FD Momentum calibration for March08 beam time

S. Dymov

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Contents

1 Installation at Uni Münster

1.1 Software

The latest version of the FdModule package is installed in /mnt/scr1/user/anke directory at PKP160 and PIKIP66 computers.

The main sorter programs are located in /home/wahlfach21/App/sorter/March08, sM08.cc for the March08 beamtime, and in /home/wahlfach21/App/sorter/Oct07, Oct07.cc for October07. The mentioned below scripts for event preselection and cuts definition can also be found in these directories.

The directory /home/wahlfach21/App/sorter/sorter0deg contains the main program for writing a 0 degree data GEvent file for fit.

The fit procedures are located in /home/wahlfach21/App/fits/fit0deg for the 0 degree data and in /home/wahlfach21/App/fits/m08fit for the fit of reactions kinematics.

The programs to obtain the HANDCRAFT geometry description are located in /home/wahlfach21/App/Positions.

A short description of these programs follows below.

1.2 Data

The processed data are stored in Gogi GEvent format at PKP160, in the /mnt/data1/user/sd/ directory, and SC1, SC2, Oct07 subdirectories for supercycles 1 and 2, and the October07 data, correspondingly. Each file contains events from all flattops used.

The data include samples processed without trigger or process selection, these are files FdEv.root, FdEv_1.root etc. The preselected samples are: single track events with momentum above 2.5 GeV (FdEvFastDp files), double track events (FdEvDbl files) and preselection of He done by DeDx and TOF criteria (FdEv_TOFHeSel files).

In addition, there are files starting with "Used", which are the results of a secondary preselection and contain the events actually used in the fit procedure.

1.3 Setup files

The geometry description and calibration files are stored in /home/wahlfach21/setup, march08_4.5MeV and October07 for the two beam times. The geometrical information is given in the HANDCRAFT format for the sorter and other c programs, and in the setup_geometry files for GEANT3.

The HANDCRAFT directory read by a sorter is defined in the following way: first, a "handcraft" directory sought under the "run_" directory (e.g., setup/october07/run_1.2/handcraft) then, if not found, under the beamtime directory (e.g., setup/october07/handcraft), otherwise the HANDCRAFTPARM environmental variable is tested. In the stand-alone programs, you can supply the HANDCRAFT directory in the call to gAnkeGeom->HANDCRAFTInit("Fd", HCDIR). The Fd wire chamber positions are described in a new format and are read from WireChamberPos.dat file instead of MWPCPosInANKE.dat.

The calibration files include the drift chamber calibration read from IntDCCalib.root files, found either under run or beamtime directories, the Fd counters relative delays in the fd_hodoscope/meantimer_correction_Fd.dat files and momentum reconstruction coefficients located in "kinematics" directories of the runs.

2 The fit procedure

Of the few factors affecting the reconstructed momenta, the wire chamber and the vertex position are considered most important and most appropriate for adjustment. The wire chamber position can be aligned at first with the use of 0 degree data obtained in the March08 beamtime. After such an alignment one

can consider only one parameter defining position of the chambers — rotation angle of the Fd platform, with the chamber positions fixed at the platform. This angle together with the vertex position are the two parameters adjusted in the reactions kinematics fit.

2.1 Fit at 0 degree

The detector positions are aligned with the use of straight tracks coming from the interaction point of the beam and the cluster jet. The two objectives of this procedure is to obtain the best alignment of the system and to stay most closely to the measured detector coordinates.

This is achieved in a two-level fit. At the lower level, the vertex position and position of the first chamber are fixed and parameters of MWPC2 and MWPC3 are adjusted by the straight tracks. The X, Y coordinates of the chamber center and the rotation angle about the perpendicular to the planes are used as the fit parameters here. The detector plane (the plane of wires) is kept unchanged while varying the X and Y coordinates. At each iteration over the detector position parameters, every track gets fit again, and the χ^2 is constructed of the residuals of the tracks at the wire planes.

In the external fit procedures, X and Y coordinates of the first (DC) chamber are varied. At each iteration, the positions and rotaion angles of MWPC2 and MWPC3 are adjusted according to the DC1 position, and χ^2 contains deviations of the positions of the 3 chambers from the measured coordinates.

Some uncertainty of the results come from the uncertainty of the vertex position during the 0 degree measurements. The vertex X coordinate of -27 mm was used in the procedure, what correspond to the information that the cluster jet is shifted by 2-3 mm from the nominal position towards the negative detector. In addition, a small trajectory rotation in the rest magnetic field of 0.0013 Tl is taken into account.

The measured values for the detector positions are obtained from the geodesic measurements made in 2007 under several beam pipe angles. The measurements were recalculated to the 0 degree position, and their average was taken as the measured 0 degree position.

From 10000 to 100000 straight tracks were used in the fit, with quite identical results. The procedure was stable and converged in 3-5 iterations.

The results are written into WireChamberPos.dat and TargetBField.dat files in the fit directory.

2.2 Fit at 5.9 degree with reactions kinematics

The varied parameters in this procedure were the rotation angle of the Fd platform and the vertex X coordinate (or, more exactly, their deviation from the starting values). The starting values of the detector positions were obtained by rotating the results of the 0 degree fit. The χ^2 was constructed of the residuals of the kinematical variables reconstructed in several identified reactions. These reactions were:

1. $pd \rightarrow pd$ elastic scattering with the fast forward scattered deuteron detected,

2. $pd \to pd$ elastic scattering with the backwad scattered deuteron, when both final state particles are detected,

3. $pd \to ppn$ charge-exchange scattering with two protons detected,

4. $pd \to {}^3He\pi^0$ with ${}^3He$ detected.

