

# Overview of Novosibirsk Experiment

A. V. Gramolin,<sup>1</sup> J. Arrington,<sup>2</sup> L. M. Barkov,<sup>1</sup> V. F. Dmitriev,<sup>1</sup>  
V. V. Gauzshteyn,<sup>3</sup> R. A. Golovin,<sup>1</sup> R. J. Holt,<sup>2</sup> V. V. Kaminsky,<sup>1</sup>  
B. A. Lazarenko,<sup>1</sup> S. I. Mishnev,<sup>1</sup> N. Yu. Muchnoi,<sup>1</sup> V. V. Neufeld,<sup>1</sup>  
D. M. Nikolenko,<sup>1</sup> I. A. Rachek,<sup>1</sup> R. Sh. Sadykov,<sup>1</sup> Yu. V. Shestakov,<sup>1</sup>  
V. N. Stibunov,<sup>3</sup> D. K. Toporkov,<sup>1</sup> H. de Vries,<sup>4</sup> S. A. Zevakov,<sup>1</sup>  
and V. N. Zhilich<sup>1</sup>

<sup>1</sup>Budker Institute of Nuclear Physics, Novosibirsk, Russia

<sup>2</sup>Argonne National Laboratory, Argonne, USA

<sup>3</sup>Nuclear Physics Institute at Tomsk Polytechnical University, Tomsk, Russia

<sup>4</sup>NIKHEF, Amsterdam, The Netherlands



**Massachusetts  
Institute of  
Technology**

Radiative Corrections Workshop @ MIT

# Experiment at the VEPP-3 storage ring (Novosibirsk)

A measurement of the ratio  $R = \sigma(e^+p)/\sigma(e^-p)$  has been performed recently at the VEPP-3 storage ring at the energy of electron/positron beams of 1.6 GeV and at lepton scattering angles around  $10^\circ$ ,  $18^\circ$  and  $64^\circ$ . The smallest angle region is used for luminosity monitoring.

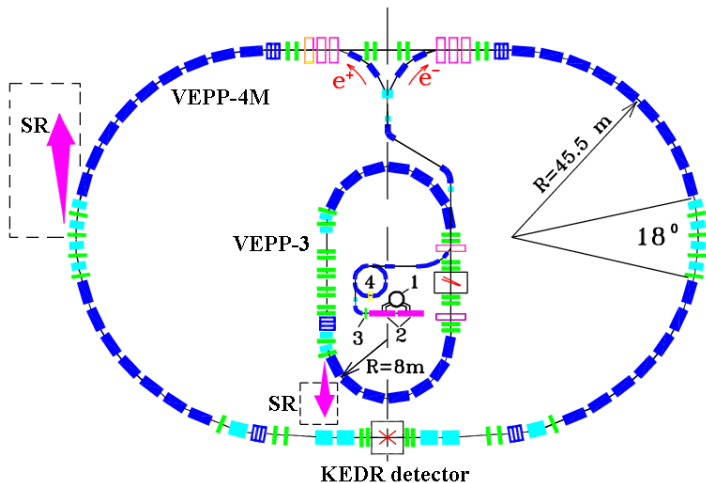
	$\theta_\ell$ ( $^\circ$ )	$Q^2$ ( $\text{GeV}^2$ )	$\varepsilon$	$\Delta R/R$ (% , stat.)
SA	$8.4 \div 12.9$	$0.05 \div 0.13$	$0.99 \div 0.97$	—
MA	$15.5 \div 22.4$	$0.18 \div 0.34$	$0.96 \div 0.92$	0.09
LA	$57.5 \div 71.0$	$1.32 \div 1.61$	$0.55 \div 0.40$	1.08

Internal hydrogen gas target was used (thickness:  $5 \cdot 10^{14}$  at./ $\text{cm}^2$ ). Data collection with electron and positron beams was alternated regularly, so that one cycle with two beams required 1.5 hours. Experiment duration was about 1500 hours with a mean luminosity of  $5 \cdot 10^{31} \text{ s}^{-1} \cdot \text{cm}^{-2}$ .

