Hall C Expert Howto

Experiment: HKS

HKS Optical Calibration

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Abstract

This document describes the method and procedure of optical calibration for HKS spectrometer system.

1 Overview

The purpose of HKS optical calibration is to optimize target angle ($xptar$, $yptar$) and momentum (δp) reconstruction matrices to get the best resolutions.

The optical calibration procedure will use the data from Enge and HKS sieve slit runs for angle reconstruction calibration and CH_2 target runs for momentum calibration. Before the experiment, the procedure has been tested by simulation.

2 General Procedure

The spectrometer optical calibration procedure is specially designed for HKS spectrometer system. It is somewhat different from other Hall C basic equipment experiment using only HMS and SOS, because of the existence of splitter magnet right after the target. This complicate both the angle and momentum calibrations.

The required calibration runs for HKS optical calibration are:

- Separate Enge and HKS sieve slit(SS) runs, using Carbon target without raster. Check the Enge and HKS focal plane correlations: Yfp vs. Xfp, $Xpfp$ vs. Xfp, $Ypfp$ vs. xdp. Statistics is enough when all the bands can be clearly seen (see fig.4 and fig.5 for Enge, fig.6 for HKS).

- Two arm coincidence runs in production kinematics, on CH_2 target to obtain Λ and Σ^0 spectra. We also need data on Carbon target for the ${}^{12}_{\Lambda}B$ ground state spectrum. The yield of Σ^0 and ${}^{12}_{\Lambda}B$ gs should reach at least 1500 events and 1500 events, respectively. We should also look at the S/A ratio under the Λ peak to keep it more than 5 to 1 after raster correction.

The general procedure for the calibration is:

1. Separate Enge and HKS sieve slit calibration to obtain angle reconstruction matrices using original momentum reconstruction matrix.

2. Raster correction for CH_2 target data using existing raster correction matrix.

3. Kinematics calibration to find deviation of beam energy, Enge and HKS central momenta from their nominal values. The central angles of the spectrometers are not used in the missing mass calculation and they are not needed for fixed-angle spectrometer.

4. Two arm coupled momentum calibration to obtain momentum reconstruction matrix.

5. After getting the calibrated momentum matrix, go back to first step again to do SS calibration using the new momentum matrix. Iterate until best resolution is reached.

3 Sieve Slit Calibration

3.1 Procedure

In HKS experiment, although the Splitter field smears the one to one correspondence between target angles and sieve slit hole position and introduces additional momentum dependence. particle trajectories scattered from a point target with given momenta still have a fixed target angle when they pass a given hole. The angle in this case is also a function of particle momentum, and depend on splitter optics. Based on this observation, the Sieve slit calibration procedure is:

1. Fit function F_{s2t}: target angles as a function of SS positions and momentum based on Splitter optics.
2. Separate events of the SS calibration run data hole by hole, thus determine corresponding SS hole center position for each event.
3. Using function F_{s2t}, calculate corrected target angles ($xptar$, $yptar$) for each event from SS center position and momentum.
4. Fit transfer matrix from focal plane to target: (xfp, $xpfp$, yfp, $ypfp$)$\longrightarrow$($xptar$, $yptar$).

A simulation of the SS calibration procedure with initial inaccurate Splitter, Enge optics reaches final resolution for e' (Enge) target angles (σ): $xptar$: 1.8 mr, $yptar$: 1.1 mr, for Kaon (HKS) angles: $xptar$: 0.4 mr, $yptar$: 2.4 mr.

