Accuracy of $Q_{\mathrm{VEM}}^{\mathrm{Peak}}$ fit for UB and UUB

Mauricio Suárez-Durán and Ioana C. Mariş

Université Libre de Bruxelles, Belgium

Abstract

From the installation of the Upgraded Unified Board (UUB) is expected to have a better accuracy for the estimation of the $Q_{\mathrm{VEM}}^{\mathrm{Peak}}$ values respect of the previous Unified Board (UB). Here, the process to calculate the accuracy of the $Q_{\mathrm{VEM}}^{\mathrm{Peak}}$ values for the UUB and UB is presented, and the results of its application on 80 UUB stations, and their respective UB version, are showed.
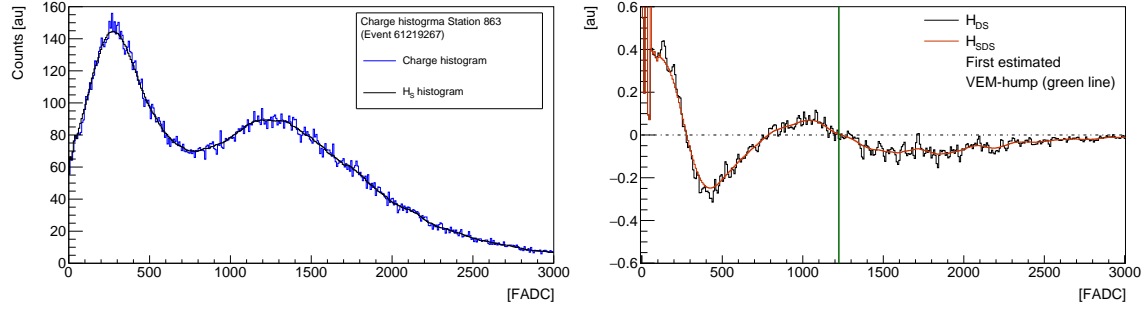
Figure 1: Algorithm's steps applied to get the $Q_{\text{VEM}}^{\text{Peak}}$ from the calibration histograms. Left: typical charge calibration histogram, where the black line represents the smoothing histogram (H_S) after applying 15-bin sliding window. Right: first derivative histogram (H_{DS}) in black, and smoothing of this last one in red (H_{SDS}); here, the green vertical line shows the maximum or the first approach of $Q_{\text{VEM}}^{\text{Peak}}$.

1 Fitting histograms

The $Q_{\text{VEM}}^{\text{Peak}}$ value is obtained from the charge calibration histogram, an algorithm based on the first derivative has been implemented and applied. The goal of this procedure is to estimate the $Q_{\text{VEM}}^{\text{Peak}}$ as the maximum of a second order polynomial, fitting the respective hump muon. In this sense, the first derivative of the histogram works as first approach to locate this hump, and from there to estimate the fit range. This algorithm is described below, and showed in figure 1:

1. Smoothing the histogram using a 15-bin sliding window, H_S.

2. Obtaining the first derivative of the H_S, by

$$\frac{f(x+1) - f(x-1)}{2h} \, , \tag{1}$$

   which is called H_{DS}.

3. Smoothing H_{DS}, by 15-bin sliding window, and obtaining H_{SDS}.

4. Searching for the estimated $Q_{\text{VEM}}^{\text{Peak}}$, i.e. first bin for H_{SDS} equal to zero, from right to left.

5. Fixing the fitting range using n-bin leftward and n-bin rightward from the estimated $Q_{\text{VEM}}^{\text{Peak}}$.

The last algorithm' step requires an extra procedure in order to fixed the number of n-bin. Using a set of histograms, the stability of the fit (in terms of RMS/$\left\langle Q_{\text{VEM}}^{\text{Peak}} \right\rangle$) was plotted as a function of the n-bin. For this, the estimated $Q_{\text{VEM}}^{\text{Peak}}$ from the derivative (step 4.) was used as initial parameter, and from this point, a number of n-bin was fixed with an extra condition of not reaching the valley of the histogram. Finally, the RMS/$\left\langle Q_{\text{VEM}}^{\text{Peak}} \right\rangle$ vs n-bin was plotted, and it is presented in the first row of figure 2. There, the stability of the fit is seen at and after 30-bin, and this last one is chosen as the number of n-bin for the algorithm' step 5. In the bottom row of figure 2, an example of applying this procedure is presented. Section 3 contains the $Q_{\text{VEM}}^{\text{Peak}}$ values obtained by this method from 75 UUB stations and for the same stations but in UB version (using the same algorithm).
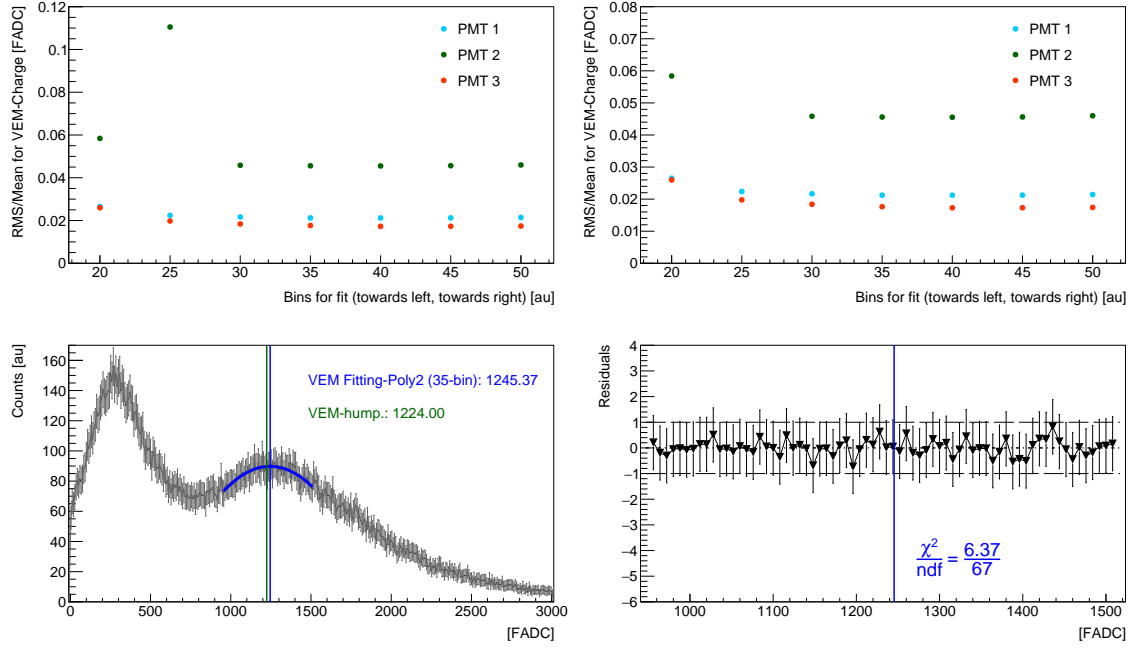
Figure 2: Top row, results for the stability of fitting the hump muon (RMS/$\langle Q_{\text{VEM}}^{\text{Peak}} \rangle$) as function of the n-bin. After 30 bins the stability is reached. Bottom row, an example of applying the algorithm; here the vertical green line shows the hump VEM obtained from the first derivative (step 4.), and the vertical blue line shows the $Q_{\text{VEM}}^{\text{Peak}}$ obtained as the maximum of the fitted second order polynomial.

2 Accuracy calculation

For the calculation of the $Q_{\text{VEM}}^{\text{Peak}}$ accuracy, each of one of these values was normalized respect the average of the respective PMT-$Q_{\text{Dist}}^{\text{Pk}}$, and a single distribution is built by summing the respective three distributions. In this way, we obtain a distribution that represents the $Q_{\text{VEM}}^{\text{Peak}}$ normalized for each station. A Gauss function is fitted to this last distribution in order to the get the first two moments of the distribution, which are used to determine the accuracy, μ/σ.

With the aim of compare the accuracy both version, UUB and UB, the former procedure was applied to same stations before to become in UUB, i.e. from August 1st, to October 19th of 2018, UB, and from August 1st, to October 19th of 2021, UUB. Figure 3, top row, shows an example for the distribution of $Q_{\text{VEM}}^{\text{Peak}}$ values ($Q_{\text{Dist}}^{\text{Pk}}$) for station 1208, UUB and UB version, meanwhile bottom row shows the distribution for the $Q_{\text{VEM}}^{\text{Peak}}$ normalized.

For some PMTs, the $Q_{\text{Dist}}^{\text{Pk}}$ has more than one peak, this imply a wide distribution for the normalized values, as it can be seen in figure 4. To avoid this kind of distribution, a selection over the stations, and PMTs, was applied. This selection consisted of choosing a time window in which the $Q_{\text{VEM}}^{\text{Peak}}$ was constant, i.e. fitting a constant function and checking for a fit quality of $\chi^2/\text{ndf} < 1.0$. Those PMT-$Q_{\text{Dist}}^{\text{Pk}}$, for the respective station, that not agree with this criteria, were not taken in to the account, for instance, if certain UB-PMT disagree, so the respective UUB-PMT was ignore too, and vice versa. In section 3 the $Q_{\text{VEM}}^{\text{Peak}}$ as function of time, for all UUB stations, is presented. There, the stations with PMT-$Q_{\text{Dist}}^{\text{Pk}}$ selected are indicated. In total, 23 stations were chosen with 52 PMT-$Q_{\text{Dist}}^{\text{Pk}}$, respectively.
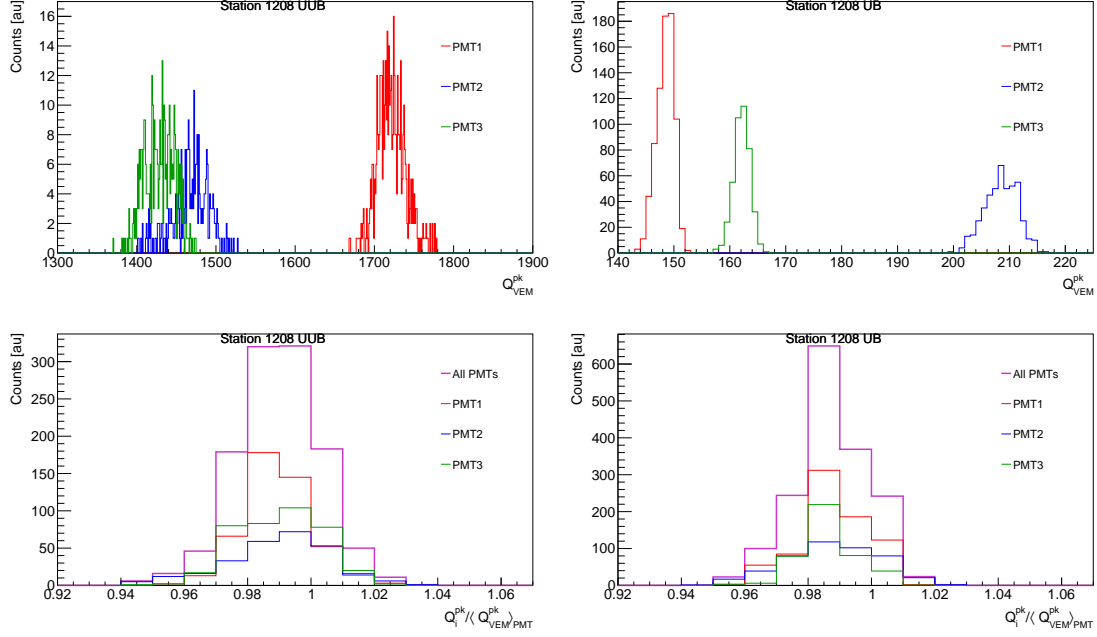
Figure 3: Upper row, distribution of the fitted $Q_{\text{VEM}}^{\text{Peak}}$ values ($Q_{\text{Dist}}^{\text{Pk}}$, in the plot) for station 1747, for each PMT (red PMT1, blue PMT2, and green PMT3), UUB (left) and UB (right) version. Lower row, For same station, results for $Q_{\text{VEM}}^{\text{Peak}}$ normalized respect the average of the respective PMTs. The magenta line represents the $Q_{\text{NormDist}}^{\text{Pk}}$, i.e. the sum of $Q_{\text{Dist}}^{\text{Pk}}$ with a RMS lower or equal to 1.3 times the σ of the preliminary distribution (see text for details). In red, a Gauss function fitted to $Q_{\text{NormDist}}^{\text{Pk}}$.

