(Some) B anomalies and rare decays

F. Martínez Vidal

IFIC-Valencia

On behalf of the LHCb collaboration

Rare decays: menu

Semileptonic B decays

d[BF's]/dq^2 of $B^{0/+} \to K^{(*)0/+}\mu\mu$, $B^0_s \to \phi\mu\mu$, $B^+ \to \pi^+\mu\mu$, $\Lambda_b \to \Lambda\mu\mu$

Angular analyses of $B \to K^{(*)}\mu\mu$, $B^0_s \to \phi\mu\mu$, $\Lambda_b \to \Lambda\mu\mu$

…

Also electrons

Hadronic uncertainties in theory predictions

Observables less form factor dependent

Leptonic B decays

BF and effective lifetime of $B \to \mu\mu$

BF's of $B \to \tau\tau$ and $B \to \mu\mu\mu\mu$

…

LFV, e.g. $B \to e\mu$

LFU tests

$B \to K^{(*)} ll$

…

$B \to D^{(*)} l \nu$

~cancellation of hadronic uncertainties in theory predictions

P. Owen's talk

Radiative decays

$B^0 \to K^{*0}\gamma$

$B^0_s \to \phi\gamma$

$B \to J/\psi\gamma$

$B \to K\pi\pi\gamma$

…

O. Deschamps' talk

Strange decays

$K^0_s \to \mu\mu$

$\Sigma^+ \to p\mu\mu$

Charm decays

$D \to \pi\pi\mu\mu$

$D \to K\pi\mu\mu$

$D \to e\mu$

$D \to \mu\mu$

…

τ decays

$\tau \to \mu\mu\mu$

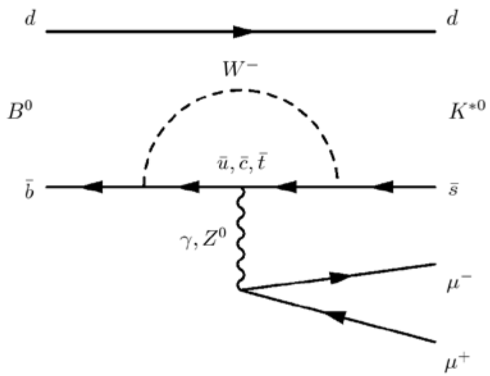
$\tau \to p\mu\mu$

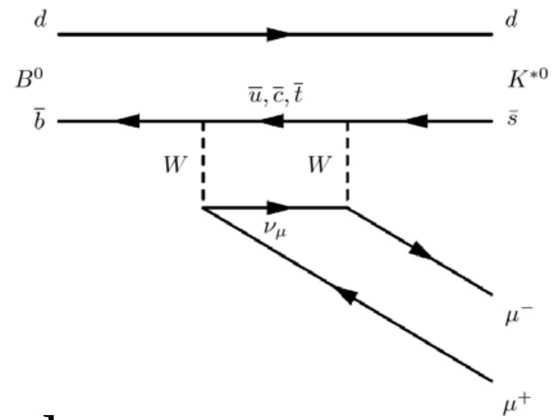
…

Enormous Physics Program, constantly expanding. Will cover only part

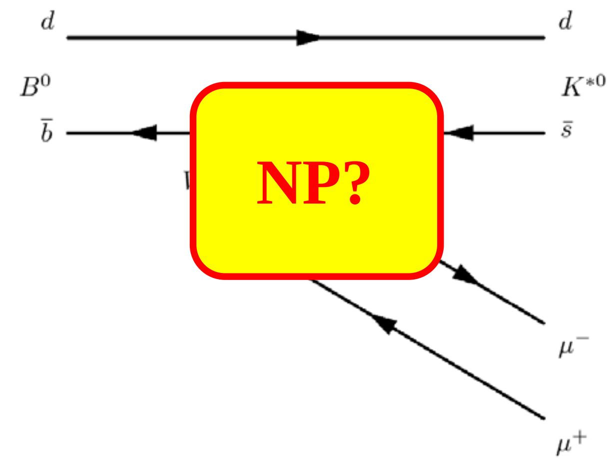
Rare decays: why?

- Decays that proceed via FCNC transitions that only occur at loop order (or beyond) in the SM





- New particles can contribute to loop or tree level diagrams by enhancing/suppressing decay rates, introducing new CPV sources or modifying the angular distribution of the final-state particles
- Probes NP models at energy scales higher than direct searches



Rare decays: how?

Prog. Part. Nucl. Phys. 92 (2017) 50

- Rare hadron decay processes over a wide energy range

0.2GeV……4GeV……80GeV…… ~ 100 TeV ?

Λ_{QCD} (non-perturbative regime) Λ_b (b mass) Λ_{EW} (W mass) Λ_{NP} (NP scale)

- Described by effective field theory and operator product expansion:

[OPE: a series of effective vertices multiplied by effective coupling constants C_j and C'_j]

LH currents RH currents (suppressed in SM)

$$A(B \to f) = \langle f | H_{\text{eff}} | B \rangle = \frac{G_F}{\sqrt{2}} \sum_j V_j^{\text{CKM}} \left(C_j \langle f | O_j | B \rangle + C'_j \langle f | O'_j | B \rangle \right)$$

Wilson coefficients
(perturbative,
short-distance physics,
sensitive to $E > \Lambda_{EW}$)

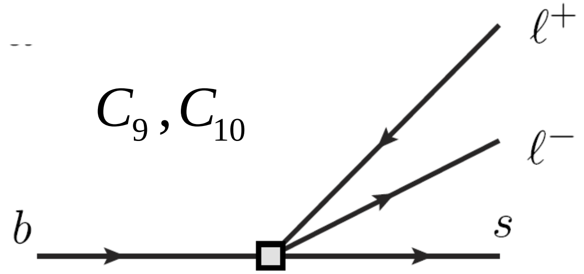
Hadronic matrix elements
(include non-perturbative QCD,
long-distance physics)

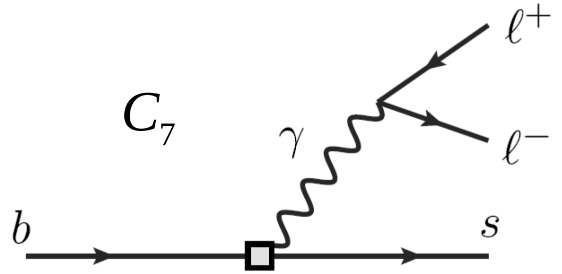
Rare decays: how?

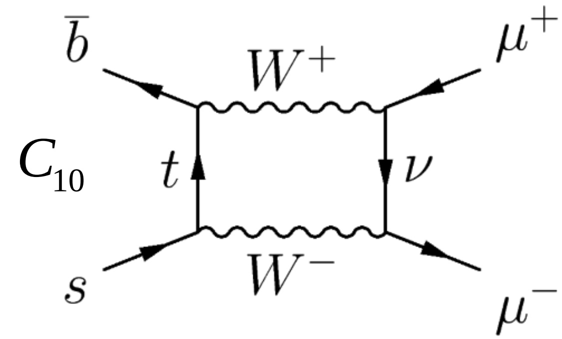
$$C_j = C_j^{\mathrm{SM}} + C_j^{\mathrm{NP}}$$

$$C'_j = C'^{\mathrm{SM}}_j + C'^{\mathrm{NP}}_j$$

- NP expected to affect the Wilson coefficients:

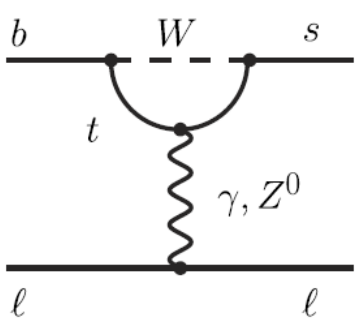






- Different q^2 regions probe different processes

eg. $d\Gamma/dq^2$ $B \to K^* ll$

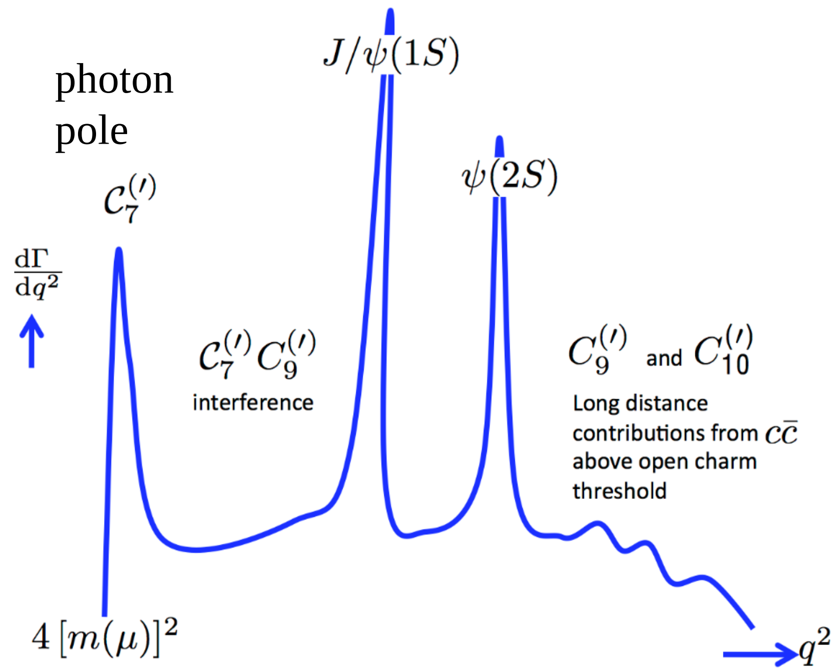


$C_7 \approx -0.33$

$C_9 \approx 4.27$

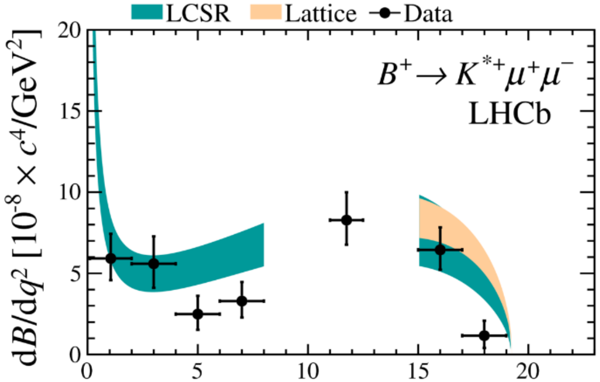
$C_{10} \approx -4.17$

(the rest negligible)