3.2 Code

The codes are written in Perl script, which calls a series of Fortran programs. Currently, they work on simulated data. All the codes start from the directory:`jlabs1:/home/yuan/HKS/optics/`

- `.enge/fsv2tarang`: Perl script to fit target angles as function of sieve slit positions (X_{sv}, Y_{sv}) and momentum by 6-order polynomials.
- `.enge/opticscalib`: Perl script to fit target angles as 6-order polynomials of focal plane quantities.
- Nominal electron arm Raytrace data card:`.enge/hksearm_tilt.dat`
- nominal electron arm reconstruction matrix:`.enge/enge_recon_coeff.dat`

4 Momentum Calibration

The method of HKS momentum calibration is making use of the known masses of Λ,Σ^0 hyperons and the narrow width of ${}^{12}_{\Lambda}$B hypernuclear ground state. The momentum reconstruction matrices for Enge and HKS arms are optimized simultaneously by minimizing the Chisquare defined as the sum of squared mass differences between the calculated mass and the PDB values. A Nonlinear Least Square method is used to optimize the matrices. The procedure uses the existing target angle reconstruction matrices.

Although there is emulsion measurement of ${}^{12}_{\Lambda}$B gs binding energy at 11.37 ± 0.06 MeV, the associate statistical error and the composite nature $(2^-/1^-)$ of the state may cause the peak center to deviate from this value. So in the calibration process, the peak position is a adjustable parameter and the calibraion is carried out in a iterative way, the gs peak center is adjusted after each iteration according to the actual fitted position of calculated ${}^{12}_{\Lambda}$B gs distribution, until an minimum Chisquare is reached.

4.1 procedure

The procedure is:

1. Calculate missing mass using the existing angle matrix and the initial (un-calibrated) momentum matrix. From CH_2 target runs, select Λ,Σ^0 events, from Carbon target runs, select ${}^{12}_{\Lambda}$B gs events from a window located around the center of the missing mass peaks.

   Inside the 5mm thick CH_2 target, the energy loss and radiative processes are significant. It shifts the missing mass distributions and forms a tail. The width of the event window has to be selected appropriately, because a too wide window will dilute the sample with too many radiated events while a too narrow window will cause a insufficient statistics in the fitting.

2. Define Chisquare as the sum of squared mass differences Δm_i^2 between the calculated mass and the PDB values or the initial assumed ${}^{12}_{\Lambda}$B gs binding energy:

   $$\chi^2 = \sum w_i \Delta m_i^2$$

   where w_i is the relative weight of Λ,Σ and ${}^{12}_{\Lambda}$B gs events.

3. χ^2 is a function of missing mass *emiss*, so a function of e' and Kaon momenta δp_e and δp_k:

$$\chi^2 = f(emiss(\delta p_e, \delta p_k)$$

   Minimizing χ^2 by by a Nonlinear Least Square method to optimize the Enge and HKS momentum reconstruction matrices .

4. fit the actual peak center of the calculated $^{12}_{\Lambda}$B gs missing mass distribution. Using this value as the new $^{12}_{\Lambda}$B gs binding energy. Go back to first step. Iteration until an minimum Chisquare is reached.

4.2 Code

All files have a path name in the front: `jlabs1:/home/yuan/HKS/optics/`:

- `.dpcal_eloss/emiss_cal.pl`: Perl script to reconstruct missing mass from focal plane quantities based on existing momentum and angle matrices.
- `.ml_dpcal/dp_cal_nls.pl`: Perl script to select events and optimize the momentum matrices.
- `.dpcal_eloss/steer.dat`: input data card to specify the parameters for the momentum calibration, such as the number of events used in the calibration, relative weights, the centers of missing mass peaks for event selection,etc.

5 Raster Correction

5.1 Procedure

To avoid burning the CH_2 target, beam will be rastered 5mm×5mm on the target. A direct reconstruction with matrices obtained for point target gives much worse resolution, for example, the δp resolution for HKS is 1.16×10^{-4}(rms) without raster, it becomes 6.64×10^{-4} with 5mm×5mm raster.

