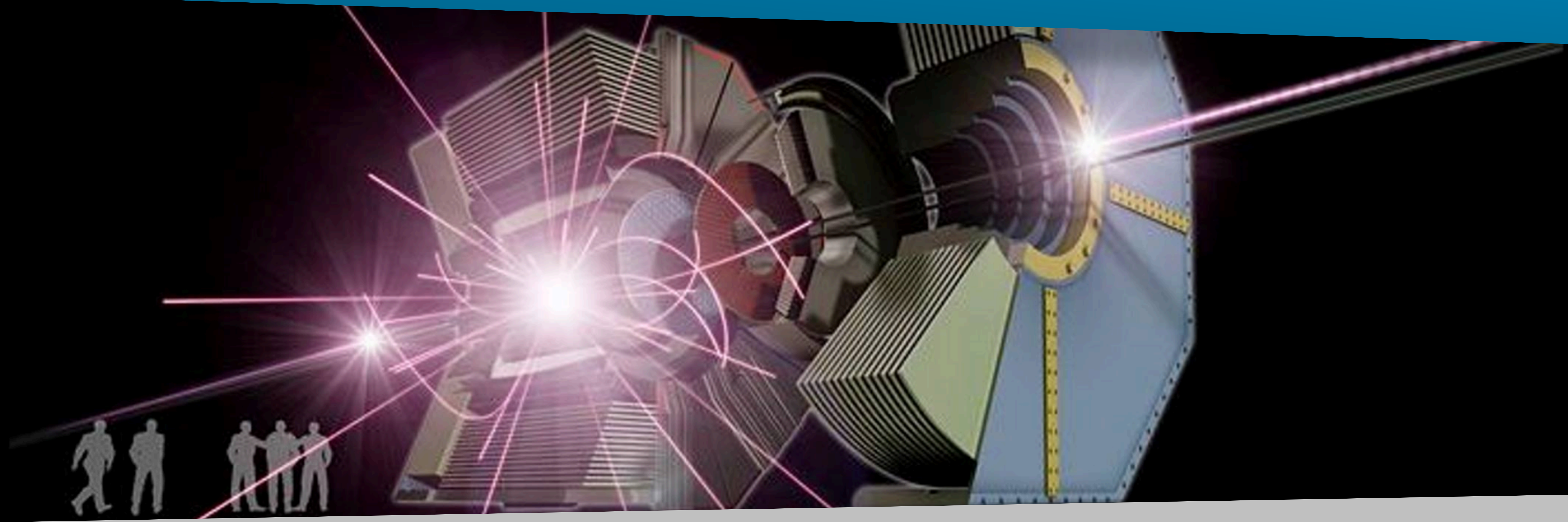
Recent Highlights of (Semi-)leptonic B Studies and Future Perspectives



