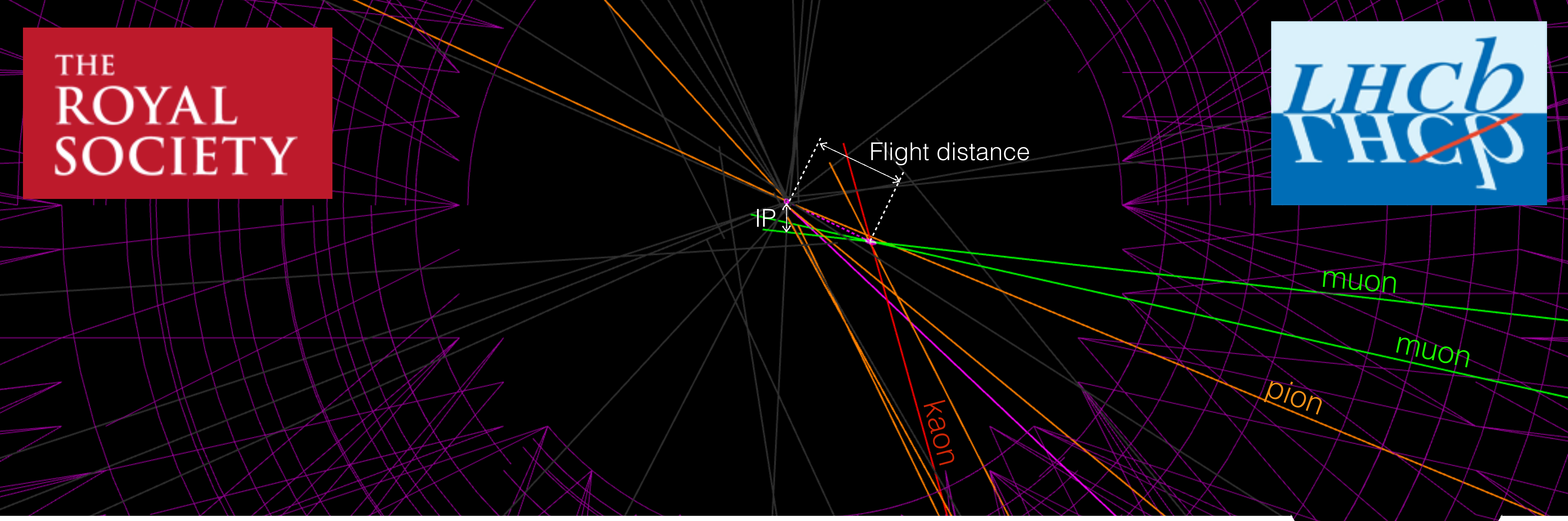


Electroweak Penguin Decays at LHCb

T. Blake for the LHCb collaboration

ICHEP 2018, Seoul

Outline

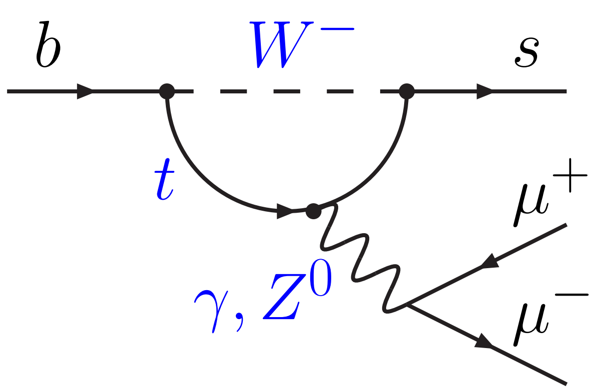
- Branching fraction and angular distribution of $b\to s\mu^+\mu^-$ processes:
  - Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$ (based on 3 fb^{-1}).
  - Angular analysis of $\Lambda_b \to \Lambda\mu^+\mu^-$ (based on 5 fb^{-1})
- Branching fraction of $b\to d\mu^+\mu^-$ processes:
  - Evidence for $B_s \to \overline{K}^{*0}\mu^+\mu^-$ (based on 4.6 fb^{-1})

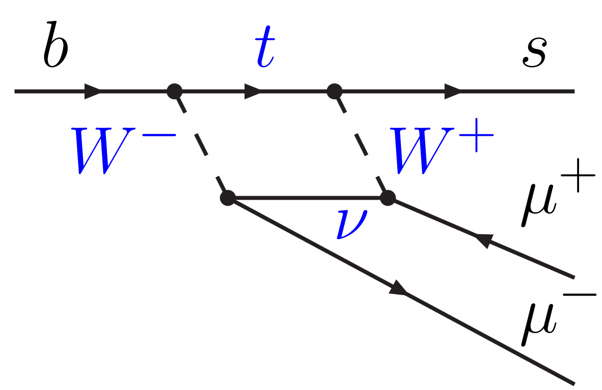
More information can be found at

http://lhcbproject.web.cern.ch/lhcbproject/Publications/LHCbProjectPublic/Summary_RD.html

Electroweak penguin decays

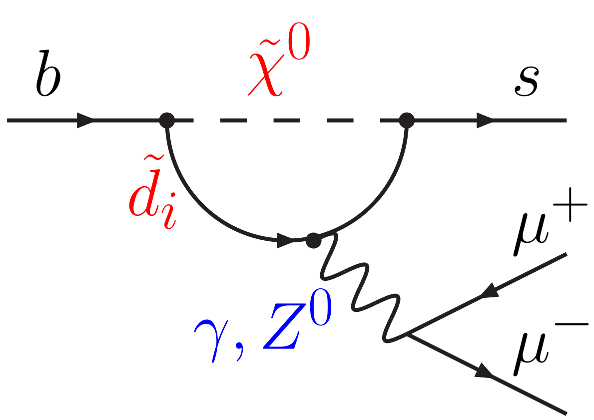
- Flavour changing neutral current transitions that only occur at loop order (and beyond) in the SM.

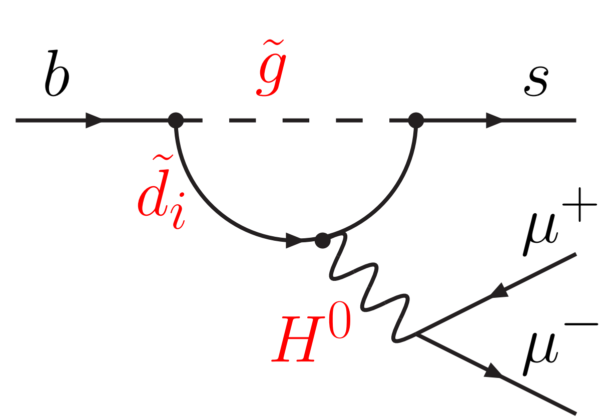


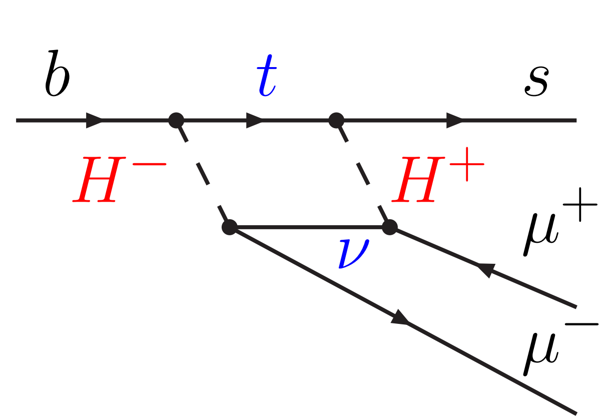


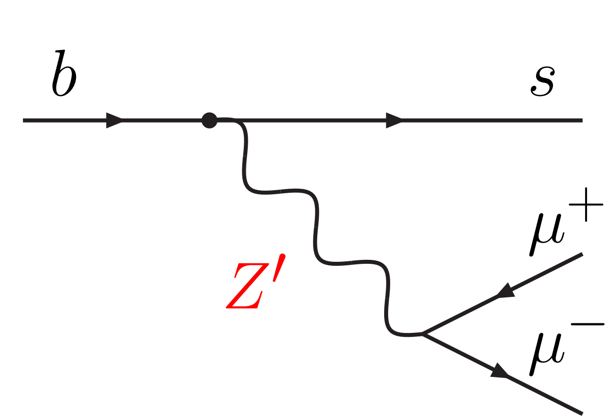
SM diagrams involve the charged current interaction.

- New particles can also contribute:



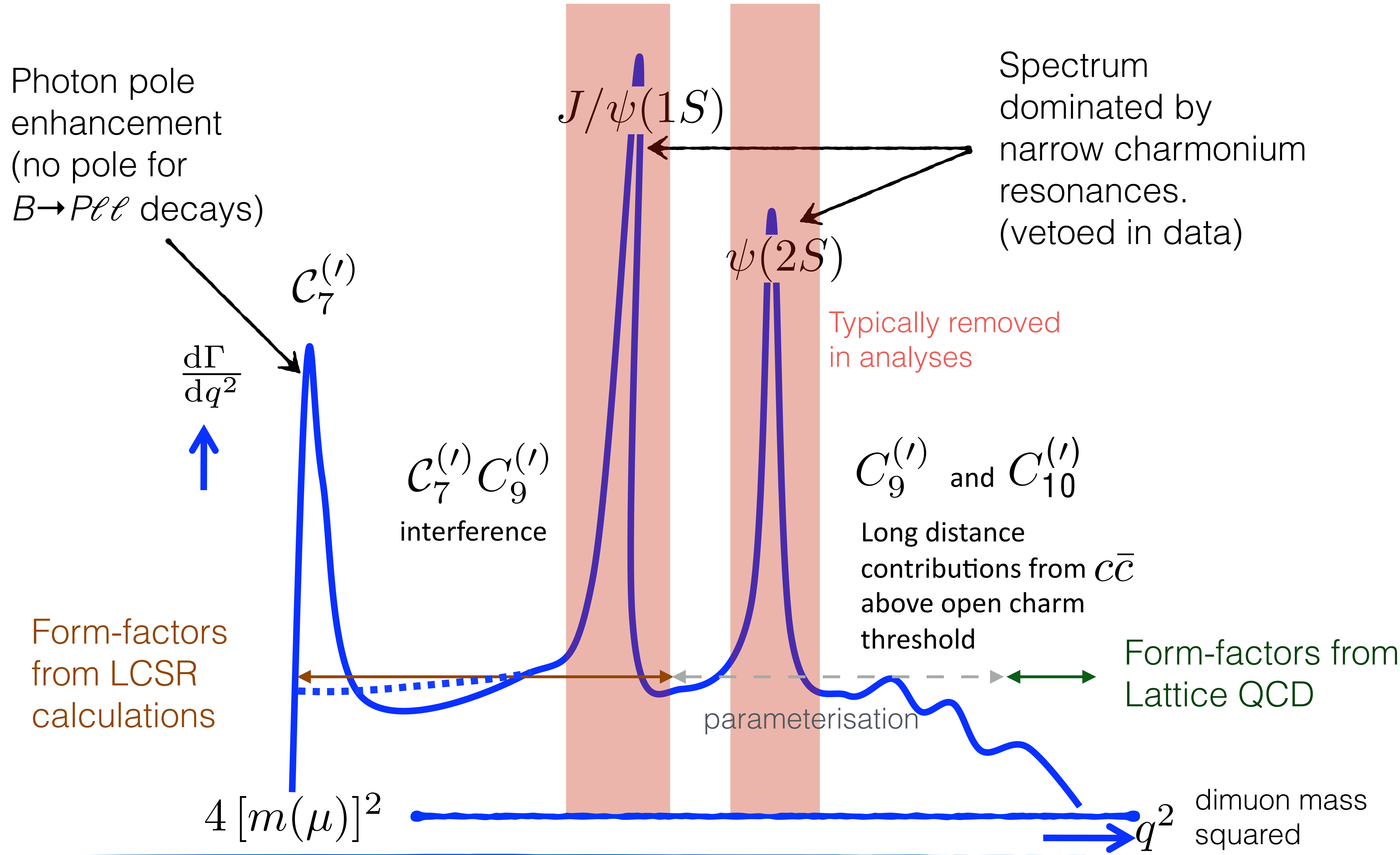






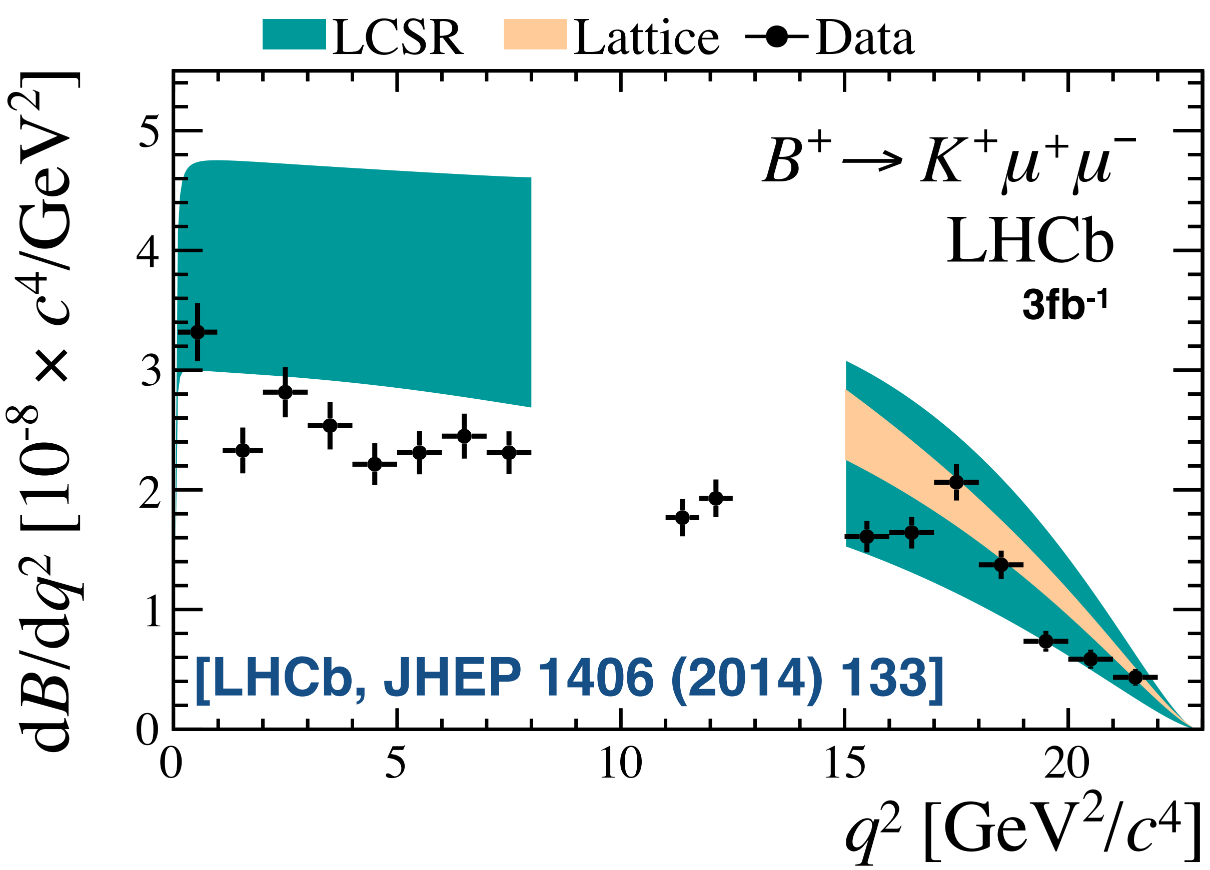
enhancing/suppressing decay rates, introducing new sources of *CP* violation or modifying the angular distribution of the final-state particles.

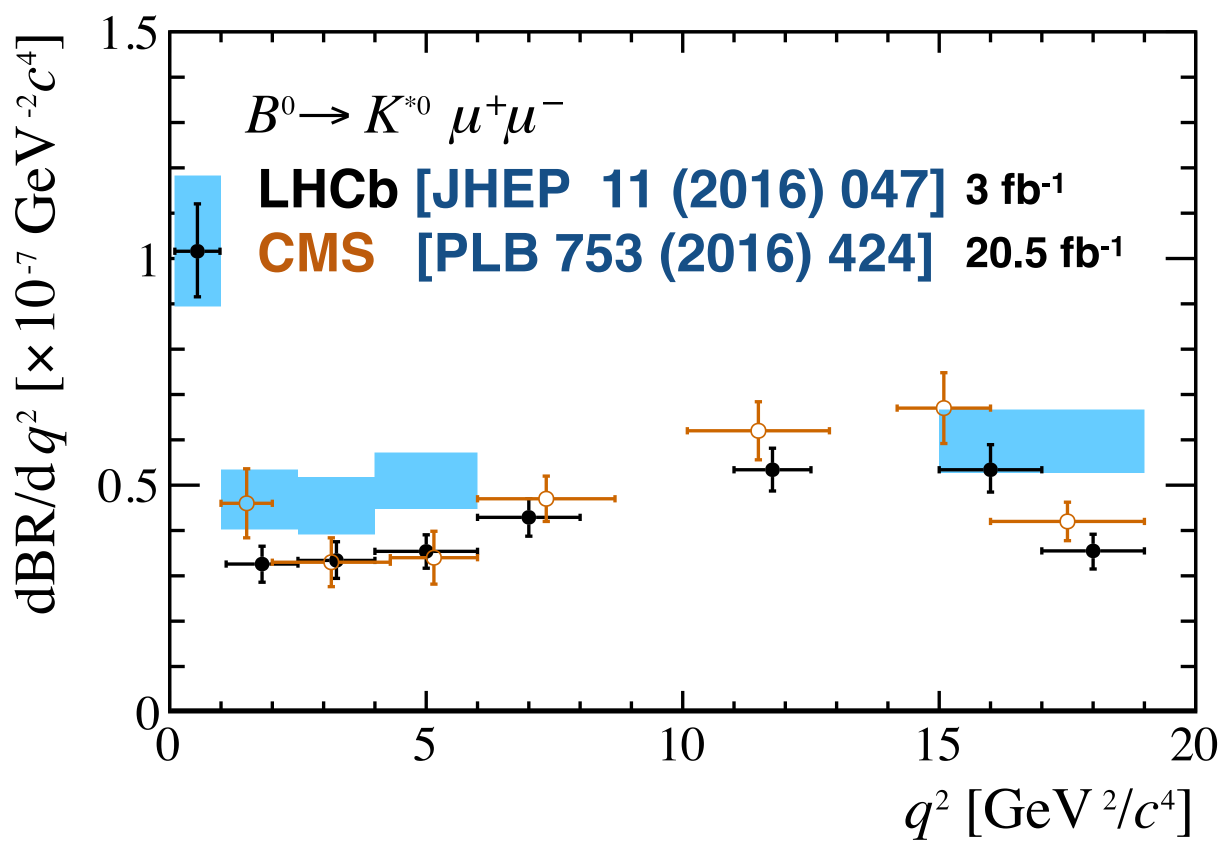
Expected dΓ/dq^2 spectrum



Branching fraction measurements

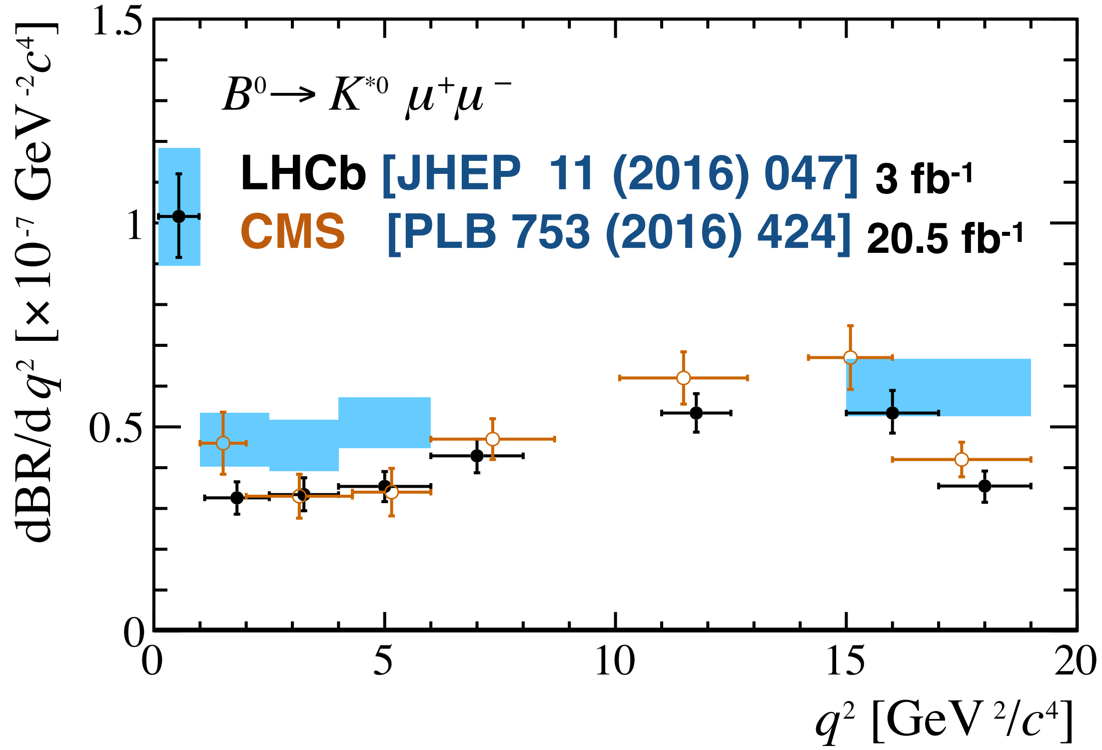
- We already have precise measurements of branching fractions from the Run1 data, with at least comparable precision to SM expectations:

