Recent measurements of inclusive $B \to X_u \ell \nu$ decays at Belle

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

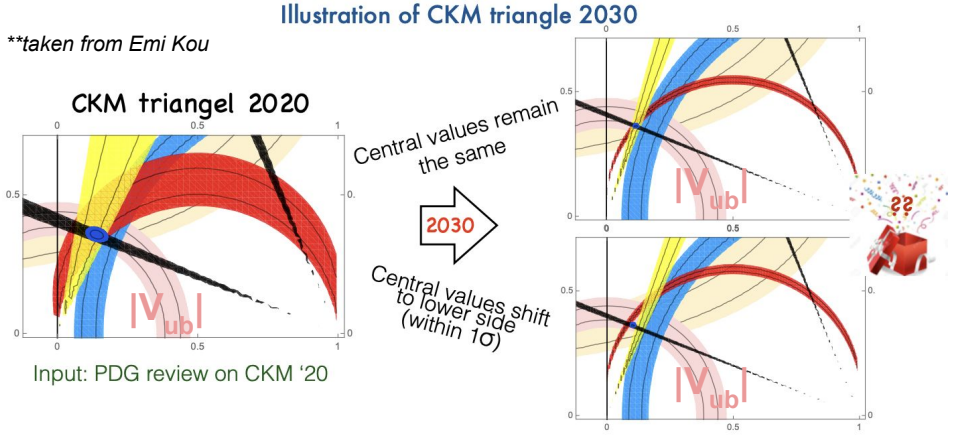
BELLE

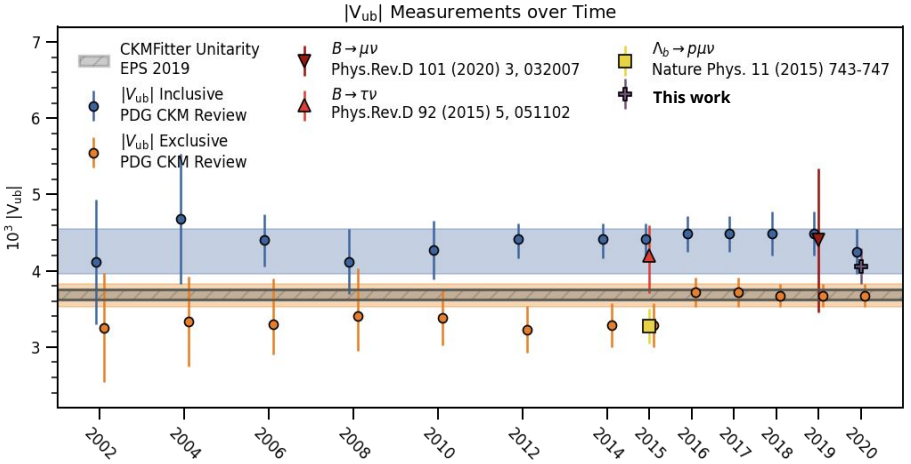
UNIVERSITÄT BONN

DESY.

Introduction

CKM unitarity triangle 2020 ⇨ 2030





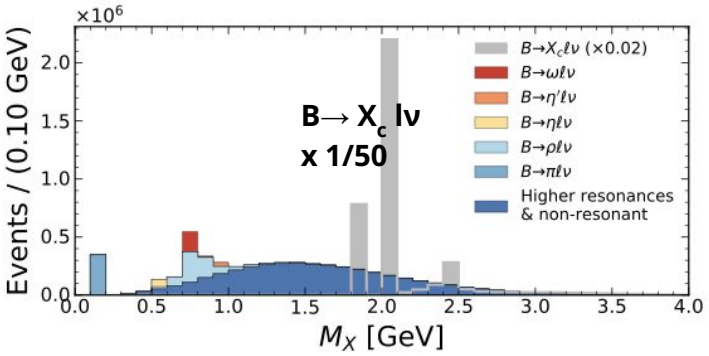
- **$|V_{ub}|$ puzzle:**

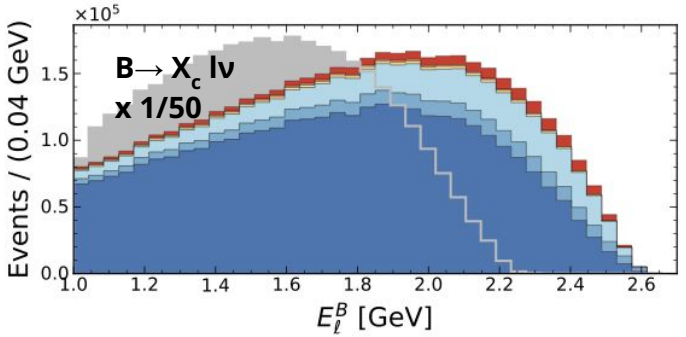
HFLAV

$$|V_{ub}^{\text{excl.}}| = (3.67 \pm 0.09 \pm 0.12) \times 10^{-3},$$
$$|V_{ub}^{\text{incl.}}| = \left(4.32 \pm 0.12^{+0.12}_{-0.13}\right) \times 10^{-3}.$$

