Outline

• Introduction
• Status of SuperKEKB
• Status of Belle II detector construction
• Commissioning status and plans
The mission of Belle II

In a nutshell: discover New Physics

• SM supported by all experimental evidence at the current level of precision and energies
  – although discrepancies, or “tensions” do exist

• However, the SM does not explain several fundamental questions
  – hierarchy of fermion masses, n. of generations, neutrino masses, matter-antimatter asymmetry, hierarchy of CKM matrix elements

Several (NP) scenarios, with new particles and interactions, which can be investigated at the “energy” or at the “intensity” frontier.
The B factory heritage

KEKB + PEP-II

Nobel prize to KM
Decisive confirmation of CKM picture
Evidence of $D^0 - \bar{D}^0$ mixing
PRL 98 211803
Evidence of $B \rightarrow \tau \nu$
PRL 97 251802
Excess in $R(D^{(*)\pm})$
PRL 109 101802
Observation of $b \rightarrow d\gamma$
PRL 96 221601
Difference in $A_{CP}(B \rightarrow K\pi)$
btw. $B^0$ and $B^+$
Nature 452 332
Direct CP violation in $B^0 \rightarrow \pi^+ \pi^-$
PRL 93 021601
Direct CP violation in $B \rightarrow K\pi$
PRL 93 131801, PRL 93 191802
Observable of CP violation in $B^0$ mixing system
PRL 87 091801, PRL 87 091802
$X(3872)$
PRL 91 262001
Observation of $B \rightarrow K^* \pi^+$
PRL 91 261601

Integrated Luminosity in fb$^{-1}$

Year

1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

May 29 2017
G. Finocchiaro - Belle II status
Past, present, and future

The UT before the B factories
The UT before the B factories

2016, 1.5 ab\(^{-1}\)

Tevatron and LHCb also included
Past, present, and future

The UT before the B factories

2016, 1.5 ab⁻¹

~2024, 50 ab⁻¹

Central values are present World average

Tevatron and LHCb also included
The overview covers the mass energies, luminosity, and plans for running at different centre-of-mass energies. The motivation for the SuperKEKB asymmetric factory is the best tested theory. Despite its tremendous success and experimental precision and at the energies reached so far, the Standard Model (SM) is, at the current level of experimental testing, the only framework which is dependent charge-parity ($CP$) violation measurements. The boost is slightly less than that at KEKB, and the range of physics achievable at Belle II, and the range of physics achievable at SuperKEKB with the Belle II experiment. The SuperKEKB has a design luminosity of $8 \times 10^{34} ab^{-1}$ which is advantageous for analyses with neutrinos in the final state that require good detector hermeticity.

### 1.1 Overview

- **Belle BaBar Belle II** (per year)
  - $B\bar{B}$: $7.7 \times 10^8$ (4.8 $\times 10^8$) $1.1 \times 10^{10}$
  - $B^+\bar{B}^-$: $7.0 \times 10^6$ (6.0 $\times 10^8$)
  - $\Upsilon(1S)$: $1.0 \times 10^8$ (1.8 $\times 10^{10}$)
  - $\Upsilon(2S)$: $1.7 \times 10^7$ (7.0 $\times 10^{10}$)
  - $\Upsilon(3S)$: $1.0 \times 10^8$ (3.7 $\times 10^{10}$)
  - $\Upsilon(5S)$: $3.6 \times 10^7$ (3.0 $\times 10^9$)
  - $\tau\tau$: $1.0 \times 10^9$ (6.0 $\times 10^8$) $1.0 \times 10^{10}$

* assuming 100% running at each energy

**Assumptions:**
- same commissioning time to reach nominal luminosity as in KEKB
- 9 months/year running
- All RF cavities in place
Complementarity/competition of Belle II with the LHCb Physics program

INTEGRATED LUMINOSITY

![Graph showing the projected integrated luminosity for Belle II and LHCb from 2015 to 2024.](image)

