The Belle II Experiment

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Belle II Collaboration

- B factories
- SuperKEKB
- Belle II
The B Factories: A Success Story

- The B factories Belle and BaBar ran from 1999 to 2010.
- They recorded over $1.5 \, \text{ab}^{-1}$ of data ($1.25 \cdot 10^9 \, \text{BB}$).
- And provided the experimental confirmation that led to the 2008 Nobel prize ‘for the discovery of the origin of the broken symmetry which predicts the existence of at least three families of quarks in nature’
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Is this the end of B-physics?
There is still room for new physics contributions. Many potential sources:

- Flavor changing neutral currents
- Lepton flavor violating decays
- $B \to \tau$ tree level new physics
- Precision CKM measurements/new sources of CPV

1. High luminosity (SuperKEKB)
2. High-resolution and large-coverage detector (Belle II)

→ Need 50 ab$^{-1}$
The SuperKEKB Accelerator

SuperKEKB: Asymmetric energy e⁺e⁻ collider
\[ E_{cm} = m(\Upsilon(4S)) = 10.58 \text{ GeV} \]

Peak luminosity: \[ \mathcal{L} = 8 \cdot 10^{35} \text{ cm}^{-2} \text{s}^{-1} \] (x40 than KEKB)

Beam size reduction (nm). Higher current (x2)
Higher luminosity implies
• Higher background
  – Radiation damage
  – Occupancy
  – Fake hits and pile-up
• Higher event rate
  – Higher trigger rate
  – Increased DAQ and computing requirements
• Changes in detector
  – $\beta\gamma$ reduced by factor 1.5
  – Improved vertexing needed

$\Rightarrow$ New detector: Belle II
The Belle II Detector

- Detector requirements
  - Light material
  - Vertexing capability
  - Particle identification
  - E.M. calorimetry
  - $K^0_L$ and muon ID
  - Data handling capabilities

Ready for physics run in 2018
Vertex Detector (VXD)
Vertex Detector

• **Silicon Vertex Detector (SVD)**
  - 4 layers of DSSD
  - $r = 3.8 \text{ cm}, 8.0 \text{ cm}, 11.5 \text{ cm}, 14 \text{ cm}$
  - $L = 60 \text{ cm}$
  - $\sim 1 \text{ m}^2$

• **Pixel Detector (PXD)**
  - 2 layers of DEPFET pixels
  - $r = 1.4 \text{ cm}, 2.2 \text{ cm}$
  - $L = 12 \text{ cm}$
  - $\sim 0.027 \text{ m}^2$
### Belle II Vertex Detector Requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupancy</td>
<td>0.4 hits/µm²/s</td>
</tr>
<tr>
<td>Radiation</td>
<td>2 Mrad/year</td>
</tr>
<tr>
<td>Radiation dose</td>
<td>$2 \cdot 10^{12}$ 1 MeV $n_{eq}$ per year</td>
</tr>
<tr>
<td>Duty cycle</td>
<td>1</td>
</tr>
<tr>
<td>Frame time</td>
<td>20 µs</td>
</tr>
<tr>
<td>Momentum range</td>
<td>Low momentum (&lt; 1 GeV)</td>
</tr>
<tr>
<td>Acceptance</td>
<td>$17^\circ$-$155^\circ$</td>
</tr>
<tr>
<td>Material budget</td>
<td>0.21% $X_0$ per layer</td>
</tr>
<tr>
<td>Resolution</td>
<td>15 µm (50x75 µm²)</td>
</tr>
</tbody>
</table>

- Modest resolution (15 µm), dominated by multiple scattering → Pixel size (50 x 75 µm²)
- Lowest possible material budget (0.2% $X_0$/layer)
  - Ultra-transparent detectors
  - Lightweight mechanics and minimal services
Belle II PXD Module

- 768x250 DEPFET Pixels
- 50x75 μm² pixel pitch
- 75 μm thickness
Belle II SVD Module

Origami

APV25

DSSD

Double Sided Strip Detectors

sensor thickness = 300-320 μm

N⁺ strip

P⁺ strip

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Layer 6 Ladders
Belle II Vertex Detector Beam Tests

- Final integration campaign happening right now
- Sector of the final Belle II vertex detector system
Belle II Vertex Detector Beam Tests
Central Drift Chamber (CDC)
Central Drift Chamber (CDC)

