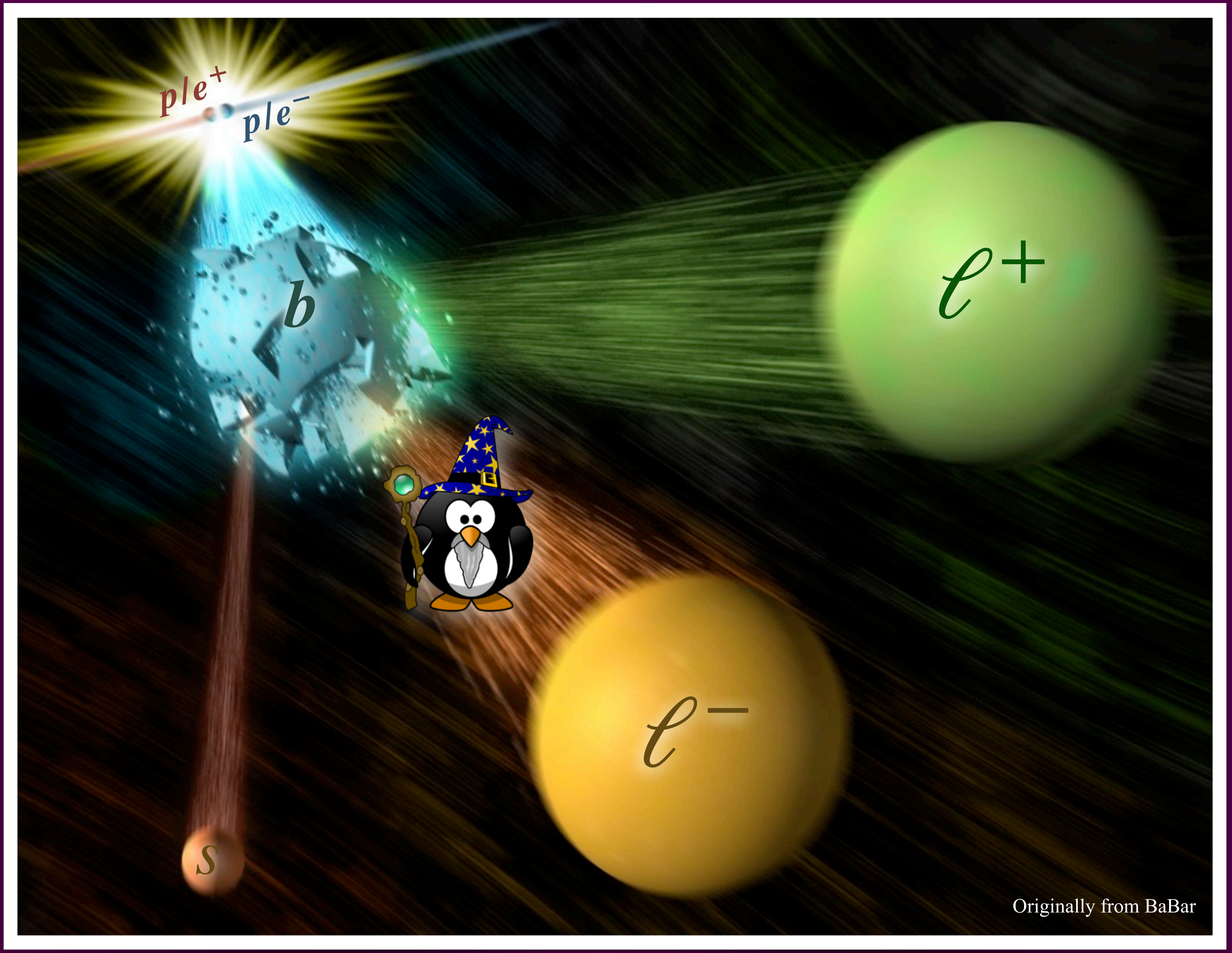
Electroweak penguin anomalies



Penguin from Jeff Brassard

Manuel Franco Sevilla

on behalf of the **ATLAS**, **Belle (II)**, **CMS**, and **LHCb** collaborations

University of Maryland

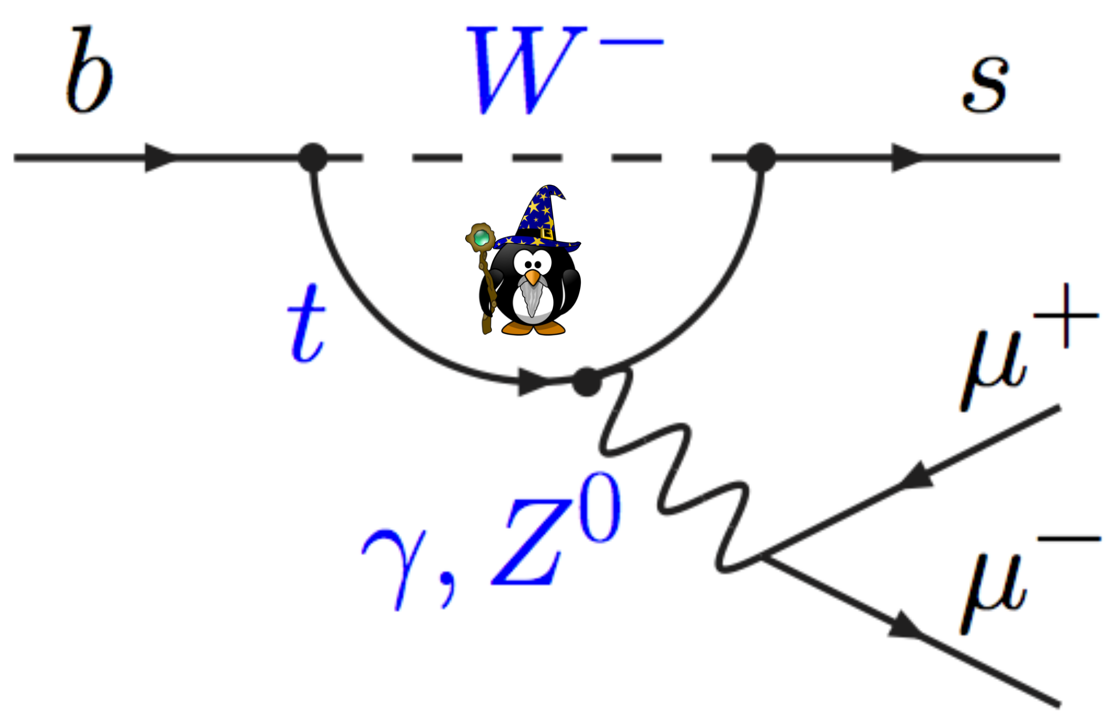
19th April 2021

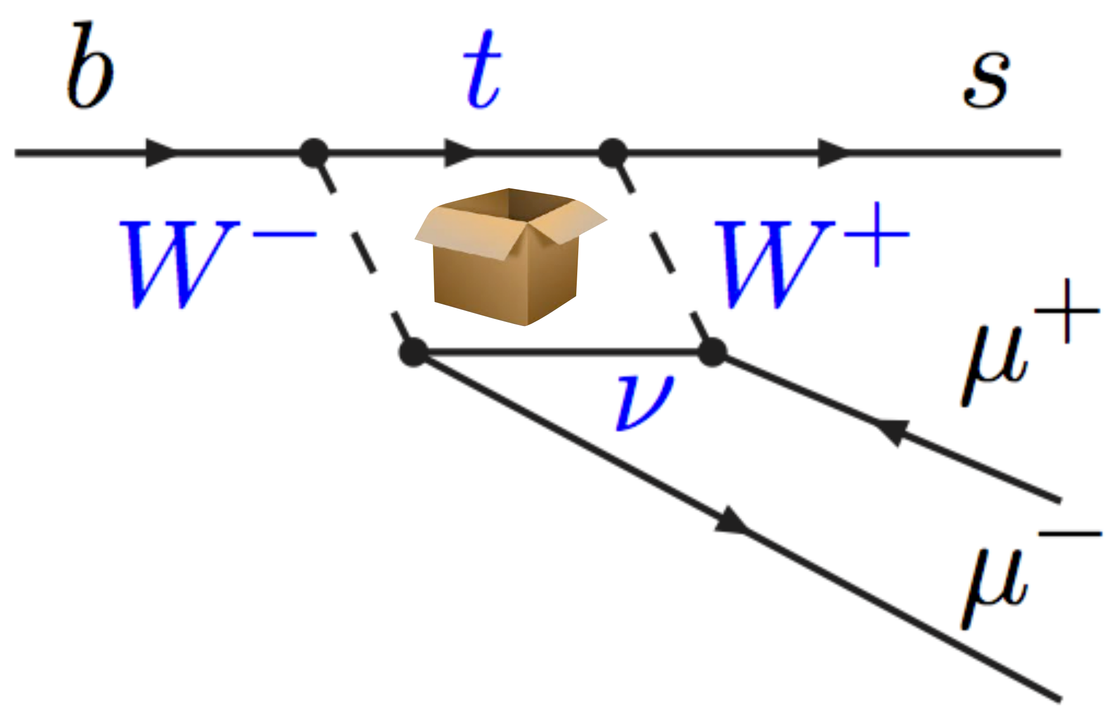
APS April Meeting

Minisymposium on Precision Measurements with Leptons

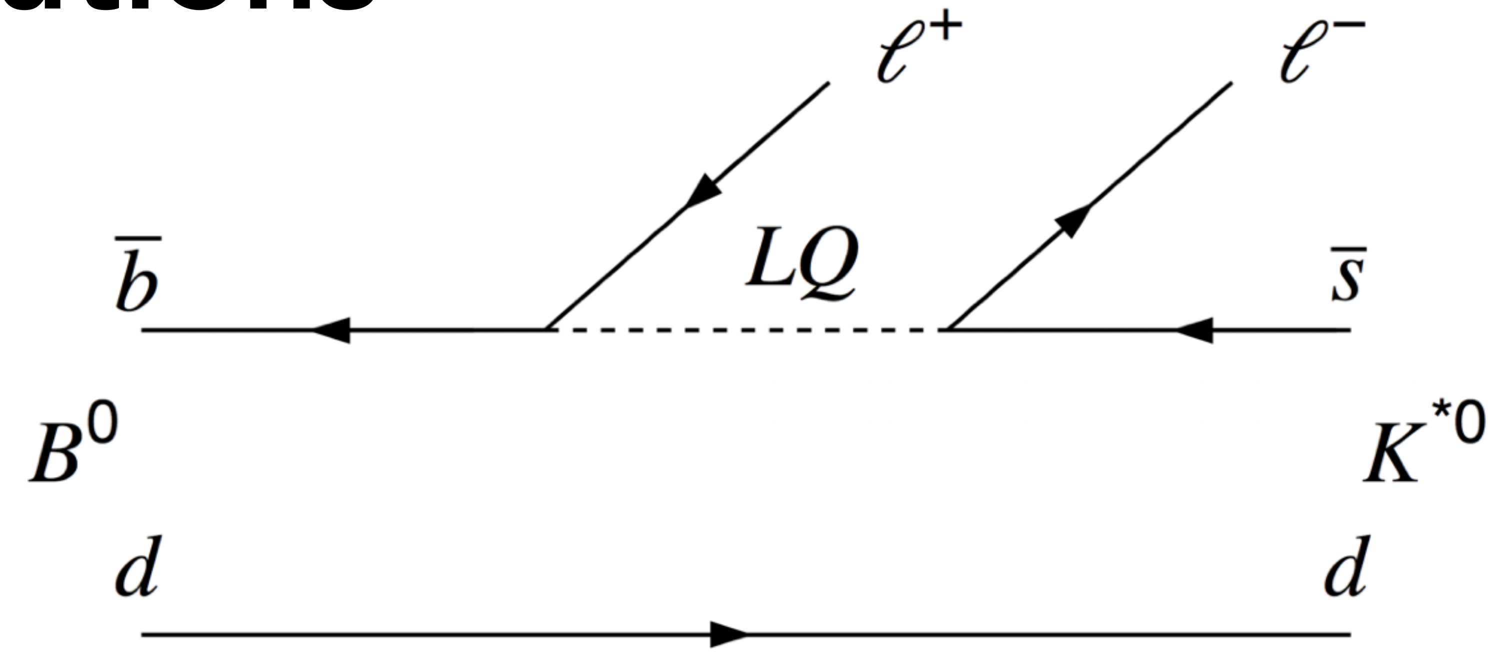
Why penguins (and boxes)

- Decays with a $b \to s\ell^+\ell^-$ transition are **heavily suppressed in the SM**
  - ➡ FCNC proceeds via loop diagrams → BFs < 10^{-6}

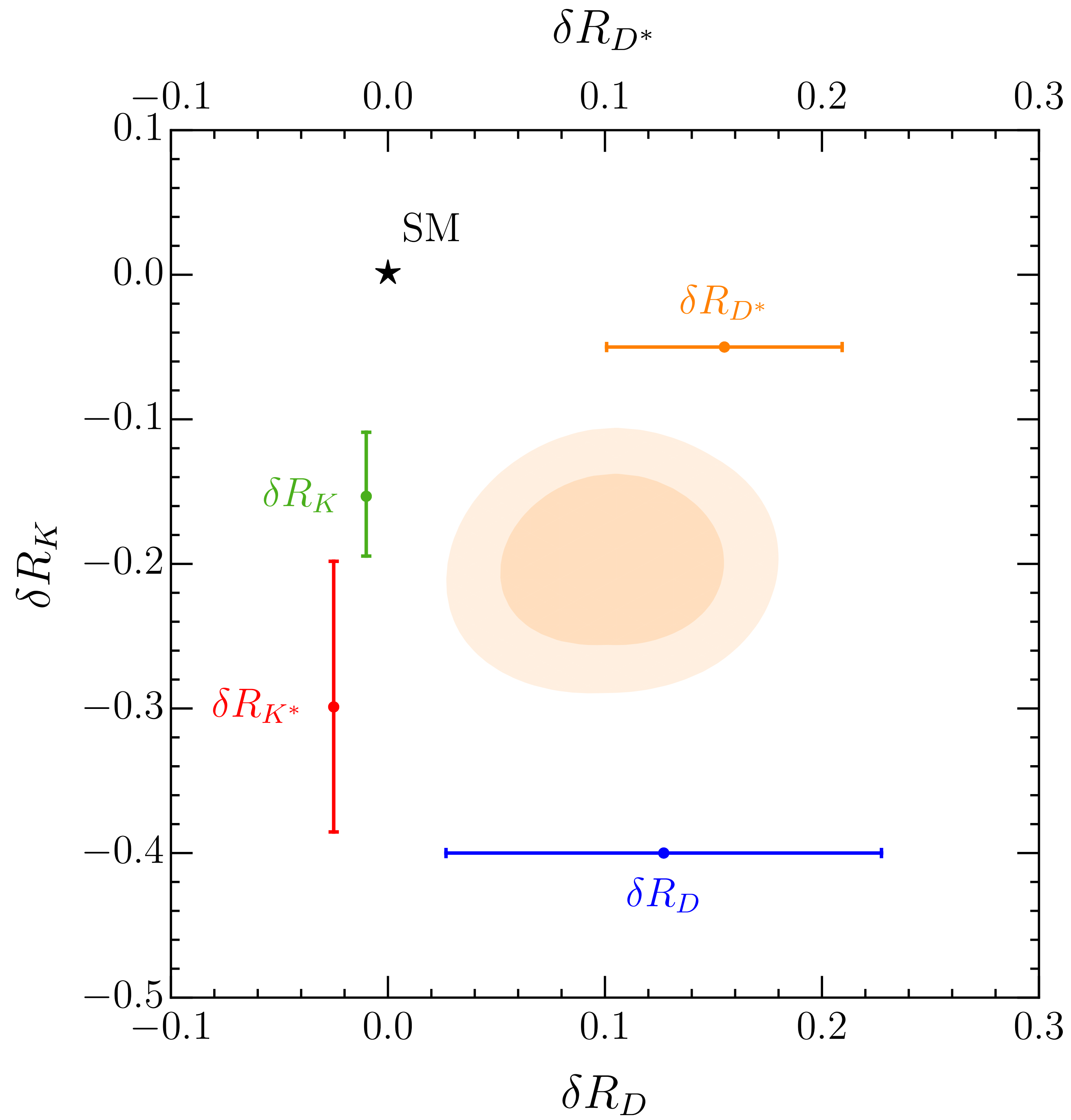




- Makes them **very sensitive** to possible **New physics contributions**



Exotic leptoquark contributing?
See Gino's earlier APS talk and [2103.16558]



Contributions from several experiments

B-factories

BaBar, Belle

$\mathcal{O}\left(10^{9}\right)$ $B^{0/+}$ **mesons**

Low uncertainty on **absolute rates**, 100% ε(trigger), PID, **low e-brem**, knowledge of collision momentum

Belle II

$\mathcal{O}\left(10^{8}\right)$ $B^{0/+}$ **mesons now!**

LHC

LHCb

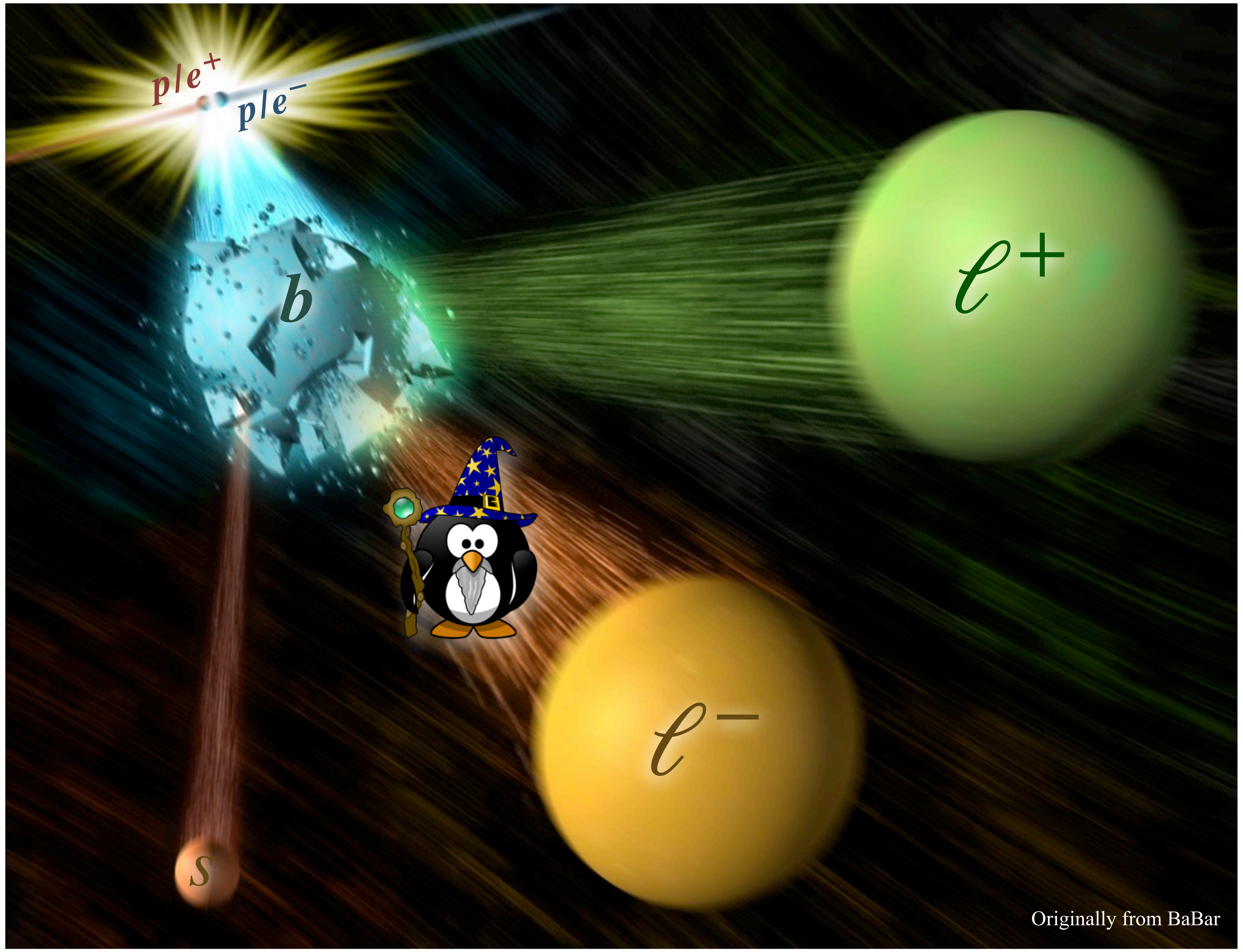
$\mathcal{O}\left(10^{11}\right)$ $B^{0/+}_{(s)}$ **mesons**

Triggers primarily for flavor, PID, VELO, **all b-hadron species**

ATLAS EXPERIMENT, CMS

$\mathcal{O}\left(10^{12}\right)$ $B^{0/+}_{(s)}$ **mesons**

All b-hadron species



Penguin from Jeff Brassard

Purely leptonic $B^0_{(s)} \to \ell^+\ell^-$

Fresh!

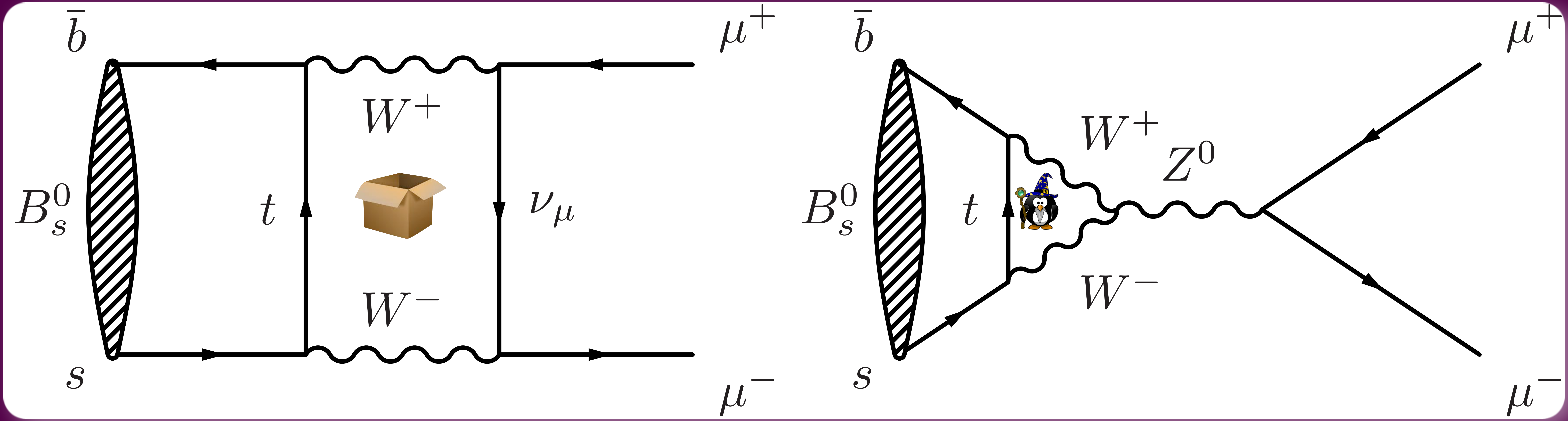
- $B^0_{(s)} \to \mu^+\mu^-$, $B^0_{(s)} \to \tau^+\tau^-$, $B^0_{(s)} \to e^+e^-$

Semileptonic $B_{(s)} \to H\ell^+\ell^-$

- **Search for $B \to K^+\nu\bar{\nu}$** Fresh!
- Differential BF rates
- $B \to K^*\ell\ell$ angular observables
- **LFU ratios $\mathscr{R}_{K^{(*)}}$** Fresh!

Purely leptonic $B^0_{(s)} \to \ell^+\ell^-$

Very rare: $\mathcal{B} \sim 10^{-9}$



$B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$

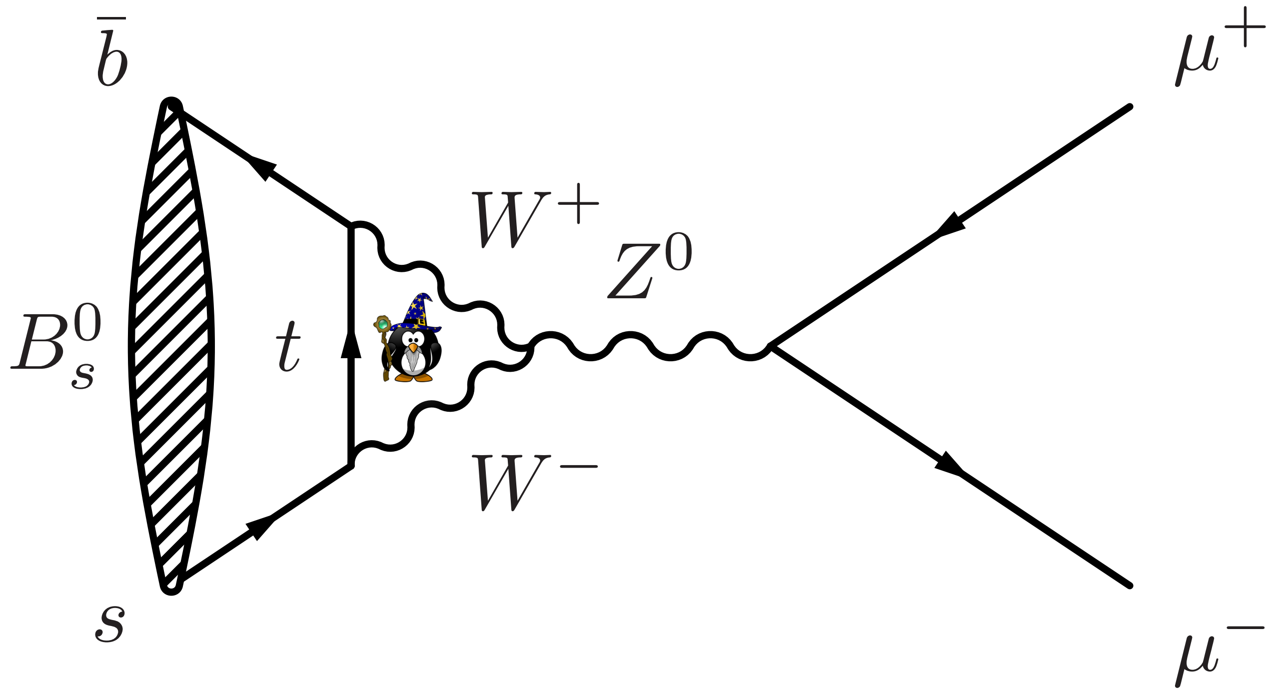
- FCNC and helicity/Cabibbo suppressed

$$\mathscr{B}(B_q^0 \to \mu^+\mu^-)_{\rm SM} = \frac{\tau_{B_q} G_F^4 M_W^4 \sin^4\theta_W}{8\pi^5} |C_{10}^{\rm SM} V_{tb} V_{tq}^*|^2 f_{B_q}^2 m_{B_q} m_\mu^2 \sqrt{1 - \frac{4m_\mu^2}{m_{B_q}^2}} \frac{1}{1-y_q} \qquad q = d, s$$

Clipped from Marco Santimaria

single Wilson coefficient & single hadronic constant (known at $\simeq 0.5\,\%$!)

[PRD 98 (2019) 074512]



SM Predictions JHEP 10 (2019) 232

$\mathscr{B}\left(B_s^0 \to \mu^+\mu^-\right) = \left(3.66 \pm 0.14\right) \times 10^{-9} \;\to\;$ **4% uncertainty**

$\mathscr{B}\left(B^0 \to \mu^+\mu^-\right) = \left(1.03 \pm 0.05\right) \times 10^{-9} \;\to\;$ **5% uncertainty**

- **BFs out of reach** from **B-factories**, but **their measurements are key**

Normalization from $B^+ \to J/\psi K^+$ (and $B^0 \to K^+\pi^-$ in LHCb)

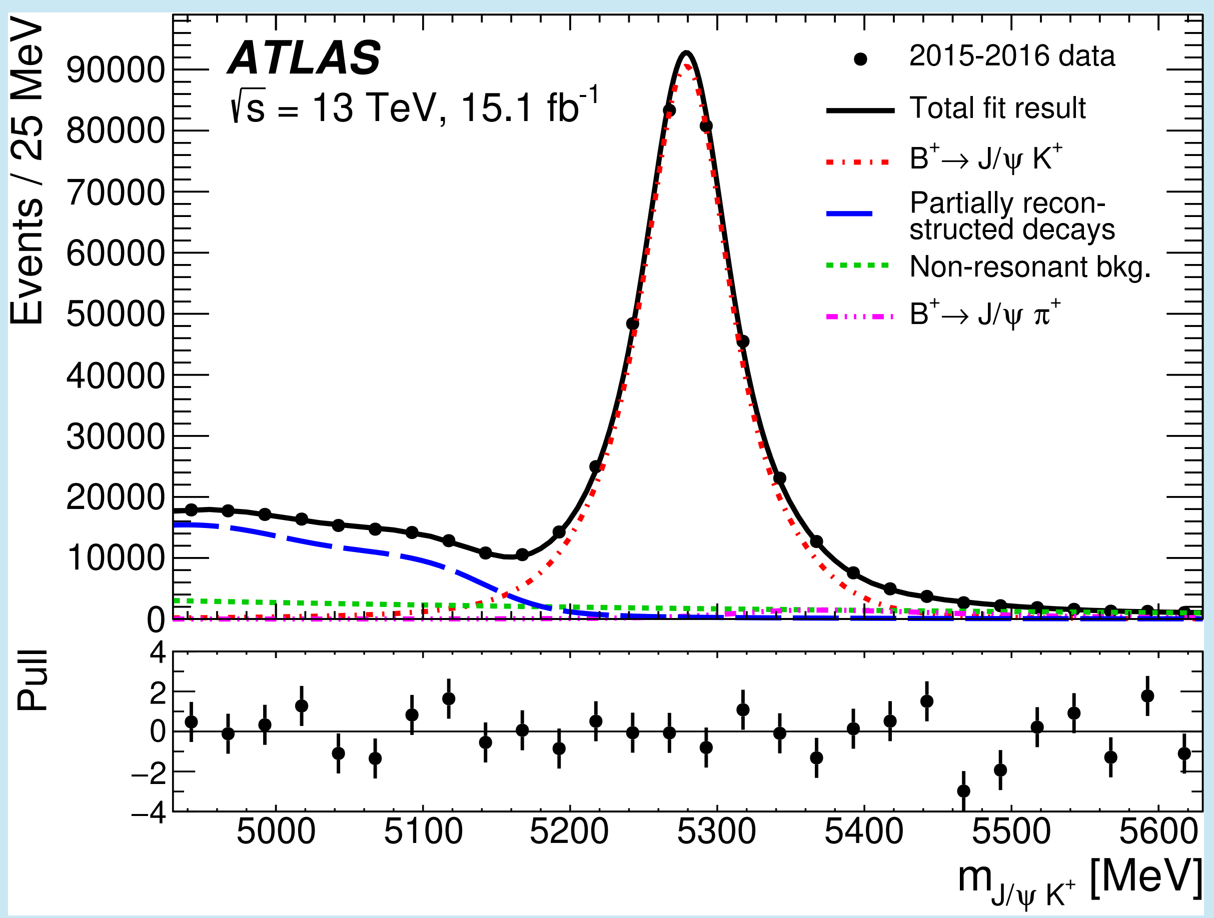
$$\mathcal{B}(\mathrm{B_s^0} \to \mu^+\mu^-) = \frac{N_{\rm S}}{N_{\rm obs}^{\rm B^+}} \frac{f_{\rm u}}{f_{\rm s}} \frac{\varepsilon_{\rm tot}^{\rm B^+}}{\varepsilon_{\rm tot}} \mathcal{B}(\mathrm{B^+} \to \mathrm{J}/\psi \mathrm{K^+}) \mathcal{B}(\mathrm{J}/\psi \to \mu^+\mu^-)$$

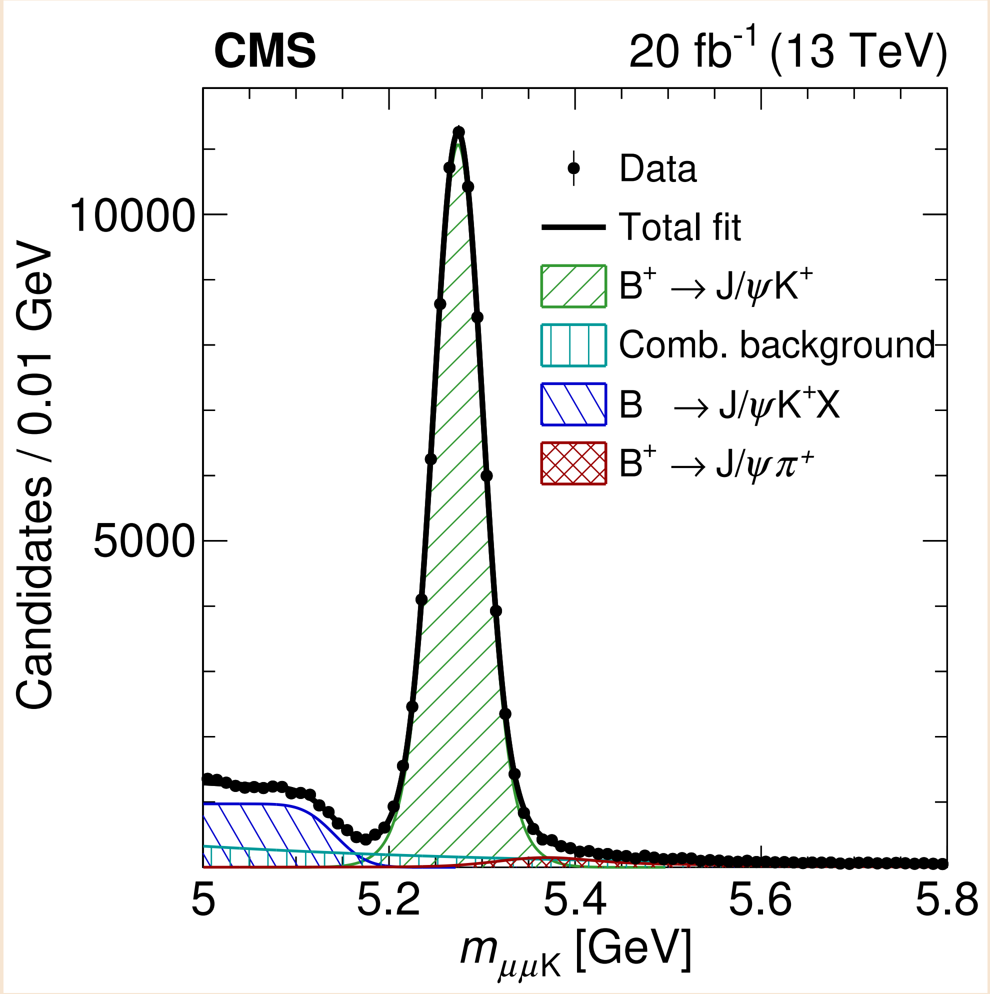
2.4% uncert. **0.6% uncert.**

3.2% uncert. from 2103.06810 (7% until last month) Fresh!

