Lepton flavour universality and rare decays with baryons in LHCb

- LHCb Padova meeting 2/12/2020

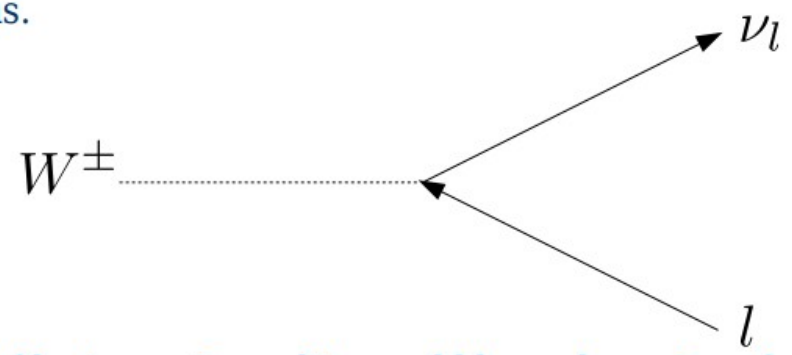
Attivita’ in corso

Lepton Flavour Universality

- In the Standard Model there are three generations of quarks and three of leptons:

$$\begin{pmatrix} e \\ \nu_e \end{pmatrix} \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix} \begin{pmatrix} \tau \\ \nu_\tau \end{pmatrix}$$

- By construction, the electroweak coupling of the gauge bosons to leptons is independent of the lepton flavour:
  - the branching fractions of decays involving leptons do not depend on the lepton kind: the only differences between e, μ and τ are the phase space and helicity-suppressed contributions.



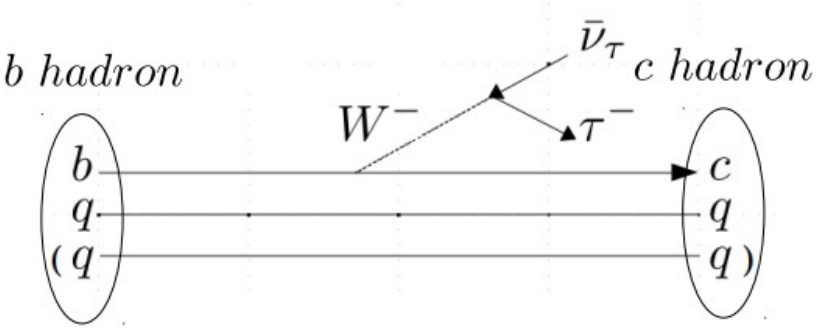
→ Any violation of lepton universality would be a clear sign of physics beyond the Standard Model

- Over the years LFU has been tested in several systems providing very strong limit.

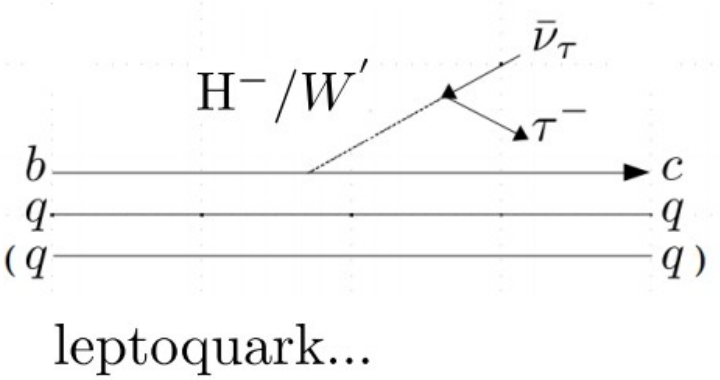
LFU test using semileptonic decays

- The semileptonic/rare decays of heavy hadrons are the natural laboratory to test the LFU:
  - They allow to access to all three generations of leptons.

- A large class of SM extensions contain new interactions that differs between generations.