Also two similar experiments have been proposed to study the  $e^+p$  and  $e^-p$  cross sections ratio: one at DORIS storage ring (OLYMPUS collaboration), and another at Jefferson Lab (CLAS collaboration) using a secondary electron/positron beam from a pair production target.

- Proposal for the experiment at VEPP-3 (2004): [nucl-ex/0408020](#)
- OLYMPUS collaboration: <http://web.mit.edu/OLYMPUS/>
- Proposal for the experiment at CLAS (Jefferson Lab): [PR-07-005.pdf](#)

# The VEPP-3 electron-positron storage ring

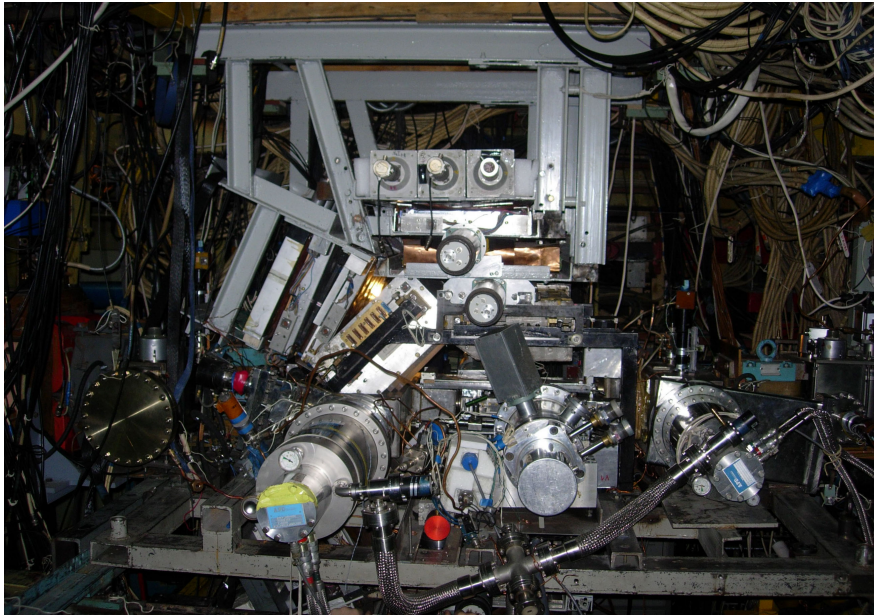


- 1 — Girokon (430 MHz)
- 2 — Linac (50 MeV)
- 3 — Electron to positron converter
- 4 — Synchrotron B-4 (350 MeV)

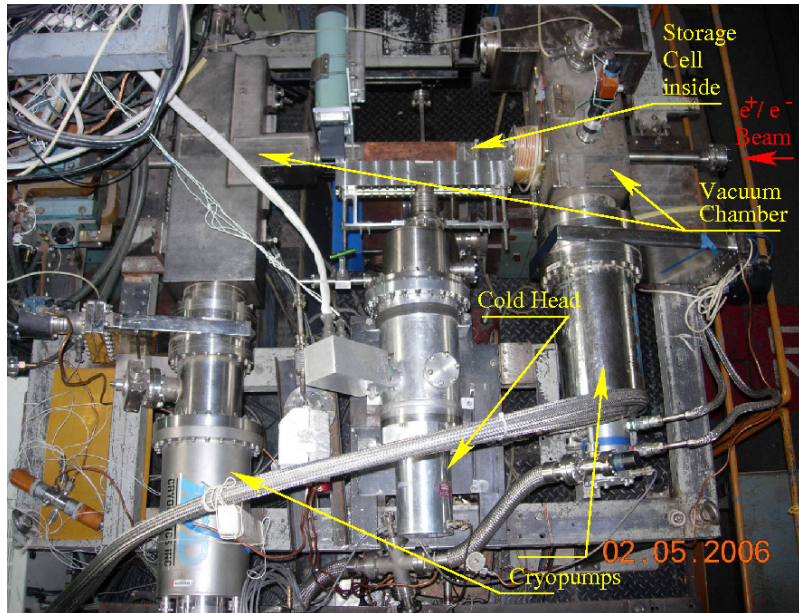
Perimeter: 74.4 m  
Injection energy: 350 MeV  
Maximal energy: 2000 MeV  
Maximal  $e^+$  current: 50 mA



