Belle II and flavor physics in $e^+e^-$

EPS-HEP, Ghent, July 16, 2019

Francesco Forti,
INFN and University, Pisa
Outline

- **Flavor** opens a window on new physics
- $e^+e^-$ colliders provide good lenses to look through the window
- Recent results from:
  - BES III
  - Babar
  - Belle
- The promise of the future: Belle II
  - Initial running and performance
  - Perspectives

Note: most links are active, just click on the ad.
Past successes of flavor

- suppression of $K_L^0 \rightarrow \mu^+ \mu^-$ decays
  $\Rightarrow$ existence of charm quark by GIM mechanism
- $K^0 \bar{K}^0$ oscillations, $B^0 \bar{B}^0$ oscillations
  $\Rightarrow$ charm and top quark masses
- CPV in $K^0$ systems
  $\Rightarrow$ 3rd generation of quarks & KM mechanism

Indirect discoveries of flavor experiments
Precision measurement of CKM elements
The power of flavor

- **Explore the origin of CP violation**
  - Key element for understanding the matter content of our present universe
  - Established in the B meson in 2001
  - Direct CPV established in B mesons in 2004

- **Precisely measure parameters of the standard model**
  - For example the elements of the CKM quark mixing matrix
  - Disentangle the complicated interplay between weak processes and strong interaction effects

- **Search for the effects of physics beyond the standard model in precision measurements**
  - Potentially large effects on rates of rare decays, time dependent asymmetries, lepton flavor violation
  - Sensitive to large New Physics scale, as well as to phases and size of NP coupling constants

- **Lepton Flavour Universality / Violation tests**
Flavor Physics \rightarrow BSM

- EW Hierarchy… driven by the top in SM
- Strong CP problem
- Origin of weak CP and matter-antimatter asymmetry
- Flavour puzzle (quarks, charged leptons, neutrinos)

*Flavour is the usual graveyard of BSM electroweak theories*
Advantages of $e^+e^-$ flavor production
(compared to hadron machines)

- Coherent and well defined initial state and no additional interactions
- Low (physics) backgrounds, high trigger efficiency, little bias
- Excellent neutral reconstruction ($\gamma, n^0, K_L$)
- Good kinematic and vertex resolution
- High flavor-tagging efficiency with low dilution
- Many channels are unique to $e^+e^-$ flavor factories
- Absolute branching fractions can be measured.
- Can look at
  - Forbidden decays, invisible decays
  - Asymmetries (CP, isospin)
  - Angular distribution
- Systematics quite different from hadronic machines. If NP is seen by one of the experiments, confirmation by the other would be important.

Price to pay: much smaller cross section

Asymmetric energies to measure $\Delta t$
Experiments and data sets

Current D/D/Λc analyses are based 2.9/3.2/0.567 fb⁻¹ data at 3.773/4.178/4.6 GeV

Beam energy: 1.0-2.3 GeV
Optimum energy: 1.89 GeV
Designed luminosity: 1.00×10³³ cm⁻²s⁻¹
Data taken from: 2009
Achieved luminosity: 1.00×10³³ cm⁻²s⁻¹

BESS III @ BEPCII: 2009--

Belle II

Belle BaBar Belle II (per year)

<table>
<thead>
<tr>
<th>Channel</th>
<th>Belle</th>
<th>BaBar</th>
<th>Belle II (per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BB</td>
<td>7.7 × 10⁶</td>
<td>4.8 × 10⁸</td>
<td>1.1 × 10¹⁰</td>
</tr>
<tr>
<td>B(±)B(±)</td>
<td>7.0 × 10⁶</td>
<td>–</td>
<td>6.0 × 10⁸</td>
</tr>
<tr>
<td>Υ(1S)</td>
<td>1.0 × 10⁸</td>
<td>–</td>
<td>1.8 × 10¹²</td>
</tr>
<tr>
<td>Υ(2S)</td>
<td>1.7 × 10⁸</td>
<td>0.9 × 10⁷</td>
<td>7.0 × 10¹⁰</td>
</tr>
<tr>
<td>Υ(3S)</td>
<td>1.0 × 10⁷</td>
<td>1.0 × 10⁸</td>
<td>3.7 × 10¹⁰</td>
</tr>
<tr>
<td>Υ(5S)</td>
<td>3.6 × 10⁷</td>
<td>–</td>
<td>3.0 × 10⁹</td>
</tr>
<tr>
<td>ττ</td>
<td>1.0 × 10⁹</td>
<td>0.6 × 10⁹</td>
<td>1.0 × 10¹⁰</td>
</tr>
</tbody>
</table>

BABAR @ PEP-II: 1999-2008

Belle II & Flavor

BELLE @ KEKB: 1999-2010
Recent results

- **BES III**
  - Charm Decays
  - Lepton Flavor Universality tests

- **BABAR**
  - 4D analysis of $B \to D^* \ell \nu$ decay
  - Rare D decays
  - Lepton Flavor and Lepton Number Violations in $D^0$ decays

- **BELLE**
  - Update on $R(K^*)$ and $R(K)$
  - Update on $R(D^*)$
BES III – Charm decays

