Polarization Data Analysis. July 03 Beam-time

Status Report

G. Macharashvili

Introduction.

The polarization data analysis at ANKE first was considered in internal note where September 2001 data analysis was discussed (see Ref.[1]). In the present paper some aspects of the software modifications and July 2003 beam-time analysis procedure are discussed.

Available data

The following table contains all available runs written at july 2003 beam-time using the polarized proton beam and deuterium cluster target.

	Run list	Beam	Triggers	Fltop	Raw evt	2-Trk evt	Comments
1	5939-5978 (36)	0.8	T1: Fd*Spect T2: Fd T3: Spect	0	205 M	472 K	
2	5981-5995 (9)	0.8 0.5 0.8	T1: Fd*Spect T2: Fd/3 T3: FdDouble	0 1 2	26 M 13 M 13 M	134 K 32 K 66 K	global jump
3	5997-6009 (13)	0.5	T1: Fd*Spect T2: Fd/2 T3: FdDouble	1	68 M	168 K	
4	6011-6048 (20)	0.8	T1: Fd*Spect T2: Fd/2 T3: FdDouble	0	95 M	346 K	

Table 1: Available run aand data list

Each *root* file is produced by *FdRootSorter* based software and contains the data (class *FdEvent*) of variable structure. The typical file length varies around 700 MB for about 6 M events. The events collected in the *root* files may contain the following types of the data

- All events contain timing, trigger, flattop, beam status and other standard information. The data are mandatory and appear in each event.
- One-track event and calibrated hodoscope data;

- Double-track event and calibrated hodoscope data, raw hodoscope data, and raw cluster lists (sorted). Each track contains the belonging cluster reference list;
- Scaler event (T_{in} and T_{out});
- Spectator data (may be with a track);
- Data file contains browsable histograms produced at the raw analysis (without kinematical analysis). The histograms are located at the corresponding subdirectories: **Common, Hodoscope, Track, TmDelay, Synch, Spectator, and Scaler**;
- Data file contains also *RunProfile* record. The record contains run summary data such as: luminosity monitoring counts, average values of the meantimers for each module, mean-timer delay difference compensation constants (see below), T_{out}, T_{in}, etc.
- Optionally *FdEvent* object can include the events of raw hodoscope data (of Pd, Nd, SW), raw cherenkov data, cluster list for any PC (also Nd, Pd). So, *FdEvent* can be used to store complettely raw data (available in *ems* format file) on the *root* file. This provides a possibility to acess any event directly using only the event identifier. For the data access the detector identifier is used, so you do not need filters used at *ems* format data analysis. The file contains also preprocessed data (calibration, tracking, some soft selection are done) ready for physics analysis.

The described data preprocessing mechanism is used successfully for deuteron break-up and charge-exchange data analysis.

Particle type definition by ΔE

The deposited energy ΔE (in MeV/cm) independent on the hodoscope module is assigned to the detected track. Since we have already got the defined momentum of the track we can calculate *Landau* p.d.f. for the assigned particletype (mass).

$$\mathcal{L} \to Landau\ pdf(\Delta E_{MPV}(\beta\gamma), W),$$

where MPV is the most probable deposited energy and W is the p.d.f. width, both depending on $\beta\gamma$. The width is defined by the hodoscope resolution. The hodoscope calibration procedure described in Ref.[2] and the performance is pesented in Ref.[3].

So we can define the probability to deposit ΔE energy in the hodoscope module by the particle of momentum (p) and the assigned mass (m).

$$P = \mathcal{L}(\beta\gamma = p/m \,|\, \Delta E). \quad (1)$$

We introduced some cut value P_{min} (to restrict the distribution tails at some level) and accepted only the events with $P > P_{min}$. So, we selected particles (protons in case of break-up) with required confidence level. The selection procedure is well illustrated in Fig.1

