Belle II first results and prospects for LFU tests
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for the Belle II Collaboration
$B$ decays and LFV/LFU

- Leptonic decays $B^\pm \rightarrow \ell^\pm \nu$

- Semileptonic decays $B \rightarrow X\ell\nu$

- FCNC processes $B \rightarrow X_{s(d)}\ell^+\ell^-$. 
Current status of LFV/LFU in B-factories
Belle: Semileptonic decays $R_D$ and $R_{D^*}$

- experimental method depends on what we measure
  - tagging,
  - signal reconstruction ($\tau$ decay channels)
- $q^2 \equiv M_W^2$ - effective mass squared of the $\tau\nu$ system
- $R_D = \frac{\mathcal{B}(B \to D \tau \nu)}{\mathcal{B}(B \to D \ell \nu)}$
- $R_{D^*} = \frac{\mathcal{B}(B \to D^* \tau \nu)}{\mathcal{B}(B \to D^* \ell \nu)}$

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Tag method</th>
<th>$\tau^-$ decays</th>
<th>Observables</th>
<th>Fit variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belle PRL 99, 191807 (2007)</td>
<td>Hadronic Inc.</td>
<td>$e^- \nu_\tau \bar{\nu}<em>\ell, \pi \nu</em>\tau$</td>
<td>$\mathcal{B}(\bar{B}^0 \to D^{*-} \tau^- \bar{\nu}_\tau)$</td>
<td>$M_{bc}^{\text{comp}}$</td>
</tr>
<tr>
<td>Belle PRD 82, 072005 (2010)</td>
<td>Hadronic Inc.</td>
<td>$\ell^- \nu_\tau \bar{\nu}<em>\ell, \pi \nu</em>\tau$</td>
<td>$\mathcal{B}(B^- \to D^{(*)0} \tau^- \bar{\nu}_\tau)$</td>
<td>$M_{bc}^{\text{comp}}$ and $p_{D^0}$</td>
</tr>
<tr>
<td>Belle PRD 92, 072014 (2015)</td>
<td>Hadronic</td>
<td>$\ell^- \nu_\tau \bar{\nu}_\ell$</td>
<td>$R_D, R_{D^*}, q^2,</td>
<td>p_\ell^*</td>
</tr>
<tr>
<td>Belle PRL 118, 211801 (2017)</td>
<td>Hadronic</td>
<td>$h^- \nu_\tau$</td>
<td>$R_{D^<em>}, P_\tau(D^</em>)$</td>
<td>$E_{ECL}$ and $\cos \theta_{\text{helo}}$</td>
</tr>
<tr>
<td>Belle PRD 94, 072007 (2016)</td>
<td>Semileptonic</td>
<td>$\ell^- \nu_\tau \bar{\nu}_\ell$</td>
<td>$R_{D^*},</td>
<td>p_\ell^*</td>
</tr>
<tr>
<td>Belle preliminary conf-1902</td>
<td>Semileptonic FEI</td>
<td>$\ell^- \nu_\tau \bar{\nu}_\ell$</td>
<td>$R_{D}, R_{D^*}$</td>
<td>$E_{ECL}$ and $O_{BDT}^{\uparrow}$</td>
</tr>
</tbody>
</table>
**$R_D$ and $R_D^*$ current status**

- New preliminary semileptonic tag based measurement of $R_D, R_D^*$ is consistent with the old result, more precise.
- Recent measurements from Belle and LHCb reduce tensions with SM
- Combined Belle result is consistent with SM at $2\sigma$ level
$R_D$ and $R_{D^*}$ current status

- New preliminary semileptonic tag based measurement of $R_D$, $R_{D^*}$ is consistent with the old result, more precise.
- Recent measurements from Belle and LHCb reduce tensions with SM
- Combined Belle result is consistent with SM at 2$\sigma$ level

