EPS-HEP 2017 (5–12 July 2017)

Rare *B* decays at LHCb

Albert Puig *on behalf of the LHCb collaboration*

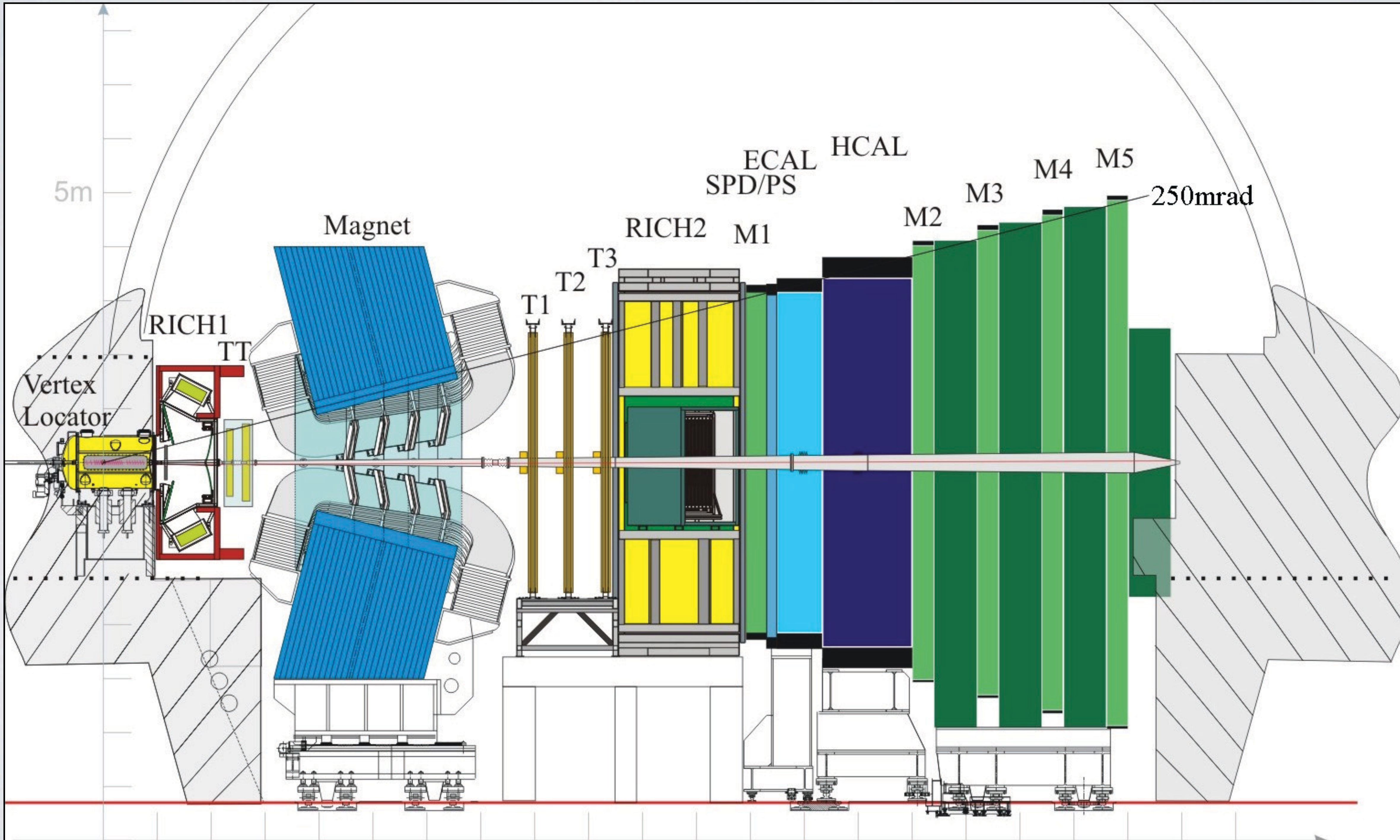
Universität Zürich[UZH]

LHCb

FNSNF
FONDS NATIONAL SUISSE
SCHWEIZERISCHER NATIONALFONDS
FONDO NAZIONALE SVIZZERO
SWISS NATIONAL SCIENCE FOUNDATION

[JINST 3 (2008) S08005]

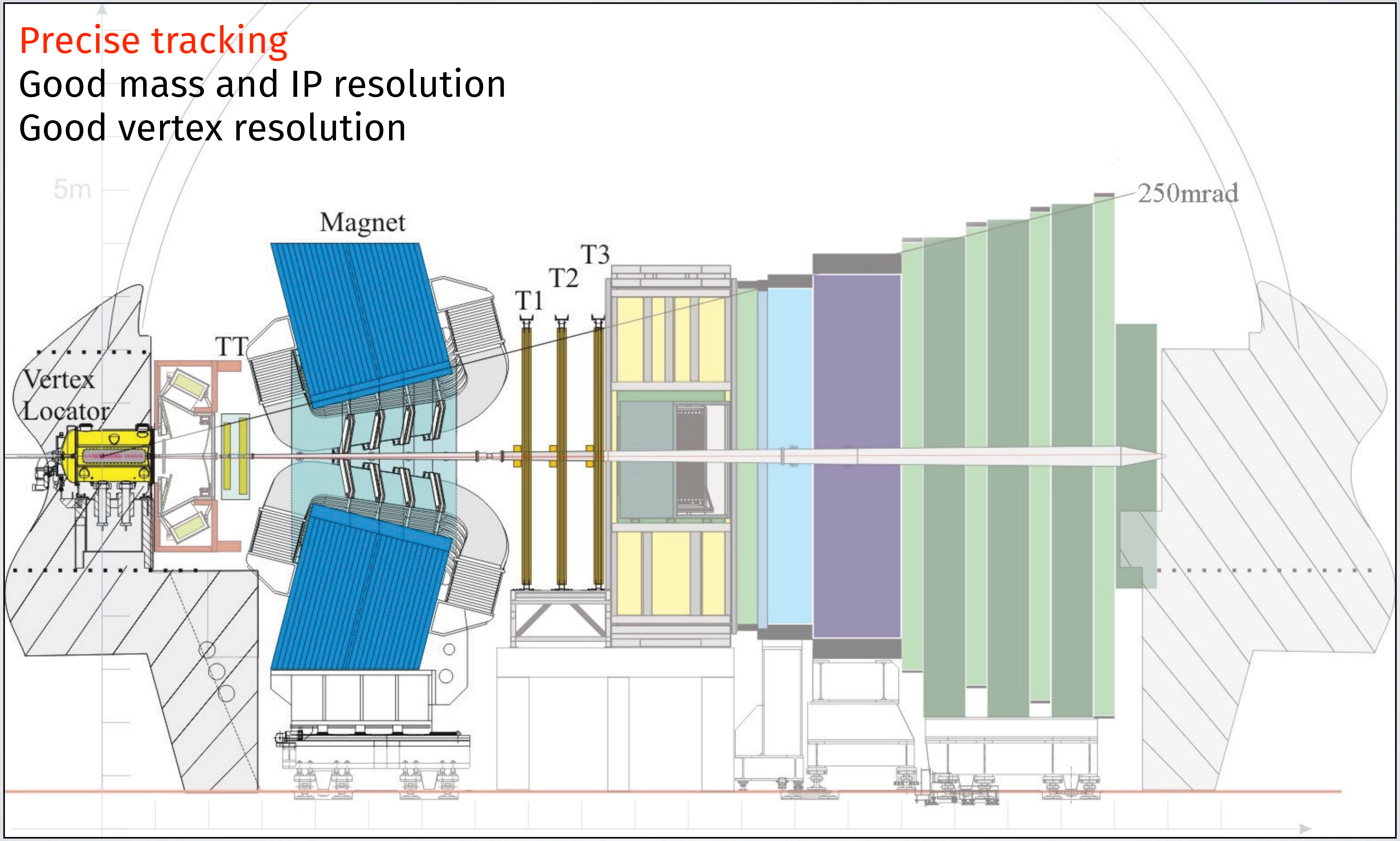
The LHCb experiment



[JINST 3 (2008) S08005]

The LHCb experiment

Precise tracking
Good mass and IP resolution
Good vertex resolution

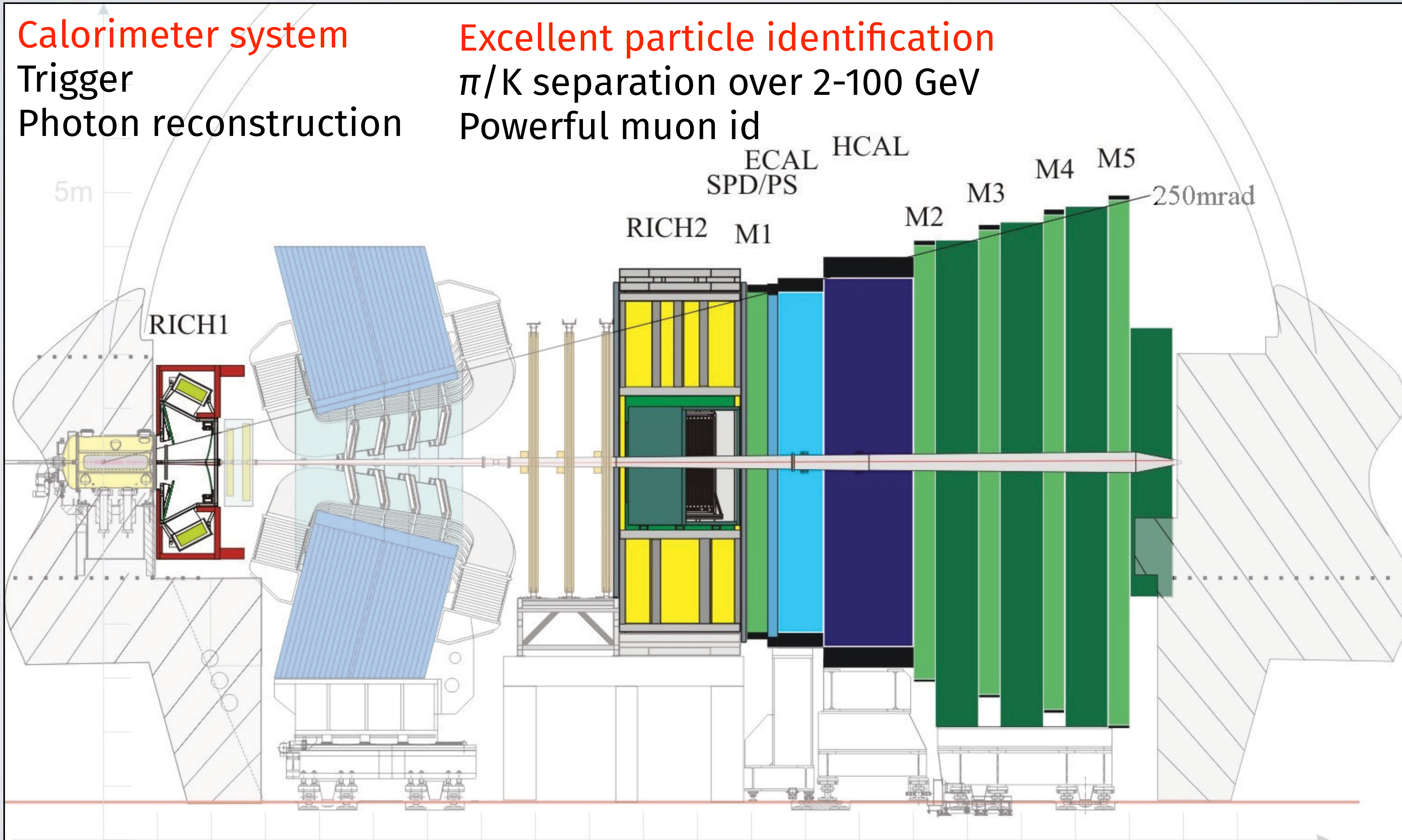


[JINST 3 (2008) S08005]

