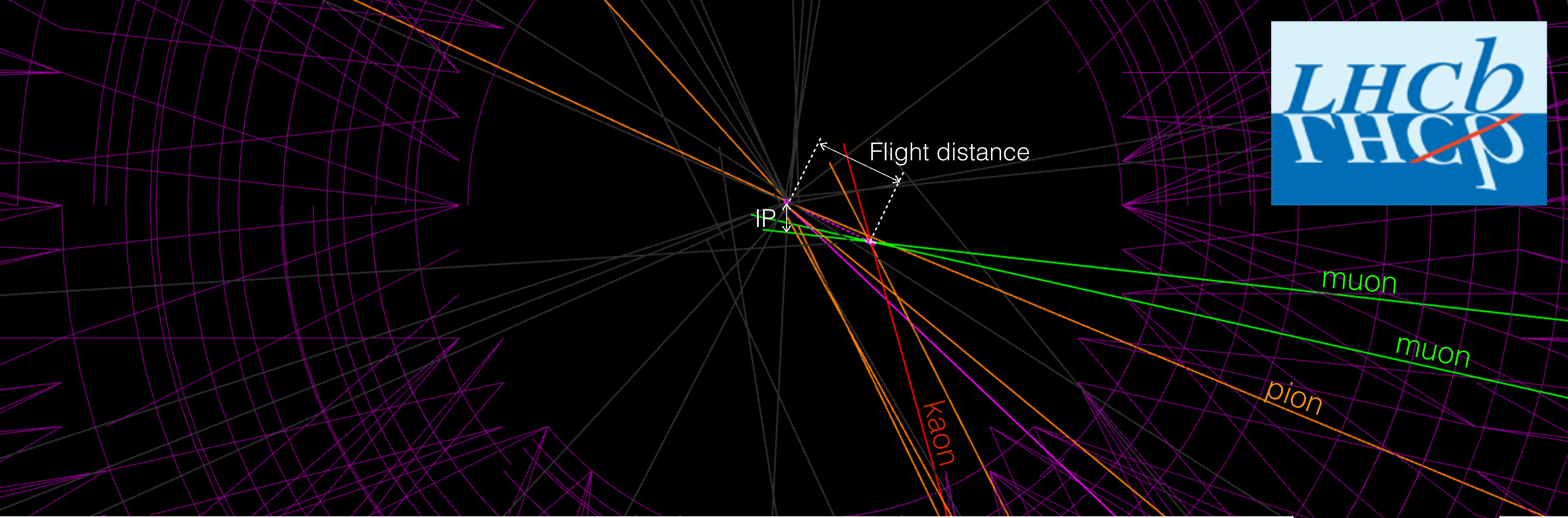


Prospects for ~~rare~~ not so rare $b \to (s,d)\ell^+\ell^-$ transitions

T. Blake for the LHCb collaboration

WARWICK
THE UNIVERSITY OF WARWICK

Beyond the LHCb Phase-1 Upgrade workshop

Prospects

- With the phase II upgrade (and 300fb^{-1}), we will have large samples of "rare" $b \to (s,d)\ell^+\ell^-$ decays.

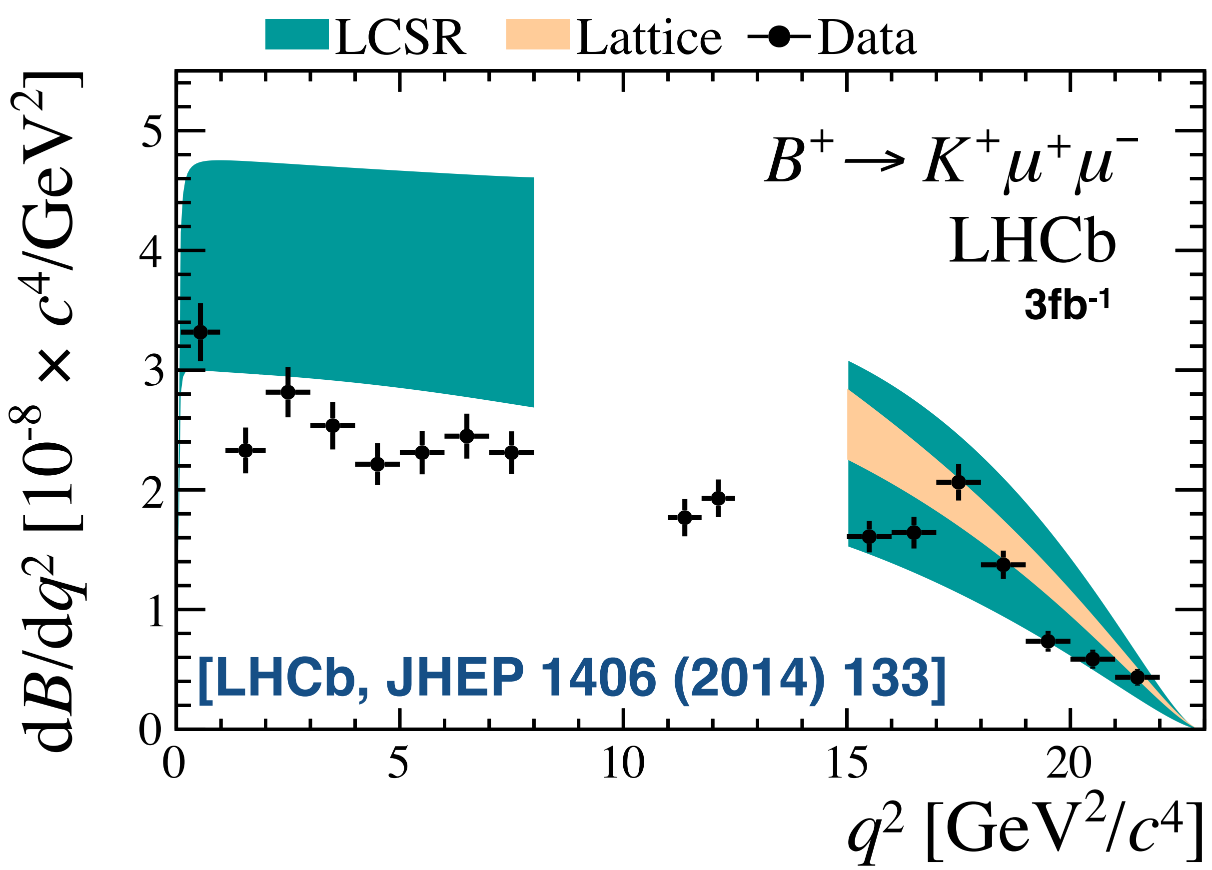
- Assuming a naive scaling with $\sqrt{s}$ and luminosity + factor of two improvement in the electron modes after removing the hardware trigger.

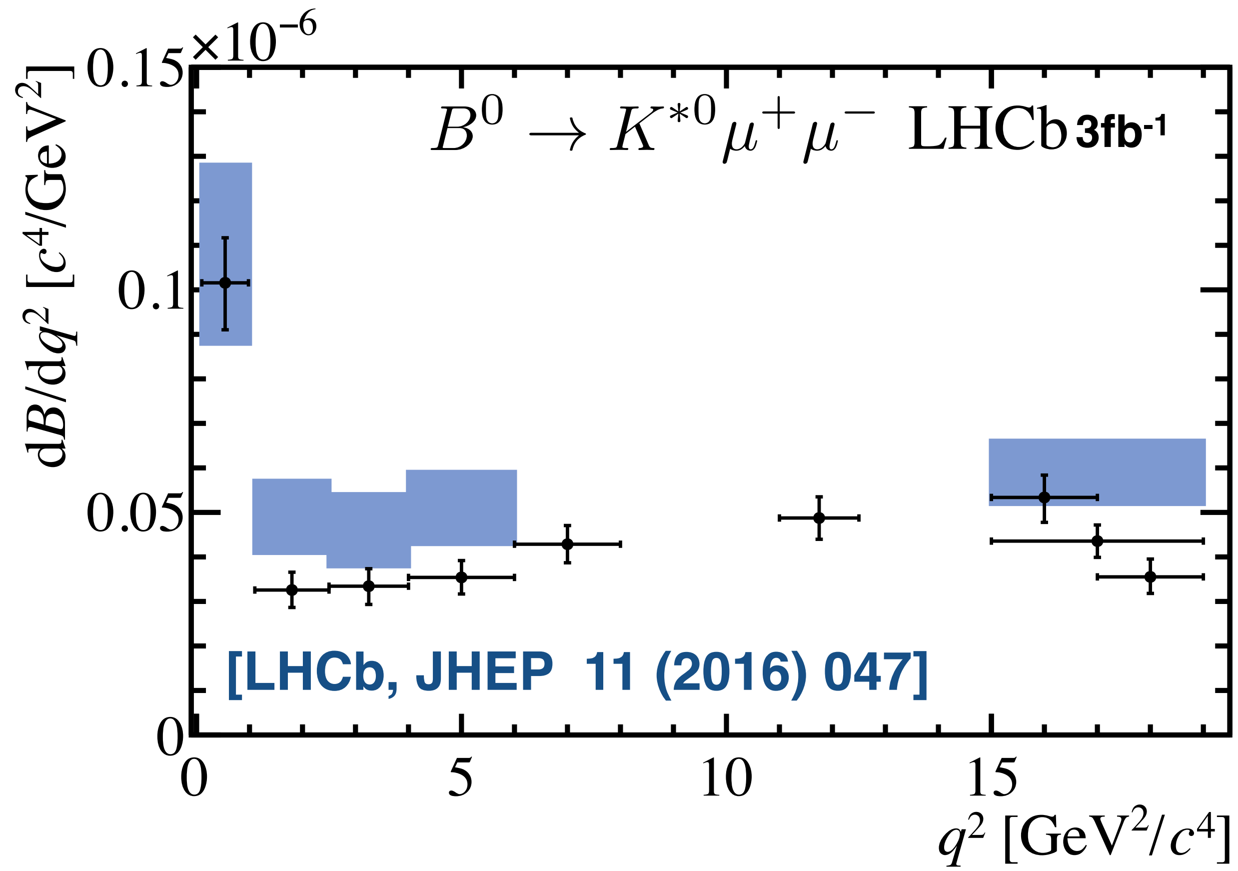
Decay	run 1	300fb^{-1}
$B^0 \to K^{*0}\mu^+\mu^-$	2 400	432 000
$B^+ \to K^+\mu^+\mu^-$	4 700	846 000
$\Lambda_b \to \Lambda^0\mu^+\mu^-$	$300^{\ddagger}$	54 000
$B^0 \to \rho^0\mu^+\mu^-$	40^*	7 200
$B^+ \to \pi^+\mu^+\mu^-$	90	16 200
$B_s^0 \to \overline{K}^{*0}\mu^+\mu^-$	–	$4\,300^{\dagger}$
$B^0 \to K^{*0}e^+e^-$ $(q^2 \in [1,6])$	110	39 600
$B^+ \to K^+e^+e^-$ $(q^2 \in [1,6])$	250	90 000

***assuming the ρ^0 dominates the ππ spectrum**
†scaled from f_s/f_d and $|V_{td}/V_{ts}|^2$
‡signal only observed at large q^2 in run 1 dataset

Branching fraction measurements

- We already have precise measurements of branching fractions in the run1 dataset 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]**. Expect improvements from Lattice on timescale of phase II upgrade.

Systematic uncertainty on branching fraction measurements

- Use $B^0 \to K^{*0}\mu^+\mu^-$ as an example to understand what systematic uncertainties are important:

[LHCb-PAPER-2016-025, JHEP 12 (2016) 065]

Source	$F_S\|_{644}^{1200}$	$d\mathcal{B}/dq^2 \times 10^{-7} (c^4/\text{GeV}^2)$
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

Uncertainty on $\mathcal{B}(B \to J/\psi X)$ normalisation modes is already a limiting factor. Encourage Belle 2 to update these measurements!

Systematic uncertainty on branching fraction measurements

- Use $B^0 \to K^{*0}\mu^+\mu^-$ as an example to understand what systematic uncertainties are important:

[LHCb-PAPER-2016-025, JHEP 12 (2016) 065]

Source	$F_S\|_{644}^{1200}$	$d\mathcal{B}/dq^2 \times 10^{-7} (c^4/\text{GeV}^2)$
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

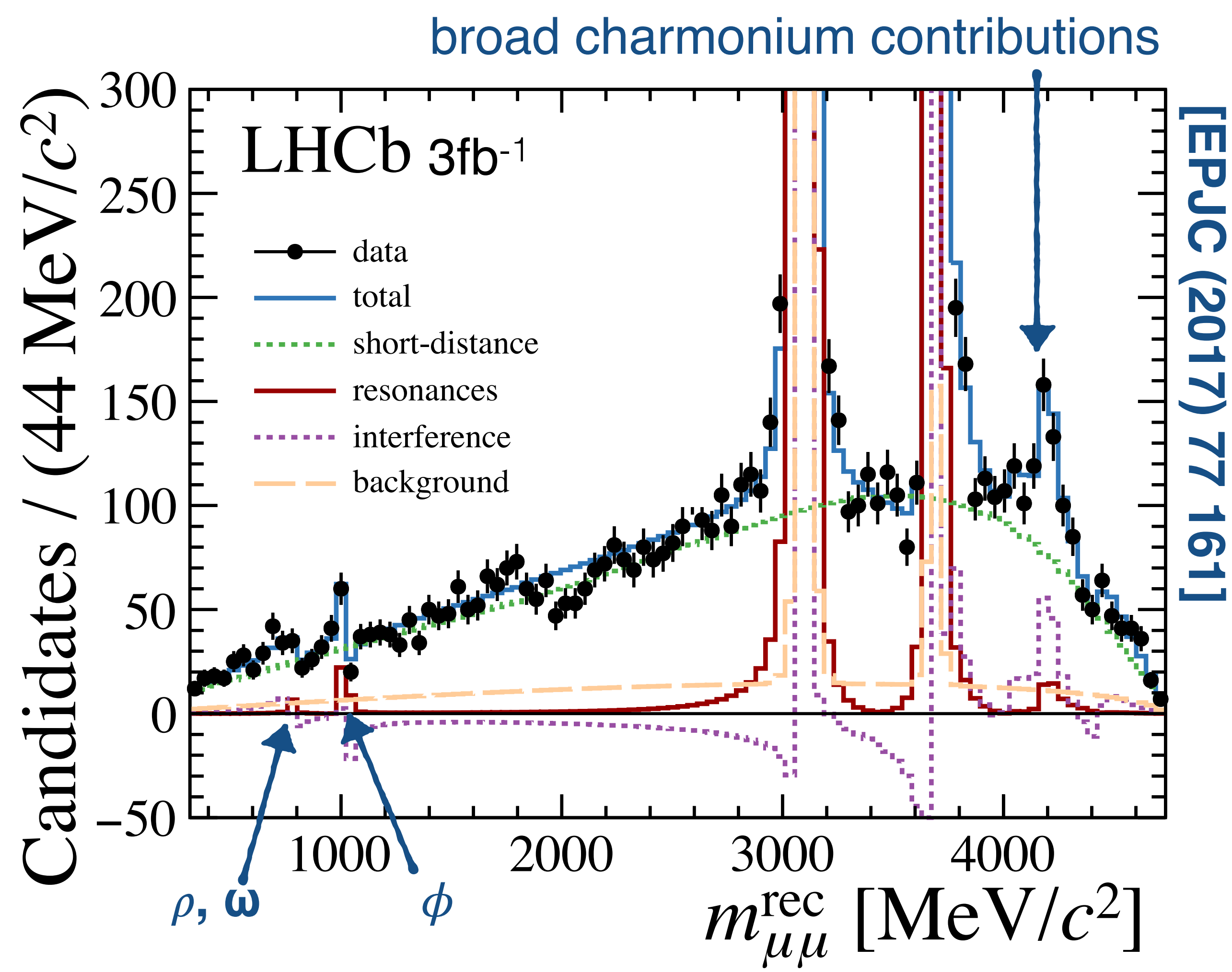
LASS vs Isobar

Partly data driven with a component that scales with integrated luminosity

To get the correct average efficiency over a q^2 bin, simulation needs to correctly model the differential angular distribution.

Resonant contributions

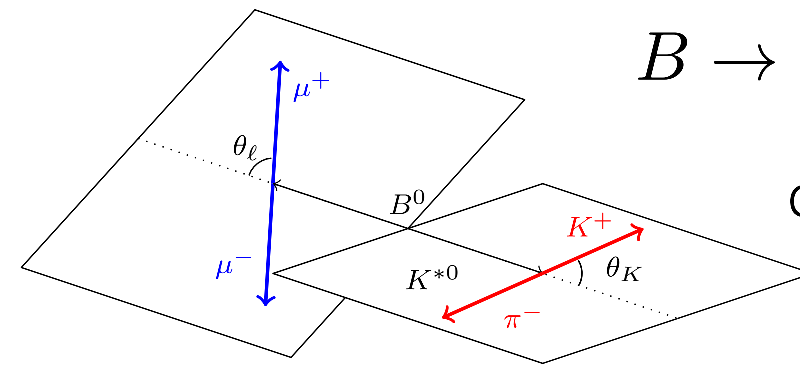
- With a 50-300fb^{-1} dataset we will have much better control of the shape of $\mathrm{d}\mathcal{B}/\mathrm{d}q^2$ than its absolute normalisation.
- Can make precise measurements of the q^2 spectrum (including resonant contributions) and test form-factor dependences → feedback to theory.



