Exp. Overview of Flavor Physics & SUSY

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tifr

Why worry about flavor physics?

Null tests of the standard model (SM)

SM suppressed and forbidden decays

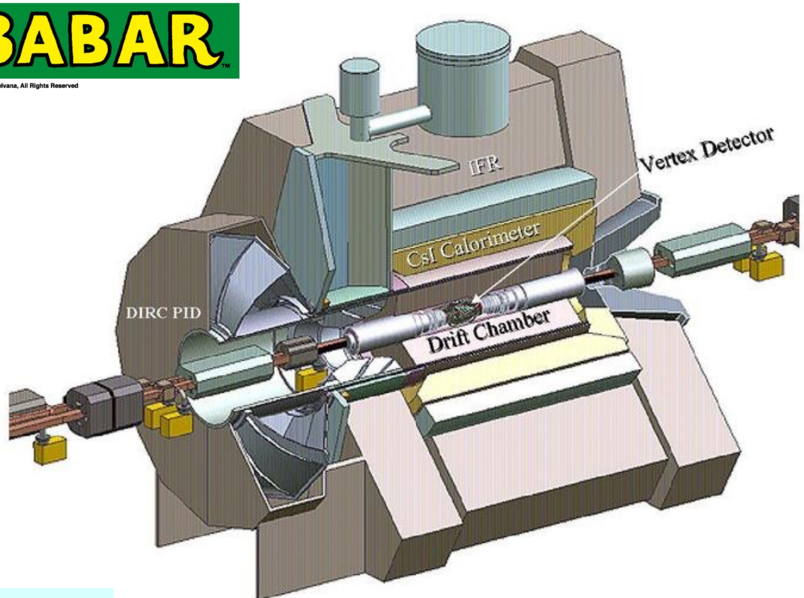
Great probe for various new physics scenarios e.g. supersymmetry

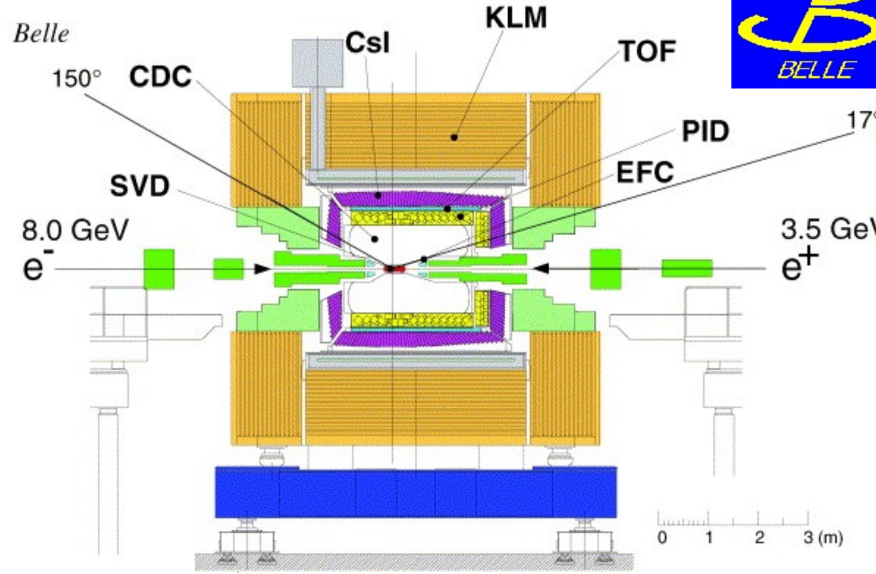
Test lepton flavor universality and search for LFV

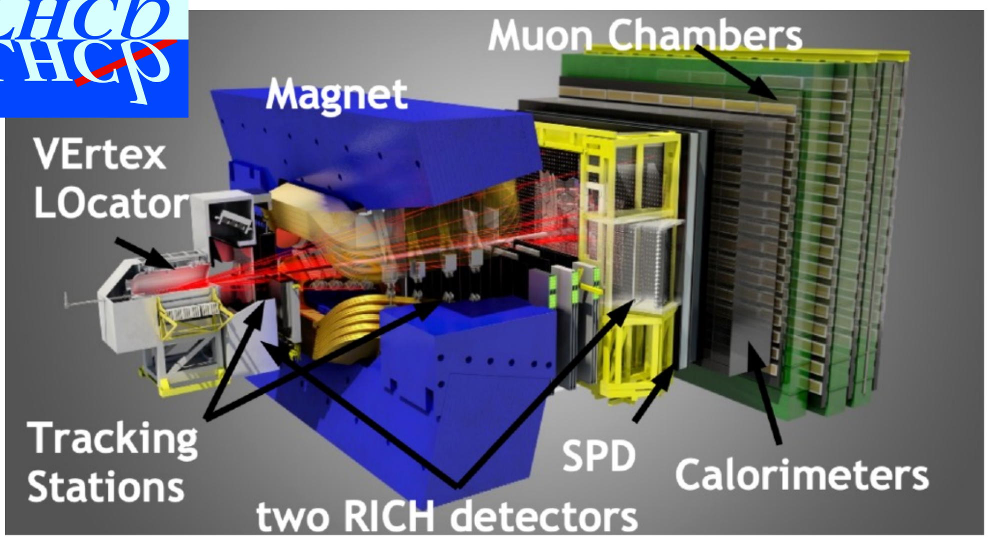
Hidden and dark sectors at GeV scale

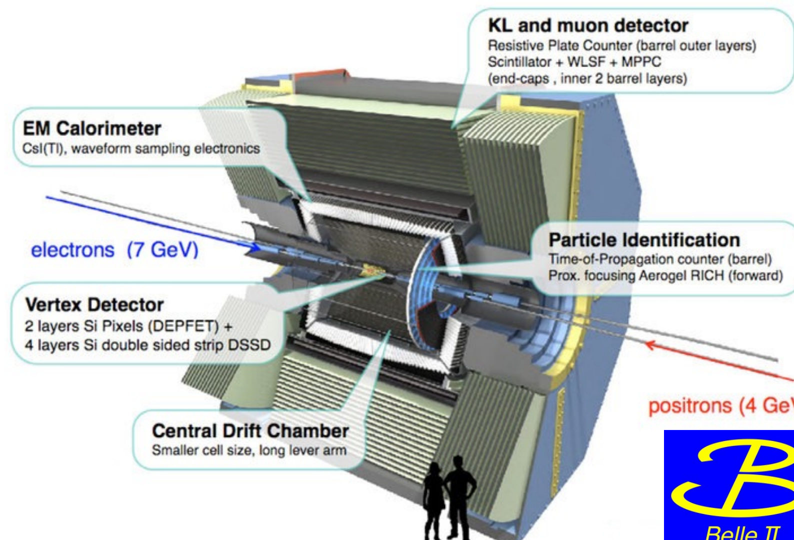
Who are the main players?