The upper row of figure 5 shows the results for the accuracy of the fitted $Q_{\text{VEM}}^{\text{Peak}}$ for the 23 chosen stations. In the left side, the accuracy is presented as function of station ID, and in right side the distribution for UUB and UB accuracy are presented. There, it can been seen that the mean for the accuracy ($\langle \sigma/\mu \rangle$) for UB is $1.08 \pm 0.06\,\%$, meanwhile for UUB this value is $1.20 \pm 0.06\,\%$. In the bottom row of the same figure, the difference between two accuracy, i.e. $(\sigma/\mu)_{\text{UB}} - (\sigma/\mu)_{\text{UUB}}$ is presented, as function of the station ID (left side), and the respective distribution of these differences (right side). As it can be seen, the mean of the this distribution is $-0.115 \pm 0.401\,\%$.
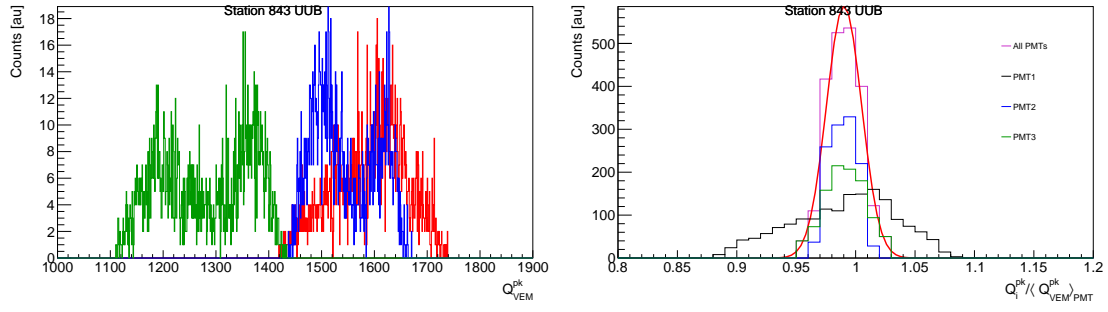
Figure 4: On left side, for station 843, $Q_{\text{Dist}}^{\text{Pk}}$ with more than one peak: PMTs 2 and 3, blue and green lines, respectively. The PMT1, red line, presents a wide distribution as can be seen on the right figure (black line). On the right, it is possible to see how the $Q_{\text{Dist}}^{\text{Pk}}$ for PMT1 is discarded to build the $Q_{\text{NormDist}}^{\text{Pk}}$ (magenta line). The red line corresponds to the Gauss function fitted to the latest distribution.
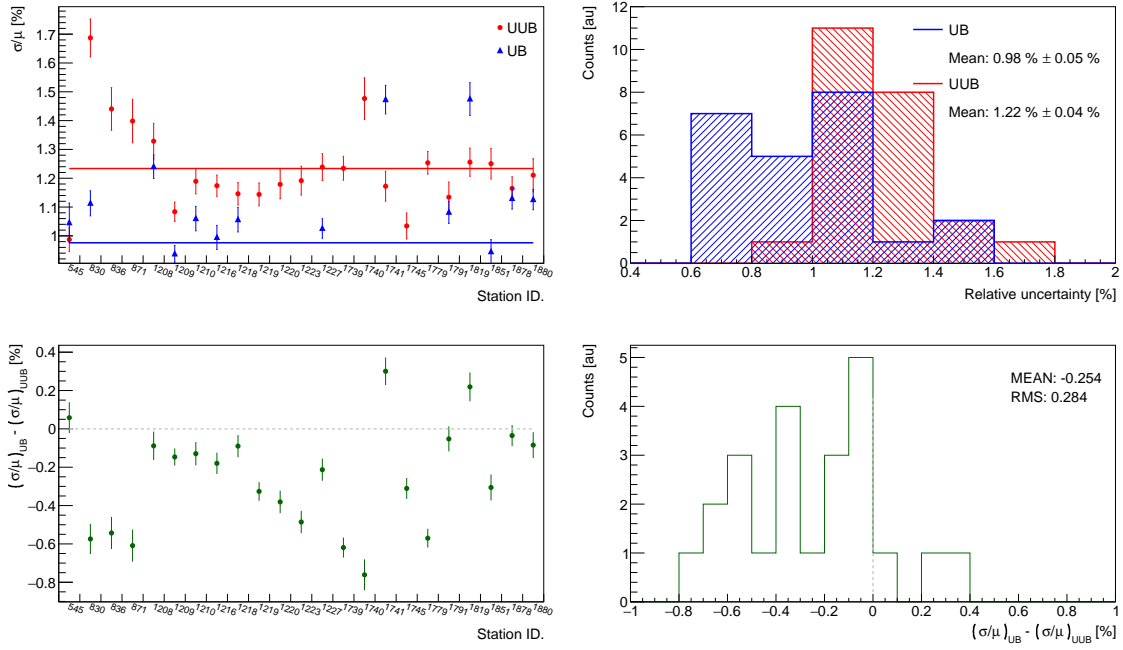
Hi.

Figure 5: Results for the accuracy of the Q_{VEM}^{Peak} fitting for 75 stations, UUB and UB. Upper row: in left side, the accuracy (σ/μ) is presented for each station. The horizontal lines represents the averages ($\langle\sigma/\mu\rangle$) for UUB (red line) and UB (blue line). In the right side, the distribution of the σ/μ values is presented for both version, UUB (red) and UB (blue). Bottom row: difference between the accuracy of UB and UUB, $(\sigma/\mu)_{UB} - (\sigma/\mu)_{UUB}$, left side as function of the station ID, right side the distribution of these values. Here, it is possible to see that the accuracy for UUB is better than the one for UB.