- We can exploit the data to search for new light GeV-scale particles, e.g. narrow resonant contributions in **[LHCb, PRL 115 (2015)161802]** and **[LHCb, PRD 95 (2017) 071101]**.
- Should be able to exclude models proposing new GeV-scale particles as an explanation for R_K/R_{K^*}. **[F. Sala & D. Straub, arXiv: 1704.06188]**

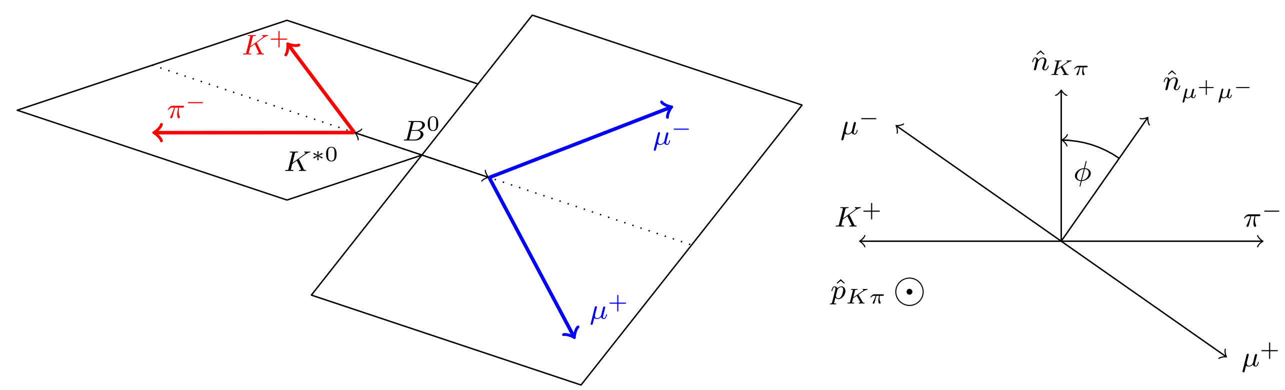
Angular observables

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



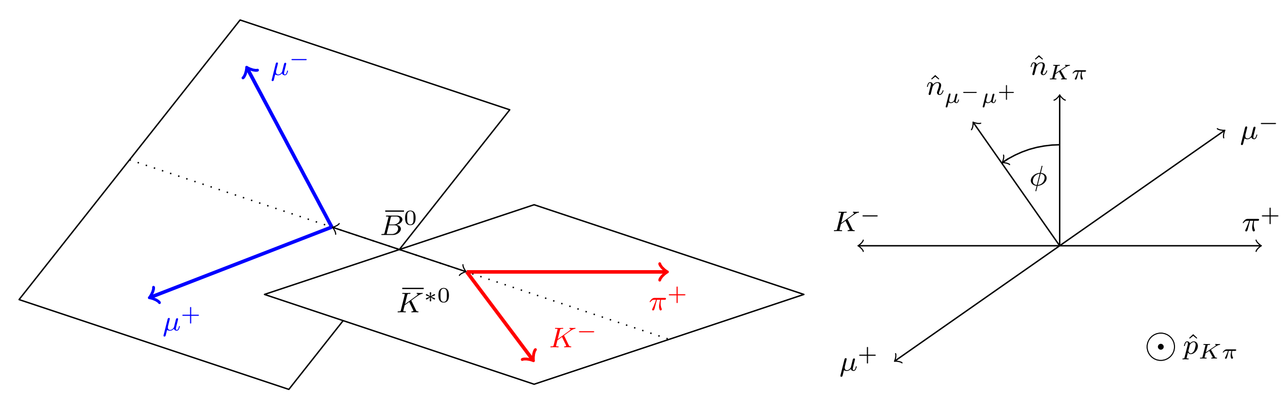
(a) θ_K and θ_ℓ definitions for the B^0 decay

- 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.



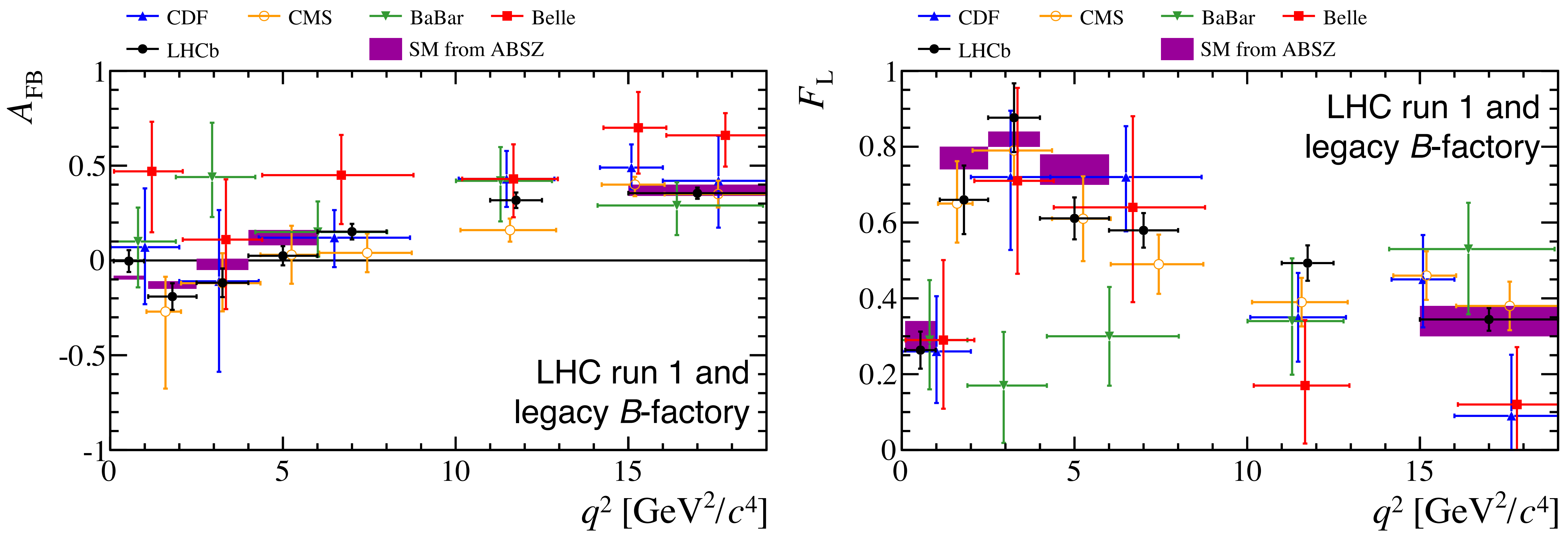
(b) ϕ definition for the B^0 decay

eg $B \to V\ell^+\ell^-$ system described by three angles and the dimuon invariant mass squared, q^2.



(c) ϕ definition for the $\overline{B}^0$ decay

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



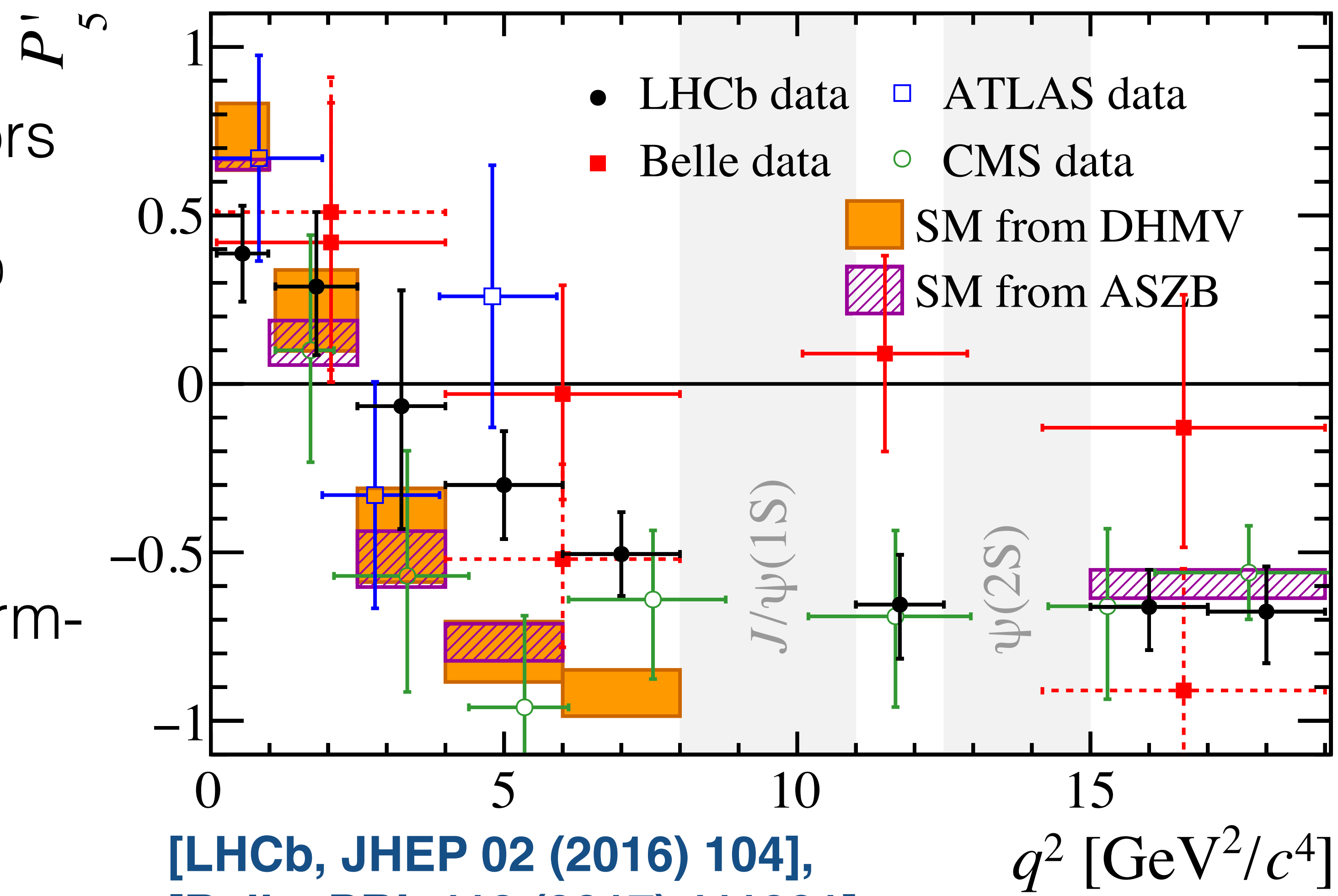
- Overlaying results for F_L and A_{FB} from LHCb **[JHEP 02 (2016) 104]** , CMS **[PLB 753 (2016) 424]** and BaBar **[PRD 93 (2016) 052015]** + measurements from CDF **[PRL 108 (2012) 081807]** and Belle **[PRL 103 (2009) 171801].**

- 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

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.

$$P'_5 = S_5/\sqrt{F_\mathrm{L}(1-F_\mathrm{L})}$$



[LHCb, JHEP 02 (2016) 104], [Belle, PRL 118 (2017) 111801], [ATLAS-CONF-2017-023], [CMS-PAS-BPH-15-008]

- 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]**.

Systematic uncertainty on angular observables

- Using $B^0 \to K^{*0} \mu^+ \mu^-$ as an example:

Source	F_L	S_3–S_9	A_3–A_9	P_1–P'_8	q_0^2 GeV$^2/c^4$
Acceptance stat. uncertainty	< 0.01	< 0.01	< 0.01	< 0.01	0.01
Acceptance polynomial order	< 0.01	< 0.02	< 0.02	< 0.04	0.01–0.03
Data-simulation differences	0.01–0.02	< 0.01	< 0.01	< 0.01	< 0.02
Acceptance variation with q^2	< 0.01	< 0.01	< 0.01	< 0.01	–
$m(K^+\pi^-)$ model	< 0.01	< 0.01	< 0.01	< 0.03	< 0.01
Background model	< 0.01	< 0.01	< 0.01	< 0.02	0.01–0.05
Peaking backgrounds	< 0.01	< 0.01	< 0.01	< 0.01	0.01–0.04
$m(K^+\pi^-\mu^+\mu^-)$ model	< 0.01	< 0.01	< 0.01	< 0.02	< 0.01
Det. and prod. asymmetries	–	–	< 0.01	< 0.02	–

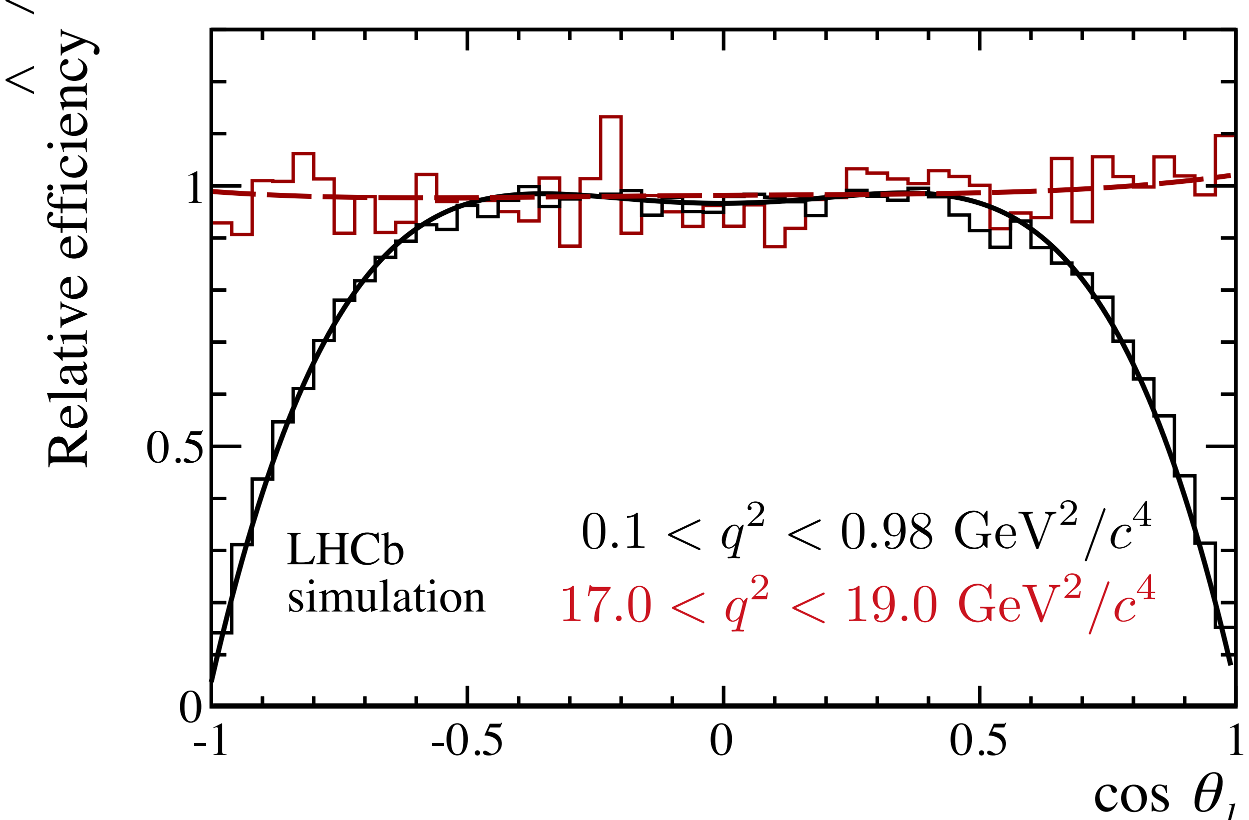
- Expect many sources of systematic uncertainty to scale as $\sqrt{N}$ with increased luminosity.
- We will likely reach systematic uncertainties of ≲0.01 on the angular observables.

