VAMOS Analysis
example on the e706 fission data (^{238}U + ^{9}Be)

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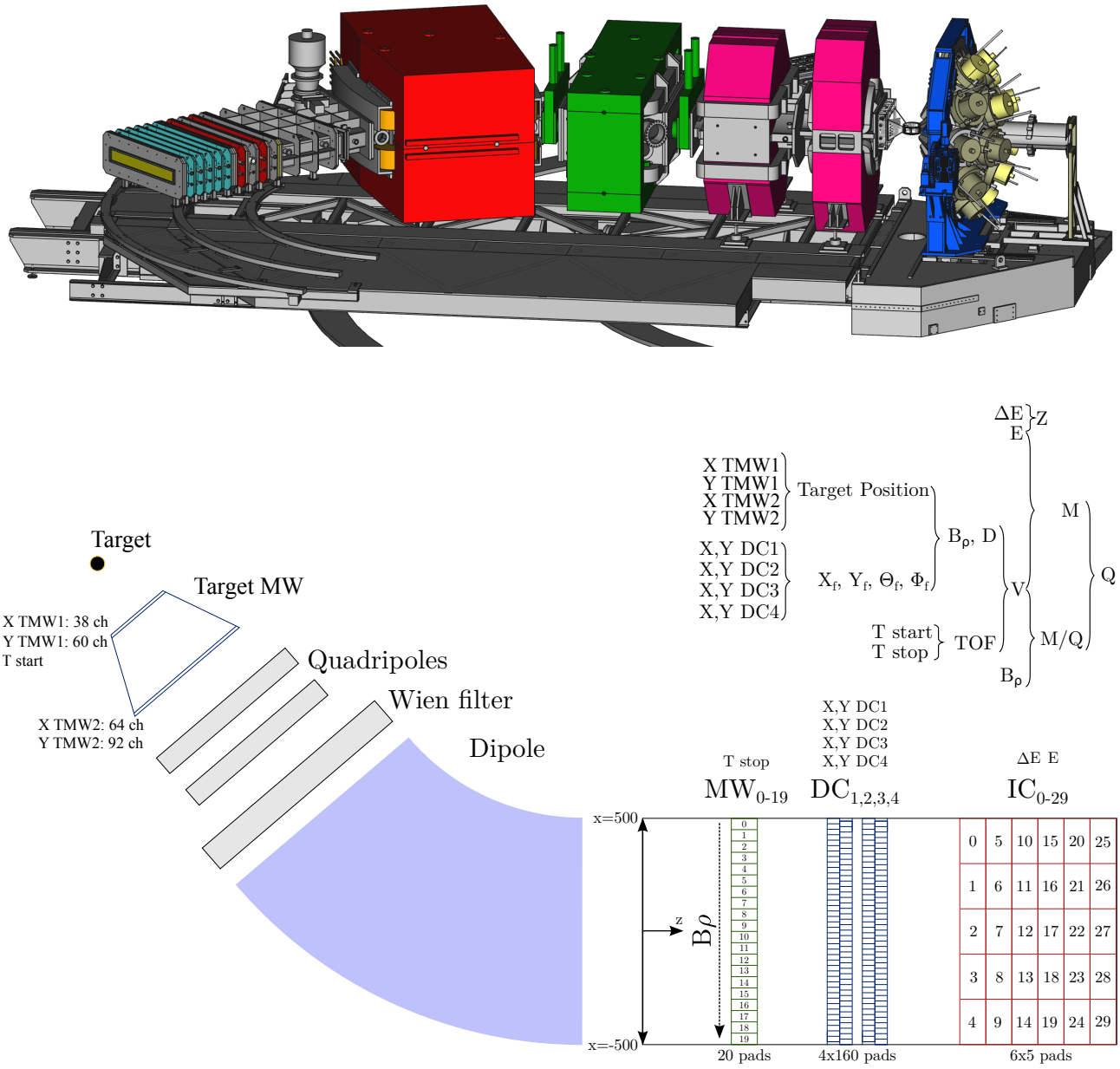

FIGURE 1 – schematic view of the various detectors used in the VAMOS analysis

1 Software installation

In order to be able to reprocess the VAMOS libraries, the needed software are :
— A root version installed
— The gammaware package installed
— The OfficialWatchers package
— MFM library
— libvamos library
— vanalysis library

for the 4 last items, the easier is to keep the one used on GANIL site. Once all is installed, the Root trees creation is done from the OfficialWatchers folder, using the StartBatch.sh script. This script needs to be modified in order to correspond the architecture of the computer used for this offline analysis.

2 reconstruction optimization

The trajectory reconstruction of the nuclei in the VAMOS optics is done by the VAMOS libraries which is very time consuming and will affect all the next corrections and calibrations. This is why this needs to be at the very beginning of the analysis.

2.1 data "decalibration"

The VAMOS reconstruction uses the positions information given by the TMW and by the DCs, and these wires needs to be calibrated. In the VAMOS analysis, the calibrations coefficients used are located in the OfficialWatchers/ConfVAMOS/Calibs folder. One need to reset all these coefficients which are not perfect and to restart the calibration. For this, the files DC{0,1,2,3}.cal and TMW{1,2}_{X,Y}.cal need to be edited to unset these coefficients and reprocess the VAMOS analysis.

For TMW files, there is 4 coefficients (a_0, a_1, a_2, a_3) and the calibration is then apply from the formula :

$$Q = Q_{Raw} - a0 + rnd$$
$$E = a1 + a2 * Q + a3 * Q^2,$$

where rnd is a random number between 0 and 1.

For DCs files, there is 3 coefficients (a_0, a_1, a_2) and the calibration is then apply from the formula :

$$Q = Q_{Raw} + rnd$$
$$E = a0 + a1 * Q + a2 * Q^2$$

The first step in thus to reset these coefficients (0 0 1 0 for TMW files, and 0 1 0 for DCs) and to restart the StartBatch.sh for a run of the beginning of the experiment with a quite large statistic.

For the calibration, three branches of the Root trees are needed :
— The wires multiplicity "N" (DC{0,1,2,3}_QVM for the DCs, TMW{1,2}_{X,Y}VM for the TMWs) which is an integer value,
— The Charge deposited in a wire (DC{0,1,2,3}_QV for the DCs, TMW{1,2}_{X,Y}V for the TMWs) which is a float array of size "N",
— The id of the hited wire (DC{0,1,2,3}_QVN for the DCs, TMW{1,2}_{X,Y}VN for the TMWs) which is a float array of size "N".

Figure 2 represents the raw matrix of the charge deposited in the wires versus the wire id after "decalibration".

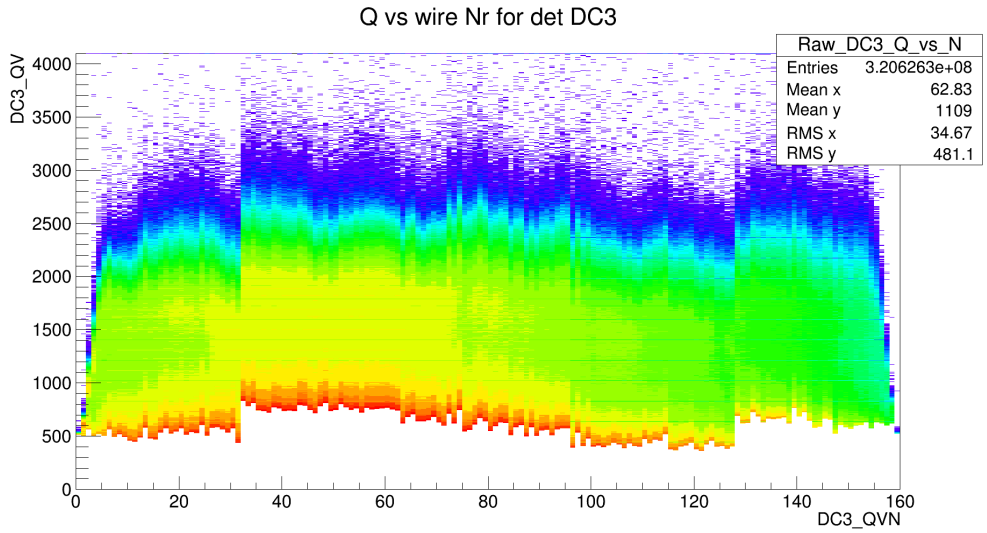

FIGURE 2 – raw matrix of the charge deposited in the wires versus the wire id after "decalibration" for DC3

2.2 pedestals determination

The first step is to determine for each wire the pedestal value in order to set the thresholds at 0. Figure 3 represents the Fig. 2 after pedestal subtraction.

