Status of SIMBA

Inclusive $|V_{ub}|$ and New Physics from Inclusive Decays

SIMBA - Spectral Inclusive Meson Analysis of B-Meson Inclusive Spectra

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DFG Deutsche Forschungsgemeinschaft

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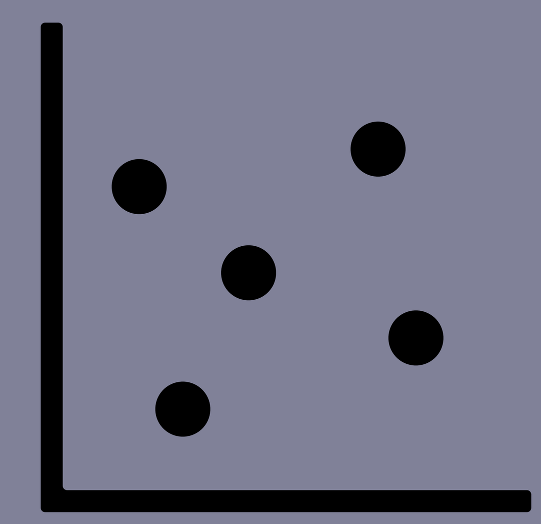
Introduction to SIMBA



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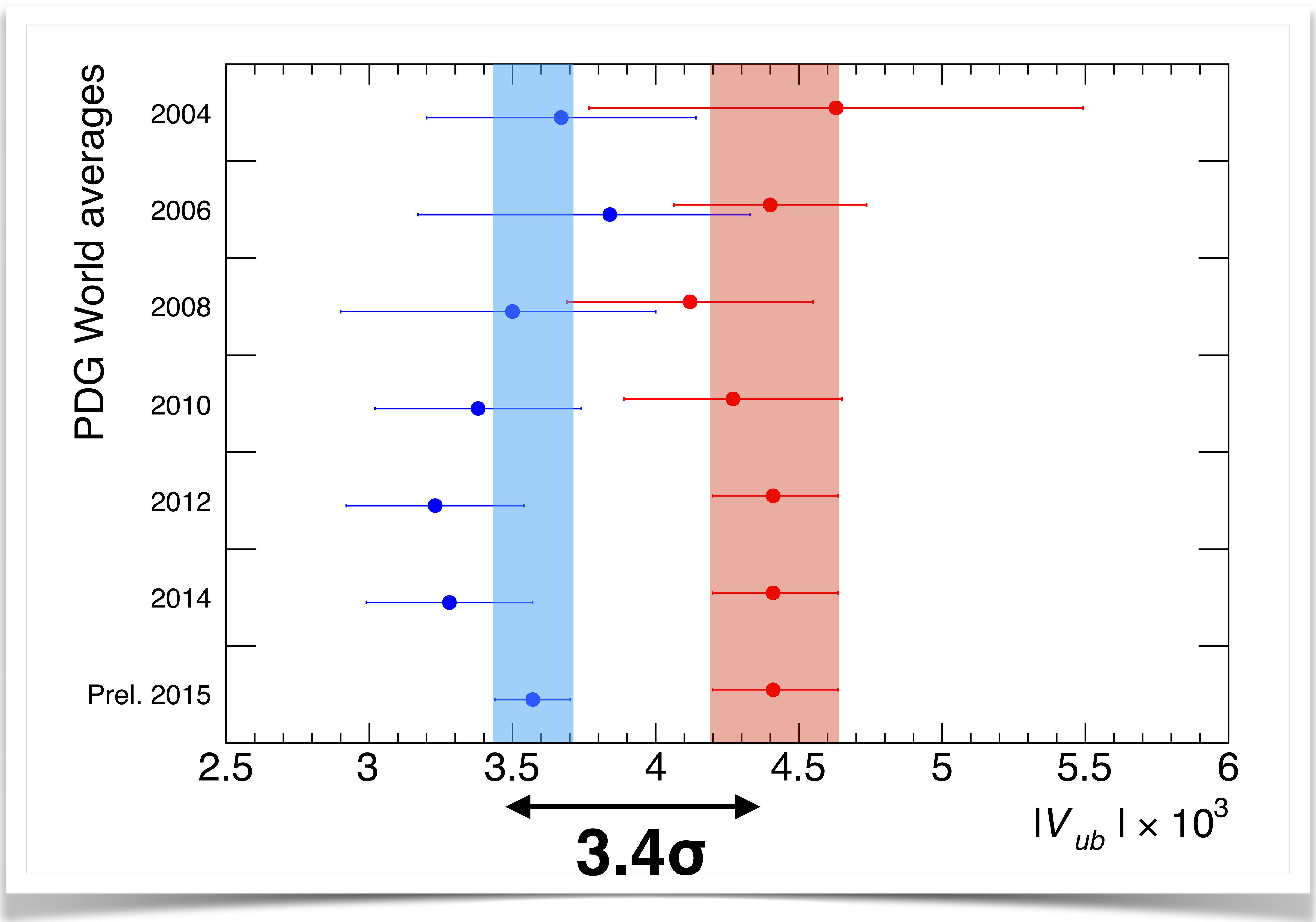
Inclusive |V$_{ub}$|



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

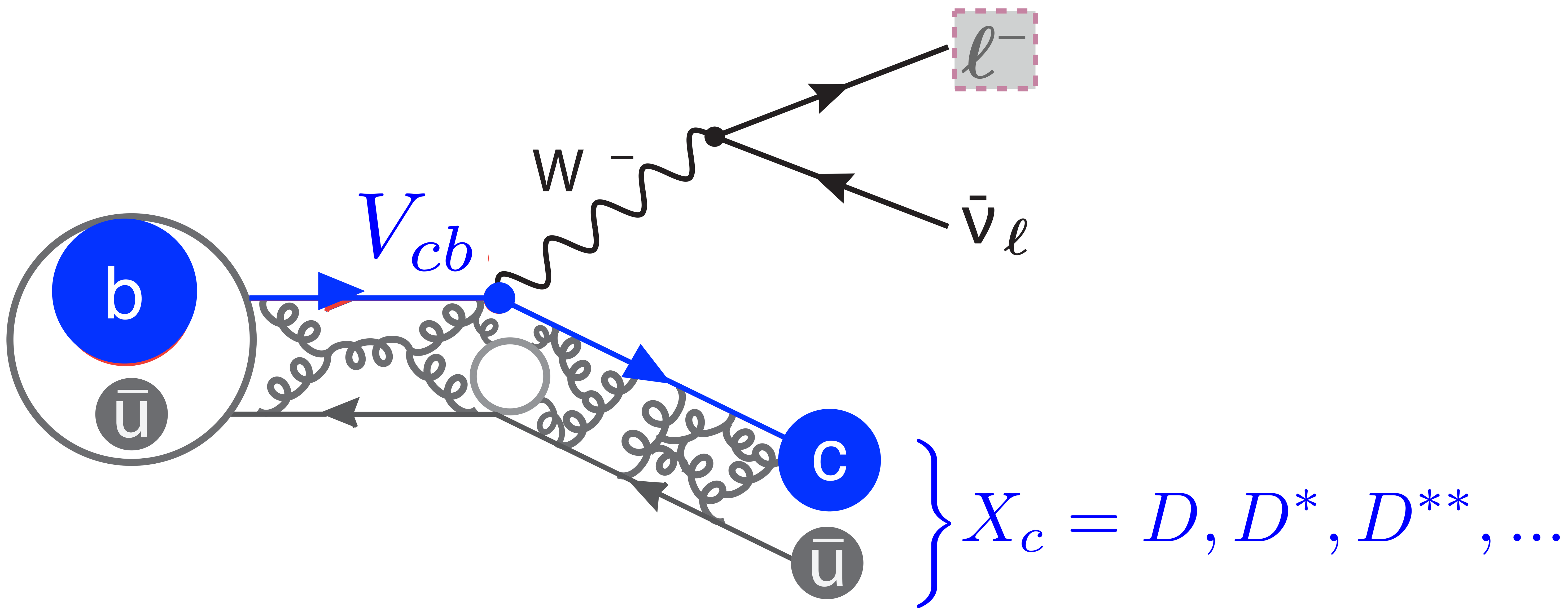
$\bar{B} \to X_u \, \ell \, \bar{\nu}_\ell$

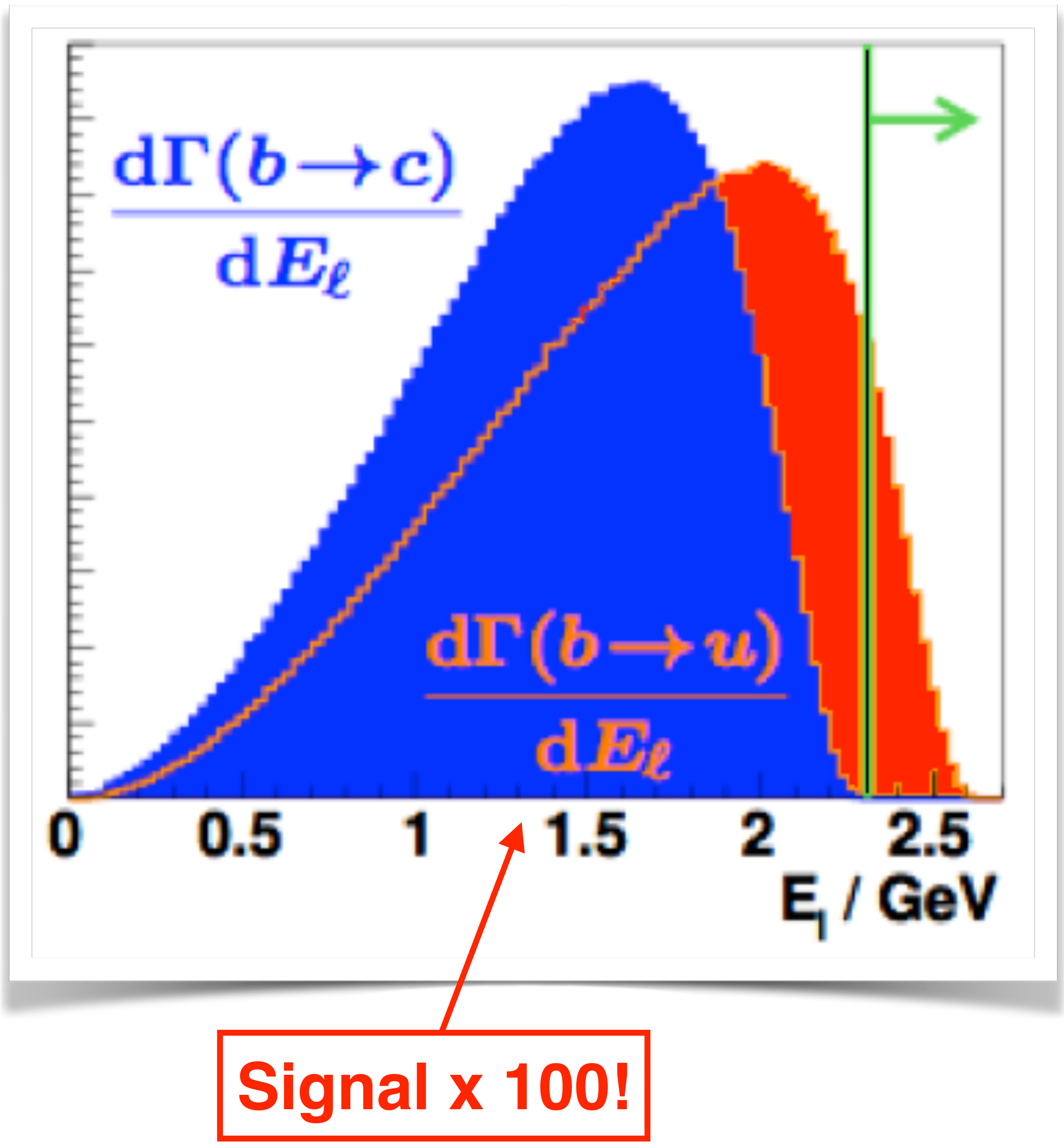
Exclusive Ansatz

Inclusive Ansatz

What makes measuring inclusive $|V_{ub}|$ difficult?

- Inclusive $|V_{ub}|$ determinations are difficult:
  - Large backgrounds from $\bar{B} \to X_c \ell \bar{\nu}_\ell$



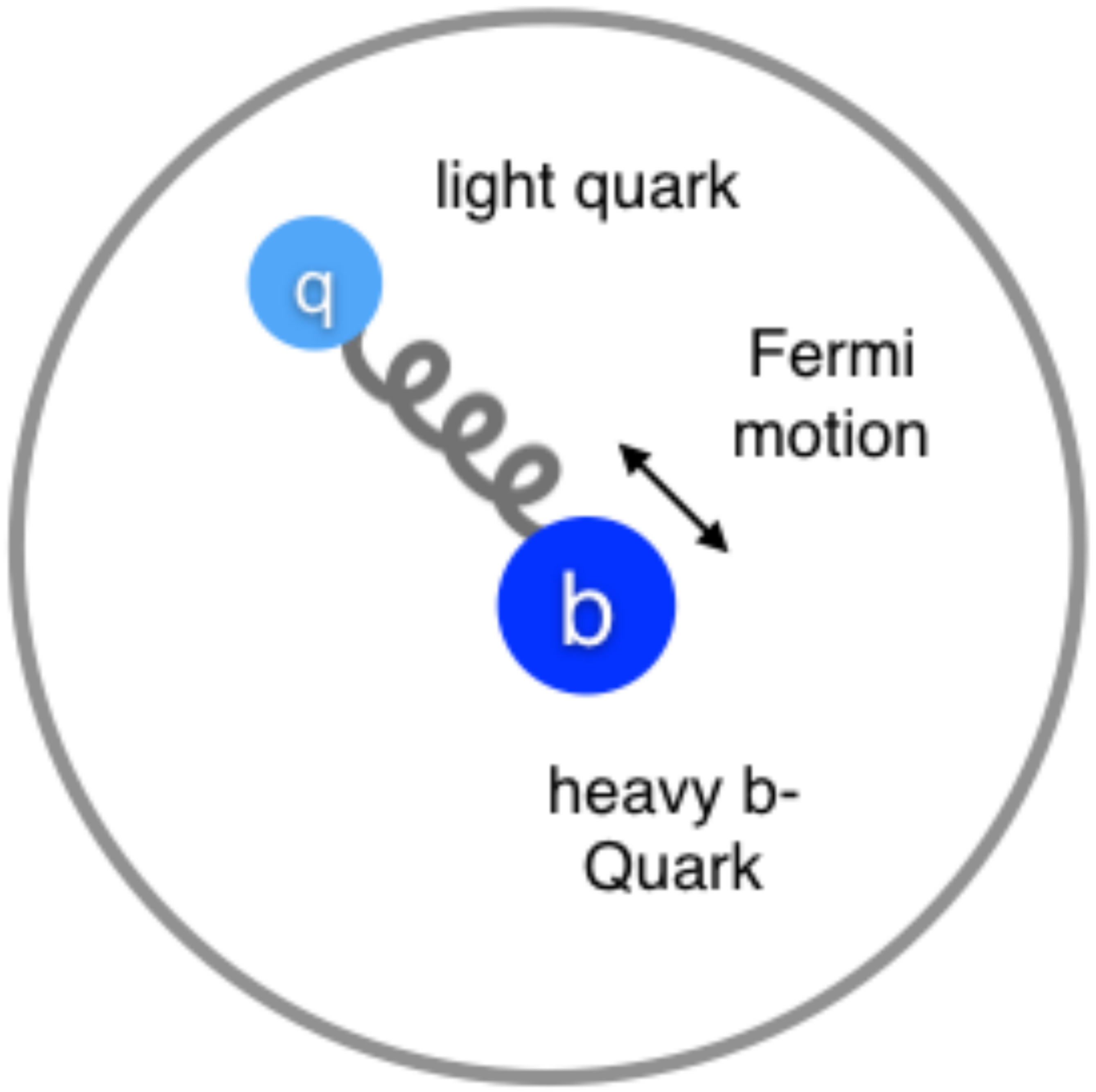


  - **O(100)** larger than signal
  - Decays involving ***D****** not well understood
  - Clear separation only possible in **corners of phase space**

What makes measuring inclusive $|V_{ub}|$ difficult?

