Measurement of the analysing power in pp elastic scattering at small angles

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Introduction

Motivation

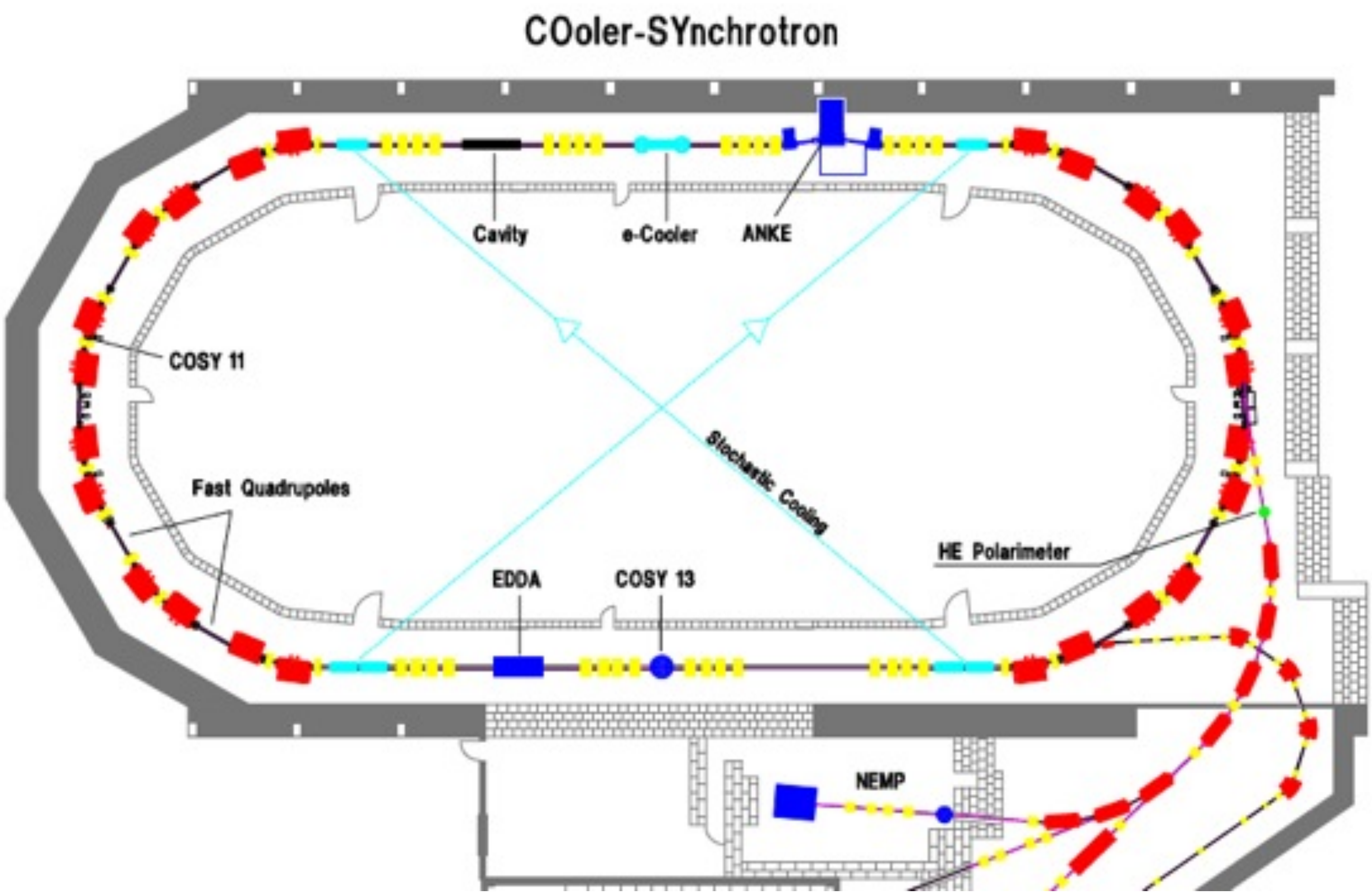
Analysing power in pp-elastic scattering at small angles is an important parameter for beam polarimetry. There are very few analysing power measurements available below 30 deg for beam energies above 1 GeV. The lack of data has left major ambiguities in the phase shift analysis.

[SAID: http://gwdac.phys.gov.edu]