To do raster correction, the beam positions on target need to be determined by raster magnets X and Y current event by event. For rastered beam, The reconstructed target quantities can be expressed as functions of focal plane quantities and beam positions at target. It can be written as, for example:

$$\delta p = f(xfp, xpfp, yfp, ypfp) + g(xtar, ytar)$$

The raster correction function g depends only on beam position. It can be fitted from nominal Raytrace data card. Even if the actual optics of the spectrometer system may deviate from the nominal data card, its effect on raster correction function g is small so we can still use the nominal function (fig.1 and fig.2).

5.2 Code

Under directory jlabs1:/home/yuan/HKS/optics/:

- `.matrixfit/matfit6_backward.f`: Fortran program to fit target quantities as a function of focal plane quantities and beam position in the form of the above equation. It fits function g as a 3-order polynomial of beam position. Need Raytrace simulation output as input data.

- `.matrixfit/expon_rastercor.dat`: input data file specifying the power of polynomial terms in functions f and g.

6 Simulation of the Calibration Procedure

Simulated events are used to test the calibration method. The simulation take account of target physics processes, spectrometer optics and detector resolution.

The simulation of target processes is based on SIMC, a physics simulation program for Hall C basic equipment experiment, adapted for HKS experiment. The ionization energy loss, Bremsstrahlung, multiple scattering and beam spread effects are included in the simulation. The simulation uses 5mm thick CH_2 target and 0.1 g/cm^2 Carbon target.

Simulated events from target are send through The spectrometers. RAYTRACE is used to simulate events in the electron arm. Since Raytrace data card is not available for the Kaon arm, the events are transfered from target to HKS focal plane by a 5-variable ($xtar$, $xptar$, $ytar$,$yptar$,δp), 6-order forward matrix. Only optical properties (no physical processes) are considered in this step.

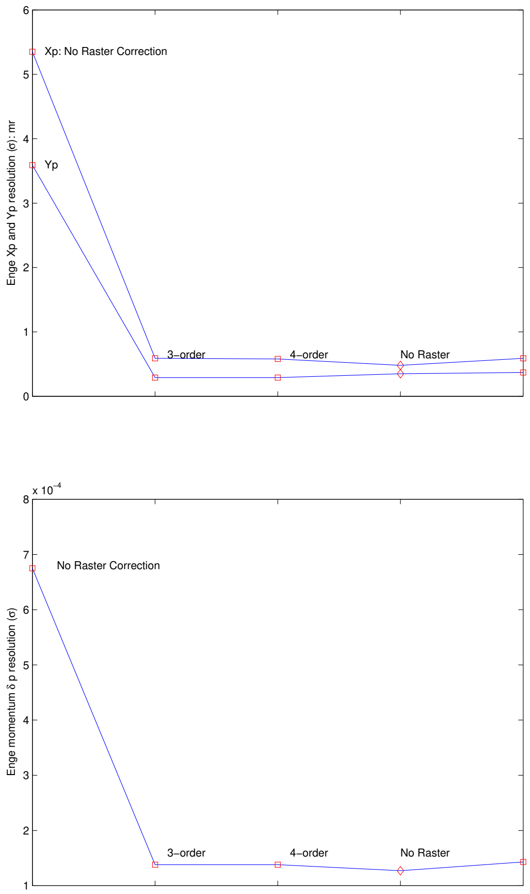

Figure 1: Comparison of Enge momentum(up) and angle(down) reconstruction resolution with rastered beam,with and without raster correction. Both resolutions are shown when the correction function g fitted as a 3-order and 4-order polynomials. The rightmost point is the resolution after raster correction with wrong Enge optics.

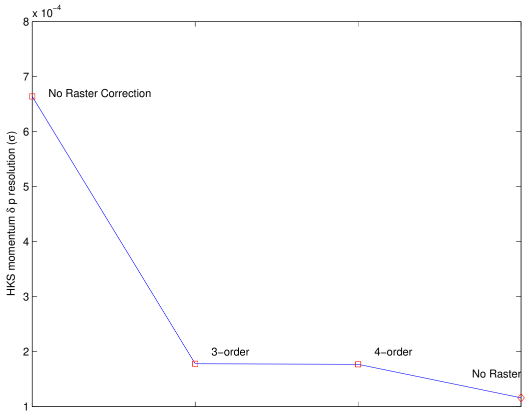

Figure 2: Comparison of HKS momentum reconstruction resolution with rastered beam,with and without raster correction.

