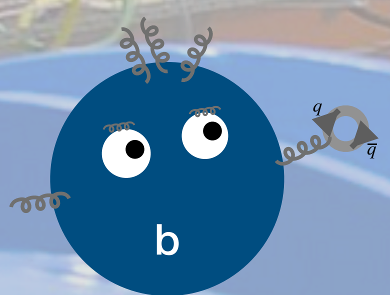
- $R(D^{(*)})$ anomaly
- $b \to s\ell\ell$ anomalies
- $|V_{ub}|, |V_{cb}|$



Use-Case: Heavy Flavor Physics

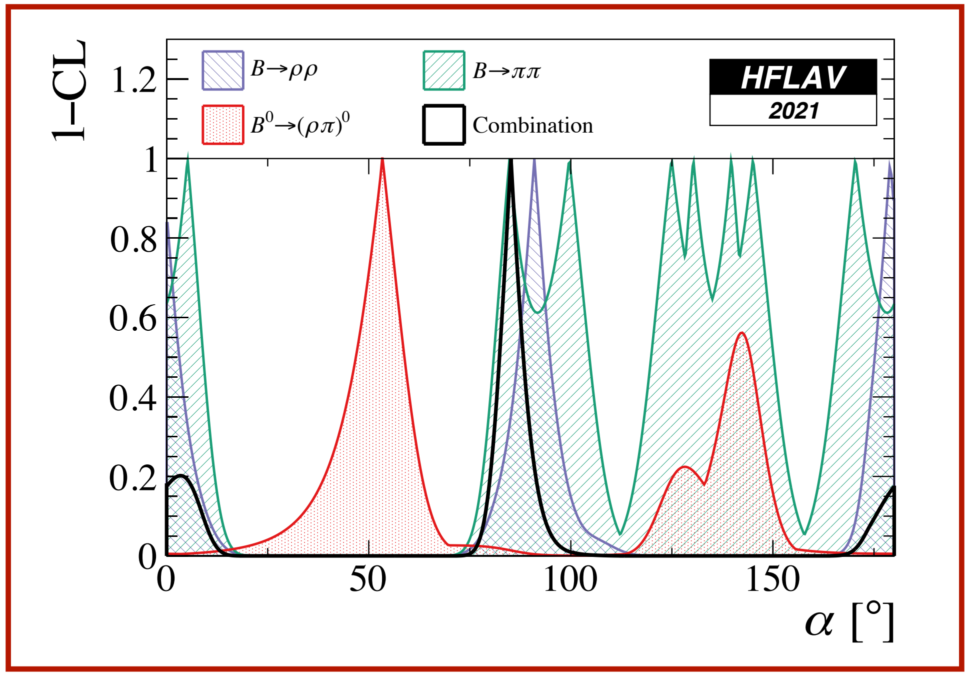
— An attempt of a brief overview —

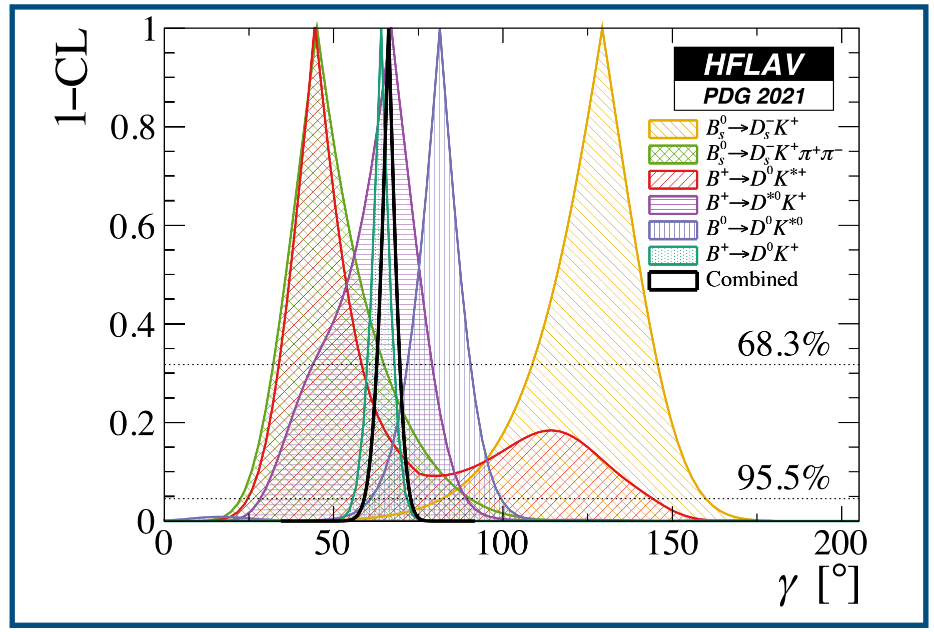
Florian Bernlochner

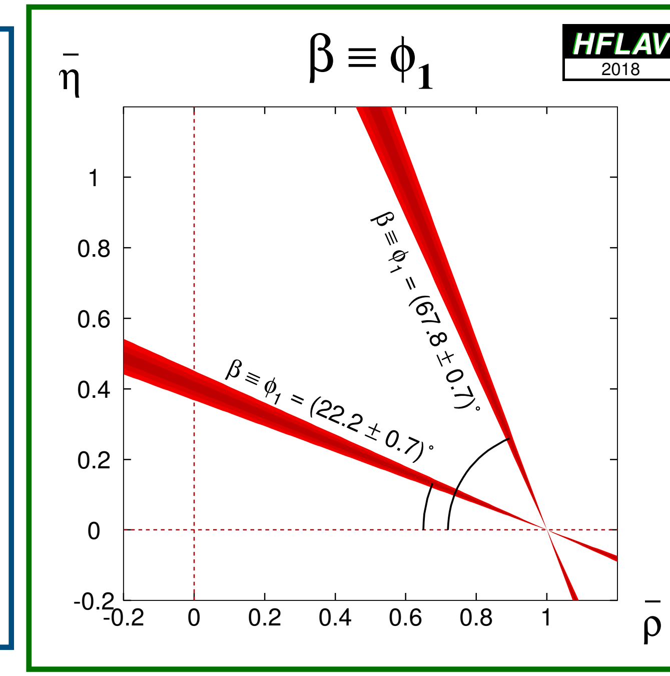
florian.bernlochner@uni-bonn.de

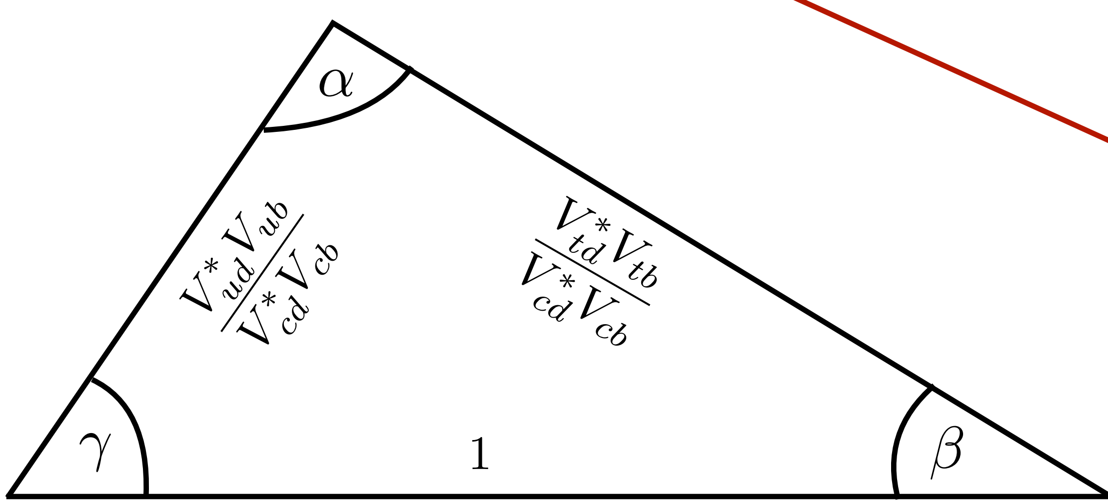
CKM Metrology & much much more

https://hflav.web.cern.ch/

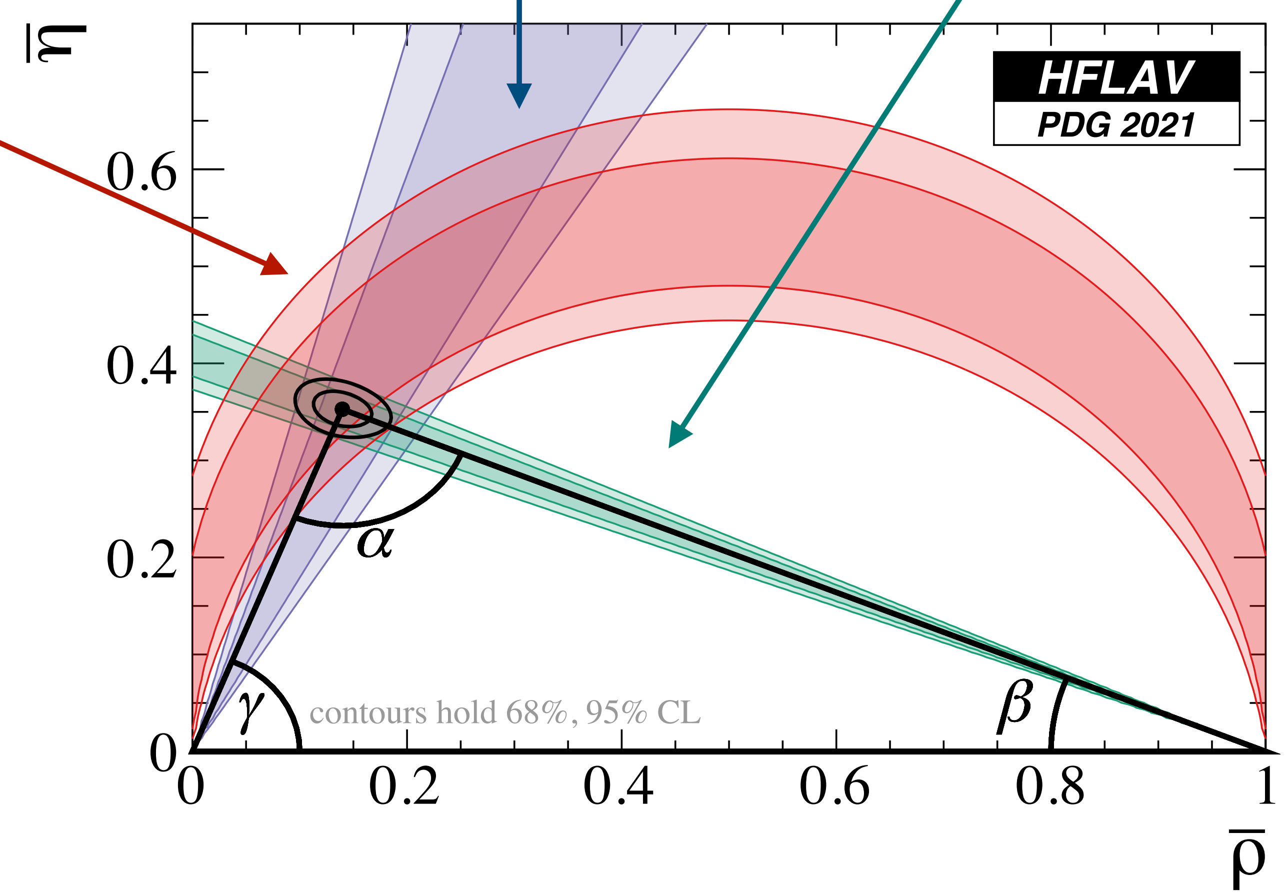




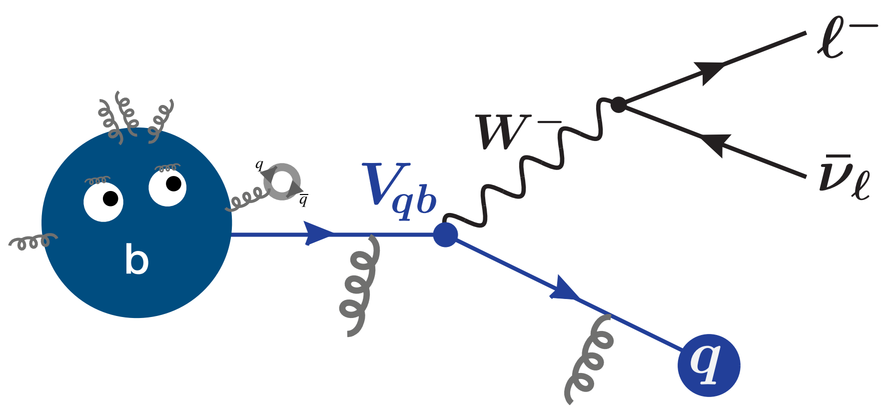




$$\underbrace{V_{ud}V_{ub}^*}_{\mathcal{O}(\lambda^3)} + \underbrace{V_{cd}V_{cb}^*}_{\mathcal{O}(\lambda^3)} + \underbrace{V_{td}V_{tb}^*}_{\mathcal{O}(\lambda^3)} = 0$$



The $\mathscr{R}(D^{(*)})$ anomaly

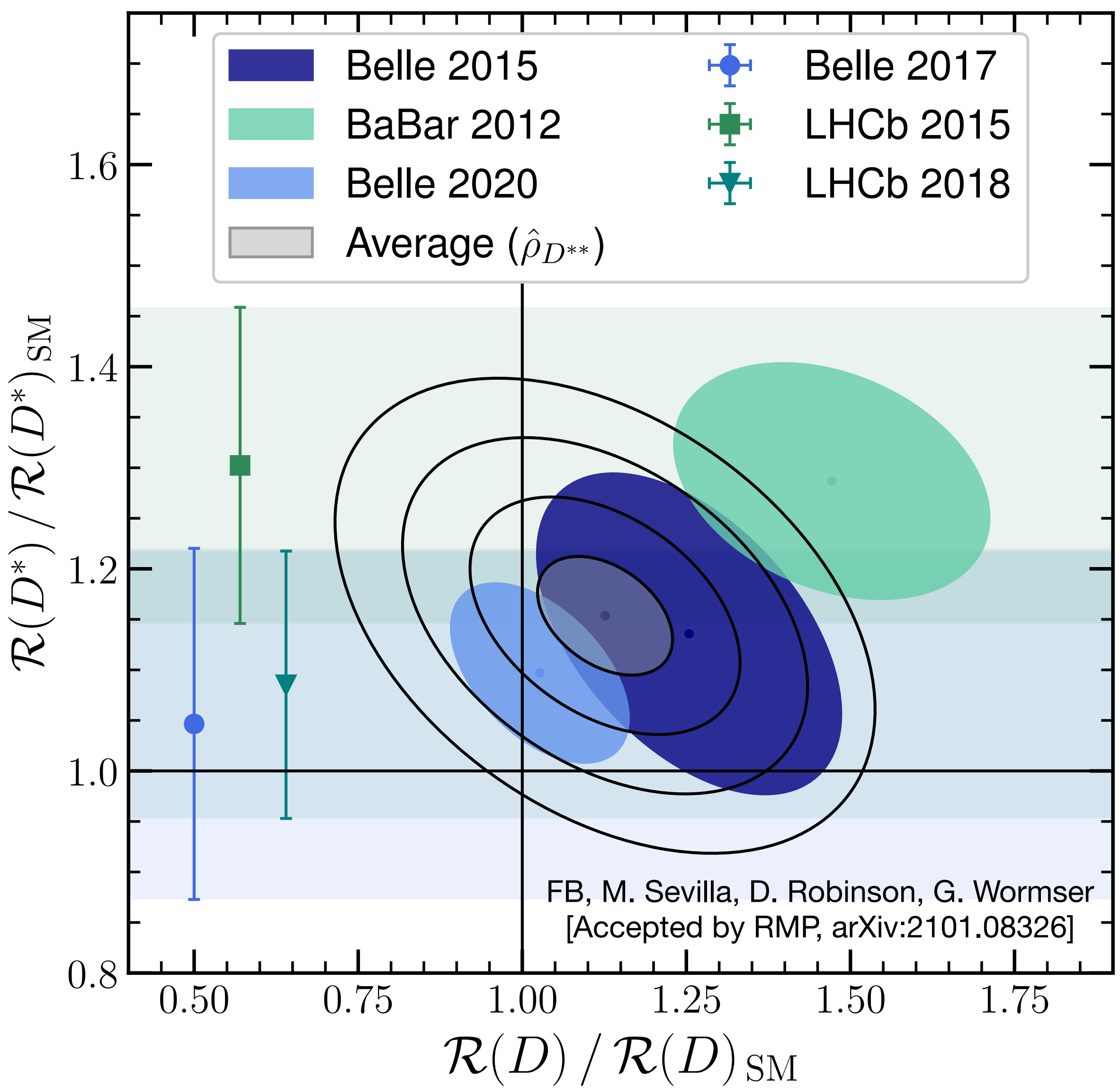


$$R = \frac{b \to q\,\tau\bar{\nu}_\tau}{b \to q\,\ell\bar{\nu}_\ell}$$

$\ell = e, \mu$

↓

Obs.	Current World Av./Data	Current SM Prediction	Significance	
$\mathcal{R}(D)$	0.340 ± 0.030	0.299 ± 0.003	1.2σ	3.1σ
$\mathcal{R}(D^*)$	0.295 ± 0.014	0.258 ± 0.005	2.5σ	
$P_\tau(D^*)$	$-0.38 \pm 0.51^{+0.21}_{-0.16}$	-0.501 ± 0.011	0.2σ	
$F_{L,\tau}(D^*)$	$0.60 \pm 0.08 \pm 0.04$	0.455 ± 0.006	1.6σ	
$\mathcal{R}(J/\psi)$	$0.71 \pm 0.17 \pm 0.18$	0.2582 ± 0.0038	1.8σ	
$\mathcal{R}(\pi)$	1.05 ± 0.51	0.641 ± 0.016	0.8σ	
$\mathcal{R}(D)$	$\mathbf{0.337 \pm 0.030}$	0.299 ± 0.003	1.3σ	$\mathbf{3.6\sigma}$
$\mathcal{R}(D^*)$	$\mathbf{0.298 \pm 0.014}$	0.258 ± 0.005	2.5σ	



→ Can **new physics** somehow explain the tension?

