CKM unitary results from Belle and Belle II

Christoph Schwanda
representing the Belle and Belle II collaborations
Cabibbo-Kobayashi-Maskawa quark mixing

The physical quark states are a mixture of the flavour eigenstates described by the unitary Cabibbo-Kobayashi-Maskawa (CKM) matrix.

\[
\begin{pmatrix}
d' \\
n' \\
b'
\end{pmatrix}
= V
\begin{pmatrix}
d \\
n \\
b
\end{pmatrix}
\]

\[
V_{\text{CKM}} =
\begin{pmatrix}
V_{ud} & V_{us} & V_{ub} \\
V_{cd} & V_{cs} & V_{cb} \\
V_{td} & V_{ts} & V_{tb}
\end{pmatrix}
\]

\[V V^\dagger = V^\dagger V = 1\]

- The physical quark states are a mixture of the flavour eigenstates described by the unitary Cabibbo-Kobayashi-Maskawa (CKM) matrix.
- The CKM element magnitudes squared determine the rate of quark flavour transitions in charged current processes.

\[
-\mathcal{L}_{W^\pm} = \frac{g}{\sqrt{2}} \bar{u}_{Li} \gamma^\mu (V_{\text{CKM}})_{ij} d_{Lj} W_{\mu}^+ + \text{h.c.}
\]
**CP violation**

However, $V_{\text{CKM}}$ also contains a complex phase, responsible for all $CP$-violating phenomena in kaon and B meson decays observed so far → extremely constrained system

• New physics would typically disturb the SM pattern of CPV

Wolfenstien parametrization of $V_{\text{CKM}}$

$$V_{\text{CKM}} = \begin{pmatrix}
1 - \lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\
-\lambda & 1 - \lambda^2/2 & A\lambda^2 \\
A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \\
\end{pmatrix} + \mathcal{O}(\lambda^4)$$
The CKM unitarity triangle
...and how to probe it with B mesons

$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$

$B \rightarrow Xl\nu$

$(\rho, \eta)$

$\alpha = \phi_2$

$\gamma = \phi_3$

$\beta = \phi_1$

$B^-/+ \rightarrow D^{(*)}K^{(*)}^-/+$

CPV in $B \rightarrow \pi\pi, \rho\rho, \rho\pi$

CPV in $B \rightarrow J/\psi K_s$
The Belle and Belle II experiments
1999 – 2010: B factory at KEK (Japan)

KEKB double ring e⁺e⁻ collider

Belle detector

\[ e^+ e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B} \]
The Belle detector

- SC solenoid: 1.5T
- CsI(Tl)
- $16X_0$
- TOF counter
- 8 GeV $e^-$
- Si vtx. det.
- 3(4) lyr. DSSD
- Central Drift Chamber
- Aerogel Cherenkov cnt.
- n=1.015~1.030
- 3.5 GeV $e^+$
- $\mu / K_L$ detection
- 14/15 lyr. RPC+Fe
- Small cell +He/C$_2$H$_5$
Comparison to the B factories (1999-2010)

> 1 ab⁻¹
On resonance:
γ(5S): 121 fb⁻¹
γ(4S): 711 fb⁻¹
γ(3S): 3 fb⁻¹
γ(2S): 24 fb⁻¹
γ(1S): 6 fb⁻¹
Off resonance/scan:
~ 100 fb⁻¹

~ 550 fb⁻¹
On resonance:
γ(4S): 433 fb⁻¹
γ(3S): 30 fb⁻¹
γ(2S): 14 fb⁻¹
Off resonance:
~ 54 fb⁻¹
From KEKB to SuperKEKB

Take advantage of existing items (KEKB tunnel, KEKB components)

- New beam pipe & bellows: TiN-coated beam pipe with antechambers
- Main ring arc and straight section: Redesign the lattices of both rings to reduce the emittance
- New beam line Tsukuba section
- New QCS magnet for Nano-beam scheme
- New superconducting / permanent final focusing quads near the IP
- Add / modify RF systems for higher beam current
- New low emittance gun
- New design for Near-IR
- New and re-use wiggler magnets are mixed:
  - Oho section (LER&HER)
  - Nikko section (LER)
- KEKB
- SuperKEKB
- Main ring arc section:
  - LER: Replace all main dipoles
  - HER: Preserve the present cells
- Positron damping ring

