Overview prospects at BINP

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BINP, 630090 Novosibirsk, Russia

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Outline

• VEPP-2000 results and plans
• BEP-booster ring upgrade to 1 GeV
• Positrons from new injector complex
• VEPP-4M
• Super tau/charm factory status
• Other proposals
Cross section $e^+e^- \rightarrow \text{hadrons}$
**VEPP-2000 collider facility**

### Main parameters at 1GeV

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumference</td>
<td>24.388 m</td>
</tr>
<tr>
<td>Beam energy</td>
<td>160 ÷ 1000 MeV</td>
</tr>
<tr>
<td>Number of bunches</td>
<td>1</td>
</tr>
<tr>
<td>Number of particles</td>
<td>$1 \times 10^{11}$</td>
</tr>
<tr>
<td>Tunes</td>
<td>4.1 / 2.1</td>
</tr>
<tr>
<td>Beta-function @ IP</td>
<td>8.5 cm</td>
</tr>
<tr>
<td>Beam-beam parameter $\xi$</td>
<td>0.1</td>
</tr>
<tr>
<td>Luminosity</td>
<td>$1 \times 10^{32}$ cm$^{-2}$s$^{-1}$</td>
</tr>
</tbody>
</table>
VEPP-2000 photo
Motivation for round beams

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

Round beam:

\[ L = \frac{4\pi \gamma^2 \xi^2 \varepsilon f}{r_e^2 \beta^*} \]

✓ Geometrical factor:

✓ Beam-beam parameter enhancement(†):

✓ Higher Touschek lifetime at low collision energies!

\[
(1 + \sigma_y / \sigma_x)^2 = 4
\]

\[
\xi \geq 0.1
\]
Solenoid of the Final Focus

1 – iron yoke, 2 – LHe vessel, 3 – LN screen, 4 – room temperature wall, 5 – LN liner, 6 – NbTi coils, 7 – Nb$_3$Sn coils, 8 – NbTi compensating detector field solenoid
Beam Sizes measured by CCD monitors
Three options with different solenoids polarities (each twists plane by 45°)

Switching between solenoid polarities causes large orbit distortions. Not easy to play!

Round beams are made by choice of a working point on the linear coupling resonance. “Flat” option showed best beam-beam limit: \( \xi > 0.1 \) while all others ~3 times lower due to DA problems.

Round beams are made by choice of a working point on the linear coupling resonance. “Flat” option showed best beam-beam limit: \( \xi > 0.1 \) while all others ~3 times lower due to DA problems.
Working point in different optics

- "Flat"
- "Normal round"
- "Single möbius"
- "Double möbius"

Graph showing the working points in different optics.
VEPP-2000: Luminosity vs. energy

\[ \beta^* \propto \gamma \]
\[ \varepsilon \propto \gamma \]
\[ \sigma^* \propto \gamma \]
\[ L \propto \gamma^2 \]

\[ L = \frac{4\pi\gamma^2 \xi^2 \varepsilon f}{r_e^2 \beta^*} = \frac{4\pi\gamma^2 \xi^2 \sigma^* f}{r_e^2 \beta^{*2}} \]
\[ \sigma^{*2} = \varepsilon \beta^* = \text{inv}(\beta^*) \]
VEPP-2000: Luminosity energy scan

DA & IBS lifetime

\[ \beta^* \propto \gamma \]
\[ \varepsilon \propto \gamma \]
\[ \sigma^* \propto \gamma \]
\[ L \propto \gamma^2 \]

\[ \beta^* = \text{const} \]
\[ \varepsilon \propto \gamma^2 \]
\[ \sigma^* \propto \gamma \]
\[ L \propto \gamma^4 \]

“Flip-flop”

Deficit of positrons

ramping

VEPP-2M with wiggler

VEPP-2M

Beam-beam parameter vs. energy

Limited by positrons production rate

ramping
Beam-Beam sigma/pi-mode measurements

E = 392.5 MeV beam energy, RF voltage 35 kV (violet points) and 17 kV (blue points).

\[ \xi_{\text{lumi}} = \frac{N^{-r_e\beta^*_\text{nom}}}{4\gamma^2_{\sigma_{\text{lumi}}} \} \]

\[ \xi = 0.125 \]
\[ \Delta \nu = 0.087 \]

\[ \Delta \nu = \arccos(\cos(\pi \nu_0) - 2\pi \xi \sin(\pi \nu_0)) / \pi - \nu_0 \]
Energy measurement: Compton Back-Scattering

Interference of the scattered light emitted at $\phi = 0$ along an arc A-C

$E = 993.662 \pm 0.016$ MeV

Energy measurement: resonance depolarization

\[ f_{\text{eff}} = \left( \frac{E_{\text{MeV}}}{40381} \right)^{-1} \]
Upgraded to 1 GeV BEP’s dipole (26 kGs)

Reduced gap: from 40 mm to 32 mm.
Narrowed width of the flat part of a pole: from 120 mm to 100 mm.
Increased width of a return yoke.
VEPP-2000 summary

• Three seasons with data taking for physics have shown very good collider performance, limited only by positrons accumulation rate. Maximum luminosity achieved $1.3 \times 10^{31} \text{ cm}^{-2}\text{s}^{-1}$ at 0.51 GeV and $3 \times 10^{31} \text{ cm}^{-2}\text{s}^{-1}$ at 0.9 GeV.