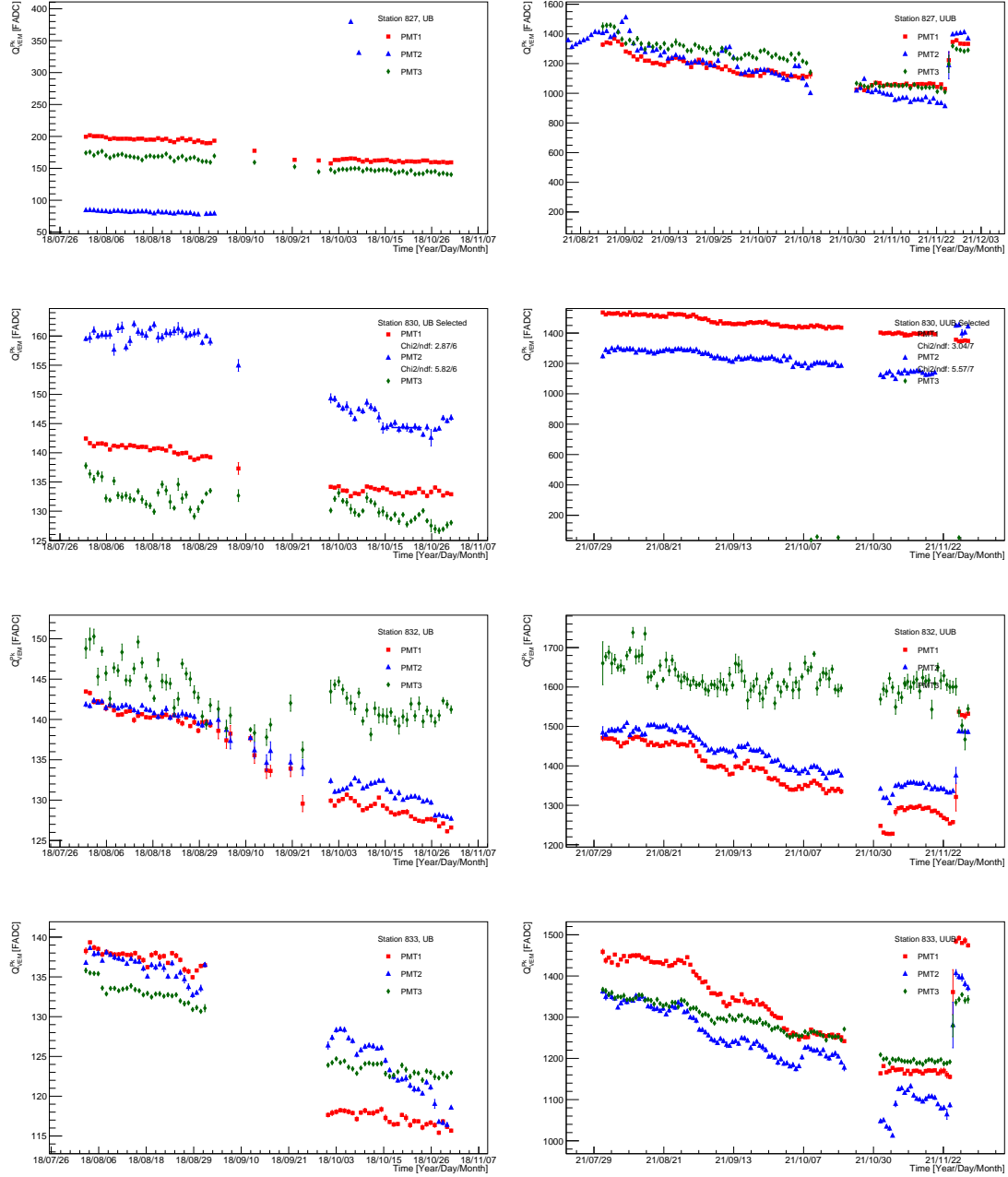# 3 $Q^{\text{Peak}}_{\text{VEM}}$ as function of time
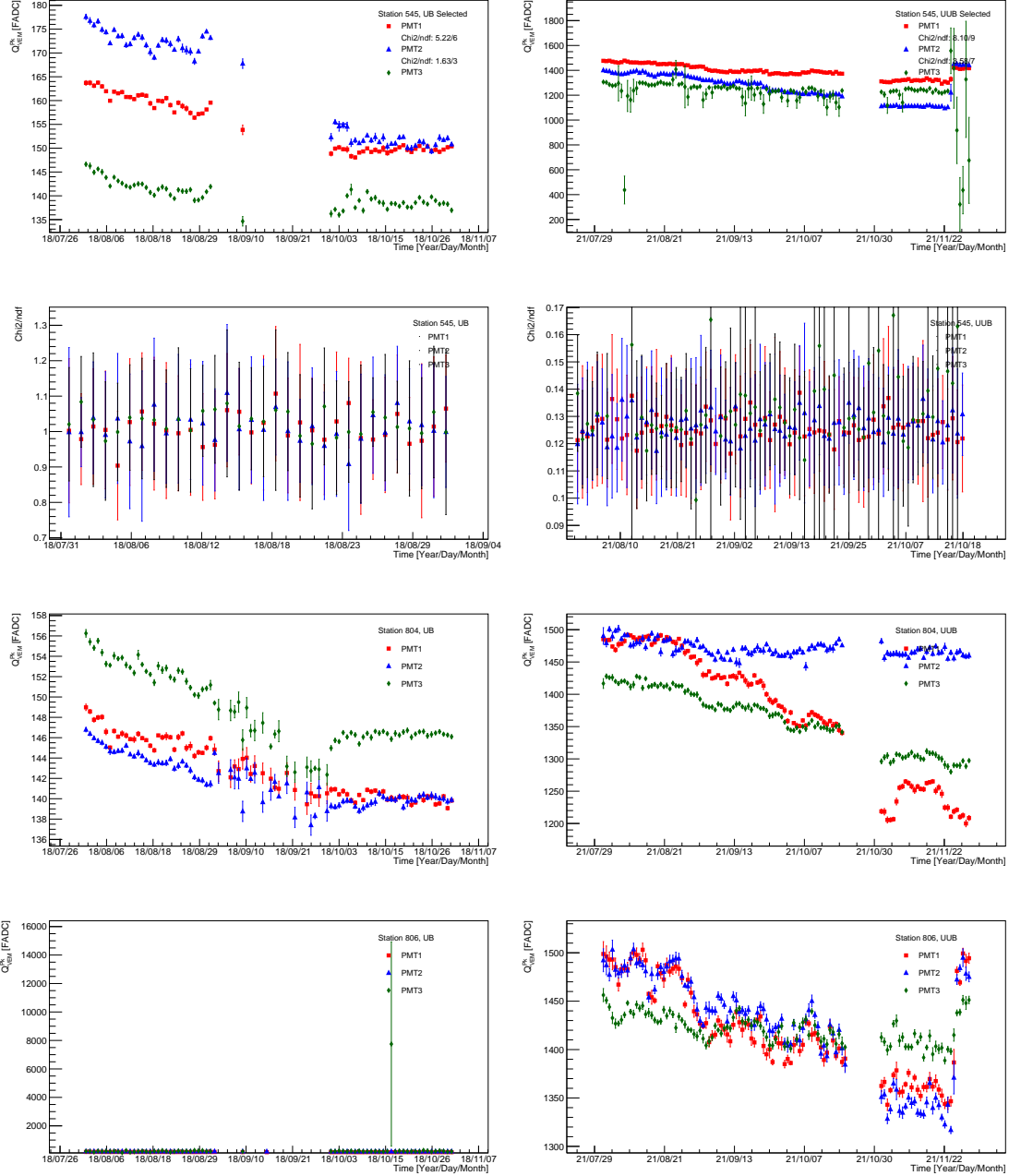
Figure 6: $Q^{\text{Peak}}_{\text{VEM}}$ values obtained applying the algorithm presented in section 1. The first row shows the average of the $Q^{\text{Peak}}_{\text{VEM}}$ per day plotting as function of time, for the station 545, left UB, and right UUB version. In the second raw, the quality of the respective fit (the average of χ^2/ndf per day), same station, is plotting as function of time. The third and fourth row present the same results as row 1, for stations 804 and 806. if the label "Selected" is seen, it means that some, or all, PMTs were chosen to calculate the accuracy of $Q^{\text{Peak}}_{\text{VEM}}$.
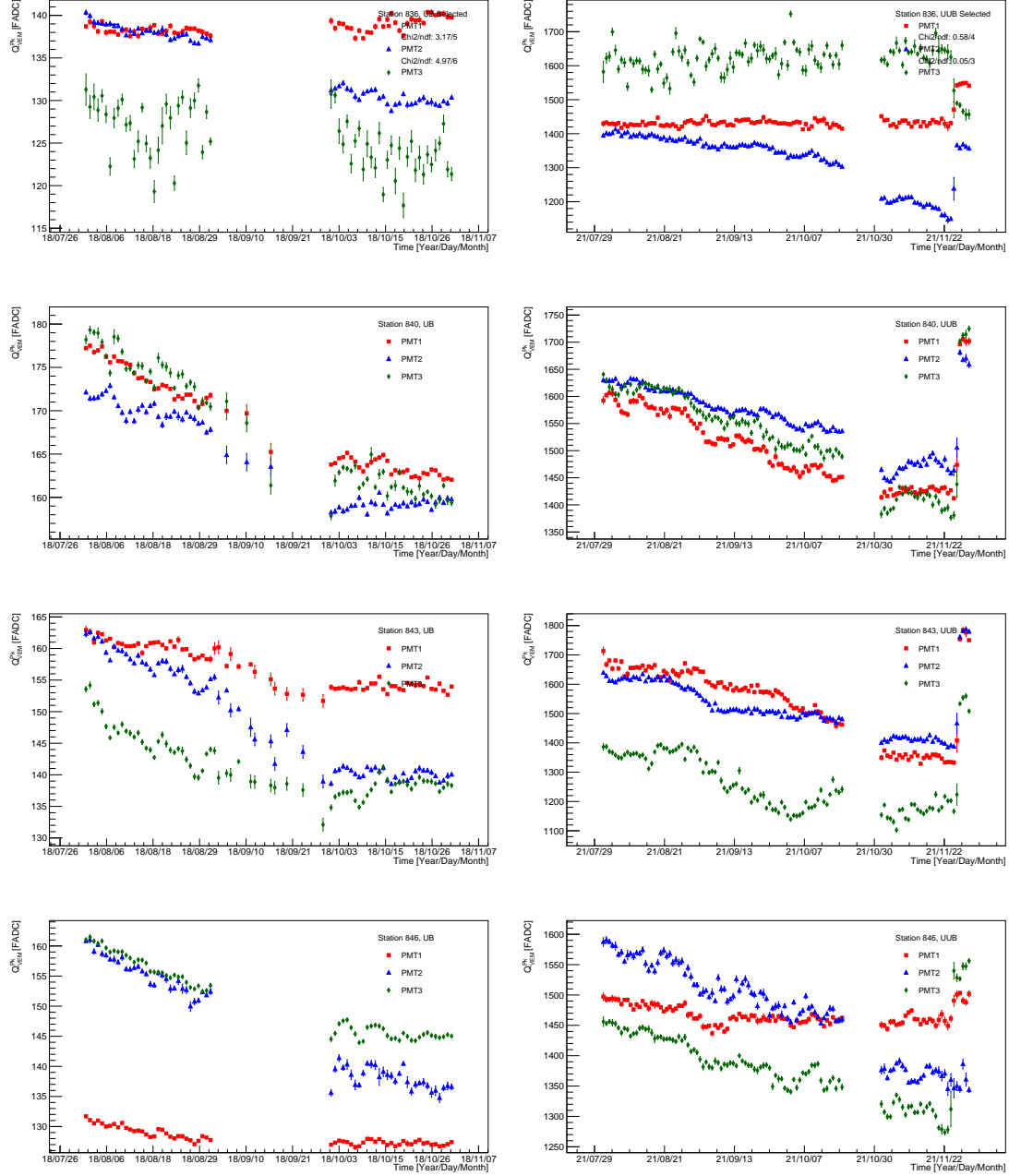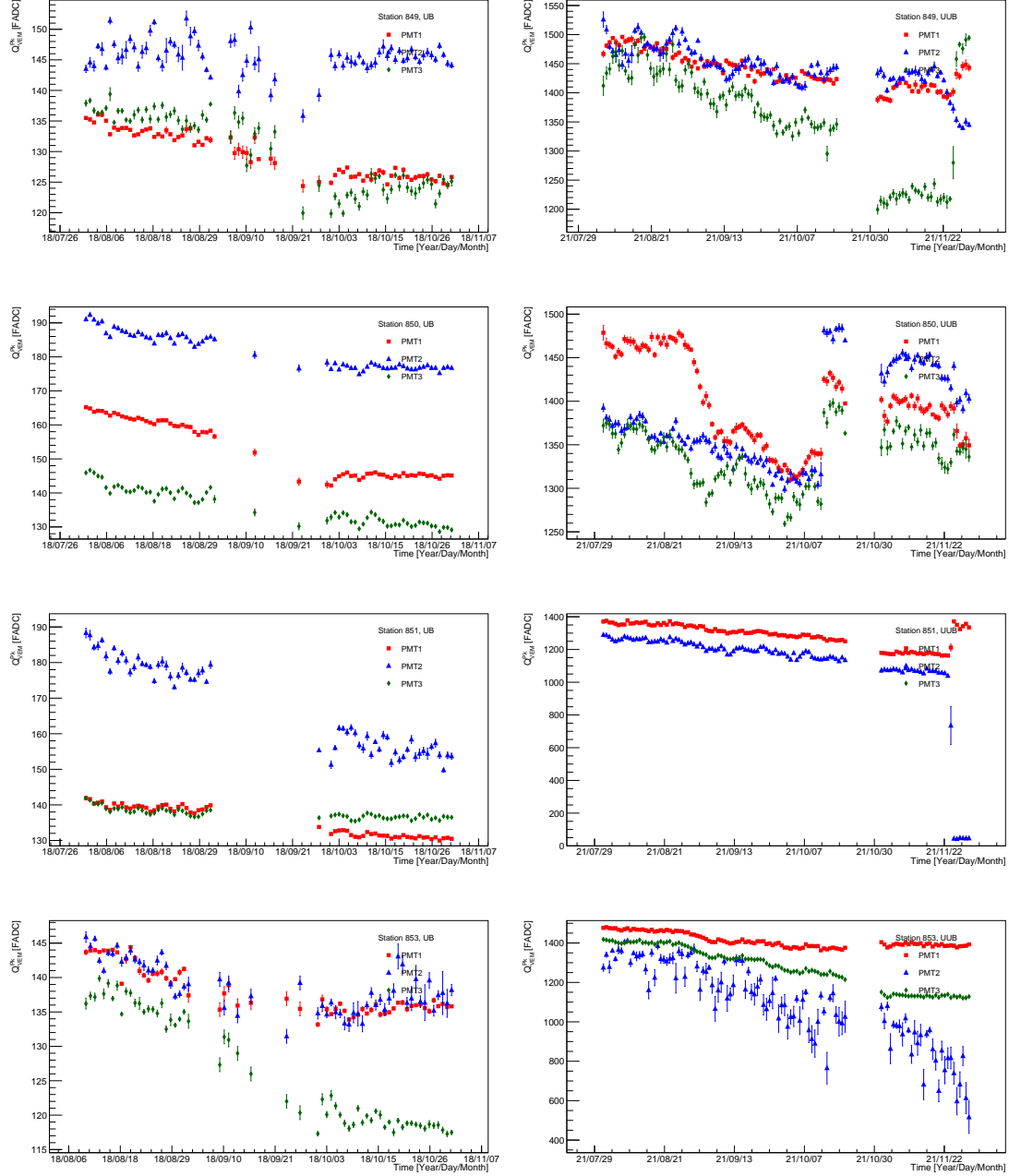
hi

Figure 7: Q_{VEM}^{Peak} values obtained applying the algorithm presented in section 1. Each row shows the average of the Q_{VEM}^{Peak} per day plotting as function of time, left UB, and right UUB version. If the label "Selected" is seen, it means that some, or all, PMTs were chosen to calculate the accuracy of Q_{VEM}^{Peak} .
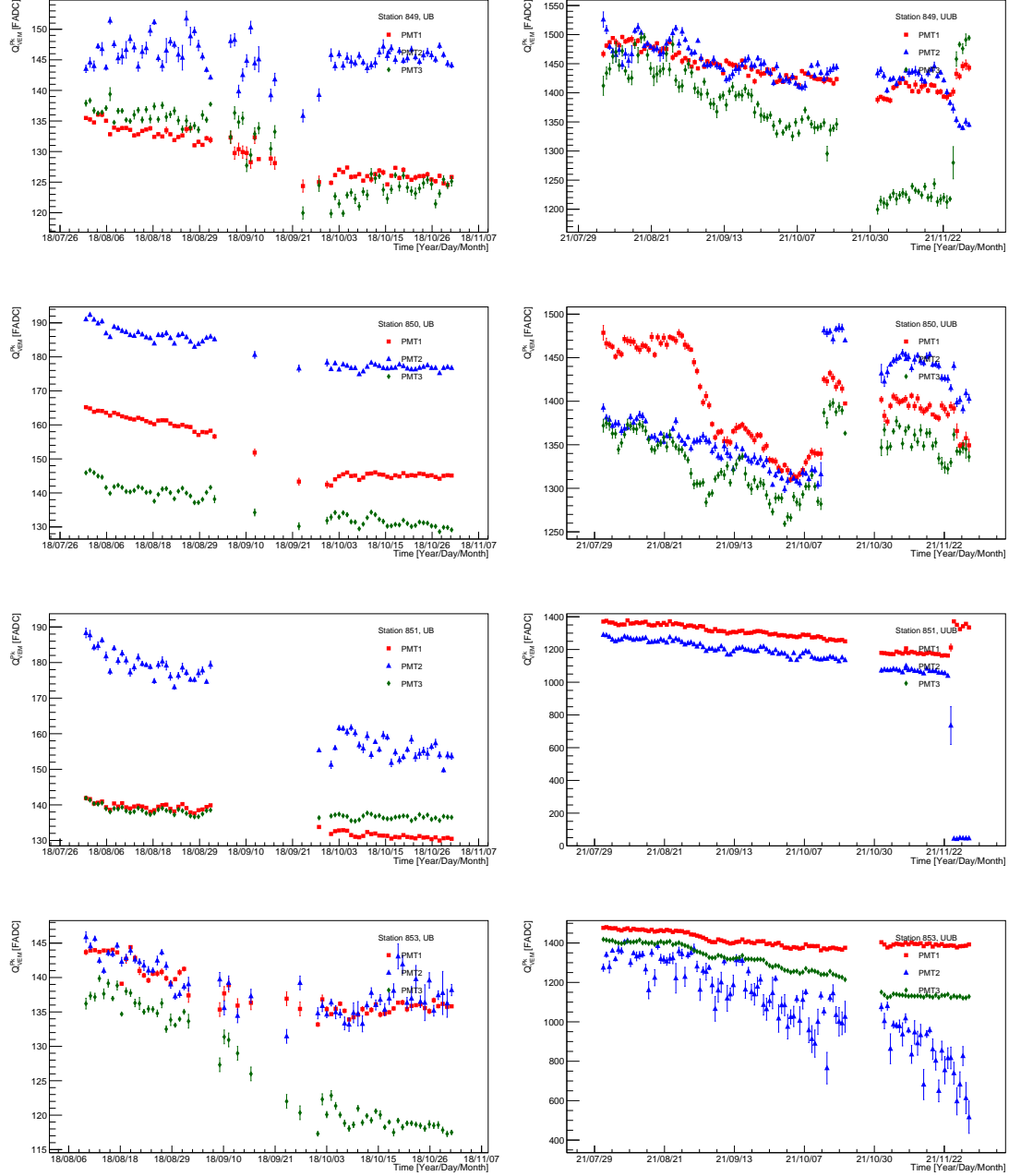
hi