3σ

- Measurements challenging due to **B→ X_c lν**





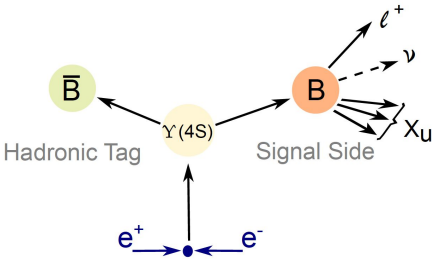
Clear **separation** only **possible** in certain **kinematic regions**, e.g. **lepton endpoint** or **low M_X**

$\Delta\mathcal{B}(B \to X_u \ell^+ \nu)$ and $|V_{ub}^{\text{incl.}}|$

PRD 104 , 012008 (2021), arXiv: 2102.00020

Reconstruction of $B \to X_u \ell \nu$

- Using **full Belle** dataset of **711 fb^{-1}**
- **Hadronic tagging** with Neural Networks (~ 0.2-0.3% efficiency)
- Use **machine learning (BDT)** to suppress backgrounds with 11 trainning features, e.g. MM^2,#K$^{\pm}$, #K$_s$, etc.



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

→ Allows to reconstruct X_u

Reconstructed kinematic variables

- Hadronic system *X*:

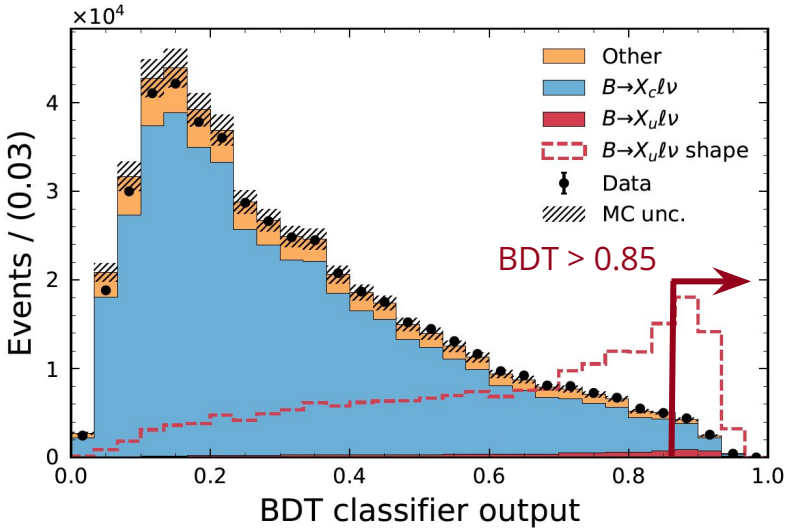
$$p_X = \sum_i (\sqrt{m_\pi^2 + |\mathbf{p_i}|^2}, \mathbf{p_i}) + \sum_i (E_i, \mathbf{k_i})$$

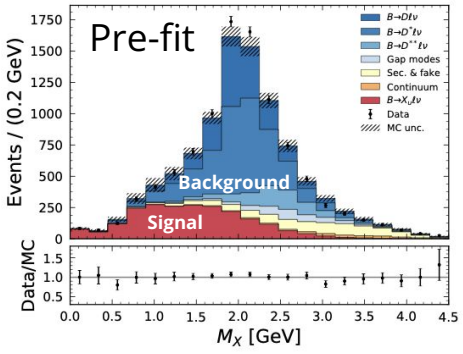
- Missing mass squared:

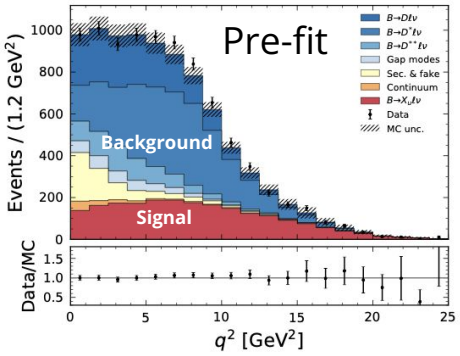
$$MM^2 = \left(P_{\Upsilon(4S)} - P_{\text{tag}} - P_X - P_\ell\right)^2$$

- Leptonic system:

$$q^2 = (P_B - P_X)^2 = (P_l + P_\nu)^2$$







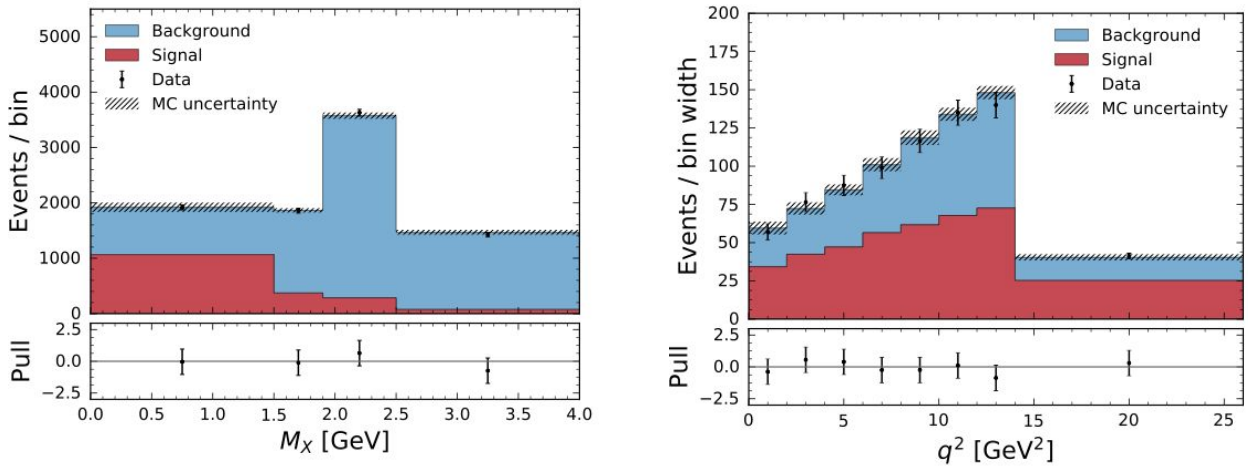
Partial Branching Fractions of $B \to X_u \ell \nu$

