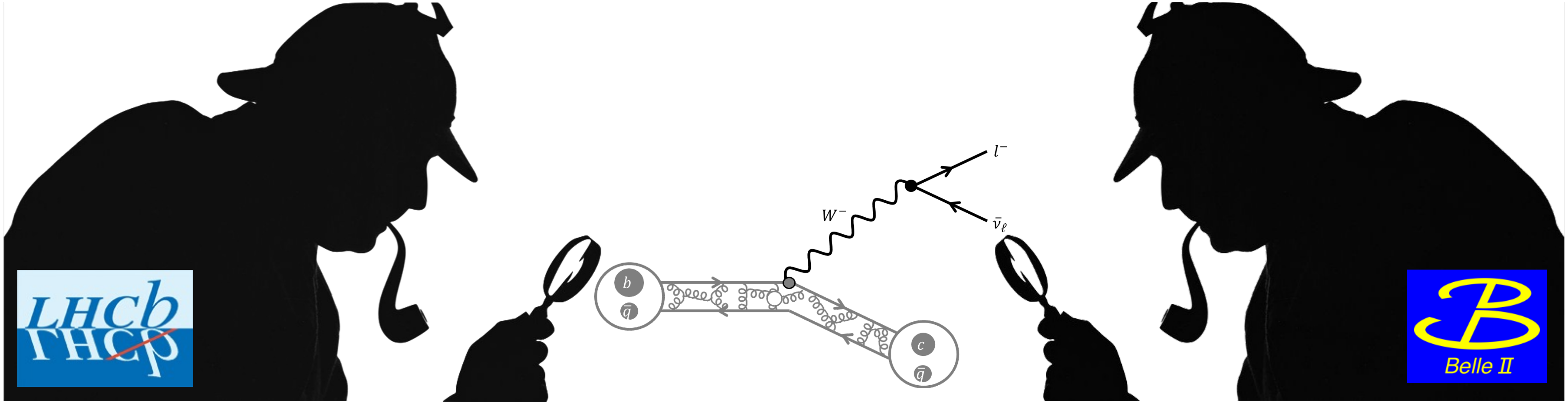
Status and prospects of RD(*) and related measurements

Beyond the flavour anomalies V

Patrick Owen

Markus Prim



Universität Zürich UZH

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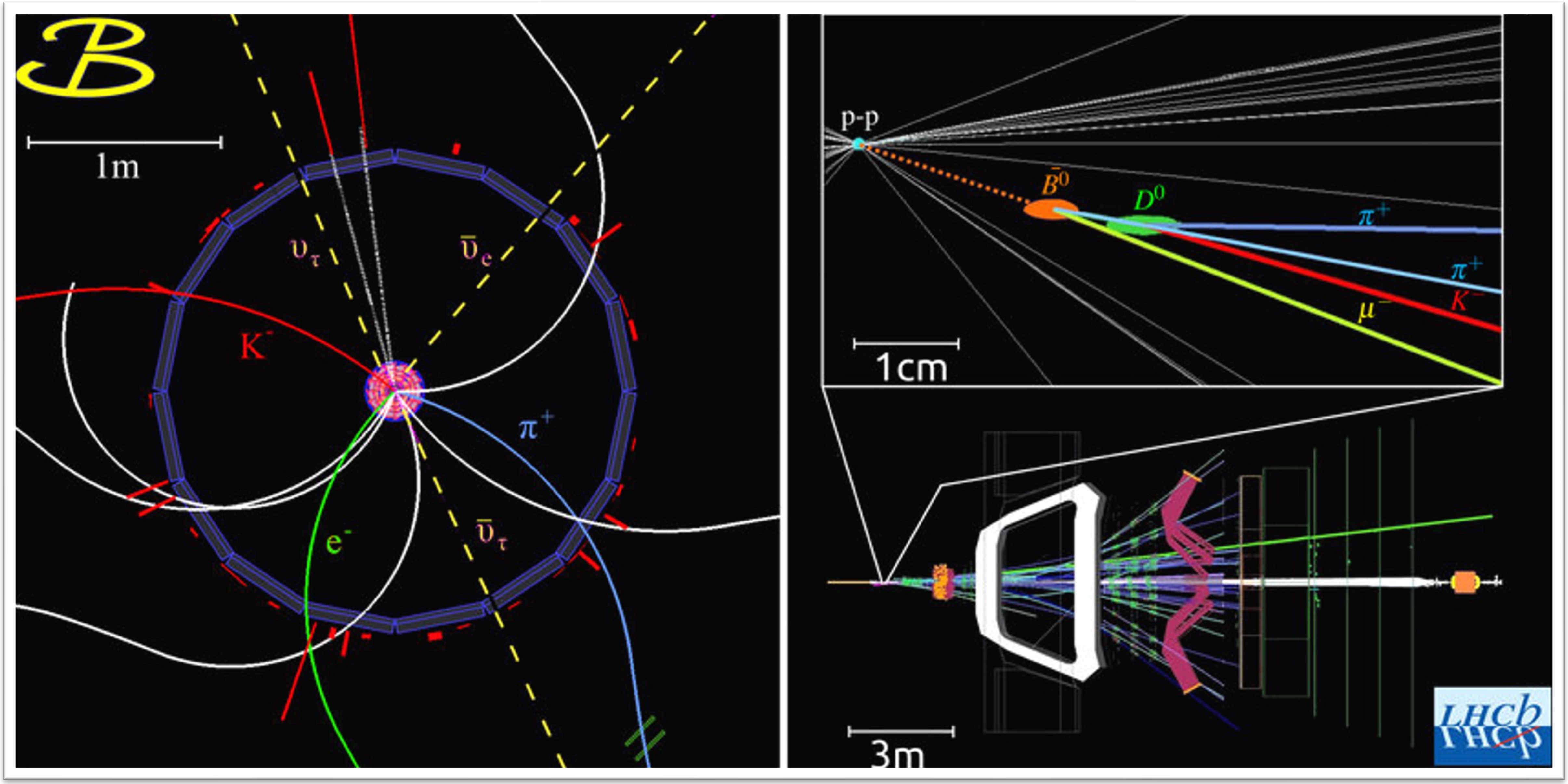

1m
υ_τ
$\bar{\upsilon}_e$
K^-
π^+
e^-
$\bar{\upsilon}_\tau$
p-p
$\bar{B}^0$
D^0
π^+
π^+
K^-
μ^-
1cm
3m

Teaming up for the hunt

Belle II

$R(D^{(*)})$	$R(X)$
Had. Tag $\tau \to \ell$	Had. Tag $\tau \to \ell$
Had. Tag $\tau \to \pi, \rho$	
SL Tag $\tau \to \ell$	
Incl. Tag $\tau \to \ell$	

LHCb

$R(D^{(*)})$	$R(J/\Psi)$	$R(\Lambda_c)$	$R(D_s^{(*)})$
$\tau \to \mu$	$\tau \to \mu$	$\tau \to \mu$	$\tau \to \mu$
$\tau \to 3\pi$	$\tau \to 3\pi$	$\tau \to 3\pi$	$\tau \to 3\pi$

The lepton flavor universality ratio in $b \to c\ell\overline{\nu}_\ell$ transitions can be accessed through various observables

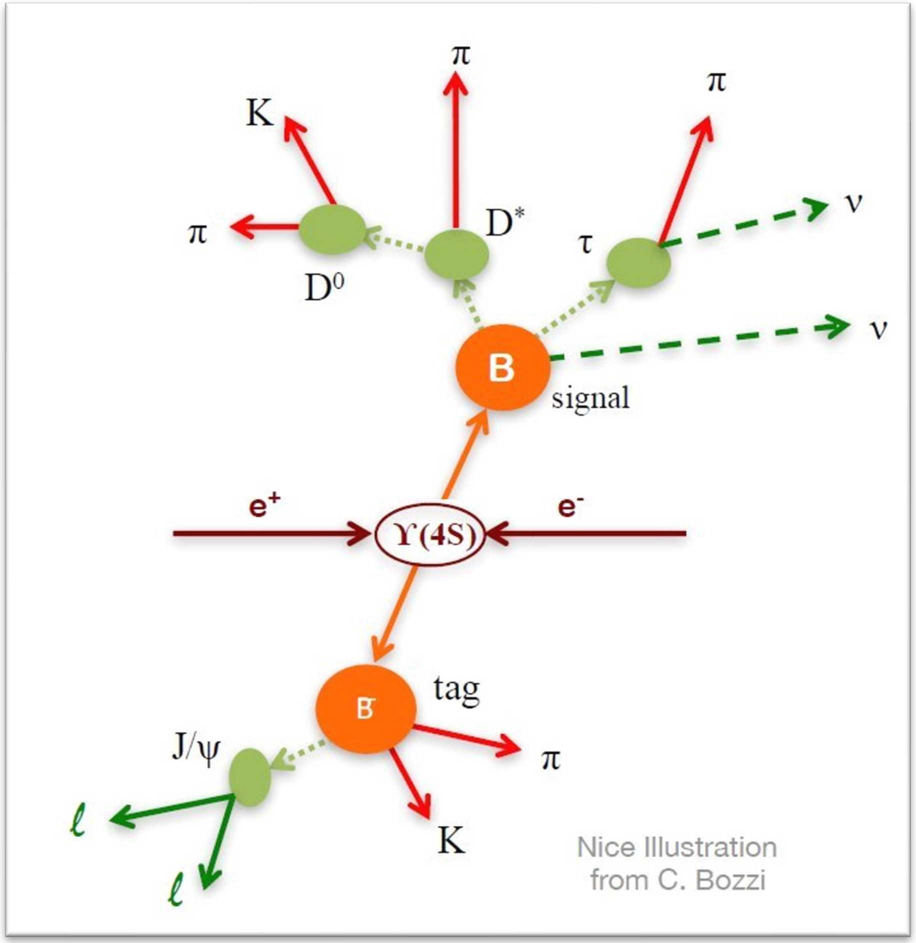
Let's start with the generic measurement ideas at Belle II and LHCb before going into analysis specifics

Food for thought: Combinations in global Wilson coefficient fits is something to be considered

