Usage of Heepcheck

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Abstract: The usage of `heepcheck` a program for analyzing offsets in two-spectrometer experiments with the ^{1}H(e,e$'$p) reaction is explained, as well as the correct implementation of the obtained offsets in the data analysis.

1 Introduction

In (two-)spectrometer experiments it is imperative to reach a correct and consistent treatment of offsets in the experimental setup. This includes offsets in the beam energy and position as well as offsets in the reconstruction of particle momenta and angles in the spectrometers.

The means to obtain a number of those offsets is to use the ^{1}H(e,e$'$p) coincidence reaction, or *Heep*. Since only two particles are present in the outgoing channel and both are detected, the reaction is overdetermined kinematically, i.e., a number of reconstructed quantities are correlated. E.g., no energy or momentum is taken away by undetected particles. Hence the missing energy E_m and the missing momentum $\mathbf{p}_m$ have to be 0. Also, since the reaction was elastic, the invariant mass W should be the proton mass. Any offset in the beam energy or one of the reconstructed spectrometer quantities (angles and momentum or delta) will show up as a deviation of these variables from their expected values. The code `heepcheck` provides a means to use these observables in order to arrive at the correct offsets for a given setup.

1.1 Limitations and Use of Caution

The out-of-plane missing momentum, p_m^{oop}, is not treated in `heepcheck`, since it depends only on the vertical angles of the particles in the spectrometers (x'_{tar}, or `xptar` in Hall C's `replay` code), and thus is decoupled from the other quantities: $W, E_m, p_m^{par}, p_m^{perp}$, which depend on the beam energy, the horizontal angles of the particles (y'_{tar}, or `yptar`) and the momenta of the particles in the spectrometers.

Since the electron beam energy is a parameter, heepchecking provides a means to determine the actual beam energy. However, it is advisable to approach this with caution: the beam energy is not the only parameter influencing the mentioned deviations, precise arc measurements give also the beam energy within 0.2%, and at low beam energies, up to about 2 GeV, there are also other methods (e.g. differential recoil method, diffractive minima method [Dut99]).

Be careful with your conclusions if you observe that the central hole in possible sieve slit measurements, or the edges of the collimator, are not where you expect them (usually they should be centered). This probably means that your beam was not where it was during the optics calibrations, and NOT that you should change matrix elements and/or offsets in them.

E.g., a vertical displacement of the beam will influence which angles are accepted, but (in first order) the angles themselves are still correctly reconstructed. (For a horizontal offset of your beam or your target you can check if the y'_{tar} of the central hole, or the asymmetry of the collimator edges are consistent with the value of y_{tar}, assuming you used a non-extended target. For a vertical offset of the beam there is no independent check, but it will influence δ by globally 0.1%/mm.) So, take the 'offcenter' or asymmetry into account in your SIMC, and not in the replay offsets.

If the calibration of the spectrometers plus their levelling were perfect, p_m^{oop} should show no deviation. Unfortunately we have found that in the Nov. 97 calibrations this is not the case. A possible explanation is that the beam was not centered vertically. As mentioned an offset in the vertical beam position can also result in an apparent momentum (`delta`) offset, which may have been observed.

2 Doing the Heepcheck analysis

The objective of the Heepcheck analysis is to find a set of beam energy and spectrometer angle and momentum offsets that minimizes the deviations of the quantities W, E_m, p_m^{par} and p_m^{perp} from their nominal values. The procedure is an iterative process. First, the experimental value at the top of the peak of these quantities has to be determined. With these at hand, a set of offsets can be searched for with the help of the `heepcheck` program that brings the deviations in these quantities to zero. In the next step, the elastic run has to be re-replayed with the found offsets applied. The process is to be repeated until satisfactory results are obtained, i.e., the values of W, E_m, p_m^{par} and p_m^{perp} are what they should be within the desired accuracy of typically 1-2 MeV(/c). In practice one iteration should be sufficient.

2.1 Using the `heepcheck` Code

The FORTRAN-77 code of `heepcheck` is available at TJNAF, in the cdaq account CUE documentation directory `/home/cdaq/documents/Heepcheck/heepcheck.f`, which is also the location of this document. Upon starting it will ask for the electron beam energy and for the electron scattering angle. From these it calculates the momenta and angles of both outgoing particles, and the effect offsets in the following quantities: beam energy `e_e`, electron scattering angle `th_e'`, electron momentum `e_e'`, proton scattering angle `th_q` and proton momentum `q`, would have on the quantities W, E_m, and the components of p_m parallel and perpendicular to the q-vector, p_m^{par} and p_m^{perp}.