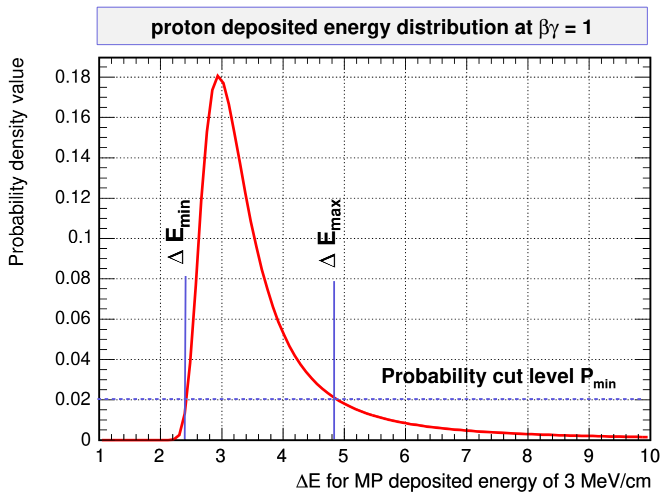

Fig. 1: particle type identification using ΔE criterium.

The method is most useful in case the time analysis is not applicable or if it defined two identical particles other than protons. The time difference method has worse performance to define two identical particles.

Track time difference calculation

In case the particles hit different modules of the scintillation hodoscope (so, we have a possibility to analyse time differences) we start with particle type identification by the time differences analysis.

For two-track events we calculated the time difference between the tracks. Using the track length and particle 4-momentum we can get the absolute time needed by the particle to reach the hodoscope first plane:

$$\tau_i[ns] \;=\; \frac{L_i}{\beta_i c}\,; \qquad (i = 1, 2). \tag{2}$$

Where L_i is the track length and β is the particle velocity (For defined particle mass or assigned proton mass). c is equal to $30\,cm/ns$. So the calculated time difference for two particles (1 and 2) is equal to:

$$\Delta\tau_{12} \;=\; \tau_1 \;-\; \tau_2. \tag{3}$$

It has to be stressed that $\Delta\tau_{12}$ varies depending only on the assigned type of particles.

Time difference calculation using hodoscope timing data

In case of two track event when each track hit the different modules of the forward hodoscope we can get time difference directly using the mean-timer TDC signals from each module. The time difference is defined as follows:

$$\Delta\tau_{ij}\,[ns] \;=\; const\,(T_i - T_j + \delta t_{ij}); \qquad (i, j = 0, ...7). \tag{4}$$

here $T_i(T_j)$ are the TDC signals from i and j -modules, respectively (in TDC channels), *const* is the scale factor, common for all TDC channels, and is equal to $0.043\,ns$. Actually each

TDC channel has its specific scale factor which will be defined using special 'calibration' runs (6750 and 6751). $\delta t_{ij} = -\delta t_{ji}$ ($\delta t_{ii} = 0$) is the 'correction term' to compensate mean-timer delay time difference for i and j counter pair.

Time difference compensation term measurement

It is necessary to introduce some notations:

- t'_k - cabling delay time from the particle hit and TDC *start* signal induced by k-th module of the first layer. Each module ($k = 0, ..., 7$) has its specific delay for "start" signal at TDC's.
- t_k - is the same signal producing the *stop* signal at its own TDC channel.
- s_k - delay time from the particle hit and TDC *stop* signal produced by the second layer k-th module's mean-timer;
- $T_k = t_k - t'_k$ - is the first layer k-th module's mean-timer value (in TDC channels) in case the module induced the hardware trigger. The RMS of the distribution is less than 1 channel of TDC.
- $S_{k(j)} = s_k - t'_j$ - is the second layer k-th module's mean-timer value when the *start* trigger signal is induced by the track in j-th module of the first layer. Evidently $j = k$ or $j = k - 1$. The RMS of the distributions are equal to about 3 channels of TDC.

The time difference between the mean-timer signals of neighbouring modules (k and $k-1$) of the first layer is equal to:

$$\Delta t_k \equiv \Delta t_{k,k-1} = \overline{(S_{k(k)} - T_k)} - \overline{(S_{k(k-1)} - T_{k-1})}, \qquad (k = 1, ..., 7). \tag{5}$$

The equation right side first and second terms (the average values) can be easily deduced at single-track data processing with high accuracy.

So, δt_{ij} correction term for modules i and j, or in other words, the time difference for two particles hitting the i and j modules at the same time, is equal to:

$$\delta t_{ij} = \sum_{k=i+1}^{k=j} \Delta t_k. \tag{6}$$

It is evident that

$$\delta t_{i-1,i} = -\delta t_{i,i-1} = \Delta t_i. \tag{7}$$

$|\Delta t_k|$ absolute values does not exceed 20 *ch.* of TDC and are defined with high precision. The average values of the two terms of eq.5 were found by fitting procedure of each distributions. Δt_k are accumulated for each run (in *RunProfile* record) at the raw data processing and are available at the analysis stage.