Will highlight new $R(D^+)$ result presented by Julian at Moriond EW

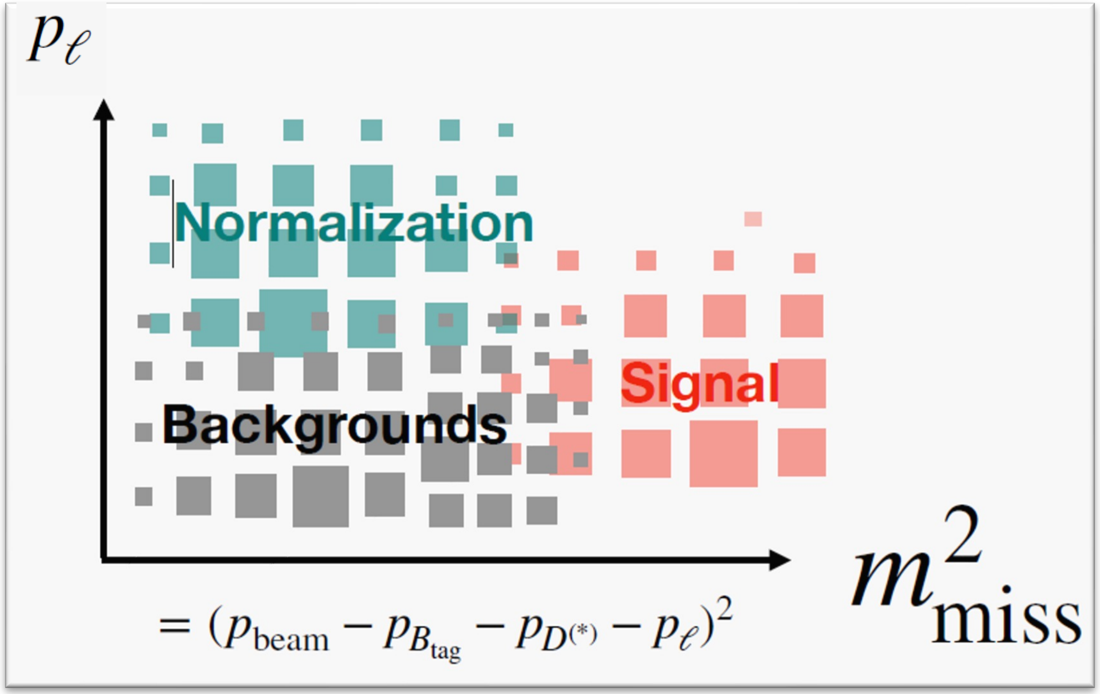
Semileptonic Decays at B-Factories

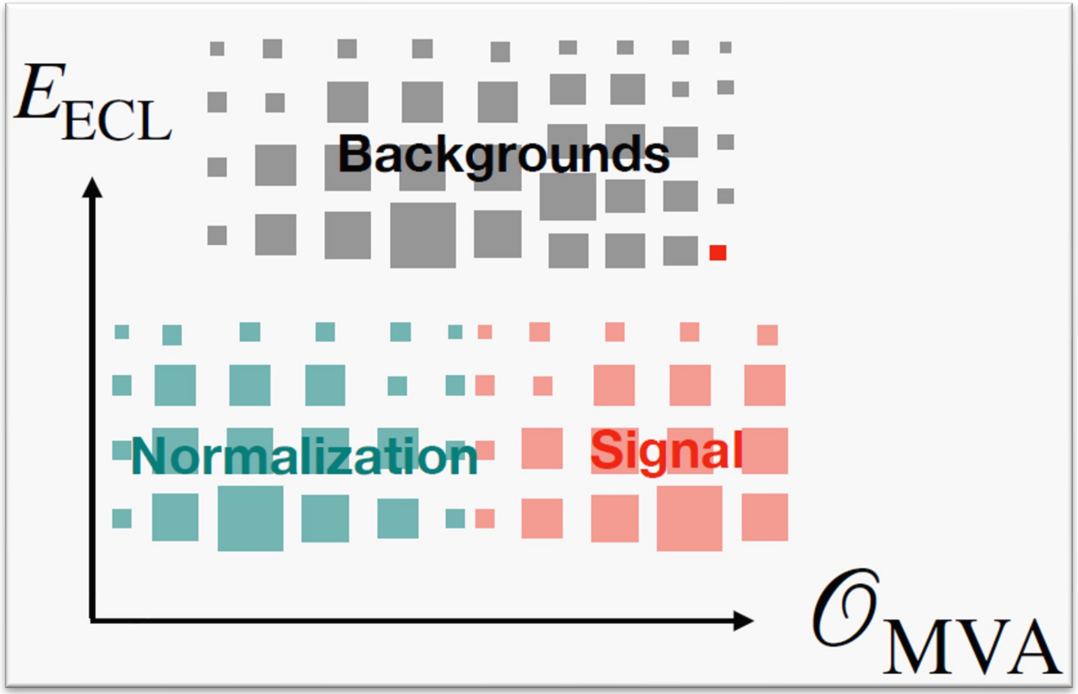
- e^+e^--collision produces $\Upsilon(4S) \to B\bar{B}$
- Fully reconstruct the tag-side B meson $\to$ gives access to signal-side B meson kinematics
- Missing four-momentum (neutrino mass) can be reconstructed
- All measured particles are assigned (completeness)
- Caveat: Small efficiency of the tagging algorithms



Generic Strategy at B-Factories

- **3-class classification problem:** signal, normalization, background
- Normalization chosen to cancel systematics (same topology and/or final state)



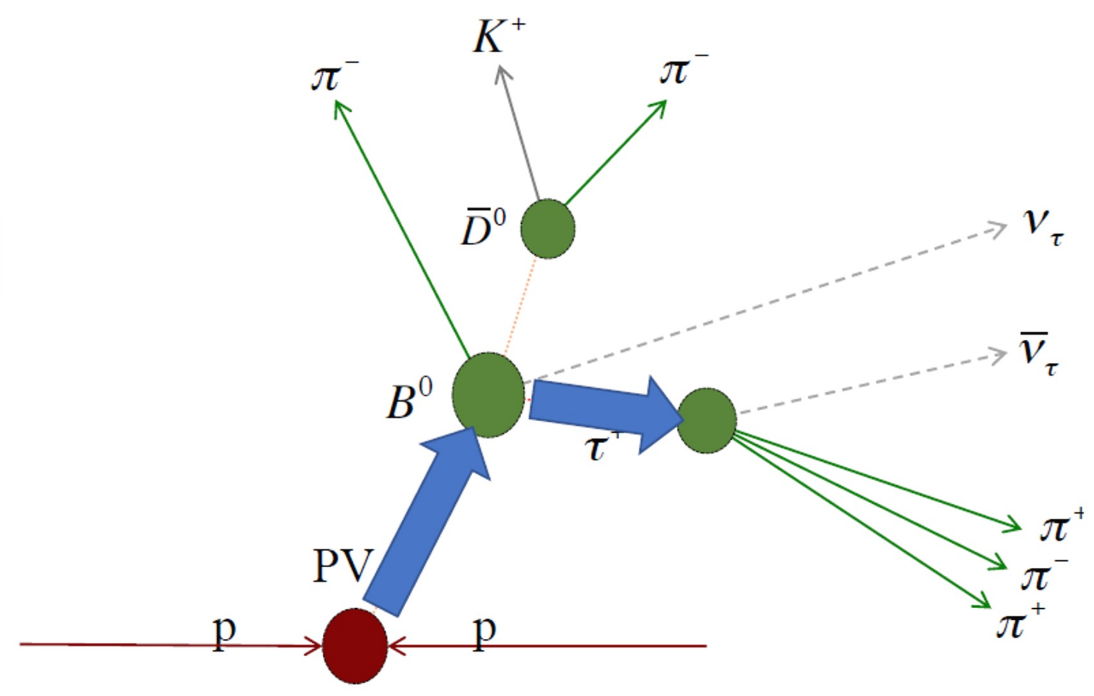


Nice illustration by F. Bernlochner

Leverage **fully known kinematics** and that **each reconstructed particle is assigned** to a decay

Semileptonic Decays at LHCb

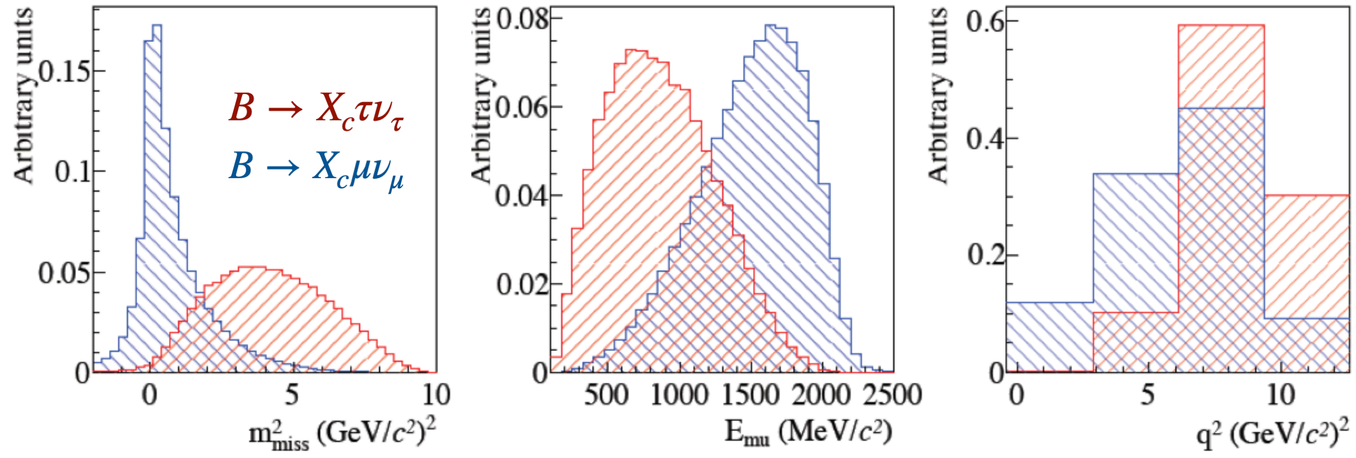
- No constraint from beam energy, but large Lorentz boost resulting in mm decay lengths.
- Well separated vertices.
- Momentum direction of decaying particle is well known from vertices.
- Two τ decay modes analysed:
  - $\tau \rightarrow \mu\nu\nu\nu$: large yields low purity.
  - $\tau \rightarrow 3\pi\nu$: lower yields higher purity.



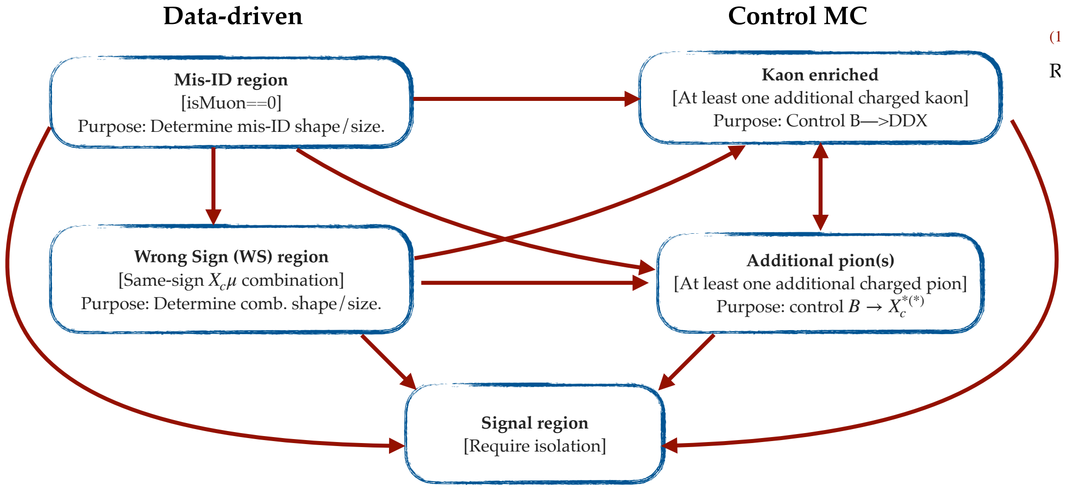
Nice Illustration from C. Bozzi

$\tau \to \mu$ strategy

- 3D fit in q^2, m_{miss}^2 and E_l^*.

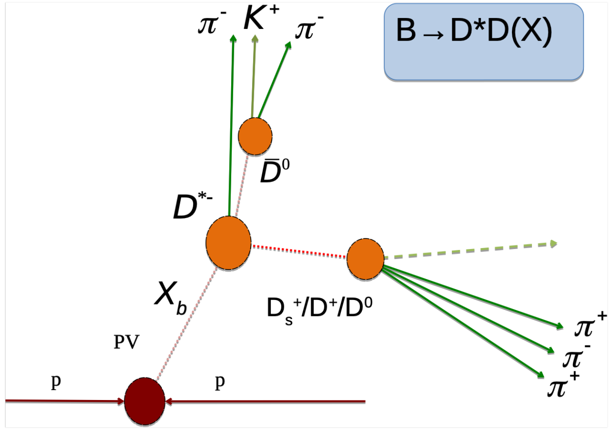


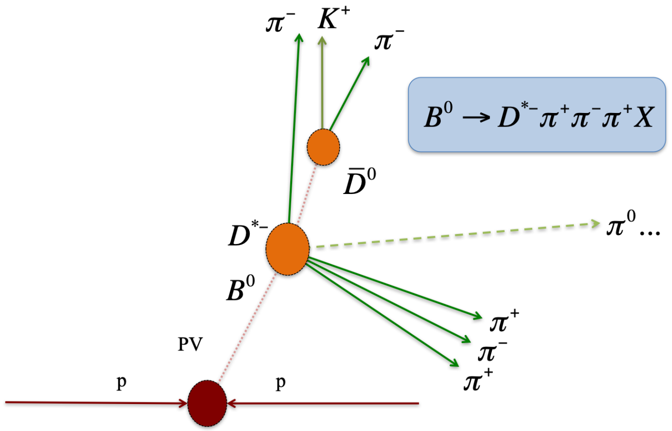
- Form factors floated in fit to data.
- Backgrounds rejected and controlled via track isolation.
- Special treatment of misID background.



