Optics Calibration of the Hall A High Resolution Spectrometers using the new optimizer

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1 Introduction

Most up-to-date version of this document can be found at
http://www.jlab.org/~nilanga/physics/optics.ps

The Hall A High Resolution Spectrometers are an identical pair of QQDQ magnetic spectrometers with optical properties that are point-to-point in the dispersive direction. The optics matrix elements allow for the reconstruction of the interaction vertex in the target from the coordinates of the detected particles at the focal plane. This document describes the optics calibration procedure used to determine the optics matrix elements. The first part of this document describes the basics of optics optimization. The second part of the document describes the testing procedure of the available data bases while the last part is a step-by-step user manual for the newly written optimize optimization routine. The input data for optimize is supplied by The Hall A event analyzer ESPACE. This manual assumes that the user has a good working knowledge of ESPACE.

Optics matrix elements for both spectrometers have been optimized over the full ranges both spectrometers[1]. This optimization has been performed for the normal tune of the HRS pair. The spectrometer tune, and hence spectrometer optics, is very sensitive to the ratio of the magnetic field in the Dipole to the magnetic fields in the second and the third quadrupoles (Q2 and Q3) . In order to ensure that normal tune of the spectrometer, Q2 and Q3 have to be cycled using the prescribed procedure[2]. The matrix elements have been tested with data obtained over one year and have been shown to be stable to the accuracy

[1] Nominal momentum ranges are: Right HRS: 0.4 GeV-3.0 GeV; Left HRS 0.4 GeV-4.0 GeV

[2] When the spectrometer momentum has to be increased, first raise Q2 and Q3 currents to the highest allowed values for that spectrometer (1400 Amp. for Right HRS, and 1600 Amp for Left HRS) and then go down to the desired momentum. **Note that Dipoles should not be cycled**

quoted in section 3.0.1. Contact Doug Higinbotham at dougjlab.org to obtain these matrix elements.

While the optics matrix elements already available will work all the experiments within the nominal ranges of the spectrometers, the focal plane detector parameters and the offsets between the actual detector coordinates and the the ideal spectrometer coordinates can change from time to time. Therefore before the available databases are used for the analysis of an experiments, these databases have to be tested for data taken during that experiment. The testing procedure is described in section 2.

2 Coordinate systems

A detailed description of the coordinate systems used in this document is given in reference [1]. For convenience, a short overview is presented here. All coordinate systems presented are Cartesian. Note that a reference to an angular coordinate in this section should be taken to refer to the tangent of the angle in question.

- **Hall Coordinate System (HCS):** The origin of the HCS is at the center of the hall, which is defined by the intersection of the electron beam and the vertical symmetry axis of the target system. $\hat{z}$ is along the beam line and points in the direction of the beam dump, and $\hat{y}$ is vertically up. See Fig. 1.

- **Target Coordinate System (TCS):** Each of the two spectrometers has its own TCS. A line perpendicular to the sieve slit surface of the spectrometer and going through the midpoint of the central sieve slit hole defines the z axis of the TCS for a given spectrometer. $\hat{z}_{tg}$ points away from the target. In the ideal case where the spectrometer is pointing directly at the hall center and the sieve slit is perfectly centered on the spectrometer, the z_{tg} axis passes through the hall center. For this case, the distance from the hall center to the midpoint of the central sieve slit hole is defined to be the constant Z_0 for the spectrometer[3]. The origin of the TCS is defined to be the point on the z_{tg} axis at a distance Z_0 from the sieve surface. In the ideal case, the origin of the TCS coincides with the hall center. The x_{tg} axis is parallel to the sieve slit surface with $\hat{x}_{tg}$ pointing vertically down. The out-of-plane angle (θ_{tg}) and the in-plane angle (ϕ_{tg}) are given by $\frac{dx_{tg}}{Z_0}$ and $\frac{dy_{tg}}{Z_0}$ respectively. See Fig. 2.

[3] $Z_0^{HRSE} = 1.181$ m, $Z_0^{HRSH} = 1.178$ m.

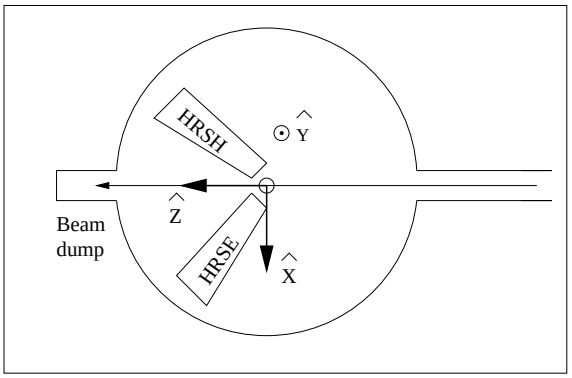


Figure 1: Hall Coordinate System (top view)

