Status and Performance of BEPCII

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For the BEPCII Team

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• Linac Status and New Upgrades
• Commissioning of Storage Rings
• Operation of BEPCII
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1. Introduction of BEPCII

- **BEPCII** — An upgrade project of BEPC
- A double-ring factory-like machine
- Deliver beams to both HEP & SR
**Strategy of luminosity upgrade**

- **DR:** multy-bunch $k_{bmax} \approx 400$, $k_b = 1 \rightarrow 93$

- **Choose large $\varepsilon_x$ & optimum param.:** $I_b = 9.8\text{mA}$, $\xi_y = 0.04$

- **$L(cm^{-2}s^{-1}) = 2.17 \times 10^{34} (1 + R) \xi_y \frac{E(\text{GeV})k_b I_b (A)}{\beta_y^*(cm)}$**

- **Micro-$\beta$:** $\beta_y^* = 5\text{cm} \rightarrow 1.5\text{ cm}$
  - SC insertion quads

- **Reduce impedance +SC RF**
  - $\sigma_z = 5\text{cm} \rightarrow <1.5\text{cm}$

- **$(L_{\text{BEPCII}}/ L_{\text{BEPC}})_{D.R.} = (5.5/1.5) \times 93 \times 9.8/35 = 96$**

- **$L_{\text{BEPC}} = 1.0 \times 10^{31} \text{ cm}^{-2}\text{s}^{-1} \rightarrow L_{\text{BEPCII}} = 1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$**

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2010-05-26

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Design Goals of BEPCII

Collision Mode

- Beam energy range: 1-2.1 GeV
- Optimized beam energy: 1.89 GeV
- Luminosity: $1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$ @1.89 GeV
- Full energy injection: 1-1.89 GeV

SR Mode

- Beam energy: 2.5 GeV
- Beam current: 250 mA
- Keep the present beam lines useable

Upgrade of BEPC: One machine, two purposes (HEP, SR)
# The Milestones

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 2004</td>
<td>Construction started</td>
</tr>
<tr>
<td>May 4, 2004</td>
<td>Dismount of 8 linac sections started</td>
</tr>
<tr>
<td>Dec. 1, 2004</td>
<td>Linac delivered e⁻ beams for BEPC</td>
</tr>
<tr>
<td>July 4, 2005</td>
<td>BEPC ring dismount started</td>
</tr>
<tr>
<td>Mar. 2, 2006</td>
<td>BEPCII ring installation started</td>
</tr>
<tr>
<td>Nov. 13, 2006</td>
<td>Phase 1 commissioning started</td>
</tr>
<tr>
<td>Aug. 3, 2007</td>
<td>Shutdown for installation of IR-SCQ’s</td>
</tr>
<tr>
<td>Oct. 24, 2007</td>
<td>Phase 2 commissioning started</td>
</tr>
<tr>
<td>Mar 28, 2008</td>
<td>Shutdown for installation of detector</td>
</tr>
<tr>
<td>June 24, 2008</td>
<td>Phase 3 commissioning started</td>
</tr>
<tr>
<td>July 19, 2008</td>
<td>First hadron event observed</td>
</tr>
<tr>
<td>May 19, 2009</td>
<td>Luminosity reached 3.3×10^{32} cm⁻²s⁻¹</td>
</tr>
</tbody>
</table>

## Peak Lum History

<table>
<thead>
<tr>
<th>Date</th>
<th>Luminosity (cm⁻²s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 2007</td>
<td>3.50×10^{32}</td>
</tr>
<tr>
<td>May 2009</td>
<td>3.00×10^{32}</td>
</tr>
<tr>
<td>May 2010</td>
<td>2.50×10^{32}</td>
</tr>
<tr>
<td>May 2011</td>
<td>2.00×10^{32}</td>
</tr>
<tr>
<td>May 2012</td>
<td>1.50×10^{32}</td>
</tr>
<tr>
<td>May 2013</td>
<td>1.00×10^{32}</td>
</tr>
<tr>
<td>May 2014</td>
<td>0.50×10^{32}</td>
</tr>
<tr>
<td>May 2015</td>
<td>0.00×10^{32}</td>
</tr>
</tbody>
</table>

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### Notes

- **May 2004**: Construction started.
- **May 4, 2004**: Dismount of 8 linac sections started.
- **Dec. 1, 2004**: Linac delivered e⁻ beams for BEPC.
- **July 4, 2005**: BEPC ring dismount started.
- **Mar. 2, 2006**: BEPCII ring installation started.
- **Nov. 13, 2006**: Phase 1 commissioning started.
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- **July 19, 2008**: First hadron event observed.
- **May 19, 2009**: Luminosity reached 3.3×10^{32} cm⁻²s⁻¹.
2. Linac Status and New Upgrades