Figure 8: Q_{VEM}^{Peak} values obtained applying the algorithm presented in section 1. Each row shows the average of the Q_{VEM}^{Peak} per day plotting as function of time, left UB, and right UUB version. If the label "Selected" is seen, it means that some, or all, PMTs were chosen to calculate the accuracy of Q_{VEM}^{Peak}.
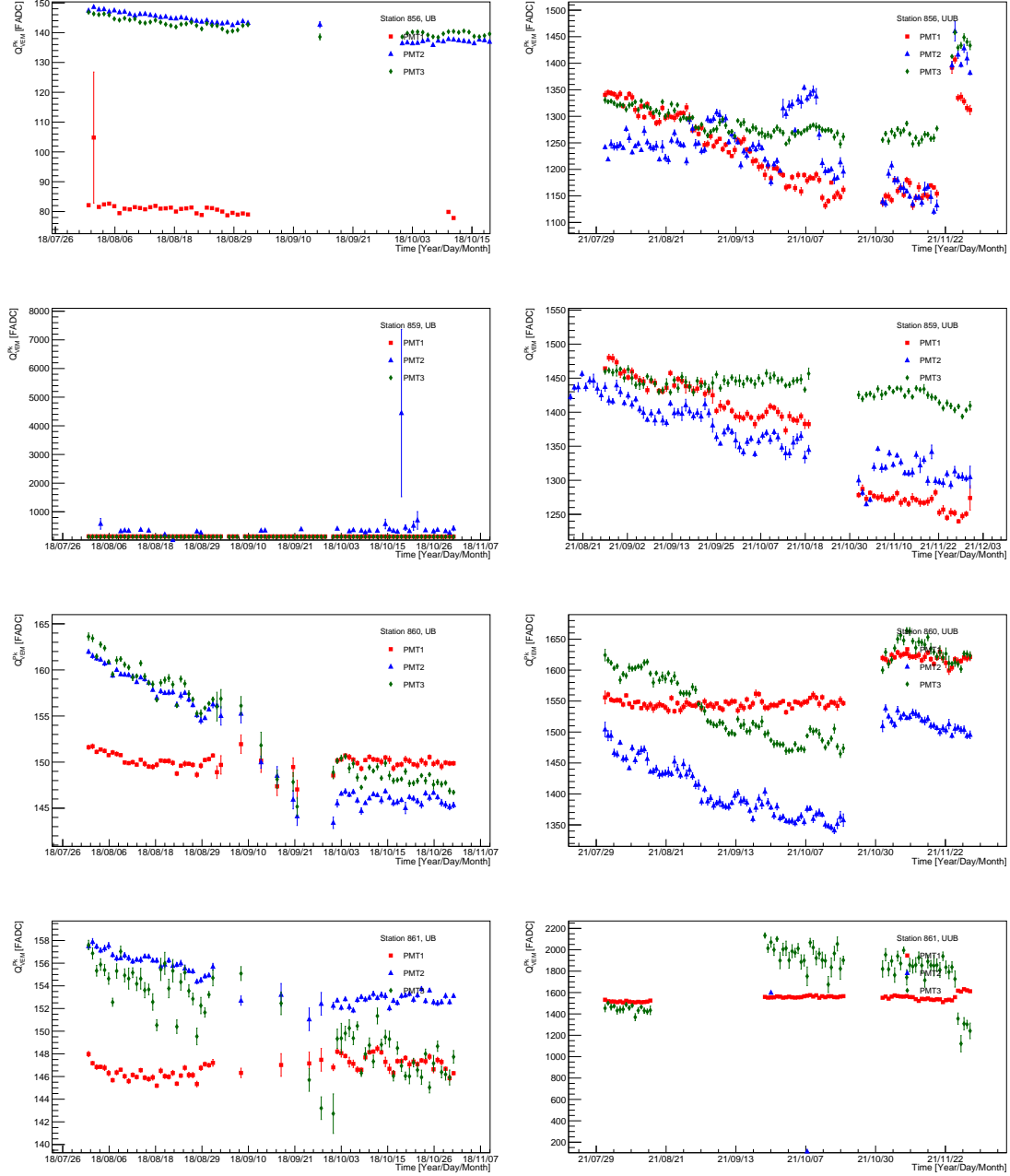
hi

Figure 9: Q_{VEM}^{Peak} values obtained applying the algorithm presented in section 1. Each row shows the average of the Q_{VEM}^{Peak} per day plotting as function of time, left UB, and right UUB version. If the label "Selected" is seen, it means that some, or all, PMTs were chosen to calculate the accuracy of Q_{VEM}^{Peak}.

10

hi

Figure 10: Q_{VEM}^{Peak} values obtained applying the algorithm presented in section 1. Each row shows the average of the Q_{VEM}^{Peak} per day plotting as function of time, left UB, and right UUB version. If the label "Selected" is seen, it means that some, or all, PMTs were chosen to calculate the accuracy of Q_{VEM}^{Peak}.
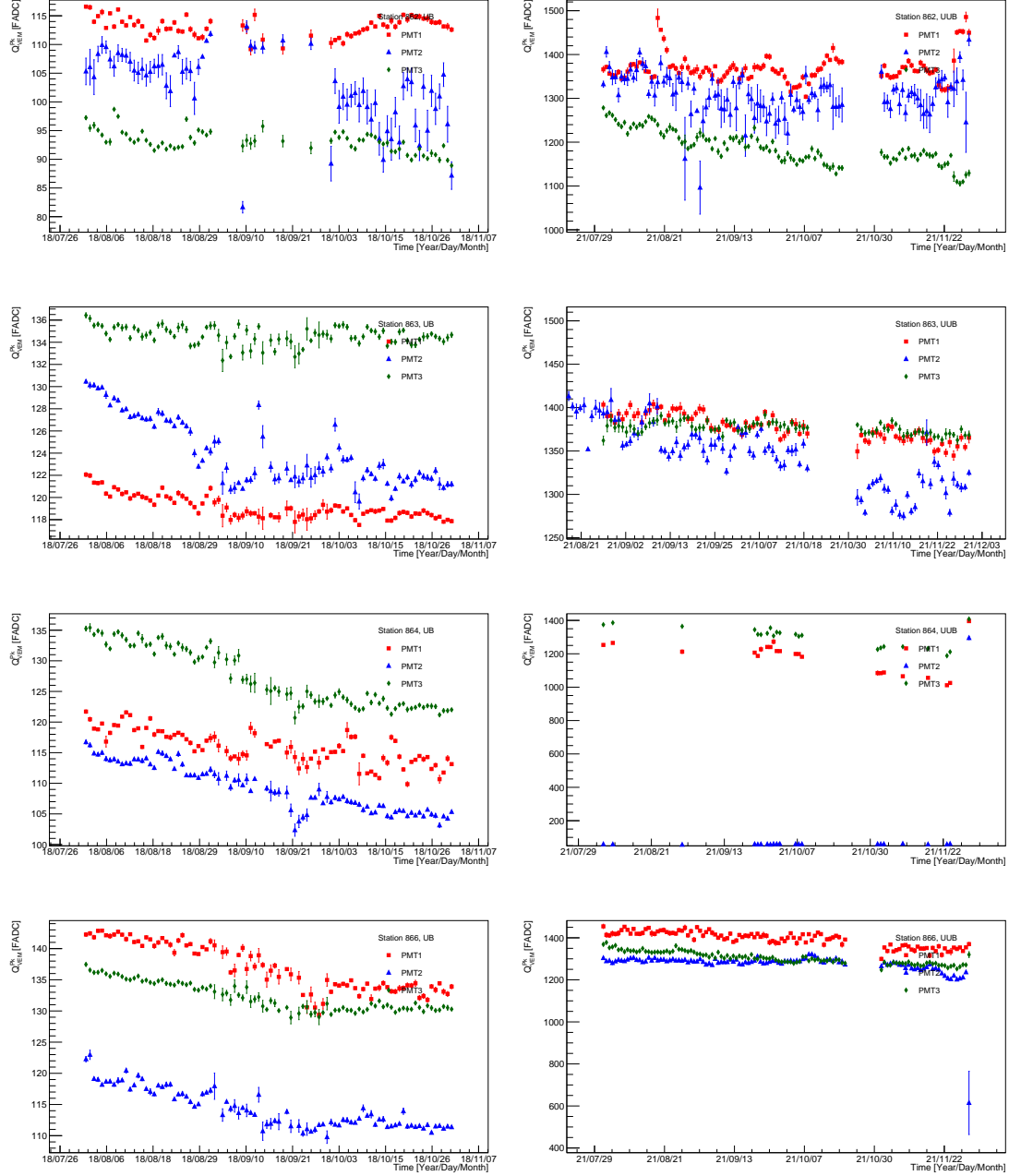
hi

Figure 11: Q_{VEM}^{Peak} values obtained applying the algorithm presented in section 1. Each row shows the average of the Q_{VEM}^{Peak} per day plotting as function of time, left UB, and right UUB version. If the label "Selected" is seen, it means that some, or all, PMTs were chosen to calculate the accuracy of Q_{VEM}^{Peak}.
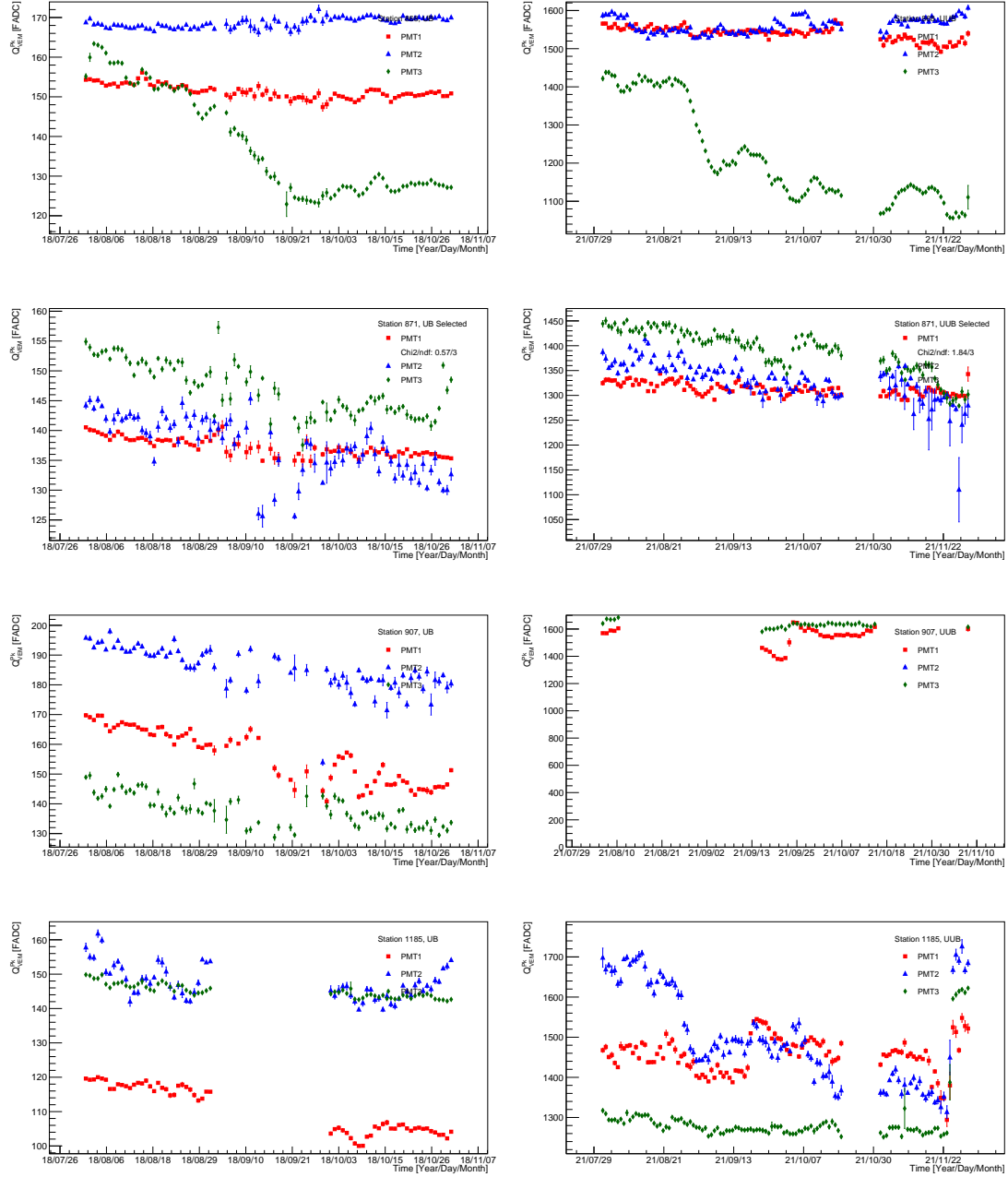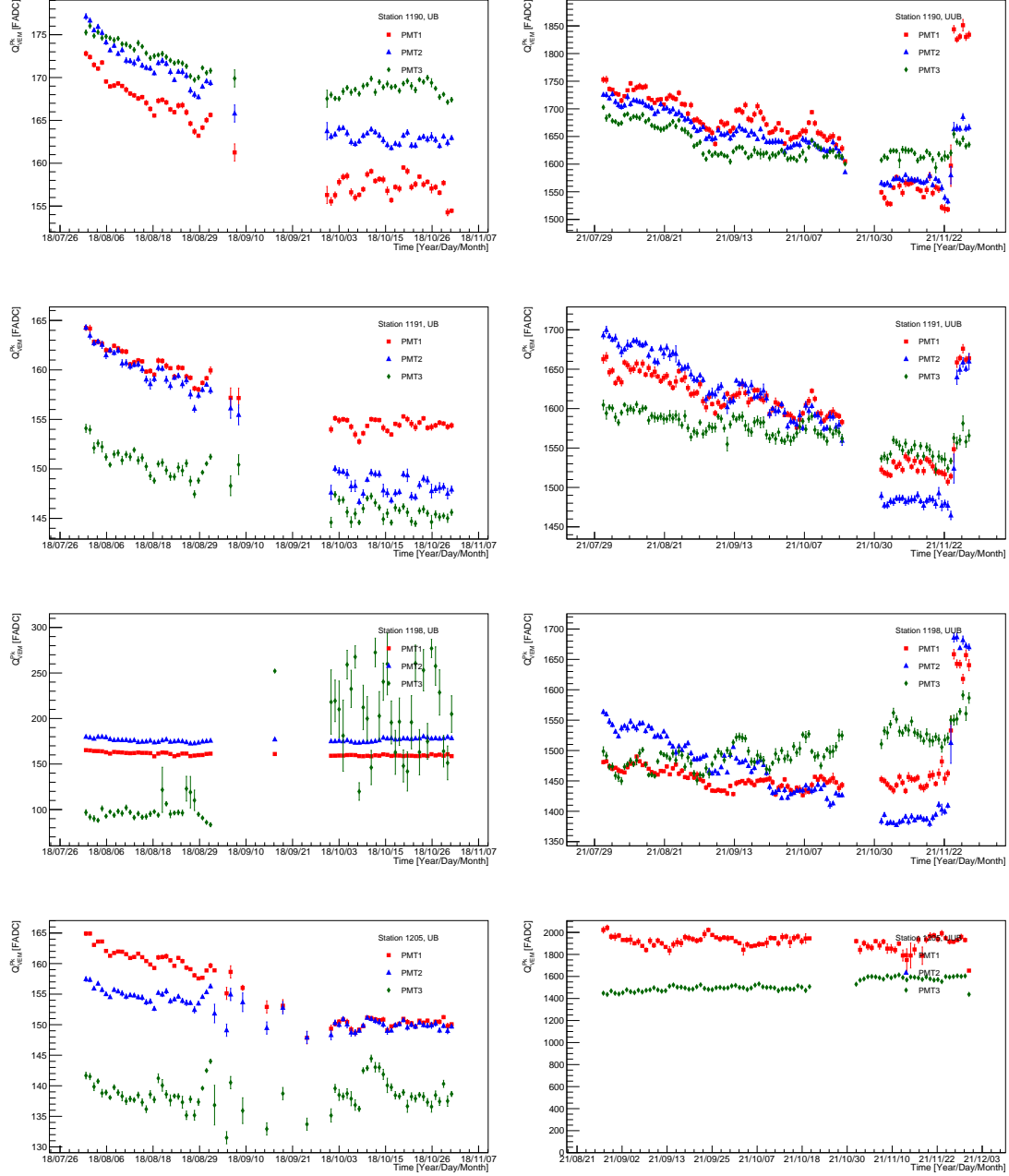
hi

