$\mathscr{R}(D^{(*)})$: Status and prospects @ Belle (II)

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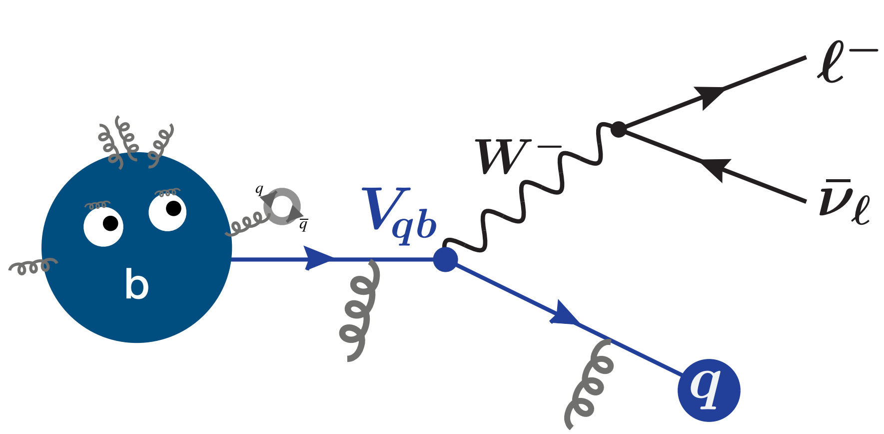
Florian Bernlochner

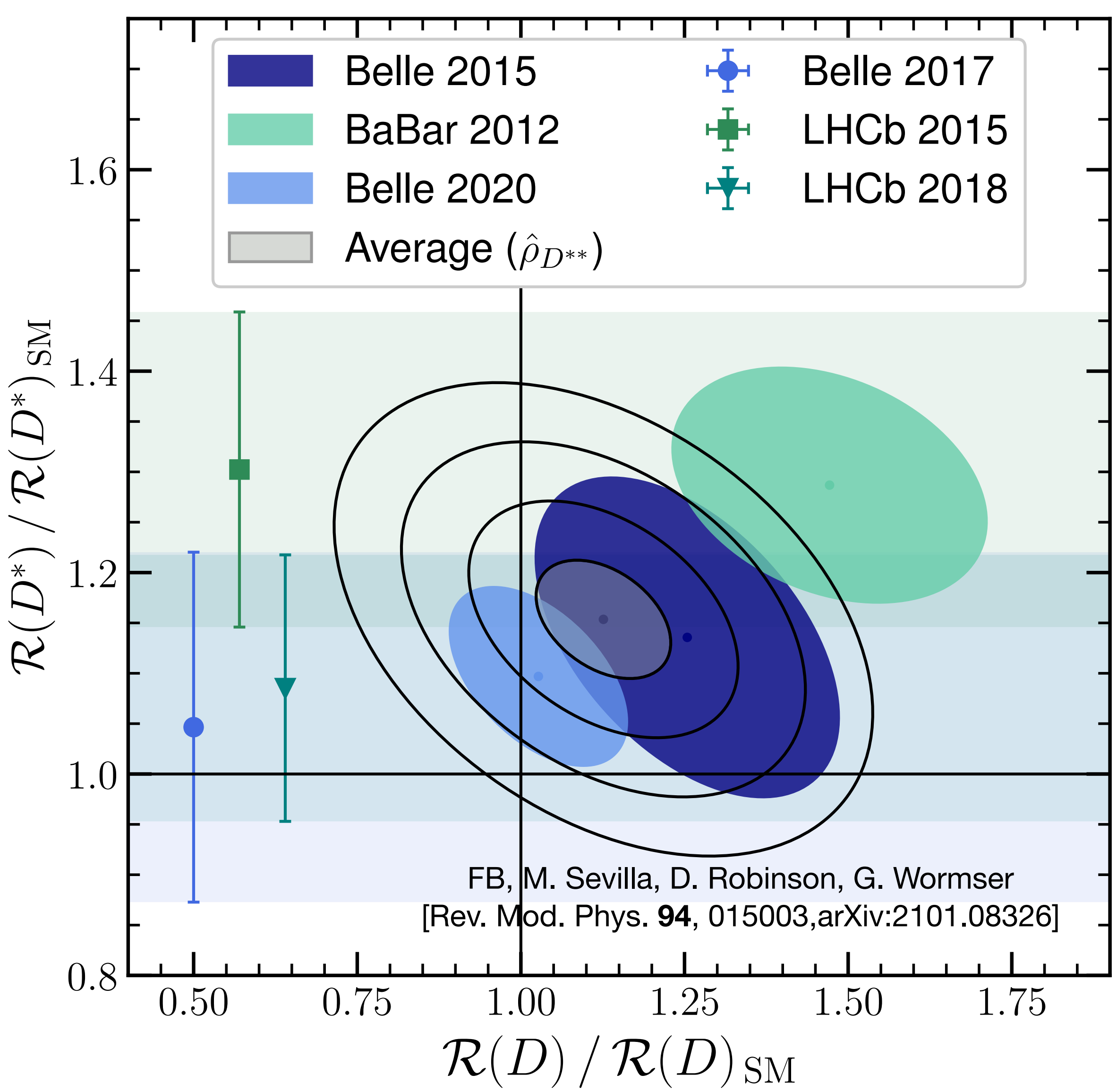
Challenges in Semileptonic B Decays 2022

Where do we stand with $H_b \to H_c \tau \bar{\nu}_\tau$?



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

$\ell = e, \mu$

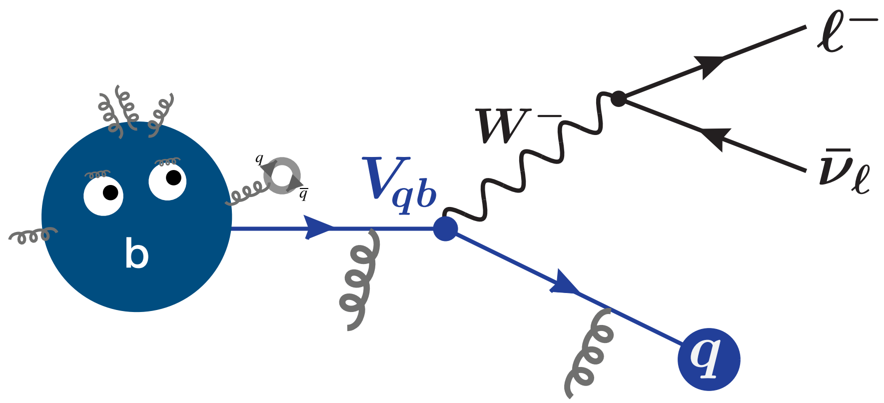


Obs.	Current World Av./Data	Current SM Prediction	Significance	
$\mathcal{R}(D)$	0.340 ± 0.030	0.299 ± 0.003	1.2σ	3.1σ
$\mathcal{R}(D^*)$	0.295 ± 0.014	0.258 ± 0.005	2.5σ	
$P_\tau(D^*)$	$-0.38 \pm 0.51^{+0.21}_{-0.16}$	-0.501 ± 0.011	0.2σ	
$F_{L,\tau}(D^*)$	$0.60 \pm 0.08 \pm 0.04$	0.455 ± 0.006	1.6σ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

Wait, why 3.6?

And why does it differ from HFLAV?

Where do we stand with $H_b \to H_c \tau \bar{\nu}_\tau$?

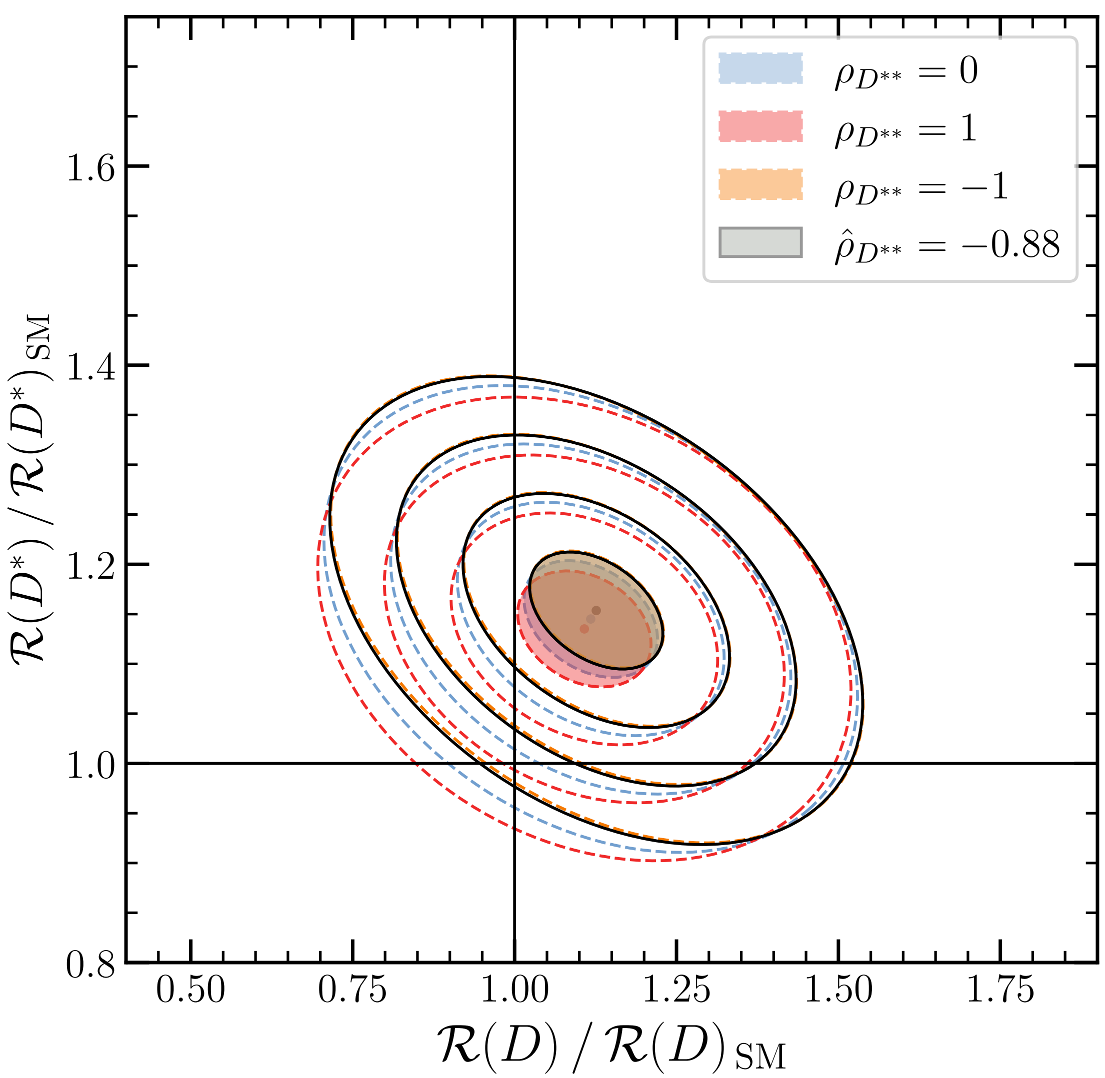


Systematic Errors from

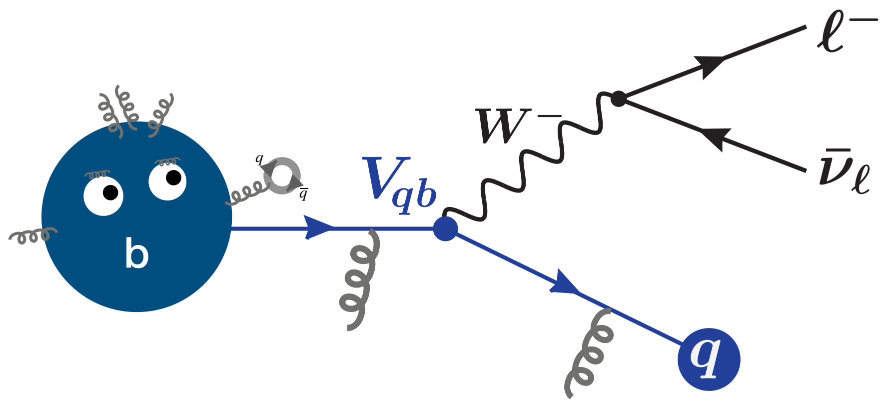
$B \to D^{**} \ell \bar{\nu}_\ell$

BaBar: $\mathcal{R}(D)$, $\mathcal{R}(D^*)$ — $\rho = 0.45$

Belle had tag: $\mathcal{R}(D)$, $\mathcal{R}(D^*)$ — $\rho = -0.15$

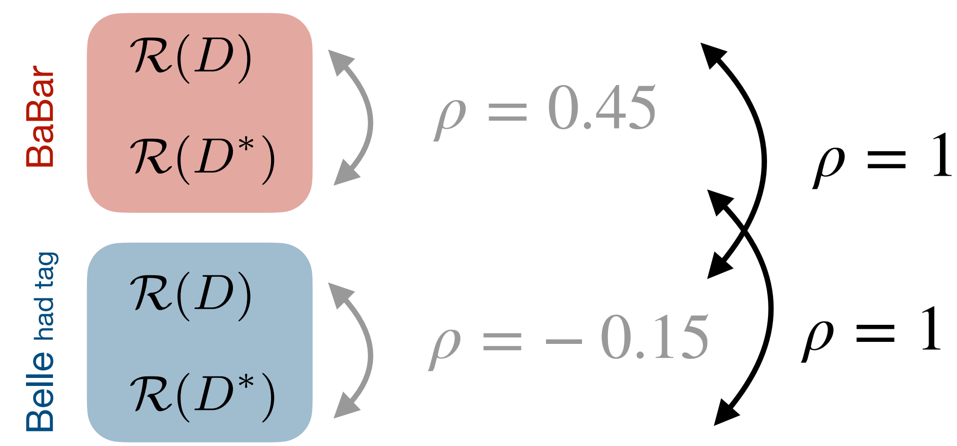


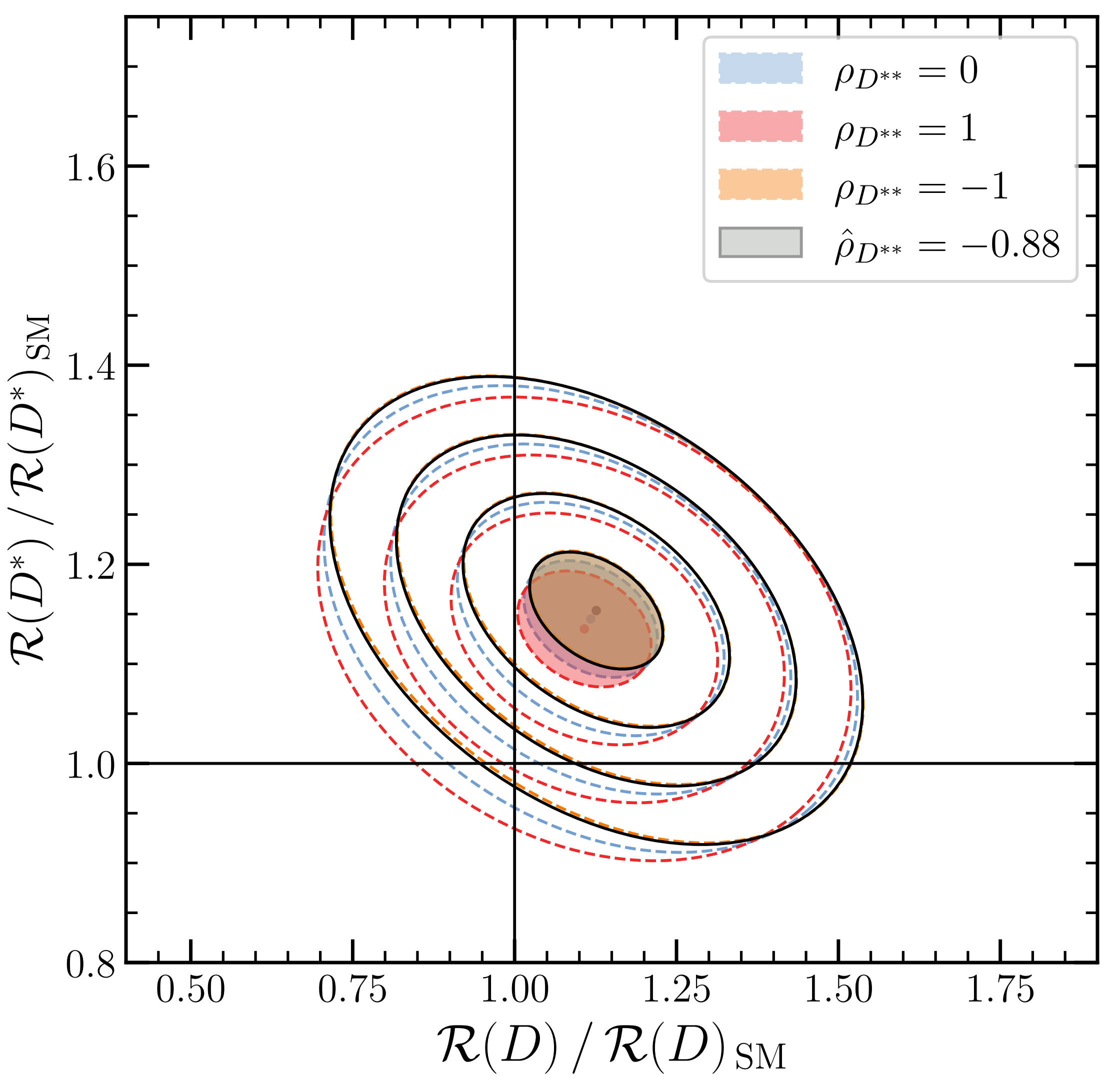
Where do we stand with $H_b \to H_c \tau \bar{\nu}_\tau$?



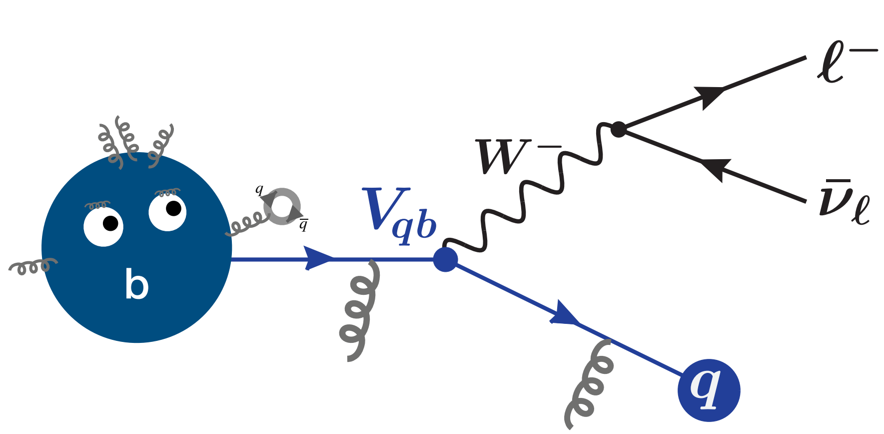
Systematic Errors from

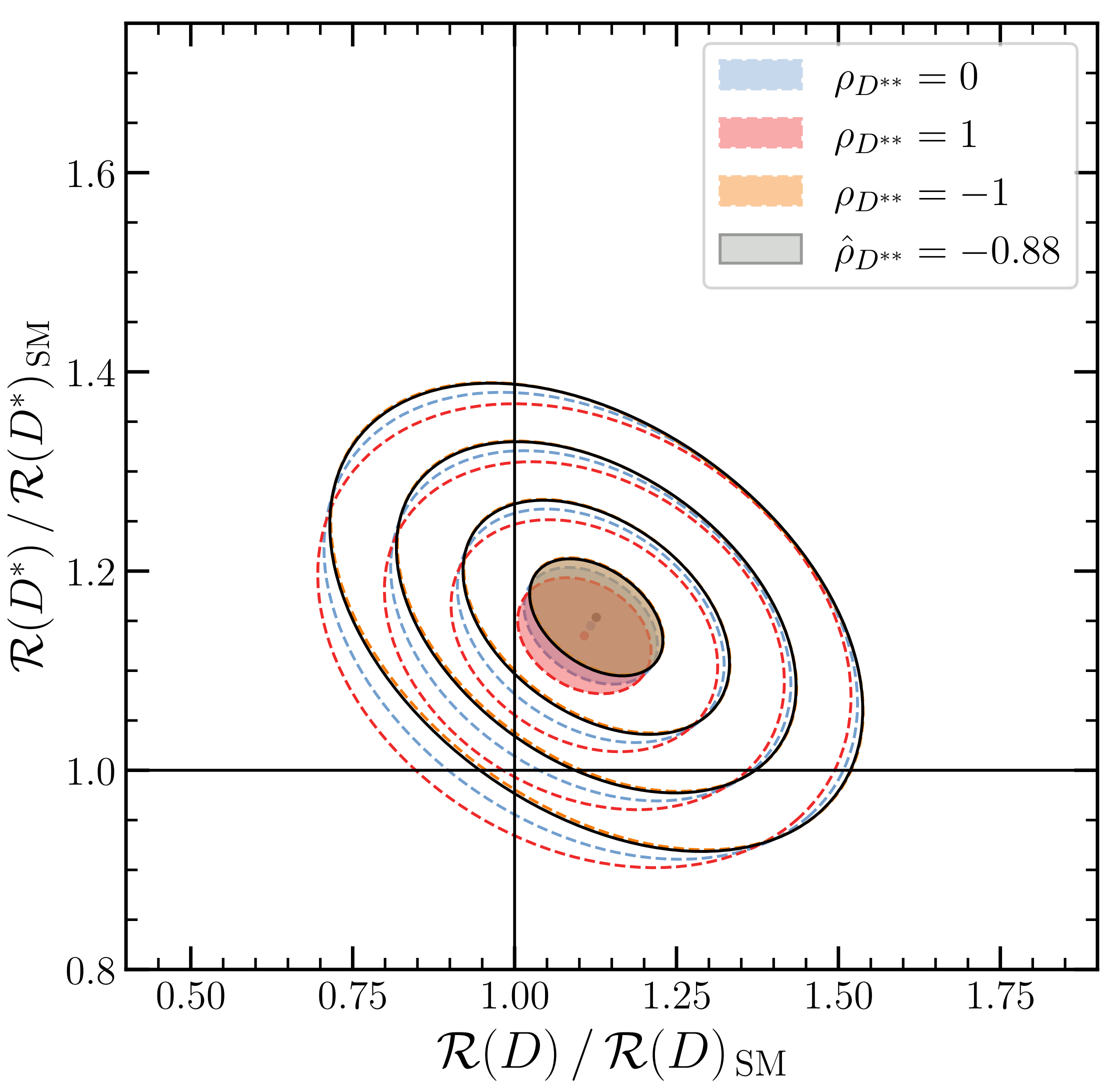
$B \to D^{**} \ell \bar{\nu}_\ell$





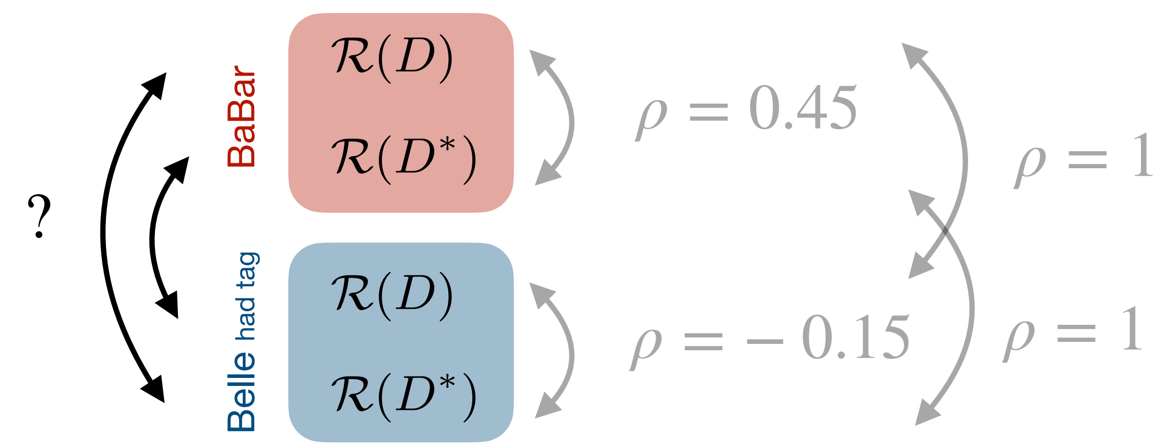
Where do we stand with $H_b \to H_c \tau \bar{\nu}_\tau$?