### TABLE IV: Extrapolations for selected charm decay measurements. See Table I for a description of the symbols.

<table>
<thead>
<tr>
<th>Observables</th>
<th>Belle Belle II LHCb</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_{CP}(D \rightarrow K^+K^-)$</td>
<td>$(2.1, 0.8) \ (0.3, 0.6) \ (1.5, 1.0) \ (0.4, 0.5)$</td>
</tr>
<tr>
<td>$A_{CP}(D \rightarrow \phi K_s)$</td>
<td>$(3.8, 1.0) \ (0.5, 0.2) \ (1.9, 1.0) \ (0.4, 0.5)$</td>
</tr>
<tr>
<td>$\phi_3$</td>
<td>$(4.1, 0.6) \ (0.6, 0.3) \ (1.6, 0.8) \ (0.4, 0.4)$</td>
</tr>
<tr>
<td>$A_T(D)$</td>
<td>$(20, 8) \ (3, 2) \ (6.2, 1.2) \ (1.3, 0.6)$</td>
</tr>
<tr>
<td>$\sin^2 \theta$ (B$\rightarrow$K$^*$X)</td>
<td>$(2.2, 1.0) \ (0.3, 0.4)$</td>
</tr>
</tbody>
</table>

To be included in future releases.

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**FIG. 2**: SuperKEKB and LHCb integrated luminosity projections in fb$^{-1}$ and ab$^{-1}$ respectively. Systematic uncertainties are taken into account in these projections. We base most projected systematic uncertainties on values presented in BELLE2-NOTE-21/BELLE2-NOTE-PH-2015-002, and LHCb EPJC 73, 2373. If projections are not provided in that report, the assumptions will be provided here.

**FIG. 3**: Expected yield enhancement for selected analysis types in Belle II and LHCb (left), and expected statistical error reduction factors (right). It assumes that Belle II will spend 70% of the time at $\phi(4S)$, which is a realistic, but conservative operating scenario.

**FIG. 4**: Projected precision for various measurements of time dependent CP violation.

**FIG. 5**: Projected precision for various measurements of direct CP violation.

**FIG. 6**: Projected precision for various measurements of indirect CP violation in 2-body all charged final state $D$ decays.
x 40!

SuperKEKB

KEKB

PEP-II

Peak Luminosity Trends (e^+e^- collider)

8 \times 10^{35}

Luminosity

Year


40 times higher luminosity
HowTo

Luminosity formula

\[ L = f_{\text{coll}} \times \frac{N^+ N^-}{4\pi \sigma_x \sigma_y} \]
HowTo

Luminosity formula

\[ L = \int f_{\text{coll}} \times \frac{N^+ N^-}{4\pi \sigma_x \sigma_y} \]

- **Lorentz factor**
- **Beam current**
- **Beam-Beam parameter**
- Geometrical reduction factors (crossing angle, hourglass effect) \((0.8-1.0)\)
- **Beam aspect ratio at IP** \((0.01-0.02)\)
- **Vertical beta function at IP**
HowTo

Luminosity formula

\[ L = \frac{1}{2e r_e} \left( 1 + \frac{\sigma_y}{\sigma_x} \right) I_{\pm} \frac{\xi_y}{\beta_{y\pm}} \frac{R_L}{R_{\xi_y}} \times \frac{N^+ N^-}{4 \pi \sigma_x \sigma_y} \]

Lorentz factor
Beam current
Beam-Beam parameter
Geometrical reduction factors (crossing angle, hourglass effect) (0.8-1.0)
Vertical beta function at IP (0.01-0.02)

“nano-beam” scheme, first proposed in the SuperB design (although eventually it was not applied there)
HowTo

Luminosity formula

$L = f_{coll} \times \frac{N^+N^-}{4\pi \sigma_x \sigma_y}$

“nano-beam” scheme, first proposed in the SuperB design (although eventually it was not applied there)

Very focused beams, large crossing angle: 83 mrad
### KEK & SuperKEKB parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>KEKB Design</th>
<th>KEKB Achieved : with crab</th>
<th>SuperKEKB Nano-Beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (GeV) (LER/HER)</td>
<td>3.5/8.0</td>
<td>3.5/8.0</td>
<td>4.0/7.0</td>
</tr>
<tr>
<td>$\beta_y$ * (mm)</td>
<td>10/10</td>
<td><strong>5.9/5.9</strong></td>
<td><strong>0.27/0.30</strong></td>
</tr>
<tr>
<td>$\beta_x$ * (mm)</td>
<td>330/330</td>
<td>1200/1200</td>
<td>32/25</td>
</tr>
<tr>
<td>$\varepsilon_x$ (nm)</td>
<td>18/18</td>
<td>18/24</td>
<td>3.2/5.3</td>
</tr>
<tr>
<td>$\varepsilon_y / \varepsilon_x$ (%)</td>
<td>1</td>
<td>0.85/0.64</td>
<td>0.27/0.24</td>
</tr>
<tr>
<td>$\sigma_y$ ($\mu$m)</td>
<td>1.9</td>
<td>0.94</td>
<td>0.048/0.062</td>
</tr>
<tr>
<td>$\xi_y$</td>
<td>0.052</td>
<td>0.129/0.090</td>
<td>0.09/0.081</td>
</tr>
<tr>
<td>$\sigma_z$ (mm)</td>
<td>4</td>
<td>6 - 7</td>
<td>6/5</td>
</tr>
<tr>
<td>$I_{\text{beam}}$ (A)</td>
<td>2.6/1.1</td>
<td><strong>1.64/1.19</strong></td>
<td><strong>3.6/2.6</strong></td>
</tr>
<tr>
<td>$N_{\text{bunches}}$</td>
<td>5000</td>
<td>1584</td>
<td>2500</td>
</tr>
<tr>
<td>Luminosity ($10^{34}$ cm$^{-2}$ s$^{-1}$)</td>
<td>1</td>
<td>2.11</td>
<td>80</td>
</tr>
</tbody>
</table>

