E.Levichev, for the VEPP-4 team

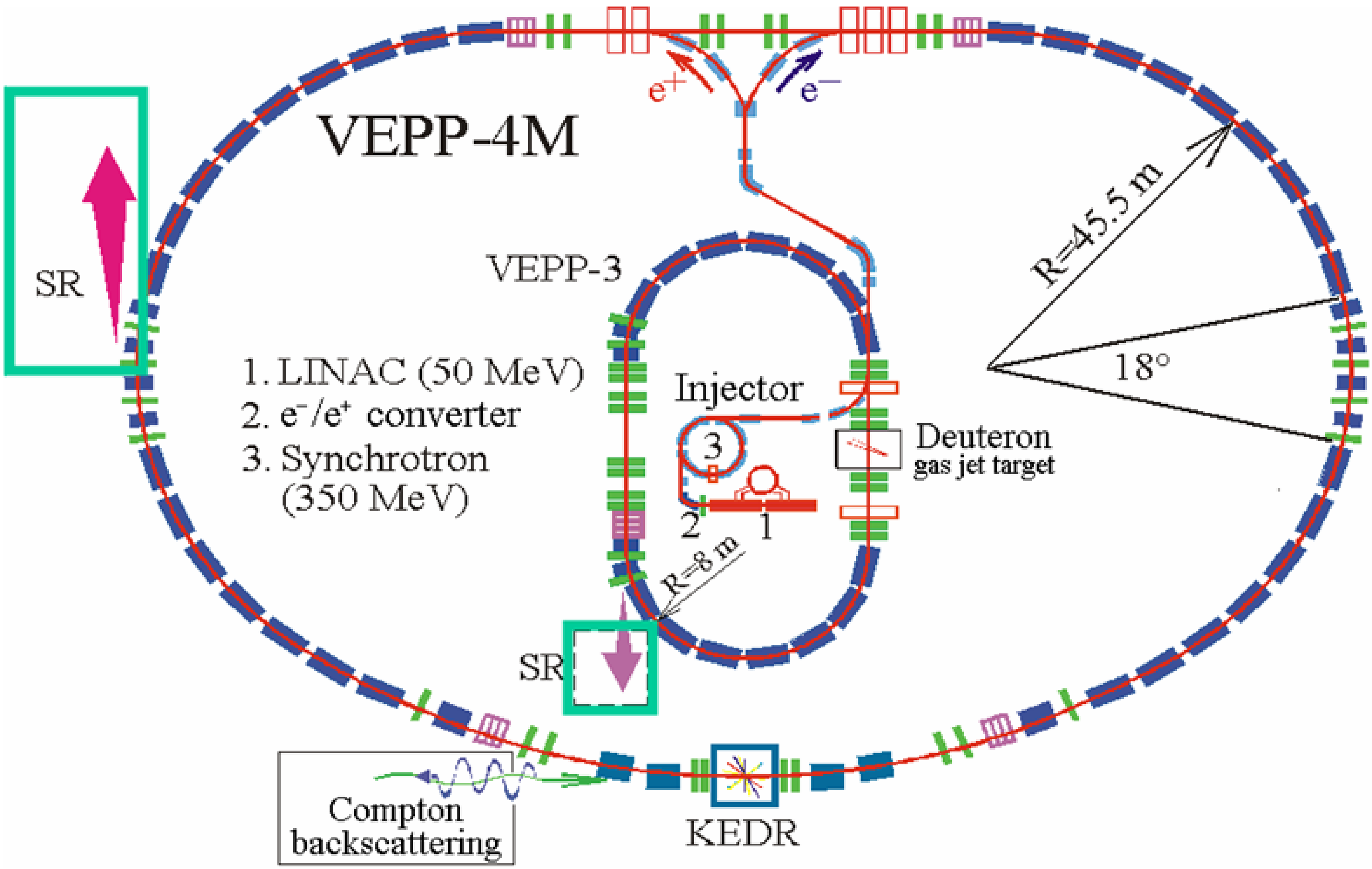
STATUS OF VEPP-4M COLLIDER: CURRENT ACTIVITY AND PLANS

VEPP-4M

24 September 2012

Contents

VEPP-4M schematic view

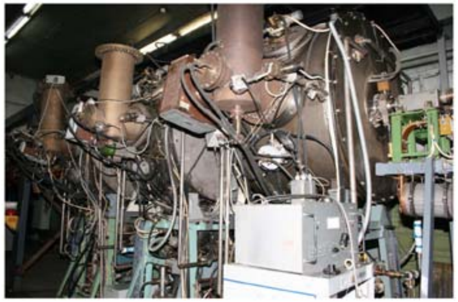


VEPP-4M parameters and experimental programs

Circumference, P (m)	366.075
Revolution frequency, f_0 (kHz)	818.924
Revolution period, T_0 (ns)	1221
Maximum energy, E (GeV)	5.3*)
Momentum compaction factor, α	0.017
Betatron tunes, Q_x/Q_z	8.54/7.58
Synchrotron tune, Q_s	0.012
Natural chromaticity, ξ_x/ξ_z	–14.5/–20.3
Parameters at 1.8 GeV	
Damping times, $\tau_x/\tau_y/\tau_s$ (ms)	70/35/70
Horizontal emittance, ε_x (nm-rad)	17
Energy spread, σ_E/E	4×10^{-4}
Bunch length, σ_L (cm)	6
Energy loss/turn, ΔU (keV)	16
IP optical functions, β_y / β_x / η_x (m)	0.05/0.7/0.78

- 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

Longitudinal FB kicker



VEPP-3 arc


VEPP-4 arc


Control room

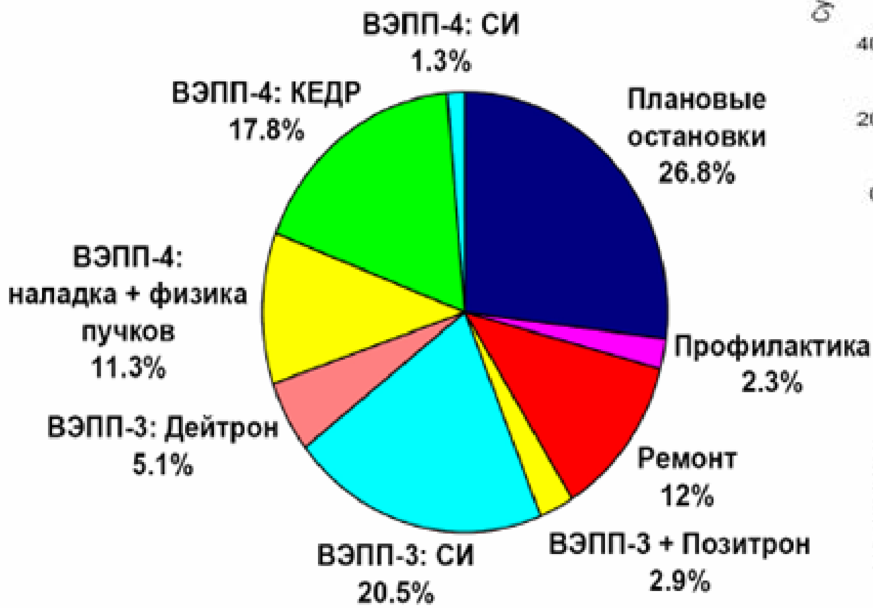

50 MeV linac

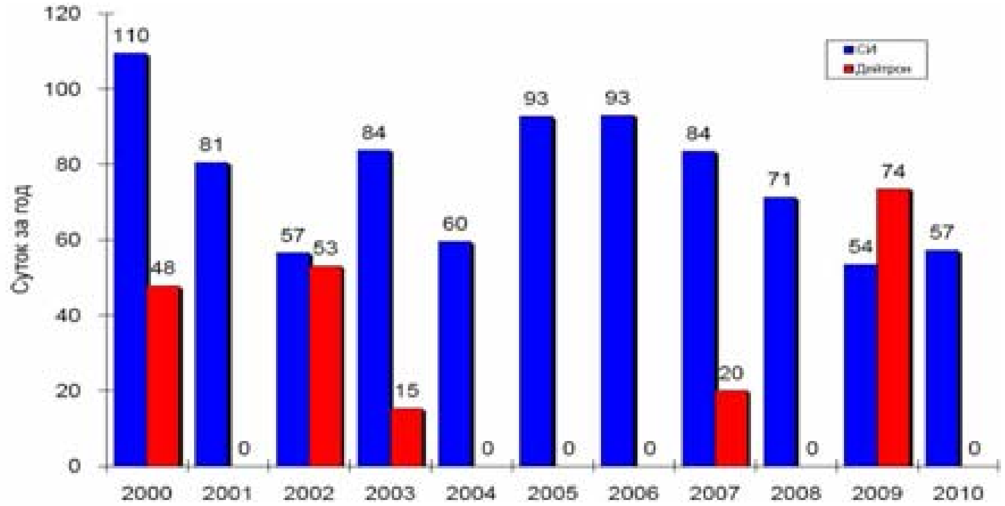

Detector KEDR


350 MeV synchrotron

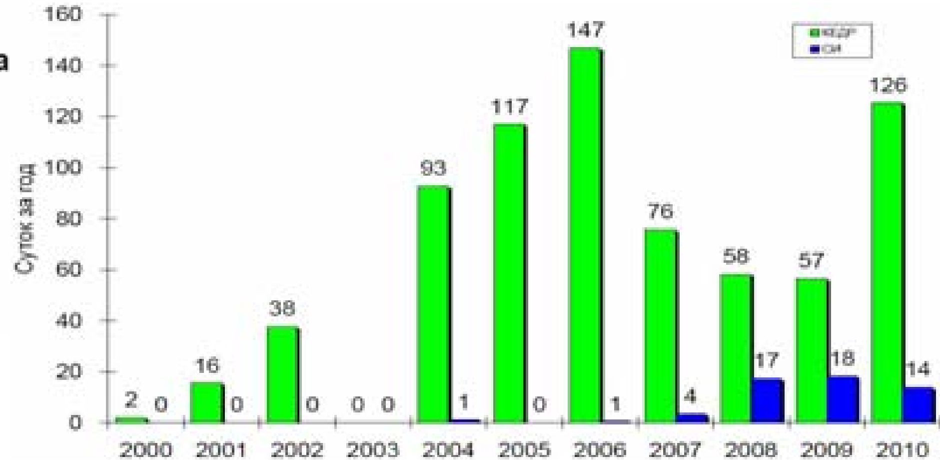

2 MeV ELIT accelerator

VEPP-4M time sharing (2000-2010)





Experiments at VEPP-3



Experiments at VEPP-4

VEPP-4M/KEDR features for HEP

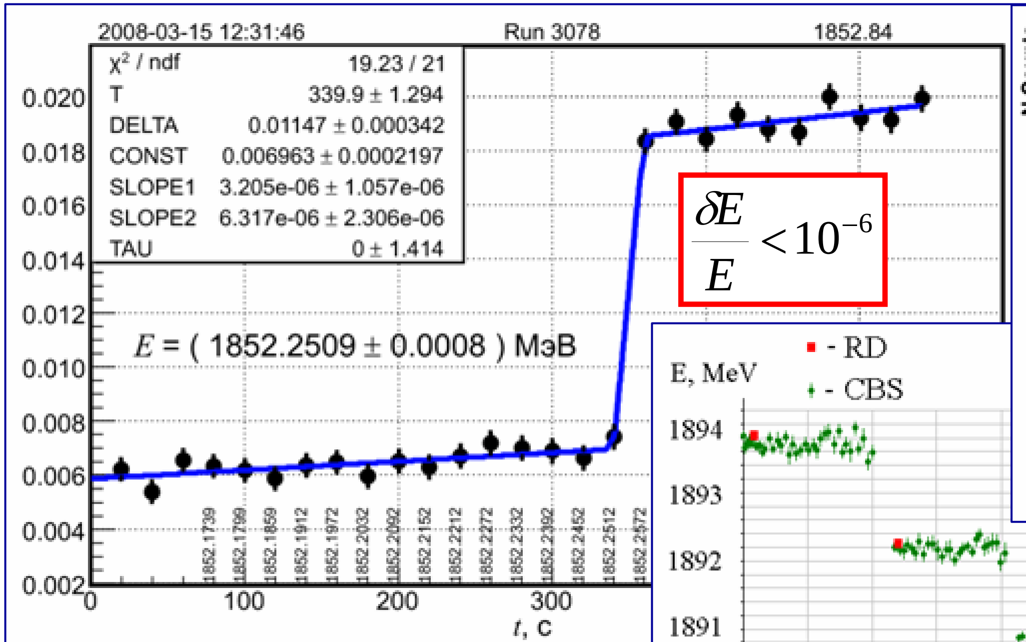
- Beam energy range varied from 0.9 GeV up to 5.0 GeV
- Beam energy calibration using resonant depolarization method with the record accuracy of 10^{-6}
- On-line monitoring of the beam energy using the Compton back scattering method with the accuracy of $5 \cdot 10^{-5}$
- Universal detector KEDR comparable 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.