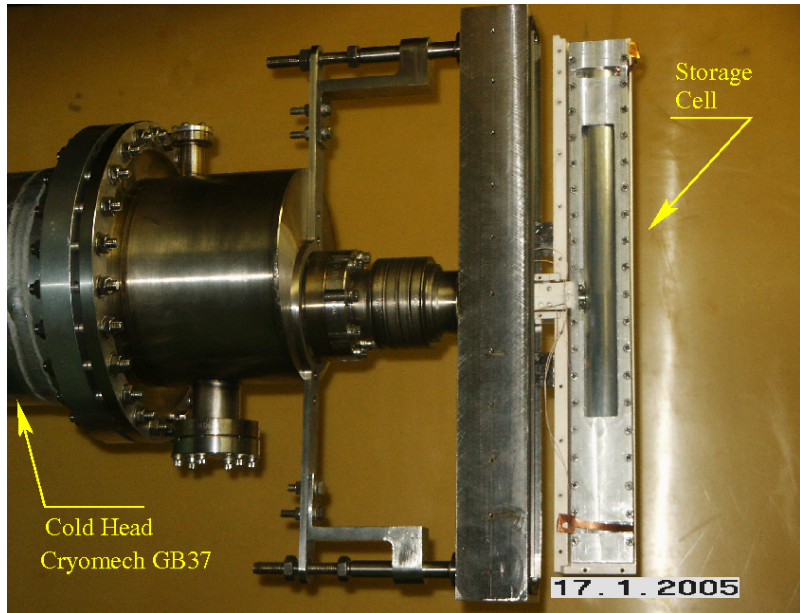
# The detector and the target installed at VEPP-3



# VEPP-3 straight section with internal target



# Internal target — storage cell cooled by Cold Head



# The main sources of systematic uncertainties

- **Different beam positions for electrons and positrons**

This effect can be suppressed in first order by averaging count rates of up-arm and down-arm. We had three sources of information on the  $e^-/e^+$  beam positions: VEPP-3 beam position monitors, moveable beam scrapers and vertex position reconstruction using coordinate system of the detector.

- **Unequal beam energy for electrons and positrons**

Electron/positron beams energies were measured regularly and with good accuracy (better than 200 keV) during data taking by Compton backscattering setup.

- **Time instability of detection efficiency**

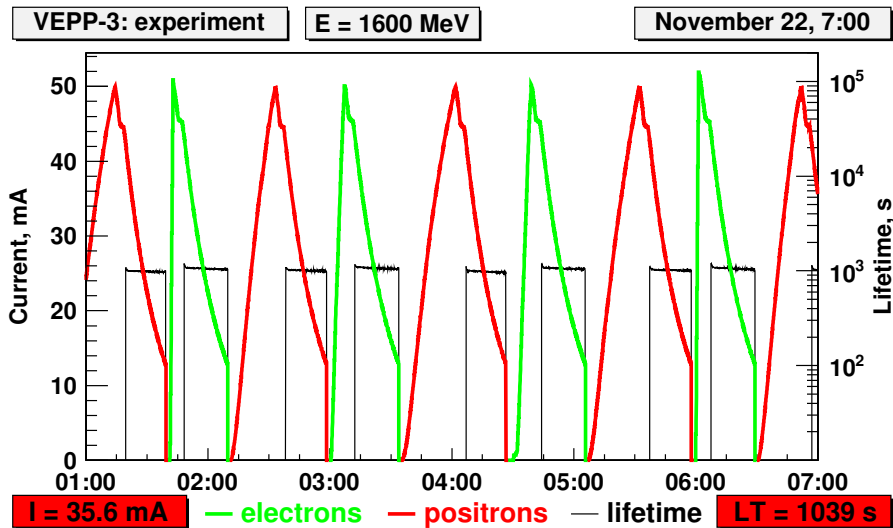
- **Drift of the target thickness in time**

Data collection with electron and positron beams was alternated regularly. This allows us to suppress effects of drift in time of the target thickness and detection efficiency.

