Towards First Physics at Belle II

Torben Ferber (torben.ferber@desy.de)
DPG Wuppertal, 10.03.2015
Overview.

- Motivation and Belle at KEKB
- Belle II at SuperKEKB
- Towards for First Physics at Belle II
  - Dark Sector
  - Precision Standard Model
- Conclusions
Motivation for B-Factories: Flavour Frontier.

➢ Energy frontier:
  - Production of New Physics (NP) from collisions
  - Limited by beam energy

➢ Flavour frontier:
  - NP in Virtual processes
Past B-Factories.

- Belle at KEKB and Babar at PEP-II

- Very high luminosity:
  - \( \sim 2 \times 10^{34} \text{ / cm}^2 \text{ / s} \) (Belle)
  - (twice the design value)

- Beam energy at \( \Upsilon(nS) \):
  - Mainly at \( E_{\text{CM}} = 10.58 \text{ GeV} \)
  - BF \( \Upsilon(4S) \rightarrow \Bb \) > 96%

- Asymmetric beams:
  - 8 GeV \( e^- \) / 3.5 GeV \( e^+ \) (Belle)
  - \( \rightarrow \) Boosted \( \Bb \) pairs
Huge statistics at B-Factories.

> At Belle:

- About 772 million $\bar{B}B$ pairs
- About 500 million tau and muon pairs each

> Many analyses remain statistically limited!

<table>
<thead>
<tr>
<th>Physics process</th>
<th>Cross section [nb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y(4S) \to BB$</td>
<td>1.2</td>
</tr>
<tr>
<td>Light quark pairs</td>
<td>2.8</td>
</tr>
<tr>
<td>Muon pairs</td>
<td>1.1</td>
</tr>
<tr>
<td>Tau pairs</td>
<td>0.9</td>
</tr>
<tr>
<td>Bhabha ($\theta_{lab}&gt;17^\circ$)</td>
<td>44</td>
</tr>
<tr>
<td>Photon pairs ($\theta_{lab}&gt;17^\circ$)</td>
<td>2.4</td>
</tr>
<tr>
<td>Two photon ($\theta_{lab}&gt;17^\circ$)</td>
<td>~80</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>~130</td>
</tr>
</tbody>
</table>
From KEKB to SuperKEKB.

\[ \int L = 50 \text{ ab}^{-1} \text{ by 2025 (50x Belle)} \]

\[ L_{\text{peak}} = 8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1} \text{ (40x KEKB)} \]
Nano beam scheme.

$$L = \frac{\gamma_{\pm}}{2er_e} \left( 1 + \frac{\sigma^*_y}{\sigma^*_x} \right) \left( I_{\pm} \xi_{y\pm} \frac{R_L}{R \xi_y} \right)$$

beam current

vertical beta function at IP

<table>
<thead>
<tr>
<th>KEKB (w/o crab)</th>
<th>Super-KEKB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1µm 100µm 5mm</td>
<td>1µm 100µm 5mm</td>
</tr>
<tr>
<td>22mrad</td>
<td>~50nm 83mrad</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>E (GeV)</th>
<th>( \beta^*_{y} ) (mm)</th>
<th>( \beta^*_{x} ) (cm)</th>
<th>( \varphi ) (mrad)</th>
<th>( I ) (A)</th>
<th>L (cm(^{-2})s(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>LER/HER</td>
<td>LER/HER</td>
<td>LER/HER</td>
<td>LER/HER</td>
<td>LER/HER</td>
<td>LER/HER</td>
</tr>
<tr>
<td>KEKB</td>
<td>3.5/8.0</td>
<td>5.9/5.9</td>
<td>120/120</td>
<td>11</td>
<td>1.6/1.2</td>
</tr>
<tr>
<td>SuperKEKB</td>
<td>4.0/7.0</td>
<td>0.27/0.30</td>
<td>3.2/2.5</td>
<td>41.5</td>
<td>3.6/2.6</td>
</tr>
</tbody>
</table>

\( x20 \) \( x(2-3) \)
Belle II at SuperKEKB.

January 2015
The Present: Belle II at SuperKEKB.

Electromagnetic Calorimeter (ECL):
CsI(Tl), waveform sampling (barrel)
Pure CsI + waveform sampling (endcaps)

Kᵌ and muon detector (KLM):
Resistive Plate Counter (barrel)
Scintillator + WLSF + MPPC (endcaps)

Particle Identification (PID):
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (fwd)

Beryllium beam pipe
2 cm diameter

Vertex Detector:
2 layers DEPFET
4 layers DSSD

Central Drift Chamber (CDC):
He(50%):C₂H₆(50%), Small cells,
long lever arm, fast electronics

electron (7 GeV)

positron (4 GeV)
Strength of $e^+e^-\rightarrow Y(4S)$ and Belle II.

- Full reconstruction of $B$
  - Modes with multiple neutrinos
  - Inclusive modes

- Hermeticity (90% of $4\pi$)

- Neutral particle reconstruction
  - $\pi^0$, $K_S^0$, $K_L^0$, $\eta$, $\eta'$, $\rho^+$,...

