A_y in $pp \to pp$ measured with Forward detector

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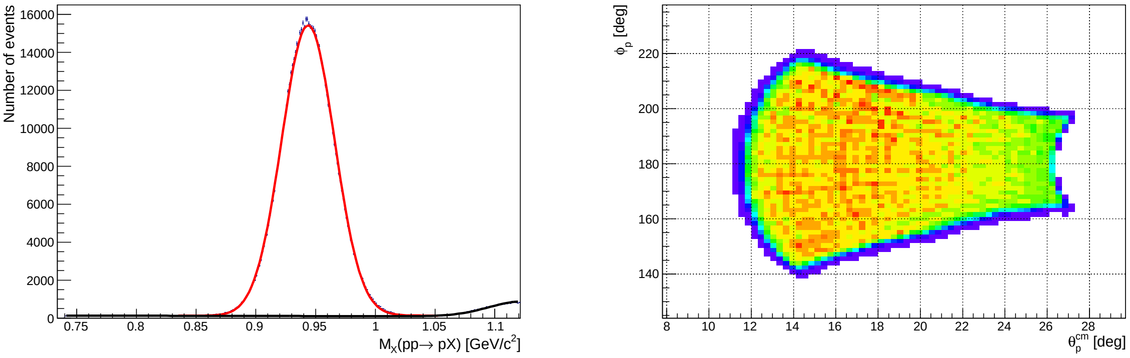
1 Data analysis

The Forward detector data collected in the ANKE March'13 $\vec{p}p$ beam time were analysed to extract the pp-elastic analysing power. The six beam energies used were: 796, 1600, 1800, 1965, 2157 and 2368 MeV. The data for the analysis were selected from the list of cycles, where the polarization could be measured reliably with EDDA detector.

The vertical vertex coordinate cut and the energy loss cut were applied to select the elastically scattered protons. The latter is of some importance only at the 0.8 GeV beam energy, where the forward going deuterons from the $pp \to d\pi^+$ reaction have the momenta close to that of the pp-elastic protons. After the cuts applied, the admixture of those deuterons did not exceed 0.02%. The number of the elastic protons was determined from the missing mass spectra after subtracting a linear background from the peak in each angular bin. Figure 1(a) demonstrates a typical missing mass spectrum, the level of background was few percent only.

The angular acceptance of Fd is shown in Fig. 1(b) for 1.6 GeV and it looks quite similar at the other energies. Although the final results were obtained without further restriction of the ϕ range use in the analysis, estimations done with several ϕ cuts showed no change beyond the statistical fluctuations.



(a) Missing mass spectrum for $\theta_p^{cm} = 7 \pm 0.5^o$

(b) Fd angular acceptance for $pp \to pp$

Figure 1: Selection of pp-elastic events at 1.6 GeV.