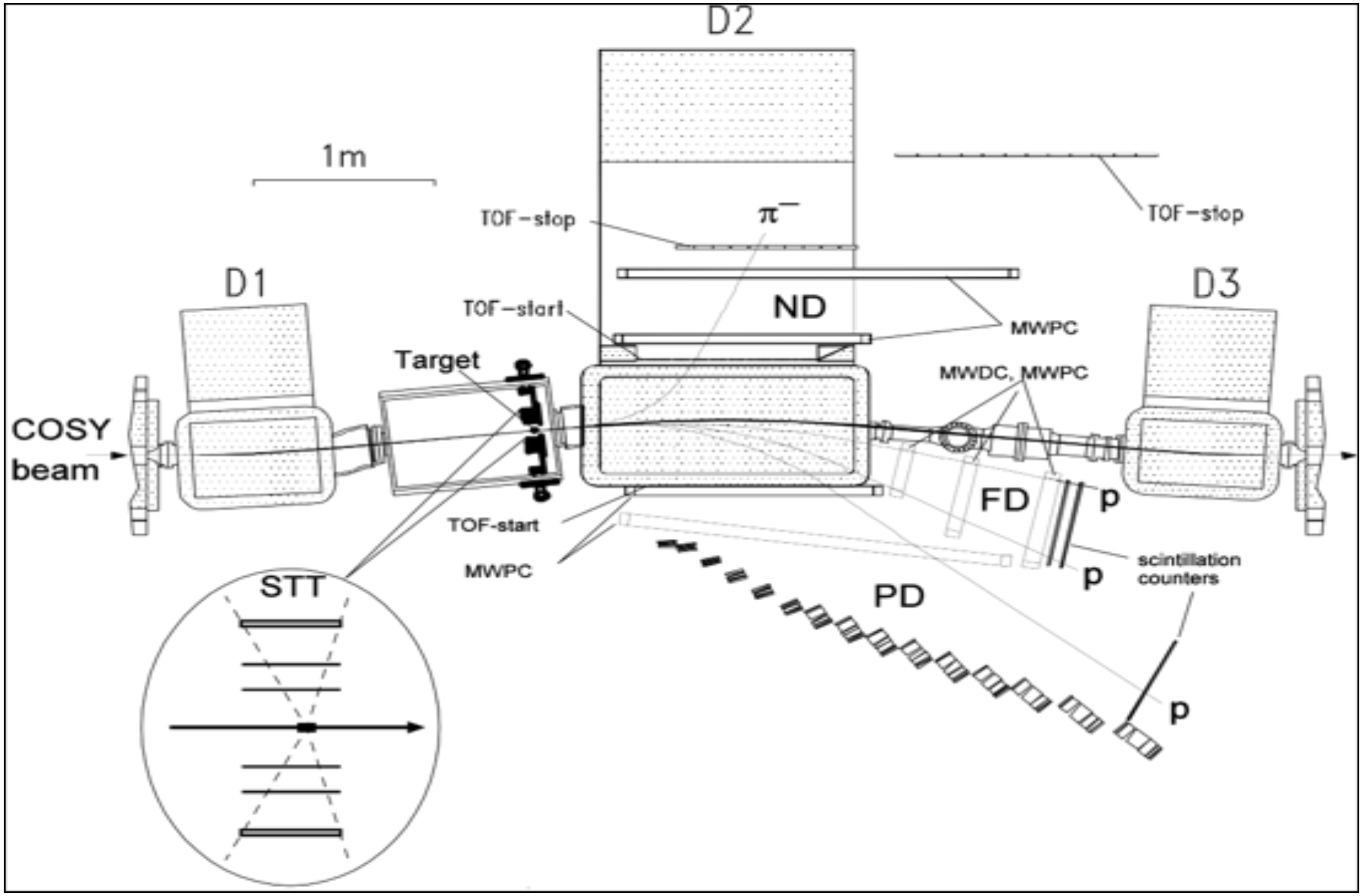
Experimental equipment and conditions

- Proton beams: Tp = 0.8, 1.6, 1.8, 2.0, 2.2, 2.4 GeV
- Hydrogen cluster jet target
- Two 3 layer Silicon Telescopes (STT) placed to the left and right symmetricaly to the beam axis.
- Single sided Forward detector with MWC tracking system and the scintillation hodoscope. The detector covers 10 — 30 degree c.m. angular range.
- EDDA detector as a beam polarimeter
- The triggering in the experiment was achieved using the STT integrated energy deposits as well as the forward detector hodoscope independently.

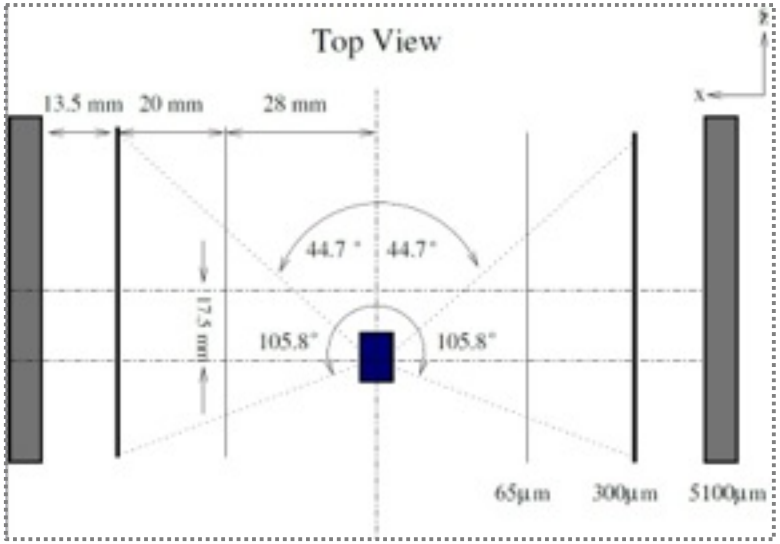
COSY and detectors arrangement

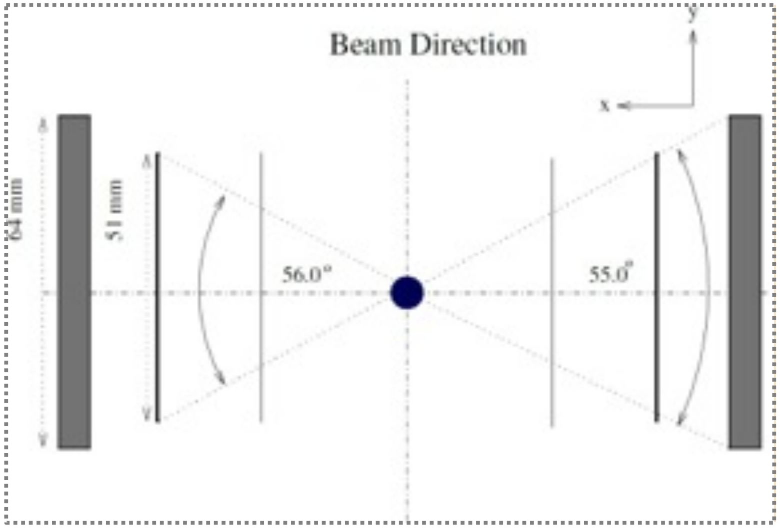


The ANKE spectrometer at COSY



STT arrangement





Some important parameters

Energy [GeV]	0.8	1.6	1.8	2.0	2.2	2.4
Beam polarization	0.554 ± 0.008	0.504 ± 0.003	0.508 ± 0.011	0.429 ± 0.008	0.501 ± 0.010	0.435 ± 0.015
θ(min-max) [deg] STT	6 - 31	3.6 - 25	3.6 - 25	3.6 - 24	3.6 - 24	3.6 - 23
θ(min-max) [deg] Fd	12 - 25	12 - 27	12 - 28	13 - 28	13 - 29	14 - 30
θ(max.stop) [deg]	22.3	15.3	15.3	14.3	13.3	13.3

Data analysis

Before analysis the recorded raw data was processed in the following way:

Raw data files → hit lists files → energy calibration → tracks files

Proton kinetic energy measurement

Kinetic energy of stopped protons is defined by the total energy deposit in a telescope (< 30 MeV). By studying the energy deposited in all three layers it was also possible to deduce the energy of punch-through protons up to 90 MeV. Thus expanding considerably the angular coverage of the telescope. The neural network approach was used for the proton kinetic energy evaluation.