Systematic uncertainty on angular observables

- Using $B^0 \to K^{*0}\mu^+\mu^-$ as an example:

Source	$F_{\rm L}$	S_3–S_9	A_3–A_9	P_1–P_8'	q_0^2 GeV$^2/c^4$
Acceptance stat. uncertainty	< 0.01	< 0.01	< 0.01	< 0.01	0.01
Acceptance polynomial order	< 0.01	< 0.02	< 0.02	< 0.04	0.01–0.03
Data-simulation differences	0.01–0.02	< 0.01	< 0.01	< 0.01	< 0.02
Acceptance variation with q^2	< 0.01	< 0.01	< 0.01	< 0.01	–
$m(K^+\pi^-)$ model	< 0.01	< 0.01	< 0.01	< 0.03	< 0.01
Background model	< 0.01	< 0.01	< 0.01	< 0.02	0.01–0.05
Peaking backgrounds	< 0.01	< [illegible]	[illegible]	[illegible]	[illegible]
$m(K^+\pi^-\mu^+\mu^-)$ model	< 0.01	< [illegible]	[illegible]	[illegible]	[illegible]
Det. and prod. asymmetries	–	[illegible]	[illegible]	[illegible]	[illegible]

- Need to understand what the detector acceptance, reconstruction and selection do to the angular distribution of our signal. This is dictated by the MC sample size ⇒ fast MC.



Systematic uncertainty on angular observables

- Using $B^0 \to K^{*0}\mu^+\mu^-$ as an example:

Source	F_L	S_3–S_9	A_3–A_9	P_1–P_8'	q_0^2 GeV$^2/c^4$
Acceptance stat. uncertainty	<0.01	<0.01	<0.01	<0.01	0.01
Acceptance polynomial order	<0.01	<0.02	<0.02	<0.04	0.01–0.03
Data-simulation differences	0.01–0.02	<0.01	<0.01	<0.01	<0.02
Acceptance variation with q^2	<0.01	<0.01	<0.01	<0.01	–
$m(K^+\pi^-)$ model	<0.01	<0.01	<0.01	<0.03	<0.01
Background model	<0.01	<0.01	<0.01	<0.02	0.01–0.05
Peaking backgrounds	<0.01	<0.01	<0.01	<0.01	0.01–0.04
$m(K^+\pi^-\mu^+\mu^-)$ model	<0.01	<0.01	<0.01	<0.02	<0.01
Det. and prod. asymmetries	–	–	<0.01	<0.02	–

Combinatorial background

Physics background

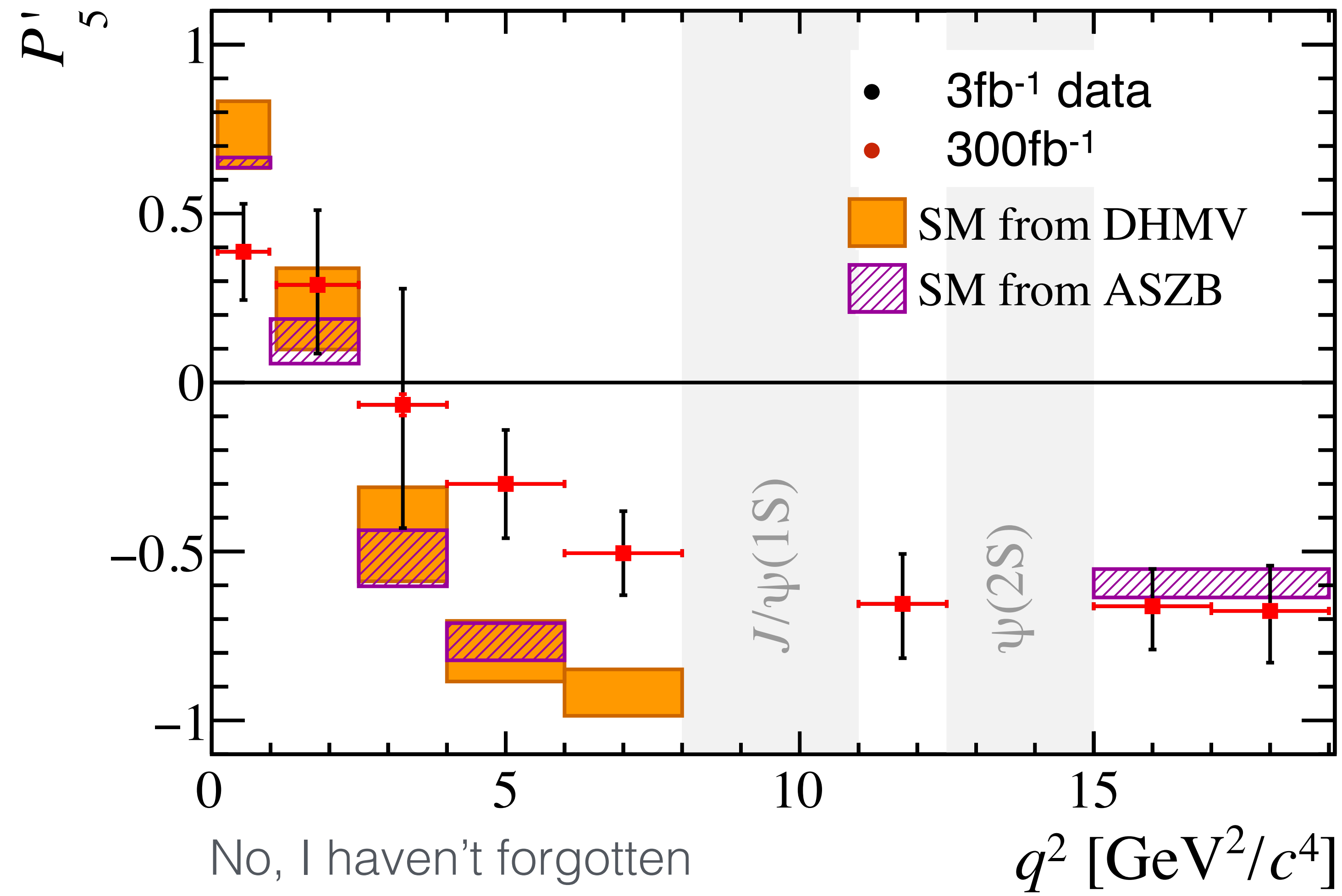
- Receive contributions from $\Lambda_b \to \Lambda^*\mu^+\mu^-$, $\bar{B}_s \to K^{*0}\mu^+\mu^-$, hadronic backgrounds etc.
  - ➡ PID performance is critical for controlling the background level.
- Can improve the systematic uncertainty by studying the angular distribution of the backgrounds in the data with a larger dataset.

Angular analyses with 300fb^{-1}?

- Can update our existing measurements in the same binning.

eg Scaling statistical uncertainty to 300fb^{-1} with a systematic uncertainty of 0.01.

- For *CP* averaged observables, we will have similar precision to SM predictions after run 2.



No, I haven't forgotten the error bars.

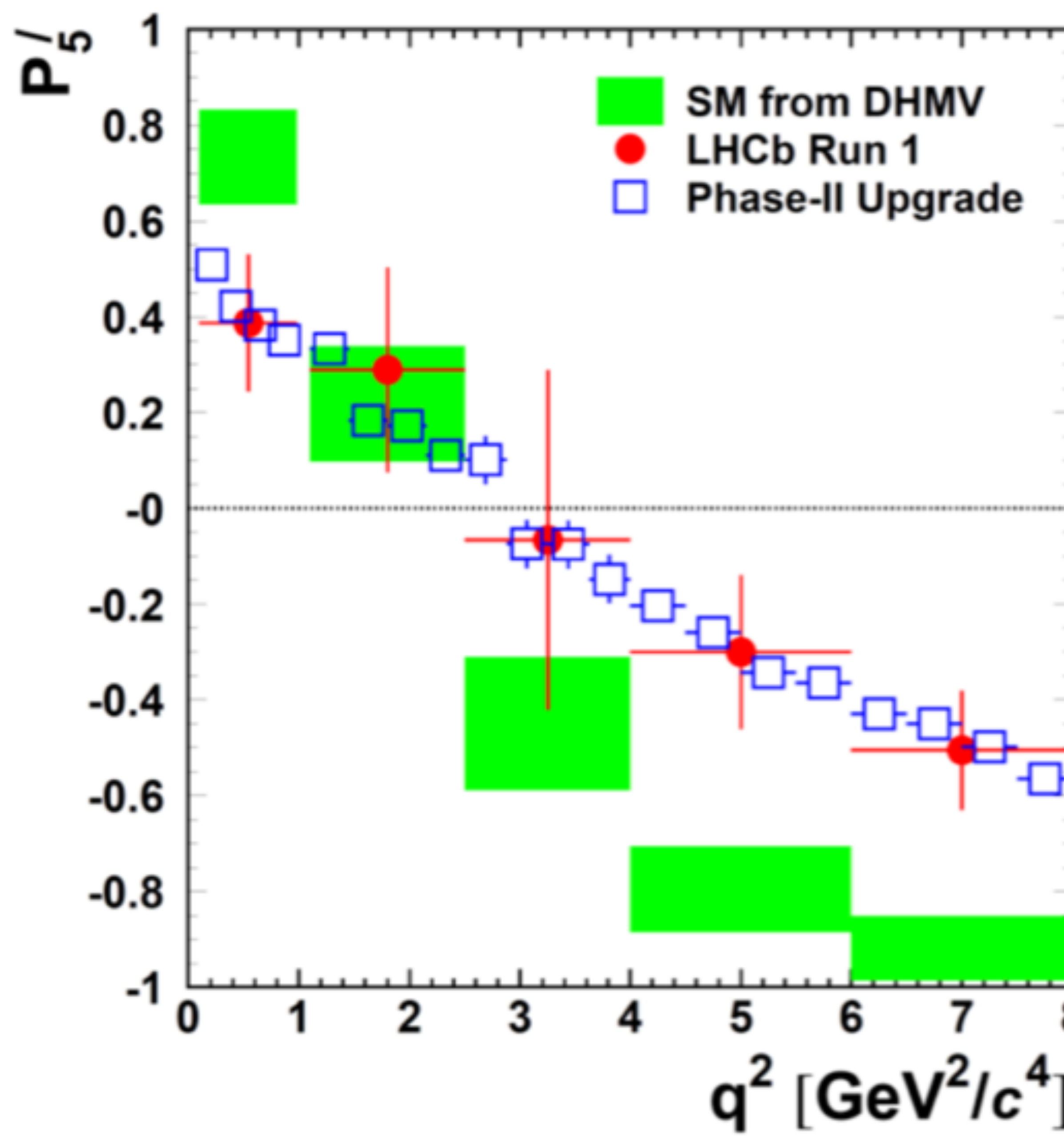
- *CP* asymmetries will remain clean up-to large luminosities. We have already demonstrated that we can control detector/production asymmetries to <1%.

Angular analyses with 300fb^{-1}

- We can also choose to bin much more finely to probe the shape of the distribution.

eg Scaling uncertainty on run 1 analysis to 300fb^{-1} with input on $d\Gamma/dq^2$ (to subdivide dataset within the existing bins).

- Finer binning allows for precise tests of zero-crossing point and end-point relationships **[G. Hiller & R. Zwicky, JHEP 03 (2014) 042]**

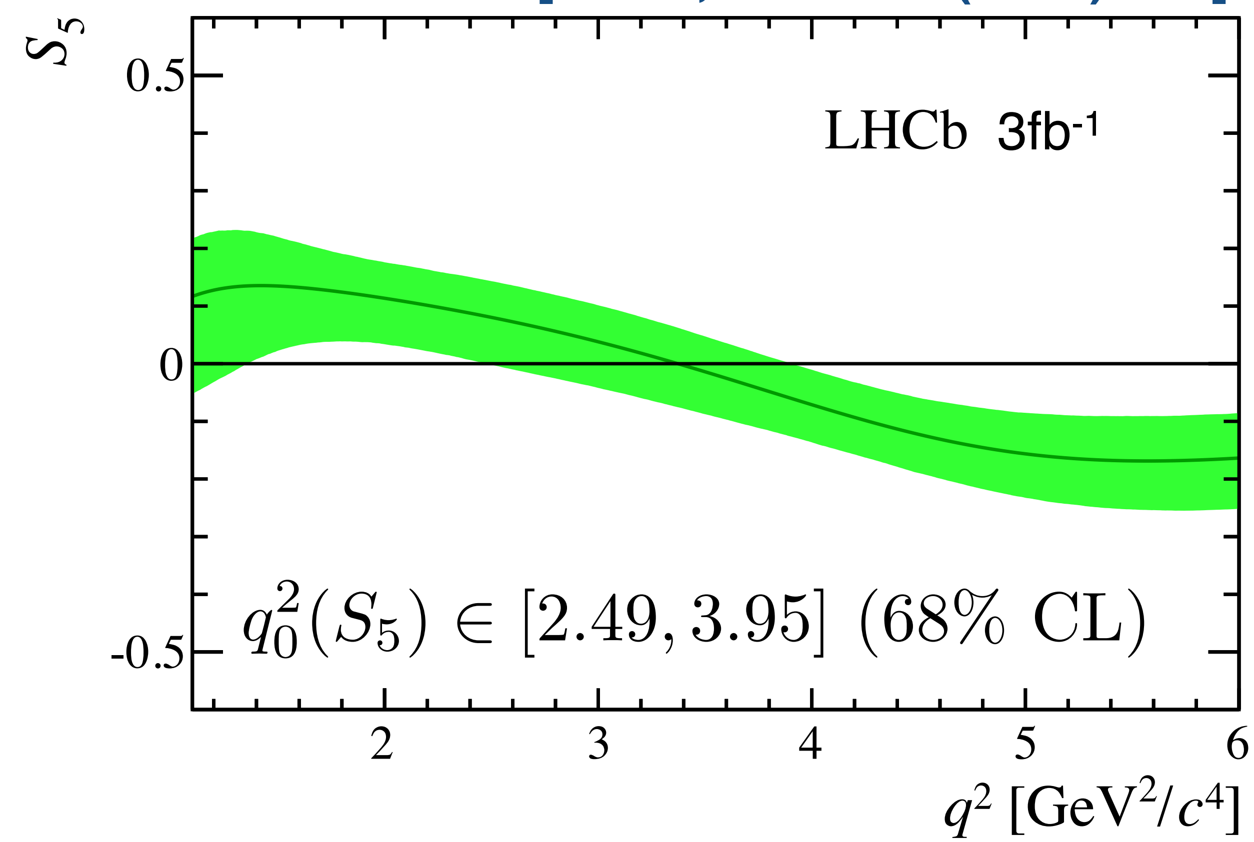


[LHCb, EOI for phase II upgrade]

Fitting for amplitudes

- Can also fit directly for q^2 dependent amplitudes.
  - ➡ Exploited to determine the zero-crossing point of A_{FB}, S_4 and S_5 in run 1.

[LHCb, JHEP 02 (2016) 104]



- Or be even more ambitious, e.g. perform a full amplitude analysis of the $K\pi\mu\mu$ final-state taking into account resonant contributions.
  - ➡ We can try to fit directly for hadronic contributions to reduce theoretical uncertainties.