The dynamics of these decays can be probed with differential distributions $q^2$, $\tau$ and $D^*$ polarizations ...
Recent $R_K$ and $R_{K^*}$

$$R_K = \frac{\mathcal{B}(B \to K\mu\mu)}{\mathcal{B}(B \to K\ell\ell)}$$

$$R_{K^*} = \frac{\mathcal{B}(B \to K^{*}\mu\mu)}{\mathcal{B}(B \to K^{*}\ell\ell)}$$

- Recent preliminary results for both $R_K$ and $R_{K^*}$ from Belle (arXiv:1904.02440)
- Belle measured $R_{K^*}^+$ and $R_{K_S}$ for first time,
- Allow measurement of CP averaged isospin asymmetry
  \[
  A_I = \frac{(\tau_{B^+}/\tau_{B^0}) \times \mathcal{B}(B^0 \to K^0 \ell\ell) - \mathcal{B}(B^+ \to K^{+} \ell\ell)}{(\tau_{B^+}/\tau_{B^0}) \times \mathcal{B}(B^0 \to K^0 \ell\ell) + \mathcal{B}(B^+ \to K^{+} \ell\ell)}
  \]
- New measurements are closer to the SM (and consistent with LHCb)
Belle II first results
The Belle II experiment

- The Belle II experiment is an upgrade of Belle detector
- Electron-positron collisions
- $E_{\text{CM}} \approx m_{\Upsilon(4S)}$
- $\Upsilon(4S) \rightarrow \bar{B}B$, quantum-entangled
- Particularly well adapted to study $B$ decays with missing energy; especially with multiple $\nu$ in final state
- Target plan 55 billion $B$ meson pairs decays recorded
- Sensitivity in $B$, charm and $\tau$ to $O(10^{-9}) - O(10^{-11})$ branching fractions
SuperKEKB/BEllE II Luminosity profile

Belle/KEKB recorded $\approx 1000 \text{ fb}^{-1}$

- Beam currents only a factor of two higher than KEKB ($\approx$ PEPII)
- "nano-beams" are the key; vertical beam size is 50nm at the IP
Spring 2019, First Physics Run with full Detector

- only 2 months of collisions
- $L(\text{peak}) \approx 5.5 \times 10^{33} / cm^2 / s$
Spring 2019, First Physics Run with full Detector

- only 2 months of collisions
- \( L(\text{peak}) \approx 5.5 \times 10^{33} / \text{cm}^2 / \text{s} \)
- \( L(\text{SuperKEKB}) \approx 1.2 \times 10^{34} / \text{cm}^2 / \text{s} \)
- Luminosity comparable to PEP-II records
- background to large to turn Belle II
$B$ meson counting

$$H_l = \sum_{i,j} \frac{|P_i||P_j|}{E_{vis}^j} P_l(\cos \theta_{ij})$$

$P_i, j$: Momentum of charged tracks or Energy neutral clusters

$\theta_{ij}$: Opening angle between $i$th and $j$th particle

**Belle II 2019 Preliminary**

$\int L dt = 2.62 \text{ fb}^{-1}$

$$R_2 = \frac{H_2}{H_0}$$
Rediscovery of $B \rightarrow D^{(*)}\pi^\pm \rho^\pm B \approx \text{few 0.1\%}$

$\int L \, dt = 2.62 \, \text{fb}^{-1}$

$$m_{bc} = \sqrt{E_{\text{beam}}^2 - p_B^*} \approx m_B^2$$
Rediscovery of $B^0 \rightarrow D^{*-}\ell^+\nu_\ell \ B \approx 11\%$

\[
m^2_{\text{miss}} = \left( \frac{1}{2}E_{\text{beam}}(0,0,0) - p_{D^*\ell}^* \right)^2 \approx p_\nu^2 = 0 \text{ GeV}^2
\]

\[
\cos \theta_{B,D^{*-}\ell} = \frac{2E_B E_{D^*\ell} - m_B^2 - m_{D^*\ell}^2}{2 | \vec{p}_B | | \vec{p}_{D^*\ell} |}
\]
Rediscovery of $B^0 \rightarrow D^{*-} \ell^+ \nu_{\ell}$

