Report on research activities in Yerevan and on Mt. Aragats concerning muon arrival time measurements

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Investigation of photomultiplier and detector in timing laboratory

Previously done measurements with FEU-49 photomulipliers (PMT) demonstrate the functioning of the timing lab but where not very useful for the special requirements of the timing measurements. The installation of the FEU-30 photomuliplier (the fast one) seems to be a difficult task (best optimization of HV divider is required) and so a FEU-30, brought from Karlsruhe, was used. Measurements in 3 different setups were carried out:

(a) PMT above a pulser controlled LED.

(b) PMT above 50*50 cm^2 scintillator coupled via pyramid shaped housing and triggered by scintillator paddle of 10*10 cm^2 dimension.

(c) PMT mounted on final (ANI) detector housing with 1 m^2 scintillator (consisting of 4 pieces 50*50 cm^2 each). The scintillator was triggered by the paddle scintillator. The latter was positioned at different positions under the 1 m^2 area in order to learn something about the geometry induced time jitter. In addition the high voltage and the CFD threshold was modified in order to find the best resolution.

Note: To have a clear trigger the use of a coincidence unit was foreseen, but after more than half a day of adjusting the setup, this was skipped, so the number of unusable events was rather high. The main problem was that the available coincidence unit was not sufficient fast and that the delay units were in bad state.

Results

Some of the results are shown in table 1. In the following (a), (b) and (c) denote the different setups previously mentioned. Fig. 1 shows an example for an obtained distribution for the resolution measurement.

		Pos. A	Pos. B	Pos. C	Pos. D
2.3 kV	σ_T [ns]	3.3	4.0	4.2	4.2
50 mV	σ_P [ns]	2.5	2.3	2.7	2.4
Peak.Pos.	[ns]				

	2.3 kV 50 mV	2.4 kV 50 mV	2.5 kV 50 mV	2.4 kV 38 mV	2.4 kV 25 mV	2.3 kV 25 mV
σ_T [ns]	4.2	3.7	4.5	3.4	4.0	4.1
σ_P [ns]	2.4	2.8	3.0	2.9	3.2	3.0

Table 1: Results obtained for timing resolution at different positions (upper table) and for different high voltages and CFD treshold (lower table). σ_T is the resolution for the complete distribution, σ_P only for the peak region. Pos. A-D mean the different positions of the paddle scintillator under the 1 m^2 scintillator.

(a) Depending on the LED pulse heights, resolutions between 0.6 and 1.0 ns could be achieved. Some of the previously done measurements were a bit misaimed as the obtained resolutions are from pulse heights comparable higher than the pulses coming from minimal ionizing particles. Furthermore it was shown that a fast preamplifier has to be used to obtain a resolution of about 1 ns for the smallest pulses. The obtained resolution is a product of the timing resolutions of the FEU-30, of the CFD (design H.Bozdog), of the preamplifier (LeCroy VV100B) and of the not measured jitter of the LED pulser system.

(b) In this setup a resolution of 1.36 ns was obtained.

(c) Besides the very inefficient triggering the following results have been obtained:
The resulting time distributions were very asymmetric, having a bump to higher delay values (see Fig. 1). Fitting the complete peak with a gaussian results in resolutions between 3.3 and 4.3 ns. Fitting only the left part of the peaks (for all distributions in the same histogram bin intervall) results in resolutions between 2.3 and 4.2 ns. The best value was obtained directly below the PMT position. Unfolding the previously measured timing resolutions of the test setup, we obtain a value not better than 2.1 ns. In addition it has to be taken into account that the time shifts between the different measuring positions is of the order of 1.1 ns which in in agreement with older estimations.

The table shows that the modification of either high voltage or CFD threshold does not affect the resolution very much and the overall dependence is not very uniform.

Conclusion and Discussion

The measurements show that the preliminary performed MC simulation of the detector performance with respect to timing resolution was done with too many simplifications. The results can be interpreted in that way, that the PMT sees not enough light, either because not enough light reaches it or because its quantum efficiency is too low. So only a long photon collecting time, thus integrating also over indirect photons (and possibly over double indirect), could explain the delayed entries which cause partly the bad timing resolution. It could be assumed, that this implies also some inefficiency for muon detection.