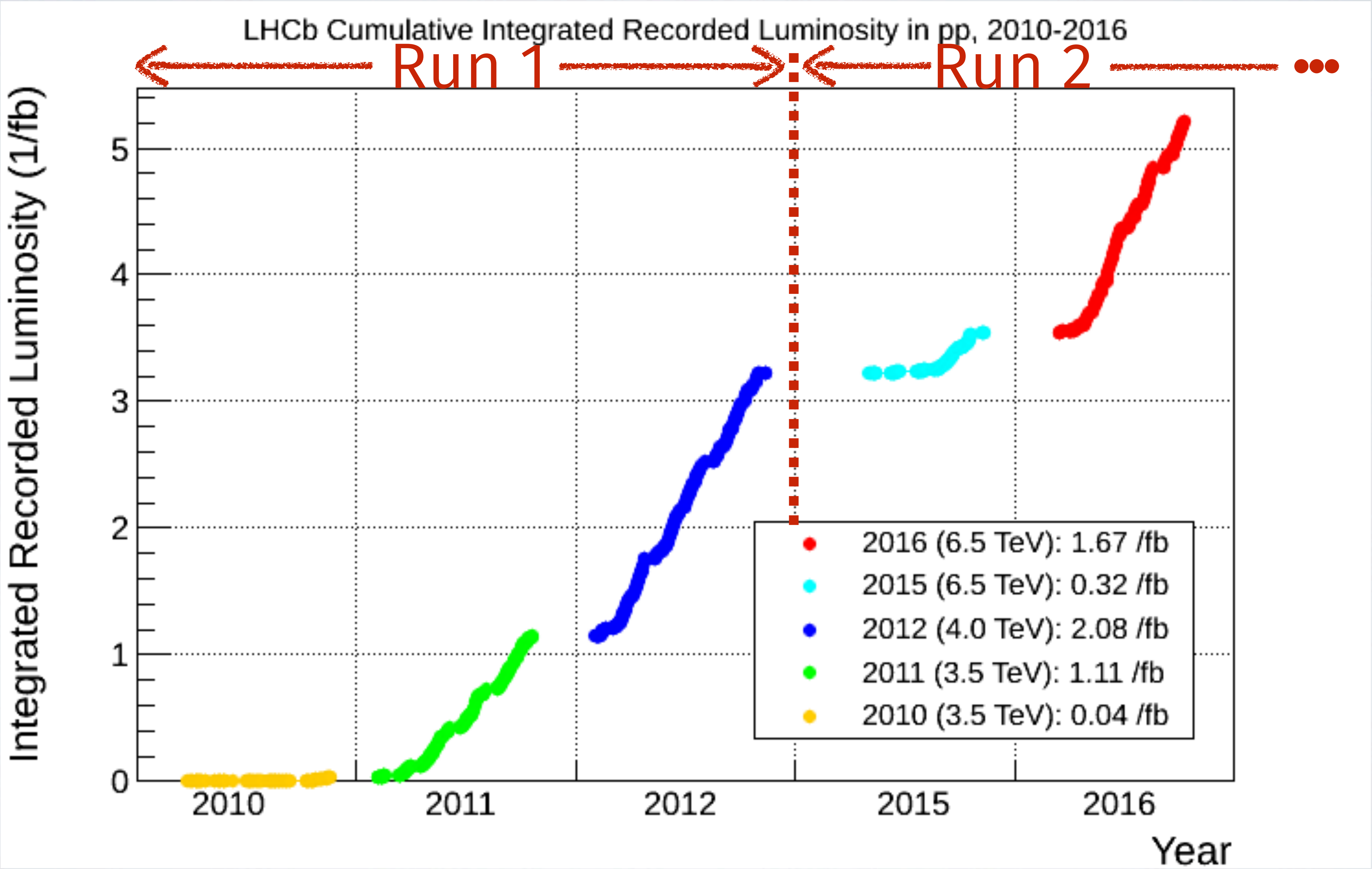
The LHCb experiment

Calorimeter system
Trigger
Photon reconstruction

Excellent particle identification
π/K separation over 2-100 GeV
Powerful muon id

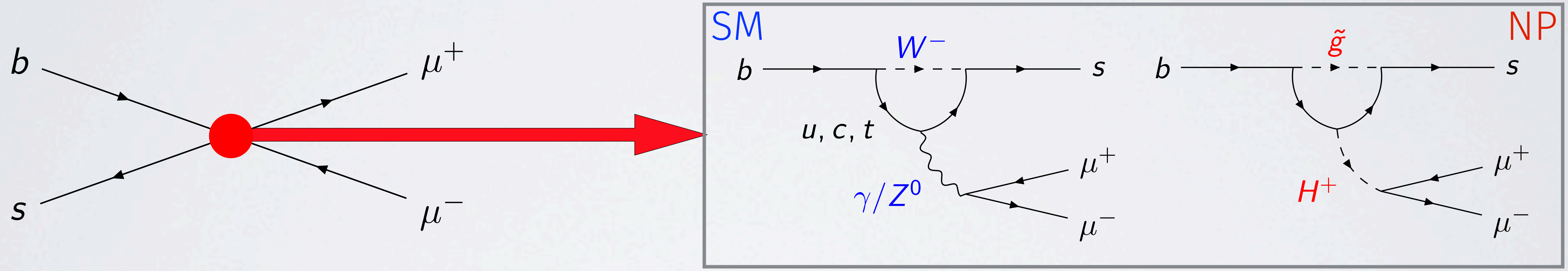


The LHCb data taking



Rare *B* decays

Rare decays of heavy mesons are FCNC (forbidden at tree level and thus highly suppressed) sensitive to quantum corrections from degrees of freedom at larger scales



Indirect approach to New Physics searches complementary to that of GPDs

- Use well-predicted observables to look for deviations

$b \to \ell^+\ell^-$ transitions in the SM

These decays can be predicted very cleanly thanks to the fact that there is only one hadronic parameter (F_B), which can be computed by lattice QCD

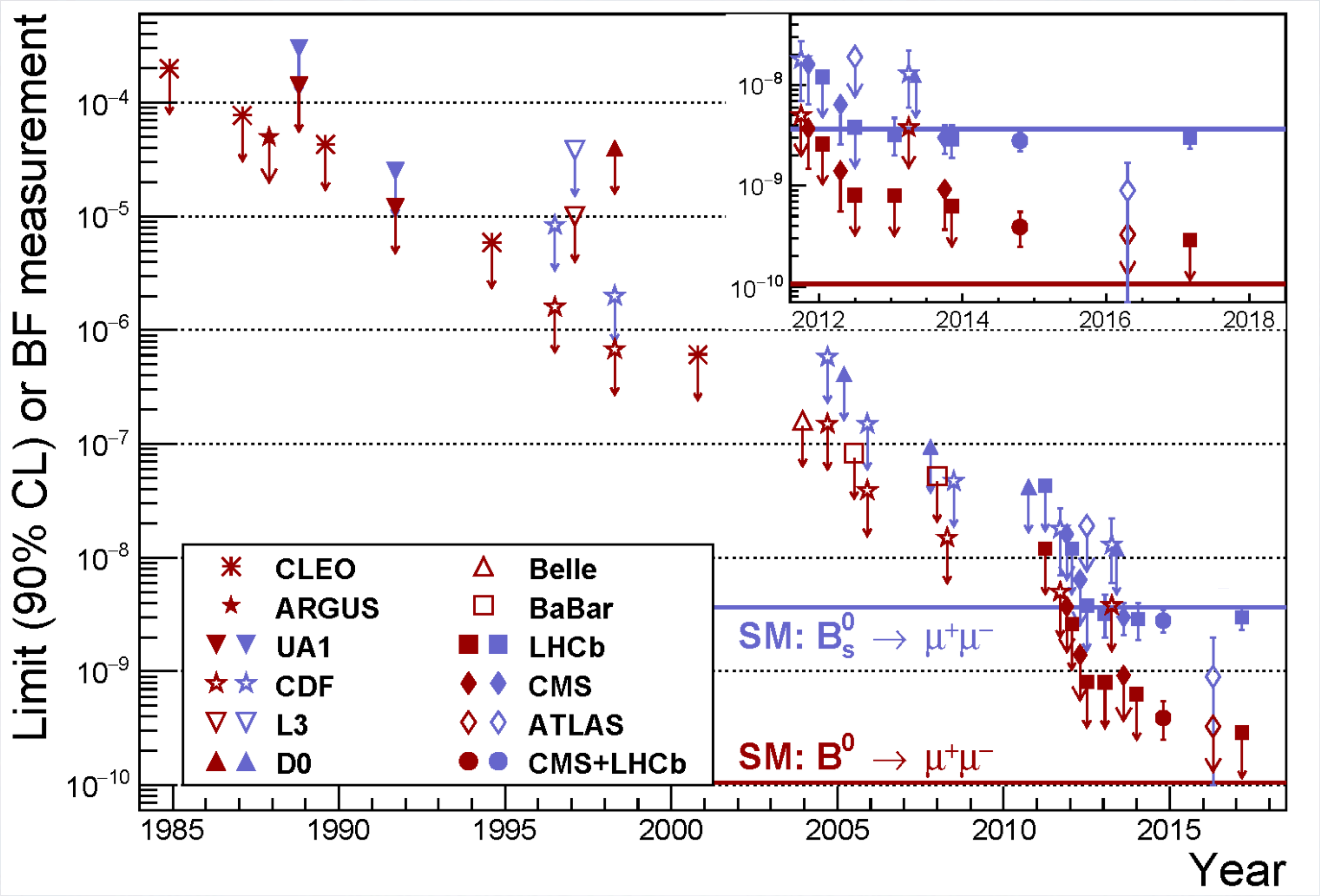
$$BR(B^0_q \to \ell^+\ell^-) = \frac{\tau_B G_F^4 M_W^2 \sin^4\theta_W}{8\pi^5} |C_{10} V_{tb} V^*_{tw}| F_B^2 m_B m_\ell^2 \sqrt{1 - \frac{4m_l^2}{m_B^2}}$$

They are doubly suppressed in the SM: FCNC and helicity

Decay with taus is x250 more abundant than the muonic one (assuming Lepton Universality), but it's experimentally very challenging

$B \to \mu^+\mu^-$: a 30-year-old story

[CMS+LHCb, Nature 522 (2015) 68]



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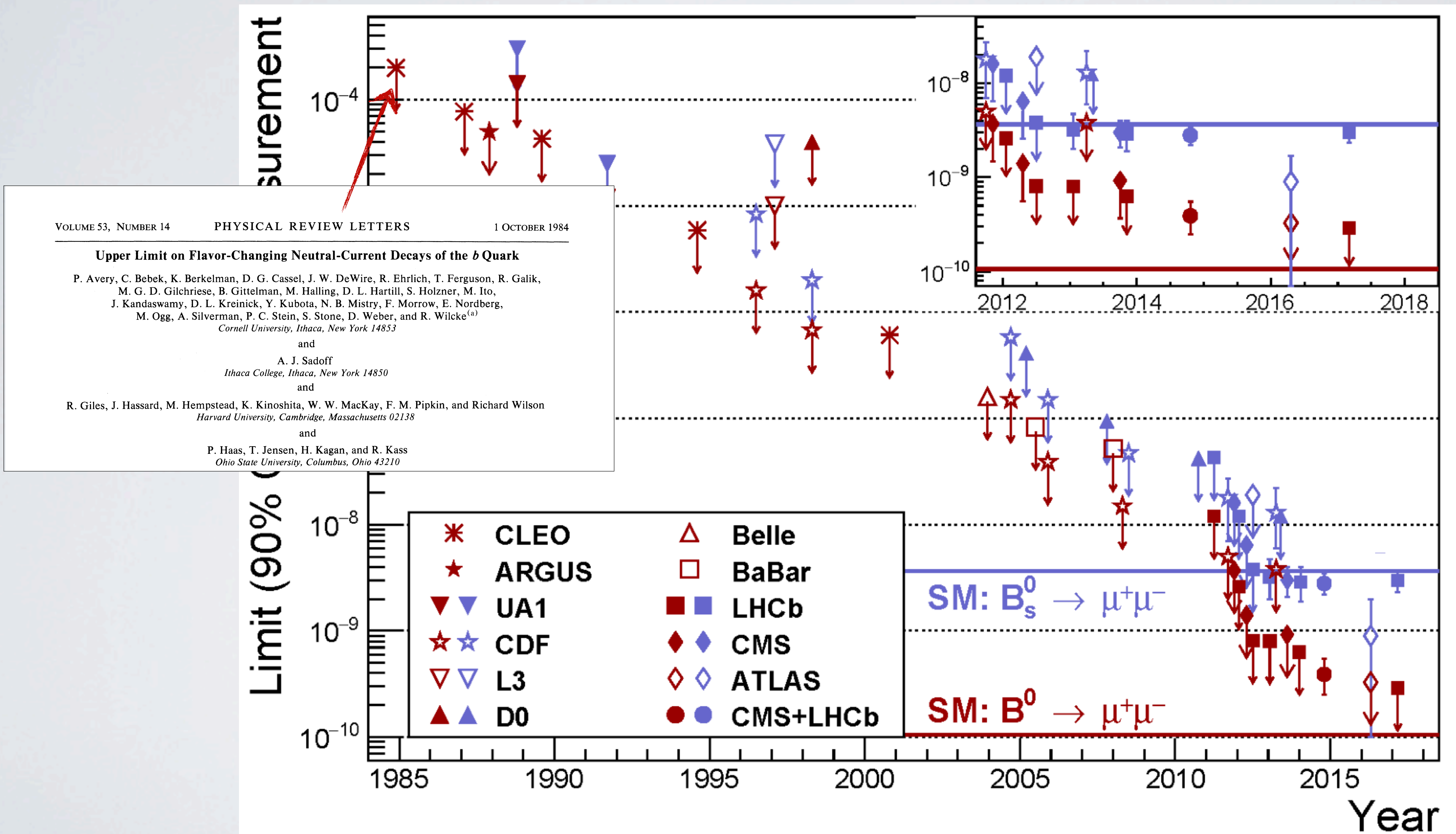