- Good PID for $\mu$ and $e$

- High flavour-tagging eff.

(vertex reso mit PXD)
The Belle II Collaboration.

- 626 colleagues, 99 institutes, 23 countries
  (83 colleagues from 11 German institutes)

http://belle2.kek.jp
Example: CKM Physics at Belle II.

\[
\begin{array}{ccc}
  \text{u} & \text{d} & \text{b} \\
  n & e^- & \ell^- \\
  p & \nu & \pi \\
  K & \ell^- & \pi \\
  D & \ell^- & K \\
  B & \ell^- & D \\
  B^0 & \bar{B}^0 & t \\
  B_s & \bar{B}_s & W \\
\end{array}
\]

\[V = \begin{pmatrix}
\Phi_1(\beta) & 0.8^\circ & 0.4^\circ \\
\Phi_2(\alpha) & 4.0^\circ & 1.0^\circ \\
\Phi_3(\gamma) & 8.5^\circ & \text{statistically limited!} \\
\end{pmatrix}
\]

From: S. Desclaux-Genon

V = world average | Belle II exp. (50ab\(^{-1}\))

| \(\Phi_1(\beta)\) | 0.8^\circ | 0.4^\circ |
| \(\Phi_2(\alpha)\) | 4.0^\circ | 1.0^\circ |
| \(\Phi_3(\gamma)\) | 8.5^\circ | \text{statistically limited!} |

\(\text{Belle: 14.5^\circ}\)
Example: τ Lepton Flavor Violation (LFV) at Belle II.

- LFV is a theoretically clean null test SM: $\text{BF}_{\text{SM}} \sim 10^{-25}$ → New Physics may induce LFV at one loop.

<table>
<thead>
<tr>
<th>Model</th>
<th>Reference</th>
<th>$\tau \rightarrow \mu\gamma$</th>
<th>$\tau \rightarrow \mu\mu\mu\mu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM + heavy Maj $\nu_R$</td>
<td>PRD 66(2002)034008</td>
<td>$10^{-9}$</td>
<td>$10^{-10}$</td>
</tr>
<tr>
<td>Non-universal $Z'$</td>
<td>PLB 547(2002)252</td>
<td>$10^{-9}$</td>
<td>$10^{-8}$</td>
</tr>
<tr>
<td>SUSY SO(10)</td>
<td>PRD 68(2003)033012</td>
<td>$10^{-8}$</td>
<td>$10^{-10}$</td>
</tr>
<tr>
<td>mSUGRA+seesaw</td>
<td>PRD 66(2002)115013</td>
<td>$10^{-7}$</td>
<td>$10^{-9}$</td>
</tr>
<tr>
<td>SUSY Higgs</td>
<td>PLB 566(2003)217</td>
<td>$10^{-10}$</td>
<td>$10^{-7}$</td>
</tr>
</tbody>
</table>
Background: CDC.

Main background in CDC:

- Radiative Bhabha (scales with L)
- Only small Touschek-increase from increased beam current, largely reduced by collimators

Main background in VTX:

- Two Photon QED
Background: ECL.

without ECL timing cut or energy threshold
Two stage trigger:

- Hardware (L1)
- Software/Physics Trigger

Fixed latency: 5μs

Bunch spacing: 2ns

>99% efficiency for BB

<table>
<thead>
<tr>
<th>Physics process</th>
<th>Cross section [nb]</th>
<th>Rate [Hz] @ final L.</th>
</tr>
</thead>
<tbody>
<tr>
<td>γ(4S) → BB</td>
<td>1.2</td>
<td>960</td>
</tr>
<tr>
<td>quark pairs</td>
<td>2.8</td>
<td>2200</td>
</tr>
<tr>
<td>Muon pairs</td>
<td>1.1</td>
<td>880</td>
</tr>
<tr>
<td>Tau pairs</td>
<td>0.9</td>
<td>720</td>
</tr>
<tr>
<td>Bhabha (θ_{lab} &gt; 17°)</td>
<td>44</td>
<td>350*</td>
</tr>
<tr>
<td>γ pairs</td>
<td>2.4</td>
<td>19*</td>
</tr>
<tr>
<td>Two photon</td>
<td>~80</td>
<td>~15000</td>
</tr>
<tr>
<td>Total</td>
<td>~130</td>
<td>~20000</td>
</tr>
</tbody>
</table>

*L1 Rate: 500 Hz, Physics Rate: 90 Hz, Event size: 40kB
Belle II: 30 kHz, 3-10 kHz, 200kB

*prescaled by 100
Schedule.

<table>
<thead>
<tr>
<th>Year</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1</td>
<td>TOP</td>
<td>CDC</td>
<td>ARICH</td>
<td>Endcaps</td>
</tr>
<tr>
<td>Phase 2</td>
<td>Global cosmics run</td>
<td>QCS</td>
<td>PXD+SVD</td>
<td></td>
</tr>
<tr>
<td>Phase 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Phase 1: 2016
Phase 2: Mid 2017- Early 2018
Phase 3: Oct 2018-

BEAST/SuperKEKB, cosmics
BEAST with Partial Belle II
Full detector
Phase 3: First Physics at Belle II.