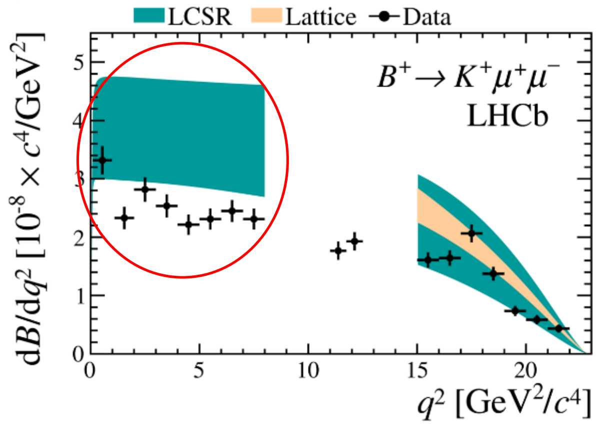


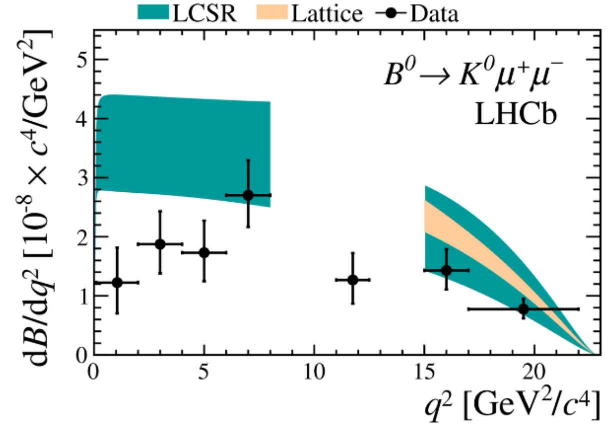
Differential BFs

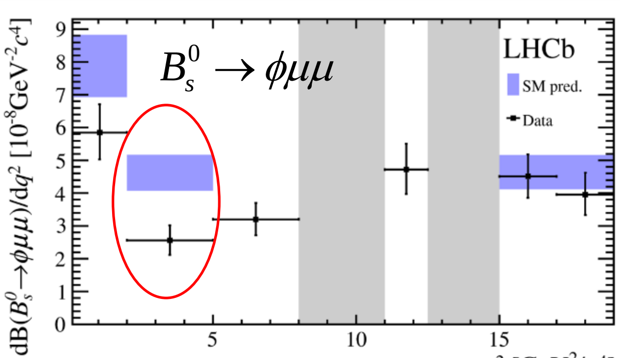
- Measured differential BFs in q^2 for $B^0 \rightarrow K^{(*)0}\mu\mu$, $B^+ \rightarrow K^{(*)+}\mu\mu$, $B^0_s \rightarrow \phi\mu\mu$, $\Lambda_b \rightarrow \Lambda\mu\mu$ consistently lower than SM predictions at 2-3σ



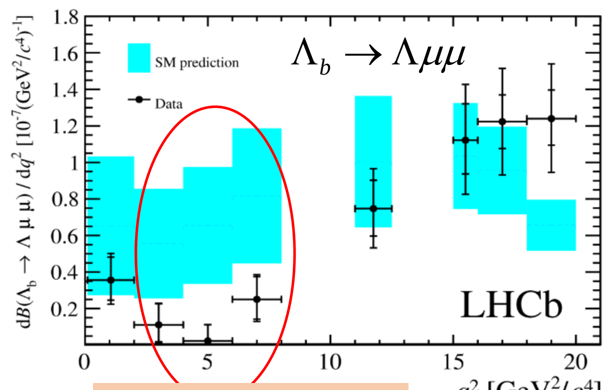
JHEP 06 (2014) 133







JHEP 09 (2015) 179



JHEP 06 (2015) 115

SM LCSR:
PRD 71 (2005) 014029
JHEP 09 (2010) 089
JHEP 08 (2016) 098

SM Lattice:
PRD 88 (2013) 054509
PRD 89 (2014) 094501
PRL 111 (2013) 162002
PRL 112 (2014) 212003
PRD 87 (2013) 074502

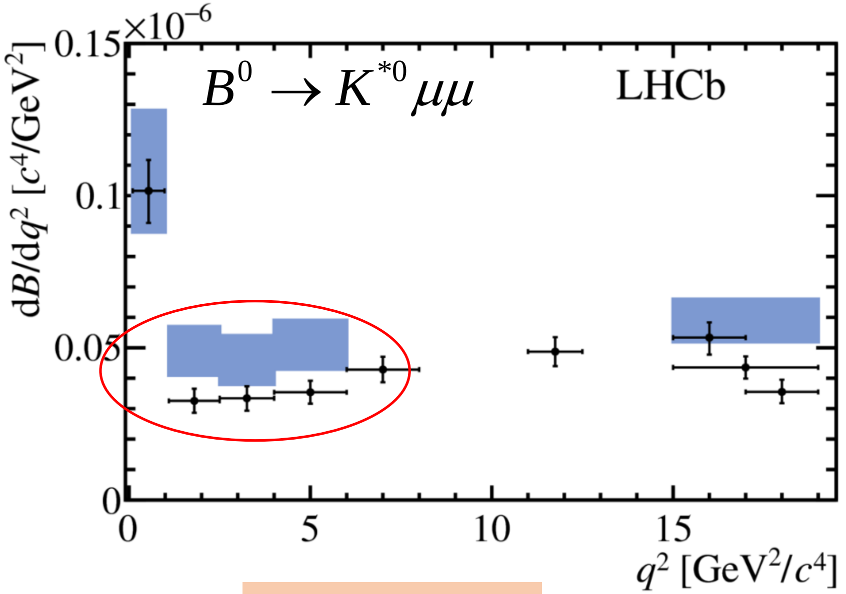
✓ Measurements statistically dominated
✓ SM predictions limited by hadronic uncertainties on form factors

$B\to K^{*0}\mu\mu$ differential BF

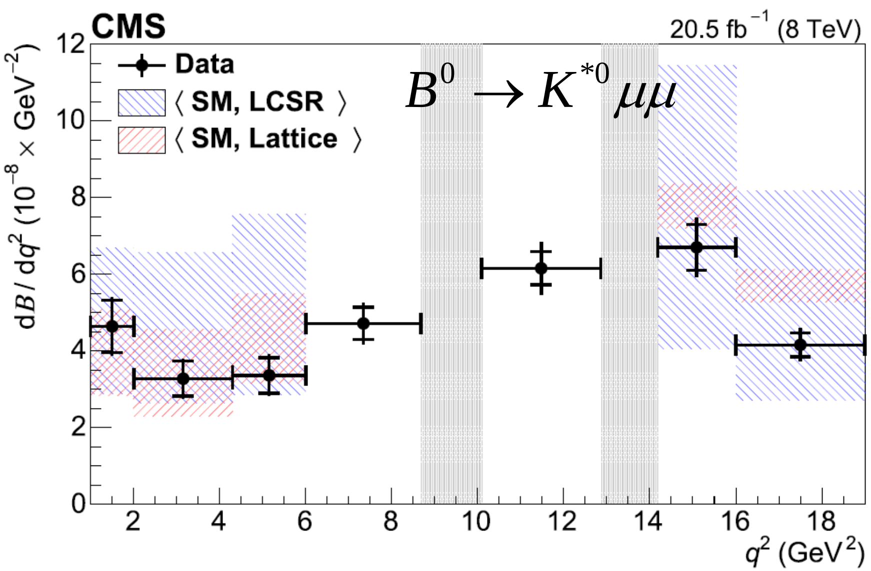
- Latest Run I LHCb and CMS BF measurements along same lines

JHEP 08 (2016) 098 (LCSR)
PRD 89 (2014) 094501 (Lattice)

JHEP 07 (2010) 098
PRD 87 (2012) 034016



JHEP 11 (2016) 047



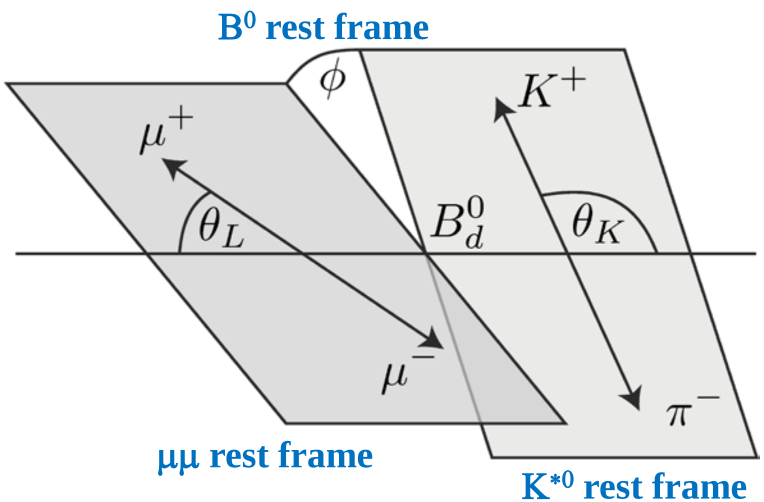
PLB 753 (2016) 424

- Main systematic uncertainty from knowledge of normalization channel, i.e. $BF(B^0\to J/\psi K^{*0})$

B→K*0μμ angular analysis

- Study of the full angular distribution of the final state particles (θ_l, θ_K, ϕ)
- Measure all CP-averaged angular terms and CP asymmetries, described by eight observables S_i, F_L, A_{FB}, function of Wilson coefficients

$$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^4(\Gamma+\bar{\Gamma})}{\mathrm{d}q^2\,\mathrm{d}\vec{\Omega}} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_\mathrm{L})\sin^2\theta_K + F_\mathrm{L}\cos^2\theta_K + \frac{1}{4}(1-F_\mathrm{L})\sin^2\theta_K\cos 2\theta_l - F_\mathrm{L}\cos^2\theta_K\cos 2\theta_l + S_3\sin^2\theta_K\sin^2\theta_l\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_l\cos\phi + S_5\sin 2\theta_K\sin\theta_l\cos\phi + \frac{4}{3}A_\mathrm{FB}\sin^2\theta_K\cos\theta_l + S_7\sin 2\theta_K\sin\theta_l\sin\phi + S_8\sin 2\theta_K\sin 2\theta_l\sin\phi + S_9\sin^2\theta_K\sin^2\theta_l\sin 2\phi\Big]$$

