V.Kiselev, for the VEPP-4 team

PARTICLE AND ACCELERATOR PHYSICS AT THE VEPP-4M COLLIDER

7 October 2014

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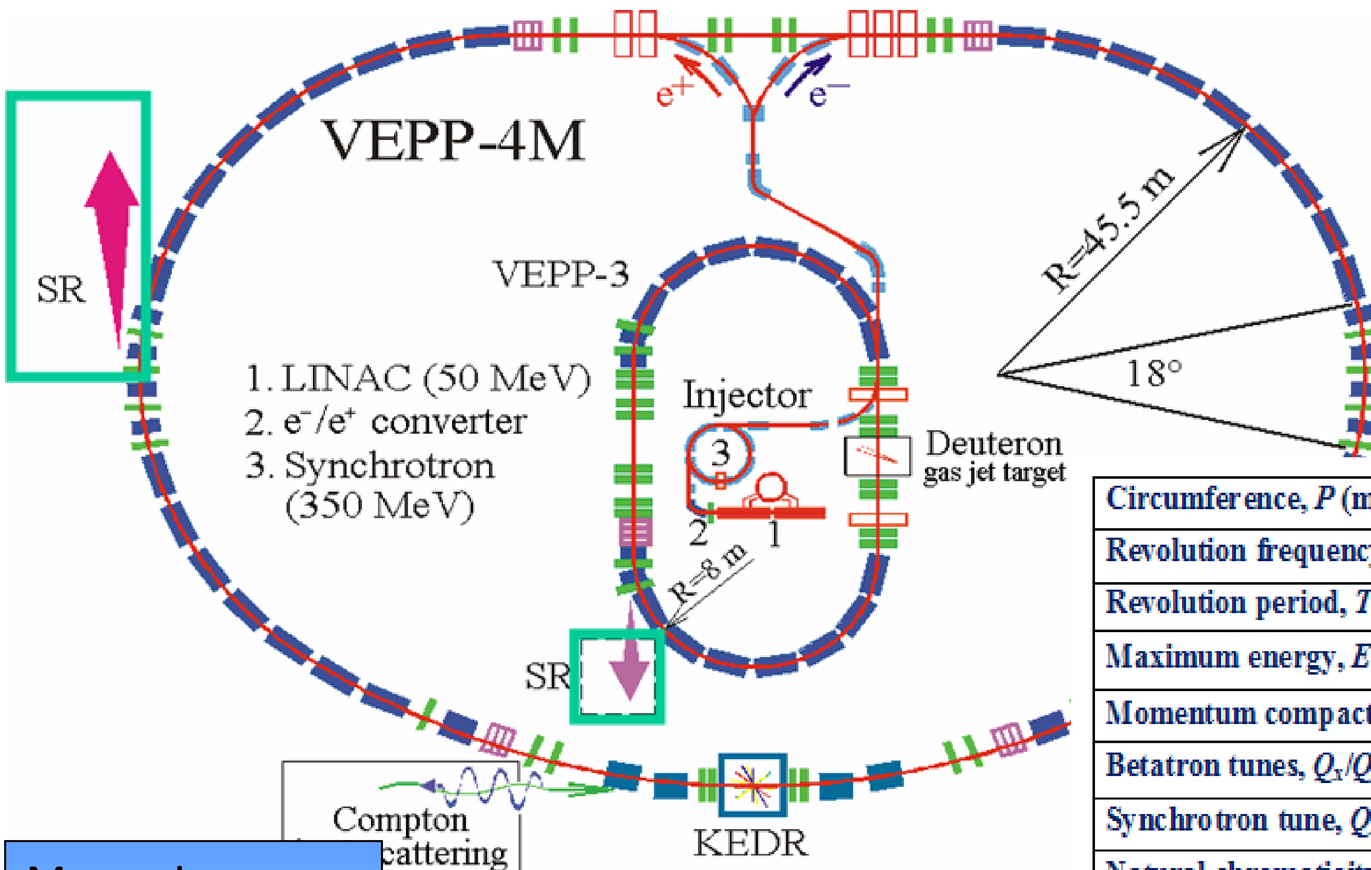
VEPP-4 accelerator facilities



Mono-ring collider with $2e^+ \times 2e^-$ bunches and electrostatic orbit separation in 3 parasitic IPs

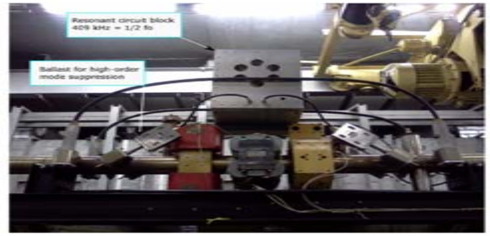
2E=2÷11 ГэВ

*L=2x10**30 см$^{-2}$с$^{-1}$*

*L= 8x10**31 см$^{-2}$с$^{-1}$*

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, $\tau_z/\tau_x/\tau_s$ (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