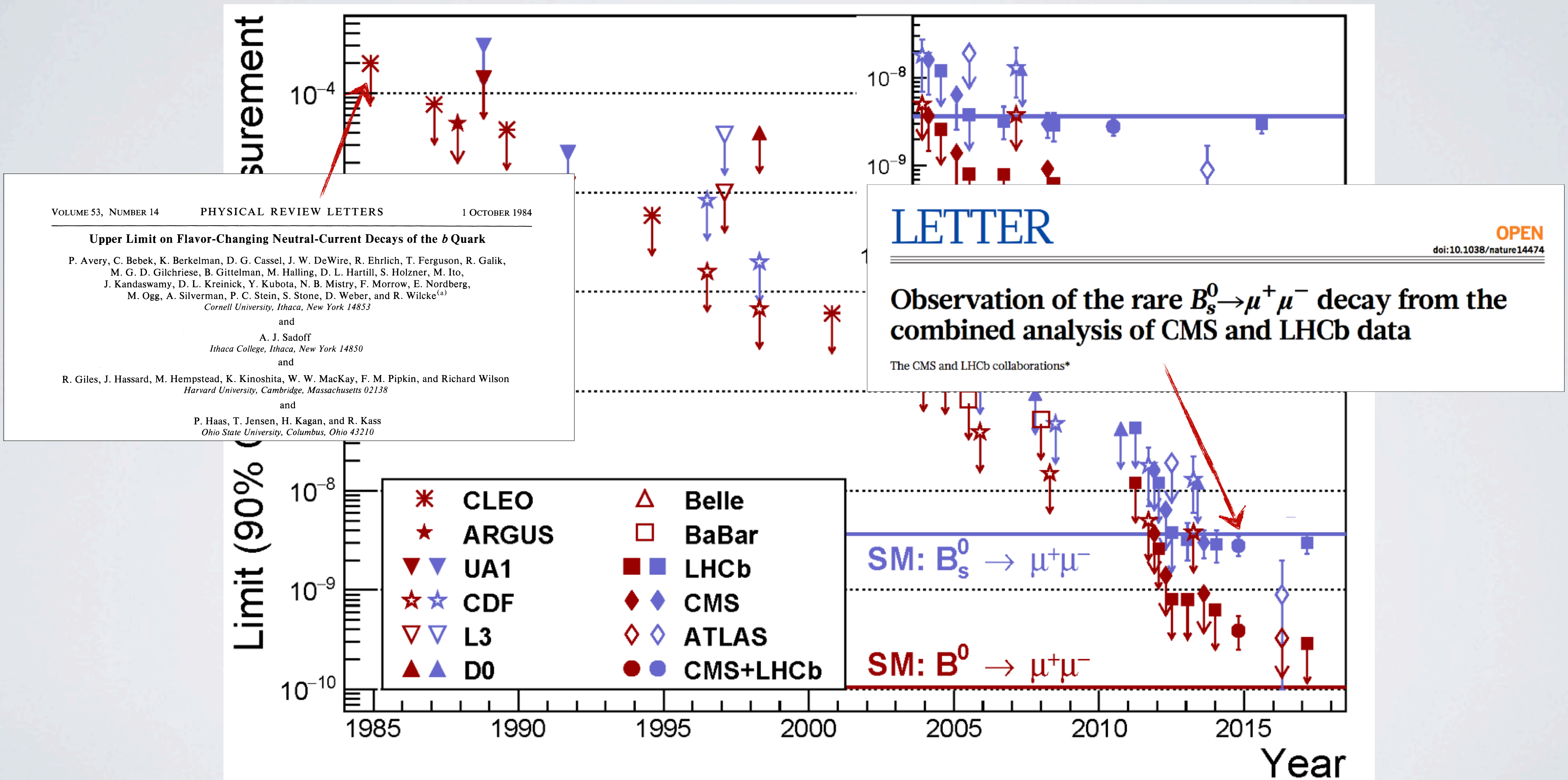
VOLUME 53, NUMBER 14 PHYSICAL REVIEW LETTERS 1 OCTOBER 1984

Upper Limit on Flavor-Changing Neutral-Current Decays of the *b* Quark

P. Avery, C. Bebek, K. Berkelman, D. G. Cassel, J. W. DeWire, R. Ehrlich, T. Ferguson, R. Galik, M. G. D. Gilchriese, B. Gittelman, M. Halling, D. L. Hartill, S. Holzner, M. Ito, J. Kandaswamy, D. L. Kreinick, Y. Kubota, N. B. Mistry, F. Morrow, E. Nordberg, M. Ogg, A. Silverman, P. C. Stein, S. Stone, D. Weber, and R. Wilcke[(a)]
Cornell University, Ithaca, New York 14853
and
A. J. Sadoff
Ithaca College, Ithaca, New York 14850
and
R. Giles, J. Hassard, M. Hempstead, K. Kinoshita, W. W. MacKay, F. M. Pipkin, and Richard Wilson
Harvard University, Cambridge, Massachusetts 02138
and
P. Haas, T. Jensen, H. Kagan, and R. Kass
Ohio State University, Columbus, Ohio 43210

$B \to \mu^+\mu^-$: a 30-year-old story

[CMS+LHCb, Nature 522 (2015) 68]



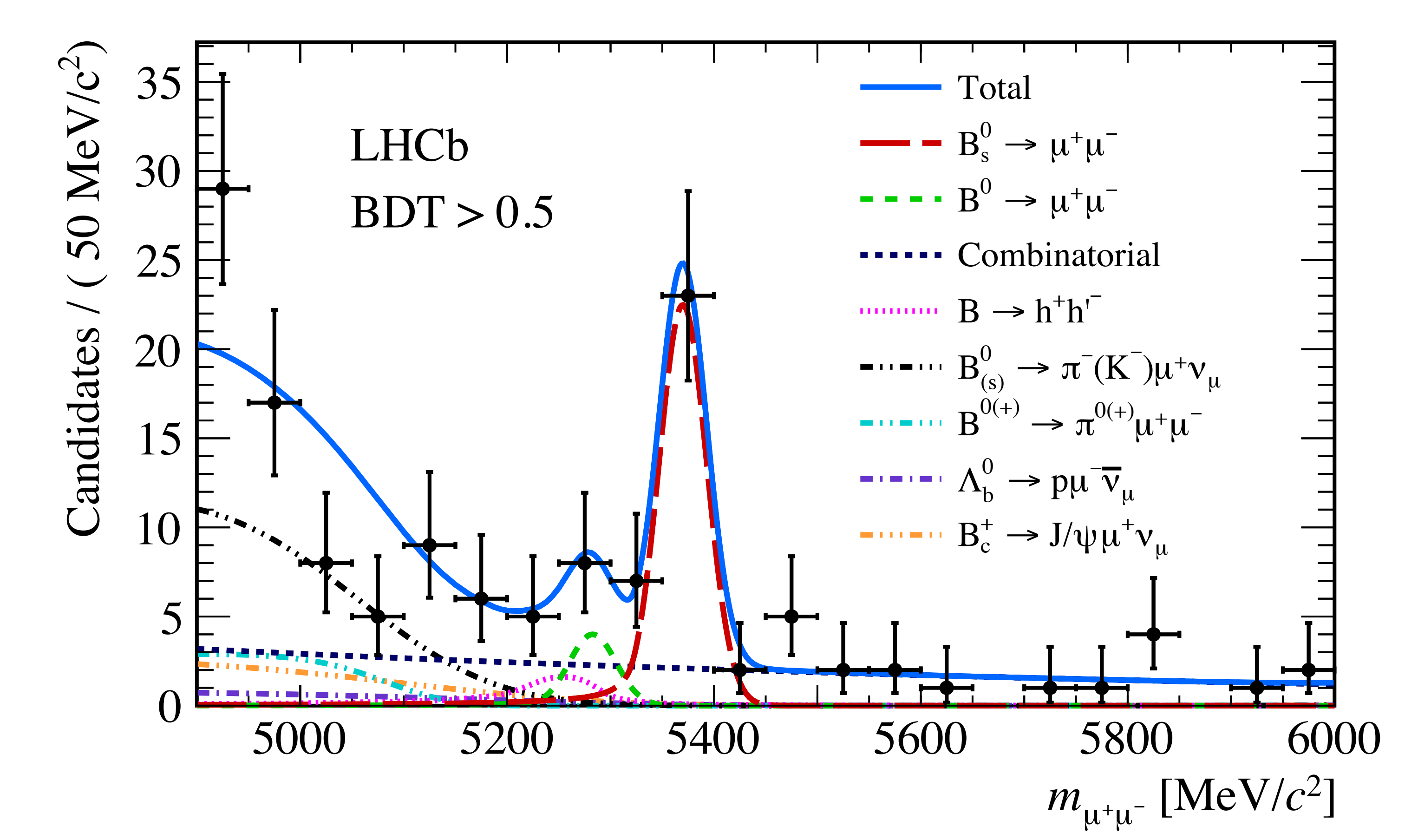
[PRL 118 (2017) 191801]

$B \to \mu^+\mu^-$ update with Run 2 data

LHCb has added part of the data collected in Run 2 (up to 4.4fb^{-1}) and largely improved the analysis (30% stat error reduction for $B^0 \to \mu\mu$)

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

$$BR(B^0 \to \mu^+\mu^-) < 3.4 \times 10^{-10} \text{ at } 95\,\% \text{ CL}$$



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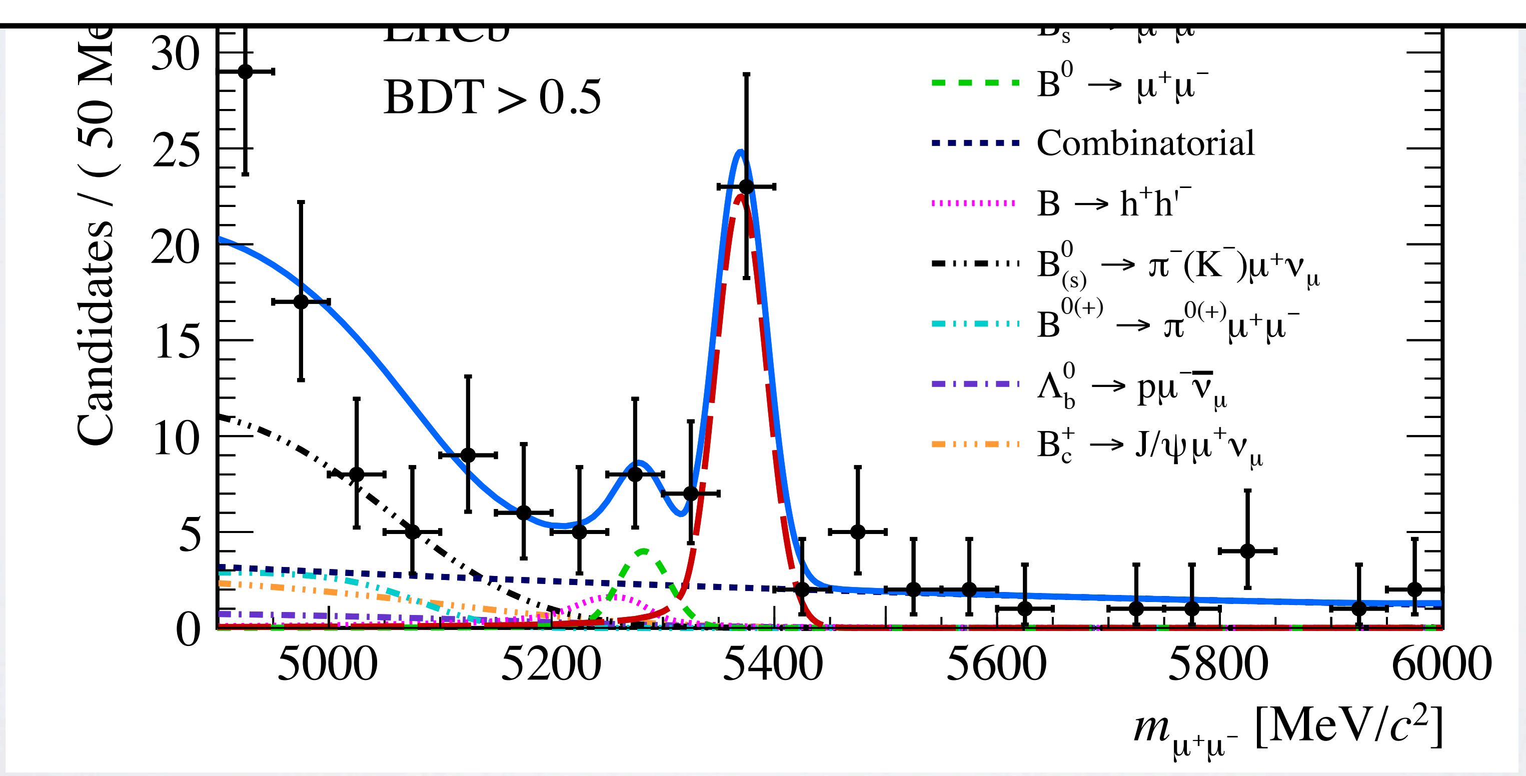
First single experiment observation of B_s mode (7.8σ)



