Time calibration of the Forward Detectors for the usage of the Time-of-Flight method with WASA-at-COSY

M. Zieliński[a,b], and P. Moskal[a,b]

Investigatins of the η' meson decays produced in $pp \to ppX$ reaction using WASA-at-COSY apparatus [1] requires a high tagging efficiency by means of the missing mass technique. Therefore a high resolution of energy measurement for two outgoing protons is needed. To this end we developed energy reconstruction method based on a Time-of-Flight measurement using the scintillating layers of the WASA Forward Detector [2,3]. Generaly all 14 layers (thin and thick) can be used for this pourpuse but for now we consider only 5 thin layers of FWC and FTH.

In order to use time information the time calibration of forward scintillating layers has to be done. For this pourpuse we analysed the experimental data from the reaction $pp \to ppX$ collected in 2008. As a first step a relative time offsets between each detection module of the FWC and FTH have to be established. The FWC detector is 48-fold segmented and is composed of two layers each with 24 elements made out of 3 mm plastic scintillator read out from one side by a photomultipler. The FTH consists of three scintillating layers composed of 96 individual modules read out by a photomiltiplier from one side. First layer is arranged with a cake-piece shaped modules and 2 others in a form of Archimedean spiral shape. The measured time information from the TDC unit for a single FWC and FTH element may be expressed as:

$$t_{TDC}^{FWC} = t_{real}^{FWC} + t_{offset}^{FWC} + t_{walk}^{FWC} + t_{light}^{FWC} - t_{trigger}, \quad (1)$$

$$t_{TDC}^{FTH} = t_{real}^{FTH} + t_{offset}^{FTH} + t_{walk}^{FTH} + t_{light}^{FTH} - t_{trigger}, \quad (2)$$

where t_{offset} denotes all the delays in the electronics and cables, t_{walk} is a effect related to the signal aplitude higth, t_{light} stands for the time of light propagation in scintillator and the $t_{trigger}$ denotes the time of the trigger signal. To calculate the Time-of-Flight TOF between FTH and FWC one can apply equations (1) and (2) as:

$$TOF = t_{TDC}^{FTH} - t_{TDC}^{FWC} + t_{offset}^{FWC} - t_{offset}^{FTH} + t_{walk}^{FWC} - t_{walk}^{FTH} + t_{light}^{FWC} - t_{light}^{FTH}. \quad (3)$$

The unknown time offsets t_{offset} and effects of t_{walk} and t_{light} have to be established for each individual element in each scintillating layer.

In order to determine the offsets we have used events with proton track of energy greater then 100 MeV passing through FWC and FTH and assuming as a first approximation that the real time-of-flight between these layers is equal to 0. First by ploting the TOF as a function of element number in the FWC_1 and by correcting mean of the time distribution to asumed $TOF = 0$ (Fig. 1 left). Next assuming that the FWC offsets are correct, we have established with the same method offsets for each modul in the FTH_1 (Fig. 1 right).

Having the offsets established for each element the time walk effect t_{walk} may be calculated based on the signal amplitude information. This effect occures due to different signal hights of signals having the same rise time. To correct for this effect one can use a linear dependence between the time and the inverse of the square root of the charge [4]:

$$t = t' - \alpha - \beta \frac{1}{\sqrt{ADC}}, \quad (4)$$

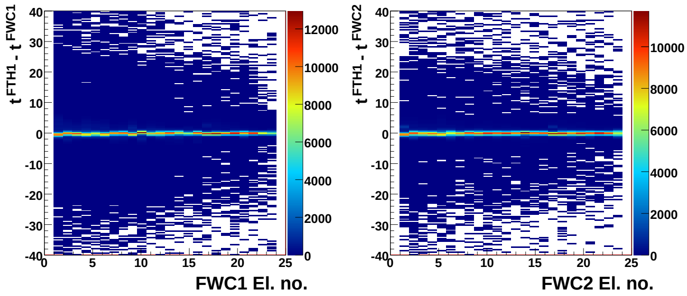

Fig. 1: Experimental data of time-of-flight as a function of element number (a) for FWC1 (b) FWC2.

