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

D. Nikolenko, BINP

35th International Conference on High Energy Physics

Paris, 22 July, 2010

COLLABORATION

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The proton electro-magnetic form factors (EMFF) are of fundamental importance for the understanding of the it's internal structure. Long time they were determined from the analysis of differential cross sections of the elastic (ep)-scattering. The EMFF can be identified with the Fourier transform of the nucleon charge and magnetization density distributions.

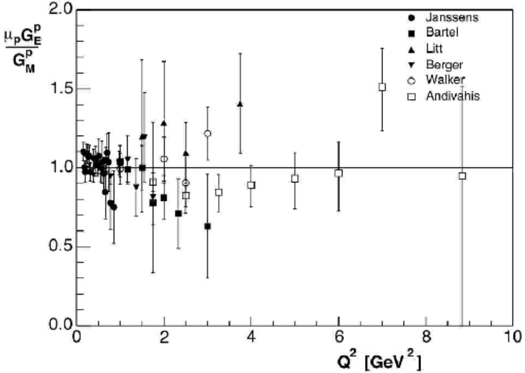
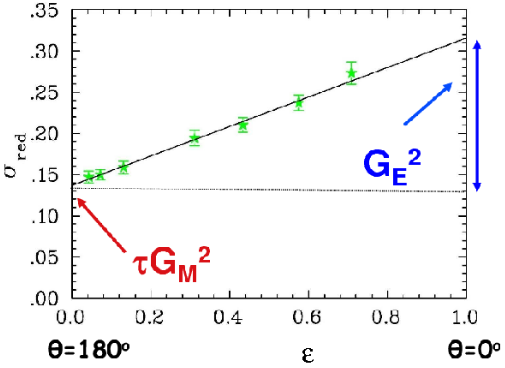


Figure from:

C. Hyde-Wright and . de Jager

Ann. Rev. Nucl. Sci. 2004 54.217

Separation of form factors by Rosenbluth method.
(one–photon approximation, assuming $P-$ and $T-$invariance formula)



$$\sigma_{red} = \tau G_M^2 + \varepsilon G_E^2 \qquad \varepsilon = \frac{1}{1 + 2(1+\tau)\tan^2\theta/2}$$

$$\tau = Q^2/4M^2$$

At the mid-90's in the study of the proton form factors was the development of methods of **polarization** experiments. It was found that the new and old methods give **conflicting** results

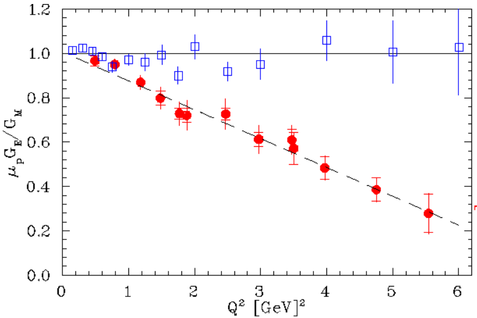


Figure from: J. Arrington, Phys. Rev. C68, 034325 (2003)

Rosenbluth measurements (hollow squares)

TJNAF measurements of recoil polarization (solid ciecles)

$$\sigma_R \equiv \frac{d\sigma}{d\Omega} \frac{\varepsilon(1+\tau)}{\sigma_{Mott}} = \tau \; G_{pM}^2(Q^2) + \varepsilon \, G_{pE}^2(Q^2)$$

Rosenbluth, 1950

$$ep \to e'p$$

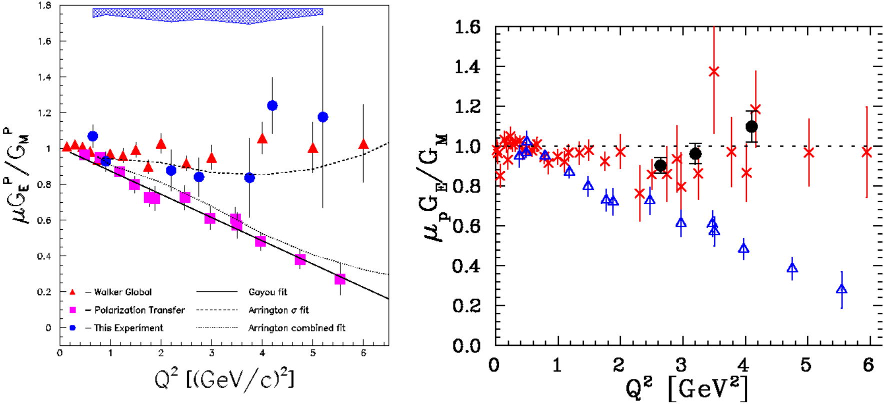
$$\frac{G_{pE}}{G_{pM}} = -\frac{P_t}{P_l} \frac{(E_e + E_{e'}) \tan(\theta_e/2)}{2M_p}$$

Akheizer and Rekalo, 1974

Arnold, Carlson and Gross, 1981

$$\vec{e}p \to e'\vec{p}$$

To verify, in TJNAF the new measurements by Rosenbluth method were performed, which confirmed the results of the old Rosenbluth measurements.