- Does not help much though, as theory prediction heavily depends on details of shape function

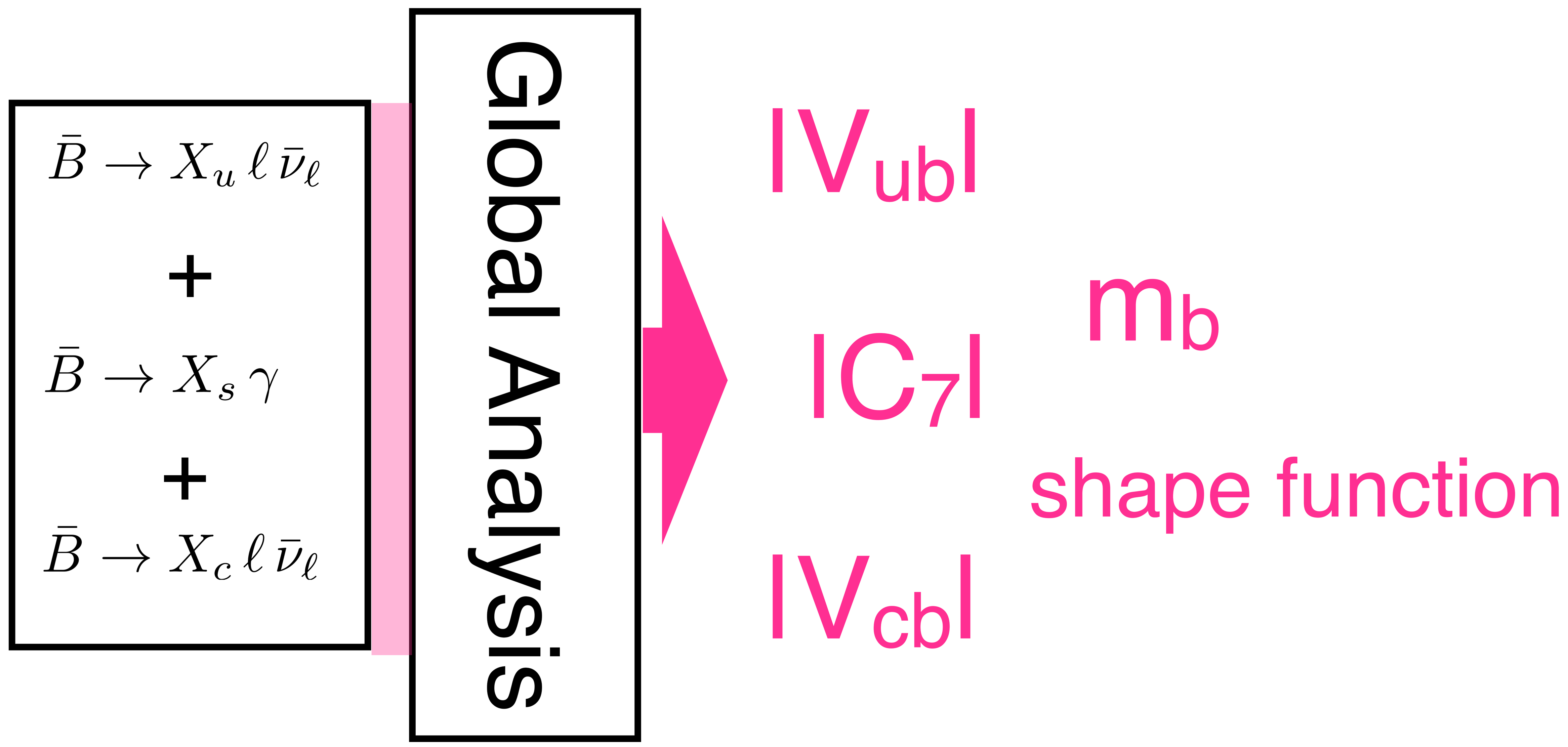
$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(B \to X_u\,\ell\,\bar{\nu}_\ell)}{\tau_B\,\Delta\Gamma(B \to X_u\,\ell\,\bar{\nu}_\ell)}}$$

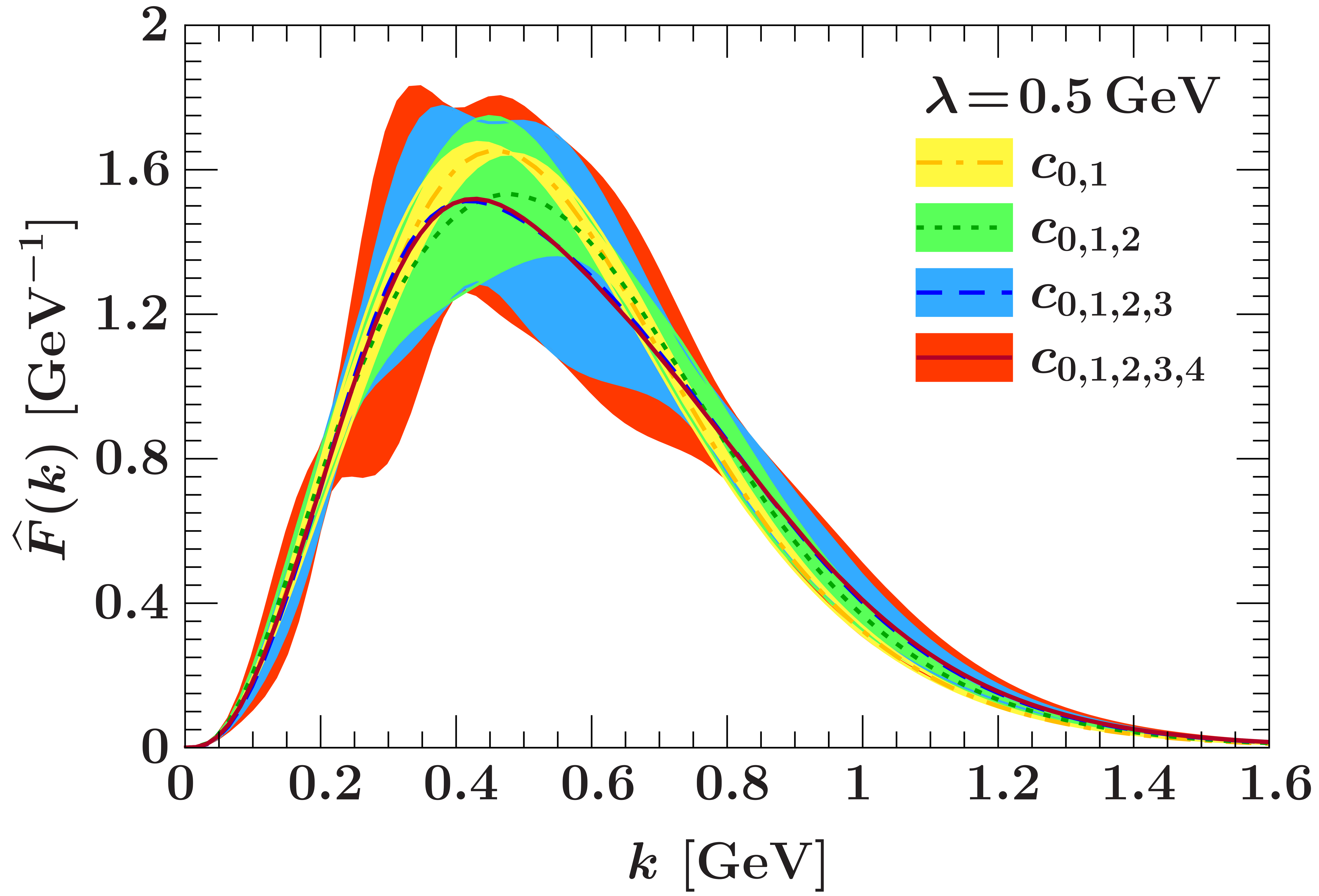


- "Experimentally wonderful region, but completely useless as no theorist can tell you what $|V_{ub}|$ you measured"

The Idea in a nutshell

- **The SIMBA idea**: turn this around:
  - **Large model dependence $\Longleftrightarrow$ sensitivity to constrain SF**
    - Most information in differential spectra
    - Can use different decay modes (same leading shape function) and cary out global analysis that propagates uncertainties:





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

+

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

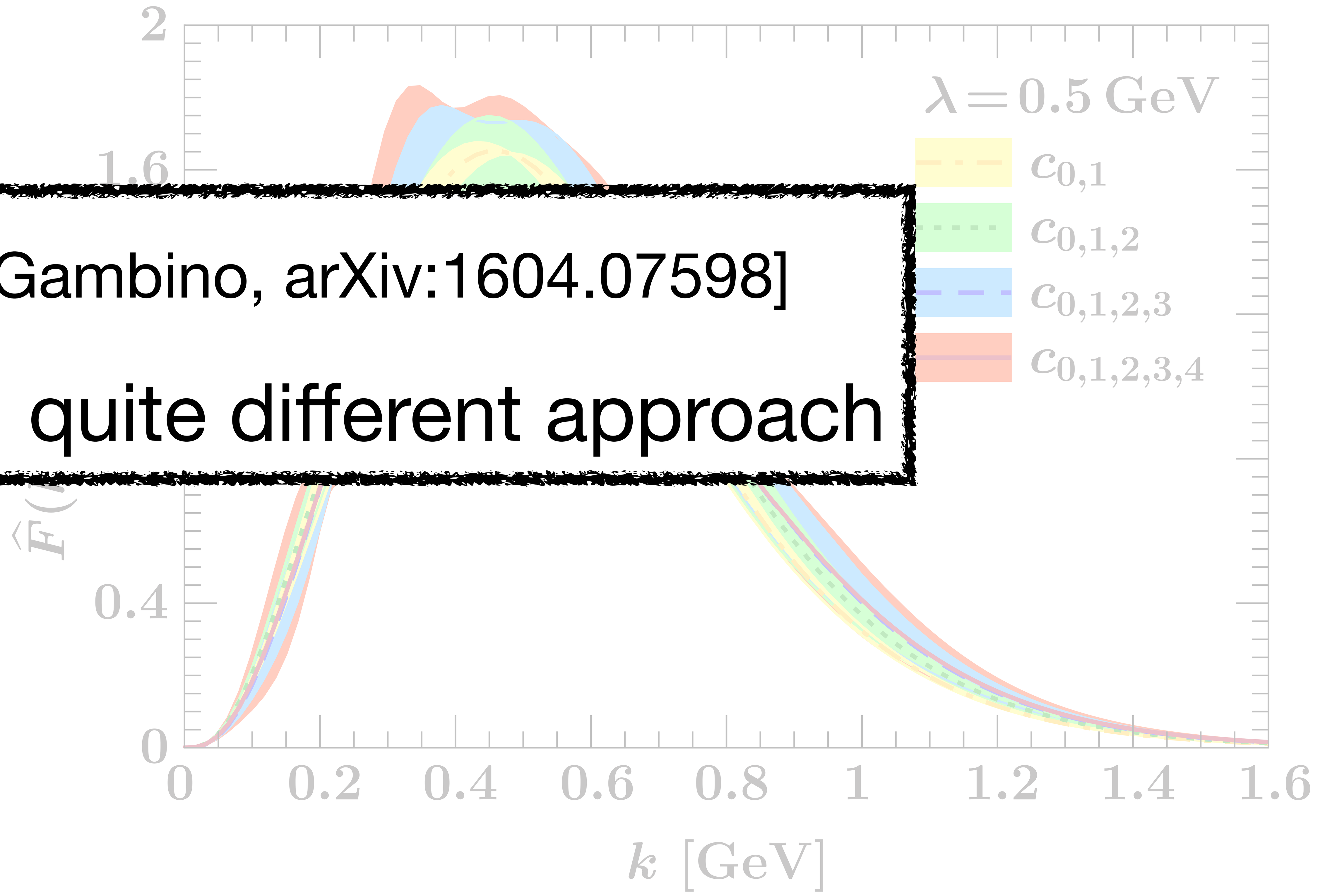
+

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

Global Analysis

shape function

$|V_{cb}|$



- NNVub [Healey, Mondino, Gambino, arXiv:1604.07598]
  - Based on same idea, quite different approach

Theory side of Global Fits

- SIMBA master formulae:

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

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

- 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:

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

$\widehat{F}(k)$ nonperturbative part

- Determines peak region
- Fit from data

$\widehat{C}_0(\omega, \mu_\Lambda)$ perturbative part

- Generates perturbative tail with correct μ_Λ dependence

Theory side of Global Fits

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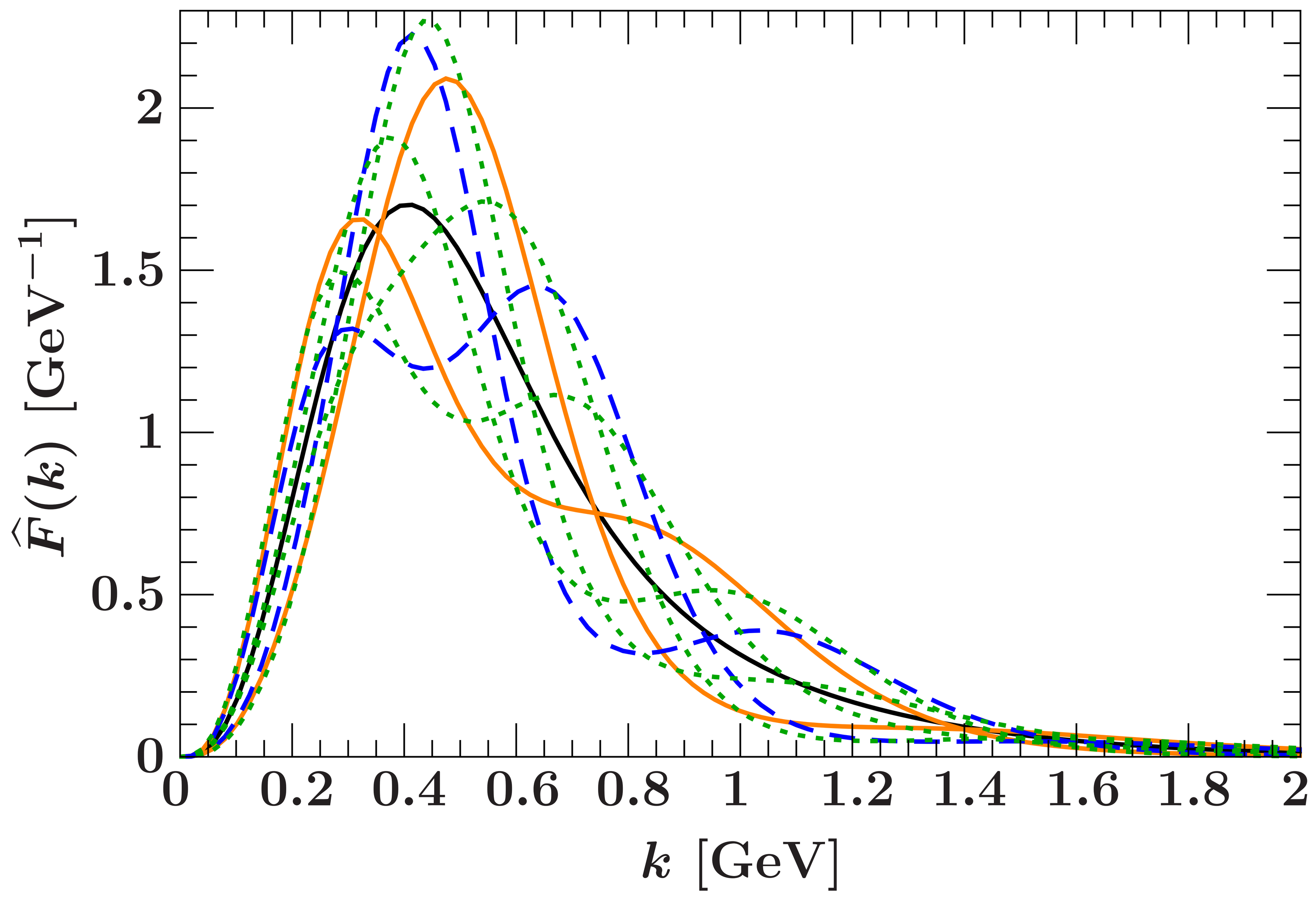
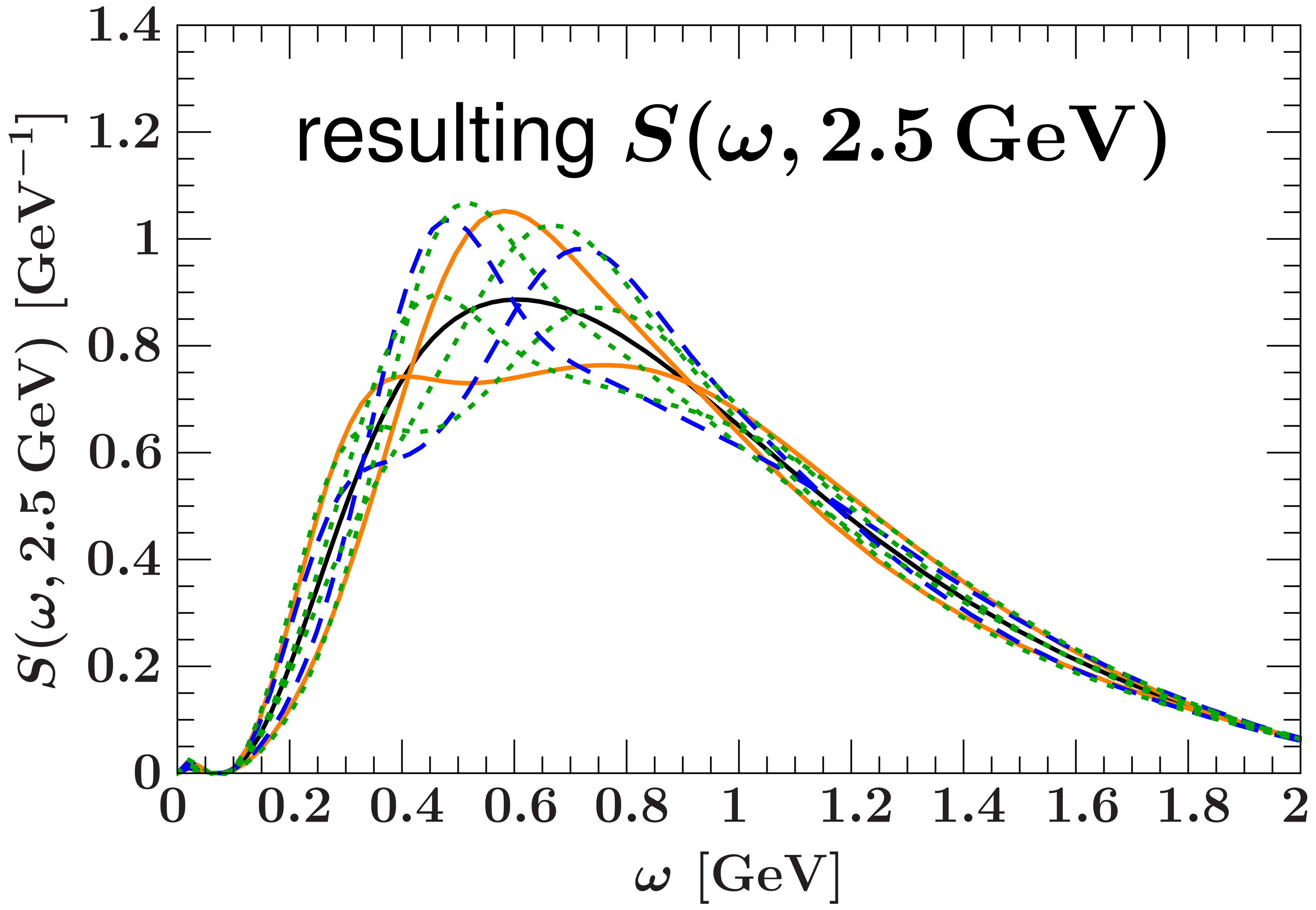