Three important roles:
• Track reconstruction and momentum determination
• Particle identification via dE/dx
• Trigger for background reduction (3D z trigger)

<table>
<thead>
<tr>
<th></th>
<th>Belle II CDC</th>
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</thead>
<tbody>
<tr>
<td>Number of layers</td>
<td>56</td>
</tr>
<tr>
<td>Total sense wires</td>
<td>14336</td>
</tr>
<tr>
<td>Gas</td>
<td>He:C₂H₆</td>
</tr>
<tr>
<td>Sense wire</td>
<td>W (Ø30 µm)</td>
</tr>
<tr>
<td>Field wire</td>
<td>Al (Ø120 µm)</td>
</tr>
</tbody>
</table>

1200 mm

250 mm
Central Drift Chamber (CDC)

Three important roles:
• Track reconstruction and momentum determination
• Particle identification via $\frac{dE}{dx}$
• Trigger for background reduction (3D z trigger)

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$\sigma_{r\phi} = 100 \text{ µm}$

200 ns dead time

$\frac{\sigma_{p_t}}{p_t} \sim 0.3\%/\beta \oplus 0.1\% \cdot p_t \text{[GeV/c]}$

$\sigma \left( \frac{dE}{dx} \right) \|_{\text{MIP}} \sim 5\%$
Time Of Propagation (TOP)
TOP will be used for PID in the barrel region

- When a charged particle passes through the quartz, it emits Cherenkov photons

- The Cherenkov angle, and hence detection time/position depends on the mass of particle (for given track parameters).
Each TOP module contains two quartz bars (2.5 m x 0.45 m x 2 cm), mirror, and array of photodetectors.

Quartz property | Belle II TOP
---|---
Flatness | < 6.3 µm
Roughness | < 0.5 nm (RMS)
Bulk transmittance | > 98% /m
Surface reflectance | > 99.9% /reflection

32 (segmented 4x4) Micro-channel plate PMT
Hamamatsu SL-10 MCP PMT
They can operate in a magnetic field
Gain = 2 \cdot 10^6
Time resolution \(\sigma = 35\) ps
QE > 24%
Aerogel Ring Imaging Cerenkov (ARICH)
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Particle identification in the forward endcap

$K/\pi$ separation at >5σ confidence level at 4 GeV/c

- Radiator: Aerogel
  $n = 1.045-1.055$
  Transmission length > 40 mm

- Photon detection: Hybrid Avalanche Photo Detectors (HAPD)
  420 units, 144 channels each, 5 mm pixelated
  Gain = $7 \cdot 10^5$
  QE > 28%

$\theta_c(\pi) \approx 307 \text{ mrad} @ 3.5 \text{ GeV/c}$
$\theta_c(\pi) - \theta_c(K) = 30 \text{ mrad} @ 3.5 \text{ GeV/c}$
- pion threshold 0.44 GeV/c,
- kaon threshold 1.54 GeV/c
Electromagnetic Calorimeter (ECL)
Electromagnetic Calorimeter (ECL)

E.M. Calorimeter to measure:
- Energy/angle of photon (20 MeV – 4 GeV)
- Electron identification
- $K_L$ detection together with KLM
- Luminosity

Need upgrade due to high backgrounds:

- Barrel: CsI(Tl), crystals reused.
  - New electronics waveform sampling
  - Time constant 1 µs
  - $16.1 X_0$ (30 cm)

- Endcaps: CsI(Tl), crystals reused.
  - Replace with pure CsI in future
  - New electronics waveform sampling
  - Time constant 30 ns
  - PMT Gain = 255
  - QE > 25 %
$K_L$ and Muon Systems (KLM)
**K_L and Muon Systems (KLM)**

- **Barrel:**
  Belle RPCs reused
  Two inner layers replaced by scintillator strips due to increased backgrounds
  Scintillator strips with WLS fibers
  Multi-pixel photon counter detectors (MPPC)

- **Endcap:**
  RPCs replaced with scintillators
  99% geometrical acceptance. $\sigma \sim 1\text{ ns}$
• B-factories had many successful physics results and hints of new physics.

• Belle II will further explore these opportunities with a target integrated luminosity of 50 ab$^{-1}$

• Detector to start operation in 2016 and start taking physics data in 2018.
Thank you