The units for the offsets are 0.1% for beam energy and the two momenta, and 1 mrad for spectrometer angles. The first output is a matrix telling how much any of the four quantities W etc. would change if any of the five parameters `e_e` etc. was changed by +1 unit. In `heepcheck`, a positive sign for an angular offset means that the angle increases. The code does not discriminate which spectrometer acts as the electron arm or proton arm.

At this point the code waits for your best estimate of the five offsets that would reproduce the observed deviations in W etc. Look at the matrix to find a good combination of offsets.

The input can be repeated.

Five offsets can be adjusted, but one has only 4 physical variables, so one offset can be fixed beforehand. However, be economical: try to find the least overall offsets giving satisfactory results.

Caution: In a normal case the offsets needed should not exceed 2 units, i.e., 0.2% for any momentum or energy, and 2 mrad for any angle.

The input can be exited by entering a value for the beam energy deviation `de0` greater or equal to 9. This manœuver takes the user to the prompt where another beam energy and electron scattering angle can be entered. Entering a zero beam energy here will stop the program execution, entering "/" will repeat the first setting.

3 Implementation in the Analysis Code

Once a suitable set of offsets has been found, it has to be implemented in the analysis code, `replay`. The signs of the offsets and the place they are put in have to be treated with care. The actual offset parameters to be used are just the opposite of what was found using `heepcheck`, since if e.g. you found that a higher beam energy reproduces the deviations found, it actually means that the original beam energy you used was too high.

The code does not discriminate which spectrometer acts as electron- or proton-arm. The user has to be aware of the fact that a positive offset means a larger angle. The sign to be applied in the analysis depends on the laboratory system used. In replay, the y-axis points to the floor and the x-axis to beam right (HMS). Therefore, signs of angular offsets have to be reversed for the SOS, but not for the HMS.

The correct place to put the found offsets on top of the beam energy and spectrometer momenta and angles is the input of the analysis package. With Hall C's replay, that is the mmmyy.kinematics table in the `DBASE` subdirectory of the main `replay` directory. Under no circumstances should the found offsets be applied on the spectrometer reconstruction variables, i.e. those in `PARAM/gconstants.param.mmmyy`. This should be reserved for offsets originating from matrix fitting (e.g. `CMOP`) by an expert on a full, well prepared calibration data set.

4 Example

In the example (Fig. 1), a 4 GeV electron beam is assumed with the electron spectrometer at 30deg. The observed deviations are -8 MeV in W, +4 MeV in E_m, +5 MeV in P_m^{par} and -5 MeV in P_m^{per}. After asking for the beam energy and electron angle, `heepcheck` first calculates the corresponding proton momentum and angle, as well as the matrix indicating the change in the observed quantities as function of the offsets (see section 2.1).

Upon entering guessed values for the offsets, `heepcheck` prints out a line with the input and the resulting change to be expected in the observed offsets. The input can be repeated as often as needed.

```
 program heepcheck, version 19.11.97
 enter electron energy(MeV) and angle; E0=0/: stop
4044 30

Nominal (correct) values:
    e_e     th_e´    e_e´     q     th_q     W
  4044.0    30.0  2563.7  2229.2    35.1   938.3

variations in W, E_m and p_m for changes in parms
     dE   dth_e´  dp_e´  dthp  dp_p    dW    dE_m   dp_m(par)  dp_m(perp)

    1.0                                2.56    4.04    3.31    2.33
           1.0                        -5.55    0.00    2.33   -1.08
                  1.0                 -4.05   -1.00   -1.08   -2.33
                         1.0           0.00    0.00    0.00    2.23
                                1.0    0.00   -2.05   -2.23    0.00

 now give your own de0, dthe, dpe, dthp, dpp;
 the units are 0.1% for momenta and 1 mrad for angles
 the input can be repeated; back to E0 with de0>=9/
1.2 1 1 0 0
    1.2    1.0    1.0    0.0    0.0   -6.53    3.85    5.22   -0.61
1.2 1 1 -2 0
    1.2    1.0    1.0   -2.0    0.0   -6.53    3.85    5.22   -5.07
1.2 1 1.2 -2 0
    1.2    1.0    1.2   -2.0    0.0   -7.34    3.65    5.00   -5.54
9/\
 enter electron energy(MeV) and angle; E0=0/: stop
0/
parana:Heepcheck:340$
```

Figure 1: Example for the usage of `heepcheck` .

References

[Blo97] H.P. Blok, FORTRAN-77 code `heepcheck` can be found in `/home/cdaq/documents/Heepcheck`

[Dut99] D. Dutta, Ph.D. thesis, Northwestern University, 1999, can be found in `/home/cdaq/documents/theses`