2 Systematic uncertainties

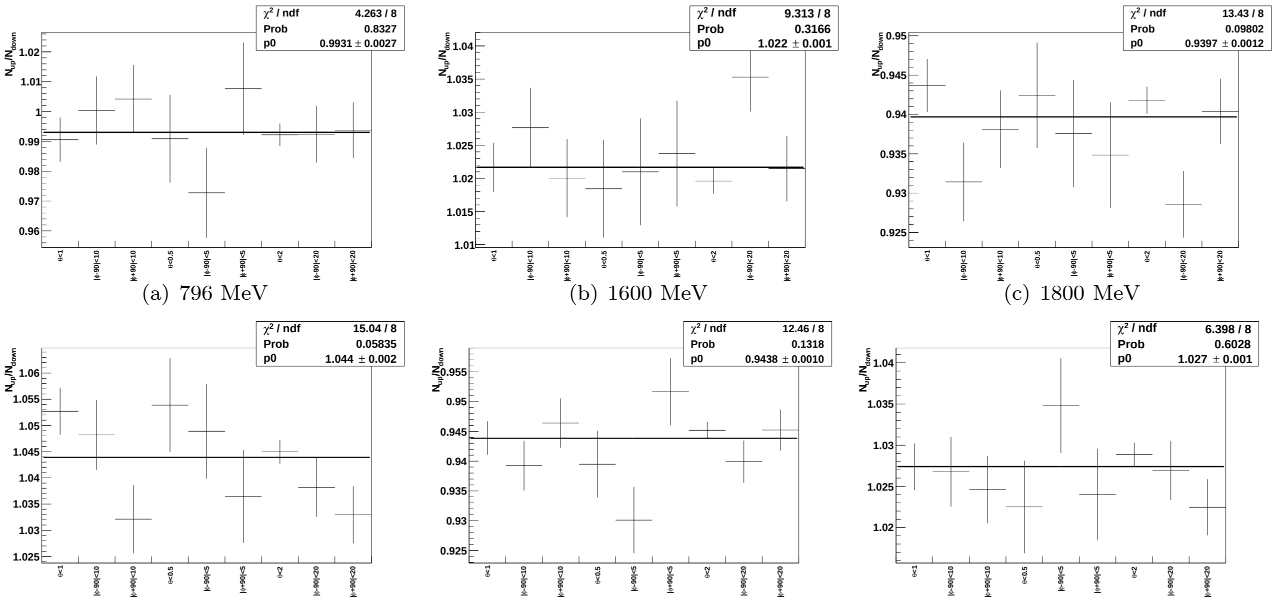
2.1 Relative luminosity

To measure asymmetry in a single side detector, one has to normalize the counts for the beam spin up and down to the corresponding luminosities. The latter can be obtained by counting events in the regions where the analysing power vanishes, e.g. at small θ or $|\phi| = 90^0$. The number of such events was found from the vertical vertex coordinate spectra, from which a linear background was subtracted.

In Fig. 2 we compare the luminosity ratios obtained this way with different angular cuts. In this figure, three groups of events are presented (by the cut tightness): *i)* $\theta < 0.5^o, ||\phi| - 90| < 5^o$, *ii)* $\theta < 1^o, ||\phi| - 90| < 10^o$, and *iii)* $\theta < 2^o, ||\phi| - 90| < 20^o$. The events within each group do not overlap, that is, if the θ cut is satisfied, the histograms for the corresponding ϕ cuts are not filled. The groups nevertheless, can shape events.

One can see that even the widest cuts result in consistent relative luminosity values. Leaving the third group out and fitting only the first 6 points changes the results within one error only, thus all the data points were used for the final analysis. The systematic uncertainty of A_y due to the luminosity normalization does not exceed 0.3%.

Since the normalizing events are selected with the same trigger (T2.4) as the ones of elastic scattering, the dead time difference for the spin up and down data is taken into account in the relative luminosity factor.



(a) 796 MeV (b) 1600 MeV (c) 1800 MeV

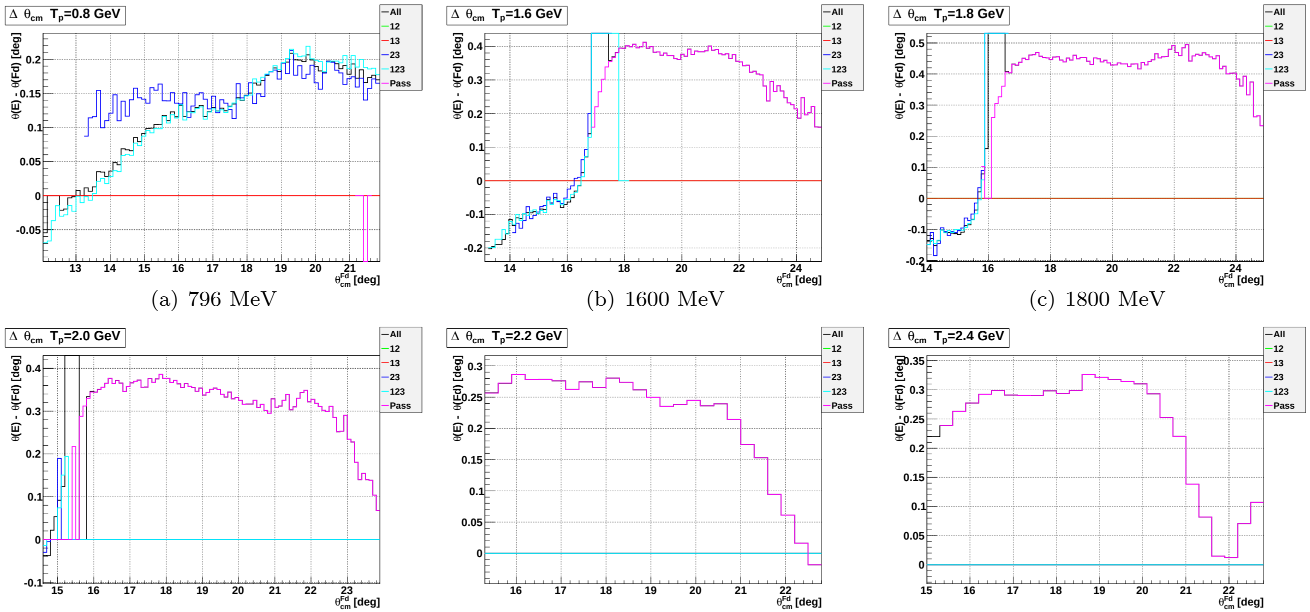
(d) 1965 MeV (e) 2157 MeV (f) 2368 MeV

Figure 2: Luminosity ratios with different angular cuts at six beam energies.