The processes $pd \to pd\pi^0$ with p and d detection suffered from an asymmetrical reconstructed missing mass distribution and was used only for monitoring. The $pd \to {}^3He\eta$ process was not used in fit due to methodical reasons, as the studied process.

The pd-backward scattering let us test the reconstructed 4-momenta conservation and the deviations of 4-momenta were used in χ^2, whereas in the other reactions the deviation of the missing mass squared was used. The fit procedure was applied to the data of supercycle 1, with all flattops being fitted at the same time.

At each iteration, the geometrical description of Fd was reinitialized and the trajectories were fitted by Runge-Kutta tracing to the new coordinates. The reconstructed kinematical values filled corresponding histograms for each process and the peaks in the histograms were fit by Gaussian with straight line background (with BackgroundFitter class by Gogi). The Gaussian mean values were used for the χ^2.

The fit was repeated with the number of events for each reaction and each flattop of 1000 an 10000, with very close results. The fit procedure does not converge but comes to iterations in the region of minimum with negligible variation of parameters. This is probably caused by numerical inaccuracies of the derivatives of χ^2 calculated by variation of parameters. Nevertheless, the values of parameters after 4-5th iteration clearly correspond to the minimum of χ^2 and the procedure can be stopped. Location of the minimum is also estimated after the first iteration under assumption of constant derivatives of the residuals. This estimation coinsides up to the 3rd significant digit with the fit result.

In the beginning and in the end of the fit procedure, as well as at each iteration, the fitted histograms stored in the ReactionFitResults.root so one can control the peak parameters determination procedure afterwards. The deviation of the fitted kinematical values are also printed in the beginning and in the end.

3 Results of the reactions fit.

For the data of the supercycle 1 of March08 beamtime were obtained the following values: the optimal X vertex coordinate should be increased by 0.2677 cm to the value -5.9873 cm, and the Fd platform rotation angle should be increased by 0.0372 degree up to 5.9378 deg. With this parameters one gets the kinematical variables reconstructed with 3 MeV accuracy. When applied to the data of supercycle 2, the fitted setup parameters produced very close accuracy of reconstructed kinematics.

One can see tables of the fit results in the appendix. The values starting with d mean deviation from the nominal value, the average missing mass values given in brackets are obtained from the M_x^2 distributions and are more correct for the cases of missing pions. The CmMom values for ${}^3He\eta$ mean the ${}^3He$ cm momentum. Some deviation of fitted mass in $dp \to dp\pi^0$ reaction comes

from asymmetry of the peak. Some small compared to the initial deviation fluctuations of fitted pion mass in $^3He\pi^0$ also a sequence some asymmetry and of a large width of π^0 mass peak. The more narrow distributions show greater agreement between different flattops. The "initial" values for the second supercycle are produced at already fitted parameters and correspond to the "final" ones of SC1. All the values are in GeV or GeV^2.

The results recalculated into chamber positions are entered into /home/wahlfach21/setup/march08_4.5MeV/handcraft_rotated_fit_reactions. Coefficients in the run directories of march08_4.5MeV are obtained with the new target position.

4 Description of software routines

4.1 Using FUMILI fit routine

The fits are done by FUMILI code included into FdModule package. The following important variables are set in the fit function:

- **npar** is the number of fitted parameters,
- **A** is the parameter array, containing initial values in the beginning and resulting values after the fit,
- **PL** is an array of suggested initial steps for parameters. If **PL**[i]=0, i-th parameter is fixed in the fit,
- **AMN** and **AMX** are arrays of minimum and maximum boundaries of parameters, correspondingly,
- **N3** is the maximum number of iterations (not including possible subiterations),
- **N1** and **N2** are the numbers of subiterations (**N1** = 2, **N2** = 2 is a standard setting),
- **eps** is the convergence parameter, reasonable values are from 0.001 to 0.1,
- **SIGMA** array contains the parameter RMS after the fit,
- **V_L** array contains the linearized lower part of the error matrix.

User has to supply an "SGZ" function address in the call to FUMILI. This function should calculate S=$\chi^2/2$, G – derivatives of $\chi^2/2$ over the parameters and Z – its second derivatives. The second derivatives are calculated in the linear approximation so that if $\chi^2 = \sum(\Delta_i^2/\sigma_i^2)$ then

$$\frac{1}{2}\frac{\partial^2\chi^2}{\partial p_\alpha \partial p_\beta} = \sum \frac{1}{\sigma_i^2}\frac{\partial \Delta_i}{\partial p_\alpha}\frac{\partial \Delta_i}{\partial p_\beta}.$$

The Z array is a linearized form of the second derivatives matrix, in the way as it is shown in the SGZ functions, and also in FdModule/src/forward/TF/ind.cc function.

4.2 0 degree fit

The fitting program is located in /home/wahlfach21/App/fits/fit0deg/lifit0deg.cc file. The main function does geometry initialization, read input events, cleans them off background, calls the fitting function "fit_DC1()" and saves the results into WireChamberPos.dat and TargetBField files in the current directory. The input events are read in GEvent format from a file produced by the 0 degree sorter (which differs only of by SetMinMomentum(-1) call to FDTracks analysis).

To calculate the derivatives, each parameter gets a variation and the residuals are estimated for each parameter value. The variation size is defined by the global constants deltaX, deltaY, deltaAlphaZ and deltaXTA, in cm and degree.

The SGZ_fit_DC1 function calls the secondary fit function fit_PC23, fitting the positions of MWPC2, MWPC3 at each iterations. This fit function and its SGZ function are constructed in a quite similar way. The SGZ function calls the fitting functions for every track, with the fit_track_to_target forming the cluster list for the track fit, and the fwd_track_fit_XTA_BF function, located in target_fit_box_field.cc file, does the actual track fit.

