Tutorial for CLAS12 Central Neutron Detector Energy and Timing Calibration

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Abstract: This document describes all the calibration steps of the CLAS12 Central Neutron Detector (CND). All the steps are fully explained, and typical results are shown in order to judge the quality of the results.

Contents

Part I
Introduction

The Central Neutron Detector (CND) is a scintillator barrel detector located in the CLAS12 Central Detector. It is used to detect neutron at backwards angles ($40° < \theta < 120°$). The CND consists of 3 radial layers of 48 plastic scintillator paddles of trapezoidal shape. Adjacent paddles are coupled two-by-two at their downstream end with a "uturn" lightguide. Three pairs of coupled paddles are stacked up, one over the other, forming a sector. Overall there are 24 sectors of 6 paddles, for a total of 144 scintillators. The paddles are numbered by their sector/layer/component (S/L/C). There are 24 sectors, 3 layers and 2 components (Left or 1 and Right or 2). The scintillation light is guided from the upstream ends of the scintillators to the PMT through 1.5m-long lightguides. The readout is done by PMTs located at the end of the lightguides.

The calibration of the CND is done in two steps. The first step is the time-based calibration which allows to extract effective velocities and time offsets. This calibration is necessary to obtain timing and position information of CND hits. The second step is the energy calibration, in which attenuation lengths and energy conversion factors are extracted. There are 6 calibration step and 8 sets of calibration constants (see Table 1). All of them but LR_{off} have to be uploaded to the CLAS12 Database.

Step	Calibration step	Output	Number of constants
1	LR (Left-Right) time offset	LR_{off}	72
2	Effective velocity	v_{eff}	144
3	U-turn time loss & LR time offset ad.	u_{tloss}, LR_{offad}	72 each
4	Global time offset	t_{off}	72
5	Attenuation length	Att_L	144
6	Energy constants	MIP_D, MIP_I	144 each

Table 1: The steps of the CND calibration.

In this document, every steps of the calibration is presented with respect to its implementation in the calibration suite. The completed presentation of the formulas used by the algorithms is done in [1].

Part II
CND Calibration Startup

1 Getting the code

The CND calibration suite is a Java code deployed as a *.jar* file. It can be executed on any machine that runs Java 1.8 or later. The compiled code can be found at the following address:

`https://ipnshare.in2p3.fr/owncloud/index.php/s/QSjoSCUnVA8GSLK`

The source code can be requested on demand at *chatagnon@ipno.in2p3.fr* or downloawded at the following address:

`https://github.com/PChatagnon/CND_Calibration_Suite`

2 Running the code

There are two main options to run the CND calibration suite :

- In Unix systems one can run the code from the command line as: *java -jar CalibrationCND.jar*
- In any other systems one can run the code by right clicking the .jar file and choose *Run with Java* or similar

3 Calibration Suite GUI Layout

The GUI interface of the CNDcalibration suite is composed of two main windows. The first window is the Configuration window. It is opened when the code is launched. The configuration window is illustrated in Figure 2. The second window is the Calibration window. It opens when the configuration has been completed and the configuration window closed. It is shown in Figure 1.

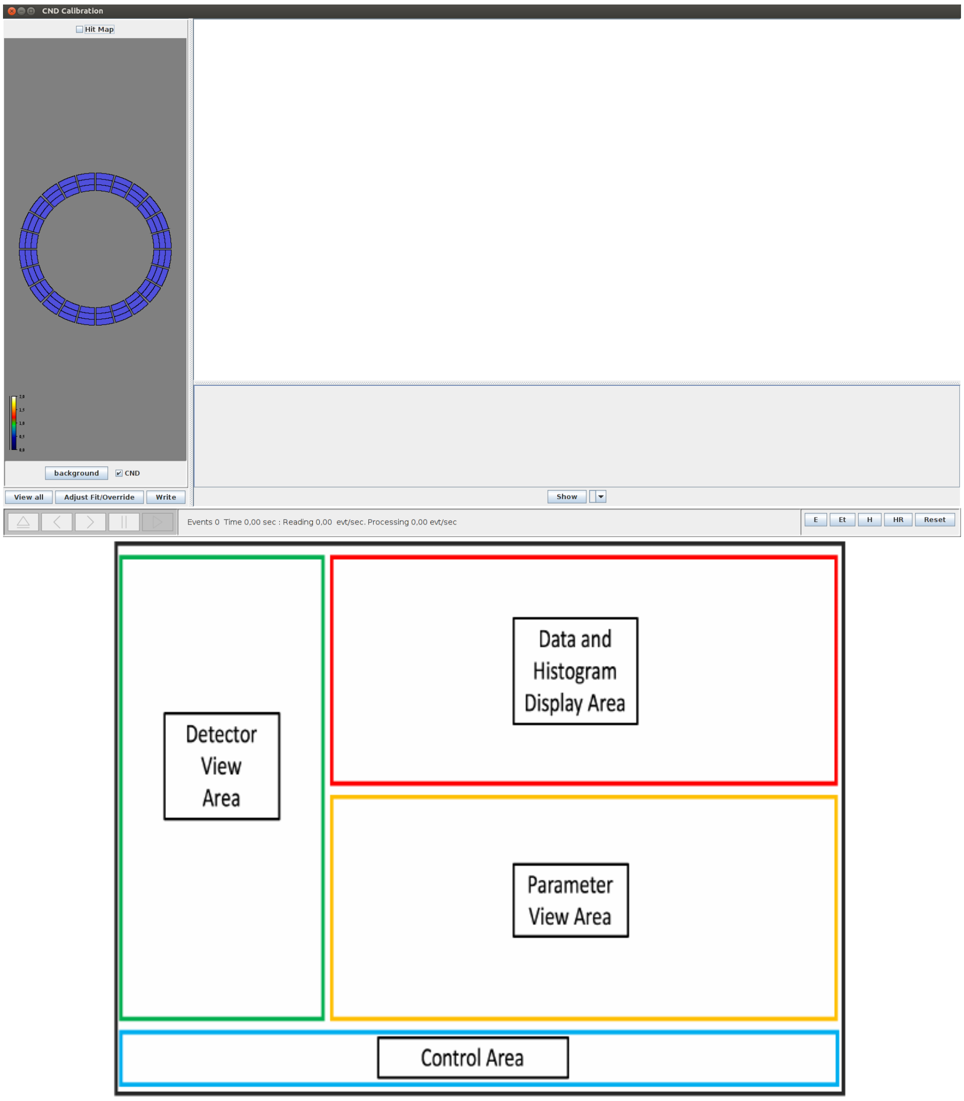

Figure 1: Top: the CND suite calibration window. Bottom: the different areas of the calibration window.

The Calibration window is composed of 4 main areas. The Detector View Area (in Green) is used to access summary plots. The Data Display Area (in Red) shows the current calibration histograms. The Parameter Area (in Gold) shows the currently extracted calibration values. The Control Area (in Blue) is used to import input files and process them. The complete function of each area is explained in details in this document.