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2023年12月14日

(Semi-)leptonic B Studies

Semileptonic

$$B \to D\ell\nu, B \to \pi\ell\nu, \ldots (\ell = e, \mu)$$

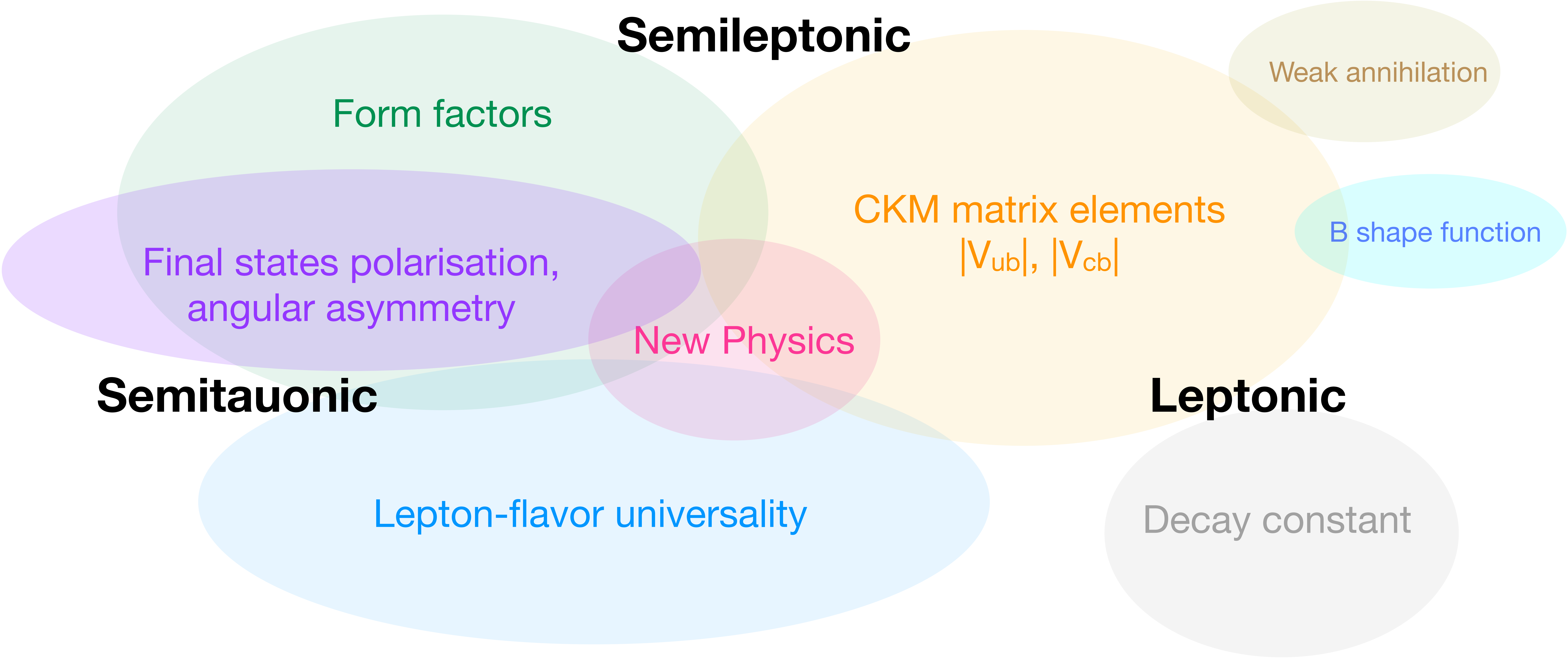
Semitauonic

$$B \to D\tau\nu, B \to \pi\tau\nu, \ldots$$

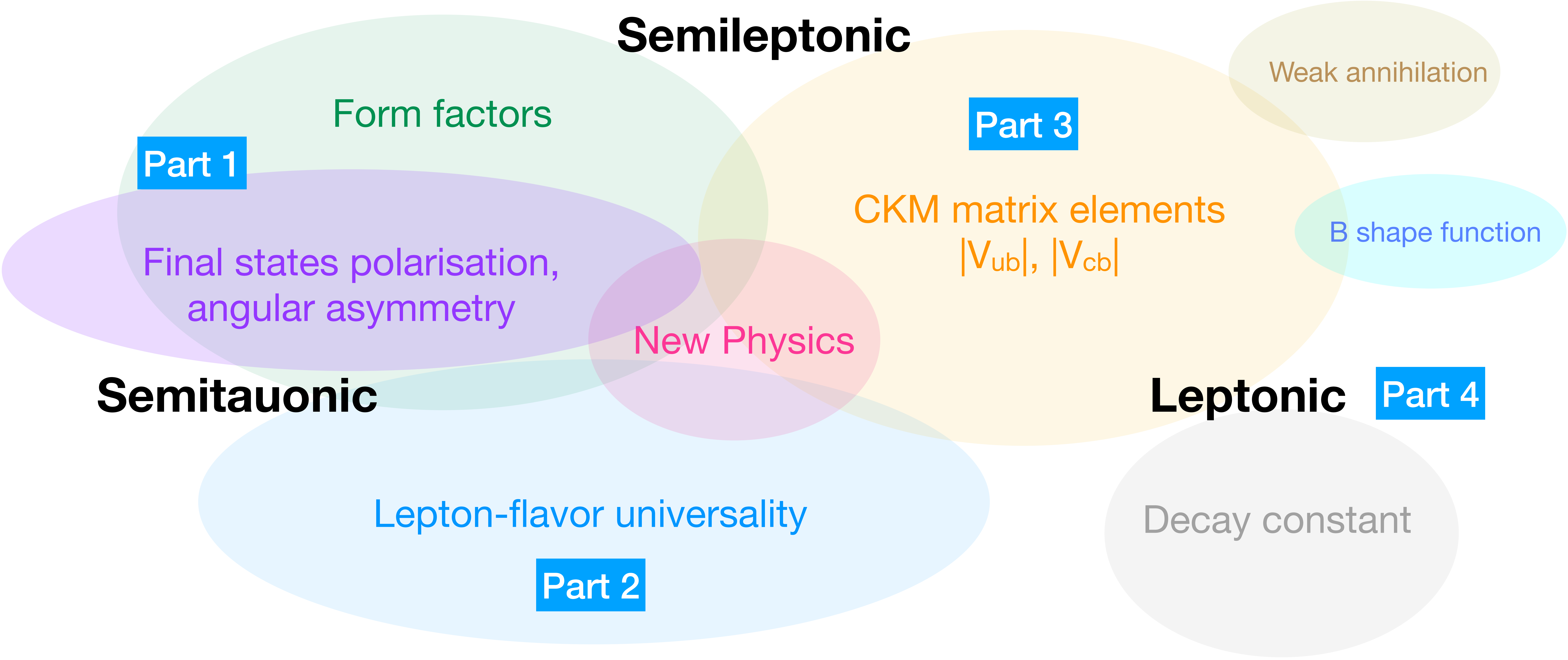
Leptonic

$$B \to \tau\nu, B \to \mu\nu, \ldots$$

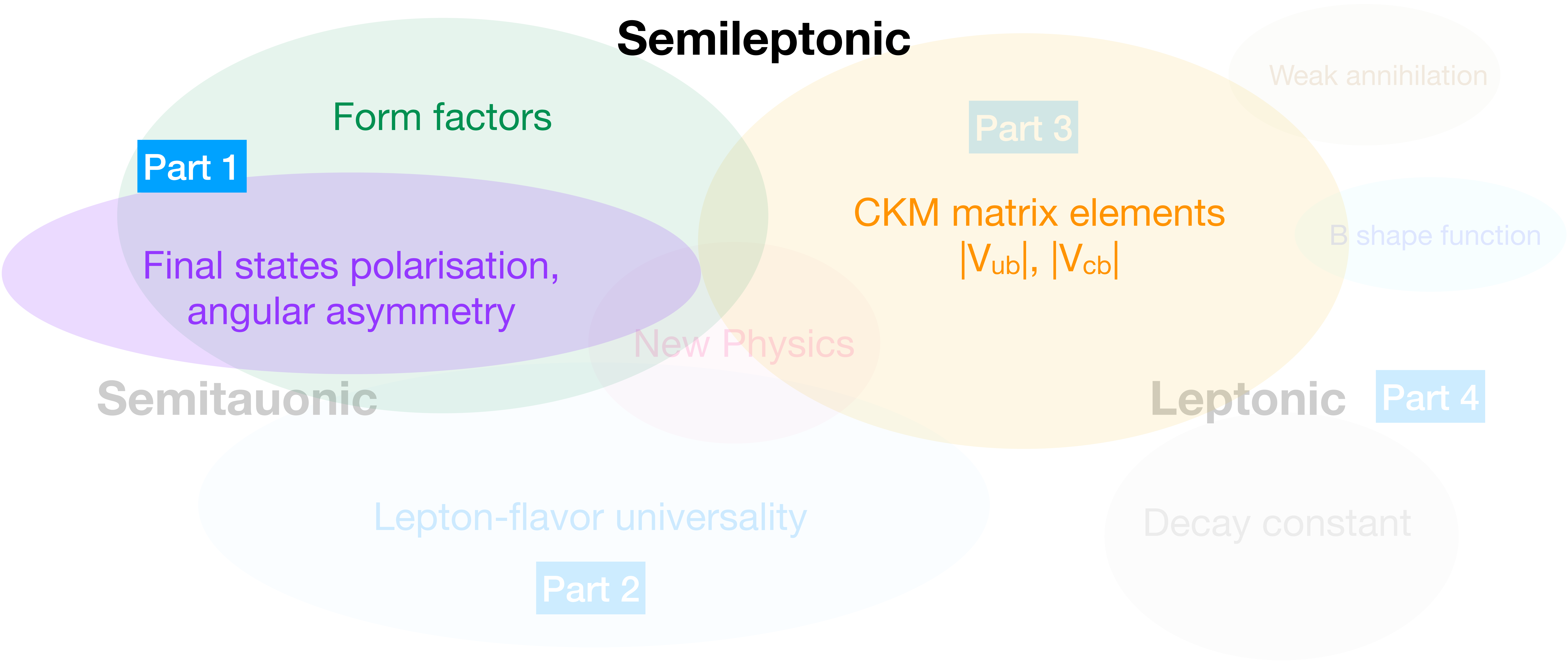
(Semi-)leptonic B Studies



(Semi-)leptonic B Studies



(Semi-)leptonic B Studies



(Semi-)leptonic B Studies

Semileptonic

Form factors

Part 1

Final states polarisation, angular asymmetry

New P

Semitauonic

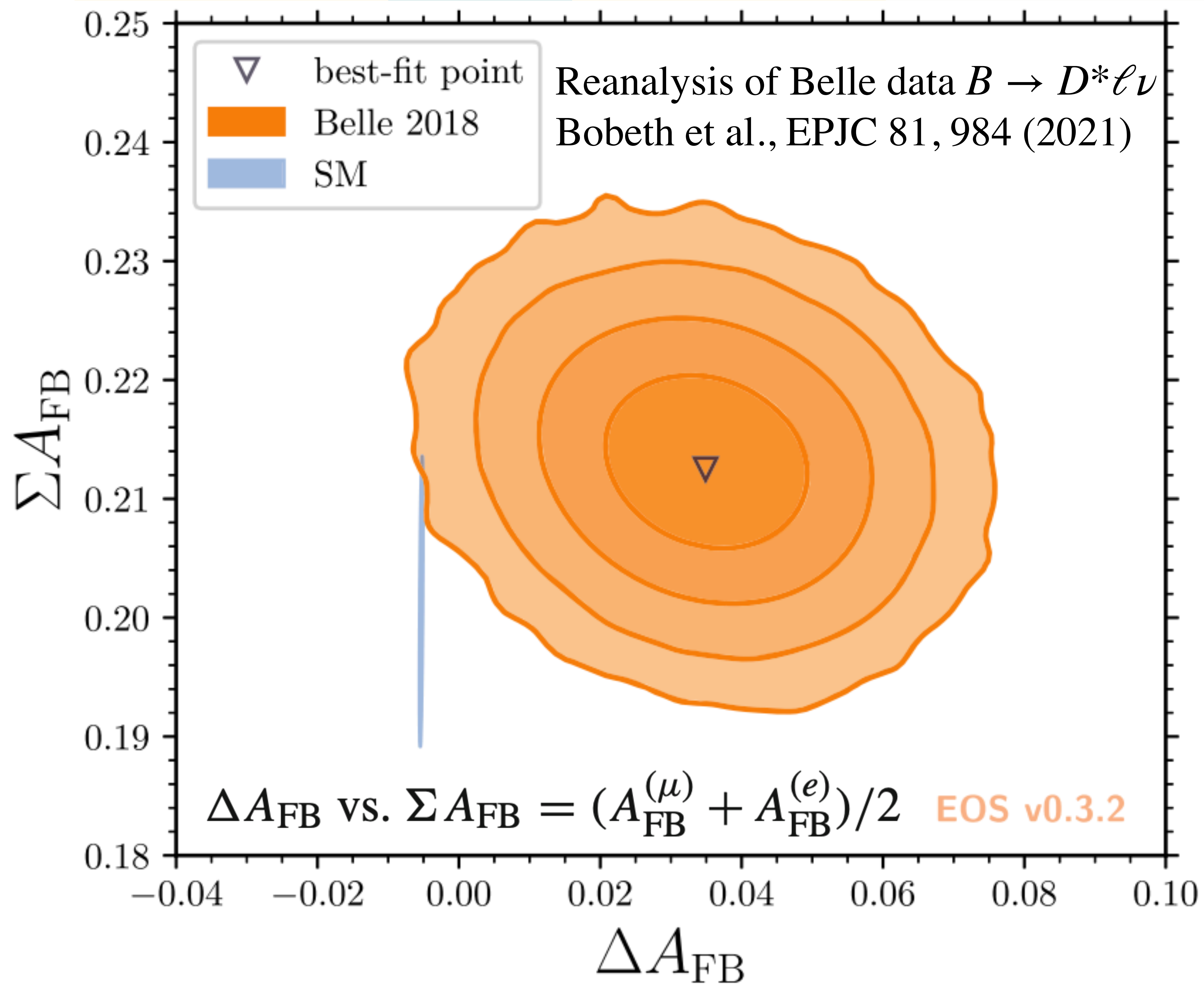
Lepton-flavor univers

Part 2

Weak annihilation

inction

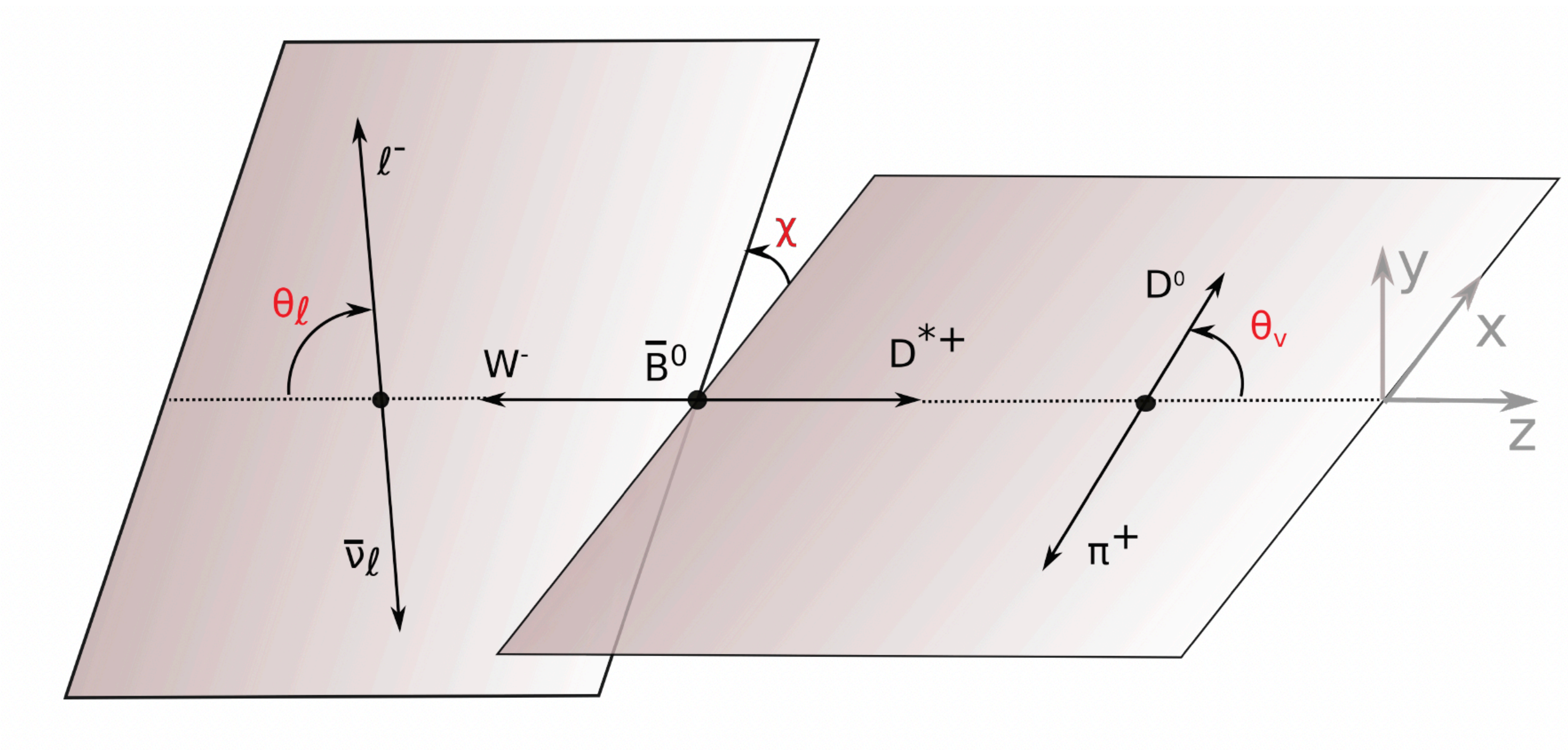
4

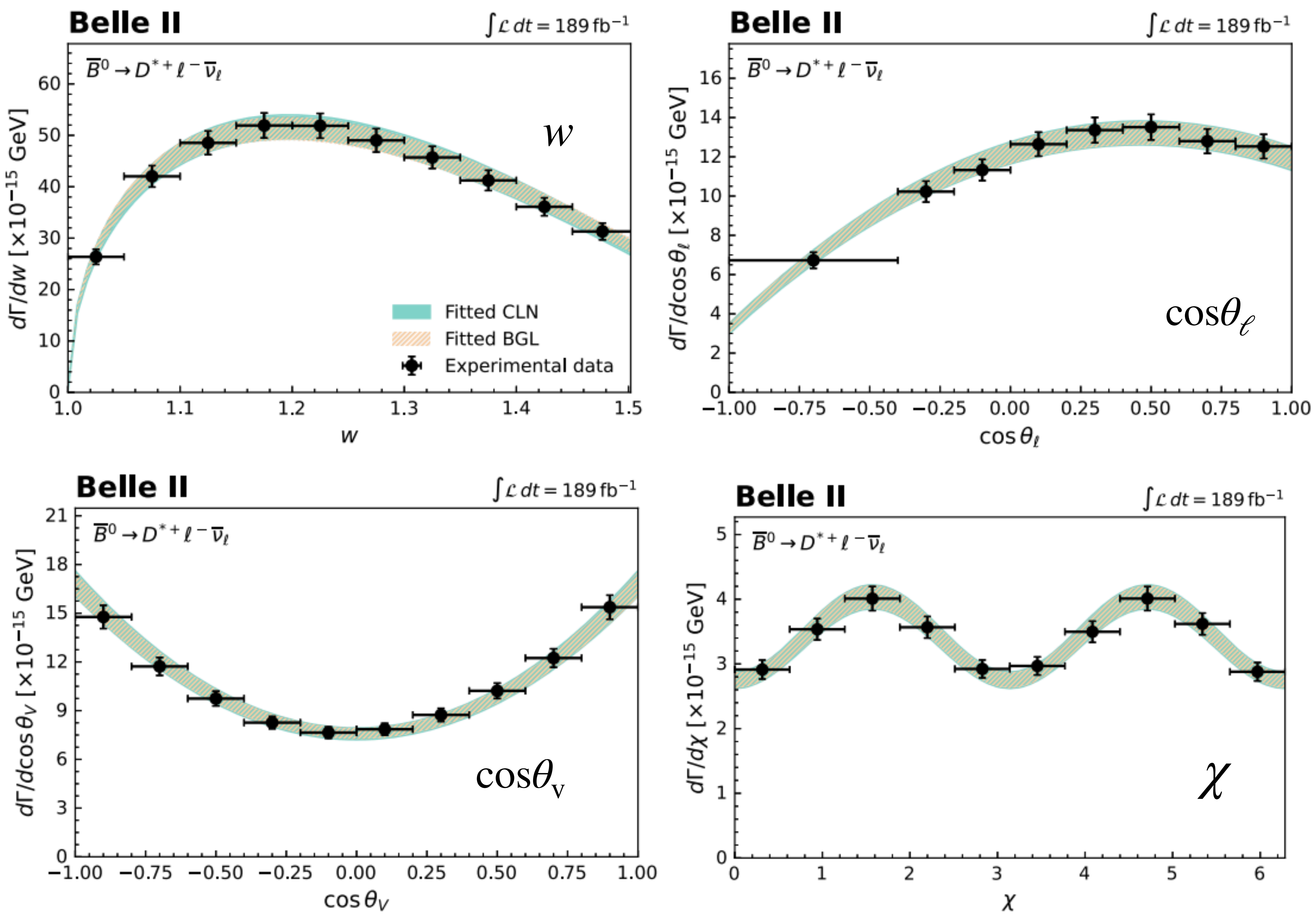


Measurement of $B^0 \to D^*\ell\nu$ Decays at Belle II

PRD 108, 092013 (2023)

- Decay chain: $\mathbf{B^0 \to D^{*+} \ell\nu}$, $\mathbf{D^{*+} \to D^0\pi^+_{slow}}$, $\mathbf{D^0 \to K^- \pi^+}$
- Untagged strategy (higher efficiency than tagged)
- Select energetic signal lepton $p^{CM} > 1.2$ GeV
- Measured total $\mathscr{B}$ and differential spectra: recoil parameter **w**, and angles $\mathbf{\cos\theta_\ell}$, $\mathbf{\cos\theta_v}$, χ
- **Extract $|V_{cb}|$, lepton angular asymmetry, D* longitudinal polarization fractions**





$$|V_{cb}|_{\mathrm{BGL}} = (40.57 \pm 0.31 \pm 0.95 \pm 0.58) \times 10^{-3}$$

$$|V_{cb}|_{\mathrm{CLN}} = (40.13 \pm 0.27 \pm 0.93 \pm 0.58) \times 10^{-3}$$

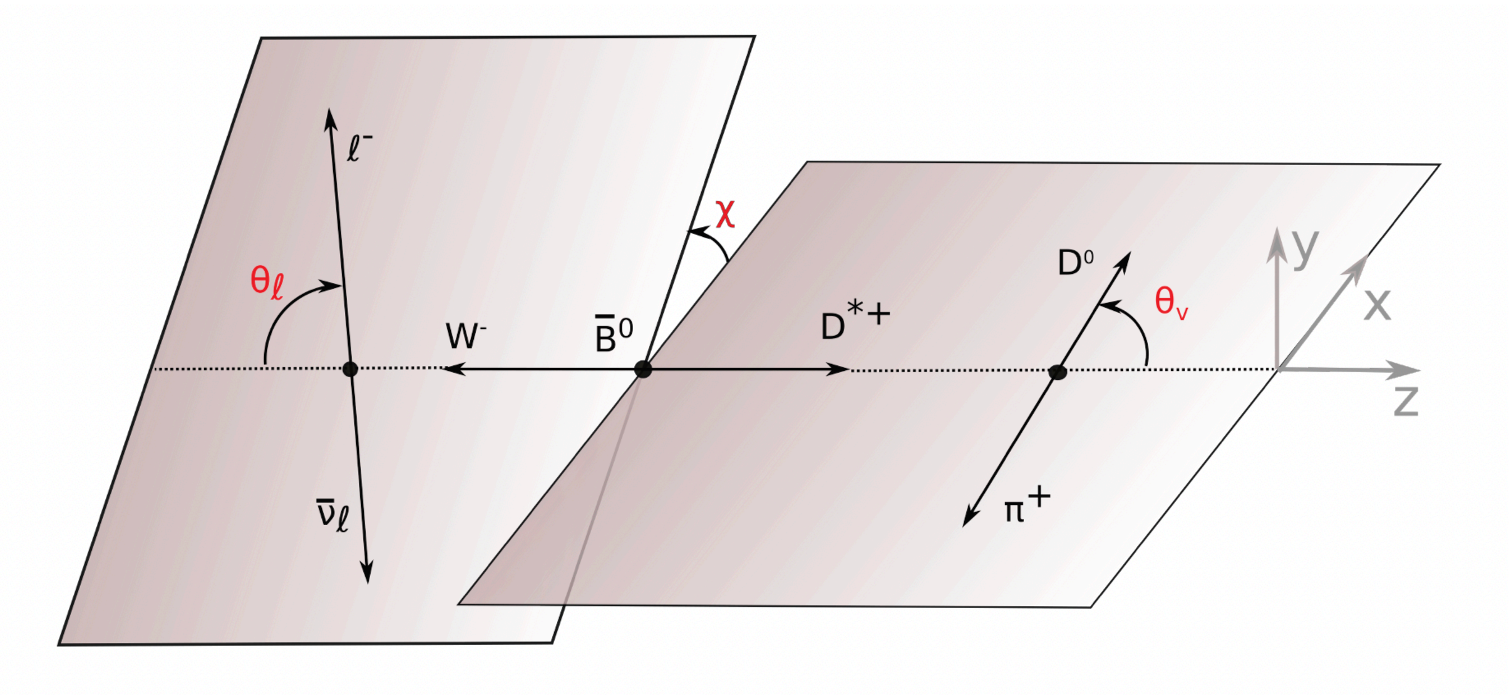
stat. syst. LQCD

Measurement of $B^0 \to D^*\ell\nu$ Decays at Belle II

PRD 108, 092013 (2023)

- Lepton-flavor-universality tested with separate results on e- & mu-mode
- All in **good agreement with SM expectations**

$$R_{e/\mu} = 0.998 \pm \underset{\text{stat.}}{0.009} \pm \underset{\text{syst.}}{0.020}$$



Test on forward-backward asymmetry

$$\mathcal{A}_{\rm FB} = \frac{\int_0^1 \mathrm{d}\cos\theta_\ell \mathrm{d}\Gamma/\mathrm{d}\cos\theta_\ell - \int_{-1}^0 \mathrm{d}\cos\theta_\ell \mathrm{d}\Gamma/\mathrm{d}\cos\theta_\ell}{\int_0^1 \mathrm{d}\cos\theta_\ell \mathrm{d}\Gamma/\mathrm{d}\cos\theta_\ell + \int_{-1}^0 \mathrm{d}\cos\theta_\ell \mathrm{d}\Gamma/\mathrm{d}\cos\theta_\ell}$$

$$\mathcal{A}_{\rm FB}^e = 0.228 \pm 0.012 \pm 0.018,$$

$$\mathcal{A}_{\rm FB}^\mu = 0.211 \pm 0.011 \pm 0.021,$$

$$\Delta\mathcal{A}_{\rm FB} = (-17 \pm 16 \pm 16) \times 10^{-3}$$

Test on D* longitudinal polarization fraction

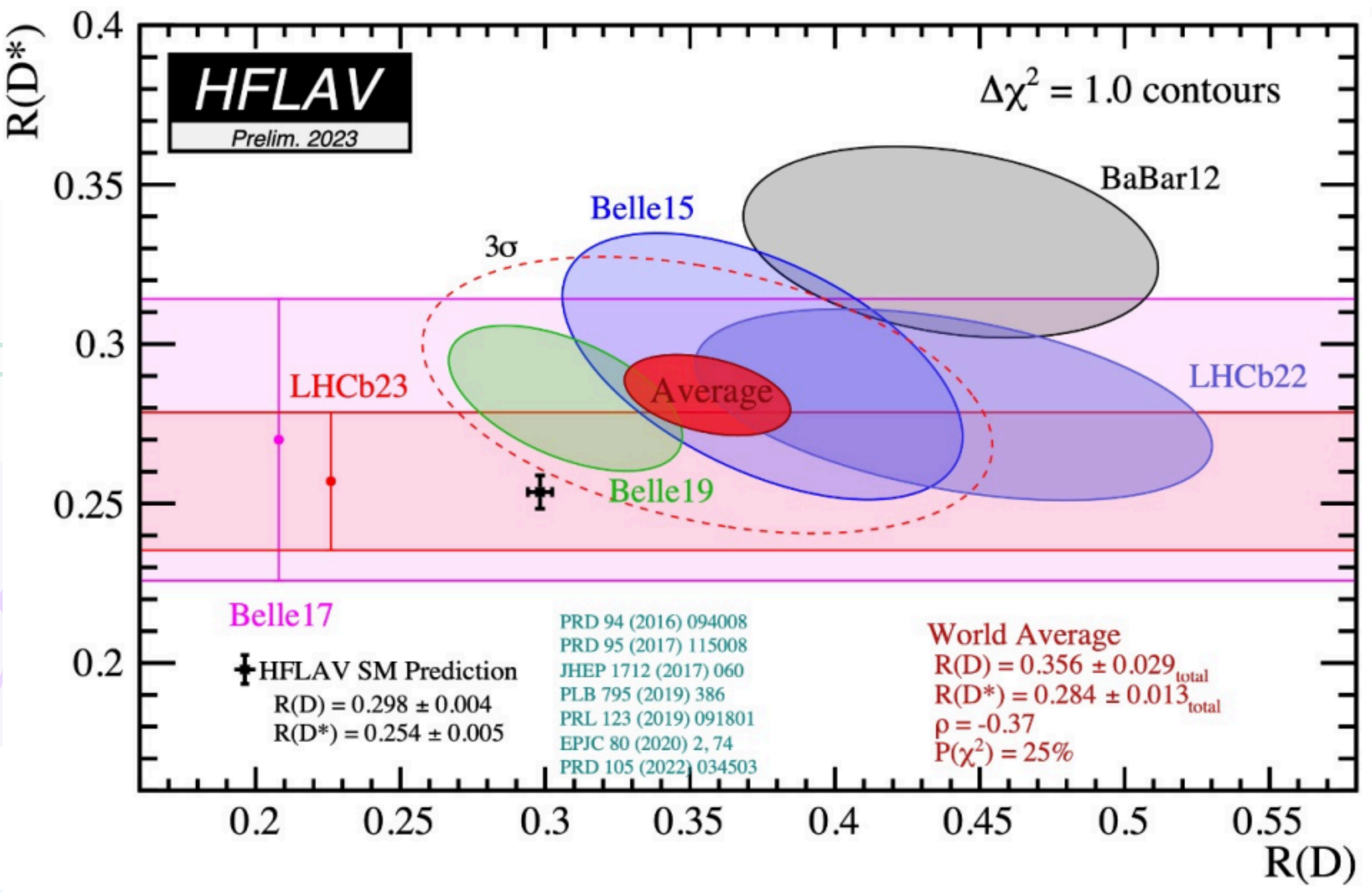
$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta_V} = \frac{3}{2}\left(F_L \cos^2\theta_V + \frac{1-F_L}{2}\sin^2\theta_V\right)$$

$$F_L^e = 0.520 \pm 0.005 \pm 0.005$$

$$F_L^\mu = 0.527 \pm 0.005 \pm 0.005$$

$$\Delta F_L = 0.006 \pm 0.007 \pm 0.005$$

(Semi-)leptonic B Studies



Form facto

Part 1

Final states polarisati
angular asymmetry

annihilation

shape function

Semitauonic

Part 4

Lepton-flavor universality

Part 2

Decay constant

$$R(H_{\tau/\ell}) = \frac{\mathcal{B}(B \to H\tau\nu)}{\mathcal{B}(B \to H\ell\nu)}$$

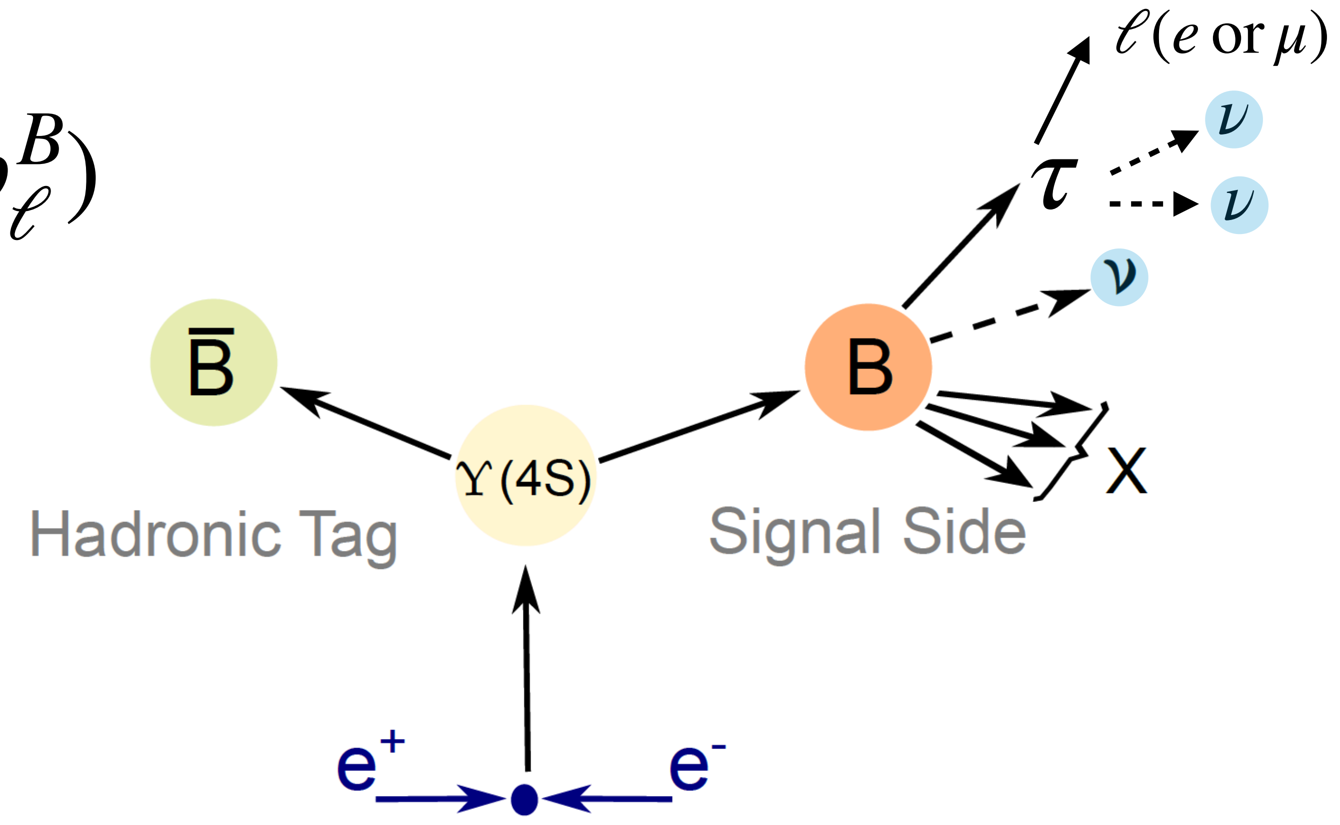
$$H = D, D^*, \pi, \text{inclusive}\, X, \ldots$$

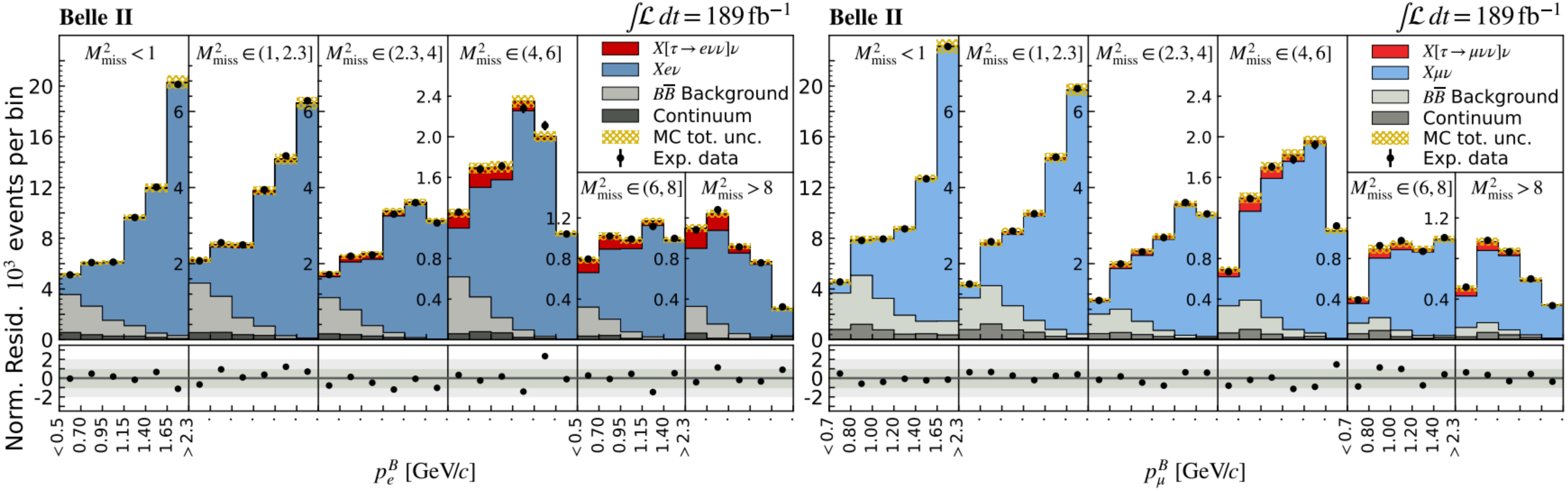
First Measurement of $R(X)_{\tau/\ell}$

arXiv:2311.07248
Preliminary

- Use 189 fb^{-1} dataset with hadronic tagging strategy
- Extract signal events simultaneously for two modes on $(M^2_{\text{miss}}, p^B_\ell)$
- Calculate branching fraction ratio

$$R(X)_{\tau/\ell} = \frac{\mathcal{B}(B \to X\tau\nu)}{\mathcal{B}(B \to X\ell\nu)}$$