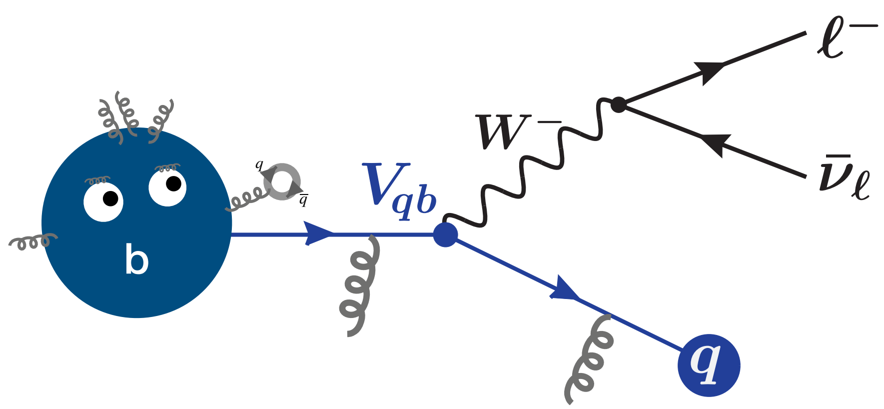


Systematic Errors from

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

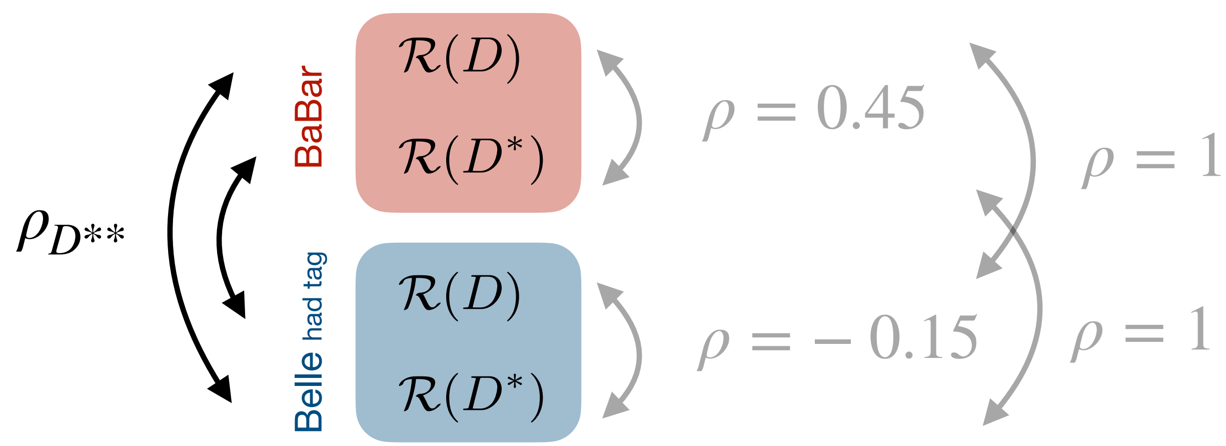


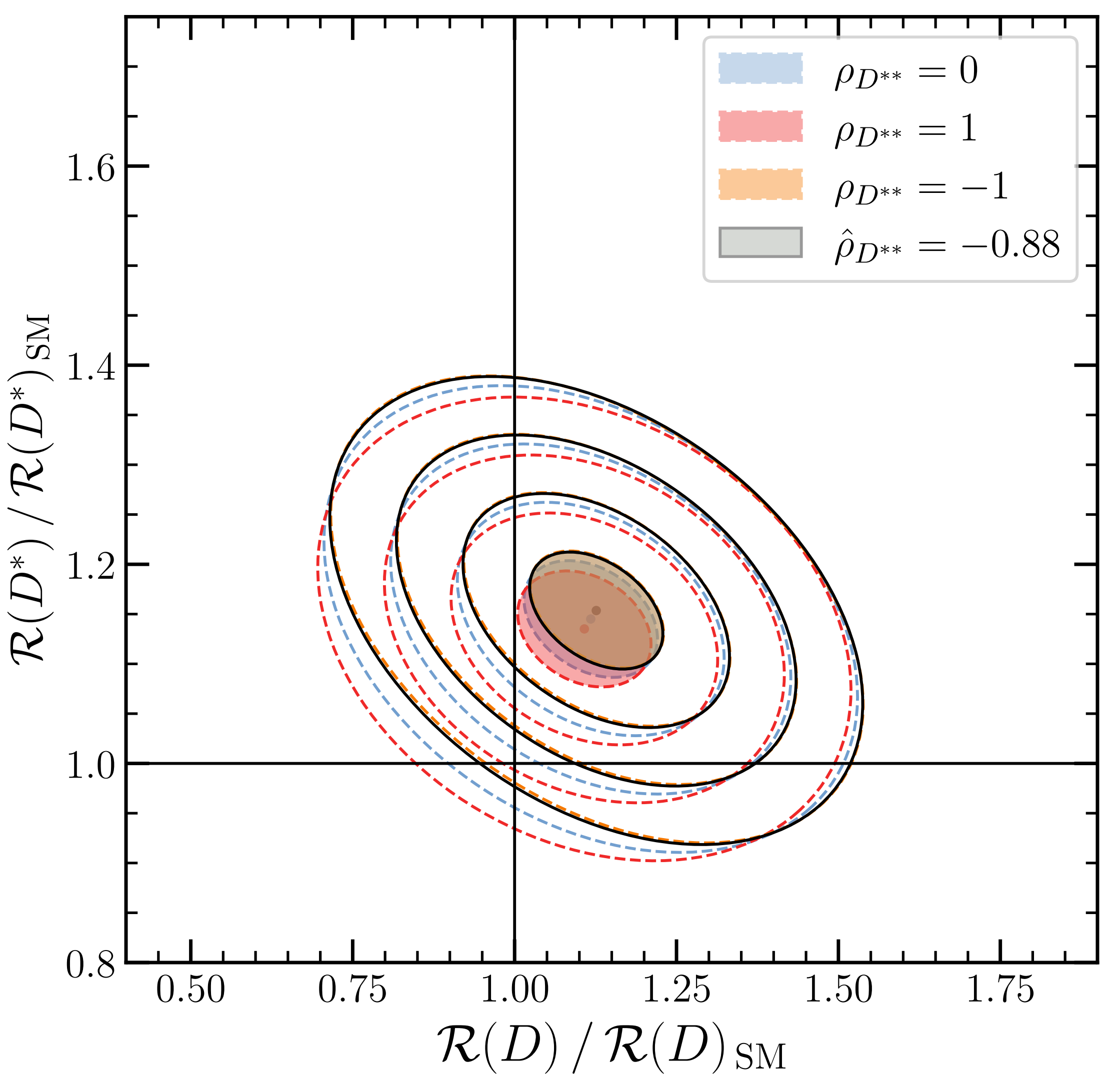
Where do we stand with $H_b \to H_c \tau \bar{\nu}_\tau$?



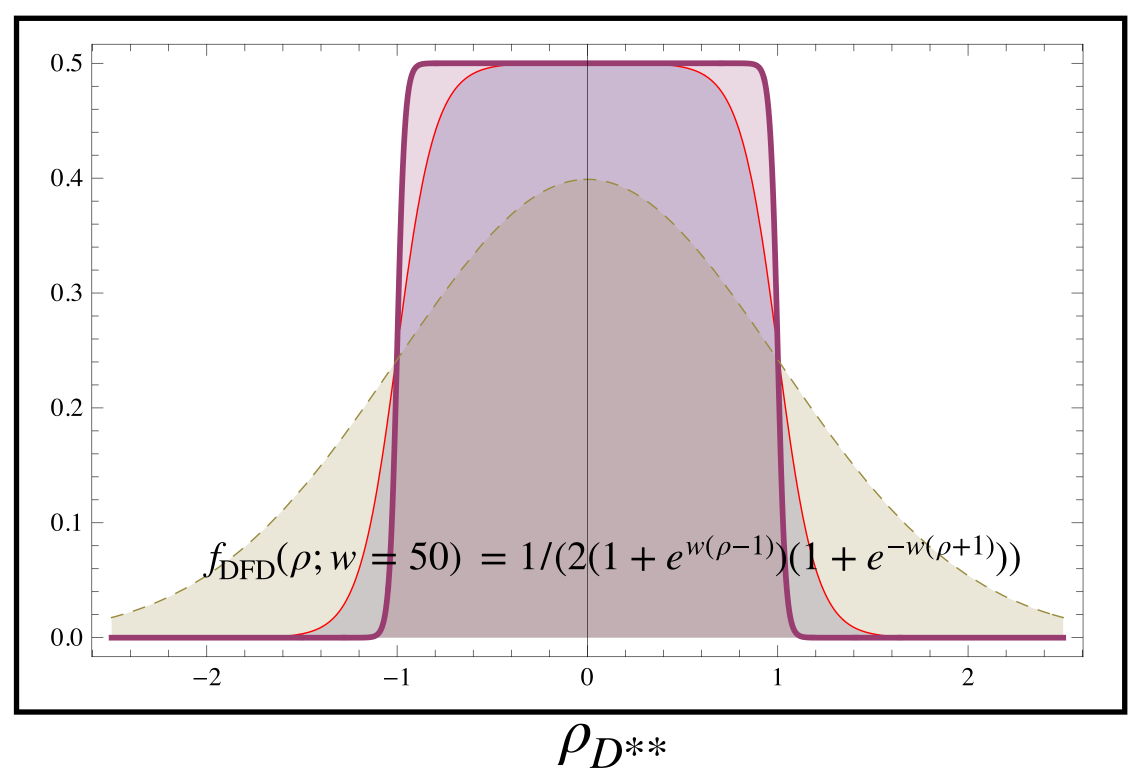
Systematic Errors from

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





$\chi^2 - 2\log(\, f_{\rm DFD}(\rho_{D^{**}})\,)$



Measurement Strategies

Signal

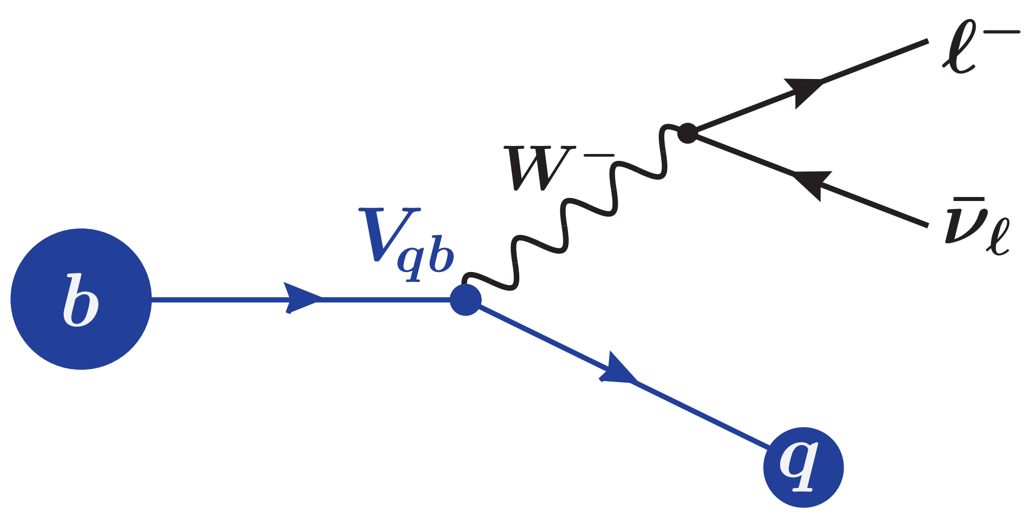
$$R = \frac{b \to q\,\tau\bar{\nu}_\tau}{b \to q\,\ell\bar{\nu}_\ell}$$

Normalization

$\ell = e, \mu$

1. Leptonic or Hadronic τ decays?

Some properties (e.g. τ **polarization**) readily **accessible** in **hadronic decays.**



2. Albeit not necessarily a rare decay of O(%) in BF, TRICKY to separate from normalisation and backgrounds

LHCb: **Isolation** criteria, **displacement** of τ, **kinematics**

B-Factories: Full reconstruction of event (**Tagging**), **matching topology, kinematics**

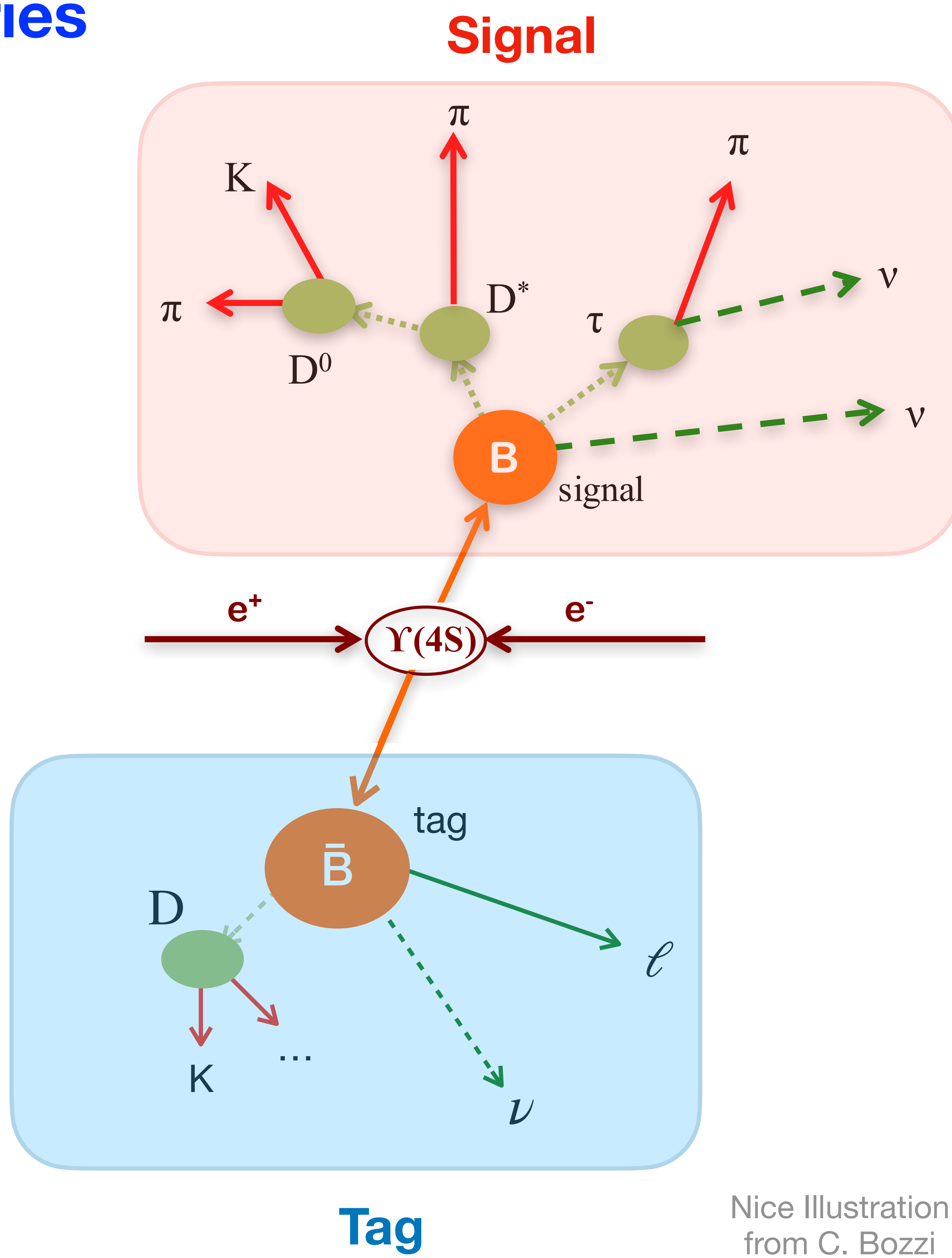
Measurement Strategies

3. Semileptonic decays at B-Factories

- e+/e- collision produces ***Y(4S)* → *BB̅***
- Fully reconstruct one of the two B-mesons ('tag') → **possible** to **assign all particles** to either signal or tag B
- **Missing four-momentum** (**neutrinos**) can be reconstructed with high precision

$$p_{\text{miss}} = (p_{\text{beam}} - p_{B\text{tag}} - p_{D^{(*)}} - p_\ell)$$

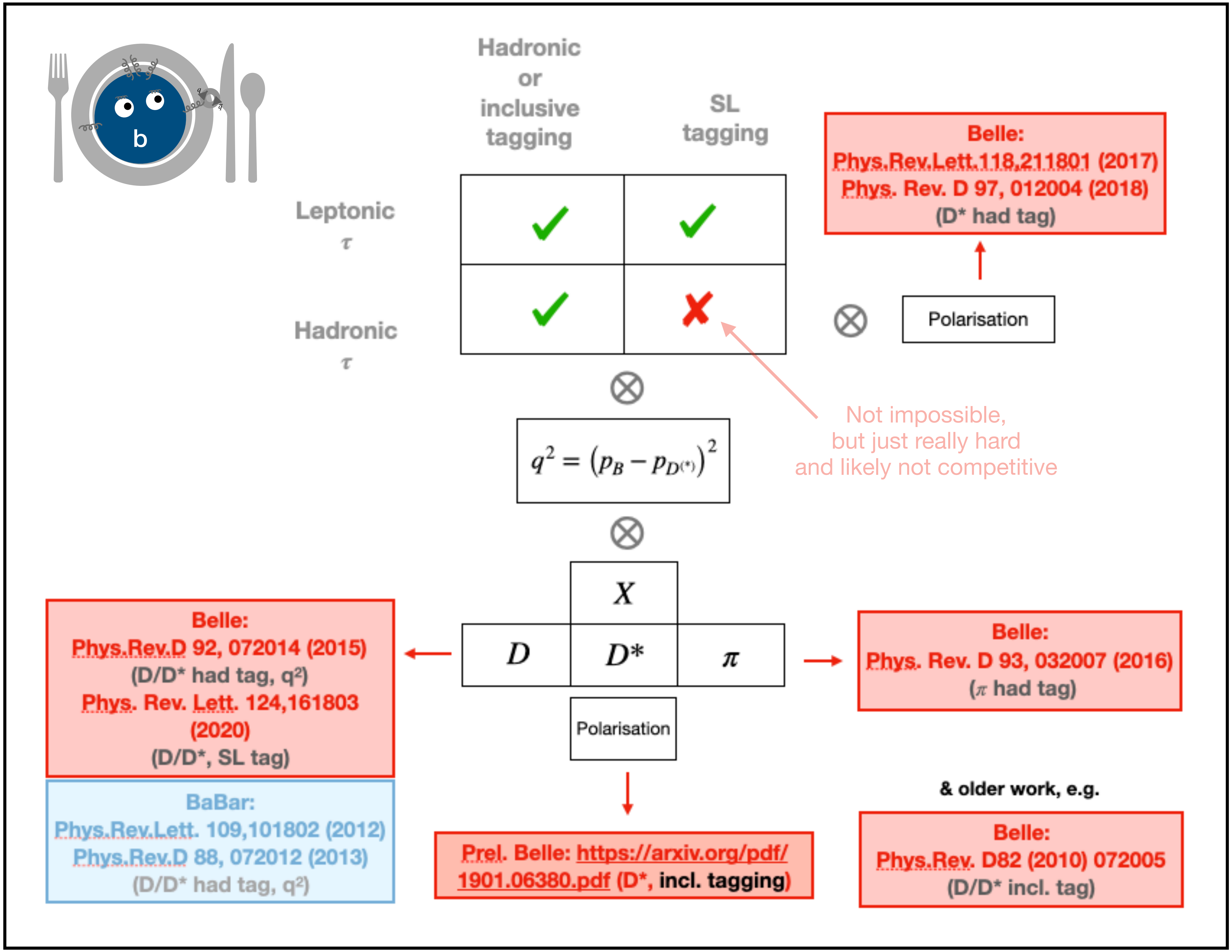
✓ **Small efficiency (~0.2-0.4%) compensated by large integrated luminosity**



