DISCRETE 2026

13–17 nov 2026 Faculty of Mathematics, Physics and Informatics, Comenius University Bratislava

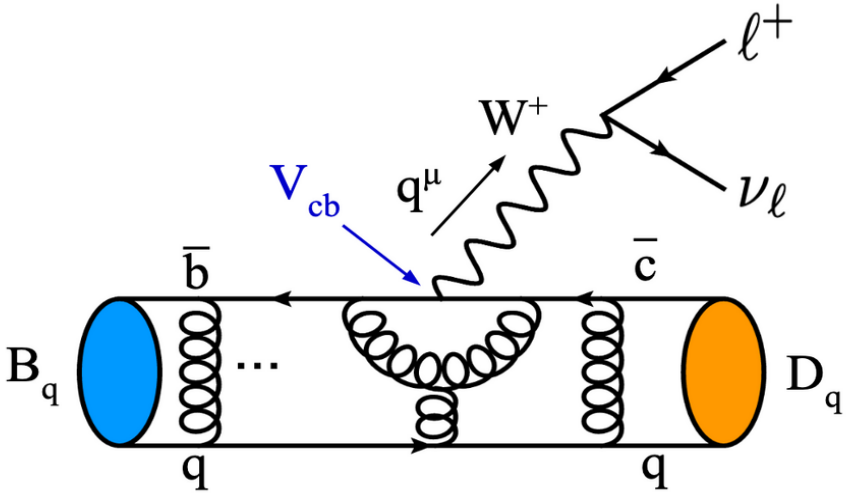
Measurement of the ratio $B \to D^{(*)}\tau\nu_\tau$ / $B \to D^{(*)}\ell\nu_\ell$ with the BaBar detector

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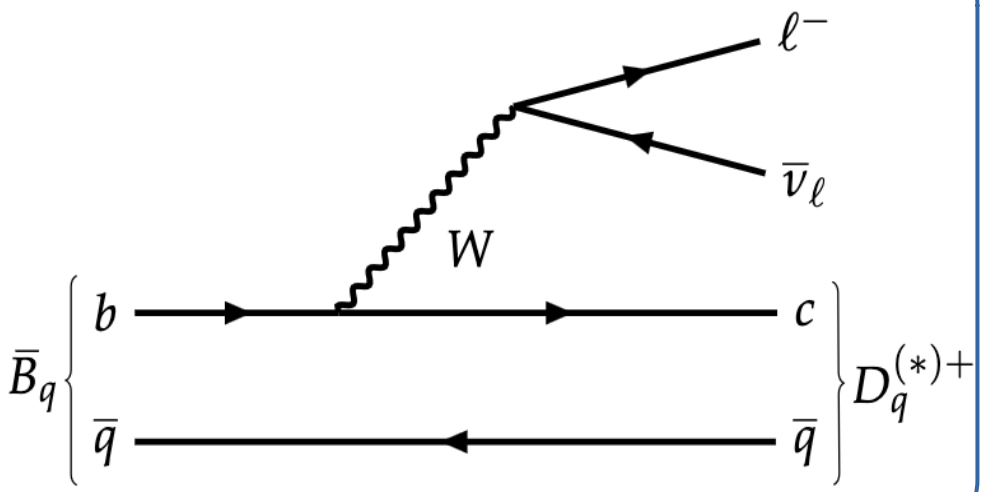
On behalf of BaBar collaboration



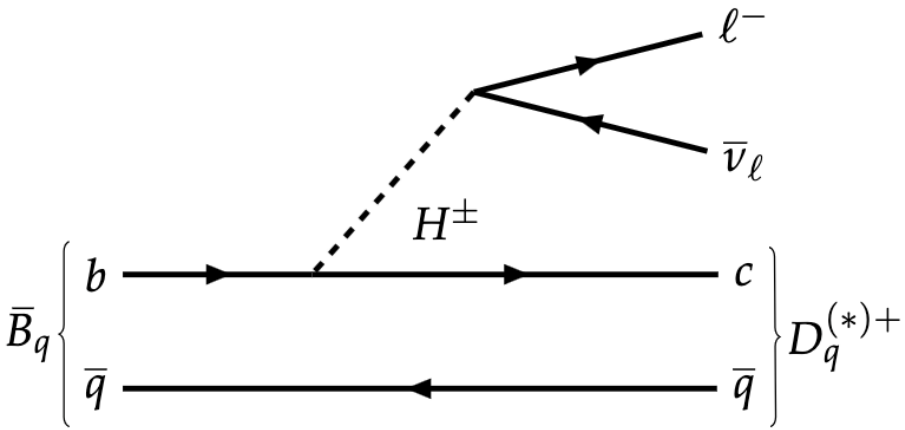
Semileptonic B decays and LFU

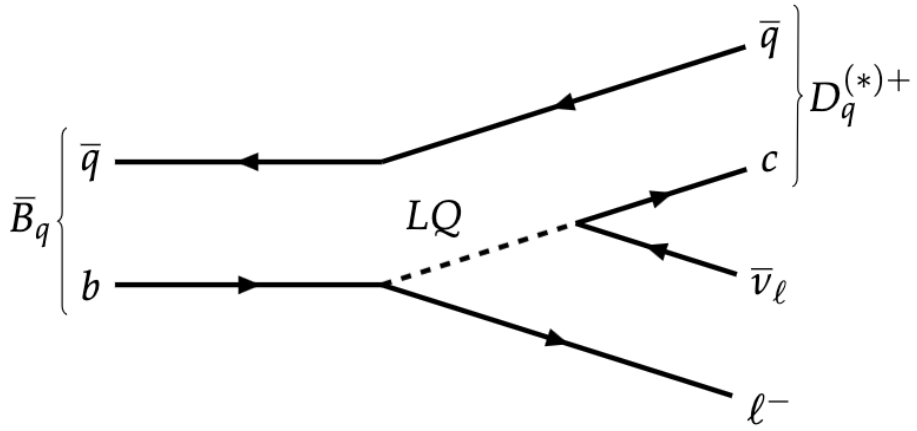
F. Bernlochner et al. Rev.Mod.Phys. 94 (2022)
Suzanne Klaver, MR, Symmetry 16 (2024)

- SL decays described by three level diagrams: theoretical clean
- All leptons couplings to gauge bosons are identical in the SM



- Tau leptons test coupling to third generation: Sensitive to New Physics





Semileptonic B decays and LFU

$$\mathcal{R}(D) = \frac{\mathcal{B}(\bar{B} \to D\tau\nu_\tau)}{\mathcal{B}(\bar{B} \to D\ell\nu_\ell)}, \qquad \mathcal{R}(D^*) = \frac{\mathcal{B}(\bar{B} \to D^*\tau\nu_\tau)}{\mathcal{B}(\bar{B} \to D^*\ell\nu_\ell)}$$

$\ell = \mathrm{e}$ or μ

Accurate SM predictions

HFLAV ICHEP26

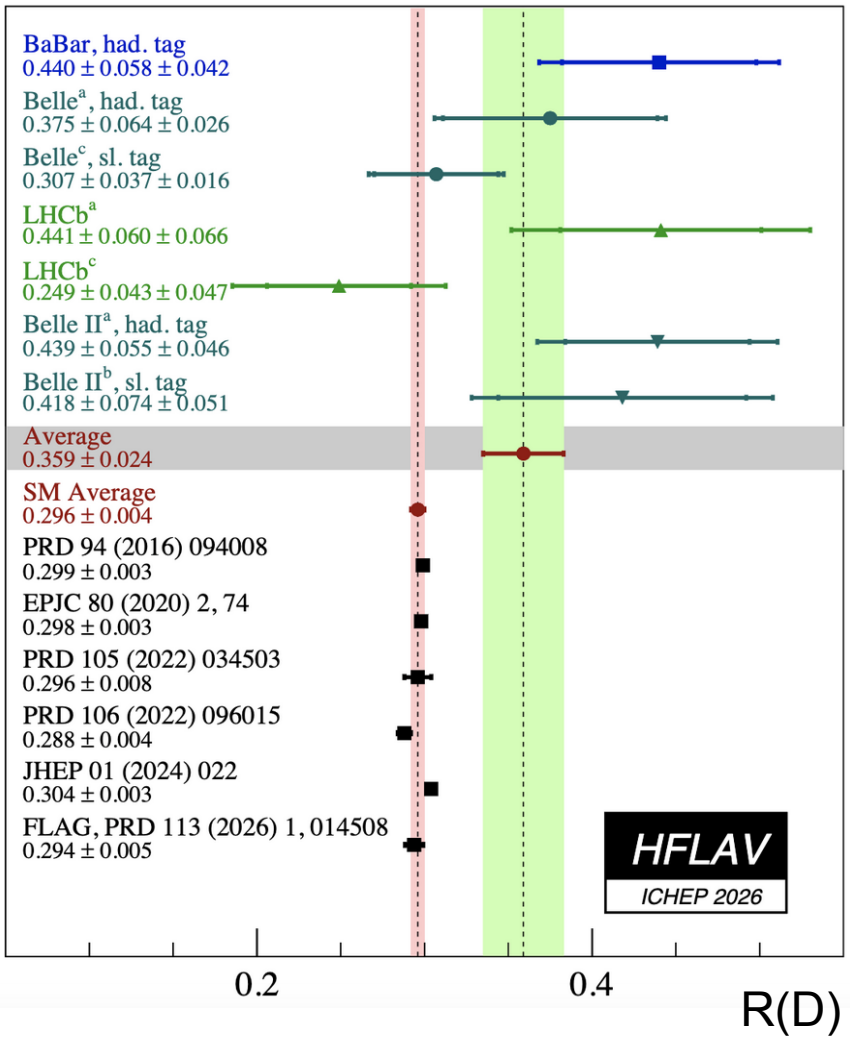
	R(D)	R(D*)
D.Bigi, P.Gambino, Phys.Rev. D94 (2016) no.9, 094008 [arXiv:1606.08030 [hep-ph]]	0.299 ± 0.003	
M.Bordone, M.Jung, Danny van Dyk, Eur.Phy.J.C 80 (2020) 2, 74 [arXiv:1908.09398 [hep-ph]]	0.298 ± 0.003	0.247 ± 0.006
G. Martinelli, S. Simula, L. Vittorio, Phys.RevD 105 (2022) 3, 034503 [arXiv:2105.08674 [hep-ph]]	0.296 ± 0.008	
F. U. Bernlochner, Z. Ligeti, M. Papucci, M. T. Prim, D. J. Robinson, C. Xiong, Phys. Rev. D 106 (2022) 096015 [arXiv:2206.11281 [hep-ph]]	0.288 ± 0.004	0.249 ± 0.003
I.Ray, S.Nandi, JHEP 01 (2024) 022 [arXiv:2305.11855 [hep-lat]]	0.304 ± 0.003	0.258 ± 0.012
FLAG Collaboration, [arXiv:2411.04268 [hep-lat]]	0.2938 ± 0.0054	
BaBar Collaboration, Phys.Rev.Lett. 123 (2019) 9, 091801 [arXiv:1903.10002 [hep-ex]]		0.253 ± 0.005
P.Gambino, M.Jung, S.Schacht, Phys.Lett.B795 (2019) 386 [arXiv:1905.08209 [hep-ph]]		0.254 + 0.007 − 0.006
G. Martinelli, S. Simula, L. Vittorio, Eur. Phys. J. C 84 (2024) 400 [arXiv:2310.03680 [hep-ph]]		0.262 ± 0.009
Arithmetic average	**0.296 ± 0.004**	**0.254 ± 0.005**
FLAG Collaboration, R(D*) Nf=2+1 [arXiv:2411.04268 [hep-lat]]	0.2938 ± 0.0054	0.2582 ± 0.0051
FLAG Collaboration, R(D*) Nf=2+1+1 [arXiv:2411.04268 [hep-lat]]	0.2938 ± 0.0054	0.275 ± 0.015
FLAG Collaboration, R(D*) G. Martinelli et. al. [arXiv:2411.04268 [hep-lat], arXiv:2310.03680 [hep-ph]]	0.2938 ± 0.0054	0.262 ± 0.009

