Recent results from LHCb on charged-current decays

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Outline

- **Lepton flavour universality in the SM**
- **Current theoretical and experimental status**
- **Recent result: measurements of $R(D^-)$, $R(D^{*-})$ and $B^- \to D^{**0}\,\tau^-\,\bar{\nu}_\tau$**
- **New result: $\Lambda \to p\,\mu^-\bar{\nu}_\mu$ branching fraction measurement**
- **Conclusions**

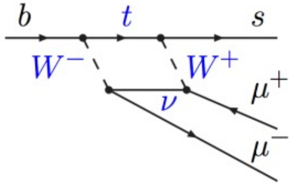
Lepton flavour universality in the SM

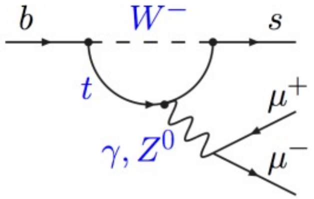
- **Lepton flavour universality: equal gauge boson coupling for all leptons**
  - Phase space and hadronic effects influence the decay rates

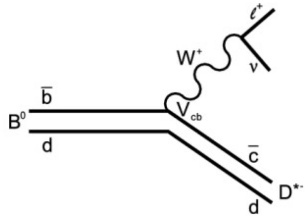
- **Tested in W and Z decays** [Phys. Rept. 427 (2006) 257] [Nature Physics 17, 813 (2021)]

$$\frac{\Gamma_{\mu\mu}}{\Gamma_{ee}} = \frac{B(Z \to \mu^+\mu^-)}{B(Z \to e^+e^-)} = 1.0009 \pm 0.0028 \qquad \frac{\Gamma_{\tau\tau}}{\Gamma_{ee}} = \frac{B(Z \to \tau^+\tau^-)}{B(Z \to e^+e^-)} = 1.0019 \pm 0.0032 \qquad \frac{\Gamma_{\tau\nu}}{\Gamma_{\mu\nu}} = \frac{B(W^\pm \to \tau^\pm\nu_\tau)}{B(W^\pm \to \mu^\pm\nu_\mu)} = 0.992 \pm 0.013$$

- **Measure rates in heavy flavour decays** [Talk by L. David Carus]
  - Flavour changing neutral currents $(b \to sl^+l^-)$
  - Flavour changing charged currents $(b \to cl^-\bar{\nu}_l)$







How to test this hypothesis with CC decays

LFU test with the $b \to c\,\tau^- \bar{\nu}_\tau / b \to c\,\mu^- \bar{\nu}_\mu$ decay ratio

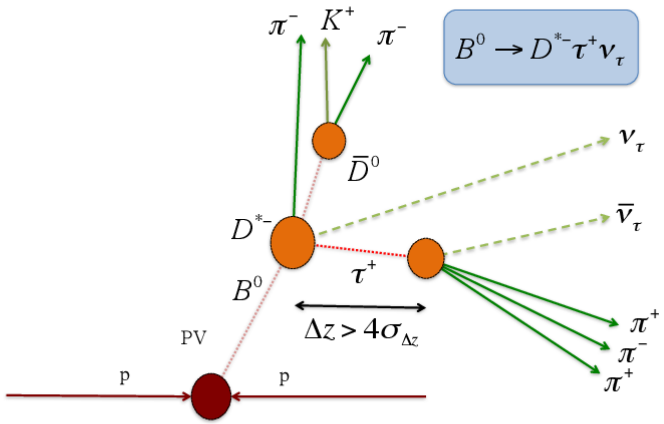
- **Ratios of branching fractions**
  - Cancellation of uncertainties
- **Family of semileptonic decay ratios**

$$R(H_c) = \frac{\mathcal{B}(H_b \to H_c\,\tau^- \bar{\nu}_\tau)}{\mathcal{B}(H_b \to H_c\,\mu^- \bar{\nu}_\mu)}$$

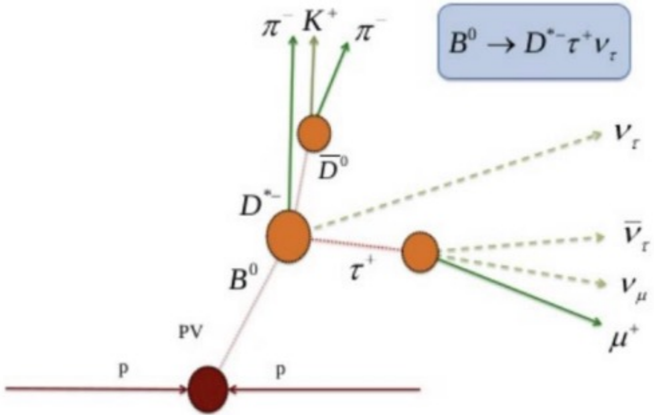
$H_b = B^0,\, B^+,\, B_s^0,\, B_c^+,\, \Lambda_b^0$
$H_c = D^0,\, D^+,\, D_s^+,\, D^{*+/0},\, D^{**+/0},\, \Lambda_c^+,\, \Lambda_c^{*+},\, J/\psi$

- **Neutrinos not reconstructed in LHCb**
  - Yields determined from fits with binned templates

- **Hadronic $\tau^+ \to \pi^+\pi^-\pi^+(\pi^0)\bar{\nu}_\tau$ decays**



- **Muonic $\tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau$ decays**



*Charge conjugate modes are included

Semileptonic LFU measurements by LHCb

- **Muonic τ^- decays**

Run 1 (2015) PRL 115 11803

$R(D^{*+}) = 0.336 \pm 0.027$ (stat) ± 0.030 (syst)

Run 1 (2023) PRL 131 11802

$R(D^{*}) = 0.281 \pm 0.018$ (stat) ± 0.024 (syst)

$R(D^{0}) = 0.441 \pm 0.060$ (stat) ± 0.066 (syst)

Run 2 (2024) PRL 134 061801

$R(D^{*+}) = 0.402 \pm 0.081$ (stat) ± 0.085 (syst)

$R(D^{+}) = 0.249 \pm 0.043$ (stat) ± 0.047 (syst)

Run 1 (2018) PRL 120 121801

$R(J/\psi) = 0.71 \pm 0.17$ (stat) ± 0.18 (syst)

- **Hadronic τ^- decays**

Run 1 (2018) PRL 120 171802

$R(D^{*+}) = 0.291 \pm 0.019$ (stat) ± 0.026 (syst) ± 0.013 (ext)

Part of Run 2 (2023) PRD 108 (2023) 012018 Erratum

$R(D^{*+}) = 0.260 \pm 0.015$ (stat) ± 0.016 (syst) ± 0.012 (ext)

Run 1 (2022) PRL 128 191803

$R(\Lambda_c^{+}) = 0.242 \pm 0.026$ (stat) ± 0.040 (syst) ± 0.059 (ext)

Run 1 & part of Run 2 (2023) longitudinal polarisation

$F_L^{D^*} = 0.41 \pm 0.06$ (stat) ± 0.03 (syst) PRL 110 092007

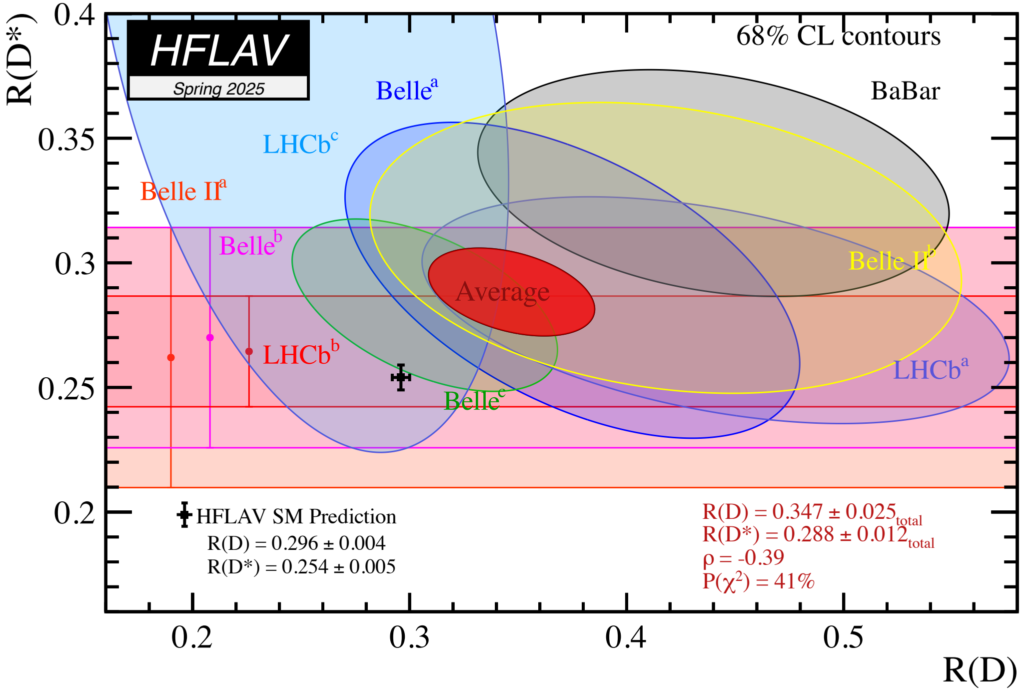
Run 1 & 2 (2025) LHCb-PAPER-2024-037

$R(D_{1,2}^{**0}) = 0.13 \pm 0.03$ (stat) ± 0.01 (syst) ± 0.02 (ext)