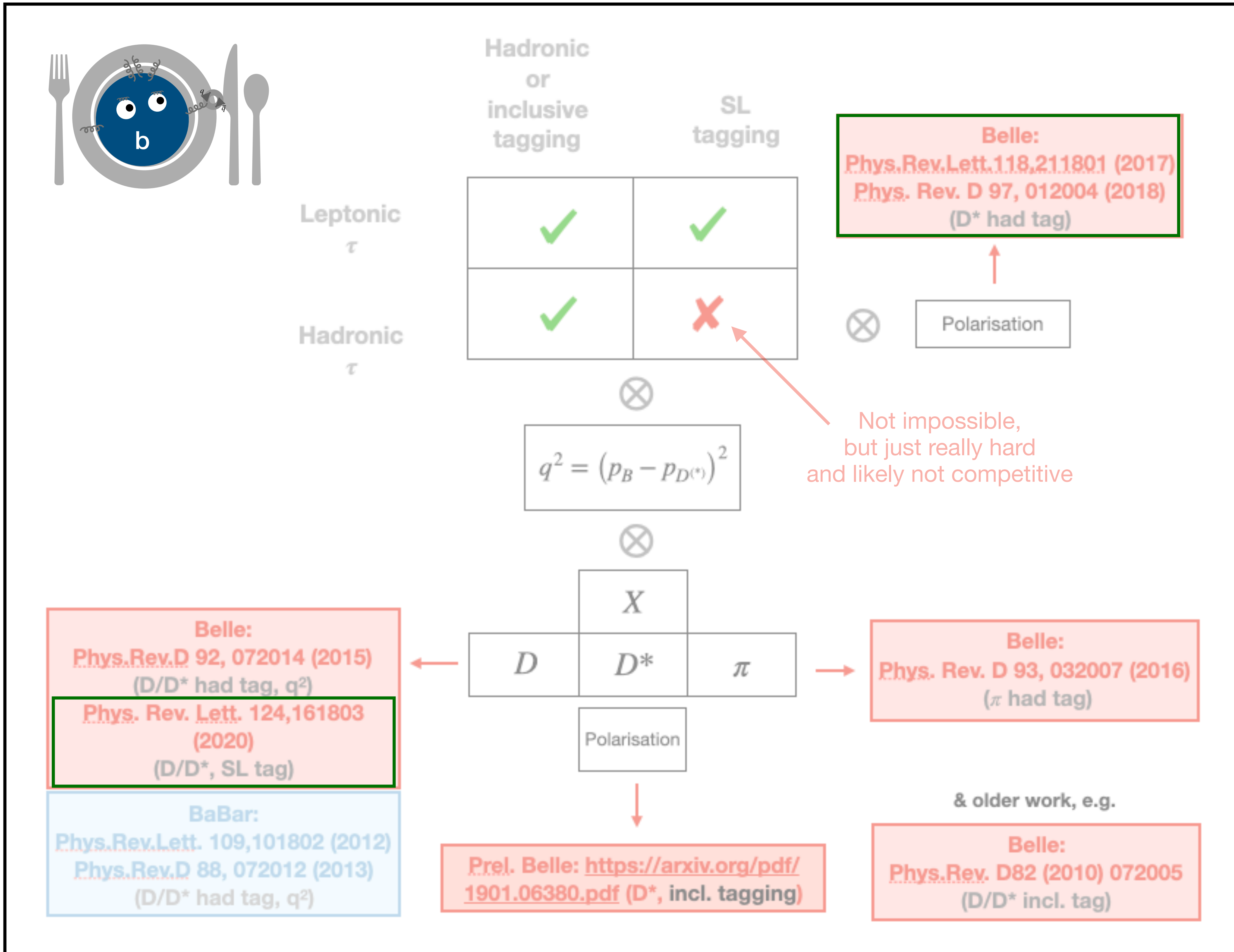
Nice Illustration from C. Bozzi

Belle Measurements

The Belle (II) Menu



The Belle (II) Menu

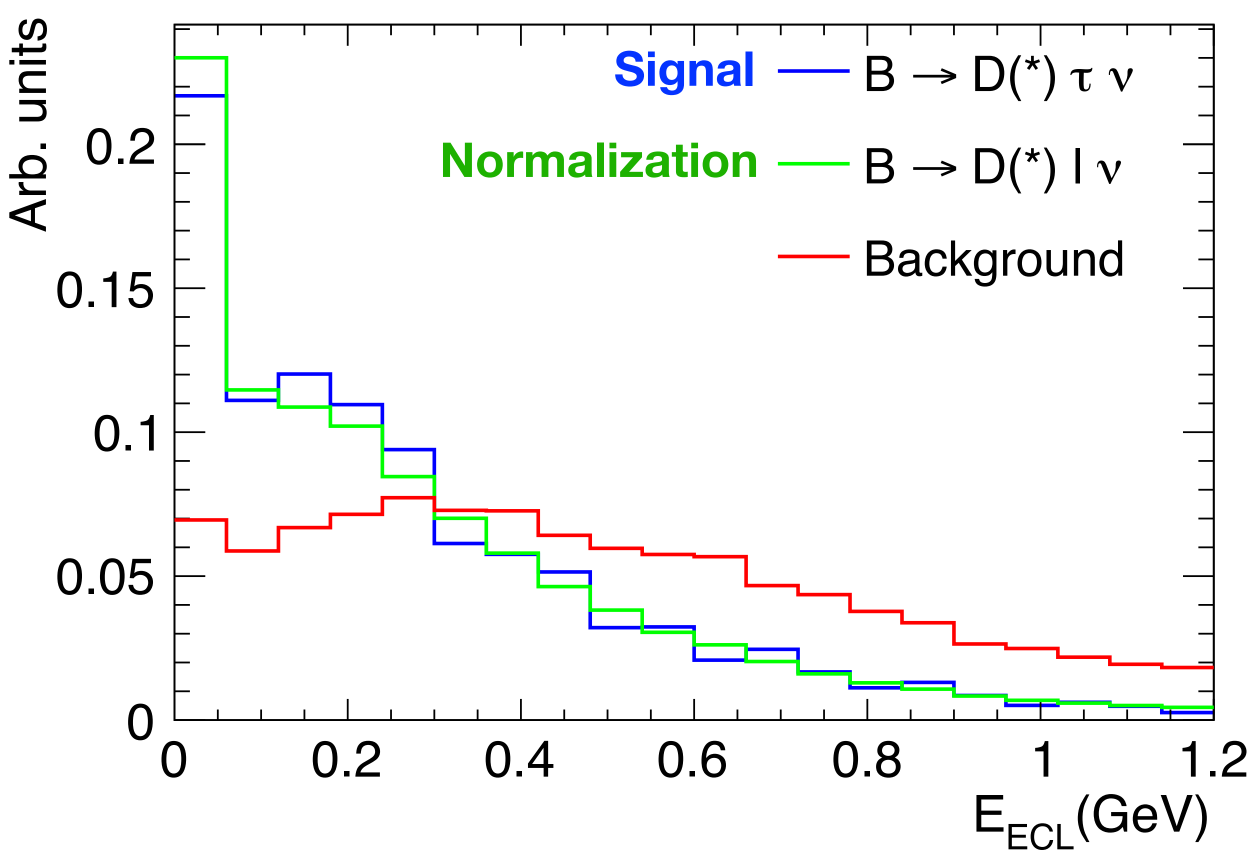


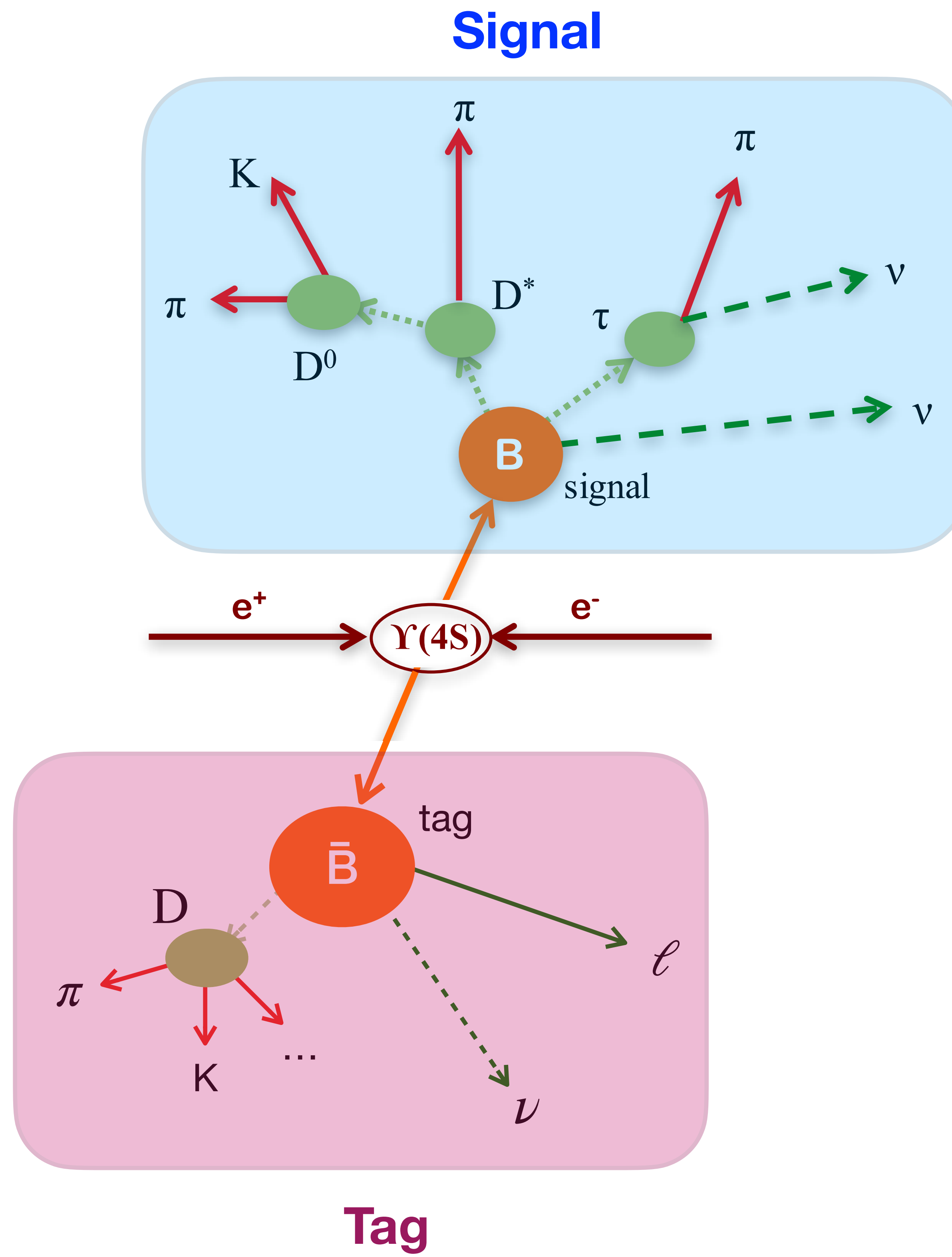
$\mathcal{R}(D^{(*)})$ from Belle with SL tagging

Phys. Rev. Lett. 124, 161803, April 2020
[arXiv:1904.08794]

- Reconstruct one of the two B-mesons ('tag') in **semileptonic modes → possible to assign all particles in detector** to tag- & signal-side
- Demand Matching topology + **unassigned** energy in the calorimeter E_{ECL} to discriminate background from signal

$$E_{\mathrm{extra}} = E_{\mathrm{ECL}} = \sum_i E_i^\gamma$$

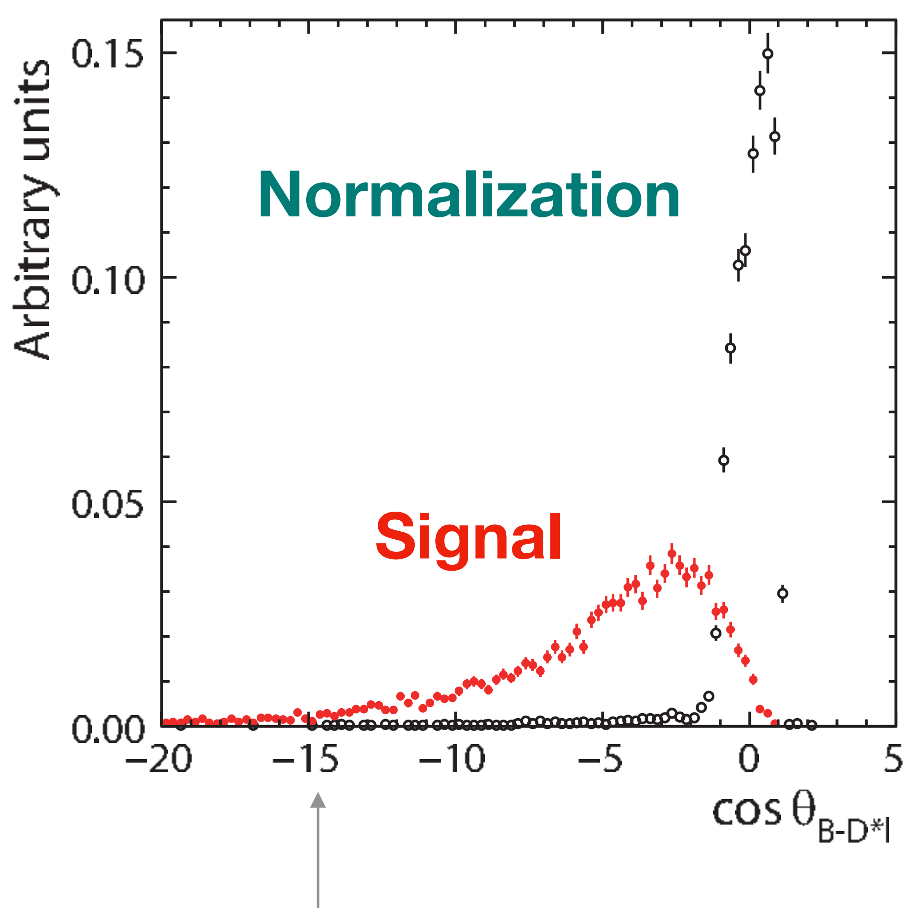


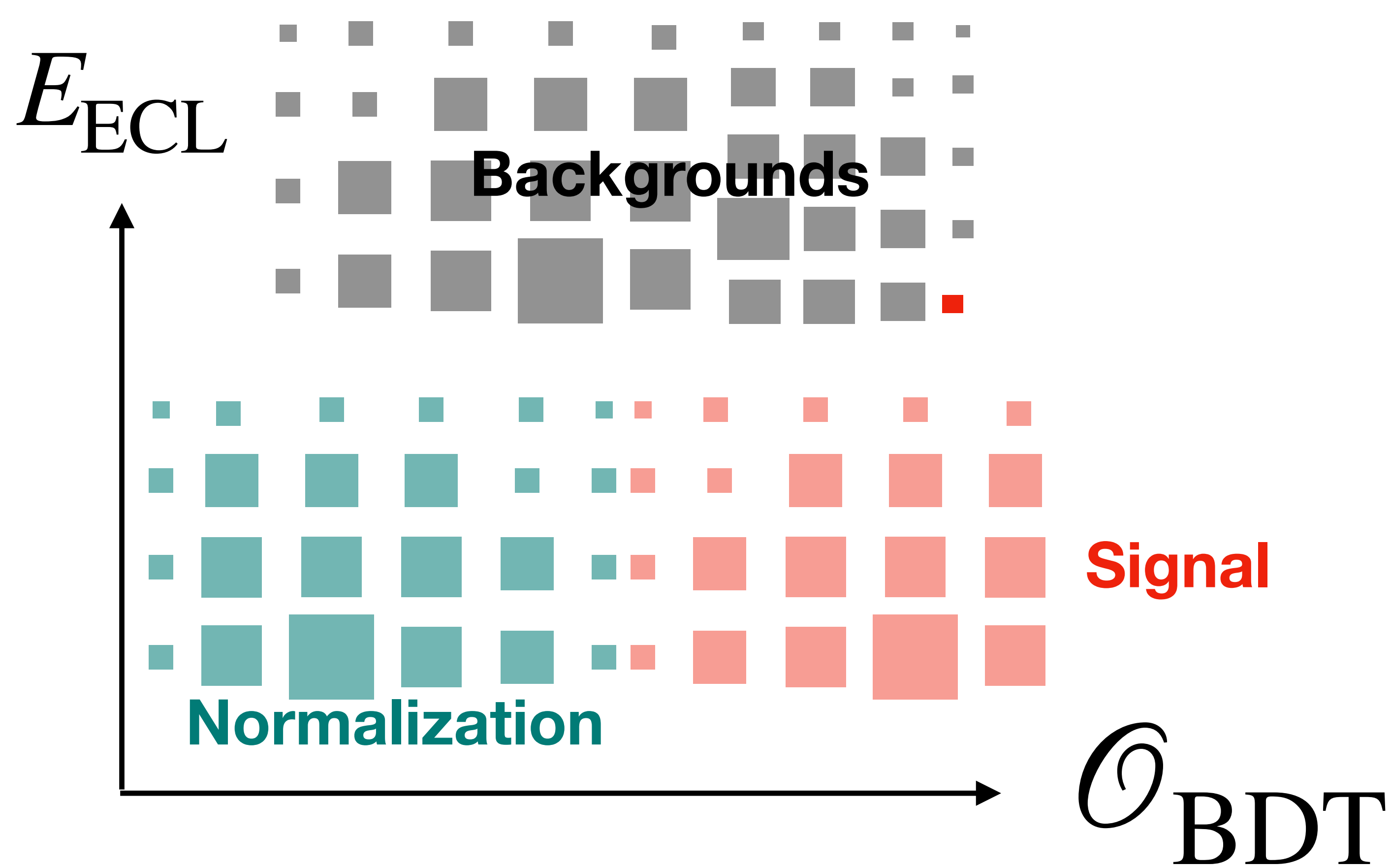


Separation of signal & normalization

- Use kinematic properties to separate $B \to D^{(*)}\tau\nu$ signal from $B \to D^{(*)}\ell\nu$ normalization

- Construct BDT with 3 variables: $\cos\theta_{B-D^{(*)}\ell}$, E_{vis}, $m^2_{\mathrm{miss}} = p^2_{\mathrm{miss}}$





In case you are wondering how a cosine can be outside [-1,1]: it's because the reconstruction uses measured energies and the definition assumes only a single missing neutrino

Separation of signal & normalization

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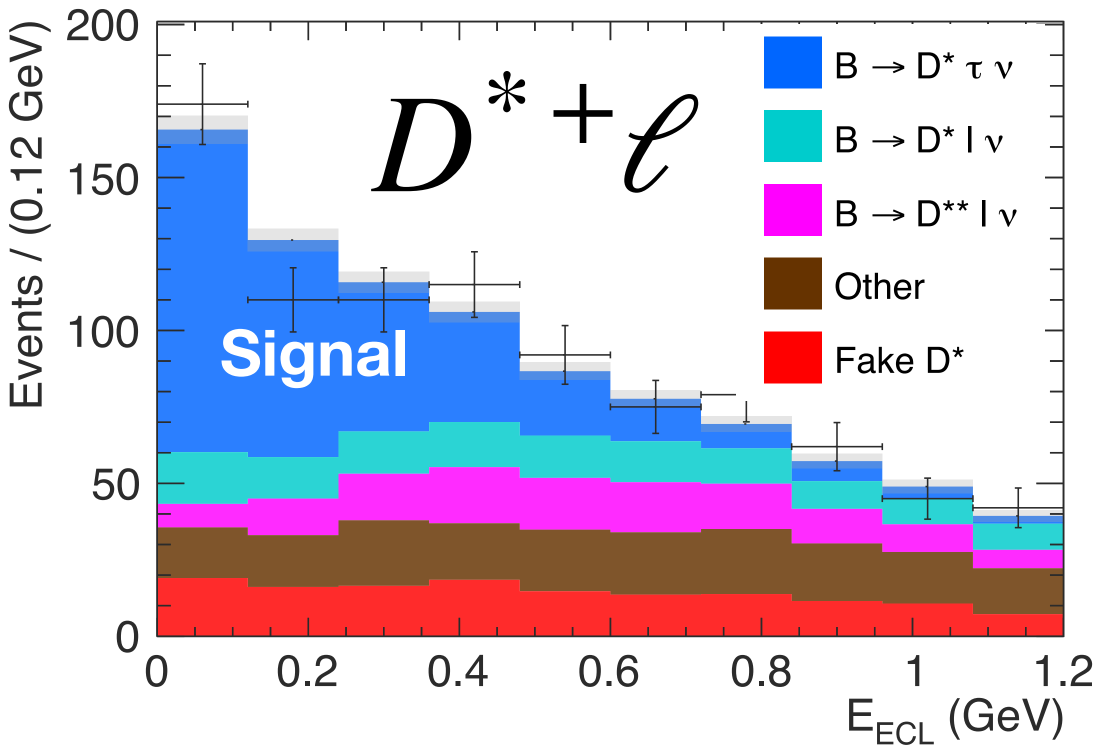
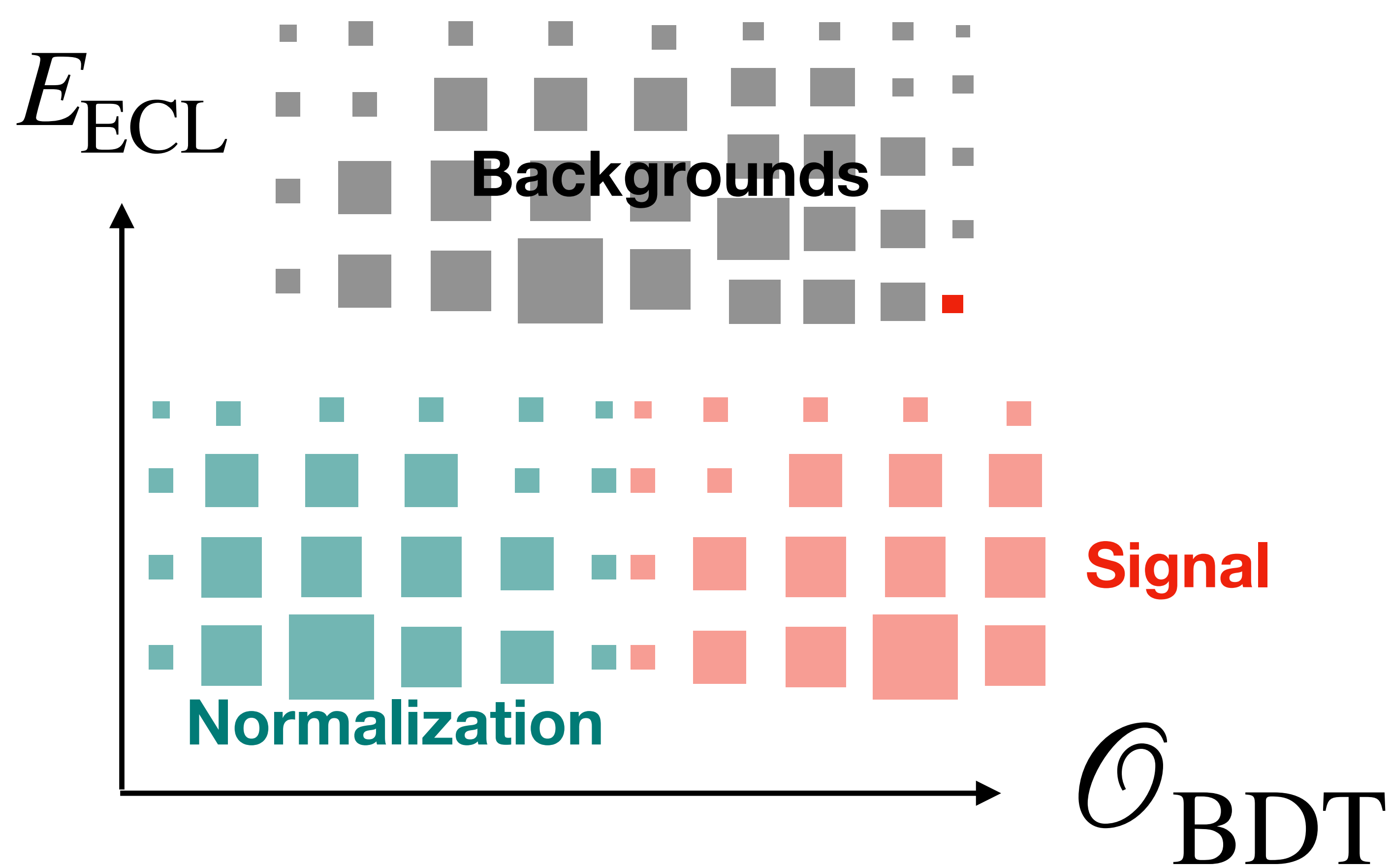