Lepton universality tests

- We have interesting hints of non-universal lepton couplings in LHCb run 1 dataset (2.6σ in R_K and 2.4-2.5σ in RK* in $1<q^2<6$ GeV^2/c^4)

$$R_{K^{*0}} = \begin{cases} 0.66 \,{}^{+\,0.11}_{-\,0.07}\,(\text{stat}) \pm 0.03\,(\text{syst}) & \text{for } 0.045 < q^2 < 1.1 \;\; \text{GeV}^2/c^4\,, \\ 0.69 \,{}^{+\,0.11}_{-\,0.07}\,(\text{stat}) \pm 0.05\,(\text{syst}) & \text{for } 1.1 \quad < q^2 < 6.0 \;\; \text{GeV}^2/c^4\,. \end{cases}$$

[LHCb, LHCb-PAPER-2017-013]

$$R_{K^+} = 0.745^{+0.09}_{-0.07}(\text{stat}) \pm 0.04(\text{syst}) \quad \text{for } 1.0 \quad < q^2 < 6.0 \;\; \text{GeV}^2/c^4\,.$$

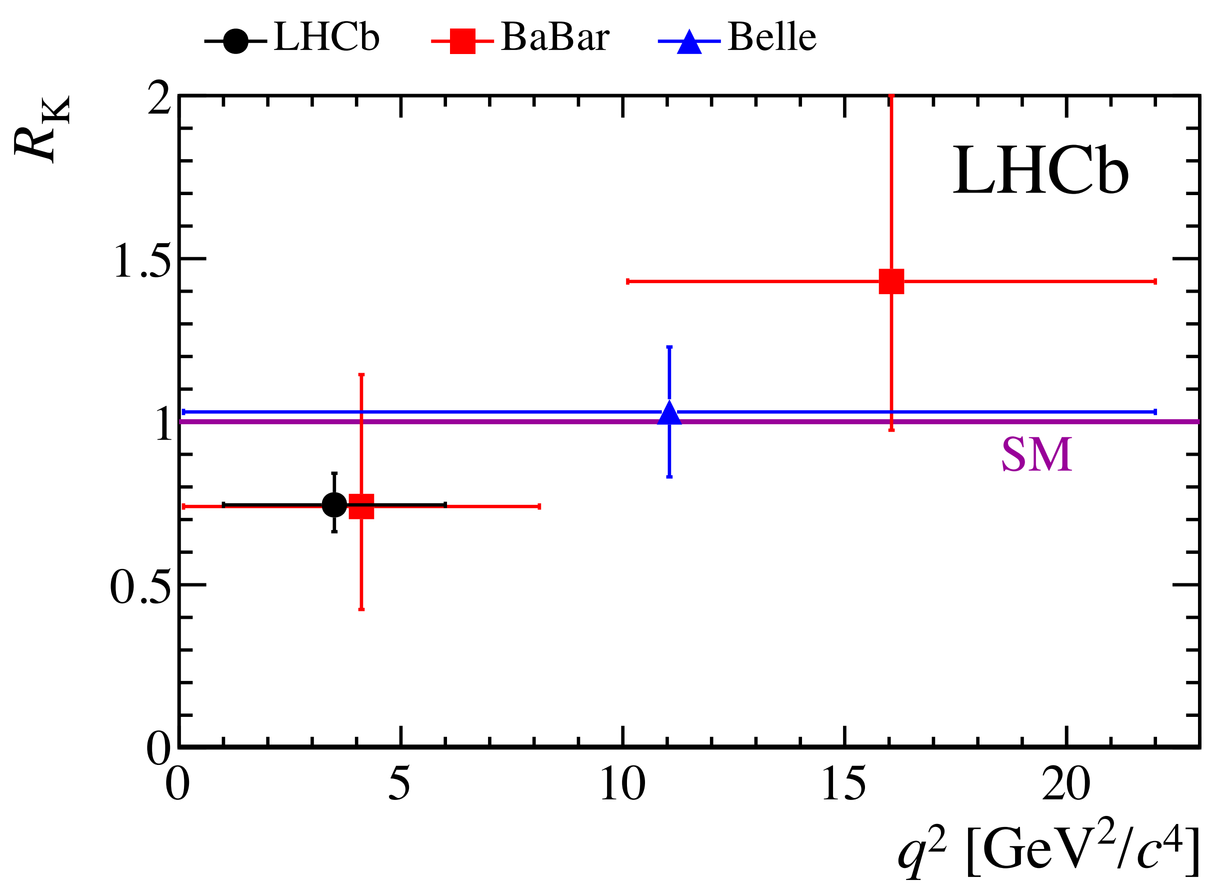
[LHCb , PRL113 (2014) 151601]

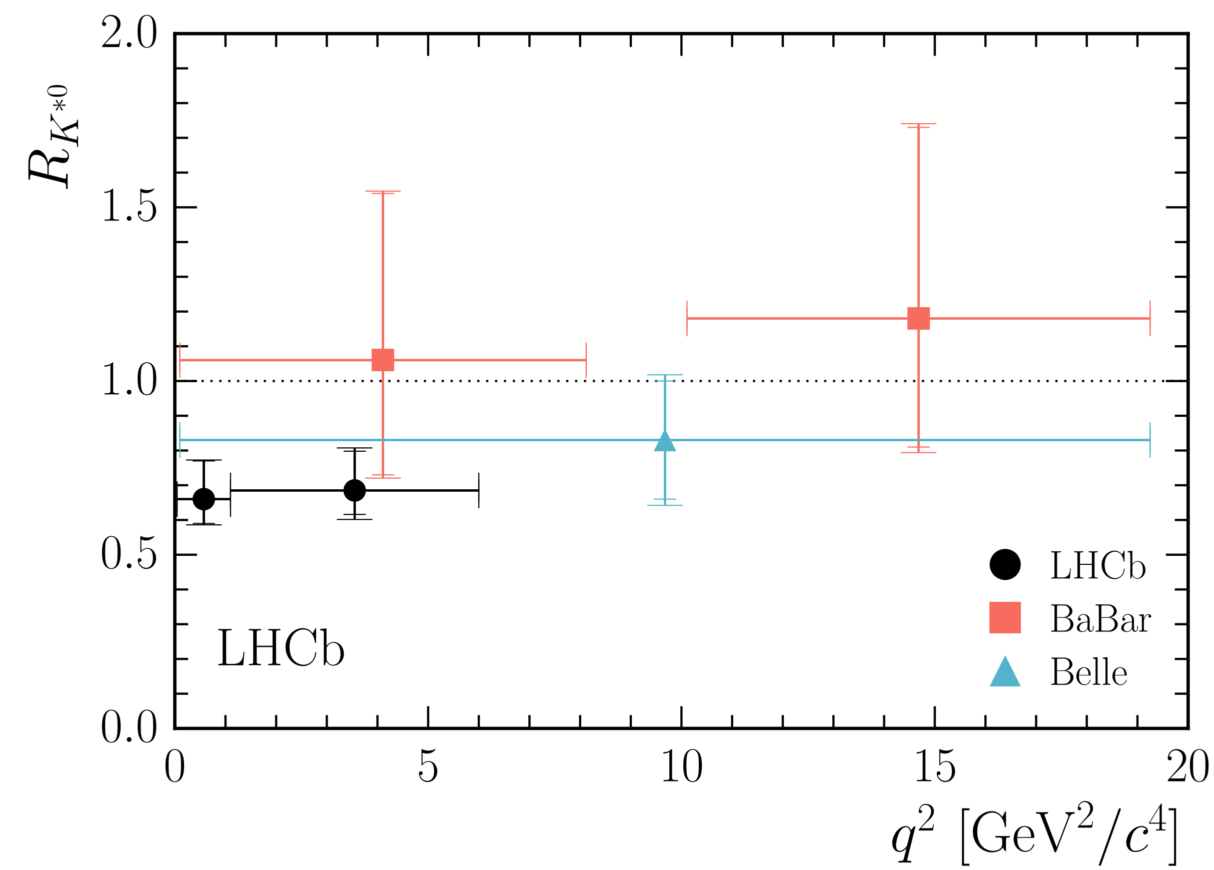
where $R_M = \dfrac{\int \mathrm{d}\Gamma[B \to M\mu^+\mu^-]/\mathrm{d}q^2 \;\mathrm{d}q^2}{\int \mathrm{d}\Gamma[B \to Me^+e^-]/\mathrm{d}q^2 \;\mathrm{d}q^2}$

NB We are statistically limited in the run 1 dataset but systematic uncertainties could become important after run 2.

Lepton universality tests

- We have interesting hints of non-universal lepton couplings in LHCb run 1 dataset (2.6σ in R_K and 2.4-2.5σ in RK* in $1<q^2<6$ GeV$^2/c^4$)



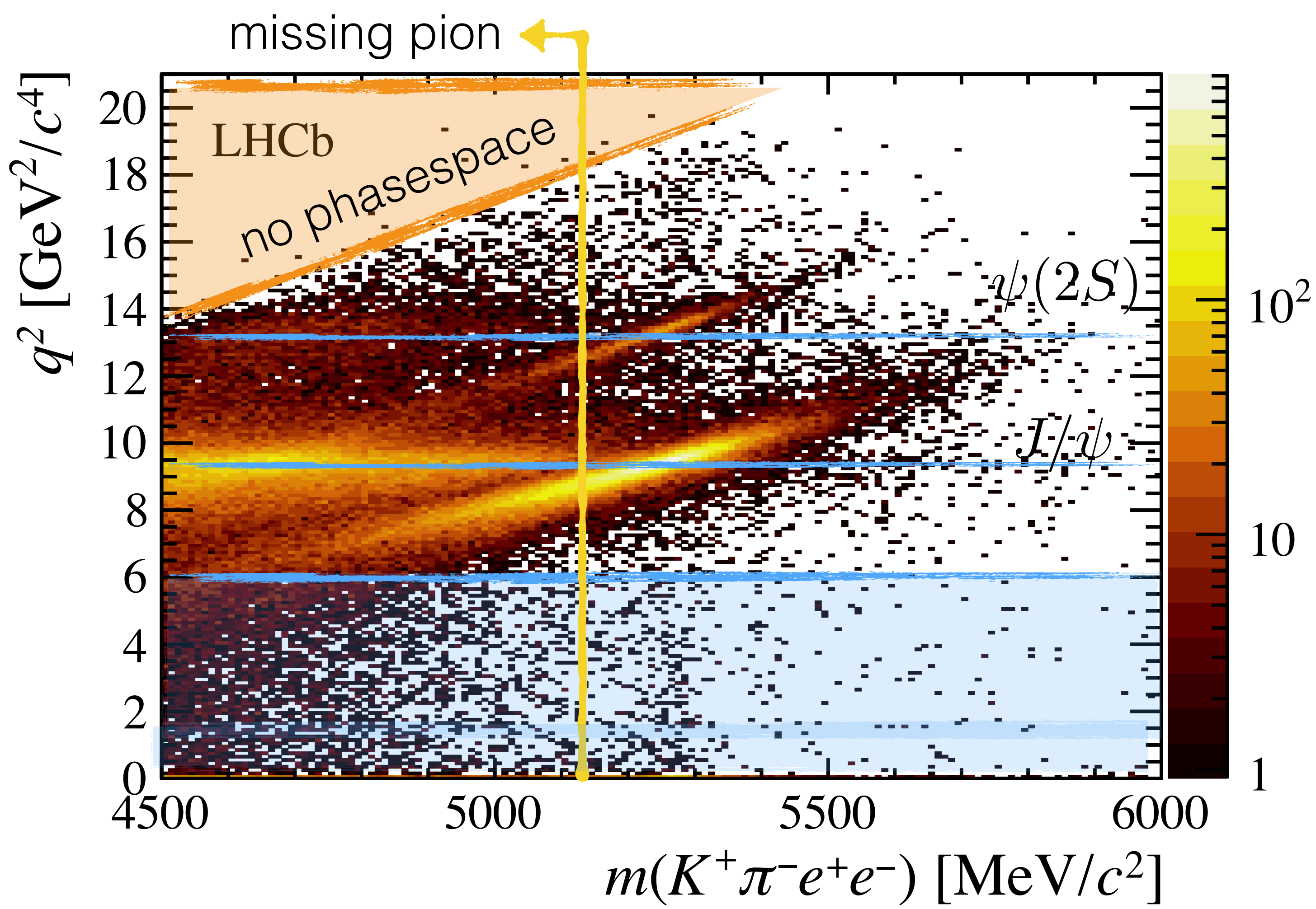


[LHCb , PRL113 (2014) 151601], [LHCb, LHCb-PAPER-2017-013], [BaBar, PRD 86 (2012) 032012], [Belle, PRL 103 (2009) 171801]

Experimental challenges

- Main experimental challenges related to energy loss by electrons by Bremsstrahlung in the detector.
  - ➡ Recover energy loss using clusters with E_T > 75MeV in ECAL.

- Can we improve?
  - ➡ Reduce Bremsstrahlung by reducing material before the magnet.
  - ➡ Finer granularity ECAL or ECAL with better energy resolution.

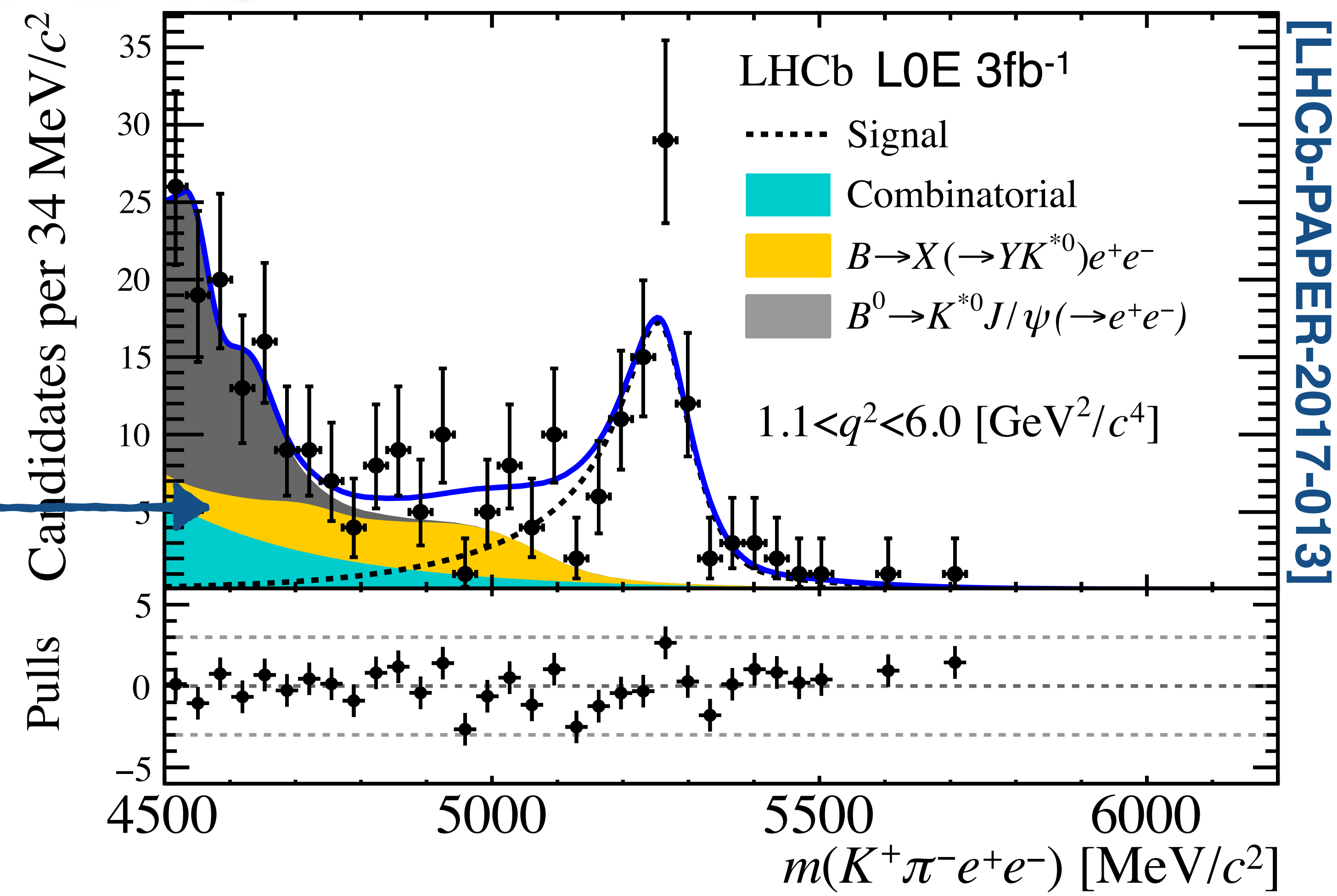


R_{K^*} systematic uncertainty

For L0E category	low-q^2	central-q^2
Corrections to simulation	2.5	2.2
Trigger efficiency	0.1	0.2
Particle identification	0.2	0.2
Kinematic selection	2.1	2.1
Residual background	–	5.0
Mass fits	1.4	
Bin migration	1.0	
$r_{J/\psi}$ flatness	1.6	
Total	4.0	

Largest uncertainty comes from the modelling of the background from $B \to K\pi\pi\ell^+\ell^-$

Partially reconstructed background is poorly known. Can reduce uncertainty by measuring the contributions in data or improving Brem. recovery



R_{K^*} systematic uncertainty

[LHCb-PAPER-2017-013]

For L0E category	low-q^2	central-q^2
Corrections to simulation	2.5	2.2
Trigger efficiency	0.1	0.2
Particle identification	0.2	0.2
Kinematic selection	2.1	2.1
Residual background	–	5.0
Mass fits	1.4	2.0
Bin migration	1.0	1.6
$r_{J/\psi}$ flatness	1.6	0.7
Total	4.0	6.4

- Related to how well we can model Bremsstrahlung in the detector/FSR and how well we know the shape of $\mathrm{d}\Gamma/\mathrm{d}q^2$

R_{K^*} systematic uncertainty

[LHCb-PAPER-2017-013]