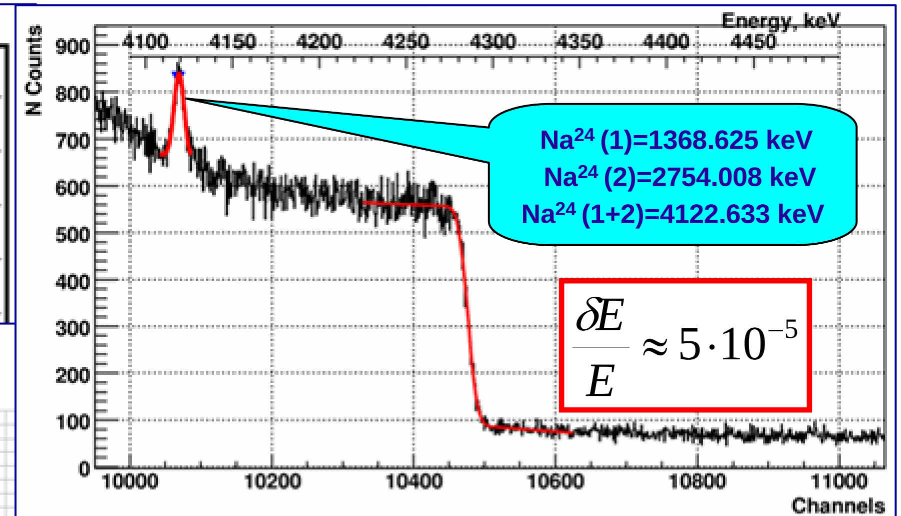
Beam energy measurement

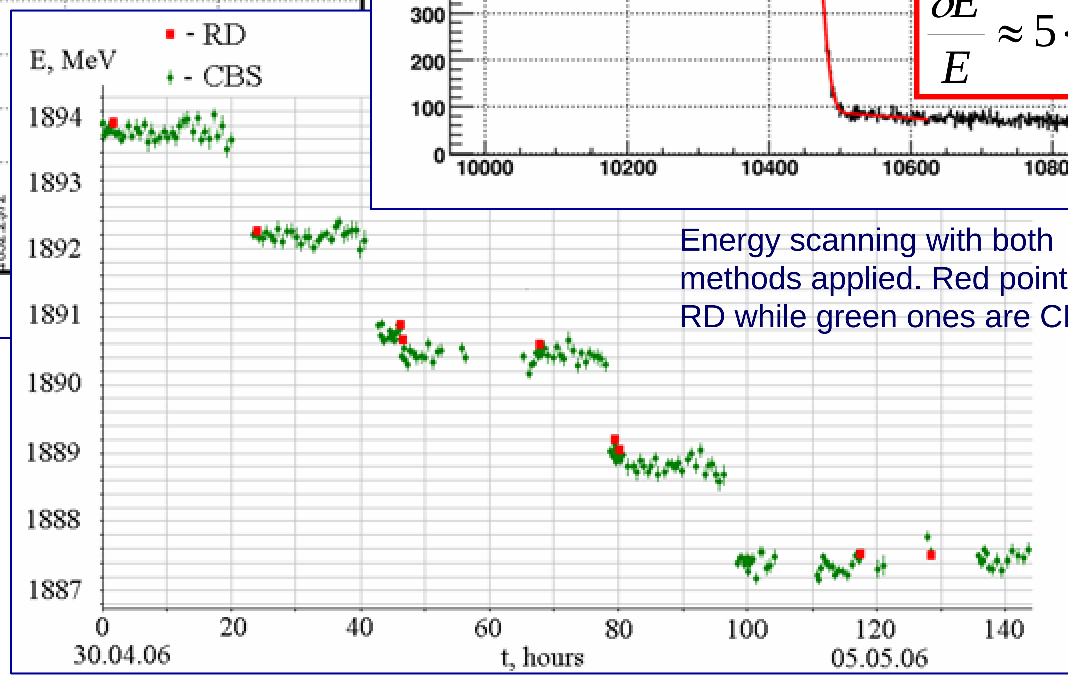
http://v4.inp.nsk.su

Resonant depolarization provides a record accuracy in energy calibration

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







Energy scanning with both methods applied. Red points are RD while green ones are CBS

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

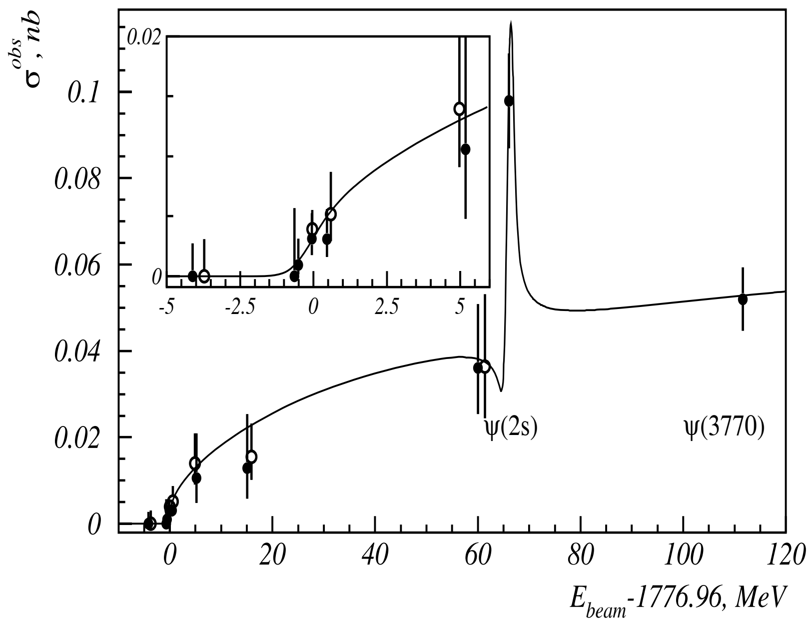
$$E = 440.65\,\mathrm{MeV} \cdot \left(\frac{\Omega_s}{\omega_0} - 1 \right)$$

Particle mass measurements at VEPP-4

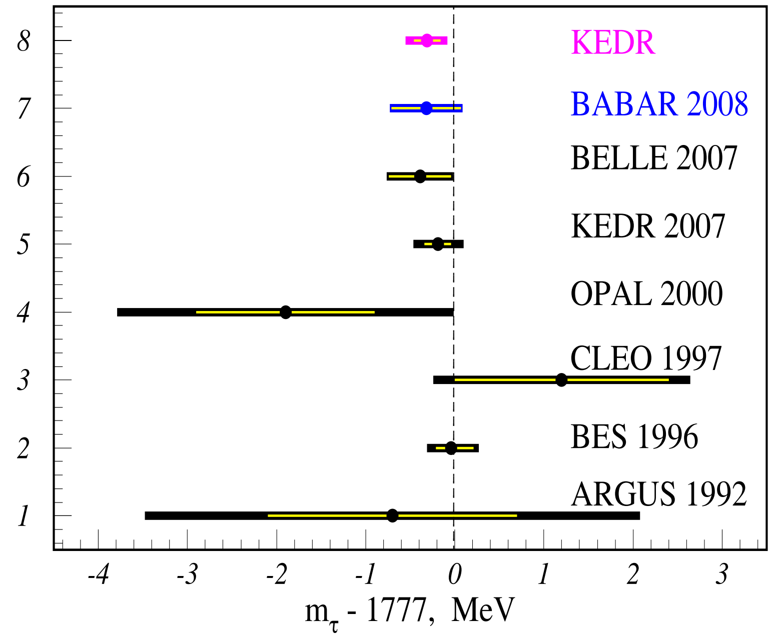
Particle	E, MeV	Accuracy, $\Delta E/E$	Detector	Years
J/ψ	3096.93 ± 0.10	$3.2 \cdot 10^{-5}$	OLA	1979-1980
ψ'	3685.00 ± 0.12	$3.3 \cdot 10^{-5}$	OLA	1979-1980
Υ	$9460.57 \pm 0.09 \pm 0.05$	$1.2 \cdot 10^{-5}$	MD-1	1983-1985
Υ'	10023.5 ± 0.5	$5.0 \cdot 10^{-5}$	MD-1	1983-1985
Υ''	10355.2 ± 0.5	$4.8 \cdot 10^{-5}$	MD-1	1983-1985
J/ψ	$3096.917 \pm 0.010 \pm 0.007$	$3.5 \cdot 10^{-6}$	KEDR	2002-2008
ψ'	$3686.119 \pm 0.006 \pm 0.010$	$3.0 \cdot 10^{-6}$	KEDR	2002-2008
ψ''	$3772.9 \pm 0.5 \pm 0.6$	$2.1 \cdot 10^{-4}$	KEDR	2002-2006
D^0	$1865.43 \pm 0.60 \pm 0.38$	$3.8 \cdot 10^{-4}$	KEDR	2002-2005
D^+	$1863.39 \pm 0.45 \pm 0.29$	$2.9 \cdot 10^{-4}$	KEDR	2002-2005
τ	$1776.69^{+0.17}_{-0.19} \pm 0.15$	$1.3 \cdot 10^{-4}$	KEDR	2005-2008

Tau lepton mass measurement

The measured cross section of e+e -> τ+ τ- versus center-of-mass energy and fit.



