Lepton Flavour Universality: LHCb results and prospects

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ON BEHALF OF THE LHCB COLLABORATION

DARK MATTER WORKSHOP , DESY, JUNE 3, 2020

Talk outline

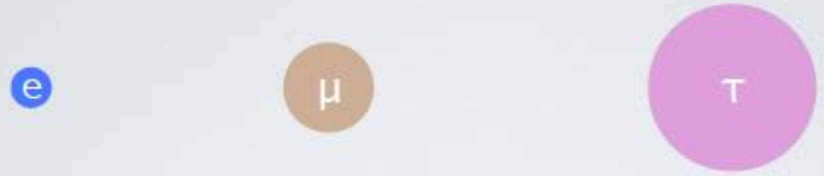
- Lepton Flavour Universality violation
- LFUV tests in LHCb
  - Charged Current : $b \to c\tau\nu$ decays (τ vs μ)
  - Neutral Current : $b \to s \ell^+ \ell^-$ decays (e vs μ)
- Theoretical interpretation(s) of LFUV present hints
- Potential link with Dark Matter
- LFUV prospects in LHCb
- Conclusion

Flavour physics in the SM

- Some key assumptions
  - Lepton Universality
  - Lepton Number conservation
  - Lepton Flavour conservation (only for charged leptons)
  - Baryon Number conservation
  - FCNC suppression
- Many many free parameters:
  - Quarks and leptons masses
  - Lifetimes
  - CKM and PMNS matrices
- ”Ugly ” but works damn well !!

We need to search for the profound difference between the three leptons!

Today: From G. Isidori, talk at HC2NP , Tenerife, 2019



Identical, save for mass ("lepton universality")

But perhaps not

Perhaps they are different
they feel different forces
ie, they transform differently under the underlying
(UV) gauge group

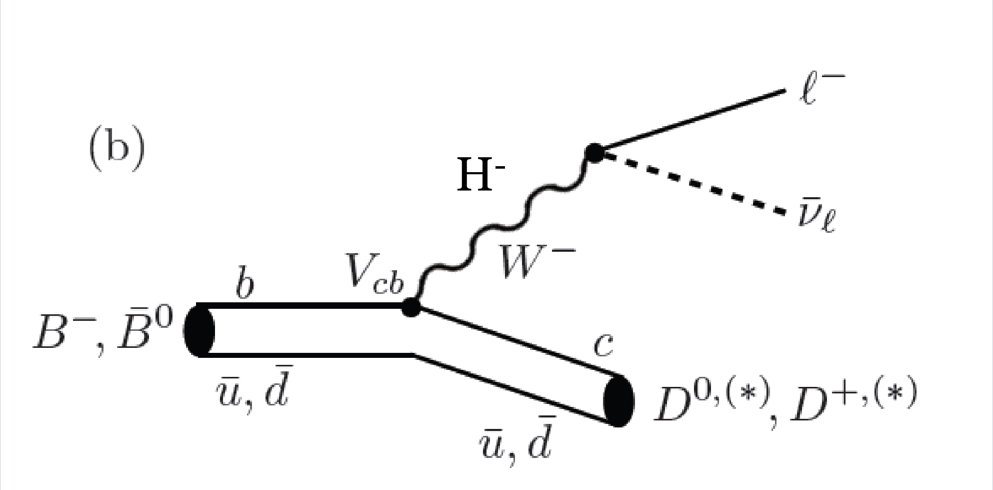
They appear the same because of accidental symmetries

We just need a bigger microscope

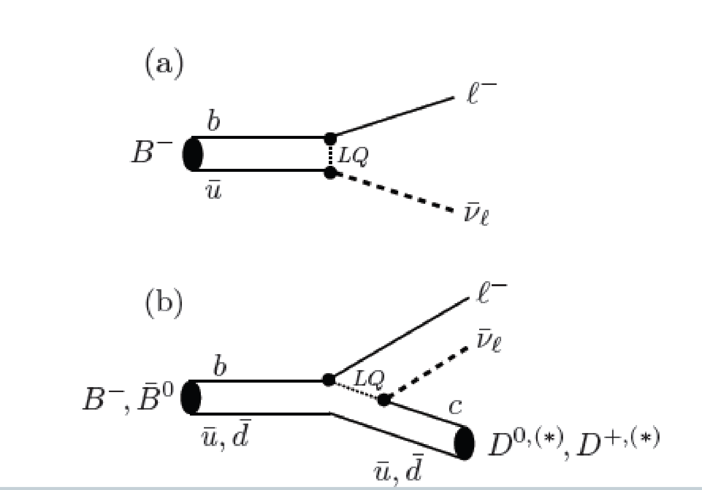
LFUV tests in charged current

Rich potential NP reach in a tree-level decay !!!

