# Experiments with polarized deuteron target at VEPP-3 storage ring

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# Novosibirsk Electron-Deuteron Collaboration

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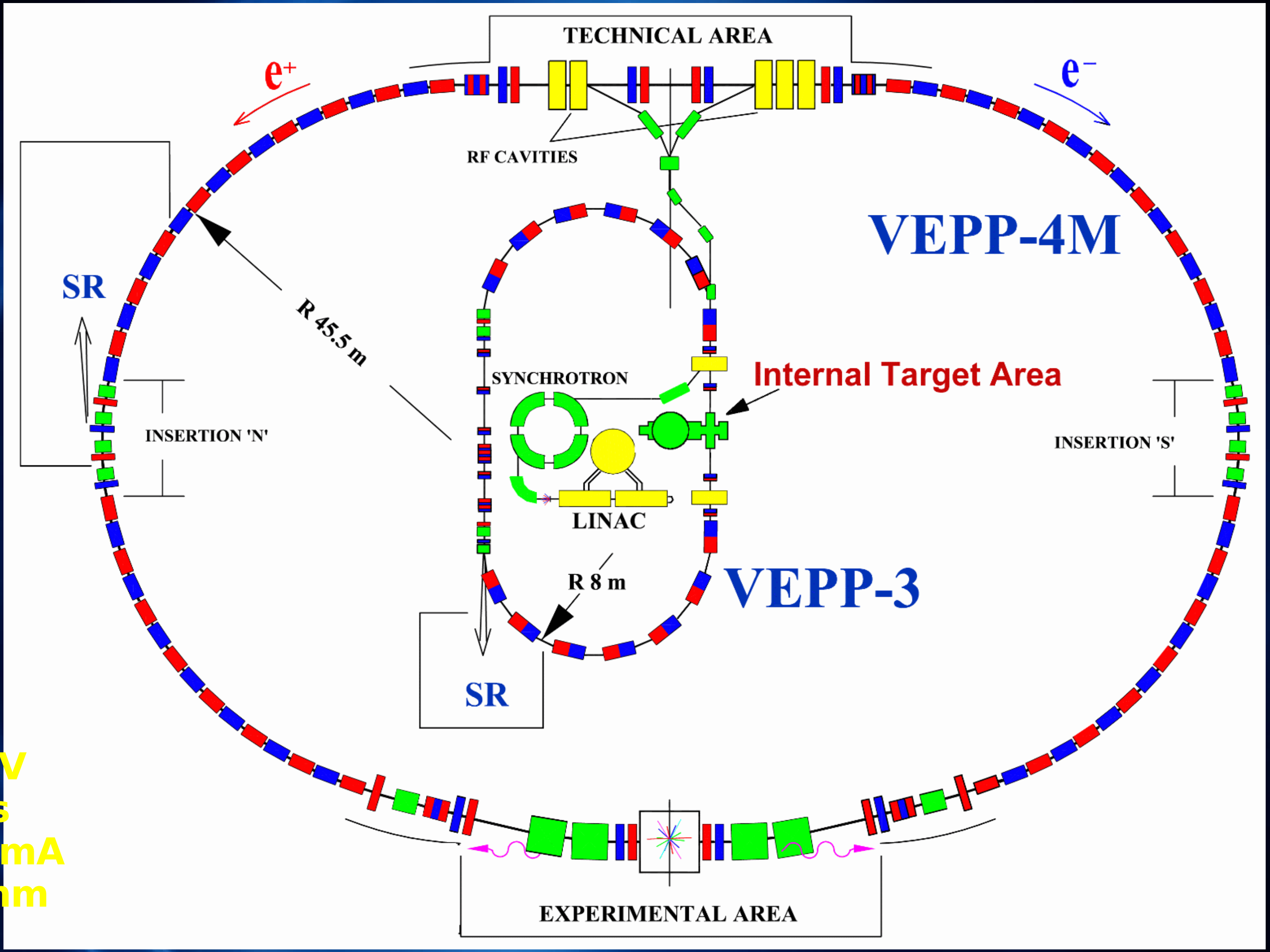
1. **Measurement of tensor analyzing powers in elastic e-d scattering (BINP, NIKHEF).**
2. **Photodisintegration of tensor polarized deuteron (BINP).**
3. **Measurement of charge form factor of the neutron (HIKHEF).**
4. **Detail investigation of *pp and pd* interaction (IUCF).**
5. **Study of nucleon spin structure (DESY)**
6. **Measurement of charge form factor of the neutron, elastic and inelastic e-d scattering (MIT-BATES)**
7. **IKP, Juelich - first experiments will come soon**

# Novosibirsk electron-positron facility



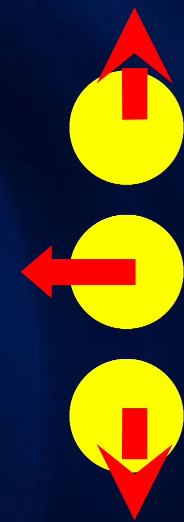

*VEPP-3*

**Energy : 2000 MeV**
**Lifetime : 20000 s**
**Av. current : 100 mA**
**Bunch : 0.7x0.3 mm**

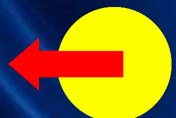
# Polarization of sample of spin 1 particles

$$P_z = \frac{N \quad - N}{N \quad + N_0 + N} = n \quad - n$$

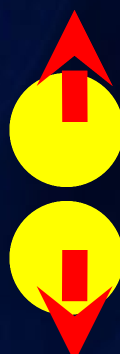
$$P_{zz} = \frac{N \quad + N \quad - 2N_0}{N \quad + N_0 + N} = 1 - 3n_0$$




Tensor polarized target allows to measure tensor-polarization observables in e-d scattering even with electron beam is not polarized

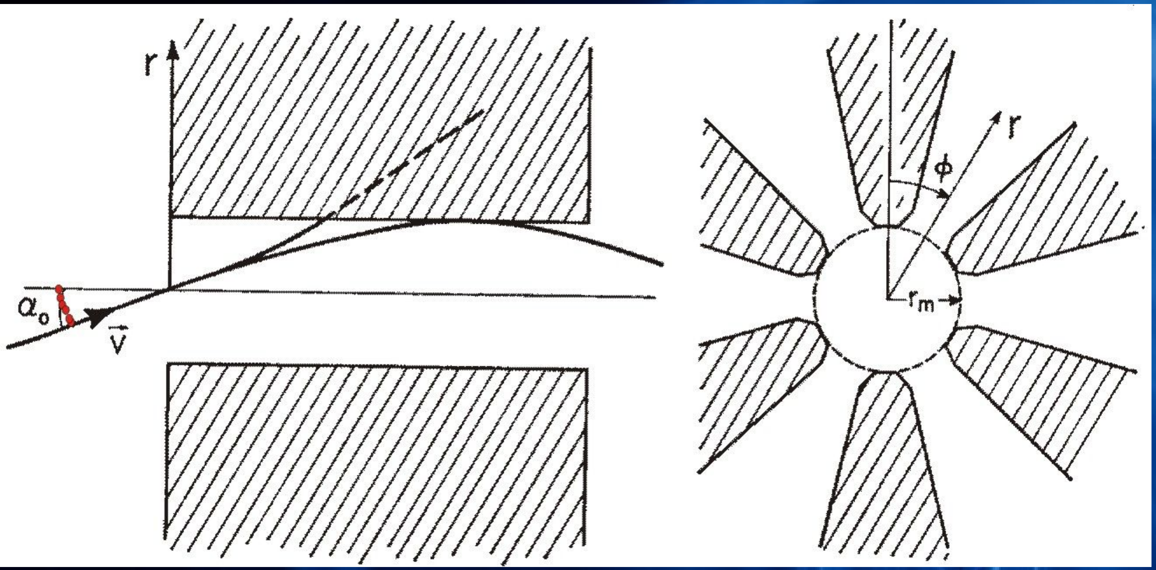


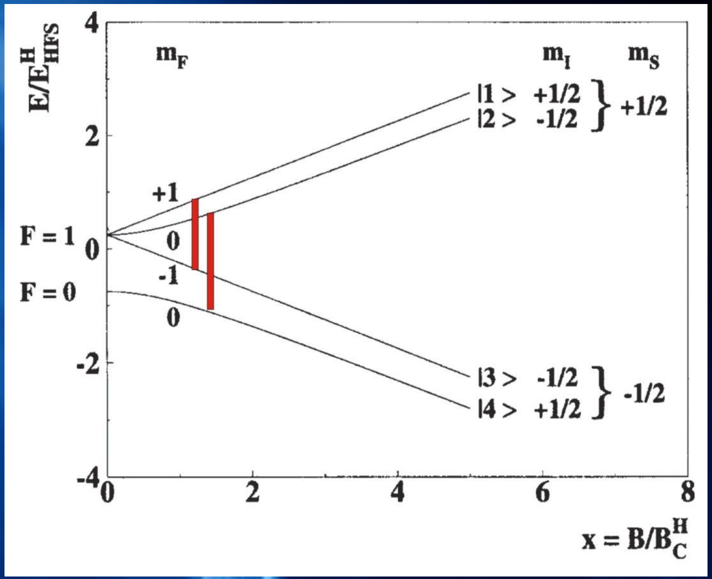
**$P_{zz}$=-2**



**$P_{zz}$=1**

# How to get polarized atoms ? Stern - Gerlach method




$$\Delta\Omega = \pi\alpha^2 = \frac{\pi\mu B}{kT}$$ B=1T T=100K $\Delta\Omega$ $10^{-2}$ sr $\alpha$ 0.05 rad

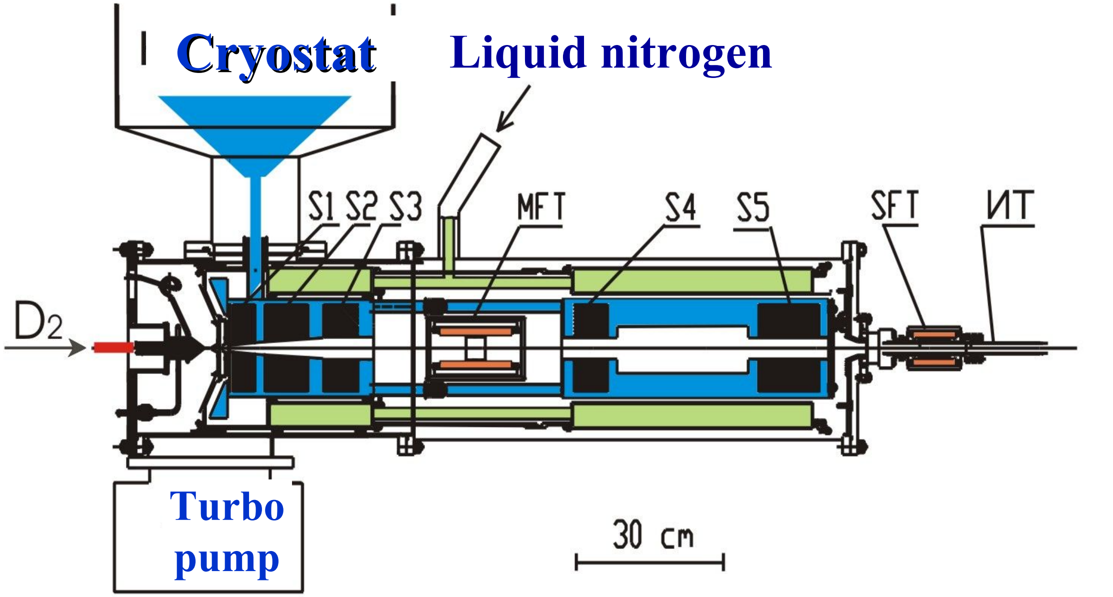
After the sextupole magnets only atoms in substates 1 and 2

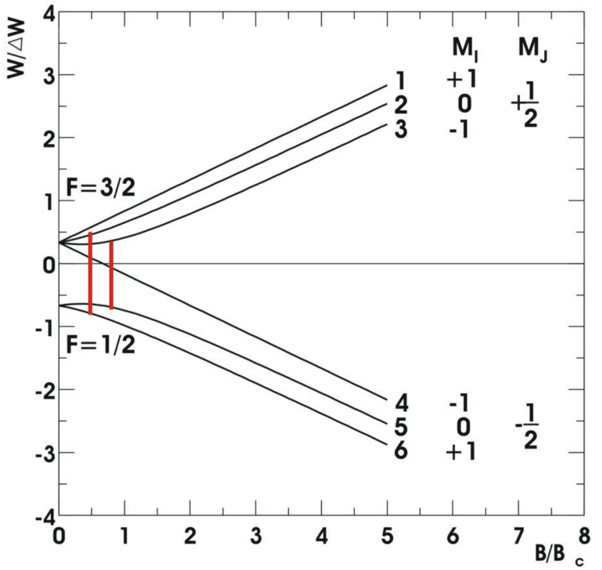
In the weak field $P_z = 0.5$

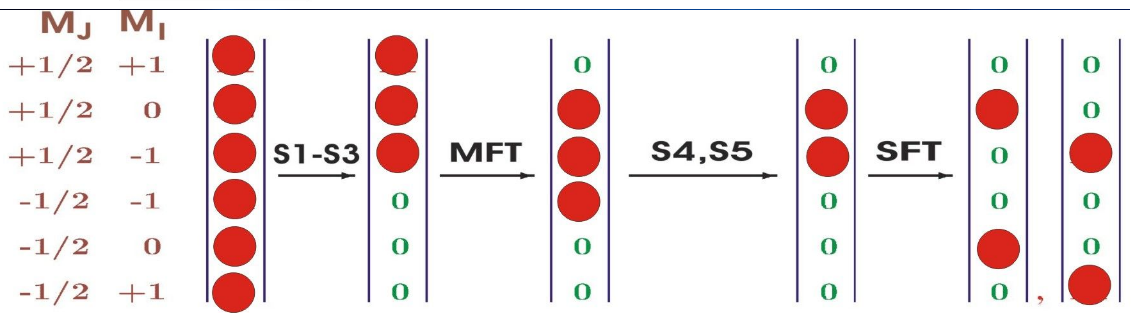
Transition 1- 3 gives $P_z = -1$ in the strong field

Transition 2- 4 gives $P_z = +1$ in the strong field

# Cryogenic Atomic Beam Source



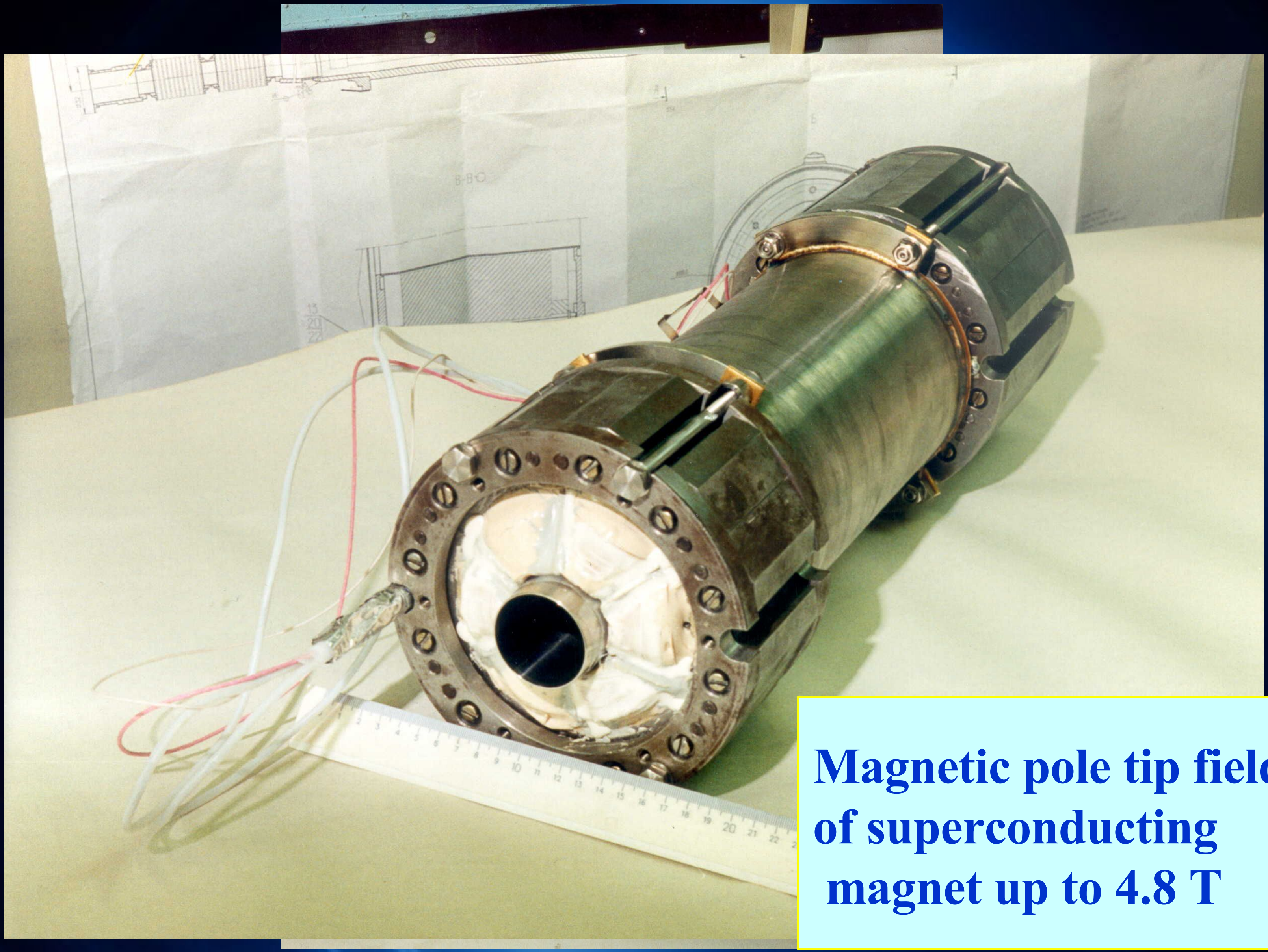




**Tensor polarization** $P_{zz}=1-3n_0= -2,+1.$

**Vector polarization** $P_z=n_+-n_- = 0.$

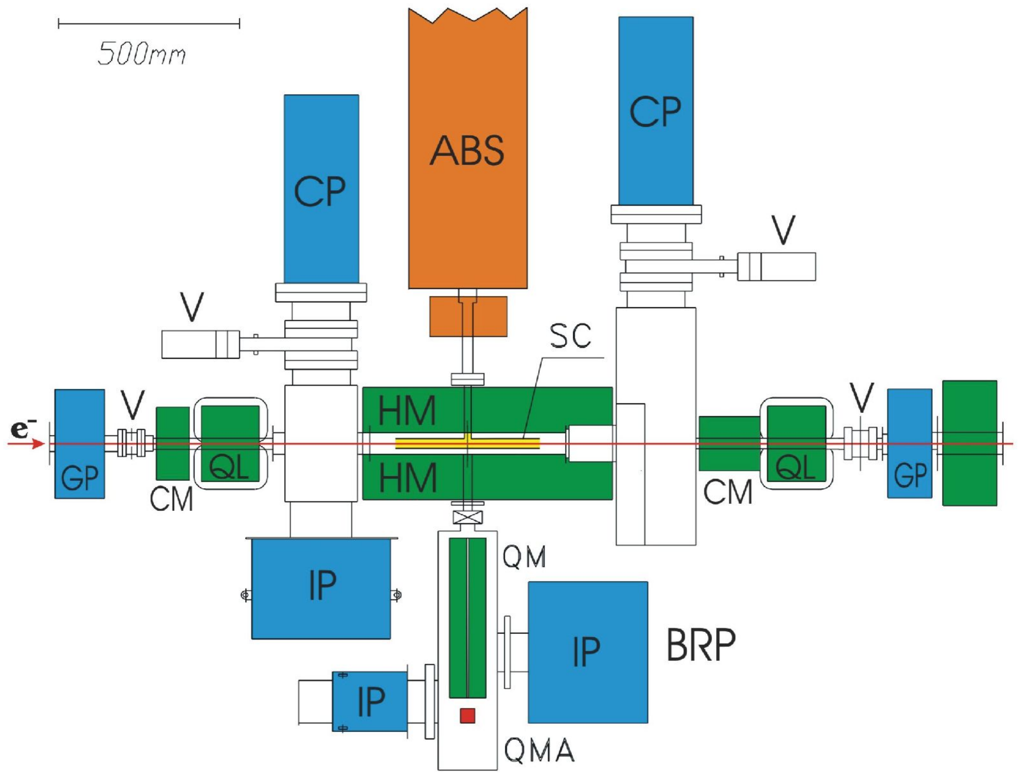
# Superconducting sextupole magnets



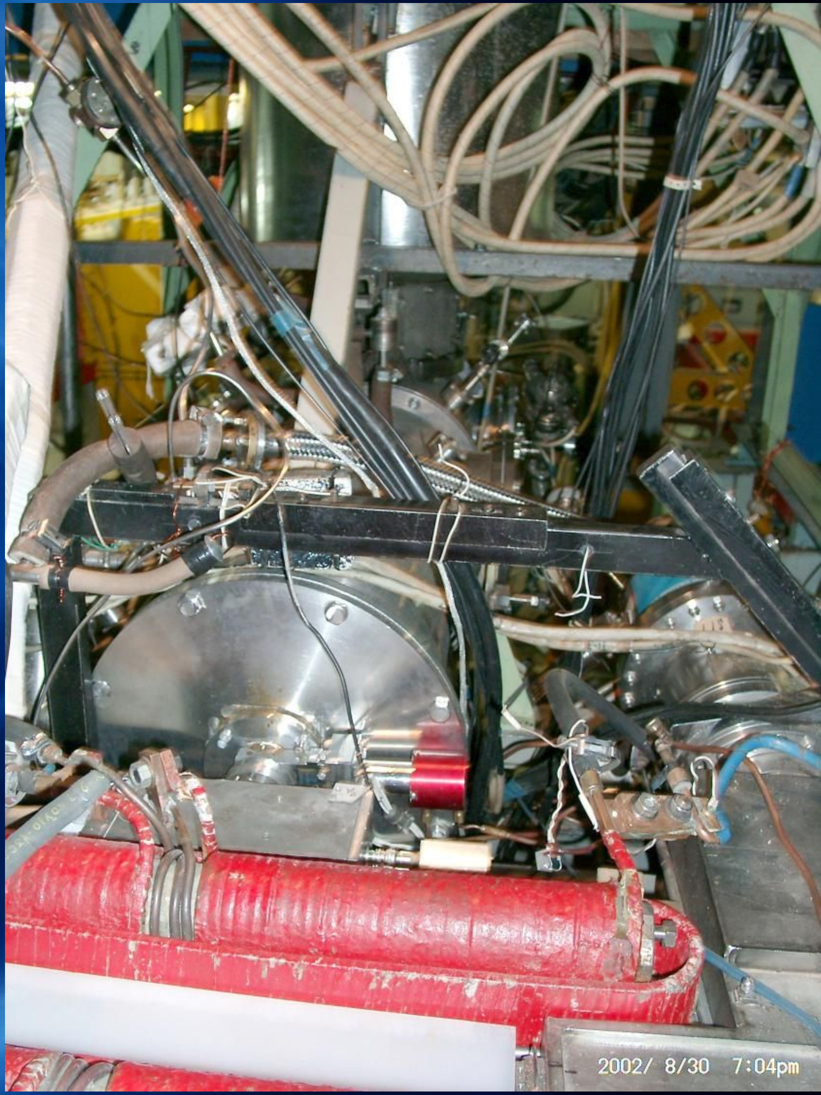
**Magnetic pole tip field of superconducting magnet up to 4.8 T**