High voltage [kV]		1.15	1.35	1.41	1.75	1.9	2.0
EMI 9902	μ-pos	130	250	300	900		
	σ_t	4.0	1.6	1.4	1.7		
FEU-30	μ-pos					125	140
U_{thr}=30 mv	σ_t					2.1	1.6
FEU-30	μ-pos					90	125
U_{thr}=10 mv	σ_t					1.4	1.4

Table 2: Results for time resolution and position of muon peak (in ADC counts) obtained from single muon measurements. The high voltages were chosen in the typical workinh range for each tube (U_{thr} is the threshold voltage of the CFD).

To prove these assumptions the following investigations must be performed very soon (preferably in this order !):

1. Optimization of PMT HV divider chain and measurement of pulse height with LED pulse.

2. Possibly the PMT under investigation was not the best one, so a few further PMTs have to be obtained and investigated. Of course this includes also step 1 of this list !

3. Quoting G.Hovsepian, the used scitillator has an attenuation length of about 50 cm. Possibly the scintillator under test has a lot of gas bubbles inside and a much lower attenuation length. This has to be checked, too.

4. Further optimization like metallic reflecting foil under the scintillator, black walls or similar things could be tried also. But one has to keep in mind, that the detectors also have the purpose of energy measurement and their behaviour should not be changed for this purpose.

5. In this field falls also the use of a light collecting cone, as it was tried out by G.Hovsepian (but for EMI phototube). This increases mainly the value for the muon peak position but doesn't decrase the timing resolution. It might increase the timing resolution, if the deficit is mainly caused by too less photons meeting the photocathode.

6. The idea of constructing a detector which is optimized for the desired purpose should not be followed, for time and financial reasons.

7. According to H.Hovsepians measurements in Karlsruhe the PMTs EMI 9902 and FEU-30 can be compared as is shown in table 7 with respect to their time resolution if they operate at their typical high voltages. The table shows also, that the energy resolution and possibly the amplification of the FEU-30 is worse, as is expressed by the peak position of the minimal ionizing particles.

Setup of a small timing experiment at GAMMA installation

This setup consist of 3 timing channels and the LeCroy multihit time converter (MTDC). The timing channels use FEU-49 photomultipliers with the ANI-specific timing discriminators and are fed via NIM-to-ECL converters to the MTDC. The MTDC is operated in Common Stop

Time	Event	Reason
0 ns	GAMMA electron detector hit	
$>$ 70 ns	GAMMA muon detector hit	approx. 20 m path for vertical muons
410 ns	individual START for MTDC	cable length
580 ns	trigger input for GAMMA	cable length
860 ns	GAMMA trigger decision made	electronic delay 280 ns
920 ns	COMMON STOP for MTDC	cable delay between both setups

Table 3: Contributions to the overall time shifts of the MTDC data

mode as the detector signals arrive earlier than the STOP signal taken from the GAMMA timing trigger decision logic.
The software required to steer the readout, making some simple data conversion (though interpreting the MTDCs data is not a simple task) and storing the data is described elsewhere.
In order to do a correct setup, all times in this experiments have been measured or estimated with an accuracy of a few tens of nanoseconds and are presented in table 3. The detector response delays are not considered here, as both setups use the same type of detectors.
So for the vertical case and for the earliest arriving muons a full scale time range of about 510 ns could be sufficient, but must be checked further (means the use of fastest readout mode)

Results

Fig. 2 shows the results of the measurements carried out over 40 hours. In this time about 42 * 10^3 GAMMA triggers have been generated and about 2590 events with at least one entry in the timing channels have been acquired. The resulting plots show the effect of detector ineffiency which is expressed in the different number of histogram entries and the influence of the possible background (also induced by noise) which is shown through histogram entries before the main peak. This guided us to state the following:

Problems

1. The MTDC works properly in the case of a START pulse and a delayed COMMON STOP. If it sees a START but no STOP, we assume that the conversion is started, but the data aren't registered and thus, could not be read out. In the case of a STOP without START, one TDC channel (CH 7) shows always data, a value slightly below the maximum time range. This seems to be an error of the MTDC.

   The case 'STOP without START' is realistic because having only a few timing signals as input, most GAMMA triggers will not 'see' muons in the selected/connected detectors.