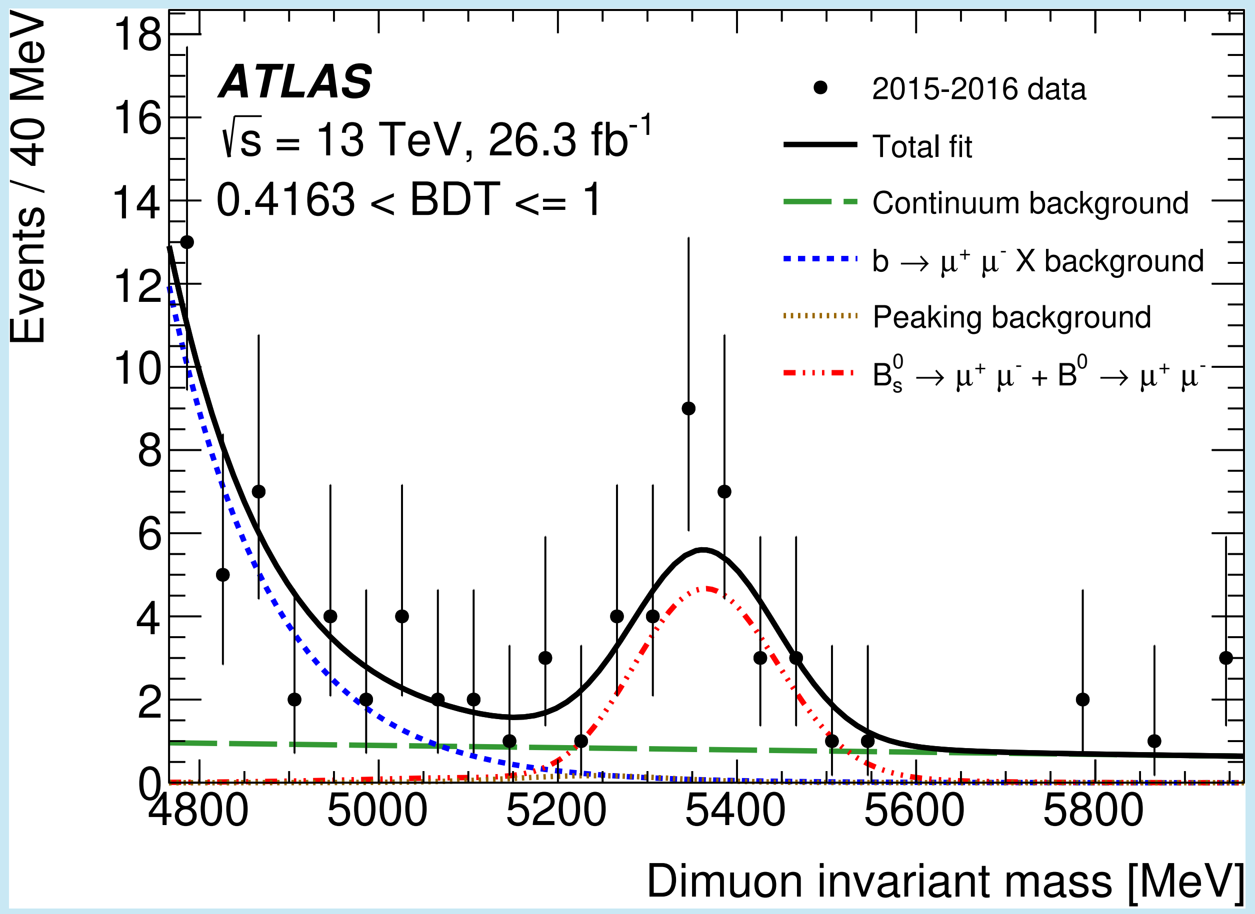
$B^0_{(s)} \to \mu^+\mu^-$: ATLAS and CMS

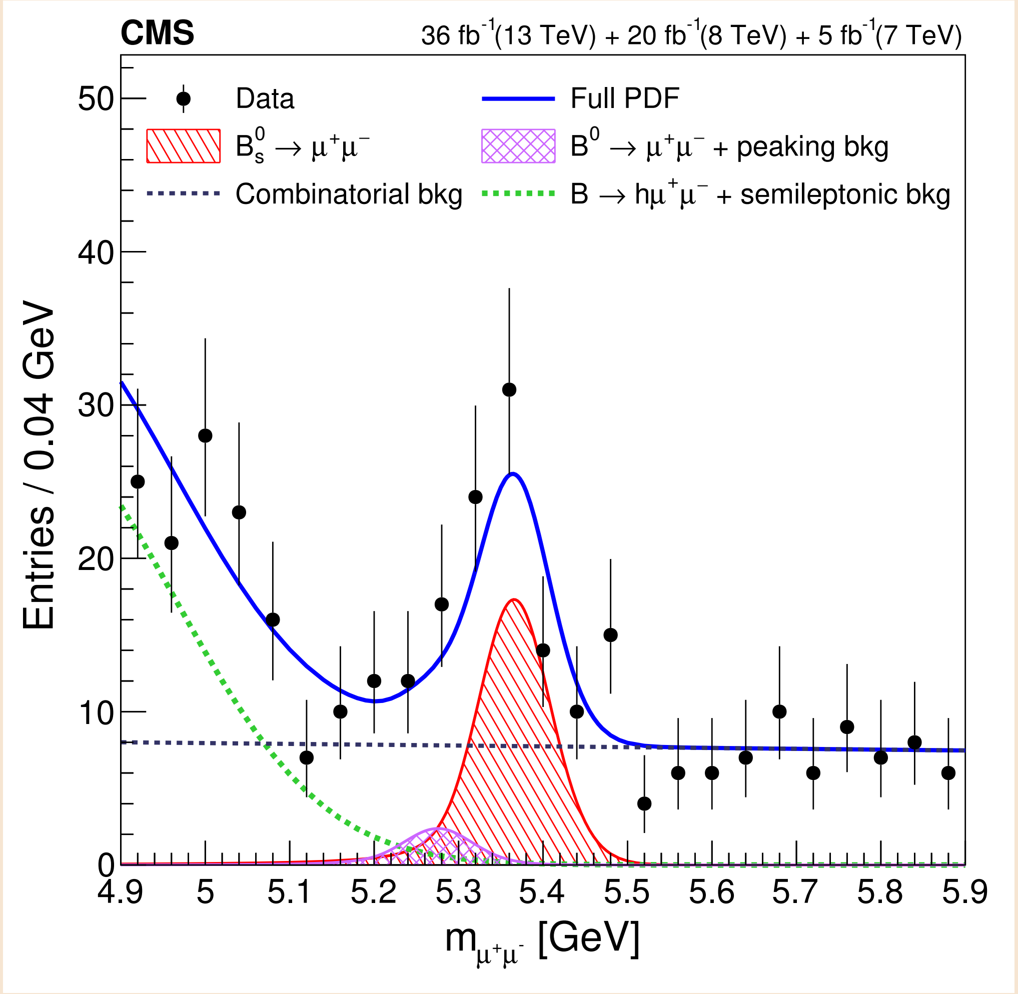
Normalization





Signal





25% of B_s in Run 1+2 dataset

$$\mathcal{B}\left(B^0_s \to \mu^+\mu^-\right) = \left(2.8^{+0.8}_{-0.7}\right) \times 10^{-9} \quad \to \quad 4.6\sigma$$

$$\mathcal{B}\left(B^0 \to \mu^+\mu^-\right) < 2.1 \times 10^{-10} \quad (95\,\%\ \mathrm{CL})$$

JHEP 04 (2019) 098

32% of B_s in Run 1+2 dataset

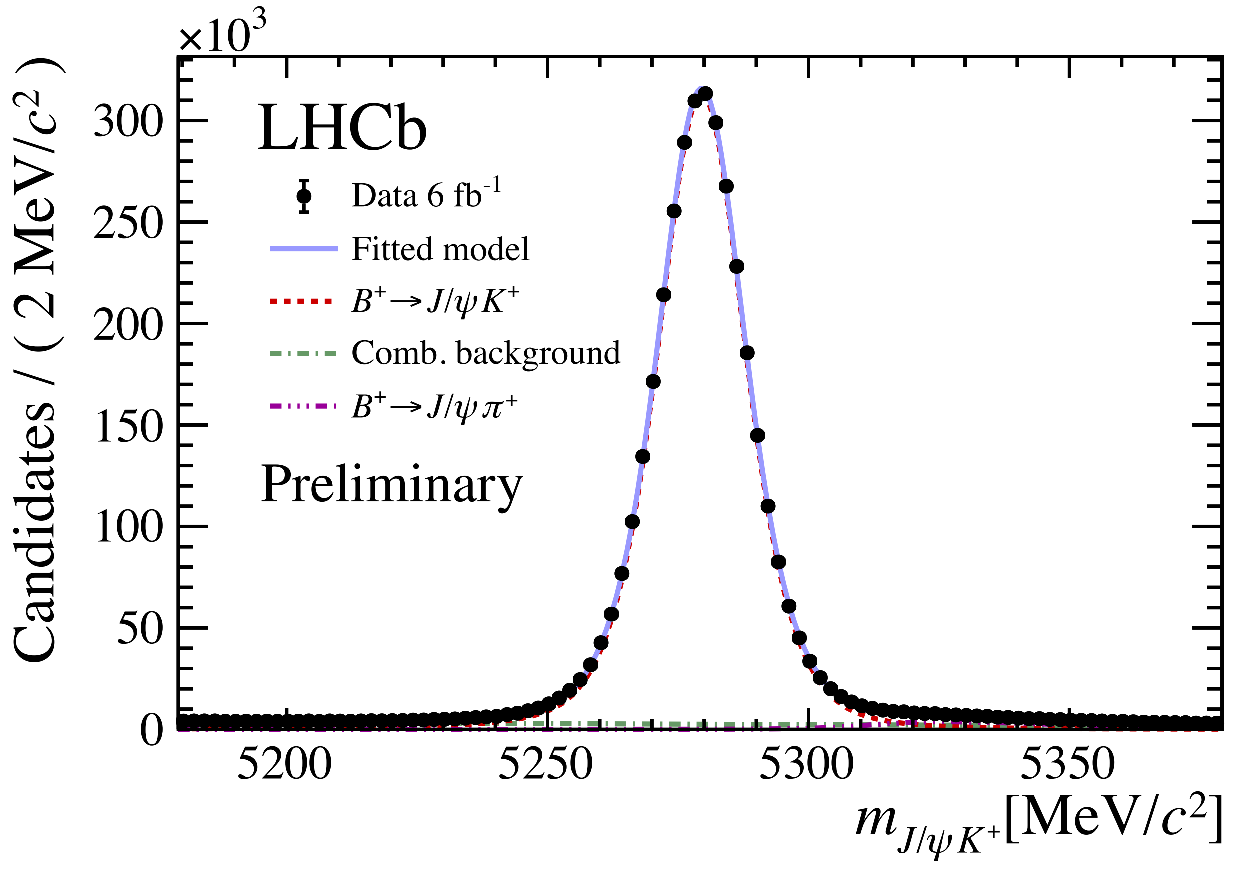
$$\mathcal{B}\left(B^0_s \to \mu^+\mu^-\right) = \left(2.9^{+0.7}_{-0.8}\right) \times 10^{-9} \quad \to \quad 5.6\sigma$$

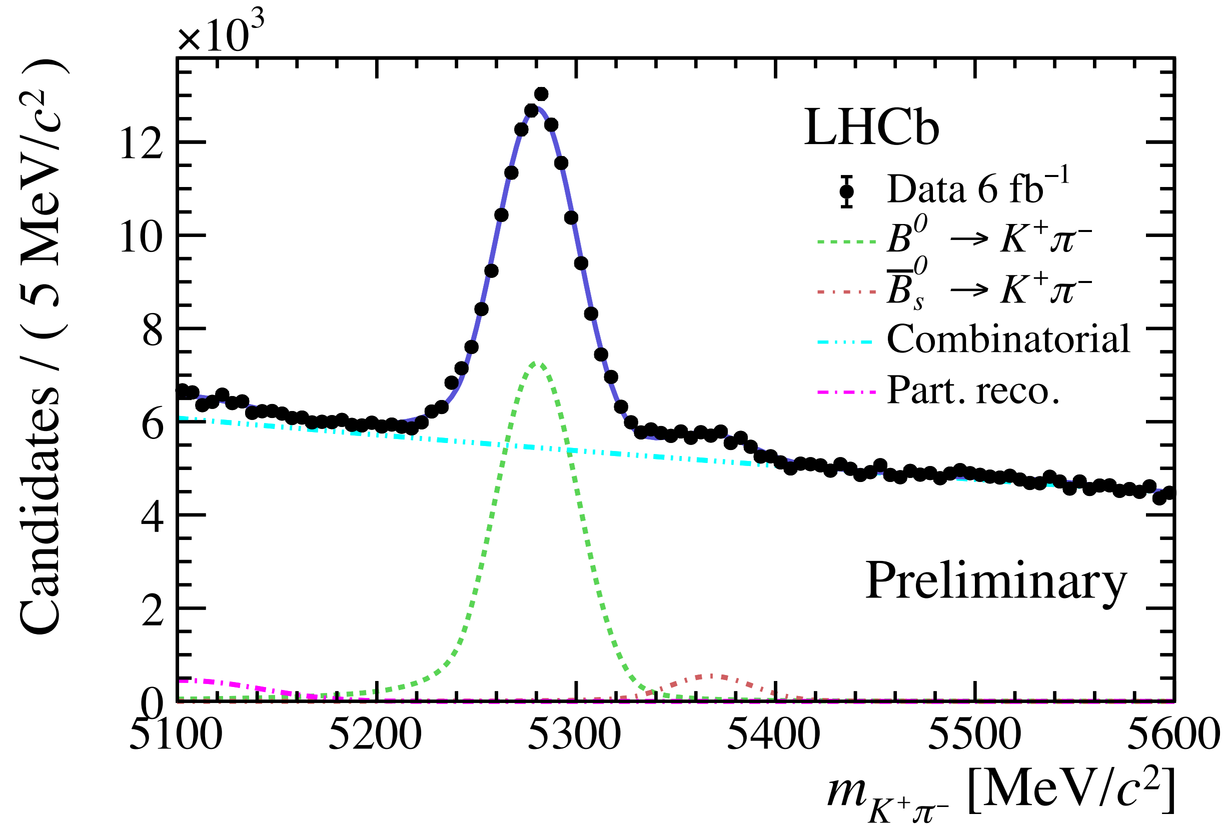
$$\mathcal{B}\left(B^0 \to \mu^+\mu^-\right) < 3.6 \times 10^{-10} \quad (95\,\%\ \mathrm{CL})$$

JHEP 04 (2020) 188

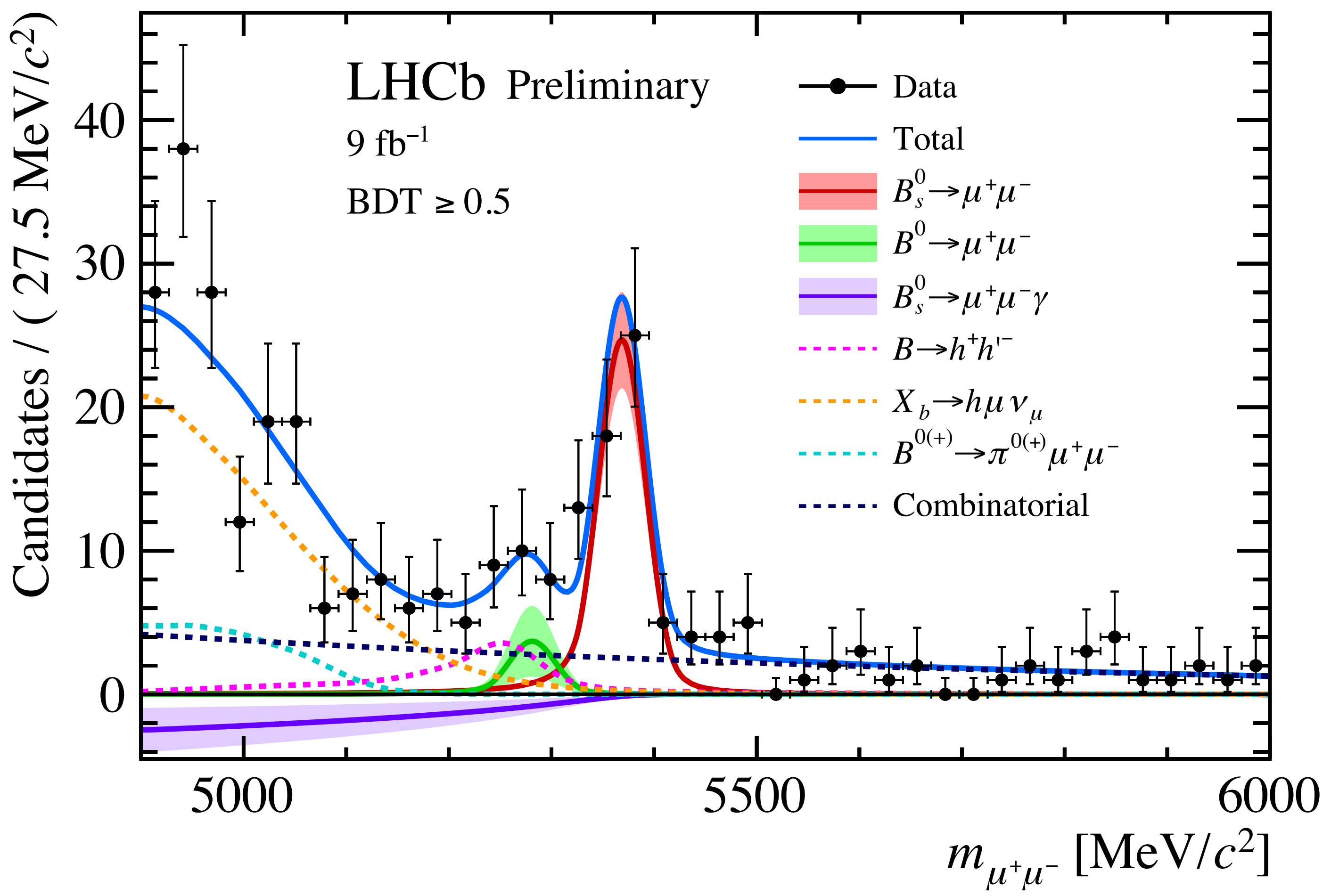
$B^0_{(s)} \to \mu^+\mu^-$: LHCb

Normalization





Signal



Fresh!

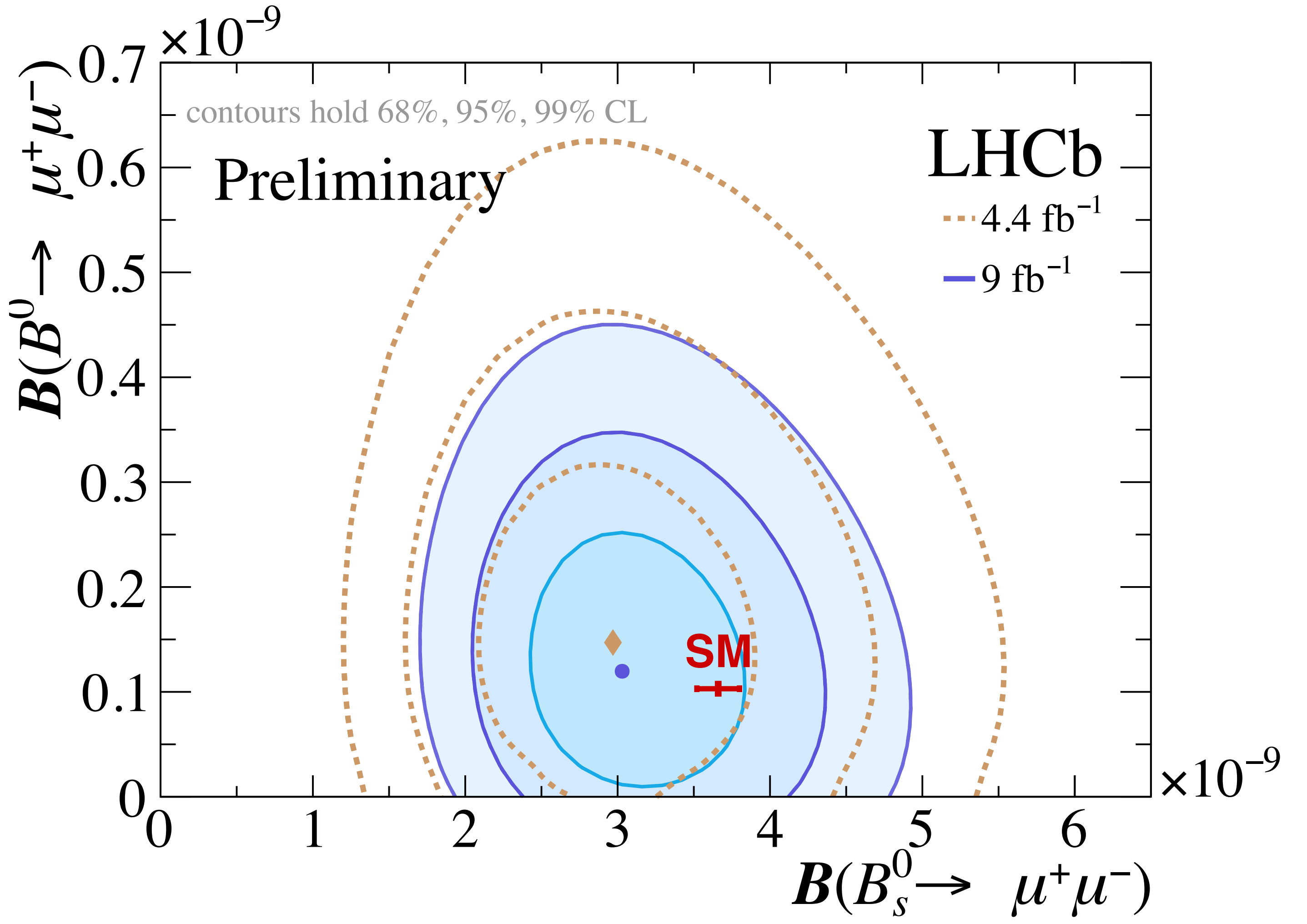
100% of B_s in Run 1+2 dataset

$\mathscr{B}\left(B^0_s \to \mu^+\mu^-\right) = \left(3.09^{+0.46+0.15}_{-0.43-0.11}\right) \times 10^{-9} \;\to\; 10.8\sigma$

$\mathscr{B}\left(B^0 \to \mu^+\mu^-\right) < 2.6 \times 10^{-10}$ (95 % CL)

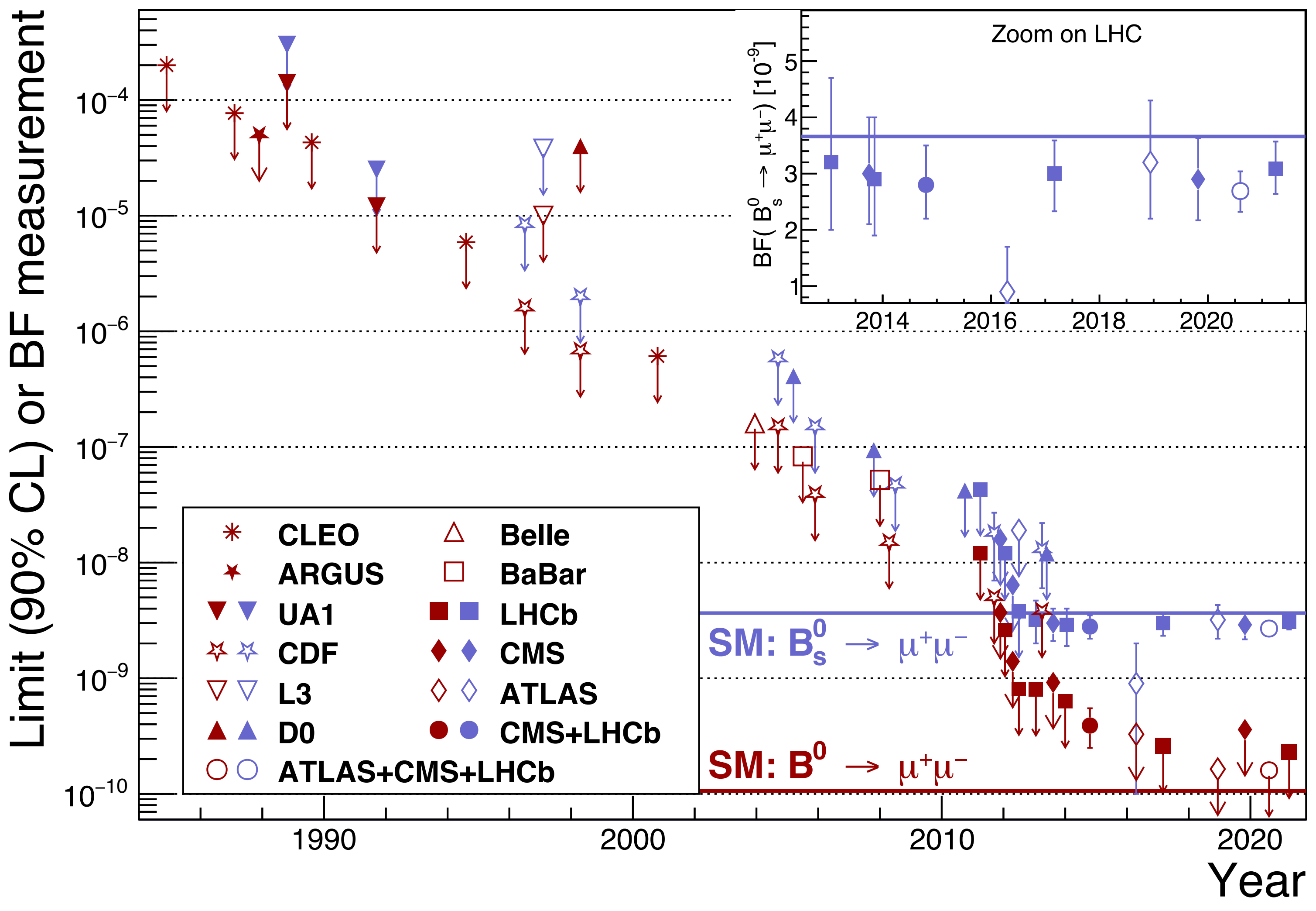
$\mathscr{B}\left(B^0_s \to \mu^+\mu^-\gamma\right)_{m_{\mu\mu}>4.9\text{ GeV}} < 2.0 \times 10^{-9}$ (95 % CL)

PAPER-2021-007 forthcoming

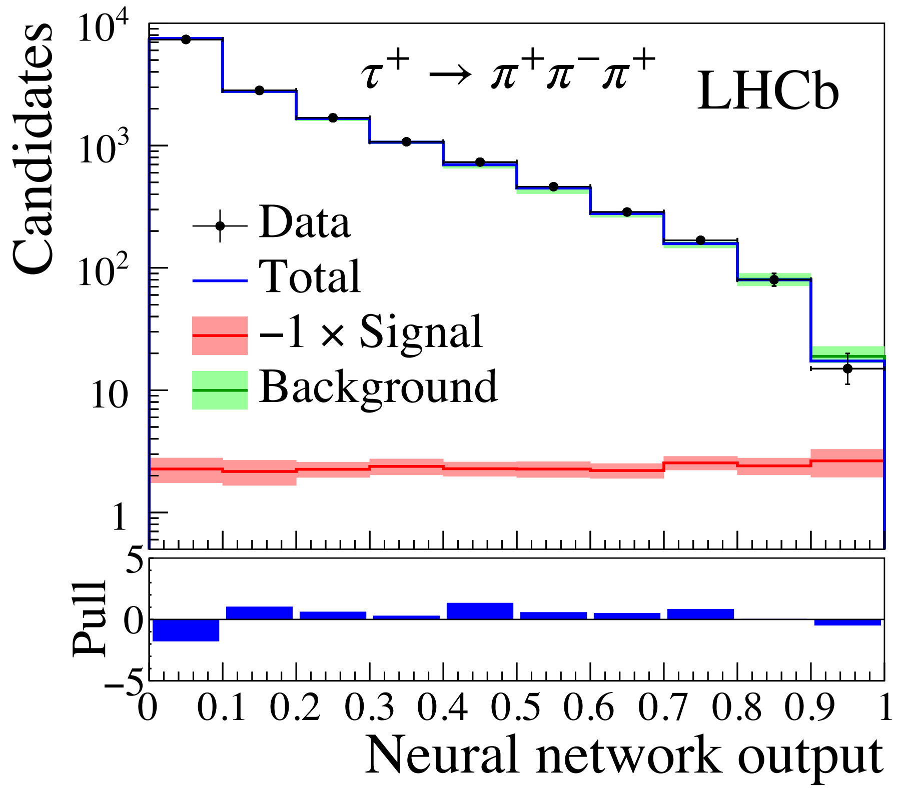


- $B^0_s \to \mu^+\mu^-$ still **~10% below SM**
- **Limit** on $B^0 \to \mu^+\mu^-$ at **2.5x the SM**
- **First limit** on $B^0_s \to \mu^+\mu^-\gamma$ at high m(μμ)
- Also measured **effective lifetime**
  $\tau_{\mu\mu} = 2.07 \pm 0.29 \pm 0.03$ ps

$B^0_{(s)} \to \tau^+\tau^-$ and $B^0_{(s)} \to e^+e^-$



- Entering era of $B_s^0 \to \mu^+\mu^-$ **precision measurements**
- Getting **close to** $B^0 \to \mu^+\mu^-$
- **Far from SM predictions for taus** and **electrons**, but **NP** could enhance rates



25% of B_s in Run 1+2

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

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

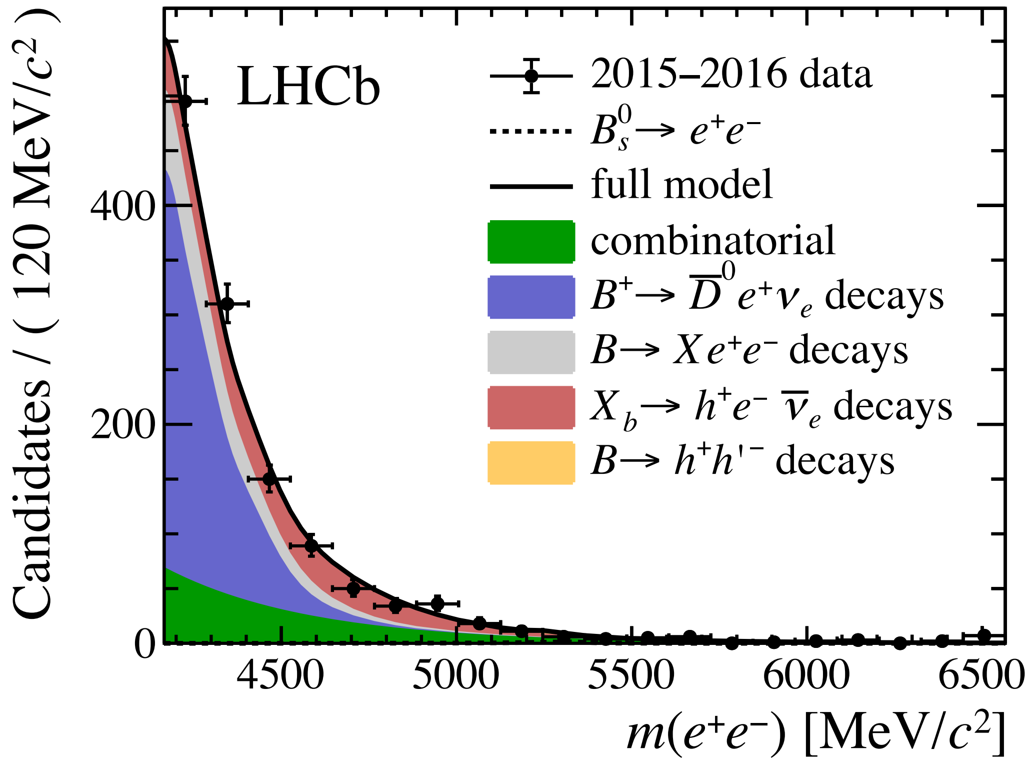
PRL 118, 251802 (2017)

$$\mathcal{B}\left(B_s^0 \to \tau^+\tau^-\right)_{\rm SM} = (7.73 \pm 0.49) \times 10^{-7}$$

$$\mathcal{B}\left(B^0 \to \tau^+\tau^-\right)_{\rm SM} = (2.22 \pm 0.19) \times 10^{-8}$$

PRL 112, 101801 (2014)

A factor of ~10^4 from SM for taus



50% of B_s in Run 1+2

$\mathcal{B}\left(B_s^0 \to e^+e^-\right) < 1.1 \times 10^{-8}$ (95 % CL)

$\mathcal{B}\left(B^0 \to e^+e^-\right) < 3.0 \times 10^{-9}$ (95 % CL)

PRL 124, 211802 (2020)

$$\mathcal{B}\left(B_s^0 \to e^+e^-\right)_{\rm SM} = (8.60 \pm 0.36) \times 10^{-14}$$

$$\mathcal{B}\left(B^0 \to e^+e^-\right)_{\rm SM} = (2.41 \pm 0.13) \times 10^{-15}$$

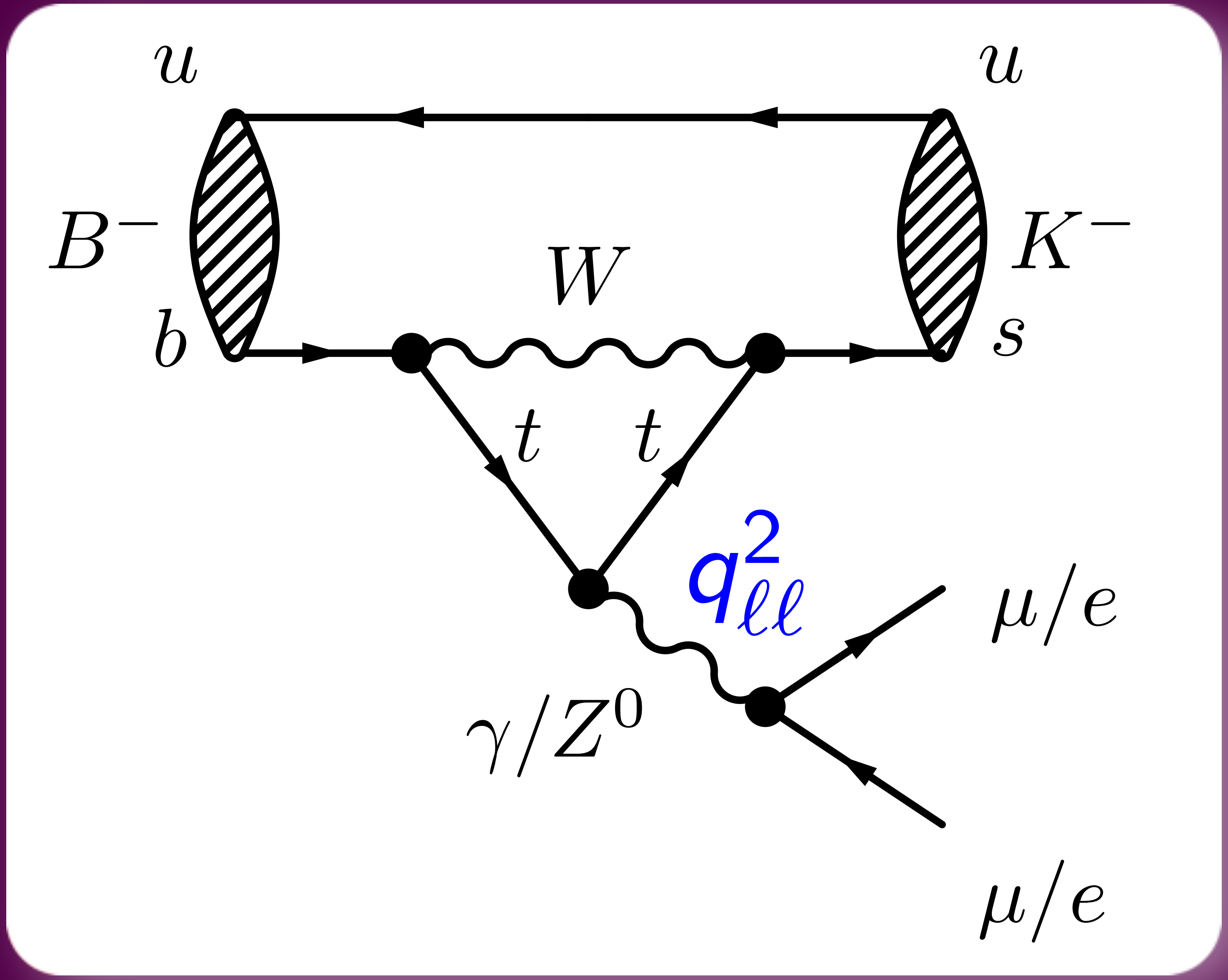
JHEP 10, 232 (2019)

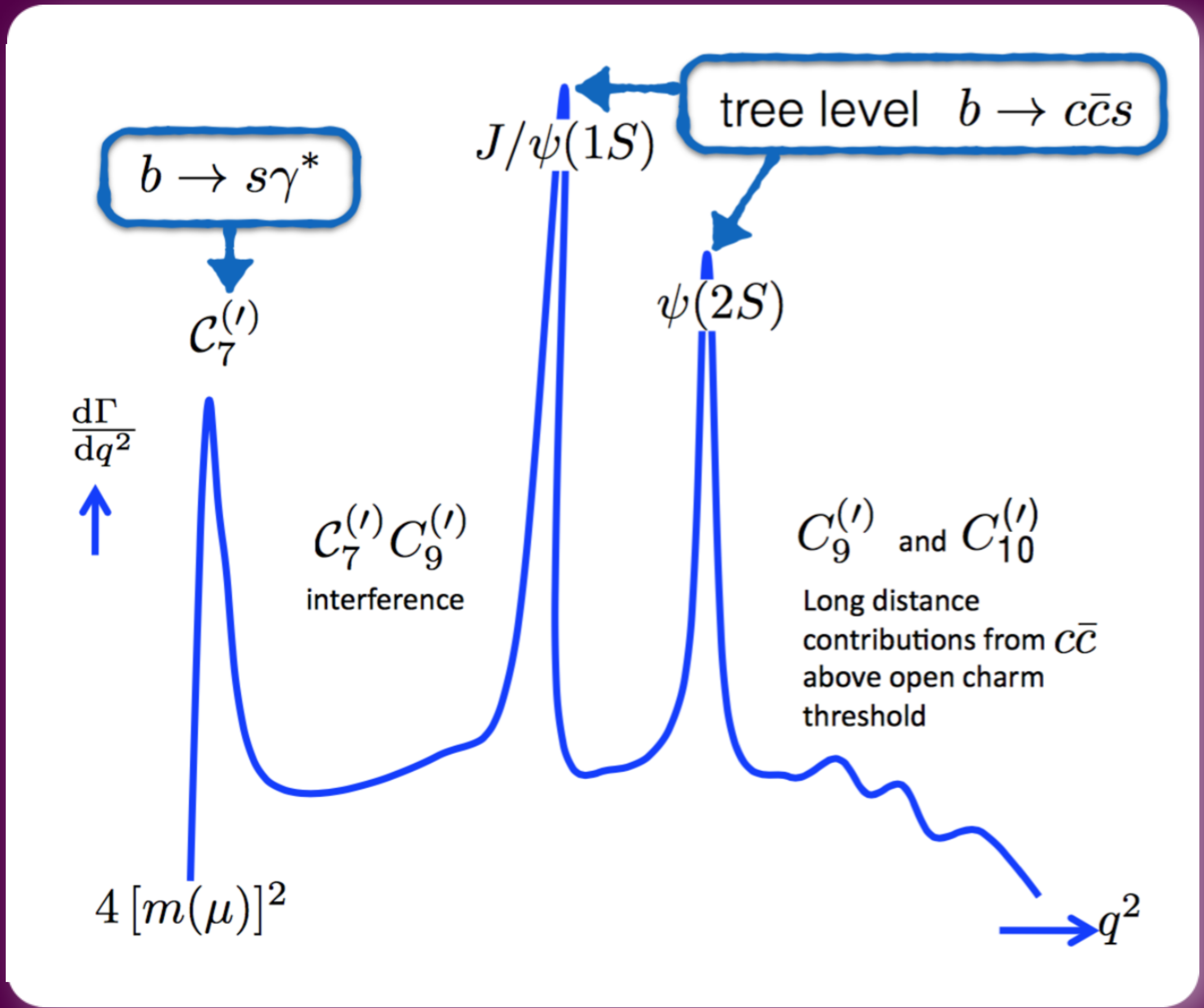
A factor of ~10^5 from SM for electrons

Semileptonic

$$B_{(s)} \to H\ell^+\ell^-$$

Medium rare: $\mathscr{B} \sim 10^{-7}$



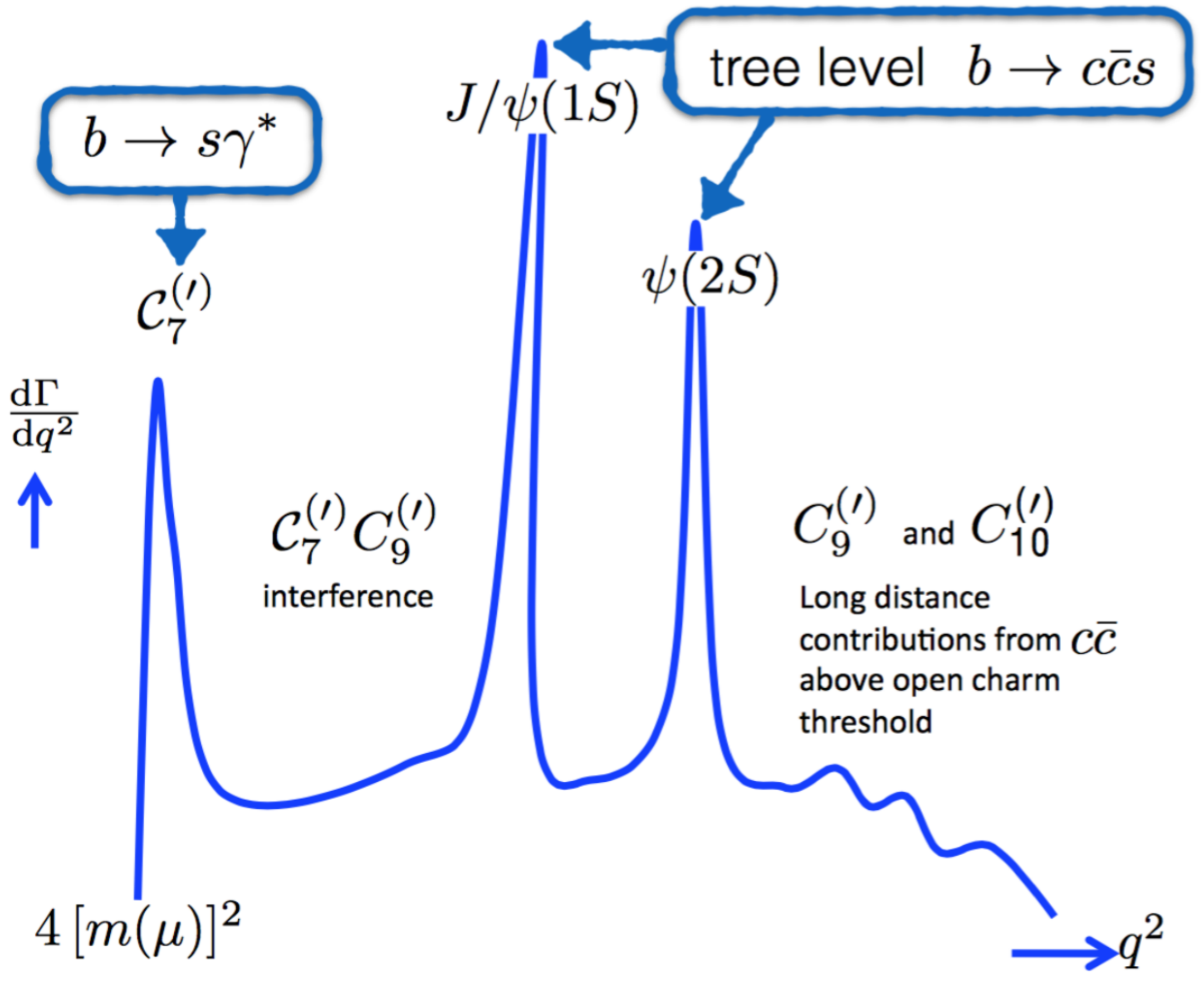


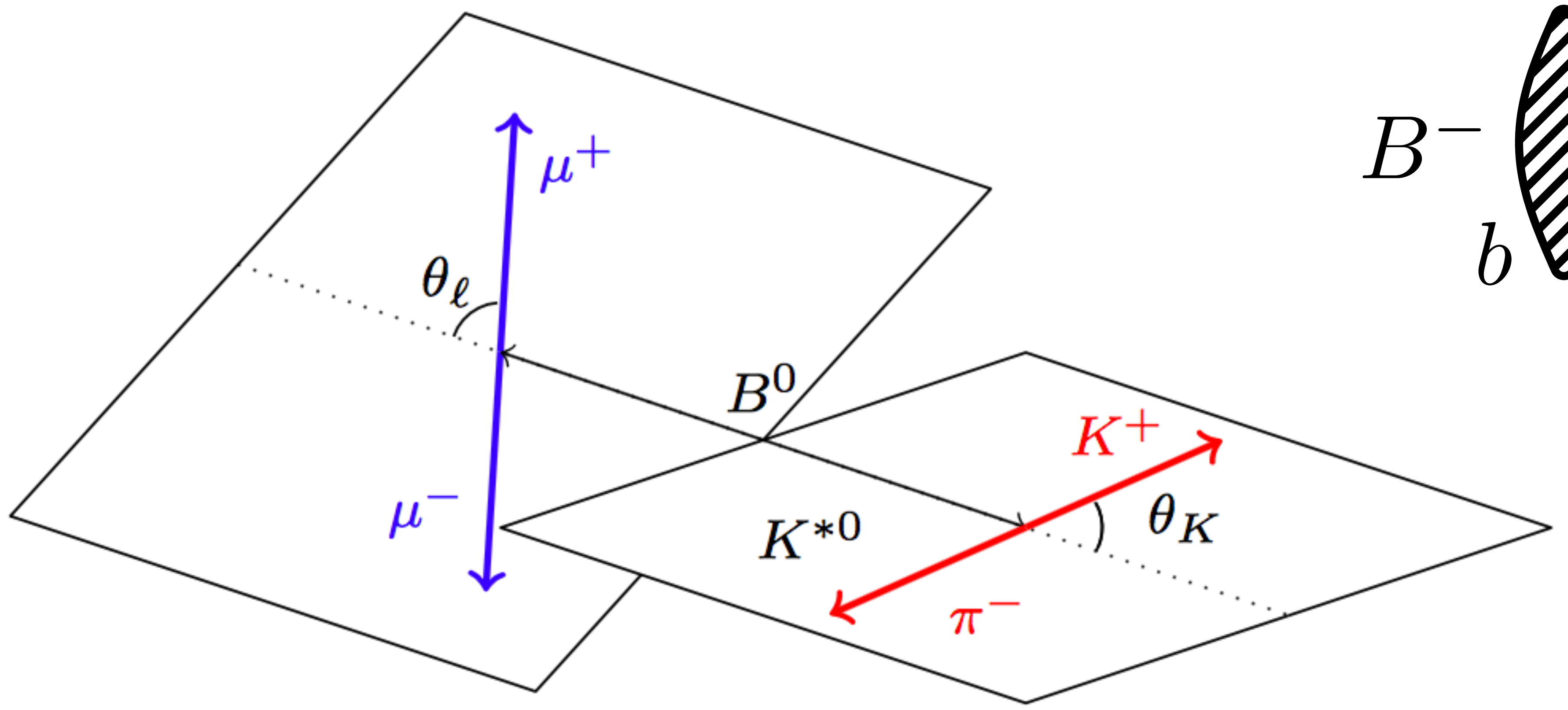
$$q^2 \equiv m\left(\ell^+\ell^-\right)$$