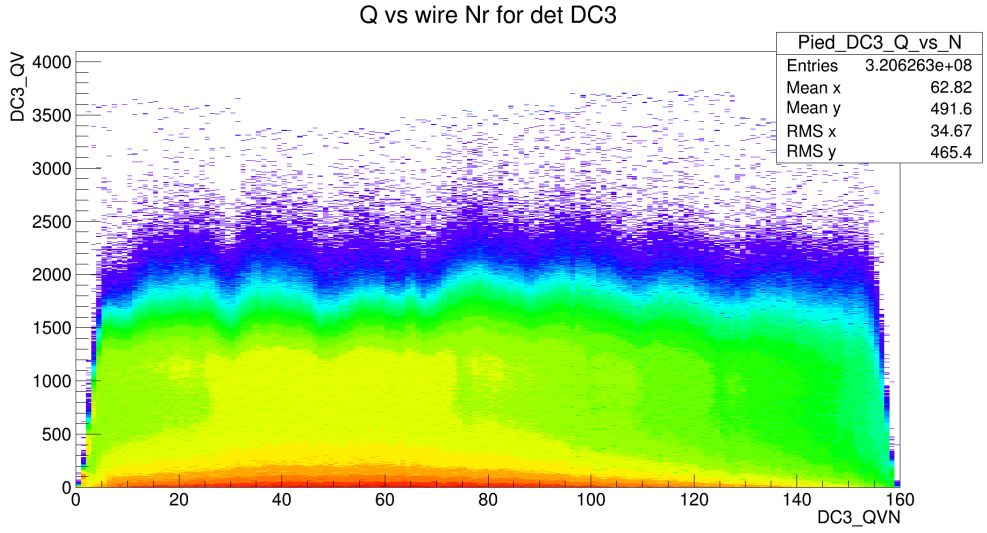

FIGURE 3 – Fig. 2 after pedestal subtraction for DC3

2.3 QMax determination

For the VAMOS reconstruction, a real energy calibration is not needed for the wire, the only important point is to obtain a coherent calibration between the wires in order to obtain a perfectly smooth Q distribution between the different wires. This alignment is done by representing for each event, only the wire for which the deposited charged is maximum. An example of charge distribution in the wires for one event (one nucleus passing threw the detector) is represented on Fig. 4.

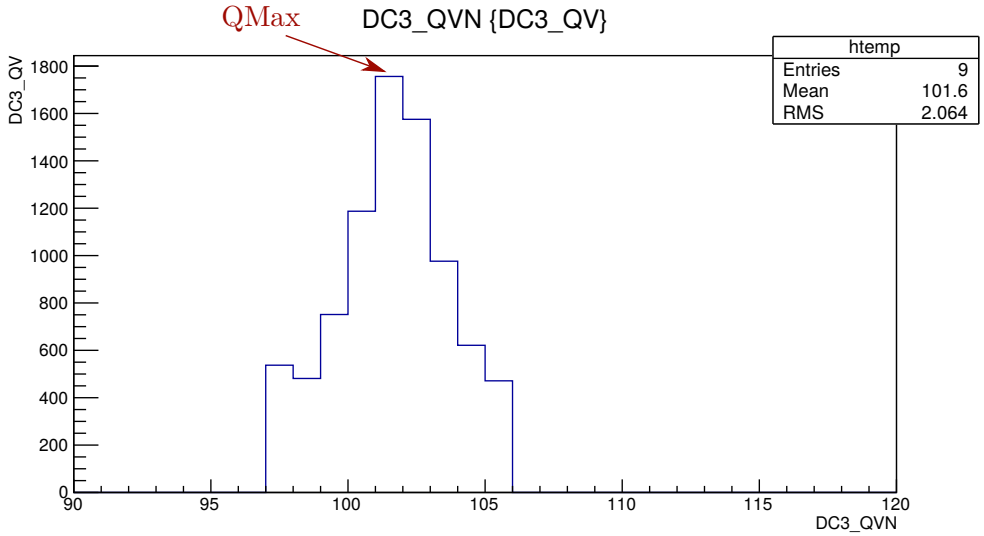

FIGURE 4 – Charge distribution in the wires for one event for DC3

The first step is thus to read the data event by event, and for each, determining the id of the wire for which the charge is maximum. Fig. 5 represents the maximum charge deposited in a wire for each event versus the id of the wire corresponding to this QMax charge (after pedestal subtraction).

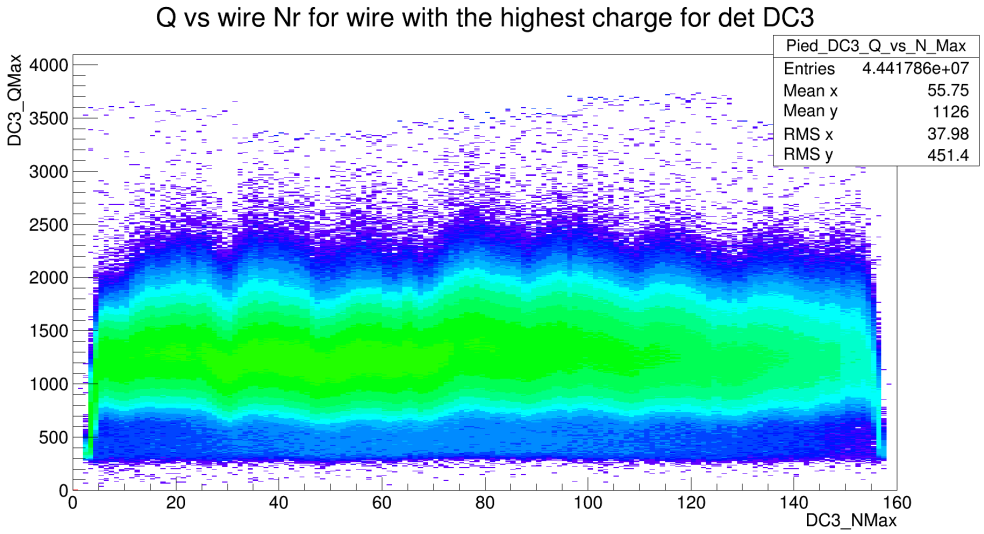

FIGURE 5 – Maximum charge deposited in a wire for each event versus the id of the wire corresponding to this QMax charge (after pedestal subtraction) for DC3

Figure 6 represents the projection of Fig. 5 for only one wire (id = 80). This is the position of the maximum of this distribution that needs to be aligned for all wires. Aligning all QMax to a fixed value can work, but the best is to take into account the fact that the physics is evolving along the X value. It is thus better to fit the Qmax position versus the wires ids in order to obtain a global behavior, and to make the alignment according to it. Fig. 7 represents such a fit. The alignment is then performed according to this fit.