$L = 8 \times 10^{-35} \left[ cm^{-2} s^{-1} \right] \times \frac{I_{e^{\pm} \xi \pm y}}{\beta_y}$
<table>
<thead>
<tr>
<th>parameters</th>
<th>KEKB</th>
<th>SuperKEKB</th>
<th>units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LER</td>
<td>HER</td>
<td>LER</td>
</tr>
<tr>
<td>Beam energy $E_b$</td>
<td>3.5</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Half crossing angle $\phi$</td>
<td>11</td>
<td></td>
<td>41.5</td>
</tr>
<tr>
<td>Horizontal emittance $\varepsilon_x$</td>
<td>18</td>
<td>24</td>
<td>3.2</td>
</tr>
<tr>
<td>Emittance ratio $\kappa$</td>
<td>0.88</td>
<td>0.66</td>
<td>0.27</td>
</tr>
<tr>
<td>Beta functions at IP $\beta_x^<em>/\beta_y^</em>$</td>
<td>1200/5.9</td>
<td>32/0.27</td>
<td>25/0.31</td>
</tr>
<tr>
<td>Beam currents $I_b$</td>
<td>1.64</td>
<td>1.19</td>
<td>3.60</td>
</tr>
<tr>
<td>beam-beam parameter $\xi_y$</td>
<td>0.129</td>
<td>0.090</td>
<td>0.0886</td>
</tr>
</tbody>
</table>
| Luminosity $L$              | $2.1 \times 10^{34}$ | $8 \times 10^{35}$ | cm$^{-2}$s$^{-1}$ |}

- **Small beam size & high current** to increase luminosity
- **Large crossing angle**
- **Change beam energies** to solve the problem of LER short lifetime
From Belle to Belle II

CsI(Tl) EM calorimeter: waveform sampling electronics, pure CsI for endcaps

RPC μ & K_L counter: scintillator + Si-PM for end-caps

Time-of-Flight, Aerogel Cherenkov Counter → Time-of-Propagation (barrel), proximity focusing Aerogel RICH (forward)

4 layers DSSD vertex detector → 2 layers PXD (DEPFET) + 4 layers DSSD

Central Drift Chamber: smaller cell size, long lever arm
Belle II timeline

Luminosity

- **LS1 (2022-23):** PXD2 installation and other maintenance/upgrade of detector & machine
- **LS2 (2026-27):** SKB IR upgrade VTX installation?
- **Goal in the mid 2030ies:** \( \mathcal{L}_{\text{recorded}} \approx 50/\text{ab} \)

We are here: \( \mathcal{L}_{\text{recorded}} = 428/\text{fb} \)
\[ |V_{cb}| \text{ and } |V_{ub}| \]
Semileptonic $B$ decays

Determination of the CKM elements $|V_{cb}|$ and $|V_{ub}|$

- SL $B$ decays are studied to determine the CKM elements $|V_{cb}|$ and $|V_{ub}|$
  - $|V_{xb}|$ are limiting the global constraining power of UT fits
  
  - Important inputs in predictions of SM rates for ultrarare decays such as $B_s \to \mu \nu$ and $K \to \pi \nu \nu$

- The determinations can be
  - **Exclusive** — from a single final state
  - **Inclusive** — sensitive to all SL final states

\[
d\Gamma \propto G_F^2 |V_{qb}|^2 \left| L_\mu \langle X | \bar{q} \gamma_\mu P_L b | B \rangle \right|^2
\]

<table>
<thead>
<tr>
<th></th>
<th>Experiment</th>
<th>Theory</th>
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</thead>
<tbody>
<tr>
<td>**Exclusive $</td>
<td>V_{cb}</td>
<td>$**</td>
</tr>
<tr>
<td>**Inclusive $</td>
<td>V_{cb}</td>
<td>$**</td>
</tr>
</tbody>
</table>
Inclusive vs. exclusive puzzle

~3σ difference between inclusive and exclusive $|V_{xb}|$
New results in this talk