where t stands for corrected time and t' for measured time. To determine the α and β coefficients we plotted the TOF for each individual module of scintillator as a function of square root of the ADC signal and fitted an linear function which is shown in Fig. 2 (left). Also the time of the light propagation

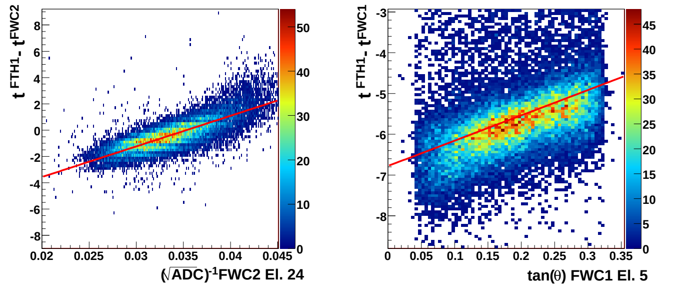

Fig. 2: (a) Experimental data of time-of-flight between FTH1 and FWC2 as a function of $\sqrt{ADC}^{-1}$ for element 24th of FWC2 with superimposed line $\Delta t = \alpha \cdot \frac{1}{\sqrt{ADC}} + \beta$ to establish a time "Walk effect". (b) Experimental data of time-of-flight between FTH1 and FWC1 as a function of $\tan\theta$ for element 4th of the FWC1 with superimposed line $\Delta t = \alpha \cdot \tan\theta + \beta$ to establish light propagation effects.

in the scintillator has to be taken in to account. To determine this effect based on the geomety of the FD we have found a time dependence on the theta angle as:

$$t = t' - \left(\frac{l_1}{v_1} - \frac{l_2}{v_2}\right) + \left(\frac{d_2}{v_2} - \frac{d_1}{v_1}\right) \cdot \tan\theta, \quad (5)$$

where l_1, l_2 denotes the particle tracks lenght from the interaction point to the hit point in the detector, d_1, d_2 stands for the position of the FWC and FTH layers with respect to the assumed interaction point, v_1, v_2 are the vielocities of the light in the scintillator elements and θ is a angle of the particle track with respect to the beam direction. To correct for this effect we have plotted the TOF as a function of $\tan\theta$ which is shown in Fig 2 (right), and by fitting a linear function we have determined parameters $\alpha = \frac{d_2}{v_2} - \frac{d_1}{v_1}$ and $\beta = \frac{l_1}{v_1} - \frac{l_2}{v_2}$.

After correcting for the walk effect and taking into account the light propagation in scintillator we made another iteration for the offset determination. Having these ralative offsets de-

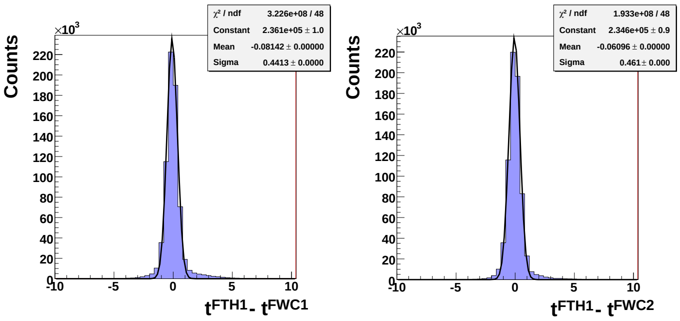

Fig. 3: Experimental data of time-of-flight between (a) FTH1 and FWC1, (b) FTH1 and FWC2 for all modules. The result of the fitted Gauss function is shown as a solid line. Fit parameter σ shows the time of flight resolution.

termined we ploted distributions of the time of flight between FTH_1-FWC_1 (Fig. 3 left) and FTH_1-FWC_2 (Fig. 3 right) and fitted the Gaussian function in range of the peak. The determined Time-of-Flight resolutions $\sigma(TOF_{FTH_1-FWC_1}) = 441ps$ and $\sigma(TOF_{FTH_1-FWC_2}) = 461ps$, which assuming the same resolution of the FWC and FTH gives σ of about 320 ps for individual layer (taking into account all detector modules).

References:

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[a] Institut für Kernphysik and Jülich Center for Hadron Physics, D-52425 Jülich, Germany

[b] Institute of Physics, Jagiellonian University, PL-30059 Cracow, Poland