Charged Higgs



Leptoquarks



Solid and precise SM prediction for B→D(*)τν decays at 1-2% level

Large BR: 1% for B°→D*τν

R(D*) LHCb muonic result (2015)

PRL 115 111803 (2015)

- First R(D*) measurement from a difference source than B factories
- 3D Fit to the muon distribution in (M_{miss}, E_{ℓ}, q^2)

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

- Compatible with SM expectation (0.258±0.05)

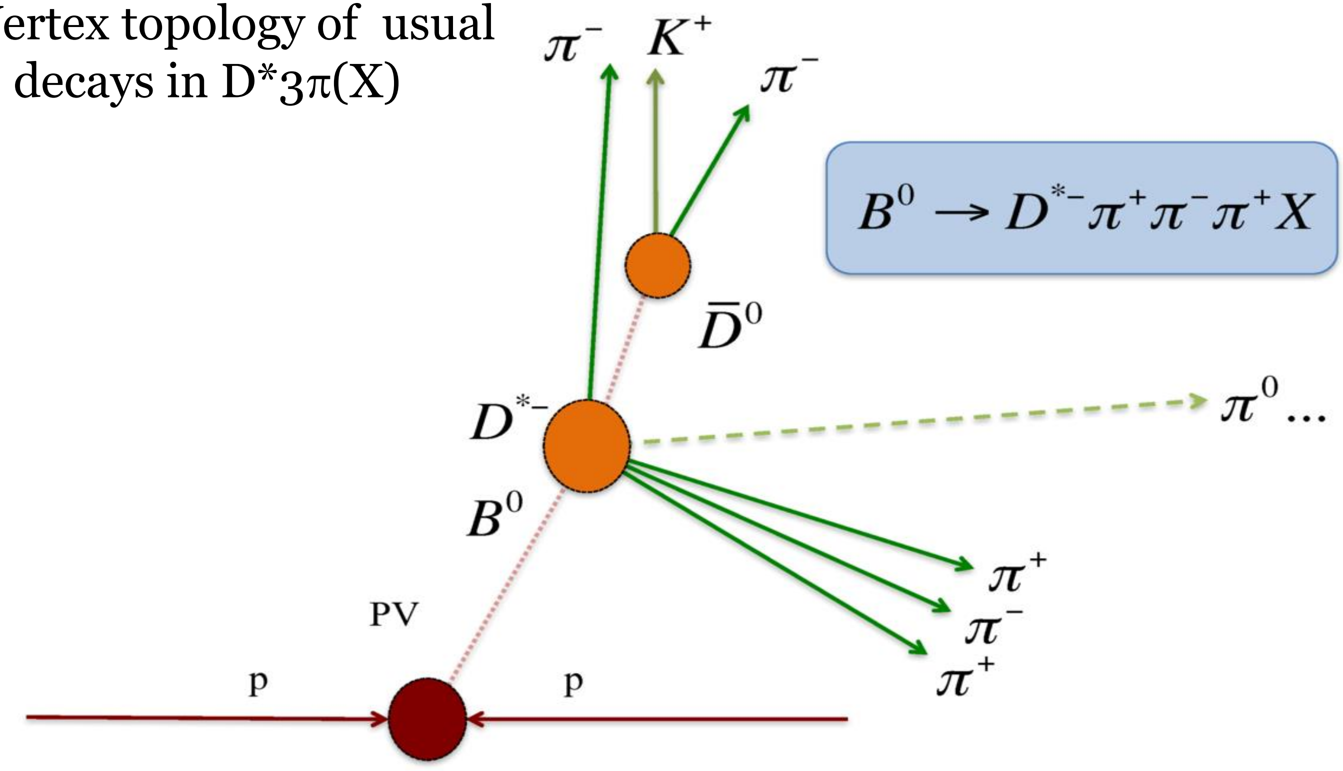
but larger as all other R(D*) measurements so far…

Measurement of B° → D*τν with τ → 3π decay

LHCb-PAPER-2017-017, LHCb-PAPER-2017-027

PRL 120,171802 (2018)/PRD 97,072013(2018)

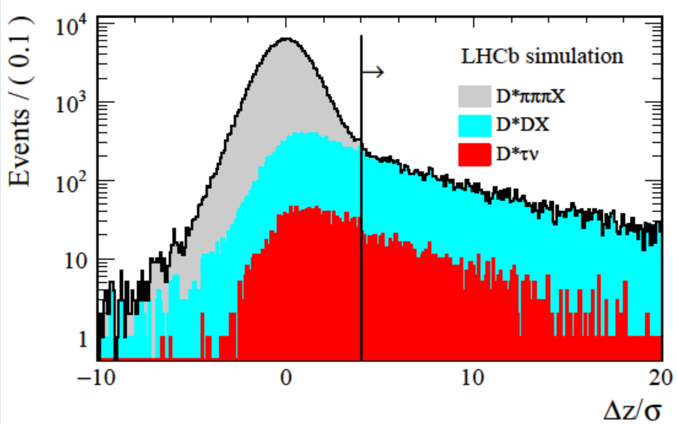
Vertex topology of usual B decays in D*3π(X)