- Extract signal using binned likelihood in **3 phase space (PS) regions:**
  - $E_\ell^B > 1$ GeV (covers 86% of available signal PS)
  - $E_\ell^B > 1$ GeV, $M_X < 1.7$ GeV (56%)
  - $E_\ell^B > 1$ GeV, $M_X < 1.7$ GeV, $q^2 > 8$ GeV^2 (31%)

→ Fit either E_ℓ^B , M_X , q^2 or 2D (M_X : q^2)

- Signal yields further corrected for efficiency & acceptance in 3 PS regions
- Split results on e, μ, B^0, B^+ modes are provided for $E_\ell^B > 1$ GeV region

Projection of 2D fit result on M_X and q^2(in 1st M_X bin)

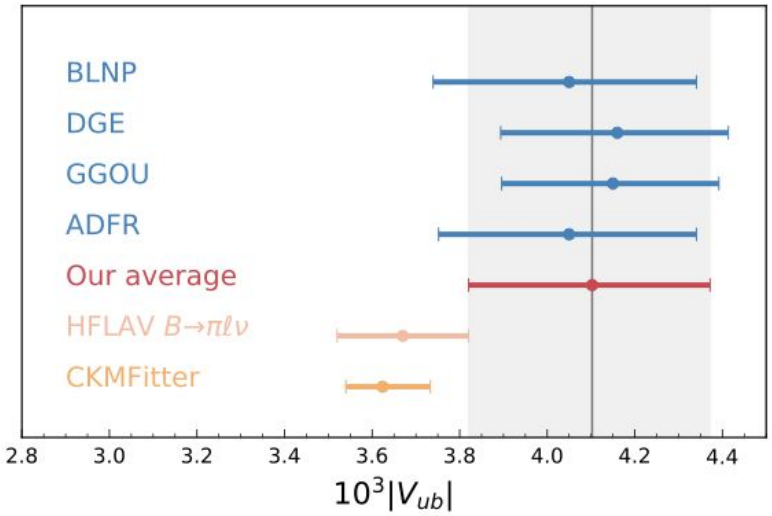


$\Delta\mathcal{B}(E_\ell^B > 1 \text{ GeV}) = (1.59 \pm 0.07_{stat} \pm 0.16_{sys}) \times 10^{-3}$ based on 2D fit

Inclusive $|V_{ub}|$

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(B \to X_u \ell^+ \nu_\ell)}{\tau_B \cdot \Delta\Gamma(B \to X_u \ell^+ \nu_\ell)}}$$

- Convert partial BF in $E_\ell^B > 1$ GeV of 2D fit result to $|V_{ub}|$
- Based on **four** calculations of the **decay rate**

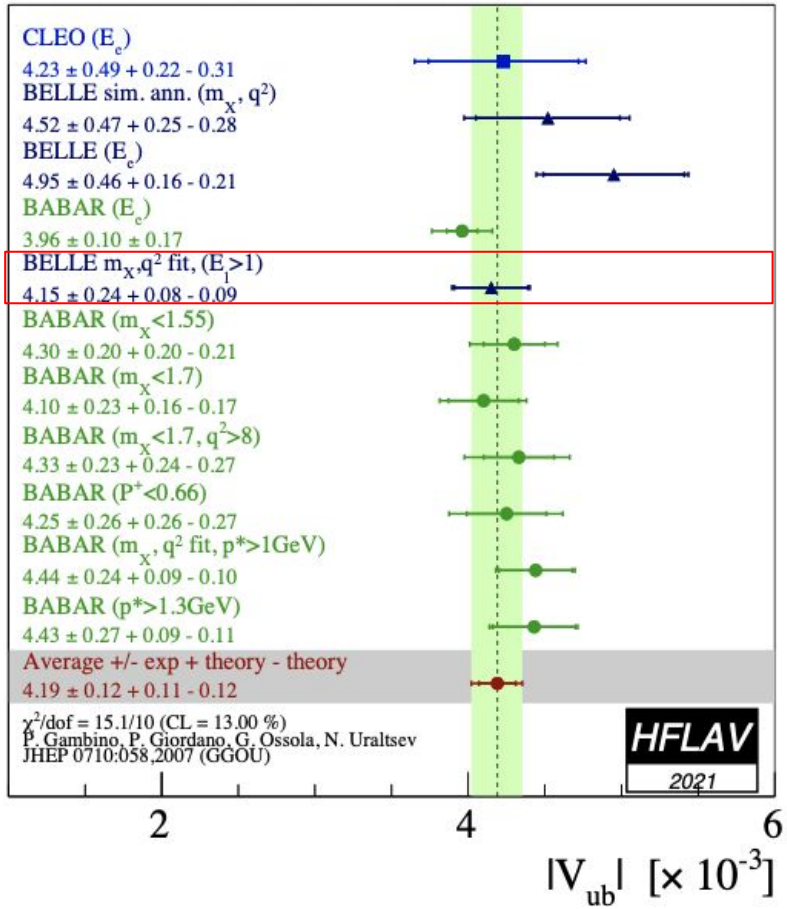


Our average:

$|V_{ub}| = (4.10 \pm 0.09_{stat} \pm 0.22_{sys} \pm 0.15_{theo}) \times 10^{-3}$

compatible with excl. and CKM expectation within **1.3σ** and **1.6σ** respectively

Comparions based on GGOU



Differential $\Delta\mathcal{B}(B \to X_u \ell^+ \nu)$

arXiv:2107.13855, accepted by PRL

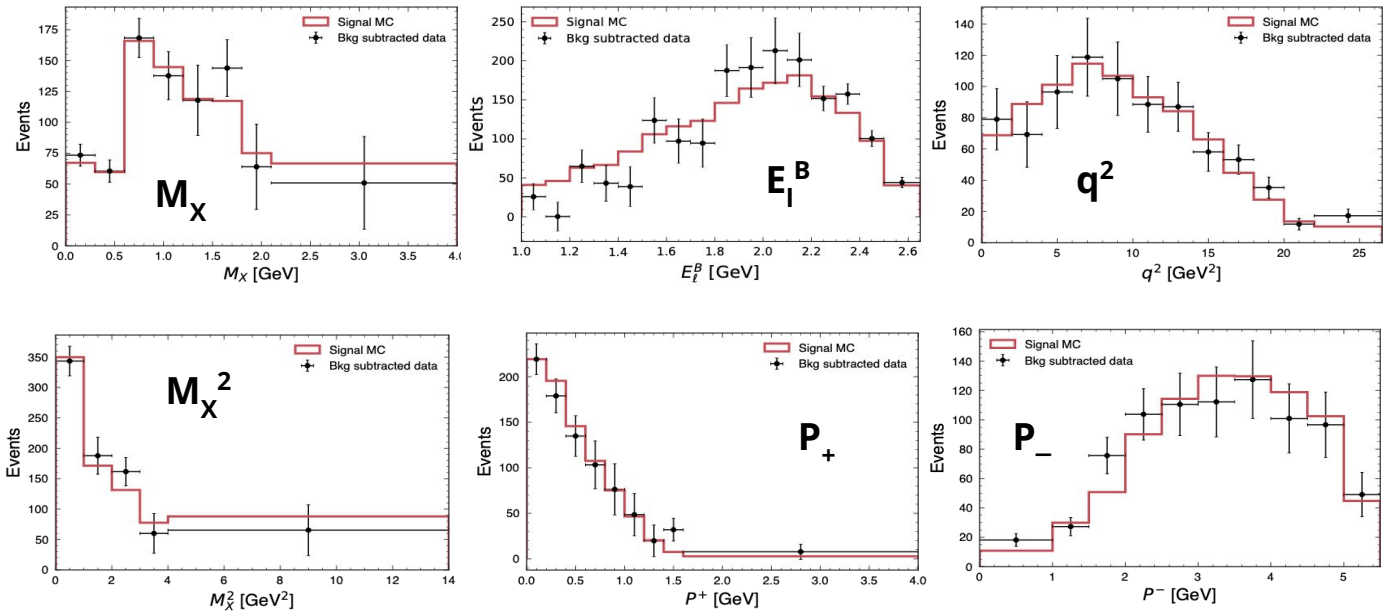
Differential BF of $B \to X_u \ell^+ \nu$

Background-subtracted spectra

- We measure the following 6 kinematic variables in the phase space of $E_l^B > 1$ GeV:

$$q^2, \quad E_l^B, \quad M_X, \quad M_X^2, \quad P_+, \quad P_- \quad \text{(light-cone momenta: } P_\pm = E_X \mp |p_X| \text{)}$$

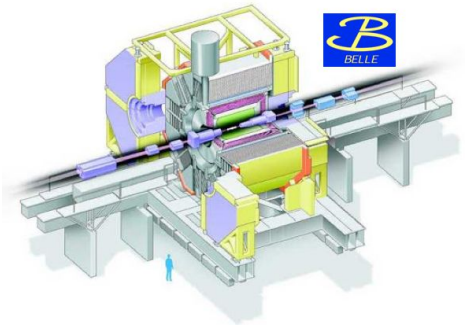
- Selection and reconstruction inherited from the partial BR measurement presented previously
- Additional selections on $|E_{miss} - P_{miss}| < 0.1$ **GeV** and reconstructed $M_X < 2.4$ **GeV** to improve resolution and reduce background shape uncertainty
- Background subtraction done via M_X **fit;** subtracted spectra are shown as below