- **Uncertainty related to radiative corrections**

**Full systematic uncertainty is estimated now as  $3 \cdot 10^{-3}$  (0.3%).**

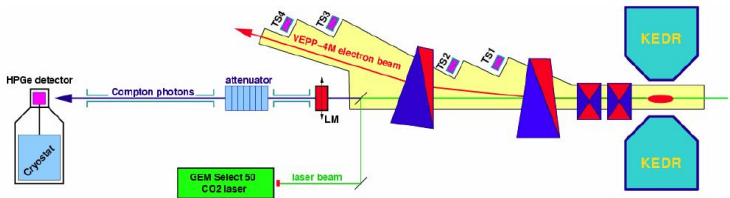
# Operating mode of VEPP-3 during the experiment



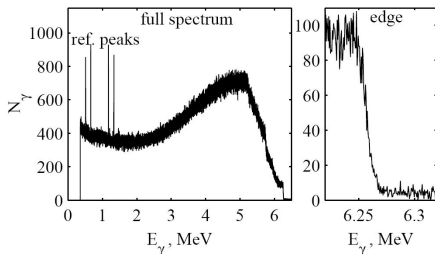
The figure shows the beam current (**green** for  $e^-$ , **red** for  $e^+$ ) and lifetime (**black**). Alternation of  $e^-$  and  $e^+$  beams allows to suppress effects of drift in time the target thickness and detection efficiency.

# Beam energy measurement by Compton backscattering

Already existing system created earlier for the VEPP-4 collider has been used.



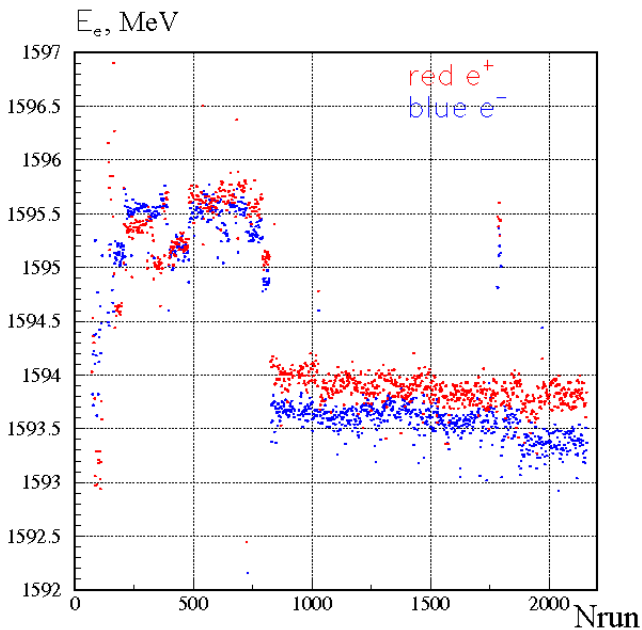
Photons from a CO<sub>2</sub> laser are scattered in a head-on collision with the stored beam. From the spectrum of the backscattered photons that are detected by an energy-calibrated high purity Ge detector the beam energy can be determined.



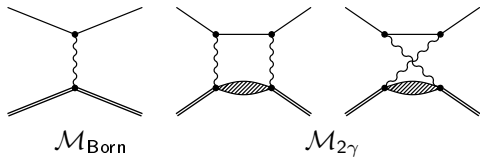
$$E = \frac{\omega_{\max}}{2} \left( 1 + \sqrt{1 + \frac{m_e^2}{\omega_0 \omega_{\max}}} \right),$$

where  $\omega_{\max}$  — maximal energy of backscattering photons (the edge of spectrum),  $\omega_0$  — energy of laser photons,  $m_e$  — electron mass.