$\Rightarrow$



Theory side of Global Fits

Expand $\widehat{F}(k)$ into suitable orthonormal basis

$$\widehat{F}(\lambda x) = \frac{1}{\lambda}\left[\sum_{n=0}^{\infty} c_n f_n(x)\right]^2$$

$$\int \mathrm{d}k\, \widehat{F}(k) = \sum_{n=0}^{\infty} c_n^2 = 1$$

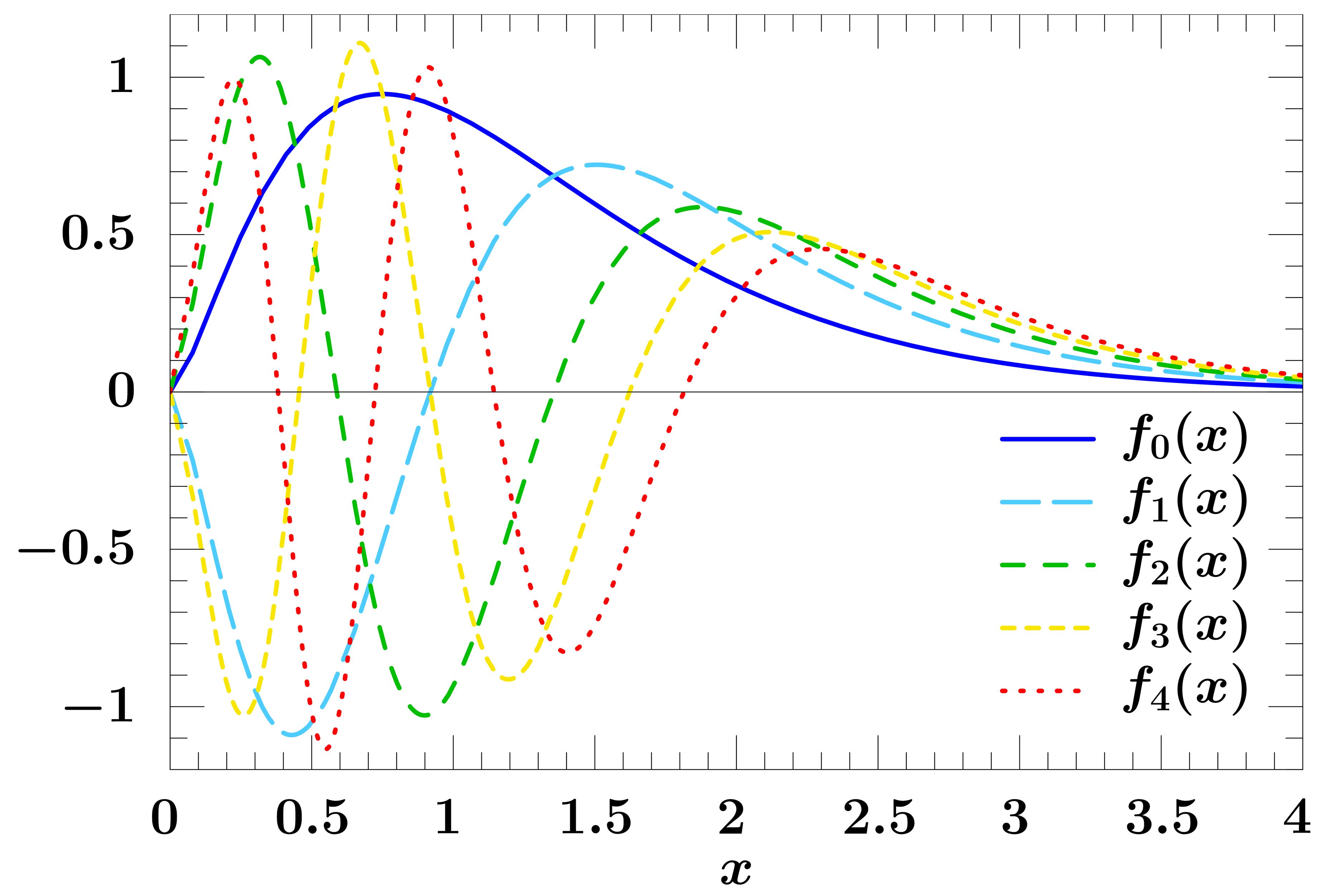
- Provides model-independent description

Fit for $\widehat{F}(k)$ by fitting basis coefficients c_n

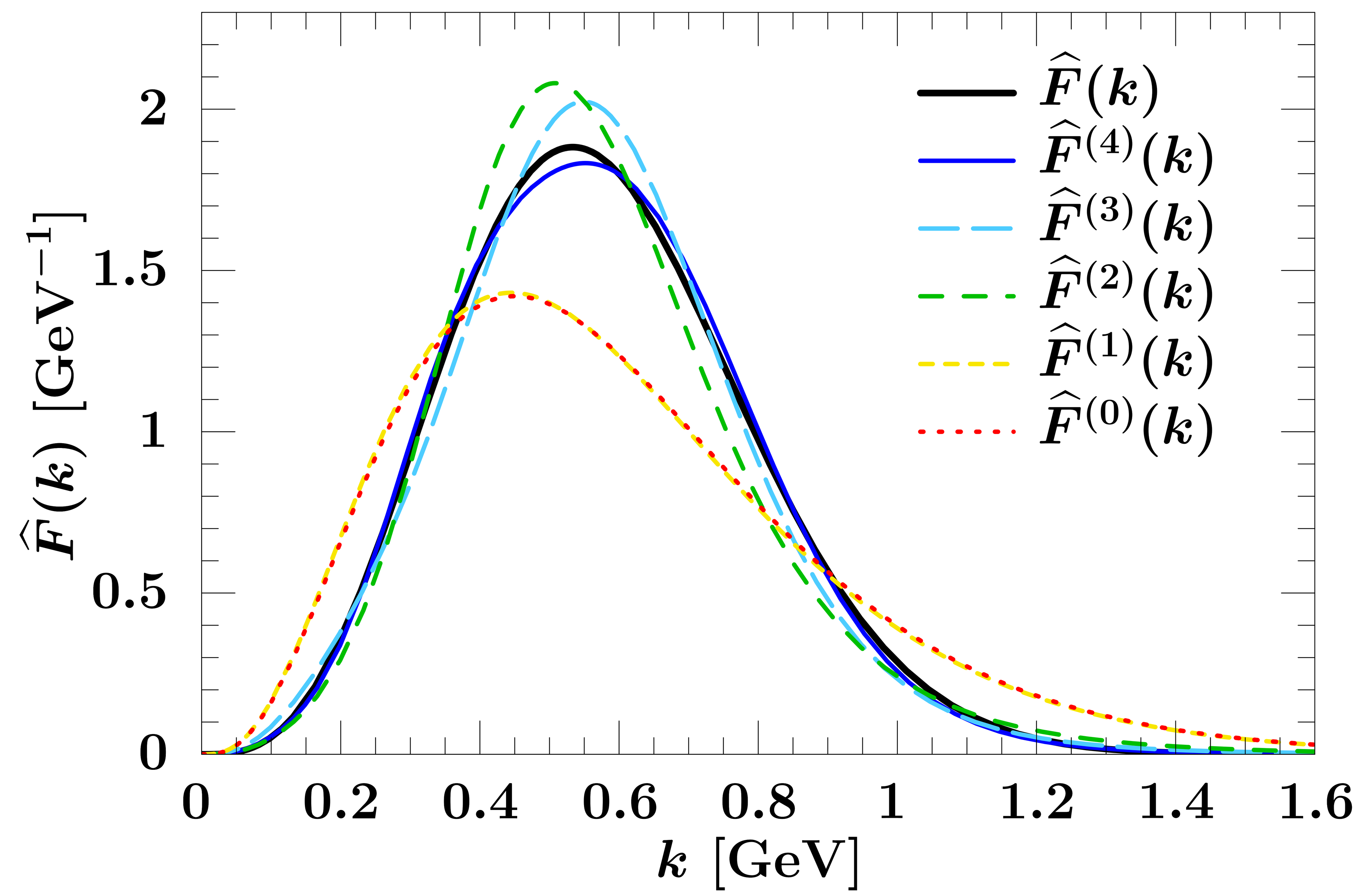
- Experimental uncertainties and correlations can be properly captured in covariance matrix of fitted coefficients c_n

$\Rightarrow$ Allows for *data-driven*, reliable estimation of SF uncertainties

Basis functions



Expansion of Gaussian $\widehat{F}(k)$



Theory side of Global Fits

$$\widehat{F}(\lambda x) = \frac{1}{\lambda}\Big[\sum_{n=0}^{N} c_n f_n(x)\Big]^2$$

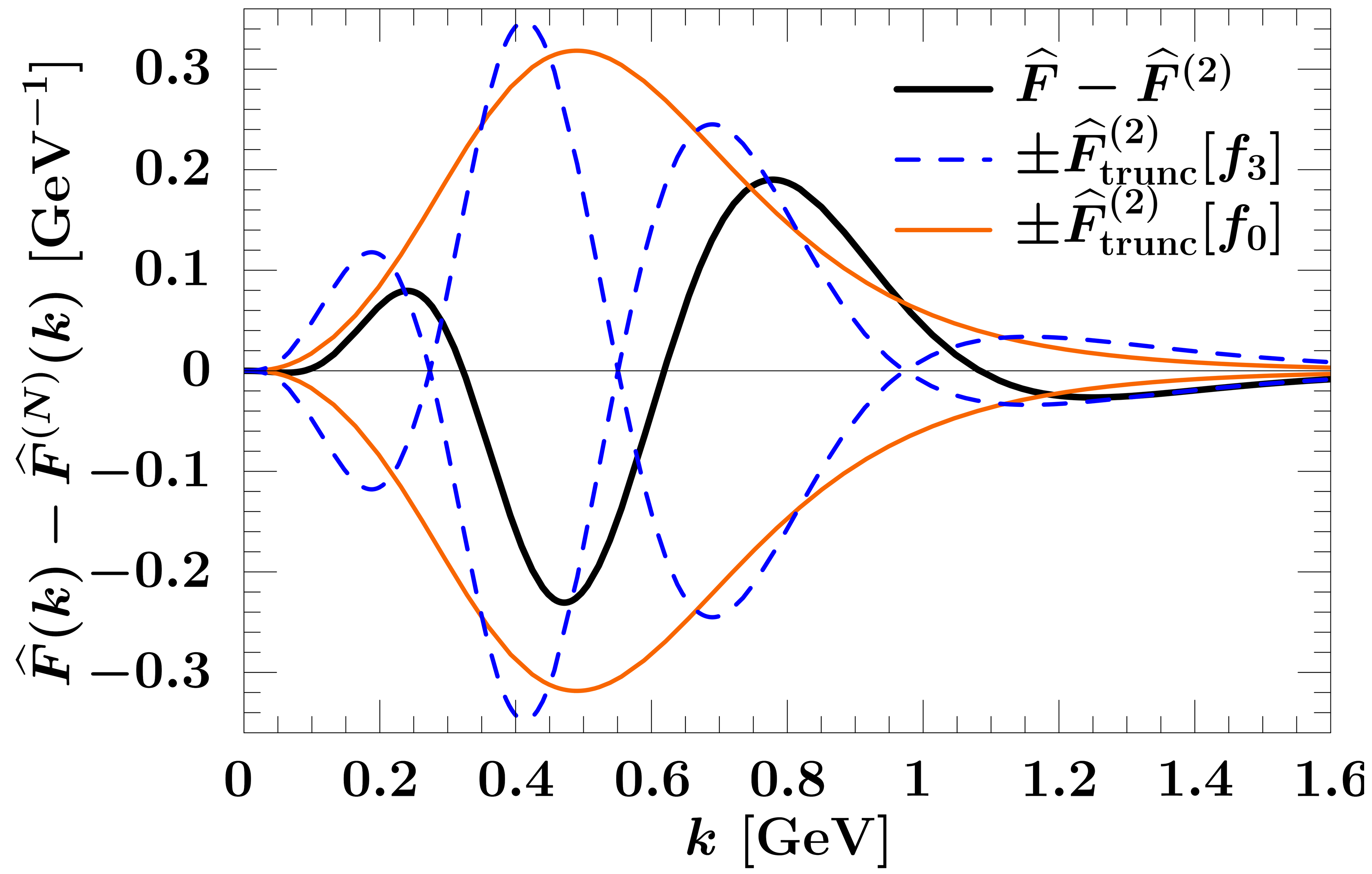
In practice, series must be truncated

- Induces residual basis (model) dependence
- Truncation error scales as $1 - \sum_{n=0}^{N} c_n^2$

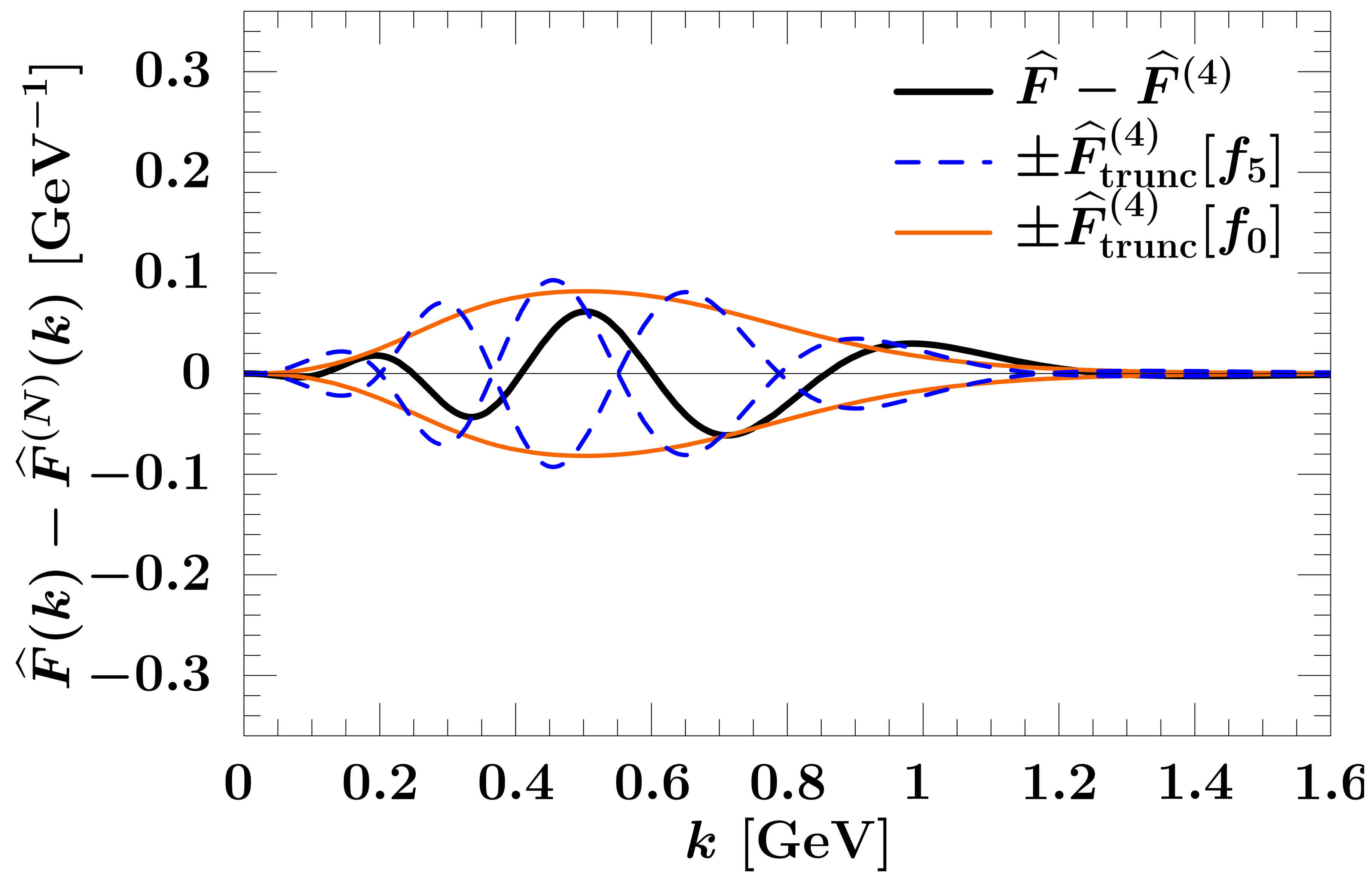
In practice most complications are in choosing good basis (λ) and N

- Want basis so series converges quickly but still unbiased (e.g. iterate)
- Choose N large enough so truncation error is smaller than to exp. uncertainties, but small enough to have stable fit and not waste statistical power
- Add coefficients with more precise data