• BEP’s upgrade to 1 GeV and 10 times higher positron production rate, demonstrated recently at new injector complex VEPP-5, will ensure realization of the project luminosity goals in the full energy range.

• Next physics run is expected in the end of 2014.
• Beam-beam test experiment with smaller beta_x but larger D_x – to prove gain in collision currents and in luminosity

• R measurements and two gamma physics with increased beam energy up to 4.5–4.7 GeV (depends on RF)

• CPT test by resonance depolarization of two beams with $10^{-8}$ accuracy

• New transfer lines from VEPP-5 positron/electron injector complex commissioning
VEPP-4 schematic view
VEPP-4 parameters and experimental facilities

- Detector KEDR for HEP experiments
- Electron tagging system at VEPP-4 for two-photon experiments
- SR experiments at VEPP-3
- SR experiments at VEPP-4
- Internal gas target for nuclear physics at VEPP-3
- Electron/gamma test beam facility for detector calibration
- Compton backscattering system
- High resolution polarization measurement system for CPT study
- Sophisticated beam diagnostics for accelerator experiments

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumference, $P$ (m)</td>
<td>366.075</td>
</tr>
<tr>
<td>Revolution frequency, $f_0$ (kHz)</td>
<td>818.924</td>
</tr>
<tr>
<td>Revolution period, $T_0$ (ns)</td>
<td>1221</td>
</tr>
<tr>
<td>Maximum energy, $E$ (GeV)</td>
<td>5.37</td>
</tr>
<tr>
<td>Momentum compaction factor, $\alpha$</td>
<td>0.017</td>
</tr>
<tr>
<td>Betatron tunes, $Q_x/Q_z$</td>
<td>8.54/7.58</td>
</tr>
<tr>
<td>Synchrotron tune, $Q_z$</td>
<td>0.012</td>
</tr>
<tr>
<td>Natural chromaticity, $\xi_x/\xi_z$</td>
<td>-14.5/20.3</td>
</tr>
</tbody>
</table>

**Parameters at 1.8 GeV**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damping times, $\tau_x/\tau_y/\tau_z$ (ms)</td>
<td>70/35/70</td>
</tr>
<tr>
<td>Horizontal emittance, $\varepsilon_x$ (nm-rad)</td>
<td>17</td>
</tr>
<tr>
<td>Energy spread, $\sigma_E/E$</td>
<td>$4\times10^{-4}$</td>
</tr>
<tr>
<td>Bunch length, $\sigma_L$ (cm)</td>
<td>6</td>
</tr>
<tr>
<td>Energy loss/turn, $\Delta U$ (keV)</td>
<td>16</td>
</tr>
<tr>
<td>IP optical functions, $\beta_x/\beta_y/\eta_z$ (m)</td>
<td>0.05/0.7/0.78</td>
</tr>
</tbody>
</table>
VEPP-4/KEDR features for HEP

- Beam energy range varied from 0.9 GeV up to 5.0 GeV
- Beam energy calibration using resonant depolarization method with the record accuracy of $10^{-6}$
- On-line monitoring of the beam energy using the Compton back scattering method with the accuracy of $5\cdot10^{-5}$
- Universal detector KEDR comparable with modern detectors used for high-energy physics experiments at the electron-positron colliders:
  - system of registration of scattered electrons and positrons with the record resolution $10^{-3}$,
  - liquid-krypton electromagnetic calorimeter,
  - system of aerogel Cerenkov counters.
Beam energy measurement

Resonant depolarization provides a record accuracy in energy calibration

Compton back-scattering – routine energy monitoring during HEP experiment runs

\[ \Omega_s = \omega_0 \left( 1 + \gamma \frac{q'}{q_0} \right) \]

\[ E = 440.65 \text{ MeV} \cdot \left( \frac{\Omega_s}{\omega_0} - 1 \right) \]

\[ \frac{\delta E}{E} < 10^{-6} \]

\[ \frac{\delta E}{E} \approx 5 \cdot 10^{-5} \]

\[ \text{Na}^{24} (1) = 1368.625 \text{ keV} \]
\[ \text{Na}^{24} (2) = 2754.008 \text{ keV} \]
\[ \text{Na}^{24} (1+2) = 4122.633 \text{ keV} \]
Particle mass measurements at VEPP-4