At focal plane of the spectrometers, the positions and angles are smeared according to detector resolution and multiple scattering. For Enge, the resolutions (σ) are: 86 μm (x), 0.7 mr(xp), 210 μm(y), 2.8 mr(yp). For HKS, they are: 160 μm (x and y), 0.33 mr (xp and yp).

The simulated focal plane events are then reconstructed back to the target using backward reconstruction matrix. The beam energy and particle momentum are corrected by the average energy loss in the target. The corrections are 0.4923 MeV (beam energy), 0.6015 MeV (e' momentum), 0.4890 MeV (Kaon momentum) for CH_2 target, 0.0820 MeV (beam energy), 0.1026 MeV (e' momentum), 0.0866 MeV (Kaon Momentum) for Carbon target.

The simulated Λ, Σ^0 and ${}^{12}_{\Lambda}$B missing mass spectra are shown in fig.3. The predicted 1^- state of ${}^{12}_{\Lambda}$B at 2.73 MeV is also included in the simulation for comparison. The quasi-free carbon background on CH_2 target is simulated with Λ and Σ^0 events by a assumed S/B ratio of 6:1 under Λ peak. The ${}^{12}_{\Lambda}$B GS has a missing mass resolution of 397 KeV (FWHM) with correct optics.

The simulated Enge focal plane sieve slit correlation patterns are shown in fig.4. Fig.5 shows the yfp vs. xfp correlations for each X-column of sieve slit holes.

The simulated HKS focal plane sieve slit patterns are shown in fig.6.

