B anomalies experimental status and prospects

Flavour Changing and Conserving Processes 2022
Anacapri 22-24 September 2022

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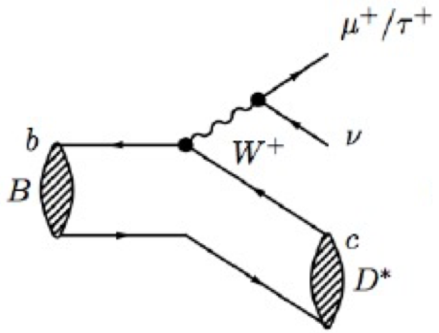
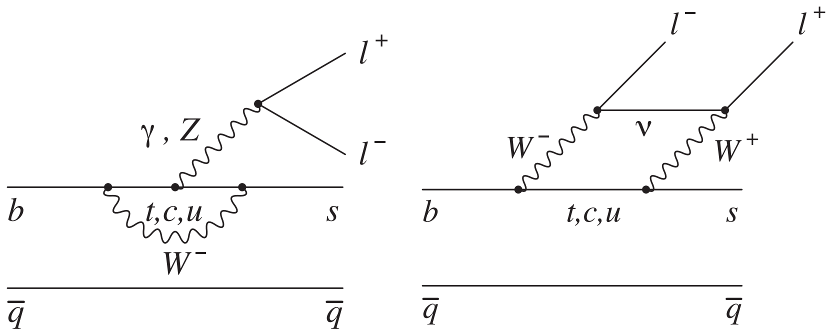
I will show material published by

Outline

- Anomalies in B decays:
  current hints of Lepton Flavour Universality (LFU) violations
  - R(K) and R(K*) anomaly found by LHCb
  - R(D) - R(D*) first found by BaBar, then tested by Belle and LHCb results
- Few words on related searches
  - LFU tests in other (semi)leptonic B decays
- Future prospects at LHCb and Belle II

LFU violating B decays





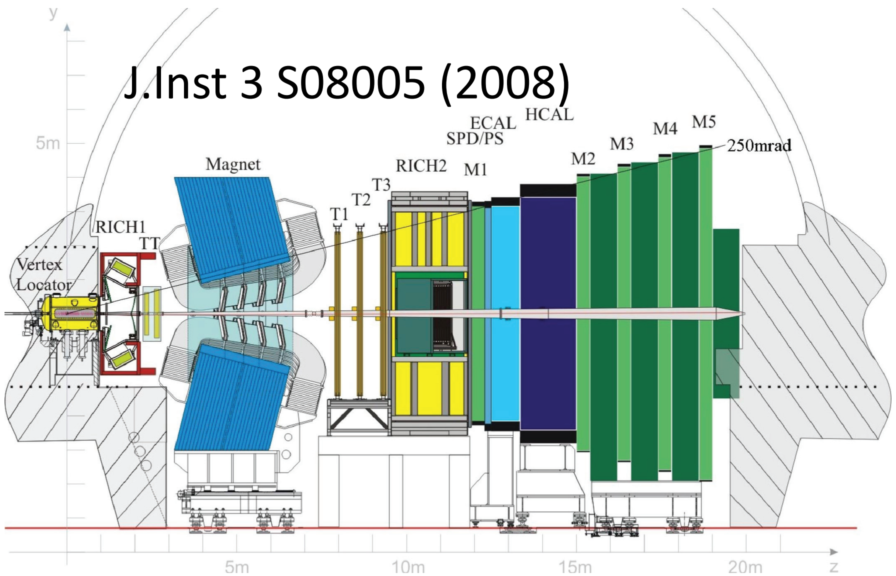
- b → c l ν decays, l = {e,μ,τ}
- Charged current tree level
  b → c process
- Large sample of events
- Observable:
  Total rates: τ leptons are found in disagreement with SM.

$$R(D^*) = \frac{\mathcal{B}(\mathrm{B} \to \mathrm{D}^{(*)}\tau\nu)}{\mathcal{B}(\mathrm{B} \to \mathrm{D}^{(*)}\ell\nu)}$$

- b → s l+ l-, l = {e,μ}
- Flavour changing neutral current, loop level in the SM
- Rare decays
- Observables:
  Angular observables: depart from SM expectations
  Muons and electrons rate different

$$\mathcal{R}(\mathrm{K}) = \frac{\mathcal{B}(\mathrm{B} \to \mathrm{K}\mu\mu)}{\mathcal{B}(\mathrm{B} \to \mathrm{Kee})}$$

LHCb vs e+e- B-Factories

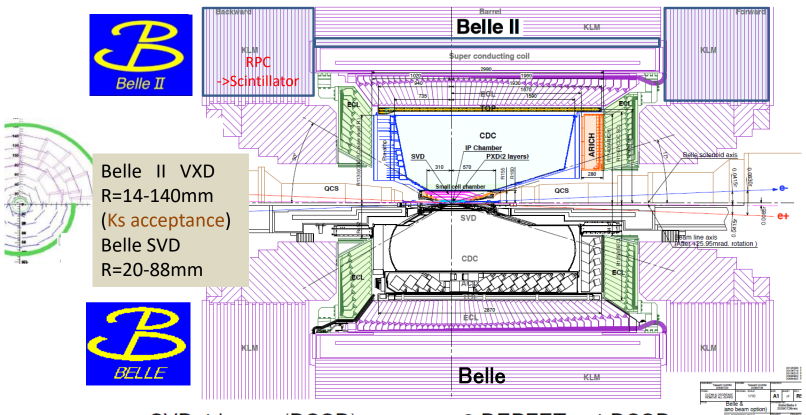


Large heavy flavour cross section production

Excellent tracking and vertexing to exploit displaced vertex and kinematics

Charged particle identification

Electrons performances less brilliant than muons' one.



SVD 4 layers (DSSD)	→	2 DEPFET + 4 DSSD
CDC:		small cell, long lever arm
ACC+TOF	→	TOP+ARICH (Better K/p separation)
ECL:		waveform sampling
KLM: RPC	→	Scintillator+SiPM

Exactly 2 (quantum correlated) B meson produced at Y(4S) and trigger efficiency close to 100%

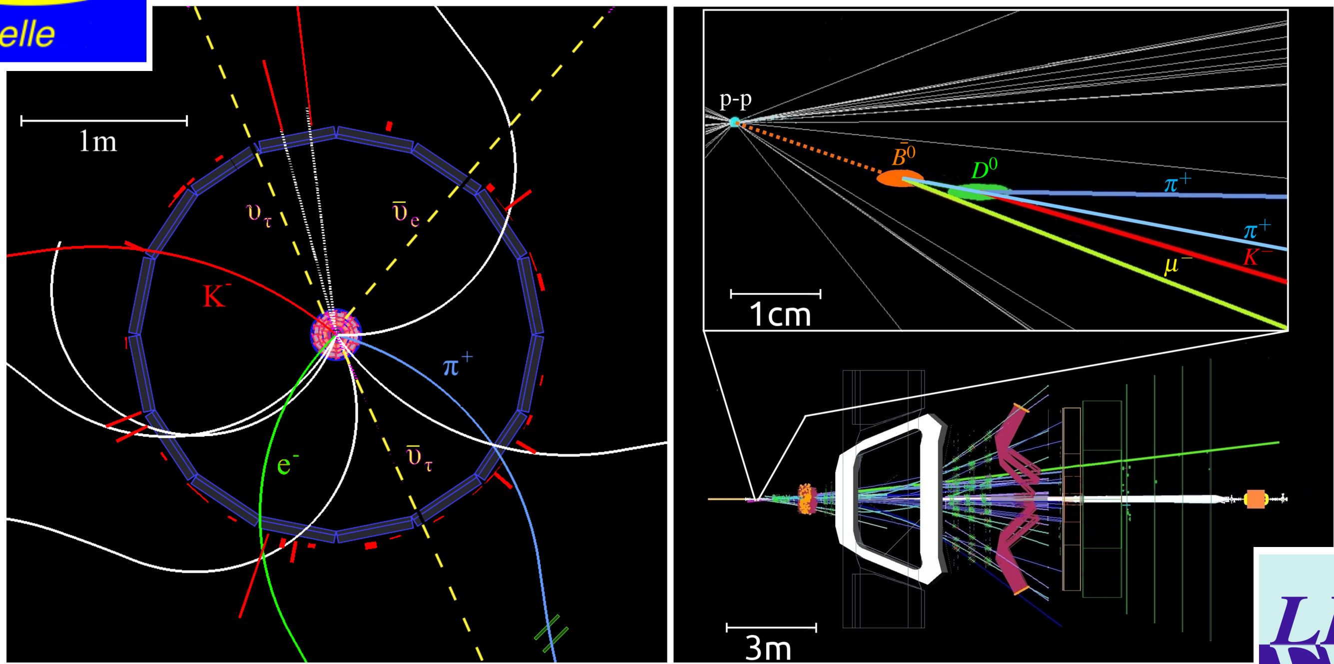
Much less B mesons produced
Belle II will accumulate in 2030 (5×10^{10} B pairs)

Excellent efficiency and resolution in tracking as well as in detecting photons, π^0, K_L

Electrons and muon performances both excellent

e+ e- environment much more "clean" → see next slide

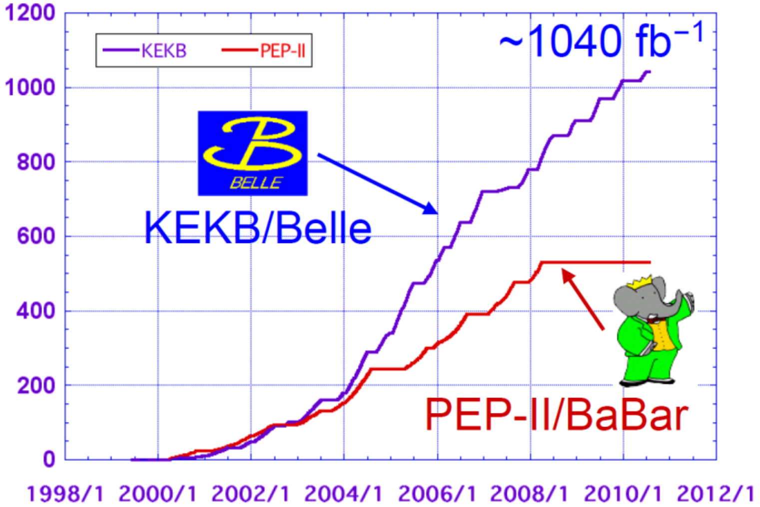
Belle vs LHCb event display

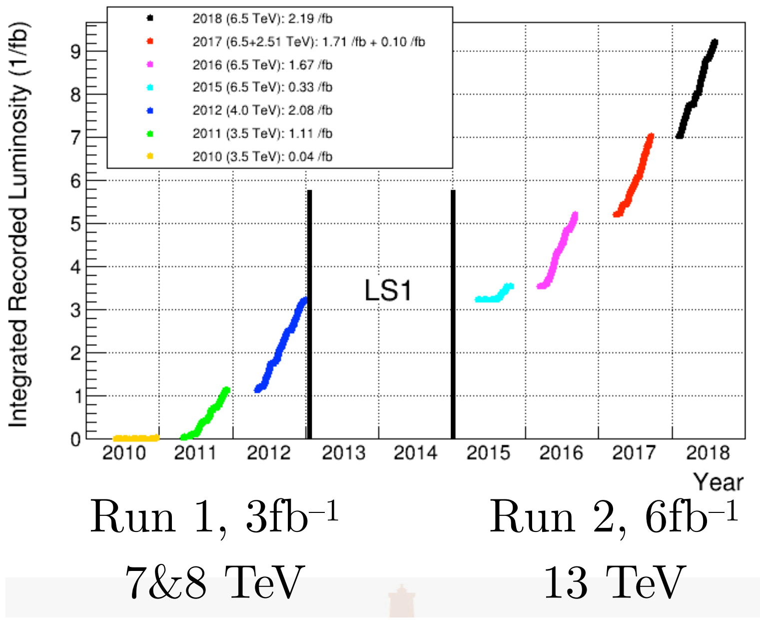


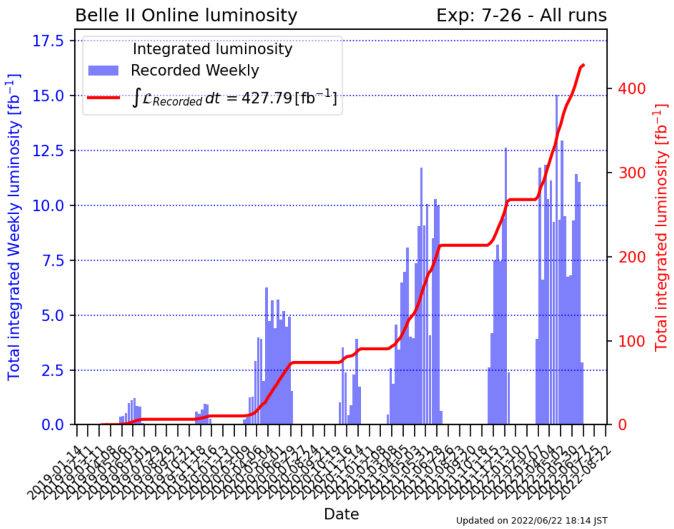
Nature **546**, 227–233 (2017)