**Note:**
- Lower $E_{\text{HER}}$ (RF power, low emittance)
- Higher $E_{\text{LER}}$ (Touschek lifetime, low emittance)
- Boost 0.42 $\rightarrow$ 0.28
Transform KEKB into SuperKEKB

- Replace short dipoles with longer ones (LER)
- Redesign the lattices of HER & LER to squeeze the emittance
- TiN-coated beam pipe with antechambers
- New beam pipe & bellows
- New IR
- Add / modify RF systems for higher beam current
- Positron source
- New superconducting / permanent final focusing quads near the IP
- Colliding bunches
- To get 40x higher luminosity
# SuperKEKB Commissioning

## Phase I (2016)
- Circulate both beams, no collisions. **Tune accelerator optics, etc.** Vacuum scrub. **Beam studies. No Belle II.**

## Phase II (2018)
- First collisions. **Develop beam abort.** Tune accelerator optics, etc. (nano-beam). **Beam studies. Belle II (w/o vertex detectors).**

### Commissioning Requirements

<table>
<thead>
<tr>
<th>SuperKEKB</th>
<th>Belle II</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Real-time monitoring of beam conditions</td>
<td>- Guarantee a safe-enough radiation environment for Belle II</td>
</tr>
<tr>
<td>- Quantify effects of tuning, collimators, etc., on beam loss</td>
<td>- Mitigate beam backgrounds (with physical shielding, electronic gating, magnet tuning, etc.) around IP</td>
</tr>
<tr>
<td>- Isolate the type and source of beam loss</td>
<td>- Inform beam background simulations so they are properly accounted for in physics analysis</td>
</tr>
<tr>
<td>- Inform beam loss simulations to optimise performance</td>
<td></td>
</tr>
</tbody>
</table>
BEAST II - phase 1

Beam Exorcisms for A Stable Belle II Experiment

Detector Systems

<table>
<thead>
<tr>
<th>System</th>
<th>Detectors Installed</th>
<th>Unique Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIN Diodes</td>
<td>64/64</td>
<td>Neutral vs charged radiation dose</td>
</tr>
<tr>
<td>Diamonds</td>
<td>4/4</td>
<td>ionizing radiation dose</td>
</tr>
<tr>
<td>Micro-TPCs</td>
<td>2/2</td>
<td>fast neutron flux++</td>
</tr>
<tr>
<td>He-3 tubes</td>
<td>4/4</td>
<td>thermal neutron flux</td>
</tr>
<tr>
<td>Crystals</td>
<td>6/6 CsI(Tl) 6/6 CsI 6/6/ LYSO</td>
<td>EM energy spectrum</td>
</tr>
<tr>
<td>BGO</td>
<td>8/8</td>
<td>luminosity</td>
</tr>
<tr>
<td>“CLAWS” Scintillator</td>
<td>8/8</td>
<td>Injection backgrounds</td>
</tr>
</tbody>
</table>
Expected SuperKEKB Backgrounds

**Phase 1** (no collisions)

- **Touschek scattering:**
  - intra-bunch scattering process
  - dominant with highly compressed beams
  - 20 times higher

- **Beam-gas scattering:**
  - Bremsstrahlung (negligible) & Coulomb interactions (up to 100 times higher) with residual gas atoms & molecules

- **Synchrotron radiation:**
  - emission of photons by charged particles ($e^+e^-$) when deflected in $B$-field