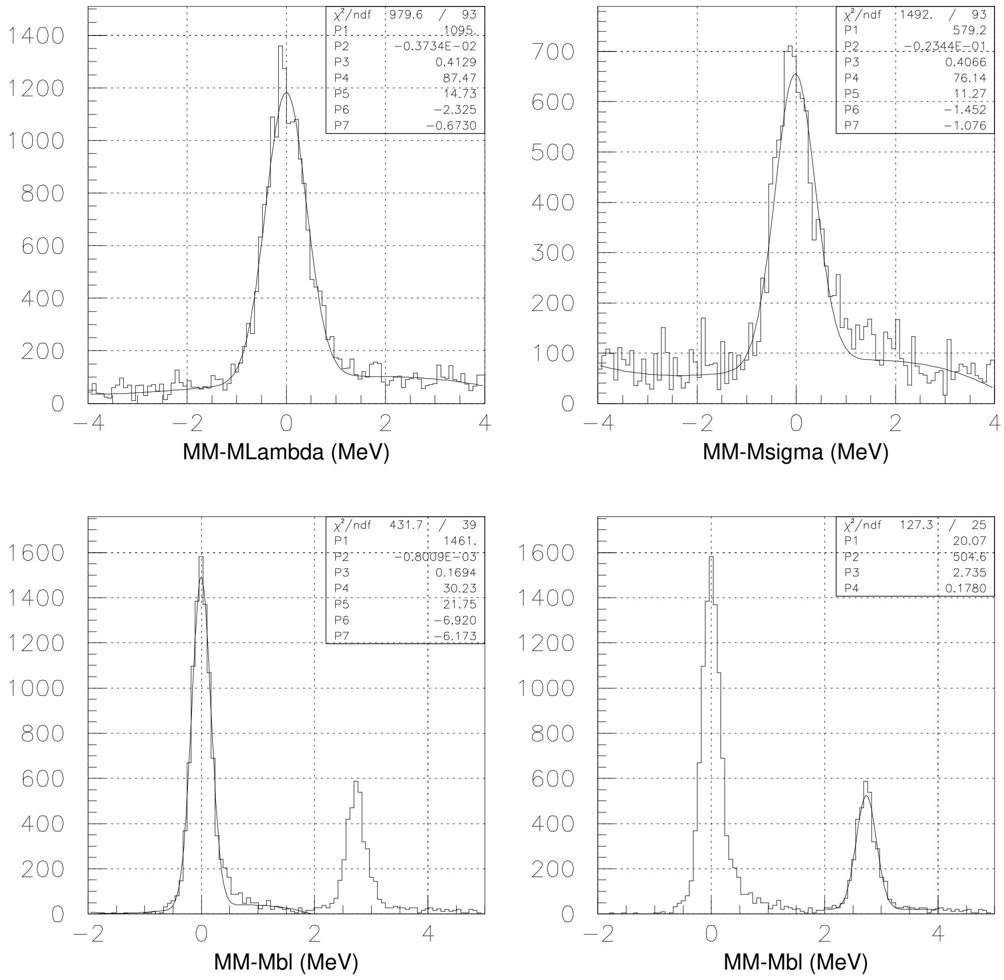

Figure 3: Simulated Λ, Σ^0 and ${}^{12}_{\Lambda}B$ missing mass spectra with Carbon QF background from CH_2 target