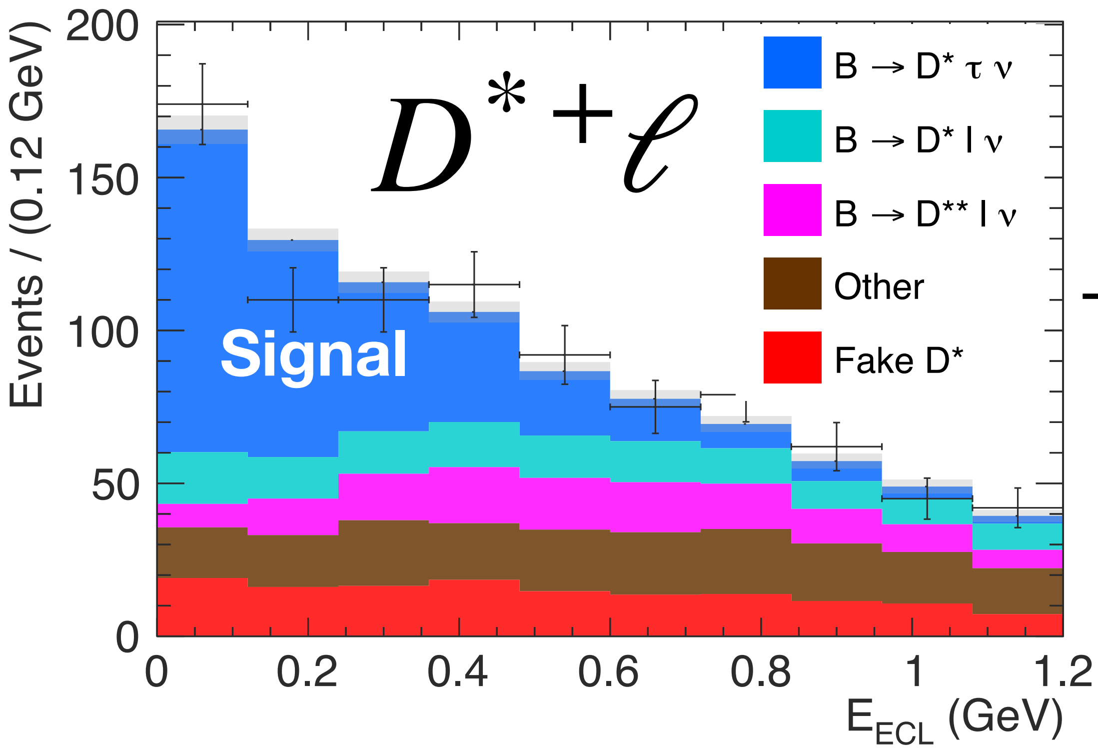
Signal-enriched selection with cut on $\mathcal{O}_{\text{BDT}}$



Separation of signal & normalization

- Use kinematic properties to separate $B \to D^{(*)}\tau\nu$ signal from $B \to D^{(*)}\ell\nu$ normalization

- Construct BDT with 3 variables: $\cos\theta_{B-D^{(*)}\ell}$, E_{vis}, $m^2_{\mathrm{miss}} = p^2_{\mathrm{miss}}$



Signal enriched selection with cut on $\mathcal{O}_{\mathrm{BDT}}$

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

Most precise measurement to date

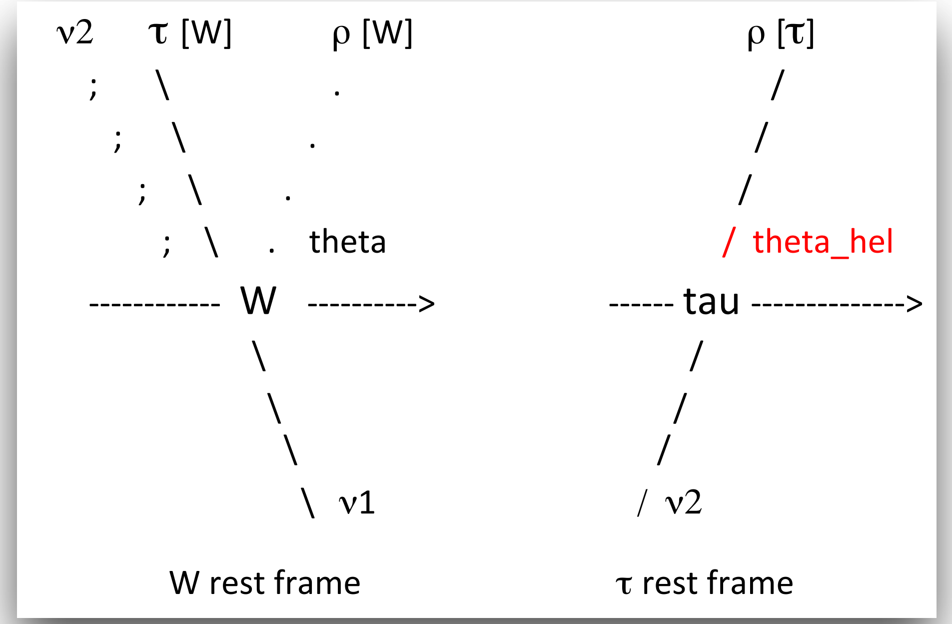
$\mathscr{R}(D^*)$ and τ-Polarization

Phys.Rev.Lett.118,211801 (2017)
[arXiv:1709.00129]

- Decay angles of $\tau \to \pi \nu$ and $\tau \to \rho \nu$ encode ***τ-polarisation***, sensitive to NP!

  ✓ **Need to reconstruct helicity angle, but a-priorio τ-restframe not accessible**

  ✓ **Luckily there is a relation between *<(τh) in $\tau\nu$-frame and this angle***



Nice Illustration from V. Luth

- **Hadronic** tagging essential to reconstruct this frame

$\mathscr{R}(D^*)$ and τ-Polarization

- Decay angles of $\tau \to \pi \nu$ and $\tau \to \rho \nu$ encode ***τ-polarisation***, sensitive to NP!
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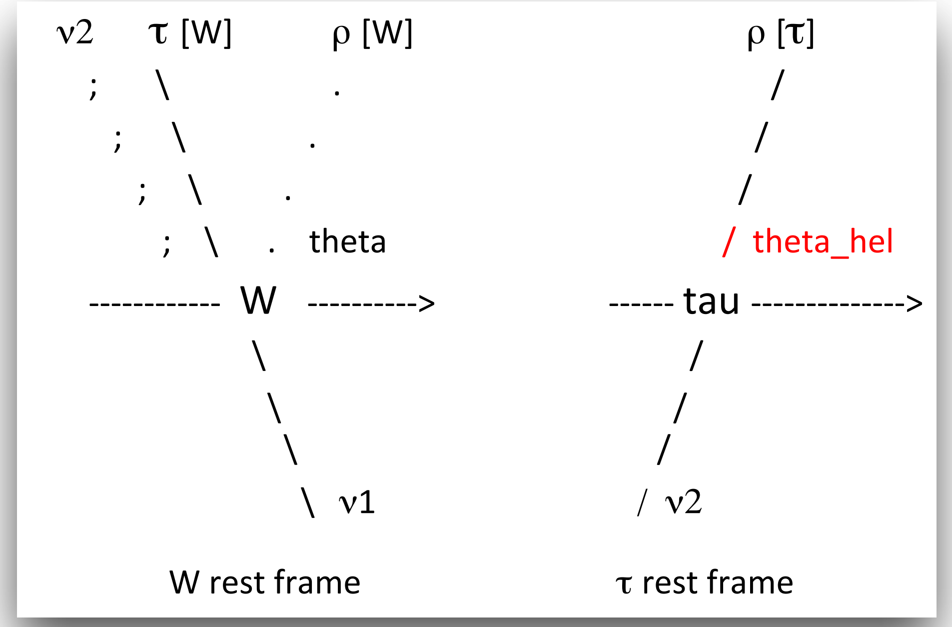
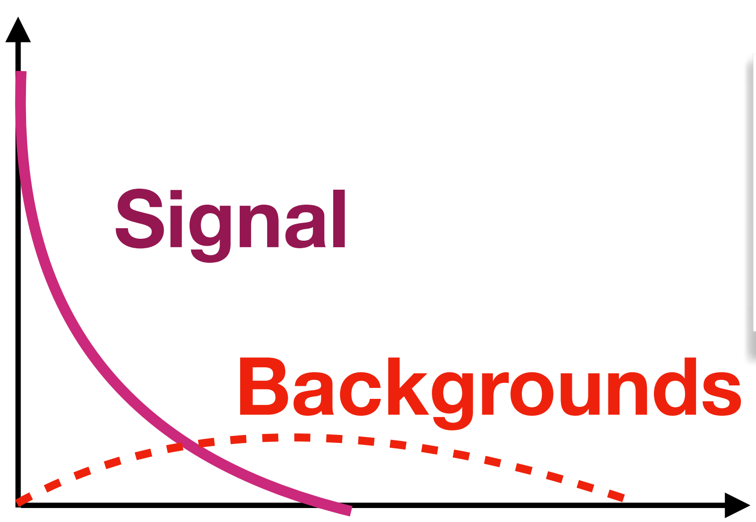


Nice Illustration from V. Luth

- Signal extraction via **E_{ECL} (unassigned energy in the calorimeter)** and in two bins of helicity angle **$\cos\Theta_{hel}$** with binned likelihood fit



E_{ECL}

$$R(D^*) = \frac{\epsilon^j_{\rm norm} N^{ij}_{\rm sig}}{\mathcal{B}^i_\tau \epsilon^{ij}_{\rm sig} N^j_{\rm norm}},$$

$$P_\tau(D^*) = \frac{2}{\alpha_i} \frac{N^{Fij}_{\rm sig} - N^{Bij}_{\rm sig}}{N^{Fij}_{\rm sig} + N^{Bij}_{\rm sig}},$$

Normalisation: $B \to D^* \ell \nu$

$\mathcal{R}(D^*)$ and τ-Polarization

- Decay angles of $\tau \to \pi\nu$ and $\tau \to \rho\nu$ sensitive to ***τ-polarisation***
  - ✓ **Need to reconstruct helicity angle, but a-priorio τ-restframe not accessible**
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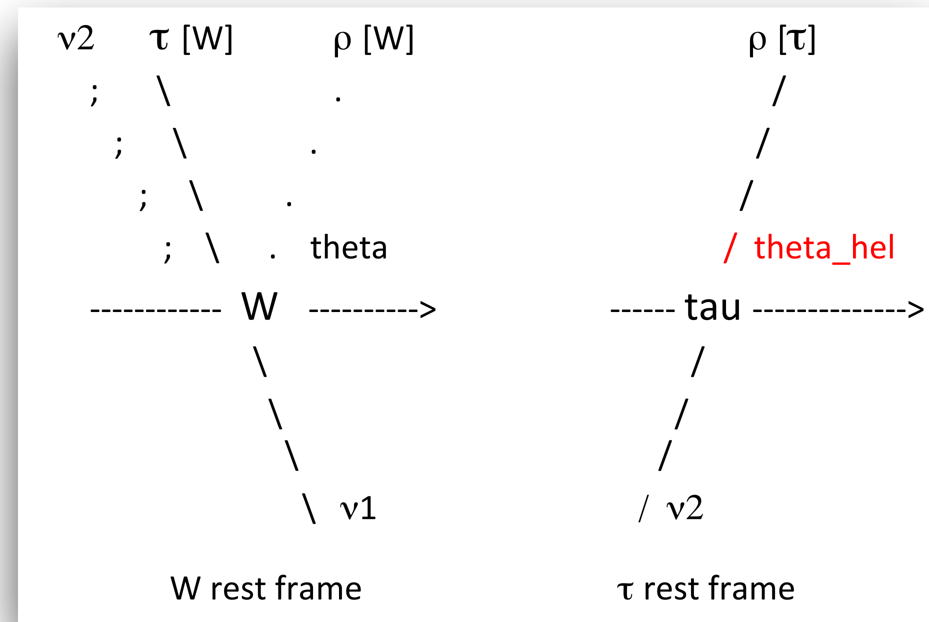
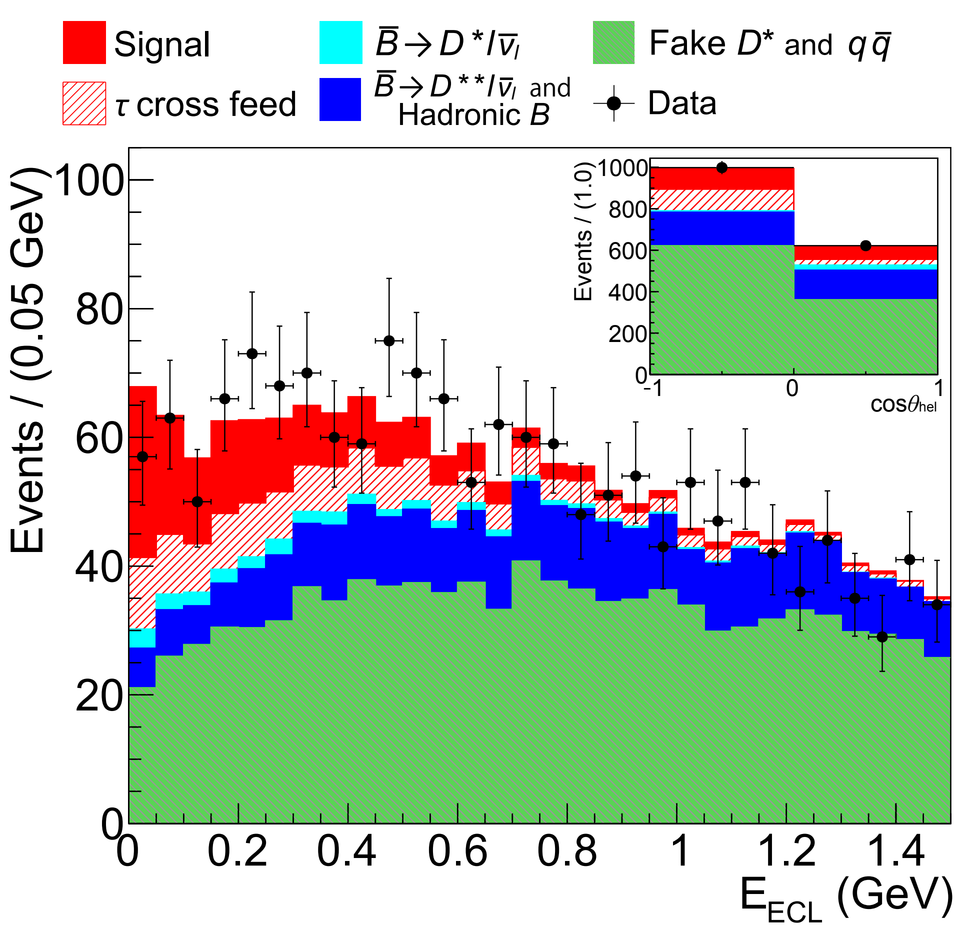
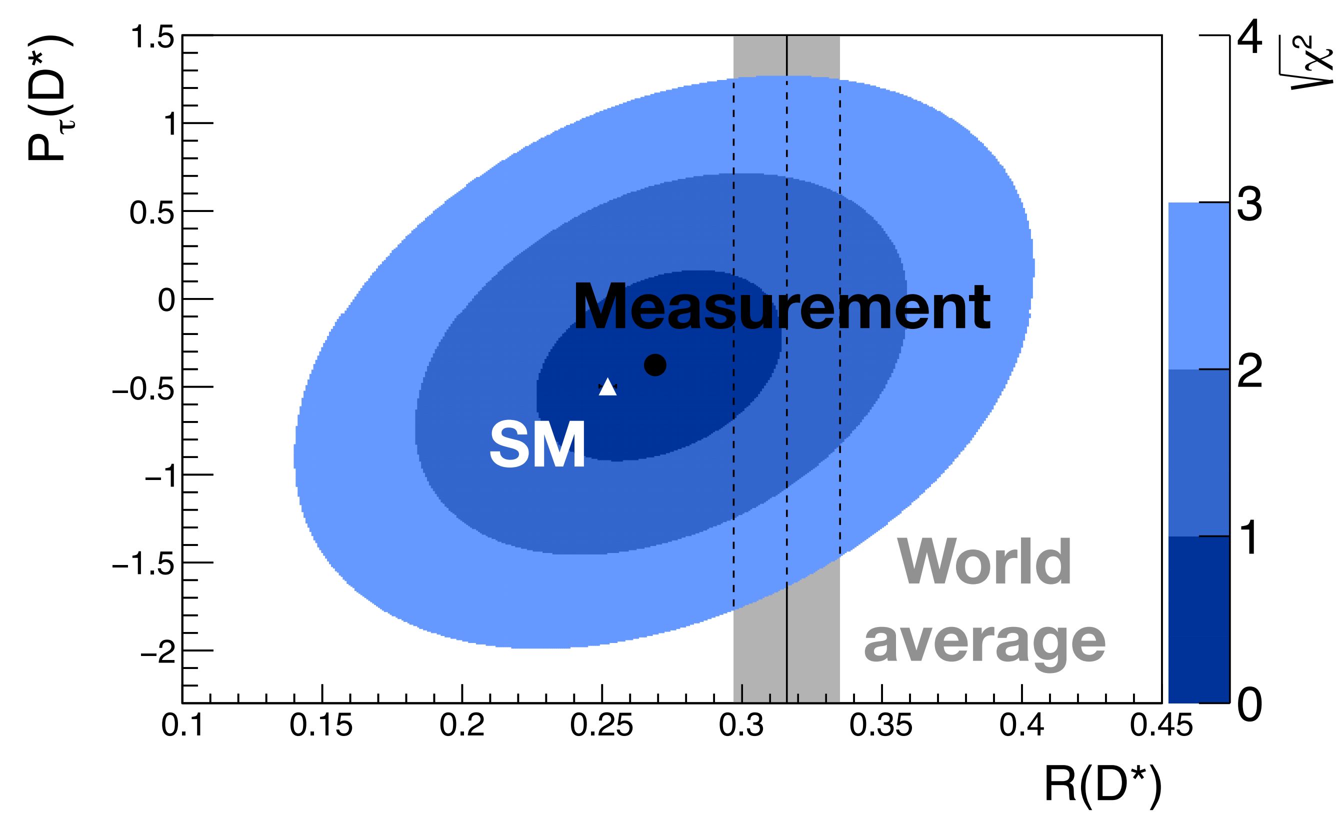


Nice Illustration from V. Lüth





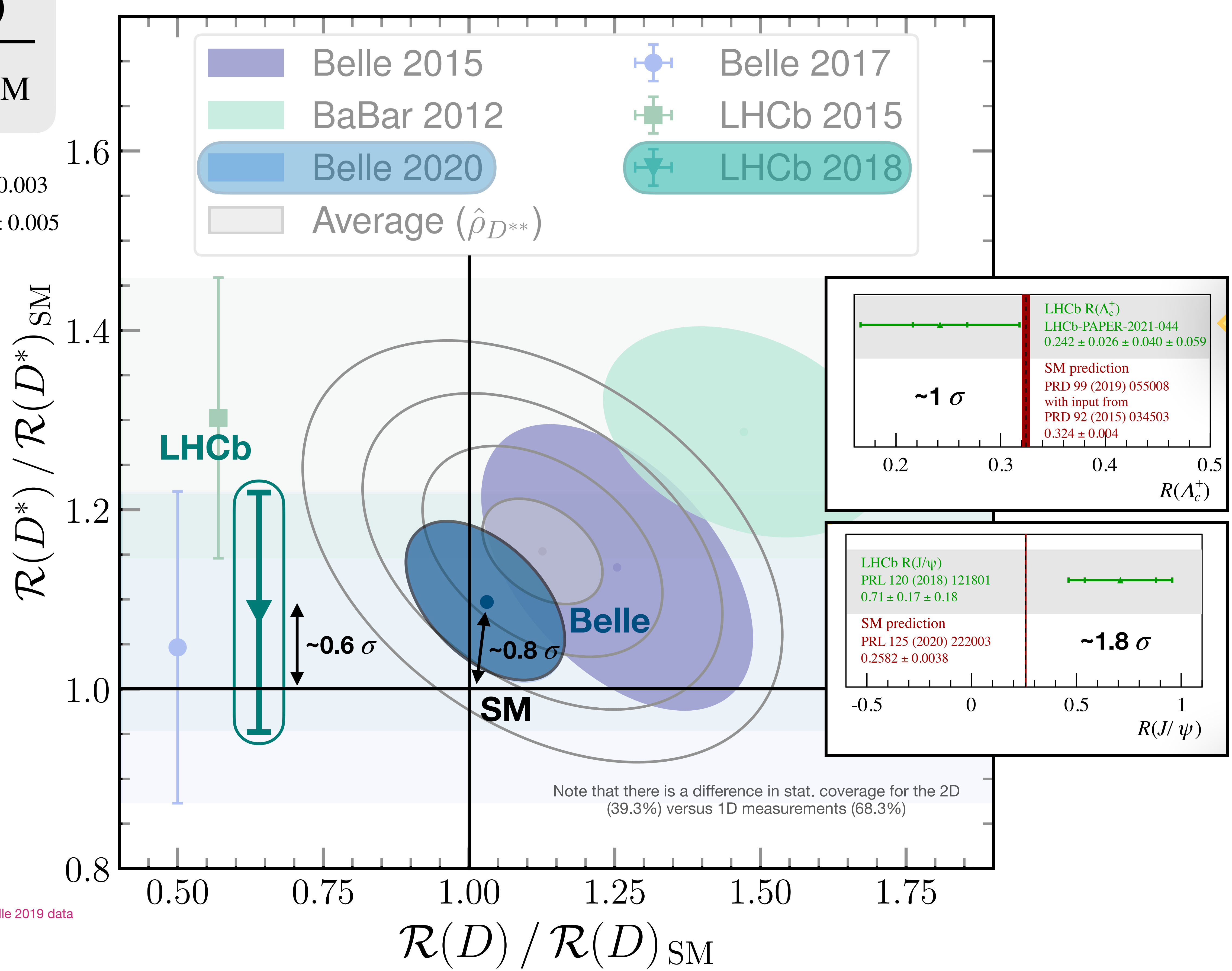
FB, M. Sevilla, D. Robinson, G. Wormser
[Rev. Mod. Phys. **94**, 015003,arXiv:2101.08326]

$$\frac{\mathscr{R}(D^{(*)})}{\mathscr{R}(D^{(*)})_{\mathrm{SM}}}$$

$\mathscr{R}(D)_{\mathrm{SM}} = 0.299 \pm 0.003$

$\mathscr{R}(D^*)_{\mathrm{SM}} = 0.258 \pm 0.005$

HFLAV arithmetic average of SM Calculations



More Recent SM Calculations:

BaBar B->D*
https://arxiv.org/abs/1903.10002
- R(D*)=0.253+-0.005

Gambino, Jung, Schacht using Belle 2019 data
https://arxiv.org/abs/1905.08209
- R(D*)=0.254 +0.007 -0.006

Bordone, Jung, van Dyk using Belle 2019 data
https://arxiv.org/abs/1908.09398
- RD=297+-0.003, RD*=0.250+-0.003

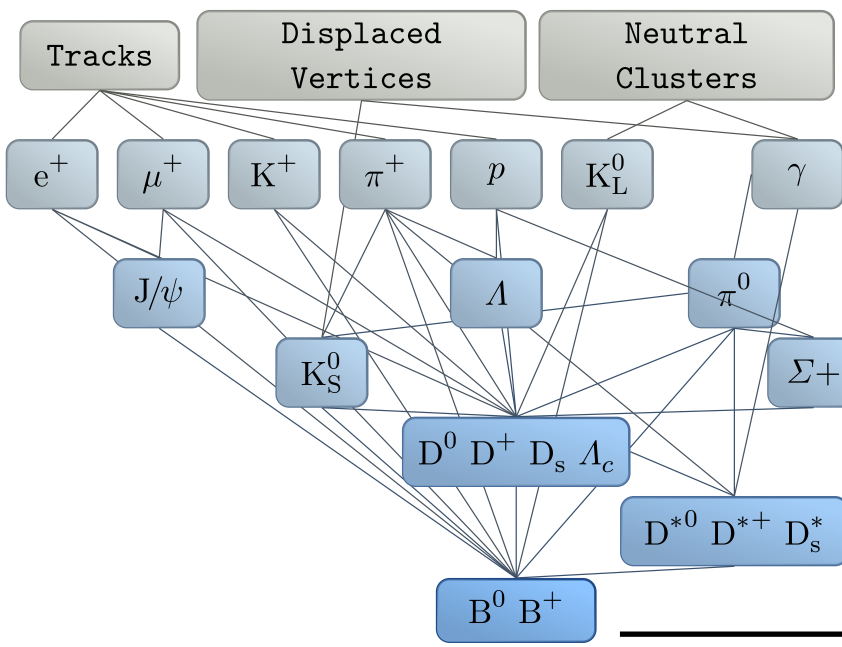
See also: https://hflav-eos.web.cern.ch/hflav-eos/semi/spring19/html/RDsDsstar/RDRDs.html