- “Maximize original physics research in the first year”

- Possible caveats:
  - PID calibration
  - VXD alignment
  - Backgrounds

- Potential benefits:
  - Looser trigger
  - Different beam energies

- ~300fb\(^{-1}\) non-\(Y(4S)\) data in first year (plus similar amount of calibration data at \(Y(4S)\))
Phase 3: First Physics at Belle II.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Scans/Off. Res.</th>
<th>$\Upsilon(5S)$</th>
<th>$\Upsilon(4S)$</th>
<th>$\Upsilon(3S)$</th>
<th>$\Upsilon(2S)$</th>
<th>$\Upsilon(1S)$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\text{fb}^{-1}$</td>
<td>$\text{MeV}$</td>
<td>$\text{MeV}$</td>
<td>$\text{MeV}$</td>
<td>$\text{MeV}$</td>
<td>$\text{MeV}$</td>
</tr>
<tr>
<td>CLEO</td>
<td>17.1</td>
<td>0.4</td>
<td>1.6</td>
<td>5.2</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>BaBar</td>
<td>54</td>
<td>$R_b$ scan</td>
<td>433</td>
<td>30</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td>Belle</td>
<td>100</td>
<td>121</td>
<td>711</td>
<td>3</td>
<td>25</td>
<td>6</td>
</tr>
</tbody>
</table>

Possible topics for the first year of data taking:

- Bottomonium(like) below and above $\Upsilon(4S)$
- Energy scans up $\Upsilon(6S)$
- Light Higgs and **Dark Sector**
- Preparation of high-precision QED and EW analyses
- PYTHIA tuning and fragmentation
Light Higgs and the Dark Sector.

➤ Light higgs:

- NMSSM models result in 3 CP-even and 2 CP-odd neutral Higgs bosons
- The lightest Higgs $A^0$ can have $m_{A^0} < 2m_b$ (not excluded by LEP):
  e.g. $Y(2S) \rightarrow \pi^+\pi^- Y(1S) [Y(1S) \rightarrow \gamma A^0[A^0 \rightarrow f\bar{f}]]$
- Belle II: $Y(2S)$ preferred, slow pion pair trigger needed

➤ Dark Sector:

- Minimal dark matter model: Dark matter particle $\chi$ and a new scalar or gauge boson $A'$ as s-channel annihilation mediator ($m_{A'} > 2m\chi$)
- Additional U(1)' symmetry → “Kinetic Mixing” of massive dark photon $A'$ with the SM photon
The Dark Photon.

- Kinetic mixing:

\[ \gamma \leftrightarrow A' \]

\[ \Delta \mathcal{L} = \frac{\epsilon}{2} F_{\mu \nu} \mathcal{Y}_{\mu \nu} \]

- If \( A' \) is the lightest "Dark Sector" particle:
  Annihilation into SM particles, \( \sigma \) proportional to \( \alpha \epsilon^2 \)
Dark Photon decaying into fermion pairs.

Since $A'$ is very narrow:

- "Scan" $ee \rightarrow \gamma_{\text{ISR}} A'$

Signal:

- Narrow peak in dilepton (ee or $\mu\mu$) mass spectrum (dominated by QED)

Belle II First Physics:

- Mass resolution $\sim 0.5$

$$ \frac{U_0}{U_0} = \left( \frac{L_0}{L} \frac{\Delta M}{\Delta M} \frac{\epsilon_{\ell\ell}}{\epsilon_{\ell\ell}} \right)^{0.25} $$

- Trigger efficiency 1.1($\mu\mu$)-2(ee)

- Add hadronic final states
Dark Photon decaying into invisible final state.

- If A’ is not the lightest “Dark Sector” particle:
  - $ee \rightarrow \gamma_{\text{ISR}} A’, A’ \rightarrow \chi \chi$ dominates

- Signal:
  - Single, mono-energetic photon $\gamma_{\text{ISR}}$ and nothing else

- Belle II First Physics:
  - Dedicated “single photon trigger” at $E_\gamma \sim 1\text{GeV}$
  - Also needed for search of a weakly interacting particle in non resonant $ee \rightarrow \gamma \chi \chi$ (via overall $\gamma$-rate increase)

\[ \gamma(3S) \rightarrow \gamma A^0[A^0 \rightarrow \text{Invisible}] \text{ e.g. Essig et al., arXiv:1309.5084} \]
Dark Higgs.

Dark U(1)' symmetry group spontaneously broken: Adding dark Higgs h' (or several of them...)