Note: It should be stressed that the described timing analysis is possible only in case when the two particles hit different hodoscope modules (of first or second layer).

The particles types in the pair are defined in the following way: for all particle combinations $(\pi, p, d, ...)$ we select the one for which the expected $\Delta\tau_{12}$ (eq.3) is closest to the measured time difference $\Delta\tau_{ij}$ (eq.4). Or, in other words: $\Delta_{\tau\tau} = |\Delta\tau_{12} - \Delta\tau_{ij}|$ is minimal. We do not make event selection by the parameter $\Delta_{\tau\tau}$ itself, we only select the event if the two particles are protons.

The particle identification quality by parameter $\Delta_{\tau\tau}$ in well illustrated in Fig.2. In case we assign masses of proton to the both detected particles we will get a plot (τ_{12}, τ_{ij}) presented in Fig.2.1. It is evident that the 2 proton hypothesis for the events out of the diagonal is wrong. Nevertheless, if we split the plot according the masses suggested by the hypothesis which minimizes the $\Delta_{\tau\tau}$ we will have to get the plots for specified particle pairs: pp, $d\pi^+$, pd, $p\pi^+$, and $t\pi^+$. The plots are presented in Fig.2.2-6. If we recalculate τ_{12} for assigned masses we get all these plots in the diagonal shape.

In case the two particles are protons, the time difference ($\Delta_{\tau\tau}$ distribution) is shown in Fig.3.1 without correction and in Fig.3.2 with correction term added. It should be noted that time resolution (and the method performance) is energy dependent.

The method is expected to be especially useful for the beam energies higher than $0.8\,GeV$.

Break-up event selection criteria

At the moment we use very simple selection criteria for the deuteron break-up selection.

(1) The double-track event is stored for subsequent analysis if $\Delta_{\tau\tau}$ method defines that both particles most probably are protons.

(2) the excitation energy (E_{pp}) for the deuteron break-up process should be less than $3\,MeV$.

(3) The missing mass for the selected double proton is in the interval: $0.88 < M_{xx} < 1.01\,GeV/c^2$;

(4) $|cos(\phi)| > 0.7$ ... is used only for asymmetry calculation.

The relative luminosity correction factor

The luminosities at the beam polarization *up* and *down* are monitored using the *pd* interaction events which are independent on the beam polarization. The following selection criteria are used for different monitoring counts:

- inclusive single particle events with production angles in the forward direction in the solid angle at $\vartheta_{CM} < 0.5°$;

