Beam Energy Spread Measurement at the VEPP-4M Electron-Positron Collider

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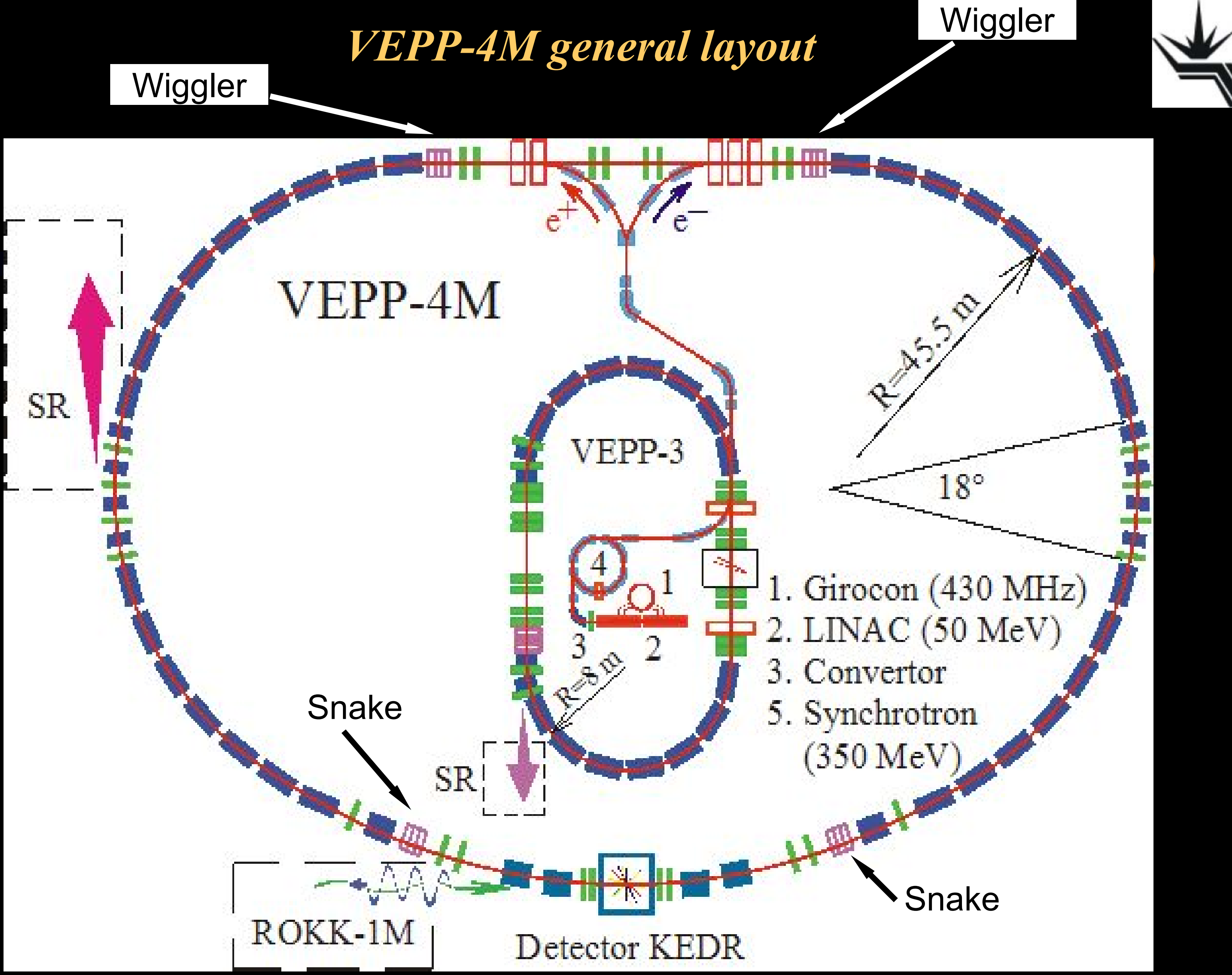
VEPP-4M general layout



Operation modes of the VEPP-4M used for energy spread measurements

The target of our experiments was not only definition of the beam energy spread for basic modes of the collider operation, but comparison of several procedures for measurement of relative energy spread yet.

Name	E, MeV	I_{WG}, A	I_{SN}, A	Comments
PSIS	1843	1055	0	ψ' meson peak
ZMEJ	1843	1055	2000	Special mode.
JPSI	1548	620	0	J/ψ meson peak.