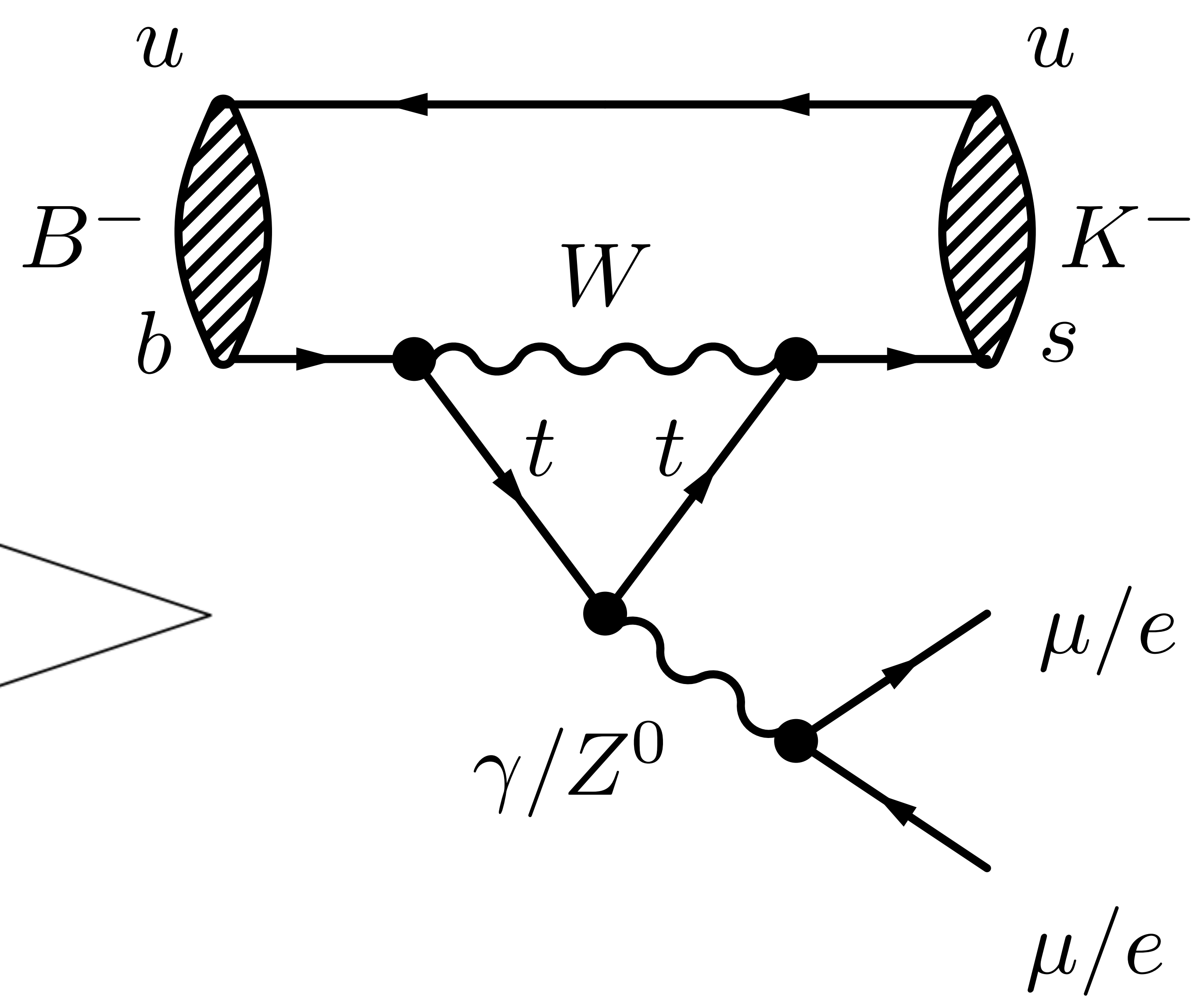
$\sim b \to s\ell^+\ell^-$ transitions can also be studied in semileptonic decays

- ➡ Not as suppressed, but **still rare with BF ~ 10^{-7}**

Clipped from Mick Mulder







Branching fractions

Simpler for LHC (focus on μ), but large theory uncertainties

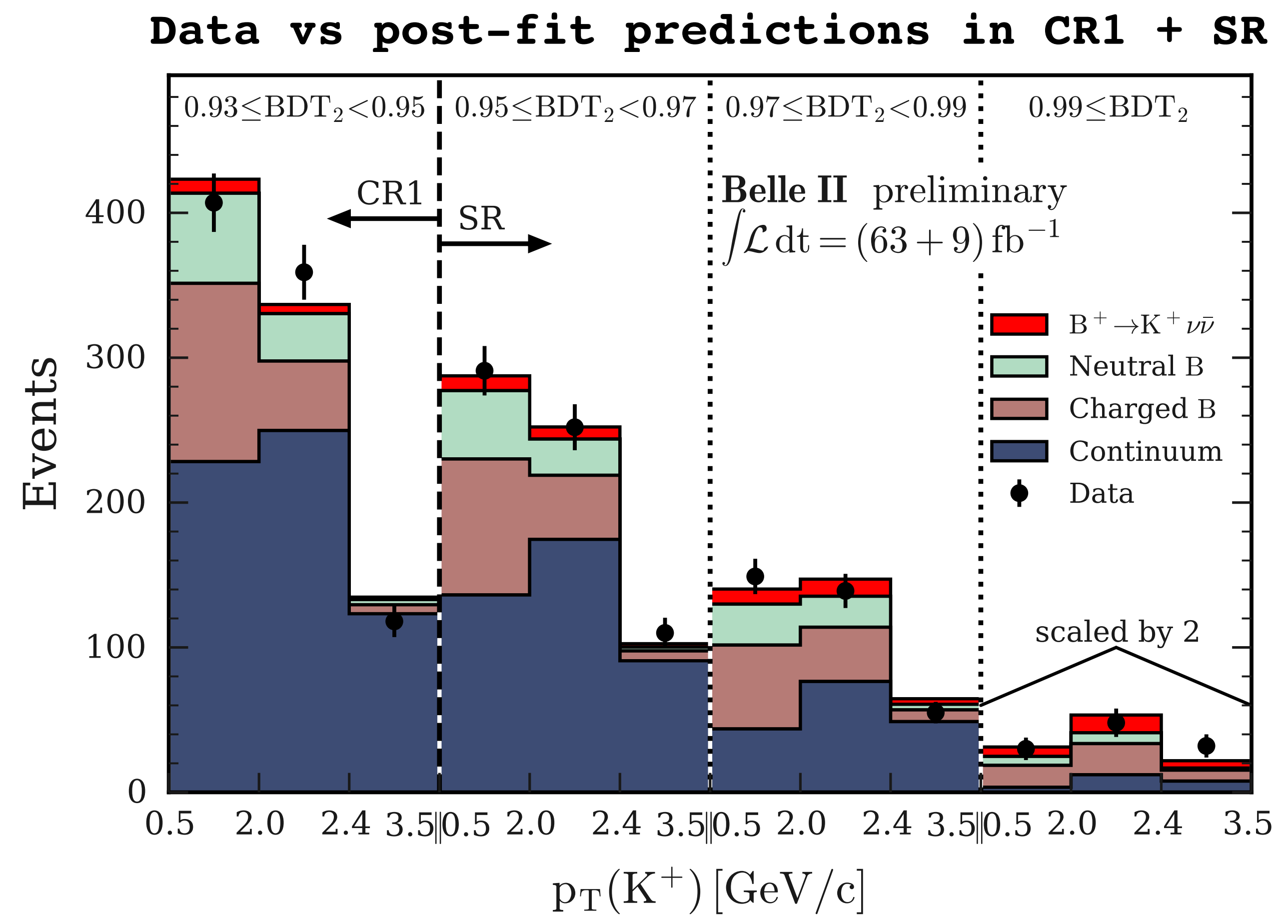
Angular observables

Minimal FF uncertainties, though sensitive to charm loops

LFU ratios $\mathcal{R}_{H_s} = \dfrac{\mathcal{B}(H_b \to H_s\mu\mu)}{\mathcal{B}(H_b \to H_s ee)}$

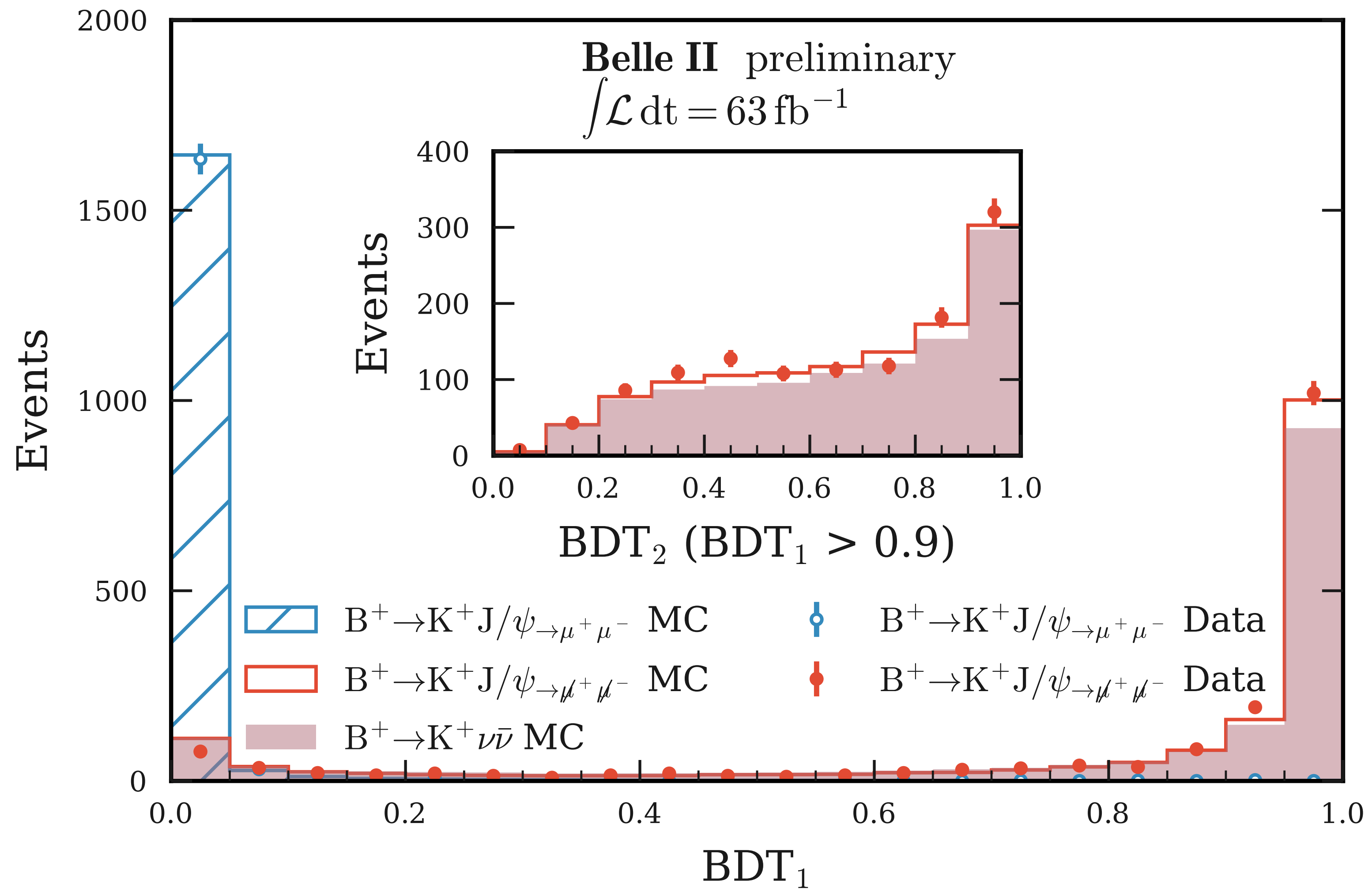
Theory uncertainty of ~1%, but electrons harder at the LHC

- **$B \to K^{(*)}\nu\bar{\nu}$ only accessible** at the **B-factories**
  - ➡ $b \to s\nu\bar{\nu}$ transition, rate enhanced by 3 neutrino flavors
- **Belle II** already **achieving milestones**
  - ➡ **Highest instantaneous lumi.** ever (2.4×10^{34} cm^{-2} s^{-1}), **recorded 100+ fb^{-1}**
- **Inclusive B$_{tag}$ reco** first selecting B$_{sig}$
  - ➡ **10x more efficient** than semileptonic tagging

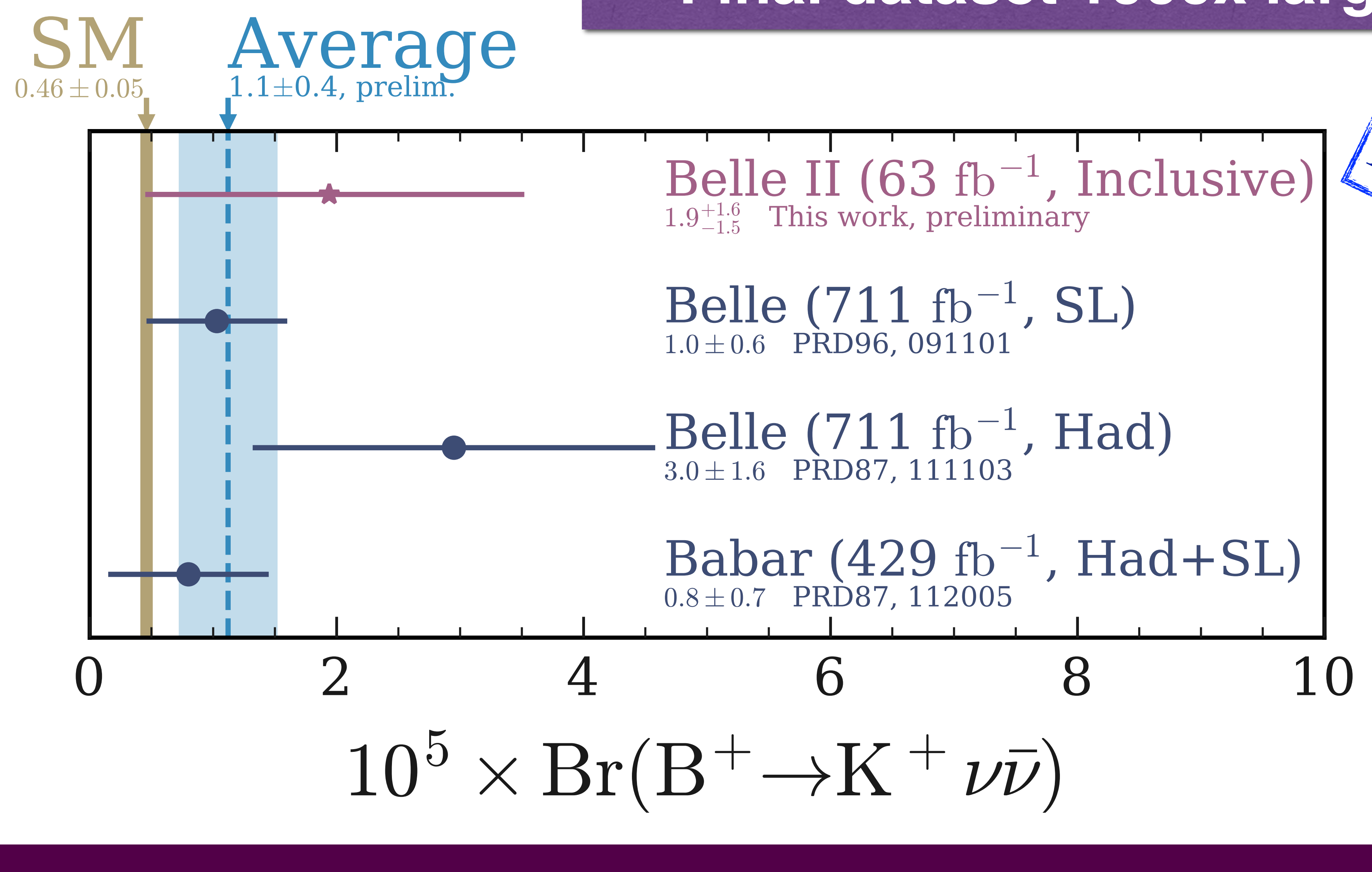


Filippo Dattola, Moriond EW 2021

Competitive with **10x less data!**
Final dataset 1000x larger



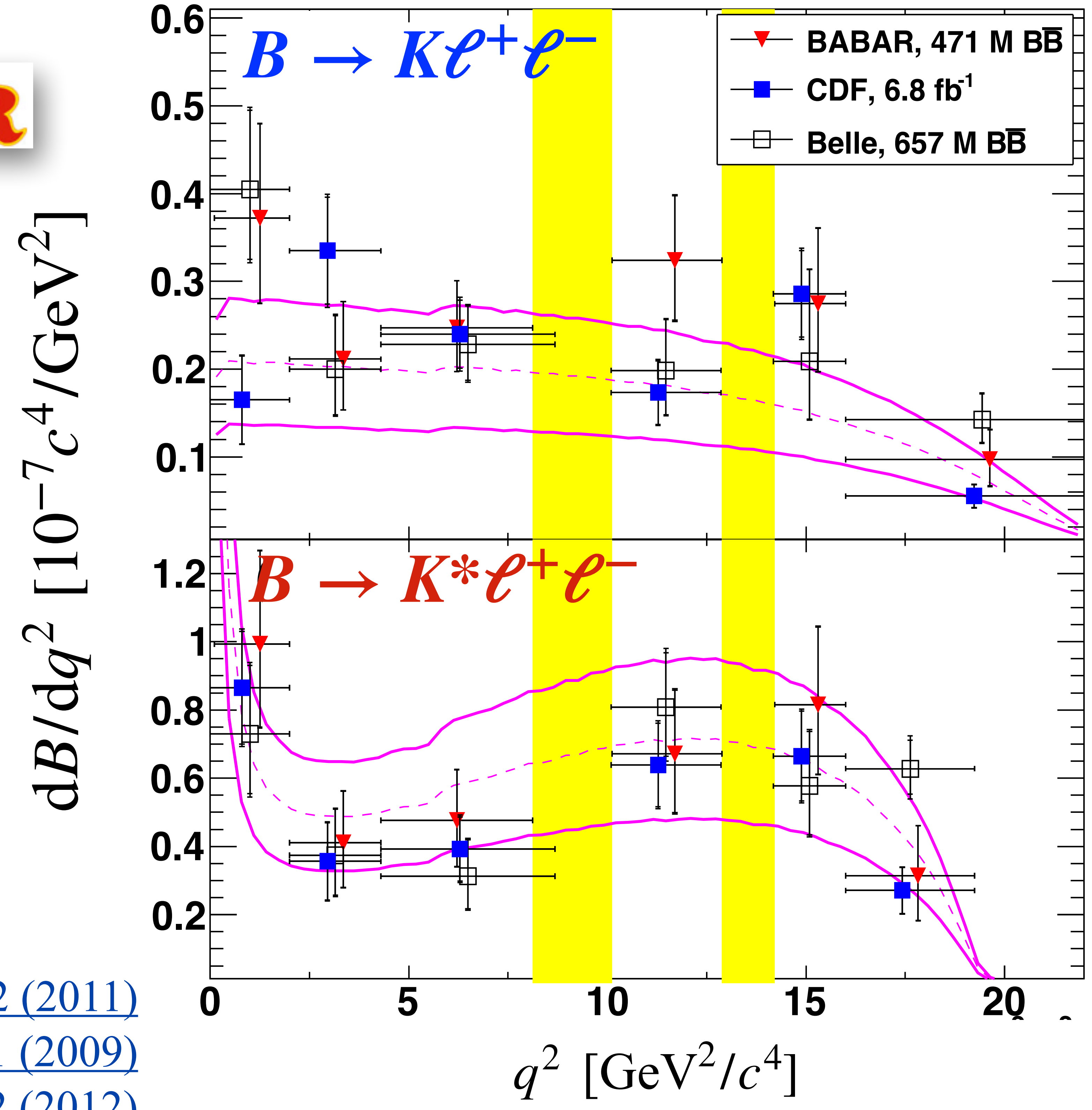
Validation with
$B^+ \to J/\psi\left(\to \mu^+\mu^-\right) K^+$
ignoring the muons,
reweighting K$^+$ kinematics



Fresh!

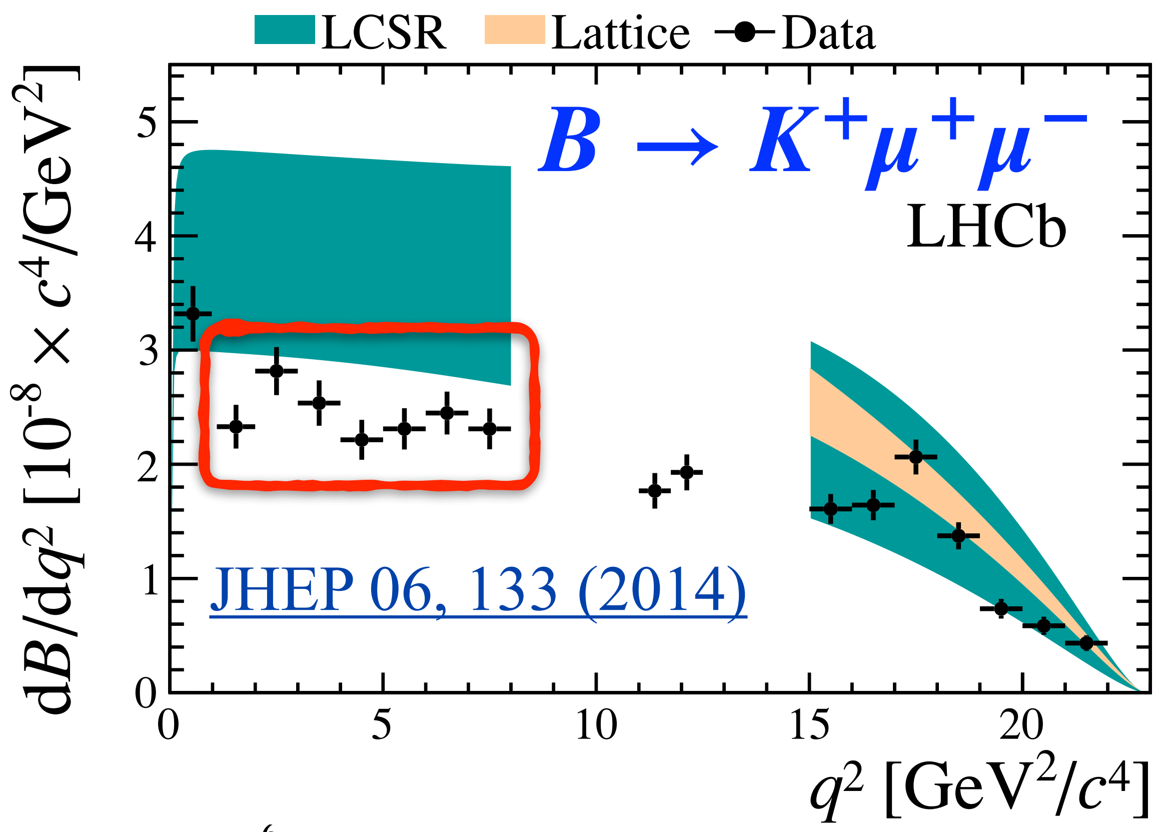
Differential BF rates

- **First measurements** of $B \to K^{(*)}\ell\ell$ at **Tevatron** and the **B-factories**
  - ➡ Consistent with expectations though **large uncertainties**

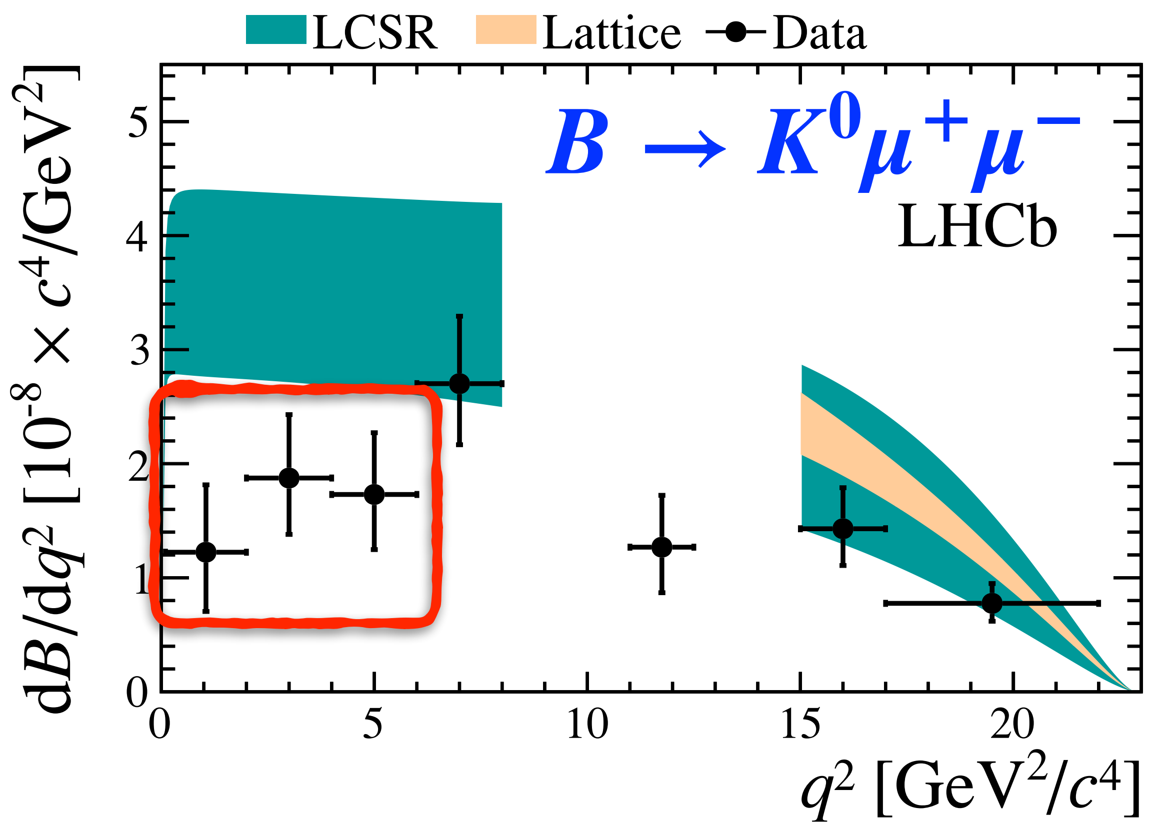


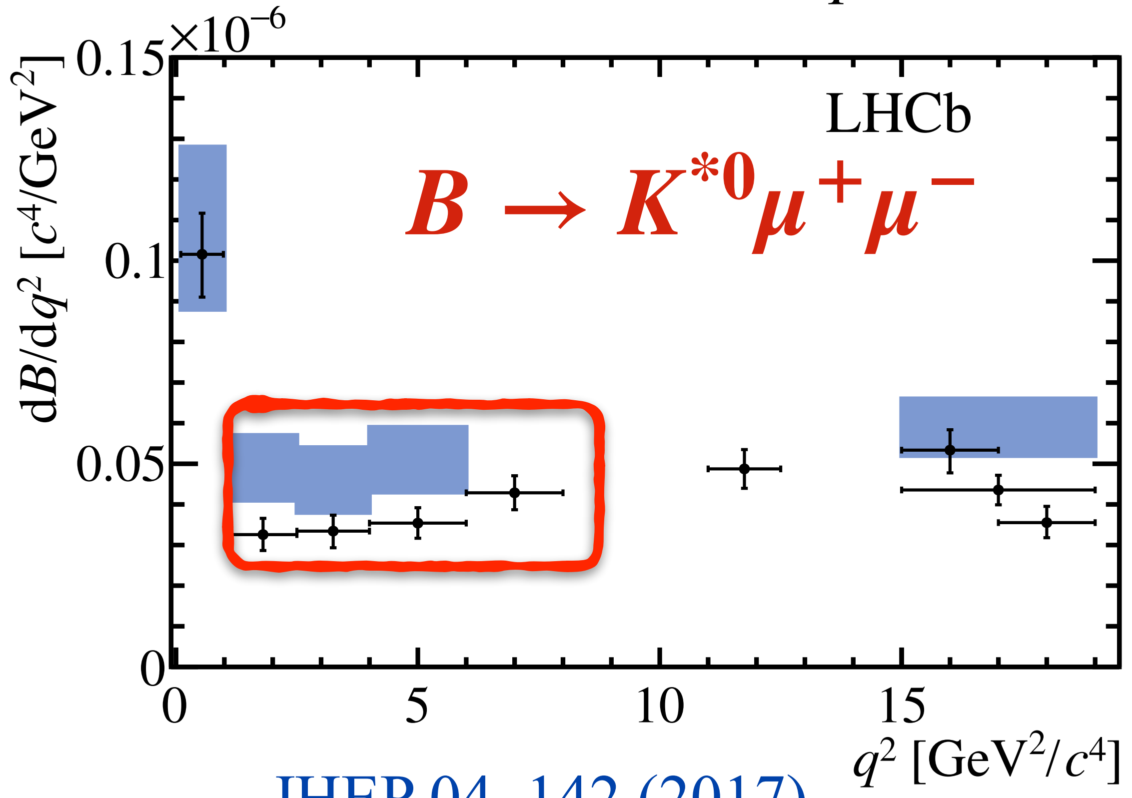
PRL 107, 201802 (2011)
PRL 103, 171801 (2009)
PRD 86, 032012 (2012)

LHCb measurements with muons below SM at low q²

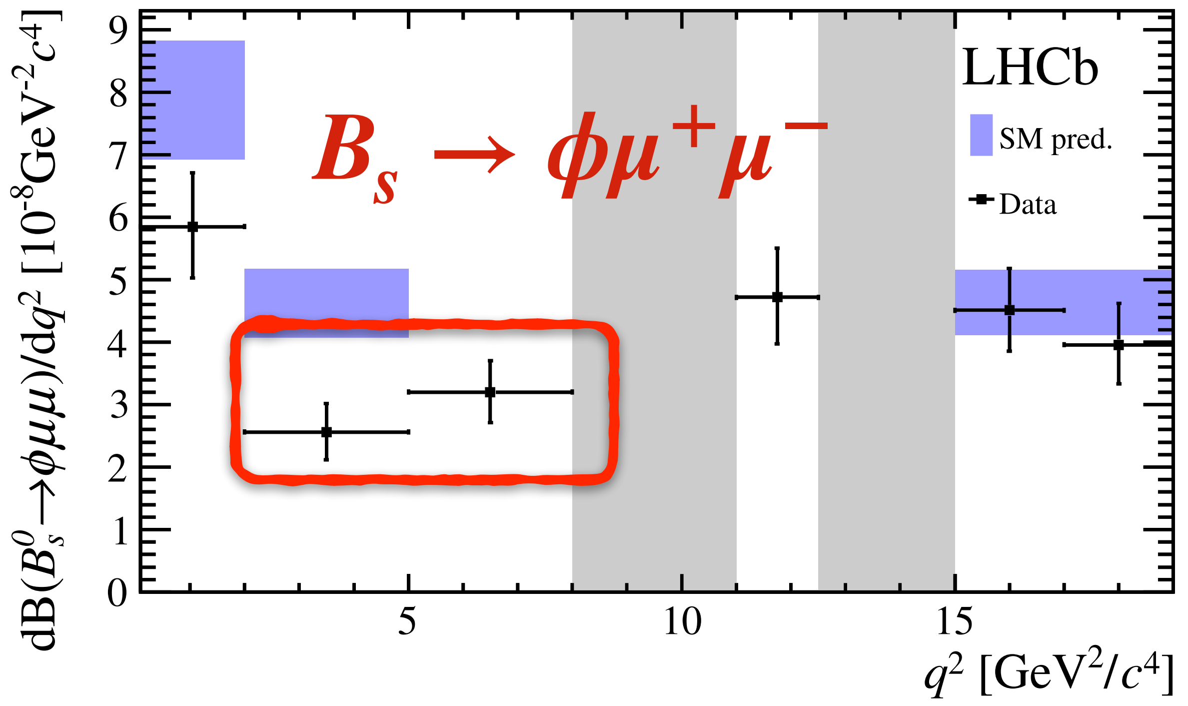


JHEP 06, 133 (2014)



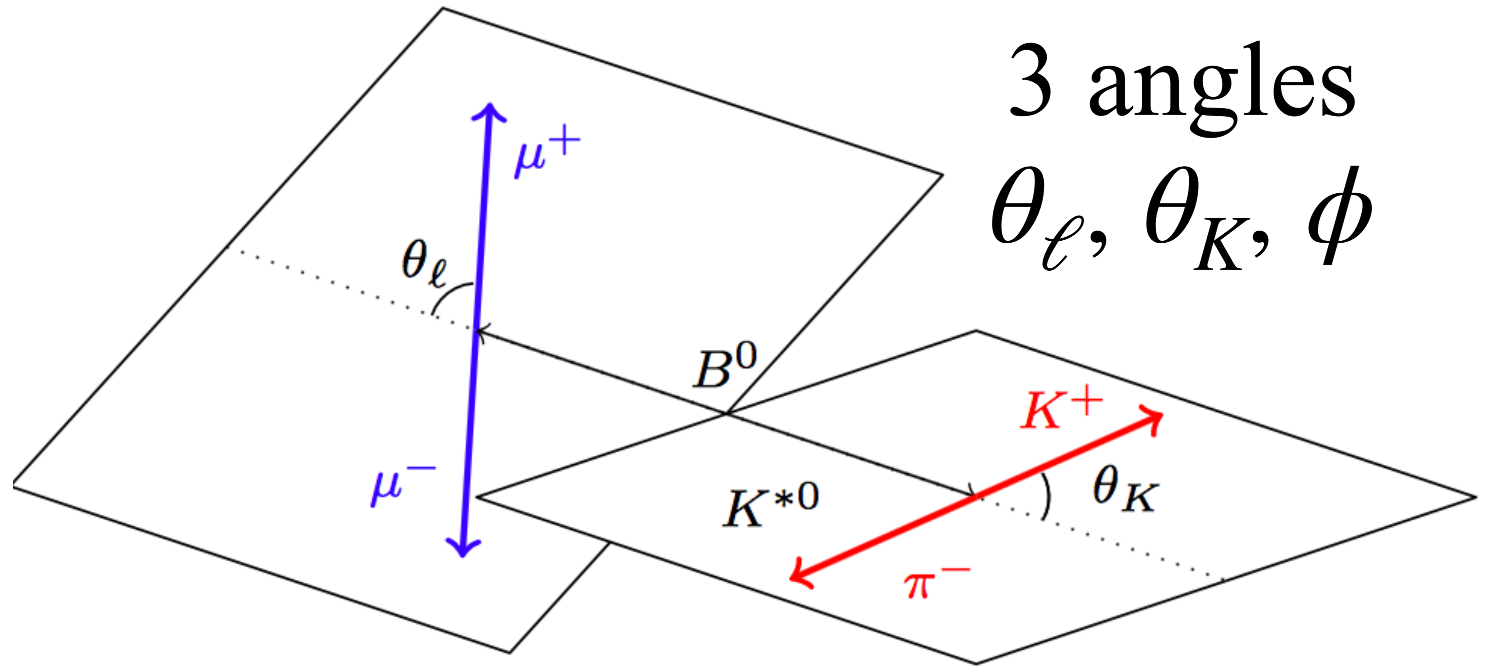


JHEP 04, 142 (2017)