4 Configuration of the calibration

Once the calibration suite is running and the configuration window is displayed, it is possible to configure the suite. The Configuration window is composed of 11 tabs that allow the users to modify most calibration histograms parameters and apply some cuts on the input data. To access the tabs, click on the tabs at the top of the window or click *Next* on the bottom right corner of the window. To Exit the calibration suite, click *Cancel*. To go to the Calibration window, click *Finish* in the *Energy* tab. In the following sections each tab of the Configuration window is presented.

4.1 *CND Calibration Suite* tab

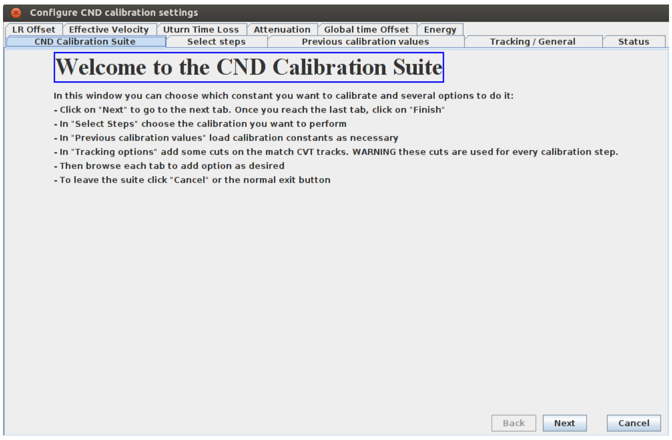

Figure 2: In the first tab of the configuration window, the CND calibration procedure is summarized. Users should read it once before using the calibration suite.

In this tab, the configuration procedure is presented and explained. Click *Next* to go to the next tab.

4.2 *Select steps* tab

In this tab, one can choose which step will be performed by the calibration suite. Tick the desired boxes and click *Next* to go to the next tab. The calibration steps have to be performed one at the time and in the specific order described in Section *Calibration constants and General Calibration Strategy*. That is to say, user should click only one box in this tab. In addition, users can click the Status tab to access raw data summary plots for CND. This step is not required to perform the calibration of the CND. It should be used only for debugging purposes.

4.3 *Previous calibration values* tab

In this tab users can upload the calibration values of LR_{off}, v_{eff} and u_{tloss}/LR_{offad} needed to complete all steps of calibration.

There are three possible ways to provide calibration constants to the calibration suite. The *Default* option will provide the expected value of the given constant. This

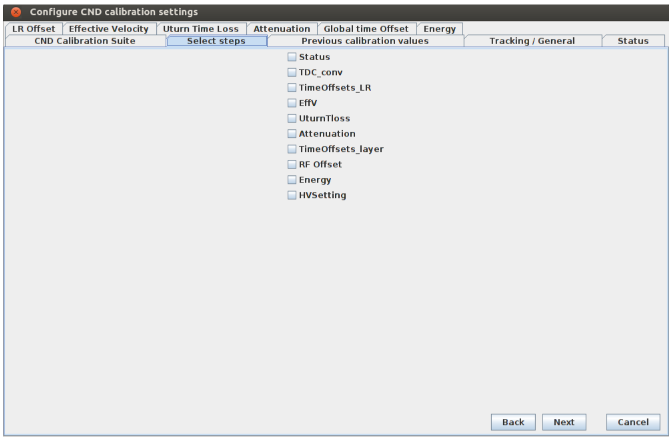

Figure 3: In the *Select steps* tab, users can tick the boxes corresponding to the calibration step they want to perform.

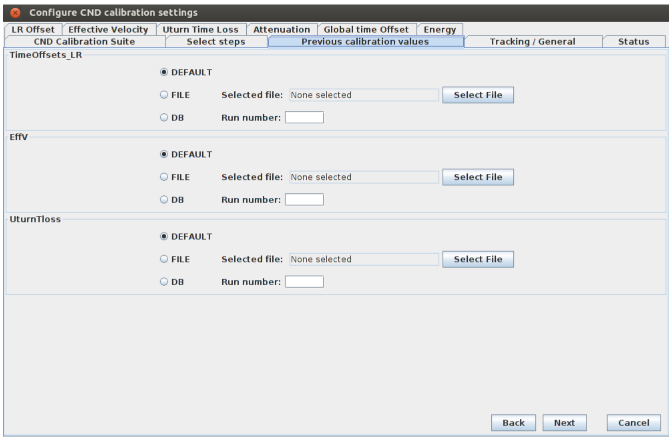

Figure 4: The *Previous calibration values* tab allows the users to upload the required calibration constants for a given step.

Constants	Output Files Prefix to upload	Upload section
LR_{off}	CND_CALIB_TIMEOFFSETS_LR	LR offset
v_{eff}	CND_CALIB_EFFV	Eff v
u_{tloss}, LR_{offad}	uturn_LRad_CND_CALIB_UTURNTLOSS	uturn and LRoffad

Table 2: Output files prefix for each calibration step.

option shouldn't be used but for testing purposes. The *File* option allows the user to download a text file containing the calibration constants. The text file containing the constants has to have the same format as the output format of the suite. Click *Select File* and choose the appropriate file to upload. The *DB* option allows the user to upload directly the calibration constant from the calibration database. Provide a run number and click *Next*. The suite will connect to the database and download the constants associated to the given run number.

LR_{off} constants has to be uploaded in the LR offset section; v_{eff} in the Eff_v section. u_{tloss} / LR_{offad} are uploaded at the same time in the u-turn and LRoffad section. The prefix of the file to upload in each section and the associated calibration constants are summarized in Table 2.

4.4 *Tracking/General* tab

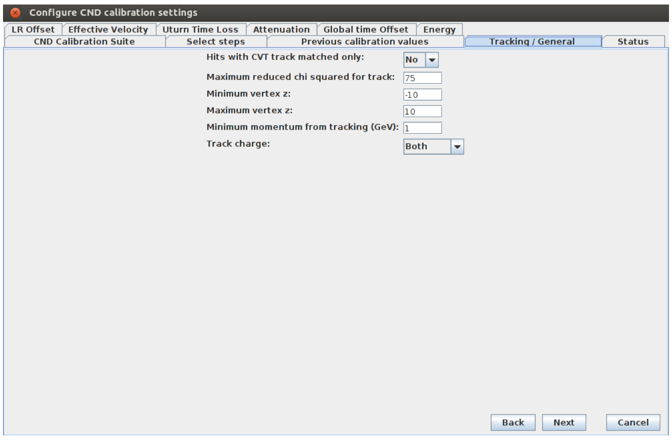

Figure 5: In the *Tracking/General* tab, users can add their own values to the cut applied to the calibrated data.