New Physics

Most general Lagrangian density for $b \to c \ell \bar{\nu}_\ell$

$$\mathcal{L} = \frac{4 G_F}{\sqrt{2}} V_{cb}\, c_{XY} \left(\bar{c}\, \Gamma_X\, b\right) \left(\bar{\ell}\, \Gamma_Y\, \nu\right),$$

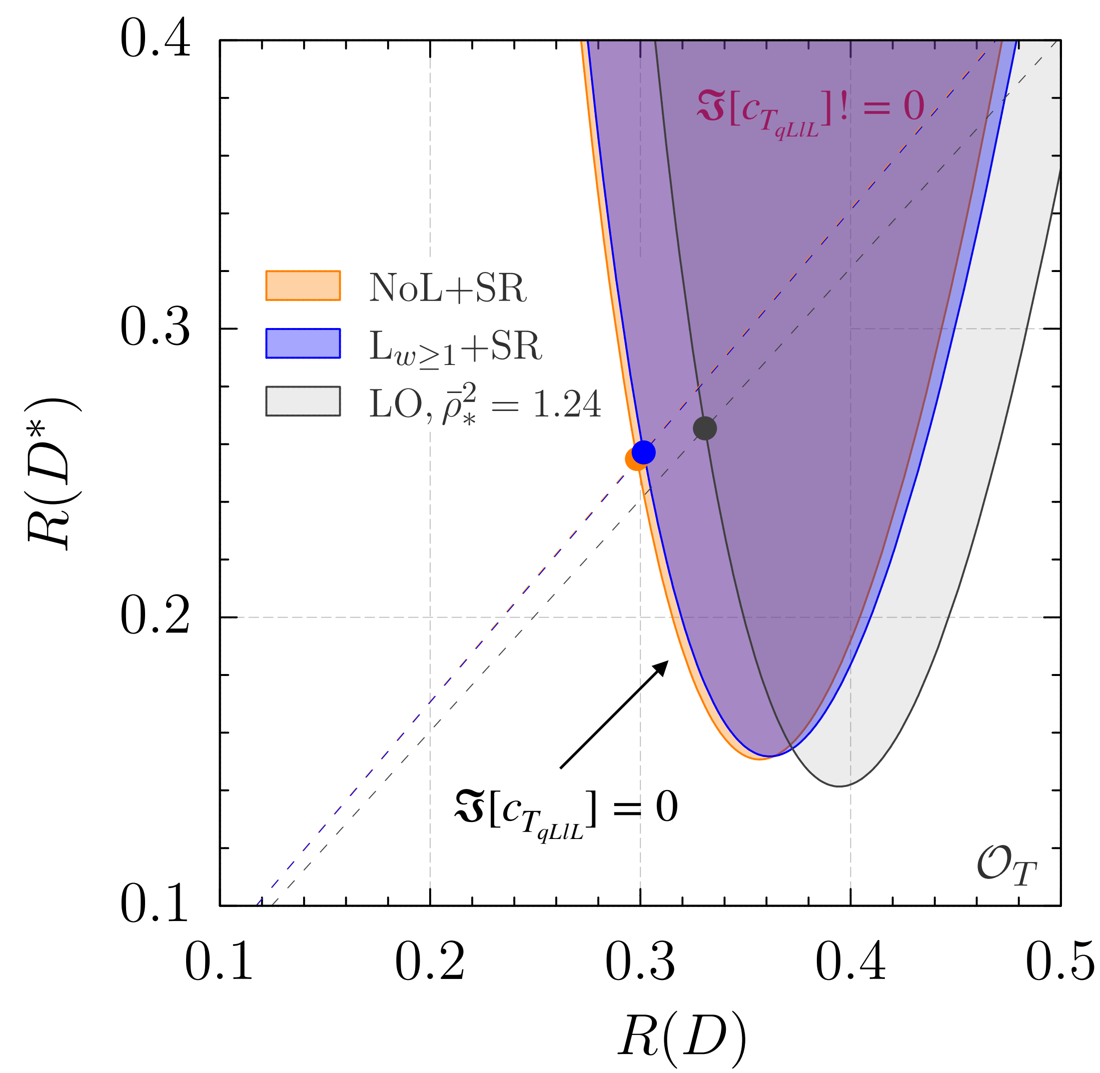
→ **10 NP** four-Fermi operators

→ **10 (complex)** Wilson coefficients = 20 dof

Current	Wilson Coefficient, c_{XY}	Operator
SM	1	$[\bar{c}\gamma^\mu P_L b]\,[\bar{\ell}\gamma_\mu P_L \nu]$
Vector	V_{qLlL}	$[\bar{c}\gamma^\mu P_L b]\,[\bar{\ell}\gamma_\mu P_L \nu]$
	V_{qRlL}	$[\bar{c}\gamma^\mu P_R b]\,[\bar{\ell}\gamma_\mu P_L \nu]$
	V_{qLlR}	$[\bar{c}\gamma^\mu P_L b]\,[\bar{\ell}\gamma_\mu P_R \nu]$
	V_{qRlR}	$[\bar{c}\gamma^\mu P_R b]\,[\bar{\ell}\gamma_\mu P_R \nu]$
Scalar	S_{qLlL}	$[\bar{c} P_L b]\,[\bar{\ell} P_L \nu]$
	S_{qRlL}	$[\bar{c} P_R b]\,[\bar{\ell} P_L \nu]$
	S_{qLlR}	$[\bar{c} P_L b]\,[\bar{\ell} P_R \nu]$
	S_{qRlR}	$[\bar{c} P_R b]\,[\bar{\ell} P_R \nu]$
Tensor	T_{qLlL}	$[\bar{c}\sigma^{\mu\nu} P_L b]\,[\bar{\ell}\sigma_{\mu\nu} P_L \nu]$
	T_{qRlR}	$[\bar{c}\sigma^{\mu\nu} P_R b]\,[\bar{\ell}\sigma_{\mu\nu} P_R \nu]$

Example for tensor (T_{qLlL}) NP + SM

Various values for $c_{T_{qLlL}}$ projected onto $R(D^{(*)})$



FB, Z. Ligeti, M. Papucci, D. Robinson
[Phys. Rev. D 95, 115008 (2017), arXiv:1703.05330]

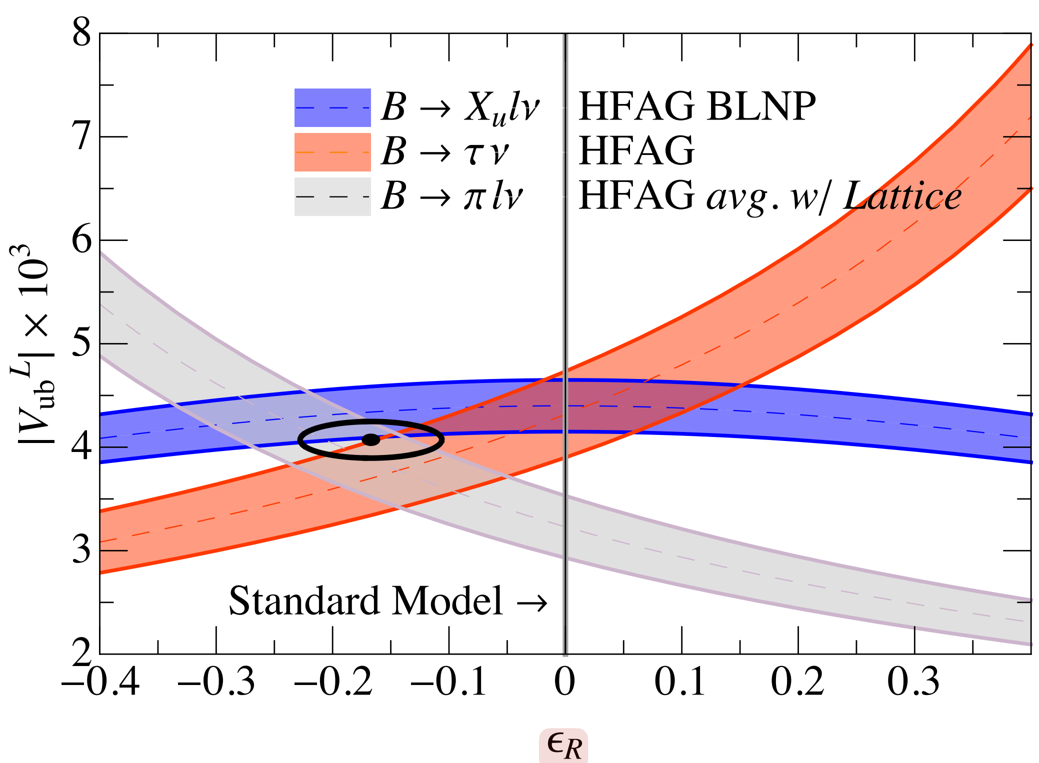
The two categories of measurements

1st Category

Measurements that have **no** or **trivial** or **negligible** dependence on parameter of interest

Example: **Right-handed currents** & $|V_{ub}|$

$$\mathcal{L}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{ub}^L \left(\bar{u}\gamma_\mu P_L b + \epsilon_R\, \bar{u}\gamma_\mu P_R b \right) \left(\bar{\nu}\gamma^\mu P_L \ell \right) + \text{h.c.},$$



Decay	$\lvert V_{ub}\rvert \times 10^3$	ϵ_R dependence
$B \to \pi\, \ell \bar{\nu}$	3.23 ± 0.30	$1 + \epsilon_R$
$B \to X_u \ell \bar{\nu}$	4.39 ± 0.21	$\sqrt{1 + \epsilon_R^2}$
$B \to \tau\, \bar{\nu}_\tau$	4.32 ± 0.42	$1 - \epsilon_R$

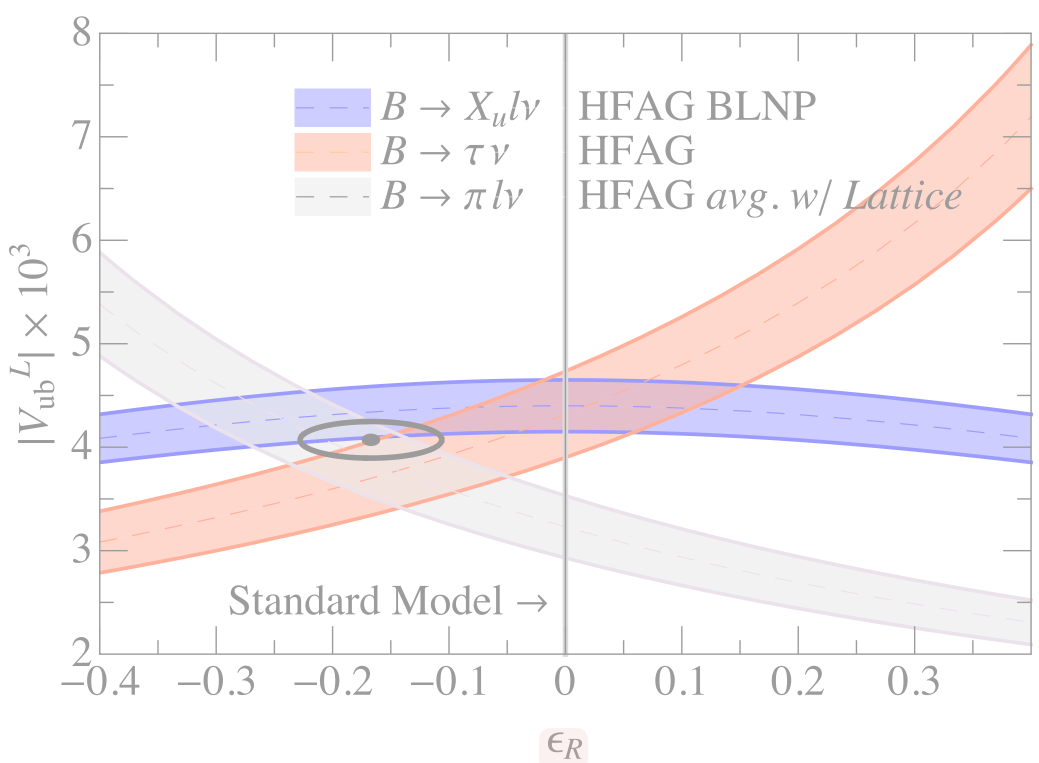
The two categories of measurements

1st Category

Measurements that have **no** or **trivial** or **negligible** dependence on parameter of interest

Example: **Right-handed currents** & $|V_{ub}|$

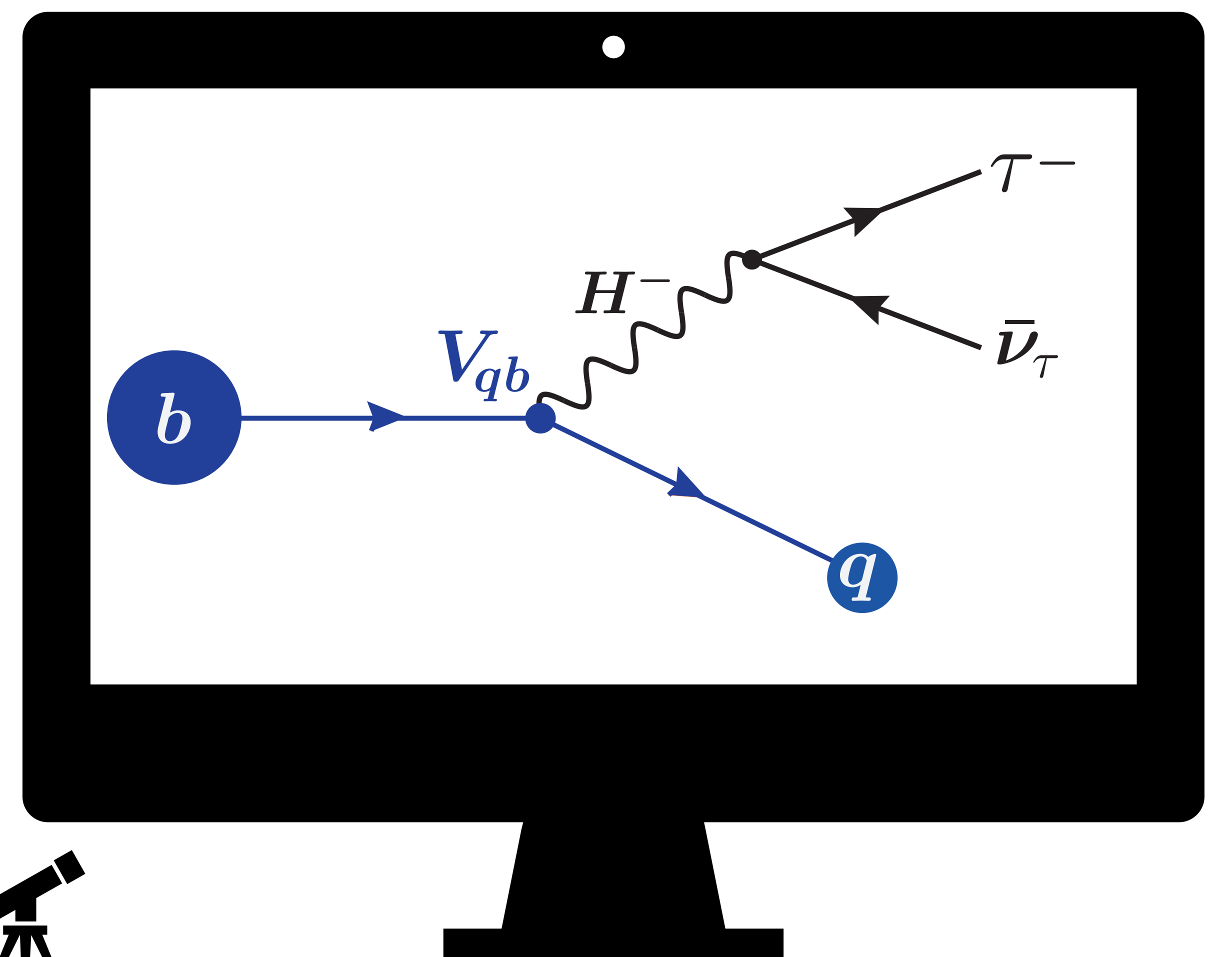
$$\mathcal{L}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{ub}^L (\bar{u}\gamma_\mu P_L b + \epsilon_R\, \bar{u}\gamma_\mu P_R b)(\bar{\nu}\gamma^\mu P_L \ell) + \text{h.c.},$$

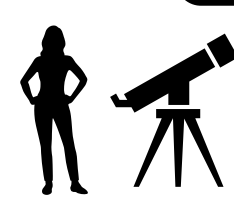


Decay	$\lvert V_{ub}\rvert \times 10^3$	ϵ_R dependence
$B \to \pi\ell\bar{\nu}$	3.23 ± 0.30	$1 + \epsilon_R$
$B \to X_u\ell\bar{\nu}$	4.39 ± 0.21	$\sqrt{1+\epsilon_R^2}$
$B \to \tau\bar{\nu}_\tau$	4.32 ± 0.42	$1 - \epsilon_R$

2nd Category

Measurements that have **non-trivial dependence** on parameter of interest / other params.





