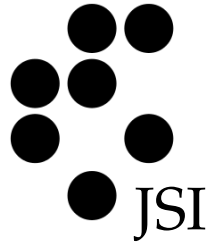


Determination of $|V_{ub}|$ at Belle II

Matic Lubej*

Moriond EW 2017, La Thuile, Italy

Friday, March 24th, 2017

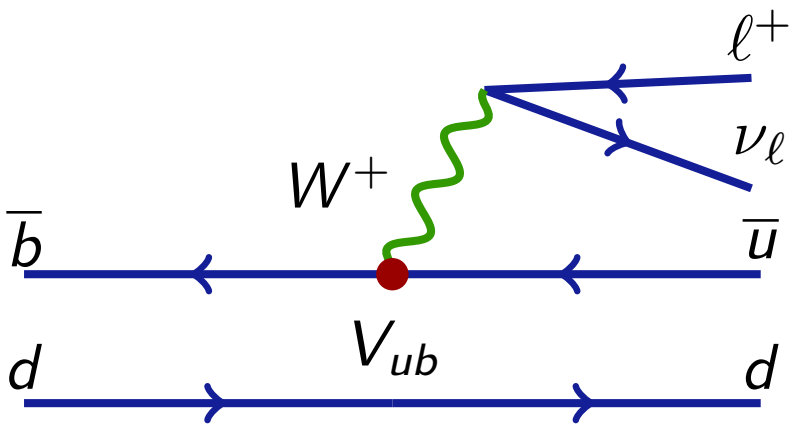
*On behalf of the Belle II collaboration

Exclusive $|V_{ub}|$

- Least precise CKM matrix element
- Current precision $\sim 4\ \%$ [HFAG, Summer 2016]
- Determined in charmless semileptonic decays
- $B \to \pi \ell \nu$ with $\ell = e,\ \mu$ most precise for $|V_{ub}|$

Pseudoscalar* differential $\mathcal{B}$

$$\frac{d\mathcal{B}(B \to \pi \ell \nu)}{dq^2} = |V_{ub}|^2 \frac{G_F^2 \tau_B}{24\pi^3} p_\pi^3 |f_+^{B\pi}(q^2)|^2$$



Experimental measurement of the branching fraction and theoretical input on form factors needed to determine $|V_{ub}|$.

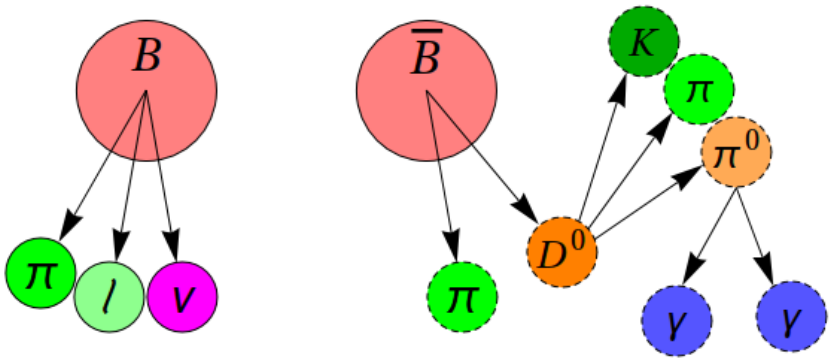
* Simplified for low mass charged leptons (e and μ)

Measurements at B factories

- Initial state well known: $e^+e^- \to \Upsilon(4S)$ (at rest)
- Neutrino escapes detection: $p_{miss} = p_{\Upsilon(4S)} - p_{B_{rec}} - p_{B_{comp}}$
- If neutrino is the only missing particle: $p_\nu = p_{miss}$