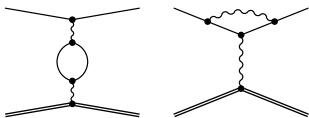
# Results of beam energy measurements



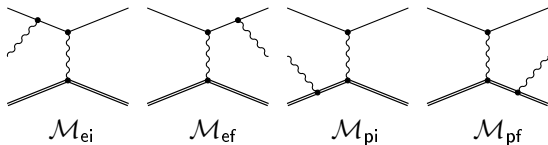
# Why is it important to take into account the RC?



The diagrams of  $ep$  scattering in the  $1\gamma$  and  $2\gamma$  approximations.



Virtual photon corrections, which don't depend on the detector geometry.



Corrections related to the bremsstrahlung of the first order. Their contribution is determined by the detector geometry!

The experimentally measured ratio  $R = \sigma(e^+ p) / \sigma(e^- p)$ :

$$R \approx \frac{e^4 |\mathcal{M}_{\text{Born}}|^2 + 2e^6 \mathcal{M}_{\text{Born}} \text{Re}(\mathcal{M}_{2\gamma}^*) + e^6 |\mathcal{M}_{\text{ei}} + \mathcal{M}_{\text{ef}} + \mathcal{M}_{\text{pi}} + \mathcal{M}_{\text{pf}}|^2 + \dots}{e^4 |\mathcal{M}_{\text{Born}}|^2 - 2e^6 \mathcal{M}_{\text{Born}} \text{Re}(\mathcal{M}_{2\gamma}^*) + e^6 |-\mathcal{M}_{\text{ei}} - \mathcal{M}_{\text{ef}} + \mathcal{M}_{\text{pi}} + \mathcal{M}_{\text{pf}}|^2 + \dots}$$

- Typically, the following formula is used to account for the RC:

$$\frac{d\sigma}{d\Omega_e}(E_\gamma < \Delta E) = \frac{d\sigma_{\text{Born}}}{d\Omega_e} [1 - \delta_1(\Delta E) - \delta_2],$$

where  $\Delta E$  is parameter that characterizes the energy resolution of the detector;  $\delta_1(\Delta E)$  is the correction related to the bremsstrahlung;  $\delta_2$  is the correction related to virtual photons.

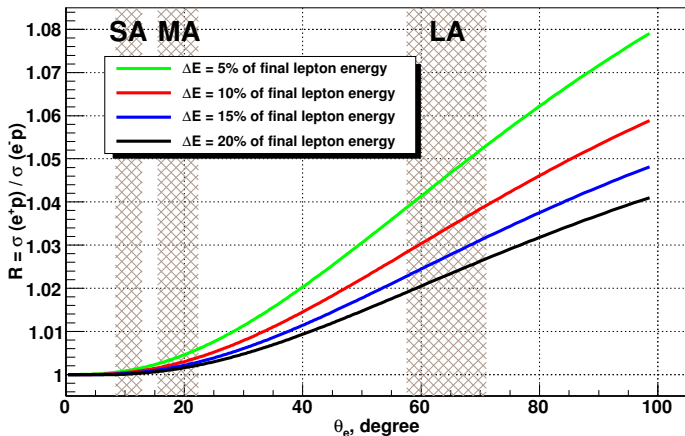
- The soft photon approximation is commonly used in the calculations of the term  $\delta_1(\Delta E)$ .
- Infrared divergences in the diagrams of bremsstrahlung and two-photon exchange diagrams cancel each other.
- Exponentiation is used to account for the multiphoton emission:

$$\frac{d\sigma}{d\Omega_e}(E_\gamma < \Delta E) = \frac{d\sigma_{\text{Born}}}{d\Omega_e} e^{-\delta_1(\Delta E)} (1 - \delta_2).$$

- *L. W. Mo and Y. S. Tsai*. Rev. Mod. Phys. **41** (1969) [205](#).
- *L. C. Maximon and J. A. Tjon*. PRC **62** (2000) [054320](#).
- *R. Ent, B. W. Filippone, N. C. R. Makins, et al.* PRC **64** (2001) [054610](#).