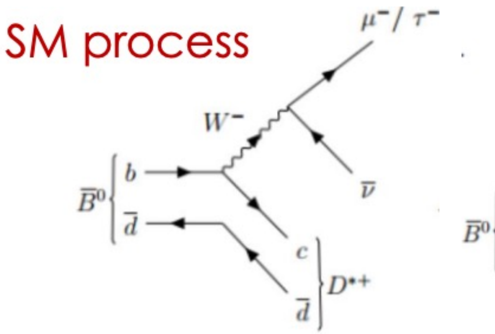
$R(D^-)$, $R(D^{*-})$

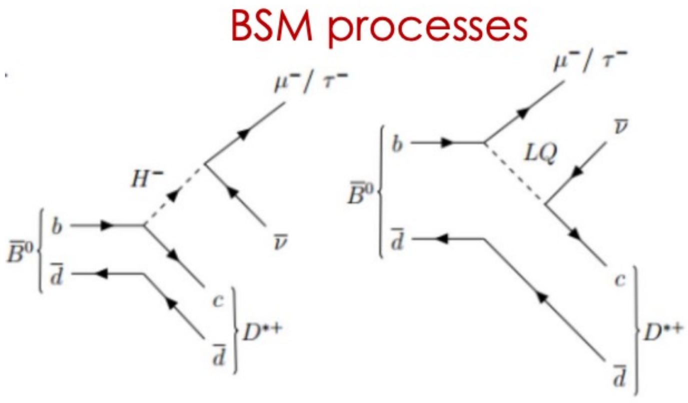
Experimental and theoretical status for $R(D^{(*)})$

- **HFLAV average of $R(D^{(*)})$**
  - 3.8 σ deviation from the SM prediction



- **BSM processes may affect these ratios**
  - Leptoquarks, two Higgs doublet, non-universal left-right models





PRD 94 (2016) 034001 PRD 87 (2013) 014014

- **Angular analysis gives additional sensitivity**
  - e.g. triple product assymmetries PRD 90 (2014) 074013

R(D⁺) and R(D*⁺) with muonic τ^- decays

- **Data collected in 2015-2016 corresponding to 2 fb⁻¹ integrated luminosity**

- **Measure** $\mathscr{B}(\bar{B}^0 \to D^{(*)+}\tau^-\bar{\nu}_\tau)/\mathscr{B}(\bar{B}^0 \to D^{(*)+}\mu^-\bar{\nu}_\mu)$

  $D^{*+} \to D^+\pi^0$, (π^0 not reconstructed)

  $D^+ \to K^-\pi^+\pi^+$

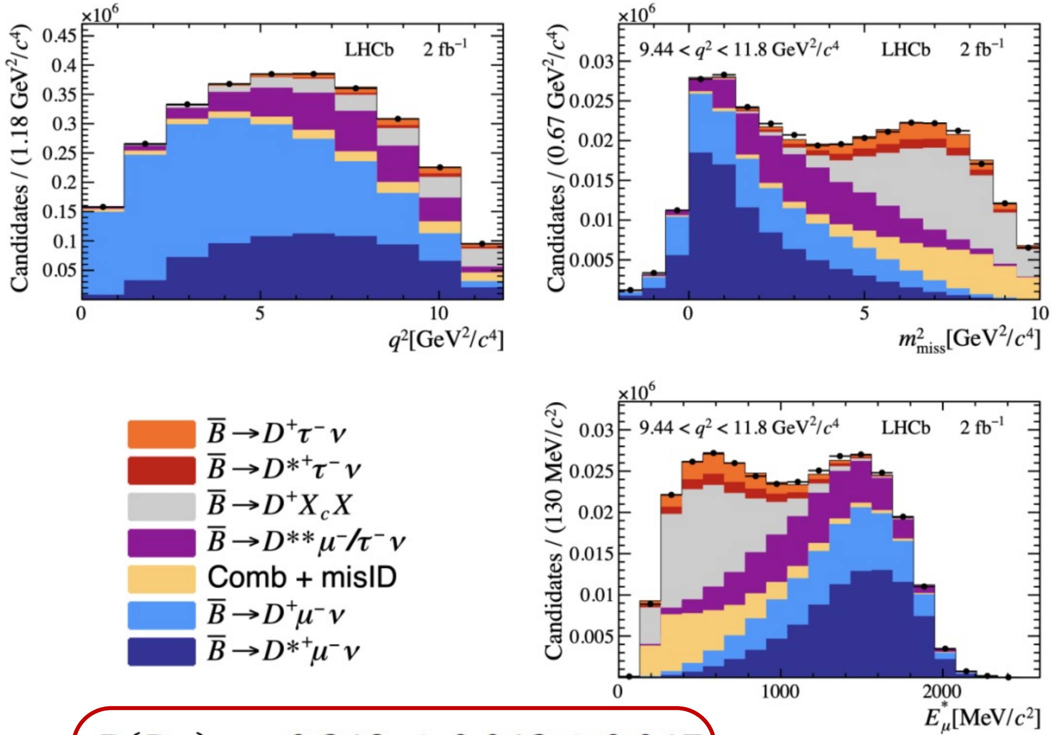
- **Yields determined from a 3D fit**

  $q^2 = (p_{B^0} - p_{D^{(*)}})^2$

  E^*_μ : muon energy in B^0 rest frame

  $m^2_{miss} = (p_{B^0} - p_{D^{(*)}} - p_{\mu^+})^2$

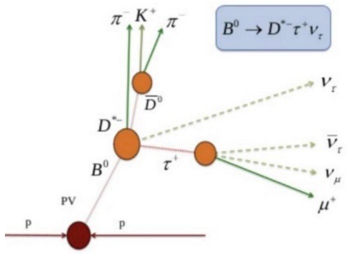
  Templates determined from simulation and control samples



$R(D^-) = 0.249 \pm 0.043 \pm 0.047$

$R(D^{*-}) = 0.402 \pm 0.081 \pm 0.085$

Correlation: $\rho = -0.39$

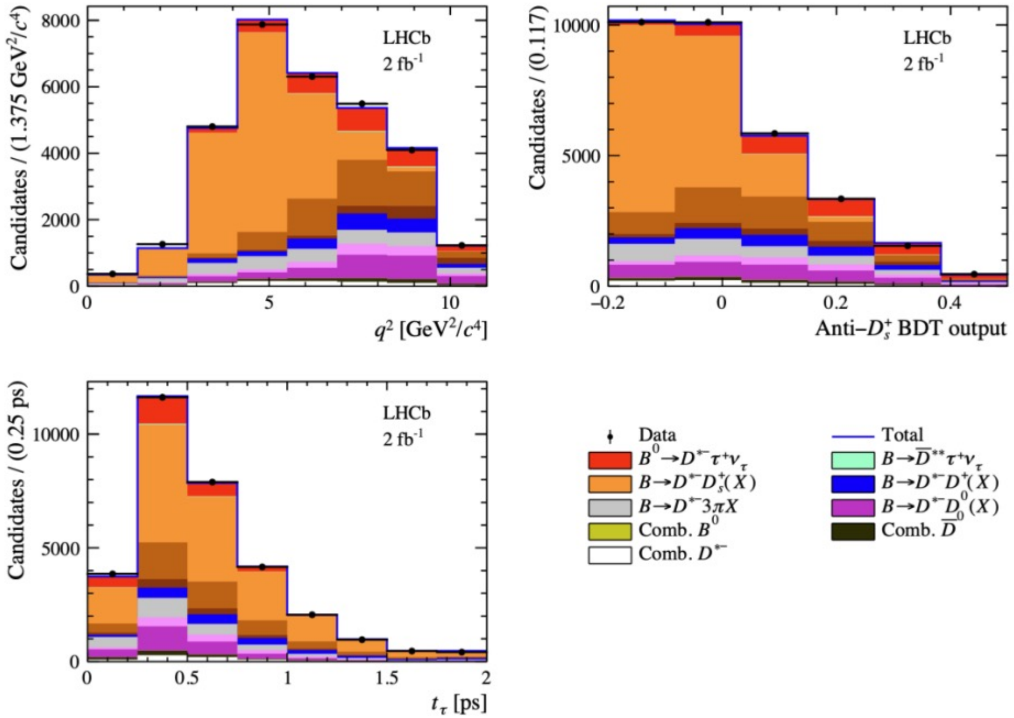


R(D*+) with hadronic τ^- decays

- **Data collected in 2015-2016 with 2 fb^{-1} integrated luminosity**
- **Measure $\mathcal{B}(\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau)$ with $D^{*+} \to D^0\pi^+$**
  - Normalised to $\bar{B}^0 \to D^{*+}\pi^-\pi^+\pi^-$
  - Using known $\mathcal{B}(\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\mu)$ gives:

$$R(D^{*+}) = 0.260 \pm 0.015 \pm 0.016 \pm 0.012$$
$$R_{comb}(D^{*+}) = 0.267 \pm 0.012 \pm 0.015 \pm 0.013$$

- **Yields determined from a 3D fit**
  - $q^2 = (p_{\bar{B}^0} - p_{D^{*+}})^2$
  - Anti-D_s^+ BDT output
  - t_τ : tau decay time
  - Templates from simulation and control samples



- **Background $B \to \bar{D}^{**}\tau^+\bar{\nu}_\tau$ with $D^{**} \to D^{*+}\pi$**
  - Set to 3.5 % from predictions and known BF.
  - These assumptions require verification

$$\mathbf{B^- \rightarrow D^{**0}\ \tau^-\ \bar{\nu}_\tau}$$

Study of $B^- \to D^{**0}\, \tau^- \bar{\nu}_\tau$ decays by LHCb

- **Goals of the analysis**
  - Search for $B^- \to D^{**0}\, \tau^- \bar{\nu}_\tau$ decays
  - Measure $\mathscr{B}(B^- \to D^{**0}_{1,2} \tau^- \bar{\nu}_\tau) \times \mathscr{B}(D^{**0}_{1,2} \to D^{*+}\pi^-)$
  - Measure $R(D^{**0}_{1,2}) = \dfrac{\mathscr{B}(B^0 \to D^{**0}_{1,2}\, \tau^- \bar{\nu}_\tau)}{\mathscr{B}(B^0 \to D^{**0}_{1,2}\, \mu^- \bar{\nu}_\mu)}$

  SM prediction 0.09 ± 0.02

  PRD 97 (2018) 075011 | JHEP 05 (2022) 29 | arXiv:2102.11608

- **Measured normalised to $\mathscr{B}\left(B^- \to D^{**0}_{1,2} D_s^{(*)-}\right)$**
  - Its BF is determined from BF measurements and amplitude analysis of $B^+ \to D^{*-} D_s^+ \pi^+$ JHEP 08 (2024) 165
  - Increase statistics by combining D_s^- and D_s^{*-}

