TechNote: Extraction of the Beam Polarization Values for pp elastic experiment at ANKE using the EDDA polarimeter

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1 Introduction

The experiment "Measurement of nucleon-nucleon elastic scattering at small angles up to the maximum COSY energy" has been held at COSY accelerator in March-April 2013. It was proposed by the ANKE collaboration in [1] that nucleon-nucleon(NN) scattering database can be significantly enlarged using the experimental setups, already existing in Jülich. Such data are necessary ingredients, not only for the understanding of nuclear forces, but also for the description of meson production and other nuclear reactions at intermediate energies.

In order to obtain the beam polarization value, necessary for the analyzing power determination, it was decided to use the EDDA detector. The following report provides the description of this procedure.

1.1 Experiment

COSY provides high quality, high precision polarized or unpolarized, proton beams in the momentum range of 0.3 to 3.7 GeV/c. For the given experiment six beam energies were chosen to be investigated (0.796, 1.6, 1.8, 1.965, 2.157, 2.368 GeV) and two targets were used at the ANKE section: hydrogen for pp, and deuterium for np investigations.

The H^- ions from the polarized ion source were accelerated to 45 MeV in the cyclotron JULIC before being stripped of their electrons and injected into COSY [7]. Two modes, with spin up (↑) and down (↓) were supplied by the source and the polarizations of the injected beam were optimized using a low energy polarimeter (LEP) in the injection beam line to COSY [8]. The measurements carried out with the LEP showed that the magnitudes of the polarizations did not differ by more than 1% and that their average was 0.92 ± 0.010.

For the beam polarization measurement the thick carbon fiber target is placed at the EDDA section during 20 seconds at the end of each cycle. Since the effective analyzing powers $A_n^{eff}(C)$ have been determined for carbon, polarization can be determined using the carbon targets, using quasi-elastic scattering of the beam protons on the carbon-bound nuclear protons. The COSY beam is polarized oppositely