# Simple estimate for the radiative corrections

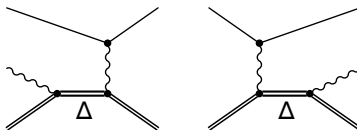
Simple estimate based on the work by Maximon and Tjon can be made. This estimate gives  $R \approx 1.03$  for the LA region (see the blue curve on the figure).



- L. C. Maximon and J. A. Tjon. PRC 62 (2000) [054320](#).

# Radiative corrections in our experiment

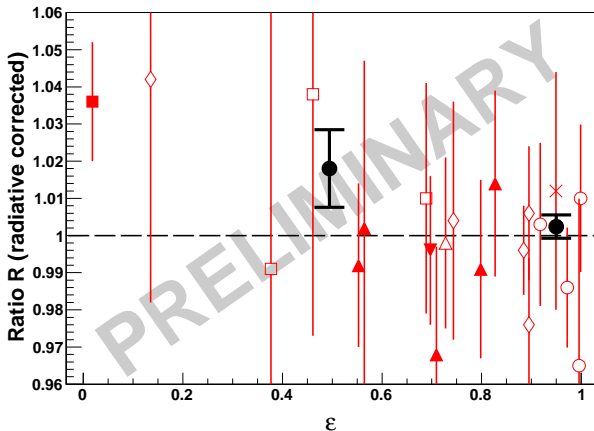
- Calculation by V. S. Fadin and A. L. Feldman is used to account for the first order bremsstrahlung. FeynCalc package is used in this calculation.
- Calculation by V. S. Fadin and R. E. Gerasimov is used to estimate the contribution of the first order bremsstrahlung with the delta-isobar  $\Delta(1232)$  excitation. FeynCalc package is used again. As far as we know, this is the first calculation of the process.



- Soft photon approximation is not used in these calculations (there is no limit on the photon energy).
- Based on the calculations, we have created an event generator called ESEPP (Elastic Scattering of Electrons and Positrons by Protons). ESEPP generates events ( $ep \rightarrow ep$  and  $ep \rightarrow ep\gamma$ ), which are then used to simulate the experiment in the Geant4 toolkit.
- Geant4 simulation allows us to accurately account for the detector geometry and kinematic cuts used in event selection (angular correlations for the detected lepton and proton; cut on the lepton energy).

# Preliminary results of the experiment

Middle angle ( $\varepsilon = 0.95$ ,  $Q^2 = 0.23 \text{ GeV}^2$ ):  $R = 1.0024 \pm 0.0009 \pm 0.003$ ,  
Large angle ( $\varepsilon = 0.5$ ,  $Q^2 = 1.43 \text{ GeV}^2$ ):  $R = 1.018 \pm 0.011 \pm 0.003$ .

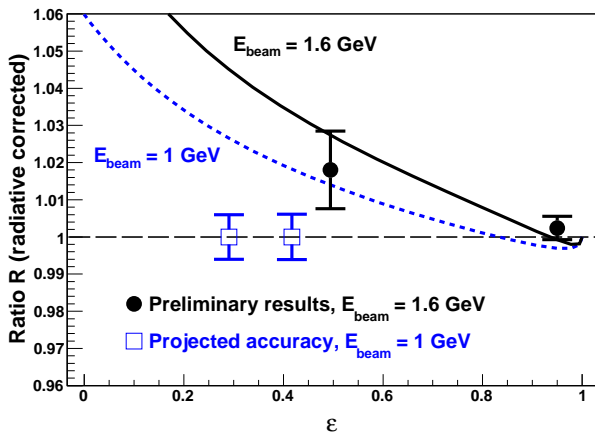


Our preliminary results and the previous measurements (for  $Q^2 < 2 \text{ GeV}^2$ ):

- ◇ Yount (1962); □ Browman (1965), run 1; △ Browman (1965), run 2;
- ▼ Anderson (1966); × Bartel (1967); ■ Bouquet (1968); ▲ Anderson (1968);
- Mar (1968); ● this experiment.