The CheckTrackQ function does the quality check of the tracks read from the GEvent-file.

4.3 Reaction kinematics fit

4.3.1 TTrackFit

The class managing fit of a single events is TTrackFit (TrackFit.h, TrackFit.cc). The member of the class are:

- **fParticle** is the vector of PDG descriptions of the particles in the events,
- **fP4** is the vector of the reconstructed 4-momenta with masses taken from fParticle,
- **fEvent** a pointer to GEvent object, holding information on the wire chamber hits for each track, the referred GEvent object is not owned by TTrackFit,
- **fHits** is the vector of Scluster objects, defining the complete wire chamber information for given MWPC positions, the vector is filled in TrackMomentumByCoe function but may later be also used in TrackMomentumByRK function,
- **fReaction** points to the reaction class object containing information on the missing particle in the process, magnetic field, beam momentum etc, common for all events of the reaction,
- **ReconstructEvent** is the main reconstruction function. It takes an argument **method**, which should be either TTrackFit::MRbyCoe or TTrackFit::MRbyRK. The function calls **TrackMomentumByCoe**, and, optionally, **TrackMomentumByRK**, and sets **fP4**.
- the getters **dMx2, dPx, dPy, dPz, dE** return the deviations of the missing mass squared and/or 4-momentum conservation deviation, calculated from **fP4** and the information from **fReaction**.

It is important that the size of **fParticle** must be equal to the number of tracks in **fEvent**, and they must be sorted in the same way.

4.3.2 TReactionFit

The class managing fit of a reaction data for certain conditions is TReactionFit (ReactionFit.h, ReactionFit.cc). The member of the class are:

- struct **Run_conditions_ext *fRC**, containing magnetic field value, beam inclination and momentum,
- forward momentum reconstruction coefficients **coef_fwd * fCoe**,
- initial system Lab. 4-momentum **fIS**,
- PDG information on the missing particle **fMissing**,
- PDG information on the detected particles **fParticle**,
- a bunch of histograms for deviations of missing mass and 4-momenta,
- the mean, RMS, RMS of mean and the peak integral values from that histograms,
- **fRefSigMx2** – predefined reference RMS of dMx2 distribution, used to check the peak fit quality,
- **fBg** is the background fitter object used to fit the peaks,
- vector of TTrackFit events **fEvents**.

One can notice that the **fParticle** information is repeated in TReactionFit and TTrackFit classes. The particles are sorted according to mass in TReactionFit fit, but they are sorted in the GEvent track order, individual for each event, in TTrackFit.

The not-so-nobvious member functions are:

- **SetRunConditionsCoe** reads run_conditions from the given path, beamtime and run, then reads the protons_fwd3 or protons_fwd4 coefficients file from the kinematics directory of the run,
- **AddParticle** adds a detected particle PDG description to **fParticle**.
- **AddEvent** adds an event of this reaction, sets the correct order in TTrackFit::fParticle according to the exchangeTracks argument,
- **ReconstructEvents** does reconstruction of all the events, fills the deviation histograms and fits them with the use of GBackgroundFitter **fBg**,
- **SaveHistograms** clones the histograms with an addition to the name defined by the argument and saves them to the current root directory,
- **HistoFitOK** checks the χ^2 values of the fitted histograms, checks that the peak integral is not very different from the number of entries in the histogram, and the RNS of dMx2 distribution is close enough to **fRefSigMx2**, if supplied. The function used for automatic control of the geometry fit iterations,

- **CompleteFS** tells if there is a missing particle in the process or all the ejectiles are detected.
- **FitHistogramBkg** does the gaus+background fit of one spectrum.

Important! It is assumed that the reaction events produce the highest peak in the histograms so the **fEvents** vector must not contain too much of surrounding background or events from the other processes.

4.3.3 TReactionFit offsprings

There are two classes derived from TReactionFit: THeEtaFit and TdpElasticDoubleFit. These classes contain additional informational spectra, not used in the geometry fit.

4.3.4 The fit procedure

The fit routines are located in /home/wahlfach21/App/fits/m08fit/m08fit.cc. The main function includes initialization, setting up vectors of reactions used for fit and for monitoring, reading the preselected events and call to the fit routine **fit_Fd**.

Each reaction is described by a global vector of TReactionFit objects of the size equal to number of flattops. In addition, the these reaction vector s are grouped into **forFit** vector, containing data actually used in the geometry fit, and **forMonitor** vector, containing all the data considered.

There are few important global constants in the program:

- **nFt** is the number of flattops considered, including the missing flattop 2,
- **BT** is the beamtime name to search for the setup files,
- **Runs** the run names for each flattop,
- **maxEvent** maximal number of events to be use in the fit per reaction per flattop,
- **maxHeEta** maximal number of $^3He\eta$ events to be read,
- **deltaAlpha, deltaXTA** are the variations of te rotation angle and X vertex coordinate used in the fit to estimate derivatives over these parameters, in cm and degree, correspondingly,
- **doLinear**: if set to true, the fit will stop after the first iteration and the final parameters are taken from minimization of a linear system under assumption of constant derivatives of the residuals over the parameters.

The **Read** functions for each process fill the corresponding reaction vectors, sorting the particle information according to the track order in GE vents. These functions also save the events selected into new files which can be used later for faster reading. There are few constants used in these functions for event selection. These constants are defined prior to the fit with the Alric.cc and Selie.C programs from the App/sorter/March08 directory.