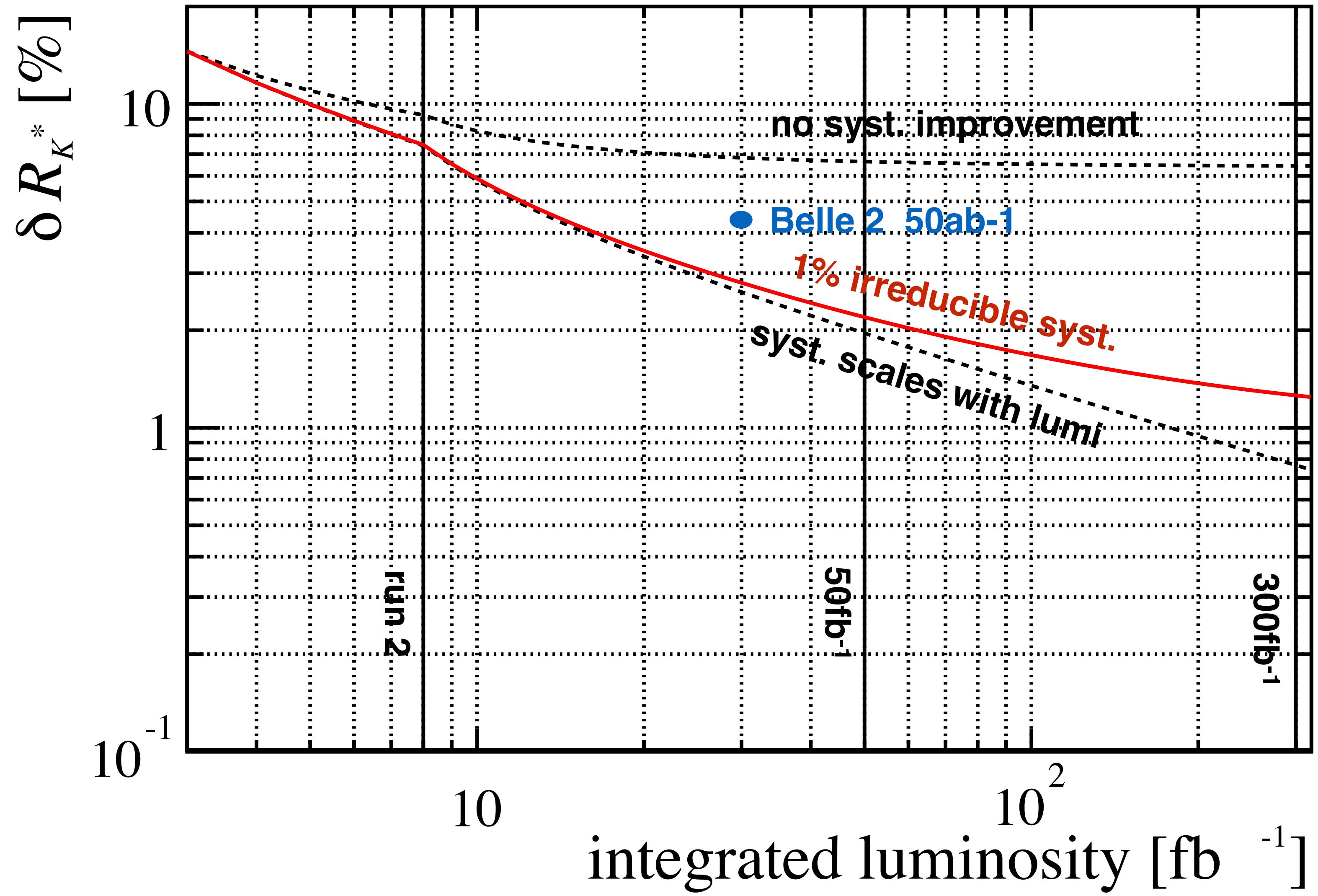
	low-q^2	central-q^2
Corrections to simulation	2.5	2.2
Trigger efficiency	0.1	0.2
Particle identification	0.2	0.2
Kinematic selection	2.1	2.1
Residual background	–	5.0
Mass fits	1.4	2.0
Bin migration	1.0	1.6
$r_{J/\psi}$ flatness	1.6	0.7
Total	4.0	6.4

Rely on data driven corrections. Expect these uncertainties to scale with increased luminosity.

- Ultimately we will probably reduce our systematic uncertainty to the level of 1-2% (caveats obviously apply).
- Can try to improve further by being smarter e.g. binning more finely and unfolding.

R_K and R_{K^*}

- Assuming an irreducible systematic uncertainty of 1% for R_{K^*} in the range $1<q^2<6$ GeV^2/c^4.
- For comparison Belle 2 expects to reach a precision of 4-5% with a systematic uncertainty of 0.4% with a 50ab^{-1} dataset **[From talk by S. Sandilya at CKM 2016]**



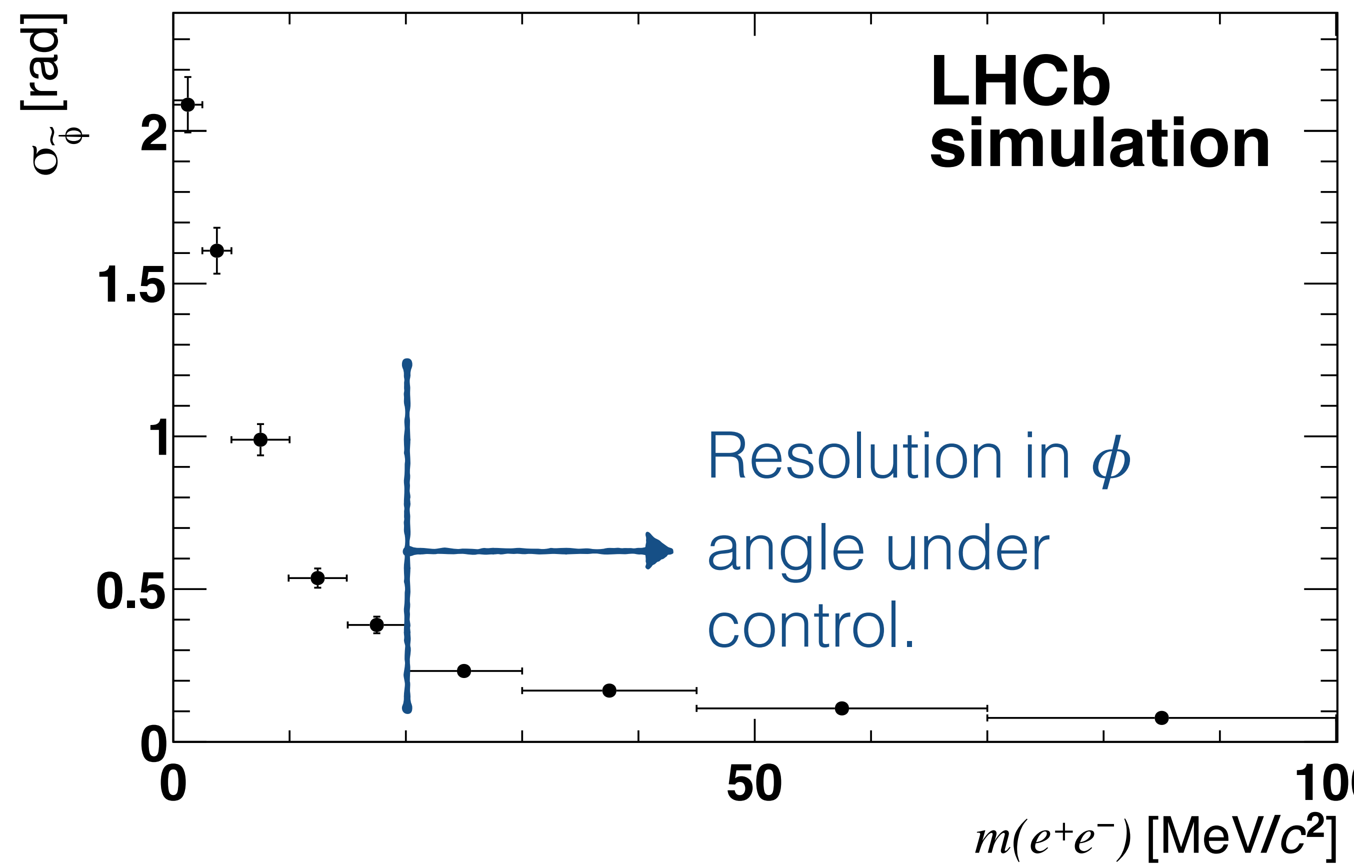
Angular analyses with electrons

- We have demonstrated that we can perform angular analyses with electrons in the run 1 data (at least at low-q^2).
- In $B^0 \to K^{*0} e^+ e^-$ measure:

$$A_T^{(2)} = -0.23 \pm 0.23 \pm 0.05$$
$$A_T^{Re} = 0.10 \pm 0.18 \pm 0.05$$
$$F_L = 0.16 \pm 0.06 \pm 0.03$$

  in the range $0.002 < q^2 < 1.120$ GeV$^2/c^4$.

- Measurements are statistically limited. Systematic uncertainties are similar in size to the dimuon mode.

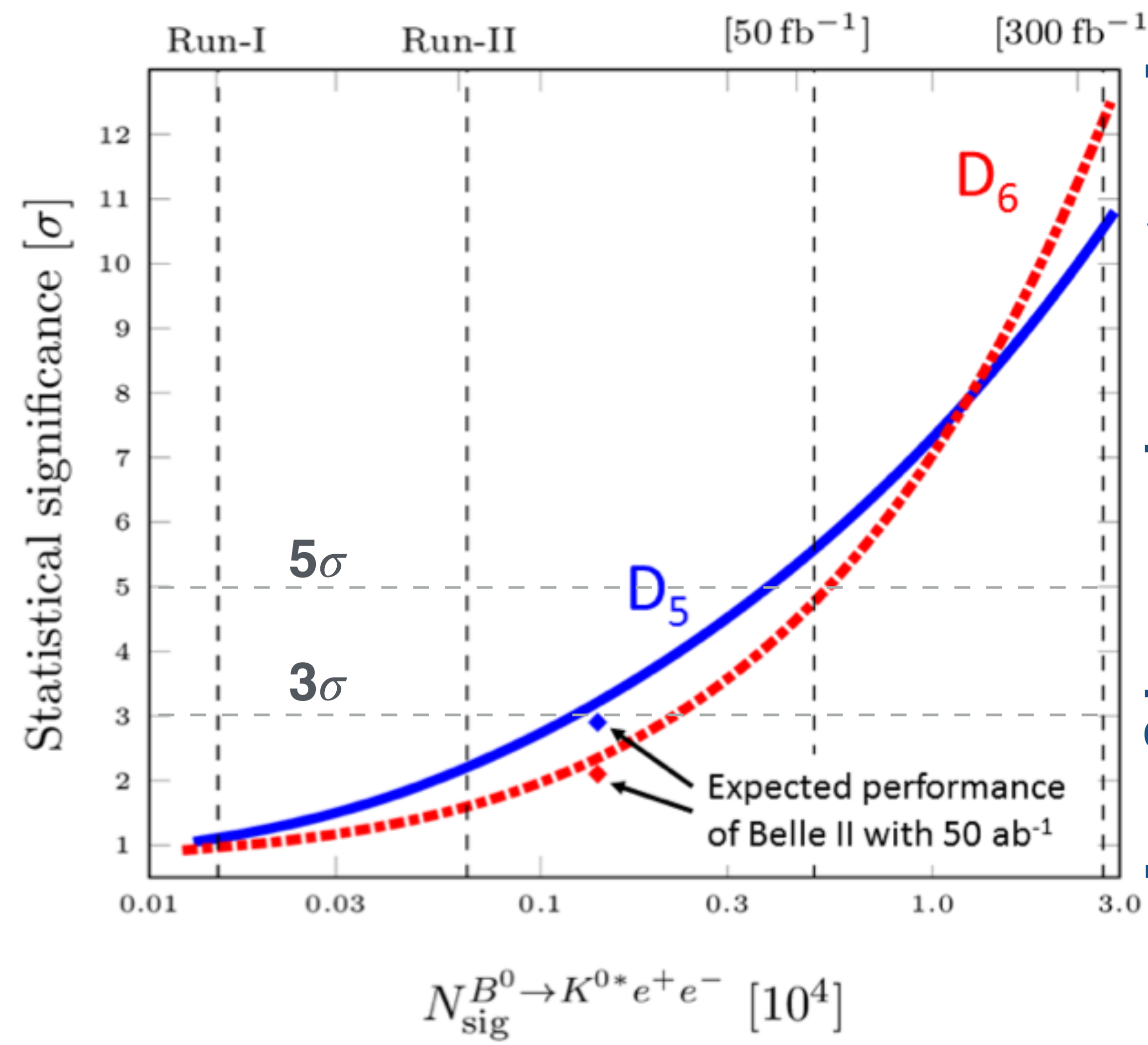


Note, resolution in θ_l and q^2 becomes important for moderate q^2 values.

Angular analyses with electrons

- Expect to have good sensitivity to differences in the angular distribution between electron/muon final-states with 50 - 300 fb^{-1}.

- Important caveat: we need to have good control over systematic uncertainties and background contamination.

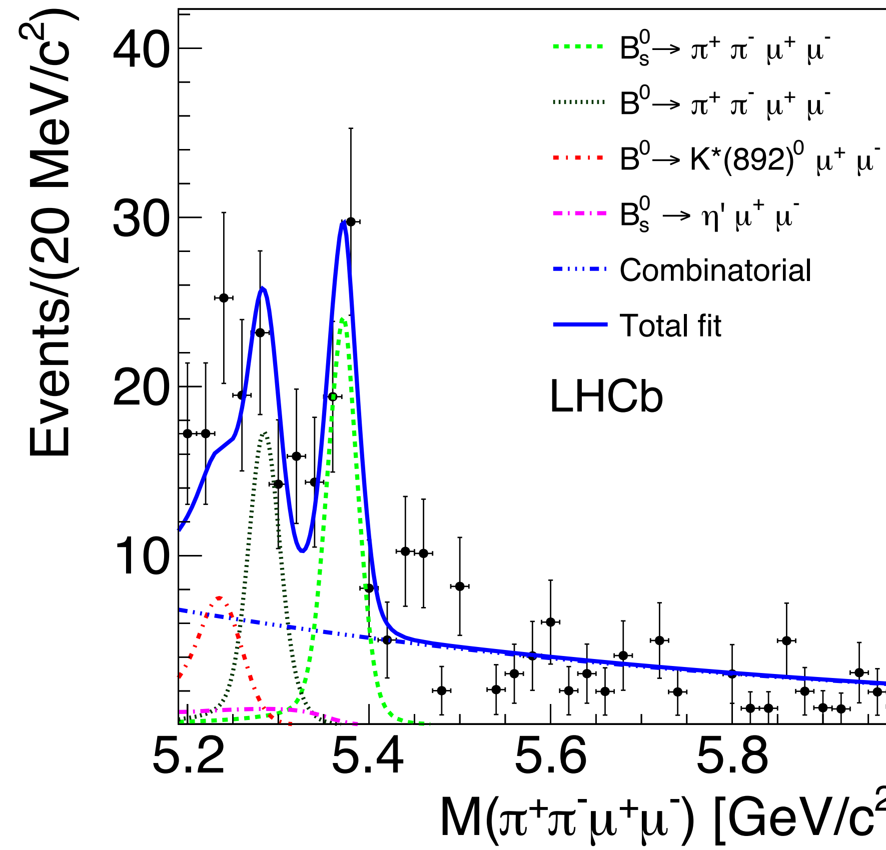


[LHCb, EOI for phase II upgrade]

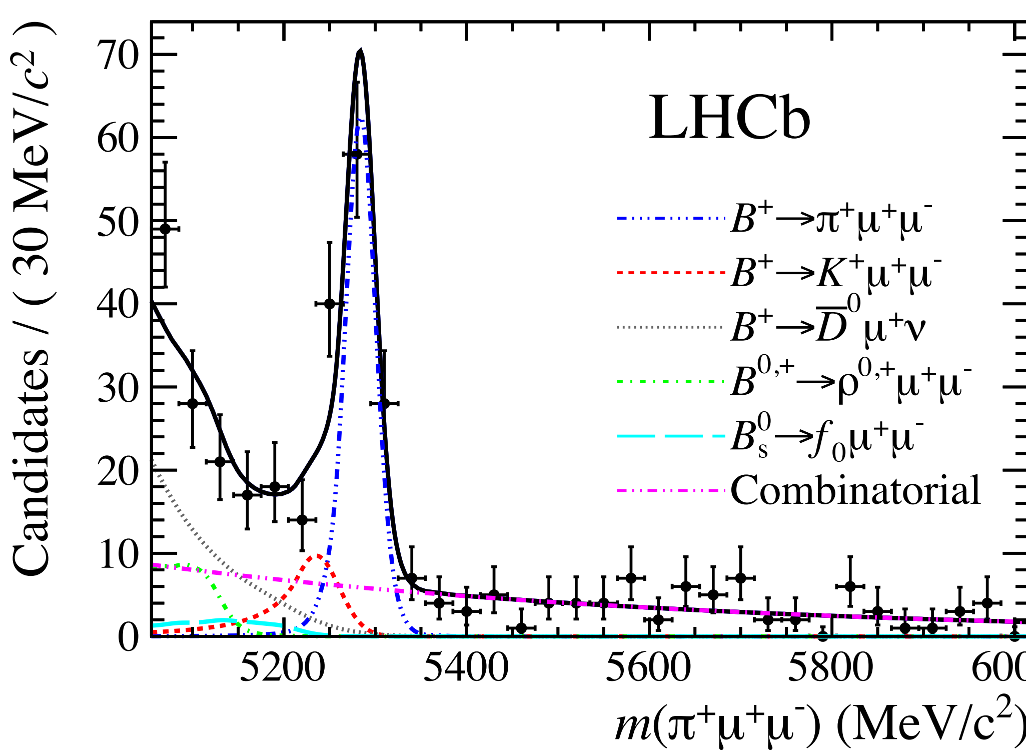
Expected difference between S_5 and S_6 (A_{FB}) between muons and electrons in NP model with non-universal couplings (at the level seen in R_K).