BABAR



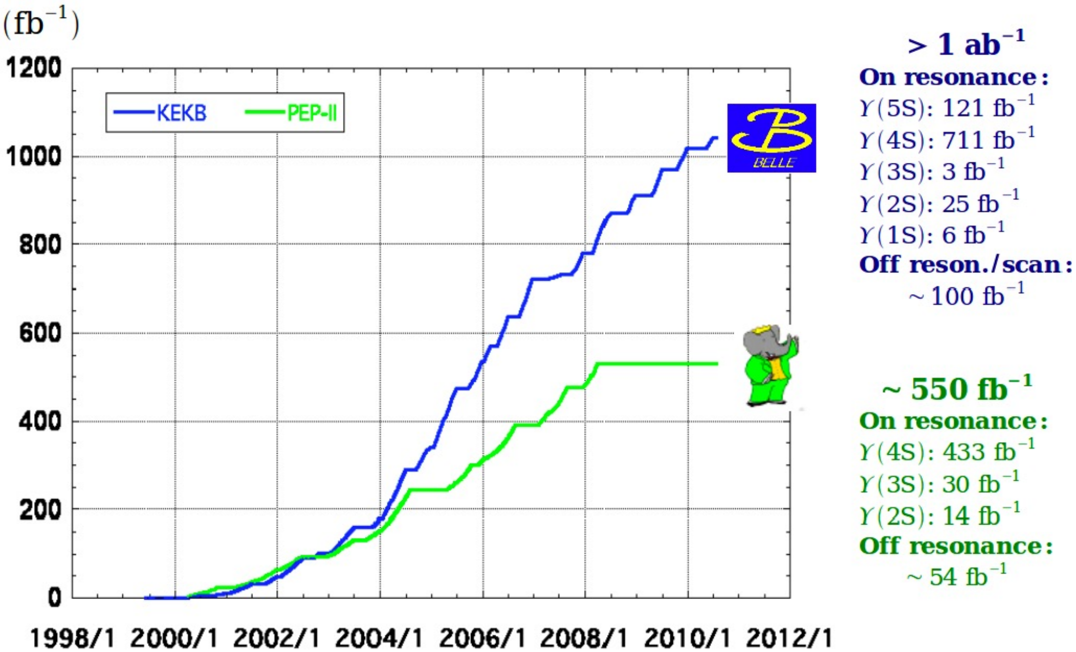


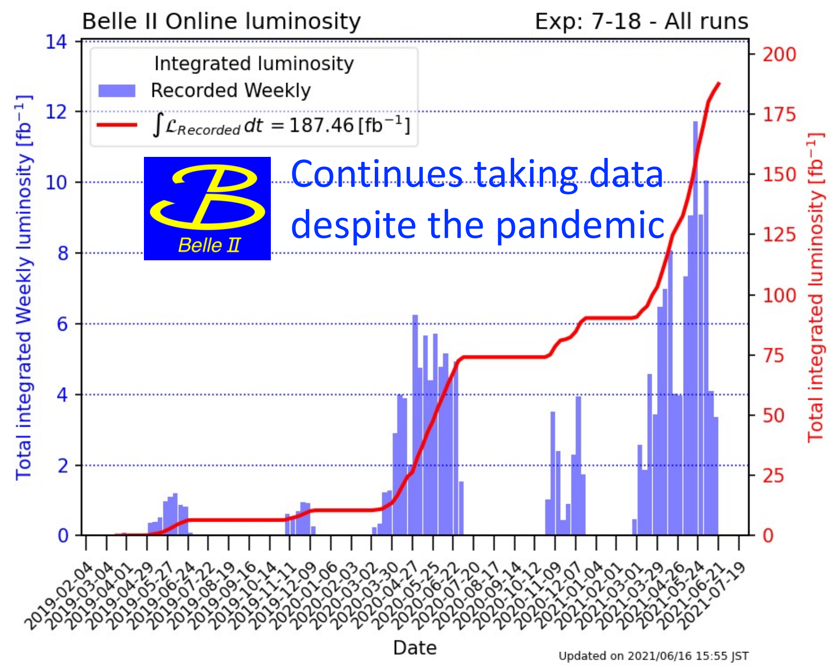


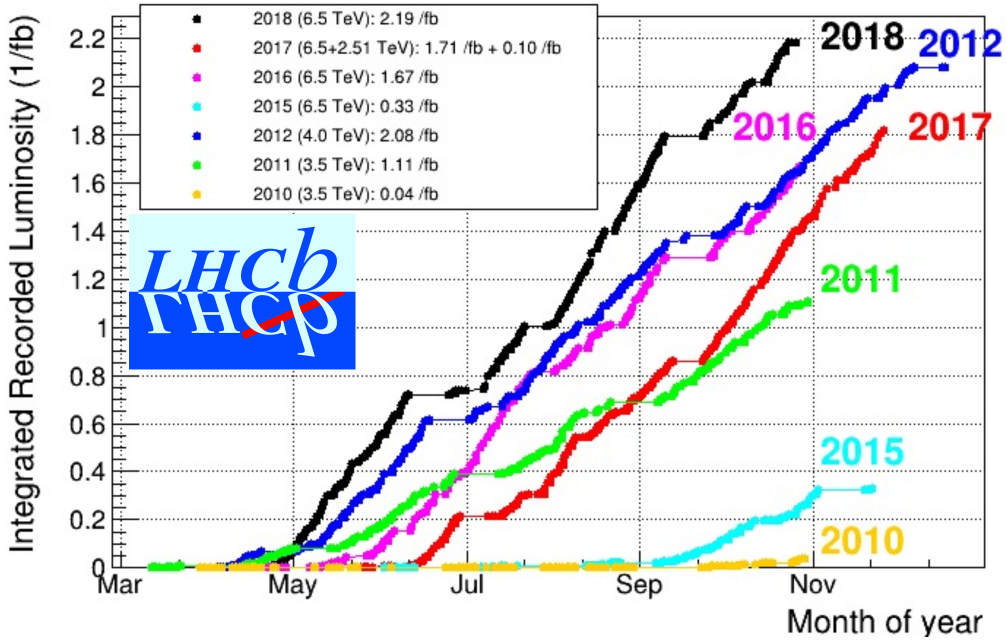


☞ ATLAS and CMS can be competitive for the final states with muons

Incredible amount of data

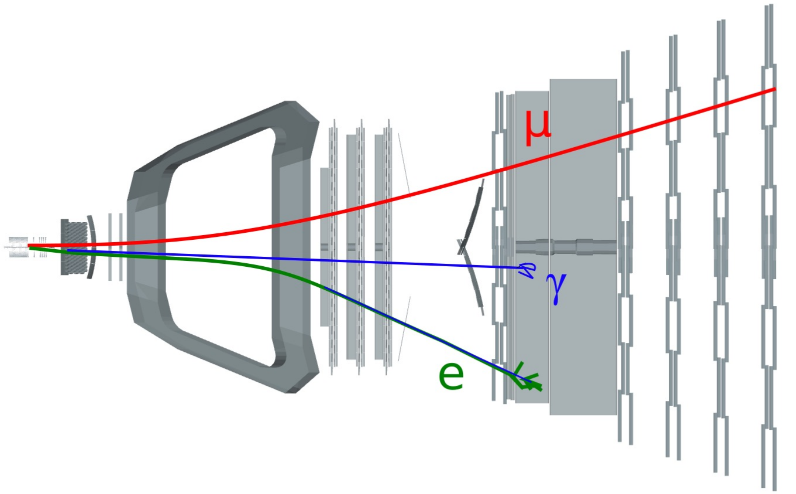


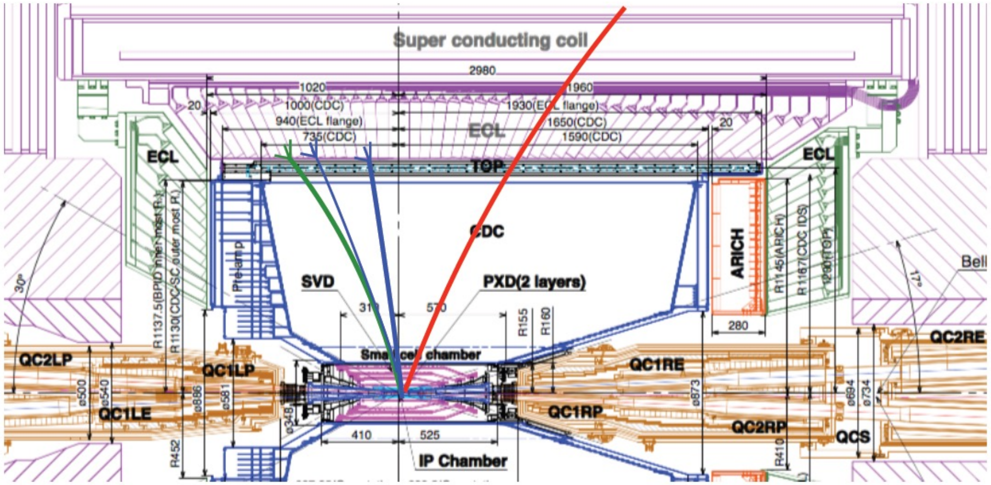




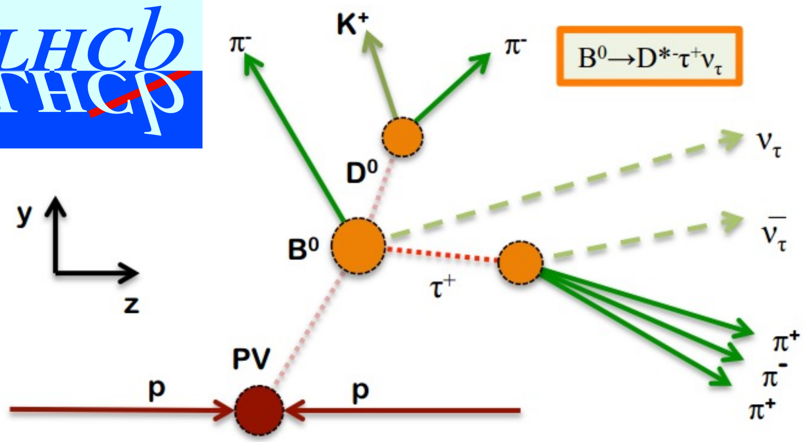
- e^+e^- flavor factories profit from clean environment, well-defined kinematics, though suffer from a low production cross section for heavy flavor hadrons
- LHC is a broadband machine giving access to all kinds of heavy flavor hadrons, but suffers from messy hadronic environment

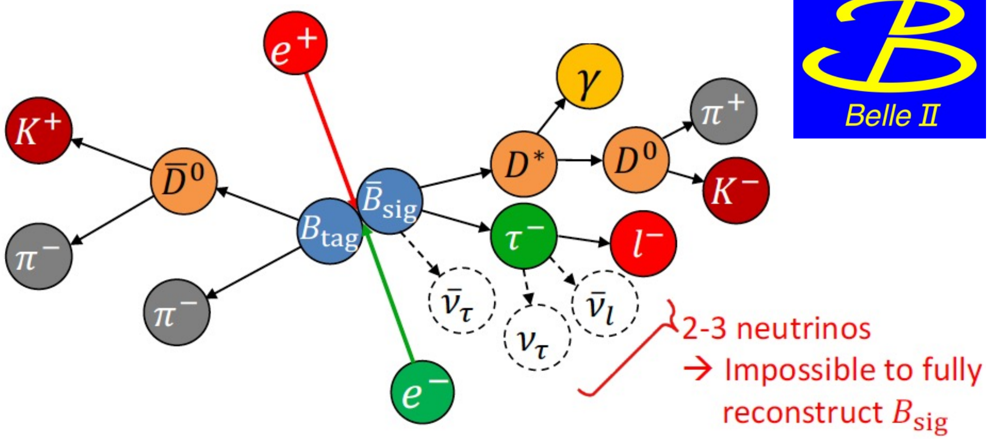
Some other key differences





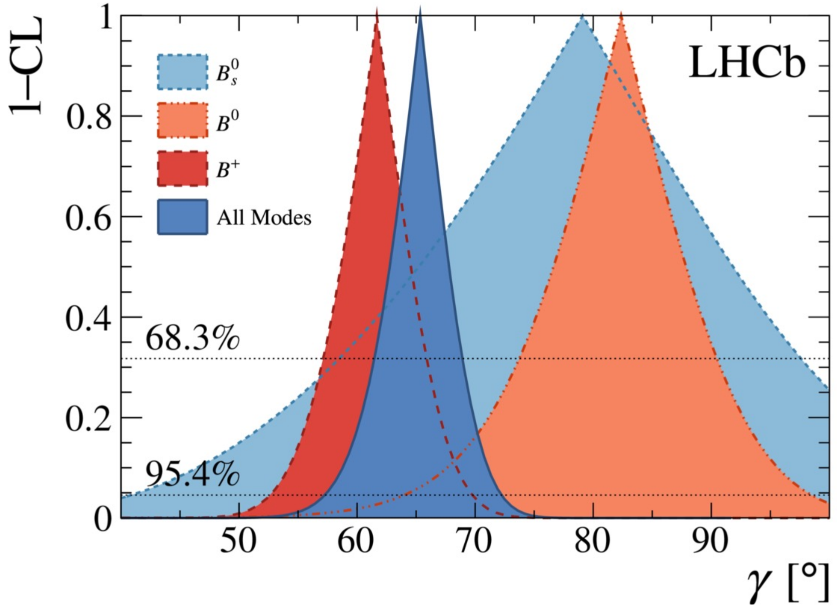
- ❑ At LHCb the electron reconstruction is not as efficient as at Belle II owing to the issue associated with Bremsstrahlung recovery