- Sub-harmonic buncher system installed
Two sub-harmonic bunchers, SHB1 and SHB2, in 142.8MHz and 571.2MHz, respectively
• Output of one bunch
• **Problems exist:**

 ✓ Phase drift from the SHB’s frequency signal generator

 ✓ Temperature control of the thermostatic chamber of the signal generator

 ● **Further improvement is needed.**
3. Commissioning of Storage Rings

- Beam optics and its realization
### Design Parameters of Ring (Col. Mode)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit(s)</th>
<th>Value(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>GeV</td>
<td>1.89</td>
</tr>
<tr>
<td>Circumference</td>
<td>m</td>
<td>237.53</td>
</tr>
<tr>
<td>Beam current</td>
<td>A</td>
<td>0.91</td>
</tr>
<tr>
<td>Bunch number</td>
<td></td>
<td>93</td>
</tr>
<tr>
<td>Bunch current</td>
<td>mA</td>
<td>9.8</td>
</tr>
<tr>
<td>Bunch spacing</td>
<td>m</td>
<td>2.4</td>
</tr>
<tr>
<td>Bunch length</td>
<td>cm</td>
<td>1.5</td>
</tr>
<tr>
<td>RF frequency</td>
<td>MHz</td>
<td>499.80</td>
</tr>
<tr>
<td>Harmonic number</td>
<td></td>
<td>396</td>
</tr>
<tr>
<td>Emittance (x/y)</td>
<td>nm·rad</td>
<td>144/2.2</td>
</tr>
<tr>
<td>$\beta$ function at IP (x/y)</td>
<td>m</td>
<td>1.0/0.015</td>
</tr>
<tr>
<td>Crossing angle</td>
<td>mrad</td>
<td>±11</td>
</tr>
<tr>
<td>Design luminosity</td>
<td>cm$^{-2}$s$^{-1}$</td>
<td>$1 \times 10^{33}$</td>
</tr>
</tbody>
</table>
• Optics Correction

• Beam based alignment to get BPM offset
• Orbit distortion correction based on the measurement of response matrix
• LOCO applied to get fudge factors of quadrupoles

Measured response matrix

Model - Measured Response Matrix

Difference between the measured and the model response matrices with LOCO
• Optics Correction (cont’d)

✓ Measured beam optics functions are in good agreement with theoretical prediction with discrepancy within ±10% at most quadrupoles,

✓ Design $\nu_x/\nu_y = 6.54, 5.59$, measured $\nu_x/\nu_y = 6.544, 5.559$

✓ Quadrupole strengths systematically 1~2% lower than design set:
  1) Interference between adjacent Quadrupole and sextupole
  2) fringe field effect.
  3) Other origin of these errors is still pursued.
In phase 3 of commissioning, the detector solenoid effect was compensated.

AS1 – 3 are connected in series, but AS2 and AS3 have trims.
• Local correction to the SCQs near IP.

BETY (Blue: No solenoid; Pink: with solenoid; yellow: after SCQ compensation)
• Beam Injection

To reduce the residual orbit oscillation of the stored beam
=> set the right timing and amplitude of the two kickers.

- Time delay scan
- Amplitude scan

⇒ After optimization with on bunch, the residual orbit oscillation of all the bunches during injection reduced to around 0.1mm/0.1σ_x.

⇒ Injection on collision possible

=> For timing: fix k1, scan k2 ; do in turn for k2
=> For amp: fix k1 or k2 amp, scan the other
• Beam Injection

To reduce the residual orbit oscillation of the stored beam:

=> set the right timing and amplitude of the two kickers.

Fixed:

=> For timing: fix k1, scan k2; do in turn for k2

=> For amp: fix k1 or k2 amp, scan the other

After optimization with on bunch, the residual orbit oscillation of all the bunches during injection reduced to around 0.1σₓ.