Оптическая схема системы диагностики

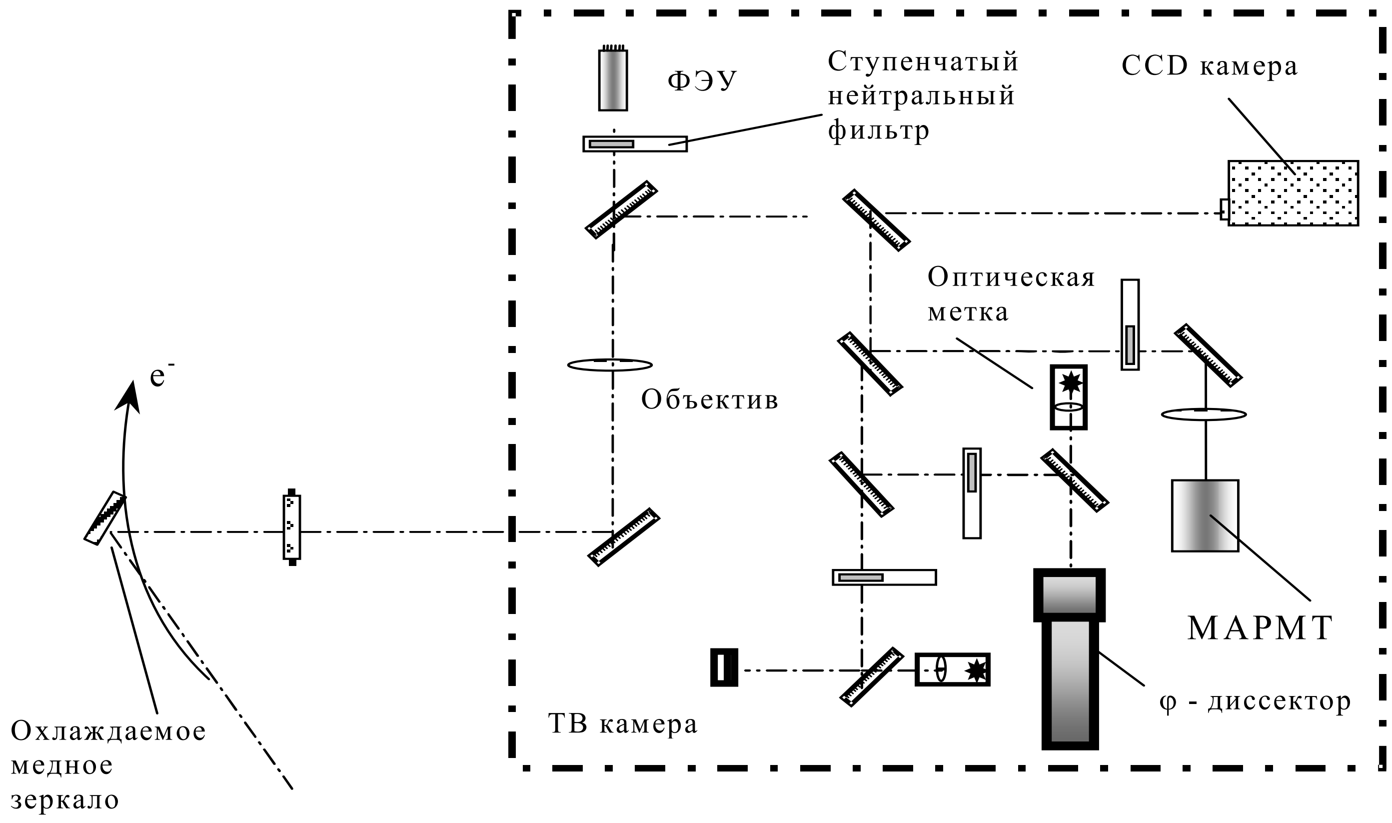


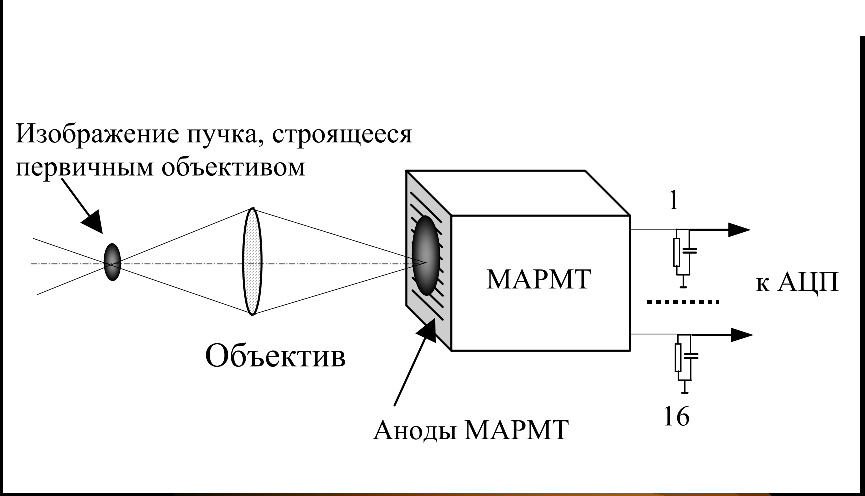
Рис. 1. Оптическая схема диагностики

- **Optical diagnostics was applied for measurement of the beam dimensions $\sigma_{x,y,z}$ and spectrum of vertical betatron oscillations.**

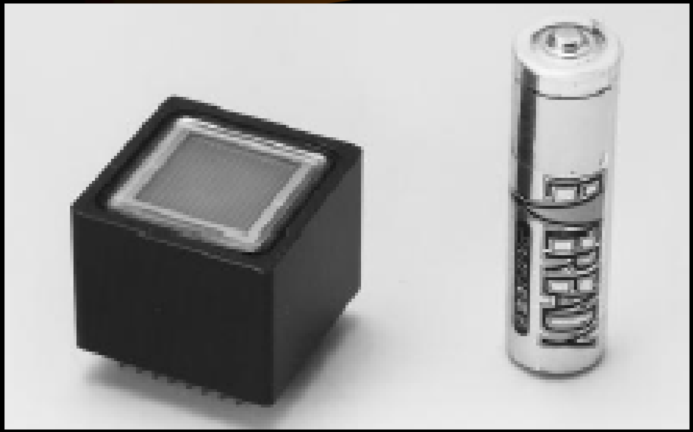
Многоанодный ФЭУ (МАРМТ)

Основные параметры устройства

Размеры	250 x 100 x 100 мм
Интерфейс	100M (Витая пара)
Объем внутренней памяти	4M (2^{17} профилей пучка в 16 точках)
Дискретность записи	Через 1 ÷ 2^8 оборотов
Анализируемый диапазон частот	Несколько Гц ÷ сотни КГц
Число каналов	16
Размер канала	0.8 x 16 мм^2