- **D^{**} states that could enter $R(D^*)$**
  - Decay to

$D_1'(2400)^0$, $m = 2412 \pm 9$ MeV/c^2, $\Gamma = 314 \pm 29$ MeV/c

$D_1(2420)^0$, $m = 2422.1 \pm 0.6$ MeV/c^2, $\Gamma = 31.3 \pm 1.9$ MeV/c

$D_2(2460)^0$, $m = 2461.1 \pm 0.8$ MeV/c^2, $\Gamma = 47.3 \pm 0.8$ MeV/c

- **D^{**0}: sum of all three in this analysis**
- **$D_{1,2}^{**0}$: sum of $D_1(2420)^0$ and $D_2(2460)^0$**

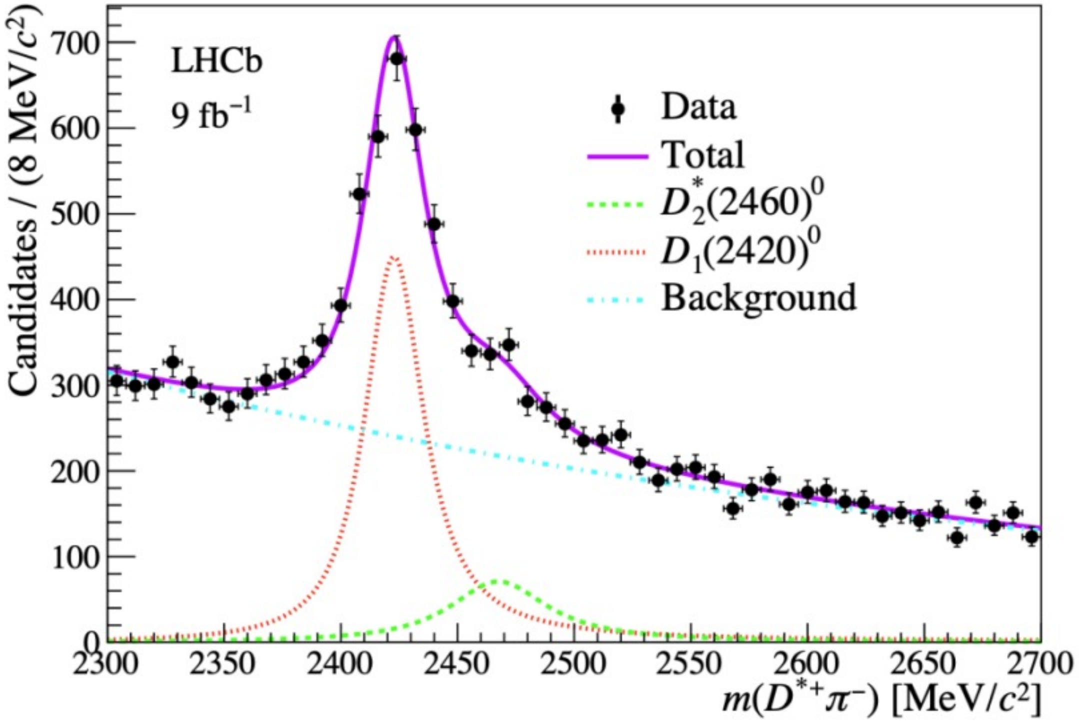
* The $D'_1(2400)^0$ is called $D_1(2430)^0$ in the PDG

Selection of $B^- \to D^{**0}\ \tau^- \bar{\nu}_\tau$

arXiv:2501.14943 , submitted to PRL

- **Run 1 & 2 dataset: $\int \mathcal{L} = 9$ fb^{-1}**
  - Hadronic τ^- decays
- **Trigger and pre-selection requirements**
- **Flight distance requirement on the τ^-**
  - Supress prompt $B \to D^{**0}\pi^-\pi^-\pi^+(X)$
- **Three multivariate BDTs to reject:**
  - Fake D^{**0} candidates
  - Multibody D_s^+ with track swap
  - $D_s^+ \to \pi^+\pi^-\pi^+(X)$ mimicking τ^+ (anti-D_s^+)
- **Fit to $D^{*+}\pi^-$ spectrum without anti-D_s^+ BDT**
  - Investigate components of the decay
  - Not possible to distinguish the broad $D'_1(2400)^0$ from combinatorial background

Selected mass spectrum, w/o the anti-D_s^+ BDT



$2456 \pm 75\ D_1(2420)^0$ candidates

$633 \pm 69\ D_2^*(2460)^0$ candidates

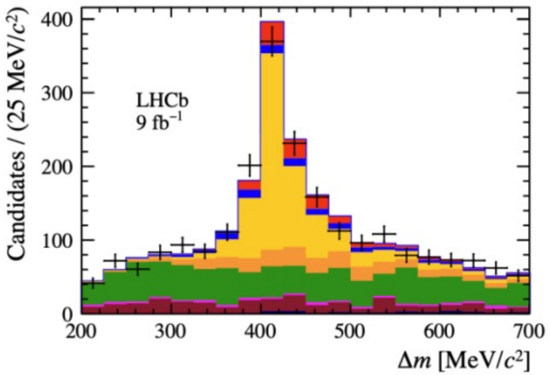
Fit to determine the $B^- \to D^{**0}\, \tau^- \bar{\nu}_\tau$ yields

- **3D Binned fit to extract the yields**
  - $\Delta m = m_{D^{**0}} - m_{D^{*+}}$
  - Anti-D_s^+ BDT output
  - $q^2 = (p_{B^0} - p_{D^{*-}})^2$ = m² of the $\tau^-\bar{\nu}_\tau$ system

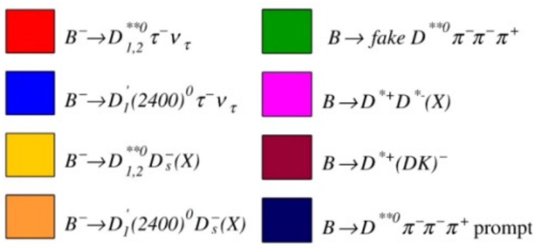
- Signal templates from simulation

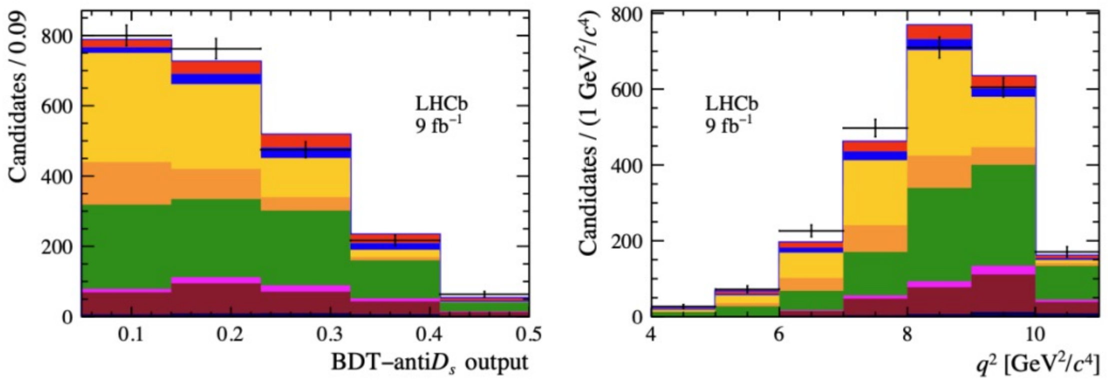
  - Combined $D_1(2420)^0$ and $D^*_2(2460)^0$ template
  - $D_1(2420)^0$, $D^*_2(2460)^0$ and $D_1'(2400)^0$ relative size fixed from simulation

- Backgrounds from simulation and control samples
- Control samples from data
  - D^0 and D^{*+} sidebands
  - Wrong sign $D^{*\pm}\,\pi^\pm$ combinations (WS)
  - Removing the τ^- flight distance requirement
  - Selecting m($\pi^+\,\pi^-\,\pi^+$) close to D_s^+ mass
  - Removing anti-D_s^+ BDT requirement



arXiv:2501.14943 , submitted to PRL





$123 \pm 23\ B^- \to D^{**}_{1,2}\tau^-\bar{\nu}_\tau$ candidates

$220 \pm 34\ B^- \to D^{**0}\tau^-\bar{\nu}_\tau$ candidates

$B^- \to D^{**0}\ \tau^-\ \bar{\nu}_\tau$ results

- **3.5 σ significance for $B^- \to D^{**0}\ \tau^-\ \bar{\nu}_\tau$**
  - Pure $D_2(2460)^0$ contribution excluded at 2.7 σ
- **Branching fraction measurement**
  - Primary quantity: $\kappa = \dfrac{\mathcal{B}(B^0 \to D_{1,2}^{**0}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(B^0 \to D_{1,2}^{**0}D_s^{(*)})} = 0.19 \pm 0.04$
  - $\mathcal{B}(B^- \to D_{1,2}^{**0}\tau^-\bar{\nu}_\tau) \times \mathcal{B}(D_{1,2}^{**0} \to D^{*+}\pi^-) = (0.051 \pm 0.017)$
- **LFU ratio measurement**
  - Uses known $\mathcal{B}(B^0 \to D_{1,2}^{**0}\mu^-\bar{\nu}_\mu)$
  - $R(D_{1,2}^{**0}) = \dfrac{\mathcal{B}(B^0 \to D_{1,2}^{**0}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(B^0 \to D_{1,2}^{**0}\mu^-\bar{\nu}_\mu)} = 0.13 \pm 0.04$
  - Agrees with SM prediction 0.09 ± 0.03