Magnitude of $V_{cb}$

|                              | $|V_{cb}| \times 10^3$ | Reference                      |
|------------------------------|------------------------|--------------------------------|
| Belle $B \to D^* \ell \nu$ tagged | 40.30 ± 0.86 (CLN)     | Moriond 2022                   |
| Belle II $B^0 \to D^{*-} \ell^+ \nu$ tagged | 38.0 ± 2.8 (CLN)       | Discrete 2022                  |
| Belle II $B \to D \ell \nu$ untagged          | 38.53 ± 1.15 (BGL)     | arXiv:2210.13143              |
| Belle $q^2$ moments in $B \to X_c \ell \nu$ | 41.69 ± 0.63           | PRD 104, 112011 (2021)        |
|                                |                        | arXiv:2205.06372              |
|                                |                        | arXiv:2205.10274              |
| Belle II $q^2$ moments in $B \to X_c \ell \nu$ | 41.69 ± 0.63           |                                 |
New results in this talk
Magnitude of $V_{ub}$

|                     | $|V_{ub}| \times 10^3$ | Reference                  |
|---------------------|------------------------|----------------------------|
| Belle II $B \rightarrow \pi e\nu$ tagged | $3.88 \pm 0.45$ | Preliminary, arXiv:2206.08102 |
| Belle II $B \rightarrow \pi \ell\nu$ untagged | $3.54 \pm 0.25$ | Preliminary, arXiv:2210.04224 |
| Belle $B \rightarrow X_u\ell\nu$         | $4.10 \pm 0.28$     | PRD 104, 012008 (2021)     |
Untagged vs. Tagged

**Untagged:**
only $B_{\text{sig}}$ is reconstructed

- high signal yield (+)
- high backgrounds (-)
- poor neutrino reconstruction (-)

**Tagged:**
$B_{\text{sig}}$ and $B_{\text{tag}}$ are reconstructed

- signal yield $O(10^3)$ lower (-)
- low backgrounds (+)
- good neutrino reconstruction (+)
- tag calibration (-)
Hadronic tagging at Belle II

• The hadronic FEI employs over 200 boosted decision trees to reconstruct 10000 B decay chains
  • $\epsilon_{B^+} \approx 0.5\%$, $\epsilon_{B^0} \approx 0.3\%$ at low purity (about 50% increase with respect to the Belle tag)
\[ B \rightarrow D^* \ell \nu \]

\[ w = v_B \cdot v_{D(*)} \]

\[ \frac{d\Gamma(B \rightarrow D^* \ell^- \bar{\nu}_\ell)}{dw} = \frac{G_F^2 m_{D^*}^3}{48\pi^3} (m_B - m_{D^*})^2 \chi(w) \eta_{EW}^2 F^2(w) |V_{cb}|^2 \]

\[ \chi(w) F^2(w) = \]

\[ h_{A_1}^2(w) \sqrt{w^2 - 1}(w + 1)^2 \left\{ 2 \left[ \frac{1 - 2wr + r^2}{(1 - r)^2} \right] \left[ 1 + R_1^2(w) \frac{w - 1}{w + 1} \right] + \left[ 1 + (1 - R_2(w)) \frac{w - 1}{1 - r} \right]^2 \right\} , \]
\[ B^0 \rightarrow D^{*} - \ell + \nu\] tagged and \[ | V_{cb} |\] exclusive

Winter 2022

- 189.3/fb of hadronic tagged Belle II events
- Reconstruct \( D^{*+} \rightarrow D^0(K^-\pi^+))^{\pi^+} \) and identify \( \ell \) (e or \( \mu \))
- Fit missing mass squared
  \[ m_{\text{miss}}^2 = (p_{\Upsilon(4S)} - p_{\text{Tag}} - p_{D^*} - p_{\ell})^2 \]
  in bins of \( w = v_B \cdot v_{D^*} \) to extract \( w \) spectrum

\[ \mathcal{B}(B^0 \rightarrow D^{*} - \ell + \nu_\ell) = (5.27 \pm 0.22 \text{ (stat.)} \pm 0.38 \text{ (syst.)})\% \]
\( B^0 \rightarrow D^* \ell^+ \nu \) tagged and \( |V_{cb}| \)

Winter 2022

- Fit of the \( w \) spectrum

\[
\frac{d\Gamma}{dw} = \frac{G_F^2 m_D^3}{48\pi^3} (m_B - m_{D^*})^2 \sqrt{w^2 - 1} \chi(w) \mathcal{F}^2(w) |V_{cb}|^2
\]