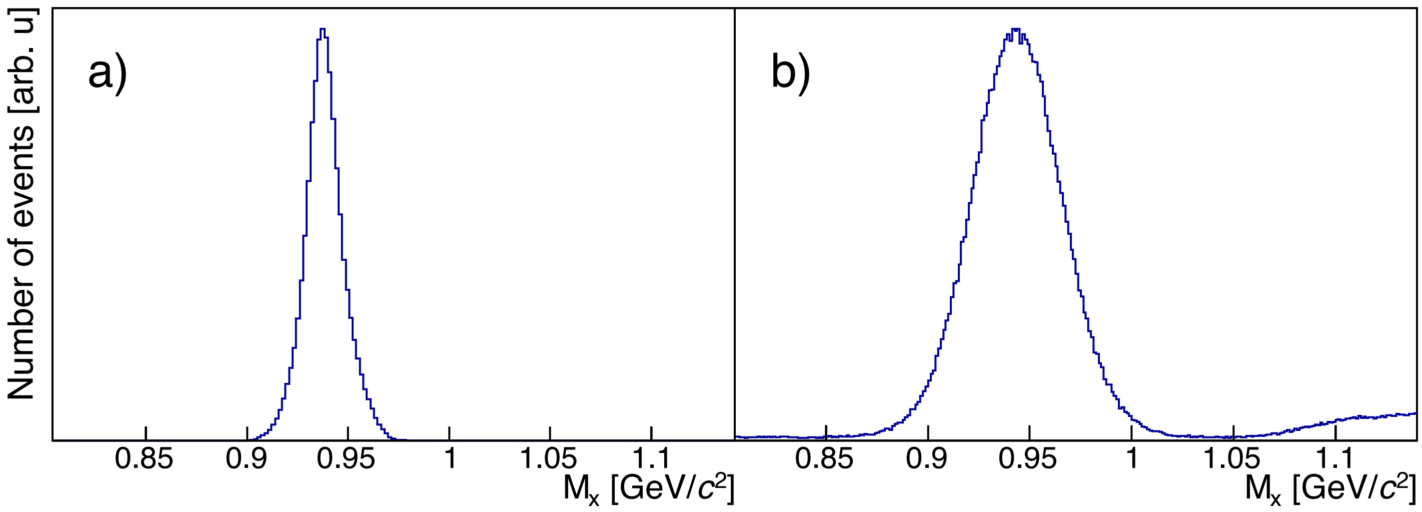
Scattering angle definition

Because of the greater precision the angle of the recoiling proton was deduced from its energy measured in the telescope. In Forward detector c.m. scattering angle is defined using a back tracing procedure.

Elastic scattering events selection

Elastic scattering events were selected through the evaluation of the missing mass in the reaction. There is very little ambiguity in the isolation of the proton peak.

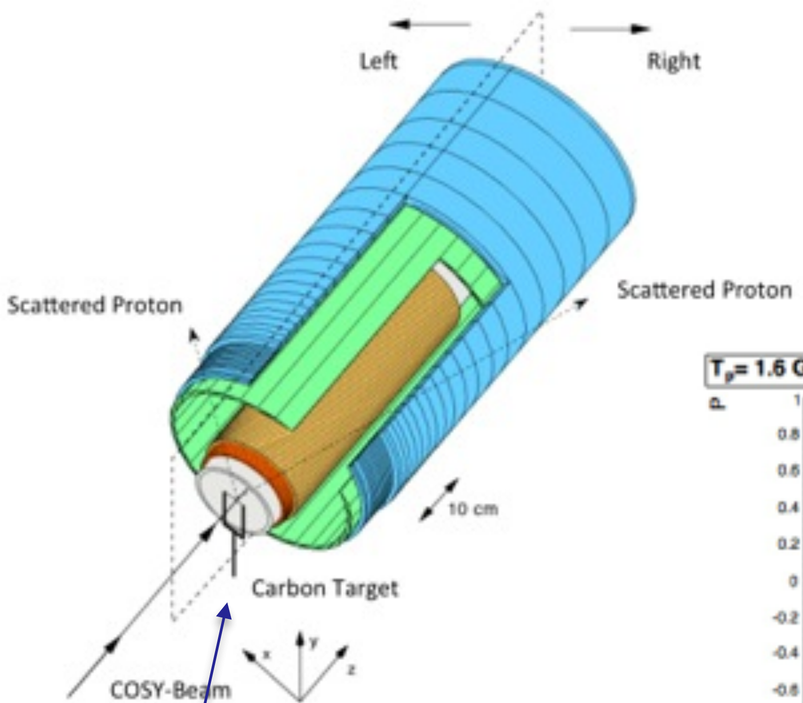
Elastic scattering events selection

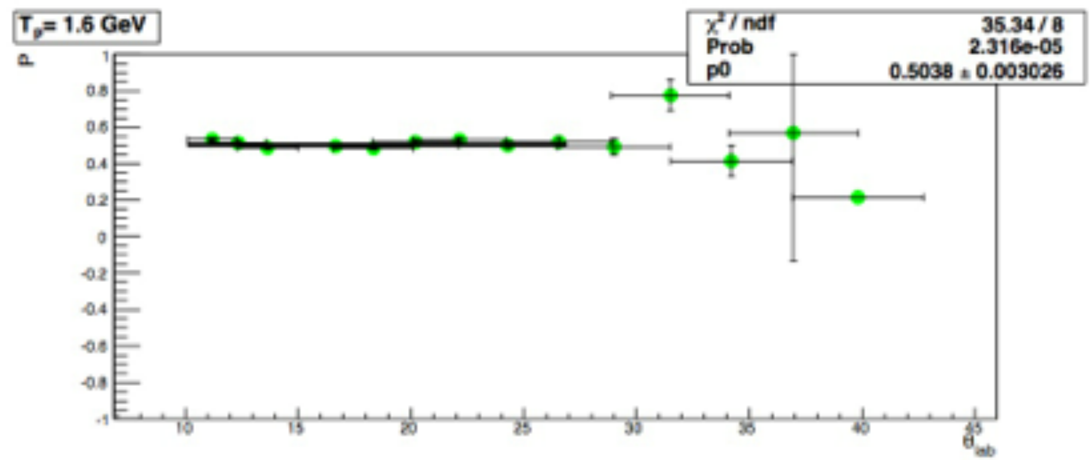


(a) missing mass for protons detected in STT at 1.6 GeV

(b) missing mass for protons detected in Forward detector at 1.6 GeV

EDDA performance





The 7 micron carbon fibre target is moved into the beam from below.

Beam polarimetry

COSY low energy polarimeter (LEP) measurements showed that the magnitudes of of the polarisations of the injected beam were about 93 % and the difference between the up and down values was smaller than the statistical uncertainty of 1 %.

The beam polarization was measured by the EDDA detector at the end of each cycle. The cycle duration equals to 180 sec so we ignored the beam depolarization during a cycle. In our measurements EDDA worked with Carbon target. Since the effective analysing powers have been determined for Carbon target, it was possible to measure beam polarization directly.