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

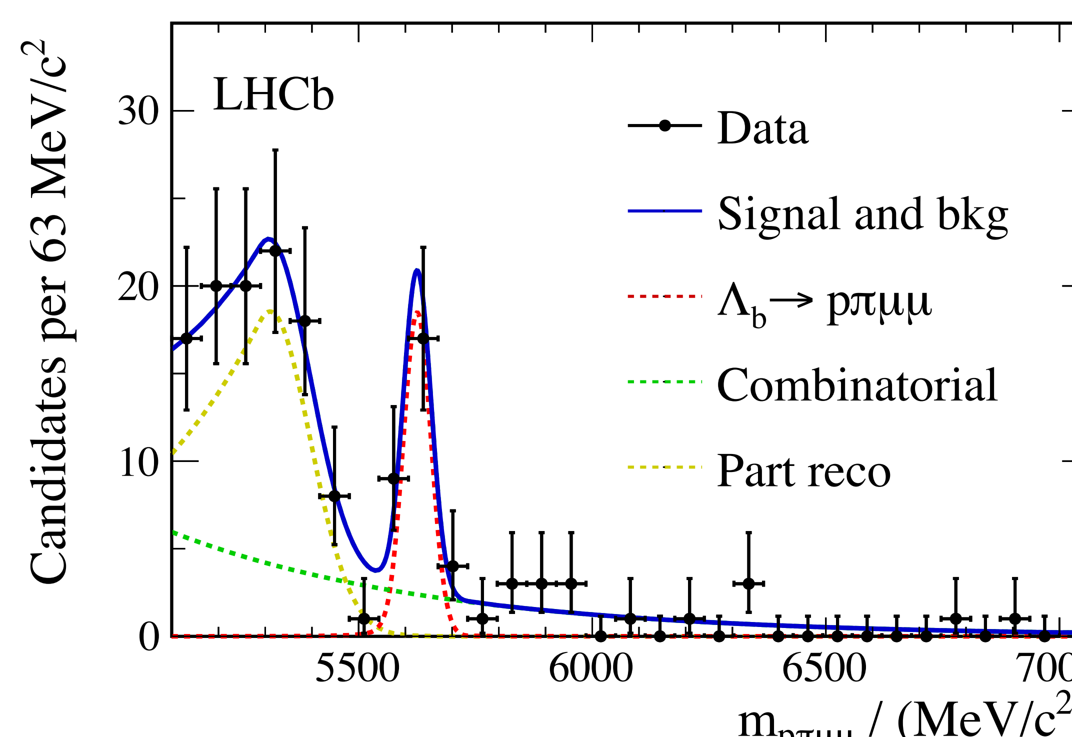
- We already have access to $b \to d\mu^+\mu^-$ processes in the run 1 dataset.
- With a 50 - 300fb^{-1} dataset, we will also be able to access $b \to de^+e^-$ processes e.g. expect O(1000) $B^+ \to \pi^+ e^+ e^-$ signal candidates in $1 < q^2 < 6$ GeV$^2/c^4$ range with 300fb^{-1}.



[PLB 743 (2015) 46]



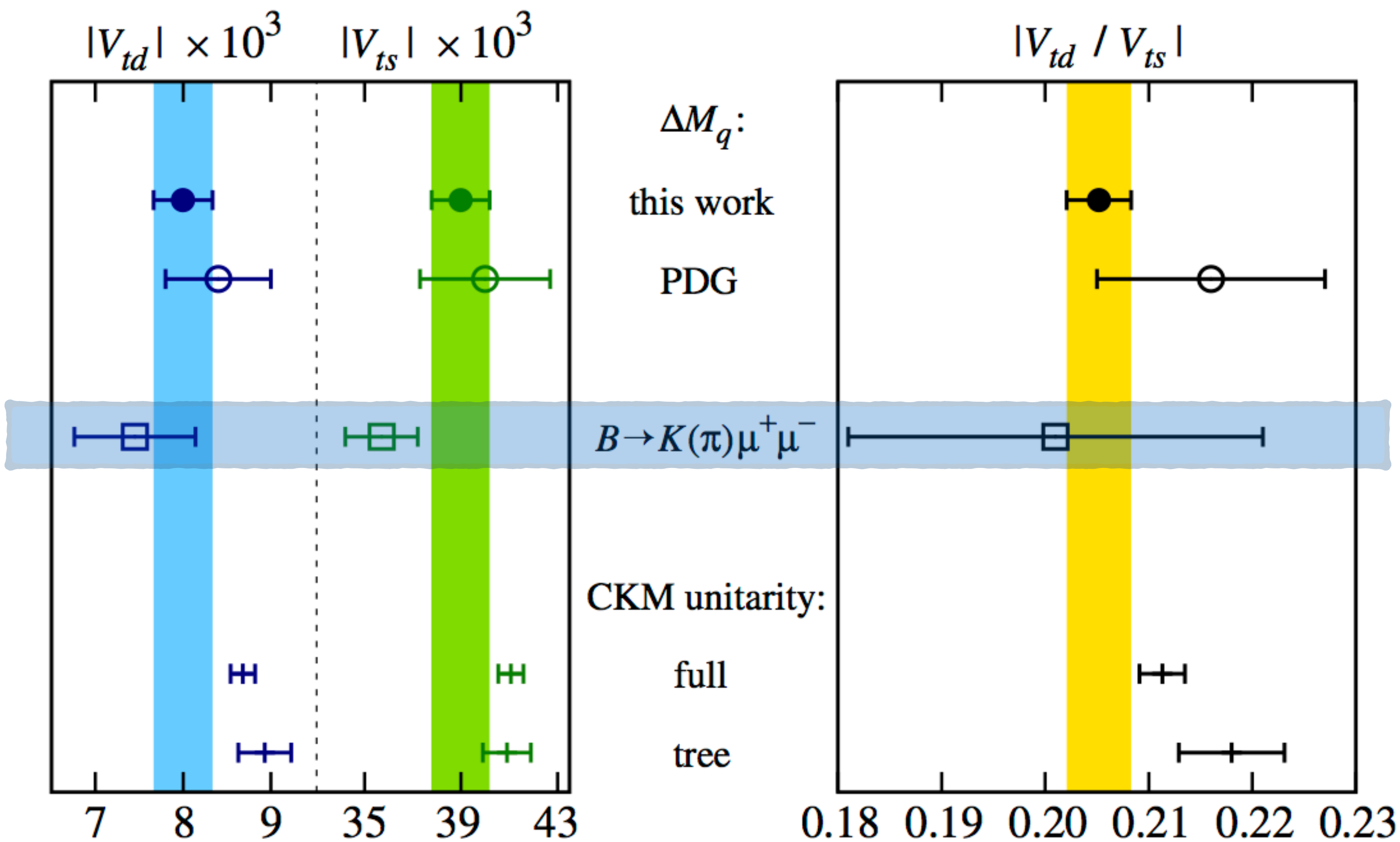
[JHEP 10 (2015) 034]



[JHEP 04 (2016) 029]

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

- With lattice input $b \to d\ell^+\ell^-$ processes can provide measurements of $|V_{td}/V_{ts}|$, see e.g. **[Du et al. PRD 93 (2016) 034005]**



[FNAL + MILC, PRD 93 (2016) 113016]

Constraint from rare decays with input on $f_+(q^2)$ form-factor from Lattice.

- Requires improvements from Lattice to get a dramatic improvement in precision on $|V_{td}/V_{ts}|$.

Global analysis of $b \to d\ell^+\ell^-$ transitions?

- With 300fb^{-1} we will have precise measurements of
  - ➡ $\mathcal{B}(B^0 \to \mu^+\mu^-)$, $\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)$, $\mathcal{B}(B^0 \to \rho^0\mu^+\mu^-)$
- Have seen in $b \to s\ell^+\ell^-$ processes how important angular measurements can be. What can we do for $b \to d\ell^+\ell^-$ processes?
  - ➡ Angular analysis of $B^0 \to \rho^0\mu^+\mu^-$ requires flavour tagging to have access to full set of observables. Effective tagging power is O(5%) in run 1. Limits sensitivity even with phase II dataset.
  - ➡ Angular analysis of $B^0_s \to \overline{K}^{*0}\mu^+\mu^-$ is possible. Depends critically on our mass resolution to separate B^0 background from B^0_s signal.
  - ➡ Angular analysis of $\Lambda_b \to p\pi\mu^+\mu^-$ (we might need to consider a large number of $p\pi$ resonance contributions).
  - ➡ Angular analysis of $B^+ \to \rho^+\mu^+\mu^-$? Flavour-tagging is not necessary and would enable a test of isospin symmetry.

$b \to s\tau^+\tau^-$ decays

- Small SM branching fractions due to limited phasespace (consequence of large τ mass).

eg Accessible branching fraction in high q^2 region is:

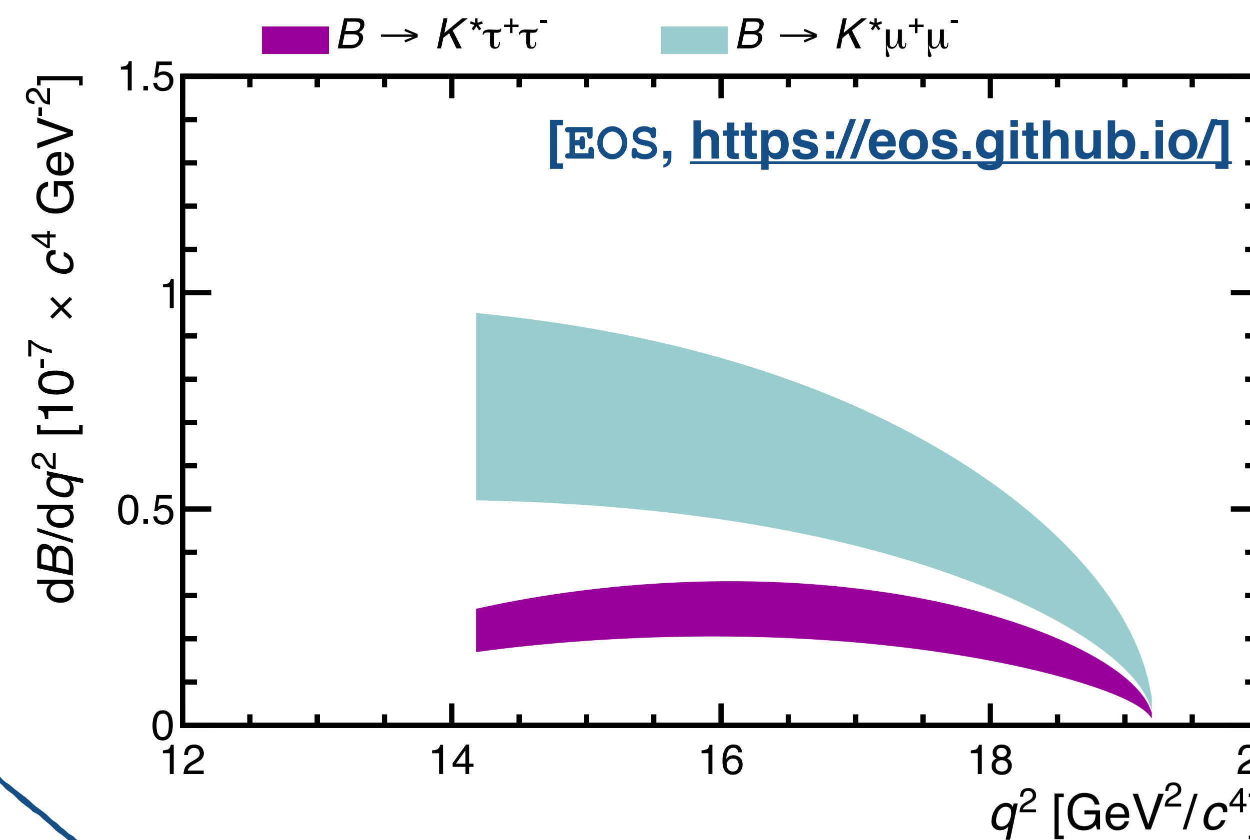
$$\mathcal{B}(B^0 \to K^{*0}\tau^+\tau^-) \approx 2 \times 10^{-7}$$
$$\mathcal{B}(B^+ \to K^+\tau^+\tau^-) \approx 1 \times 10^{-7}$$

- Only existing limit of the rate of $b \to s\tau^+\tau^-$ decays gives

$$\mathcal{B}(B^+ \to K^+\tau^+\tau^-) \approx 2.3 \times 10^{-3}$$

at 90% CL.

[BaBar, PRL 118 (2017) 031802]



Large difference between existing limits and SM prediction.

- In contrast to dimuon and dielectron final-states, need to use ψ(2S) for normalisation.

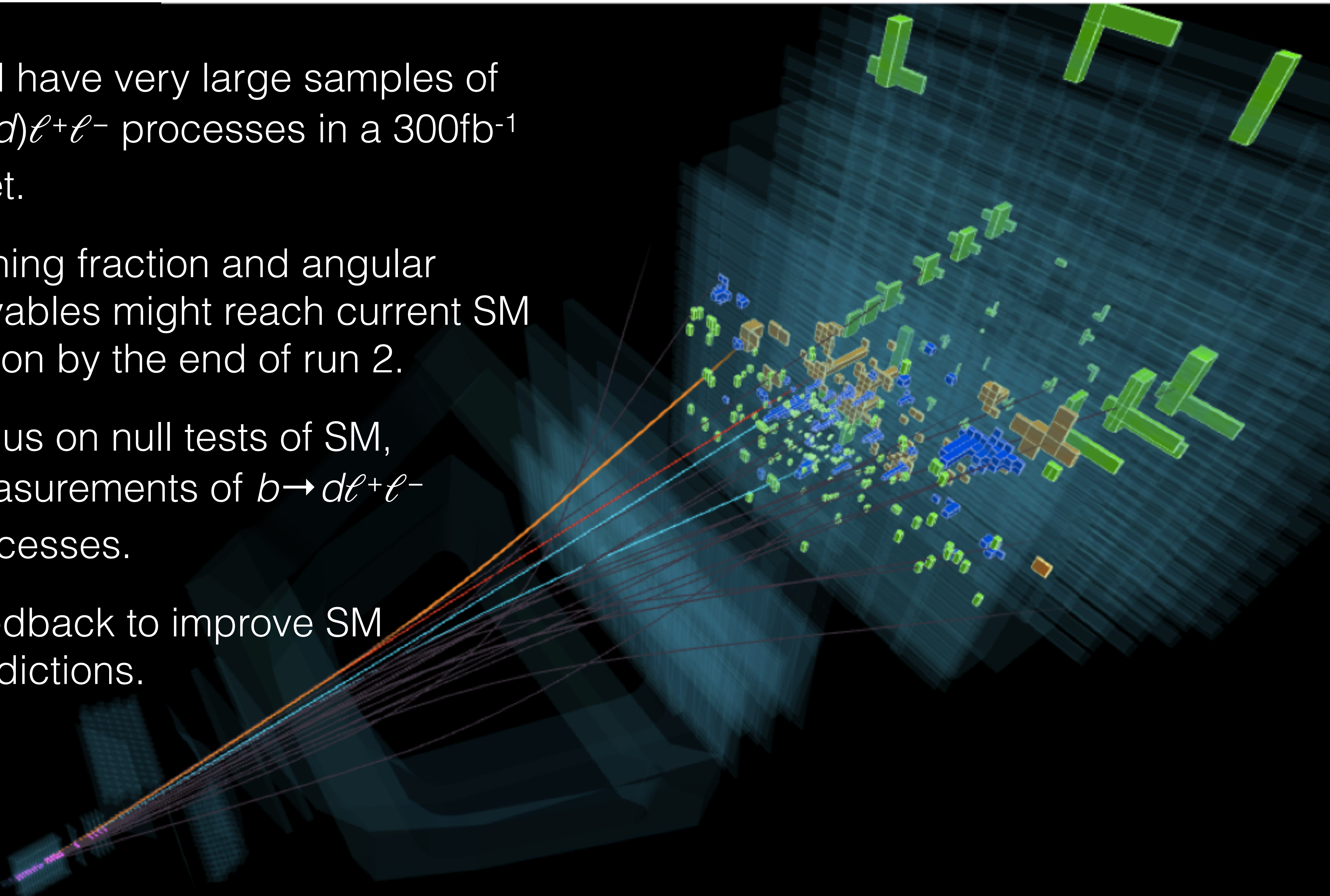
$b \to s\tau^+\tau^-$ decays

- Assuming the SM branching fraction, in 300fb^{-1} expect to reconstruct:
  - ➡ 30 events with $\tau^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}\nu$
  - ➡ 3 500 events with $\tau^{\pm} \to \mu^{\pm}\nu_{\mu}\nu_{\tau}$

Need to reconstruct 4 extra tracks but can exploit *B*/$\boldsymbol{\tau}$ lifetimes to constrain the system.