- Let's say you want to use the **measured** $R(D^{(*)})$ **ratios** to learn something about the anomaly and **your favorite model** that could explain it!

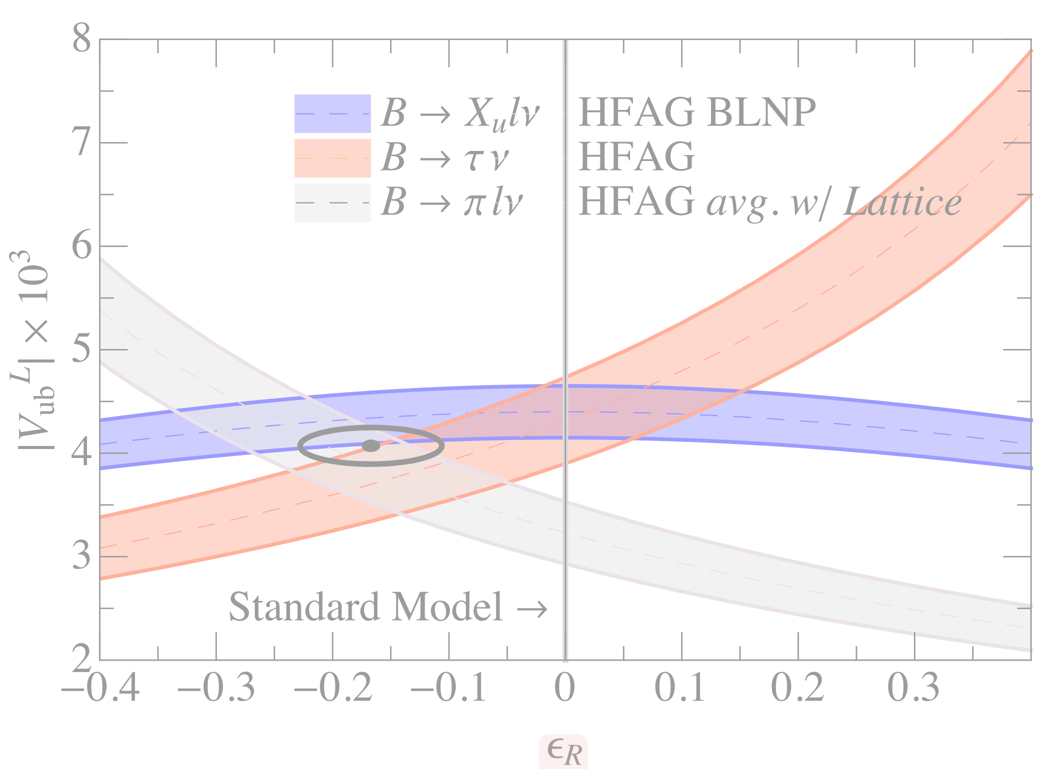
The two categories of measurements

1st Category

Measurements that have **no** or **trivial** or **negligible** dependence on parameter of interest

Example: **Right-handed currents** & $|V_{ub}|$

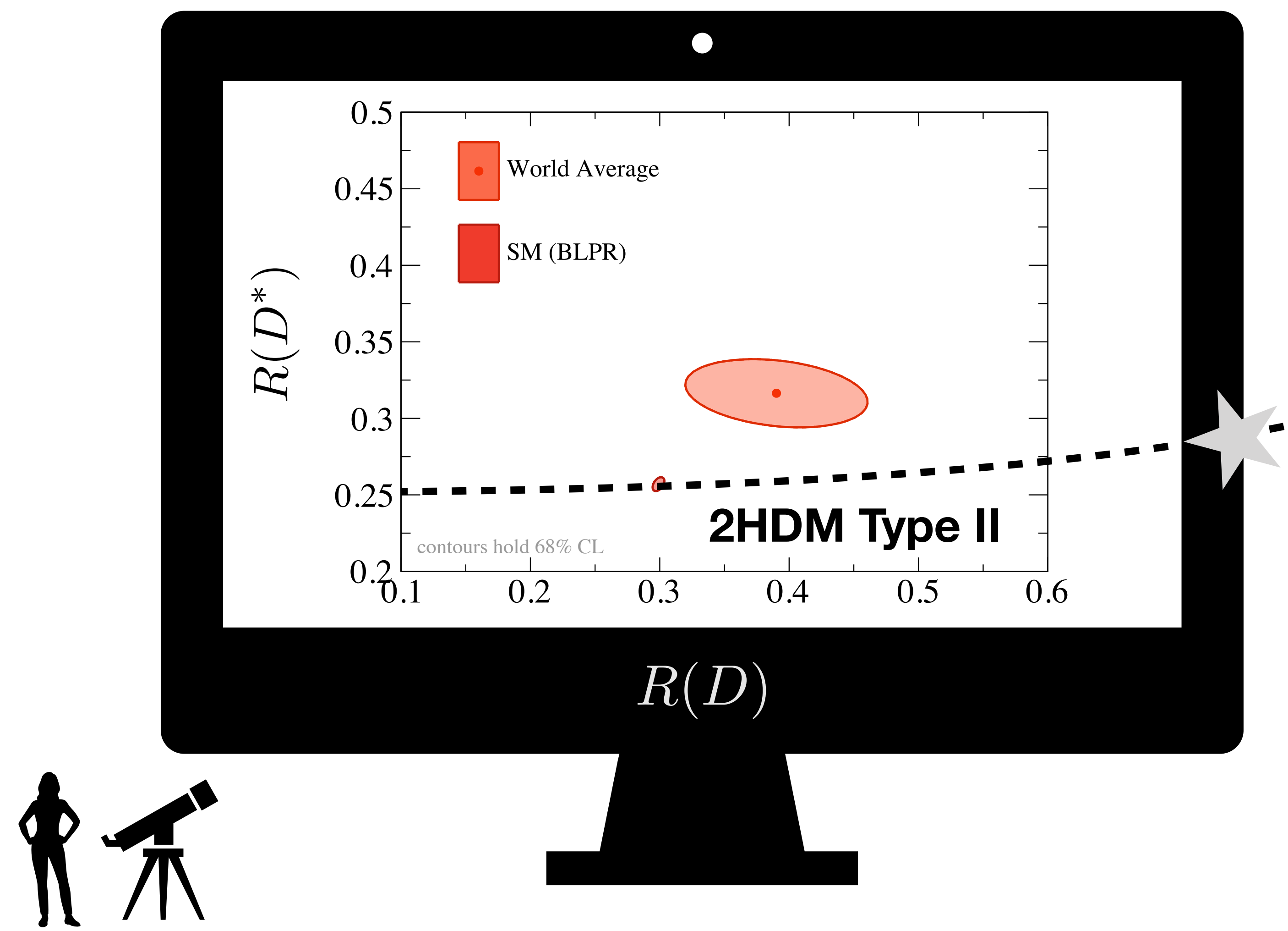
$$\mathcal{L}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{ub}^L (\bar{u}\gamma_\mu P_L b + \epsilon_R \bar{u}\gamma_\mu P_R b)(\bar{\nu}\gamma^\mu P_L \ell) + \text{h.c.},$$



Decay	$\lvert V_{ub}\rvert \times 10^3$	ϵ_R dependence
$B \to \pi\,\ell\bar{\nu}$	3.23 ± 0.30	$1 + \epsilon_R$
$B \to X_u\ell\bar{\nu}$	4.39 ± 0.21	$\sqrt{1+\epsilon_R^2}$
$B \to \tau\,\bar{\nu}_\tau$	4.32 ± 0.42	$1 - \epsilon_R$

2nd Category

Measurements that have **non-trivial dependence** on parameter of interest / other params.



- Let's say you want to use the **measured** $R(D^{(*)})$ **ratios** to learn something about the anomaly and **your favorite model** that could explain it!

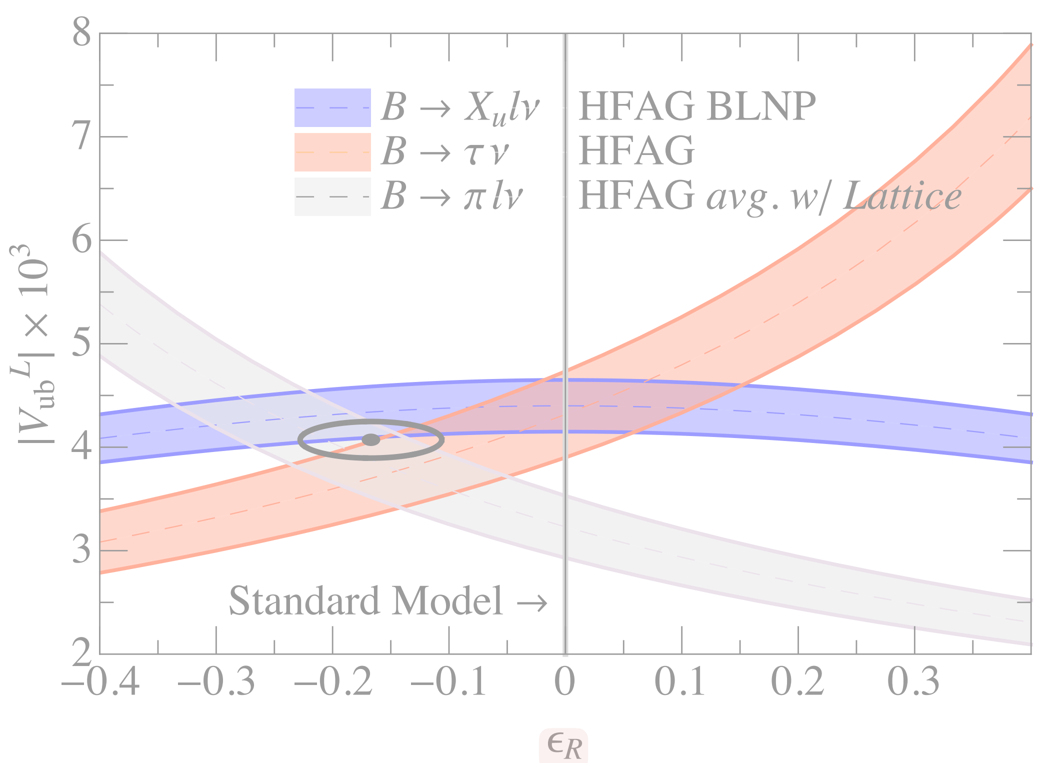
The two categories of measurements

1st Category

Measurements that have **no** or **trivial** or **negligible** dependence on parameter of interest

Example: **Right-handed currents** & $|V_{ub}|$

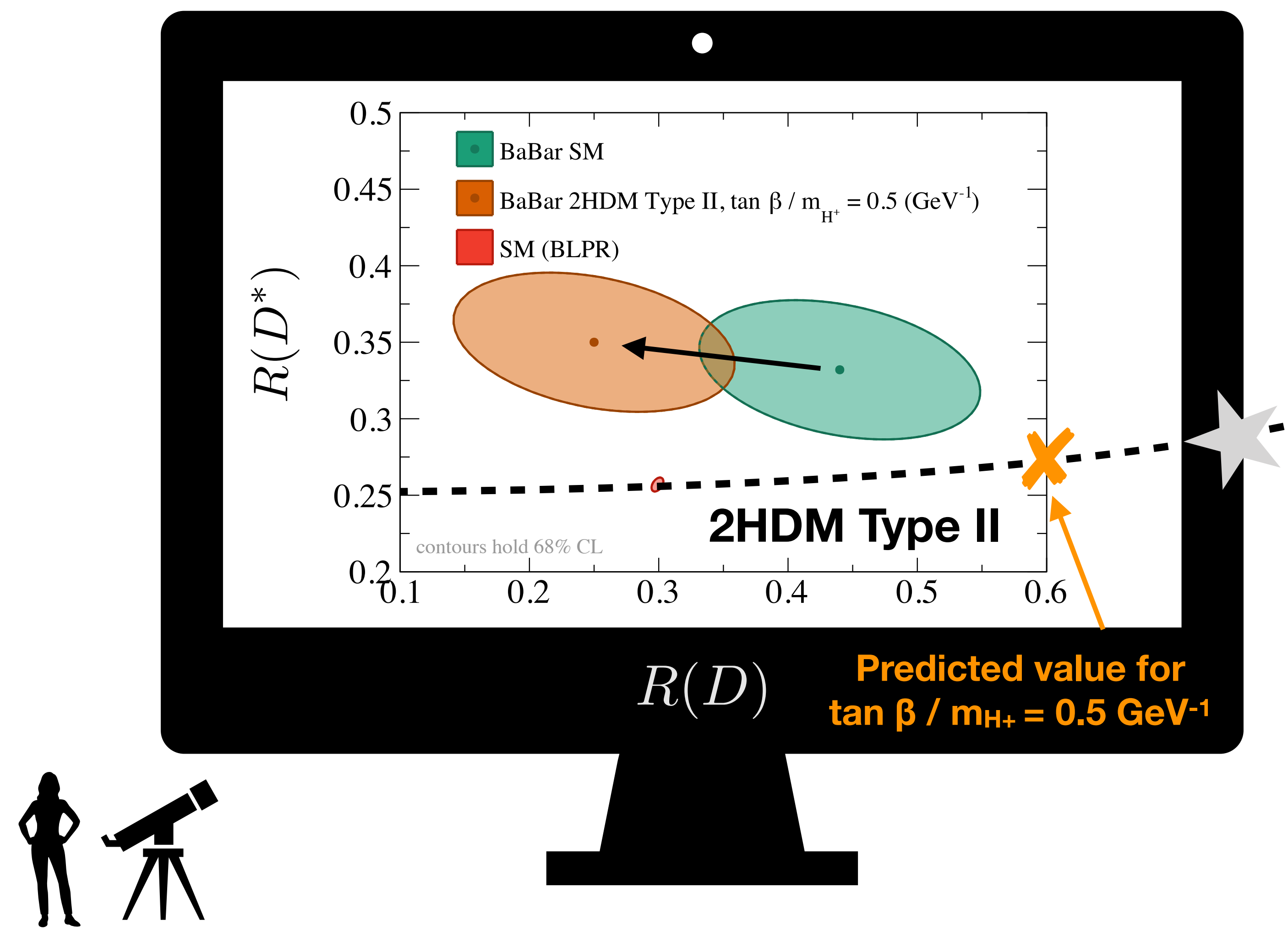
$$\mathcal{L}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{ub}^L \left(\bar u \gamma_\mu P_L b + \epsilon_R\, \bar u \gamma_\mu P_R b\right)\left(\bar \nu \gamma^\mu P_L \ell\right) + \text{h.c.},$$



Decay	$\lvert V_{ub}\rvert \times 10^3$	ϵ_R dependence
$B \to \pi \ell \bar\nu$	3.23 ± 0.30	$1 + \epsilon_R$
$B \to X_u \ell \bar\nu$	4.39 ± 0.21	$\sqrt{1+\epsilon_R^2}$
$B \to \tau \bar\nu_\tau$	4.32 ± 0.42	$1 - \epsilon_R$

2nd Category

Measurements that have **non-trivial dependence** on parameter of interest / other params.



