Two - photon exchange and elastic scattering of electrons/positrons on the proton.

D.M. Nikolenko

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XII WORKSHOP ON HIGH ENERGY SPIN PHYSICS

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Rosenbluth separation of the form factors

Differential cross section of the elastic scattering in one-photon approximation can be written as:

$$\frac{d\sigma}{d\Omega}(E,\theta)=\sigma_M\left[\frac{G_E^2+\tau G_M^2}{1+\tau}+2\tau G_M^2\tan^2\left(\frac{\theta}{2}\right)\right],$$

σ_M - Mott cross section, θ - electron scattering angle, $\tau=\frac{Q^2}{4M^2}$,

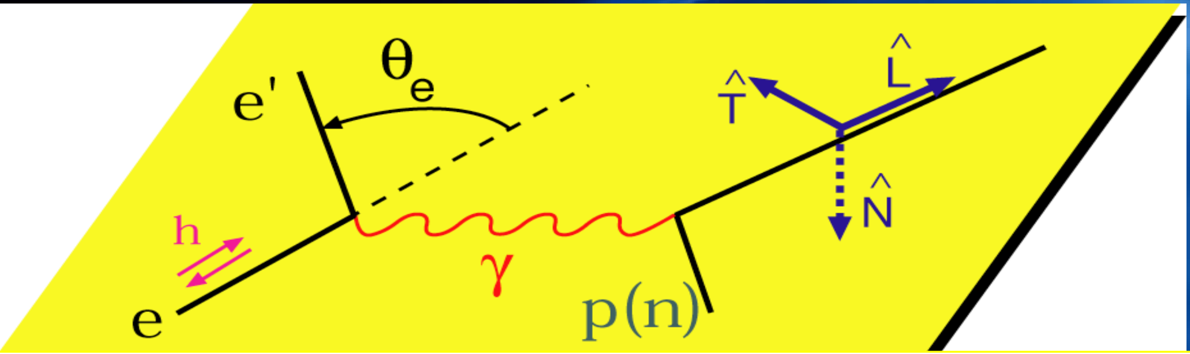
One can re-write the above formula as:

$$\frac{d\sigma}{d\Omega}=\frac{\tau\sigma_M}{\varepsilon(1+\tau)}\left[G_M^2+\frac{\varepsilon}{\tau}G_E^2\right]$$

- longitudinal virtual photon polarization $\varepsilon=\frac{1}{1+2(1+\tau)\tan^2(\theta/2)}$

G_E and G_M can be defined by measuring cross sections at different initial electron energies and scattering angles while keeping Q the same.

Form factors measurements through polarization transfer experiments



A.I.Akhiezer et al., JETP v.33(1957)765, in Russian

In the mid-nineties, it became possible to use polarization transfer experiments to study nucleon electromagnetic form factors.
In this case the ratio of proton form factors can be extracted by:

$$\frac{G_E}{G_M} = -\frac{P_t}{P_l}\frac{(E+E')}{2M}\tan\frac{\theta}{2},$$

E and E' - electron energy before and after scattering, P_t and P_l - transverse and longitudinal polarization of recoil protons from elastic scattering of longitudinally polarized electrons.

The results of polarization transfer experiments were unexpected, indicating the ratio of form factors depends strongly on Q^2.

Data and possible explanations for different results for values G_E/G_M

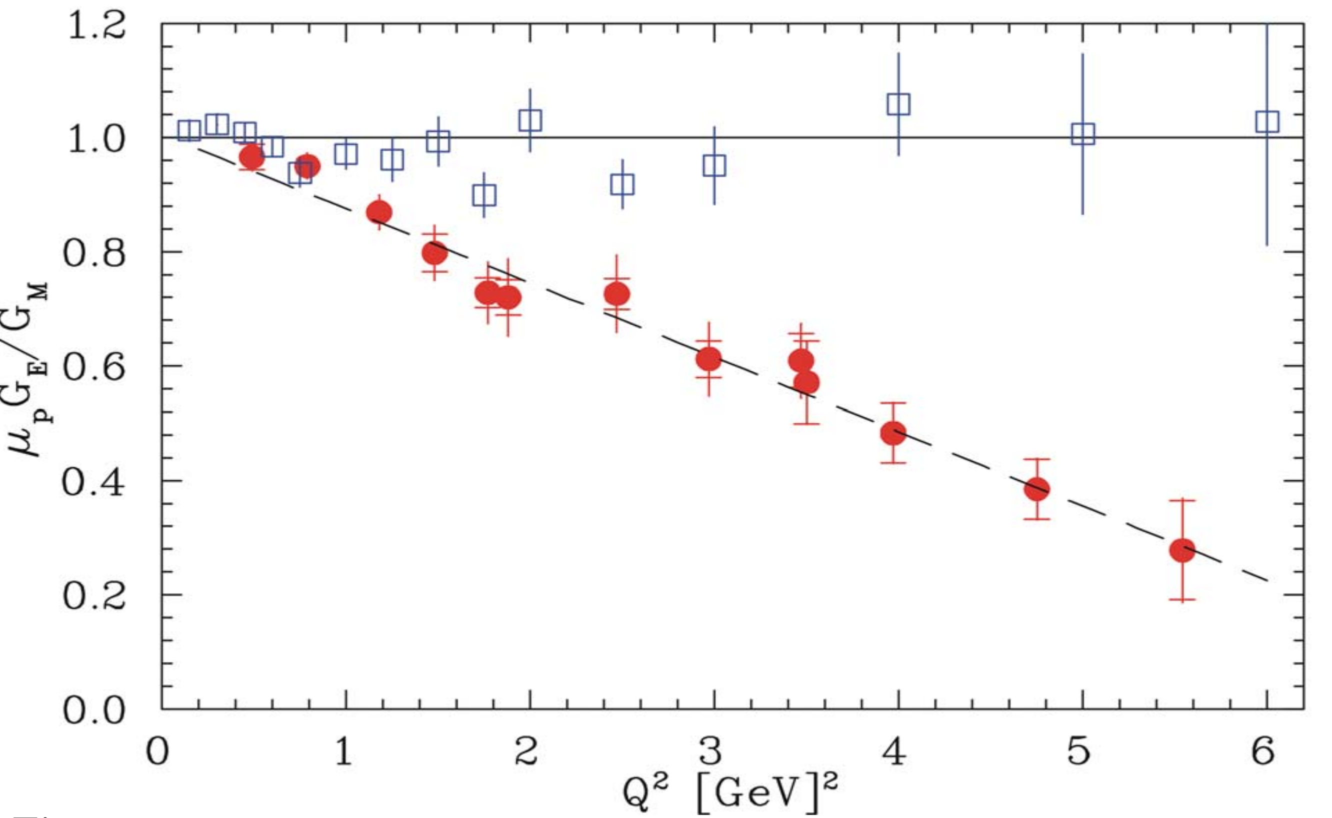


Figure: comparison of form factors ratio, obtained by Rosenbluth technique (hollow squares) with data of polarized measurements (full circles).

J.Arrington et al., Phys. Rev. C68 (2003); arXiv:nucl-ex/0305009

At present there are two physical reasons why these two methods would give different results:

- **radiative corrections;**
- **two photons exchange contributions.**

Yu.M.Bystritskiy et al., arXiv:hep-ph/0603132:"the results of numerical estimations show that the present calculation of radiative corrections can bring into agreement the conflicting experimental results on proton form factors and that the two photon contribution is very small".