The main fitting function is **fit_Fd**, and the SGZ function is naturally, **SGZ_fit_Fd**. The one unusual constant in the latter is **ConstDeriv** which

defines wheather the derivatives should be calculated on each iteration or the fit is done in assumption of the constant derivatives of the residuals (but not of χ^2), and the derivatives are defined only once in the latter case. This is not equivalent to setting **doLinear** to true since the χ^2 estimation is done in the usual way on each iteration, only the derivatives get fixed. The fit results are practically independent on this choice. The minimum position is estimated in linear approximation after the first iteration and printed, but not applied unless **doLinear** is set to true.

5 FdModule sorter options and analyzes

The most important sorter options of FdModule :

- **FdSetupDir** shows location of the "setup" tree,
- **FdBeamTime** gives the beamtime directory name in the "setup" tree,
- **FdRun** gives the main run directory where the geometry description, efficiency map, calibration files are to be found,
- **NumberOfFlattops** if equal to 1, the next option is ignored
- **FdFlattopNRun**, where N=1-8 gives the run directory from which the run_conditions file and coefficients for momentum reconstruction for N-th flattop are to be read,
- **FdAlgorithmType**, if equal 2, the combinatorial track search using all chambers will be used, if equal to 1, then the two MWPCs will be used in a simple search with fixed base planes. The latter option is used e.g., for drift chamber calibration.
- **FDsingleTrackMomentum**: valid values are rk and coe, this is the choice of momentum reconstruction method for the single-track-in-Fd events,
- **FDdoubleTrackMomentum**: same for double-track-in-Fd events
- **FdCoeType**: valid values 3 or 4. Tells that MR coefficients of 3rd or 4th power to be used.
- **OptFlattop**: bit mask of flattops (i.e., Ft1=1, Ft2=2, Ft3=4 etc) to be analyzed, -1 means all flattops.
- **OptTracks**: tells how may tracks should be in the events saved into GEvent file: 1, 2, 3 (1 or 2), 0 (write also events without tracks).
- **WriteClusterList**: valid values are always, never, otherwise anything (default). Tells when to save the wire cluster information in GEvent file, the latter choice means saving clusters for 2-track events only.
- **FDGeomType** defines the source of geometry information, values can be setup_geometry (for old data) of handcraft (default),
- **FdRunTF2PC** (default 1), **FdGetEffMode** (default "use") are obsolete,

- **FDEffDir** (default "sp") tells where to search for the efficiency maps. If the path is relative, then it starts from the run directory of the "setup" tree.

The analises of FdModule :

- **EventFillInit** must go first. Clears gGEvent, checks flattop bit mask, set the time, trigger, flattop information in gGEvent,
- **FDTracks** main analisys analisys. Does the track search and momentum reconstruction. Fills track and wire cluster information in gGEvent. Possible option is NoCTrack to skip filling the CTrack interface data.
- **EventWrite** saves gGEvent tree to file gROFile, if the latter is open. Can be skipped if one does not want to write the GEvent output file.
- optional **WriteRawHod** add raw Fd hodoscope information to gGEvent,
- optional **CalibHodAnalysis** add calibrated Fd hodoscope information to gGEvent,
- optional **PDTracks** does a rudimentary Pd analisys. If option "SwOnly" given, just adds the raw side wall2 counters information to gGEvent,
- **IntCalibDC** calibrates the drift chamber by integration method. Result is saved into IntDCCalib.root file in the current directory and to be copied into run or beamtime directory of the "setup" tree. Should be run with **FdAlgorithmType**=1,
- **FdChamberEff** calculates Fd chamber efficiencies and saves the maps into **FDEffDir**, which must exist before the sorter run.