JHEP 09, 179 (2015)

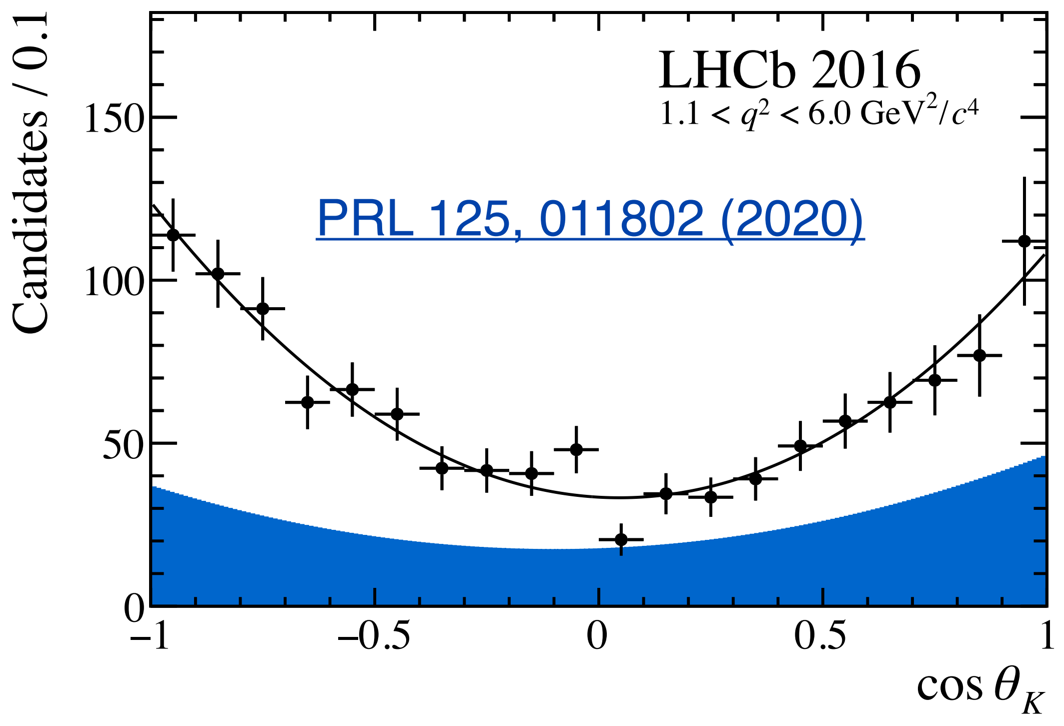
Angular observables in $B \to K^*\ell\ell$

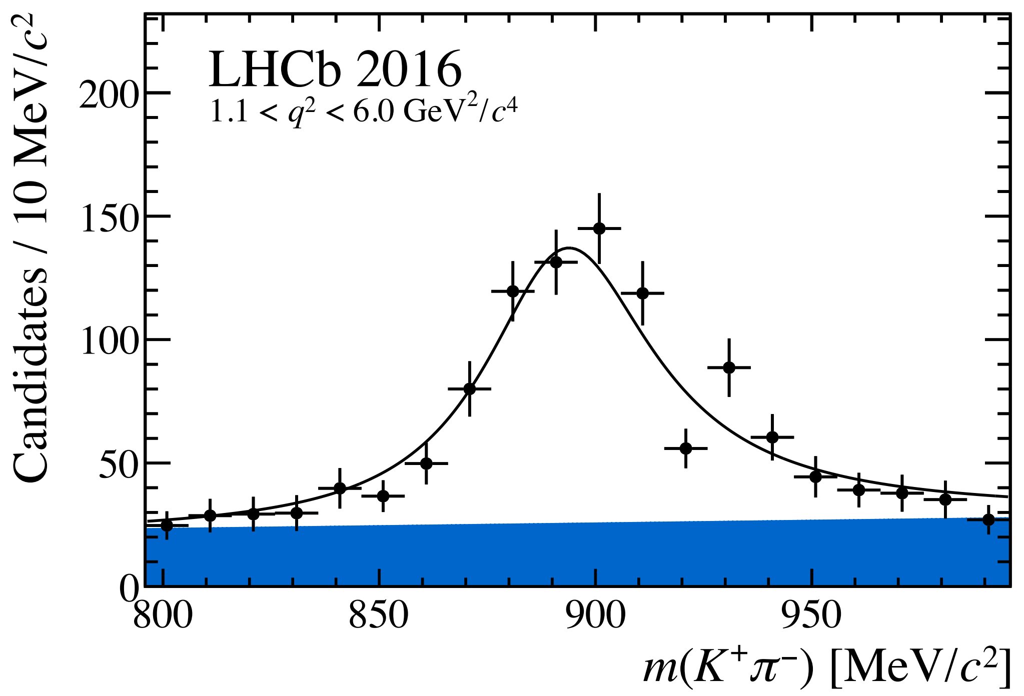


3 angles
$\theta_\ell, \theta_K, \phi$

$$\frac{1}{\Gamma}\frac{d^3(\Gamma+\bar{\Gamma})}{d\cos\theta_\ell\, d\cos\theta_K\, d\phi} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell$$
$$- F_L\cos^2\theta_K\cos 2\theta_\ell +$$
$$S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi +$$
$$S_5\sin 2\theta_K\sin\theta_\ell\cos\phi + S_6^s\sin^2\theta_K\cos\theta_\ell +$$
$$S_7\sin 2\theta_K\sin\theta_\ell\sin\phi +$$
$$S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$

P-wave



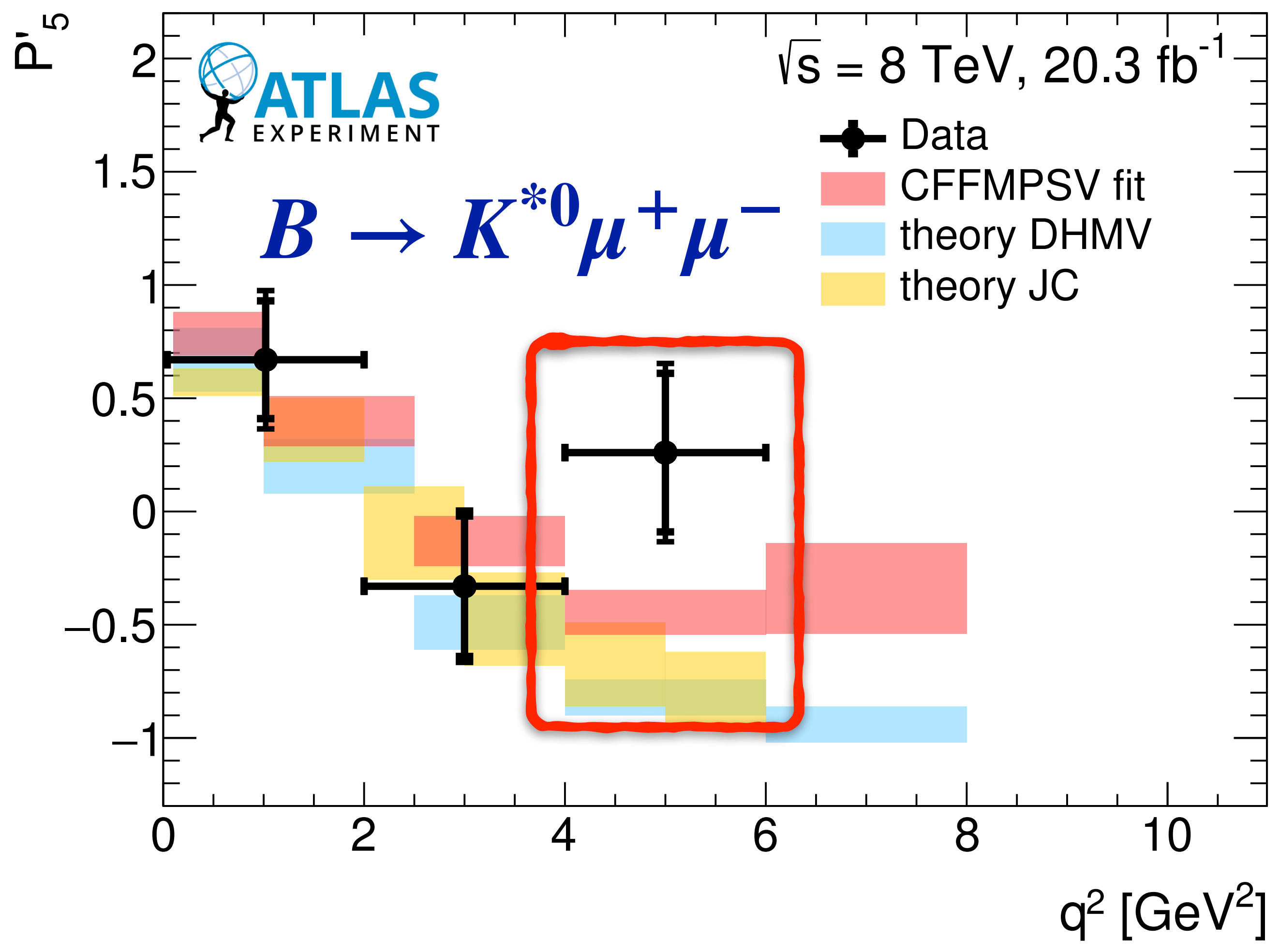


- **Optimized** $P'_{4,5,8} = \dfrac{S_{4,5,8}}{\sqrt{F_L(1-F_L)}}$ **observables** make a clever use of the symmetries to cancel soft FF at LO
  JHEP 1301, 048 (2013)
- Also, **LFU** $Q_i = P_i^\mu - P_i^e$ **observables** independent of long distance charm contributions JHEP 10, 075 (2016)

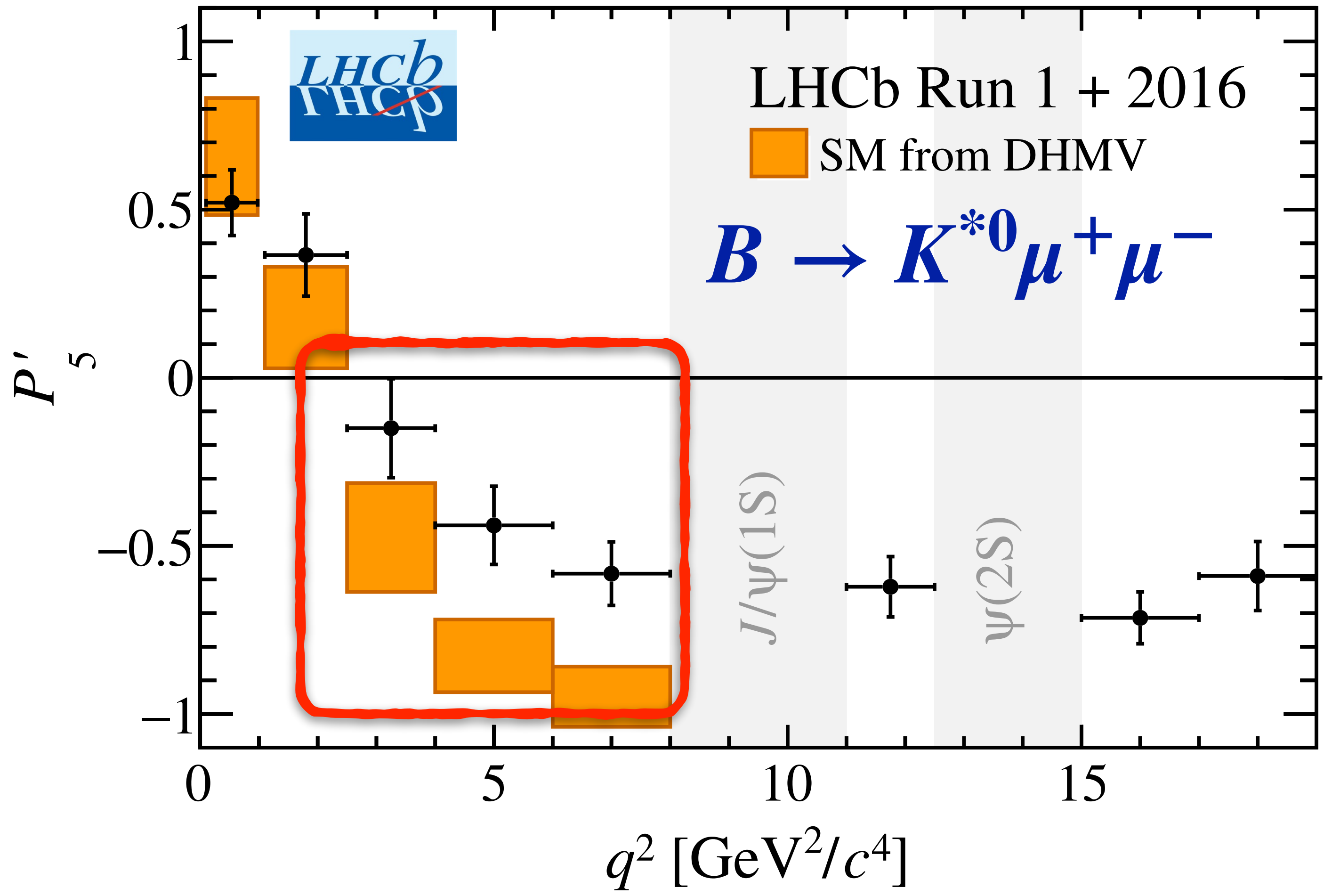
P'_5 and $Q_{4,5}$ in $B \to K^*\ell\ell$

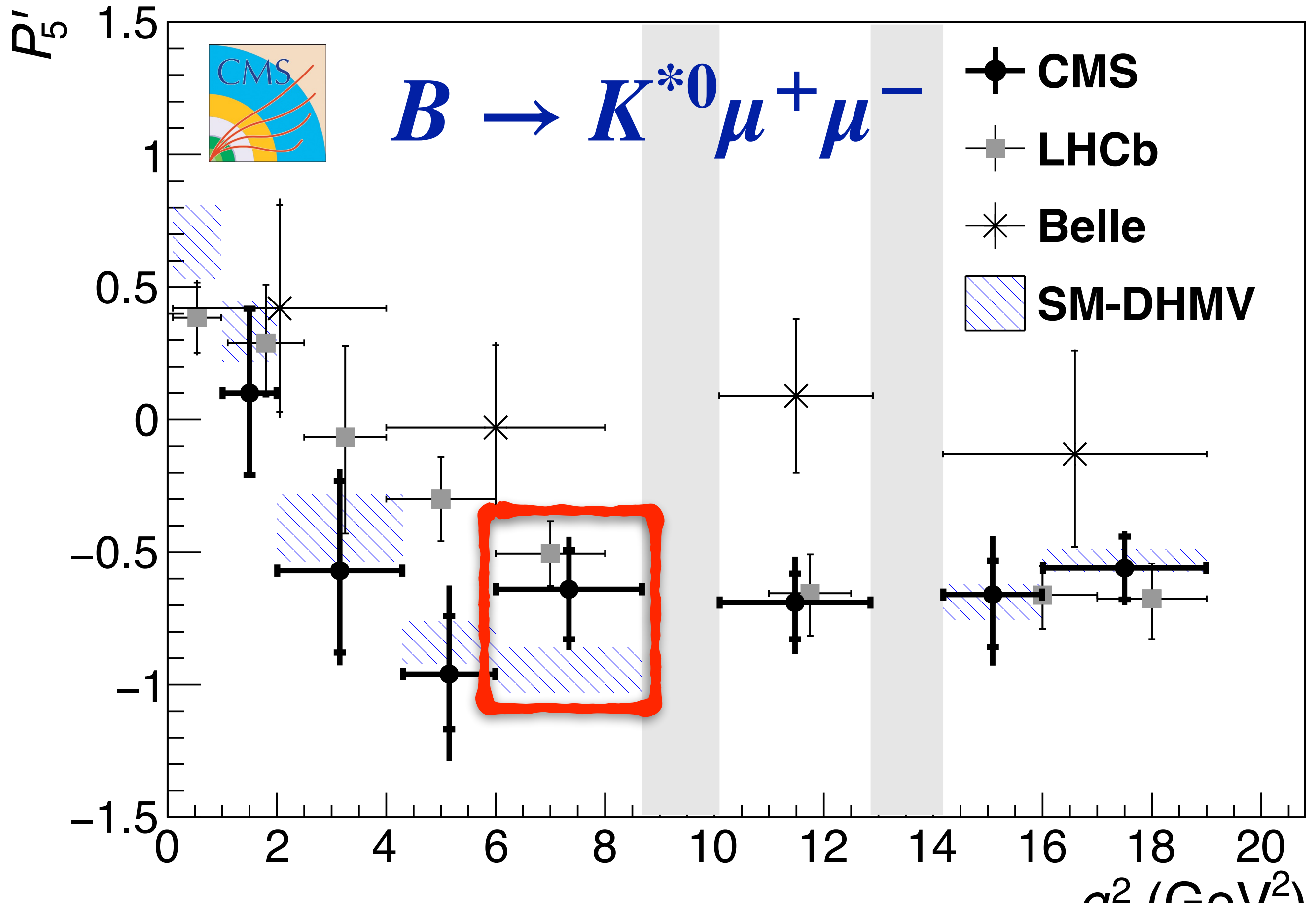
P'_5

JHEP 10, 047 (2018)

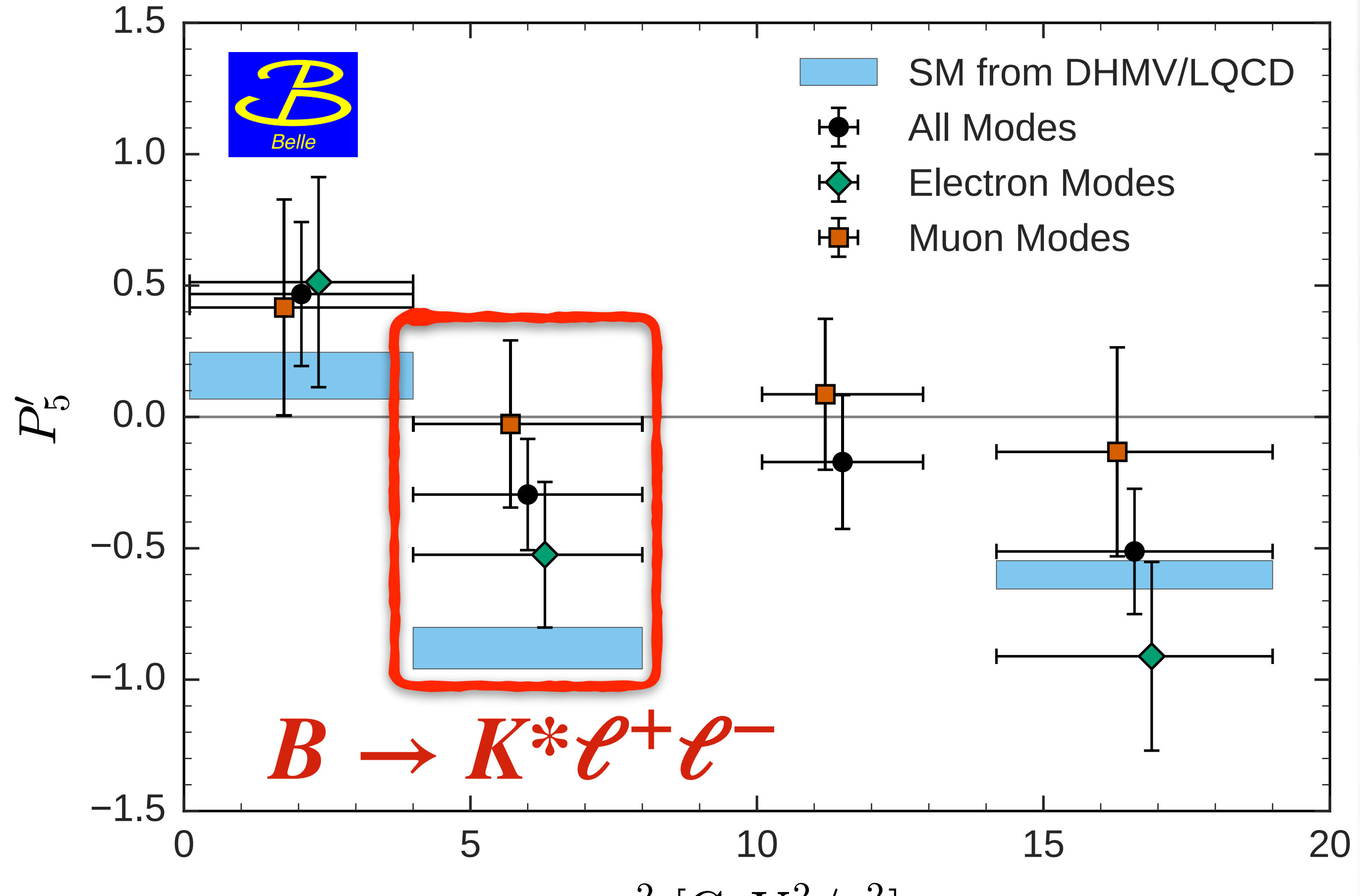


PRL 125, 011802 (2020)



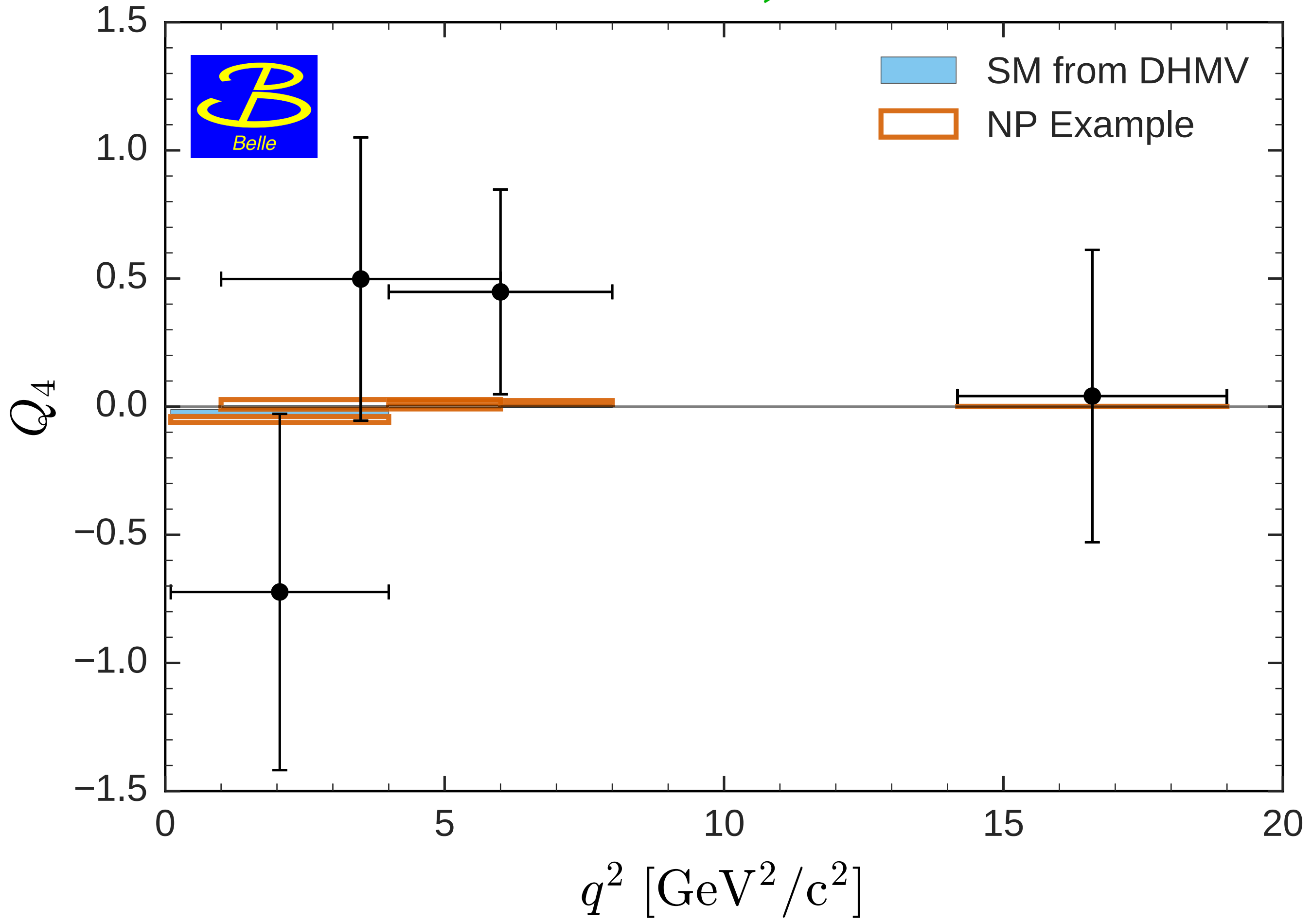


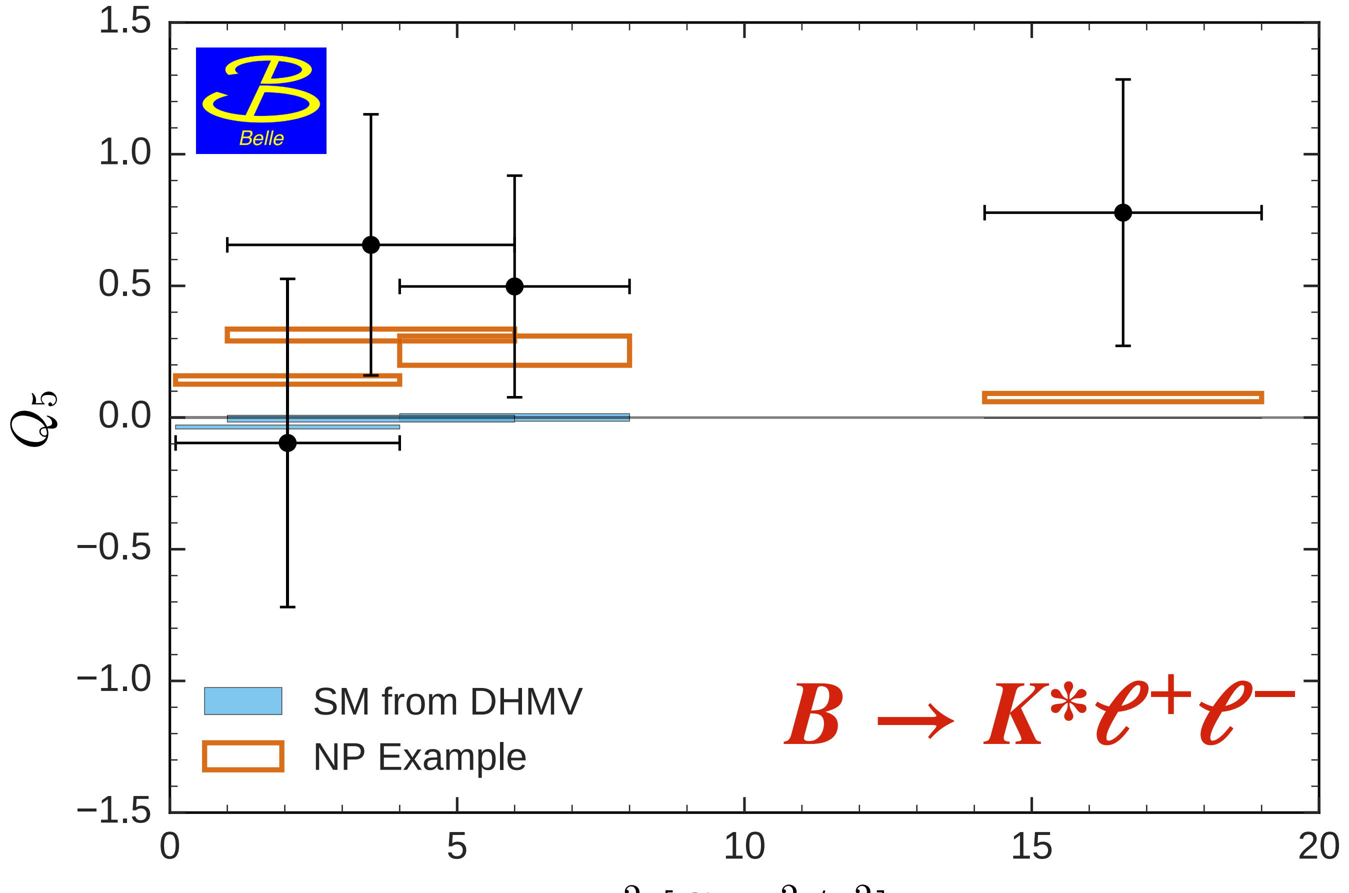
PLB 781, 517 (2018)



PRL 118, 111801 (2017)

$Q_{4,5} = P'^{\mu}_{4,5} - P'^{e}_{4,5}$





PRL 118, 111801 (2017)

Possible discrepancies at **low q²**, driven by **muons**

- Measured all isospin variants for $\mathscr{R}_{K^{(*)}} = \dfrac{\mathscr{B}(B \to K^{(*)}\mu\mu)}{\mathscr{B}(B \to K^{(*)}ee)}$
  - ➡ $K^+, K_S^0, K^{*+}\left(\to K^+\pi^0, K_S^0\pi^+\right), K^{*0}\left(\to K^+\pi^-, K_S^0\pi^0\right)$
- Fit $M_{bc} = \sqrt{E^2_{\text{beam}} - p_B^2}$
  - ➡ $\mathscr{R}_K$ also fits NN and $\Delta E = E_B - E_{\text{beam}}$, $\mathscr{R}_{K^*}$ cuts on them
- **Similar mass resolution for μ and e**
- **Powerful check** with $B \to J/\psi(\to \ell\ell)\, K^{(*)}$

$$r^K_{J/\psi} = \frac{\mathscr{B}\left[B \to K\, J/\psi(\to \mu\mu)\right]}{\mathscr{B}\left[B \to K\, J/\psi(\to ee)\right]} = 0.994 \pm 0.015$$

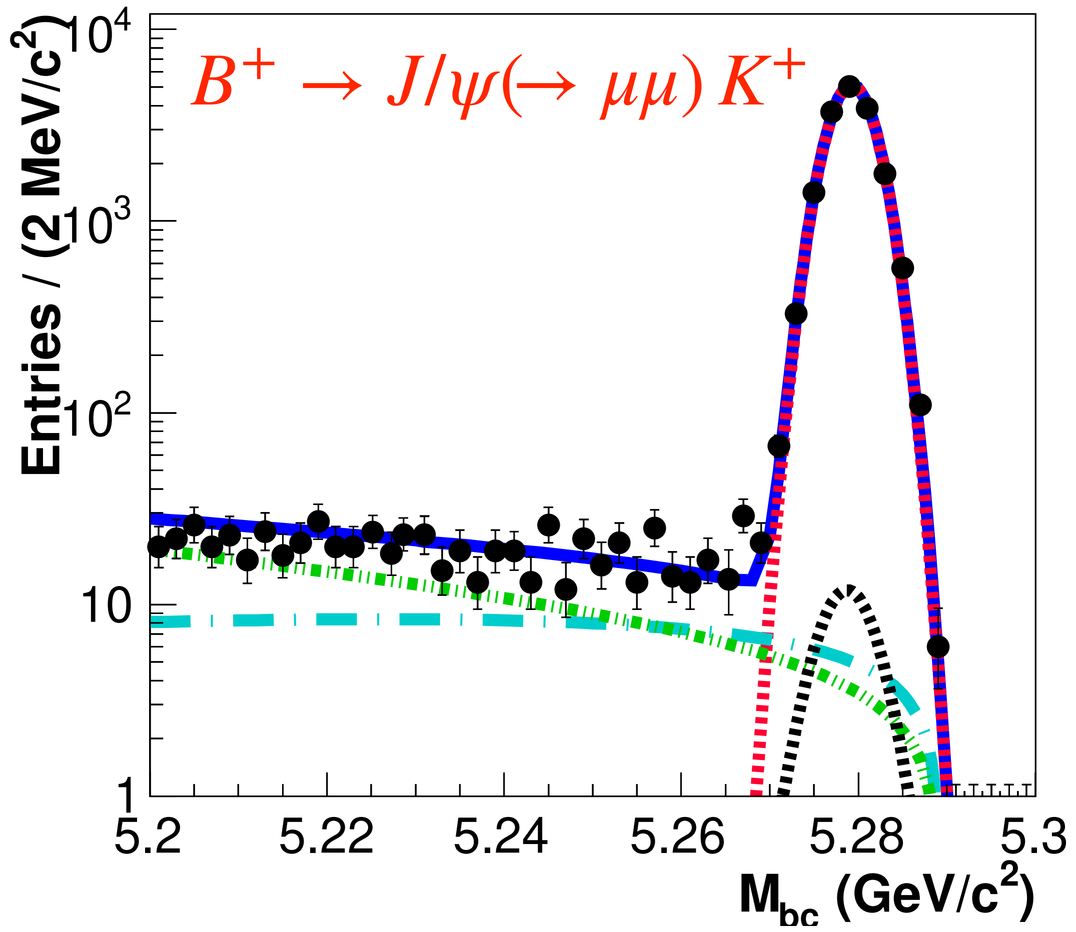
JHEP 03, 105 (2021)

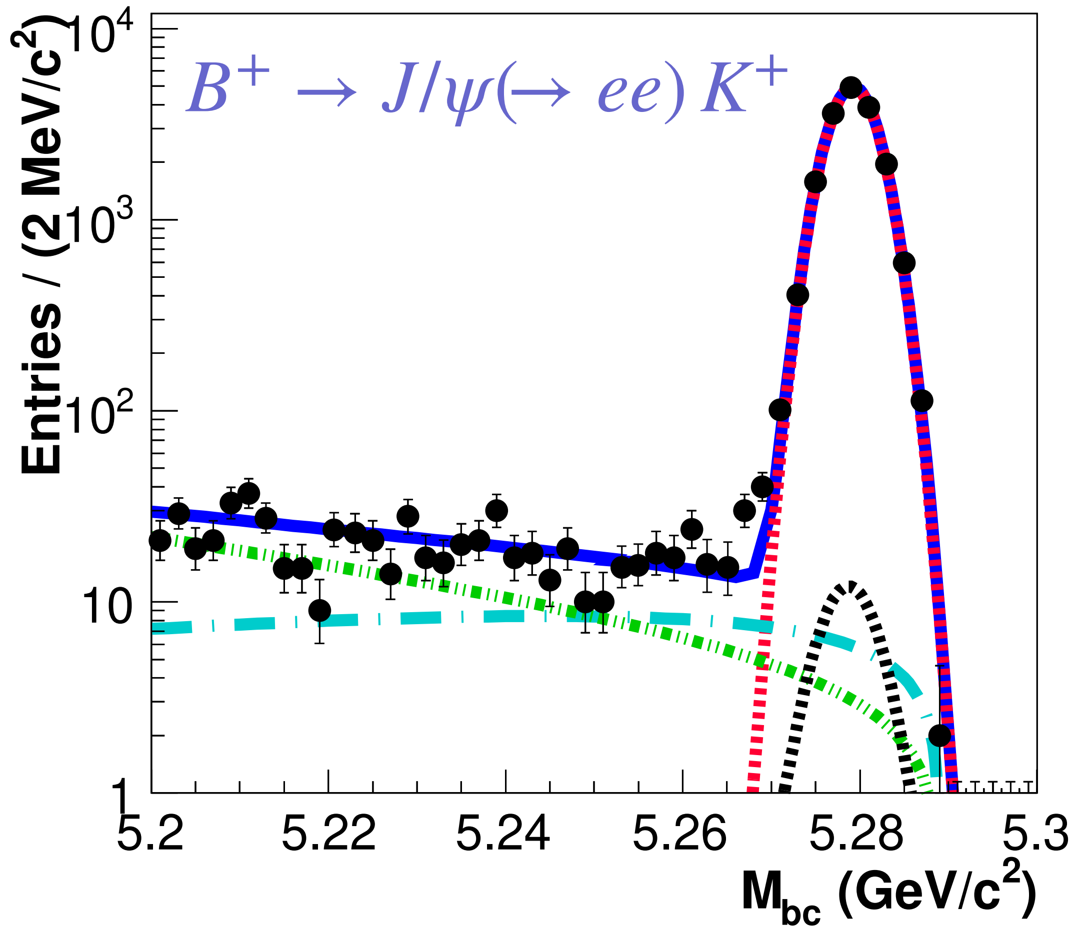
$$r^{K^*}_{J/\psi} = \frac{\mathscr{B}\left[B \to K^*\, J/\psi(\to \mu\mu)\right]}{\mathscr{B}\left[B \to K^*\, J/\psi(\to ee)\right]} = 1.015 \pm 0.045$$

arXiv:1904.02440

Aside: most precise $\mathscr{B}\left(B \to J/\psi K\right)$ in the world, just added to PDG