2.2 Accuracy of the reconstructed angle

Reconstruction of the horizontal transverse momentum P_x in Fd is controlled in the geometry fit by the $pp \to d\pi^+$ process with both ejectiles detected in Fd. The precision of ΔP_x achieved in the fit is $|\Delta P_x| < 1.5$ MeV, what corresponds to the systematic deviation of the laboratory scattering angle $\Delta\theta < 0.07^o$. For the pp-elastic scattering this leads to $\Delta\theta^{cm} < 0.15^o$. Although there is no guaranty that the elastic scattering will show quite the same systematics, this is the best estimate we can have from Fd alone.

Next, one can compare the angles in the $pp \to pp$ process when one proton is detected in Fd and another in STT. Fig. 3 shows the difference of the results from the two detectors. The STT angle is calculated from the energy deposited, and the different curves show the tracks reconstructed with the corresponding STT layers. The energy of the protons passing the 3rd layer is reconstructed with the neural network method, which showed somewhat better results then the analytical calculation. It is not possible to judge which detector is responsible for the difference.



(a) 796 MeV (b) 1600 MeV (c) 1800 MeV

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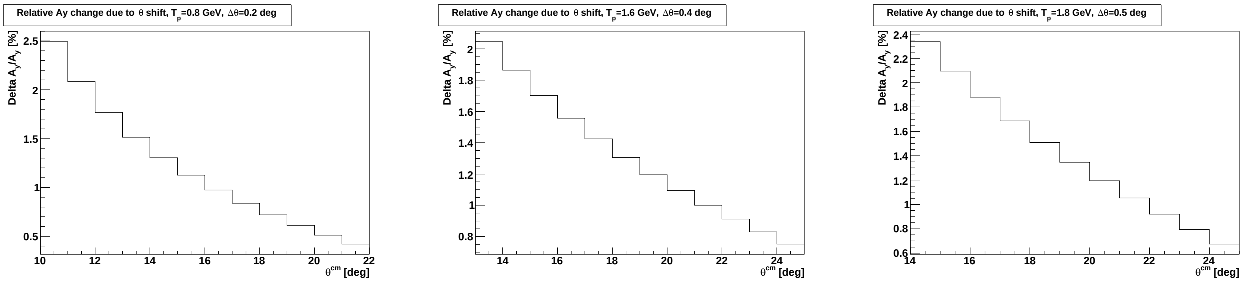
Figure 3: Difference of scattering angle reconstructed in Fd and STT at six beam energies.

To estimate the impact of the angular deviation onto A_y, for each energy we approximated the reconstructed A_y dependence with a parabola. Then, one can calculate the relative change of A_y occuring due to the constant shift in angle $\delta A_y = (A_y(\theta) - A_y(\theta + \delta\theta))/A_y(\theta)$ (Fig. 4). The maximal error of 2.5% is obtained.



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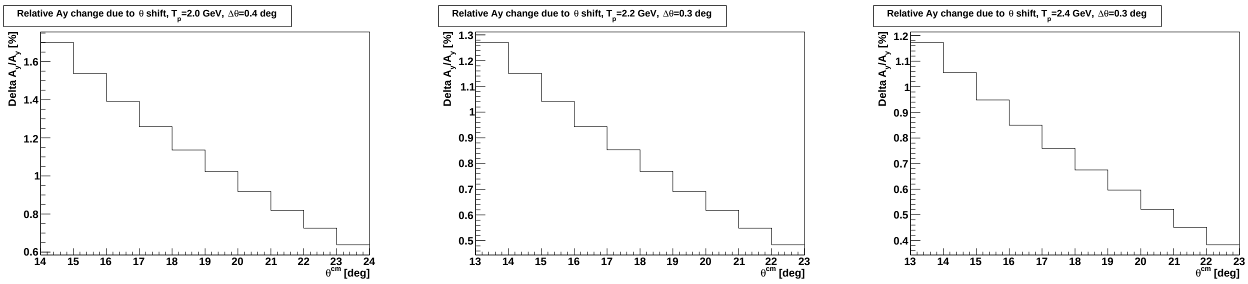