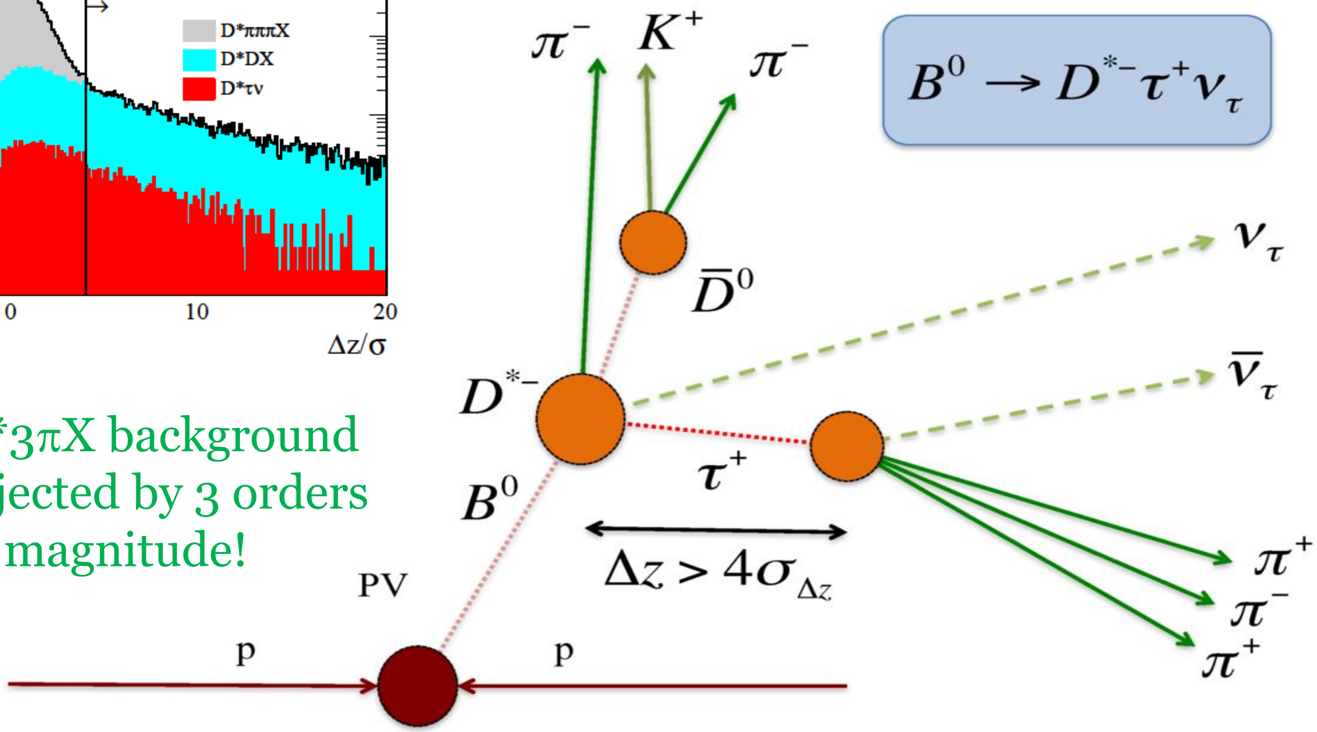
Key requirement: detached 3π vertex

LHCb-PAPER-2017-017, LHCb-PAPER-2017-027

PRL 120,171802 (2018)/PRD 97,072013(2018)



D*3πX background rejected by 3 orders of magnitude!

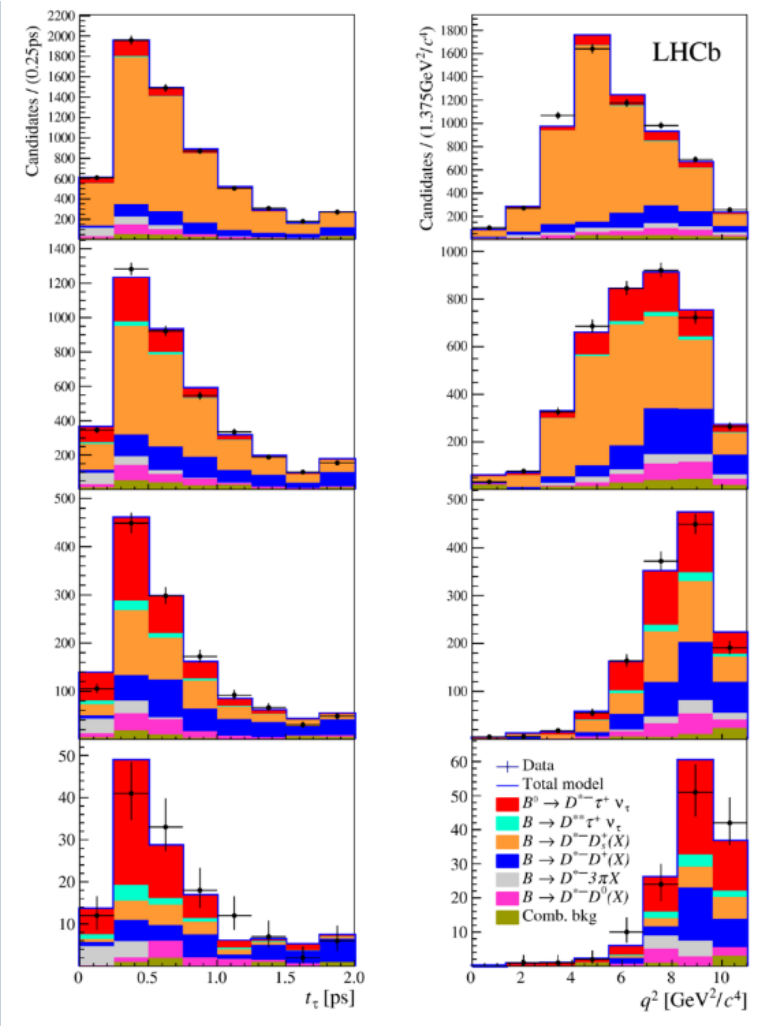


Fit results

LHCb-PAPER-2017-017, LHCb-PAPER-2017-027

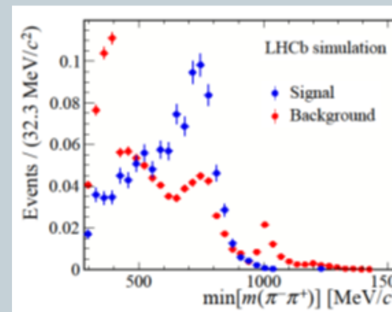
PRL 120,171802 (2018)/PRD 97,072013(2018)