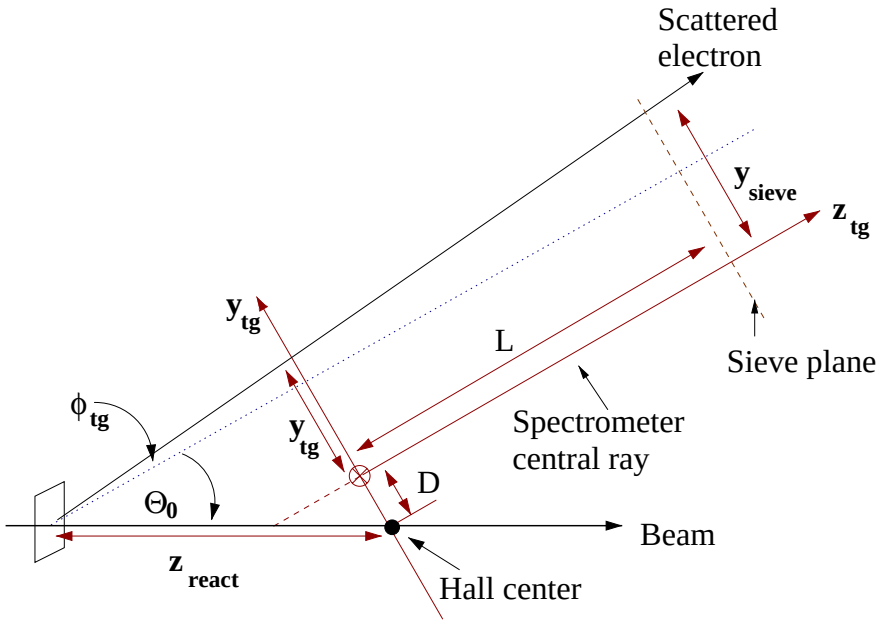


Figure 2: Target coordinates for electrons scattering from a thin foil target, as seen from above. **L** is the distance from Hall center to the sieve plane, while **D** is the horizontal displacement of the spectrometer axis from its ideal position. Spectrometer central angle is denoted by Θ_0. Note that x_{tg} and x_{sieve} are vertically down (into the page)

- **Detector Coordinate System (DCS):** The intersection of wire 184 of the VDC1 U1 plane and the perpendicular projection of wire 184 in the VDC1 V1 plane onto the VDC1 U1 plane defines the origin of the DCS.

$\hat{y}$ is parallel to the short symmetry axis of the lower VDC (see Fig. 3). $\hat{z}$ is perpendicular to the VDC1 U1 plane pointing vertically up, and $\hat{x}$ is along the long symmetry axis of the lower VDC pointing away from the center of curvature of the dipole (see Fig. 4).

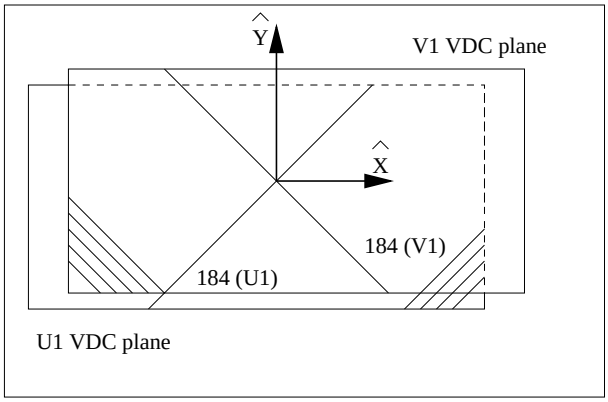


Figure 3: Detector Coordinate System (top view)

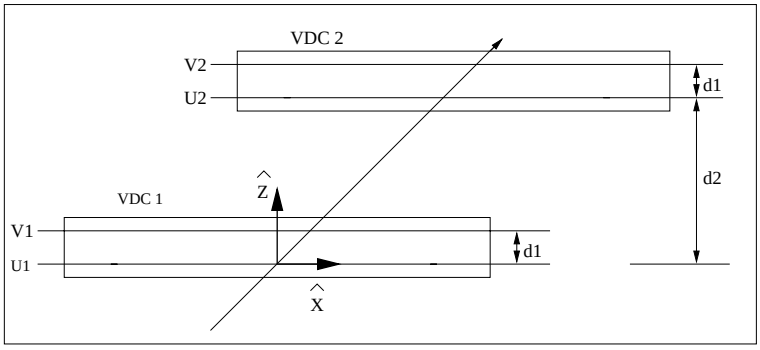


Figure 4: Detector Coordinate System (side view)

Using the trajectory intersection points $p_{vdc,n}$ (where n=1-4), with the four VDC planes, the coordinates of the detector vertex can be calculated

according to

$$\tan \eta_1 = \frac{p_{vdc,3} - p_{vdc,1}}{d_2}, \tag{1}$$

$$\tan \eta_2 = \frac{p_{vdc,4} - p_{vdc,2}}{d_2}, \tag{2}$$

$$\theta_{det} = \frac{1}{\sqrt{2}} \left(\tan \eta_1 + \tan \eta_2\right), \tag{3}$$

$$\phi_{det} = \frac{1}{\sqrt{2}} \left(-\tan \eta_1 + \tan \eta_2\right), \tag{4}$$

$$x_{det} = \frac{1}{\sqrt{2}} \left(p_{vdc,1} + \left(p_{vdc,2} - d_1 \tan \eta_2\right)\right), \text{ and} \tag{5}$$

$$y_{det} = \frac{1}{\sqrt{2}} \left(-p_{vdc,1} + \left(p_{vdc,2} - d_1 \tan \eta_2\right)\right)' \tag{6}$$

where the distances $d1$ and $d2$ are defined in Fig. 4. These equations may be derived based on the following assumptions:

- the VDC sense wires are oriented at 45° with respect to the wire frame.
- the wires are positioned in planes.
- the wire planes are parallel to each other and are separated by known distances.
- the location of the center of each wire plane is known.

Any deviation from the above assumptions leads to offsets in the DCS coordinates. These offsets are corrected when the focal plane vertex is calculated.

- **Transport Coordinate System (TRCS) at the focal plane:** The TRCS at the focal plane is generated by rotating the DCS clockwise around its y-axis by 45°. Ideally, the $\hat{z}$ of the TRCS coincides with the central ray of the spectrometer. However, due to the deviations mentioned above, the TRCS used by ESPACE can differ from the ideal spectrometer Transport Coordinate System.

