A Study of the Nucleon Spin Structure in Strong and Electromagnetic Interactions

Experiments with Polarized Targets and Beams

Project ”GDH & SPASCHARM & NN”

Dubna-Protvino-Prague-Moscow-Mainz-Glasgow-Los-Angeles-Basel-Lund-Zagreb-Pavia-Kharkov-Bochum-Bonn-Amherst-Giessen-Halifax-Jerusalem-Kent-Regina-Sackville-Washington-York

2019

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1. GDH and meson photoproduction

Experiments with a real photon beam: meson photoproduction on nucleons and nuclei and Compton scattering on nucleons.

The main goals: experimental verification of the Gerasimov-Drell-Hearn (GDH) sum rule, investigation the helicity structure of different reaction channels, electro-magnetic polarizabilities of hadrons, study of the excitation spectra of baryons, search for missing baryon resonances, exotic states (dibaryons, narrow nucleon resonances), parity doublets.

2. SPASCHARM

Experimental study of single-spin asymmetries in the production of various light particles with the use negative particles ($\pi^- K^- p^-$) beam of 28 GeV, at the first stage, and later study of single-spin and double-spin asymmetries in dozens of reactions using a new polarized proton (10-45 GeV) and antiproton (~16 GeV) beams.

The ultimate goal of the project is to study gluon contribution $\Delta g(x)$ to the proton spin at large values of the Bjorken variable x through a study of double- spin effects in charmonium production. ("Spin crisis" is not yet solved.)

3. NN

Measurement of $\Delta\sigma_T$ and $\Delta\sigma_L$ in the nd transmission experiment at neutron energies < 16 MeV. A limited experimental data exist so far. Theory predicts an sizable effect of the 3NF.

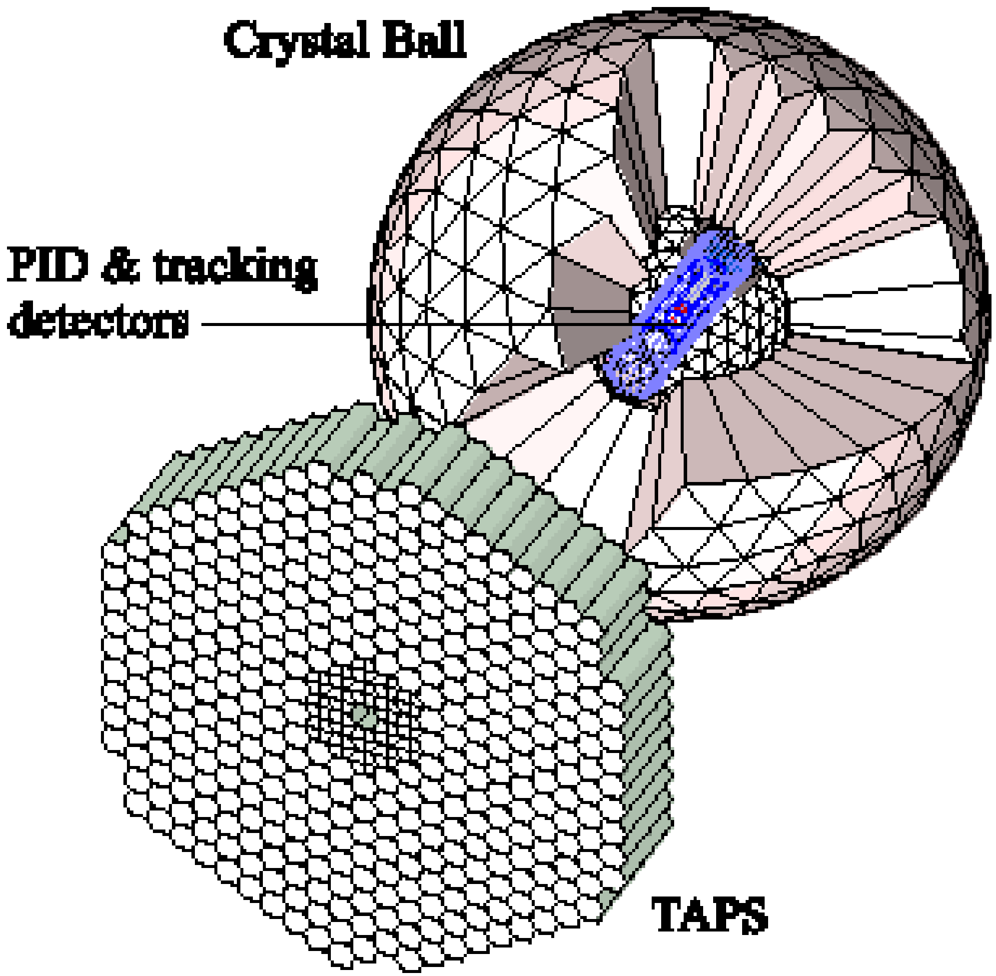
A continuation of the same observables measurements in np scattering being performed previously.

I. GDH and mesons photo-production

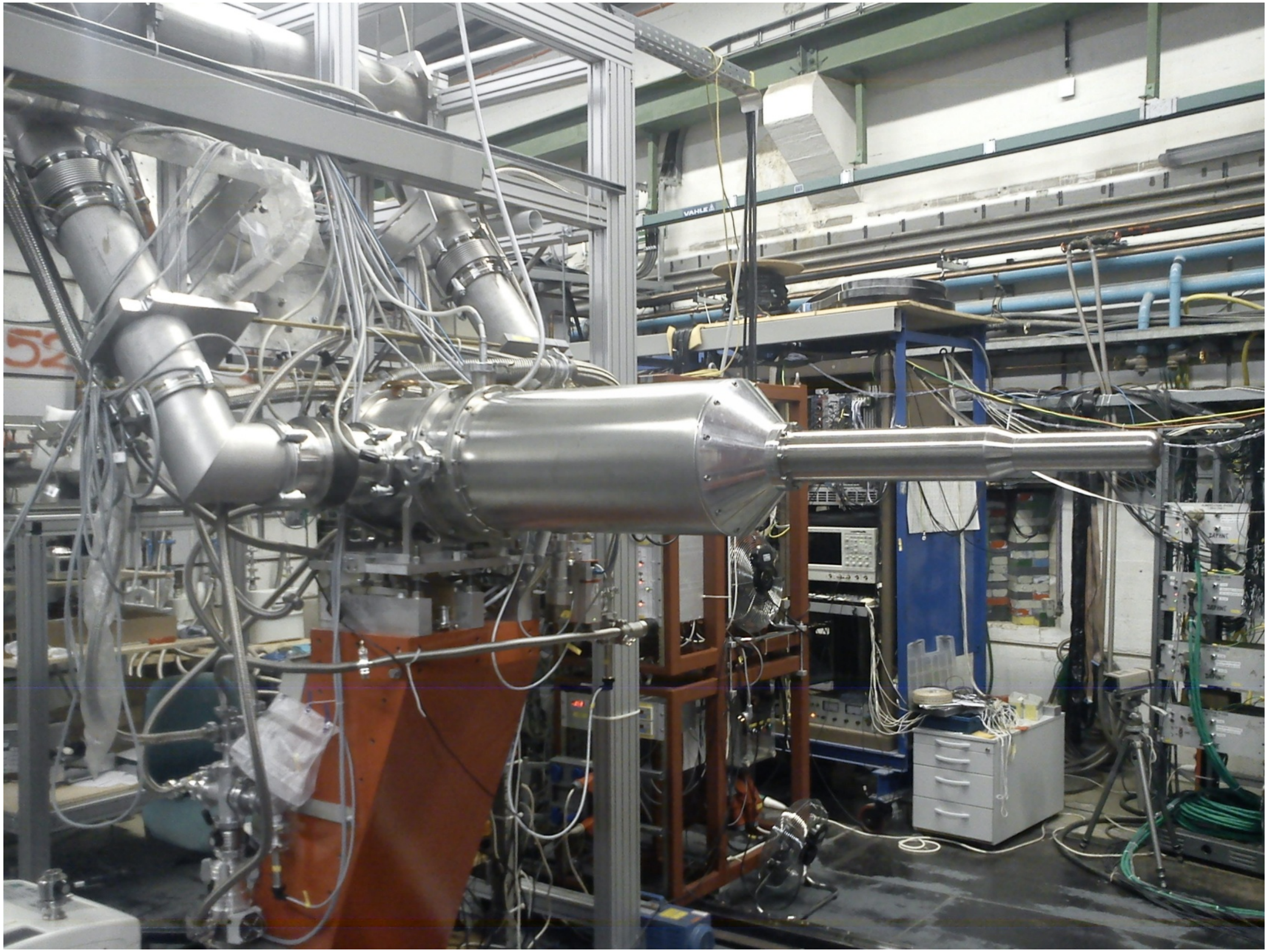
Experiments are performed at MAMI-C (Mainz) with **tagged photons** at energy up to 1600 MeV both **circularly and linearly polarized.**

A2 DETECTOR SETUP

Because of its high-granularity and large acceptance the CB/TAPS setup is a suitable detector system for measurements of reactions with multi-photon final states like in $\pi^0 \rightarrow 2\gamma$, $\eta \rightarrow 2\gamma$ or $\eta \rightarrow 3\pi^0 \rightarrow 6\gamma$



Mainz polarized target



Dubna-Mainz Frozen Spin Target (available since 05.2010). For the double polarization measurements planned with the Crystal Ball detector on polarized protons and deuterons a specially designed, large horizontal $^{3}He/^{4}He$ dilution refrigerator has been built in cooperation with the Joint Institute for Nuclear Research. Superconducting holding magnet permits longitudinal and transverse polarizations. Butanol and trityl doped deuterated butanol are used in experiments.

Main parameters are:

At a total tagged photon flux of 5×10^{7} and a target temperature 30 mK relaxation times of about 2000 hours was obtained.

Target proton density in 2 cm diameter cell: $N_T \approx 9.1 \times 10^{22}$ cm^{-2} (including dilution and filling factors).

Maximum polarizations at 2.5 T are: for protons ≈90%, for deuterons ≈75%.

EXPERIMENTS

1. **Experimental verification of the GDH sum rule**

   Prediction on the absorption of circularly polarized photons by longitudinally polarized hadrons

$$I_{GDH} = \int_{\nu_{thr}}^{\infty} \frac{\sigma_p(E_\gamma) - \sigma_a(E_\gamma)}{\nu} d\nu = 4\pi^2 S \frac{e^2}{M^2} \kappa^2$$

   where **κ** is anomalous magnetic moment, $\boldsymbol{\nu_{thr}}$ is pion production threshold (for nucleons) or photodisintegration threshold (nuclei).

2. **Helicity dependence of meson photoproduction**

   More detailed information on resonance properties and multipole amplitudes by investigating the helicity structure of different channels, for example,

   π^0 production , ($D_{13}(1520)$, $F_{15}(1680)$)

   η production, $S_{11}(1535)$, $D_{13}(1520)$),

   double-pion production, $D_{13}(1520)$, $P_{11}(1440)$, $P_{11}(1710)$), …..

Electromagnetic polarizabilities

Fundamental properties of composite systems. Response of the system to applied electric or magnetic field. Magnetic moments provide information about the ground-state properties of a system, polarizabilities are related to the excited states of the system. Nucleon polarizabilities cause a deviation of the Compton cross section from the prediction of Compton scattering from a point-like Dirac particle.

Compton scattering Hamiltonian (expansion in incident photon energy)

Zeroth Order - Mass and Electric Charge

$$H_{\rm eff}^{(0)} = \frac{\vec{\pi}^2}{2m} + e\phi \qquad (\text{where } \vec{\pi} = \vec{p} - e\vec{A})$$

First Order - Anomalous Magnetic Moment

$$H_{\rm eff}^{(1)} = -\frac{e(1+\kappa)}{2m}\vec{\sigma}\cdot\vec{H} - \frac{e(1+2\kappa)}{8m^2}\vec{\sigma}\cdot\left[\vec{E}\times\vec{\pi} - \vec{\pi}\times\vec{E}\right]$$

Second Order - Electric and Magnetic polarisabilities

$$H_{\rm eff}^{(2)} = -4\pi\left[\frac{1}{2}\alpha_{E1}\vec{E}^2 + \frac{1}{2}\beta_{M1}\vec{H}^2\right]$$

Compton scattering Hamiltonian (expansion in incident photon energy)

Third Order - Spin Polarisabilities

$$H_{\rm eff}^{(3)} = -4\pi\left[\frac{1}{2}\gamma_{E1E1}\vec{\sigma}\cdot(\vec{E}\times\dot{\vec{E}}) + \frac{1}{2}\gamma_{M1M1}\vec{\sigma}\cdot(\vec{H}\times\dot{\vec{H}}) - \gamma_{M1E2}E_{ij}\sigma_i H_j + \gamma_{E1M2}H_{ij}\sigma_i E_j\right]$$

Subscripts give multipolarities of incident and scattered photons

Spin-polarizabilities describe the response of the nucleon spin to an incident polarized photon.

To date, these four observable have not been individually determined. Only two linear combinations of them have been measured.