World average m_τ = 1776.99 +0.29-0.19 MeV



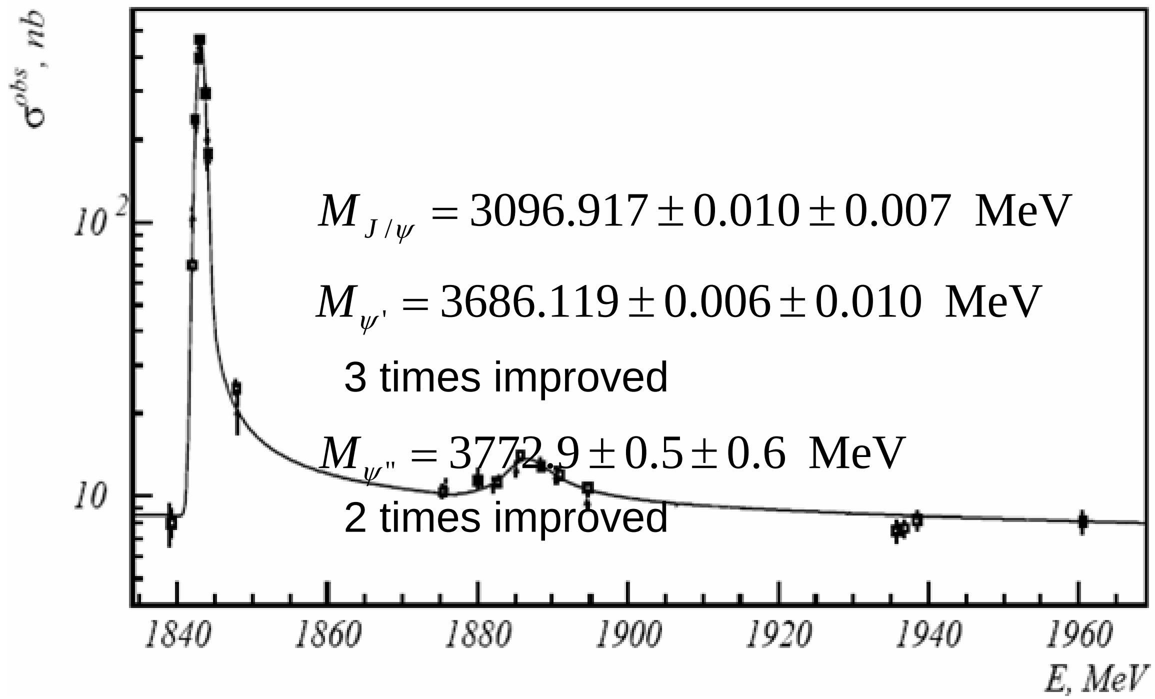
KEDR m_τ=1776.69+0.17-0.18 (stat.) +- 0.15 (syst.) MeV

Tau mass measurement at KEDR. Nuclear Physics B (Proc. Suppl.) 189(2009)21-23

High-energy physics: J/ψ, ψ' and ψ''

High-precision measurements of the ψ-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.

Particle	$\Delta M/M$ (PDG)
p	$0.1\cdot10^{-6}$
n	$0.1\cdot10^{-6}$
e	$0.1\cdot10^{-6}$
μ	$0.1\cdot10^{-6}$
$\pi^{\pm}$	$2.5\cdot10^{-6}$
ψ'	$3.0\cdot10^{-6}$
J/ψ	$3.5\cdot10^{-6}$
π^{0}	$4.5\cdot10^{-6}$



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

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

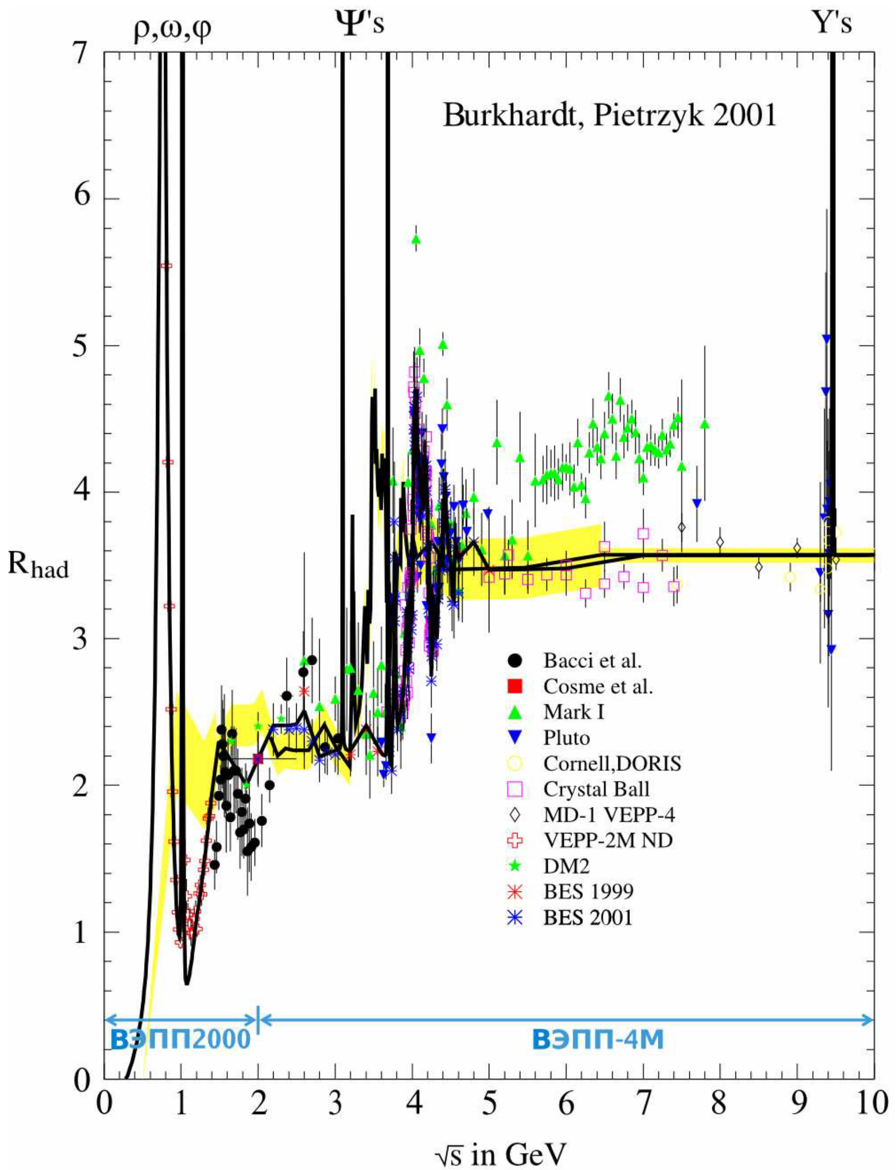
3 times improved

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

2 times improved

Only 5 particle masses has been measured with higher accuracy

Hadron cross-section (R) measurement

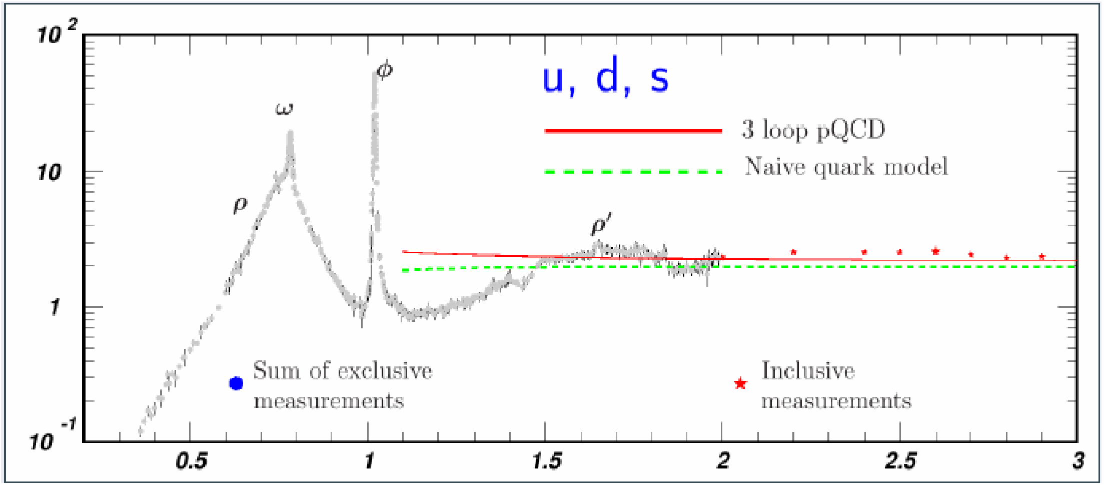


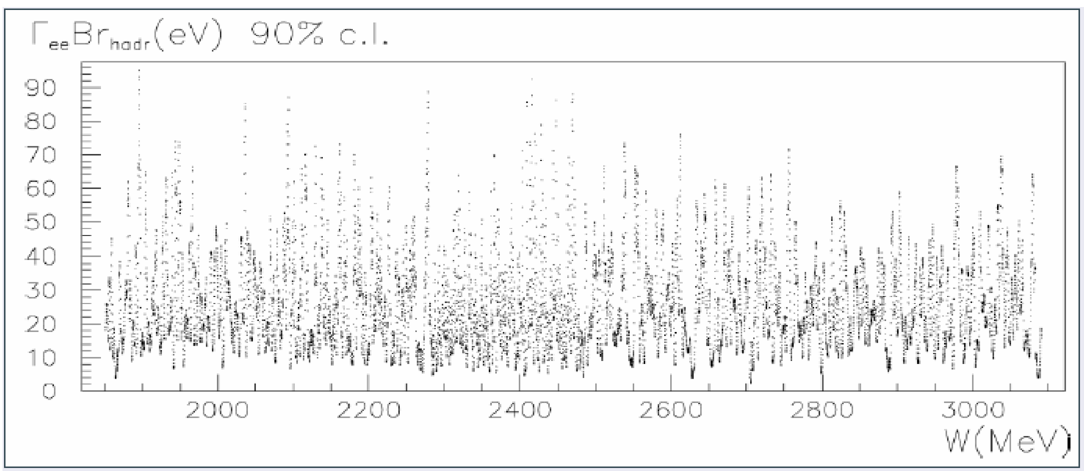
$$R = \frac{\sigma(e^+e^- \to hadrons)}{\sigma_B(e^+e^- \to \mu^+\mu^-)}$$

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

R measurement at low energy





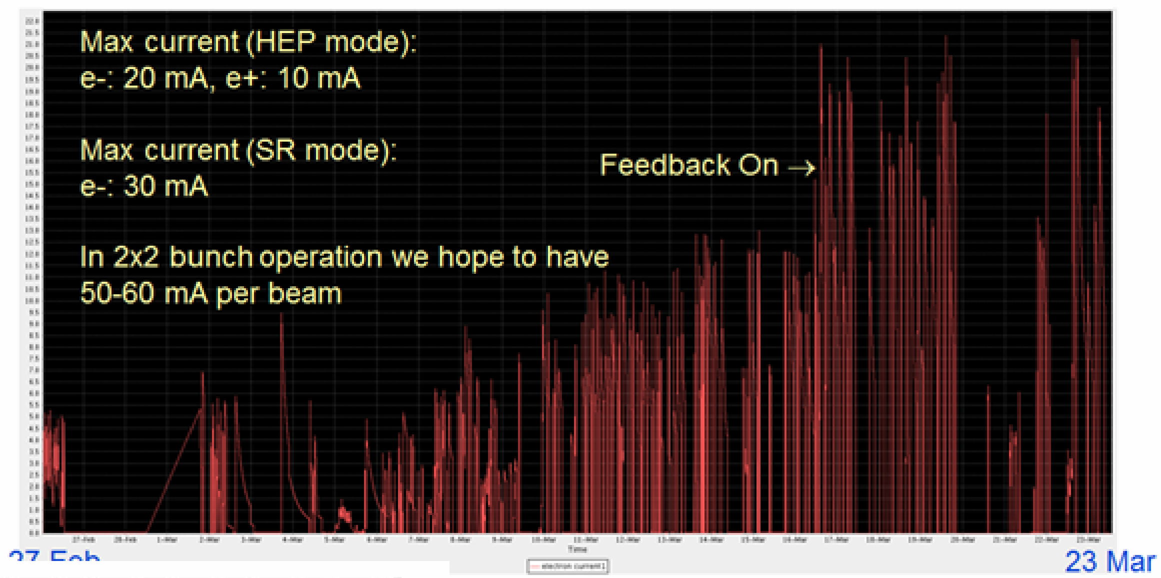
- $\Gamma^{R}_{ee} \times Br(R \rightarrow hadrons) < 120$ эВ, 95%CL