Standard Model



Physics beyond the Standard Model

R(X) measurements

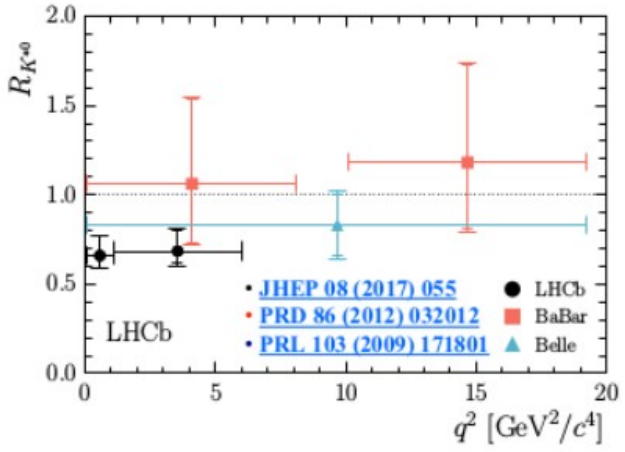
- Hints of lepton non universality effects have already seen measuring the ratios:

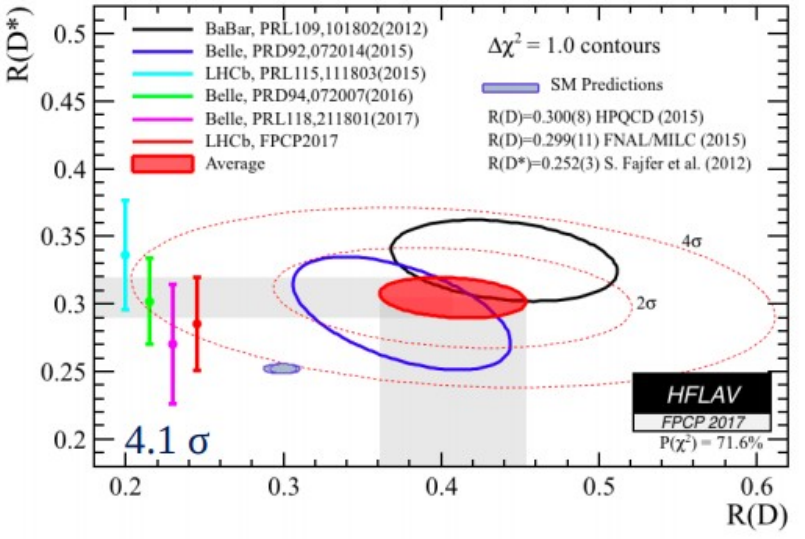
$$R(K^{(*)}) = \frac{\mathcal{B}(B \to K^{(*)} \mu^- \mu^+)}{\mathcal{B}(B \to K^{(*)} e^- e^+)}$$

$$R(D^{(*)}) = \frac{\mathcal{B}(\bar{B}^0 \to D^{(*)+} \tau^- \bar{\nu}_\tau)}{\mathcal{B}(\bar{B}^0 \to D^{(*)+} \mu^- \bar{\nu}_\mu)}$$

- Compatibility with the SM:
  - R(K*)_low q^2 : (2.1-2.3)σ
  - R(K*)_central q^2 : (2.4-2.5)σ
  - R(K): 2.6σ

- HFLAV average of R(D) and R(D*) is 4.1 σ from the SM prevision





$R(\Lambda_c^*)$ measurement

- In this project I focused on the measurement of the ratio:

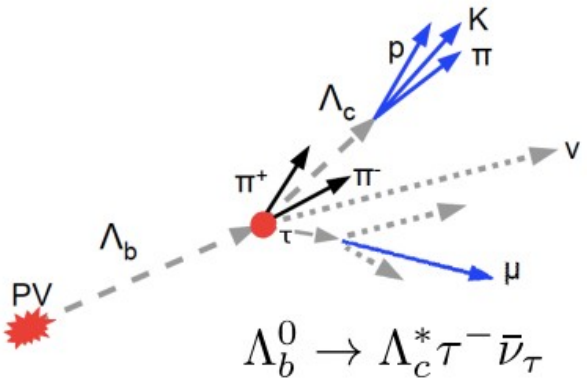
$$R(\Lambda_c^*) = \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^* \tau^- \bar{\nu}_\tau)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^* \mu^- \bar{\nu}_\mu)}$$

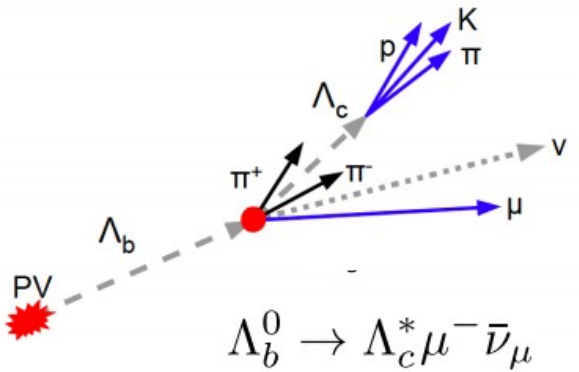
- The R (Λ_c*) measurement is of great interest:
  - It would be the first measurement with baryons, different spin structure so the sensitivity to New Physics would be different.