A Results of reactions kinematics fit

```
---------------   SuperCycle 1 results ----------------------------------------------------
Initial

He3pi0_Ft0: dMx2= 0.0100 +-  0.0002, dMx= 0.0327 +-  0.0006, Mx= 0.1676 ( 0.1681), RMS= 0.0506
He3pi0_Ft2: dMx2= 0.0096 +-  0.0002, dMx= 0.0328 +-  0.0006, Mx= 0.1678 ( 0.1667), RMS= 0.0500
He3pi0_Ft3: dMx2= 0.0093 +-  0.0002, dMx= 0.0306 +-  0.0005, Mx= 0.1656 ( 0.1658), RMS= 0.0512
He3pi0_Ft4: dMx2= 0.0093 +-  0.0002, dMx= 0.0305 +-  0.0005, Mx= 0.1654 ( 0.1658), RMS= 0.0520
He3pi0_Ft5: dMx2= 0.0091 +-  0.0002, dMx= 0.0304 +-  0.0006, Mx= 0.1654 ( 0.1654), RMS= 0.0521
He3pi0_Ft6: dMx2= 0.0090 +-  0.0002, dMx= 0.0301 +-  0.0006, Mx= 0.1651 ( 0.1650), RMS= 0.0525
He3pi0_Ft7: dMx2= 0.0087 +-  0.0002, dMx= 0.0301 +-  0.0006, Mx= 0.1651 ( 0.1640), RMS= 0.0524
dpElDouble_Ft0: dPx= 0.0074, dPy= 0.0007,  dPz=-0.0145, dE=-0.0132: Mx(d)= 0.9372, RMS= 0.0123: Mx(p)= 1.8846, RMS= 0.0101
dpElDouble_Ft2: dPx= 0.0074, dPy= 0.0007,  dPz=-0.0137, dE=-0.0132: Mx(d)= 0.9378, RMS= 0.0120: Mx(p)= 1.8847, RMS= 0.0100
dpElDouble_Ft3: dPx= 0.0073, dPy= 0.0007,  dPz=-0.0130, dE=-0.0126: Mx(d)= 0.9381, RMS= 0.0119: Mx(p)= 1.8845, RMS= 0.0100
dpElDouble_Ft4: dPx= 0.0068, dPy= 0.0006,  dPz=-0.0126, dE=-0.0117: Mx(d)= 0.9387, RMS= 0.0118: Mx(p)= 1.8840, RMS= 0.0098
dpElDouble_Ft5: dPx= 0.0070, dPy= 0.0007,  dPz=-0.0128, dE=-0.0125: Mx(d)= 0.9394, RMS= 0.0119: Mx(p)= 1.8844, RMS= 0.0106
dpElDouble_Ft6: dPx= 0.0069, dPy= 0.0008,  dPz=-0.0134, dE=-0.0124: Mx(d)= 0.9389, RMS= 0.0116: Mx(p)= 1.8842, RMS= 0.0107
dpElDouble_Ft7: dPx= 0.0065, dPy= 0.0007,  dPz=-0.0115, dE=-0.0111: Mx(d)= 0.9389, RMS= 0.0115: Mx(p)= 1.8835, RMS= 0.0114
dpElFastD_Ft0: dMx2= 0.0448 +-  0.0005, dMx= 0.0234 +-  0.0003, Mx= 0.9617 ( 0.9618), RMS= 0.0237
dpElFastD_Ft2: dMx2= 0.0446 +-  0.0005, dMx= 0.0233 +-  0.0003, Mx= 0.9616 ( 0.9618), RMS= 0.0236
dpElFastD_Ft3: dMx2= 0.0449 +-  0.0005, dMx= 0.0235 +-  0.0003, Mx= 0.9618 ( 0.9619), RMS= 0.0236
dpElFastD_Ft4: dMx2= 0.0442 +-  0.0005, dMx= 0.0231 +-  0.0003, Mx= 0.9614 ( 0.9615), RMS= 0.0237
dpElFastD_Ft5: dMx2= 0.0452 +-  0.0005, dMx= 0.0236 +-  0.0003, Mx= 0.9619 ( 0.9621), RMS= 0.0239
dpElFastD_Ft6: dMx2= 0.0442 +-  0.0005, dMx= 0.0231 +-  0.0003, Mx= 0.9614 ( 0.9615), RMS= 0.0242
dpElFastD_Ft7: dMx2= 0.0443 +-  0.0005, dMx= 0.0230 +-  0.0003, Mx= 0.9613 ( 0.9616), RMS= 0.0249
ppn_Ft0: dMx2= 0.0185 +-  0.0003, dMx= 0.0098 +-  0.0002, Mx= 0.9494 ( 0.9494), RMS= 0.0127
ppn_Ft2: dMx2= 0.0173 +-  0.0003, dMx= 0.0091 +-  0.0002, Mx= 0.9487 ( 0.9488), RMS= 0.0125
ppn_Ft3: dMx2= 0.0161 +-  0.0003, dMx= 0.0085 +-  0.0002, Mx= 0.9481 ( 0.9481), RMS= 0.0123
ppn_Ft4: dMx2= 0.0166 +-  0.0003, dMx= 0.0087 +-  0.0002, Mx= 0.9483 ( 0.9483), RMS= 0.0124
ppn_Ft5: dMx2= 0.0161 +-  0.0003, dMx= 0.0085 +-  0.0002, Mx= 0.9481 ( 0.9481), RMS= 0.0123
ppn_Ft6: dMx2= 0.0152 +-  0.0003, dMx= 0.0081 +-  0.0002, Mx= 0.9476 ( 0.9476), RMS= 0.0128
ppn_Ft7: dMx2= 0.0147 +-  0.0003, dMx= 0.0078 +-  0.0002, Mx= 0.9474 ( 0.9474), RMS= 0.0129
He3eta_Ft0: Mx=-11.9750 ( 0.5206), RMS= 0.0006: CmMom= 0.1477, RMS= 0.0497
He3eta_Ft2: Mx= 0.5478 ( 0.5478), RMS= 0.0005: CmMom= 0.0332, RMS= 0.0068
He3eta_Ft3: Mx= 0.5478 ( 0.5478), RMS= 0.0006: CmMom= 0.0390, RMS= 0.0071