LO, NLO, NNLO in ChPT (V. Lensky et al EPJ C75 (2015)

Fig. 1 Born graphs and the anomaly graph. *Dots* are vertices from the lowest-order Lagrangians

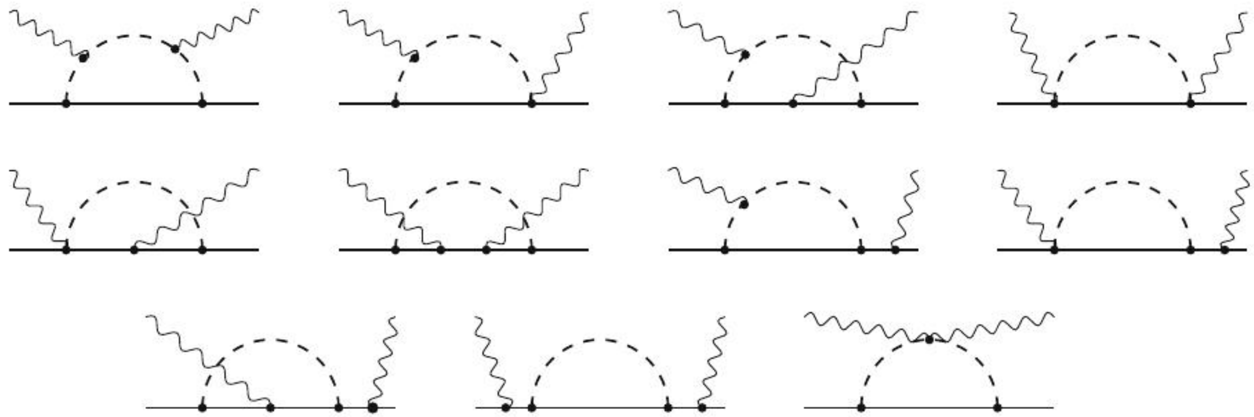


Fig. 2 Pion–nucleon loops that contribute to nucleon polarisabilities at leading order. Crossed and time-reversed graphs are not shown but are included in the calculation

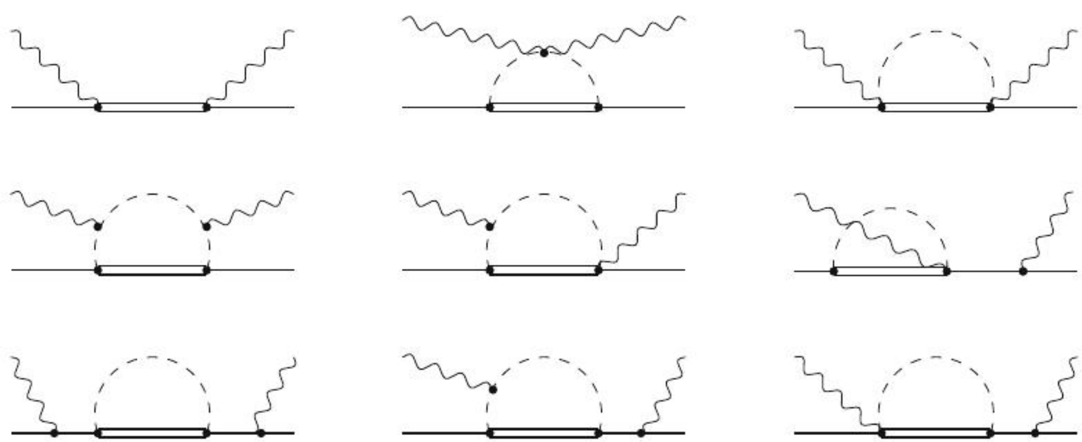
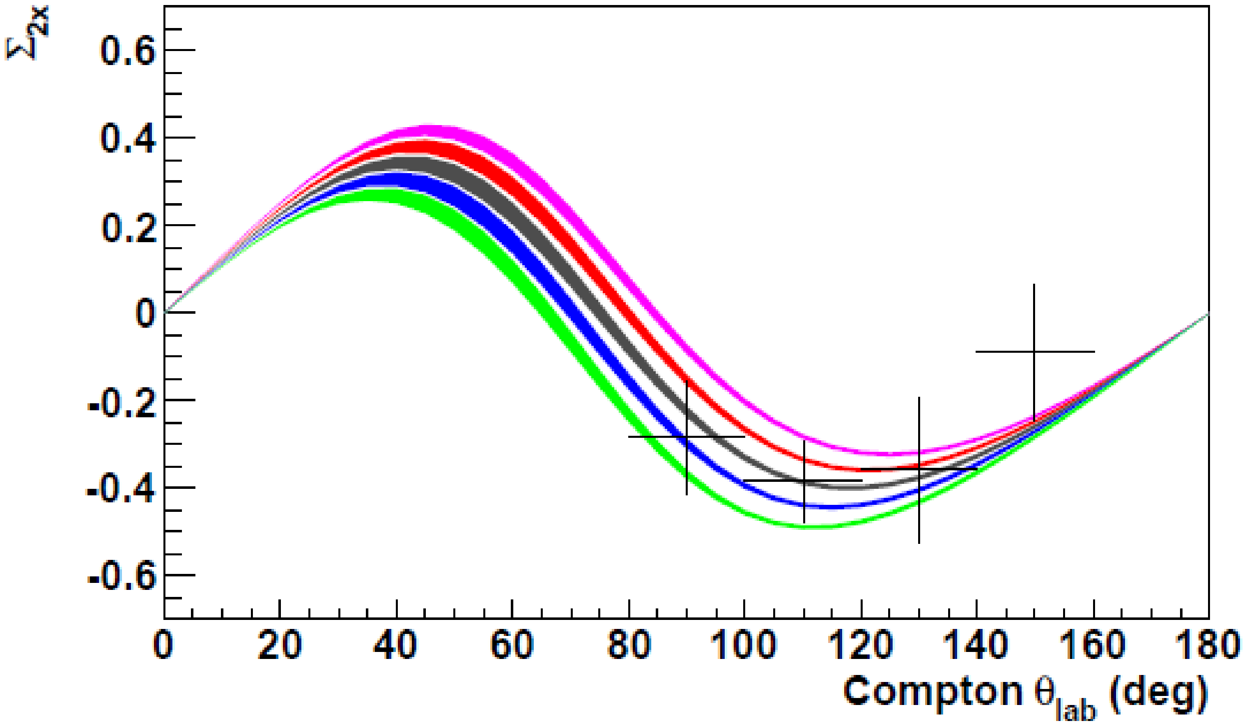


Fig. 3 Pion–Delta loops and the Delta tree graph that contribute to nucleon polarisabilities at next-to-leading order. Crossed and time-reversed graphs are not shown but are included in the calculation. *Double lines* denote the propagator of the Delta

Σ_{2x} asymmetry (theory and Mainz experiment (2015))



Σ_{2x} for E_γ =273 – 303 MeV. The curves are from a dispersion theory calculation* with α, β, γ_0, and γ_π held fixed at their experimental values, and γ_{M1M1} fixed at 2.9. The green, blue, brown, red and magenta bands are for γ_{E1E1} equal to –6.3, –5.3, –4.3, –3.3, and –2.3, respectively. The width of each band represents the propagated errors from α, β, γ_0, and γ_π combined in quadrature.

*** D. Drechsel, B. Pasquini, and M. Vanderhaeghen, Phys. Rep. 378, 99 (2003).**

MAIN RESULTS from MAINZ

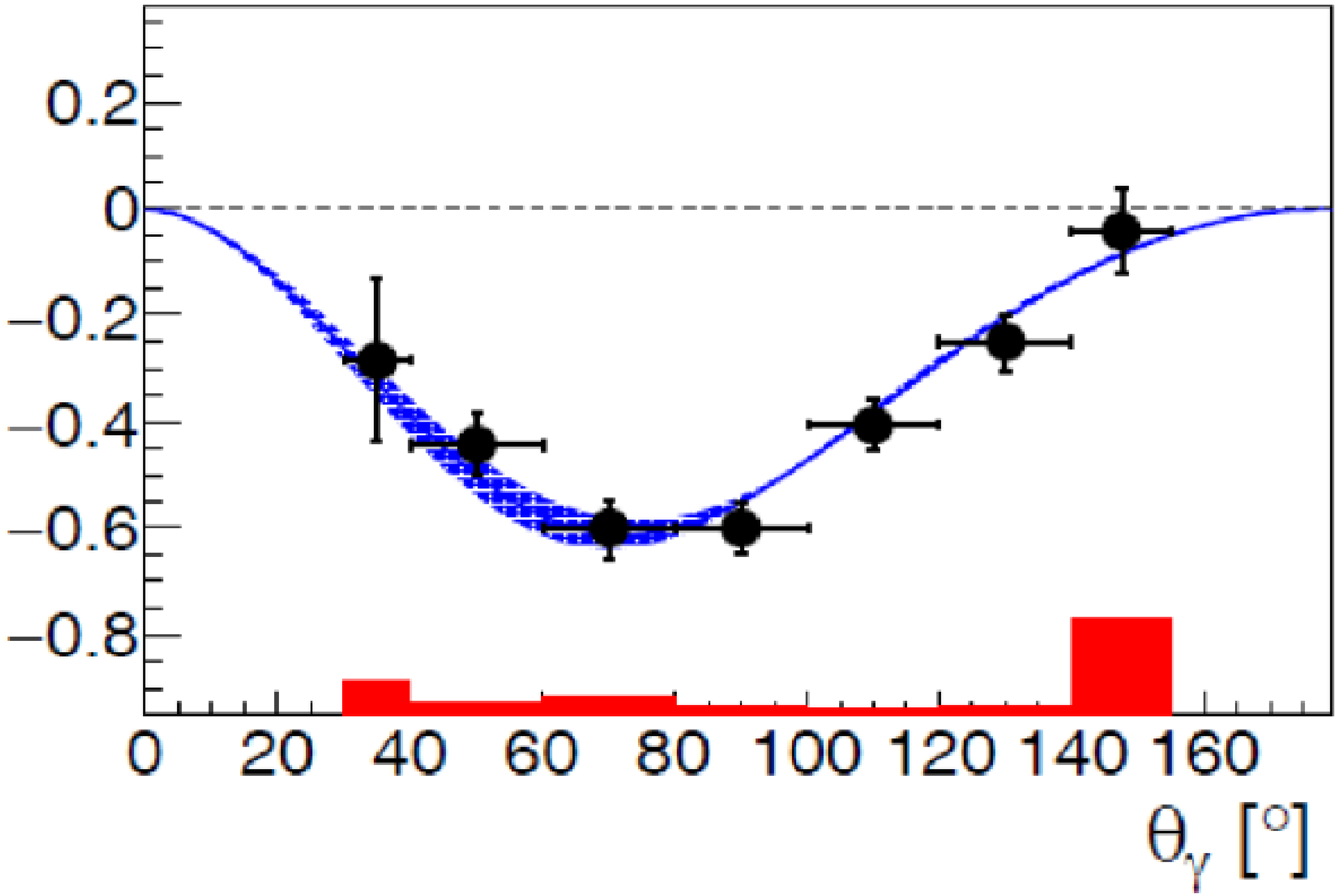
Several successful experiments has been realized with the beam of circularly and linearly polarized tagged photons and polarized target at the MAMI accelerator. As example,

1. First ever measurements of the beam asymmetry $\Sigma3$ for Compton scattering below pion photoproduction threshold have been performed . Determination of scalar polarizabilities of the proton. (An alternative to unpolarized Compton scattering)

2. The differential cross sections of the reactions $\gamma p \rightarrow \eta p$ and $\gamma p \rightarrow \eta' p$ have been measured from their thresholds up to the center-of-mass energy W = 1.96 GeV. The observed cusp-behavior was explained by contribution of the N*(1895)1/2− nucleon resonance. (MAID2017)

3. Most precise, at the moment, data on the $\eta \rightarrow 3\pi^0$ decay were obtained from these measurements providing a sensitive test for the magnitude of isospin breaking in QCD.

Toward scalar polarizabilities



Beam asymmetry Σ_3 in the range 119-139 MeV.

Points – experiment, the curve – ChPT;

V. Sokhoyan, N.Borisov, G.Gurevich et al. Eur. Phys. J. **A 53** No. 2 (2017) 14.

PUBLICATIONS **with coauthors from Dubna**: N.S. Borisov, G.M. Gurevich, V.L. Kashevarov, A.B. Lazarev, A.B. Neganov, Yu.A. Usov.

1. V. Sokhoyan et al.[A2 Collabortion] Determination of the scalar polarizabilities of the proton using beam asymmetry Σ_3 in Compton scattering. Eur. Phys. J. **A 53** No. 2 (2017) 14.

2. V.L. Kashevarov, et al. .[A2 Collabortion] Study of η and η photoproduction at MAMI. Phys. Rev. Lett. **118** Iss. 21, 212001 (2017).

3. S. Prakhov, et al. [A2 Collabortion] High-statistics measurement of the η $3\pi^0$ decay at the Mainz Microtron. Phys. Rev. **C 97** No. 6, 065203 (2018).

4. P. Adlarson et al., . [A2 Collabortion] Measurement of the ω $\pi^0 e^+e^-$ and η $e^+e^-\gamma$ Dalitz decays with the A2 setup at MAMI. Phys. Rev. **C 95** (2017) 035208.

5. P. Adlarson et al., . [A2 Collabortion] Measurement of the π^0 $e^+e^-\gamma$ Dalitz decay at the Mainz Microtron. Phys. Rev. **C 95** (2017) 025202.

PRL -1, PRC -6, PLB-3, EPJ-1

6. L. Witthauer et al., Helicity-dependent cross sections and double-polarization observable E in η hotoproduction from quasifree protons and neutrons. Phys. Rev. **C 95** (2017) 055201.

7. M. Dieterle et al., First measurement of the polarization observable E and helicity- dependent cross sections in single π^0 photoproduction from quasi-free nucleons. Phys. Lett. **B 770** (2017) 523.

8. P. Adlarson et al., Measurement of the decay $\eta' \pi^0\pi^0\eta$ at MAMI. Phys. Rev. **D 98** (2018) 012001.

9. M. Dieterle et al., Photoproduction of π^0 Mesons off Protons and Neutrons in the Second and Third Nucleon Resonance Region. Phys. Rev. **C 97** (2018) 065205.

10. A. Ka¨ser et al., First measurement of helicity-dependent cross sections in $\pi^0\eta$ photo- production from quasi-free nucleons. Phys. Lett. **B 786** (2018) 305.

11. M. Bashkanov et al., Deuteron photodisintegration by polarized photons in the region of the d^*(2380). Phys. Lett. **B 789** (2019) 7.