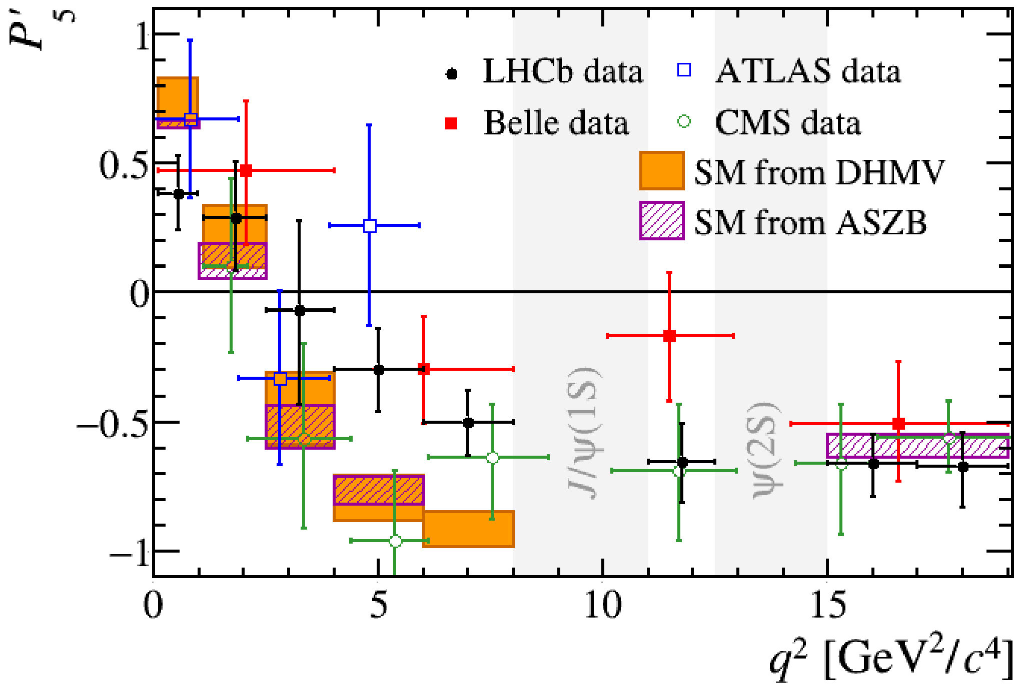


- Define observables in which hadronic form factor uncertainties cancel at leading order, like

$$P_5' = \frac{S_5}{\sqrt{F_L(1-F_L)}}$$

JHEP 05 (2013) 137

$B \to K^{*0}\mu\mu$ angular analysis



JHEP 02 (2016) 104
ATLAS-CONF-2017-023
CMS-PAS-BPH-15-008
PRL 118 (2017) 111801

DHMV: JHEP 12 (2014) 125 & JHEP 10 (2016) 075
ASZB: Proc.Sci.LATTICE2014 (2015) 372

- P'_5 LHCb local deviation from SM
  - ✓ 2.8σ in $4 < q^2 < 6$ GeV^2/c^4
  - ✓ 3.0σ in $6 < q^2 < 8$ GeV^2/c^4
- $B \to J/\psi K^{*0}$ angular distribution in excellent agreement with existing measurem.
- Statistically dominated measurement
- $B^0_s \to \phi\mu\mu$ angular analysis consistent with SM predictions

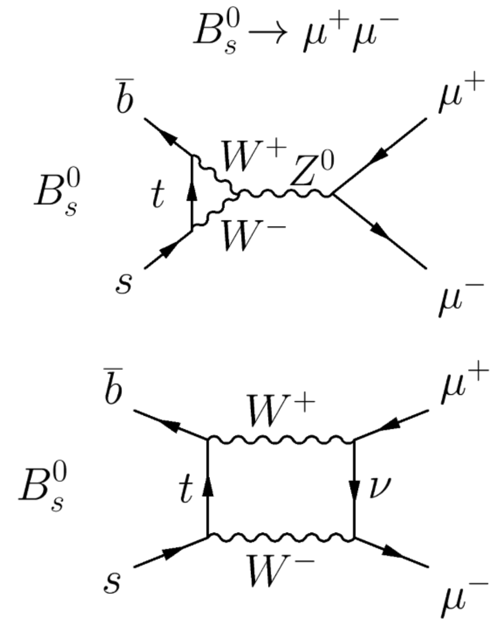
JHEP 09 (2015) 179

B→μμ BF

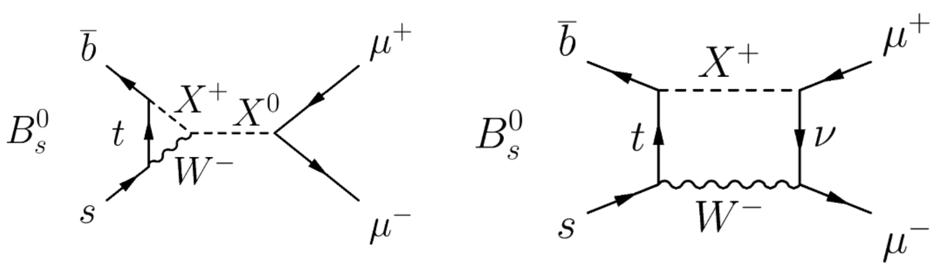
- FCNC process, additional helicity & CKM suppression, theoretically clean

$$BF(B_s^0 \to \mu^+\mu^-) = (3.66 \pm 0.23) \times 10^{-9}$$
$$BF(B^0 \to \mu^+\mu^-) = (1.06 \pm 0.09) \times 10^{-10}$$

PRL112 (2014) 101801



- Sensitive to scalar/pseudoscalar contributions (no longer helicity suppressed)

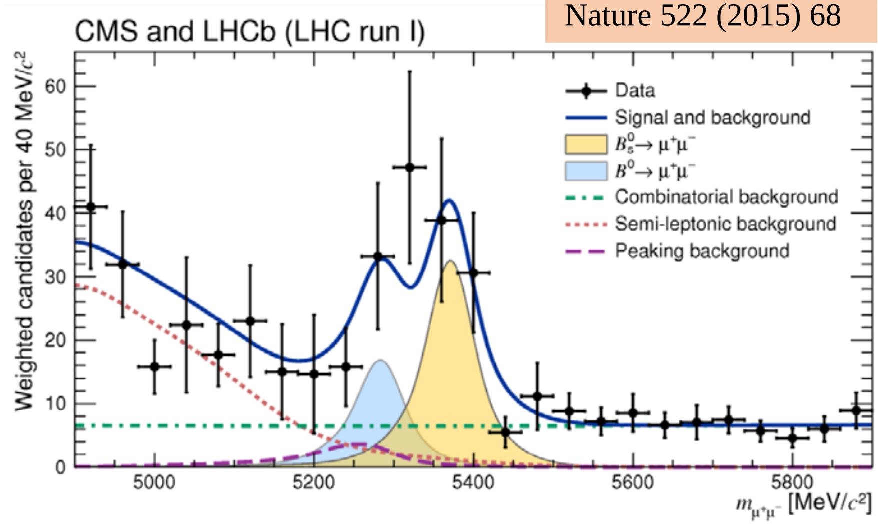


- LHCb+CMS Run I combination:

$$BF(B_s^0 \to \mu^+\mu^-) = (2.8^{+0.7}_{-0.6}) \times 10^{-9} \qquad 6.2\sigma$$
$$BF(B^0 \to \mu^+\mu^-) = (3.9^{+1.6}_{-1.4}) \times 10^{-10} \qquad 3.0\sigma$$

✓ Consistent with SM

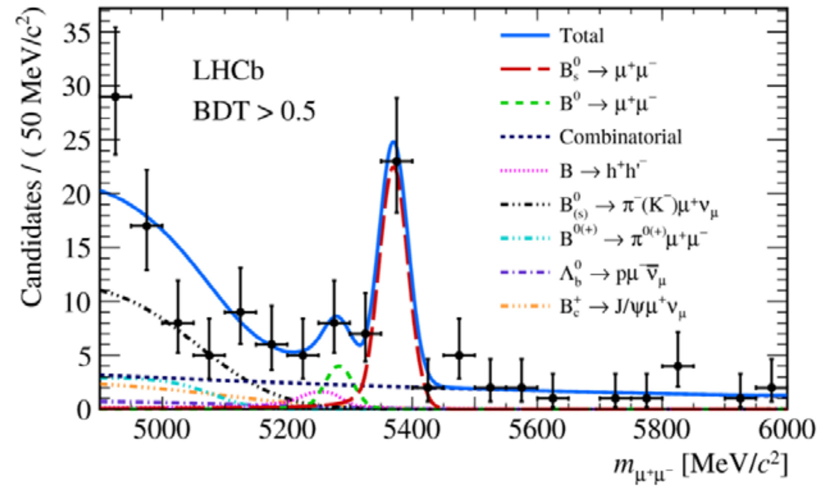
Nature 522 (2015) 68



PRL 118 (2017) 191801

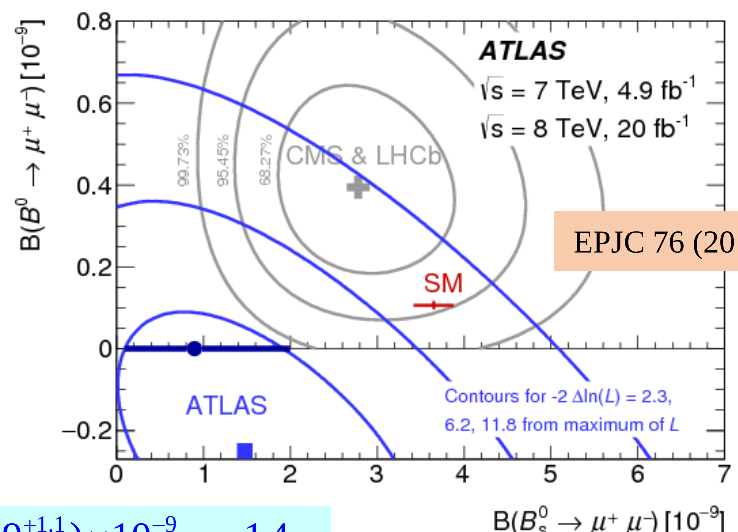
$B \to \mu\mu$ BF

- Recent new result from LHCb adding 1.4 fb^{-1} Run II data
- Same analysis strategy as previously
  - ✓ $B^+ \to J/\psi(\mu\mu)K^+$ and $B^0 \to K^+\pi^-$ normalization channels
  - ✓ Improved $B \to hh$ rejection, ~50% less
  - ✓ Improved BDT and signal isolation
- Also, first measurement from ATLAS