   This case required an interaction of the controlling computer, because the MTDC contains data. Even if these data are useless, the interaction is needed in order to enable a new acquisition and thus a increase of the dead time is expected.

2. The case 'START without STOP' is the most interesting case because it covers the background and the deadtime considerations. Here all channels in parallel contribute to this 'START noise'.

Until now, it is not clear, which deadtime such random starts imply. Probably the deadtime caused by a background signal is the length of the MTDC full scale plus the time needed, to reset it internally for a new measurement.

Future work

In the following we describe a few steps of the future work with the MTDC system in order to solve some of the above mentioned problems and to establish good measurements and data analysis. The mentioned tasks could be done by separate persons (some of the tasks even in parallel) according to their special skills.

1. Investigate dead time behaviour and background behaviour of MTDC. Herefore a circuit with two adjustable delays, to simulate a background signal, a real signal and the STOP signal (utilizing some monostables like 74123 seem to be sufficient). For background investigations, some measurements with larger time window are required, too.

2. Investigate detector quality and efficiency. The first acquisition showed different counting rates of the individual detectors. Try to establish procedure (easy to follow by technicans) to optimize detector quality.

3. Write software that allows to merge MTDC acquisition data with at minimum the interesting GAMMA or MAKET data. For this, an exact synchronisation of the MTDC experiment and the triggereing experiment is required.

4. Investigate and check methods to calibrate the detector time offsets:

   - test pulses
   - individual trigger by paddle scintillator (equal setup in all cases, including same position of paddle)
   - if sufficient number of detectors: shower plane fit
   - if energy information is available and shower core on small area: same arrival times in all hit detectors could be assumed
   - if equal distribution of shower cores with respect to the detectors to be calibrated: arrival time distribution of individual detectors should be centered around 0.0 (i.e. center of distribution is the desired offset value)

   The meaning and application of these proposed methods have been explained and discussed in detail amongst the authors of this report.

5. Establish working analysis procedure and equip them with histogramming facilities. This procedure, of course, has to be materialized into some software running on the analysis computer, Linux in our case. This could be a first guide for the analysis steps:

   - offset correction
   - correlation with GAMMA muon information i.e. energy values are needed
   - discard detectors with too high energy deposit

- calculate detector multiplicities after these cuts
- calculate arrival time quantities
- fill Ntuples with these quantities plus additional shower information (from experiment producing the trigger)
- analyse Ntuples in different bins of shower quantities

6. Attach more timing detectors to the setup. Possibly a setup pattern with holes (only every second detector used) could be better. Continue at the beginning of the tunnel because of larger core distance and lower energy threshold.

7. Integrate next MTDC into the system. If after all necessary, PMT and detector related, measurements, a resolution of 2 ns is sufficient, the Bulgarian MTDC 1102 could be used additionally (assuming that it is properly working...) because it has only a resolution of 2 ns.

8. Try to find a solution for the damaged MTDC timing channel.

9. ...

Other topics

This part is mainly about the software work done during the research visit and about some future outlooks.

MTDC software

Due to the lack of a C-Compiler for the PC or a sufficient support for another operating system (OS), for instance Linux, all controlling software was written in Turbo Pascal (like other ANI software, too) Using the previously developed code for the MTDC (development in Karlsruhe in C) and porting the hardware relevant functions to Pascal was not that difficult. During the code writing is was tried to adopt a C-like, quasi object-oriented coding style, which should lateron ease the porting back to C or even C++, if this intended.
In my opinion (H.-J. Mathes), a later porting of the software is still possible and not a very big effort even if the source code contains now about 70 KBytes. A short description of the software work is added to this report.
Especially the readout procedure for the MTDC module and the decoding of the time data I explained in detail to all persons, who where present, though that this could be not a general lection about programming.

General DAQ considerations

All the software related to experiment control and data acquisition of the Mt. Aragats experiment site is currently written in Pascal. Though this is not the most modern way of how things could be done, it is nevertheless working ans seemingly fast enough. Nevertheless it is obvious, that this has also some drawbacks, as could seen recently, when the linking of two or more experiments is considered. Another general problem which I met here, is that the programming experience is not very much evolved or that the people able to do it are not present. In order to reach the goals of the second phase of the research visit, I decided to make most of the software by my own. This type of software need a special type of experience, both from the technical i.e. electronics view, and from the physical side, that means not to loose the major goal from ones eyes.