(d) 1965 MeV (e) 2157 MeV (f) 2368 MeV

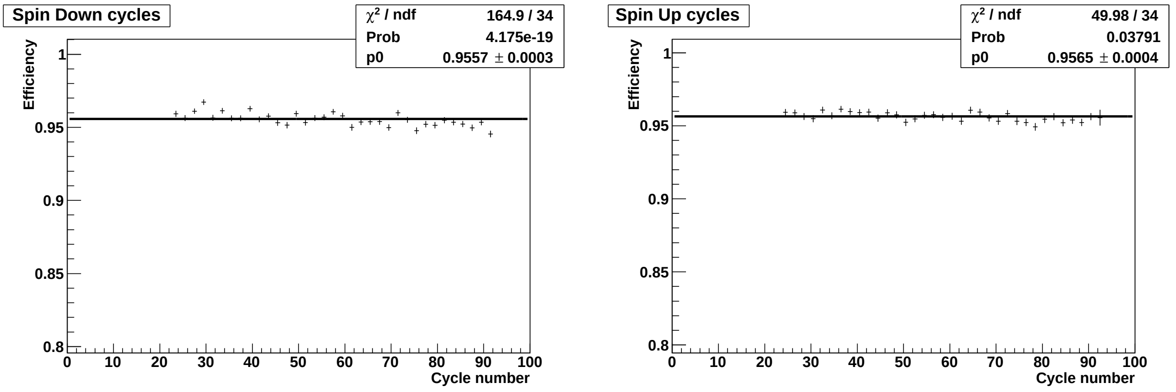
Figure 4: Systematic error due to shift of the scattering angle at six beam energies.

2.3 Detector efficiency

The efficiency of reconstruction of the elastic events in Fd can be studied using data from STT for the normalization. Among the the elastic events with one proton reconstructed in STT, one select those with the second proton momentum falling into the Fd acceptance. At the $T_p = 0.8$ GeV beam energy these are the protons in STT with $T_p = (10 - 25)$ MeV and $|P_y| < 60$ MeV, stopped in the third layer of the left telescope (the cuts are set away from the acceptance limits). In addition to the proton identification, the missing mass criterion was applied to the STT protons $|M_x^{STT} - M_p + 0.6| < 3.5 * \sigma M_x^{STT}$ MeV, where M_p is the proton mass, and $\sigma M_x^{STT} = 2.5$ MeV. The tracks reconstructed in Fd had to pass the missing mass cut $|M_x^{Fd} - M_p + 1.4| < 3.5 * 18$ MeV and to match the scattering angle of the STT proton $|\theta_{cm}^{STT} - \theta_{cm}^{Fd} - 0.13| < 0.3 * 3.5$ degree.

The efficiencies obtained per cycle are shown in Figs. 5 (beam spin direction flips every cycle). This value is expected to be lower then 100% due to a small fraction of misidentified protons in STT as well as the possibility of multiple particles recorded in STT or Fd within single trigger. There is also a small inefficiency of the Fd trigger OR ($\lesssim$ 1%) and a loss of particles due to the large angle scattering or interaction with the detector material.

The important conclusion here is that the Fd efficiency for spin up and down cycles differs by less than 10^{-3}, and this difference is within its statistical uncertainty. One could expect such result since the rates in Fd were far from the level at which the rate effects in the wire chambers and counters could show up.



(a) Cycles with beam spin Up (b) Cycles with beam spin Down

Figure 5: Efficiency of the elastic event reconstruction in Fd.

2.4 Difference in polarization for spin up and down

The observed number of events in a θ bin is

$$N_{\uparrow\downarrow} = N_0 \cdot (1 \pm P_{\uparrow\downarrow} A),$$

where N_0 includes the spin averaged cross section, the (equalized) luminosity and acceptance factors, $P_{\uparrow\downarrow}$ is the polarization for the beam spin up/down states, and $A = A_y(\theta) \cdot < cos\phi >$. Let $\delta P = \frac{P\uparrow - P\downarrow}{2}$ and $P = \frac{P\uparrow + P\downarrow}{2}$, the latter being the average polarization value measured by EDDA. The experimental asymmetry is

$$\xi = \frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow} = A \cdot \frac{P_\uparrow + P_\downarrow}{2 + A \cdot (P_\uparrow - P_\downarrow)} = A \cdot \frac{P}{1 + A \cdot \delta P}.$$

It differs from the asymmetry obtained with the same P but $\delta P = 0$ by

$$\frac{\delta\xi}{\xi} = \frac{A \cdot P[1 - \frac{1}{1+A \cdot \delta P}]}{A \cdot P} = \frac{A\delta P}{1 + A\delta P} \approx A \cdot \delta P.$$

For the extreme case of $P \uparrow - P \downarrow = 0.1$ and $\delta P = 0.05$, and $A \lesssim 0.5$, the relative error of reconstructed A_y is less then 2.5%.