Outlook for Belle II
b
q
q

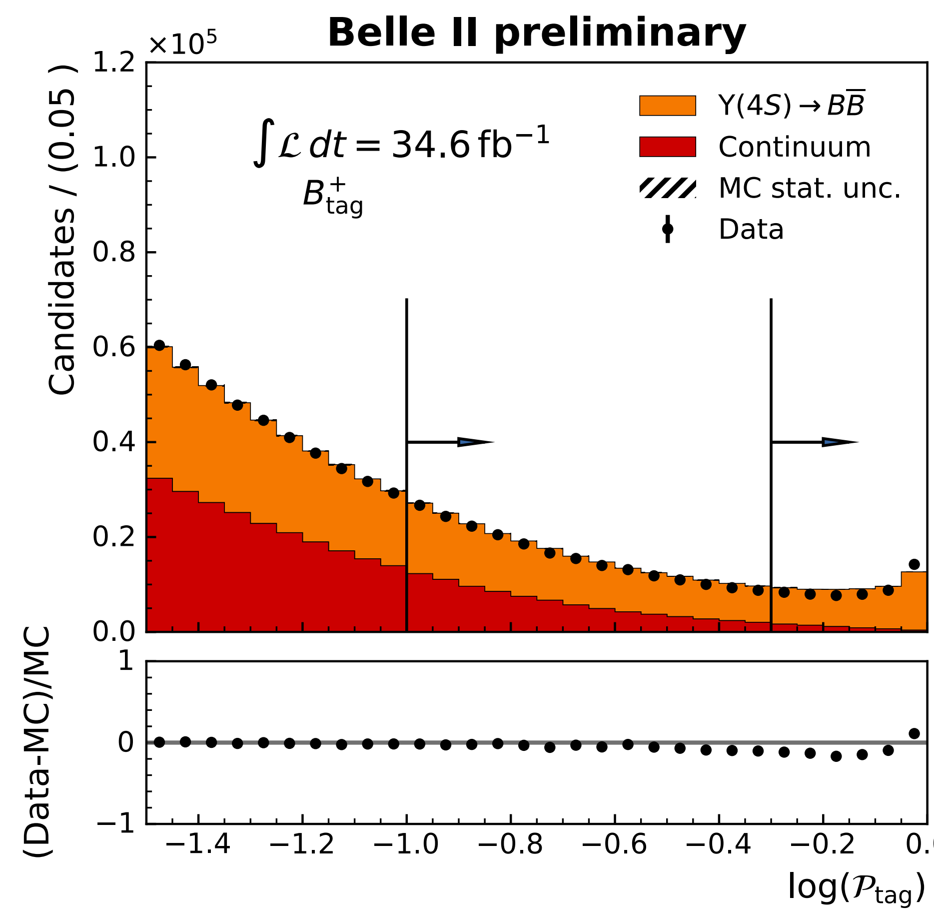
The tools are in place

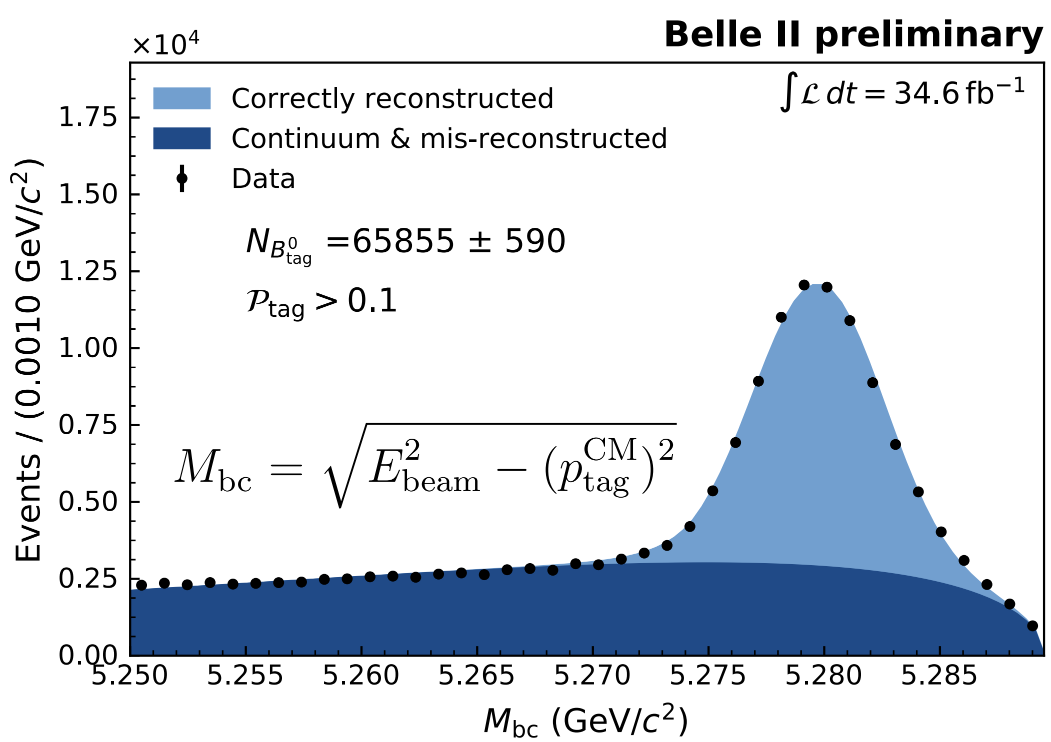
arXiv:1807.08680 [hep-ex]
arXiv:2008.06096 [hep-ex]

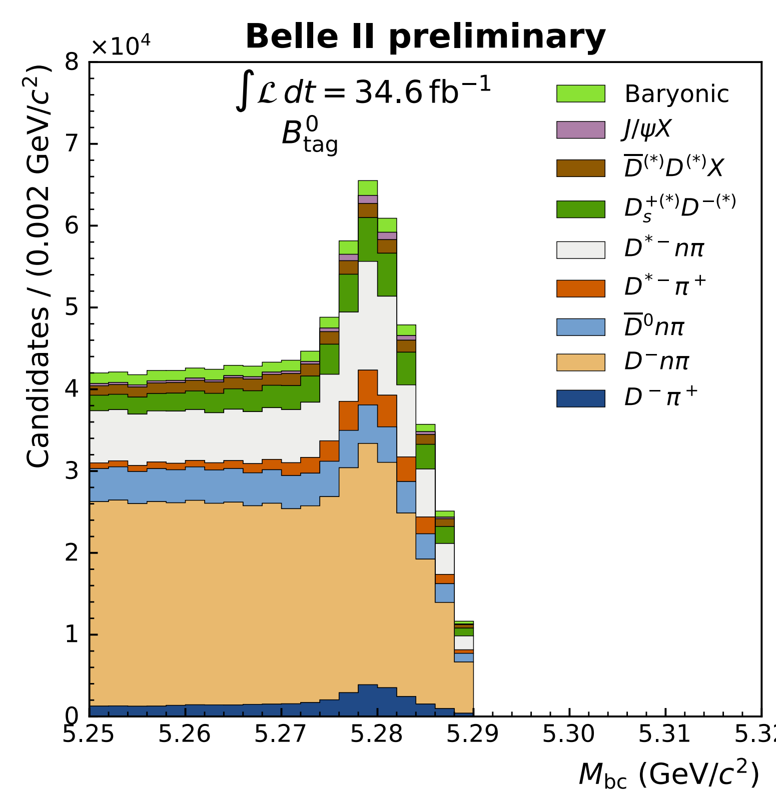
New multivariate tagging:

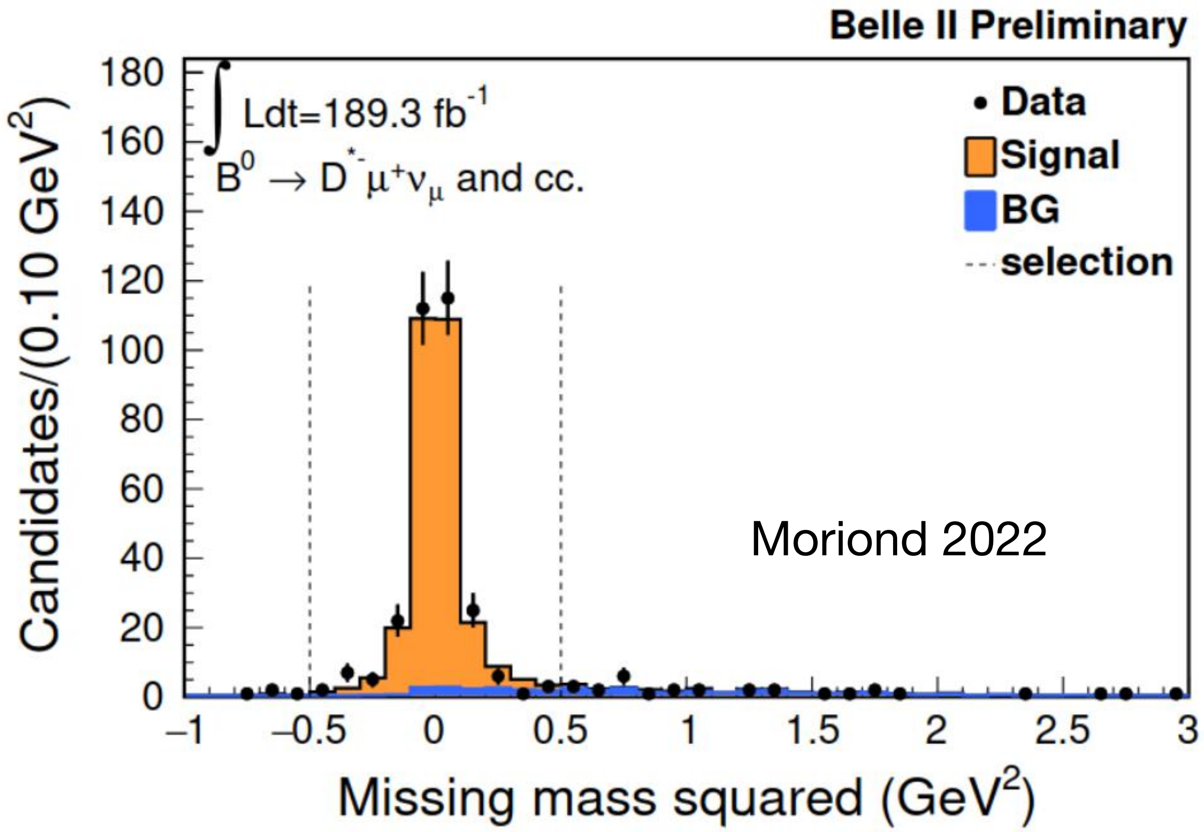


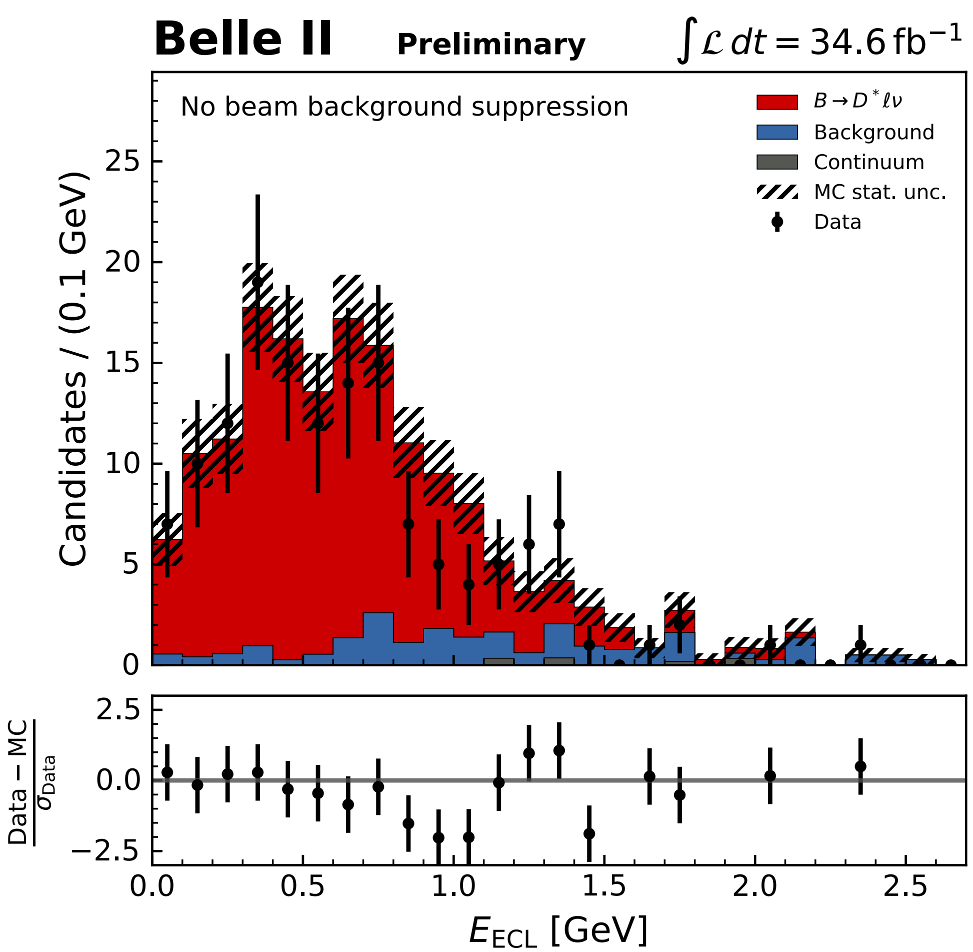
Tag quality: $\mathscr{P}_{\rm tag}$

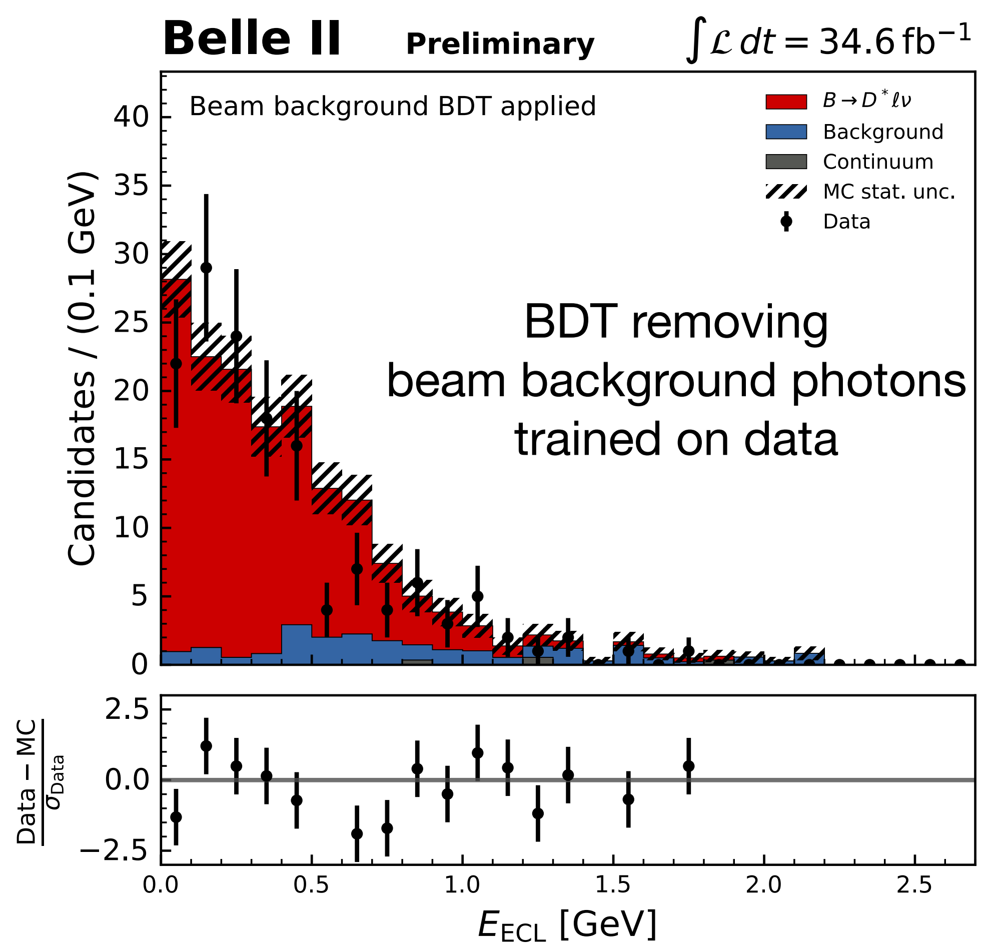




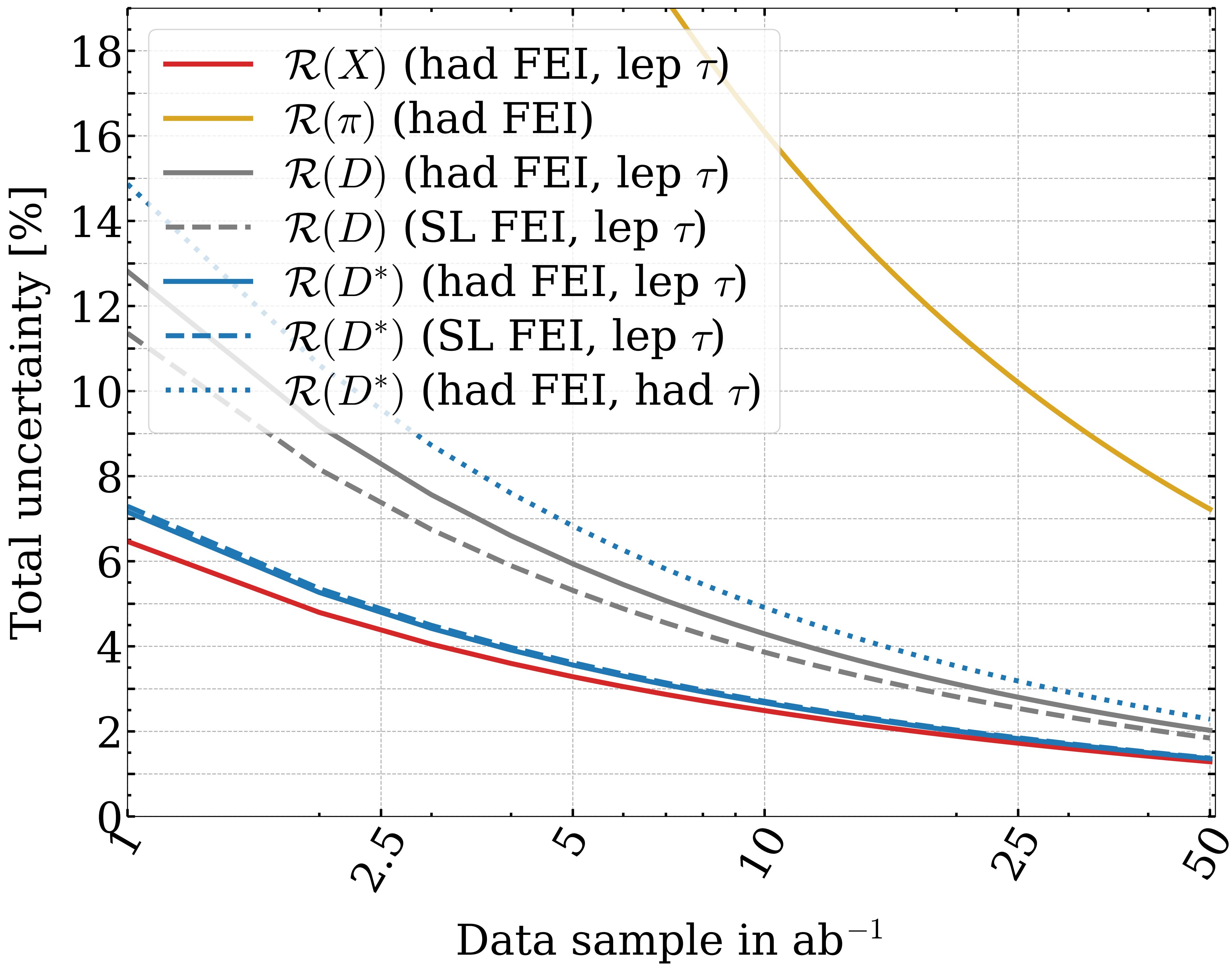



Belle II Preliminary
∫ Ldt=189.3 fb^{-1}
$B^0 \to D^{*-}\mu^+\nu_\mu$ and cc.
Data
Signal
BG
selection
Moriond 2022
Candidates/(0.10 GeV^2)
Missing mass squared (GeV^2)


Belle II Preliminary
$\int \mathcal{L}\, dt = 34.6\,\mathrm{fb}^{-1}$
No beam background suppression
$B \to D^*\ell\nu$
Background
Continuum
MC stat. unc.
Data
Candidates / (0.1 GeV)
$\frac{\mathrm{Data-MC}}{\sigma_{\mathrm{Data}}}$
E_{ECL} [GeV]


Belle II Preliminary
$\int \mathcal{L}\, dt = 34.6\,\mathrm{fb}^{-1}$
Beam background BDT applied
$B \to D^*\ell\nu$
Background
Continuum
MC stat. unc.
Data
BDT removing
beam background photons
trained on data
Candidates / (0.1 GeV)
$\frac{\mathrm{Data-MC}}{\sigma_{\mathrm{Data}}}$
E_{ECL} [GeV]