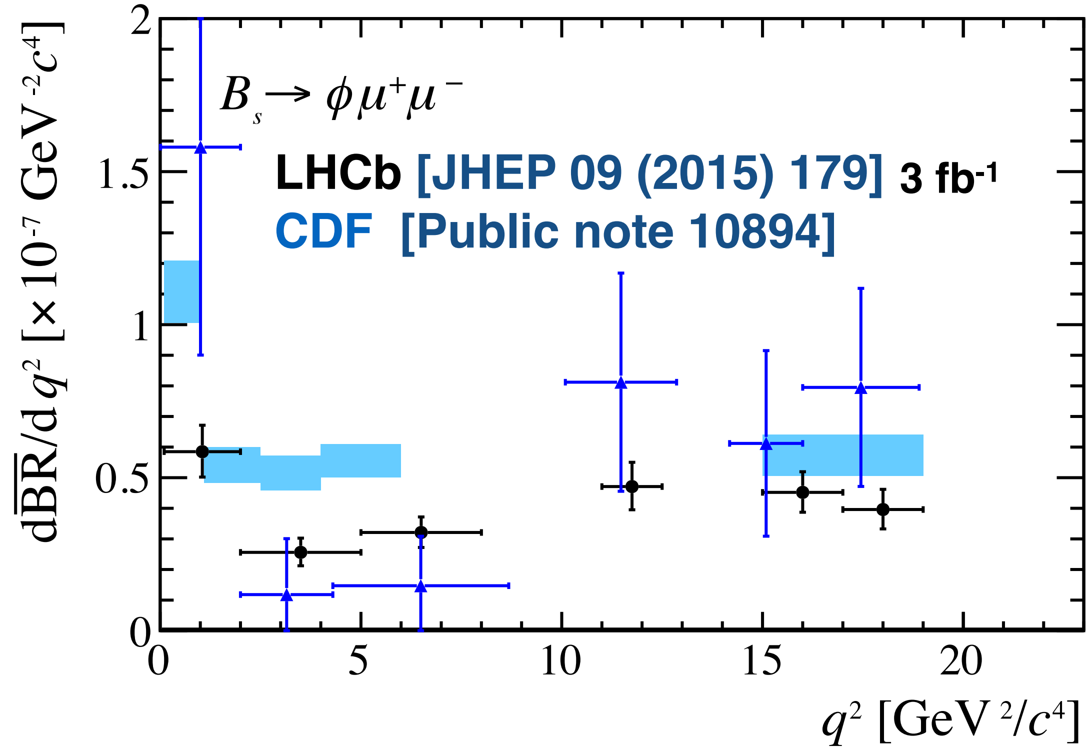


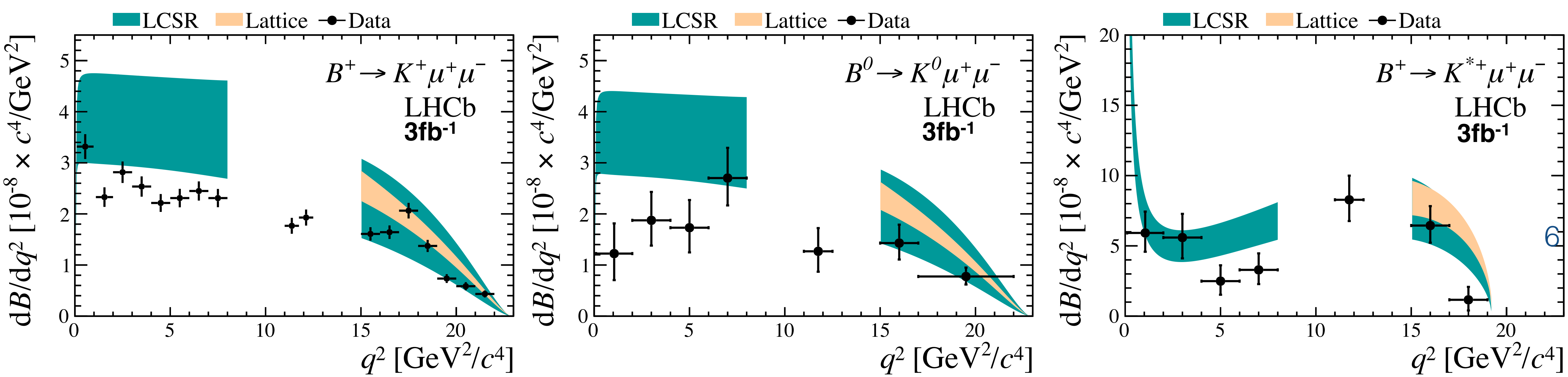


- SM predictions have large theoretical uncertainties from hadronic form factors (3 for $B \to K$ and 7 for $B \to K^*$ decays). For details see **[Bobeth et al JHEP 01 (2012) 107] [Bouchard et al. PRL111 (2013) 162002] [Altmannshofer & Straub, EPJC (2015) 75 382]**.

Branching fraction measurements







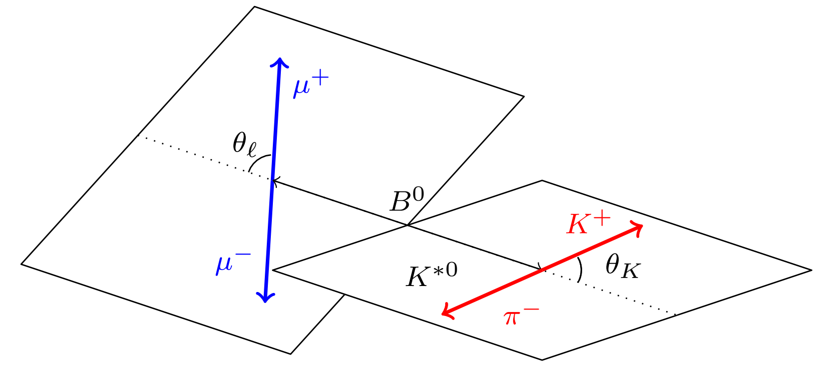
[JHEP 1406 (2014) 133]

Measure smaller branching fractions than predicted by the SM

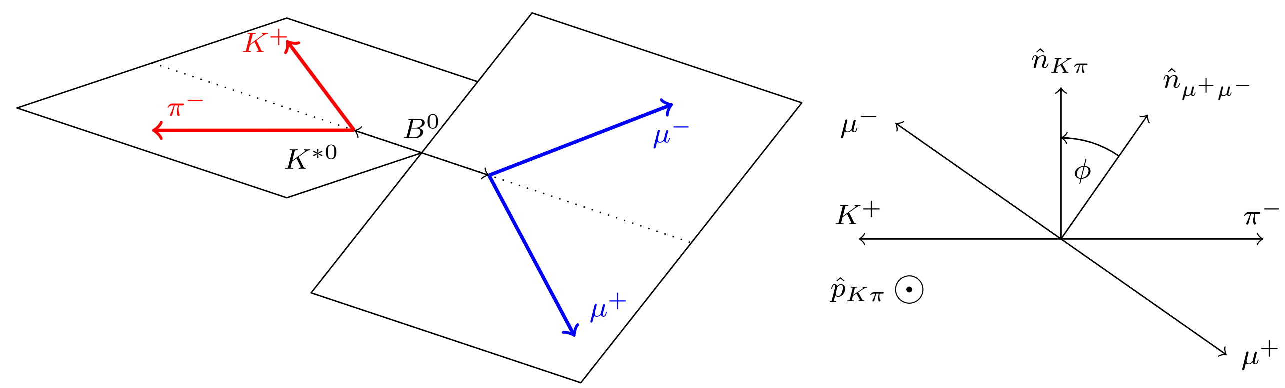
Angular observables

- Multibody final-states:
  - ➡ Angular distribution provides many observables that are sensitive to BSM physics.
  - ➡ Constraints are orthogonal to branching fraction measurements, both in their impact in global fits and in terms of experimental uncertainties.

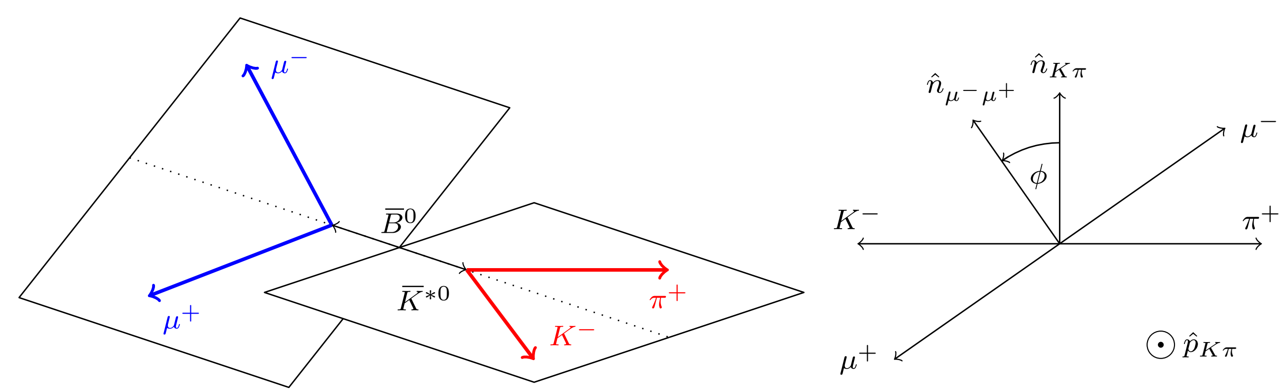
eg $B \to K^{*0}\mu^+\mu^-$ decay described by three angles and q^2.



(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 $\overline{B}^0$ decay

$B^0 \to K^{*0}\mu^+\mu^-$ angular distribution

Complex angular distribution:

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

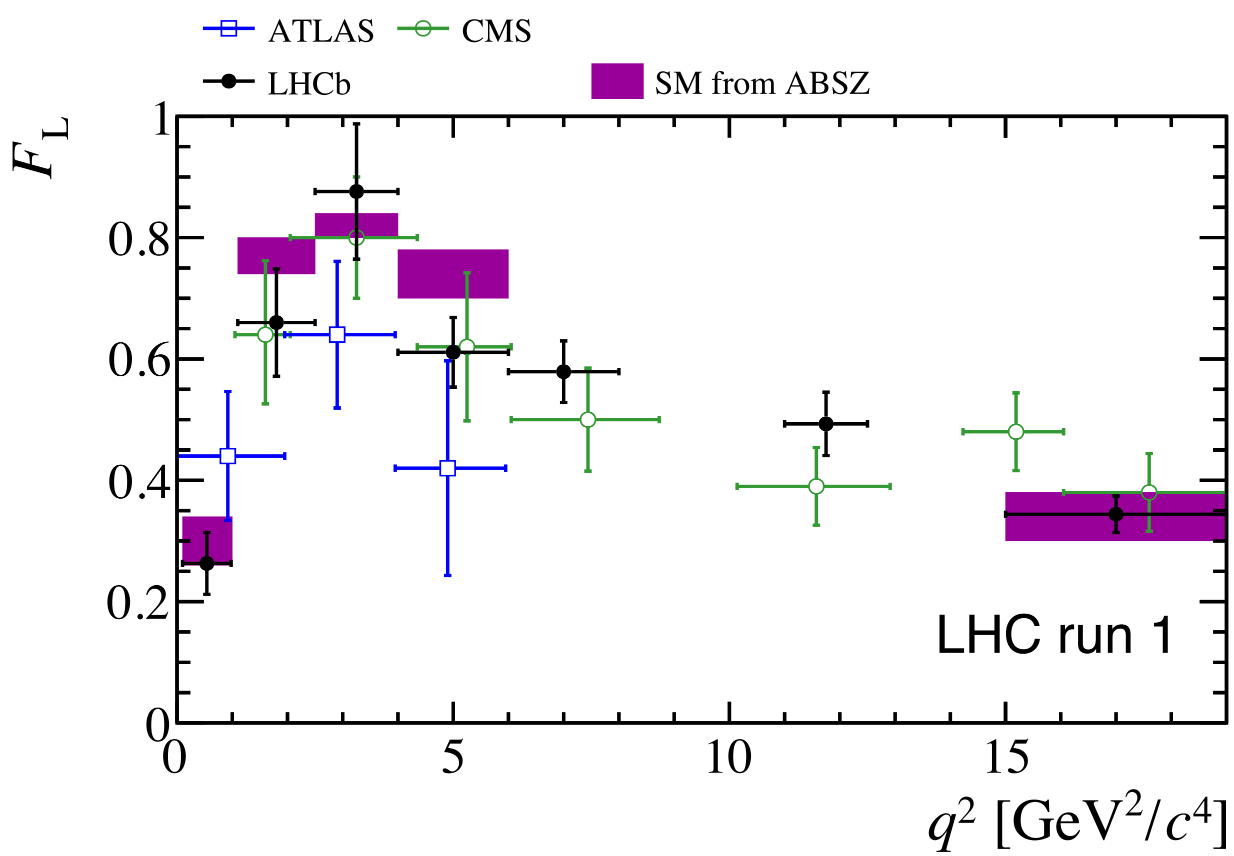
fraction of longitudinal polarisation of the K^*

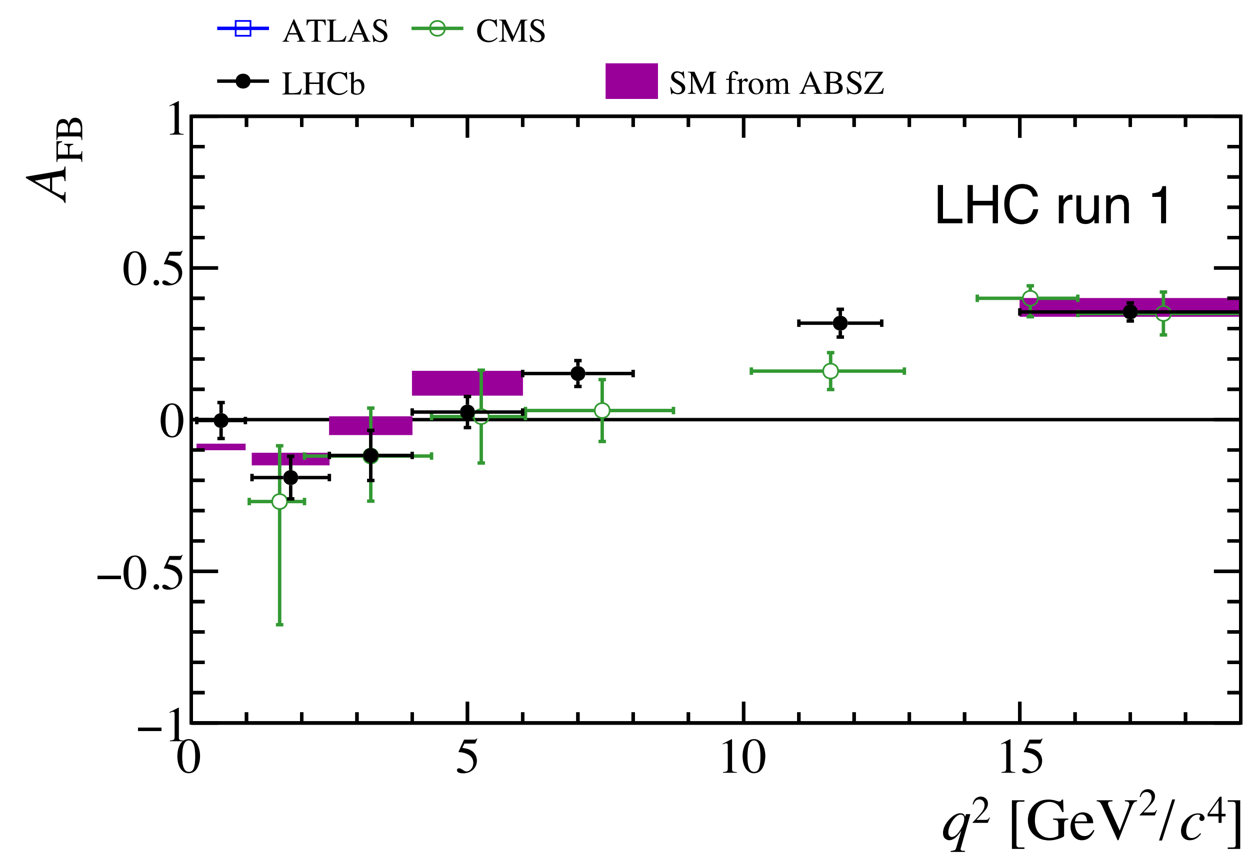
forward-backward asymmetry of the dilepton system

The observables depend on form-factors for the $B \to K^*$ transition plus the underlying short distance physics (Wilson coefficients).

Experiments can reduce the complexity by folding the angular distribution, see **[LHCb, PRL 111 (2013) 191801]**

$B^0 \to K^{*0}\mu^+\mu^-$ angular observables





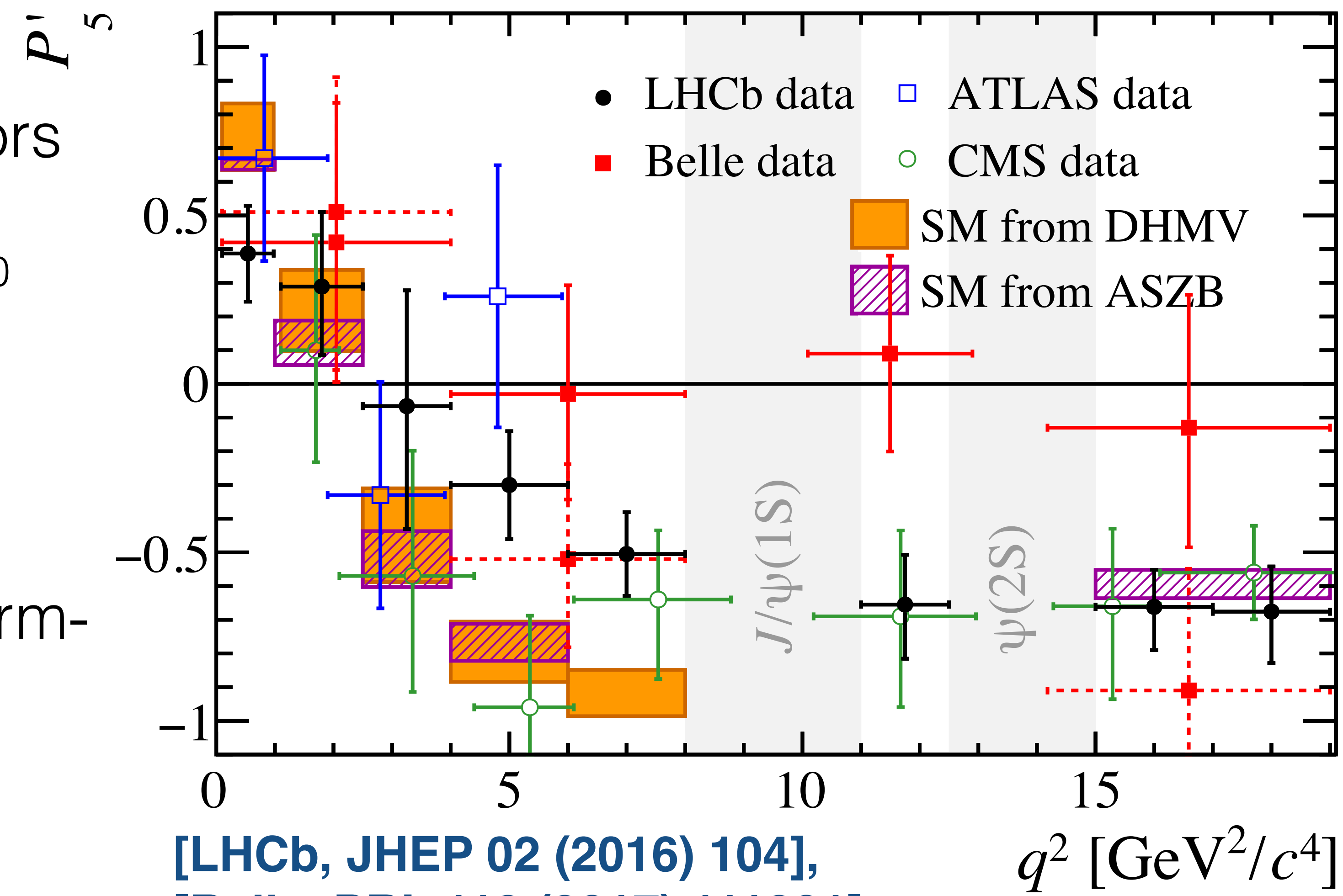
- Overlaying results for F_L and A_{FB} from LHCb **[JHEP 02 (2016) 104]** , CMS **[PLB 753 (2016) 424]** and ATLAS **[ATLAS-CONF-2017-023]**.