Truncation error at $N = 2$



Truncation error at $N = 4$



$B \to X_s\, \gamma$

m_b^{1S}, $|C_7^{eff}|$ & the Shape Function

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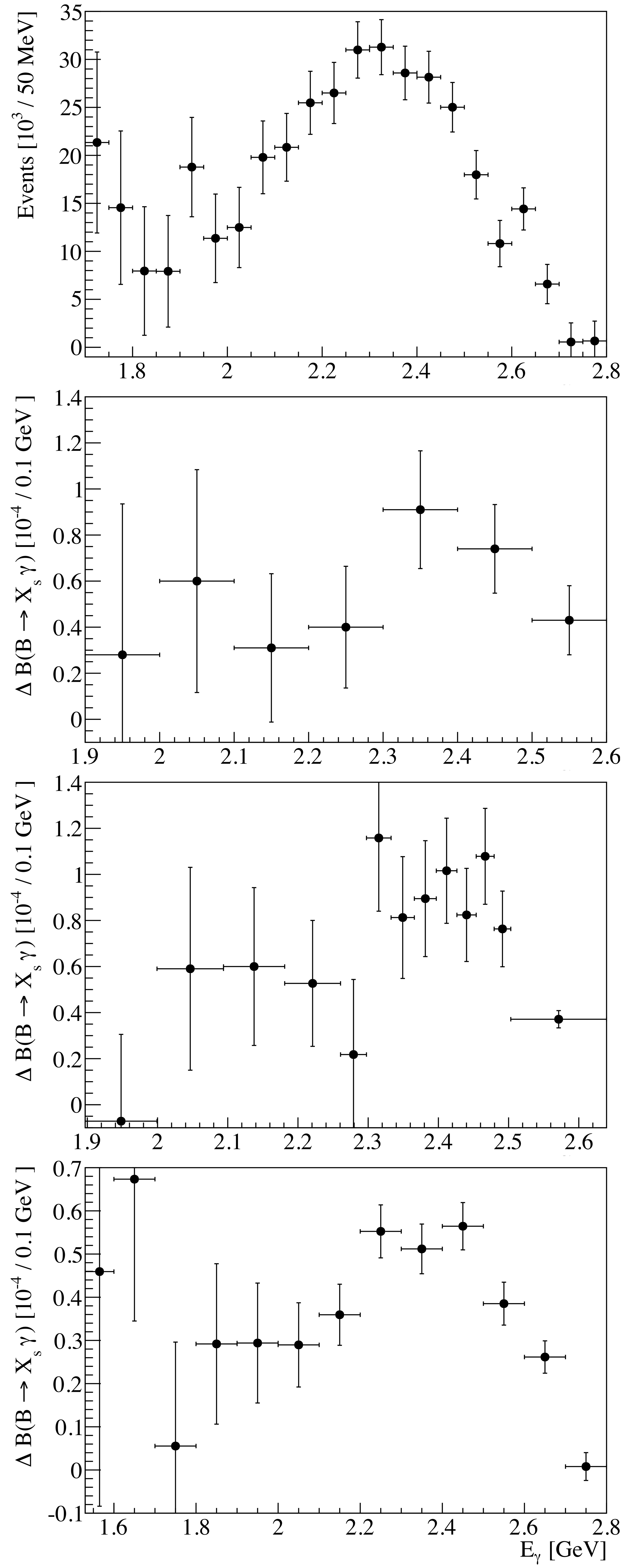
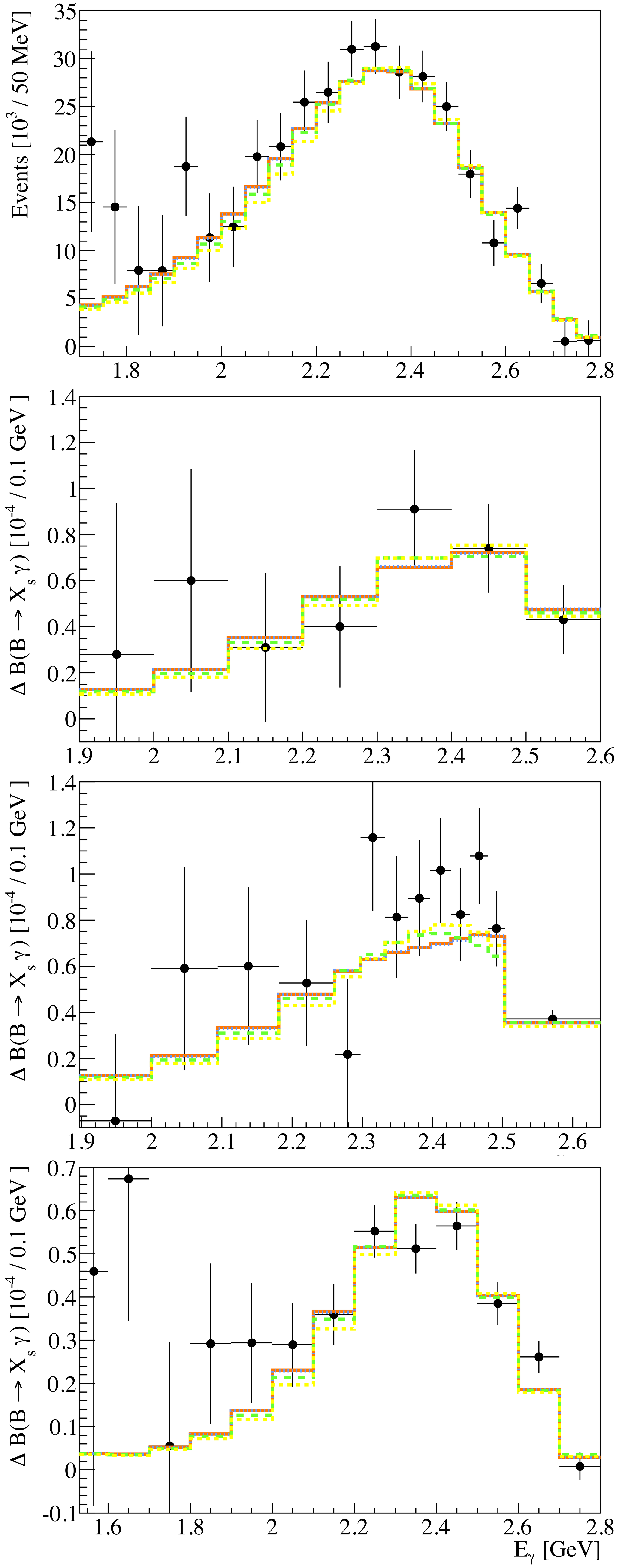
Global Fit to $B \to X_s\, \gamma$

- Theory
  - NNLL’ + NNLO
  - non-C_7 contributions fixed to SM
- Experimental Inputs
  - Belle Inclusive (in *Y(4S)* frame)
    - arXiv:0907.1384
  - BaBar hadronic (in *B* frame)
    - arXiv:0711.4889
  - BaBar sum-over-exclusive (in *B* frame)
    - hep-ex/0508004
  - BaBar inclusive (in *Y(4S)* frame)
    - arXiv:1207.5772



Global Fit to $B \to X_s \gamma$



- Too few coefficients lead to clear bias and underestimates uncertainties
- Extracted $|C_7^{eff} V_{tb} V_{ts}^*|$ consistent with SM

Global Fit to $B \to X_s \gamma$

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- Extracted $|C_7^{eff} V_{tb} V_{ts}^*|$ consistent with SM

Global Fit to $B \to X_s \gamma$

- Perturbative uncertainties:
  - Dominant source of uncertainties
  - Important to take into account correlations
  - Evaluated via set of profile scale variations
  - Expected theory uncertainties of comparable size of fit uncertainties

(Illustration only)

Open issues End of 2017

- Consistent treatment of charm contributions
  - Integrate out charm loops vs keeping charm dynamic
  - Include known massive results
    - In the end small effect, but good to get it right
- Four-quark shape functions
- Sub-leading shape functions
  - irrelevant for fit, but important for interpretation
- Fix fit strategy

Open issues Now

DESY 14-xxx
MIT–CTP xxxx
January 10, 2018 – 17:06

Precision Global Analysis of $B \to X_s\gamma$

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Iain W. Stewart,[4] Frank J. Tackmann,[5] and Kerstin Tackmann[5]
(The SIMBA Collaboration)

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We perform a model independent global fit to all available inclusive $B \to X_s\gamma$ data from BaBar and Belle. We extract the normalization of the $B \to X_s\gamma$ decay rate, which is a sensitive probe of physics beyond the standard model, together with the nonperturbative b-quark distribution function and the b-quark mass, m_b. Our theoretical framework consistently combines the correct descriptions

- ~~Consistent treatment of charm con~~
  - ~~Integrate out charm loops vs keeping~~
  - ~~Include known massive results~~
    - ~~In the end small effect, but good to get it right~~
- ~~Four-quark shape functions~~
- ~~Sub-leading shape functions~~
  - ~~irrelevant for fit, but important for interpretation~~
- ~~Fix fit strategy~~

Meet up in early January at KIT and finished all open items
Will meet up again soon and write the $B \to X_s \gamma$ paper and start working on $B \to X_u \, l \, \nu$

$B \to X_u \, l \, \nu$

m_b^{1S}, $|C_7^{eff}|$ & the Shape Function

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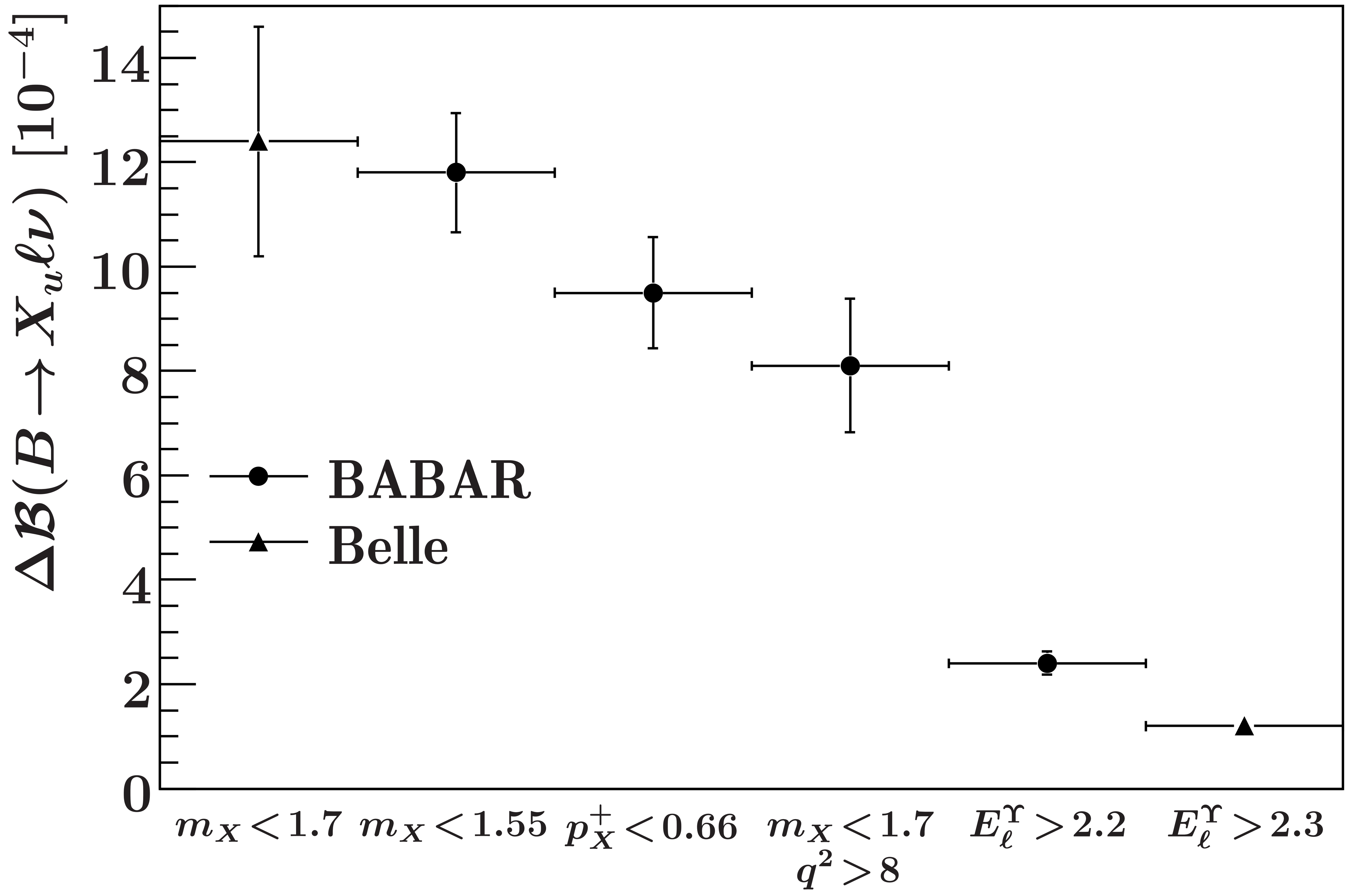
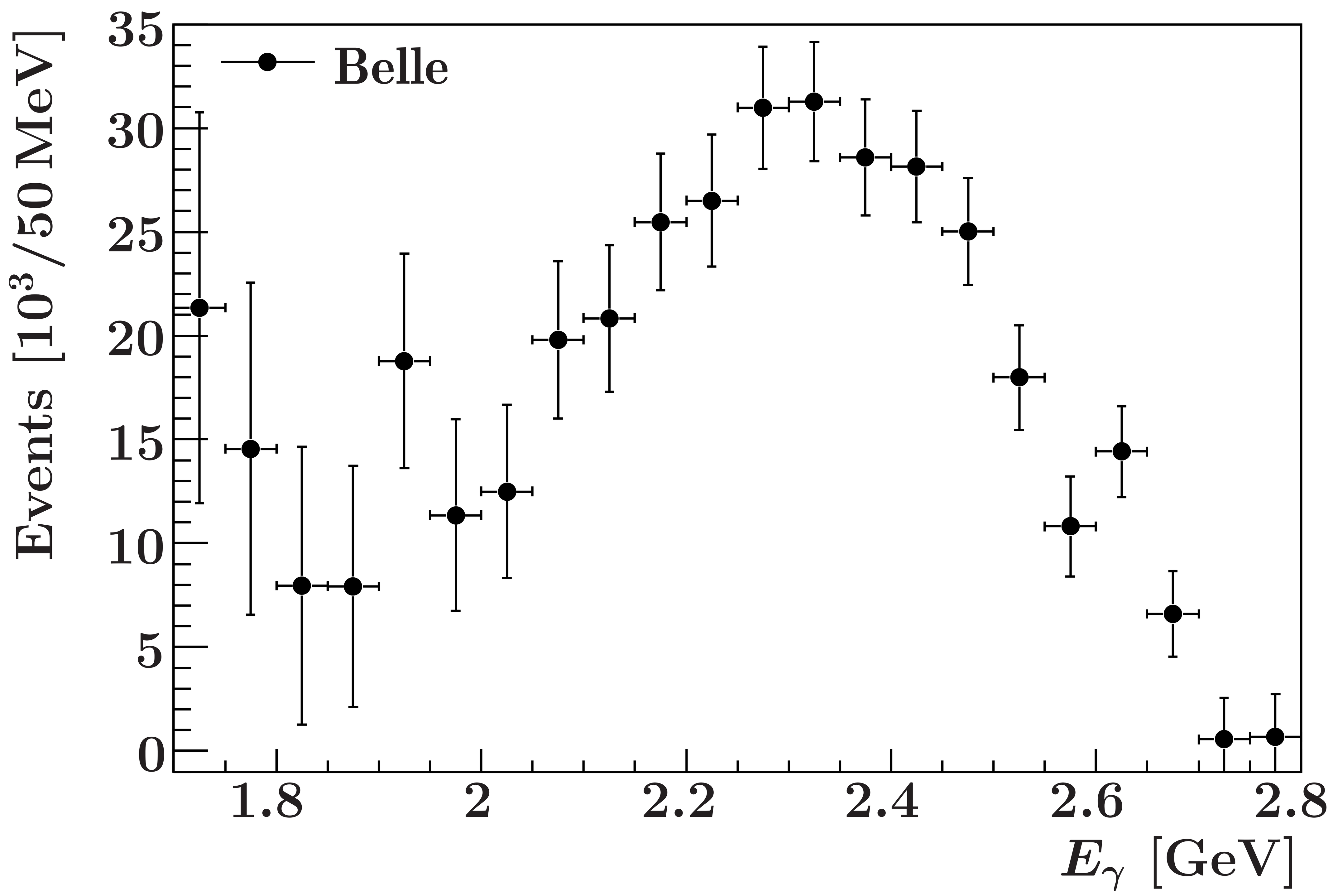
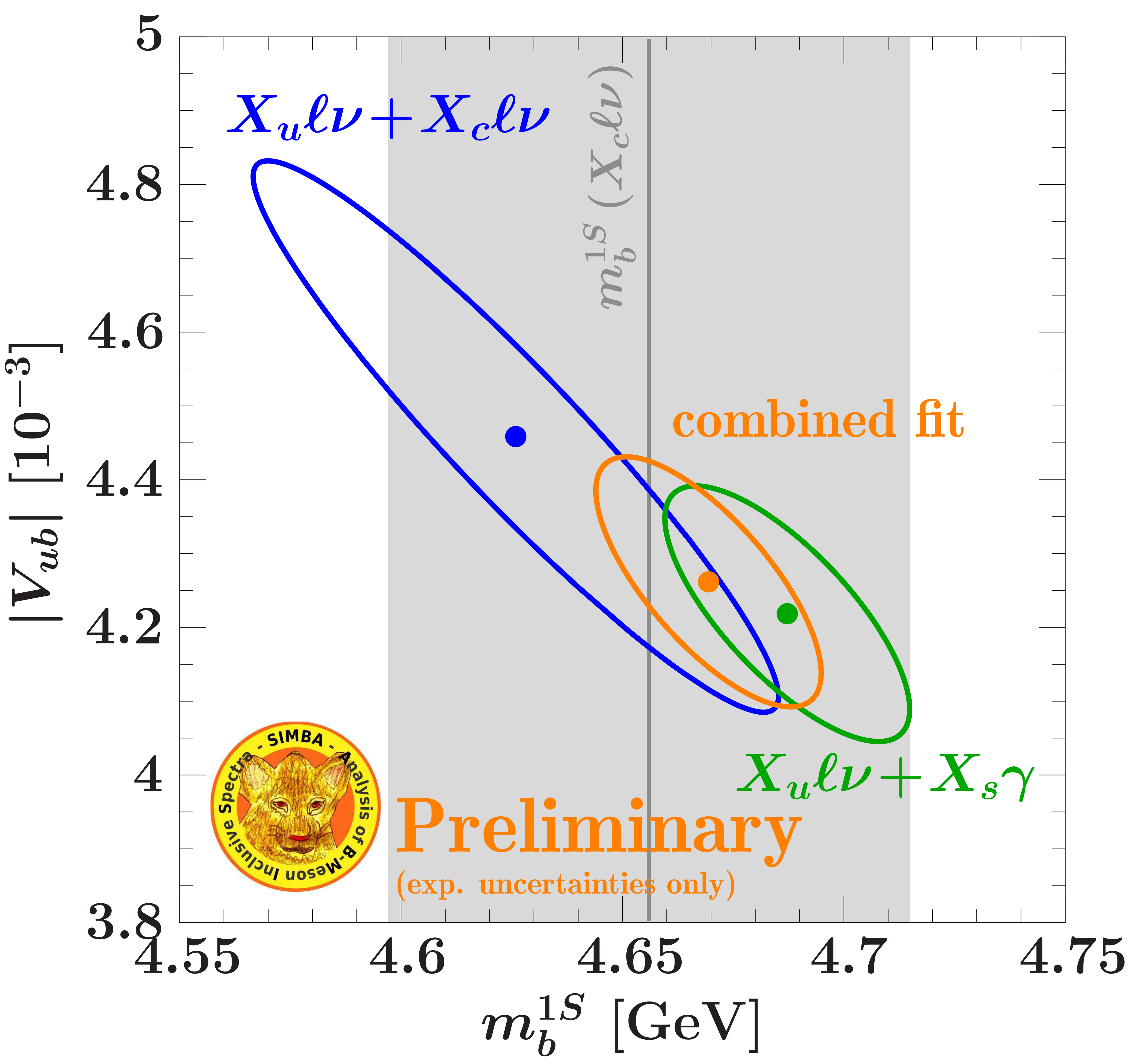
Global $|V_{ub}|$ fit