The another group of theorists said that it's not a correct to use the one photon approximation in Rosenbluth technique and contribution of two photon exchange is considerable. (J.Arrington, Phys. Rev. C69(2004)032201;P.G.Blundend et al., Phys.Rev.Lett. 91(2003)142304;Y.Chen, arXiv:hep-ph/0403058)

Two photon exchange contribution in elastic e-p scattering

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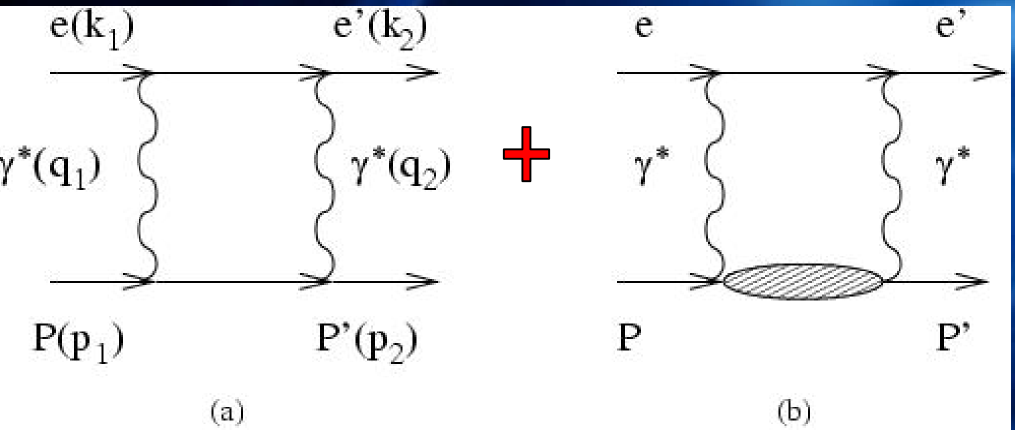
H. de Vries

Proposal for a comparison of electron-proton and positron-proton scattering at VEPP-3.

E-print: nucl-ex/0408020



Complications arising in the calculation of the two photon exchange corrections are connected with difficulties in accounting for proton excitations in the intermediate state.

The Born amplitude is proportional to the lepton charge, e, while the two photon exchange (TPE) amplitude is proportional to e^2. The Born cross section is proportional to e^2, while the interference term to the cross section goes like e^3. Hence the interference term, which is the dominant part of the TPE contribution (since the TPE amplitude is small compared to the Born amplitude) changes sign with respect to the Born cross section and can therefore be Determined by comparing electron-proton and positron-proton scattering.

Existed data on e^{+-} - p elastic scattering

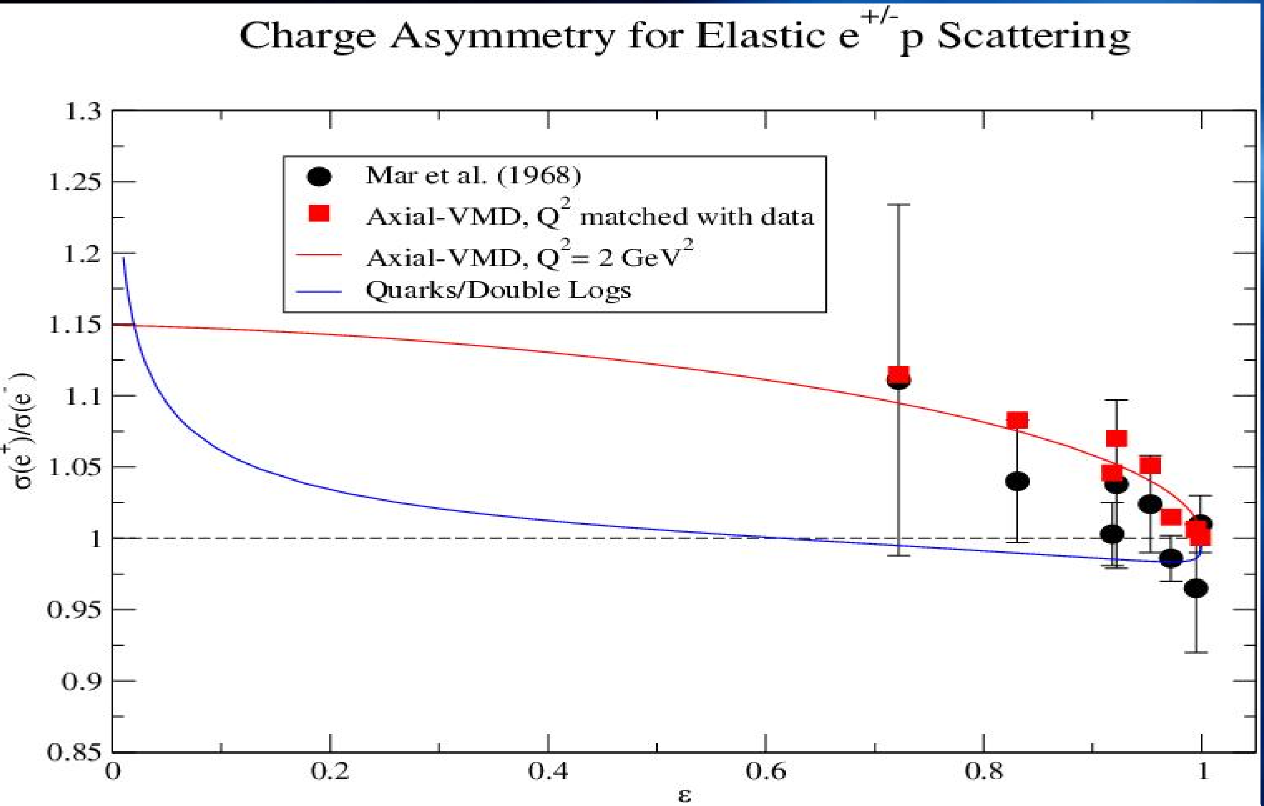


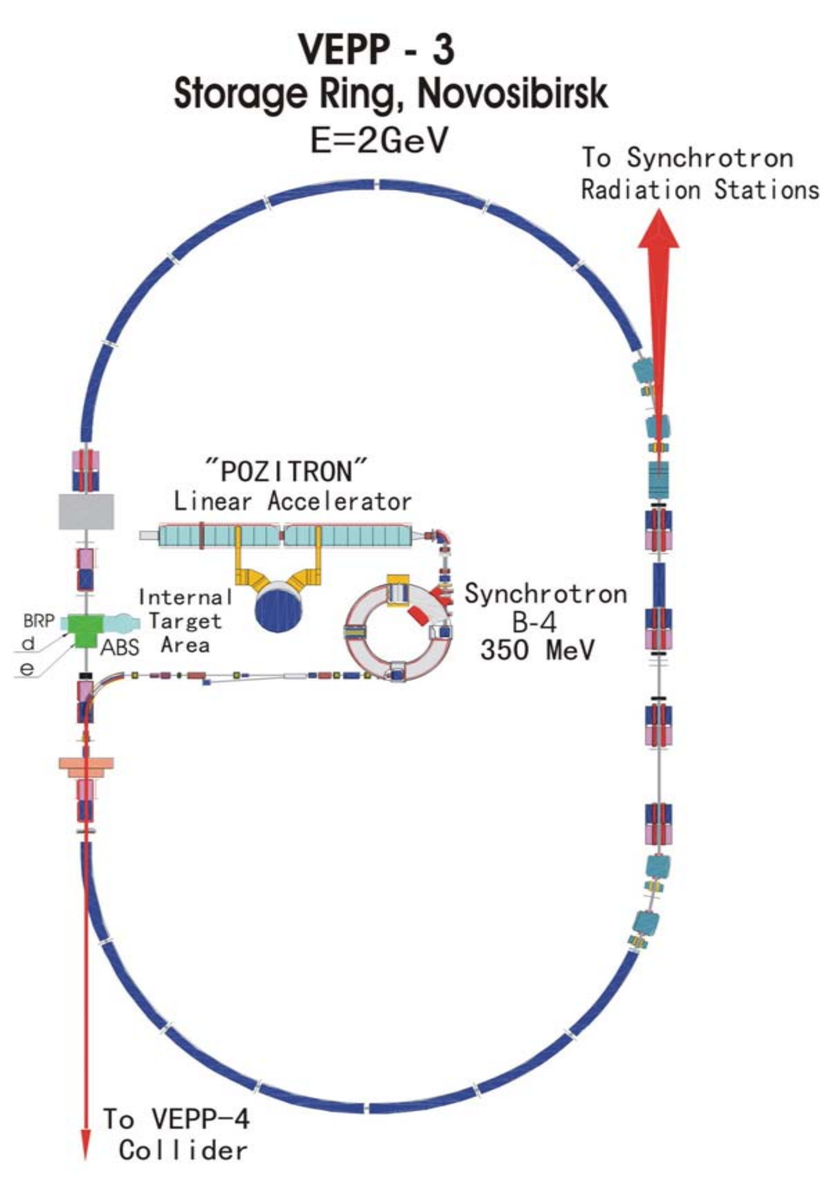
Figure: theoretical predictions (square points and curves) and experimental data (circles) for the ratio $R=\sigma(e^{+})/\sigma(e^{-})$ as a function of ε.