Figure 12: $Q_{\text{VEM}}^{\text{Peak}}$ values obtained applying the algorithm presented in section 1. Each row shows the average of the $Q_{\text{VEM}}^{\text{Peak}}$ per day plotting as function of time, left UB, and right UUB version. If the label "Selected" is seen, it means that some, or all, PMTs were chosen to calculate the accuracy of $Q_{\text{VEM}}^{\text{Peak}}$.

hi

Figure 13: $Q_{\text{VEM}}^{\text{Peak}}$ values obtained applying the algorithm presented in section 1. Each row shows the average of the $Q_{\text{VEM}}^{\text{Peak}}$ per day plotting as function of time, left UB, and right UUB version. If the label "Selected" is seen, it means that some, or all, PMTs were chosen to calculate the accuracy of $Q_{\text{VEM}}^{\text{Peak}}$.
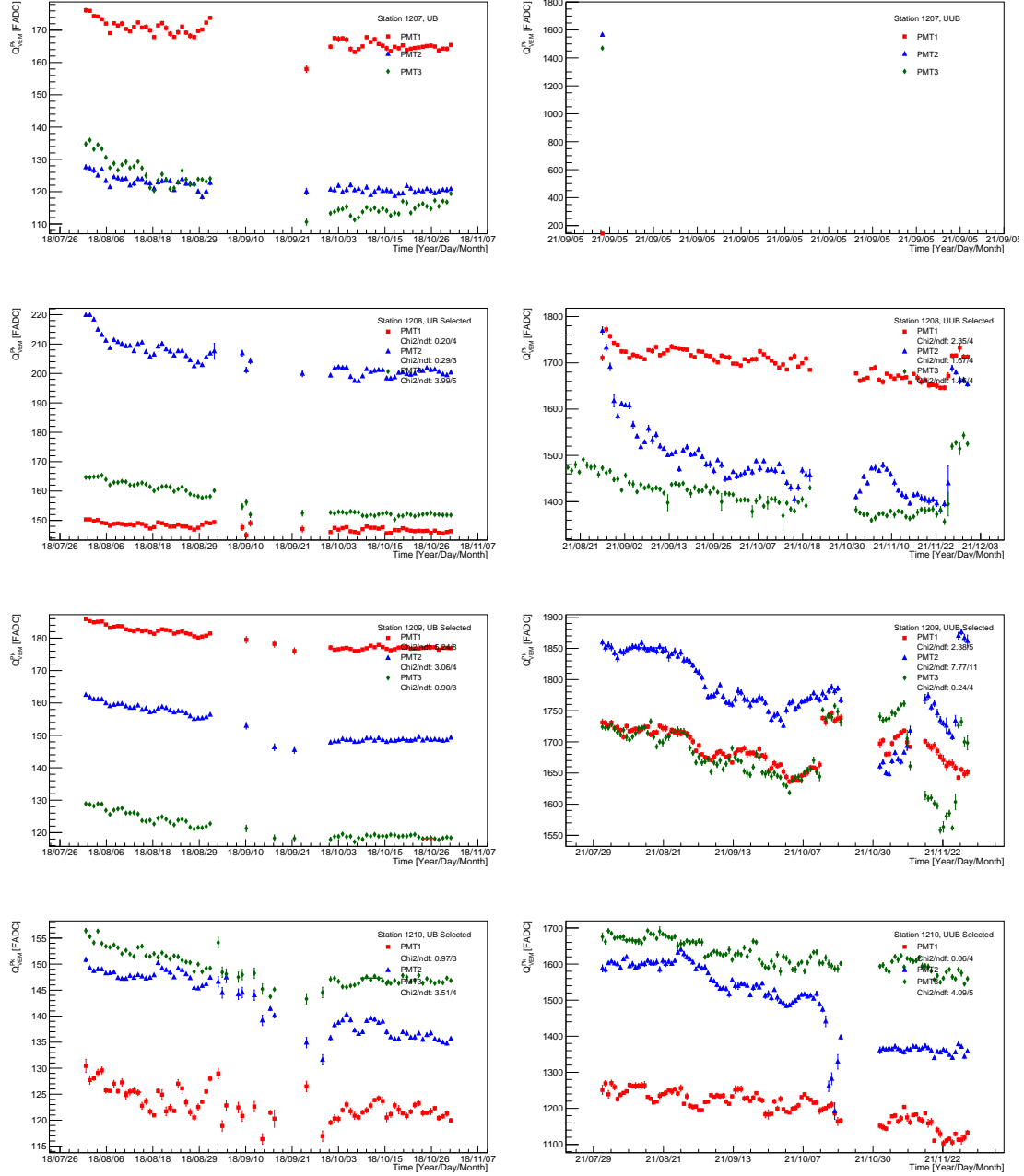
hi

Figure 14: $Q_{\text{VEM}}^{\text{Peak}}$ values obtained applying the algorithm presented in section 1. Each row shows the average of the $Q_{\text{VEM}}^{\text{Peak}}$ per day plotting as function of time, left UB, and right UUB version. If the label "Selected" is seen, it means that some, or all, PMTs were chosen to calculate the accuracy of $Q_{\text{VEM}}^{\text{Peak}}$.
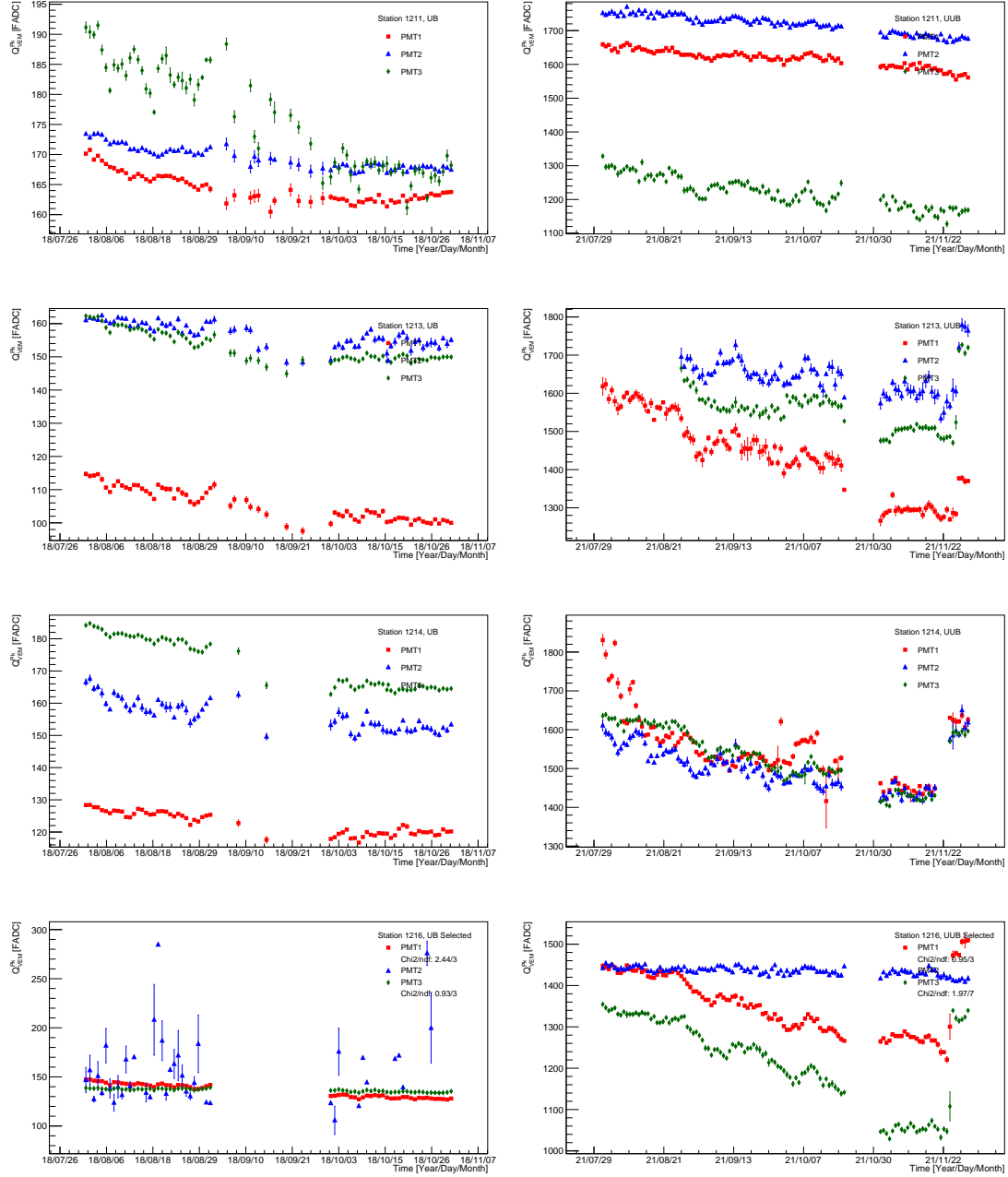
hi