Left panel: figure from M.E. Christy *et al*, Phys. Rev. C 70, 015206 (2004).

Right panel: figure from I.A. Qattan *et al*, Phys. Rev. Lett. 94, 142301 (2005).

Recently the results of new TJNAF polarization measurements are published, which confirmed the existence of the problem

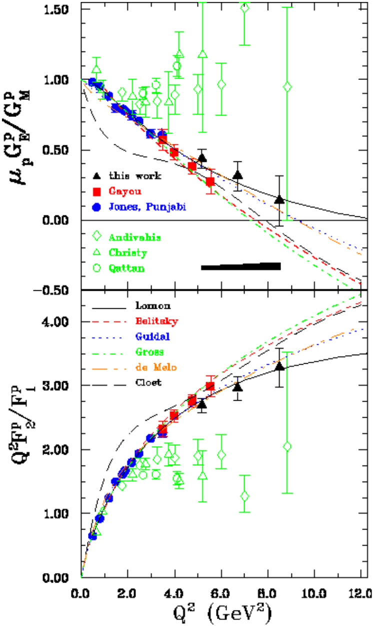
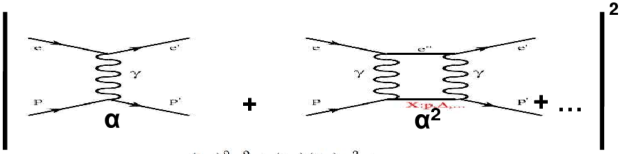


Figure from

A.J.R. Puckett *et al*

Phys.Rev.Lett.104:242301,2010

As a reason of disagreement often called the invalidity of the *one-photon* approximation when interpreting the results differential cross section measurements. Consideration of the corrections of *two-photon* exchange, however, encounters difficulties, both theoretical and experimental character.



$$\sigma = (1\gamma)^2\alpha^2 + (1\gamma)(2\gamma)\alpha^3 + ...$$

$$e^- \Longleftrightarrow e^+ \Rightarrow \alpha \Longleftrightarrow -\alpha$$

$$\sigma(\text{electron-proton}) = (1\gamma)^2\alpha^2 - (1\gamma)(2\gamma)\alpha^3 + ..$$

$$\sigma(\text{positron-proton}) = (1\gamma)^2\alpha^2 + (1\gamma)(2\gamma)\alpha^3 + ..$$

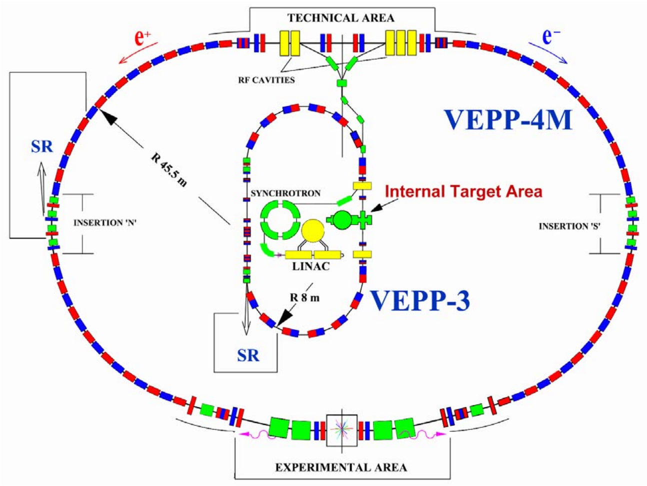
$$\mathrm{R}^{e+/e-} = \frac{\sigma(e^+p)}{\sigma(e^-p)} = 1 + (2\alpha)\frac{2\gamma}{1\gamma}$$

The problem caused the appearance of many new theoretical work performed in the various approaches

P.A.M. Guichon, M. Vanderhaeghen Phys. Rev. Lett. 91, 142303 (2003)
P.G. Blunden, W. Melnitchouk and J.A. Tjon Phys. Rev. Lett. 91, 142304 (2003)
M.P, Rekalo and E.Tomasi-Gustafson, Eur. Phis. Jour. A22, 331 (2004)
Y.C. Chen et al., Phys. Rev. Lett. 93, 122301 (2004)
A.V. Afanasev and N.P. Merenkov, Phys. Rev. D70, 073002 (2004)
A.V. Afanasev et al., Phys. Rev. D72, 013006 (2005)
P.G. Blunden, W. Melnitchouk and J.A. Tjon Phys. Rev. C72, 034612 (2005)
Y.C. Chen et al., Phys. Rev. C72, 034642 (2005)
S. Kondratyuk et al., Phys. Rev. Lett. 95, 172503 (2005)
D. Borisyuk and A. Kobushkin Phys. Rev. C78, 025206 (2008)
etc.

as well as the suggestions of new experiments for the determination of two-photon exchange contribution through the measurement $R^{e+/e-}$, since old data of 60th are not accurate enough.