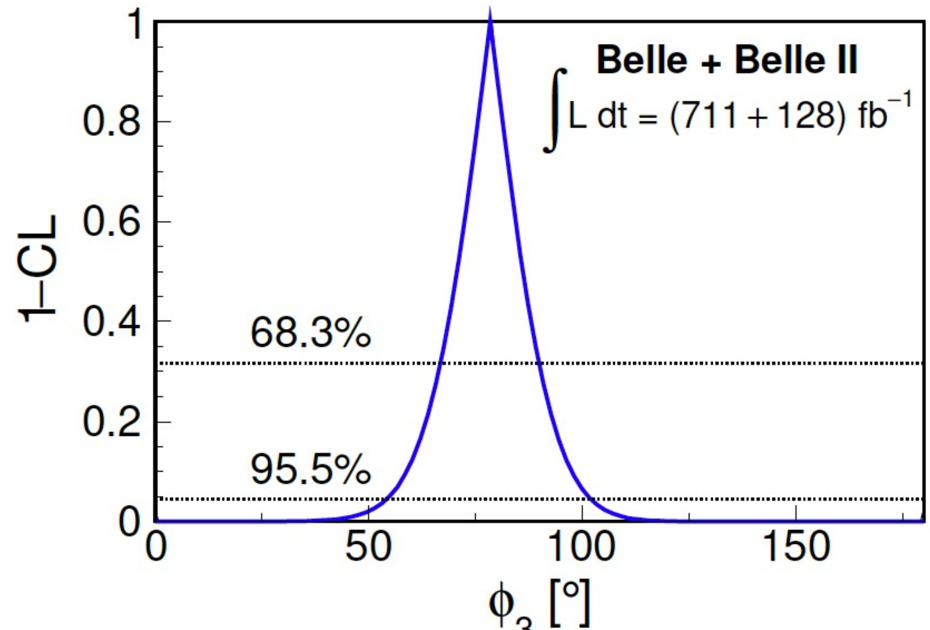




- ❑ Identification of τ leptons is very challenging: LHCb relies on decay vertex separation and Belle II on initial kinematics to deal with B decays to τ's

Checking an SM candle





- Theoretically clean
- Single most precise value from LHCb:

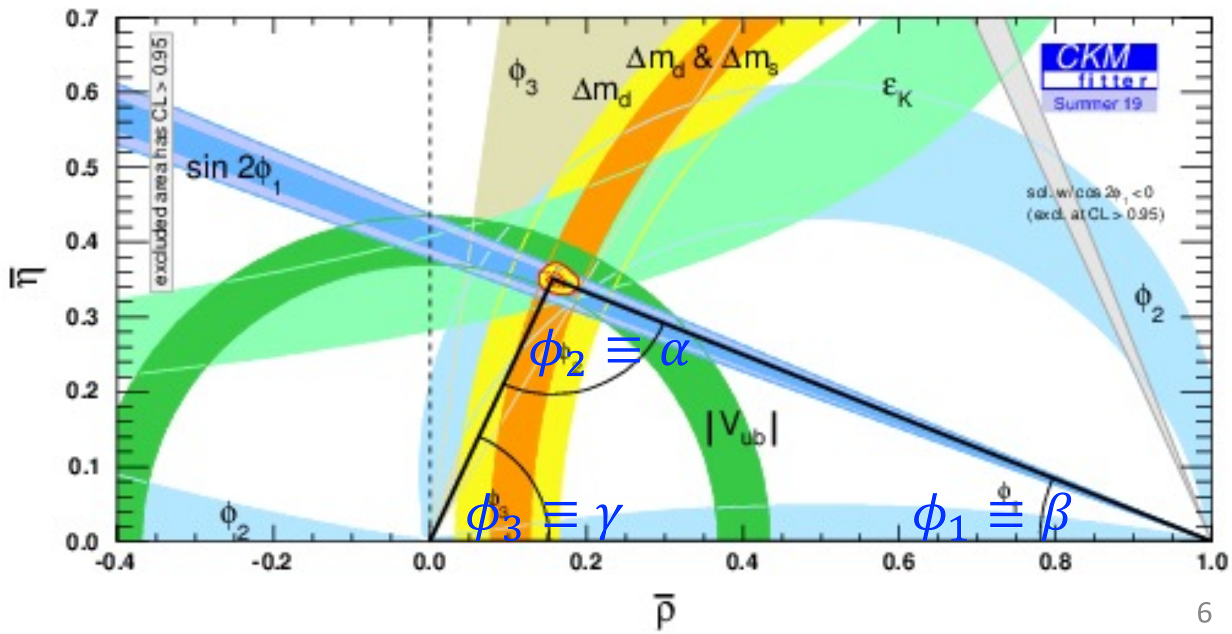
$$\gamma = (65.4^{+3.8}_{-4.2})^\circ$$

LHCb-PAPER-2021-033

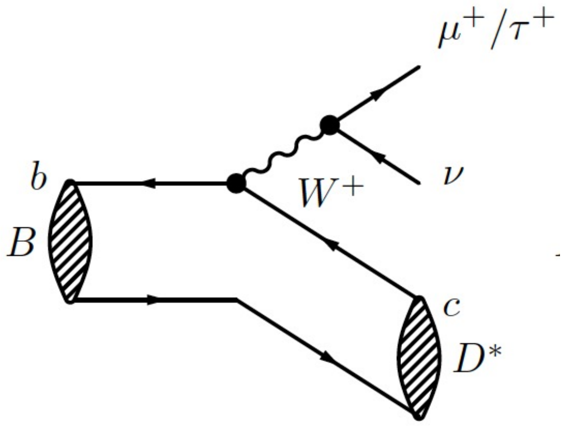
- First Belle plus Belle II combined analysis:

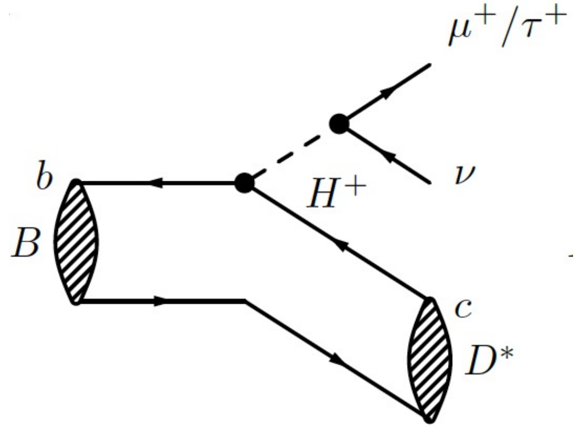
$$\phi_3 = (78.4 \pm 11.4 \pm 0.5 \pm 1.0)^\circ$$

