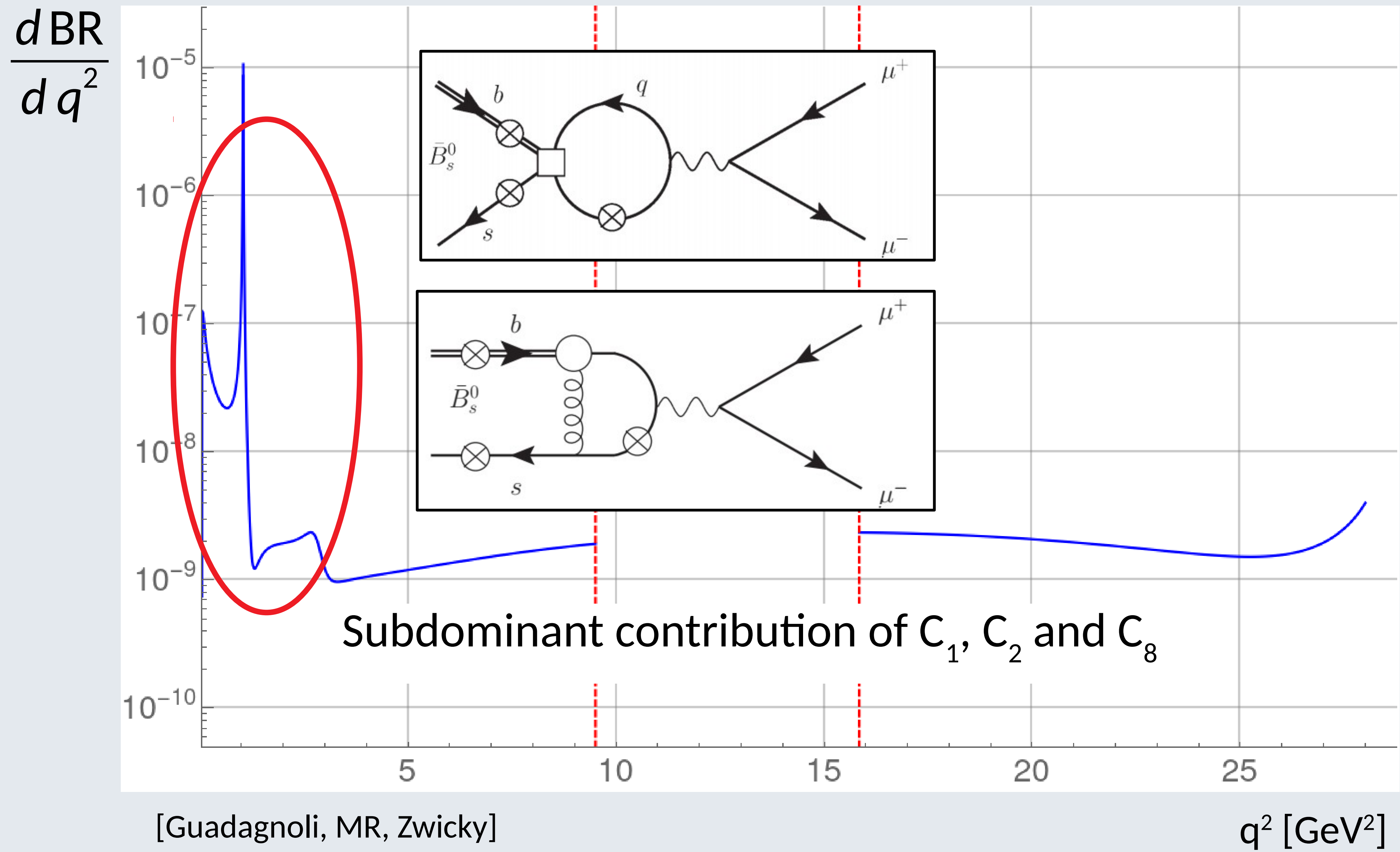
Initial state radiation (ISR) $\propto$ C_7/q^2