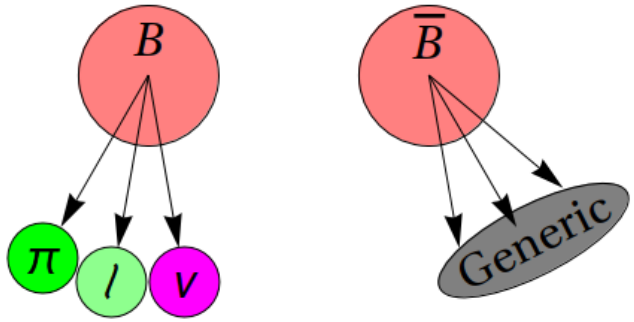
Reconstruction methods

Tagged measurement



Many hadronic modes

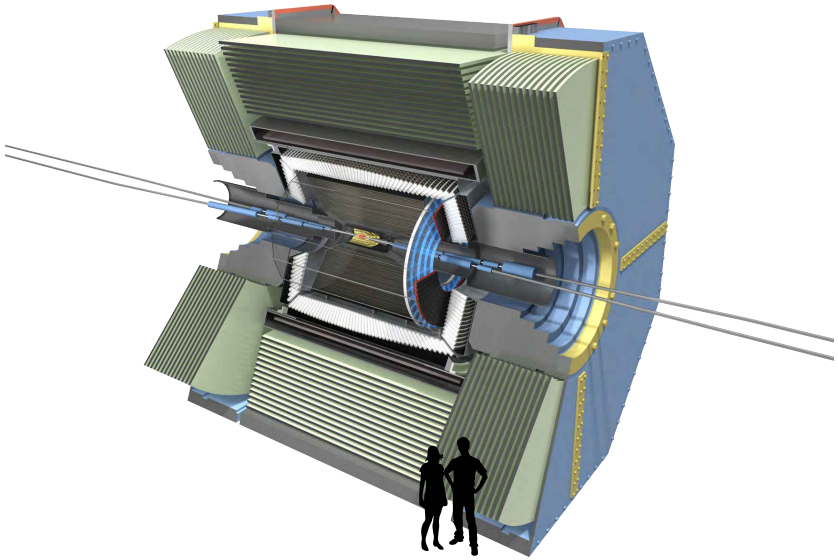
Untagged measurement

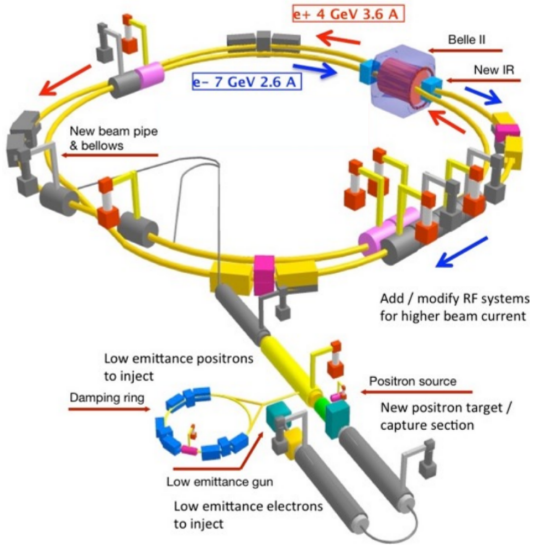


Remaining tracks and clusters

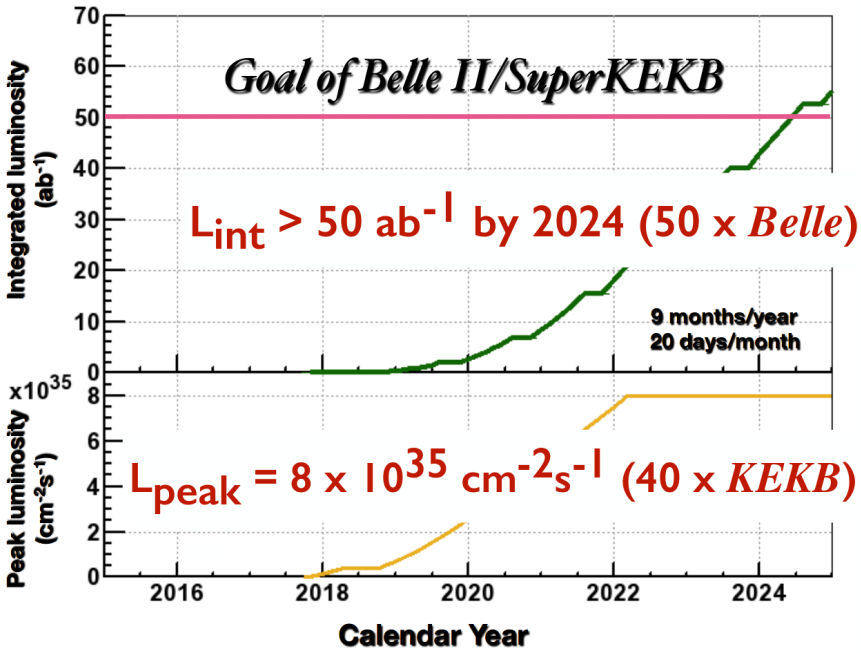
Tagged $\to$ Efficiency $\to$ Untagged
Tagged $\leftarrow$ q^2 res. $\leftarrow$ Untagged

Belle II detector and SuperKEKB upgrade

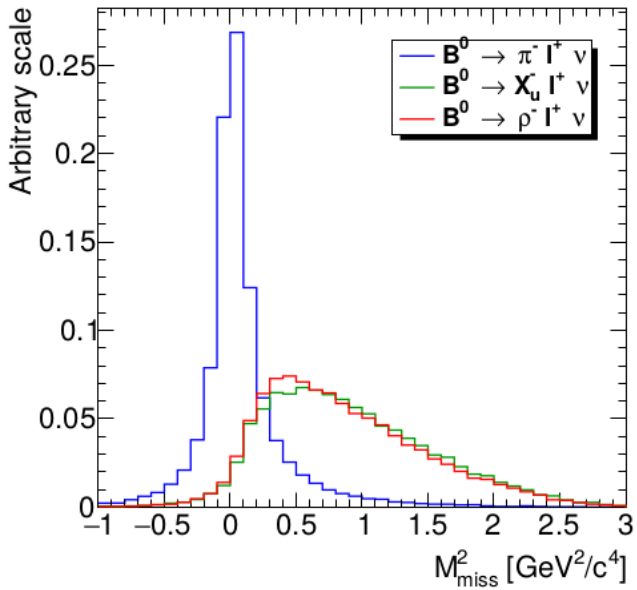


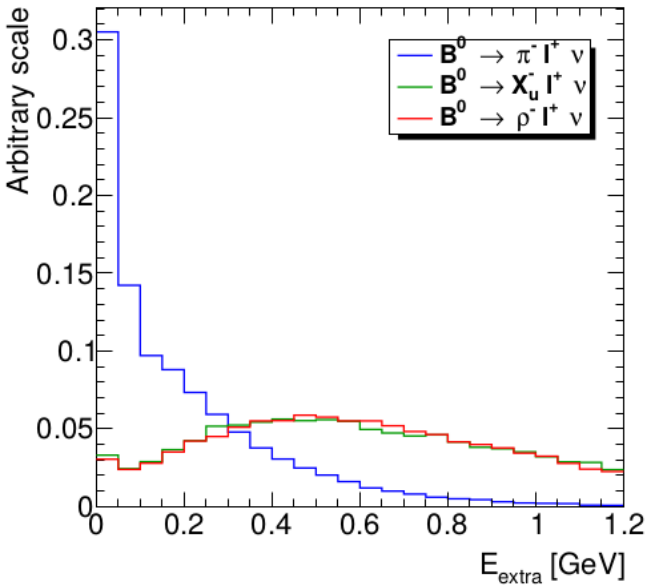


- Improved detector efficiency, tracking, PID, . . .
- Improved reconstruction neutral particles
- Smarter software, more precise algorithms

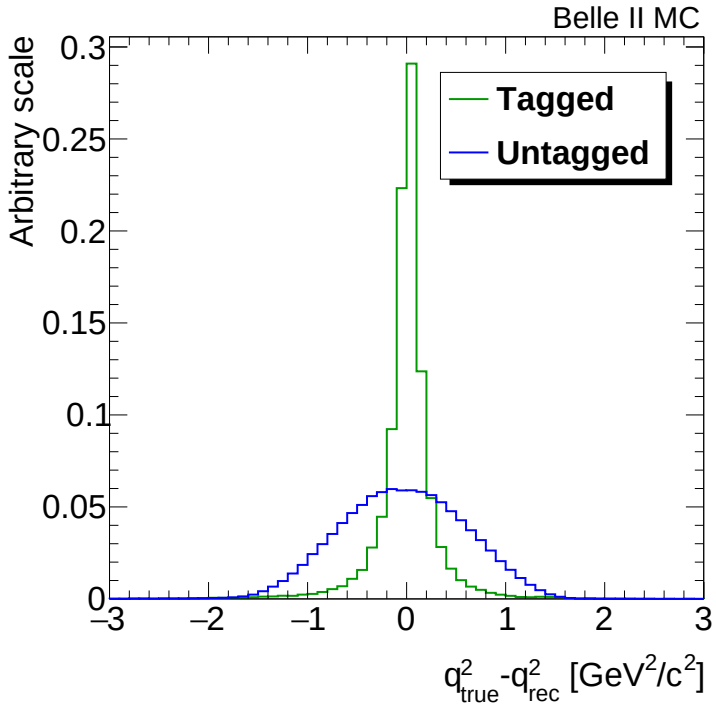


$B \to \pi \ell \nu$ tagged at Belle II (MC study)