- Copious amount of Λ_b at LHCb (~ 40% of B mesons produced).

- Λ_c* correspond to L=1 excited Λ_c. They consist of an isospin doublet:
  - Λ_c (2625) is a J = 3/2
  - Λ_c (2593) is a J = 1/2

Signature of $\Lambda_b \to \Lambda_c^* \tau \nu$ and $\Lambda_b \to \Lambda_c^* \mu \nu$





- Signature of $\Lambda_b \to \Lambda_c^* \tau \nu$ and $\Lambda_b \to \Lambda_c^* \mu \nu$:
  - Displaced Λ_c^* vertexes (1cm) reconstructed with good quality;
  - Large impact parameters of final products;
  - Long tracks associated with a μ candidate in the muon station.

Status

A.Lupato, G.Simi, M.Rotondo

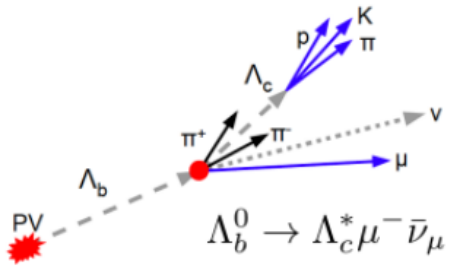
- R(Λ_c^*) run I measurement → LHCb-ANA-2018-026
- R(Λ_c^*) run II measurement:
  - Add the contribution of $\Lambda_b \to \Lambda^*_c(2595)\mu\nu$ decays → Phenomenological Model implemented: Blechman et al. [10.1103/PhysRevD.67.074033] → done, Roofit tool
  - Large systematic due to lack of form factor measurements

→ $\Lambda_b \to \Lambda^*_c\mu\nu$ form factors measurement → winter conferences (see FF presentation)

  - Inability to constrain the double charmed decays does not enable a precise measurement of R(Λ_c^*) ratio → BF($\Lambda_b \to \Lambda^*_c D_s$)
    - Selection, Δm fit → done
    - Fit → in progress

Why $\Lambda_b \rightarrow \Lambda_c^*$ form factors

- Copious amount of Λ_b at LHCb (~ 40% of B mesons produced)
- These Λ_c^* resonances decay in $\Lambda_c \pi^- \pi^+$ with a $B \sim 67\%$
  → The two charged pions give good vertex reconstruction and clean experimental signature
- These Λ_c^* excited states avoid contamination due higher mass c-baryons
  → reduce the feed-down from higher order excited states
- The widths of these Λ_c^* resonances are narrow:
  - $\Gamma(\Lambda_c(2625)) < 0.97$ MeV (PR D84 012)
  - $\Gamma(\Lambda_c(2595)) = 2.59 \pm 0.30$ (Chin. Phys. C, 40, 100001 (2016))