In this tab one can provide kinematic cuts on the data used in the suite. It is possible to:

1. use every CND hit or only the ones associated to a CVT track
2. require a cut on the chi square of the associated CVT tracks
3. cut on the position of the vertex (extracted from the DOCA of the track)
4. cut on the minimum momentum of the track
5. ask for positive or negative tracks

4.5 Calibration tabs

The other 7 tabs are associated to one of the calibration steps. In each of these tabs one can define the range and the binning of the associated plots.

5 Importing and reading input files

5.1 Filtering the file to calibrate

The calibration suite is able to read hipo files. However such files can become very heavy if they record many banks per event. Besides, the CND calibration only requires a small amount of banks to run. It is thus convenient to filter the input file before using it in the calibration suite. The CND calibration only uses the following banks:

- CND::Hits (ID 20321)

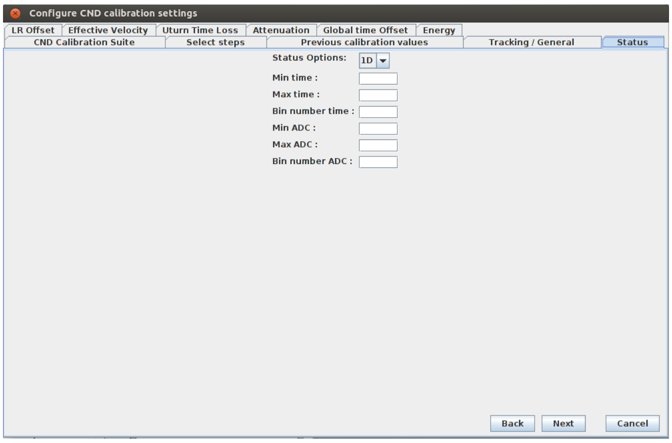

Figure 6: There are 7 calibration tabs. Each tab allows to modify plot range and binning of the displayed plots.

- CND::ADC (ID 20311)
- CND::TDC (ID 20312)
- CVT::Tracks (ID 20526)
- REC::Event (ID 330)
- RUN::config (ID 11).

In order to reduce the size of the input file it is possible to filter it with the following command line :

```
\$CLARA_HOME/plugins/clas12/bin/hipo-utils -filter  -l
    330:20321:20311:20312:20526:11
-e 20321 -merge -o outputfile.hipo list_of_file_to_filter
```

In order to produce good quality calibration constants, the file to calibrate should contain at least 20M CND events.

Once the CND file has be filtered, a further step of filtering can be applied to lower the weight of the file to process. Events with a negative tracks in the CVT are kept. To do so use the code located at JLab:

`/work/clas12/pierre/CNDCalibUtils`

To use the code copy the cndCalibFilter.class in your current folder. To run it use the following command line :

```
java -DCLAS12DIR="\$COATJAVA" -cp "\$COATJAVA/lib/clas
    /*:\$COATJAVA/lib/utils/*:." CNDCalibFilter [inputfile
    ] [outputfile]
```

This command will filter [inputfile] and keep negative tracks events, create the filtered file [outputfile] and write it in the current folder.

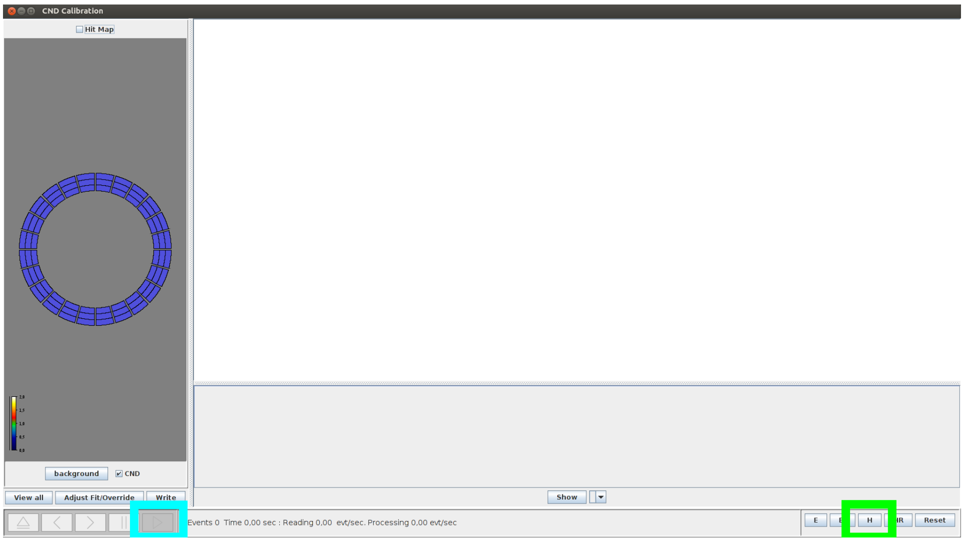

Figure 7: To import a file to calibrate in the suite, click on the *H* button in green. Once the file is successfully imported, the *Play* button will become clickable. Click this button and the calibration begins.

5.2 Importing and reading the input file in the calibration suite

Once the configuration of the calibration suite is done, the Calibration window appears. Users then need to import the file, read it, and calibrate it. This is done by clicking the *H* button in the Control Area highlighted in green in Figure 7. This will display a new window where it is possible to choose the input file. Click *Open* to import the file. Once the file is imported in the suite, the *Play* button will appear in the Control Area (see Figure 7, highlighted in blue). Click the *Play* button. The file is running and the current event number is displayed in the Control Area. Clicking the *Pause* button will stop the reading of the file. The calibration plots and the fits are performed once the file has been fully read.

5.3 Calibration options

Once the file has been read the calibration algorithms determine the constants. Each algorithm is explained in the next section of this document. The user has to check the results of each calibration step according to the procedure described later. Here we explain the options available for the user during the calibration procedure.

5.3.1 *View all* button

This button is located in the left bottom part of the detector view area. It allows the user to display summary plots for each calibration constant of the current tab.

5.3.2 *Adjust Fit/Override* button

The *Adjust Fit/Override* button is important in the calibration process. It allows the user to change the conditions of the fit and, in case the fit doesn't work, to adjust

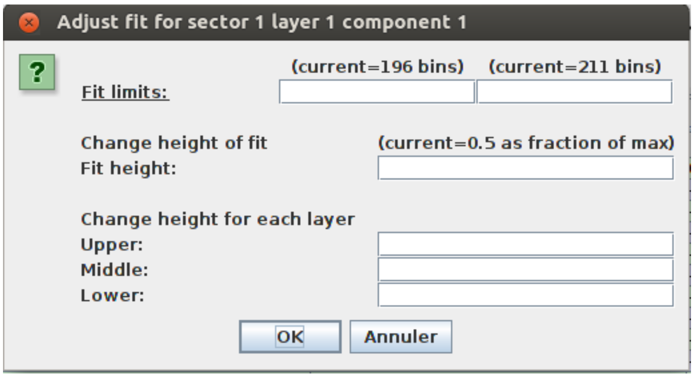

Figure 8: The *Adjust Fit/Override* window for LR_{off} step. In this window users can adjust the range (or the height) of the fit in order to improve their quality.