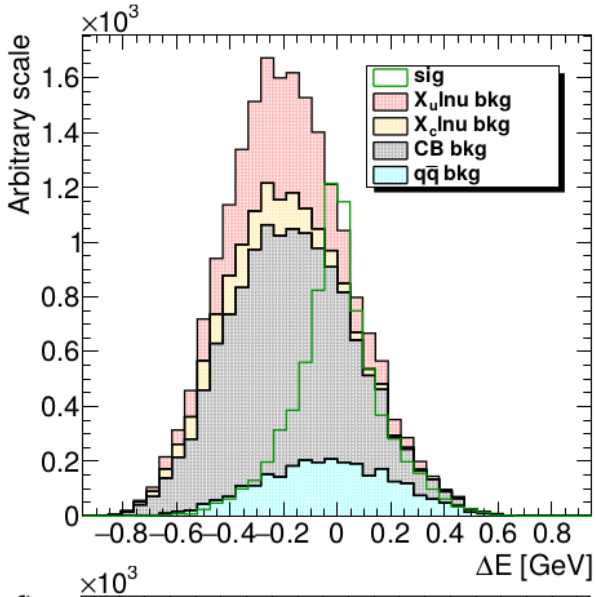
[B2TiP, to be published]

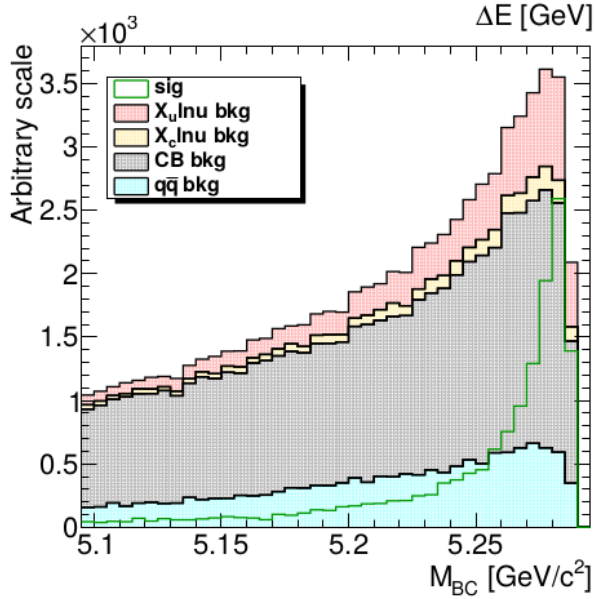


Better tagging algorithm with significantly higher tagging reconstruction efficiency

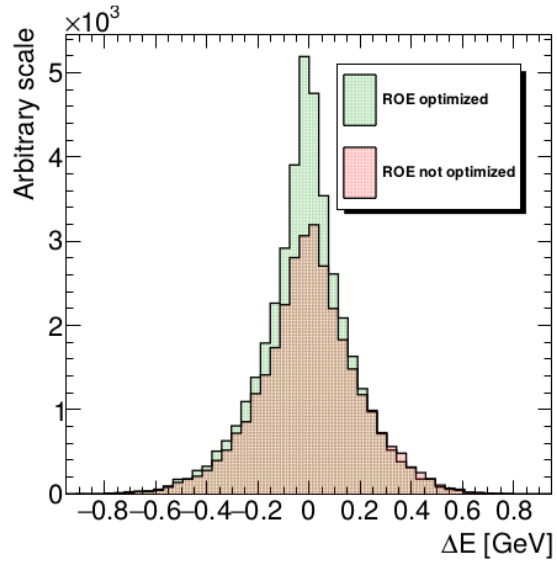
$B \to \pi \ell \nu$ efficiency compared to Belle tagged [Phys.Rev. D88 (2013) no.3, 032005]: 0.3 % $\to$ 0.55 %

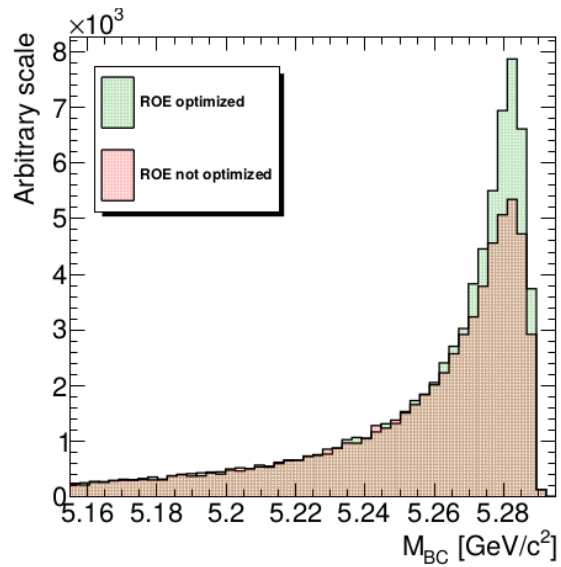
$B \to \pi \ell \nu$ untagged at Belle II (MC study)





[B2TiP, to be published]





RestOfEvent (ROE): tracks and cluster not used in signal B reco

Perform "clean-up" of ROE to discard extra tracks and clusters from beam BKG

$B \to \pi \ell \nu$ efficiency compared to Belle untagged [Phys.Rev. D83 (2011) 071101]: 11 % $\to$ 20 %

Error scaling

Total error scaling with integrated luminosity $\mathcal{L}$

$$\sigma_{\text{tot}}(\mathcal{L}) = \sqrt{(\sigma^2_{\text{stat}}(\mathcal{L}_0) + \sigma^2_{\text{sysred}}(\mathcal{L}_0)) \times \frac{\mathcal{L}_0}{\mathcal{L}} + \sigma^2_{\text{sysirred}}(\mathcal{L}_0)}$$

