

Lepton Flavour Universality in B decays: $R(D)$ and $R(D^*)$

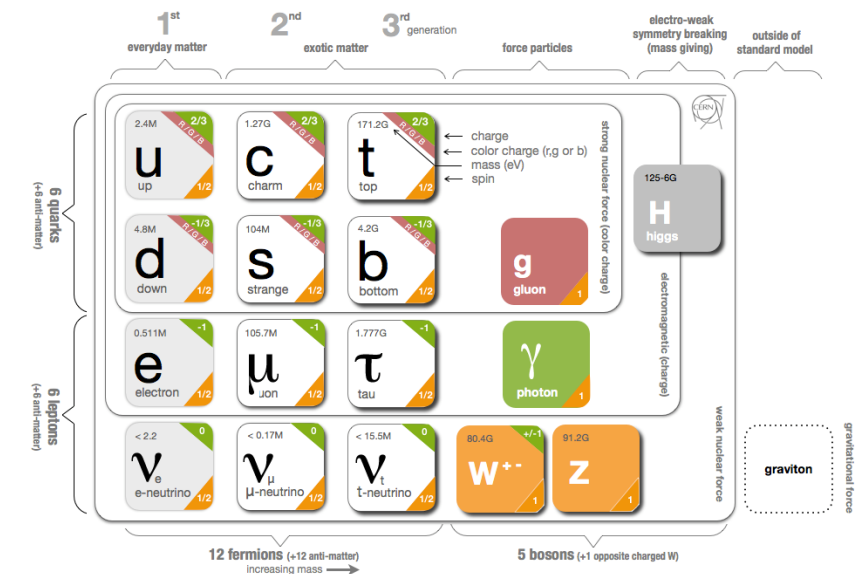
Antonio Romero Vidal
antonio.romero@usc.es

Instituto Galego de Física de Altas Enerxías (IGFAE)
Universidade de Santiago de Compostela (USC), Spain

Beyond the Flavour Anomalies Workshop, 15th April 2026

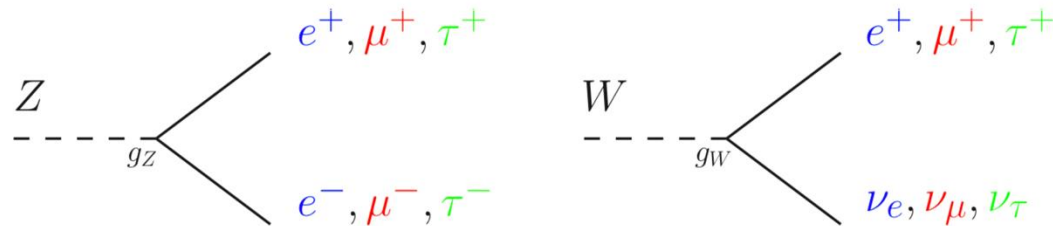
Motivation

- The SM has been **successful** in describing particle physics phenomena with remarkable precision.
- **Not a complete theory**: no explanation for dark matter, matter-antimatter asymmetry, neutrino masses...
- Motivation to look for **deviations** from its predictions in processes where uncertainties are under control.
- Semileptonic B decays well suited for this purpose.
 - They provide clean tests of the SM, and in particular of **Lepton Flavour Universality (LU)**.
- Any significant **deviation** in these observables could be a clear indication of **new physics** beyond the SM.



Lepton Flavour Universality

- **Lepton Flavour Universality:** In the SM, **couplings** of the charged leptons — electrons, muons, and taus — to electroweak gauge bosons are **identical**.



- The **only differences** between these particles arise from their **masses** and associated kinematic effects.
- Two main effects associated with lepton mass:
 - **Phase space:** heavier leptons kinematically suppressed due to reduced phase space (\downarrow).
 - **Helicity suppression:** less severe for heavier leptons (\uparrow).
- **Relative rates** of processes involving different leptons are precisely predicted within the SM.

Why taus?

- The tau lepton plays a special role due to its large mass.
- More sensitive to possible contributions from new physics, especially from **scalar** or **tensor** interactions.
 - **Scalar** contributions **proportional** to lepton **mass**.

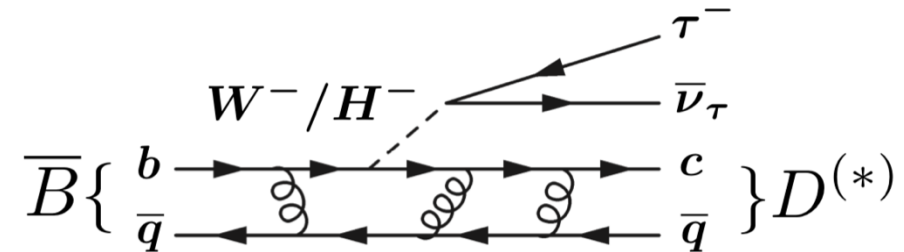
$$\text{NP contribution} \propto m_\ell$$

- Effects that are helicity suppressed for light leptons become much more relevant in processes involving taus.
- **Semileptonic B decays to taus** are a particularly powerful probe of physics beyond the SM.

Definitions of $R(D)$ and $R(D^*)$

- Definitions:

$$R_D = \frac{\mathcal{B}(B \rightarrow D \tau \nu)}{\mathcal{B}(B \rightarrow D \ell \nu)} \quad R_{D^*} = \frac{\mathcal{B}(B \rightarrow D^* \tau \nu)}{\mathcal{B}(B \rightarrow D^* \ell \nu)} \quad \ell = e, \mu$$



- These ratios directly test LU by comparing tau modes to light-lepton modes in the **same decay topology**.
- Any deviation from the SM prediction would indicate a **violation of LU**.
- Among the **cleanest probes** of LU in the flavour sector.

Why ratios?

- A key feature of these observables is that they are **defined as ratios**.
- **Partial cancellation** of hadronic uncertainties, such as **form factors**, which are otherwise a major source of theoretical uncertainty.
- On the experimental side, many **systematic effects** also reduced, since numerator denominator have very similar topologies.
- Altogether, this makes these observables particularly **clean and robust tests** of LU.

$B \rightarrow D \tau \nu$	same hadronic system
$B \rightarrow D \ell \nu$	same form factors different lepton

τ : $ V_{cb} ^2 \times \text{FF} \times \text{phase space}$
ℓ : $ V_{cb} ^2 \times \text{FF} \times \text{phase space}$

New physics contributions in $b \rightarrow c\ell\nu$

- A convenient way to describe possible contributions from NP is through an Effective Field Theory (EFT) framework.
- In the SM, the transition is mediated by a single vector operator with a V–A structure, which strongly constrains the possible helicity configurations.
- However, new physics could introduce additional operators, such as scalar or tensor operators.
- These contributions are particularly enhanced in tau modes due to its large mass, making R(D) and R(D*) sensitive probes of such effects.

SM:

$$\mathcal{O}_V = (\bar{c}\gamma^\mu b)(\bar{\ell}\gamma_\mu\nu)$$

NP:

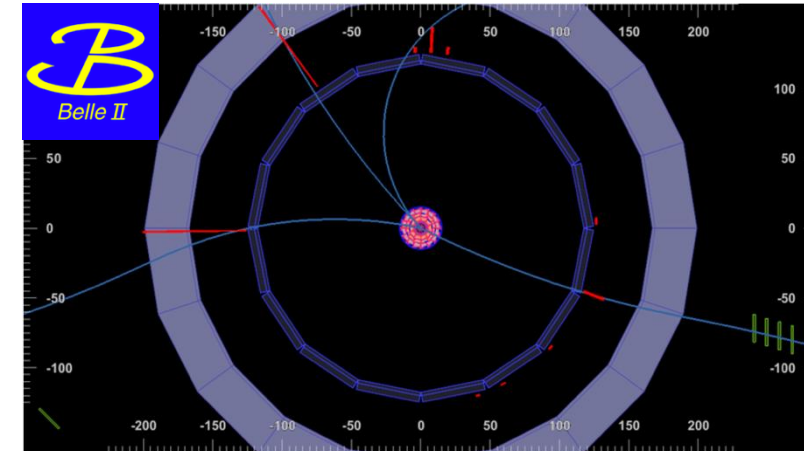
$$\mathcal{O}_S = (\bar{c}b)(\bar{\ell}\nu)$$

$$\mathcal{O}_T = (\bar{c}\sigma^{\mu\nu}b)(\bar{\ell}\sigma_{\mu\nu}\nu)$$

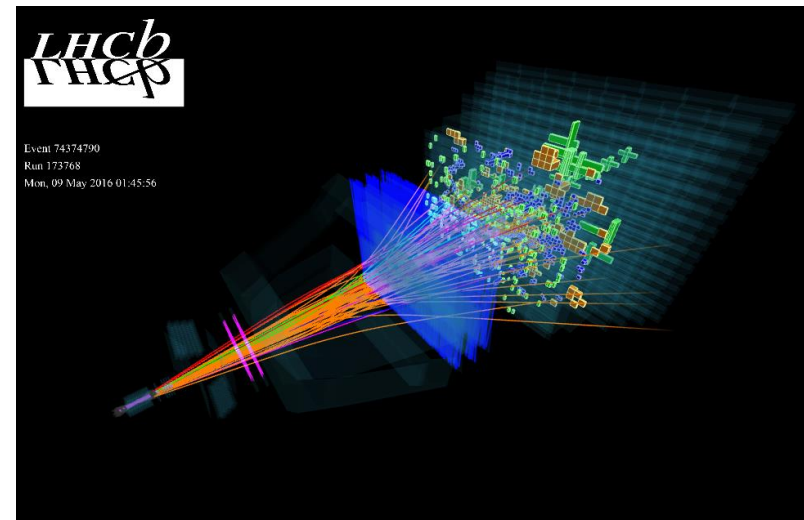
Experiments

- $R(D)/R(D^*)$ have been measured by several experiments, in **two very different environments**.
 - B factories: **BaBar, Belle, and now Belle II**.
 - **e^+e^- collisions**. Full event can often be reconstructed.
 - **LHCb**:
 - **hadronic environment**, with higher statistics but more challenging backgrounds.
- These **complementary** approaches provide **independent** and robust measurements of $R(D)$ and $R(D^*)$.
- At the LHC, B_s^0 , B_c^+ mesons and Λ_b^0 baryons are also produced, which allows to perform measurements of other ratios: $R(D_s^+)$, $R(J/\Psi)$, $R(\Lambda_c^+)$...