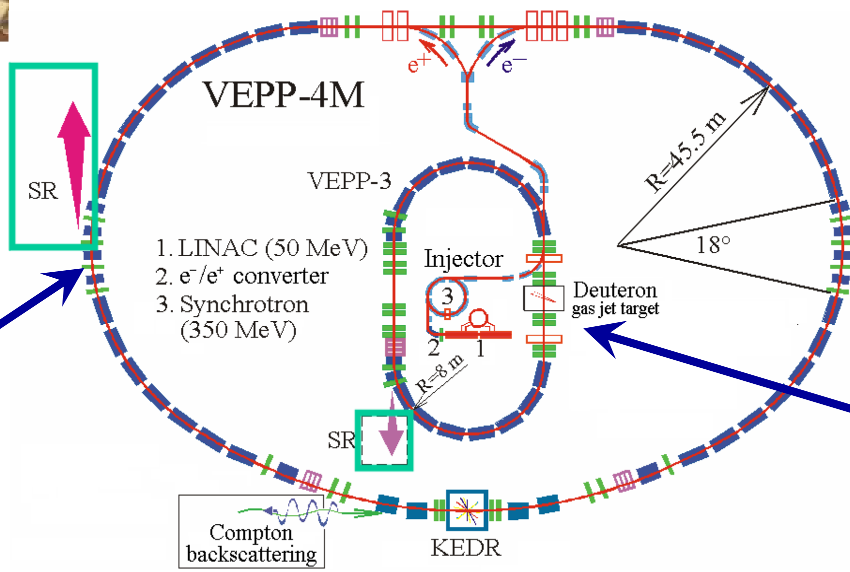
VEPP-4 complex pictures

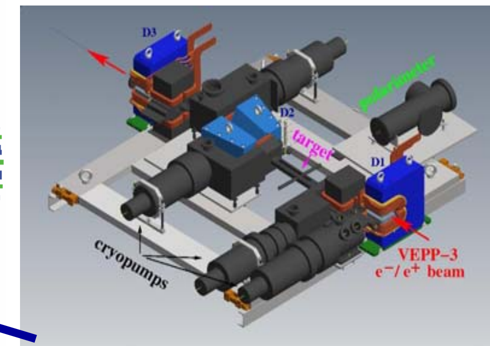


RF separation system

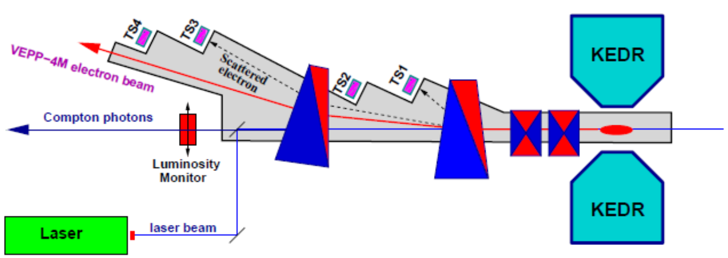
New experimental station for fast processes study at VEPP-4M

7-pole electromagnet wiggler Installed recently at VEPP-4M



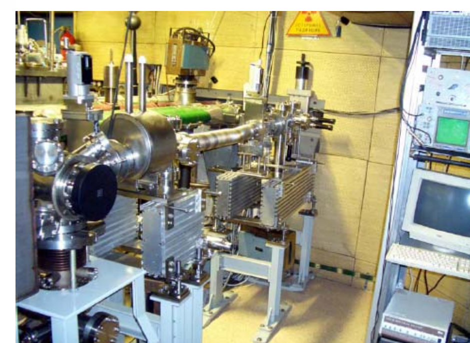


Internal gas target for nuclear physics at VEPP-3 (Deutron)



Electron tagging system for two-photon experiments
Compton backscattering system

Detector KEDR



SR experiments at VEPP--3

High-energy physics: some advantages of VEPP-4 - KEDR

- Unique beam energy range from 0.9 up to 5.5 GeV;
- Measurement of the beam energy using resonant depolarization method with the record accuracy 10^{-6}, not reached at any other laboratory of the world;
- Routine monitoring of the beam energy using the Compton backscattering 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},
  - the fine energy and spatial resolution in a LKr calorimeter (3.5% and 1 mm, E =1.8 GeV) ,
  - system of aerogel Cerenkov counters.

Mass measurements at VEPP-4: history

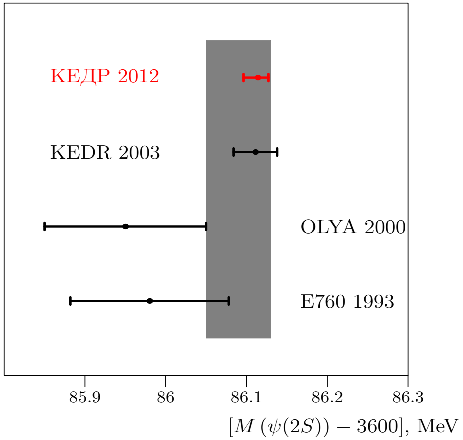
Particle	*E*, MeV	Accuracy, $\Delta E/E$	Detector	Years
J/ψ	3096.93±0.10	$3.2\cdot10^{-5}$	OLYA	1979-1980
Ψ (2S)	3685.00±0.12	$3.3\cdot10^{-5}$	OLYA	1979-1980
ϒ	9460.57±0.09±0.05	$1.2\cdot10^{-5}$	MD-1	1983-1985
ϒ'	10023.5±0.5	$5.0\cdot10^{-5}$	MD-1	1983-1985
ϒ''	10355.2±0.5	$4.8\cdot10^{-5}$	MD-1	1983-1985
J/ψ	3096.917±0.010±0.007	$3.5\cdot10^{-6}$	KEDR	2002-2008
Ψ (2S)	3686.114±0.006±0.010	$2.0\cdot10^{-6}$	KEDR	2013
ψ(3770)	3772.9±0.5±0.6	$2.1\cdot10^{-4}$	KEDR	2002-2006
D^0	1865.43±0.60±0.38	$3.8\cdot10^{-4}$	KEDR	2002-2005
D^+	1863.39±0.45±0.29	$2.9\cdot10^{-4}$	KEDR	2002-2005
τ	$1776.69^{+0.17}_{-0.19}\pm0.15$	$1.3\cdot10^{-4}$	KEDR	2005-2008

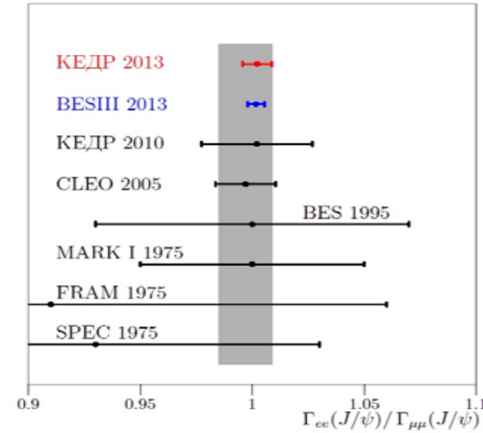
KEDR J/ψ, .ψ(2S): in order improved as compared with OLYA

Why mass measurement?

- Fundamental parameter
- Test of theoretical models
- Bench mark on the mass scale of elementary particles
- Bench mark on the energy scale of a given collider (J/ψ, ψ(2s) masses used in BEPC-II τ- lepton mass experiment)
- Absolute calibration of momentum measurements in detector tracking systems

Recent results





The compilation of the results on ψ(2S) mass.
Relative accuracy of the KEDR result is about $2*10^{-6}$.