EDDA detals in: **E.Weise. Ph.D. Thesis, University of Bonn, 2000**

The average beam polarization was calculated averaging the beam polarizations with weights cycle by cycle. Useful event numbers were used as a cycle weight.

The relative systematic uncertainty in the polarization measurement arising from normalization equals to 3 %

Z.bagdasarian, ANKE note #31,

http://collaborations.fz-juelich.de/ikp/anke/internal.shtml

Some formulae

The number of counts recorded in the telescopes (1,2) at opposite beam polarization directions may be written as follows: **[G.G.Ohlsen, P.W.Keaton, NIM 109, 41, 1973]**

$$N_1(\vartheta,0) \equiv L_1 = L\uparrow = B_\uparrow \cdot \Omega_1 \; (1 + P_\uparrow \langle cos\phi \rangle_1 A(\vartheta))$$

$$N_2(\vartheta,\pi) \equiv R_2 = R\uparrow = B_\uparrow \cdot \Omega_2 \; (1 - P_\uparrow \langle cos\phi \rangle_2 A(\vartheta))$$

$$N_1(\vartheta,\pi) \equiv R_1 = L\downarrow = B_\downarrow \cdot \Omega_1 \; (1 - P_\downarrow \langle cos\phi \rangle_1 A(\vartheta))$$

$$N_2(\vartheta,0) \equiv L_2 = R\downarrow = B_\downarrow \cdot \Omega_2 \; (1 + P_\downarrow \langle cos\phi \rangle_2 A(\vartheta))$$

From now on we use P to denote the *effective* beam polarization omitting <cosΦ> factor. Details are given in:

G.Macharashvili, ANKE note #29,

http://collaborations.fz-juelich.de/ikp/anke/internal.shtml

Instability correction

$$\omega_\uparrow = \frac{L_1}{R_2} \equiv \frac{L_\uparrow}{R_\uparrow} = r_\uparrow \frac{1 + P_\uparrow A}{1 - P_\uparrow A} \quad \text{with} \quad r_\uparrow = \left(\frac{\Omega_1}{\Omega_2}\right)_\uparrow ,$$

$$\omega_\downarrow = \frac{R_1}{L_2} \equiv \frac{L_\downarrow}{R_\downarrow} = r_\downarrow \frac{1 - P_\downarrow A}{1 + P_\downarrow A} \quad \text{with} \quad r_\downarrow = \left(\frac{\Omega_1}{\Omega_2}\right)_\downarrow ,$$

The only factor affecting the asymmetry measured with symmetric detector is the instability of the ratio of the efficiencies of the left and right telescopes

$$\frac{\omega_\uparrow}{\omega_\downarrow} = \frac{r_\uparrow}{r_\downarrow} \frac{1 + 2PA + P^2A^2(1 - \varepsilon_P^2)}{1 - 2PA + P^2A^2(1 - \varepsilon_P^2)} \simeq \frac{r_\uparrow}{r_\downarrow} \frac{1 + 2PA + P^2A^2}{1 - 2PA + P^2A^2} .$$

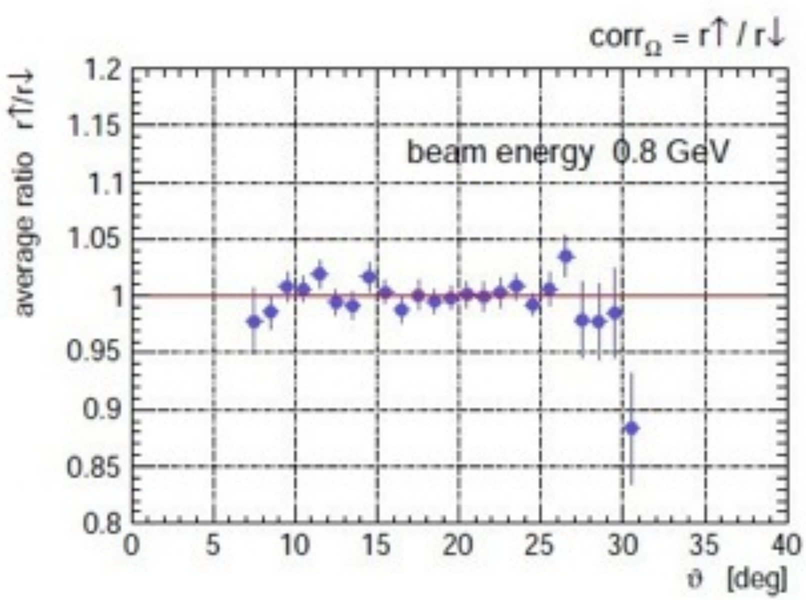
$$\Delta A(\vartheta) \simeq (1 - \frac{r_\uparrow}{r_\downarrow})\, A(\vartheta) \equiv c_\Omega(\vartheta)\, A(\vartheta) .$$

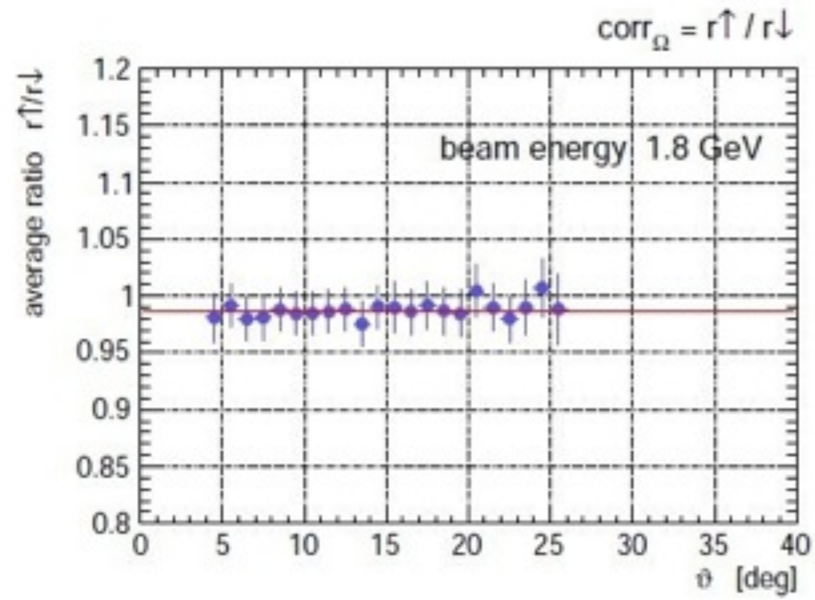
$$c_\Omega = \frac{1 + P^2A^2}{2PA} \left(1 - \sqrt{\frac{r_\uparrow}{r_\downarrow}}\right)$$

Averaged |c| does not exceed 1.3 % for all energies.