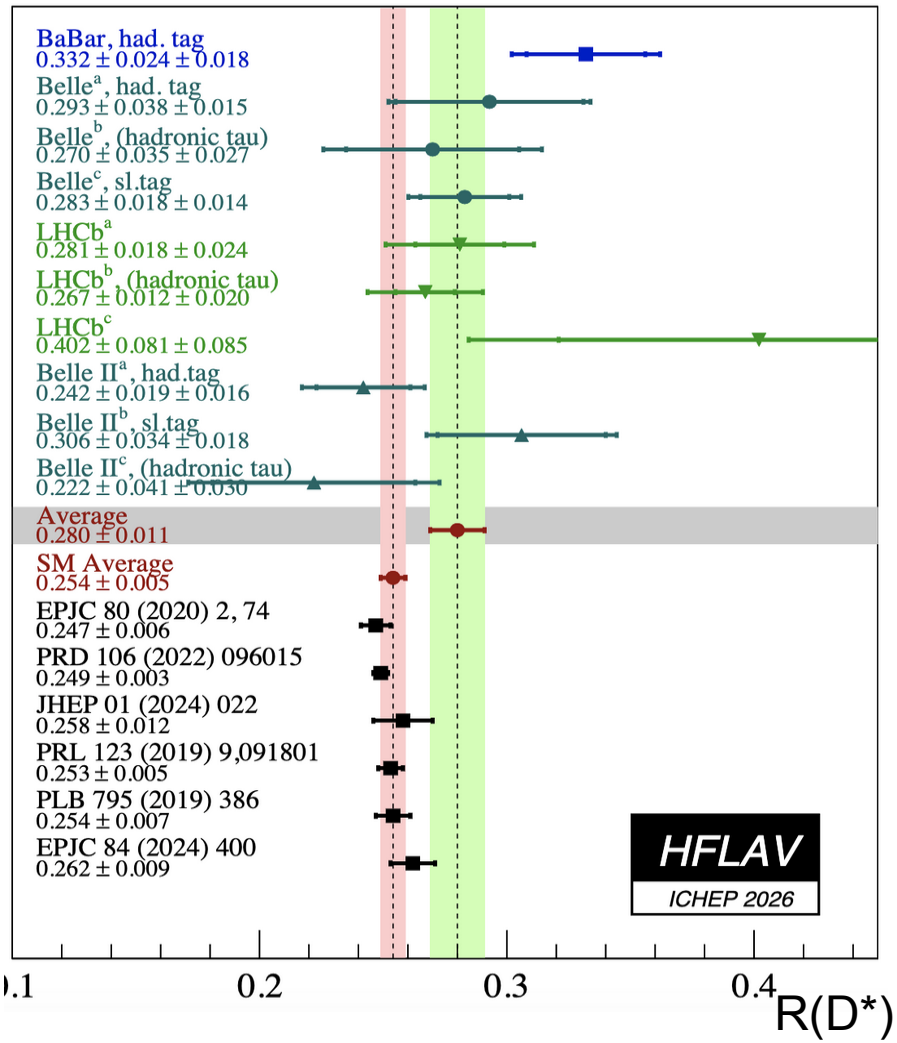
Status at ICHEP2026

- First tension with SM in 2012 by BaBar at 3.4 sigma
- Wide spread of experimental (and theoretical) efforts
  - Combined deviations from SM is at 3.7σ

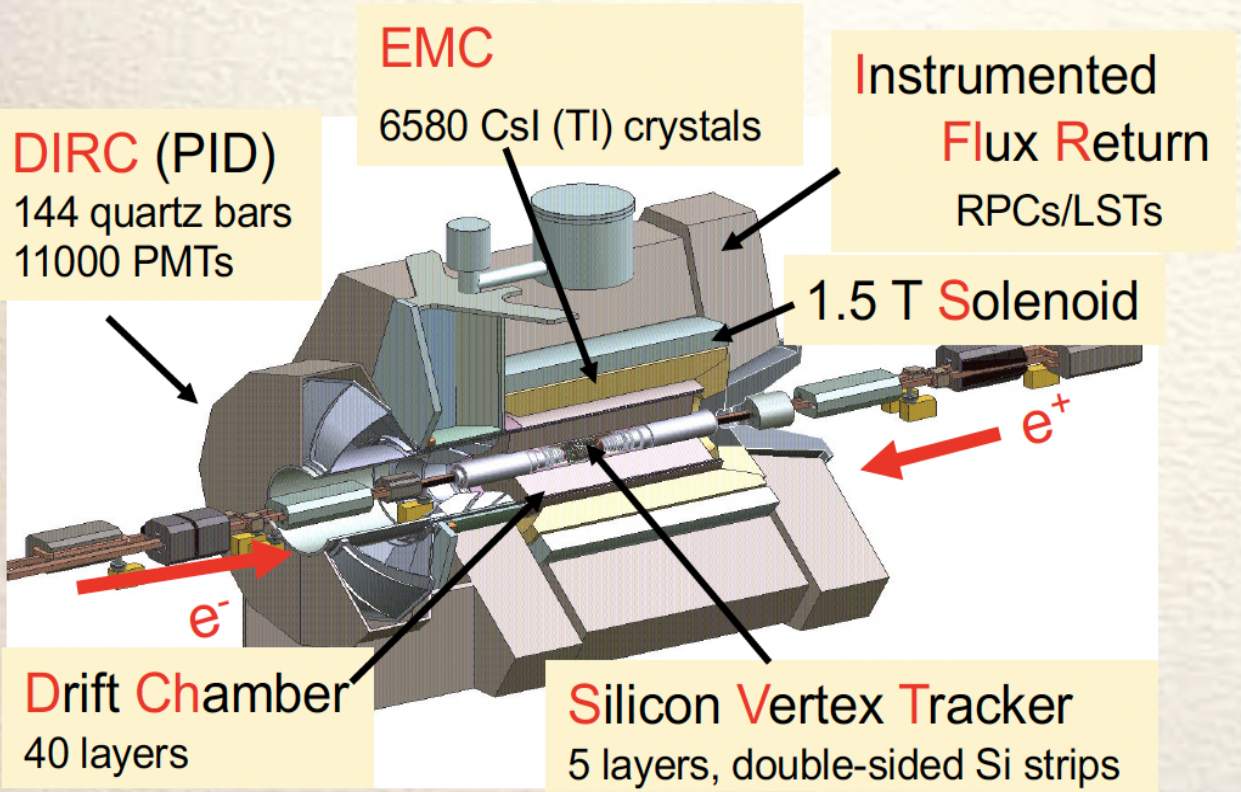
BaBar 2012
Phys.Rev.D 88, 072012 (2013)
Phys. Rev. Lett. 109, 101802 (2012)