Figure 15: $Q_{\text{VEM}}^{\text{Peak}}$ values obtained applying the algorithm presented in section 1. Each row shows the average of the $Q_{\text{VEM}}^{\text{Peak}}$ per day plotting as function of time, left UB, and right UUB version. If the label "Selected" is seen, it means that some, or all, PMTs were chosen to calculate the accuracy of $Q_{\text{VEM}}^{\text{Peak}}$.
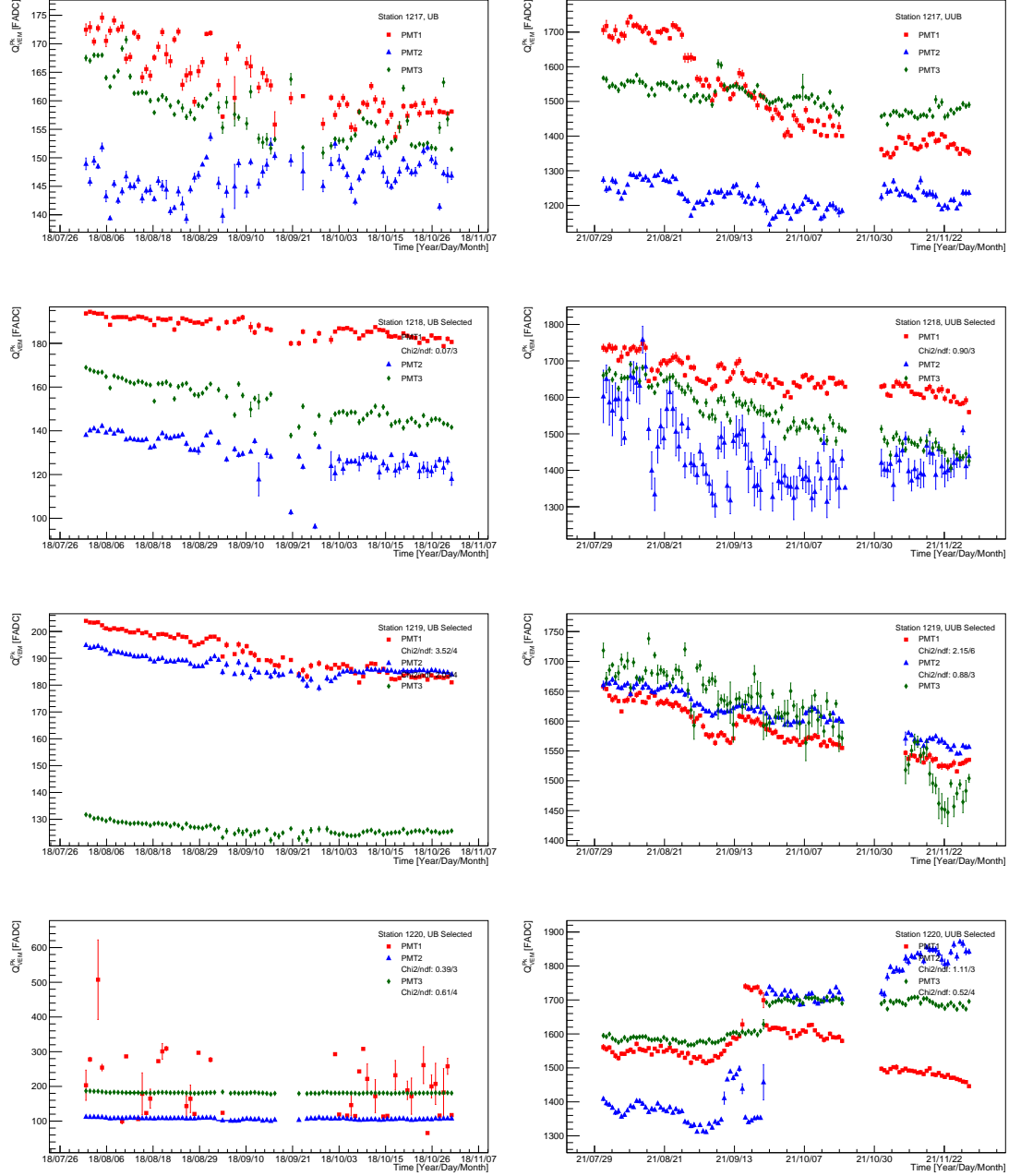
hi

Figure 16: Q_{VEM}^{Peak} values obtained applying the algorithm presented in section 1. Each row shows the average of the Q_{VEM}^{Peak} per day plotting as function of time, left UB, and right UUB version. If the label "Selected" is seen, it means that some, or all, PMTs were chosen to calculate the accuracy of Q_{VEM}^{Peak}.
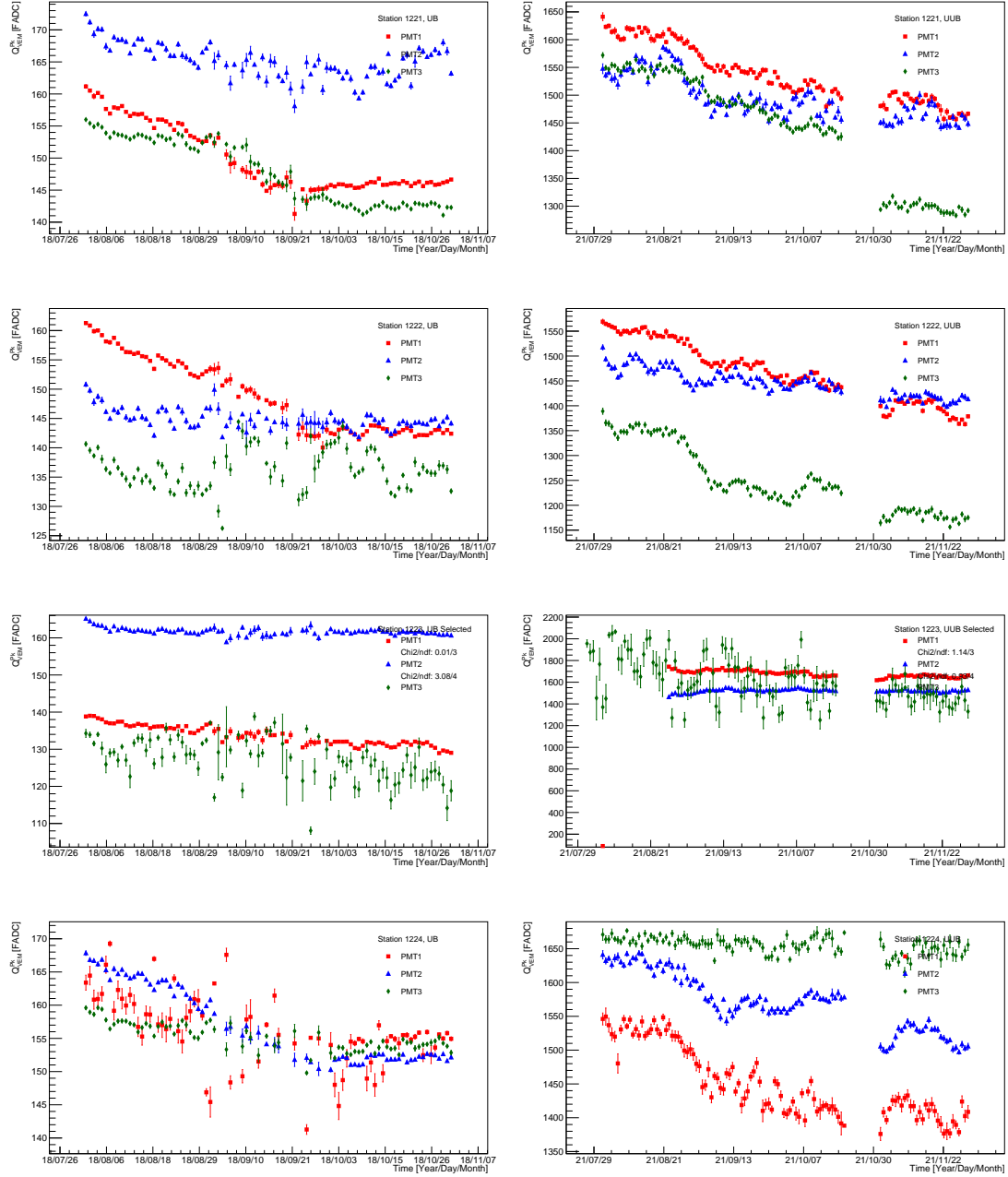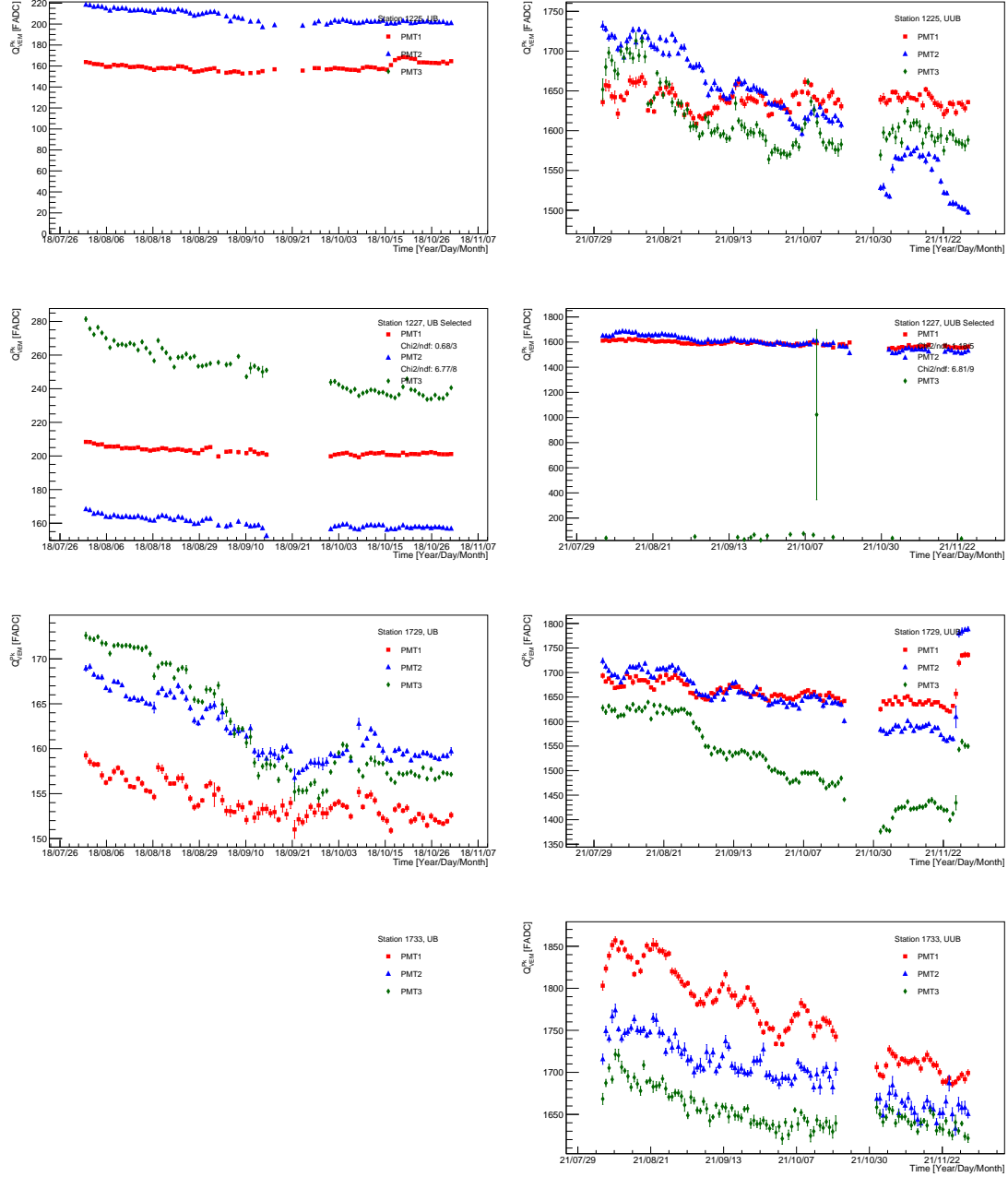
17

hi

Figure 17: Q_{VEM}^{Peak} values obtained applying the algorithm presented in section 1. Each row shows the average of the Q_{VEM}^{Peak} per day plotting as function of time, left UB, and right UUB version. If the label "Selected" is seen, it means that some, or all, PMTs were chosen to calculate the accuracy of Q_{VEM}^{Peak}.