Instability correction term ΔA equals in average ±0.004 .

Instability correction





$\Delta A_y = c \cdot A_y$ is the fake asymmetry due to the time instability of the telescopes efficiencies ratio. So we corrected $A_y(\theta)$ points adding these corrections and the corresponding uncertainties.

Systematic errors and systematic uncertainties

The luminosity and the dead-time differences for up and down polarized beams cancel out, so do not cause the systematics.

Numerical tests were performed to estimate of some sources of systematic errors.

We selected the useful events applying the cuts on missing mass and the interaction point. Varying the selection criteria in reasonable ranges does not change the results beyond the 67 % confidence intervals ($\pm\sigma$).

Systematic errors and systematic uncertainties

The exact formula of analysing power calculation including the second order corrections is taken from

H.Spinka, The 50 MeV Polarimeter, ANL-HEP-Pr-80-02, 1980

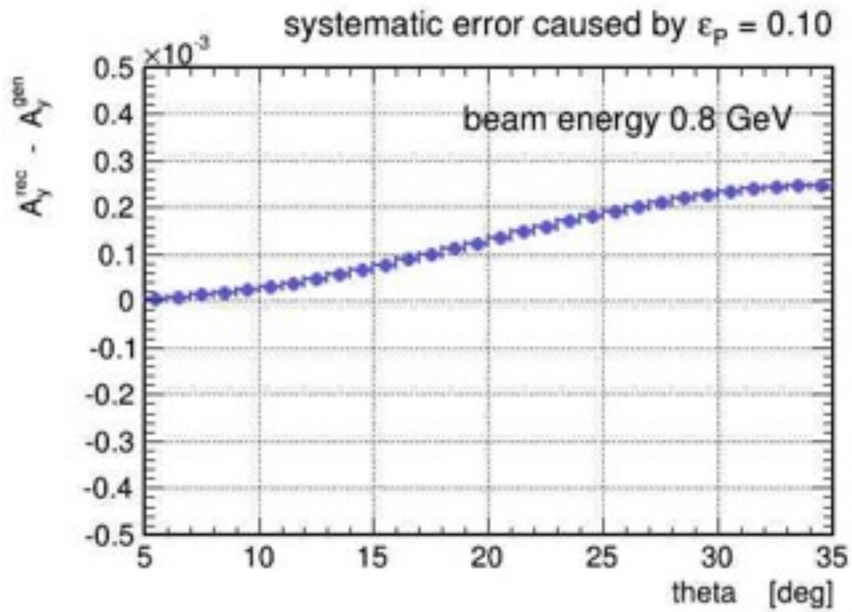
$$\alpha_9[2] \equiv \varepsilon = \frac{\sqrt{L_\uparrow R_\downarrow} - \sqrt{R_\uparrow L_\downarrow}}{\sqrt{L_\uparrow R_\downarrow} + \sqrt{R_\uparrow L_\downarrow}} = \frac{\sqrt{L_1 L_2} - \sqrt{R_1 R_2}}{\sqrt{L_1 L_2} + \sqrt{R_1 R_2}}$$

$$= PA\left[1 - \frac{2\,PA}{1 - P^2 A^2}\,\varepsilon_P \varepsilon_A + \frac{P^2 A^2}{1 - P^2 A^2}\,(\varepsilon_P^2 + \varepsilon_A^2)\right] + \mathcal{O}(\varepsilon^4)\,;$$

We estimated the systematic errors (the fake asymmetry) induced by these two asymmetries ε_A and ε_p.

Systematic errors and systematic uncertainties

The systematic error induced by the beam polarization up and down asymmetry has been estimated assuming that ε_p = 0.10 (extremly unfavorable case). The simulation reveals that it can be ignored.

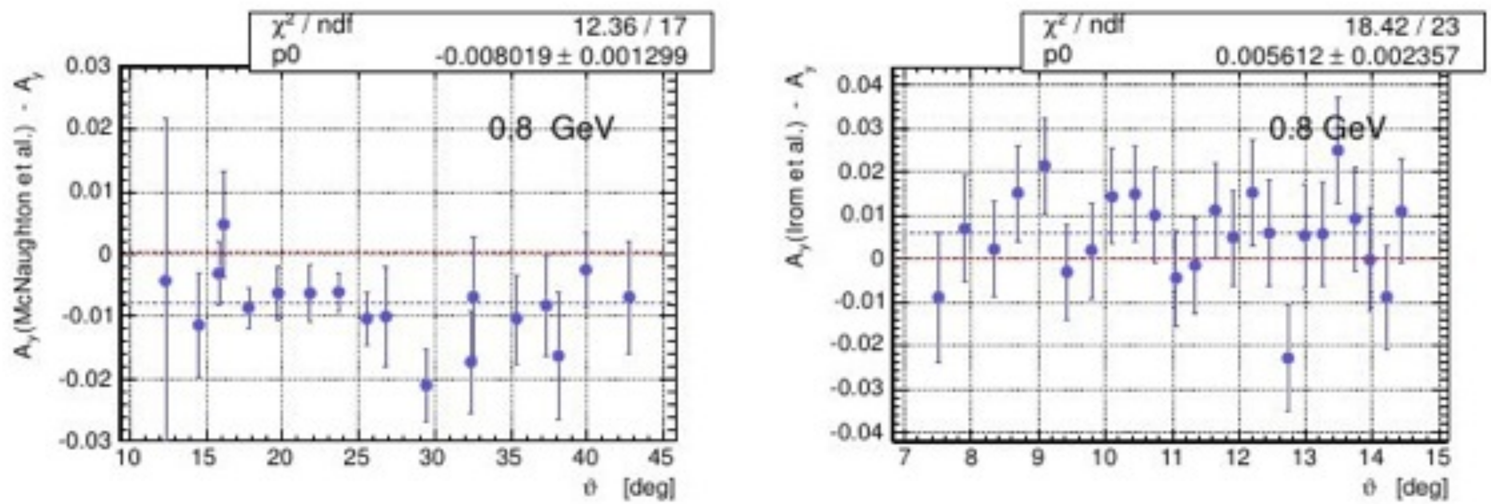


The asymmetry of analyzing power ε_A comes from misalignment of the left and right telescopes (or nonequal energy calibration), so the measured angles are different. The estimate of ε_A gives that it does not exceed 0.03 (at 0.8 GeV and θ = 30 deg).