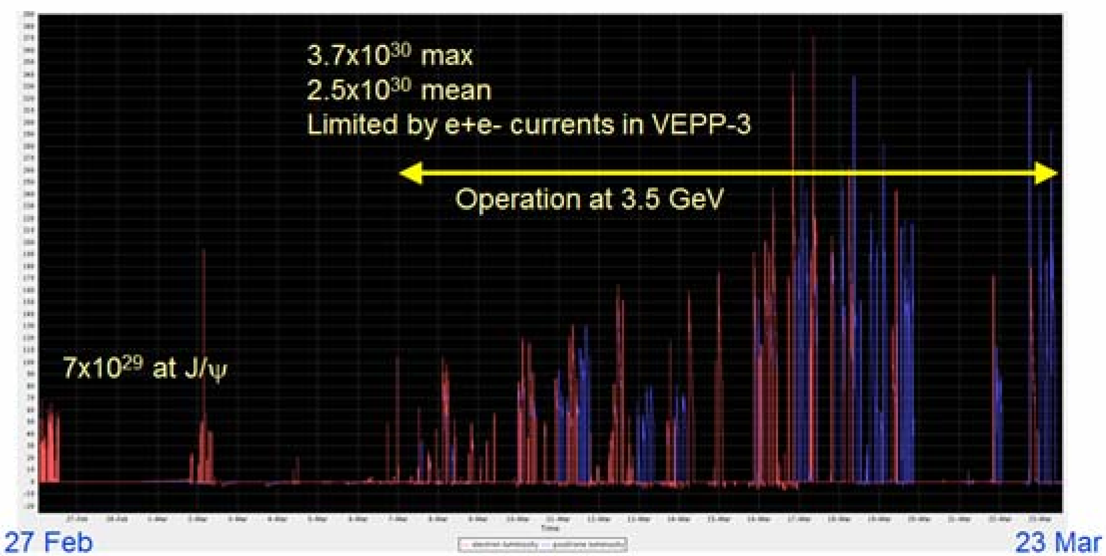
To adjust VEPP-2000 and VEPP-4M energy scales, we have measured R in low energy region from 2E = 1.85 GeV to 3 GeV.

Searching of narrow resonance states in this region was performed.

Near future – high energy run

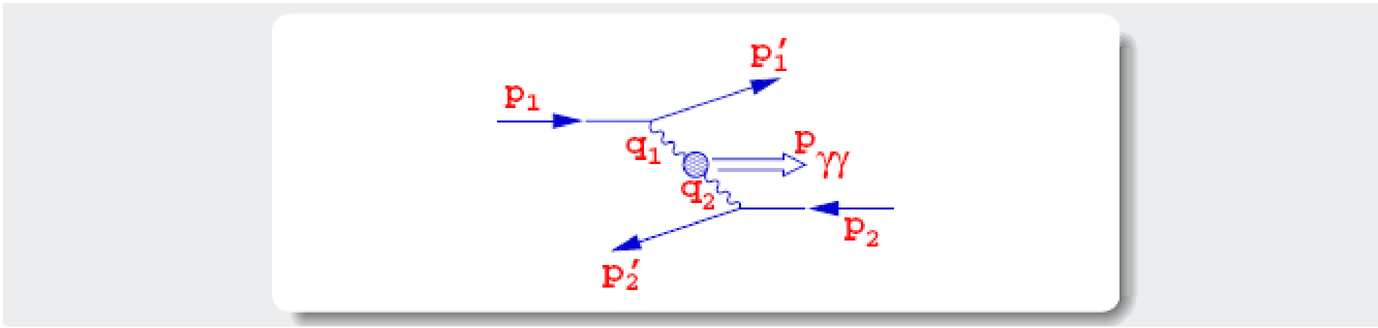
Nearest future plans: measurement of the hadron cross-section R and $\gamma\gamma$-physics in the beam energy range up to 4.5 GeV



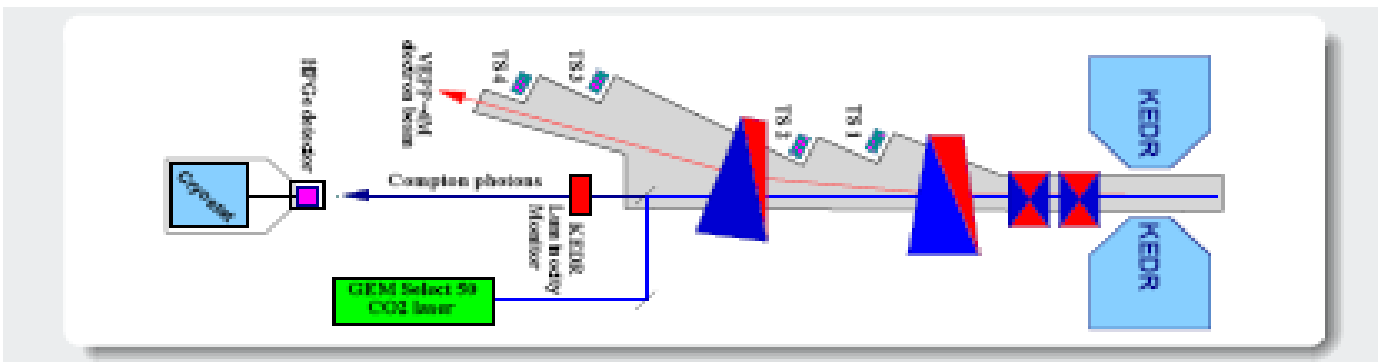


VEPP-4M test run in 2011 at high energy.
Maximum current with feedback systems ON (up)
Luminosity at 3.5 GeV (left)

High resolution tagging system for two photon physics



Resolution for 2γ invariant mass is 0.1%



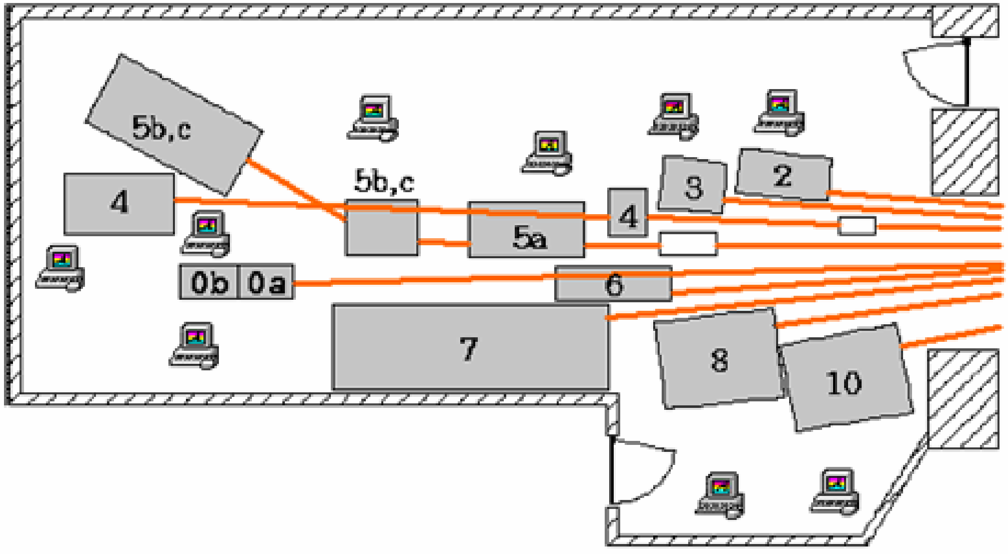
The only facility where the total cross section of $\gamma\gamma \rightarrow$ ***hadrons*** can be measured precisely and reliably

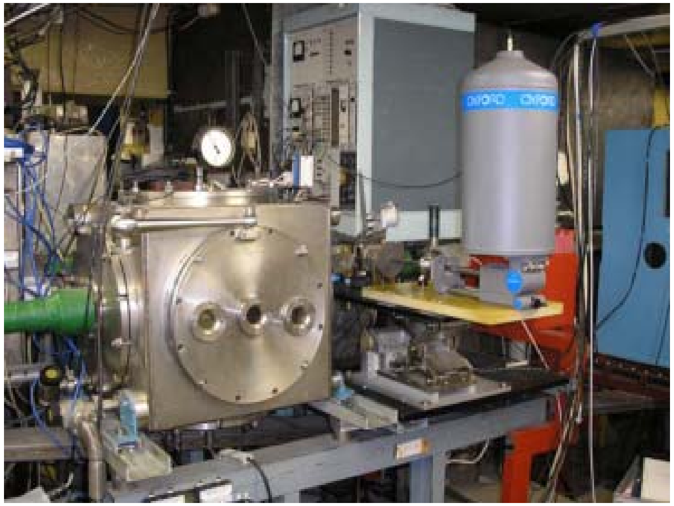
SR experiments at VEPP-3

VEPP-4M

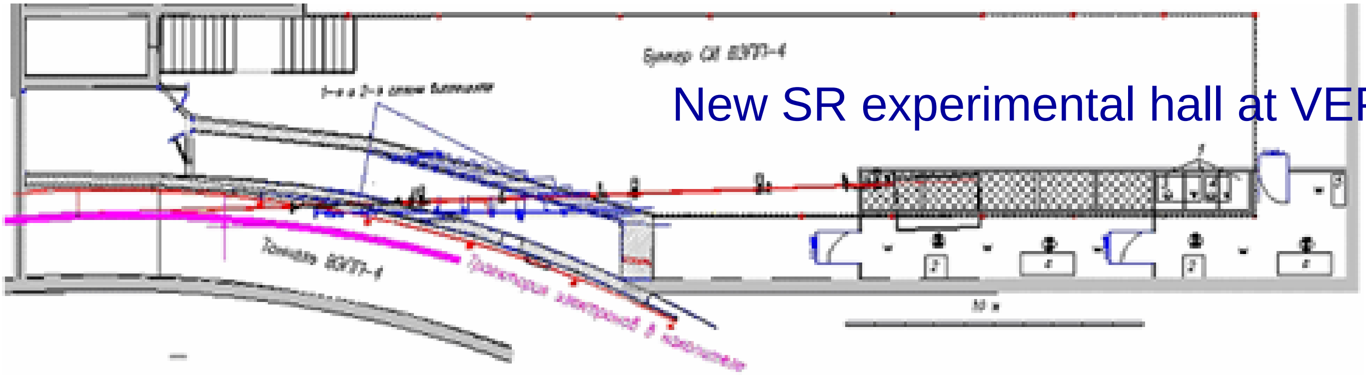
http://ssrc.inp.nsk.su

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





SR experiments at VEPP-4



New SR experimental hall at VEPP-4

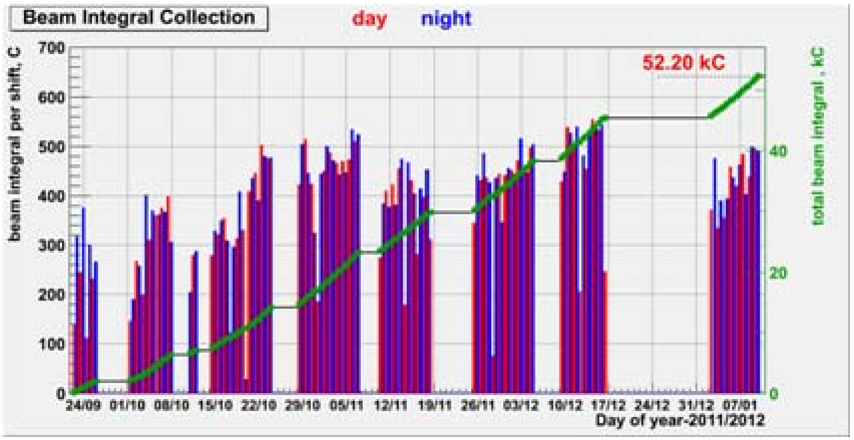
7-pole electromagnet wiggler
Installed recently at VEPP-4