Figure 18: $Q_{\mathrm{VEM}}^{\mathrm{Peak}}$ values obtained applying the algorithm presented in section 1. Each row shows the average of the $Q_{\mathrm{VEM}}^{\mathrm{Peak}}$ per day plotting as function of time, left UB, and right UUB version. If the label "Selected" is seen, it means that some, or all, PMTs were chosen to calculate the accuracy of $Q_{\mathrm{VEM}}^{\mathrm{Peak}}$.

hi

Figure 19: Q_{VEM}^{Peak} values obtained applying the algorithm presented in section 1. Each row shows the average of the Q_{VEM}^{Peak} per day plotting as function of time, left UB, and right UUB version. If the label "Selected" is seen, it means that some, or all, PMTs were chosen to calculate the accuracy of Q_{VEM}^{Peak}.
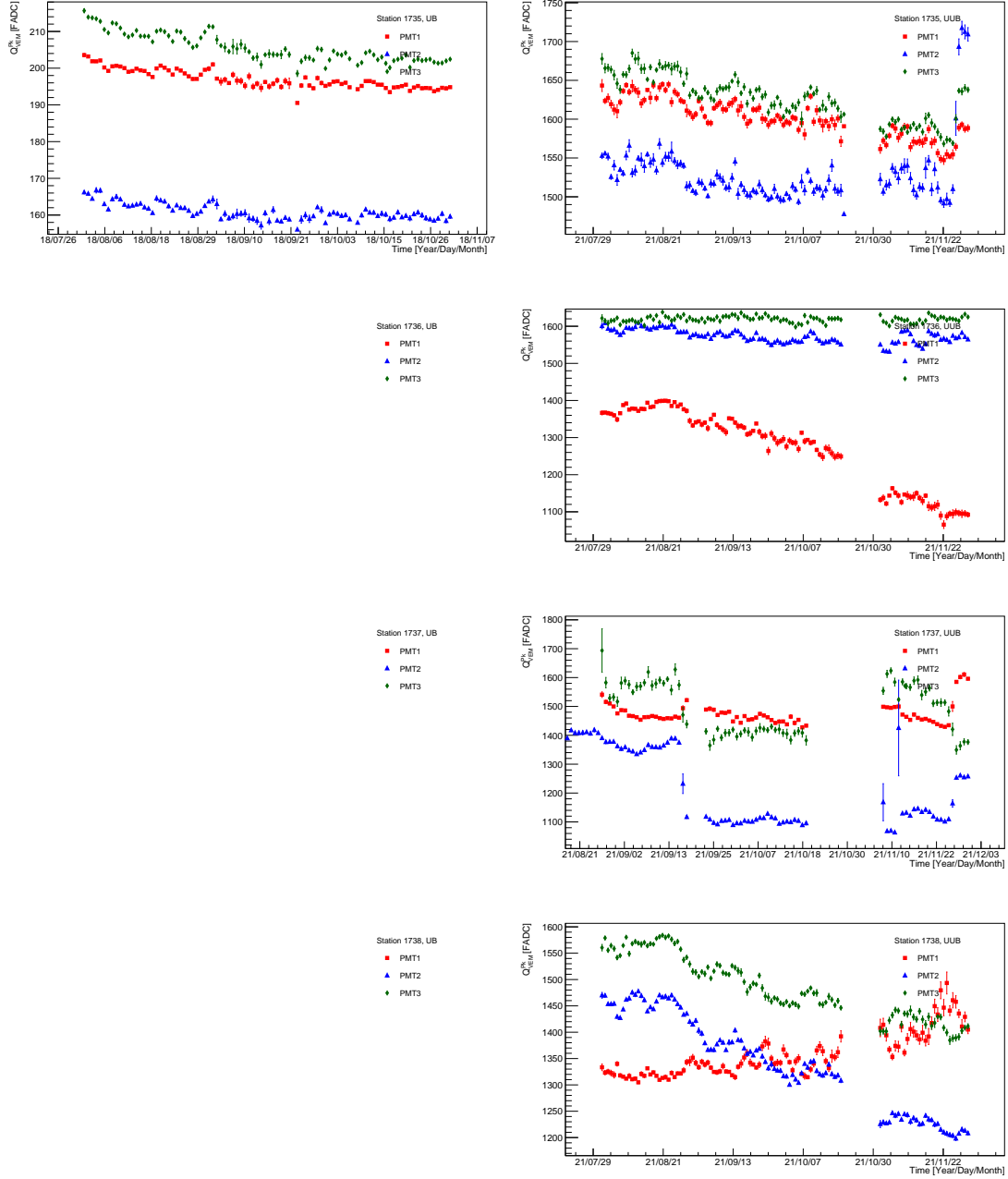
hi

Figure 20: Q_{VEM}^{Peak} values obtained applying the algorithm presented in section 1. Each row shows the average of the Q_{VEM}^{Peak} per day plotting as function of time, left UB, and right UUB version. If the label "Selected" is seen, it means that some, or all, PMTs were chosen to calculate the accuracy of Q_{VEM}^{Peak}.
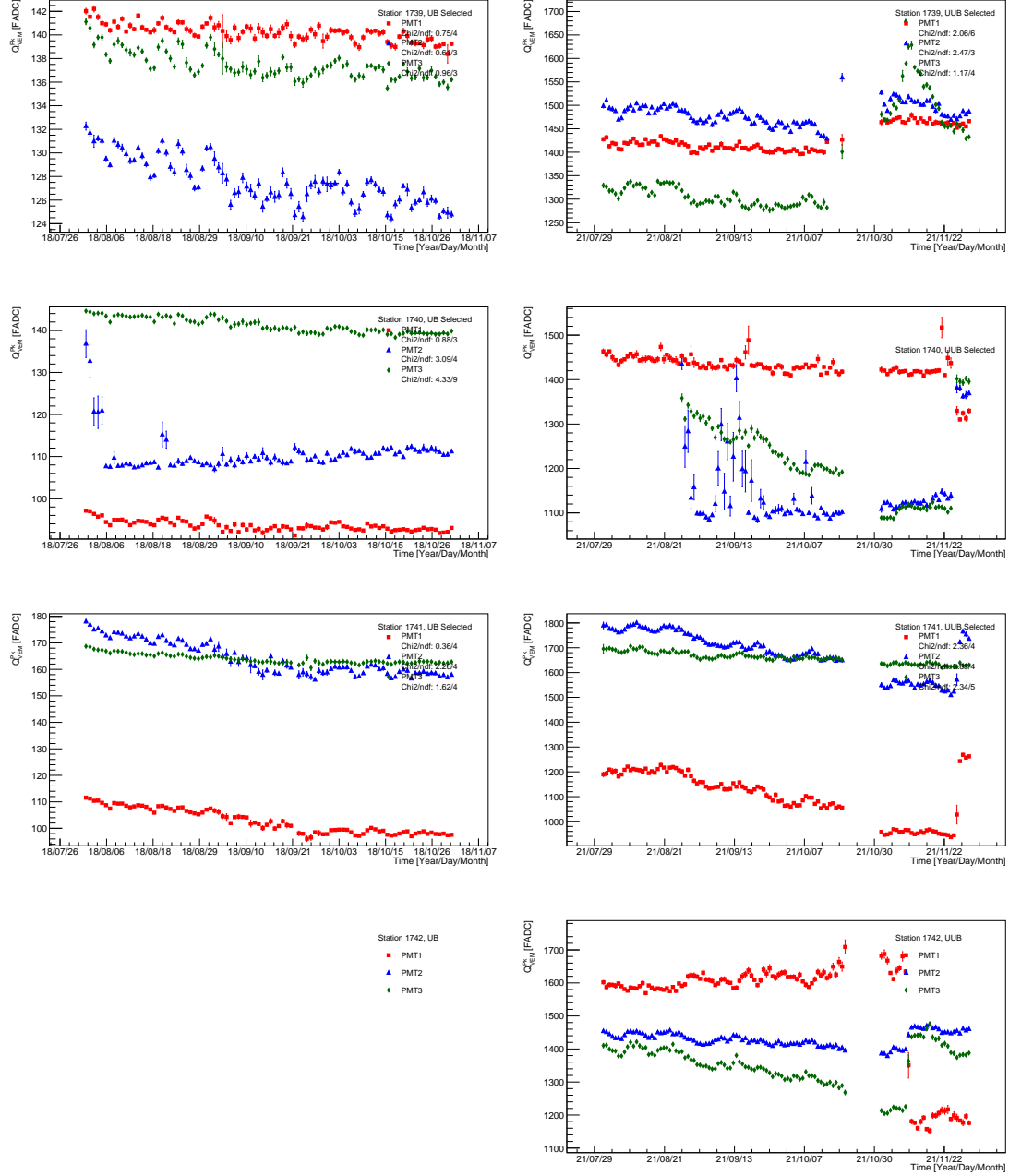
hi

Figure 21: Q_{VEM}^{Peak} values obtained applying the algorithm presented in section 1. Each row shows the average of the Q_{VEM}^{Peak} per day plotting as function of time, left UB, and right UUB version. If the label "Selected" is seen, it means that some, or all, PMTs were chosen to calculate the accuracy of Q_{VEM}^{Peak}.
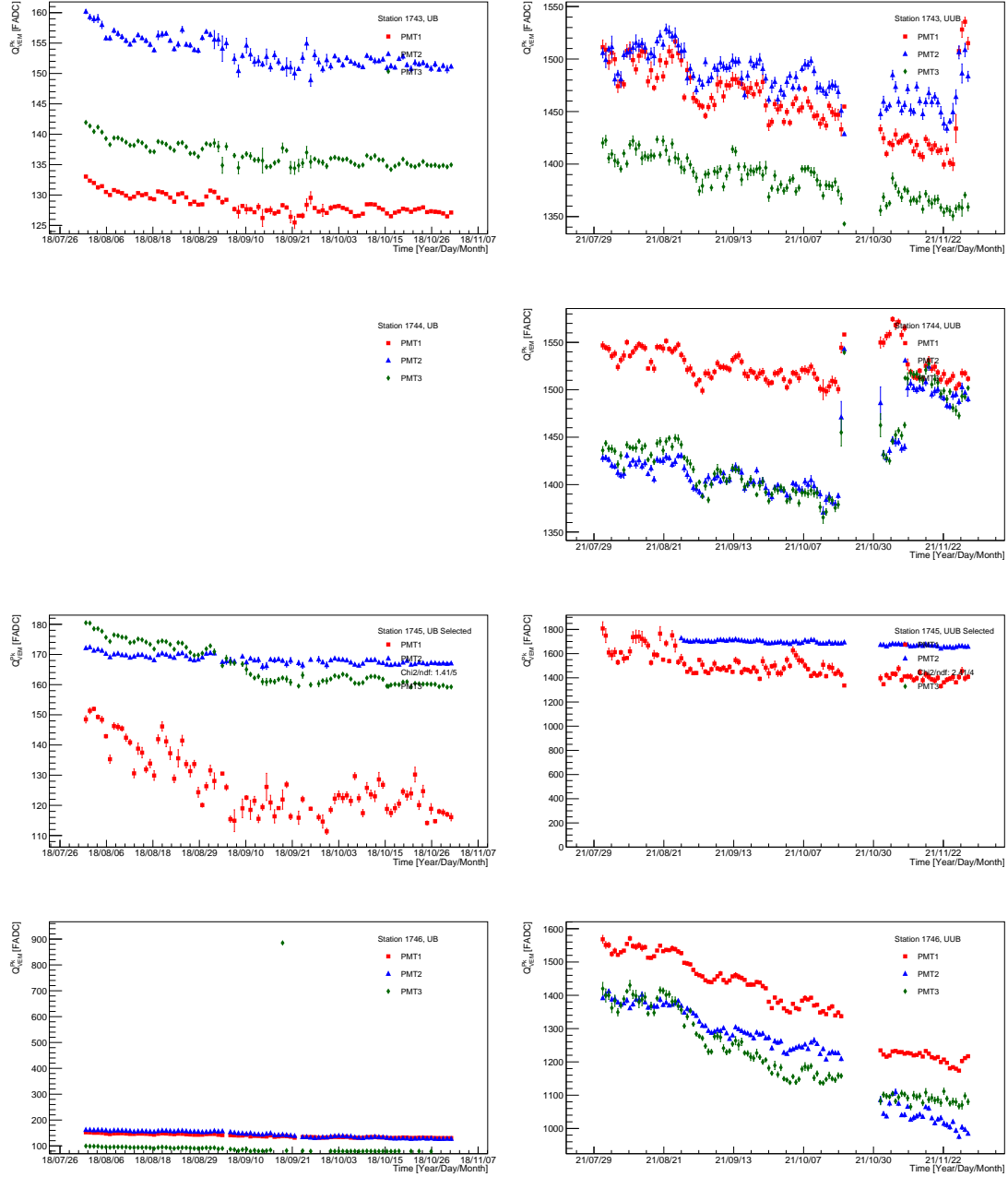
hi