First Measurement of $R(X)_{\tau/\ell}$

arXiv:2311.07248
Preliminary

$$R(X)_{\tau/\ell} = \frac{\mathscr{B}(B \to X\tau\nu)}{\mathscr{B}(B \to X\ell\nu)}$$

- **World first** inclusive measurement
- Consistent with SM expectations
- $R(X_{e/\mu})$ published on PRL 131, 051804 (2023)

$$R(X_{\tau/e}) = 0.232 \pm 0.020\ (\text{stat}) \pm 0.037\ (\text{syst})$$
$$R(X_{\tau/\mu}) = 0.222 \pm 0.027\ (\text{stat}) \pm 0.050\ (\text{syst})$$

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

dominated by gap modes branching fraction,
$B \to D^*$ form factors, background shape

First Measurement of $R(X)_{\tau/\ell}$

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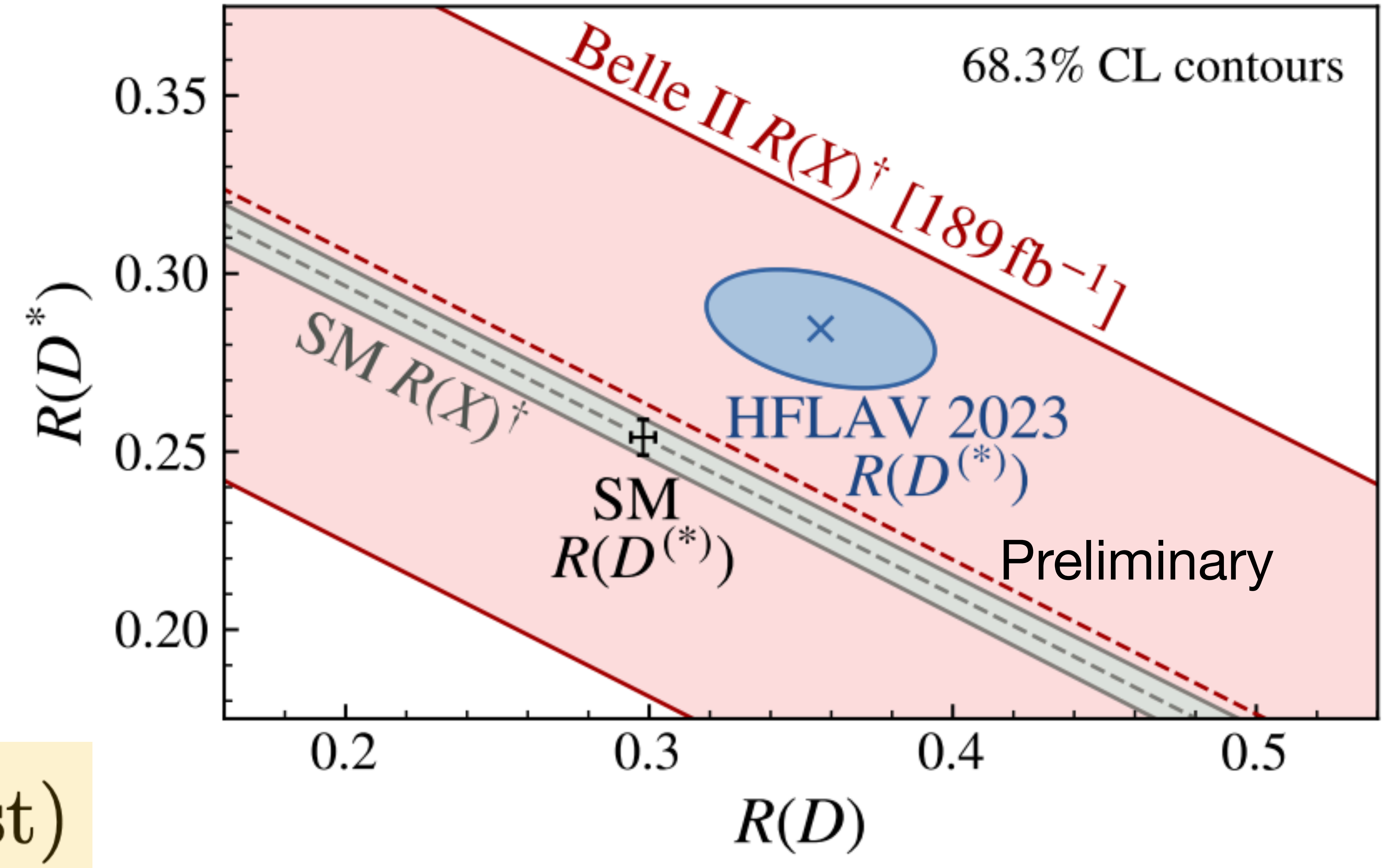
$R(X)^{\dagger} \cdot \mathcal{B}(B \to X\ell\nu) =$ [x axis] $\cdot\, \mathcal{B}(B \to D\ell\nu)$ + [y axis] $\cdot\, \mathcal{B}(B \to D^{*}\ell\nu)$

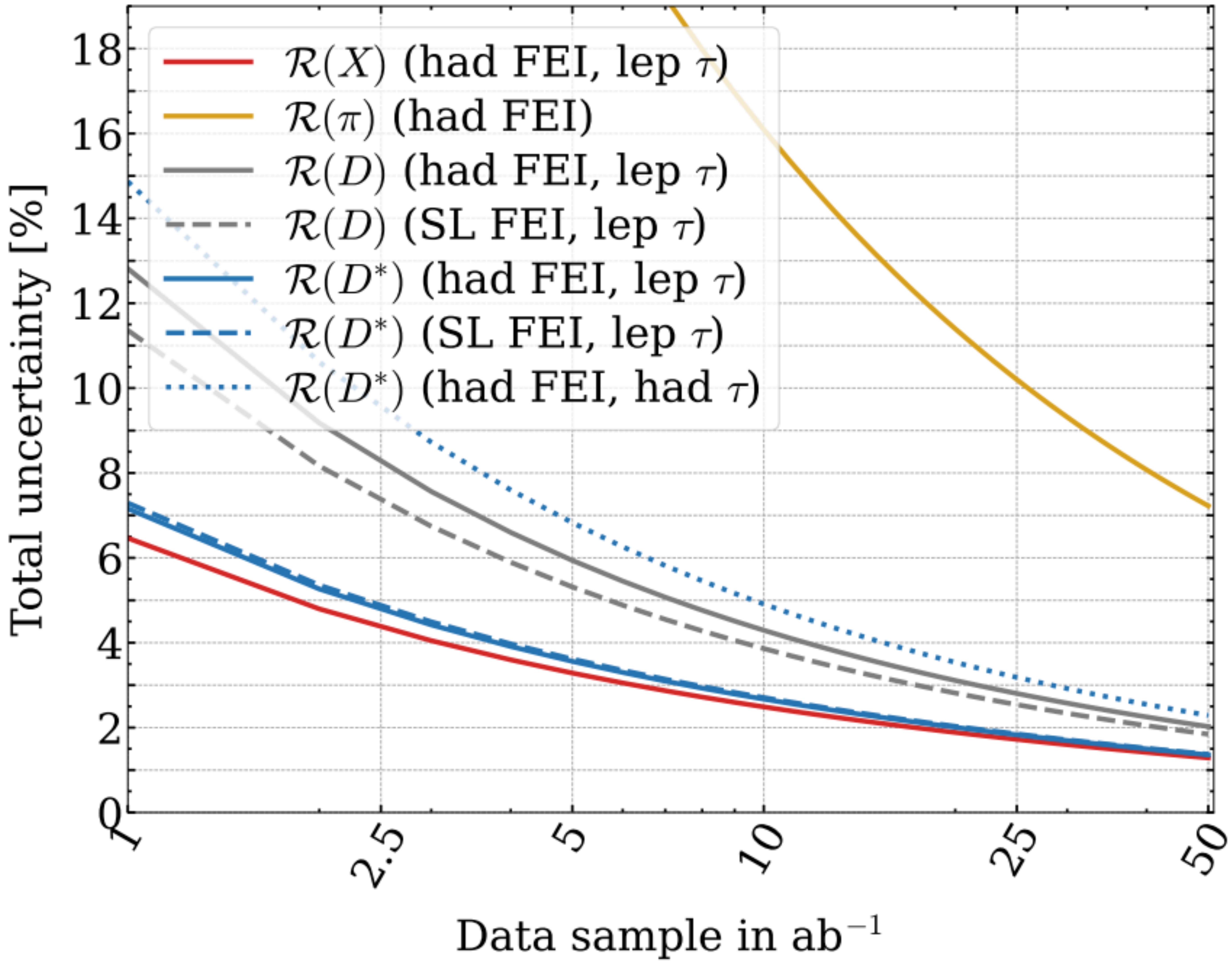
$\dagger$ = with expected SM contributions of $D^{**}_{(\text{gap})}, X_u$ removed



dominated by gap modes branching fraction,
$B \to D^{*}$ form factors, background shape

Expected Sensitivity for R Measurements

- New results targeting **2024 spring**
  - $R(D^{(*)})$ with semileptonic tag
  - $R(D^*)$ with hadronic tag
  - $R(D^{(*)})$ with hadronic tag [Belle]



(Semi-)leptonic B Studies

Semileptonic

Weak annihilation

Form factors

Part 3

Part 1

CKM matrix elements

$|V_{ub}|$, $|V_{cb}|$

B shape function

Final states polarisation, angular asymmetry

New Physics

Semitauonic

Leptonic Part 4

Lepton-flavor universality

Decay constant

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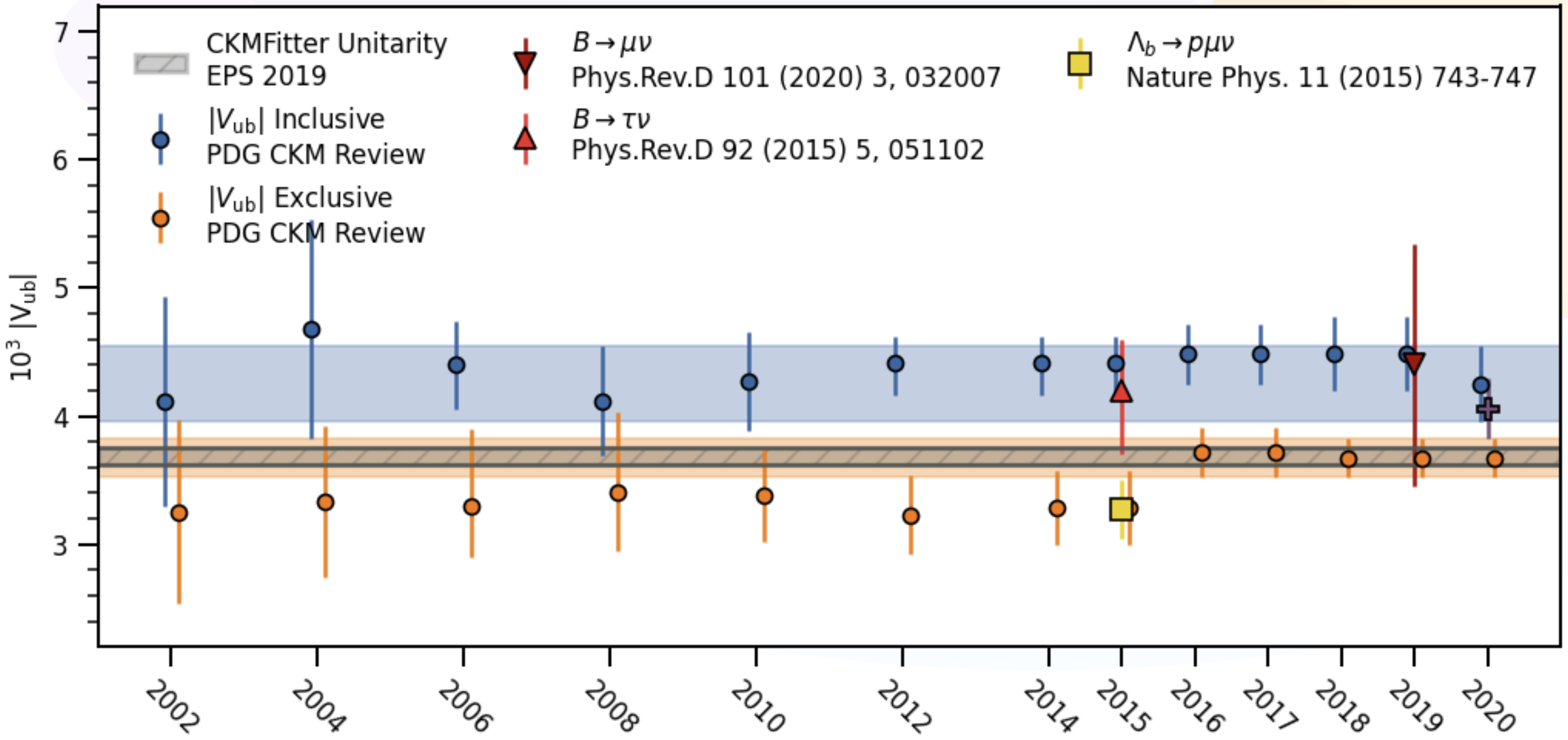
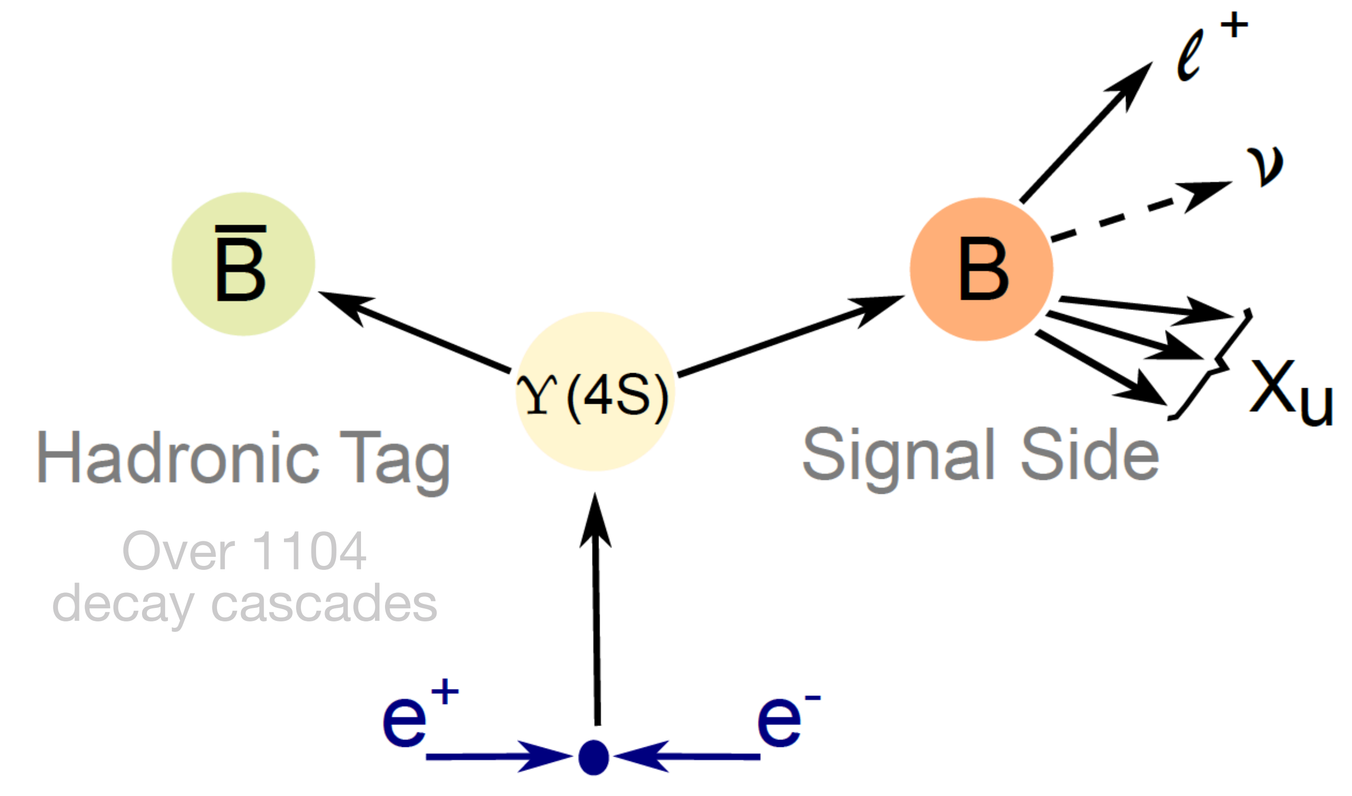


First Simultaneous Determination of $|V_{ub}^{\rm incl.}|$ & $|V_{ub}^{\rm excl.}|$

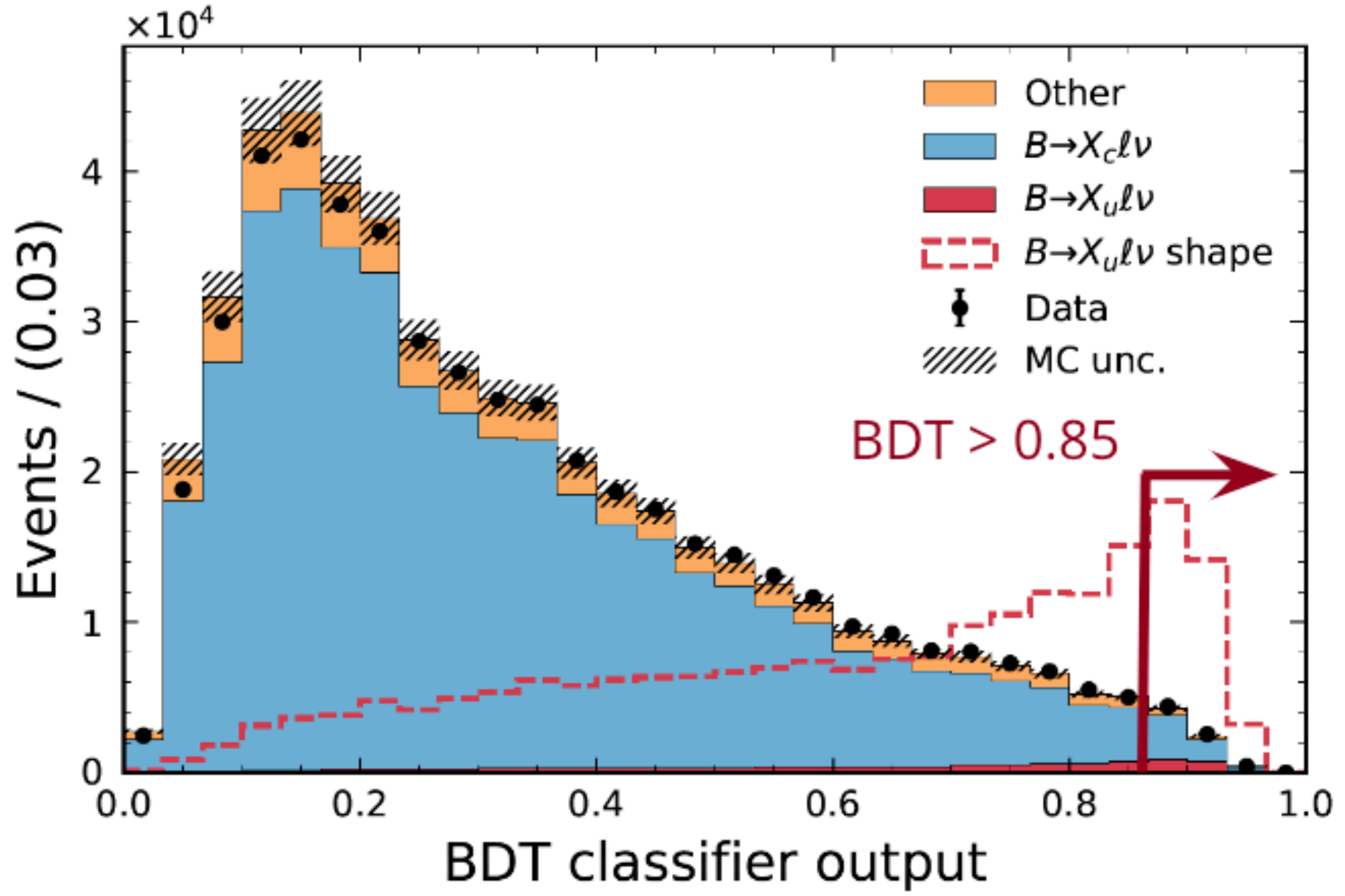
PRL 131, 211801 (2023)