II. SPASCHARM

Goals:

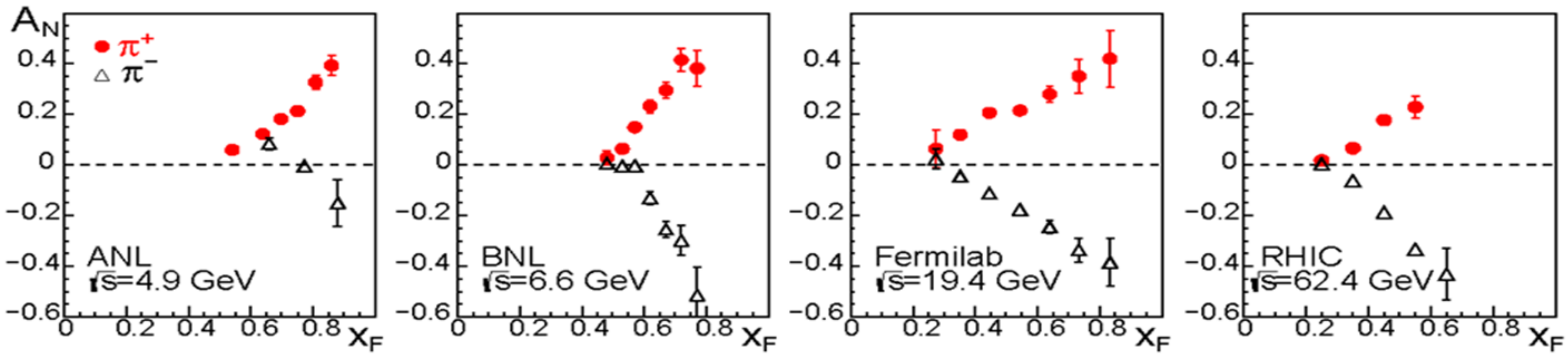
- Study of the spin dependent dynamics of strong interaction and the spin structure of the proton.
  - A study of the spin effects in dozen of reactions with different polarized beams or/and targets (inclusive, exclusive reactions and elastic scattering will be studied simultaneously).
- Determination of the gluon contribution $\Delta G/G(x)$ into the proton spin at large values of the Bjorken x.
  - Double-spin asymmetry A_{LL} measurements in the process:

  $p_{\rightarrow} + p_{\rightarrow} \rightarrow \chi_{c2}$ (J/Ψ) + X, ($\chi_{c2} \rightarrow$ J/Ψ + γ) to study $\Delta G/G(x)$.

  Simultaneously A_{NN} and A_N in J/ψ, χ_{c1}/χ_{c2} – production will be studied.

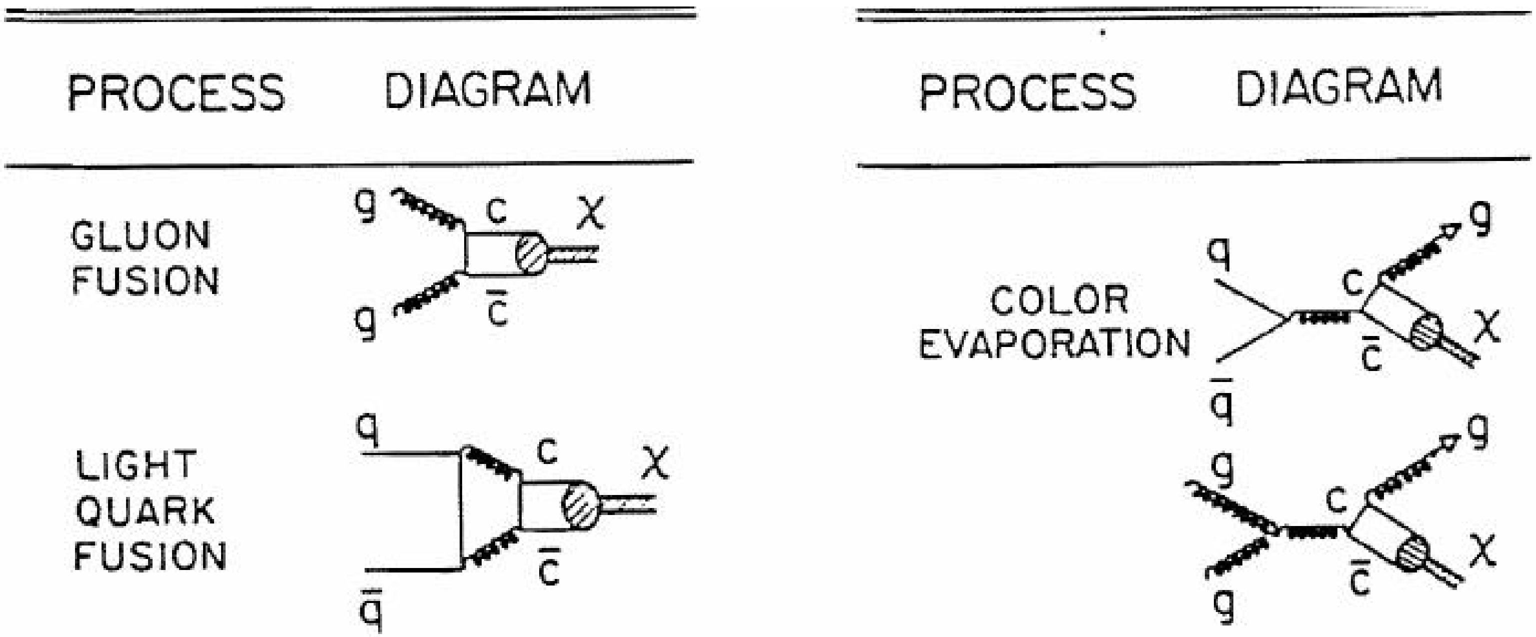
  - A_{NN} measurements for Drell-Yan pairs to study transversity h(x).

Мотивация проведения исследований



Асимметрия инклюзивного образования ненулевая и практически не зависит от энергии

Gluon contribution to the proton spin first was proposed by M.E. Beddo et al, Fermilab Proposal N 838, 1991



It is generally believed that the χ_2 (3555) state is mainly produced by gluon-gluon fusion. In Eq.(1), if the initial helicity state is (+-), then J_z = 2

The gluon contribution ΔG to the proton spin from the RHIC data analysis (E.R. Nocera et al. Nucl. Phys.B 887 (2014))

$\Delta G = 0.20^{+0.06}_{-0.07}$ for DSSV14
$\Delta G = 0.23 \pm 0.06$ for NNPDFpol1.1
integrated over x= 0.05-1 at $Q^2 = 10$ GeV^2.

Results are model dependent.
SPASCHARM measurements will give a unique possibility to measure ΔG directly.

For future perspective:

Search for CP violation in the CP neutral p˜p system with polarized both protons and antiprotons potentially opens up a new perspective for studying CP, inaccessible for collisions of unpolarized particles.

Recent data from the LHCb give for the CP violation in charm particles decay:

ΔA_{CP} = (-0.154±0.029)%

Dubna polarized frozen-spin target at Protvino

The authors of the project suggest to use the modernized frozen-spin target based at the one, developed earlier at LNP JINR.

In the DNP mode, the magnet poles are in the position when the magnetic circuit is closed, the magnetic field is as high as 2.5 T and the homogeneity is no worse than 10^{-4} within the target volume. When the poles are open, the magnetic field is 0.4 T in a gap of 20 cm and the homogeneity is 10^{-2}.

Target material is 1,2-propanediol $C_3H_8O_2$ (volume 20 cm_3) with a paramagnetic Cr(V) impurity. The maximum obtained proton polarization was 93% and 98% for positive and negative values, respectively. In the DNP mode, T = 200 mK.

A transistor with quartz oscillator with output power of 400 mW at a frequency of 67 GHz is used for the dynamic build-up of polarization. In the frozen spin mode the target is maintained at a temperature of 20 mK in the holding magnetic field of 0.45 T. Under these conditions, the spin relaxation time was 1200 h for positive polarization and 800 h for negative polarization.

The target polarization measurement is carried out using a multipurpose Q-meter with phase shift detector at operating frequency of about 102 MHz.

The polarized target magnet

Main results from SPASCHARM

First data on single-spin asymmetries in the SPASCHARM experiment were being taking in 2018 (analysis just started).

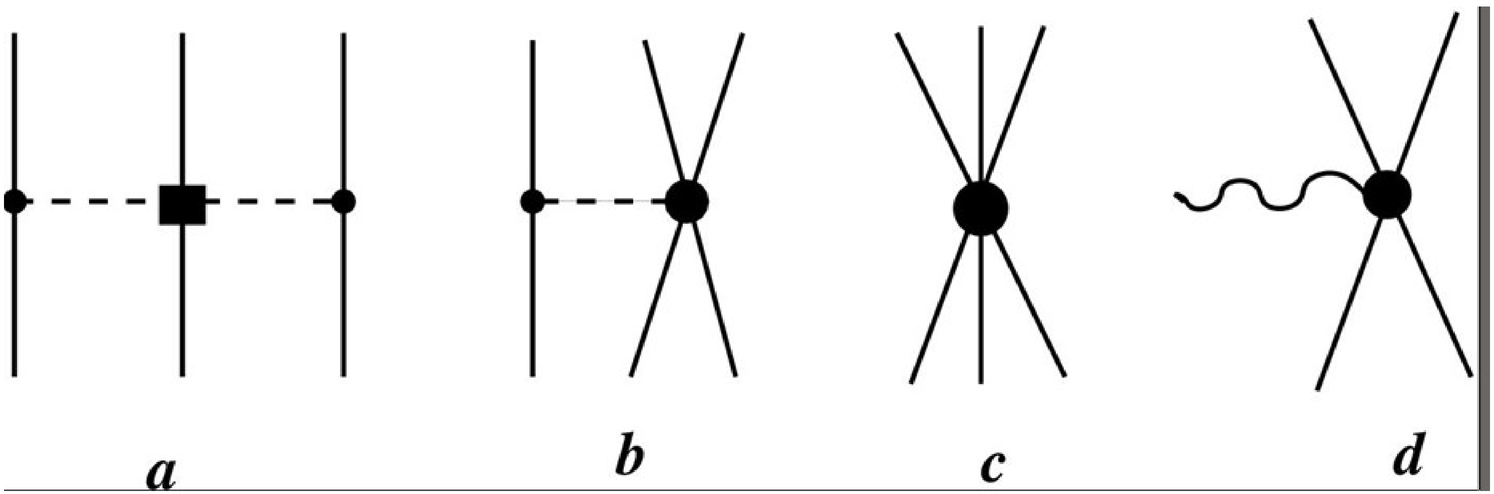
Publications:

1. Study of single-spin asymmetries with polarized target at the SPASCHARM experiment at U-70 accelerator V.V. Abramov (Serpukhov, IHEP), … N.S. Borisov, A.B. Lazarev, A.B. Neganov, O.N. Shchevelev, Y.A. Usov … et al.. 2017. 5 pp. Published in J.Phys.Conf.Ser. 798 (2017) no.1, 012096.
2. The polarized proton and antiproton beam project at U-70 accelerator V.V. Abramov (Serpukhov, IHEP & Kurchatov Inst., Moscow) et al.. 2018. 7 pp. Published in Nucl. Instrum. Meth. **A 901** (2018) 62.
3. Measurements of the Beam and Target Analyzing Powers and Spin Correlation Parameter ANN in Elastic pp Scattering at 45 Gev/c. V.V. Abramov (Serpukhov, IHEP) et al.. 2018, Published in KnE Energ. Phys. 3 (2018) 326.

4. Comparative study of the inclusive asymmetries induced by polarized protons and antiprotons at 16 GeV/c at the U–70 accelerator V.A. Okorokov (Moscow Phys. Eng. Inst.) et al.. Oct 16, 2017. 7 pp. Published in J. Phys. Conf. Ser. 938 (2017) no.1, 012014.
5. Polarized proton and antiproton beams for the SPASCHARM experiment at U-70 accelerator. I.I. Azhgirey et al, Published in J. Phys. Conf. Ser. 798 (2017) no.1, 012177.
6. Beam polarimetry at the SPASCHARM experiment at IHEP U-70 accelerator A.A. Bogdanov (Moscow Phys. Eng. Inst. & Kurchatov Inst., Moscow) et al.. 2017. 5 pp. Published in J. Phys. Conf. Ser. 798 (2017) no.1, 012179.
7. Simultaneous measurements of spin observables A_N and A_{NN} in elastic pp scattering (extension of the SPASCHARM program at U-70). V.V. Abramov (Serpukhov, IHEP) et al.. 2017, Published in J. Phys. Conf. Ser. 938 (2017) no.1, 012006.

III. NN- and NNN-interactions

Modern nuclear forces connected to QCD are developing within the ChPT. The NN- and 3NFs- are produced on the same footing using spontaneously broken chiral symmetry. Fundamental low energy constants (LEC) have to be extracted from experimental data on the few–nucleon (hadron) systems. **3NFs**



Three-nucleon forces (a,b,c) and contact MEC (d) appearing in ChPT at NNLO.

The contact term in the two-body current (d) involves the same constant c_D as the NN-π-N term (b) [C.Hanhart, U. van Kolck, G.A. Miller, PRL 85 (2000) 2905].

3H binding energy, Nd-Nd, NN ->πNN (ANKE@COSY), πNN-> γNN, NN->deν_e , μd->nnν_μ

$\Delta\sigma_L$(nd) as a source of the 3NFs LECs

$\Delta\sigma_L$(nd) =σ_p - σ_a is the difference in the nd total cross section for beam and target spins parallel and anti-parallel to each other. Similarly, with the transversal polarizations **$\Delta\sigma_T$(nd).**

The 3NFs changes $\Delta\sigma_L$ by 5-10% as compared to pure NN interaction potential (H. Witala et al. 1999)

The $\Delta\sigma_L$ (nd) was measured firstly at TUNL for incident neutron energies of 5.0, 6.9 and 12.3 MeV (R.D. Foster et al. PRC 73 (2006))

However, “the obtained data are not of sufficient precision to distinguish the presence or absence of 3NFs contributions to the cross-sections ".