- SM predictions based on
  [Altmannshofer & Straub, EPJC 75 (2015) 382]
  [LCSR form-factors from Bharucha, Straub & Zwicky, JHEP 08 (2016) 98]
  [Lattice form-factors from Horgan, Liu, Meinel & Wingate arXiv:1501.00367] } Joint fit performed

Form-factor “free” observables

- In QCD factorisation/SCET there are only two form-factors
  - ➡ One is associated with A_0 and the other $A_{||}$ and $A_{\perp}$.
- Can then construct ratios of observables which are independent of these soft form-factors at leading order, e.g.

$$P_5' = S_5/\sqrt{F_{\rm L}(1 - F_{\rm L})}$$



[LHCb, JHEP 02 (2016) 104], [Belle, PRL 118 (2017) 111801], [ATLAS-CONF-2017-023], [CMS, PLB 781 (2018) 517].

- P'_5 is one of a set of so-called form-factor free observables that can be measured **[Descotes-Genon et al. JHEP 1204 (2012) 104]**.

Effective theory

- Can write a Hamiltonian for an effective theory of *b*→*s* processes:

Wilson coefficient (integrating out scales above *μ*)

Local 4 fermion operators with different Lorentz structures

$$\mathcal{H}_{\text{eff}} = -\frac{4\,G_F}{\sqrt{2}} V_{tb} V_{ts}^{*} \frac{\alpha_e}{4\pi} \sum_i C_i(\mu) \mathcal{O}_i(\mu),$$

$$\Delta\mathcal{H}_{\text{eff}} = \frac{\kappa_{\text{NP}}}{\Lambda_{\text{NP}}^2} \mathcal{O}_{\text{NP}}$$

NP scale

NP can modify SM contribution or introduce new operators

κ_{NP} can have all/some/none of the suppression of the SM, e.g MFV inherits SM CKM suppression.

c.f. Fermi theory of weak interaction where at low energies:

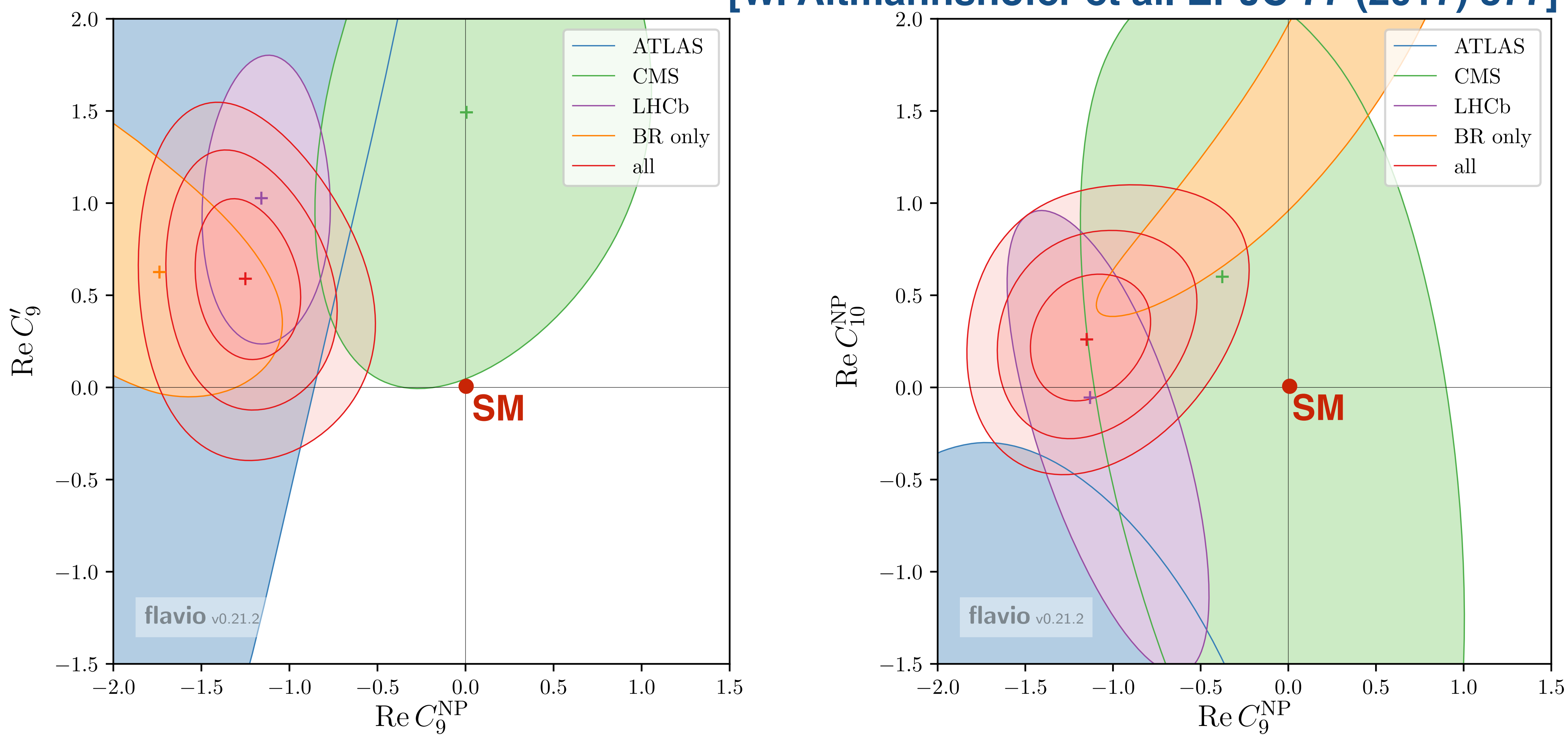
$$\lim_{q^2 \to 0} \left(\frac{g^2}{m_W^2 - q^2} \right) = \frac{g^2}{m_W^2}$$

i.e. the full theory can be replaced by a 4-fermion operator and a coupling constant, G_F.

Global fits

- Several attempts to interpret our results through global fits to $b \to s$ data.

[W. Altmannshofer et al. EPJC 77 (2017) 377]



Data are consistent between experiments/measurements and favour a modified vector coupling ($C_9^{NP} \neq 0$) at 4-5σ.

$\Lambda_b \to \Lambda\mu^+\mu^-$ decay

- First observed by the CDF collaboration in **[PRL 107 (2011) 201802]**
- Decay has unique phenomenology:
  - ➡ Diquark pair as a spectator rather than single quark;
  - ➡ Λ_b can be produced polarised in *pp* collisions;
  - ➡ and the Λ baryon decays via the weak interaction.
- Based on **[JHEP 06 (2015) 115]**, expect signal predominantly at low hadronic-recoil ($15<q^2<20\ \mathrm{GeV}^2/c^4$).

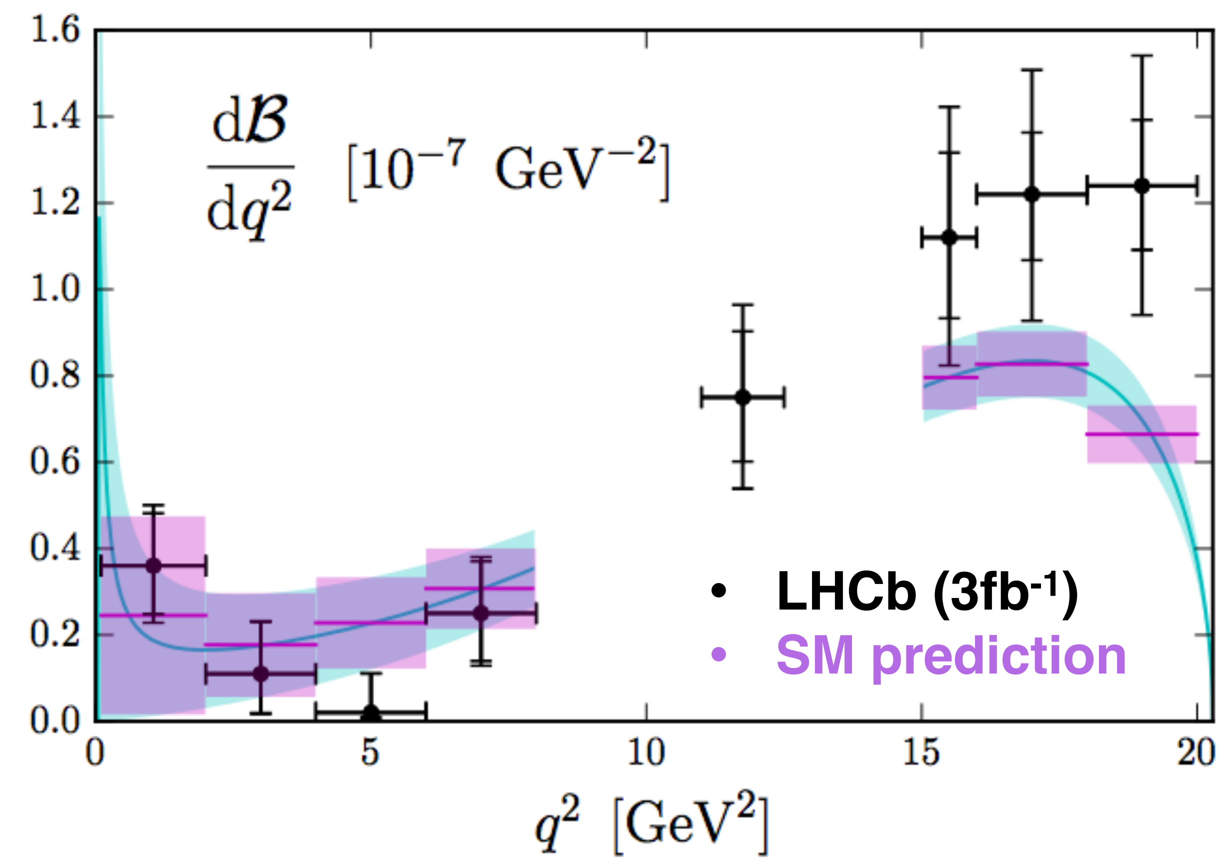
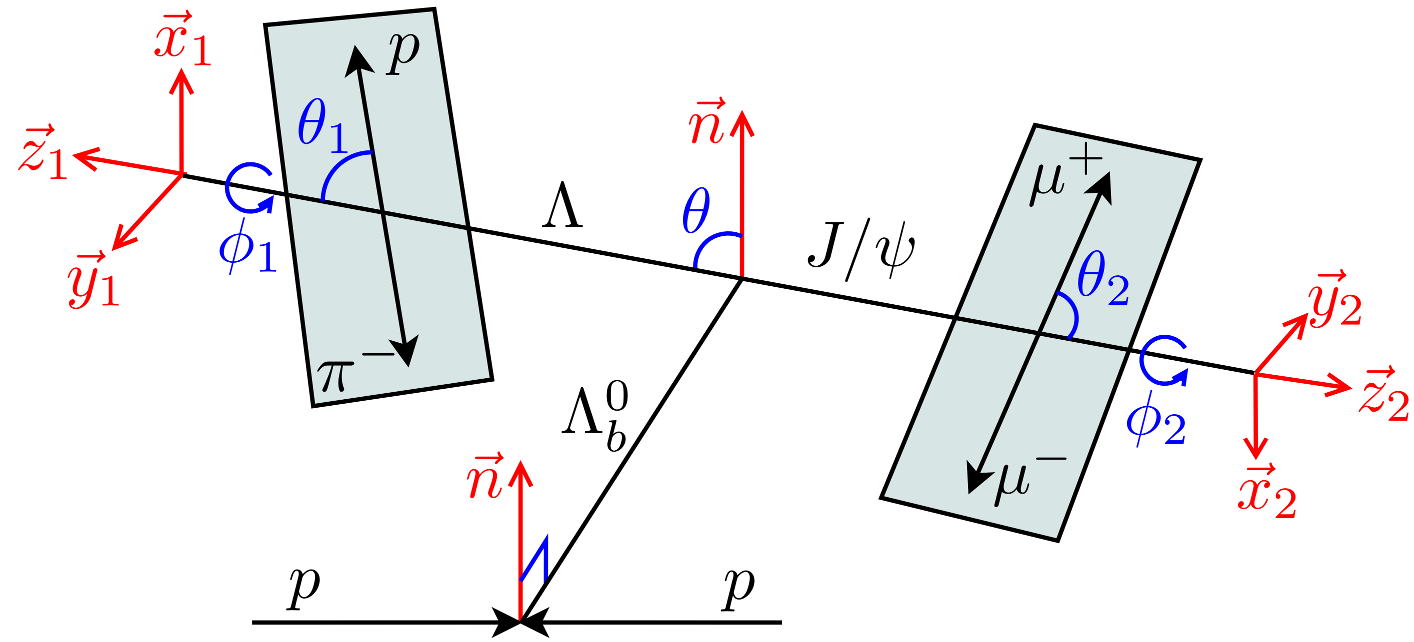


Figure and SM prediction from:
[Detmold et al. Phys.Rev. D93 (2016) 074501]

Data from:
[LHCb, JHEP 06 (2015) 115]

$\Lambda_b \to \Lambda\mu^+\mu^-$ angular distribution

- If the Λ_b is produced polarised the decay is described by 5 angles and normal-vector, $\hat{n}$.



- Large number of observables:

$$\frac{\mathrm{d}^5\Gamma}{\mathrm{d}\vec{\Omega}} = \frac{3}{32\pi^2}\sum_i^{34} K_i(q^2) f_i(\vec{\Omega})$$

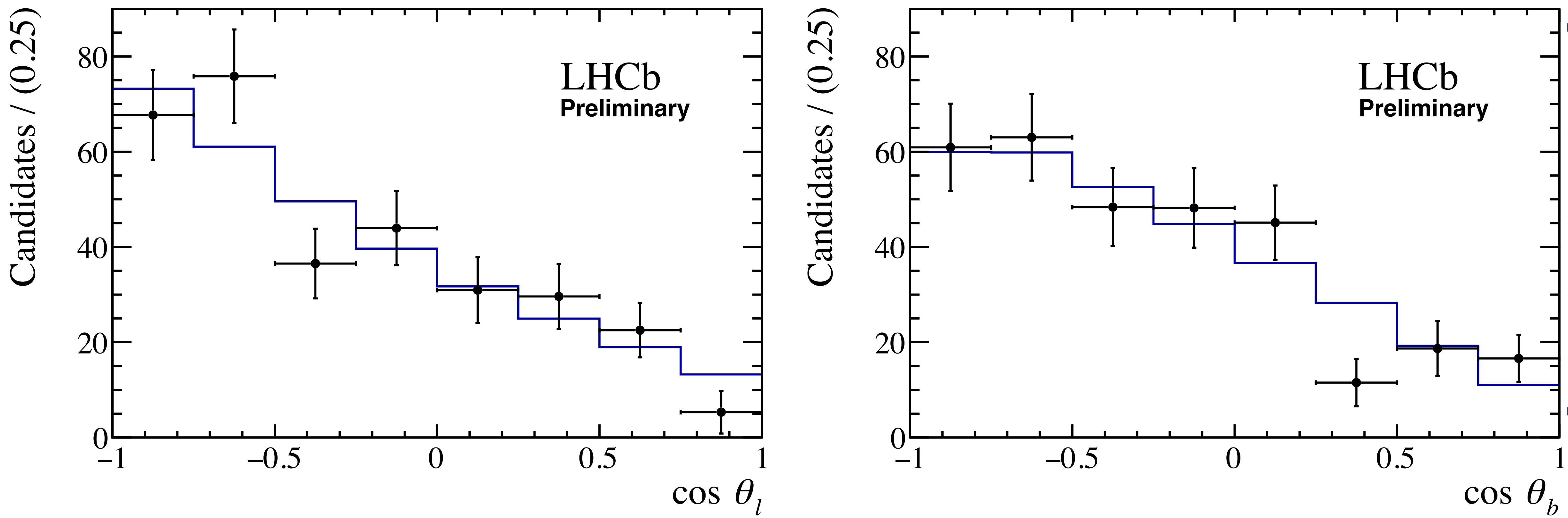
  where K_{11}—K_{34} are zero if the Λ_b is unpolarised. **[Blake et al. JHEP 11 (2017) 138]**

- Determine observables using the *method of moments* and a set of orthogonal weighing functions.

- Correct for angular efficiency using per-candidate weights determined on simulated phasespace events.

- Analysis cross-checked using $B^0 \to J/\psi K_S$ and $\Lambda_b \to J/\psi\Lambda$ decays selected in same way as the signal.

$\Lambda_b \to \Lambda \mu^+ \mu^-$ angular distribution



[LHCb-PAPER-2018-029]

- Large asymmetries on both the lepton- and hadron-side:

$$A_{\rm FB}^{\ell} = -0.39 \pm 0.04\,({\rm stat}) \,\pm 0.01\,({\rm syst})$$ **Preliminary**

$$A_{\rm FB}^{h} = -0.30 \pm 0.05\,({\rm stat}) \,\pm 0.02\,({\rm syst})$$ **Preliminary**

$$A_{\rm FB}^{\ell h} = +0.25 \pm 0.04\,({\rm stat}) \,\pm 0.01\,({\rm syst})$$ **Preliminary**

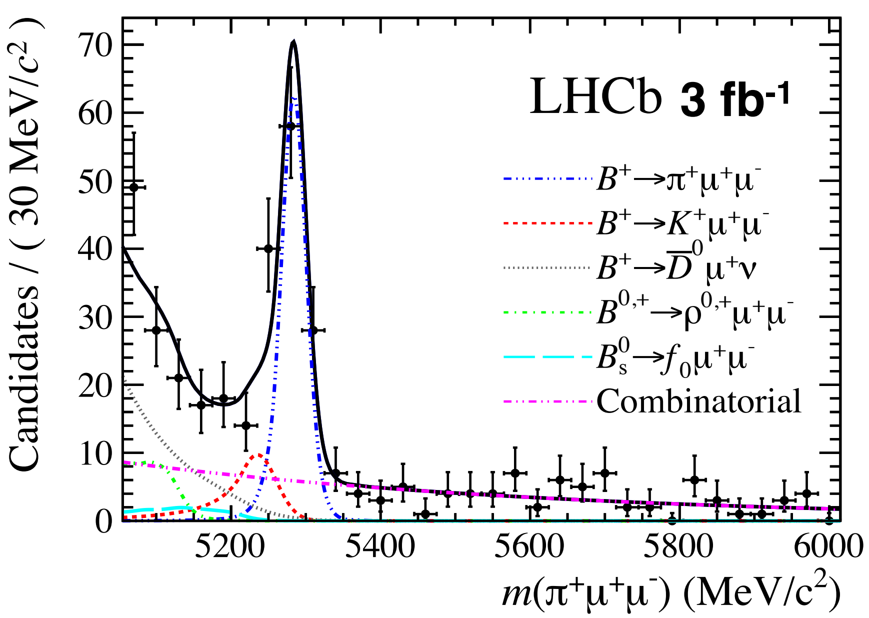
Consistent with SM predictions **[PRD 93 (2016) 074501]**

($A_{\rm FB}^{\ell h}$ is ~2σ from its prediction)

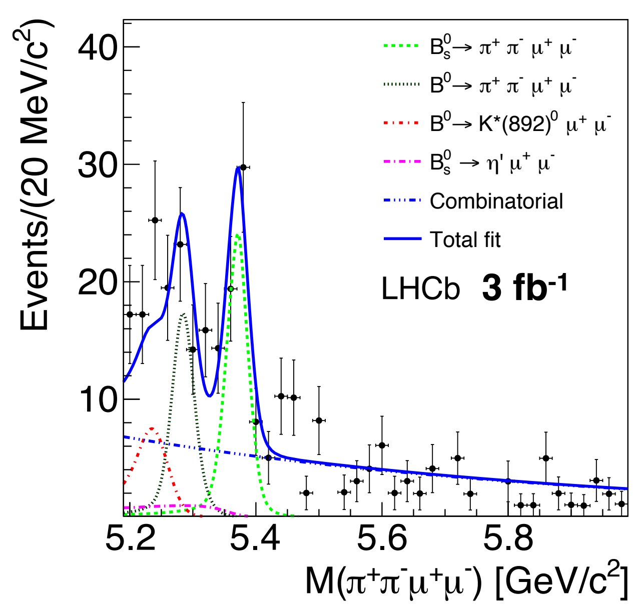
- Hadron-side asymmetry due to the weak decay of the Λ baryon.