- Using **full Belle** dataset of 711 fb^{-1}
- **Hadronic tagging** with Neutral Networks
- Use BDT to suppress backgrounds with 11 training features, e.g. $M^2_{\rm miss}$, #K±, #Ks, etc.
- Reconstruction strategy inherited from recent Belle's $B \to X_u \ell \nu$ measurements (phase space region $E_\ell^B > 1$ GeV)
  - $\Delta\mathscr{B}$, $|V_{ub}|$ @ PRD 104 , 012008 (2021)
  - Differential spectra @ PRL 127, 261801 (2021)



Can fully assign each final state particle to either the tag side or signal side

=> Allows to reconstruct X_u



Reconstructed kinematic variables

- Hadronic system X:

$$p_X = \sum_i \left(\sqrt{m_\pi^2 + |\mathbf{p_i}|^2}, \mathbf{p_i}\right) + \sum_i (E_i, \mathbf{k_i})$$

tracks neutrals

- Missing mass squared:

$$M^2_{\rm miss} = (p_{\Upsilon(4S)} - p_{\rm tag} - p_X - p_\ell)^2$$

- Leptonic system:

$$q^2 = (p_B - p_X)^2 = (p_\ell - p_\nu)^2$$

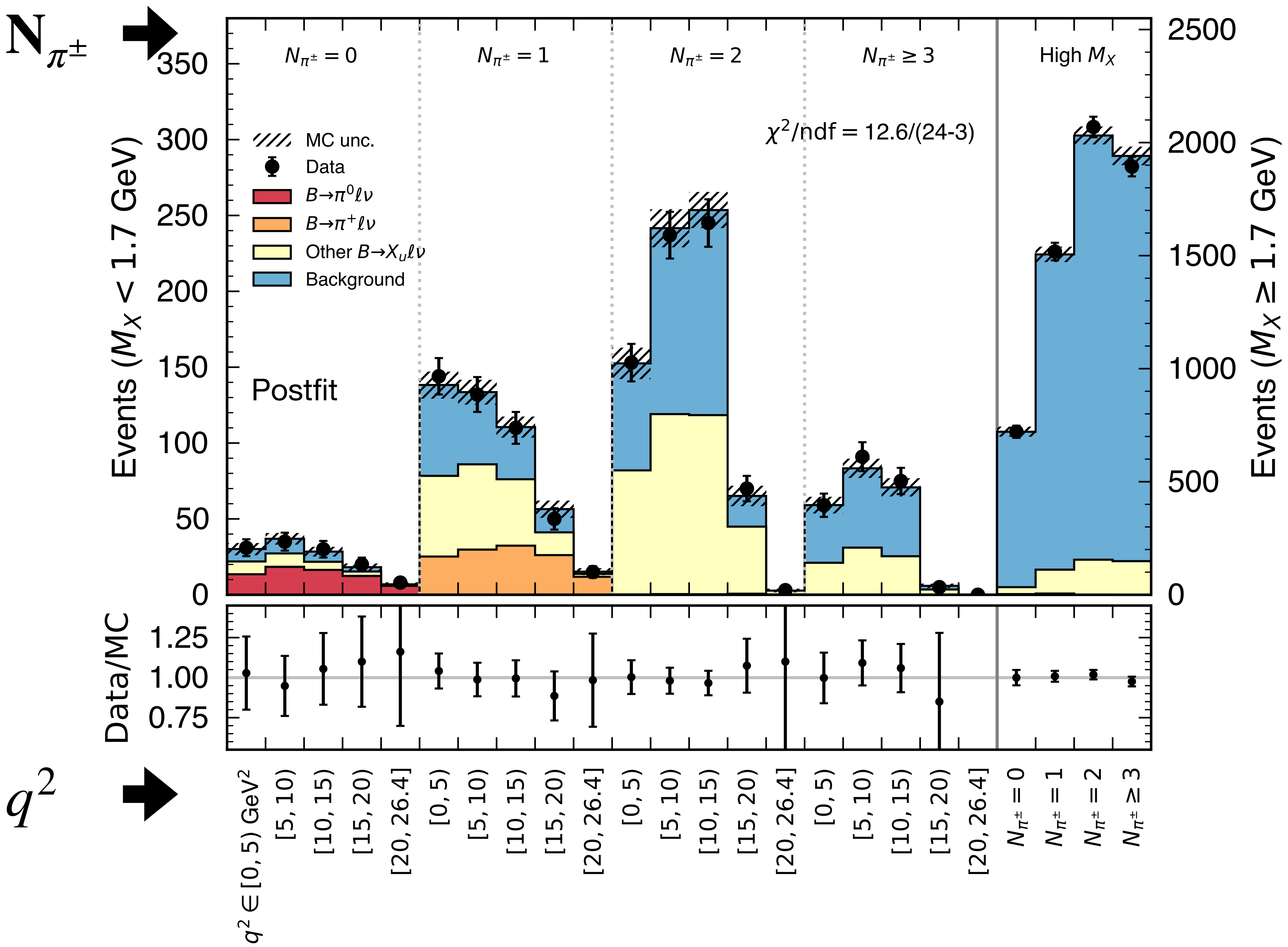
Signal Extraction of Incl. & Excl. $B \to X_u \ell \nu$

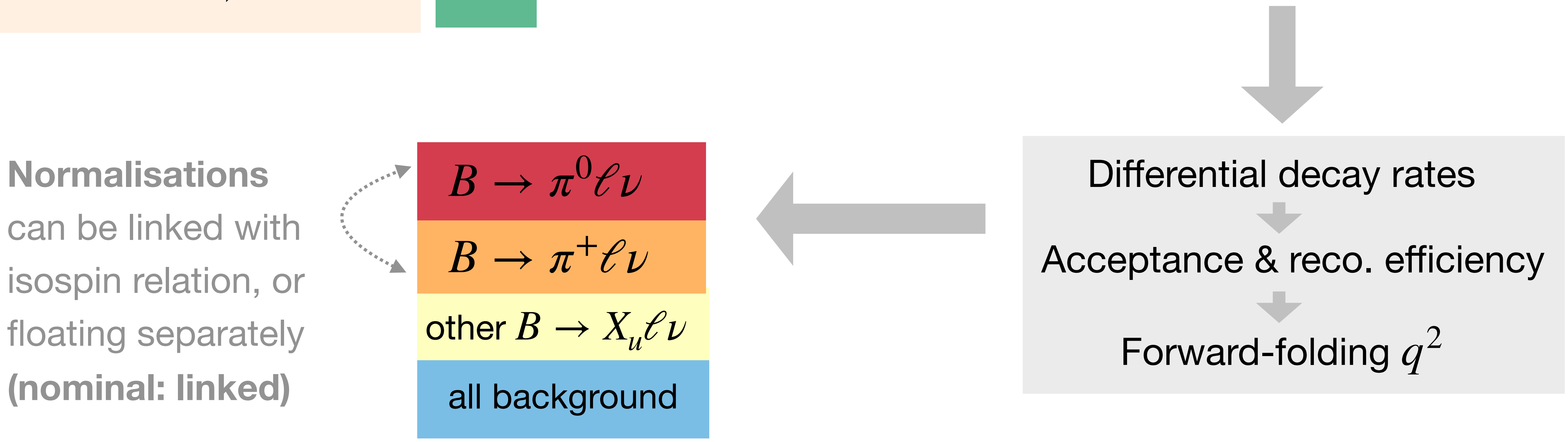
PRL 131, 211801 (2023)

- Additional selections on thrust ***T*** of X system in c.m.s to **increase significance** of $B \to \pi \ell \nu$
- Extract signal in $\mathbf{q^2}$: $\mathbf{N}_{\pi^\pm}$ for $B \to \pi \ell \nu$ and other $B \to X_u \ell \nu$ events
- Simultaneous determination of **signal yields** and **$B \to \pi \ell \nu$ form factor (FF) parameters**
- Systematic uncertainties included via **bin-wise Nuisance para.** θ of each template

$$-2 \log \mathscr{L} = -2 \log \prod_i \text{Poisson}\left(\eta_{\text{obs}}, \eta_{\text{pred}} \cdot (1 + \epsilon \cdot \theta)\right) + \theta \rho_\theta^{-1} \theta^T + \chi^2_{\text{FF}}$$

Constraints on BCL parameters , input taken from LQCD / LQCD+exp fits in FLAG Review 2021





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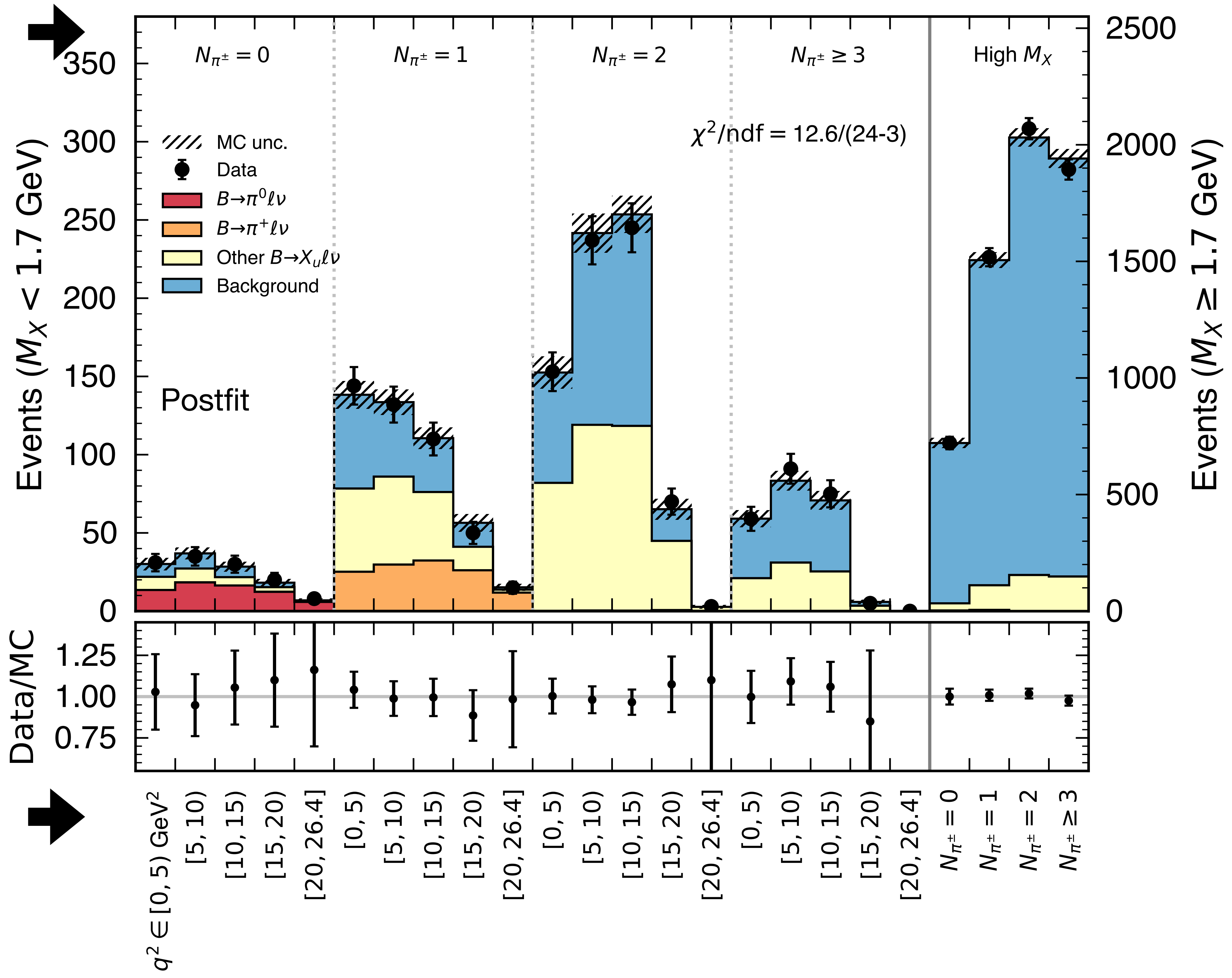
$\mathbf{N}_{\pi^\pm}$ →



q^2 →

Differential decay rates

Acceptance & reco. efficiency

Forward-folding q^2

Normalisations can be linked with isospin relation, or floating separately **(nominal: linked)**

$B \to \pi^0 \ell \nu$

$B \to \pi^+ \ell \nu$

other $B \to X_u \ell \nu$

all background

$$\mathscr{B}(B \to \pi^0 \ell \nu) + \mathscr{B}(B \to \pi^+ \ell \nu) + \mathscr{B}(B \to X_u^{\text{other}} \ell \nu) = \mathscr{B}(B \to X_u \ell \nu)$$

$$\Delta \mathscr{B}(B \to X_u \ell \nu) = \mathscr{B}(B \to X_u \ell \nu) \cdot \epsilon_{\Delta \text{PS}: E_\ell^B > 1\text{GeV}}$$

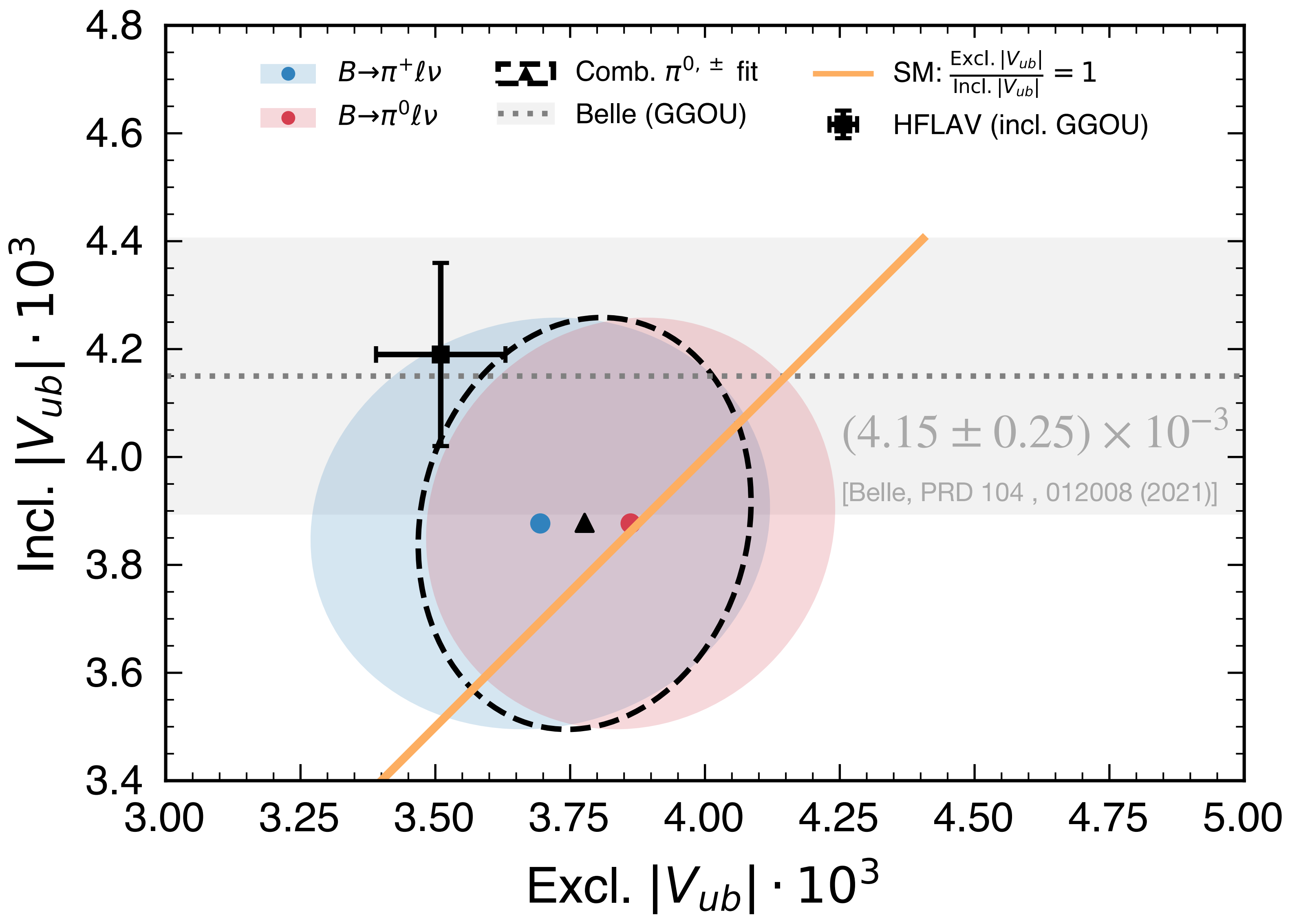
$$\left| V_{ub}^{\text{excl.}} \right| = \sqrt{\frac{\mathscr{B}(B \to \pi \ell \nu)}{\tau_B \cdot \Gamma_{\text{FF}}}}$$

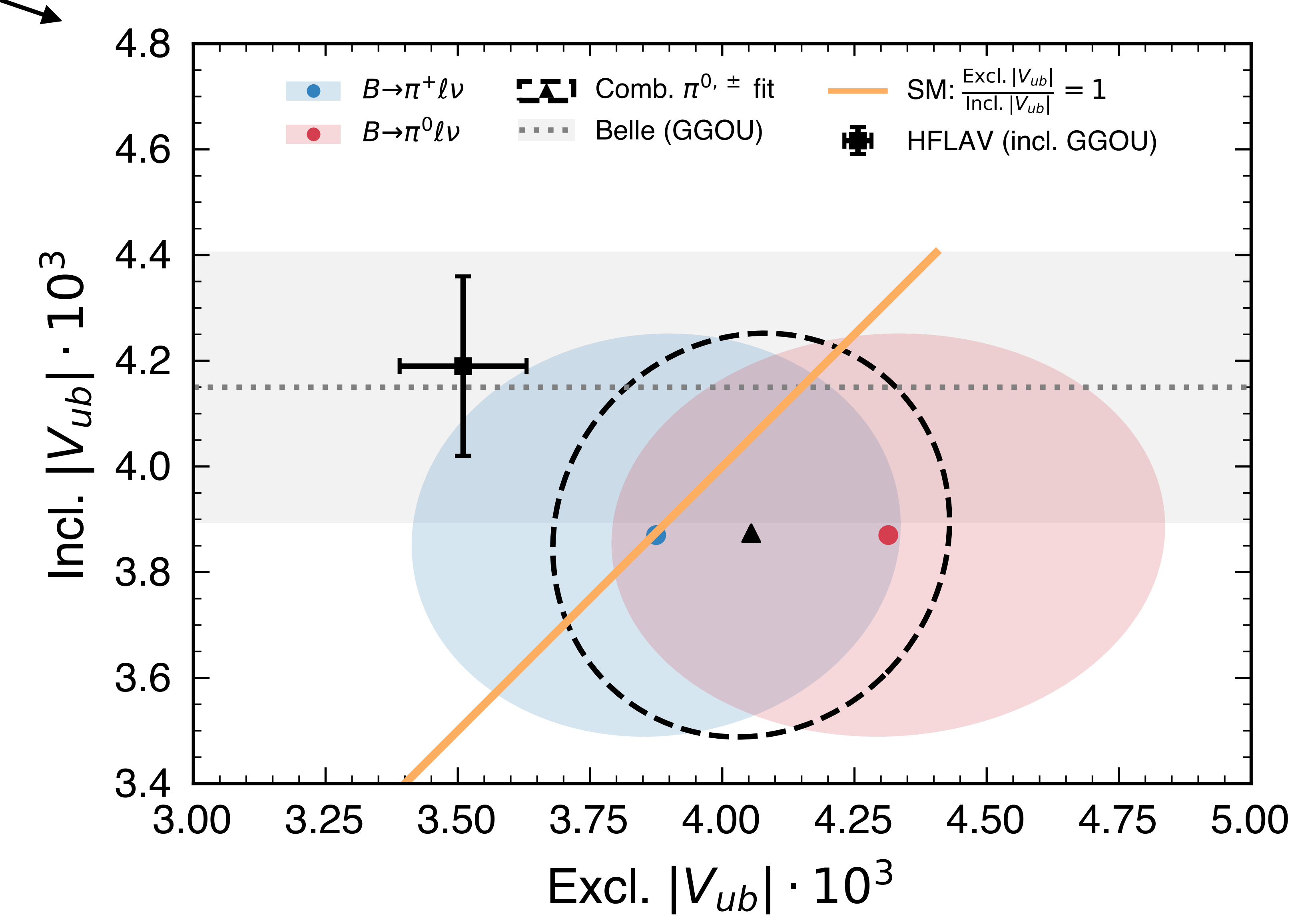
$$\left| V_{ub}^{\text{incl.}} \right| = \sqrt{\frac{\Delta \mathscr{B}(B \to X_u \ell \nu)}{\tau_B \cdot \Delta \Gamma_{\text{GGOU}}}}$$