$\tau \to 3\pi$ strategy

- 3D fit in q^2 τ decay time and BDT output.
- Key selection to reject $B \to D^*\pi^+\pi^-\pi^+X$ background.





- No direct normalisation to semimuonic mode:

$$\mathcal{K}(D^*) = \frac{\mathcal{B}(B^0 \to D^{*-}\tau^+\nu_\tau)}{\mathcal{B}(B^0 \to D^{*-}3\pi^\pm)} \qquad R(D^*) = \mathcal{K}(D^*)\left\{\frac{\mathcal{B}(B^0 \to D^{*-}3\pi^\pm)}{\mathcal{B}(B^0 \to D^{*-}\mu^+\nu_\mu)}\right\}$$

- Smaller yields but higher purity compared to leptonic mode.

A History of Measurements

Had. Tag
$\tau \to \ell$

Belle, Phys.Rev.D 92, 072014 (2015)

$$R(D) = 0.375 \pm 0.064 \pm 0.026$$
$$R(D^*) = 0.293 \pm 0.038 \pm 0.015$$

SL Tag
$\tau \to \ell$

Belle, Phys. Rev. Lett. 124, 161803 (2020)

$$R(D) = 0.307 \pm 0.037 \pm 0.016$$
$$R(D^*) = 0.283 \pm 0.018 \pm 0.014$$

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BaBar, Phys.Rev.D 88, 072012 (2013)

$$R(D) = 0.440 \pm 0.058 \pm 0.042$$
$$R(D^*) = 0.332 \pm 0.024 \pm 0.018$$

Had. Tag
$\tau \to \pi, \rho$

Belle, Phys. Rev. D 97, 012004 (2018)

$$P_\tau(D^*) = -0.38 \pm 0.51 \pm^{0.21}_{0.16}$$
$$R(D^*) = 0.270 \pm 0.035 \pm^{0.028}_{0.025}$$

And the Start of a New Era

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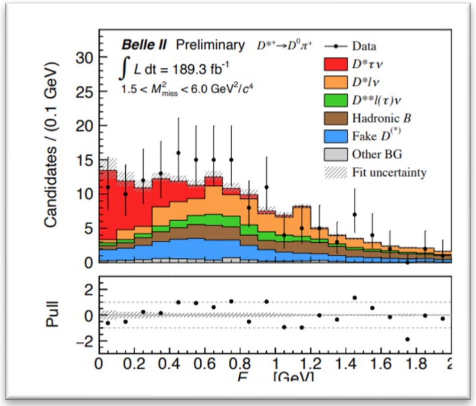
Had. Tag
$\tau \to \ell$

Belle II, arXiv:2401.02840

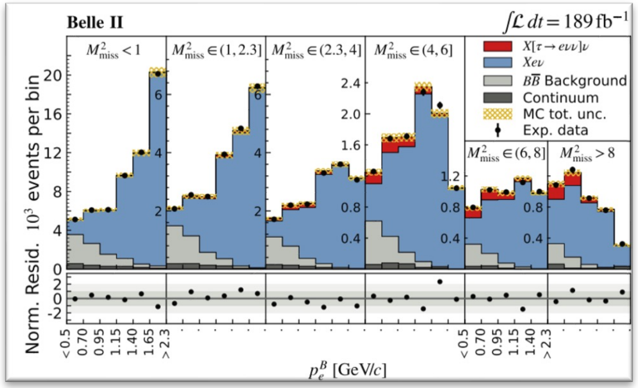
$$R(D^*) = 0.262 \pm^{0.041}_{0.039} \pm^{0.035}_{0.032}$$



Had. Tag
$\tau \to \ell$

Belle II, arXiv:2311.07248

$$R(X) = 0.228 \pm 0.016 \pm 0.036$$



LHCb measurements

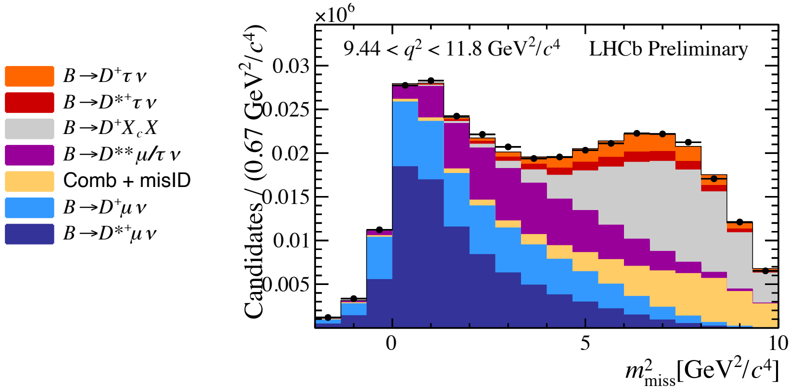
2015
$\tau \to \ell$

Phys. Rev. Lett. 115 (2015) 111803
$R(D^*) = 0.336 \pm 0.027 \pm 0.030$

Superseeded by:

2023
$\tau \to \ell$

Phys. Rev. Lett. 131 (2023) 111802
$R(D) = 0.281 \pm 0.018 \pm 0.024$
$R(D^*) = 0.441 \pm 0.060 \pm 0.066$



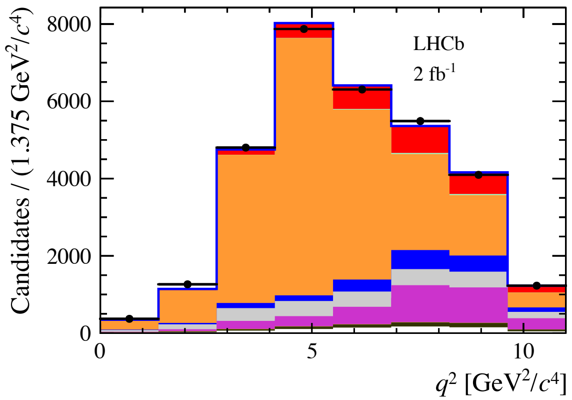
2017
$\tau \to 3\pi$

Phys. Rev. Lett. 120, 171802
Phys. Rev. D 97, 072013
$R(D^*) = 0.291 \pm 0.019 \pm 0.026 \pm 0.013$

Combined with:

2023
$\tau \to 3\pi$

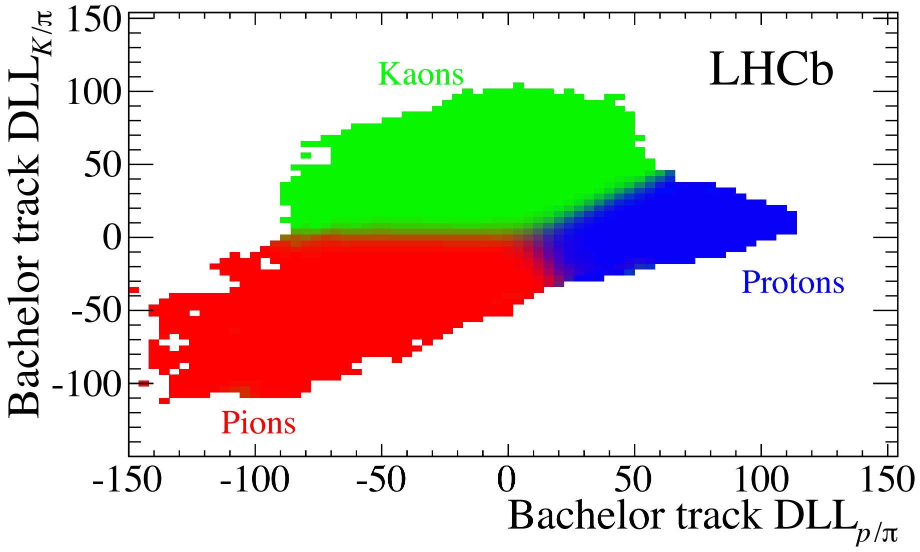
Phys. Rev. D108 (2023) 012018
$R(D^*) = 0.247 \pm 0.015 \pm 0.015 \pm 0.012$



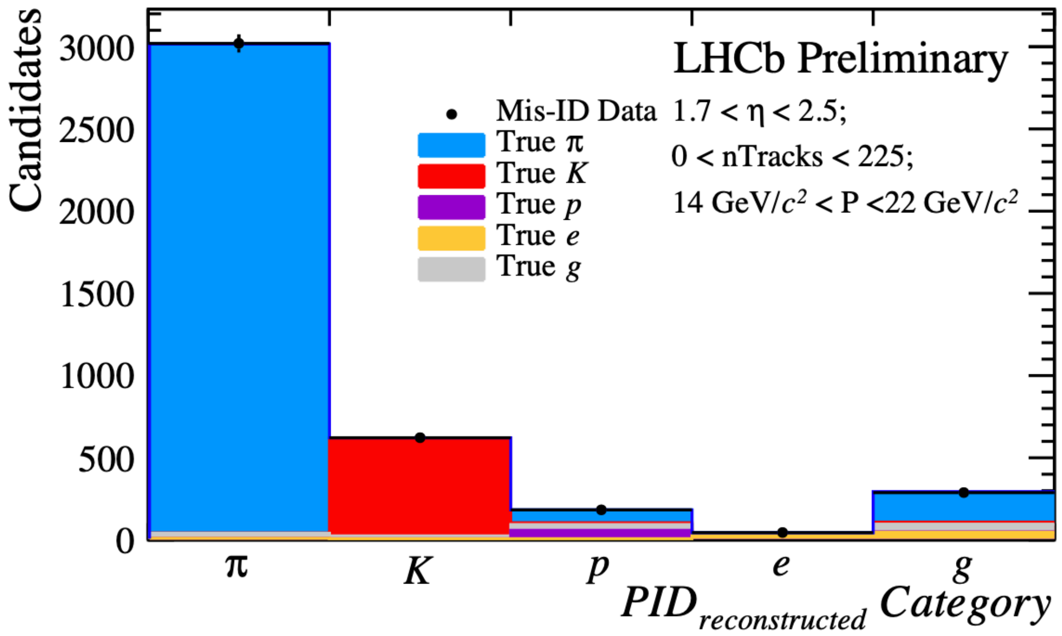
Challenges: Misidentified muons

- Background from $B \to D^{(*)}hX$ a serious challenge to control at LHCb.
- Problem: Multiple sources which cannot be predicted or specifically measured.
- Solution: Reverse offline/trigger muon ID to select inclusive sample in data.
- Problem: Multiple different track types each with each $h \to \mu$ probabilities.
- Solution: Split sample into different track categories and fit them.