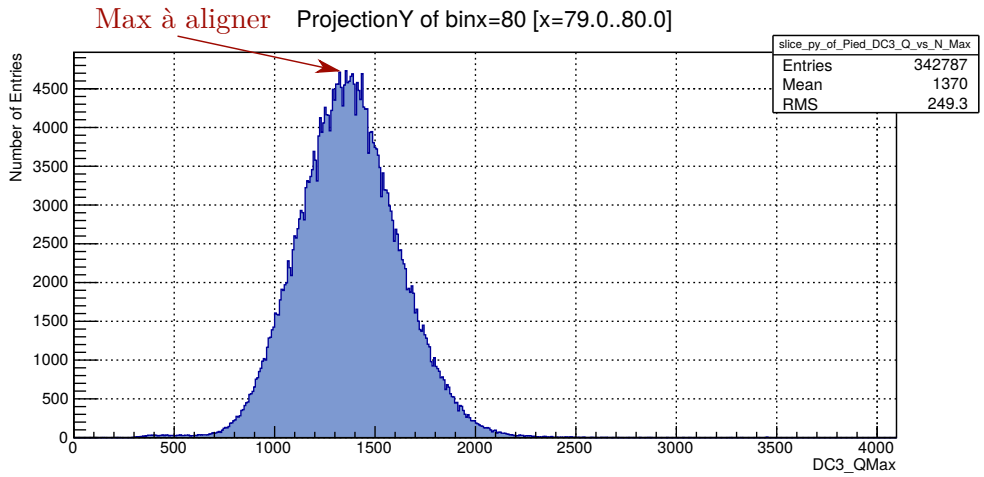

FIGURE 6 – projection of Fig. 5 for only one wire (id = 80)

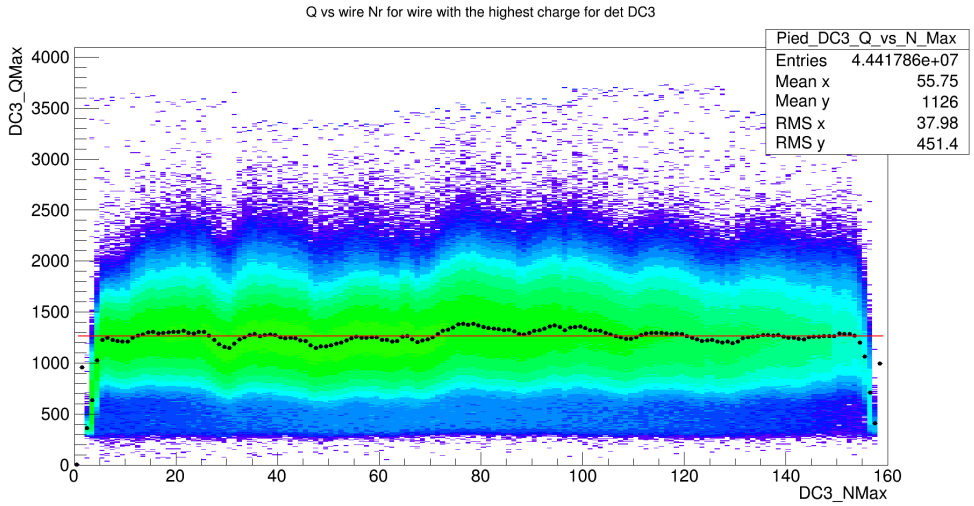

FIGURE 7 – fit of the global behavior of QMax versus the wire ids for DC3

2.4 "Gain matching"

The final step is the gain matching. One need to adjust the gain factors (a2 for TMWs and a1 for DCs) to obtain a smooth QMax distribution. The second order is not necessary. Fig. 8 represents the final results obtained for DC3. This is an iterative operation, indeed, the modification of the gain factors can affect the wires distribution, and consequently the QMax determination.

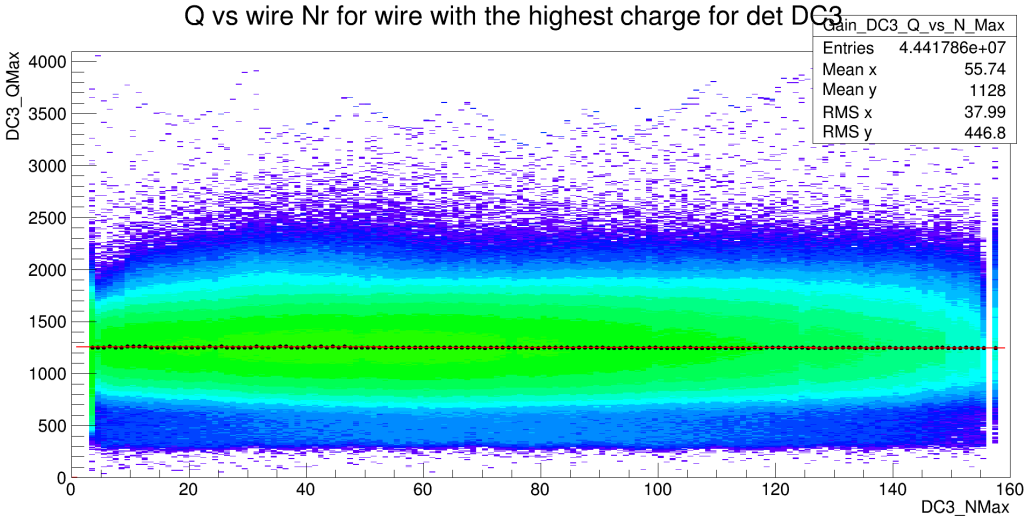

FIGURE 8 – Final results obtained for DC3

Once all the calibration coefficients are determined, the calibration files of the ConfVAMOS/Calibs folder must be updated, the run reprocessed. The calibrated run obtained need to be carefully analyzed in order to check that the calibration coefficients have been well taking into account in the VAMOS libraries.

3 Events selection

In the following steps, some will be done MW per MW, and some others IC section per IC section (one IC section represents a complete line of IC pads in the nuclei directions, I will note it P_i in the following. For example, P_2 corresponds to the line of ionization chamber pads (ICs) 2, 7, 12, 17, 22, 27 on Fig. 1).

For a faster and simpler analysis, it is advise to pre-build different data-sets for each of these cases (one data set per MW, and one data set per P_i). Different possibilities are possible, one *TTree* per data-set, using the *TEntryList* of root or your preferred other choice.

For a easier analysis, it is also advised to limit the data-sets to what I call "clean" data-sets, which means data-sets excluding events where the deposited energy in the ICs is shared between different P_i. Figure 9 represents the distribution of events in the different ICs selected for MW 7 without (left) and with (right) this "clean" data-set selection.

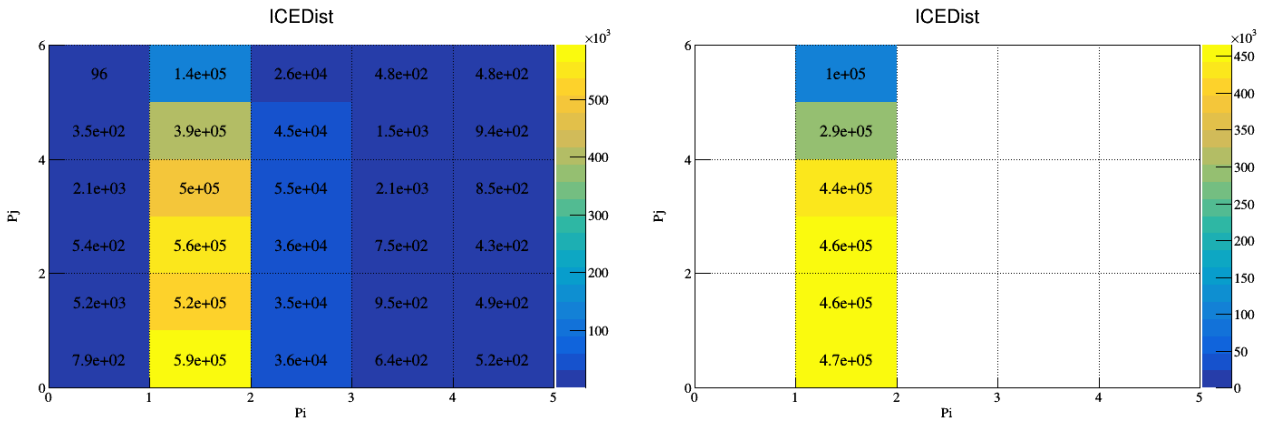

FIGURE 9 – distribution of events in the different ICs selected for MW 7 without (left) and with (right) this "clean" data-set selection.