New experimental station for
fast processes study

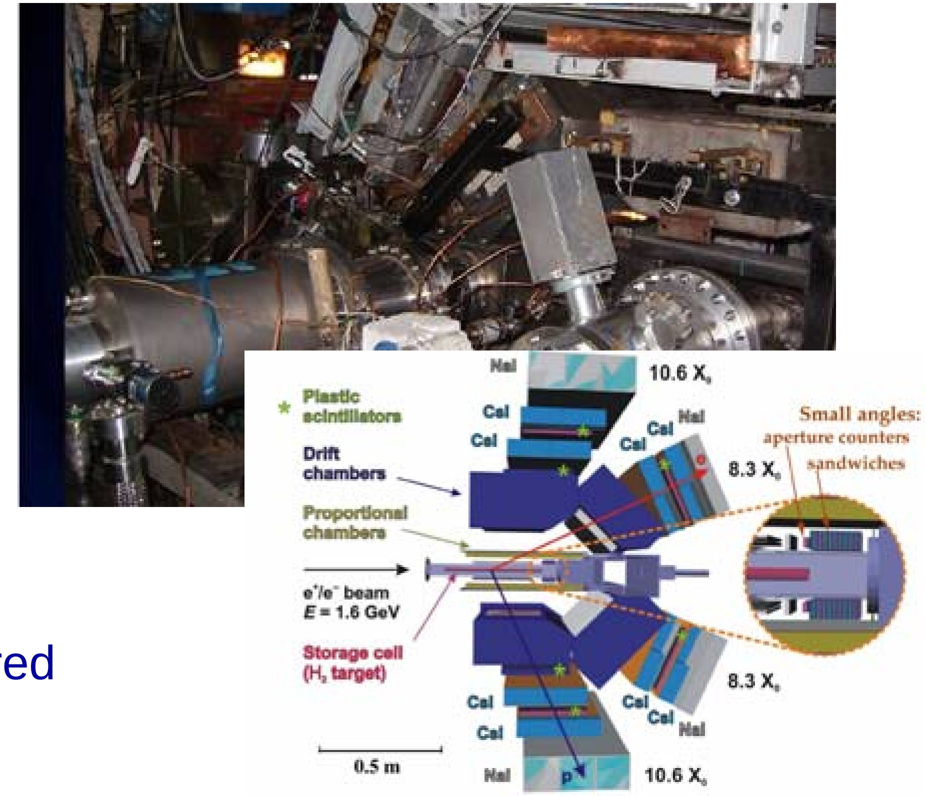
Beam lines in the VEPP-4
SR experimental hall

Nuclear physics at VEPP-3

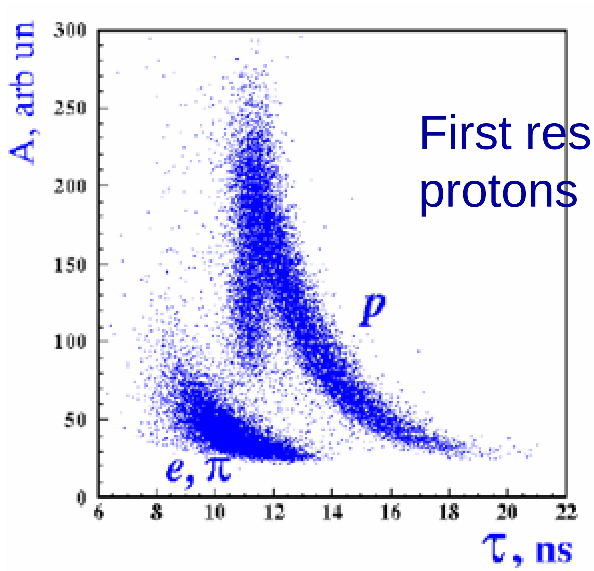
Experiments with internal gas target (H or D, polarized or unpolarized) have been carried out for many years



Beam integral collection



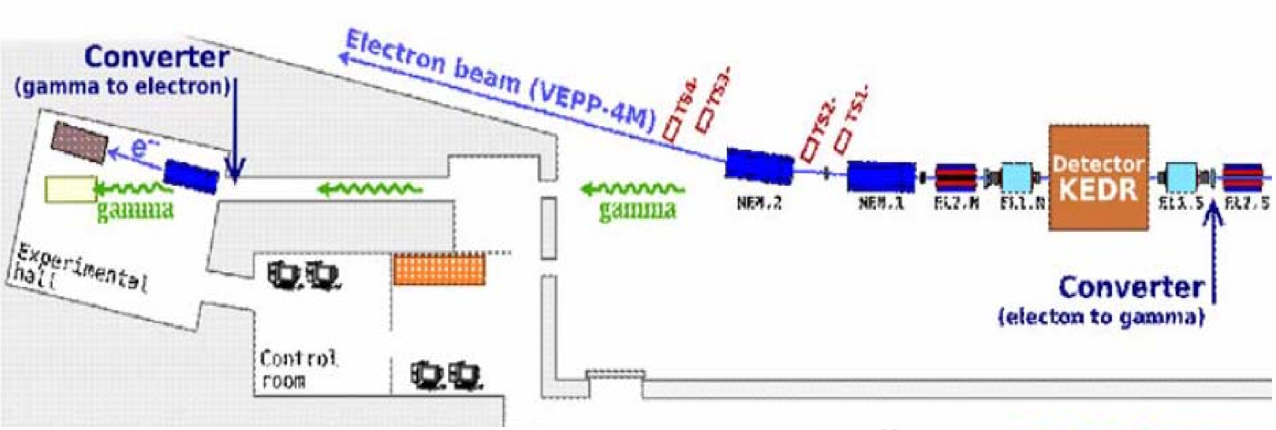
Detector schematically and in reality



First results: scattered protons resolution

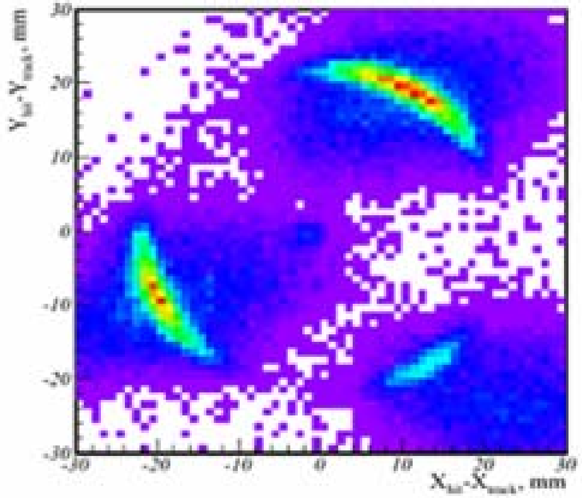
Extracted e$^-$ gamma test beams for methodology

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



	e$^-$	γ
E, GeV	0.1 ÷3.0	0.1 ÷3.0
σ_E/E, %	0.5 ÷5.0	~ 1
Intensity, Hz	10 ÷1000	1000
Resolution, mm	0.5	-

Test beams parameters

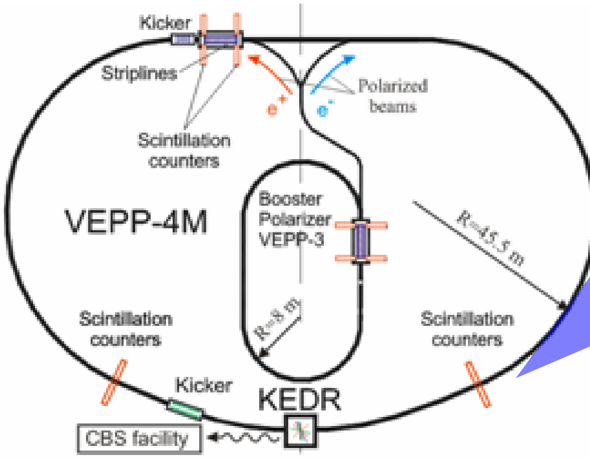


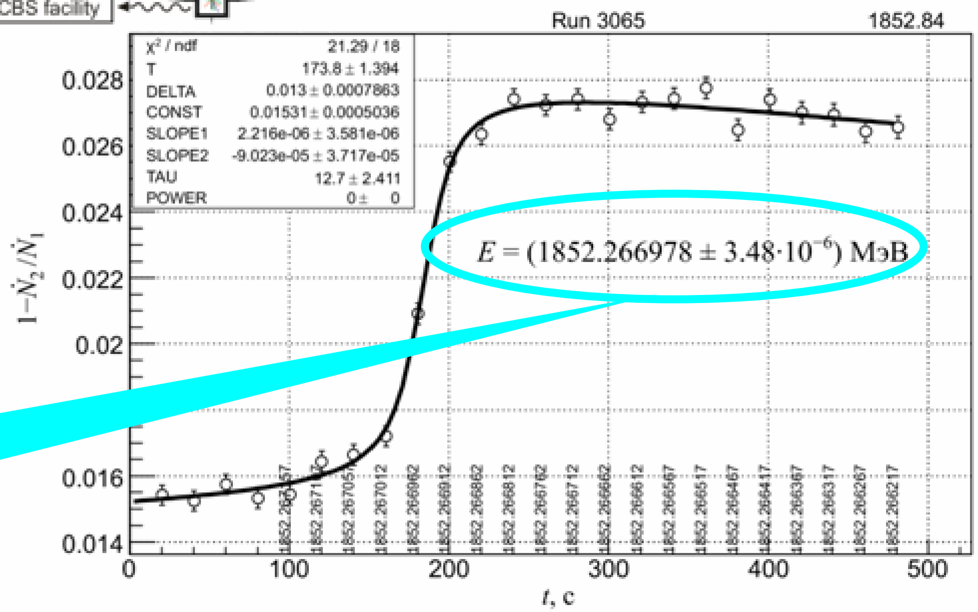
Cherenkov light focusing by the aerogel with varied refraction index

VEPP-4M

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.