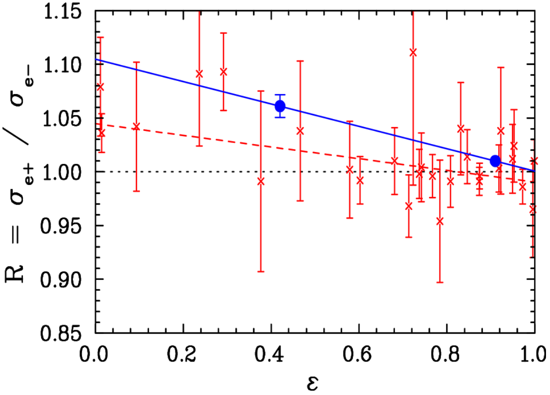
Novosibirsk/VEPP-3 TJNAF/CLAS/PR04-116 OLYMPUS: DORIS/BLAST


TECHNICAL AREA
e+
e−
RF CAVITIES
VEPP-4M
SR
R 45.5 m
SYNCHROTRON
Internal Target Area
INSERTION 'N'
INSERTION 'S'
LINAC
R 8 m
VEPP-3
SR
EXPERIMENTAL AREA

Proposal for VEPP-3 storage ring.

J. Arrington, V.F. Dmitriev, R.J. Holt, D.M. Nikolenko, I.A. Rachek, Yu.V.Shestakov, V.N. Stibunov, D.K. Toporkov, H.de Vries, Two–photon exchange and elastic scattering of electrons/positrons on the proton. arXiv:nucl-ex/0408020.

e^+/e^- **beams energy** 1.6 **ГэВ,**
e^+/e^- **scattering angles**
$\theta \approx 10^o,\ 20^o,\ 60^o$
Projected uncertainty (blue circles) for the proposed measurement
red "x" is previous data J. Mar *et al.*, Phys. Rev. Lett. **21** (1968).
Note that the previous measurements have an average Q^2 value of approximately 0.5 GeV^2 for the data below $\epsilon = 0.5$, and thus should have a smaller TPE contribution than the proposed measurement. The dashed line is a linear fit to the combined worlds data on R, and yields a slope of $-(5.7 \pm 1.8)\%$



$$\varepsilon = (1+2(1+\tau)\tan^2(\theta/2))^{-1} \qquad \tau = Q^2/4M$$

Schematic side view of the particle detection system.

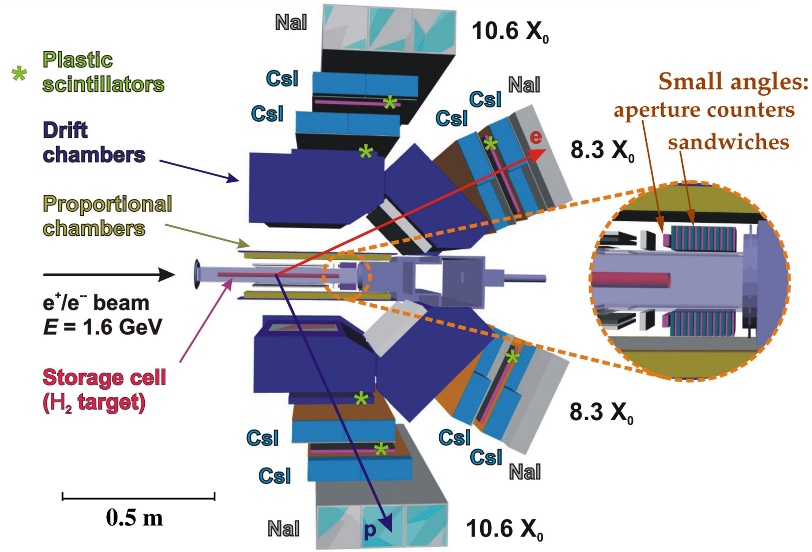
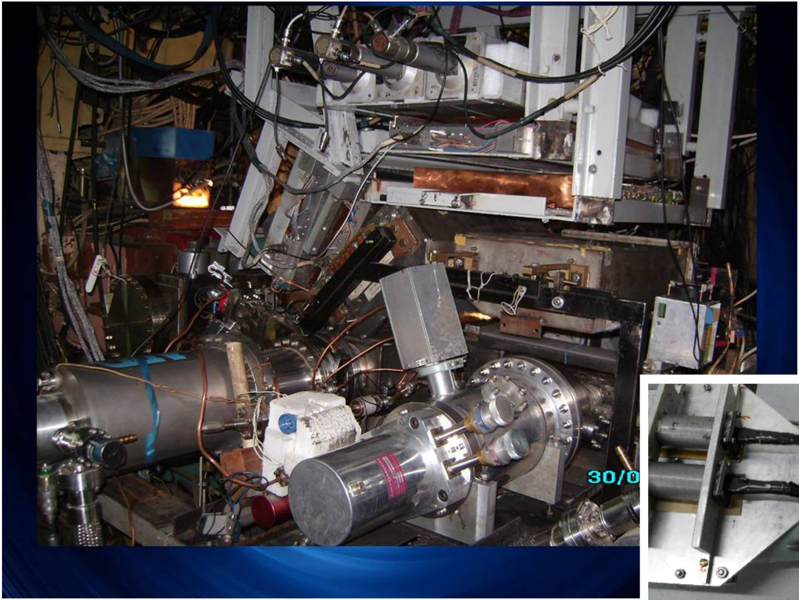
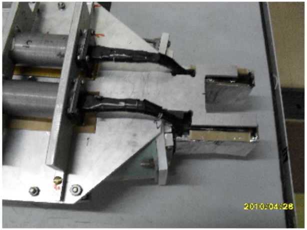
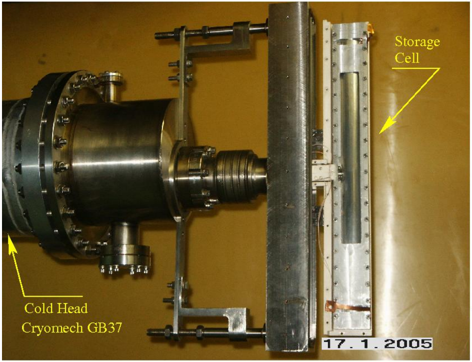