- As it turns out, **not that easy** — the **measured points** themselves are **extracted assuming** the **SM** and kinematic distributions sensitive to the PoI are altering the measurement

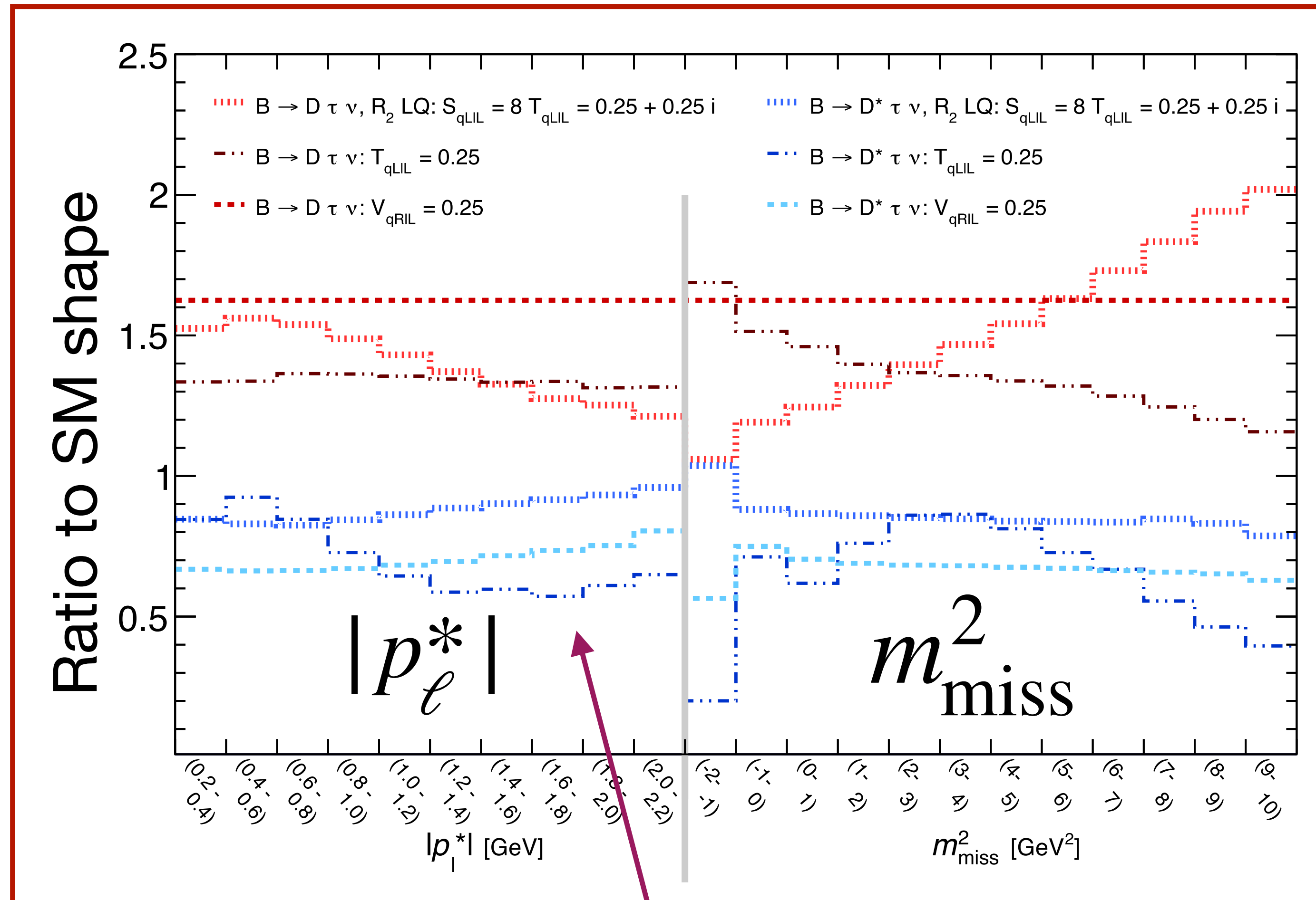
$b \to c\tau\bar{\nu}_\tau$

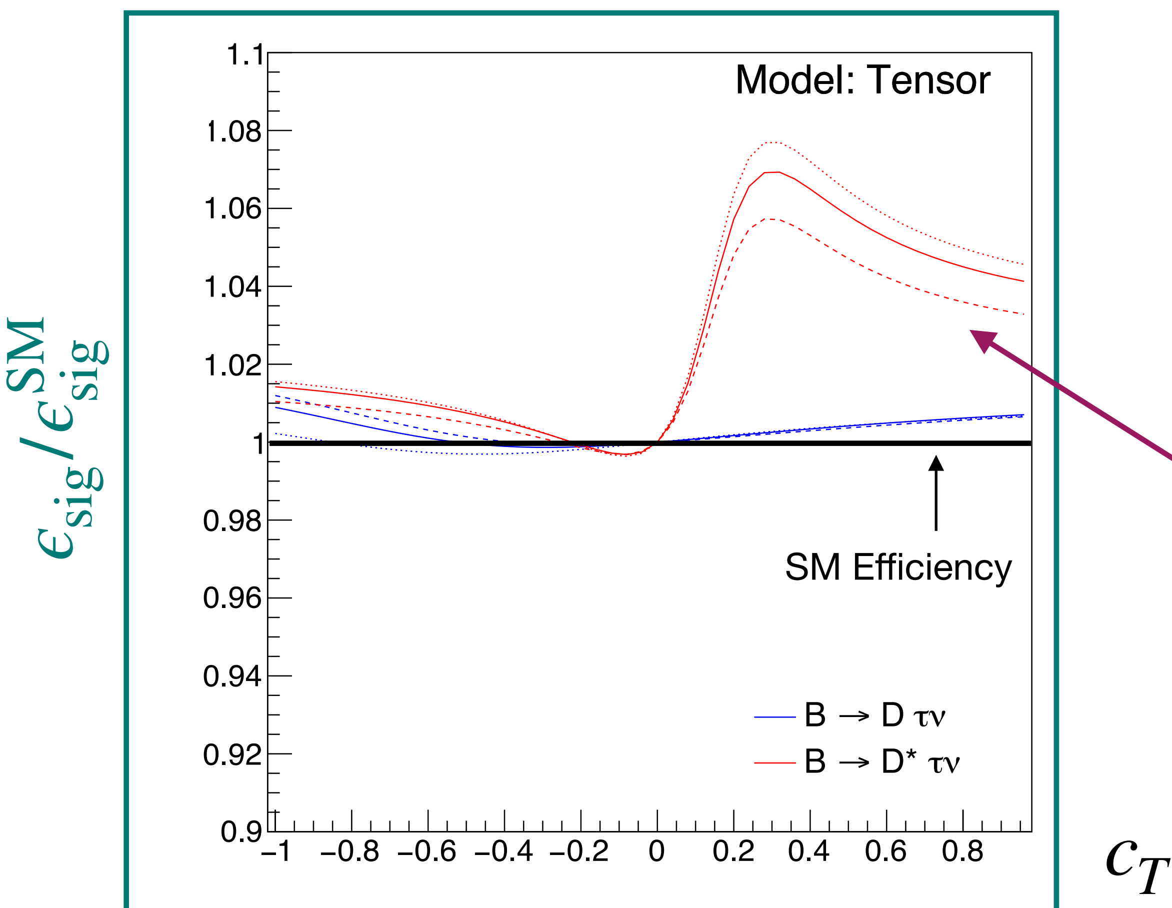
$\tau \to \ell\bar{\nu}_\ell\nu_\tau$

Use **kinematic** quantities (e.g. $|p_\ell^*|$, $m^2_{\rm miss}$, q^2)
to **subtract background**

$$\mathscr{R}(D^{(*)}) = \frac{N_{\rm sig}}{N_{\rm norm}} \times \frac{\epsilon_{\rm norm}}{\epsilon_{\rm sig}}$$

Assume **SM** acceptance x efficiency





Colored curves: different NP working points

NP Interpretation Strategies for $H_b \to H_c \tau \bar{\nu}$

What you can do today

#1

Just fit ratios, hope that **bias** is small with respect to the current precision

Frankly a perfectly sane strategy; after all the experiments do not provide any other information one could use and not all measurements might have such a strong dependence as e.g. BaBar

What we should allow you to do

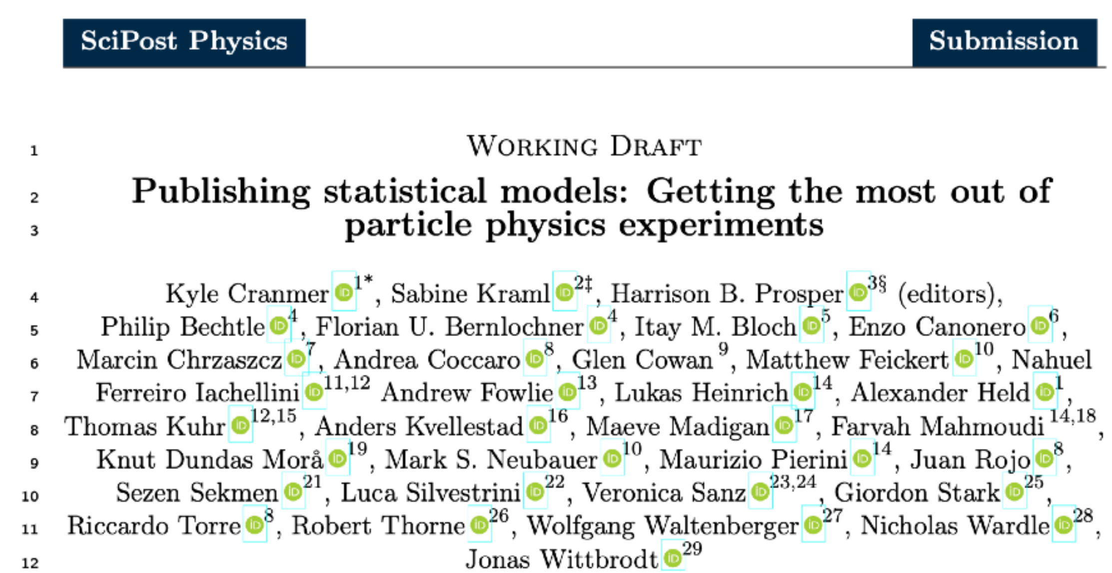
#2

Fold your model into the MC simulation, directly confront the data

#3

Provide theorists with direct measurements of Wilson coefficients; these can be used to confront your favorite model

Highlighted in the report


SciPost Physics — Submission

WORKING DRAFT

Publishing statistical models: Getting the most out of particle physics experiments

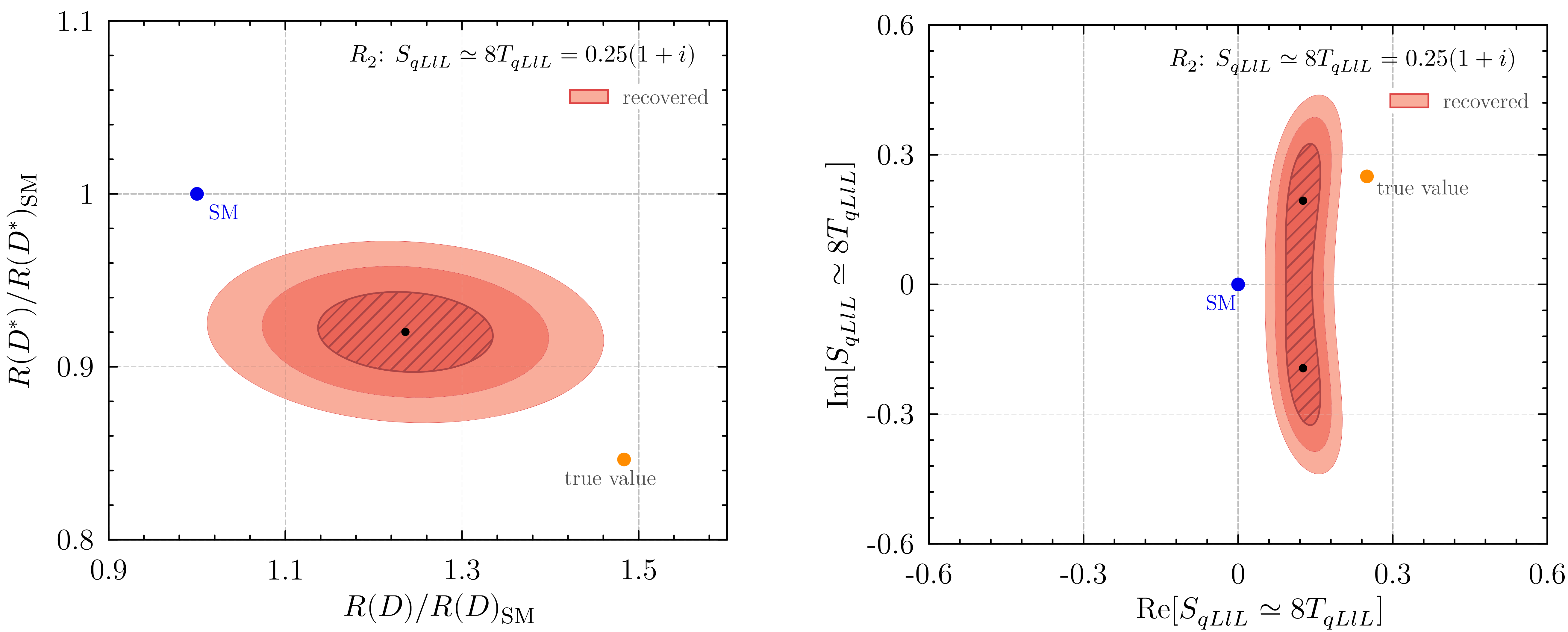
Kyle Cranmer[1*], Sabine Kraml[2†], Harrison B. Prosper[3§] (editors), Philip Bechtle[4], Florian U. Bernlochner[4], Itay M. Bloch[5], Enzo Canonero[6], Marcin Chrzaszcz[7], Andrea Coccaro[8], Glen Cowan[9], Matthew Feickert[10], Nahuel Ferreiro Iachellini[11,12] Andrew Fowlie[13], Lukas Heinrich[14], Alexander Held[1], Thomas Kuhr[12,15], Anders Kvellestad[16], Maeve Madigan[17], Farvah Mahmoudi[14,18], Knut Dundas Morå[19], Mark S. Neubauer[10], Maurizio Pierini[14], Juan Rojo[8], Sezen Sekmen[21], Luca Silvestrini[22], Veronica Sanz[23,24], Giordon Stark[25], Riccardo Torre[8], Robert Thorne[26], Wolfgang Waltenberger[27], Nicholas Wardle[28], Jonas Wittbrodt[29]

↓

Benefit: no biases, more sensitivity as shape of **all** kinematic distributions help distinguish between models

Slightly dramatic example of what could happen

Produce fit shapes / eff. with some NP → Determine $\mathscr{R}(D^{(*)})$ using SM shapes / eff. → Determine NP couplings from measured $\mathscr{R}(D^{(*)})$



Note: the values were chosen intentionally not to reproduce the measured values to avoid the temptation to correct measured values..

HAMMER — a tool to correct $H_b \to H_c \tau \bar{\nu}$ to arbitrary NP

Challenge: Produce MC for each NP working point

- **Need** a **MC generator** that incorporates **all NP effects** and **modern form factors** (e.g. EvtGen does not)

- **Very expensive**; MC statistics is already one of the largest systematic uncertainties on these measurements

HAMMER — a tool to correct $H_b \to H_c \tau \bar{\nu}$ to arbitrary NP

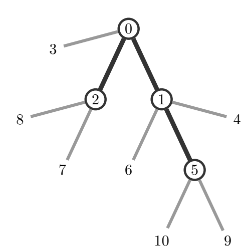
Challenge: Produce MC for each NP working point

- **Need** a **MC generator** that incorporates **all NP effects** and **modern form factors** (e.g. EvtGen does not)
- **Very expensive**; MC statistics is already one of the largest systematic uncertainties on these measurements

HAMMER offers a solution to these problems

$$r_I = \frac{d\Gamma_I^{\rm new}/d\mathcal{PS}}{d\Gamma_I^{\rm old}/d\mathcal{PS}} \, ,$$

Helicity Amplitude Module for Matrix Element Reweighting



To correct angular distributions one needs to do this for all D* and τ decay products

SM or Phase-space MC can be corrected to NP or FFs via ratio of event weights

encode hadronic form factors

tensor that encodes amplitudes of given process

$$\sum_{\alpha,i,\beta,j} c_\alpha c_\beta^\dagger F_i F_j^\dagger W_{\alpha i \beta j} \, ,$$

sum independent of Wilson coefficients c_α
→ can exploit this to create **fast predictions**

https://hammer.physics.lbl.gov/

The work program

0. Do the SM analyses :-)

It's a very sensible null-test in its own right and these are very complicated analyses by their own right.