  The transport coordinates can be expressed in terms of the detector coordinates by

$$\theta_{tra} = \frac{\theta_{det} + \tan \rho_0}{1 - \theta_{det} \tan \rho_0} \tag{7}$$

$$\phi_{tra} = \frac{\phi_{det}}{\cos \rho_0 - \theta_{det} \sin \rho_0} \tag{8}$$

$$x_{tra} = x_{det} \cos \rho_0 \left(1 + \theta_{\mathrm{tra}} \tan \rho_0\right) \tag{9}$$

$$y_{tra} = y_{det} + \sin \rho_0 \phi_{tra} x_{det} \tag{10}$$

where ρ_0 is the rotation angle, $-45°$.

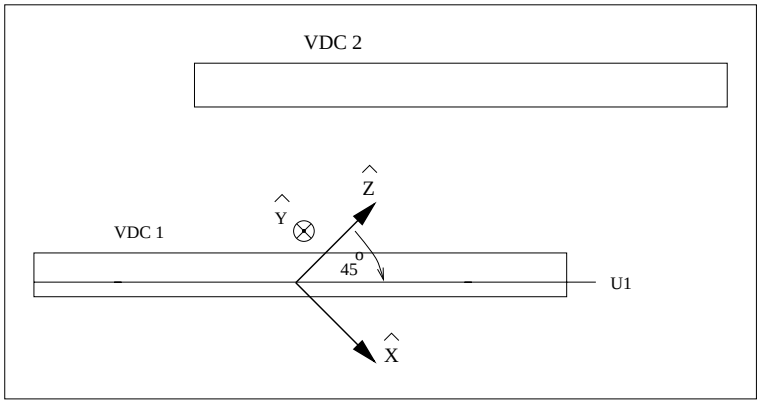


Figure 5: Transport Coordinate System (side view).

- **Focal plane Coordinate System (FCS):** The focal plane coordinate system chosen for the HRS analysis is a rotated coordinate system. This coordinate system is obtained by rotating the DCS around its y-axis by an angle ρ, where ρ is the angle between the **local** central ray[4] and the $\hat{z}$ axis of the DCS. As a result, the $\hat{z}$ axis of the FCS rotates as a function of the relative momentum $\frac{\Delta p}{p}$ (see Fig. 6). In this rotated coordinate system the dispersive angle θ is small for all points across the focal plane. As a result, the expressions for the reconstructed vertex converge faster during optics calibrations.

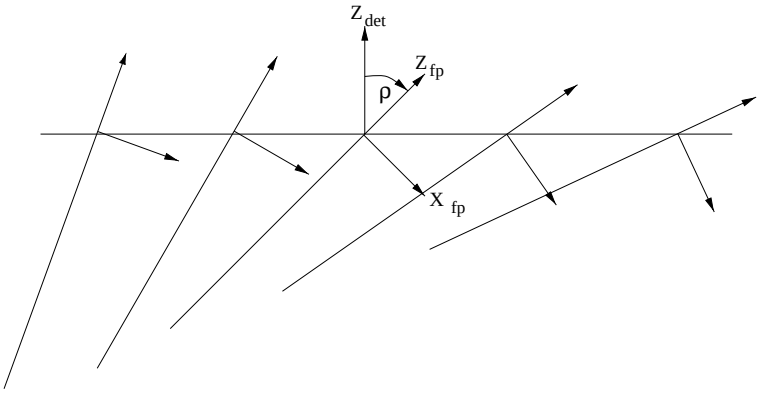


Figure 6: The focal plane (rotated) coordinate system as a function of the focal plane position.

[4]The ray with $\theta = \phi = 0$ for the corresponding relative momentum $\frac{\Delta p}{p}$.

The transformation to the FCS also includes corrections for the offsets incurred due to misalignments in the VDC package.

The coordinates of focal plane vertex can be written as follows:

$$y_{fp} = y_{tra} - \sum y_{i000} x_{fp}^{i} \tag{11}$$

$$x_{fp} = x_{tra} \tag{12}$$

$$\theta_{fp} = \frac{\theta_{det} + \tan\,\rho}{1 - \theta_{det}\tan\,\rho} \tag{13}$$

$$\phi_{fp} = \frac{\phi_{det} - \sum p_{i000} x_{fp}^{i}}{\cos\,\rho - \theta_{det}\sin\,\rho}, \tag{14}$$

where

$$\tan\,\rho = \sum t_{i000} x_{fp}^{i}. \tag{15}$$

2.1 Approach

For each event, two angular coordinates (θ_{det} and ϕ_{det}) and two spatial coordinates (x_{det} and y_{det}) are measured at the focal plane. The position of the particle and the tangent of the angle made by its trajectory along the dispersive direction are given by x_{det} and θ_{det}, while y_{det} and ϕ_{det} give the position and tangent of the angle perpendicular to the dispersive direction. These observables are used to calculate x, θ, y, ϕ, and δ[5] for the particle at the target. To reduce the number of unknowns at the target to four, the x_{tg} value was effectively fixed at zero during the optics calibration by requiring that the beam position on target was within 250 μm of the origin of the HCS.

The Transport Tensor links the focal plane coordinates to the target coordinates. The relationship between the focal plane and target coordinates can be written (in a first-order approximation) as

$$\begin{bmatrix} \delta \\ \theta \\ y \\ \phi \end{bmatrix}_{tg} = \begin{bmatrix} \langle\delta|x\rangle & \langle\delta|\theta\rangle & 0 & 0 \\ \langle\theta|x\rangle & \langle\theta|\theta\rangle & 0 & 0 \\ 0 & 0 & \langle y|y\rangle & \langle y|\phi\rangle \\ 0 & 0 & \langle\phi|y\rangle & \langle\phi|\phi\rangle \end{bmatrix} \begin{bmatrix} x \\ \theta \\ y \\ \phi \end{bmatrix}_{fp.} \tag{16}$$

The null tensor elements result from the mid-plane symmetry of the spectrometer.