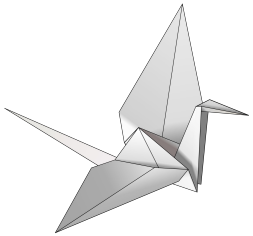


- **Full bkg-sub. uncertainties** are propagated

- **Overlaid MC** signal hybrid X_u (& normalised to fitted signal yields)

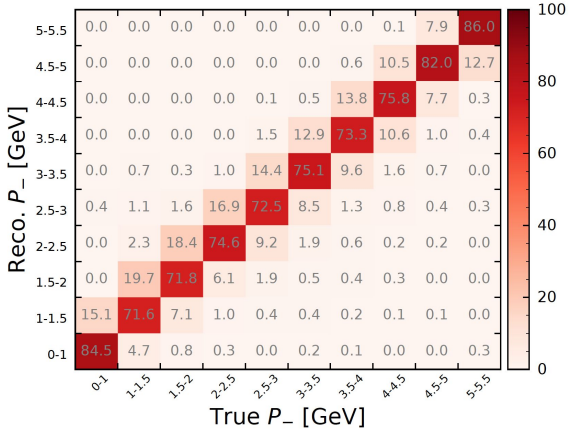
Unfolding





***X*: true distribution** | ***M*: detector response** | ***Y*: measured distribution**

- The detector response is represented by a migration matrix ***M***
- *M*(*i*, *j*) indicates the probability (%) to observe an event in bin *i* if it had a generator-level value in bin *j*



$$MX = Y$$

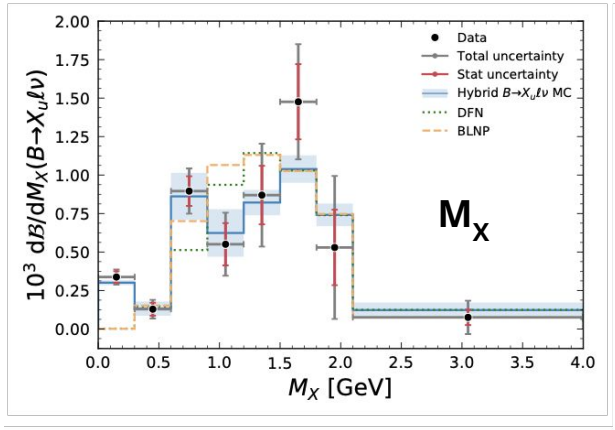
Direct solution for X is

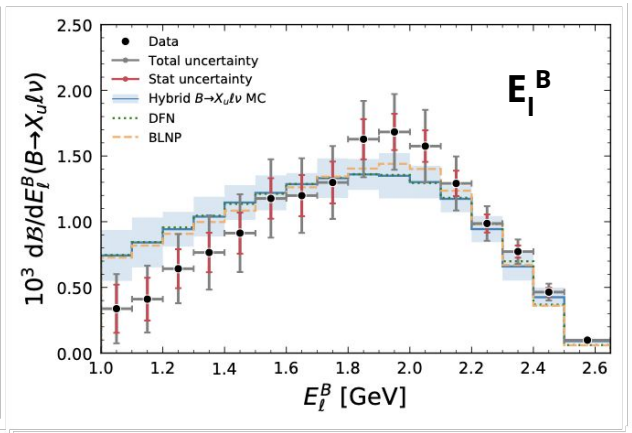
$$X = M^{-1}Y$$

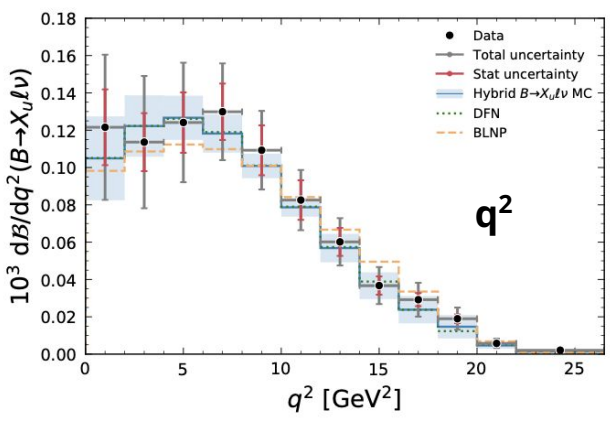
- **Singular-Value-Decomposition (SVD)** [NIMA 372:469(1996)] is used in this analysis

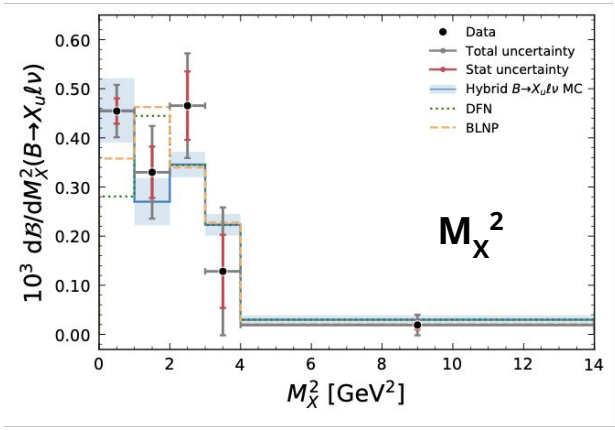
Differential Spectra of $B \to X_u \ell^+ \nu$