Injection on collision possible
Luminosity commissioning

**Optics compensation** ($\beta^*$, $\beta_{\text{IR}}$, $\alpha^*$, tune) and Golden orbit

- Set vertical bump at NCP ($4 \sim 5\sigma_x$)
- Longitudinal position tuning (bunch spacing $\sim 3.6\text{ns}$)
- Scan $e^+/e^-$ orbit to get collision offset
- Scan $e^+/e^-$ offset at IP, optimize luminosity according to background
- Single bunch luminosity tuning (tune, coupling, $\beta$-waist, etc.)
- Scan orbit again to optimize luminosity
- Multi-bunch injection and collision (BCM to watch the uniform injection)
- Multi-bunch optimization (instability, filling pattern, background)
- Luminosity with multi-bunch
Scan $e^-/e^+$ orbit
Step for tuning orbit $< 1 \mu m$

Scan RF phase to get the vertical crossing angle
Angle tuning at IP

β*-waist tuning

2009-12-10

Seminar at LNF

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On-line tune scan for two rings

Scan BPR

Scan BER

2009-12-10
Seminar at LNF
Instability Issues

A bunch-by-bunch “lengthening” in BPR observed

BER: 420mA/70 bunches

BPR: 386mA/70 bunches

2010-05-26
Quadrupole oscillations of head and tail of e- and e+ bunch train

2010-05-26
Quadrupole oscillations of head and tail of e- and e+ bunch train
### Source of the impedance: the temporary screen monitor in BPR

(Courtesy T.M. Huang)

<table>
<thead>
<tr>
<th>Model</th>
<th>Frequency (GHz)</th>
<th>Q</th>
<th>R</th>
<th>R/Q</th>
<th>Field decay time (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small cavity</td>
<td>1.8171</td>
<td>2256.9</td>
<td>86160</td>
<td>38.1774</td>
<td>198</td>
</tr>
<tr>
<td>Vacuum pump</td>
<td>2.3432</td>
<td>8335.6</td>
<td>4579</td>
<td>0.54933</td>
<td>556</td>
</tr>
</tbody>
</table>

**Difference from the BER and BPR!**

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2010-05-26
Simulation on beam oscillation in longitudinal
Luminosity recovery after removing the SM

![Graph showing luminosity recovery over current](image)
Moving tunes close to half integers

\[ \nu_x \rightarrow 6.51 \text{(nominal)}, \ 6.508 \text{(meas.)} \]

\[ \nu_y \rightarrow 5.58 \text{(nominal)}, \ 5.587 \text{(meas.)} \]

BPR: \( \beta_y^* \approx 1.38 \text{ cm (measured)} \)

BER: \( \beta_y^* \approx 1.33 \text{ cm (measured)} \)
$L_{\text{peak}} = 3.3 \times 10^{32} \text{cm}^{-2} \text{s}^{-1}$!
Main parameters achieved in collision mode

<table>
<thead>
<tr>
<th>parameters</th>
<th>design</th>
<th>Achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BER</td>
<td>BPR</td>
</tr>
<tr>
<td>Energy (GeV)</td>
<td>1.89</td>
<td>1.89</td>
</tr>
<tr>
<td>Beam curr. (mA)</td>
<td>910</td>
<td>650</td>
</tr>
<tr>
<td>Bunch curr. (mA)</td>
<td>9.8</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Bunch number</td>
<td>93</td>
<td>93</td>
</tr>
<tr>
<td>RF voltage</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>*ν_s @1.5MV</td>
<td>0.033</td>
<td>0.032</td>
</tr>
<tr>
<td>β_x*/β_y* (m)</td>
<td>1.0/0.015</td>
<td>~1.0/0.0135</td>
</tr>
<tr>
<td>Inj. Rate (mA/min)</td>
<td>200 e^-/50 e^+</td>
<td>&gt;200</td>
</tr>
<tr>
<td>Lum. (× 10^{33}cm^{-2}s^{-1})</td>
<td>1</td>
<td>0.33</td>
</tr>
</tbody>
</table>
Luminosity with 80 bunches collision

Luminosity reduction due to longitudinal dipole oscillation
• Longitudinal feedback system was installed in both rings in last summer to cure the longitudinal dipolar oscillation.
- Grow/damp at $182.4 \text{ mA}$;
- Growth rate of $0.1 \text{ ms}^{-1}$ — growth time of 10 ms;
- Fast damping of $0.66 \text{ ms}^{-1}$ (1.5 ms damping time);
- Eigenmode 63 is unstable;
- 50+ data sets to analyze at currents from 135 to 182 mA.

Courtesy J.H. Yue and D. Teytelman

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Growth Rates: $e^+$ (Continued)

- Four trains, 59 bunches total;
- Threshold estimated quite nicely;
- Extrapolate to 0.98 ms$^{-1}$ at 1 A;
- Clear difference from one train fill pattern.