1. Use HAMMER to directly fit for Wilson coefficients $\mathbf{c}$ using experimental spectra, ideally combining the statistical power of several channels and observables

e.g. Belle II can access to several orthogonal measurements and properties

$\mathscr{R}(D^{(*)})$

had. Tagging leptonic τ

had. Tagging hadronic τ

SL Tagging leptonic τ

incl. Tagging leptonic τ

($\mathscr{R}(X_c)$: had. Tagging leptonic τ — $\mathscr{R}(\pi/\rho/\omega)$: had. Tagging all τ)

$$\prod_i \mathscr{L}_i(\mathbf{c}, \theta)$$

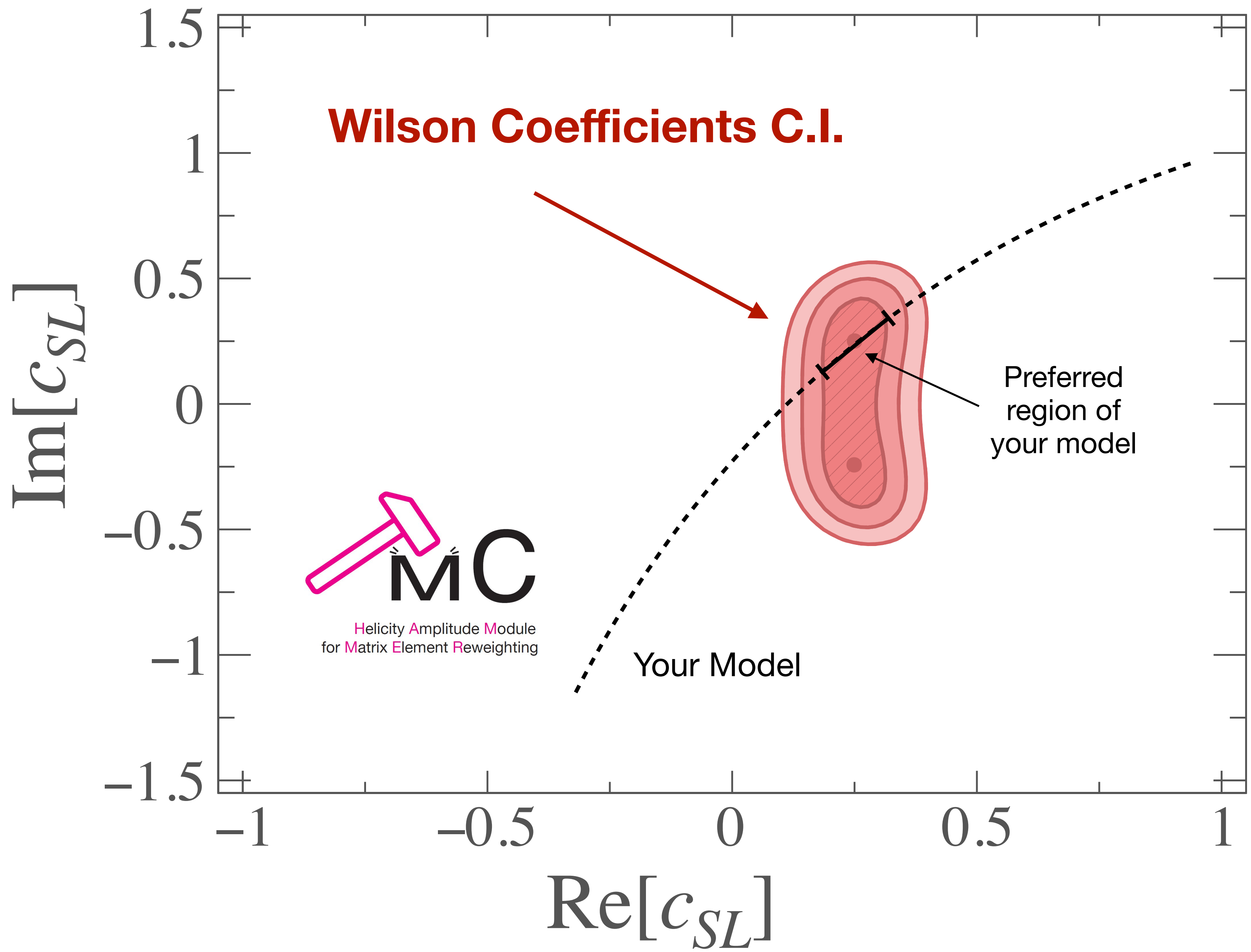
full experimental likelihoods with full dependence on systematic NPs θ (and Wilson coefficients)

↔

Lepton ID
Hadron ID
D** Bkgs
Other common Bkgs

2. Provide theorists with **direct limits on Wilson** coefficients, that **incorporate all experimental effects** on *kinematic shape* changes and *efficiency x acceptance*

FB, S. Duell, Z. Ligeti, M. Papucci, D. Robinson
Eur. Phys. J. C (2020) **80**: 883 [arXiv:2002:00020]



With the profile likelihood contour or C.I. contours you can directly fit your model to all our data

The full work program: include the LHC

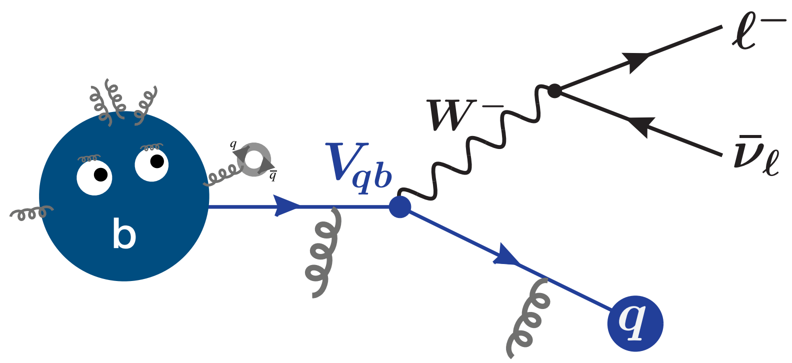
Belle II + LHCb

$\mathscr{R}(D^{(*)})$	$\mathscr{R}(X_{(c)})$	$\mathscr{R}(\pi/\rho/\omega)$
had. Tagging leptonic τ	had. Tagging leptonic τ	had. Tagging all τ
had. Tagging hadronic τ		
SL Tagging leptonic τ		
incl. Tagging leptonic τ		

$\mathscr{R}(D^{(*)})$	$\mathscr{R}(J/\psi)$	$\mathscr{R}(\Lambda_c)$
leptonic τ	leptonic τ	leptonic τ
hadronic τ	hadronic τ	hadronic τ

$\mathscr{R}(D_s^{(*)})$

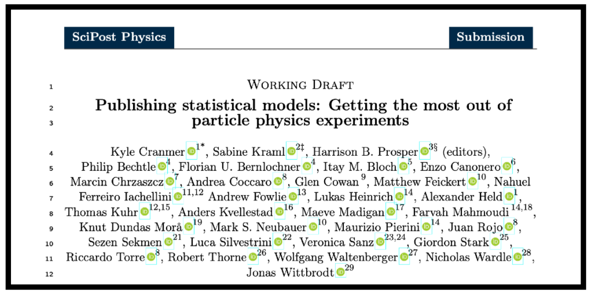
- leptonic τ
- hadronic τ



Create a **truly global** fit for $b \to c\tau\bar{\nu}_\tau$ (or $b \to q\tau\bar{\nu}_\tau$) that avoids biases & SM priors

Adding additional observables (e.g. polarizations) is straightforward as the kinematic regions sensitive to such can be readily included

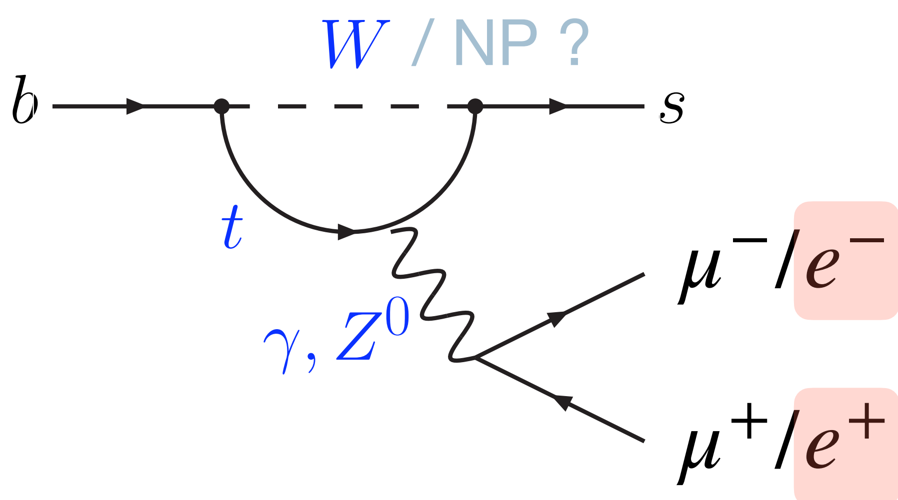
Drawback: FFs are convolved with measured Wilson Coefficient
→ we should provide the entire framework to allow future updates →


SciPost Physics Submission

Working Draft

Publishing statistical models: Getting the most out of particle physics experiments

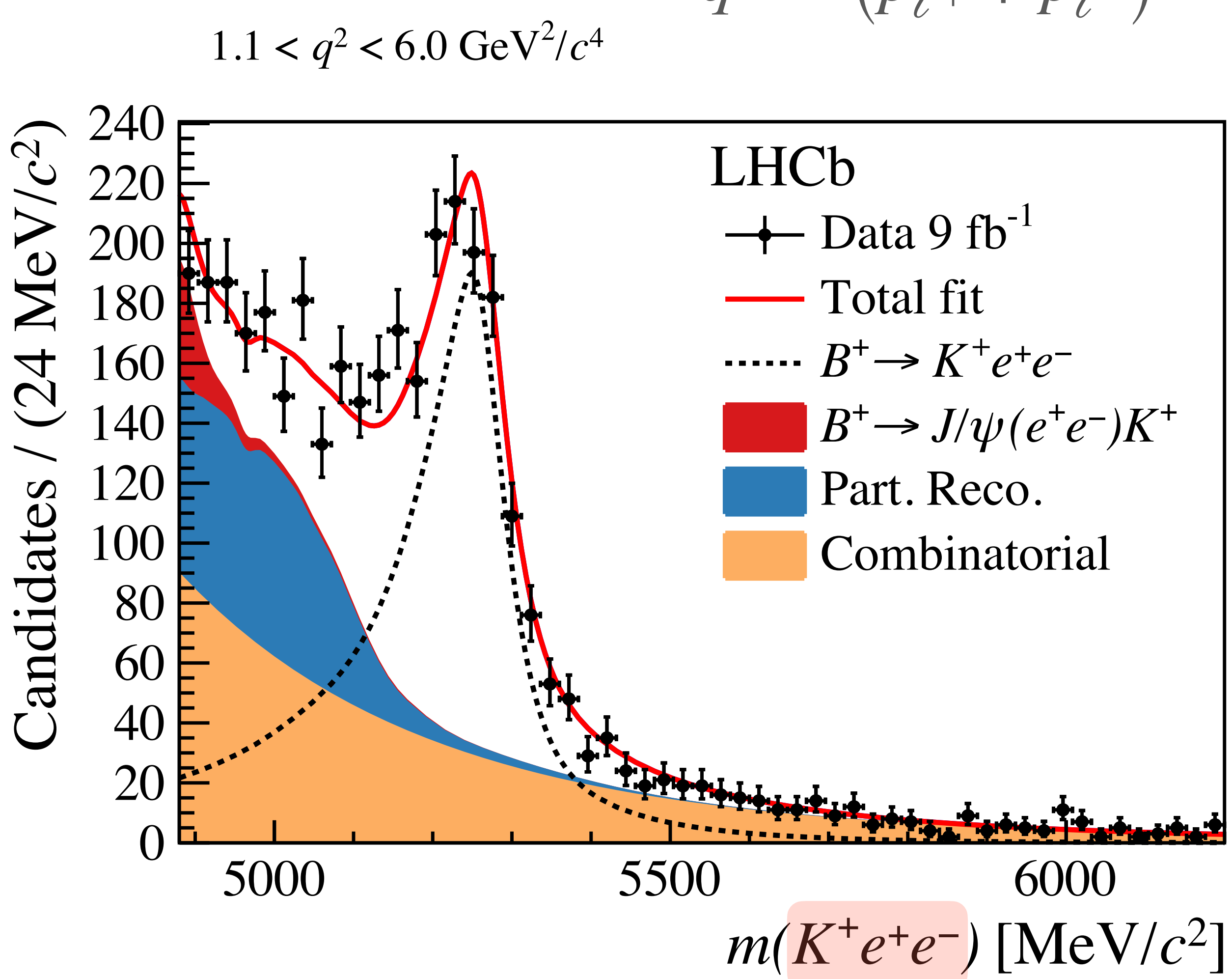
The $b \to s\ell\ell$ anomalies



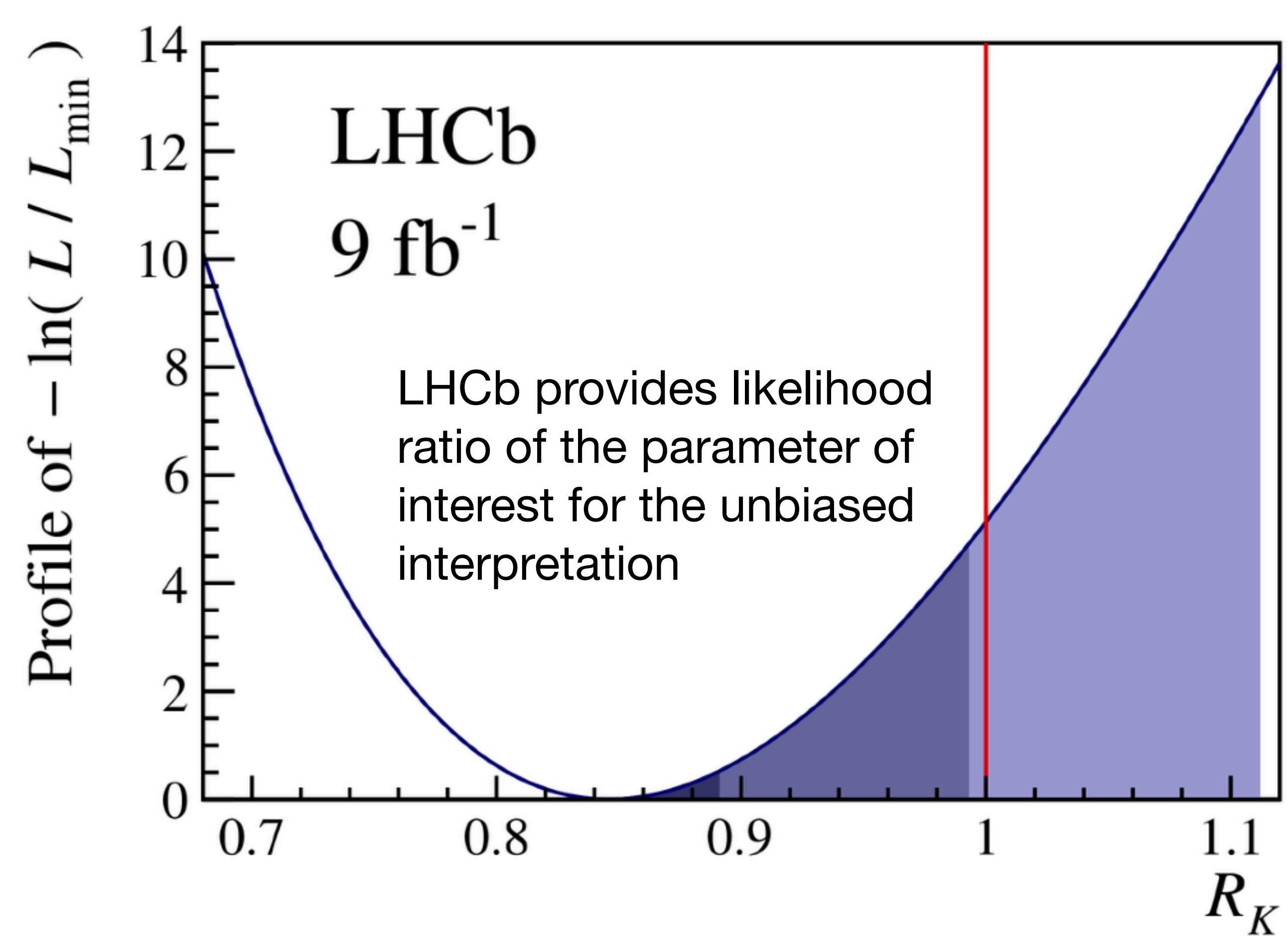
→ Ratio again excellent probe to search for NP

$$R(K) = \frac{\mathscr{B}(B \to K\mu\mu)}{\mathscr{B}(B \to Kee)}$$

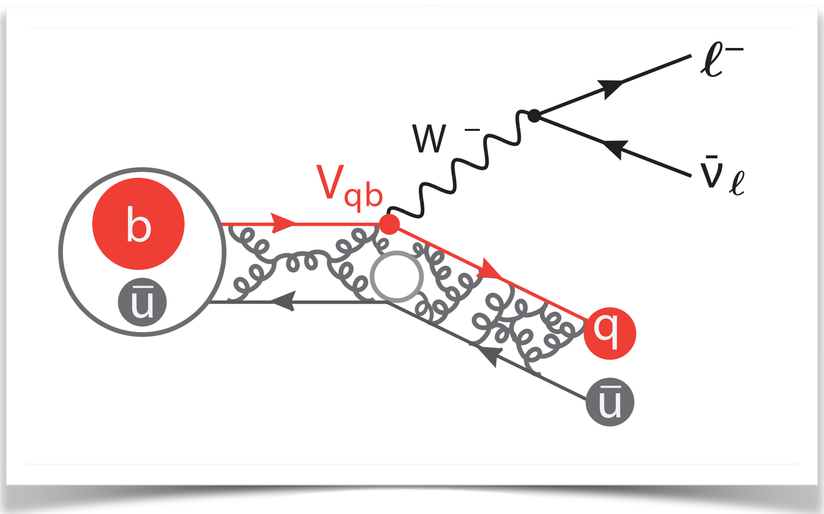
$$q^2 = (p_{\ell^+} + p_{\ell^-})^2$$



1.1 < q^2 < 6.0 GeV^2/c^4 2103.11769 [hep-ex]



A quick boot-camp: how do we measure $\left|V_{ub}\right|$ & $\left|V_{cb}\right|$?