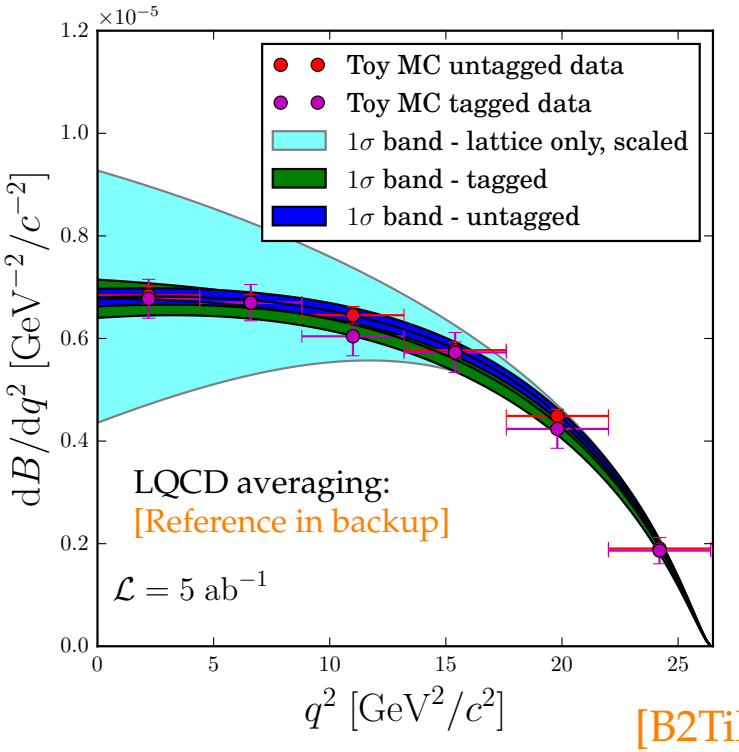
Systematics

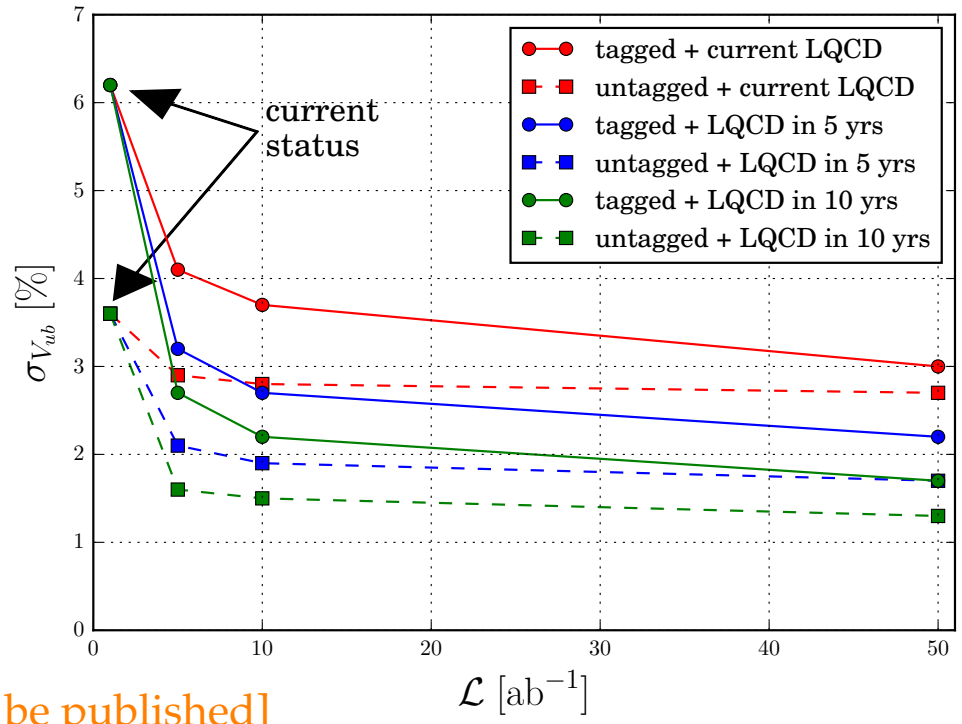
- Belle II systematics estimated from Belle
- Reducible and irreducible systematics (with $\mathcal{L}$)
- Tagged: 4.6 % red., 2.0 % irred., biggest contribution: tagging algorithm
- Untagged: 4.2 % red., 1.6 % irred., biggest contribution: $X_{u,c}\ell\nu$, FF shapes and background

[B2TiP, to be published]

$|V_{ub}|$ from $B \to \pi \ell \nu$ @ Belle II

Toy MC studies based on Belle II MC, LQCD forecasts estimated at 5 years (5, 10 ab^{-1}) and 10 years (50 ab^{-1})





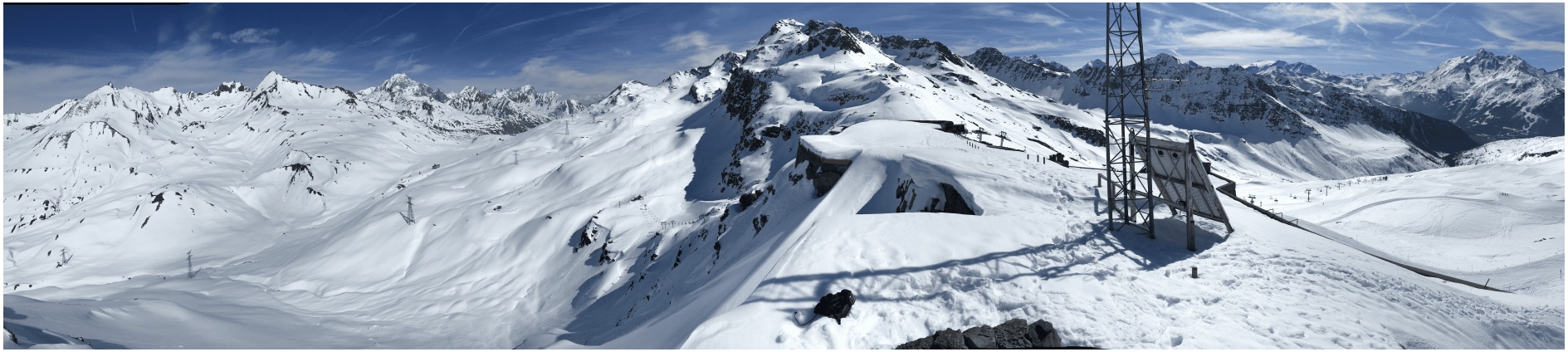
[B2TiP, to be published]

$|V_{ub}|^{\pi \ell \nu}$ from simultaneous fit for $\mathcal{L} = 5$ ab^{-1}, including lattice forecasts and error scaling.

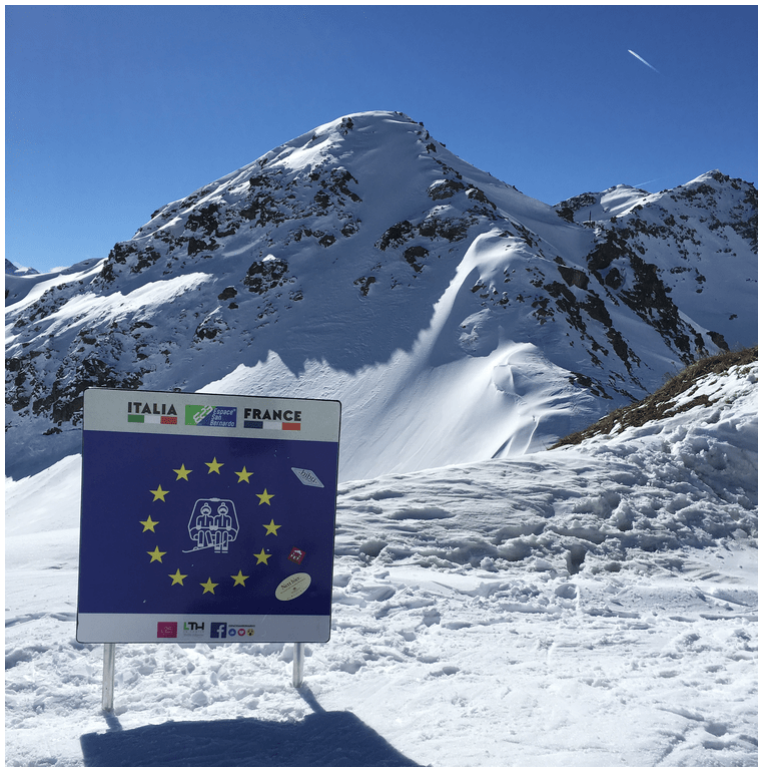
$\delta_{|V_{ub}|^{\pi \ell \nu}}$ estimates for 5, 10 and 50 ab^{-1}:
Tagged: 3.2, 2.7 and 1.7 %
Untagged: 2.1, 1.9 and 1.3 %