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

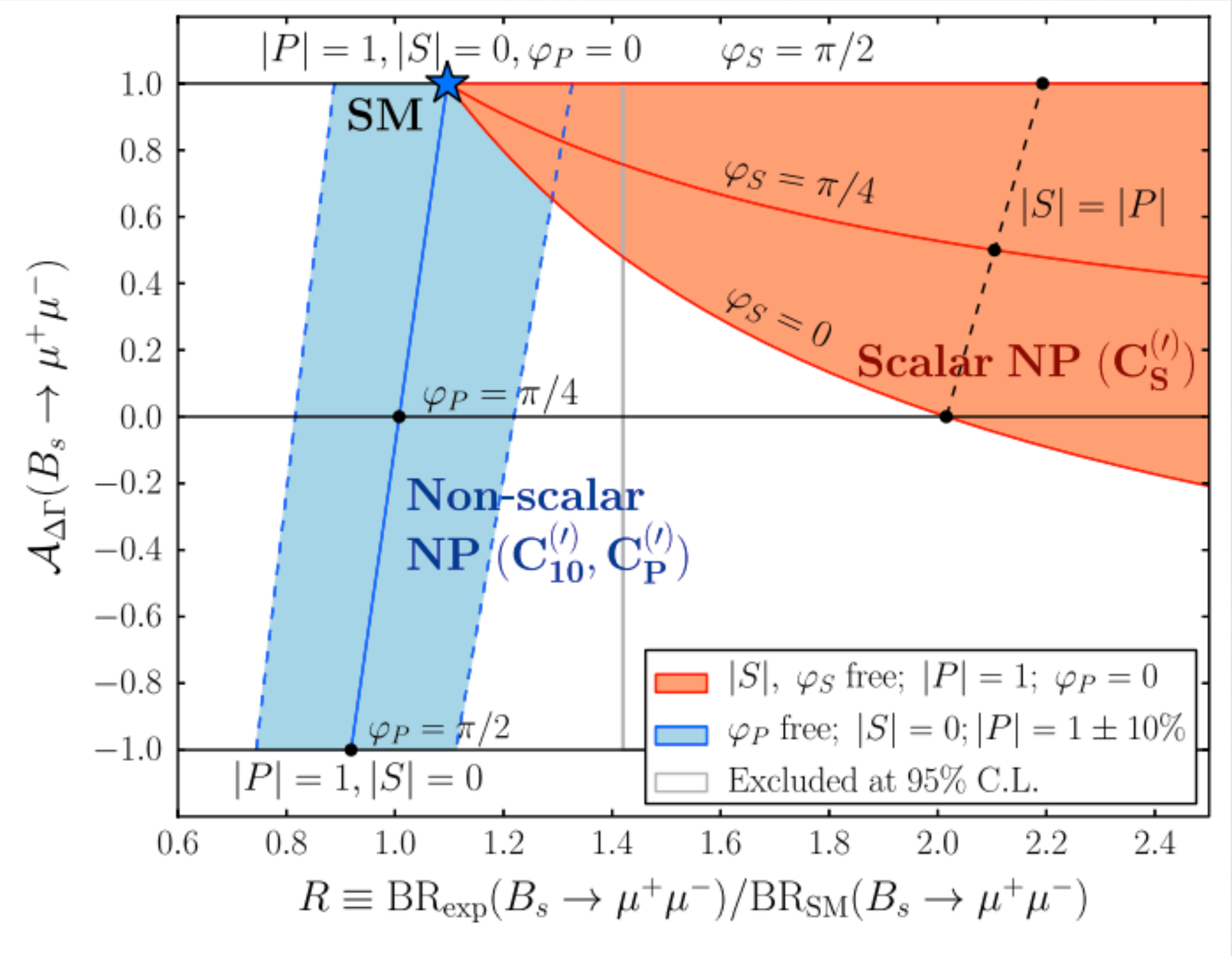
In the case of NP, new contributions can come from C_S and C_P (more details in Tom's talk)

While large effects are ruled out, observables such as

$$\mathcal{A}_{\Delta\Gamma}^{\ell^+\ell^-} = \frac{\Gamma_{B_{s,H}\to\ell^+\ell^-} - \Gamma_{B_{s,L}\to\ell^+\ell^-}}{\Gamma_{B_{s,H}\to\ell^+\ell^-} + \Gamma_{B_{s,L}\to\ell^+\ell^-}}$$

can be used to break degeneracy

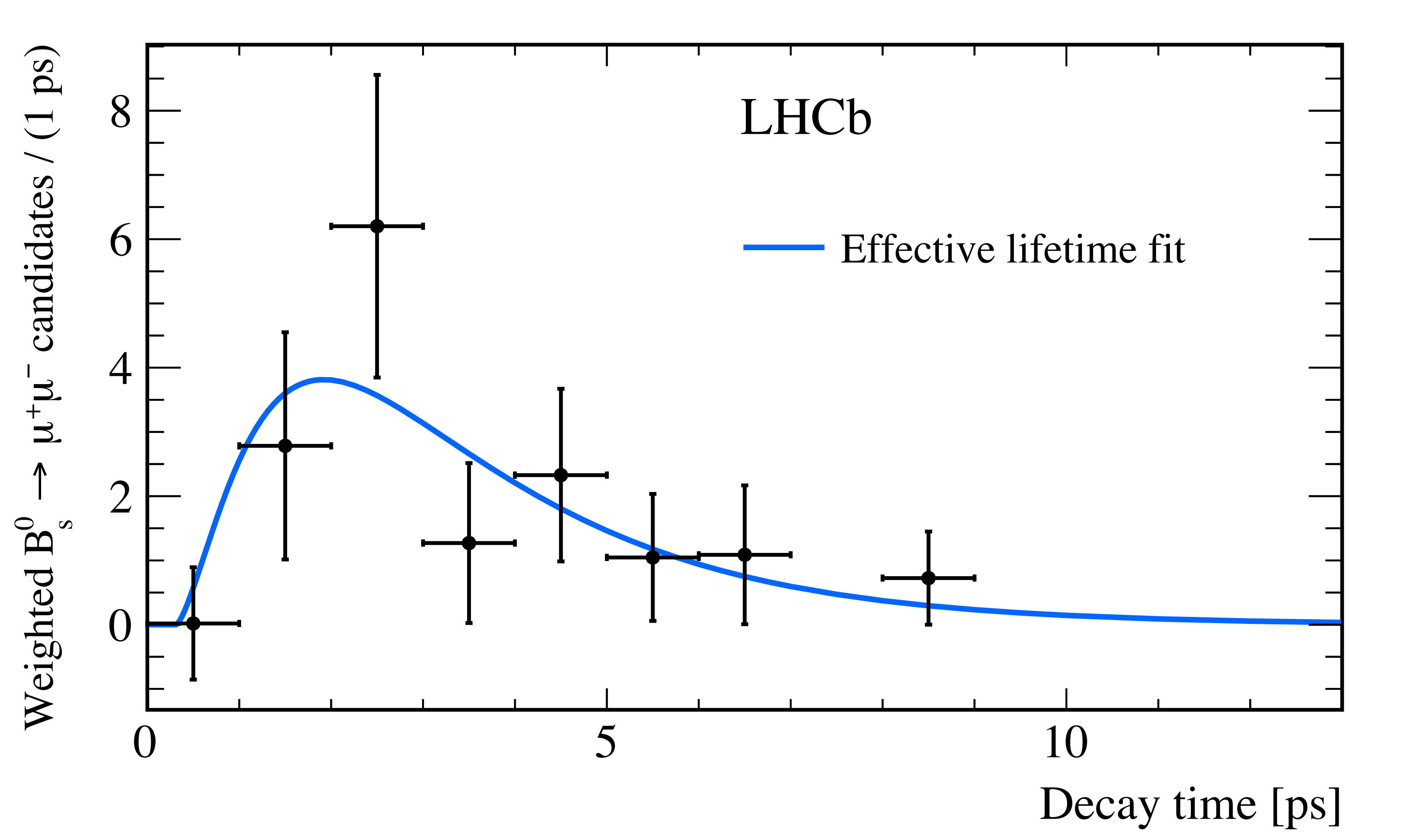
[PRL 109 (2012) 041801]



[PRL 118 (2017) 191801]

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

$$\tau(B_s^0 \to \mu^+\mu^-) = 2.04 \pm 0.44 \pm 0.05\,\mathrm{ps}$$



[PRL 118 (2017) 251802]

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

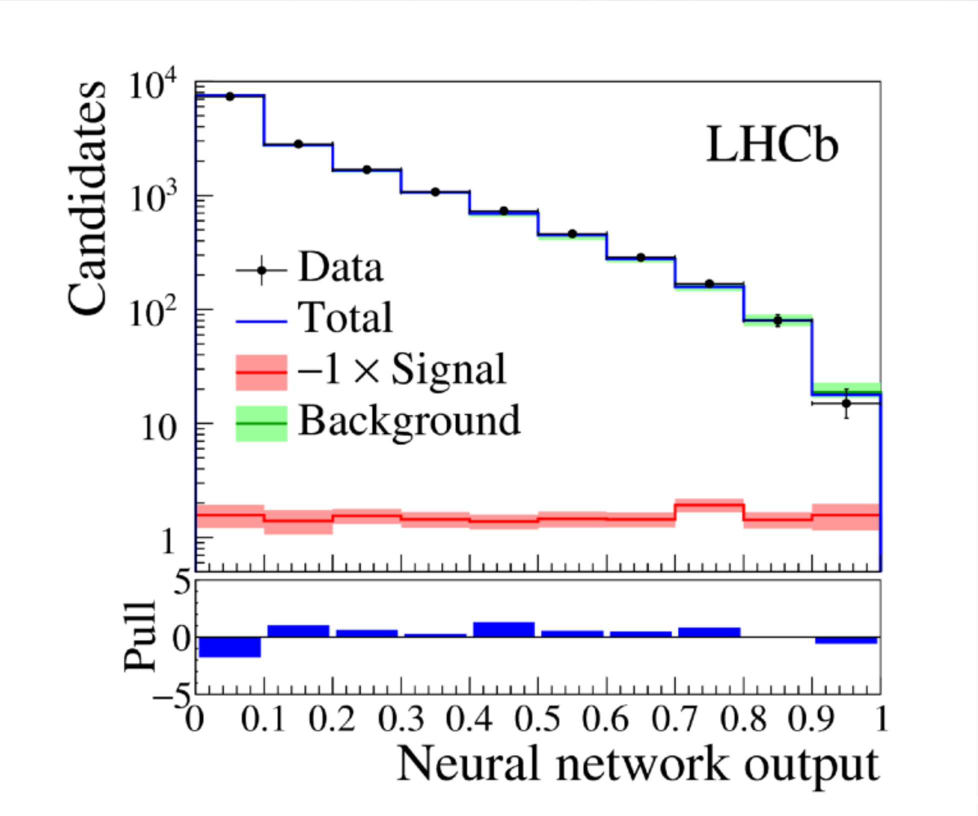
More abundant than $B_s \to \mu\mu$, but extremely challenging