Clean environment

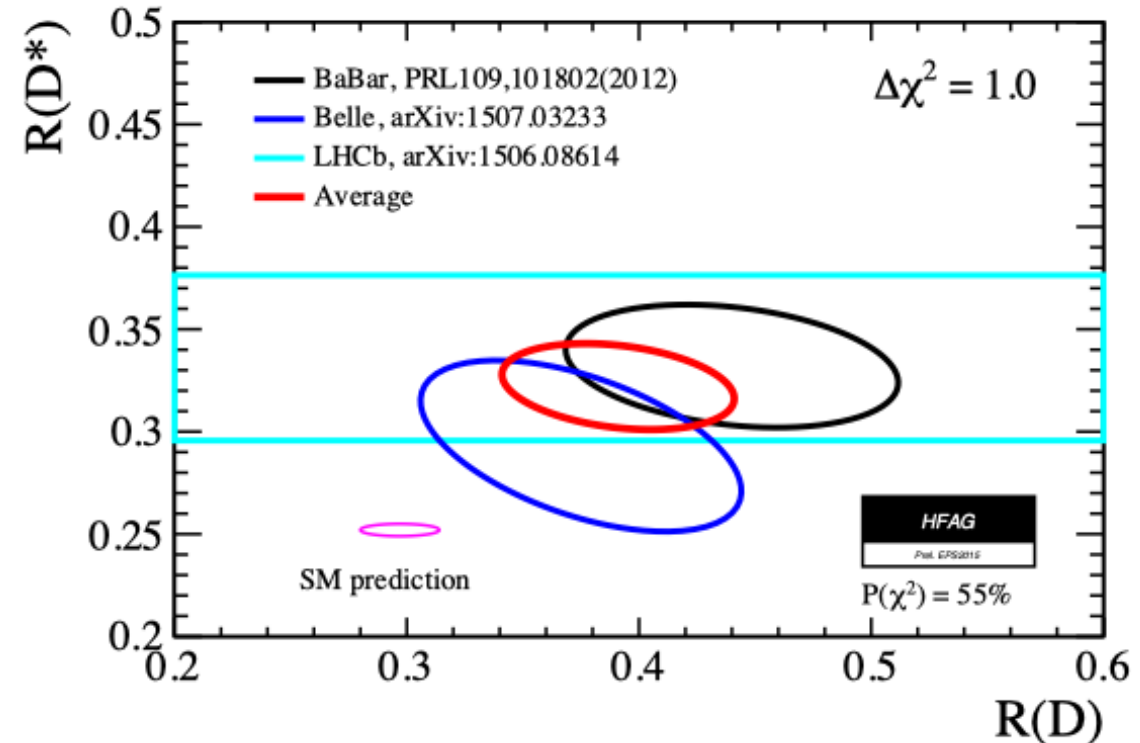


High multiplicity



First tensions

- First deviations from the SM:
 - BaBar (2012): $R(D)/R(D^*)$
 - Belle (2015): $R(D)/R(D^*)$
 - LHCb (2015): $R(D^*)$.
- Observed an excess in decays involving taus compared to the SM expectations.
- When combined, these results showed a discrepancy at the level of about $3-4\sigma$, generating significant interest in the community.

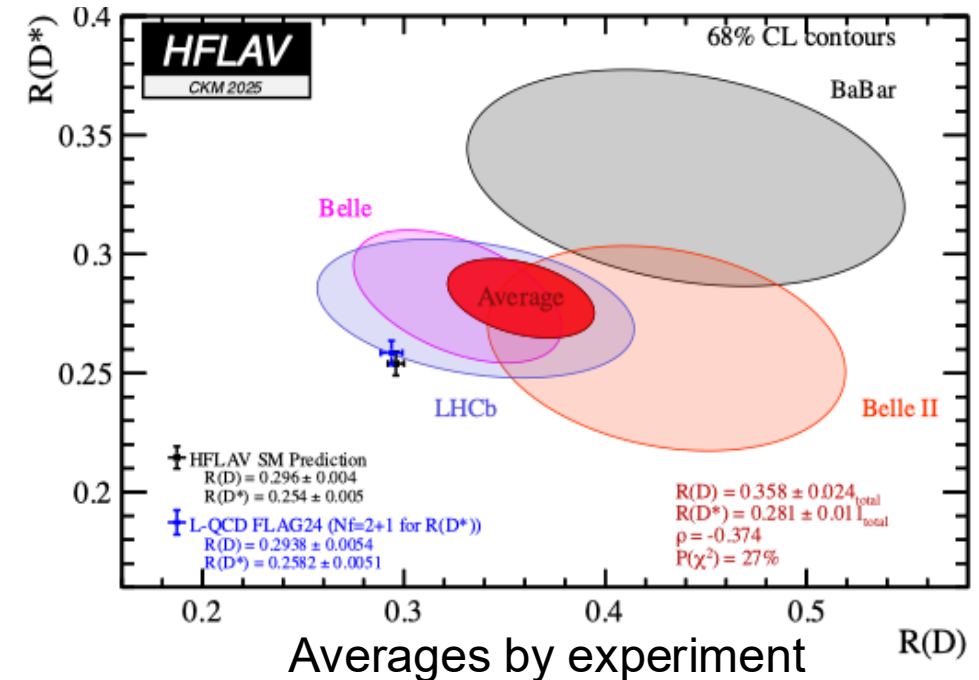
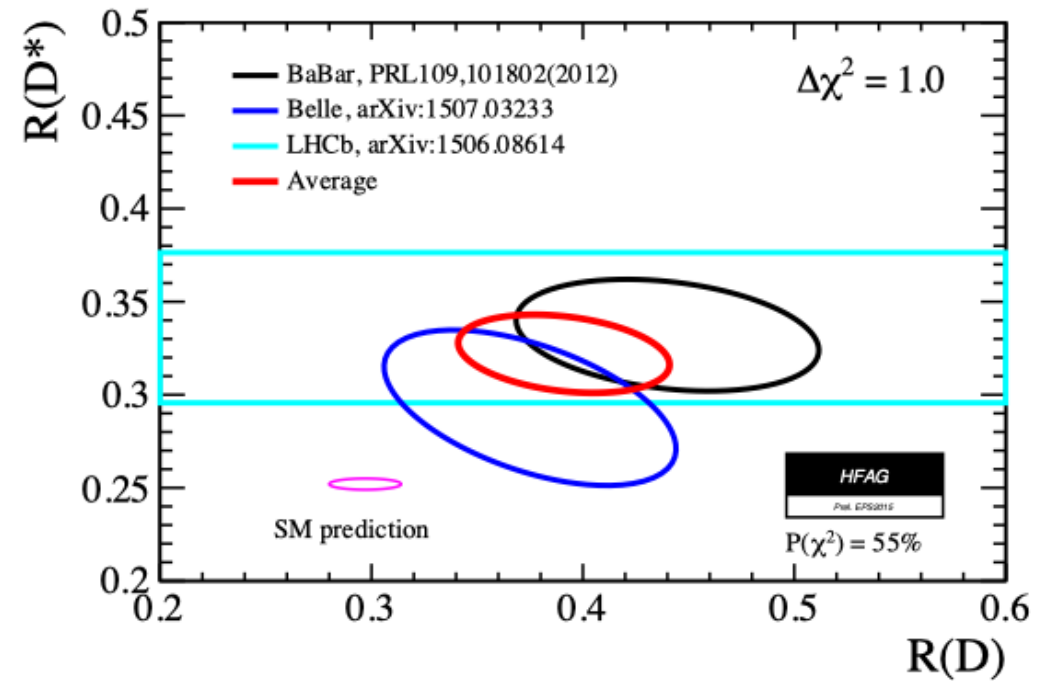


Time evolution

- Increasing experimental input over time.
- Fluctuations in central values and tensions.
- Highlights the importance of independent measurements and increasing precision.

Experiment	R(D*)	R(D)	Rescaled Correlation (stat/total)
BaBar	$0.332 \pm 0.024 \pm 0.018$	$0.440 \pm 0.058 \pm 0.042$	-0.45/-0.27
BELLE ^a	$0.293 \pm 0.038 \pm 0.015$	$0.375 \pm 0.064 \pm 0.026$	-0.56/-0.49
BELLE ^b	$0.270 \pm 0.035 \pm 0.028$ 0.025	-	-
BELLE ^c	$0.283 \pm 0.018 \pm 0.014$	$0.307 \pm 0.037 \pm 0.016$	-0.53/-0.51
LHCb ^a	$0.281 \pm 0.018 \pm 0.024$	$0.441 \pm 0.060 \pm 0.066$	-0.49/-0.43
LHCb ^b	$0.267 \pm 0.012 \pm 0.019$	-	-
LHCb ^c	$0.402 \pm 0.081 \pm 0.085$	$0.249 \pm 0.043 \pm 0.047$	-0.48/-0.39
Belle II ^b	$0.306 \pm 0.034 \pm 0.018$	$0.418 \pm 0.074 \pm 0.051$	-0.27/-0.22
Belle II ^a	$0.242 \pm 0.019 \pm 0.016$	$0.439 \pm 0.055 \pm 0.046$	-0.40/-0.20

Babar: 1 measurement
 Belle: 3 measurements
 LHCb: 3 measurements
 Belle II: 2 measurements



B-factories measurements

BaBar 2013

[PRD88 072012 \(2013\)](#)

$$R(D) = 0.440 \pm 0.058 \pm 0.042$$

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



Had. Tag
 $\tau \rightarrow \ell$

Belle 2015

[PRD92 072014 \(2015\)](#)

$$R(D) = 0.375 \pm 0.064 \pm 0.026$$

$$R(D^*) = 0.293 \pm 0.034 \pm 0.015$$

SL. Tag
 $\tau \rightarrow \pi^+, \rho^+$

Belle 2018

[PRD97 012004 \(2018\)](#)

$$R(D^*) = 0.270 \pm 0.035 \pm 0.028$$

$$P_{\tau}(D^*) = -0.38 \pm 0.051 \pm 0.021$$

Had. Tag
 $\tau \rightarrow \ell$

Belle 2020

[PRL124 161803 \(2020\)](#)

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

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

Had. Tag
 $\tau \rightarrow \ell$

Belle II 2024

[PRL132 211804 \(2024\)](#)

$$R(X_{\tau/\ell}) = 0.228 \pm 0.016 \pm 0.036$$

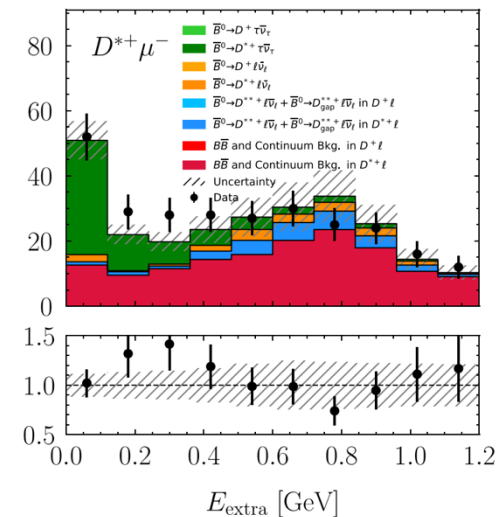
Had. Tag
 $\tau \rightarrow \ell$

Belle II 2025

[PRD112 032010 \(2025\)](#)

$$R(D) = 0.418 \pm 0.074 \pm 0.051$$

$$R(D^*) = 0.306 \pm 0.034 \pm 0.018$$



LHCb measurements



$\tau \rightarrow \ell$

LHCb 2015

[PRL115 111803 \(2015\)](#)

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

run1 2011-2012 data

superseded by

$\tau \rightarrow \ell$

LHCb 2023

[PRL131 111802 \(2023\)](#)

$R(D^0) = 0.441 \pm 0.060 \pm 0.066$

$R(D^*) = 0.281 \pm 0.018 \pm 0.024$

run1 2011-2012 data

$\tau \rightarrow 3\pi$

LHCb 2018

[PRL120 171802 \(2018\)](#)

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

run1 2011-2012 data

combined with

$\tau \rightarrow 3\pi$

LHCb 2023

[PRD108 012018 \(2023\)](#)

$R(D^{*+}) = 0.247 \pm 0.015 \pm 0.015 \pm 0.012$

run2 2015-2016 data

$\tau \rightarrow \ell$

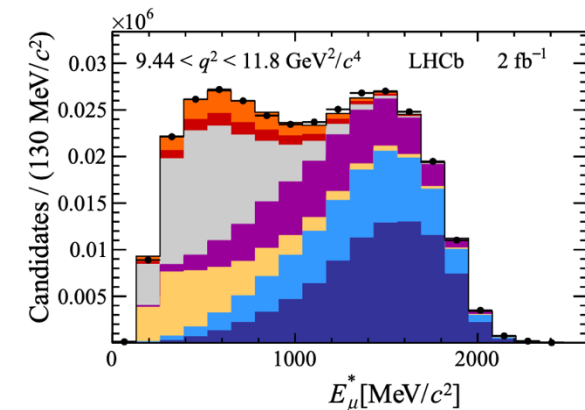
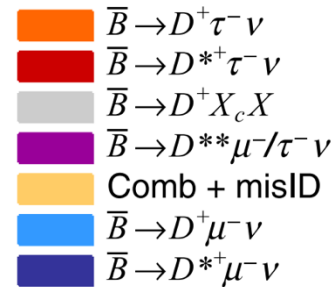
LHCb 2025