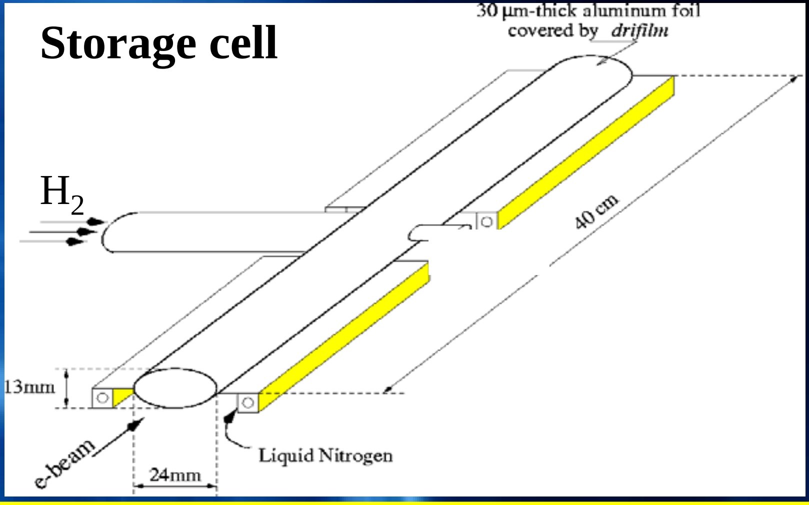
K.Joo et al., Letter of Intent to PAC 25, TJNAF, 2004

Attempts to measure the TPE contribution were made in the 1960s, but either the accuracy of the measurements was insufficient: $\delta R/R \sim 5\%$ were $R=\sigma(e^{+})/\sigma(e^{-})$,or scattering angles were too small and therefore ε - where most theories predict R=1 (see Fig.)

We propose to perform a measurement of R at the VEPP-3 storage ring at an energy of electron/positron beams of 1.6 GeV and at electron/positron scattering angles approximately 25^0, 65^0 (corresponding to) ε = 0.90, 0.45 and Q^2 = 0.3, 1.5 GeV^2/c^2).

VEPP-3 storage ring and internal target



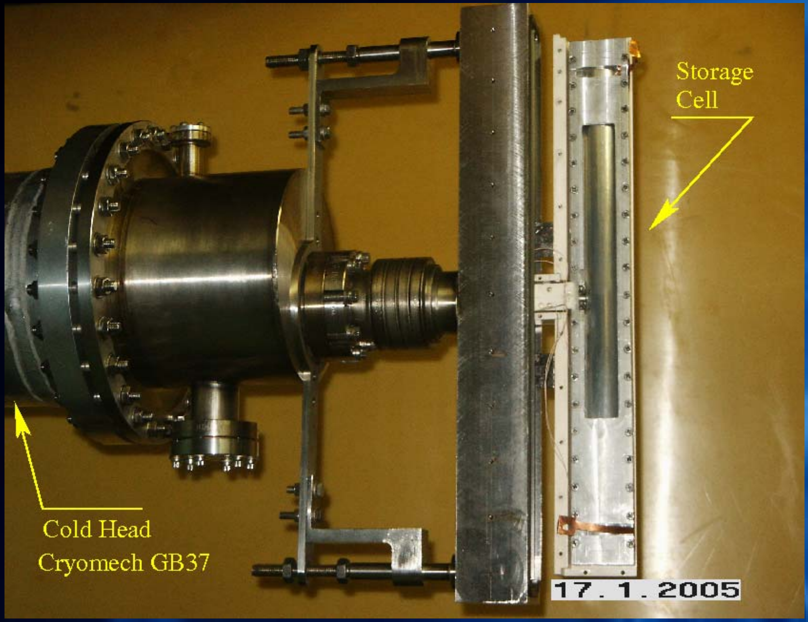


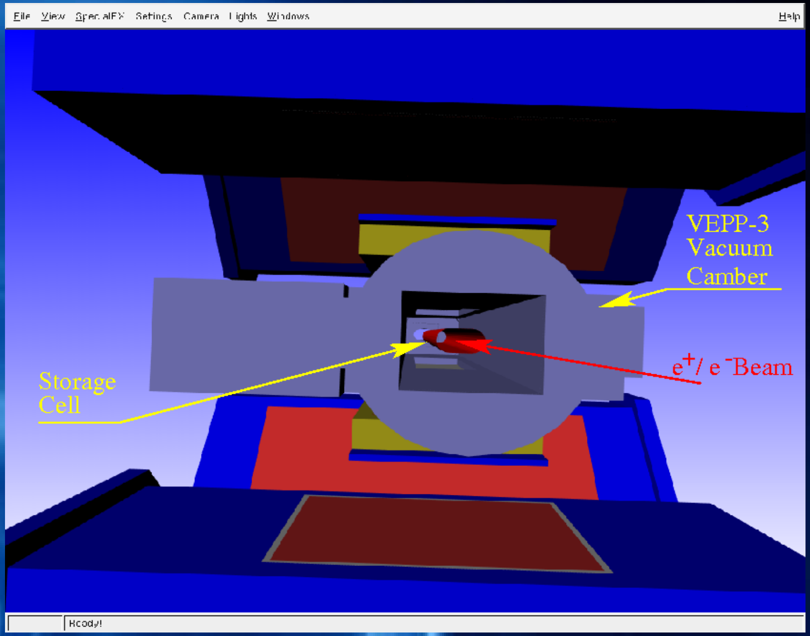
In previous experiments at VEPP-3 a polarized deuterium target was used. It consists of the ABS and storage cell was used to increase the target thickness.

In the new unpolarized H_2 target we are going to use a similar storage cell: having elliptical cross section 13x24 mm, length 400 mm, cooled by liquid nitrogen.

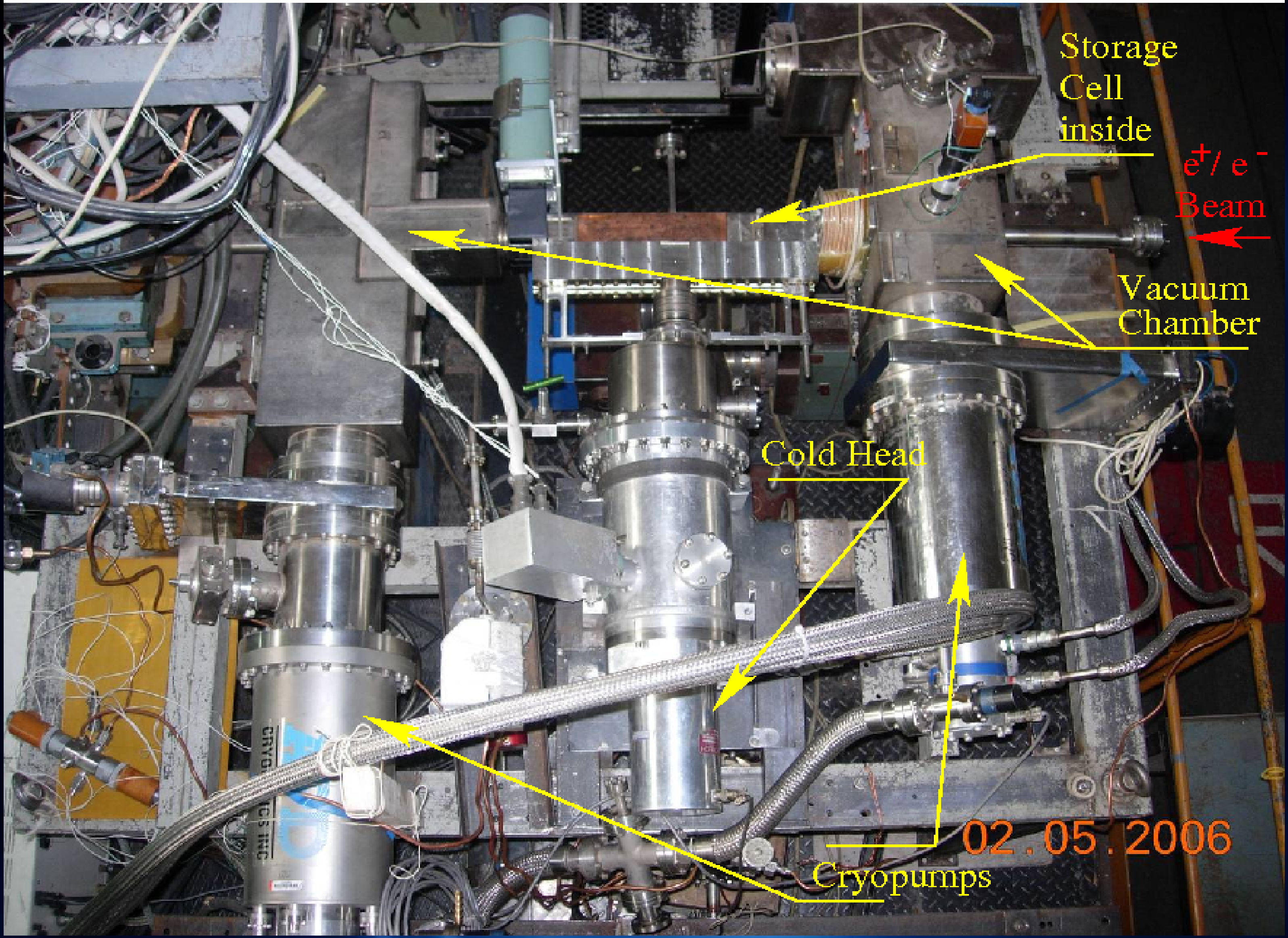
Hydrogen flux directed to the cell is going to be 10^{18} at/sec, providing a target thickness of about 10^{15} at/cm^2.