LQCD forecasts: [A. Kronfeld, T. Kaneko, S. Simula]

Summary



- Current precision $\delta^{\pi\ell\nu}_{|V_{ub}|} \approx 4\ \%$
- Expected $|V_{ub}|$ precision with full Belle II dataset and LQCD forecasts for $B \to \pi\ell\nu$ channel:
  - Tagged: 1.7 %
  - Untagged: 1.3 %

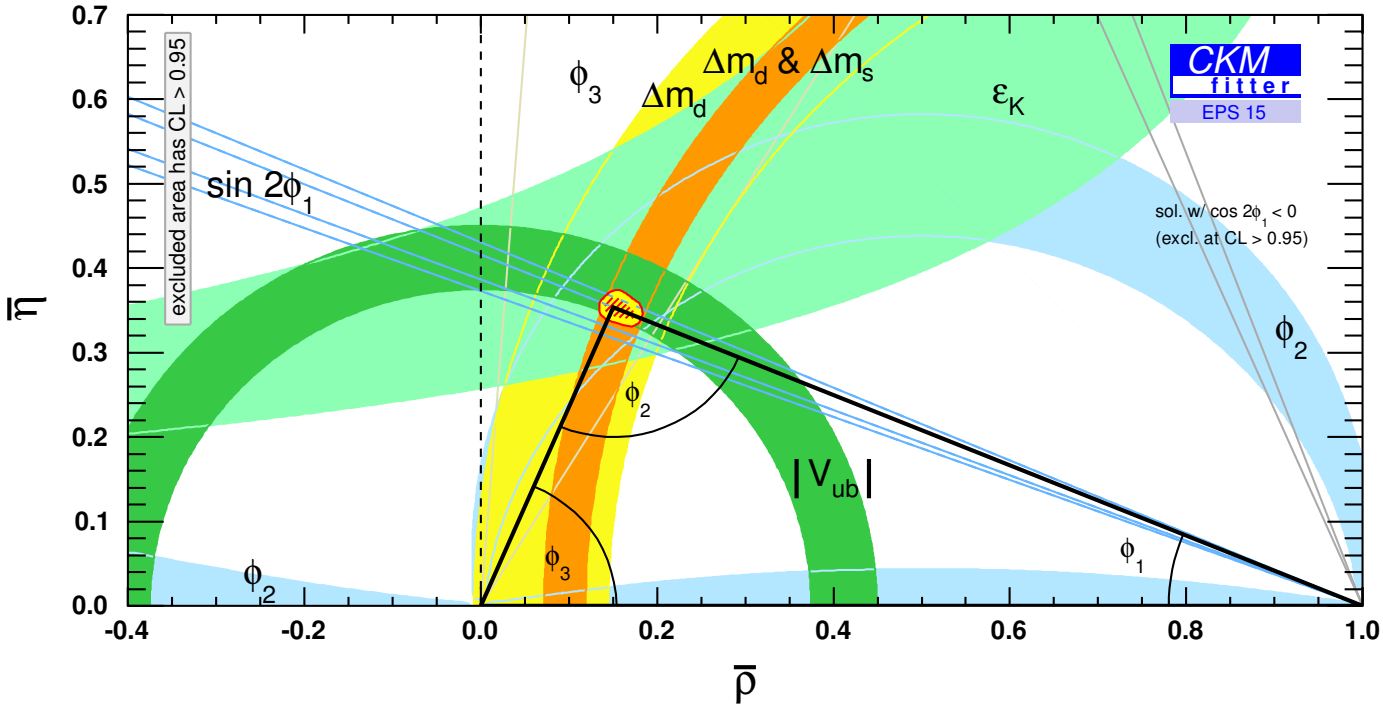


Thank you!

BACKUP

Why $|V_{ub}|$?

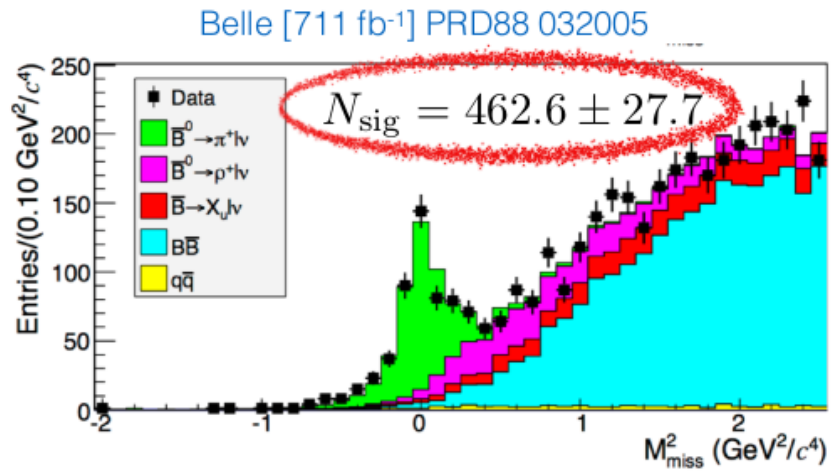
Best handle on NP!