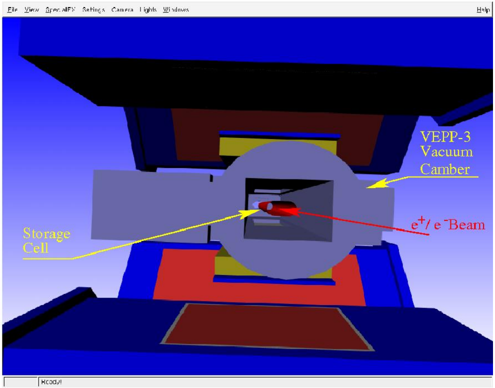
Photo of the detector and the target are installed at the VEPP-3





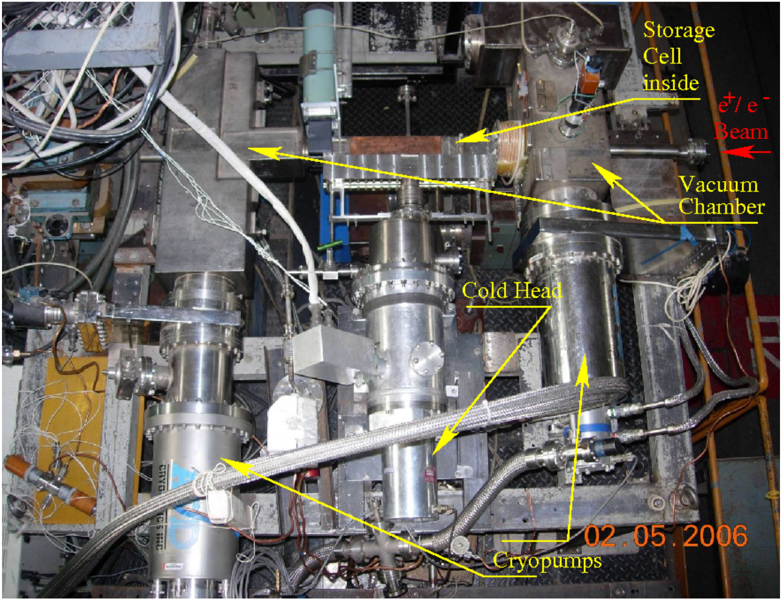
Hydrogen gas target



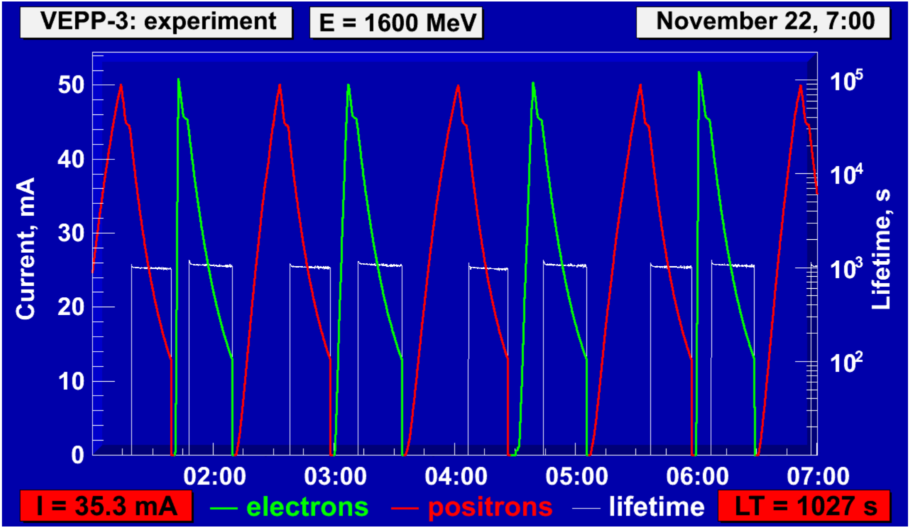


Storage cell: 13 x 24 x 400 mm3

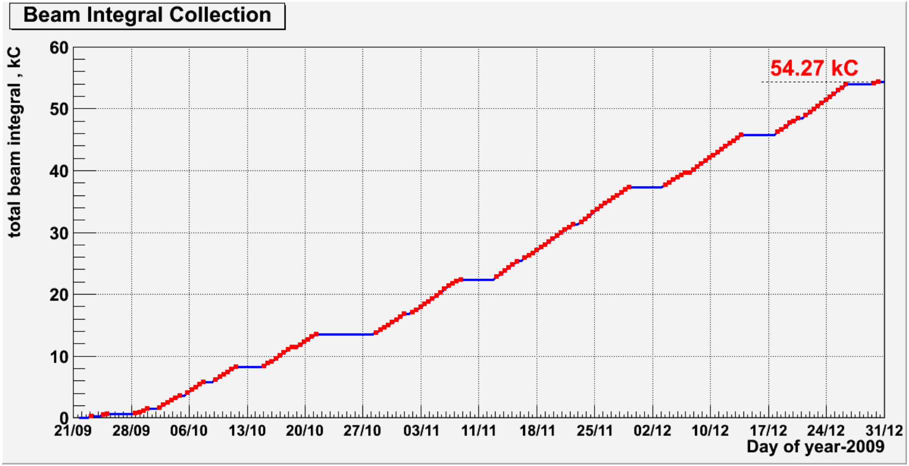
VEPP-3 Straight Section with Internal Target



Typical picture of the e^+/e^- currents of VEPP-3 during data taking.

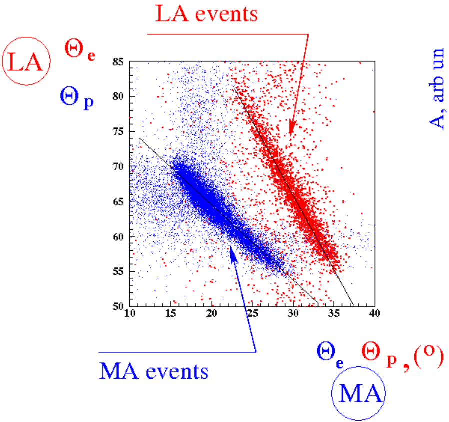


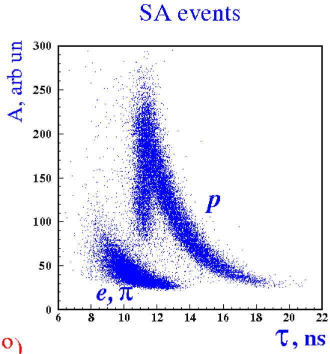