Courtesy J.H. Yue and D. Teytelman
Effect of longitudinal feedback

![Graph showing longitudinal feedback effects with measurements and data points.](image)
Beam-beam Issue

Specific luminosity vs bunch current [mA]

2009 (Qx~0.53) 2009 (Qx~0.51) 2010 (Qx~0.53)

Luminosity vs beam current [mA]

2009 (Qx~0.53) 2009 (Qx~0.51) 2010 (Qx~0.53)
Achieved beam-beam limit

Reasons of beam-beam limit:
• Crossing angle at the IP (11mrad×2)
• Not high bunch current (9.8mA in design)
Problems met during luminosity commissioning

Background of detector

- 2 horizontal moveable masks installed, each for one ring, ~8m upstream from the IP.
- They reduced ~50% of the beam-related background.
New masks installed last summer to reduce background
• Data taking @ E=1.84GeV, $\psi(s)$
• Higher dark current for high beam current @ $\nu_x \sim 0.51$
Detector dark current measurement

Source of background:

• Beam-gas scattering --- vacuum needs to be improved
• Touschek scattering --- beam optics needs to be modified
• Other sources?

P\_e^+ > P\_e^–
4. Operation of BEPCII

- Running for HEP ($\psi(2S)$, $J/\psi$, $\psi(3770)$)

Data taking of 100M $\psi(2S)$ and 200M $J/\psi$ events, 2009
Running at $\psi(3770)$ in 2010, aiming at 1 fb$^{-1}$
Primary physics results of BESIII

- Confirmation of BESII results
  - threshold enhancement $\gamma p\bar{p}$, $\gamma \omega \phi$, $X(1835)$, ...
- New improved measurements
  - $h_c$, $\eta_c$, $\chi_{cJ}$, ...
- New observations
  - $\chi_{cJ}$ decays
  - $h_c$ decays
  - Light hadrons, ...

Three papers published
Many in memo stage

Observation of $h_c$ in $\psi(2S) \rightarrow \pi^0 h_c, h_c \rightarrow \gamma \eta_c$


Courtesy Y.F. Wang
• Running for SR

➢ Dedicated SR mode
• Running with parasitic mode

- Beam collision with a wiggler on
- Luminosity tuning with the wiggler on

- Deliver beam to HEP and SR users simultaneously!
HOMs heating problem

1) More than 1000 thermal couplers used

2) Display in colour according to dangerousness: green, yellow and red.

3) In most case, the temperature rise (SR) => flux of cooling water adjusted
Bad contact of the RF finger in the shielding of bellows caused HOM heating, vacuum leakage in April 2009.
• Replace the new bellows
• Re-design the RF fingers of the shielding
• Cooling water and wind for the new bellows
• Restrain the bunch current and beam current ($I_b<6\text{mA}$, $\Sigma I < 550\text{mA}$)
Kicker problem (ceramic board broke in Mar. 2010)

Normal case

Bad vacuum in BPR-K2
• Beam experiment to determine the problem

Top-up 400mA
50 bunches

Ion = 5700 μA
P_k2 = 4.4E-7 Torr

Top-up 400mA
90 bunches

Ion = 990 μA
P_k2 = 4.4E-8 Torr
5. Discussions and Summary

• Commissioning and more stable running of Linac are necessary.

• 1/3 of the design luminosity reached, further studies are needed.

• The dark current of detector limits the beam current right now, and needs to be improved.
To enhance luminosity

- Normal measures:
  - Increase bunch current, beam current
  - Shorten bunch spacing, to get more bunches
  - Squeeze $\beta_y^*$
  - Tunes closer to half integers

Possible peak luminosity: $L \sim 4 - 5 \times 10^{32} \text{cm}^{-2}\text{s}^{-1}$
Issues on the ways of further upgrades

- Heating of bellows, vacuum chamber, etc.
- Background when bunch current increases
- Possible ECI after bunch current increases or bunch spacing shortening
- Longitudinal instabilities after bunch spacing shortening
- Etc, etc.
Long term upgrade of the BEPC-II

• Crab-waist for higher luminosity

• Collision with polarized beam
  ✓ Physics requirement
  ✓ Possibility of realization (e-beam? Location for rotators? Other solutions?)
  ✓ Budget
  ✓ Other problems…
Acknowledgement

- Commissioning team of BEPCII
- Colleagues from BNL, LBNL, INFN-LNF, KEK, and SLAC
- All others from labs around world…
Thanks for your attentions!