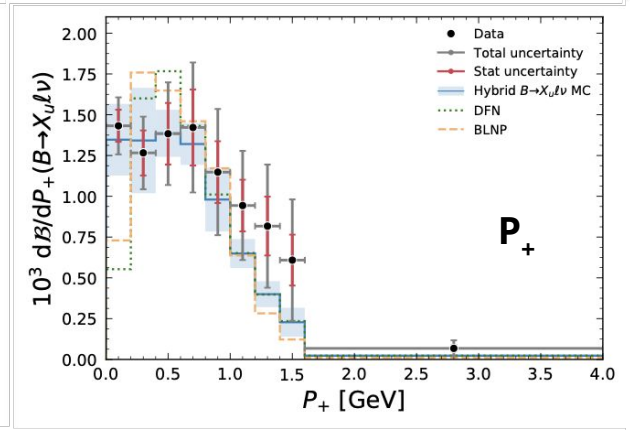
- Convert unfolded yield to $\Delta\mathcal{B}$ in each bin considering reco. efficiency & acceptance
- Differential braching fractions ($E_l^B > 1$ GeV) are measured **for the first time**
- Necessary input for future **model-independent** determinations of $|V_{ub}|$ (e.g. NNVub, SIMBA)

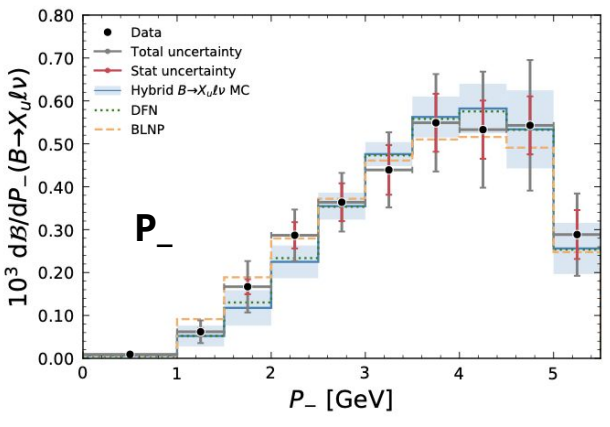








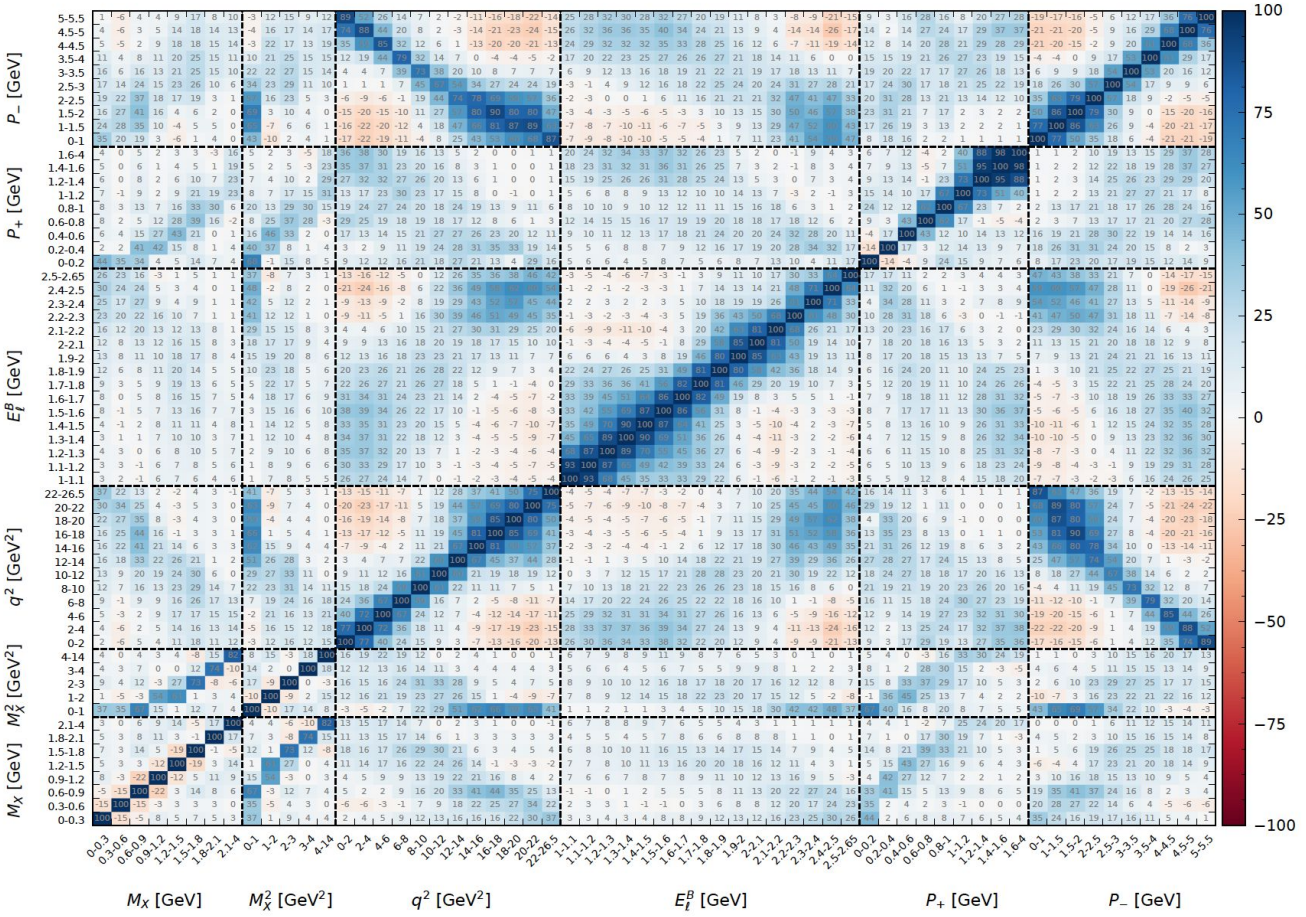


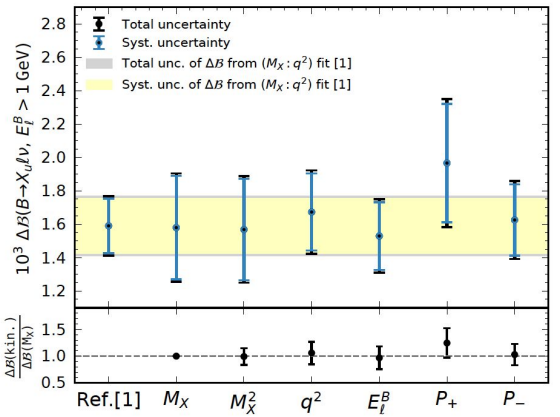