In practice, the expansion of the focal plane coordinates is performed up to the fifth order. A set of tensors $Y_{jkl}, T_{jkl}, P_{jkl}$ and D_{jkl} link the focal plane

[5] $\delta = \frac{P - P_0}{P_0}$, where P is the measured momentum of a particle and P_0 is the central momentum of the spectrometer.

coordinates to target coordinates according to[6]

$$y_{tg} = \sum_{j,k,l} Y_{jkl}\theta^j_{fp}y^k_{fp}\phi^l_{fp}, \tag{17}$$

$$\theta_{tg} = \sum_{j,k,l} T_{jkl}\theta^j_{fp}y^k_{fp}\phi^l_{fp}, \tag{18}$$

$$\phi_{tg} = \sum_{j,k,l} P_{jkl}\theta^j_{fp}y^k_{fp}\phi^l_{fp}, \text{ and} \tag{19}$$

$$\delta = \sum_{j,k,l} D_{jkl}\theta^j_{fp}y^k_{fp}\phi^l_{fp}, \tag{20}$$

where the tensors $Y_{jkl}, T_{jkl}, P_{jkl}$ and D_{jkl} are polynomials in x_{fp}. Consider, for example, Y_{jkl}:

$$Y_{jkl} = \sum_{i=1}^{m} C_i^{Y_{jkl}} x^i_{fp}. \tag{21}$$

Thus the final expression for y_{tg} is:

$$y_{tg} = \sum_{j,k,l}\sum_{i=1}^{m} C_i^{Y_{jkl}} x^i_{fp}\theta^j_{fp}y^k_{fp}\phi^l_{fp} \tag{22}$$

Mid-plane symmetry of the spectrometer requires that for Y_{jkl} and P_{jkl}, *(k+l)* is odd, while for D_{jkl} and T_{jkl}, *(k+l)* is even.

The optics matrix elements $C_i^{Y_{jkl}}$ are read from the database for ESPACE analysis. An optics matrix line from the database is given below:

```
0 0 0 1  7.0170E-01 -1.2796E+00 -6.4398E-01  1.0002E-01  0.0000E+00   Y001
```

The **Y** in Y001 indicates that this is a y_{tg} matrix elements. Similarly there are **D, P** and **T** matrix elements that correspond to δ, ϕ and θ respectively. The first number in the line (vary code) is used during optimization to indicate the order in x_{fp} up to which $C_i^{Y_{jkl}}$ need to be optimized. A vary code of **0** indicates that the corresponding line should not be changed during optimization. The next three numbers give j, k and l for the matrix element. The real numbers are the $C_i^{Y_{jkl}}$ matrix elements, in the order of increasing i (order in x_{fp})

The transfer tensors are obtained by the minimization of the aberration functions

$$\Delta(y) = \sum_s [\frac{\sum_{j,k,l} Y_{jkl}\theta^j_{fp}y^k_{fp}\phi^l_{fp} - y^0_{tg}}{\sigma^s_y}]^2, \tag{23}$$

where $|y^s_{tg} - y^0_{tg}| \leq w_y$,

[6]Note that the superscripts denote the power of each focal plane variable.

$$\Delta(\theta,\phi) = \sum_s [\frac{\sum_{j,k,l} T_{jkl}\theta_{fp}^j y_{fp}^k \phi_{fp}^l - \theta_{tg}^0}{\sigma_\theta^s}]^2 + \sum_s [\frac{\sum_{j,k,l} P_{jkl}\theta_{fp}^j y_{fp}^k \phi_{fp}^l - \phi_{tg}^0}{\sigma_\phi^s}]^2, \tag{24}$$

where $|\theta_{tg}^s - \theta_{tg}^0| \leq w_\theta$ and $|\phi_{tg}^s - \phi_{tg}^0| \leq w_\phi$, and

$$\Delta(\delta) = \sum_s [\frac{\sum_{j,k,l} D_{jkl}\theta_{fp}^j y_{fp}^k \phi_{fp}^l - \delta^0}{\sigma_p^s}]^2, \tag{25}$$

where $|\delta^s - \delta^0| \leq w_p$.

In practice the basic variables $y_{tg}, \theta_{tg}, \phi_{tg}$ do not form a good set of variables to work with. For a foil target not located at the origin of the target coordinate system, y_{tg} varies with ϕ_{tg}. In the case of a multi-foil target, ϕ_{tg} calculated for a given sieve slit hole depends on y_{tg}. Further, all three variables depend on the horizontal and vertical beam positions (x_{beam} and y_{beam}[7]). On the other hand, the interaction position along the beam, z_{react}, and vertical and horizontal positions at the sieve plane, x_{sieve} and y_{sieve} are uniquely determined for a set of foil targets and a sieve-slit collimator. These three variables are calculated by combining the "basic" variables defined above using the equations (see fig 2):

$$z_{react} = -(y_{tg} + D)\frac{\cos\phi_{tg}}{\sin(\Theta_0 + \phi_{tg})} + x_{beam}\cot(\Theta_0 + \phi_{tg}) \tag{26}$$

$$y_{sieve} = y_{tg} + L\tan\phi_{tg} \tag{27}$$

$$x_{sieve} = x_{tg} + L\tan\theta_{tg} \tag{28}$$

The vertical coordinate x_{tg} in the target (transport) coordinate system of the spectrometer is calculated using the beam position in the vertical direction, vertical displacement of the spectrometer from its ideal position, θ_{tg} and z_{react}.

[7]Note that beam variables are measured in the hall coordinate system, centered at the center of the hall with $\hat{z}$ along the beam direction and $\hat{y}$ vertically up.