Results of Incl. & Excl. $|V_{ub}|$

PRL 131, 211801 (2023)

- Various fit scenarios applied:
  - **Combined** or separate $B \to \pi^+ \ell \nu$, $B \to \pi^0 \ell \nu$ (isospin relation)
  - Input BCL constraint: **LQCD + exp.** or **only LQCD** [FLAG: Eur. Phys. J. C 82, 869 (2022)]





$|V_{ub}|$ in **combined** scenario with **LQCD+exp** const.:

Excl. $(3.78 \pm 0.23_{\text{stat}} \pm 0.16_{\text{syst}} \pm 0.14_{\text{theo}}) \times 10^{-3}$

Incl. $(3.88 \pm 0.20_{\text{stat}} \pm 0.31_{\text{syst}} \pm 0.09_{\text{theo}}) \times 10^{-3}$

Ratio $0.97 \pm 0.12 \quad (\rho = 0.11)$ compatible with the world average within 1.2σ

Weighted average of excl. & incl. $(3.84 \pm 0.26) \times 10^{-3}$

This is consistent with CKM global fit (w/o $|V_{ub}|$):

$(3.64 \pm 0.07) \times 10^{-3}$ **within 0.8σ**

Global Fits

$B \to X_s \gamma$ Global fit:
PRL 127, 102001 (2021)

SIMBA (ANALYSIS OF B MESON INCLUSIVE SPECTRA)

- Large model dependence $\Longleftrightarrow$ sensitivity to constrain B meson shape function (SF)
- Most information in differential spectra
- Can use different decay modes (same leading SF) and cary out global analysis that propagates uncertainties

$$d\Gamma_s = |V_{tb}V_{ts}^*|^2 m_b^2 \, |C_7^{\rm incl}|^2 \int dk \, \widehat{W}_{77}(E_\gamma; k) \, \widehat{F}(m_B - 2E_\gamma - k) + \cdots$$

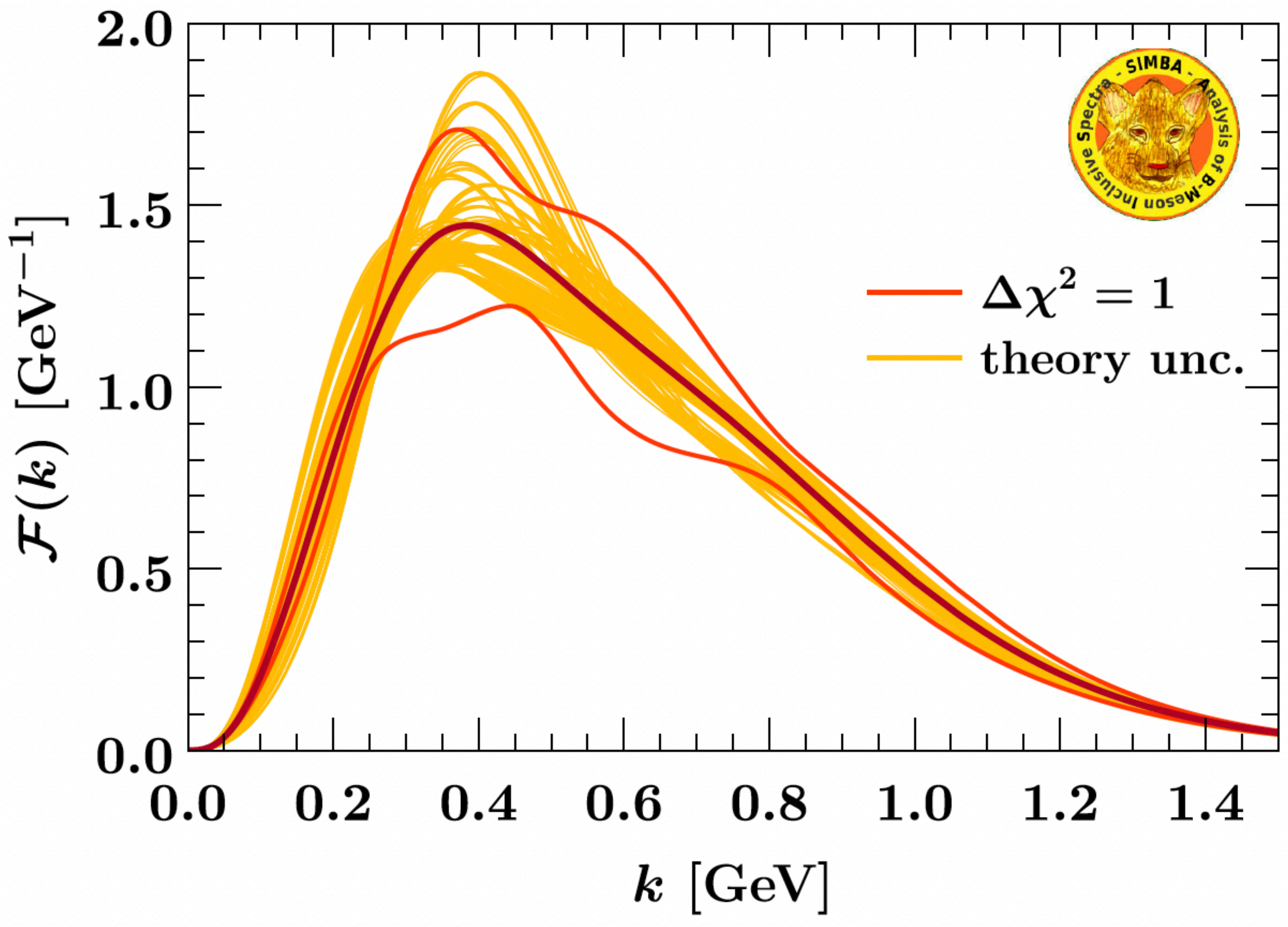
$$d\Gamma_u = |V_{ub}|^2 \int dk \, \widehat{W}_u(p_X^-, p_X^+, E_\ell; k) \widehat{F}(p_X^+ - k) + \cdots$$

- Fit parameters: $|V_{tb}V_{ts}^*|^2 m_b^2$, $|V_{ub}|^2$, $\widehat{F}(\lambda x) = \frac{1}{\lambda}\left[\sum_{n=0}^{\infty} c_n f_n(x)\right]^2$
  - Theory Input: $\widehat{W}_i(\ldots; k)$ computed to (N)NNL'+NNLO in 1S scheme
  - Factorized shape function:

$$S(\omega, \mu_\Lambda) = \int dk \, \widehat{C}_0(\omega - k, \mu_\Lambda) \, \widehat{F}(k)$$

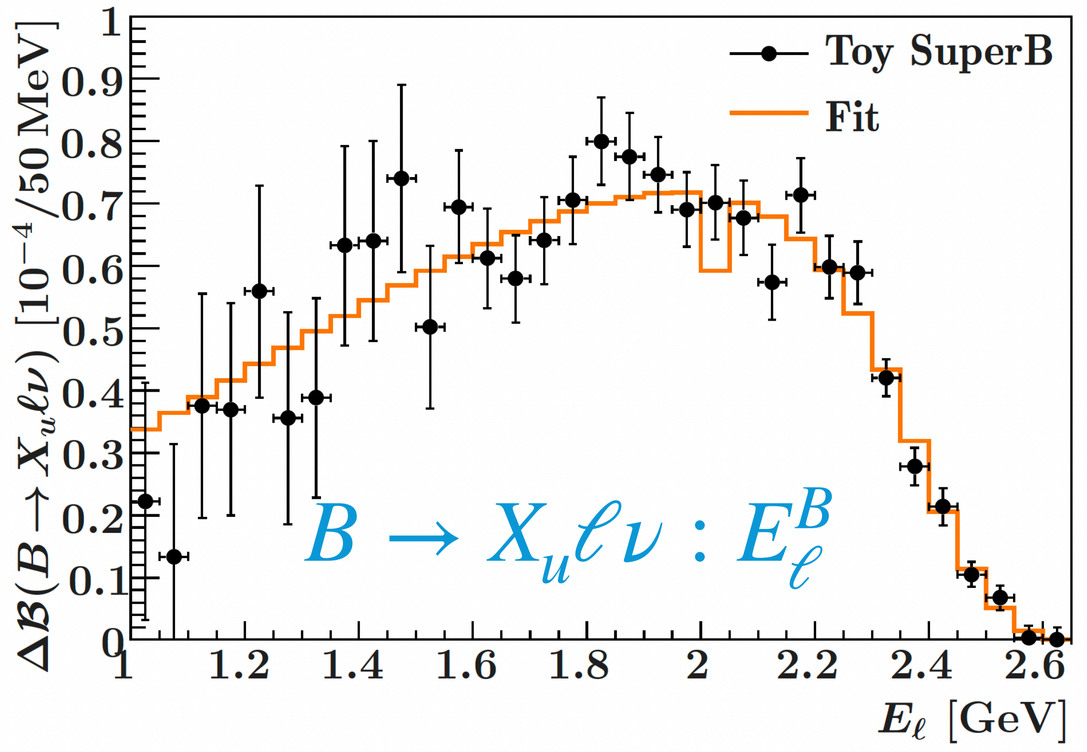
$\widehat{F}(k)$ nonperturbative part
- Determines peak region
- Fit from data

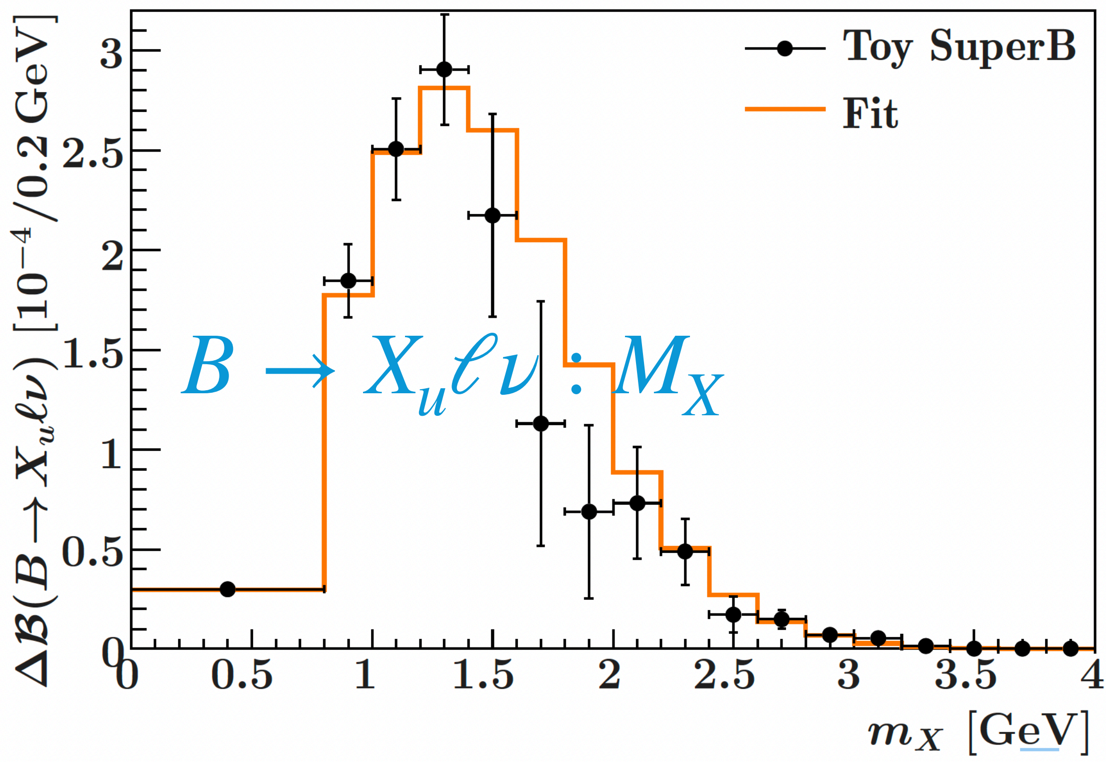
$\widehat{C}_0(\omega, \mu_\Lambda)$ perturbative part
- Generates perturbative tail with correct μ_Λ dependence

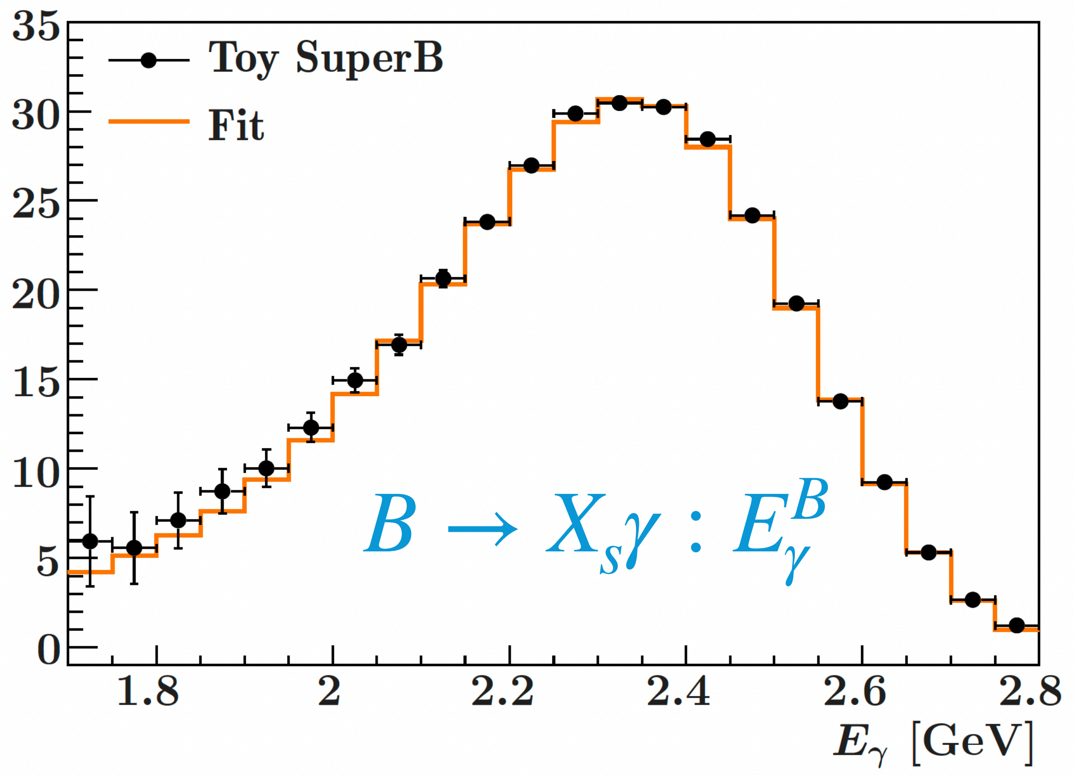


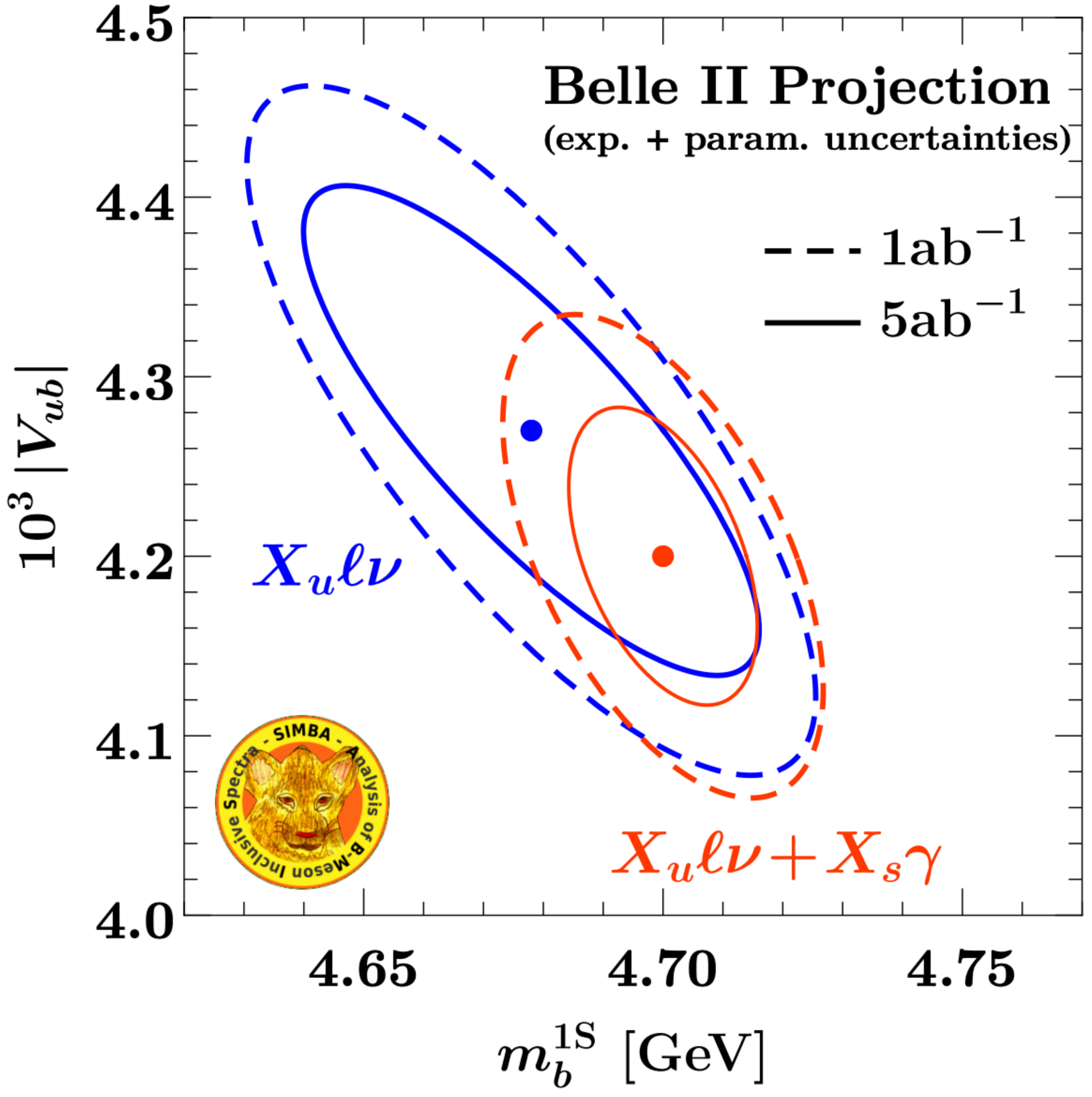
Global Fits Prospects on $B \to X_s\gamma + B \to X_u\ell\nu$

- Theory
  - NLL’ + NLO
  - ignore subleading SFs
- Toy study
  - Generate mX, El, and Eɣ from theory
  - Smeared from uncertainties and correlations inspired by BaBar hadronic tag analysis, Belle II hadronic tagging efficiency is much better by now
  - Target lumi: 1/ab, 5/ab
  - **Caveats:**
    - No resolution effects considered
    - No theory uncertainties included (!)
    - Not done with Belle II MC