He3eta_Ft4: Mx= 0.5478 ( 0.5478), RMS= 0.0008: CmMom= 0.0491, RMS= 0.0074
He3eta_Ft5: Mx= 0.5478 ( 0.5478), RMS= 0.0010: CmMom= 0.0616, RMS= 0.0075
He3eta_Ft6: Mx= 0.5479 ( 0.5478), RMS= 0.0013: CmMom= 0.0765, RMS= 0.0077
He3eta_Ft7: Mx= 0.5478 ( 0.5478), RMS= 0.0014: CmMom= 0.0892, RMS= 0.0075
dppi0_Ft0: dMx2= 0.0067 +-  0.0001, dMx= 0.0199 +-  0.0003, Mx= 0.1549 ( 0.1578), RMS= 0.0330
dppi0_Ft2: dMx2= 0.0065 +-  0.0002, dMx= 0.0198 +-  0.0005, Mx= 0.1548 ( 0.1571), RMS= 0.0318
dppi0_Ft3: dMx2= 0.0070 +-  0.0002, dMx= 0.0222 +-  0.0005, Mx= 0.1572 ( 0.1589), RMS= 0.0319
dppi0_Ft4: dMx2= 0.0069 +-  0.0002, dMx= 0.0217 +-  0.0005, Mx= 0.1567 ( 0.1584), RMS= 0.0320
dppi0_Ft5: dMx2= 0.0055 +-  0.0002, dMx= 0.0218 +-  0.0005, Mx= 0.1568 ( 0.1539), RMS= 0.0318
dppi0_Ft6: dMx2= 0.0072 +-  0.0002, dMx= 0.0220 +-  0.0005, Mx= 0.1569 ( 0.1594), RMS= 0.0320
dppi0_Ft7: dMx2= 0.0057 +-  0.0002, dMx= 0.0234 +-  0.0005, Mx= 0.1584 ( 0.1546), RMS= 0.0317
It start 0 A=0 2.13254e-317
0 central
0 par 0
0 par 1
Linear : 1 A=0.0372242 0.271686
It1 end 0 A=0.000000 0.000000  S=54281.169723, G=1754226.000105 -631722.644890
-----------------------------------------------
```

```
It1 end 18 A=0.037089 0.267653  S=1205.121942, G=-2404.770483 861.233369
-----------------------------------------------
End A 0.037089 0.267653 0.000002 0.000005 0.000014 0.001319 0.003729 Converged: No
Final
He3pi0_Ft0: dMx2=-0.0005 +-  0.0002, dMx= 0.0112 +-  0.0006, Mx= 0.1462 ( 0.1330), RMS= 0.0531
He3pi0_Ft2: dMx2=-0.0004 +-  0.0002, dMx= 0.0101 +-  0.0006, Mx= 0.1451 ( 0.1335), RMS= 0.0535
He3pi0_Ft3: dMx2=-0.0014 +-  0.0002, dMx= 0.0086 +-  0.0006, Mx= 0.1436 ( 0.1295), RMS= 0.0539
He3pi0_Ft4: dMx2=-0.0016 +-  0.0002, dMx= 0.0094 +-  0.0006, Mx= 0.1444 ( 0.1289), RMS= 0.0544
He3pi0_Ft5: dMx2=-0.0017 +-  0.0002, dMx= 0.0087 +-  0.0006, Mx= 0.1437 ( 0.1286), RMS= 0.0548
He3pi0_Ft6: dMx2=-0.0015 +-  0.0002, dMx= 0.0087 +-  0.0006, Mx= 0.1437 ( 0.1292), RMS= 0.0549
He3pi0_Ft7: dMx2=-0.0017 +-  0.0003, dMx= 0.0089 +-  0.0007, Mx= 0.1439 ( 0.1284), RMS= 0.0544
dpElDouble_Ft0: dPx= 0.0002, dPy= 0.0007,  dPz=-0.0001, dE=-0.0004: Mx(d)= 0.9402, RMS= 0.0123: Mx(p)= 1.8760, RMS= 0.0104
dpElDouble_Ft2: dPx= 0.0002, dPy= 0.0007,  dPz= 0.0009, dE=-0.0002: Mx(d)= 0.9408, RMS= 0.0121: Mx(p)= 1.8760, RMS= 0.0098
dpElDouble_Ft3: dPx= 0.0001, dPy= 0.0007,  dPz= 0.0016, dE= 0.0005: Mx(d)= 0.9411, RMS= 0.0118: Mx(p)= 1.8758, RMS= 0.0102
dpElDouble_Ft4: dPx=-0.0004, dPy= 0.0006,  dPz= 0.0023, dE= 0.0013: Mx(d)= 0.9417, RMS= 0.0117: Mx(p)= 1.8753, RMS= 0.0101
dpElDouble_Ft5: dPx=-0.0003, dPy= 0.0006,  dPz= 0.0019, dE= 0.0007: Mx(d)= 0.9423, RMS= 0.0118: Mx(p)= 1.8757, RMS= 0.0108
dpElDouble_Ft6: dPx=-0.0004, dPy= 0.0008,  dPz= 0.0014, dE= 0.0007: Mx(d)= 0.9418, RMS= 0.0116: Mx(p)= 1.8755, RMS= 0.0109
dpElDouble_Ft7: dPx=-0.0008, dPy= 0.0007,  dPz= 0.0032, dE= 0.0020: Mx(d)= 0.9420, RMS= 0.0116: Mx(p)= 1.8748, RMS= 0.0115
dpElFastD_Ft0: dMx2= 0.0062 +-  0.0005, dMx= 0.0032 +-  0.0003, Mx= 0.9415 ( 0.9416), RMS= 0.0248
dpElFastD_Ft2: dMx2= 0.0057 +-  0.0005, dMx= 0.0028 +-  0.0003, Mx= 0.9411 ( 0.9413), RMS= 0.0248
dpElFastD_Ft3: dMx2= 0.0060 +-  0.0005, dMx= 0.0030 +-  0.0003, Mx= 0.9413 ( 0.9414), RMS= 0.0247