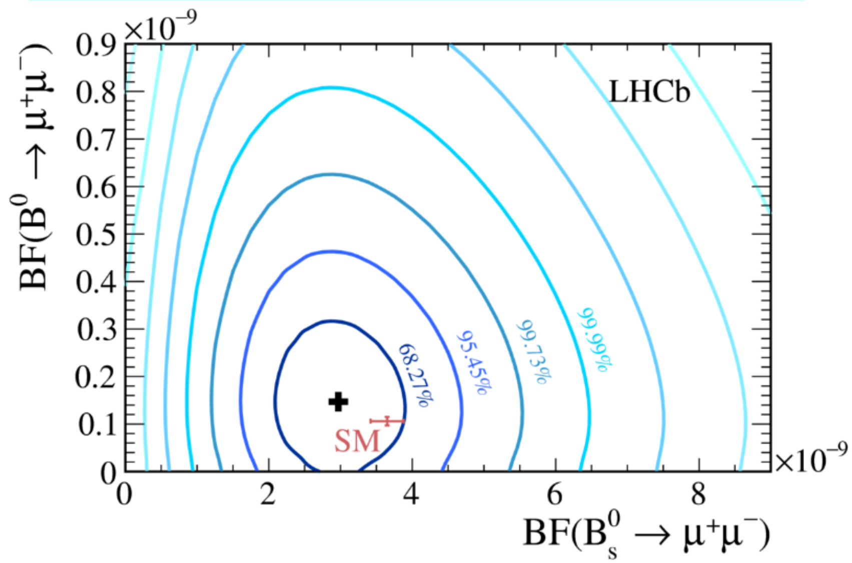


$BF(B_s^0 \to \mu^+\mu^-) = (3.0 \pm 0.6^{+0.3}_{-0.2}) \times 10^{-9}$ 7.8σ

$BF(B^0 \to \mu^+\mu^-) < 3.4 \times 10^{-10}$ @95%CL



EPJC 76 (2016) 513



$(0.9^{+1.1}_{-0.8}) \times 10^{-9}$ 1.4σ

$< 4.2 \times 10^{-10}$ @95%CL

B→μμ effective lifetime

PRL109 (2012) 041801

- Is the $B_s^0 \to \mu\mu$ decay CP-even or CP-odd?
  - ✓ The two B^0_s weak eigenstates differ by about 12% in lifetime, $\Delta\Gamma_s/\Gamma_s \approx 0.12$
  - ✓ In the SM only the H eigenstate (almost purely CP-odd) decays as $B^0_s \to \mu\mu$, i.e. $A^{\Delta} \approx +1$

$$A_{\Delta\Gamma} = \frac{\Gamma(B_s^H \to \mu^+\mu^-) - \Gamma(B_s^L \to \mu^+\mu^-)}{\Gamma(B_s^H \to \mu^+\mu^-) + \Gamma(B_s^L \to \mu^+\mu^-)}$$

  - ✓ Does not necessarily hold in NP scenarios
- Measurement of effective lifetime in $B_s^0 \to \mu\mu$

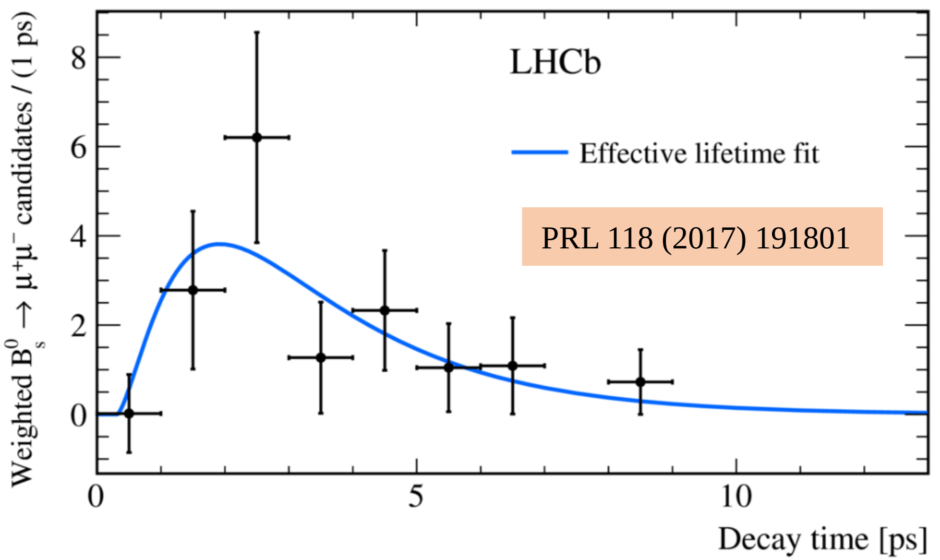
$$\Gamma_{B_s^0\to\mu\mu}(t) \propto e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) - A_{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma_s t}{2}\right)\right] \approx \exp(-\Gamma_{B_s^0\to\mu\mu} t)$$

$$\Gamma_{B_s^0\to\mu\mu} \approx \Gamma_s + \frac{A_{\Delta\Gamma}\Delta\Gamma_s}{2}$$

- $B^0 \to K^+\pi^-$ control mode
- First measurement (3+1.4 fb^{-1})

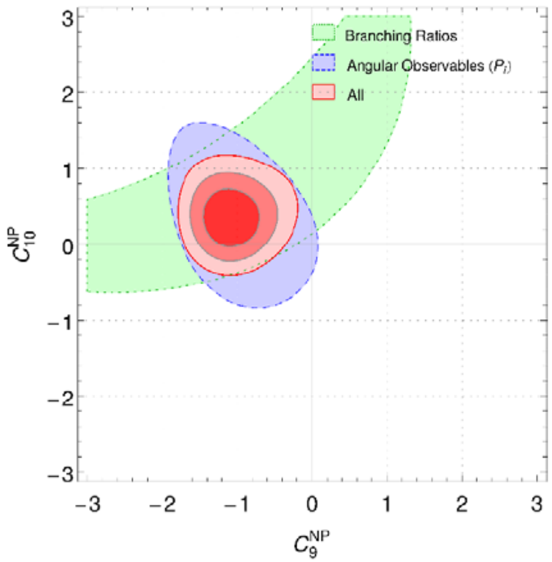
$$\tau_{B_s^0\to\mu\mu} = 2.04 \pm 0.44 \pm 0.05 \text{ ps}$$

  - ✓ Consistent with $A_{\Delta\Gamma} = +1$ ($A_{\Delta\Gamma} = -1$) at 1σ (1.4σ)

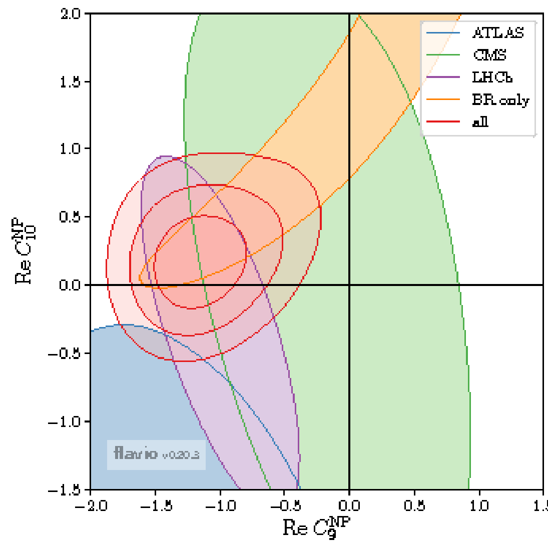


Global fits

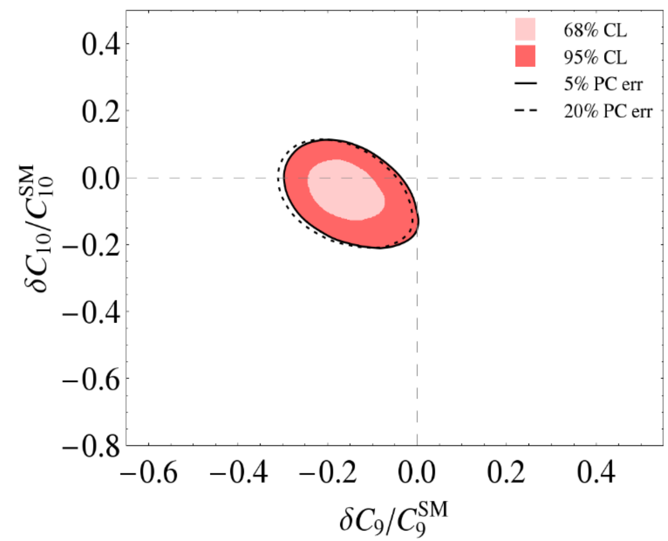
- Global fits using b→s*ll* (including LFU), B→μμ and b→sγ data, ~90 observables
- All global fits require an additional BSM contribution to accommodate the data, with a preference for NP in C_9 at ~4σ level



JHEP 06 (2016) 092



arXiv:1703.09189



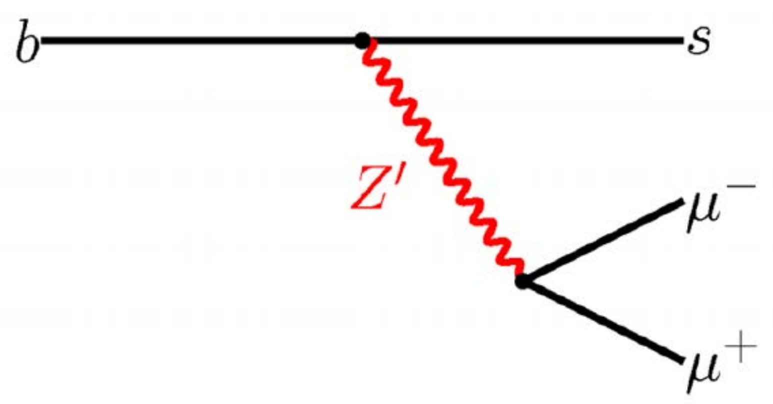
Nucl.Part.Phys.Proc. 285 (2017) 39

- Or there is a problem with the understanding of QCD, e.g. estimating correctly the contributions from charm loops?