Estimated Belle II Sensitivities



New Physics

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

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

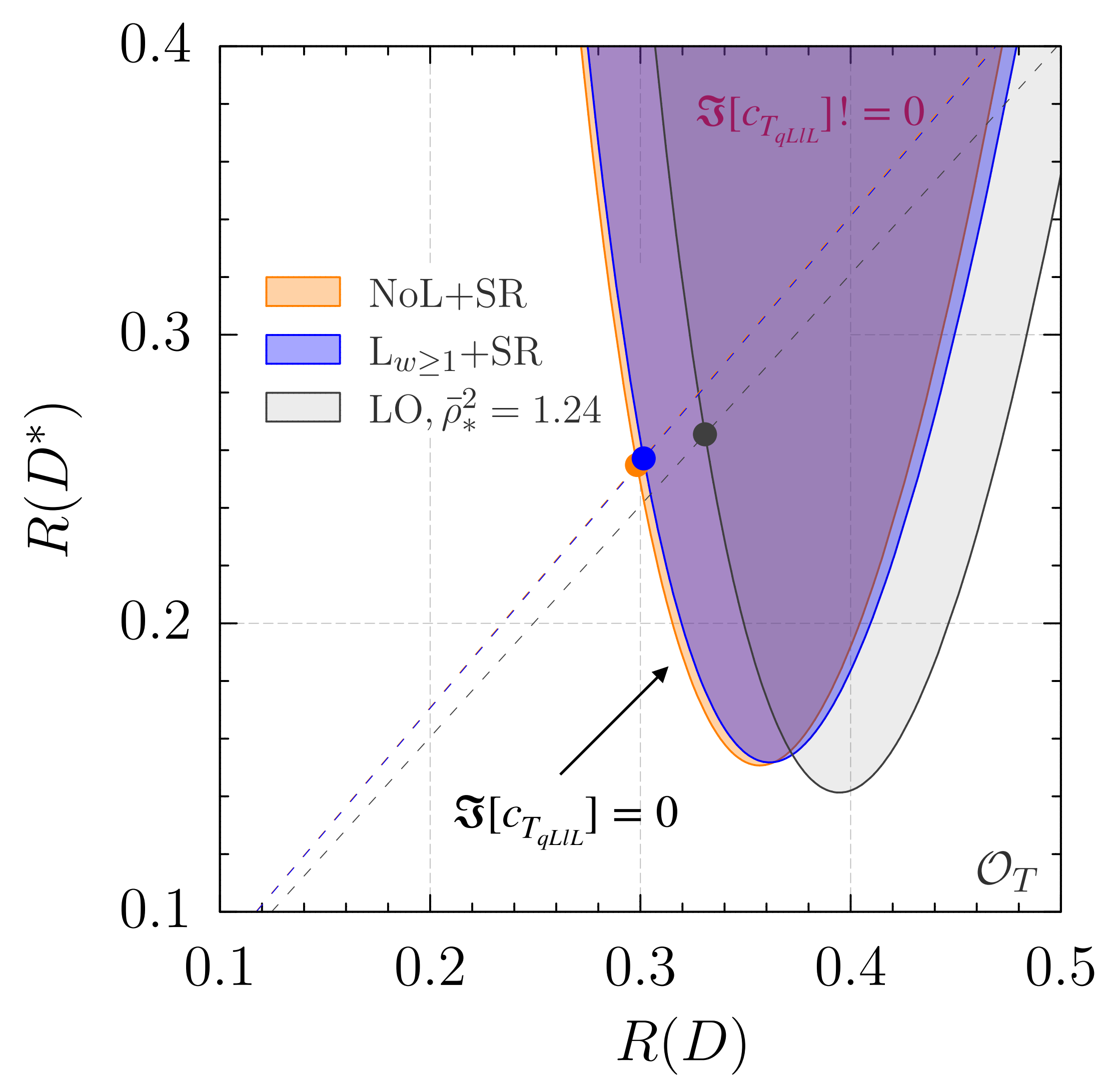
→ **10 NP** four-Fermi operators

→ **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]

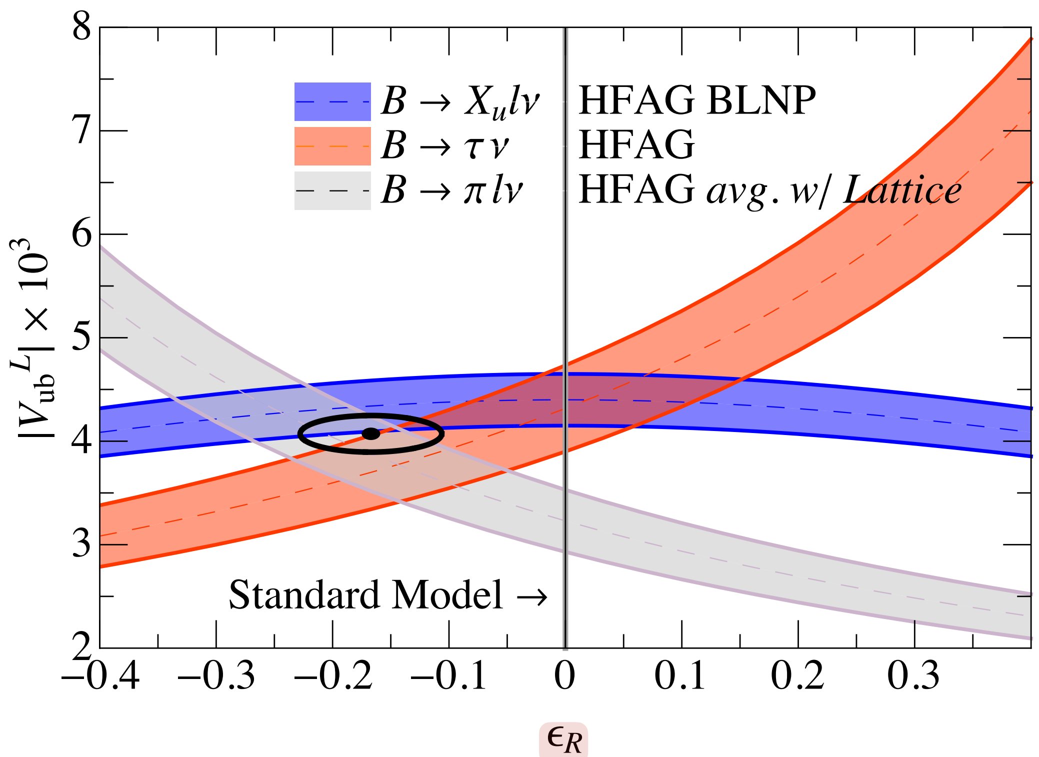
The two categories of measurements

1st Category

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

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

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



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	$1 - \epsilon_R$

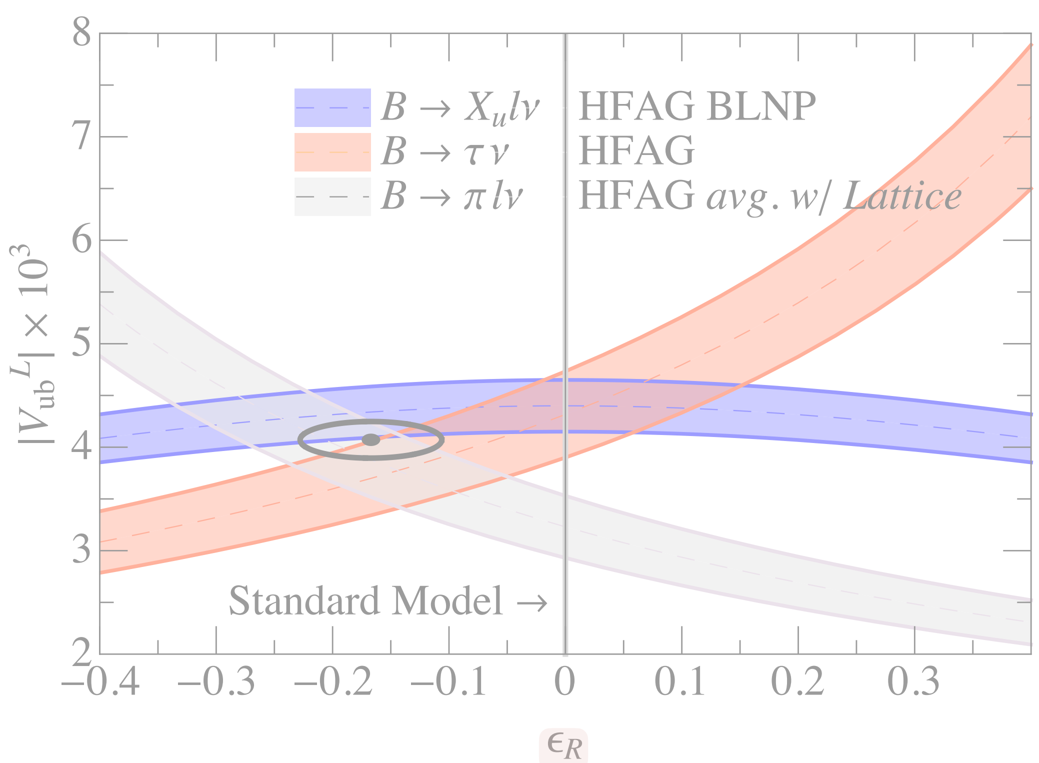
The two categories of measurements

1st Category

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

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

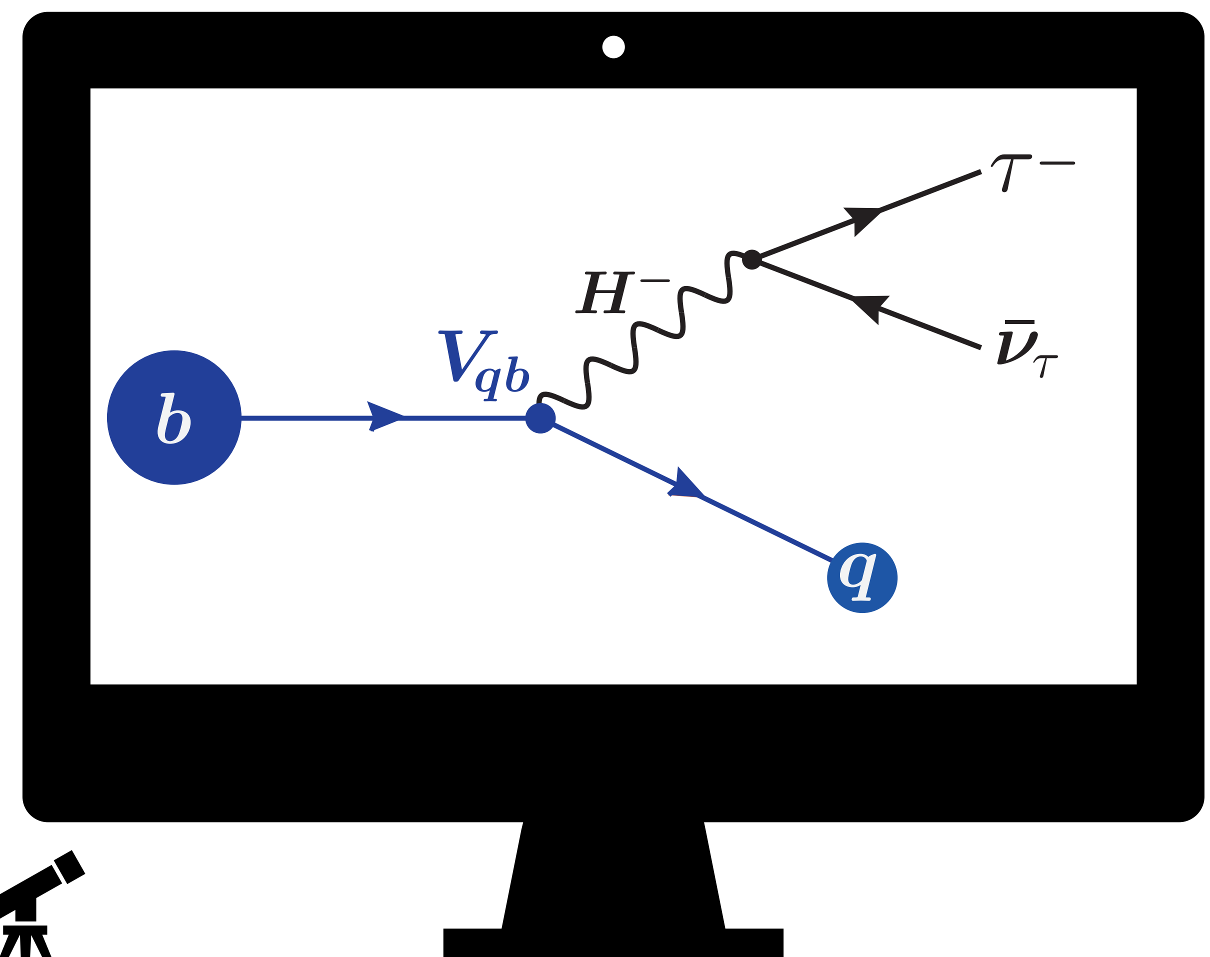
$$\mathcal{L}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{ub}^L \left(\bar{u}\gamma_\mu P_L b + \epsilon_R\, \bar{u}\gamma_\mu P_R b\right)\left(\bar{\nu}\gamma^\mu P_L \ell\right) + \text{h.c.},$$

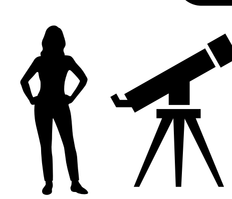


Decay	$\lvert V_{ub}\rvert \times 10^3$	ϵ_R dependence
$B \to \pi \ell \bar{\nu}$	3.23 ± 0.30	$1 + \epsilon_R$
$B \to X_u \ell \bar{\nu}$	4.39 ± 0.21	$\sqrt{1+\epsilon_R^2}$
$B \to \tau \bar{\nu}_\tau$	4.32 ± 0.42	$1 - \epsilon_R$

2nd Category

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





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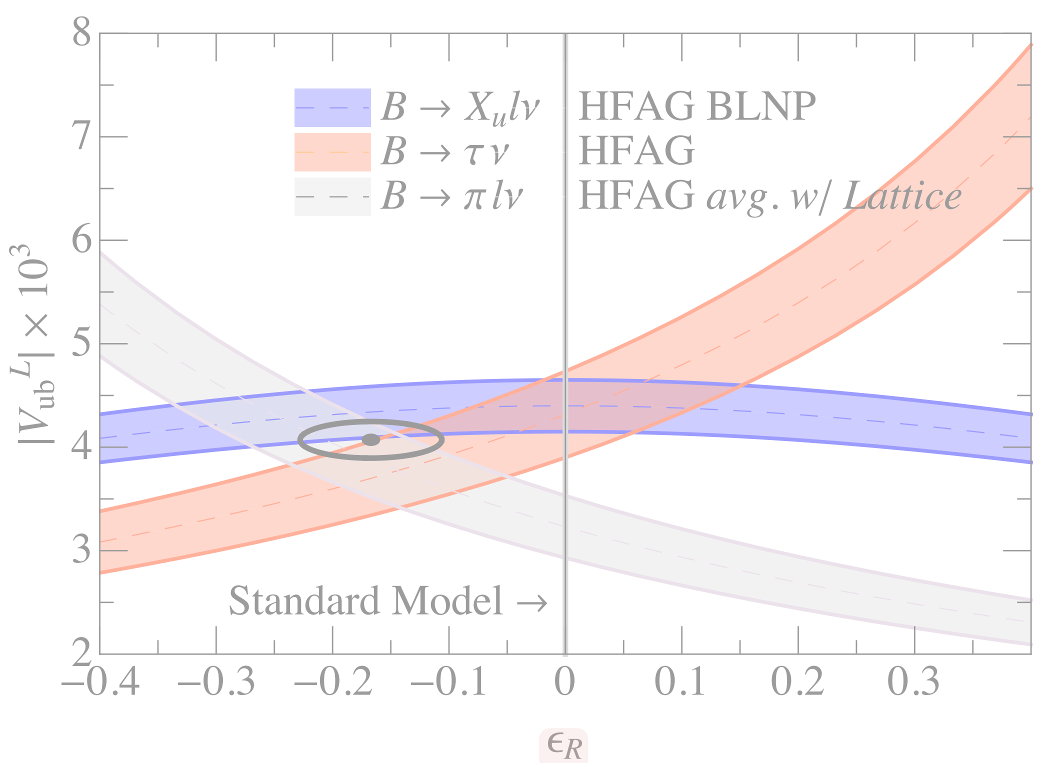

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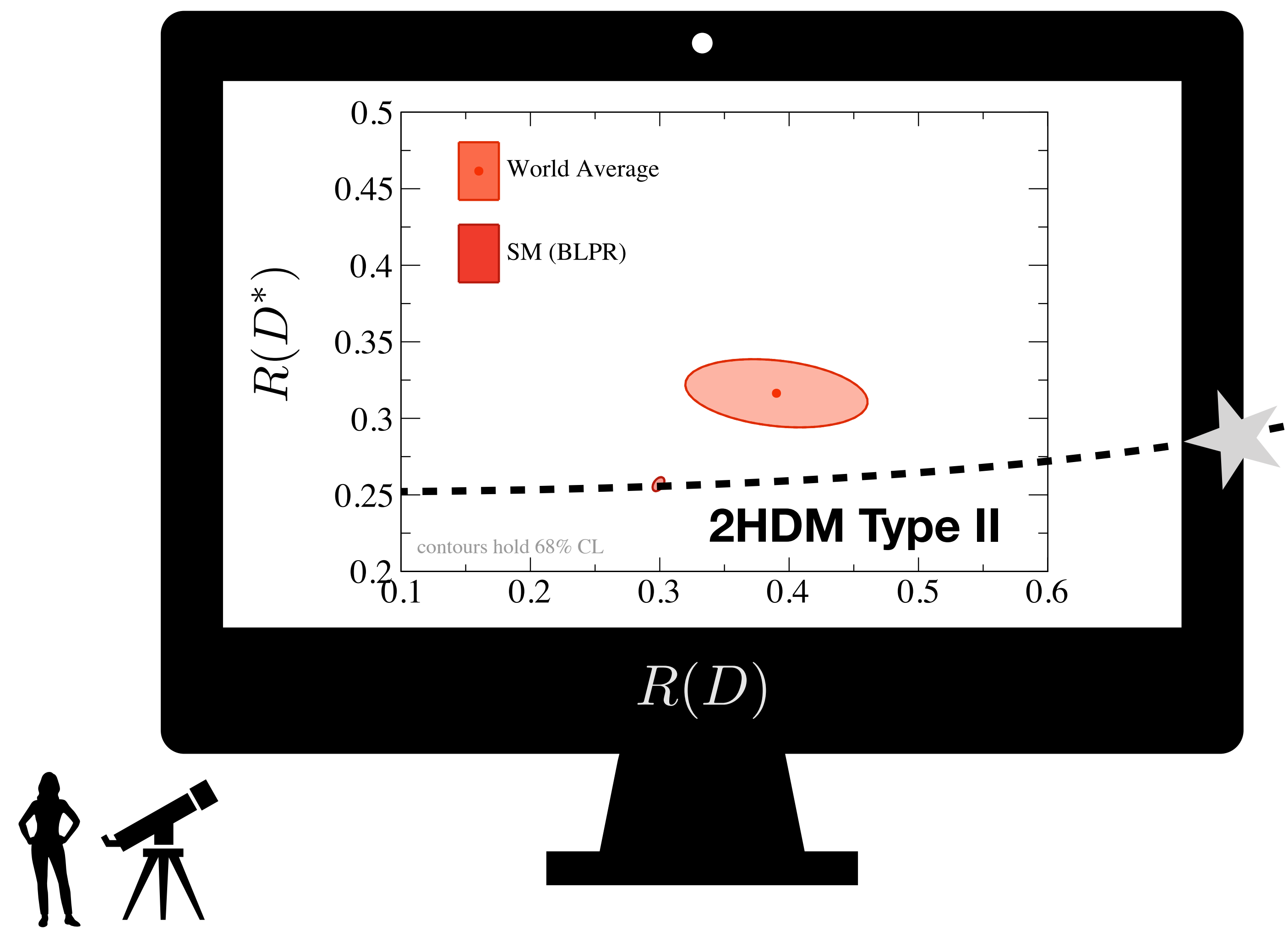

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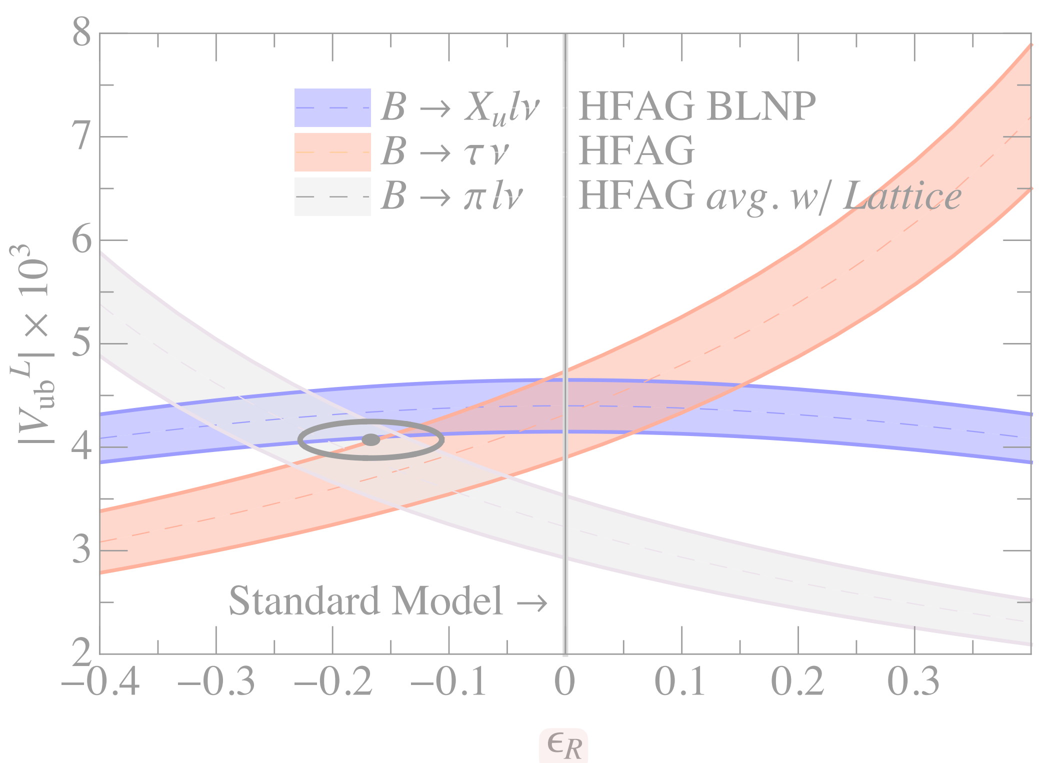

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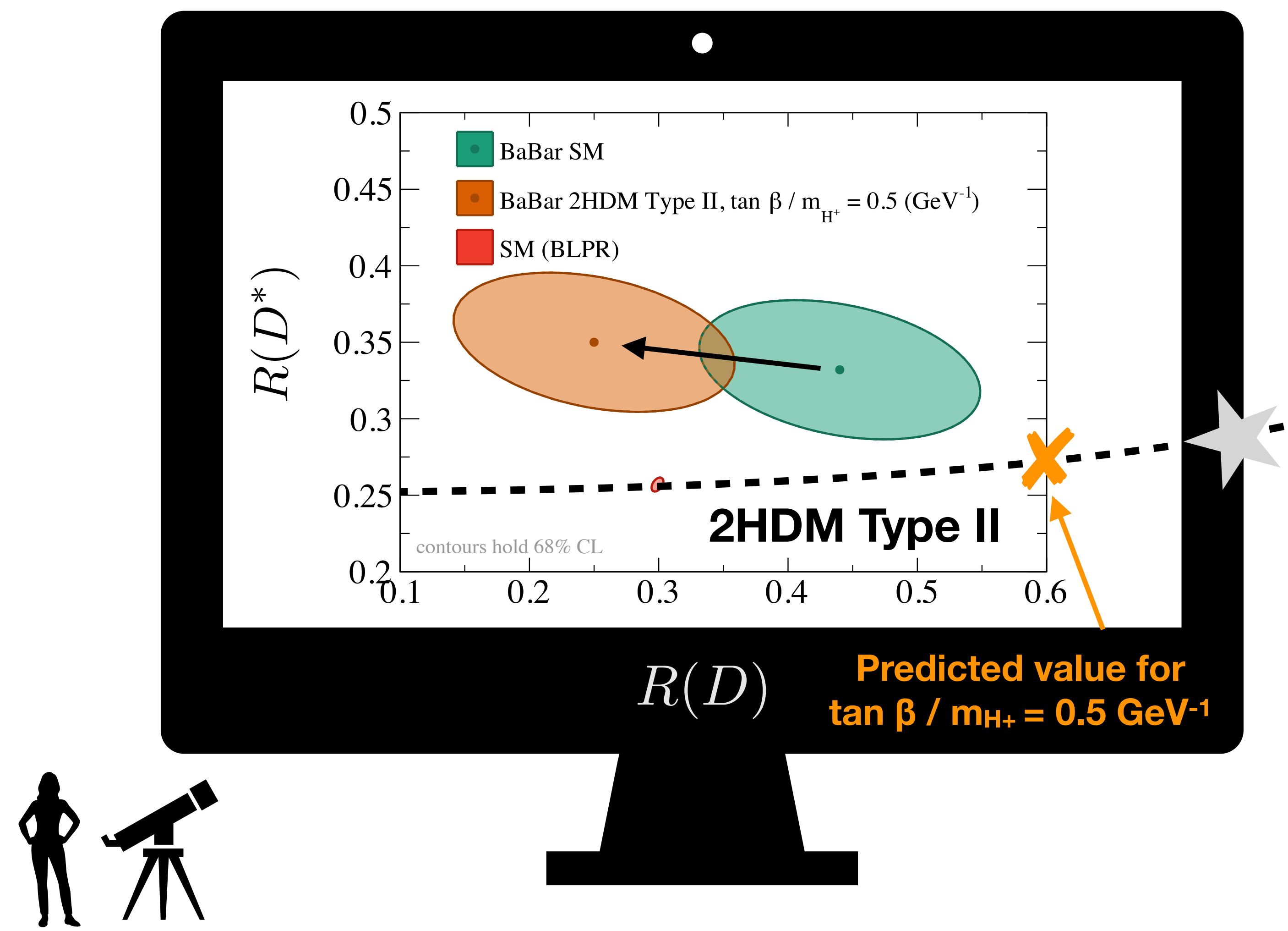