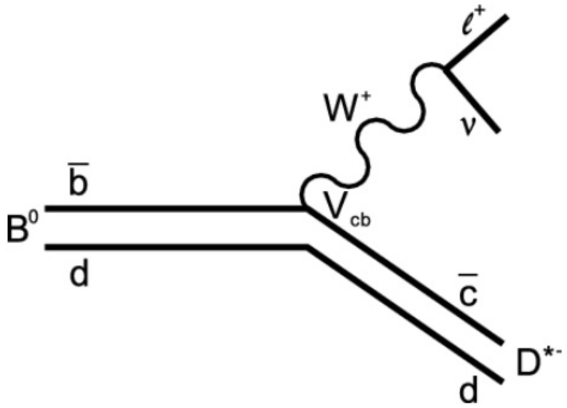
PRD 107 (2023) 092003

PRD 77 (2008) 091503

PRL 103 (2009) 051803

PRL 101 (2008) 261802

Systematic uncertainty on κ	
Decay model	3.7%
$D_1(2420)^0/D_1(2420)^0$ ratio	4.4%
Simulation sample size	5.9%
Binning scheme	5.0%
$B^- \to D^{**0}(DK)^-$ contamination	3.6%
Selection efficiency	2.0%
τ^- flight distance requirement	4.0%
WS background description	2.0%
Total	11.4%



- **Estimate D^{**0} yield in $R(D^{*-})$ hadronic**
  - (8.9 ± 2.1) % and < 13.1 % at 95% C.L.
    Assumed 3.5 % - compatible at 2.6 σ
  - Corresponds to a shift in $R(D^{*-})$ of 0.013

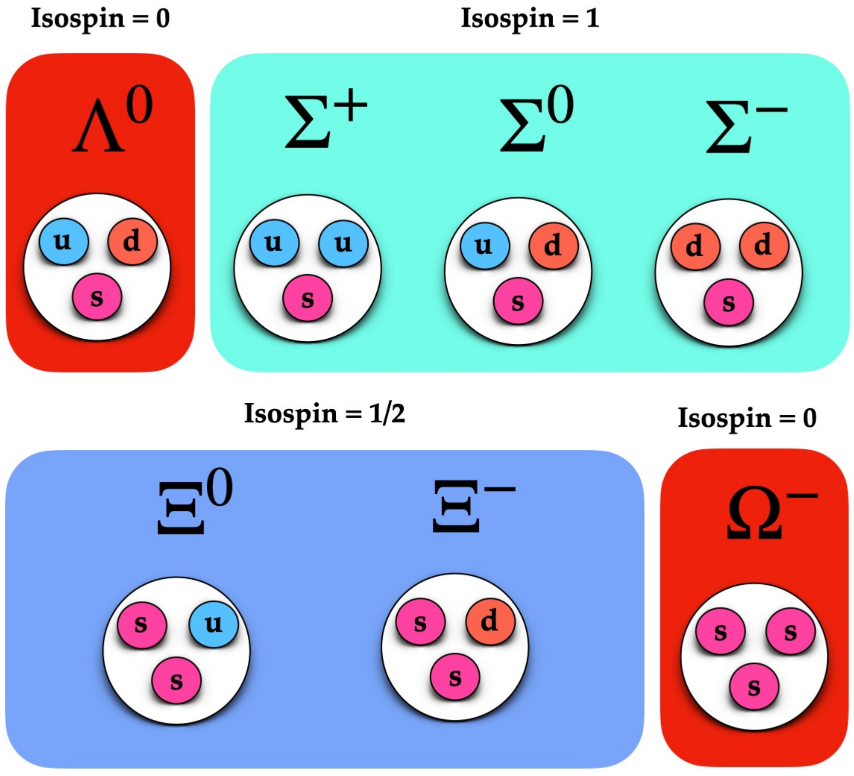
Important input for future measurements

PRD 108 (2023) 012018

$$\Lambda \to p\,\mu^{-}\,\bar{\nu}_{\mu}$$

NEW RESULT!

Semileptonic Hyperon Decays



Approximate SU(3)-flavour symmetry

- The **LFU test observable** defined as the ratio between muon and electron modes

$$R^{\mu e} = \frac{\Gamma(B_1 \to B_2 \mu^- \bar{\nu}_\mu)}{\Gamma(B_1 \to B_2 e^- \bar{\nu}_e)}$$

is **sensitive** to non standard scalar and tensor contributions.

- In the SM, the **dependence** on the form factors is anticipated to **simplify** when considering the **ratio**

$$R^{\mu e}_{\mathrm{SM}} = \sqrt{1 - \frac{m_\mu^2}{\Delta^2}}\left(1 - \frac{9}{2}\frac{m_\mu^2}{\Delta^2} - 4\frac{m_\mu^4}{\Delta^4}\right) + \frac{15}{2}\frac{m_\mu^4}{\Delta^4}\mathrm{arctanh}\left(\sqrt{1 - \frac{m_\mu^2}{\Delta^2}}\right)$$

PRL 114 161802

$\Lambda \to p\, \mu^- \bar{\nu}_\mu$

- Improved measurement directly translates into tighter **bounds on LFU (s → u)**, since the electron mode has already been measured very precisely, $\mathcal{B}(\Lambda \to p\, e^- \nu_e) = (8.34 \pm 0.14) \times 10^{-4}$ (PDG)

$$\mathbf{R}^{\mu e} = \mathcal{B}\,(\Lambda \to p\, \mu^- \bar{\nu}_\mu) \,/\, \mathcal{B}\,(\Lambda \to p\, e^- \bar{\nu}_e)$$

$$R^{\mu e}_{prediction} = 0.153 \pm 0.008,\ R^{\mu e}_{exp} = 0.178 \pm 0.028,$$

- Best branching fraction measurement until now from BESIII (2021): PRL 127 121802

$$\mathcal{B}\,(\Lambda \to p\, \mu^- \bar{\nu}_\mu) = (1.48 \pm 0.21) \times 10^{-4}$$ **14.2 % Uncertainty**

- Discriminate against $\Lambda \to p\, \pi^-$ with the pion decaying in flight is challenging.

[LHCb-PAPER-2025-030 (in preparation)]

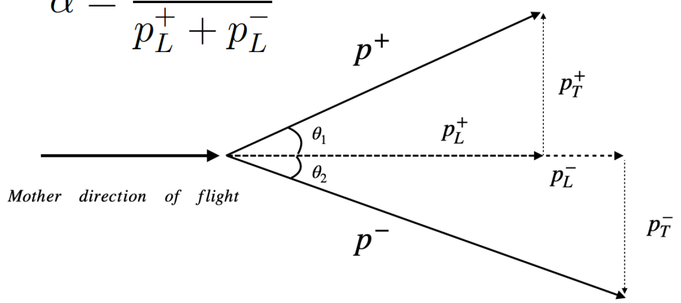
Normalisation

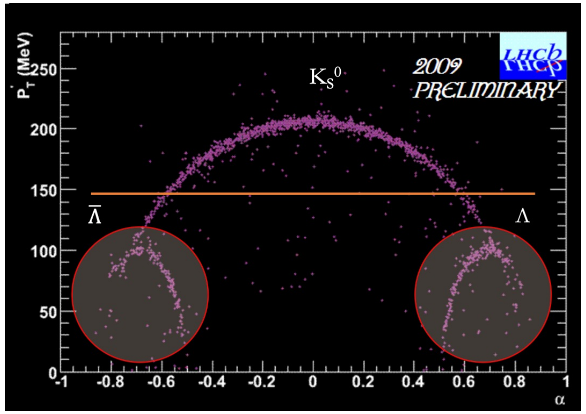
- **Preselection** for $\Lambda \to p\,\pi^-$ and $\Lambda \to p\,\mu^-\bar{\nu}_\mu$ **aligned** to reduce systematic uncertainties.

- Difference only in the PID cuts and mass window.

- $\Lambda \to p\,\pi^-$ selection using the Armenteros-Podolanski plot.

$$\alpha = \frac{p_L^+ - p_L^-}{p_L^+ + p_L^-}$$





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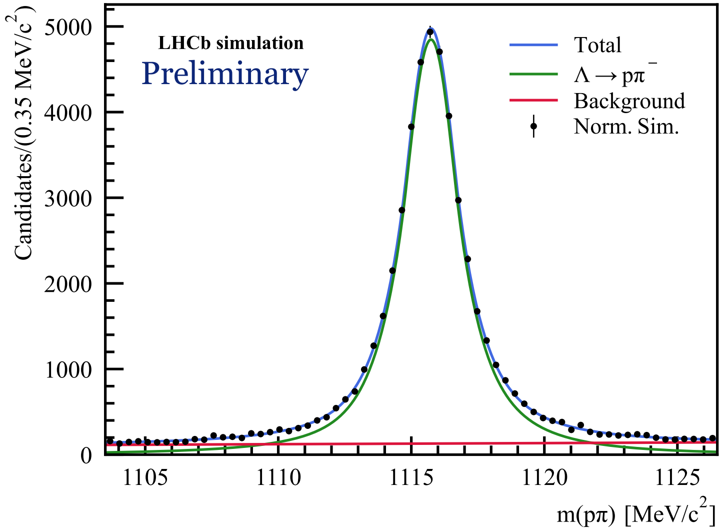
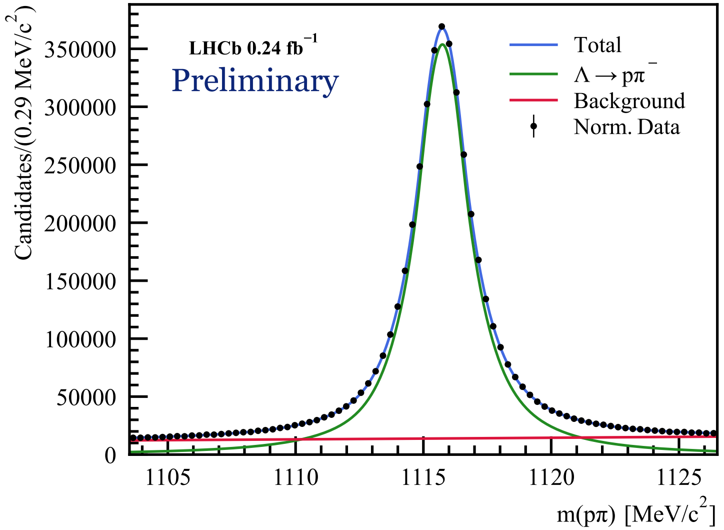




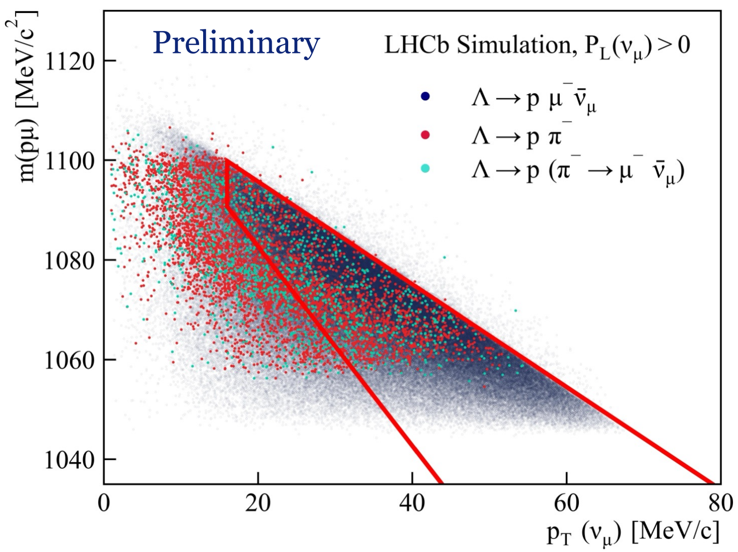
- Using known $\mathcal{B}(\Lambda \to p\,\pi^-)$ to extract the $\mathcal{B}(\Lambda \to p\,\mu^-\bar{\nu}_\mu)$.