Two couplings involved: $\alpha_D$ and kinetic mixing $\sim \varepsilon^2$

Dark Higgs-strahlung:

- Case A: $m_{h'} < m_{A'} \rightarrow h'$ long lived (decay outside detector), $A' \rightarrow ll$ or $hh$
- Case B: $m_{A'} < m_{h'} < 2m_{A'} \rightarrow h' \rightarrow A'A^* $, six leptons/hadrons
- Case C: $m_{h'} > 2m_{A'} \rightarrow h' \rightarrow A'A$, six leptons/hadrons
Belle II First Physics:

- Case A: Not studied at B factories, new low momentum leptons and missing energy trigger needed
- Case C: Improved mass resolution for finer mass scans

Jaegle et al., arXiv: 1502.00084
Legg et al., arXiv:1202.1313
Muon anomalous magnetic moment:

- \( a_\mu^{SM} = (11\,659\,180.4 \pm 4.3 \, (\text{HVP}) \pm 2.6 \, (\text{LBL}) \pm 0.2 \, (\text{EW})) \times 10^{-10} \)

Dominant contribution to LO HVP: \( \pi^+\pi^- \) (~73% of \( a_\mu^{\text{had}} \))
Experimental challenge: Total error <1%

- Correlated track loss, PID, trigger, ...

Belle: Limited by L1 trigger
Bhabha veto ($E_{ECL} > 5$ GeV)

Belle II simulation

$\pi^+ \pi^- = 0.30$ GeV

Belle II First Physics:
Optimize electron-vetoed track trigger
Preferred direction of muons produced in $e^+e^-$ collisions?

\[ A_{FB} = \frac{N_F - N_B}{N_F + N_B} \]

Born QED predicts symmetric distribution ($N_F = N_B$, $A_{FB} = 0$)

Interference of $\gamma$ and $Z$ leads to energy dependent asymmetry $A_{FB} < 0$ for $s < m_Z^2$
The Standard Model (Born level): $ee \rightarrow \mu\mu$. 

\[
\frac{2s}{\pi} \frac{d\sigma}{d\cos(\theta^*)} \left( e^+ e^- \rightarrow \mu^+ \mu^- \right) = \\
\left| \alpha(s) \right|^2 (1 + \cos^2(\theta^*)) \\
\left. \sigma^\gamma \right| \\
+ 8 \text{Re} \left[ \alpha^*(s) \chi(s) \left\{ G_{ve} G_{\nu\mu} (1 + \cos^2(\theta^*)) + 2G_{ae} G_{a\mu} \cos(\theta^*) \right\} \right] \\
\left. \sigma^\gamma Z \right| \\
+ 16|\chi(s)|^2 \left( \left| G_{ve} \right|^2 + \left| G_{ae} \right|^2 \right) \left( \left| G_{\nu\mu} \right|^2 + \left| G_{a\mu} \right|^2 \right) (1 + \cos^2(\theta^*)) \\
\left. + 8 \text{Re}(G_{ve} G_{ae}^*) \text{Re}(G_{\nu\mu} G_{a\mu}^*) \cos(\theta^*) \right]\left. \sigma^Z \right|,
\]

with

\[
\chi(s) = \rho \frac{G_F}{8\pi\sqrt{2}} \frac{M_Z^2 s}{s - M_Z^2 + i\Gamma_Z M_Z}
\]

\[
G_{Vf} = \sqrt{R_f} \left( T_3^f - 2 \sin^2 \theta_W^{\text{eff.}} \right)
\]
The Standard Model (Born level): \( ee \rightarrow \mu \mu \).

\[
\frac{2s}{\pi} \frac{d\sigma}{d\cos(\theta^*)} (e^+e^- \rightarrow \mu^+\mu^-) = \\
|\alpha(s)|^2 (1 + \cos^2(\theta^*)) \\
+ 8 \Re [\alpha^*(s)\chi(s) \left\{ G_{ve} G_{v\mu} (1 + \cos^2(\theta^*)) + 2 G_{ae} G_{a\mu} \cos(\theta^*) \right\}] \\
+ 16 |\chi(s)|^2 \left[ (|G_{ve}|^2 + |G_{ae}|^2) \left(|G_{v\mu}|^2 + |G_{a\mu}|^2\right) (1 + \cos^2(\theta^*)) \right.
\]

\[
+ \left. 8 \Re (G_{ve} G_{ae}^*) \Re (G_{v\mu} G_{a\mu}^*) \cos(\theta^*) \right],
\]

with

\[
\chi(s) = \rho \frac{G_F}{8\pi\sqrt{2}} \frac{M_Z^2 s}{s - M_Z^2 + i\Gamma Z M_Z}
\]

\[
G_{Vf} = \sqrt{R_f} \left( T^f_3 - 2 \sin^2 \theta_{\text{eff.}}^W \right)
\]
The Standard Model (Born level): $e^+ e^- \rightarrow \mu^+ \mu^-$. 