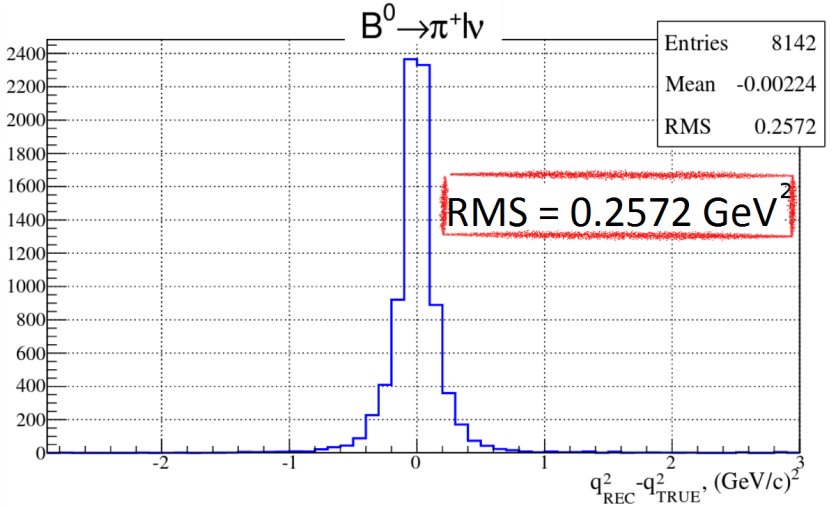


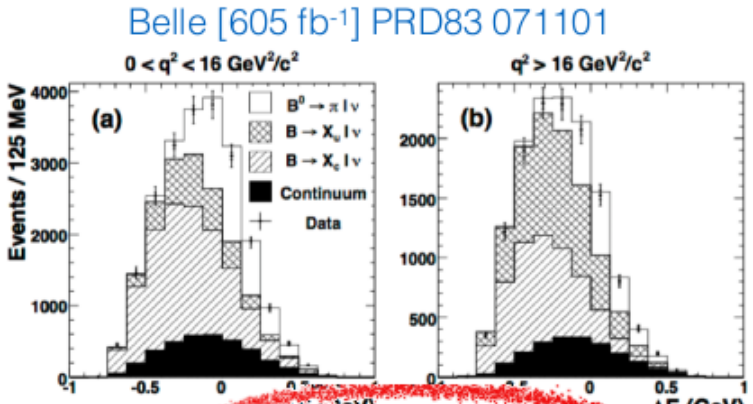
Precision from semi-leptonic decays: 3 – 4 %

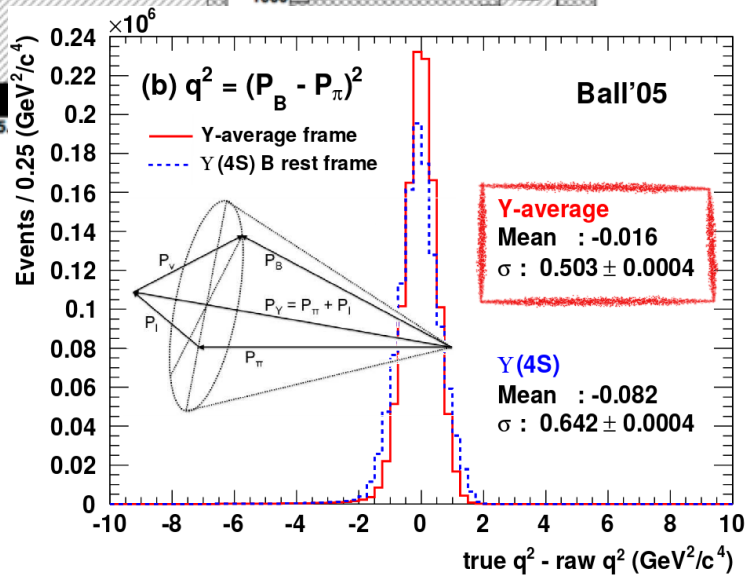
- Era of searching for new physics (NP) → precision measurements
- $|V_{ub}|$ has **largest** error among unitarity triangle (UT) parameters

Tagged (Belle) vs. Untagged (Belle)





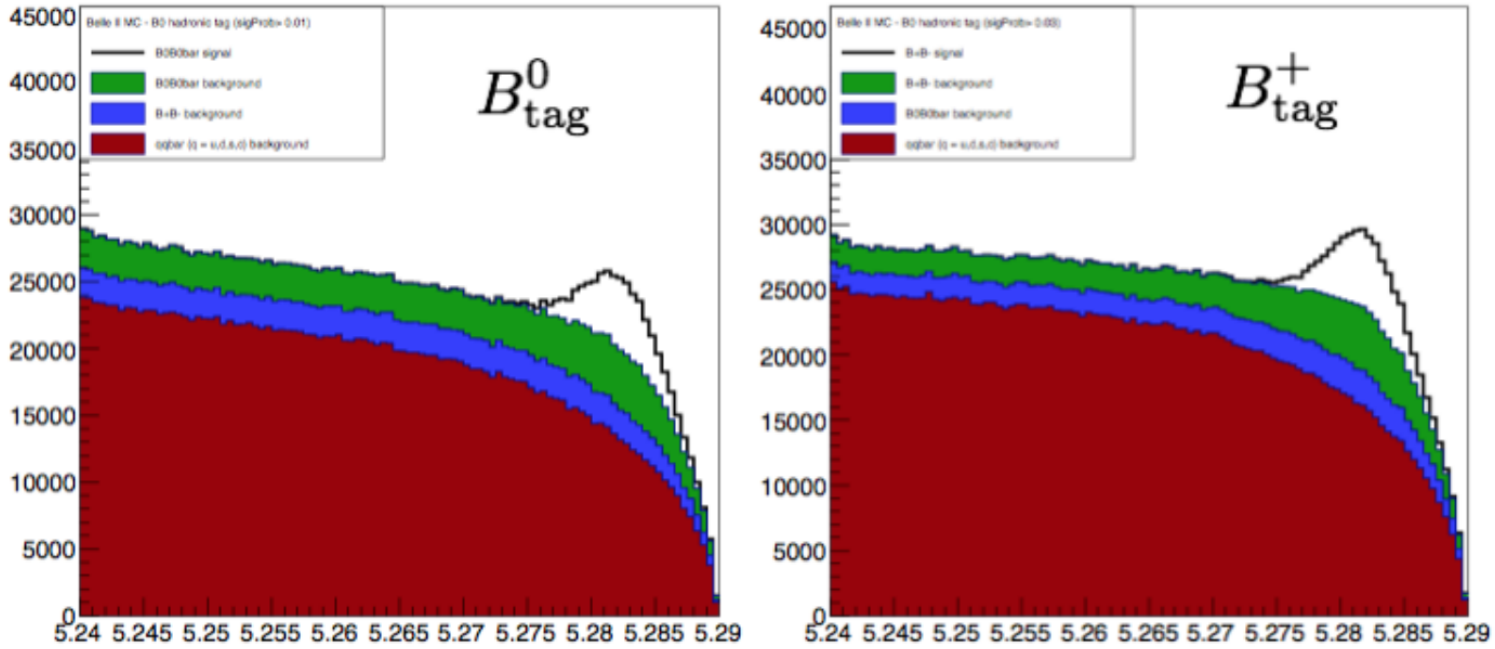




Tagged → Efficiency → Untagged

Tagged ← q^2 res. ← Untagged

B_{tag} efficiency



$$\varepsilon(B^0_{\rm tag}) = 0.33\% \quad \textbf{Belle II} \quad \varepsilon(B^+_{\rm tag}) = 0.36\%$$

$$\varepsilon(B^0_{\rm tag}) = 0.19\% \quad \textbf{Belle} \quad \varepsilon(B^+_{\rm tag}) = 0.28\%$$