4 Time and energy calibration

The only way to be sure of the time calibration is to check that the masses are correct, which imply to make selections on the Q vs M/Q matrix. But this matrix is directly correlated to the time and energy calibration. This is why these two steps needs to be done together.

The time of flight (TOF) is obtained from the time between the first target multi-wire plane (TMW1) and the focal plane multi-wire (MW). The TOF calibration needs thus to be done for each MW pad (20). In order to avoid to propagate errors, the best is to work on the raw data. The raw time branch name is : *TMWT1_TMWFP_D*. For its calibration, we needs to first apply the TAC gain, and the the correct offset. You can use for the beginning the initial values used during the experiment in the file ConfVAMOS/Calibs/TACS.cal for the TAC gain and ConfVAMOS/Calibs/TCoeff.cal for the initial offsets of each MW. The final time will thus be :

$$
\begin{aligned}
T(MW) &= (TMWT1\_TMWFP\_D + rnd) * TAC_{gain} + Offset(MW) \\
v &= D/T \\
\beta &= V/29.9792458 \\
\gamma &= 1./\sqrt{1-\beta^2} \\
\frac{M}{Q} &= \frac{B_\rho}{3.105 \times \gamma \times \beta}
\end{aligned}
$$

The time calibration is made by looking at the M/Q value. The M/Q distribution will automatically promote integer values. For example, Fig. 10 represents a M/Q distribution obtained by dividing random integer values of M and Q (centered around the ones of fissions studies). It doesn't represents physics, only mathematics. Peaks can be seen at integer M/Q values (2,3,4)

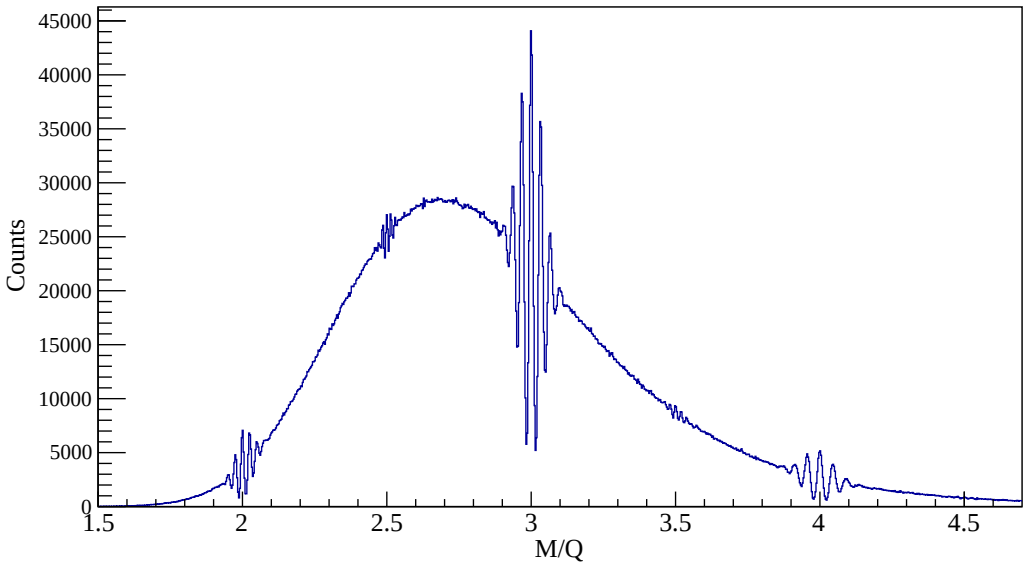

FIGURE 10 – M/Q distribution obtained by dividing random integer values of M and Q (centered around the ones of fissions studies)

The time calibration will thus consist in finding the good gain and offset to apply in order to align the M/Q peaks on integer values (in general 3 and 4 in fission studies).

4.1 first approximative time calibration

The first step is only to make an approximative calibration of the time on one of the most populated MW in order to maximize the statistics (MW 7 is good). We will not play on the gain of the TACS for

the moment,only on the offset, in order to have a peak of the M/Q distribution on an integer value. Fig. 11 represents the M/Q distribution for MW 7 using the initial parameters (left), and after a first approximative calibration ($M/Q = 4$ is on a maximum) (right).

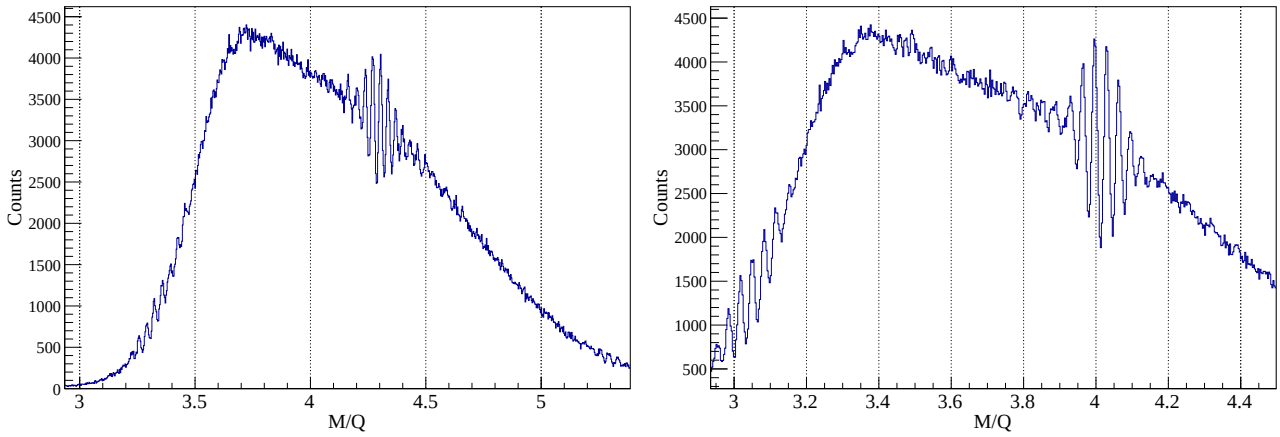

FIGURE 11 – M/Q distribution for MW 7 using the initial parameters (left), and after a first approximative calibration ($M/Q = 4$ is on a maximum)

4.2 energy calibration

In order to know if the maximum used for the time calibration is correct (because the peak with $M/Q = 4$ is not always the one corresponding to the integer value, 4 in the example of Fig. 11), we then need to obtain a calibrated total energy, indeed, the reconstructed mass identification (Mr) is obtained from the charge state (Q) like :

$$M_0 = \frac{E}{931.5016 \times (\gamma - 1)}$$
$$Q = \frac{M_0}{M/Q}$$
$$Mr = M/Q \times nint(Q) \qquad nint \text{ corresponds to the nearest integer}$$

The charge state Q is thus directly proportional to the total energy E.
The total energy is calculated P_i per P_i as following (for a first order calibration) :

$$E(P_i) = \sum_{n=0}^{5} (IC[i + 5 \times n] + rdn - pedestal) \times \alpha_{in} \quad (MeV),$$

where α_{in} corresponds to the calibration coefficient of the pad corresponding to $P_i = i$, and $P_j = n$, $IC[j]$ corresponds to the raw energy deposited in the the pad j (cf. Fig. 1).