$b \to d\mu^+\mu^-$ transitions

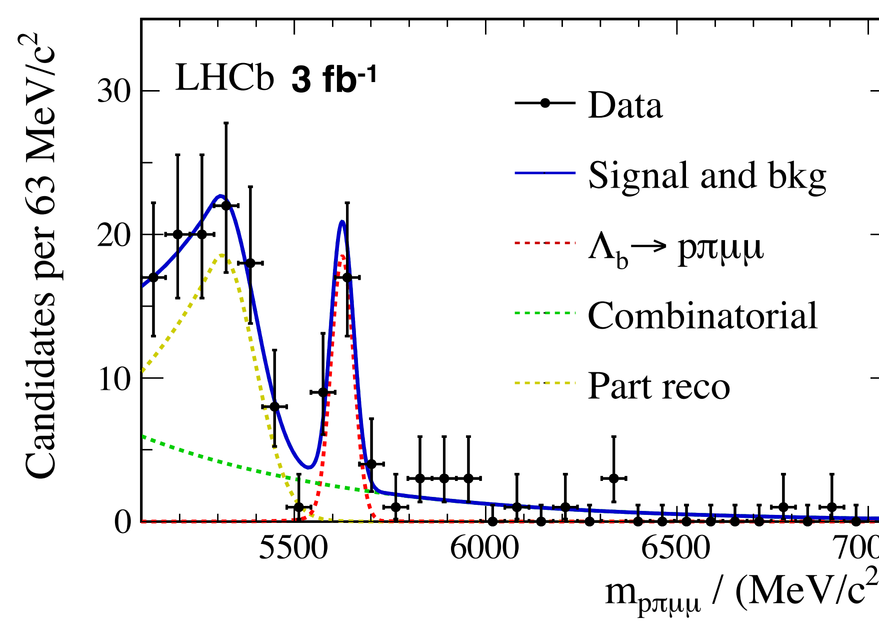
- Decays are strongly suppressed in the SM, due to the small size of V_{td}, with branching fractions of $\mathcal{O}(10^{-8})$.
- We already have access to $b \to d\mu^+\mu^-$ processes in the Run 1 data set:



[JHEP 10 (2015) 034]



[PLB 743 (2015) 46]



[JHEP 04 (2016) 029]

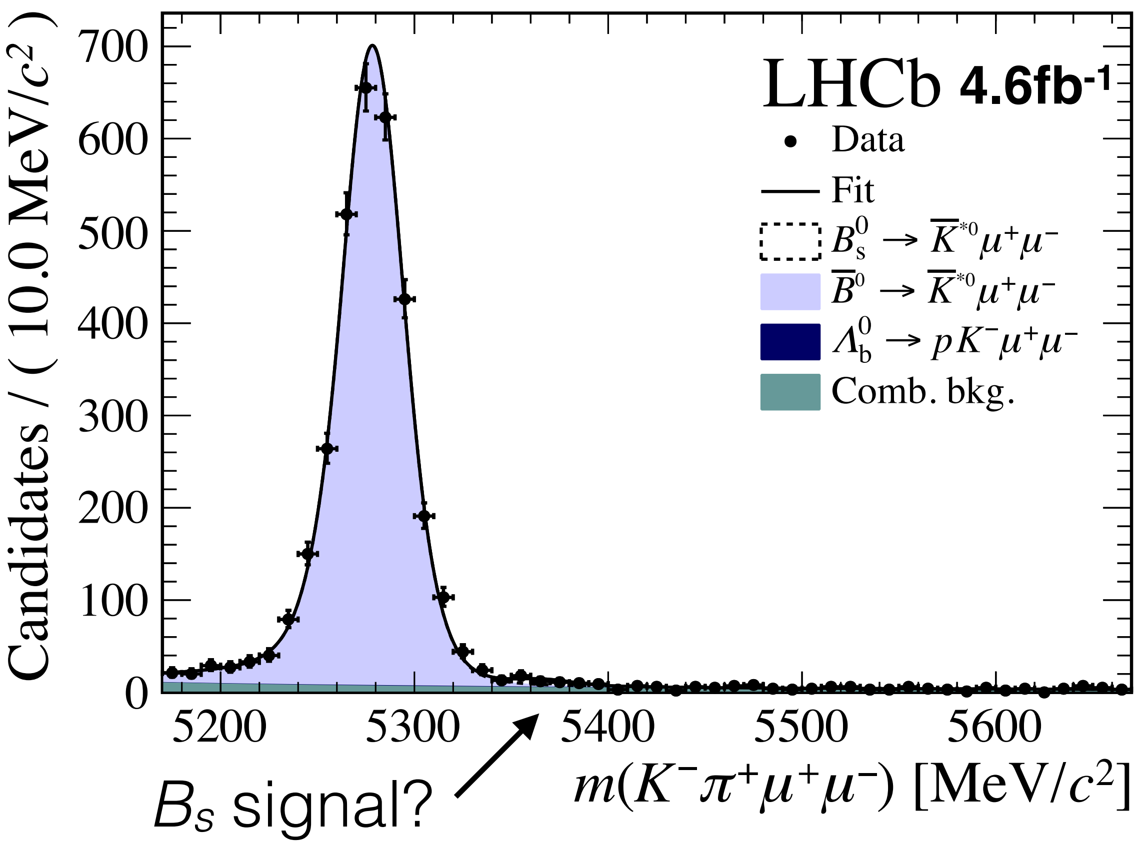
- Can use ratios of branching fractions between $b \to d\mu^+\mu^-$ and $b \to s\mu^+\mu^-$ processes to determine $|V_{td}/V_{ts}|$, e.g.

$$\frac{\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)} \Rightarrow |V_{td}/V_{ts}| = 0.20 \pm 0.02$$

[Du et al. PRD 93 (2016)034005]

$B_s \to \overline{K}^{*0} \mu^+ \mu^-$

- Could be used in conjunction with $B^0 \to K^{*0}\mu^+\mu^-$ to determine $|V_{td}/V_{ts}|$.
- Need good mass resolution to separate the Bs and $B^0 \to K^{*0}\mu^+\mu^-$ decays.
- Perform a search for the decay using a data set corresponding to 4.6fb^{-1} (3fb^{-1} +1.6fb^{-1}).

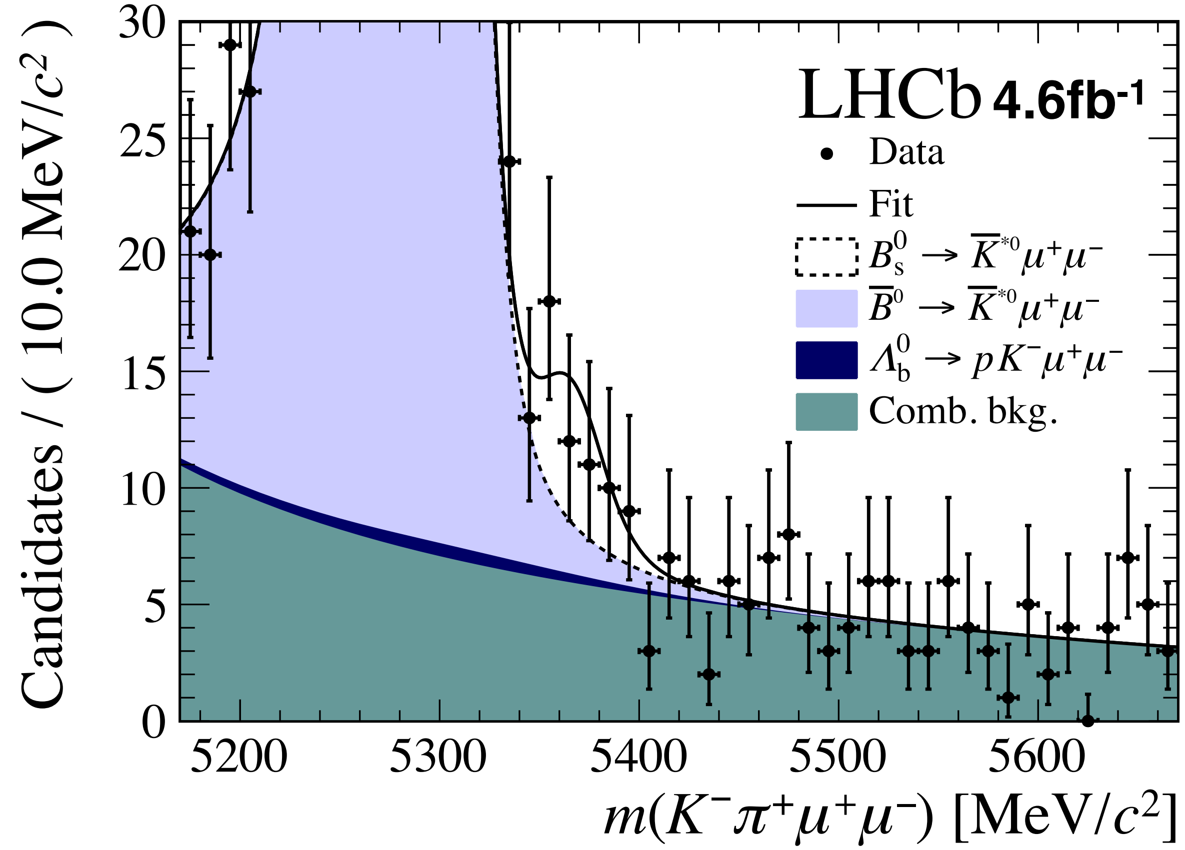


[LHCb, arXiv:1804.07167]

$B_s \to \bar{K}^{*0} \mu^+ \mu^-$ branching fraction

- Analysis binned in 4 bins of NN response.
- Signal yield determined from a simultaneous fit to the NN response bins.
- Normalise signal using $B^0 \to J/\psi K^{*0}$ and f_s/f_d from **[LHCb-CONF-2013-011]**.

Combining 3 highest NN response bins



[LHCb, arXiv:1804.07167]

- Find first evidence for the decay with a significance of 3.4σ.
- Resulting branching is:

$$\mathcal{B}(B_s \to \bar{K}^{*0}\mu^+\mu^-) = [2.9 \pm 1.0\,(\text{stat}) \pm 0.2\,(\text{syst}) \pm 0.3\,(\text{norm})] \times 10^{-8}$$

➡ Consistent with SM predictions, see e.g. **[EPJC 73 (2013) 2593, arXiv:1803.05876]**

$B_s \to \overline{K}^{*0} \mu^+ \mu^-$ branching fraction

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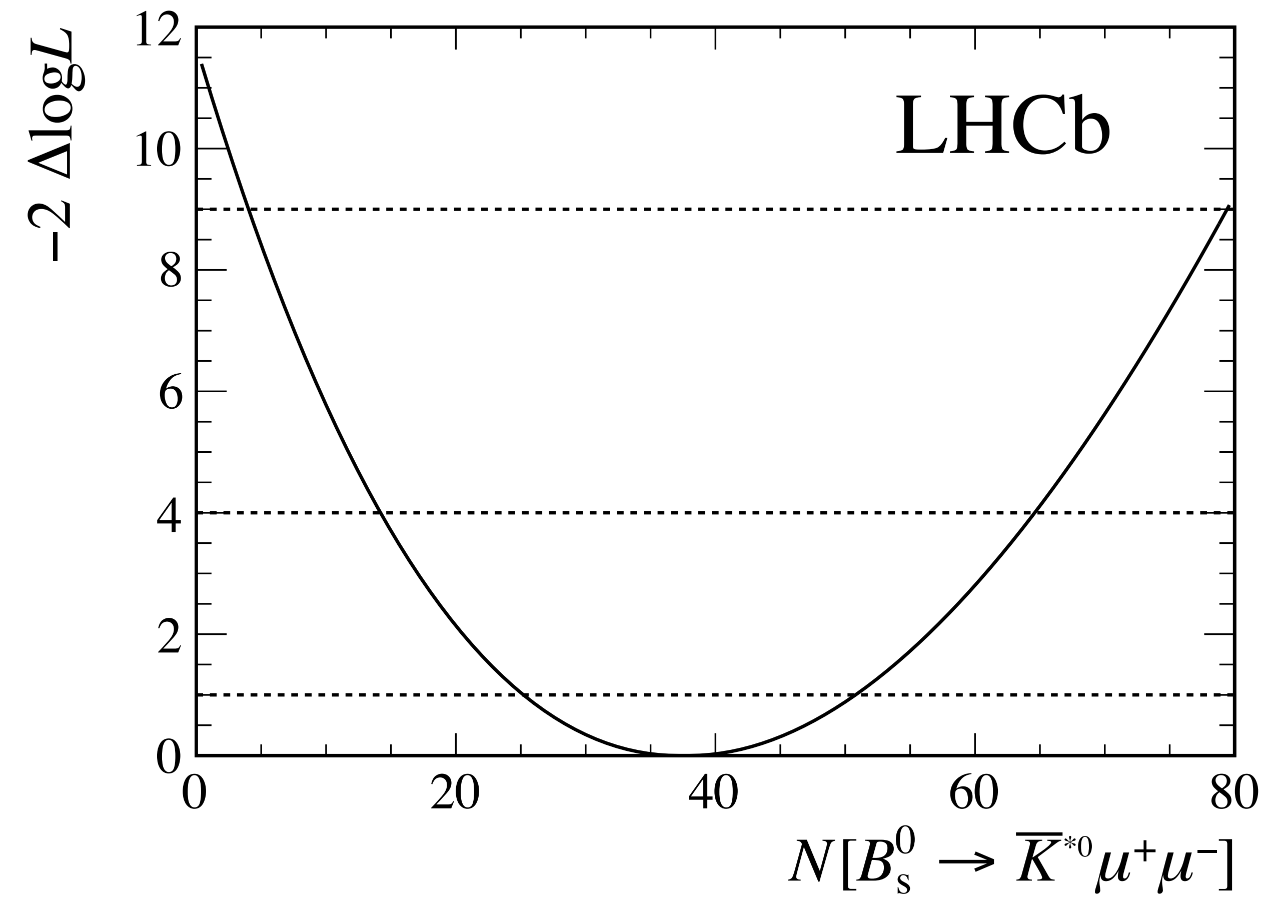

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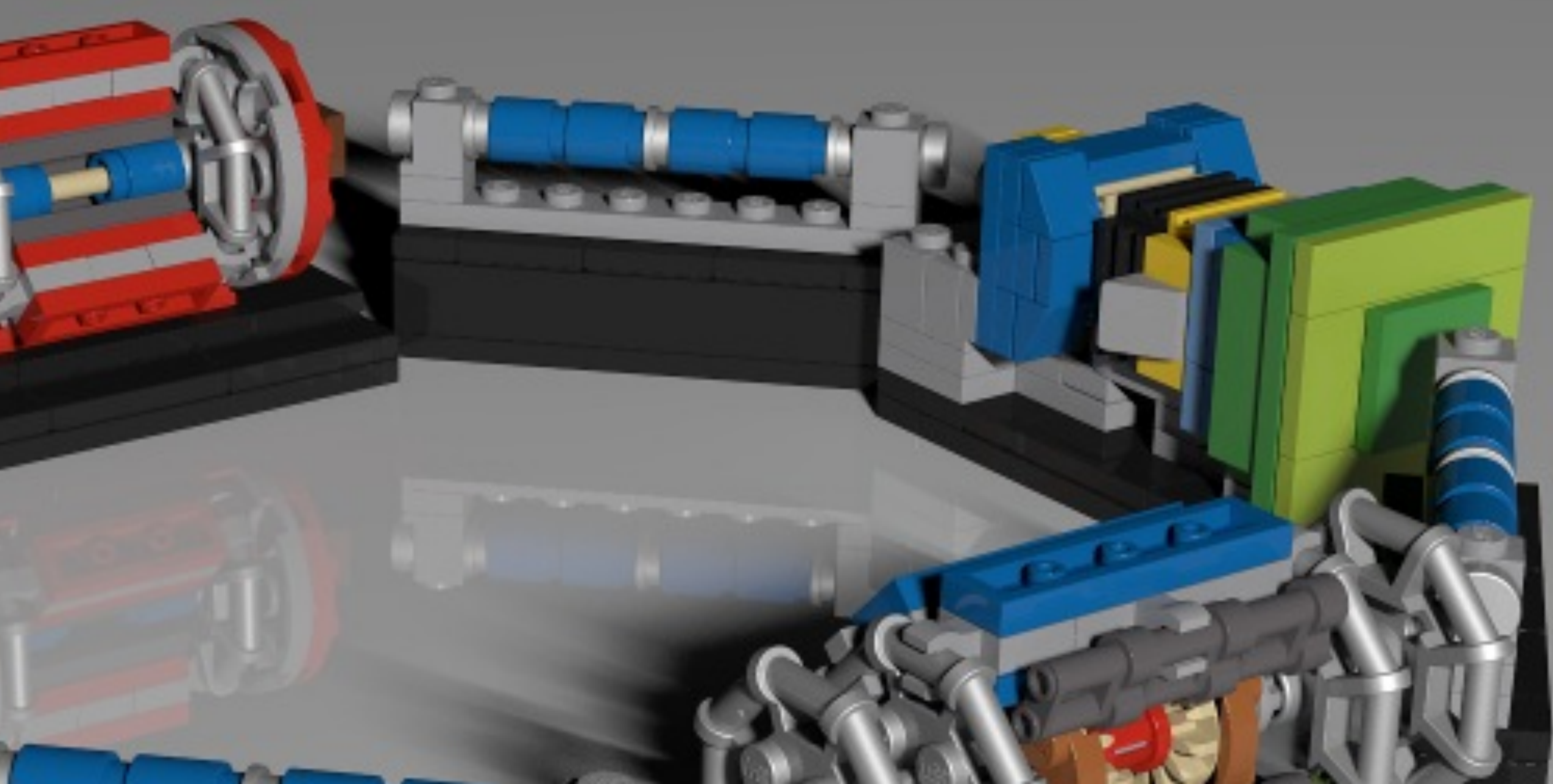
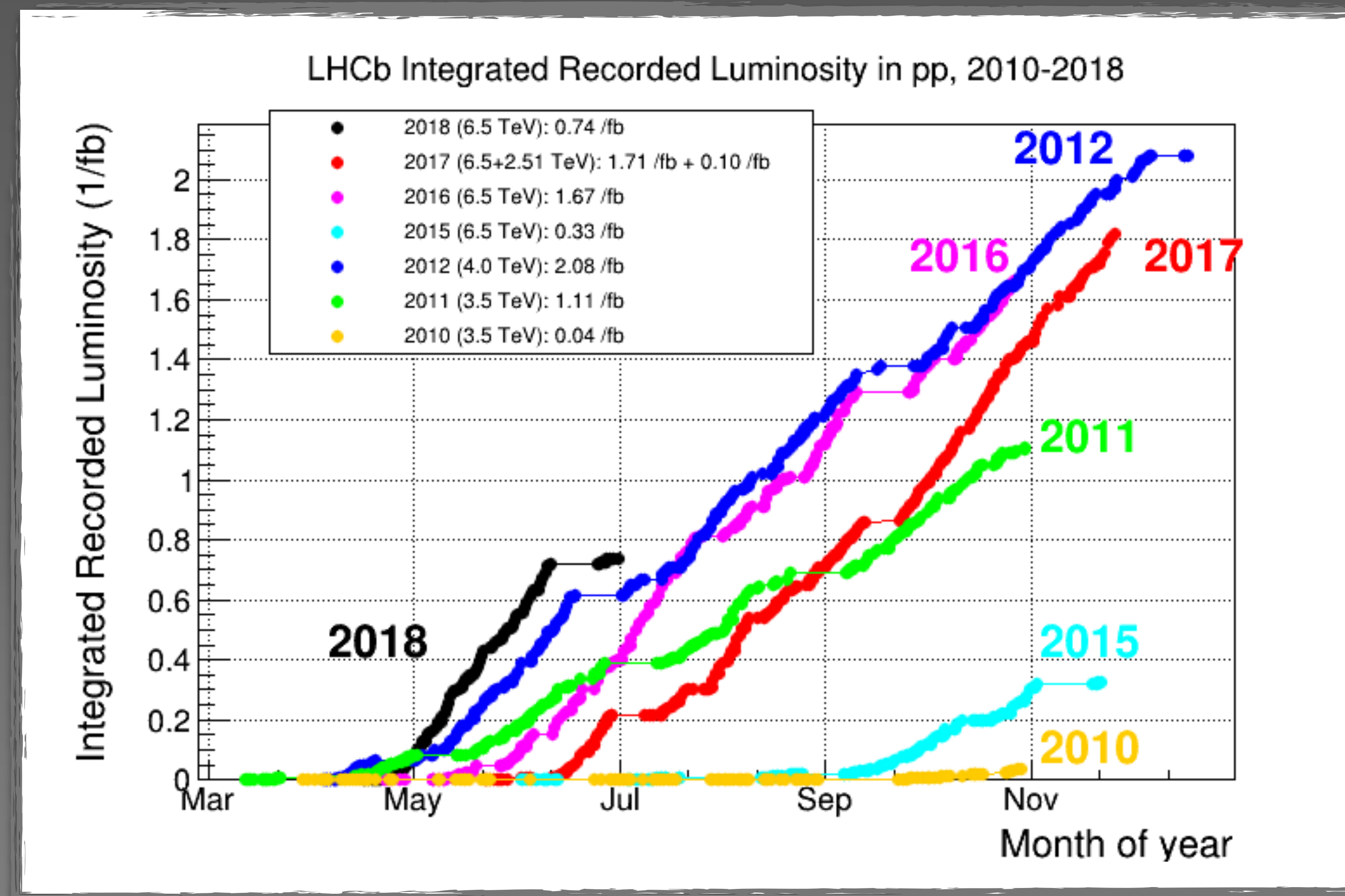
Summary