Linux driver for K200 Camac Controller

Having the above mentioned prospects of data acquision at CRD and ANI laboratory into mind, the first and most important step of the migration to other OS and/or programming language is to have hardware support for the new environment. This could mean in a first phase, that the old hardware is still supported. Using the experience previously gained in a similar project in Karlsruhe, writing a simple device driver for the used Camac Controller K200 (Yerevan Phys. Dept. development) was started and should be continued.
This could be guided by Karlsruhe, if locally people are found which have experience in the Linux system, in C and in general hardware topics. Only in this case, the invested work will be of any use.

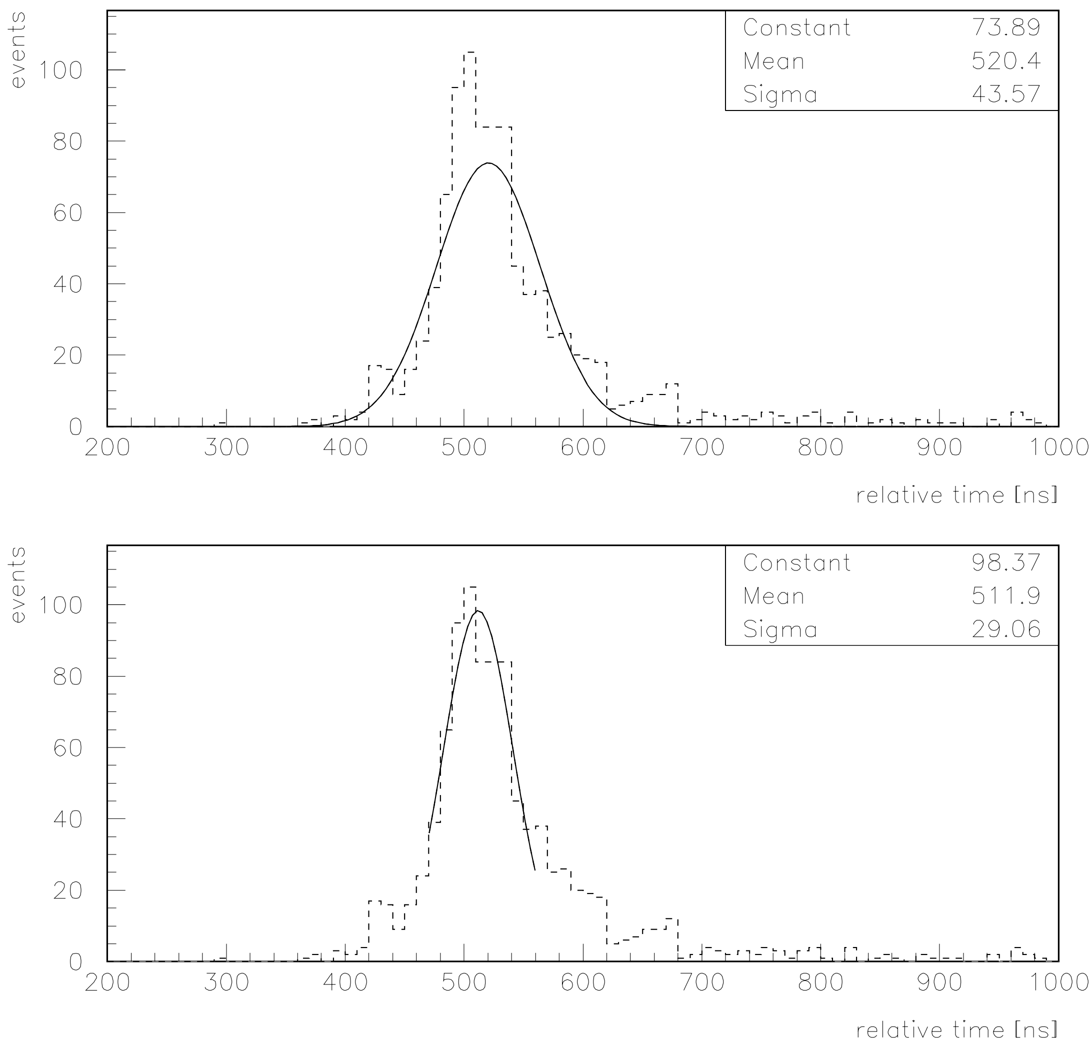

Fig. 1: Example for the obtained distributions of measured times for MTDC channels 8 .. 10 in the detector setup. The upper graph shows a fit to all measured data points, the lower restricts the fit interval. In both graphs the resulting fint parameters are also shown.