Understanding effects from charm

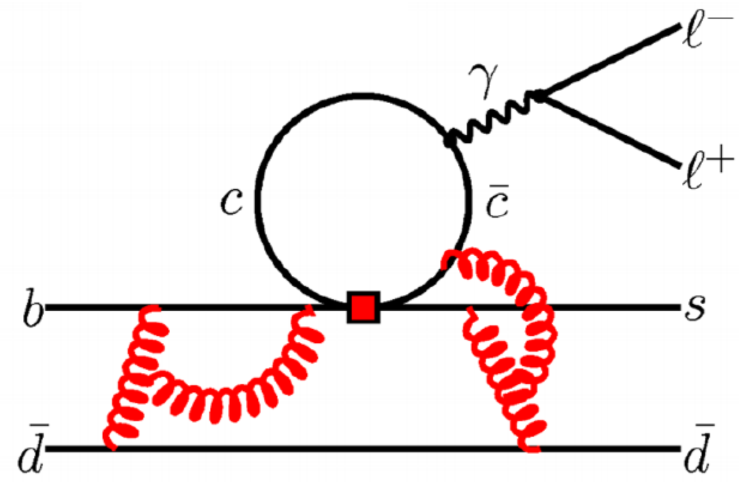
Prog. Part. Nucl. Phys. 92 (2017) 50

- Z', leptoquarks



$$C_9 + C_9^{\mathrm{NP}}$$

- Hadronic SM effects



$$C_9^{\mathrm{eff}} = C_9 + \sum_j \eta_j e^{i\delta_j} A_j(q^2)$$

Large long-distance charm resonance effects far from the resonances on the q^2 plane

- Measure the resonance effects in C_9 in an inclusive analysis

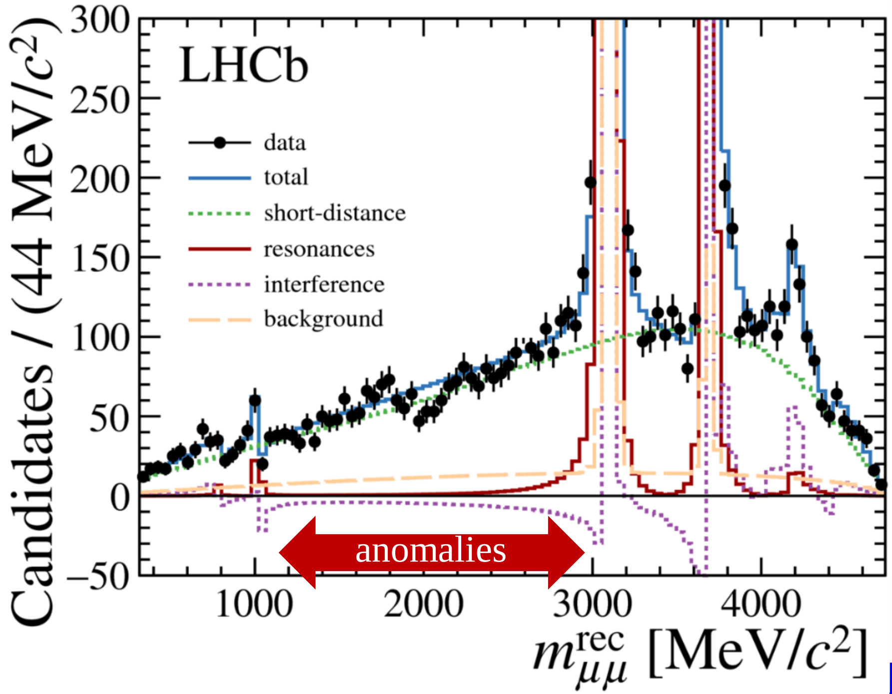
$$B^+ \to K^+\mu^+\mu^- \quad + \quad B^+ \to K^+ X_{c\bar{c}}(\mu^+\mu^-)$$

Measuring resonance effects in C_9

- Measure phase difference between short- and long-distance contributions to $B^+ \to K^+\mu\mu$ decays EPJC 77 (2017) 161
- Use expression of differential decay rate in terms of short- and long-distance contributions (depends on the Wilson coefficients)
  - ✓ Model resonances as RBW × relative scale and phase arXiv:1406.0566
  - ✓ $C_9^{\text{eff}} = C_9 + \sum_j \eta_j e^{i\delta_j} A_j(q^2)$

relative phase to C_9 | Breit-Wigner/ Flatté Φ(3770)

Resonance	
$\rho(770)$	$\psi(2S)$
$\omega(782)$	$\psi(3770)$
$\phi(1020)$	$\psi(4040)$
J/ψ	$\psi(4160)$
	$\psi(4415)$

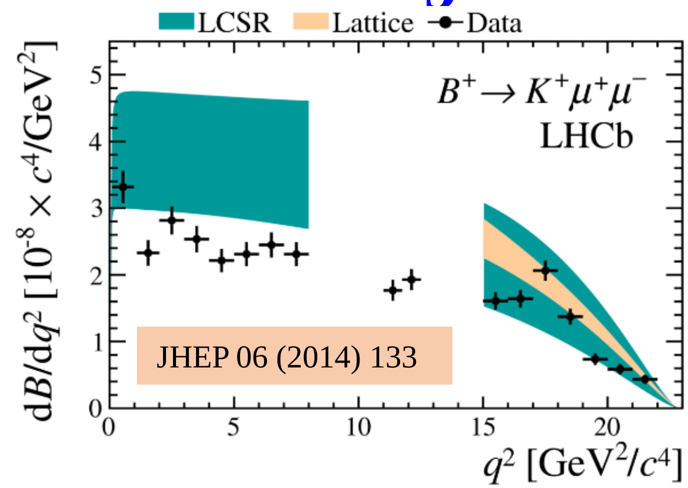


- Fit dimuon spectrum to obtain:
  - ✓ Relative amplitudes
  - ✓ C_9 and C_{10}

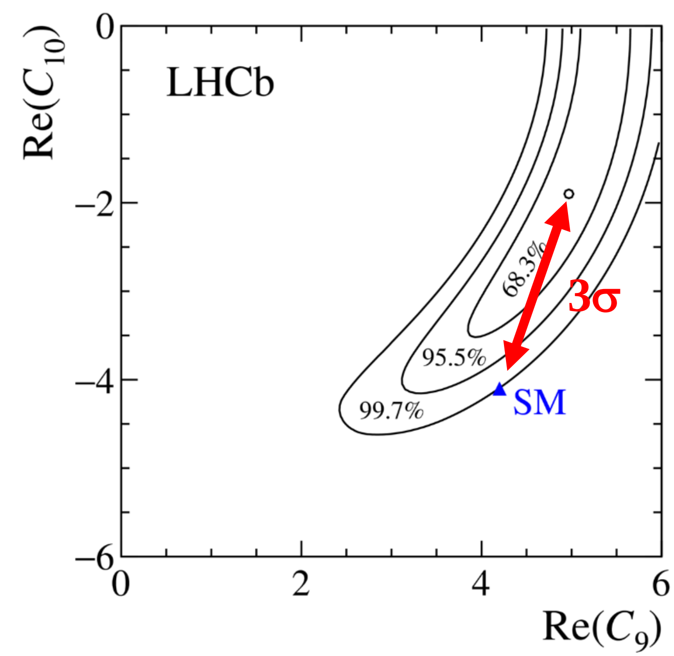
Measuring resonance effects in C_9

- The short-distance branching fraction agrees with the previous (exclusive) result:

$$BF(B^+ \to K^+ \mu^+ \mu^-) = (4.29 \pm 0.07 \pm 0.21) \times 10^{-7} \quad \text{old}$$
$$BF(B^+ \to K^+ \mu^+ \mu^-) = (4.37 \pm 0.15 \pm 0.23) \times 10^{-7} \quad \text{new}$$



- 1D (C_9,C_{10}=SM) fit:
  - ✓ C_9<SM (as the global fits)
- 2D (C_9,C_{10}) fit:
  - ✓ C_9>SM, C_{10}<SM
- No interference between penguin and J/ψ and ψ(2S) resonances ⇒ minimal effect below their pole mass
- Inclusive $B^0 \to K^*\mu\mu$ analysis under way



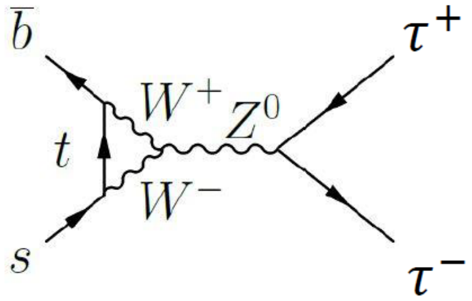
B→ττ

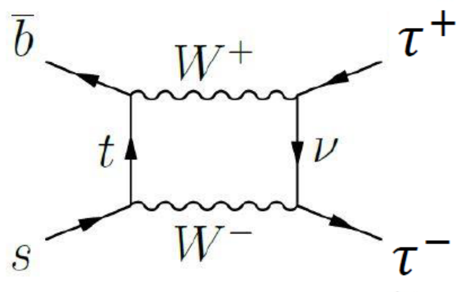
- Analogous to B→μμ, but much less helicity suppressed (lepton mass)

PRL112 (2014) 101801

$$BF(B_s^0 \to \tau^+\tau^-) = (7.73 \pm 0.49) \times 10^{-7}$$
$$BF(B^0 \to \tau^+\tau^-) = (2.22 \pm 0.19) \times 10^{-8}$$