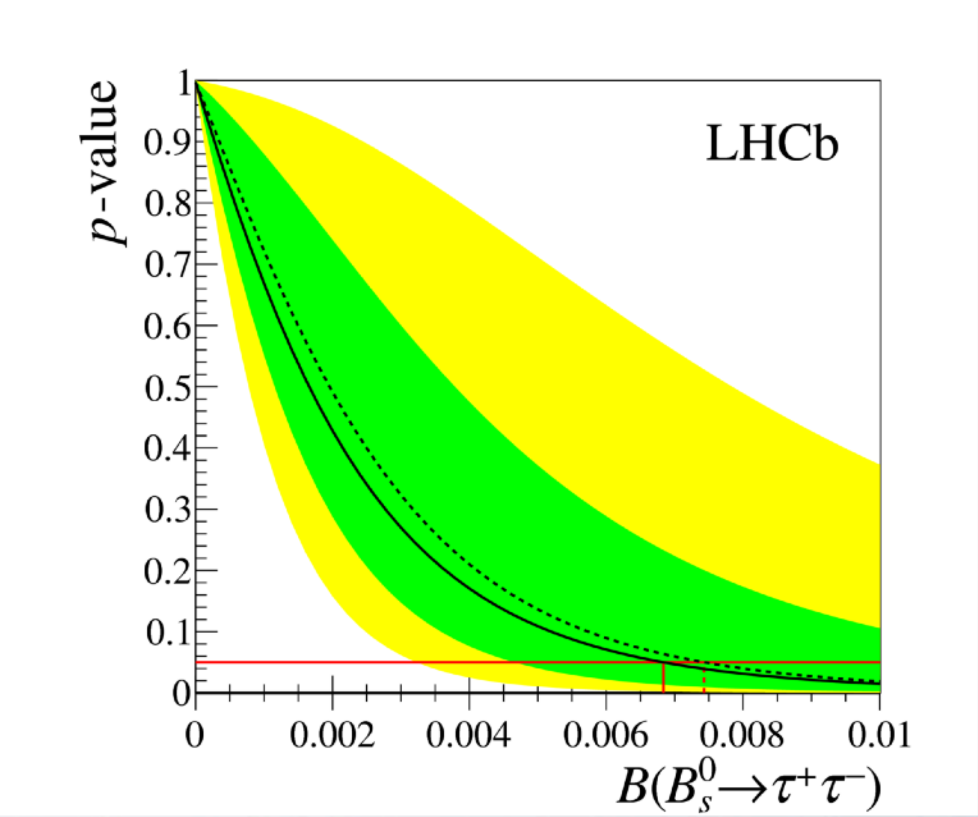
- No separation between B_s and B^0

Analysis of Run 1 data with $\tau \to 3\pi\nu$

- Use $B \to D^+(\to K\pi\pi)D_s^-(KK\pi)$ as control channel
- Use Dalitz plane to separate signal/background, then fit MVA

$$BF(B_s^0 \to \tau\tau) < 6.8 \times 10^{-3} \text{ at } 95\,\% \text{ CL}$$
$$BF(B^0 \to \tau\tau) < 2.1 \times 10^{-3} \text{ at } 95\,\% \text{ CL}$$

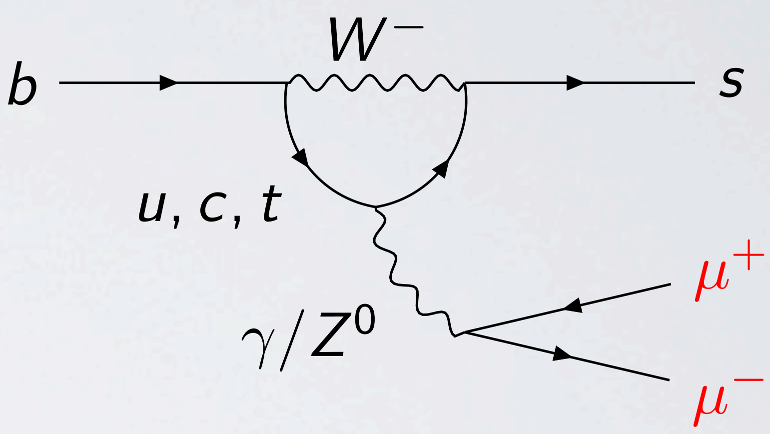




Lepton flavour universality

In the SM, leptons are identical copies of one another so processes involving *e*, *μ*, *τ* must have the same strength up to Higgs corrections and lepton-mass-dependent phase space effects

Measurements of lepton flavour universality constitute a theoretically very clean way to access the effects of new physics phenomena



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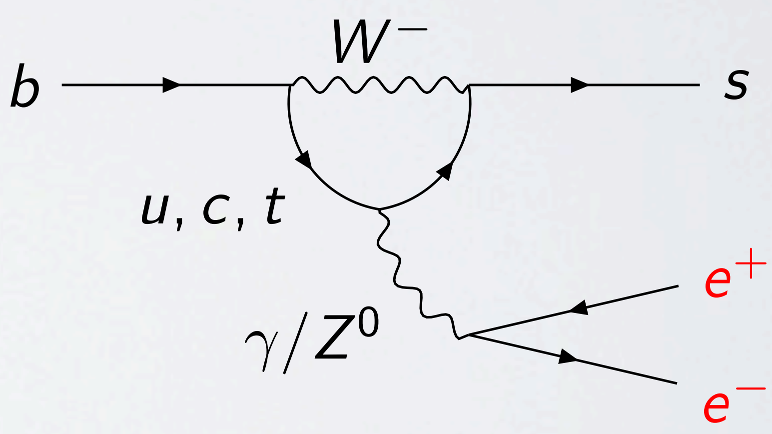


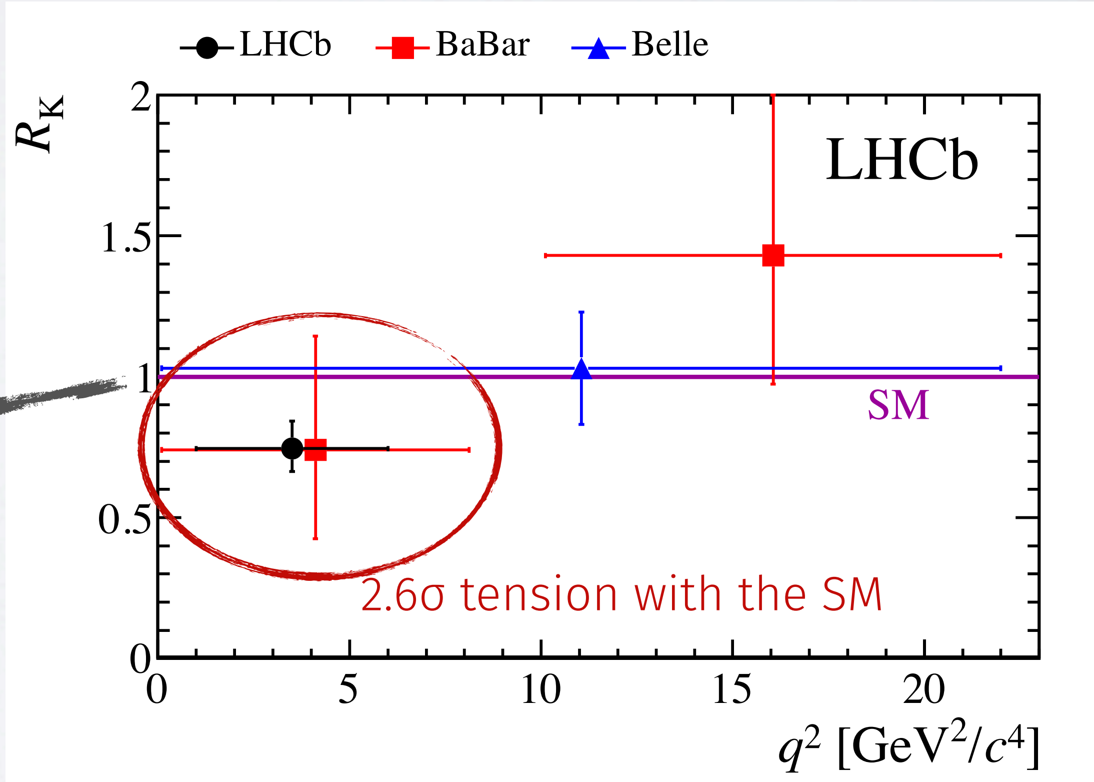
[PRL 113 (2014) 151601]

R_K

In 2014, a discrepancy of 2.6σ with the SM was observed in the ratio of branching fractions of $B^+ \to K^+\mu^+\mu^-$ with respect to $B^+ \to K^+e^+e^-$

$$R_K = \frac{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+e^+e^-)} = 0.745^{+0.090}_{-0.074}\,(\text{stat}) \pm 0.036\,(\text{syst})$$

[Belle, PRL 103 (2009) 171801]
[BaBar, PRD 86 (2012) 032012]
[LHCb, PRL 113 (2014) 151601]



Theory predicts R_K to be unity up to a very good precision

$$R_K^{\text{SM}} = 1 + \mathcal{O}(10^{-2})$$

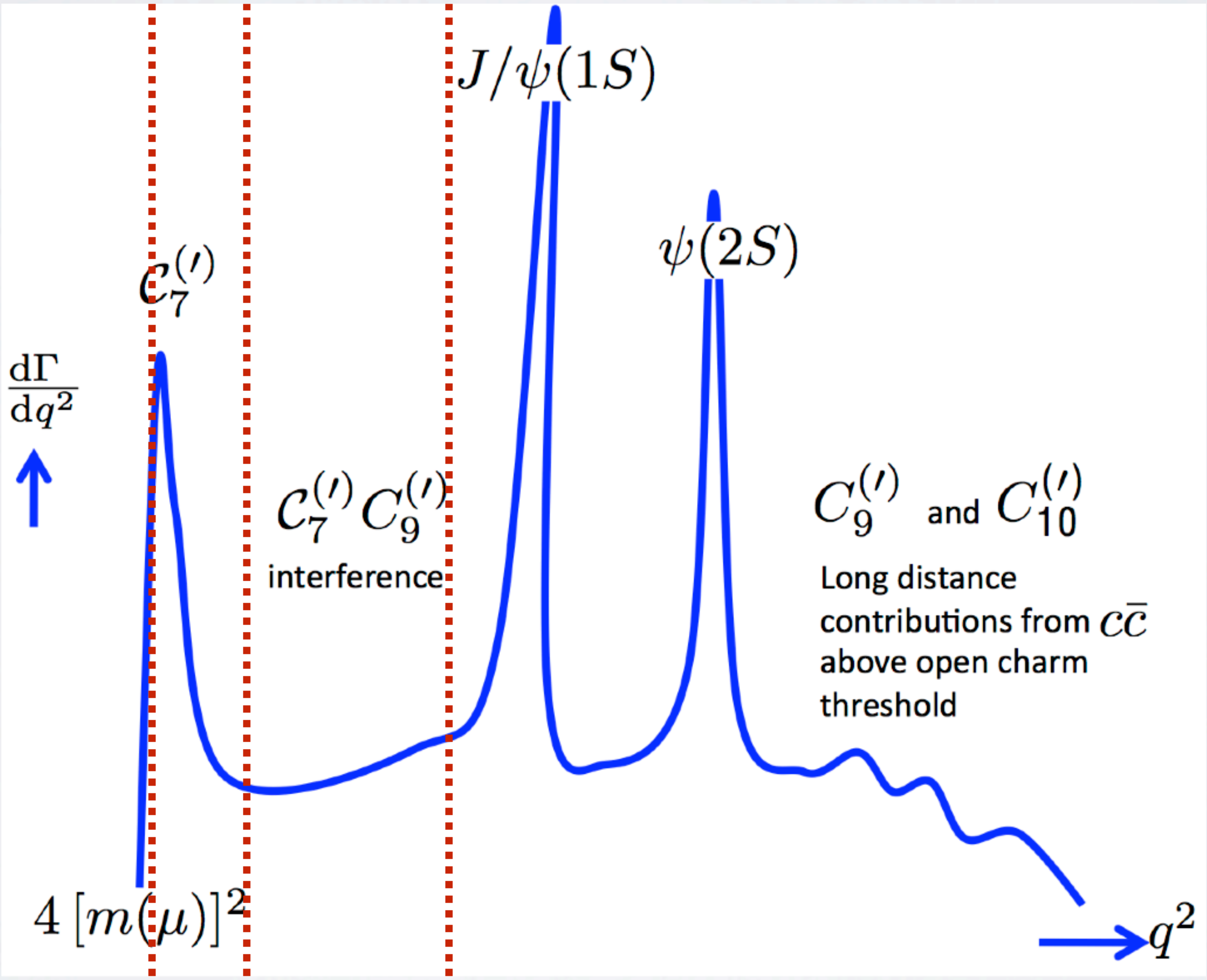
[Bobeth *et al*, JHEP 12 (2007) 040]

[arXiv:1705.05802]

R_{K^*}

Similar to R_K, also with a similar prediction

- Split analysis in two q^2 bins: low (0.045–1.1 GeV^2) and central (1.1–6 GeV^2), with different physics contributions