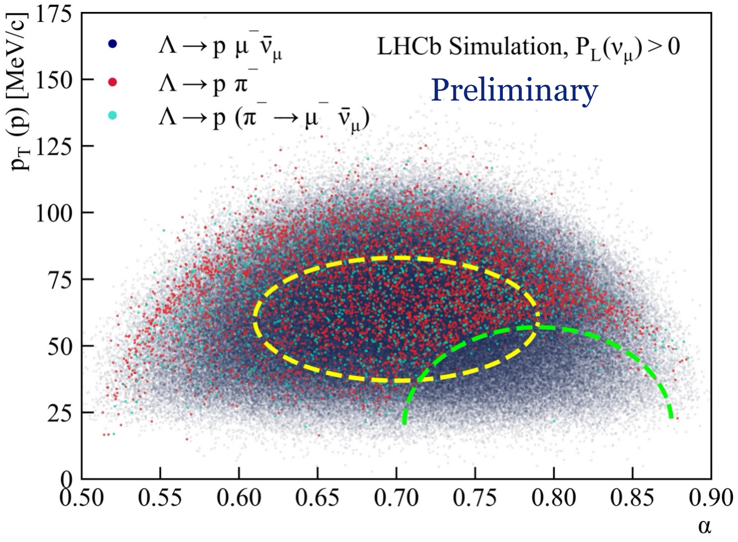
[LHCb-PAPER-2025-030 (in preparation)]

Signal Selection

- Selection based on kinematic variables:

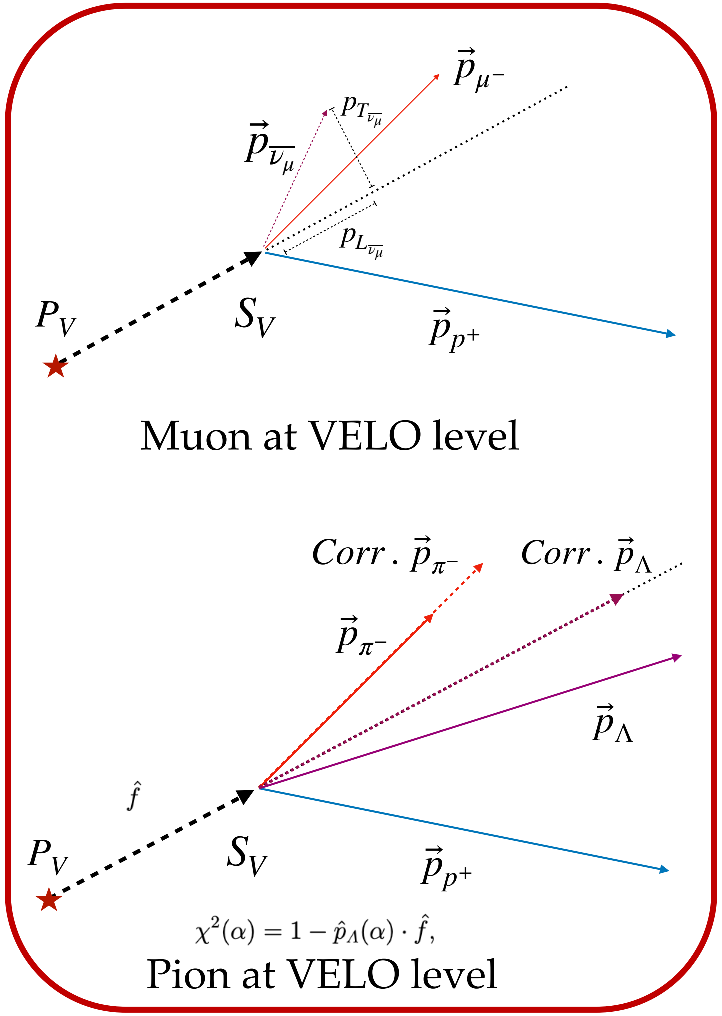
$$\alpha = \frac{p_L^+ - p_L^-}{p_L^+ + p_L^-}$$





- Kinematic strategies developed to reconstruct the missing information due to the neutrino in the final state.

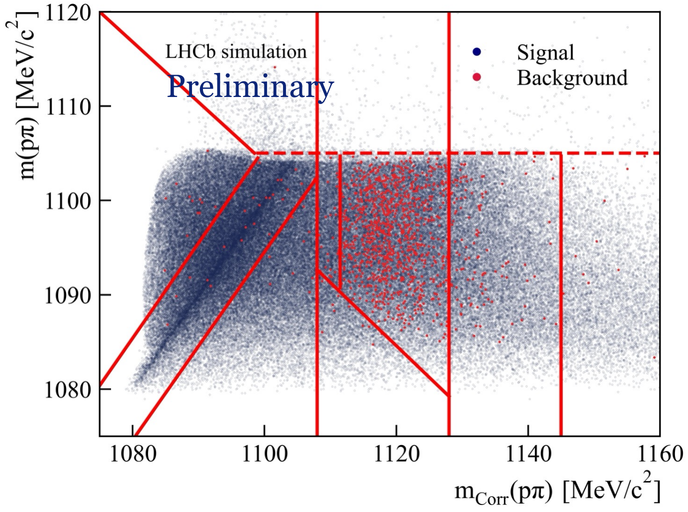
- $m_{corr}(p\pi)$ variable computed using the corrected pion momentum.

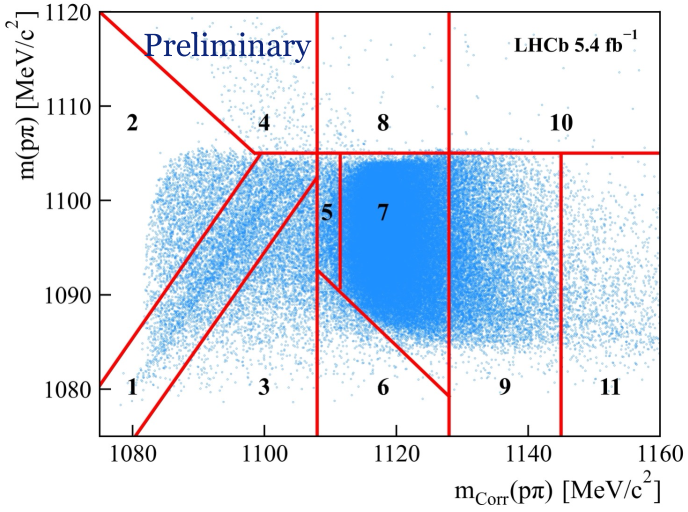


LHCb-PAPER-2025-030
(in preparation)

Signal Fit

- Two-dimensional binned maximum likelihood fit:

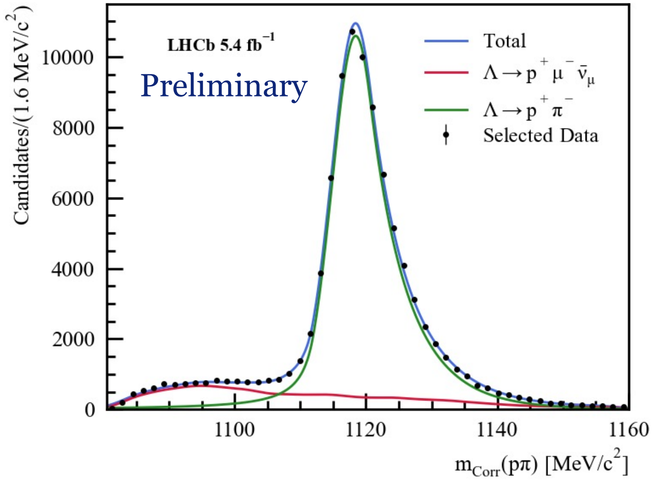




- Different binning schemes and background components used to validate the result and to compute systematic uncertainties.

$\mathcal{B}\,(\Lambda \to p\,\mu^{-}\bar{\nu}_{\mu})$ = (1.462 ± 0.016 (stat.) ± 0.100 (sys.) ± 0.011 (norm)) x 10^{-4}
Preliminary

One-dimensional fit check:



- 1D fit repeated in p_T bins.
- 2D fit repeated using ML to define binning scheme.
- Results in good agreement.

Conclusions

- LHCb has performed the **world best** $\mathcal{B}(\Lambda \to p\,\mu^- \bar{\nu}_\mu)$ measurement, total **uncertainty of 6.9 %:**

$\mathcal{B}(\Lambda \to p\,\mu^- \bar{\nu}_\mu)$ = (1.462 ± 0.016 (stat) ± 0.100 (sys) ± 0.011 (norm)) x 10^{-4} = **(1.46 ± 0.10) x 10^{-4}**

Preliminary

- The result is in good agreement with BESIII measurement. PRL 127 121802

- Since there is a long-standing tension in the determination of V_{us}, we indirectly measured V_{us} :

V_{us} = 0.253 ± 0.011

- Uncertainty very large compared to the PDG extractions using kaon decays:

(Kl3, V_{us} = 0.22362 ± 0.00055) and (Kmu2, 0.22535 ± 0.00045)

- This measurement implies **new constraints in $R^{\mu e}$** (LFU in s -> u transitions).