  ✓ Sensitivity to NP suppressed compared to B→μμ



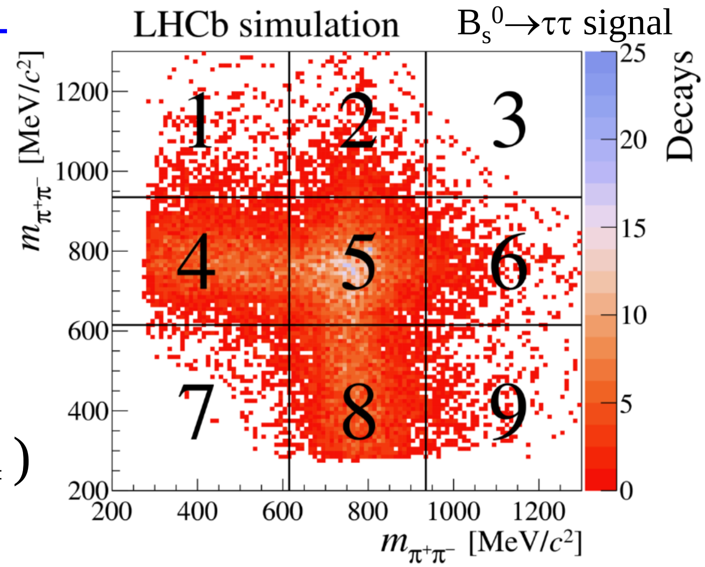


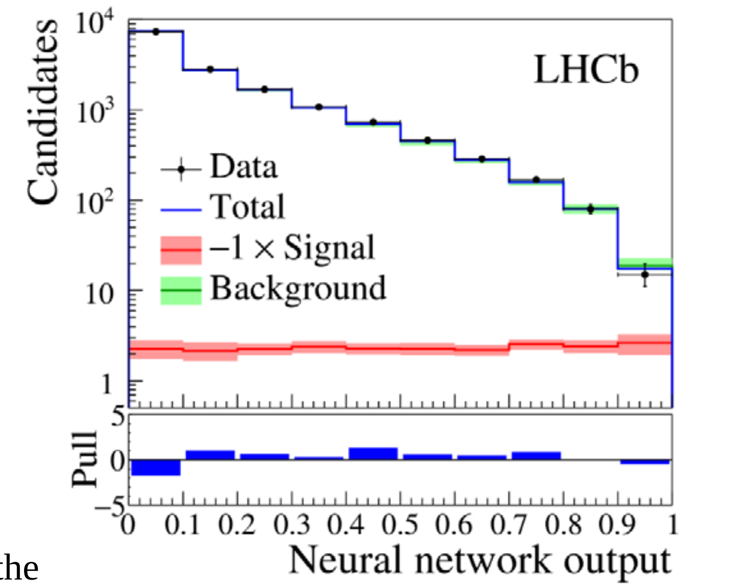
- With B→μμ can be used to test LFU
- τ leptons selected in $\tau^+ \to a_1^-(\rho^0\pi^-)\overline{\nu}_\tau \to \pi^+\pi^-\pi^+\overline{\nu}_\tau$
  ✓ Decay model tuned on CLEO data PRD61 (2000) 112002
- Experimentally very challenging due to two neutrinos in final state
- B^0_s and B^0 cannot be separated: assumption on one decay needed to extract limit on the other

$B \to \tau\tau$

arXiv:1703.02508

- Approximate reconstruction by exploiting geometrical, kinematical and topological (isolation) variables
- Definition of *signal*, *control* and *background* samples based on $(m_{\pi_1^\pm \pi_2^\mp}, m_{\pi_3^\pm \pi_2^\mp})$ of $\tau^\pm \to \pi_1^\pm \pi_2^\mp \pi_3^\pm \nu_\tau$ decays
  - ✓ Signal region: both τ in 5
  - ✓ Control region: one τ in 4 or 8, the other in 4, 5 or 8
- $B^0 \to D^+[K^-\pi^+\pi^+]D_s^-[K^+K^-\pi^-]$ used as calibration and normalization channel
- Signal extracted from NN fit in 5





$$BF(B_s^0 \to \tau^+\tau^-) < 6.8\times10^{-3}\ @\,95\%\mathrm{CL}$$
$$BF(B^0 \to \tau^+\tau^-) < 2.1\times10^{-3}\ @\,95\%\mathrm{CL}$$

Assuming no contributions from the other mode

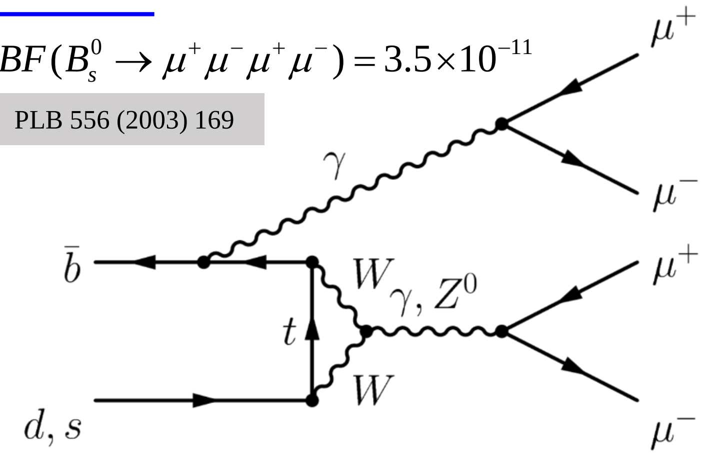
$$N_{B_s^0 \to \tau\tau} = -23 \pm 63 \pm 31$$

B→μμμμ

- $B^0 \to \mu^+\mu^-\mu^+\mu^-$ and $B^0_s \to \mu^+\mu^-\mu^+\mu^-$ strongly suppressed in the SM
- Decays can proceed via resonant (dominant) and non resonant modes
- BF can significantly be enhanced, up to ~10^{-4}
  - ✓ E.g. MSSM allows $B^0_{(s)} \to P(\mu^+\mu^-)S(\mu^+\mu^-)$, S and P sgoldstino particles

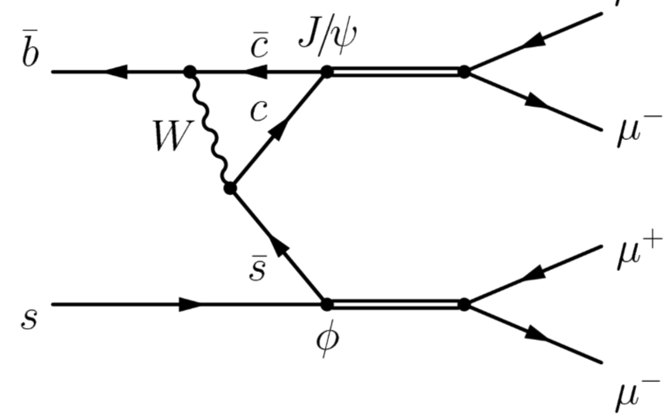
$BF(B^0_s \to \mu^+\mu^-\mu^+\mu^-) = 3.5\times10^{-11}$

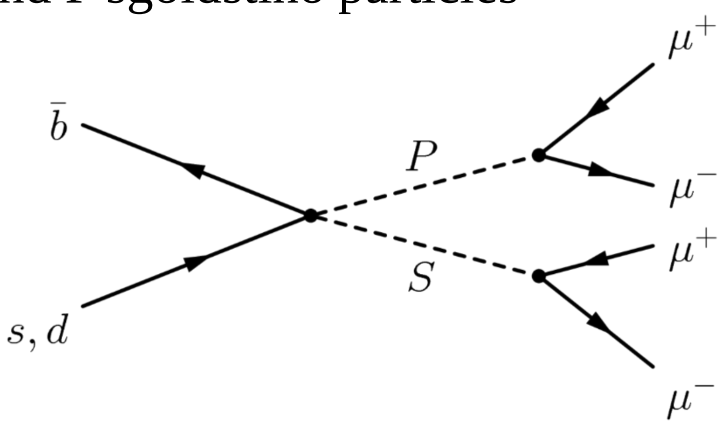
PLB 556 (2003) 169



$BF(B^0_s \to J/\psi(\mu^+\mu^-)\phi(\mu^+\mu^-)) = (1.83\pm0.18)\times10^{-8}$

ChPC 40 (2016) 1000001



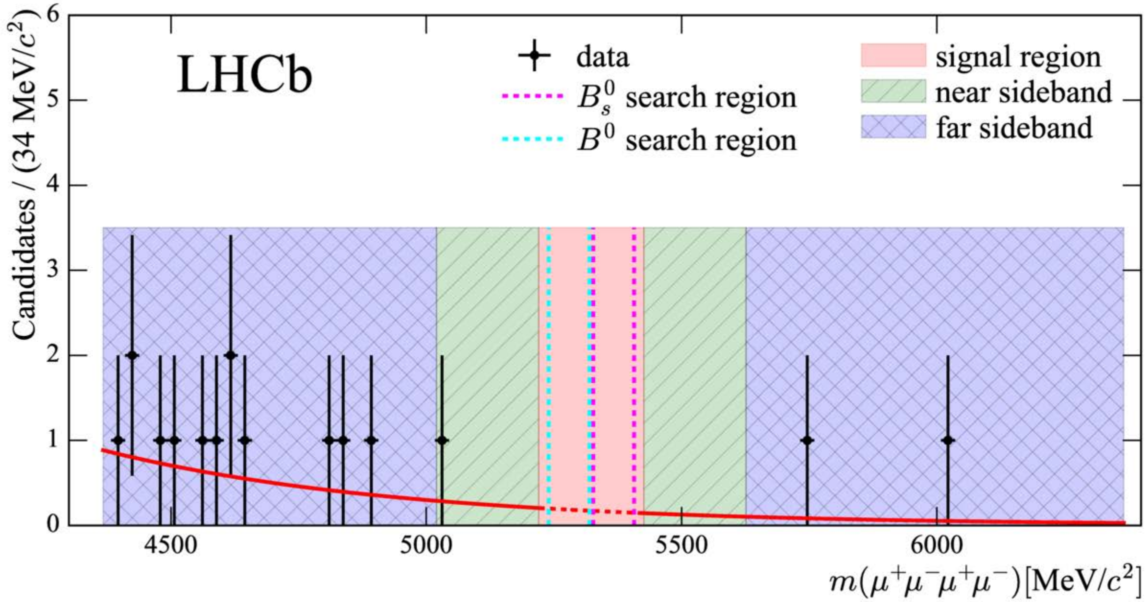


- Interest also related to possible resonant contribution in $\Sigma^+ \to p\mu^+\mu^-$