- Leptonic and hadronic decays of charmed hadrons ($D^0$, $D^+$, $D_s^+$, $\Lambda_c^+$) provide ideal test-beds to explore weak and strong effects

1. $|V_{cs(d)}|$: better test on CKM matrix unitarity
2. [Semi-]leptonic $D_{(s)}$ decays allow for LFU tests
3. $f_{D(s)+}$, $f_{+}^{K(\pi)}(0)$: better calibrate LQCD
BES III LFU Tests

- **Leptonic $D_{(s)}$ decays**
  
  \[
  \frac{B[D^+ \to \tau^+ \nu]}{B[D^+ \to \mu^+ \nu]} = 3.21 \pm 0.64_{\text{stat}}
  \]

- **Semileptonic $D$ decays to $\pi$ & $K$**
  
  \[
  \frac{\Gamma[D^0 \to \pi^- \mu^+ \nu]}{\Gamma[D^0 \to \pi^- e^+ \nu]} = 0.922 \pm 0.030 \pm 0.022 (0.985)
  \]

- **Semileptonic $D_s$ decays to $\phi/\eta$**
  
  \[
  \frac{\Gamma[D_s^+ \to \phi \mu^+ \nu]}{\Gamma[D_s^+ \to \phi e^+ \nu]} = 0.86 \pm 0.29
  \]

- **Semileptonic $\Lambda_c$ decays**
  
  \[
  \frac{\Gamma[\Lambda_c^+ \to \Lambda \mu^+ \nu]}{\Gamma[\Lambda_c^+ \to \Lambda e^+ \nu]} = 0.96 \pm 0.16 \pm 0.04
  \]

SM prediction: (xxx)

- \[
  \frac{B[D_{s}^{+} \to \tau^{+} \nu]}{B[D_{s}^{+} \to \mu^{+} \nu]} = 9.98 \pm 0.52
  \]

- \[
  \frac{\Gamma[D^+ \to \pi^0 \mu^+ \nu]}{\Gamma[D^+ \to \pi^0 e^+ \nu]} = 0.964 \pm 0.037 \pm 0.026 (0.985)
  \]

- \[
  \frac{\Gamma[D^+ \to K^0 \mu^+ \nu]}{\Gamma[D^+ \to K^0 e^+ \nu]} = 1.00 \pm 0.03 (0.97)
  \]

- \[
  \frac{\Gamma[D_{s}^{+} \to \bar{K}^0 \mu^+ \nu]}{\Gamma[D_{s}^{+} \to \bar{K}^0 e^+ \nu]} = 1.14 \pm 0.68
  \]

No significant deviation seen

More statistic is coming

See additional material slides for references
Summary and prospect at BESIII

**Important constants**

<table>
<thead>
<tr>
<th>Constant</th>
<th>Systematic error</th>
<th>Statistical error</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta f_{D^+/f_{D^+}} )</td>
<td>~0.9%</td>
<td>2.6%</td>
</tr>
<tr>
<td>( \Delta f_{D_{s^+/f_{D_{s^+}}} \rightarrow K/f_{D_{s^+}}} )</td>
<td>~1%</td>
<td>1.2%</td>
</tr>
<tr>
<td>( \Delta f_{D_{s^+/f_{D_{s^+}}} \rightarrow K/f_{D_{s^+}}} )</td>
<td>~0.5%</td>
<td>0.35%</td>
</tr>
<tr>
<td>(</td>
<td>V_{cs}</td>
<td>_{D^0 \rightarrow K^+l^-} )</td>
</tr>
<tr>
<td>(</td>
<td>V_{cs}</td>
<td>_{D^0 \rightarrow K^+l^-} )</td>
</tr>
<tr>
<td>(</td>
<td>V_{cd}</td>
<td>_{D^0 \rightarrow \mu^-} )</td>
</tr>
<tr>
<td>(</td>
<td>V_{cd}</td>
<td>_{D^0 \rightarrow \pi^-} )</td>
</tr>
</tbody>
</table>

**LFU tests**

<table>
<thead>
<tr>
<th>Decay</th>
<th>Syst. Error</th>
<th>Statistical error</th>
</tr>
</thead>
<tbody>
<tr>
<td>( D^+ \rightarrow l^+ \nu )</td>
<td>[\mu/\tau]</td>
<td>~10%</td>
</tr>
<tr>
<td>( D_{s^+} \rightarrow l^+ \nu )</td>
<td>[\mu/\tau]</td>
<td>~3%</td>
</tr>
<tr>
<td>( D^0 \rightarrow K^+l^- \nu )</td>
<td>[e/\mu]</td>
<td>~1%</td>
</tr>
<tr>
<td>( D^0 \rightarrow \pi^+l^- \nu )</td>
<td>[e/\mu]</td>
<td>~2%</td>
</tr>
<tr>
<td>( D_{s^+} \rightarrow \phi l^- \nu )</td>
<td>[e/\mu]</td>
<td>~4%</td>
</tr>
<tr>
<td>( D_{s^+} \rightarrow \phi l^- \nu )</td>
<td>[e/\mu]</td>
<td>~3%</td>
</tr>
<tr>
<td>( \Lambda_{c^+} \rightarrow \Lambda l^- \nu )</td>
<td>[e/\mu]</td>
<td>~4%</td>
</tr>
</tbody>
</table>