Experimental data

Integrated Luminosity [fb-1]







Belle and BaBar finished collecting data 10 years ago

Data still analysed today

Belle : 1 ab^{-1} Babar: 500 fb^{-1}

Belle II 428 fb-1 (362 on Y(4S)+ 42 below + 19 above)

Belle II will collect 50 ab^{-1}

LHCb Run1+Run2 9fb^{-1}

LHCb will collect 50 fb^{-1} before upgrade II then 300 fb^{-1}

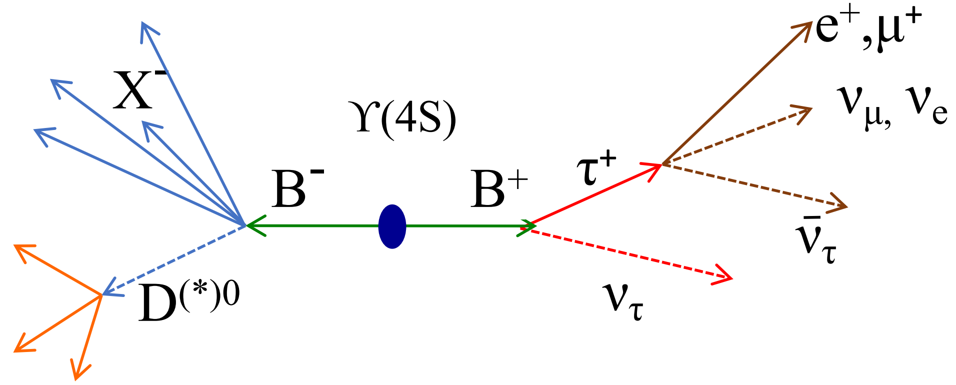
R(D) and R(D*)

Searches at B-factories vs LHCb

BaBar, Belle and Belle II

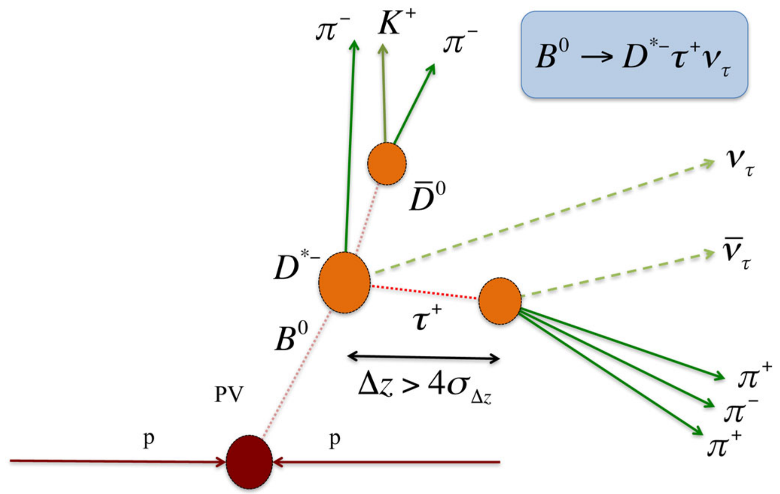
- Can do tagged analyses:
  two kind of tags have been developed
  - HAD tag B → D(*) X , X hadronic system of several $\pi^{\pm}$, π^{0}, $K^{\pm}$
    - pure, lowest efficiency,
    - pBsig = pbeams – pBtag
    - Nothing left in the event
  - SL B → D(*) e/μ ν
    - Less clean, higher efficiency, not fully reco

Fully reco **Look for signal**



LHCb

- Large b quark production cross section
  - Much higher statistics to start with!
- Hadronic enviroment not as clean as e+e-
- Exploit LHCb excellent tracking and vertexing for final states with all charged particles



BaBar RD and RD*

PRL 109, 101803(2012)

Tagged analysis (hadronic tags)
Identify $\tau \rightarrow l \nu\nu$ decays

Reconstruct B_{sig} as a $D^{(*)}$ + $l = \{e,\mu\}$
determine M^2_{miss} from kinematics (pBsig = pbeams – Pbtag)

Normalization sample $B \rightarrow D^{(*)}$ l n at M^2_{miss} near 0
Signal sample at high M^2_{miss}

Despite Standard Model prediction theoretically clean:
q^2 distribution from a form factor precisely calculated in the SM
Experimentally hard:
signature is not a peak on a smooth background!

MV classifier trained to suppress backgrounds retaining signal and normalization events

Most dangerous background $B \rightarrow D^{**} l \nu$
Constrain yield using Data control samples of $B \rightarrow D^* \pi l \nu$ events used

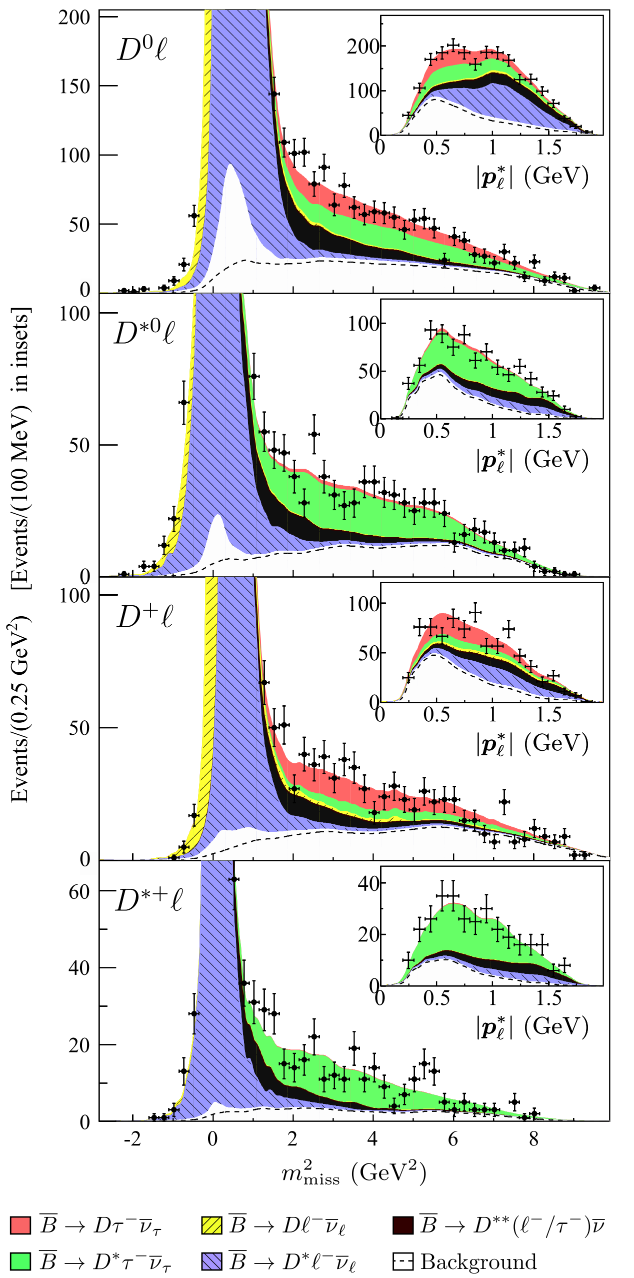


FIG. 1 (color online). Comparison of the data and the fit projections for the four $D^{(*)}\ell$ samples. The insets show the $|p^*_\ell|$ projections for $m^2_{miss} > 1$ GeV^2, which excludes most of the normalization modes. In the background component, the region above the dashed line corresponds to charge cross-feed, and the region below corresponds to continuum and $B\bar{B}$.

$$R(D^*) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}\ell\nu)}$$

$$\mathcal{R}(D) = 0.440 \pm 0.058 \pm 0.042$$

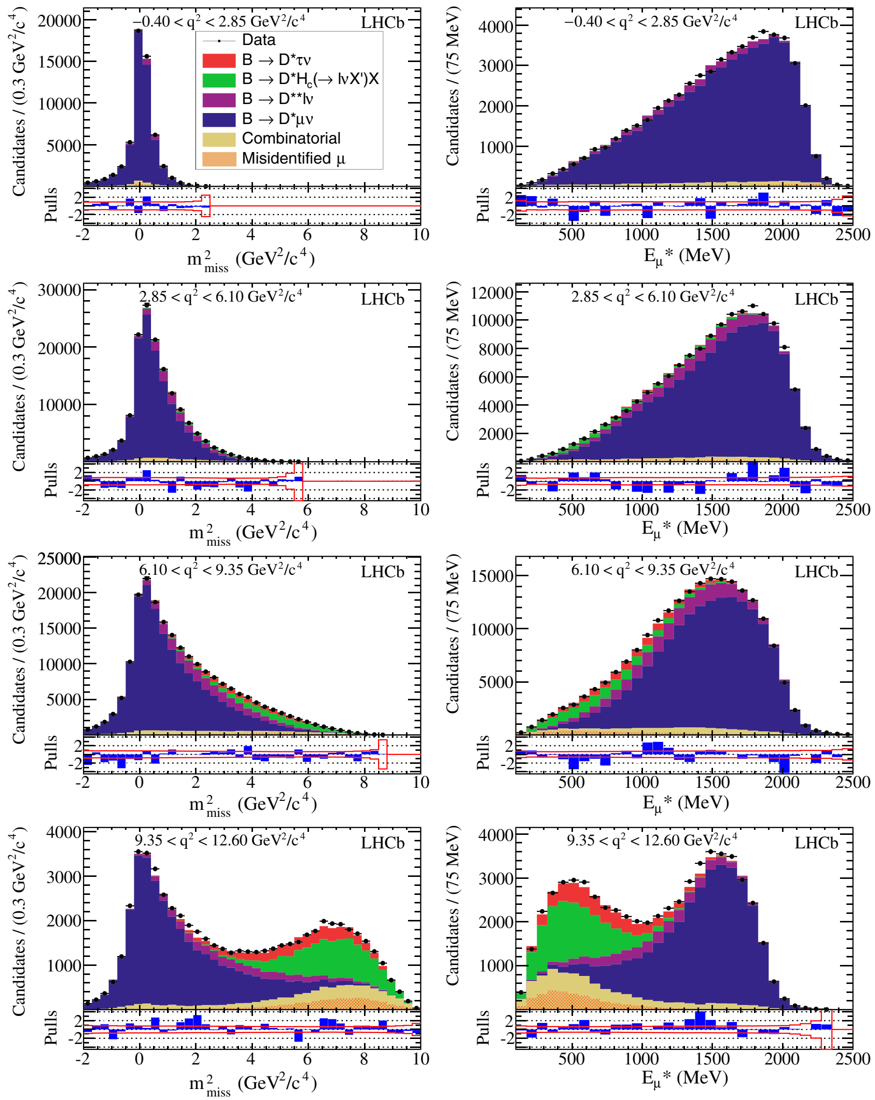
$$\mathcal{R}(D^*) = 0.332 \pm 0.024 \pm 0.018$$

LHCb B $\rightarrow$ D* τ ν

Phys.Rev.Lett. 115 111803 (2015)