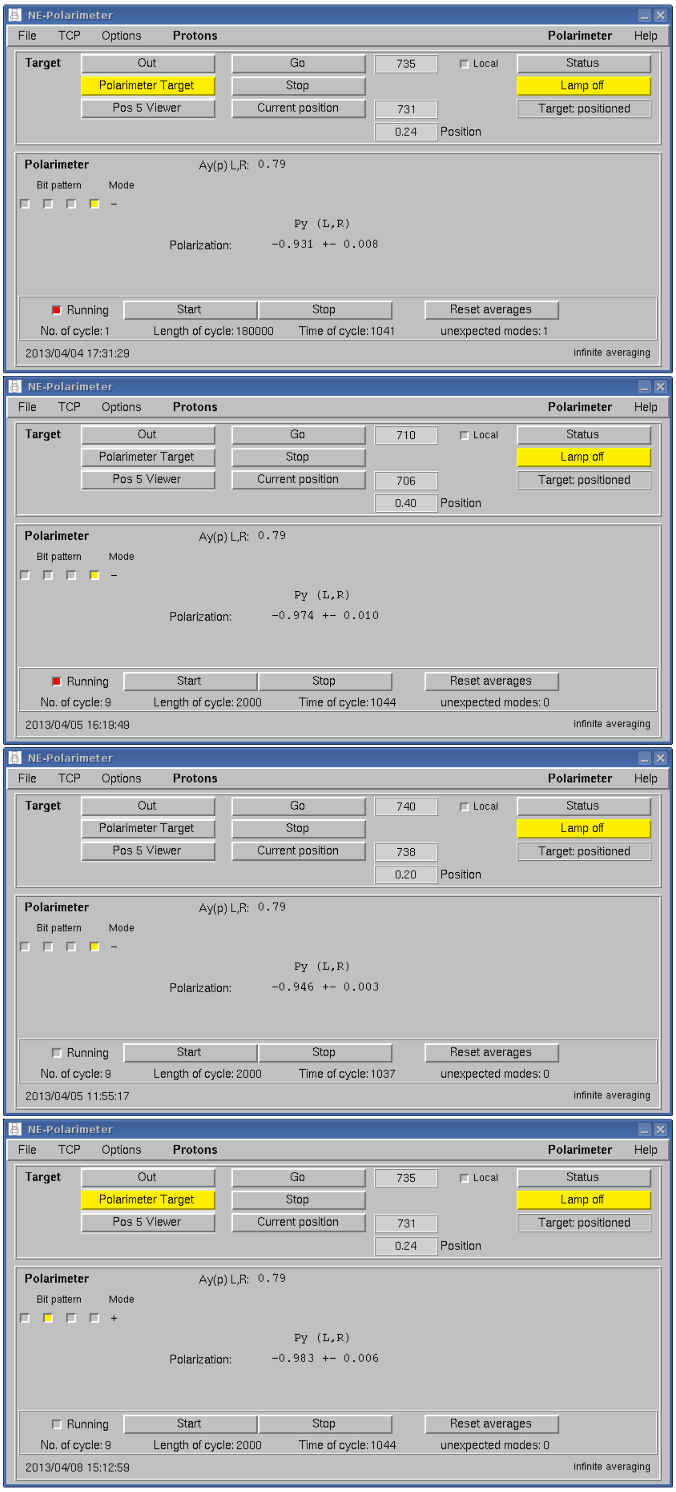

Fig. 1: Screenshots from LEP measurements during the beam time

in the subsequent cycles, in order to take advantage of Ohlsen method [10] for the determination of the asymmetry ε

$$\varepsilon = \frac{L-R}{L+R} = \frac{2pA_y[nn'NN'\Omega_1\Omega_2E_1E_2]^{\frac{1}{2}}\sigma_0}{2[nn'NN'\Omega_1\Omega_2E_1E_2]^{\frac{1}{2}}\sigma_0} = pA_y(\theta) \quad (1)$$

which is independent of relative detector efficiencies (E_1, E_2), solid angles (Ω_1, Ω_2), relative intensities (nn') and target thickness variations. (NN'). n and N, quantities common to the two channels, are averaged over the data acquisition time (in one run); E and Ω, quantities different in two channels, must not vary with time.

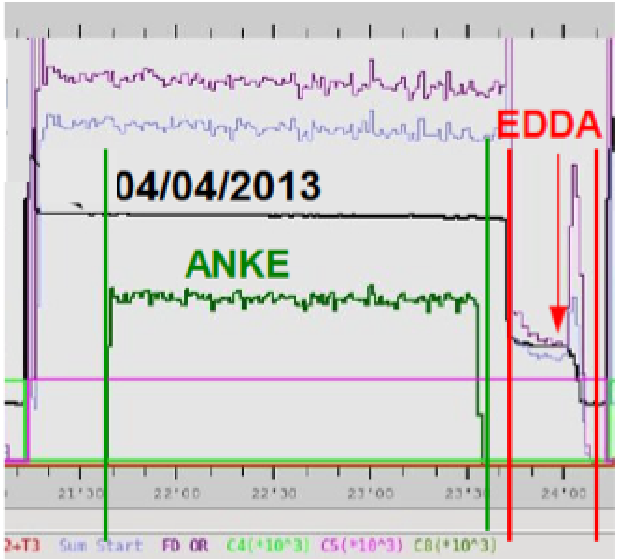

Fig. 2: Screenshot from data acquisition control display in the given experiment. The data at EDDA is accumulated only at the end of each cycle.

1.2 EDDA's legacy

The EDDA experiment [2], [3], [4], [5] was conceived to provide high-precision elastic-scattering data in the COSY energy range (0.5-2.5 GeV), but later has been modified to be used as the internal polarimeter in order to observe the polarization evolution during the beam acceleration.

$p -^{12} C$-inclusive measurements have been introduced into EDDA data acquisition as a fast diagnostic tool for COSY beam polarization development. It has been possible to measure the beam polarization during both flattop and beam acceleration.