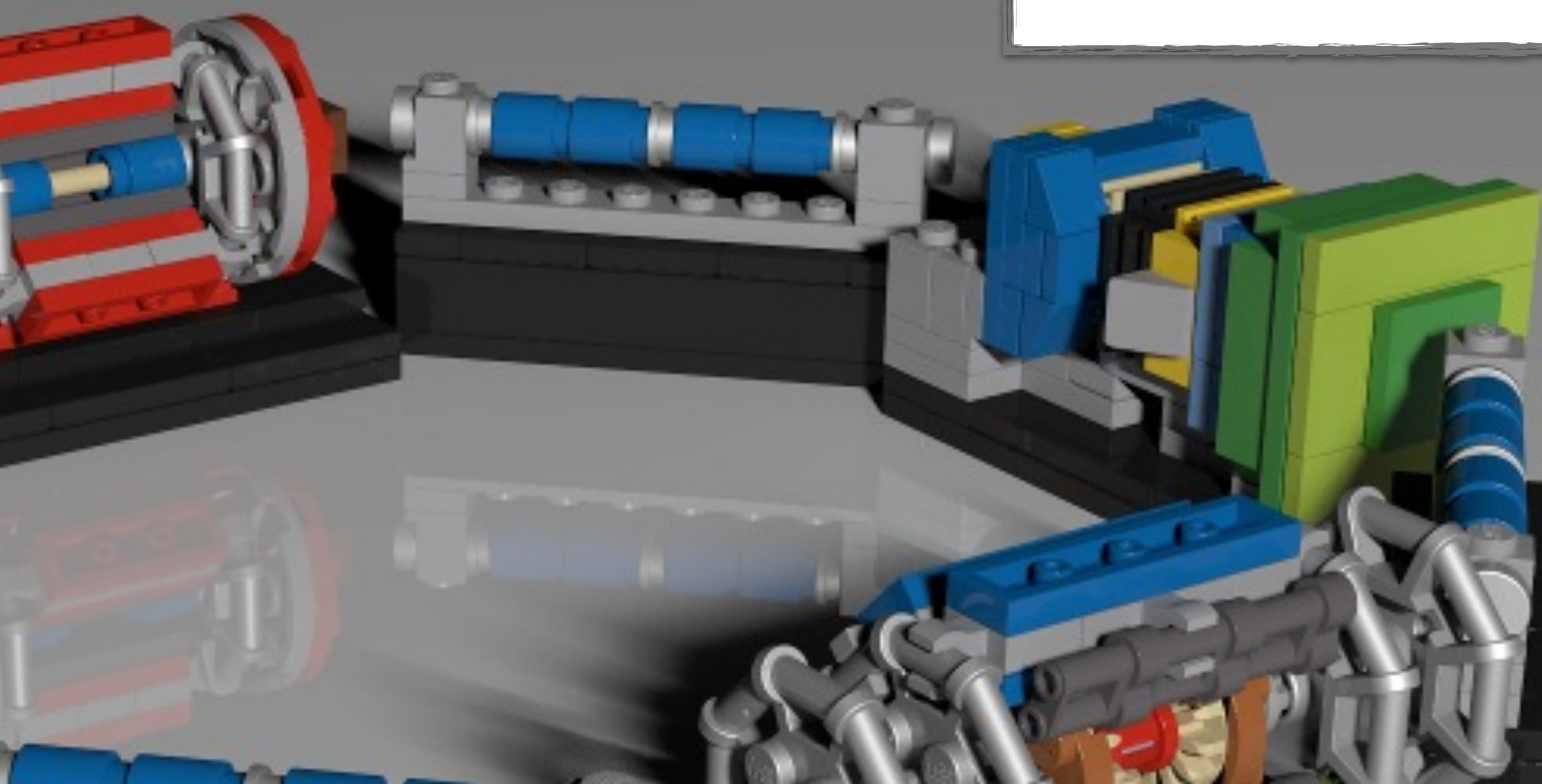
- FCNC processes provide powerful constraints on extensions of the SM.
- Large $b\bar{b}$ cross-section at the LHC provides large samples of “rare” decay processes.
- Several interesting tensions are seen in data on $b\to s\ell^+\ell^-$ processes.



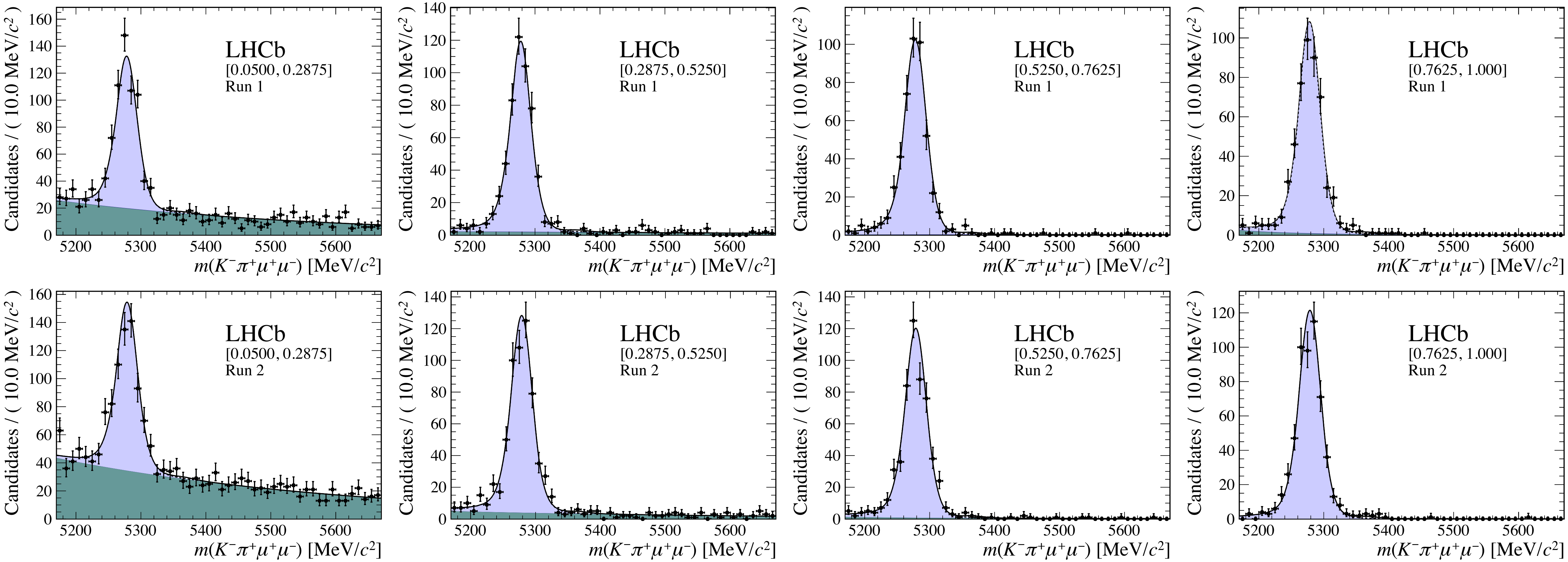
Summary

- Huge progress expected in the next five years with new data from the LHC experiments and from Belle II.



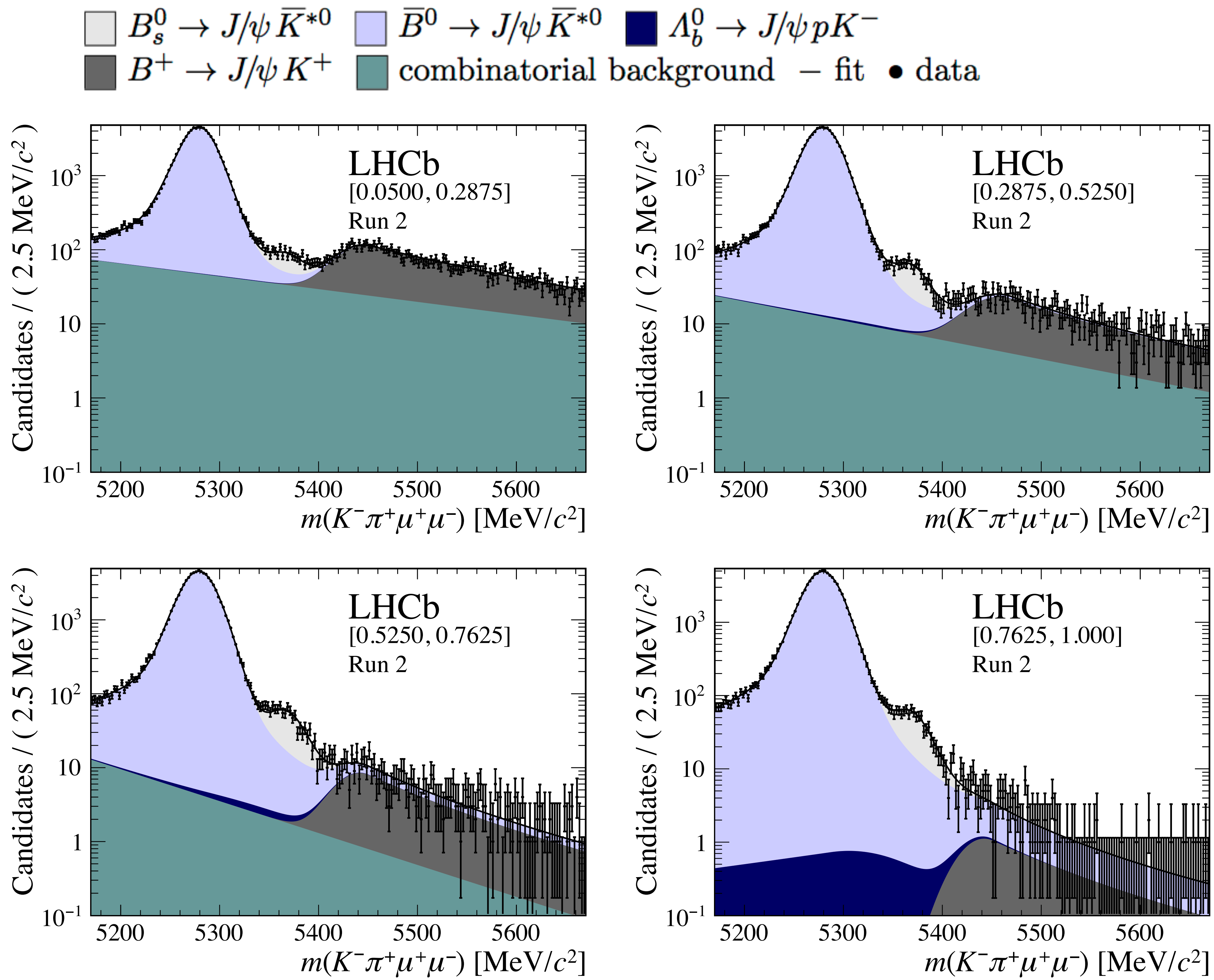


$B_s \to \bar{K}^{*0}\mu^+\mu^-$



[LHCb-PAPER-2018-004]

$B_s \to J/\psi \bar{K}^{*0}$



[LHCb-PAPER-2018-004]

Operators

- Different processes are sensitive to different 4-fermion operators.
  - ➡ Can exploit this to over-constrain the system.

$$\mathcal{O}_7 = (m_b/e)\,(\bar{s}\sigma^{\mu\nu}P_R b F_{\mu\nu})$$

photon (constrained by radiative decays and $b \to s\ell^+\ell^-$ processes at small q^2)

$$\mathcal{O}_9 = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell)$$

vector current (constrained by $b \to s\ell^+\ell^-$ processes)

$$\mathcal{O}_{10} = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu\gamma_5 \ell)$$

axial vector current (constrained by leptonic decays and $b \to s\ell^+\ell^-$ processes)

$$\mathcal{O}_S = (\bar{s}P_R b)(\bar{\ell}\ell)$$
$$\mathcal{O}_P = (\bar{s}P_R b)(\bar{\ell}\gamma_5\ell)$$

scalar and pseudoscalar operators (constrained primarily by leptonic decays)

e.g.

$B^0_s \to \mu^+\mu^-$ constrains $C_{10} - C'_{10},\ C_S - C'_S,\ C_P - C'_P$

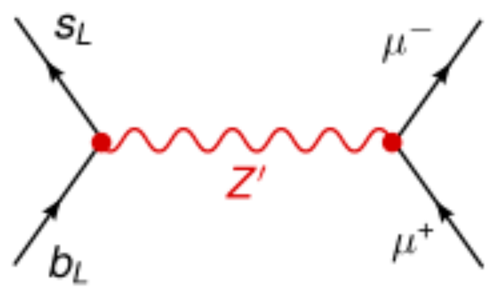
$B^+ \to K^+\mu^+\mu^-$ constrains $C_9 + C'_9,\ C_{10} + C'_{10}$

$B^0 \to K^{*0}\mu^+\mu^-$ constrains $C_7 \pm C'_7,\ C_9 \pm C'_9,\ C_{10} \pm C'_{10}$

The primes denote right-handed counterparts of the operators whose contribution is small in the SM.

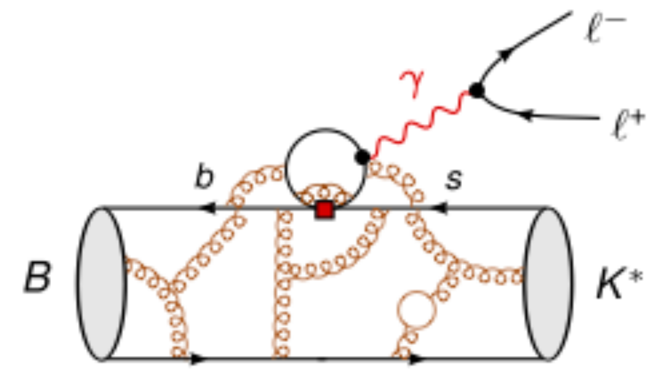
Interpretation of global fits

Optimist's view point



Vector-like contribution could come from e.g. new tree level contribution from a Z' with a mass of a few TeV.

Pessimist's view point

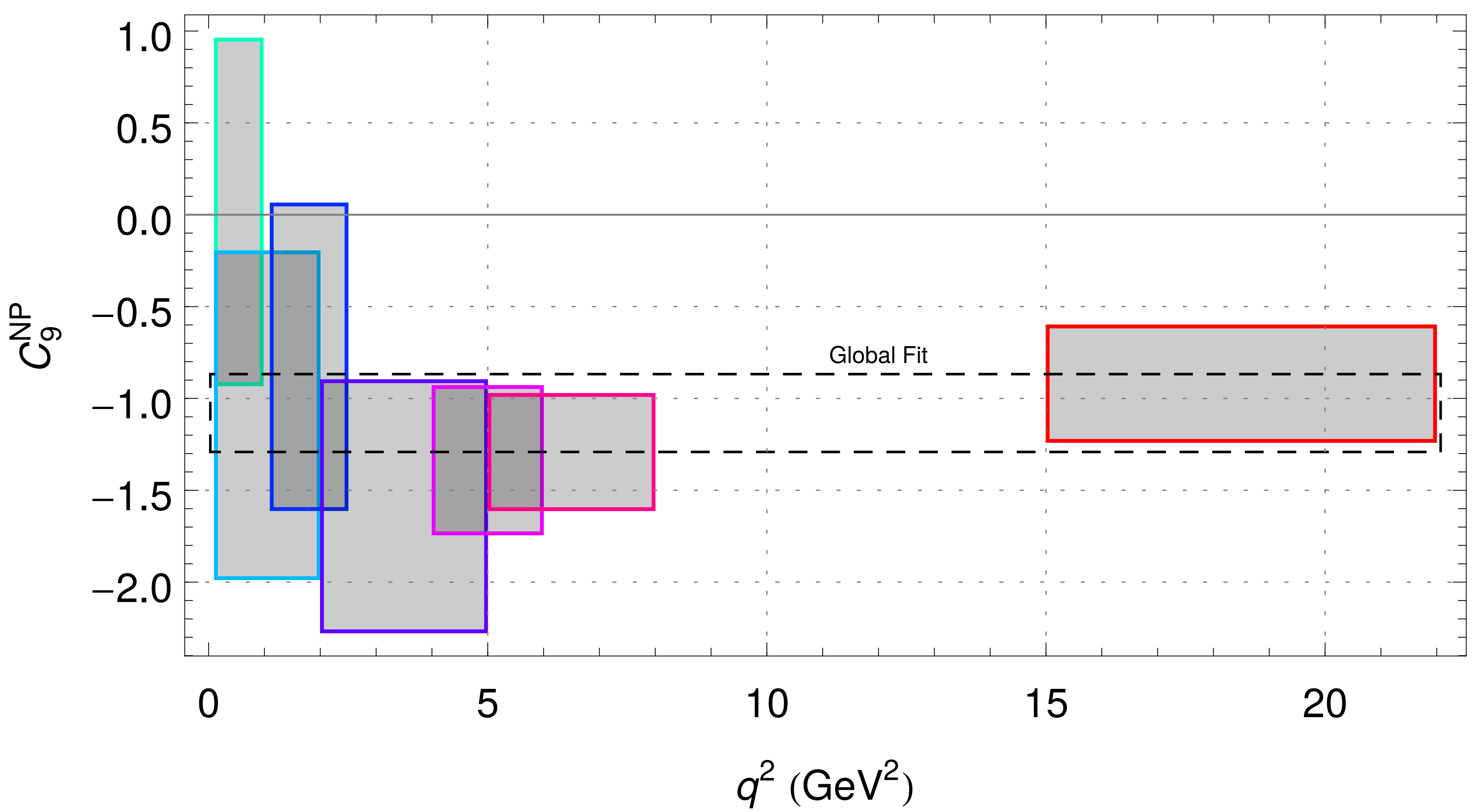


Vector-like contribution could point to a problem with our understanding of QCD, e.g. are we correctly estimating the contribution for charm loops that produce dimuon pairs via a virtual photon?

More work needed from experiment/theory to disentangle the two

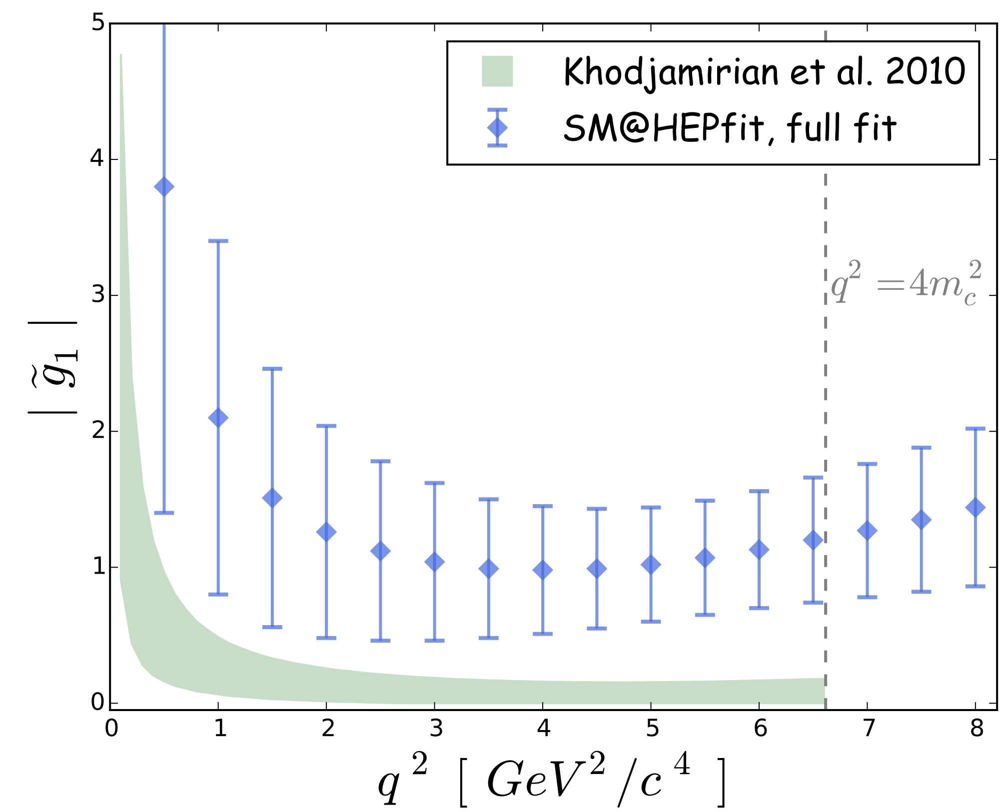
What can we learn from the data?