- Select a sample with μ + D* final state ($D^{*+} \rightarrow D^0 \pi$, $D^0 \rightarrow K \pi$)
- Same reconstruction procedure for signal mode (D* τ ν , $\tau \rightarrow \mu \nu \nu$) and normalization mode (D* μ ν)
- B meson flight information used to constrain kinematics
- BDT trained to separate signal + normalization vs background
- Largest backgrounds B $\rightarrow$ D* H_c ($\rightarrow \mu \nu Y$)X, partially reconstructed B decays, B --> D** l ν decays.
- signal, normalization and backgrounds yields from 3D binned maximum likelihood fit to q^2 x m^2_{miss} x E^*_μ
- combinatorial, D** l ν backgrounds constrained on data control samples (D* μ π and D* μ π π)

$$R(D^*) = 0.336 \pm 0.027 \pm 0.030$$

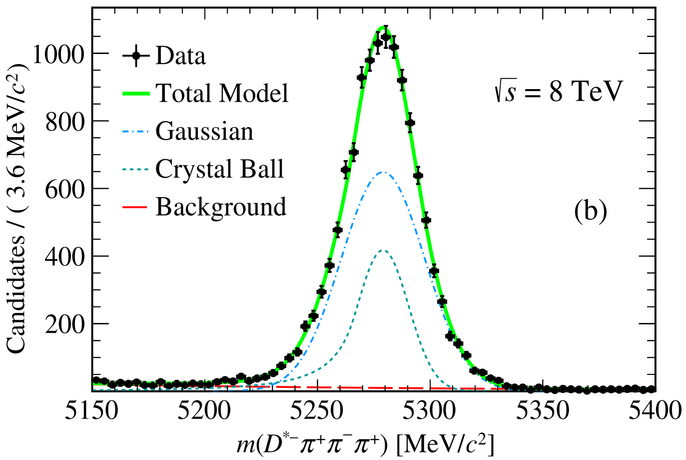


LHCb R(D*) with $B^0 \rightarrow D^{*-} \tau^+ \nu$ ($\tau \rightarrow 3\pi\nu$)

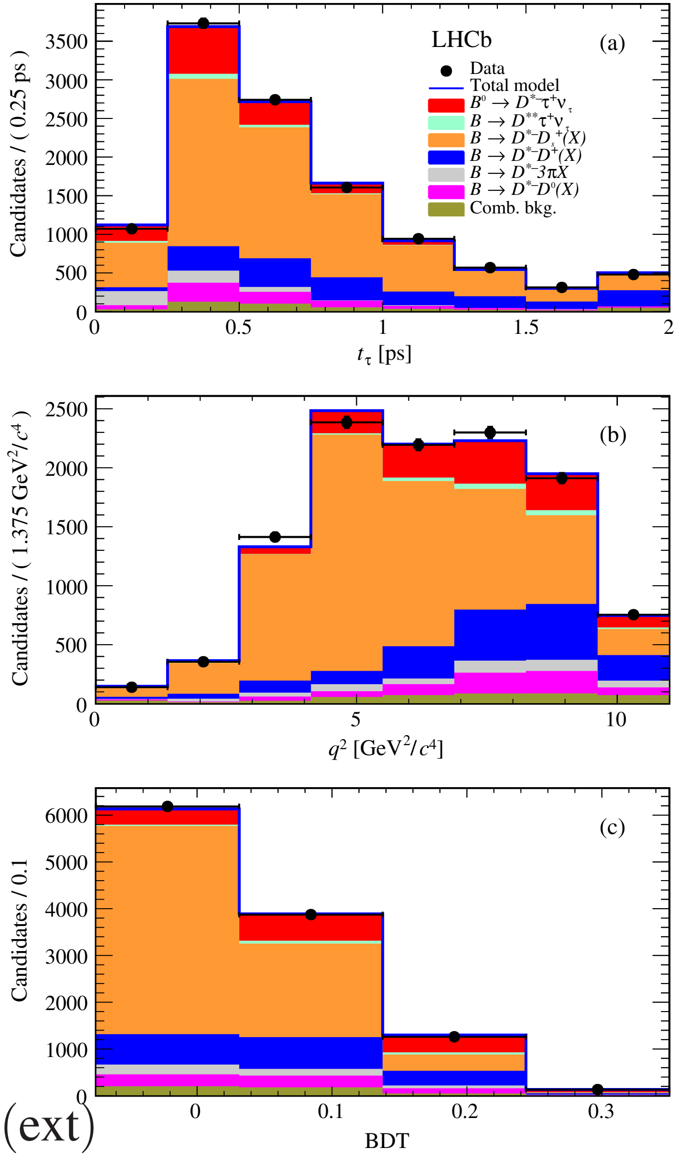
Phys.Rev. D, 97 072013 (2018)

- Signal mode $B0 \rightarrow D^* \tau (\rightarrow 3\pi(\pi^0)\nu) \nu$
  normalization mode $B \rightarrow D^* 3\pi$
- Binned maximum likelihood fit to 3D distribution of ($\pi\ \pi\ \pi$) decay time (8 bins), q^2 (8 bins) and MV classifier output (4 bins) to extract signal yield

Normalization yield fit



Signal yield fit



$$\mathcal{K}(D^{*-}) \equiv \frac{\mathcal{B}(B^0 \rightarrow D^{*-}\tau^+\nu_\tau)}{\mathcal{B}(B^0 \rightarrow D^{*-}3\pi)}$$
$$= \frac{N_{\rm sig}}{N_{\rm norm}} \frac{\varepsilon_{\rm norm}}{\varepsilon_{\rm sig}} \frac{1}{\mathcal{B}(\tau^+ \rightarrow 3\pi\bar{\nu}_\tau) + \mathcal{B}(\tau^+ \rightarrow 3\pi\pi^0\bar{\nu}_\tau)}$$

$$R(D^*) = \frac{\mathcal{B}(\mathrm{B} \rightarrow \mathrm{D}^{*-}3\pi)}{\mathcal{B}(\mathrm{B} \rightarrow \mathrm{D}^{*-}\ell\nu)} \mathcal{K}$$
$$= 0.291 \pm 0.019(\mathrm{stat}) \pm 0.026(\mathrm{syst}) \pm 0.013(\mathrm{ext})$$

Belle B → D* τ ν (τ→ l ν ν) SL tags

PRL 124, 161803(2020)

- Simultaneous measurement of R(D) and R(D*) with SL tag Method
- Tag side: $B^{0/+} \rightarrow D^{(*)+/0}\, l^-\, \nu$
  signal side: signal $B \rightarrow D^{(*)+/0}\, \tau^-\, \nu\, (\tau \rightarrow e/\mu\, \nu\, \nu)$ normalization $B \rightarrow D^{(*)}\, l\, \nu$

D+ l-

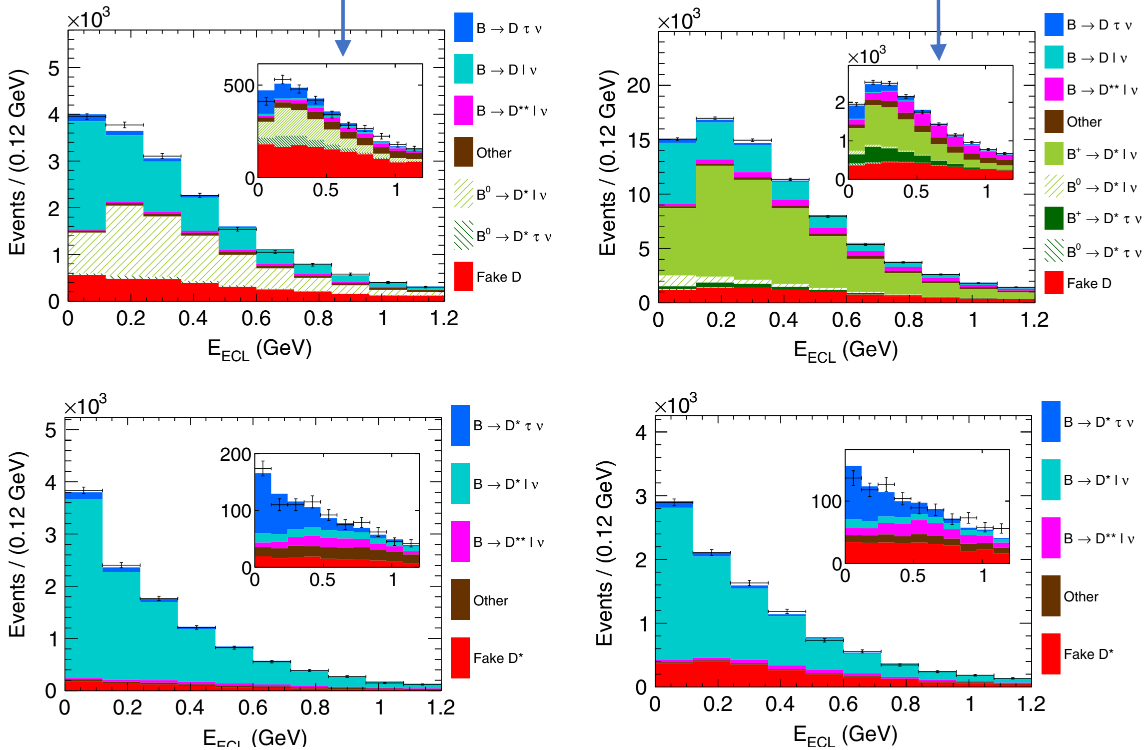
SR: $O_{cls} > 0.9$

D0 l-

Signal and BG yields by 2D binned max likelihood fit to E_{ECL} and O_{cls}

E_{ECL} energy in calorimeter not assigned to tag or sig B (expect zero for signal)

O_{cls} multivariate classifier output to suppress BG (ML based)



$$\mathcal{R}(D^{(*)}) = \frac{1}{2\mathcal{B}(\tau^- \rightarrow \ell^- \bar{\nu}_\ell \nu_\tau)} \frac{\varepsilon_{\rm norm}}{\varepsilon_{\rm sig}} \frac{N_{\rm sig}}{N_{\rm norm}}$$

$$R(D^*) = 0.283 \pm 0.018 \pm 0.014$$

$$R(D) = 0.307 \pm 0.037 \pm 0.016$$

D*+l-

D*0+l-

Combined value consistent to SM within 1.6 σ

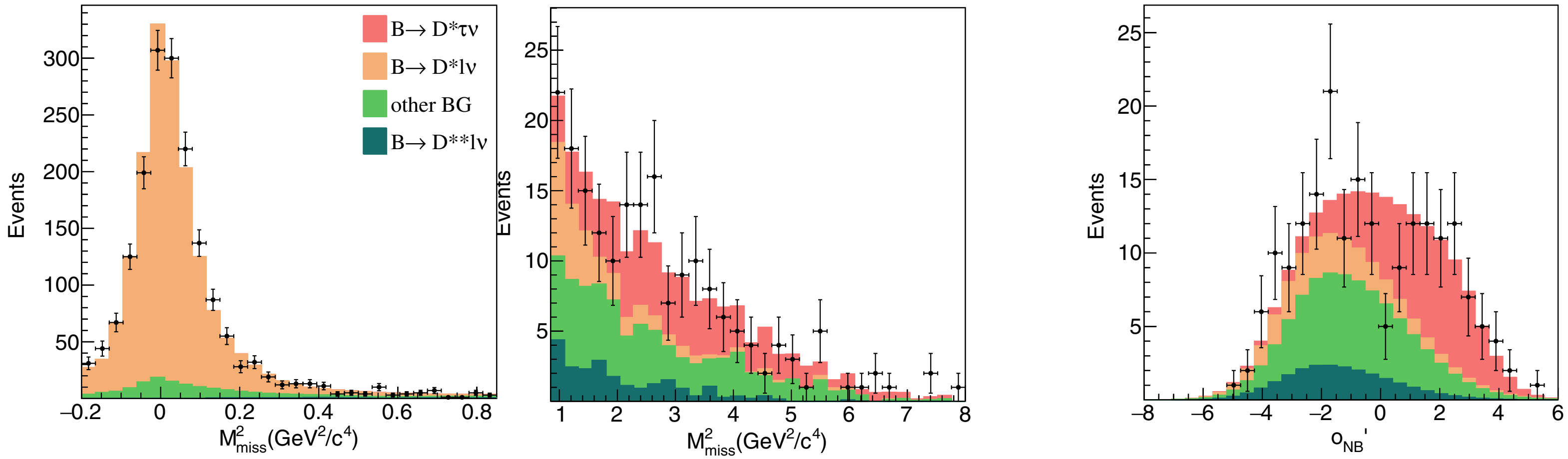
Belle B → $D^{(*)} \tau \nu$ Hadronic tags

Leptonic decays $\tau \to l \nu \nu$ PRD 92, 072014 (2015)

unbinned maximum likelihood using MV classifier out O_{NB} and missing mass

4 samples ($D^{*+} l^-$, $D^{*0} l^-$, $D^+ l^-$, $D^0 l^-$)