LHCb-PAPER-2013-063



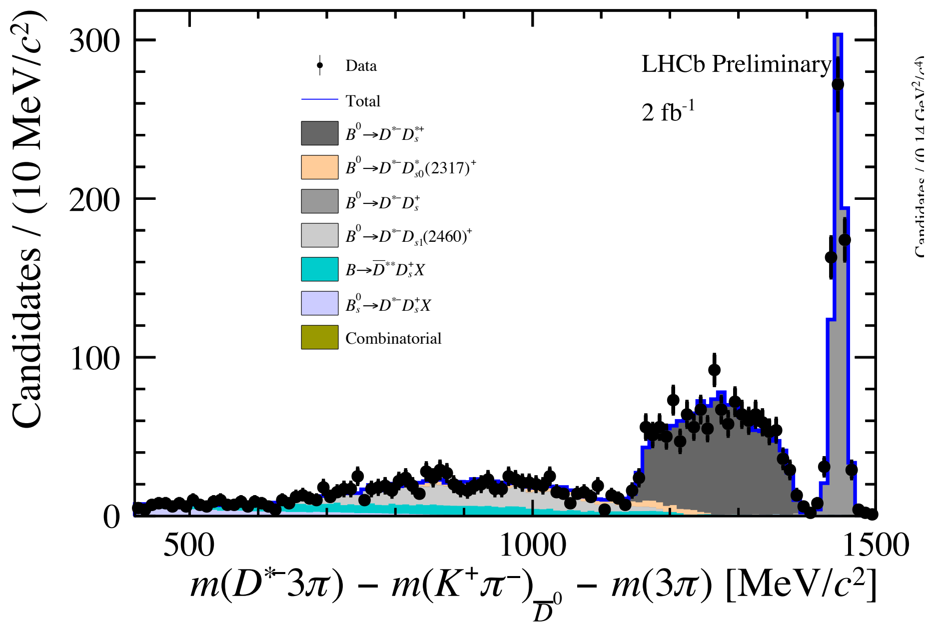
LHCb-PAPER-2024-007



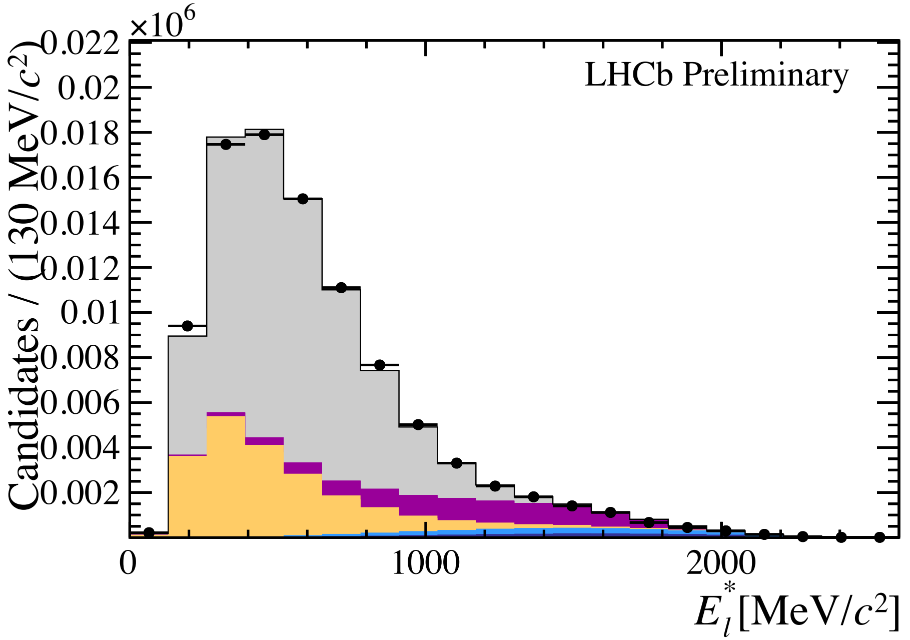
Challenges: $B \to DDX$ background

- Most signal like background originates from $B \to DDX$ decays.
  - Charm hadrons have similar lifetime and mass.

LHCb three-prong analysis: arXiv:2311.05224



$R(D^+)$ analysis: LHCb-PAPER-2024-007



- Allow for independent variation of this background in latest $R(D^+)$ analysis.

- Less of a problem at Belle II.

Challenges: Form Factors

Result	Experiment	τ decay	Tag	Systematic uncertainty [%] MC stats	$D^{(*)}l\nu$	$D^{**}l\nu$	Other bkg.	Other sources	Total uncert. [%] Syst.	Stat.	Total
$\mathcal{R}(D)$	*BABAR* [a]	$\ell\nu\nu$	Had.	5.7	2.5	5.8	3.9	0.9	**9.6**	**13.1**	**16.2**
	Belle[b]	$\ell\nu\nu$	Semil.	4.4	0.7	0.8	1.7	3.4	**5.2**	**12.1**	**13.1**
	Belle[c]	$\ell\nu\nu$	Had.	4.4	3.3	4.4	0.7	0.5	**7.1**	**17.1**	**18.5**
$\mathcal{R}(D^*)$	*BABAR* [a]	$\ell\nu\nu$	Had.	2.8	1.0	3.7	2.3	0.9	**5.6**	**7.1**	**9.0**
	Belle[b]	$\ell\nu\nu$	Semil.	2.3	0.3	1.4	0.5	4.7	**4.9**	**6.4**	**8.1**
	Belle[c]	$\ell\nu\nu$	Had.	3.6	1.3	3.4	0.7	0.5	**5.2**	**13.0**	**14.0**
	Belle[d]	$\pi\nu$, $\rho\nu$	Had.	3.5	2.3	2.4	8.1	2.9	**9.9**	**13.0**	**16.3**
	LHCb[e]	$\pi\pi\pi(\pi^0)\nu$	—	4.9	4.0	2.7	5.4	4.8	**10.2**	**6.5**	**12.0**
	LHCb[f]	$\mu\nu\nu$	—	6.3	2.2	2.1	5.1	2.0	**8.9**	**8.0**	**12.0**

[a] (Lees *et al.*, 2012, 2013)
[b] (Caria *et al.*, 2020) [c] (Huschle *et al.*, 2015) [d] (Hirose *et al.*, 2018) [e] (Aaij *et al.*, 2015c) [f] (Aaij *et al.*, 2018b)

F. Bernlochner, M. Franco Sevilla, D. Robinson, G. Wormser
arXiv:2101.08326, Review of Modern Physics

Source	Uncertainty
PDF shapes	$^{+9.1\%}_{-8.3\%}$
Simulation sample size	$^{+7.5\%}_{-7.5\%}$
$\overline{B} \to D^{**}\ell^-\overline{\nu}_\ell$ branching fractions	$^{+4.8\%}_{-3.5\%}$
Fixed backgrounds	$^{+2.7\%}_{-2.3\%}$
Hadronic B decay branching fractions	$^{+2.1\%}_{-2.1\%}$
Reconstruction efficiency	$^{+2.0\%}_{-2.0\%}$
Kernel density estimation	$^{+2.0\%}_{-0.8\%}$
Form factors	$^{+0.5\%}_{-0.1\%}$
Peaking background in ΔM_{D^*}	$^{+0.4\%}_{-0.4\%}$
$\tau^- \to \ell^-\nu_\tau\bar{\nu}_\ell$ branching fractions	$^{+0.2\%}_{-0.2\%}$
$R(D^*)$ fit method	$^{+0.1\%}_{-0.1\%}$
Total systematic uncertainty	$^{+13.5\%}_{-12.3\%}$

Belle II $R(D^*)$
arXiv:2401.02840

Source	Uncertainty [%] e	μ	ℓ
Experimental sample size	8.8	12.0	7.1
Simulation sample size	6.7	10.6	5.7
Tracking efficiency	2.9	3.3	3.0
Lepton identification	2.8	5.2	2.4
$X_c\ell\nu$ M_X shape	7.3	6.8	7.1
Background (p_ℓ, M_X) shape	5.8	11.5	5.7
$X\ell\nu$ branching fractions	7.0	10.0	7.7
$X\tau\nu$ branching fractions	1.0	1.0	1.0
$X_c\tau(\ell)\nu$ form factors	7.4	8.9	7.8
Total	18.1	25.6	17.3

Belle II $R(X)$
arXiv:2311.07248

$B \to D^{(*)}\ell\overline{\nu}_\ell$ **form factors** impact the efficiency determination

- Lots of progress from lattice community:
  nonzero-recoil $B \to D^*$ form factors

  Fermilab/MILC arXiv:2105.14019 | HPQCD arXiv:2304.03137 | JLQCD arXiv:2306.05657

- Lots of progress from the experimental community:
  new Belle & Belle II measurements of $B \to D^{(*)}\ell\bar{\nu}_\ell$
  - differential distributions
  - angular coefficients

  Belle arXiv:2301.07529, PRD
  Belle II arXiv:2310.01170, PRD
  Belle arXiv:2310.20286

LHCb $R(D^+)$ LHCb-PAPER-2024-007

Source	$\mathcal{R}(D^+)$	$\mathcal{R}(D^{*+})$
Form factors	0.023	0.035
$B \to D^{**}[D^+X]\mu/\tau\nu$ fractions	0.024	0.025
$\overline{B}^{+/0} \to D^+X_cX$ fraction	0.020	0.034
Misidentification	0.019	0.012
Simulation size	0.009	0.030
Combinatorial background	0.005	0.020
Data/simulation agreement	0.016	0.011
Muon identification	0.008	0.027
Multiple candidates	0.007	0.017
Total systematic uncertainty	0.047	0.086

Challenges: Feeddown from $\bar{B} \to D^{**}\ell\bar{\nu}_\ell$

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Muon identification	0.008	0.027
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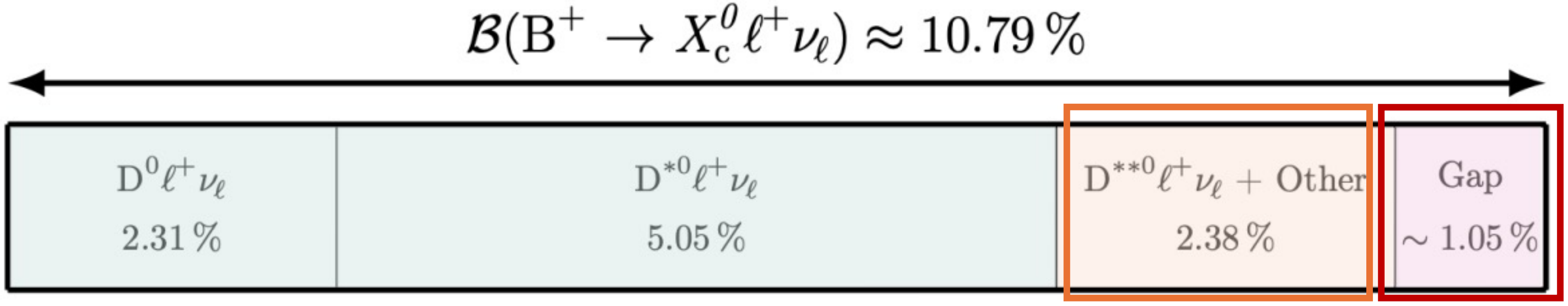
Sizeable systematic impact from $B \to D^{**}\ell\bar{\nu}_\ell$ decays

Challenges: Feeddown from $\bar{B} \to D^{**}\ell\bar{\nu}_\ell$



Discrepancies in the measurements of $B \to D^{**}\ell\bar{\nu}_\ell$

- Tension in the available measurements
- Tension with theory prediction: $^1/_2 \leftrightarrow {}^3/_2$ puzzle
- The nature of the D^{**} states is unclear

inclusive ≠ sum of exclusive

- These poorly understood components lead to a sizeable systematic effect in the experimental measurements
- Common for Belle II & LHCb

U.G. Meißner
arXiv:2005.06909, Symmetry

Challenges: Feeddown from $\bar{B} \to D^{**}\ell\bar{\nu}_\ell$

- Is the $D_0^*(2300)$ a resonance from the quark model, or a more complex structure described by $\boldsymbol{U\chi PT}$?
- Form factors for semileptonic $\bar{B} \to D^{**}\ell\bar{\nu}_\ell$ decays assume the narrow width approximation for the broad D^{**}

