

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

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Presented are the results of a VEPP-4M collider operation at Budker Institute of Nuclear Physics during 2004-2005 as well as the plans for the nearest future.

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## 1. INTRODUCTION

The VEPP-4M electron-positron collider is now operating with a general-purpose detector KEDR within 1.5...2.0 GeV energy range for high-energy physics (HEP) applications. A series of experiments on mass measurements of  $J/\psi$ ,  $\psi'$  mesons was conducted at the VEPP-4M collider in 2002 [1]. An accuracy of mass value measurements obtained much exceeded (by 3 times or more) the accuracy reported by other experimental groups.

The modernization of the KEDR detector was completed in 2004; the main super-conducting solenoid with maximum field of 0.6 T and two 3 T compensation coils were successfully commissioned; field compensation is at a satisfactory level with regards to a beam dynamics. In experimental runs during 2004-2005 we have continued to collect data for  $\psi'$  and provide data acquisition for  $\psi''(3770 \text{ MeV})$  to measure its mass with an accuracy of 3...4 times higher than that published in the PDG table as well as to study  $D^+$  and  $D^0$  mesons.

The next experiment on  $\tau$ -lepton mass precision measurement close to a  $\tau$  production threshold ( $E = 1777 \text{ MeV}$ , the beam energy) is underway. We plan to perform  $\tau$ -lepton mass measurements with the relative accuracy higher than  $10^{-4}$ .

To provide a high performance of the VEPP-4M collider, a number of investigations on the accelerator as well as further improvements of its facility has been performed. Most essential are:

- a luminosity increase within the low energy range;
- an improvement in the energy measurement accuracy using a resonant depolarization method;
- a routine energy measurement using Compton Backscattering (CBS) method;
- development of beam diagnostics instrumentation.

## 2. LUMINOSITY

Last year we significantly increased the average integrated luminosity per week (up to  $300 \text{ nb}^{-1}$ ). The main steps to achieve this goal were: doubling the number of bunches (now we have  $2 \times 2$ ), decreasing  $\beta_y$  at the IP from 5 to 4 cm, and increasing the overall reliability of the VEPP-4M complex. The maximum achieved peak luminosity was  $2 \times 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$ .

We also considered other possibilities to further increase the luminosity. It is well known and proved (e.g. in KEKB) that one of them is moving the working point very close to the half-integer resonance. As a result, the

actual tune shift is becoming significantly smaller than the nominal  $\xi$  parameter. However, for the VEPP-4M collider we cannot benefit from this feature because of a large horizontal dispersion function at the IP. Indeed, in the VEPP-4M lattice the horizontal particle's coordinate at the IP is mainly determined by the synchrotron motion, that strongly emphasizes synchro-betatron (horizontal) resonances. If we place the horizontal tune close to 0.5, the nearest synchrotron satellites would be well inside the footprint, resulting in a strong horizontal blow-up. In order to confirm this statement we performed simple weak-strong simulations with the beam-beam code LIFETRAC. We made a betatron tune scan in the area of  $\nu_x=(0.505\dots0.55)$ ,  $\nu_y=(0.53\dots0.58)$  with a step of 0.0025 in both directions, the synchrotron tune being  $\nu_s=0.012$ . We set the tune shift parameters close to the realistic values for VEPP-4M, that is  $\xi_x=0.02$ ,  $\xi_y=0.05$ . Of course, the purpose of going close to the half-integer resonance must be increasing  $\xi_x$  significantly, but for our tune scan it was better to keep  $\xi_x$  within realistic boundaries for the whole area of scanned betatron tunes. The simulation results are presented in Fig. 1.

As we expected, strong synchro-betatron resonances near  $\nu_x=0.5$  resulted in a horizontal blow-up, decreasing the luminosity by a factor of 2, as compared to our nominal working point:  $\nu_x=0.535$ ,  $\nu_y=0.565$ .

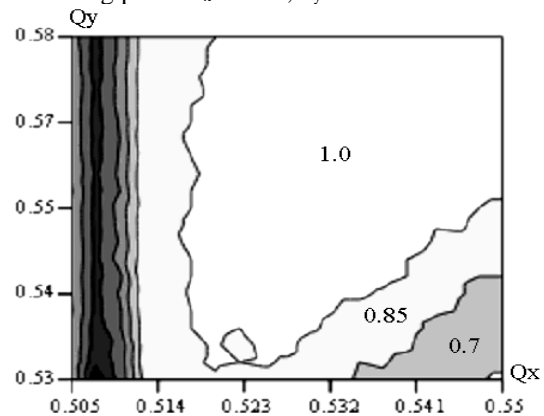


Fig.1. Luminosity of the VEPP-4M (arbitrary units) vs. betatron tune

Another promising way to raise the luminosity is based on increasing the number of colliding bunches. The length of the area in the technical straight section, where the  $e^+$  and  $e^-$  bunches are separated vertically, allows us to have two counter-rotating trains of 15 bunches each. In the experimental straight section bunches will be separated horizontally, and collide at the IP with a crossing

angle of 3 mrad. This scheme can be realized when a modern Injection Complex is put into operation. One of its components is a buster synchrotron for 2.5 GeV [2], where the 15-bunches trains are supposed to be prepared and then injected to the VEPP-4M collider.