1. $\ell = e$

2. $\ell = \mu$
Hadronic Tagging with the Full Event Interpretation

**Inclusive Tag**
- $\epsilon = \mathcal{O}(100)\%$
- Consistency of $B_{\text{tag}}$

**Semileptonic Tag**
- $\epsilon = \mathcal{O}(1)\%$
- Knowledge of $B_{\text{tag}}$

**Hadronic Tag**
- $\epsilon = \mathcal{O}(0.1)\%$
- Exact knowledge of $B_{\text{tag}}$

$$p_\nu = \left( p_{e^+e^-} - p_{B_{\text{tag}}} - p_\ell \right)$$
Hadronic Tagging with the Full Event Interpretation

- Tracks
- Displaced Vertices
- Neutral Clusters

≤e⁺, μ⁻, K⁺, π⁺, K_L⁰, γ

J/ψ

K_S⁰

D⁺ D_S⁻, D⁻ D⁺ S

B⁰, B⁺

- signal-side
  - B_π
  - B_π
  - ν_
  - ν_

- tag-side
  - Υ(4S)
  - B_π
Hadronic Tagging with the Full Event Interpretation

- Significant improvement of performance

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Hadronic</th>
<th>Semileptonic</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEI</td>
<td>B^±</td>
<td>B^0</td>
</tr>
<tr>
<td>FEI with FR channels</td>
<td>0.53% 0.33%</td>
<td>0.76% 0.46%</td>
</tr>
<tr>
<td>FEI</td>
<td>0.33% 0.46%</td>
<td>0.53% 0.33%</td>
</tr>
<tr>
<td>FEI</td>
<td>1.80% 2.04%</td>
<td>1.80% 2.04%</td>
</tr>
<tr>
<td>FEI</td>
<td>0.53% 0.33%</td>
<td>0.53% 0.33%</td>
</tr>
</tbody>
</table>

Published in Computing and Software for Big Science
Full Event Interpreter (FEI) at Belle II

**Loose Selection**

**Tight Selection**

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**B^±_tags**

\[ \text{Belle II preliminary} \quad \int \mathcal{L} \, dt = 0.41 \text{fb}^{-1} \]

- Correctly reconstructed
- Continuum & mis-reconstructed
- Data

- \( N_{\text{tag}} = 1066 \pm 77 \)
- \( \rho_{\text{tag}} > 0.1 \)

---

**B^0_\text{tags**}

\[ \text{Belle II preliminary} \quad \int \mathcal{L} \, dt = 0.41 \text{fb}^{-1} \]

- Correctly reconstructed
- Continuum & mis-reconstructed
- Data

- \( N_{\text{tag}} = 663 \pm 35 \)
- \( \rho_{\text{tag}} > 0.1 \)

---

**B^±_tags**

\[ \text{Belle II preliminary} \quad \int \mathcal{L} \, dt = 0.41 \text{fb}^{-1} \]

- Correctly reconstructed
- Continuum & mis-reconstructed
- Data

- \( N_{\text{tag}} = 409 \pm 31 \)
- \( \rho_{\text{tag}} > 0.5 \)

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**B^0_\text{tags**}

\[ \text{Belle II preliminary} \quad \int \mathcal{L} \, dt = 0.41 \text{fb}^{-1} \]

- Correctly reconstructed
- Continuum & mis-reconstructed
- Data

- \( N_{\text{tag}} = 299 \pm 26 \)
- \( \rho_{\text{tag}} > 0.5 \)
Belle II prospects for LFU tests
$D^*$ and $\tau$ polarizations in $B \to D^*\tau\nu_{\tau}$

Observables that can give a better insight into the dynamics of $b \to c\tau\nu$ transitions: $q^2$, longitudinal and transverse polarizations of $\tau$ and $D^*$.
So far experiments measured $q^2$ distributions (and lepton spectra)
Belle measured longitudinal polarizations:

- $P_\tau(D^*) = \frac{\Gamma^+(D^*) - \Gamma^-(D^*)}{\Gamma^+(D^*) + \Gamma^-(D^*)}$
  $\Gamma^\pm(D^*)$: decay rate with $\tau$ helicity $\lambda_\tau = \pm \frac{1}{2}$

- $F_L^{D^*} = \frac{\Gamma(D^*_{L,T})}{\Gamma(D^*_{L,T}) + \Gamma(D^*_{T,T})}$
  $\Gamma(D^*_{L,T})$: decay rate of longitudinally (transversely) polarized $D^*$

$B \to \bar{D}^* \tau^- \nu_\tau$ distribution : $\tau$ polarisation


Measured from the two body semileptonic $\tau (\to \pi \nu, \to \rho \nu)$ decays -experimentally challenging

$$P_\tau(D^*) = -0.38 \pm 0.51{_{\text{stat}}}^{+0.16}_{-0.16}{_{\text{syst}}}$$

Belle II perspectives:

<table>
<thead>
<tr>
<th>$P_\tau(D^*)$</th>
<th>5 ab$^{-1}$</th>
<th>50 ab$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pm 0.18 \pm 0.08$</td>
<td>$\pm 0.06 \pm 0.04$</td>
<td></td>
</tr>
</tbody>
</table>
$B \rightarrow \bar{D}^* \tau^- \nu_\tau$ distribution : $D^*$ polarisation

$$\frac{1}{\Gamma} \frac{d\Gamma}{d \cos \theta_{\text{hel}}(D^*)} = \frac{3}{4} \left[ 2 F_{L}^{D^*} \cos^2(\theta_{\text{hel}}(D^*)) + (1 - F_{L}^{D^*}) \sin^2(\theta_{\text{hel}}(D^*)) \right]$$

All $\tau$ decays are usable.

Preliminary Belle result arXiv:1903.03102

Large efficiency variation $\rightarrow$ experimentally difficult

Belle: $F_{L}^{D^*} = 0.60 \pm 0.08(\text{stat}) \pm 0.04(\text{sys})$

$F_{L}^{D^*} = 0.60 \pm 0.08(\text{stat.}) \pm 0.035(\text{syst.})$

SM: $F_{L}^{D^*} = 0.46 \pm 0.03$ (Phys. Rev. D 95, 115038 (2017), A.K. Alok, et al) (1.5 $\sigma$)

SM: $F_{L}^{D^*} = 0.441 \pm 0.006$ (arXiv:1808.03565, Z-R. Huang, et al) (1.8 $\sigma$)

Expected number of events for $F_{L}^{D^*}$ in full data set is $\sim 15000$. 
Prospects for $B \rightarrow D^{(*)+} \tau \nu$ at Belle II

### Composition of the systematic uncertainties in each Belle analysis

<table>
<thead>
<tr>
<th>Source</th>
<th>$R_D$</th>
<th>$R_{D^*}$</th>
<th>$R_{D^*}$</th>
<th>$R_{D^*}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MC statistics</td>
<td>4.4%</td>
<td>3.6%</td>
<td>2.5%</td>
<td>+4.0%</td>
</tr>
<tr>
<td>$B \rightarrow D^{**} \ell \nu_\ell$</td>
<td>4.4%</td>
<td>3.4%</td>
<td>+1.0%</td>
<td>2.3%</td>
</tr>
<tr>
<td>Hadronic $B$</td>
<td>0.1%</td>
<td>0.1%</td>
<td>1.1%</td>
<td>+7.3%</td>
</tr>
<tr>
<td>Other sources</td>
<td>3.4%</td>
<td>1.6%</td>
<td>+1.8%</td>
<td>5.0%</td>
</tr>
<tr>
<td>Total</td>
<td>7.1%</td>
<td>5.2%</td>
<td>+3.4%</td>
<td>+10.0%</td>
</tr>
</tbody>
</table>