HFLAV ICHEP26

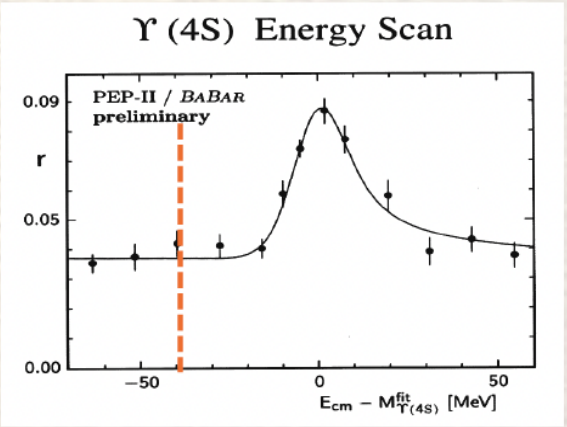




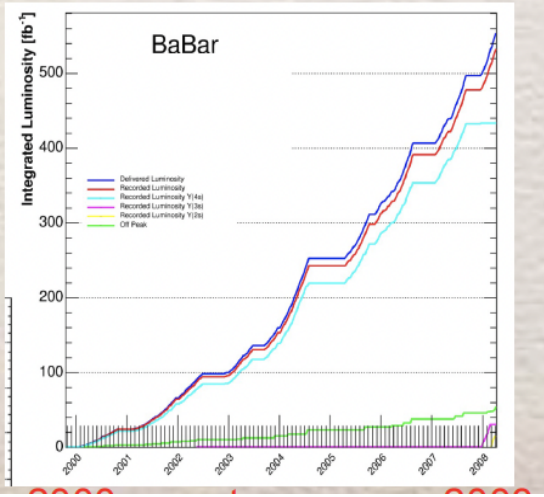
BaBar detector 1999-2008

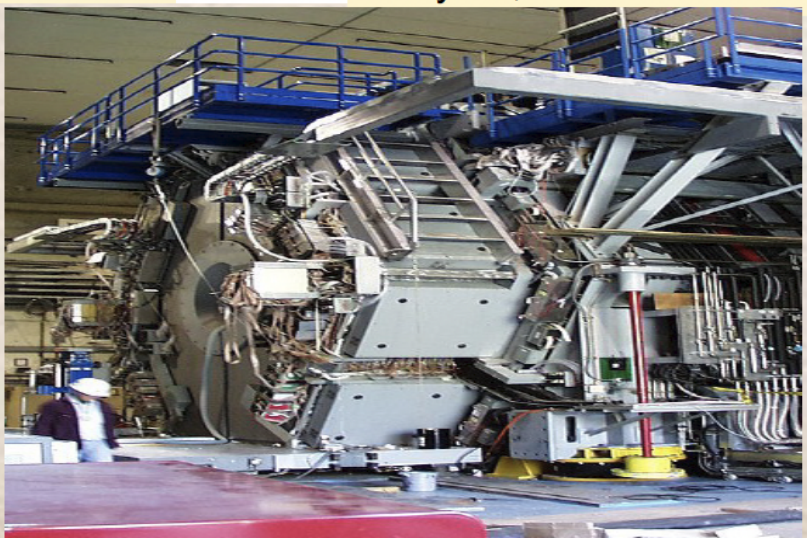


- 426 fb^{-1} collected at Υ(4S)
- 40 fb^{-1} 40 MeV below Υ(4S) study continuum background



- Integrated luminosity



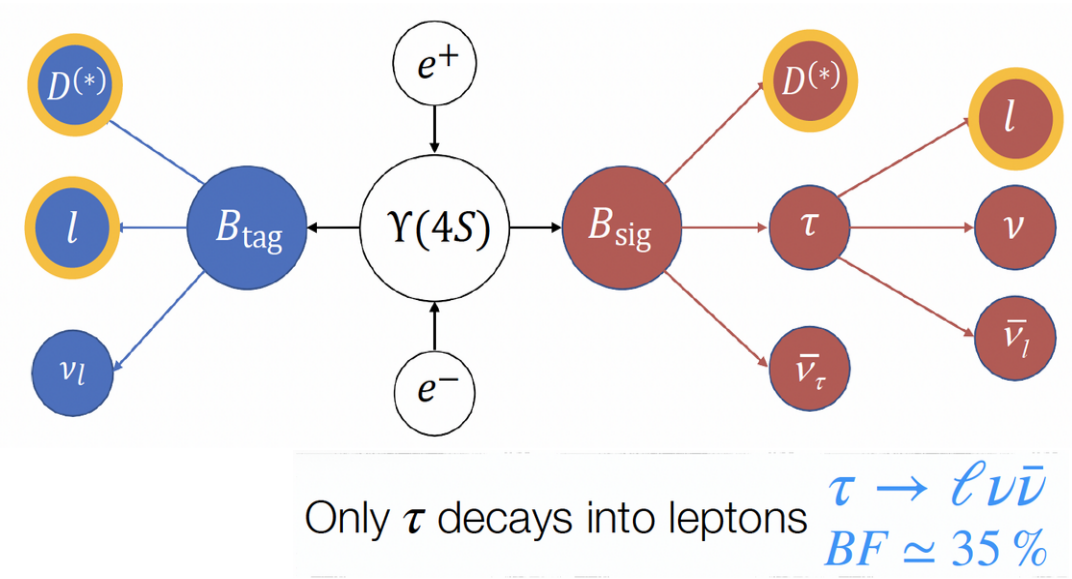


G.Eigen

NIM A 479, 1

Analysis strategy

- Reconstruct the tag side B_{tag} with semileptonic decays
- Reconstruct B_{sig}:
  - signal $B \to D(*)\ \tau\ \nu$ and normalization $B \to D(*)\ \ell\ \nu$



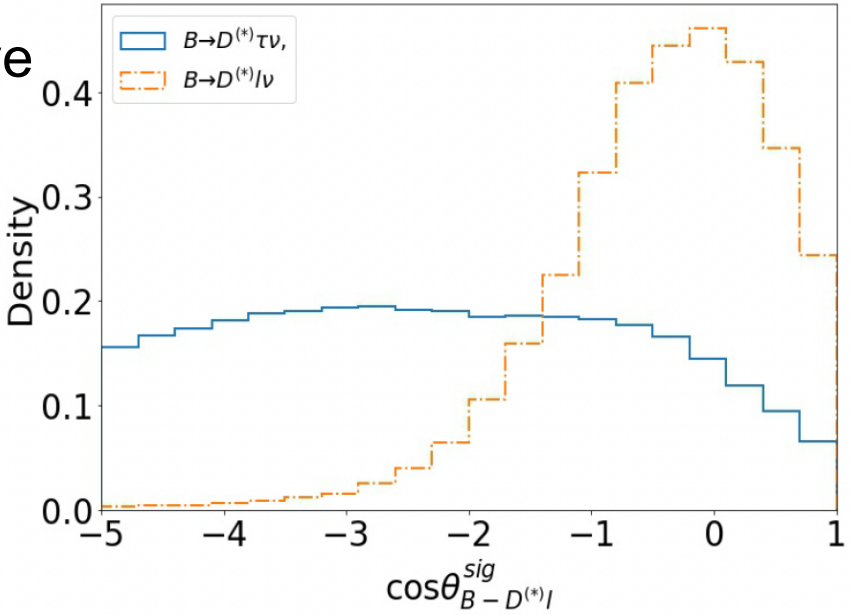
Only τ decays into leptons $\tau \to \ell \nu \bar{\nu}$ $BF \simeq 35\,\%$

- Background contributions:
  - Semileptonic decays into excited D mesons: $B \to D^{**}\ \ell/\tau\ \nu$
  - Other: combinatorics from generic $\Upsilon(4S) \to BB$ decays, and background from $e^+e^- \to qq$
- Construct multivariate classifiers to:
  - separate signal+normalization from background
  - separate $B \to D(*)\ \tau\ \nu$ from $B \to D(*)\ \ell\ \nu$
- Fit the classifiers output to extract signal and background yields
  - Minimize the usage of the MC

$\Upsilon(4S) \rightarrow B_{tag} B_{sig}$

- A correctly reconstructed B_{tag} is defined to have $\cos\theta_{BY}$ in the range of [-2,1]

$$\cos\theta_{B-D^{(*)}l} = \frac{2E_{\rm beam}E_{D^{(*)}\ell} - m_B^2 - m_{D^{(*)}\ell}^2}{2|\mathbf{p}_B||\mathbf{p}_{D^{(*)}}|}$$



- In each event with a selected B_{tag} we search for D(*) ℓ among the remaining tracks and calorimeter clusters in four tags

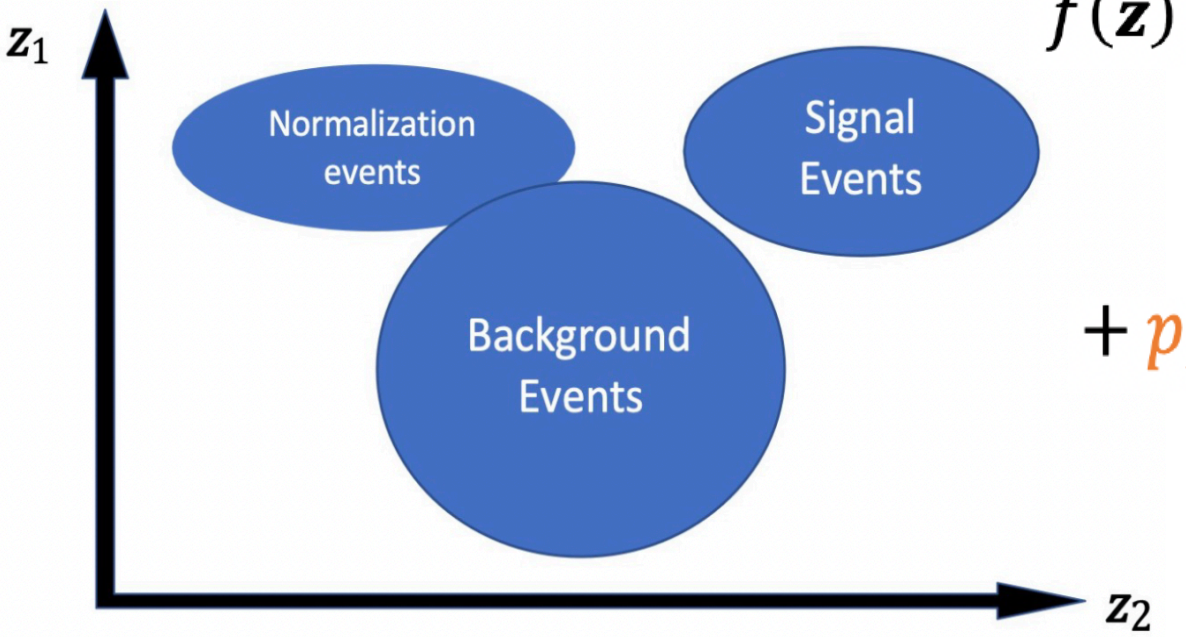
  – **D^0 ℓ, D^+ ℓ, D^{*0} ℓ, D^{*+} ℓ**