- As it turns out, **not that easy** — the **measured points** themselves are **extracted assuming** the **SM** and kinematic distributions sensitive to the PoI are altering the measurement

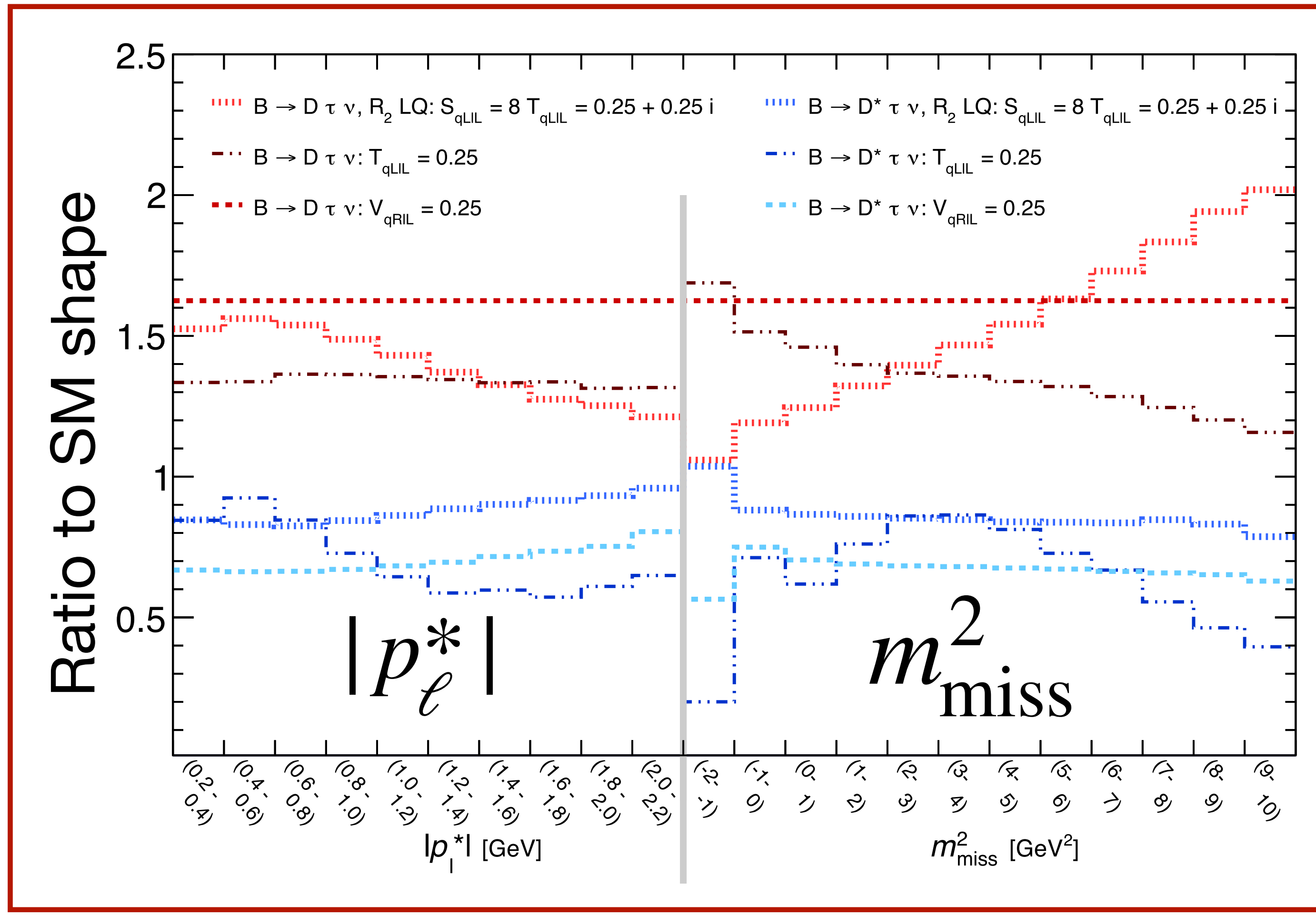
$b \to c\tau\bar{\nu}_\tau$

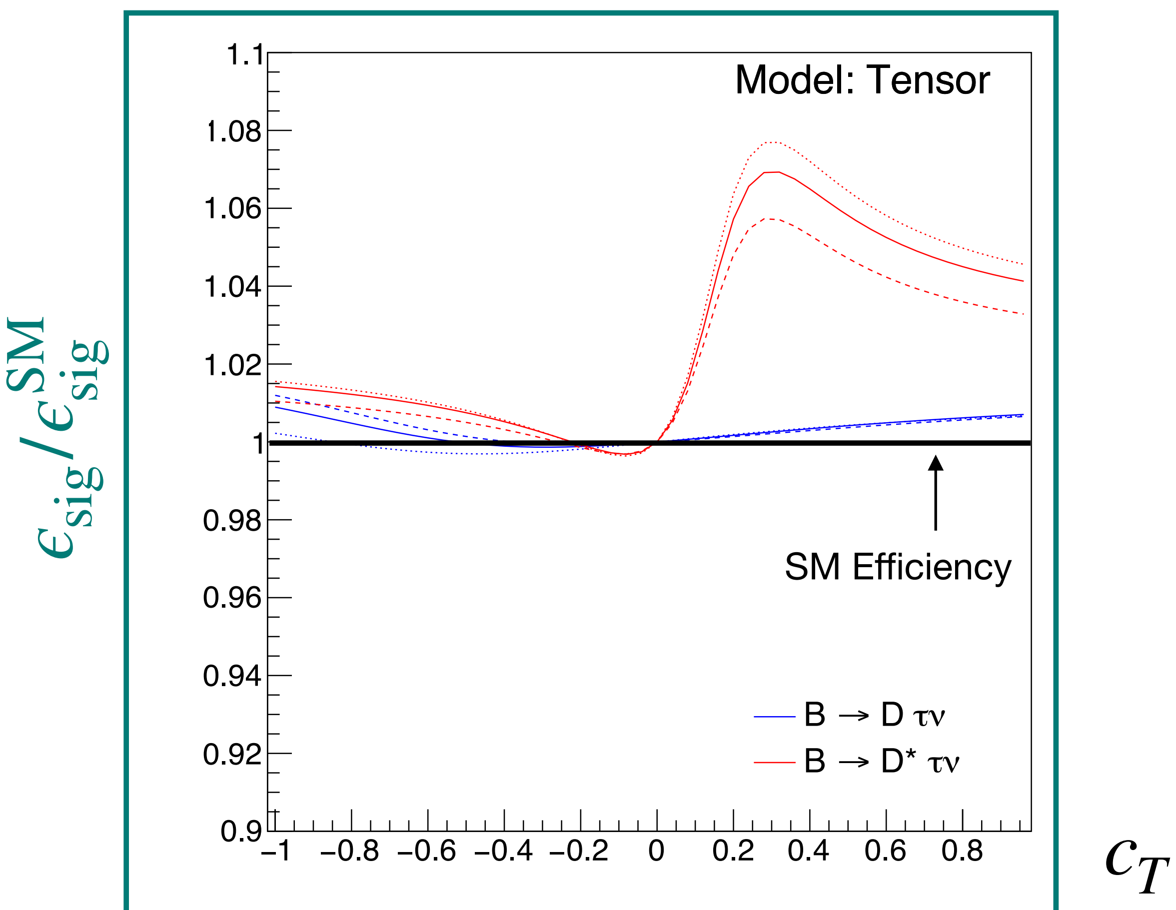
$\tau \to \ell\bar{\nu}_\ell\nu_\tau$

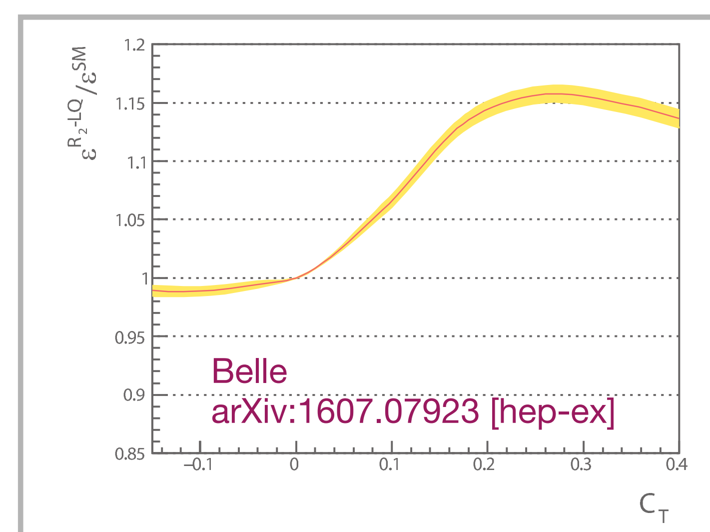
Use **kinematic** quantities (e.g. $|p^*_\ell|$, $m^2_{\rm miss}$, q^2) to **subtract background**

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

Assume **SM** acceptance x efficiency







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

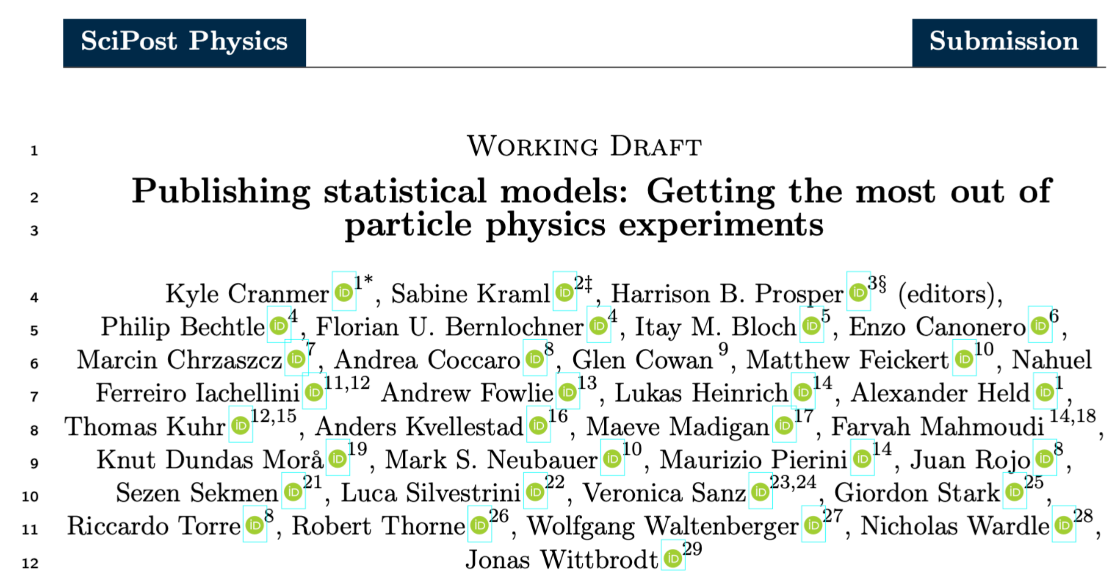
#2

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

a fairly prominent problem


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]

SciPost Phys. 12, 037 (2022)

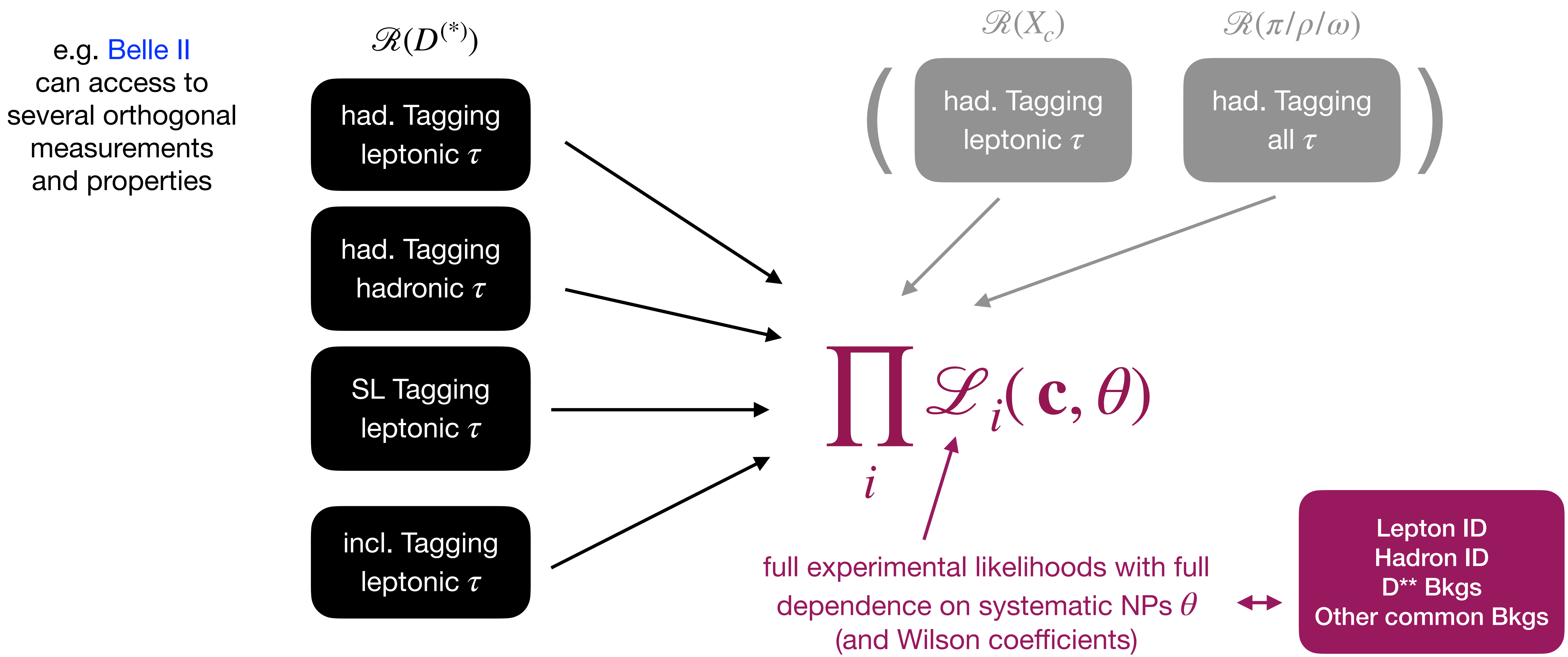
Benefit: no biases, more sensitivity as shape of **all** kinematic distributions help distinguish between models

The work program

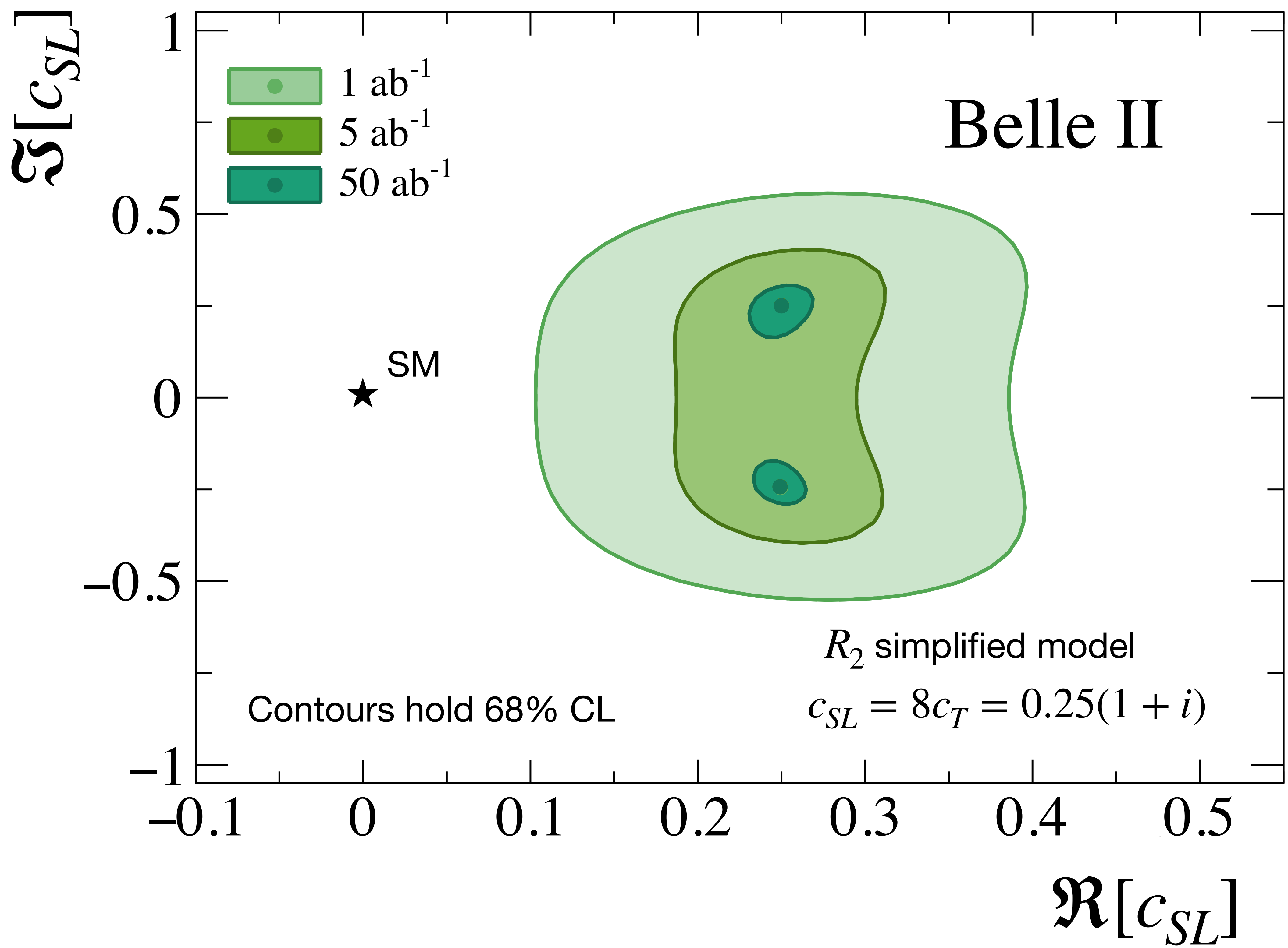
0. Do the SM analyses :-)

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

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



Example sensitivity for such an extraction using shape & normalization information in $p_\ell : m^2_{\text{miss}}$



The full work program: include the LHC

Belle II + LHCb

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

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

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

leptonic τ

hadronic τ

$\mathscr{R}(J/\psi)$

leptonic τ

hadronic τ

$\mathscr{R}(\Lambda_c)$

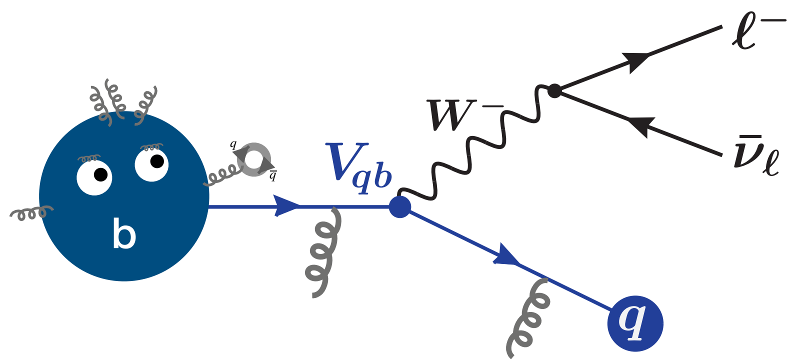
leptonic τ

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

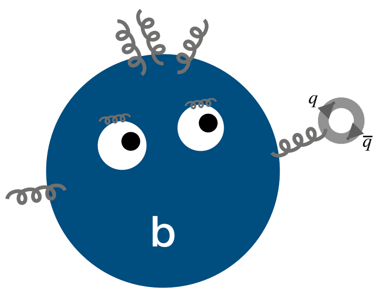
Adding additional observables (e.g. polarizations) is straightforward as the kinematic regions sensitive to such can be readily included

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

Summary & Outlook

Summary & Conclusions

Semileptonic offer excellent probe to search for new physics



Measurements of **semileptonic** decays with τ make use of **SM nature** of **process** in extraction $(q^2, m^2_{\text{miss}}, p_\ell)$, i.e. not straightforward to make interpretations of enhancements

Hint of **Lepton Flavor Universality violation** in combinations $\sim \mathbf{3}\sigma$

Latest measurements, however, show smaller overall tension with SM expectation.

Need **new experimental** measurements to confirm or rule out anomaly

Belle II will provide insights with **inclusive** and **exclusive** final states, also targeting **properties**.