Оптическая схема и расположение анодов ФЭУ относительно пучка



Внешний вид 16 анодного ФЭУ R5900U-00-L16 HAMAMATSU

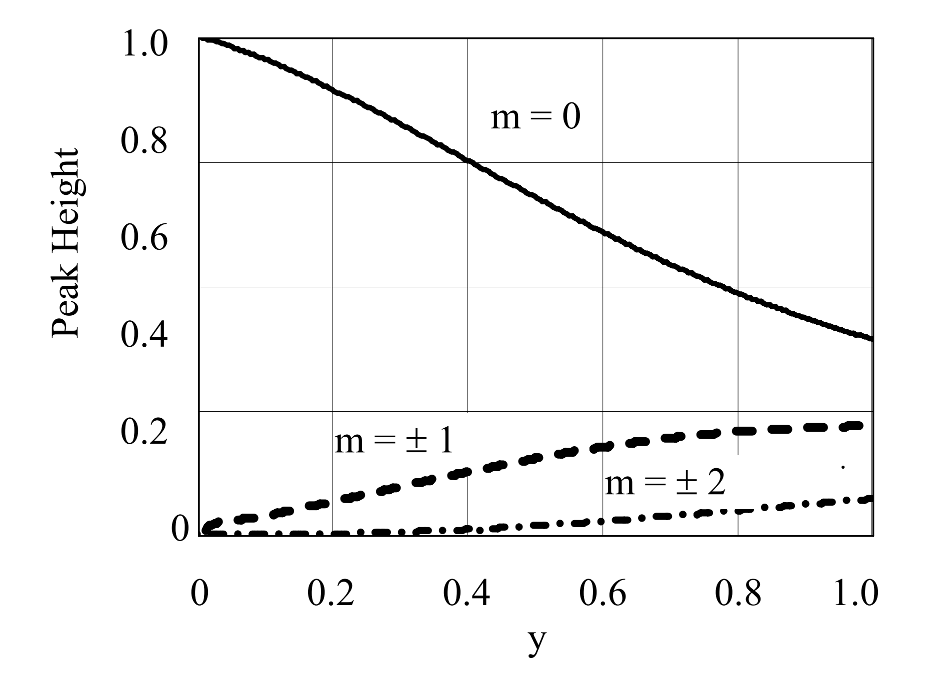
METHOD I. *Spectral analysis of chromatic synchro-betatron modes of beam oscillation*

$$R_m(y) = \frac{1}{y^2}\int_0^\infty J_m^2(x) e^{-\frac{x^2}{2y^2}} x dx$$

$$y = \left(\frac{\omega_\beta \alpha}{\omega_s} + \frac{\omega_0 C_y}{\omega_s}\right)\delta_E$$

$$\delta_E = \frac{\sigma_E}{E}$$

$$y \approx C_y \delta_E / \upsilon_S$$



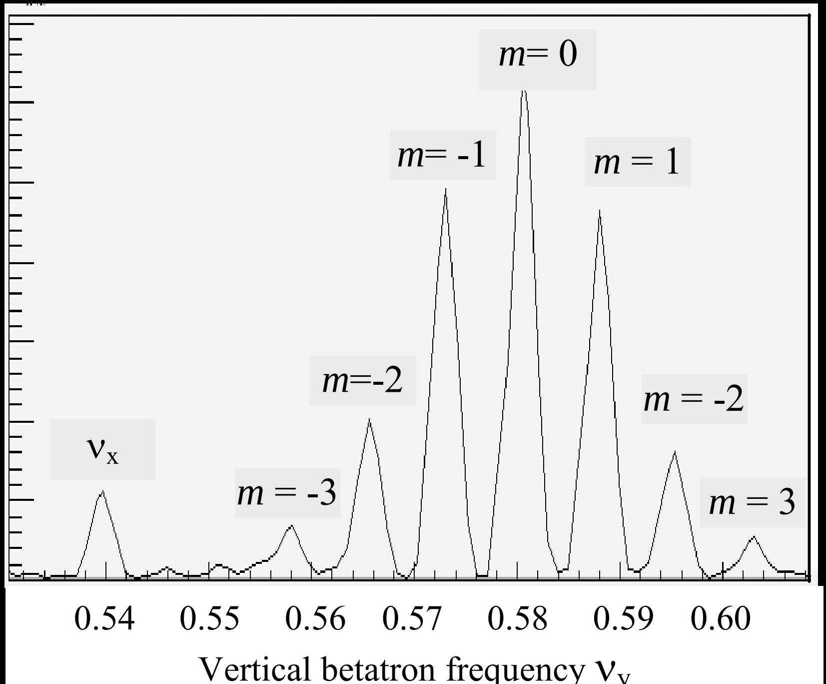
Relative intensities of the betatron peak and synchrotron satellites
α=0.017 ν_S=0.0061Q_Y=7.571 δ_E=4x10^{-4}

(I) T.Nakamura et al. Chromaticity for energy spread measurement and for cure of transverse multi-bunch instability in the SPRING-8 storage ring. Proceed. Of the PAC01, Chicago, p. 1972-1974.

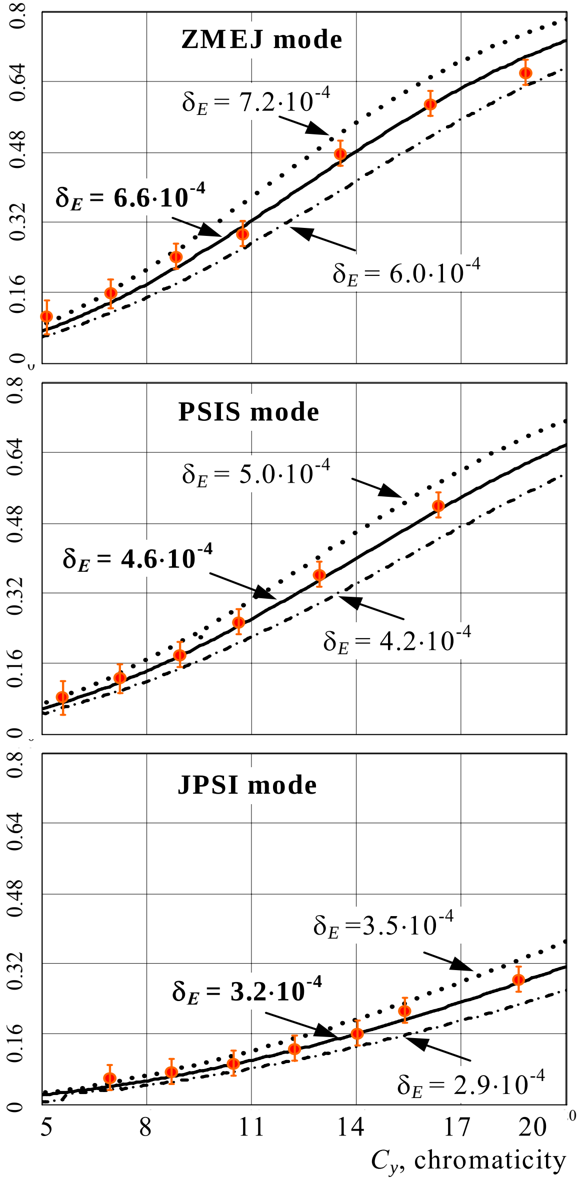
Method (I)

- Beam oscillation was excited by a short kick with amplitude of $b \geq \sigma_y$. Spectrum of betatron motion was derived with FFT.