3.5%
2.2%

Credit: F. Bernlochner

Global Analysis

Differential Information

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

E_ℓ, m_X, q^2

+

$\bar{B} \to X_s\,\gamma$

E_γ

+

$\bar{B} \to X_s\,\ell\ell$

q^2

+

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

E_ℓ, q^2

+

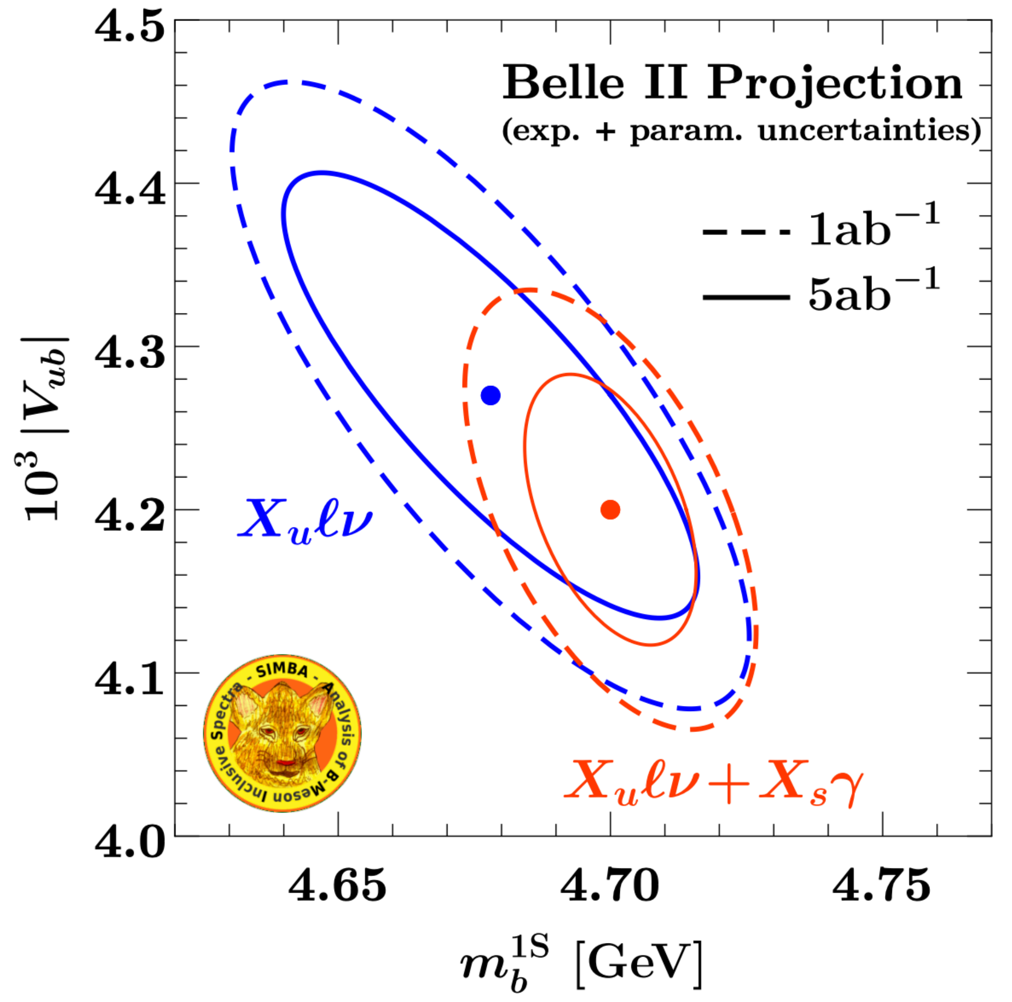
$\bar{B} \to X\,\tau\,\bar{\nu}_\tau$

q^2

SIMBA - Spectra Analysis of B-Meson Inclusive

Global Analysis

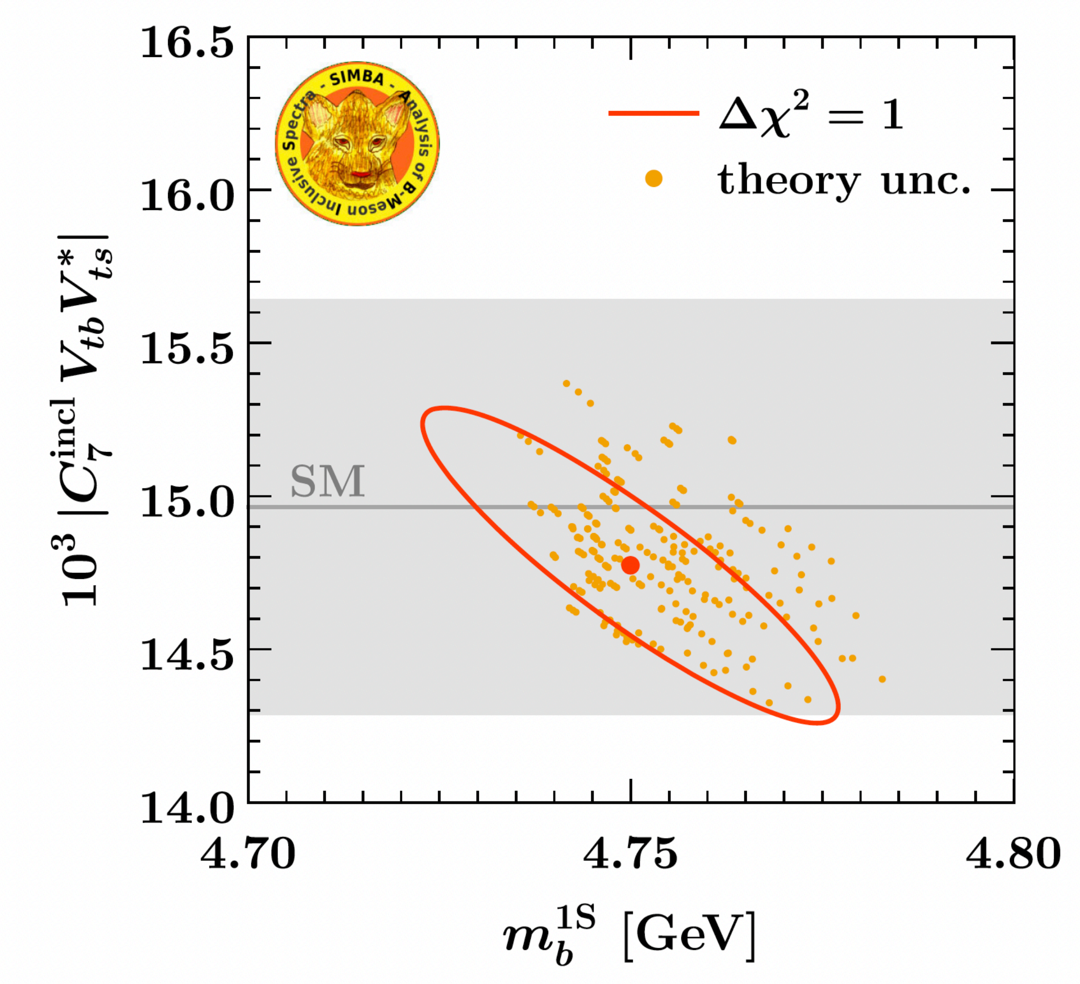
$|V_{ub}|$ → Incl. versus Excl. Problem (3.4 σ)



b-Quark momentum distribution → Unknown distribution, equivalent to **Proton PDF for LHC**

$|C_7|$, C_9, C_{10} → Search for **New Physics**

m_b → **Fundamental parameter** of the Standard Model



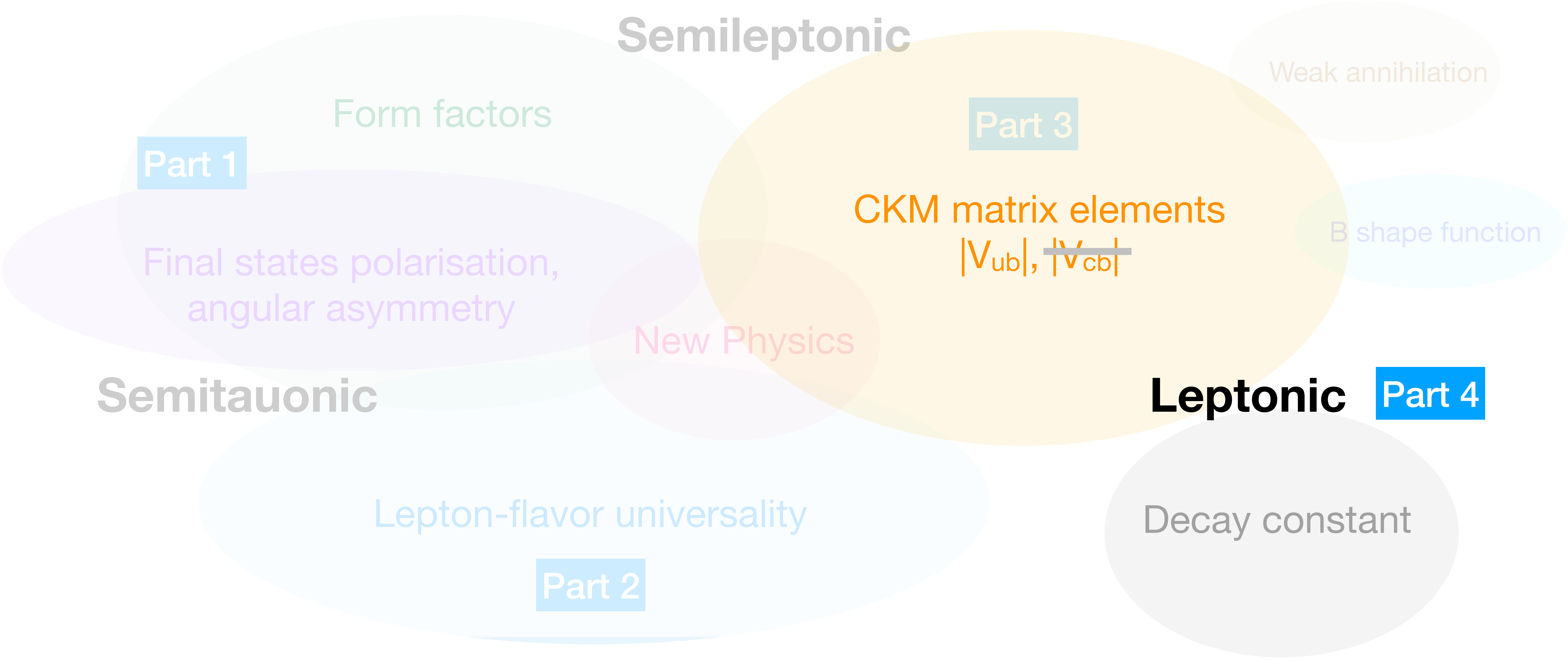
$|V_{cb}|$ → Incl. versus Excl. Problem (2.4 σ)

$R(X)$ → 4 σ difference in semi-tauonic decays

$$R(X) = \frac{\mathcal{B}(\bar{B} \to X\,\tau\,\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to X\,\ell\,\bar{\nu}_\ell)}$$

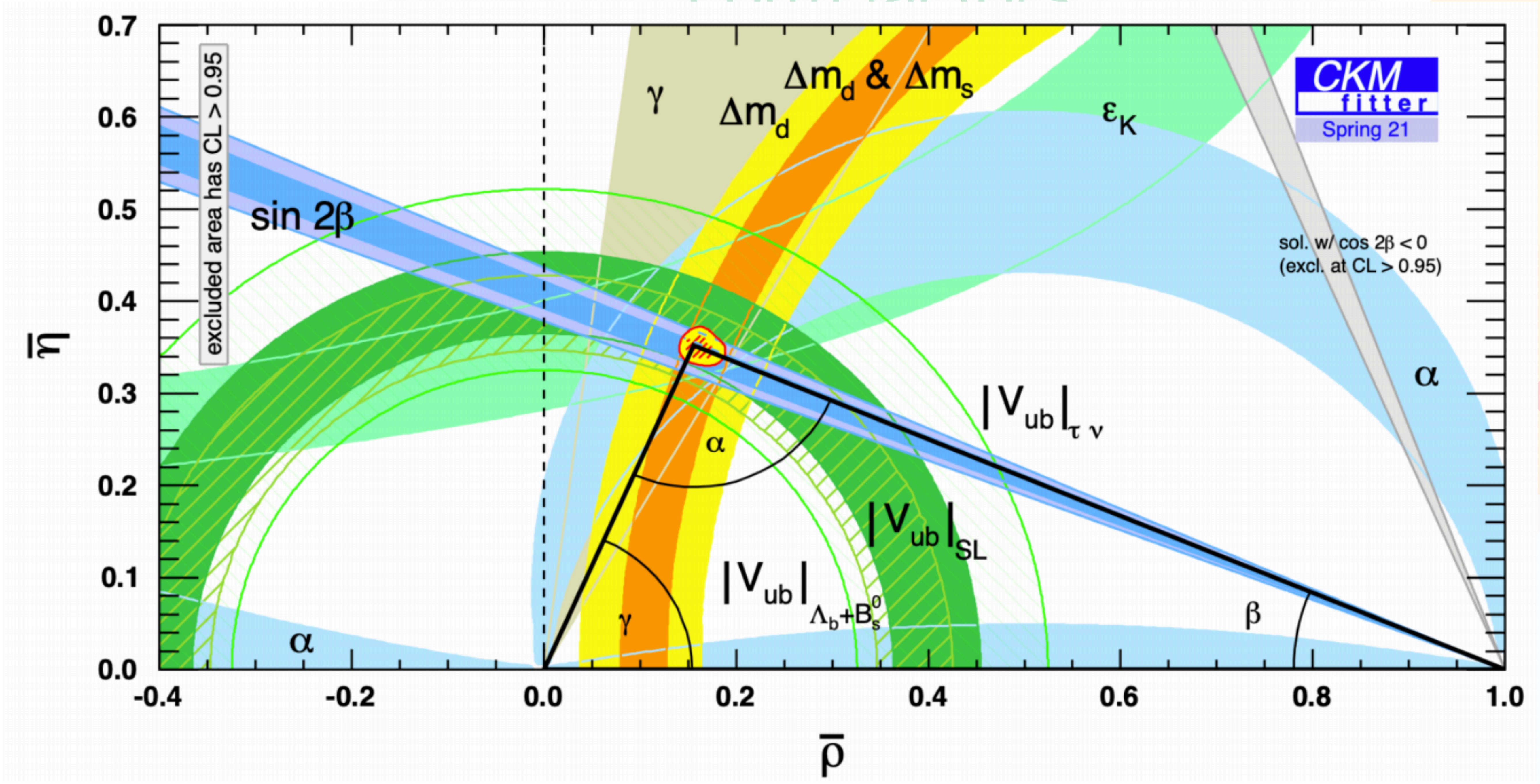
Credit: F. Bernlochner

Leptonic B Studies



Leptonic B Studies

Semileptonic



Part 2

Part 3

CKM matrix elements

$|V_{ub}|$, ~~$|V_{cb}|$~~

Weak annihilation

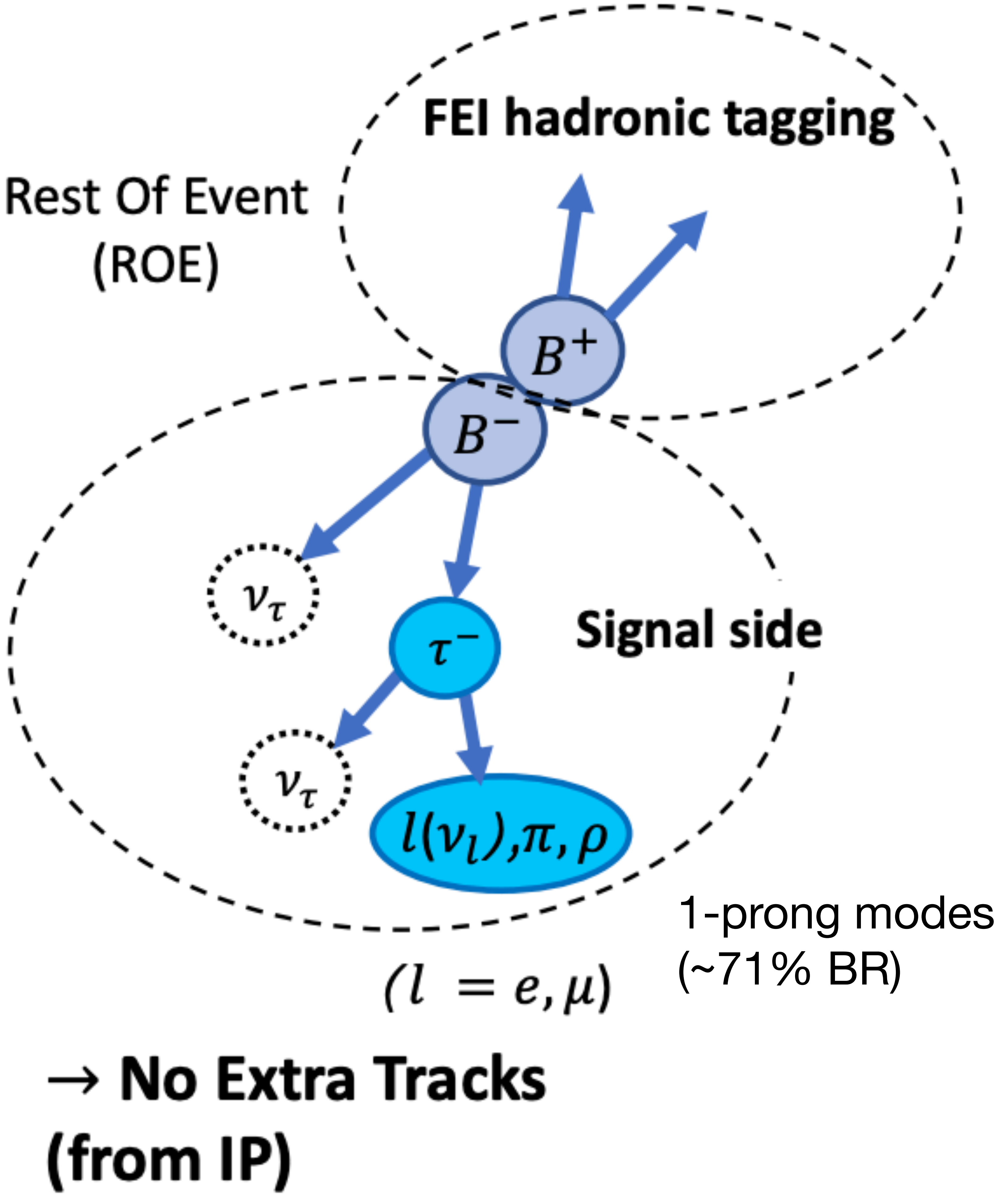
B shape function

Leptonic Part 4

Decay constant

Search for $B \to \tau\nu$ at Belle II

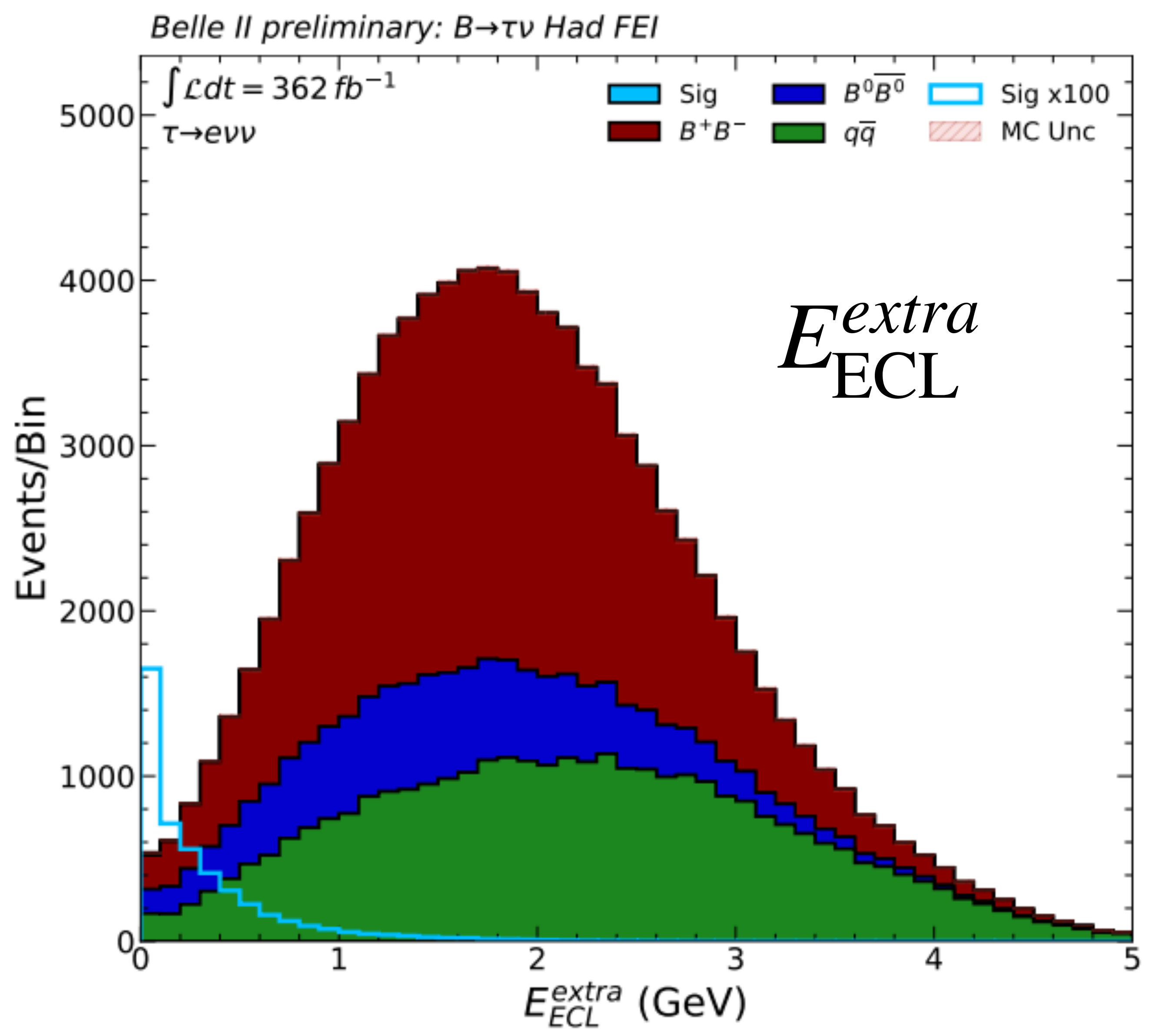
- Sensitivity based on a data set of 362 fb^{-1} studied with MC simulations
- Full analysis chain validated in pseudo-data
- With optimized signal selection: statistical uncertainty 37% (2.8σ from null hypothesis), systematic uncertainty ~13 %
- Results expected to be released in **2024 spring**!!