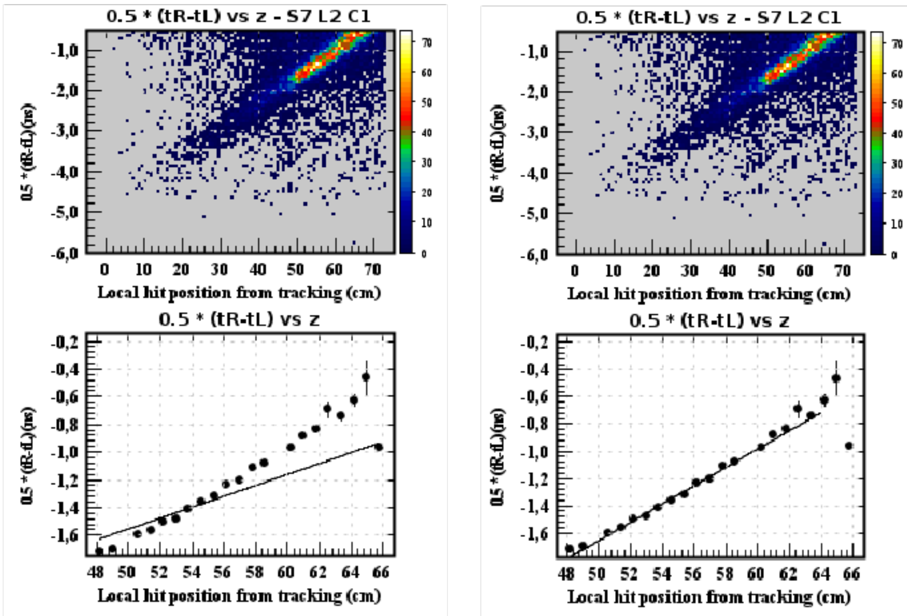

Figure 9: Fits of the $\frac{t_R - t_L}{2}$ vs z_{CND} distribution before (left) and after (right) the fit has been adjusted. The right fit is obtained by restricting the fit range to 64 cm.

the range (or height) of the fit by themselves to obtain the best possible value of the current calibration constant.

The *Adjust Fit/Override* button is located at the bottom of the detector view area. It can be used in any calibration tab. Once the user clicks on the button, a new window appears as shown in Figure 8. Users can adjust the fit conditions to improve it. Once the new constraints are set, click *OK*.

5.3.3 *Write* button

Once the calibration has been performed, each fit has been assessed and each constant has been checked, users can produce the calibration constants file by clicking on the *Write* button. This will display a new window as in Figure 11, and write a text file in the current directory. This file can then be used for the next calibration step and uploaded to the CCDB.

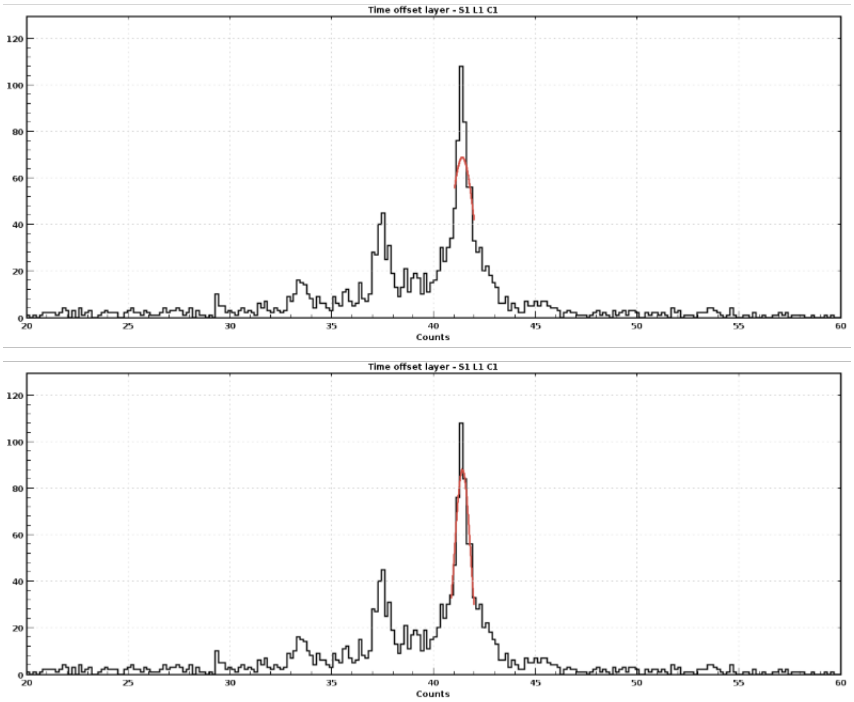

Figure 10: Fits of the t_{off} distribution before (up) and after (bottom) the fit has been adjusted. The bottom fit is obtained by restricting the fit range to the width of the peak at a 0.4 fraction of its maximum value.

Figure 11: This window appears when users click the *Write* button. It confirms that the current calibration values have been recorded in the given file.

The names of the produced file are as follow:

`<prefix>_<date>.<version>.txt`

where the various *prefix* are defined in Table 3, *date* is the current date, *version* is incremented from 0 for every different prefix and date.

Step	Calibration step	Output Files Prefix
1	LR time off.	CND_CALIB_TIMEOFFSETS_LR
2	Eff. v	CND_CALIB_EFFV
3	U-turn & LR t. offset ad.	LRoffset_adjusted_CND_CALIB_UTURNTLOSS uturn_LRad_CND_CALIB_UTURNTLOSS
4	Global t.offset	CND_CALIB_TIMEOFFSETS_LAYER
5	Att. length	CND_CALIB_ATTENUATION
6	Energy	CND_CALIB_Energy

Table 3: Output files prefix for each calibration step.

Part III
CND Calibration Steps

6 Calibration constants and General Calibration Strategy

There are 7 calibration steps. Each step has to be performed in the order shown in Table 4. 5 steps are associated with one calibration constant each ; 2 steps are required to calibrate the Left-Right Time offset. The output of the first step of the Left Right offset calibration is refered as LR_{off}, the output of the second step is referred as LR_{offad}.

Each step has to be performed individually. That is to say, the calibration suite has to be run again for each step. At each step the user has to make sure the required constants have been uploaded. The required constants for each step are summarized in Table 5. The way constants have to be uploaded in the suite is detailed in section *Previous calibration values tab*. In the section *Previous calibration values tab*, Table 2 summarizes where to upload the previous calibration file in the suite.