- No additional charged tracks, K, or π candidates
- Extra energy in calorimeter due to noise or background to be $E_{extra} < 1.2$ GeV
- Continuum bkg reduced with Fox-Wolfram moment shape variable, $R_2 \leq 0.4$
- 8.7% of the events have more than one $\Upsilon(4S)$ candidate: we retain that with smallest E_{extra}

Signal extraction strategy

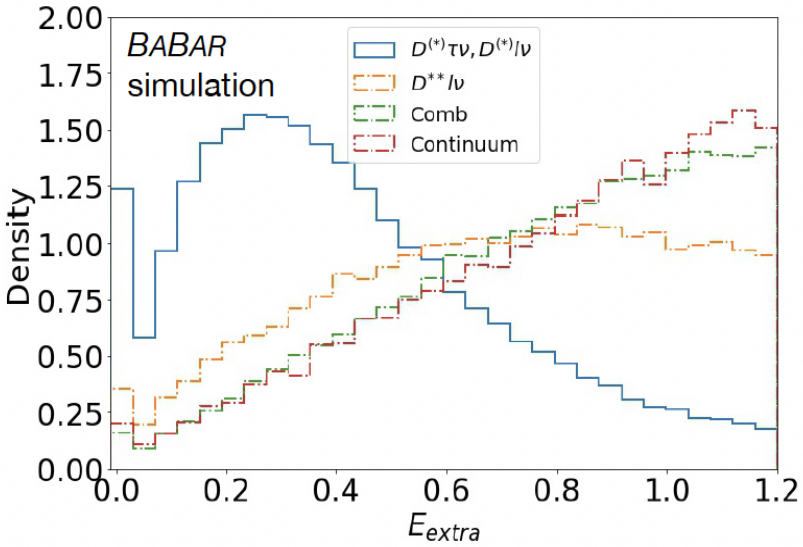
- Signal extracted from 2-D unbinned Maximum Likelihood
  - C1: z_1 is the output of a BDT to separate $B \to D(*)\, \ell/\tau\, \nu$ from background
  - C2: z_2 is the output of a BDT to separate $B \to D(*)\, \tau\, \nu$ from $B \to D(*)\, \ell\, \nu$

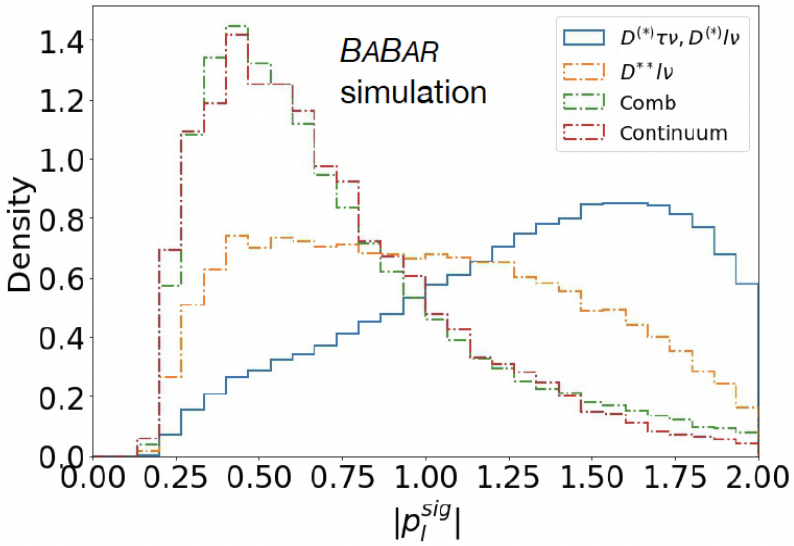
$\mathbf{z} = (z_1, z_2)$



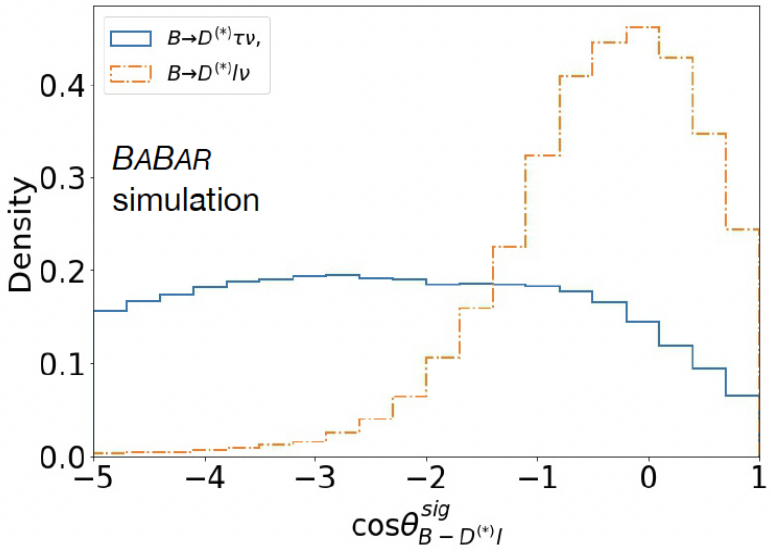
$$f(\mathbf{z}) = p_{D\tau} \cdot f_{D\tau}(\mathbf{z}) + p_{D^*\tau} \cdot f_{D^*\tau}(\mathbf{z})$$
$$+ p_{Dl} \cdot f_{Dl}(\mathbf{z}) + p_{D^*l} \cdot f_{D^*l}(\mathbf{z})$$
$$+ p_{D^{**}} \cdot f_{D^{**}}(\mathbf{z}) + p_{other} \cdot f_{other}(\mathbf{z})$$