- If we are underestimating $c\bar{c}$ contributions then naively expect to see the shift in C_9 get larger closer to the narrow charmonium resonances.



[Decotes-Genon et al JHEP 06 (2016) 092]

Fitting separately for C_9 in different q^2 regions.



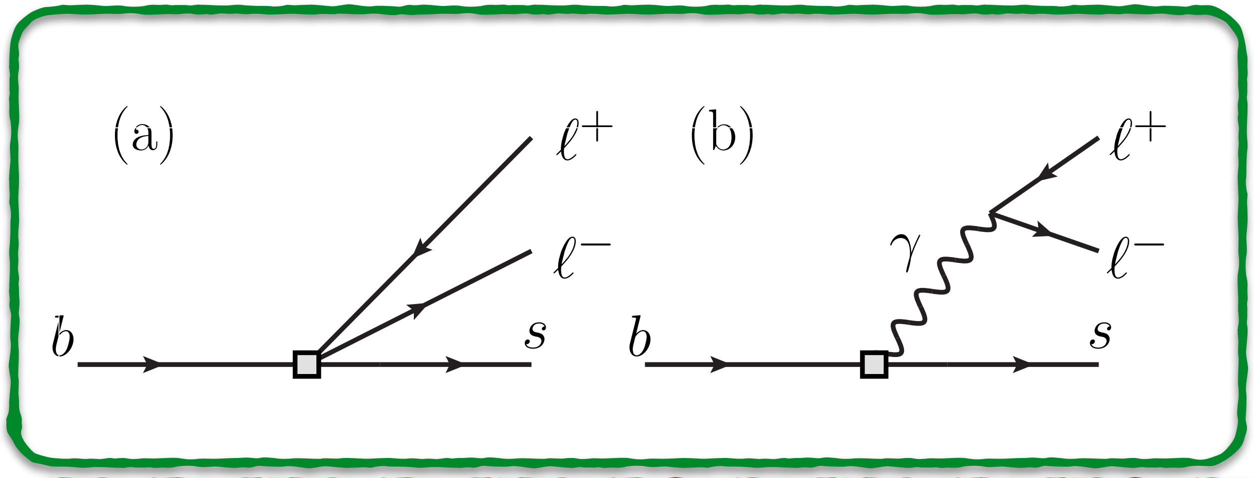
[M. Ciuchini et al, JHEP 06 (2016) 116]

Parameterised fit for charm contributions in $B^0 \to K^{*0}\mu^+\mu^-$ decays with $C_9 = C_9^{SM}$.

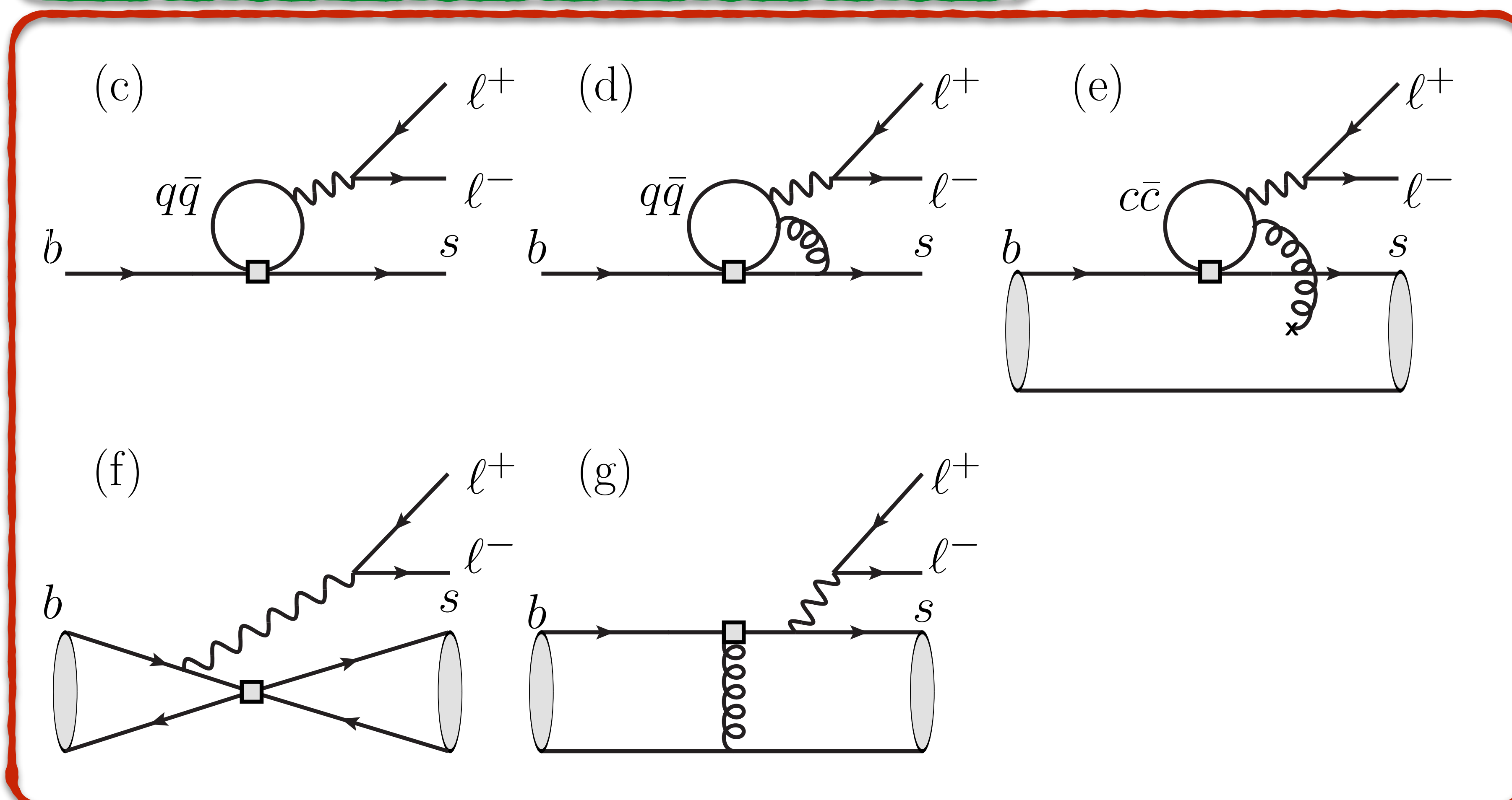
No clear evidence for a rise in the data (but more data is needed).

SM contributions

- Interested in new short distance contributions.
- We also get long-distance hadronic contributions.
- Need estimate of non-local hadronic matrix elements
[Khodjamirian et al. JHEP 09 (2010) 089]



Short distance part integrates out (as a Wilson coefficient)



Theoretical Framework

- In leptonic decays the matrix element for the decay can be factorised into a leptonic current and *B* meson decay constant:

$$\begin{aligned}\langle \ell^+\ell^- | j_\ell \, j_q | B_q \rangle &= \langle \ell^+\ell^- | j_\ell | 0 \rangle \langle 0 | j_q | B_q \rangle \\ &\approx \langle \ell^+\ell^- | j_q | 0 \rangle \cdot f_{B_q}\end{aligned}$$

- In semileptonic decays, the matrix element can be factorised into a leptonic current times a form-factor:

$$\begin{aligned}\langle \ell^+\ell^- M | j_\ell \, j_q | B \rangle &= \langle \ell^+\ell^- | j_\ell | 0 \rangle \langle M | j_q | B_q \rangle \\ &\approx \langle \ell^+\ell^- | j_\ell | 0 \rangle \cdot F(q^2) + \mathcal{O}(\Lambda_{\rm QCD}/m_B)\end{aligned}$$

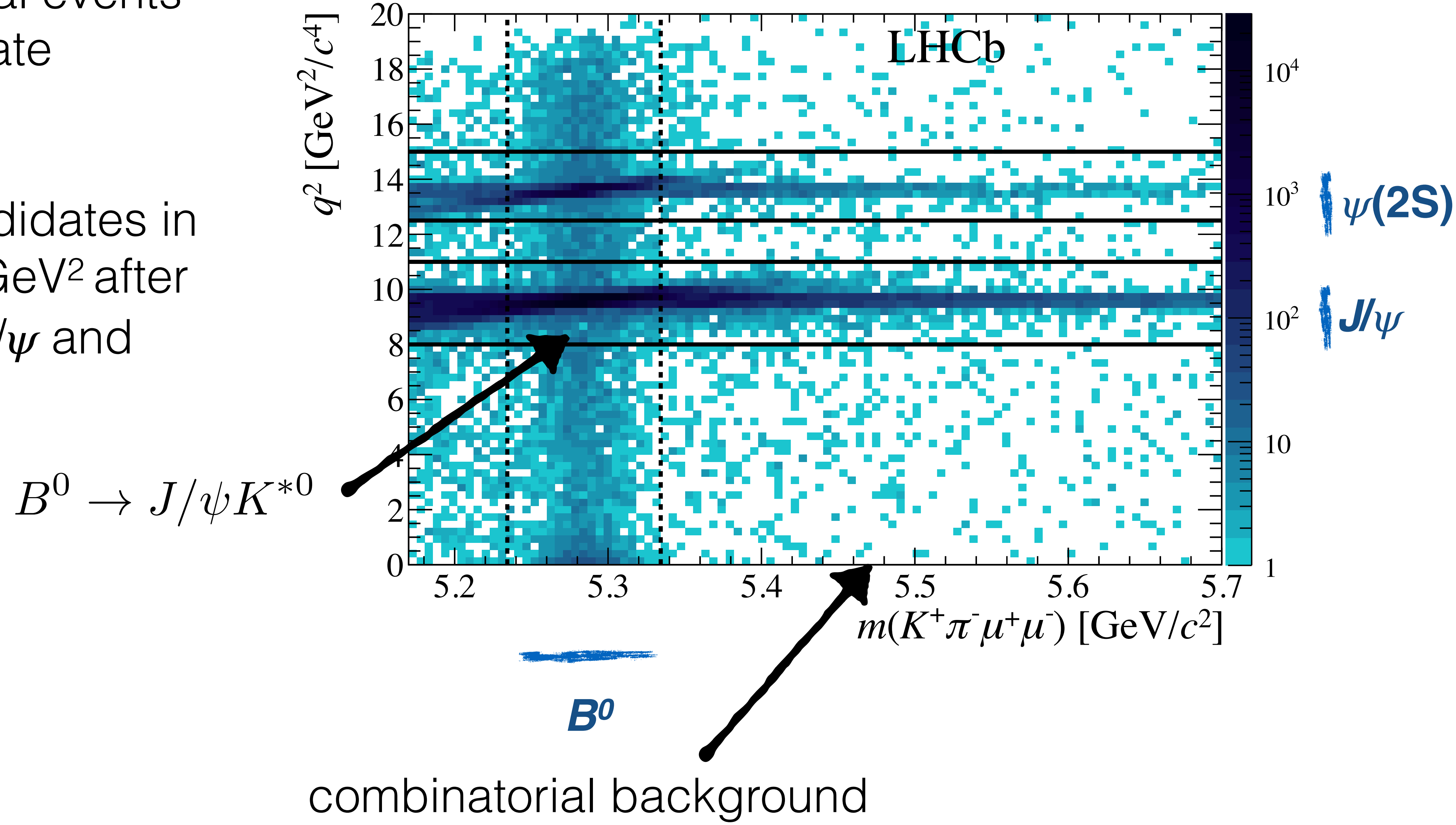
however this factorisation is not exact (due to hadronic contributions).

$B^0 \to K^{*0}\mu^+\mu^-$ reconstructed candidates

Can select a clean sample of signal events using multivariate classifier.

2398 ± 57 candidates in $0.1 < q^2 < 19$ GeV^2 after removing the J/ψ and $\psi(2S)$.

[JHEP 02 (2016) 104]



Systematic uncertainty on branching fraction measurements

- Normalise measurements to $B \to J/\psi X$ control channel.
  - ➡ Cancels luminosity/cross-section/efficiency scale uncertainties.
- Use $B^0 \to K^{*0}\mu^+\mu^-$ at LHCb as an example of what systematic uncertainties are important:

[LHCb, JHEP 12 (2016) 065]

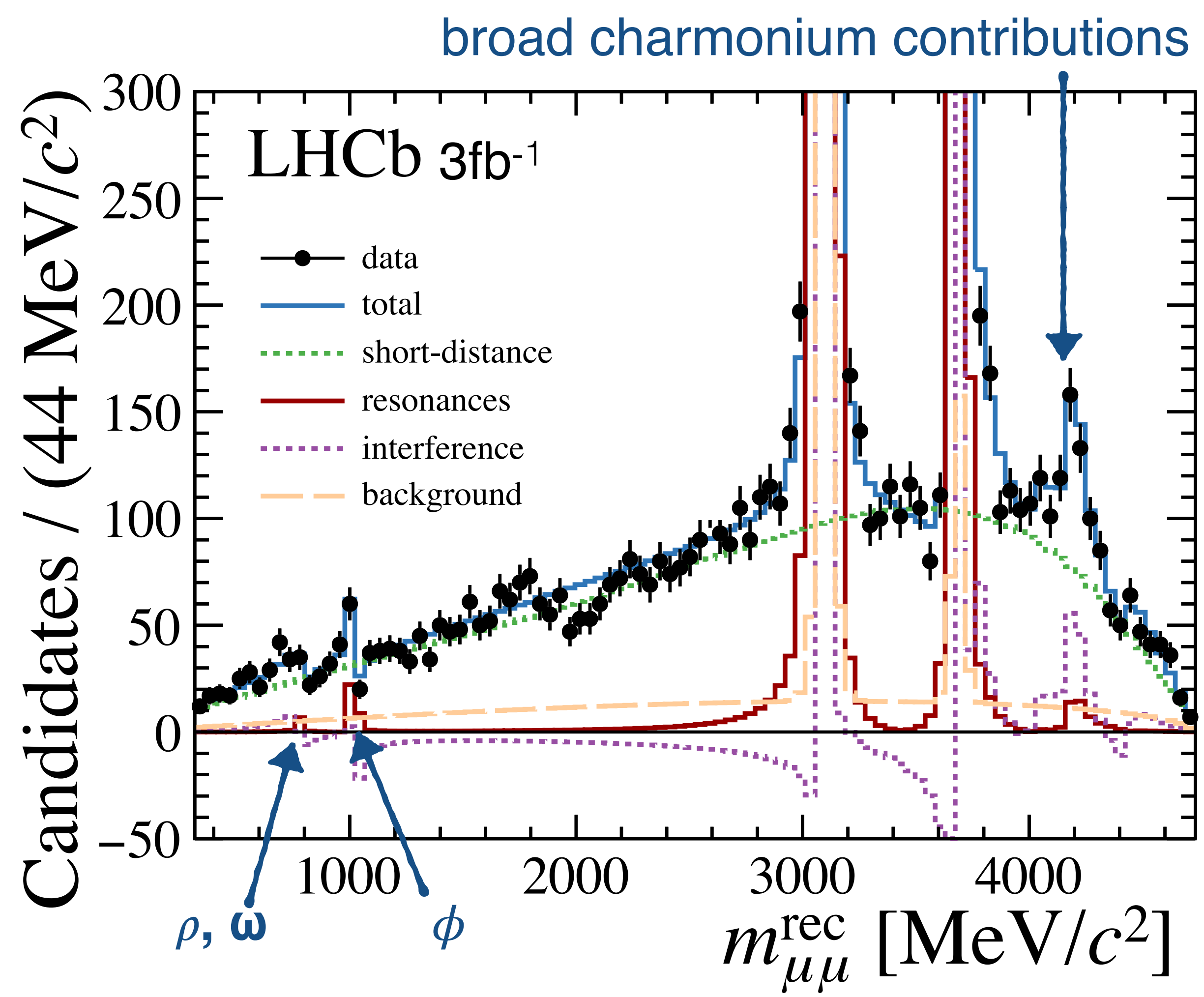
Source	$F_S\vert_{644}^{1200}$	$\mathrm{d}\mathcal{B}/\mathrm{d}q^2 \times 10^{-7}(c^4/\mathrm{GeV}^2)$
Data-simulation differences	0.008–0.013	0.004–0.021
Efficiency model	0.001–0.010	0.001–0.012
S-wave $m_{K\pi}$ model	0.001–0.017	0.001–0.015
$B^0 \to K^*(892)^0$ form factors	–	0.003–0.017
$\mathcal{B}(B^0 \to J/\psi(\to \mu^+\mu^-)K^{*0})$	–	0.025–0.079

Need to separate $K^*(892)^0$ from other $K\pi$ contributions (→ S-wave $m_{K\pi}$ model)

Uncertainty on $\mathcal{B}(B \to J/\psi X)$ normalisation modes is already a limiting factor. Encourage Belle II to update these measurements!

Resonant contributions

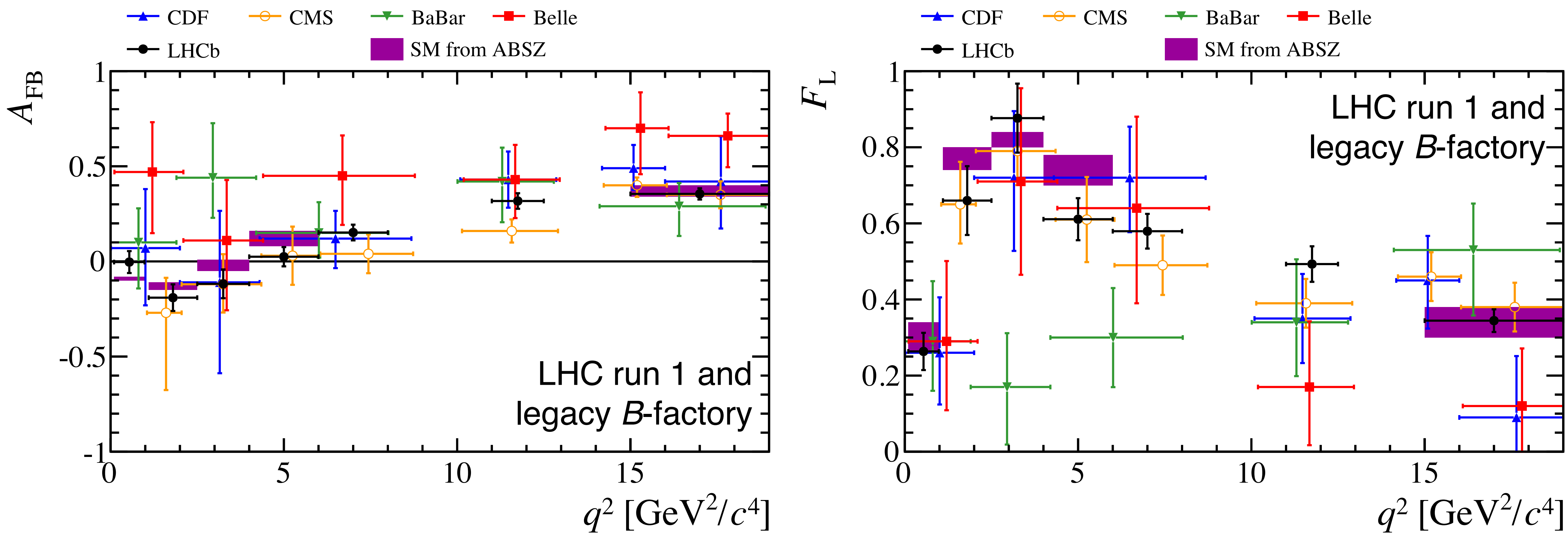
- With the large LHC datasets can also explore the shape of the $d\Gamma/dq^2$ spectrum in detail.
- See evidence for broad charmonium states and light quark contributions.
- Can determine relative magnitude/phases of the different contributions.