- The extracted **$R^{\mu e}$ = 0.175 ± 0.012 agrees with the SM prediction at the level of 1.5 σ**.

- **Several semileptonic LFU measurements are in the pipeline:**

  - LFU $R(D^*) - (e, \mu)$ $R(D_s^*)$ $R(J/\Psi)$

  - Study New Physics sensitivity: measuring angular and Wilson coefficients.

  - Angular $B \to D^* \mu\nu$ $B \to D^* \tau\nu$ $\Lambda_b \to \Lambda_c \mu\nu$

- **Analyses with Run3 data are in progress.**

- **Thank you for your attention!**

Back up

Study of $B^- \to D^{**0}\ \tau^-\ \bar{\nu}_\tau$ decays by LHCb

- **D^{**} states that could enter $R(D^*)$**
  - Decay to $D^{*-}\pi^+$

$$D_1'(2400)^0, \quad m = 2412 \pm 9\ \text{MeV}/c^2, \quad \Gamma = 314 \pm 29\ \text{MeV}/c$$

$$D_1(2420)^0, \quad m = 2422.1 \pm 0.6\ \text{MeV}/c^2, \quad \Gamma = 31.3 \pm 1.9\ \text{MeV}/c$$

$$D_2(2460)^0, \quad m = 2461.1 \pm 0.8\ \text{MeV}/c^2, \quad \Gamma = 47.3 \pm 0.8\ \text{MeV}/c$$

- **D^{**0}: sum of all three in this análisis**
- **$D_{1,2}^{**0}$: sum of $D_1(2420)^0$ and $D_2(2460)^0$**

- **Goals of the análisis**
  - Search for $B^- \to D^{**0}\ \tau^-\ \bar{\nu}_\tau$ decays
  - Measure $\mathscr{B}(B^- \to D_{1,2}^{**0}\tau^-\bar{\nu}_\tau) \times \mathscr{B}(D_{1,2}^{**0} \to D^{*+}\pi^-)$
  - Measure $R(D_{1,2}^{**0}) = \dfrac{\mathscr{B}(B^0 \to D_{1,2}^{**0}\tau^-\bar{\nu}_\tau)}{\mathscr{B}(B^0 \to D_{1,2}^{**0}\mu^-\bar{\nu}_\mu)}$

SM prediction 0.09 ± 0.02

PRD 97 (2018) 075011 | JHEP 05 (2022) 29 | arXiv:2102.11608

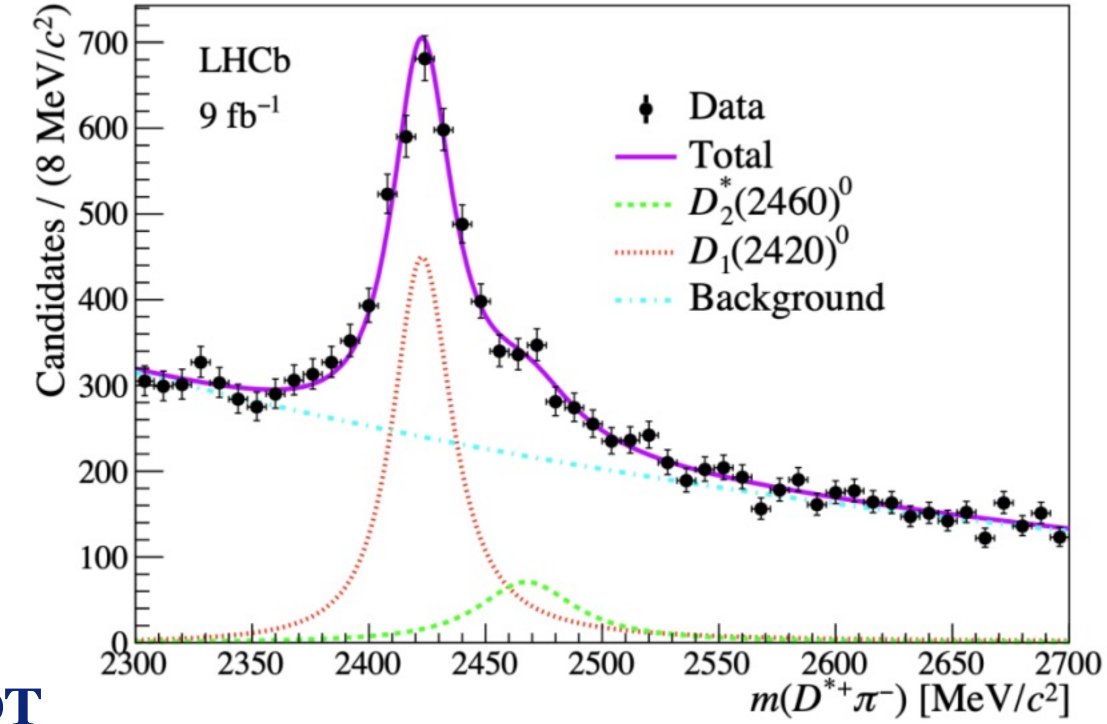
- **Measured normalised to $\mathscr{B}\left(B^- \to D_{1,2}^{**0} D_s^{(*)-}\right)$**
  - Its BF is determined from BF measurements and amplitude analysis of $B^+ \to D^{*-}D_s^+\pi^+$ JHEP 08 (2024) 165
  - Increase statitistics by combining D_s^- and D_s^{*-}

* The $D'_1(2400)^0$ is called $D_1(2430)^0$ in the PDG

Selection of $B^- \to D^{**0}\ \tau^- \bar{\nu}_\tau$

- **Run 1 & 2 dataset: $\int \mathcal{L} = 9\ \text{fb}^{-1}$**
  - Hadronic τ^- decays
- **Trigger and pre-selection requirements**
- **Flight distance requirement on the τ^-**
  - Supress prompt $B \to D^{**0}\pi^-\pi^-\pi^+(X)$
- **Three multivariate BDTs to reject:**
  - Fake D^{**0} candidates
  - Multibody D_s^+ with track swap
  - $D_s^+ \to \pi^+\pi^-\pi^+(X)$ mimicking τ^+ (anti-D_s^+)
- **Fit to $D^{*+}\pi^-$ spectrum without anti-D_s^+ BDT**
  - Investigate components of the decay
  - Not posible to distinguish the broad $D'_1(2400)^0$ from combinatorial background

Selected mass spectrum, w/o the anti-D_s^+ BDT

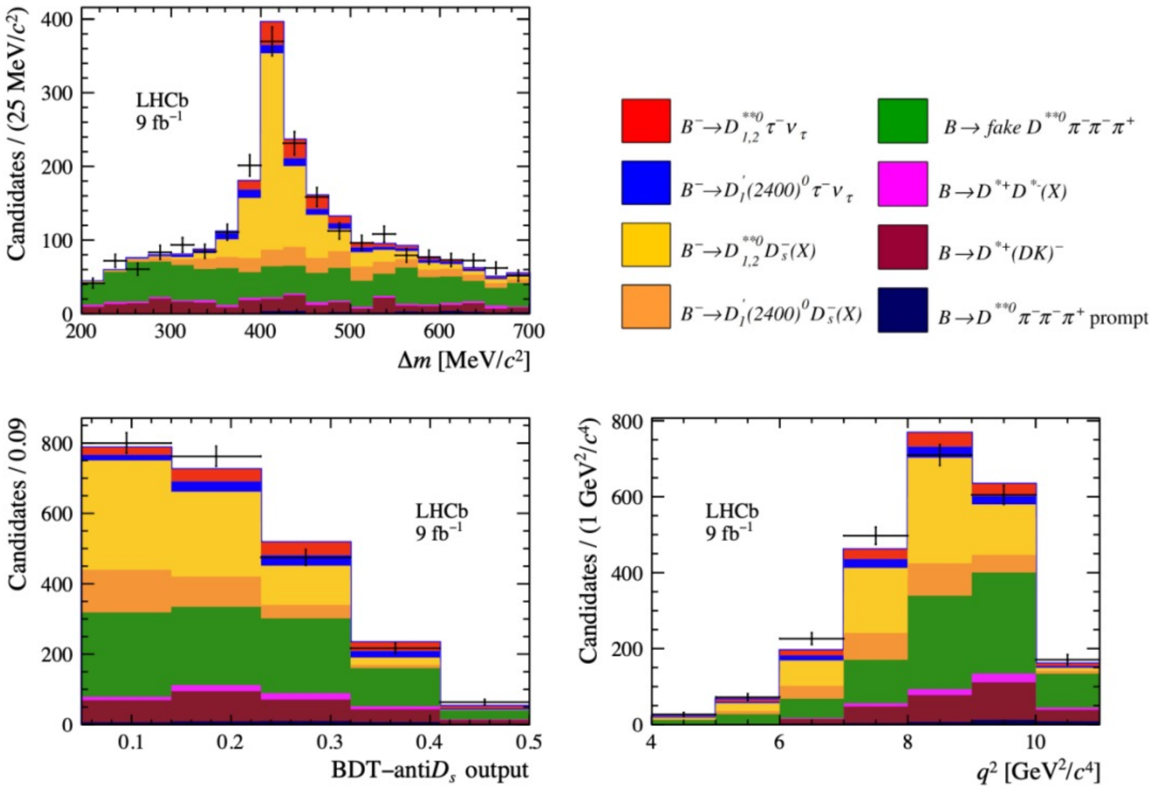


$2456 \pm 75\ D_1(2420)^0$ candidates

$633 \pm 69\ D_2^*(2460)^0$ candidates

Fit to determine the $B^- \to D^{**0}\ \tau^- \bar{\nu}_\tau$ yields

- 3D Binned fit to extract the yields
  - $\Delta m = m_{D^{**0}} - m_{D^{*+}}$
  - Anti-D_s^+ BDT output
  - $q^2 = (p_{B^0} - p_{D^{*-}})^2$ = m² of the $\tau^- \bar{\nu}_\tau$ system
- Signal templates from simulation
  - Combined $D_1(2420)^0$ and $D_2^*(2460)^0$ template
  - $D_1(2420)^0$, $D_2^*(2460)^0$ and $D_1'(2400)^0$ relative size fixed from simulation
- Backgrounds from simulation and control samples
- Control samples from data
  - D^0 and D^{*+} sidebands
  - Wrong sign $D^{*\pm}\ \pi^\pm$ combinations (WS)
  - Removing the τ^- flight distance requirement
  - Selecting m($\pi^+\ \pi^-\ \pi^+$) close to D_s^+ mass
  - Removing anti-D_s^+ BDT requirement