In the CLN parameterisation \([\text{NPB530, 153 (1998)}]\), \( \mathcal{F}(w) \) depends on \( \mathcal{F}(1), \rho^2, R_1(1) \) and \( R_2(1) \)

- Largest systematics: tag calibration, slow pion tracking

\[ \eta_{\text{EW}} \mathcal{F}(1) |V_{cb}| = (34.6 \pm 2.5) \cdot 10^{-3} \]

\[ \rho^2 = 0.94 \pm 0.21 \]
$B \rightarrow D^* \ell \nu$ lattice QCD input

- FLAV 2021 average [arXiv:2111.09849]: $\eta_{EW} \mathcal{F}(1) = 0.910 \pm 0.013$
- New lattice calculations beyond zero recoil ($w > 1$)
  - FNAL/MILC under review A. Bazarov et al. [arXiv:2105.14019]
  - HPQCD & JLQCD in preparation
\[ B \to D^* \ell \nu \text{ tagged and } |V_{cb}| \text{ exclusive} \]

Preliminary

- Based on 711/fb, 4 samples \((B^0 e, B^0 \mu, B^+ e \text{ and } B^+ \mu)\)
- Belle II hadronic tag is used
- Signal is extracted from the \(M_{\text{miss}}^2\) distribution in bins of the kinematic variables \((w, \cos \theta_l, \cos \theta_V, \chi)\)
$B \rightarrow D^{*}\ell\nu$ tagged and $|V_{cb}|$ exclusive

Preliminary

Measured Shapes + External Branching Ratio Input

<table>
<thead>
<tr>
<th>BGL(121)</th>
<th>Value</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_0 \times 10^3$</td>
<td>24.93 ± 1.41</td>
<td>1.00 0.25 -0.21 0.26 -0.30</td>
</tr>
<tr>
<td>$b_0 \times 10^3$</td>
<td>13.11 ± 0.18</td>
<td>0.25 1.00 -0.01 -0.01 -0.62</td>
</tr>
<tr>
<td>$b_1 \times 10^3$</td>
<td>-11.93 ± 12.72</td>
<td>-0.21 -0.01 1.00 0.25 -0.48</td>
</tr>
<tr>
<td>$c_1 \times 10^3$</td>
<td>-0.87 ± 0.97</td>
<td>0.26 -0.01 0.25 1.00 -0.49</td>
</tr>
<tr>
<td>$</td>
<td>V_{cb}</td>
<td>\times 10^3$</td>
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</table>

<table>
<thead>
<tr>
<th>CLN</th>
<th>Value</th>
<th>Correlation</th>
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</thead>
<tbody>
<tr>
<td>$\rho^2$</td>
<td>1.25 ± 0.09</td>
<td>1.00 0.56 -0.89 0.38</td>
</tr>
<tr>
<td>$R_1(1)$</td>
<td>1.32 ± 0.08</td>
<td>0.56 1.00 -0.63 -0.03</td>
</tr>
<tr>
<td>$R_2(1)$</td>
<td>0.85 ± 0.07</td>
<td>-0.89 -0.63 1.00 -0.15</td>
</tr>
<tr>
<td>$</td>
<td>V_{cb}</td>
<td>\times 10^3$</td>
</tr>
</tbody>
</table>

Based on the lattice input at zero-recoil:

$h_{A_1}(1) = 0.906 \pm 0.013$
$B \to D^{\ast} \ell \nu$ tagged, comparison to non-zero recoil lattice

Preliminary

$h_{A_1}(w)$

$R_1(w)$

$R_2(w)$

Here: beyond zero-recoil points overlayed (not in fit)
$B \to D\ell\nu$ untagged and $|V_{cb}|$ exclusive

arXiv:2210.13143

- 189.3/fb of Belle II data, four subsamples ($B^0e$, $B^0\mu$, $B^+e$ and $B^+\mu$)