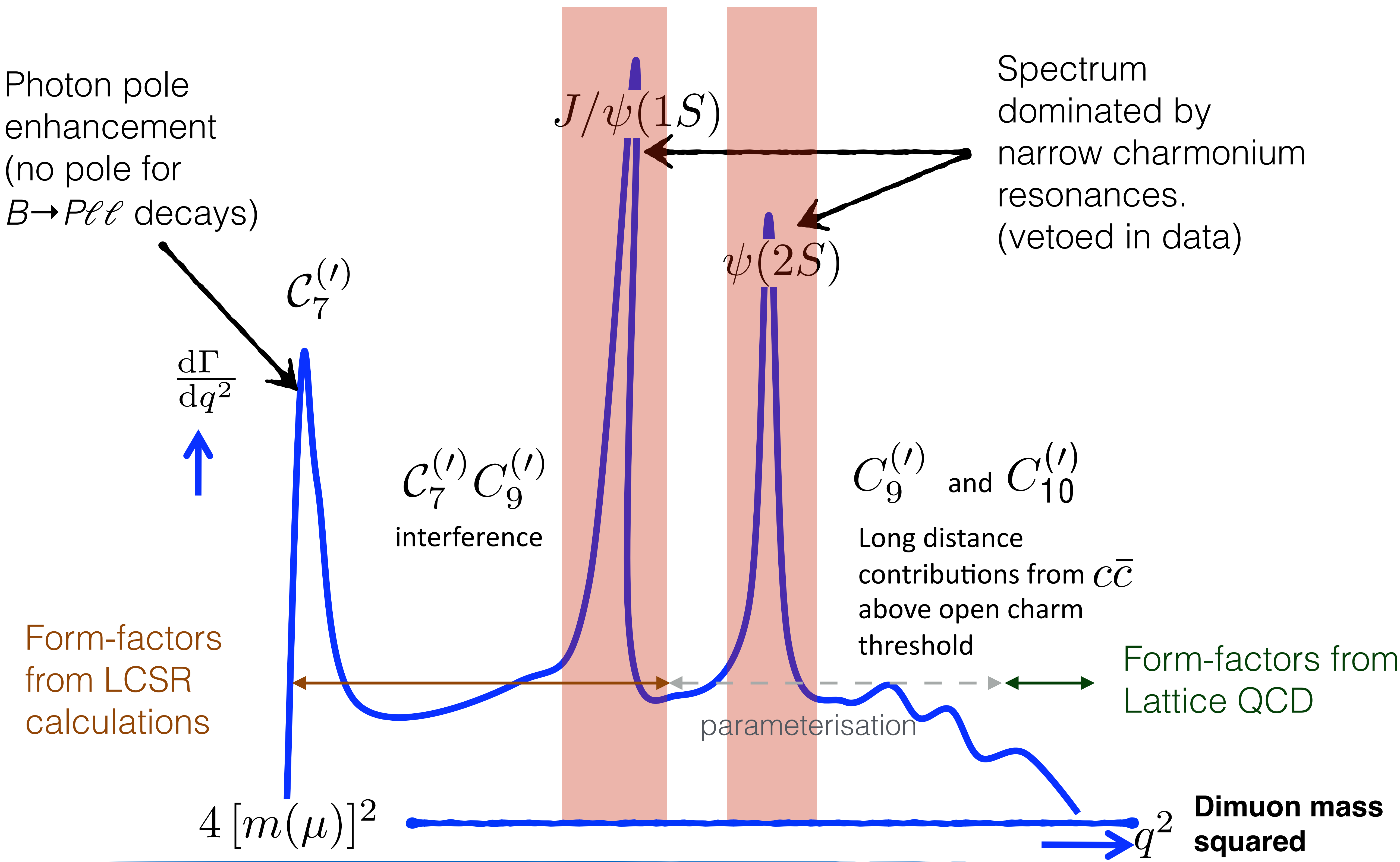
- Backgrounds are more complicated to estimate and will be large (studies are ongoing).
- It will be tough to reach the SM branching fraction but we can be sensitive to large branching fraction enhancements, e.g. **[Alonso et al. JHEP 10 (2015) 184]** where enhancements of 10^3 are possible.

Summary



- We will have very large samples of $b \to (s,d)\ell^+\ell^-$ processes in a 300fb^{-1} dataset.
- Branching fraction and angular observables might reach current SM precision by the end of run 2.
  - ➡ Focus on null tests of SM, measurements of $b \to d\ell^+\ell^-$ processes.
  - ➡ Feedback to improve SM predictions.

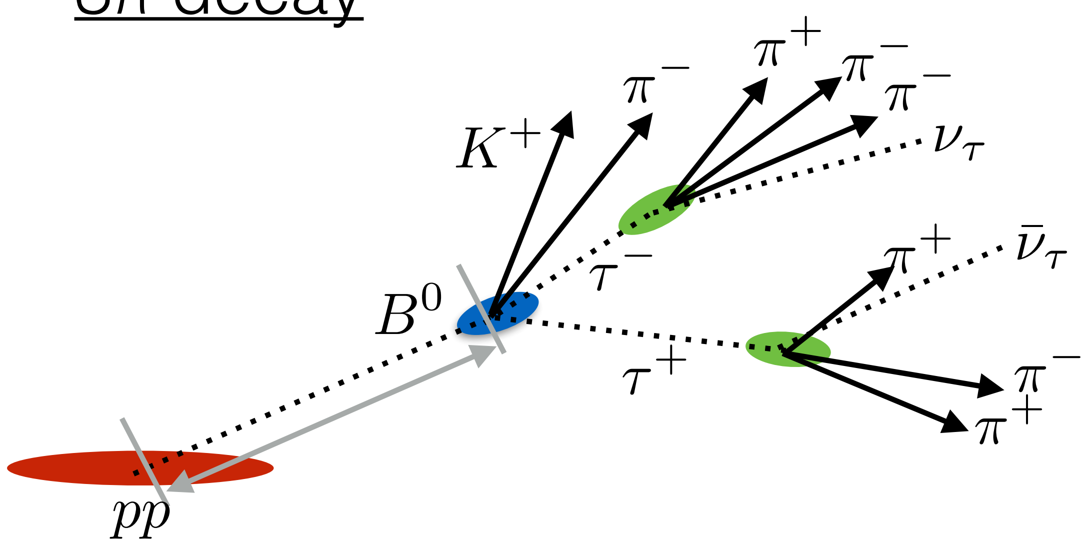
Dilepton mass spectrum



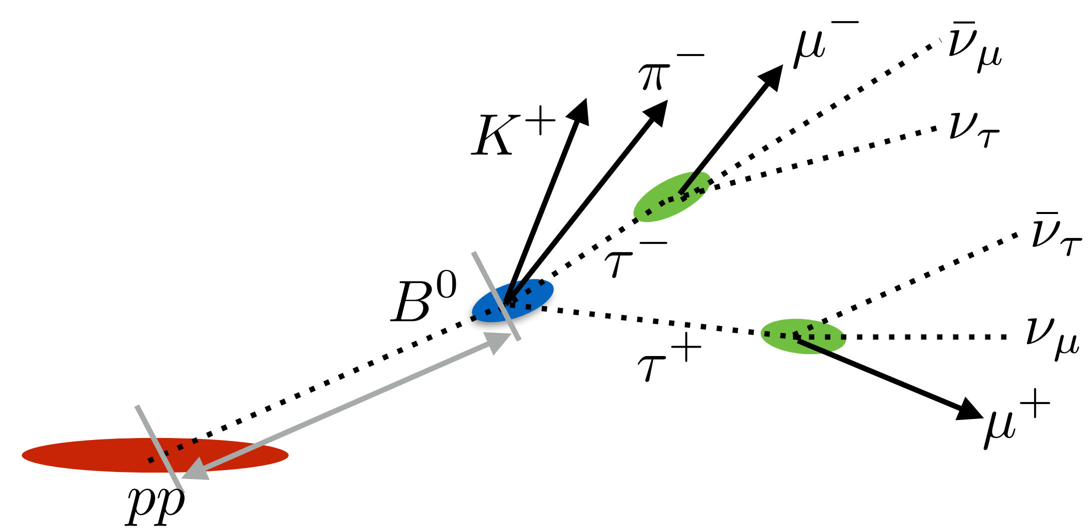
Ditau decays

- Consider two different final-states:

3π decay



Leptonic decay



✓ Can exploit lifetime of the *B* and taus to constrain the system.

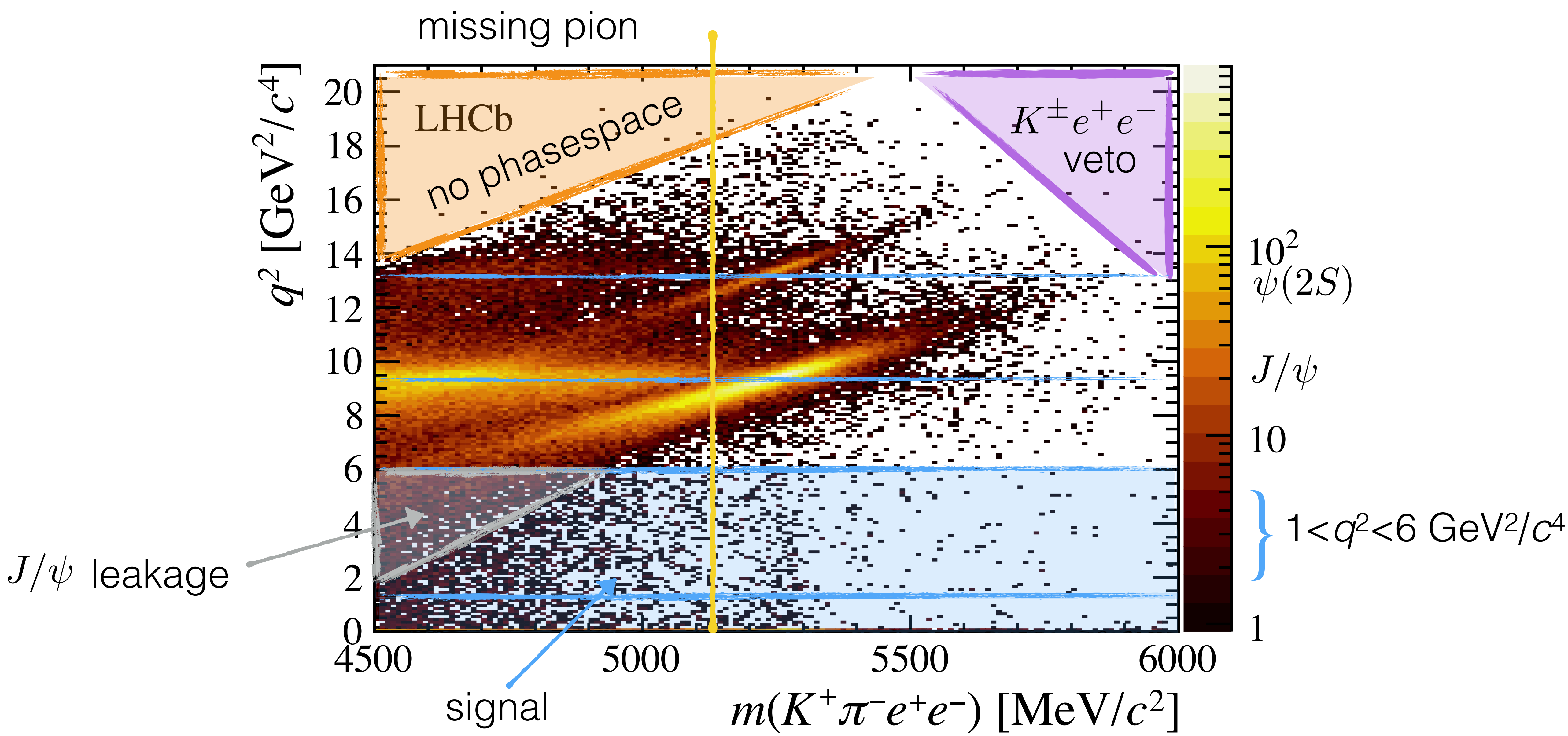
x Need to reconstruct an 8 track (hadronic) final-state.

✓ Dilepton final-state.

x Large missing mass/energy and background from semileptonic decays.

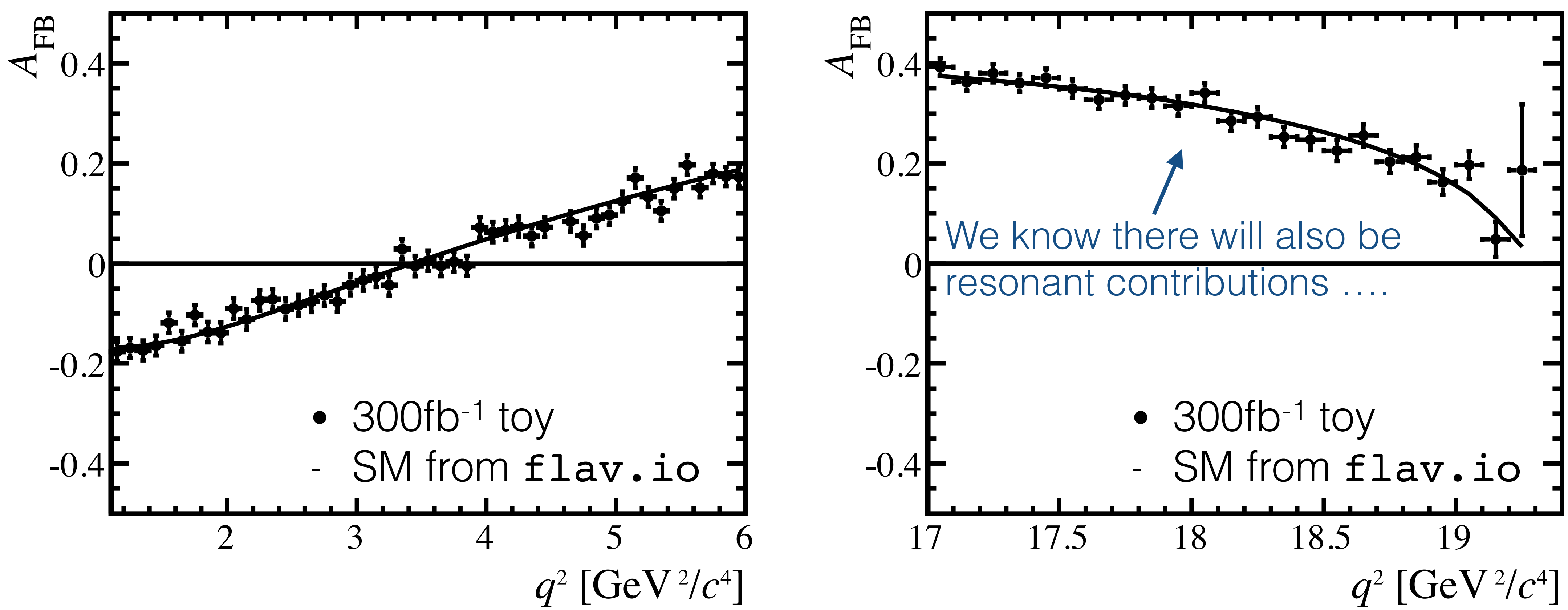
R_{K^*} backgrounds

- It is much more difficult to separate dielectron final-state from physics backgrounds.