$D^{*+} l^-$



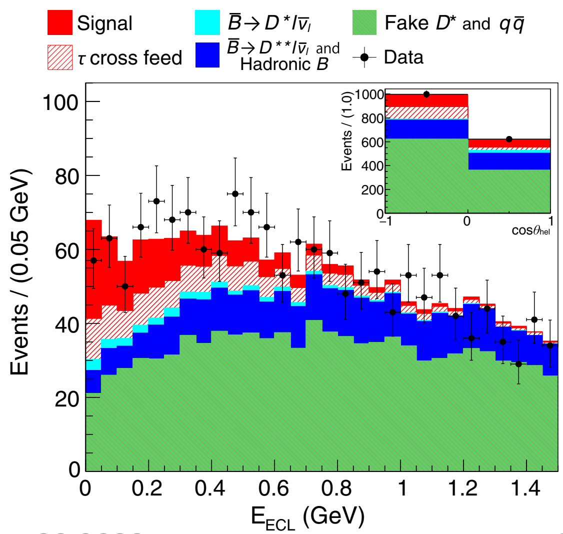
$R(D) = 0.375 \pm 0.064 \quad R(D^*) = 0.293 \pm 0.038$

hadronic decays $\tau \to \pi\nu$, $\rho\nu$

PRD 97, 012004 (2018)

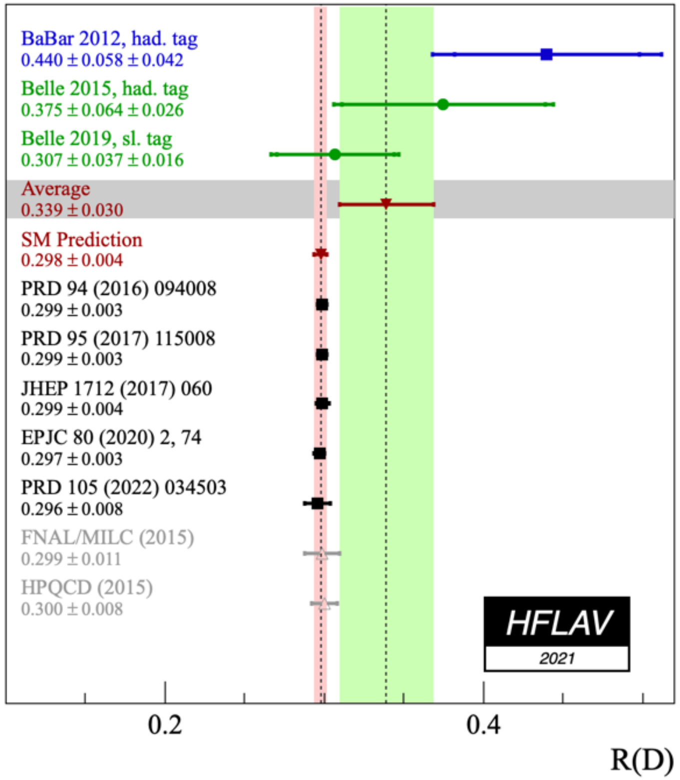
PRL 118,211801 (2017) $R(D^*) = 0.270 \pm 0.035(\mathrm{stat})^{+0.028}_{-0.025}(\mathrm{syst}),$

$$P_\tau(D^*) = -0.38 \pm 0.51(\mathrm{stat})^{+0.21}_{-0.16}(\mathrm{syst})$$

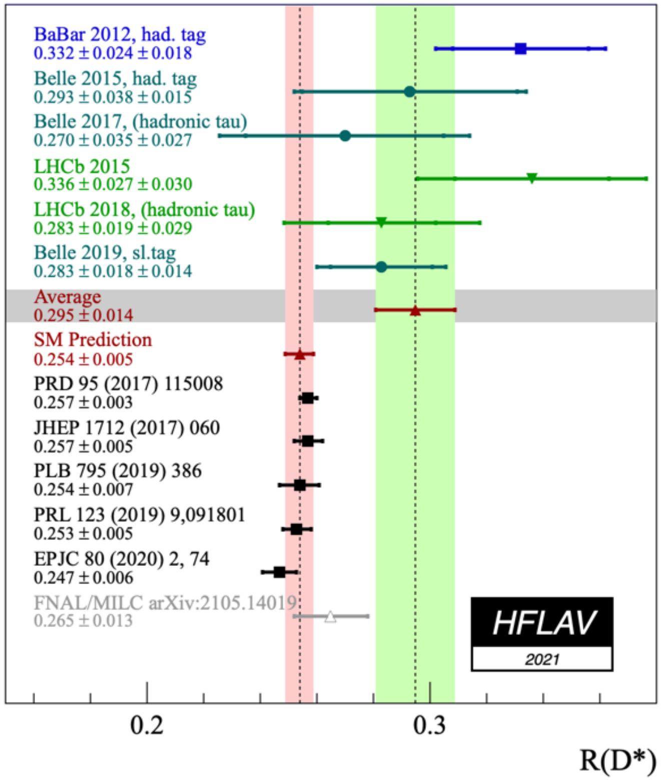


Comparison and average from HFLAV

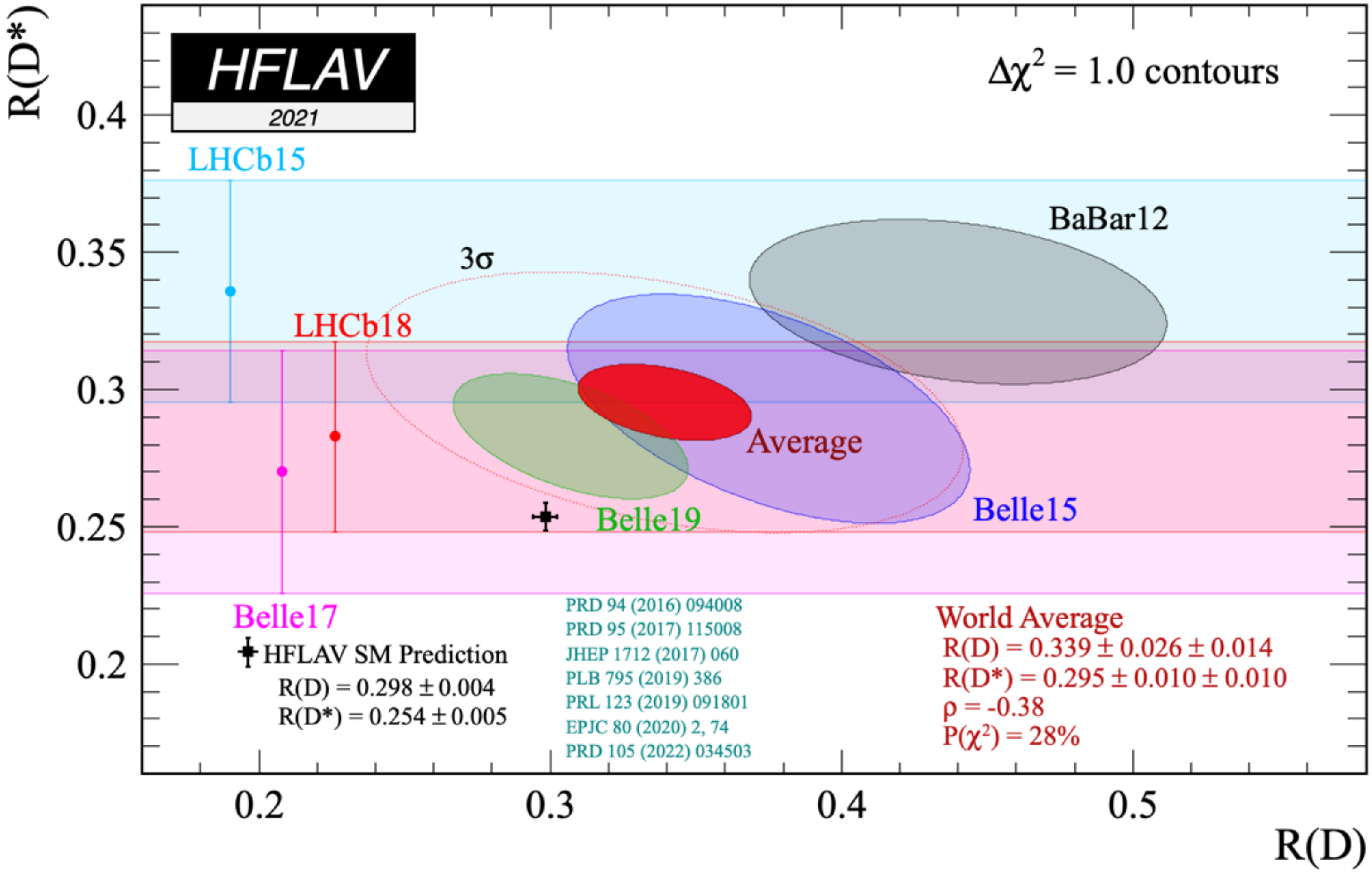
R(D)



R(D*)

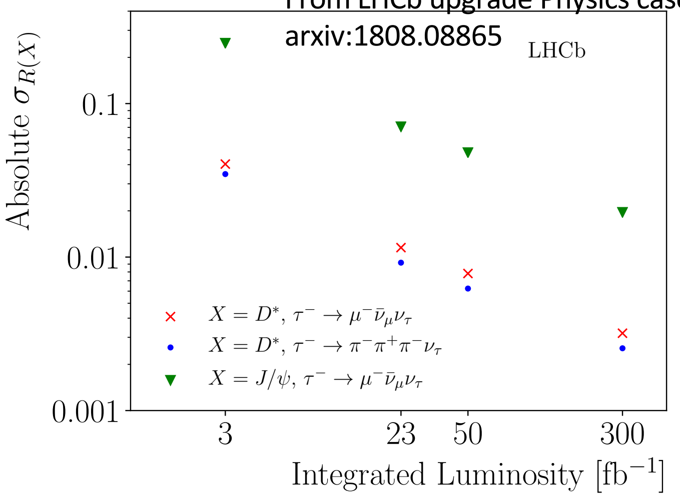


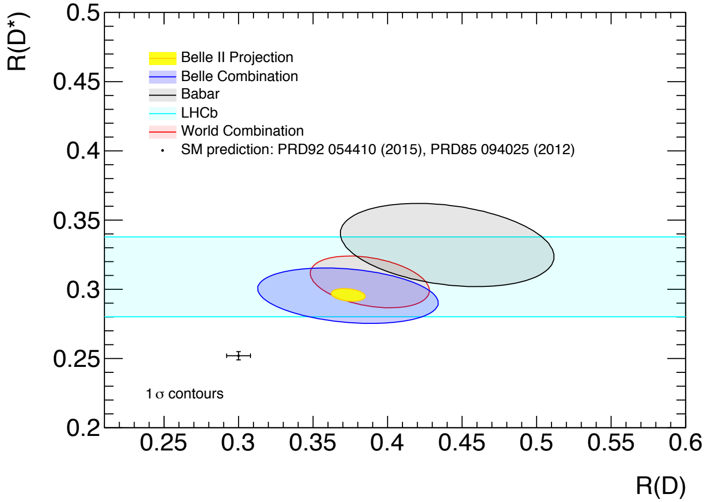
Current R(D*)-R(D) landscape



R(D*) projections LHCb and Belle II

From LHCb upgrade Physics case
arxiv:1808.08865



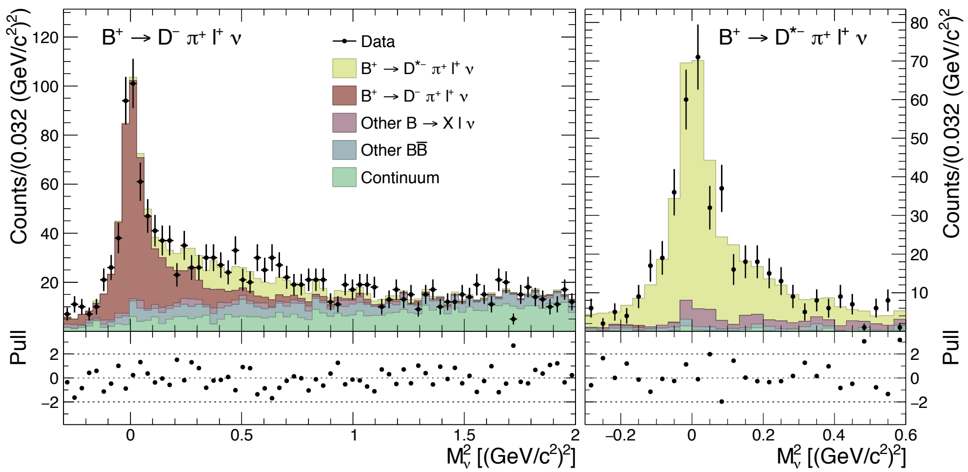


Belle II and LHCb expected to greatly improve the uncertainty on R(D) and R(D*)
Belle II expect to reach 2% and 3% limited by systematics. LHCb quotes 1% with 300 fb^{-1}

