# Field direction measurements

## 1 Introduction

For $G_{en}$, we need to know the direction of the B-field of the polarized target to about $\pm 0.1°$ accuracy (see previous memo by I.S.). The approach proposed to measure this direction comprises:
1. Use of a Hall probe mounted on a stick that is lowered into the polarized target. By locating the angles at which the probe is exactly perpendicular to the field (zero output voltage) one can determine the direction of the field relative to the endstation coordinate system. This is possible up to a constant angle $\Delta\theta$ which describes the difference of orientation of the Hall probe and the reference direction on top of the Hall stick used by the surveyors.
2. Calibration of $\Delta\theta$ in an external magnet with exactly known field direction
3. Determination of the field direction of this external magnet using a special set-up involving a $5-10\mu m$ thick flat Fe-foil (Co-foil) that in the field orients itself parallel to the field to $< 0.01°$ accuracy (estimate and test measurement by M. Steinacher).

The present note discusses the general approach, and first test measurements, and the measurements done together with the alignment group in both hall C and at UVA.

## 2 Hall-Effect

The LINEAR HALL effect yields a voltage proportional to $\vec{v}\mathrm{x}\vec{B}$, i.e. it is proportional to $sin(\theta)$. The PLANAR HALL EFFECT, resulting from the currents induced in the probe by the Hall voltage and a misalignment of the probe in $\phi$-direction, gives a voltage proportional to $B^2 cos(\theta)^2$, where $\theta$ is the angle between $B$ and $v_e$. OFFSETS in the Hall voltage (which can be strongly temperature dependent) are present as well.

In order to get the field direction with a A $sin(\theta)$ + B $cos(\theta)^2$ + C angular dependence of the Hall voltage, one determines the two zero crossings of the Voltage at approximately opposite angles, $\Theta_1$ and $\Theta_2$. The angle $(\Theta_1+\Theta_2)/2$ +90 gives the direction of the B-field independent of OFFSET and PLANAR

HALL EFFECT.

# 3 Sequence of measurements

Five types of measurements are envisaged, and described in this note.
1) Test of principle
2) Actual measurement with pol. target and surveyed direction of Hall probe handle. This in principle should be done for every $Q^2$-setting.
3) Test of principle of determination of field direction of external magnet with Fe-foil (to be done in Basel).
4) Calibration of B-field direction of external magnet at UVA.
5) Determination of $\Delta\theta$ of hall probe using this external magnet.

# 4 Test of principle

With the hall stick built at UVA and target field at the nominal value of 5.05T, we have (on July 22) carried out measurements of the hall voltage as function of the orientation of the probe (relative to an arbitrary zero). The results are given below:

For the interpretation, we will ignore runs 1, 2, where the field possible was still changing.

We observe that the readings of the zeroes are very reproducible. Fluctuation in the readings are ±2'.

We also observe that the two zeroes are almost 180 degrees apart (180 10'). The effects of the planar hall effect and offset thus are small, or nearly cancel. It then will be easy to deduce the B-field orientation from the average of the two angles.

The effect of the offset alone is not large; it can, to a degree, be deduced from the difference of the +maxima and –maxima values +50.36 and -50.58 (apart from a difference of the + and – readings of the probe, which is given by Lakeshore for fields below 3T, but which we do not know at 5T).

The effect of the Q1 field is minor. Taken at face value, the shift is 2'.

Conclusion from these test measurements: we should be able to do the B-field direction measurement as envisaged, subject to point 3).

| run | Hall field | angle | comment |
|---|---|---|---|
| 1 | –50.050 | 34 20’ | |
| 2 | +50.830 | 239 30’ | |
| 3 | –50.030 | — | |
| 4 | 0.00 | 122 41’ | |
| 5 | –50.580 | — | maxi |
| 6 | +50.290 | — | maxi |
| 7 | –50.570 | — | maxi |
| 8 | 0.00 | 122 44’ | |
| 9 | 0.00 | 302 52’ | first zero scan |
| 10 | +1.996 | 300 46’ | |
| 11 | +0.996 | 301 49’ | |
| 12 | –1.008 | 303 53’ | |
| 13 | –1.996 | 305 00’ | |
| 14 | –1.998 | 120 36’ | second zero scan |
| 15 | –0.995 | 121 42’ | |
| 16 | 0.001 | 122 45’ | |
| 17 | +0.992 | 123 50’ | |
| 18 | +1.984 | 124 52’ | |
| 19 | +50.430 | — | maxi |
| 20 | –50.590 | ∼32 30’ | |
| 21 | –50.520 | — | Q1 at nominal current |
| 22 | +50.450 | — | |
| 23 | 0.000 | 122 47’ | |
| 24 | 0.000 | 302 53’ | |
| 25 | –50.470 | ∼32 20’ | |
| 26 | +50.460 | ∼ 213 20’ | |
| 27 | –25.000 | 332 48’ | |
| 28 | –25.000 | 93 26’ | |
| 29 | –25.000 | 152 03’ | |
| 30 | +25.000 | 273 16’ | |

Table 1: First test measurements.