$123 \pm 23\ B^- \to D_{1,2}^{**}\tau^-\bar{\nu}_\tau$ candidates

$220 \pm 34\ B^- \to D^{**0}\tau^-\bar{\nu}_\tau$ candidates

$B^- \to D^{**0}\ \tau^-\ \bar{\nu}_\tau$ results

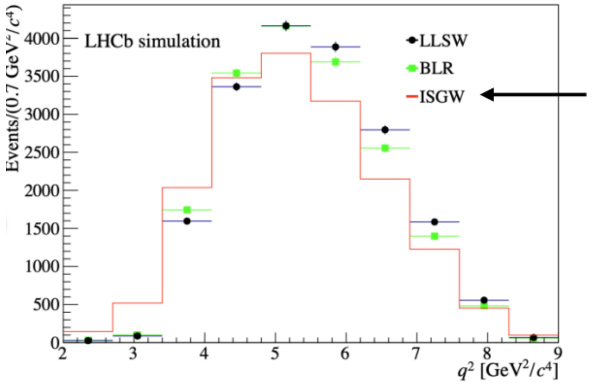
- **3.5 σ significance for $B^- \to D^{**0}\ \tau^-\ \bar{\nu}_\tau$**
  - Pure $D_2(2460)^0$ contribution excluded at 2.7 σ
- **Branching fraction measurement**
  - Primary quantity: $\kappa = \frac{\mathcal{B}(B^0 \to D_{1,2}^{**0}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(B^0 \to D_{1,2}^{**0}D_s^{(*)})} = 0.19 \pm 0.04$
  - $\mathcal{B}(B^- \to D_{1,2}^{**0}\tau^-\bar{\nu}_\tau) \times \mathcal{B}(D_{1,2}^{**0} \to D^{*+}\pi^-) = (0.051 \pm 0.017)$
- **LFU ratio measurement**
  - Uses known $\mathcal{B}(B^0 \to D_{1,2}^{**0}\mu^-\bar{\nu}_\mu)$
  - $R(D_{1,2}^{**0}) = \frac{\mathcal{B}(B^0 \to D_{1,2}^{**0}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(B^0 \to D_{1,2}^{**0}\mu^-\bar{\nu}_\mu)} = 0.13 \pm 0.04$
  - Agrees with SM prediction 0.09 ± 0.03

PRD 107 (2023) 092003 | PRL 103 (2009) 051803
PRD 77 (2008) 091503 | PRL 101 (2008) 261802

PRD 97 (2018) 075011
PRD 38 (1989) 799
PRD 57 (1998) 308

Systematic uncertainty on κ	
Decay model	3.7%
$D_1(2420)^0/D_1(2420)^0$ ratio	4.4%
Simulation sample size	5.9%
Binning scheme	5.0%
$B^- \to D^{**0}(DK)^-$ contamination	3.6%
Selection efficiency	2.0%
τ^- flight distance requirement	4.0%
WS background description	2.0%
Total	11.4%

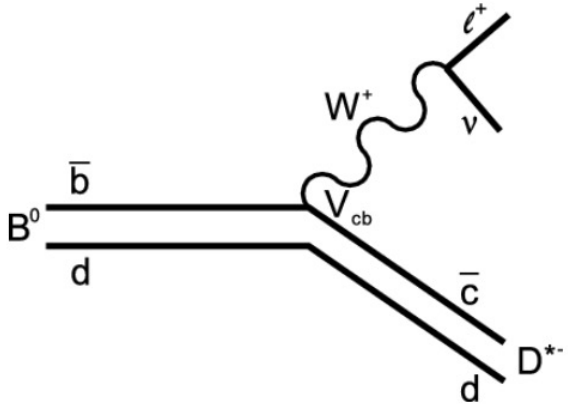
$D_2^*(2460)^0$ q^2 distribution for three decay models



Conclusions and comparison with $R(D^{*-})$ analysis

- **SM has the same gauge boson coupling for all leptons**
- **Semileptonic decay ratios test this asumption**

$$R(H_c) = \frac{\mathcal{B}(H_b \to H_c\,\tau^-\,\bar{\nu}_\tau)}{\mathcal{B}(H_b \to H_c\,\mu^-\,\bar{\nu}_\mu)}$$



- **Study of $B^- \to D^{**0}\ \tau^-\ \bar{\nu}_\tau$ decays**
  - Evidence for this family of decays
  - Branching fraction measurements:

$$\mathcal{B}(B^- \to D_{1,2}^{**0}\tau^-\bar{\nu}_\tau) \times \mathcal{B}(D_{1,2}^{**0} \to D^{*+}\pi^-) = (0.051 \pm 0.017)\,\%$$

  - Lepton flavour universality ratio:

$$R(D_{1,2}^{**0}) = \frac{\mathcal{B}(B^0 \to D_{1,2}^{**0}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(B^0 \to D_{1,2}^{**0}\mu^-\bar{\nu}_\mu)} = 0.13 \pm 0.04$$

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- **Estimate D^{**0} yield in $R(D^{*-})$ hadronic**
  - (8.9 $\pm$ 2.1) % and < 13.1 % at 95% C.L.
    Assumed 3.5 % - compatible at 2.6 σ
  - Corresponds to a shift in $R(D^{*-})$ of 0.013

Important input for future measurements

BSM in SHD

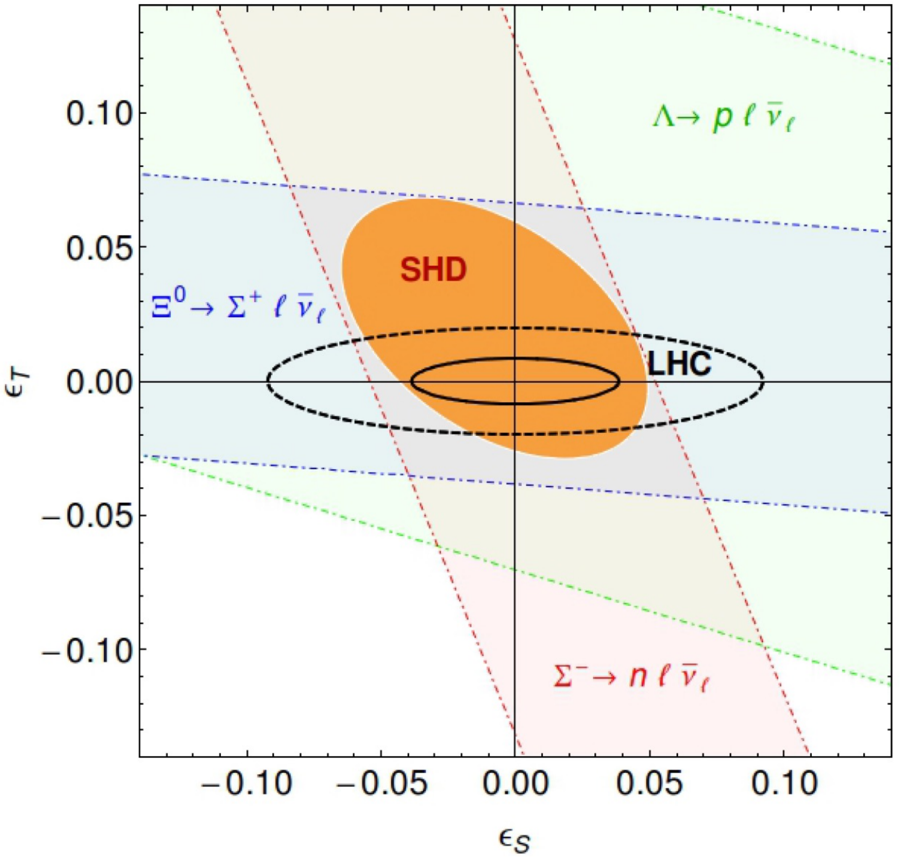


FIG. 1: 90% CL constraints on $\epsilon_{S,T}$ at $\mu = 2$ GeV from the measurements of $R^{\mu e}$ in different channels (dot-dashed lines) and combined (filled ellipse). LHC bounds obtained from CMS data at $\sqrt{s} =$ 8 TeV (7 TeV) are represented by the black solid (dashed) ellipse.

- It is useful to express the ratio of $R^{\mu e}{}_{\mathrm{NP}}$ and $R^{\mu e}{}_{\mathrm{SM}}$ encapsulating the scalar and tensor related dimensionless contributions in r_S and r_T in order to express the sensitivity to the Wilson coefficients

$$\frac{R^{\mu e}_{\mathrm{NP}}}{R^{\mu e}_{\mathrm{SM}}} = 1 + r_S \epsilon_S + r_T \epsilon_T$$

- Being the SHD sensitivity to the Wilson coefficients very channel-dependent. Given that the SM-NLO predictions, $R^{\mu e}{}_{\mathrm{SM}}$, for the various SHD modes are precise, these decays are excellent candidates for performing tests of LFU.

H.-M. Chang, M. González-Alonso, and J. Martin Camalich, "Nonstandard Semileptonic Hyperon Decays", Phys. Rev. Lett. 114 no. 16, (2015) 161802,arXiv:1412.8484 [hep-ph].