Large contribution to systematics is the uncertainty in D** component.
→ Belle II will study in detail B → D** l ν

A simultaneous R(D), R(D*) and R(D**) determination may be feasible

Belle B → D* π l ν
Phys Rev D 98 012005 (2018)



FCNC $B \to K^{(*)} l l$ and $R(K^{(*)})$

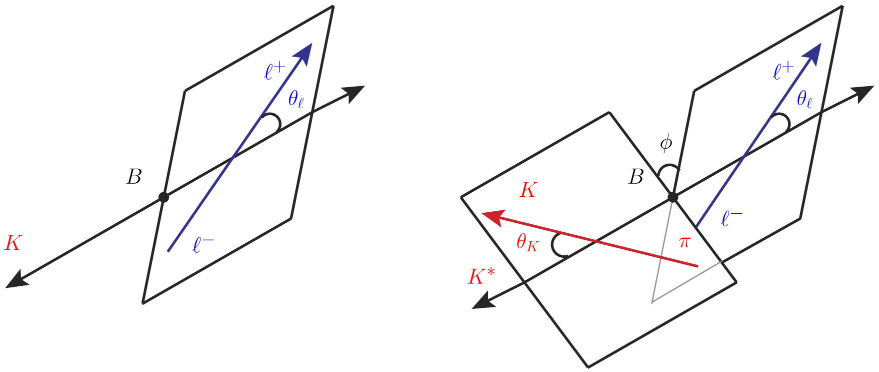
$B^0 \rightarrow K^{*0} \mu^+ \mu^-$ angular analysis

Select 2 high opposite charge energy muons

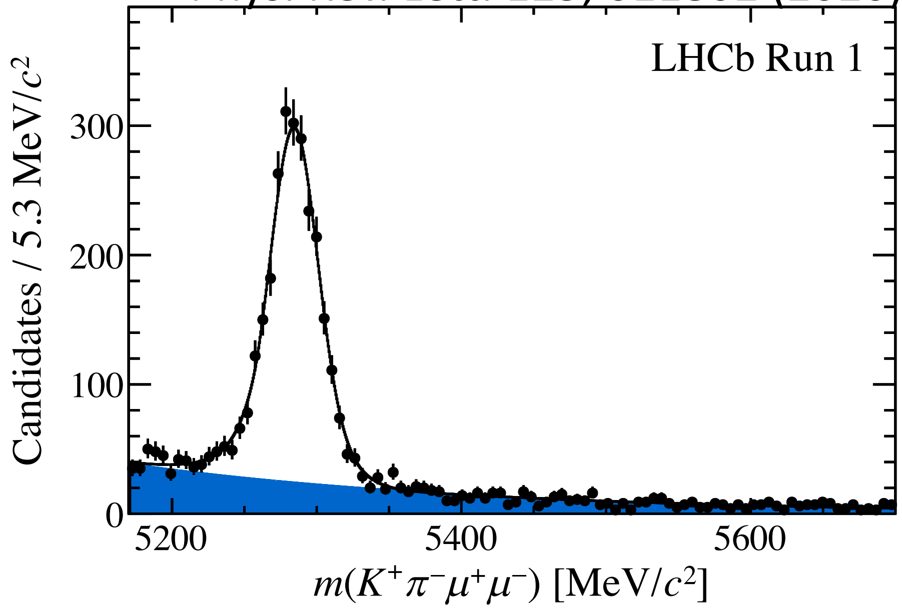
Look for $K^{*0} \rightarrow K \pi$ decays

$B \rightarrow J/\psi K^*$, $J/\pi \rightarrow \mu \mu$ used as data control sample

Very clean and enough statistics at LHCb to perform angular analysis



Phys. Rev. Lett. 125, 011802 (2020)



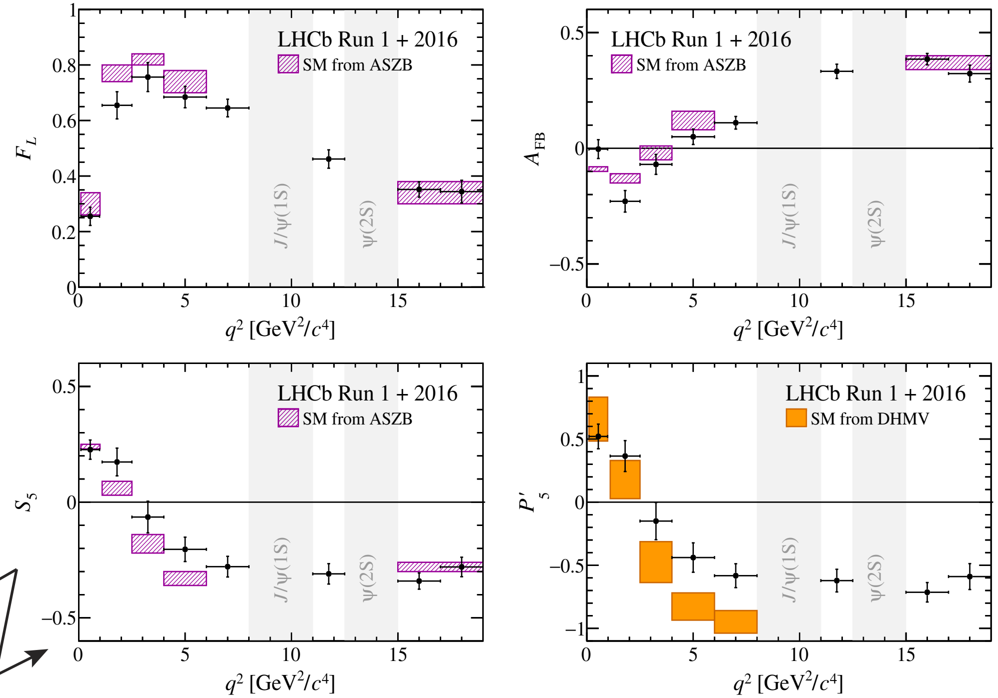
$$\frac{d^4\Gamma(B \to K^*\ell^+\ell^-)}{d\cos\theta_\ell \, d\cos\theta_K \, d\phi \, dq^2} = \frac{9}{32\pi} \sum_j \bar{I}_j f_j(\cos\theta_\ell, \cos\theta_K, \phi),$$

Differential decay rate affected significant theory uncertainties

Different re-parameterization aiming at minimize theory uncert. have been adopted, like the P'_i series

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

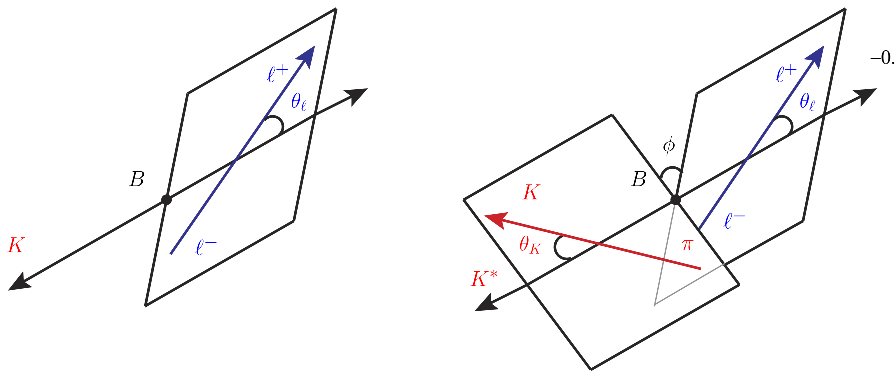
Phys. Rev. Lett. 125, 011802 (2020)



Select 2 high opposite charge energy muons
Look for $K^{*0} \to K\,\pi$ decays

$B \to J/\psi\, K^*$, $J/\pi \to \mu\,\mu$ used as data control sample

Very clean and enough statistics at LHCb to perform angular analysis



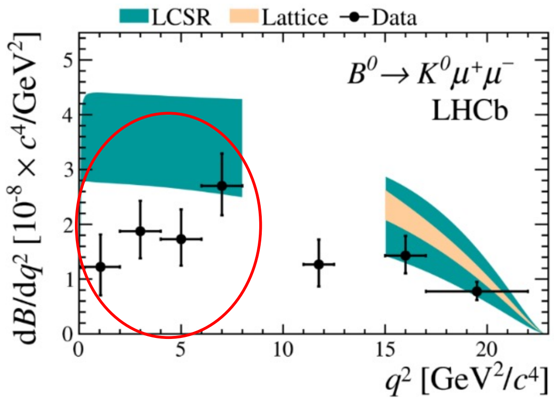
Using the FLAVIO toolkit LHCb collaboration quote a 3.3 σ shift from SM.

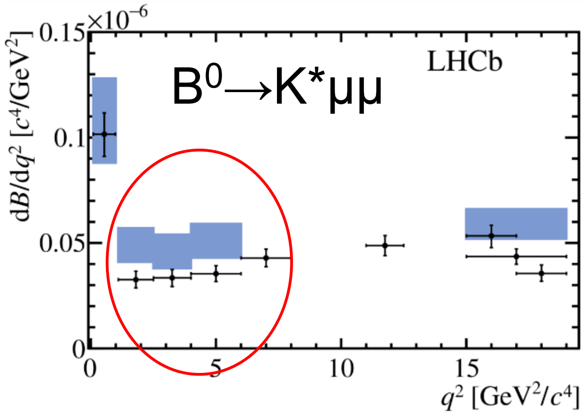
LHCb exploited several final states

LHCb exploited several final states.
All modes seem to show the same pattern of disagreement with SM expectations at low q2

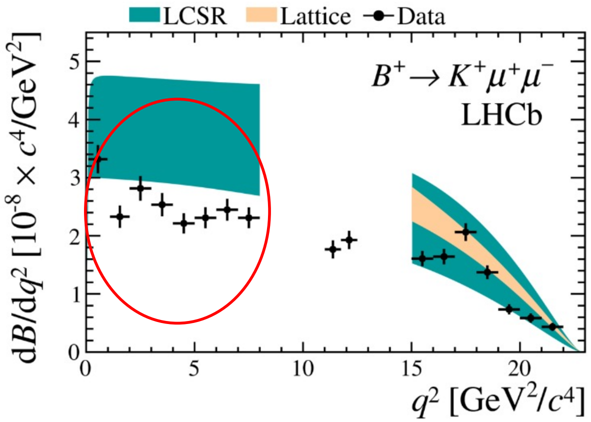
... or systematic (hadronic) effects not fully constrained in theory (much dabated)

[JHEP 06 (2014) 133]



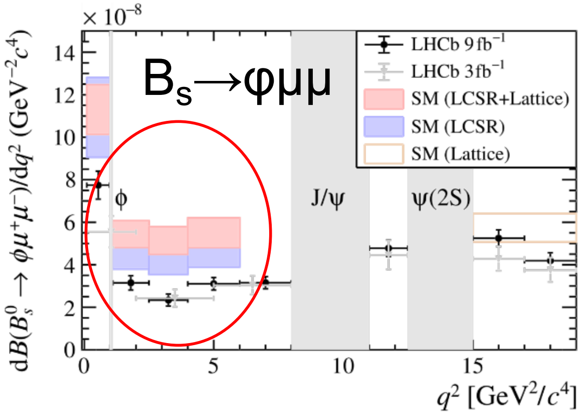


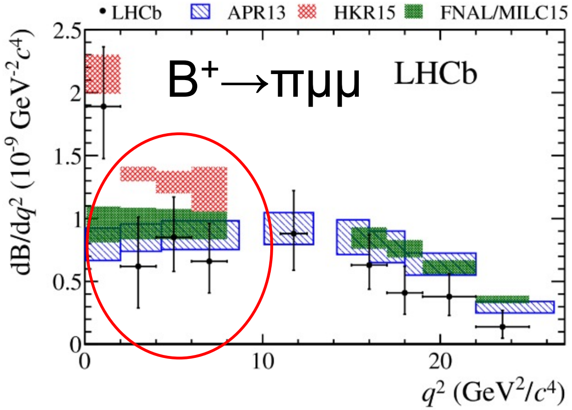
[JHEP 04 (2017) 142]