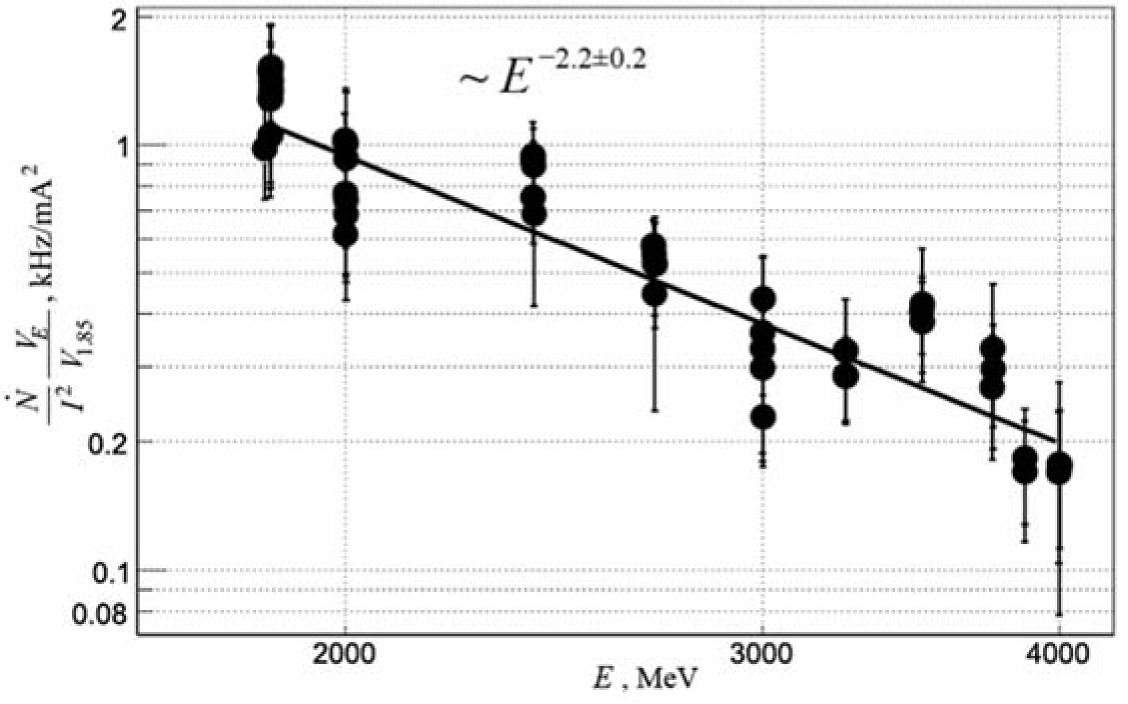




“Nano- resolution”:
scan rate = **2.5 eV/s**
relative error **$\sim 10^{-9}$**

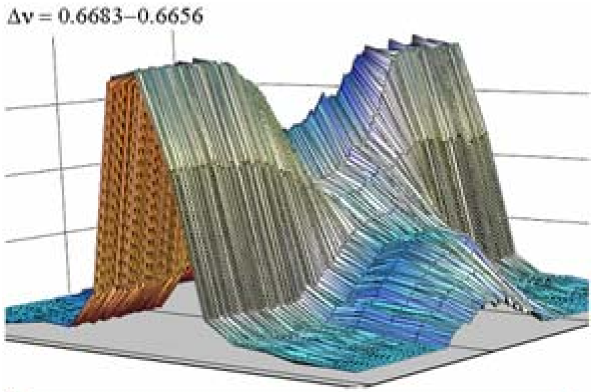
Touschek count rate vs beam energy

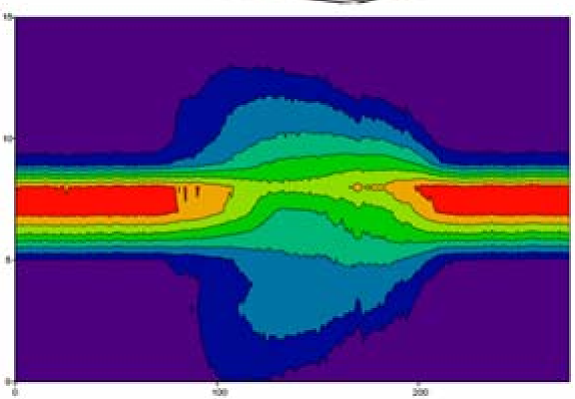
- Touschek count rate has been measured in a wide energy range at the same machine.
- The degree of energy dependence measured is -2.2± 0.2 for the counting rate normalized by the bunch current squared and multiplied by the ratio of the reference beam volume (at 1.85 GeV) to the actual one.
- Theoretical 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 theTouschek polarimeter for the RD technique.



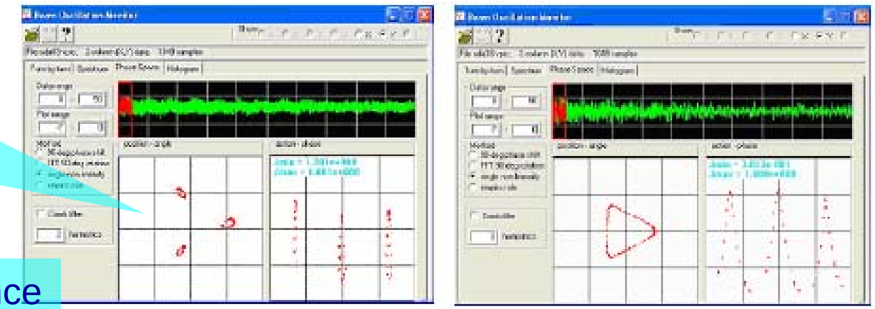
Resonance crossing observation

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:

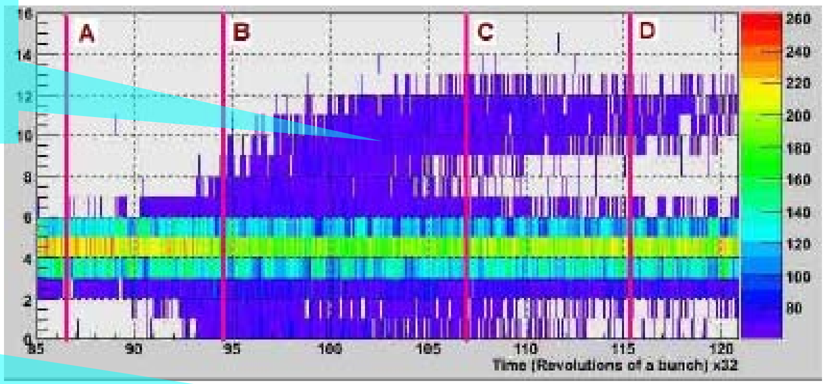




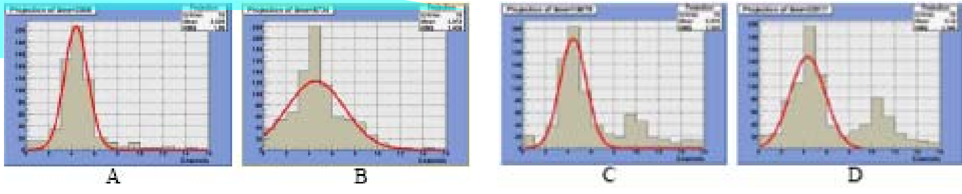
The vertical beam profile blowing up while crossing the resonance



Phase trajectories at the resonance $3\nu_y=23$ (left) and near the resonance (right)



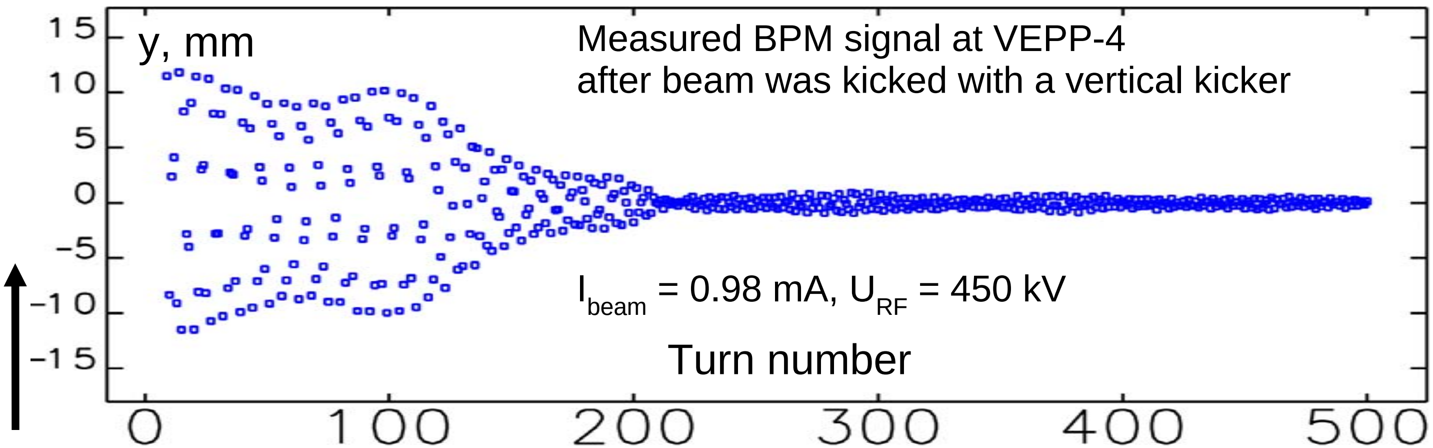
Creation of the resonance island and particles trapping in the adiabatic limit.

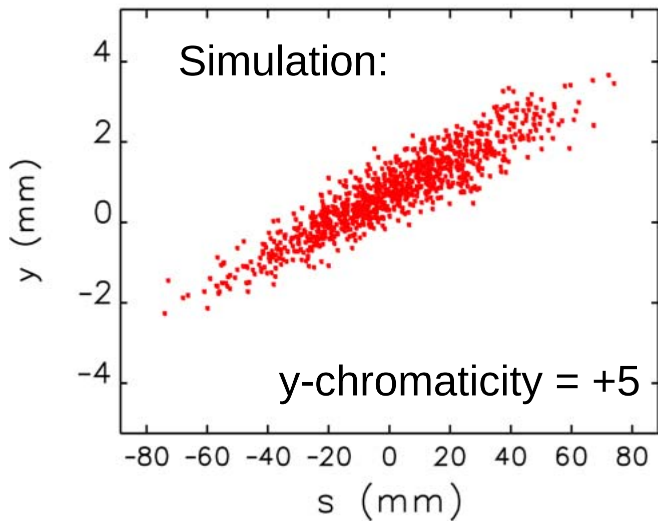


Time evolution of the vertical beam distribution in the case of particle trapping in the resonance island