Accumulation of integral beam current VEPP-3 during the experiment.



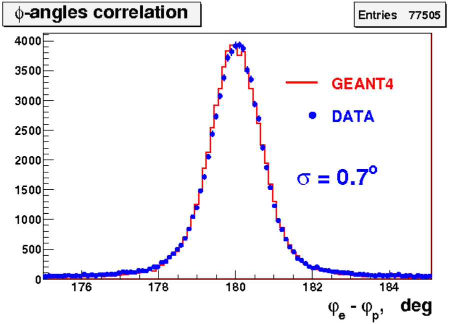
Selection of the elastic e–p scattering events

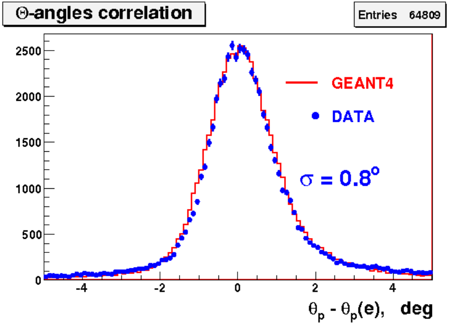
1. Correlation between polar angles
2. Correlation between azimuthal angles
3. Correlation between electron scattering angle and proton energy
4. Correlation between electron scattering angle and electron energy
5. ΔE–E analysis
6. Time–of–flight analysis for proton with low energy



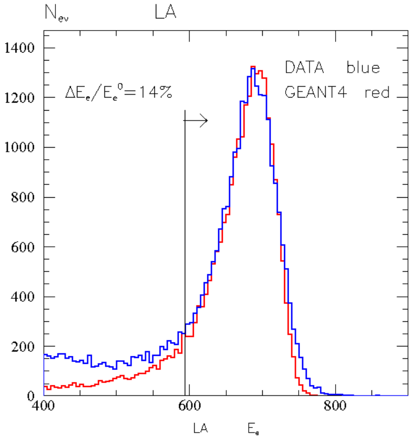


Event selection.