### 3. ENERGY MEASUREMENTS

Absolute calibration of particle energy ( $E$ ) in the VEPP-4M is in measurement of an effective spin precession frequency  $\nu = E$  [MeV]/440.65 (in units of a revolution frequency) that needs polarized electron (positron) beams. We scan a depolarizer device frequency and fix the latter when an event of resonant depolarization of beam particles occurs [1]. Polarimeter based on comparison of counting rates of Touschek particles from two bunches – polarized and unpolarized ones – determines the spin frequency by a jump in a relative counting rate. In the measurement of  $\tau$ -lepton mass near its production threshold the energy of experiment is rather close to the strong spin integer resonance  $\nu = 4 = k$  ( $E \approx 1763$  MeV). Because of a small distance to the resonance ( $\epsilon_k = \nu - k \approx 0.03$ ) the depolarizing effect of quantum fluctuations related to field imperfections is significantly strengthened. By this reason one cannot obtain the radiative polarization in the VEPP-3 booster, which serves as a source of polarized particles for the VEPP-4M, at energies close to 'tau-threshold' [3]. Therefore, the radiative polarization in the VEPP-3 is realized at  $E \geq 1850$  MeV. Then an injection of the polarized beam into the VEPP-4M is executed and, at last, the beam energy is adjusted downwards to the 'tau-threshold'. A 'life time' of beam polarization (PLT) in a final state may appear rather small due to a high rate of radiative depolarizing processes. The depolarizing influence of different perturbations, caused by misalignment of magnetic elements (100  $\mu\text{m}$ ) and routine vertical orbit correction in the VEPP-4M, was shown in numerical simulations to result with high probability in more than 1 hour of PLT [3]. In experiments polarization life time was about 10 minutes (Fig.2).

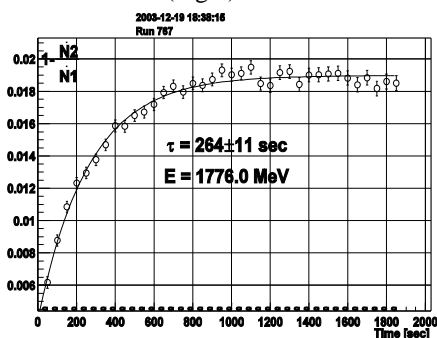


Fig.2. Spin relaxation time, or the polarization life time

Therefore, the conclusion was made that significant influence on PLT could be exerted by special vertical orbit distortions created for operation with colliding beams. This assumption was verified in an experiment with switching off the electrostatic separators of electron and positron beams in parasitic interaction points. As a result, PLT was raised up to about hour, that increased reliability and accuracy of the precise energy calibration as well as of  $\tau$ -lepton mass measurement ex-

periment in a whole (Fig.3).

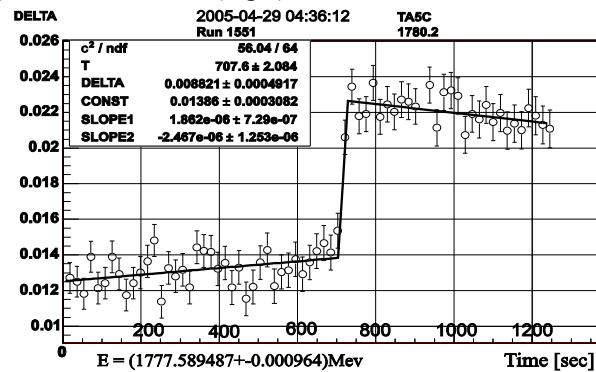


Fig.3. Depolarization jump in one of energy measurements in the vicinity of the 'tau-threshold'

Assigning energy to the statistics acquisition runs between the calibrations cycles is done by known influence on the beam energy of the monitored accelerator parameters, like temperature of the magnets, orbit position, NMR measurements of the magnetic field etc. In contrast to RD technique, a method of Compton backscattering (CBS) allows a continuous monitoring of the electron beam energy during the luminosity runs. Therefore, it was developed and applied. System for absolute beam energy measurement uses the head-on interaction of  $\text{CO}_2$  laser radiation with a VEPP-4M electron beam [4]. The maximum energy of backscattered  $\gamma$ -rays is strictly coupled with the electron energy. High purity Germanium detector Canberra GC2518 (120 ml of active volume) is used to measure the spectrum of backscattered photons.