Involve $B \to \gamma$ form factors and light neutral mesons resonances

[Guadagnoli, MR, Zwicky]

q^2 [GeV^2]

$B_s \to \mu\mu\gamma$ in the SM



[Guadagnoli, MR, Zwicky]

Measurement strategies

- **Direct** measurement
  - Full reconstruction of the final state
  - Challenging in hadron colliders:
    - No tracking of photons (converted photon ~ a few %)
    - Large background $\pi^0 \to \gamma\gamma$
    - **Trigger issues**
      - Dimuon trigger selects high q^2 events
      - Single muon trigger is constrained
      - Photon trigger overwhelmed by background

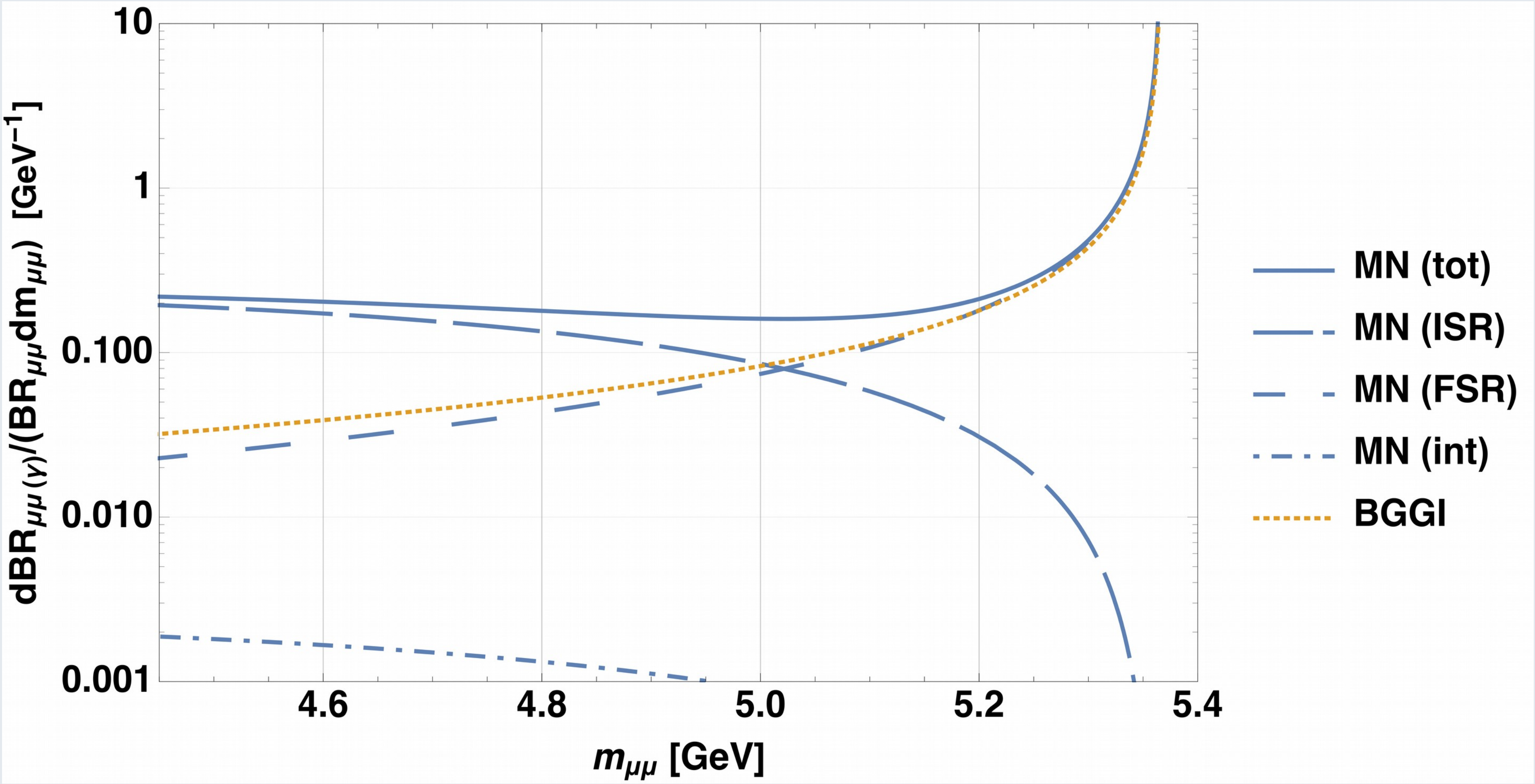
Measurement and spectrum

Measurement strategies

- **Indirect** measurement
  - Idea: measuring $B_s \to \mu\mu\,\gamma$ as a **background** of $B_s \to \mu\mu$
    1. The muons emit photons (Final State Radiation)
    2. This is included in the simulation (PHOTOS)
    3. Enlarging the mass windows gives access to the $B_s \to \mu\mu\,\gamma$ spectrum

Indirect measurement

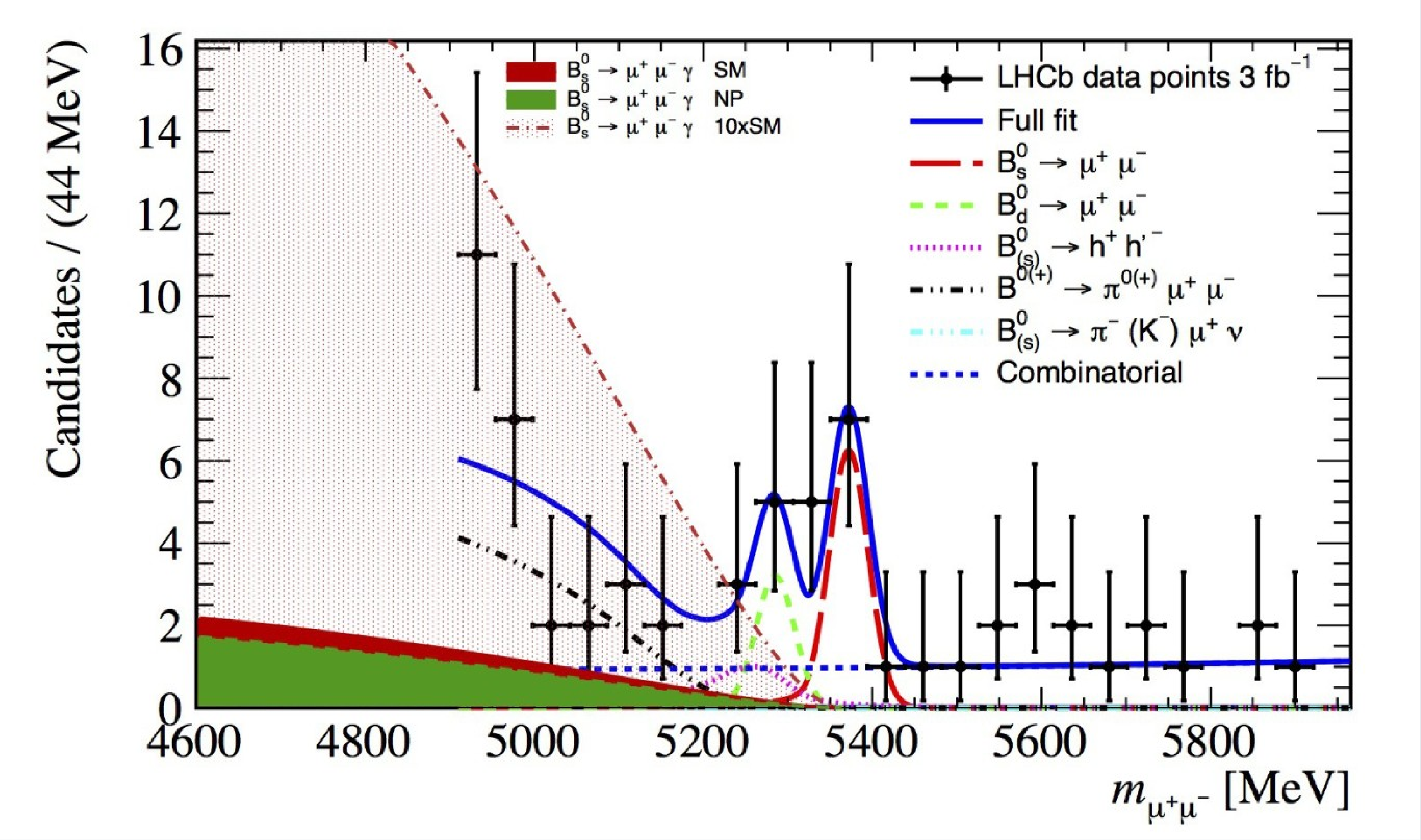
[Dettori, Guadagnoli, MR, Phys.Lett. B768 (2017) 163-167]