[PRL134 061801 \(2025\)](#)

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

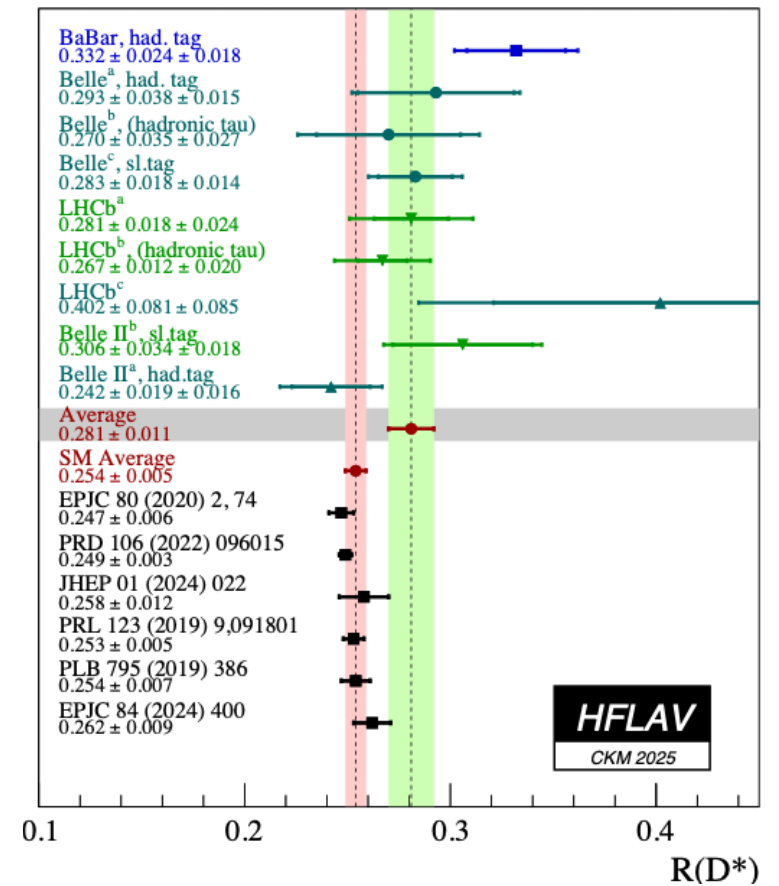
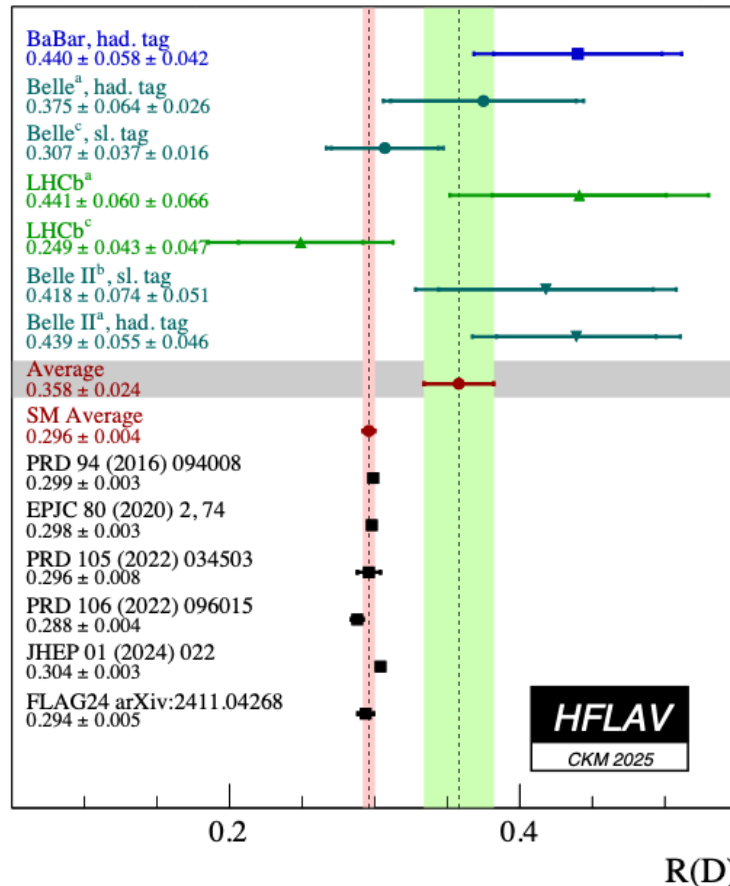
$R(D^{*+}) = 0.402 \pm 0.081 \pm 0.085$

run2 2015-2016 data



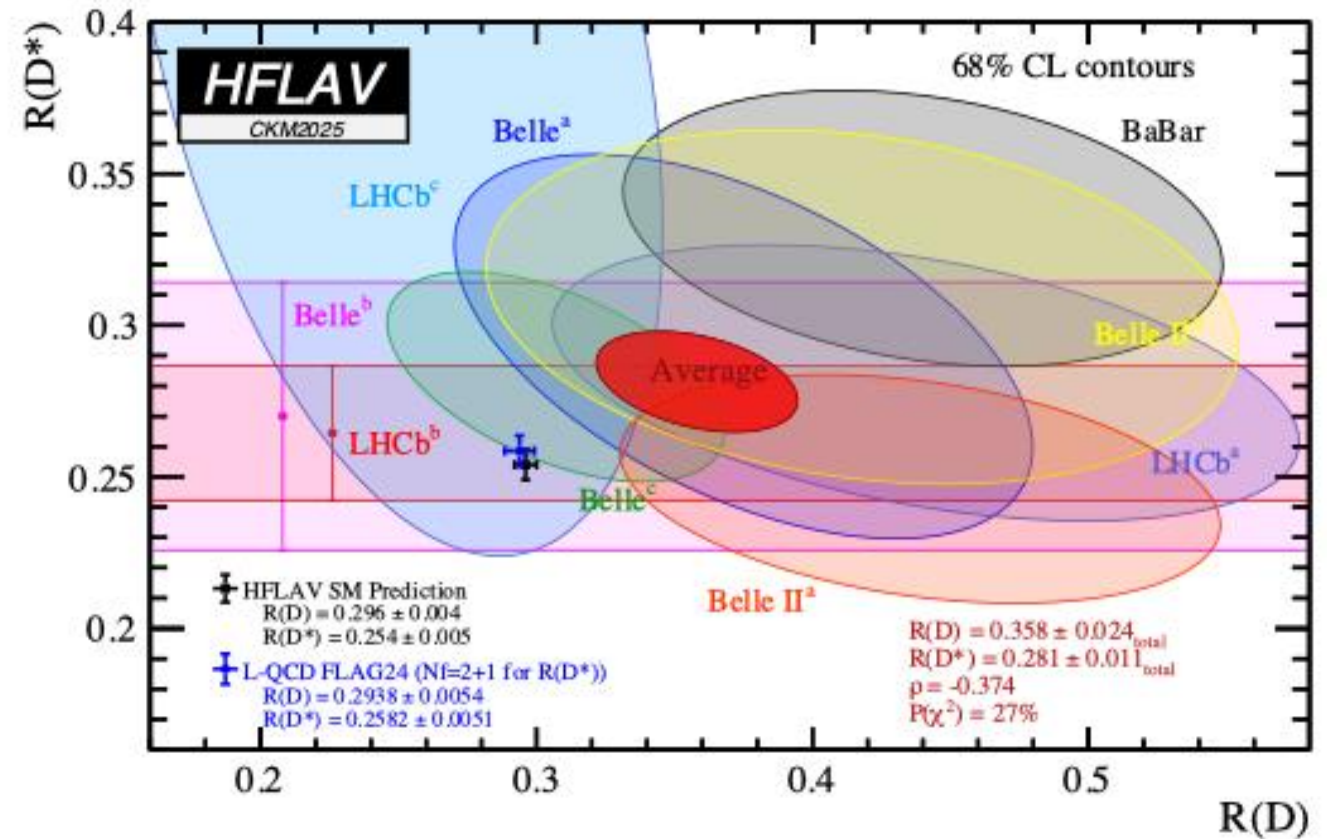
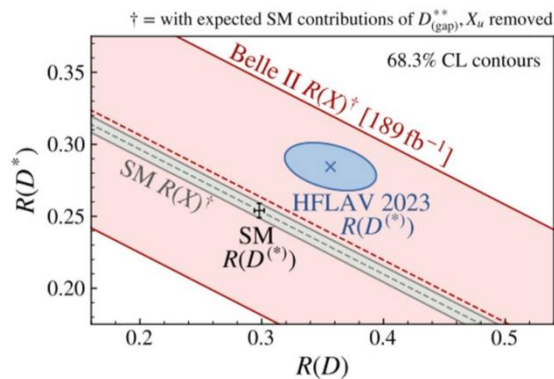
R(D) and R(D*) measurements

- Measurements broadly consistent across experiments.
 - R(D): 7 measurements.
 - R(D*): 9 measurements.
- Moderate tension with the SM.
 - R(D): $\sim 2.5\sigma$ tension with SM.
 - R(D*): $\sim 2.3\sigma$ tension with SM
- Larger experimental uncertainties for R(D).



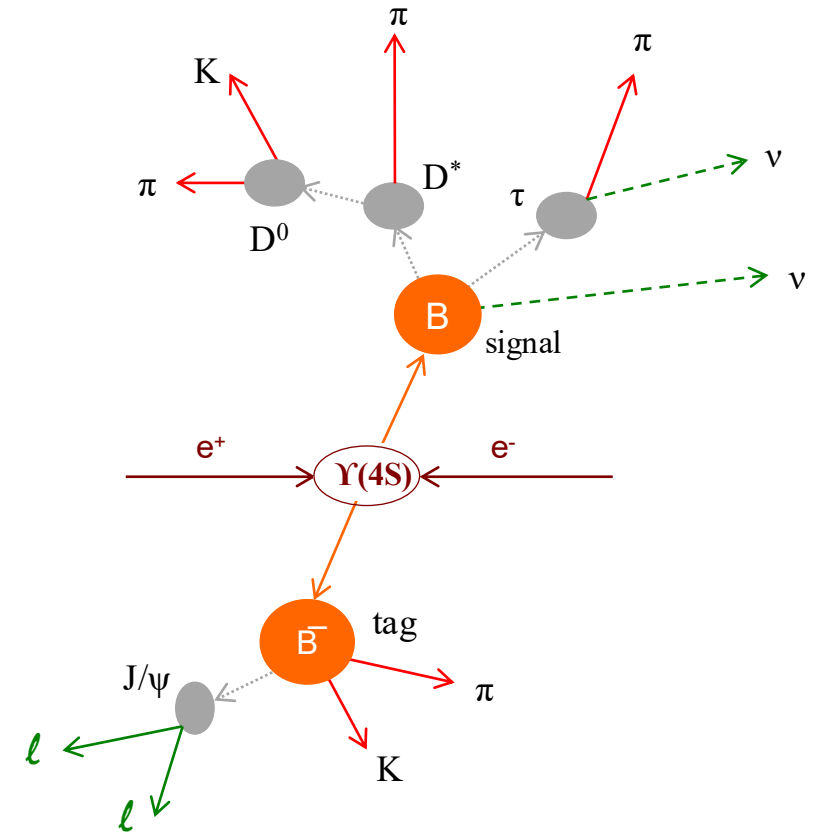
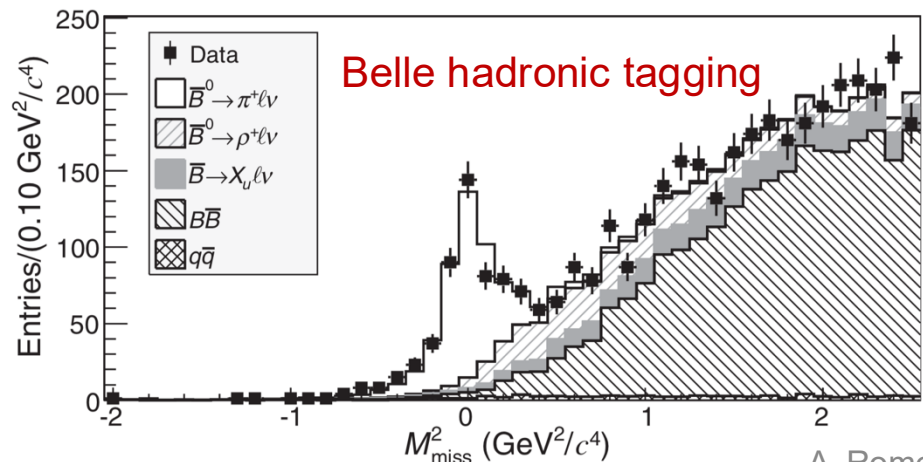
Combined World average