3 Experimental procedure

A general set of tensors describing the entire $y_{tg}, \theta_{tg}, \phi_{tg}$ and $\frac{dP}{P}$ space may be obtained by acquiring data that covers the full range of these variables. In the past these data were achieved in practice by performing the following series of calibration experiments:

- at a nominal incident energy of 845 MeV, electrons were scattered from a stack of thin ^{12}C targets covering the y_{tg} acceptance of the spectrometer.
- for each of the y_{tg} runs above, five open collimator measurements were performed at $\frac{dP}{P}$ values varying from -4.5% to 4.5% in steps of 2%, so that the ^{12}C elastic peak moves across the focal plane.
- all of the above measurements were then repeated with a sieve slit collimator that had 49 holes with well-defined x_{sieve} and y_{sieve} values (see Fig. 7). The holes were drilled in a rectangular grid perpendicular to the plane of the sieve slit and parallel to x and y coordinates at the plane of the sieve slit (x_{sieve} and y_{sieve}).

The intersection point of the beam with the thin target foil provided a point target (to within the spectrometer resolution). The following positions and distances were then surveyed:

- the target position.
- the spectrometer central angle, defined to be the angle between the geometric center axis of the dipole and the ideal beam line.
- the displacement of the spectrometer dipole axis from the hall center.
- the position of the sieve slit center with respect to the spectrometer central axis.
- the position of the beam position monitors with respect to the ideal beam line.

The results from these surveys were used to calculate the z^0_{react} position for each target foil, and x_{sieve} and y_{sieve} values for each hole center in the sieve slit.

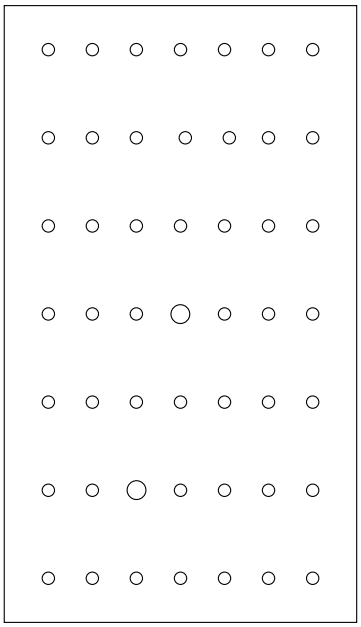


Figure 7: Sieve slit: The large holes allow for unambiguous identification of the orientation of the image at the focal plane.

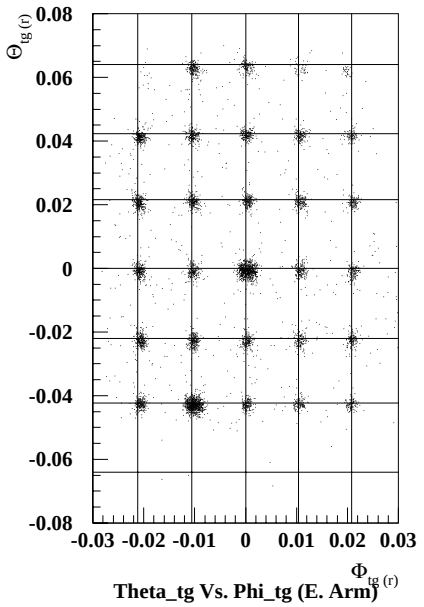


Figure 8: Reconstructed image of the sieve slit for the thin ^{12}C foil at $z_{react} = 0.0$.

3.0.1 Optics Commissioning results

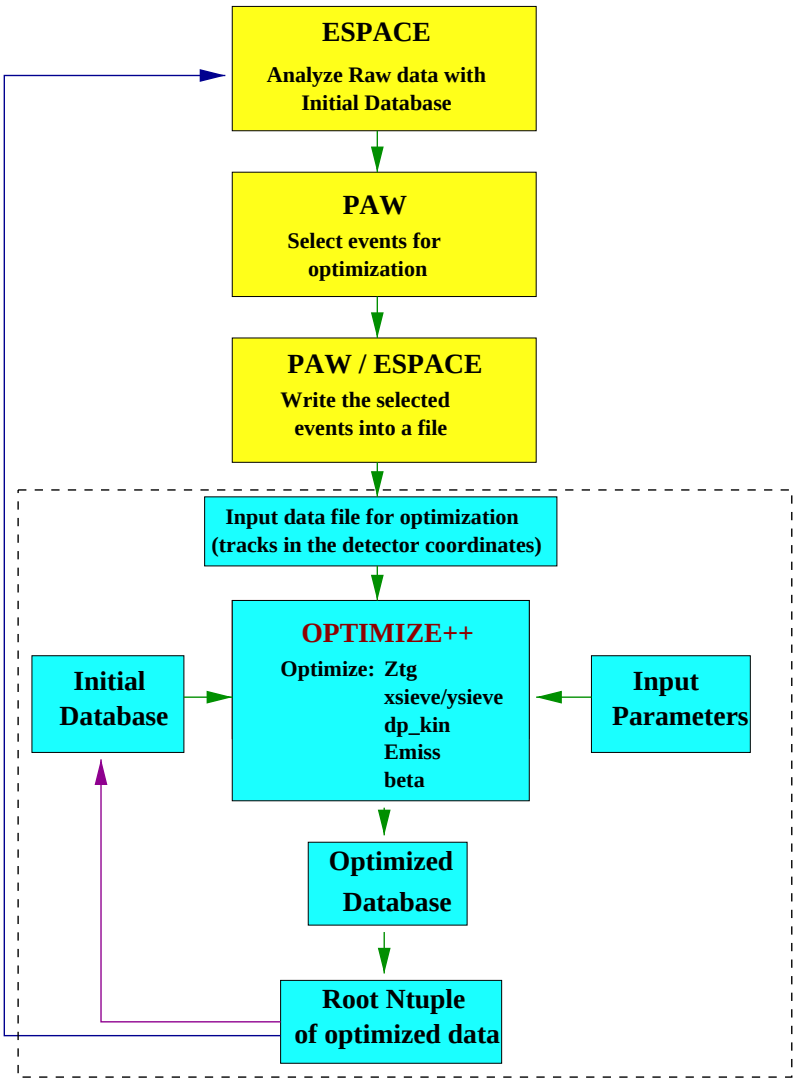
The following results were obtained from optics data taken at $E_0 = 845$ MeV with a thin ^{12}C target. All the quantities are measured at the target.