So the corresponding systematic error upper limit equals 0.0015 and can be ignored.

Comparison with other experiments

At the beam energy of 0.8 GeV there are several measurements in our angular range. We compared our data with other two most reliable measurements. Red line shows the fitted value of our exp points.



Left panel: data from **M. W. McNaughton et al, Phys.Rev.C, 23, 1128, 1981**

Right panel: data from **F. Irom et al, Phys.Rev.C., 25, 373, 1982**

Forward detector. Systematics

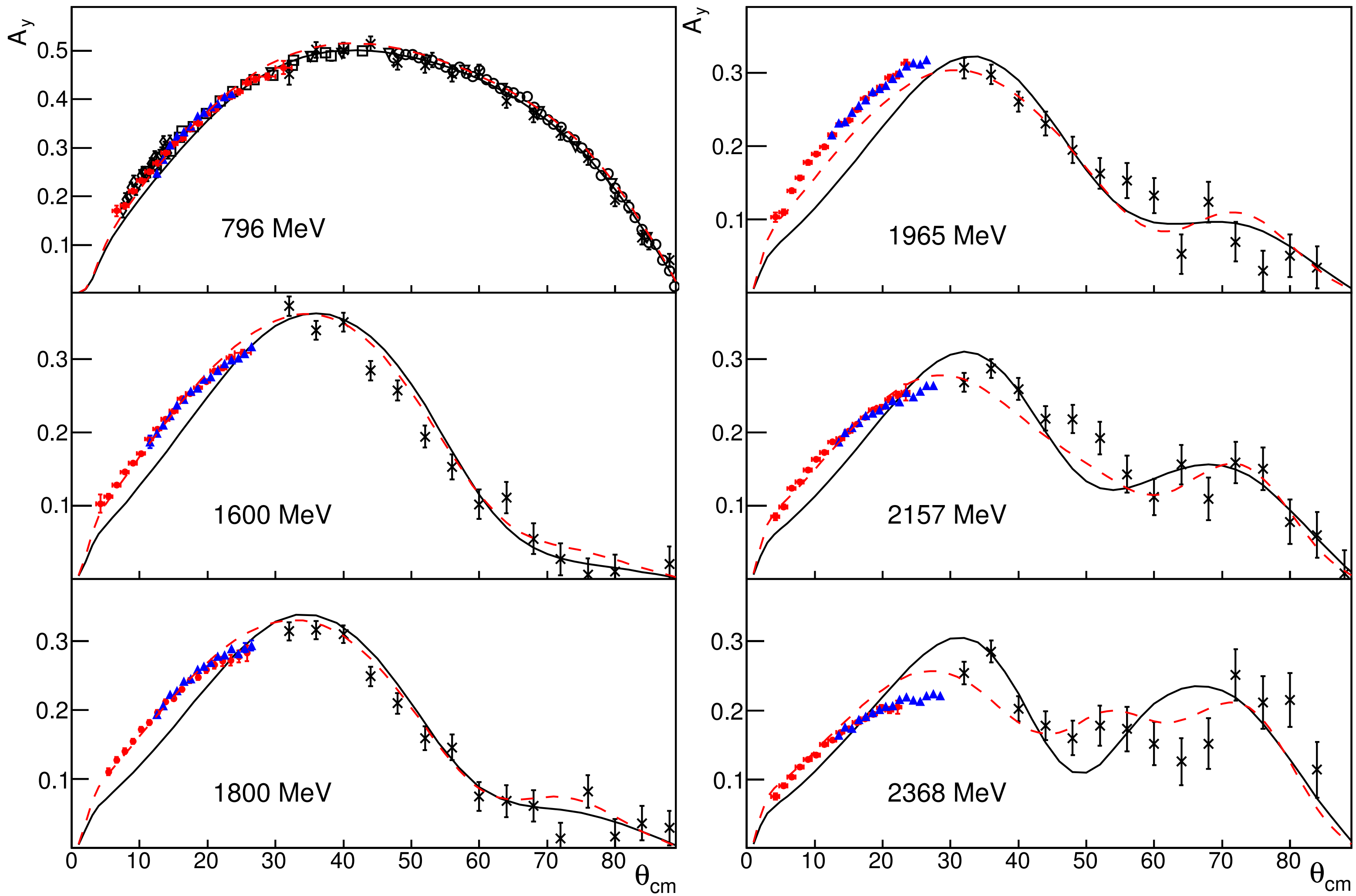
the overall (relative) uncertainty in the analyzing power measurement with the Forward detector equals 5.5 % including the uncertainty of polarimetry.

The systematic uncertainty sources are the following: uncertainty in the luminosity normalisation estimate and the beam polarization modules inequality for up and down polarised beams.

S.Dymov, ANKE note #30,

http://collaborations.fz-juelich.de/ikp/anke/internal.shtml

Results



http://arxiv.org/abs/1409.8445 submitted to PLB …

today morning we got a message that the paper is accepted

Results. SAID solution

SAID solution SP07 describes well the ANKE data at 0.8 GeV.
[SAID: http://gwdac.phys.gov.edu]

At higher energies the data deviate significantly from the predictions of the SP07 solution. The shapes of the data are very different rising much steeply at small angles. The new fit (red dashed curves) corresponds to modest changes to the parameters of the lower partial waves.The average normalisation (scale) factor equals <N> = 1.00 ± 0.02.

Summary

- The analysing power in pp elastic scattering is measured at first time at beam energies of 1.6 – 2.4 GeV in the angular range 4 – 30 degree. The results obtained with two independent detectors coincide.

- The measured analysing power at 0.8 GeV beam coincides with the results of other experiments.

- At the beam energies >1.6 GeV the measured analysing power deviate from the SAID predictions SP07.

- The statistical uncertainties does not exceed 0.015.