# ABS just before the installation at the straight section

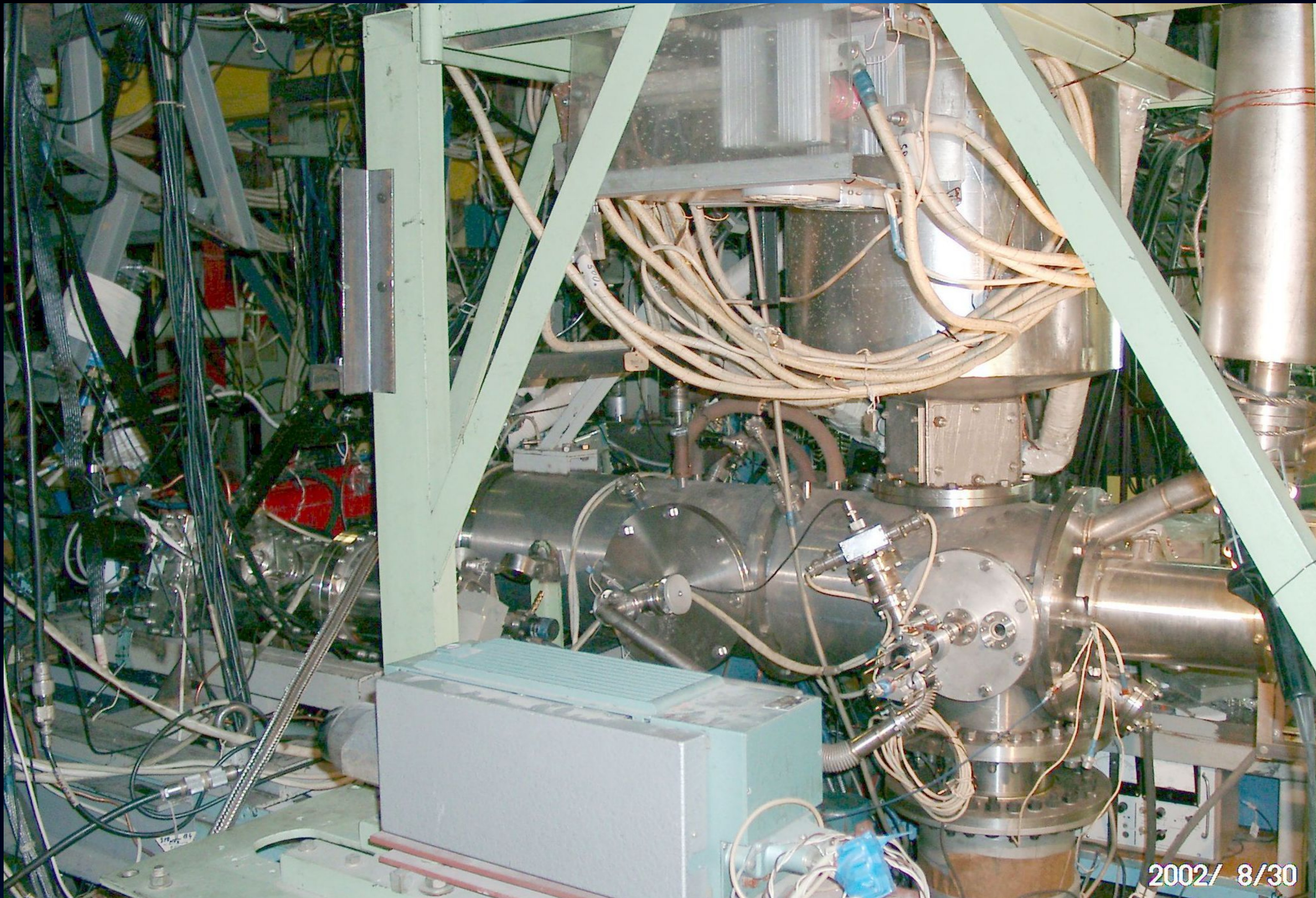
# Top view of the internal target at VEPP-3 electron ring



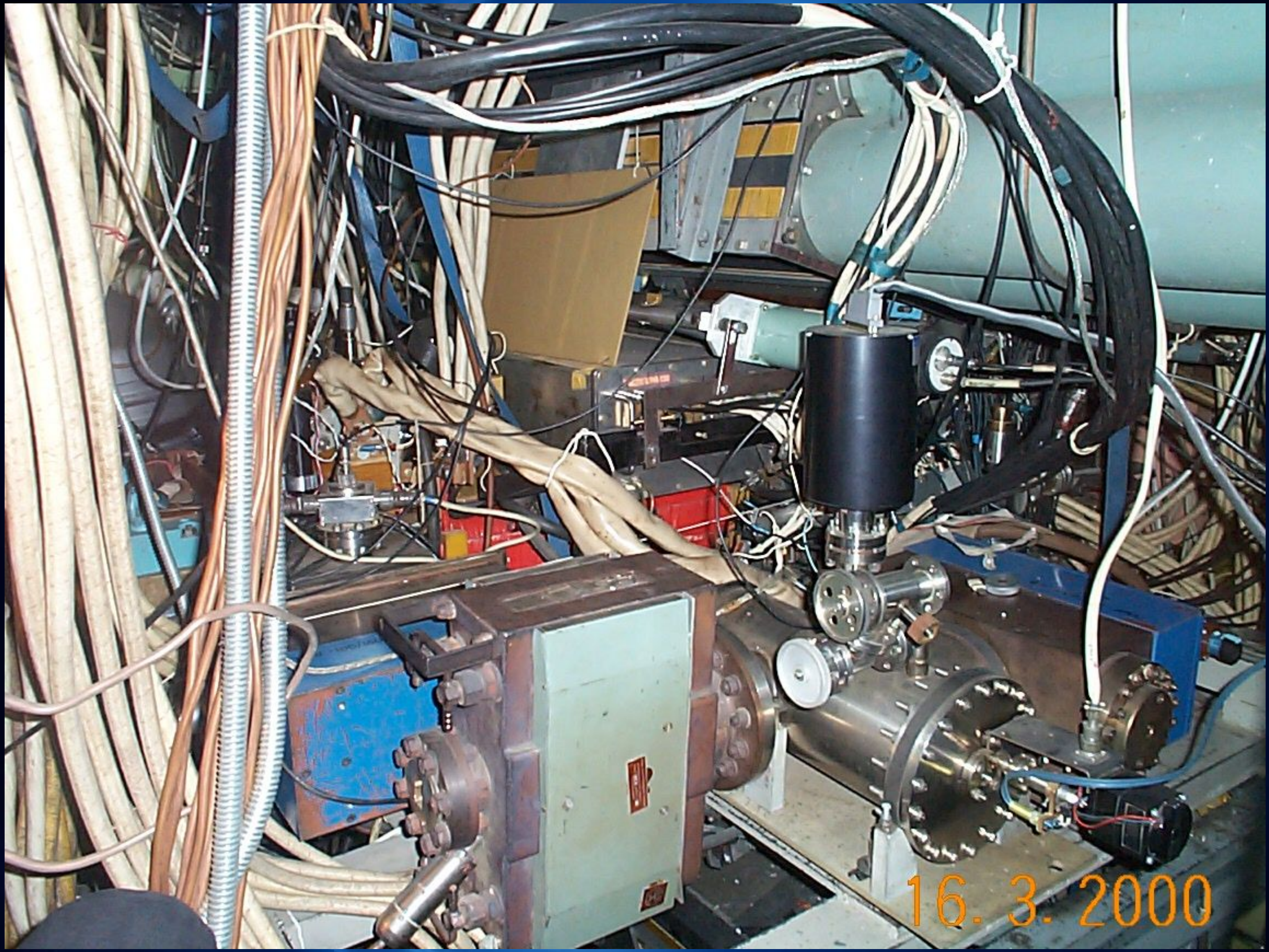

ABS - atomic beam source, SC - storage cell, BRP - Breit - Rabi polarimeter, HM - holding field magnet, QM - quadrupole magnet, GP - getter pump and QMA - quadrupole mass analyzed



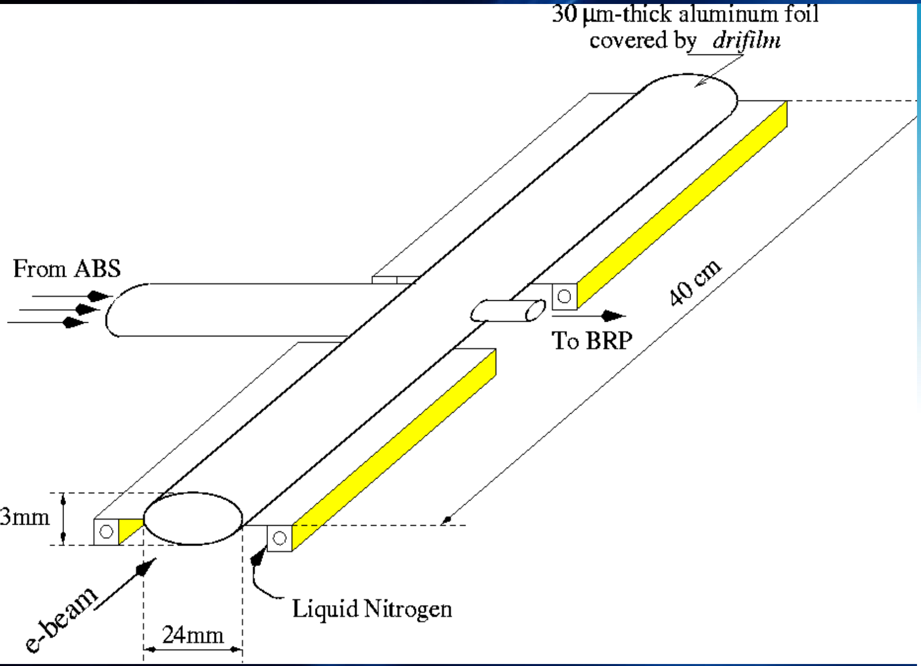
# ABS being installed at VEPP-3

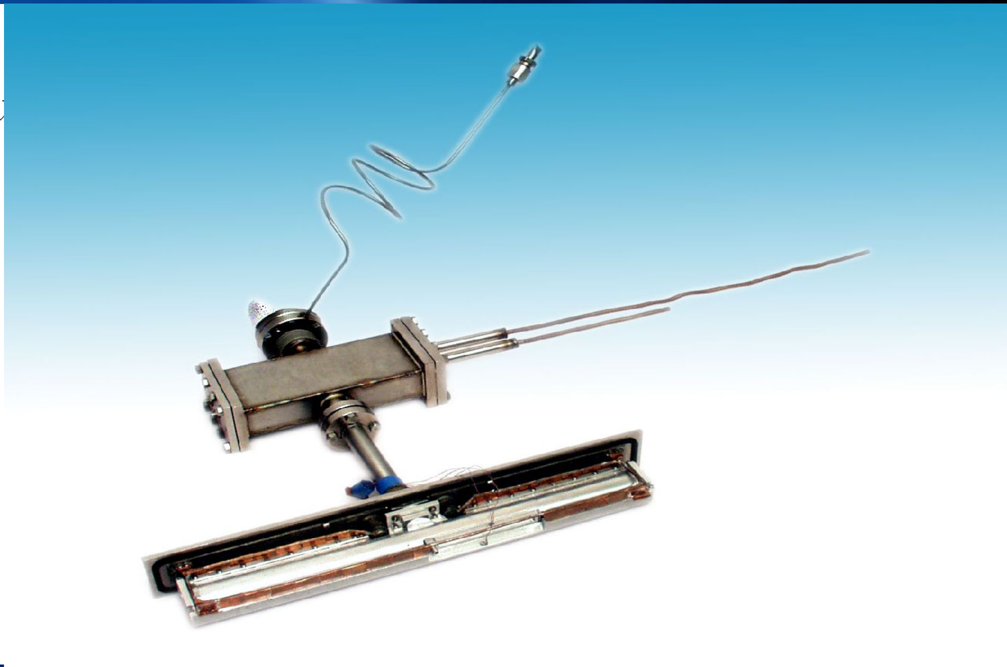


# Breit-Rabi polarimeter



# Storage cell for polarized atoms

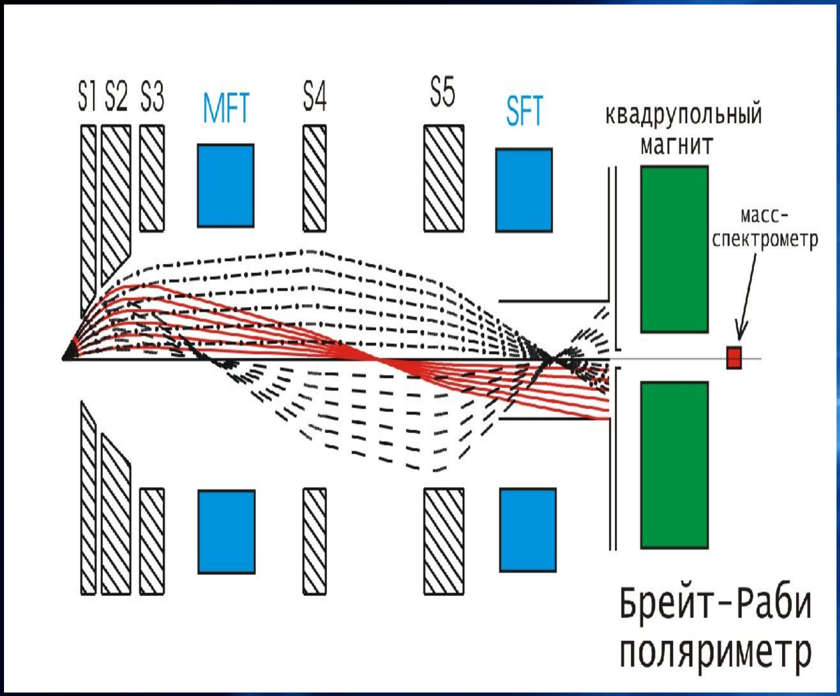


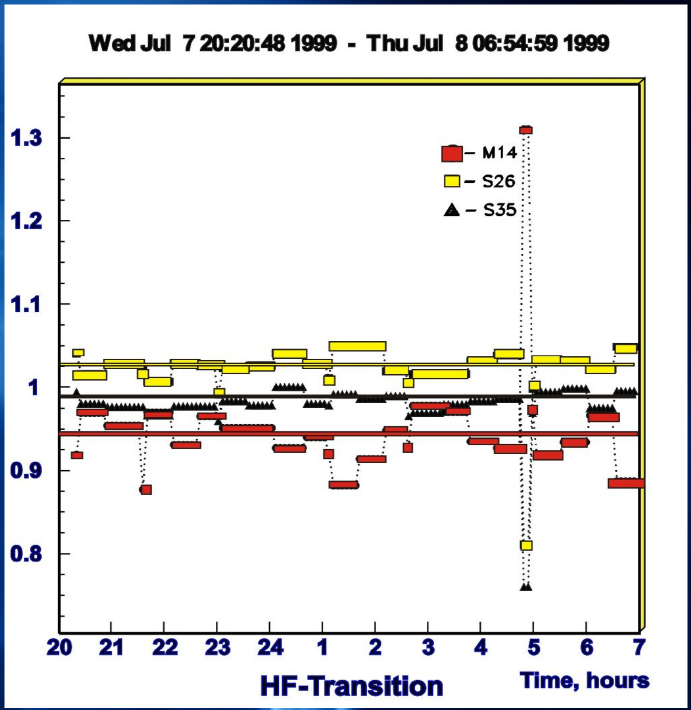



Beam flux of polarized deuterium atoms $8.2 \times 10^{16}$ at/sec

The measured target thickness $8 \times 10^{13}$ at/cm$^2$

# The efficiency of the RF units




The polarization of the injected atoms into the storage cell was found to be high enough.

The average polarization of the atoms along the cell should be measured additionally ( LQ polarimeter )

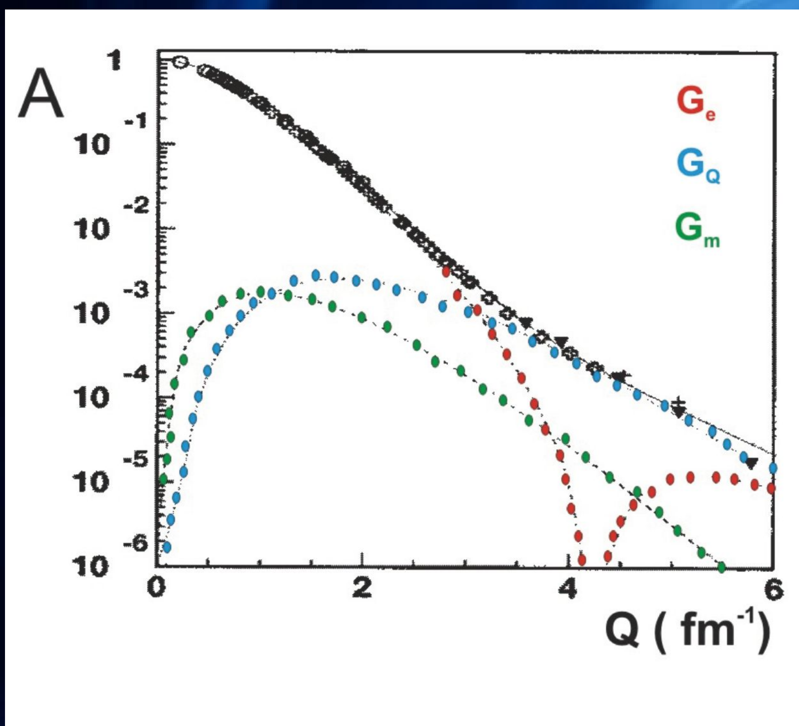
# Elastic e-d scattering

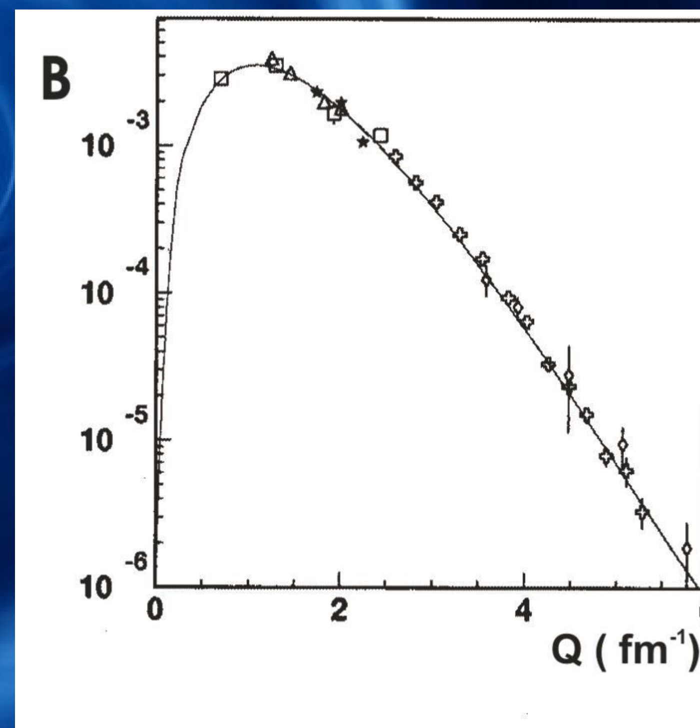
$$\frac{d\sigma}{d\Omega} = \sigma_m (A + B \; tg^2(\theta_e / 2))$$