For that faster polarization determination, so-called effective analyzing powers for the individual rings have been tested by the EDDA collaboration in November 1999 beam time [6]. These effective analyzing power values at the investigated energies have been used in the current analysis.

The EDDA-detector is comprised of the 7μm diameter carbon fibre target and the $2*29$ semi-ring scintillators. that intercept protons scattering through the range of polar angles from 11.1°to 42.7°in the laboratory system.

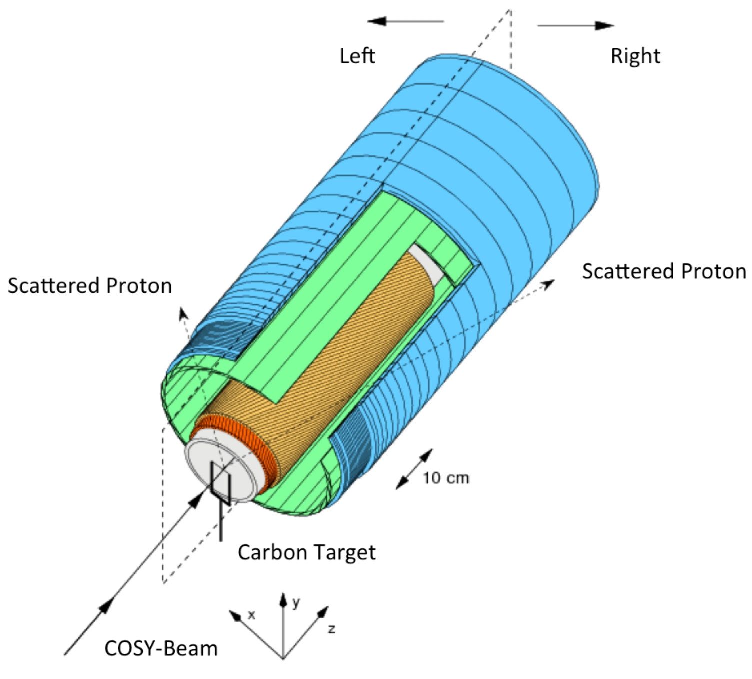

Fig. 3: Schematic diagram of the EDDA detector

Due to its construction the EDDA experiment is an excellent tool for investigating and verifying beam properties of COSY with the high precision.

2 Method

The polarized protons are scattered from the EDDA target. The differential cross section of the scattered protons is given by

$$\frac{d\sigma}{d\Omega} = \sigma_0(\theta)(1 + PAcos\phi) \tag{2}$$

θ is the polar scattering angle, ϕ is the azimuthal scattering angle. P denotes the polarization of incoming protons, and A is the analyzing power of the target. The unpolarized differential cross section is modulated by a cosines shaped ϕ-dependence. The asymmetry term can be averaged according to the EDDA setup.

Since the EDDA detector consists of half ring shaped scintillators to detect θ_{lab}, it is possible to compare left and right count rates for each θ_{lab} range while averaging over ϕ in every half ring. Thus we get

$$\overline{\varepsilon}(\theta_{lab}) = \overline{PA_y(\theta_{lab})cos\phi} \approx \frac{2}{\pi}PA_y(\theta_{lab}) \tag{3}$$

using

$$\frac{\int_0^{180} cos\phi d\phi}{\int_0^{180} \phi d\phi} \tag{4}$$

$$\varepsilon^p(\theta_{lab}) = \frac{L(\theta_{lab}) - R(\theta_{lab})}{L(\theta_{lab}) + R(\theta_{lab})} \tag{5}$$

where p denotes COSY proton beam polarization orientation, and $N^p_{left,right}(\theta_{lab})$ is the number of events detected in left/right detector elements at θ_{lab} with a polarization along p. We can deduce the beam polarization P from ε:

$$P \approx \frac{\varepsilon(\theta_{lab})}{A_{eff}(\theta_{lab})} \tag{6}$$

where A_{eff} is the effective analyzing power

$$A_{eff}(\theta_{lab}) = \frac{2}{\pi} A(\theta_{lab}) \tag{7}$$

Obviously, the beam polarization P is independent of the polar angle θ_{lab}. In order to decrease the statistical uncertainty of P we take the advantage of this independence and form the weighted average of all $P_{\theta_{lab}}$ as a final result for P