JHEP 03 (2017) 001

B→μμμμ

- Search for 4 muons originating from single vertex and far from the primary vertex
- J/ψ, ψ(2S) and ϕ mass vetoes
- $B^+ \to J/\psi(\mu\mu)K^+$ used as normalization channel
- 0 events, consistent with background expectation



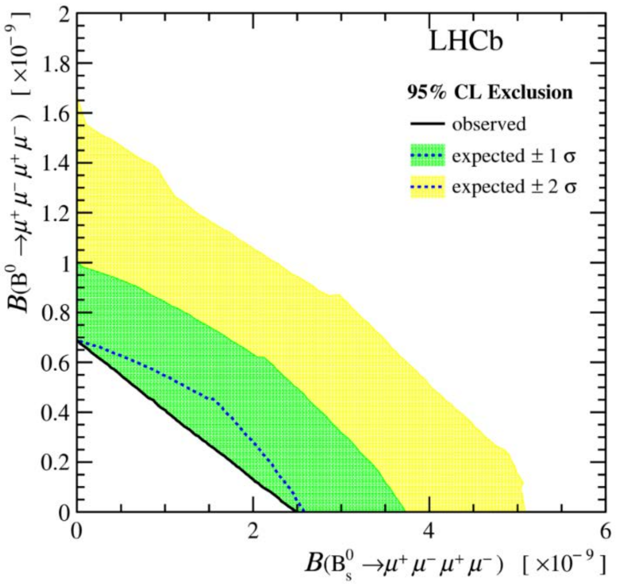
$$BF(B^0 \to \mu^+\mu^-\mu^+\mu^-) < 6.9\times10^{-10}\ @95\%CL$$

$$BF(B_s^0 \to \mu^+\mu^-\mu^+\mu^-) < 2.5\times10^{-9}\ @95\%CL$$

Assume $m_S = 2.6$ GeV/c^2 and $m_P = 241.3$ MeV/c^2

$$BF(B^0 \to S(\mu^+\mu^-)P(\mu^+\mu^-)) < 6.0\times10^{-10}$$

$$BF(B_s^0 \to S(\mu^+\mu^-)P(\mu^+\mu^-)) < 2.2\times10^{-9}$$



$K^0_s \rightarrow \mu\mu$

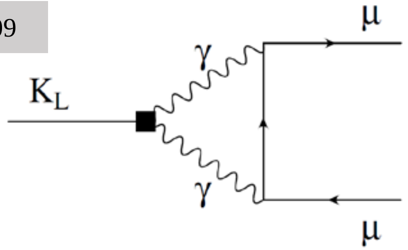
LHCb-PAPER-2017-009

- FCNC process, dominated by long distance contribution through $K^0 \rightarrow \gamma\gamma$
  - ✓ Can proceed only through P wave in absence of CPV
- SM prediction: $BF(K^0_s \rightarrow \mu^+\mu^-) = (5.0 \pm 1.5) \times 10^{-12}$
  - ✓ Can be enhanced by NP, e.g. new light scalars
- $K^0_s \rightarrow \pi^+\pi^-$ used as calibration and normalization channel (also main background)
- BDTs based on kinematic, geometric, topological and PID variables
- Fit $K^0_s \rightarrow \mu\mu$ mass in all BDTs × bins × trigger categories

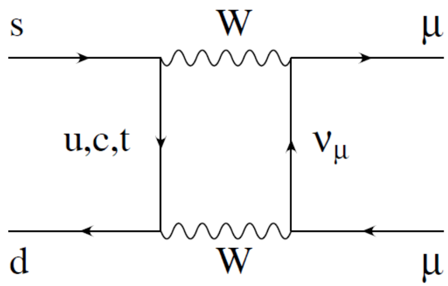
$$BF(K^0_s \rightarrow \mu^+\mu^-) < 1.0 \times 10^{-9} \text{ @ } 95\%\text{CL}$$

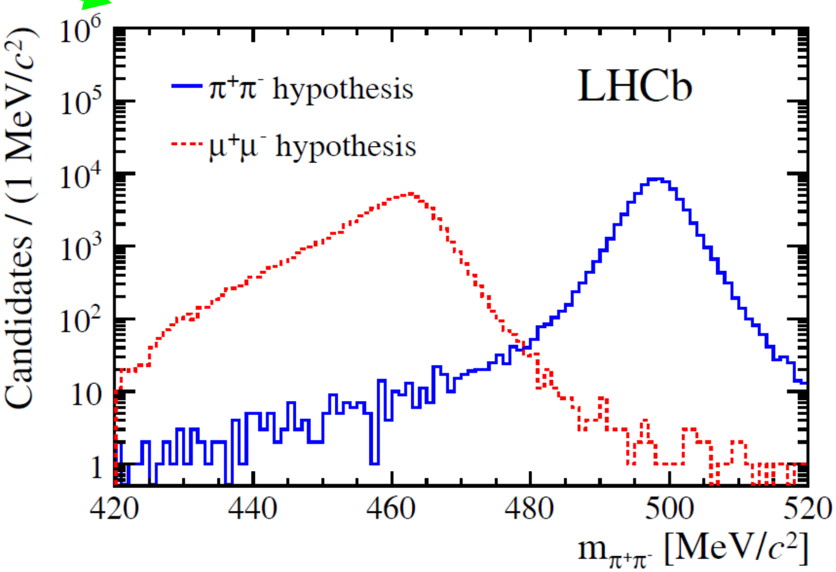
Long distance contribution

JHEP 01 (2004) 009



Example of short distance contribution



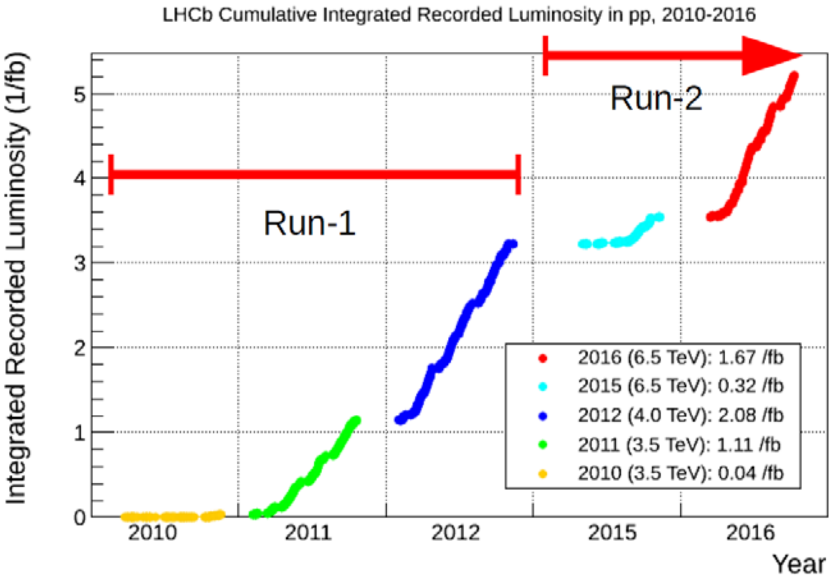


Conclusion

- Many FCNC decays analysed, few anomalies…
- Differential BF in $b \to s\mu\mu$ processes consistently lower than SM predictions at 2-3σ level, compatible with LFU results (P. Owen's talk)
- Anomaly at 3σ level for P'_5 angular observable in $B^0 \to K^{*0}\mu\mu$
- $B^0/B^0_s \to \mu\mu$ BF probed down to $10^{-9}/10^{-10}$ level, consistent with SM, challenging NP scenarios
- Proof of concept measurement of $B_s^0 \to \mu\mu$ effective lifetime
- Improved BF upper limit of $B^0_{(s)} \to \mu^+\mu^-\mu^+\mu^-$ and $K_s^0 \to \mu^+\mu^-$
- First search for $B^0_s \to \tau^+\tau^-$
- Global fits in tension with SM at ~4σ level

Prospects: short and long term

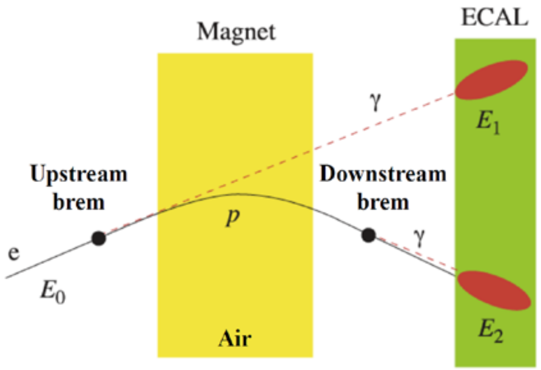
- Nearly all results from LHCb so far use Run I data, 3 fb^{-1} @ 7/8 TeV (only exceptions are $B\to\mu\mu$ and cross sections, use partial 2016 data)
- Run II data is taken @ 13 TeV, where b-hadron cross sections are nearly twice as high



- Current detector will be used until the end of Run II (2018)
  - ✓ ~factor 5 on Run I yield
  - ✓ Increasing precisions by a factor ~2.5 with Run II, no limiting systematic uncertainties foreseen
- The LHCb upgrade will take data for 6 years starting 2021
  - ✓ ~factor 25, ignoring trigger improvements
- A proposed LHCb upgrade phase II will take data after ~2030
  - ✓ ~factor 200

Prospects: angular analyses

- Given current landscape, try $b \to s\ell\ell$ angular analyses providing:
  - ✓ Orthogonal constraints
  - ✓ Measurements depending on different experimental effects
  - ✓ Measure size of long-distance charm effects
- $B^0 \to K^{*0}\mu\mu$
  - ✓ Run I has ~2400 signal candidates, expect ~10^4 in Run II
- $B^+ \to K^+\ell\ell$, sensitive to pseudo-scalar couplings
  - ✓ Run I has ~4800 signal candidates
- $\Lambda_b \to \Lambda\mu\mu$ offers additional observables giving orthogonal constraints compared to $B^0_{(s)} \to K^{(*)}(\phi)$ decay. Mostly relevant with LHCb upgrade
- Run II data allows for precise measurements with electrons
  - ✓ Expect similar yields to muons with Run I
  - ✓ Worse q^2 resolution and larger backgrounds, different experimental effects compared to LFU