**Phase 2** (collisions)

- **Radiative Bhabha process:**
  - photon emission prior or after Bhabha scattering
  - interaction with iron in the magnets leads to neutron background

- **Two photon process:**
  - very low momentum $e^+e^-$ pairs via $e^+e^-\rightarrow e^+e^-e^+e^-$
  - increased hit occupancy in inner detectors

- **Injection Background:**
  - covered later in the talk
Testing background heuristic model

Beam-Gas & Touschek

- Size-sweep (5 runs) and current (3 runs) scan
- Observable comes from BGO crystals
- Rewrite so beam-gas is flat:
  \[
  \frac{\text{Observable}}{IPZ_e^2} = B + T \cdot \frac{I}{PZ_e^2\sigma_y}
  \]
- Quality of linear fit validates model
- Fit measures sensitivities B (offset) and T (slope)

Ze: an “effective” atomic number of the gas mixture in the pipe, recorded by a residual gas analyser

Good agreement with the model!

However, MC and data do not agree (yet) when comparing different detector data. We understand some of the disagreements, but not all of it. This is good, it proves we needed BEAST!

Ongoing work to refine our understanding of SuperKEKB, BEAST and simulation for phase II
Beam scrubbing in phase 1

Cleaning a new beam pipe

- A key goal of phase 1 was to “scrub” the beam pipes
  - High currents stimulate desorption of impurities from beam pipe walls
  - Over time, vacuum improves lowering beam-gas backgrounds
- BEAST quantified distinct improvements in beam-gas in phase 1
- Scrubbing not yet at final physics run quality

SuperKEKB measurements of $dP/dI$ vs integrated current

BEAST measurements of Rates$/I^2$ vs integrated current
Continuos injection @ 100 Hz during B-factory operation
- Belle injection ECL DAQ veto scheme would produce 10% dead time!
- \( \Rightarrow \) Study background time structure
Injection perturbs the orbit parameters of (almost) only the injected bunch
- \( \Rightarrow \) High backgrounds lasting few ms after injection are highly correlated in time with the injected bunch

**Figure 105:** LER Injection. Plot of the hit time after injection (time within one turn) all the bunches filled in the machine will have passed the interaction point every period.

**Figure 106:** Plot of the time of hit after injection (Tturn) during LER injection.

**Table 26:** Measured values of the synchrotron oscillation period obtained from injection background data. The measurement is compared with those obtained from a tracking-based, simulation of the beam orbits, using for the machine parameters the same values in use during each run.

<table>
<thead>
<tr>
<th>Run #</th>
<th>Data (# of turns)</th>
<th>Simulation (# of turns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>52.5(\pm)0.5</td>
<td>52.3</td>
</tr>
<tr>
<td>3</td>
<td>53.1(\pm)1.4</td>
<td>53.3</td>
</tr>
<tr>
<td>10</td>
<td>40.6(\pm)0.7</td>
<td>40.6</td>
</tr>
<tr>
<td>9</td>
<td>41.7(\pm)1.0</td>
<td>42.4</td>
</tr>
</tbody>
</table>
June 21, 2016: LER beam current exceeded 1 Ampere

SuperKEKB vacuum scrubbing too
Startup of SuperKEKB (3 months)

• Much faster startup than KEKB
  – KEKB beam currents achieved after first 3 months
    • LER: ~300mA, HER: ~200mA (540mA, 300mA: 4 months)
  – SuperKEKB beam currents achieved after first 3 months
    • LER: ~650mA, HER: ~590mA (820mA, 740mA: 4 months)

• Compared with KEKB...
  – Each hardware component has been upgraded with experiences at KEK and has worked fine (RF, Magnet, Vacuum...)
  – The bunch-by-bunch feedback system has more effectively suppressed instabilities.
  – Operational tools (such as closed orbit correction system) has worked fine based on experiences at KEKB.
  – Less machine troubles than KEKB so far
Factor x40 luminosity also brings in:
- Higher occupancy, pile-up, fake hits
- Increased trigger and DAQ rates
- Radiation damage

Upgrade the detector
- Starting point is the Belle detector
- In practice, reuse the crystal CsI(Tl) calorimeter, the solenoid, the KLM barrel detector

**Backgrounds are ~ x20 Belle**

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**Table 22: Beam background types (12th background campaign).**