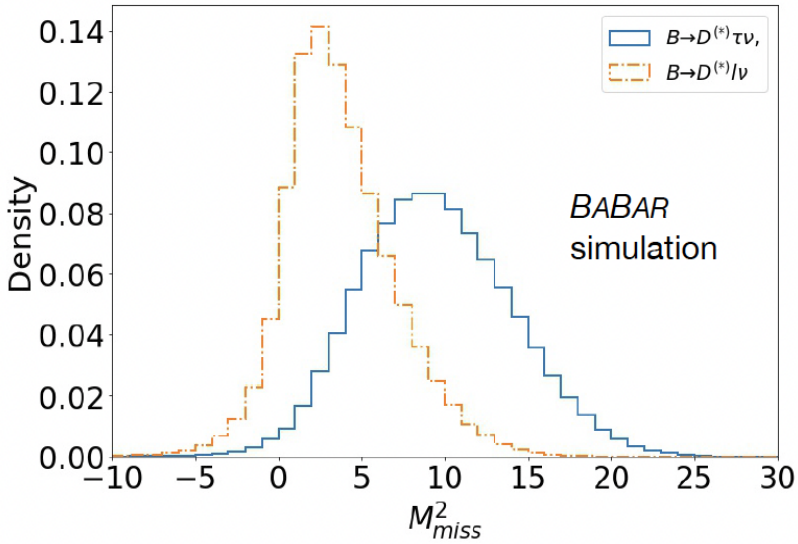
Classifier input variables





C1
24 input variables
Most discriminant
E_{extra} and lepton momentum



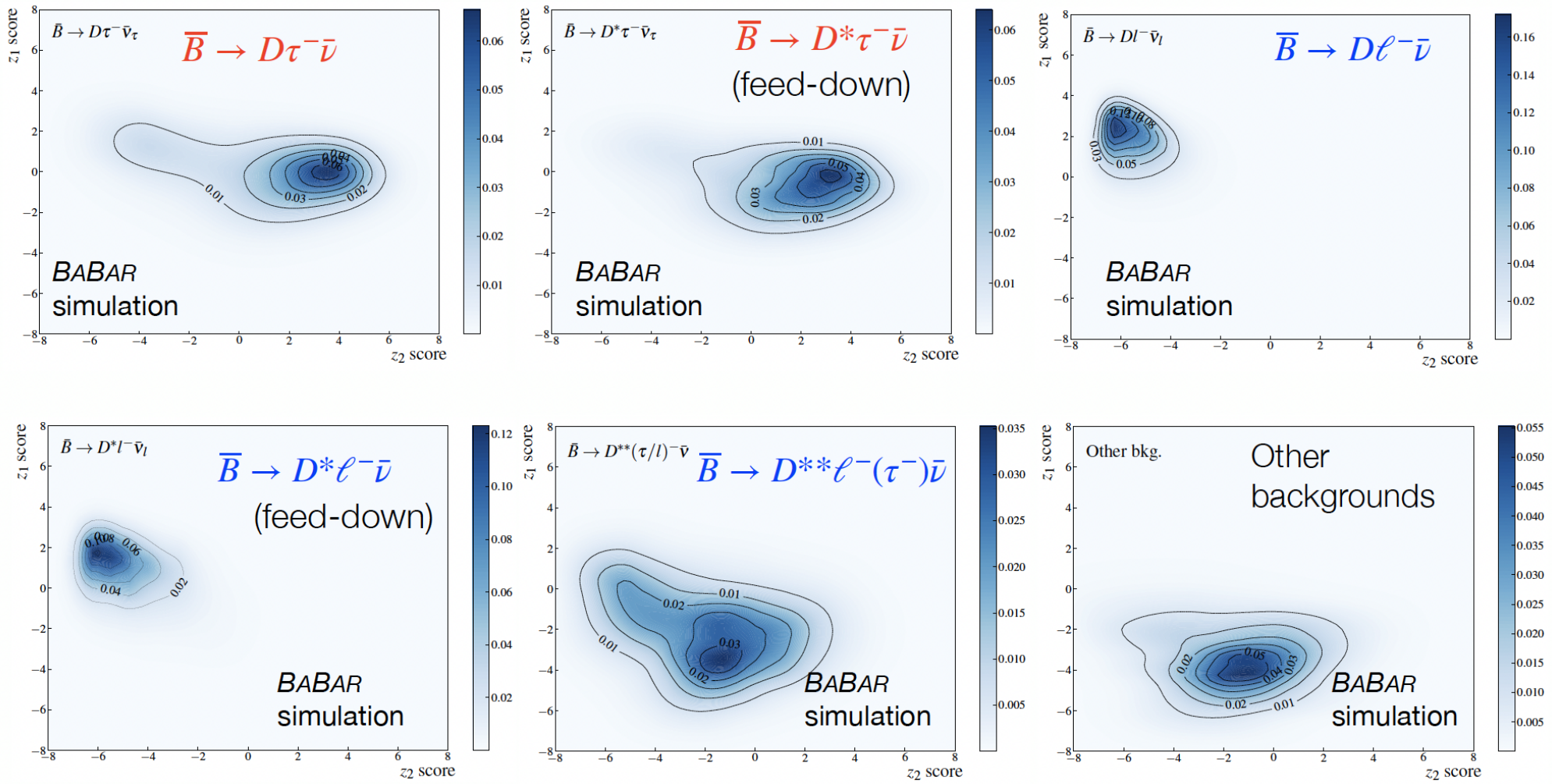


C2
26 input variables
Most discriminant
$\cos\theta_{BY}$ and M_{miss}^2

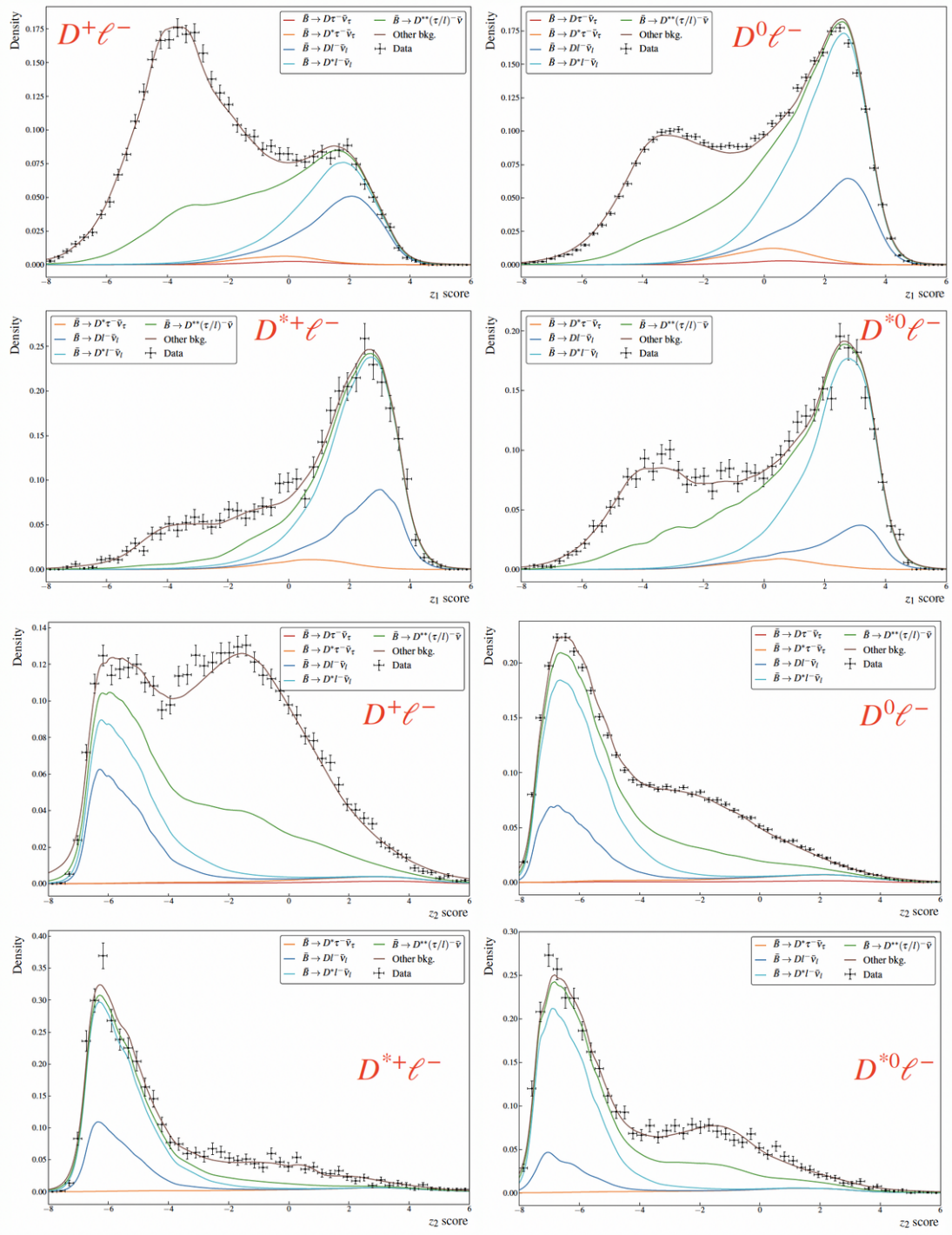
Signal extraction PDF

- The z_1 and z_2 component densities are smoothed through an adaptive kernel-density estimation (KDE) with local bandwidth adjusted to the event density

Example for $D^+\ell$ densities

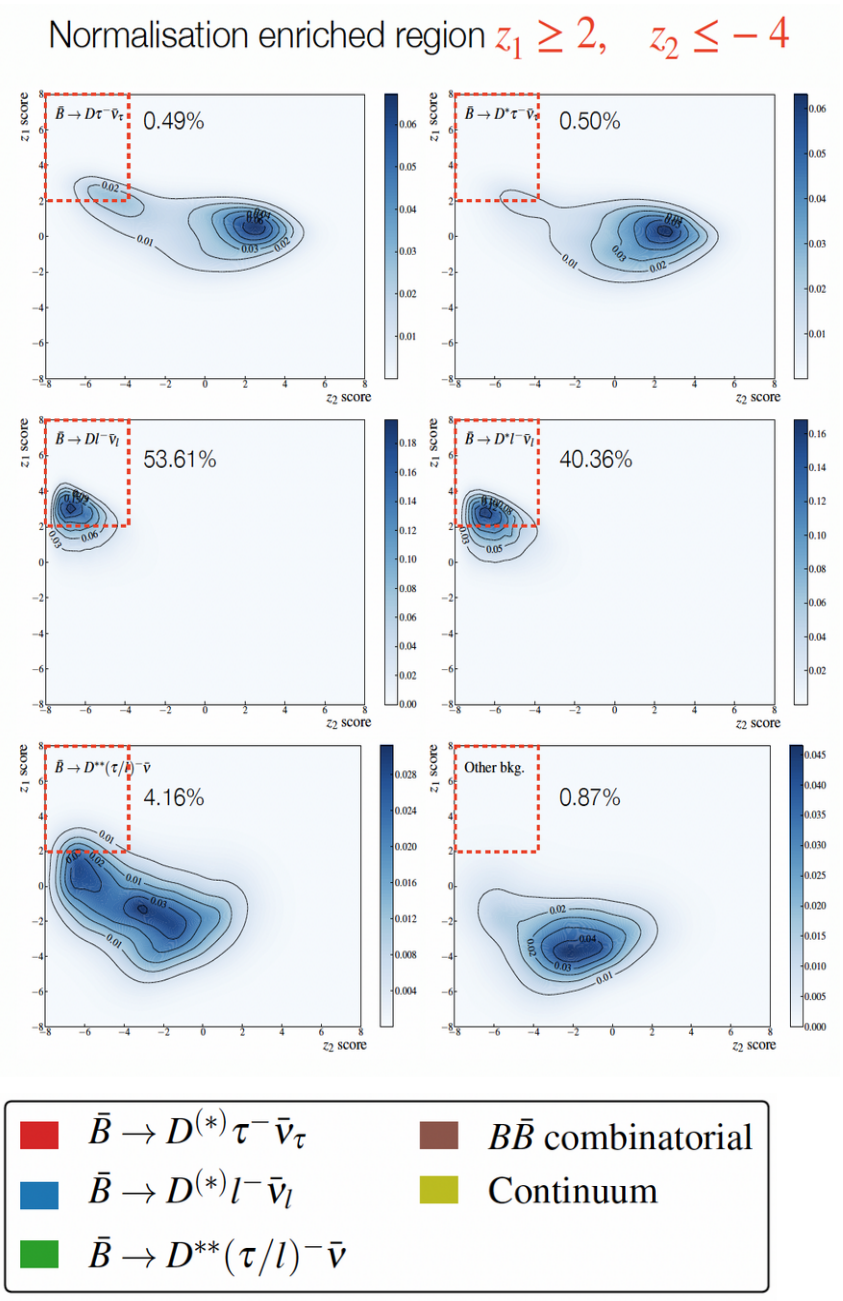


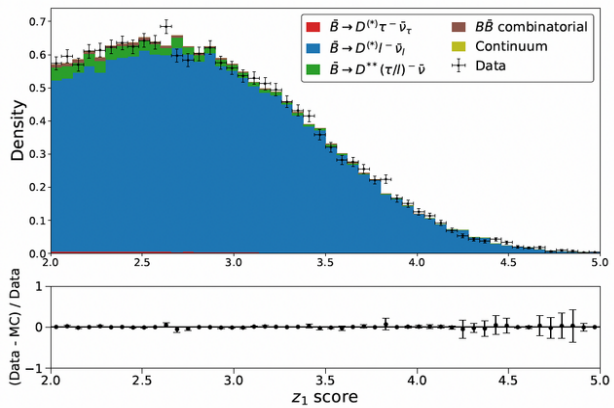
Projections on z_1 and z_2 of fit results

