Status of the SuperKEKB construction

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Accelerator Laboratory
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Contents

• Introduction
  – Achievement of KEKB – Luminosity frontier – SuperKEKB project
  – Parameters – Main items to upgrade – Commissioning strategy

• Construction status
  – Critical situation of vertical collimator – Optics issue at present

• Summary

Acknowledgement

Most of figures, pictures, and tables in this slide are prepared by colleagues in the Accelerator Laboratory and the Institute of Particle and Nuclear Studies. Since I omit the sources for simplicity, here, I would like to express my sincere thanks to them.
Achievement of KEKB

KEKB = Asymmetric Double-Ring Collider for B-Physics
8 GeV Electron (HER) + 3.5 GeV Positron (LER)

- May 1999: Belle Detector rolled in.
- Apr 2001: Luminosity world record \(3.4 \times 10^{33} \text{cm}^{-2} \text{s}^{-1}\)
- Oct 2002 Integrated Luminosity world record (100 fb\(^{-1}\))
- 9 May 2003, 07:26: Design Luminosity \(10^{34} \text{cm}^{-2} \text{s}^{-1}\) was achieved.
- 2008 Physics Nobel Prize for Kobayashi & Masukawa
- 17 June 2009, 17:12: Peak luminosity \(2.1 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}\) was achieved.
- 30 June 2010, 09:00 Shut down, integrated luminosity is 1040.863 fb\(^{-1}\).
SuperKEKB project

- Increase the highest luminosity of KEKB by 40 times ($= 8 \times 10^{35} \text{cm}^{-2}\text{s}^{-1}$) based on “Nano-Beam” scheme, which was first proposed for SuperB by P. Raimondi.
  - Low emittance ring.
  - Beam crossing angle is 83 mrad.
  - $\beta_y^* \approx 300 \mu\text{m}$
  - Beam current is twice of KEKB.
- Use the components of KEKB as much as possible.
  - Preserve the present cells in HER.
- Beam energy: $3.5/8.0 \rightarrow 4.0/7.0$ GeV.
  - LER: Longer Touschek lifetime and mitigation of emittance growth due to the intra-beam scattering.
  - HER: Lower emittance and lower SR power.
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  - LER: Longer Touschek lifetime and mitigation of emittance growth due to the intra-beam scattering.
  - HER: Lower emittance and lower SR power.
- Design $E_{\text{CM}}$ is $10.57940$ GeV ($\Upsilon(4s)$). And $E_{\text{CM}}$ covers from $\Upsilon(1s)$ to $\Upsilon(6s)$.

\[ L \approx \frac{\gamma^\pm \xi_y \pm I^\pm}{2e r_e \beta_y^\pm} \quad \xi^\pm_q = \frac{N^\pm r_e}{\gamma^\pm} \frac{\beta^\pm_q}{2\pi \sigma^\pm_q \left( \sigma^\pm_x + \sigma^\pm_y \right)} \]

$\beta_x$ and $\beta_y$: Horizontal and vertical betatron amplitude function.
$\xi_x$ and $\xi_y$: Horizontal and vertical linear beam-beam parameter.
<table>
<thead>
<tr>
<th></th>
<th>KEKB achieved LER/HER</th>
<th>Super KEKB nano-beam scheme LER/HER</th>
<th>Essential factor for the new Luminosity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy</strong></td>
<td>3.5/8.0</td>
<td>4.000/7.007</td>
<td>GeV</td>
</tr>
<tr>
<td><strong>Crossing angle</strong></td>
<td>22</td>
<td>83</td>
<td>mrad</td>
</tr>
<tr>
<td>(\beta_y^*)</td>
<td>5.9/5.9</td>
<td>0.27/0.30</td>
<td>mm</td>
</tr>
<tr>
<td>(\beta_x^*)</td>
<td>1200/1300</td>
<td>32/25</td>
<td>mm</td>
</tr>
<tr>
<td>(\varepsilon_x)</td>
<td>18/24</td>
<td>3.2/4.6</td>
<td>nm</td>
</tr>
<tr>
<td>(\varepsilon_y/\varepsilon_x)</td>
<td>0.85/0.64</td>
<td>0.27/0.28</td>
<td>%</td>
</tr>
<tr>
<td>(\sigma_y^* = (\beta_y^* \varepsilon_y)^{1/2})</td>
<td>0.94</td>
<td>0.048/0.062</td>
<td>(\mu m)</td>
</tr>
<tr>
<td>(\xi_y)</td>
<td>0.129/0.090</td>
<td>0.088/0.081</td>
<td></td>
</tr>
<tr>
<td>(\sigma_z)</td>
<td>6~7</td>
<td>6/5</td>
<td>mm</td>
</tr>
<tr>
<td>(I)</td>
<td>1.64/1.19</td>
<td>3.6/2.6</td>
<td>A</td>
</tr>
<tr>
<td>(N_B)</td>
<td>1584</td>
<td>2500</td>
<td></td>
</tr>
<tr>
<td><strong>Luminosity</strong></td>
<td>2.11</td>
<td>80</td>
<td>(10^{34} \text{ cm}^{-2}\text{s}^{-1})</td>
</tr>
</tbody>
</table>
Main items to upgrade