**More results will be coming in the near future**

Now: Current D/D_s/\Lambda_c analyses are based 2.9/3.2/0.567 fb^{-1} data at 3.773/4.178/4.6 GeV

Exp.: Expected precision is based on 12/12/5 fb^{-1} data at 3.773/4.178/4.65 GeV

Jul 16, 2019
F.Forti, Belle II & Flavor
Babur: $B \rightarrow D^* \ell \nu$ tagged full 4d angular analysis

- Persisting tension between inclusive/exclusive $V_{cb}$ and $V_{ub}$.
- Form Factors also important for $R(D^*)$.
- First full 4d angular analysis to extract the FF’s.
- Two parametrizations: BGL, CLN. Test of HQET
- Effect of increasing the error on the $R(D^*)$ prediction.
- Also polarizations are very sensitive to FF (and NP).

$P_2$: $-0.483 \pm 0.027$ (BaBar-BGL), $-0.38 \pm 0.51^{+0.21}_{-0.16}$ (Belle’17)
$F_L^{D^*}$: $+0.454 \pm 0.011$ (BaBar-BGL), $+0.60 \pm 0.08 \pm 0.035$ (Belle’19)

485. Study of $B \rightarrow D^{(*)} \ell \nu$ decays with a full angular analysis at $\mathcal{BABAR}$, Bipab Dey
Babar rare D decays

Rare or forbidden processes in the SM that provide windows on new physics

For $m(ee) \in [675, 875]$ MeV:

$$Br = (4.0 \pm 0.5 \pm 0.2 \pm 0.1) \times 10^{-6}$$

For $m(ee) \in [1005, 1035]$ MeV:

$$Br = (0.11^{+0.15}_{-0.06}) \times 10^{-6}$$

For $m(ee)$ in the non-resonant range (unshaded):

- $Br = (1.6 \pm 0.6 \pm 0.7) \times 10^{-6}$, Significance = 2.6$\sigma$
- 90% CL UL: $Br < 3.1 \times 10^{-6}$

Probing short distance and potential NP
Violations in $D^0 \to hh'll'$

- Lepton-flavor violating (LFV):
  - $\pi^-\pi^+e^±\mu^\mp$, $K^-\pi^+e^±\mu^\mp$, $K^-K^e^±\mu^\mp$
- Lepton-number violating (LNV):
  - $\pi^-\pi^+e^+$, $\pi^-\pi^+\mu^+\mu^+$, $\pi^-\pi^+e^+\mu^+$
  - $K^-\pi^{-}e^+\mu^+$, $K^-\pi^+\mu^+\mu^+$, $K^-\pi^{-}e^+\mu^+$
  - $K^-K^+e^+e^+$, $K^-K^-\mu^+\mu^+$, $K^-K^e^+\mu^+$

### Decay modes

<table>
<thead>
<tr>
<th>Decay mode</th>
<th>$N_{sig}$ (candidates)</th>
<th>$\epsilon_{sig}$ (%)</th>
<th>$\mathcal{B}$ ($\times 10^{-7}$)</th>
<th>$\mathcal{B}$ 90% U.L. ($\times 10^{-7}$)</th>
<th>Previous best limit ($\times 10^{-7}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^0 \to \pi^-\pi^+e^+$</td>
<td>0.22 ± 3.15 ± 0.54</td>
<td>4.38</td>
<td>0.27 ± 3.90 ± 0.67</td>
<td>9.1</td>
<td>1120</td>
</tr>
<tr>
<td>$D^0 \to \pi^-\pi^-\mu^+\mu^+$</td>
<td>6.69 ± 4.88 ± 0.80</td>
<td>4.91</td>
<td>7.40 ± 5.40 ± 0.91</td>
<td>15.2</td>
<td>290</td>
</tr>
<tr>
<td>$D^0 \to \pi^-\pi^-e^+\mu^+$</td>
<td>12.42 ± 5.30 ± 1.45</td>
<td>4.38</td>
<td>15.4 ± 6.59 ± 1.85</td>
<td>30.6</td>
<td>790</td>
</tr>
<tr>
<td>$D^0 \to \pi^-\pi^-e^+\mu^+$</td>
<td>1.37 ± 6.15 ± 1.28</td>
<td>4.79</td>
<td>1.55 ± 6.97 ± 1.45</td>
<td>17.1</td>
<td>150</td>
</tr>
<tr>
<td>$D^0 \to K^-e^+e^+$</td>
<td>-0.23 ± 0.97 ± 1.28</td>
<td>3.19</td>
<td>-0.38 ± 1.60 ± 2.11</td>
<td>5.0</td>
<td>2060</td>
</tr>
<tr>
<td>$D^0 \to K^-e^+\mu^+$</td>
<td>-0.03 ± 2.10 ± 0.40</td>
<td>3.30</td>
<td>-0.05 ± 3.34 ± 0.64</td>
<td>5.3</td>
<td>3900</td>
</tr>
<tr>
<td>$D^0 \to K^-e^+\mu^+$</td>
<td>3.87 ± 3.96 ± 2.36</td>
<td>3.48</td>
<td>5.84 ± 5.97 ± 3.56</td>
<td>21.0</td>
<td>2180</td>
</tr>
<tr>
<td>$D^0 \to K^-e^+\mu^+$</td>
<td>2.52 ± 4.60 ± 1.35</td>
<td>3.65</td>
<td>3.62 ± 6.61 ± 1.95</td>
<td>19.0</td>
<td>5530</td>
</tr>
<tr>
<td>$D^0 \to K^-e^+\mu^+$</td>
<td>0.30 ± 1.08 ± 0.41</td>
<td>3.25</td>
<td>0.43 ± 1.54 ± 0.58</td>
<td>3.4</td>
<td>1520</td>
</tr>
<tr>
<td>$D^0 \to K^-e^+\mu^+$</td>
<td>-1.09 ± 1.29 ± 0.42</td>
<td>6.21</td>
<td>-0.81 ± 0.96 ± 0.32</td>
<td>1.0</td>
<td>950</td>
</tr>
<tr>
<td>$D^0 \to K^-e^+\mu^+$</td>
<td>1.93 ± 1.92 ± 0.83</td>
<td>4.63</td>
<td>1.93 ± 1.93 ± 0.84</td>
<td>5.8</td>
<td>570</td>
</tr>
<tr>
<td>$D^0 \to K^-e^+\mu^+$</td>
<td>4.09 ± 3.00 ± 1.59</td>
<td>4.83</td>
<td>3.93 ± 2.89 ± 1.45</td>
<td>10.0</td>
<td>1800</td>
</tr>
</tbody>
</table>