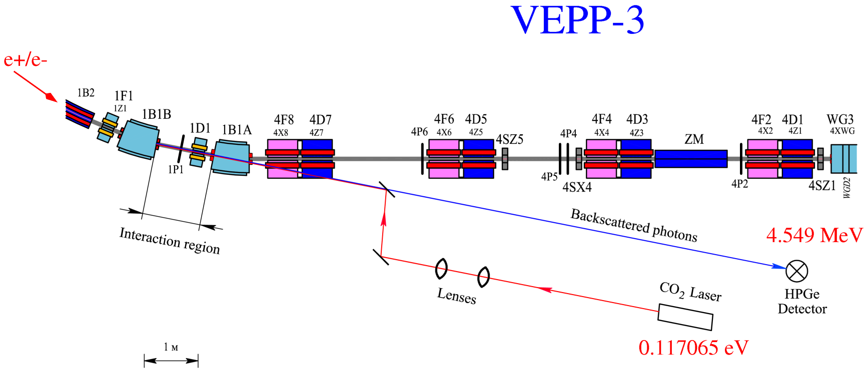




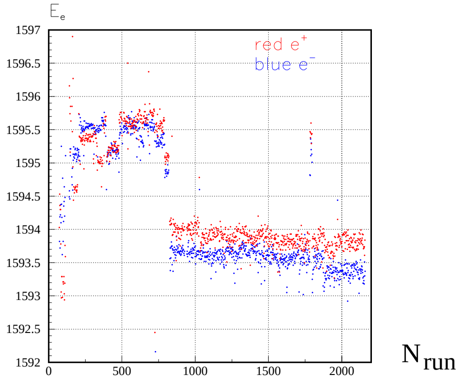
Energy in LA calorimeter

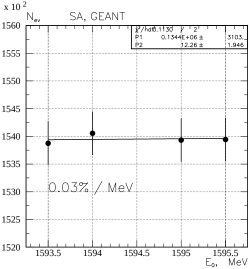


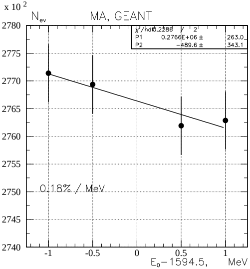
Back Compton scattering set up for measurement energy of e^+/e^- beams.

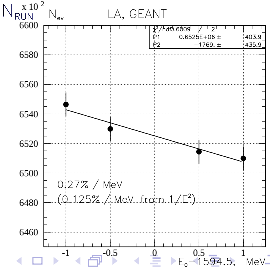


Beams energy measurements during experiment and E_e corrections.





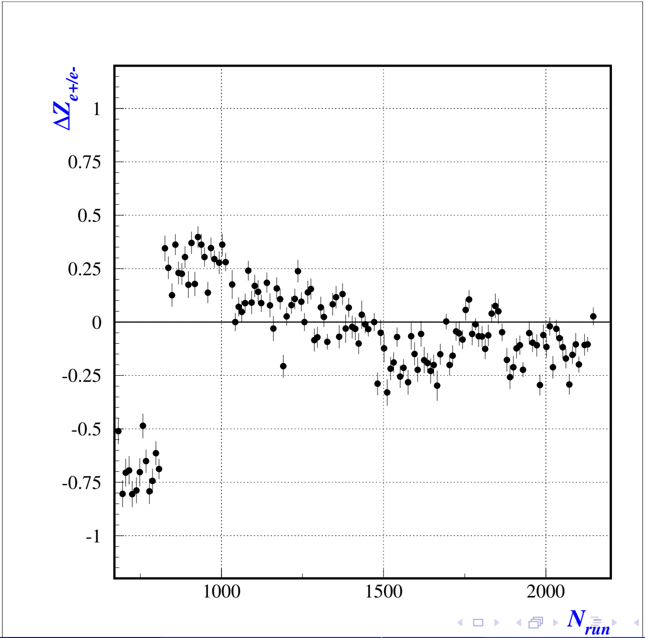




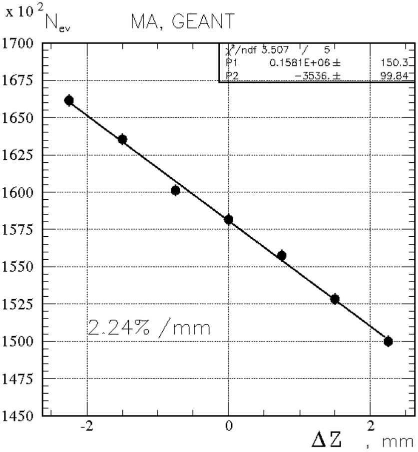
The information on the e^+/e^- beam positions came from three sources:

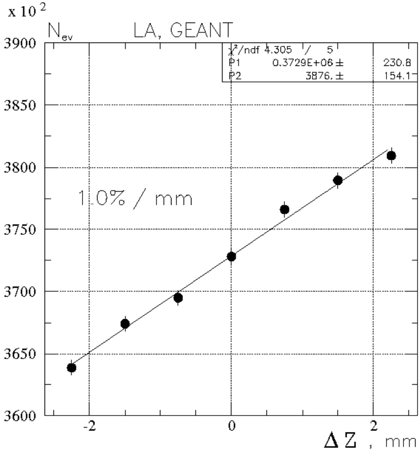
1. Beam position monitors of VEPP-3. They are located rather far from the target center and give only information on beams position stability.
2. Four beam scrapers. They are located more close to the target and provide the information about absolute position of beams. But they are rarely used because with them the data taking should be interrupted.
3. Coordinate systems of the detector give the possibility in the off-line regime to determine both the horizontal and the vertical ralative shift of e^+/e^- beams with an accuracy of ~ 0.1 mm

The measurement of differences in the vertical position e^+/e^+ beams on the events SA scattering.