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# 5 Measurements on the pivot

On Aug. 25, a number of measurements of the B-field direction were performed by the CEBAF surveyors. This involved:
— dismounting all RF-equipment above the polarized target, removing the target stick,
— mounting the hall probe in the polarized target,
— cooldown for about 2 hours,
— rapid removal of the cold stick, transporting the stick to a region of low B-field, placing the $\mu$-metal shields over the probe, zeroing the Gaussmeter, mounting the stick again in the target,
— cooldown for another hour,
— performing in rapid sequence measurements (both by the alignment group using the theodolite, and by the physicists using the (relative) angle readout) at the two angular positions where the hall probe read $\pm 0$ voltage. The angles differing by 180 degrees were measured in rapid sequence in order to minimize the effect of drifts (mainly thermal ones) of the hall probe voltage.

Below we give the measurements performed by the physicists, together with some other useful details. These measurements then will have to be coordinated with the numbers to be calculated by the alignment group.

## 1. Measurements of alignment group

The distances between the line of sight (established by the theodolite) and the alignment balls at the ends of the handle are measured. The line of sight is established relative to alignment balls mounted on the can of the polarized target (upper platform) which were at some earlier point measured relative to the beam . Roughly speaking, the line of sight runs parallel to the beam, on the right-hand side (in beam direction). Each individual measurement involved the reading of the distance of both the upstream- and downstream ends of the handle to the line of sight.

## 2. Preliminaries

Readings of the angles of the zero crossings, during cooldown:
303 18', 303 16', 303 22', 123 10', 122 51', 303 46', 303 42', 303 55'.
These measurements were done *before* zeroing the hall probe, and while the temperature was not yet stable. No corresponding measurements by the alignment group were taken.

## 3. Measurements

See table 2. The measurements are identified by a run-number, which will allow the connection between the data given below and the results to be furnished by the alignment group.

Comment: the data on the max. fields were rather un-reproducible. They seemed to depend on time, and on the exact way one got to the point where one measured (the probe does have some freedom to move sideways, but this a priori should not effect us given the homogeneity of the field). Possibly there was also a problem with the response time of the hall-meter; depending on the setting it employs some non-transparent algorithm; the measurements of the field-maxima were done very quickly as compared to the measurements of the zeroes. For sure, the readings are quite sensitive to the probe temperature; perhaps we did not wait long enough. These problems should not affect the zero-voltage measurements, however.

## 4. Orientation of the handle of the hall-probe

The handle of the probe is mounted such that, in the position where the hall probe reads zero voltage, the handle is roughly *perpendicular* to $\vec{q}$.

In order to facilitate the calculation of corrections (signs!!) and the comparability to future measurements, we give below the rough readings for specific settings of the probe handle.
a. Handle parallel to beam, wires below handle facing towards downstream of beam: 282 degrees, +16kG
b. Handle perpendicular to beam, wires facing towards right of beam: 12 degrees, –47kG

| run | angle | hall-voltage (kG) | comment |
|---|---|---|---|
| 1 upstream | 301 57’ | –.012 | |
| 1 downstream | | –.008 | |
| 2 up | 122 26’ | +.080 | |
| 2 down | | +.080 | |
| 3 down | 302 00’ | +.008 | |
| 3 up | | +.025 | |
| 4 up | 122 28’ | –.007 | |
| 4 down | | –.052 | |
| 5 down | 302 14’ | +.040 | |
| 5 up | | +.040 | |
| | | –50.130 | maximum |
| | | +50.900 | maximum |
| 6 up | 122 09’ | –.030 | |
| 6 down | | +.019 | |
| 7 down | 302 14’ | +.030 | |
| 7 up | | +.050 | |
| | | –50.000 | |
| | | +50.920 | |
| 8 up | 122 40’ | +.020 | |
| 8 down | | +.120 | |
| 9 down | 302 12’ | –.008 | |
| 9 up | | –.008 | |
| 10 up | 122 28’ | +.095 | |
| 10 down | | +.110 | |
| | | +50.900 | not reproducible |
| | | –49.900 | not reproducible |
| | | +50.55 | 30 min later |
| | | –50.53 | |

Table 2: Data (relative angles) measured in hall C parallel to measurements of alignment group

c. Handle parallel to beam, wires facing upstream: 102 degrees, –18kG
d. Handle perpendicular to beam, wires to the left: 192 degrees, +48kG

## 5. Quick analysis of angles read on dial

Average of 5 measurements: 302 09', 122 32'. The scatter of the individual measurements is about 7', the average should be good to about 3'.