dpElFastD_Ft4: dMx2= 0.0051 +-  0.0005, dMx= 0.0025 +-  0.0003, Mx= 0.9408 ( 0.9410), RMS= 0.0249
dpElFastD_Ft5: dMx2= 0.0061 +-  0.0005, dMx= 0.0031 +-  0.0003, Mx= 0.9413 ( 0.9415), RMS= 0.0251
dpElFastD_Ft6: dMx2= 0.0048 +-  0.0005, dMx= 0.0024 +-  0.0003, Mx= 0.9406 ( 0.9408), RMS= 0.0254
dpElFastD_Ft7: dMx2= 0.0048 +-  0.0005, dMx= 0.0024 +-  0.0003, Mx= 0.9407 ( 0.9408), RMS= 0.0262
ppn_Ft0: dMx2=-0.0001 +-  0.0003, dMx= 0.0000 +-  0.0002, Mx= 0.9396 ( 0.9395), RMS= 0.0130
ppn_Ft2: dMx2=-0.0016 +-  0.0003, dMx=-0.0009 +-  0.0002, Mx= 0.9387 ( 0.9387), RMS= 0.0128
ppn_Ft3: dMx2=-0.0028 +-  0.0003, dMx=-0.0015 +-  0.0002, Mx= 0.9381 ( 0.9381), RMS= 0.0126
ppn_Ft4: dMx2=-0.0024 +-  0.0003, dMx=-0.0013 +-  0.0002, Mx= 0.9383 ( 0.9383), RMS= 0.0128
ppn_Ft5: dMx2=-0.0030 +-  0.0003, dMx=-0.0016 +-  0.0002, Mx= 0.9380 ( 0.9380), RMS= 0.0127
ppn_Ft6: dMx2=-0.0038 +-  0.0003, dMx=-0.0020 +-  0.0002, Mx= 0.9375 ( 0.9376), RMS= 0.0131
ppn_Ft7: dMx2=-0.0044 +-  0.0003, dMx=-0.0024 +-  0.0002, Mx= 0.9372 ( 0.9372), RMS= 0.0133
He3eta_Ft0: Mx= 0.5224 ( 0.5204), RMS= 0.0106: CmMom= 0.1481, RMS= 0.0500
He3eta_Ft2: Mx= 0.5477 ( 0.5478), RMS= 0.0124: CmMom= 0.0331, RMS= 0.0062
He3eta_Ft3: Mx= 0.5477 ( 0.5478), RMS= 0.0124: CmMom= 0.0391, RMS= 0.0061
He3eta_Ft4: Mx= 0.5478 ( 0.5478), RMS= 0.0007: CmMom= 0.0492, RMS= 0.0062
He3eta_Ft5: Mx= 0.5478 ( 0.5478), RMS= 0.0008: CmMom= 0.0616, RMS= 0.0060
He3eta_Ft6: Mx= 0.5478 ( 0.5478), RMS= 0.0010: CmMom= 0.0766, RMS= 0.0061
He3eta_Ft7: Mx= 0.5478 ( 0.5478), RMS= 0.0011: CmMom= 0.0897, RMS= 0.0058
dppi0_Ft0: dMx2= 0.0027 +-  0.0001, dMx= 0.0084 +-  0.0003, Mx= 0.1433 ( 0.1448), RMS= 0.0275
dppi0_Ft2: dMx2= 0.0023 +-  0.0001, dMx= 0.0058 +-  0.0004, Mx= 0.1408 ( 0.1432), RMS= 0.0291
dppi0_Ft3: dMx2= 0.0025 +-  0.0001, dMx= 0.0093 +-  0.0004, Mx= 0.1442 ( 0.1440), RMS= 0.0279
dppi0_Ft4: dMx2= 0.0026 +-  0.0001, dMx= 0.0086 +-  0.0004, Mx= 0.1436 ( 0.1441), RMS= 0.0280
dppi0_Ft5: dMx2= 0.0023 +-  0.0001, dMx= 0.0089 +-  0.0004, Mx= 0.1439 ( 0.1433), RMS= 0.0277
dppi0_Ft6: dMx2= 0.0028 +-  0.0002, dMx= 0.0088 +-  0.0004, Mx= 0.1438 ( 0.1449), RMS= 0.0276
dppi0_Ft7: dMx2= 0.0031 +-  0.0002, dMx= 0.0095 +-  0.0005, Mx= 0.1445 ( 0.1460), RMS= 0.0284
```

```
------------------------- Supercycle 2 results ---------------------------------------
Initial

He3pi0_Ft0: dMx2=-0.0011 +-  0.0003, dMx= 0.0075 +-  0.0008, Mx= 0.1425 ( 0.1310), RMS= 0.0503
He3pi0_Ft2: dMx2=-0.0020 +-  0.0003, dMx= 0.0067 +-  0.0008, Mx= 0.1417 ( 0.1275), RMS= 0.0519
He3pi0_Ft3: dMx2=-0.0021 +-  0.0003, dMx= 0.0059 +-  0.0008, Mx= 0.1409 ( 0.1270), RMS= 0.0509
He3pi0_Ft4: dMx2=-0.0016 +-  0.0003, dMx= 0.0072 +-  0.0008, Mx= 0.1422 ( 0.1291), RMS= 0.0521
He3pi0_Ft5: dMx2=-0.0020 +-  0.0003, dMx= 0.0074 +-  0.0008, Mx= 0.1424 ( 0.1273), RMS= 0.0527
He3pi0_Ft6: dMx2=-0.0025 +-  0.0003, dMx= 0.0051 +-  0.0009, Mx= 0.1401 ( 0.1252), RMS= 0.0534
He3pi0_Ft7: dMx2=-0.0027 +-  0.0003, dMx= 0.0058 +-  0.0009, Mx= 0.1408 ( 0.1245), RMS= 0.0529
dpElDouble_Ft0: dPx= 0.0006, dPy= 0.0008,  dPz=-0.0001, dE=-0.0007: Mx(d)= 0.9402, RMS= 0.0117: Mx(p)= 1.8763, RMS= 0.0107