*"The Belle II Physics Book", arXiv:1808.10567*

- The uncertainty due to MC statistic is reducible
  - MC statistic affects the estimation of the reconstruction efficiency, understanding of the cross-feed components and PDFs for the fit
- Efficiency is model dependent: $q^2$ and others distributions with used model. Belle II will reduce model dependency by measuring differential distribution.
- The uncertainties from $\mathcal{B}(B \rightarrow D^{**} \ell \nu_\ell)$, $D^{**}$ decays and hadronic $B$ decays have to be reduced.
  - Need for dedicated measurements of $B \rightarrow D^{**} \ell \nu_\ell$ and hadronic $B$ decays with a large data sample.
Testing lepton flavor universality with leptonic $B$ decays

Very clean theoretically, hard experimentally SM is helicity suppressed
Sensitive to NP contribution (charged Higgs)

\[
R^{\mu\mu} = \frac{\Gamma(B \to \mu\nu)}{\Gamma(B \to \tau\nu)} \\
R^{e\mu} = \frac{\Gamma(B \to e\nu)}{\Gamma(B \to \tau\nu)} \\
R^{\tau\tau} = \frac{\Gamma(B \to \tau\nu)}{\Gamma(B \to \pi l\nu)}
\]

\[
B(B \to l\nu) = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B
\]

SM test in $B$ measurement

<table>
<thead>
<tr>
<th>Mode</th>
<th>SM BR</th>
<th>Current meas.</th>
<th>Belle II 5 ab-1</th>
<th>Belle II 50 ab-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau\nu$</td>
<td>$10^{-4}$</td>
<td>20% uncertainty</td>
<td>15%</td>
<td>6%</td>
</tr>
<tr>
<td>$\mu\nu$</td>
<td>$10^{-6}$</td>
<td>40% uncertainty*</td>
<td>20%</td>
<td>7%</td>
</tr>
<tr>
<td>$e\nu$</td>
<td>$10^{-11}$</td>
<td>Beyond reach</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* arXiv:1712.04123 2.4σ excess [2.9,10.7]x10^{-7} at 90% C.L.

Belle II Full simulation with expected background conditions (hadronic tags only)
S.L. tag expected to have similar sensitivity

Extrapolation of Belle Analysis
Semileptonic $B$ decays with $b \to s \ell^+ \ell^-$ transitions

- reconstruction of exclusive decays is very straightforward and well established at Belle
  - improvement in reconstruction possible at Belle II
- Belle II have tools (FEI) for fully inclusive measurement; unique position for measurement with different systematic errors.
- $B$ and $q^2$ distributions are already systematic dominated at LHCb
  - still we can test the deficit of muon modes observed by LHCb
  - and recheck the region of higher charmonium contributions of $q^2 > 14.4 \text{ Gev}^2$
- Belle measurement of $A_{I}(B \to K \ell^+ \ell^-)$ lead to isospin violation check
- angular analysis is a very important topic at Belle II
New Physics in $b \to s \ell^+ \ell^-$

Prepared by D. Straub et al. for the Belle II Physics Book (edited by P. Urquijo and E. Kou)

Belle II can do both inclusive and exclusive. Equally strong capabilities for electrons and muons.
Prospects on LFU

NP discovery

\[ b \rightarrow s\tau\tau \]

\[ R_{pl} = \frac{\Gamma(B \rightarrow \tau\nu)}{\Gamma(B \rightarrow \mu\nu)} \]

\[ R(D), \ R(D^*) \ 5\sigma \]

Siege

\[ B \rightarrow D(\ast)\tau\nu \ q^2 \text{ distr. and polarizations} \]