- The same measurements were made for various vertical chromaticity $C_y = 5 \div 20$. Chromaticity was changed with sextupole magnets and measured from the dependence of betatron tune on the rf frequency shift.



A spectrum of vertical betatron oscillations.



Ratio of R_1/R_0 for different modes of the VEPP-4M operation. Experimental points and theoretical curves are shown.

Method (I)

The measured dependence of height of synchrotron satellite to the main peak is shown on the figure. The best fit of experimental points corresponds to the energy spread

$\delta_E = 3.2\cdot10^{-4}$ for JPSI mode;

$\delta_E = 4.6\cdot10^{-4}$ for PSIS mode;

$\delta_E = 6.6\cdot10^{-4}$ for ZMEJ mode.

METHOD II. *Chromaticity dependence of envelope of betatron oscillations*

This approach was proposed in *(II).* It was been shown that envelope $A(t)$ of free coherent betatron oscillations, excited by kick with amplitude of b, is described as

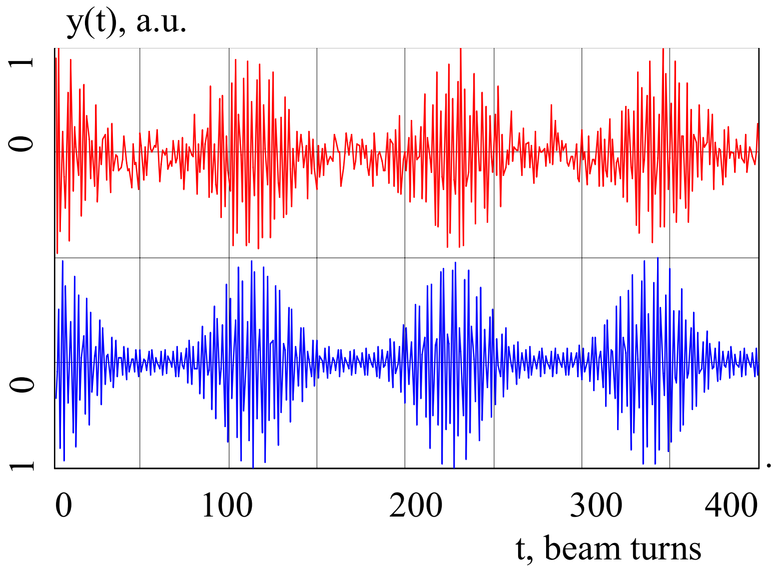
$$A(t) \propto \exp\left(-\frac{t^2}{2\tau^2}\right)\cdot\exp\left(-\left(\frac{\partial\omega_\beta}{\partial E}\frac{\sigma_E}{\omega_s}\right)^2\cdot\left(1-\cos(\omega_s t)\right)\right),$$

$$\tau = \left(2\frac{\partial\omega_y}{\partial a^2}b\cdot\sigma_y\right)^{-1}$$

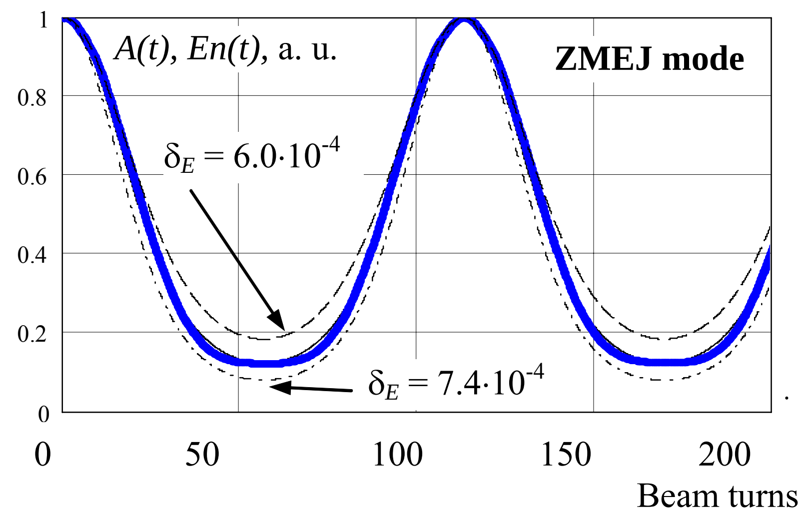
Experimentally, energy spread was determined from comparison of measured beam betatron motion with the theoretical curve $A(t)$.

(II). N.A.Vinokurov et al. The influence of chromaticity and cubic nonlinearity on kinematic of betatron oscillations. Preprint BINP 76-87, Novosibirsk, 1976 (in Russian).

Method (II)



Comparison of initial betatron motion of the electron beam (upper curve) and result of the reverse Fourier transform (down curve)



Comparison of $A(t)$ (2) and the envelope $En(t)$ of the down curve, presented at the left Figure. Only upper part of the symmetrical curves is shown.

$C_y = 18.5$, $\delta_E = 6.7\cdot10^{-4}$, $\nu_s = 0.0089$.