The raw values of the ionization chamber are obtained from the branches *ICRawM*, *ICRaw[ICRawM]* and *ICRawNr[ICRawM]*. These branches are built on the same method that the DCs in the previous section. *ICRawM* gives the number of IC pads that have been triggered. *ICRaw[ICRawM]* and *ICRawNr[ICRawM]* are arrays of size *ICRawM*. *ICRaw[ICRawM]* returns the energy deposited in each pad, and *ICRawNr[ICRawM]* returns the id of the triggered pad. The first step, for a easier analysis is thus to build a new array *IC[30]* containing the deposited energy in each pad.

The first step in the calibration is to determine the pedestals of each pad. Fig. 12 represents the value to take for the pedestal of IC[1].

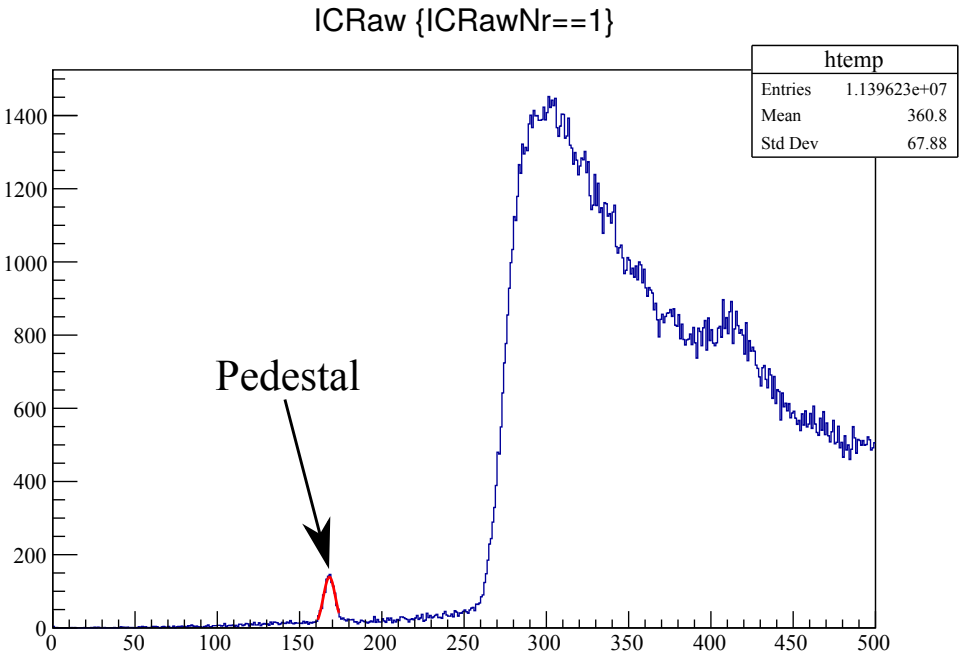

FIGURE 12 – pedestals determination for IC[1]

We then need to adjust the gain of each pad. As for the previous steps, for initialize the gains, one can use the one of the experiment, located in the file ConfVAMOS/Calibs/IC.cal, where one can found for each pad a_0, a_1, a_2 (not necessary, at least at the beginning), and a global scale parameter : 0.03. The initial gain you need to use is thus $a_1 \times 0.03$.

The adjustment of the 6 α_{in} coefficients will then be done by looking at the $QvsM/Q$ matrix. The goal is to obtain the Q lines the more flat possible, centered on an integer value (in the e706 experiment, Q distributions are centered around Q=29,30). Fig. 13 represents this $QvsM/Q$ matrix using the initial calibration parameters (left), and after the calibration parameters adjustment.

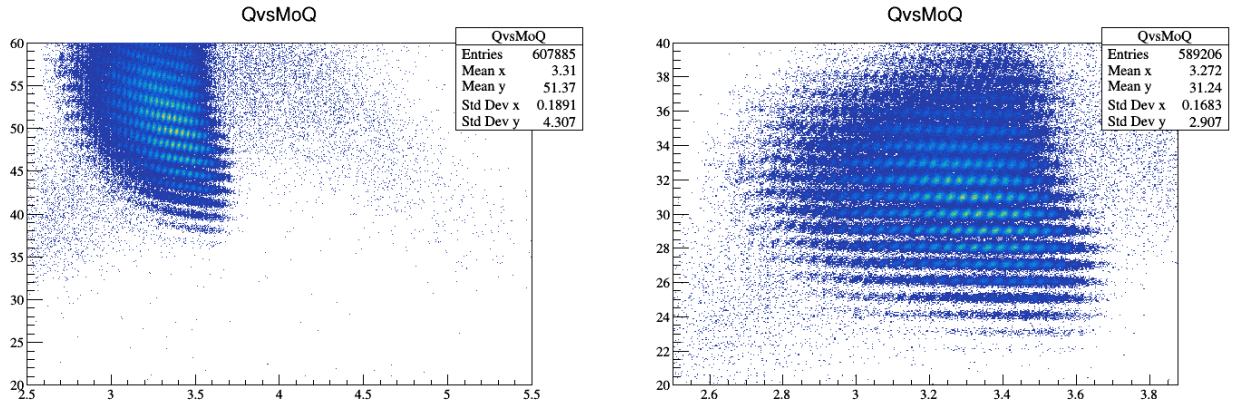

FIGURE 13 – $QvsM/Q$ matrix using the initial calibration parameters (left), and after the calibration parameters adjustment

Once the $QvsM/Q$ matrix is well aligned, we still cannot be sure that we are correctly aligned on the good M/Q peaks, and on the good charge state value. To confirm this, we need to check the gamma spectra. We thus need to find a gamma spectrum corresponding to a well known nucleus, easy to identify ($^{100}_{40}$Zr is my favorite !). We need first to make a Z selection on the ΔE-E matrix, where ΔE

represented the energy deposited in the three first pads :

$$\Delta E(P_i) = \sum_{n=0}^{3} (IC[i + 5 \times n] + rdn - pedestal) \times \alpha_{in} \quad (MeV),$$

and E, the total P_i energy.

By doing a *TCutG* selection on the ΔE-E matrix, we select a Z (the most intense should correspond to $Z = 40$), and we then plot the $QvsM/Q$ matrix, for events in this Z selection. Fig. 14 represents on the left the ΔE-E matrix (restricted on nuclei that have deposit energy up to $P_j = 3$ for MW 7, with the over-imposed Z selection (in red), and on the right the $QvsM/Q$ matrix for events in the Z selection, with an over-imposed mass selection on the most intense charge state (in red). On this last plot, each blob for a given charge state corresponds to a specific mass. The graphical selection on a blob is thus made on a mass. The goal is to find the gamma distribution of your favorite nucleus ($^{100}_{40}$Zr in my case), by adjusting the Z and M selections.