$$
\frac{2s}{\pi} \frac{d\sigma}{d \cos(\theta^*)} \left( e^+ e^- \rightarrow \mu^+ \mu^- \right) = 
$$

$$
|\alpha(s)|^2 (1 + \cos^2(\theta^*)) 
$$

$$
\sigma^{\gamma} 
$$

$$
+ 8 \text{Re} \left[ \alpha^*(s) \chi(s) \left\{ G_{ve} G_{\nu \mu} (1 + \cos^2(\theta^*)) + 2 G_{ae} G_{a \mu} \cos(\theta^*) \right\} \right] 
$$

$$
\sigma^{\gamma - Z} 
$$

$$
+ 16 |\chi(s)|^2 \left( |G_{ve}|^2 + |G_{ae}|^2 \right) \left( |G_{\nu \mu}|^2 + |G_{a \mu}|^2 \right) (1 + \cos^2(\theta^*)) 
$$

$$
+ 8 \text{Re}(G_{ve} G_{ae}^*) \text{Re}(G_{\nu \mu} G_{a \mu}^*) \cos(\theta^*) 
$$

$$
\sigma^Z 
$$

with

$$
\chi(s) = \rho \frac{G_F}{8\pi \sqrt{2}} \frac{M_Z^2 s}{s - M_Z^2 + i\Gamma_Z M_Z} 
$$

$$
G_{Vf} = \sqrt{R_f} \left( T_f^3 - 2 \sin^2 \theta_W^{\text{eff.}} \right) 
$$
An asymmetry over energy and time.
An asymmetry over energy and time.
Precision physics far below the Z pole.

>Precision measurement at Z pole:

- \( A_{FB} \sim g_V^2 g_A^2 / (g_V^2 + g_A^2)^2 \) → Sensitive to the weak mixing angle and \( \rho \)

>Precision measurement at Belle II:

- \( A_{FB} \sim \rho g_A^2 \) (dominated by interference \( \sigma_{yz} \)) → Only sensitive to \( \rho \)

- 50 ab\(^{-1}\) yield ~25 billion detected muon pairs at 10.58 GeV CM energy

- Expected statistical uncertainty: \( \sigma_{abs}(A_{FB}) \approx 10^{-5} \) with \( A_{FB(EW)} \approx -10^{-2} \) at Belle II
  → Measurement of weak loop corrections to \( \rho \)

- Largest corrections and systematics: QED asymmetry (theory: KKMC, ZFITTER, ...) and detector charge asymmetry

>Belle II First Physics:

- Fine tuning of two track trigger
Precision physics far below the Z pole.

Oblique parameter $T$ at low energy (complementary to APV): Isospin violation from different NP loop contributions to $Z$ and $W$

$$\Delta \rho^\text{new} = \frac{\hat{\Pi}^\text{new}_{WW}(0) - \hat{c}_Z^2 \hat{\Pi}^\text{new}_{ZZ}(0)}{M_W^2 (1 - \Delta \hat{r}_W)} \equiv \frac{\alpha T}{1 - \Delta \hat{r}_W} \approx \alpha_Z T$$

90% C.L., $A_{FB}^\text{W} = 50.00 \text{ ab}^{-1}$, (stat. only)

Contact Interactions at low energy are sensitive to TeV scale NP (involving the second generation)

$$\mathcal{L}_{\text{eff}} = \frac{1}{2} \frac{g^2}{(\Lambda^\pm)^2} \sum_{i,j=L,R} \eta_{ij} \bar{e}_i \gamma_\mu e_i \bar{f}_j \gamma^\mu f_j$$
Belle II offers high sensitivity to New Physics at the Flavour frontier, largely complementary to LHCb

Unique data set of non-Y(4S) data in the first year

Broad low multiplicity program at Belle II, including Dark Sector and Electroweak Precision

Significantly improved two track trigger, better Bhabha veto and single photon trigger

Belle II physics data taking will start 2018
Belle II Theory Interface Platform (B2TIP).

- Joint theory-experiment effort to study the potential impacts of the Belle II program

What's new in Belle II compared to Belle and Babar?
- Efficiencies, precision of hardware
- New software
- New analysis methods
- ...

What's new in theory after Belle, Babar and LHCb?
- Progress in QCD
- New Physics models and constraints
- New observables
- ...

NEW IDEAS!

Next open B2TIP workshop: 27.-29.04.2015, Krakau
http://kds.kek.jp/conferenceDisplay.py?confld=17654
Backup
TABLE XLI: Expected errors on several selected flavour observables with an integrated luminosity of 5 ab$^{-1}$ and 50 ab$^{-1}$ of Belle II data. The current results from Belle, or from BaBar where relevant (denoted with a †) are also given. Items marked with a ‡ are estimates based on similar measurements. Errors given in % represent relative errors.