The CND calibration is an iterative process. Once the user has completed a full set of calibration constants, it is possible to improve it. This can be done without recooking the data. The process is similar to the first pass of calibration described above. However for further passes, the user has to make sure that the calibration suite uses the LR_{offad} and v_{eff} values of the previous pass. This is done by uploading the files with prefix *uturn_LRad_ CND_ CALIB_ UTURNTLOSS* and *CND_ CALIB_ EFFV* from the previous pass for steps 1,2 and 3 of the current calibration. These files contain the LR_{offad} and v_{eff} values that will be used by the suite to improve the calibration. Each step of the calibration is then performed as described above. The constants to be uploaded to the suite for pass i are described in Table 6. The full calibration process is described in Figure 12. We advise to perform at least two passes of calibration before uploading the constants on the CCDB.

Step	Calibration step	Output	Number of constants
1	LR (Left-Right) time offset	LR_{off}	72
2	Effective velocity	v_{eff}	144
3	U-turn time loss & LR time offset ad.	u_{tloss}, LR_{offad}	72 each
4	Global time offset	t_{off}	72
5	Attenuation length	Att_L	144
6	Energy constants	MIP_D, MIP_I	144 each

Table 4: The steps of the CND calibration.

Step	Calibration step	Required constants
1	LR time offset	none
2	Effective velocity	LR_{off}
3	U-t. t. loss & LR t.offset ad.	LR_{off}
4	Global time offset	LR_{offad}, v_{eff}, u_{tloss}
5	Attenuation length	LR_{offad}, v_{eff}
6	Energy constants	LR_{offad}, v_{eff}

Table 5: Required previous constants for 1st pass calibration step.

Step	Calibration step	Required constants (pass i)
1	LR time offset	none
2	Effective velocity	From pass i: LR_{off} From pass i-1: LR_{offad}, v_{eff}
3	U-t. t. loss & LR t.offset ad.	From pass i: LR_{off} From pass i-1: LR_{offad}, v_{eff}
4	Global time offset	From pass i: LR_{offad}, v_{eff}, u_{tloss}
5	Attenuation length	From pass i: LR_{offad}, v_{eff}
6	Energy constants	From pass i: LR_{offad}, v_{eff}

Table 6: Required previous constants for ith pass calibration step.

Table 4 summarizes the order in which each step has to be performed and the calibration constants associated with these steps. Table 3 presents that file prefix associated with the files produced by each calibration step. Table 5 shows the calibrated constants that are used for each steps. These constants have to be calibrated before the calibration of the given step.

7 Left-Right timing offset calibration (1st step)

The goal of this step is to calibrate the time difference between two coupled paddle. The calibration of this constant has to be done in two steps. In this part only the first calibration step is described. For a full description of the calibration algorithm see [1]. The first calibration step of the LR time offset is done in two different ways depending on the nature of the run to calibrate. In both cases the raw time difference between two coupled paddle is plotted. If the run is done without any magnetic field, it is expected that this ditribution will show a dip due to the fact that

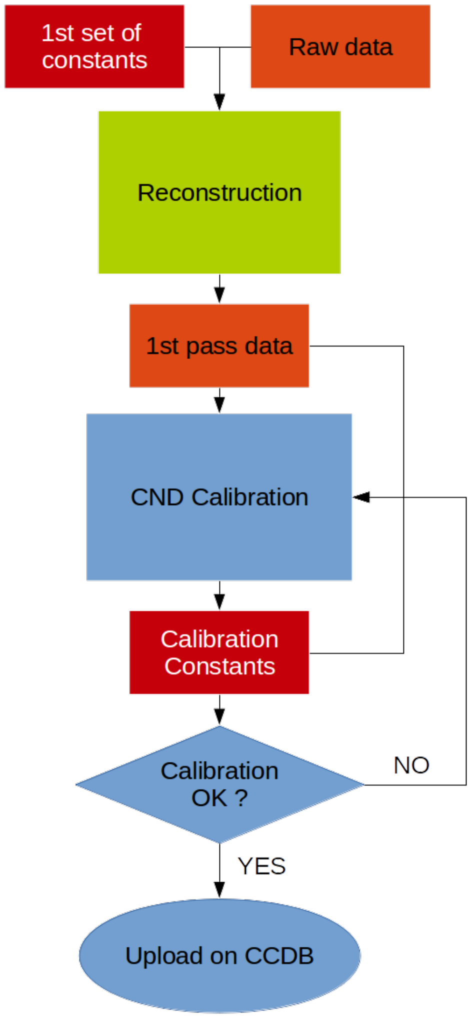

Figure 12: Flowchart of the CND calibration. The user retrives pass0 data that have been processed by the reconstruction sofware once. Then the user processes this set of data through the calibration suite. If the calibration is good, constants can be uploaded to the CCDB. Otherwise the calibration has to be performed again using LR_{offad} and v_{eff} constants from the previous pass.

no hit will occur in the u-turn (see Figure 13). In the case of a run with magnetic field, the dip disappears and a peak appears (see Figure 14). This peak is due to double hits (illustrated in Figure 15). The LR_{off} is defined as the position of the dip (resp. the peak). This value gives an estimate of the time offset between two coupled paddles. However this value does not take into account the effective velocity difference between these coupled paddles. To take into account these differences, a second step of calibration is required. This second step is described in a further section.

In the configuration panel, it is possible to choose between both magnetic field configurations. By default, the configuration is field OFF. It is also possible to change the range of the plots.

Once the file to calibrate has been read and the calibration completed, users have to check the quality of the fits and adjust them accordingly. To adjust the fit

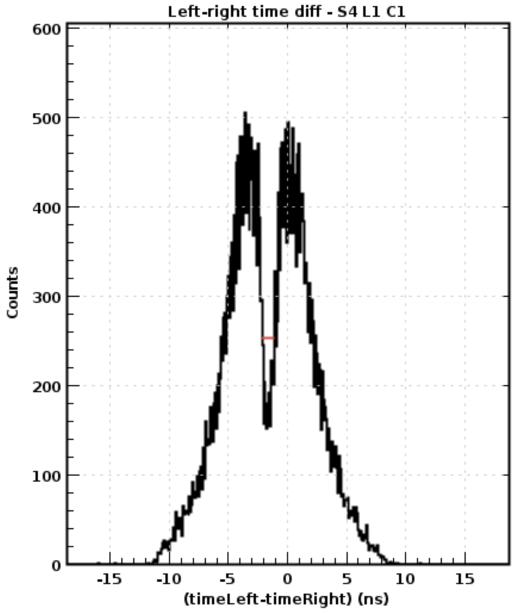

Figure 13: Left-Right time difference distribution when the magnetic field is off. The dip in the distribution is caused by the u-turn light guide.