Inclusive |V_ub|

$$\bar{B} \to X_u \, \ell \, \bar{\nu}_\ell$$

+ Fermi Motion / Shape Function

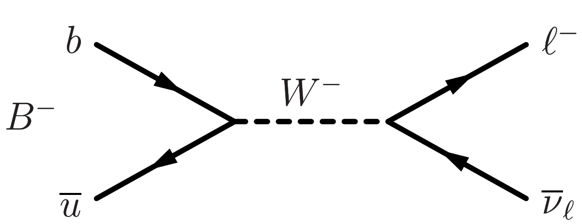
Inclusive |V_cb|

$$\bar{B} \to X_c \, \ell \, \bar{\nu}_\ell$$

Operator Product Expansion

$$\mathcal{B} = |V_{qb}|^2 \left[\Gamma(b \to q \, \ell \, \bar{\nu}_\ell) + 1/m_{c,b} + \alpha_s + \ldots \right]$$

'Leptonic' |V_ub|



$$\mathcal{B} \propto |V_{ub}|^2 \, f_B^2 \, m_\ell^2$$

B-Meson decay constant

Exclusive |V_ub|

$$\bar{B} \to \pi \, \ell \, \bar{\nu}_\ell, \Lambda_b \to p \, \mu \, \bar{\nu}_\mu$$

Exclusive |V_cb|

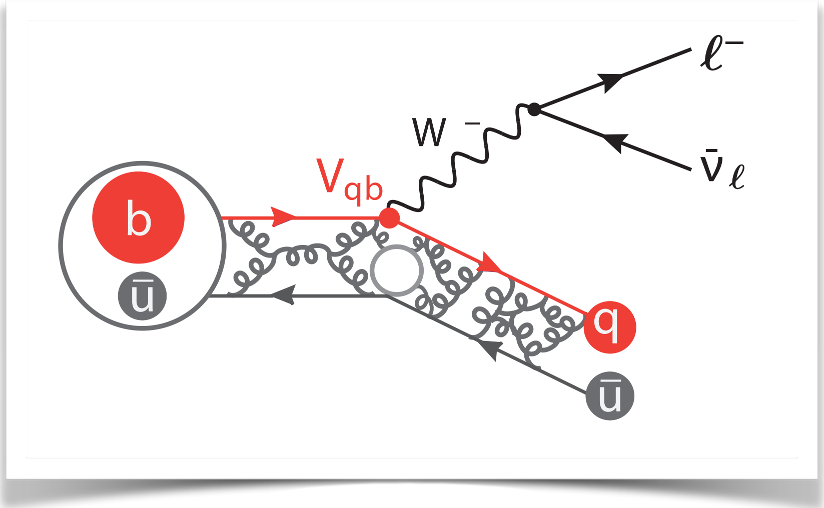
$$\bar{B} \to D \, \ell \, \bar{\nu}_\ell, \bar{B} \to D^* \, \ell \, \bar{\nu}_\ell$$

$$\mathcal{B} \propto |V_{cb}|^2 \, f^2$$

Form Factors

$$\langle B | H_\mu | P \rangle = (p + p')_\mu \, f_+$$

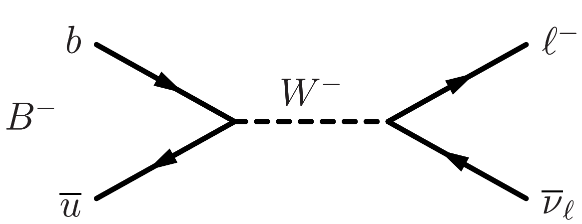
A quick boot-camp: how do we measure $|V_{ub}|$ & $|V_{cb}|$?



Inclusive $|V_{ub}|$

Inclusive $|V_{cb}|$

‘Leptonic’ $|V_{ub}|$



$$\mathcal{B} \propto |V_{ub}|^2 f_B^2 m_\ell^2$$

B-Meson decay constant

Measured
Branching Fraction

$$|V_{qb}| = \sqrt{\frac{\mathcal{B}(\bar{B} \to X_q \, \ell \, \bar{\nu}_\ell)}{\tau \, \Gamma(\bar{B} \to X_q \, \ell \, \bar{\nu}_\ell)}}$$

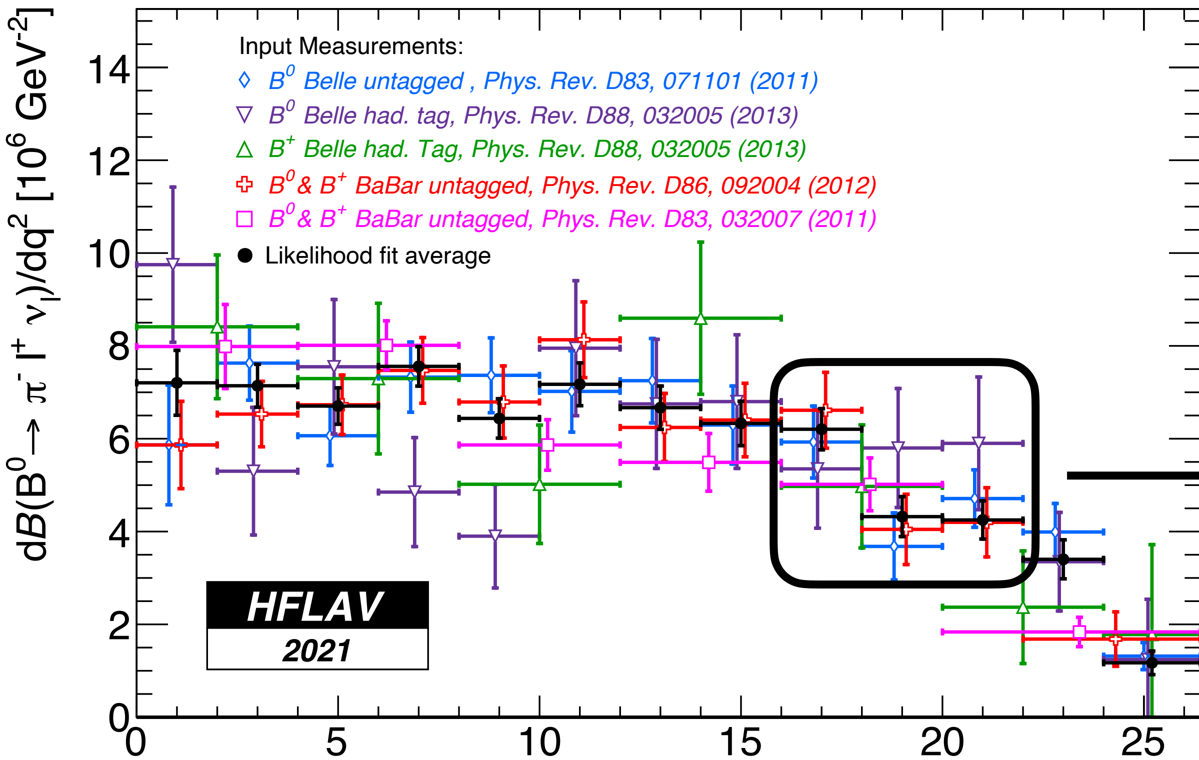
Prediction from
Theory but often also constrained
from **measured differential distributions**

Theory from non-perturbative Methods:

- Lattice QCD (high q^2)
- QCD Sum rules (low q^2)

$$q^2 = (p - p')^2$$

Global averages on the example of $B \to \pi \ell \bar{\nu}_\ell$



$$q^2 = (p_B - p_\pi)^2 = (p_\ell + p_\nu)^2 \quad [\mathrm{GeV}^2]$$

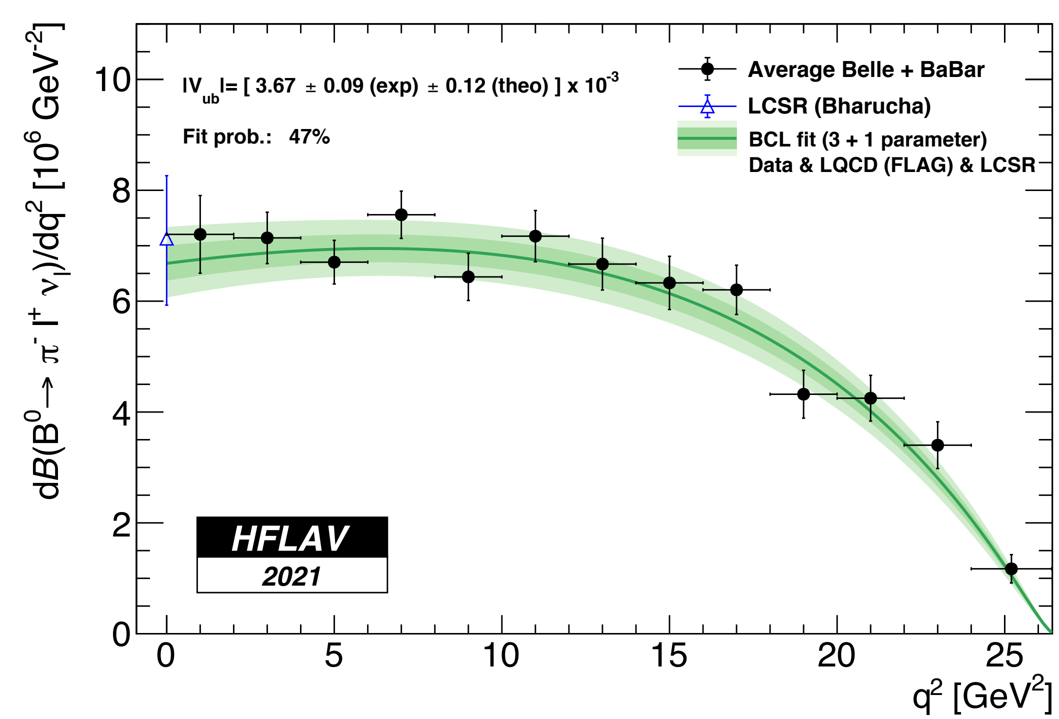
Use **coarse** bins to **constrain sum** of **fine bins** to retain finest granularity in average

$$\prod_i \mathcal{G}_i(x_i^m; \sum_j x_{ij}, \sigma_i)$$

includes correlated systematic errors as NPs

Average can be fitted with **any choice** of form factor parametrization and also by theorists;

$$|V_{ub}| = (3.70 \pm 0.10_{\,\mathrm{exp}} \pm 0.12_{\,\mathrm{theo}}) \times 10^{-3} \;\; (\mathrm{data} + \mathrm{LQCD}),$$
$$|V_{ub}| = (3.67 \pm 0.09_{\,\mathrm{exp}} \pm 0.12_{\,\mathrm{theo}}) \times 10^{-3} \;\; (\mathrm{data} + \mathrm{LQCD} + \mathrm{LCSR}),$$



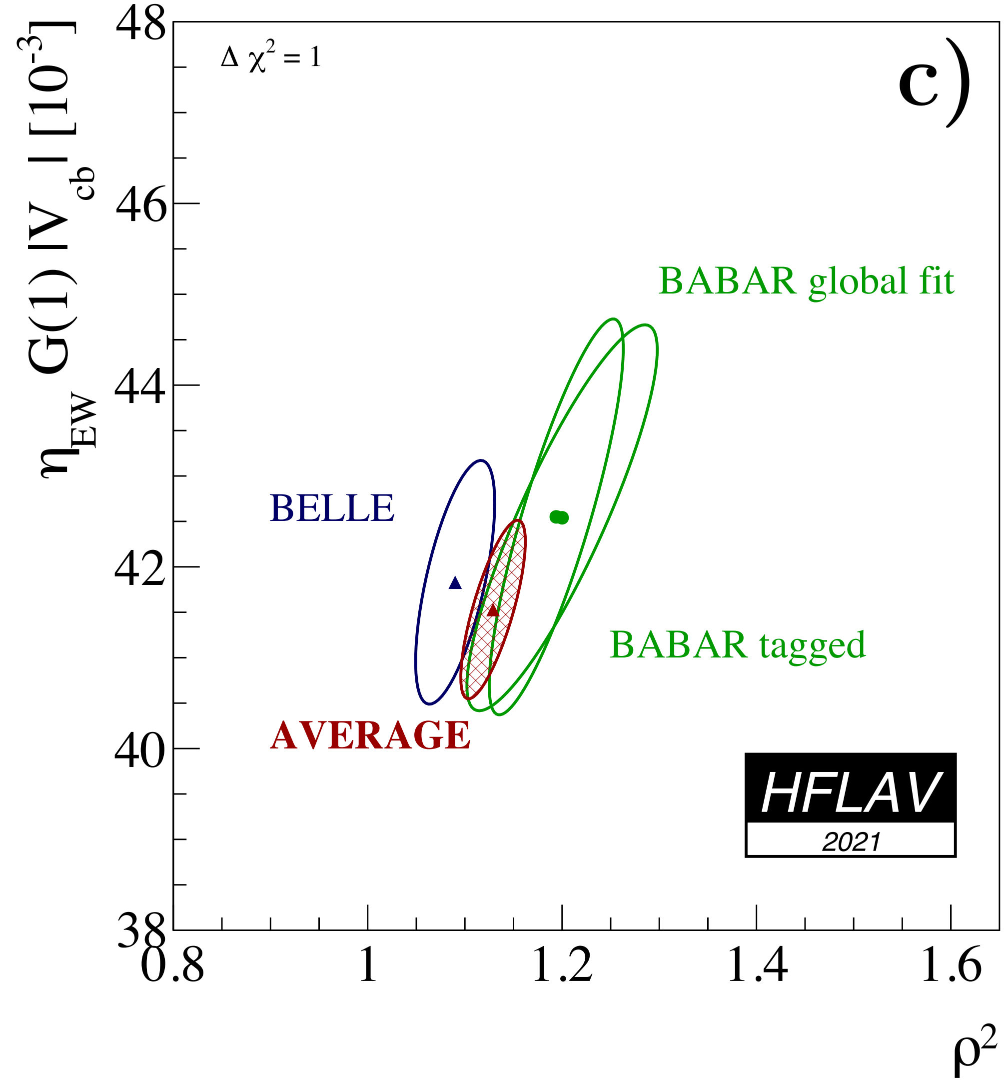
Global averages on the example of $B \to D^{(*)}\ell\bar{\nu}_\ell$

For $B \to D^{(*)}\ell\bar{\nu}_\ell$ traditionally **single form factor** parametrization (CLN) was used.

Measurements directly determined the parameters and quoted these with correlations.

