Status and schedule of SuperKEKB

2011.07.23 EPS-HEP2011 Accelerator Session
Kyo Shibata (on behalf of KEKB Group)
KEKB was shut down on Jun 30\textsuperscript{th} 2010, and Upgrade of KEKB Has Started.

- KEKB B-factory
  - Electron-positron collider with asymmetric energies of 8 GeV (e-) and 3.5 GeV (e+)
  - Operating period: 1998 to 2010
  - Total integrated luminosity: 1040 /fb
  - Made a great contribution to confirm CP violation in the neutral B meson system.

Shut down ceremony (Jun 30\textsuperscript{th} 2010, AM9:00 @ KEKB control room)  
Prof. Suzuki (Director General of KEK) pressed the beam abort switch of KEKB.
History of KEKB Operation

Luminosity of KEKB
Oct. 1999 - June 2010

Crab Crossing
Peak luminosity
21.1 /pb/s

1479 /pb/day

8.43 /fb/7 days
30.2 /fb/30 days

1041 /fb

Integrated luminosity (/fb)
History of Peak & Integrated Luminosity

Trend of Peak Luminosity \( [10^{33} \text{ /cm}^2\text{/s}] \)

Integrated Luminosity \( [/\text{fb}] \)
Mission of SuperKEKB

• Design Luminosity of SuperKEKB is $8 \times 10^{35} \text{ /cm}^2/\text{s}$, which is 40 times larger than the KEKB’s record.

• 50 /ab can be accumulated within several years.
Design Concept of SuperKEKB 1
To Increase Luminosity by 40 Times

- $\beta_y^*$ at IP: 5.9 -> 0.27/0.30 mm (e+/e-)
  - Nano-beam scheme (first proposed for SuperB by P. Raimondi)
  - Luminosity gain: $\times 20$
- Beam current: 1.7/1.4 A -> 3.6/2.6 A (e+/e-)
  - Luminosity gain: $\times 2$
- Beam-beam parameter: 0.09 -> 0.09
  - Luminosity gain: $\times 1$
- Total Luminosity Gain: $20 \times 2 \times 1 = 40$

### Lorentz Factor
\[
L = \frac{\gamma_{\pm}}{2er_e} \left( 1 + \frac{\sigma_y^*}{\sigma_y} \right)
\]

### Beam current
\[
I_{\pm} = \frac{\sigma_y^*}{\sigma_y}
\]

### Beam-Beam parameter
\[
R_L = \frac{R_{\xi_y}}{\xi_y}
\]

Geometrical reduction factors (crossing angle, hourglass effect)

### Vertical beta function at IP
\[
\beta_y^* = \frac{L_{\pm} \xi_y}{\sigma_y}
\]

### Beam aspect ratio at IP
Collision Scheme
(Nano Beam Scheme)

KEKB
Head-on (crab crossing)

SuperKEKB
Nano Beam scheme

Overlap region = bunch length

Hourglass requirement

\[ \beta_y^* \geq \sigma_z \approx 6 \text{ mm} \]

In nano-beam scheme:

Vertical beta function at IP can be squeezed to \( \sim 300 \text{ \mu m} \).
Small horizontal beam size at IP is necessary.

Low emittance, small horizontal beta function at IP
Design Concept of SuperKEKB 2

- To reduce the construction costs
  - Use the KEKB tunnel
  - Use the components of KEKB as much as possible.
    - Preserve the present cells in HER.
    - Replace dipole magnets keeping other main magnets in LER arcs.

- Other features
  - No option for polarization at present.
  - Changing beam energy: 3.5/8.0 -> 4.0/7.0 GeV (e+/e-)
    - LER: Longer Touschek lifetime and mitigation of emittance growth due to the intra-beam scattering
    - HER: Lower emittance and lower SR power
### Comparison of Parameters between KEKB and SuperKEKB

<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>5.9/5.9</td>
<td>0.27/0.30</td>
</tr>
<tr>
<td>$\beta_x^*$ (mm)</td>
<td>330/330</td>
<td>1200/1200</td>
<td>32/25</td>
</tr>
<tr>
<td>$\epsilon_x$ (nm)</td>
<td>18/18</td>
<td>18/24</td>
<td>3.2/5.3</td>
</tr>
<tr>
<td>$\epsilon_y / \epsilon_x$ (%)</td>
<td>1</td>
<td>0.85/0.64</td>
<td>0.27/0.24</td>
</tr>
<tr>
<td>$\sigma_y$ (µm)</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>1.64/1.19</td>
<td>3.6/2.6</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>