3 EDDA Polarimetry

The counted trigger rate of the scaler is the heart of the fast polarization measurement. The (semi)ring-shaped scintillators of the outer shell of the detector each cover a fixed polar angle in the laboratory system. The triggers are generated for each solid semi-ring (ring number 14 to 29, the right and left with respect to the beam direction) counted in so-called scalers. The time-marking system uses a clock to provide a precise time for each event trigger. These times are stored and passed to the event processing software. The scaler rates are read out separately for each ring and the two spin directions.

During the online measurement, the weighted value of the polarization was presented as a function of time, and the polarization was estimated as the linear fit parameter (Fig. 5).

The fiber target quickly destroys the beam, so it is more reliable to use counts from the beginning of the EDDA DAQ, once the target has been brought into the detector. The asymmetry behavior has been investigated for each energy and the period of time, where the polarization value is constant was chosen for the polarization value extraction.

The way to represent the polarization is to use Ohlsen formula for the integral counts of the semi-rings in the time slot where asymmetry behavior is stable.

$$p = \frac{\varepsilon}{A_y} = \frac{1}{A_y}\frac{L-R}{L+R} \tag{8}$$

with the statistical uncertainty

$$\Delta p = \frac{1}{A_y}\left(\frac{LR}{(L+R)^2}\sqrt{\frac{1}{L_1}+\frac{1}{L_2}+\frac{1}{R_1}+\frac{1}{R_2}}\right) \tag{9}$$

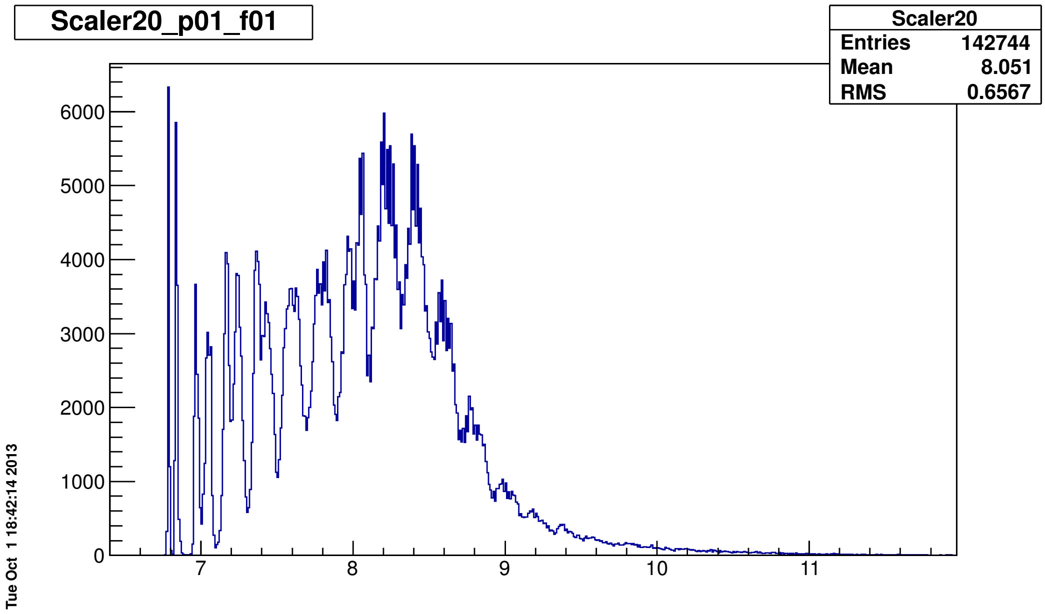

Fig. 4: Scaler signal typical profile. Time stamps are synchronized by cycles.