First shots

\[ B \rightarrow \tau\nu \ 5\sigma \]

\[ B \rightarrow \mu\nu \ 3\sigma \]

\[ R(D^*) \text{ first result} \]
• Belle II experiment has started physics runs and expect to accumulate ≈ 50 times larger data sample then previous B-factories, which will be crucial for rare and decays with missing energy
• Belle II is an excellent detector for lepton universality studies, especially for the channels involving missing energy. Same is true for $ee$ vs $\mu\mu$ channels, due to similar reconstruction efficiency.
• The $B \to D(\ast)\ell\nu$ channels at Belle II are statistically limited, however for $R_{D(\ast)}$ better modeling of $B \to D^{\ast\ast}\ell\nu$ and generally hadronic $B$ decays is necessary.
• Belle II ML-based full event interpretation tagging method improves $B$ meson tagging compared to Belle.
Backup
Kinematic variables describing $B \rightarrow \bar{D}(\ast)\tau^{-}\nu_{\tau}$

- $q^2 \equiv M_W^2$ - effective mass squared of the $\tau\nu$ system
- $\theta_{\tau}$ - angle between $\tau$&$B$ in $W^*$ rest frame
- $\chi$ - angle between the $\tau\nu$ and $D^*$ decay planes
- $\theta_{\text{hel}}(D^*)$ - angle between $D$&$B$ in $D^*$ rest frame
- $\theta_{\text{hel}}(\tau)$ - angle between $\pi$& direction opposite to $W^*$ in $\tau$ rest frame

\[
\frac{d\Gamma}{d\cos\theta_{\text{hel}}(\tau)} = \frac{1}{2} (1 + \alpha P_{\tau} \cos\theta_{\text{hel}}(\tau))
\]

- $\alpha = 1.0$ for $\tau \rightarrow \pi\nu$; $\alpha = 0.45$ for $\tau \rightarrow \rho\nu$

\[
\frac{1}{\Gamma} \frac{d\Gamma}{d\cos\theta_{\text{hel}}(D^*)} = \frac{3}{4} [2F_L^{D^*} \cos^2(\theta_{\text{hel}}(D^*)) + (1 - F_L^{D^*}) \sin^2(\theta_{\text{hel}}(D^*))]
\]

$q^2, \cos\theta_{\text{hel}}(\tau)$ and $\cos\theta_{\text{hel}}(D^*)$ can be reconstructed at B-factories with hadronic decays of $B_{\text{tag}}$
Testing lepton flavor universality in $b \to u$ semileptonic decays

$$R(\pi) = \frac{\mathcal{B}(B \to \pi \tau^+ \nu_\tau)}{\mathcal{B}(B \to \pi \ell^+ \nu_\tau)}$$

Feasibility already demonstrated with Belle. No statistically significant signal was observed $\mathcal{B}(B \to \pi \tau^+ \nu_\tau) < 2.5 \times 10^{-4}$


Central value:

$\mathcal{B}(B \to \pi \tau^+ \nu_\tau) = (1.52 \pm 0.72 \pm 0.13) \times 10^{-4}$

Belle II extrapolation of uncertainty:

$R_{5}^{5ab^{-1}} \pm 0.23$ or $R_{5}^{50ab^{-1}} \pm 0.09$
General Outlook for next years

- Uncertainties of CKM $\alpha, \gamma < 2^\circ$
- Fully establish or rule out NP in $R(D/D^*)$
- Resolve $|V_{ub}|/|V_{cb}|$
- Discovery of $B \to K^{(*)}\nu\nu$
- ?
- Discovery of $B \to \mu\nu$

[Graph showing integrated luminosity and peak luminosity over different years]
Lepton Flavor Violation in $\tau$ Decays at Belle II

- **Super B-Factory, and $\tau$ factory too!**
  $\sigma(e^+e^- \rightarrow \gamma(4s)) = 1.05 \text{ nb}$
  $\sigma(e^+e^- \rightarrow \tau\tau) = 0.92 \text{ nb}$

- Charged LPV process occur oscillations in loops. In SM, small rate is immeasurable ($10^{-49} \sim 10^{-54}$) for all LFV decays.

  $$B(l_1 \rightarrow l_2 \gamma) = \frac{3\alpha}{32\pi} \left| \sum_{i=2,3} U_{l_1,i}^* U_{l_2,i} \frac{\Delta m_{l_1}^2}{M_W^2} \right|^2$$

- Charged LFV enhanced in many NP models ($10^{-7} \sim 10^{-10}$)

Talk by Ami Rostomyan at TAU 2018

- Thrust axis (T) is maximising the event shape variable

Thrust and visible energy are useful variables in analysis.
Belle II physics

Very Rich Physics Program!