[LHCb, EPJC (2017) 77 161]

- Data could be used to exclude models proposing new GeV-scale particles as an explanation for R_K/R_{K^*}. **[F. Sala & D. Straub, arXiv:1704.06188]**

$B^0 \to K^{*0}\mu^+\mu^-$ angular observables

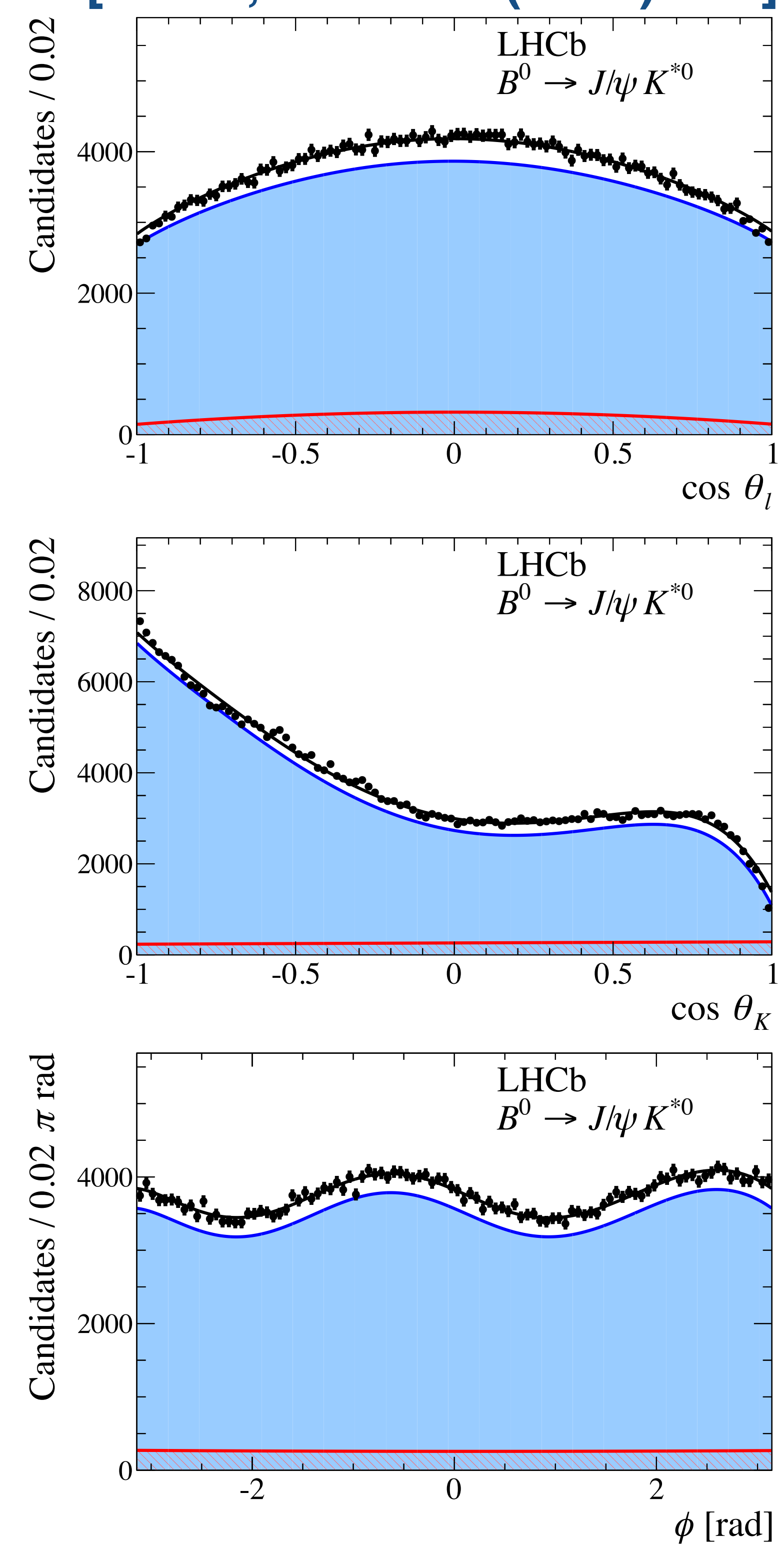


- Overlaying results for F_L and A_{FB} from LHCb **[JHEP 02 (2016) 104]** , CMS **[PLB 753 (2016) 424]** and BaBar **[PRD 93 (2016) 052015]** + measurements from CDF **[PRL 108 (2012) 081807]** and Belle **[PRL 103 (2009) 171801].**
- SM predictions based on
  [Altmannshofer & Straub, EPJC 75 (2015) 382]
  [LCSR form-factors from Bharucha, Straub & Zwicky, arXiv:1503.05534]
  [Lattice form-factors from Horgan, Liu, Meinel & Wingate arXiv:1501.00367] } Joint fit performed

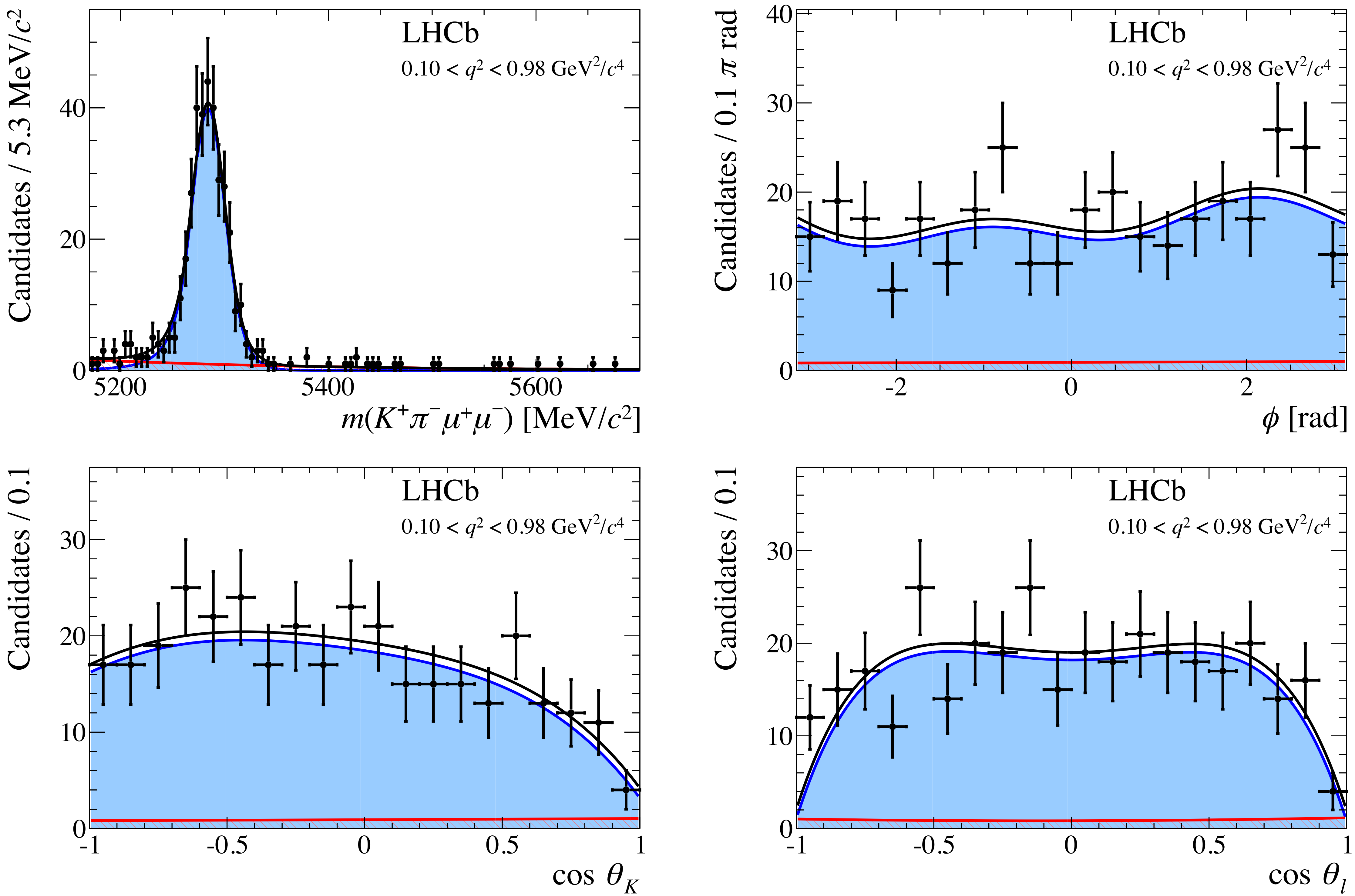
$B^0 \to K^{*0}\mu^+\mu^-$ angular analysis

[LHCb, JHEP 02 (2016) 104]

- Typically integrate over all but one angle or perform angular folding to reduce the number of observables.
- **LHCb has performed the first full angular analysis of the decay.**
  - ➡ **Access the full set of angular observables and their correlations.**
- Experiments need good control of detector efficiencies and to understand background from decays where the $K\pi$ is in an S-wave configuration.
- Use $B^0 \to J/\psi K^{*0}$ as a control channel to understand the acceptance of the detector.



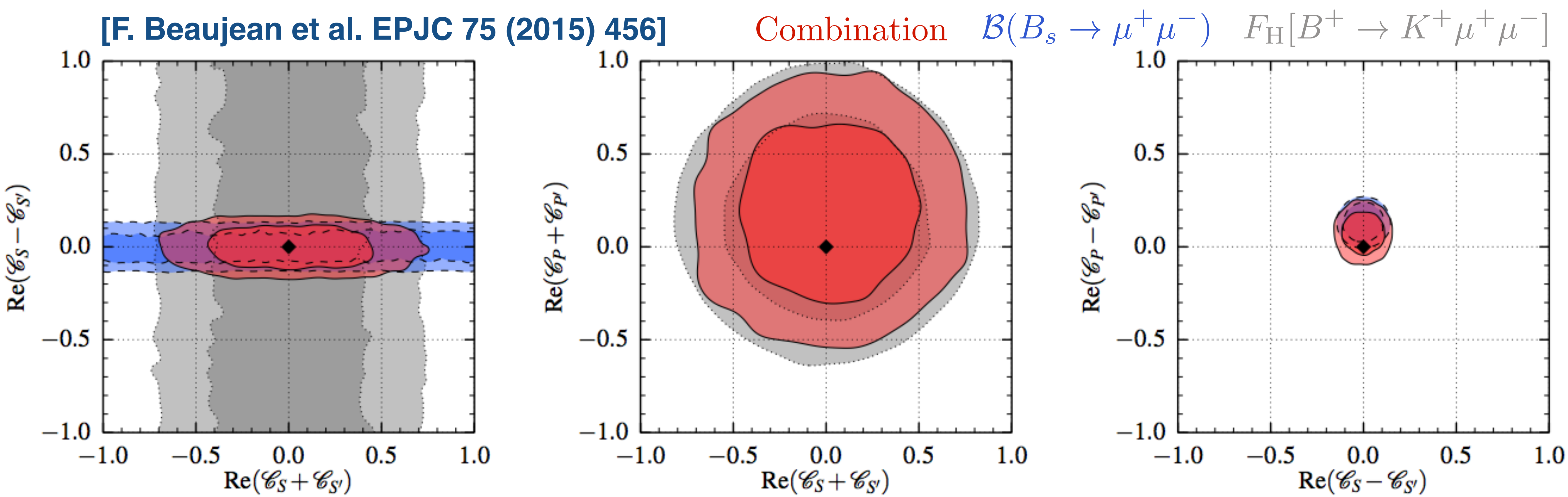
$B^0 \to K^{*0}\mu^+\mu^-$ example fit



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

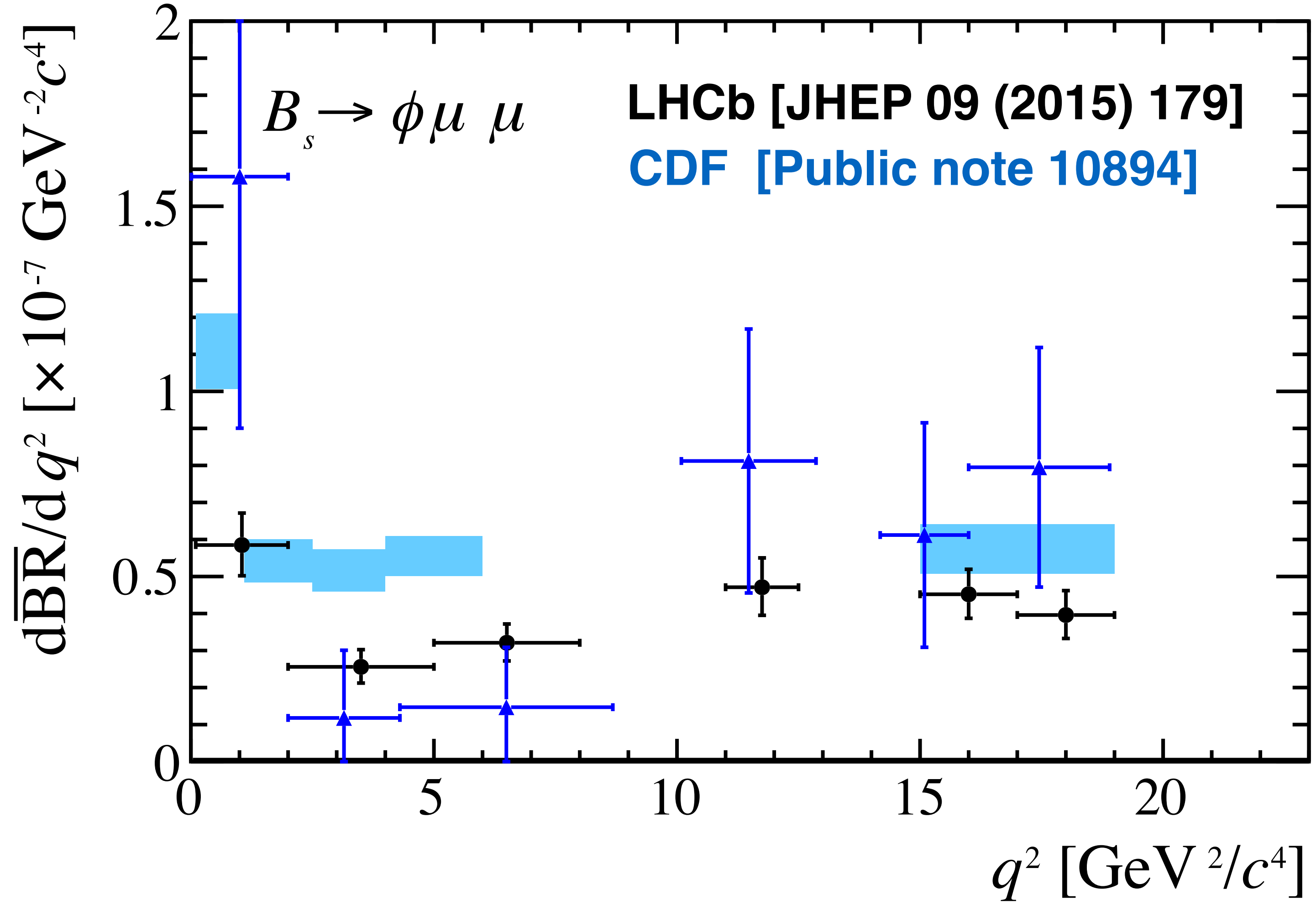
- Angular distribution of $B^+ \to K^+ \ell^+ \ell^-$ is a null test of SM, but can be sensitive to new scalar/pseudoscalar/tensor contributions, e.g.

[F. Beaujean et al. EPJC 75 (2015) 456]



$B_s \to \phi \mu^+ \mu^-$ decay rate

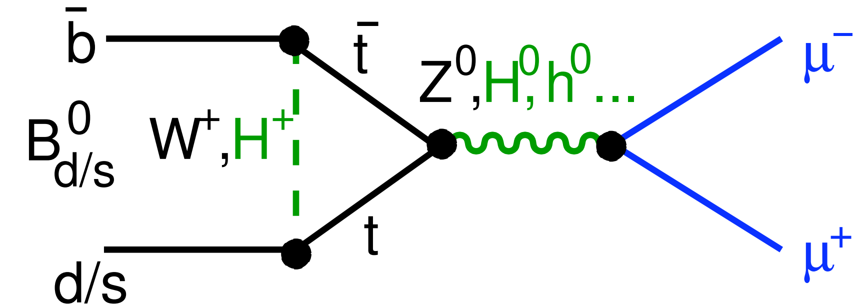
- Large tension between the SM prediction and the data at low q^2 (~3σ).

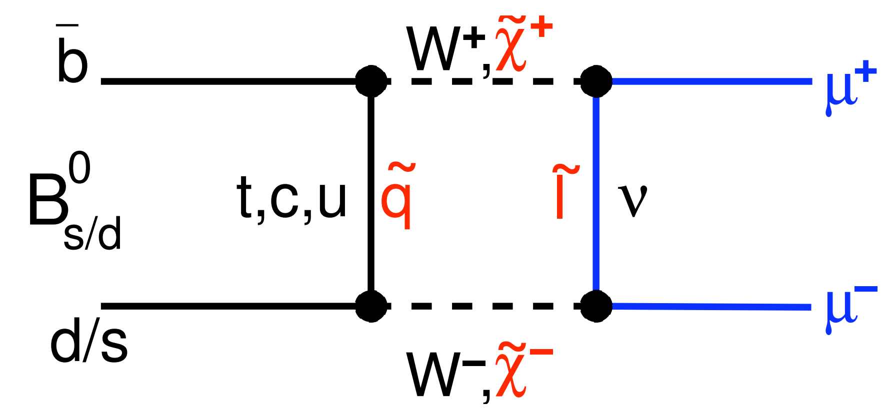


SM predictions based on
[Altmannshofer & Straub, arXiv:1411.3161]
[LCSR form-factors from Bharucha, Straub & Zwicky, arXiv:1503.05534]

Rare leptonic decays

- $B_{(s,d)} \to \boldsymbol{\mu}^+\boldsymbol{\mu}^-$ are golden modes to study at the LHC.
  - ➡ CKM suppressed, loop suppressed and helicity suppressed.
  - ➡ Powerful probe of models with new enhanced (pseudo)scalar interactions, e.g. SUSY at high tan$\boldsymbol{\beta}$.