2011/7/23 Europhysics Conference on High-Energy Physics 2011, Grenoble (France)
Outline of Upgrade to SuperKEKB

- Colliding bunches
- Belle II
- New beam pipe & bellows
- New IR
- New superconducting/permanent final focusing quads near the IP
- e+ 4 GeV 3.6 A
- e- 7 GeV 2.6 A

- Add / modify RF systems for higher beam current
- Replace short dipoles with longer ones (LER)
- Redesign the lattices of both rings to reduce the emittance
- TiN-coated beam pipe with antechambers
- Damping ring
- Positron source
- New positron target / capture section
- Low emittance positrons to inject
- Low emittance electrons to inject

- SuperKEKB
Major Items for Construction

- In order to reduce the horizontal emittance of both beams to $1/5 \sim 1/10$ of KEKB’s values, a large number of magnets need to be rearranged, replaced and added.

- **LER arc section:**
  - Replace bending magnets (~100) with new longer ones.

- **LER wiggler section:**
  - New 56 single pole wigglers and 112 half pole wigglers will be added to the existing normal ones to double the wiggler cycles.

- **HER wiggler section:**
  - Wiggler magnets will be installed.
  - For 6 wiggler sections among 10, present LER wiggler magnets will be reused.

**LER B**

$\mathbf{L} = 0.89 \text{ m} \rightarrow 4 \text{ m}$
Major Items for Construction 2
Beam pipe

- To cope with the electron cloud issues and heating problems, ante-chamber type beam pipes are adopted with a combination of TiN coatings, grooved shape surfaces and clearing electrodes.

- LER arc section:
  - Beam pipes are replaced with new aluminum-alloy pipes with antechambers. (~2000 m)

- HER arc section:
  - Present copper beam pipes are reused.
  - Since the HER energy is reduced from 8.0 to 7.0 GeV, SR power at normal arc section is more or less the same as KEKB.

- Wiggler section (both ring):
  - Copper beam pipes with antechambers are used.
Major Items for Construction 3
Countermeasure against E-cloud

➢ Wiggler section:
  ✓ Electrons are attracted by the clearing electrode, which is mounted on the inner surface of beam pipe.

➢ In bending magnet (Arc section):
  ✓ Effective SEY is structurally reduced by the groove surface with TiN coating on top and bottom of beam channel.

➢ Drift space:
  ✓ Electron cloud is mitigated by TiN coating and solenoid field.
Major Items for Construction 4
Interaction Region

- A new final focus magnet system is being designed to squeeze $\beta_y^*$.

- Final SC quads are located as close to the IP as possible.
  - Independent magnets in LER and HER are used.
  - IR design needs to be fixed until the autumn this year.
  - Optics design, local chromaticity correction scheme, hardware design (QCS, beam pipe, monitors and supports) and assembly procedure are under discussion now.
  - Evaluation of B.G. issues are under way, too.

 Prototype Q-magnet

Very compact superconducting magnets for final focusing system

Detector Solenoid axis

Beam crossing angle = 83 mrad
Major Items for Construction 5
RF system

- Beam powers required for HER and LER are 1.5 and 2.5 times higher than KEKB.
- It is necessary to increase the beam power per cavity and the number of RF stations where one klystron feeds one ARES cavity.

- ARES cavity (normal conducting cavity):
  - Add HP&LL RF system and rearrange ARES cavities.
  - Change ARES input couplers to larger coupling ones.
  - Improve HOM dampers.

- SCC (superconducting cavity):
  - Improve HOM dampers.

Start with low beam current. At T=0 the maximum current is less than the design value (maybe 60~70%). Increase to the design current will take about two years or more.
Major Items for Construction 6
Linac and beam transport system

- Upgrades to the injector linac and beam transport system are designed to improve the rate and quality of injected beams to deliver the required beams with increased injection efficiencies.
  - New low-emittance RF electron gun
  - Improvement of the positron source
  - Installation of a 1.1 GeV positron damping ring
  - And so on...

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For both e+ and e-: Emittance preservation through whole linac

Nominal acceleration
S-band 160MeV / RF unit
+ C-band 8m at 4-4

For Photon Factory
2.5 GeV
0.1nC x 1

For HER
7.0 GeV
5nC x 2

For AR
e- or e+?

---

For both e+ and e-
Emittance preservation through whole linac

Nominal acceleration
S-band 160MeV / RF unit
+ C-band 8m at 4-4

For Photon Factory
2.5 GeV
0.1nC x 1

For HER
7.0 GeV
5nC x 2

For AR
e- or e+?
The beam monitor and control system will also be improved.
Cooling system will be reinforced for the magnets and vacuum system.
Tunnel and buildings and additional transformers for damping ring will be built.
Dismantlement of KEKB, R&D, design, fabrication and installation of components, checking and adjustment for commissioning.
And so on...
Total budget for upgrade is 31.4 billion yen ($392 Million). (JFY2010-2014)

- Operation budget is expected in FY2014 and later.