<table>
<thead>
<tr>
<th>Particle</th>
<th>$E$, MeV</th>
<th>Accuracy, $\Delta E/E$</th>
<th>Detector</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>J/ψ</td>
<td>3096.93±0.10</td>
<td>3.2·10⁻⁵</td>
<td>OLA</td>
<td>1979-1980</td>
</tr>
<tr>
<td>ψ'</td>
<td>3685.00±0.12</td>
<td>3.3·10⁻⁵</td>
<td>OLA</td>
<td>1979-1980</td>
</tr>
<tr>
<td>γ</td>
<td>9460.57±0.09±0.05</td>
<td>1.2·10⁻⁵</td>
<td>MD-1</td>
<td>1983-1985</td>
</tr>
<tr>
<td>γ'</td>
<td>10023.5±0.5</td>
<td>5.0·10⁻⁵</td>
<td>MD-1</td>
<td>1983-1985</td>
</tr>
<tr>
<td>γ''</td>
<td>10355.2±0.5</td>
<td>4.8·10⁻⁵</td>
<td>MD-1</td>
<td>1983-1985</td>
</tr>
<tr>
<td>J/ψ</td>
<td>3096.917±0.010±0.007</td>
<td>3.5·10⁻⁶</td>
<td>KEDR</td>
<td>2002-2008</td>
</tr>
<tr>
<td>ψ'</td>
<td>3686.119±0.006±0.010</td>
<td>3.0·10⁻⁶</td>
<td>KEDR</td>
<td>2002-2008</td>
</tr>
<tr>
<td>ψ''</td>
<td>3772.9±0.5±0.6</td>
<td>2.1·10⁻⁴</td>
<td>KEDR</td>
<td>2002-2006</td>
</tr>
<tr>
<td>D⁰</td>
<td>1865.43±0.60±0.38</td>
<td>3.8·10⁻⁴</td>
<td>KEDR</td>
<td>2002-2005</td>
</tr>
<tr>
<td>D⁺</td>
<td>1863.39±0.45±0.29</td>
<td>2.9·10⁻⁴</td>
<td>KEDR</td>
<td>2002-2005</td>
</tr>
<tr>
<td>τ</td>
<td>1776.69^{+0.17}_{-0.19}±0.15</td>
<td>1.3·10⁻⁴</td>
<td>KEDR</td>
<td>2005-2008</td>
</tr>
</tbody>
</table>
Precise polarization experiments

- New Touschek polarimeter is commissioned. The registration efficiency is increased by an order of magnitude.
- Total count rate at 2 mA beam current is now 1.5-2.0 MHz (was 0.1-0.2 MHz).
- An absolute record 1.5⋅10^{-9} accuracy of the measurement of depolarization frequency is achieved.
- For CPT test experiment, the 10^{-8} accuracy of comparison of the electron and positron spin frequency is real now.

“Nano-resolution”: scan rate = 2.5 eV/s relative error ~10^{-9}
Increase in VEPP-4M luminosity at low energy (proposal)

We plan to test this proposal in a special experiment.

Luminosity formulae (flat beam)

\[ L = \frac{\gamma}{2e} \frac{I \xi_x}{\beta_y^*} \]

\[ \xi_x = \frac{N \beta_x^*}{2\pi\gamma \sigma_x^2} \]

\[ \xi_y = \frac{N \beta_y^*}{2\pi\gamma \sigma_y \sigma_x} \]

Monochromatization parameter

\[ \lambda_m = \frac{\sigma_{x\beta}}{\sigma_{x\beta}} = \frac{\eta_x \sigma_E}{\sqrt{\epsilon_x \beta_x}} \]

\[ \sigma_x = \sqrt{\sigma_{x\beta}^2 + \sigma_{x\eta}^2} = \sigma_{x\beta} \sqrt{1 + \lambda_m^2} \]

\[ x = x_{\beta} + \eta_x \Delta E \]

IP with dispersion

Increase in \( \lambda_m \) owing to reducing \( \beta_x \) (not \( \epsilon_x - \) emittance!) results in:

- increase of critical current due to decrease of \( \xi_x \)
- Increase of critical \( \xi_y \) because of coupling resonance suppression

VEPP-4M base structure

Reduced by half

With beta_x in IP

BB Footprint

Red \( \rightarrow \) betatron resonances up to 6th order

Blue \( \rightarrow \) synchro - betatron satellites

Distribution in betatron amplitude plane

\( I_b = 3.0 \) mA, \( \beta_x = 65 \) cm, \( \xi = 0.036 \)