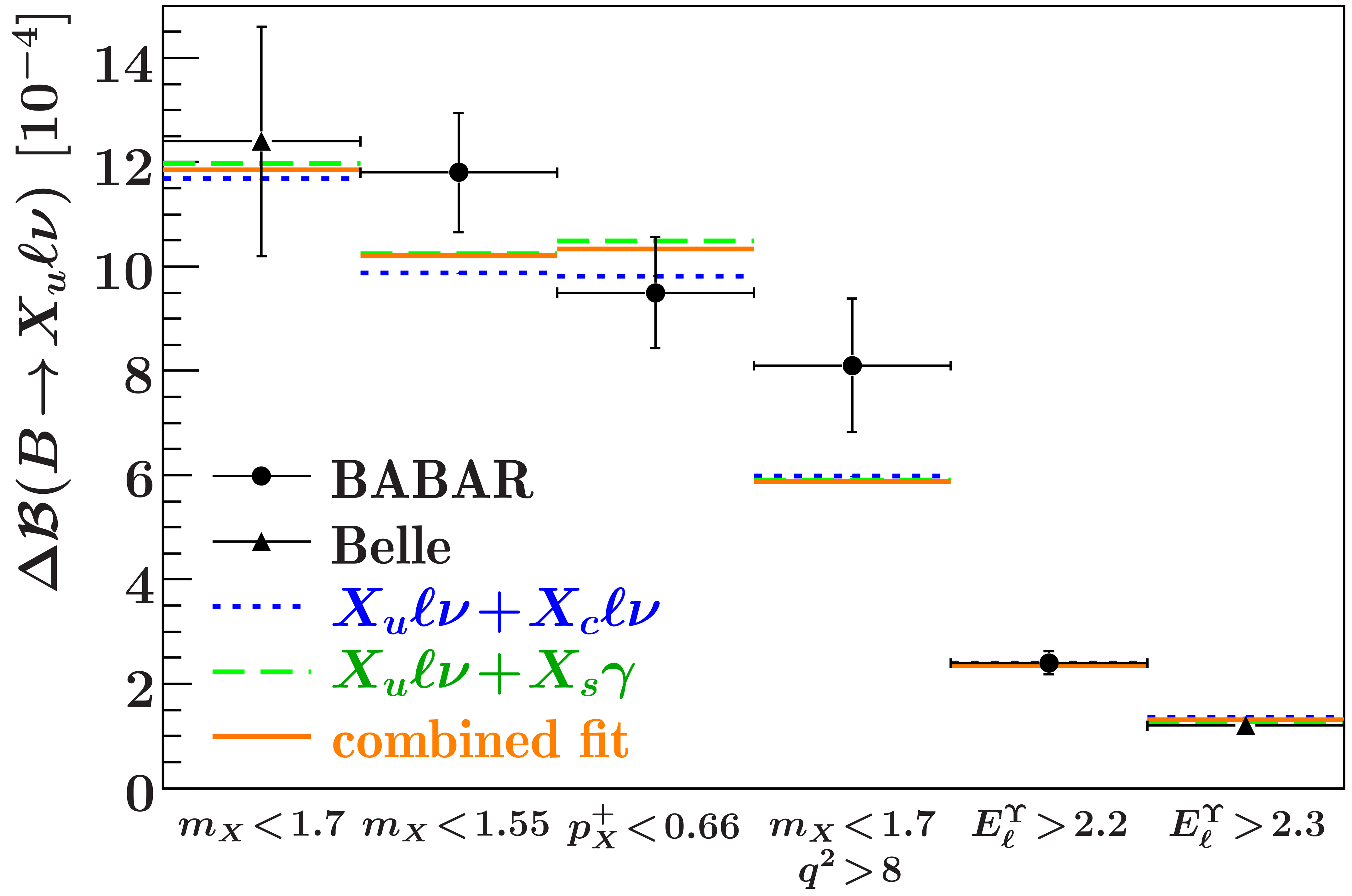
- Theory
  - NLL' + NLO
  - ignoring sub-leading shape functions
- Experimental Inputs
  - $B \to X_u\, l\, \nu$ partial branching fractions
    - picked measurement for which we are sure enough that they have negligible (SF) model dependence
    - BaBar & Belle hadronic tag
    - BaBar & Belle lepton endpoint
  - $B \to X_s\, \gamma$ partial branching fractions
    - Belle inclusive (shown)
    - (old) BaBar sum-over-exclusive (not shown)
    - BaBar hadronic tag (not shown)
  - $B \to X_c\, l\, \nu$
    - m_b^{1S}, λ_1 from moment fits

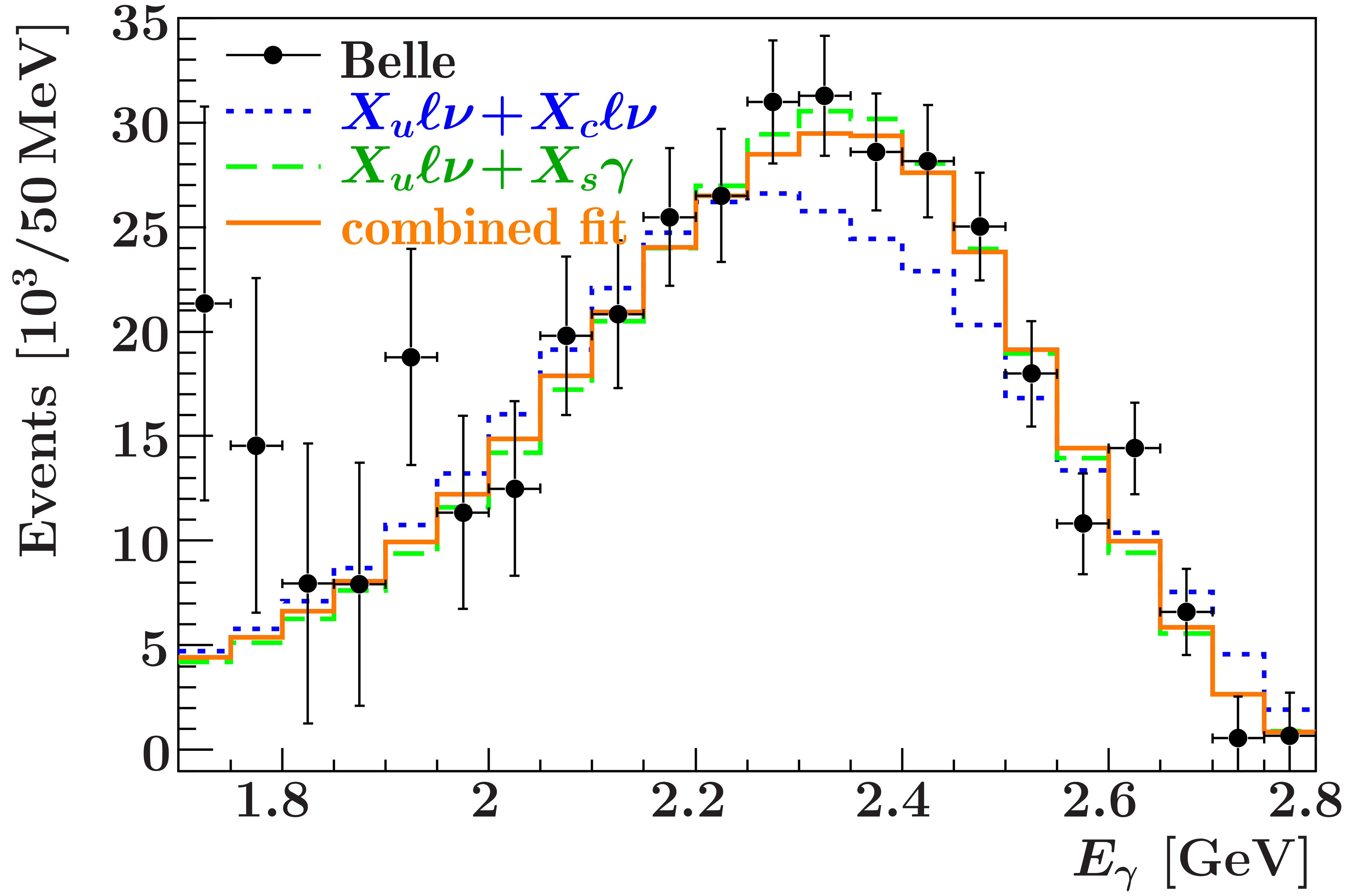




Global $|V_{ub}|$ fit



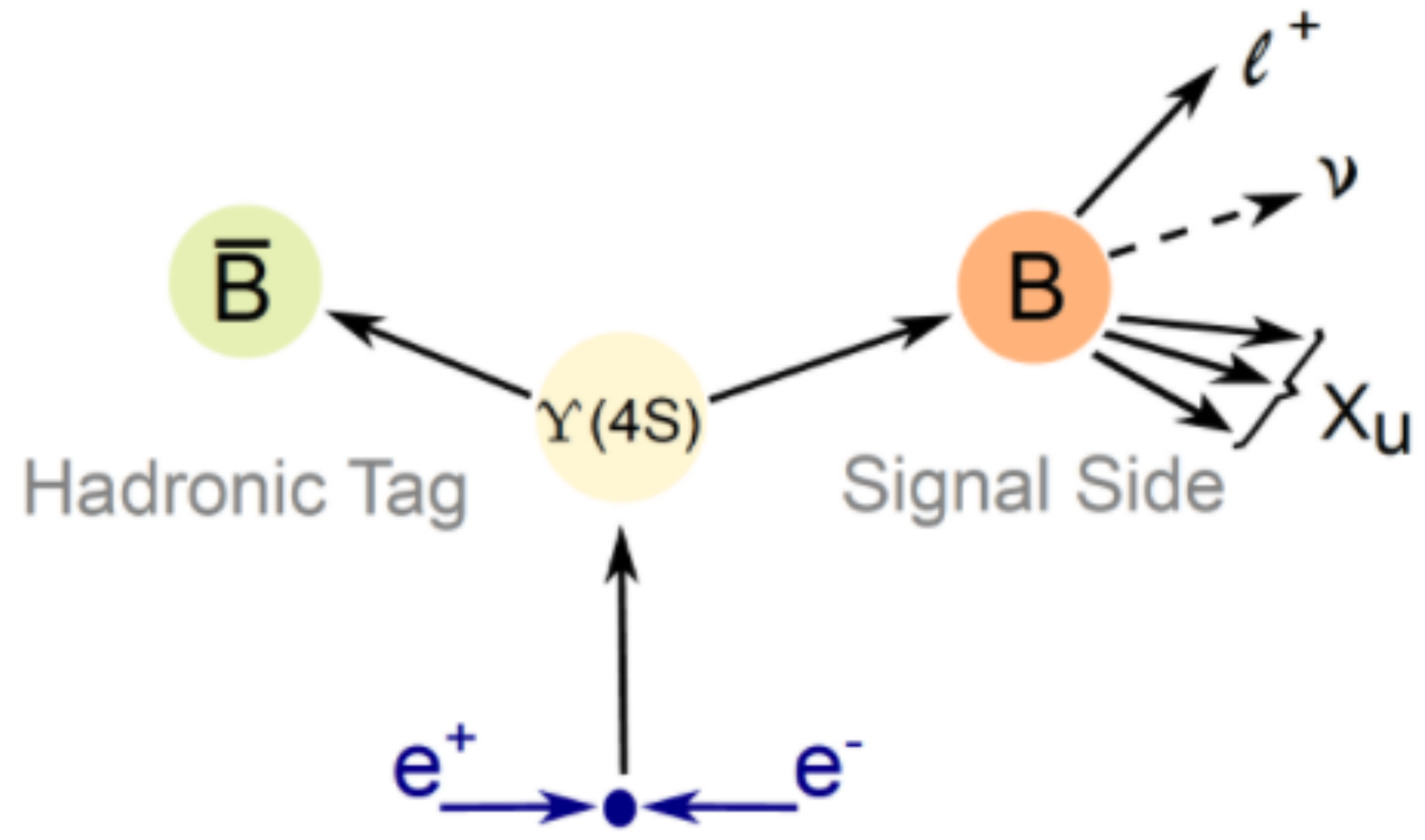


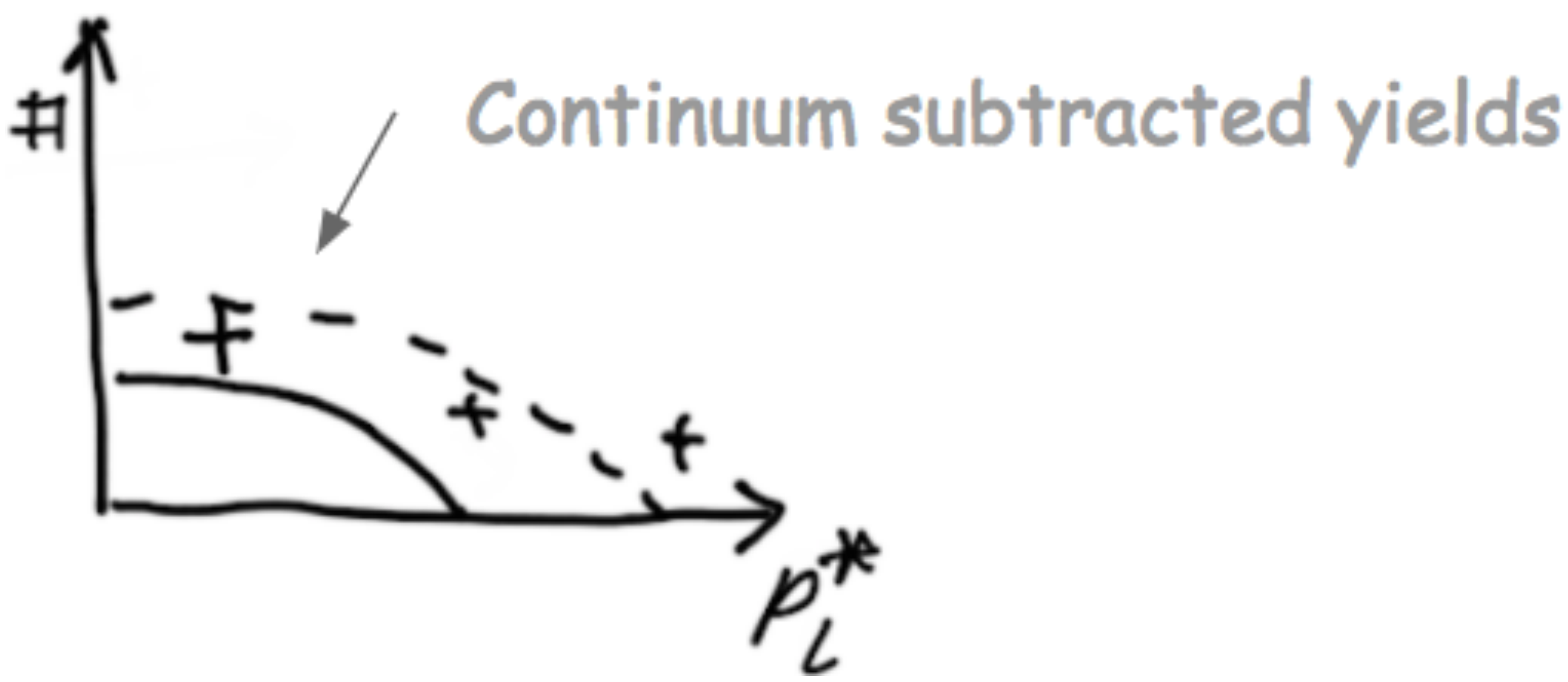


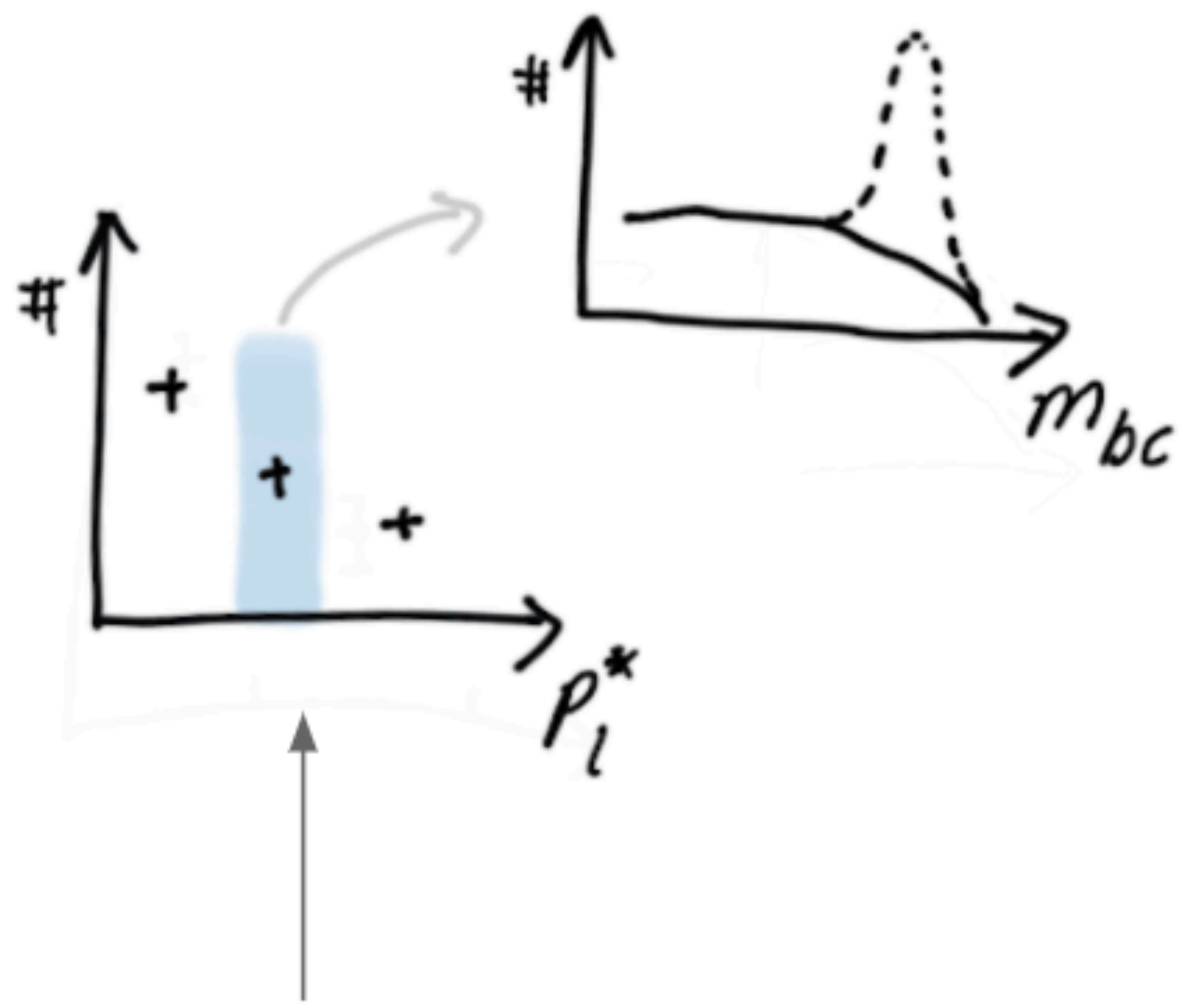
- Parametric unc. (SF, mb) are part of fit, no pert. unc. included
- Without $B \to X_s\gamma$: ~ 10% uncertainties on $|V_{ub}|$
- With $B \to X_s\gamma$: ~ 5% uncertainty, but also shift in $|V_{ub}|$