<table>
<thead>
<tr>
<th>type</th>
<th>source</th>
<th>rate [MHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>radiative Bhabha</td>
<td>HER</td>
<td>1320</td>
</tr>
<tr>
<td>radiative Bhabha</td>
<td>LER</td>
<td>1294</td>
</tr>
<tr>
<td>radiative Bhabha (wide angle)</td>
<td>HER</td>
<td>40</td>
</tr>
<tr>
<td>radiative Bhaba (wide angle)</td>
<td>LER</td>
<td>86</td>
</tr>
<tr>
<td>Touschek scattering</td>
<td>HER</td>
<td>31</td>
</tr>
<tr>
<td>Touschek scattering</td>
<td>LER</td>
<td>83</td>
</tr>
<tr>
<td>beam-gas interactions</td>
<td>HER</td>
<td>1</td>
</tr>
<tr>
<td>beam-gas interactions</td>
<td>LER</td>
<td>156</td>
</tr>
<tr>
<td>two-photon QED</td>
<td>-</td>
<td>206</td>
</tr>
</tbody>
</table>

*Total number of hits per event in each sub-detector*
Belle II detector upgrade

- Fast signal shaping and waveform fit of e.m. calorimeter signals to preserve excellent energy resolution in high-pileup environment
- Increase $K_S$ efficiency by ~30%
- Improve IP and secondary vertex resolution (~factor 2)
- Better $K/\pi$ separation ($\pi$ fake rate decreases by ~2.5)
- Improve $\pi^0$ reconstruction

In the end, a better detector than Belle, in a harsher environment

Reduced boost (0.44 $\rightarrow$ 0.28) yields better hermeticity for rare searches
Highlights of Belle II construction and commissioning

Belle II eagerly waiting for inner sub-systems installation... which has just started!

First Time-Of-Propagation module installation

Central-Drift-Chamber wiring

Silicon-Vertex-Detector

Aerogel RICH photon-detectors

Instead of summary

Very exciting time ahead! with lots of (new) physics to follow from 2018 -!
# The tracking system

<table>
<thead>
<tr>
<th>Component</th>
<th>Type</th>
<th>Configuration</th>
<th>Readout</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam pipe</td>
<td>Beryllium double-wall</td>
<td>Cylindrical, inner radius 10 mm, 10 μm Au, 0.6 mm Be, 1 mm coolant (paraffin), 0.4 mm Be</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PXD</td>
<td>Silicon pixel (DEPFET)</td>
<td>Sensor size: 15×100 (120) mm², pixel size: 50×50 (75) μm², 2 layers: 8 (12) sensors</td>
<td>10 M</td>
<td>impact parameter resolution $\sigma_{z_c} \sim 20 \mu$m (PXD and SVD)</td>
</tr>
<tr>
<td>SVD</td>
<td>Double sided Silicon strip</td>
<td>Sensors: rectangular and trapezoidal, Strip pitch: 50(p)/160(n) - 75(p)/240(n) μm, 4 layers: 16/30/56/85 sensors</td>
<td>245 k</td>
<td></td>
</tr>
<tr>
<td>CDC</td>
<td>Small cell drift chamber</td>
<td>56 layers, 32 axial, 24 stereo, $r = 16 - 112$ cm, $-83 \leq z \leq 150$ cm</td>
<td>14 k</td>
<td>$\sigma_{r\phi} = 100 \mu$m, $\sigma_z = 2$ mm, $\sigma_{p_t} = \sqrt{(0.2%p_t)^2 + (0.3%/\beta)^2}$, $\sigma_{p_t}/p_t = \sqrt{(0.1%p_t)^2 + (0.3%/\beta)^2}$ (with SVD)</td>
</tr>
</tbody>
</table>
Combined PXD+SVD beam test at DESY

- Reco Track: blue line
- Strip/pixel candidates: purple lines
- Strip/pixel selected: yellow lines
- Magnet: not visible (out of screen, solenoid // beam direction)

Track Finder:
Used VXDTF1 in first runs and VXDTF2 in second part

• Measure efficiency and resolution, test Region Of Interest PXD readout scheme on HLT module (online!), test new track-finding algorithm
• Extrapolations of detector performance confirmed after beam-test results, and realistic software implementation

• Currently, in spite of \( \langle \beta \gamma \rangle_{\text{Belle II}} = 28/44 \cdot \langle \beta \gamma \rangle_{\text{Belle}} \)

\[
\sigma_{\Delta t}^{\text{Belle II}} \sim \frac{3}{4} \sigma_{\Delta t}^{\text{Belle}}
\]
The Central Drift Chamber (CDC)

