BINP electron-positron facilities

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on behalf of
IC, VEPP-4M, VEPP-2000 teams

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BINP - IHEP Seminar
IC Parameters (2016)
Beam Energy: 395 MeV
Storage rate $e^-$ @ 12.5 Hz: $4.0 \cdot 10^{10}/s$ (70 mA/s)
Storage rate $e^+$ @ 12.5 Hz: $4.0 \cdot 10^9/s$ (7 mA/s)
Experimental program:
- $e^+e^-$ HEP at VEPP-4M with KEDR detector
- SR at VEPP-3 (2 GeV)
- SR at VEPP-4M (2÷4 GeV)
- Nuclear physics at VEPP-3 with Deuteron facility
- Test Beam Facility at VEPP-4M
- Accelerator physics activity

<table>
<thead>
<tr>
<th>Energy</th>
<th>0.925 ÷ 4.75 (5.3)</th>
<th>GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumference</td>
<td>366</td>
<td>m</td>
</tr>
<tr>
<td>N of bunches</td>
<td>$2e^+ \times 2e^-$ (16$e^-$)</td>
<td></td>
</tr>
<tr>
<td>Harmonic number</td>
<td>222</td>
<td></td>
</tr>
<tr>
<td>Betatron tunes, h/v</td>
<td>8.54/7.57</td>
<td></td>
</tr>
<tr>
<td>Coupling</td>
<td>0.05%</td>
<td></td>
</tr>
<tr>
<td>Bunch length</td>
<td>5</td>
<td>cm</td>
</tr>
<tr>
<td>Beam Energy</td>
<td>1.5 1.9 4.7 5.2</td>
<td>GeV</td>
</tr>
<tr>
<td>Emittance</td>
<td>16 25 167 200</td>
<td>nm·rad</td>
</tr>
<tr>
<td>Energy Spread</td>
<td>2.5 3.0 7.8 8.5 $\cdot 10^{-4}$</td>
<td></td>
</tr>
<tr>
<td>Bunch Current</td>
<td>1.6 3.5 25 25</td>
<td>mA</td>
</tr>
<tr>
<td>Luminosity</td>
<td>0.9 3.3 44 25 $10^{30}$ cm$^{-2}$·s$^{-1}$</td>
<td></td>
</tr>
</tbody>
</table>

- Universal magnetic detector KEDR
- Electron-positron tagging system
- Wide energy range 0.9÷6 GeV
- Energy spread control
- Precision beam energy calibration by resonance depolarization ($10^{-6}$ accuracy!)
- The first collider with beam energy monitoring by Compton backscattering
HEP VEPP-4M with KEDR

2001-2017 low energy luminosity run $2x(0.9\div1.9)$ GeV
✓ $J/\psi, \psi’, \psi'', \psi(3770)$ meson masses
✓ $\tau$ lepton mass
✓ $D^0$ mesons masses
✓ $D^\pm$ mesons masses
✓ Search for narrow resonances $1.85\div3.1$ GeV
✓ R-scan $1.85\div3.1$ GeV
✓ $R_{uds^{-}}$ and R-scan $3.12\div3.72$ GeV
✓ $J/\psi \rightarrow \gamma\eta_c$
✓ $\psi$-mesons, $\eta_c$, ... parameters

High energy luminosity run $2x(1.9\div\text{Max energy})$ GeV
✓ R scan $2x(2.3\div3.5)$ GeV ($\sim 10 \text{ pb}^{-1}$)
✓ $Y$-mesons study ($\sim 50 \text{ pb}^{-1}$)
✓ gamma-gamma physics ($\sim 200 \text{ pb}^{-1}$)

➢ $R$ measurement at VEPP-4M collider
(K.Yu. Todyshev, BINP)
Run 2017/18 highlights

In 2017 hadron cross section measurement from 2.3 to 3.5 GeV in two runs was started.

First luminosity $\Upsilon(1S)$
Deuteron VEPP-3

Tensor-polarized deuteron photodisintegration at the VEPP-3 storage ring

The two-body deuteron photodisintegration is one of the most studied process in nuclear physics. Tensor analyzing power T20 reaction will be measured in an unexplored region of the photon energy up to 1.5 GeV.