The luminosity (defined by positrons) will be: $L=I*t=0.009*6*10^{18}*10^{15}=5*10^{31}$, t – target thickness, I – average positron current.

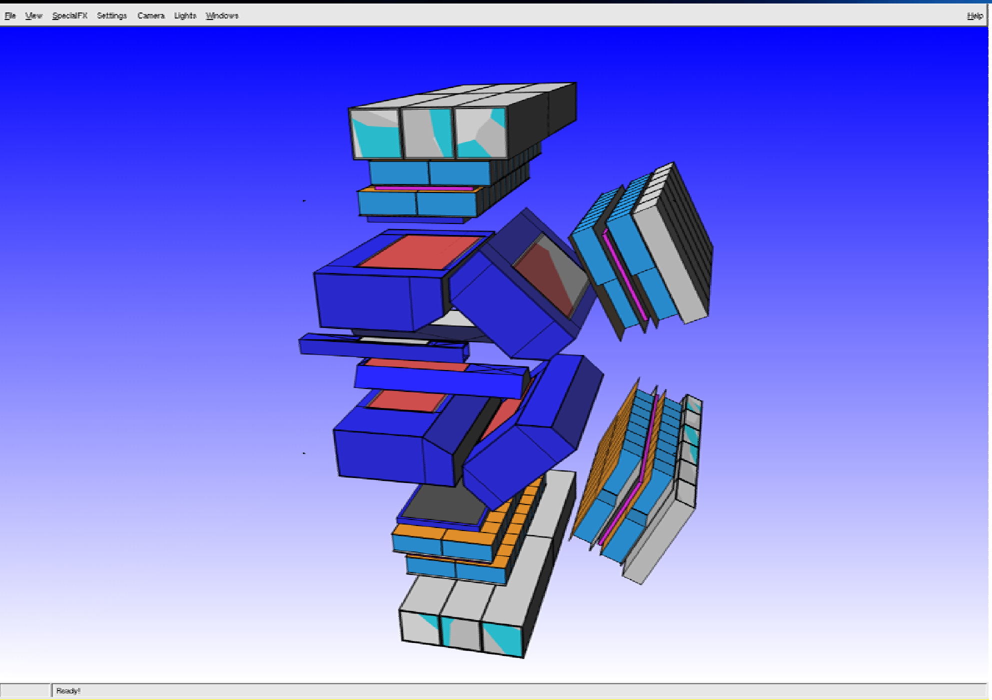

Storage
Cell
Cold Head
Cryomech GB37
17.1.2005

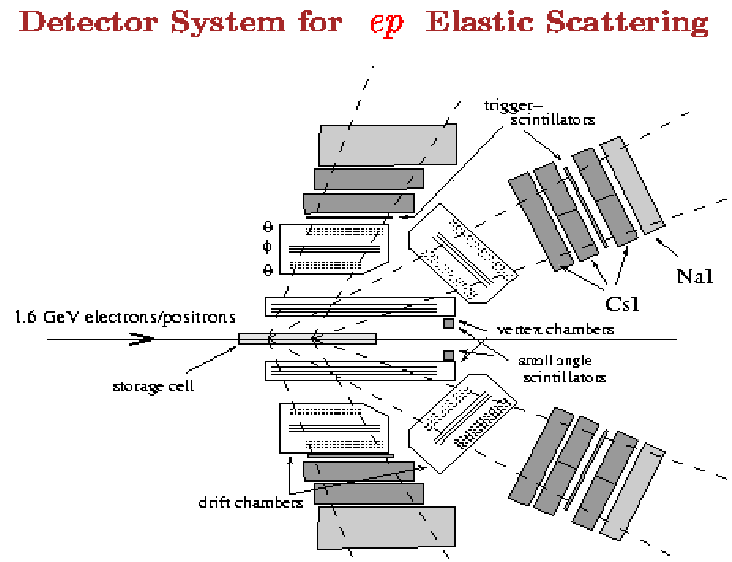

VEPP-3
Vacuum
Camber
e^+/ e^-Beam
Storage
Cell

VEPP-3 Straight Section with Internal Target



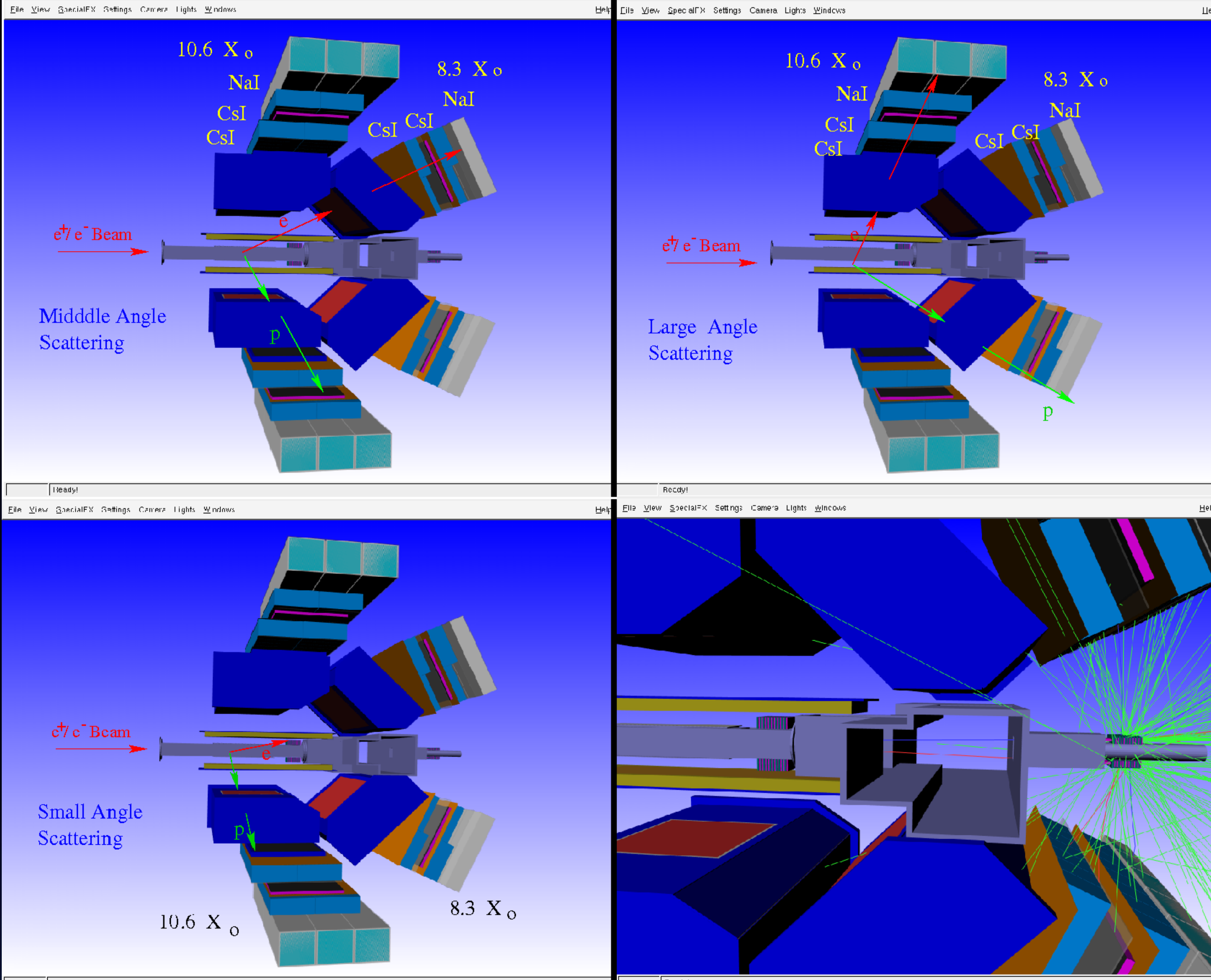
Side view of the detector for experiment