- Signal extracted from

$$\cos \theta_{BY} = \frac{2E_B^*E_Y^* - m_B^2 - m_Y^2}{2|p_B^*||p_Y^*|}$$

\[\eta_{EW}|V_{cb}|_{BGL} = (38.53 \pm 1.15) \times 10^{-3}\]
| $V_{cb}$ | from inclusive decays |

$$\Gamma = \frac{G_F^2 m_b^5}{192\pi^3} |V_{cb}|^2 \left(1 + \frac{c_5(\mu) \langle O_5 \rangle(\mu)}{m_b^2} + \frac{c_6(\mu) \langle O_6 \rangle(\mu)}{m_b^3} + \mathcal{O}\left(\frac{1}{m_b^4}\right)\right)$$

- Based on the Operator Product Expansion (OPE)
- $\langle O_i \rangle$: hadronic matrix elements (non-perturbative)
- $c_i$: coefficients (perturbative)
- Parton-hadron duality $\rightarrow$ the hadronic ME depend only on the initial state

<table>
<thead>
<tr>
<th></th>
<th>Kinetic</th>
<th>1S</th>
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<tbody>
<tr>
<td></td>
<td>[JHEP 1109 (2011) 055]</td>
<td>[PRD70, 094017 (2004)]</td>
</tr>
<tr>
<td>$O(1)$</td>
<td>$m_b, m_c$</td>
<td>$m_b$</td>
</tr>
<tr>
<td>$O(1/m_b^2)$</td>
<td>$\mu^2_{\pi}, \mu^2_G$</td>
<td>$\lambda_1, \lambda_2$</td>
</tr>
<tr>
<td>$O(1/m_b^3)$</td>
<td>$\rho^3_D, \rho^3_{LS}$</td>
<td>$\rho_1, \tau_{1-3}$</td>
</tr>
</tbody>
</table>
Motivated by JHEP 02 (2019) 177 [arXiv:1812.07472]

Semileptonic $B$ decays are reconstructed in 62.8/fb of hadronic tagged Belle II events

Signal weight $w$ as a function of $q^2$ determined from fitting the hadronic mass $M_X$

$q^2$ spectra are calculated as event-wise average

Leading systematics: background, moment calibration

$$q^2 = (p_\ell + p_\nu)^2$$

$q^2$ moments in $B \to X_c \ell \nu$

arXiv:2205.06372, submitted to PRD
$q^2$ moments in $B \rightarrow X_c \ell \nu$

arXiv:2205.06372, submitted to PRD

- Belle II $q^2$ moments compared to Belle $q^2$ moments PRD 104, 112011 (2021) [arXiv:2109.01685]

- And fit by Bernlochner et al. [arXiv:2205.10274]

- This fit gives $|V_{cb}| = (41.69 \pm 0.63) \cdot 10^{-3}$
$B \to \pi \ell \nu$

The golden mode for $|V_{ub}|$ exclusive

- Differential rate in terms of $q^2 = (p_\ell + p_\nu)^2$

$$\frac{d\Gamma(B^0 \to \pi^- \ell^+ \nu)}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{ub}|^2 |p_\pi|^3 |f_+(q^2)|^2$$

  - Measure the differential rate in bins of $q^2$
  - Theory calculates $f_+(q^2)$ at values of $q^2$
  - Combined fit to the BCL expansion to determine $|V_{ub}|$ and $b_k$ ($z$ is a map of $q^2$)

$$f_+(q^2) = \frac{1}{1 - q^2/m_B^*} \sum_{k=0}^{K-1} b_k \left[ z^k - (-1)^{k-K} \frac{k}{K} z^K \right]$$
$B \rightarrow \pi e\nu$ tagged and $|V_{ub}|$ exclusive

arXiv:2206.08102

- 189.3/fb of Belle II, tag side is reconstructed by hadronic tag

| Decay mode          | Fitted $|V_{ub}|$ |
|---------------------|------------------|
| $B^0 \rightarrow \pi^- e^+ \nu_e$ | $(3.71 \pm 0.55) \times 10^{-3}$ |
| $B^+ \rightarrow \pi^0 e^+ \nu_e$ | $(4.21 \pm 0.63) \times 10^{-3}$ |
| Combined fit         | $(3.88 \pm 0.45) \times 10^{-3}$ |
$B \rightarrow \pi \ell \nu$ untagged and $|V_{ub}|$ exclusive

arXiv:2210.04224

- 189.3/fb of Belle II data
\( B \rightarrow X_u \ell^\nu \) and  \( |V_{ub}| \) inclusive