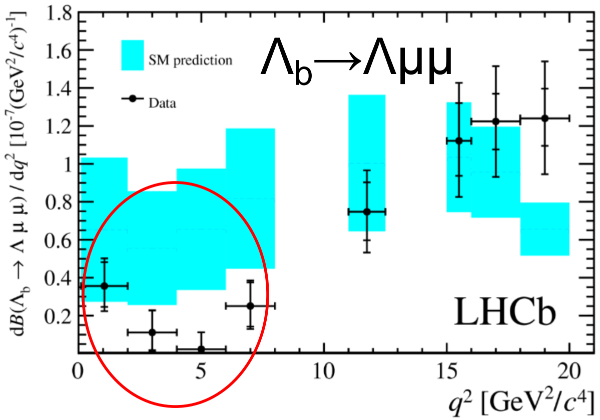
[JHEP 06 (2014) 133]

[PRL 127 (2021) 151801]





[JHEP 10 (2015) 034]



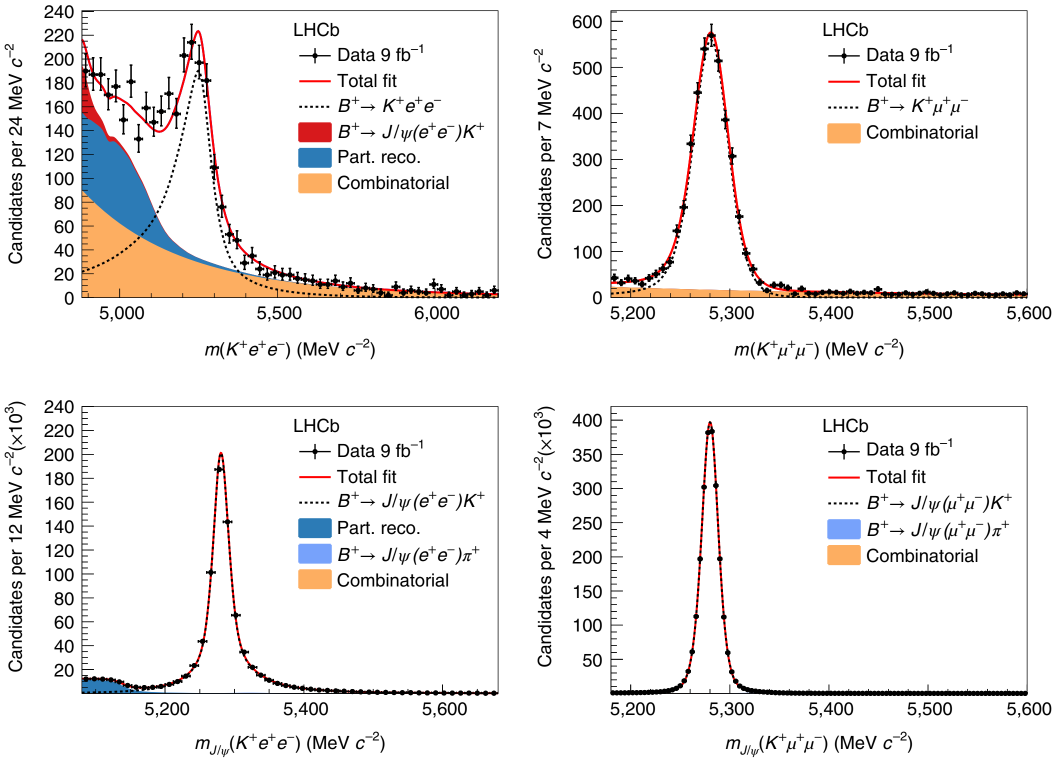
[JHEP 06 (2015) 009]

LFU with B → K l l at LHCb

$$R_H \equiv \frac{\int_{q^2_{\min}}^{q^2_{\max}} \frac{\mathrm{d}\mathcal{B}\ (B\to H\mu^+\mu^-)}{\mathrm{d}q^2}\mathrm{d}q^2}{\int_{q^2_{\min}}^{q^2_{\max}} \frac{\mathrm{d}\mathcal{B}\ (B\to He^+e^-)}{\mathrm{d}q^2}\mathrm{d}q^2}$$

expect R = 1 in the SM

Nature Physics 18, 277 (2022)



Signal modes (1.1 < q^2 < 6 GeV^2)
B → K e e and B → K μ μ

Normalization modes:
B → K J/ψ(→ee) and B → K J/ψ(→μ μ)

$$R_K = 0.846^{+0.042}_{-0.039}(stat.)^{+0.013}_{-0.012}$$

3.1 σ away from SM

Partially reconstructed B estimation may be a concern?

R_{K*} from Belle

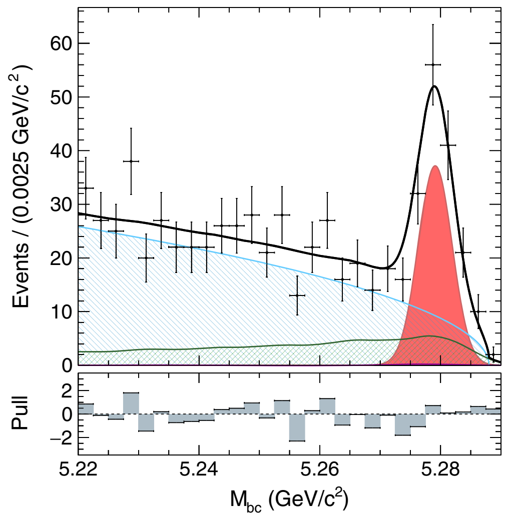
Phys.Rev.Lett. 126, 161801 (2021)

- Reconstruction of
  $B^0 \rightarrow K^{*0} (K^+\pi^-, K^0_S\, \pi^0)\, l^+ l^-$
  $B^+ \rightarrow K^{*+} (K^+\pi^0, K^0_S\, \pi^+)\, l^+ l^-$
- Background suppressed by NN selection
- Kinematics distribution to extract the signal

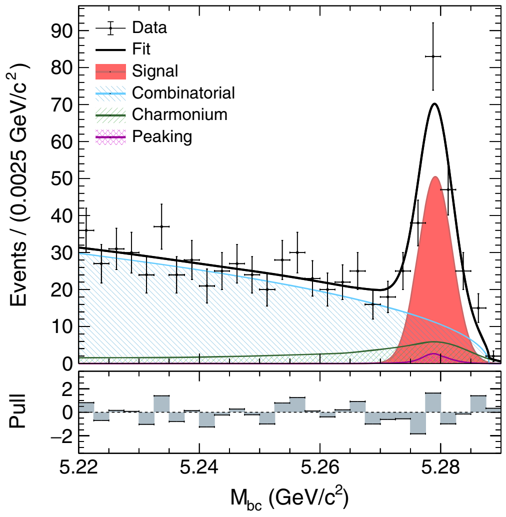
$$M_{\rm bc} = \sqrt{E^2_{beam}/c^4 - |p_B|^2/c^2}$$
$$\Delta E = E_B - E_{beam}$$

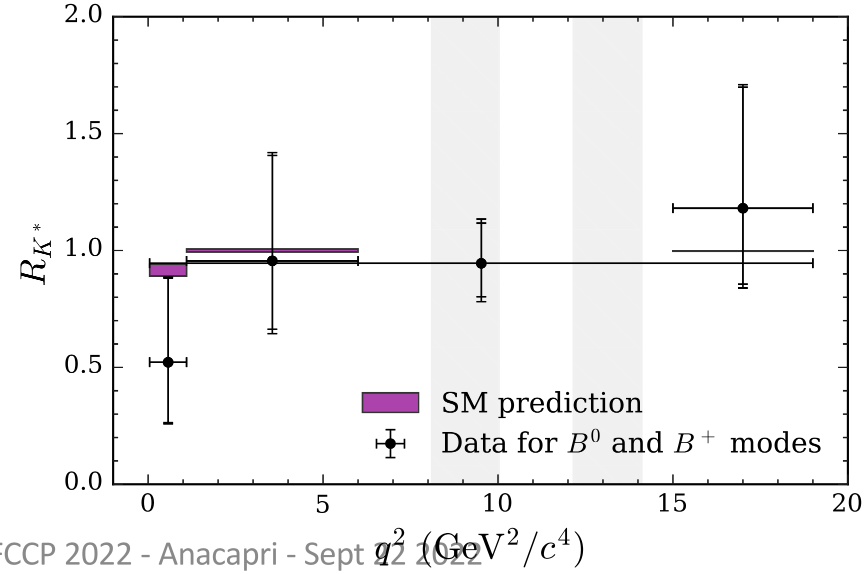
- 1D unbinned maximum likelihood fit to extract signal yields
- 103 ± 13 electrons and 140 ± 16 muons

electrons



muons





Belle II will accumulate 40x Belle statistics

R_K from Belle

JHEP 03, 105 (2021)

- Reconstruction of
  $B^0 \rightarrow K^0_S\, l^+ l^-$
  $B^+ \rightarrow K^+ l^+ l^-$
- Background suppressed using a NN

- Fit signal on kinematics distributions Mbc, ΔE and MV classifier O

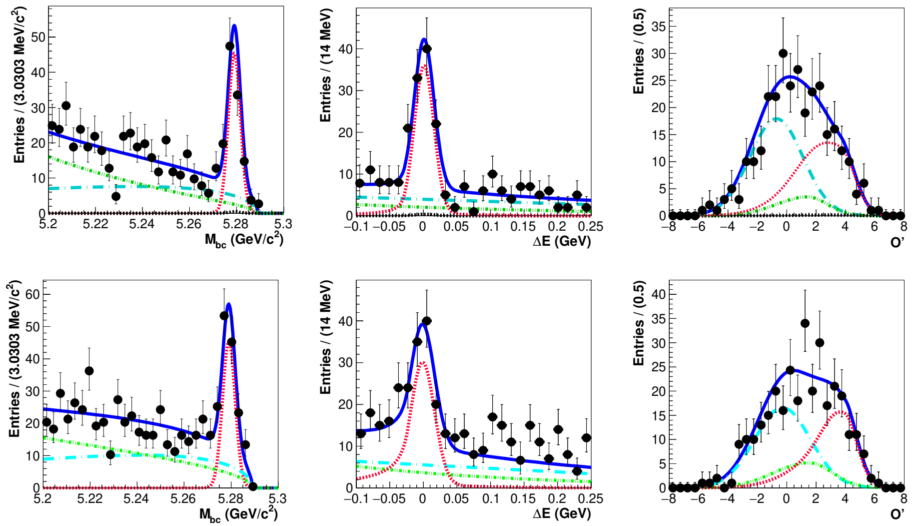
$$M_{\rm bc} = \sqrt{E_{beam}^2/c^4 - |p_B|^2/c^2}$$
$$\Delta E = E_B - E_{beam}$$

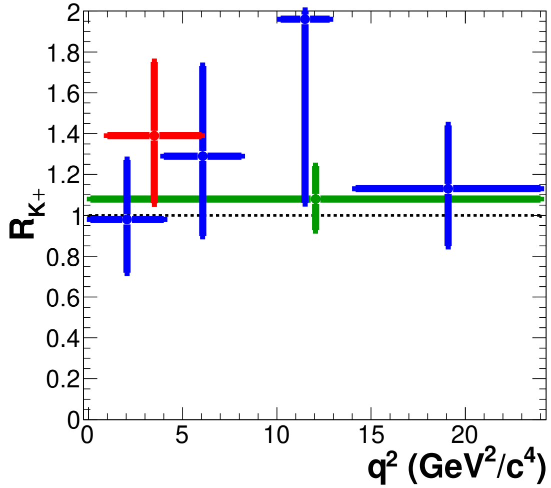
- 1D unbinned maximum likelihood fit to extract signal yields
- 138 ± 15 $B^+ \rightarrow K^+ e^+ e^-$ events and 137 ± 14 $B^+ \rightarrow K^+ \mu^+ \mu^-$ events