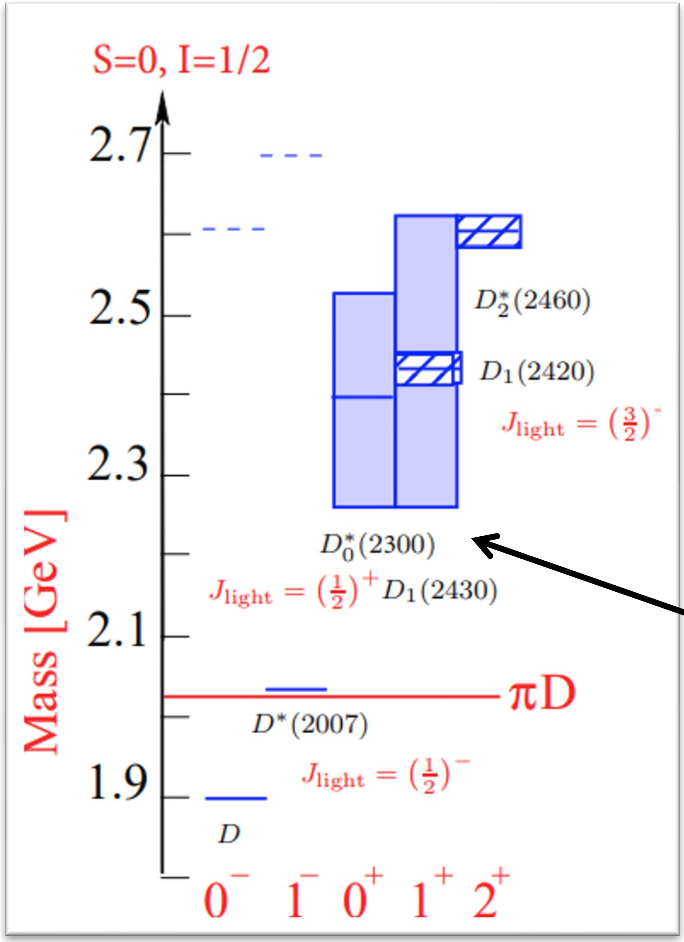
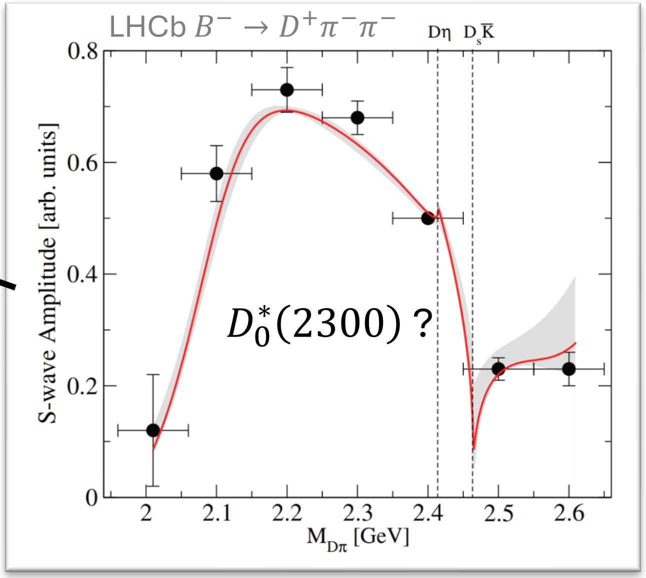
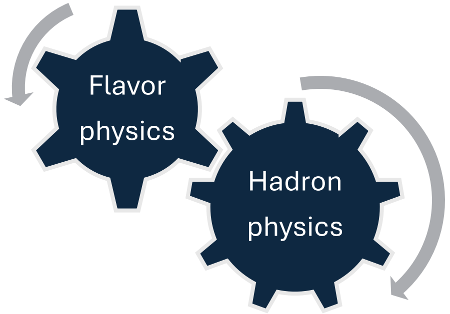


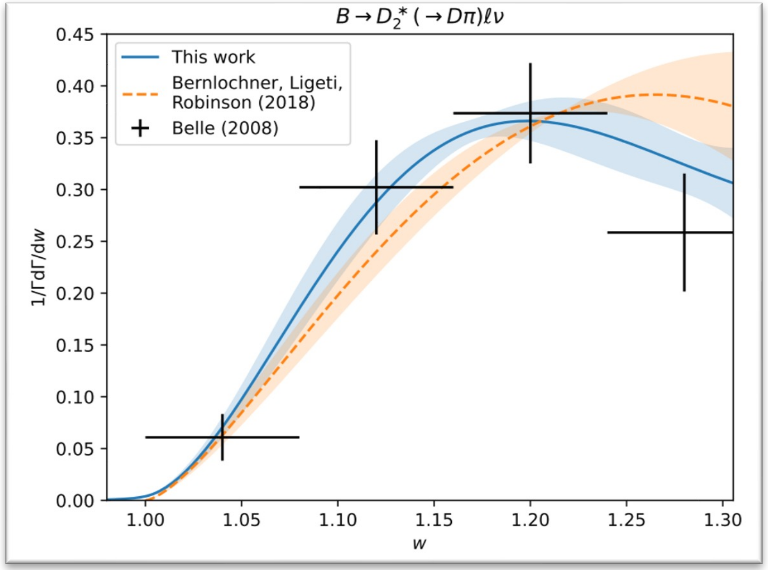
Illustration by C. Hanhart





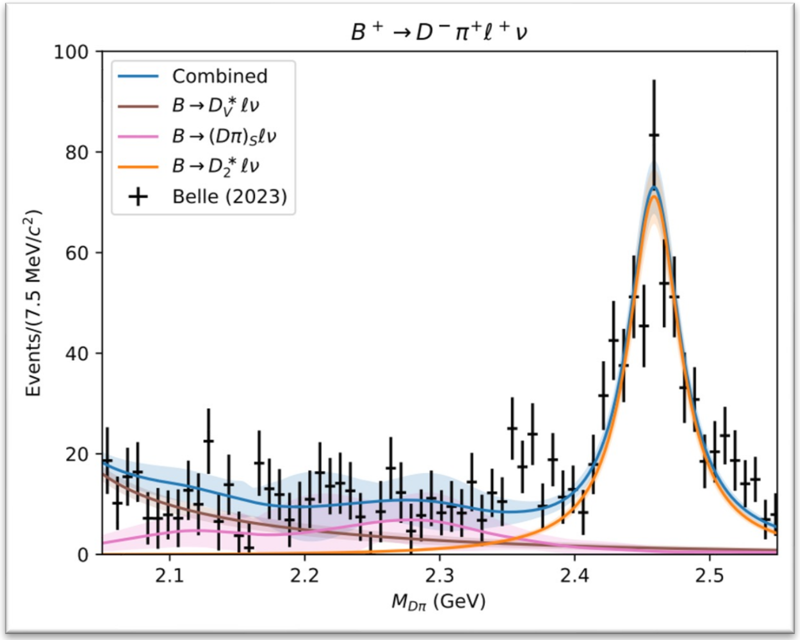
Inputs from hadron physics (theory and experiment) will drive us forward

Challenges: Feeddown from $\bar{B} \to D^{**}\ell\bar{\nu}_\ell$



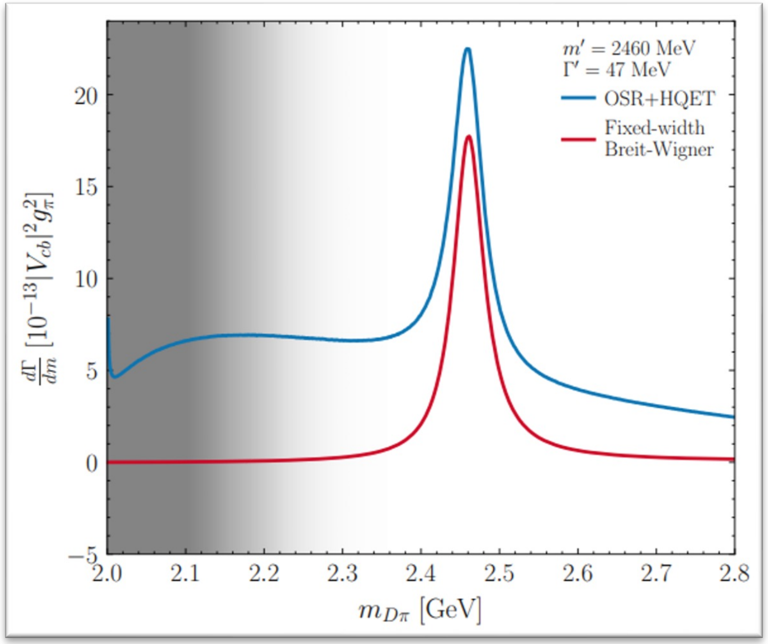
- Is the $D_0^*(2300)$ a resonance from the quark model, or a more complex structure described by $\boldsymbol{U\chi PT}$?
- Form factors for semileptonic $\bar{B} \to D^{**}\ell\bar{\nu}_\ell$ decays assume the narrow width approximation for the broad D^{**}

- Modelling of $\bar{B} \to D^{**}\ell\bar{\nu}_\ell$ decays in simulation depends on proper knowledge of form factors
- Background estimation challenging
- Active progress from our theory colleagues



BGL generalization

E. J. Gustafson, F. Herren, R. S. Van de Water, R. van Tonder, M. L. Wagman
arXiv:2311.00864



On-shell recursion + HQET

C. A. Manzari, D. J. Robinson
arXiv:2402.12460

Challenges: Simulation Sample Size

Result	Experiment	τ decay	Tag	Systematic uncertainty [%]: MC stats	$D^{(*)}l\nu$	$D^{**}l\nu$	Other bkg.	Other sources	Total uncert. [%]: Syst.	Stat.	Total
$\mathcal{R}(D)$	*BABAR* [a]	$\ell\nu\nu$	Had.	5.7	2.5	5.8	3.9	0.9	**9.6**	**13.1**	**16.2**
	Belle[b]	$\ell\nu\nu$	Semil.	4.4	0.7	0.8	1.7	3.4	**5.2**	**12.1**	**13.1**
	Belle[c]	$\ell\nu\nu$	Had.	4.4	3.3	4.4	0.7	0.5	**7.1**	**17.1**	**18.5**
$\mathcal{R}(D^*)$	*BABAR* [a]	$\ell\nu\nu$	Had.	2.8	1.0	3.7	2.3	0.9	**5.6**	**7.1**	**9.0**
	Belle[b]	$\ell\nu\nu$	Semil.	2.3	0.3	1.4	0.5	4.7	**4.9**	**6.4**	**8.1**
	Belle[c]	$\ell\nu\nu$	Had.	3.6	1.3	3.4	0.7	0.5	**5.2**	**13.0**	**14.0**
	Belle[d]	$\pi\nu$, $\rho\nu$	Had.	3.5	2.3	2.4	8.1	2.9	**9.9**	**13.0**	**16.3**
	LHCb[e]	$\pi\pi\pi(\pi^0)\nu$	—	4.9	4.0	2.7	5.4	4.8	**10.2**	**6.5**	**12.0**
	LHCb[f]	$\mu\nu\nu$	—	6.3	2.2	2.1	5.1	2.0	**8.9**	**8.0**	**12.0**

[a] (Lees *et al.*, 2012, 2013)
[b] (Caria *et al.*, 2020) [c] (Huschle *et al.*, 2015) [d] (Hirose *et al.*, 2018) [e] (Aaij *et al.*, 2015c) [f] (Aaij *et al.*, 2018b)

F. Bernlochner, M. Franco Sevilla, D. Robinson, G. Wormser
arXiv:2101.08326, Review of Modern Physics

Source	Uncertainty
PDF shapes	$^{+9.1\%}_{-8.3\%}$
Simulation sample size	$^{+7.5\%}_{-7.5\%}$
$\overline{B} \to D^{**}\ell^-\overline{\nu}_\ell$ branching fractions	$^{+4.8\%}_{-3.5\%}$
Fixed backgrounds	$^{+2.7\%}_{-2.3\%}$
Hadronic B decay branching fractions	$^{+2.1\%}_{-2.1\%}$
Reconstruction efficiency	$^{+2.0\%}_{-2.0\%}$
Kernel density estimation	$^{+2.0\%}_{-0.8\%}$
Form factors	$^{+0.5\%}_{-0.1\%}$
Peaking background in ΔM_{D^*}	$^{+0.4\%}_{-0.4\%}$
$\tau^- \to \ell^-\nu_\tau\bar{\nu}_\ell$ branching fractions	$^{+0.2\%}_{-0.2\%}$
$R(D^*)$ fit method	$^{+0.1\%}_{-0.1\%}$
Total systematic uncertainty	$^{+13.5\%}_{-12.3\%}$