The ratio of the electron and muon widths of the J/ψ meson has been measured using direct J/ψ decays.
The measurement result $\Gamma_{e+e}/\Gamma_{\mu+\mu}$ is in a good agreement with the lepton universality

Recent papers on the VEPP-4 HEP activity :

- **High precision particle mass measurements using the KEDR detector at the VEPP-4M collider(In Russian) . Uspekhi Fizicheskikh Nauk 184(1) 75-88(2014)**
- **Results of measurement of psi(3770) parameters at KEDR/VEPP-4M.(In Russian) Yadernaya Fizika, 76(2013)92-97**
- **Measurement of the ratio of the lepton widths Gamma_{ee}/Gamma_{mumu} for the J/psi meson. Phys. Lett. B731(2014)227**
- **Measurement of psi(3770) parameters Physics Letters B711(2012)292-300**

The following experiments are planned for 2014:

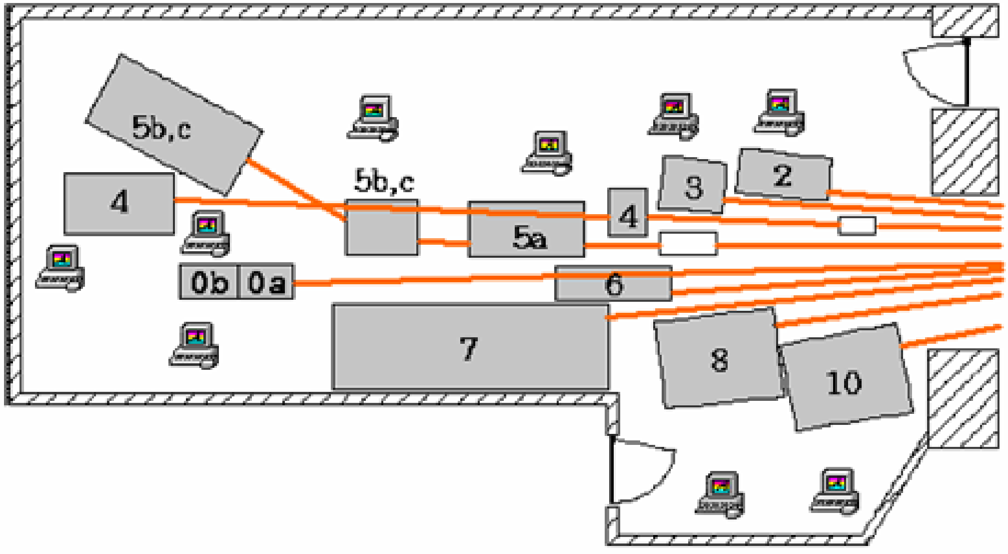
- **scanning at energy 2E = 3.1-4.0 GeV for the measurement of R**
- **collection of statistical data at the peak of the ψ (3770) meson to measure the mass D_mesons**

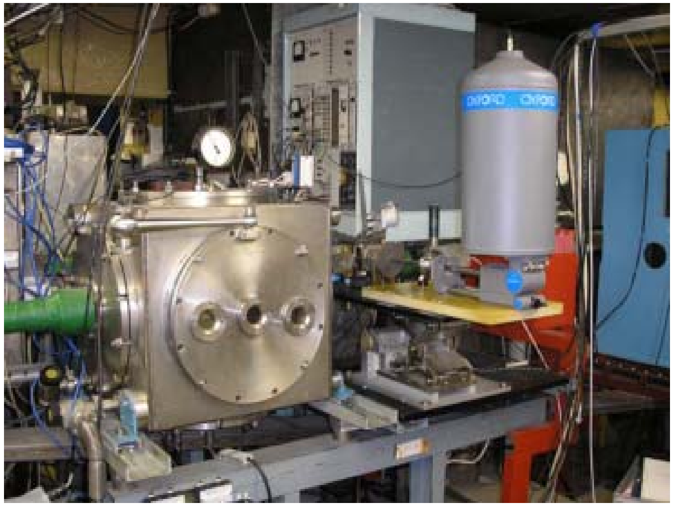
VEPP-4M

SR experiments at VEPP-3

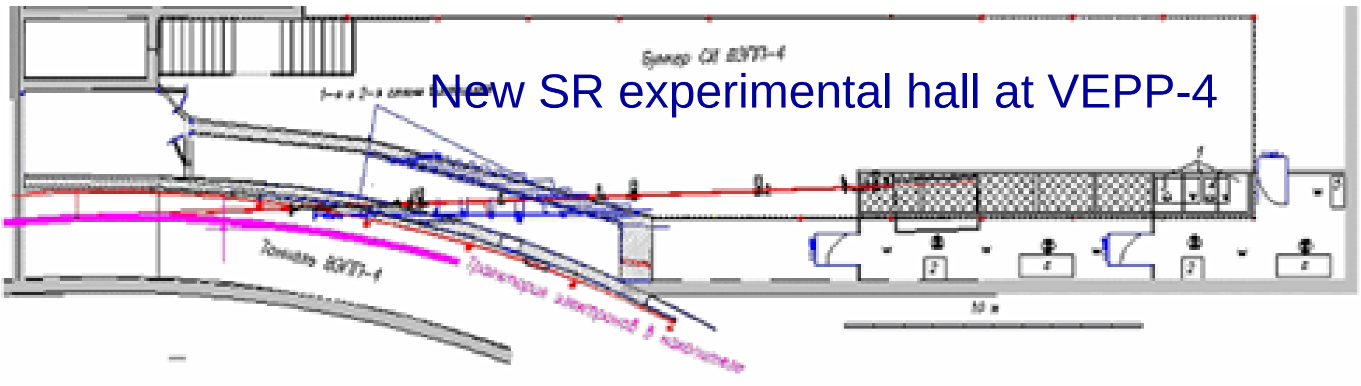
http://ssrc.inp.nsk.su/conf/SR2014

- 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

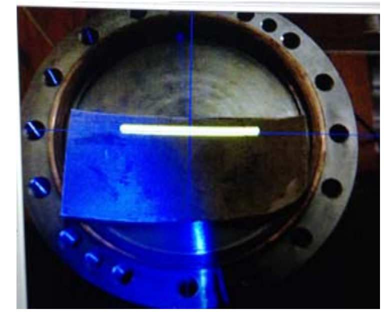




SR experiments at VEPP-4



New SR experimental hall at VEPP-4



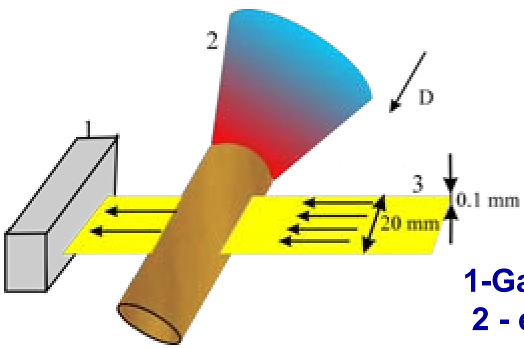
7-pole electromagnet wiggler
Installed recently at VEPP-4