X-s beam rotation for ultra-short bunch generation

Beam tilt develops in 1/2 of synchrotron oscillation after transverse kick



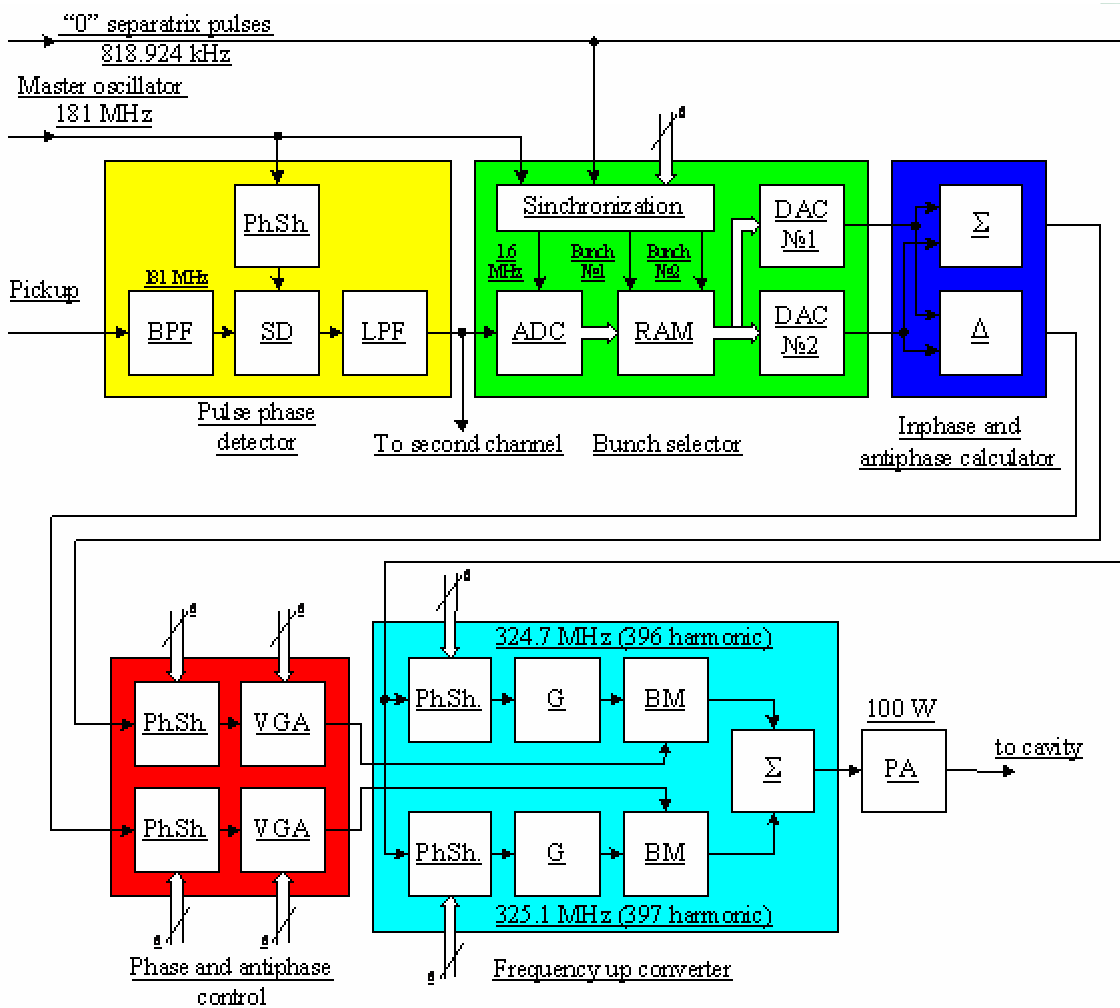


Tilted bunch (or X-rays from it) can be transversely collimated I n order to generate much shorter bunch of particles (or X-rays).

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_{beam} < 1 mA ($N < 10^{10}$ particles). For more intense beams decoherence of betatron oscillations due to head-tail interaction becomes important.

Longitudinal feedback system

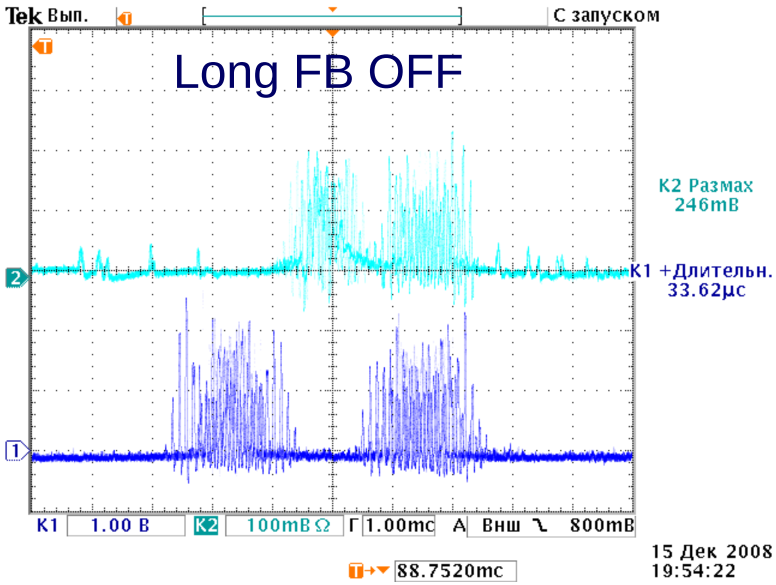


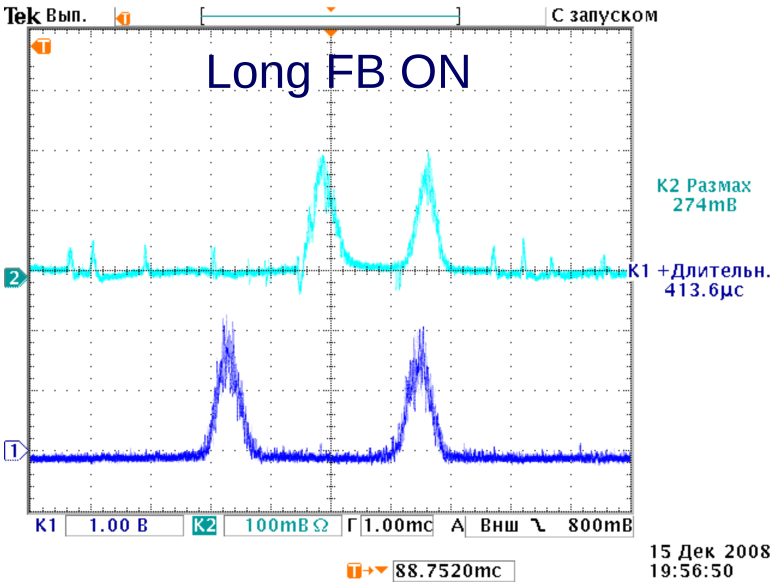
The system is designed to suppress longitudinal beam instability in 2×2 bunch mode.

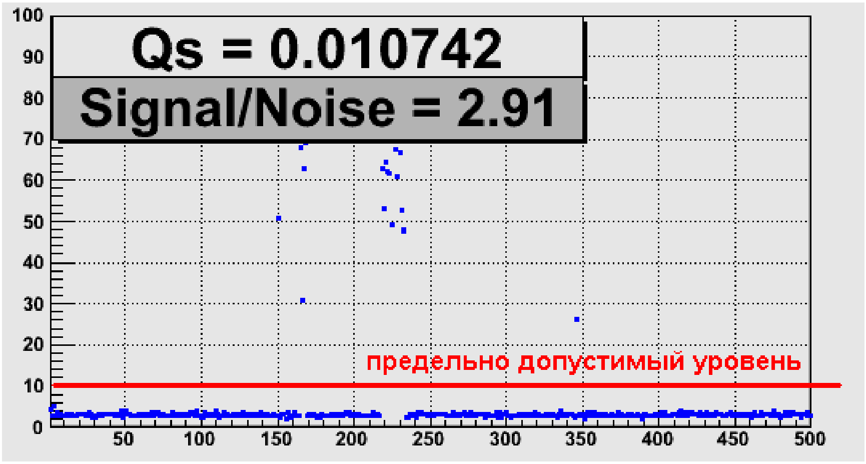
- 2 systems for e- and e+ of 2 channels for synphase and antiphase oscillation modes;
- synchronous detector for beam phase measurement;
- analog superheterodyne modulator;
- 100 W output RF power;
- feedback decrement 500 s^{-1}

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

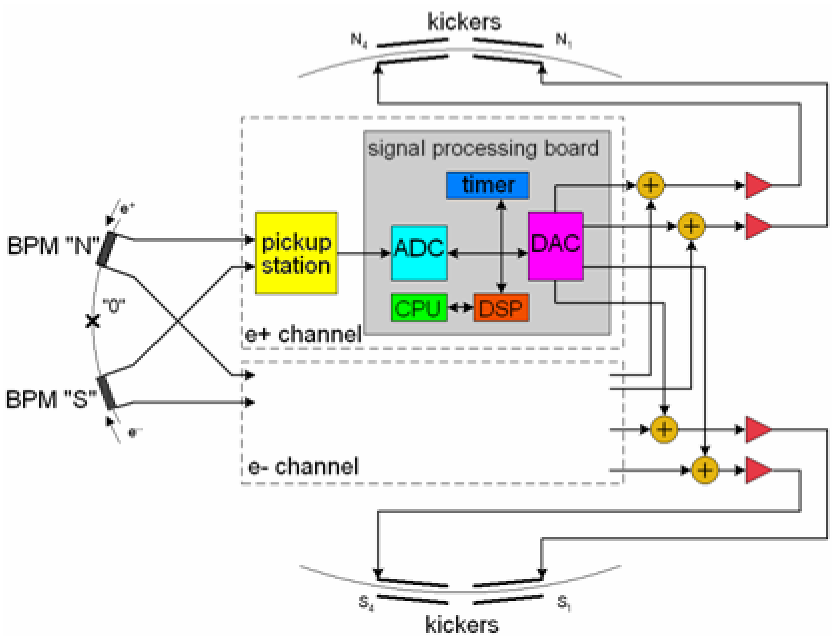


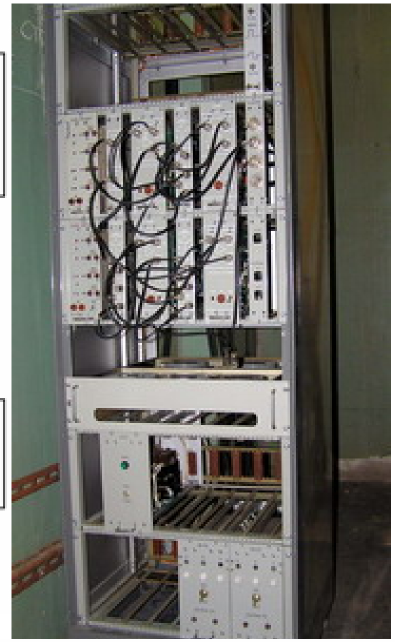


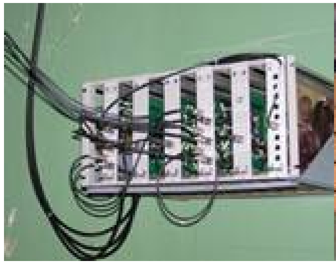


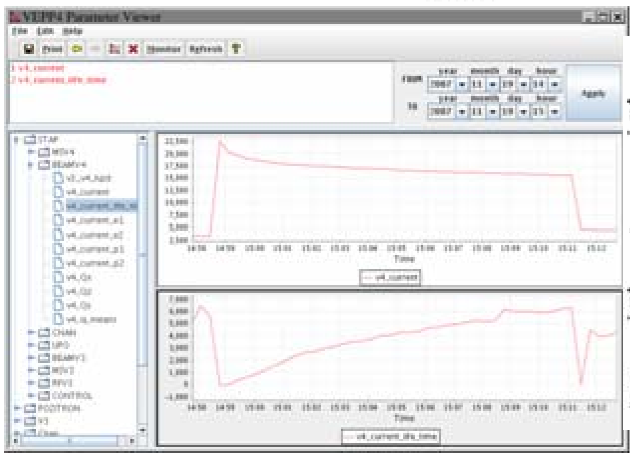
Phase oscillation monitoring system

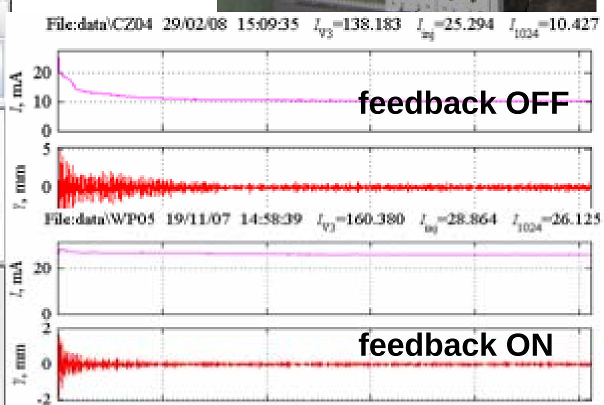
Transverse bunch-by-bunch feedback system