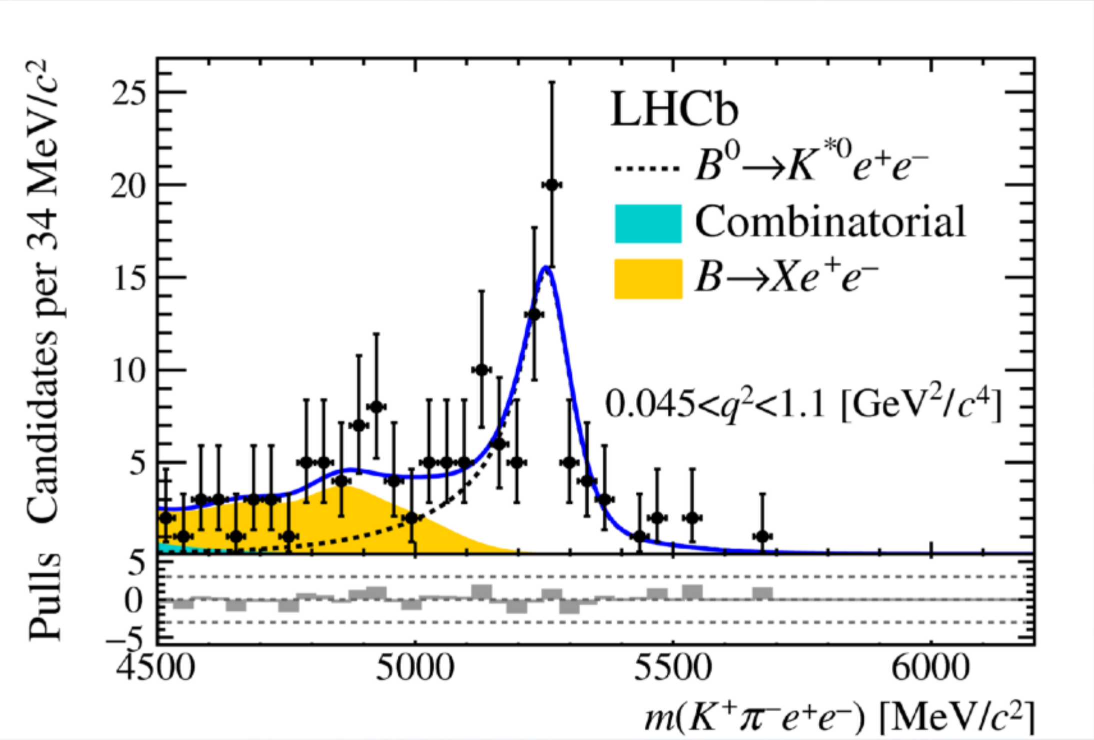


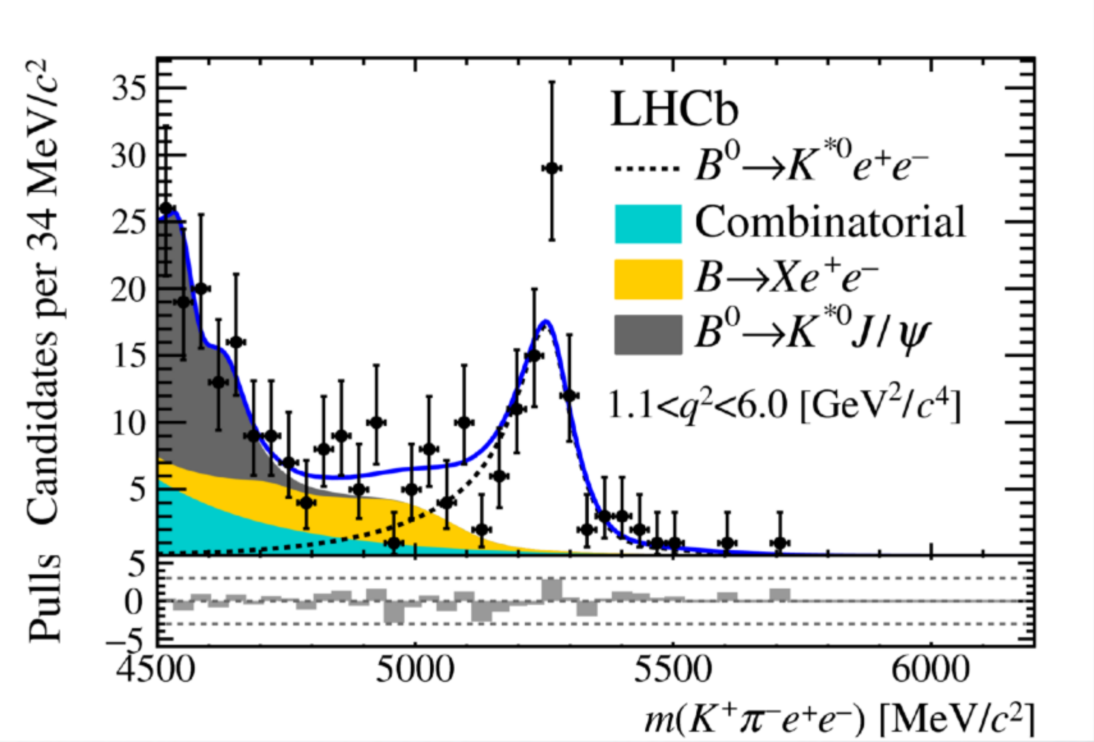
[arXiv:1705.05802]

R_{K^*}

Very complex analysis, need to control muon/electron efficiencies with very high confidence

- Use a double ratio with non-rare, control $B^0 \to K^{*0} J/\psi(\to \ell^+\ell^-)$ modes to control systematics
- Fit sample according to the number of bremsstrahlung photons recovered in the electron reconstruction
- Split sample according to how it was triggered (electron, hadron, other) and merge likelihoods



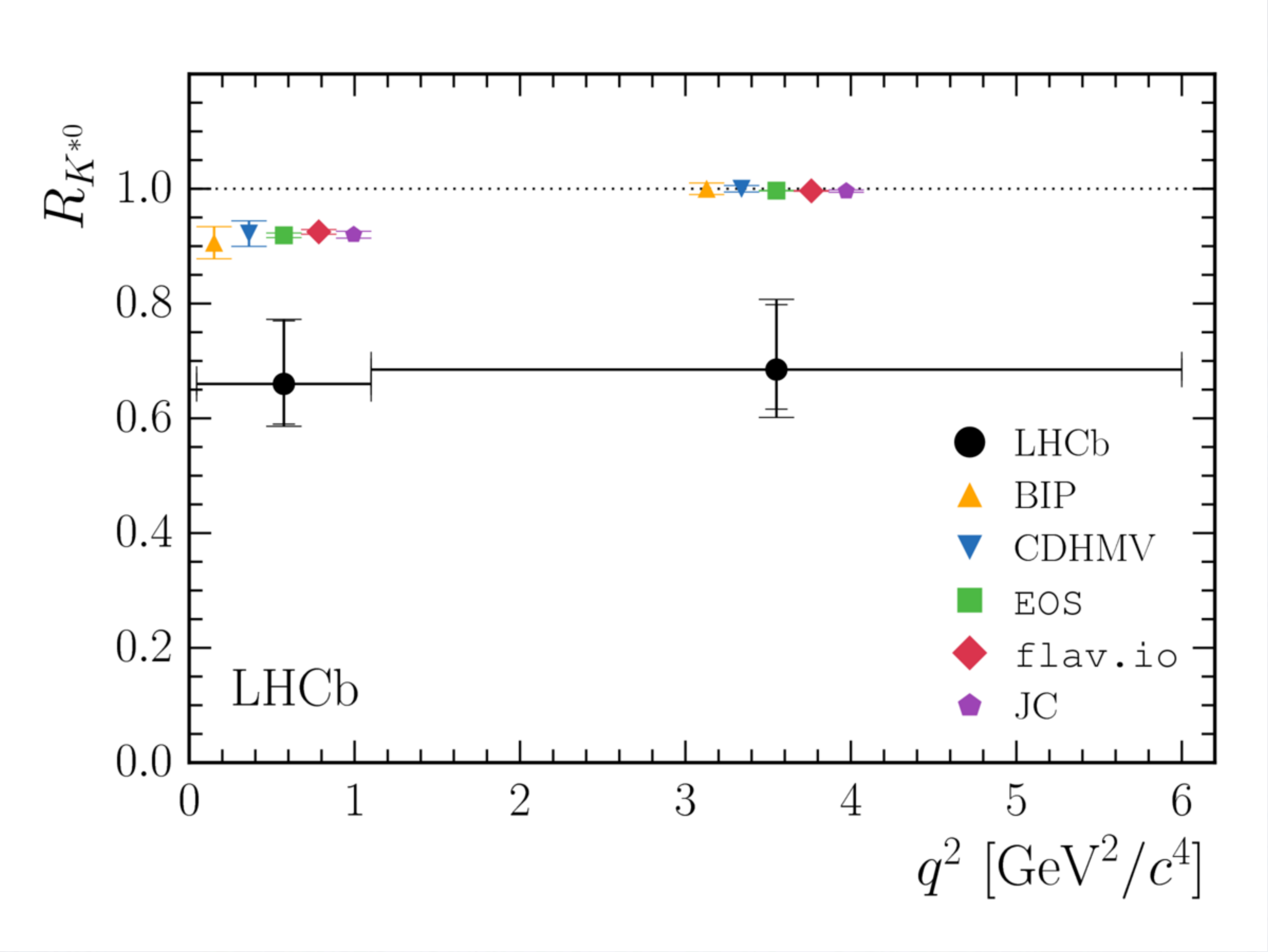


[arXiv:1705.05802]

R_{K^*}

$$R_{K^{*0}}(0.045 < q^2 < 1.1\,\mathrm{GeV}^2/c^4) = 0.660^{+0.110}_{-0.070} \pm 0.024$$

$$R_{K^{*0}}(1.1 < q^2 < 6.0\,\mathrm{GeV}^2/c^4) = 0.685^{+0.113}_{-0.069} \pm 0.047$$



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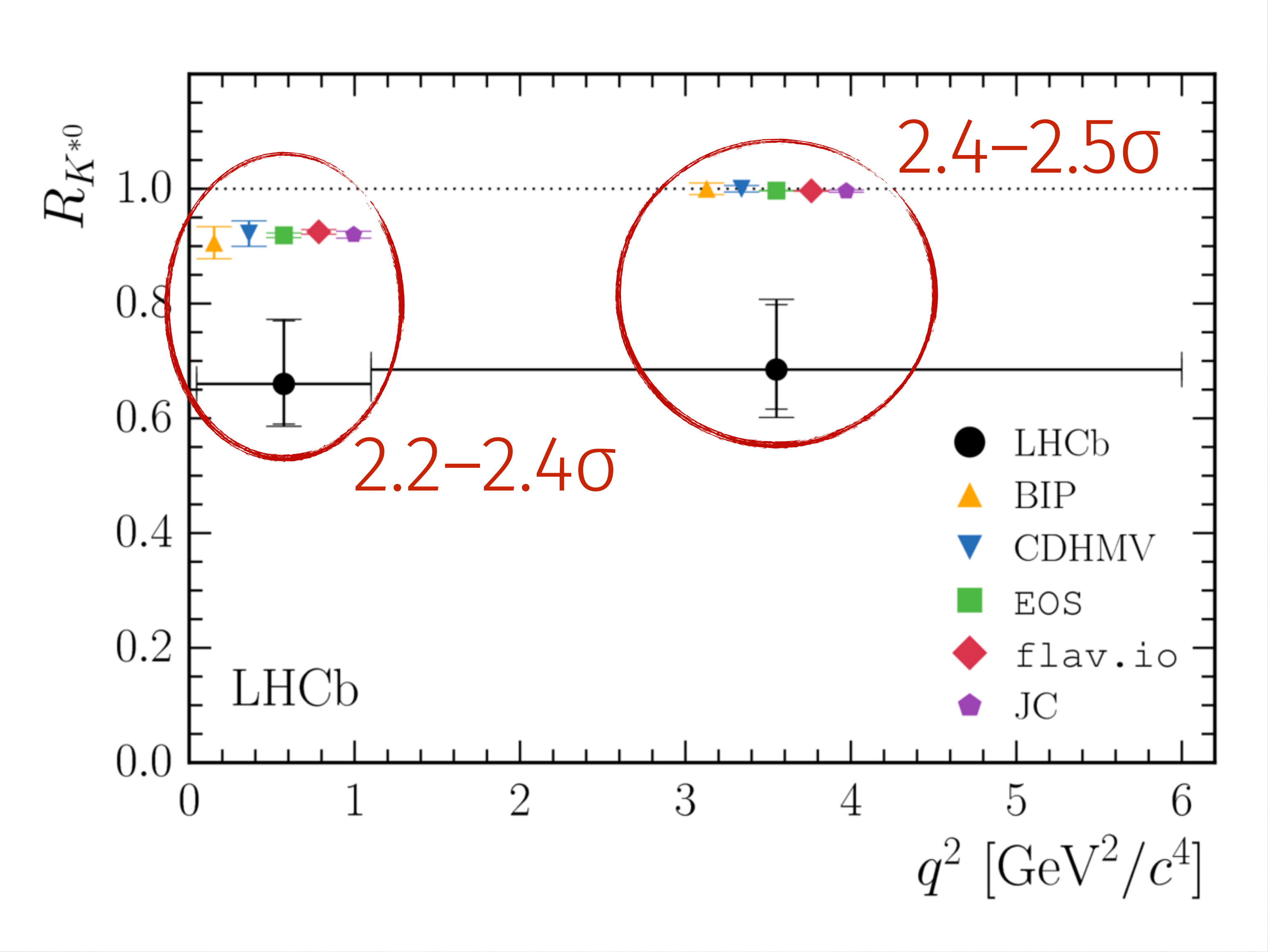