- **The reverse Fourier transform was applied to the measured spectrum of betatron oscillations, but only $\nu_y \pm m\nu_s$ harmonics were taken into account. The result of this operation for ZMEJ mode and $C_y = 18.5$ is shown at the left figure.**
- **The envelope of the derived betatron motion *En*(*t*) was compared the theoretical curve *A*(*t*). Energy spread δ_E was used as a fitting parameter. The fitting was done for the same measurements, i.e. for the same values of chromaticity C_y, that for the method (*I*). An example of comparison of theoretical curve with experimental data is presented at the right figure.**

Method (II)

The averaged derived data are:

$\delta_E = (3.2 \pm 0.3) \cdot 10^{-4}$ **for JPSI mode**

$\delta_E = (4.6 \pm 0.4) \cdot 10^{-4}$ **for PSIS mode**

$\delta_E = (6.6 \pm 0.5) \cdot 10^{-4}$ **for ZMEJ mode.**

METHOD III. **Current dependence of energy spread**

The experiments with the methods of (*I*) и (*II*) were done at the small beam current I_0 = 10 ÷ 50 mkA, when collective effects are negligible. Under experiments with mesons mass measurements beam currents were closed to beam-beam effects threshold restriction. This value was of 1.5 ÷ 3.5 мА, depending on the beam energy spread. The measurements of radial and longitudinal beam dimensions $\sigma_{x,z}$ were done for determination of current dependence. Energy spread of the beam was derived from measured radial size and known amplitude functions in the observation point.

$$\sigma_x = \left[\beta_x \varepsilon_x + \left(\eta_x \delta_E\right)^2\right]^{1/2}$$

$$\delta_E = \sqrt{\delta_o^2 + \delta_{ET}^2}$$

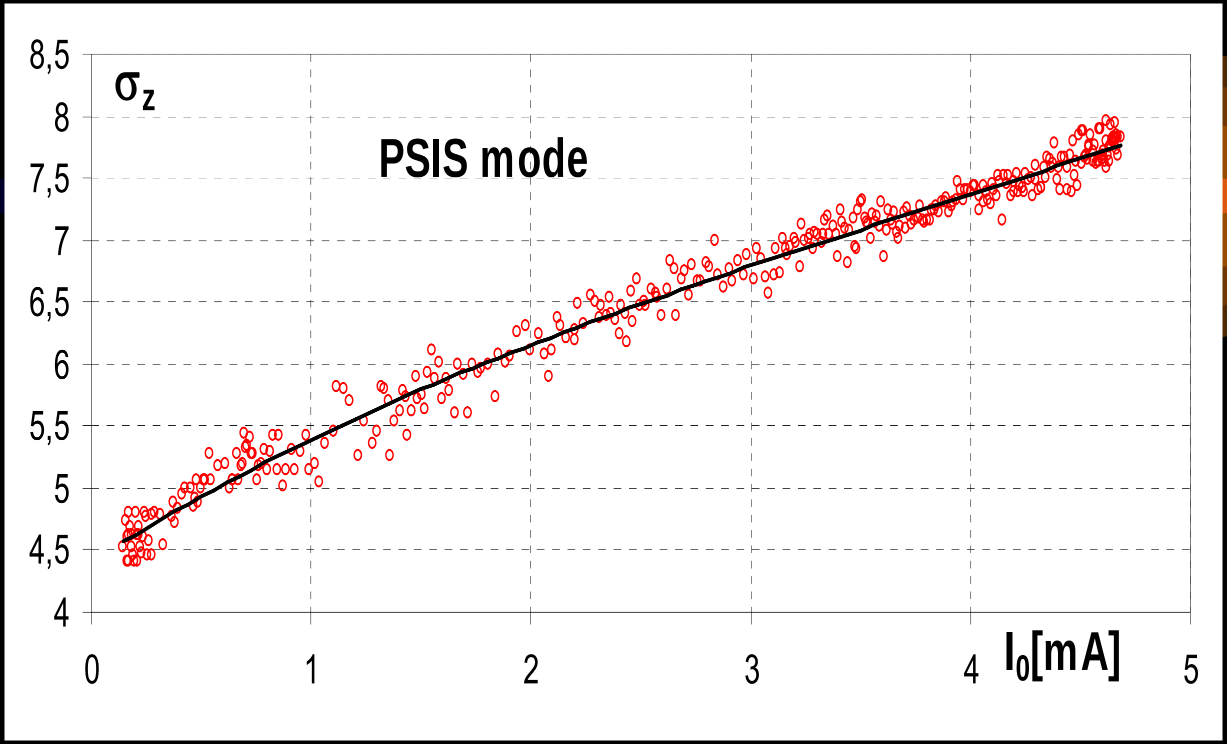
$$\delta_{ET} \approx \frac{5.1 \cdot 10^{-4}}{E[Gev]} \left(\frac{I_0[mA] \cdot \nu_s}{K}\right)^{\frac{1}{6}} \qquad (1)$$

It was supposed that main reason, caused σx size and energy spread σE growing, was Touschek effect. The formula (1) was used for adjustment of the energy spread dependence with the beam current:

$$K = \sqrt{\frac{\varepsilon_y}{\varepsilon_x}}$$

$\varepsilon_y, \varepsilon_x$ - beam emittance

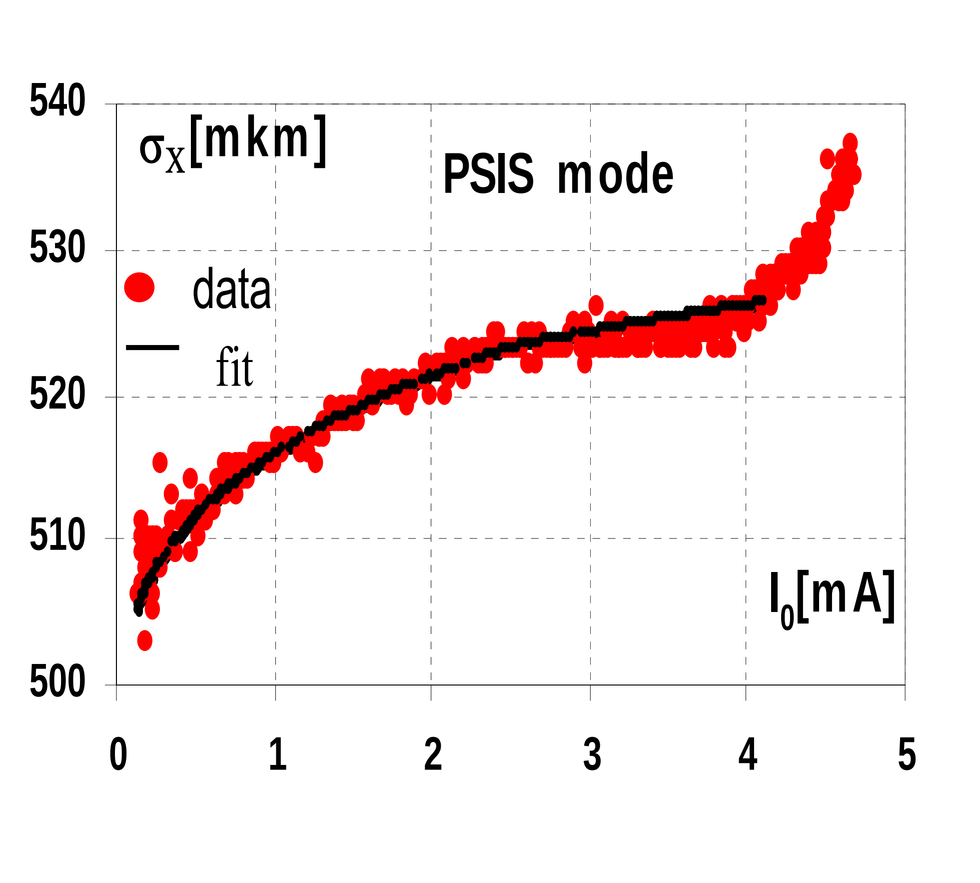
Method III. Longitudinal beam size



Dependence of the longitudinal beam size σ_z vs beam current I_0 at the PSIS mode. $\nu s = 0.0089$, $\delta_{E0} = 4.2 \cdot 10\text{-}4$.

Measurement of the longitudinal beam size σ_z enables us to derive the energy spread at $I_0 = 0$. Further beam lengthening is and caused with the ring longitudinal impedance $Z_{||}/n \approx 6$ Ohm that has an inductive type .

Method III. Radial beam size



•Radial beam size σ_x vs. beam current I_0.
•Dots-measured beam size theoretical
• Line - theoretical curve calculated from the energy spread growth (caused by Touschek effect.)

At the current higher than I = 4 mA, the $\sigma_X(I)$ dependence has a threshold behavior and needs in additional studying. This threshold might be caused by microwave instability with the threshold depending on the accelerating voltage V_{RF}.
The methods (*I*), (*II*) were applied with reduced value of V_{rf}= 150 ÷ 250 kV for to decrease a synchrotron frequency ν_s that improved a resolution of the measurements described above. The collider runs of 2002-2006 years were performed at $V_{rf} \geq$ 400 kV, and instability threshold was significantly higher then the currents of the operated beams that were restricted by the beam-beam effects.

DISCUSSION

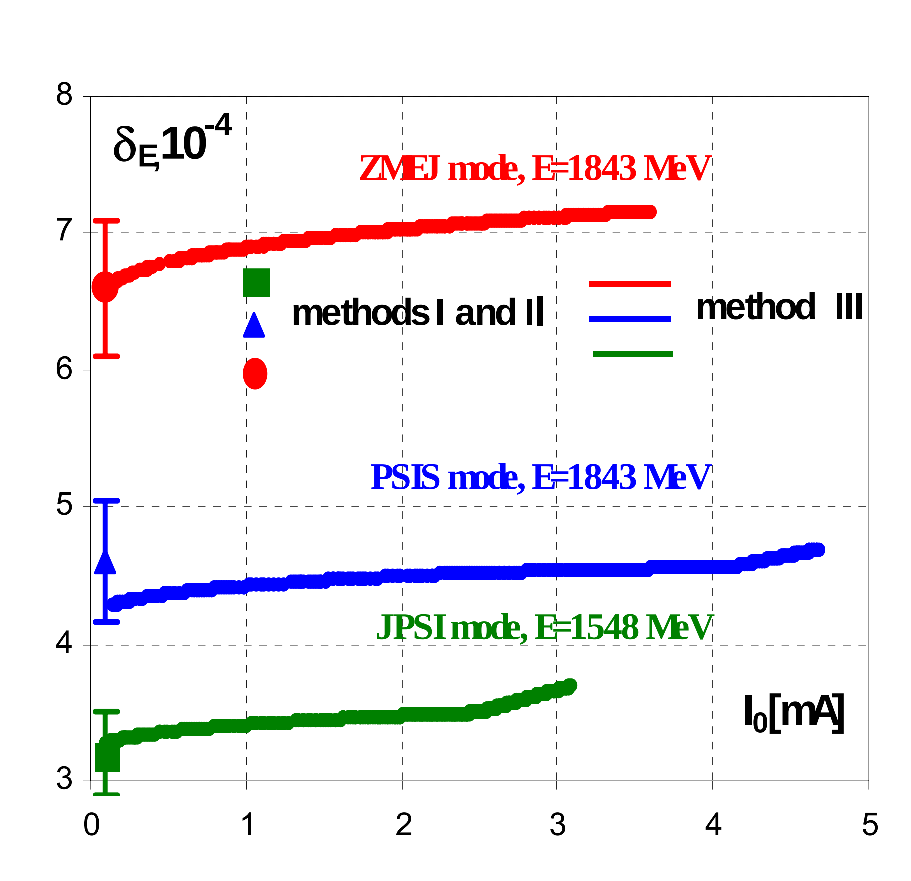
•One can note that measurements by all three methods are in a good agreement with data of the J/y resonance scan at the *E* = 1548 ± 10 MeV energy performed in 2002, with reduced current WG = 652 A of the gradient wiggler

•All these methods are also in good agreements with the y' meson scan at the *E* = 1843 ± 10 MeV energy performed in 2005-2006.