SuperKEKB: the nano beam scheme

Lower emittance beam
DR for LER
and RF gun

Beam current

Beam-beam parameter

σ: beam size

β function

<table>
<thead>
<tr>
<th></th>
<th>KEKB</th>
<th>SuperKEKB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LER</td>
<td>HER</td>
</tr>
<tr>
<td>Beam energy</td>
<td>$E_b$</td>
<td>3.5</td>
</tr>
<tr>
<td>Beam crossing angle</td>
<td>$\varphi$</td>
<td>22</td>
</tr>
<tr>
<td>$\beta$ function @ IP</td>
<td>$\beta_x/\beta_y$</td>
<td>1200/5.9</td>
</tr>
<tr>
<td>Beam current</td>
<td>$I_b$</td>
<td>1.64</td>
</tr>
<tr>
<td>Luminosity</td>
<td>$L$</td>
<td>$2.1 \times 10^{34}$</td>
</tr>
</tbody>
</table>
Belle II detector

- The Belle II detector has better resolution, PID and capability to cope with higher background.
New Physics in $b \rightarrow s\ell^+\ell^-$

- **Dilepton**
  - Electron selected from dE/dx in CDC and ECL
  - Muon from KLM
  - We might be able to use TOP and ARICH for low momentum region which improve efficiency for low $q^2$ region

- **$X$s**
  - is reconstructed from $K^n\pi$ ($0 \leq n \leq 4$).
  - We can add three kaon modes and $\eta$ modes (two pi0 modes?)

- **Backgrounds**
  - Dominated by $B \rightarrow X\ell\nu$ and $B \rightarrow Y\ell\nu$
    - Second largest is $ee \rightarrow cc$ but event shape information can suppress the background.
  - Can be suppressed with missing energy and vertex information.

---

Challenges for $D^*$ polarisation measurement

Main experimental problem:
strong acceptance effects for $\cos \theta_{hel}(D^*) \geq 0.0$

efficiency

distribution of slow $\pi^{\pm}$ from $D^*$

Effectively only $\cos \theta_{hel}(D^*) < 0$ is useful for $F_{L}^{D^*}$ measurement
Measurement of $\tau$ polarization in $B$ decays

- both $\bar{B}^0$ and $B^-$ decays are used; only 2 body $\tau$ decays: $\tau \rightarrow \pi\nu, \rho\nu$
- sample divided into two bins of $\cos\theta_{hel}$:
  - I: $-1 < \cos\theta_{hel} < 0$
  - II: $0 < \cos\theta_{hel} < 0.8$ (for $\tau \rightarrow \pi\nu$)

**Experimental challenges**

- Distribution of $\cos\theta_{hel}(\tau)$ is modified by:
  - cross-feeds from other $\tau$ decays (contribute mainly in the region of $\cos\theta_{hel}(\tau) < 0$)
  - peaking background (concentrated around $\cos\theta_{hel}(\tau) \approx 1$)
- corrections for detector effects: acceptance, asymmetric $\cos\theta_{hel}$ bins, crosstalks between different $\tau$ decays
- for $\tau \rightarrow \pi(\rho)\nu$ modes combinatorial background from poorly known hadronic $B$ decays

$$P_\tau = \frac{2}{\alpha} \frac{\Gamma_{\cos\theta_{hel}>0} - \Gamma_{\cos\theta_{hel}<0}}{\Gamma_{\cos\theta_{hel}>0} + \Gamma_{\cos\theta_{hel}<0}}$$
Differential distribution can be measured to constrain NP contributions
Detailed measurement of $q^2$ and other kinematic distributions including polarization of the $\tau$ and $D^*$

Belle II MC are generated in the SM hypothesis
Block histograms is a 2HDM-type II benchmark