✓ SR @ VEPP-3 – 1.2 or 2.0 GeV with 2 T shifter
✓ SR @ VEPP-4M – 1.9 or 4.5 GeV with new 9-poles hybrid 2 T wiggler

VEPP-3
- LIGA-technology and X-ray lithography.
- Fast dynamic process.
- Precise diffraction and anomalous scattering.
- X-ray fluorescence analysis.
- High pressure diffraction.
- X-ray microscopy and micro-tomography.
- Time resolved diffraction.
- Time resolved luminescence.
- Precise diffraction.

VEPP-4M
- Metrology experiments.
- Phase contrast microscopy, micro-tomography and hard X ray fluorescence.
- Nanosecond spectroscopy of fast processes.
- Material study under extremal conditions
- Material study for thermonuclear applications
VEPP-2000

- Round beams concept!
- Single-ring head-on collisions
- 13 T superconducting solenoids for FF
- 2.4 T NC dipoles at 1 GeV
- CBS for energy control

Design parameters @ 1 GeV

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Circumference</td>
<td>24.388 m</td>
</tr>
<tr>
<td>Beam energy</td>
<td>150 ÷ 1000 MeV</td>
</tr>
<tr>
<td>N of bunches</td>
<td>1×1</td>
</tr>
<tr>
<td>N of particles</td>
<td>1×10^{11}</td>
</tr>
<tr>
<td>Betatron tunes</td>
<td>4.14 / 2.14</td>
</tr>
<tr>
<td>Beta*</td>
<td>8.5 cm</td>
</tr>
<tr>
<td>Luminosity</td>
<td>1×10^{32} cm^{-2}s^{-1}</td>
</tr>
</tbody>
</table>

* Operating with IC since 2016
Recent results from SND detector at VEPP-2000 collider.
Measurement of pion formfactor. (A.S. Kupich, BINP)
Study of electron-positron annihilation to hadrons with CMD-3 at VEPP-2000

1. Precision measurement of $R = \sigma(e^+e^- \rightarrow \text{hadrons})/\sigma(e^+e^- \rightarrow \mu^+\mu^-)$ exclusive approach, up to $<1\%$ for major modes
2. Study of hadronic final states:
   $$e^+e^- \rightarrow 2h, 3h, 4h, \ldots \quad h = \pi, K, \eta$$
3. Study of vector mesons and theirs excitations:
   $$\rho', \rho'', \omega', \varphi', \ldots$$
4. Comparison of cross-sections $e^+e^- \rightarrow \text{hadrons} \ (T = 1)$ with spectral functions of $\tau$-decays
5. Study of nucleon electromagnetic formfactor at threshold
   $$e^+e^- \rightarrow p\bar{p}, n\bar{n}$$
6. Measurement of the cross-sections using ISR
7. Study of higher order QED processes

Target luminosity integral is 1 fb$^{-1}$ per detector
Beam-beam limit (for lepton collider)

\[
L = \frac{N_1 N_2 n_b f_0}{4\pi \sigma_x \sigma_y} = \frac{\pi \gamma^2 \xi_x \xi_y \varepsilon_x f_0}{r_e^2 \beta_y^*} \left(1 + \frac{\sigma_y}{\sigma_x}\right)^2
\]

\[
\xi_{x,y} = \frac{r_e \beta_{x,y}^*}{2\pi \gamma \sigma_{x,y} (\sigma_x + \sigma_y)} N
\]

Final limit:
1) emittance blowup,
2) lifetime reduction,
3) flip-flop effect
Round Colliding Beams

stochastic particles motion

Final limit:
1) emittance blowup,
2) lifetime reduction,
3) flip-flop effect

Axial symmetry of counter beam force $R_{CB}$
+ X-Y symmetry of transfer matrix IP2IP

Additional integral of motion (angular momentum $M_z = x'y - xy'$)
Particle dynamics remains nonlinear, but becomes 1D

Lattice requirements:
• Head-on collisions!
• Small and equal $\beta$-functions at IP:
• Equal beam emittances:
• Equal fractional parts of betatron tunes:

Make motion “more integrable” and stable
Beam-beam limit at VEPP-2000

\[ L = \frac{N_1 N_2 n_b f_0}{4\pi \sigma_x \sigma_y} = \frac{\pi \gamma^2 \xi_x \xi_y \varepsilon_x f_0}{r_e^2 \beta_y^*} \left( 1 + \frac{\sigma_y}{\sigma_x} \right)^2 \]

\[ \xi_{x,y} = \frac{r_e \beta_{x,y}^*}{2\pi \gamma \sigma_{x,y}(\sigma_x + \sigma_y)} N \]

\[ \xi_{\text{nom}} = \frac{N^- r_e \beta_{\text{nom}}^*}{4\pi \gamma \sigma_{\text{nom}}^2} \] - normalized beam current

\[ \xi_{\text{lumi}} = \frac{N^- r_e \beta_{\text{lumi}}^*}{4\pi \gamma \sigma_{\text{lumi}}^2} \] - “beam-beam parameter”

\[ L = \frac{N^+ N^-}{4\pi \sigma^*_{\text{lumi}}} f_0 = \frac{N f_0 \gamma}{r_e} \frac{\xi_{\text{lumi}}}{\beta_{\text{nom}}^*} \]
Flip-flop effect

\[ \xi \approx \Delta \nu = \nu_\pi - \nu_\sigma \]

[Graph showing pickup spectrum of coherent oscillations]

Regular

Blown-up e-

Blown-up e+

E = 240 MeV,
\[ I_{\text{beam}} \sim 5 \times 5 \text{ mA} \]

Coherent beam-beam \( \pi \)-mode interaction with machine nonlinear resonances
A: Flip-flop suppression with long bunch

\[ E = 392.5 \text{ MeV} \]

**Bunch lengthening & mw instability**

Single bunch length measurement with phi-dissector as a function of single beam current for different RF voltage @ 478 MeV.

Energy spread dependence, restored from beam transverse profile measurements.
B: Beam shaking *

*Idea (I.Koop):* kicked bunch oscillations decoheres very fast in the presence of counter beam’s strongly nonlinear field. Weak and frequent kicks should effectively increase the emittance, similarly to quantum excitation by wiggler.

At low energies emittance growth is available up to aperture restriction. That allow with the same beam-beam parameter (particles density) increase the beam current and luminosity.

Typical values: 50-100 V, 300 ns, 50 µs

\[ T_{\text{rev}} = 81.4 \text{ ns} \]

*Experimentally:* permanent excitation of “strong” beam size prevent it from shrinkage to natural value during injection cycle of “weak” beam, or whatsoever. Very effective suppression of flip-flop meta-stable states.

In addition large emittance results in a lifetime enhancement.
C: Machine tuning
Data collection

Below 500 MeV

Above 500 MeV

Highest luminosity achieved

\[ L_{\text{peak}} = 5 \times 10^{31} \text{ cm}^{-2}\text{s}^{-1} \]

at 550 MeV

“yesterday”

CMD-3 luminosity, averaged over 10% of the best runs

2017-2018 data

2010-2013 data
Total luminosity integral

Lowest energy ever obtained in $e^+e^-$ colliders
Beam energy measurements: CBS system

Inverse Compton Scattering at Budker INP: experiments & prospects
(N.Yu.Muchnoi, BINP)
Future projects

Super-CT Project

- e⁺e⁻ collider
- Beam energy range from 1 to 2.5 GeV
- Extremely high luminosity (~ $10^{35}$ cm⁻²·s⁻¹)
- Longitudinal polarization of electron beam at the IP.

The facility can study:
- tau leptons
- charmed particles
- light quark spectroscopy in the unique manner.

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**Super Tau-Charm project in BINP (V.S. Vorobyov, BINP)**
Dimuonium, bimuonium or true muonium is a lepton atom ($\mu^+\mu^-$).
- Dimuonium is pure QED system (no strong interaction, calculable).
- From 6 leptonic atoms ($e^+e^-$), ($\mu^+e^-$), ($\mu^+\mu^-$), ($\tau^+e^-$), ($\tau^+\mu^-$), ($\tau^+\tau^-$) only two ($e^+e^-$), ($\mu^+e^-$) were observed.
- Very compact (large $m_\mu$), more sensitive to new physics than other exotic atoms.

Details are in: https://arxiv.org/abs/1708.05819
Thanks for your attention