Measurements of $\Delta\sigma_L$(np) and $\Delta\sigma_T$ (np) were performed at the Charles University Nuclear Center (Prague) using the transmission method with the polarized neutron beam (Pz=(-13.5 ± 1.4)%).

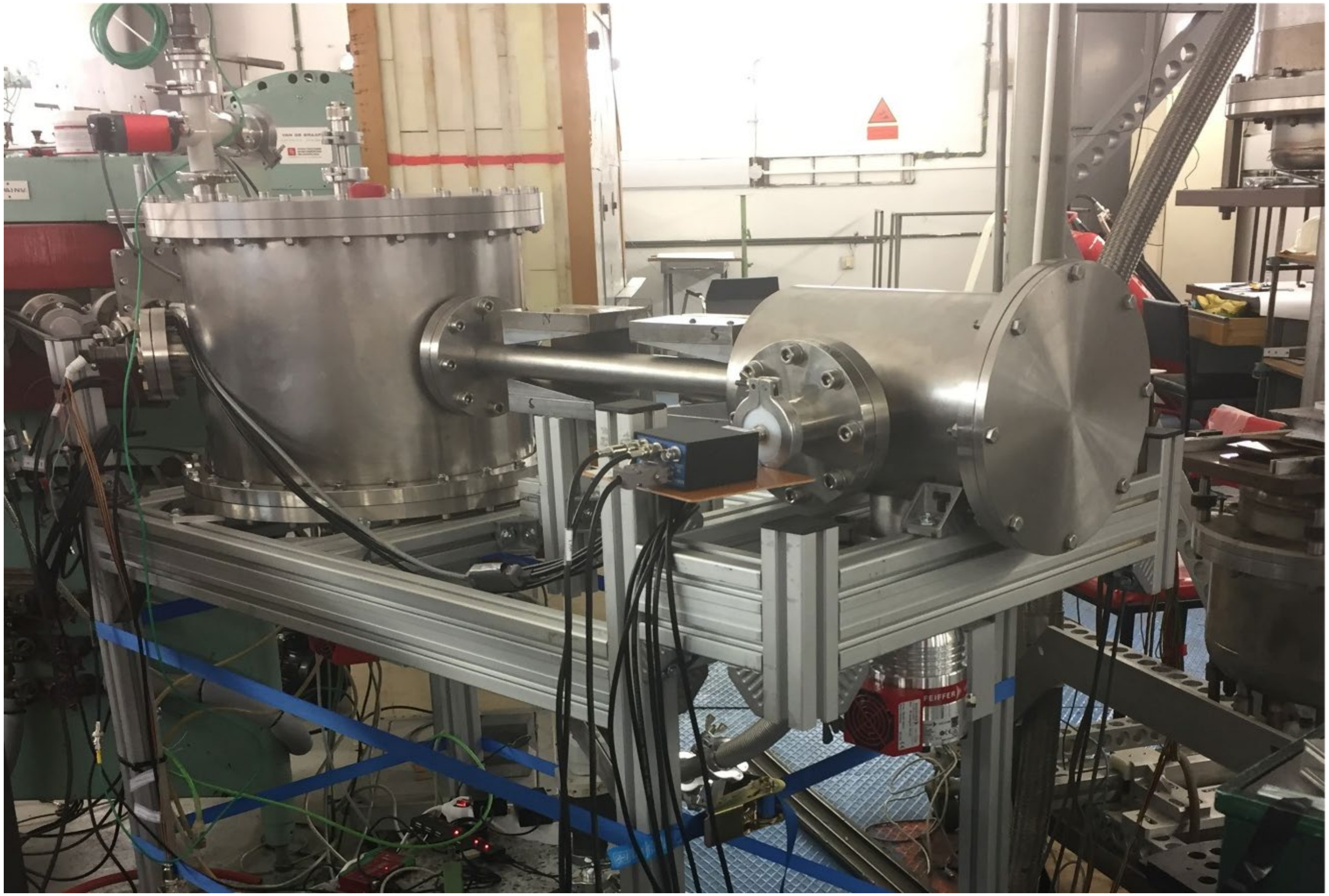
Similar measurements for nd collision are curying out.

A modernization is in progress to increase
i) the deuteron target polarization and ii) the intensity and polarization of the neutron beam.

To improve the parameters of the neutron beam it is proposed to use the reaction T(d, n)^{4}He with polarized deuterons of an energy 100-150 keV (Kaminsky's method, PRL, 23 (1969) 819).

The buildup of the polarized deuteron beam. First, channeling of the unpolarized deuteron (200 keV) beam through magnetized Ni film which contains polarized electrons. On this step we apply the Sona method (P.G. Sona,Energ. Nucl. 14 (1967) 295), with maximal transfer of the electron polarization to deuterons in the atomic beam.

On the second step, usage of the d+3H->4He+n reaction, in which the14-MeV neutrons are produced at the angle of 90° relatively deuteron spin direction with almost the same vector polarization as the initial deuterons.



Experimental setup from DLNP.

The deuteron vector polarization is measured preliminary using the reaction D(d, p)T .

The tensor polarization is Pzz is necessary to calculate the neutron polarization.

The Pzz is measured in the reaction T(d, n)^{4}He

$$\sigma(\theta) = \sigma_0[1-0.25(3\cos^2\theta-1)P_{zz}],$$

where θ is the c.m.s. angle between the spin and α-particle direction.

The result iz $P_{zz} = -0.12 \pm 0.04$ at the deuteron energy of 200 keV (therefore, $p^n_z \approx 0.25$)

Error estimation

If the neutron detector efficiency is 10^{-2} and solid angle of the polarized target 3×10^{-4}, then in order to get statistical error of 7 mb, it is necessary 180 hours of data taking.
At a neutron energy of 14 MeV $\Delta\sigma_T \approx$ 300 mb including 3NF decrease the cross section difference to 20 mb, so we can try to detect this difference.

Main results of the NN part.

1. An experimental setup has been developed i) to produce the beam of deuterium atoms at energies of 100-400 keV with polarized deuteron nuclei and ii) to measure tensor and vector polarizations of the deuterons.
2. The deuteron tensor polarization was measured via the reaction T(d, n)^{4}He.

Publications:

1. Yu.A. Plis et al., Research and Development of the Polarized Deuteron Sources for the Van de Graaff Accelerator. PEPAN 16 (2019) 256-263;
2. Preprint JINR E13-2018-69. Dubna, 2018;
3. Report SPIN2018, to be published

This work was supported in part by European Regional Development Fond, Project "Van de Graff Accelerator…" , N0 CZ.02.1.01 (2017-2019)

Working plan: 2020- 2021- 2022

SPASCHARM - Data taking run will be carried out using a negative particle beam and the Dubna polarized frozen target.

0. Single spin asymmetries will be measured in inclusive production of charged pions. Single-spin asymmetry in inclusive production of ρ (770), ω(782), η'(958),, f0(980), a0(980), f2(1270)…

1. The possibility to measure the polarization of hyperon and the alignment of vector mesons will be investigated also.

2. Multichannel Cherenkov counters will be added to measure spin effects with K-mesons.

Working plan: 2020- 2021- 2022

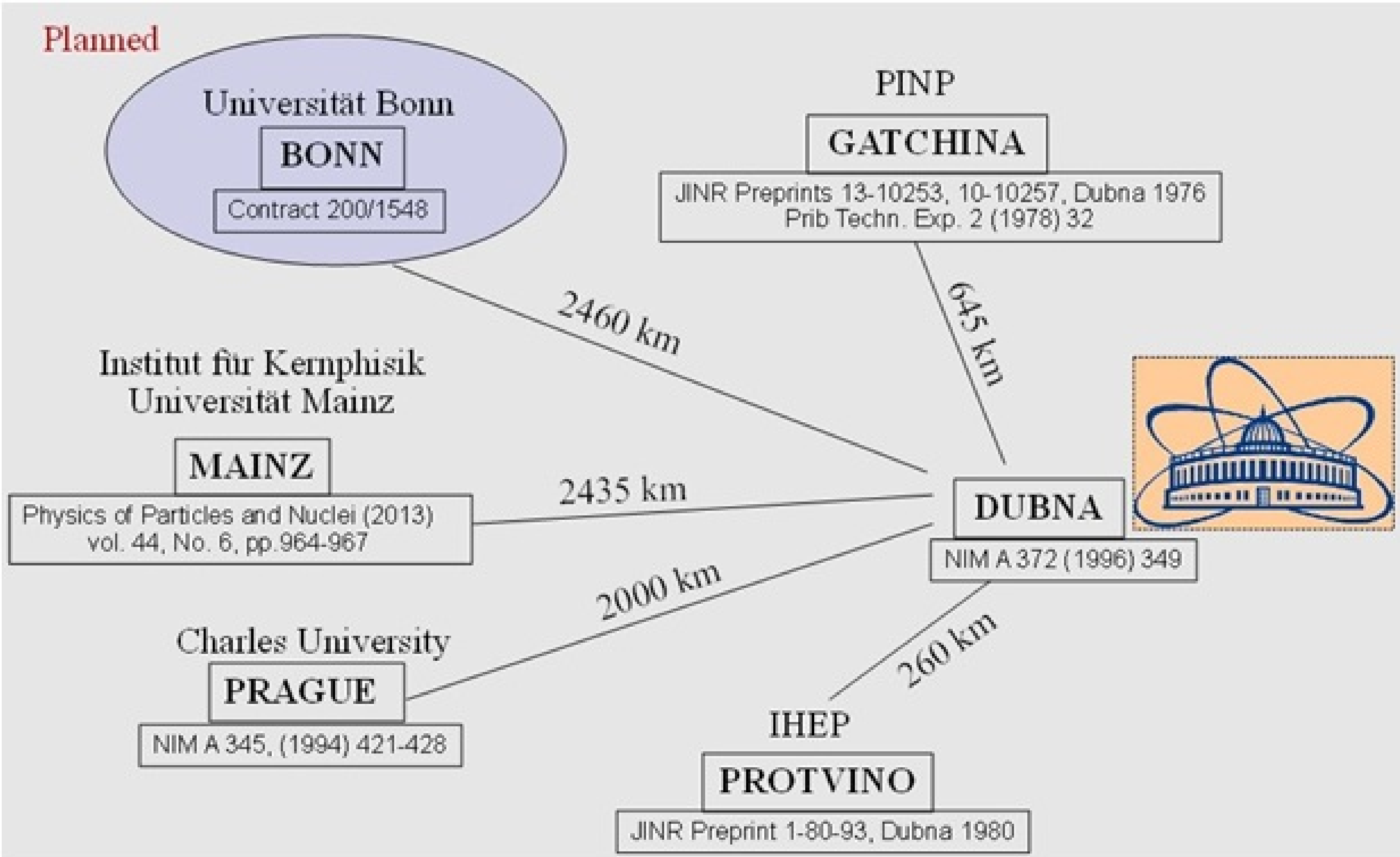
GDH

0. Commissioning of the new frozen spin target for experiments with Crystal Ball/ELSA facility at the Bonn University.
1. Precision large-acceptance measurements of the beam-spin asymmetry for deuteron photodisintegration in the region of the dibaryon state **d*(2380)**.
2. Study of the spectra and properties of the baryon resonances through the measurements of the polarization observables in meson photoproduction

NN

0. Experiments on channeling of the deuterons at the stand of the polarized deuteron source.
1. Build up of the polarized neutron source on the base of polarized deuteron source and to join it with the frozen polarized deuteron target. The exact measurement the vector and tensor polarizations of the deuterons. Preparation of special devices for usage of new target material based on Trityl-doped butanol.
2. To prepare apparatus for measurements of the neutron polarization via scattering on the ^4He target.

MAP OF ACTIVITY



Form №29

Estimate of the expenses for the Project "SPASCHARM-GDH-NN" (k$)

	Title of expense item	Total cost	2020	2021	2022
1	R & D agreement expenses	12.0	8.0	2.0	2.0
2	Job cost at the LNP’s experimental shop	3.0	1.0	1.0	1.0
3	Materials	66.0	22.0	22.0	22.0
4	Transport expenses	4.5	1.5	1.5	1.5
5	Unforeseen expenses	6.0	2.0	2.0	2.0
6	Electronic instruments	45.0	15.0	15.0	15.0
7	Travel expenses	24.0	8.0	8.0	8.0
	inclusive	124.5	41.5	41.5	41.5
	a) to nonruble zone countries	108.0	36.0	36.0	36.0
	b) to ruble zone countries	12.0	4.0	4.0	4.0
	c) visits to JINR	4.5	1.5	1.5	1.5
		285.0	99.0	93.0	93.0

THANK YOU
FOR YOUR ATTENTION!