- Installed Oct, 2016
- Commissioning with cosmic ray tracks is ongoing

![CDC Installation](image)

- 250mm spatial layers of small cell
- 4 x stereo layers for z information
- 3 x axial layers for 2D tracking

![Track Fitting](image)

- One cosmic ray track is track-fitted as separated tracks in upper and lower regions
- Mean is shifted due to mis-alignment of wire position

![Cosmic Ray Test Results](image)

- D01-D02
  - \( \sigma_1 = 122\mu m (75\%) \)
  - \( \sigma_2 = 307\mu m (25\%) \)
- Z01-Z02
  - \( \sigma_1 = 2.1mm (70\%) \)
  - \( \sigma_2 = 3.6mm (30\%) \)
Electromagnetic calorimeter (ECL)

Belle calorimeter: 8736 CsI(Tl) crystals
- 6624 Barrel
- 1152 Fwd Endcap
- 960 Bwd Endcap

• High rates (machine+physics) ⇒ upgrade of electronics
  - shorter signal shaping (1μs → 500ns)
  - the waveform is sampled (~2MHz)
  - waveform fit to extract signal time and amplitude

Early prototype tested at Belle
ECL commissioning

Jan 2017
BWD endcap installation

Barrel ECL under CR test since 2015
Endcap calorimeter CR test ongoing

150GeV shower!

CDC-ECL cosmic ray test
Barrel PID: Time Of Propagation (TOP)

Cherenkov ring imaging with precision time measurement (better than 100ps)

Installation completed! 2016, May 11
TOP: running the installed detector

Gain operational experience in 1.5 T B-field!

- Issue with PMTs discovered: PMT-MCPs use a magnetic Kovar (Cobalt-Nickel alloy)... and move with the B-field on!
- Repair to main issue completed (added shims between PMT and FE board to push PMTs in place).
- Result of GEANT4 simulation of air gaps (different thickness) between quartz and PMT inserted in Belle II reconstruction for different fractions of affected PMTs ==> Effect on pion or K mis-id/efficiency very small
- Cause delay on global installation schedule

- High statistics laser/cosmic running for all modules with stable ASIC configuration completed, both with and without B-field to understand performance differences
- Significant progress on firmware, including the crucial feature extraction
Forward PID: the **Aerogel RICH**

- Use two aerogel layers in focusing configuration to increase n. of photons without resolution degradation

\[ n_1 = 1.045, \quad n_2 = 1.055 \]

**HAPD – Hybrid Avalanche Photo-Detector**

- Developed in collaboration with Hamamatsu photonics
- Basic requirements: 1.5 T, 10^{-12} n/cm² tolerance
- Position resolution
- Large coverage (3.5 m²)

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**Beam test measurements**

- Excellent performance in desired momentum range!
- ~12 photons / track @ 3.5 GeV

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May 29 2017  
G. Finocchiaro - Belle II status
ARICH Rings from cosmic ray muons

First events from CR tracks recorded in a partially instrumented sector of the ARICH

Production of aerogel tiles and HAPDs is finished. Expect to complete installation on the structure before July, and install in Belle II in September.
The KLong a Muon detector KLM

- 14 iron layers 4.7cm thick
- 15 barrel active layers
  ✓ 2 x [scintillator strips + WLS + SiPM] ⇐ NEW
  ✓ 13 x [double glass RPC + 5 cm orthogonal phi, z strips]
- 14 endcap active layers
  ✓ 14 x [scintillator strips + WLS + SiPM] ⇐ NEW

• All endcap active layers + 2 innermost layers in barrel replaced with scintillator strips to resist neutron background
• Installation is complete
• Commissioning with cosmic rays ongoing
Barrel KLM commissioning

CR track fitted independently in the two sectors

Readout on all octants will be installed and commissioned by the Summer
SuperKEKB: Preparations for Phase 2 Commissioning

- Collision feedback
- Add collimators
- More migration for e-cloud
- QCS and related works at IR
- Change injection part for injection from DR
- Injector Linac upgrade:
  - RF electron gun
  - Improve e+ source
  - Pulse magnets for top-up injection
- SuperKEKB phase 2

Renovation for phase 2 ongoing.

New e+ Damping Ring

RF cavities for DR

DR arc section
Final focus magnets

Superconducting quadrupole magnets with 30+25 coils

The second one delivered on Feb 13

World’s most complex SC final focus!
April 11, 2017 - Belle II Milestone!