- Angle determination accuracy
  - in-plane: ± 0.2 mrad
  - out-of-plane: ± 0.6 mrad
- Angular Resolution (FWHM)
  - in-plane: 2.0 mrad
  - out-of-plane: 6.0 mrad
- Momentum Resolution (FWHM)
  2.5×10^{-4}

- Transverse position determination accuracy
  ±0.3 mm
- Transverse position resolution (FWHM)
  4.0 mm

4 User manual for Optimize

Optimize is a stand-alone routine used to optimize HRS optics and scintillator database. The input data for optimize is generated by ESPACE. The flow chart in Figure 4 shows how Optimize works.



4.1 Getting things ready

The optimization routine optimizes spectrometer focal plane offsets (off), y coordinate at the target (ytg), θ and ϕ angles at the target (ang), kinematically corrected momentum (dpk) and emiss (emi). The detector optimizations are

handled by espace and other routines and are described else where.

In order to test an existing database or to optimize the database, one needs the following:

- **A data set** At lower momenta (< 1GeV) one should perform an elastic delta scan with a heavy nuclear target of several thin foils covering the y_{tg} acceptance of the spectrometer. Data should be taken at each setting with and without the sieve slits. The sieve slit data is needed for angle and position optimizations. Tight cuts on the elastic peak help eliminate sieve-slit punch-through events in this case. Open collimator data which does not suffer any degradation of momentum resolution due to sieve punch-through and edge scattering, can be used for momentum optimization.

  At higher momenta it is not possible to use elastic scattering from a target like ^{12}C due to low cross sections. In this case quasi-elastic scattering ^{12}C foil stack can be used for angle and position optimizations. While this data is not as clean as in the elastic case, such a measurement takes less time than an elastic delta-scan because the whole focal plane is covered by one or two momentum settings of the spectrometer. Since single-arm data do not define a sharp peak in momentum for quasi-elastic scattering, one has to use a series of coincidence ^{12}C(ee$'$p) runs for the momentum optimization.

- **A startup database**. Doug Higinbotham maintains a library of generic optics databases.

- **The Official version of espace** All kumac files assume the "official" left-right notation of espace.

  If you are using an old version of espace with the electron-hadron notation, change all the kumac files accordingly and re-compile your espace with the routines from
  /work/halla/e89003/nilanga/optimize/espace_changes/
  (replace your espace_lib/*.f or spectra/*.f with these routines and recompile espace)

- **Optimization code**. Copy everything from
  /work/halla/e89003/nilanga/optimize/optimize_src/ to your directory. Add the following lines to your .login file:

  ```
  if ( $OSNAME == "Linux" ) then
  use root/2.23
  endif
  set path = ($ROOTSYS/bin $path)
  setenv LD_LIBRARY_PATH "/usr/dt/lib:$ROOTSYS/lib"
  ```

- Login to a Jlab CUE Linux machine (like ifarml2) and cd to your directory.

- type: make

- this will give you an executable called optimize
- Note that the include file locations in **optimize.cpp** have been hardwired in for ifarml machines.

  To run the program you need to give the command optimize with two arguments:

  ```
  > optimize [arg1] [arg2]
  ```

  arg1 can be off, ytg, ang dpk or emi for different reconstructions while *arg2* can be **test** or **optimize**. The first time you run optimize for each spectrometer *arg1* must be **kumac** and *arg2* must be **test**. This will generate zreact and sieve-slit grid kumacs needed at subsequent steps of the optimization (or testing).

- **Sample files for optimization** A complete set of sample files required for optimization can be found in /work/halla/e89003/nilanga/optimize/optimize_example. Here is a short description of the files you need. The sample files (and the description given here) are for the left-spectrometer. For the case of the right-spectrometer, just replace _l by _r in the sample files.

  - **espace kumac files**
    These files are named espace_xxx_l.kumac, where xxx stand for off, ang, ytg dpk and emi for the optimization given above. Another espace kumac espace_test_l.kumac is used for testing the databases. Before you start, go through the sample kumacs carefully and change the file names etc. to match your situation. The optimization sequence is labeled by the iteration number **itr**, which is given as an argument at the execution of the kumac. When the kumac files are executed, the run number also has to be supplied as an argument. For example:

    ```
    espace> exec espace_ang_l.kumac nrun=1336 itr=1
    ```

  - **paw kumac files**
    There are two sets of paw kumac files you need: the first set named test_xxx_l.kumac is for testing the reconstruction of different coordinates using a given database. The second set named cuts_xxx_l.kumac are used to define cuts and generate input files for optimization.
  - **Fortran subroutines**
    The subroutines write_y.f and write_angle.f are called by the paw kumacs.
  - **Files for running espace**
    Please refer to the espace manual for the files you need to run espace.

- **sub-directory for hbook files**
  The kumac files assume a sub-directory called **hbook** in your working directory for hbook files.
- **Input files for optimization**
  These files are labeled opt_xxx.dat for optimizations and test.dat for testing the database. The files for single arm optimizations (xxx = off, ytg or ang) and test.dat have the same format. The line items in this file are described in the appendix. Change these files with the values for your setup before you start. If you are only doing a visual test (see below) you only need to update test.dat.

4.2 Testing a database

There are two levels of testing available to check the quality of the database.

1. Visual inspection of peak positions compared to the grids of surveyed positions. This requires running the optimize code only once.
2. Quantitative comparison of the average reconstructed variable for each peak to the surveyed value of that variable for that peak. This test requires running the optimize code for each set of reconstructed variables separately.