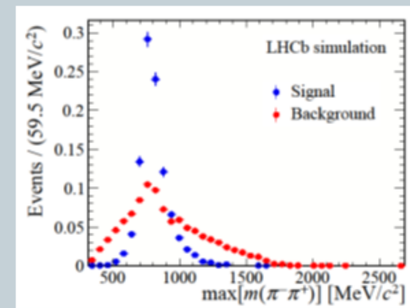
BDT →



- A BDT is constructed to distinguish 3π from τ decays from 3π from D_s

Min(mass($\pi^+\pi^-$)) Max(mass($\pi^+\pi^-$))

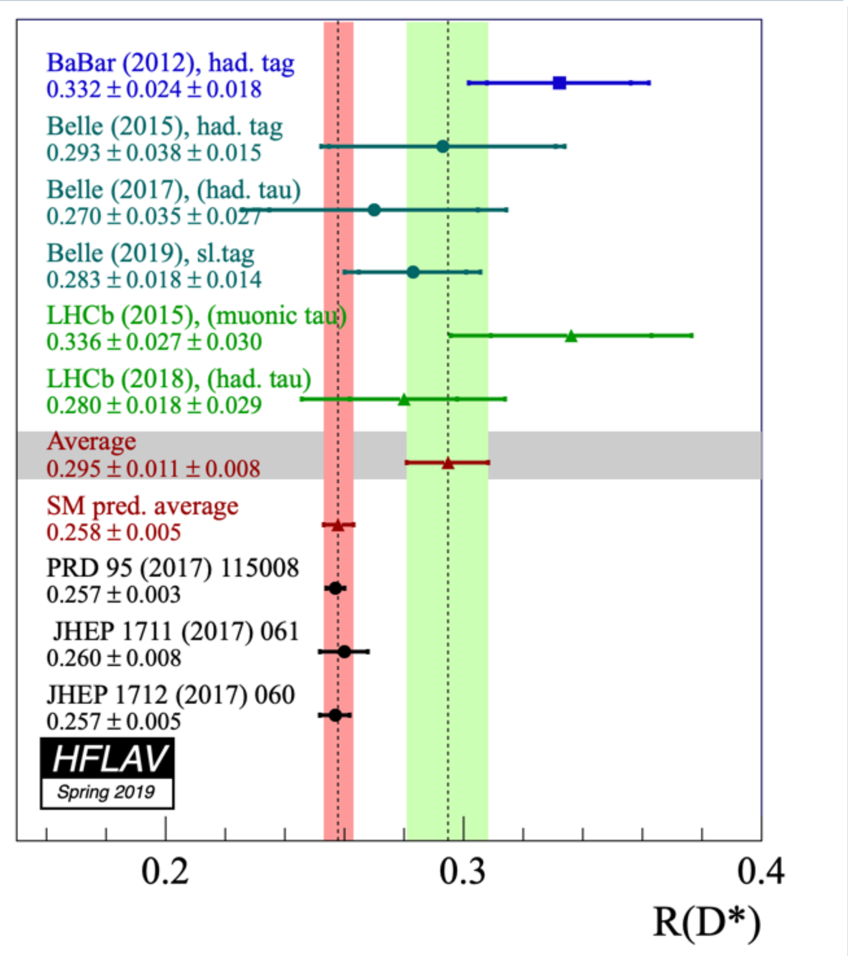


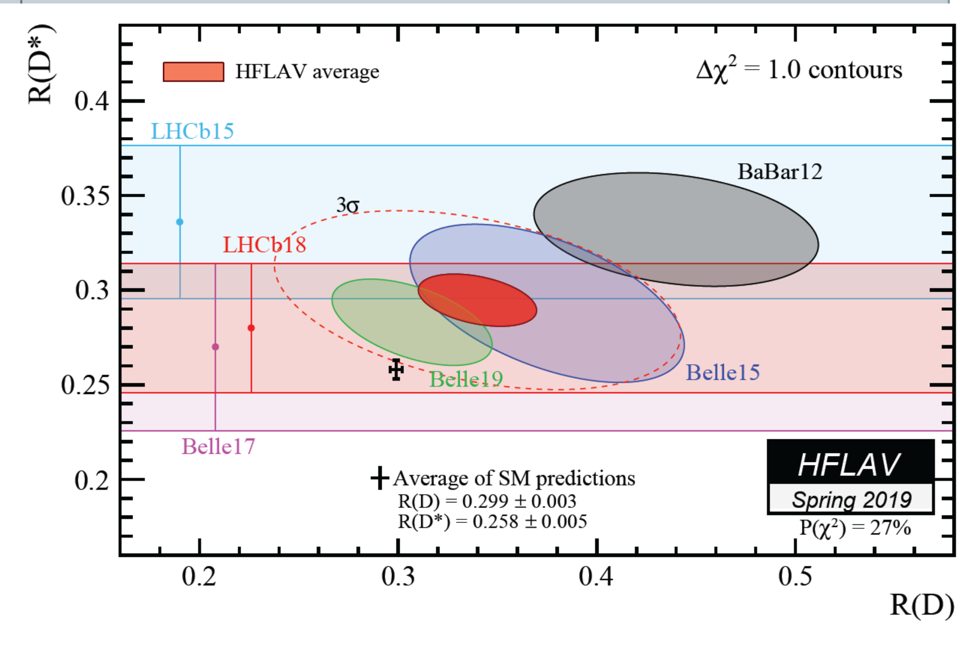


The 3D template binned likelihood fit results for lifetime and q^2 in four BDT bins.