New experimental station for
fast processes study

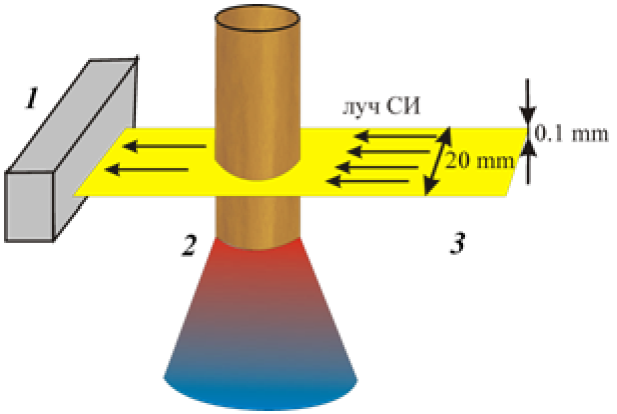
Beam lines in the VEPP-4
SR experimental hall

SR experiments at VEPP-4

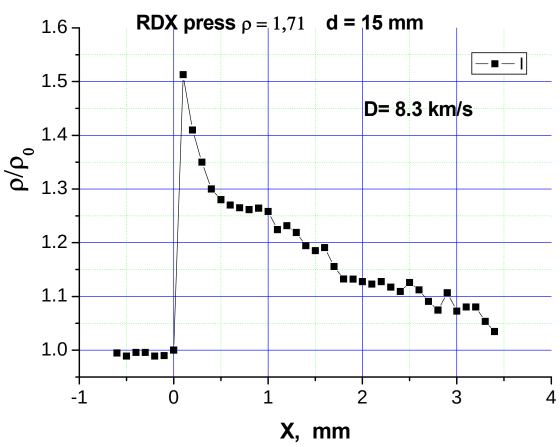
Study the fast processes proceeding in a detonation wave, at the front of a shock wave



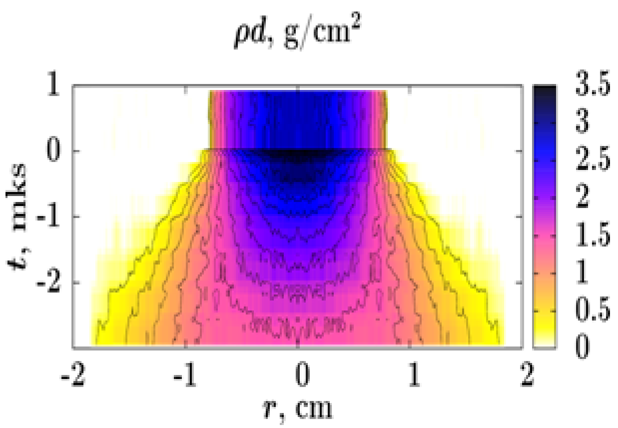
1-Gas X-ray detector DIMAX ,
2 - explosive 3 – SR



Experimental setup for density distribution reconstruction.

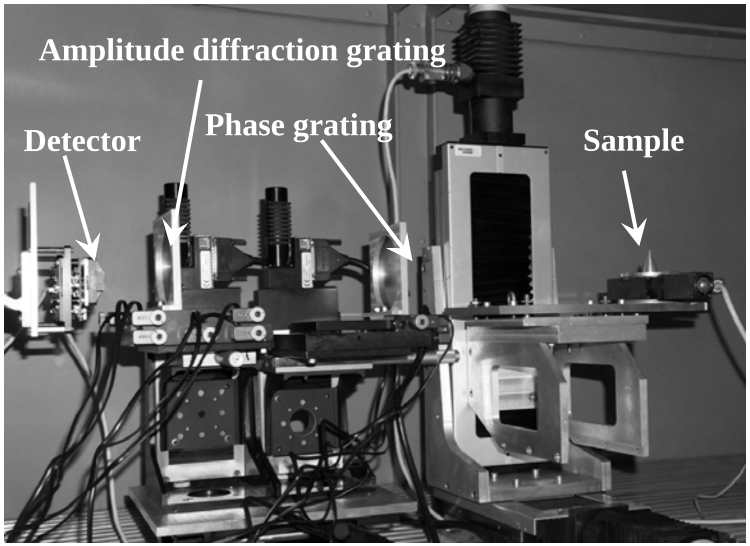


Shock front is measured in a single pulse



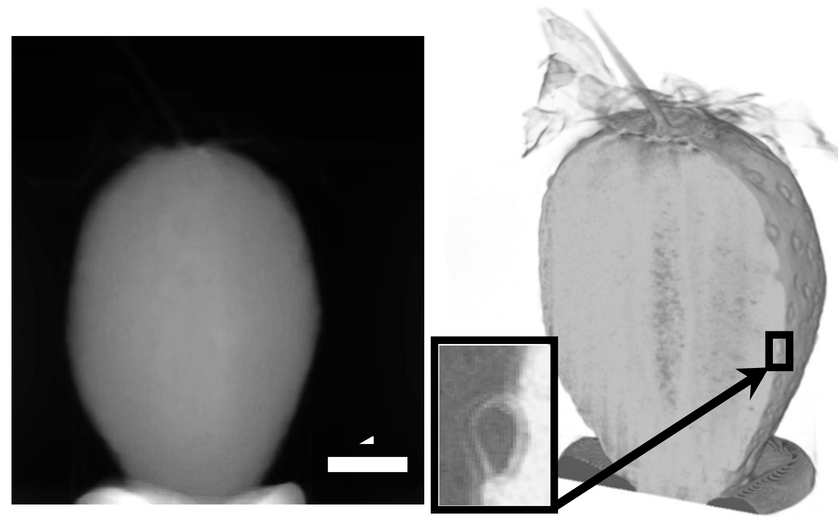
Turn by turn measuring the density distribution in shock
Recorded up to 500 frames

SR experiments at VEPP-4



Talbot interferometer

The Talbot interferometer, created at VEPP-4M and used for solving problems of a computer X-ray tomography and microscopy, opens up possibilities for research in such science fields as: geology, materials technology, archeology, biology and are especially important for medical research.