LFU: prospects

R_K and R_{K^*} have produced interesting tensions with the SM, which need to be explored further

LHCb is pursuing a wide program of LFU studies in $b \to s\ell\ell$ decays

- Further R measurements, including both Run 2 data and other decay channels
- LFU in angular distributions

Also studying LFU in tree-level semileptonic decays (see C. Bozzi's talk)

Conclusions

Searches for New Physics with rare *B* decays have pushed the SM to the limit, and interesting tensions have appeared

$B_s \to \mu\mu$ BF compatible with SM so far, but more precision needed. Measurements of $B^0 \to \mu\mu$ BF and the $B_s \to \mu\mu$ lifetime also needed, as there is still room for NP

Interesting hints of Lepton Flavour Universality violation have been observed and need to be pursued harder

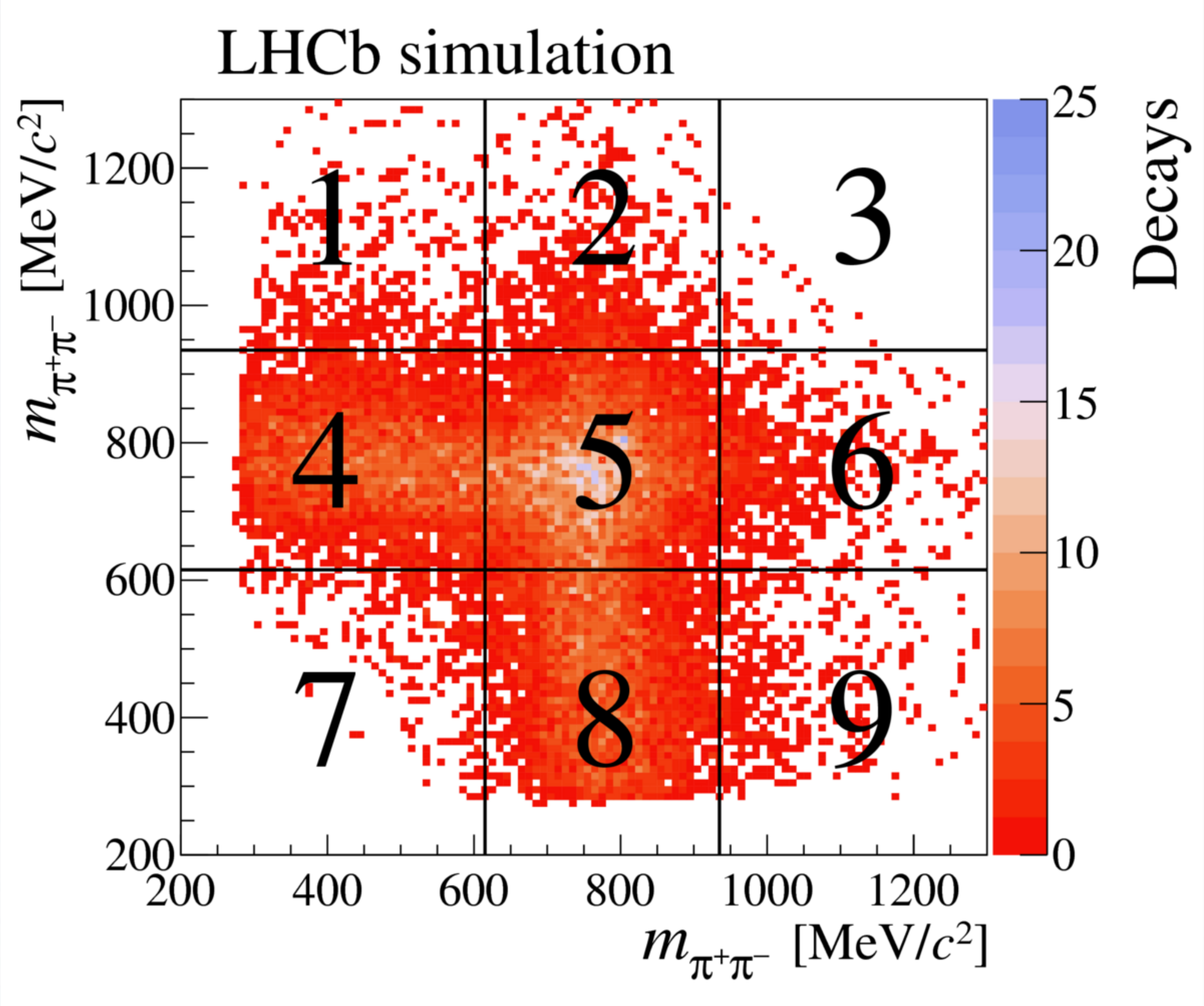
- Other tensions with the SM observed in $b \to s\mu\mu$ decays will be discussed in C. Marin's talk

Stay tuned, New Physics may be around the corner!

Thank you

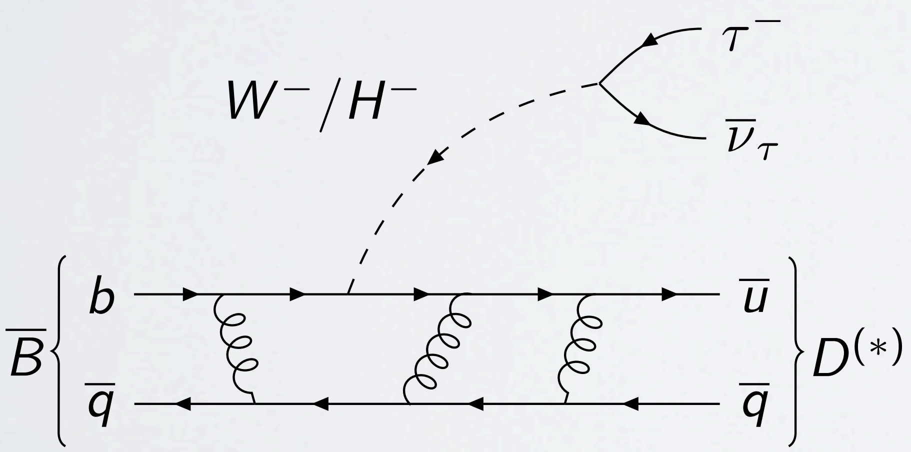
[PRL 118 (2017) 251802]

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

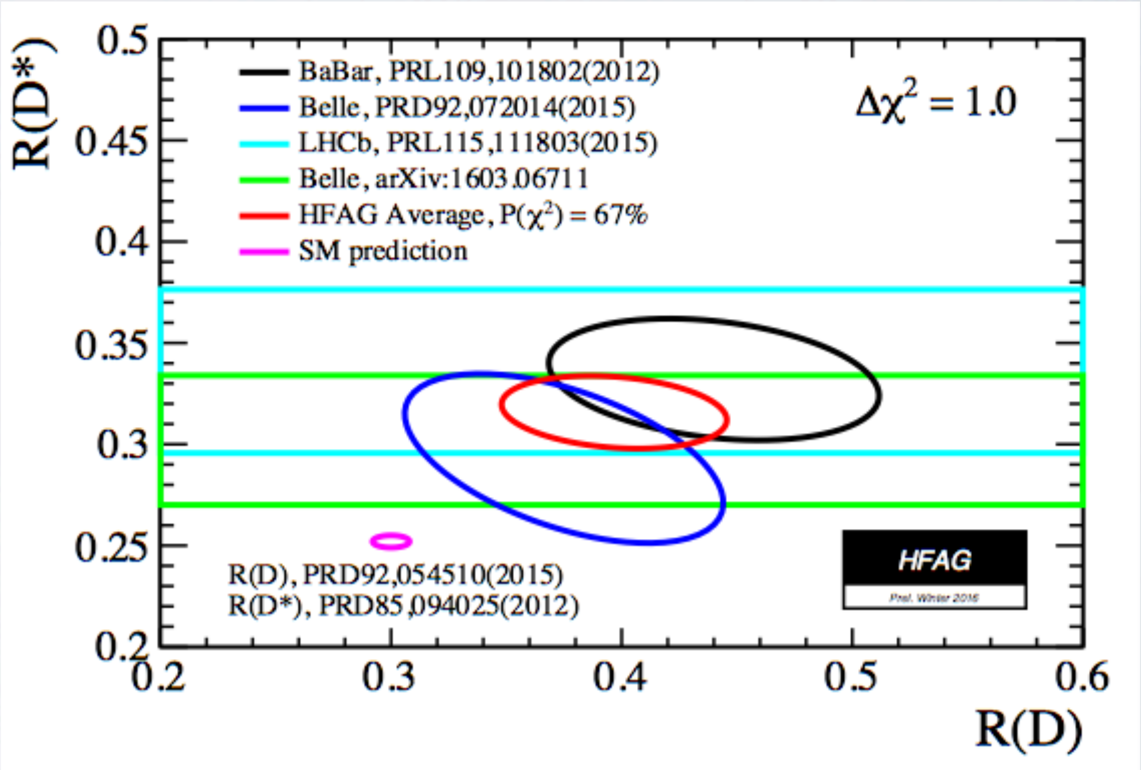


FLU at tree level

BaBar, Belle and LHCb have observed an enhancement of τ with respect to μ in $B \to D^{(*)}\ell\nu_\ell$ *decays* at the level of 4.0σ with respect to SM predictions



[HFLAV, Winter 2016]



[Na *et al*, PRD 92 (2015) 054410]
[Fajfer *et al*, PRD 85 (2012) 094025)

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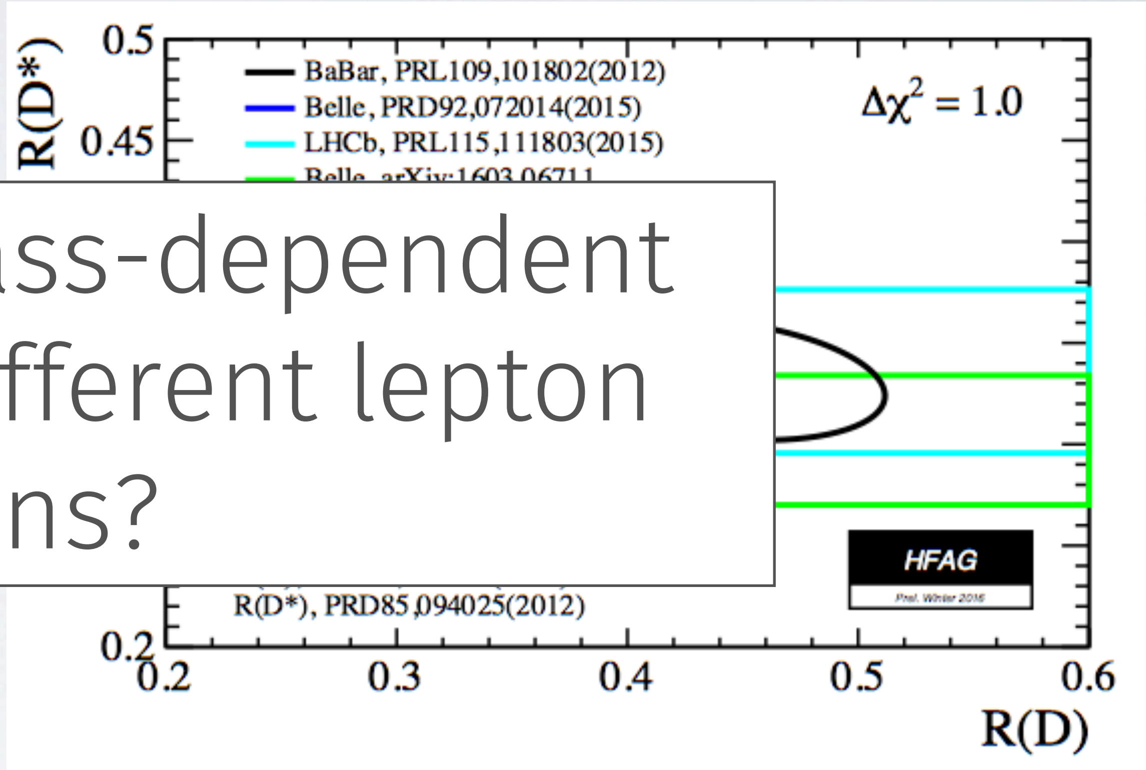
BaBar, Belle and LHCb have observed an enhancement of τ with resp
decays a
respect t

Possible pattern: mass-dependent coupling of NP to different lepton generations?