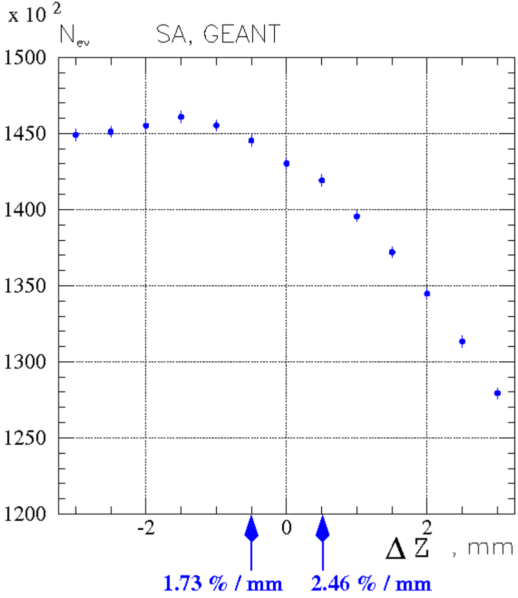


Dependence counting rate of the detectors from vertical shift of the beam.





Dependence counting rate of the detectors from vertical shift of the beam.

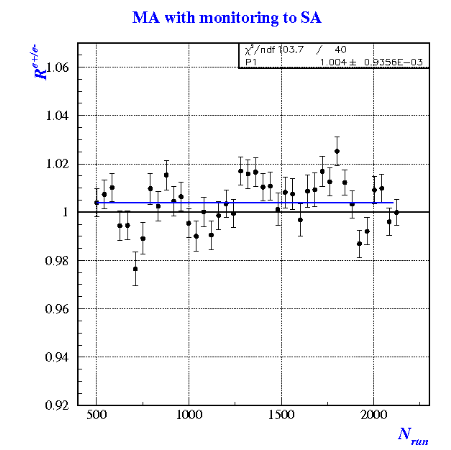


absolute position 0.5 $\pm$ 0.2 mm

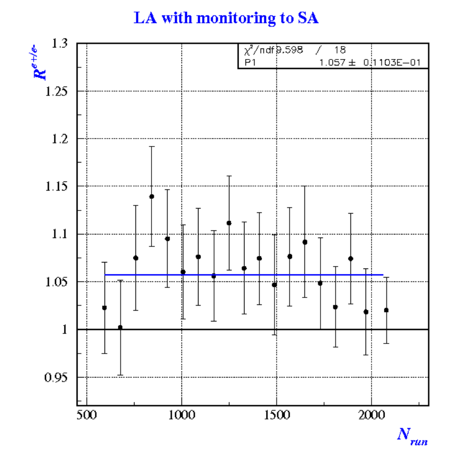
with $\Delta Z_{e+/e-}$ =0.1 mm

Δ (N1+N2) / (N1+N2)=0.12 %

Raw ratio $R^{e+/e-}$ (no corrections) for MA and LA, both are monitoring to SA.



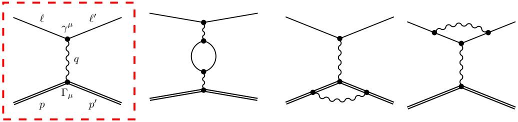
R=1.00412 ±0.00094

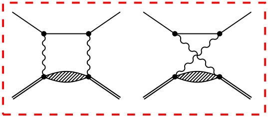


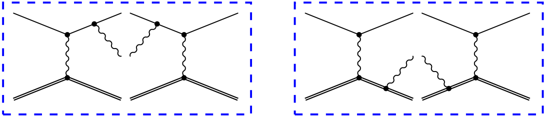
R=1.057 ±0.011

Radiative corrections for *ep* - scattering.