The polarization values, calculated by rings look like Fig. 6 and Fig. 7. The beam polarization is the arithmetic, weighted average of the polarizations, deduced for each ring.

The polarization value and its statistical uncertainty is calculated by the weighted average:

$$P_{ave} = \sum_{i=1}^{n} \frac{p_i}{\sigma_i^2} / \sum_{i=1}^{n} \frac{1}{\sigma_i^2} \tag{10}$$

$$\sigma_{P_{ave}}^2 = 1 / \sum_{i=1}^{n} \frac{1}{\sigma_i^2} \tag{11}$$

For different energies, the counts in the rings, and hence their input in the value are changing, because each ring corresponds to the polar angle range, and the value of cross section changes with the energy. That's why excluding some rings on some energies can just decrease the uncertainty value, without influencing the value itself.

3.1 Systematic Errors

The effective analyzing powers of the rings were determined in [6] as the ratio properties from the asymmetry of the proper ring and the beam polarization for the two used target types CH_2 and C, where the necessary calibration standard was provided by the EDDA pp data.

$$A_{00n0}^{eff}(\Delta\theta_{lab}^i, p) = \frac{\varepsilon_{pp}(\theta_{lab}^i, p)}{P_{beam,y}(p)} \tag{12}$$

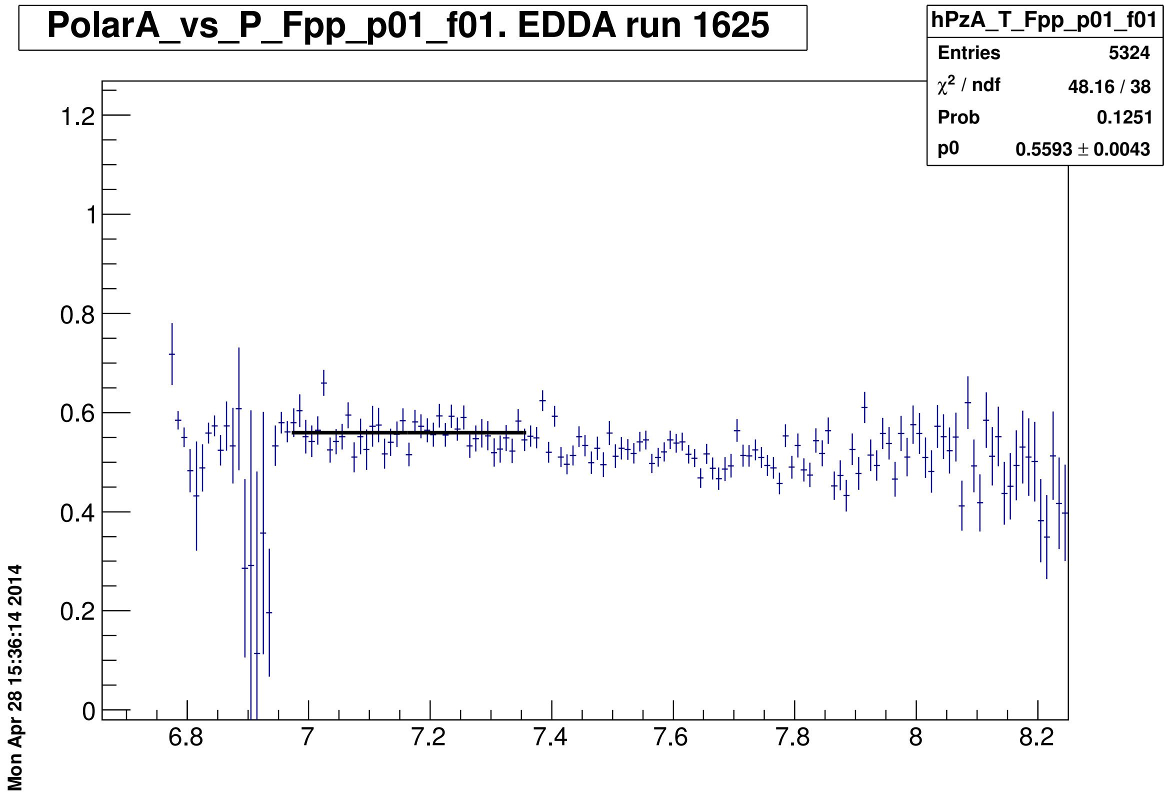

Fig. 5: The polarization values from the scaler asymmetry analysis as the function of time.

θ^i_{lab} is the laboratory polar angle range of the i ring, p is the beam momentum and $P_{beam,y}$ is the y-component of the beam polarization. The systematic error for the A_n^{eff}, unfortunately, could be estimated only very roughly from the change of polarization values for individual samples of the entire calibration data set. Since asymmetry $\varepsilon = P_{beam} \cdot A_n^{eff}$ is the only measured variable, and it was determined with the averaged over the entire data set effective analyzing power and polarization, it is not possible to determine whether P_{beam} or A_n^{eff} has changed at the time of measurement. The systematic unceratinty was estimated to be 3%.