$$\Lambda_b^0 \rightarrow \Lambda_c^* \mu^- \bar{\nu}_\mu$$

$$\Lambda_c^{*+} \rightarrow \Lambda_c^+ \pi^+ \pi^-$$

$$\Lambda_c^+ \rightarrow p K^- \pi^+$$

$$\tau^- \rightarrow \mu^- \bar{\nu}_\mu \nu_\tau$$

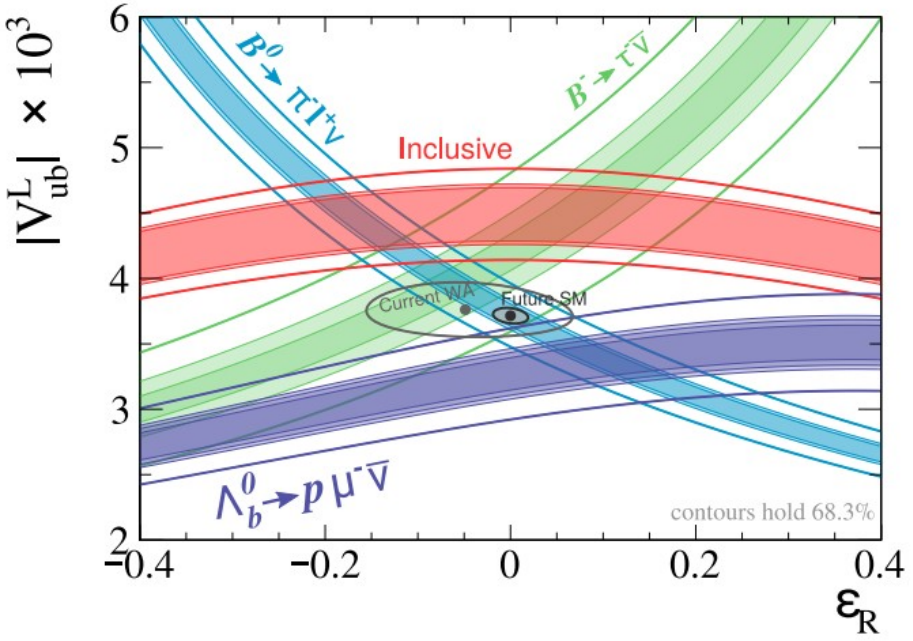
Lb → Lc* Ds

- Inability to constrain the double charmed decays does not enable a precise measurement of $R(\Lambda_c^*)$ ratio → $BF(\Lambda_b \to \Lambda^*_c D_s)$
  - Selection, Δm fit → done
  - Fit → in progress
  - Tesi triennale P. Argenton
    - Selezione del segnale Lb → Lc* 3pi
  - Prospettive
    - Selezione del segnale Lb → Lc* Ds e misura del BF
    - Decadimento mai osservato, possibilita’ concreta di pubblicare il risultato velocemente

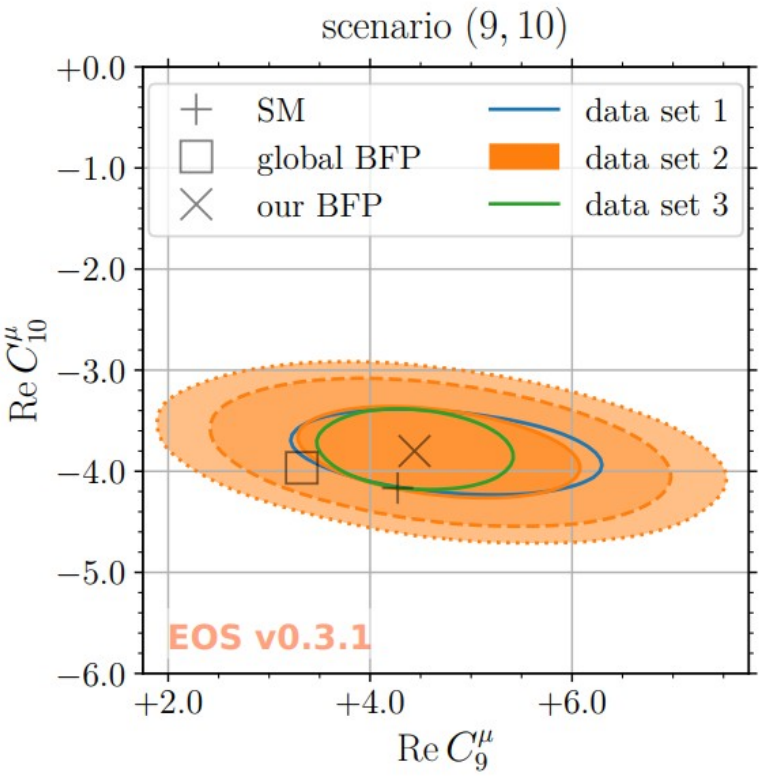
Perspectives

- LHCb is the only experiment capable of exploring new physics effects in b-baryon decays since BelleII cannot produce b-baryons
- Recent workshop on b-barion analysis perspectives in LHCb https://indico.in2p3.fr/event/20198/contributions/88389/
- Many interesting ideas, I just mention a few of them