Contact term C_D

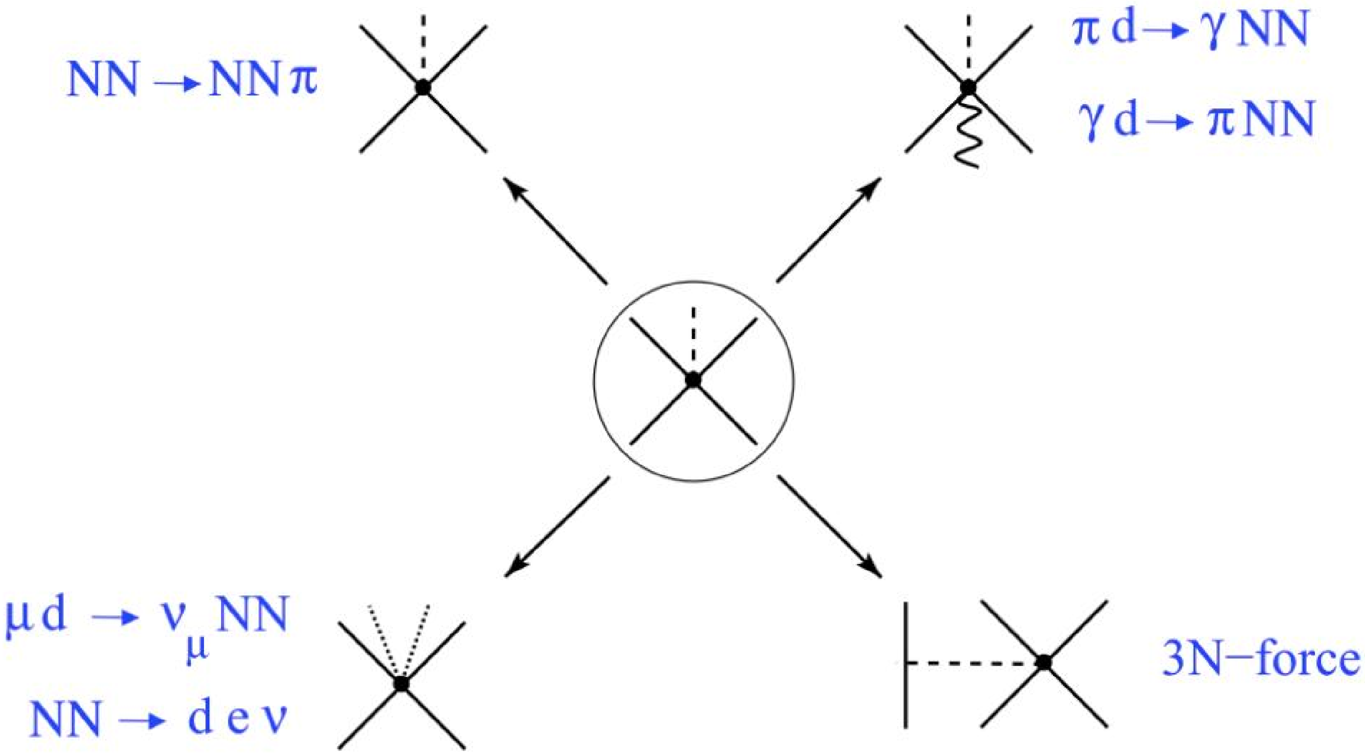
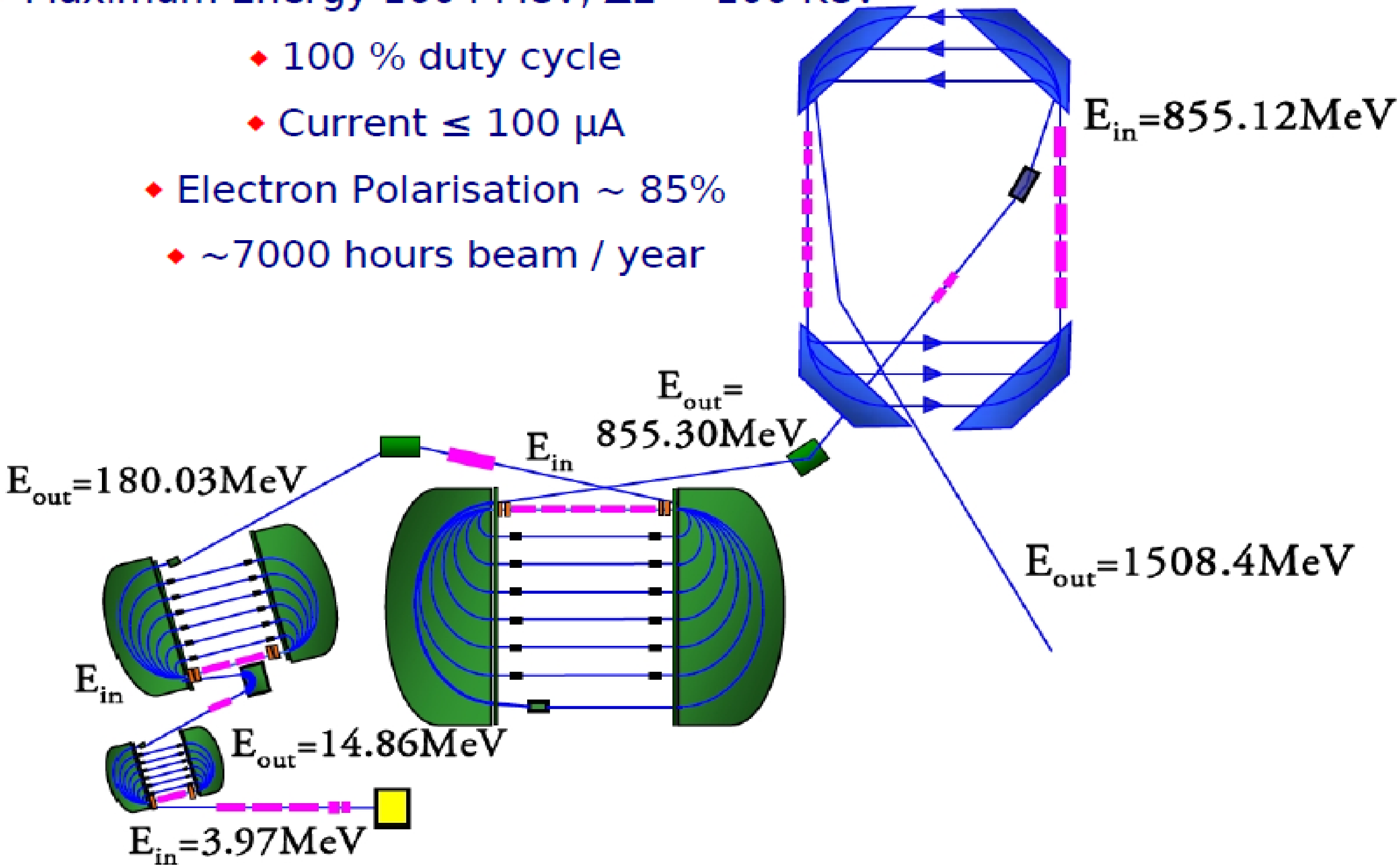


Рис. 1.3 — Малонуклонные реакции, включающие одну и ту же низкоэнергетическую константу d [32]

The pp->{pn}_s π^- reaction was used at ANKE@COSY to get the c_D term

MAMI electron accelerator

- Maximum Energy 1604 MeV, ΔE = 100 KeV
- 100 % duty cycle
- Current ≤ 100 μA
- Electron Polarisation ~ 85%
- ~7000 hours beam / year



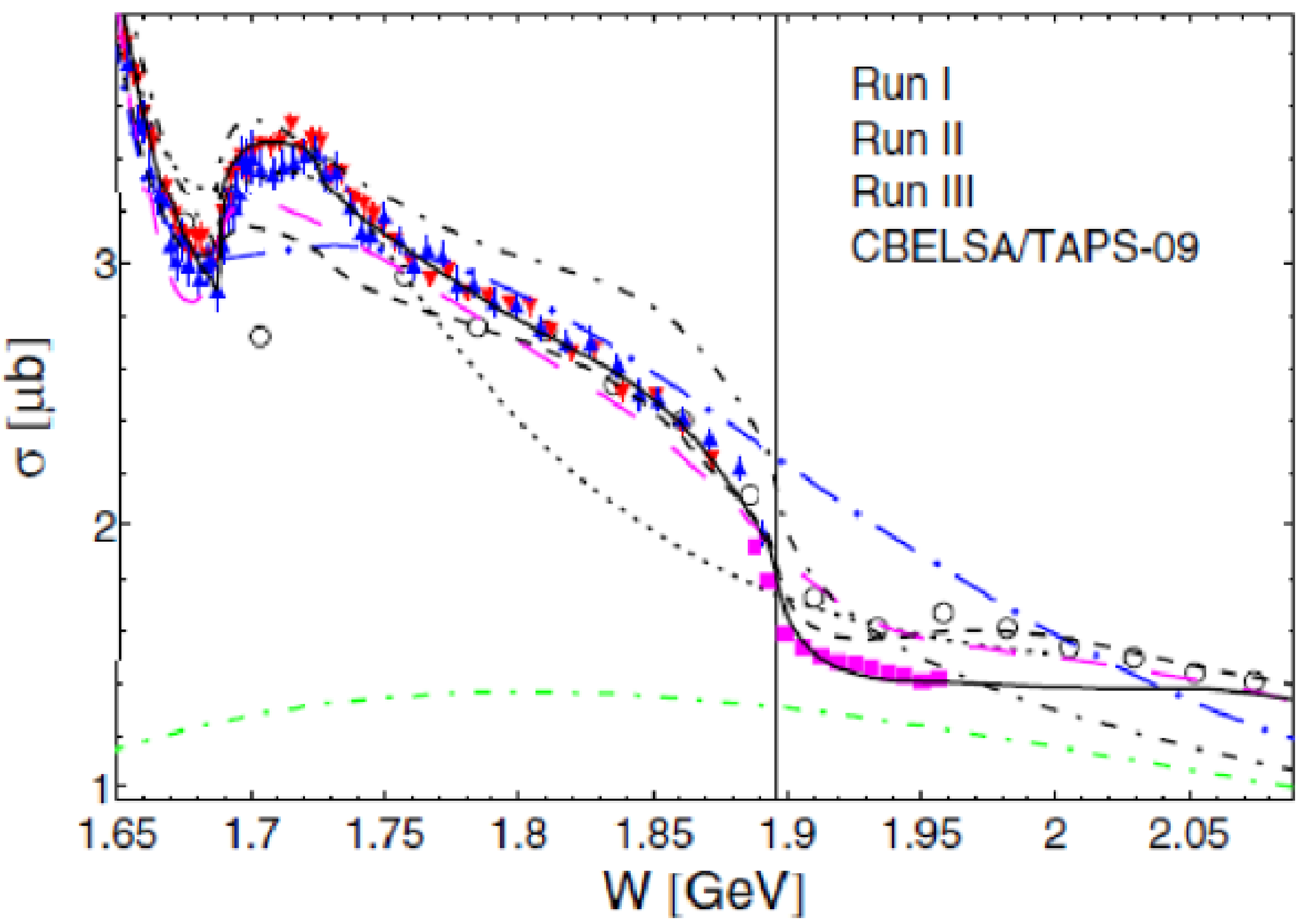


Fig. 2. $\gamma p \to \eta p$ total cross section.

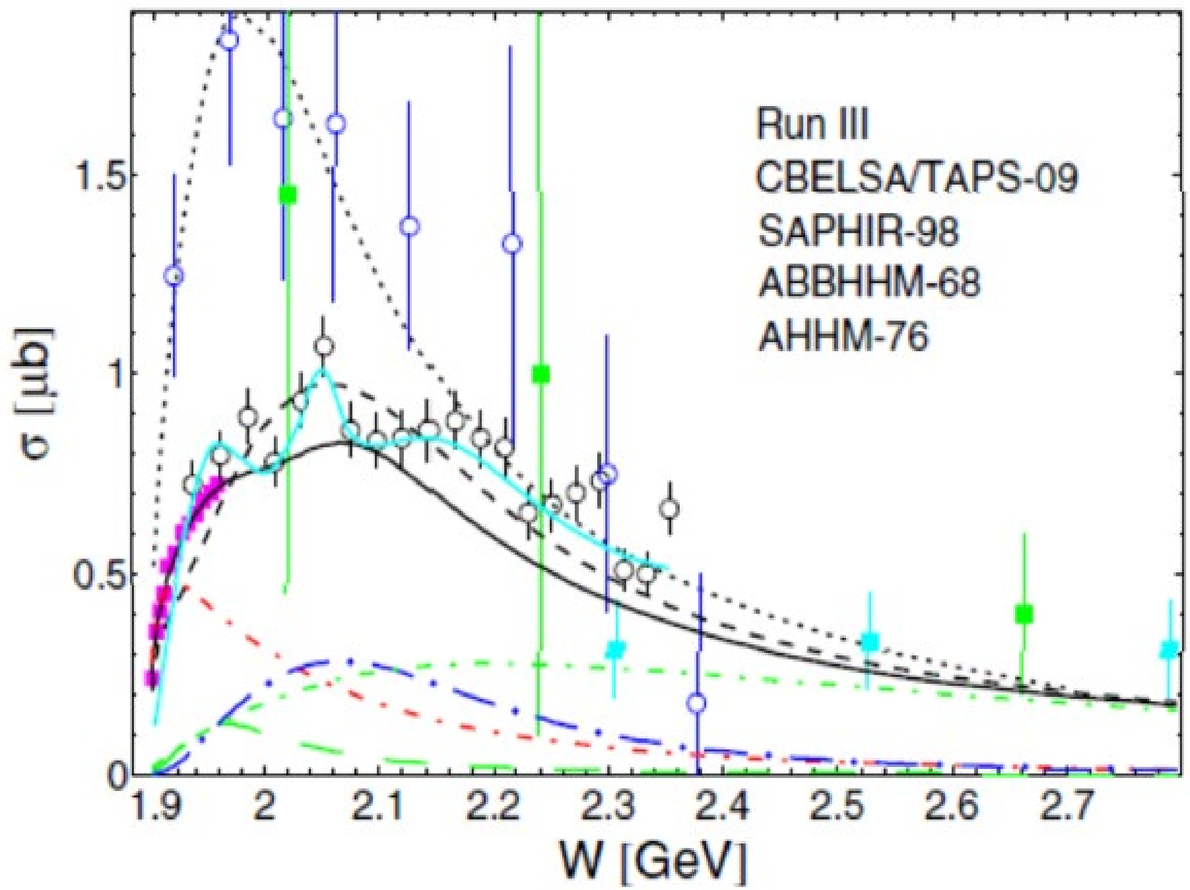


Fig. 3. $\gamma p \rightarrow \eta' p$ total cross section.