Previous results: $\times 10^{-7}$

- BABAR results:
  - Previous best limit
  - $E791, PRL 86 3969 (2001)$
\[ R_{K^*} = \frac{BR(B \rightarrow K^* \mu^+ \mu^-)}{BR(B \rightarrow K^* e^+ e^-)} \]

- Test of lepton flavor universality
- Theoretically clean
- Sensitive to new physics
- All measured values are in accordance with the SM and other recent measurements.

S. Choudhury, Measurement of Lepton Flavor Universality in B decays at Belle, Flavor and CP Violation, Friday 14:50

\[ 103.0^{+13.4}_{-12.7} (139.0^{+16.0}_{-15.4}) \text{ events in the electron (muon) modes.} \]
$R_K = \frac{BR(B^+ \rightarrow K^+ \mu^+ \mu^-)}{BR(B^+ \rightarrow K^+ e^+ e^-)}$

- New measurement with 711 fb$^{-1}$ (was 605 fb$^{-1}$)
- Both charged and neutral mode
- Multidimensional $M_{bc}$ $\Delta E$ fit to extract the yield

Previous results

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**Jul 16, 2019**

F.Forti, Belle II & Flavor
Belle \( R(K) \)

New result: no discrepancy

- New measurement with 711 fb\(^{-1}\) (was 605 fb\(^{-1}\))
- Both charged and neutral mode
- Multidimensional \( M_{bc} \Delta E \) fit to extract the yield

\[
R_K = \frac{BR(B^+ \rightarrow K^+ \mu^+ \mu^-)}{BR(B^+ \rightarrow K^+ e^+ e^-)}
\]

Color corresponds to different binning

442. Measurement of Lepton Flavor Universality in B decays at Belle, Seema Choudhury
• Long standing tension with SM prediction (was 3.8σ)
• New measurement using semileptonic tag (first measurement for $R(D^*)$)
• Single most precise result: compatible with SM @ 1.2σ
  • Still statistically limited
• $R(D)$-$R(D^*)$ exp. world average tension with SM decreases to 3.1σ
The promise for the future
Belle II @ SuperKEKB
The intensity frontier

SuperKEKB is the $e^+e^-$ intensity frontier
40 times higher luminosity

KEKB

PEP-II

BEPC-II
The path to higher luminosity

- **Reduce Beam size**
  - KEKB: 100µm x 2µm
  - SuperKEKB: 10µm x 0.06µm

- **Change beam energies** to solve the problem of short lifetime for the LER
  - Consequence $\beta\gamma$: decrease $0.42 \rightarrow 0.28$

- **Nano-beams and more beam current** to increase luminosity
- **Large crossing angle**
Replace short dipoles with longer ones (LER)

Redesign the lattices of HER & LER to squeeze the emittance

TiN-coated beam pipe with antechambers

Low emittance positrons to inject

Damping ring

Low emittance electrons to inject

Positron source

New positron target / capture section

Add / modify RF systems for higher beam current

KEKB → SuperKEKB

Jul 16, 2019

F. Forti, Belle II & Flavor
Belle II detector

K_L and muon detector:
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC (end-caps, inner 2 barrel layers)

EM Calorimeter:
CsI(Tl), waveform sampling

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

Beryllium beam pipe
2cm diameter

Vertex Detector
2 layers DEPFET + 4 layers DSSD

Central Drift Chamber
He(50%):C_2H_6(50%), Small cells, long lever arm, fast electronics

electron (7GeV)

positron (4GeV)
VXD Installed in Dec 2018
Partial PXD layer 2, will be completed in 2021