MN: standard model O(α_{em}) prediction [Melikhov, Nikitin]

BGGI: $B_s \to \mu\mu$ + n soft γ resumed [Buras, Girrbach, Guadagnoli, Isidori]

Indirect measurement



[Phys. Rev. Lett. 111 (2013) 101805 for LHCb data and fits, and Dettori, Guadagnoli, MR, Phys.Lett. B768 (2017) 163-167 for the colored areas]

Indirect measurement

[-] Needs a good knowledge of the backgrounds

[-] Not independent w.r.t $B_s \rightarrow \mu\mu$

[+] Build on $B_s \rightarrow \mu\mu$, so this a “simple” analysis

[+] Scans the high-q^2

- Sensitivity to C_9 and C_{10}
- Form factors can be computed on lattice

[+] Complementary to the direct method

Atlas, CMS, Belle II

- Direct measurement @ **Belle II**
  - $B_d \to \mu\mu\gamma$ (or $B_d \to ee\gamma$)
    - BR is one order of magnitude smaller than for B_s!
    - Different light neutral meson resonances
  - **Almost background free!** Dominant backgrounds are:
    - π^0 and charmonium decays (far smaller than in the LHC!)
    - continuum background from $ee \to ff$ ($f = u, d, s, c$ or τ)

Atlas, CMS, Belle II

- Direct measurement @ **Belle II**
  - **Babar '08**: 292 fb^{-1} → BR(B_d → μμγ) < 1.6 10^{-7}
  - **Belle II**: 50 ab^{-1} in 2025
    - With Babar sensitivity: expected limit ~ 10^{-8}
    - More optimistic guess: 10^{-10} - 10^{-9}

TABLE I. Summary of the systematic uncertainties in the signal yields.

	$e^+e^-\gamma$ (%)	$\mu^+\mu^-\gamma$ (%)
Signal calculation	2.3	3.8
$\mathcal{B}(\Upsilon(4S) \to B^0\bar{B}^0)$	1.6	1.6
Photon reconstruction	1.6	1.6
Lepton identification	0.7	1.3
Number of $B\bar{B}$ pairs	1.1	1.1
Data/MC comparison	1.3	0.4
Tracking efficiency	0.9	0.9
Total	3.8	4.8

Improved signal modeling (Form factors...)

Improved measurement

Improved calorimeter

...and new selection tools (Machine Learning)

[BaBar, PRD-RC 77, 011104 (2008)]

Conclusion

- $B_{(s)} \to \mu\mu\gamma$ are good channels to probe new physics in $b \to s$ and $b \to d$ transition
- SM value will improve thanks to lattice
- The measurements are not trivial but LHCb, CMS and Belle II are working/will work on them
- The indirect method should rapidly yield a first result