$B \to X_u\, l\, \nu$ differential Information

- Ongoing measurement with Belle to measure **E_l, $p_\pm$, m_X, q^2**
  - Uses NeuroBayes hadronic tagging
    - Eff. (0.3/0.2% for B^+ and B^0)
  - Pre- and fine-selection finished:
    - 25% Signal efficiency with 2.2% Bkg retention
      - BaBar: 32% / 2.2%
  - Analysis strategy:
    - Normalise against $B \to X\, l\, \nu$
    - Subtract continuum and bad tags via m_{bc} fit



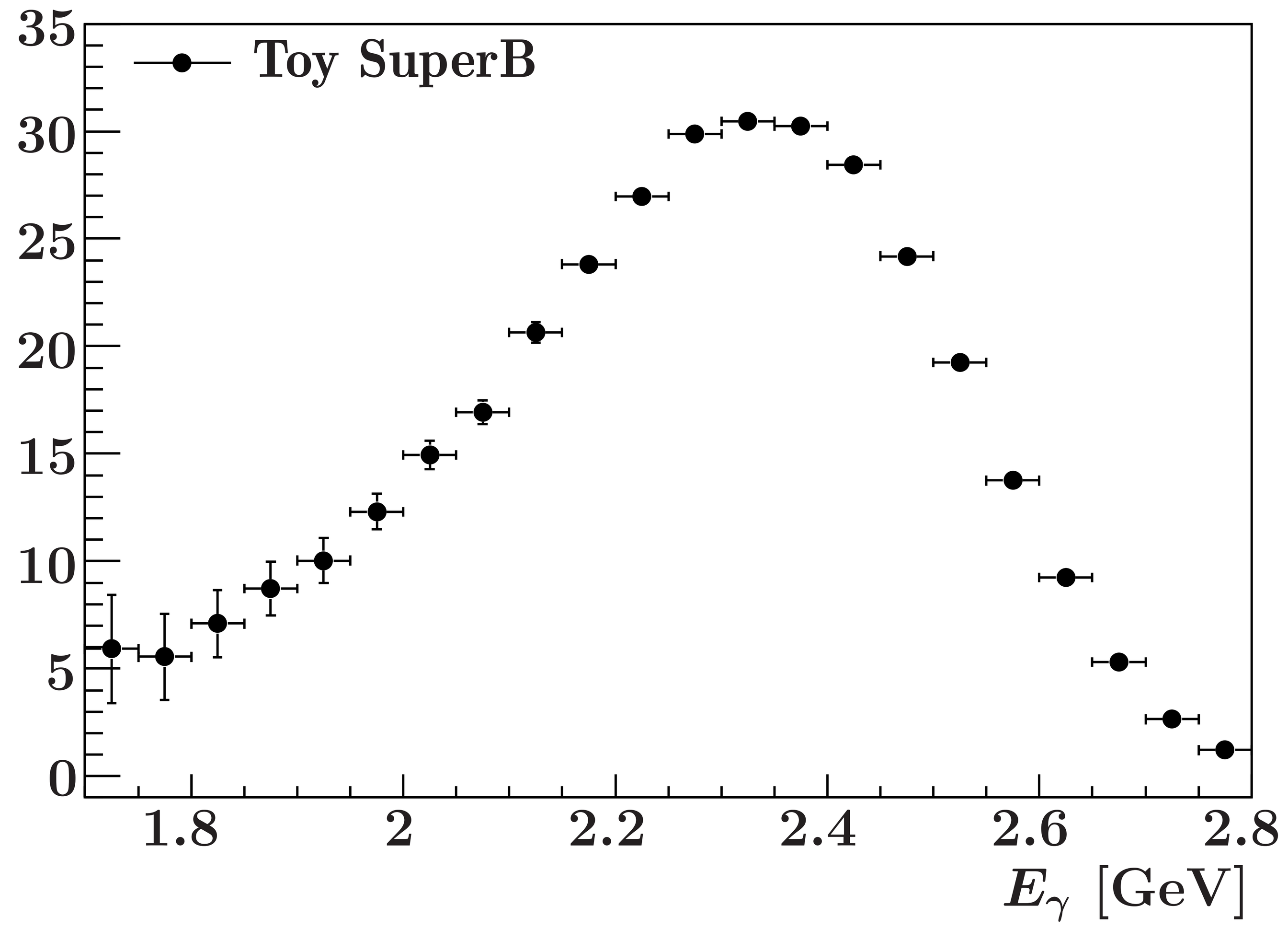


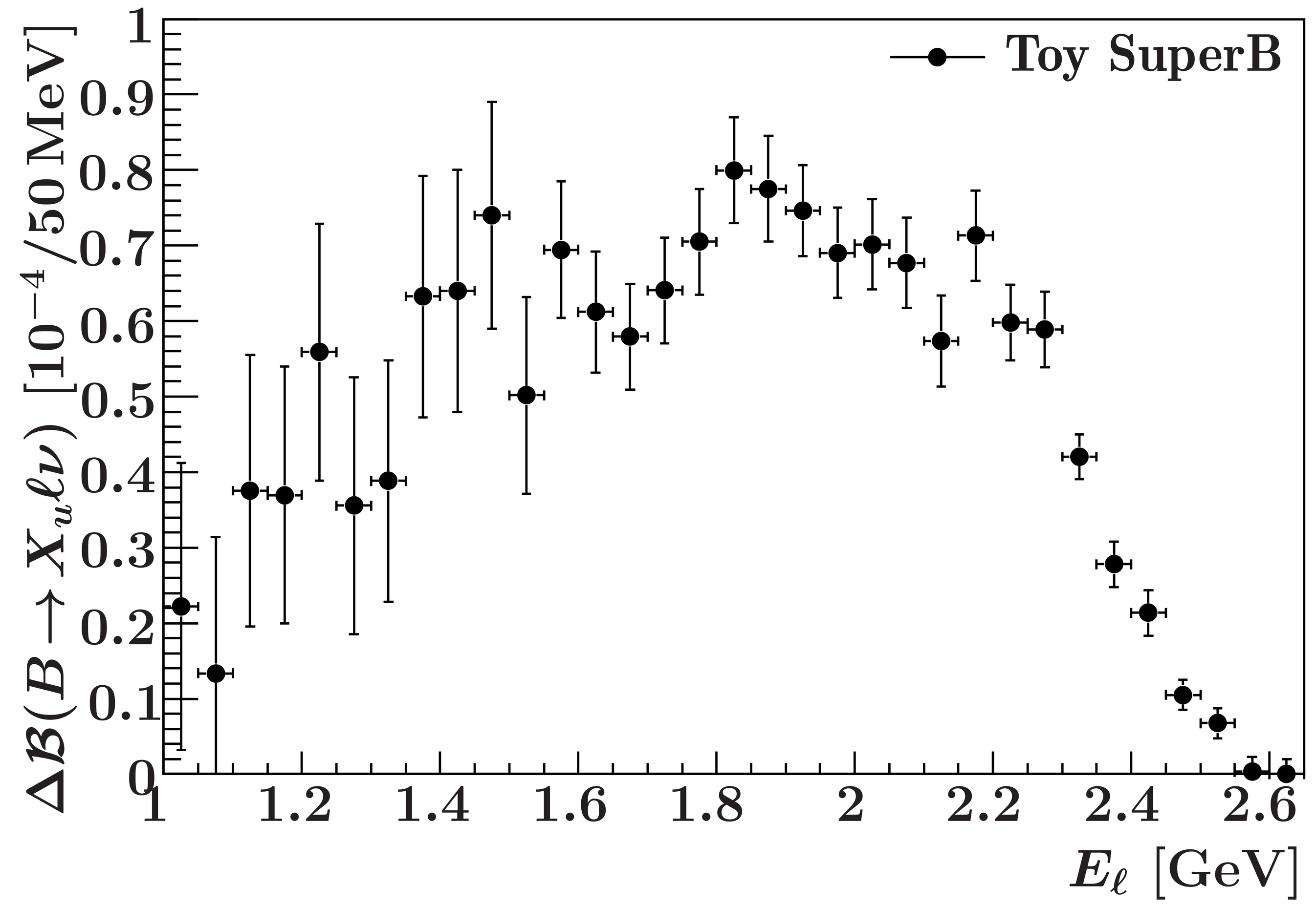


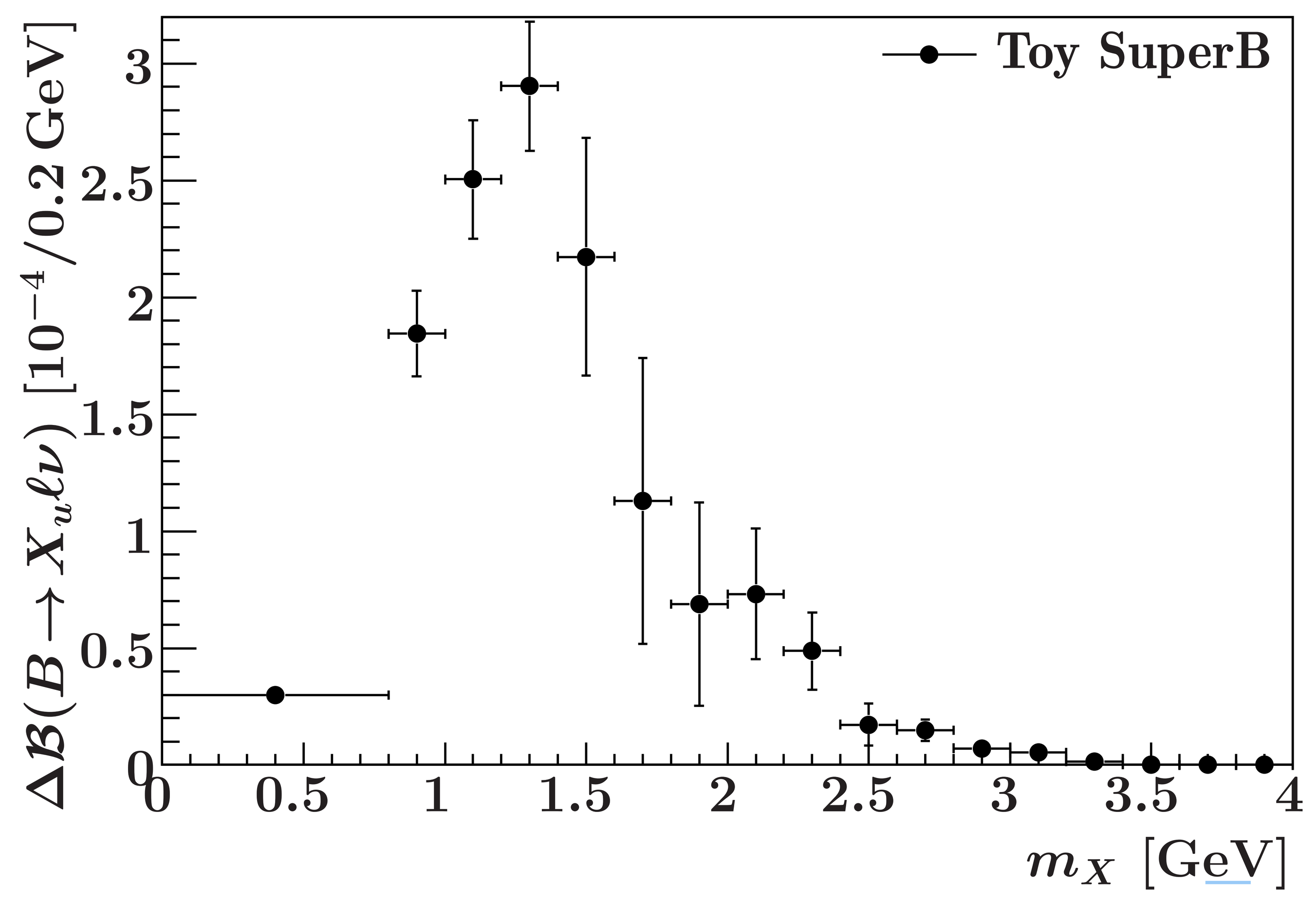
In each bin of an observable we fit m_{bc} to subtract continuum and not properly reconstructed B-meson events

Projections for Belle II

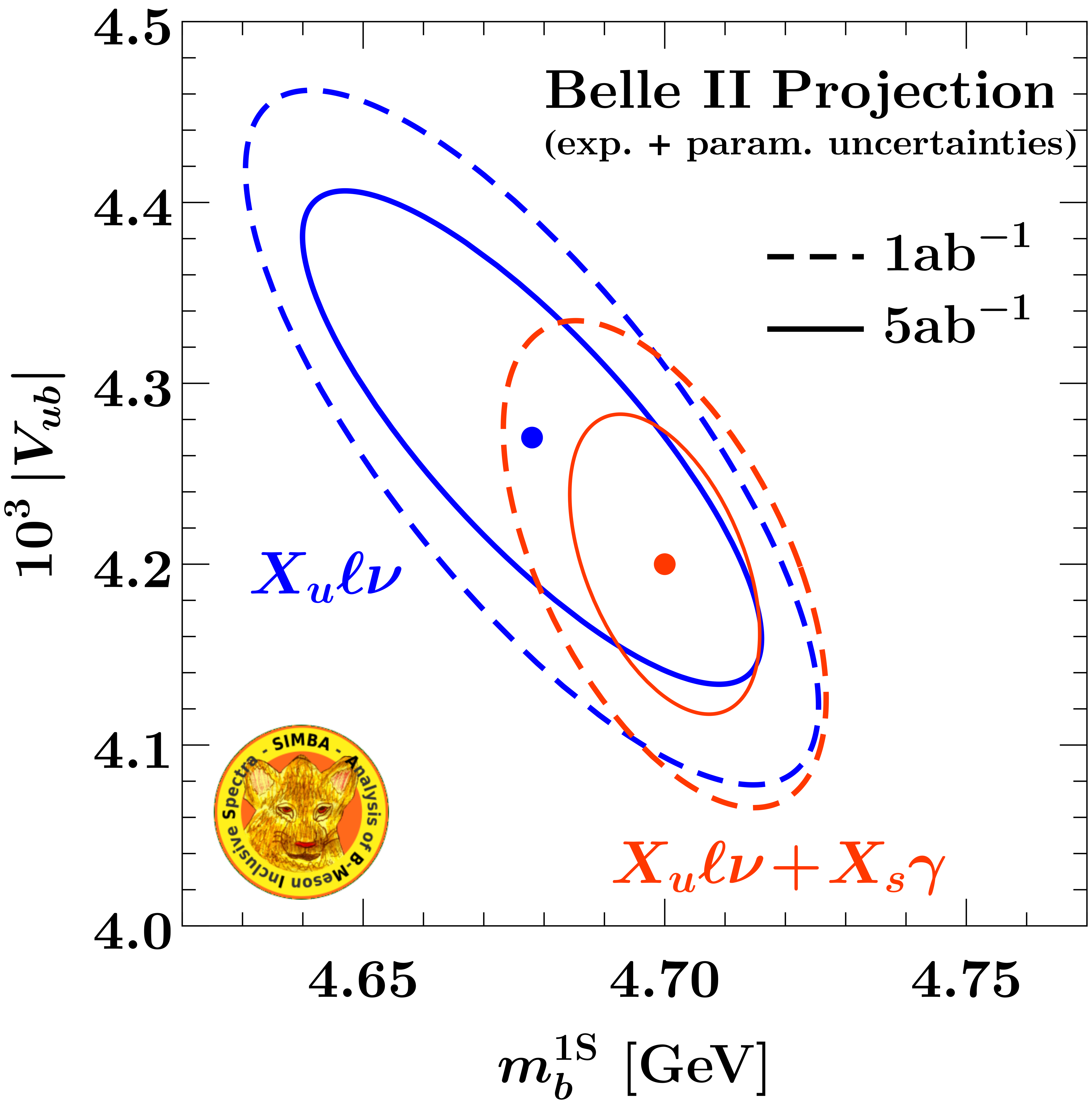
- Theory
  - NLL’ + NLO
  - ignore subleading SFs
- Toy study
  - Generate mX, El, and Eɣ from theory
  - Smeared from uncertainties and correlations inspired by BaBar hadronic tag analysis, Belle II hadronic tagging efficiency is much better by now
  - Target lumi: 1/ab, 5/ab
  - **Caveats:**
    -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