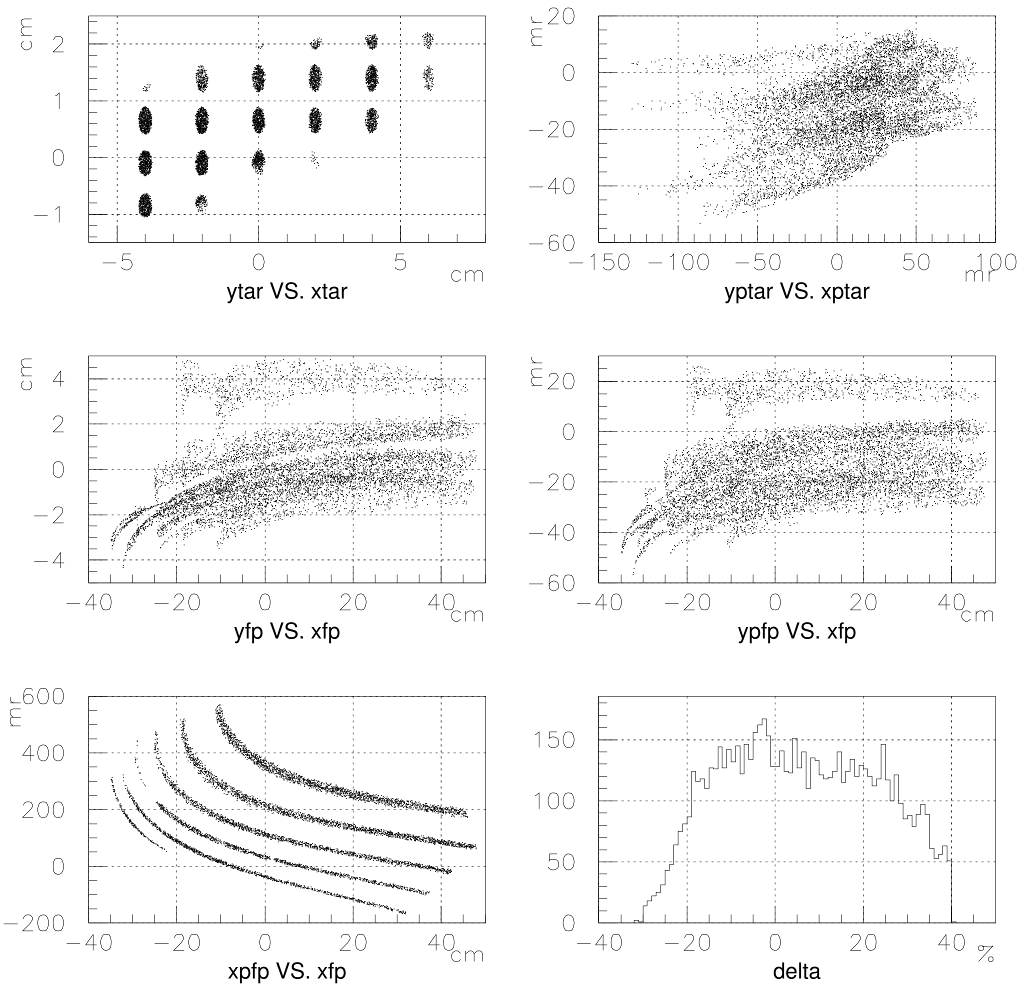

Figure 4: Simulated Enge focal plane sieve slit correlation and hole patterns.

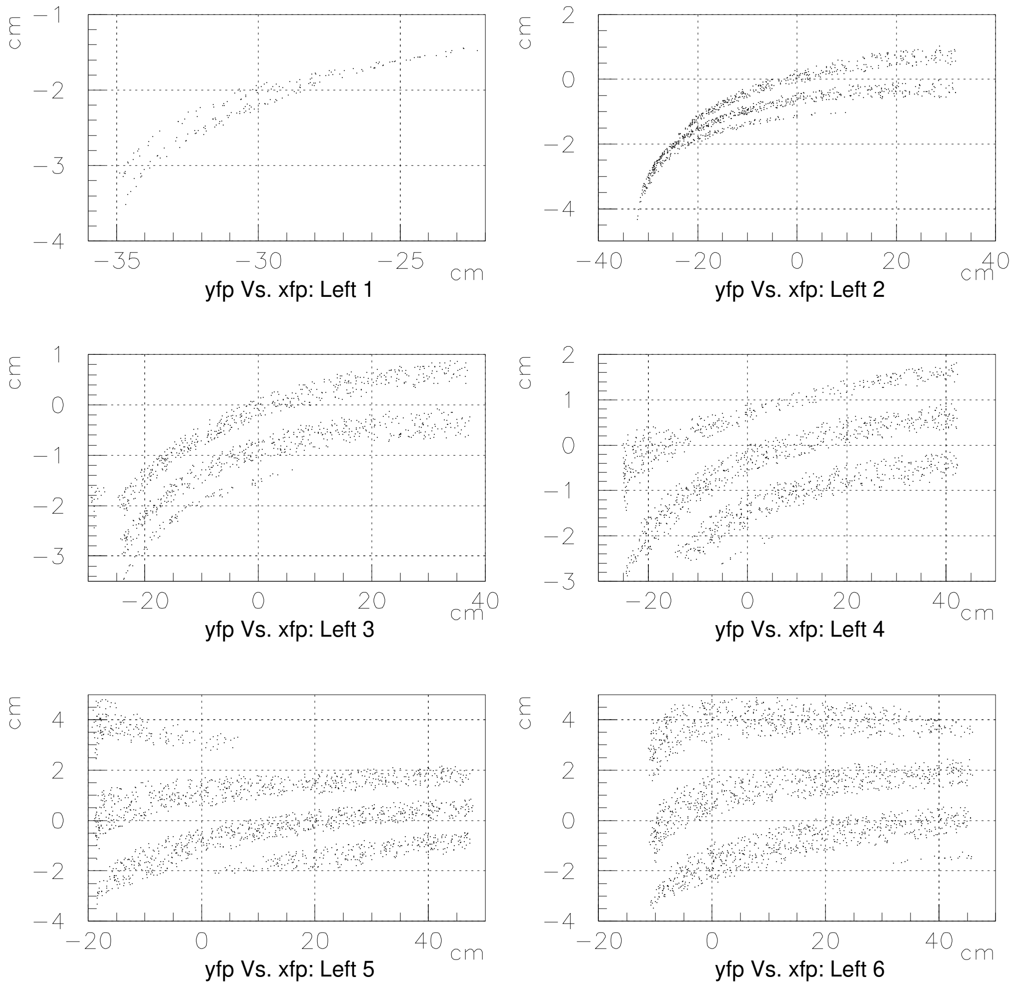

Figure 5: Simulated Enge focal plane yfp vs. xfp correlations for each X-column of sieve slit holes.