[HFLAV, Winter 2016]



[Na *et al*, PRD 92 (2015) 054410]
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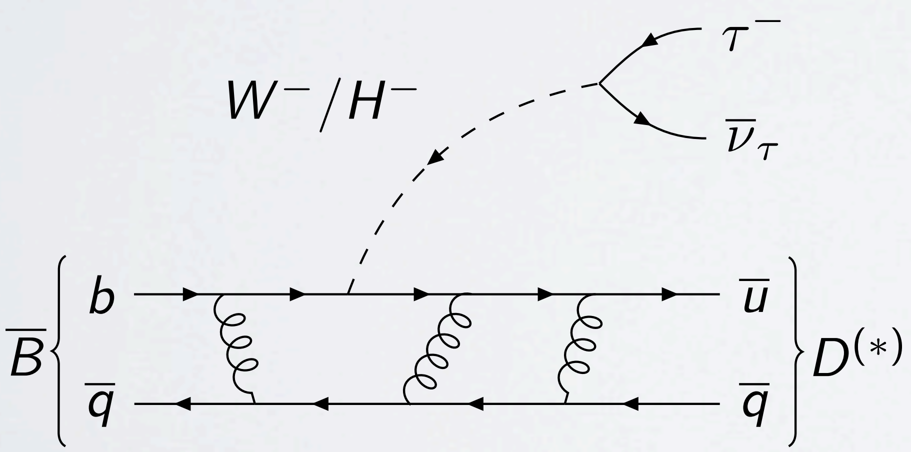
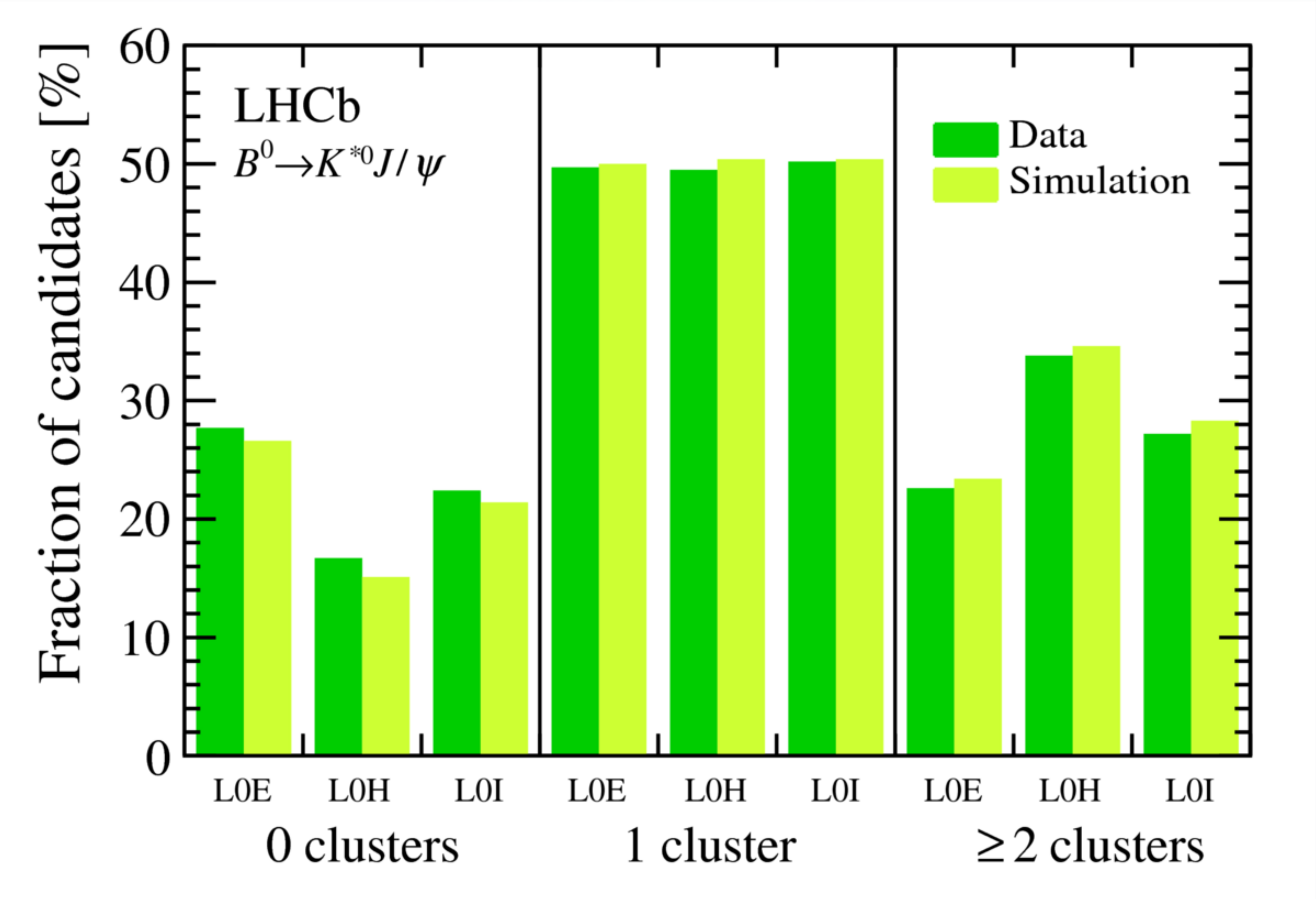
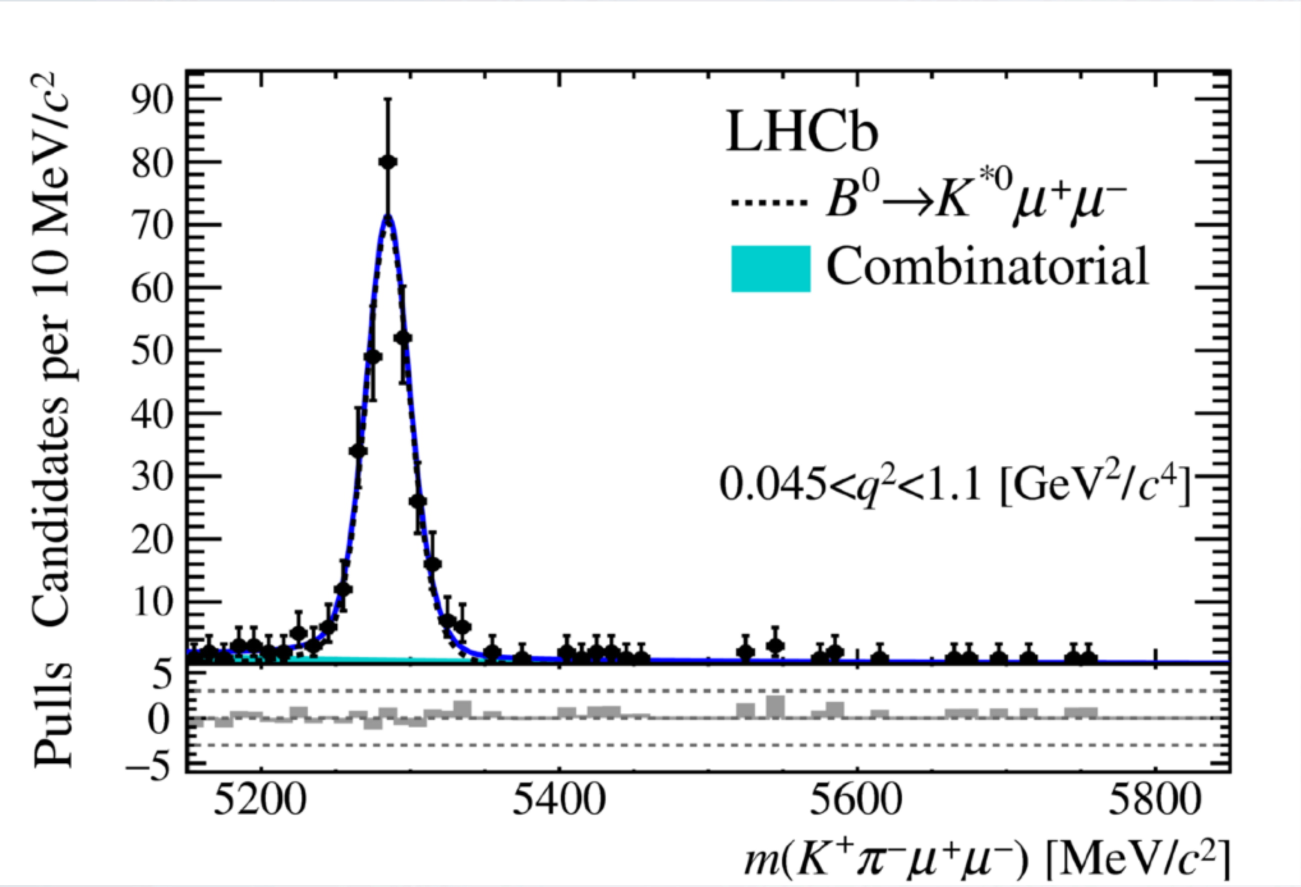
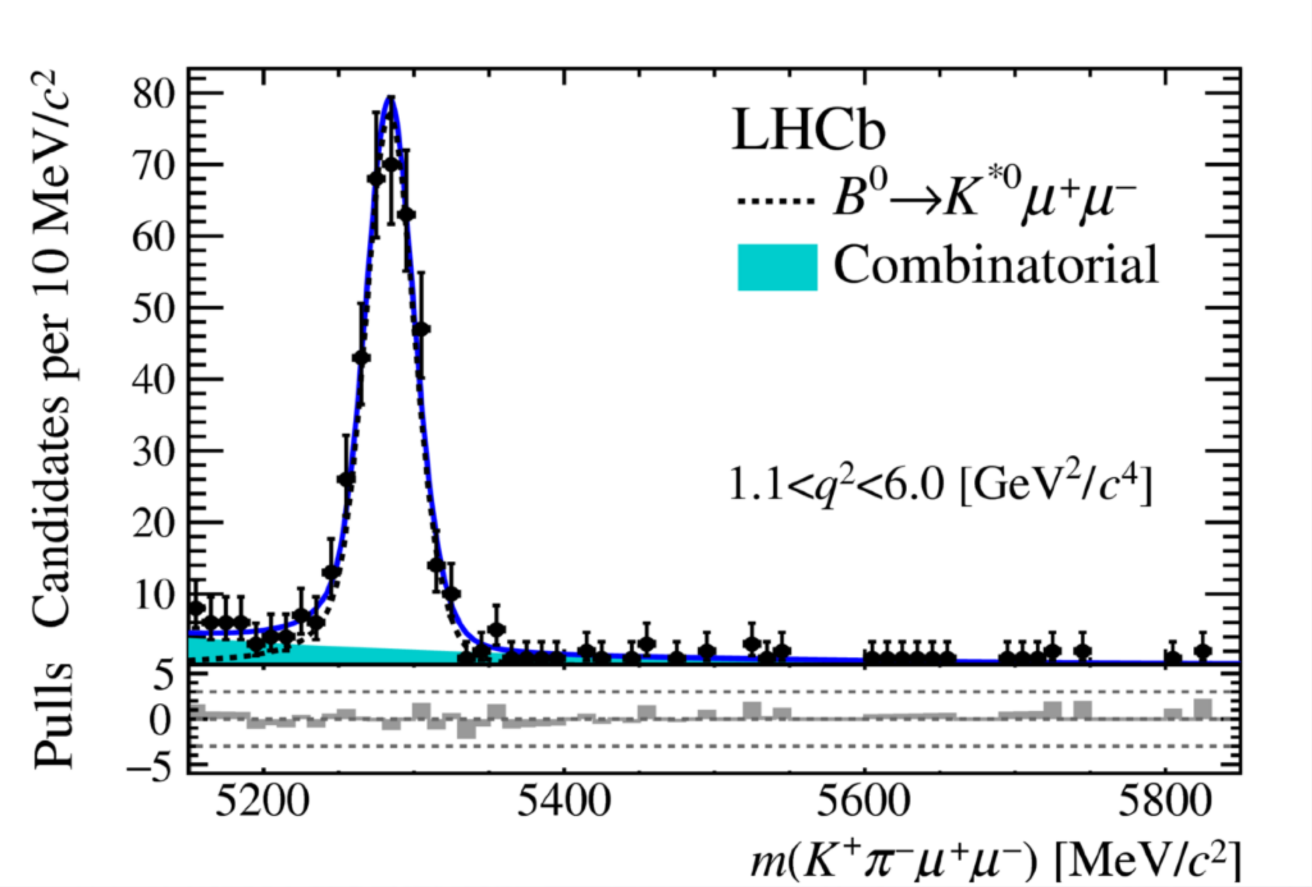


R_{K^*} remmstrahlung photons



R_{K^*} muon fits


LHCb
$B^0 \to K^{*0}\mu^+\mu^-$
Combinatorial
$0.045<q^2<1.1$ [GeV$^2/c^4$]
Candidates per 10 MeV/c^2
Pulls
$m(K^+\pi^-\mu^+\mu^-)$ [MeV/c^2]


LHCb
$B^0 \to K^{*0}\mu^+\mu^-$
Combinatorial
$1.1<q^2<6.0$ [GeV$^2/c^4$]
Candidates per 10 MeV/c^2
Pulls
$m(K^+\pi^-\mu^+\mu^-)$ [MeV/c^2]

[arXiv:1705.05802]

R_{K^*} combined likelihoods