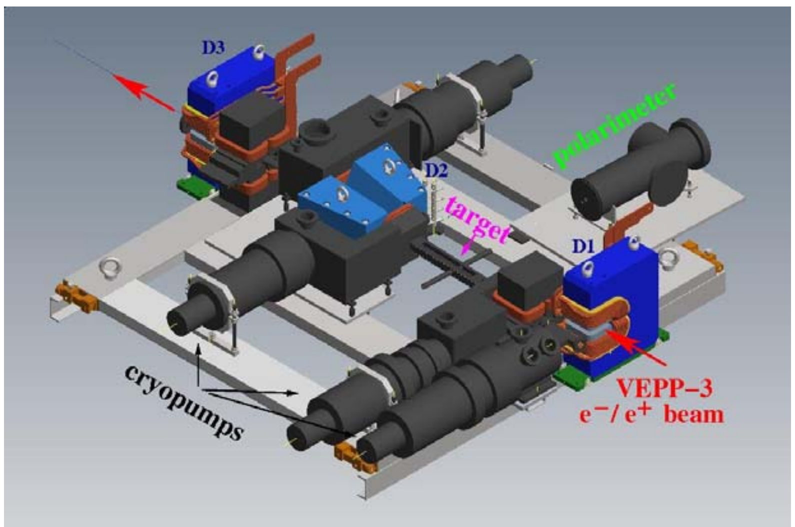
a) **b)**

(a) – Absorption contrast,
(b) – Tomographically reconstructed three-dimensional structure of a strawberry from a set of phase projections.

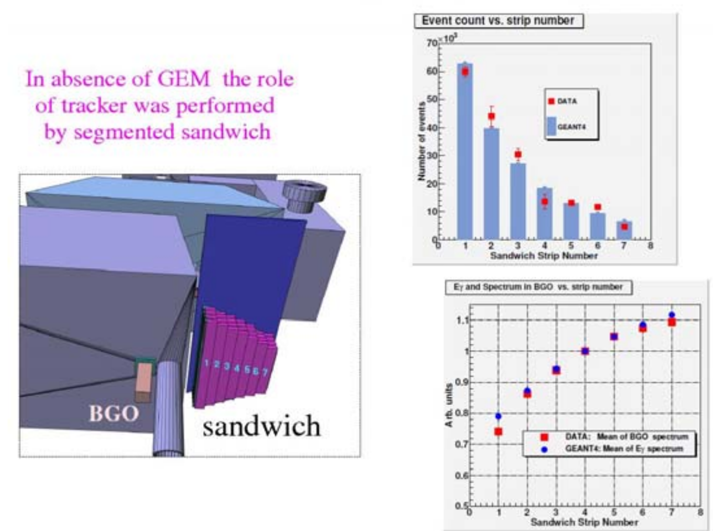
Small low-contrast details, such as a stalk, leaves and seeds which are not distinguishable at absorption contrast are well visible.

Nuclear physics at VEPP-3

The electro-nuclear experiments with internal targets at the electron-positron storage ring VEPP – 3 have been performed by BINP for several years . During this time the data on the tensor analyzing power in reactions with deuteron have been obtained, the two-photon exchange contribution in (ep) -scattering have been measured . Further progress of experiments is connected with introduction into VEPP-3 a quasi-real photon tagging system, which will allow performance of a series of measurements of the polarization observables in various reactions with photon energy of up to 1.5 GeV.



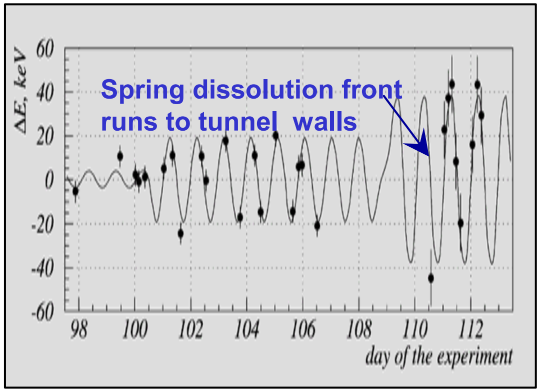
Layout of a new experimental section "Deuteron".

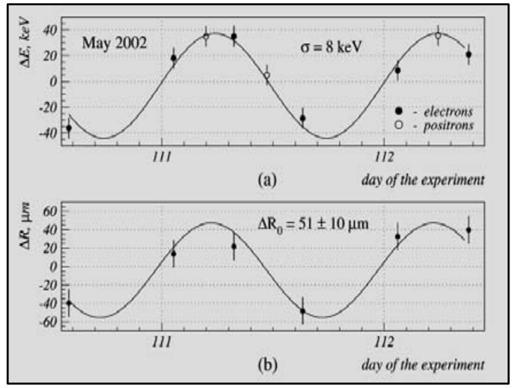


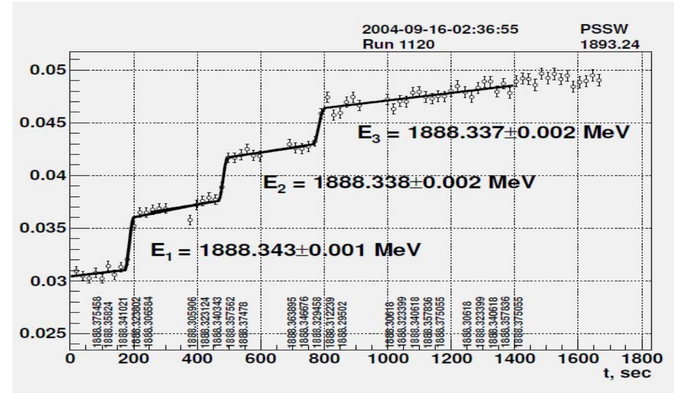
Test of the photon tagging system trigger