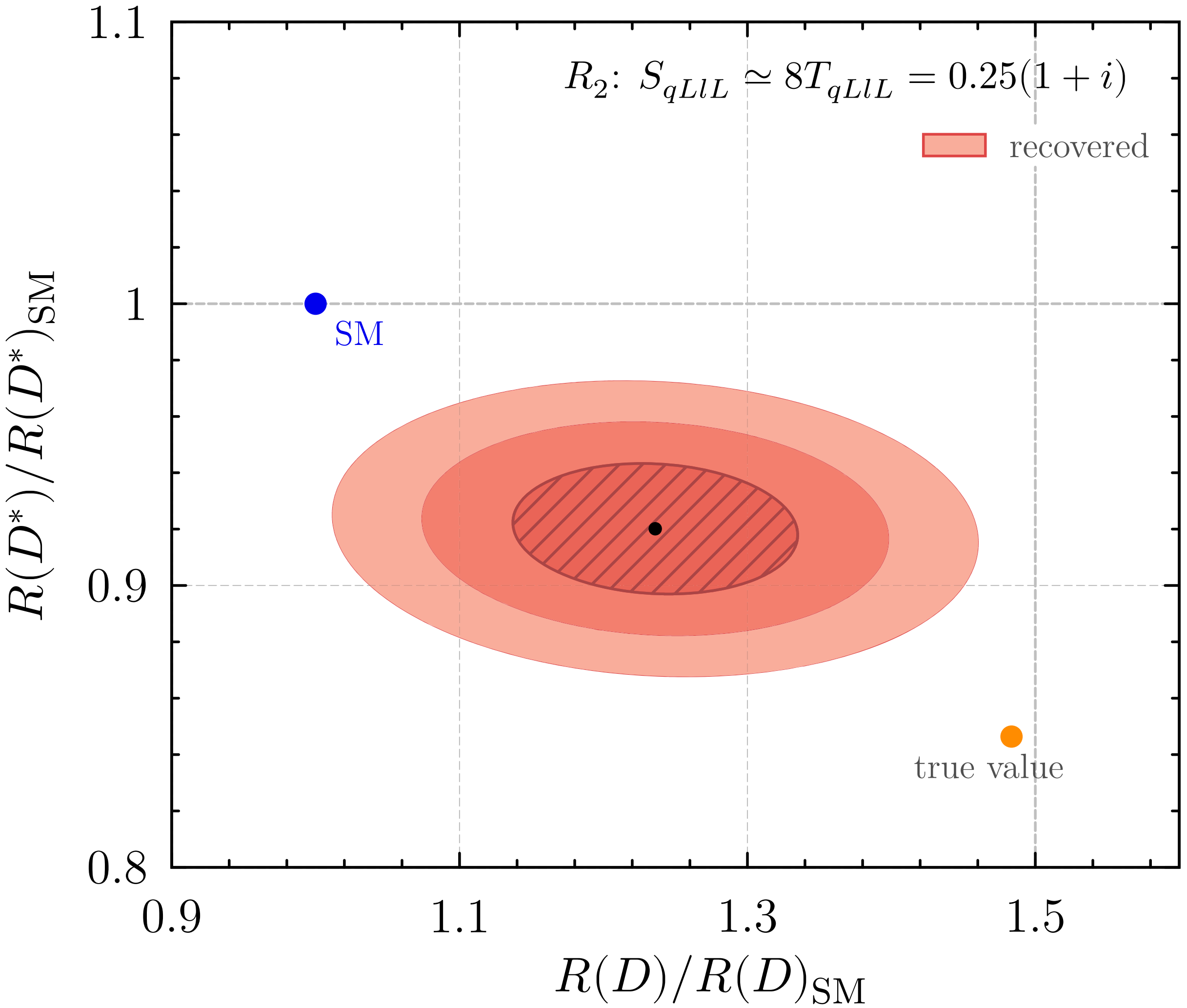
Belle is preparing **legacy** measurement of $\mathscr{R}(D^{(*)})$ in had. tagged channel.

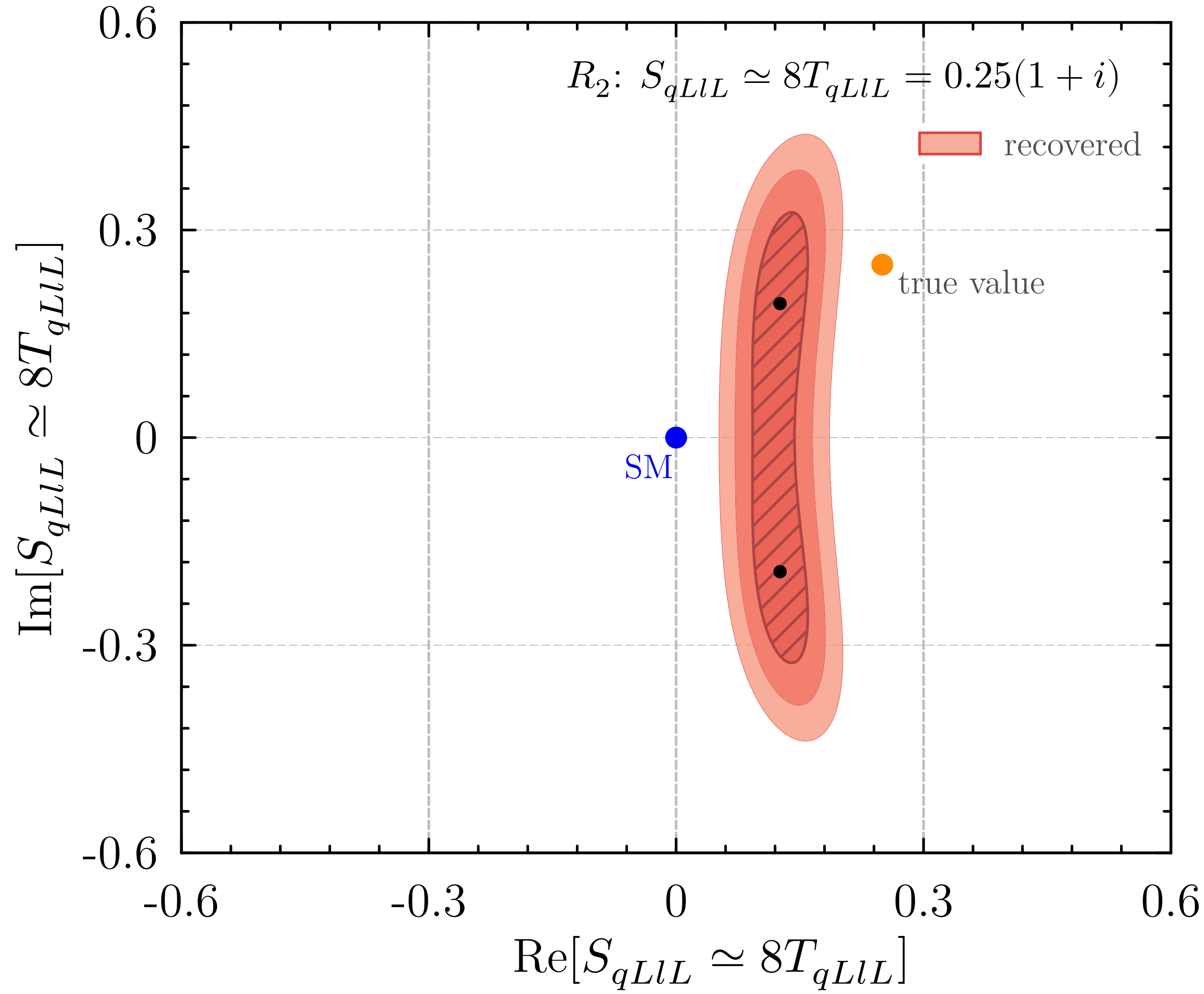
Measurements involving $b \to u\tau\bar{\nu}_\tau$ will require a lot of statistics, i.e. will not help to resolve things in the near future


Backup
b
q
$\overline{q}$

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

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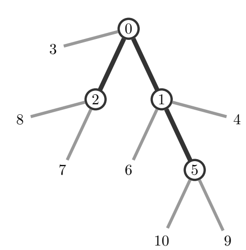
HAMMER offers a solution to these problems

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

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

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

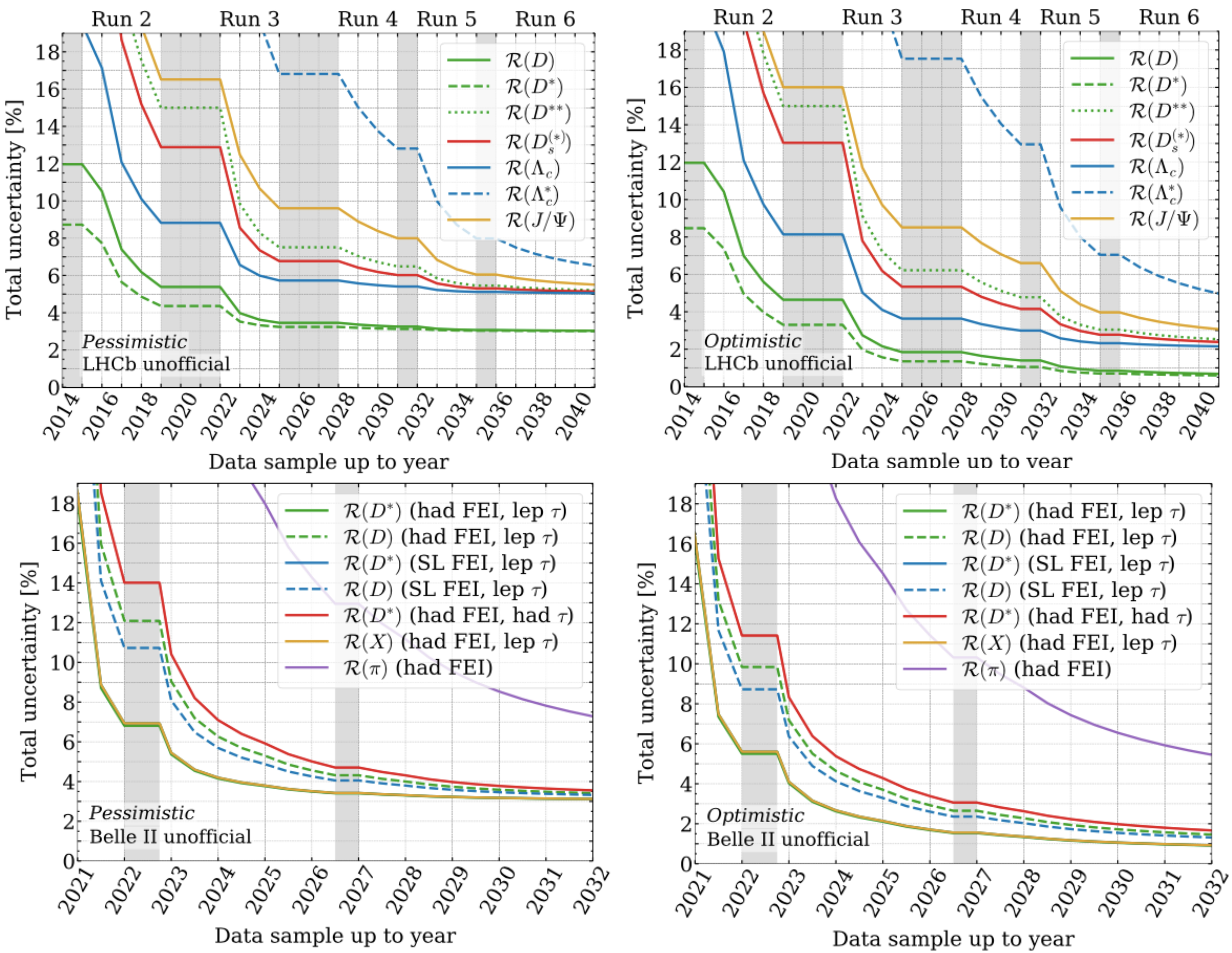
$F_i F_j^\dagger$: encode hadronic form factors

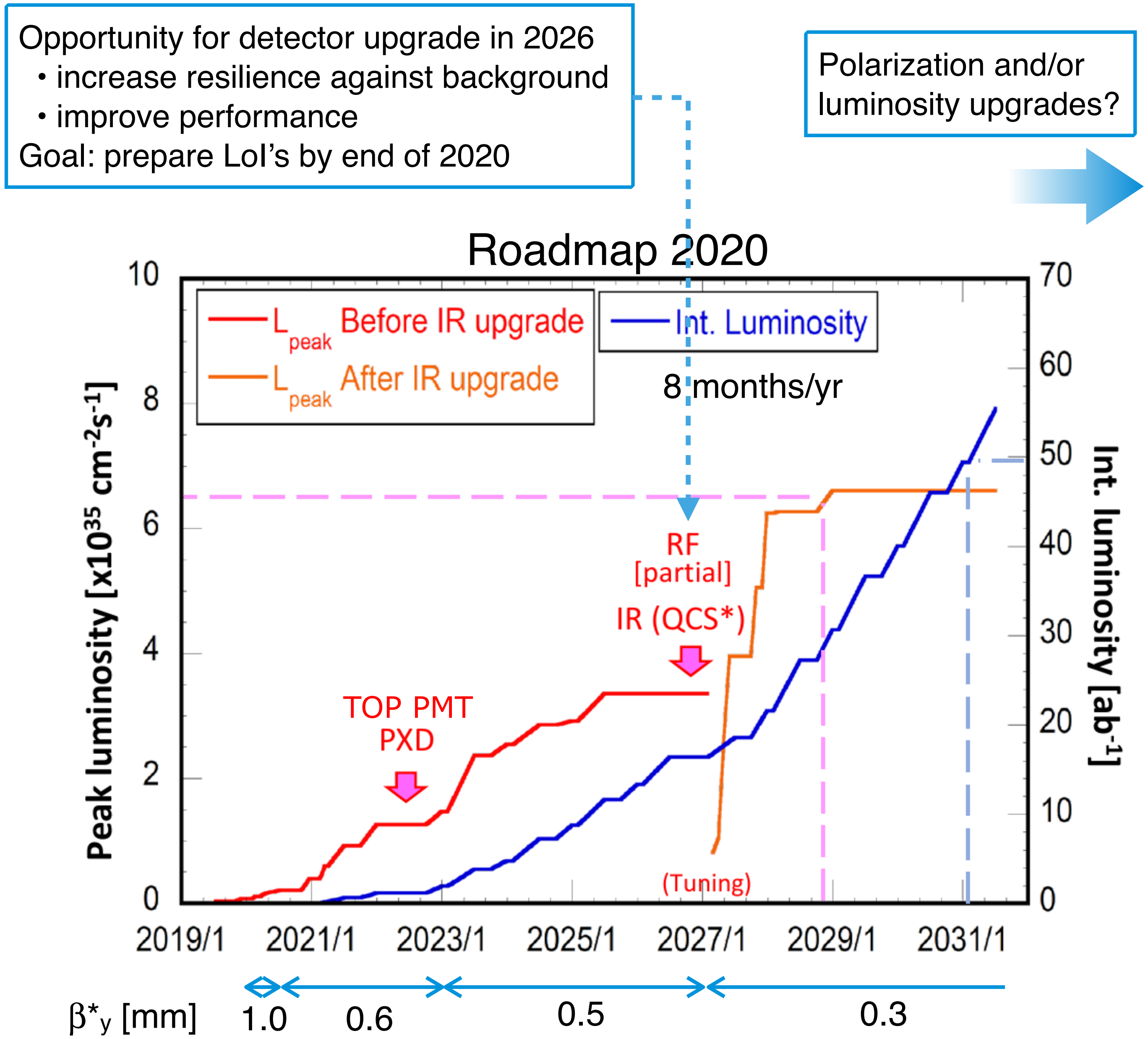
$W_{\alpha i \beta j}$: tensor that encodes amplitudes of given process

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

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

FB, M. Sevilla, D. Robinson, G. Wormser
[Rev. Mod. Phys. **94**, 015003,arXiv:2101.08326]





Run 1		LS1		Run 2				LS2			Run 3			LS3			Run 4			LS4	Run 5			LS5	Run 6		
2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	
1.1	**2.0**	-	-	**0.3**	**1.7**	**1.7**	**2.2**	-	-	-	**8.3**	**8.3**	**8.3**	-	-	-	**8.3**	**8.3**	**8.3**	-	**50**	**50**	**50**	-	**50**	**50**	**fb^{-1}**

Limiting Systematics

Result	Experiment	τ decay	Tag	Systematic uncertainty [%]					**Total uncert. [%]**		
				MC stats	$D^{(*)}l\nu$	$D^{**}l\nu$	Other bkg.	Other sources	**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**

Latest $R(D^{(*)})$ from Belle: *Systematics*

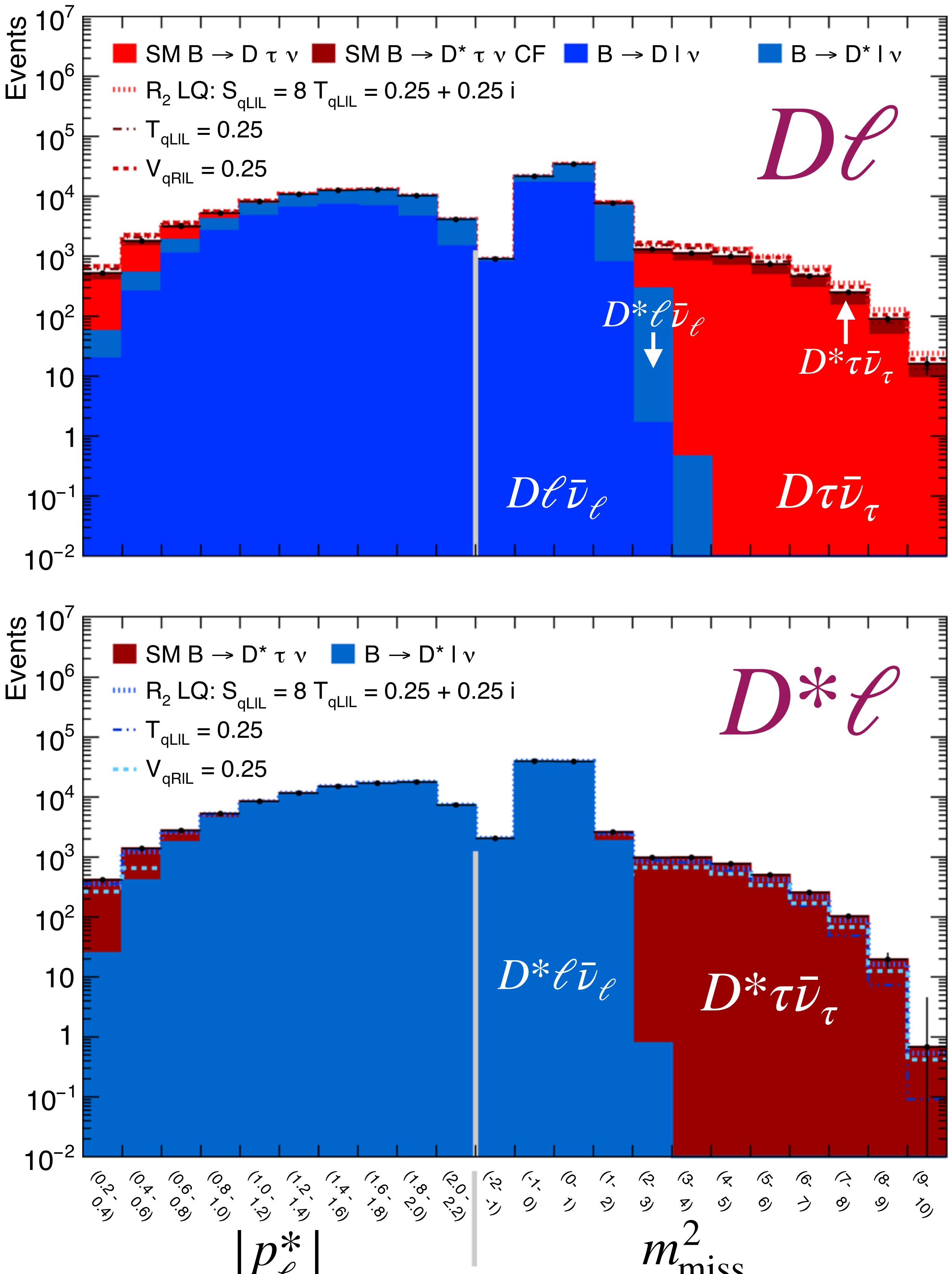
Result	Contribution	Uncertainty [%] Sys.	Stat.
$\mathcal{R}(D)$	$B \to D^{**}\ell\bar{\nu}_\ell$	0.8	
	PDF modeling	4.4	
	Other bkg.	2.0	
	$\epsilon_{\text{sig}}/\epsilon_{\text{norm}}$	1.9	
	Total systematic	**5.2**	
	Total statistical		**12.1**
	Total	**13.1**	
$\mathcal{R}(D^*)$	$B \to D^{**}\ell\bar{\nu}_\ell$	1.4	
	PDF modeling	2.3	
	Other bkg.	1.4	
	$\epsilon_{\text{sig}}/\epsilon_{\text{norm}}$	4.1	
	Total systematic	**4.9**	
	Total statistical		**6.4**
	Total	**8.1**	

LHCb Measurement of $R(D^*)$: *Systematics*

Contribution	Uncertainty [%]		
	Sys.	Ext.	Stat.
Double-charm bkg.	5.4		
Simulated sample size	4.9		
Corrections to simulation	3.0		
$B \to D^{**} l \nu$ bkg.	2.7		
Normalization yield	2.2		
Trigger	1.6		
PID	1.3		
Signal FFs	1.2		
Combinatorial bkg.	0.7		
Modeling of τ decay	0.4		
Total systematic	**9.1**		
$\mathcal{B}(B \to D^* \pi\pi\pi)$		3.9	
$\mathcal{B}(B \to D^* \ell \nu)$		2.3	
$\mathcal{B}(\tau^+ \to 3\pi\nu)/\mathcal{B}(\tau^+ \to 3\pi\pi^0\nu)$		0.7	
Total external		**4.6**	
Total statistical			**6.5**
Total		**12.0**	

An illustrative Toy Example

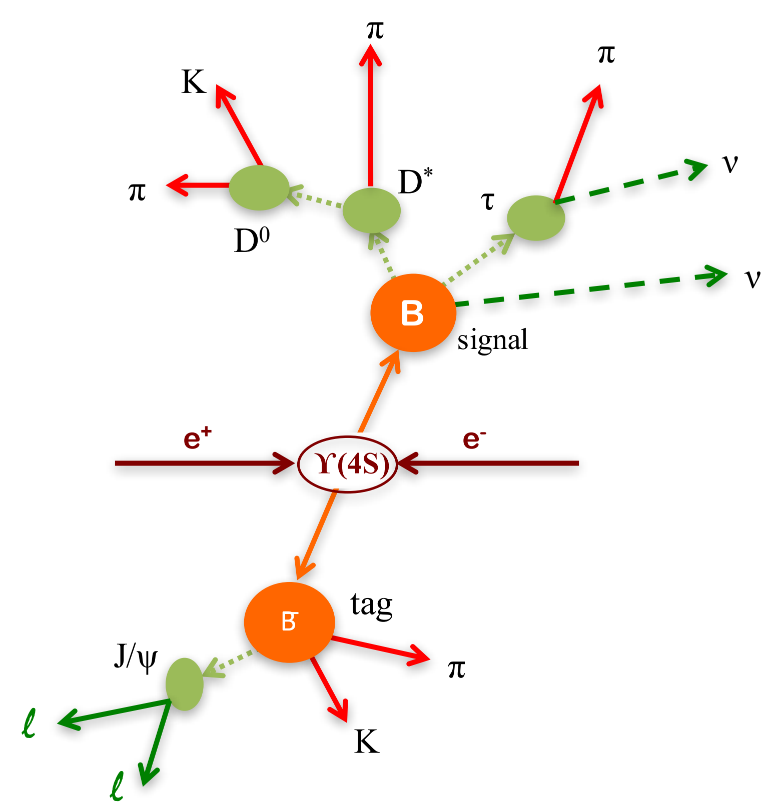
FB, S. Duell, Z. Ligeti, M. Papucci, D. Robinson
Eur. Phys. J. C (2020) **80**: 883 [arXiv:2002:00020]



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

Binned 2D fit in $m^2_{\rm miss}$: $|p^*_\ell|$

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