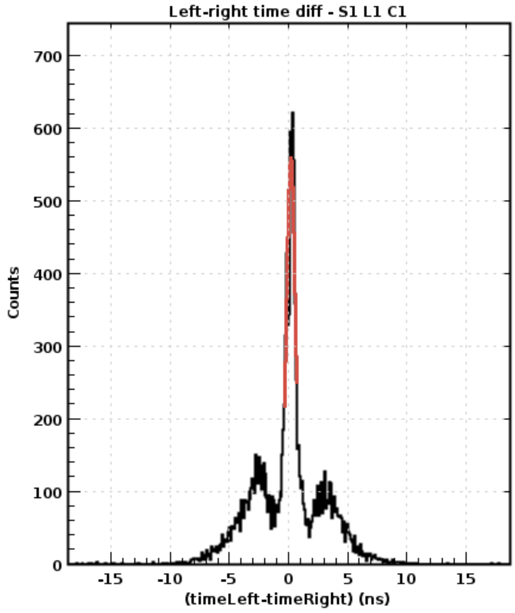

Figure 14: Time difference when the magnetic field is on. The peak is due to the double hits decribed in Figure 15

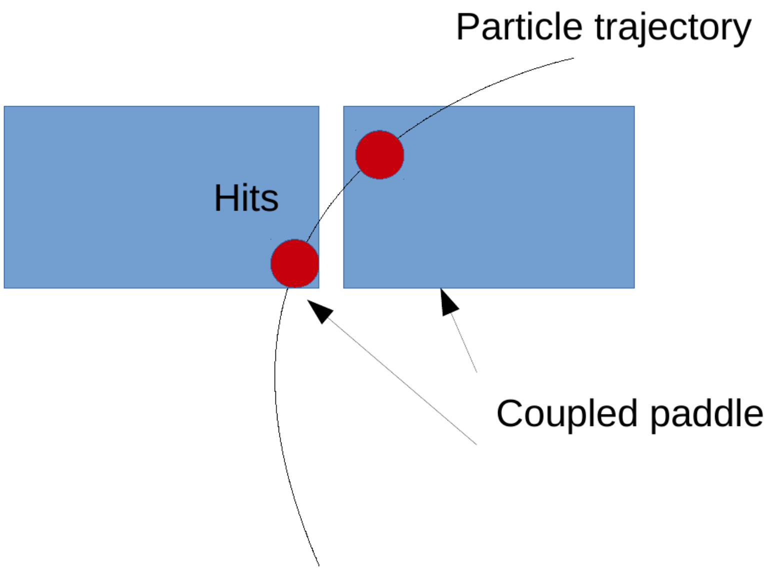

Figure 15: The CND double hits happen when a charged particle hits both coupled paddles. The two times associated with this hit are almost the same thus producing a peak in the time-difference distribution. This peak should be located at zero in the ideal case of zero time offset between the two paddles and equal effective velocities.

in this step, the user gives the fraction of the peak (resp. dip) height at which the fit range stops. Examples of good fits are shown in Figure 13 and Figure 14.

8 Effective velocity

The goal of this step is to determine the effective velocity of the light signal in each paddle. There are 144 values of effective velocities. This calibration step requires the LR_{off} values to be uploaded in the suite.

In the configuration panel, users can change the range and the binnings of the displayed plots.

Once the file is processed, the $\frac{t_R - t_L}{2}$ vs z_{CND} plots are shown, together with their fitted version. The fitted line also appears in the fitted plots. The effective velocity is calculated from the gradient of this line (for full description of the procedure see [1]). Users have to assess the quality of the fit. To do so one can change the range for the fitted line by using the *Adjust fit* menu. Good v_{eff} plots are shown in Figure 16.

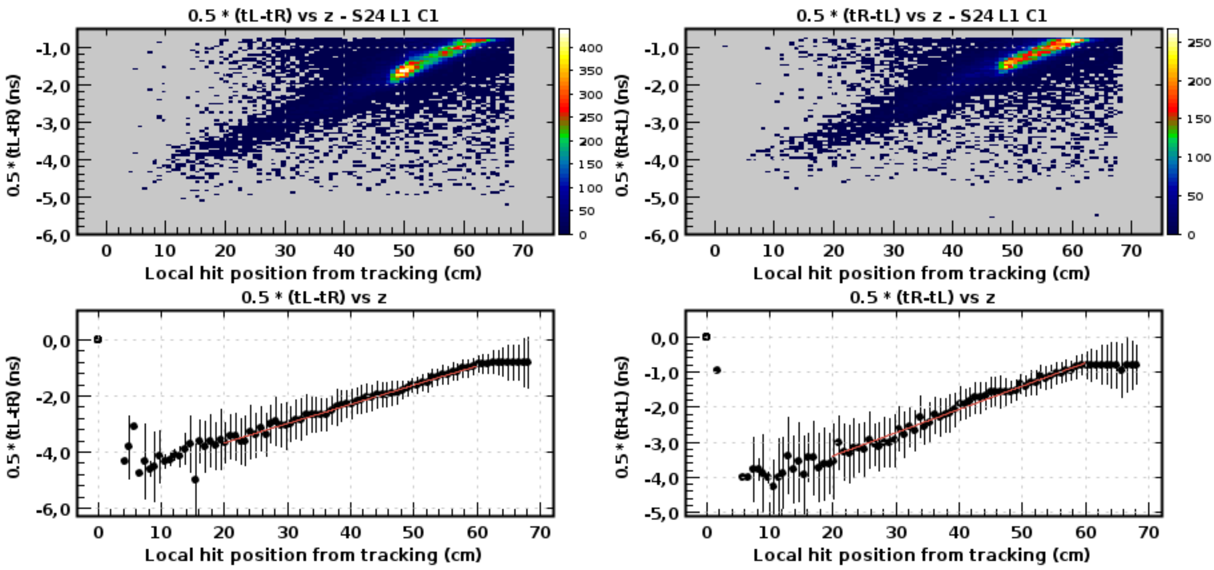

Figure 16: Plots displayed in the v_{eff}, u_{tloss} and LR_{offad} steps. The two top plots diplayed the raw $\frac{t_R - t_L}{2}$ vs z_{CND} distribution for both coupled paddles. The two bottom plots show the positions of the peak of the gaussian fit of each slice of the raw distribution. They also display the fitted lines that interpolate these points.

9 U-turn time loss

The goal of this step is to determine the time lost by the signal while crossing the u-turn light guide coupling two paddles. They are 72 u_{tloss} values. This calibration step requires LR_{off} to be uploaded to the calibration suite. This is done by uploading the corresponding LR_{off} file in the *Previous calibration values* tab using the *FILE* option.

In the configuration panel, users can change the range and the binnings of the displayed plots.

Once the file is processed, the $\frac{t_R - t_L}{2}$ vs z_{CND} plots are shown together with their fitted versions. The fitted line also appears in the fitted plots. The u_{tloss} is calculated from the intercept of the fitted line from two coupled paddles (for a full description of the procedure see [1]). Users have to assess the quality of the fit. To do so one can change the range for the fitted line by using the *Adjust fit* menu. Good u_{tloss} plots are shown in Figure 16 as they are the same as for v_{eff} calibration.