- The increase in signal purity (red) as function of BDT is very clearly seen, as well as the decrease of the D_s component (orange)

R(D)-R(D*) results

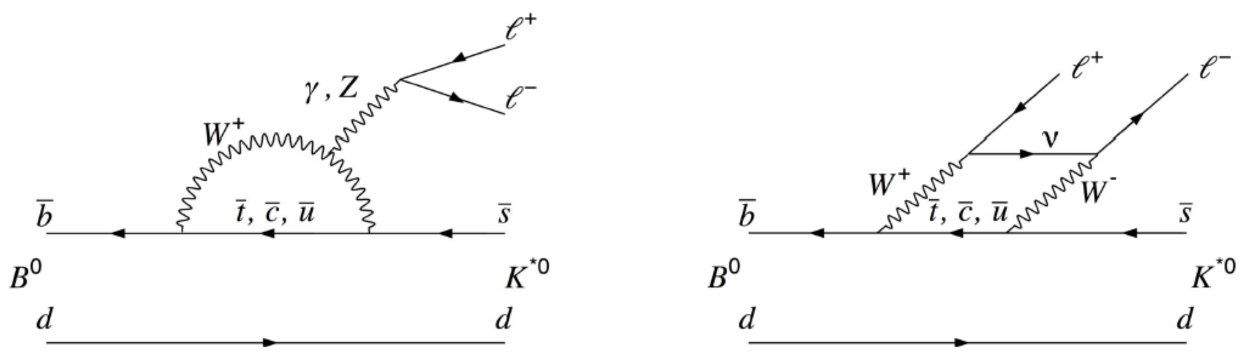




Present discrepancy with SM : 3.08 σ

Rare b-hadron decays

- FCNC sensitive to indirect effects of New Physics (NP) in loops
  - branching fractions, angular distributions, etc.
- Access to much larger scales than direct searches



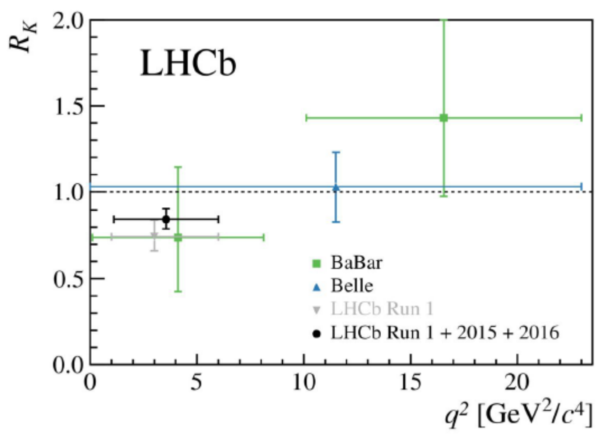
R_K and R_{K^*} results from LHCb

Intriguing deviations in rare B decays

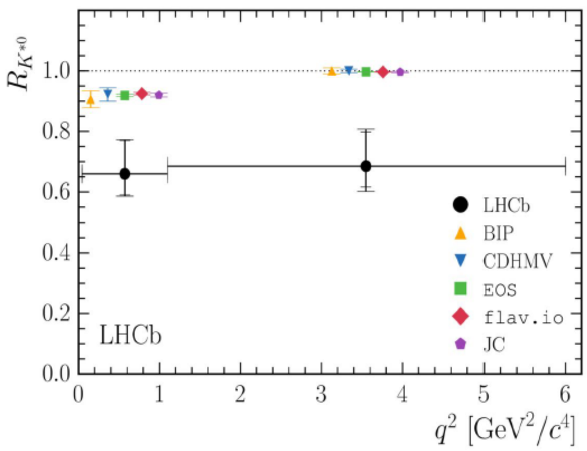
Lepton Universality (LU) tests

$$R_H \equiv \frac{\int \frac{d\Gamma(B\to H\mu^+\mu^-)}{dq^2}\, dq^2}{\int \frac{d\Gamma(B\to He^+e^-)}{dq^2}\, dq^2}$$