\( I_b = 5.0 \) mA, \( \beta_x = 32.5 \) cm, \( \xi = 0.053 \)

Resume

Reducing \( \beta_x \) by half yields increase of critical current from 3 to 5 mA
SR source in the VEPP-4 tunnel as an option

- $E = 3$ GeV
- Emittance = 1 nm
- Current = 500 mA
- RF 180 MHz exists

In a long (~70 m) straight section a set of IDs is located.
Longitudinally polarized beams (wait approval)

(Project for VEPP-4: 1981, 1983)

Depolarization time with SS:
\[ \tau_d \approx \frac{54}{11} \cdot \frac{\tau_{S-T}}{\pi^2 V^2} \cdot B(\nu, \nu_x) \propto E^{-7} \]

\[ \nu = \gamma a \]

\( B(\nu, \nu_x) \) – betatron factor

VEPP - 4M Sokolov - Ternov time:
\[ \tau_{S-T}[h] = \frac{1540}{E^3[GeV]} \]

70 hours at 1.85 GeV

Estimate with \( B(\nu, \nu_x) \)
(no optimization):

\[ \tau_d = 160 \text{ min at } E = 1777 \text{ MeV} \]
\[ \tau_d = 120 \text{ min at } E = 1846 \text{ MeV} \]
\[ \tau_d = 425 \text{ min at } E = 1548 \text{ MeV} \]

Both electron and positron polarizations available in luminosity run.

Effects @ 1.85 GeV \( \propto \langle \zeta_+ \zeta_- \rangle_{\text{time}} = \frac{2 \tau_d}{t_{\text{run}}} P_+ P_- \left[ \exp \left( - \frac{2t_{\text{run}}}{\tau_d} \right) - 1 \right] \approx 0.3 \),

\[ t_{\text{run}} = 1 \text{ h - run duration} \]

\[ P_+ = 0.92 \left[ 1 - \exp \left( - \frac{t}{\tau_{p,VEPP - 3}} \right) \right] = e^+ \text{ initial degree} \]

\[ t \approx 3000 \text{ s}; \quad P_- = P_+ \exp \left( - \frac{t}{\tau_d} \right) = e^- \text{ initial degree} \]

Siberian Snake (SS) insert with decoupling:
Two SC 124 cm × 72 kG solenoids (1.98 GeV)
Five 20 cm×(up to 2.8 kG/cm) quads
Total length=430 cm
Super Cτ Factory Prototype (from φ to ψ)

Crab Waist e^+e^- Factory providing in the energy range from 0.5 GeV to 1.55 GeV the peak luminosity from 10^{34} to 5\times10^{34} cm^{-2}s^{-1}

10 times cheaper than SuperCτ Factory
VEPP-4 summary

• Since 2002 VEPP-4M collider with detector KEDR provides world-class results for HEP community

• Many other experimental programs (SR, nuclear physics, test beams, accelerator physics study, etc.) are successfully performed at the accelerator facility

• Different scenarios of the future at VEPP-4 (or with the help of its infrastructure) are considered intensively
Positrons at VEPP-5
Injector complex
NEW INJECTOR COMPLEX FOR BINP’s COLLIDERS

Damping ring

300 MeV e⁻ linac

510 MeV linac

Transfer line to VEPP-2000, VEPP-3, Tau/Charm Linac
LINACS to GENERATE $e^+$ and ACCELERATE $e^+$ and $e^-$ to 500 MeV.
DAMPING RING for STORAGE $e^+, e^-$
Novosibirsk Super Tau-Charm factory

Existing Injection facility VEPP-5
(will be used for VEPP-4M and VEPP-2000)

Tunnel for the linac and the technical straight section of the factory is ready

\[ L = 1 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}, \quad \text{Variable energy } E_{\text{cm}} = 2 \text{ – } 5 \text{ GeV} \]

Status of the project:
• Conceptual design of the machine and detector is complete
• Civil engineering and infrastructure design is complete
• Road map is ready (6 years for realization)
• Project is preliminary approved by the Russian government
Super C/tau Factory at Novosibirsk

(physics)

- D-Dbar mixing
- CP violation searches in charm decays
- Rare and forbidden charm decays
- Standard Model tests in $\tau$ lepton decays
- Searches for lepton flavor violation $\tau \rightarrow \mu \gamma$
- CP/T violation searches in $\tau$ lepton decays

Requirements: $L > 10^{35}$ cm$^{-2}$ s$^{-1}$, longitudinal polarization

(Polarization may increase sensitivity by several times!)

Project waits of final government’s approval!