A – longitudinal and B – transversal structure function

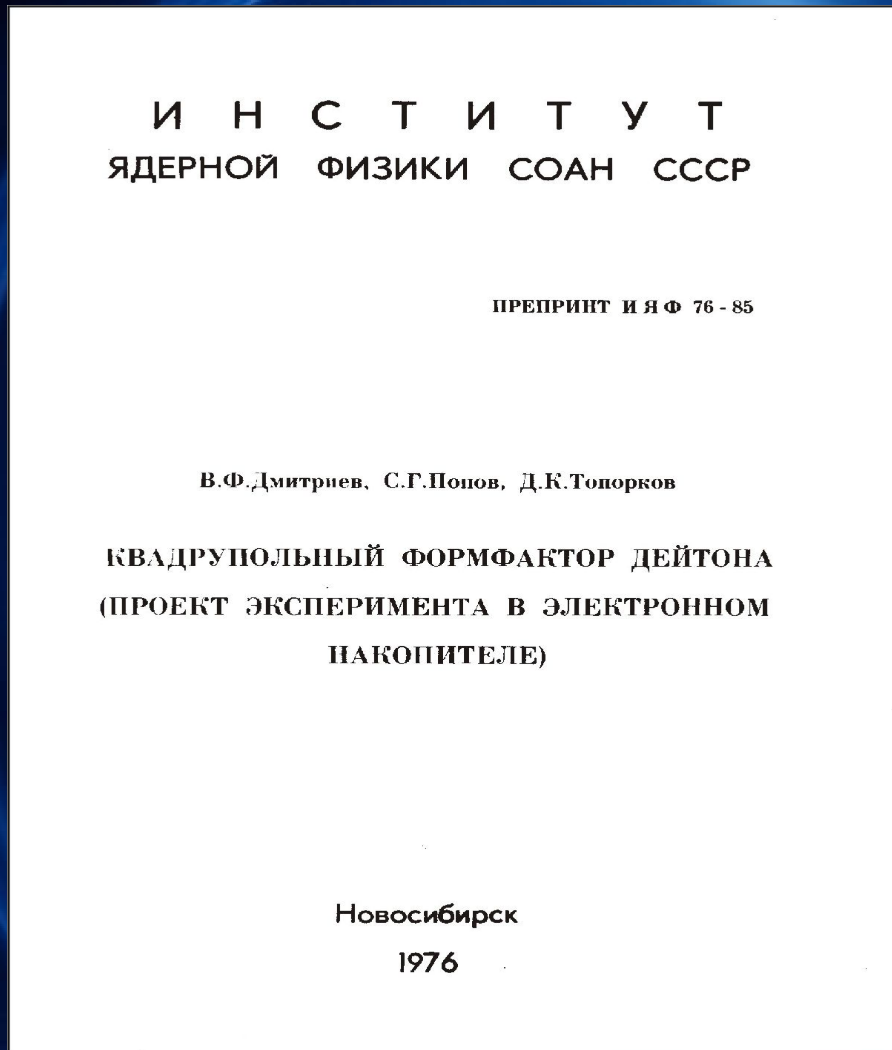
$$\eta = Q^2 / 4M_d^2$$

$Q$ - momentum transfer



# Suggestion to measure the quadrupole form factor of deuteron was stimulated discussion with D.P.Grechukhin



И Н С Т И Т У Т
ЯДЕРНОЙ ФИЗИКИ СОАН СССР

ПРЕПРИНТ И Я Ф 76 - 85

В.Ф.Дмитриев, С.Г.Попов, Д.К.Топорков

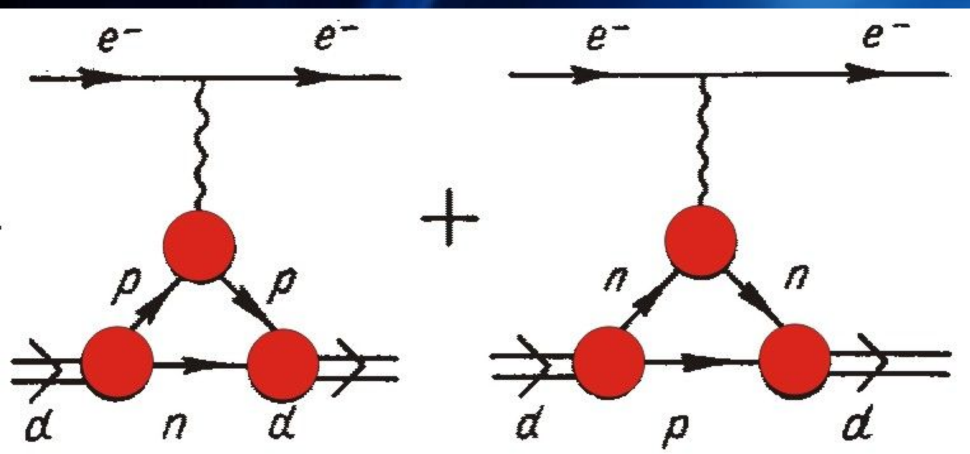
КВАДРУПОЛЬНЫЙ ФОРМФАКТОР ДЕЙТОНА (ПРОЕКТ ЭКСПЕРИМЕНТА В ЭЛЕКТРОННОМ НАКОПИТЕЛЕ)

Новосибирск
1976

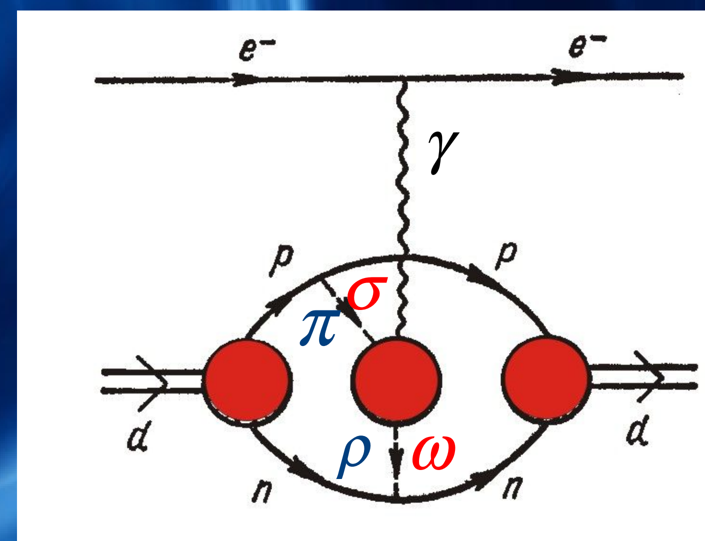
# Elastic scattering by tensor polarized deuteron

$$\frac{d\sigma_{pol}}{d\Omega} = \frac{d\sigma_0}{d\Omega}[1 + \frac{P_{zz}}{\sqrt{2}} \sum_{i=0}^{2} d_{2i}(\theta^*) T_{2i}]$$

$$T_{20} = -\sqrt{2}\frac{x(x+2) + y/2}{1 + 2(x^2 + y)} \quad x = \frac{2}{3}\eta G_Q / G_C \quad y = \frac{2}{3}(1 + 2(1+\eta)tg^2(\theta_e/2))G_M^2 / G_C^2$$



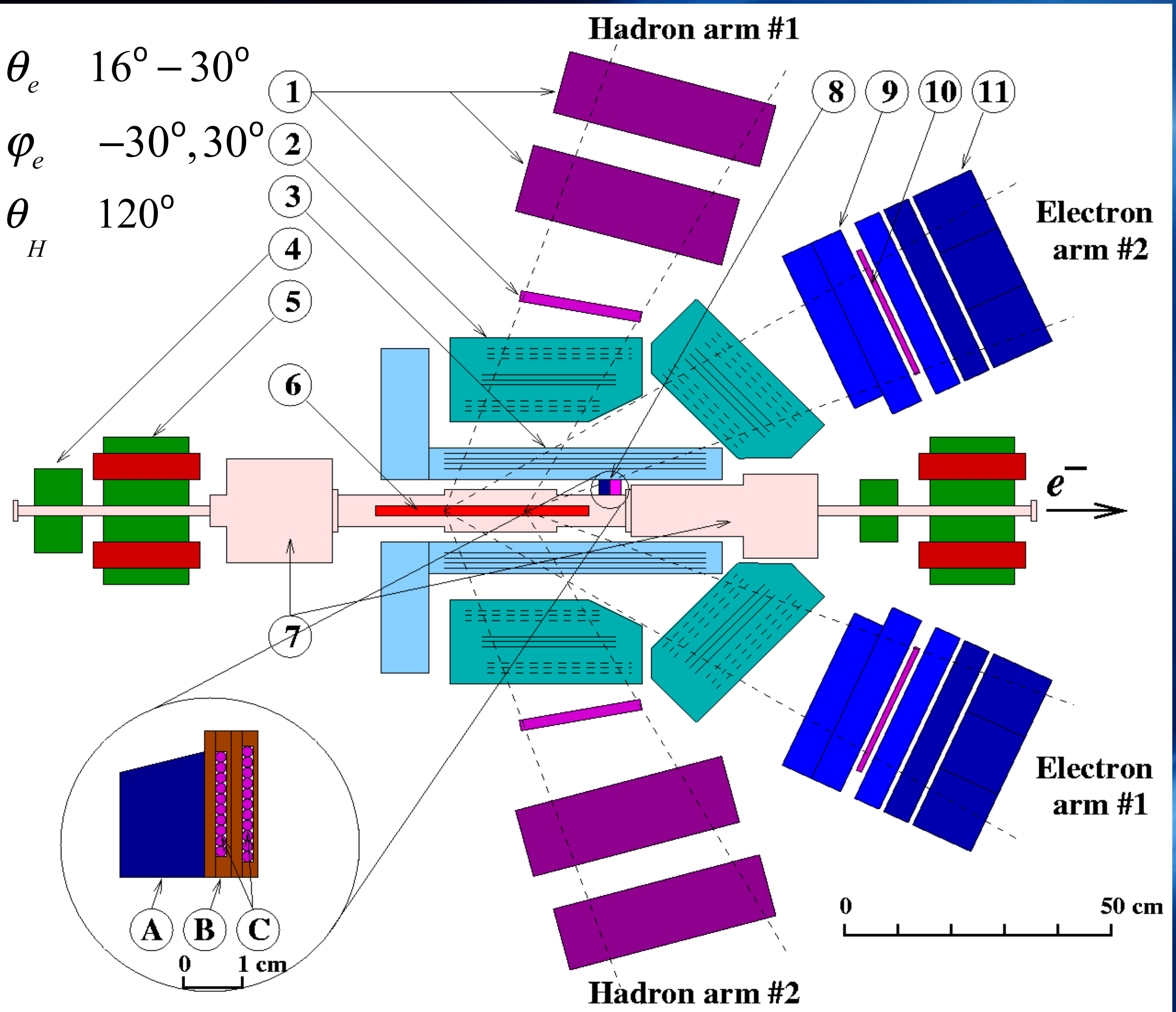

Non relativistic impulse approximation




$$G_Q = \frac{3}{\eta\sqrt{2}}(G_E^p + G_E^n) \quad w(u - \frac{w}{\sqrt{8}}) j_2(\frac{qr}{2}) dr$$

$$G_C = (G_E^p + G_E^n) \quad (u^2 + w^2) j_0(\frac{qr}{2}) dr$$

# Layout of the detector system, side view




1- hodoscope of three layers of plastic scintillators

2,3 – drift chambers

4 – compensating magnet

5 – quadrupole lenses

6 – storage cell

7 – vacuum chamber

8 – detector of low momentum transfer

9 – crystals of CsI

10 – trigger's scintillator

11 – crystals of NaI

A – tungsten convertor
B – body
C – scintillator fibers

# LQ polarimeter features

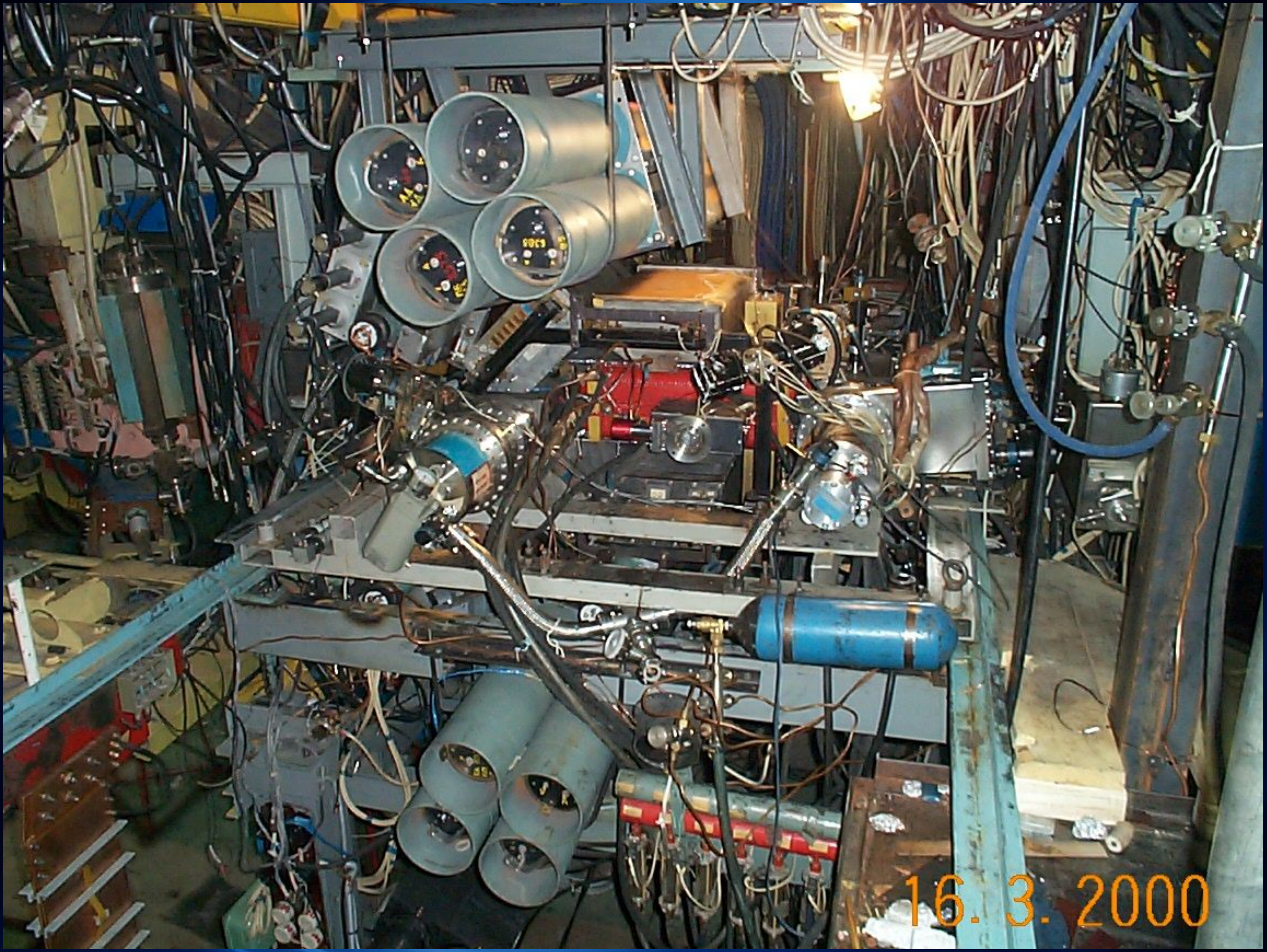
- The measure of asymmetry in elastic *ed* scattering at small momentum transfer, centered at
  $\theta_e = 9.3^\circ$, $Q^2 = 0.105\ (\mathrm{GeV/C})^2$

- At small momentum transfers
  $T_{20} \approx -\sqrt{2/3}\ \boldsymbol{Q}_D\ Q^2$
  $\boldsymbol{Q}_D = 0.2859\ \mathrm{fm}^2$ - deuteron static quadrupole moment

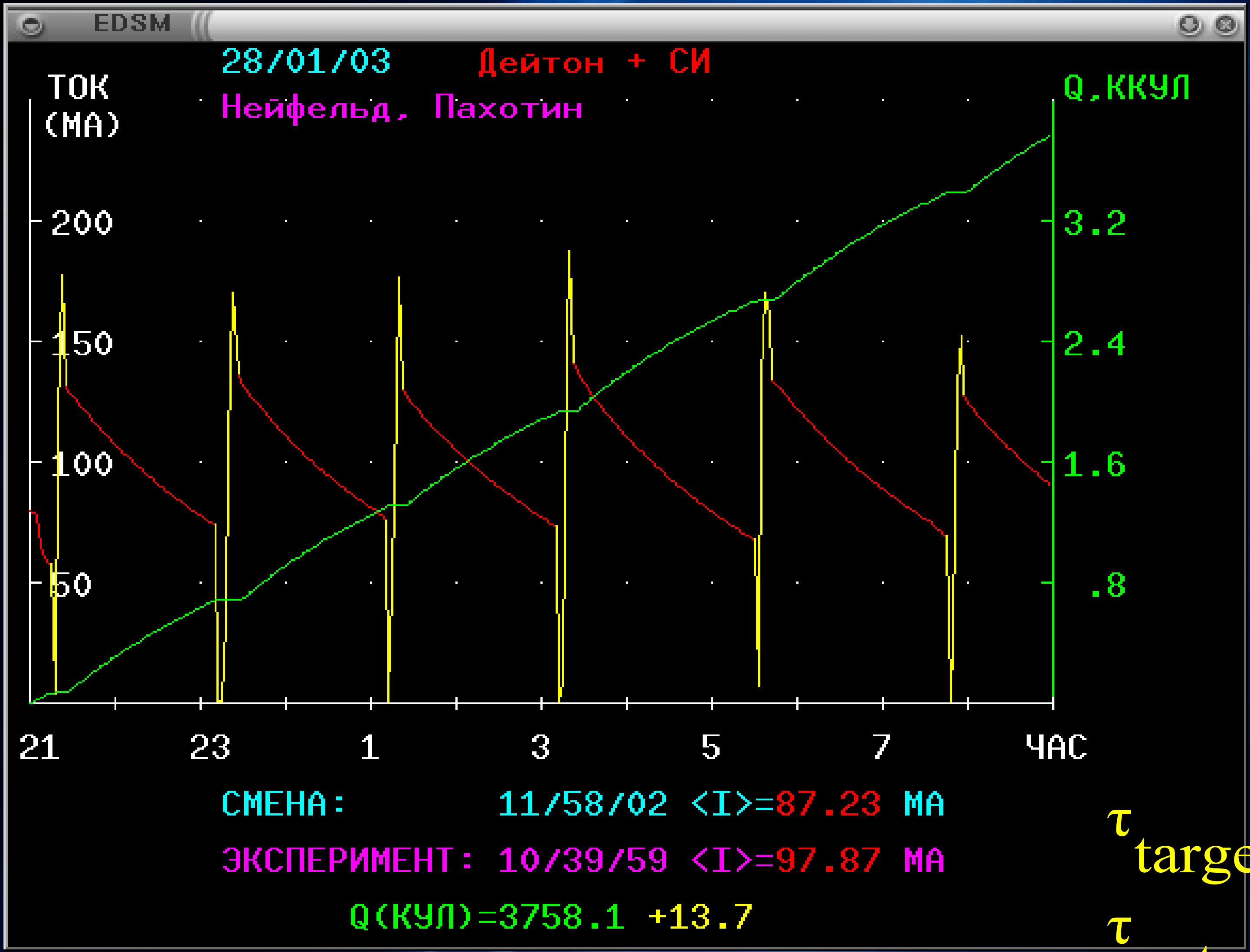
- At $Q^2 = 0.105\ (\mathrm{GeV/C})^2$ all 'reasonable' theoretical predictions for $T_{20}$ coincide within ±5% range

- An absolute measurement of $T_{20}$ performed at NIKHEF, further restricts the models

# Layout of the detector system, side view



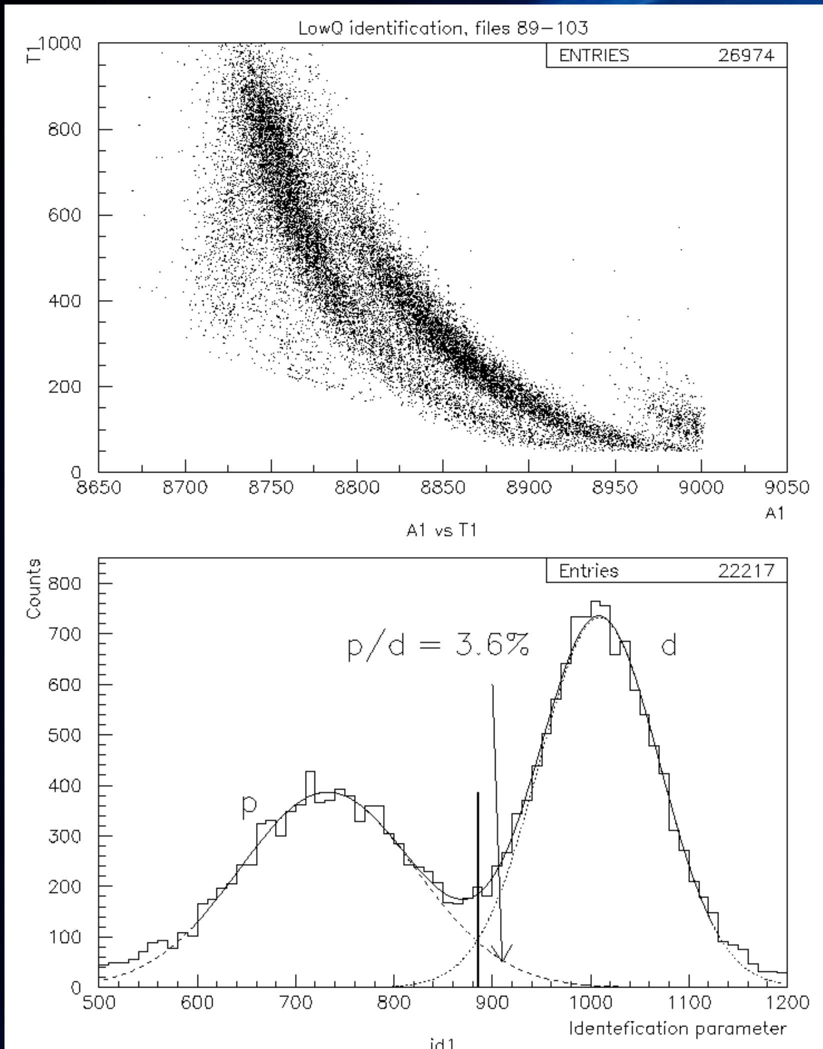
# Beam life-time in the VEPP-3 ring during the experiment