774. Commissioning of the Belle II Pixel Vertex Detector, Dr Hua Ye

722. Performance of the Belle II Silicon Vertex Detector, Antonio Paladino
Phase 1 (2016): SuperKEKB commissioning and background estimation – no collisions
Phase 2 (2018): Collision runs with final focus, but without VXD → first physics data
Phase 3 (2019--->): Physics run started in March 2019. Will continue with 7-9 months/year
First collisions in Phase 2

Collisions

$e^+e^- \rightarrow B\bar{B}$

First collisions in Phase 3

Apr 26, 2018

March 26, 2019
Luminosity

- Backgrounds are still high
- Luminosity limited by beam blow-up
- New machine: lot of tuning required

Recovery from fire near LINAC

### Integrated Luminosity

\[ \int \mathcal{L} \, dt = 6.49 \, [\text{fb}^{-1}] \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Achieved</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I_{LER}(\text{max})(A) )</td>
<td>0.880</td>
<td>2.6</td>
</tr>
<tr>
<td>( I_{HER}(\text{max})(A) )</td>
<td>0.940</td>
<td>3.6</td>
</tr>
<tr>
<td>( \beta_y^* , (\text{mm}) )</td>
<td>2</td>
<td>0.3</td>
</tr>
<tr>
<td># bunches</td>
<td>1576</td>
<td>2364</td>
</tr>
<tr>
<td>( L_{\text{peak}} , (\text{cm}^{-2} , \text{s}^{-1}) )</td>
<td>( 6.1 \times 10^{33} )</td>
<td>( 8 \times 10^{35} )</td>
</tr>
<tr>
<td>( L(\text{det OFF}) )</td>
<td>( 12 \times 10^{33} )</td>
<td></td>
</tr>
</tbody>
</table>
Results

• The run has just finished (July 1\textsuperscript{st})
• In this talk present performance studies and initial cross checks and results
• Data sample: 410 pb\textsuperscript{-1} calibrated, aligned and reprocessed data.
• Less than 1/10 of the total data 6.49 fb\textsuperscript{-1}
Tracking performance

- Impact parameter resolution 2-track events
- V0s from pp

Beam profile computed with $\sigma_x = 14.8 \mu m$ and $\sigma_y = 1.5 \mu m$.

Confirmation of Beam Profile

Ryan MacGibbon
Event shape and B counting

\[ H_l = \sum_{ij} |p_i| |p_j| P_l(\cos \theta_{ij}) \]

\[ R_2 = \frac{H_2}{H_0} \]

• Using continuum MC find excess events in data.
• Most likely due to an imperfect machine background modelling
• Use off-resonance data for continuum modelling

\[ R_2 \text{ distribution} \]

\[ \int \text{Ldt} = 410 \text{ pb}^{-1} \]

Belle II 2019 Preliminary

- Y(4S) data
- B\bar{B}
- off-resonance

Start of the Belle II Experiment at SuperKEKB: rediscovery of B Physics, Oskar Hartbrich
Mass peaks

• Identify Kaons, pions, ....
Mass peaks

- ...electrons, muons
- Reconstruct vertices.

\[ \int L \, dt = 0.41 \text{ fb}^{-1} \]

\[ N_{\text{sig}} = 315 \pm 31 \]

\[ \int L \, dt = 0.41 \text{ fb}^{-1} \]

\[ N_{\text{sig}} = 164 \pm 16 \]

FIG. 6: The dielectron invariant mass for $J/\psi \rightarrow e^+e^-$ with the same selection criteria as FIG. 5. The number of background events within the mass window $[3.06, 3.12]$ GeV/c$^2$ is estimated to be 912 $\pm$ 11.

FIG. 7: The dielectron invariant mass for $J/\psi \rightarrow e^+e^-$ for an integrated luminosity of 0.41 fb$^{-1}$ with the same selection criteria as FIG. 5 as well as a vertex fit with TreeFit, requiring a confidence level of $>0.001$. The number of background events within the mass window $[3.06, 3.12]$ GeV/c$^2$ is estimated to be 499 $\pm$ 8.

FIG. 12: The dimuon invariant mass for $J/\psi \rightarrow \mu^+\mu^-$ for an integrated luminosity of 0.41 fb$^{-1}$, using the same selection criteria as FIG. 8 and applying a cut of (global) muonID $>0.95$ to both muon candidates.

FIG. 13: The dimuon invariant mass for $J/\psi \rightarrow \mu^+\mu^-$ for an integrated luminosity of 0.41 fb$^{-1}$ with the same selection criteria as FIG. 12. The number of background events within the mass window $[3.06, 3.12]$ GeV/c$^2$ is estimated to be 76 $\pm$ 3.
B→Dh exclusive reconstruction