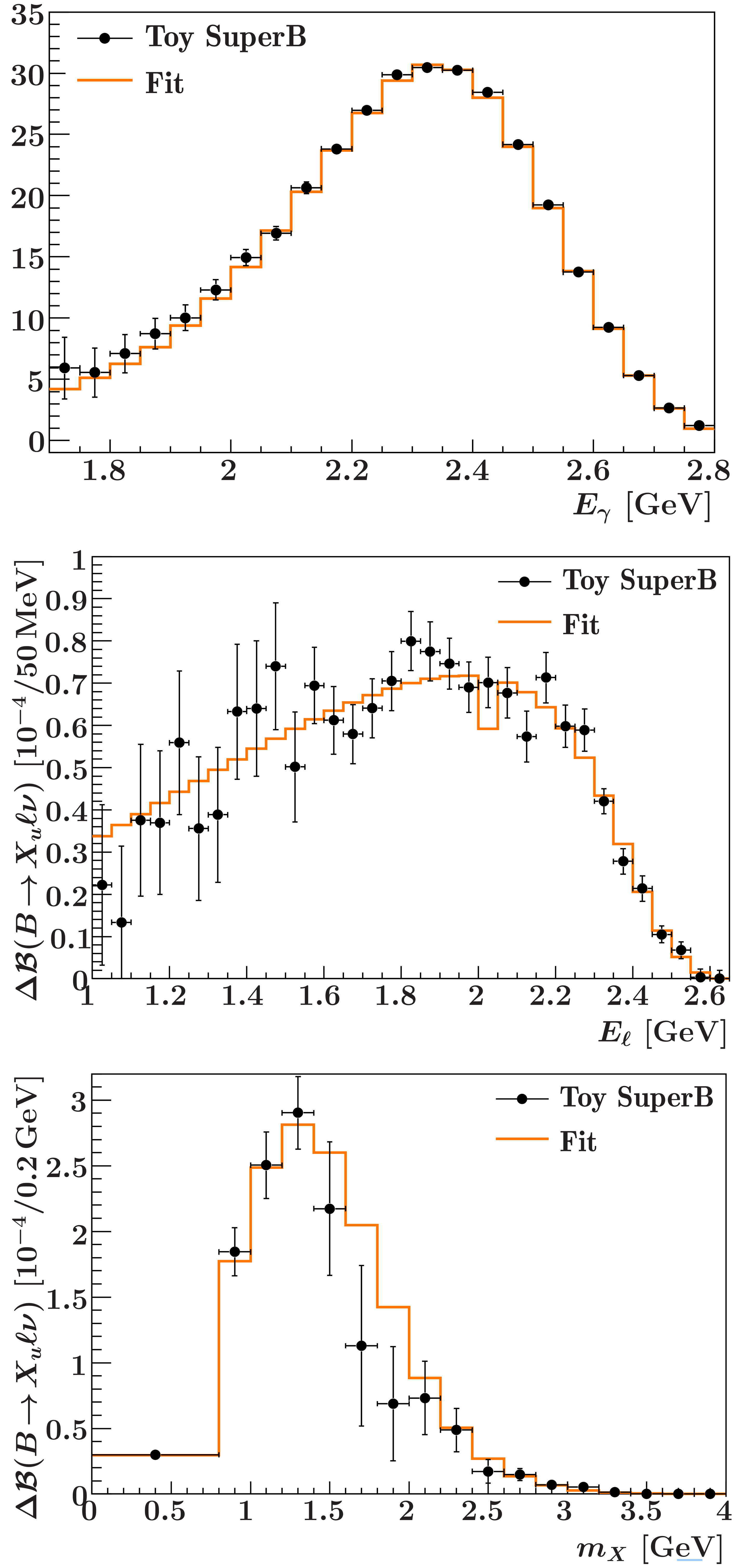




Projections for Belle II

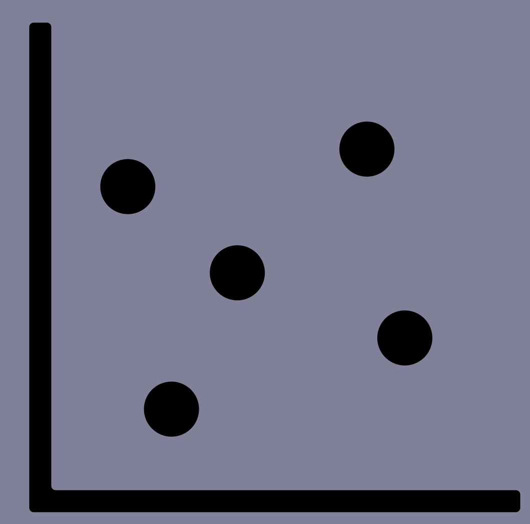


3.5%
2.2%



$B \rightarrow X_s\, l\, l$

C_9 & C_{10}



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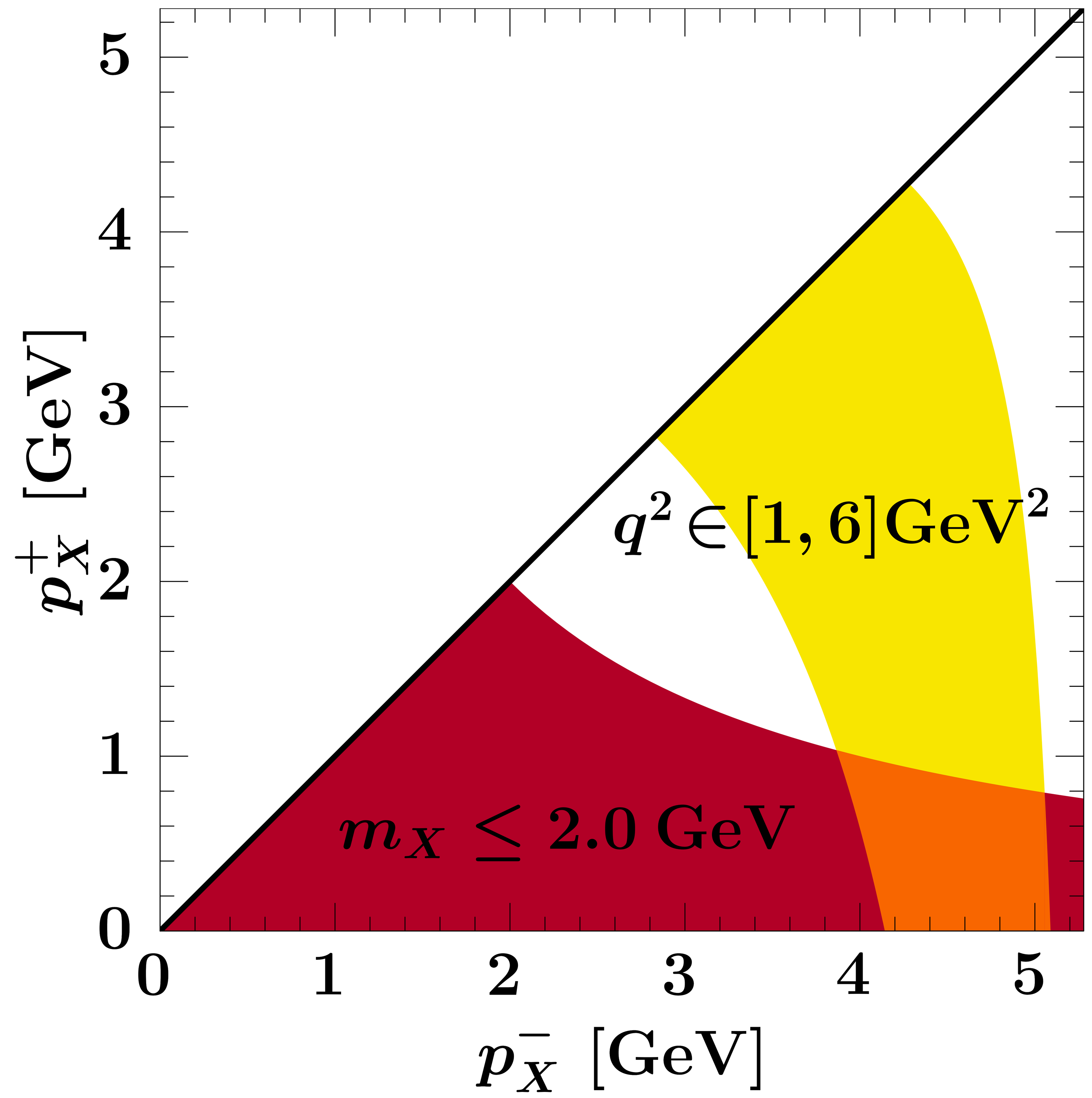
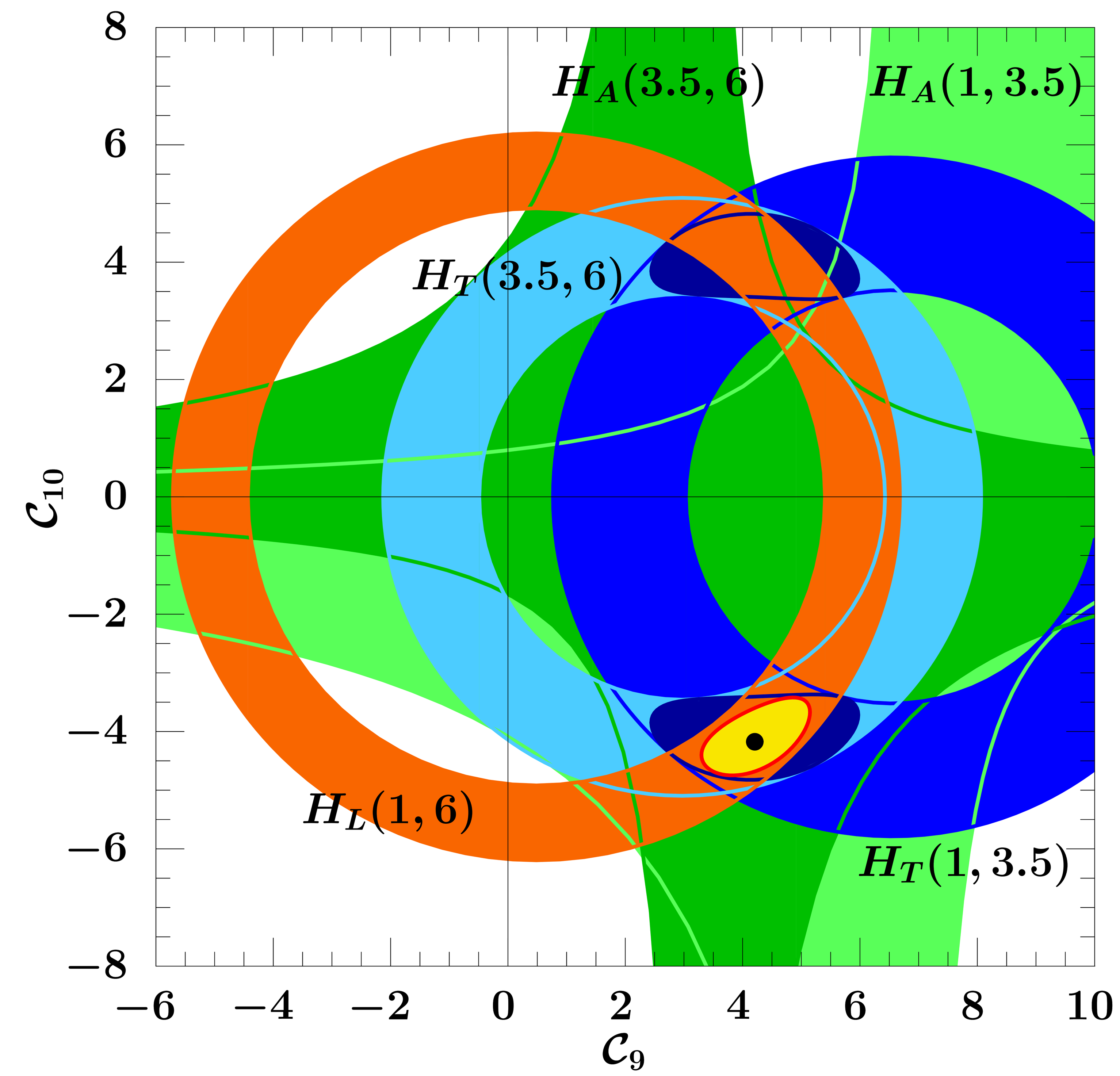
$B \to X_s \, l \, l$

- Experimental kinematic cuts for $B \to X_s \, l \, l$
  - $1 < q^2 < 6$ GeV^2, $m_X < m_X^{cut} \sim 2$ GeV
  - Unavoidable to suppress huge $B \to X_c \, l \, \nu \to X_s \, l \, l \, \nu \, \nu$ background
  - Shape function effects must be taken into account to retain NP sensitivity
- Helicity decomposition for inclusive rate
  - [Lee, Ligeti, Stewart, Tackmann (2008)]

$$\frac{d^3\Gamma}{dp_X^+ dp_X^- dz} = \frac{3}{8}\Big[(1+z^2)H_T(p_X^\pm) + 2zH_A(p_X^\pm) + 2(1-z^2)H_L(p_X^\pm)\Big]$$

$$z = \cos\theta = 2\,\frac{E_\ell - E_{\bar\ell}}{p_X^- - p_X^+}$$: angle between lepton and B in W rest frame





$B \to X_s\, l\, l$

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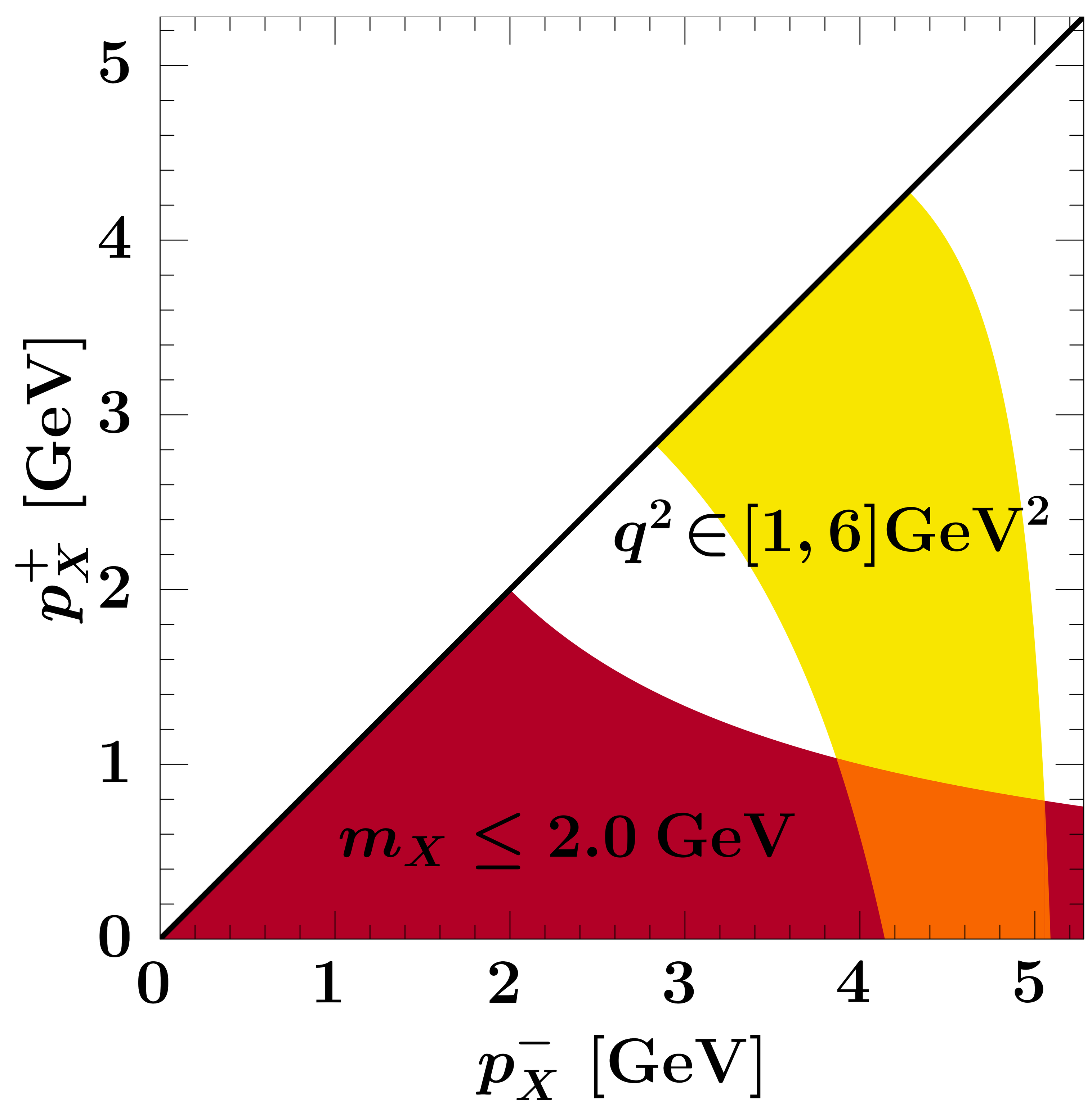
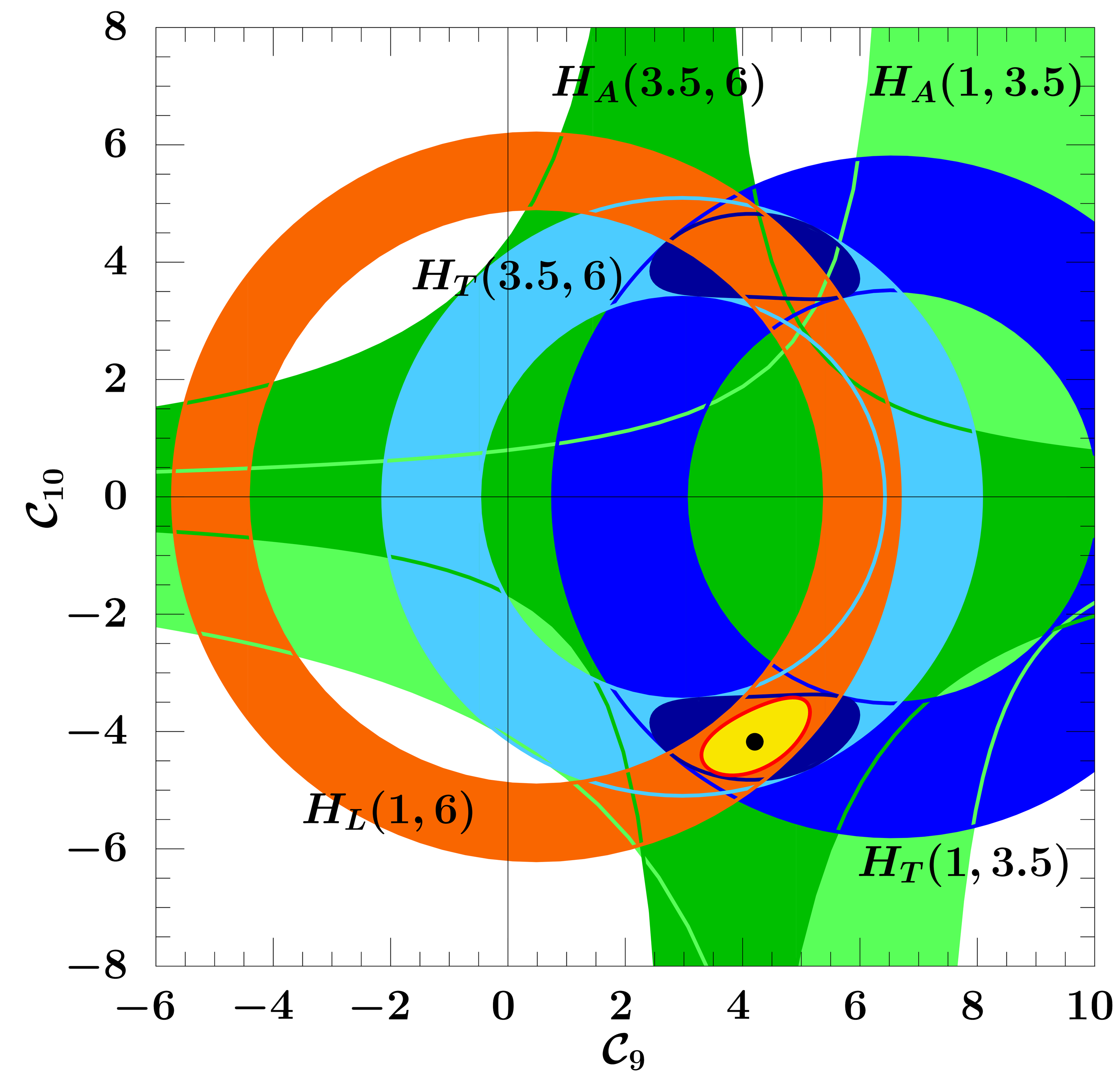