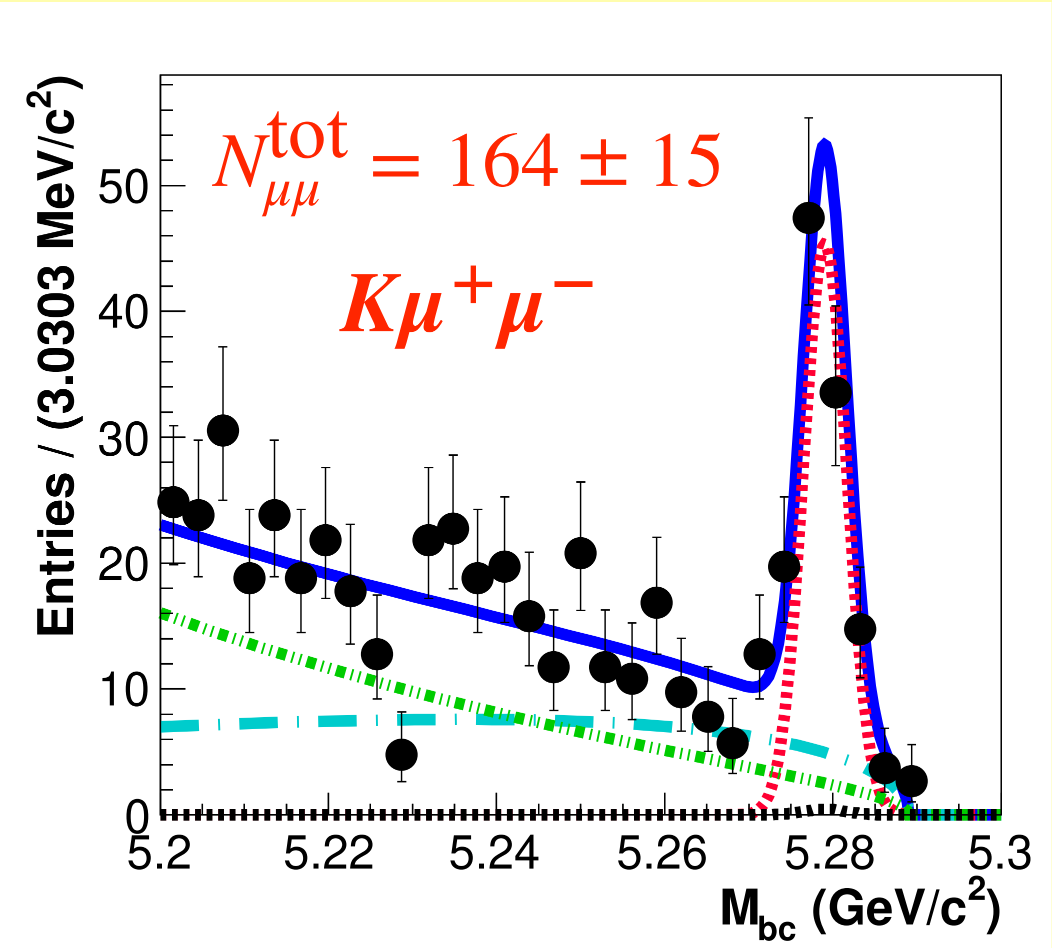
$$\mathscr{B}\left(B^+ \to J/\psi K^+\right) = \left(1.032 \pm 0.025\right) \times 10^{-3}$$
$$\mathscr{B}\left(B^0 \to J/\psi K^0\right) = (0.902 \pm 0.028) \times 10^{-3}$$

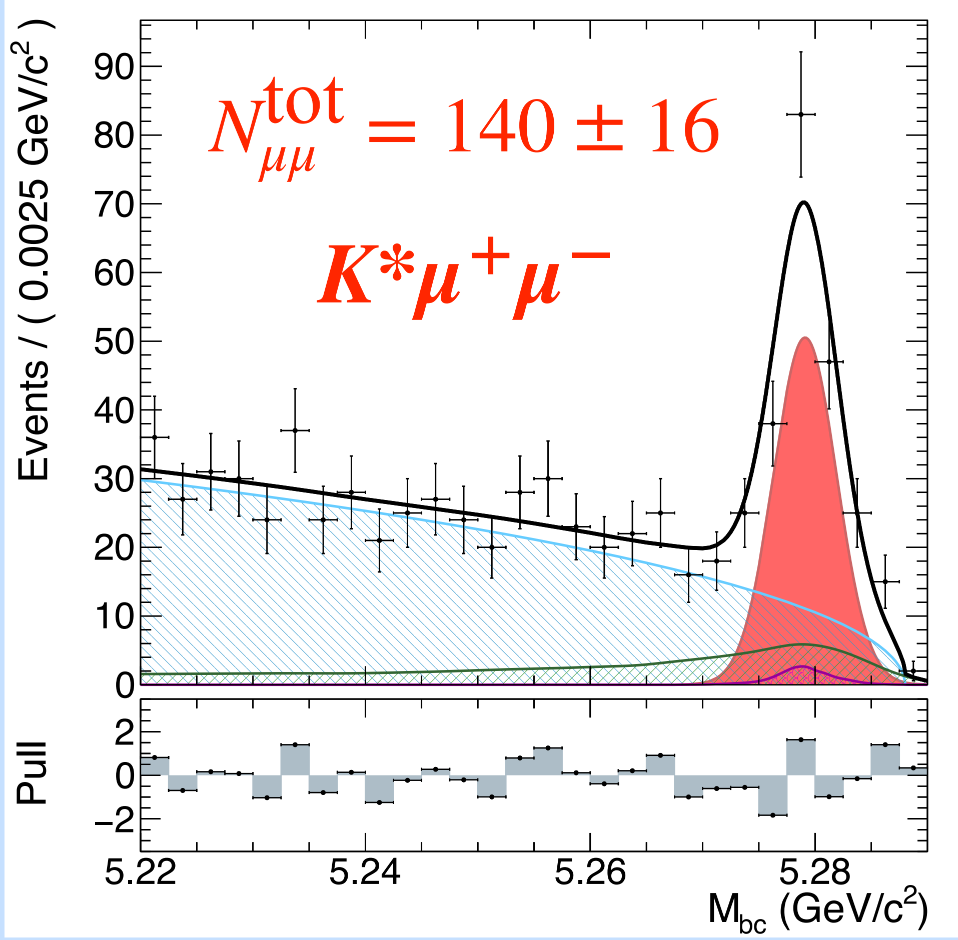




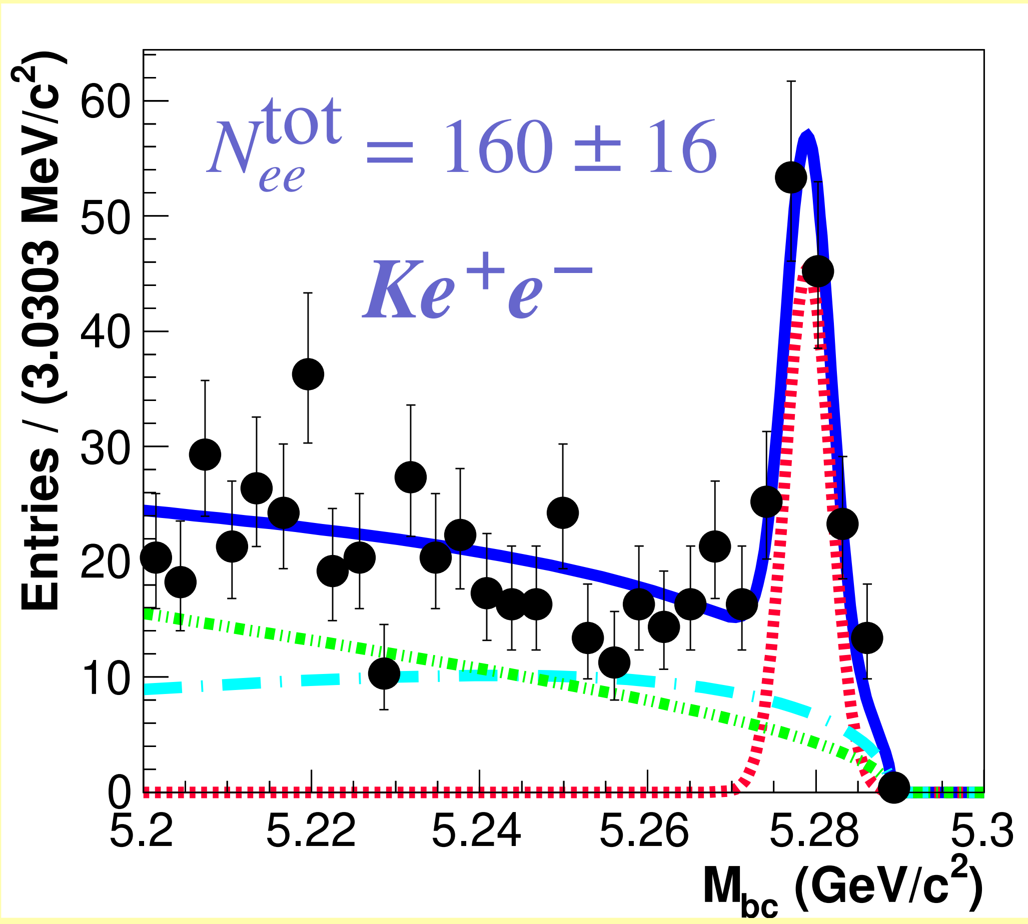
LFU $\mathcal{R}_{K^{(*)}}$ at Belle: results

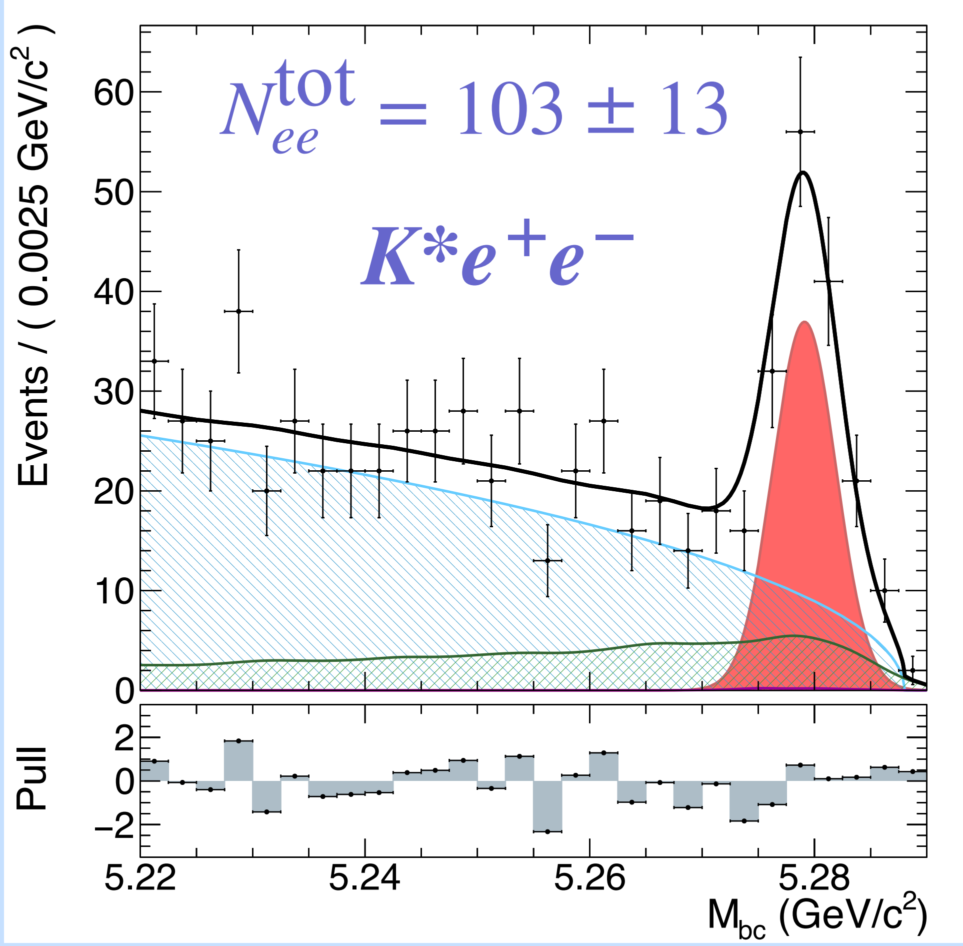
Muons





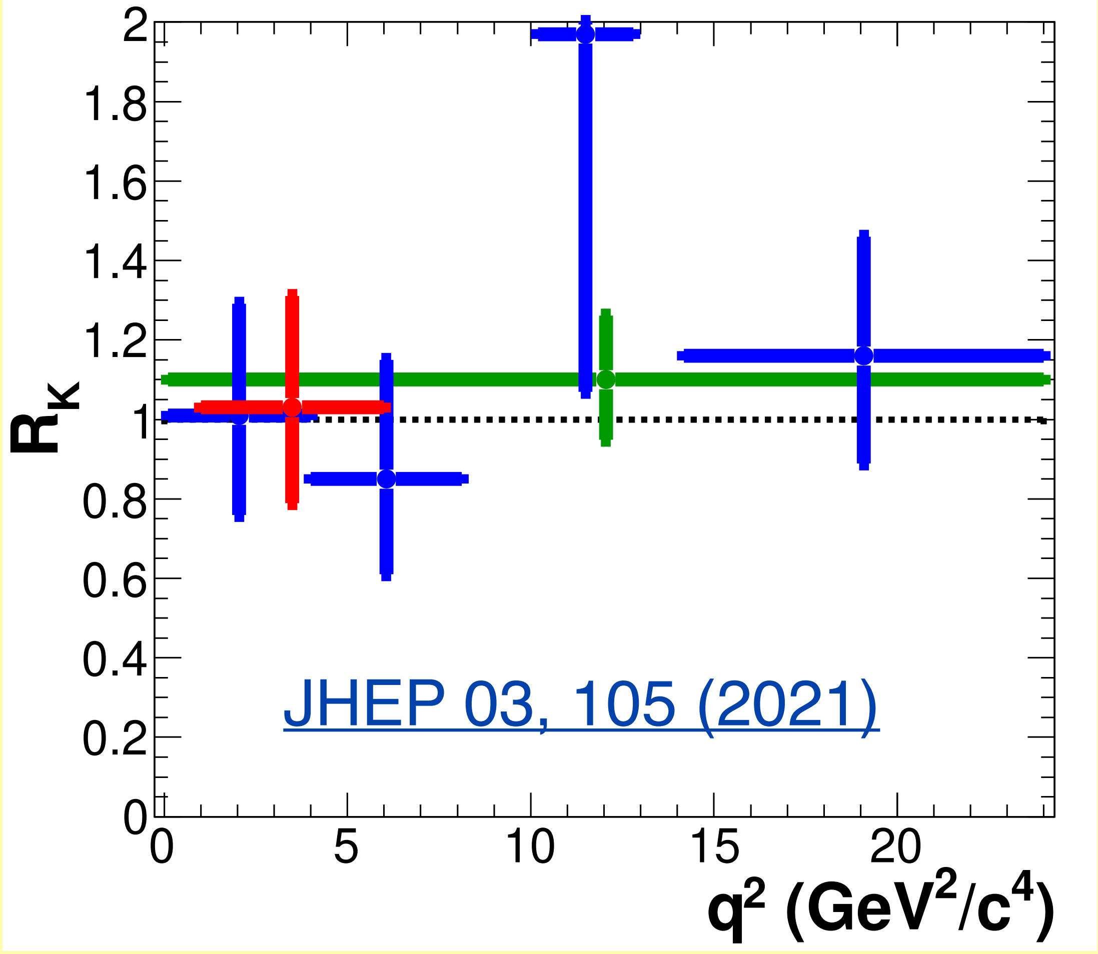
Electrons



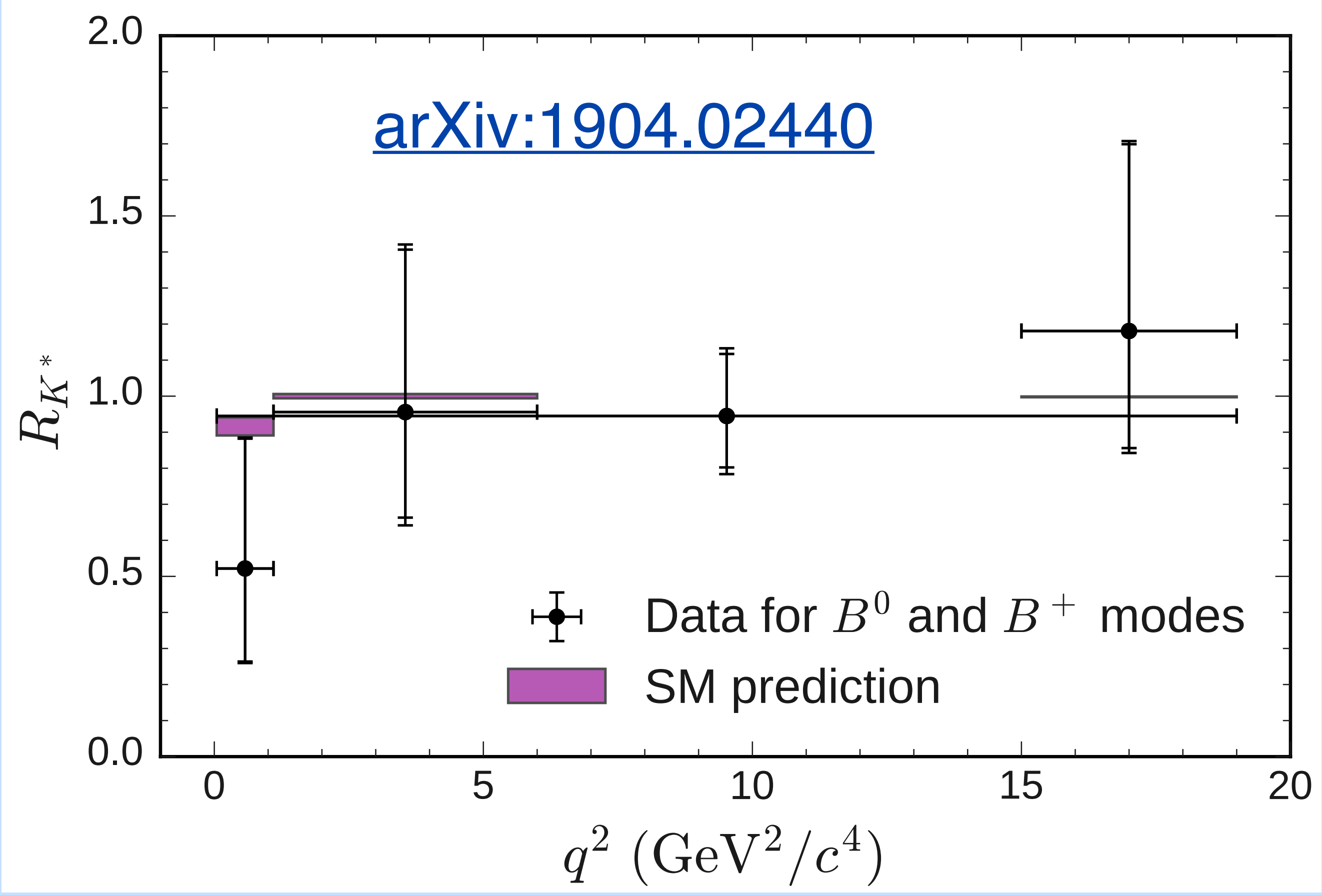


$\mathcal{R}_{K^{(*)}}$ with 100% of Belle's dataset: 711 fb^{-1}

Belle



Compatible with $\mathcal{R}_K^{SM} \approx 1$

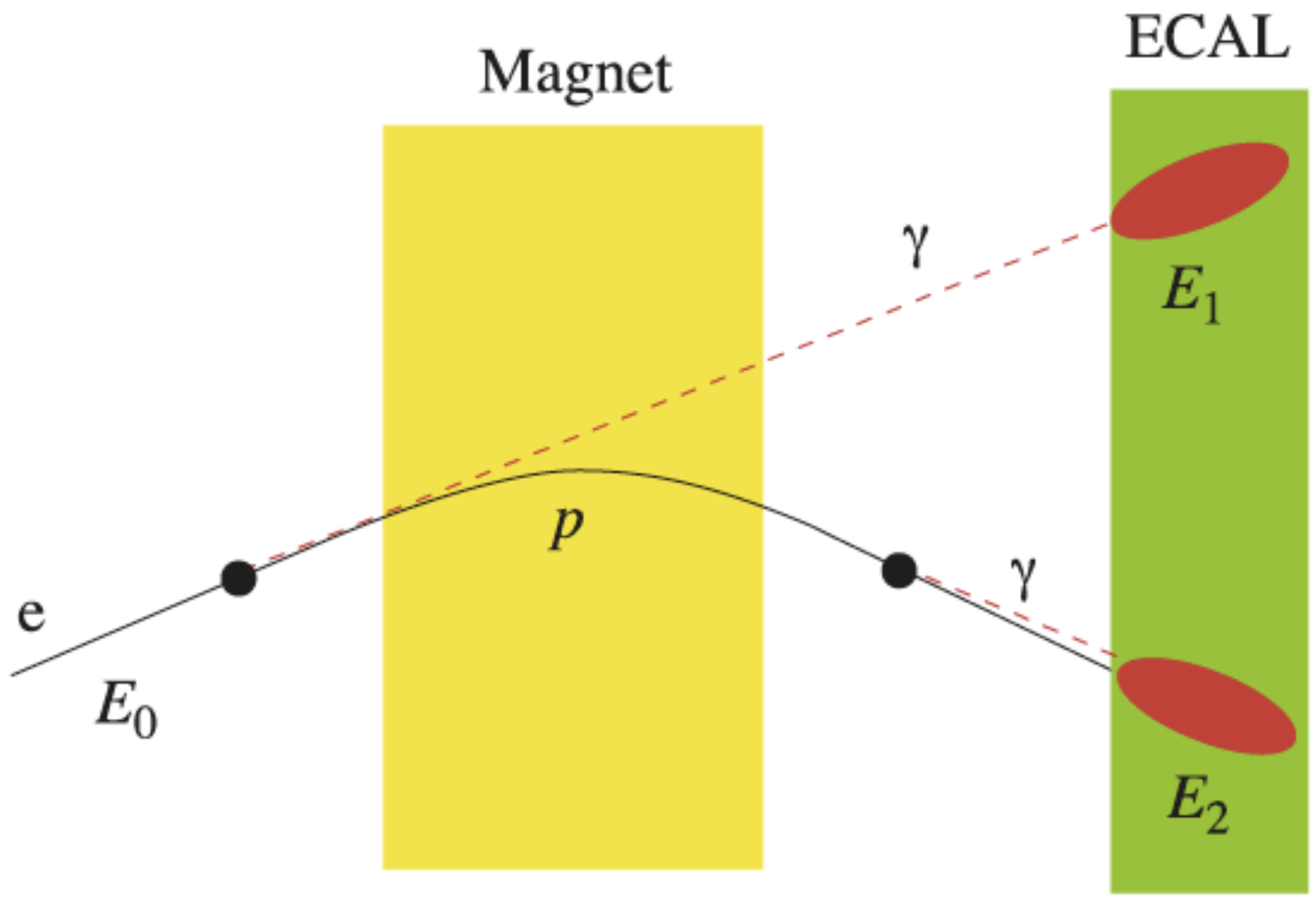


Compatible with $\mathcal{R}_{K^*}^{SM} \approx 1$

LFU $\mathcal{R}_{K^{(*)}}$ at LHCb

JHEP 08, 055 (2017) arXiv 2103.11769 Fresh!

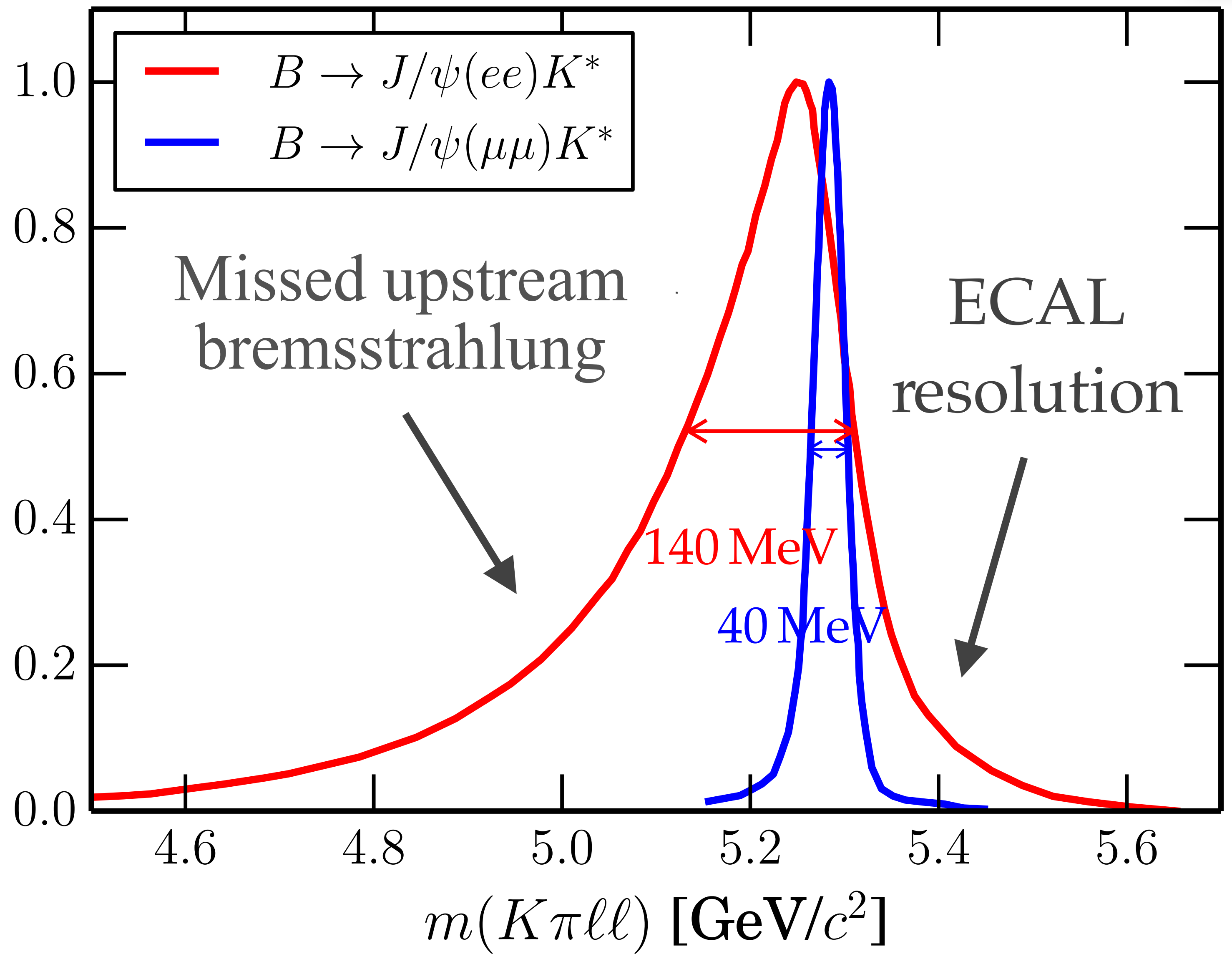
- Measurements of $\mathcal{R}_{K^{*0}}$ (3 fb^{-1}) and $\mathcal{R}_{K^+}$ (9 fb^{-1})
- At LHCb, **electrons** are **major challenge**



Algorithm to recover **upstream bremsstrahlung** when $E_\gamma > 75$ MeV

Downstream bremsstrahlung follows the track: easy to find

Unofficial from M. Borsato



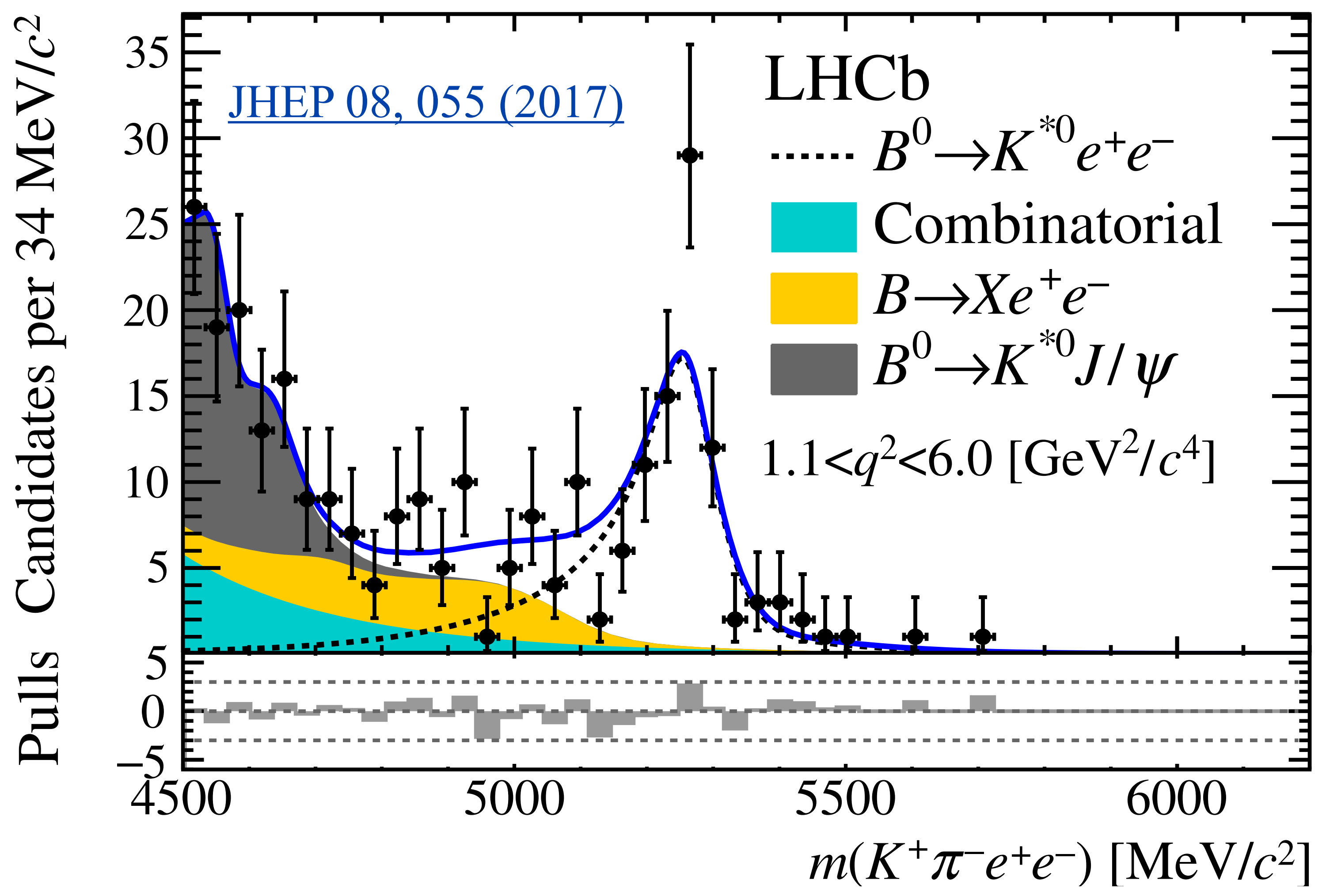
Electrons have **worse mass resolution** and are **more difficult to trigger on**

- Use **double ratio** with $B \to K^{(*)} J/\psi(\to \ell\ell)$

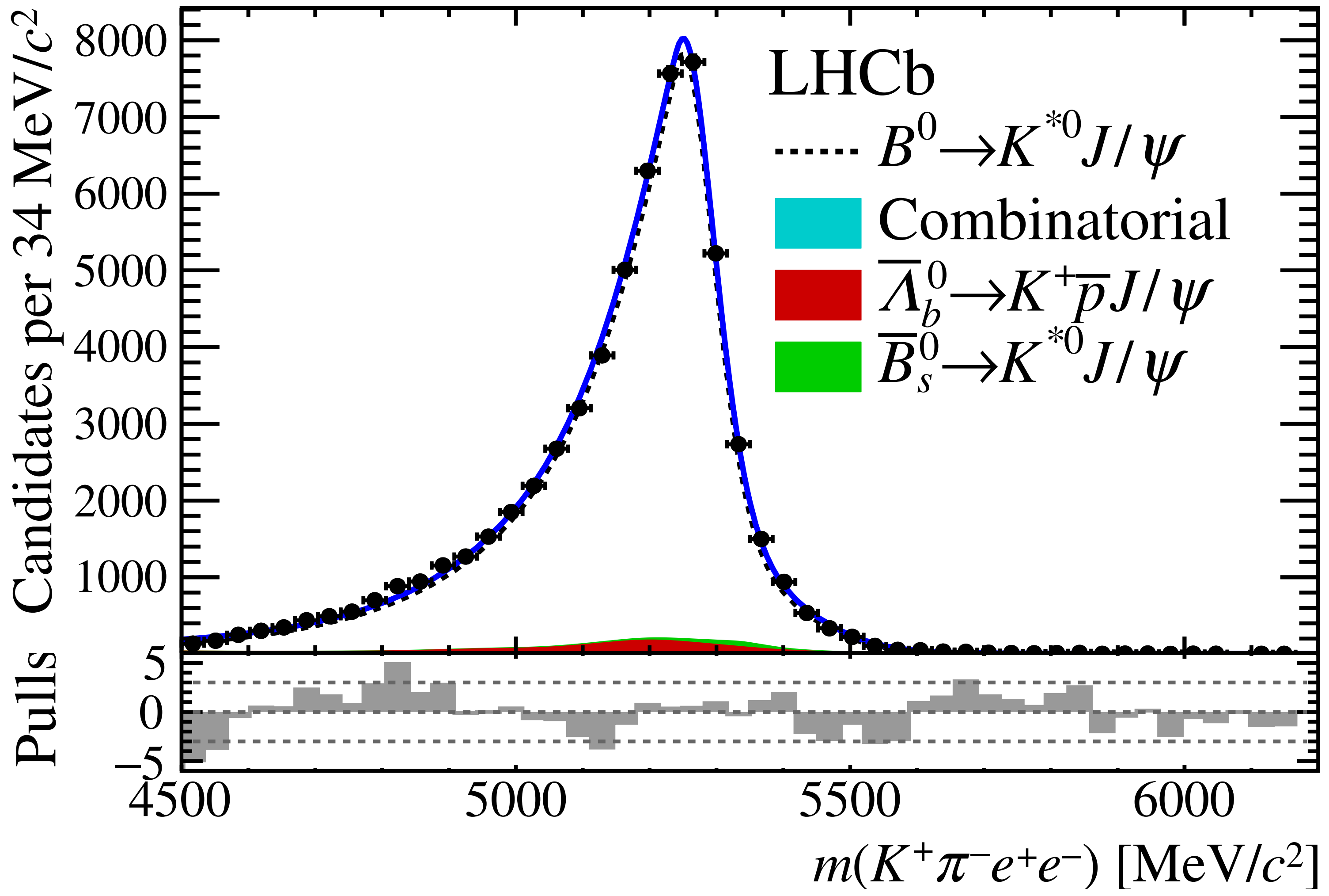
$$R_K = \frac{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+J/\psi(\mu^+\mu^-))} \Bigg/ \frac{\mathcal{B}(B^+ \to K^+e^+e^-)}{\mathcal{B}(B^+ \to K^+J/\psi(e^+e^-))} = \frac{N^{\rm rare}_{\mu^+\mu^-}}{N^{J/\psi}_{\mu^+\mu^-}} \boxed{\frac{\varepsilon^{J/\psi}_{\mu^+\mu^-}}{\varepsilon^{\rm rare}_{\mu^+\mu^-}}} \times \frac{N^{J/\psi}_{e^+e^-}}{\boxed{N^{\rm rare}_{e^+e^-}}} \boxed{\frac{\varepsilon^{\rm rare}_{e^+e^-}}{\varepsilon^{J/\psi}_{e^+e^-}}}$$

LFU $\mathscr{R}_{K^{(*)}}$ at LHCb: bkgs & signal shape

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



$B^0 \to K^{*0} J/\psi(\to ee)$



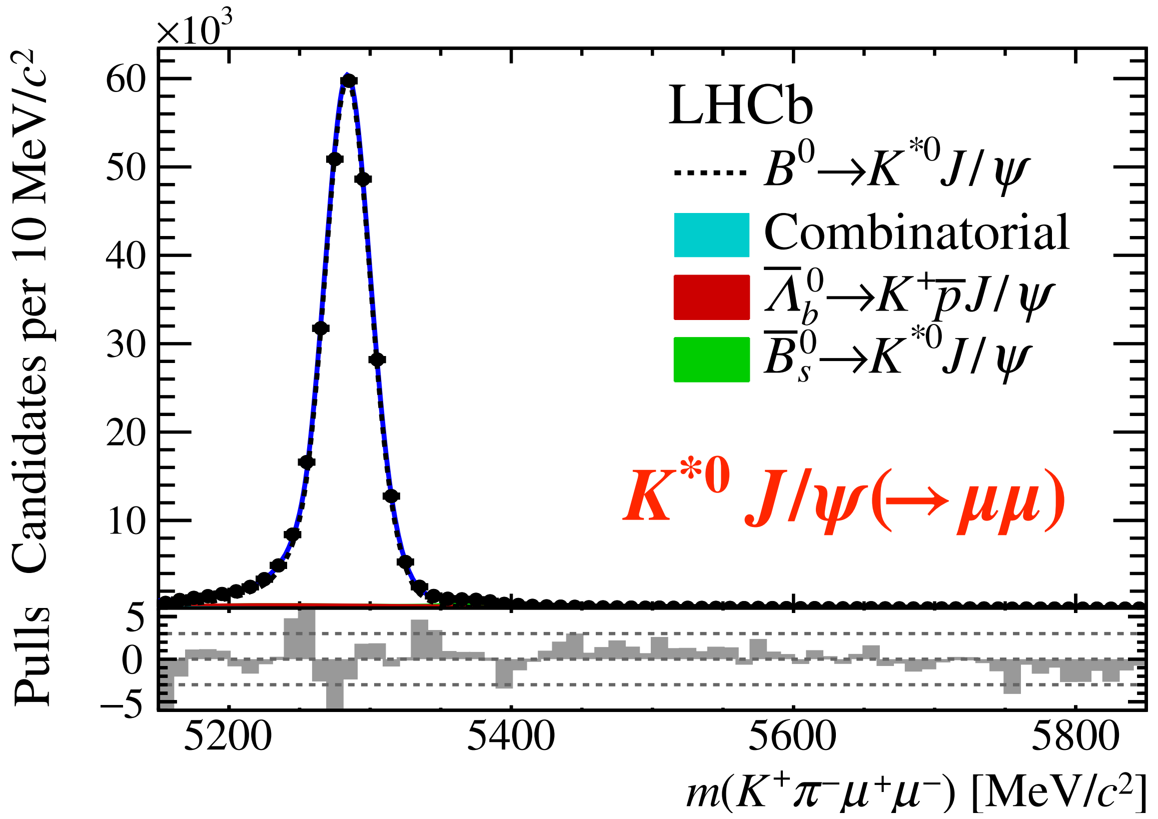
- **Backgrounds reduced** with
  - Tight PID
  - Vetoes on invariant masses, eg $m(K^+e) > m(D^0)$
  - Multivariate classifiers
- **Combinatorial** and **partially-reco** **bkgs** free in fit
- $B \to K^{(*)} J/\psi(\to \ell\ell)$ **contamination** from resonant fit
- **Signal shapes** taken from **simulation**
  - Small corrections obtained from clean $B \to K^{(*)} J/\psi(\to \ell\ell)$