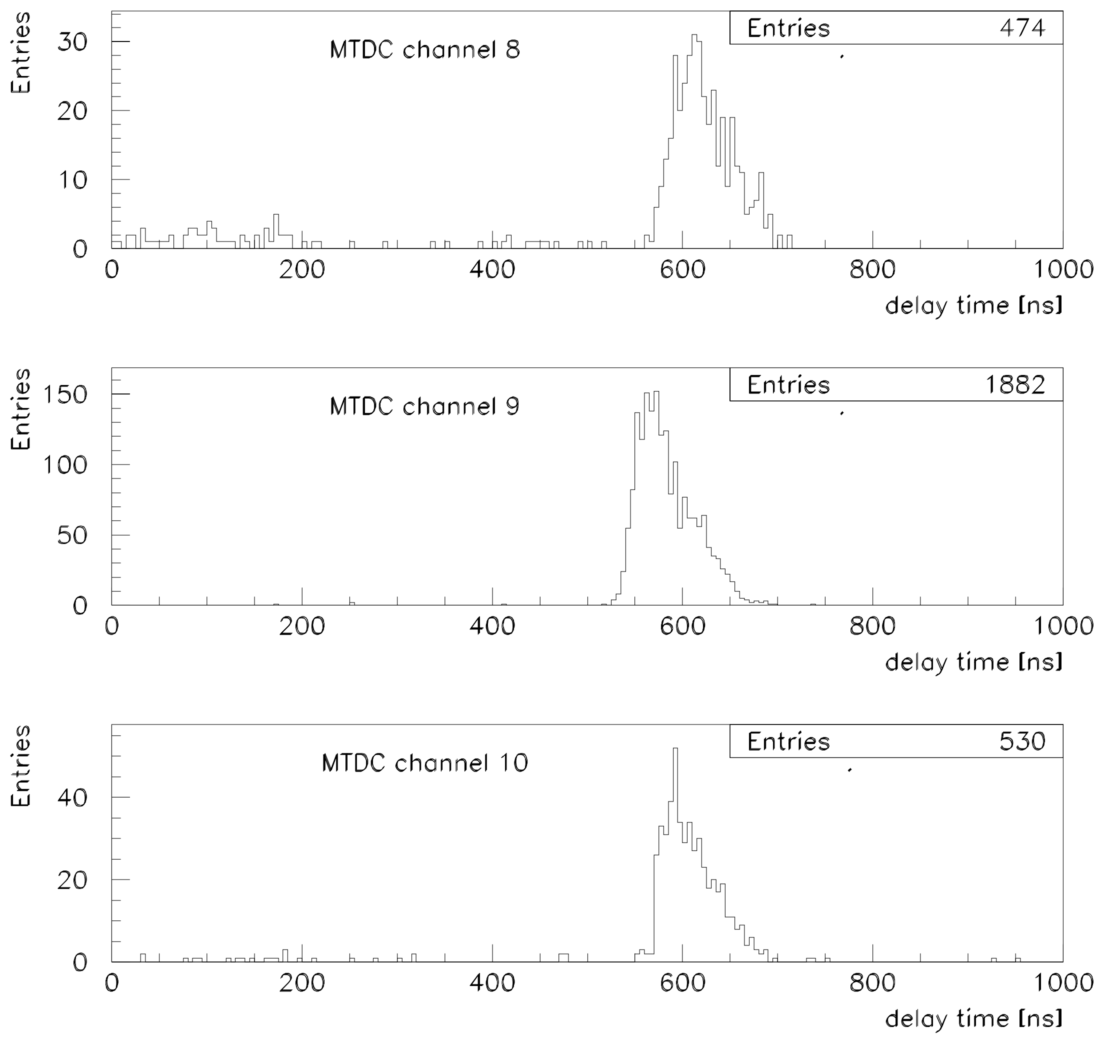

Fig. 2: Resulting arrival time distributions in the 3 detectors of the first setup without any further corrections.