In 2013 the tagging system was introduced into VEPP-3 ring and tested with electron and positron beams. The spectra of the bremsstrahlung and the annihilation radiation were detected at zero angle of the tagging system

Energy stability







Processing of energy data with "predication function" in J/Psi run

Correlation of daily energy oscillations with mean orbit radius deviations

Thrice-repeated partial depolarization
All three measured energy values are in the 6 keV interval (3× 10-6) due to guide field drift

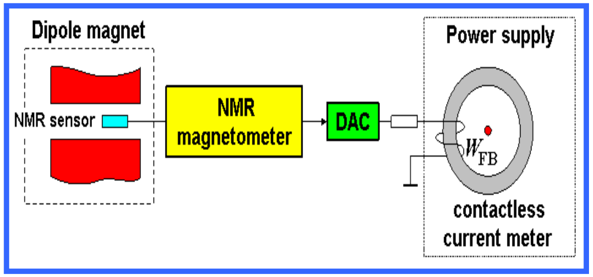
In the precision measurements of the mesons masses resonance depolarization method was used for beam energy calibration with accuracy 10^-6 . An energy drift 10^-4 was critical for thous experiments therefor NMR data of guiding magnetic field measurement and temperatures of magnets, tunnel and cooling water were used for beam energy reconstruction between energy calibrations. Accuracy achieved (3 - 10) x 10^-6 was enough for thouse experiments.

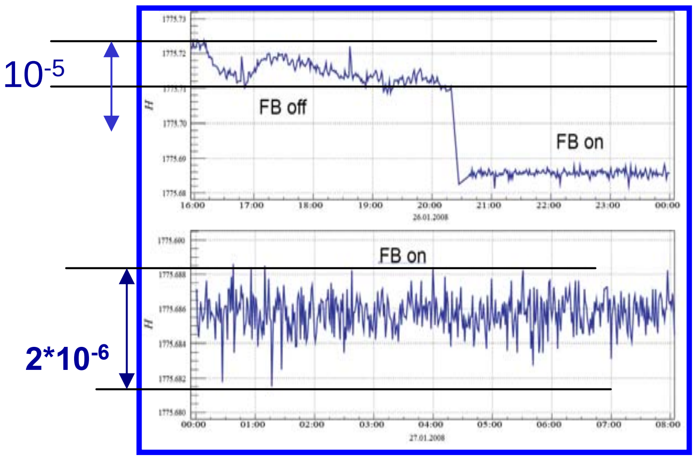
But at VEPP-4M another **experiment of CPT-invariance test** by comparison of spin precession frequencies of electron and positron simultaneously circulating in VEPP-4M storage ring with **accuracy 10^-8 is planned**. The error of this experiment directly depends on stability of guiding magnetic field therefore long term stability and field pulsation are the great of importance.

Long term (hours) stability 10^-6 allow one to find optimal parameter for the measurement. High-frequency pulsation (up to 5 Hz) lead to broadening of resonance spin precession frequency. This effect increases statistical error of the experiment.

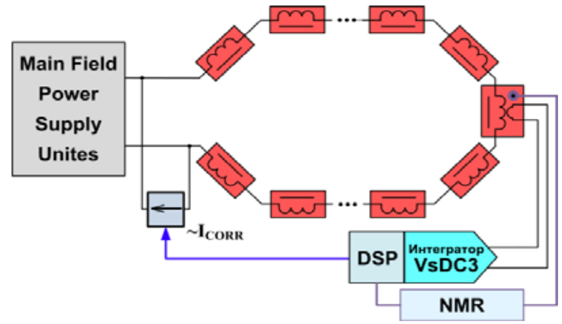
GUIDING FIELD STABILIZATION SYSTEM

NMR-based system

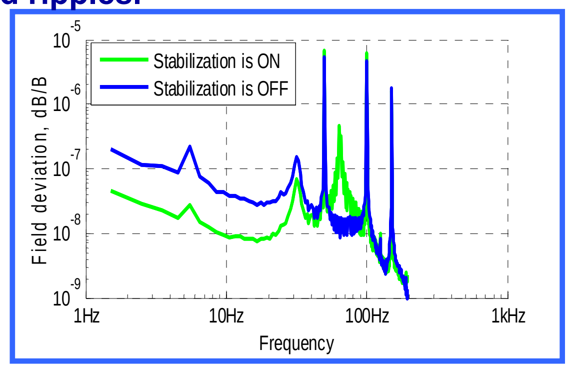




Induction method



The essence of the method is measuring the field ripples by the induction sensor to adjust the current in the magnet with the help of parallel connected to IST current generator, which is opposite to the measured ripples.



The graph shows that at a frequency of 5 Hz suppression of ripples is more than by 10 times, at a frequency of 10 Hz - 3 times, at a frequency of 30 Hz - 2 times.

Field measurement error	$< 0.5\cdot10^{-6}$
System bandwidth	0.1 Hz
Range of the field deviation	$\pm10^{-4}$
Field variation with the feedback loop closed in 0 - 0.1 Hz bandwidth	$2\cdot10^{-6}$

Field measurement error	$< 0.5\cdot10^{-7}$
System bandwidth	10 Hz
Range of the field deviation	$\pm 2*10^{-4}$
Field variation with the feedback loop closed in 1-30 Hz bandwidth	$4\cdot10^{-7}$