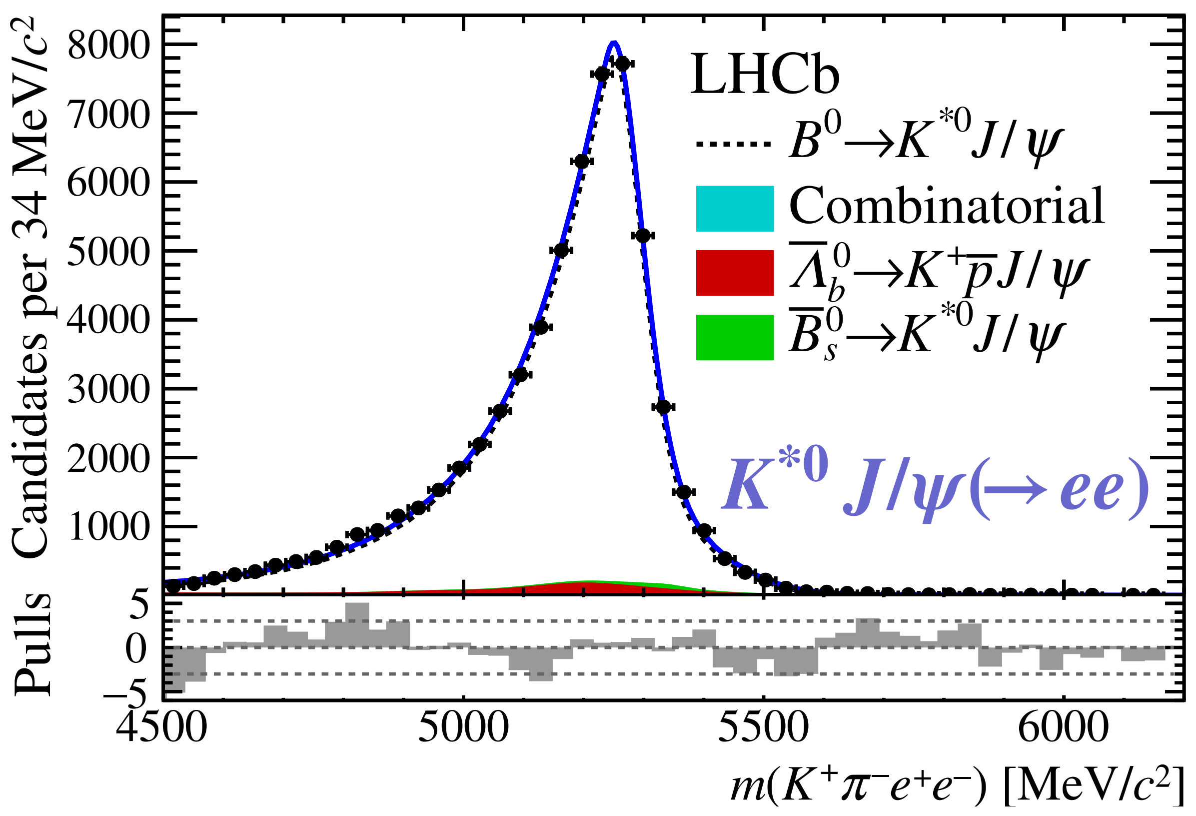
LFU $\mathcal{R}_{K^{(*)}}$ at LHCb: efficiencies

- Rare and J/Ψ events have **identical final states, difference** only **q^2**

➡ Check **if we understand ε** with $r^{K^{(*)}}_{J/\psi} = \dfrac{\mathcal{B}\left[B \to K^{(*)}\, J/\psi(\to \mu\mu)\right]}{\mathcal{B}\left[B \to K^{(*)}\, J/\psi(\to ee)\right]} = 1$

Also in bins of lab angle, p_T

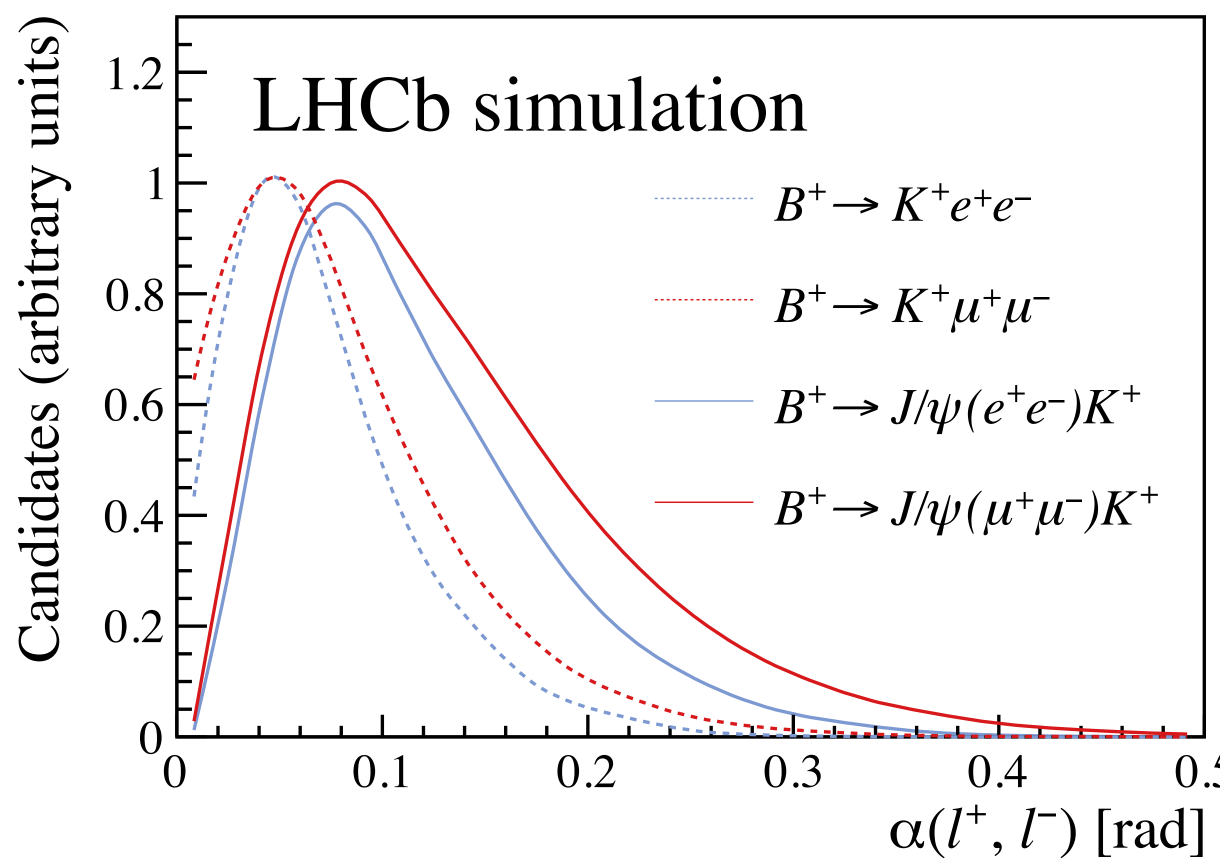


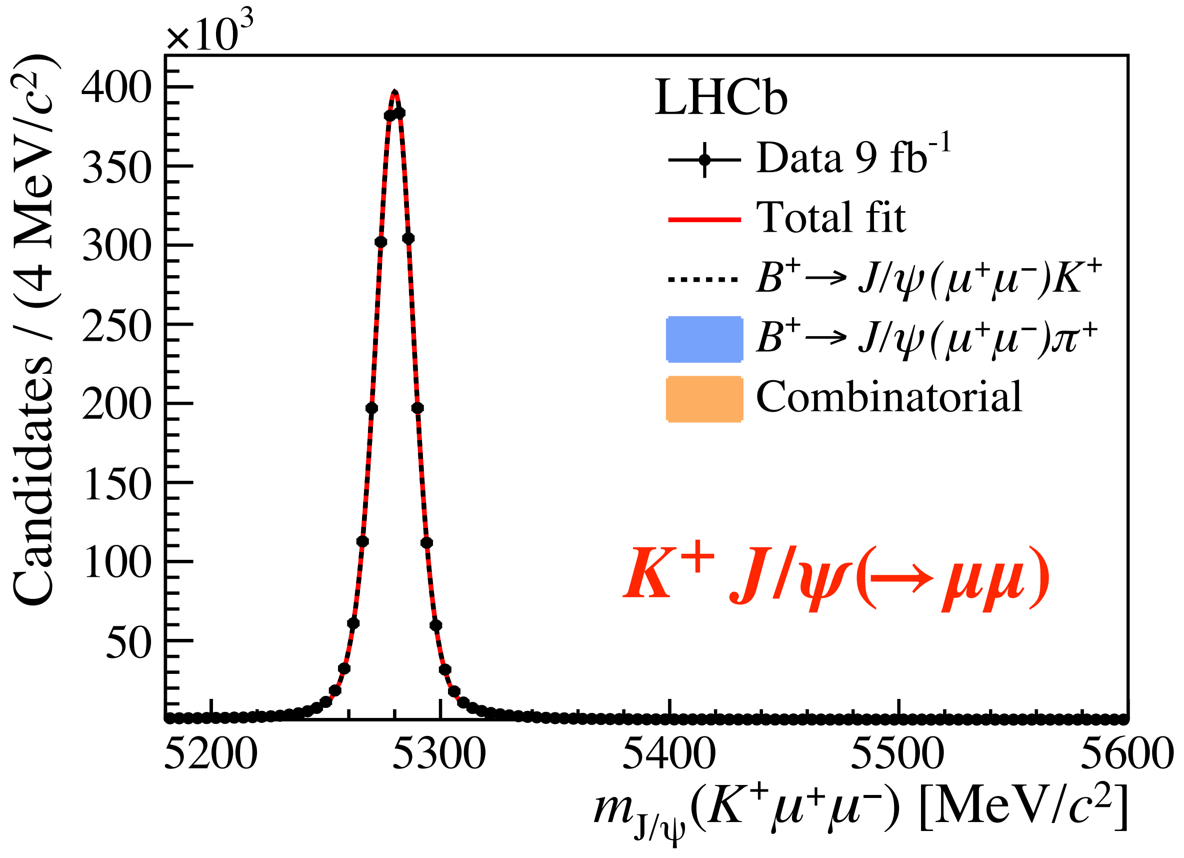


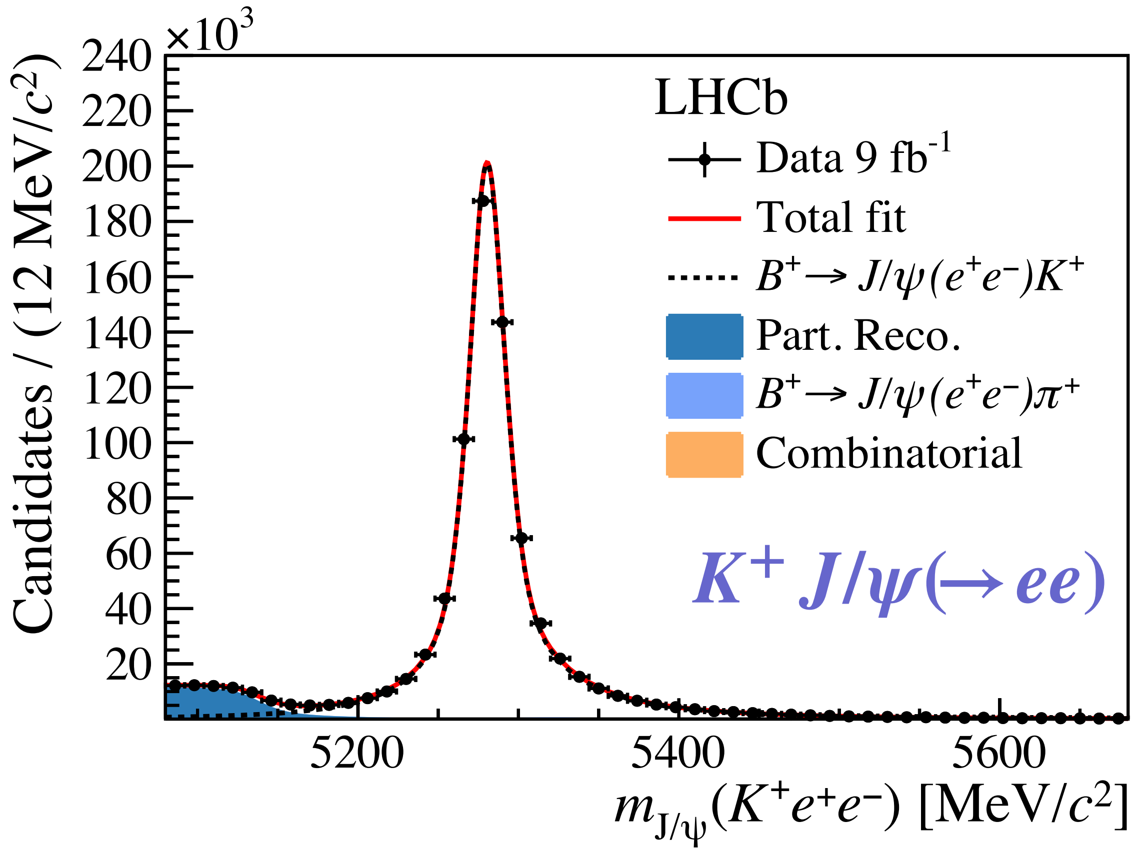
JHEP 08, 055 (2017)

$$r^{K^*}_{J/\psi} = 1.043 \pm 0.045$$

$$r^{K^*}_{\psi(2S)} / r^{K^*}_{J/\psi} = 0.980 \pm 0.040$$





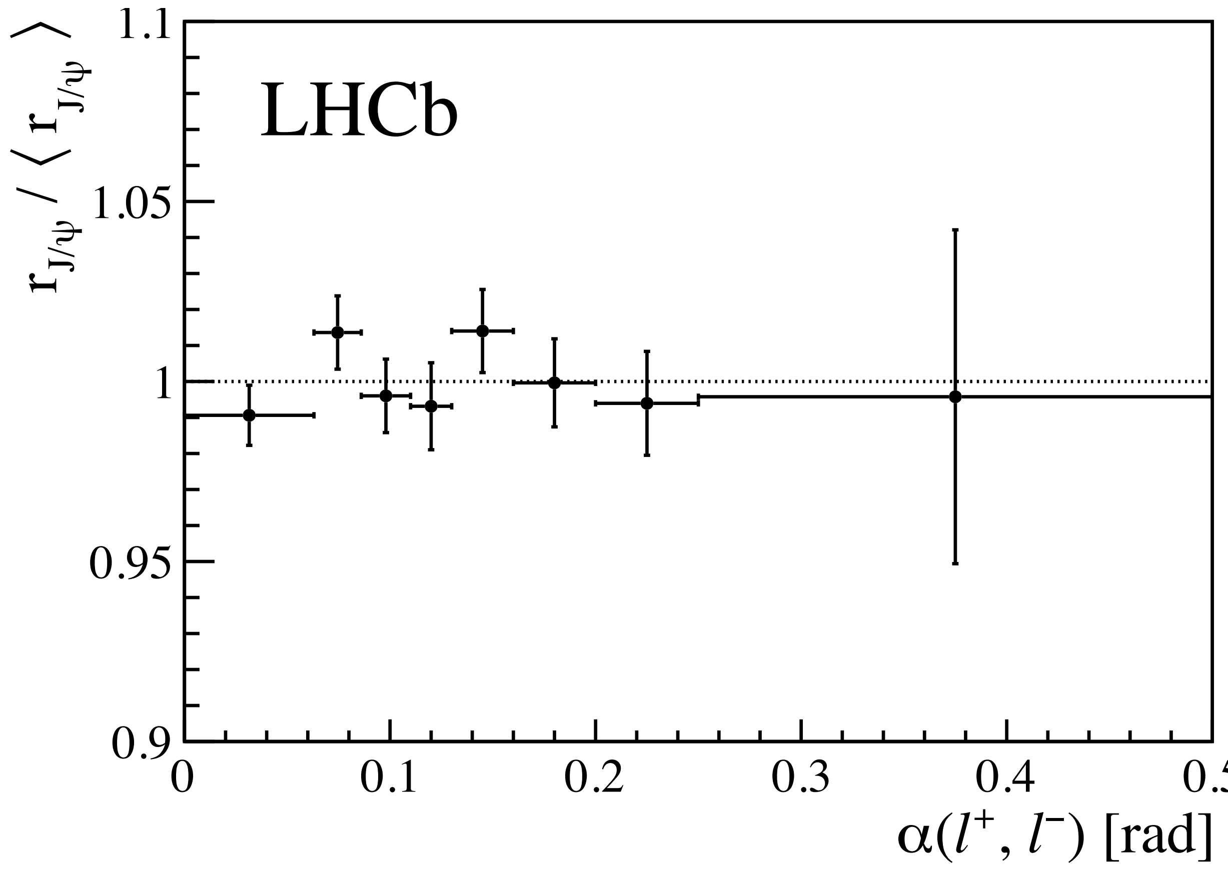


arXiv 2103.11769

$$r^{K}_{J/\psi} = 0.981 \pm 0.020$$

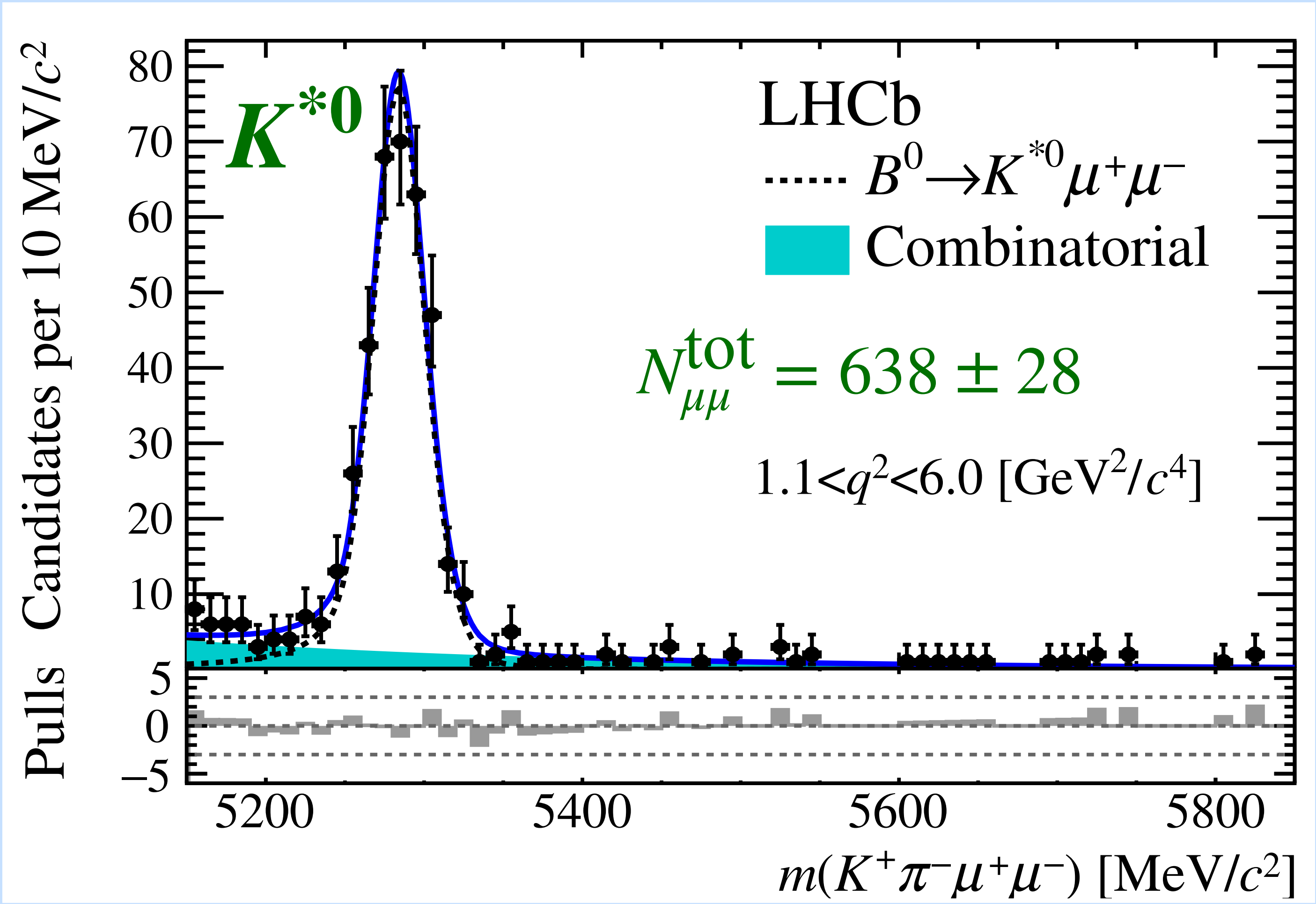
$$r^{K}_{\psi(2S)} / r^{K}_{J/\psi} = 0.997 \pm 0.011$$

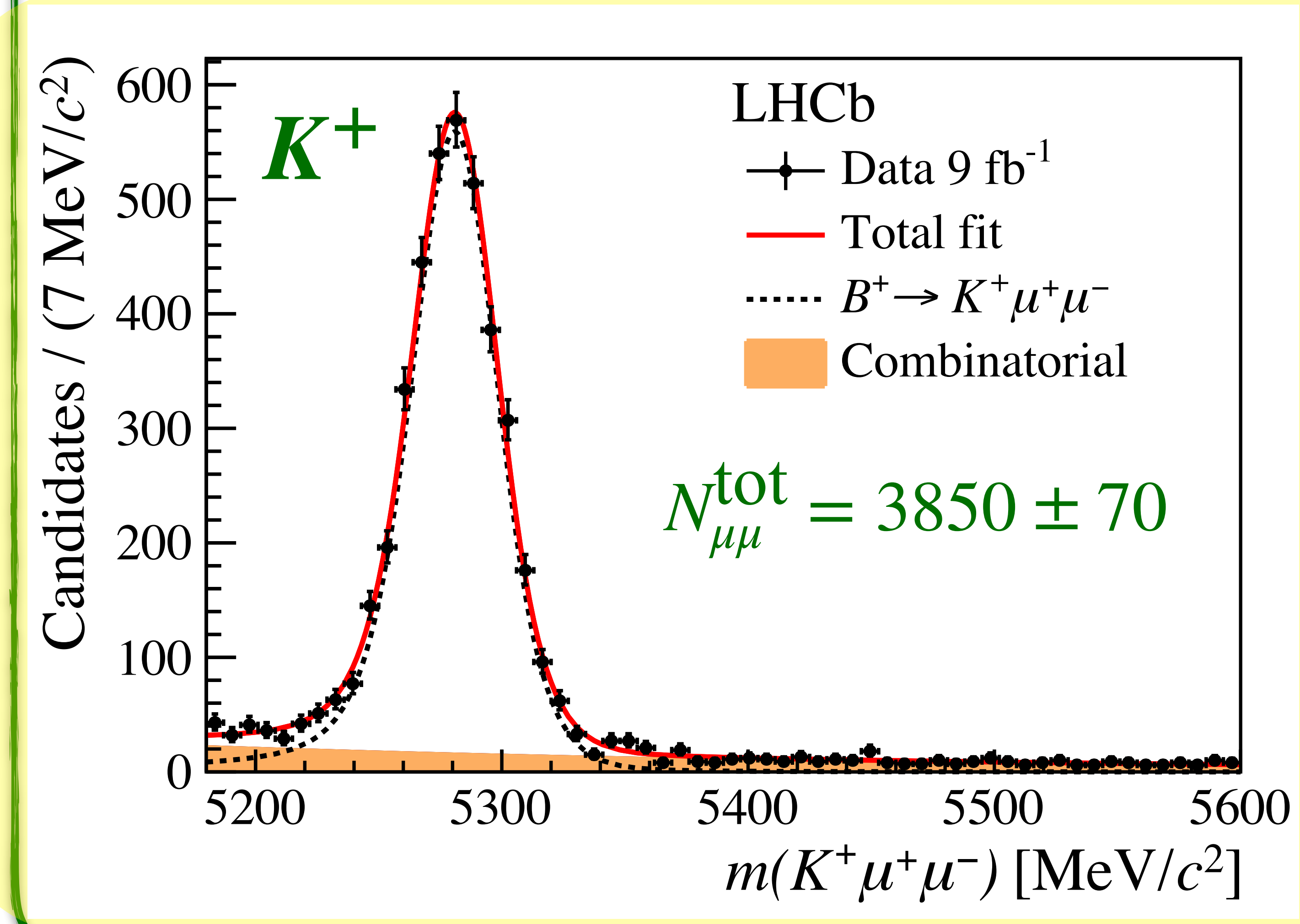
Apply **J/Ψ mass constraint,**
but **check without** as well



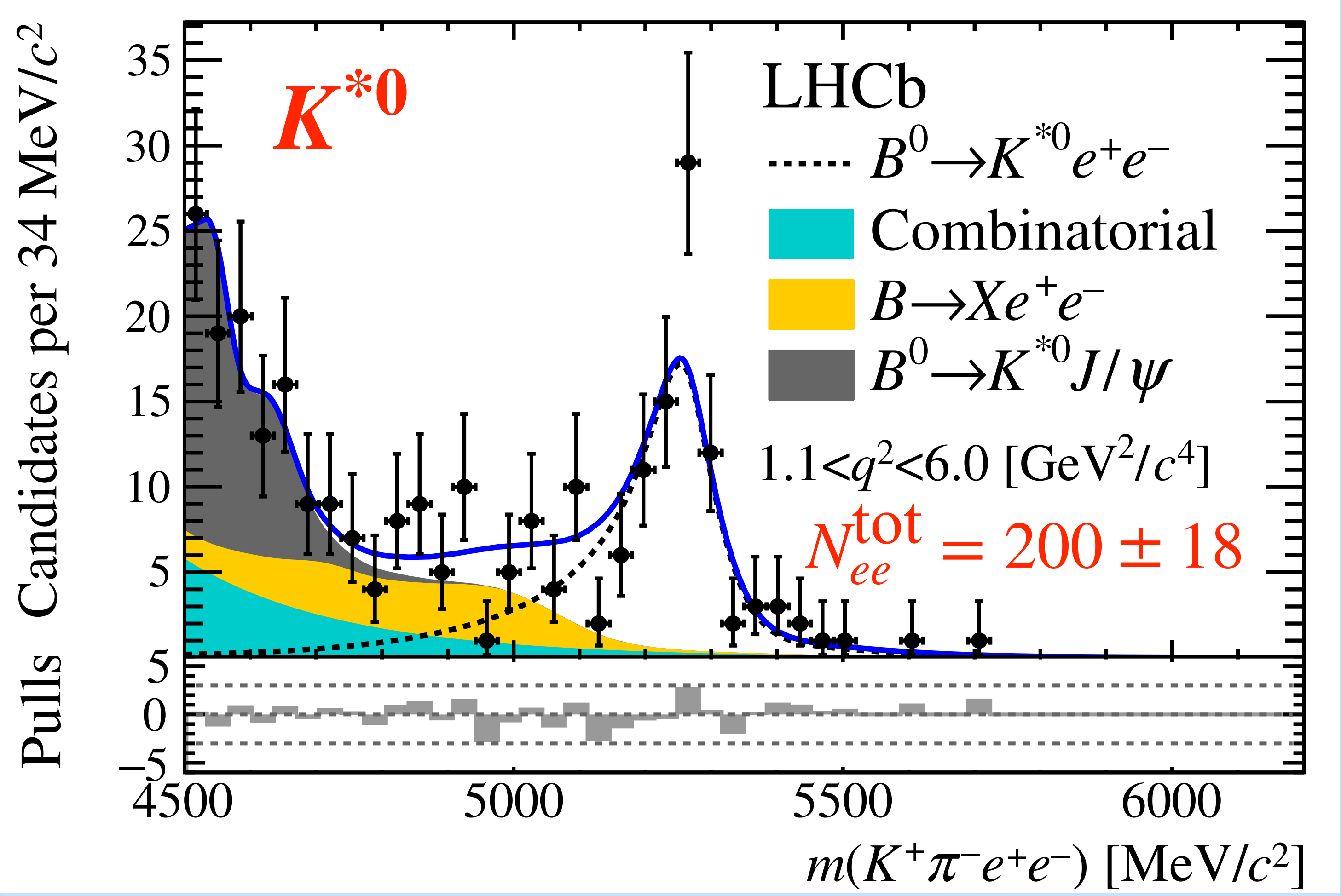
LFU $\mathcal{R}_{K^{(*)}}$ at LHCb: results

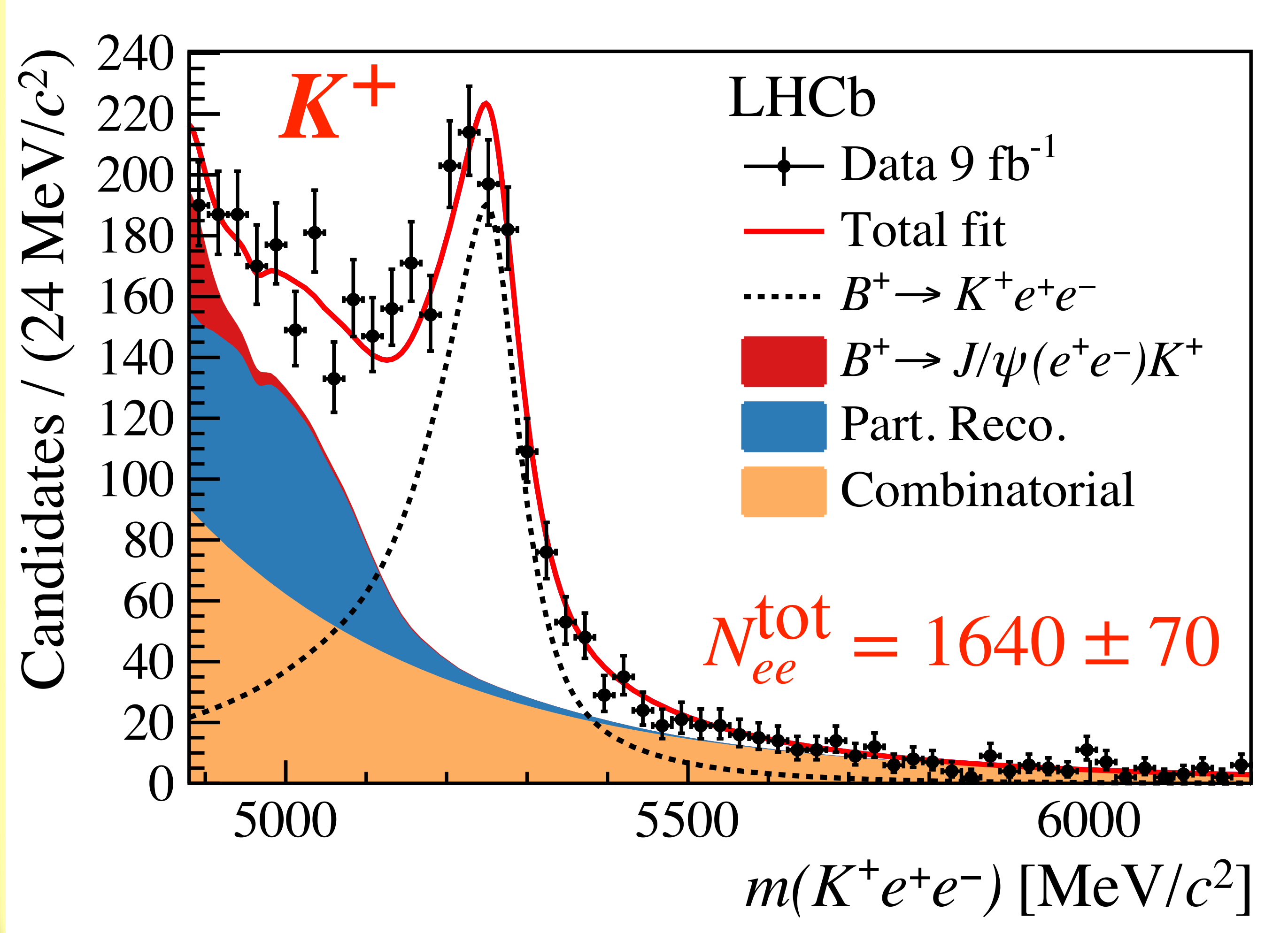
$B \to K^{(*)}\mu^+\mu^-$





$B \to K^{(*)}e^+e^-$





$\mathcal{R}_{K^{*0}}$ with 25% of Run 1+2

$$\mathcal{R}^{[0.045,1.1]}_{K^{*0}} = 0.66^{+0.11}_{-0.07} \pm 0.03$$

2.1σ from SM

$$\mathcal{R}^{[1.1,6]}_{K^{*0}} = 0.69^{+0.11}_{-0.07} \pm 0.05$$

2.4σ from SM

JHEP 08, 055 (2017)

$\mathcal{R}_{K^+}$ with 100% of Run 1+2

Fresh!

$$\mathcal{R}^{[1.1,6]}_{K^+} = 0.846^{+0.042+0.013}_{-0.039-0.012}$$

3.1σ from SM

arXiv 2103.11769

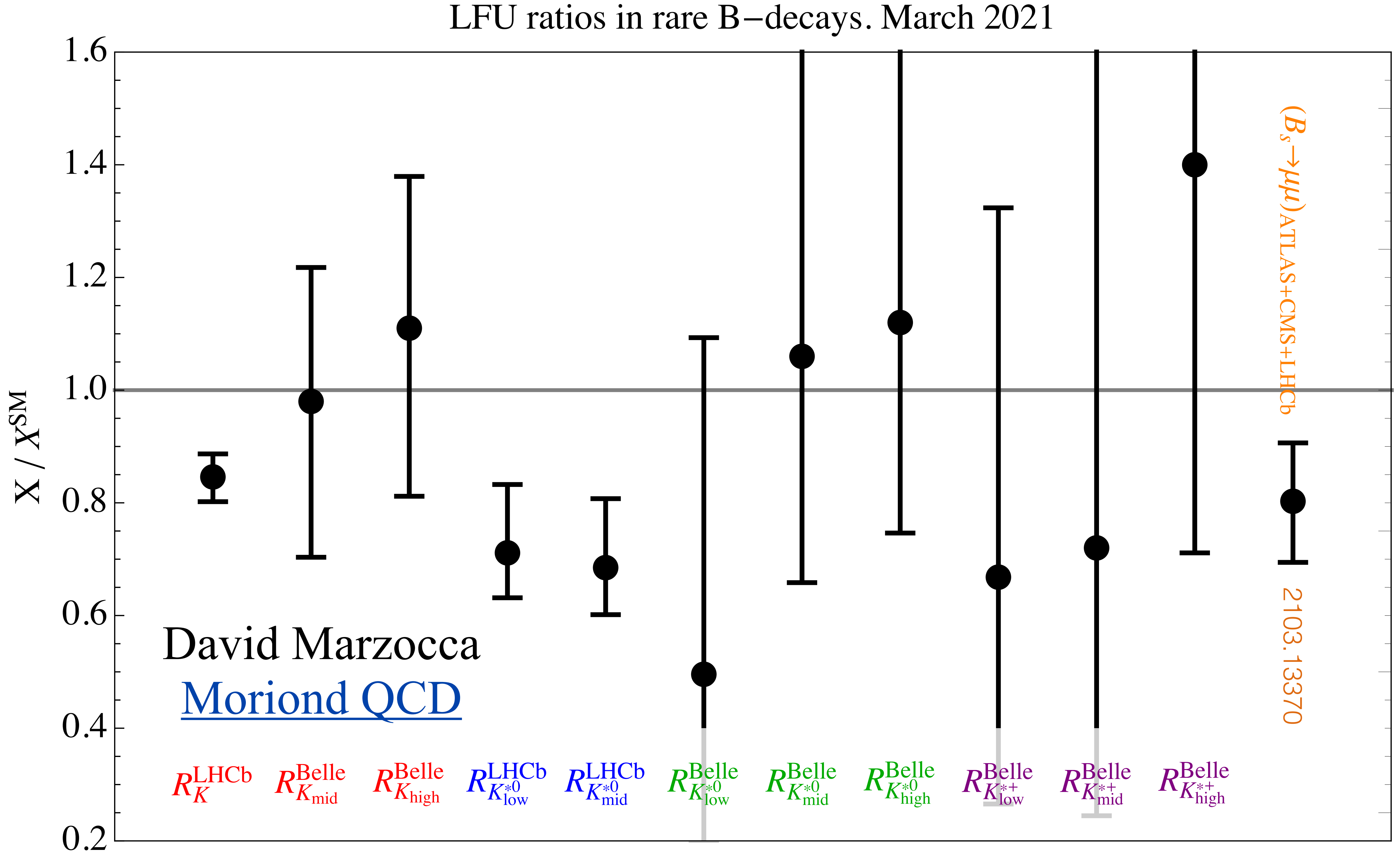
Conclusions

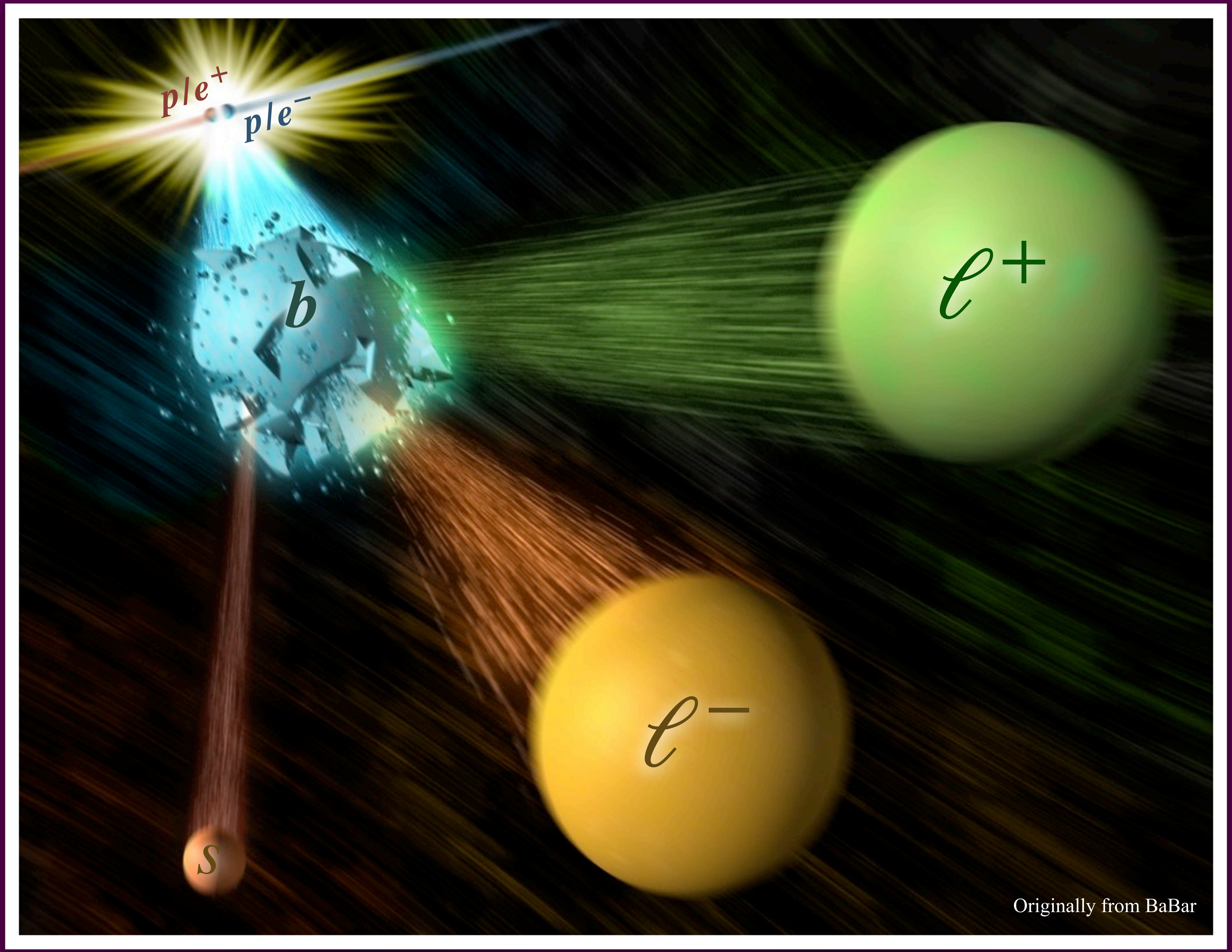
- $b \to s\ell^+\ell^-$ transitions are **excellent probes of NP**
  - Large $b\bar{b}$ samples at LHC are key
  - B-factories measurements very important too
- **Rates** involving **muons seem systematically low**
  - **Individual 2-3σ** results, but **global fit to clean observables** over **4σ significance deviation**
- Exciting times ahead
  - **LHC** still **analyzing Runs 1+2 data**
  - **Run 3** to start next year with **5x inst. lumi at LHCb**
  - **Belle II** will increase **B-factories dataset** by **50x**
  - **HL-LHC** will increase **current dataset** by **100x**