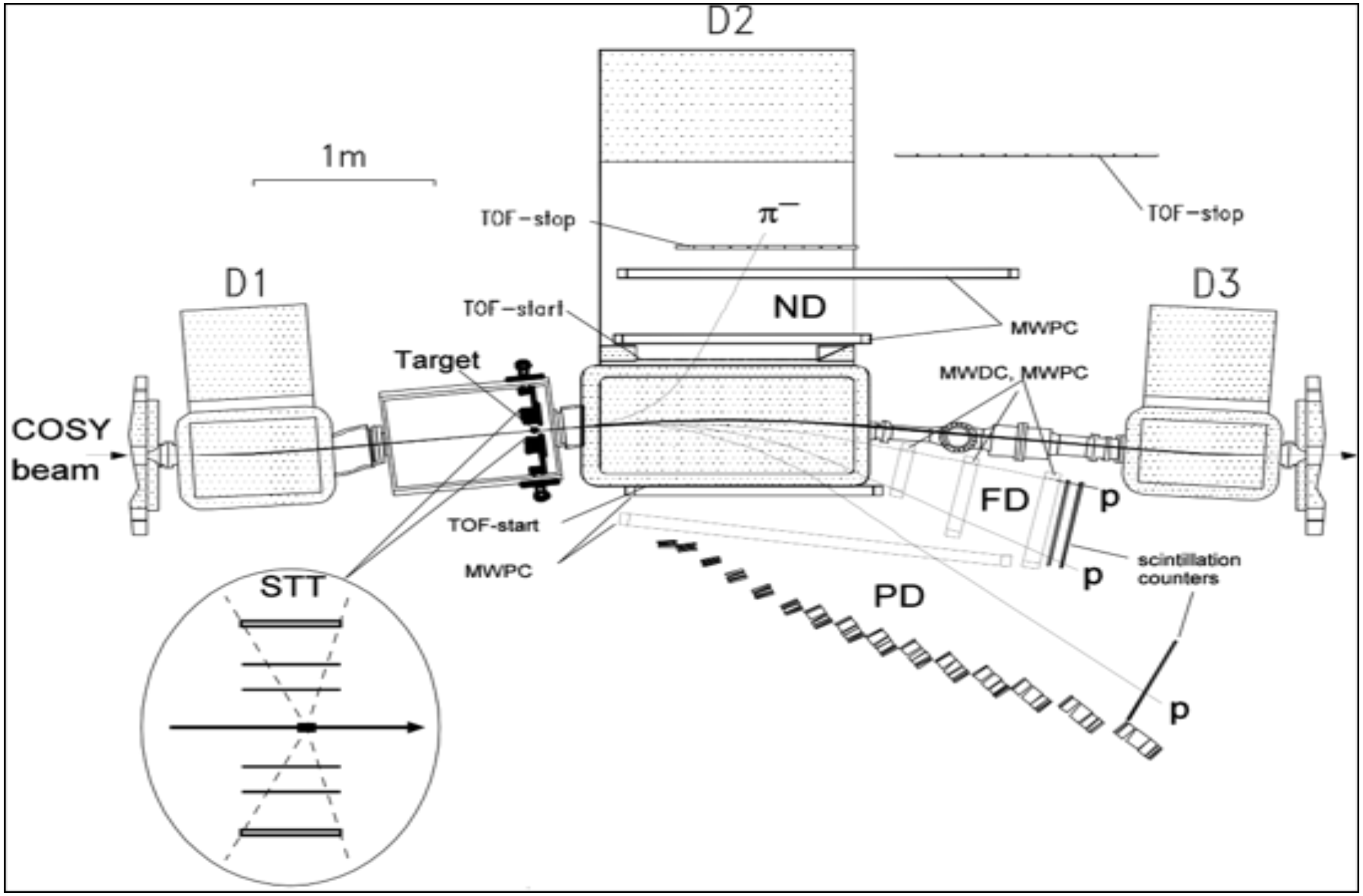
- Study of the sources of the systematic errors revealed that all of them are negligible with reliable confidence for both STT and Forward detectors. The summary systematic uncertainty in the asymmetry measurement with STT does not exceed 0.003.

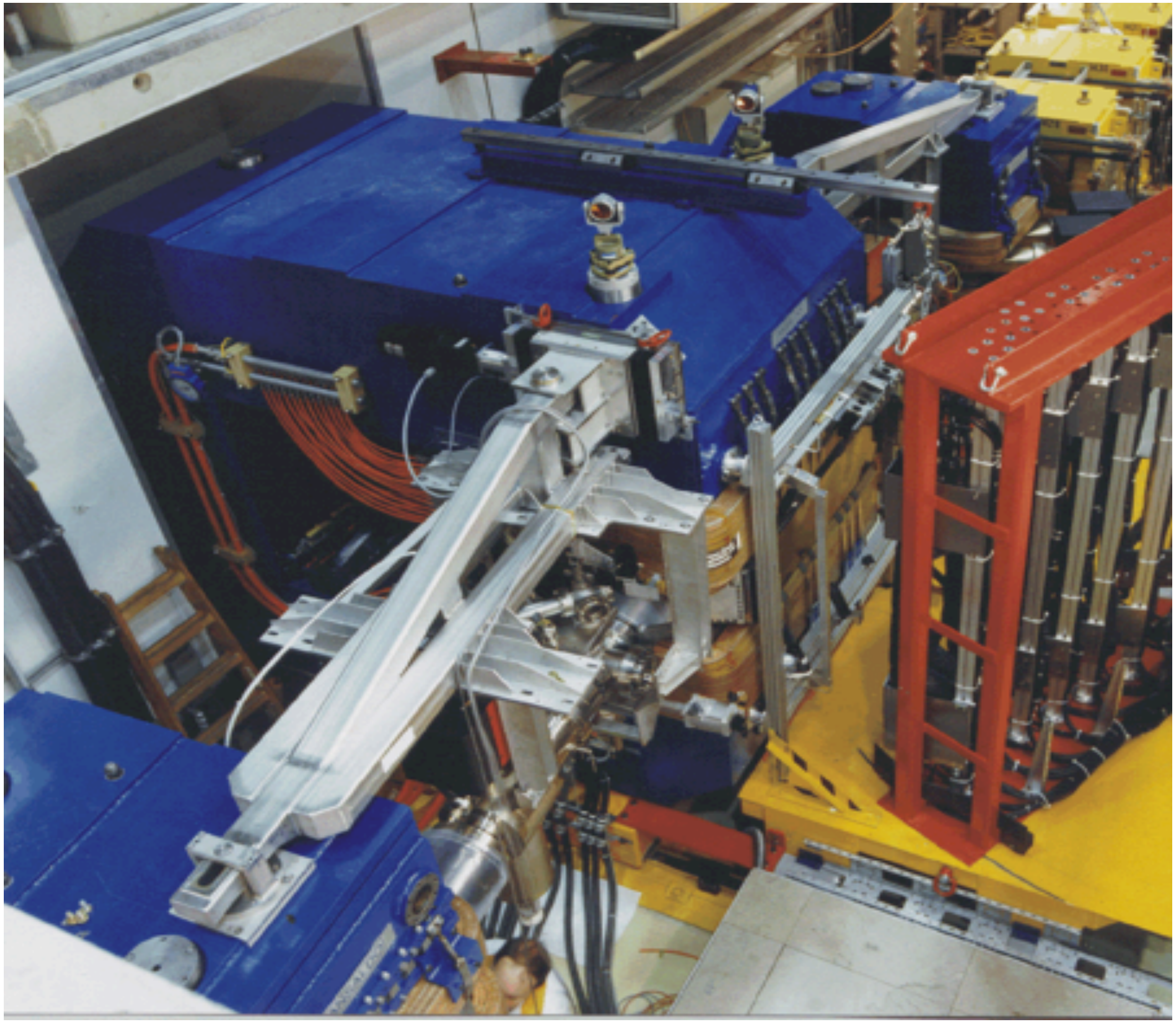
- The detector stability control provides the systematic error correction factor for STT compensating the left and right telescopes efficiencies ratio instability.