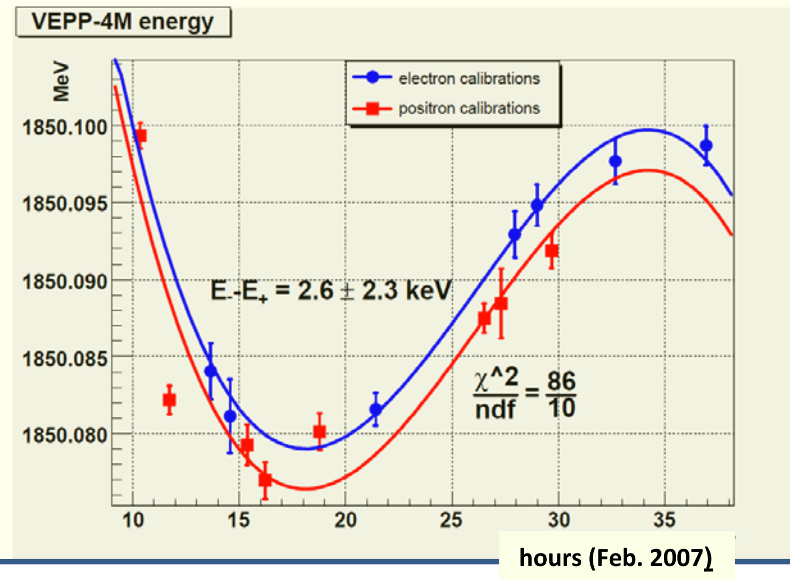
A. Pavlenko et. al. METHOD OF BROADBAND STABILIZATION OF THE VEPP-4 MAIN FIELD. Poster session A, October 07

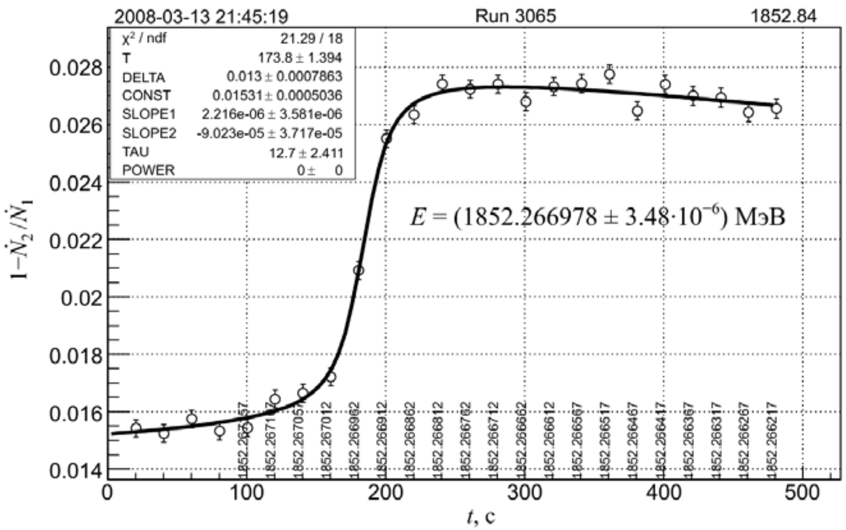
Comparison of e^+ and e^- beam energies

Distinct-in-time comparison:
measured beam energy in series of consecutive calibrations of e^+ and e^- with electrostatic orbit bumps ON

Ep - Ee =2.3÷2.6 keV

Reason of difference:
electrostatic orbit separation in 4 IPs





“Nano-resolution”:

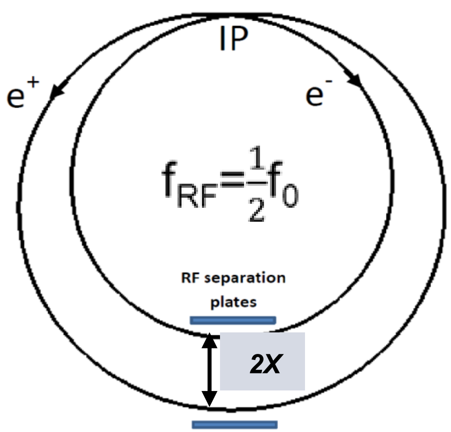
scan rate = **2.5eV/s**

relative error ~ **2*10-9**

RF separation of colliding beams at the technical section

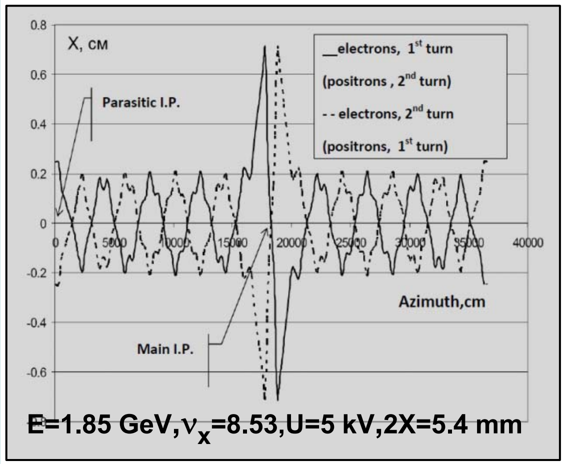
Goal: to exclude contribution (~10^{-6}) of electrostatic orbit separator influence to systematic error in CPT test experiment based on comparison of spin frequencies of electron and positron

Principle scheme

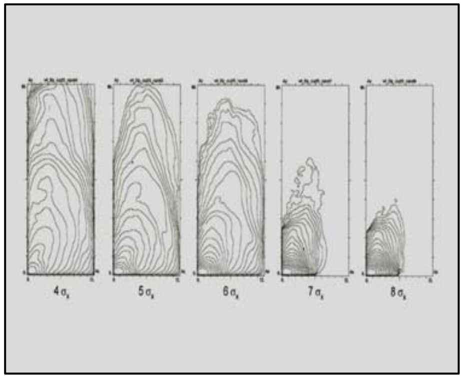


$$X = \frac{\chi\beta}{2\sin 2\pi\nu_x}\cdot(\cos 2\pi\nu_x - 1)$$

Design two-turn closed orbit



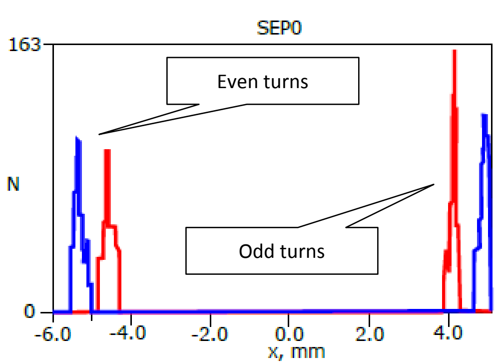
Beam-beam simulation



Distribution in plane of betatron amplitudes at various values of orbit separation in TS

Some first experimental data of the RF separation system test in the end of 2012-begin of 2013

BPM data with 2 e^- bunches



$1e^-\times1e^+$ bunches separation test

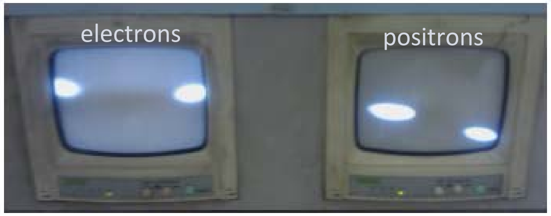


Figure 6: SR images of the 1.1 mA electron (left) and the 0.3 mA positron (right) bunches on the TV monitors while applying the RF separation at the 6.5 kV peak voltage. Electrostatic separation system is fully off.