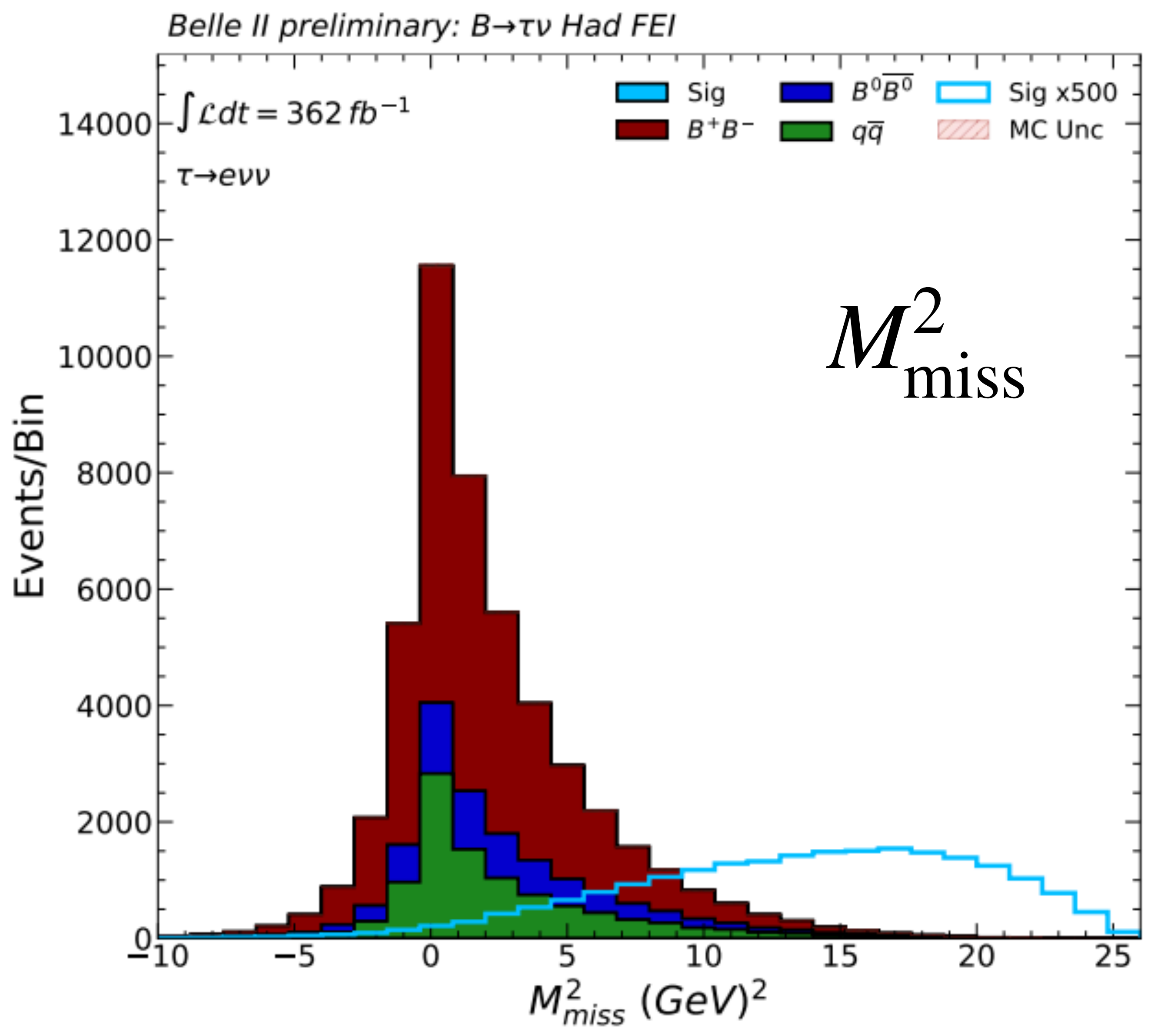


Most discriminating variables for signal:

- E_{ECL}^{extra}**, the extra energy not associated with the** B_{tag} **and** B_{sig} **(Rest of Event).**
- $M_{miss}^2 = E_{miss}^2 - p_{miss}^2$**, squared magnitude of the four-momentum** p_{miss}**.**

A data-driven correction is applied to both the variables to correct the distributions.

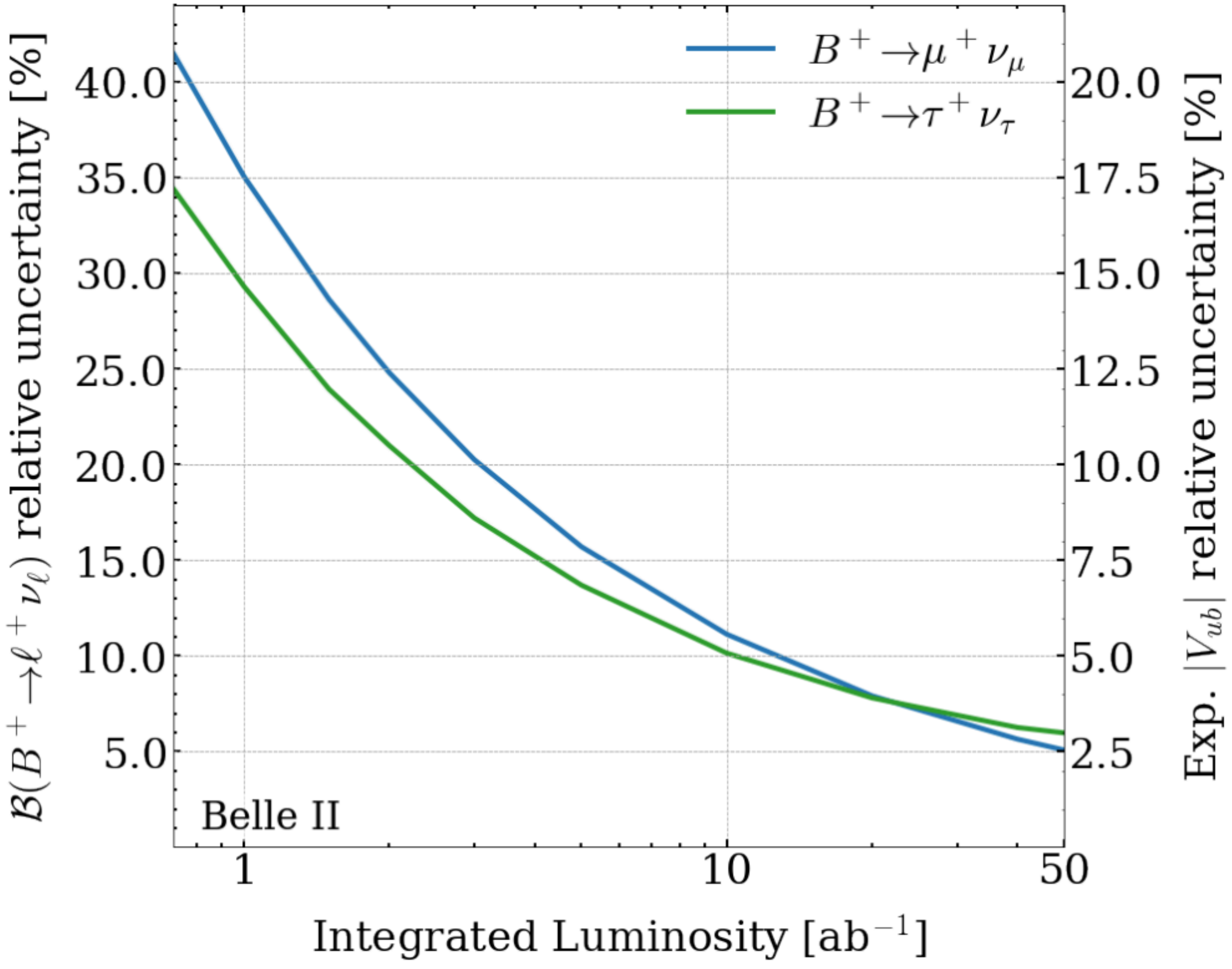




Expected Sensitivity on Belle II

- Expected event yields and precisions on the branching fraction and determined $|V_{ub}|$
- Ultimate precision on $|V_{ub}|$ at ~2.5% level from $B \to \tau\nu, B \to \mu\nu$
- $B \to e\nu$ is extremely suppressed in SM

ℓ	$\mathcal{B}_{SM}$	711 fb^{-1}	5 ab^{-1}	50 ab^{-1}
τ	$(7.71 \pm 0.62) \times 10^{-5}$	61200 ± 5000	430000 ± 35000	4300000 ± 350000
μ	$(3.46 \pm 0.28) \times 10^{-7}$	275 ± 23	1930 ± 160	19300 ± 1600
e	$(0.811 \pm 0.065) \times 10^{-11}$	0.0064 ± 0.0005	0.0453 ± 0.0037	0.453 ± 0.037



Perspectives of $B_c \to \tau\nu$ on CEPC

- Tera-Z at CEPC can deliver ~3×10^12 Z decays providing many opportunities from $Z \to b\bar{b}, Z \to c\bar{c}$
- Dedicated sensitivity study of $B_c \to \tau\nu$ trigged in 2019, published in 2021

The 1st CEPC Physics Workshop toward Physics Whitepaper and TDR

Jul 1 – 5, 2019
PKU CHEP
Asia/Shanghai timezone

Enter your search term

In addition to B-> tau nu and B_c -> tau nu,

Other semileptonic decays of interest

Sebastien's talk

Other channels of potential interest (with Br from 10^{-2} to 10^{-5})

	$b \to c\ell\nu$	$b \to u\ell\nu$
B	$B \to D^{(*)}\ell\nu$ ✓	$B \to \pi\ell\nu$ ✓, $B \to \rho\ell\nu$ ✓
B_s	$B_s \to D_s^{(*)}\ell\nu$ ✓	$B_s \to K^{(*)}\ell\nu$ ✓
B_c	$B_c \to \eta_c\ell\nu$ ✓, $B_c \to J/\psi\ell\nu$ ✓	$B_c \to D^{(*)}\ell\nu$
Λ_b	$\Lambda_b \to \Lambda_c\ell\nu$ ✓, $\Lambda_b \to \Lambda_c^*\ell\nu$	$\Lambda_b \to p\ell\nu$ ✓

- ✓ lattice estimate available for most of these decays
- $\ell = e, \mu$ or τ sensitive to different NP contributions/form factors
- CEPC seems interesting for last 3 lines compared to Belle II
- Which advantages compared to LHCb (τ, $D_{(s)}$, neutral...) ?
- "Extreme" proposal: $B_c \to D\ell\nu$? or others better suited ?

Branching ratios interesting,
but also differential decay rate and angular analysis !

S. Descotes-Genon (LPT-Orsay) | Leptonic and semileptonic *b*-decays | Beijing, 2/7/19 | 28

Continued discussions with Abi, Sebastien, Manqi, Taifan, Dan, etc.

Proposal for MC study (5 July 2019)

Decay	Comment	Ref.	Priority
$B_c \to \tau\nu$	extend to 2 or 3 prong tau decay	Slides from Fenfen An	high
$B \to \tau\nu$	Import bkg for $B_c \to \tau\nu$	Belle 2015	high
$B \to \pi\tau\nu$		Belle II projection	high
$B \to D\tau\nu$			high
$B_c \to \eta_c, J/\psi\ell\nu$		LHCb 2017	medium
$\Lambda_b \to \Lambda_c^*\ell\nu$	tauonic mode		medium
other channels on previous slide			medium
$b \to X\tau\nu$	challenging in modelling	OPAL 2001	low

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Analysis of $B_c \to \tau\nu_\tau$ at CEPC*

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Abstract: Precise determination of the $B_c \to \tau\nu_\tau$ branching ratio provides an advantageous opportunity for understanding the electroweak structure of the Standard Model, measuring the CKM matrix element $|V_{cb}|$, and probing new physics models. In this paper, we discuss the potential of measuring the process $B_c \to \tau\nu_\tau$ with τ decaying leptonically at the proposed Circular Electron Positron Collider (CEPC). We conclude that during the Z pole operation, the channel signal can achieve five-σ significance with $\sim 10^9$ Z decays, and the signal strength accuracies for $B_c \to \tau\nu_\tau$ can reach around 1% level at the nominal CEPC Z pole statistics of one trillion Z decays, assuming the total $B_c \to \tau\nu_\tau$ yield is 3.6×10^6. Our theoretical analysis indicates the accuracy could provide a strong constraint on the general effective Hamiltonian for the $b \to c\tau\nu$ transition. If the total B_c yield can be determined to $O(1\%)$ level of accuracy in the future, these results also imply $|V_{cb}|$ could be measured up to $O(1\%)$ level of accuracy.

Keywords: CEPC, Flavor, B_c meson

DOI: 10.1088/1674-1137/abcf1f

I. INTRODUCTION

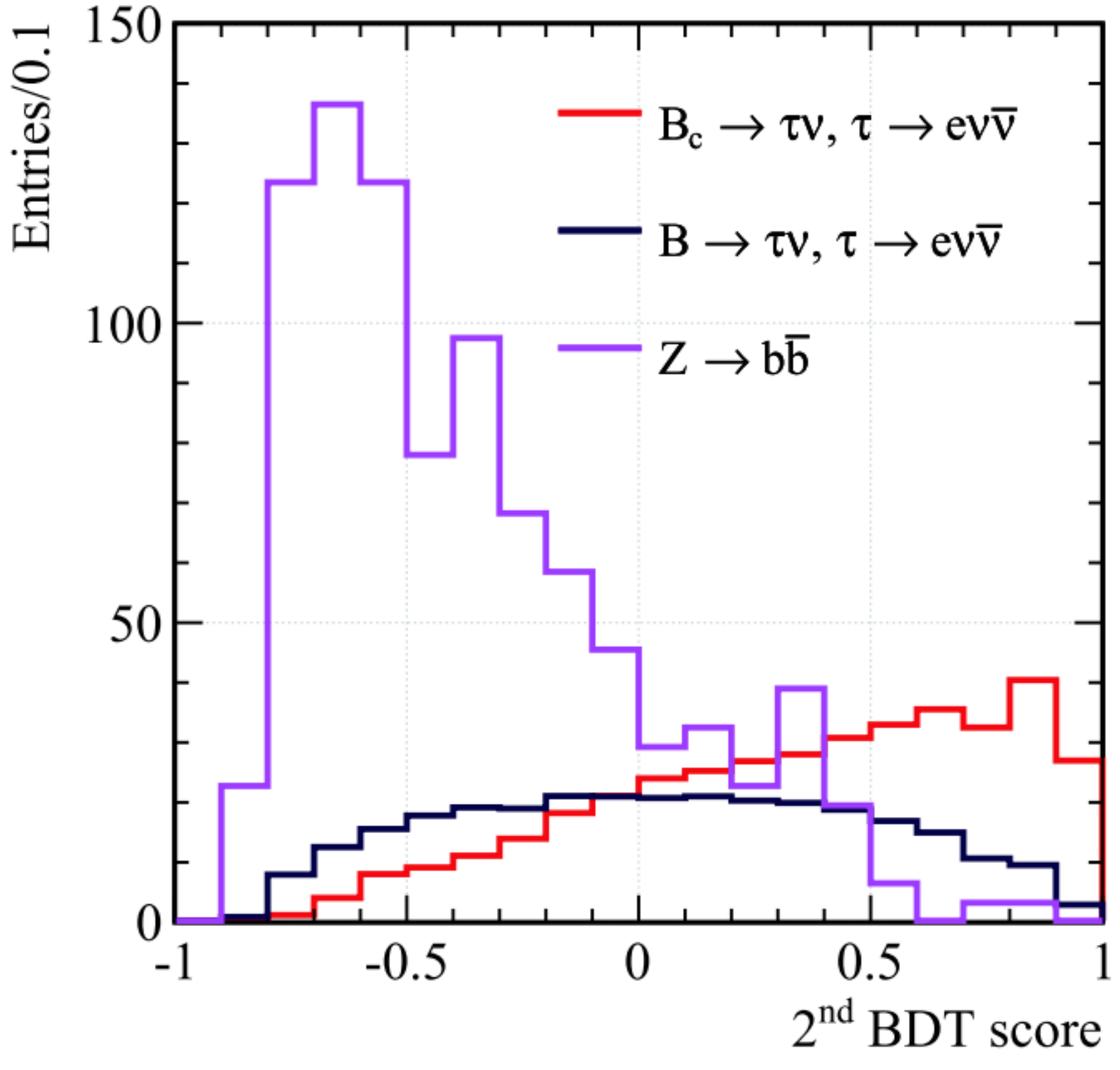
Weak decays of heavy mesons not only provide a unique platform to test the electroweak structures of the Standard Model (SM), but can also shed light on new physics (NP) beyond the SM. Among different species of heavy mesons, the B_c^+[1)] meson, discovered in 1998 by the CDF collaboration [1, 2], is of particular interest in this regard. The B_c^+ meson has specific production and decay mechanisms, and accordingly the measurement of its mass, lifetime and decay branching ratios would help to