Figure 22: $Q_{\mathrm{VEM}}^{\mathrm{Peak}}$ values obtained applying the algorithm presented in section 1. Each row shows the average of the $Q_{\mathrm{VEM}}^{\mathrm{Peak}}$ per day plotting as function of time, left UB, and right UUB version. If the label "Selected" is seen, it means that some, or all, PMTs were chosen to calculate the accuracy of $Q_{\mathrm{VEM}}^{\mathrm{Peak}}$.
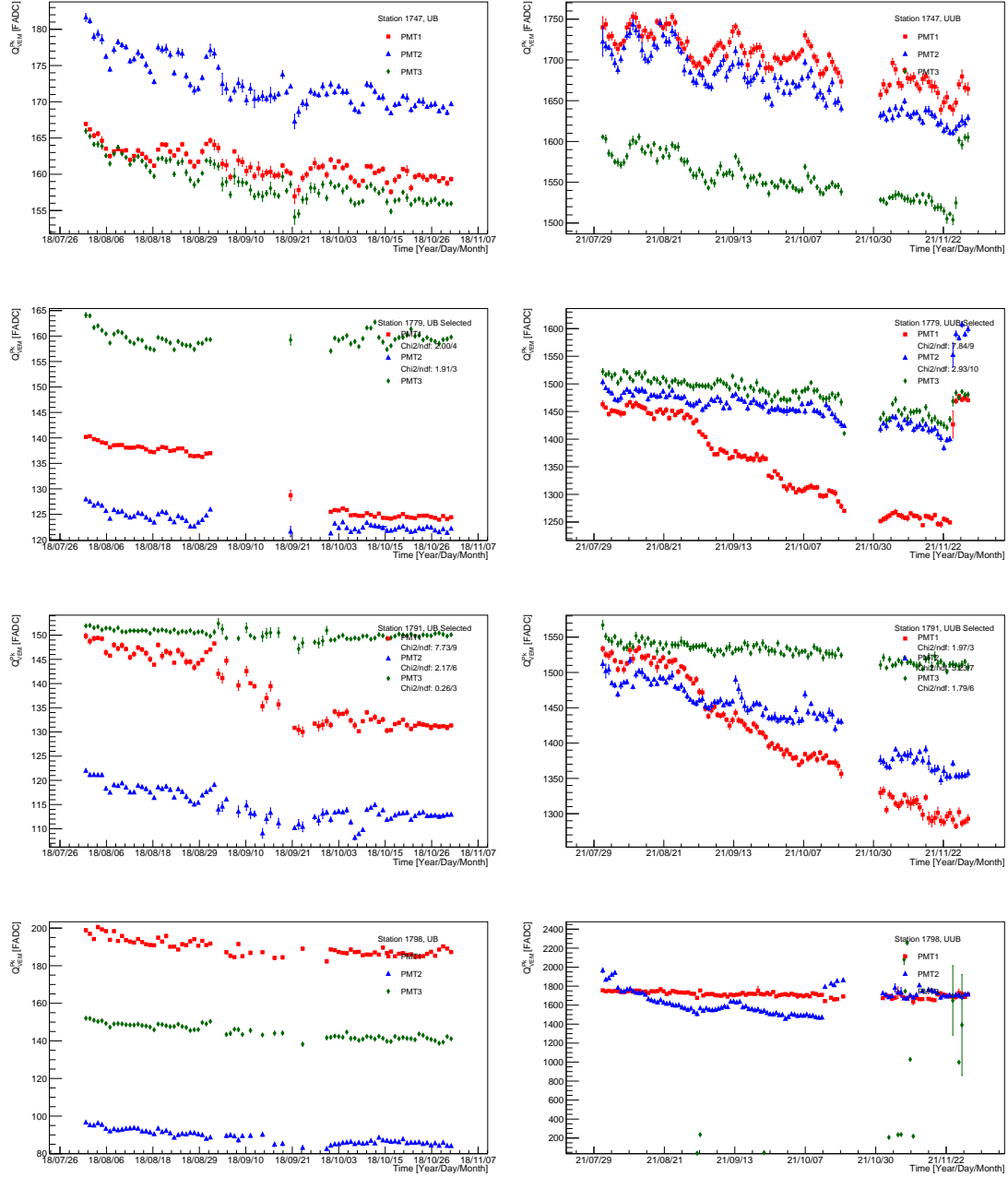
23

hi

Figure 23: Q_{VEM}^{Peak} values obtained applying the algorithm presented in section 1. Each row shows the average of the Q_{VEM}^{Peak} per day plotting as function of time, left UB, and right UUB version. If the label "Selected" is seen, it means that some, or all, PMTs were chosen to calculate the accuracy of Q_{VEM}^{Peak}.
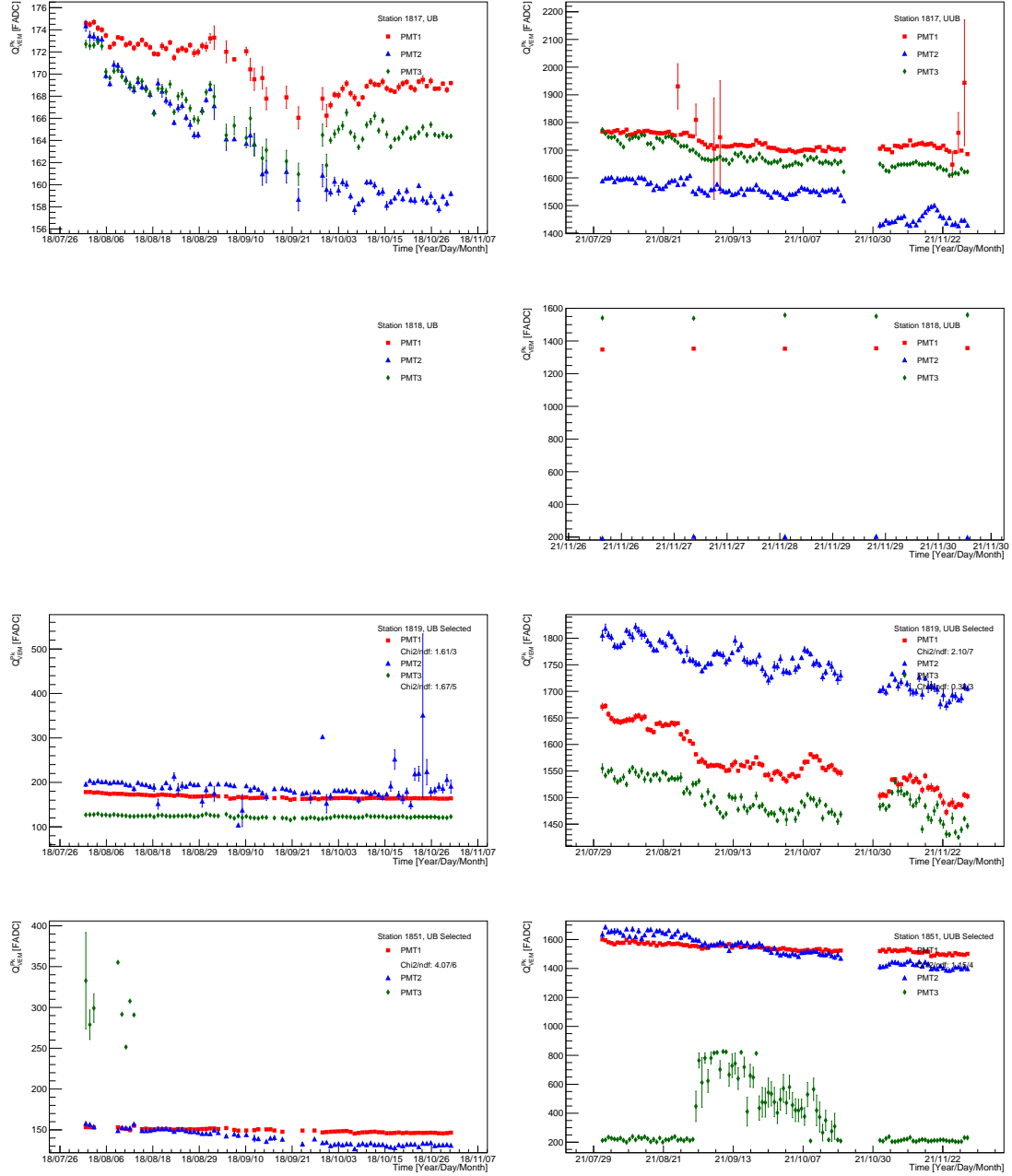
hi

Figure 24: Q_{VEM}^{Peak} values obtained applying the algorithm presented in section 1. Each row shows the average of the Q_{VEM}^{Peak} per day plotting as function of time, left UB, and right UUB version. If the label "Selected" is seen, it means that some, or all, PMTs were chosen to calculate the accuracy of Q_{VEM}^{Peak} .
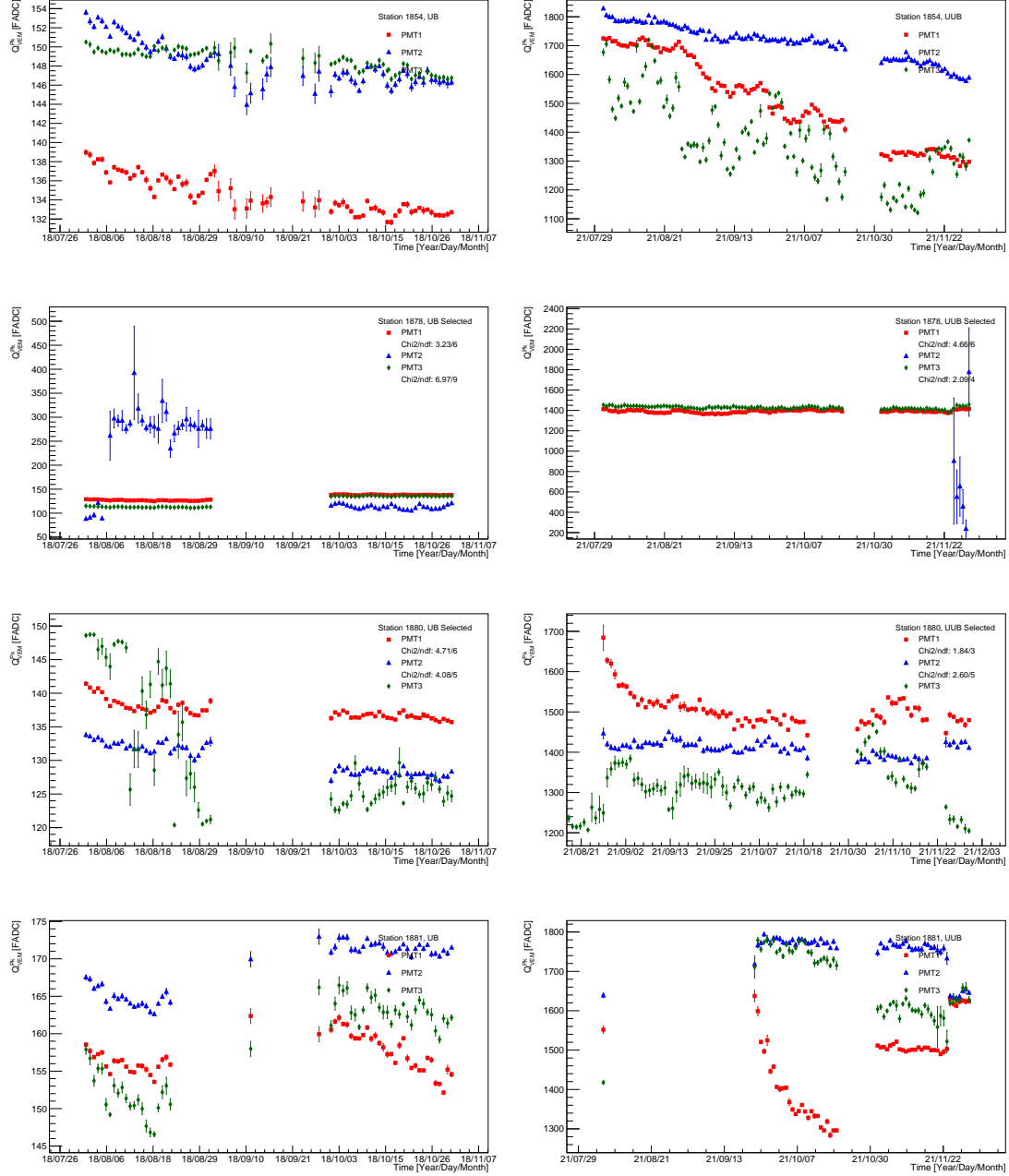
hi

Figure 25: Q_{VEM}^{Peak} values obtained applying the algorithm presented in section 1. Each row shows the average of the Q_{VEM}^{Peak} per day plotting as function of time, left UB, and right UUB version. If the label "Selected" is seen, it means that some, or all, PMTs were chosen to calculate the accuracy of Q_{VEM}^{Peak}.