All MC shapes are normalised to 1.59 x 10^{-3} [Belle, PRD 104 , 012008 (2021)]

Correlations of All Measured $\Delta\mathcal{B}$

- Full experimental correlations of differential $\Delta\mathcal{B}$ are extracted (important for global fit)
- Summed $\Delta\mathcal{B}$ agree well with $(1.59 \pm 0.07 \pm 0.16)\times10^{-3}$ from $(M_X{:}q^2)$ fit result of [1]



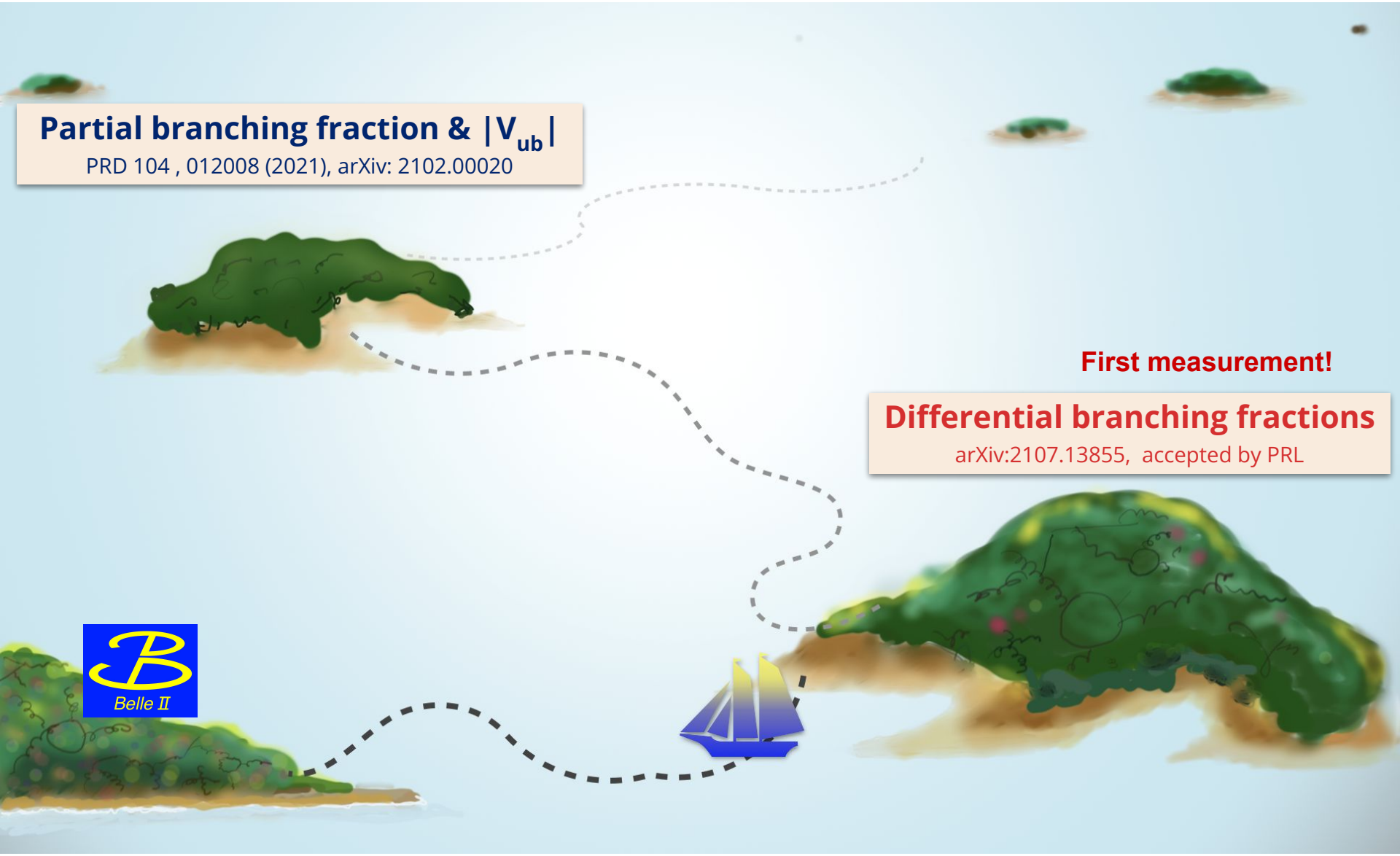


[1] Belle, PRD 104 , 012008 (2021)