<table>
<thead>
<tr>
<th>Observables</th>
<th>Belle or LHCb*</th>
<th>Belle II</th>
<th>LHCb</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(2014)</td>
<td>5 ab$^{-1}$</td>
<td>50 ab$^{-1}$</td>
</tr>
<tr>
<td>UT angles</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sin 2\beta$</td>
<td>0.667 ± 0.023 ± 0.012(1.4°)</td>
<td>0.7°</td>
<td>0.4°</td>
</tr>
<tr>
<td>$\alpha$ [°]</td>
<td>85 ± 4 (Belle+BaBar)</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>$\gamma$ [°] (B $\rightarrow$ D$(s)K(s))$</td>
<td>68 ± 14</td>
<td>6</td>
<td>1.5</td>
</tr>
<tr>
<td>$2\beta_s(B_s \rightarrow J/\psi\phi)$ [rad]</td>
<td>0.07 ± 0.09 ± 0.01*</td>
<td>0.053</td>
<td>0.018</td>
</tr>
<tr>
<td>Gluonic penguins</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S(B \rightarrow \phi K^0)$</td>
<td>0.90$^{+0.09}_{-0.10}$</td>
<td>0.053</td>
<td>0.018</td>
</tr>
<tr>
<td>$S(B \rightarrow \eta' K^0)$</td>
<td>0.68 ± 0.07 ± 0.03</td>
<td>0.028</td>
<td>0.011</td>
</tr>
<tr>
<td>$S(B \rightarrow K^0_S K^0_S K^0_S)$</td>
<td>0.30 ± 0.32 ± 0.08</td>
<td>0.100</td>
<td>0.033</td>
</tr>
<tr>
<td>$\beta^\text{eff}_s(B_s \rightarrow \phi \phi)$ [rad]</td>
<td>$-0.17 \pm 0.15 \pm 0.03^*$</td>
<td>0.12</td>
<td>0.03</td>
</tr>
<tr>
<td>$\beta^\text{eff}_s(B_s \rightarrow K^0\bar{K}^0)$ [rad]</td>
<td>$-0.17 \pm 0.15 \pm 0.03^*$</td>
<td>0.12</td>
<td>0.03</td>
</tr>
<tr>
<td>Direct CP in hadronic Decays (\mathcal{A}_L(B \rightarrow K^0\pi^0))</td>
<td>$-0.05 \pm 0.14 \pm 0.05$</td>
<td>0.07</td>
<td>0.04</td>
</tr>
<tr>
<td>UT sides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$</td>
<td>V_{cb}</td>
<td>$ incl.</td>
<td>$41.6 \cdot 10^{-3}(1.2%)$</td>
</tr>
<tr>
<td>$</td>
<td>V_{cb}</td>
<td>$ excl.</td>
<td>$37.5 \cdot 10^{-3}(1\pm 3%<em>{\text{ex.}} \pm 2.7%</em>{\text{th.}})$</td>
</tr>
<tr>
<td>$</td>
<td>V_{ub}</td>
<td>$ incl.</td>
<td>$4.47 \cdot 10^{-3}(1\pm 6%<em>{\text{ex.}} \pm 2.5%</em>{\text{th.}})$</td>
</tr>
<tr>
<td>$</td>
<td>V_{ub}</td>
<td>$ excl. (had. tag.)</td>
<td>$3.52 \cdot 10^{-3}(1\pm 10.8%)$</td>
</tr>
<tr>
<td>Leptonic and Semi-tauonic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mathcal{B}(B \rightarrow \tau\nu)$ [10$^{-6}$]</td>
<td>96(1 ± 26%)</td>
<td>10%</td>
<td>5%</td>
</tr>
<tr>
<td>$\mathcal{B}(B \rightarrow \mu\nu)$ [10$^{-6}$]</td>
<td>&lt; 1.7</td>
<td>20%</td>
<td>7%</td>
</tr>
<tr>
<td>$R(B \rightarrow D\tau\nu)$ [Had. tag]</td>
<td>0.440(1 ± 16.5%)†</td>
<td>5.6%</td>
<td>3.4%</td>
</tr>
<tr>
<td>$R(B \rightarrow D^*\tau\nu)$† [Had. tag]</td>
<td>0.332(1 ± 9.0%)†</td>
<td>3.2%</td>
<td>2.1%</td>
</tr>
<tr>
<td>Radiative</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mathcal{B}(B \rightarrow X_s\gamma)$</td>
<td>3.45 · 10$^{-4}(1 \pm 4.3% \pm 11.6%)$</td>
<td>7%</td>
<td>6%</td>
</tr>
<tr>
<td>$A_{CP}(B \rightarrow X_s\tau\gamma)$ [10$^{-2}$]</td>
<td>$2.2 \pm 4.0 \pm 0.8$</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>$S(B \rightarrow K^0\pi^0\gamma)$</td>
<td>$-0.10 \pm 0.31 \pm 0.07$</td>
<td>0.11</td>
<td>0.035</td>
</tr>
<tr>
<td>$2\beta_s^\text{eff}(B_s \rightarrow \phi\gamma)$</td>
<td>$-0.17 \pm 0.15 \pm 0.03^*$</td>
<td>0.12</td>
<td>0.03</td>
</tr>
<tr>
<td>$S(B \rightarrow \rho\gamma)$</td>
<td>$-0.83 \pm 0.65 \pm 0.18$</td>
<td>0.23</td>
<td>0.07</td>
</tr>
<tr>
<td>$\mathcal{B}(B_s \rightarrow \gamma\gamma)$ [10$^{-6}$]</td>
<td>&lt; 8.7</td>
<td>0.3</td>
<td>-</td>
</tr>
<tr>
<td>Electroweak penguins</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mathcal{B}(B \rightarrow K^{*+}\nu\bar{\nu})$ [10$^{-6}$]</td>
<td>&lt; 40</td>
<td>&lt; 15</td>
<td>30%</td>
</tr>
<tr>
<td>$\mathcal{B}(B \rightarrow K^{+}\nu\bar{\nu})$ [10$^{-6}$]</td>
<td>&lt; 55</td>
<td>&lt; 21</td>
<td>30%</td>
</tr>
<tr>
<td>$C_7/C_9$ (B $\rightarrow X_s\ell\ell$)</td>
<td>$\sim$20%</td>
<td>10%</td>
<td>5%</td>
</tr>
<tr>
<td>$\mathcal{B}(B_s \rightarrow \tau\tau)$ [10$^{-3}$]</td>
<td>-</td>
<td>&lt; 2</td>
<td>-</td>
</tr>
<tr>
<td>$\mathcal{B}(B_s \rightarrow \mu\mu)$ [10$^{-9}$]</td>
<td>$2.9^{+1.1}_{-1.0}$</td>
<td>0.5</td>
<td>0.2</td>
</tr>
</tbody>
</table>
### Backup: Belle II and LHCb