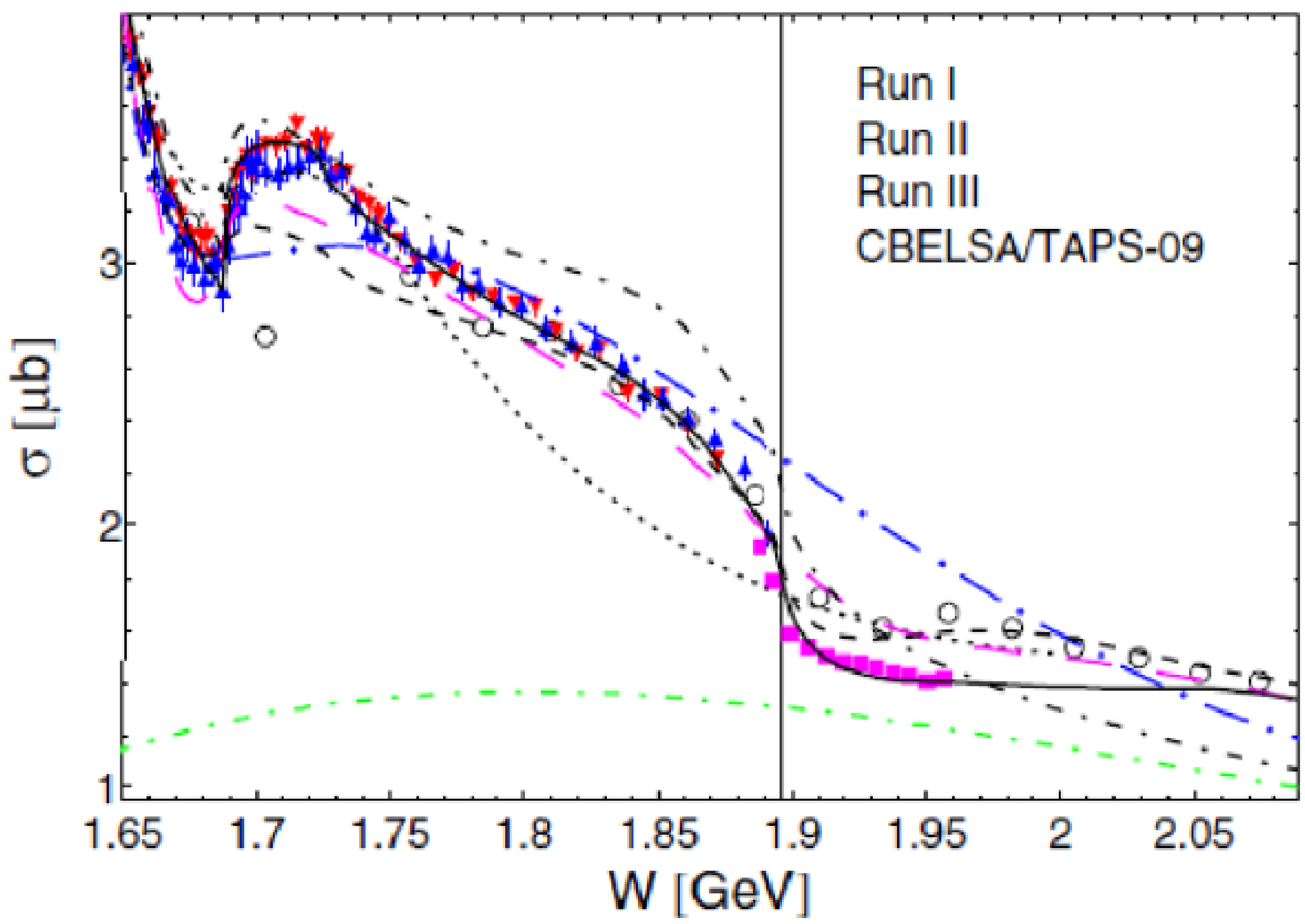


Fig. 2. $\gamma p \to \eta p$ total cross section.

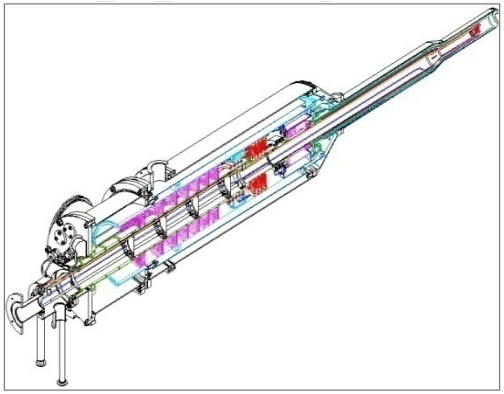
Components of the polarized target for the Crystal Ball detector

Similar to Bonn Target
[C.Bradtke et al., NIM **A436**, 430 (1999)]

He^3/He^4 Roots
4000m^3/h
Vacuum system

Targetmaterial
[Meyer, Bochum]
H-Butanol

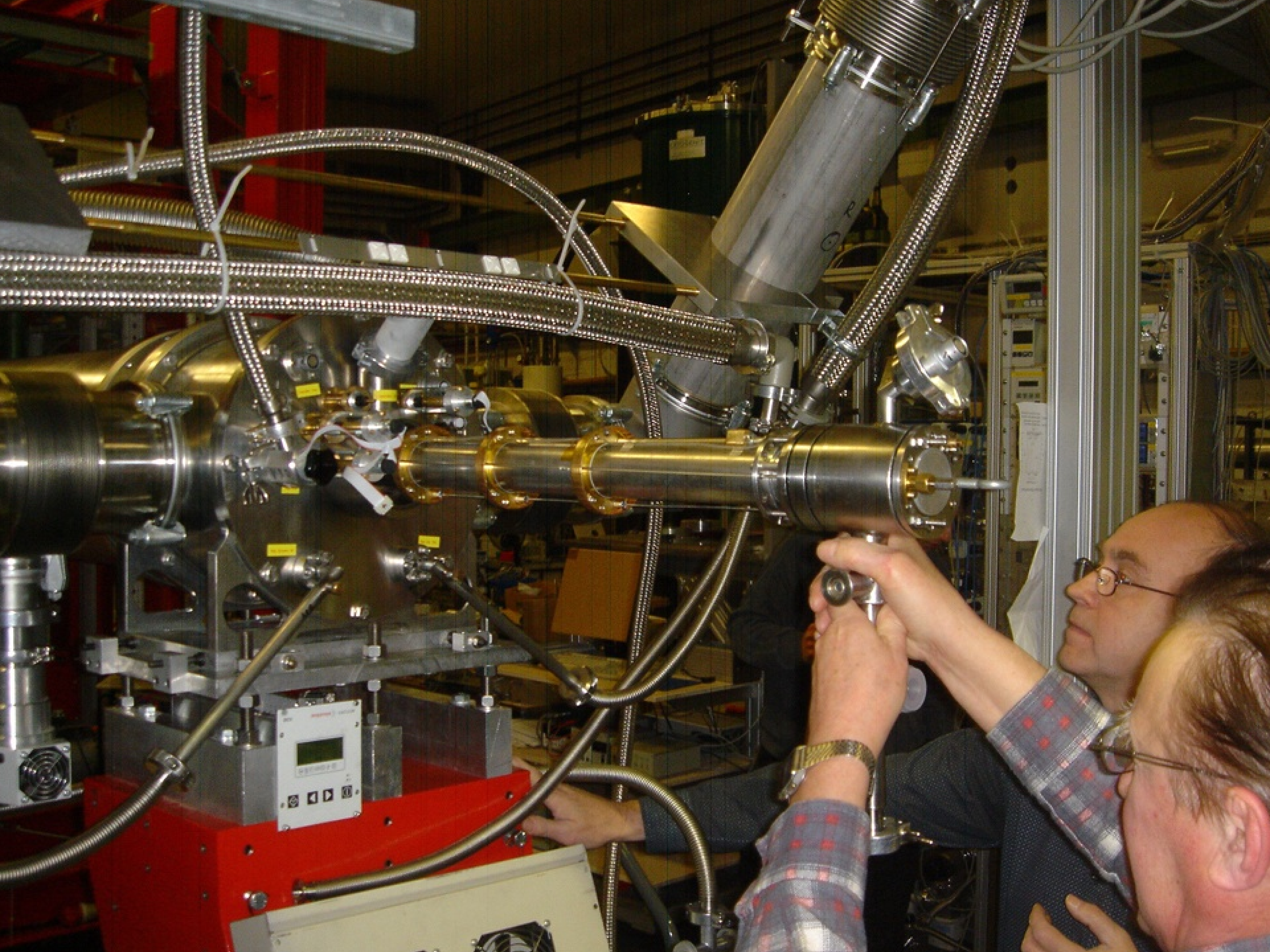
Mikrowaves
70GHz
Dynamic
Nuclear
Polarization



NMR-Apparatus
106MHz
Polarisation meas.

Horizontal He^3/He^4
Dilutionrefrigerator
(25mKelvin)
with internal
Holding coil

Superconducting
Polarization magnet
5Tesla

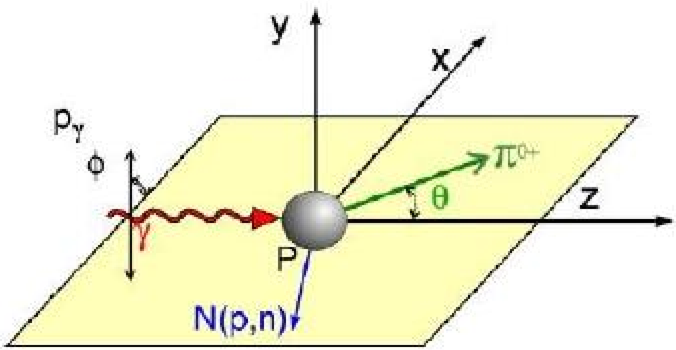


Beam-Target Polarization Observables

photoproduction of pseudoscalar mesons with polarized beam and target :

- all three single polarization observables Σ, P , T and cross section σ
- 4 double polarization observables G , E , F and H

can be measured



photon pol.		target pol. axis		
		x	y	z
unpolarized	σ		T	
linear	$-\Sigma$	H	$-P$	$-G$
circular		F		$-E$

$$\frac{d\sigma}{d\Omega}(\theta,\phi) = \frac{d\sigma}{d\Omega}(\theta) \cdot \Big[1 - P_\gamma^{\text{lin}}\,\Sigma(\theta)\cos(2\phi)$$

$$\phi) + P_\gamma^{\text{circ}}\,F(\theta)\big)$$

$$\phi) - T(\theta)\big)$$

$$\phi) + P_\gamma^{\text{circ}}\,E(\theta)\big)\Big]$$

<u>ELSA- Experiments:</u>

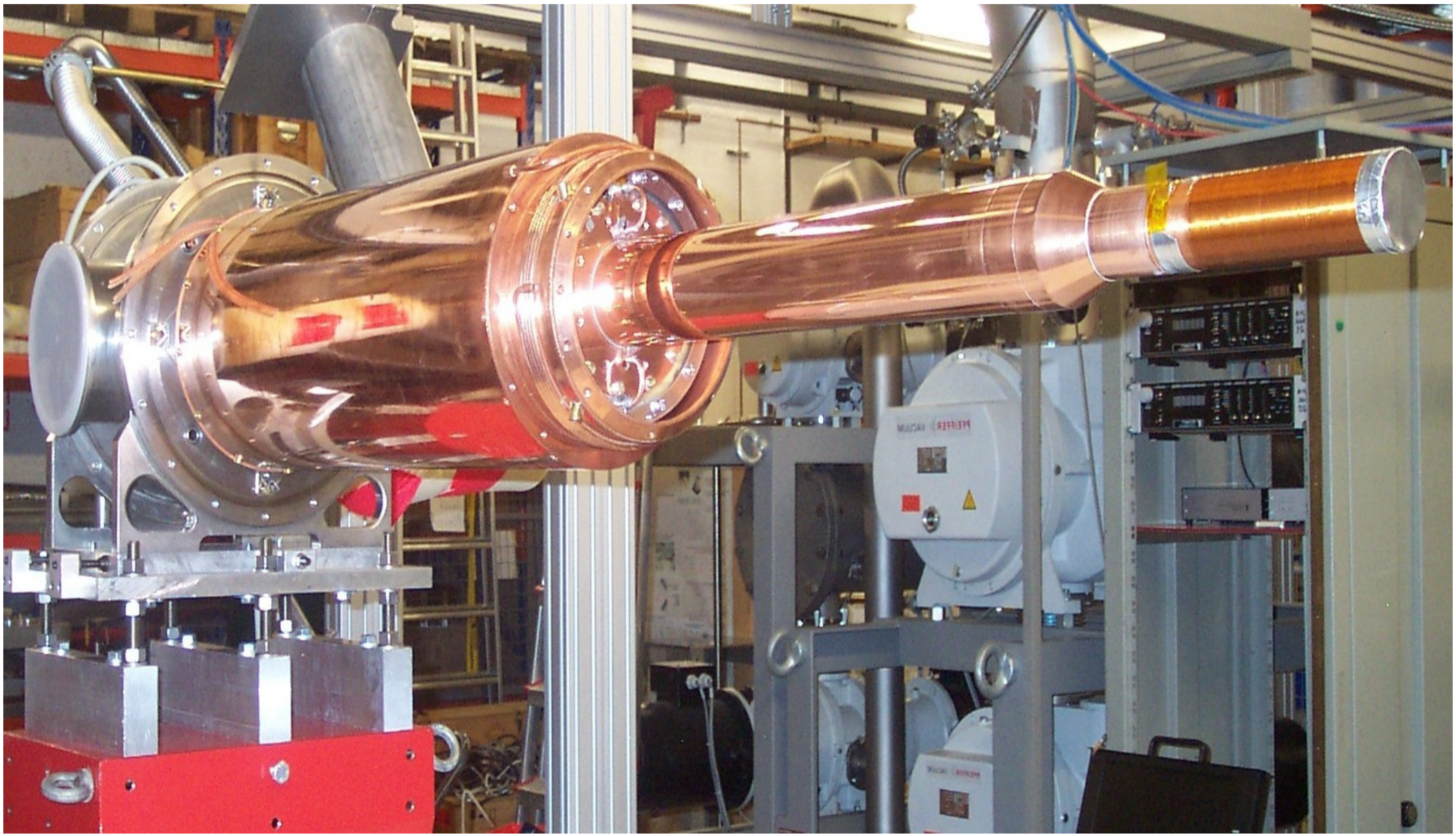
Data on all three single pol. observables Σ, P , T and diff. cross section σ

and on four double polarization observables G , E and H and (F)

for $\gamma\ p \rightarrow p\,\pi^0$ and $p\,\eta$, $p\eta'$, $p\omega$, $p\pi^0\pi^0$, $p\pi^0\eta$, $K^0\Sigma^+$, ...