No time to cover, but also

$$\mathscr{R}_{pK}^{[0.1,6]} = \frac{\Lambda_b^0 \to pK^-\mu\mu}{\Lambda_b^0 \to pK^-ee} = 0.86^{+0.14}_{-0.11} \pm 0.05$$

LHCb
JHEP 2020, 40 (2020)

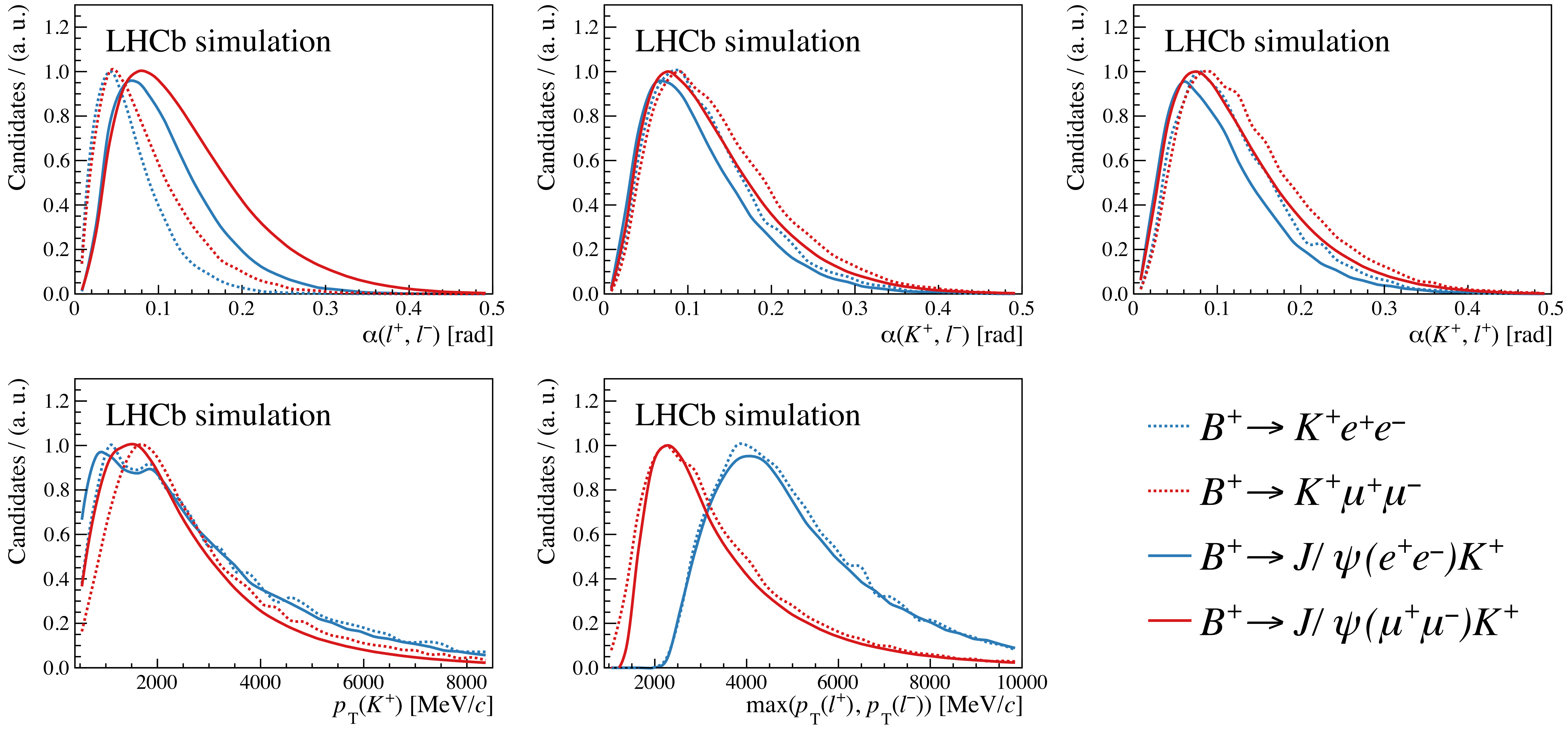


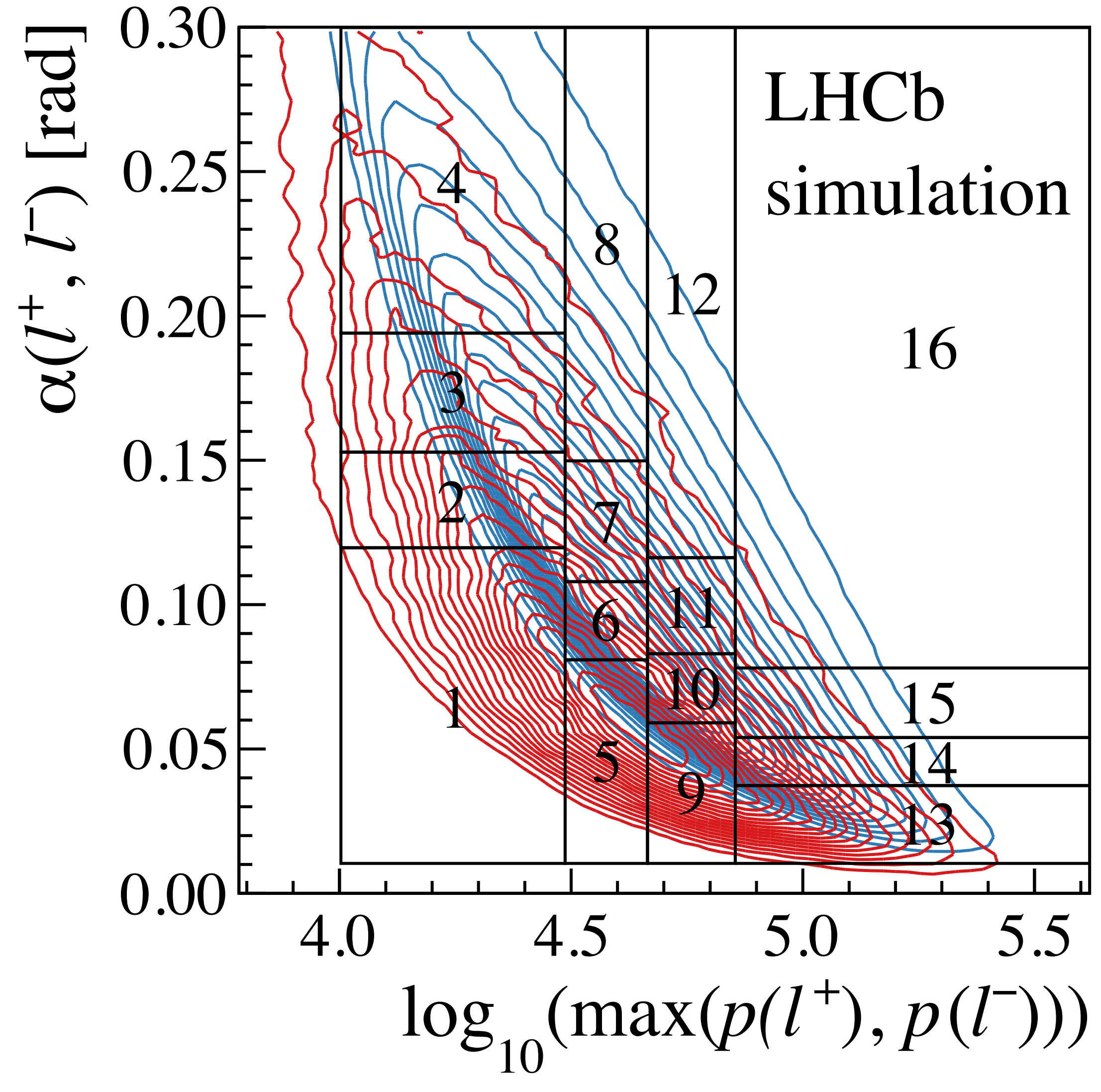


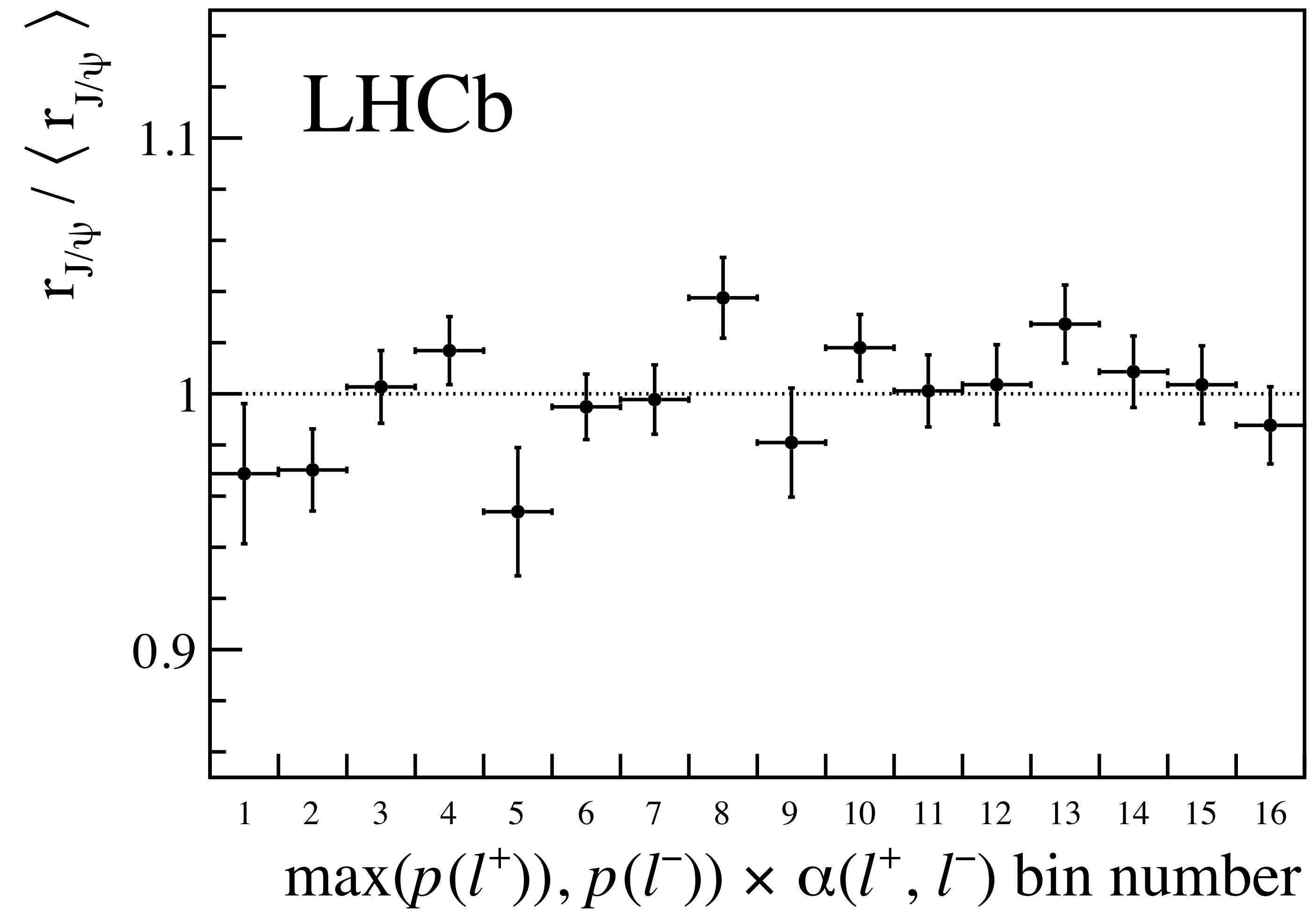
Backup

Penguin from Jeff Brassard

$\mathcal{R}_{K+}$ at LHCb: ε validation





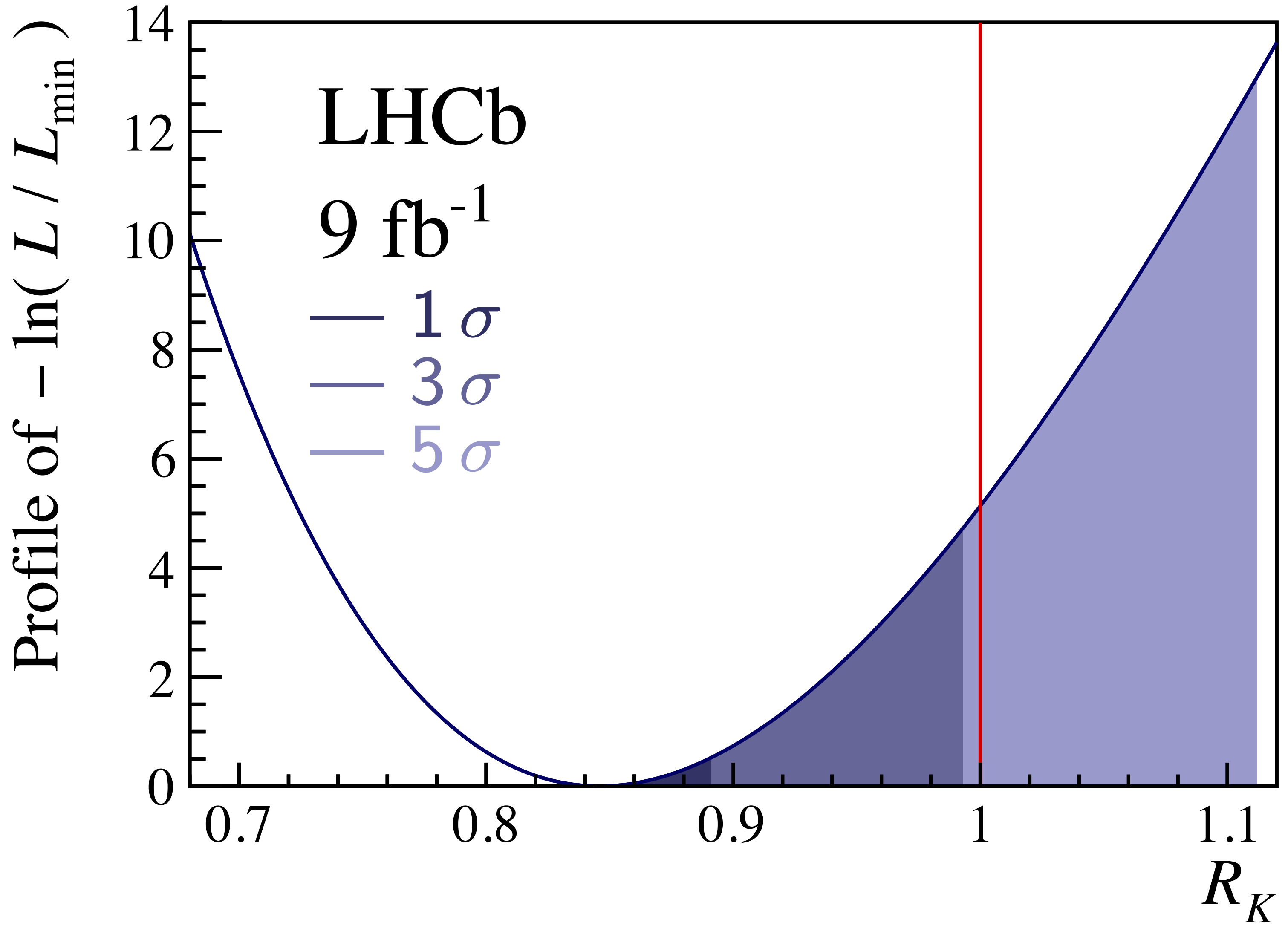


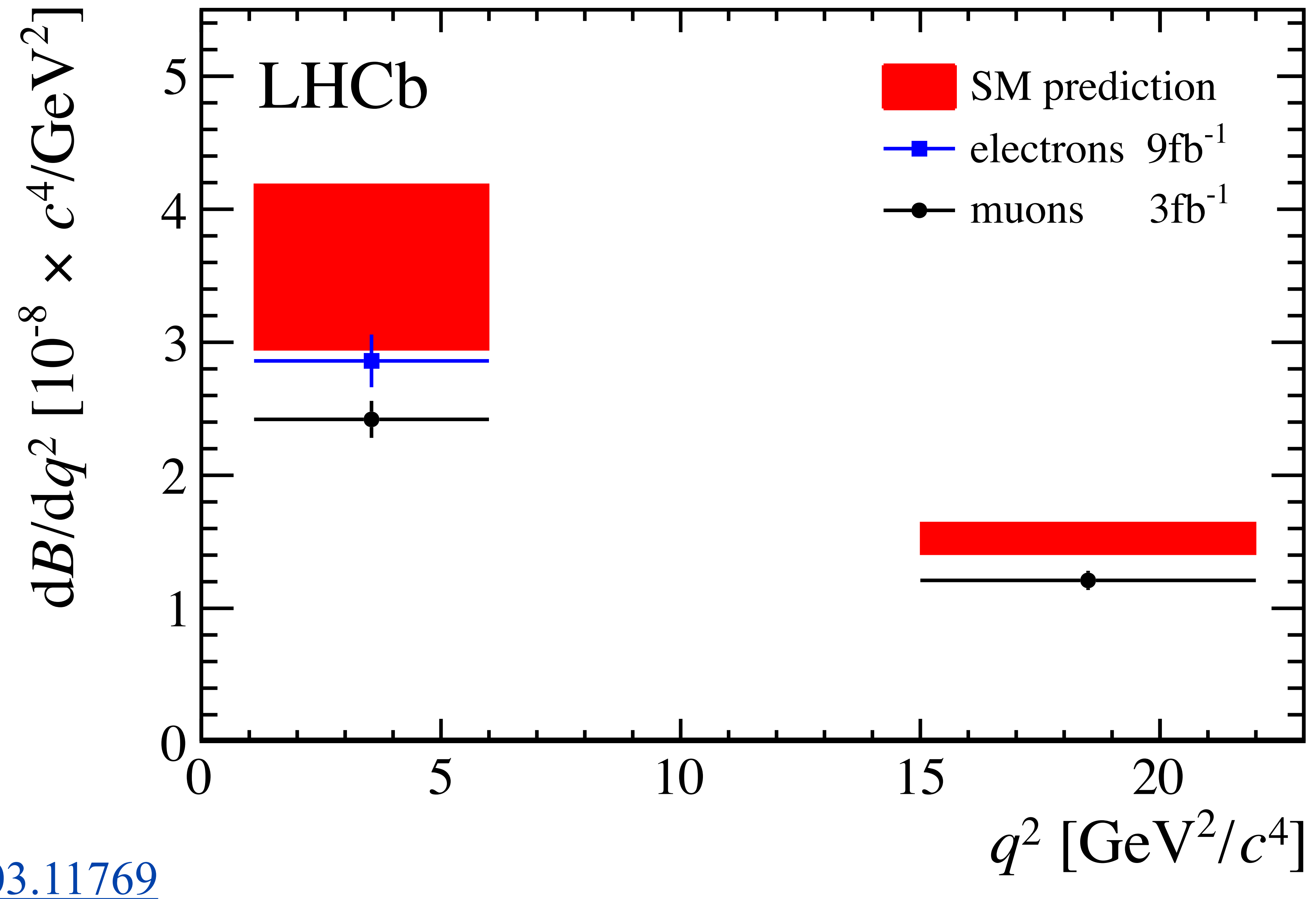
- Enough overlap between rare and resonant to check $r^{K^{(*)}}_{J/\psi} = \dfrac{B \to K^{(*)}\ J/\psi(\to \mu\mu)}{B \to K^{(*)}\ J/\psi(\to ee)} = 1$

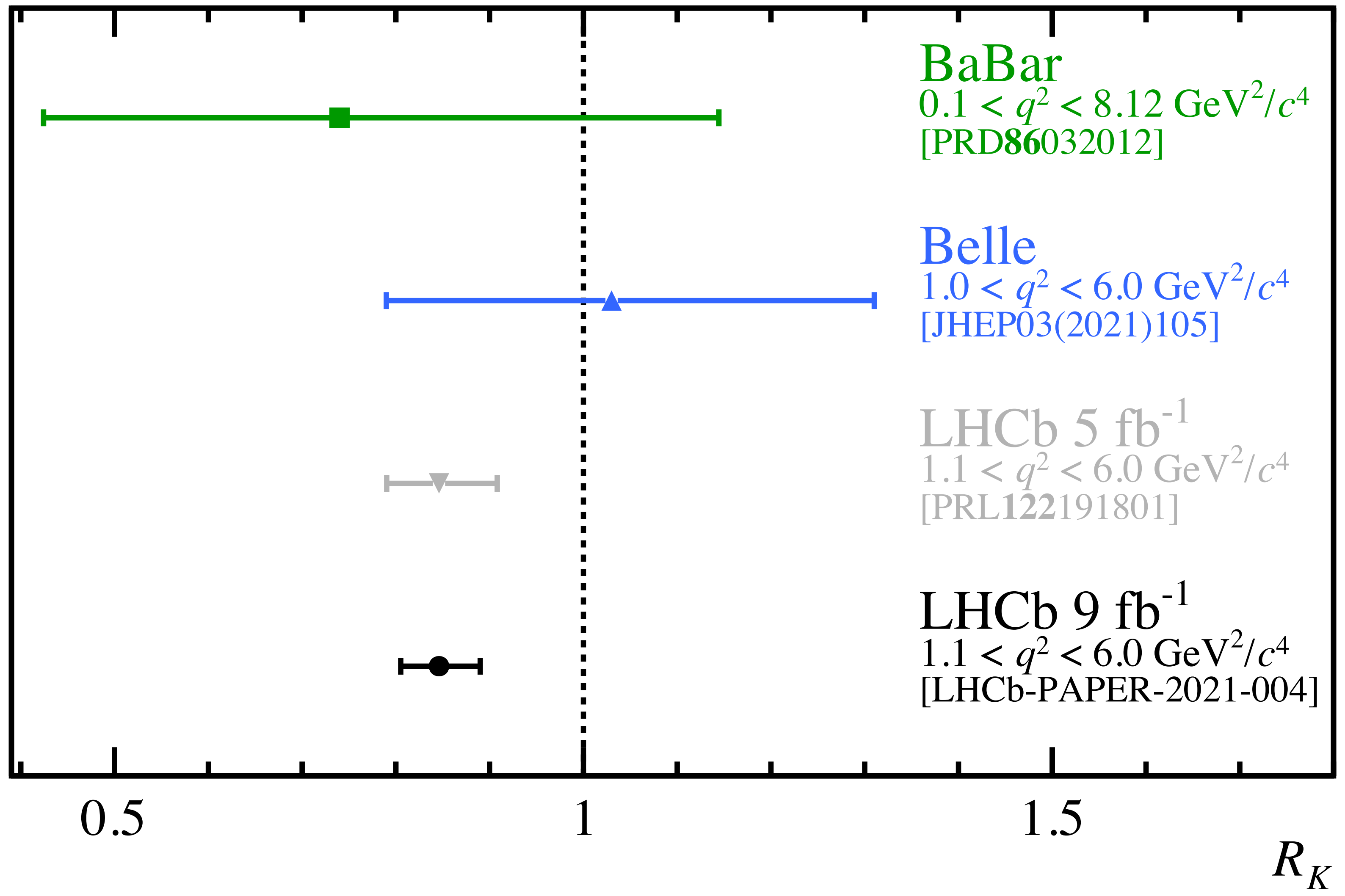
arXiv 2103.11769

$\mathcal{R}_{K+}$ at LHCb: results

- Likelihood slightly non-parabolic
- Electron BF consistent with SM
  - ➡ Based on the low muon BF



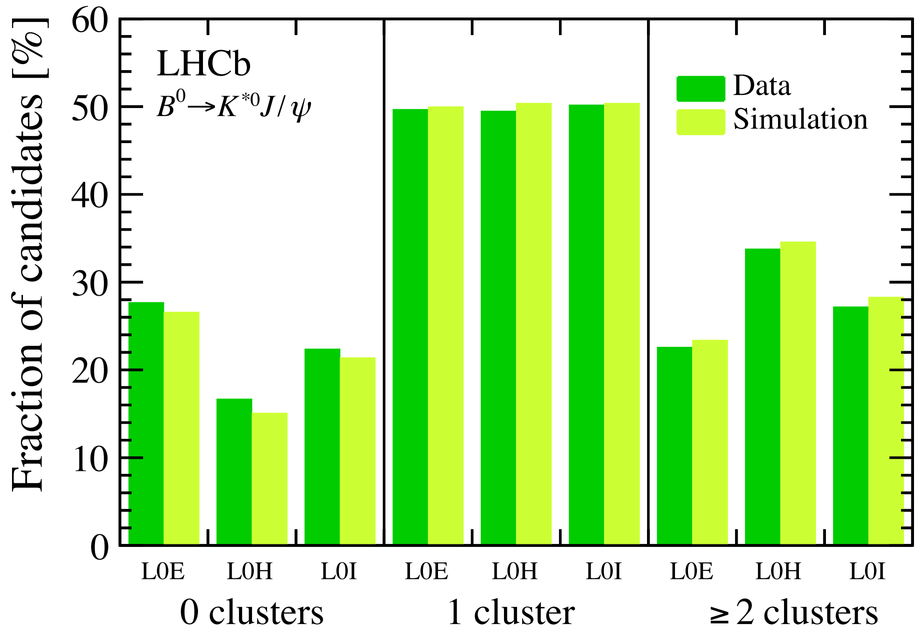


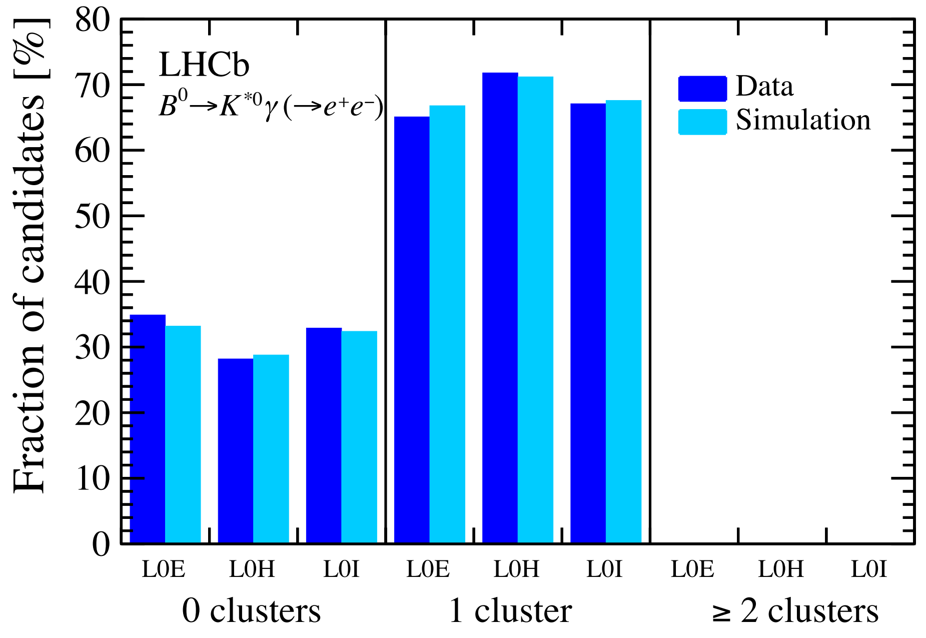


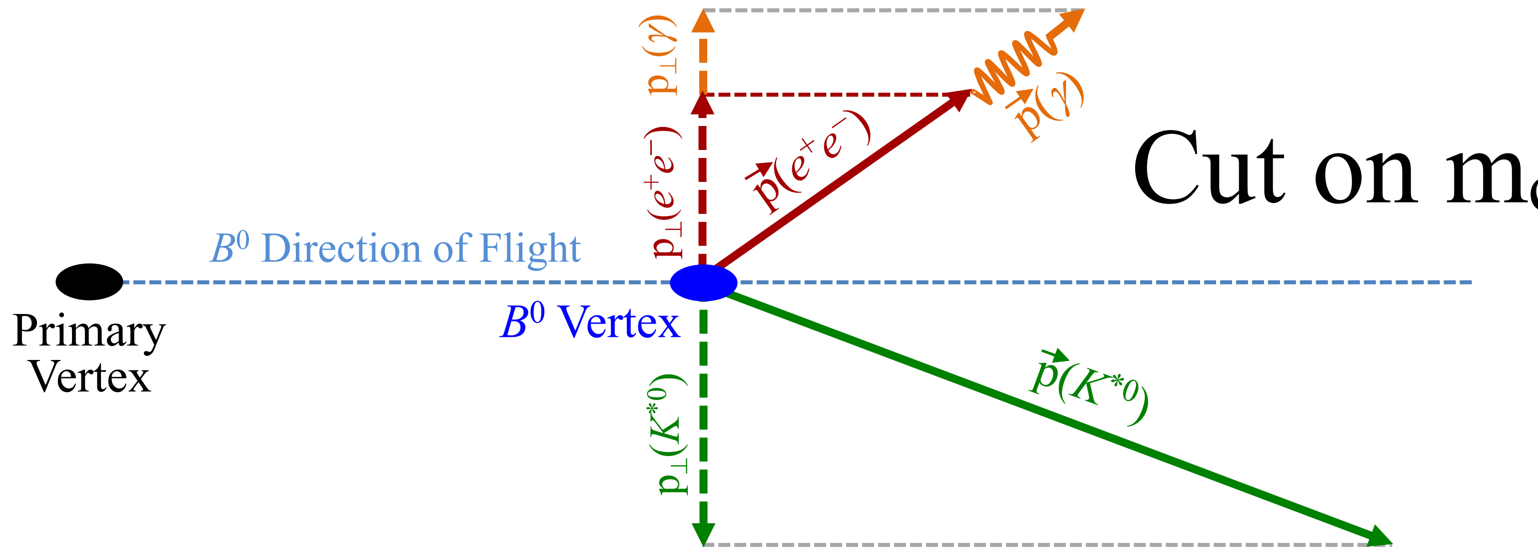
arXiv 2103.11769

$\mathcal{R}_{K^{*0}}$ at LHCb

- Compare the Bremsstrahlung categories between data and simulation
- Compare kinematic distribution obtained from background-substracted data and simulation

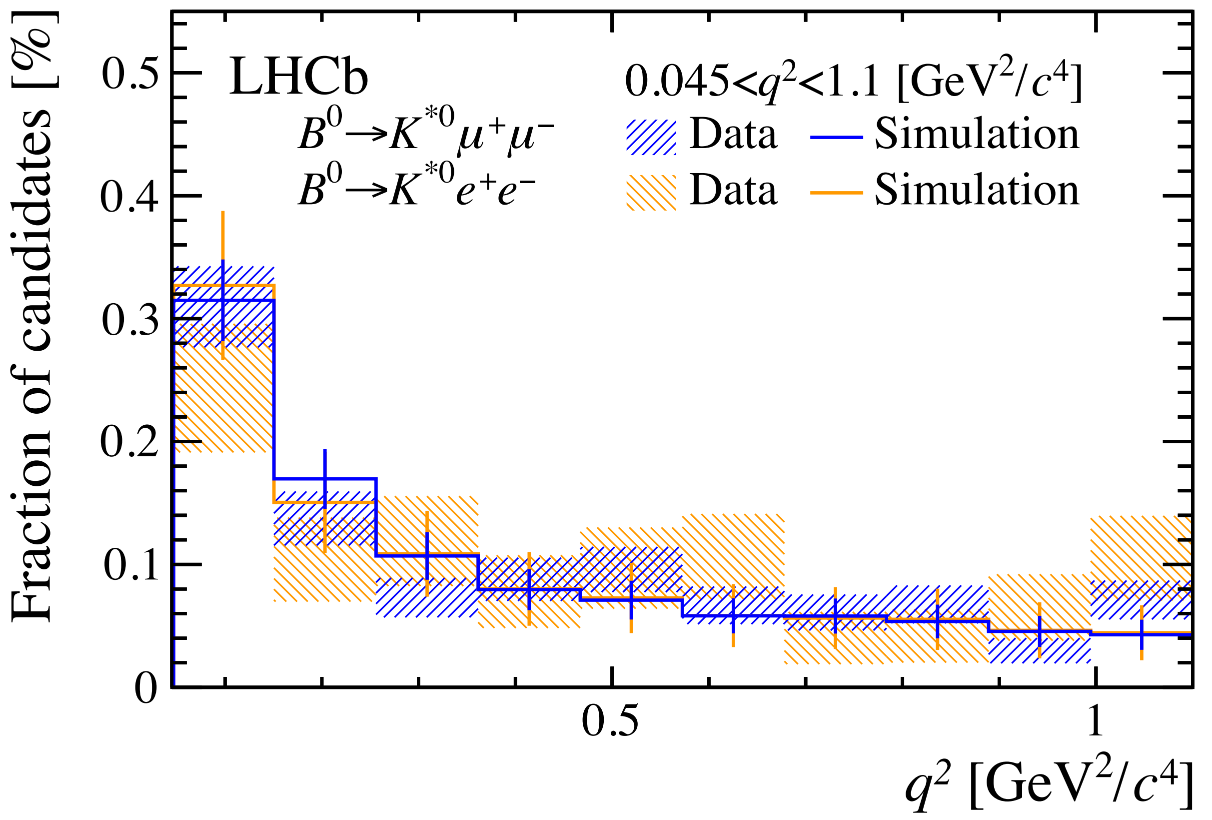


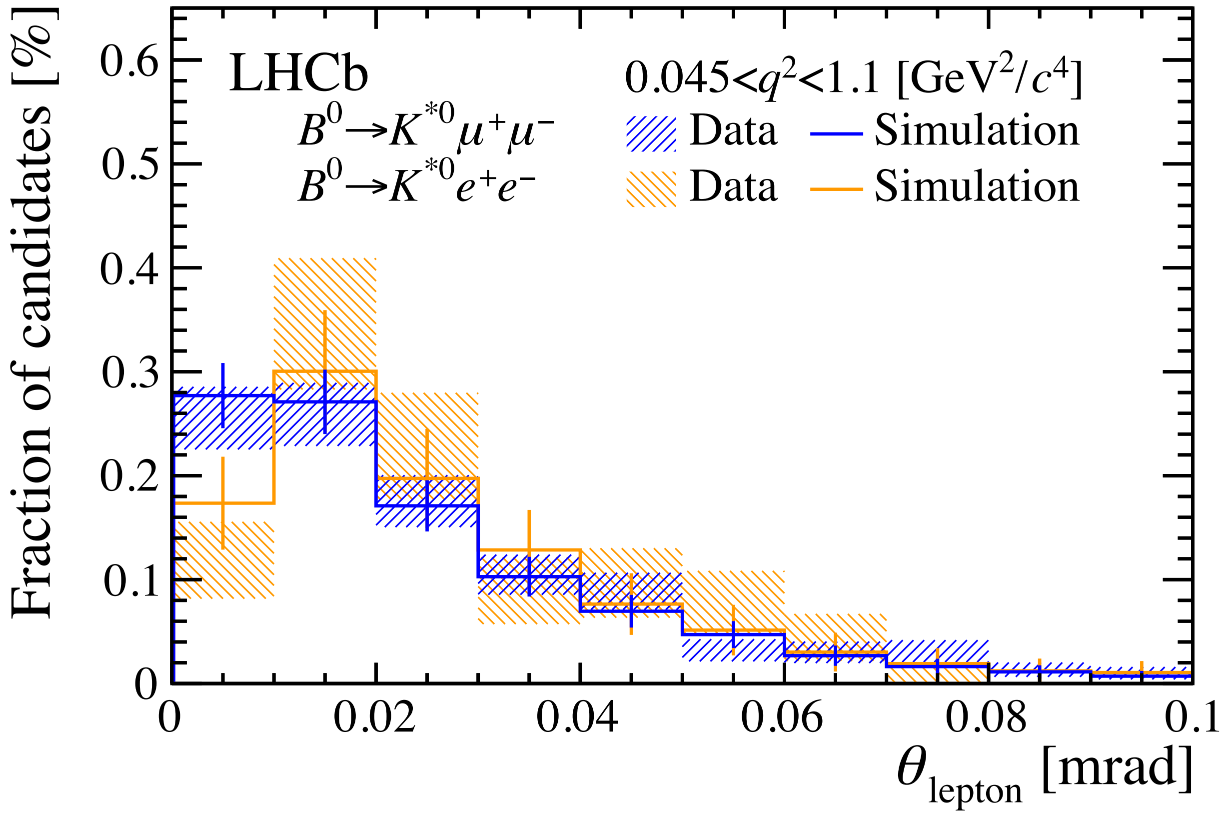




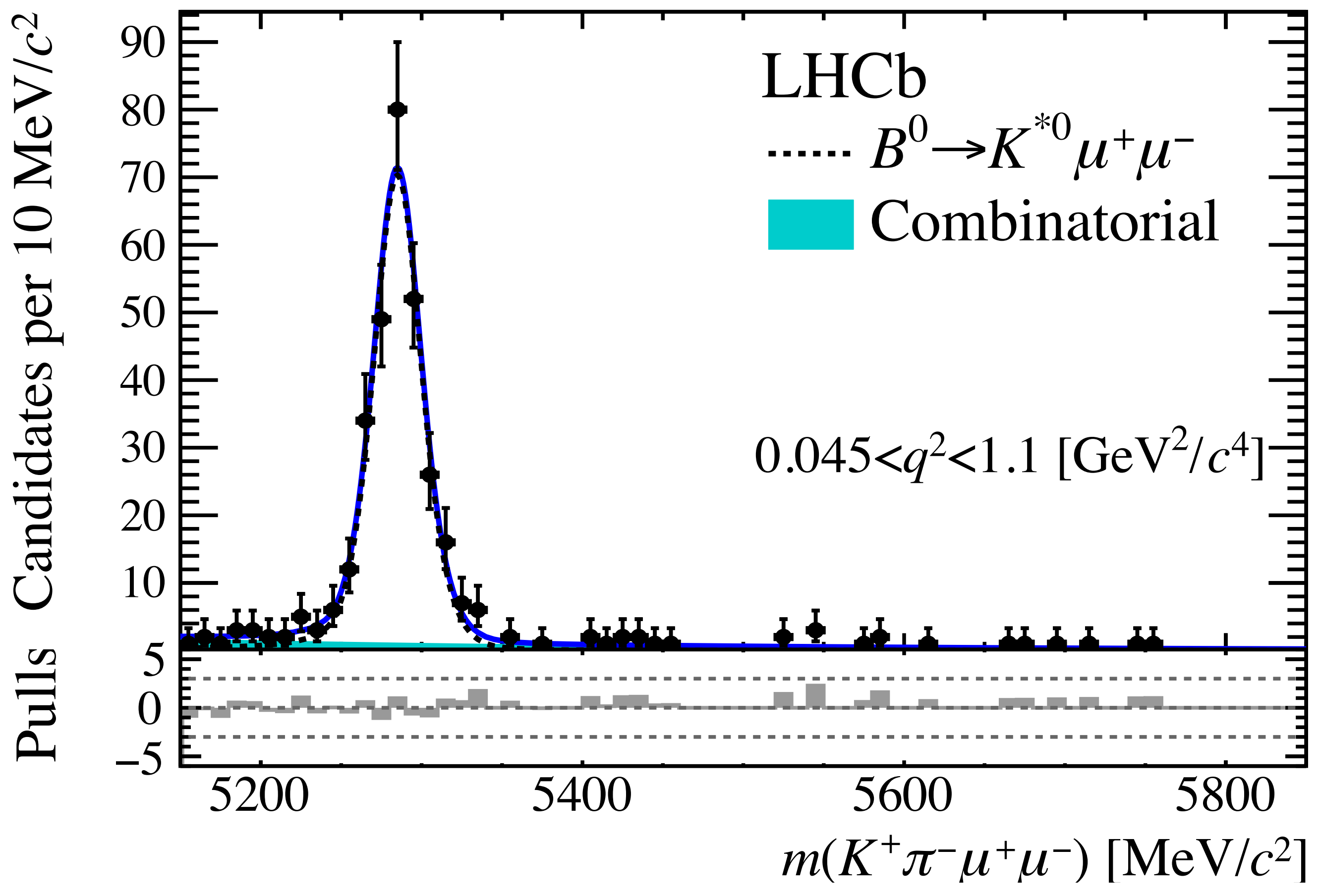
Cut on m_{corr}

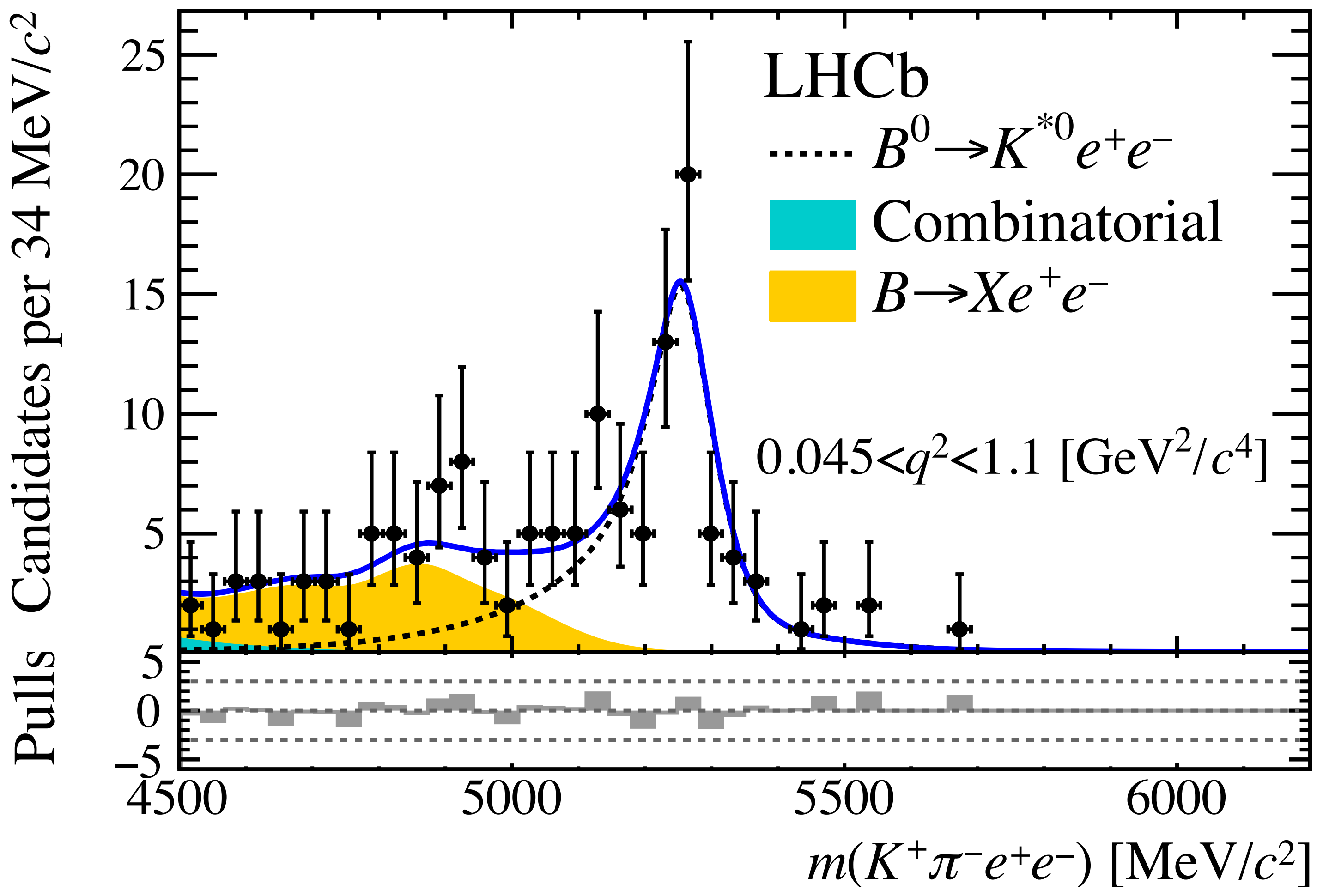
JHEP 08, 055 (2017)





