The Phase 2 Run of the Belle II PXD

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Here just an appetizer. For more details:

- Performance of Belle II tracking in central drift chamber. A. Glazov
- Performance of the Belle II SVD stand alone track finder. G. Casarosa
The Japanese Super Flavor Factory: SuperKEKB

Phase 2 (BEAST II)

2019  2021  2023  2025  2027

Phase 2: BEAST and partial Belle II
Phase 3: Full Belle II detector

$\mathcal{L} \sim \frac{N_1 N_2}{\sigma_x \sigma_y}$

• SuperKEKB: Asymmetric energy $e^+e^-$ collider
  $E_{cm} = m(\Upsilon(4S)) = 10.58$ GeV
• Peak luminosity: $\mathcal{L} = 8 \cdot 10^{35}$ cm$^{-2}$ s$^{-1}$ (x40 than KEKB)
  Beam size reduction. Higher current (x2 higher).
The Japanese Super Flavor Factory: SuperKEKB

- **Phase 2 (BEAST II)**
  - 2019
  - 2021
  - 2023
  - 2025
  - 2027

- **Phase 3: Full Belle II detector**

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### Goal of Belle II

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### Belle II

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Goal of Belle II

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Phase 3: Full Belle II detector

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50 nm

Nano beams!

Phase 2 (BEAST II)
2019 2021 2023 2025 2027

Peak Luminosity [cm^{-2}s^{-1}]

2019 2021 2023 2025 2027

Intensity L [ab^{-1}]

SuperKEKB

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40 times higher luminosity implies

- **Higher event rate**
  - Higher trigger rate
  - Increased DAQ and computing requirements

- **Higher background**
  - Radiation damage
  - Occupancy
  - Fake hits and pile-up

- Changes in detector
  - $\beta \gamma$ reduced by factor 1.5
  - Improved vertexing needed

- Results in significant upgrade

→ Belle II
The Belle II Collaboration

113 Institutions
920 Members
26 Nations
The Belle II Detector

- **e^- (7 GeV)**
- **e^+ (4 GeV)**

**Vertex Detectors**
- **EM Calorimeter**
- **K_L-Muon Detector**
- **solenoid @ 1.5T**
- **Central Drift Chamber**
- **Barrel and Forward Particle ID Detector**
6- Layers Vertex Detector: PXD and SVD

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

- **Silicon Vertex Detector (SVD)**
  4 layers of DSSD
  \( r = 3.8 \text{ cm}, 8.0 \text{ cm}, 11.5 \text{ cm}, 14 \text{ cm} \)
  \( L = 60 \text{ cm} \)
  \( \sim 1 \text{ m}^2 \)
**Belle II PXD Requirements and Parameters**

<table>
<thead>
<tr>
<th><strong>Belle II PXD</strong></th>
<th></th>
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<tbody>
<tr>
<td><strong>Occupancy</strong></td>
<td>0.4 hits/μm²/s (3% max)</td>
</tr>
<tr>
<td><strong>Radiation</strong></td>
<td>2 Mrad/year</td>
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<tr>
<td><strong>Integration time</strong></td>
<td>20 μs</td>
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<tr>
<td><strong>Momentum range</strong></td>
<td>Low p (50 MeV - 3 GeV)</td>
</tr>
<tr>
<td><strong>Acceptance</strong></td>
<td>17º-155º</td>
</tr>
<tr>
<td><strong>Material budget</strong></td>
<td>0.21% X₀ per layer</td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>15 μm (50x75 μm²)</td>
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</tbody>
</table>

- Impact parameter resolution (15 μm), dominated by multiple scattering mainly in BP → Pixel size (50 x 75 μm²)
- Lowest possible material budget (0.21% X₀/layer)
  - Ultra-transparent detectors
  - Lightweight mechanics and minimal services in physics acceptance

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The PXD Ladder

SwitcherB
Row control
AMS/IBM HVCMOS 180 nm
Size 3.6 × 1.5 mm²
Gate and Clear signal
Fast HV ramp for Clear