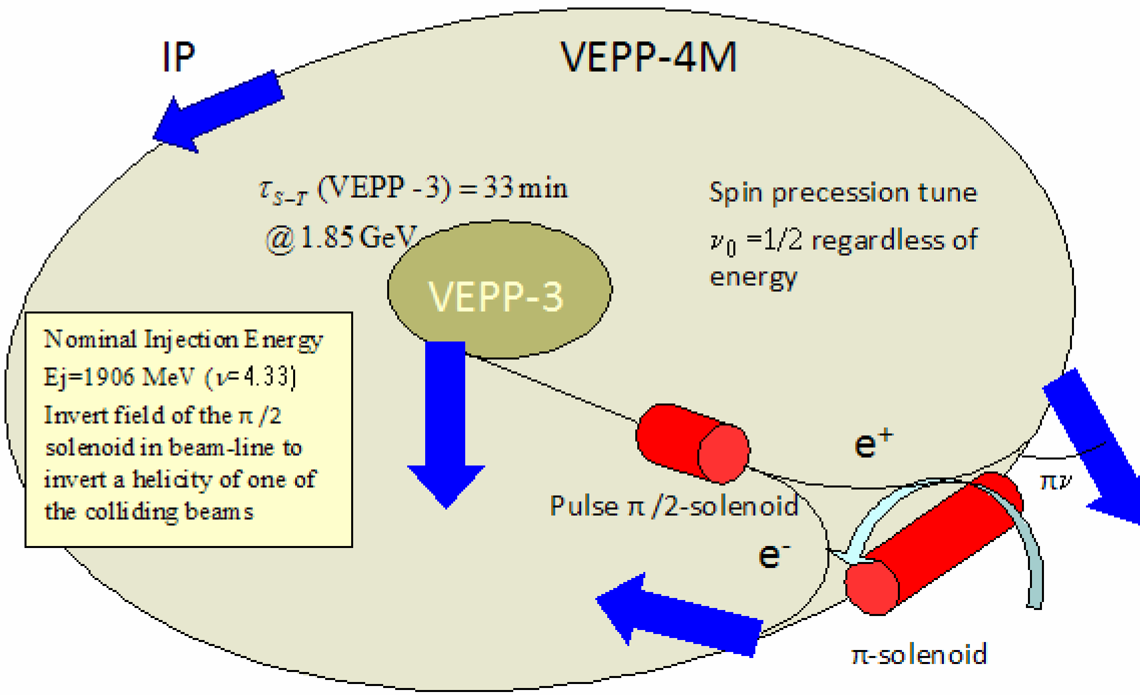
Transverse bunch-by-bunch digital feedback to suppress the TMCI (fast head-tail) instability limiting the VEPP-4M single-bunch current.

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)



Depolarization time with SS :

$$\tau_d \approx \frac{54}{11} \cdot \frac{\tau_{S-T}}{\pi^2 \nu^2} \cdot B(\nu, \nu_x) \propto E^{-7}$$

$\nu = \gamma a$

$B(\nu, \nu_x)$ – betatron factor

VEPP - 4M Sokolov - Ternov time :

$$\tau_{S-T}[h]\Big]^{\text{VEPP-4M}} = \frac{1540}{E^5[GeV]}$$

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

Both electron and positron polarizations available in luminosity run.

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

$t_{run} = 1$ h - run duration; $P_+ = 0.92 \left[1 - \exp\left(-\dfrac{t}{\tau_{p,\text{VEPP-3}}} \right) \right] = e^+$ initial

degree for time $t \approx 3000$ s; $P_- = P_+ \exp\left(-\dfrac{t}{\tau_d} \right) = e^-$ initial degree

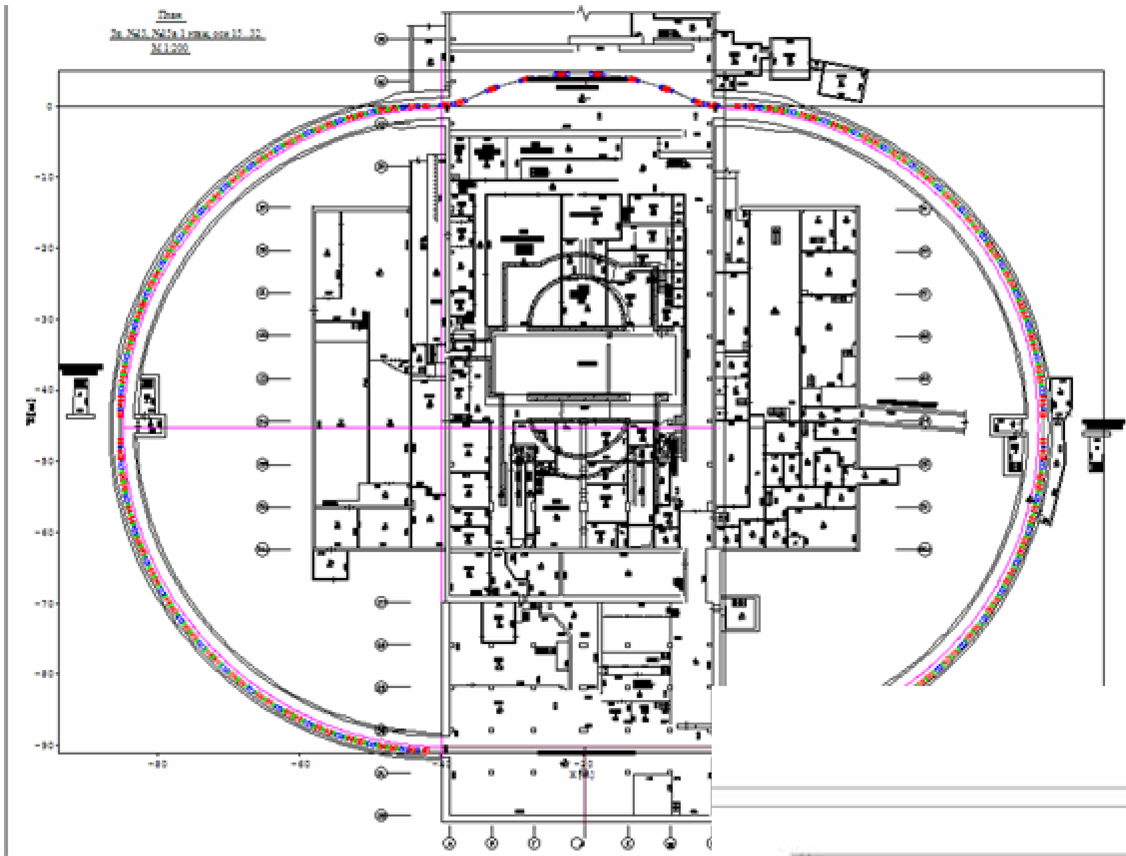
Siberian Snake (SS) insert with decoupling:

Two SC 124 cm × 72 kG solenoids (1.98 GeV)

Five 20 cm×(up to 2.8 kG/cm) quads

Total length=430 cm

SR source in the VEPP-4 tunnel

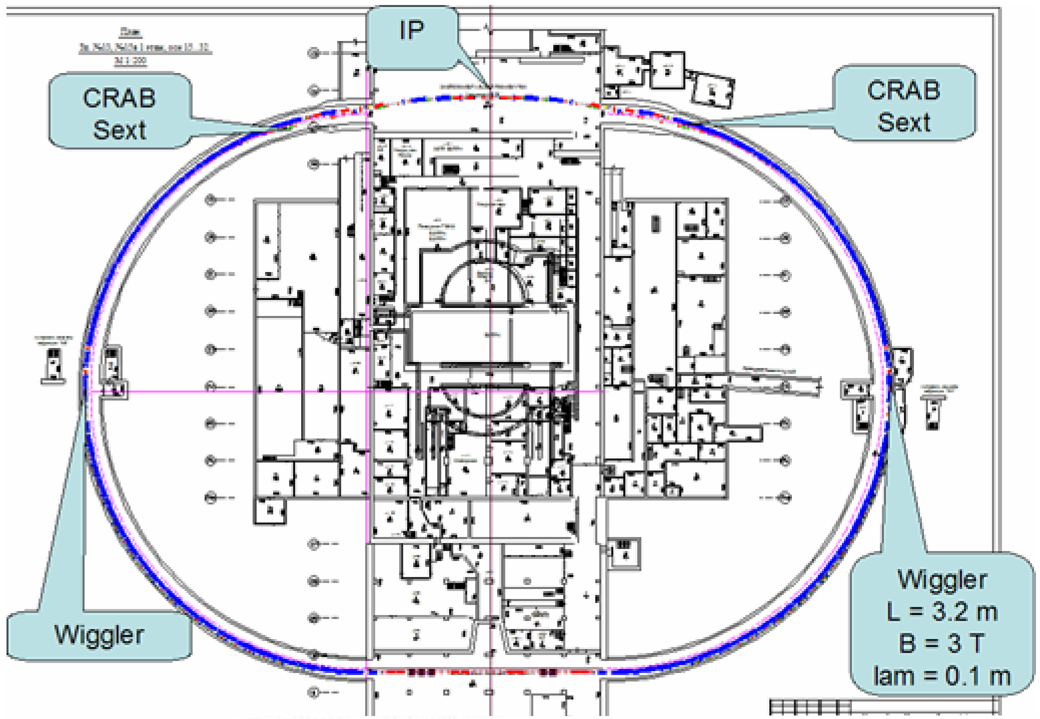


E = 3 GeV
Emittance = 1 nm
Current = 500 mA
RF 180 MHz exists

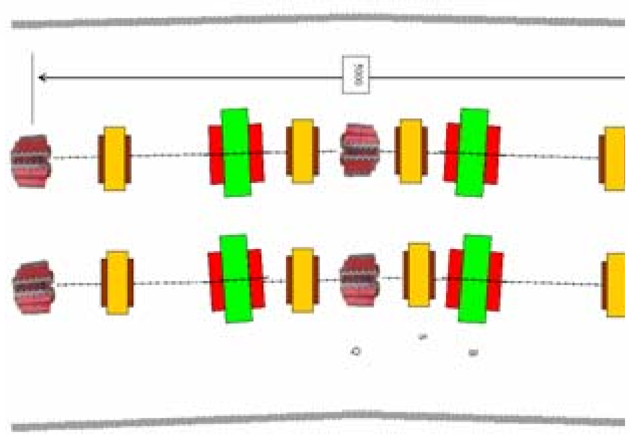
In a long (~70 m) straight section a set of IDs is located

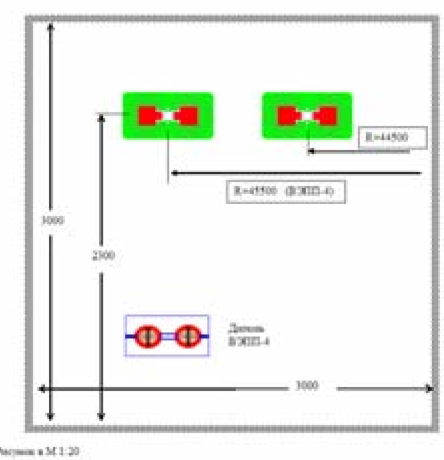
Super Cτ Factory Prototype (from ϕ to ψ)

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 5×10^{34} $cm^{-2}s^{-1}$



Energy per beam E (GeV)	0.5	1	1.55
Emittance ε_x (nm)	10	4	2.5
Hor.damping τ_x (ms)	70	30	15
Bunch length σ_s (mm)	9	5	4
Energy spread $\sigma_E \times 10^3$	1.3	1	0.96
RF voltage U_{RF} (MV)	0.26	1	2.2
Particles per bunch $n_b \times 10^{10}$	1.4		
Lifetime Touschek τ_T	1000	2000	3000
BB parameter ξ_y	0.06	0.12	0.12
Luminosity ($cm^{-2}s^{-1}$) $\times 10^{34}$	1	5	6





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

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