PRL 122 (2019) 191801



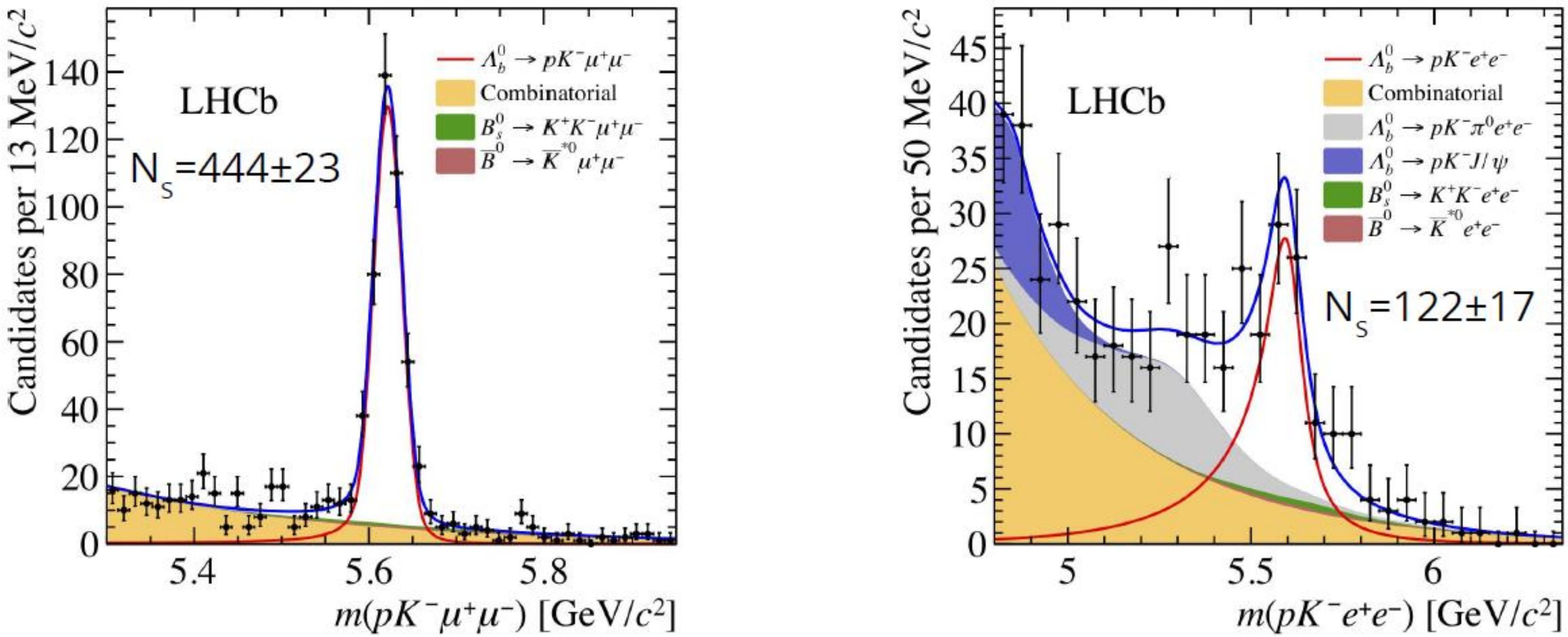
JHEP 08 (2017) 055



Crucial to add more data and measure LU in other modes

First LFUV test with B baryons : measurement of R_{pK} using $\Lambda_b \to pK\ell^+\ell^-$

J. High Energ. Phys. 2020, 40 (2020)



$pK\ell^+\ell^-$ mass distributions

R(pK) results

J. High Energ. Phys. 2020, 40 (2020)

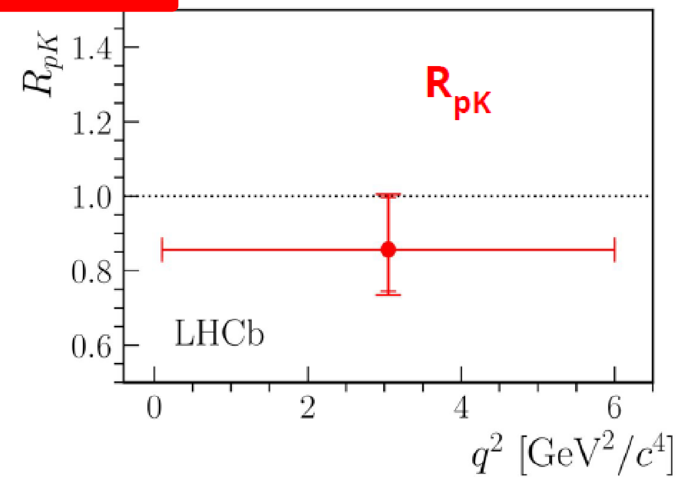
$$R_{pK}^{-1}\big|_{0.1<q^2<6\,\mathrm{GeV}^2/c^4} = 1.17^{+0.18}_{-0.16} \pm 0.07$$

- inverting likelihood profile:

$$R_{pK}\big|_{0.1<q^2<6\,\mathrm{GeV}^2/c^4} = 0.86^{+0.14}_{-0.11} \pm 0.05$$

Electron efficiency controlled through $\Lambda b \rightarrow pKJ/\psi$, $J{:}\psi \rightarrow e^+e^-$

First LFUV measurement in the baryonic world !



A unique mediator can explain all anomalies ! a vector leptoquark with mass in the TeV range

G. Isidori – *New prospects for BSM physics* — *HC2NP 2019, Tenerife*

General considerations

Which LQ explain which anomaly?

	Model	$R_{K^{(*)}}$	$R_{D^{(*)}}$	$R_{K^{(*)}}$ & $R_{D^{(*)}}$
Scalars	$S_1 = (\mathbf{3}, \mathbf{1})_{-1/3}$	✗	✓	✗
	$R_2 = (\mathbf{3}, \mathbf{2})_{7/6}$	✗	✓	✗
	$\widetilde{R}_2 = (\mathbf{3}, \mathbf{2})_{1/6}$	✗	✗	✗
	$S_3 = (\mathbf{3}, \mathbf{3})_{-1/3}$	✓	✗	✗
Vector	$U_1 = (\mathbf{3}, \mathbf{1})_{2/3}$	✓	✓	✓
	$U_3 = (\mathbf{3}, \mathbf{3})_{2/3}$	✓	✗	✗

There is one clear winner [U_1]...