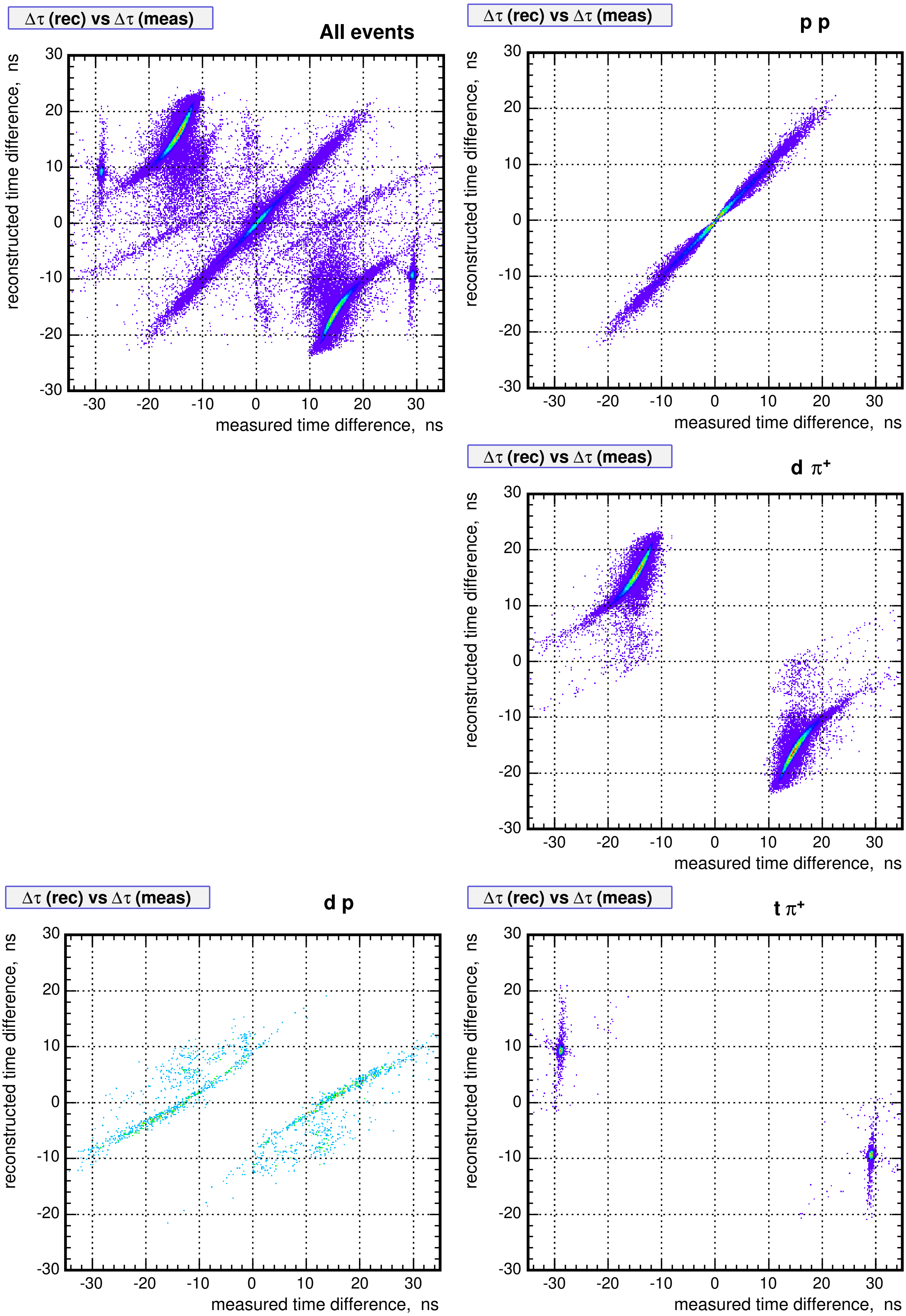

Fig. 2: Particle-pair identification using the hodoscope timing information.

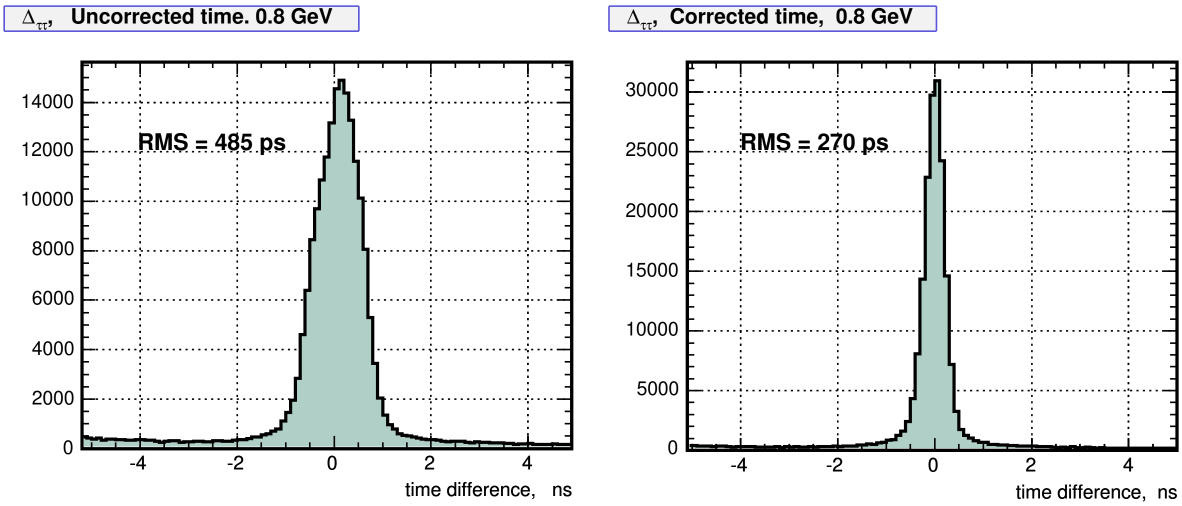

Fig. 3: $\frac{1}{\sqrt{2}}(\Delta\tau_{12} - \Delta\tau_{ij})$ distribution for double proton hypothesis. $d\pi^+$ and other double track events are out of the histogram bounds.