Low q² fit

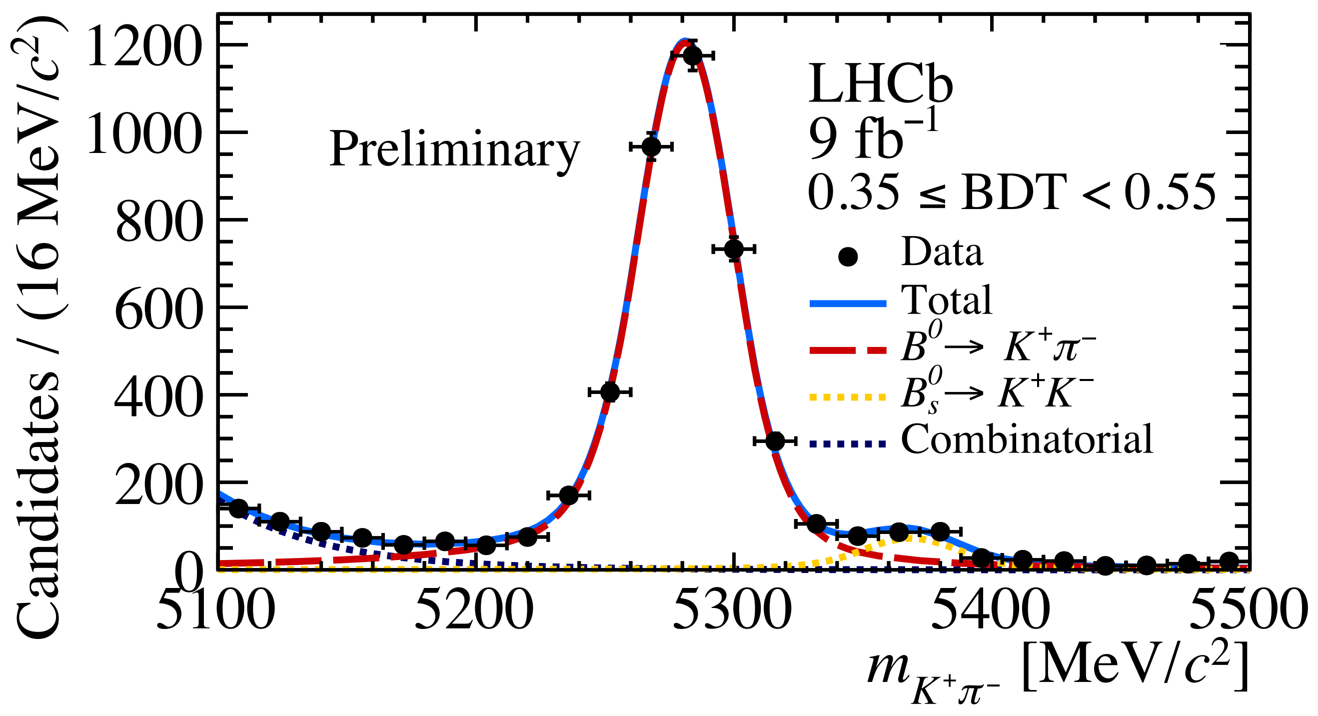


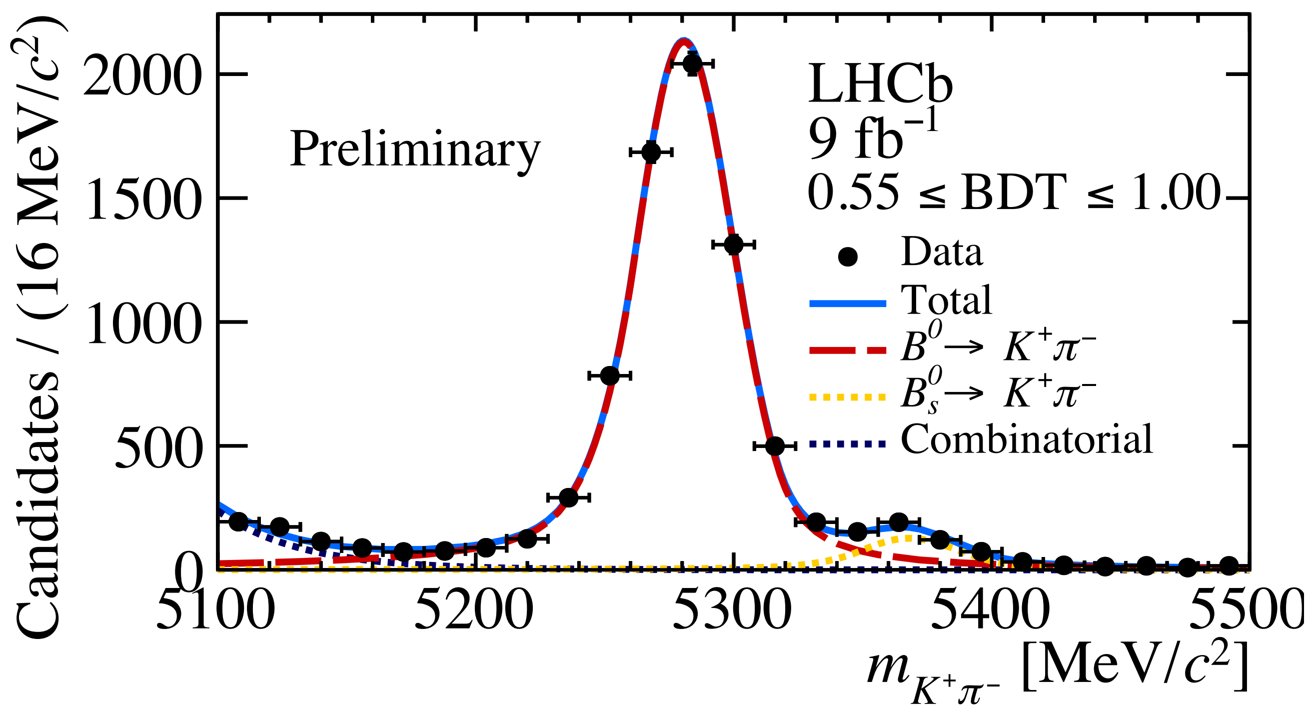


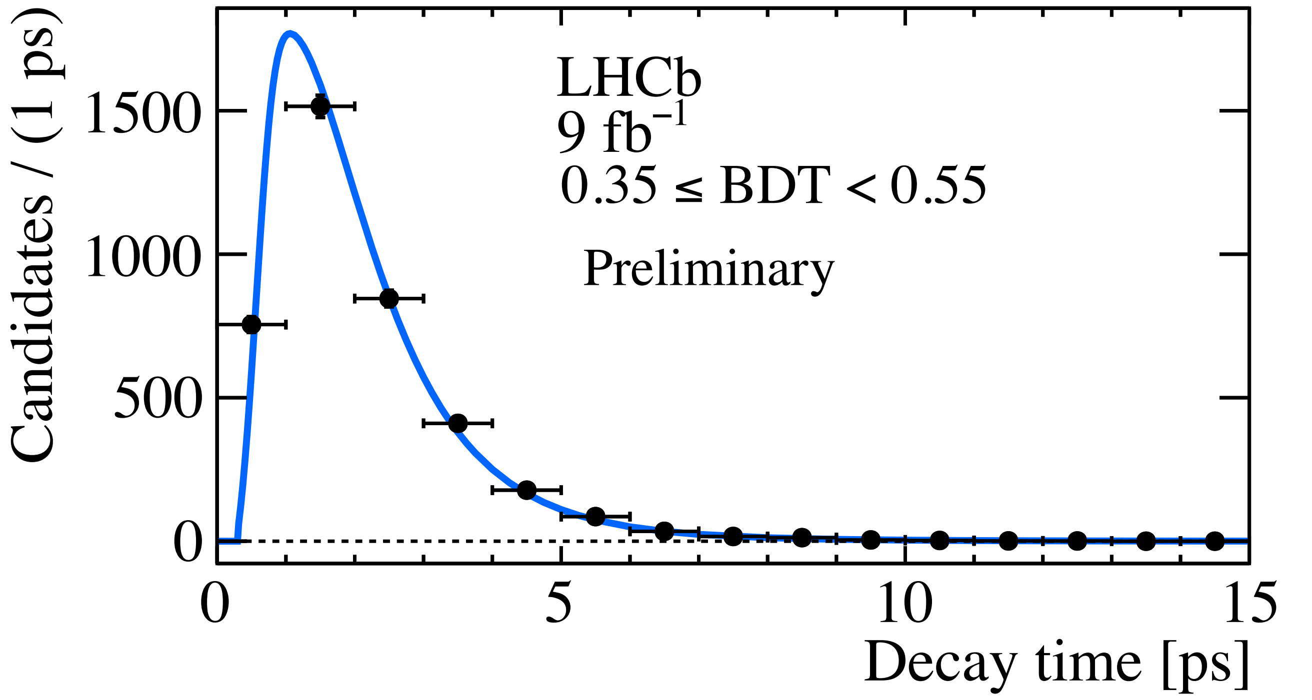
$B^0_{(s)} \to \mu^+\mu^-$: LHCb

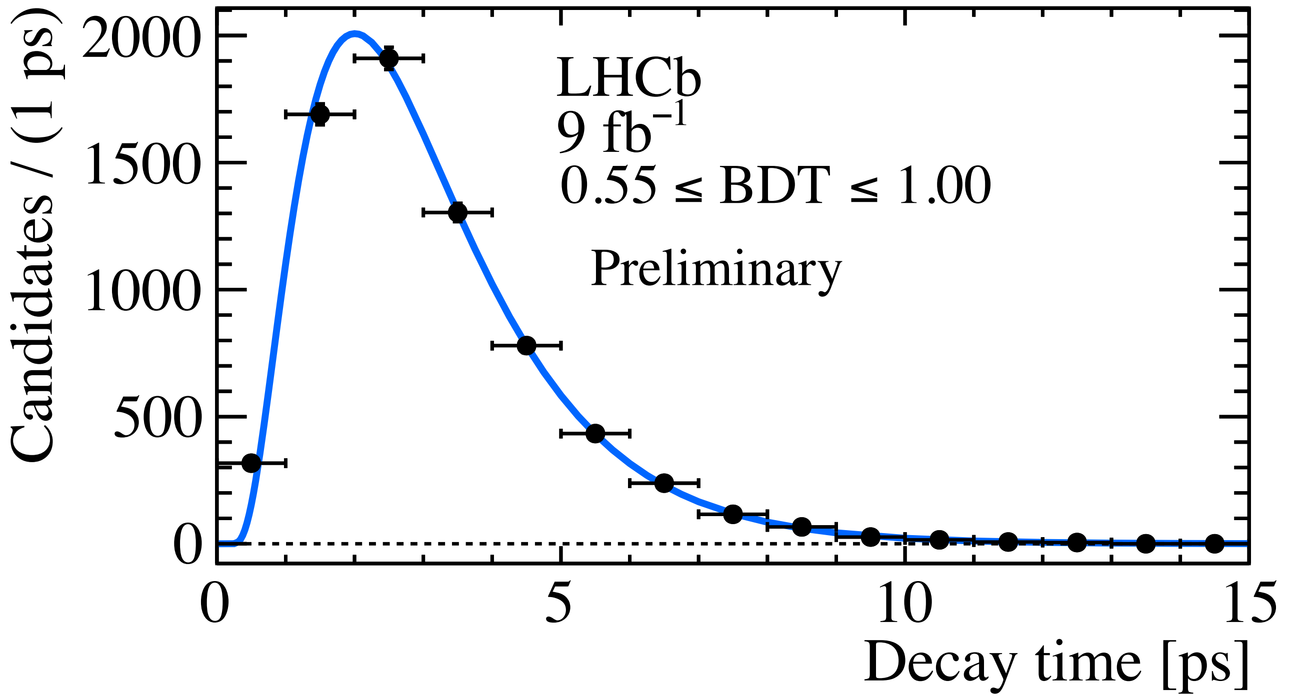
- **Mean of mass shape** obtained from $B_s^0 \to K^+K^-$ and $B^0 \to K^+\pi^-$
- **Mass resolution** interpolated from cc and bb resonances
- **Acceptance** for **effective lifetime** tested with $B_s^0 \to K^+K^-$ and $B^0 \to K^+\pi^-$

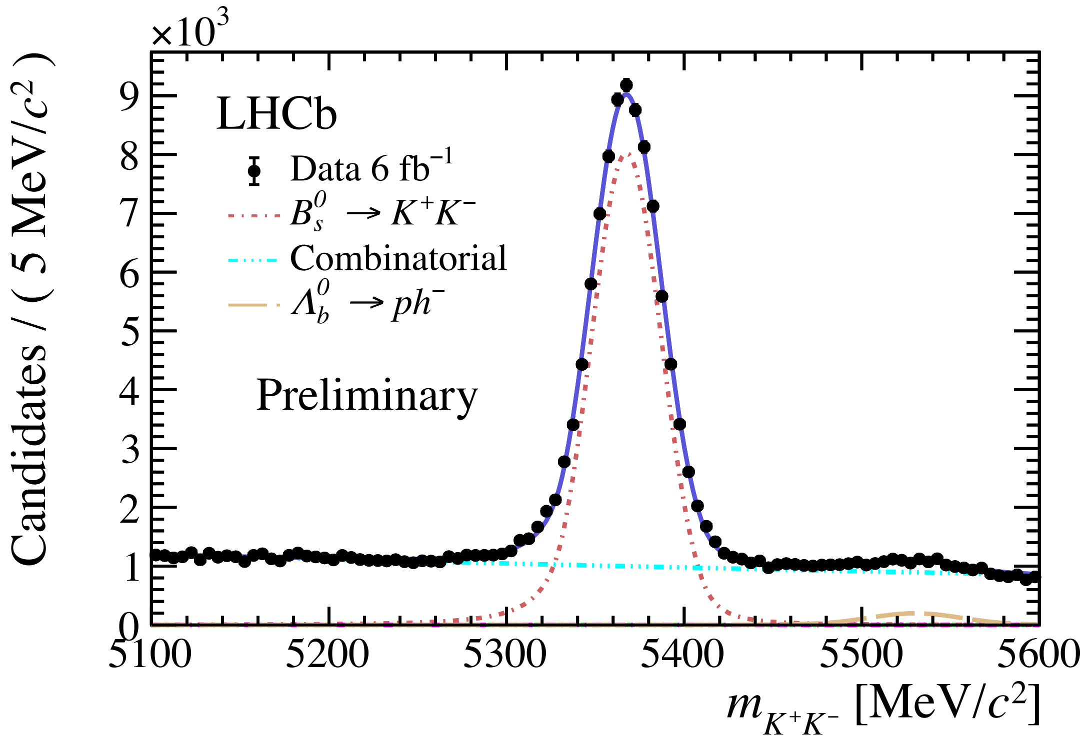
PAPER-2021-007 forthcoming

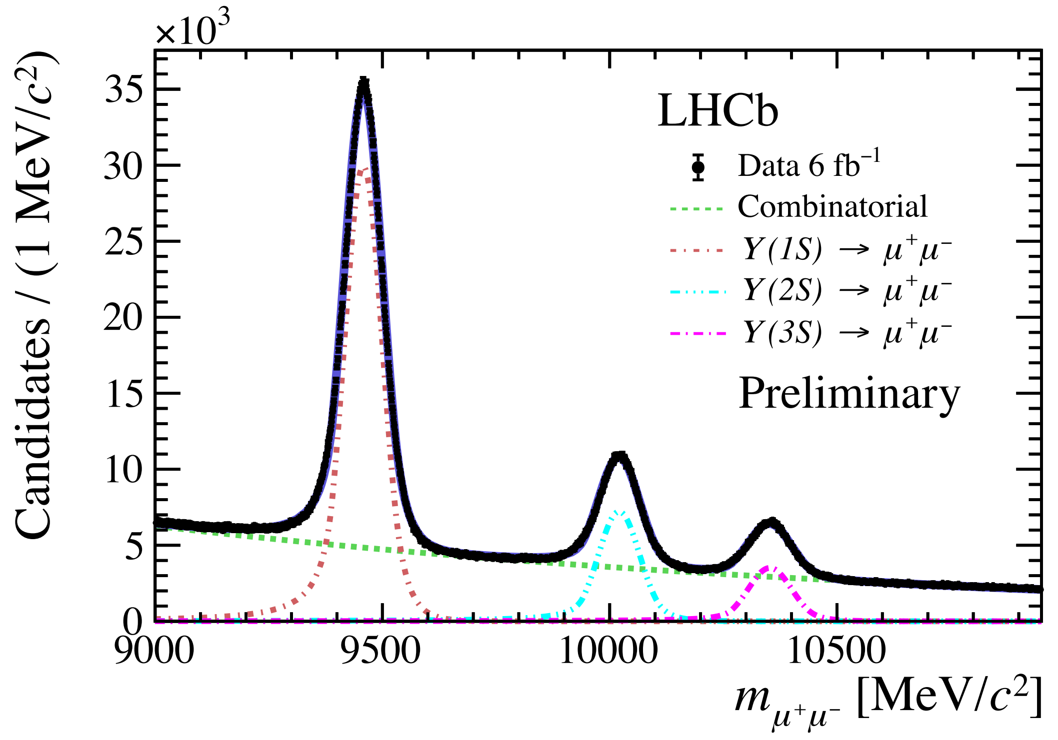


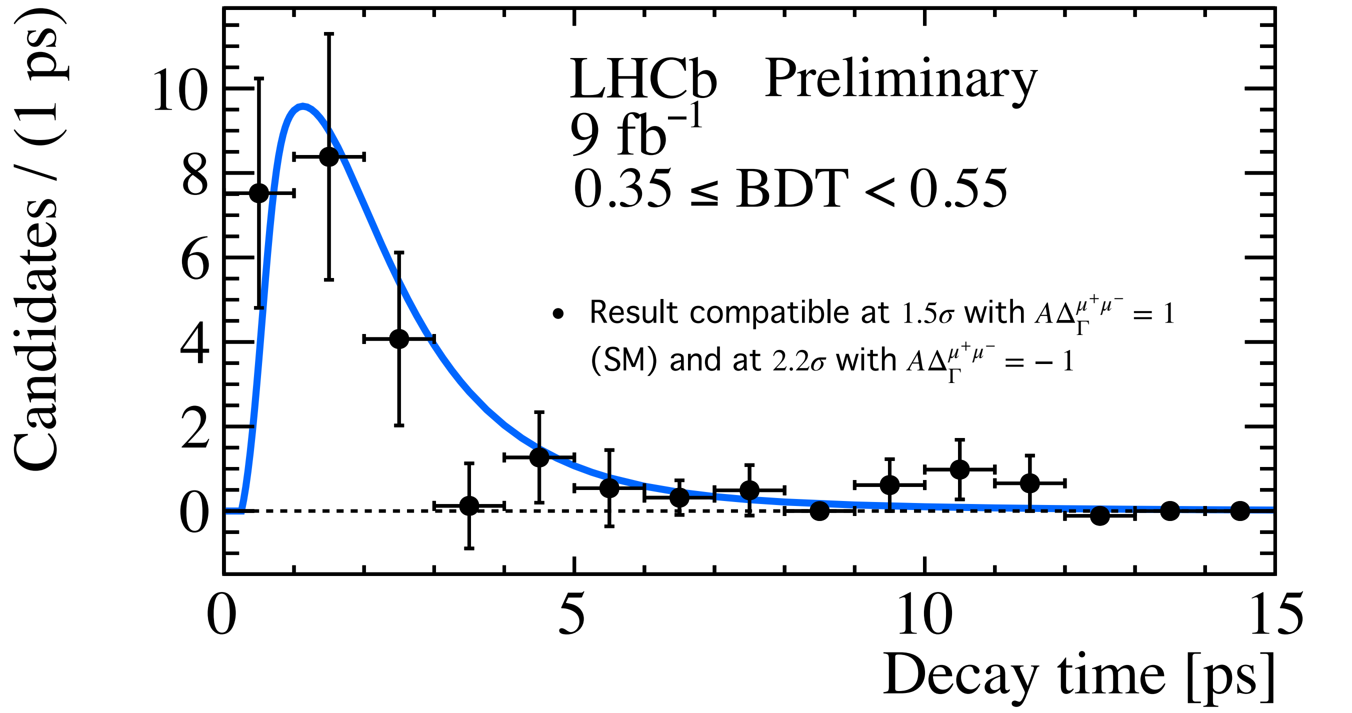


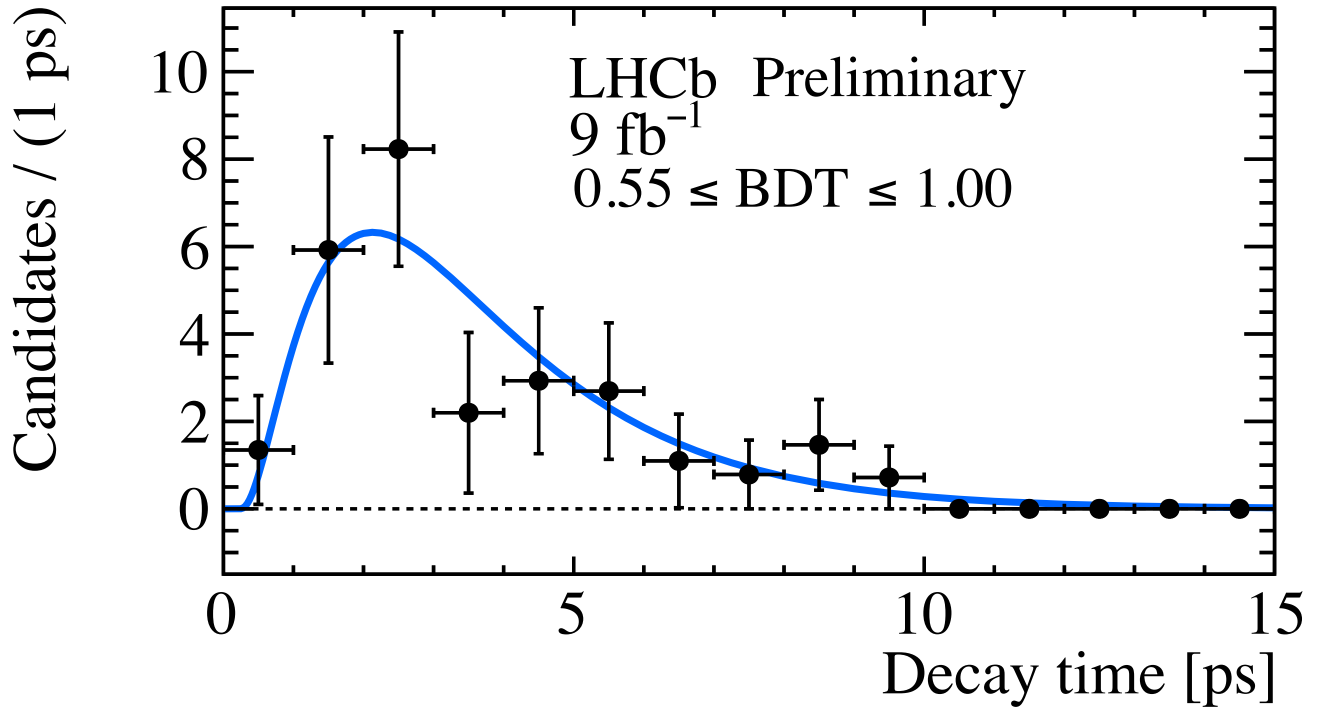












Future prospects

9 fb^{-1} — Goal: 50 fb^{-1} — Goal: 250 fb^{-1}

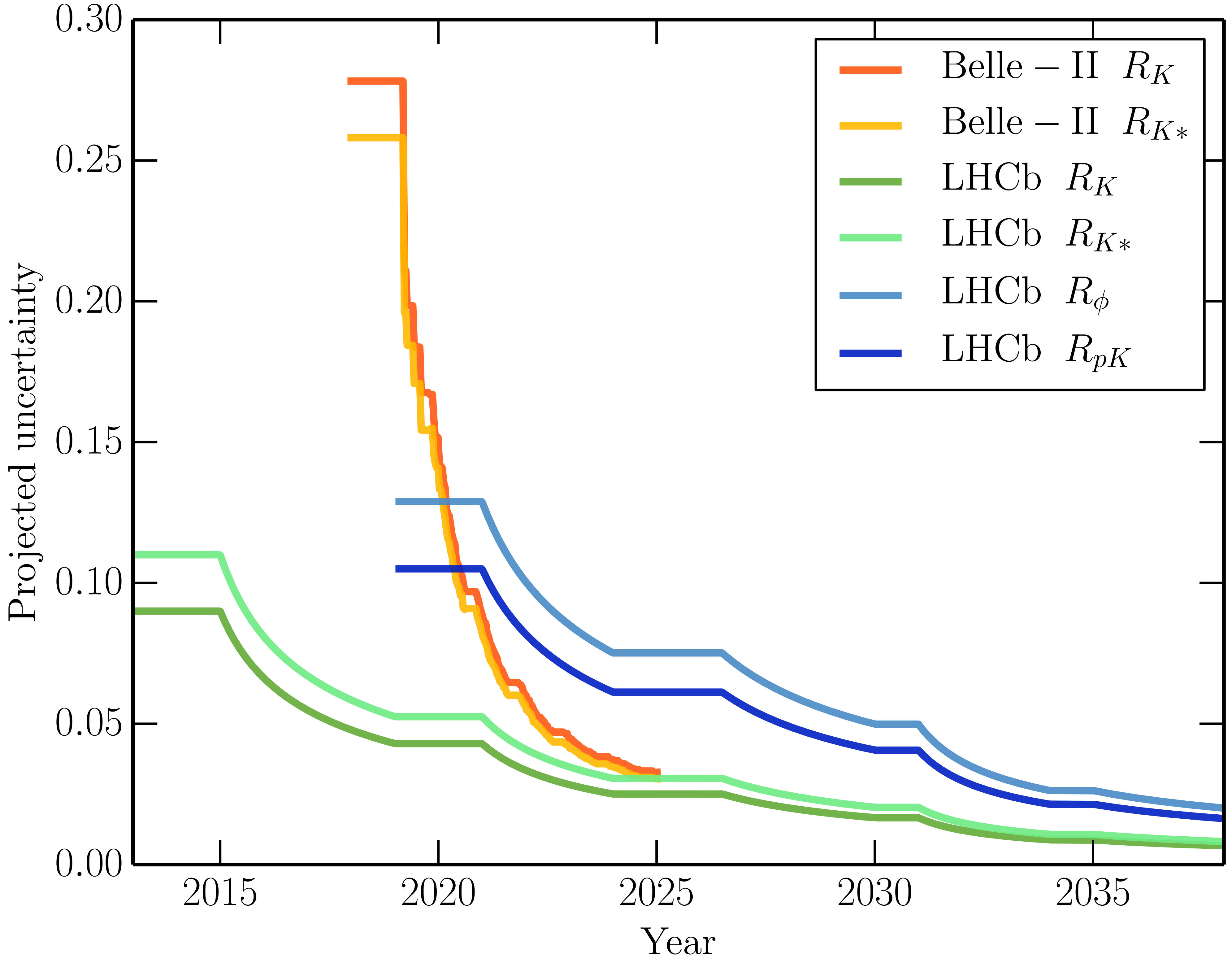
Upgrade I — Upgrade II

Run 1		LS1		Run 2				LS2			Run 3			LS3			Run 4			LS4	Run 5			LS5	Run 6	
2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037

Belle II

- **Uncertainties** on the **LFU ratios** expected to reach about **2-3% with 2025 LHCb dataset**
  - ➡ Belle II expected to take longer than in plot

Bifani, Descotes-Genon, Romero Vidal, Schune
[Journal of Physics G: Nuclear and Particle Physics, 46, 2 (2018)]



LHCb upgrades

9 fb^{-1} — Goal: 50 fb^{-1} — Goal: 250 fb^{-1}

Upgrade I — Upgrade II

Run 1	LS1	Run 2	LS2	Run 3	LS3	Run 4	LS4	Run 5	LS5	Run 6
2011 2012	2013 2014	2015 2016 2017 2018	2019 2020 2021	2022 2023 2024	2025 2026 2027	2028 2029 2030	2031	2032 2033 2034	2035	2036 2037

Belle II

Runs 1 and 2

40 MHz pp collisions → **L0** Hardware → 1.1 MHz Detector readout → **HLT** Software → 12.5 kHz (0.6 GB/s) Events on disk

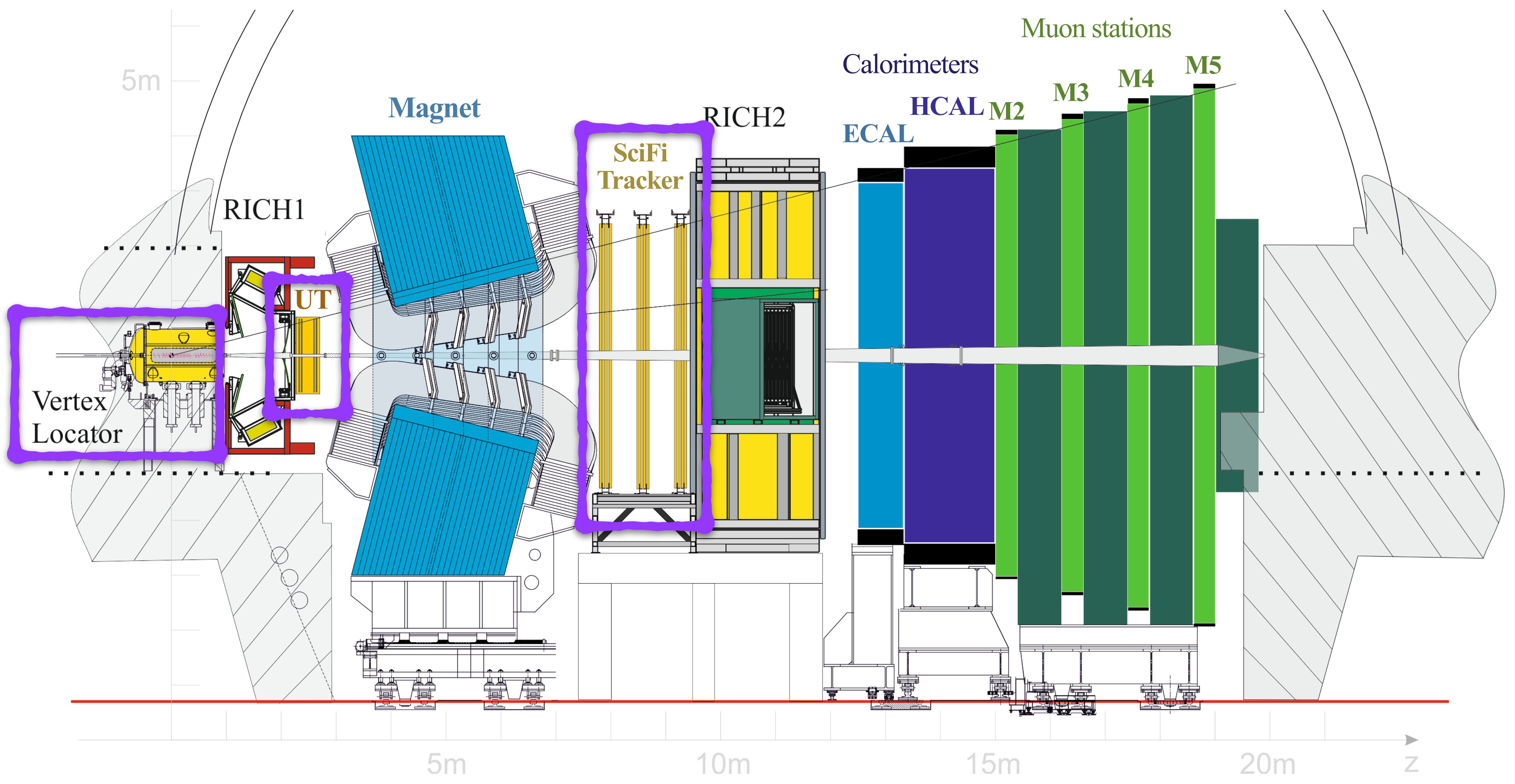
Upgrade I (being installed)

40 MHz pp collisions Detector readout → **HLT** Software → 100 kHz (2-5 GB/s) Events on disk

Flexible software and better trackers

Upgrade II (proposed)

Even better granularity, improved calorimeter, and fast timing



Some $\mathscr{R}\left(K^{(*)}\right)$ measurements

arXiv	Observable	Exper.	Lumi [fb^{-1}]	Journal
2103.11769	**RK+**	**LHCb**	**9**	**Sub. to Nature 17/03/2021**
2012.13241	Angular K*+μμ	LHCb	9	Accepted by PRL 11/03/2021
2003.04831	CP-averaged K*0μμ	LHCb	4.7	Phys. Rev. Lett. 125, 011802 (2020)
1912.08139	RpK	LHCb	4.7	JHEP 2020, 40 (2020)
1908.01848	**RK0 and RK+**	**Belle**	**711**	**BELLE-CONF-1904, Belle Preprint 2020-11**
1904.02440	**RK*0 and RK*+**	**Belle**	**711**	**Sub. to PRL 29/09/2020**
1903.09252	**RK+**	**LHCb**	**5**	**Phys. Rev. Lett. 122 (2019) 191801**
1705.05802	**RK*0**	**LHCb**	**3**	**JHEP 08 (2017) 055**
1612.05014	Angular K*ℓℓ	Belle	711	Phys. Rev. Lett. 118, 111801 (2017)
1512.04442	Angular K*0μμ	LHCb	3	JHEP 02 (2016) 104
1506.08777	Angular/BF Bs→ϕμμ	LHCb	3	JHEP 09 (2015) 179
1406.6482	**RK+**	**LHCb**	**3**	**Phys. Rev. Lett. 113, 151601 (2014)**