dpElDouble_Ft2: dPx=-0.0001, dPy= 0.0008,  dPz= 0.0009, dE= 0.0002: Mx(d)= 0.9410, RMS= 0.0116: Mx(p)= 1.8760, RMS= 0.0104
dpElDouble_Ft3: dPx=-0.0004, dPy= 0.0008,  dPz= 0.0022, dE= 0.0012: Mx(d)= 0.9410, RMS= 0.0124: Mx(p)= 1.8752, RMS= 0.0106
dpElDouble_Ft4: dPx=-0.0003, dPy= 0.0006,  dPz= 0.0022, dE= 0.0011: Mx(d)= 0.9413, RMS= 0.0123: Mx(p)= 1.8755, RMS= 0.0099
dpElDouble_Ft5: dPx=-0.0002, dPy= 0.0008,  dPz= 0.0007, dE=-0.0005: Mx(d)= 0.9417, RMS= 0.0122: Mx(p)= 1.8760, RMS= 0.0105
dpElDouble_Ft6: dPx=-0.0012, dPy= 0.0007,  dPz= 0.0025, dE= 0.0014: Mx(d)= 0.9415, RMS= 0.0128: Mx(p)= 1.8752, RMS= 0.0105
dpElDouble_Ft7: dPx=-0.0022, dPy= 0.0008,  dPz= 0.0047, dE= 0.0033: Mx(d)= 0.9427, RMS= 0.0116: Mx(p)= 1.8738, RMS= 0.0118
dpElFastD_Ft0: dMx2= 0.0036 +-  0.0017, dMx= 0.0021 +-  0.0009, Mx= 0.9404 ( 0.9402), RMS= 0.0226
dpElFastD_Ft2: dMx2= 0.0035 +-  0.0017, dMx= 0.0019 +-  0.0009, Mx= 0.9402 ( 0.9401), RMS= 0.0234
dpElFastD_Ft3: dMx2= 0.0071 +-  0.0016, dMx= 0.0036 +-  0.0009, Mx= 0.9419 ( 0.9421), RMS= 0.0246
dpElFastD_Ft4: dMx2= 0.0034 +-  0.0016, dMx= 0.0018 +-  0.0009, Mx= 0.9401 ( 0.9401), RMS= 0.0240
dpElFastD_Ft5: dMx2= 0.0059 +-  0.0017, dMx= 0.0030 +-  0.0009, Mx= 0.9413 ( 0.9414), RMS= 0.0254
dpElFastD_Ft6: dMx2= 0.0031 +-  0.0017, dMx= 0.0014 +-  0.0009, Mx= 0.9397 ( 0.9399), RMS= 0.0267
dpElFastD_Ft7: dMx2= 0.0022 +-  0.0018, dMx= 0.0008 +-  0.0009, Mx= 0.9391 ( 0.9395), RMS= 0.0275
ppn_Ft0: dMx2=-0.0027 +-  0.0011, dMx=-0.0014 +-  0.0006, Mx= 0.9382 ( 0.9382), RMS= 0.0125
ppn_Ft2: dMx2=-0.0008 +-  0.0011, dMx=-0.0003 +-  0.0006, Mx= 0.9393 ( 0.9392), RMS= 0.0114
ppn_Ft3: dMx2=-0.0051 +-  0.0011, dMx=-0.0028 +-  0.0006, Mx= 0.9368 ( 0.9368), RMS= 0.0123
ppn_Ft4: dMx2=-0.0025 +-  0.0011, dMx=-0.0013 +-  0.0006, Mx= 0.9383 ( 0.9383), RMS= 0.0120
ppn_Ft5: dMx2=-0.0042 +-  0.0012, dMx=-0.0022 +-  0.0006, Mx= 0.9373 ( 0.9373), RMS= 0.0118
ppn_Ft6: dMx2=-0.0060 +-  0.0012, dMx=-0.0032 +-  0.0006, Mx= 0.9363 ( 0.9363), RMS= 0.0126
ppn_Ft7: dMx2=-0.0069 +-  0.0011, dMx=-0.0037 +-  0.0006, Mx= 0.9359 ( 0.9359), RMS= 0.0142
He3eta_Ft0: Mx= 0.5218 ( 0.5197), RMS= 0.0106: CmMom= 0.1495, RMS= 0.0493
He3eta_Ft2: Mx= 0.5477 ( 0.5478), RMS= 0.0127: CmMom= 0.0365, RMS= 0.0058
He3eta_Ft3: Mx= 0.5478 ( 0.5478), RMS= 0.0006: CmMom= 0.0447, RMS= 0.0067
He3eta_Ft4: Mx= 0.5478 ( 0.5478), RMS= 0.0006: CmMom= 0.0538, RMS= 0.0060
He3eta_Ft5: Mx= 0.5478 ( 0.5478), RMS= 0.0009: CmMom= 0.0685, RMS= 0.0054
He3eta_Ft6: Mx= 0.5478 ( 0.5478), RMS= 0.0010: CmMom= 0.0824, RMS= 0.0055
He3eta_Ft7: Mx= 0.5477 ( 0.5477), RMS= 0.0014: CmMom= 0.0987, RMS= 0.0064
dppi0_Ft0: dMx2=-0.0011 +-  0.0003, dMx= 0.0004 +-  0.0012, Mx= 0.1353 ( 0.1310), RMS= 0.0237
dppi0_Ft2: dMx2= 0.0008 +-  0.0004, dMx= 0.0077 +-  0.0011, Mx= 0.1427 ( 0.1379), RMS= 0.0192
dppi0_Ft3: dMx2=-0.0013 +-  0.0003, dMx= 0.0013 +-  0.0011, Mx= 0.1363 ( 0.1299), RMS= 0.0244
dppi0_Ft4: dMx2=-0.0020 +-  0.0003, dMx=-0.0008 +-  0.0011, Mx= 0.1342 ( 0.1274), RMS= 0.0243
dppi0_Ft5: dMx2=-0.0011 +-  0.0004, dMx= 0.0028 +-  0.0011, Mx= 0.1377 ( 0.1310), RMS= 0.0244
dppi0_Ft6: dMx2=-0.0004 +-  0.0004, dMx= 0.0024 +-  0.0012, Mx= 0.1374 ( 0.1335), RMS= 0.0239
dppi0_Ft7: dMx2=-0.0002 +-  0.0004, dMx= 0.0039 +-  0.0014, Mx= 0.1389 ( 0.1343), RMS= 0.0227
```