PXD

DHP (Data Handling Processor)
First data compression
TSMC 65 nm
Size 4.0 × 3.2 mm²
Stores raw data and pedestals
Common mode and pedestal correction
Data reduction (zero suppression)
Timing and trigger control

DCDB (Drain Current Digitizer)
Analog frontend

UMC 180 nm
Size 5.0 × 3.2 mm²
TIA and 8-bit ADC
92 ns sampling time
Pedestal compensation
• **DHH** (Data Handling Hybrid)
  Electrical - optical interface
  Slow control master (JTAG)
  Clustering

• **ONSEN**
  Data buffer
  Reduction via ROI selection (DATCON, HLT)
More intelligence needed for reducing services

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Phase 2 Commissioning Phase

- The SuperKEKB accelerator operated in 2018, for the first time, with QCS magnets
  - First operation with focused beams
  - First beam collisions
- The Belle II detector, minus the vertex detector (VXD), rolled into the beam line
Phase 3 VXD Volume
Motivation for **BEAST II:**

- Machine commissioning
- Radiation safe environment for the VXD:
  - Two layers PXD
  - Four layers SVD
  - Dedicated radiation monitors
Phase 2 PXD

- Modules arrived at KEK in September 2017
- Attached to the beam pipe and integrated with the rest of the BEAST detectors during Sep-Nov
- Insertion inside Belle II in mid Nov
Two Months later... Phase 2 Set Up

After final detector verification in the clean room, VXD volume transported across the experimental hall and pushed inside Belle II
Belle II First Collision (26 April 2018)

IP size: 400 µm in X, 4 µm in Y
Peak Luminosity: \(7 \cdot 9 \cdot 10^{31} \text{ cm}^{-2}\text{s}^{-1}\)
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IP size: 400 µm in X, 4 µm in Y

Peak Luminosity: \(7 \times 10^{31} \, \text{cm}^{-2} \, \text{s}^{-1}\)
Phase 2 Integrated Luminosity

The target in Phase 2 was twofold:
- Verification of the nano-beam scheme
- Luminosity target of $\sim 10^{34}$ cm$^{-2}$s$^{-1}$

- Peak Luminosity $5.5 \times 10^{33}$ cm$^{-2}$ s$^{-1}$
- $\beta^*_{y} = 3$ mm; $\sigma^*_{y} \sim 333$ nm (Target $\beta^*_{y} = 0.3$ mm)

$\int_{14.07.2018}^{19.05.2018} L = 472$ pb$^{-1}$
In June 2018 we found our first peak in the beam-constrained mass distribution with 88 events... but many more results came soon afterwards.
PXD Performance: Pedestals and Noise

- Enough room for signal
- After compression and threshold voltage shift compensation, clean and stable pedestal distribution and centered in the dynamic range
- Homogeneous noise $\sim 100$ e$^{-}$ ENC
**PXD Performance: SNR and Homogeneity**

- SNR > 50 (10% spread)
- Sensitive to low keV photons (SR)
- Threshold ~900 e⁻
High efficiency requires module optimization: Adaptive biasing during Phase 2

- HV and Drift
- GateON

Resolution ~ 12 \mu m (x2 better than Belle)
Phase 3 Physics Run

- The SuperKEKB accelerator in final configuration
  Steady increase of Luminosity
- Completed Belle II detector

→ First beams for Phase 3 on 2019, March 11th
Due to high failure rate of ladder gluing process, only a de-scoped PXD was installed in 2018
Phase 3 VXD

First cosmic passing VXD
Phase 3 Started

- Already now surfing at $10^{33}$ cm$^{-2}$ s$^{-1}$ luminosity and acquiring data routinely

March 25$^{th}$ 2019, 19h44 JST

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Summary

• Belle II will search for New Physics at the intensity frontier with a target integrated luminosity of 50 ab$^{-1}$

• Phase 2 experience:
  – PXD performance verified under realistic beam conditions

• Phase 3 readiness:
  – VXD installed and taking data already
  – Ladder gluing problems → Installation de-scoped PXD (50%)
  – Preparations for full PXD replacement in 2020 started

• **Physics data started 11$^{th}$ March 2019** (Phase 3)
Thank you