$1 = 80 yen

Very Advanced Research Support Program (10 Billion Yen) MR and DR commissioning
Other budgets for construction (21.4 Billion Yen) Operation budget (continues - - - )

We are here now.
SuperKEKB Construction Schedule

Revised on Jun. 28, 2011

<table>
<thead>
<tr>
<th>FY2010</th>
<th>FY2011</th>
<th>FY2012</th>
<th>FY2013</th>
<th>FY2014</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beam pipes and vacuum components</strong></td>
<td>Fabrication</td>
<td>Baking, TiN coating</td>
<td>Install, system check</td>
<td></td>
</tr>
<tr>
<td><strong>Magnets and power supplies</strong></td>
<td>Fabrication</td>
<td>Field measurement</td>
<td>Install, alignment, system check</td>
<td></td>
</tr>
<tr>
<td><strong>RF system</strong></td>
<td>Strengthen and rearrangement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Monitor &amp; control, Beam transport</strong></td>
<td>R&amp;D</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>QCS and IR hardware</strong></td>
<td></td>
<td>Fabrication</td>
<td>Install, system check</td>
<td></td>
</tr>
<tr>
<td><strong>Damping Ring</strong></td>
<td></td>
<td>Optics and hardware design</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>e+e- Injector</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>MR infrastructure</strong></td>
<td>Components Fabrication</td>
<td></td>
<td>Install, alignment, system check</td>
<td></td>
</tr>
<tr>
<td><strong>Upgrade and operation for PF/PF-AR</strong></td>
<td></td>
<td></td>
<td>Install, alignment, system check</td>
<td></td>
</tr>
<tr>
<td><strong>DR tunnel construction</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>DR buildings construction</strong></td>
<td></td>
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</tbody>
</table>

SuperKEKB commissioning
Dismantlement of KEKB is now in progress
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A huge earthquake hit eastern Japan on March 11.

- All KEK personnel and users were safe.
- At KEK-Tsukuba site some infrastructures and components of accelerators were damaged, even though we are some 300 km away from the epicenter.
- The damage to the KEKB main rings appears to be less serious, though non-negligible.
- No serious damage has been reported so far at Belle.

Damaged air-fin cooler for klystron

Crack on the campus road.
Damages from Earthquake
Damage of Magnet
Aftermath of Earthquake

• Damage of components of accelerator
  ➢ Some components, such as an air-fin cooler for klystron, RF control system, equipments for beam monitor, etc. were damaged.
  ➢ Some magnets, which were removed from tunnel and kept above ground for reuse, collided with each other and were damaged.
  ➢ These damaged components should be repaired or replaced.
  ➢ We are determining the extent of the damage of other components by an operational check with electric power supplied to the devices.
  ➢ Detailed checks including high-power test are necessary for the final judgment on the damage situation.

• Damage of buildings and tunnel
  ➢ Distortion of the tunnel made large gaps of up to 4 mm at the expansion joints.
  ➢ Survey and realignment of magnets and reference points are necessary.

• Dismantlement works
  ➢ We are trying to eliminate 1.5 month delays in the dismantlement works within a time frame of the construction.
Commissioning Plan

• Machine commissioning
  - Main Ring and Damping Ring commissioning will start in the second half of FY2014.
  - Linac is in operation for PF and PF-AR during the construction period. Test operation for the upgrade will be performed in parallel. Commissioning of Linac for SuperKEKB will start in the beginning of FY2014.

• Detector
  - The detector people want that the machine operation starts without Belle II. So the machine commissioning will start with some dummy chambers with a luminosity monitor at the IR (so called BEAST).
  - IR configuration before Belle II roll-in is under discussion (for example, “Do we need solenoids or special skew-Q, special radiation shield in the place of Belle, etc. with an extra cost?”). We have no concrete plan for this so far.
Projection of Luminosity

- **1.2/ab/month**
  - (8 x10^{35} /cm^2/s)
- **0.9/ab/month**
  - (6 x10^{35} /cm^2/s)
- **0.6/ab/month**
  - (4 x10^{35} /cm^2/s)

ShUTDOWN FOR UPGRADE

LEARNING CURVE

PHYSICS PROGRAM EVALUATION

2005 - 2025
Thank you very much for your attention.
Backup