10 Left-Right timing offset calibration (2nd step)

The goal of this step is to adjust the LR_{off} extracted from the position of the peak or the dip in the TDC ditribution. Effective light velocity differences in coupled paddles can affect strongly the LR_{offadd} value. The Left-Right offsets are adjusted at the same time as the u_{tloss} values are calculated. LR_{offad} are also obtained from the intercept of $\frac{t_R - t_L}{2}$ vs z_{CND} plots (for a full description of the procedure see [1]).

As this step is done in the same tab as u_{tloss}, users have provided the required LR_{off} values. These values will be adjusted by the suite and the final values displayed in the adjusted_LR_offset column. This calibration step produces two files, one for u_{tloss} and one for LR_{offad}.

11 Global time offset

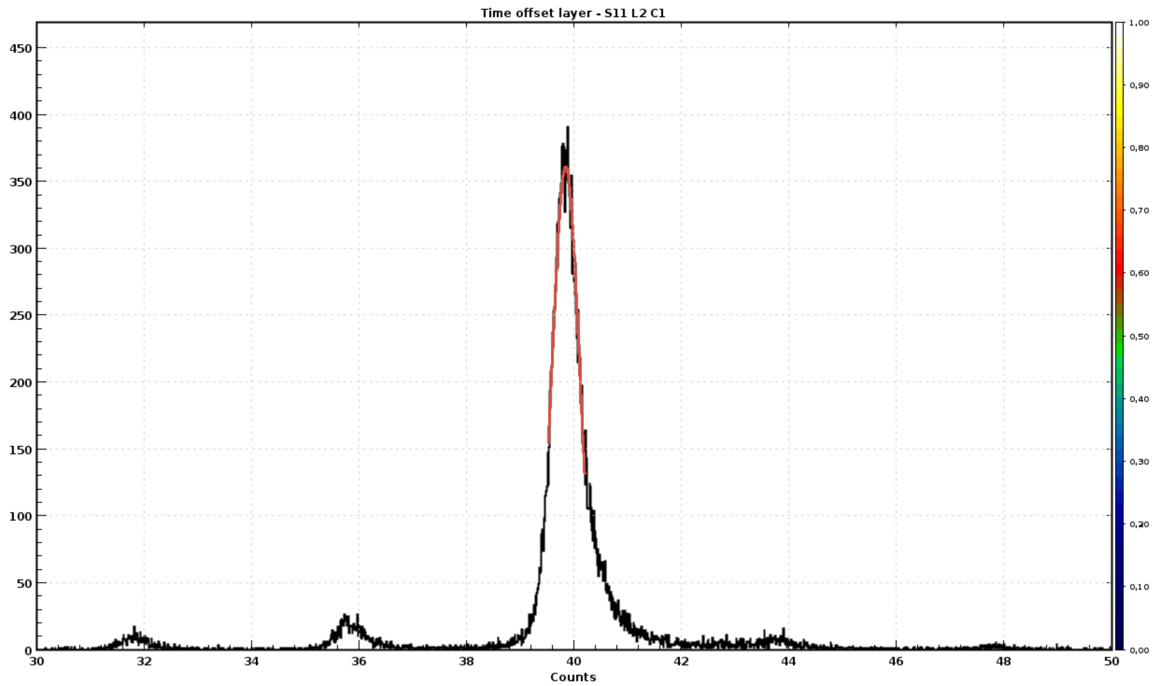

Figure 17: Vertex time distribution and the gaussian fit to extract t_{off}. The multiple peaks are due to mismatched RF times.

The goal of this step is to align the vertex time measured by the CND and the vertex time measured using the CLAS12 start time. This steps requires all previous constants to be calibrated. It is very important to use LR_{offad} values. For each CND hit with a negative charge associated, t_{off} is calculated (for a full description of the procedure see [1]). The obtained distribution is fitted with a gaussian and the mean value defines the t_{off} value.

In the configuration panels, users can adjust binning and range of the time plots.

Users can assess the fit and produce a better one by using the *Adjust fit* button. Users can choose the fraction of the peak height from which the fit range is calculated. A example of good fit is given in Figure 17.

12 Attenuation length

The goal of this step is to determine the characteristic light attenuation length of each paddle, Att_L. There is one Att_L value for each paddle, 144 in total. To see the description of the algorithm, refer to [1]. After the file is processed, $ln(\frac{ADC_D}{ADC_I})$ vs z_{CND} distribution is plotted. Each slice of the distribution is fitted with a gaussian. The peak distribution of this gaussian is fitted with a line. From this line the Att_L value is calculated. Users have to check the quality of this fit and can adjust the range of the line fit.

In the configuration panel, it is possible to change the range and binning of all the displayed plots.

A good example of the mentioned plots and fits is shown in Figure 18.

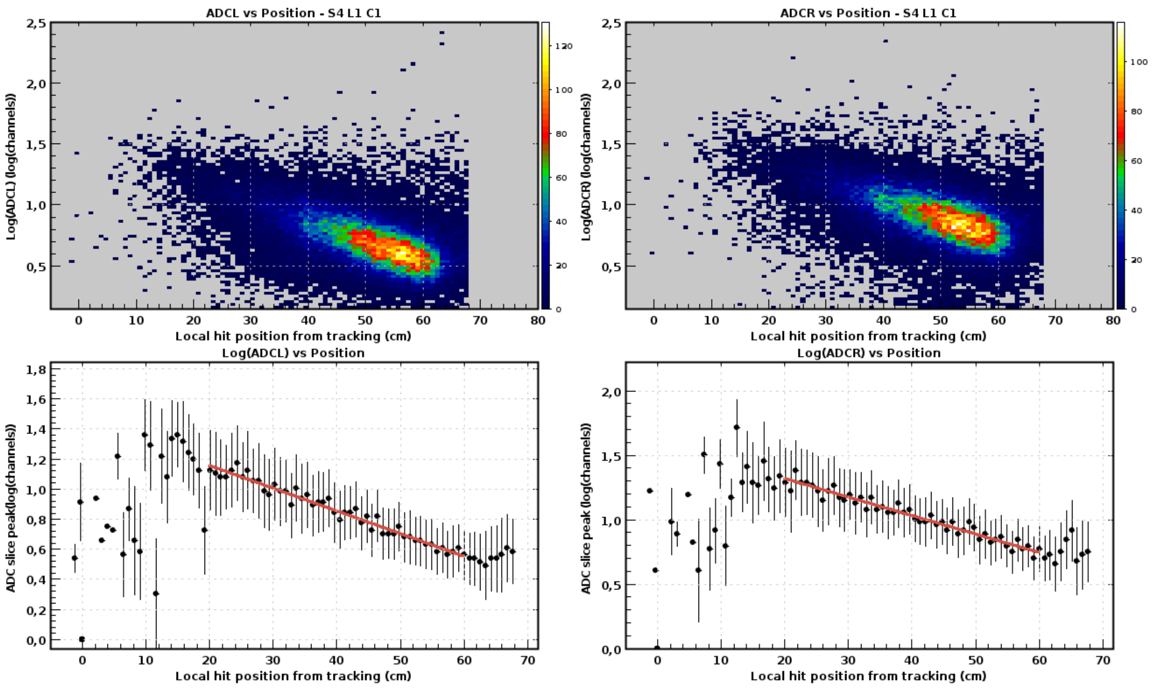

Figure 18: Plots displayed in the Att_L and MIP_D, MIP_I steps. The two top plots diplay the raw $ln(\frac{ADC_D}{ADC_I}$ vs z_{CND} distribution for both coupled paddle. The two bottom plots show the positions of the maximum of each slice of the raw distribution. They also display the fitted lines that interpolate the points.