- Low emittance
  - Improve optics in the arcs and wiggler sections.
  - Change the LER beam pipes (electron cloud mitigation).
  - Replace LER bends with longer ones.
  - Upgrade Linac, including the construction of a positron damping ring, strengthening the positron source, and installation of a low-emittance gun for electrons.
  - Fine alignment of magnets.
- Increase of currents
  - Strengthen the cooling facilities.
  - Strengthen and reconfigure the RF system.
- Nano-beam collision scheme
  - Rebuild the IR and Tsukuba straight section.
  - Implement speed and resolution improvements to the beam diagnostics and control system.
SuperKEKB Upgrade

- Redesign the lattices of both rings to reduce the emittance
- Replace short dipoles with longer ones (LER)
- New beam pipe & bellows
- New positron source
- Add / modify RF systems for higher beam current
- New superconducting final focusing quads near the IP
- New Interaction region
- Colliding bunches
- Belle II
- Electrons to inject
- Low emittance positrons to inject
- Low emittance electrons to inject
- Electrons cloud mitigation for LER beam pipes
- Damping ring
- Low emittance gun

Intensity up

ICHEP2014
Commissioning strategy

- Phase 1 (from 2015 Oct., 5 ~ 7 months)
  - No superconducting final focus magnets (QCS), No Belle II, No beam collision
  - Basic commissioning of machine
  - Vacuum scrubbing (with 0.5 ~ 1A, at least one month)
  - Damping ring commissioning (last one month of Phase 1)
  - Low emittance optics tuning
  - Study of beam instability (FII, e-cloud) and bunch-by-bunch feedback

- Phase 2 (late 2016 ~ early 2017, 4.5 ~ 6.5 Months)
  - With QCS, Belle II without vertex detector (VXD)
  - Optics tuning
    - Target value of $\beta^*_y$ : 2.2 mm
  - Beam back ground study with collimator tuning
  - Increase of beam currents (instability, RF power, vacuum issues)
    - Target beam currents: 1000/800 mA (LER/HER)
  - Beam collision tuning (Orbit feedback: fast vertical feedback, dithering system)
  - Luminosity tuning
    - Target luminosity: $1 \times 10^{34}$ cm$^{-2}$ s$^{-1}$ (design of KEKB)

- Phase 3 (from 2017 Oct. ~ )
  - With VXD
  - The first important milestone in Phase 3 is to achieve the luminosity $1 \times 10^{35}$ cm$^{-2}$ s$^{-1}$. 
Linac

- Commissioning of the new low emittance RF-gun and the new positron source has just started.

<table>
<thead>
<tr>
<th></th>
<th>Now</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>June 2014</td>
<td>Phase 1</td>
</tr>
<tr>
<td>Low emittance RF-</td>
<td>ring</td>
<td></td>
</tr>
<tr>
<td>gun (e)</td>
<td>0.5×2</td>
<td>1×2</td>
</tr>
<tr>
<td>W target</td>
<td></td>
<td>5×2</td>
</tr>
<tr>
<td>Positron source</td>
<td>0.02×2</td>
<td>2×2</td>
</tr>
</tbody>
</table>
Fabrication of accelerator components is ongoing.
Installation will start in FY2014.
DR commissioning will start in 2015.