Belle II $R(D^*)$
arXiv:2401.02840

Source	Uncertainty [%]: e	μ	ℓ
Experimental sample size	8.8	12.0	7.1
Simulation sample size	6.7	10.6	5.7
Tracking efficiency	2.9	3.3	3.0
Lepton identification	2.8	5.2	2.4
$X_c\ell\nu$ M_X shape	7.3	6.8	7.1
Background (p_ℓ, M_X) shape	5.8	11.5	5.7
$X\ell\nu$ branching fractions	7.0	10.0	7.7
$X\tau\nu$ branching fractions	1.0	1.0	1.0
$X_c\tau(\ell)\nu$ form factors	7.4	8.9	7.8
Total	18.1	25.6	17.3

Belle II $R(X)$
arXiv:2311.07248

MC statistics is often the leading systematic uncertainty, needed for:

- Fit templates
- Efficiency determination
- Training of MVA classifiers

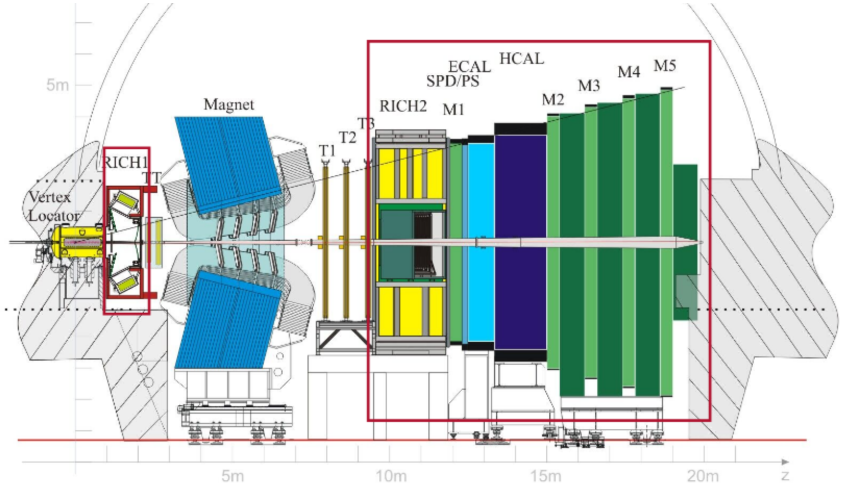
"trivial but costly" to improve

LHCb $R(D^+)$ LHCb-PAPER-2024-007

Source	$\mathcal{R}(D^+)$	$\mathcal{R}(D^{*+})$
Form factors	0.023	0.035
$\overline{B} \to D^{**}[D^+X]\mu/\tau\nu$ fractions	0.024	0.025
$\overline{B}^{+/0} \to D^+X_cX$ fraction	0.020	0.034
Misidentification	0.019	0.012
Simulation size	0.009	0.030
Combinatorial background	0.005	0.020
Data/simulation agreement	0.016	0.011
Muon identification	0.008	0.027
Multiple candidates	0.007	0.017
Total systematic uncertainty	0.047	0.086

Tracker-only simulation

- New fast simulation technique which turns off RICH photon propogation and Calo showers.
  - Eight times faster and 40% less disk space.
  - Requires involved set of emulations to obtain trigger/PID response.



- Finite simulation size demoted from first to fifth largest systematic.

$R(D^0)$

Internal fit uncertainties	$\sigma_{\mathcal{R}(D^*)}$ ($\times10^{-2}$)	$\sigma_{\mathcal{R}(D^0)}$ ($\times10^{-2}$)	Correlation
Statistical uncertainty	1.8	6.0	−0.49
Simulated sample size	1.5	4.5	
$B \to D^{(*)}DX$ template shape	0.8	3.2	
$\bar{B} \to D^{(*)}\ell^-\bar{\nu}_\ell$ form factors	0.7	2.1	
$\bar{B} \to D^{**}\mu^-\bar{\nu}_\mu$ form factors	0.8	1.2	
$\mathcal{B}\ [\bar{B} \to D^* D_s^-(\to \tau^-\bar{\nu}_\tau)X]$	0.3	1.2	
MisID template	0.1	0.8	
$\mathcal{B}\ (\bar{B} \to D^{**}\tau^-\bar{\nu}_\tau)$	0.5	0.5	
Combinatorial	< 0.1	0.1	
Resolution	< 0.1	0.1	

$R(D^+)$

Source	$\mathcal{R}(D^+)$	$\mathcal{R}(D^{*+})$
Form factors	0.023	0.035
$\bar{B} \to D^{**}[D^+X]\mu/\tau\nu$ fractions	0.024	0.025
$\bar{B}^{+/0} \to D^+X_cX$ fraction	0.020	0.034
Misidentification	0.019	0.012
Simulation size	0.009	0.030
Combinatorial background	0.005	0.020
Data/simulation agreement	0.016	0.011
Muon identification	0.008	0.027
Multiple candidates	0.007	0.017
Total systematic uncertainty	0.047	0.086

- Different fast simulation to that used for three-prong mode (ReDecay).

LHCb-PAPER-2024-007

Latest RD+ measurement from LHCb

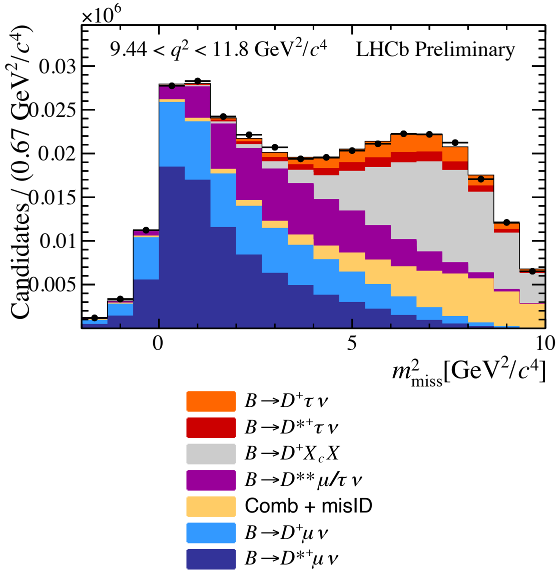
- New measurement of RD(*) with the $D^+ \rightarrow K^-\pi^+\pi^+$decay.

- Largely follows the $R(D^0)$ analysis, with a few exceptions:
  - Six times less feed-down from D^* decays.
  - Neutral isolation to reduce $D^{*+} \rightarrow D^+\pi^0$ feed-down.
  - More conservative B→DDX treatment.
  - New fast "tracker-only" simulation used.
  - Using HAMMER in the minimisation procedure.

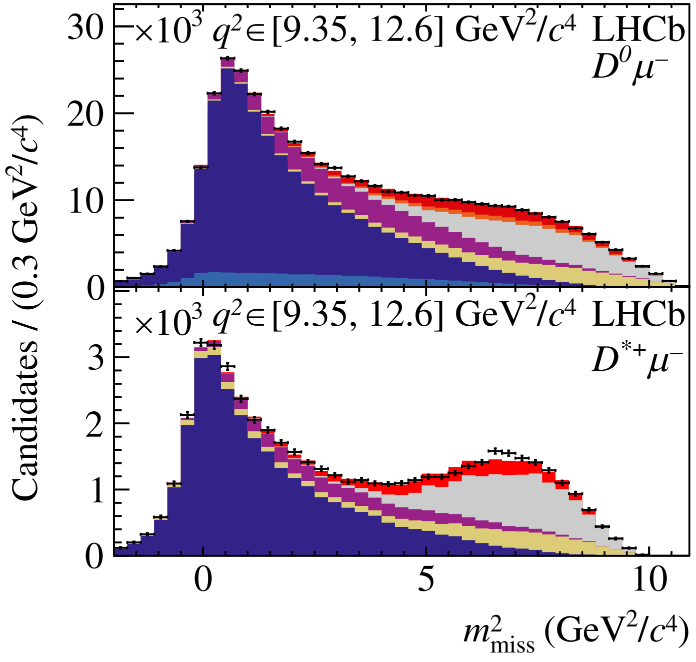
- Results:

$$R(D^+) = 0.249 \pm 0.043 \pm 0.047$$
$$R(D^{*+}) = 0.402 \pm 0.081 \pm 0.085$$

$R(D^+)$

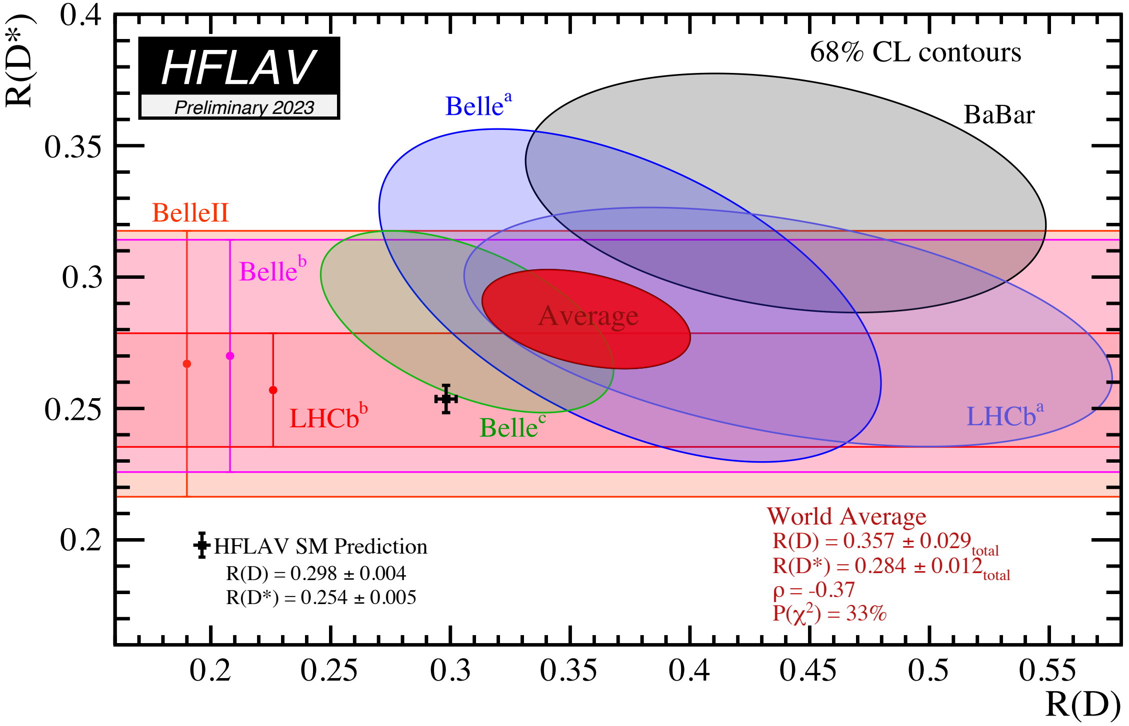


$R(D^0)$

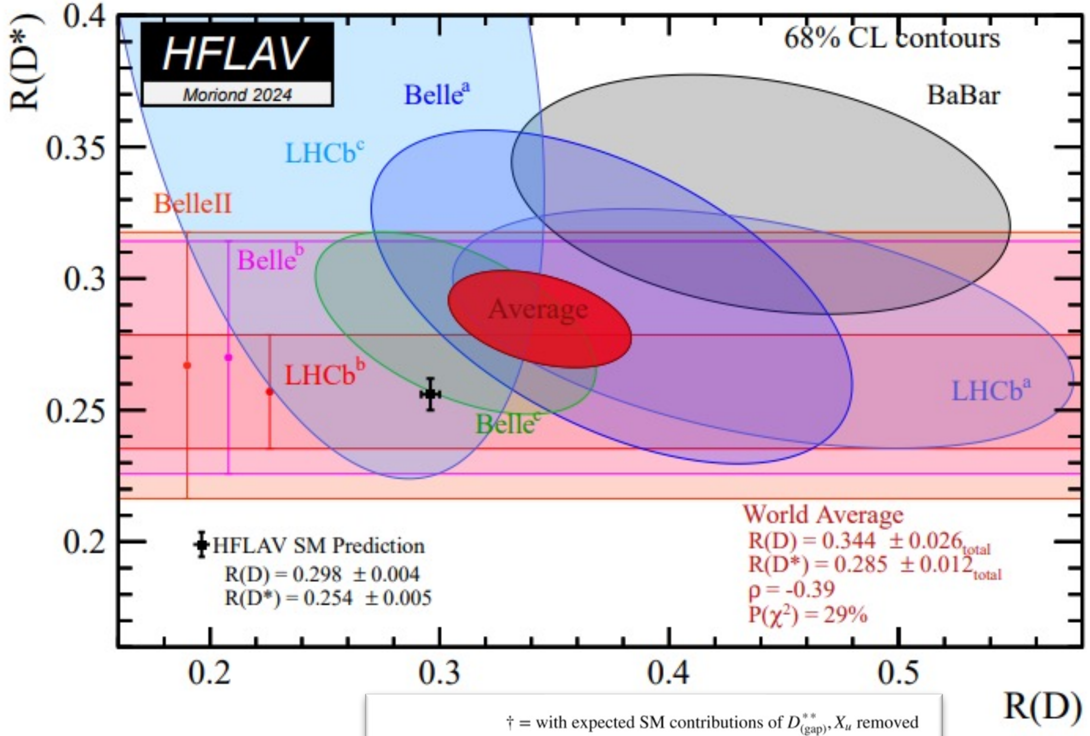


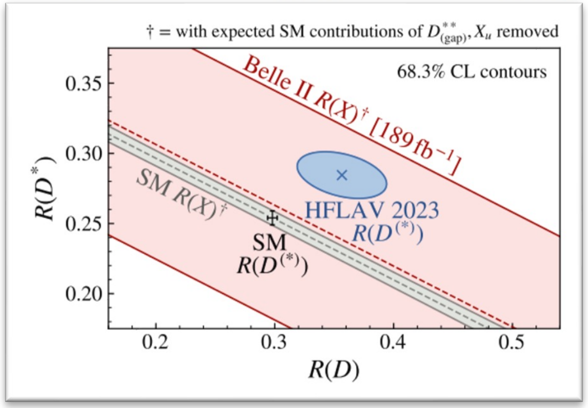
Status Quo & Quo Vadis

[HFLAV] Before $R(D^+)$



After $R(D^+)$

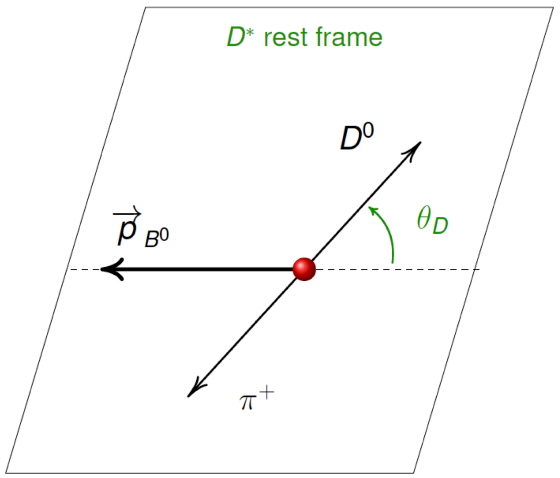




- Significance from SM goes from 3.3 σ to 3.1σ.
- $R(X)$ shows no tension

arXiv:2311.05224

Beyond R ratios: $F_L^{D^*}$ at LHCb



- Recent measurement of $F_L^{D^*}$ at LHCb.

$$\frac{d^2\Gamma}{dq^2 d\cos\theta_D} = \mathbf{a}_{\theta_D}(\mathbf{q}^2) + \mathbf{c}_{\theta_D}(\mathbf{q}^2)\cos^2\theta_D \qquad F_L^{D^*} = \frac{\mathbf{a}_{\theta_D}(\mathbf{q}^2) + \mathbf{c}_{\theta_D}(\mathbf{q}^2)}{3\mathbf{a}_{\theta_D}(\mathbf{q}^2) + \mathbf{c}_{\theta_D}(\mathbf{q}^2)}$$

unpolarised signal fraction

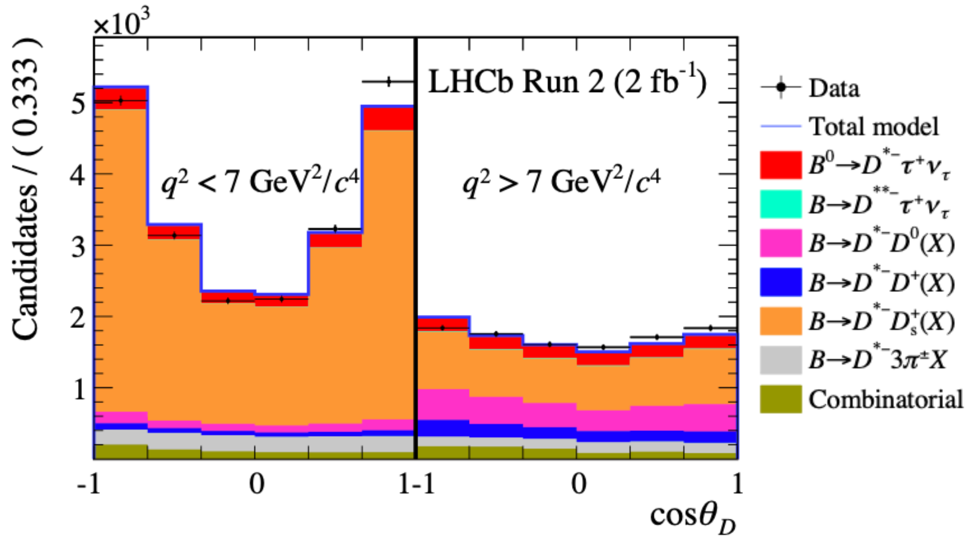
polarised signal fraction

BELLE $F_L^{D^*} = 0.60 \pm 0.08 \pm 0.04$ [arXiv:1903.03102]

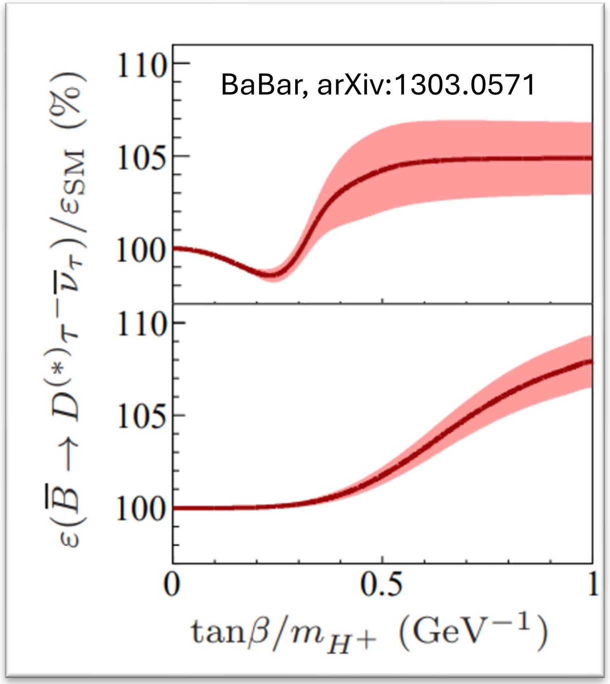
$$F_L^{D^*} = 0.43 \pm 0.06\,(\text{stat}) \pm 0.03\,(\text{syst})$$

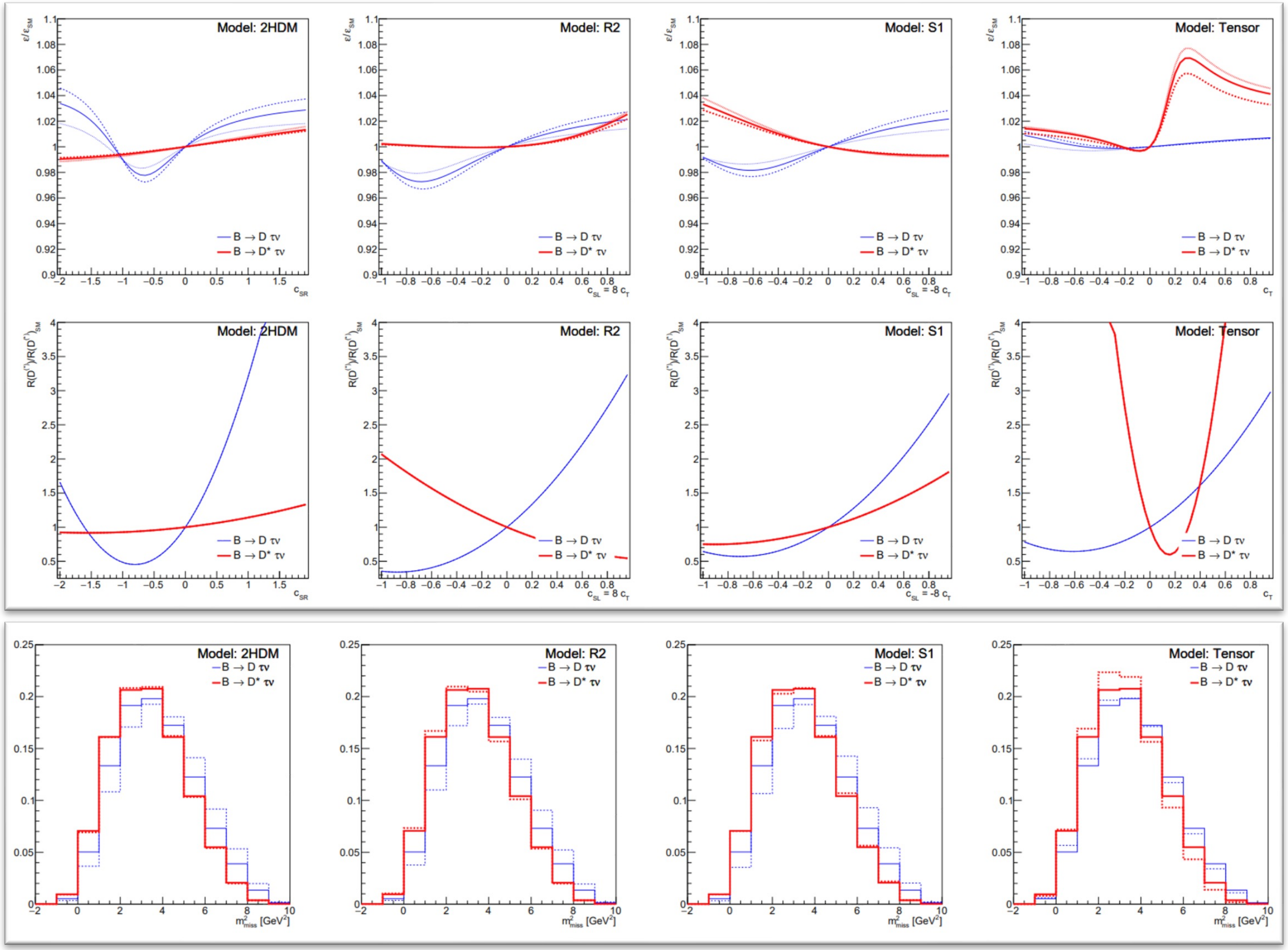
- Compatible with SM:

$F_L^{D^*} = 0.441 \pm 0.006$ [PRD 98 (2018) 095018]
$F_L^{D^*} = 0.457 \pm 0.010$ [Eur. Phys. J. C 79, 268 (2019)]
$F_L^{D^*} = 0.467 \pm 0.009$ [Eur. Phys. J. C 80, 347 (2020)]
$F_L^{D^*} = 0.422 \pm 0.010$ [arXiv:2310.03680]
$F_L^{D^*}[q^2 < 7 GeV^2/c^4] = 0.495 \pm 0.017$ [arXiv:2310.03680]
$F_L^{D^*}[q^2 > 7 GeV^2/c^4] = 0.383 \pm 0.006$ [arXiv:2310.03680]



Searching for New Physics





New physics contribution **alter signal and background decay distributions** → Impact on the acceptance and fitting templates

arXiv:2101.08326

Searching for New Physics

Challenge: We need MC for each NP working point

- Our standard generator EvtGen does not incorporate NP effects
- **Very** costly to re-produce MC at various NP working points

Luckily for us, this problem has been solved!