Reasons for improvement:

- More channels included in the tag reconstruction
- Best candidate selection allows also inclusion of high multiplicity modes

Form factor calculations

Low $\longleftarrow$ q^2 region $\longrightarrow$ High

LCSR

- Low q^2 region ($q^2 <$ 6-7 GeV^2), mostly at $q^2 = 0$
- Unperturbative
- For pseudoscalar an vector decays

LQCD

- Intermediate to high q^2 region ($q^2 > 14$ GeV^2)
- Unquenched (quark-loops in QCD vacuum incorporated)
- For a limited set of decays, hard to figure out for complex states

$|V_{ub}|$ extraction

- Need to extrapolate theory input to a certain or full q^2 region
- Model dependent/independent: Whether the model makes any assumptions regarding FF shape

Calculation from $\Delta\mathcal{B}$

- Measure partial branching ratio in a q^2 region
- Calculate reduced branching ratio in same region

$$|V_{ub}|^2 = \frac{\Delta\mathcal{B}(q^2_{min}, q^2_{max})}{\tau_B \Delta\zeta(q^2_{min}, q^2_{max})}$$

Simultaneous fit to data and theory

- Measure $\Delta\mathcal{B}/\Delta q^2$ spectrum in bins of q^2
- Extract from simultaneous fit to data (shape + scale) and theory input (shape) by minimizing

$$\chi^2 = \chi^2_{data} + \chi^2_{theory}$$

Fit function

From-factor parametrization (BCL function):

$$f_+(q^2) = \frac{1}{1 - q^2/m_{B^*}^2} \sum_{n=0}^{N-1} a_n^+ \left[z^n - (-1)n - N\frac{n}{N} z^N \right]$$

with 3 (shape) + 1 (normalisation) parameters

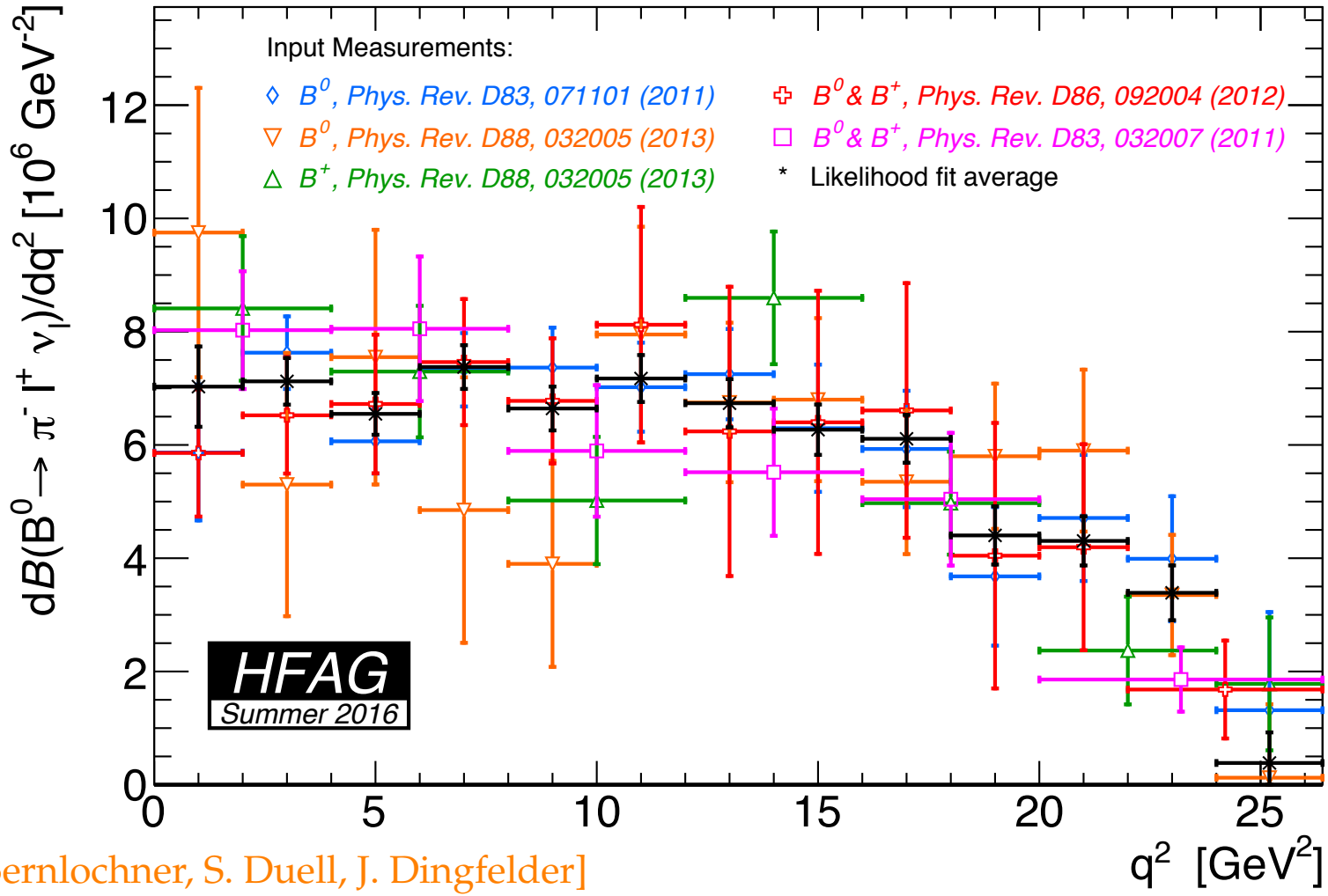
Assumptions for lattice forecasts

We provide 5 types of the lattice input

- current: input with the current precision basically taken from the updated FLAG-3 review (in preparation; to be appeared on the FLAG webpage: `http://itpwiki.unibe.ch/flag/`).
- 5 yr w/o EM: We assume a factor of 2 reduction of the lattice QCD uncertainty in the next five years and that the uncertainty of the EM correction is negligible (for processes insensitive to the EM correction).
- 5 yr w/ EM: LQCD uncertainty is reduced by a factor of 2 but add in quadrature 1% uncertainty from the EM correction.
- 10 yr w/o EM: We assume a factor of 5 reduction of the lattice QCD uncertainty in the next ten years (or as a milestone of lattice QCD simulations). We also assume that the EM correction will be under control and its uncertainty is negligible.
- 10 yr w/ EM: LQCD uncertainty is reduced by a factor of 5 but add in quadrature 1% uncertainty from the EM correction.