4.2.1 Visual test

1. In case you are using data from an elastic delta scan, filter the events from the elastic peak at each momentum setting into a new set of data files and use this filtered data for your optimization.
2. Use espace_test_l.kumac to analyze the data with your database.
3. Make sure that the input file test.dat has been updated with the correct values.
4. Run optimize with *arg1*=kumac *arg2*=test
5. Now you are ready for the database test. In paw run the kumac files test_off_l.kumac, test_ytg_l.kumac and test_ang_l.kumac. Answer the questions and select cuts when prompted. These kumacs will display y_tg and x_sieve versus ph_tg plots for the selected peaks on grids of surveyed locations of these peaks. You will also get a set of .ps files labeled test_xxx_l_itr_n.ps, containing all the plots generated by the kumac files.

4.2.2 Quantitative test

1. Follow steps 1-4 of the visual test.
2. Execute the following steps for xxx= off, ytg and ang

3. In paw, run cuts_xxx_l.kumac. Answer the questions and define cuts. Note in the case of react_z vs. y_rot plots you need to define a polygon around the peak while in the case of x_sieve vs. y_sieve plots you only need to select one point at the center of each peak.

4. This kumac will generate i_holes.dat (i = 1,2...) file(s). Use the peak information from these file(s) to update opt_xxx.dat. (See the appendix for a description of opt_xxx.dat files)

5. In espace, analyze data using espace_xxx_l.kumac, this will generate a fort.51 file containing input data for the test. Copy fort.51 into the file name you are using in xxx_off.dat

6. Run optimize with *arg1*=xxx *arg2*=test

7. You will get a file labeled 0_compare_xxx. For each peak you have selected, this file will compare the surveyed value, xx_0, to the average value xx_av of the reconstructed variables (here xx stands for y, ph and th). The final column of this file will give the χ^2 computed for this peak (at the moment this is not the reduced χ^2)

8. Execute test_xxx_l.kumac in paw to generate plots.

4.3 Optics optimization

1. Follow steps 1-5 of the quantitative test

2. Change the vary-codes of the optics matrix elements you wish to optimize. See the description of the database optics matrix line given in page 8. A vary code (vc) selection where

$$vc + j + k + l = 6 \tag{29}$$

   allows the optimization of optics matrix elements to the 6^{th} order. Make sure that the vary-codes of all matrix elements (of both spectrometers) that you are not optimizing are set to zero.

3. Run optimize with *arg1*=xxx *arg2*=optimize

4. optimize will print the following information onto the screen:

   - A list of peaks it is using for optimization with corresponding z_react, y_sieve and x_sieve values.
   - Current optics matrix elements for both spectrometers
   - A list of optics matrix elements it is going to optimize with step sizes and limits.
   - Maximum number of events per peak
   - Number of points used for optimization from each peak.

- Other things related to optimization.

Make sure that this information is correct and the program is doing what you want it to do.

5. After some time (can be a few hours for the angle optimization) the program will generate the new database and write-out 0_compare_xxx and 1_compare_xxx files. For each peak you have selected, these files will compare the surveyed value, xx_0, to the average value xx_av of the reconstructed variables (here xx stands for y, ph and th) before and after optimization respectively.

6. Execute test_xxx_1.kumac in paw to test the new data base and to generate plots.

4.4 Emiss Optimization

The missing energy for a coincidence experiment is calculated using the momenta measured by the two spectrometers. Therefore, the momentum optimization should, in principle, optimize the width of the missing energy peak. However in cases where the momentum was optimized at a lower momentum and one of the spectrometers is set at a higher momentum for coincidence kinematics, Emiss might have correlations with the focal plane variables. In this case Emiss can be optimized by optimizing momentum matrix elements (D elements) for the spectrometer with higher momentum while keeping the matrix elements of the other spectrometer constant.

For the Emiss optimization one needs to choose an (e,e'p) coincidence data set with a sharp Emiss peak (For example the two body breakup peak for the 3He(e,e'p) reaction).

1. Analyze data with the database optimized in the previous steps using ana_emiss.kumac.

2. Generate a histograms of Emiss vs. focal plane variable θ_{rot}, x_{rot}, y_{rot}, and ϕ_{rot} of the spectrometer that need optimization. (Fig [?])

3. In the example shown in Fig [?], there is a clear correlation between Emiss and θ_{rot}.

4. Use a polygon cut in Emiss vs. θ_{rot} to select events for the Emiss peak for optimization.

5. Analyze again with the starting database, using ana_emiss.kumac. Make sure that you have the " calibrate/optimize emiss emiss_cut" line turned on in the .kumac file.

6. At the end of espace analyzing you would get a file named fort.52 containing the input data for the optimization code. You should rename this file into something like emiss.dat.

7. Before running the optimization code, edit the input file opt_emiss.dat (See appendix)

8. Edit the vary codes in the start-up database to select the matrix elements you want to optimize. Please see the description of the optics database given in section 2.1. Note that in this case you have only one peak to optimize, so you can restrict only a few matrix elements. Therefore open up only those terms that absolutely needs optimization. In the case of the example shown I opened up only D1000 and D2000 terms for the electron spectrometer.