•One can see the distinctions of resonance width obtained with the equal wiggler current. It is an evidence of need for radial orbit stability inside wiggler and control of dispersion function into it

Data of ψ' and J/ψ resonance scanning

	dW	$\sigma_E \cdot 10^{-4}$	WG [A]	I_0 [mA]	Year
ψ' width	1.33	5.15	1135	2.0	2002
	1.24	4.77	1135	2.0	2004
	1.15	4.42	1055	2.5	2005
	1.09	4.19	1055	2.5	2006
J/ ψ width :	0.858	3.93	952	1.7	2002
	0.664	3.04	652	1	2002

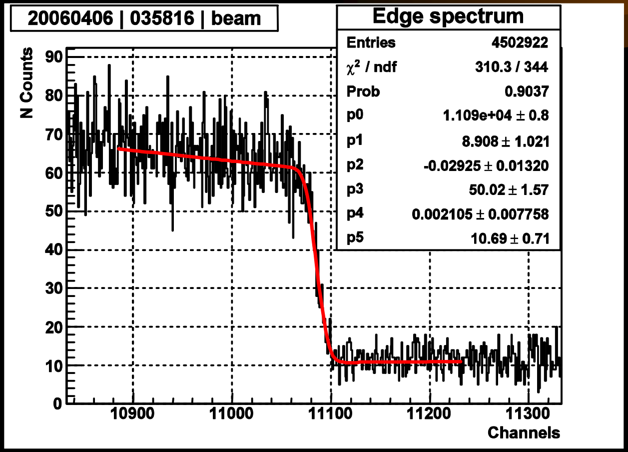


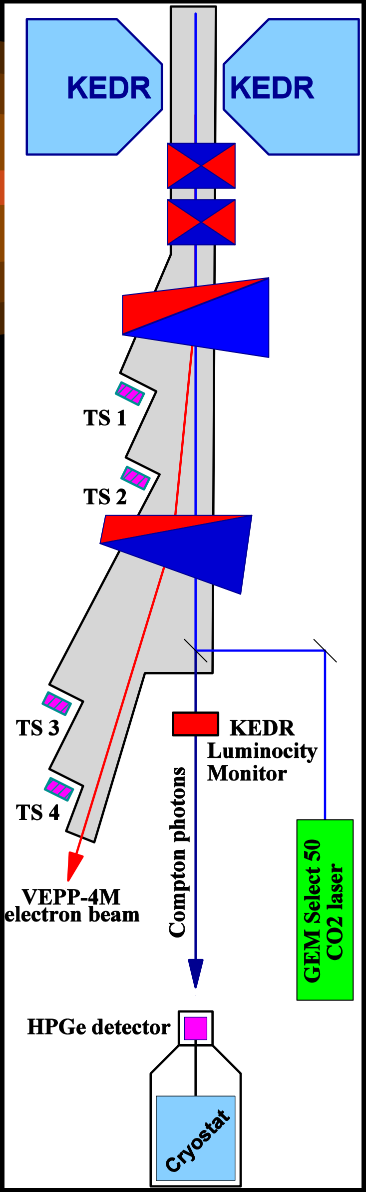
SUMMARY

- Note that the methods I and II are perturbing in respect to the machine parameters, because to measure the energy spread with reasonable accuracy, we have to change much the chromaticity and therefore to disturb the magnet lattice.
- To summarize, we should recognize that reliable measurement of the beam energy spread is a nontrivial problem. It requires careful use of several diagnostic techniques to have a possibility of cross validation of the measurement results.

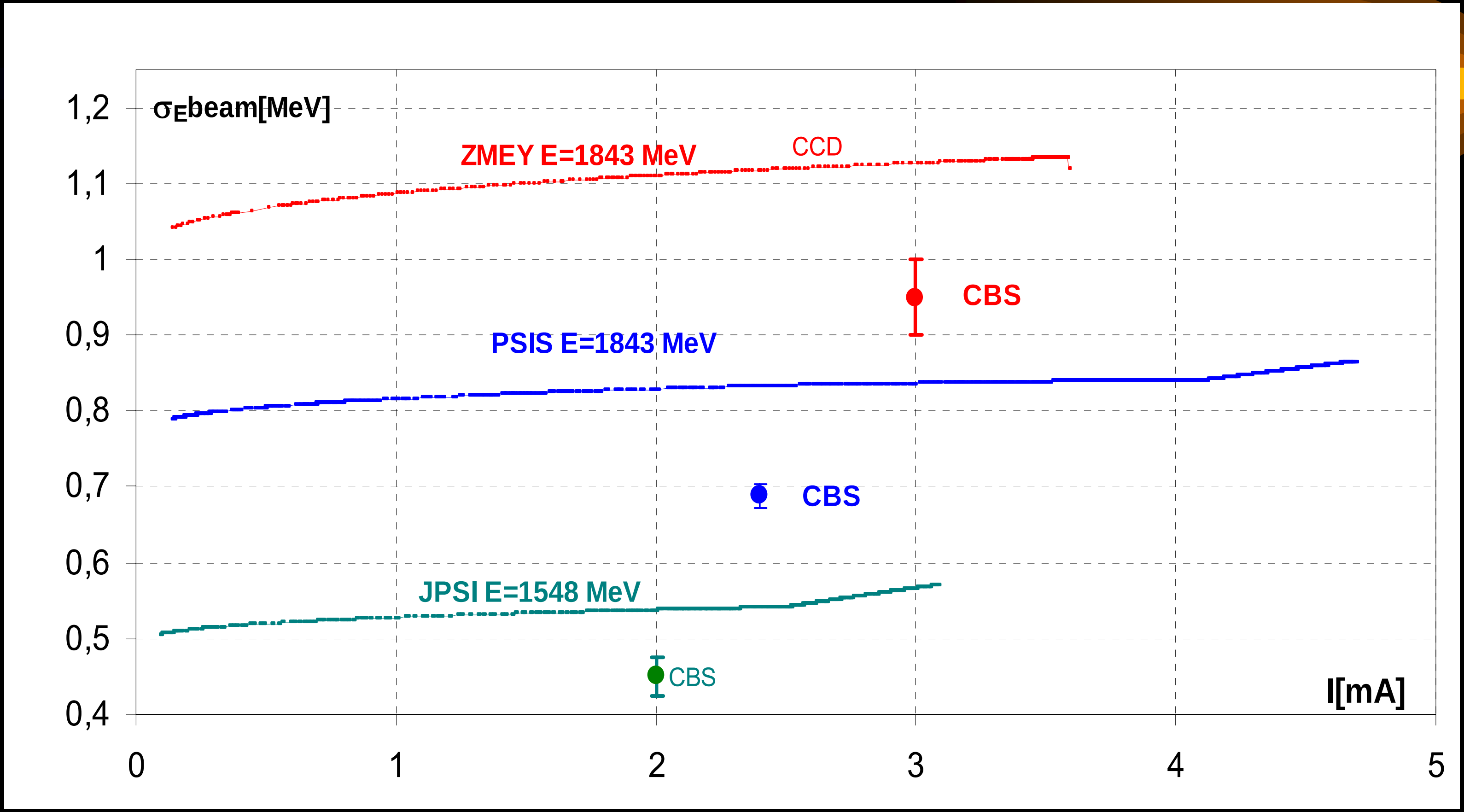
Compton Back Scattering (IV)