Approximately 300 selected events in 410 pb⁻¹

\[ M_{bc} = \sqrt{E_{\text{beam}}^* + p_B^*} \]

\[ \Delta E = E_B^* - E_{\text{beam}}^* \]
Full Event Interpretation

- Fully reconstruct B decays in many many modes to reduce backgrounds and provide tagging
- Useful for channels with weak exp. signature
  - Missing momentum (many neutrinos in the final state)
  - Inclusive analyses
- Tag with semileptonic decays
  - PRO: Higher efficiency $\varepsilon_{\text{tag}} \sim 1.5\%$
  - CON: more background, B momentum unmeasured
- Tag with hadronic decays
  - PRO: cleaner events, B momentum reconstructed
  - CON: smaller efficiency $\varepsilon_{\text{tag}} \sim 0.3\%$

Hadronic FEI

Classifier output to discriminates tag side from background

Belle II preliminary $\int dt = 0.41 \text{fb}^{-1}$

### Loose

- Correctly reconstructed
- Continuum & mis-reconstructed
- Data

**B$^+$**

$N_{B^+} = 1066 \pm 77$

$P_{tag} > 0.1$

**B$^0$**

$N_{B^0} = 409 \pm 31$

$P_{tag} > 0.5$

### Tight

- Correctly reconstructed
- Continuum & mis-reconstructed
- Data

**B$^+$**

$N_{B^+} = 663 \pm 55$

$P_{tag} > 0.1$

$M_{bc} = \sqrt{E_{beam}^2 - p_B^2}$

**B$^0$**

$N_{B^0} = 299 \pm 26$

$P_{tag} > 0.5$

---

61. Missing energy and electroweak penguin modes in early Belle II data, William Sutcliffe

Jul 16, 2019

F.Forti, Belle II & Flavor
Semileptonic decays

• Look e.g. at missing mass distribution

\[ m^2_{\text{miss}} = (p^*_e - e^- p^*_B - p^*_\ell - p^*_X)^2 \]

B \rightarrow X_l \nu with hadronic tag

Untagged B \rightarrow D^* \nu
DO lifetime

\[ D^* \rightarrow D^0 \pi^+ \quad D^0 \rightarrow K^+ \pi^- \]

\[ m_{D^0} = (1864.83 \pm 0.05) \text{ MeV/c}^2 \text{ (PDG - 2018)} \]
Physics potential and timeline

All the details are in “The Belle II Physics Book”
E. Kou, P. Urquijo et al.,

https://inspirehep.net/record/1692393/

421. First look at CKM parameters from early Belle II data, Isabelle Ripp-Baudot
Belle II Improvement program

• Short term
  • Replacement of TOP PMTs with ALD PMTs
  • Replacement of the PXD with complete detector
  • DAQ upgrade

• Medium term
  • Looking at options to make the detector more robust against background and radiation bursts

• Longer term
  • Started looking at luminosity upgrade possibilities
Conclusion and perspectives

• Flavor physics provide an extremely rich landscape of measurements opening windows on New Physics

• High luminosity $e^+e^-$ colliders offer a pristine and well defined environment

• Existing data sets (Babar, Belle) are still providing new results more than 10 years after the end of data taking

• BES III is providing more and more measurement at the tau/charm energy

• Belle II just started data taking with good performance and looking forward to more luminosity
KEEP
CALM
AND
COLLECT
MORE DATA
Belle II Presentations @ EPS-HEP

• First Physics:
  • I.Ripp-Baudot: “First look at CKM parameters from early Belle II data”, Flavour Physics and CP Violation: Thursday 09:00
  • O.Hartbrich: “Start of the Belle II Experiment at SuperKEKB”, Flavour Physics and CP Violation: Thursday 14:50
  • K.Lautenbach: “Exotic and Conventional Quarkonium Physics Prospects at Belle II” QCD and Hadronic Physics: Thursday 14:45
  • S. Cunliffe: “Dark Sector Physics with Belle II“ Dark Matter: Thursday 15:10
  • W.Sutcliffe: “Missing energy and electroweak penguin modes in early Belle II data” Flavour Physics and CP Violation: Friday 09:45
  • F.Forti: “BELLE II and flavor physics in e+e-“ Plenary: Tuesday 10:00

• Detectors:
  • H.Ye: “Commissioning of the Belle II Pixel Vertex Detector” Detector R&D and Data Handling: Thursday 10:15
  • O.Hartbrich: “First Experiences with the Novel Time of Propagation (TOP) Barrel PID Detector in the BelleII Experiment”, Detector R&D and Data Handling: Thursday 11:30
  • S.Longo: “A Novel Approach to Calorimeter-based Particle Identification at the Belle II Experiment using Scintillator Pulse Shape Discrimination”, Detector R&D and Data Handling: Friday 09:30
  • A.Paladino: “Performance of the Belle II Silicon Vertex Detector”, Poster: Monday 18:30
  • L.Santelj: “The Aerogel RICH detector of the Belle II experiment”, Poster: Monday 18:30
Additional material
BESIII detector: all new!