- R_K measured in different q^2 bins

K+μ+μ-

K+e+e-

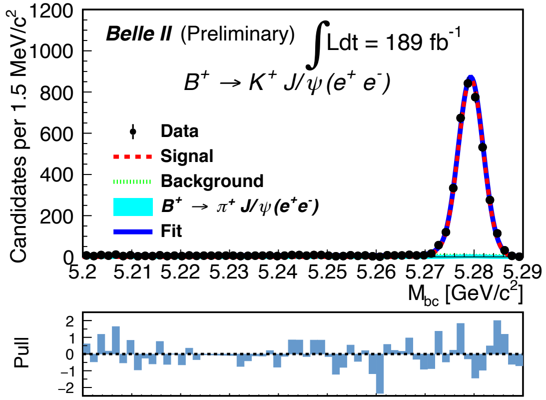


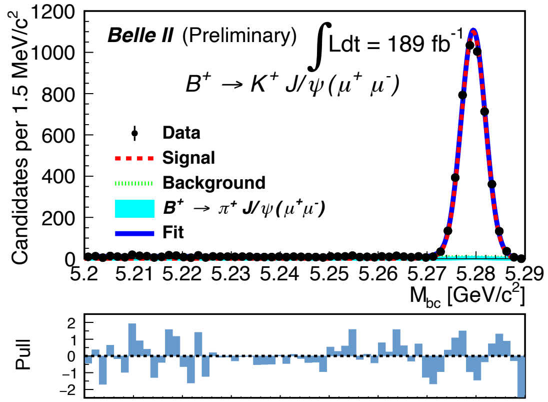


Belle II BR(B → K* l l) and J/ψ(→ll) K

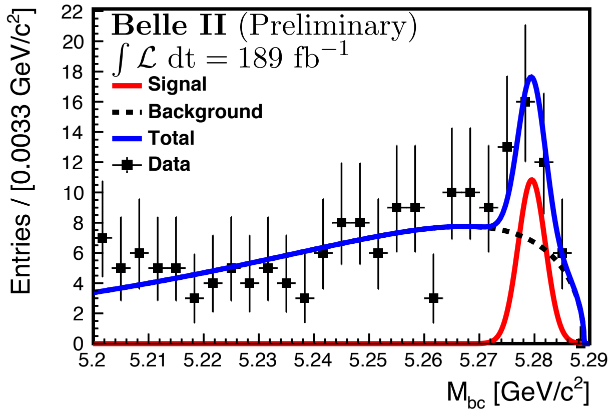
Also Belle II started participating to the efforts this year with 189 fb^{-1}

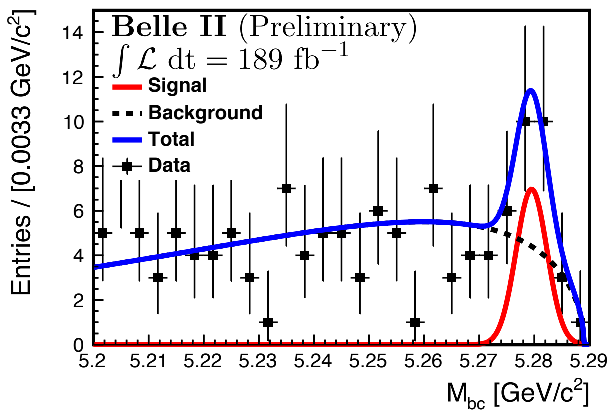
arxiv:2207.11275





arxiv:2206.05946

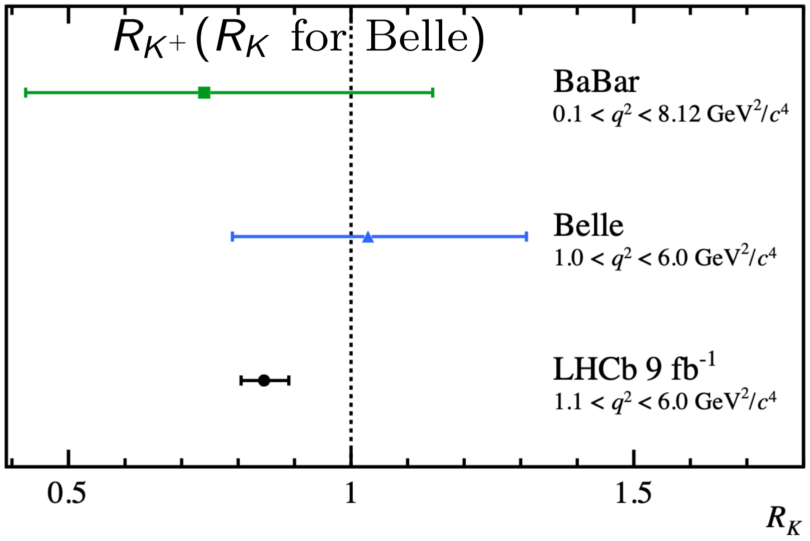


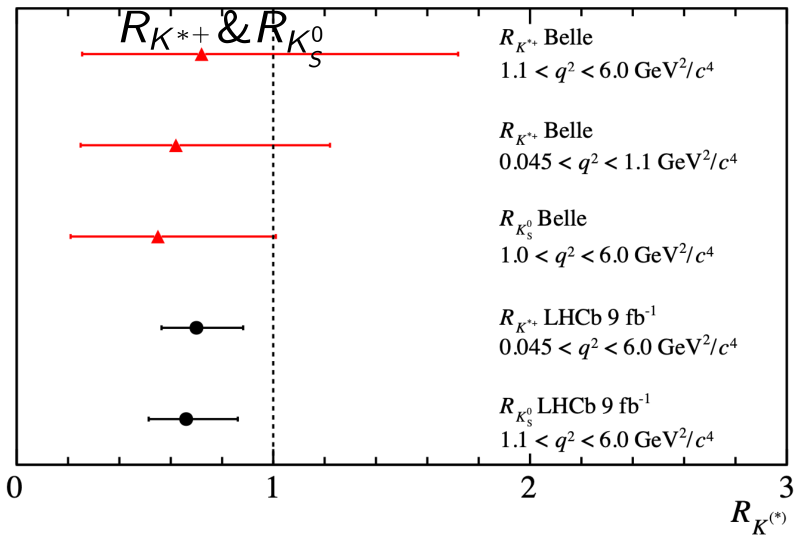


$$\mathcal{B}(B \to K^* \mu^+ \mu^-) = (1.19 \pm 0.31^{+0.08}_{-0.07}) \times 10^{-6},$$
$$\mathcal{B}(B \to K^* e^+ e^-) = (1.42 \pm 0.48 \pm 0.09) \times 10^{-6}$$

$$R_{K+}(J/\psi) = 1.009 \pm 0.022 \pm 0.008$$

Summary of current results



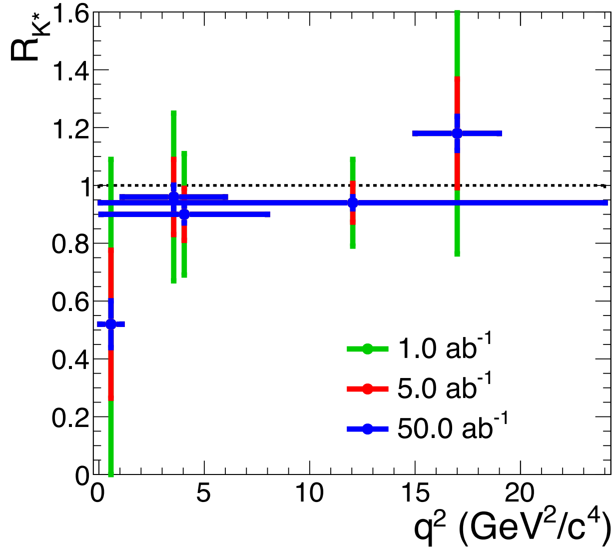


LHCb leading the race.

Belle II can perform measurement for low as well high q^2

Independent measurement when few ab^{-1} will be collected

Statistical sensitivity reach 1-2% for full q^2 region



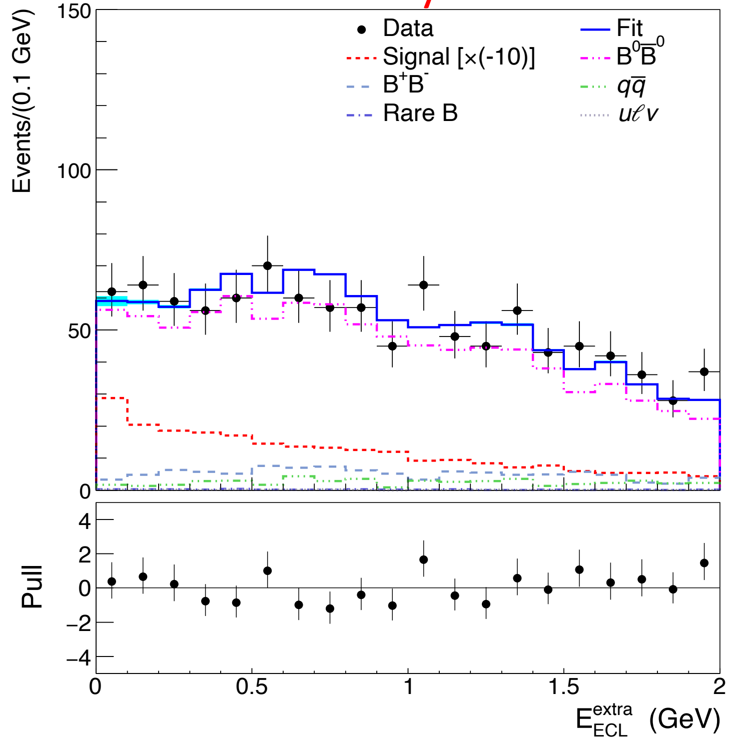
Other promising channels

$B^0 \to K^{*0} \tau^+ \tau^-$ (Belle)

arxiv:2110.03871

- Tagged analysis (hadronic tagging)
- Reconstruct $K^{*0} \to K^+ \pi^-$ + 1 prong τ decays
  - 6 final states topologies {ee,eμ,eπ,$\mu\mu$,$\pi\pi$}
- Requirements on $M_{K^*\pi}$ and M_{miss} to suppress backgrounds
- No residual activity in Calorimeter expected for signal
- Fit signal and background yields on E_{extra}
  - E_{extra} energy in calorimeter not assigned to tag or signal (expect zero for signal)
- No signal found U.L. at BF < 2.0×10^{-3}

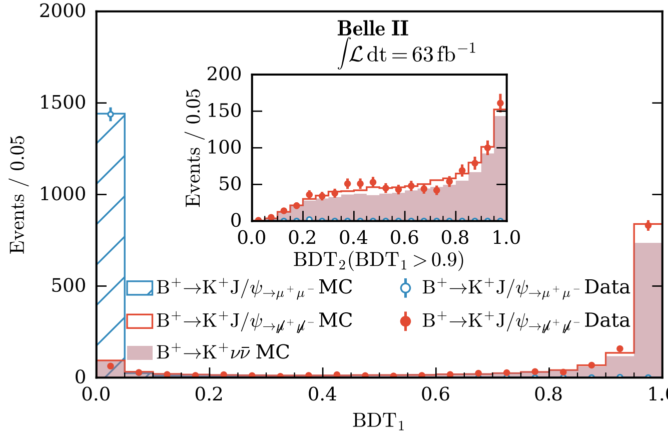
Preliminary result

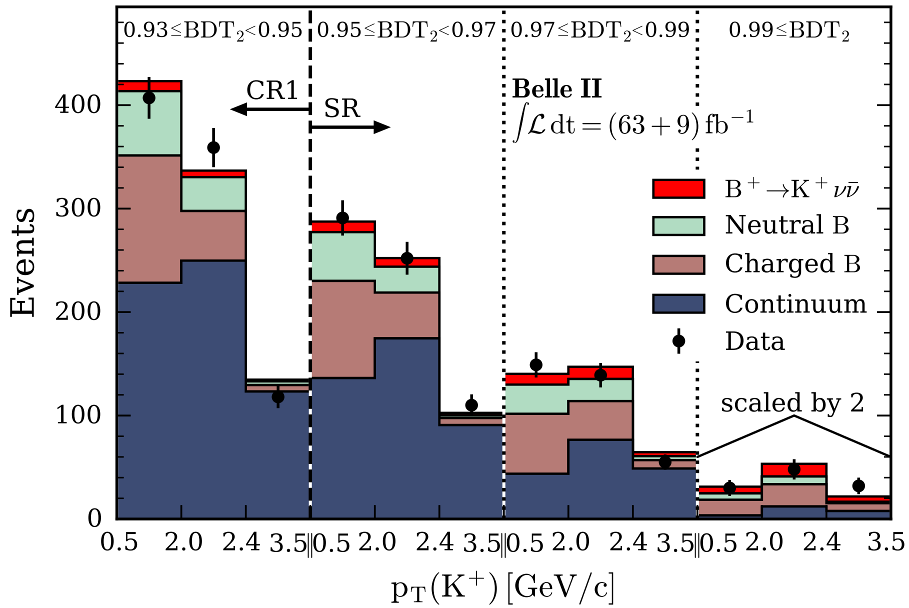


$B^+ \to K^+ \nu \nu$ at Belle II

PRL 127, 181802 (2021) with 63 fb^{-1}
Belle II has already recorded 400 fb^{-1}

- SM prediction BR = $(4.6 \pm 0.5) \times 10^{-6}$.
- Untagged analysis using highest p_T track as signal Kaon and
  2 BDTs to separate signal from background
  - Data control sample of $B^+ \to J/\psi K^+$ ($J/\psi \to \mu \mu$)
  - Use classifier output BTD2 to define 1 control region and 3 signal regions
  - Data further divided in 3 bins of Kaon p_T





$$\mathcal{B}(\mathcal{B} \to K^+ \nu\nu) = (1.9 \pm 1.3^{+0.8}_{-0.7}) \times 10^{-5}$$
$$< 4.1 \times 10^{-5} \text{ at } 90\% \text{ C.L.}$$