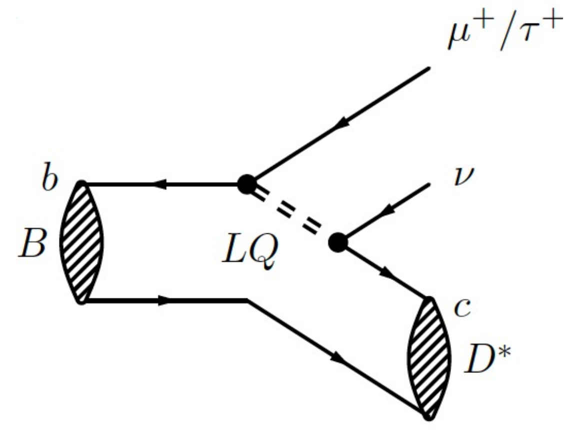
arXiv:2110.12125



Looking at a tree-level decay



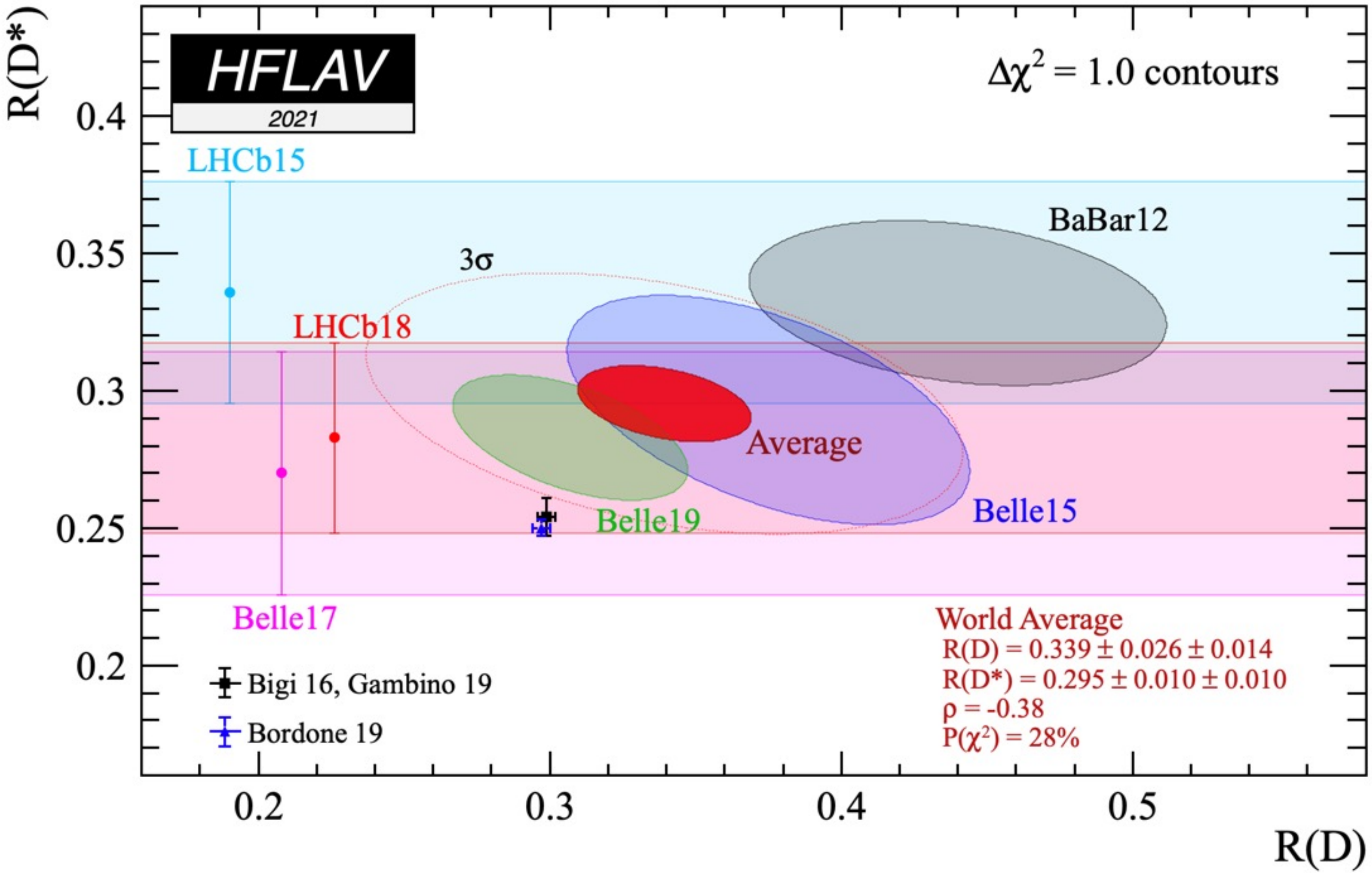




- In SM, the only difference between $B \to D^{(*)}\tau\nu$ and $B \to D^{(*)}\mu\nu$ decays is the mass of the lepton
  - Form factor mostly cancel in the ratio of decay rates

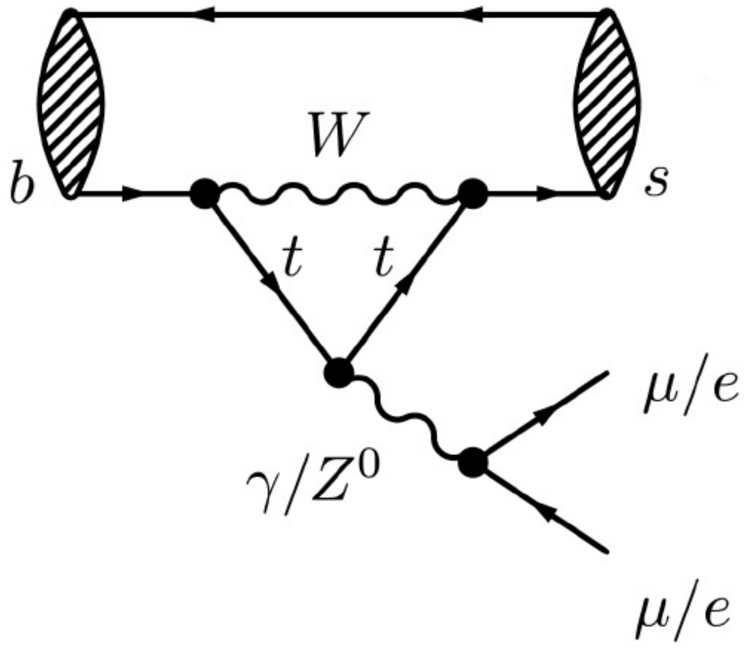
- The ratio $R(D^{(*)}) = \mathcal{B}(B \to D^{(*)}\tau\nu)/\mathcal{B}(B \to D^{(*)}\mu\nu)$ is sensitive to new physics e.g., charged Higgs boson, leptoquarks

We have a tension!



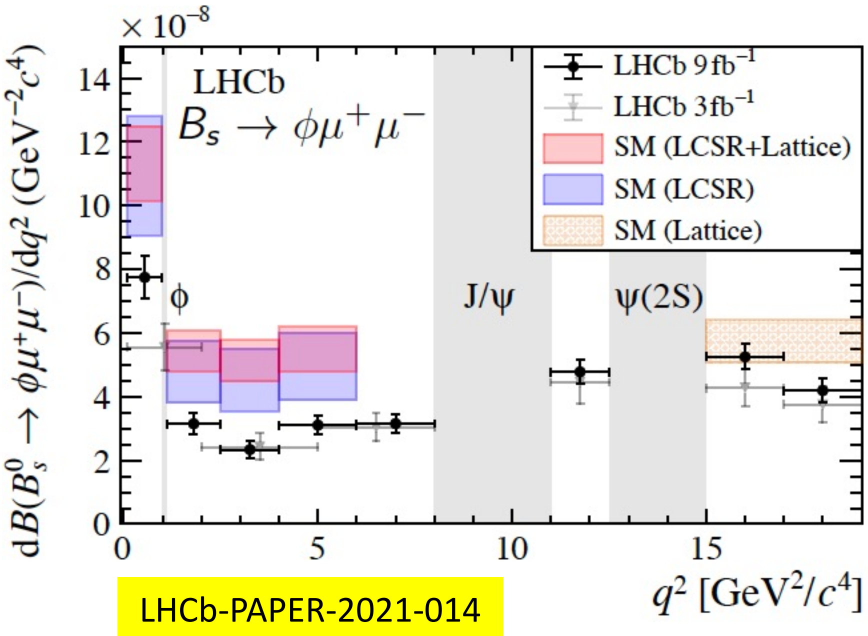
- ❑ 3.4σ discrepancy with respect to SM predictions
- ❑ Mostly driven by the BaBar result PRL 109, 101802 (2012)

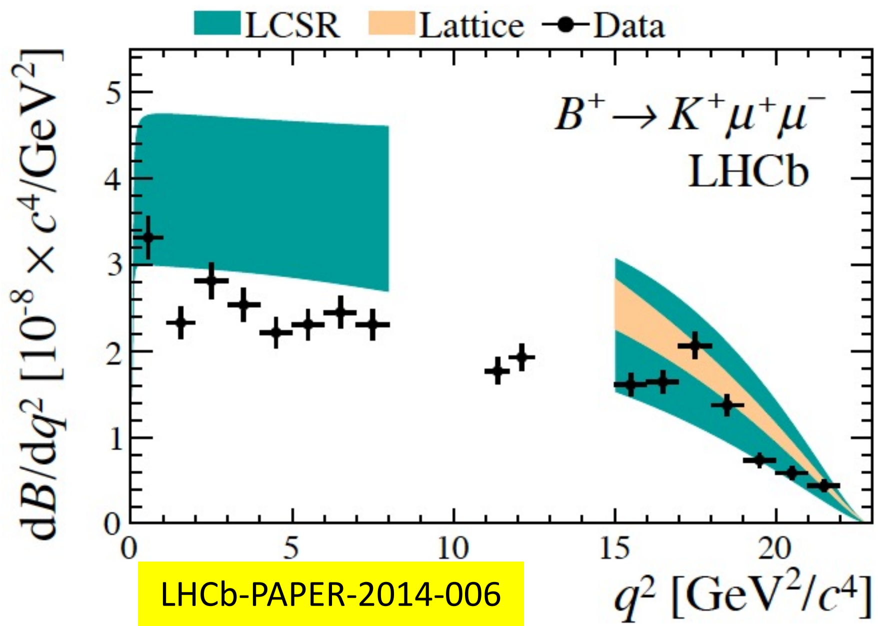
Poster child of NP search

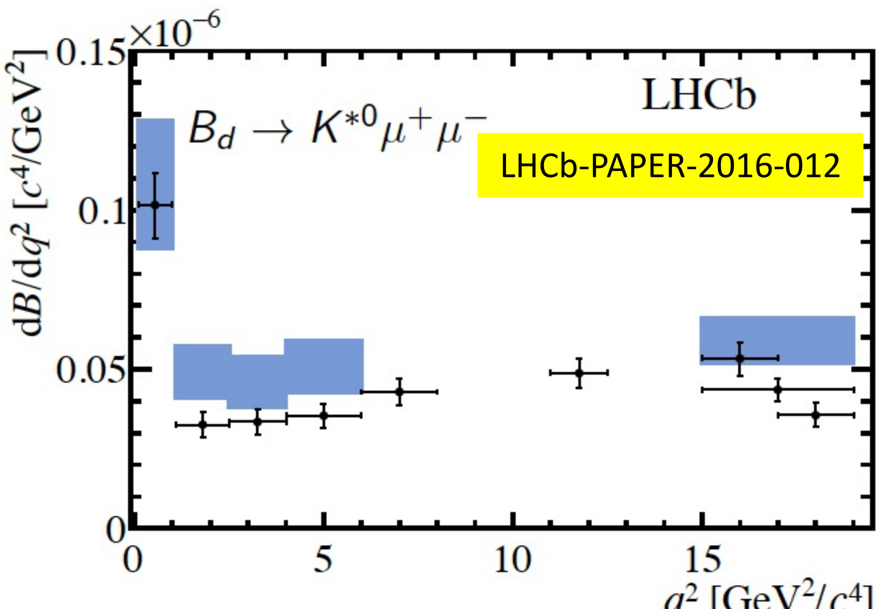


- Highly suppressed in the SM ⇒ long history as an NP probe
- Plethora of observables to deal with: branching fractions, angular distributions, lepton universality ratio