Belle II rolls in

On 11 April, the Belle II detector at the KEK laboratory in Japan was successfully "rolled-in" to the collision point of the upgraded SuperKEKB accelerator, marking an important milestone for the international B-physics community. The Belle II experiment is an international collaboration hosted by KEK in Tsukuba, Japan, with related physics goals to those of the LHCb experiment at CERN but in the pristine environment of electron–positron collisions. It will analyze copious quantities of B mesons to study CP violation and signs of physics beyond the Standard Model (CERN Courier September 2016 p32).

"Roll-in" involves moving the entire 8 m-tall, 1400-tonne Belle II detector system from its assembly area to the beam-collision point 13 m away. The detector is now integrated with SuperKEKB and all its seven subdetectors, except for the innermost vertex detector, are in place. The next step is to install the complex focusing magnets around the Belle II interaction point. SuperKEKB achieved its first turns in February, with operation of the main rings scheduled for early spring and phase-II "physics" operation by the end of 2018.

Compared to the previous Belle experiment, and thanks to major upgrades made to the former KEKB collider, Belle II will allow much larger data samples to be collected with much improved precision.

"After six years of gruelling work with many unexpected twists and turns, it was a moving and gratifying experience for everyone on the team to watch the Belle II detector move to the interaction point," says Belle II spokesperson Tom Browder. "Flavour physics is now the focus of much attention and interest in the community and Belle II will play a critical role in the years to come."
So, **when do we start** Belle II?
So, when do we start Belle II?

WHAT’S NEXT:

- **June 2017**: B-field measurement, global cosmic ray run
- **September 2017**: ARICH and forward ECL (+ commissioning vertex detector) installation
- **Nov 2017 - Spring 2018**: Phase 2 commissioning, with two main goals:
  - ✓ tune SuperKEKB with nanobeams - eventually reach KEKB design luminosity
  - ✓ ensure background levels are compatible with vertex detector operation
  - ✓ then, if compatible with the above, also do some physics without vertex detectors - at the Y(6S)?
- **Summer 2018**: install vertex detectors
- **End 2018**: full detector operation - start of Physics run
SuperKEKB/Belle II schedule

Calendar year
- 2016
- 2017
- 2018
- 2019

Japan FY
- JFY2016
- JFY2017
- JFY2018
- JFY2019

- Summer shutdown (power saving)
- Power saving after mid July 2018
- Summer shutdown (power saving)
- Summer shutdown (power saving)

Phase 1
- w/o QCS
- w/o Belle II

Phase 2 (MR)
- MR renovation for phase 2, including installation of QCS and Belle II
- w/ QCS
- w/ Belle II (no VXD)
- HER start
- LER start
- DR commissioning

Phase 3
- w/ full Belle II
- phase 3 operation 9 months / year

DR installation & startup

NOW
SuperKEKB/Belle II schedule

Calendar year  |  2016  |  2017  |  2018  |  2019  | ...
--- | --- | --- | --- | --- | ---
Japan FY  |  JFY2016  |  JFY2017  |  JFY2018  |  JFY2019  | ...
Summer shutdown (power saving)  |  |  |  |  | ...

Phase 1
- MR startup
- DR installation & startup
- w/o QCS
- w/o Belle II

Phase 2 (MR)
- MR renovation for phase 2, including installation of QCS and Belle II
- w/QCS
- w/ Belle II (no VXD)
- HER start
- LER start
- VX5 installation  
- DR commissioning

Phase 3
- w/full Belle II
- phase 3 operation 9 months / year

ご清聴ありがとうございました (GOSEICHOU ARIGATOU GOSAIMASHITA)
Backup slides
Verification of Nano-Beam Scheme

Low Emittance with Large Piwinski Angle

Specific Luminosity, $L_{sp} > 4 \times 10^{31} \text{[cm}^{-2}\text{s}^{-1}/\text{mA}^2]\]$

Beam-Beam Parameter, $\xi_y > 0.05$

Reduce Beam Background for Belle II detector before we move on Phase 3

Phase-2 commissioning is only 5 months from mid of February to mid of July.
Commissioning phase 2 (~5 months)

