E. Levichev, for the VEPP-4 team

STATUS OF VEPP-4M COLLIDER: CURRENT ACTIVITY AND PLANS

24 September 2012
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• VEPP-4M general information
• High energy physics experiments
• SR experimental program
• Nuclear physics at VEPP-3
• Test beam facility
• Accelerator physics experiment
• Future plans
• Summary
### VEPP-4M parameters and experimental programs

#### Table: VEPP-4M Parameters

<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>5.3^7</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/\zeta )</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/\zeta/\xi ) (ms)</td>
<td>70/35/70</td>
</tr>
<tr>
<td>Horizontal emittance, ( \varepsilon ) (nm-rad)</td>
<td>17</td>
</tr>
<tr>
<td>Energy spread, ( \sigma_E/E )</td>
<td>4x10^{-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/\beta_c/\eta_c ) (m)</td>
<td>0.05/0.7/0.78</td>
</tr>
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</table>

- Detector KEDR for HEP experiments
- Electron tagging system at VEPP-4M for two-photon experiments
- SR experiments at VEPP-3
- SR experiments at VEPP-4M
- 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
VEPP-4M complex pictures

- 180 MHz RF cavities
- VEPP-4 arc
- Longitudinal FB kicker
- VEPP-3 arc
- Control room
- VEPP-4 arc
- 50 MeV linac
- Detector KEDR
- 350 MeV synchrotron
- 2 MeV ELIT accelerator
VEPP-4M time sharing (2000-2010)

Experiments at VEPP-3

Experiments at VEPP-4
• 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 $5 \cdot 10^{-5}$

• 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.
Resonant depolarization provides a record accuracy in energy calibration

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

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

\[ E = 440.65 \text{ MeV} \cdot \left( \frac{\Omega_s}{\omega_0} - 1 \right) \]
### 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>$\psi'$</td>
<td>3685.00±0.12</td>
<td>3.3·10^{-5}</td>
<td>OLA</td>
<td>1979-1980</td>
</tr>
<tr>
<td>$\Upsilon$</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>$\Upsilon'$</td>
<td>10023.5±0.5</td>
<td>5.0·10^{-5}</td>
<td>MD-1</td>
<td>1983-1985</td>
</tr>
<tr>
<td>$\Upsilon''$</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>$\psi'$</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>$\psi''$</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>D$^0$</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>$\tau$</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>
Tau lepton mass measurement

The measured cross section of $e^+e^- \rightarrow \tau^+\tau^-$ versus center-of-mass energy and fit.

World average $m_\tau = 1776.99 \pm 0.29 - 0.19$ MeV

KEDR $m_\tau = 1776.69 \pm 0.17 - 0.18$ (stat.) $\pm 0.15$ (syst.) MeV

High-energy physics: $J/\psi$, $\psi'$ and $\psi''$

High-precision measurements of the $\psi$-family meson masses provide the energy scale in the range around 3 GeV, which is the basis for accurate determination of masses of all charmed particles.

<table>
<thead>
<tr>
<th>Particle</th>
<th>$\Delta M/M$ (PDG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p$</td>
<td>$0.1 \cdot 10^{-6}$</td>
</tr>
<tr>
<td>$n$</td>
<td>$0.1 \cdot 10^{-6}$</td>
</tr>
<tr>
<td>$e$</td>
<td>$0.1 \cdot 10^{-6}$</td>
</tr>
<tr>
<td>$\mu$</td>
<td>$0.1 \cdot 10^{-6}$</td>
</tr>
<tr>
<td>$\pi^\pm$</td>
<td>$2.5 \cdot 10^{-6}$</td>
</tr>
<tr>
<td>$\psi'$</td>
<td>$3.0 \cdot 10^{-6}$</td>
</tr>
<tr>
<td>$J/\psi$</td>
<td>$3.5 \cdot 10^{-6}$</td>
</tr>
<tr>
<td>$\pi^0$</td>
<td>$4.5 \cdot 10^{-6}$</td>
</tr>
</tbody>
</table>

Only 5 particle masses have been measured with higher accuracy.