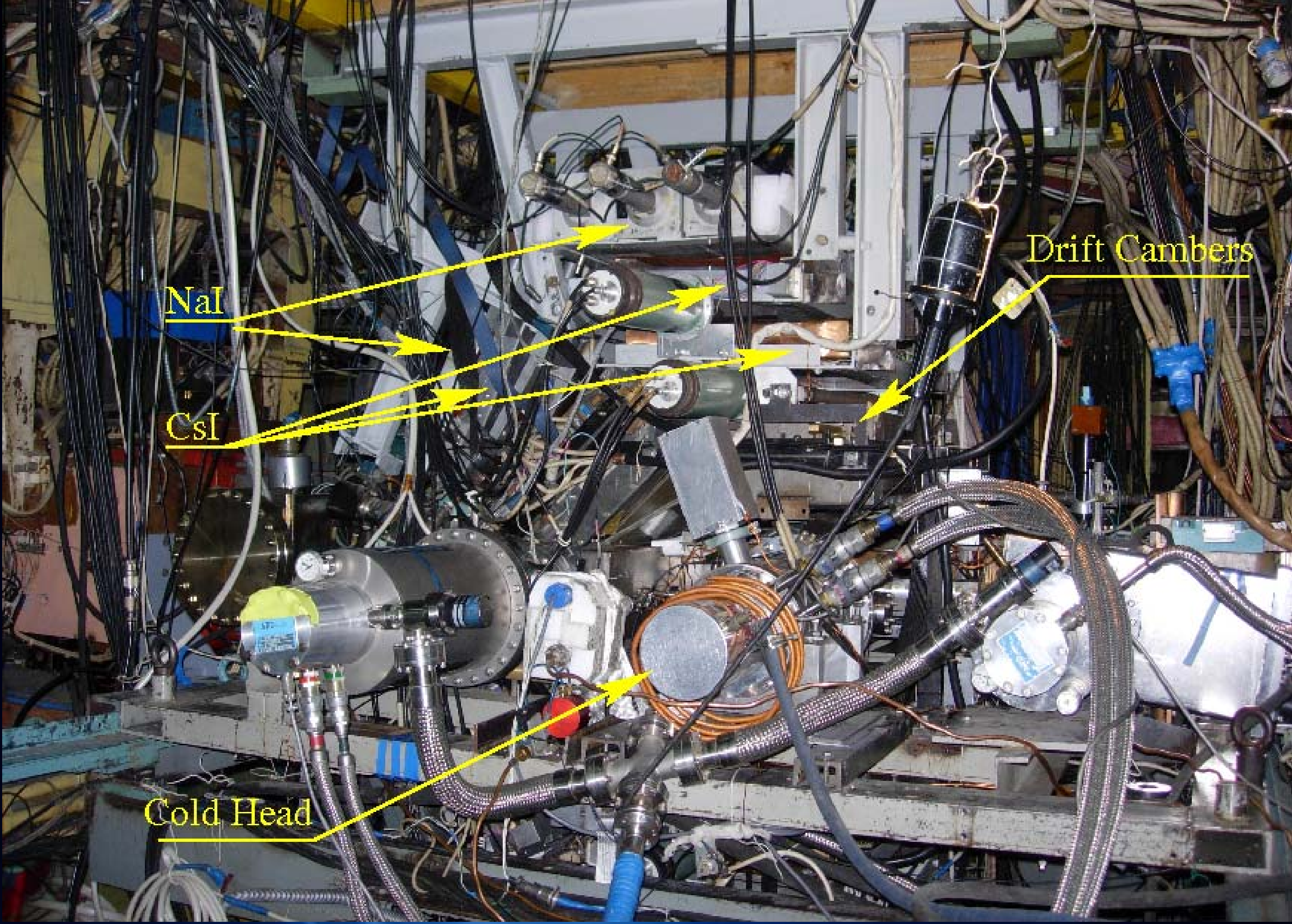


The detector for the measurement of (e^+p) and (e^-p) elastic scattering will be build on the basis of the detector used in the previous experiment. Scattered electron and recoil proton will be detected in coincidence, which allows to use kinematical correlations between their emission angles and energies. This is important for separation of the events from the process Under study from those of various background processes.

The detector consists of two identical systems placed symmetrically in median plan of the storage ring. Azimuthal angle acceptance of each system is 60^0. Regarding the polar angles – electron/positron scattered at angles close to 12^0, 25^0, 65^0 will be detected. Application of two detector systems not only increases the detecting solid angle but also allows to suppress systematic errors related to instability of the electron/positron beam position