- Combination of combined experimental results:
 - $\sim 3.8\sigma$ tension with SM.
- Measurement of the inclusive ratio $R(X_{\tau\ell})$ shows no tension.
- More data and improved analyses are needed to clarify this.



Semitauconic B decays at B-factories

- At B-factories (Belle(II) and BaBar), e^+e^- collisions producing $\Upsilon(4S) \rightarrow B\bar{B}$. e^+ and e^- with different energies to produce **boosted B's**.
- B-tagging** allows to constrain the momentum of the **B-signal**:
 - Hadronic B-tag**: precise measurement of $p_{B,\text{sig}}$. Good determination of q^2 and m_{miss}^2 (**eff. $\sim 0.3\%$**)
 - SL B-tag**: weaker constraint on p_B (**eff. $\sim 1\%$**)
- The **missing mass** (neutrinos) can be measured with high precision.



Semitauonic measurements at LHCb

Muonic tau decays

- Measurement using $\tau^- \rightarrow \mu^- \nu_\mu \nu_\tau$ decays.
- **3 neutrinos** present in $B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$
- Important **contributions** from exclusive $B^0 \rightarrow D^{*-} \mu^+ \nu_\mu$ (normalisation) and inclusive $B \rightarrow D^{*-} \mu^+ \nu_\mu X$ decays, i.e. ($D^{**} \rightarrow D^* \pi \pi$).
- Important contribution from **doubly-charmed** $B \rightarrow D^{*-} D(X)$ decays with $D \rightarrow X \mu^+ \nu_\mu$.
- **R(D*) directly measured** from the same data sample ($D^{*-} \mu^+$).

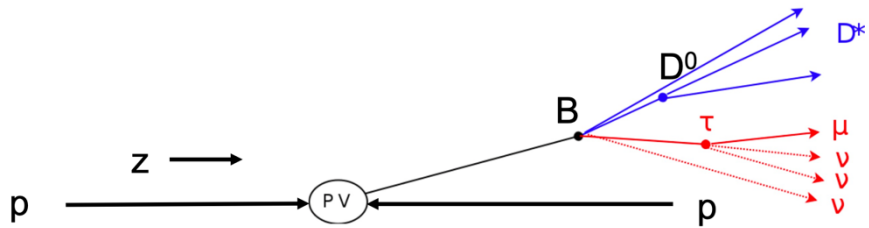
Hadronic tau decays

- Measurement using $\tau^- \rightarrow \pi^- \pi^+ \pi^- (\pi^0) \nu_\tau$ decays.
- **Only 2 neutrinos** present in $B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$
- **tau vertex is known** (3π vertex). This gives access to the **tau decay time**, which can be used to discriminate between signal and background.
- **No** contamination from **semileptonic** $B \rightarrow D^{*-} \mu^+ \nu_\mu (X)$ decays.
- **Large** contribution from **doubly-charmed** $B \rightarrow D^{*-} D(X)$ decays with $D \rightarrow \pi^+ \pi^- \pi^+ X$.
- **Measure BR($B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$)** with respect to, i.e. $B^0 \rightarrow D^{*-} \pi^+ \pi^- \pi^+$. Then, use WA BR($B^0 \rightarrow D^{*-} \mu^+ \nu_\mu$) to obtain R(D*).

R(D^(*)): Muonic reconstruction



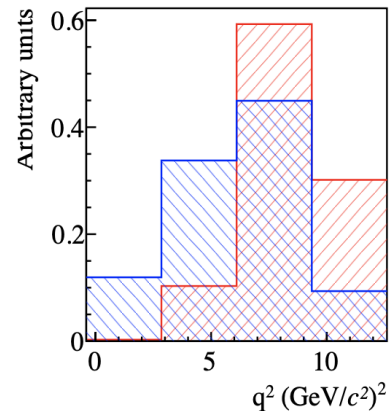
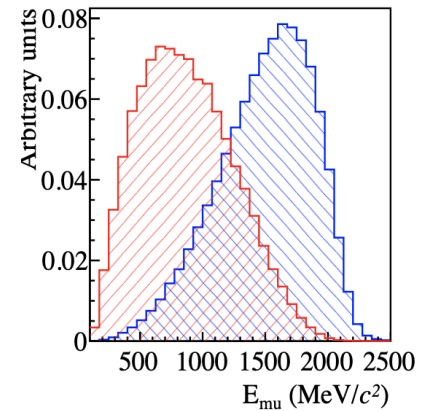
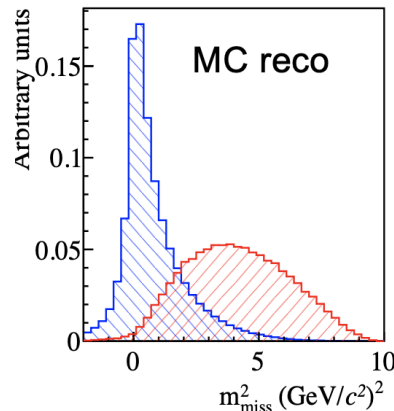
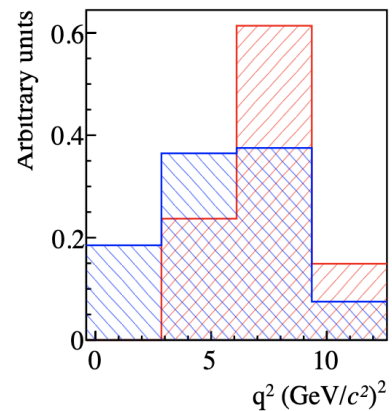
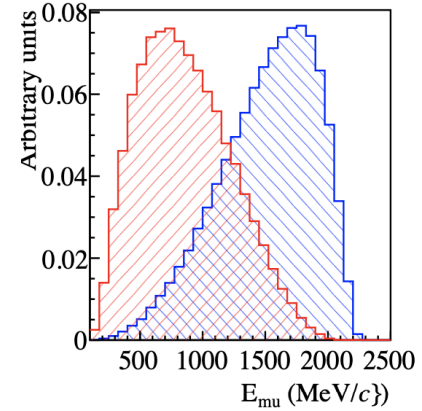
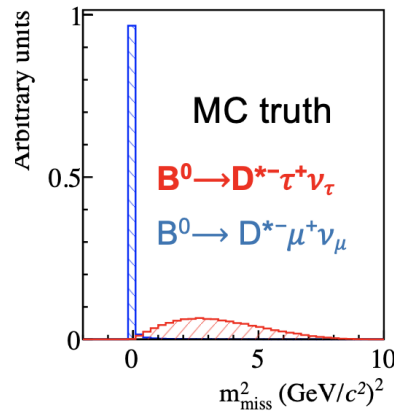
- At LHCb, B momentum cannot be constrained from beam energy (no $Y(4S) \rightarrow B\bar{B}$ decay as in B-factories).



- Approximation used to estimate B momentum: B boost along z \gg boost of decay products in B rest frame.

$$(\gamma\beta_z)_B = (\gamma\beta)_{D^*\mu} \Rightarrow (p_z)_B = \frac{m_B}{m(D^*\mu)} (p_z)_{D^*\mu}$$

- $\sim 18\%$ resolution on p_B , still good enough to preserve signal and background discrimination.
- 3D template fit to: m_{miss}^2 , E_μ^* and q^2 .



R(D⁺)/R(D^{*+}) muonic at LHCb

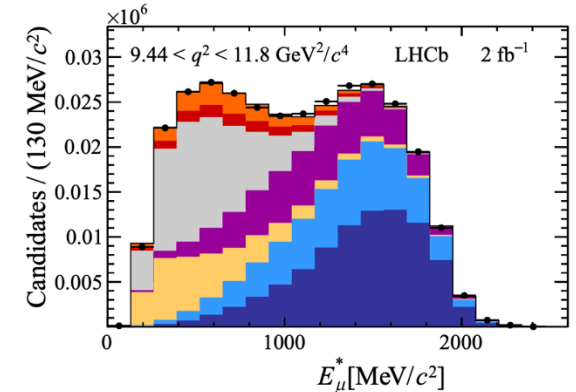
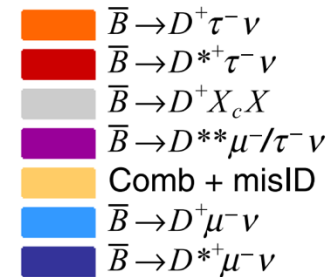
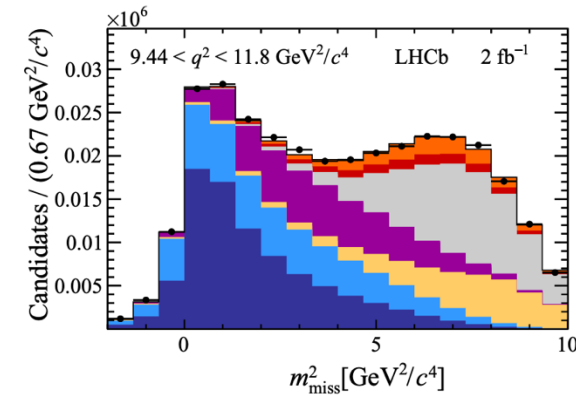
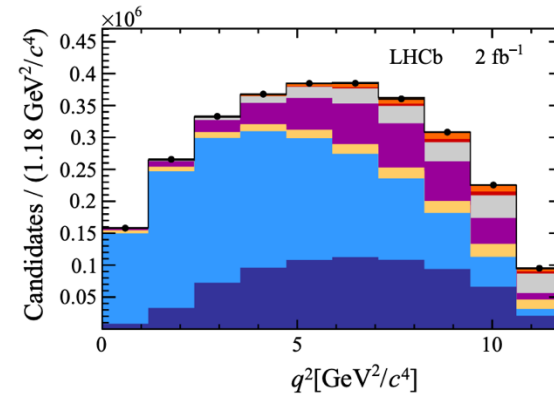
[PRL134 061801 \(2025\)](#)

- Measurement of R(D⁺) and R(D^{*+}) using D⁺ → K⁻π⁺π⁺ decay (D^{*+} → D⁺π⁰/γ).
- Visible final state K⁻π⁺π⁺μ⁻.
- Use of charged isolation to isolate signal candidates and produce background-enriched control samples.
- Simultaneous fit to 4 samples, with enhanced sensitivity to specific components.
 - Signal sample: D⁺μ⁻.
 - 1π sample: D⁺μ⁻π⁻.
 - 2π sample: D⁺μ⁻π⁺π⁻.
 - 1K sample: D⁺μ⁻K[±].