b baryons provide important constraints on physics beyond the SM

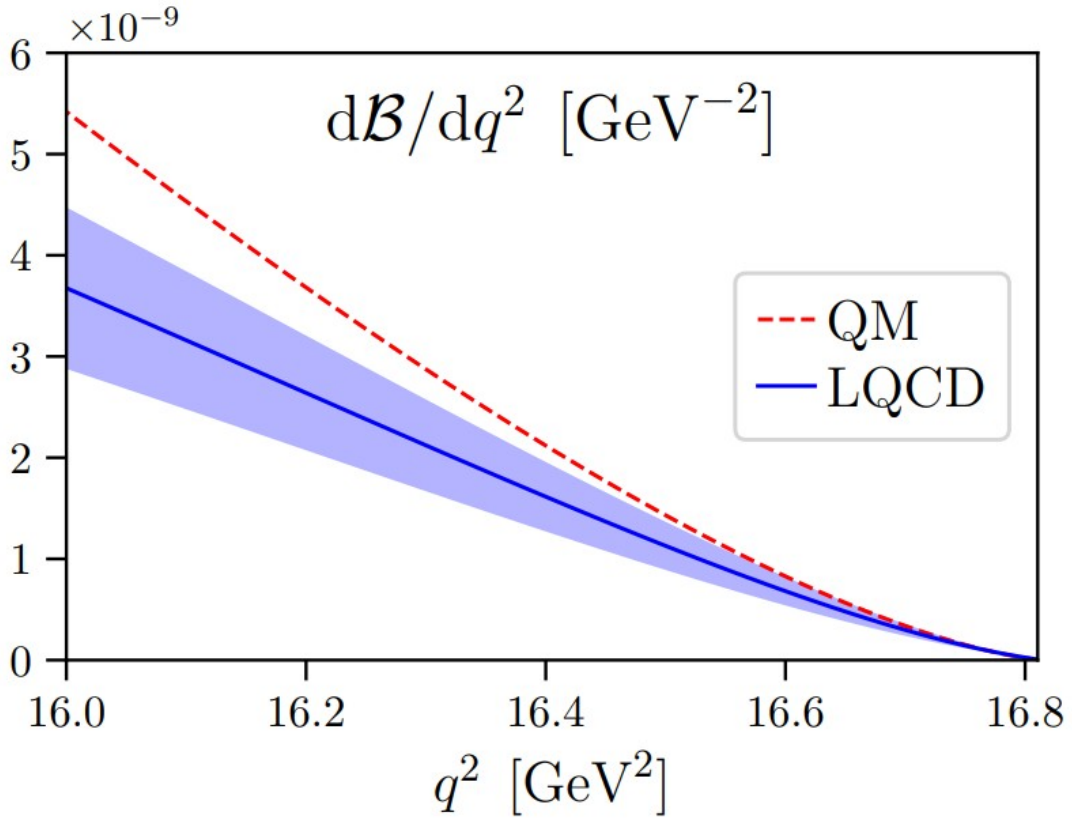


[J. Albrecht *et al.*, arXiv:1709.10308]



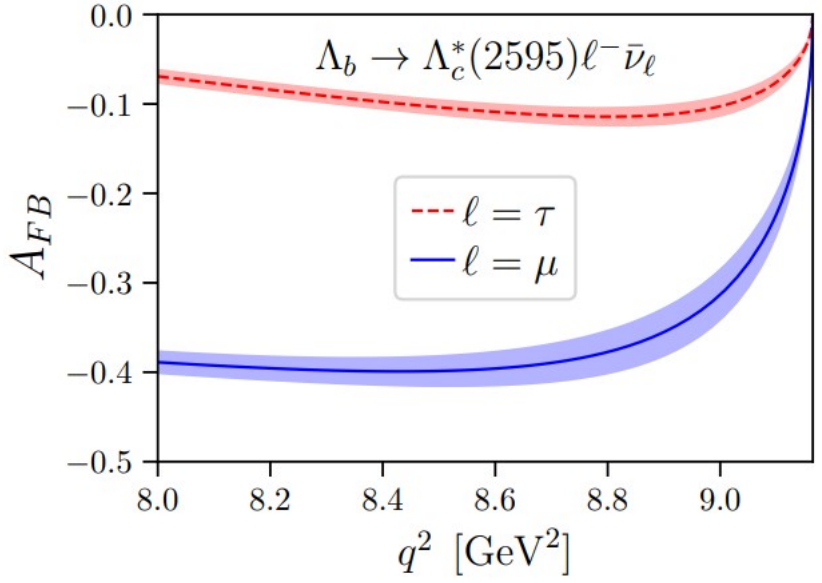
[T. Blake *et al.*, arXiv:1912.05811/PRD 2020]