Let's look at branching fractions

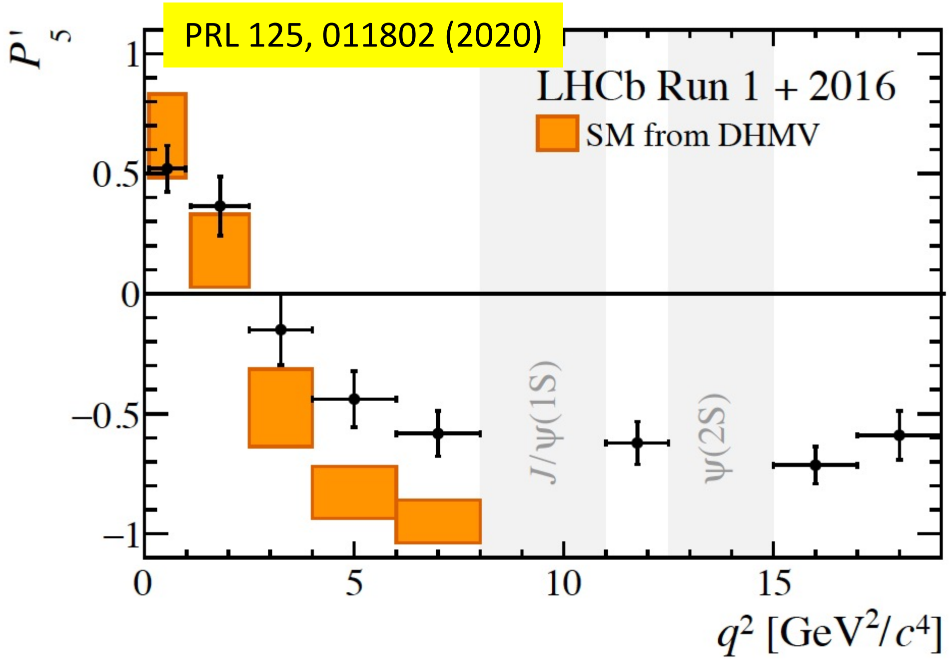


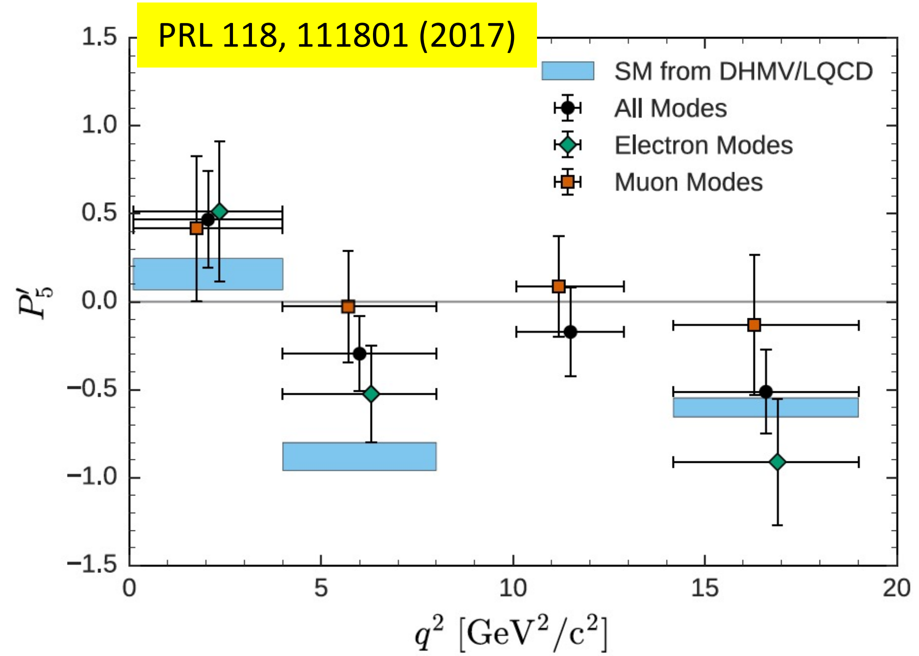


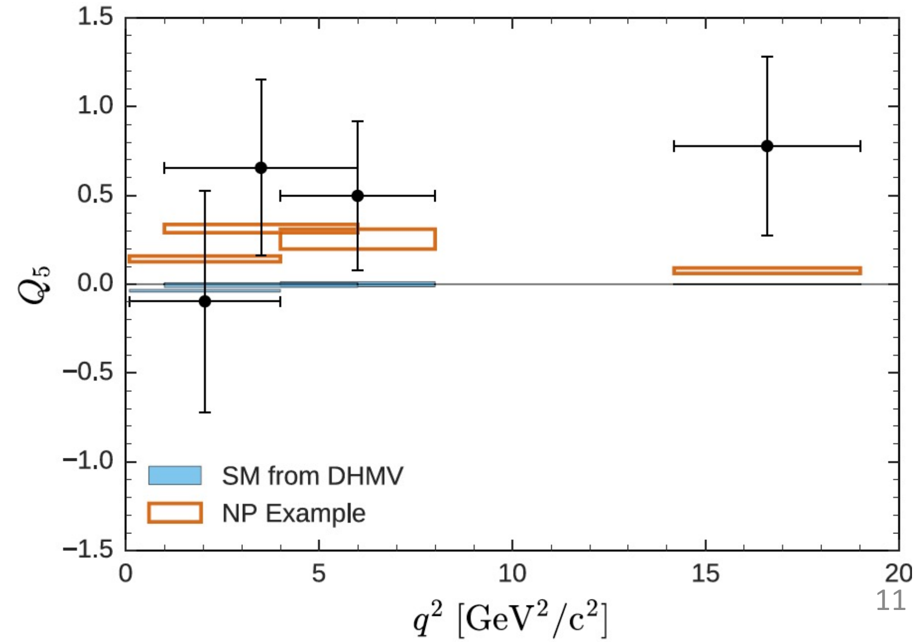


- ❑ Consistently low values
- ❑ Theoretical uncertainty (virtual charm loops) is the real killer
- ❑ Need to check other observables

Optimized angular observables

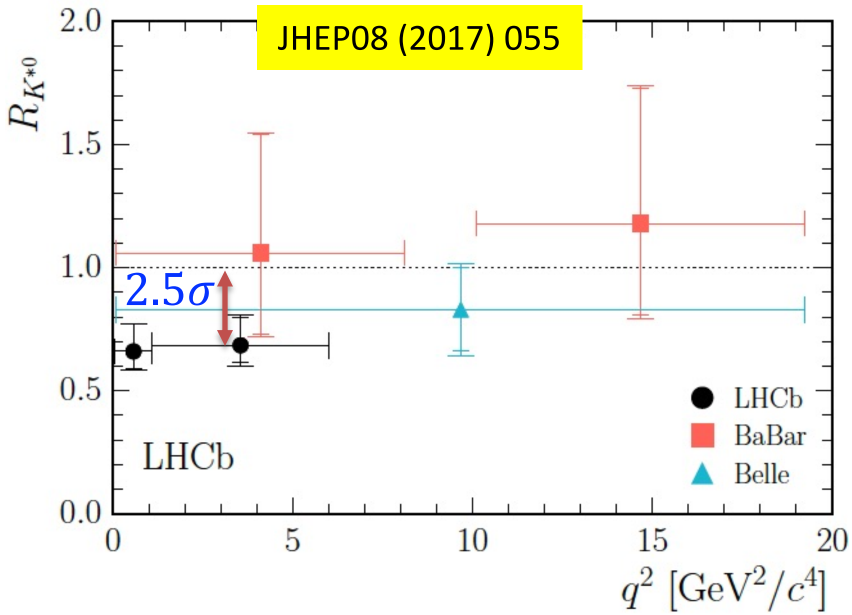


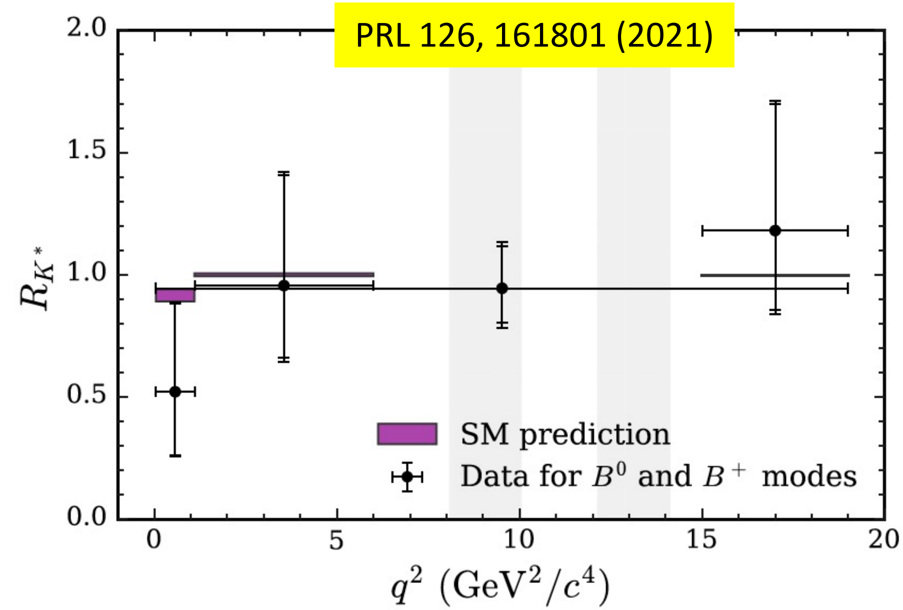




- ❑ Various polarization combinations created in a bid to minimize theory uncertainties ⇒ P'_5 and related lot
- ❑ Apparently electron mode seems to be more SM like than the muon one