Angular analyses with $300fb^{-1}$

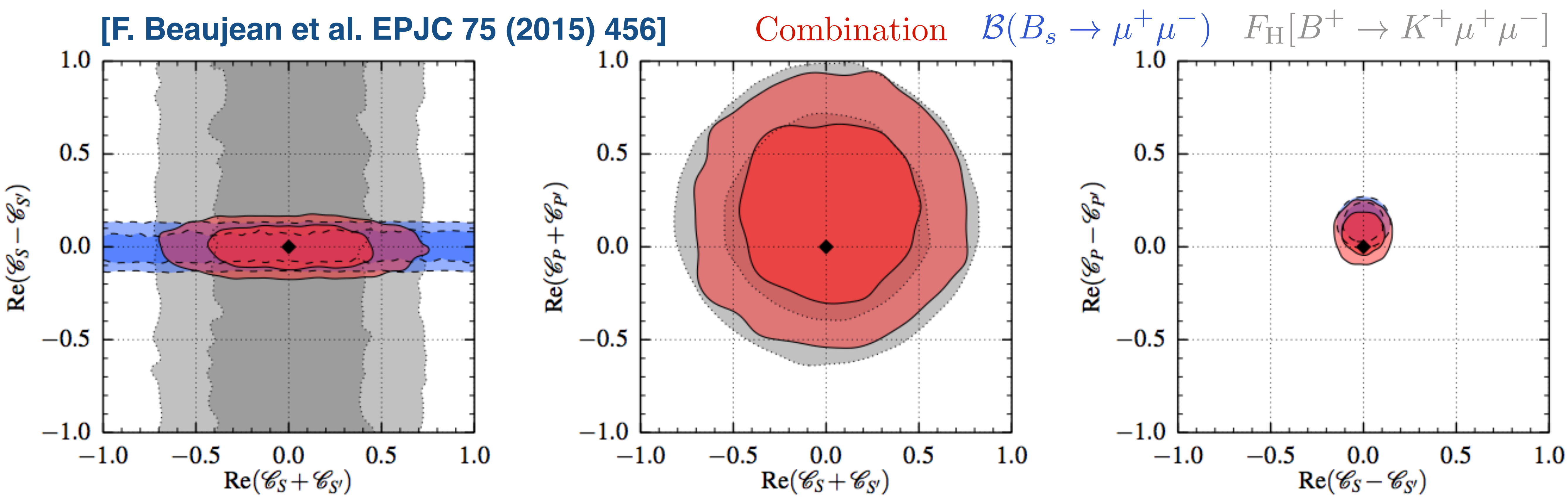
- Finer binning allows for precise tests of zero-crossing point and end-point relationships **[G. Hiller & R. Zwicky, JHEP 03 (2014) 042]**
- Toy experiment with 300fb-1 dataset, assuming SM and scaling uncertainties based on our existing measurement in $1<q^2<6$ GeV$^2/c^4$.



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

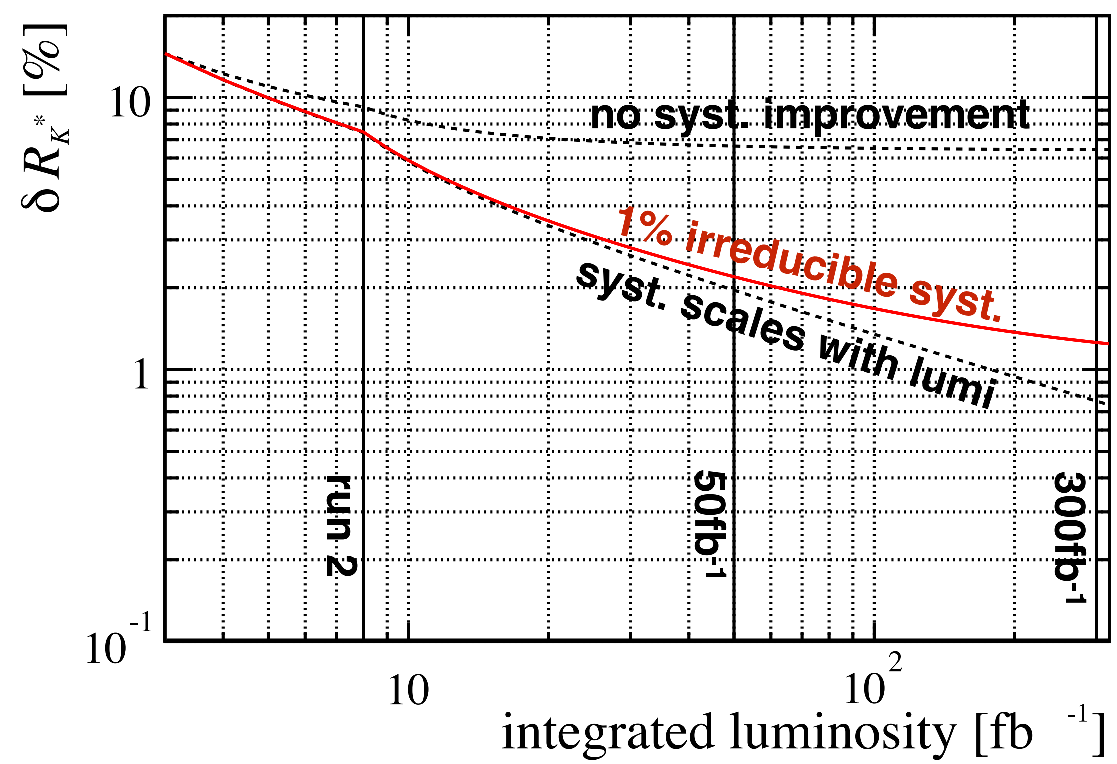
- Angular distribution of $B^+ \to K^+ \ell^+ \ell^-$ is a null test of SM, but can be sensitive to new scalar/pseudoscalar/tensor contributions, e.g.

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

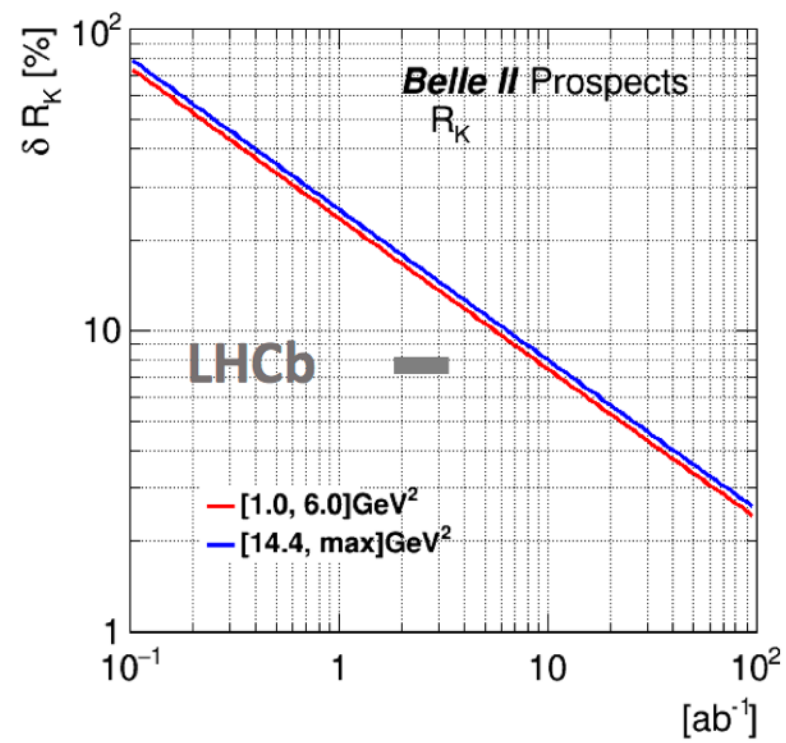


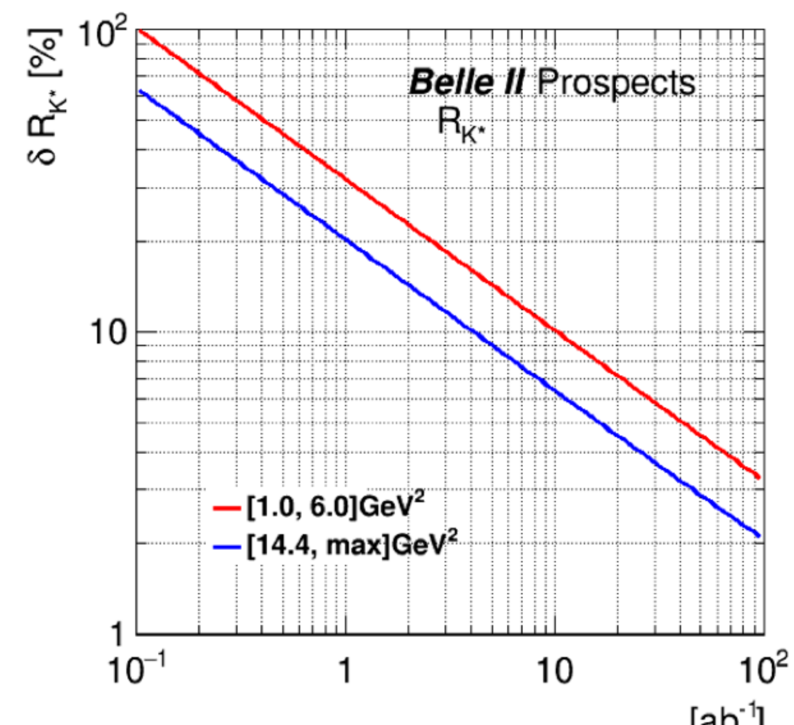
R_K and R_{K^*}

- Assuming an irreducible systematic uncertainty of 1% for R_{K^*} in the range $1<q^2<6\ \mathrm{GeV}^2/c^4$.



- For comparison Belle 2 expects to reach a precision of 2-3% with a systematic uncertainty of 0.4% with their full dataset **[From talk by S. Sandilya at CKM 2016]**





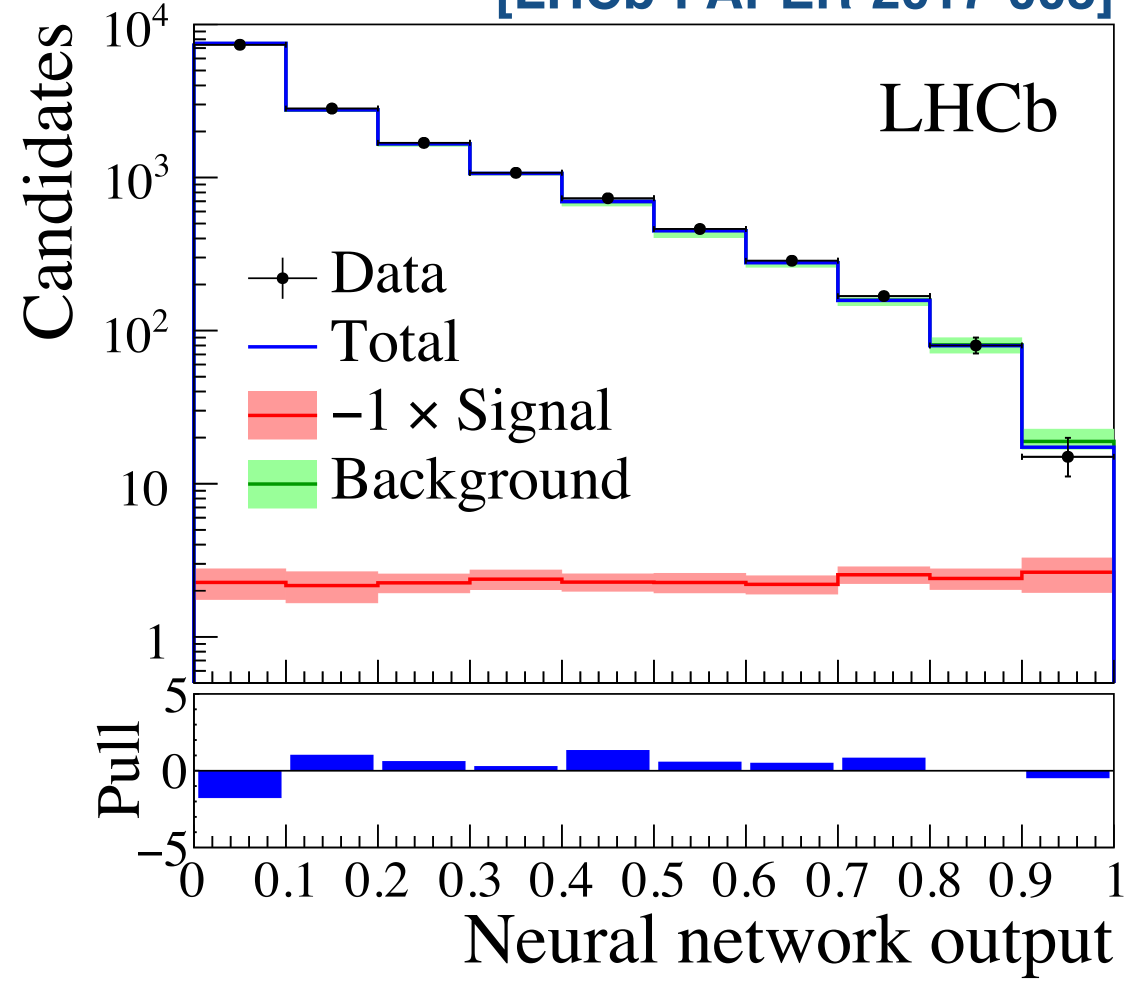
$B \to \tau^+\tau^-$

- Reconstructing $\tau^\pm \to \pi^+\pi^-\pi^\pm\nu$ set limit on:

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

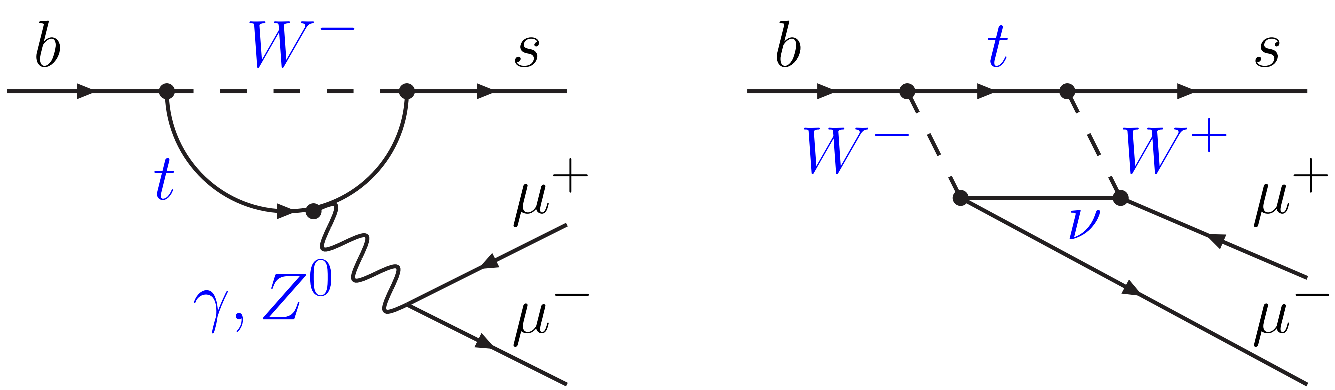
- Due to missing neutrinos there is only weak separation between signal and backgrounds hadronic B meson decays (and no separation between B^0 and B_s)

[LHCb-PAPER-2017-003]



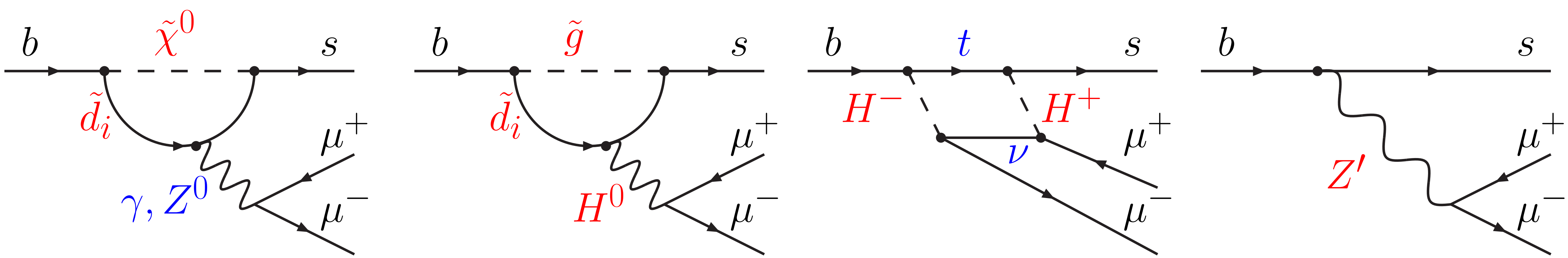
Reminder: Rare FCNC decays

- Flavour changing neutral current transitions 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.

Ditau decays

- Estimate expected yields for $K^*\tau\tau$:

Need to select/reconstruct 4 extra tracks

$$\tau^\pm \to \pi^\pm\pi^+\pi^-\nu$$

$$\frac{N_{\tau\tau}}{N_{\mu\mu}} \sim \frac{2.1\times10^{-7}}{7.5\times10^{-7}} \times (9.4\%)^2 \times (50\%)^4 \approx 1.5\times10^{-4}$$

⇒ 60 events in 300fb^{-1}

$$\tau^\pm \to \mu^\pm\nu_\mu\nu_\tau$$

$$\frac{N_{\tau\tau}}{N_{\mu\mu}} \sim \frac{2.1\times10^{-7}}{7.5\times10^{-7}} \times (17.\%)^2 \approx 8\times10^{-3}$$

⇒ 3 500 events in 300fb^{-1}

- Backgrounds are more complicated to estimate and could be large.
- It will be tough to reach the SM branching fraction but we can be sensitive to large branching fraction enhancements, e.g. **[Alonso et al. JHEP 10 (2015) 184]** where enhancements of 10^3 are possible.