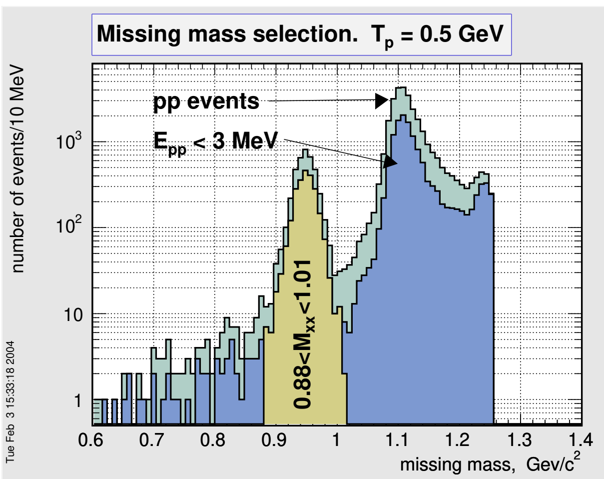

Fig. 4: Missing mass selection. pp events are selected using only the timing information.

- inclusive single particle events with production angles in the forward direction in the solid angle at $\vartheta_{CM} < 1°$;
- inclusive single particle events with the azimuthal angles:

$$90° - \delta < \phi < 90° + \delta, \tag{8}$$

$$270° - \delta < \phi < 270° + \delta, \tag{9}$$

Usually we used ($\delta = 5°$).

So, we have got four independent luminosity monitoring counts. **We will also use the up and down scattered events also for stability check of the measurement conditions.**

Luminosities ineqality correction factor ($f_i, (i = 1, ...4)$) is defined as follows:

$$f = \frac{N_o}{N_1}, \qquad \sigma = f\sqrt{\frac{1}{N_o} + \frac{1}{N_1}}. \tag{10}$$

where the numbers of events (N_o, N_1) correspond to the *beam polarization indeces* as it appear in the data stream and really does not refer directly to the beam polarization direction. The beam polarization unit vector values for different *indeces* are presented in Table 2. The correction factors ($f_i \pm \sigma_i$) were checked for cross compatibility. The two factors f_i and f_j are compatible if

$$\frac{|f_i - f_j|}{\sigma_i + \sigma_j} < 1\,. \tag{11}$$

The correction factors vary in the interval $0.8 \div 1.2$ and the statistical weights are high enough not to include in the asymmetry uncertainty calculation. To normalize the selected break-up events, or to equalize the luminosities for the beam polarization *up* and *down*, the counts for the *polarization index 1* have been multiplied by the factor f independently on the beam polarization direction.

Beam polaarization sign definition

The definition of the beam polarization signs are given in the following table.

Beam energy, GeV	0.8			0.5		
polarization index (PI)	0	1	2	0	1	2
P_B sign (unit vector along y)	-1	+1	0	+1	-1	0

Table 2: The beam polarization unit vector correspondence to the beam polarizatin indeces.

The correctness of the definitions are checked by the analysing power in *pd* elastic and quasielastic scattering for the beam energy of $0.8\,GeV$. We define the beam polarization sign using the available $A_y(\vartheta)$ experimental values for *pd* elastic scattering at $0.8\,GeV$ Ref.[7].

Beam polarization averaging

For the analysing power calculation we need the averaged value of COSY beam polarization module P_B. The averaging is done over the selected break-up events in each run:

$$\overline{P_B} = \frac{1}{L+R}\sum_r (L^r + R^r)P_B^r, \tag{12}$$

where P_B^r is the beam polarization measured in run r. The beam polarimetry is based on the asymmetry measurement in $pd \to pd$ scattering using the spectator detector and its comparison to the available data of A_y^p at $0.8\,GeV$ [7].