HAMMER

Helicity Amplitude Module for Matrix Element Reweighting

F. Bernlochner, S. Duell, Z. Ligeti, M. Papucci, D. J. Robinson
arXiv:2002.00020, EPJC

It also allows us to perform **truly global** fits for $b \to c\tau\bar{\nu}_\tau$ transitions that **avoid biases and remove SM priors**

Belle II $R(D^*)$

Belle II $\mathrm{R}(X)$

Belle $\mathrm{P}_\tau(D^*)$

LHCb $R\left(D^{(*)}\right)$

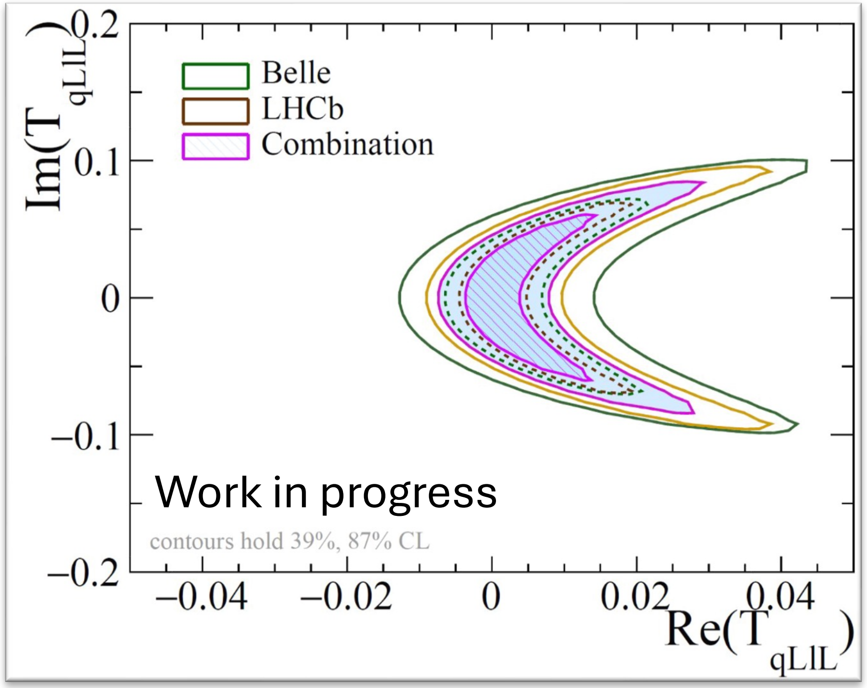
$$\Pi_i \mathcal{L}_i(C, \theta)$$

Full experimental Likelihood

Correlation of common systematic uncertainties

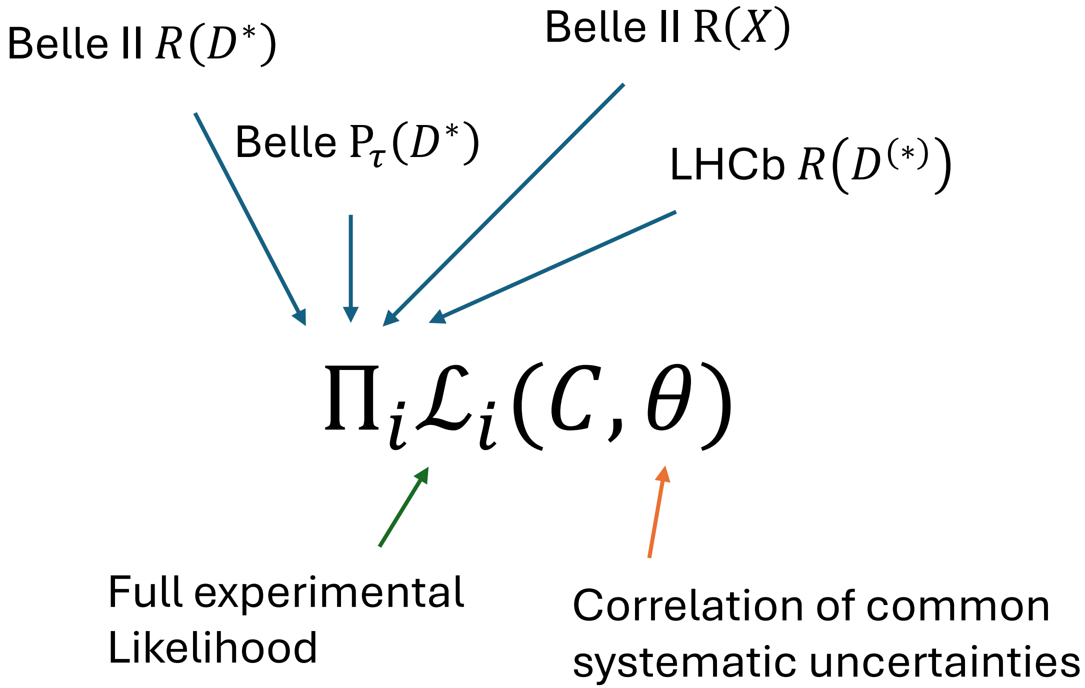
Searching for New Physics

Proof of concept
based on LHCb simulation and a Belle toy



J. Albrecht, F. Bernlochner, M. Colonna, B. Mitreska, M. Prim, I. Tsaklidis
Work in progress

It also allows us to perform **truly global** fits for $b \to c\tau\bar{\nu}_\tau$ transitions that **avoid biases and remove SM priors**



Idea currently being discussed internally within the respective collaborations.

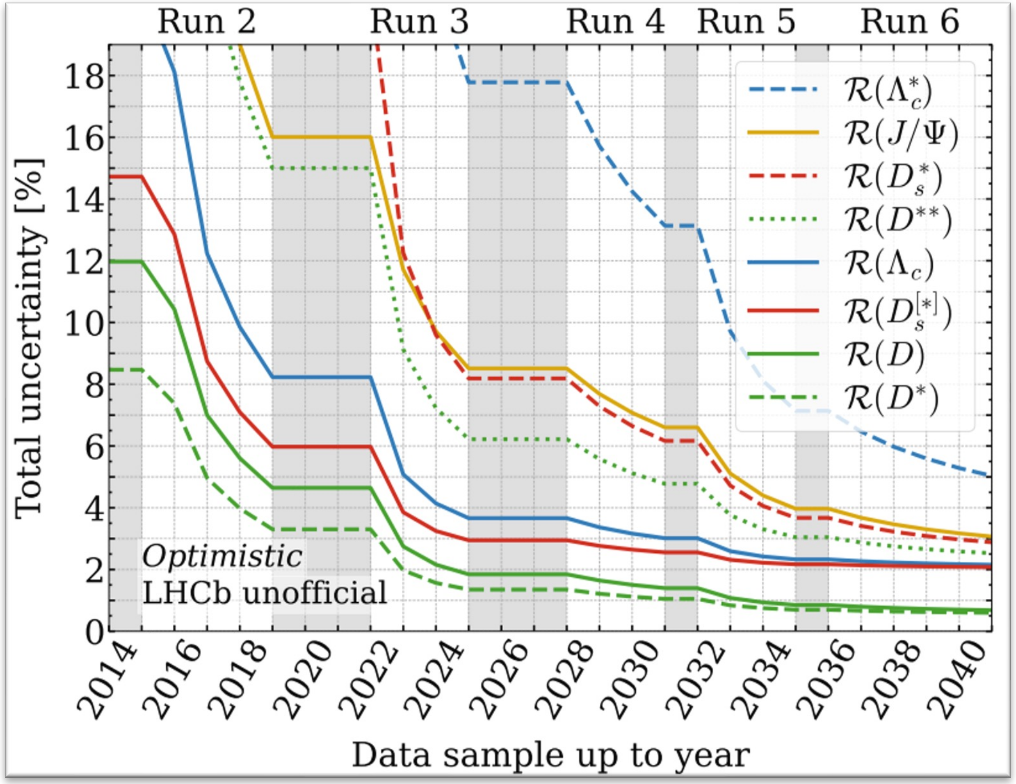
F. Bernlochner, M. Franco Sevilla, D. Robinson, G. Wormser
arXiv:2101.08326, Review of Modern Physics

Belle II Collaboration
arXiv:2207.06307, Snowmass White Paper

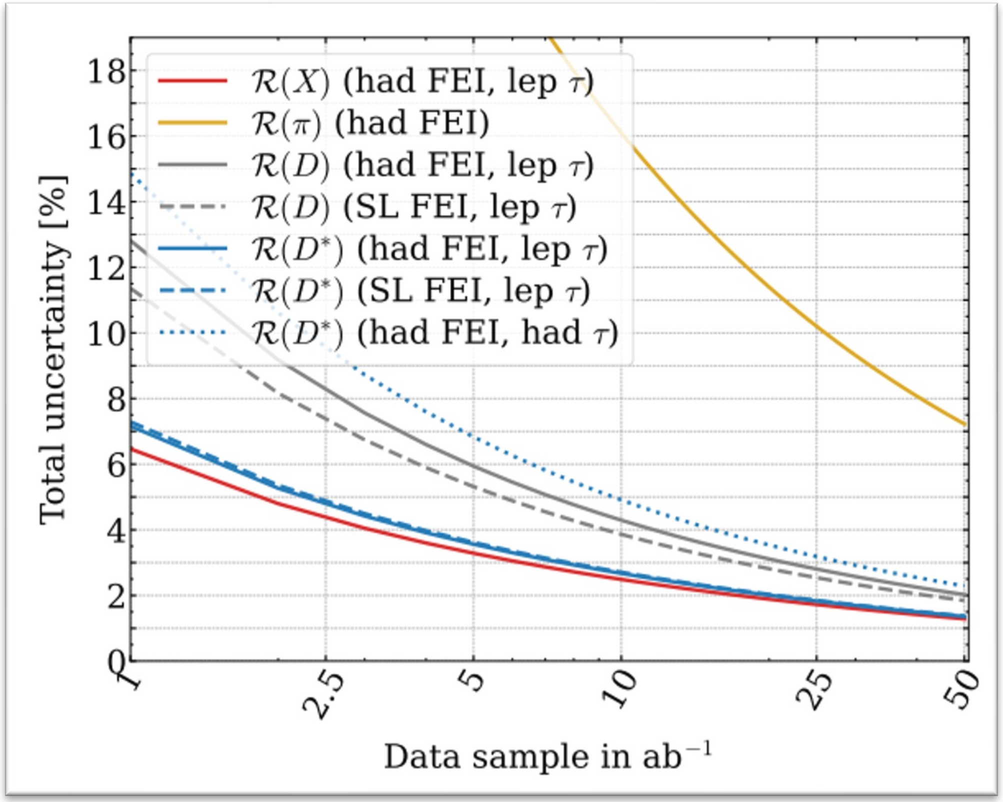
Glimpse into the future

More data to come! Will push precision of the $b \to c$ LFU ratios considerably

LHCb



Belle II



Discussion!

Backup

Challenges: Form Factors