Check lepton flavor universality

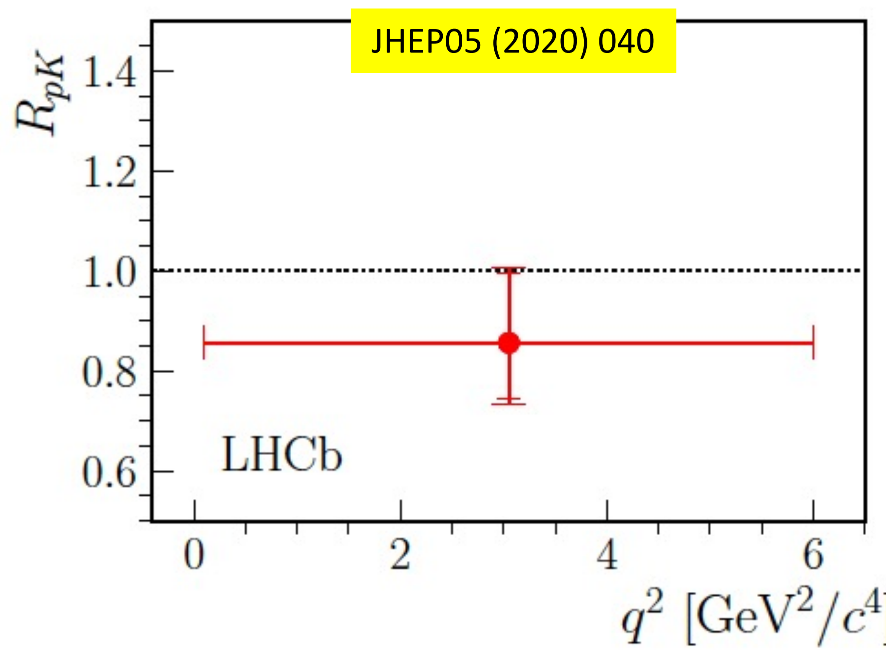




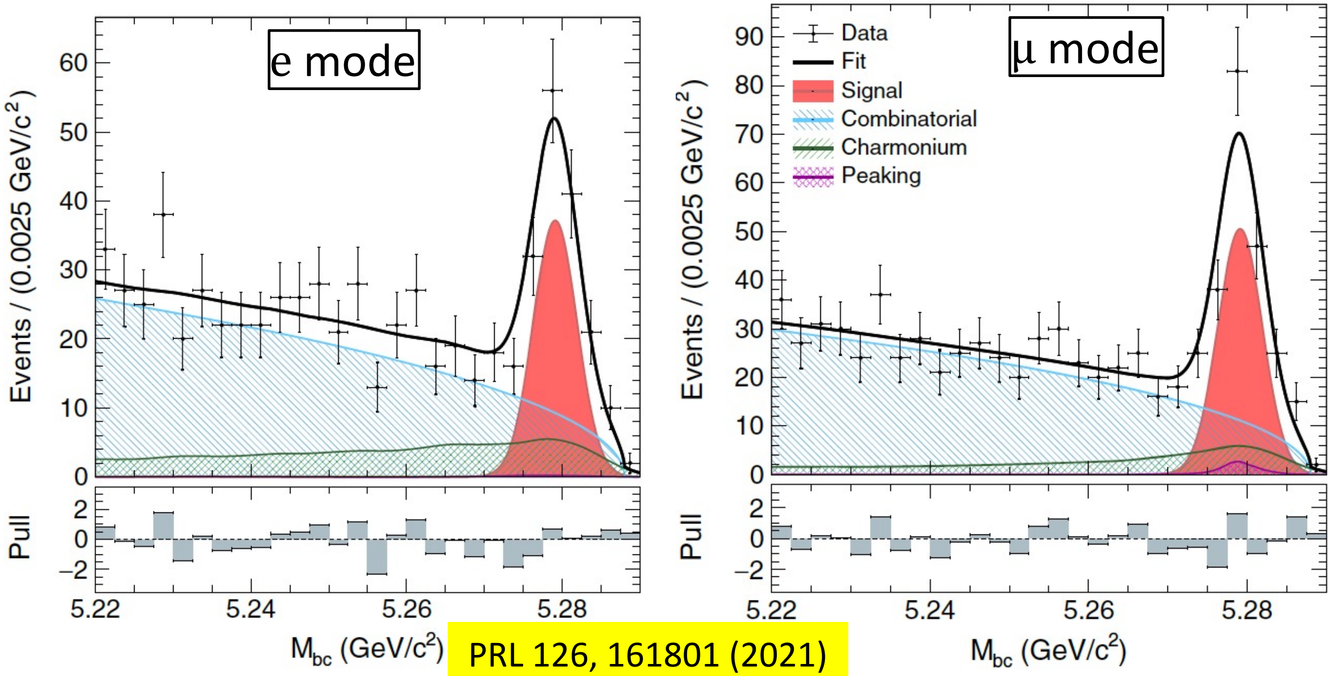
- Test lepton flavor universality

$$R(K^{(*)}) = \frac{\mathcal{B}(B \to K^{(*)}\mu\mu)}{\mathcal{B}(B \to K^{(*)}ee)}$$

- Theoretically pristine ⇒ QCD effects cancel down to $\mathcal{O}(10^{-4})$
- Similar trend is seen in the $\Lambda_b^0 \to pK^-\ell^+\ell^-$ decay



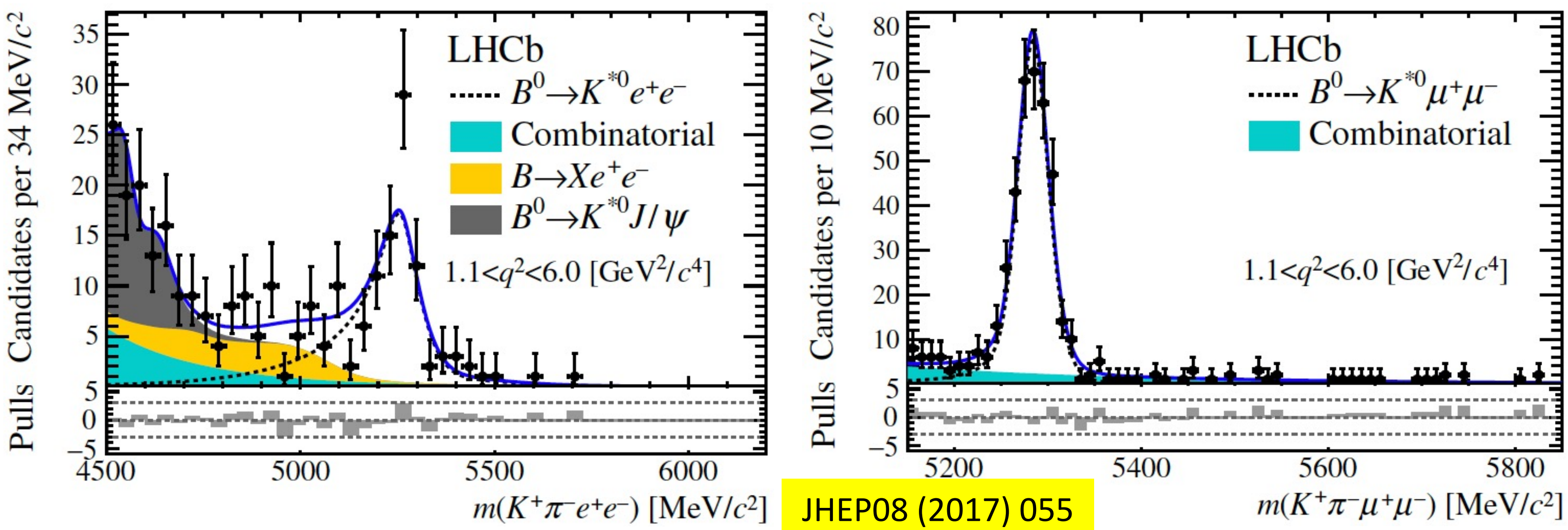
Something not to forget about



PRL 126, 161801 (2021)

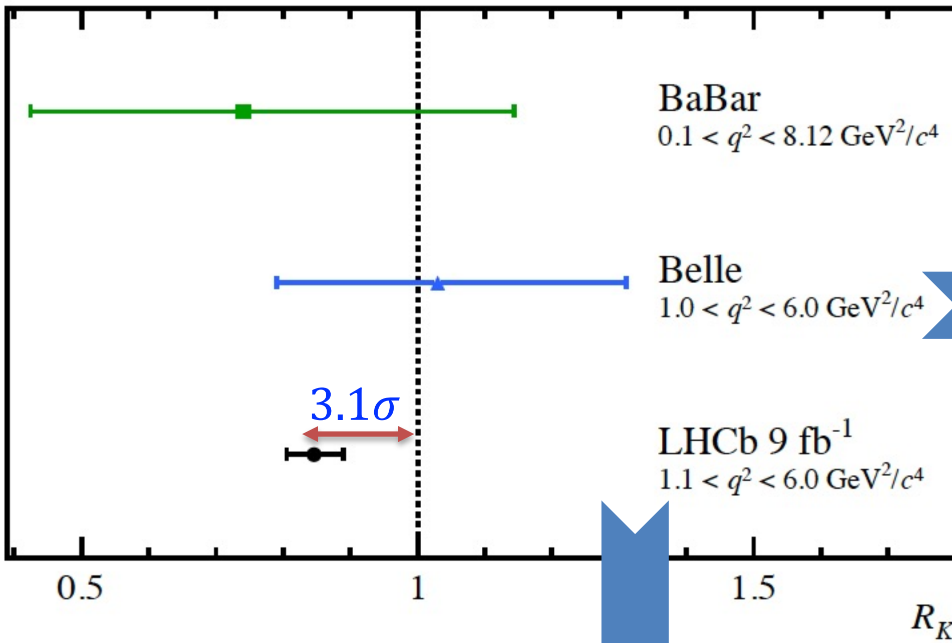
- Belle (II) has got similar sensitivity to both electron and muon modes

- Electron is not so clean for LHCb (lower two plots)