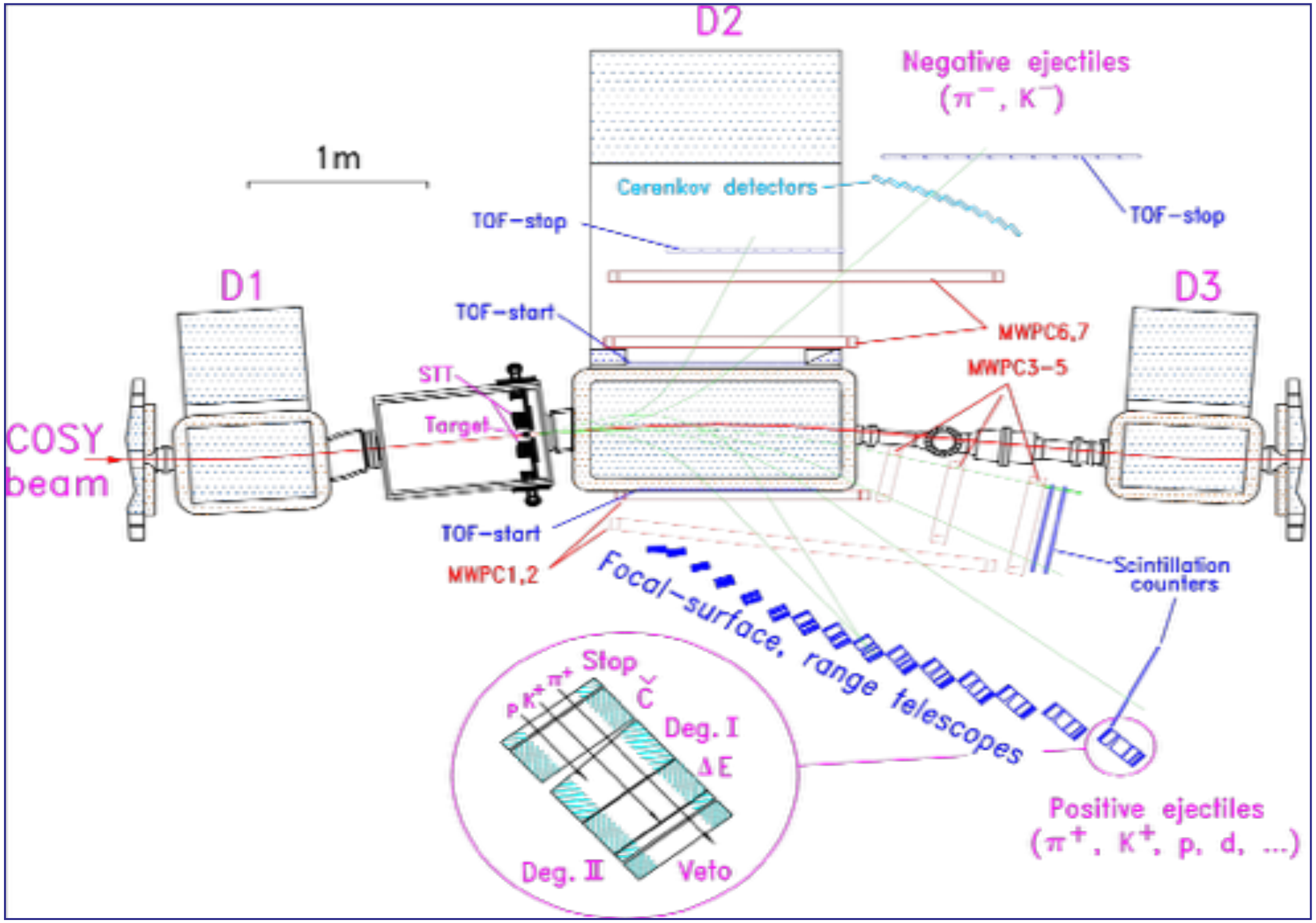
- The beam polarization measurement relative uncertainty of 3 % dominates in the final results obtained with STT. The estimate of the summary systematic uncertainties for the Forward detector equals 5.5 %.

Thank you

The ANKE spectrometer at COSY






D2
Negative ejectiles
(π⁻, K⁻)
1m
Cerenkov detectors
TOF−stop
TOF−stop
D1
D3
TOF−start
MWPC6,7
STT
MWPC3−5
Target
COSY
beam
TOF−start
MWPC1,2
Scintillation
counters
Focal−surface, range telescopes
Stop
p K⁺ π⁺
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Deg. I
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Positive ejectiles
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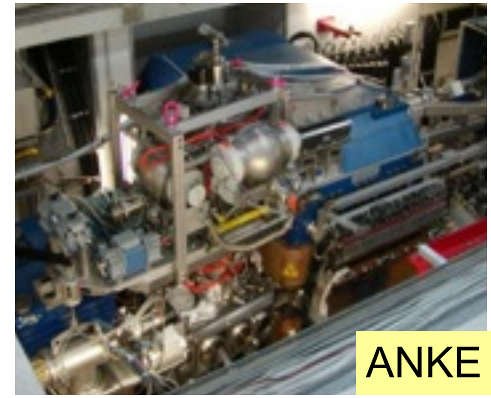
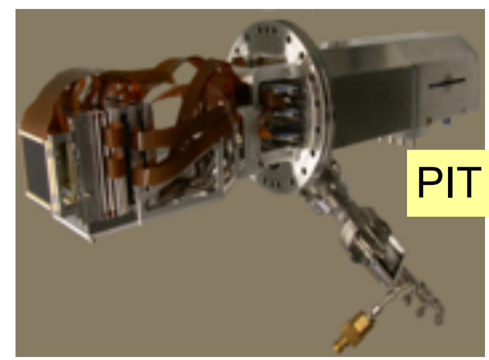

ANKE


PIT

STT

Results

preliminary