- Results:

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

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



Main systematics:

- Form factors.
- B → D^{**}τ/ℓν.
- Doubly-charmed B → DD^X.
- misID.
- Simulation size



R(D^{*+}) hadronic at LHCb



- What is measure:

$$K_{had}(D^*) = \frac{BR(B^0 \rightarrow D^{*-} \tau^+ \nu_\tau)}{BR(B^0 \rightarrow D^{*-} \pi^+ \pi^- \pi^+)} = \frac{N(B^0 \rightarrow D^{*-} \tau^+ (\pi^+ \pi^- \pi^+ (\pi^0) \bar{\nu}_\tau) \nu_\tau)}{N(B^0 \rightarrow D^{*-} \pi^+ \pi^- \pi^+)} \cdot \frac{1}{BR(\tau^+ \rightarrow \pi^+ \pi^- \pi^+ (\pi^0) \bar{\nu}_\tau)} \cdot \frac{\epsilon(B^0 \rightarrow D^{*-} \pi^+ \pi^- \pi^+)}{\epsilon(B^0 \rightarrow D^{*-} \tau^+ (\pi^+ \pi^- \pi^+ (\pi^0) \bar{\nu}_\tau) \nu_\tau)}$$

- Signal and normalization share **same visible final state** (D^{*-}π⁺π⁻π⁺).

- Most of the systematic uncertainties cancel in the ratio (PID, trigger ...).

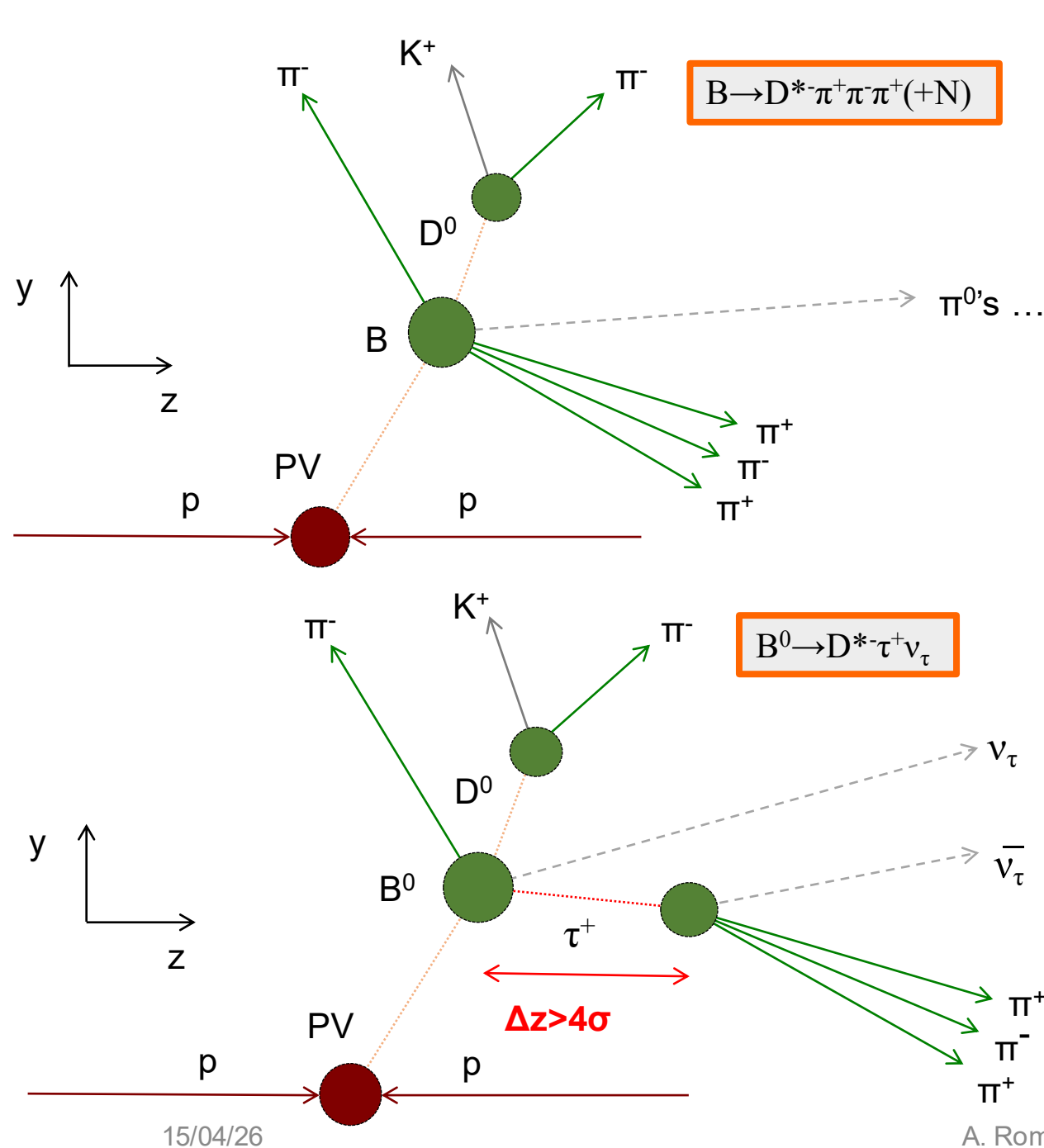
- R(D^{*}) obtained from:

$$R(D^*) = K_{had}(D^*) \cdot \frac{BR(B^0 \rightarrow D^{*-} \pi^+ \pi^- \pi^+)}{BR(B^0 \rightarrow D^{*-} \mu^+ \nu_\mu)} \quad \begin{array}{l} [\sim 4\% \text{ precision}] \\ [\sim 2\% \text{ precision}] \end{array}$$

- N(B⁰→D^{*+}π⁻π⁺π⁻) from a un-binned likelihood fit to m(D^{*-}π⁺π⁻π⁺).

- N(B⁰→D^{*+}τ⁻(→π⁻π⁺π⁻(π⁰)ν_τ)ν_τ) from a 3D template fit.

Displaced tau vertex



- The most abundant background is due to (“prompt”) $B \rightarrow D^* \pi^+ \pi^- \pi^+ (+X)$ where the 3 pions come from the B vertex (about 100 times higher than signal).
- Suppressed by requiring minimum distance between B and τ vertices ($>4\sigma$).
- This background suppressed by ~ 3 orders of magnitude. 35% efficient on signal.
- Possible due to the excellent LHCb vertex precision.

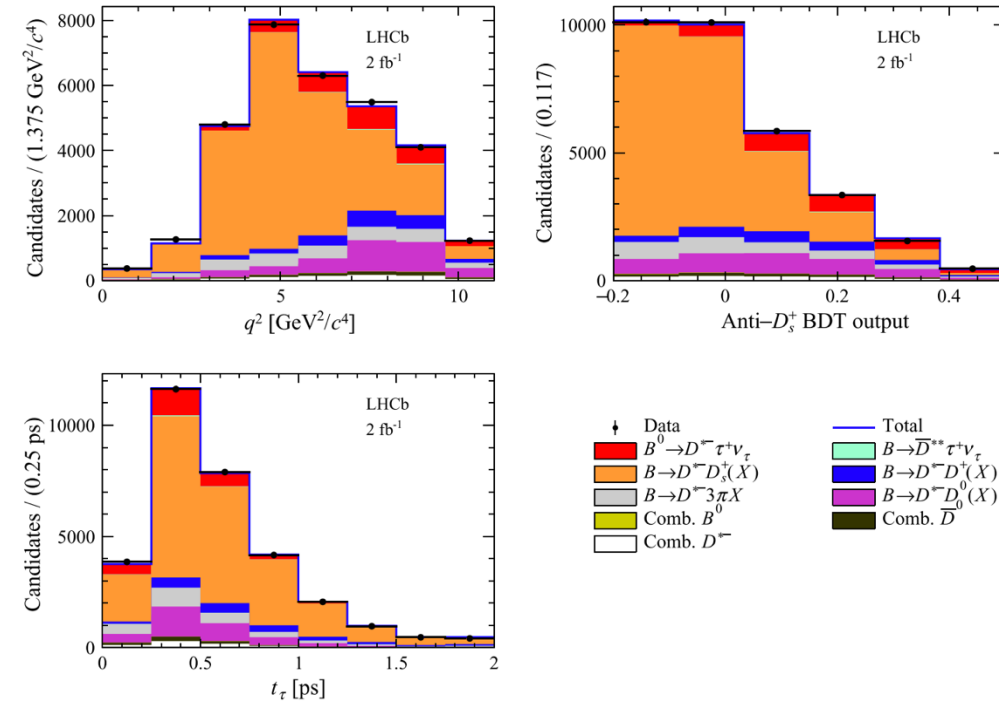
R(D^{*+}) hadronic at LHCb

PRD108 012018 (2023)

- Main background in signal sample due to $B \rightarrow D^{*-} D_s^+ X$ decays.
 - Anti- D_s^+ BDT trained and used in fit.
- 3D binned fit to data in (q^2 , τ decay time, BDT) with (8,8,4) bins.
- Model:

1. **Signal** $B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$: $\tau^- \rightarrow \pi^- \pi^+ \pi^- \nu_\tau$ and $\tau^- \rightarrow \pi^- \pi^+ \pi^- \pi^0 \nu_\tau$ (ratio constrained according to known BF's). Free in the fit.
2. $B \rightarrow D^{**} \tau \nu_\tau$. Fixed to the expected yield, 11% of signal (assign syst. uncertainty).
3. Doubly-charmed B decays:
 - a) $B \rightarrow D^{*-} D_s^+ X$. Includes $B^0 \rightarrow D^{*-} D_s^+$, $B^0 \rightarrow D^{*-} D_s^{*+}$, $B^0 \rightarrow D^{*-} D_{s0}^{*+}$, $B^0 \rightarrow D^{*-} D_{s1}$, $B_s^0 \rightarrow D^{*-} D_s^+ X$, $B \rightarrow D^{**} D_s^+ X$. Shape constrained from control sample.
 - b) $B \rightarrow D^{*-} D^0 X$. Yield fixed from control sample.
 - c) $B \rightarrow D^{*-} D^+ X$. Free in the fit.
4. Prompt $B \rightarrow D^{*-} 3\pi X$. Yield constrained from control sample.
5. **Comb. background**. Yield fixed from control sample.

$$\mathcal{R}(D^{*-}) = 0.247 \pm 0.015(\text{stat}) \pm 0.015(\text{syst}) \pm 0.012(\text{ext})$$



Main systematics:

- Doubly-charmed $B \rightarrow DD X$.
- Simulation size.
- Form factors.