CsI calorimeter
Precision tracking
Time-of-flight + dE/dx PID

Magnet: 1 T Super conducting

MDC: small cell & Gas:
He/C$_3$H$_8$ (60/40), 43 layers
$\sigma_{xy} = 130 \, \mu m$
$\sigma_{y}/p = 0.5\% @1\,GeV$
dE/dx = 6\%

TOF:
$\sigma_T = 100 \, \text{ps} \, \text{Barrel}$
$110 \, \text{ps} \, \text{Endcap}$

EMC: CsI crystal, 28 cm
$\Delta E/E = 2.5\% @1 \, \text{GeV}$
$\sigma z = 0.6 \, \text{cm/}\sqrt{E}$

Data Acquisition:
Event rate = 4 kHz
Total data volume ~ 50 MB/s

Muon ID: 9 layers RPC
8 layers for endcap

60 ps for ETOF after upgraded in 2015

<table>
<thead>
<tr>
<th>Reference</th>
<th>Journal: Year, Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Lambda_c$ weak decay asymmetry</td>
<td>[submitted to PRL]</td>
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<tr>
<td>Amplitude analysis of $D^+ \rightarrow \eta\pi\pi^0$</td>
<td>1903.04164</td>
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<tr>
<td>Amplitude analysis of $D^+ \rightarrow K^0\pi^+\pi^-$</td>
<td>[Submitted to Phys.Rev.D]</td>
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<td>Measurement of $\Lambda_c \rightarrow \Sigma(\eta)$</td>
<td>1811.08028</td>
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<td>Measurement of $D^+ \rightarrow K^0_{sL}/K^-\pi^+$</td>
<td>1903.04118</td>
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<td>Amplitude analysis of $D^0 \rightarrow K^+\pi^-\eta^0\eta^0$</td>
<td>1903.06316</td>
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<td>Search for the radiative decay $D^+_s \rightarrow \gamma\pi^+$</td>
<td>1902.03351</td>
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<td>Measurements of $D^+_s \rightarrow \omega\pi^+$ and $\omegaK^+$</td>
<td>Ph. Rev. D99(2019)092008</td>
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<tr>
<td>Study of the dynamics of $D^+<em>s \rightarrow \eta^{(*)}</em>{e'\nu}$</td>
<td>1811.00392</td>
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<td>Study of $\Lambda_c \rightarrow \Lambda\pi\eta$</td>
<td>Ph. Rev. D99(2019)091101</td>
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<tr>
<td>Measurement of $D^* \rightarrow \mu^+\nu$</td>
<td>1812.10731</td>
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<td>Study of $D^0 \rightarrow p\bar{n}$</td>
<td>Ph. Rev. Lett.122(2019) 071802</td>
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<td>Study of $D^0 \rightarrow K^0_{sL}/K^\ast(\pi^0)$</td>
<td>1811.00752</td>
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<td>Study of $D^* \rightarrow K^{(\ast)}\pi^0\nu$</td>
<td>Ph. Rev. D99(2019)031101</td>
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<td>Study of $D^0 \rightarrow K^0\pi K^\ast(\pi^0)$</td>
<td>1812.05400</td>
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<td>Study of $D^0 \rightarrow K^{(\ast)}\pi^0\nu$</td>
<td>Ph. Rev. Lett.122(2019) 061801</td>
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<td>Study of $D^0 \rightarrow \pi^+\pi^-\gamma$</td>
<td>1811.02911</td>
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<tr>
<td>Study of $D^0 \rightarrow K^{(\ast)}\pi^0\nu$</td>
<td>Ph. Rev. D99(2019)011103</td>
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<tr>
<td>Study of $D^0 \rightarrow K^0\bar{n}\pi^+\nu$</td>
<td>1811.11349</td>
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<tr>
<td>Measurement of $\Lambda_c \rightarrow eX$</td>
<td>Ph. Rev. Lett.122(2019) 011804</td>
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<tr>
<td>Analysis of $D \rightarrow K\pi\eta'$</td>
<td>1805.09060</td>
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<td>Branching Fractions of $D \rightarrow \pi\mu\nu$</td>
<td>Phys. Rev. Lett. 121, L71803(2018)</td>
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<tr>
<td>Measurement of $\Lambda_c \rightarrow \Lambda\pi\eta$</td>
<td>1803.05492</td>
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<tr>
<td>Observation of $D \rightarrow a_0\pi\nu$</td>
<td>Phys. Rev. Lett. 121, 062003(2018)</td>
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<td>Branching Fractions of $\Lambda_c \rightarrow \Xi^-\phi\nu$</td>
<td>1803.02166</td>
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<td>Analysis of $D \rightarrow (\eta,\eta')\mu\nu$</td>
<td>Phys. Rev. D 97, 092009(2018)</td>
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<td>Study of SCS decays $D^0 \rightarrow 3\pi^0$ and $D^0 \rightarrow 2\pi^0\eta$</td>
<td>1803.05769</td>
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<tr>
<td>Measurements of the branching fractions of the singly Cabibbo-suppressed decays $D^0\rightarrow \omega\eta(\etap)\pi^0$, and $\eta^{(*)}\eta$</td>
<td>Phys. Rev. D 97, 052005(2018)</td>
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<tr>
<td>Measurements of the branching fractions for the singly semileptonic decays $D^0 \rightarrow \phi\nu$ and $D^+ \rightarrow \phi\nu \rightarrow (\phi,\eta,\etap)\mu\nu$,</td>
<td>Phys. Rev. D 97, 012006(2018)</td>
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<tr>
<td>Measurements of the branching fractions for the singly semileptonic decays $D^0 \rightarrow \phi\nu$ and $D^+ \rightarrow \phi\nu \rightarrow (\phi,\eta,\etap)\mu\nu$,</td>
<td>1801.05988</td>
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<tr>
<td>Measurements of the branching fractions for the singly semileptonic decays $D^0 \rightarrow \phi\nu$ and $D^+ \rightarrow \phi\nu \rightarrow (\phi,\eta,\etap)\mu\nu$,</td>
<td>1709.03680</td>
</tr>
</tbody>
</table>
The Belle Experiment

Belle recorded 711 fb on the \( (4S) \) resonance.