- Helicity decomposition for inclusive rate
  - [Lee, Ligeti, Stewart, Tackmann (2008)]
  - Same basic structure:

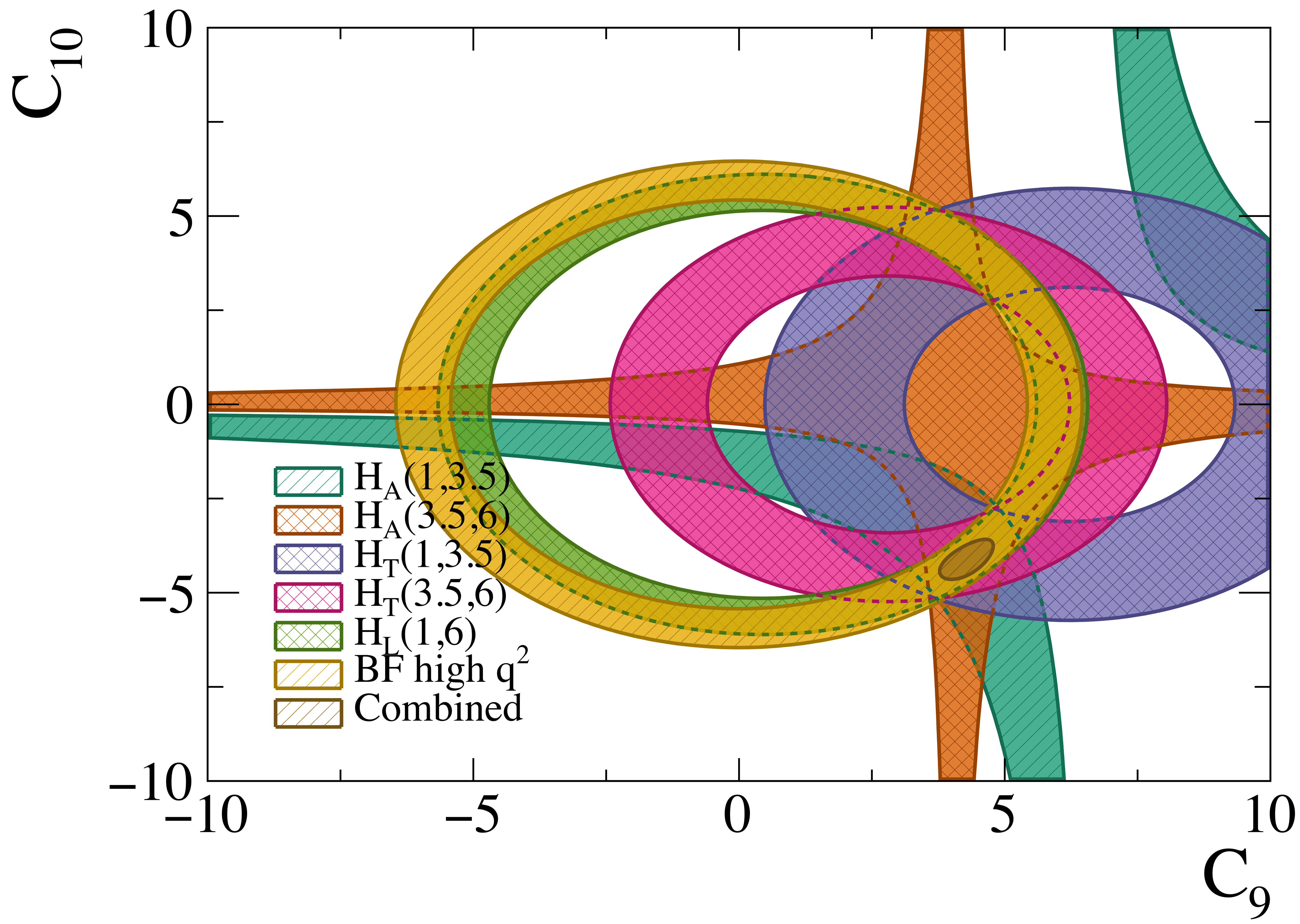
$$\mathrm{d}H_{T,A,L} = \sum_{ij} C_i^{\rm incl} C_j^{\rm incl} \int \mathrm{d}k\, \widehat{W}_{ij}^{A,T,L}(p_X^+, E_\ell, E_{\bar{\ell}}; k)\, \widehat{F}(p_X^+ - k) + \cdots$$

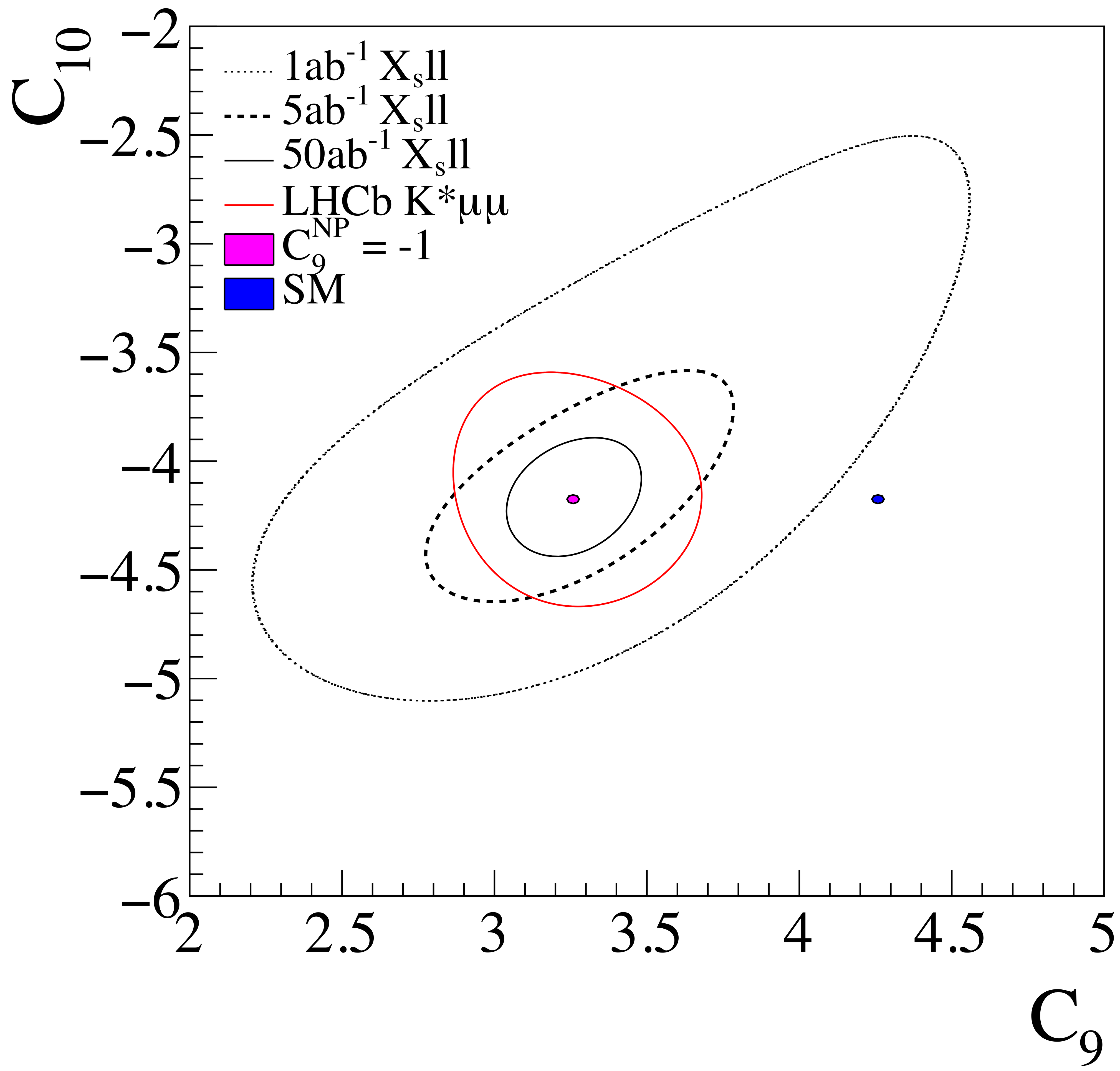
  - Combined fit of $B \to X_s\, l\, l$ *and* $B \to X\, l\, \nu$
    - Best way to get clean extraction of C_9, C_{10} with inclusive decays



$B \to X_s \, l \, l$

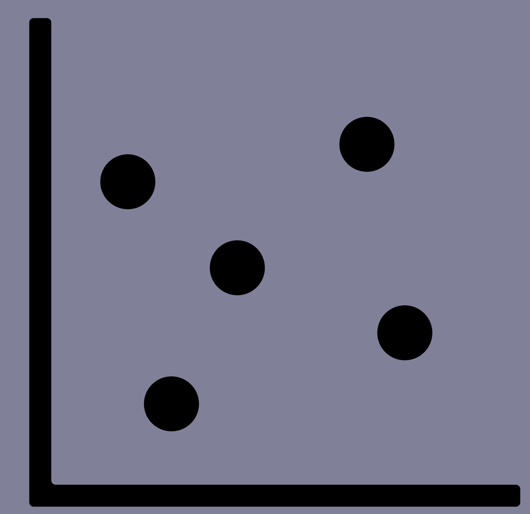
- Belle II sensitivity study from William Sutcliffe
  - Unbinned fit in z for 2 q^2 bins (1-3.5 GeV^2, 3.5 - 6 GeV^2)





$B \to X_c \, l \, \nu$

$|V_{cb}|$ and $R(X)$



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$B \to X_c\, l\, \nu$ & $B \to X\, \tau\, \nu$

- Combined analysis of $B \to X_c\, l\, \nu$ and $B \to X_u\, l\, \nu$
  - Measure very precisely the lepton energy spectrum
  - Allows for fully consistent and correlated treatment of both channels
    - Can constrain leading SF from b → c
  - Combined fit to directly extract $|V_{ub}| / |V_{cb}|$
- $B \to X\, \tau\, \nu$ and $R(X)$
  - Belle II should obviously measure R(X)
    - if R(D*) is due to NP, it must also manifest itself in R(X)
  - Theory for inclusive decay is as clean
  - Combined analysis of $B \to X\, l\, \nu$ and $B \to X\, \tau\, \nu$ to measure $R(X)(q^2)$

Summary

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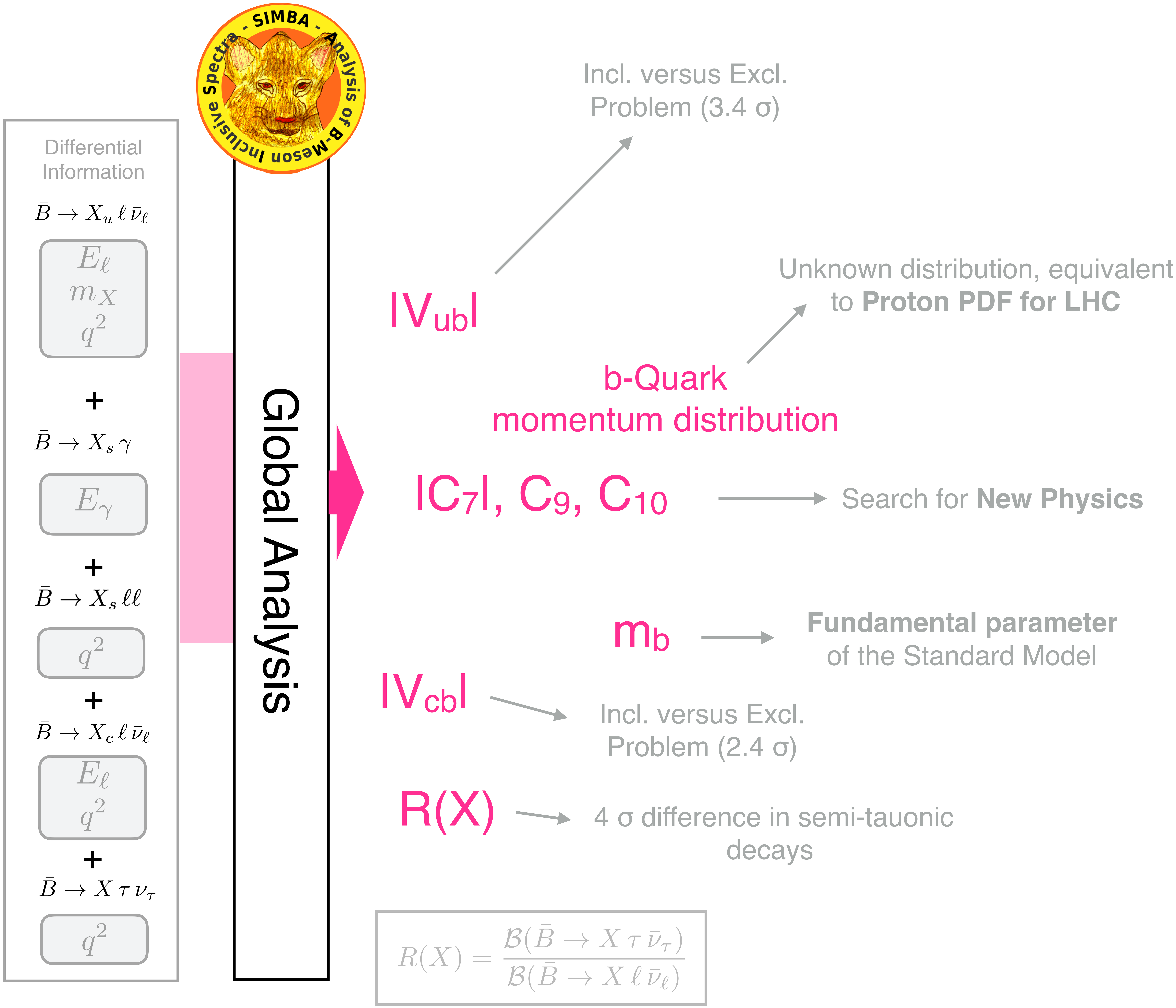
- **Inclusive $|V_{ub}|$** and **$|V_{cb}|$** with current approaches are **theory limited**, but not in a way that more calculations alone will help
- Strategy for Belle II should be to exploit increased data sets **to help** theory by providing maximal amount of information in the form of differential branching fractions measured as model-independent as possible.

- **Global fit** to **inclusive rare and semileptonic data** with model-independent treatment of shape function will be **key** to **reach** the **ultimate** precision for **inclusive $|V_{ub}|$**
- **Global analysis** will be **essential** to fully exploit **NP** sensitivity of **inclusive $B \to X_s \gamma$ and $B \to X_s ll$**



SIMBA - Analysis of B-Meson Inclusive Spectra
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
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
$R(X) = \frac{\mathcal{B}(\bar{B} \to X \, \tau \, \bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to X \, \ell \, \bar{\nu}_\ell)}$