Signal EvtGen Model

Kinematic Distributions for $B_1 \rightarrow B_2$ lepton ν

We start with angular coefficients of the 3 body decay ($I_{1,2,3}$)

$$\frac{d\Gamma}{dq^2 d(cos(\theta))} = \frac{G_F^2 f_1(0)^2 |V_{us}^2|}{2^7 \pi^3} (q^2 - m_l^2)^2 \frac{|\vec{q}|\Delta^2}{q^2} [I_1(q^2) + I_2(q^2) cos(\theta) + I_3(q^2) cos^2(\theta)]$$

Where q^2 is the invariant mass squared of the dilepton pair, $f_1(0)$ the vector coupling,

$\Delta = M_1 - M_2$, with M_1 (M_2) the parent (daughter) baryon mass and $\delta = (M_1 - M_2)/M_1$.

f1(0) is the vector coupling, g1(0) axial-vector coupling, f2(0) weak magnetic coupling

f1(0) connected by SU(3) to p and n charges, g1(0)/f1(0) from the E spectrum electronic modes, f2(0) related by SU(3) with magnetic moments of proton and neutron.

Signal EvtGen Model

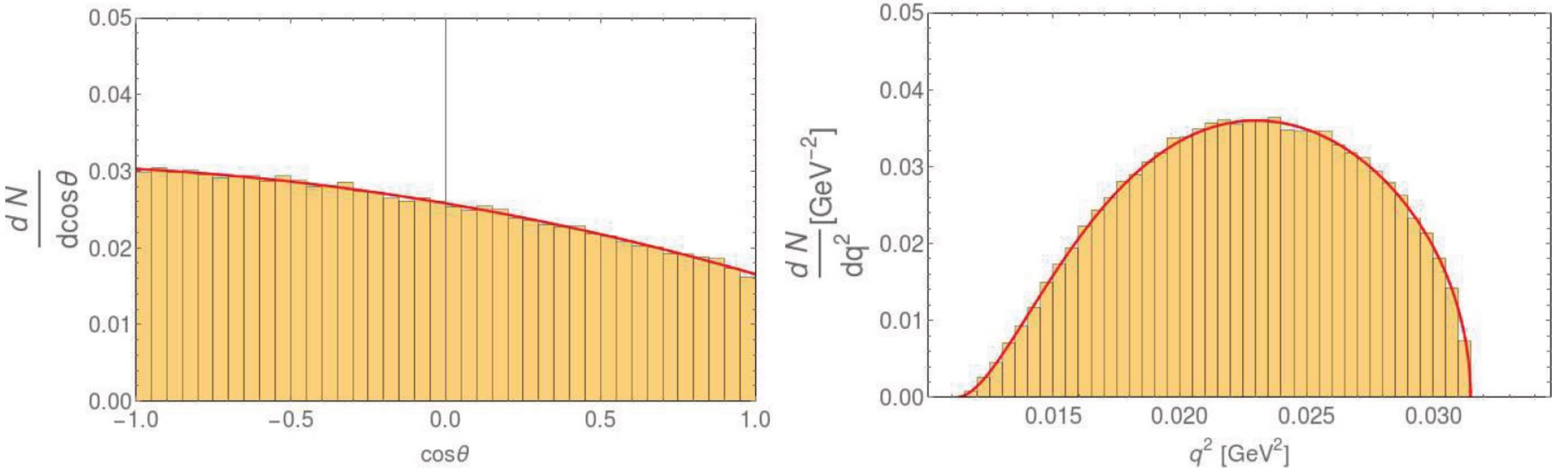
Signal (3-body decay) behaviour different from Phase Space. Specific EvtGen model needed.

Kinematic Distributions for $B_1 \rightarrow B_2$ lepton ν

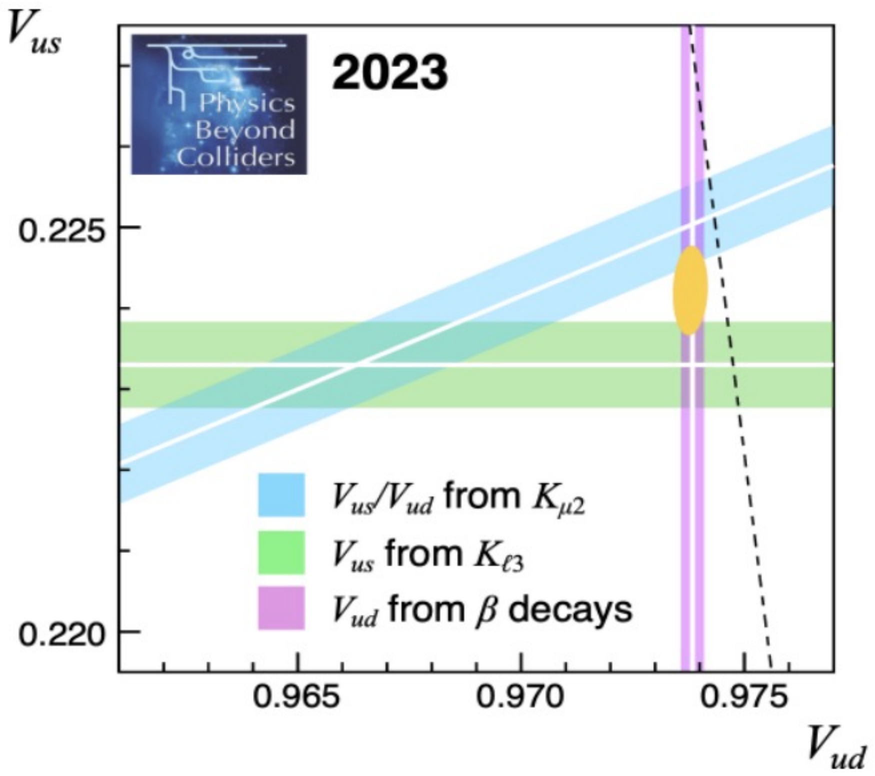
$$\frac{d\Gamma}{dq^2 d(cos\theta)} = \frac{G_F^2 f_1(0)^2 |V_{us}^2|}{(2\pi)^3}(q^2 - m_l^2)^2 \frac{q_3 \Delta^2}{16 q^2}[I_1(q^2) + I_2(q^2)cos(\theta) + I_3(q^2)cos^2(\theta))]$$

EvtDecayProb allows to calculate a probability for the decay. This probability is then used in the accept-reject method.

The resulting EvtGen model is called SHD. **It is written to be compatible with any Semileptonic Hyperon Decay.**



V_{us}



- Strangeness changing SL decays can provide the most sensitive test of the unitarity of the CKM matrix (since $|V_{ub}|^2$ is negligible) through the relation

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$$

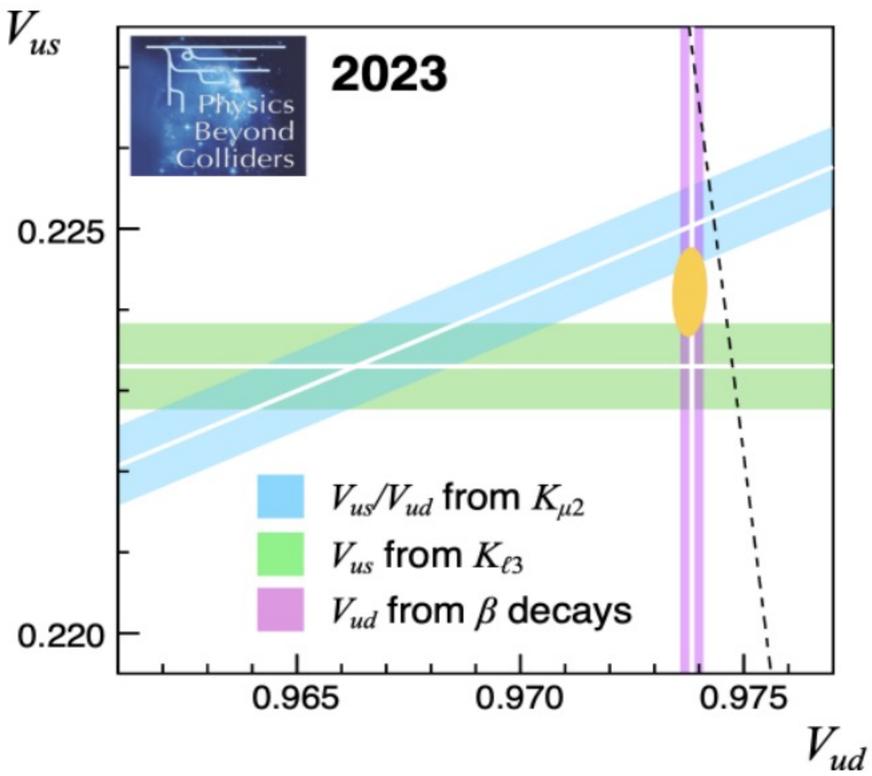
The experimental result is:

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9985 \pm 0.0007$$

Showing a **2.2σ tension with the expected unitarity** in the first CKM row.

The measurements of V_{us} **in leptonic ($K\mu 2$) and semileptonic ($Kl3$)** kaon decays exhibit a 3σ **discrepancy.** Such a disagreement can hint towards two potential scenarios:
the existence of physics beyond the SM or a significant, yet unidentified, systematic effect within the SM itself.

Unblinding Results



$$|V_{us}|^2 \simeq \frac{\Gamma^{SM}(B_1 \to B_2 \mu^- \bar{\nu}_\mu)\, 60\pi^3}{R^{\mu e} G_F^2\, f_1(0)^2 \Delta^5 \left[\left(1-\frac{3}{2}\delta\right) + 3\left(1-\frac{3}{2}\delta\right)\frac{g_1(0)^2}{f_1(0)^2}\right]}$$

- Strangeness changing SL decays can provide the most sensitive test of the unitarity of the CKM matrix (since $|V_{ub}|^2$ is negligible) through the relation

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$$

The experimental result is:

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9985 \pm 0.0007$$

Showing a **2.2σ tension with the expected unitarity** in the first CKM row. Also **3.0σ between semileptonic and leptonic kaon decays.**

Our extraction is:

$V_{us} = 0.253 \pm 0.011$ (large uncertainty)