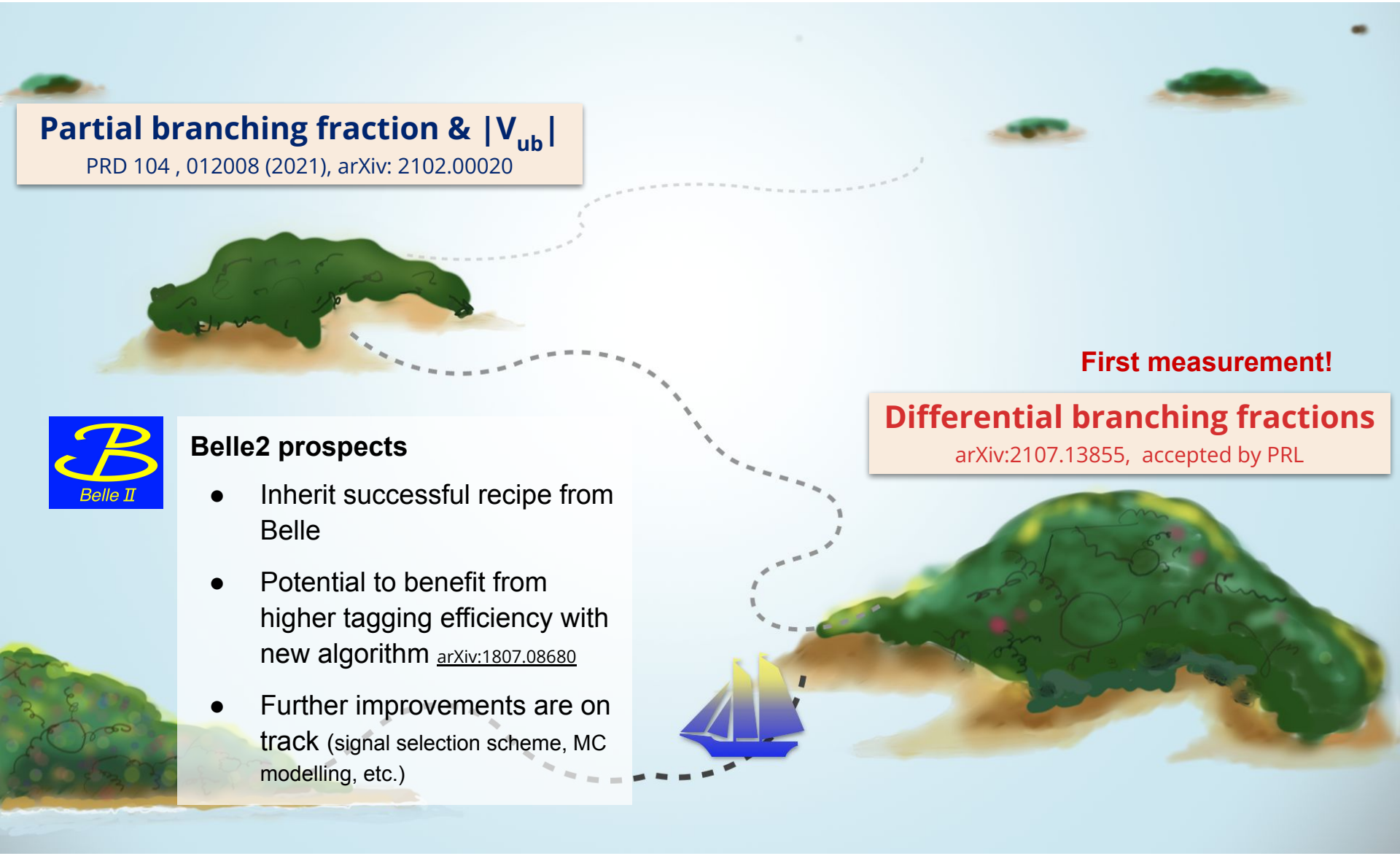
Numerical results will be available in HEPData for future global fit and also allow forward-folding.

HEPData
Repository for publication-related High-Energy Physics data

Adventure of Inclusive $B \to X_u \ell \nu$



Adventure of Inclusive $B \to X_u \ell \nu$



Partial branching fraction & $|V_{ub}|$

PRD 104 , 012008 (2021), arXiv: 2102.00020

First measurement!

Differential branching fractions

arXiv:2107.13855, accepted by PRL

Belle2 prospects

- Inherit successful recipe from Belle
- Potential to benefit from higher tagging efficiency with new algorithm arXiv:1807.08680
- Further improvements are on track (signal selection scheme, MC modelling, etc.)

Thank You

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