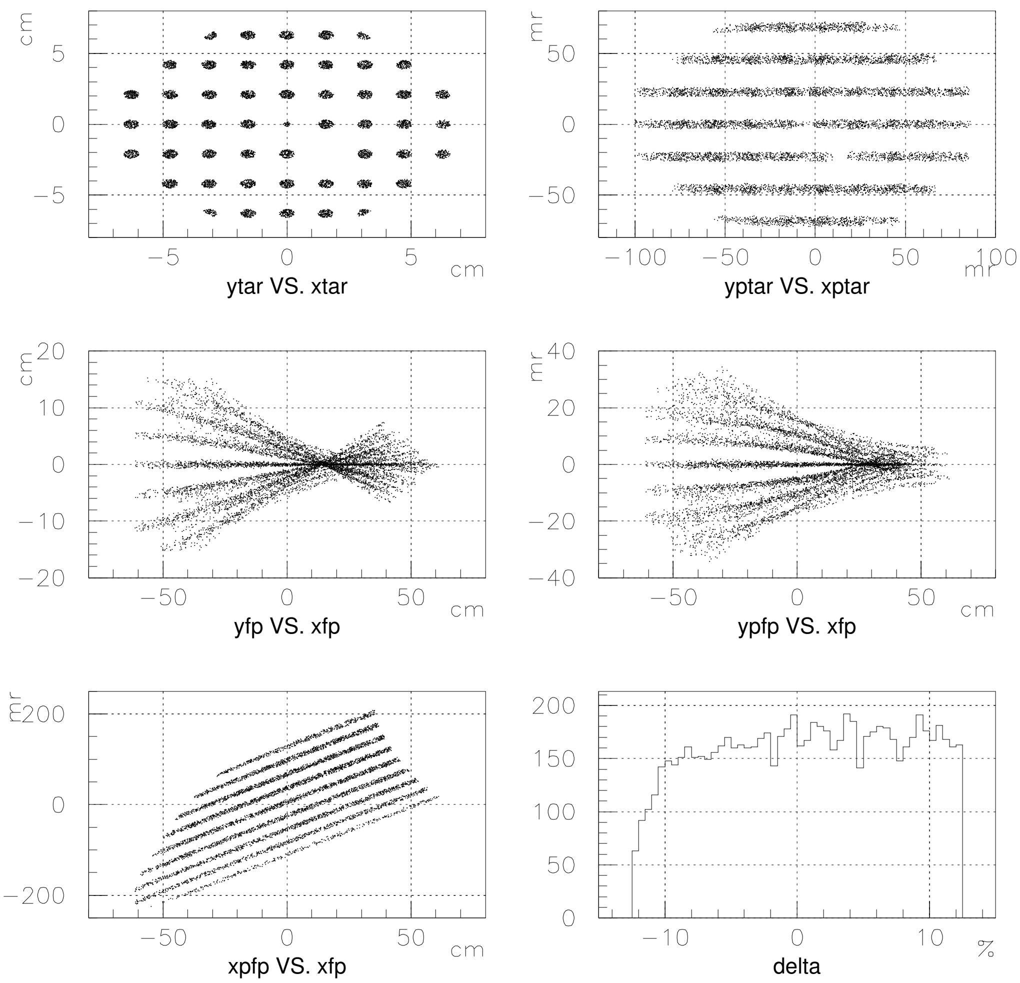

Figure 6: Simulated HKS focal plane sieve slit correlation and hole patterns.