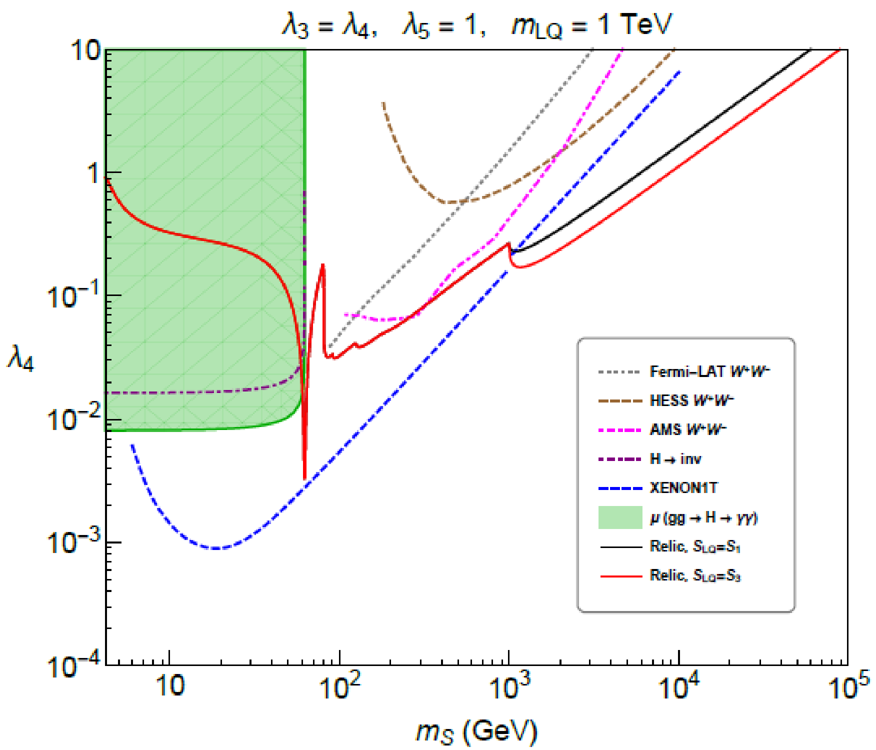
...but the single-mediator case is definitely an over simplification [*as we learned in the last ~ 2 years...*]

3 interesting options:

- U_1 + colorless-vectors
  Being a massive vector, U_1 requires an appropriate UV compl. → always accompanied by (at least) a Z'
  Alonso, Grinstein, Camalich '15
  Barbieri, GI , Pattori, Senia '15
  + wide literature
- S_1 & S_3
  Good option for the EFT "pure-LH" solution
  Crivellin, Muller, Ota '17
  Buttazzo *et al.* '17
  Marzocca '18
- R_2 & S_3
  GUT-inspired option for EFT solution including also RH currents
  Becirevic *et al.* '18

Large litterature devoted to links between B physics anomaly and Dark Matter

- Many references can be found in a recent paper by D.G. Cerdeno et al., arxiv:1902.01789



Lepto-Quark portal to Dark Matter, Soo-Min Choi et al., JHEP 10 (2018) 104, [1807.06547].

Scalar Dark Matter particle mass vs couplings in leptoquark model consistent with the B anomalies
Lot of parameter space still available.
Future experiments such as Xenon 1T (blue) can test these types of models
(The red and black solid lines correspond to the correct DM relic density)

LFUV Prospects in LHCb : a very large comprehensive program

- More statistics
  - Full Run2 dataset (6 fb^{-1})= ~6-10 times Run1 dataset (3 fb^{-1}) (higher energy- better trigger conditions)
  - Future statistical precision on R(D*) 2-3 % range
- More particles
  - CC muonic : R(D°)-R(D*), R(D^+),R(Λ_c),R(pp),R(D_s),R(J/ψ)
  - CC hadronic: R(Λ_c),R(D**),R(J/ψ),R(D°),R(D^+),R(D_c)
  - NC R(ϕ), R(τ)
- More informations
  - D* polarisation
  - Limits on NP through effective Wilson coefficients
  - τ polarisation
  - ....

Conclusion

- LFUV violation hints still present in charged current and neutral current B decays
- Recent result from LHCb : $R_{pK}\big|_{0.1<q^2<6\,\mathrm{GeV}^2/c^4} = 0.86\,^{+\,0.14}_{-\,0.11} \pm 0.05$
- No stones are going to be left unturned in the next coming years! With all tools in hand, a definitive answer on the present anomalies could be given before the end of the decade!!
- Very interesting theoretical ideas coming up from the current anomalies, giving an exciting coherent picture (too good to be true?)
- Potential links with Dark Matter being actively explored!