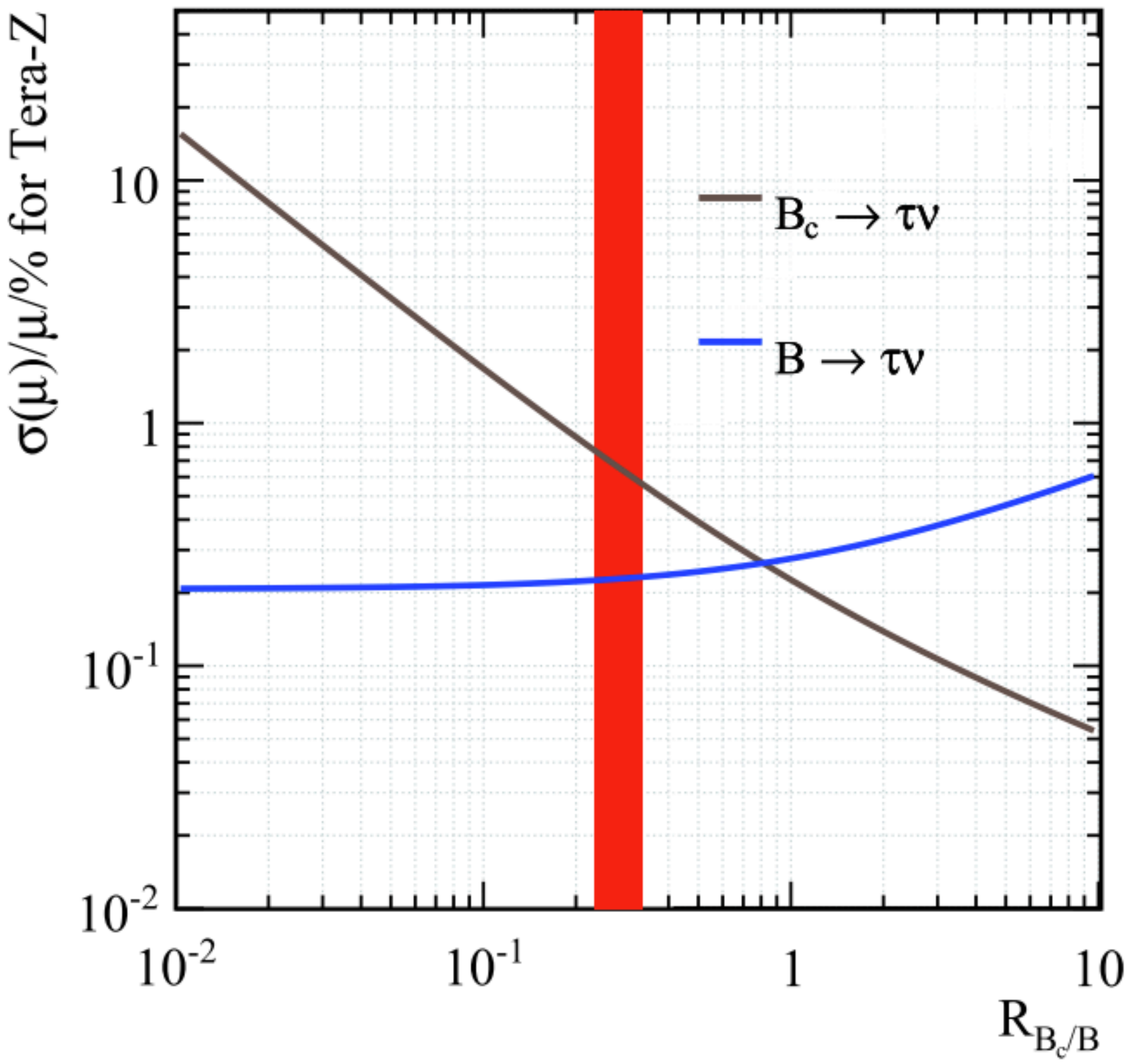
termination of $|V_{cd}|$ and $|V_{cs}|$ in $D^+/D_s^+ \to \tau^+\nu_\tau, \mu^+\nu_\mu$ [3]. For $|V_{cb}|$, since the $B_c^+ \to \tau^+\nu_\tau$ channel has not been discovered, it is measured using inclusive semileptonic $b \to c$ transitions and the exclusive channel of $\bar{B} \to D^*l\bar{\nu}_l$. However, even if $B_c^+ \to \tau^+\nu_\tau$ had been discovered, the decay $\bar{B} \to D^*l\bar{\nu}_l$ would still provide a more precise $|V_{cb}|$ measurement.

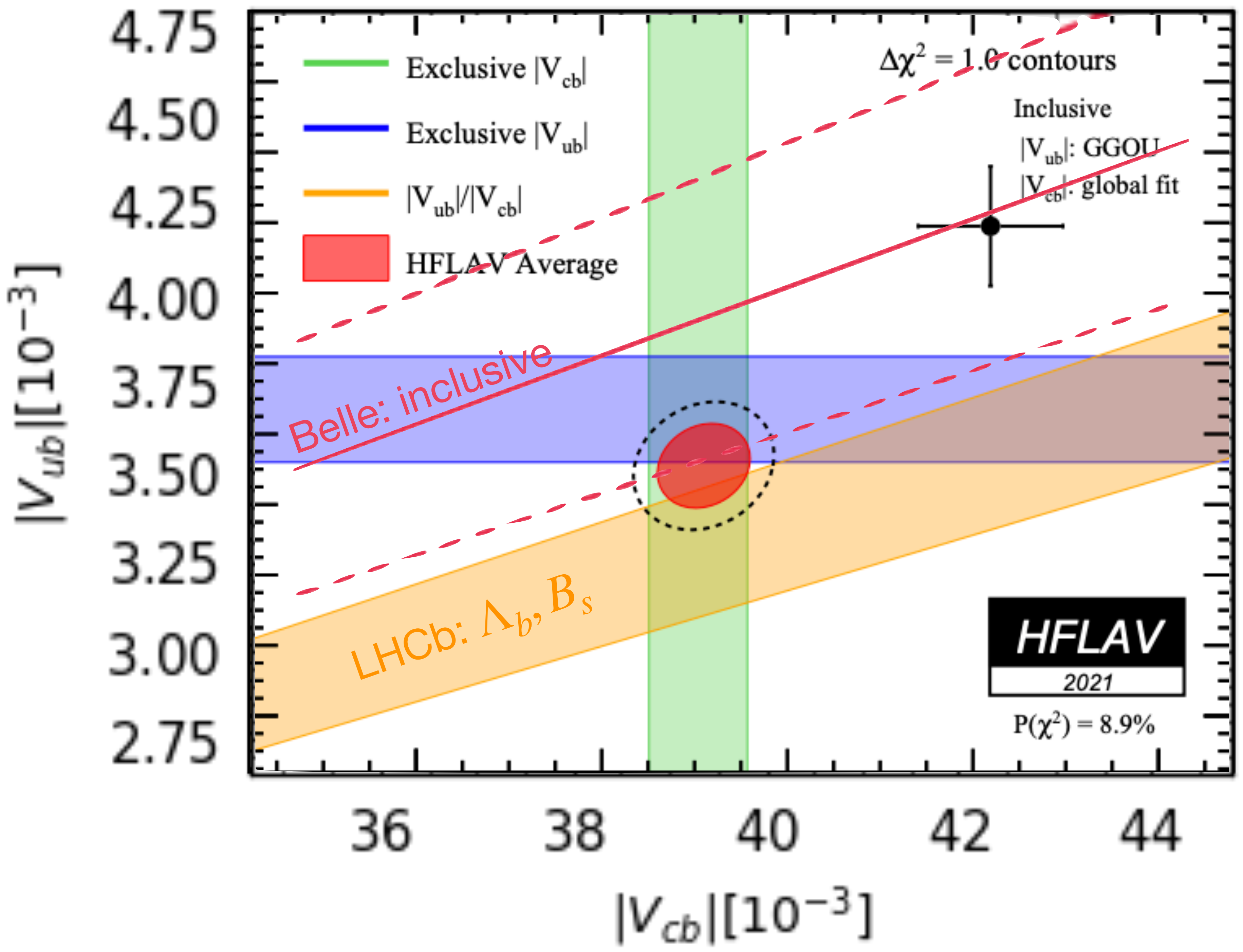
In recent years a few discrepancies have been found between the SM predictions and different experimental measurements in the bottom sector, especially in tauonic decay modes of B mesons [4-6]. In view of there being no

Future Perspectives of $B_c \to \tau\nu$ on CEPC

- Within ~10^9 Z decays, the signal strength accuracies can reach ~1% level
- Result implies a high precision of obtained $|V_{cb}|$ => $\mathcal{O}(1\%)$
- Also possible to measure $|V_{ub}|/|V_{cb}|$ ratio (partial reduction of uncertainties, no leptonic result yet)







Future Perspectives on CEPC

- Other flavour potentials at Tera-Z on CEPC

High precision measurements:

- Orthogonal complementary for Belle II & LHCb
- B_c, Λ_b, inclusive, multiple neutrals, …
- Not only branching fractions, but also shapes, polarizations, etc.

Signal search in (extremely) rare decays:

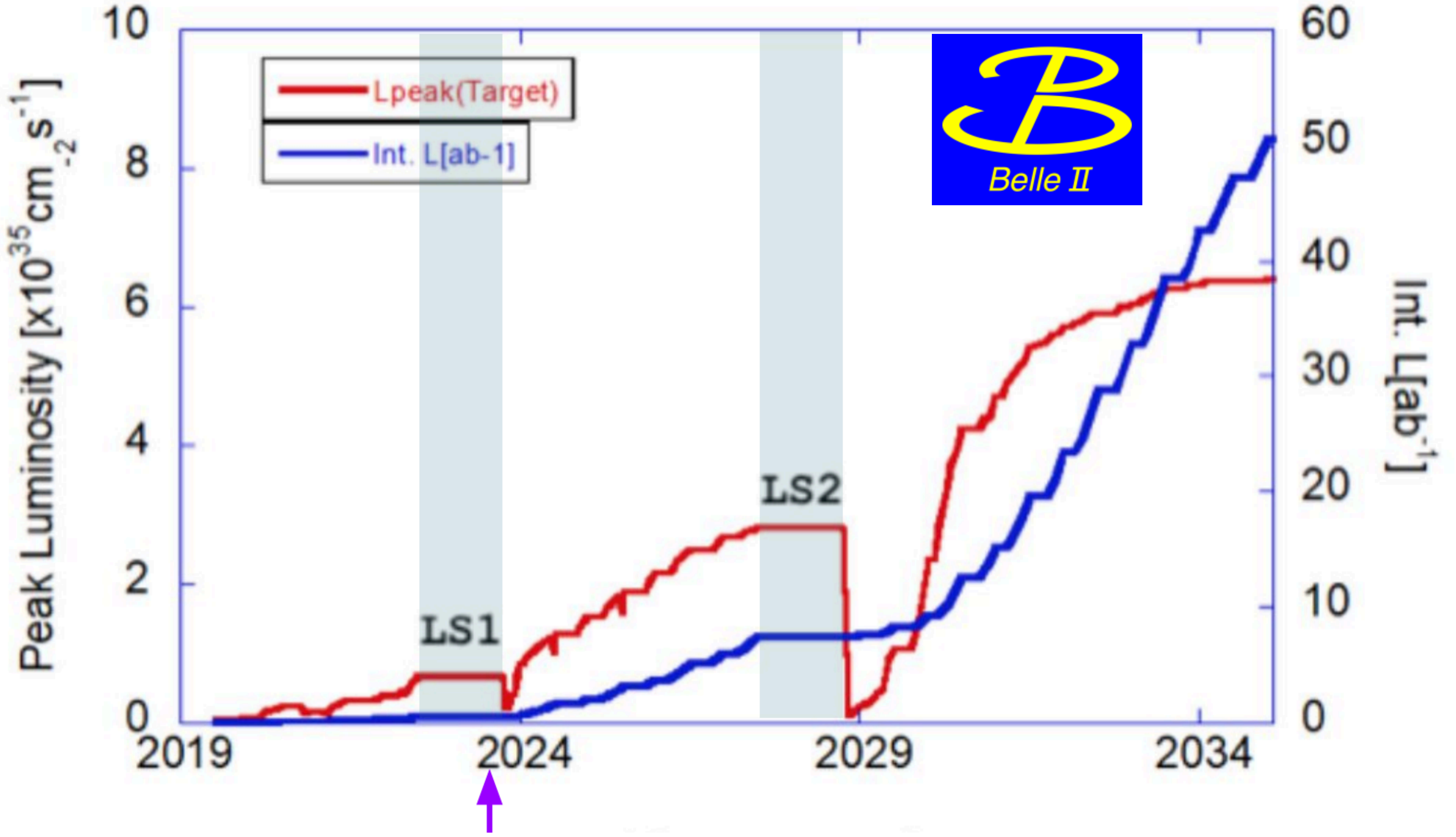
- Benefit from high statistics
- Shrink current upper limit
- Sensitive to NP

Summary

- Several new results on **Semileptonic & leptonic B decays** measured recently at Belle and Belle II

- More results are on the way!!

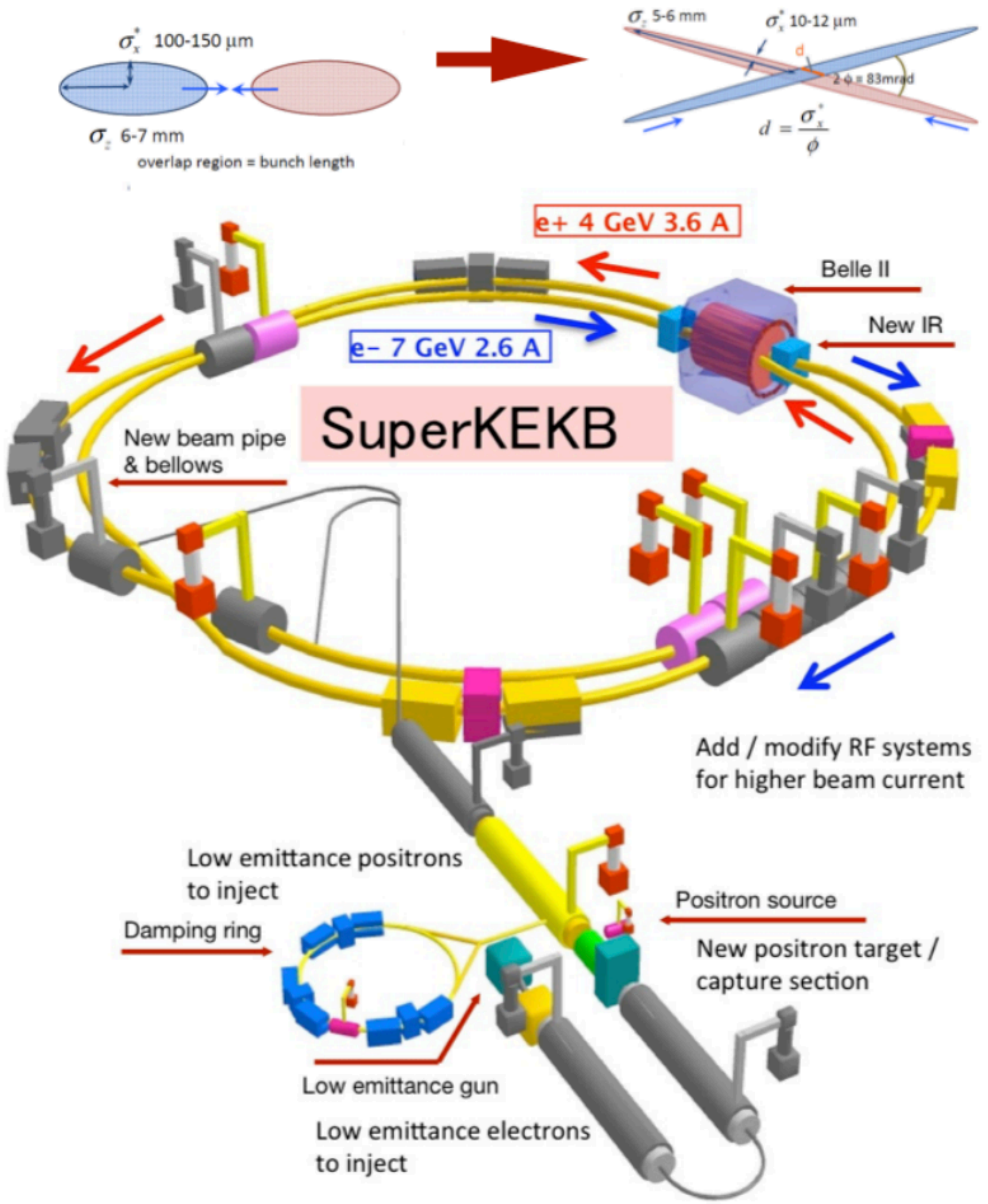
- **Tera-Z @ CEPC** can provide great complementary of existing experiments on B flavours physics

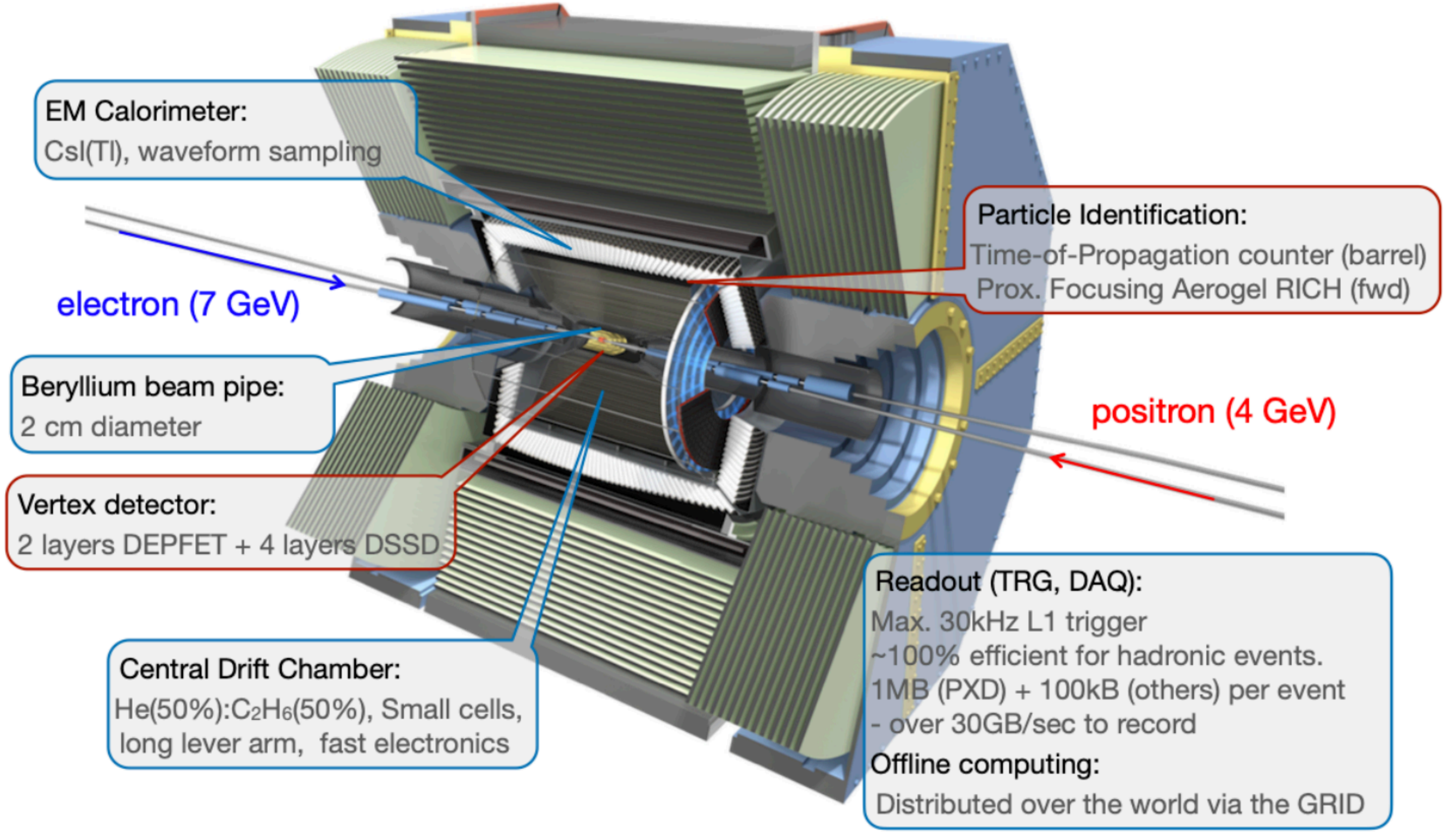


Thank you !

Backup Slides

Upgraded detector and accelerator





arXiv:1011.0352 [physics.ins-det]

First Measurement of $R(X)_{\tau/\mu}$

arXiv:2311.07248
Preliminary

Preliminary

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