Problem: Theory knowledge advances; **today more** general parametrizations are preferred (BGL, BLPR, …)

Experiment	$\eta_{EW}\mathcal{F}(1)\lvert V_{cb}\rvert[10^{-3}]$ (rescaled) $\eta_{EW}\mathcal{F}(1)\lvert V_{cb}\rvert[10^{-3}]$ (published)	ρ^2 (rescaled) ρ^2 (published)
ALEPH [497]	$31.38 \pm 1.80_{stat} \pm 1.24_{syst}$ $31.9 \pm 1.8_{stat} \pm 1.9_{syst}$	$0.488 \pm 0.226_{stat} \pm 0.146_{syst}$ $0.37 \pm 0.26_{stat} \pm 0.14_{syst}$
CLEO [501]	$40.16 \pm 1.24_{stat} \pm 1.54_{syst}$ $43.1 \pm 1.3_{stat} \pm 1.8_{syst}$	$1.363 \pm 0.084_{stat} \pm 0.087_{syst}$ $1.61 \pm 0.09_{stat} \pm 0.21_{syst}$
OPAL excl [498]	$36.20 \pm 1.58_{stat} \pm 1.47_{syst}$ $36.8 \pm 1.6_{stat} \pm 2.0_{syst}$	$1.198 \pm 0.206_{stat} \pm 0.153_{syst}$ $1.31 \pm 0.21_{stat} \pm 0.16_{syst}$
OPAL partial reco [498]	$37.44 \pm 1.20_{stat} \pm 2.32_{syst}$ $37.5 \pm 1.2_{stat} \pm 2.5_{syst}$	$1.090 \pm 0.137_{stat} \pm 0.297_{syst}$ $1.12 \pm 0.14_{stat} \pm 0.29_{syst}$
DELPHI partial reco [499]	$35.52 \pm 1.41_{stat} \pm 2.29_{syst}$ $35.5 \pm 1.4_{stat}\ {}^{+2.3}_{-2.4 syst}$	$1.139 \pm 0.123_{stat} \pm 0.382_{syst}$ $1.34 \pm 0.14_{stat}\ {}^{+0.24}_{-0.22 syst}$
DELPHI excl [500]	$35.87 \pm 1.69_{stat} \pm 1.95_{syst}$ $39.2 \pm 1.8_{stat} \pm 2.3_{syst}$	$1.070 \pm 0.141_{stat} \pm 0.153_{syst}$ $1.32 \pm 0.15_{stat} \pm 0.33_{syst}$
Belle [502]	$34.82 \pm 0.15_{stat} \pm 0.55_{syst}$ $35.06 \pm 0.15_{stat} \pm 0.56_{syst}$	$1.106 \pm 0.031_{stat} \pm 0.008_{syst}$ $1.106 \pm 0.031_{stat} \pm 0.007_{syst}$
BABAR excl [503]	$33.37 \pm 0.29_{stat} \pm 0.97_{syst}$ $34.7 \pm 0.3_{stat} \pm 1.1_{syst}$	$1.182 \pm 0.048_{stat} \pm 0.029_{syst}$ $1.18 \pm 0.05_{stat} \pm 0.03_{syst}$
BABAR D^{*0} [507]	$34.55 \pm 0.58_{stat} \pm 1.06_{syst}$ $35.9 \pm 0.6_{stat} \pm 1.4_{syst}$	$1.124 \pm 0.058_{stat} \pm 0.053_{syst}$ $1.16 \pm 0.06_{stat} \pm 0.08_{syst}$
BABAR global fit [509]	$35.45 \pm 0.20_{stat} \pm 1.08_{syst}$ $35.7 \pm 0.2_{stat} \pm 1.2_{syst}$	$1.171 \pm 0.019_{stat} \pm 0.060_{syst}$ $1.21 \pm 0.02_{stat} \pm 0.07_{syst}$
Average	$\mathbf{35.00 \pm 0.11_{stat} \pm 0.34_{syst}}$	$\mathbf{1.121 \pm 0.014_{stat} \pm 0.019_{syst}}$



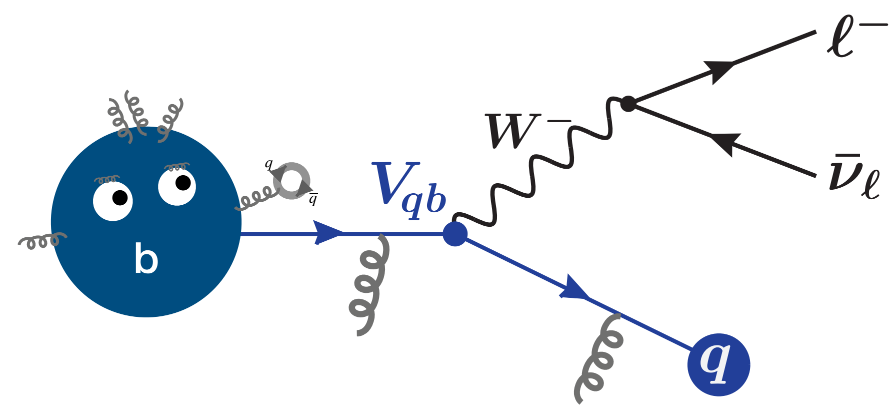
Old measurements **cannot be updated** to such as not the underlying distributions were provided but only the result.

We should **avoid** this in the future.

Summary

Two categories of flavor measurements:

Measurements with **no / trivial / negligible** model-dependence on their observable of interest



Measurements with **non-trivial** dependence on parameter of interest

→ publishing the full statistical model opens a **world of applications**

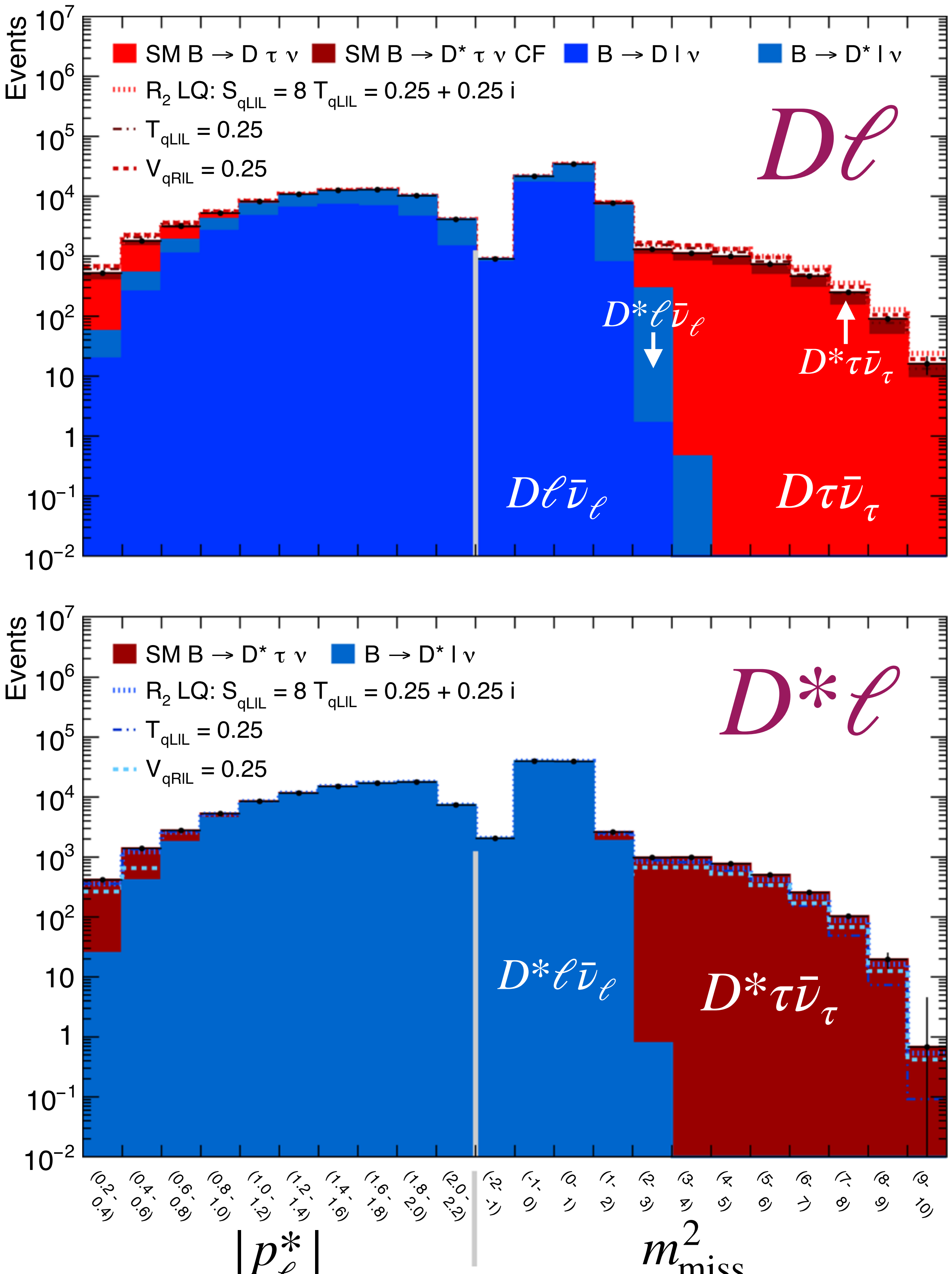
Publishing the full statistical model also **future-proofs** a result; desired parameterizations and applications change over time; new ideas emerge.

Let's make our results **ready** for them.

More Information

An illustrative Toy Example

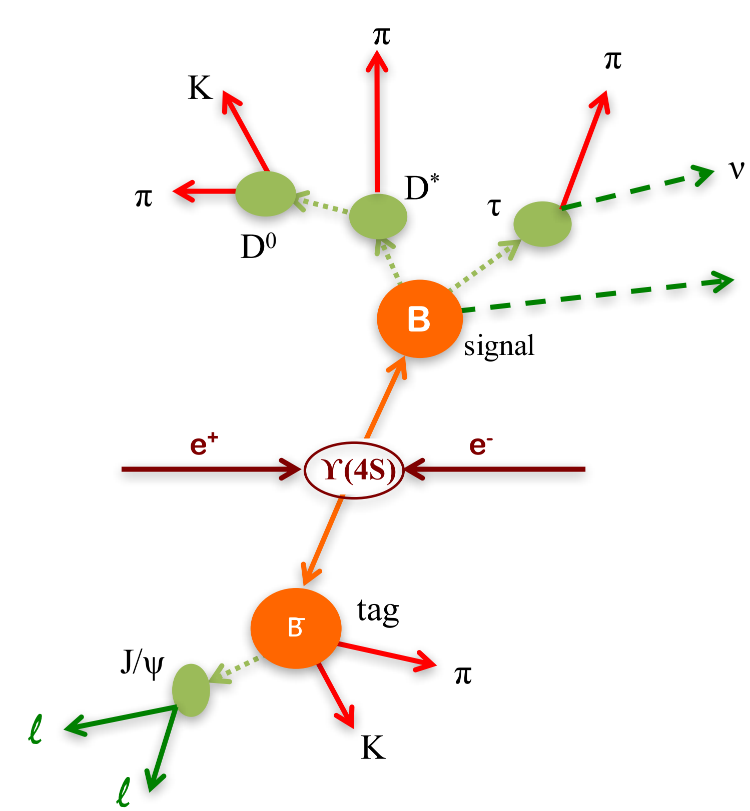
FB, S. Duell, Z. Ligeti, M. Papucci, D. Robinson
Eur. Phys. J. C (2020) **80**: 883 [arXiv:2002:00020]



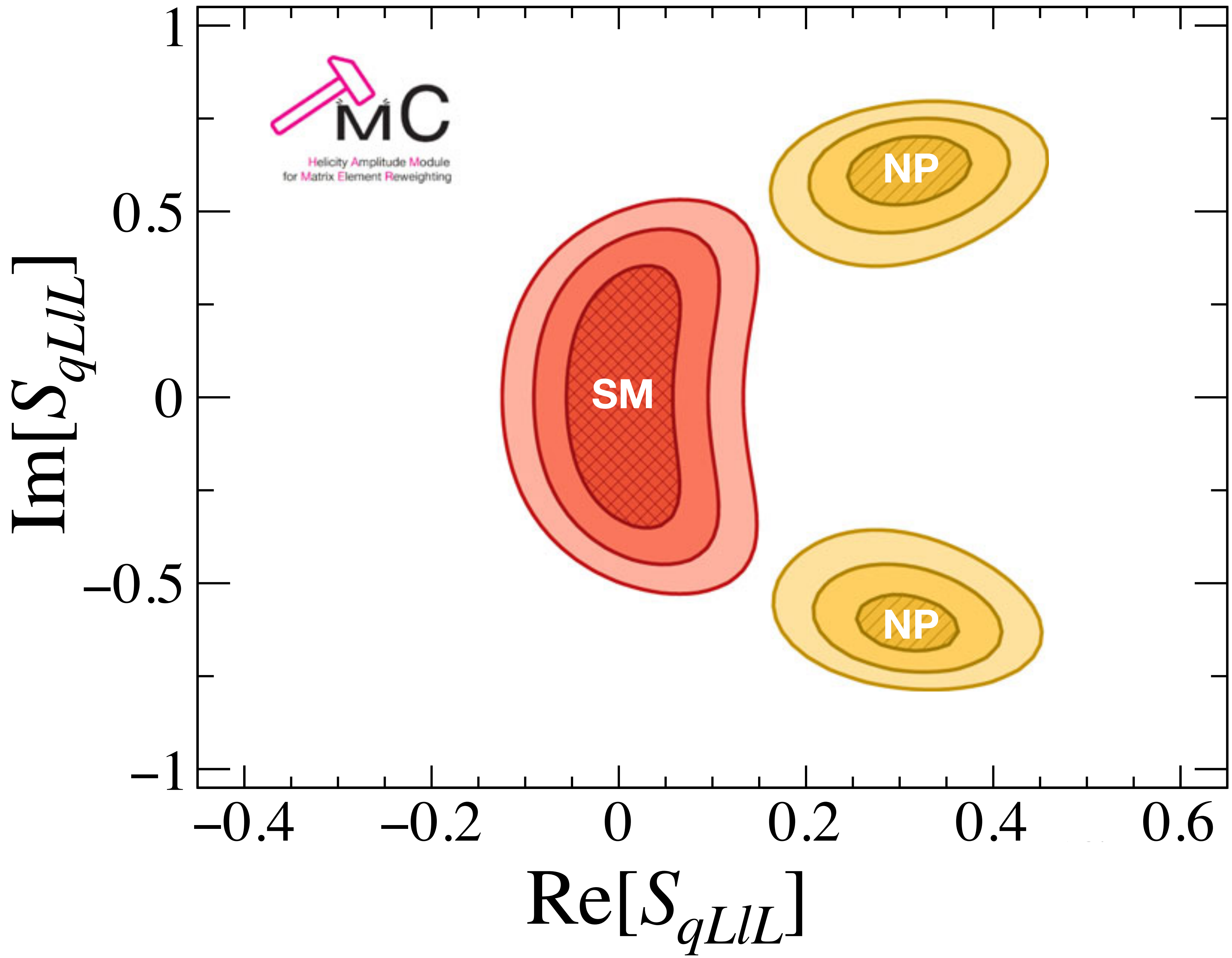
2 Categories: $D\ell, D^*\ell$

Binned 2D fit in $m_{\rm miss}^2 : |p_\ell^*|$

Corresponds to a guestimate of how an analysis with 5/ab of Belle II data could look like in a single channel



A toy example



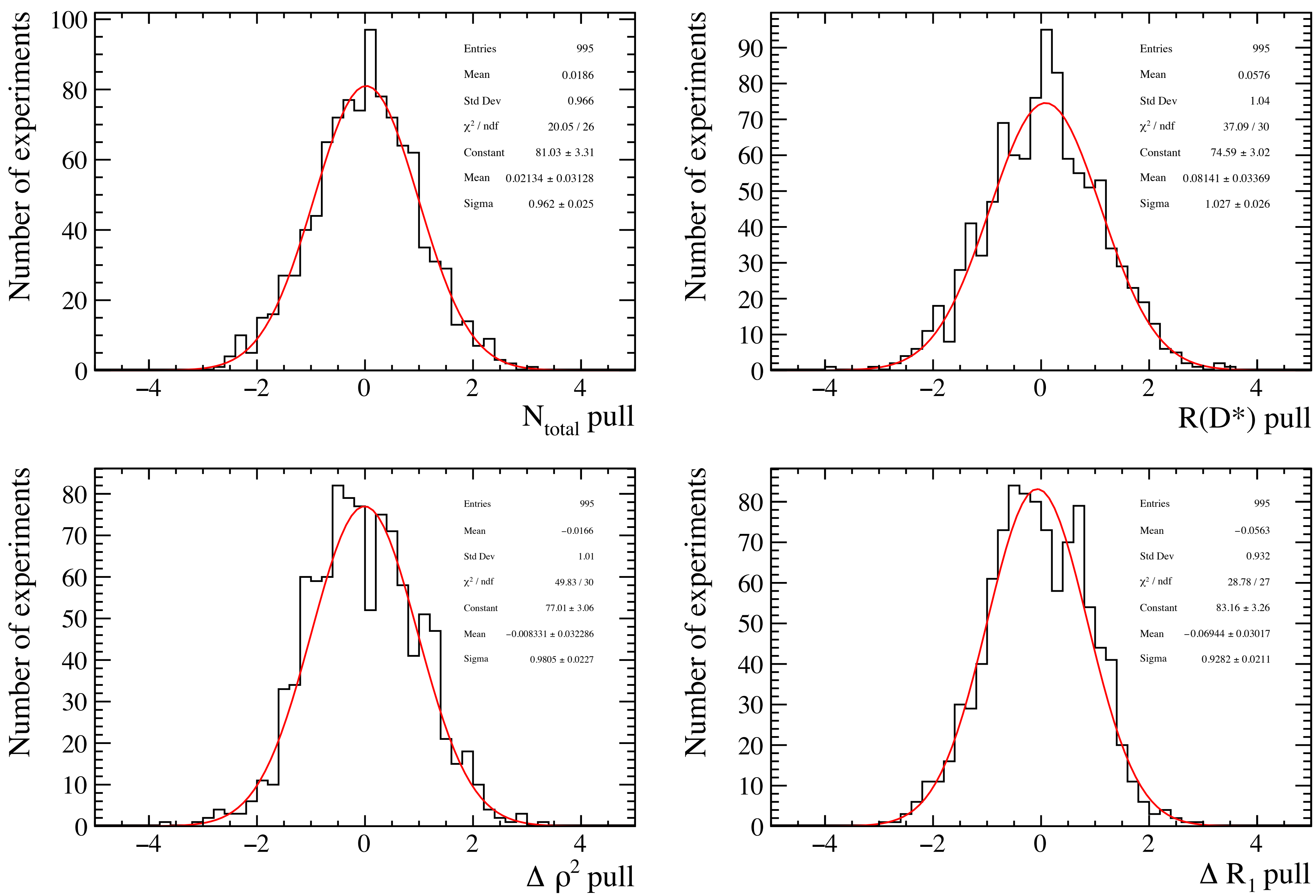
RooHammerModel

RooHammerModel: interfacing the HAMMER software tool with the HistFactory package