Increase in VEPP-4M luminosity at low energy

In 2014, we performed an experiment in order to increase the luminosity of the collider VEPP- 4M at a low energy (<2 GeV).

Luminosity formulae (flat beam)

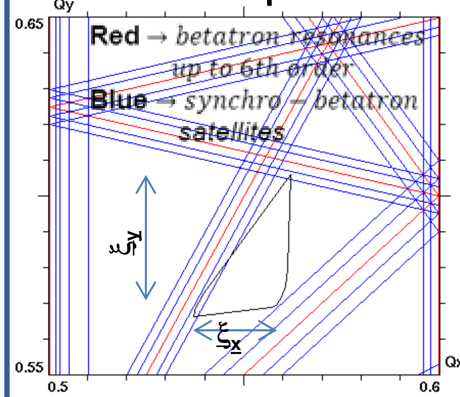
$$L = \frac{\gamma}{2er_e}\frac{I\xi_y}{\beta_y^*},\ \xi_x = \frac{Nr_e}{2\pi\gamma}\cdot\frac{\beta_x^*}{\sigma_x^2},\ \xi_y = \frac{Nr_e}{2\pi\gamma}\cdot\frac{\beta_y^*}{\sigma_y^*\cdot\sigma_x}$$

Monochromatization parameter

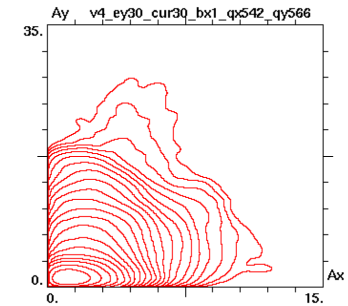
$$\lambda_m = \frac{\sigma_{xs}}{\sigma_{x\beta}} = \frac{\eta_x\sigma_E}{\sqrt{\varepsilon_x\beta_x}},\ \sigma_x = \sqrt{\sigma_{x\beta}^2+\sigma_{xs}^2} = \sigma_{x\beta}\sqrt{1+\lambda_m^2}$$

$$x = x_\beta + \eta_x\frac{\Delta E}{E}$$

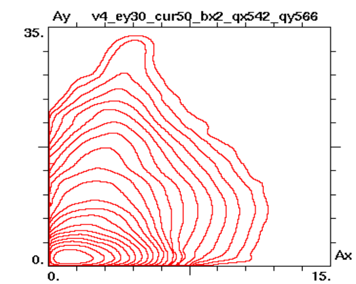
BB Footprint



Distribution in betatron amplitude plane



I_b=3.0 mA, β_x=65cm, ξ_y=0.036



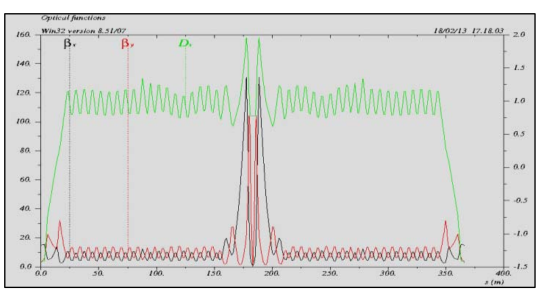
I_b=5.0 mA, β_x=32.5cm, ξ_y=0.053

IP with dispersion

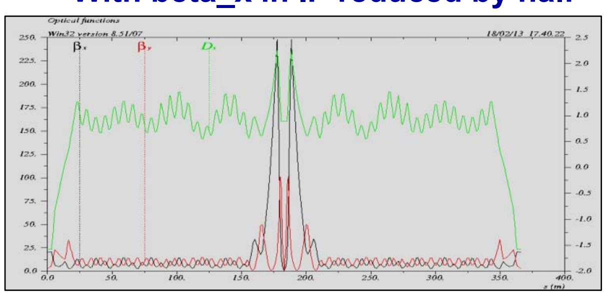
Increase in λ_m owing to reducing β_x (not ε_x – emittance!) results in:

- **increase of critical current due to decrease of ξ_x**
- **Increase of critical ξ_y because of coupling resonance suppression**

VEPP-4M base structure



With beta_x in IP reduced by half



The result of the experiment

After double decrease of βx resulted in increasing of a threshold current by half. accompanied by βx beating at the ring though. After studying the problem, experiments will be continued

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

Plans for the coming two years :

- Scanning at energy 2E = 3.1-4.0 GeV for the measurement of R
- Collection of statistical data at the peak of the ψ (3770) meson to measure the mass D_mesons

Co-authors

A.Aleshaev, V.Anashin, O.Anchugov, A. Batrakov, E. Behtenev, V.Blinov,
A. Bogomyagkov, D. Burenkov, S. Vasichev, S. Glukhov, Yu. Glukhovchenko,
O. Gordeev, V. Erokhov, K. Zolotarev, V. Zhilich, A. Zhmaka, A. Zhuravlev,
V. Kaminsky, S. Karnaev, G. Karpov, V. Kiselev, G. Kulipanov, E. Kuper, K. Kuper
G. Kurkin, O. Meshkov, S. Mishnev, I. Morozov, N. Muchnoi, V. Neifeld, S. Nikitin,
I. Nikolaev, D. Nikolenko, I. Okunev, A. Onuchin, A. Pavlenko, V.Petrov, P. Piminov,
O. Plotnikova, A. Polyansky, Yu. Pupkov, V. Sandyrev, V .Svistchev, I. Sedliarov,
E. Simonov, S. Sinyatkin, A. Skrinsky, E. Starostina, D. Sukhanov, Yu. Tikhonov,
D. Toporkov, K. Todyshev G. Tumaikin, V. Tsukanov, A. Shamov, D. Shatilov,
D. Shvedov, E. Shubin,

Thank you for your attention!