Other LHCb measurements: $F_L(D^{*+})$



- Measurement of $F_L(D^{*+})$ at LHCb using 3-prong hadronic tau decays.
 - $B^0 \rightarrow D^{*-} \tau^+ \nu_\tau$

$$\frac{1}{\Gamma} \frac{d^2\Gamma}{dq^2 d\cos\theta_D} = a_{\theta_D}(q^2) + c_{\theta_D}(q^2)\cos^2\theta_D, \quad F_L^{D^*}(q^2) = \frac{a_{\theta_D}(q^2) + c_{\theta_D}(q^2)}{3a_{\theta_D}(q^2) + c_{\theta_D}(q^2)}$$

a_{θ_D} : unpolarized signal fraction

c_{θ_D} : polarized signal fraction

$$F_L^{D^*} = 0.43 \pm 0.06 \text{ (stat)} \pm 0.03 \text{ (syst)}$$

$$F_L^{D^*} = 0.60 \pm 0.08 \text{ (stat)} \pm 0.04 \text{ (syst)}$$

- Compatible with the SM

[arXiv:1903.03102](https://arxiv.org/abs/1903.03102)



$$F_L^{D^*} = 0.441 \pm 0.006 \text{ [PRD 98 (2018) 095018]}$$

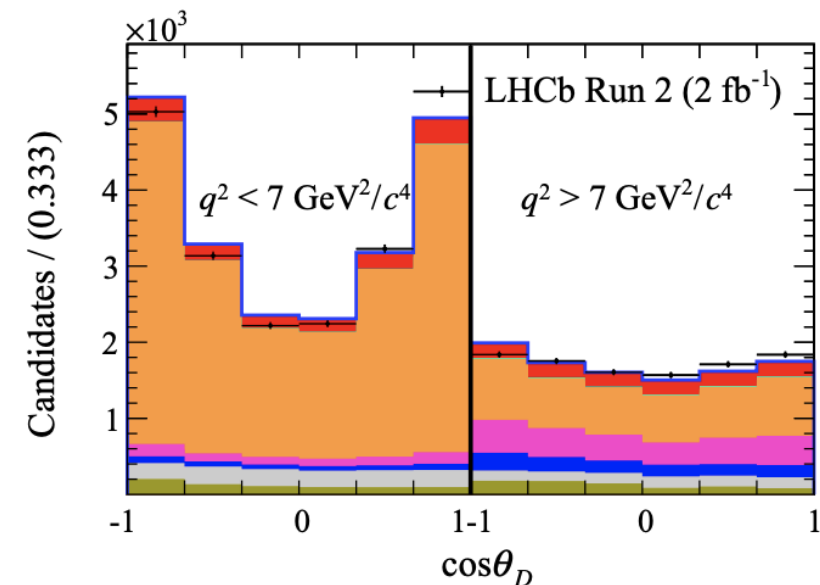
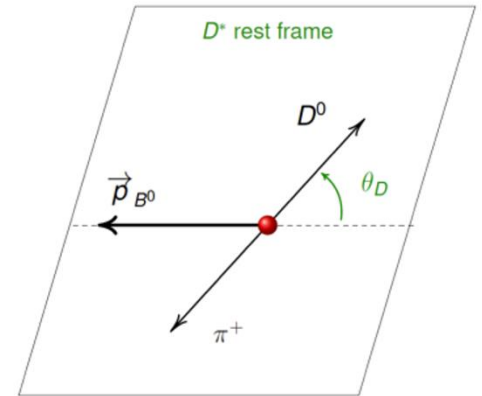
$$F_L^{D^*} = 0.457 \pm 0.010 \text{ [Eur. Phys. J. C 79, 268 (2019)]}$$

$$F_L^{D^*} = 0.467 \pm 0.009 \text{ [Eur. Phys. J. C 80, 347 (2020)]}$$

$$F_L^{D^*} = 0.422 \pm 0.010 \text{ [arXiv:2310.03680]}$$

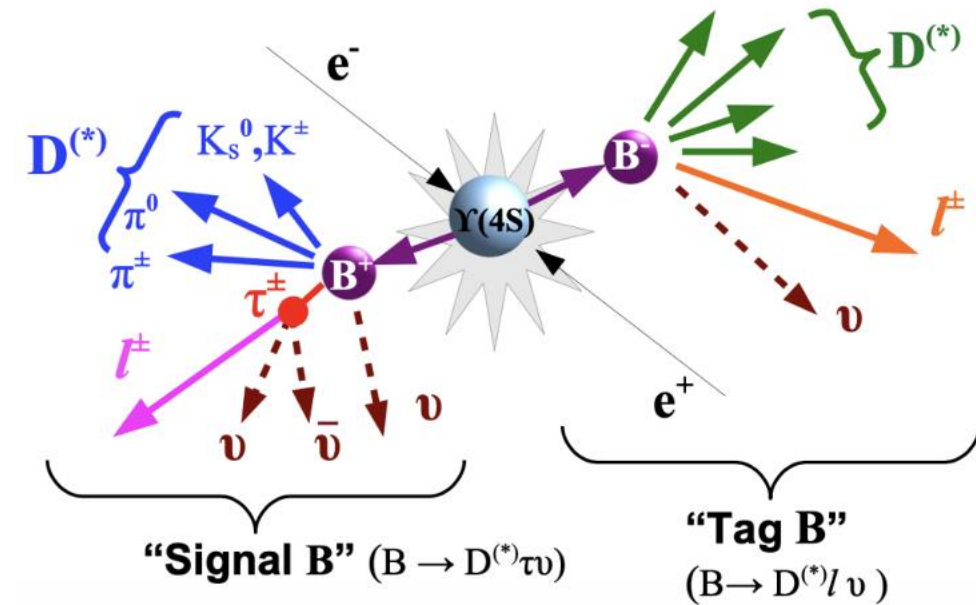
$$F_L^{D^*}[q^2 < 7 \text{ GeV}^2/c^4] = 0.495 \pm 0.017 \text{ [arXiv:2310.03680]}$$

$$F_L^{D^*}[q^2 > 7 \text{ GeV}^2/c^4] = 0.383 \pm 0.006 \text{ [arXiv:2310.03680]}$$



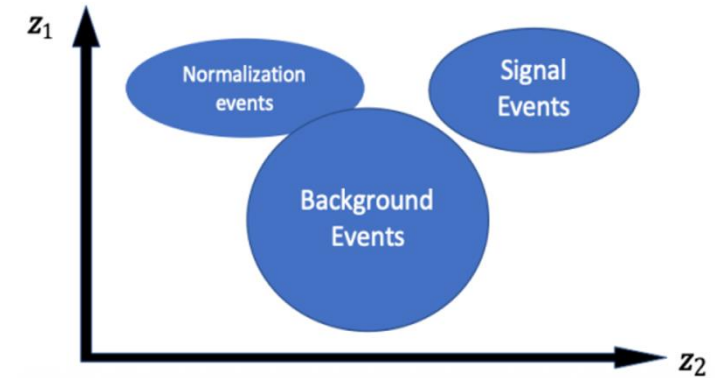
New BaBar $R(D)/R(D^*)$ measurement

- First Babar (2013) analysis used hadronic tagging.
- New analysis, presented at Moriond 2026 (24/03/2026), uses **SL tagging**.
- **Signal:** $B \rightarrow D^{(*)}\tau\nu$ with $\tau \rightarrow \ell\nu\nu$.
- **Normalisation:** $B \rightarrow D^{(*)}\ell\nu$ with $\ell = \mu, \nu$.
- 3 backgrounds:
 - **D** events:** At least one B decays to $D^{**}(\tau)/\ell\nu$.
 - **Combinatorial:** $B\bar{B}$ events other than signal/normalisation.
 - **Continuum:** $q\bar{q}$ events with $q \neq b$.
- Analysis statistically independent of 2013 analysis.
 - Does **not supersede** previous analysis.

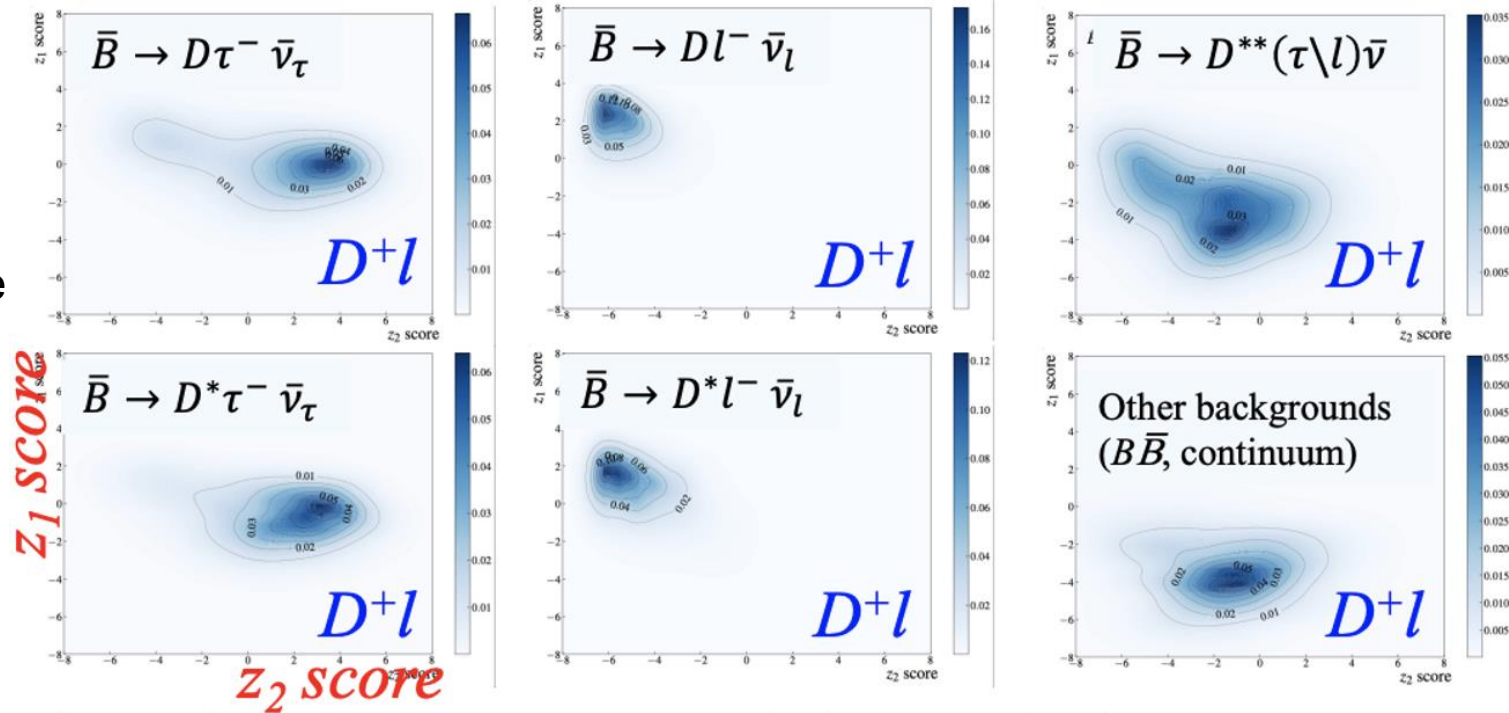


Signal, normalisation and background discrimination

- Two BDT classifiers trained:
 - z1** to discriminate **signal/normalisation** from **background**.
 - z2** to discriminate **signal** from **normalisation**.