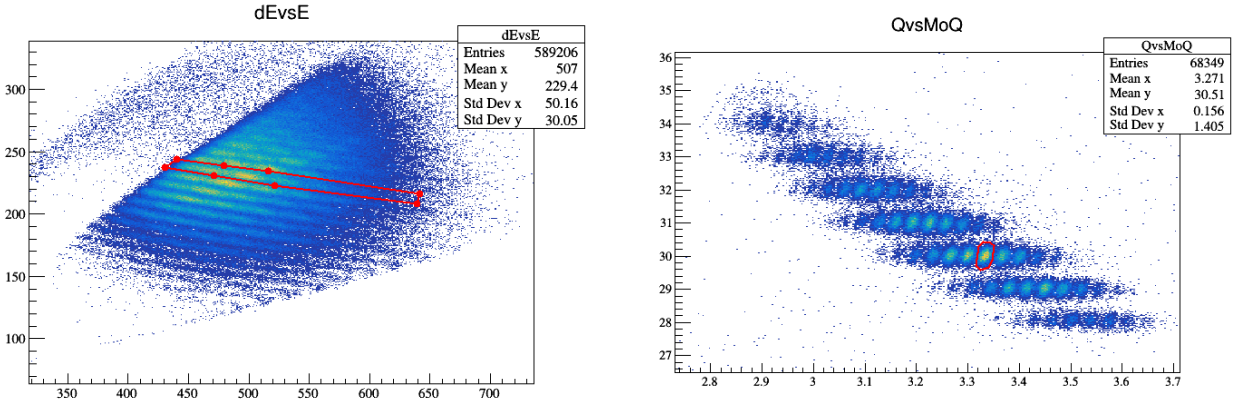

FIGURE 14 – (left) ΔE-E matrix (restricted on nuclei that have deposit energy up to $P_j = 3$ for MW 7, with the over-imposed Z selection (in red). (right) $QvsM/Q$ matrix for events in the Z selection, with an over-imposed mass selection on the most intense charge state (in red)

Figure 15 represents the Doppler corrected tracked gamma spectrum obtained according to the Z and M selections of Fig. 14. Its spectra well corresponds to the $^{100}_{40}$Zr nucleus. This means that I know the real mass, and I have all the information to check if my charge state and my time are well calibrated (I will not tell more about that, you need to play with the data).

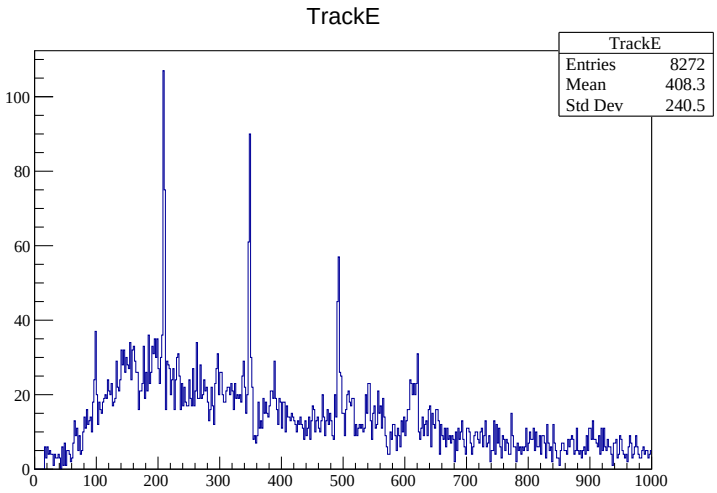

FIGURE 15 – Doppler corrected tracked gamma spectrum obtained according to the Z and M selections of Fig. 14.

Once your calibrations are good for the selected charge state, the next step is to adjust the gain of the TAC (and consequently to re-adjust the time offset, to be sure that all the masses are well aligned on there theoretical M/Q value). Once the gain is perfectly set, it must not be adapted for the other MW, only the offsets will be set MW per MW.

These operations needs to be done for each MW of the focal plane. The energy calibration only depends on the P_i, so for each Pi, start with the MW with the higher statistics to do the energy calibration, and then do the time alignments for each MW that are associated with this P_i.

5 Time corrections

The next step is the times corrections. Due to detectors effects, the time determination can be non-linear as a function of where the interaction appends in the detectors. The direct effect of such phenomenon is a bad M/Q determination. It is thus necessary to correct from these possible fluctuations. The corrections that need to be done are :

1. M/Q as a function of Y_f,
2. M/Q as a function of X_f,
3. M/Q as a function of $TMW1_{YWA}$,
4. M/Q as a function of $TMW1_{YWA}$

These corrections need to be done MW per MW and step by step. Indeed, the correction of M/Q as a function of Y_f will also clean some dependences to X_f. One thus need to correct for each MW M/Q as a function of Y_f, and after that passing to the next step... etc. To determine these corrections, it is necessary to plot M/Q versus the different variables, and to extract the correction factor (a scaling to apply) in order to have a straight $M/Q = 3$ or $M/Q = 4$ line. Figure 16 represents these matrices before (left) and after correction (right), for MW 5.

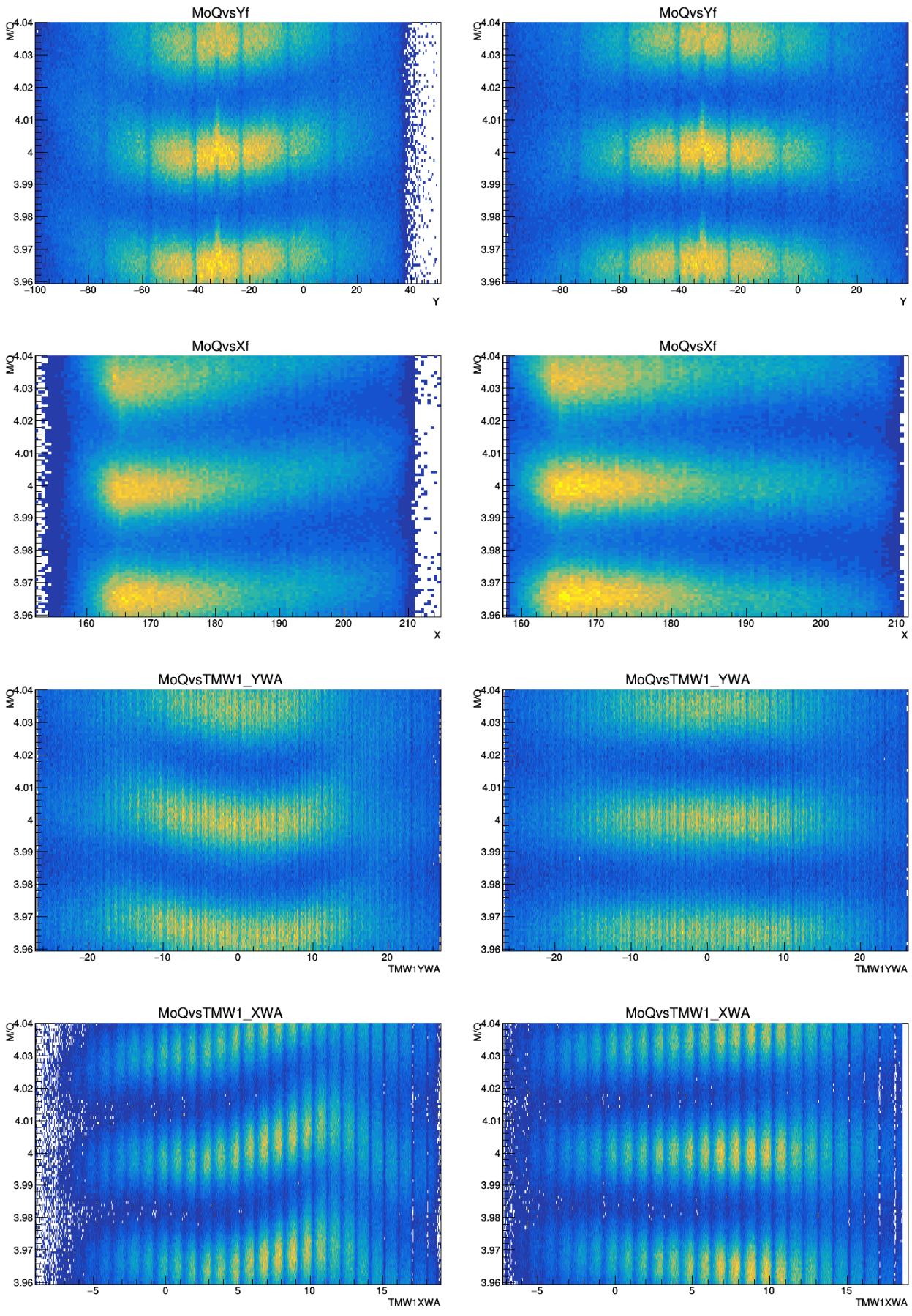

FIGURE 16 – Matrices before (left) and after correction (right), for MW 5.