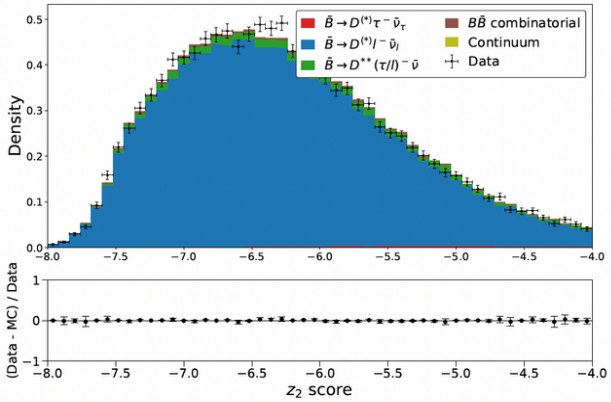


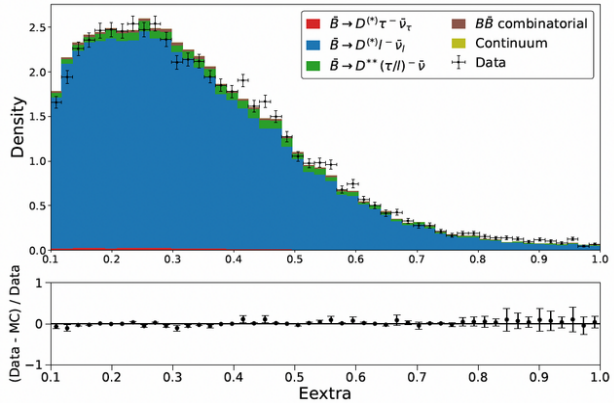
Subset	Component	Extracted Yield
D^+l	$B \to D\tau\nu$	117 ± 44
	$B \to D^*\tau\nu$	191 ± 57
	$B \to Dl\nu$	1965 ± 110
	$B \to D^*l\nu$	1261 ± 146
	$B \to D^{**}l\nu$	3248 ± 233
	Other Bkgs	7258 ± 182
D^0l	$B \to D\tau\nu$	726 ± 273
	$B \to D^*\tau\nu$	2452 ± 285
	$B \to Dl\nu$	12012 ± 555
	$B \to D^*l\nu$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

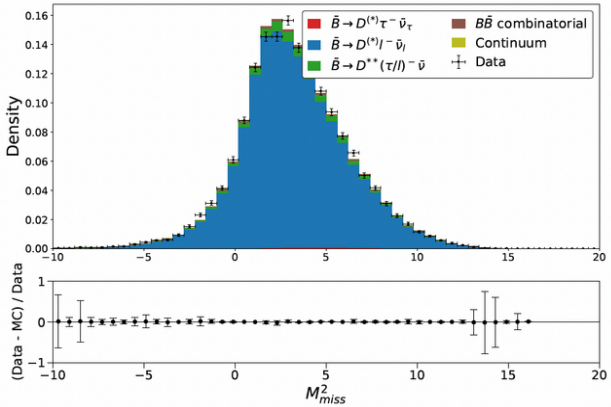
Data/MC validation for normalization

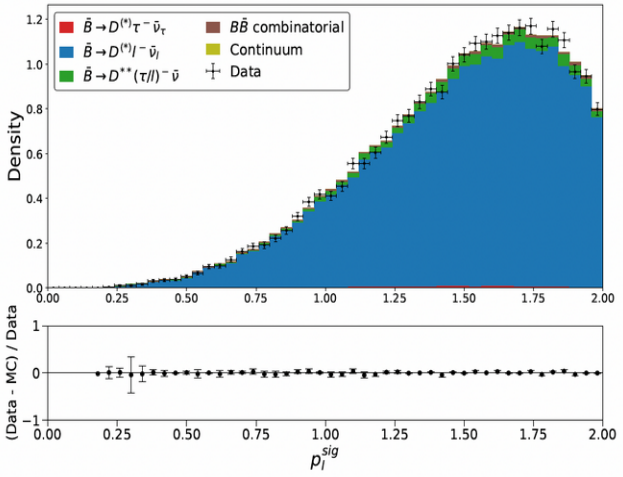


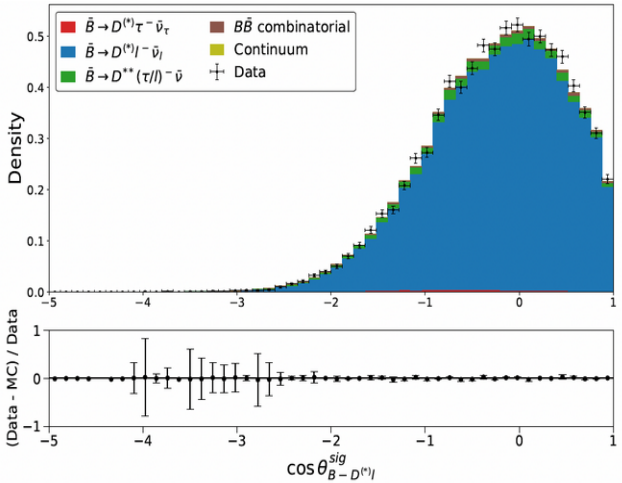






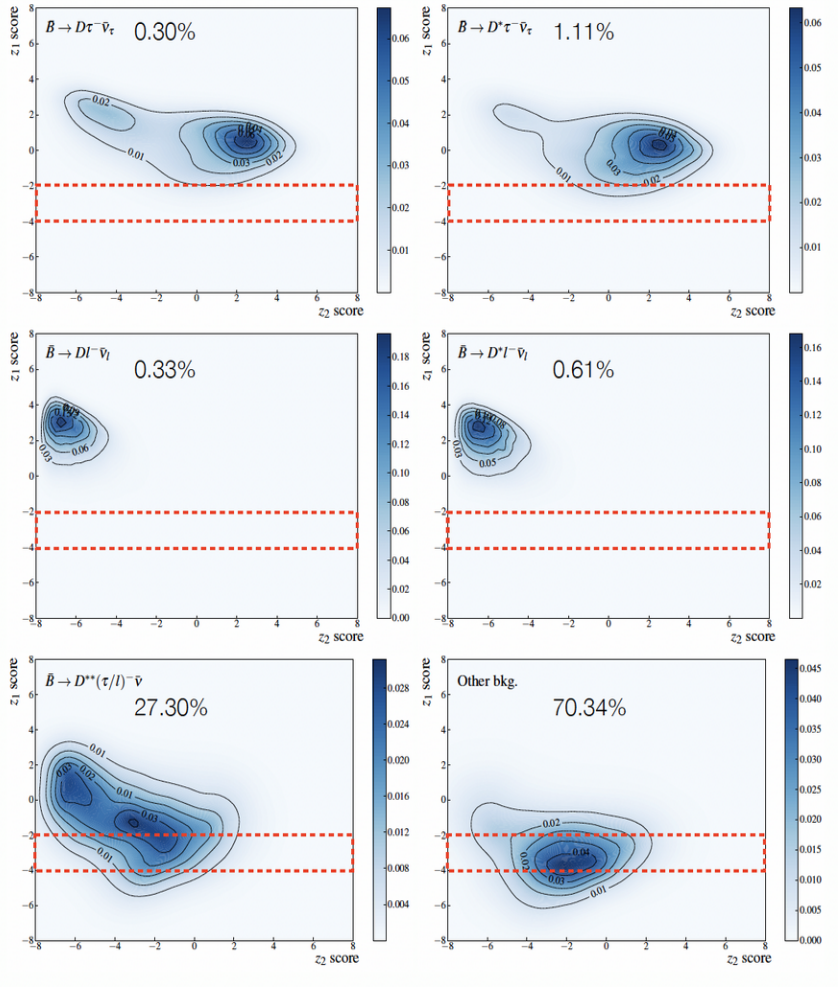


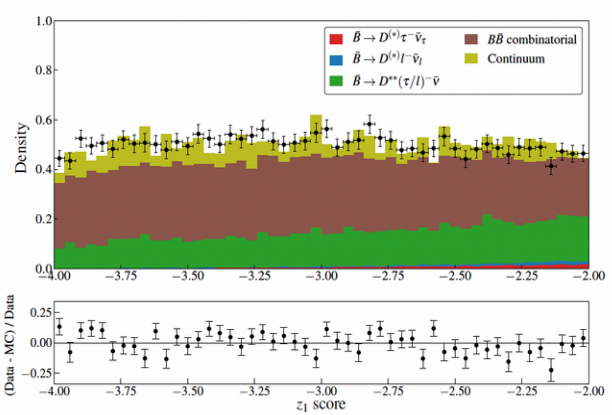


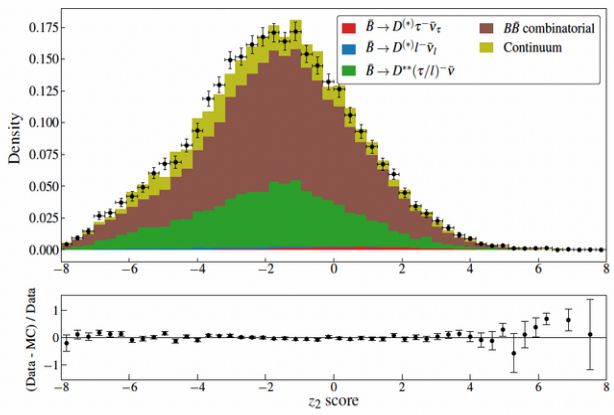


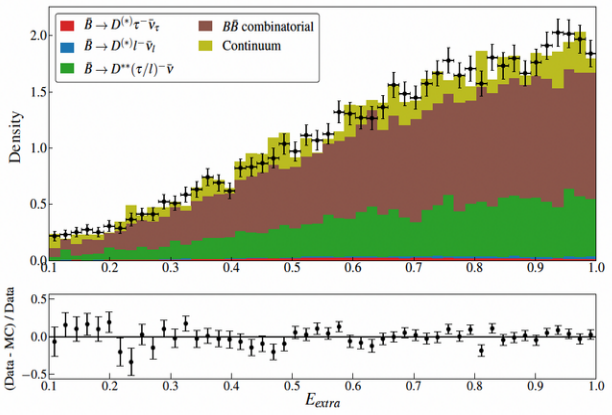
Data/MC validation for background

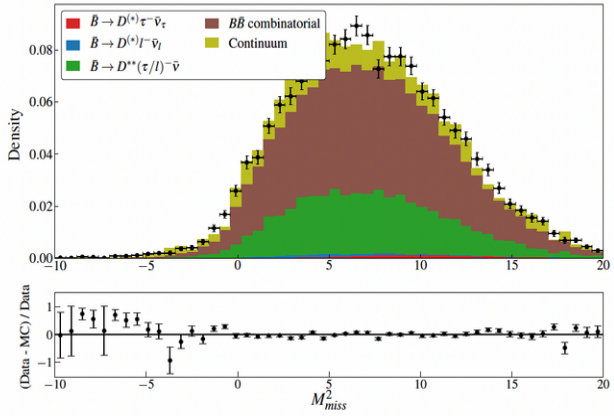
Background-enriched region $-4 \leq z_1 \leq -2$