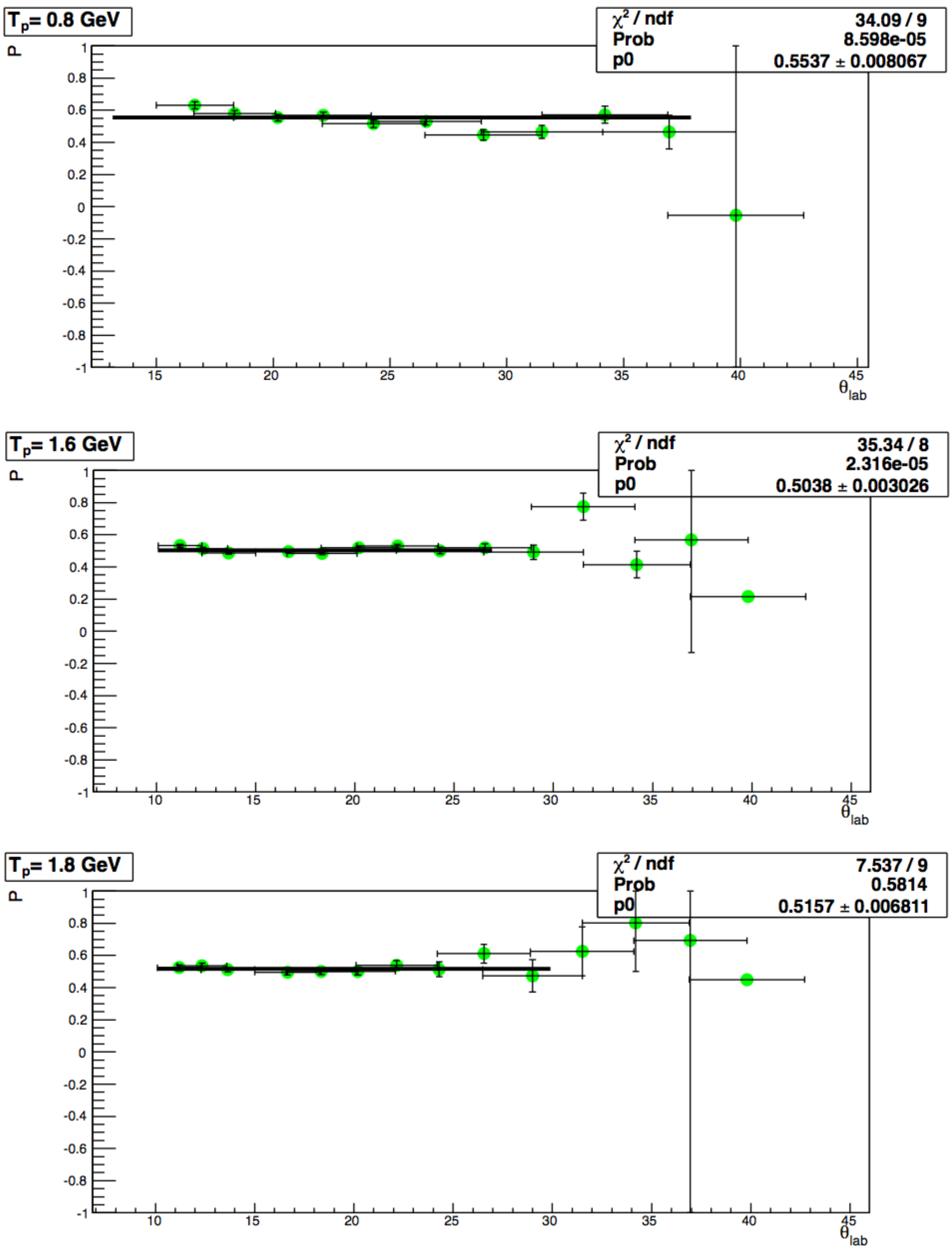

Fig. 6: The polarization values, calculated ring by ring, are shown versus corresponding lab polar angles (according to Appendix1)

4 Appendix A

4.1 Polar angle ranges of the rings

5 Appendix B: Results

The weighted averages of the beam polarization, for all the energies when pp elastic scattering was studied are given in the following table:

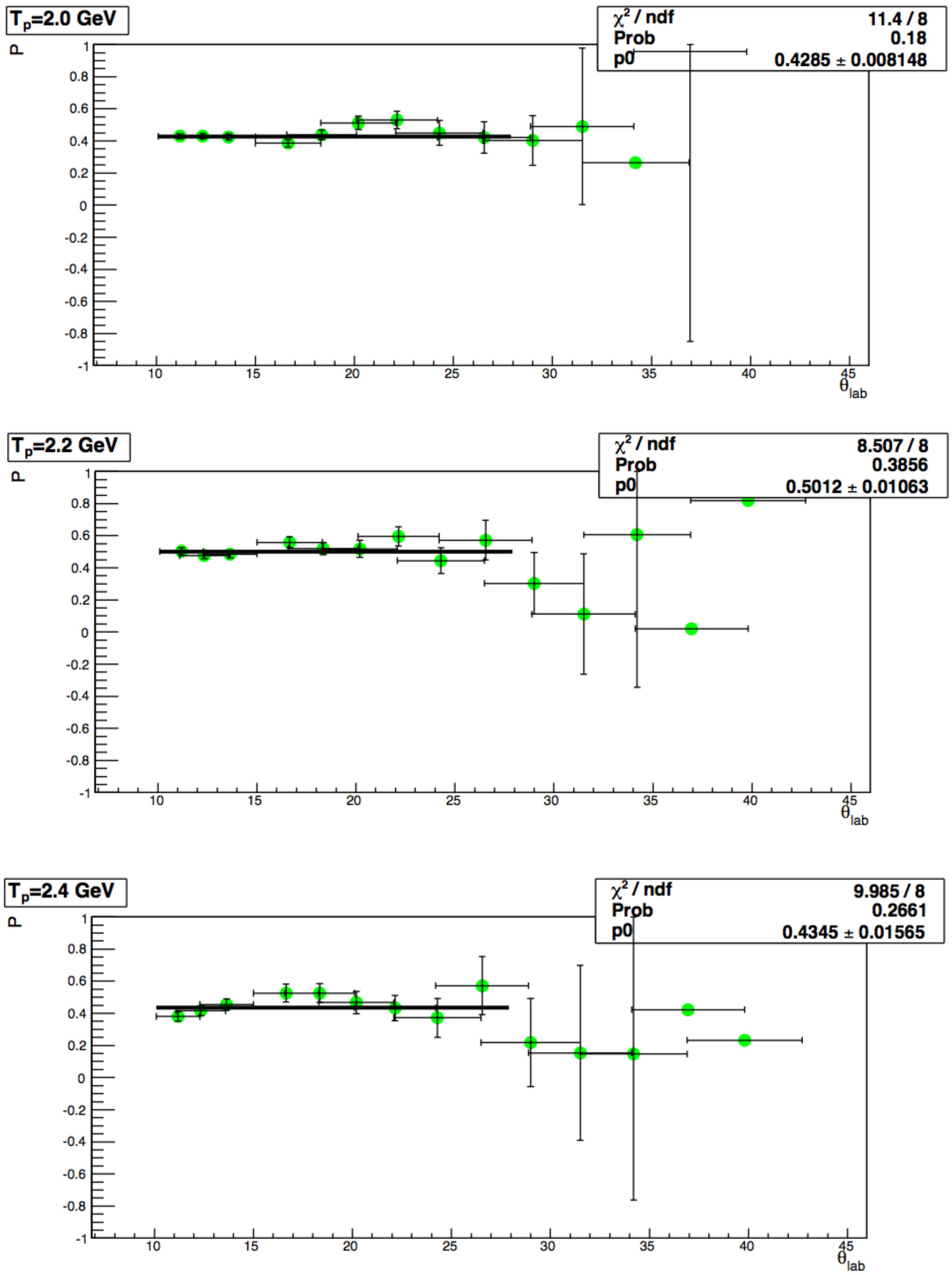

Fig. 7: The polarization values, calculated ring by ring, are shown versus corresponding lab polar angles (according to Appendix1)

5.1 Note on the polarization values

A strong-focusing synchrotron like COSY has two different types of depolarizing resonances: 1) imperfection resonances, caused by magnetic field errors and mis-

Ring Number	$\Delta\theta_{lab}$
14	42.7°... 36.9°
15	39.8°... 34.1°
16	36.9°... 31.5°
17	34.1°... 28.9°
18	31.5°... 26.5°
19	28.9°... 24.2°
20	26.5°... 22.1°
21	24.2°... 20.1°
22	22.1°... 18.3°
23	20.1°... 16.6°
24	18.3°... 15.0°
25	16.6°... 13.6°
26	15.0°... 12.3°
27	13.6°... 11.1°
28	12.3°... 10.1°
29	11.1°... 9.9°

Tab. 1: Laboratory angle ranges, corresponding to EDDA rings, in the coordinate system, associated with the detector.

Beam Energy[Mev]	Average Polarization	Statistical Error
796	0.554	0.008
1600	0.504	0.003
1800	0.516	0.006
1965	0.428	0.008
2157	0.501	0.01
2368	0.435	0.016

Tab. 2: Polarization values at the kinetic energy 796 MeV, corresponding to EDDA and ANKE runs

alignments of the magnets and 2) intrinsic resonances excited by horizontal fields due to the vertical focusing. Intrinsic resonances arise when there is simple relation between the spin tune and the vertical betatron tune. Depolarizing resonances may also arise due to a simple relation between spin tune and orbit or the synchrotron frequency. Here, spin tune is the net precession angle of the particle's magnetic moment during one turn in the machine. Hence there is a need to conserve the polarization of protons during the acceleration. The imperfection resonances which depend only on the momentum are increased in strength by a vertical orbit bump to excite a total spin flip. The momentum and tune dependent intrinsic resonances are compensated by a fast tune jump which increases the speed of resonance crossing. For the energies that have been used in the experiment, the following imperfection resonances encounter:

Imperfection Resonance[γG]	Resonance momentum p(MeV/c)	Resonance strength ϵ_r (10^{-3})
2	464	0.95
3	1259	0.61
4	1871	0.96
5	2443	0.90
6	2996	0.46

Tab. 3: The list of the relevant imperfection resonances [9]

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