$M_{J/\psi} = 3096.917 \pm 0.010 \pm 0.007$ MeV

$M_{\psi'} = 3686.119 \pm 0.006 \pm 0.010$ MeV

3 times improved

$M_{\psi''} = 3772.9 \pm 0.5 \pm 0.6$ MeV

2 times improved
Hadron cross-section (R) measurement

\[ R = \frac{\sigma(e^+e^- \rightarrow \text{hadrons})}{\sigma_B(e^+e^- \rightarrow \mu^+\mu^-)} \]

R is used to estimate hadron vacuum polarization.

Previous measurements are not consistent well, so new measurement in wide energy range at one facility with one detector is highly desirable.
To adjust VEPP-2000 and VEPP-4M energy scales, we have measured $R$ in low energy region from $2E = 1.85$ GeV to 3 GeV.

Searching of narrow resonance states in this region was performed.
Near future plans: measurement of the hadron cross-section $R$ and $\gamma\gamma$-physics in the beam energy range up to 4.5 GeV.

VEPP-4M test run in 2011 at high energy. Maximum current with feedback systems ON (up). Luminosity at 3.5 GeV (left).
The only facility where the total cross section of $\gamma \gamma \rightarrow \text{hadrons}$ can be measured precisely and reliably.
SR experiments at VEPP-3

0a – LIGA and X-ray lithography
0b – “Explosion”
2 – Precision diffractometry
   and anomalous scattering
3 – X-ray fluorescence analysis
4 – High-pressure diffractometry
5a – X-ray microscopy and
   micro-tomography
5b – Time-resolution diffractometry
5c – Small-angle X-ray scattering
6 – Time-resolution luminescence
7 – SR beam stabilization
8 – EXAFS spectroscopy
10 – Metrology/EXAFS in soft
    X-ray

http://ssrc.inp.nsk.su
SR experiments at VEPP-4

New SR experimental hall at VEPP-4

7-pole electromagnet wiggler
Installed recently at VEPP-4

New experimental station for fast processes study

Beam lines in the VEPP-4 SR experimental hall
Experiments with internal gas target (H or D, polarized or unpolarized) have been carried out for many years.

First results: scattered protons resolution

Detector schematically and in reality
Electrons circulating in VEPP-4M produce gamma rays, which can be used directly or generate $e^+e^-$ pairs to calibrate detector components.

### Test beams parameters

<table>
<thead>
<tr>
<th></th>
<th>$e^-$</th>
<th>$\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E$, GeV</td>
<td>0.1 ±3.0</td>
<td>0.1 ±3.0</td>
</tr>
<tr>
<td>$\sigma_E/E$, %</td>
<td>0.5 ±5.0</td>
<td>$\sim 1$</td>
</tr>
<tr>
<td>Intensity, Hz</td>
<td>10 ±1000</td>
<td>1000</td>
</tr>
<tr>
<td>Resolution, mm</td>
<td>0.5</td>
<td>-</td>
</tr>
</tbody>
</table>

Cherenkov light focusing by the aerogel with varied refraction index.
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 $1.5 \cdot 10^{-9}$ 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 $\sim 10^{-9}$
• Touschek count rate has been measured in a wide energy range at the same machine.
• The degree of energy dependence measured is $-2.2 \pm 0.2$ for the counting rate normalized by the bunch current squared and multiplied by the ratio of the reference beam volume (at 1.85 GeV) to the actual one.
• Theoretical estimations give the corresponding degree of -3.5.
• In accordance to the experiment, one can rely on 12 kHz count rate of Touschek particles at 5 GeV and 10 mA of the beam current.
• The rate is sufficient to apply the Touschek polarimeter for the RD technique.
Resonance crossing observation

A unique SR monitor – Fast Beam Profilometer allows us to observe the transverse beam profile evolution in a turn-by-turn manner during $10^{17}$ turns. As an example of the device potential, the resonance crossing experiment results are shown below:

- Phase trajectories at the resonance $3\nu_y=23$ (left) and near the resonance (right)
- Creation of the resonance island and particles trapping in the adiabatic limit.
- Time evolution of the vertical beam distribution in the case of particle trapping in the resonance island.
- The vertical beam profile blowing up while crossing the resonance.
Beam tilt develops in 1/2 of synchrotron oscillation after transverse kick

Measured BPM signal at VEPP-4 after beam was kicked with a vertical kicker

\[ y, \text{ mm} \]

\[ I_{\text{beam}} = 0.98 \text{ mA}, U_{\text{RF}} = 450 \text{ kV} \]

Turn number

Simulation:

Tilted bunch (or X-rays from it) can be transversely collimated in order to generate much shorter bunch of particles (or X-rays).

Train of short bunches suitable for plasma wake-field acceleration experiments can be produced using this technique.

Experiments at VEPP-4 showed that this method works for \( I_{\text{beam}} < 1 \text{ mA} \) (\( N < 10^{10} \) particles). For more intense beams decoherence of betatron oscillations due to head-tail interaction becomes important.
The system is designed to suppress longitudinal beam instability in 2×2 bunch mode.
- 2 systems for e- and e+ of 2 channels for synphase and antiphase oscillation modes;
- synchronous detector for beam phase measurement;
- analog superheterodyne modulator;
- 100 W output RF power;
- feedback decrement 500 s⁻¹

In 2007, the broad-band resonance kicker and signal processing electronics have been manufactured and installed.
In 2008, the system commissioning has been started.
Longitudinal feedback system ON/OFF

Phase oscillation monitoring system

Qs = 0.010742
Signal/Noise = 2.91
Transverse bunch-by-bunch feedback system

Transverse bunch-by-bunch digital feedback to suppress the TMCI (fast head-tail) instability limiting the VEPP-4M single-bunch current.

Energy, GeV 1.8 – 5.2
Number of bunches 2 x 2
Design bunch current 40 mA
Number of kickers 4
RF power per kicker 400 W

With the feedback ON, a beam with current ~ 3 times exceeding the TMCI threshold has been injected.
Longitudinally polarized beams

Project for VEPP-4: 1981, 1983

VEPP-4M

Spin precession time $\nu \gamma = 1/2$ regardless of energy

$\tau_{3-T} (VEPP-3) = 33$ min @ 1.85 GeV

Nominal Injection Energy $E_j = 1906$ MeV ($\gamma = 4.33$)
Invert field of the $\pi/2$ solenoid in beam-line to invert a helicity of one of the colliding beams

$e^+$
$e^-$
$\pi^+$
$\pi^-$

Pulse $\pi/2$-solenoid

Depolarization time with SS:

$\tau_d \approx \frac{54}{11} \cdot \frac{\tau_{3-T}}{\nu^2} \cdot B(\nu, \nu_x) \propto E^{-\gamma}$

$\nu = \gamma a$

$B(\nu, \nu_x)$ – 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):

$\tau_d = 160$ min at $E = 1777$ MeV
$\tau_d = 120$ min at $E = 1846$ MeV
$\tau_d = 425$ min at $E = 1548$ MeV

Siberian Snake (SS) insert with decoupling:
Two SC 124 cm x 72 kG solenoids (1.98 GeV)
Five 20 cm x (up to 2.8 kG/cm) quads
Total length=430 cm
SR source in the VEPP-4 tunnel

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
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 $5 \times 10^{34}$ cm$^{-2}$s$^{-1}$.
Summary

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

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

- Different scenarios of the future studies at VEPP-4 (or with the help of its infrastructure) are considered intensively.
A.Aleshaev, V.Anashin, O.Anchugov, V.Blinov, A.
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Morozov, N. Muchnoi, V. Neifeld, I. Nikolaev, D. Nikolenko, I.
Okunev, A. Onuchin, A.Petrenko, V.Petrov, P. Piminov, O.
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I,Churkin