Moller/Bhabha Monitor


NaI
CsI
Drift Cambers
Cold Head

ommissioning run on the VEPP-3

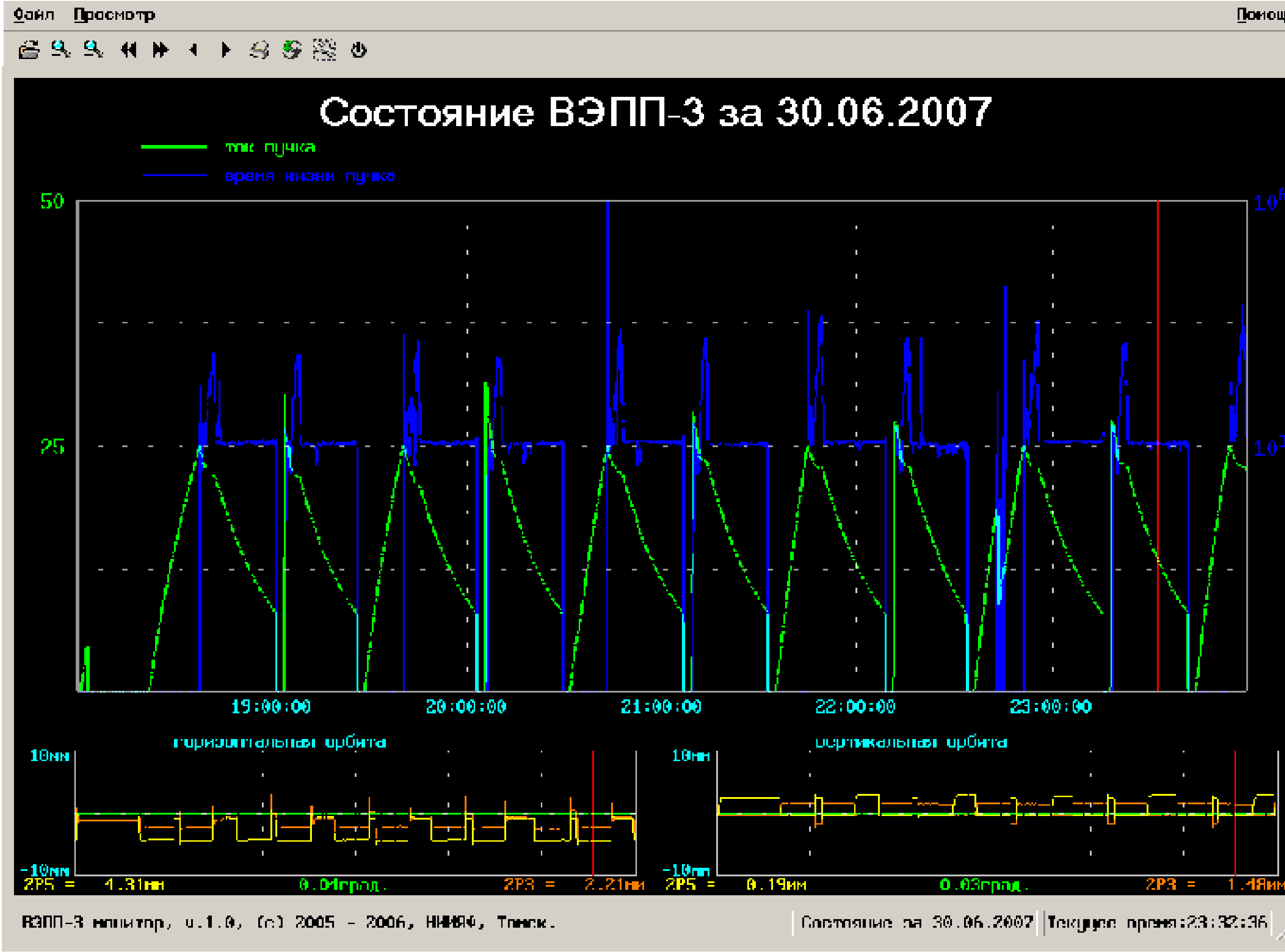
16 April – 2 July 2007

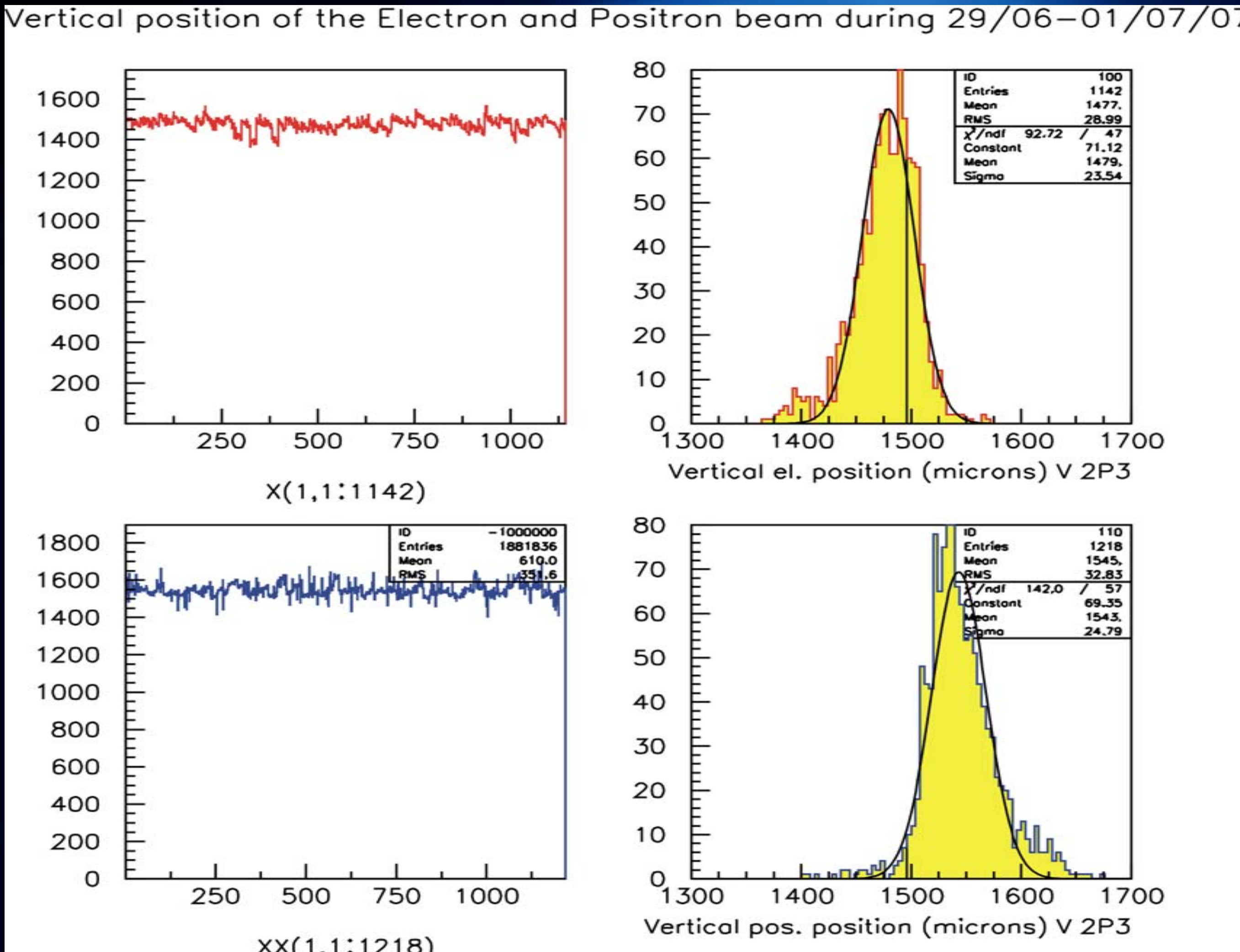
ion of the internal target and the particles de-
n the for VEPP-3, the change of the magnetic
VEPP-3 (duration – about 1 month).

ablishing VEPP-3 working regimes with new
c optics and internal target (duration – about
h).

ablishing of the working regimes of particles
, the background suppressing (the change in
er and installation of cleaning magnet).

ing (totally – 6 kC).




Vertical position of the Electron and Positron beam during 29/06–01/07/07
X(1,1:1142)
ID 100
Entries 1142
Mean 1477.
RMS 28.99
χ^2/ndf 92.72 / 47
Constant 71.12
Mean 1479.
Sigma 23.54
Vertical el. position (microns) V 2P3
XX(1,1:1218)
ID −1000000
Entries 1881836
Mean 610.0
RMS 351.6
ID 110
Entries 1218
Mean 1545.
RMS 32.83
χ^2/ndf 142.0 / 57
Constant 69.35
Mean 1543.
Sigma 24.79
Vertical pos. position (microns) V 2P3

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stract

ccurate knowledge of the colliding beam energies is tial for the current experiments with the KEDR [1] ctor at the VEPP-4M collider. Now the experimental ity is focused on the new precise measurement of the ton mass by studying the behavior of the τ produc- cross-section near the reaction threshold. To achieve desired quality of the experiment, an on-line beam en- monitoring by the Compton backscattering of laser t was performed. This approach is found to be a very l supplement to rare energy calibration by the reso- depolarization technique, saving the beam time for lu- sity runs. The method itself does not require electron n polarization and additionally allows one to measure lectron beam energy spread. The achieved accuracy e method in the beam energy range ε=1.7–1.9 GeV is ≈ 60 keV.

INTRODUCTION

mpton scattering basics

he kinematics of Compton scattering is given by the -momenta conservation:

$$p + k_0 = p' + k, \qquad (1)$$

e $p = (\varepsilon, \vec{p})$ and $k_0 = (\omega_0, \vec{k_0})$ — four-momenta of lectron and photon before interaction, and $p' = (\varepsilon', \vec{p'})$ $(\omega, \vec{k})$ — after interaction. In relativistic case when $m \gg \omega_0$ the scattered photons form a narrow cone g the initial electron momenta. This particular case is ed inverse Compton scattering. For head-on collision maximal energy of back-scattered photon is given by:

$$\omega_{max} = \frac{\varepsilon^2}{(\varepsilon + m^2/4\omega_0)}. \qquad (2)$$

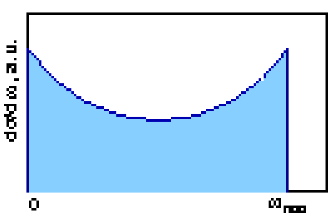

Figure 1: Energy spectrum of scattered photons.

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The photons with maximal energy ω_{max} form a sharp edge in the energy spectrum, illustrated by Figure 1. In that way one can obtain the absolute value of the electron energy ε by measuring ω_{max}:

$$\varepsilon = \frac{\omega_{max}}{2}\left(1 + \sqrt{1 + \frac{m^2}{\omega_0\omega_{max}}}\right) \qquad (3)$$

The measurement accuracy is limited by the knowledge of the electron rest mass and initial photon energy. In practice the electron beam energy measurement is based on inverse Compton scattering of laser radiation with well-known energy.

Resonant spin depolarization technique

At the VEPP-4M collider an extremely precise measurement of the beam energy is performed by resonant spin depolarization technique (RDP) [3]. This technique provides an accuracy about 5-7 keV for the instant average beam energy value, but requires a special regime of collider and consumes about 1.5 – 2 hours to obtain polarized beam from the VEPP-3 booster ring. Moreover, various resonance effects in spin dynamics lead to very small beam polarization lifetime at some particular energy regions, one of them is very close to the τ-lepton production threshold.