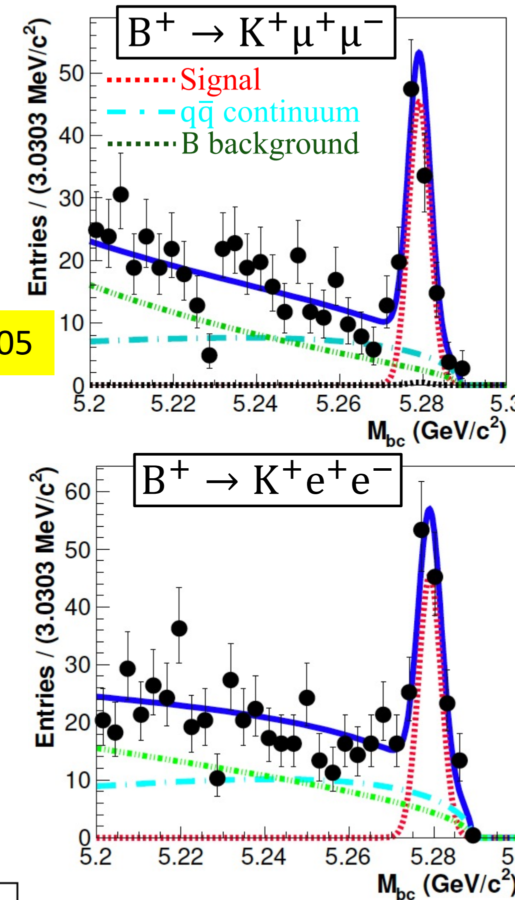


JHEP08 (2017) 055

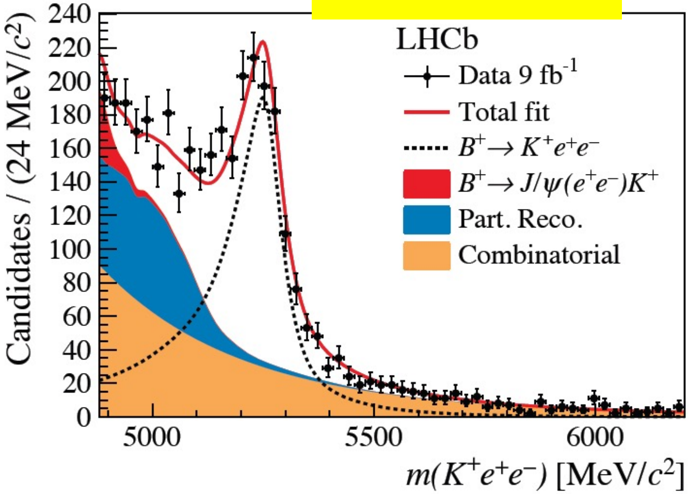
How about R_K?

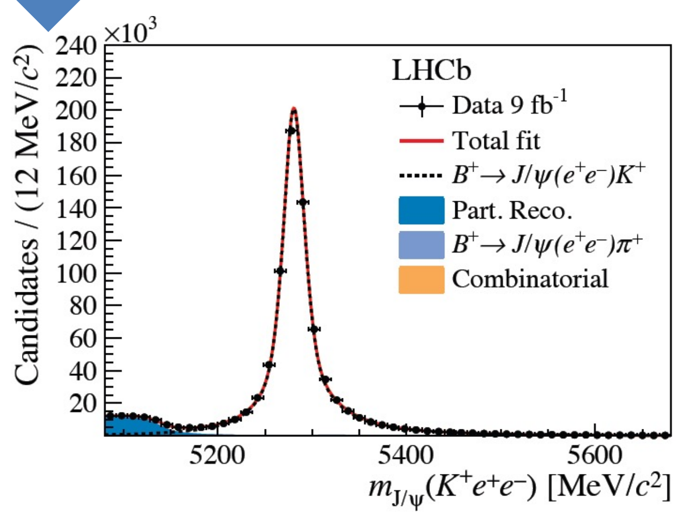


JHEP03 (2021) 105



arXiv:2103.11769





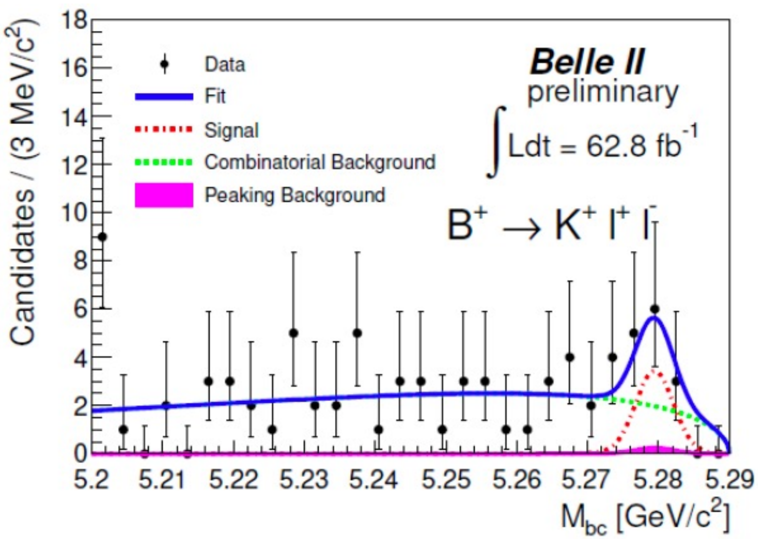
What does future hold for LFU test?

PTEP 2019 (2019) 12, 123C01

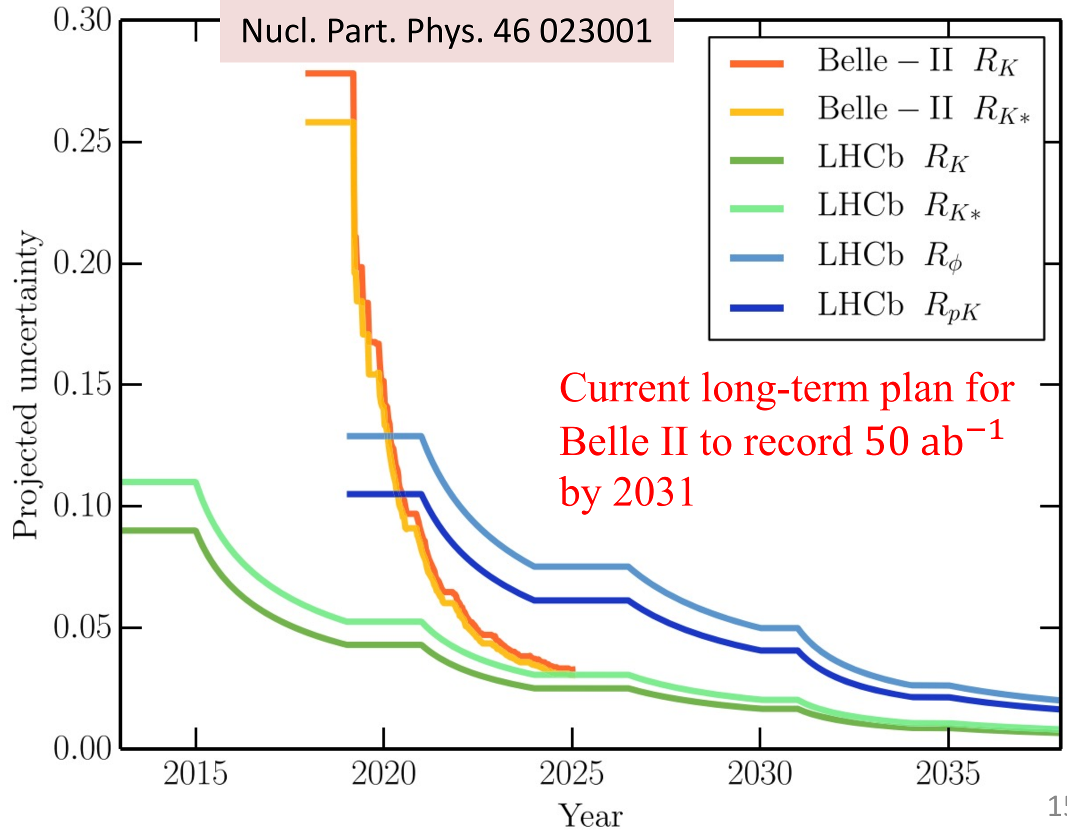
Observables	Belle $0.71\ ab^{-1}$	Belle II $5\ ab^{-1}$	Belle II $50\ ab^{-1}$
R_K ([1.0, 6.0] GeV^2)	28%	11%	3.6%
R_K (>14.4 GeV^2)	30%	12%	3.6%
R_{K^*} ([1.0, 6.0] GeV^2)	26%	10%	3.2%
R_{K^*} (>14.4 GeV^2)	24%	9.2%	2.8%
R_{X_s} ([1.0, 6.0] GeV^2)	32%	12%	4.0%
R_{X_s} (>14.4 GeV^2)	28%	11%	3.4%

- Using more data, we can reduce both stat and syst uncertainties
- Belle II offers a complementary setup with respect to LHCb
  - Similar performance for muon and electron channels
  - Upper hand in inclusive modes

- While we have a long way to go, a beginning has been made with the rediscovery of one related channel