9. Run the optimization by typing "optimize emiss"

10. After some time you should get the optimized database.

11. Do a "diff" between old and new databases to make sure that the changes are what you expected.

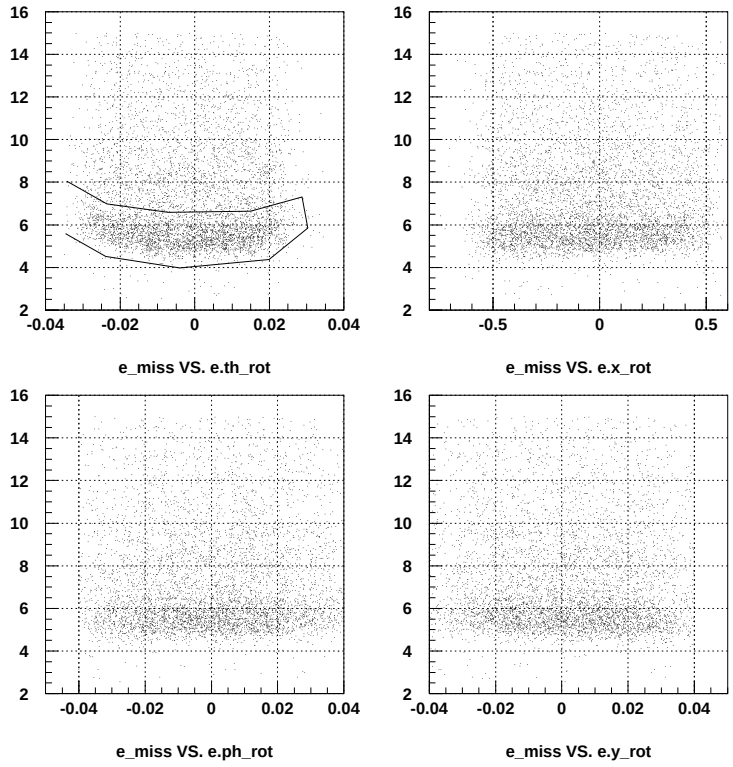


Figure 9: Emiss vs. focal plane variables. Also shown is the polygon cut to select events for Emiss optimization

A Optimization input file description

A.1 Single arm optics

The input files opt_off.dat, opt_ytg.dat, opt_ang.dat, and opt_dpk.dat are used to input variables for the optics optimization. Please see the examples given in my directory. The first part of these files are the same. Here is a sample opt_y.dat file.

```
dat_file        l_off.data
db_in           db_e99117_l_kin1
db_out          db_itr_1
e0              1197.0
arm             2
th_0            19.985
sp_v_off        -0.00047
sp_h_off        0.0023
target_angle    90.0
n_zreact        7
zreact_1        -0.2000
zreact_2        -0.1334
zreact_3        -0.0667
zreact_4         0.0000
zreact_5         0.0667
zreact_6         0.1334
zreact_6         0.2000
n_ysieve        7
y_sieve_1       -0.0378
y_sieve_2       -0.0254
y_sieve_3       -0.0129
y_sieve_4       -0.0004
y_sieve_5        0.0121
y_sieve_6        0.0246
y_sieve_7        0.0371
n_xsieve        7
x_sieve_1       -0.0785
x_sieve_2       -0.0535
x_sieve_3       -0.0285
x_sieve_4       -0.0035
x_sieve_5        0.0215
x_sieve_6        0.0465
x_sieve_7        0.0715
npeak 4
         3         3         2
         3         3         3
         3         3         4
         3         3         5
```

1. **dat_file** is the name of your data file (new name of fort.51)
2. **db_in** is the starting database
3. **db_out** is the name for the new optimized database
4. **e0** Beam energy in MeV.
5. **arm** Spectrometer number: spectrometer that comes first in the data base is 1 and the other one is 2. In the new left-right notation of espace spec_r = 1, spec_l = 2.
6. **th_0** central angle of the spectrometer (see above) (angles measured on the left side of the beam line are positive)
7. **sp_v_off** Vertical offset of the spectrometer axis from the ideal hall center (in meters in the spectrometer target coordinate system)
8. **sp_h_off** Horizontal offset of the spectrometer axis from the ideal hall center (in meters in the spectrometer target coordinate system)
9. **target_angle** Angle of the target foil with respect to the beam line.
10. Total number of target foils (N1)
11. N1 lines containing z_react value of each target foil (in meters in the hall coordinate system).
12. Total number of vertical columns in the sieve slit (N2)
13. N2 lines containing y_sieve value of each hole column (in meters in the spectrometer target coordinate system)
14. Total number of horizontal raws in the sieve slit (N3)
15. N3 lines containing x_sieve value of each hole raw (in meters in the spectrometer target coordinate system)
16. Number of peaks selected for optimization (N4). You define these peaks when you run cuts_xxx_l.kumac. At the end of the execution of this kumac it prints the total number of peaks selected as: nr. of peaks N4.
17. **Case of opt_off.dat, opt_ytg.dat, and opt_ang.dat:**

    N4 lines containing target foil number, vertical column number and the horizontal raw number. When you run cuts_xxx_l.kumac, for each target foil (i) a file named i_holes.dat is written, this file contains the required peak information, just cut and paste these files in to the input file

    Case of opt_dpk.dat:

    N4 lines containing the following information for each peak: magnetic field of the spectrometer (B0) in kG, mass of the target nuclei (in MeV), Energy loss before scattering, energy loss after scattering.

A.2 Emiss

opt_emiss.dat is similar to what is described above except for that **e_arm** and **zoffset** are not in it. The peak lines in opt_emiss.dat should give:
location of the Emiss peak (MeV), B0 for HRS-1 in kG, B0 for HRS-2 in kG, mass of the target nucleus (in MeV), mass of the recoiling nucleus (in MeV).

References

[1] Jefferson Lab Hall A ESPACE users guide; available at http://hallaweb.jlab.org/espace/docs.html.

[2] E.A.J.M. Offerman, Ph.D thesis (1988).

[3] F. Garibaldi *et al.,* Nucl. Instrum. Methods **A314,** 1 (1992).

[4] M. Liang, Survey Summary Report, (http://www.cebaf.gov/Hall-A/publications/technotes.html/survey_summary.ps.gz)

[5] E.A.J.M. Offerman *et al.,* The Hall A sextupole crisis: an evaluation of the magnitude of the problem and possible solutions (1995).