13 Energy constants

In this final calibration step, the ADC-to-energy conversion constants are determined. The full algorithm is described in [1]. Two raw distributions are plotted:

$ln(\frac{ADC_D}{ADC_R})$ vs z_{CND} and $\sqrt{ADC_D \cdot ADC_I} \cdot \frac{h}{path}$. The fitted ditribution for $ln(\frac{ADC_D}{ADC_R})$ vs z_{CND} is also shown. The quality check for this fit is the same as for Att_L. On the same plot as $\sqrt{ADC_D \cdot ADC_I} \cdot \frac{h}{path}$, a Landau fit is shown. The quality of this plot has to be assessed by the user. Examples of good fits for both distributions can be seen in Figure 18 and Figure 19.

In the configuration panel, it is possible to change the range and binning of all the displayed plots.

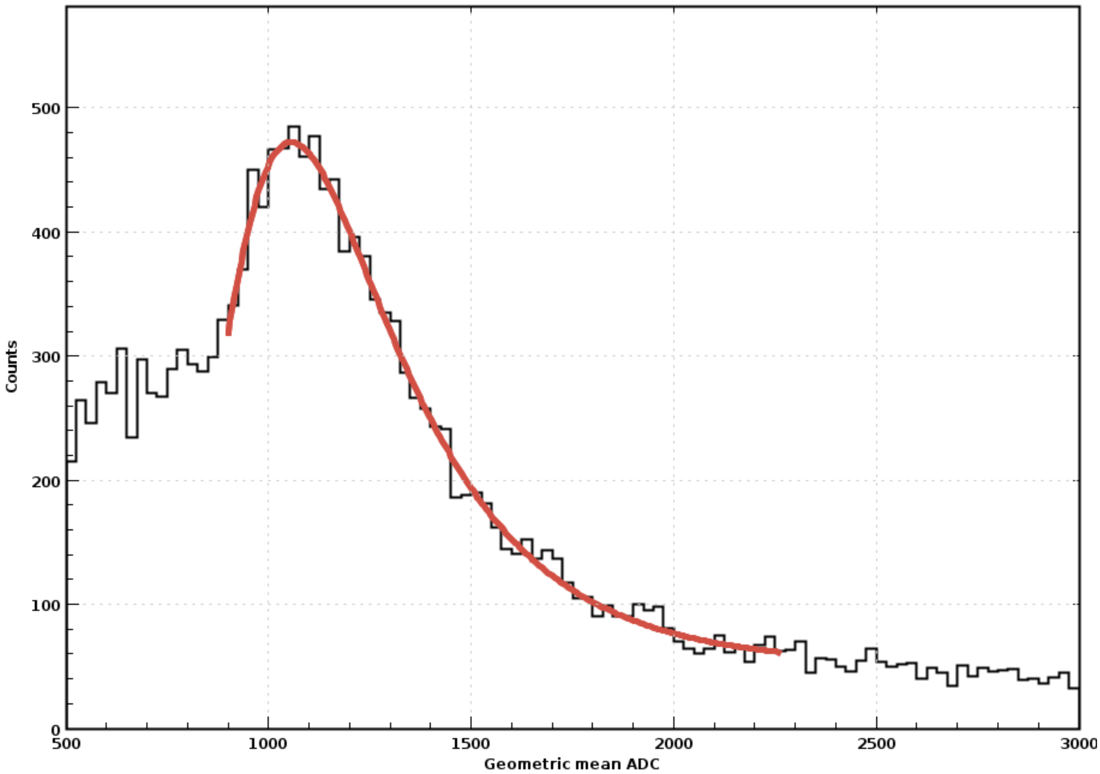

Figure 19: Raw $\sqrt{ADC_D \cdot ADC_I} \cdot \frac{h}{path}$ distribution and the Laudau fit that is diplayed in the energy calibration step.

Part IV

Uploading calibration constants

Once every constant file has been produced, it has to be written in the CCDB. There are 6 files to be uploaded: v_{eff}, u_{tloss}, LR_{offad} ,t_{off} , Att_L , $Energy$ (containing MIP_D and MIP_I constants). Each file has to be uploaded in its CCDB directory. The list of CCDB directory associated to each file is summarized in Table 7.

Before uploading the calibration file, users have to make sure that the common CLAS12 environment is set.

```
source /group/clas12/environment.csh
```

Users may want to change the CCDB_CONNECTION variable to:

```
mysql://clas12writer:geom3try@clasdb.jlab.org/clas12
```

Access the ccdb using the command:

```
clas12-ccdb -i
```

Once in the CCDB interface, the user can add the calibration file with the following command:

```
add <table_path> -v <variation> -r <run_min>-<run_max> file_to_import
```

where *<table_path>* is the CCDB entry name listed in Table 7, *<variation>* is *default*, *<run_min>-<run_max>* is the run range for which the calibration is valid, and *file_to_import* is the calibration constants file.

Constants name	DB entry name
LR_{offad}	/calibration/cnd/TimeOffsets_LR
v_{eff}	/calibration/cnd/EffV
u_{tloss}	/calibration/cnd/UturnTloss
t_{off}	/calibration/cnd/TimeOffsets_layer
Att_L	/calibration/cnd/Attenuation
MIP_D, MIP_I	/calibration/cnd/Energy

Table 7: Calibration constants, their locations in the CLAS12 CCDB and the associated file prefix.

Constant name	Output Files Prefix
LR_{offad}	LRoffset_adjusted_CND_CALIB_UTURNTLOSS
v_{eff}	CND_CALIB_EFFV
u_{tloss}	uturn_LRad_CND_CALIB_UTURNTLOSS
t_{off}	CND_CALIB_TIMEOFFSETS_LAYER
Att_L	CND_CALIB_ATTENUATION
MIP_D, MIP_I	CND_CALIB_Energy

Table 8: Calibration constants and their associated file prefix.

References

[1] Pierre Chatagnon, Gavin Murdoch, Silvia Niccolai, and Daria Sokhan. Description of the calibration algorithms for the clas12 central neutron detector.