$\tau_{target}$ =8000sec

$\tau_{notarget}$ =20000sec

# The measurement of polarization of the target




$$A^t = \sqrt{2}\,\frac{(N^+ - N^-)}{(N^- P_{zz}^+ - N^+ P_{zz}^-)}$$

$$A^t = \sum_{i=0}^{2} d_{2i} T_{2i}$$

$Q^2 = 2.6\ fm^{-2}$

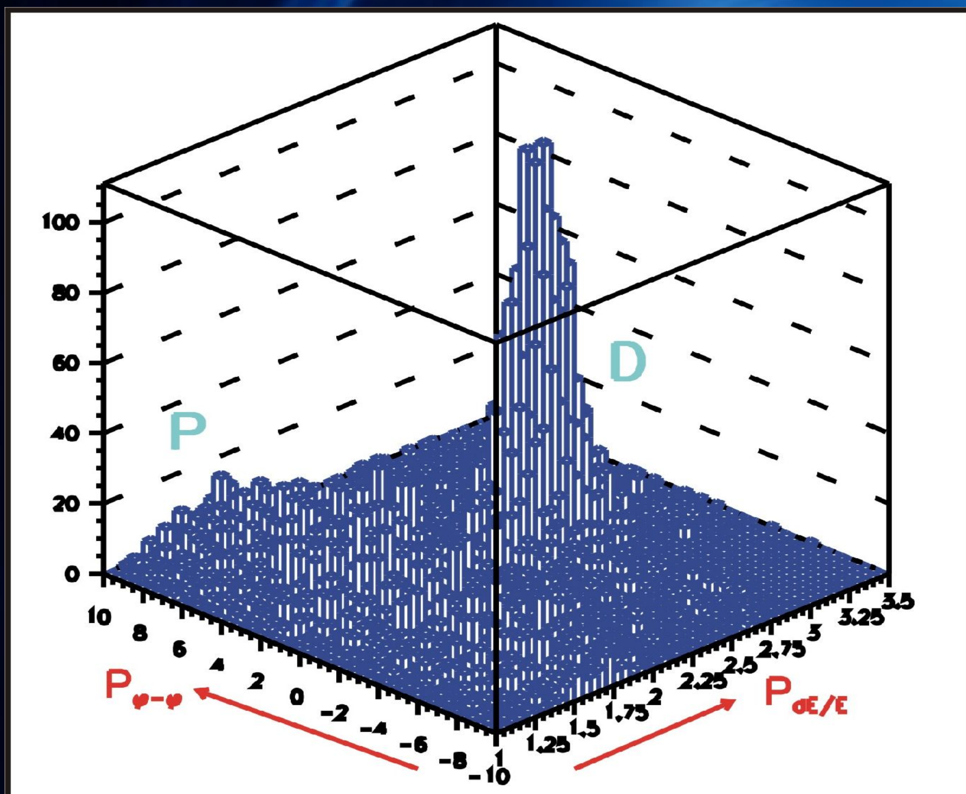
Averaged over the time of experiment polarization of the target

$$P_{ZZ}^+ = 0.397 \quad 0.013 \quad 0.018 \quad 0.012$$

The dominant contributions to the systematic error were given by uncertainties of detector geometry and holding magnetic field direction

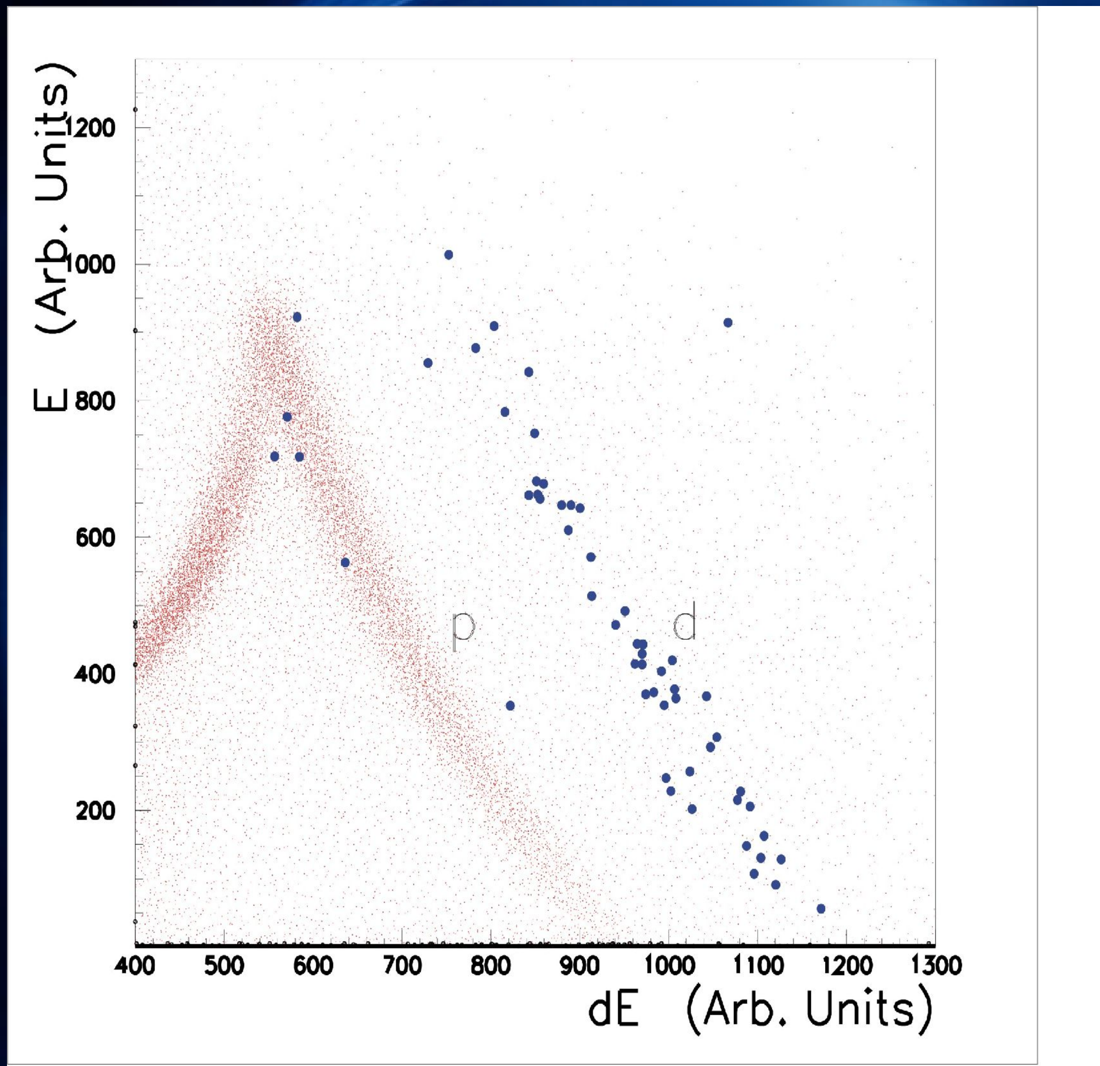
# Selection of the events of elastic $e - D$ scattering

1. (e-d) polar angles correlation
2. (e-d) azimuthal angles correlation
3. Electron scattering angle – deuteron energy correlation
4. Analisys $\Delta E - E$ in hadron arm of the detector
5. Time of flight analisys in hadron arm of the detector




The background was find to be:
for high $Q^2$ 3.0+/-1.5%
for small $Q^2$ 8+/-2%

# Selection of the events of elastic $e-D$ scattering with $\Delta E-E$ method



# The results on $T_{20}$ and $T_{21}$ measurement

$$A^t = \sqrt{2}\,\frac{(N^+ - N^-)}{(N^- P_{zz}^+ - N^+ P_{zz}^-)}$$

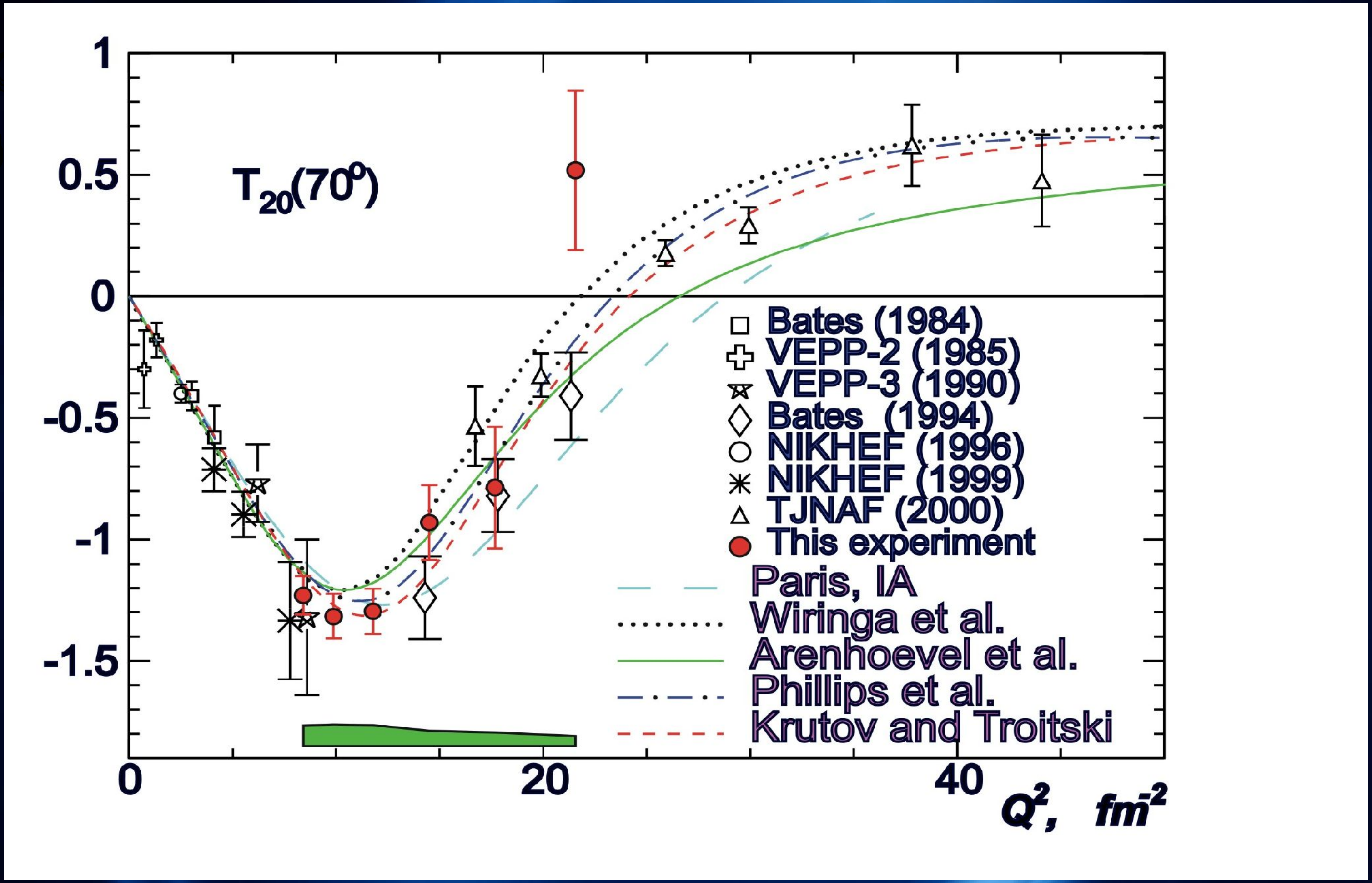
$$A^t = \sum_{i=0}^{2} d_{2i} T_{2i}$$

| $Q^2$ fm$^{-2}$ | $\theta_e$ deg | $T_{20}$ | $T_{21}$ | $G_C$ | $G_Q$ |
|---|---|---|---|---|---|
| 8.41 | 16.8 | $-1.294^{\pm 0.084}_{\pm 0.088}$ | $.234^{\pm 0.093}_{\pm 0.022}$ | $0.0403^{+0.0046}_{-0.0082}$ | $1.772^{+0.320}_{-0.233}$ |
| 9.88 | 18.3 | $-1.398^{\pm 0.100}_{\pm 0.093}$ | $.318^{\pm 0.086}_{\pm 0.142}$ | $0.0257^{+0.0052}_{-0.0018}$ | $1.279^{+0.063}_{-0.182}$ |
| 11.78 | 20.1 | $-1.384^{\pm 0.102}_{\pm 0.092}$ | $.521^{\pm 0.083}_{\pm 0.150}$ | $0.0143^{+0.0035}_{-0.0039}$ | $0.877^{+0.062}_{-0.077}$ |
| 14.50 | 22.5 | $-0.982^{\pm 0.169}_{\pm 0.066}$ | $.435^{\pm 0.140}_{\pm 0.111}$ | $0.0041^{+0.0032}_{-0.0026}$ | $0.549^{+0.017}_{-0.029}$ |
| 17.67 | 25.1 | $-0.818^{\pm 0.269}_{\pm 0.058}$ | $.808^{\pm 0.279}_{\pm 0.092}$ | $0.0011^{+0.0028}_{-0.0023}$ | $0.336^{+0.010}_{-0.014}$ |
| 21.56 | 28.1 | $0.557^{\pm 0.342}_{\pm 0.044}$ | $.299^{\pm 0.410}_{\pm 0.057}$ | $-.0078^{+0.0025}_{-0.0020}$ | $0.154^{+0.032}_{-0.037}$ |

The upper errors of $T_{20}$ and $T_{21}$ is statistical, the lower one is systematic

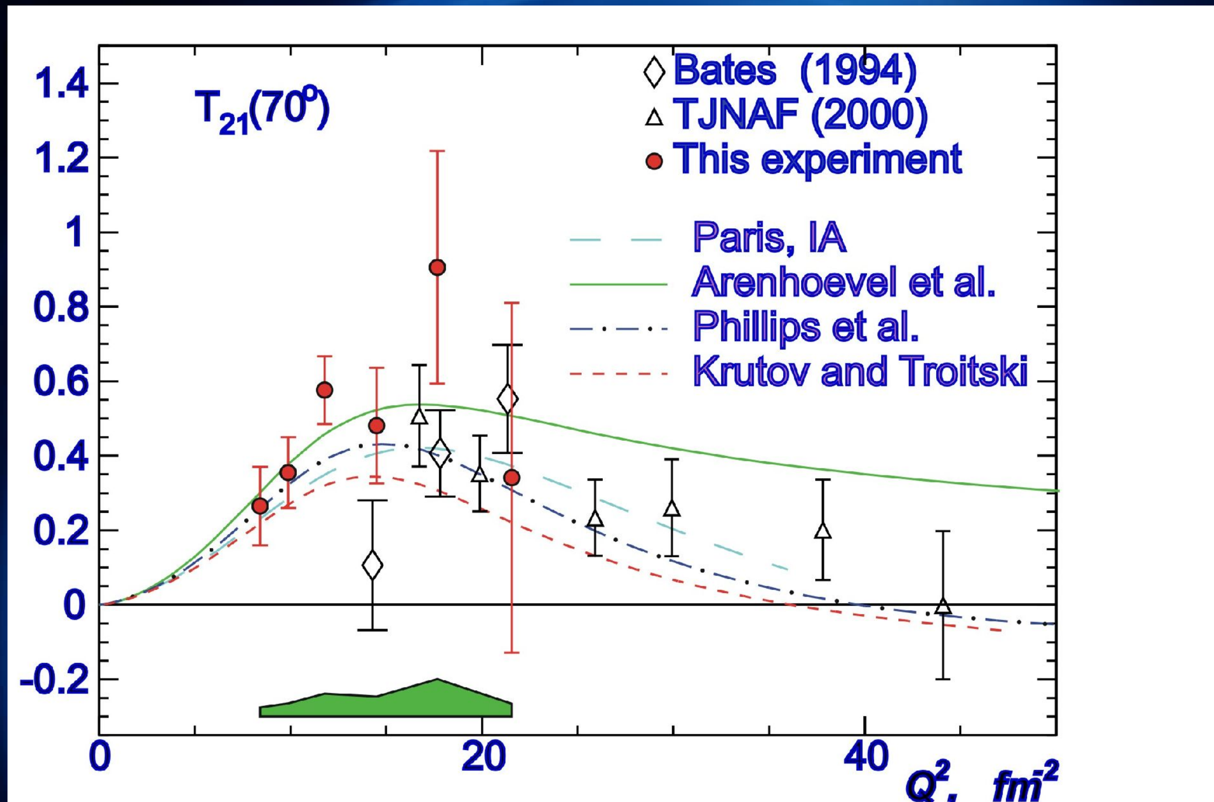
# The measurement of $T_{20}$ in elastic e-d scattering at VEPP-3 storage ring

Phys. Rev. Lett. 90(2003)072501



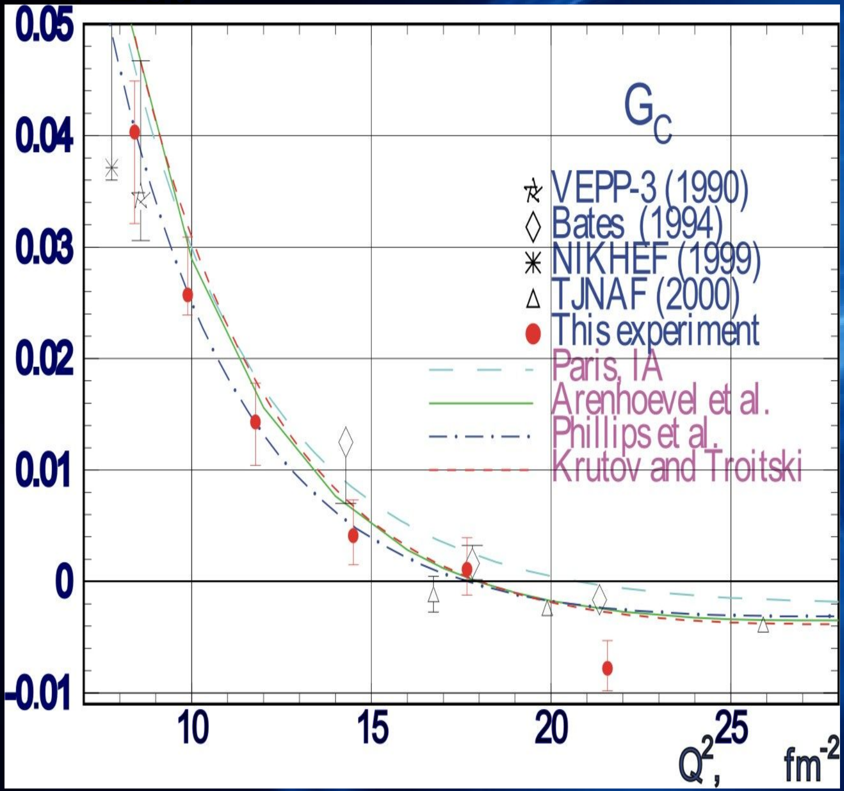

M.Lacombe et al. Non-Relativistic Impulse Approximation
R.B.Wiringa et al. Argonne-V18 full: NRIA + RC + MEC
H.Arenhovel et al. BONN: NRIA + RC + MEC
D.R.Phyllips: Current-Covariant Description of Relativistic Bound States +MEC
A.Krutov and V. Troitsky: RIA in Instant Form of the Relativistic Hamilton Dinamics

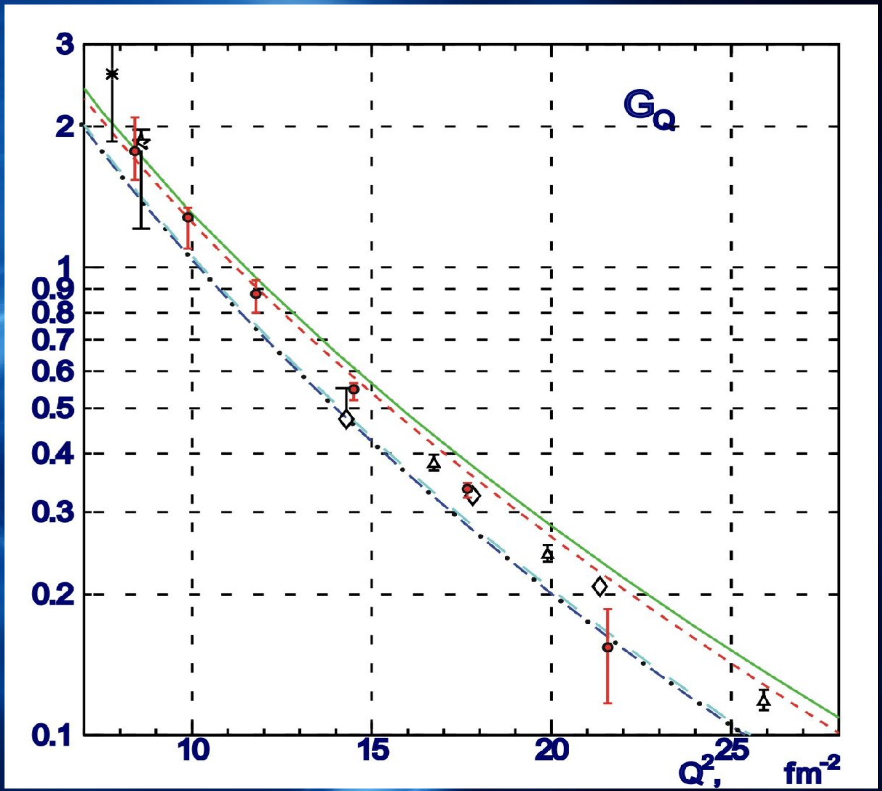
# The measurement of $T_{21}$ in elastic e-d scattering at VEPP-3 storage ring




| Theory | Paris | Aren. | Phil. | Krutov | Wiringa |
|---|---|---|---|---|---|
| $T_{20}$ | 3.43 | 1.87 | 1.40 | 1.41 | 1.49 |
| $T_{21}$ | 1.59 | 0.58 | 1.18 | 2.25 | — |
| $G_c$ | 2.88 | 1.38 | 0.83 | 1.83 | — |
| $G_Q$ | 4.23 | 7.11 | 5.21 | 2.74 | — |

# Experimental results and theoretical predictions for monopole $G_C$ and quadrupole $G_Q$ form factors of deuteron



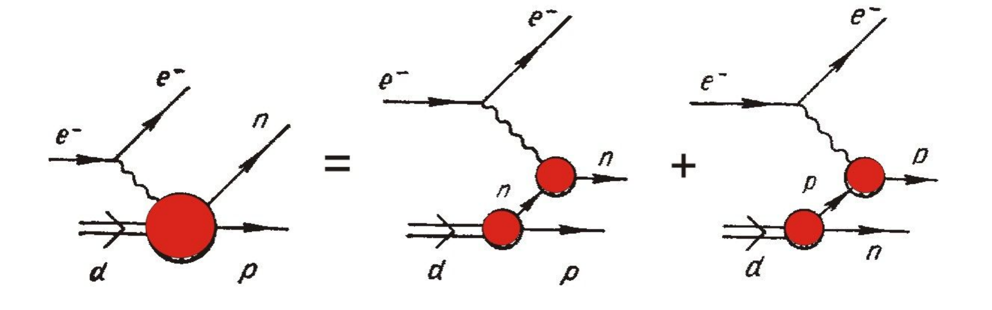




The node position from our data was found at $Q^2 = 16.9^{+1.8}_{-1.0}$ fm$^{-2}$ and from all data and this experiment at $Q^2 = 17.41 \pm 0.32$ fm$^{-2}$

# Conclusions

- The tensor analyzing power components $T_{20}$ and $T_{21}$ have been measured at momentum transfer 8.4 – 21.6 fm$^{-2}$ with the use of tensor polarized target.
- The results don't contradict the previous measurements.
- In the region 8-12 fm$^{-2}$ new results significantly improve the accuracy for $T_{20}$ and $T_{21}$.
- Charge form factors $G_C$ and $G_Q$ are extracted from the obtained data and A and B data in important range of momentum transfer where the first node of monopole form factor is located.
- Comparison with several theoretical predictions shows some advantage of relativistic calculations in general.