Corrections due to offsets in hall voltage: near 302 degrees an offset of the field of +.015kG leads to a correction of +1' in the angle, at 122 degrees a +0.015kG offset induces a correction of –1'. The corrections due to offsets from zero hall voltage (3. column in table 2) are not significant.

## 6. Results from alignment group

See table 3. The individual angles (runs 1 – 5) provided by the alignment group track quite well with the ones read out on the mechanical angular scale. (Note: fractional angles by alignment group are decimal fractions, not minutes; angles of alignment group are counted counter-clockwise, angle on mechanical dial is clockwise.)

For the measurement of the field direction, we are interested in the "mean angle", i.e. the average of the angles at 302deg and 122 deg. This angle, according to the alignment group, is 9.07 degrees, with an rms scatter of 0.08 deg. The average should be good to 0.04 deg. This is good enough for our purposes.

These measurements were taken at an angle of 28.41 degrees between the geometrical axis of the target and the beam, corresponding to the q**2=0.5 setting. When using the 7.21 degrees angle between the (somewhat arbitrary) plane on which the hall probe is mounted and the handle, this yields an 1.86 degrees difference. This difference is the sum of a potential true misalignment of the B-field, and a possible difference between the magnetic plane of the hall probe and the mechanical plane on which the probe is glued. This latter difference will have to be determined in the calibration experiment, to be performed in September at UVA.

| run | angle ($\sim$302deg) | angle ($\sim$122deg) | mean |
|---|---:|---:|---:|
| 1 | 9.35 | 8.90 | 9.12 |
| 2 | 9.35 | 8.97 | 9.16 |
| 3 | 9.06 | 9.20 | 9.13 |
| 4 | 9.06 | 8.81 | 8.94 |
| 5 | 9.18 | 8.83 | 9.01 |
| average | | | 9.07 |

Table 3: Data measured by alignment group. The angle quoted is the one between the handle of the hall probe and the geometrical axis of the can of the polarized target.

# 6 Measurements at UVA

On Sept. 29, the hall probe was calibrated at UVA. To do so, we used a magnet existing in the UVA physics department, running at a field of $\sim$1.2T. In this magnet, we mounted alternatively
– the hall probe, with the stick in vertical direction
– the field probe
Hall probe and sensor were placed alternatively in the center of the B-field. Given the positioning accuracy of 2–3mm and the width of the pole tips of 20cm, hall probe and sensor see the same field direction.

The hall probe was in the configuration used at CEBAF; the cables had to be resoldered as all the connections had been ripped off during the mounting process of the probe.

The field probe consisted of Fe or Co foils, 5 - 10 mg/cm$^2$ thick, 2 by 2 cm$^2$ in size, glued between optically flat glass plates (flatness $<$0.02 degrees). One side of the glass plates was covered with a mirror (Al evaporated onto the glass, with a protective $SiO_2$ covering placed over it). This ensemble was held by an extremely thin vertical plastic wire (nylon, 0.15mm diameter), held taught by a nonmagnetic spring. When placed in the horizontal B-field, the plate orients itself into the direction of the field, with very high accuracy ($<$0.01 degrees).

At UVA, the survey group from CEBAF set up an optical path that allowed to transfer the direction perpendicular to the mirror, measured by

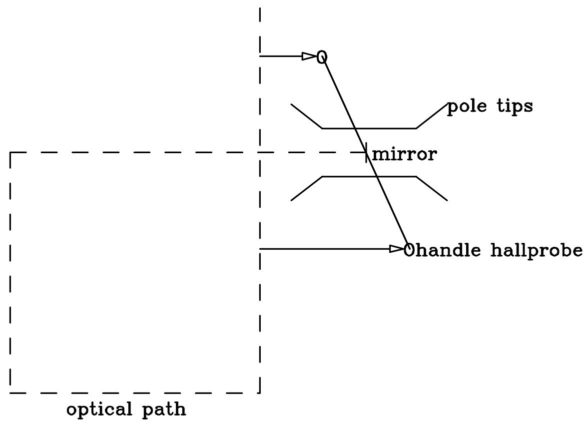


Figure 1: Setup for measuring angle between hall probe and handle. The optical path involves angles of exactly 90 degrees.