# The next phase of the experiment

The measurement will be continued at other kinematics:  
 $\varepsilon = 0.42$ ,  $Q^2 = 0.82 \text{ GeV}^2$  &  $\varepsilon = 0.29$ ,  $Q^2 = 0.96 \text{ GeV}^2$ .



The figure shows projected statistical accuracy (blue squares) and our preliminary results (black circles). The lines represent the corresponding results of the theoretical prediction by Blunden, et al.

- P. G. Blunden, W. Melnitchouk, and J. A. Tjon. PRC 72 (2005) [034612](#).

- The first precision measurement of the ratio  $R = \sigma(e^+p)/\sigma(e^-p)$  has been performed. Preliminary results of the experiment have been presented.
- Procedure of account of the radiative corrections has been developed (ESEPP event generator + Geant4 simulation of the detector).
- Exact calculation by V. S. Fadin and A. L. Feldman has been used to account for the first order bremsstrahlung beyond the soft photon approximation.
- Calculation by V. S. Fadin and R. E. Gerasimov has been used to account for the first order bremsstrahlung with the delta-isobar  $\Delta(1232)$  excitation. As far as we know, this is the first calculation of the process.
- The measurement will be continued at other kinematics.

Thank you for attention!

- The first precision measurement of the ratio  $R = \sigma(e^+p)/\sigma(e^-p)$  has been performed. Preliminary results of the experiment have been presented.
- Procedure of account of the radiative corrections has been developed (ESEPP event generator + Geant4 simulation of the detector).
- Exact calculation by V. S. Fadin and A. L. Feldman has been used to account for the first order bremsstrahlung beyond the soft photon approximation.
- Calculation by V. S. Fadin and R. E. Gerasimov has been used to account for the first order bremsstrahlung with the delta-isobar  $\Delta(1232)$  excitation. As far as we know, this is the first calculation of the process.
- The measurement will be continued at other kinematics.

Thank you for attention!

- Bremsstrahlung in the soft-photon approximation (SPA) [▶ Go to the slide](#)
- Selection of the elastic  $ep$  scattering events [▶ Go to the slide](#)

# Bremsstrahlung in the soft-photon approximation (SPA)

Kinematics of the reaction:

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

where  $\ell, \ell'$  — initial and final lepton four-momenta;  $p, p'$  — initial and final proton four-momenta;  $k$  — photon four-momentum.

Formulas simplify greatly in the limit that the photon energy  $E_\gamma$  is much less than the momenta of the initial lepton and final state fermions. This limit is referred to as the *soft-photon approximation* (SPA). In this case, the differential cross section for single-photon bremsstrahlung is given by

$$\frac{d\sigma}{d\Omega_\ell d\Omega_\gamma dE_\gamma} = \frac{-\alpha E_\gamma}{4\pi^2} \left[ \pm \frac{\ell'}{k \cdot \ell'} - \frac{p'}{k \cdot p'} \mp \frac{\ell}{k \cdot \ell} + \frac{p}{k \cdot p} \right]^2 \frac{d\sigma_0}{d\Omega_\ell},$$

where  $d\sigma_0/d\Omega_\ell$  is the one-photon exchange electron-proton cross section (given by Rosenbluth formula). The first and third terms in brackets have different signs in the case of  $e^-p$  and  $e^+p$  scattering.

- R. Ent, B. W. Filippone, N. C. R. Makins, et al. PRC **64** (2001) [054610](#).

# Selection of the elastic $ep$ scattering events

- 1 Correlation between polar angles ( $\theta_\ell$  vs.  $\theta_p$ )
- 2 Correlation between azimuthal angles ( $\phi_\ell$  vs.  $\phi_p$ )
- 3 Correlation between lepton scattering angle and proton energy ( $\theta_\ell$  vs.  $E_p$ )
- 4 Correlation between lepton scattering angle and electron energy ( $\theta_\ell$  vs.  $E_\ell$ )
- 5  $\Delta E-E$  analysis
- 6 Time-of-flight analysis for low energy protons