J. García Pardiñas[1,*], S. Meloni[2,3,†],
L. Grillo[4], P. Owen[1], M. Calvi[2,3], and N. Serra[1]

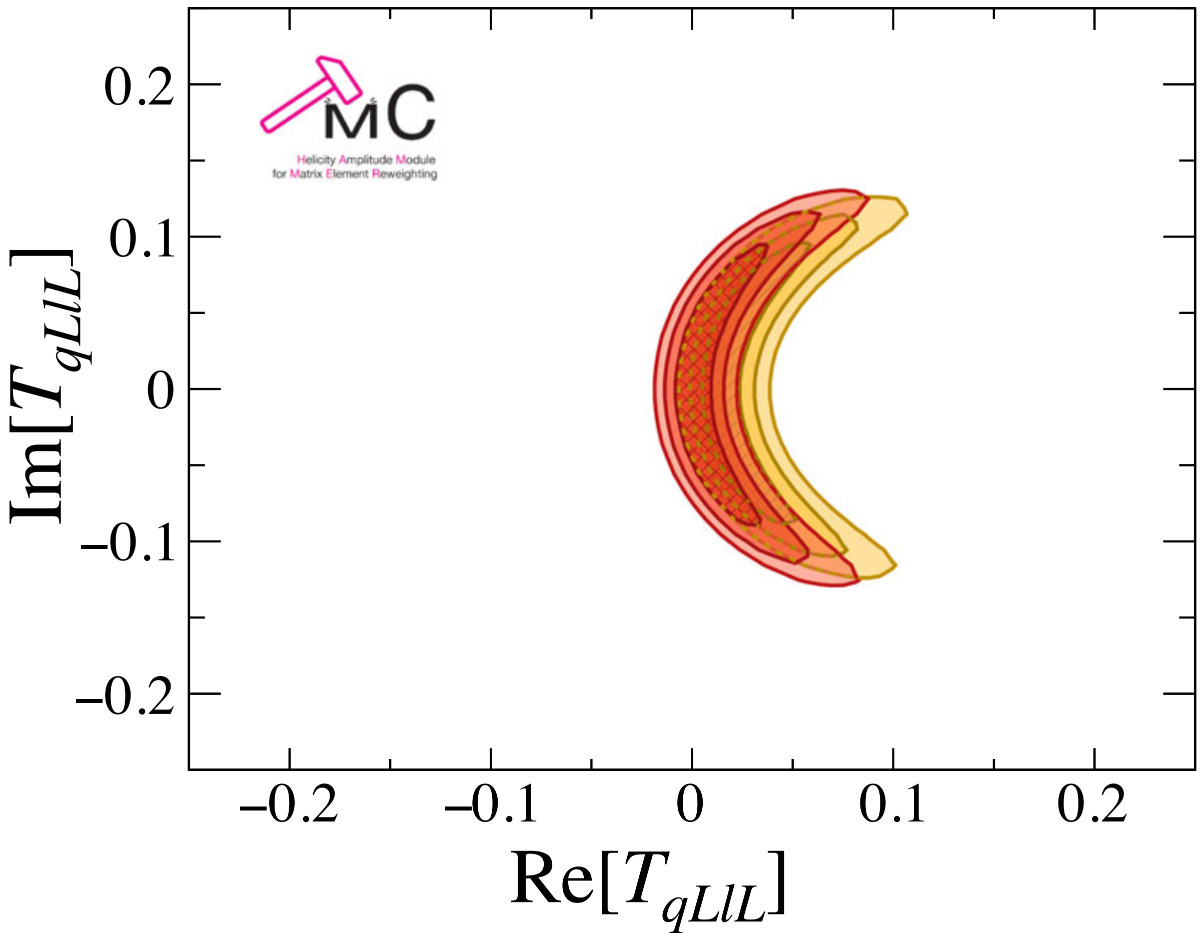
[1] Physik-Institut, Universität Zürich, Zürich, Switzerland
[2] Università di Milano Bicocca, Milano, Italy
[3] INFN Sezione di Milano-Bicocca, Milano, Italy
[4] School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom

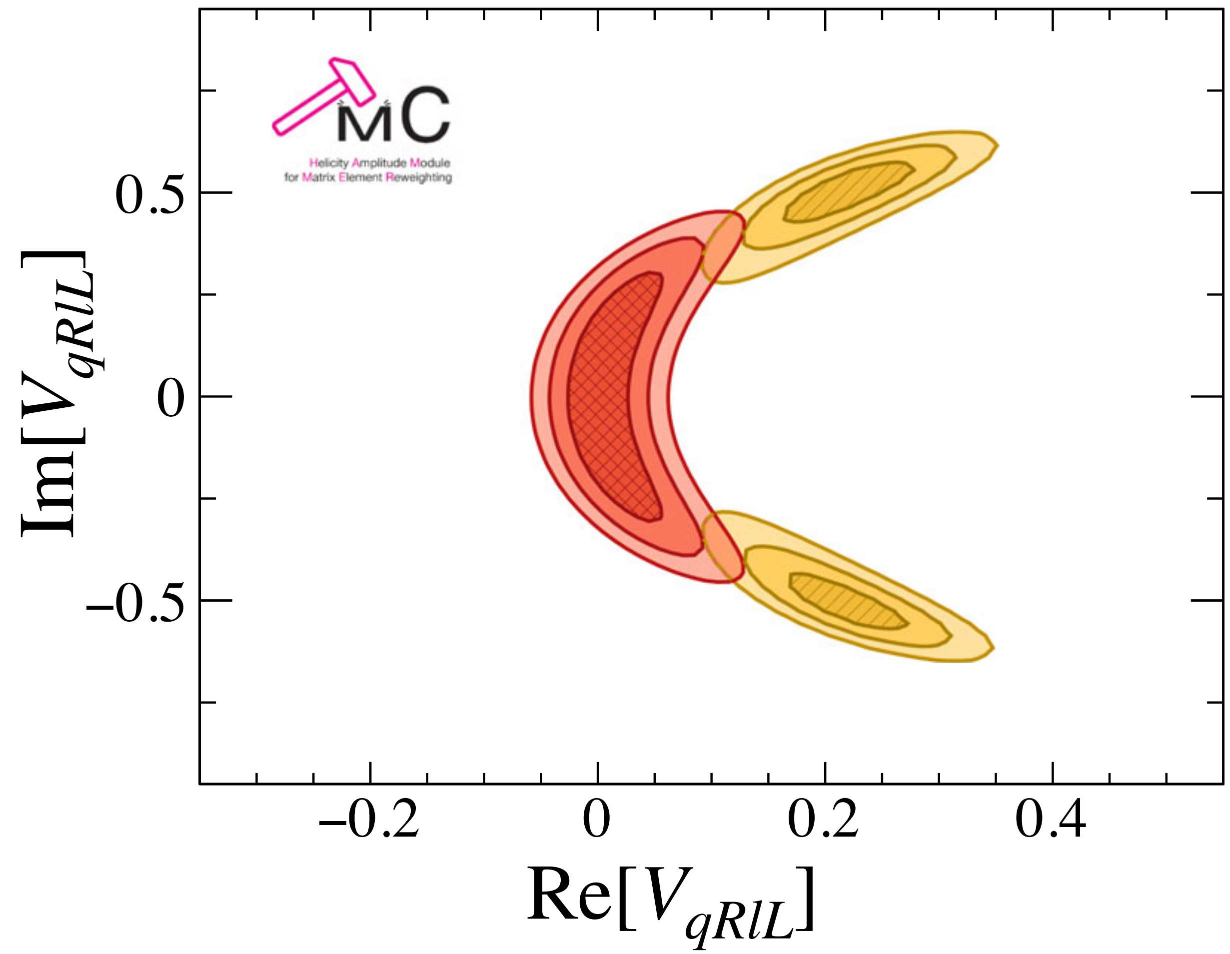
arXiv:2007.12605 **[hep-ph]**



More examples

FB, S. Duell, Z. Ligeti, M. Papucci, D. Robinson
Eur. Phys. J. C (2020) **80**: 883 [arXiv:2002:00020]





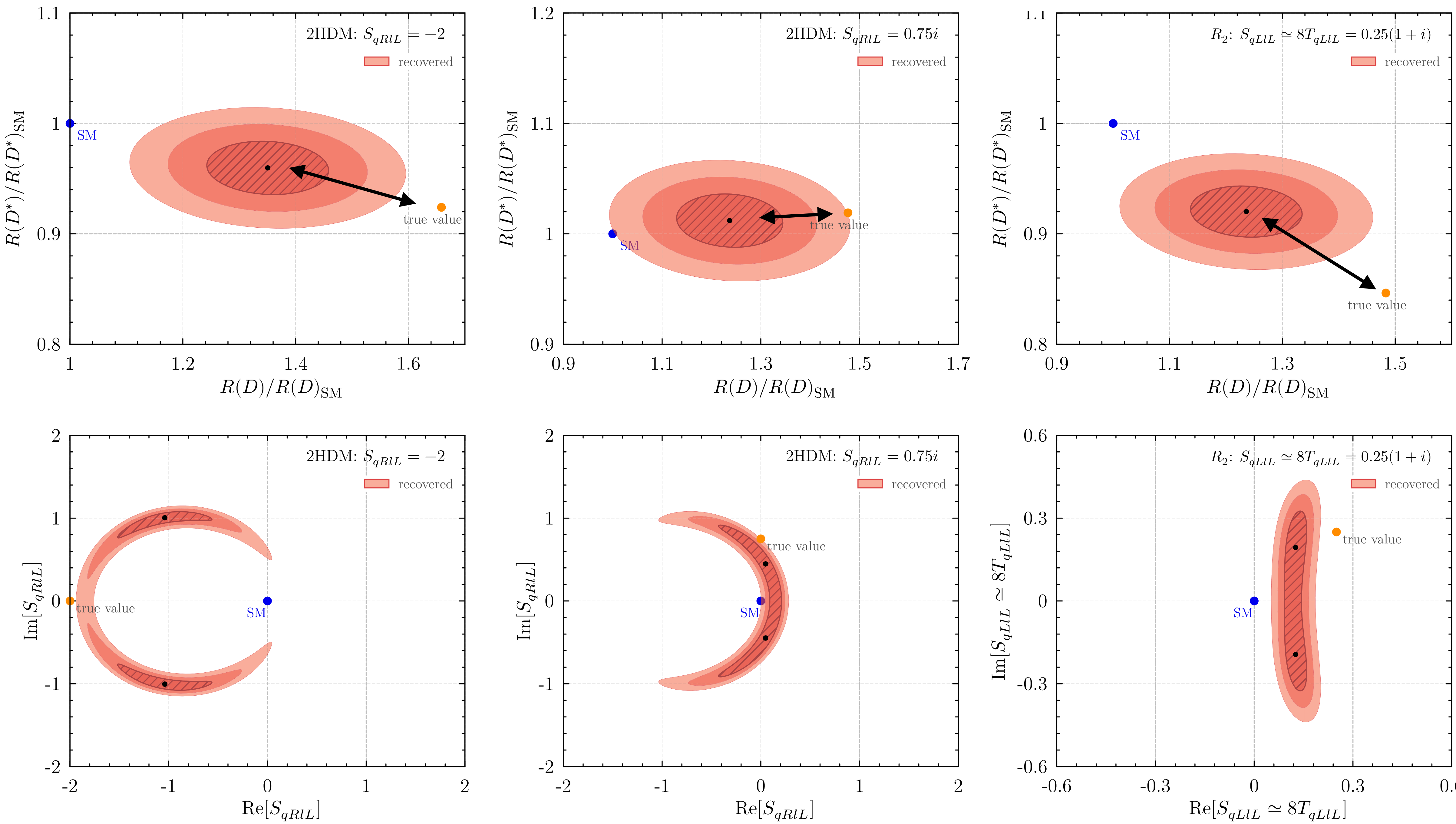
Form factors implemented in the HAMMER-library

Process	Form factor parametrizations
$B \to D^{(*)}\ell\nu$	ISGW2* [41, 42], BGL* [43–45], CLN*‡ [46], BLPR‡ [19]
$B \to (D^* \to D\pi)\ell\nu$	ISGW2*, BGL*‡, CLN*‡, BLPR‡
$B \to (D^* \to D\gamma)\ell\nu$	ISGW2*, BGL*‡, CLN*‡, BLPR‡
$\tau \to \pi\nu$	—
$\tau \to \ell\nu\nu$	—
$\tau \to 3\pi\nu$	RCT* [47–49]
$B \to D_0^*\ell\nu$	ISGW2*, LLSW* [50, 51], BLR‡ [52, 53]
$B \to D_1^*\ell\nu$	ISGW2*, LLSW*, BLR‡
$B \to D_1\ell\nu$	ISGW2*, LLSW*, BLR‡
$B \to D_2^*\ell\nu$	ISGW2*, LLSW*, BLR‡
$\Lambda_b \to \Lambda_c\ell\nu$	PCR* [54], BLRS‡ [55, 56]
Planned for next release	
$B_{(c)} \to \ell\nu$	MSbar
$B \to (\rho \to \pi\pi)\ell\nu$	BCL* [57], BSZ [58]
$B \to (\omega \to \pi\pi\pi)\ell\nu$	BCL*, BSZ
$B_c \to (J/\psi \to \ell\ell)\ell\nu$	EFG* [59], BGL*‡ [60]
$\Lambda_b \to \Lambda_c^*\ell\nu$	PCR*, ...
$\tau \to 4\pi\nu$	RCT*
$\tau \to (\rho \to \pi\pi)\nu$	—

More bias scenarios

$$
\begin{aligned}
\text{2HDM } (-2): \quad & \hat{R}(D)_{\rm rec} = 1.35(7)\,, && \hat{R}(D)_{\rm th} = 1.66 \\
& \hat{R}(D^*)_{\rm rec} = 0.96(2)\,, && \hat{R}(D^*)_{\rm th} = 0.92 \\
\text{2HDM } (0.75i): \quad & \hat{R}(D)_{\rm rec} = 1.24(7)\,, && \hat{R}(D)_{\rm th} = 1.48 \\
& \hat{R}(D^*)_{\rm rec} = 1.01(2)\,, && \hat{R}(D^*)_{\rm th} = 1.02 \\
R_2: \quad & \hat{R}(D)_{\rm rec} = 1.24(7)\,, && \hat{R}(D)_{\rm th} = 1.48 \\
& \hat{R}(D^*)_{\rm rec} = 0.92(2)\,, && \hat{R}(D^*)_{\rm th} = 0.85\,.
\end{aligned}
$$

FB, S. Duell, Z. Ligeti, M. Papucci, D. Robinson
Eur. Phys. J. C (2020) **80**: 883 [arXiv:2002:00020]



Take home message: the actual true value of the NP coupling could be ruled out by your interpretation of $\mathscr{R}(D/D^*)$

Impact of τ**-polarisation in** $\tau^- \to \ell^- \bar{\nu}_\ell \nu_\tau$ **decays :**

- **secondary lepton** emitted preferentially **in** the **direction** of the τ
  - **Carries more momentum of the τ-lepton**
+ **secondary lepton** emitted preferentially **against** the **direction** of the τ
  - **Carries less momentum of the τ-lepton**