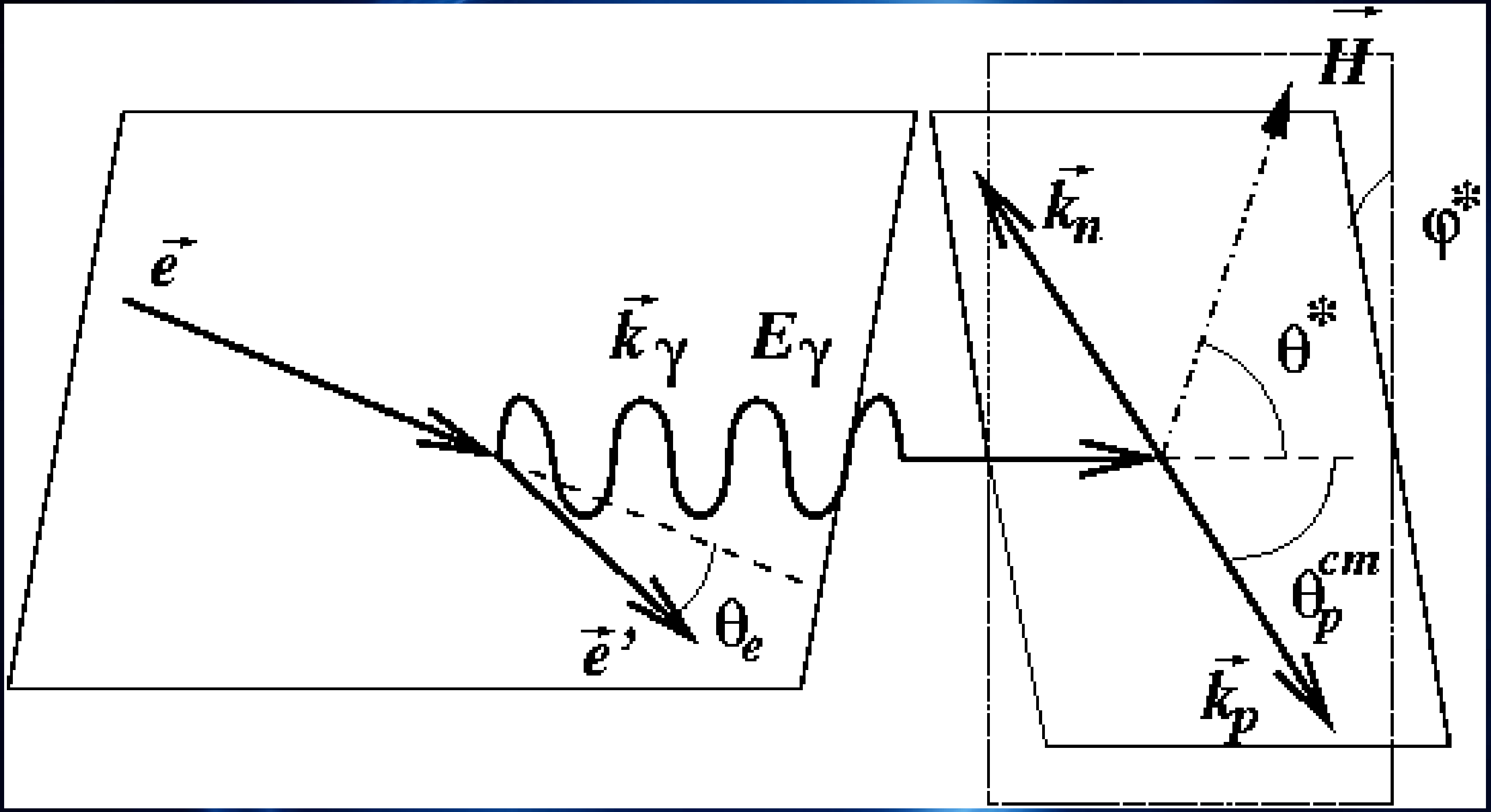
# Photodisintegration of polarized deuteron




**Scattering angle is small, therefore $q^2$ close to zero and photon is almost real.**
**Process is photodisintegration**

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega}\left\{1 + \frac{1}{\sqrt{2}} P_{ZZ} \ \frac{1}{2}(3\cos^2\theta^* - 1)T_{20} + \sqrt{\frac{3}{8}}\sin 2\theta^* \cos\varphi^* T_{21} + \sqrt{\frac{3}{8}}\sin^2\theta^* \cos 2\varphi^* T_{22} \right\}$$

## Definition of kinematic variables for the reaction ( $\gamma$d, pn) in the center of mass frame

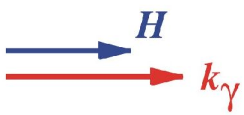


# Measurement of tensor analysing powers

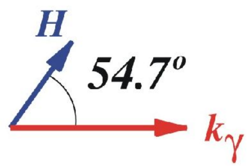
...through measurement of tensor moments :

$$a^T = \frac{N_+ - N_-}{P_{zz}^+ N_- - P_{zz}^- N_+}$$

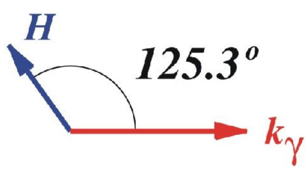
Separation of $T_{20}$, $T_{21}$ And $T_{22}$ — By measuring under the different orientation of the magnetic field




$$a_0^T \sim c_0 \cdot T_{20}$$




$$a_1^T \sim +c_1 \cdot T_{21} \; +c_2 \cdot T_{22}$$

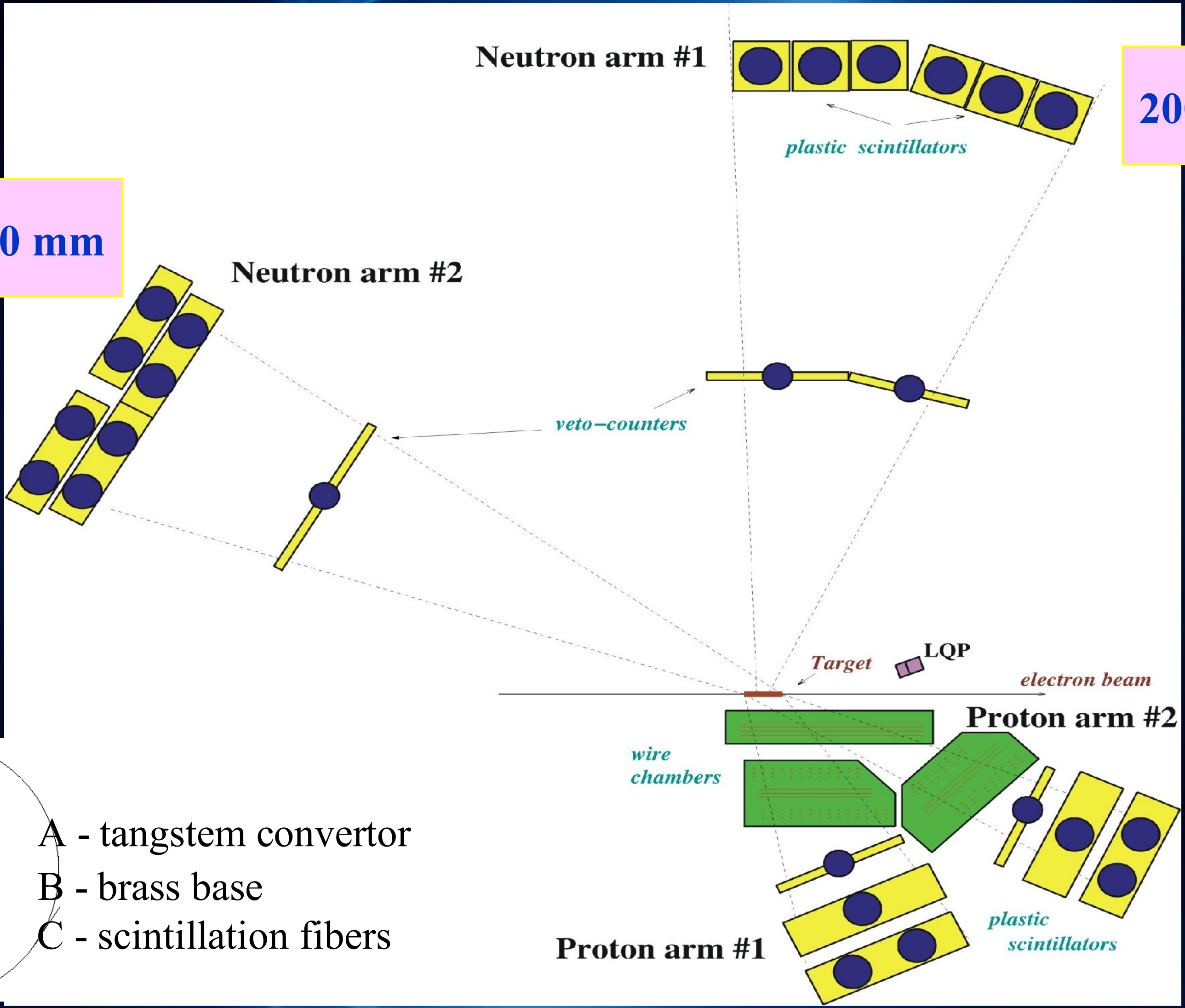



$$a_2^T \sim -c_1 \cdot T_{21} \; +c_2 \cdot T_{22}$$

Then

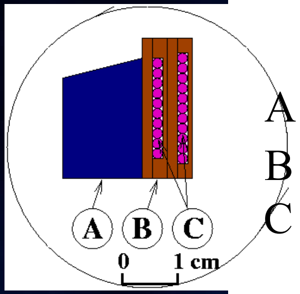
$$T_{20} = \frac{a_0^T}{c_0}, \qquad T_{21} = \frac{a_1^T - a_2^T}{2c_1}, \qquad T_{22} = \frac{a_1^T + a_2^T}{2c_2}$$

# The layout of the detector system, side view




200x200x1000 mm

120x400x1000 mm




A - tangstem convertor

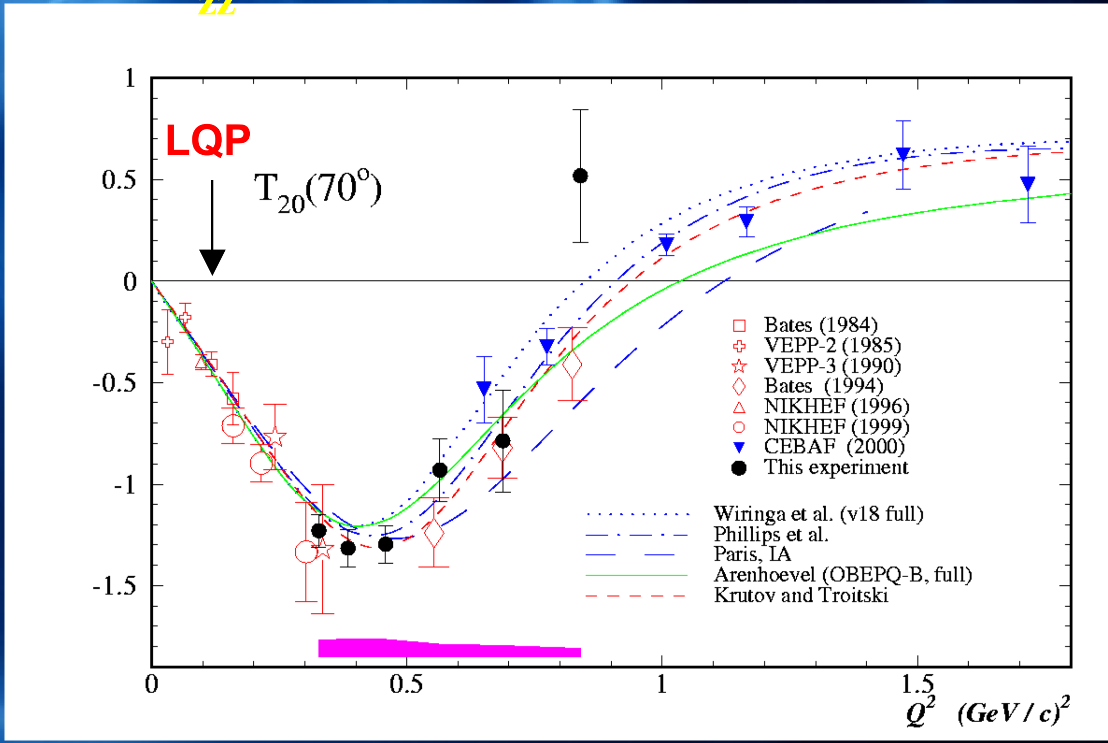
B - brass base

C - scintillation fibers

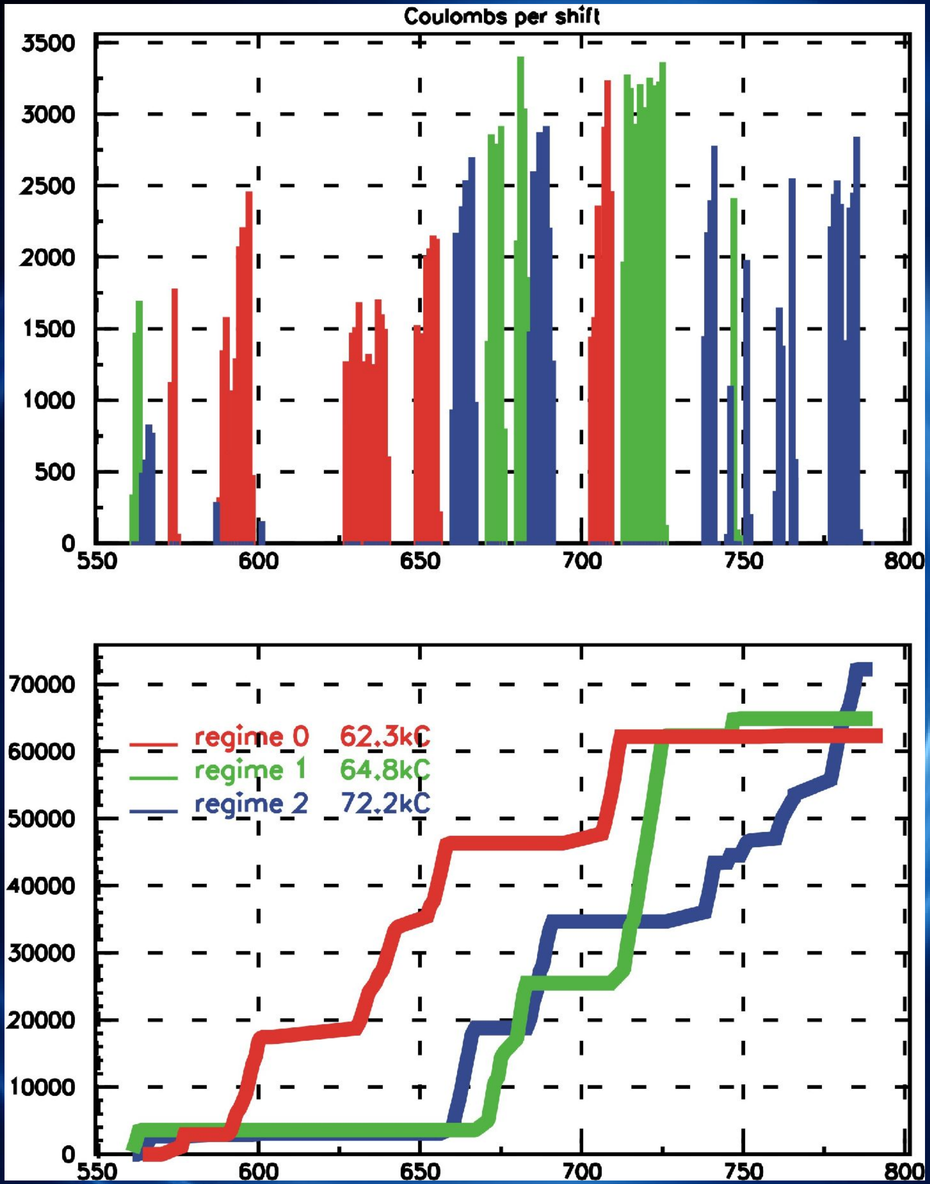
The average degree of target polarization during the run was found to be

**$P^{+}_{zz}$ = 0.341+-0.025+-0.011**

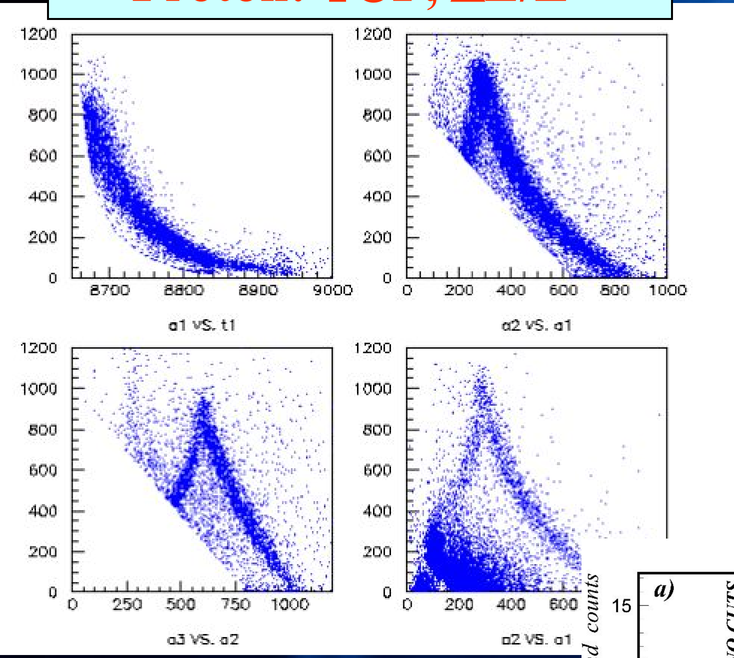
**$P^{-}_{zz}$ =- 0.580+-0.042+-0.019**



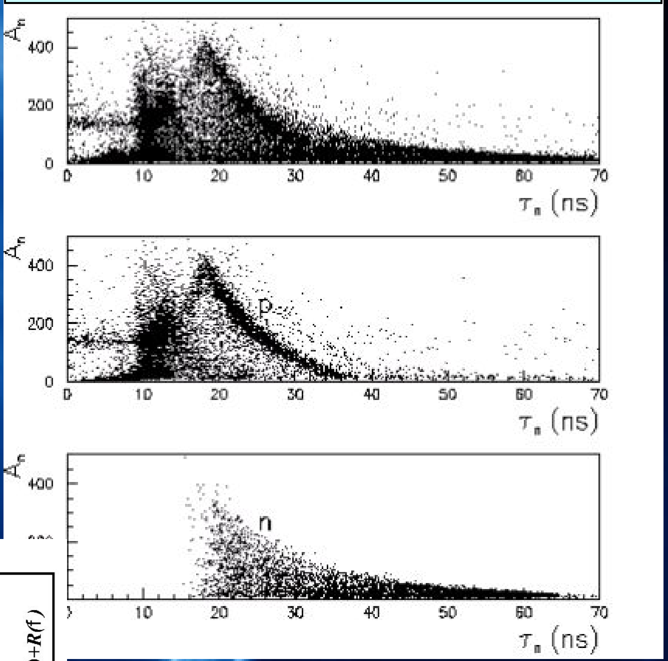
# Charge accumulation during the experiment