#### TABLE XLII: Continued from previous page.

<table>
<thead>
<tr>
<th>Observables</th>
<th>Belle (2014)</th>
<th>Belle II 5 ab(^{-1})</th>
<th>Belle II 50 ab(^{-1})</th>
<th>LHCb 2018 50 fb(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Charm Rare</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(B(D_s \rightarrow \mu \nu))</td>
<td>(5.31 \cdot 10^{-3}(1 \pm 5.3% \pm 3.8%))</td>
<td>2.9%</td>
<td>0.9%</td>
<td></td>
</tr>
<tr>
<td>(B(D_s \rightarrow \tau \nu))</td>
<td>(5.70 \cdot 10^{-3}(1 \pm 3.7% \pm 5.4%))</td>
<td>3.5%</td>
<td>2.3%</td>
<td></td>
</tr>
<tr>
<td>(B(D^0 \rightarrow \gamma \gamma)) [10(^{-6})]</td>
<td>&lt; 1.5</td>
<td>30%</td>
<td>25%</td>
<td></td>
</tr>
<tr>
<td><strong>Charm CP</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(A_{CP}(D^0 \rightarrow K^+K^-)) [10(^{-4})]</td>
<td>(-32 \pm 21 \pm 9)</td>
<td>11</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>(\Delta A_{CP}(D^0 \rightarrow K^+K^-)) [10(^{-4})]*</td>
<td>3.4</td>
<td>0.5</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>(A_T) [10(^{-2})]</td>
<td>0.22</td>
<td>0.1</td>
<td>0.03</td>
<td>0.02 0.005</td>
</tr>
<tr>
<td>(A_{CP}(D^0 \rightarrow \pi^0\pi^0)) [10(^{-2})]</td>
<td>(-0.03 \pm 0.64 \pm 0.10)</td>
<td>0.29</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td>(A_{CP}(D^0 \rightarrow K_S^0\pi^0)) [10(^{-2})]</td>
<td>(-0.21 \pm 0.16 \pm 0.09)</td>
<td>0.08</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td><strong>Charm Mixing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(x(D^0 \rightarrow K^0_S\pi^+\pi^-)) [10(^{-2})]</td>
<td>0.56 \pm 0.19 \pm 0.07 \pm 0.13</td>
<td>0.14</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>(y(D^0 \rightarrow K^0_S\pi^+\pi^-)) [10(^{-2})]</td>
<td>0.30 \pm 0.15 \pm 0.05 \pm 0.08</td>
<td>0.08</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>(</td>
<td>q/p</td>
<td>(D^0 \rightarrow K^0_S\pi^+\pi^-))</td>
<td>0.90 \pm 0.16 \pm 0.08 \pm 0.06</td>
<td>0.10</td>
</tr>
<tr>
<td>(\phi(D^0 \rightarrow K^0_S\pi^+\pi^-)) [(^\dagger)]</td>
<td>(-6 \pm 11 \pm 4)</td>
<td>6</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td><strong>Tau</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\tau \rightarrow \mu \gamma) [10(^{-9})]</td>
<td>&lt; 45</td>
<td>&lt; 14.7</td>
<td>&lt; 4.7</td>
<td></td>
</tr>
<tr>
<td>(\tau \rightarrow e \gamma) [10(^{-9})]</td>
<td>&lt; 120</td>
<td>&lt; 39</td>
<td>&lt; 12</td>
<td></td>
</tr>
<tr>
<td>(\tau \rightarrow \mu\mu) [10(^{-9})]</td>
<td>&lt; 21.0</td>
<td>&lt; 3.0</td>
<td>&lt; 0.3</td>
<td></td>
</tr>
</tbody>
</table>
Backup: Belle II: $B \to \tau v$. 

**Belle II Projection**

Exp. $L_{\text{sys}} = 46 \text{ ab}^{-1}$

- **Total**
- **Statistics**
- **Systematics**
- **Theory (expected)**
- **Theory (current)**

![Graph showing Belle II projection]

**Integrated Luminosity [ab^{-1}]**
Backup: Belle II $B \rightarrow D^{*}\tau\nu$ and $B \rightarrow D\tau\nu$. 

(a) $B \rightarrow D^{*}\tau\nu$

(b) $B \rightarrow D\tau\nu$
Backup: First physics “Bottomonium below $\Upsilon(4S)$”.