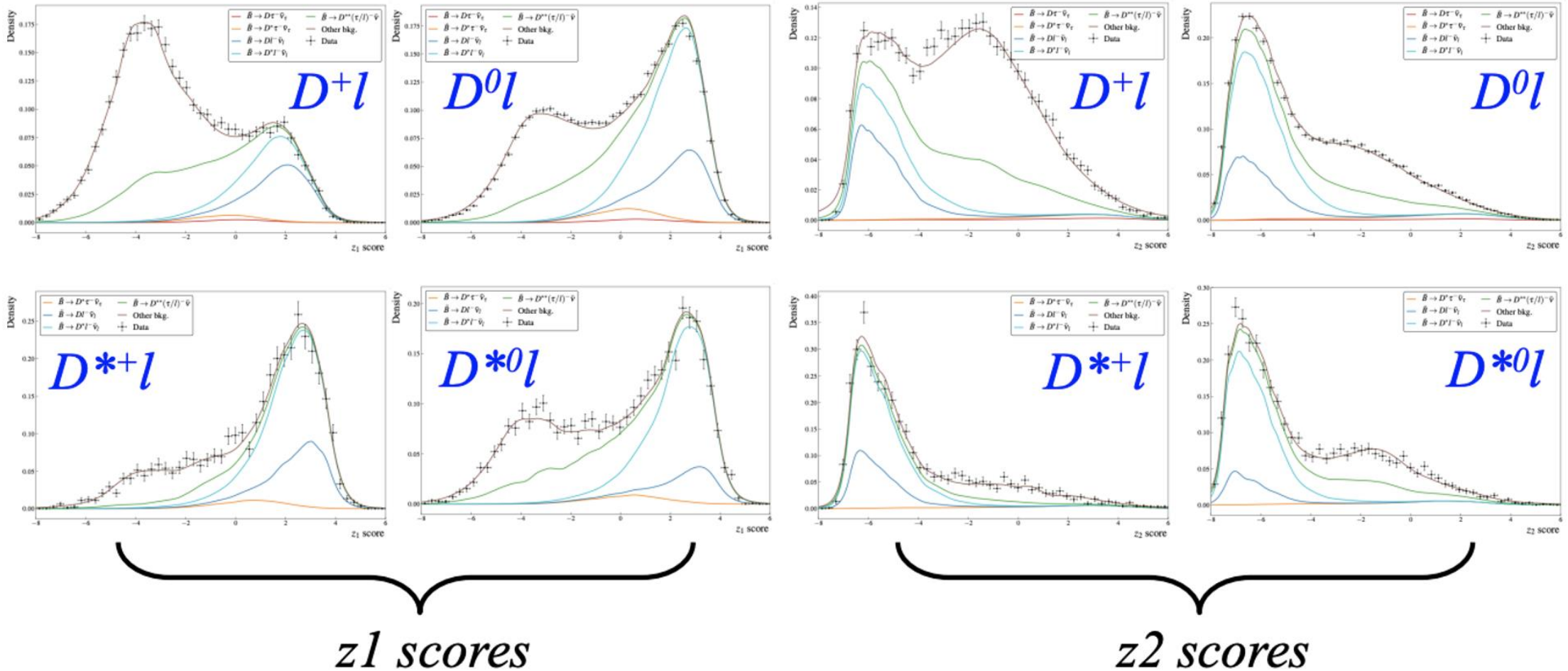
- 4 datasets** used:
 - $D^+\ell, D^0\ell, D^{*+}\ell, D^{*0}\ell$.
- Yields obtained from a simultaneous maximum likelihood fit to the 4 datasets in the z_1/z_2 plane.
- 2D PDFs obtained using Adaptive Kernel Density Estimation (KDE).



Fit projections



- **z1** discriminates **signal/normalisation** from **background**.
- **z2** discriminates **signal** from **normalisation**.



Yields and uncertainties



- **Yields** are extracted **separately** for the 4 datasets and then are combined.
- All components are **free** to vary in the fit.
- Measurement dominated by statistical uncertainty.
- Dominant systematics:
 - **PDF shapes** and MC statistics.
 - $B \rightarrow D^{**} \ell \nu$ shape and branching fractions.
 - Data-driven **corrections** and background calibration.

Subset	Component	Extracted Yield
D^+l	$B \rightarrow D\tau\nu$	117 ± 44
	$B \rightarrow D^*\tau\nu$	191 ± 57
	$B \rightarrow Dl\nu$	1965 ± 110
	$B \rightarrow D^*l\nu$	1261 ± 146
	$B \rightarrow D^{**}l\nu$	3248 ± 233
	Other Bkgs	7258 ± 182
D^0l	$B \rightarrow D\tau\nu$	726 ± 273
	$B \rightarrow D^*\tau\nu$	2452 ± 285
	$B \rightarrow Dl\nu$	12012 ± 555
	$B \rightarrow D^*l\nu$	22808 ± 648
	$B \rightarrow D^{**}l\nu$	15594 ± 445
	Other Bkgs	22065 ± 307
$D^{*+}l$	$B \rightarrow D^*\tau\nu$	110 ± 17
	$B \rightarrow Dl\nu$	614 ± 127
	$B \rightarrow D^*l\nu$	1246 ± 139
	$B \rightarrow D^{**}l\nu$	292 ± 54
	Other Bkgs	665 ± 42
$D^{*0}l$	$B \rightarrow D^*\tau\nu$	175 ± 25
	$B \rightarrow Dl\nu$	479 ± 126
	$B \rightarrow D^*l\nu$	2154 ± 149
	$B \rightarrow D^{**}l\nu$	1387 ± 101
	Other Bkgs	1415 ± 70

Source	$\Delta R(D)$ (%)	$\Delta R(D^*)$ (%)	Correlation
$B \rightarrow Dl\nu$ form factor	0.42	0.13	-0.18
$B \rightarrow D^*l\nu$ form factor	0.92	0.31	-0.19
$B \rightarrow D^{**}l\nu$ form factor	0.48	0.18	-0.90
$\mathcal{B}(B \rightarrow D^{(*)}l\nu)$	0.47	0.38	0.97
$\mathcal{B}(b \rightarrow c\bar{c})$	0.34	0.13	1
▶ $\mathcal{B}(B \rightarrow D^{**}l\nu)$	2.83	1.60	-0.97
$\mathcal{B}(D)$	0.84	0.70	-0.40
▶ PDF shapes MC statistics	4.12	4.37	-0.15
▶ On-peak background calibration	2.45	0.44	-0.05
$\mathcal{B}(\Upsilon(4S))$	0.48	0.43	1
PID efficiency	0.29	0.40	1
Soft π^0 efficiency	0.84	1.25	1
$\mathcal{B}(\tau \rightarrow l^- \bar{\nu}_l \nu_\tau)$	0.16	0.16	1
Systematic Total	5.86	4.96	-0.20
Statistical Uncertainty	19.8	9.9	-0.92
Total	20.65	11.07	-0.82

R(D)/R(D*) results

HFLAV average (CKM 2025)
 excluding new BABAR result
 $R(D) = 0.358 \pm 0.024$
 $R(D^*) = 0.281 \pm 0.011$
 $\rho = -0.374$

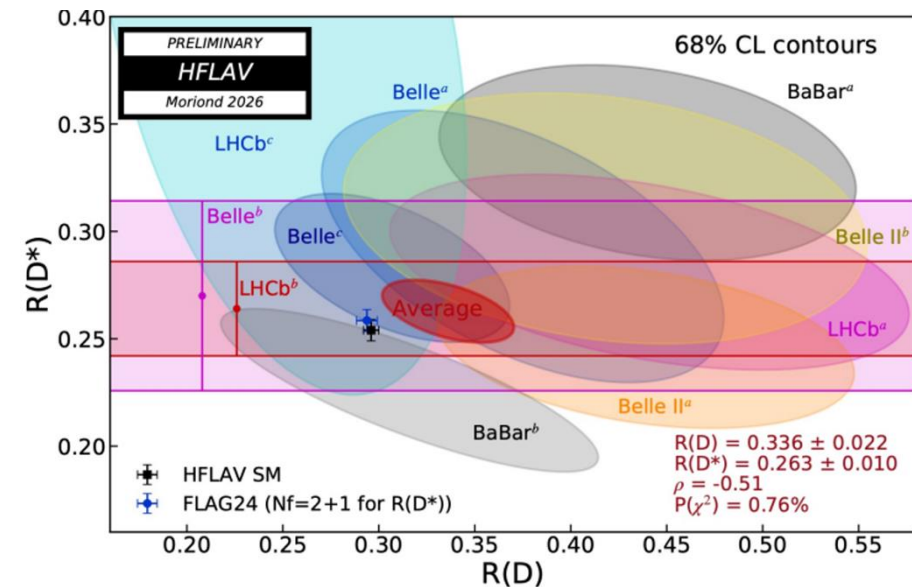
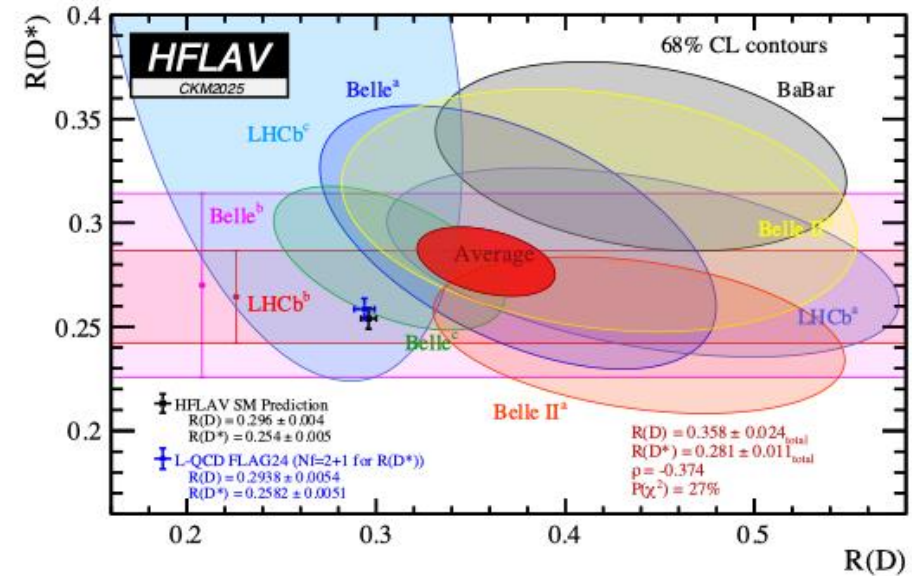
- New preliminary BaBar result:

$$R(D) = 0.316 \pm 0.062 \text{ (stat)} \pm 0.019 \text{ (syst)}$$

$$R(D^*) = 0.226 \pm 0.022 \text{ (stat)} \pm 0.012 \text{ (syst)}$$

$$\rho = -0.82$$

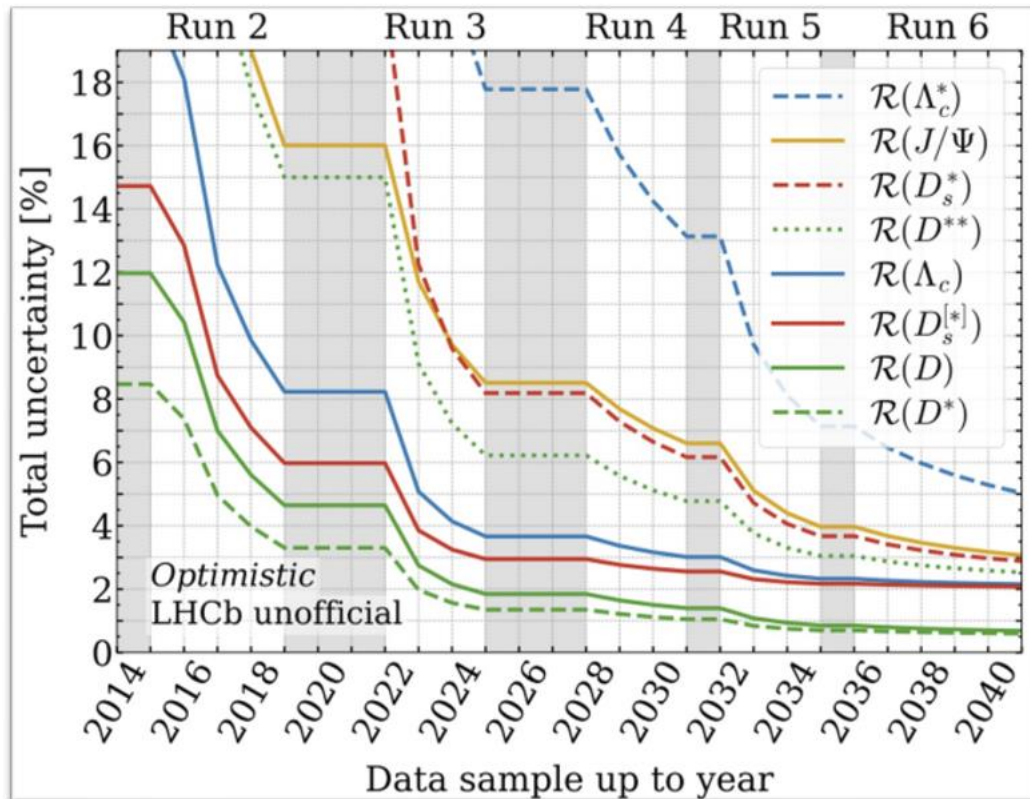
- Consistent with SM at $\sim 1.5\sigma$.
- New WA consistent with the SM at $\sim 2\sigma$.