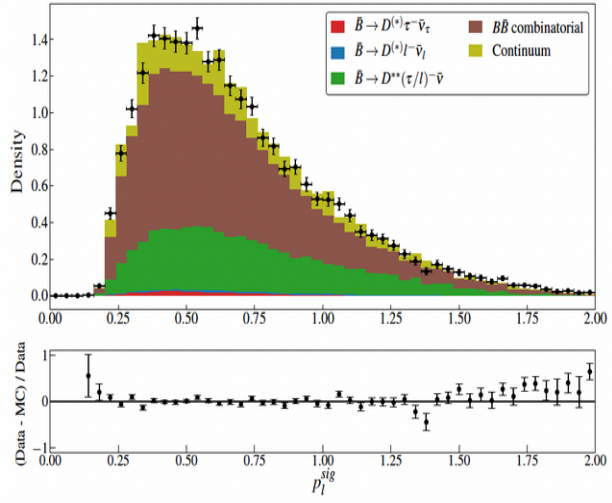


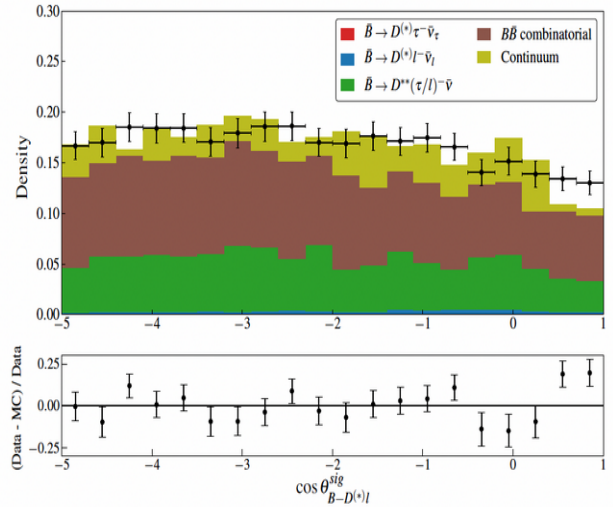






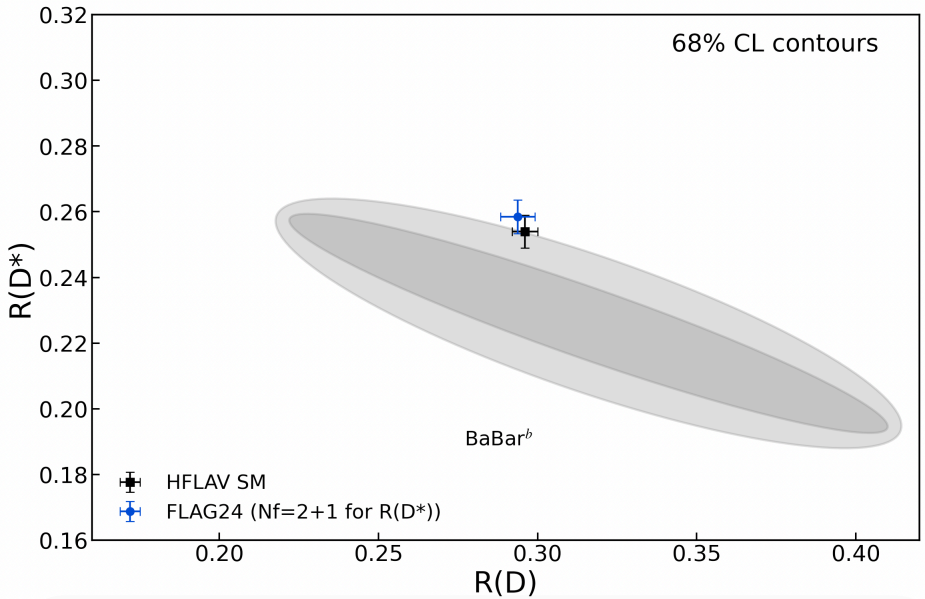






Result (& systematics)

$$\mathcal{R}(D) = 0.316 \pm 0.062 \pm 0.019$$
$$\mathcal{R}(D^*) = 0.226 \pm 0.022 \pm 0.012$$
$$\rho = -0.82$$



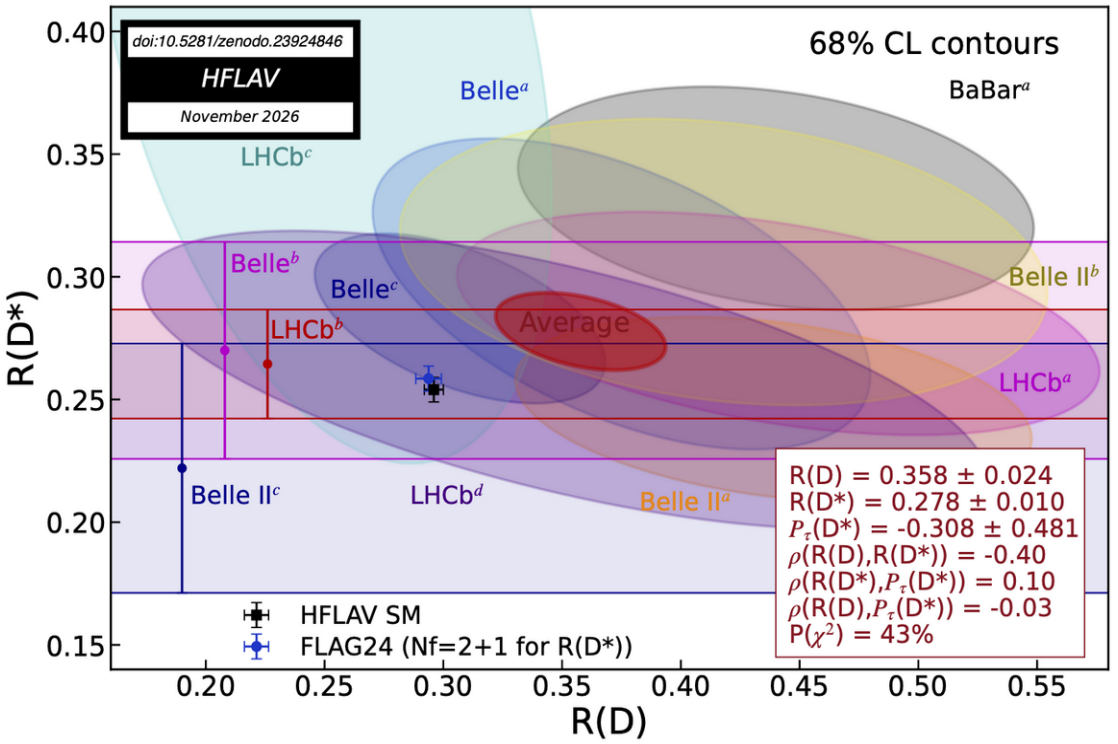
Source	$\Delta R(D)$ (%)	$\Delta R(D^*)$ (%)	Correlation
$B \to Dl\nu$ form factor	0.42	0.13	-0.18
$B \to D^*l\nu$ form factor	0.92	0.31	-0.19
$B \to D^{**}l\nu$ form factor	0.48	0.18	-0.90
$\mathcal{B}(B \to D^{(*)}l\nu)$	0.47	0.38	0.97
$\mathcal{B}(b \to c\bar{c})$	0.34	0.13	1
$\mathcal{B}(B \to D^{**}l\nu)$	2.83	1.60	-0.97
$\mathcal{B}(D)$	0.84	0.70	-0.40
MC statistics	4.12	4.37	-0.15
On-peak bkg. 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
$\mathcal{B}(\tau \to l^-\bar{\nu}_l\nu_\tau)$	0.16	0.16	1
Total	5.86	4.96	-0.20

World Average

HFLAV November 2026

R(D) = 0.358 ± 0.024
R(D*) = 0.278 ± 0.010
Pτ(D*) = -0.31 ± 0.48
$\rho_{RD\text{-}RD^*}$ = -0.40

3.4σ from SM



World Average

[HFLAV November 2026]