<table>
<thead>
<tr>
<th>$\eta_b(1S')$</th>
<th>Resolve discrepancies on the mass and width, based on measurements of radiative transitions.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta_b(2S')$</td>
<td>Independent confirmation of $\Upsilon(2S')$ properties, and tests of hyperfine splitting against theoretical predictions.</td>
</tr>
<tr>
<td>$\Upsilon(1^3D_1), \Upsilon(1^3D_3)$</td>
<td>Precise measurement of multi-photon cascade decays to separate $J = 1, 3$ (not seen) states from the $J = 2$ (seen) state.</td>
</tr>
<tr>
<td>$\Upsilon(1^3D_1)$</td>
<td>Inclusive photon spectra of $\Upsilon(3S)$ decays.</td>
</tr>
<tr>
<td>$R_b$ near $\Upsilon(3S), \Upsilon(2^3D_2)$-triplet</td>
<td>Search for unseen $\Upsilon(1D)$ states and the unseen $\Upsilon(2^3D_2)$ triplet via $R_b$ scan methods.</td>
</tr>
<tr>
<td>$h_b$</td>
<td>First observation and resonance characterisation.</td>
</tr>
<tr>
<td>Inclusive decays ($\chi_b, \Upsilon$)</td>
<td>Surveys of inclusive hadronic transitions of $\chi_b$ and $\Upsilon(2S, 3S)$.</td>
</tr>
<tr>
<td>Dipion transitions</td>
<td>Surveys of dipion transitions between $\chi_b$ states (analogous to $\Upsilon$).</td>
</tr>
</tbody>
</table>
Backup: First physics “Bottomonium below Y(4S)”.

The diagram shows the spectrum of bottomonium states with their corresponding masses in MeV/c² and angular momentum JPC. The chart includes not only the Y(4S) and Y(5S) states but also other open flavour threshold states such as Y(2D₂) and Z(10650). The figure is a representation of the open charm and bottomonium physics, highlighting the theoretical predictions and established experimental data.
Backup: First physics “Bottomonium above $\Upsilon(4S)$”.

<table>
<thead>
<tr>
<th>$R_b$</th>
<th>Inclusive $b$ cross section as a function of $E_{CM}$ up to $\Upsilon(6S)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z_b$ from scans</td>
<td>Analysis of $\pi + Z_b$ substructure through $\sigma(\Upsilon + 2\pi)$ and $\sigma(h_b(nP) + 2\pi)$ through an $E_{CM\text{scan}}$</td>
</tr>
<tr>
<td>$Z_b$ near resonance</td>
<td>Analysis of $Z_b$ charged and neutral from $\Upsilon(6S)$</td>
</tr>
<tr>
<td>Tetra quark states</td>
<td>Analysis of radiative or $2\pi$ transitions from $\Upsilon(6S)$</td>
</tr>
<tr>
<td>Other exotica</td>
<td>Searches for exotic states with single $\pi$ transitions from $\Upsilon(5S)$ and $\Upsilon(6S)$</td>
</tr>
<tr>
<td>$\sigma(B^{(<em>)}B^{(</em>)})$ and $\sigma(B_s^{(<em>)}B_s^{(</em>)})$</td>
<td></td>
</tr>
<tr>
<td>$W_b$, $X_b$</td>
<td>Studies of radiative transitions from $\Upsilon(6S)$ to new bottomonium-like states and $\chi_{bJ}$.</td>
</tr>
<tr>
<td>$m_b$</td>
<td>Accurate determination of $m_b$ via bottomonium sum-rules. Precision tests of discrepancies between pQCD and $e^+e^-$ data near the accelerator threshold region.</td>
</tr>
</tbody>
</table>
Backup: First physics “Bottomonium above Y(4S)”.

Voloshin PRD84, 031502 (2011)

\[
\begin{align*}
|Z_s\rangle &= \frac{1}{\sqrt{2}} 0_b^- \otimes 1_{Q_y}^+ - \frac{1}{\sqrt{2}} 1_{bb}^- \otimes 0_{Q_y}^+ \\
|Z_s\rangle &= \frac{1}{\sqrt{2}} 0_{bb}^- \otimes 1_{Q_y}^+ + \frac{1}{\sqrt{2}} 1_{bb}^- \otimes 0_{Q_y}^+ \\
|W_{s0}\rangle &= \frac{\sqrt{3}}{2} 0_{bb}^- \otimes 0_{Q_y}^+ - \frac{1}{2} 1_{bb}^- \otimes 1_{Q_y}^+ \\
|W_{s0}\rangle &= \frac{1}{2} 0_{bb}^- \otimes 0_{Q_y}^+ + \frac{\sqrt{3}}{2} 1_{bb}^- \otimes 1_{Q_y}^+ \\
|W_{s1}\rangle &= (1_{bb}^- \otimes 1_{Q_y}^+)^{i=1} \\
|W_{s2}\rangle &= (1_{bb}^- \otimes 1_{Q_y}^+)^{i=2}
\end{align*}
\]