EXPERIMENTAL SETUP

The design parameters of the Compton beam energy monitor at the VEPP-4M collider were based on the experimental demand to control the beam energy with absolute accuracy $\Delta\varepsilon/\varepsilon = 3 \cdot 10^{-5}$ in the beam energy range 1.5 – 2.0 GeV. The following items were realized to fulfill these requirements:

- The carbon dioxide laser line 10P20 with wavelength λ = 10.591035 μm and photon energy ω_0 = 0.117065223 eV was chosen in order to have ω_{max} in the 4 – 7 MeV energy range.
- The High Purity Germanium (HPGe) detector with ultimate energy resolution was found to be the best calorimeter for measuring the energy spectrum of backscattered photons.
- Precise calibration of the HPGe detector absolute energy scale is possible due to well-known radioactive sources of γ-radiation in a few MeV energy range.

These approach was first realized experimentally at the BESSY-I and BESSY-II synchrotron radiation facilities [4].

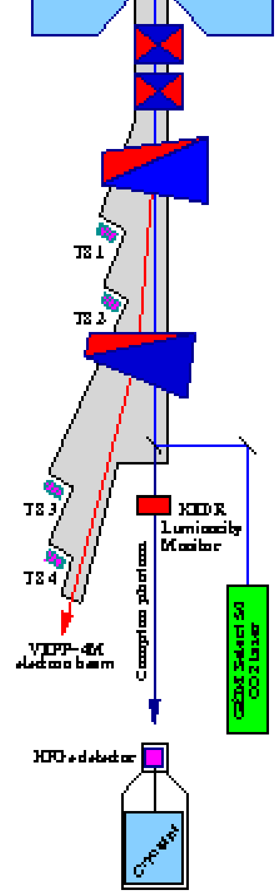


Figure 2: Experimental setup

The experiment layout is shown on Figure 2. Carbon dioxide laser OEM Select 50 by COHERENT Inc. is used as a source of photons. The average energy of laser photons could be treated as constant mentioned above at the level of $\Delta\omega_0/\omega_0 = 10^{-7}$. The 25 to 50 W CW power laser radiation goes inside the VEPP-4M vacuum chamber through the system of mirrors, zooming telescope and input window made from ZnSe crystals. It interacts with the electron beam in the long straight section of the VEPP-4M collider, and backscattered high-energy photons go back and hit the

Measurement procedure

During 2005-2006 VEPP-4M - KEDR experiment the Compton beam energy monitor was operating continuously. The calibration γ-sources (^{60}Co, ^{137}Cs, ^{22}Na, ^{241}Am) were placed around the HPGe detector giving the counting rate about 1 kHz. The average counting rate of backscattered Compton photons was about 10 kHz. The detector was set to gather the photon spectra with about 5 million counts. As a result, each spectrum provides an information about the detector energy scale, Compton spectrum edge position and width. Data acquisition time for one spectrum was 5 – 20 min. The typical spectrum example is shown on figure 3.

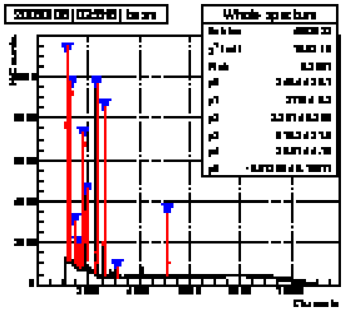


Figure 3: Experimental spectrum of backscattered photons with calibration lines.

The energy scale and resolution of the detector is controlled by calibration peak positions and widths, the last one is shown on figure 4.

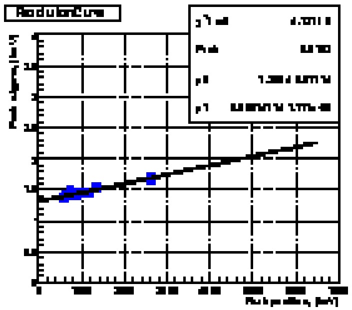
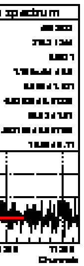


Figure 4: Detector energy resolution



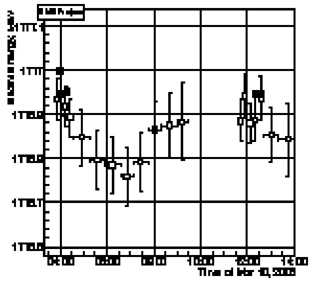


Figure 6: Beam energy vs time. Filled squares are obtained by RDP, empty squares by Compton energy monitor

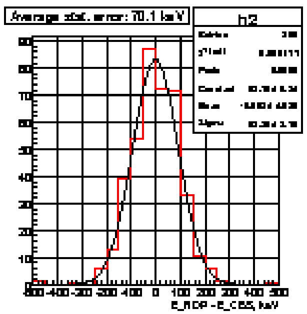


Figure 7: Accuracy check with RDP

CONCLUSION

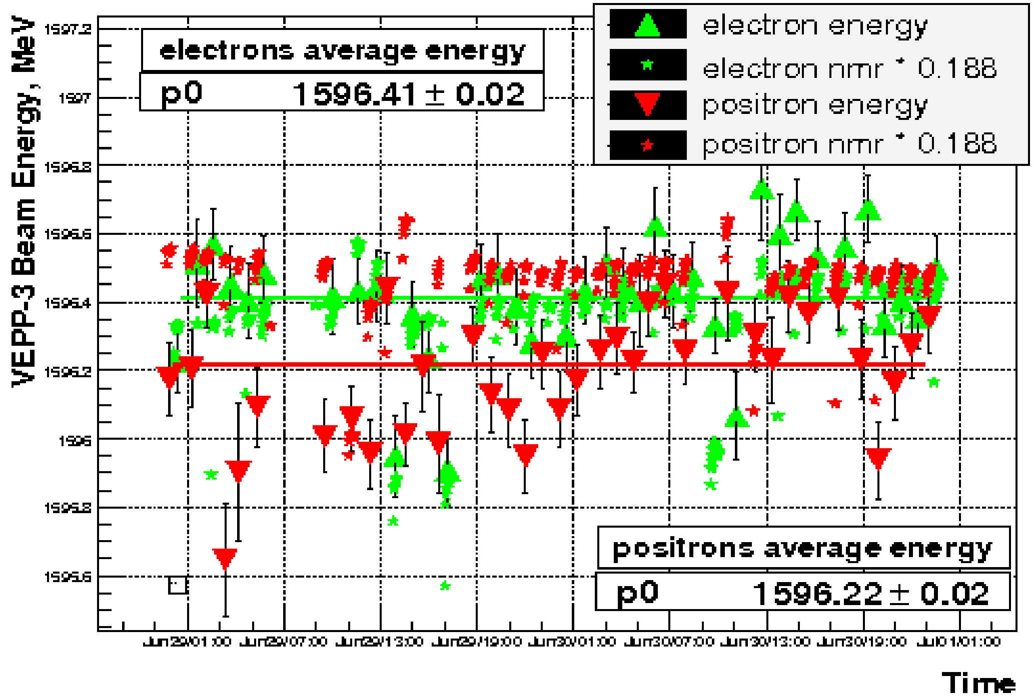
The VEPP-4M electron beam energy monitor, based on inverse Compton scattering of laser radiation, allows to measure the energy with 50 keV error per one measurement in the energy range $E = 1.7 - 1.9$ GeV. The overall accuracy of the method is $\Delta E \approx 60$ keV, or $\Delta E/E \approx 3 \cdot 10^{-5}$ for the mentioned energy range.