Prospects: $B \to ll$

- A clear goal for Run II is the observation of the $B^0 \to \mu\mu$ decay
- Expected sensitivity $B^0_s \to \mu\mu$ BF for Run II
  - ✓ LHCb: ≈ 0.33×10^{-9}, as current systematic uncertainties. Main systematic source given by knowledge of f_s / f_d
  - ✓ CMS: ≈14% CMS-PAS-FTR-14-015
- $B^0_s \to \mu\mu$ effective lifetime needs 300 fb^{-1} to make important measurement
- $B^0_s \to \tau\tau$ would need huge enhancement factor to be visible

Prospects: message to go home

- Exciting program on rare decays, LFU and CPV ahead (Run II and beyond) (much more in P. Owen, O. Deschamps, J.J. Saborido's talks)
- LHCb is a multipurpose experiment, moving far beyond just a "dedicated" heavy flavour experiment
  - ✓ Electroweak precision measurements, e.g. $\sin 2\theta_W$
  - ✓ Exotic hadronic states, e.g. Pentaquarks
  - ✓ Search for long living particles, e.g. $B \to \chi K^*$, $\chi \to \mu\mu$
  - ✓ Central exclusive production, J/ψ production
  - ✓ Heavy ions, pPb PbPb
  - ✓ And the LHCb detector has a "fixed-target like" geometry and can work as such, e.g. SMOG
- The fully flexible, software-based trigger at 40 MHz starting in 2021 will dramatically improve most areas

Backup slides

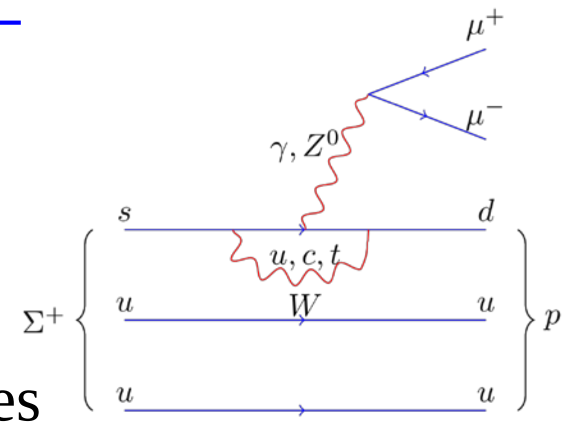
$\Sigma^+ \to p\mu\mu$

- FCNC process, in SM PRD 72 (2005) 074003

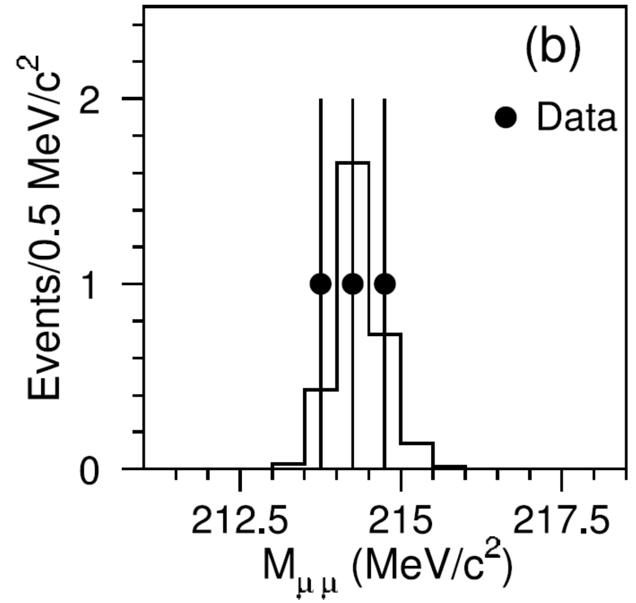
$$1.6\times10^{-8} < BF(\Sigma^+ \to p\mu^+\mu^-) < 9.0\times10^{-8}$$

- In 2005, HyperCP observed 3 signal candidates

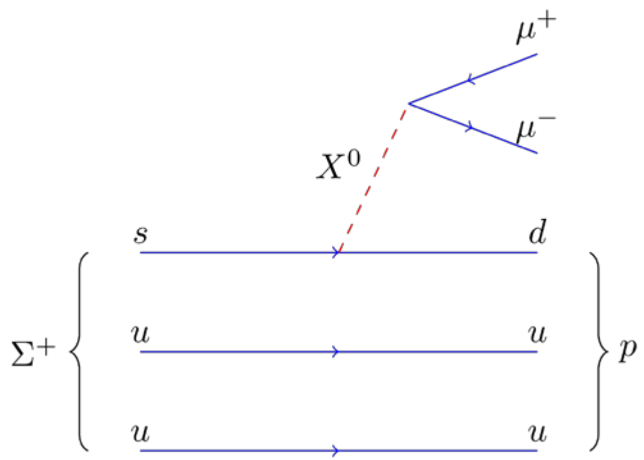
$$BF(\Sigma^+ \to p\mu^+\mu^-) = (8.6^{+6.6}_{-5.4} \pm 5.5)\times10^{-8}$$



PRL 94 (2005) 021801



- Very similar dimuon mass
  - ✓ Indication of $\Sigma^+ \to pX^0(\mu^+\mu^-)$?

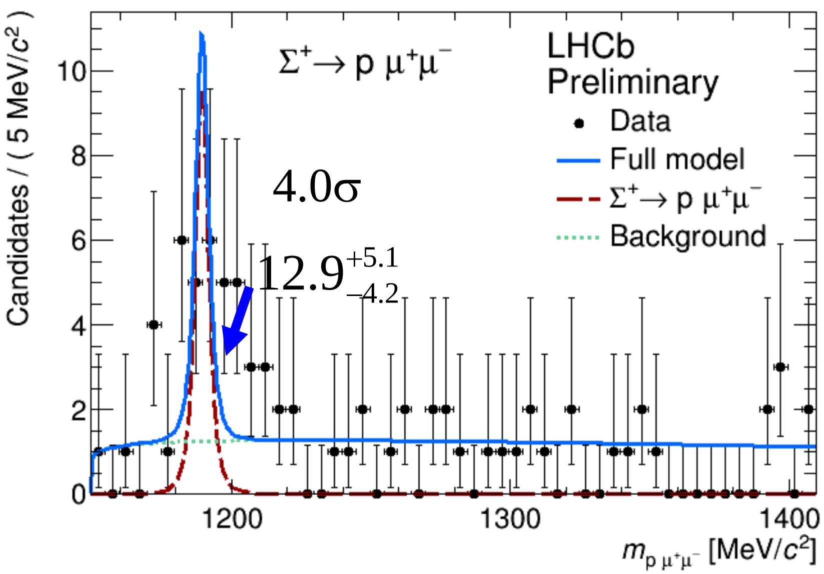


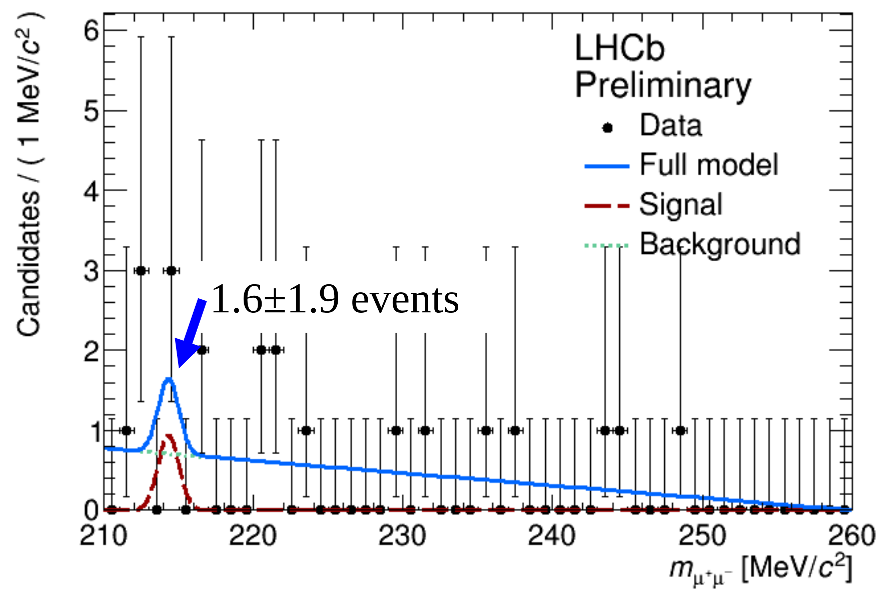
Resonance mass would be 214.3±0.5 MeV/c²

$\Sigma^+ \to p\mu\mu$

- The $\Sigma^+ \to p\mu^+\mu^-$ decay has been confirmed by LHCb
- $K^+ \to \pi^+\pi^+\pi^-$ and $\Sigma^+ \to p\pi^0$ used as calibration and normalization channels
- 13 events, 4.0σ evidence
- No enhancement at m(μμ) = 214 MeV/c²

LHCb-CONF-2016-013





LHCb status and prospects

- Run I: recorded 1 and 2 fb^{-1} at 7 and 8 TeV, respectively
- Run II: recorded 2 fb^{-1} at 13 TeV by end 2016, expected 8 fb^{-1} by end 2018
- B-hadron cross section in LHCb acceptance doubled at Run II energy:

$$\frac{\sigma(pp \to b\bar{b}X \ @13\ \text{TeV})}{\sigma(pp \to b\bar{b}X \ @7\ \text{TeV})} = 2.14 \pm 0.02 \pm 0.13$$

PRL 118 (2017) 052002

- B-hadron events recorded by end 2016 (ignoring trigger improvements):

$$\frac{N_{b-\text{hadrons}}(\text{Run I} + 2015\text{-}16)}{N_{b-\text{hadrons}}(\text{Run I})} \approx 2.4$$

  ✓ Statistical uncertainties ÷1.5

- B-hadron events expected after Run II completion (end 2018):

$$\frac{N_{b-\text{hadrons}}(\text{Run I} + \text{Run II})}{N_{b-\text{hadrons}}(\text{Run I})} \approx 6.7$$

  ✓ Statistical uncertainties ÷2.6