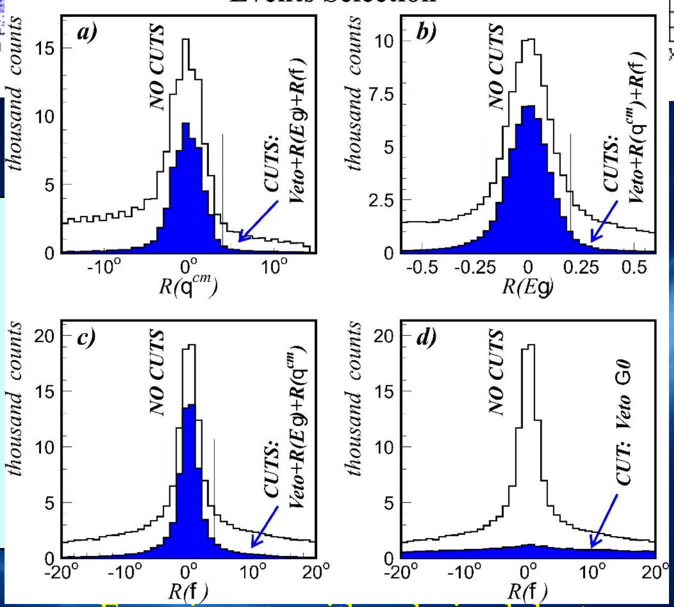
## Proton: TOF, ΔE/E




## Neutron: TOF, charge veto




**Events Selection**



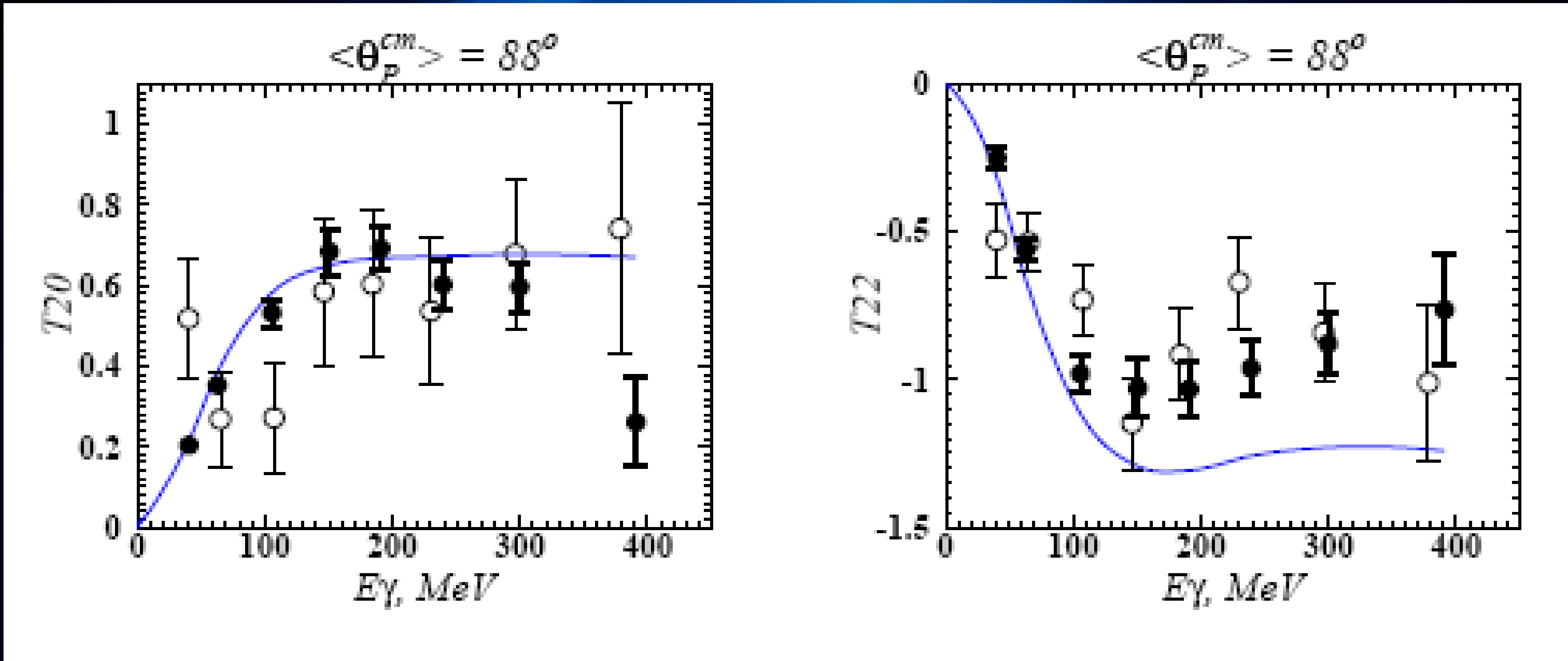

## Kinematic correlations:

**p-n energy**

**p-n polar angle**

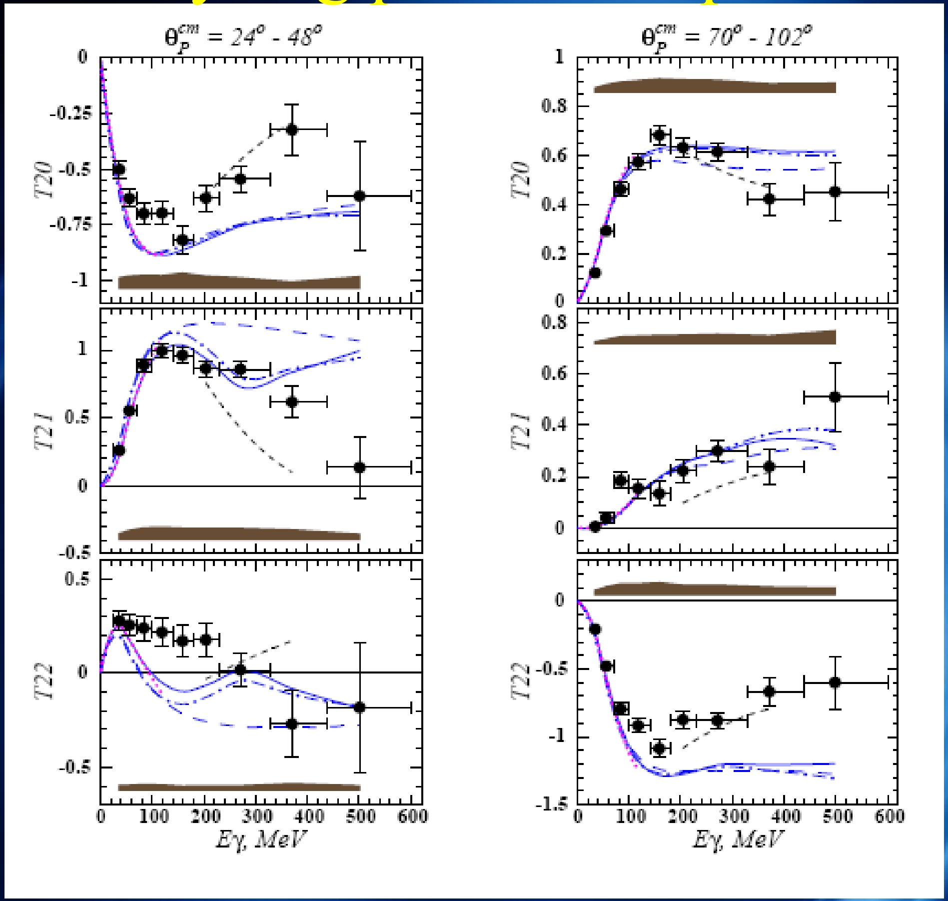
**p-n azimuthal angle**

# Phys. Rev. Lett. 98, 182303 (2007)



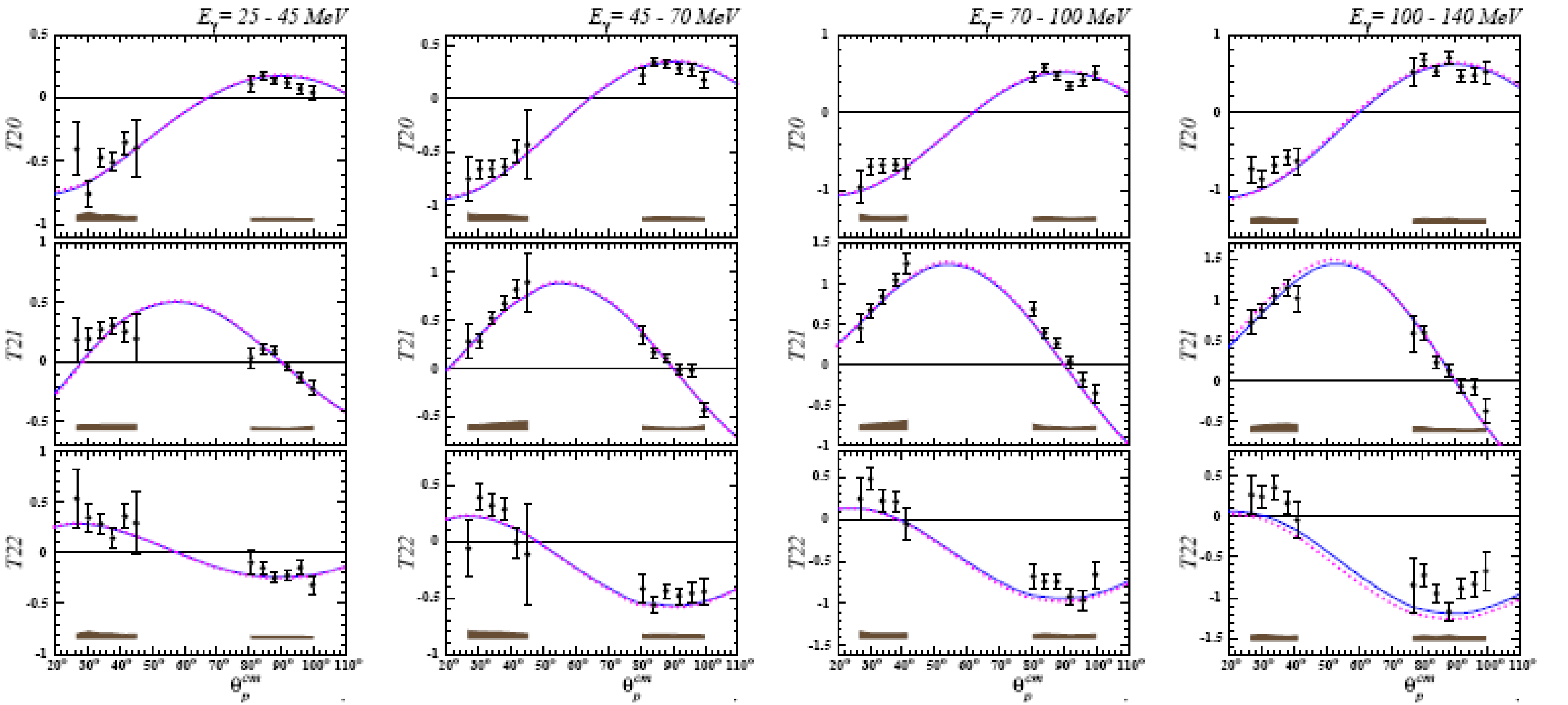

Comparison of previous data [Phys.Lett. B 302, 23 (1993)] (open circles) and this work (filled circles). Only the part of the new data which corresponds to the kinematic conditions of the previous measurement is shown. Theoretical curve is the full calculation from [F. Ritz, H. Arenh¨ovel, and T. Wilbois, Few-Body Syst. 24, 123 (1998)]

# Tensor analyzing powers vs. photon energy.



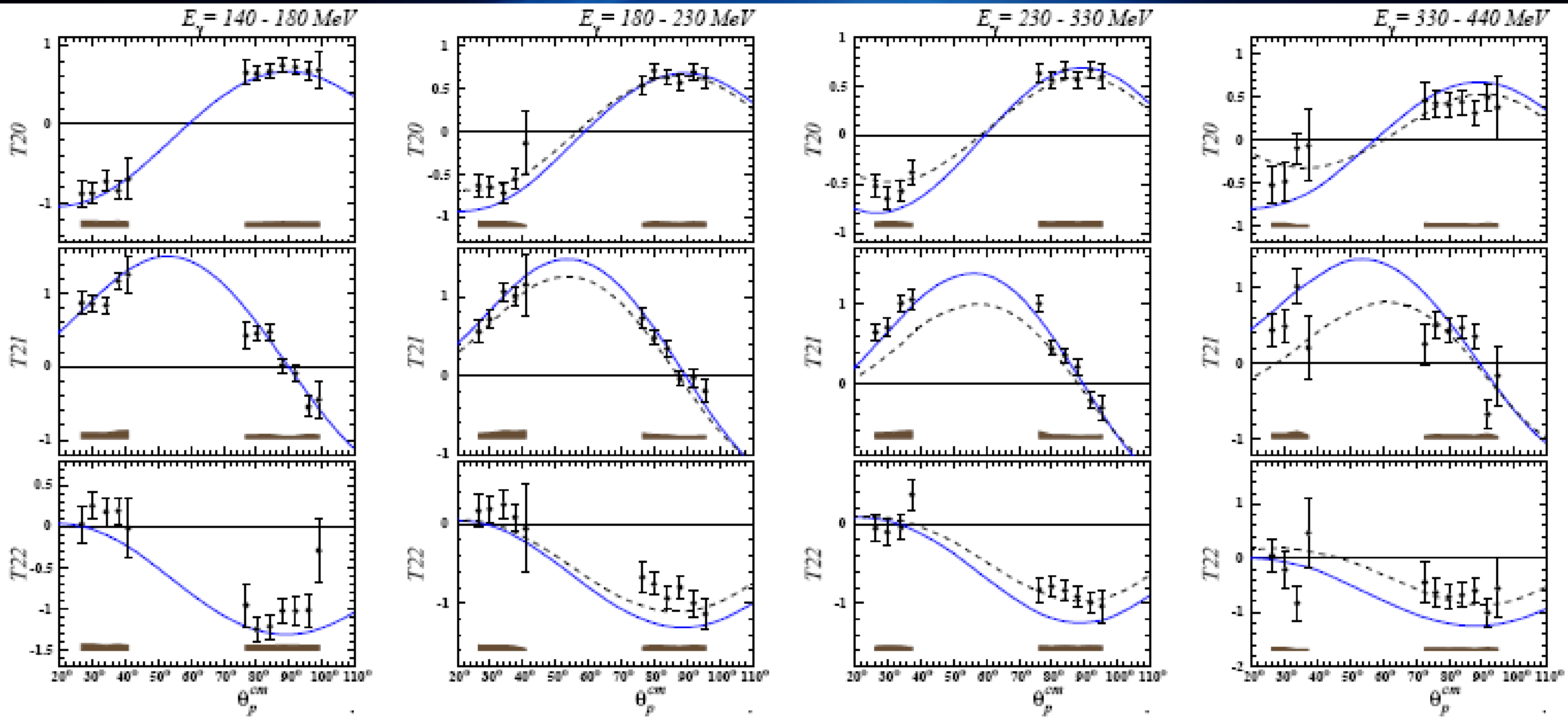

Vertical bars are statistical uncertainties; horizontal bars indicate the bin size. Shaded bands show systematic uncertainties. Theoretical predictions are from Arenh¨ovel ”N+MEC” (blue long-dashed line), ”N+MEC+IC” (blue dash-dotted line), and ”N+MEC+IC+RC”(solid line) models, from Levchuk [Few-Body Syst. 19,77(1995)] (magenta dotted line), and from Schwamb [Hab. Thises,2006] (black short-dashed line).

# Tensor analyzing powers vs. proton emission angle




Theoretical predictions are from Arenh¨ovel [7] ”N+MEC” (blue long-dashed line), ”N+MEC+IC” (blue dash-dotted line), and ”N+MEC+IC+RC” (solid line) models, from Levchuk [8] (magenta dotted line), and from Schwamb [10] (black short-dashed line).

# Tensor analyzing powers vs. proton emission angle

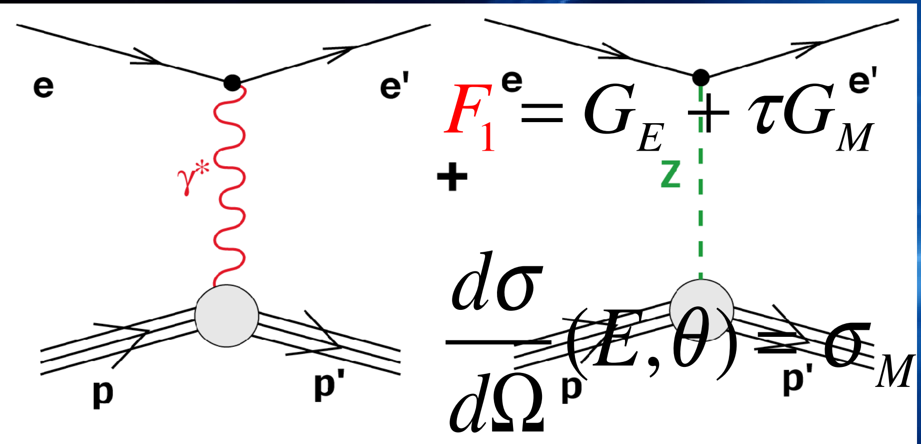



Theoretical predictions are from Arenh¨ovel ”N+MEC” (blue long-dashed line), ”N+MEC+IC” (blue dash-dotted line), and ”N+MEC+IC+RC” (solid line) models, from Levchuk (magenta dotted line), and from Schwamb (black short-dashed line).

# Summary

- A new measurement of tensor analyzing powers T20, T21 and T22 in deuteron photodisintegration, substantially enhancing the quality and kinematic span of the existing experimental data, has been performed.
- Theoretical calculations provide an excellent description of these polarization data below pion production threshold, while above pion production threshold a very good description of T20 and T22 is demonstrated by a novel approach incorporating $\pi$-MEC retardation mechanism.
- The remaining discrepancies could reflect the theoretical uncertainties or some missing or poorly modeled underlying dynamics.

# Two photon exchange contribution in elastic e-p scattering




$$F_1 = G_E + \tau G_M$$

$$F_2 = \frac{G_M - G_E}{\kappa(1+\tau)} \qquad \tau = \frac{Q^2}{4M^2}$$

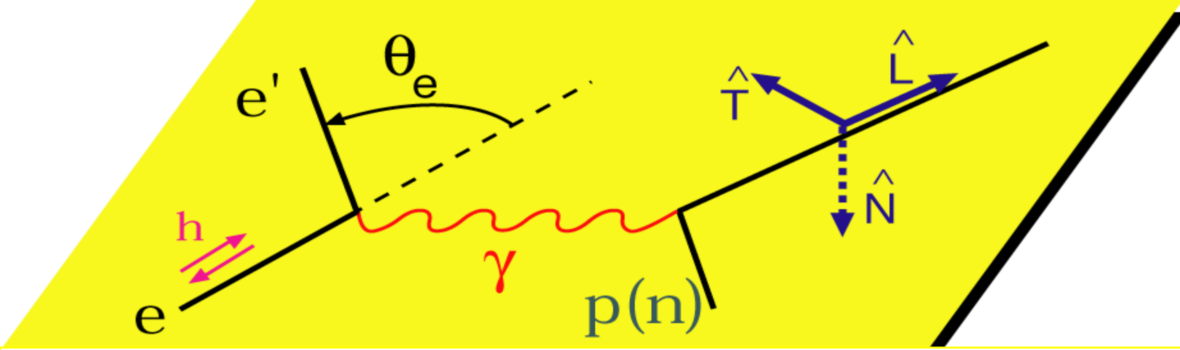
$$\frac{d\sigma}{d\Omega}(E,\theta) = \sigma_M \left[ \frac{G_E^2 + \tau G_M^2}{1+\tau} + 2\tau G_M^2 \tan^2\left(\frac{\theta}{2}\right) \right]$$

$$\sigma_R(Q^2,\varepsilon) = \varepsilon\left(1+\frac{1}{\tau}\right)\frac{E}{E'}\frac{\sigma(E,\theta)}{\sigma_{Mott}} = (G_M^p)^2(Q^2) + \frac{\varepsilon}{\tau}(G_E^p)^2(Q^2)$$

$$Q^2 = 4EE'\sin^2\left(\frac{\theta}{2}\right) \qquad \varepsilon = \frac{1}{1+2(1+\tau)\tan^2(\theta/2)}$$

$G_E$ 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 $G_E/G_M$

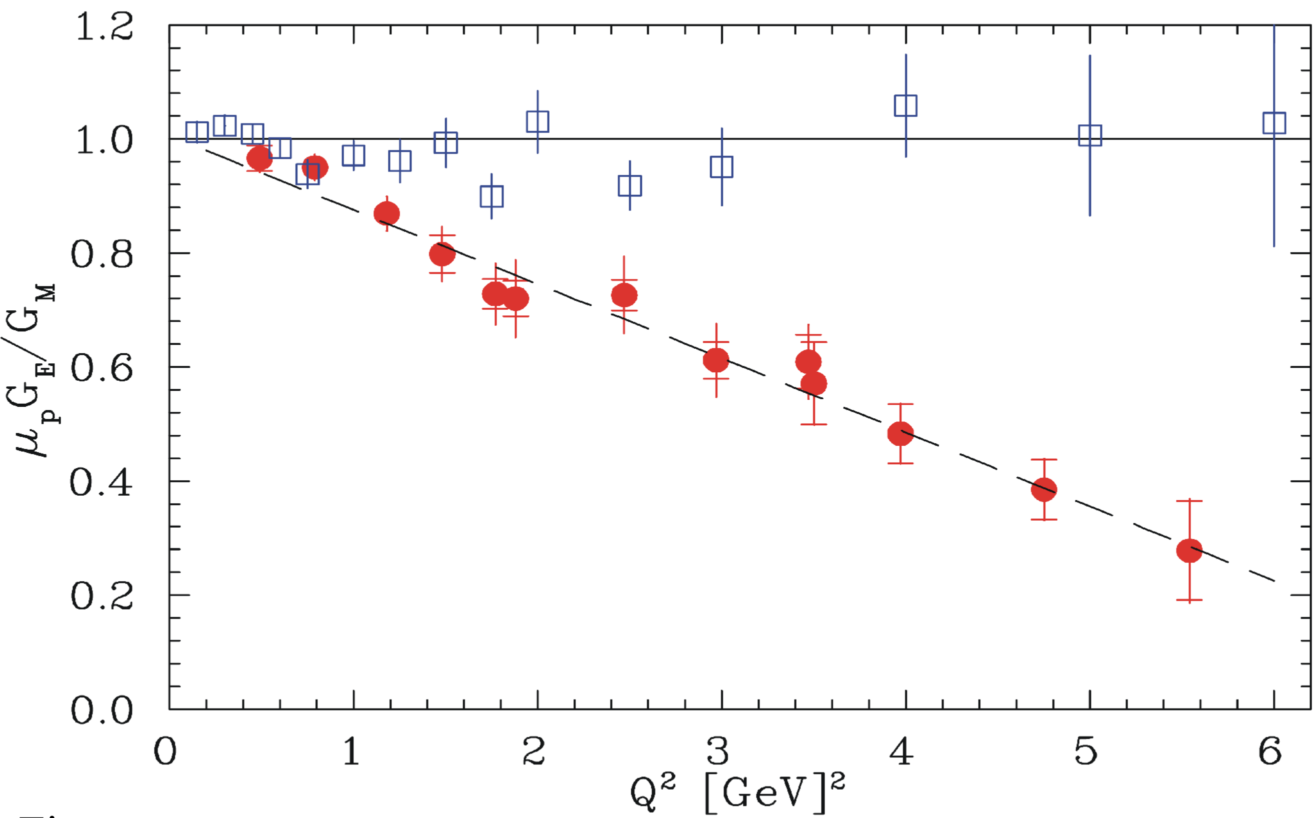



Figure: comparison of form factors ratio, obtained by Rosenbluth technique (hollow squares) with data of polarized measurements (full circles).