REFERENCES

[1] "Status of the KEDR detector". V.V. Anashin et al. Nucl.Instrum.Meth. A478: 420-425, 2002

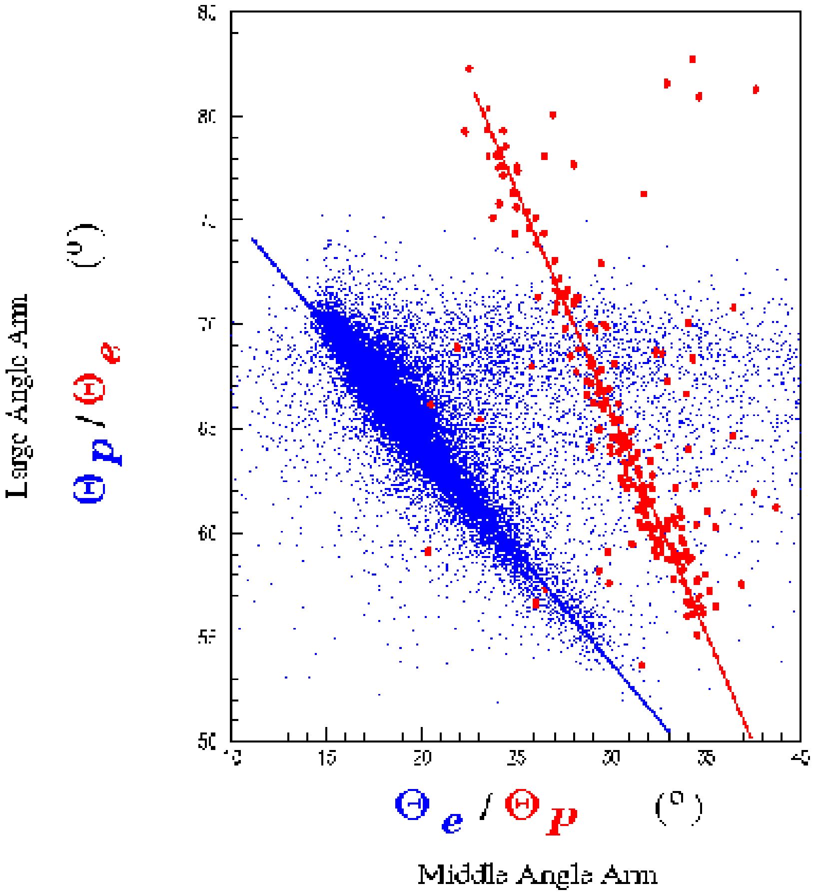
[2] "Measurement of the BESSY II electron beam energy by Compton-backscattering of laser photons". R. Klein et al. Nucl.Instrum.Meth. A486: 545-551, 2002

[3] "Absolute calibration of particle energy at VEPP-4M" V.E. Blinov et al. Nucl.Instrum.Meth. A494: 81-85, 2002



Selection of the elastic e–p scattering events

1. Correlation between polar angles
2. Correlation between azimuthal angles
3. Correlation between electron scattering angle and proton energy
4. Correlation between electron scattering angle and electron energy
5. ΔE–E analysis
6. Time–of–flight analysis for proton with low energy



$R = \underline{\sigma}(e^+) / \underline{\sigma}(e^-)$, $N_- = 2 N_+$

$\underline{\theta_e}$	$\underline{\varepsilon}$	$Q^2 (GeV/c)^2$	N_+ events	$\underline{\Delta} R/R$ %
10 –12	0.98	0.08–0.11	$8.7 \cdot 10^6$	----
19 – 27	0.91	0.26–0.47	$3.1 \cdot 10^6$	0.7
60 – 80	0.40	1.40–1.76	$1.5 \cdot 10^4$	1.00

Systematic errors

- **Different energy of e^+, e^- beams ($\underline{\Delta\sigma/\sigma}$ for three intervals 0.1, 0.2, 0.2 % / MeV)**
- **Different position of beams ($\underline{\Delta\sigma/\sigma}$ for three intervals 5.0, 1.4, 0.9 % / mm)**
- **Drift of the efficiency over the time of experiment (~ 1% during one time cycle)**
- **Drift of the target thickness during the experiment ($\Delta R / R \leq 0.1\%$)**
- **Difference of the radiation corrections for electrons and positrons**

The total systematical error for the largest Q^2 is expected to be $\Delta R / R \sim 0.3\%$

Expected results of the measurement

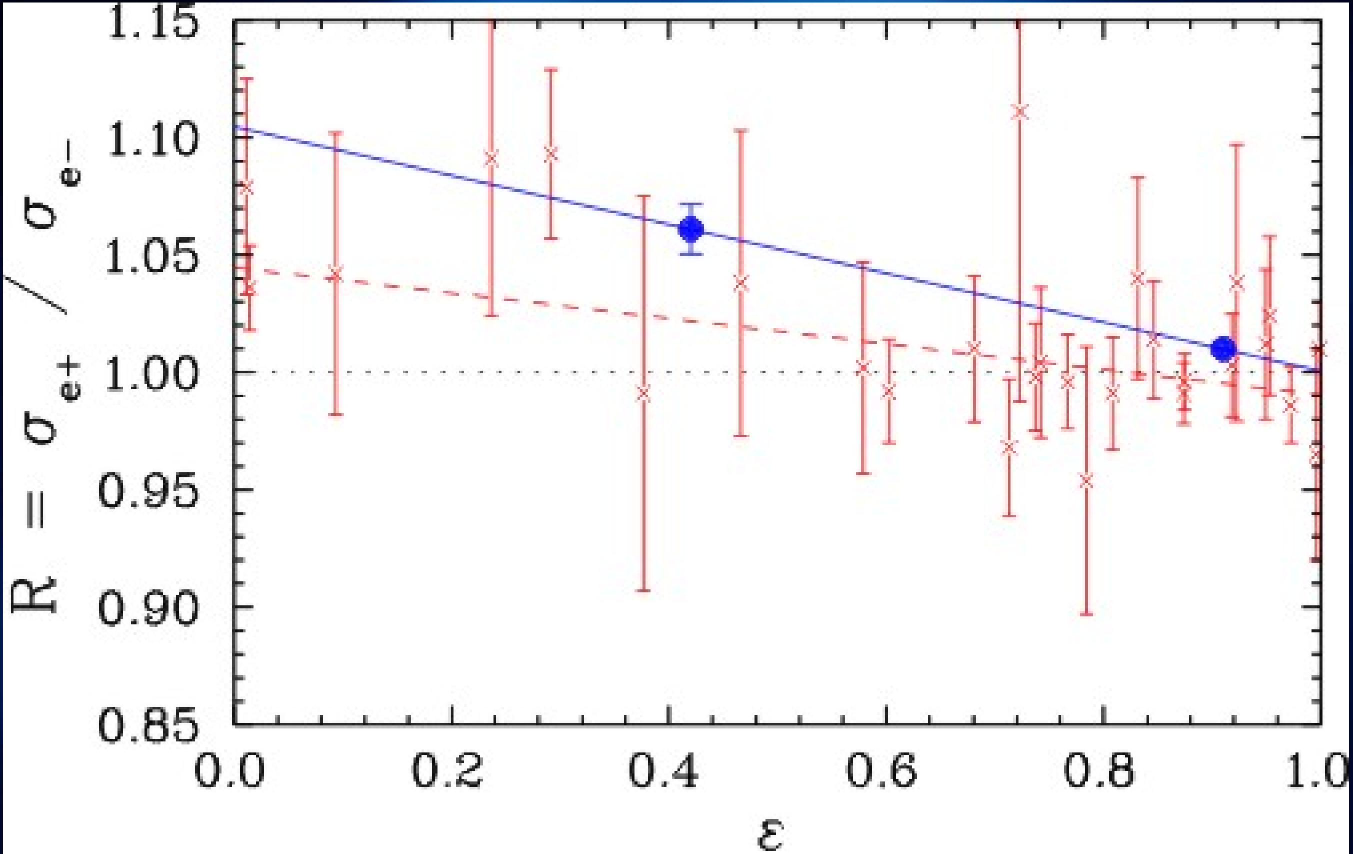


Figure: Projected uncertainty (combined statistical and systematic) for the proposed measurement (blue circles), compared to previous data (red “x” – J.Arington, Phys.Rev. C69, 2004). Note that the previous measurements have an average Q^2 value of approximately 0.5 GeV^2 for the data below ε = 0.5, and thus should have a smaller TPE contribution than the proposed measurement.

Summary

- Internal target and particles detector for the measurement of $R = \sigma(e^+)/\sigma(e^-)$ were developed, constructed and tested during the commissioning run on the VEPP-3.
- Storage ring, internal target and particle detector were adjusted for the good condition.
- Good stability of electron/positron beam position as well the precise measurement of electron/positron beam energy will give possibility to suppress systematic errors.
- The analisis of the received data is in progress.
- Some actions should be performed before the main run: to repair the cold head, two additional scrappers for the absolute beam position measurement should be installed, we need also more flexible cleaning magnet (electromagnet).