observing the image of the crosshair of the telescope after reflection off the mirror, to a vertical plane parallel to the B-field, some 20cm away from the axis of the B-field (see figure). The position of the alignment balls on the hall-probe stick were measured relative to this plane. This allows to measure the the orientation of the hall-probe stick relative to the B-field direction. A series of measurements were taken with the hall probe place at the angle where the read voltage was close to zero. At these positions, both the angle of the probe on the mechanical dial ($\rightarrow$ relative angle) and the angle relative to the B-field were recorded.

In the present measurements, we used sensors 1 and 2 in order to check that the results were indeed insensitive to the sensor used. Both sensor 1 and sensor 2 are made using 5mg/cm$^2$ Co foils.

Between run 4 and 5 the sensor was exchanged. We found a change of 35" in the direction of the reflected light, the better part of which was due to a change of alignment of the theodolite setup (25").

Note that the transition sensor $\leftrightarrow$ hall probe involved moving mechani-

| run | angle | residual B | comments |
|---|---|---|---|
| 1 | 346 19’ | +2.0G | sensor 2 |
| 2 | 165 21’ | +0.7G | |
| 3 | 346 22’ | –0.5G | |
| 4 | 165 22’ | –0.5G | |
| 5 | 165 58’ | +1.3G | sensor 1 |
| 6 | 346 58’ | –3.0G | |
| 7 | 165 58’ | 0.0G | |
| 8 | 346 58’ | 0.1G | |
| 9 | ∼75 00’ | +12660.0G | +maxi |
| 10 | ∼257 00’ | –12750.0G | –maxi |

Table 4: Data (relative angles) from mechanical readout measured at UVA parallel to measurements by alignment group

cally the hall probe. The relative angles in table 4 of runs 1–4 thus are *not* comparable to the ones of runs 5–8.

The orientation of the hall probe was such that for run 1 the wires as the come out of the tube were facing the telescope.

The measurements indicated a non-negligible planar hall effect at the field of 1.2T employed, so it is important to take the average over the two readings at angles $\sim$ 180 degrees apart.

The measurements shown in table 4 were taken in parallel to the measurements of the alignment group. The data measured by the alignment group are given in table 5.

The arcsin(average difference of distances/443.01mm) gives the angle of the magnetic axis of the hall probe relative to the B-field. The two values from table 5 give 9.1805 and 9.1687 degrees, the average is 9.1746 degrees $\pm$ 0.008 degrees.

From these numbers we conclude:

1. The measurements with two different sensors and the hall probe mounted to within the quoted accuracy at the same place give the same field orientation to better than 0.01 degrees.

2. The angle between the magnetic plane of the hall probe and the handle

| run | d1 (mm) | d2 (mm) B | difference (mm) | comment |
|---|---|---|---|---|
| 1 | 327.18 | 259.86 | 67.32 | |
| 2 | 330.26 | 256.24 | 74.01 | |
| 3 | 327.25 | 260.13 | 67.12 | |
| 4 | 330.54 | 256.29 | 74.26 | |
| | | | 70.68 | average |
| 5 | 337.66 | 263.26 | 74.41 | |
| 6 | 334.08 | 267.17 | 66.91 | |
| 7 | 337.48 | 263.45 | 74.02 | |
| 8 | 334.14 | 267.12 | 67.02 | |
| | | | 70.59 | average |

Table 5: Distances between line of sight and handle of hall probe. The larger distance corresponds to the alignment ball closer to the theodolite.

is 9.175 degrees, with an error of less than 0.01 degrees.

# 7 Final results

The measurements performed in hall C gave 9.07 degrees for the angle between the mechanical axis of the polarized target can and the hall probe handle at the orientation where the hall voltage is equal 0. The measurements at UVA give 9.175 degrees for the angle between the B-field and the hall probe handle in the orientation where the hall voltage is zero.

This means that our B-field is misaligned by $0.105 \pm 0.05$ degrees. The sign of the difference is such that the effective angle between the B-field and the beam direction is *smaller* than the nominal one.

The small size of the misalignment implies that for the coming q**2-points (and the one presently being measured) we probably can skip further measurements with the hall probe. Another measurement at the end of the experiment should be performed, however.

I. Sick, September 7, 1999