Internal longitudinal Holding coil

(solenoid coil manufactured of 0.227-µm multifilamental NbTi cable and consisting of four layers, each having 600 turns wound around a 0.3-mm thick copper holder, T ≈ 1.5 K)



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Mikrowaves
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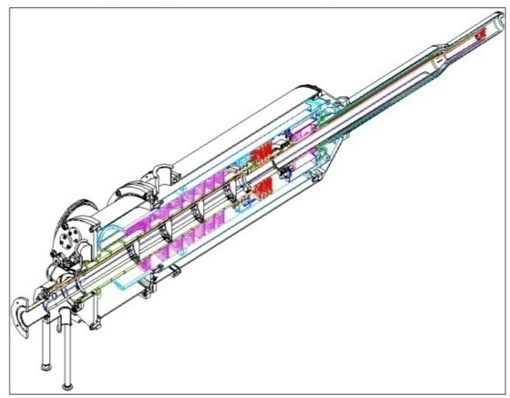
Nuclear
Polarization

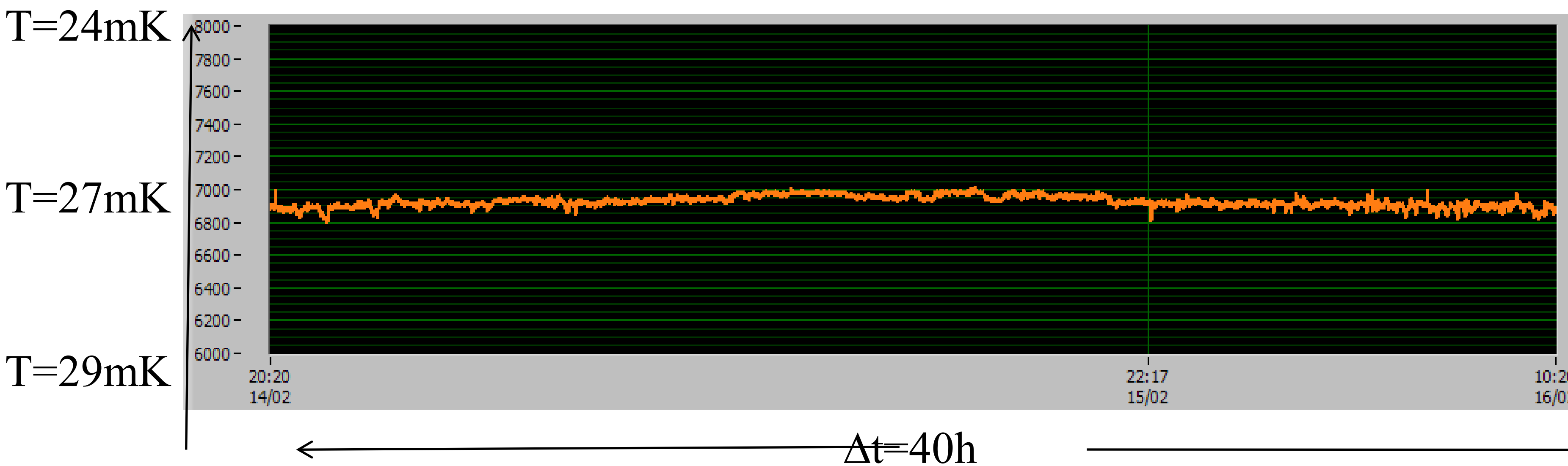


NMR-Apparatus
106MHz
Polarisation meas.

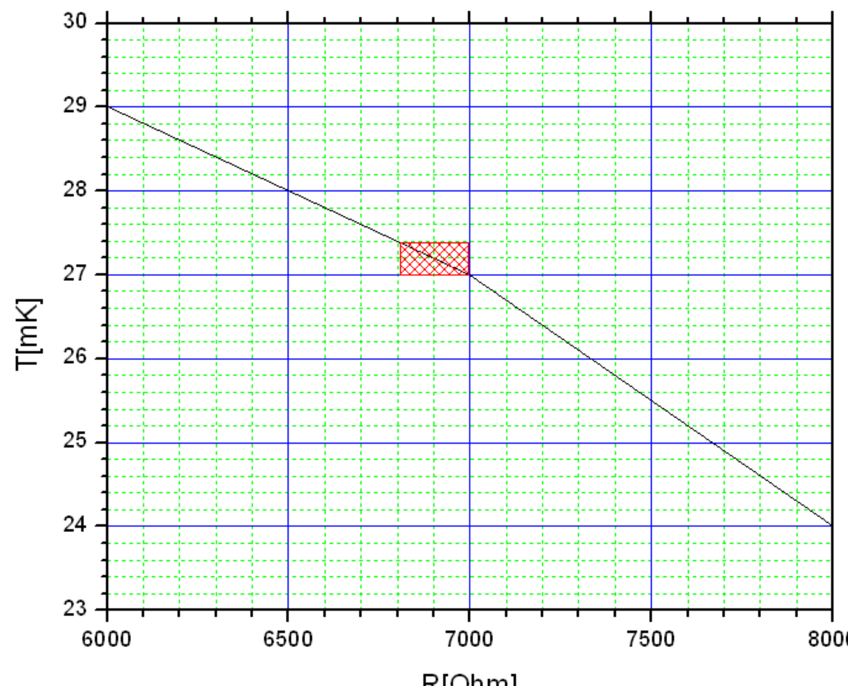
Horizontal He^3/He^4
Dilutionrefrigerator
(25mKelvin)
with internal
Holding coil

Superconducting
Polarization magnet
5Tesla

Cryostat Performance



Temperature stability:
ΔT ~ +- 0.2mKelvin (one day)
(typical one week measurement period).



Spin polarizabilities - Theory and Experiment

γ	ChPT 1	ChPT 2	K-matrix	Lχ	χEFT	DR1	DR2	DR3	Experiment with LEGS Σ_3 data*	Experiment with Mainz Σ_3 data**
E1E1	-5.4	-1.3	-4.8	-3.7	-1.1	-3.4	-4.3	-3.8	-3.5 ± 1.2	−5.0 ± 1.5
M1M1	1.4	3.3	3.5	2.5	2.2	2.7	2.9	2.9	3.16 ± 0.85	3.13 ± 0.88
E1M2	1.0	0.2	1.8	1.2	-0.4	0.3	-0.02	0.5	-0.7 ± 1.2	1.7 ± 1.7
M1E2	1.0	1.8	1.1	1.2	1.9	1.9	2.2	1.6	1.99 ± 0.29	1.26 ± 0.43

Experimental results for the multipole basis spin-polarizabilities are from the combined analysis of Σ_{2x} (Mainz data) and Σ_3 (LEGS or Mainz data**) asymmetries using a dispersion model calculation***.*
The size of the experimental uncertainties is too large to discriminate between these various predictions. One of the largest uncertainties in the analysis is due to the error on γ_π, ±1.8. The data on the asymmetry Σ_{2z}, should reduce the uncertainty by a factor of approximately four, which should reduce the uncertainty on M1M1 by a factor of approximately two. Polarizabilities (in units 10^{-4} fm^4):

* G. Blanpied et al. (The LEGS Collaboration), Phys. Rev.C 64, 025203 (2001).
** Preliminary.
*** D. Drechsel, B. Pasquini, and M. Vanderhaeghen, Phys. Rep. 378, 99 (2003).

Experiments are conducted with the photon beam of the electron accelerator MAMI-C, Mainz, Germany.
Main experimental apparatus:

1) Tagged photon beam (unpolarized, circular and linear polarization).
2) Detector system:

- 4π- photon spectrometer CB/TAPS (100% solid angle covering for particles decaying into two or more secondary photons, 97% of 4 for single photons, detection of neutrons and charged particles is also possible at restricted energy regions.

- Crystal Ball (CB) overlaps polar angle range (20 - 160) and TAPS: (1 - 20). CB consists of 672 NaI(Tl) crystals with 15.7 radiation lengths.
- TAPS consists of 366 BaF2 crystals with 12 radiation lengths and is supplemented by 5-mm

MWPC, 2 cylindrical multi-wire proportional chambers for vertex reconstruction, target position correction (z), and beam position control (x, y).

- PID (Particle Identification Detector) consists of a barrel of 24-mm-thick plastic scintillator strips. This is a VETO detector for photons in Crystal Ball, also it works as $\Delta E/E$ detector for charged particles identification in Crystal Ball.
- Recoil proton polarimeter. Method: detection of proton scattered in the graphite analyzer and comparison its angle with kinematic reconstruction.

GDH. Results (Mainz, Bonn)