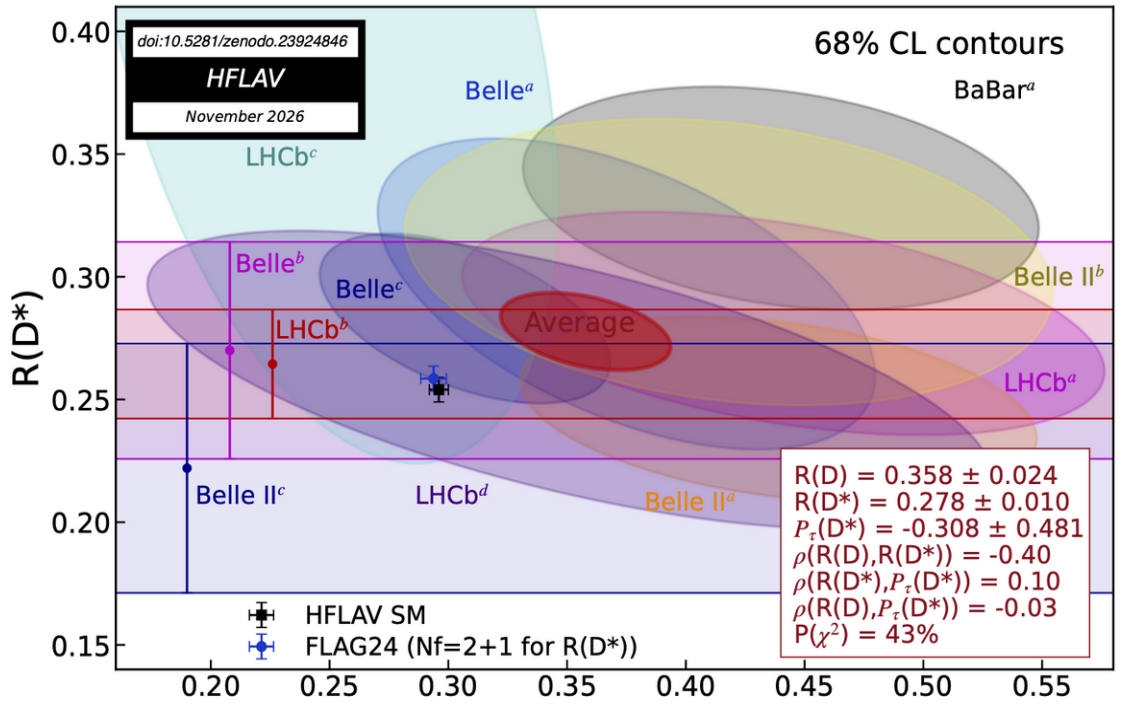
$R(D) = 0.358 \pm 0.024$
$R(D^*) = 0.278 \pm 0.010$
$P\tau(D^*) = -0.31 \pm 0.48$
$\rho_{RD\text{-}RD^*} = -0.40$

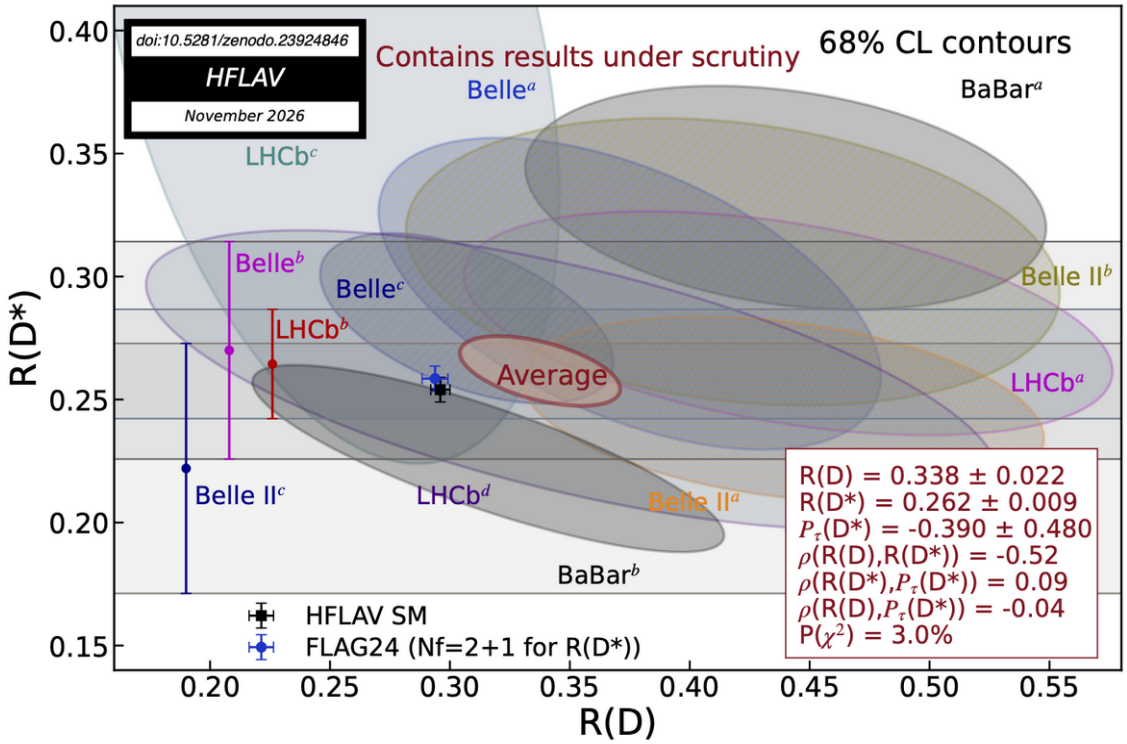
3.4σ from SM

$R(D) = 0.338 \pm 0.022$
$R(D^*) = 0.262 \pm 0.009$
$P\tau(D^*) = -0.39 \pm 0.48$
$\rho_{RD\text{-}RD^*} = -0.52$

1.8σ from SM

Including this BaBar result, the average p-value drops from 43% to 3%





Summary

- New preliminary simultaneous measurement of R(D) and R(D*) from BaBar with SL tagging
- Significant impact on global average: reduced tension with the SM
- Compatibility with BaBar12 is at the p~ 1.4×10^{-4} level

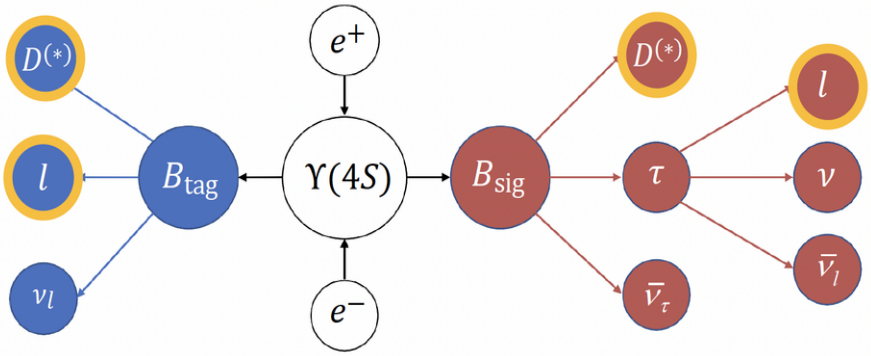
Summary

- New preliminary simultaneous measurement of R(D) and R(D*) from BaBar with SL tagging
- Significant impact on global average: reduced tension with the SM
- Compatibility with BaBar12 is at the p~ 1.4×10^{-4} level

- Status: post Internal Circulation, several additional cross checks to verify the results, a reevaluation of systematic uncertainties is ongoing
- Plan: finish the internal review and release the paper as soon as possible!

BACKUP

Event reconstruction



- Identify $K^{\pm}, \ell^{\pm}$ with loose PID criteria
- $\pi^0 \to \gamma\gamma$ candidates with mass ∈ [115, 150] MeV
- $K_s \to \pi^+\pi^-$ candidates with mass ∈ [472.67, 522.67] MeV
- D^0 and $D^{\pm}$ candidates:

Decay Modes	Branching Fraction (%)	
$D^+ \to K^-\pi^+\pi^+$	9.46 ± 0.24	~20%
$D^+ \to K_S\pi^+$	1.53 ± 0.06	
$D^+ \to K_S\pi^+\pi^0$	7.24 ± 0.17	
$D^+ \to K^-K^+\pi^+$	0.99 ± 0.026	
$D^0 \to K^-\pi^+$	3.88 ± 0.05	~30%
$D^0 \to K^-\pi^+\pi^0$	14.3 ± 0.80	
$D^0 \to K^-\pi^+\pi^-\pi^+$	8.06 ± 0.23	
$D^0 \to K_S\pi^+\pi^-$	2.85 ± 0.20	
$D^0 \to K_S\pi^0$	1.20 ± 0.04	
$D^0 \to K^-K^+$	0.40 ± 0.007	

Only τ decays into leptons $\tau \to \ell\nu\bar{\nu}$ $BF \simeq 35\,\%$

$$|m_D - \text{PDG}| \in \begin{cases} [-15, 15]\ \text{MeV}, & \text{no } \pi^0 \\ [-45, 30]\ \text{MeV}, & D^0 \to \pi^0 \\ [-36, 24]\ \text{MeV}, & D^+ \to \pi^0 \end{cases}$$

$$\left.\begin{matrix} D^{*+} \to D^0\pi^+, D^+\pi^0 \\ D^{*0} \to D^0\pi^0 \end{matrix}\right\} \quad |m_{D^*} - m_D - \text{PDG}| < \begin{cases} 2.5\ \text{MeV}, & D^0\pi^+ \\ 2.0\ \text{MeV}, & D\pi^0 \end{cases}$$

Check of BF(B → D(*)ℓνℓ)

- Since we simultaneously extract the signal and normalisation yield we can compare the normalisation *BF* with other result (a check not performed in previous $R(D^{(*)})$ measurements)
- Our fitted measurement of $BF(\overline{B} \to D^{(*)}\ell^- \bar{\nu}_\ell)$ does not agree with the WA:

Source	$\mathcal{B}(B \to D\ell\nu)$ (%)	$\mathcal{B}(B \to D^*\ell\nu)$ (%)	$\frac{\mathcal{B}(B\to D^*\ell\nu)}{\mathcal{B}(B\to D\ell\nu)}$
This analysis	1.36 ± 0.25	5.77 ± 0.28	4.24 ± 0.91
World average	2.16 ± 0.04	5.04 ± 0.11	2.33 ± 0.07
	-3.2σ	$+2.4\sigma$	$+2.1\sigma$

- If $BF(\overline{B} \to D^{(*)}\ell^- \bar{\nu}_\ell)$ is constrained to the WA in MC, the z_1, z_2 still look good, and $R(D^{(*)})$ change by only a few % (!)
- MC studies showed that this stability arises from the correlation pattern