Born



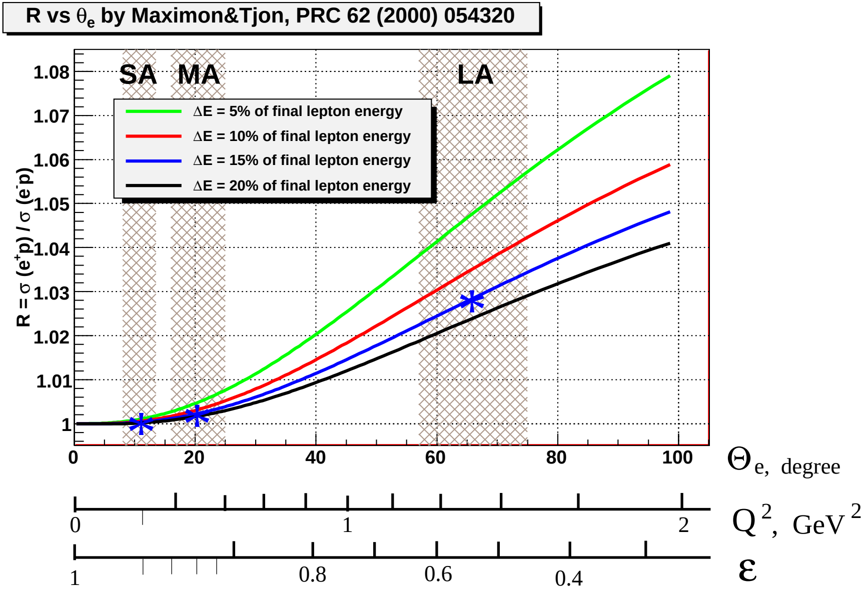




Bremsstrahlung

Radiative corrections with real photons emission, integration on photon angles.

E_e=1.6 GeV



Soft Photon Approximation (SPA)

Reaction:

$$k + p = k' + p' + \omega,$$

where k, k' — initial and final lepton four-momenta, p, p' — initial and final proton four-momenta, ω — photon four-momentum.

$$\omega^0 \ll |\vec{k}|, |\vec{k}'|, |\vec{p}'|$$

In this case, the total cross section for single-photon bremsstrahlung is given by

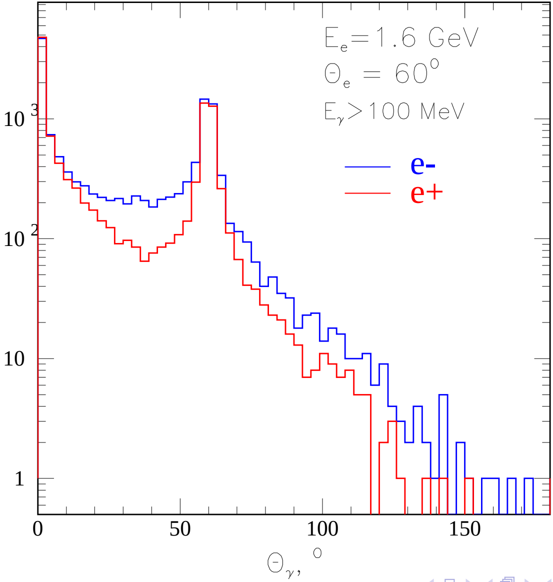
$$\frac{d\sigma}{d\,\Omega_e\ d\,\Omega_\gamma\ d\,\omega^0} = \left.\frac{d\sigma^{(1)}}{d\,\Omega_e}\right|_{ep} \frac{-\alpha\,\omega^0}{4\pi^2}\left[\pm\frac{k'}{\omega\cdot k'} - \frac{p'}{\omega\cdot p'} \mp \frac{k}{\omega\cdot k} + \frac{p}{\omega\cdot p}\right]^2,$$

where

$$\left.\frac{d\sigma^{(1)}}{d\,\Omega_e}\right|_{ep}$$

is the one-photon exchange (Born) electron-proton cross section. The first and third terms in brackets have different signs in the case of e^-p and e^+p scattering.

SPA, dependence on emission photon angle.



SPA, LA, GEANT4, dependence cuts on the correction for $R^{e+/e-}$.

Cuts	correction for $R^{e+/e-}$
no	1.0151
C_ϕ	1.0182
C_θ	1.0290
C_E	1.0196
$C_\phi\ C_\theta$	1.0288
$C_\phi\ C_\theta\ C_E$	1.0297

Cuts:

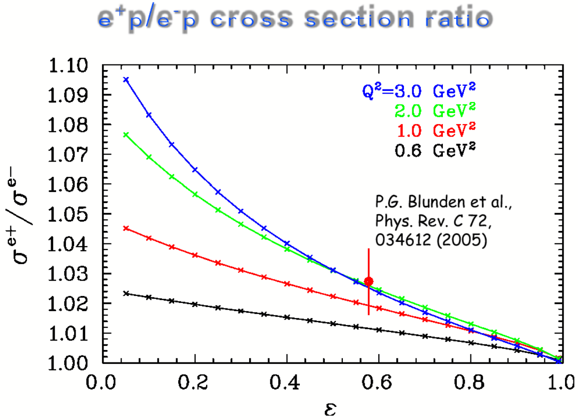
C_ϕ correlation $\phi_e - \phi_p$

C_θ correlation $\theta_e - \theta_p$

C_E cut $E_{e'}$

More correct calculation of radioactive corrections (V. Fadin and A. Feldman, Private communication), where no restriction on the photon energy and also proton form factor is taken into account, will be used soon.

Preliminary result for $R^{e+/e-}$ in comparison with calculations of P.G. Blunden et al.



$\varepsilon = 0.58 \ , \ Q^2 = 1.43 \ GeV^2$

Concusion.

1. Experiment on a precise comparison $(e^{+}p)$ and $(e^{-}p)$ scattering cross sections had performed
2. The preliminary result is in agreement with the TPE hadron calculations of P.G. Blunden et al.