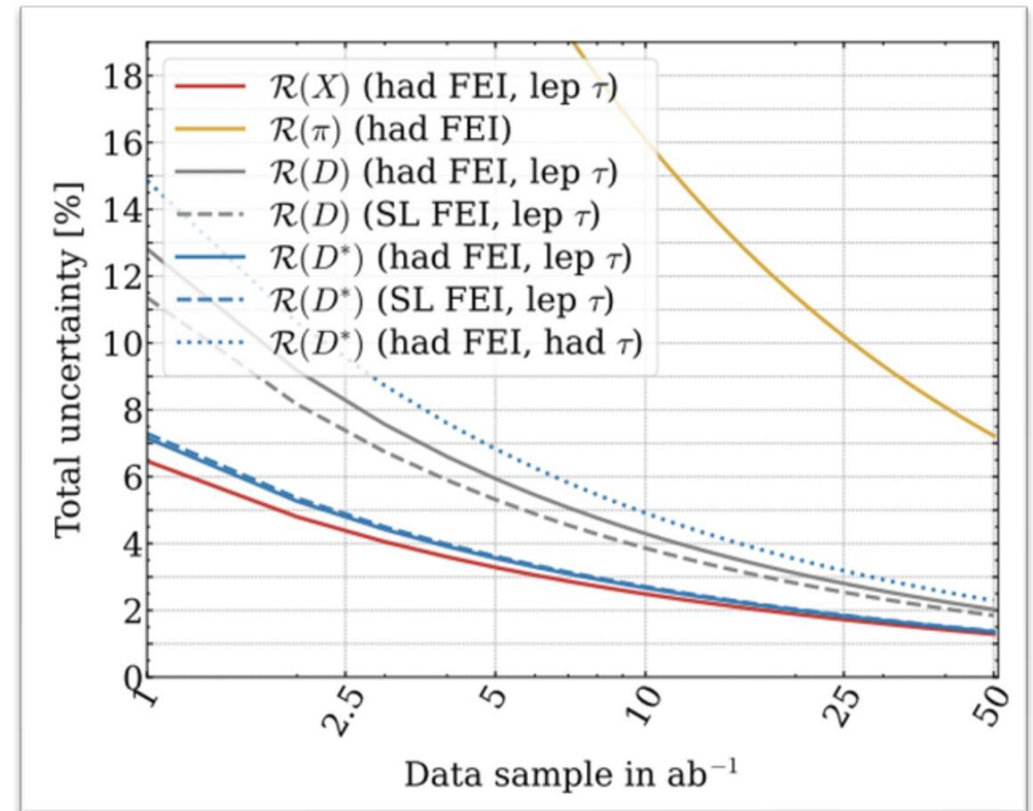
Prospects on $R(D)/R(D^*)$

- The inclusion of more data will reduce both the statistical and systematic uncertainties.

LHCb



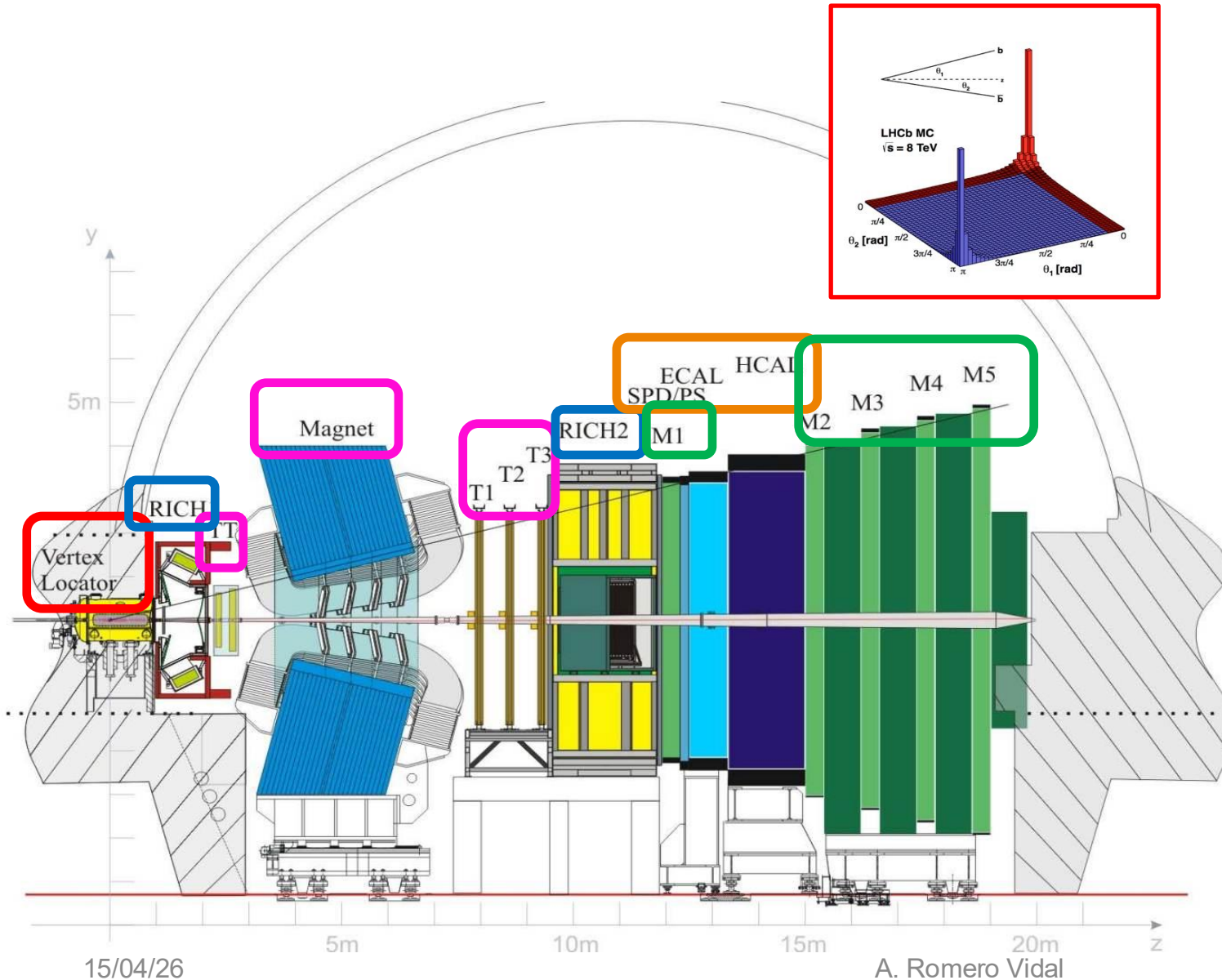
Belle II



Conclusions

- Lepton flavour universality provides a powerful test of the SM.
- Measurements of $R(D)/R(D^*)$ shows presently a tension of $\sim 4\sigma$.
- After the new preliminary BaBar $R(D)/R(D^*)$ result, the $R(D)/R(D^*)$ tension with the SM is reduced to $\sim 2\sigma$.
- However, precision in measurements still needs to improve to provide a definite picture.
- Belle II and LHCb run3 data will help to improve the current precision.

The (old) LHCb detector



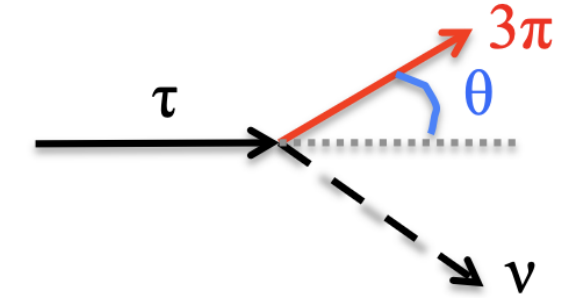
- In pp collisions b/\bar{b} pairs produced with very small opening angle. **LHCb** detector is a **forward** spectrometer.
- **Vertex detector (VELO):**
 - Excellent vertex resolution: $20\mu\text{m}$ resolution on impact parameter.
 - Decay time resolution $\sim 45\text{ps}$.
- **Tracking system (plus a 4T magnet):**
 - Momentum resolution $\Delta p/p \sim 0.4\% - 0.6\%$
- **RICH detectors:**
 - Excellent $K/\pi/p$ separation.
- **Calorimeter systems:**
 - Energy measurement (i.e. π^0, γ).
- **Muon system:**
 - Very high efficiency for muons.

Signal reconstruction

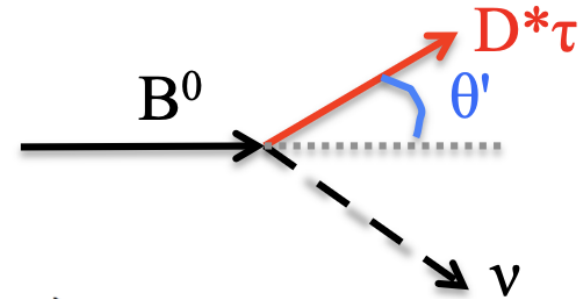
- **4-fold ambiguity:**

$$|\vec{p}_\tau| = \frac{(m_{3\pi}^2 + m_\tau^2)|\vec{p}_{3\pi}| \cos \theta \pm E_{3\pi} \sqrt{(m_\tau^2 - m_{3\pi}^2)^2 - 4m_\tau^2 |\vec{p}_{3\pi}|^2 \sin^2 \theta}}{2(E_{3\pi}^2 - |\vec{p}_{3\pi}|^2 \cos^2 \theta)}$$

$$|\vec{p}_{B^0}| = \frac{(m_{D^*\tau}^2 + m_{B^0}^2)|\vec{p}_{D^*\tau}| \cos \theta' \pm E_{D^*\tau} \sqrt{(m_{B^0}^2 - m_{D^*\tau}^2)^2 - 4m_{B^0}^2 |\vec{p}_{D^*\tau}|^2 \sin^2 \theta'}}{2(E_{D^*\tau}^2 - |\vec{p}_{D^*\tau}|^2 \cos^2 \theta')}$$



Lab. frame



- **Can be approximated by doing:**

$$\theta_{max} = \arcsin \left(\frac{m_\tau^2 - m_{3\pi}^2}{2m_\tau |\vec{p}_{3\pi}|} \right) \quad \theta'_{max} = \arcsin \left(\frac{m_{B^0}^2 - m_{D^*\tau}^2}{2m_{B^0} |\vec{p}_{D^*\tau}|} \right)$$

- **Possible to reconstruct rest frame variables such as tau decay time and q^2 .**
- **These variables have negligible biases, and sufficient resolution to preserve good discrimination between signal and background.**