PRD 104, 012008 (2021), PRL 127, 261801 (2021)

4 predictions of the partial rate

BLNP
DGE
GGOU
ADFR

Our average
HFLAV \( B \rightarrow \pi \ell \nu \)
CKMFitter

Exclusive Average for \( B \rightarrow \pi \ell \nu \):
\[ |V_{ub}| = (3.67 \pm 0.09 \pm 0.12) \times 10^{-3} \]

CKM Unitarity:
\[ |V_{ub}| = (3.62^{+0.11}_{-0.08}) \times 10^{-3} \]

Arithmetic average:
\[ |V_{ub}| = (4.10 \pm 0.09 \pm 0.22 \pm 0.15) \times 10^{-3} \]

Can be used for future shape-function independent determination of \( V_{ub} \)

$\phi_3/\gamma$
CKM angle $\phi_3/\gamma$

BPGGSZ method (binned model-independent) *Phys.Rev.D68, 054018*

- $\phi_3/\gamma$ is the phase between $b \rightarrow u$ and $b \rightarrow c$ transitions
- The interference between these two diagrams gives access to the amplitude ratio, which contains $\phi_3/\gamma$
CKM angle $\phi_3/\gamma$

BPGGSZ method (binned model-independent) Phys.Rev.D68, 054018

- To observe interference, we need to reconstruct $D^0$ in a self-conjugate mode

- To avoid model dependence, the strong phase difference between the $D^0$ and $\bar{D}^0$ decays is measured by CLEO/BES III

\[(x_\pm, y_\pm) = r_B \left( \cos(\gamma + \delta_B), \sin(\gamma + \delta_B) \right)\]

$c_i, s_i$: $D^0-\bar{D}^0$ strong phase differences (inputs from BES III/CLEO)

$F_i$: fraction of $D$ decays to $i$-th bin

\[N_{i}^{\pm} = h_B^{\pm} \left[ F_i + r_B^2 F_i + 2 \sqrt{F_i F_i} (c_i x_\pm + s_i y_\pm) \right] \]
Belle+Belle II measurement of $B \to DK$

JHEP 02, 063 (2022), arXiv:2110.12125

- 711/fb of Belle and 128/fb of Belle II data
- Using both $D^0 \to K_S^0 \pi^+ \pi^-$ and $D^0 \to K_S^0 K^+ K^-$
- Yields extracted in simultaneous fit to $B \to DK$ and $B \to D\pi$ (misID rate determined from data)

Signal yields:

<table>
<thead>
<tr>
<th></th>
<th>Belle:</th>
<th>Belle II:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_S^0 \pi \pi$:</td>
<td>$1467 \pm 53$</td>
<td>$280 \pm 21$</td>
</tr>
<tr>
<td>$K_S^0 KK$:</td>
<td>$194 \pm 17$</td>
<td>$34 \pm 7$</td>
</tr>
</tbody>
</table>
Belle+Belle II measurement of $B \to DK$

\[ \delta_B[^\circ] = 124.8 \pm 12.9 \text{ (stat)} \pm 0.5 \text{ (syst)} \pm 1.7 \text{ (ext)} \]
\[ r_B^{DK} = 0.129 \pm 0.024 \text{ (stat)} \pm 0.001 \text{ (syst)} \pm 0.002 \text{ (ext)} \]
\[ \gamma[^\circ] = 78.4 \pm 11.4 \text{ (stat)} \pm 0.5 \text{ (syst)} \pm 1.0 \text{ (ext)} \]
Summary

• Current data of the B factories confirms 3-generation quark mixing and fits the CKM unitarity triangle extremely well
  • There is however an experimental anomaly in the CKM magnitudes $|V_{cb}|$ and $|V_{ub}|$ and the precision of the angle $\phi_3/\gamma$ is still largely limited by statistics
• Belle II is an upgrade programme for the Belle B factory which aims accumulating about 50 times more data
  • 428/fb have been recorded by Belle II by summer 2022
• Belle II has produced first results for $|V_{cb}|$ and $|V_{ub}|$ in 2022
  • Once these analyses are finalised, we will revisit the inclusive vs. exclusive situation
• $\phi_3/\gamma$ has been measured combining the Belle and Belle II data samples
  • We need an order of magnitude more data to be competitive with hadron collider experiments