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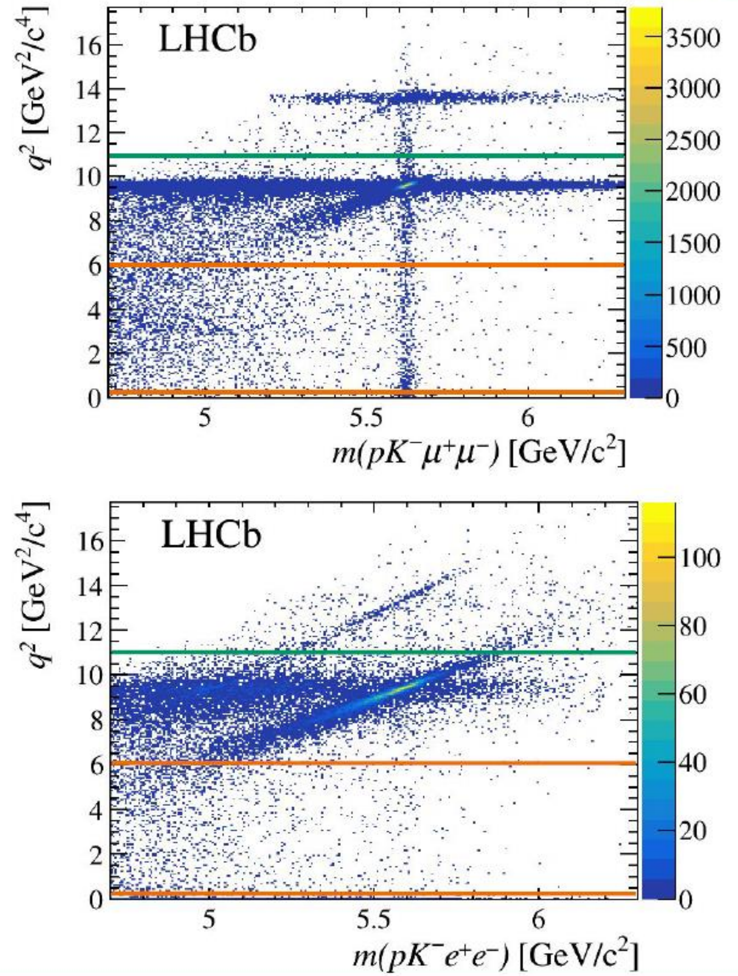
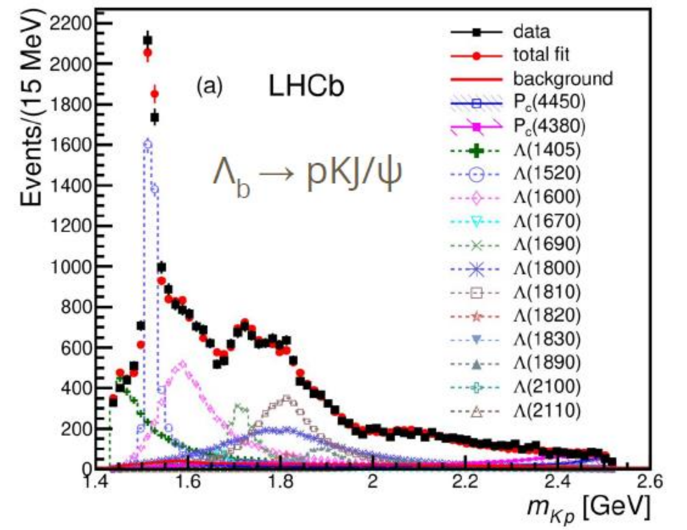
arXiv:1912.0813





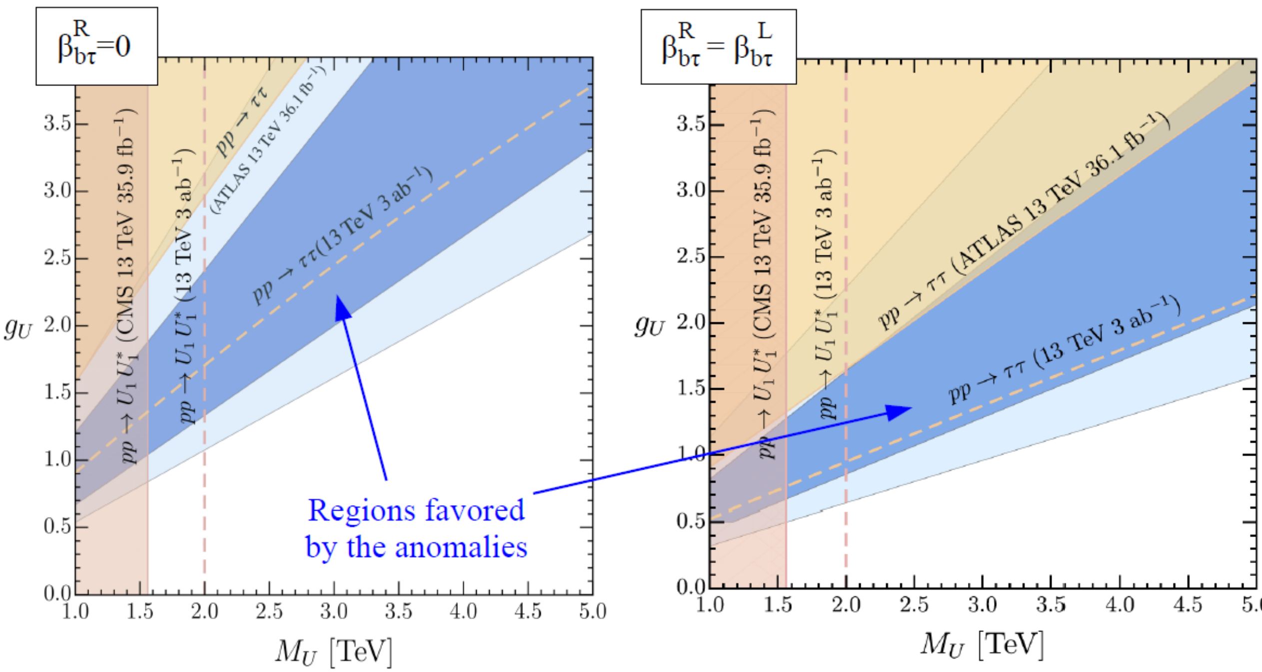
Phys. Rev. Lett. 115 (2015) 072001

Important consequences for the channel pp→ττ

G. Isidori – New prospects for BSM physics *HC2NP 2019, Tenerife*

▶ *A "consistent" simplified model for the* U_1

The presence of RH couplings leads to significant differences at high-p_T:



Baker, Fuentes-Martin, GI, König, '19

At the border of sensitivy of HL-LHC !