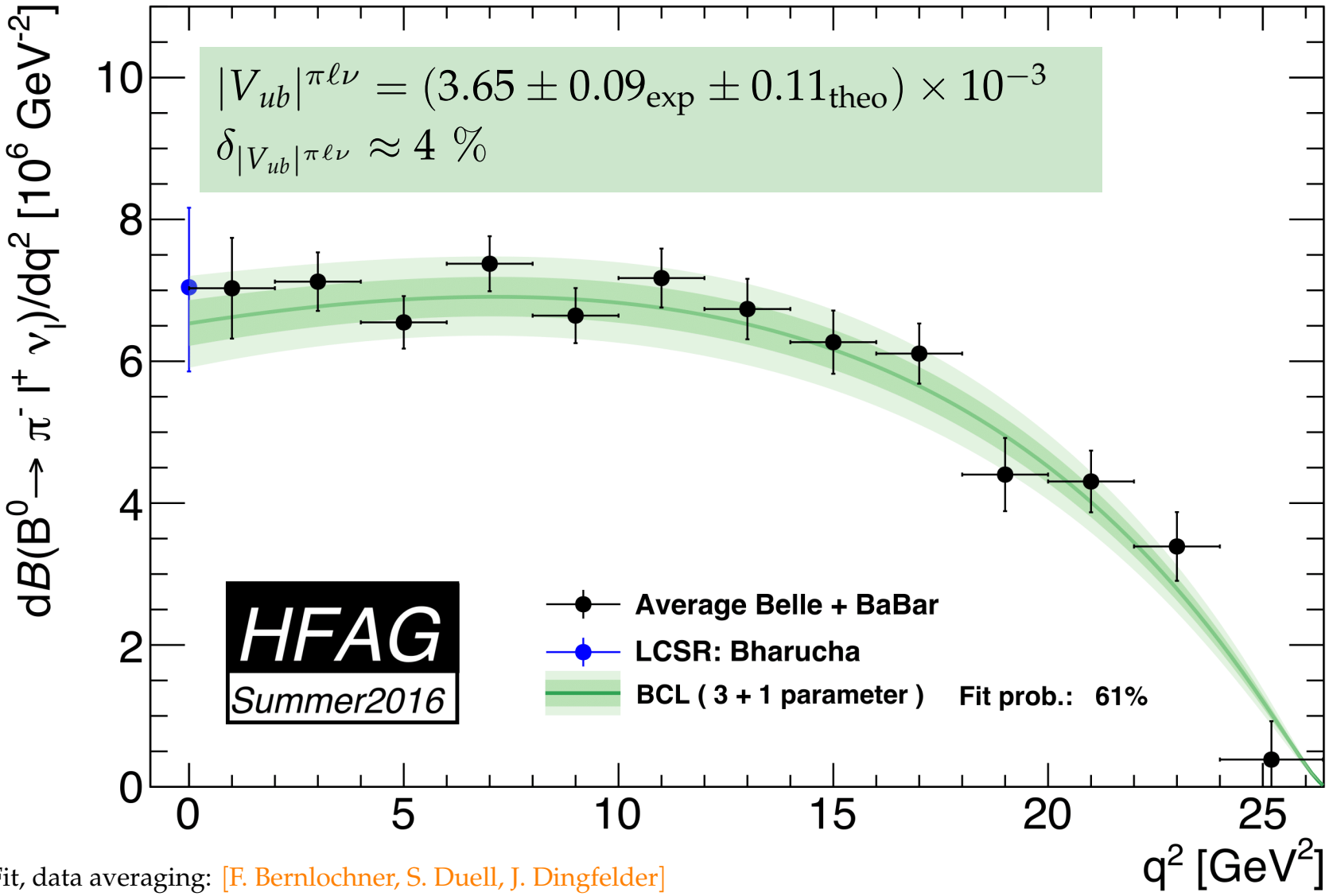
$B \to \pi \ell \nu$

The most precise measurements can be averaged with a likelihood fit.



[F. Bernlochner, S. Duell, J. Dingfelder]

$B \to \pi \ell \nu$



Fit, data averaging: [F. Bernlochner, S. Duell, J. Dingfelder]
LQCD averaging: [FLAG-3 review (arXiv:1607.00299)]
LQCD: [Fermilab/MILC, Phys.Rev. D92 (2015) no.1, 014024]
LQCD: [RBC/UKQCD, Phys.Rev. D91 (2015) no.7, 074510]
LCSR: [A. Bharucha, JHEP 1205 (2012) 092]

Belle II prospects for exclusive $|V_{ub}|$: $B \to \pi\ell\nu$

Tagged $B \to \pi\ell\nu$

- Efficiency: 0.3 % $\to$ 0.55 %
- $\sigma^{exp}_{\Delta\mathcal{B}/\Delta q^2}$ scaling with $\mathcal{L}$: 2.7, 2.4 and 2.1 % for 5, 10 and 50 ab^{-1}
- Irreducible systematics: 2.0 %
- $|V_{ub}|$ precision: $\delta_{|V_{ub}|} = 3.2$, 2.7 and 1.7 % for 5, 10 and 50 ab^{-1}

Untagged $B \to \pi\ell\nu$

- Efficiency: 11 % $\to$ 20 %
- $\sigma^{exp}_{\Delta\mathcal{B}/\Delta q^2}$ scaling with $\mathcal{L}$: 2.2, 1.9 and 1.7 % for 5, 10 and 50 ab^{-1}
- Irreducible systematics: 1.6 %
- $|V_{ub}|$ precision: $\delta_{|V_{ub}|} = 2.1$, 1.9 and 1.3 % for 5, 10 and 50 ab^{-1}

Projections include lattice forecasts. [A. Kronfeld, T. Kaneko, S. Simula]

Belle II prospects for exclusive $|V_{ub}|$: $B \to (\rho, \omega)\ell\nu$

No extensive studies for these projections.
Possible to assume sample sizes in the future based on Belle (hadronic tag) @ 711 fb^{-1} with efficiency improvements:

- $N_{\rho^0} = (621.7 \pm 35.0) \to\sim$ 80k ($\delta_{\text{stat}} \approx 0.5\%$) @ 50 ab^{-1}
- $N_{\rho^+} = (343.3 \pm 28.3) \to\sim$ 44k ($\delta_{\text{stat}} \approx 0.7\%$) @ 50 ab^{-1}
- $N_{\omega(3\pi)} = (96.7 \pm 14.5) \to\sim$ 12.5k ($\delta_{\text{stat}} \approx 1.3\%$) @ 50 ab^{-1}

- With such sample possible to do a full helicity angle analysis
- Also possible to check for right-handed currents
- Will contribute to better understanding of the $b \to u$ spectrum
- Can we expect lattice for these modes by then?