- **VEPP-4M collider has a system of Compton Back Scattering for permanent measurement of average beam energy and energy spread. Spectrum of the scattered quanta has a shape of a flat "table" with a steep edge from the side of high energy.**
- **Width of the edge is about 6-8 keV that determines by the beam energy spread.**
- **VEPP-4M collider has a system of Compton Back Scattering for permanent measurement of average beam energy *E* and energy spread.** σ_E **.**
- **The energy resolution of the scattered quanta is about 1-2 keV that provides the precision about 80 keV for average energy *E* and energy spread** σ_E measurement **during each 10 minutes**
- Should be mentioned, that reducing of δ_E with CBS data took place only for 2006 year run that needs in additional investigation. The data of (*III*) and CBS are in a good agreement for 2004 – 2005 year runs.

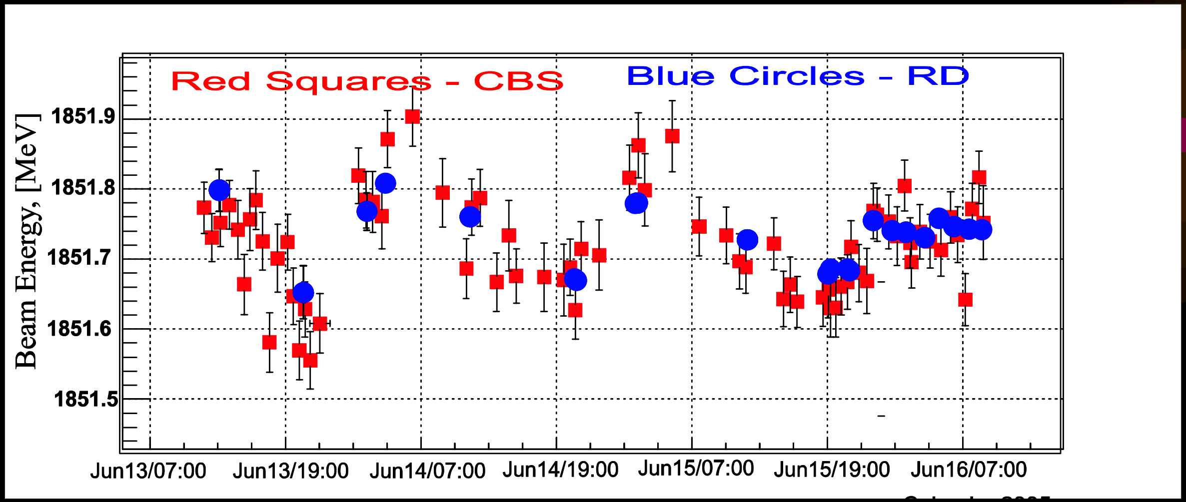




Compton Back Scattering (IV)

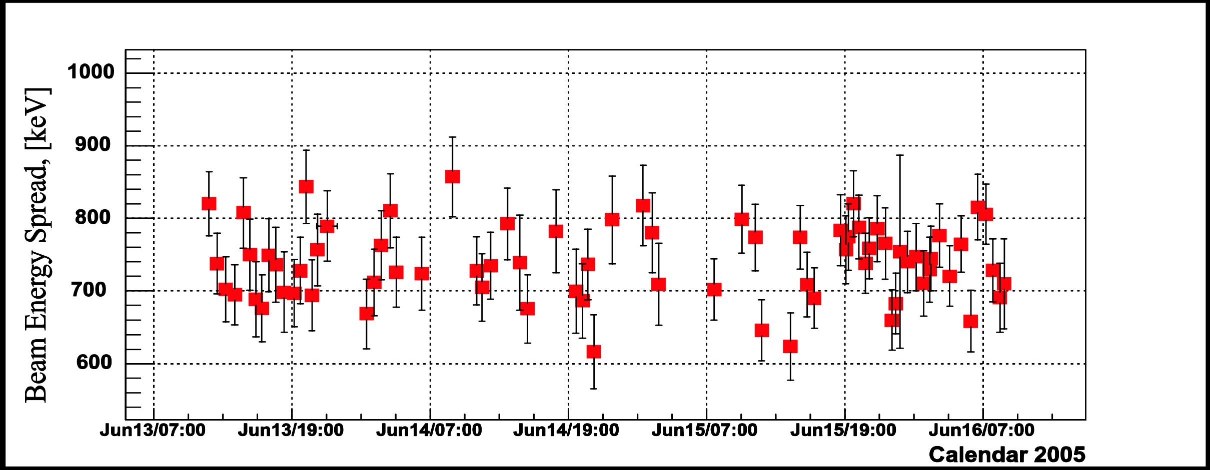


Compton Back Scattering (IV) *Измерение энергии ВЭПП-4М двумя методами*



Измерение энергии ВЭПП-4М двумя методами
13-15 июня в процессе набора интеграла светимости,
16 июля –заход на стабильность энергии

Точность определения энергии:
CBS 3*10-5 RD 10-6



Измерение энергетического разброса в пучке CBS методом
(точность ~10%.)