### Parameter Values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>1.1 GeV</td>
</tr>
<tr>
<td>Bunches</td>
<td>2 x 2</td>
</tr>
<tr>
<td>Circumference</td>
<td>135.5 m</td>
</tr>
<tr>
<td>H. damping</td>
<td>10.87 ms</td>
</tr>
<tr>
<td>Ext. emittance (H/V)</td>
<td>42.5/3.15 nm</td>
</tr>
<tr>
<td>Max. current</td>
<td>70.8 mA</td>
</tr>
</tbody>
</table>

**DR tunnel construction**
- **Jun. 2012**
- **Dec. 2012**
- **Mar. 2013** Completed
Utility

- Reinforcing work of cooling system is nearly complete.
- A large part of the delivery pipe in the tunnel was renewed.
- The construction of a shaft which connects the tunnel and a ground level water-cooler building is in progress.

Renewal of delivery pipes is performed in a limited space between accelerator components and a tunnel wall.
RF system

- Rearrangement of cavities was over.
- Preparation work for the aging at early 2015 is now on-going.
- The number of klystron will be increased step-by-step after Phase 1.

SuperKEKB-RF (phase 1)

- Add 5 klystrons, HP&LL
- Add 3 power supplies
- Convert to LER
- Remove 4 ARES
- Add 2 ARES

Klystron, HP&LLRF system

- Type “A” power supply (for two klystrons)
- Type “B” power supply (for one klystron)

ARES cavity

SC cavity

SC crab
Magnet production and installation

- Production of all new magnets was over.
- Installation of all magnets will be complete January 2015.

LER dipole

Field measurement

Sextupole tilting system (for chromatic coupling correction)

Skew Q

Tsukuba straight
Survey and alignment

- Alignment work is ongoing. It is difficult to coexist with the heavy duty construction work above ground. Effects of the new utility buildings and new tunnel are clearly seen.
- First overall survey is planned from October 2014 to February 2015.
Beam feedback system

- Beam Position Monitors
  - Gated turn-by-turn detectors are being fabricated. 117 units will be available by phase 1 commissioning.
  - R&D of IP orbit feedback system is in progress. A down-converter for signal detection has completed.

- Bunch-by-bunch Feedback System
  - Transverse kickers, button electrodes, power cables and power amplifiers have been installed.
  - LER longitudinal kickers have been ordered and will be installed in August 2014.
Photon monitors

1) Visible light monitors (horizontal and longitudinal size measurements)
   - Design of the mirror, the holder and the chamber have been finalized.
   - Fabrication of the mirrors and the holders will finish in this FY (2014).

2) X-ray monitors (vertical size measurements)
   - Beam line design have been finalized.
   - Under fabrication are downstream section of beam line vacuum components, high-efficiency pixel detectors and 64-channel readout system.

3) Large-Angle Beamstrahlung Monitor (collision size/position offsets monitor)
   - Design of the extraction chamber has been finalized.
   - Optics boxes, optical-transfer-line components and extraction mirrors are being fabricated.

Diamond mirror for visible light monitors
64-channel readout system for x-ray monitors
Optics box and extraction mirror for LABM
Beam pipes

**HER**
- 82% of vacuum components are reused.
- Tsukuba straight regions, and wiggler sections, etc. are new.
- New beam collimators will be installed before Phase-2.
- 20% of new beam pipes have been installed in the tunnel.
- 86% of the total are placed in the tunnel.

**LER**
- 94% of vacuum components should be renewed until Phase-1.
- Injection region will be changed before Phase-2.
- 84% of new beam pipes have been installed in the tunnel.
- 85% of the total are placed in the tunnel.
Electron cloud mitigation in LER

- Avoid emittance growth due to the electron cloud.

<table>
<thead>
<tr>
<th>Sections</th>
<th>L [m]</th>
<th>L [%]</th>
<th>Countermeasure</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>3016</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drift space (arc)</td>
<td>1629</td>
<td>54</td>
<td>TiN coating (200nm) + Solenoid</td>
<td>Al (arc)</td>
</tr>
<tr>
<td>Steering mag.</td>
<td>316</td>
<td>10</td>
<td>TiN coating + Solenoid</td>
<td>Al</td>
</tr>
<tr>
<td>Bending mag.</td>
<td>519</td>
<td>17</td>
<td>TiN coating + Grooved surface</td>
<td>Al</td>
</tr>
<tr>
<td>Wiggler mag.</td>
<td>154</td>
<td>5</td>
<td>Clearing Electrode</td>
<td>New Cu</td>
</tr>
<tr>
<td>Q &amp; SX mag.</td>
<td>254</td>
<td>9</td>
<td>TiN coating</td>
<td>Al (arc)</td>
</tr>
<tr>
<td>RF section</td>
<td>124</td>
<td>4</td>
<td>(TiN coating +) Solenoid</td>
<td>Cu</td>
</tr>
<tr>
<td>IR section</td>
<td>20</td>
<td>0.7</td>
<td>(TiN coating +) Solenoid</td>
<td>Cu</td>
</tr>
</tbody>
</table>