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:**

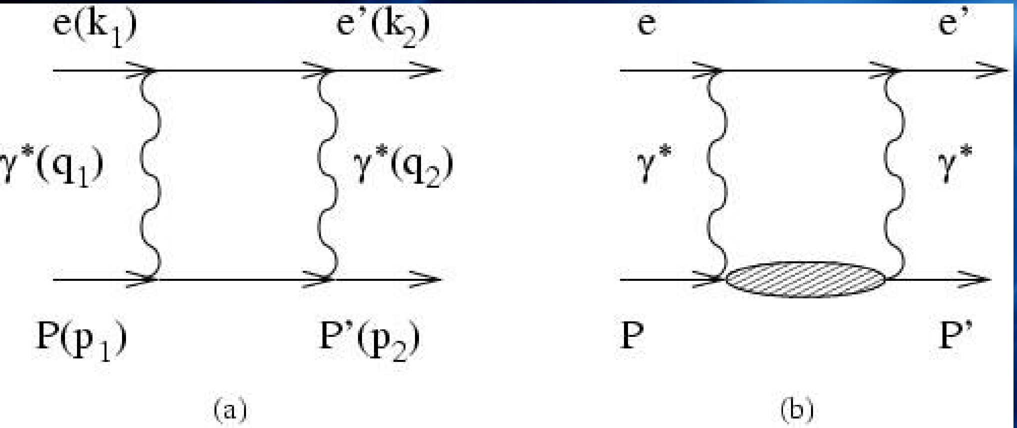
- **radiative corrections;**
- **two photons exchange contributions.**

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

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
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

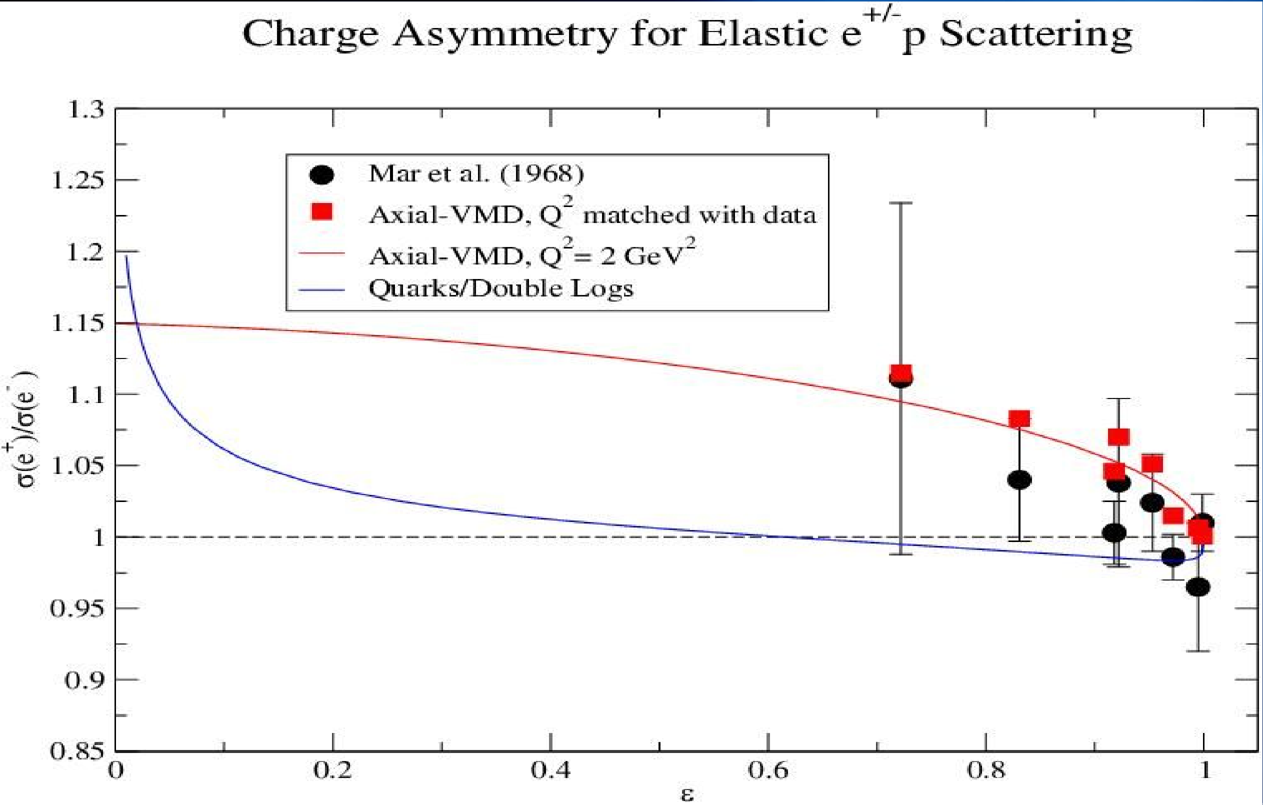
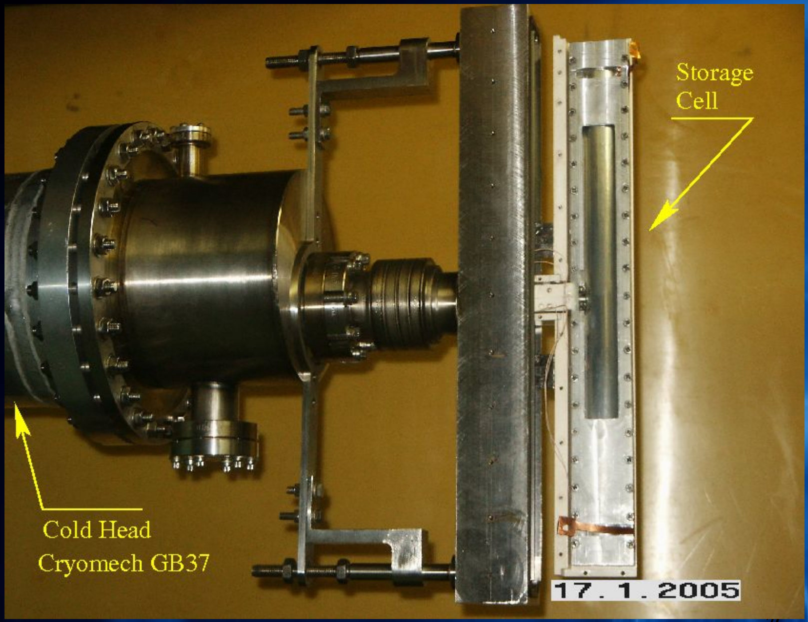


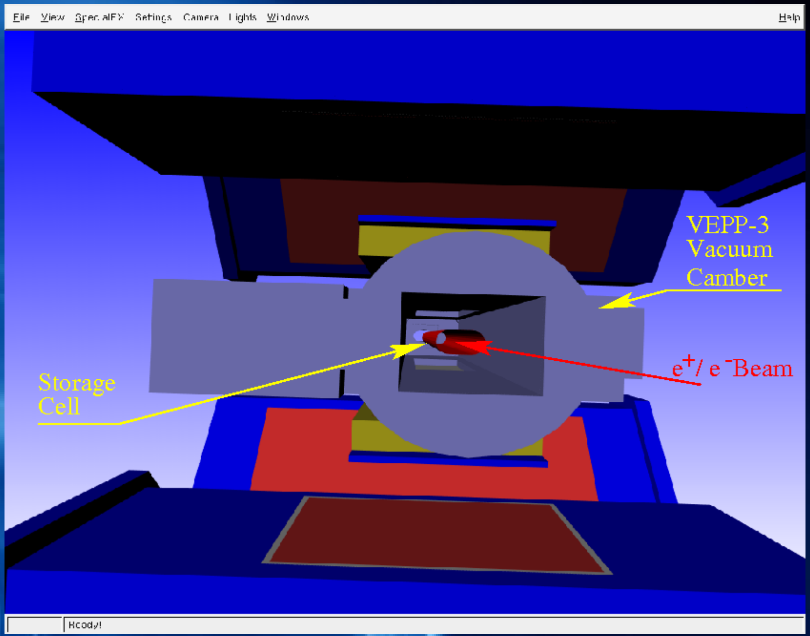

Figure: theoretical predictions (square points and curves) and experimental data (circles) for the ratio $R = \sigma(e^+)/\sigma(e^-)$ as a function of $\varepsilon$.

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: $\delta R/R$ : 5% were $R = \sigma(e^+)/\sigma(e^-)$ ,or scattering angles were too small and therefore $\varepsilon$ - where most theories predict $R$=1 (see Fig.)**

**We performed a first attempt to measure 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 ) $\varepsilon$= 0.90, 0.45 and $Q^2$ = 0.3, 1.5 $GeV^2/c^2$).**



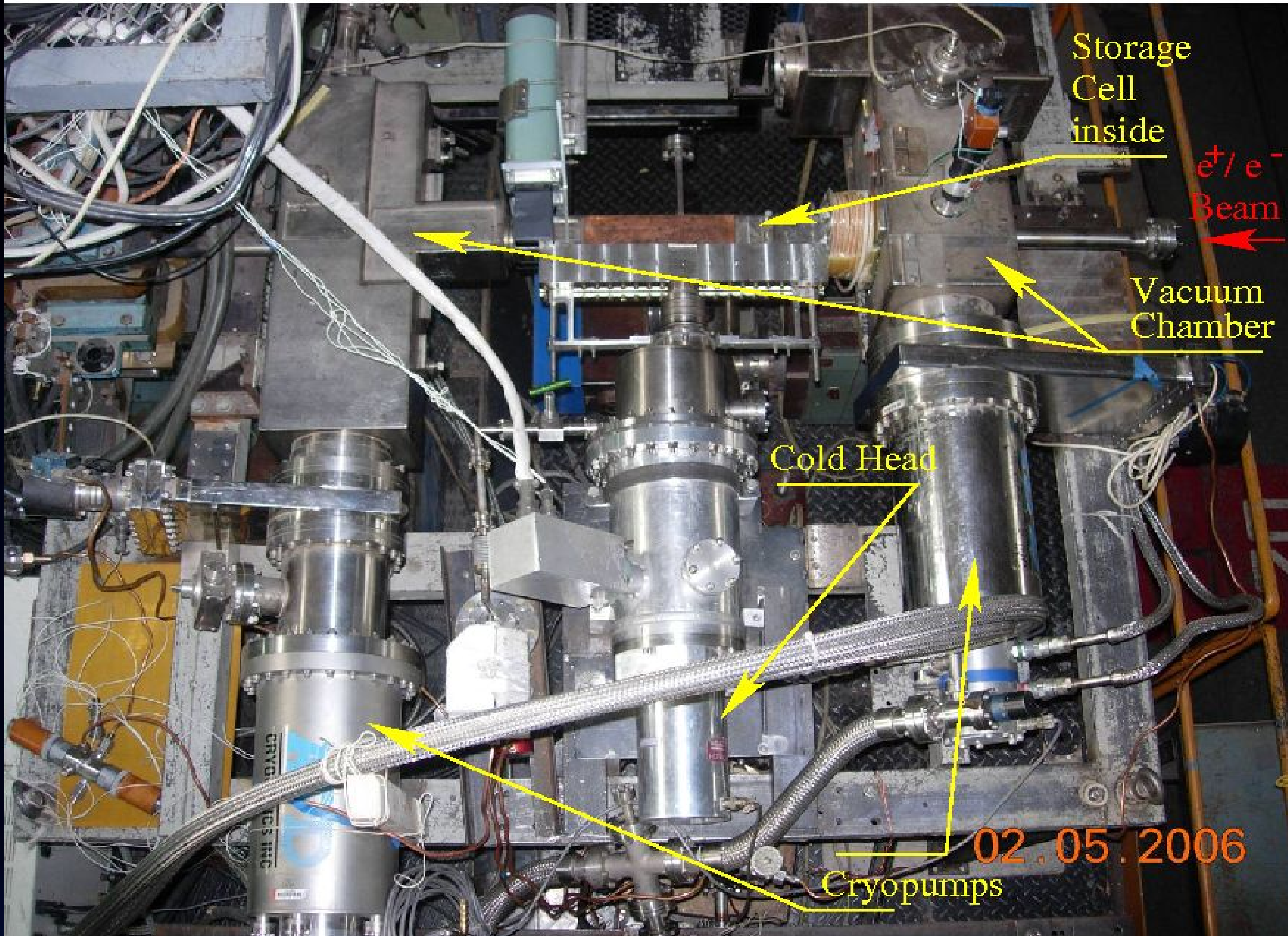

New unpolarized $H_2$ target was used the same storage cell: having elliptical cross section 13x24 mm, length 400 mm, cooled by cryocooler.

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.

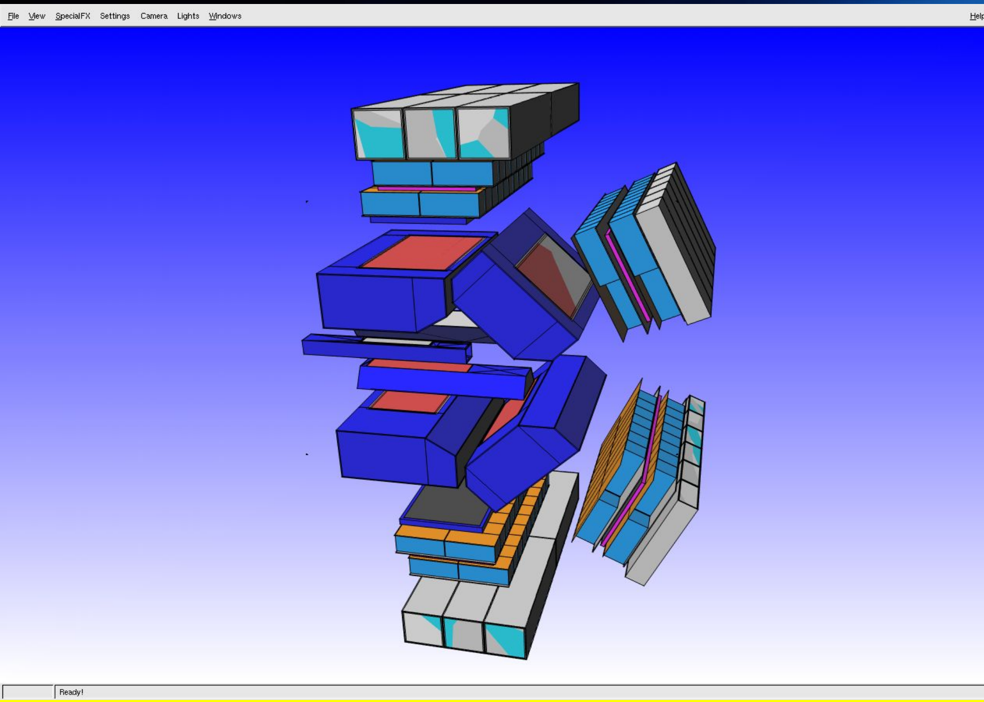
# VEPP-3 Straight Section with Internal Target

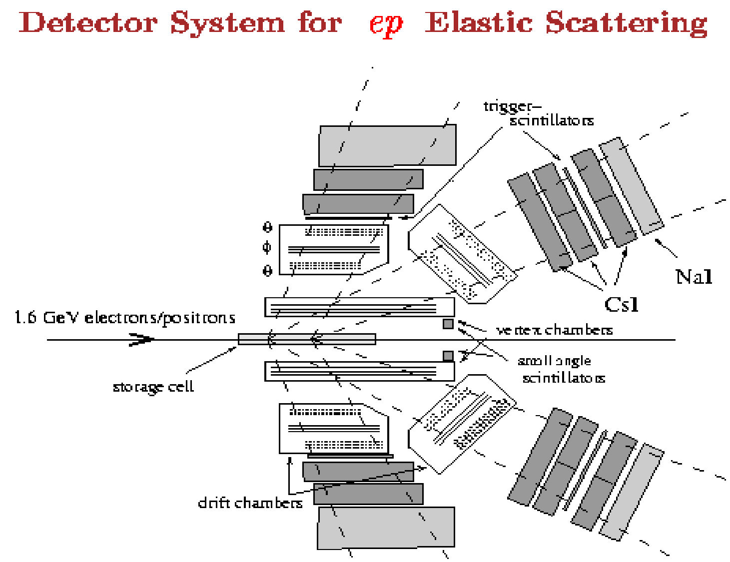



],

$P_l$ -

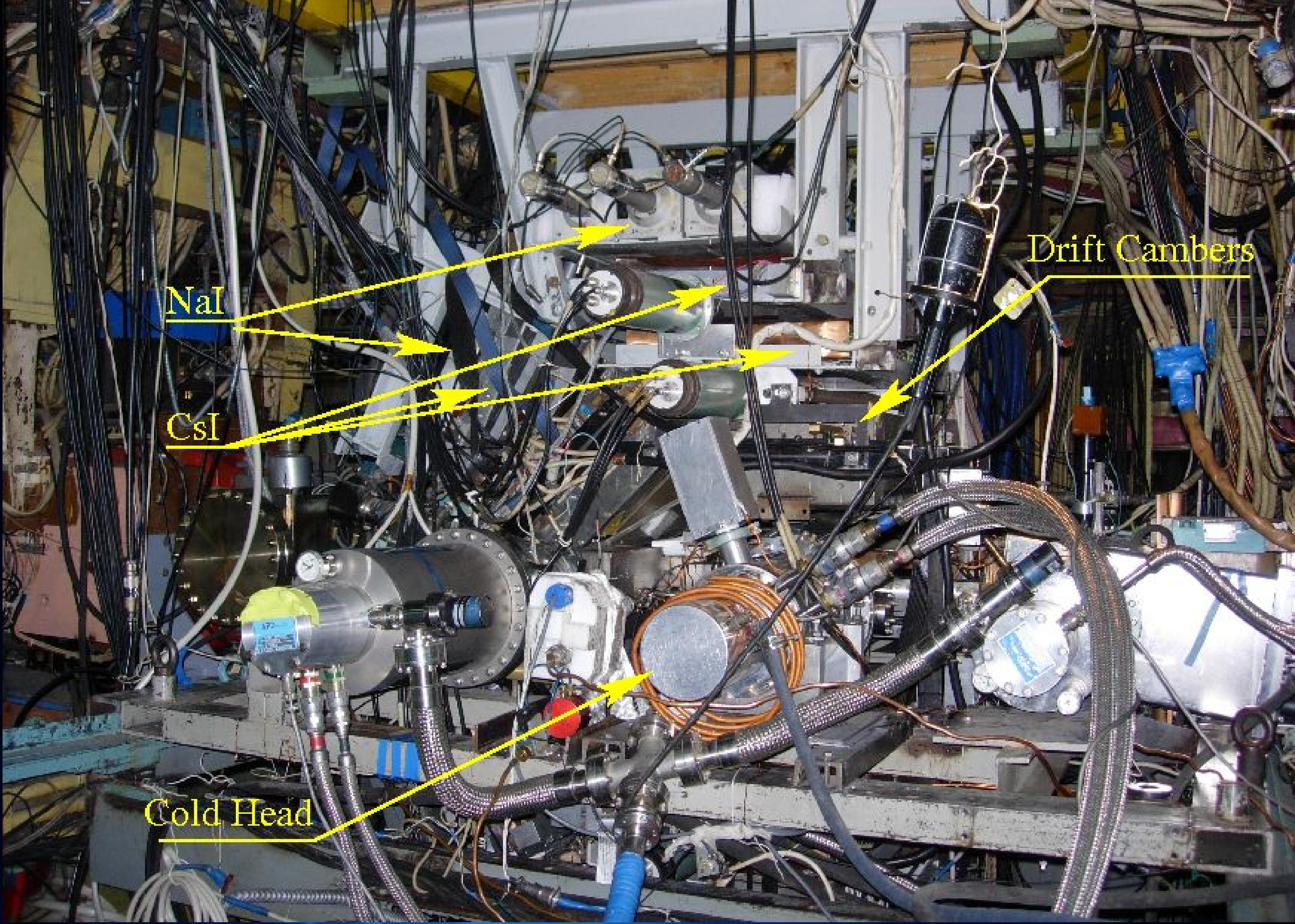
# Side view of the detector for experiment