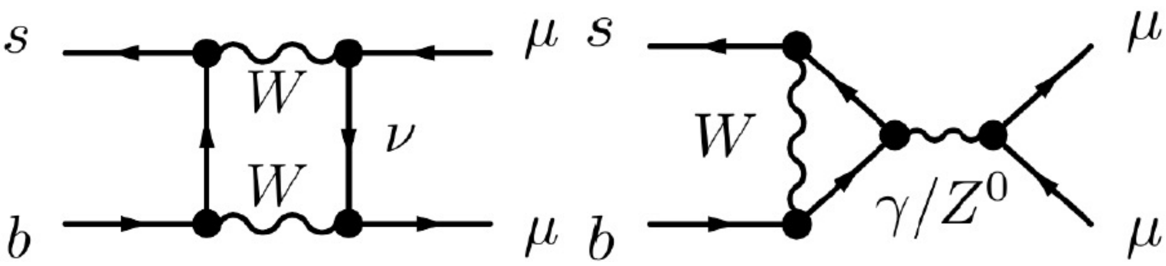


Nucl. Part. Phys. 46 023001

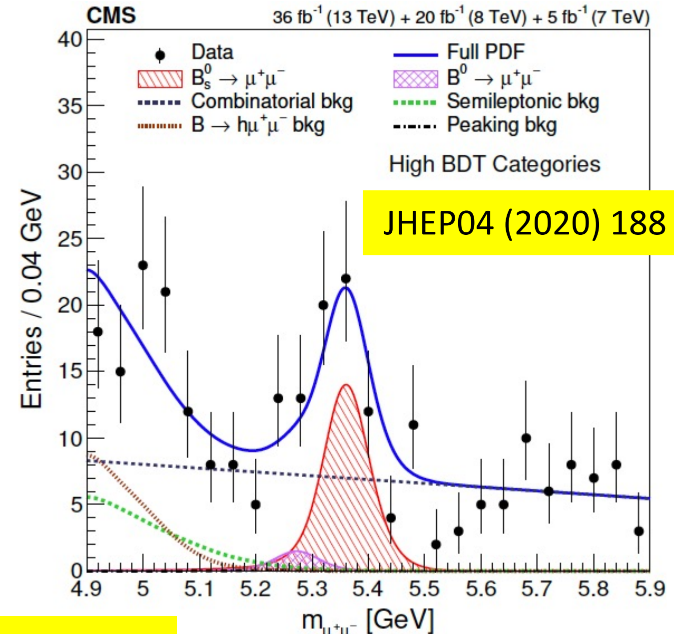


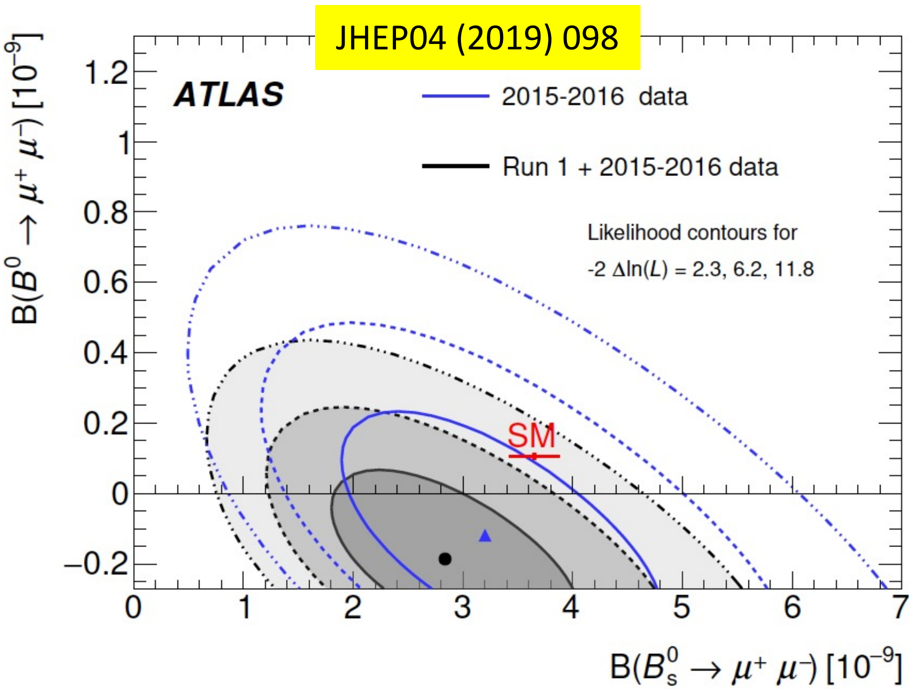
Current long-term plan for Belle II to record 50 ab^{-1} by 2031

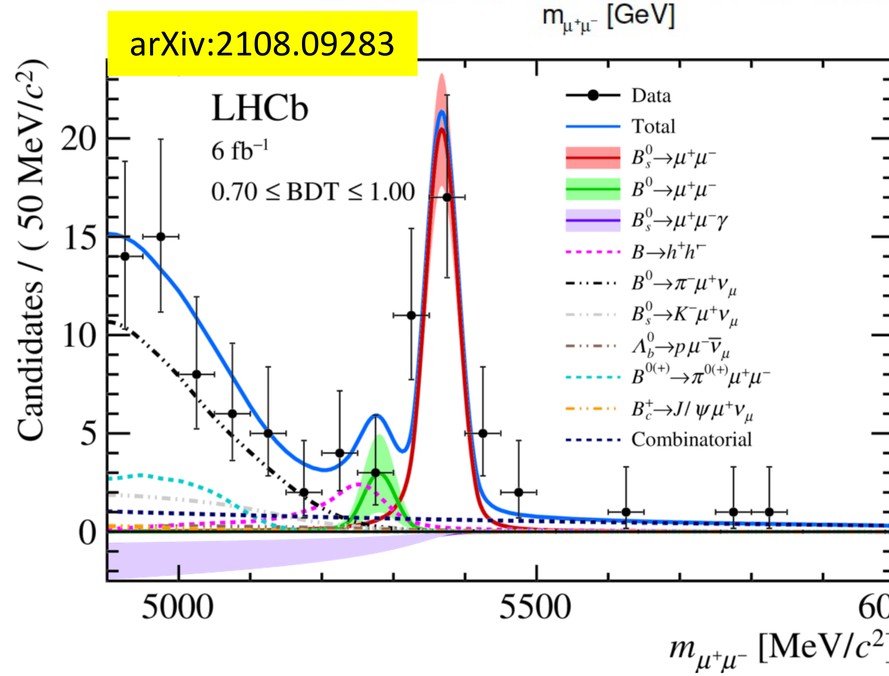
A rare decay loved by SUSY enthusiasts



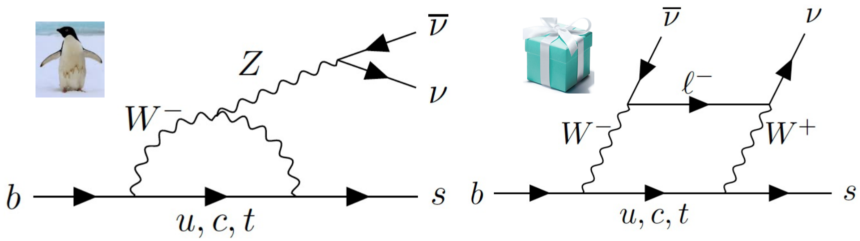
- Very suppressed in the SM
- Need a huge suppression of combinatorial and misidentified backgrounds
- Results are consistent with SM predictions







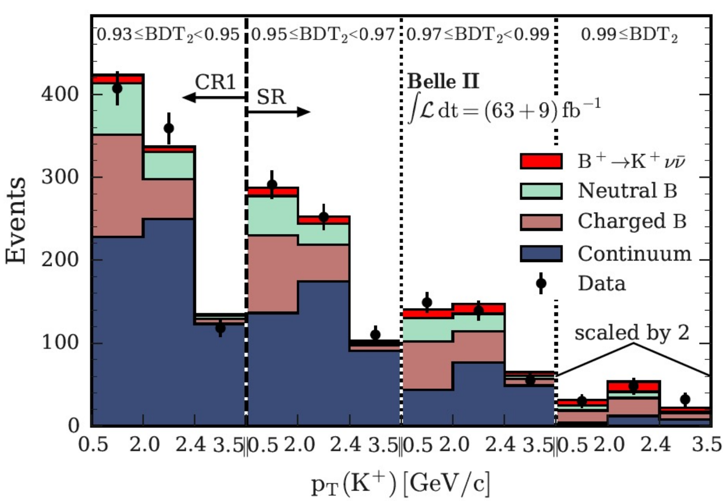
Search for $B^+ \to K^+\nu\bar{\nu}$ decays



- This suppressed FCNC decay offers a complementary probe of NP scenarios proposed to explain flavor anomalies

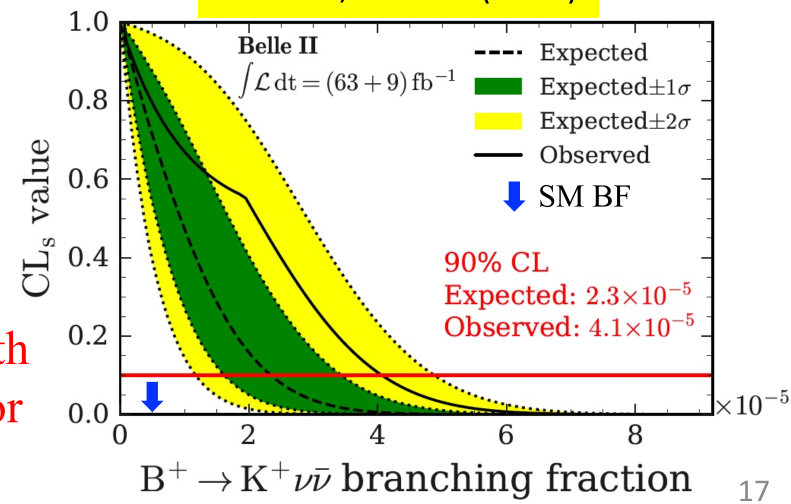
PRD 98, 055003 (2018); 102, 015023 (2020); 101, 095006 (2020)

- It could help constrain models with leptoquarks, axions, or DM particles
- Experimentally very challenging with two (escaping) neutrinos
- Belle II deployed a novel inclusive tagging method
  - Substantially larger signal efficiency of ~ 4% compared to ≪ 1% of the earlier approaches at the cost of higher background levels
- Two boosted decision tree classifiers, of which the 2nd one is nested, to fight against various backgrounds



☞ Competitive with earlier results for similar data

PRL 127, 181802 (2021)



Closing words

- Focus on some decays sensitive to new physics including SUSY
- Two set of anomalies: 3.4σ tension in tree-level $B \to D^{(*)}\tau\nu$ decays and similar level of tension in $b \to s\ell\ell$ transitions
- In either case, leptons seem to be non-universal
- Whether genuine signal for NP or a ploy of statistics, only time will tell us
- LHCb, Belle II, CMS and ATLAS will all have a lot to say in this regard

➢ Stay tuned …