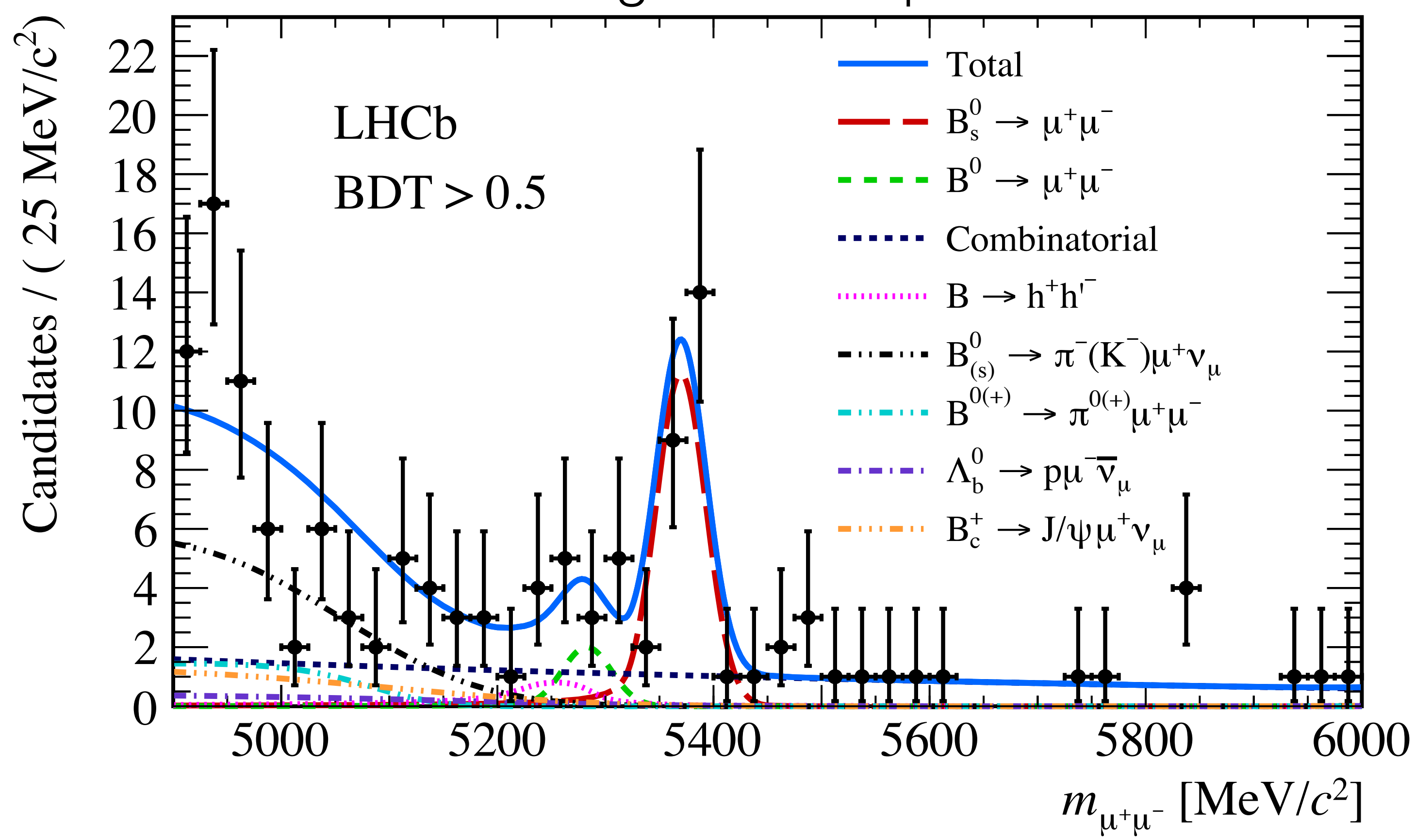


$$\frac{\mathcal{B}(B_q \to \ell^+\ell^-)_{\rm NP}}{\mathcal{B}(B_q \to \ell^+\ell^-)_{\rm SM}} = \frac{1}{|C_{10}^{\rm SM}|^2}\left\{\left(1 - 4\frac{m_\ell^2}{m_{B_q}}\right)\left|\frac{m_{B_q}}{2m_\ell}(C_S - C_S')\right|^2 + \left|\frac{m_{B_q}}{2m_\ell}(C_P - C_P') + (C_{10} - C_{10}')\right|^2\right\}$$

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

- Recent LHCb analysis using run 1 and 2 data ($3fb^{-1}$ +$1.4fb^{-1}$) provided the first single experiment observation of $B_s \to \mu^+\mu^-$ at more than 7σ.
  [LHCb, PRL 118 (2017) 191801]

Candidates at large BDT response

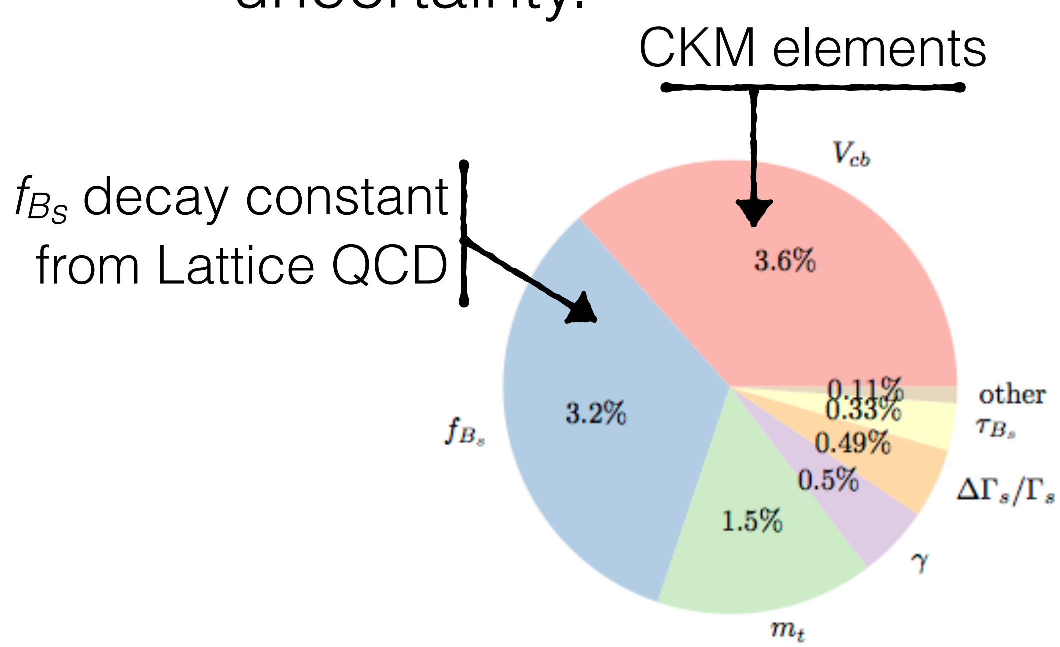


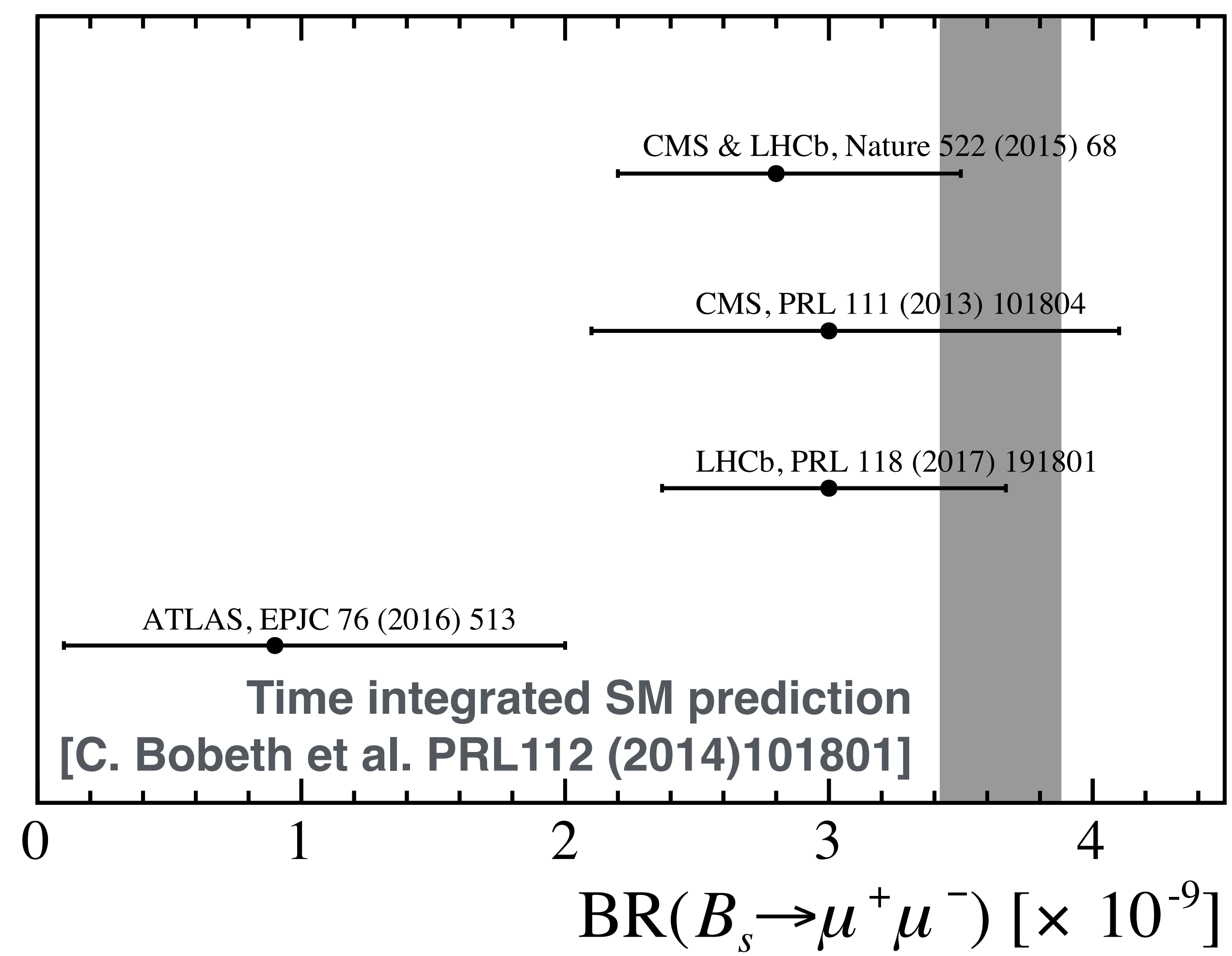
$B_s \to \mu^+ \mu^-$

- Recent LHCb analysis using run 1 and 2 data ($3fb^{-1}$ $+1.4fb^{-1}$) provided the first single experiment observation of $B_s \to \mu^+\mu^-$ at more than 7σ.
  [LHCb, PRL 118 (2017) 191801]

- Measurements are all consistent with the SM expectation.
  - ➡ Can exclude large scalar contributions.

- Branching fraction predicted precisely in the SM with a ~6% uncertainty.





Effective lifetime

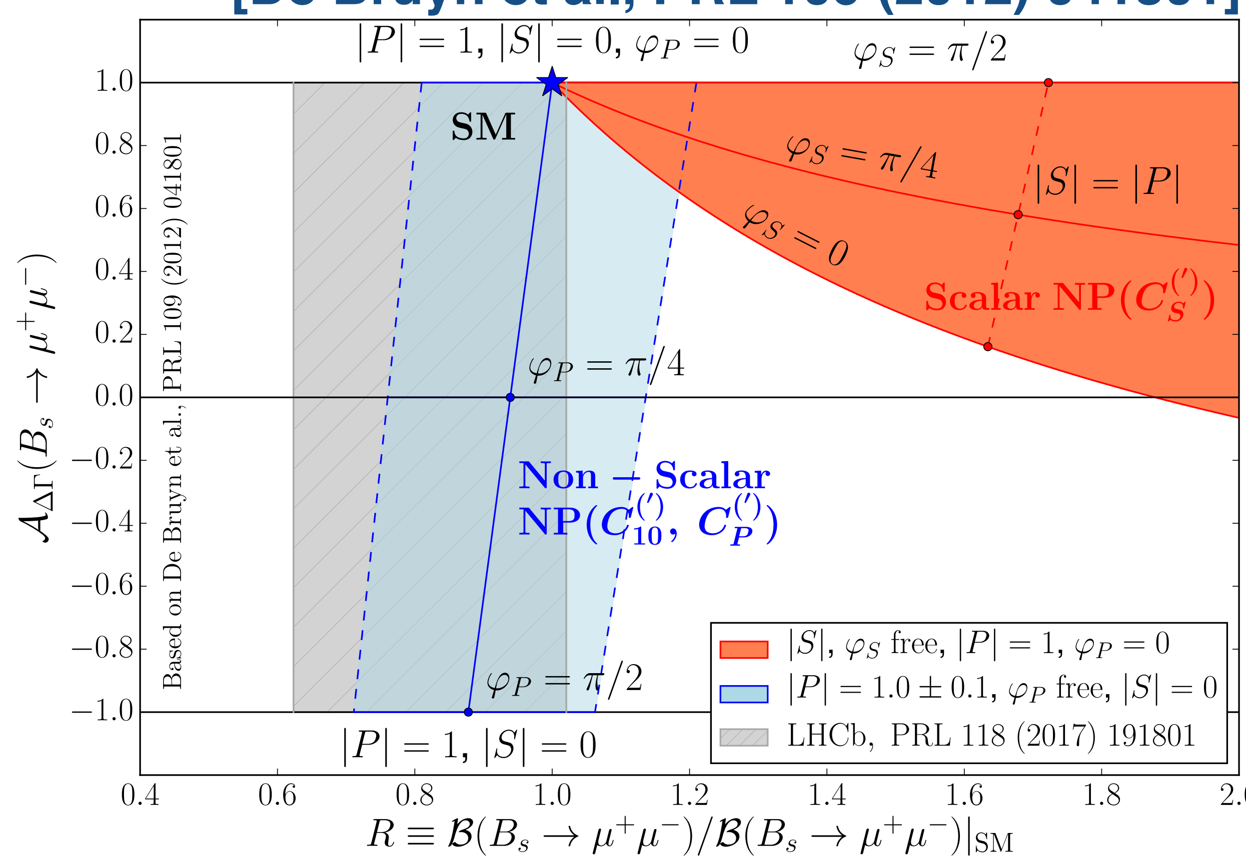
- The untagged time dependent decay rate is

$$\Gamma[B_s(t) \to \mu^+\mu^-] + \Gamma[\bar{B}_s(t) \to \mu^+\mu^-] \propto$$
$$e^{-t/\tau_{B_s}} \left\{ \cosh\left(\frac{\Delta\Gamma_s}{2} t\right) + A_{\Delta\Gamma} \sinh\left(\frac{\Delta\Gamma_s}{2} t\right) \right\}$$

- $A_{\Delta\Gamma}$ provides additional separation between scalar and pesudoscalar contributions.

- In the SM $A_{\Delta\Gamma} = 1$ such that the system evolves with the lifetime of the heavy B_s mass eigenstate.

[De Bruyn et al., PRL 109 (2012) 041801]



$B_s \to \mu^+\mu^-$ effective lifetime

- The $A_{\Delta\Gamma}$ parameter modifies the effective lifetime of the decay:

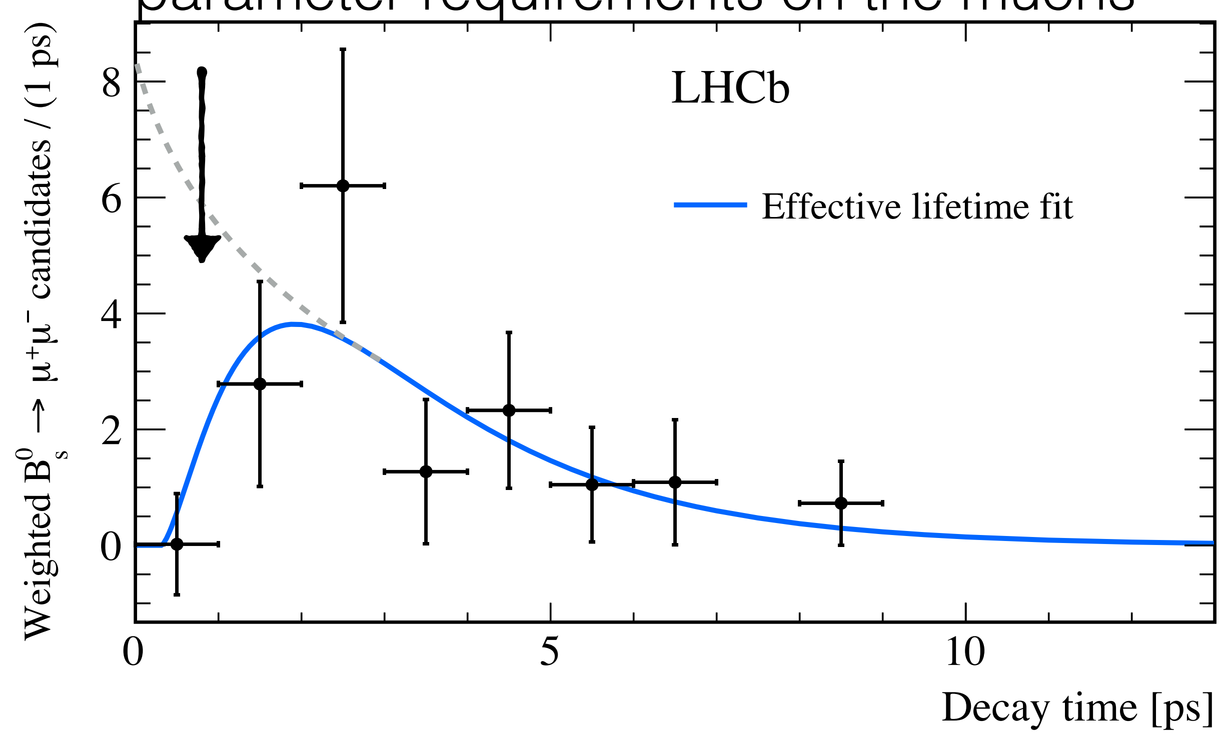
$$\tau_{\rm eff} = \frac{\tau_{B_s}}{1-y_s^2}\left(\frac{1+2A_{\Delta\Gamma}\,y_s+y_s^2}{1+A_{\Delta\Gamma}\,y_s}\right) \quad \text{where} \quad y_s = \tau_{B_s}\frac{\Delta\Gamma}{2}$$

- LHCb have performed a first measurement of $\tau_{\rm eff}$, giving

$$\tau[B_s^0 \to \mu^+\mu^-] = 2.04 \pm 0.44 \pm 0.05\,{\rm ps}$$

NB Not yet sensitive to $A_{\Delta\Gamma}$ (the stat. uncertainty is larger than the change in the lifetime from $\Delta\Gamma_s$). This will become more interesting during runs 3 and 4.

lifetime acceptance, due to impact parameter requirements on the muons



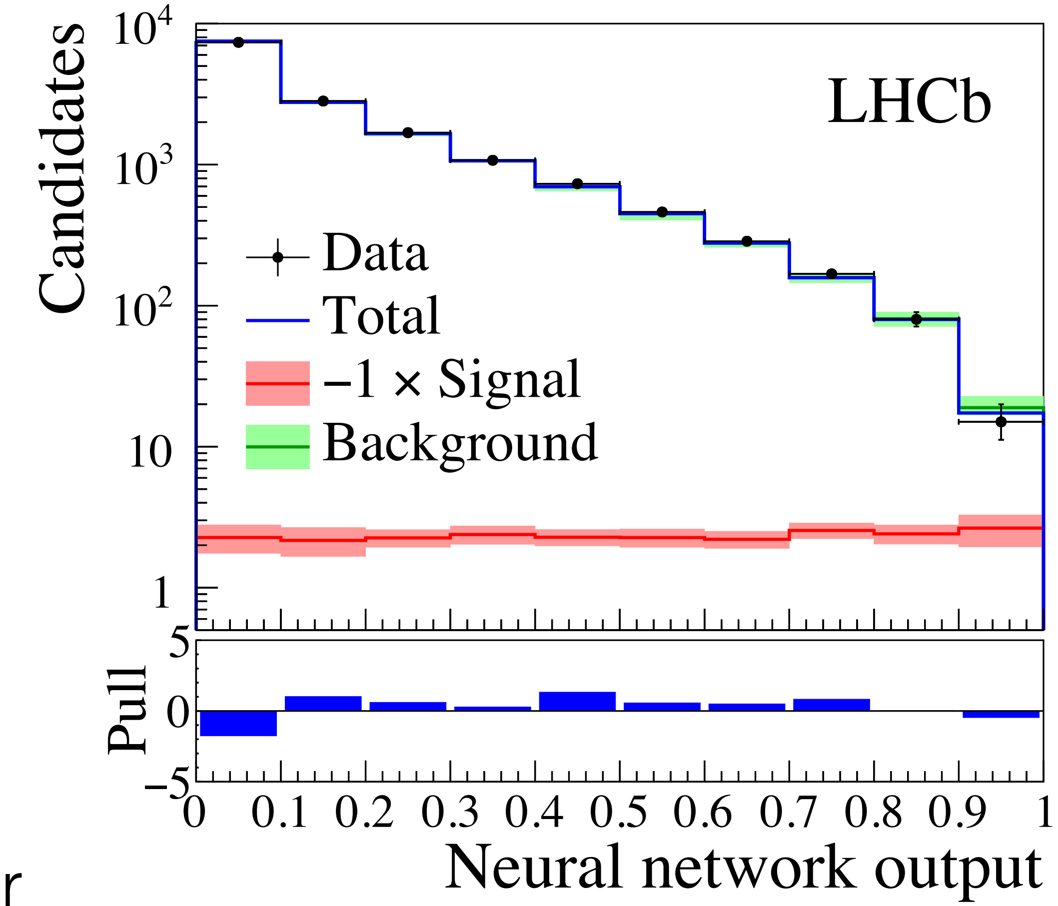
[LHCb, PRL 118 (2017) 191801]

$B_{(s,d)} \to \tau^+\tau^-$

- LHCb performs a search for $B_{(s,d)} \to \tau^+\tau^-$ decays using $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$.
  - ➡ Exploit the $\tau^- \to a_1(1260)^-\nu_\tau$ and $a_1(1260)^- \to \rho(770)^0\pi^-$ decays to select signal/control regions of dipion mass.
- Fit Neural network response to discriminate signal from background.
  - ➡ Ditau mass is not a good discriminator due to missing neutrino energy.
- LHCb sets limits on:

$$\mathcal{B}(B_s^0 \to \tau^+\tau^-) < 6.8 \times 10^{-3} \ (95\% \text{ CL})$$

$$\mathcal{B}(B^0 \to \tau^+\tau^-) < 2.1 \times 10^{-3} \ (95\% \text{ CL})$$



[LHCb, PRL 118 (2017) 251802]

First limit on $B_s \to \tau^+\tau^-$ and worlds best limit on $B^0 \to \tau^+\tau^-$