Finally, it can be useful to check if the M/Q has been stable along time on the whole experiment. If not, a correction should be applied to take it into account.

Fig. 17 represents the comparison of the M/Q distributions before (blue) and after (red) the time corrections for MW 5. The effect of these corrections is very clear.

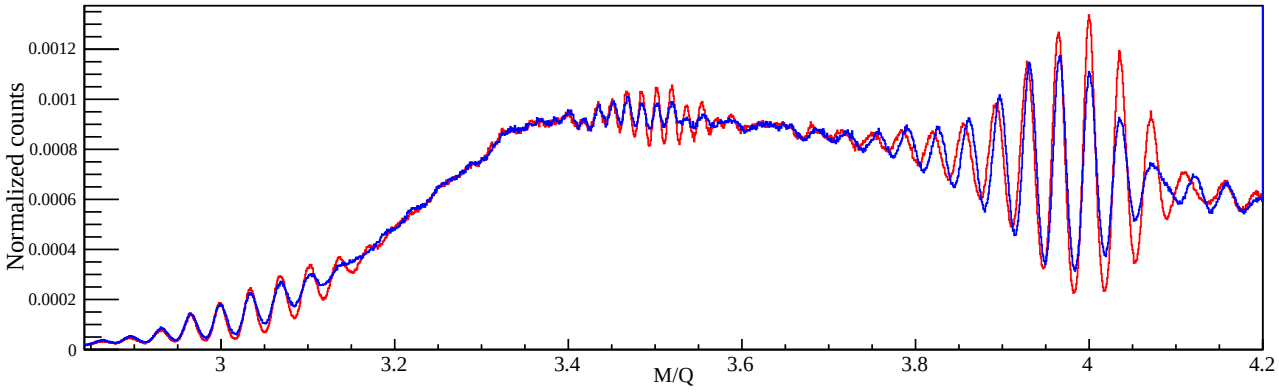

FIGURE 17 – Comparison of the M/Q distributions before (blue) and after (red) the time corrections for MW 5.

6 Energy corrections

Next step concerns energy corrections. Due to charge collection defaults, and to the shape of the Mylar window at the entrance of the ionization chamber which is deformed due to gas pressure, a correction of the energy needs to be applied along Y_f and X_f. The correction is different for ΔE and E, because these effects are not of the same amplitude whether we consider the whole pads, or only the first 2 or 3. For the total energy, the easier way to determine this correction is to follow the evolution of a charge state (which is proportional to the total energy) along Y_f and X_f. Figure **??** represents the evolution of the charge states along Y_f and X_f before (left) and after (right) correction for IC 1.

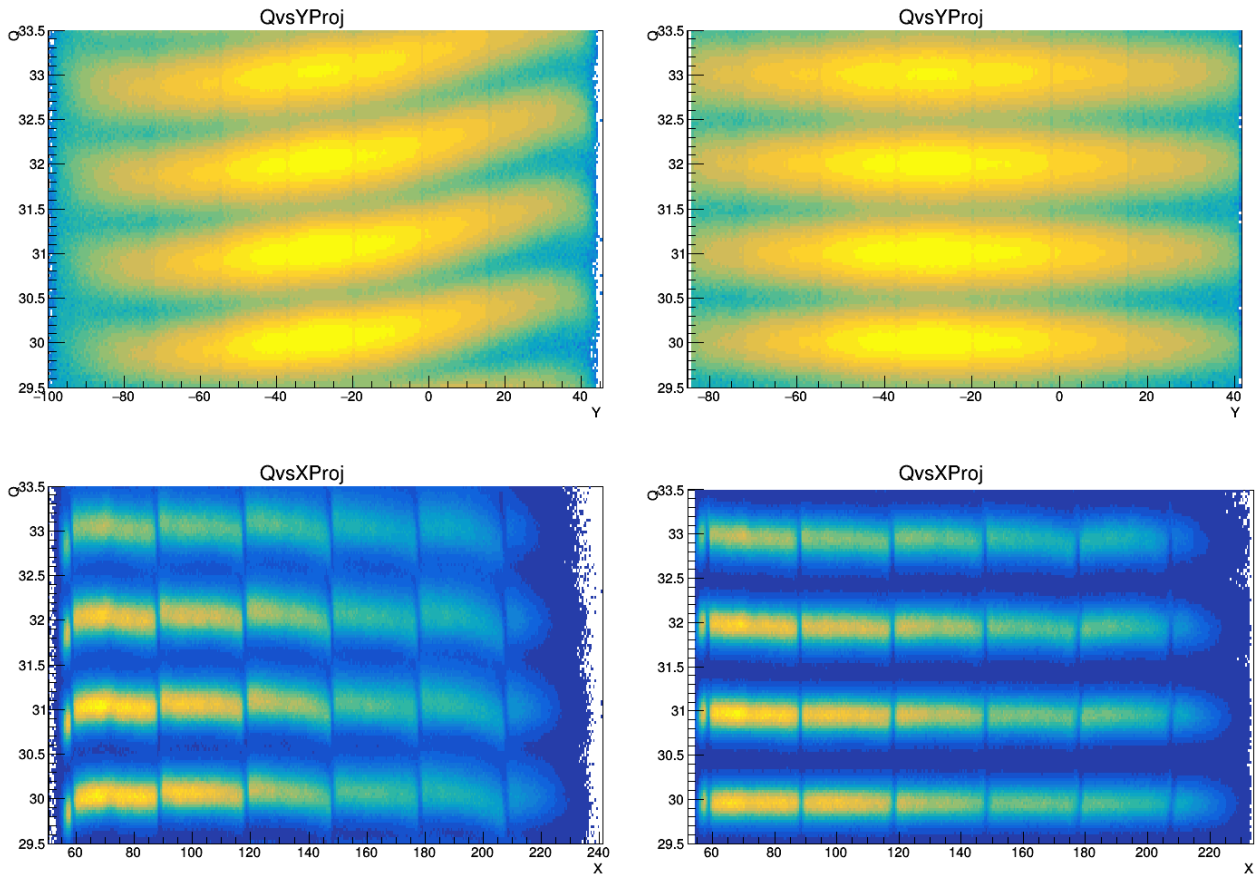

FIGURE 18 – Matrices before (left) and after Q correction (right), for IC 1.

For the ΔE corrections, we have not such simple thing like a charge state value to follow. The method is to use the position of a Z line on the ΔE-β matrix. This is an other possibility to extract the Z lines. The resolution is worse than in ΔE-E method, but have the advantage to be independent of the total energy, which is better for the correction. Figure 19 represents the ΔE-β matrix for IC 1 (left) and its projection (right) around a β value (red zone of left part).