LFU with b →u semileptonic decays

$$R(\pi) = \frac{\mathcal{B}(B \to \pi\tau\bar{\nu}_\tau)}{\mathcal{B}(B \to \pi\ell\bar{\nu}_\ell)}$$

Feasibility already demonstrated with Belle.
No statistically significant signal observed
Phys. Rev. Lett. 118, 211801 (2017)

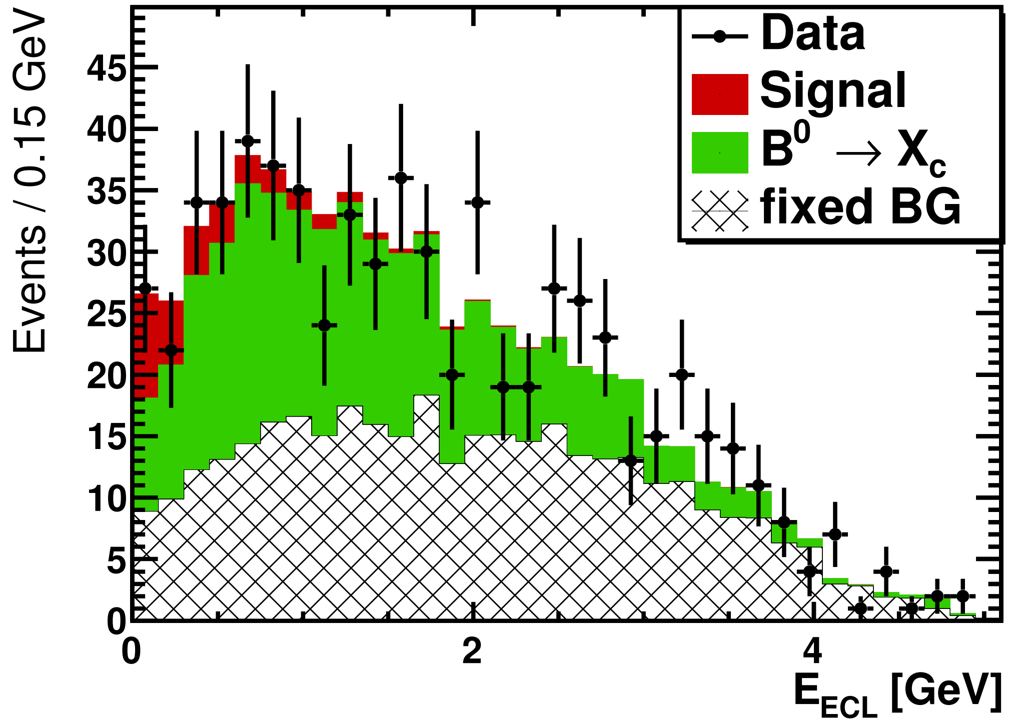
$$\mathcal{B}(B \to \pi\tau\bar{\nu}) < 2.5 \times 10^{-4}.$$

Corresponding central value:

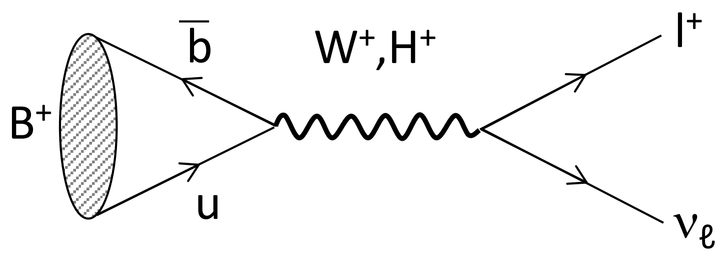
$$\mathcal{B}(B \to \pi\tau\bar{\nu}) = (1.52 \pm 0.72 \pm 0.13)$$

Belle II extrapolation

$$\boxed{\begin{aligned} R_\pi^{5\,\mathrm{ab}^{-1}} &= 0.64 \pm 0.23\,, \\ R_\pi^{50\,\mathrm{ab}^{-1}} &= 0.64 \pm 0.09\,. \end{aligned}}$$



LFU test with leptonic decays



Very clean theoretically, hard experimentally

SM is helicity suppressed

Belle II can test LFU also with

$$R^{\tau\mu} = \frac{\Gamma(B \to \mu\nu)}{\Gamma(B \to \tau\nu)}$$

$$R^{\tau e} = \frac{\Gamma(B \to e\nu)}{\Gamma(B \to \tau\nu)}$$

$$R^{\tau\pi} = \frac{\Gamma(B \to \tau\nu)}{\Gamma(B \to \pi l\nu)}$$

$$\mathcal{B}(B \to l\nu) = \frac{G_F^2 m_B}{8\pi} m_l^2 (1 - \frac{m_l^2}{m_B^2})^2 f_B^2 |V_{ub}|^2 \tau_B$$

$$\mathcal{B}(B \to l\nu) = \mathcal{B}(B \to l\nu)_{SM} \times r_H$$

$$r_H = (1 - \tan^2\beta \frac{m_B^2}{m_H^2})^2$$ *in 2HDM type II*

Mode	SM BR	Current meas.	Belle II 5 ab-1	Belle II 50 ab-1
τν	10^{-4}	20% uncertainty	9%	4%
μν	10^{-6}	40% uncertainty*	20%	6%
eν	10^{-11}	Beyond reach	-	-

Belle II Full simulation with expected background conditions with hadronic tags only

Extrapolation of untagged Belle analysis

* PRD 101 032007

Conclusions

- R_K and R_{K*} measurements very promising.
  More data coming from LHCb and Belle II
  - LHCb will improve the measurement better constraining critical backgrounds in electron sample
  - Belle II can significantly contribute especially in K* samples
- R_D and R_{D*} current pattern unclear. Is there a real physics or some systematics to fix?
  - Data coming in the next few years will settle this
  - Highly desirable to have both Belle II and LHCb to compare
- With high statistics sample of LHCb and Belle II, q^2 spectra of $B \rightarrow D^{(*)} \tau \nu$ and $B \rightarrow K^{(*)} l\, l$ can be studied in detail
- Belle II will also add other interesting LFU observables

Back up

Belle II upgrade Snowmass White paper

arxiv:2203.11349

Observable	2022 Belle(II), BaBar	Belle-II $5\ \mathrm{ab}^{-1}$	Belle-II $50\ \mathrm{ab}^{-1}$	Belle-II $250\ \mathrm{ab}^{-1}$
$\sin 2\beta/\phi_1$	0.03	0.012	0.005	0.002
γ/ϕ_3 (Belle+BelleII)	11°	4.7°	1.5°	0.8°
α/ϕ_2 (WA)	4°	2°	0.6°	0.3°
$\|V_{ub}\|$ (Exclusive)	4.5%	2%	1%	$< 1\%$
$S_{CP}(B \to \eta' K^0_S)$	0.08	0.03	0.015	0.007
$A_{CP}(B \to \pi^0 K^0_S)$	0.15	0.07	0.025	0.018
$S_{CP}(B \to K^{*0}\gamma)$	0.32	0.11	0.035	0.015
$R(B \to K^* \ell^+ \ell^-)^\dagger$	0.26	0.09	0.03	0.01
$R(B \to D^* \tau\nu)$	0.018	0.009	0.0045	<0.003
$R(B \to D\tau\nu)$	0.034	0.016	0.008	<0.003
$\mathcal{B}(B \to \tau\nu)$	24%	9%	4%	2%
$B(B \to K^* \nu\bar{\nu})$	–	25%	9%	4%
$\mathcal{B}(\tau \to \mu\gamma)$ UL	42×10^{-9}	22×10^{-9}	6.9×10^{-9}	3.1×10^{-9}
$\mathcal{B}(\tau \to \mu\mu\mu)$ UL	21×10^{-9}	3.6×10^{-9}	0.36×10^{-9}	0.073×10^{-9}

LHCB-TDR-023 Framework TDR Upgrade II

Observable	Current LHCb (up to 9 fb^{-1})		Upgrade I (23 fb^{-1})	Upgrade I (50 fb^{-1})	Upgrade II (300 fb^{-1})
CKM tests					
γ ($B \to DK$, *etc.*)	$4°$	[9,10]	$1.5°$	$1°$	$0.35°$
ϕ_s ($B_s^0 \to J/\psi\phi$)	32 mrad	[8]	14 mrad	10 mrad	4 mrad
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$ ($\Lambda_b^0 \to p\mu^-\overline{\nu}_\mu$, *etc.*)	6%	[29,30]	3%	2%	1%
$a_{\rm sl}^d$ ($B^0 \to D^-\mu^+\nu_\mu$)	36×10^{-4}	[34]	8×10^{-4}	5×10^{-4}	2×10^{-4}
$a_{\rm sl}^s$ ($B_s^0 \to D_s^-\mu^+\nu_\mu$)	33×10^{-4}	[35]	10×10^{-4}	7×10^{-4}	3×10^{-4}
Charm					
ΔA_{CP} ($D^0 \to K^+K^-, \pi^+\pi^-$)	29×10^{-5}	[5]	13×10^{-5}	8×10^{-5}	3.3×10^{-5}
A_Γ ($D^0 \to K^+K^-, \pi^+\pi^-$)	11×10^{-5}	[38]	5×10^{-5}	3.2×10^{-5}	1.2×10^{-5}
Δx ($D^0 \to K_{\rm S}^0\pi^+\pi^-$)	18×10^{-5}	[37]	6.3×10^{-5}	4.1×10^{-5}	1.6×10^{-5}
Rare Decays					
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	69%	[40,41]	41%	27%	11%
$S_{\mu\mu}$ ($B_s^0 \to \mu^+\mu^-$)	—		—	—	0.2
$A_{\rm T}^{(2)}$ ($B^0 \to K^{*0}e^+e^-$)	0.10	[52]	0.060	0.043	0.016
$A_{\rm T}^{\rm Im}$ ($B^0 \to K^{*0}e^+e^-$)	0.10	[52]	0.060	0.043	0.016
$\mathcal{A}_{\phi\gamma}^{\Delta\Gamma}(B_s^0 \to \phi\gamma)$	$^{+0.41}_{-0.44}$	[51]	0.124	0.083	0.033
$S_{\phi\gamma}(B_s^0 \to \phi\gamma)$	0.32	[51]	0.093	0.062	0.025
$\alpha_\gamma(\Lambda_b^0 \to \Lambda\gamma)$	$^{+0.17}_{-0.29}$	[53]	0.148	0.097	0.038
Lepton Universality Tests					
R_K ($B^+ \to K^+\ell^+\ell^-$)	0.044	[12]	0.025	0.017	0.007
R_{K^*} ($B^0 \to K^{*0}\ell^+\ell^-$)	0.12	[61]	0.034	0.022	0.009
$R(D^*)$ ($B^0 \to D^{*-}\ell^+\nu_\ell$)	0.026	[62,64]	0.007	0.005	0.002