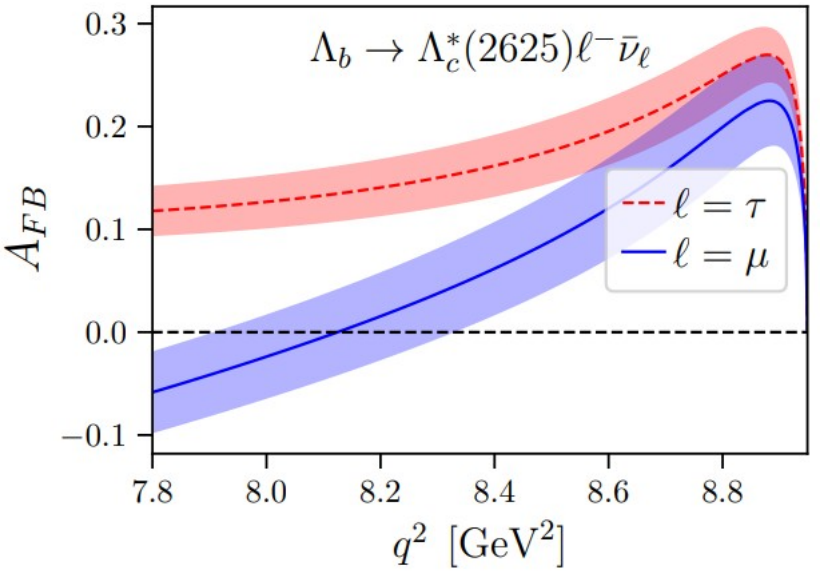
$\Lambda_b \to \Lambda^*(1520)\ell^+\ell^-$ observables



QM = using form factors from [L. Mott, W. Roberts, arXiv:1108.6129/IJMPA 2012]

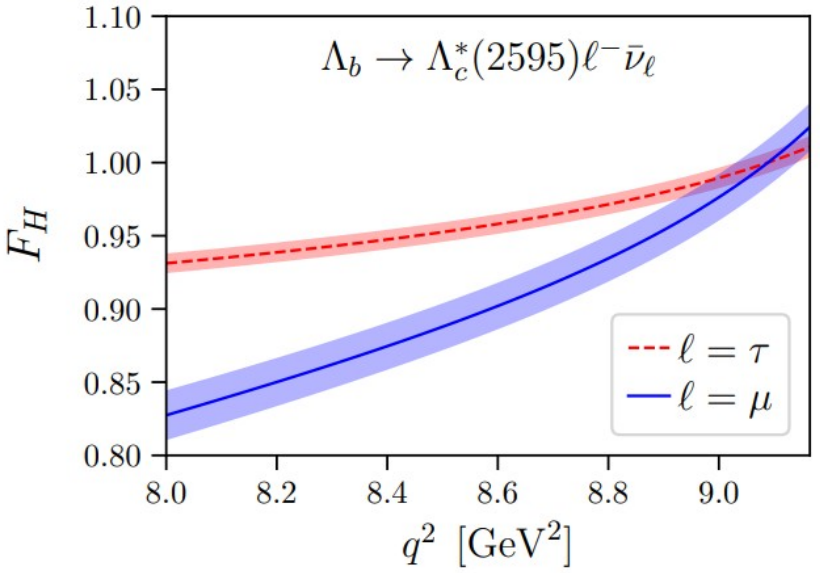
$\Lambda_b \to \Lambda_c^* \ell^- \bar{\nu}_\ell$ observables

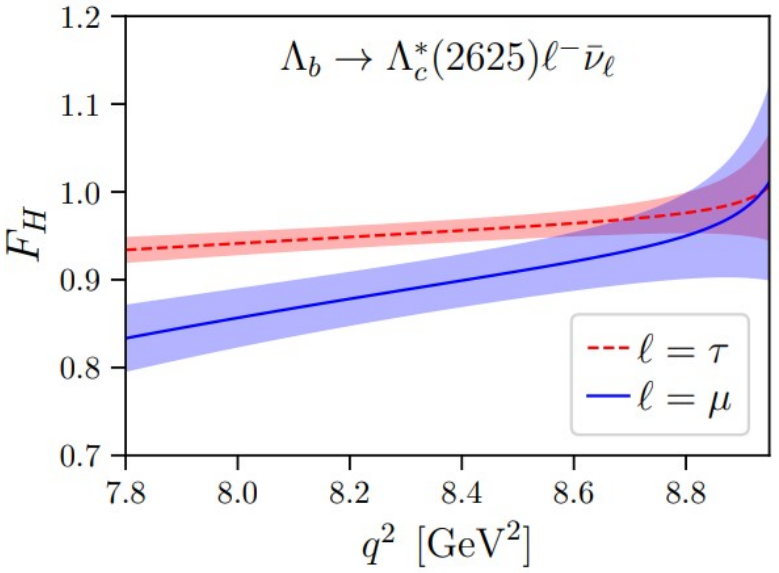




See [P. Böer *et al.*, arXiv:1801.08367/JHEP 2018] for definitions

$\Lambda_b \to \Lambda_c^* \ell^- \bar{\nu}_\ell$ observables





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