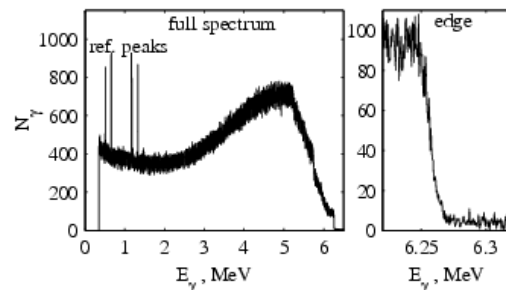


Fig.4. Compton spectrum

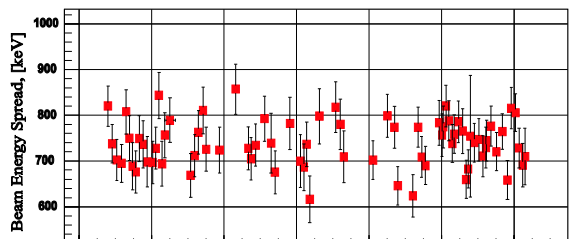
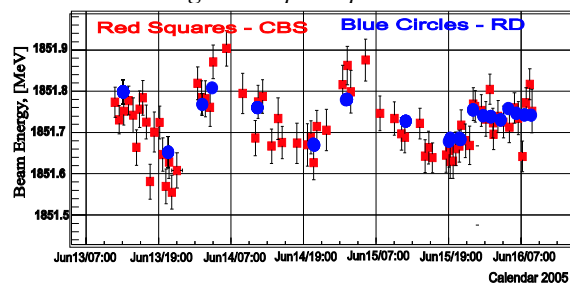


Fig.5. Beam energy and energy spread measurement

during the luminosity runs (June 13-15) as well as the energy stability test (June 16). Circles and squares stand for RD and CBS energy data, respectively

The sharp edge of the Compton spectrum (Fig.4) allows determination of beam energy with statistical uncertainty about  $3 \times 10^{-5}$  for a 10 min data acquisition cycle.

At the same time, the energy spread of the electron beam is measured with 10% accuracy (Fig.5). Energy variations are due to day-to-day energy cycle phenomena found in [5] and field relaxation in magnets just after each routine magnetization cycle completed (the experiment and injection energies differ by the value of  $\sim 80$  MeV).

#### 4. NEW BEAM DIAGNOSTICS

Effectiveness of collider tuning depends primarily on the beam diagnostic system feature. In order to study beam dynamics effects (especially those related to the beam-beam interaction and transverse instability), a fast multi-anode photomultiplier tube (PMT) were developed and installed on the VEPP-4M. This system bases on the Hamamatsu R5900-L16 16-channel linear array with a  $0.8 \times 16$  mm anode area.

This device can measure and store up to  $2^{17}$  samples of transverse beam profile. Fig.6 depicts one of them. Proper processing of the stored data gives a detailed picture of turn-by-turn evolution both of the beam center of mass and of the r.m.s. beam size. As an example the PMT was used for beam convergence observation.

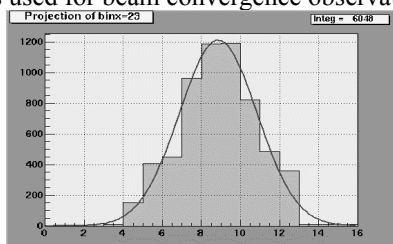


Fig.6 Single-turn particle distribution

The standard procedure of the beams convergence is described at [6]. Fig.7 presents a turn-by-turn measurement of the electron beam size and position behavior in the case of beam-beam instability. The currents of the beams were restricted by beam-beam effects ( $I_{e^+} = 3.4$  mA,  $I_{e^-} = 3.0$  mA.), and the positron beam is the “strong” one. During evolution of instability taking place, both, dipole oscillations and beam size, increase. Every “flash” of oscillations is accompanied by beam losses.

Frequently beam convergence is accompanied by instability; this looks like beam “twinkling” on the TV screen. The image looks like a small periodical kick applied to the beam. As a matter of fact, this “twinkling” is caused by the oscillation of vertical beam

size as Fig.8 demonstrates.

Another applications of the PMT can include fast instability study, injected beam evolution study, precise tune measurements etc.

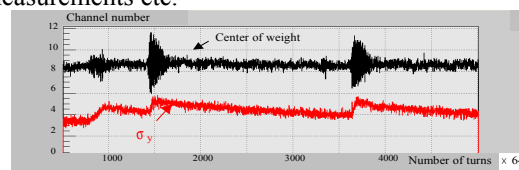


Fig.7. Beam dipole oscillations (black plot) and  $\sigma_y$  behavior (red plot) during the beams convergence in the IP. Duration of the single turn is 1220 ns. Channel constant is 0.12 mm.  $I_{e^+} = 3.4$  mA,  $I_{e^-} = 3.0$  mA

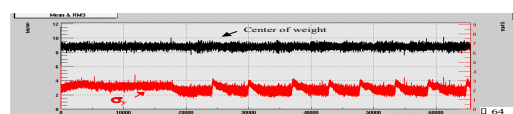


Fig.8. Convergence of the beams with currents of  $I_{e^+} = 2.4$  mA,  $I_{e^-} = 2.9$  mA, accompanied by quadrupole instability

#### 5. FUTURE PLANS

One of the major experimental tasks on the VEPP-4M in 2005-2006 season is the study the  $\tau$ -lepton at its production energy threshold (1777 MeV).

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#### СТАТУС ВЭПП-4М: СОСТОЯНИЕ ДЕЛ И ПЛАНЫ

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#### СТАТУС ВЕПП-4М: СТАН СПРАВ І ПЛАНИ

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