- **Machine condition**
  - w/ QCS, w/ Belle II (w/o VXD), full accelerator tuning
- **Tuning items**
  - **Optics tuning**
    - Tentative target values of IP beta’s: $\beta_x^* : x4$, $\beta_y^* : x8$
    - Optics tuning with QCS and Belle II solenoid
    - Low emittance tuning w/ Belle II solenoid
    - Optics tuning w/ beam collision
  - **Detector beam background**
    - Study with Belle II detector, test of continuous injection (BEAST)
  - **Beam collision tuning**
    - Orbit feedback (fast feedback, dithering system)
    - Collision tuning w/ “Nano-Beam” scheme
  - **Luminosity tuning**
    - Tuning knobs (x-y coupling at IP etc.)
    - Tentative target luminosity: $1 \times 10^{34} \, \text{cm}^{-2} \, \text{s}^{-1}$ (design of KEKB)
  - **Increase of beam currents (instability, RF power, vacuum issues)**
    - Detector background may possibly give some restriction.
    - Continue upgrade for RF system (support ~70% of design beam currents)
History of Phase 1 operations

Red: total beam current
Purple: vacuum pressure
Cyan: beam lifetime

HER:
870 mA, 5.7x10^{-8} Pa, ~200 min. (6/17)

LER:
1010 mA, 4.7x10^{-7} Pa, ~60 min. (6/22)
Luminosity profile of a next generation B factory

- Assumptions:
  - same commissioning time to reach nominal luminosity as in KEKB
  - 9 months/year running
  - All RF cavities in place

Expected yearly data sample @ full luminosity

<table>
<thead>
<tr>
<th>Channel</th>
<th>Belle</th>
<th>BaBar</th>
<th>Belle II (per year)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B\bar{B}$</td>
<td>$7.7 \times 10^8$</td>
<td>$4.8 \times 10^8$</td>
<td>$1.1 \times 10^{10}$</td>
</tr>
<tr>
<td>$B_{d+s}^0 \bar{B}_{s}^0$</td>
<td>$7.0 \times 10^6$</td>
<td>-</td>
<td>$6.0 \times 10^8$</td>
</tr>
<tr>
<td>$\Upsilon(1S)$</td>
<td>$1.0 \times 10^8$</td>
<td>-</td>
<td>$1.8 \times 10^{11}$</td>
</tr>
<tr>
<td>$\Upsilon(2S)$</td>
<td>$1.7 \times 10^8$</td>
<td>$0.9 \times 10^7$</td>
<td>$7.0 \times 10^{10}$</td>
</tr>
<tr>
<td>$\Upsilon(3S)$</td>
<td>$1.0 \times 10^7$</td>
<td>$1.0 \times 10^8$</td>
<td>$3.7 \times 10^{10}$</td>
</tr>
<tr>
<td>$\Upsilon(5S)$</td>
<td>$3.6 \times 10^7$</td>
<td>-</td>
<td>$3.0 \times 10^9$</td>
</tr>
<tr>
<td>$\tau\tau$</td>
<td>$1.0 \times 10^9$</td>
<td>$0.6 \times 10^9$</td>
<td>$1.0 \times 10^{10}$</td>
</tr>
</tbody>
</table>

* assuming 100% running at each energy
NP-sensitivity at Belle II and comparison with LHCb

- Comparison table in 2008
- Must revise the extrapolations in view of recent developments (e.g. LHCb achievements)
- Extrapolation of Belle II sensitivity by scaling B-factory measurements as:

\[
\sigma_{\text{BelleII}} = \sqrt{\left(\sigma^2_{\text{stat}} + \sigma^2_{\text{sys}}\right) \frac{L_{\text{Belle}}}{50 \text{ ab}^{-1}} + \sigma^2_{\text{irred}}} 
\]

- SuperB
  - has no handle on \(B_s\) time-dependent measurements
  - is much better in modes with neutrals
  - has no competition in channels with missing energy
- Programs are largely complementary

SuperB vs. LHCb

SuperB (50/ab) vs LHCb 10/fb
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**SuperB (50/ab) vs LHCb 10/fb**

**Yield gain in a few data taking configurations**
The hourglass effect

- Small amplitude @ IP not efficient with long bunches
  - particles in the head and tail of the bunch will see a larger $\beta_y$
  - “$\beta_y^*$ should be comparable to the overlapping area”
- In a storage ring
  - it is comparably easier to achieve small horizontal size and emittance than to make short bunches
  - vertical emittance/size scale with the horizontal ones

\[ L \propto \frac{I_{\pm\xi_{\pm y}}}{\beta_y^*} R_l \]

\[ R_l \sim 1 - \left( \frac{\sigma_z}{2\beta_y} \right)^2 + \mathcal{O} \left( \frac{\sigma_z}{\beta_y} \right)^4 \]