In case we have the different beam polarization modules for *up* and *down* polarizatins $|P_B|_\pm = |P_B|(1 \pm \delta)$, it changes the measured asymmetry in the following way [8]:

$$\varepsilon \to \varepsilon' = \frac{L-R}{L+R} = \frac{\varepsilon}{1+\varepsilon\delta} \tag{13}$$

The effect of a finite δ is of first order (in case of single-sided detector). So, the asymmetry, corresponding to A_y ($pd \to pd$ at $0.8\,GeV$) is equal to:

$$\varepsilon = \frac{\varepsilon'}{1+\varepsilon'\delta} = P_B A_y. \tag{14}$$

Asymmetry calculation

Below we use the CM scattering angle (ϑ_{CM}) without the subscript. The definition of useful events numbers, with proton pair production angles in the interval ($\vartheta \pm \Delta\vartheta$, $\Delta\vartheta = 0.5°$ or $1°$) is summarized in the following table.

beam	$L(\vartheta)$	$R(\vartheta)$	f (see eq.10)	$\overline{cos\phi}$ interval
$0.5\,GeV$	$\sum_{r,i}\omega_{ri}$; *PI=0*	$f\cdot\sum_{r,i}\omega_{ri}$; *PI=1*	1.035 ± 0.002	$0.90 \div 0.98$
$0.8\,GeV$	$f\cdot\sum_{r,i}\omega_{ri}$; *PI=1*	$\sum_{r,i}\omega_{ri}$; *PI=0*	–	

Table 3: Statistics summation scheme **for back scattered neutron**. For the proton-pair the asymmetry has the opposite sign.

Here w_{ri} denotes the weight of $i-$th event in run r and is defined by the track detection efficiency inhomogenity over the solid angle (see Ref.[4]), and r - the run index. In case of large statistics we would ignore the events weights. Sometimes we use the notation L^r and R^r being the numbers of the break-up events collected in the run r for *left* and *right* (in the sense of [5]) scattering, respectively.

<u>Note:</u> ϕ is the proton-pair summary momentum vector azimuthal angle defined in the ANKE set-up system (not in the conventional coordinate system connected with the beam polarization direction). The ANKE geometrical acceptance covers the break-up proton pair phase space mostly at $cos\phi < 0$. The final result (Analysing power) we express in (ϑ, ϕ) of backward scattered neutron. The asymmetry for neutron is of opposite sign in comparison with the proton-pair asymmetry.

The *left/right* measured asymmetry (ε) for all selected runs is calculated in the conventional way [5, 6]:

$$\varepsilon(\vartheta) = \frac{1}{(\overline{cos\phi})_\vartheta} \cdot \frac{L(\vartheta) - R(\vartheta)}{L(\vartheta) + R(\vartheta)} \, . \tag{15}$$

$$\delta\varepsilon(\vartheta) = \frac{1}{L+R}\sqrt{(1-\varepsilon)^2 L + (1+\varepsilon)^2 R}. \tag{16}$$

The average value of $(cos\phi)_\vartheta$ is calculated independentely in each ϑ bin. It is equal by definition:

$$(\overline{cos\phi})_\vartheta \;=\; \frac{\int_{\Delta\Omega} E(\vartheta,\phi) cos\phi d\phi}{\int_{\Delta\Omega} E(\vartheta,\phi) d\phi} = \frac{1}{L+R}\sum_{i=1}^{i=L+R} |cos\phi_i|. \tag{17}$$

Where $E(\vartheta, \phi)$ is the forward detector total acceptance (including luminosity, cross section, geometrical acceptance, detection efficiencies, event reconstruction efficiency, analysis cuts, etc ...) for the analysing process. $E(\vartheta, \phi)$ **is independent on the beam polarization direction**.

At the asymmetry uncertainty calculation we ignore the uncertainty of $\sigma(\overline{cos\phi})$ much less than the statistical uncertainties of L and R counts.

$$\sigma(\overline{cos\phi})_\vartheta \;=\; \frac{\sigma(cos\phi)_\vartheta}{\sqrt{L+R}}. \tag{18}$$

The proton analysing power in the deuteron break-up process is equal to:

$$A^p_y(\vartheta) = \frac{\varepsilon(\vartheta)}{P_B} \, . \tag{19}$$

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