- By using these countermeasures, the average electron density on the order of $10^{10}$ e$^-$/m$^3$ will be obtained.
  - Threshold of head-tail instability: $\sim 1.6 \times 10^{11}$ e$^-$/m$^3$
Electron cloud mitigation in LER

Solenoid

Antechamber

Clearing electrode (Wiggler)

Groove (Bend)

Vertical DC magnetron sputtering apparatus.

Oho vacuum Laboratory

ICHEP2014
Final focus magnets (OCS)

- All are Superconducting magnets.
- The left cryostat will be delivered in December 2014.
- The right cryostat will be delivered in July 2015.
- Target mechanical tolerance is 0.1 mm.
- Installation of QCS-L and -R are scheduled after phase1 commissioning.

Collaring has been done for all magnets
Beam collimators

• New types are developed based on the PEP II collimator design.
• Two horizontal types are in production, and will be installed until Phase-1 at an arc section of LER. (For Phase 1, HER collimator is an old type)
• Others will be installed after Phase 1.

Schematic drawing of a horizontal type

Cut view of a vertical collimator
Critical situation of vertical collimator

LER as an example
The vertical aperture is narrowest at the QC1P. To reduce the beam background due to Coulomb scattered particles hitting a QC1P pipe, vertical collimators must make a narrower aperture than QC1P pipe. On the other hand, the collimator should not approach the beam too close to induce the transvers mode coupling instability (TMCI). Therefore, the distance of the vertical collimator from the beam and the value of betatron amplitude function of the collimator location must satisfy two inequalities at the same time. This results in:

• The location of the vertical collimator should be a low beta region.
• The number of the vertical collimator (to stop the background at QC1) is one or two.
• The background depends sharply on the collimator position. The tunable range is narrow.

<table>
<thead>
<tr>
<th>Collimator width d [mm]</th>
<th>( \beta_y ) [m]</th>
<th>IR loss [GHz]</th>
<th>Total loss [GHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.40</td>
<td>0.04</td>
<td>149.5</td>
<td></td>
</tr>
<tr>
<td>2.50</td>
<td>0.05</td>
<td>137.8</td>
<td></td>
</tr>
<tr>
<td>2.60</td>
<td>0.09</td>
<td><strong>127.4</strong></td>
<td></td>
</tr>
<tr>
<td>2.70</td>
<td>0.24</td>
<td>118.1</td>
<td></td>
</tr>
<tr>
<td>2.80</td>
<td>0.81</td>
<td>110.0</td>
<td></td>
</tr>
<tr>
<td>2.90</td>
<td>8.48</td>
<td>109.3</td>
<td></td>
</tr>
<tr>
<td>3.00</td>
<td>18.98</td>
<td>109.3</td>
<td></td>
</tr>
</tbody>
</table>

Allowed region

TMCI condition

(r=10.5mm)

(r=13.5mm)

Acceptable loss level

ICHEP2014
Optics issue at present

- With beam-beam effect, optimized LER lifetime (chromaticity & tune working point) is still half of design target.
- Crab waist scheme to cure beam-beam effect is proposed, but we don't have feasible crab waist lattice design at this moment.
Summary

• SuperKEKB aims for a luminosity of $8 \times 10^{35}\text{cm}^{-2}\text{s}^{-1}$ with the nano-beam collision scheme.
• Commissioning proceeds in three phases.
• Preparation for Phase 1 will complete early 2015.
• LER adopted present available mitigation technologies against electron cloud. The effect is studied in Phase 1.
• Collimators are fully equipped in Phase 2. Coulomb background is very sensitive on the aperture of vertical collimator.
• Beam-beam effect degrades the Touschek lifetime of LER to the half of the design value.
Thank you for your attention!

This is our quest
To follow that star
No matter how hopeless
No matter how far

(from ‘The impossible dream’, partly modified)