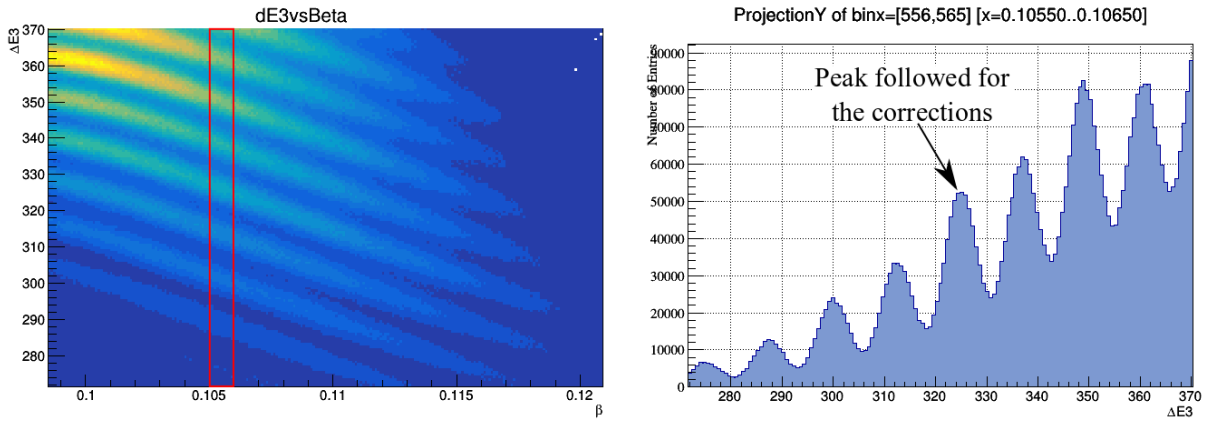

FIGURE 19 – ΔE-β matrix for IC 1 (left) and its projection (right) around a β value (red zone of left part).

As the line are not straight, we need this projection to be able to follow a peak corresponding to a Z value, otherwise, the different lines would be mixed on the total projection. Once this is done, we

can select a peak to follow along Y_f and X_f. Figure 20 represents the evolution of the Z selected peak along Y_f and X_f before (left) and after (right) correction for IC 1.

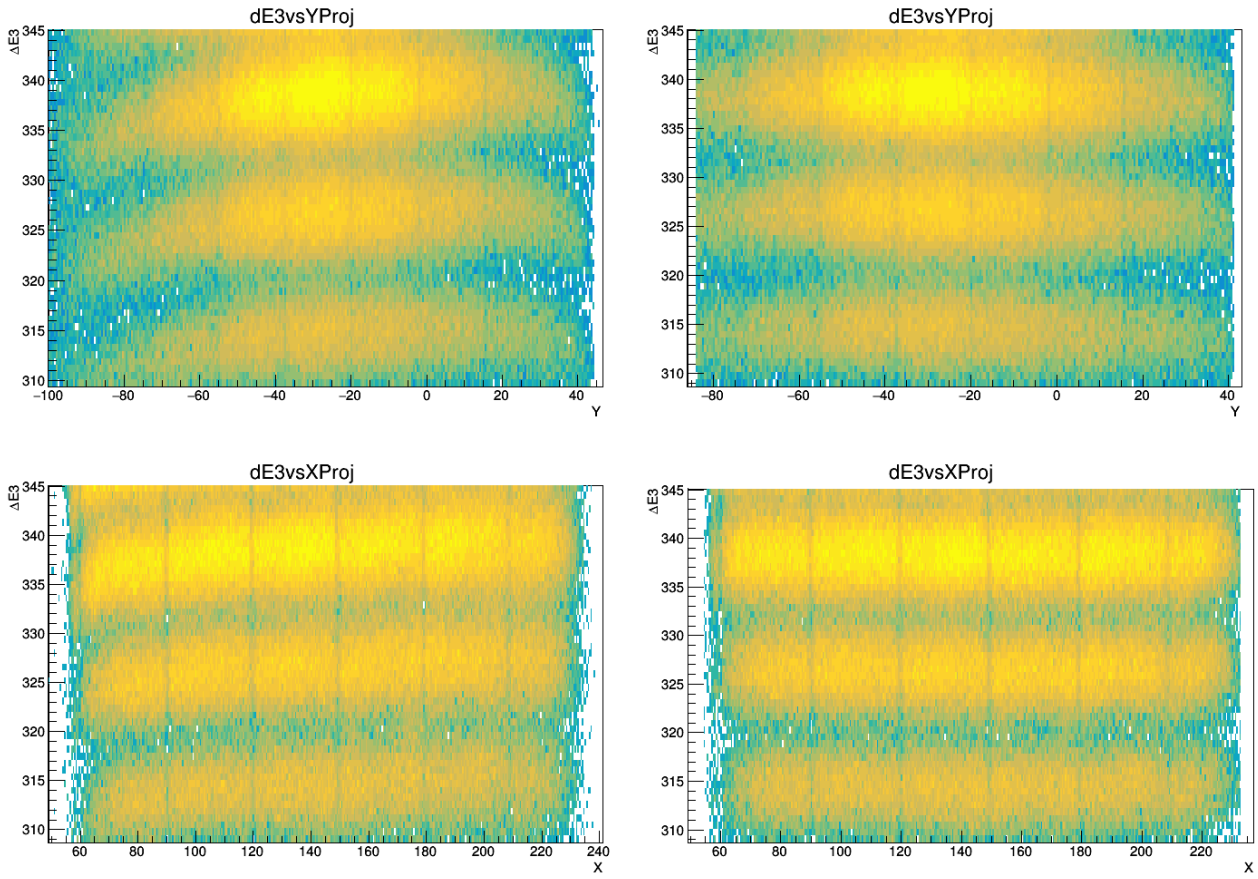

FIGURE 20 – Matrices before (left) and after ΔE correction (right), for IC 1.

As for the time corrections, it is necessary to check the stability of these values on the whole experiment. If not, a correction should be applied to take it into account.

Fig. 21 represents the comparison of the charge state (left) and ΔE projected on a β cut (right) distributions before (blue) and after (red) the energy corrections for IC 1.

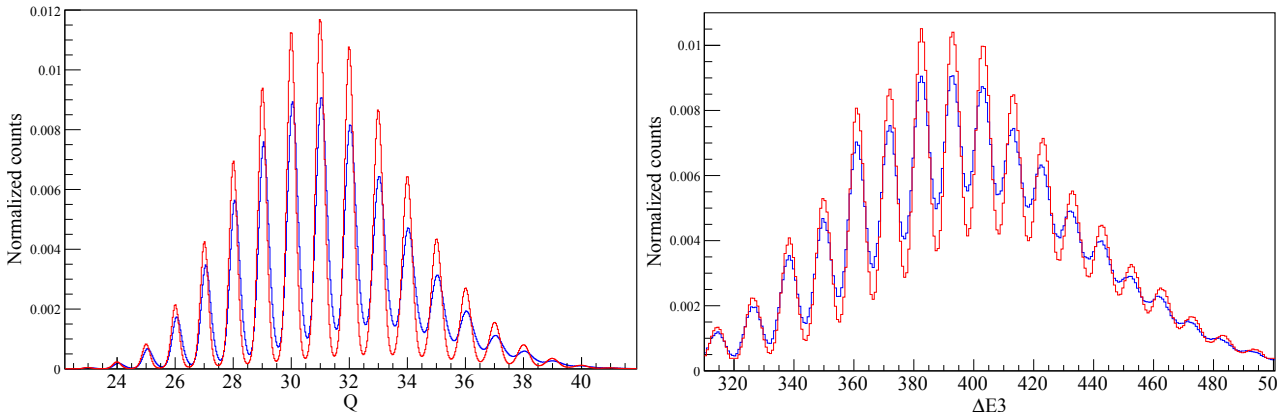

FIGURE 21 – Comparison of the charge state (left) and ΔE projected on a β cut (right) distributions before (blue) and after (red) the energy corrections for IC 1.