Search for \( B^+ \rightarrow \mu^+\nu \) and Test of Lepton Universality with \( R(K^\ast) \) at Belle - Markus Prim 22nd March 2019 2/23
Babar Detector

Čerenkov Detector (DIRC)
144 quartz bars
11000 PMTs

Electromagnetic Calorimeter
6580 CsI(Tl) crystals

Drift Chamber
40 stereo layers

Instrumented Flux Return
iron/RPCs (muon/neutral hadrons)

Silicon Vertex Tracker
5 layers, double sided strips

1.5 T solenoid

e+ (3.1 GeV)
e- (9 GeV)

SVT: 97% efficiency, 15 μm z hit resolution (inner layers, \perp tracks)
SVT+DCH: \( \sigma(p_T)/p_T = 0.13 \% \times p_T + 0.45 \% \)
DIRC: \( K-\pi \) separation 4.2σ @ 3.0 GeV/c \( \rightarrow \) >3.0σ @ 4.0 GeV/c
EMC: \( \sigma_E/E = 2.3 \% \times E^{-1/4} + 1.9 \% \)
The 4D variables

- 4-body decay topology
- $\sqrt{q^2}$: di-lepton mass.
- 3 angles: $\Omega \in \{\theta_l, \theta_V, \chi\}$
- Spin-1 $D^*$ retains full spin info of the recoiling $W^*$ in $b \rightarrow cW^{*-}$, unlike spin-0 $D$, where this info is reduced $\Rightarrow$ richer pheno!
How to increase the luminosity?

1. **Smaller** $\beta_y^*$
2. **Increase beam currents**
3. **Increase** $\xi_y$

---

**Collision with very small spot-size beams**

Invented by Pantaleo Raimondi for SuperB

---

Luminosity

$$L = \frac{\gamma_e \pm \sqrt{\sigma_y^*}}{2e}\left(1 + \frac{\sigma_y^*}{\sigma_x}\right)\left(\frac{I_{e^+e^-} \xi_y^* \beta_y^*}{\beta_y^* R_L \xi_y}\right)$$

Lumi. reduction factor (crossing angle) & Tune shift reduction fac (hour glass effect) 0.8 - 1 (short bunch)

Classical electron radius

Beam current

Lorentz factor

Beam size ratio@IP 1 - 2 % (flat beam)

Vertical beta function@IP

---

Collinear beams

```
\text{e}^+ \\
\text{e}^-
```

$\sigma_x \sim 10 \mu m, \sigma_y \sim 60 \text{nm}$

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Jul 16, 2019

F.Forti, Belle II & Flavor
### SuperKEKB design parameters

<table>
<thead>
<tr>
<th>parameters</th>
<th>KEKB</th>
<th>SuperKEKB</th>
<th>units</th>
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<tr>
<td></td>
<td>LER</td>
<td>HER</td>
<td>LER</td>
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<tr>
<td>Beam energy $E_b$</td>
<td>3.5</td>
<td>8</td>
<td>4</td>
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<tr>
<td>Half crossing angle $\phi$</td>
<td>11</td>
<td></td>
<td>41.5</td>
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<tr>
<td>Horizontal emittance $\varepsilon_x$</td>
<td>18</td>
<td>24</td>
<td>3.2</td>
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<tr>
<td>Emittance ratio $\kappa$</td>
<td>0.88</td>
<td>0.66</td>
<td>0.37</td>
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<tr>
<td>Beta functions at IP $\beta_x^<em>/\beta_y^</em>$</td>
<td>1200/5.9</td>
<td>32/0.27</td>
<td>25/0.30</td>
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<tr>
<td>Beam currents $I_b$</td>
<td>1.64</td>
<td>1.19</td>
<td>3.60</td>
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<tr>
<td>beam-beam parameter $\xi_y$</td>
<td>0.129</td>
<td>0.090</td>
<td>0.0881</td>
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<tr>
<td>Luminosity $L$</td>
<td>$2 \times 10^{34}$</td>
<td>$8 \times 10^{35}$</td>
<td>cm$^{-2}$s$^{-1}$</td>
</tr>
</tbody>
</table>

- Nano-beams and a factor of two more beam current to increase luminosity
- Large crossing angle

- Change beam energies to solve the problem of short lifetime for the LER
- Consequence $\beta_y$: decrease $0.42 \rightarrow 0.28$
Belle → Belle II

SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
CDC: small cell, long lever arm
ACC+TOF → TOP+A-RICH
ECL: waveform sampling (+pure CsI for endcaps)
KLM: RPC → Scintillator +MPPC (endcaps, barrel inner 2 lyrs)