Protons: Theory GDH_{Int}=204 μb

Exp. (255 ± 5 ± 12) μb (0.2 – 1.8) GeV

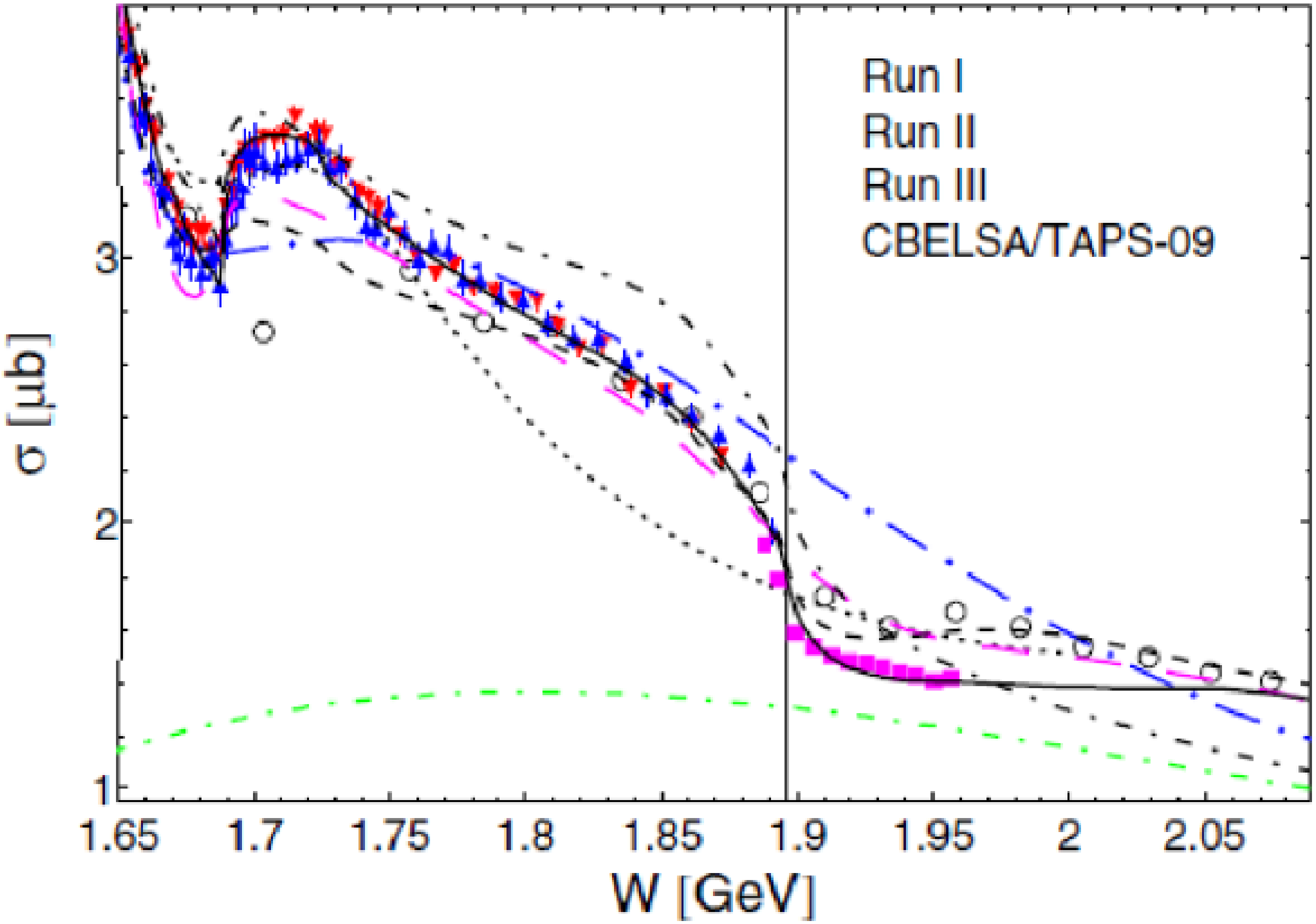
Deuterons: Theory GDH_{Int}=0.65 μb

Exp. (452 ± 9 ± 24) μb (0.2 – 1.8) GeV

Neutrons: Theory GDH_{Int}=233 μb

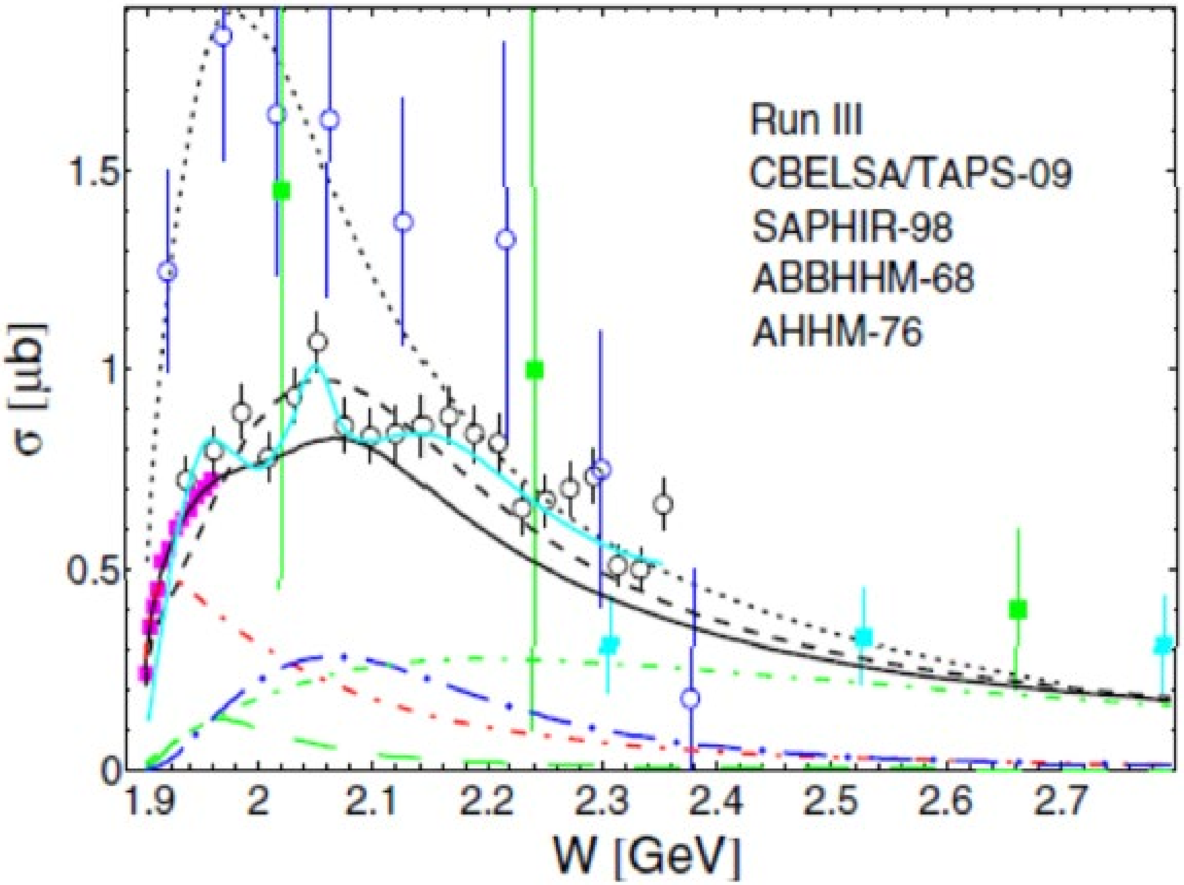
Exp. 197 μb (0.2 – 1.8) GeV

L. Witthauer et al., Phys. Rev. **C 95** (2017) 055201.



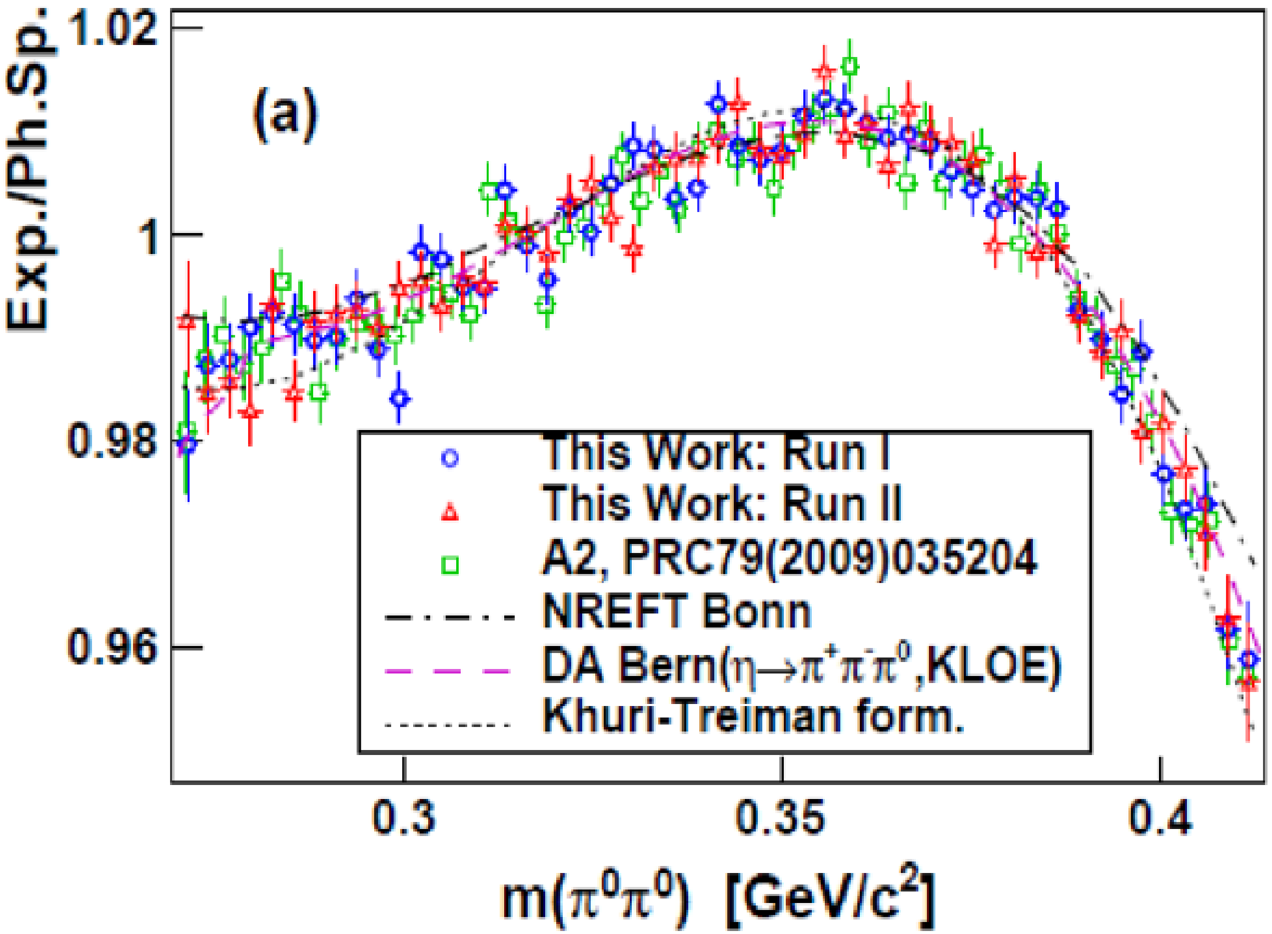
γp→ηp total cross section.

V.L. Kashevarov, N.S. Borisov, G.M. Gurevich, et al
Phys. Rev. Lett. **118** Iss. 21, 212001 (2017).



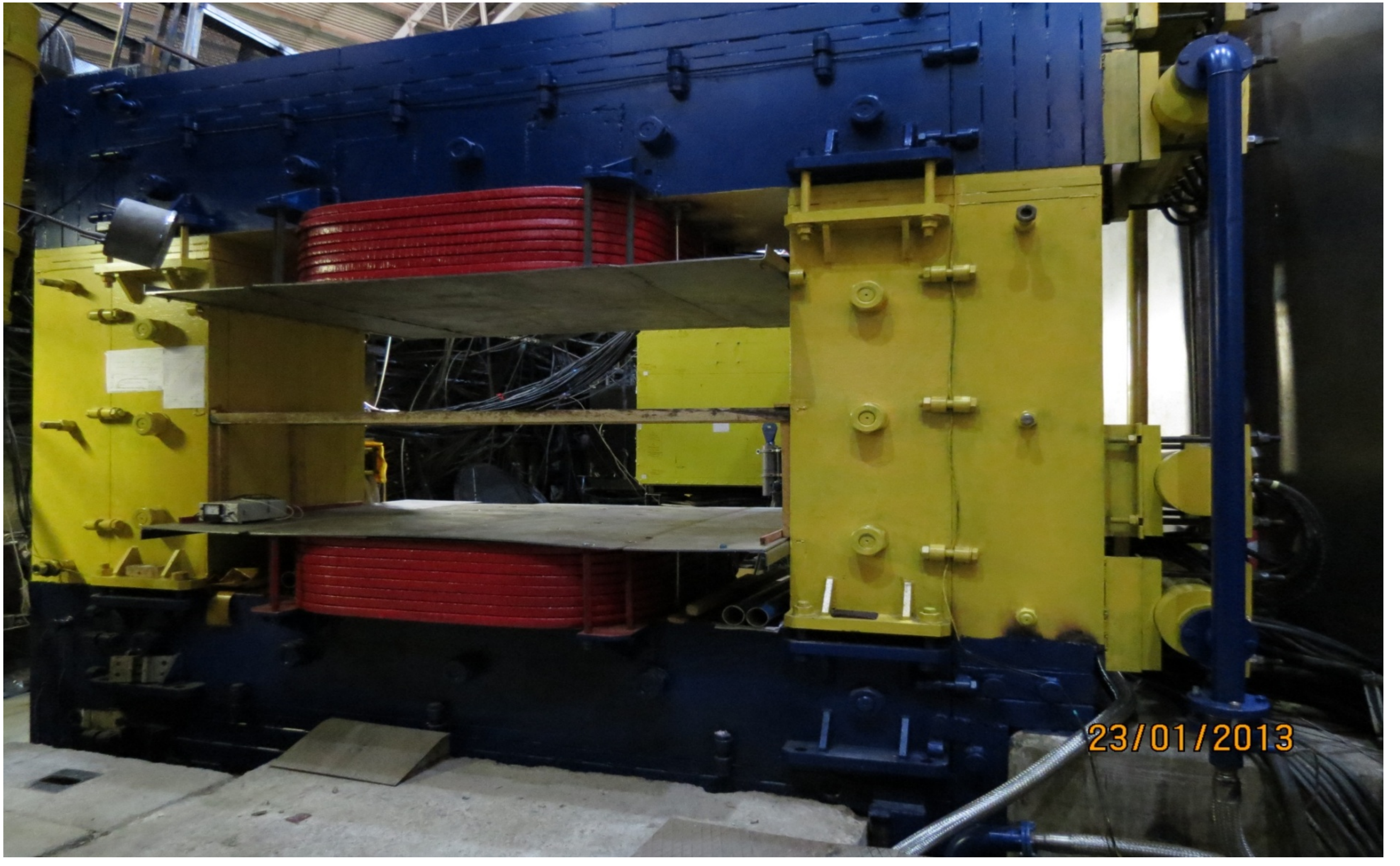
γp→ η'*p* total cross section.

V.L. Kashevarov, ...G.M. Gurevich, et.al
Phys. Rev. Lett. **118** Iss. 21, 212001 (2017).



S. Prakhov,…. N.S. Borisov, G.M. Gurevich, et. Al
Phys. Rev. **C 97** No. 6, 065203 (2018).

SPASCHARM spectrometric magnet



Working plan

2020:

GDH Commissioning of the new frozen spin target for experiments with Crystal Barrel/ELSA facility at the Bonn University.

SPASCHARM Data taking run will be carried out using a negative particle beam and the Dubna polarized frozen target. The magnet of the polarized target will be optimized (it is necessary to achieve field uniformity at the level of 0.012%). The technical design of the polarized beam-line will be finished while the construction will started (subject to appropriate funding).

NN Experiments on channeling of the deuterons at the stand of the polarized deuteron source.

2021

GDH Precision large-acceptance measurements of the beam-spin asymmetry for deuteron photodisintegration in the region of the exotic six-quark state **d*(2380)**.

SPASCHARM Data taking run will be carried out using a negative particle beam and a Dubna polarized frozen target. Single spin asymmetries will be measured in inclusive production of charged pions. Conceptual design of the SPASCHARM experiment will be prepared and published (in Russian) as well as the proposal to study systematically spin effects in elastic reactions.

NN Build up of the polarized neutron source on the base of polarized deuteron source and to join it with the frozen polarized deuteron target. The exact measurement the vector and tensor polarizations of the deuterons.
Preparation of special devices for usage of new target material based on Trityl-doped butanol.

2022

GDH Study of the spectrum and properties of the baryon resonances through the measurements of the polarization observables in meson photoproduction.

SPASCHARM Single-spin asymmetry in inclusive production will be measured for such "lying on the surface" resonances like ρ (770), ω(782), η'(958), f_0(980), a_0(980), f_2(1270). The possibility to measure the polarization of hyperon and the alignment of vector mesons will be investigated also. The concept of the polarized beam tagging system will be developed and prototypes of the detectors of the tagging system will be developed and tested.

NN To prepare apparatus for measurements of the neutron polarization via scattering on the ^{4}He target.

Form №26

Proposed schedule and necessary resources for realization of the project "SPASCHARMGDH-NN" (k$)

Title of expense item	Total cost	Laboratory proposal for distribution of finances		
		2020	2021	2022
1. The modification of the UHF system of the polarized target	15.0	9.0	2.0	4.0
2. Design and preparation of the parts of "Active Target"	6.0	4.0	2.0	-
3. Modification of the polarization measurement system	4.0	2.0	2.0	-
4. Purchase of standard devices	41.0	16.0	14.0	11.0
Total (equipment)	66.0	31.0	20.0	15.0
Materials	26.0	10.0	8.0	8.0
TOTAL	158.0	72.0	48.0	38.0
Finance sources				
Budget expenses				
a) direct (immediate)	201.0	71.0	65.0	65.0
b) grant of Germany (BMBF)	30.0	10.0	10.0	10.0
c) grants of CR	54.0	18.0	18.0	18.0
Total immediate expenses	285.0	99.0	93.0	93.0