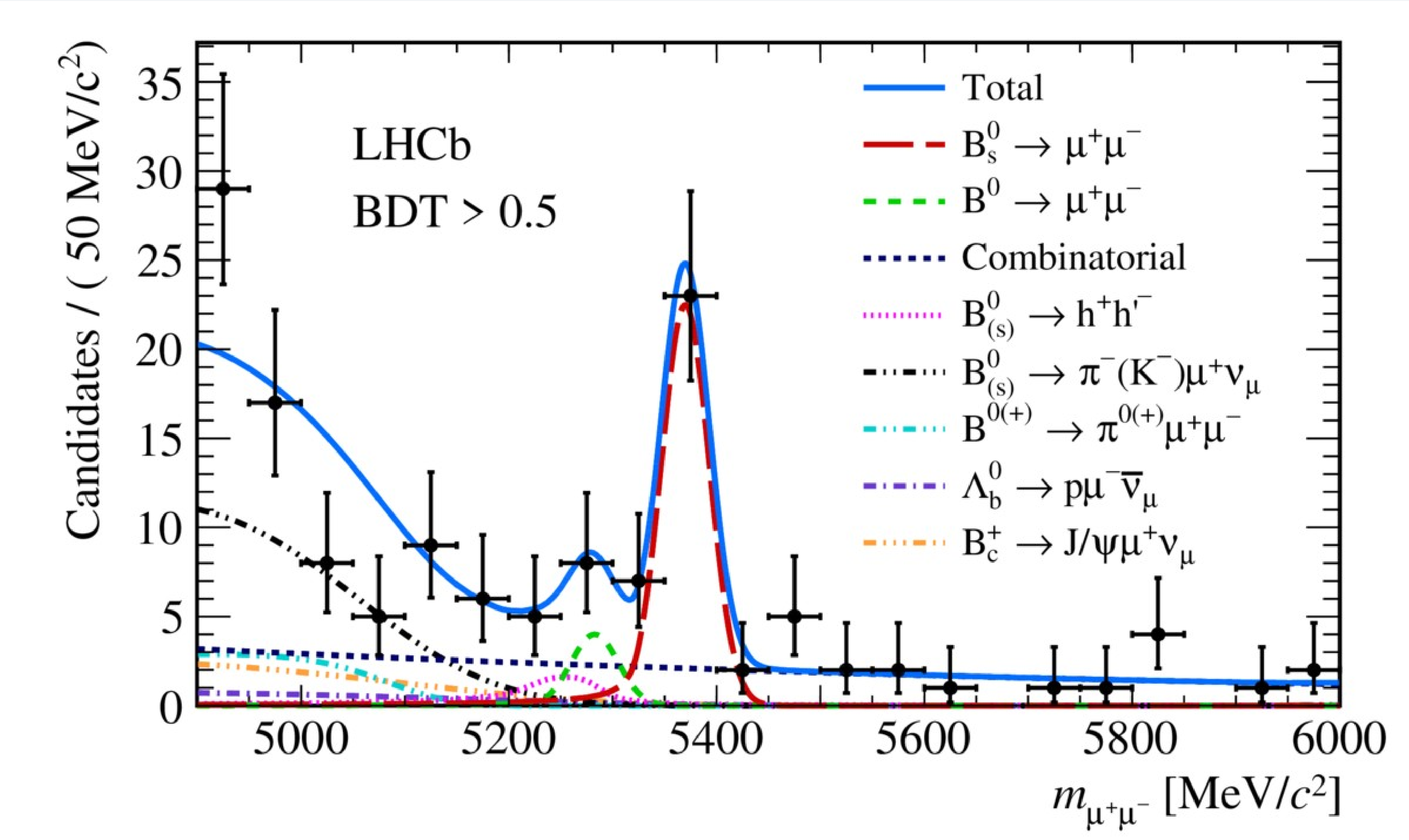
Thanks!

Backup

Atlas, CMS, Belle II

- Direct measurement @ **CMS and Atlas**
  - Different acceptance, higher statistics
  - CMS has a **better calorimeter**
  - Limited by the dimuon mass range in the **B_s trigger**
  - Photon trigger overwhelmed by **π^0 decays**
  - CMS analysis is planned (for Run III)

LHCb 2017



[Phys. Rev. Lett. 118 (2017) 191801]