**The detector for the measurement of ($e^+p$) and ($e^-p$) elastic scattering is builded on the basis of the detector used in the previous experiment. Scattered electron and recoil proton are 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 the 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


NaI
CsI
Drift Cambers
Cold Head

The commissioning run on the VEPP-3

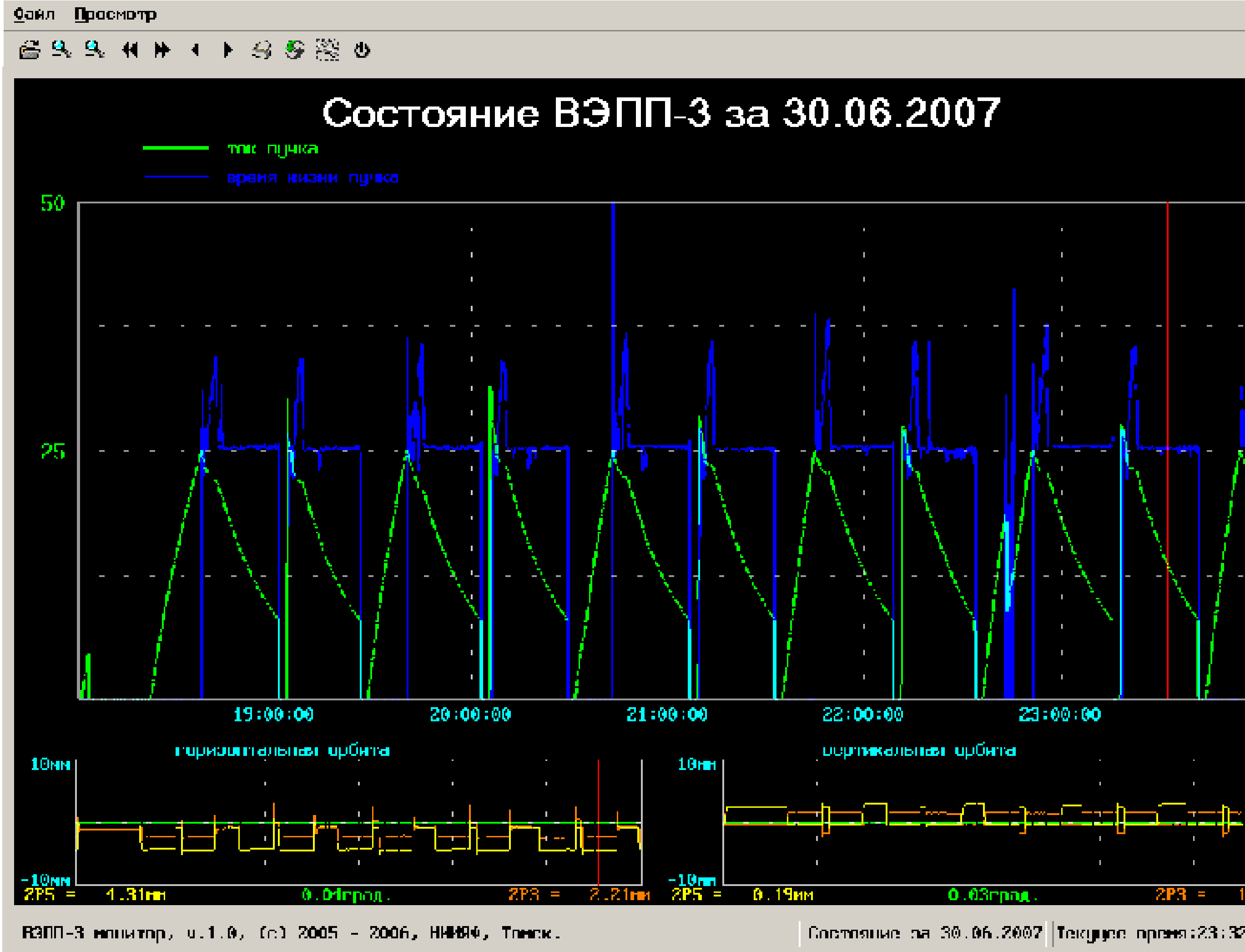
16 April – 2 July 2007

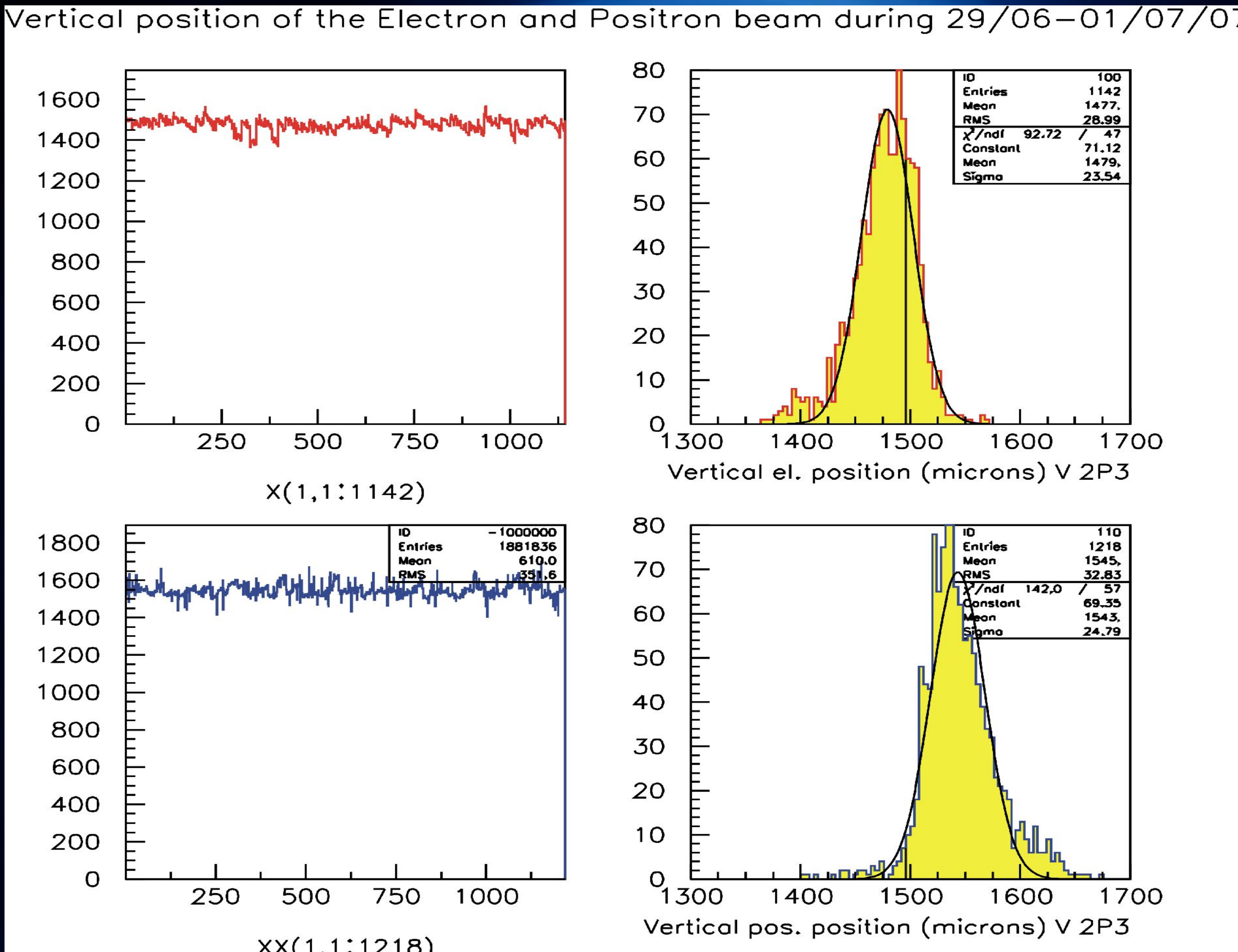
stallation of the internal target and the particles de-
ctor on the for VEPP-3, the change of the magnetic
ptics of VEPP-3 (duration – about 1 month).

he establishing VEPP-3 working regimes with new
agnetic optics and internal target (duration – about
5 month).

he establishing of the working regimes of particles
etector, the background suppressing (the change in
e trigger and installation of cleaning magnet).

ata taking ( 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
χ²/ndf 92.72 / 47
Constant 71.12
Mean 1479.
Sigma 23.54
Vertical el. position (microns) V 2P3
ID -1000000
Entries 1881836
Mean 610.0
RMS 351.6
XX(1,1:1218)
ID 110
Entries 1218
Mean 1545.
RMS 32.83
χ²/ndf 142.0 / 57
Constant 69.35
Mean 1543.
Sigma 24.79
Vertical pos. position (microns) V 2P3

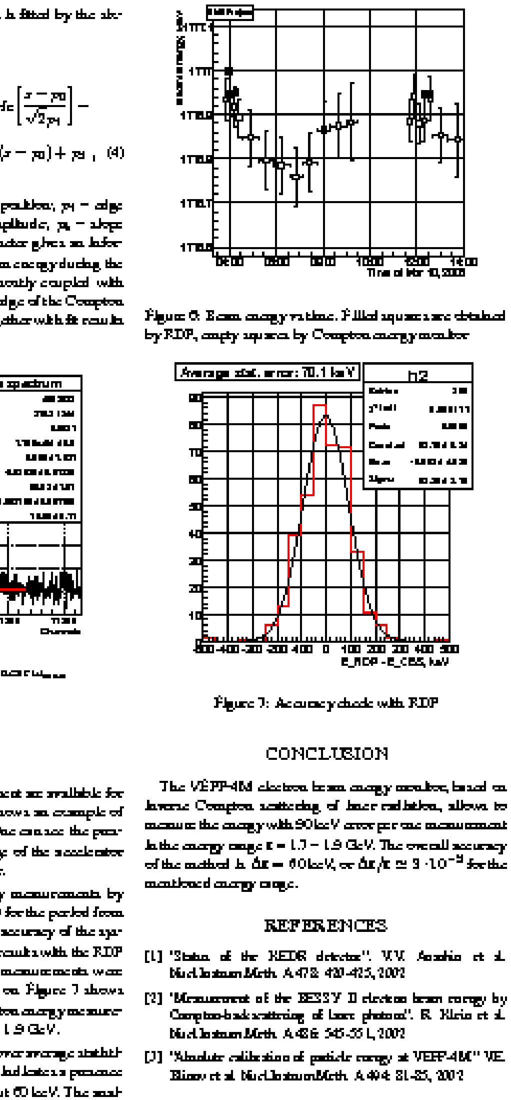


Figure 6: Beam energy vs time. Filled squares are obtained by RDP, empty squares by Compton energy monitor

Figure 7: Accuracy check with RDP

CONCLUSION

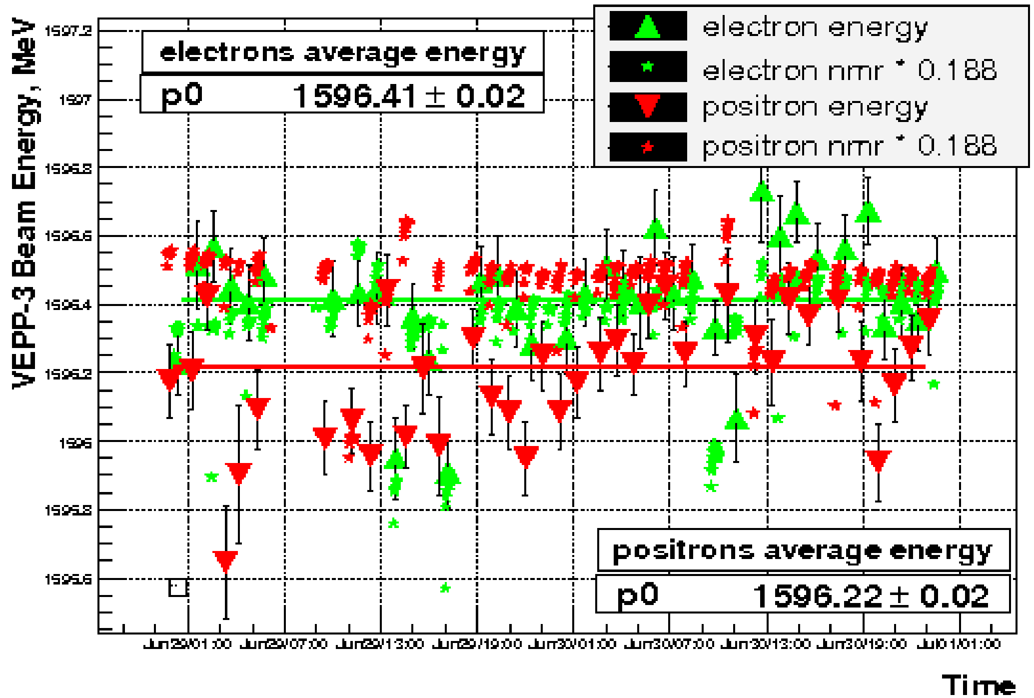
The VEPP-4M electron beam energy monitor, based on Inverse Compton scattering of laser radiation, allows to measure the energy with 50 keV error per one measurement in the energy range E = 1.7 – 1.9 GeV. The overall accuracy of the method is $\delta E \approx 60$ keV, or $\delta E/E \simeq 3 \cdot 10^{-5}$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

REFERENCES


[1] "Status of the KEDR detector", V.V. Anashin et al. Nucl.Instrum.Meth. A 478: 420-425, 2002

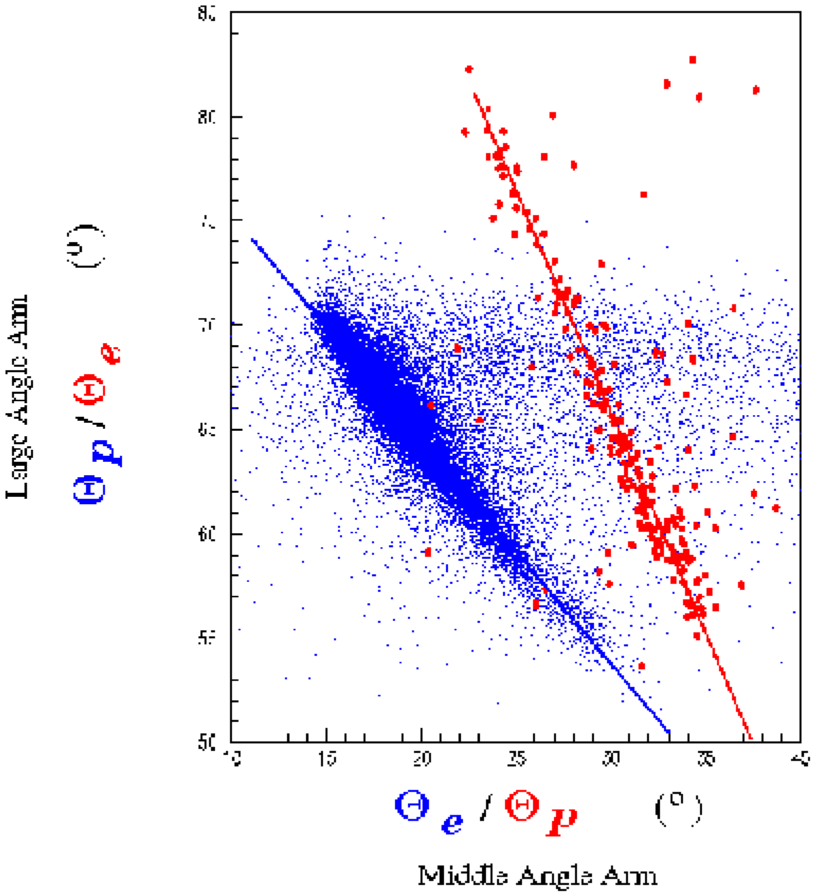
[2] "Measurement of the BESSY II electron beam energy by Compton-backscattering of laser photons", R. Klein et al. Nucl.Instrum.Meth. A 486: 545-551, 2002

[3] "Absolute calibration of particle energy at VEPP-4M" V.E. Blinov et al. Nucl.Instrum.Meth. A 494: 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



## $R = \sigma(e^+)/\sigma(e^-)$, $N_- = 2N_+$

| $\theta_e$ | $\varepsilon$ | $Q^2 (GeV/c)^2$ | $N_+$ events | $\delta R/R$ % |
|---|---|---|---|---|
| 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 ( Ds/s for three intervals 0.1, 0.2, 0.2 % / MeV)
- Different position of beams ( Ds/s 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 ( $\nabla R/R$ 0.1%)
- Difference of the radiation corrections for electrons and positrons
- The total systematical error for the largest $Q^2$ is expected to be $\nabla R/R :$ 0.3%

# Expected results of the measurement

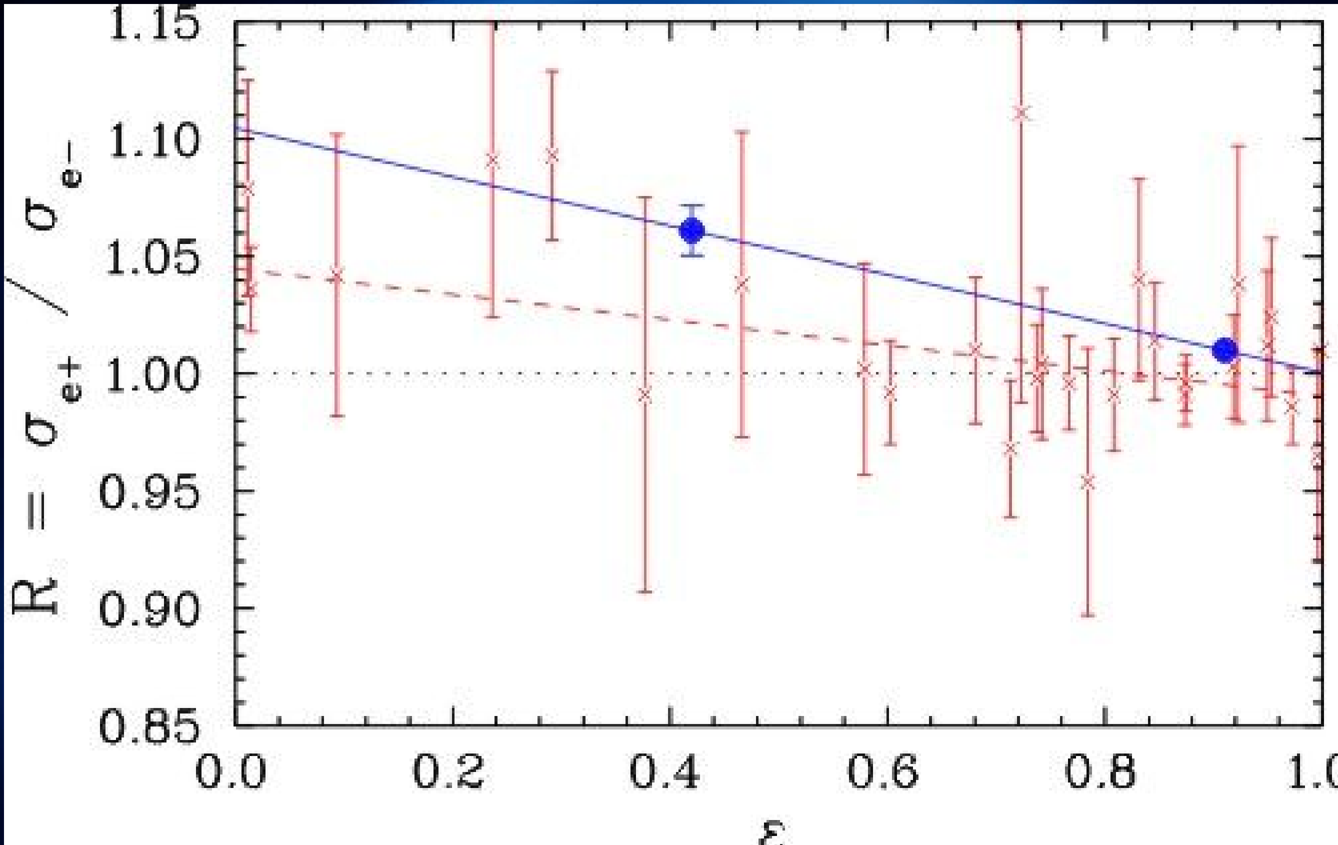



Figure: Projected uncertainty (combined statistical and systematic) for the proposed measurement (blue circles), compared to previous data (red "x" – J.Arington, Phys.Rev. C69, 2004). Note that the previous measurements have an average $Q^2$ value of approximately 0.5 $GeV^2$ for the data below $\mathcal{E}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

# Part of people, who did the experiment