Current status of Fast Muon Veto detector prototype for NA62 experiment

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MuV detector purpose

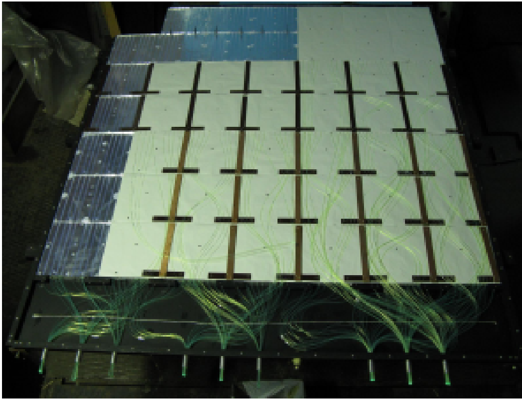
To fullfil NA62 plan to measure ultra-rare decay $K^+ \to \pi^+ \nu \overline{\nu}$, $Br \approx 10^{-10}$, the detector should suppress huge background due to Kaon decays with muon ($K^+ \to \mu^+ \nu$, $Br = 63.6\%$).
Fast **Muon veto detector** (**MuV** a.k.a. MUV3) is intended to reject extra muons in L0 trigger and help hadronic calorimeter to achieve high overall muon rejection factor. The rejection factor is assumed to be around 100.
It should be very "fast", e.g. have times resolution $\sigma \sim 1$ *ns* or better.
The more σ — the more dead time! For instance, when $\sigma = 1.2$ *ns* and muon rates $r = 20$ *MHz* the dead time is 11.6% (see p. 14 for details).
It should also have high efficiency: more than 99% to provide rejection factor of 100.

MuV: prototype detector description

MuV prototype is scintillator hodoscope, where WLS-fibers are used for light collection. There are 2 layers of scintillator in longitudinal direction.

In transversal section hodoscope is divided into 3×3 pads of not-equal size.

Fibers of each pad go along grooves of corresponding scintillator only, beeing fully isolated from scitillators of other pads, e.g. collecting light only from one pad.

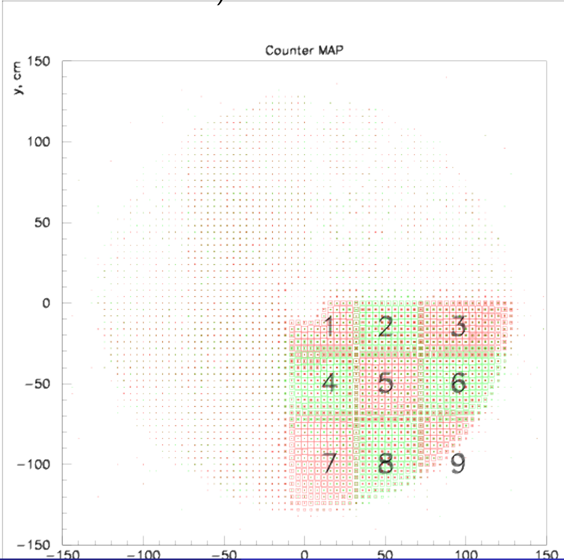


Fibers are gathered in 9 bundles read by 9 PMTs.

MuV test

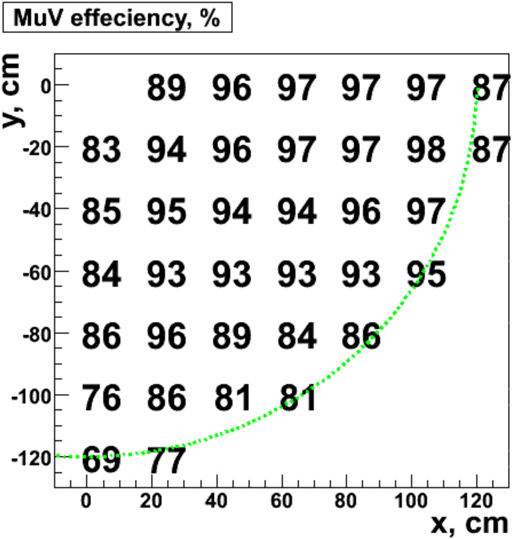
The prototype was placed at the beam and overlapped a fourth part of muon tracks. The protype was tested during muon run on 3rd October 2008.
There was trigger with only 1 charged track. Track coordinates are drawn in picture in case when there was at least 1 signal in the prototype.
Red color highlihgts hits when this signal was in counters with number 1,3,5,7,9; green —2,4,6,8.

Map of 9 pads is shown for MuV (with **counter** numbers):



Detector registration efficiency

Muons after 2 meter of iron reach MuV. Coordinates are from track system. Mean efficiency is $\approx 95\%$ for typical counters.
We are going to decise the problem of low detector efficiency during October 2009 runs. We suppose it is due to low attenuation coefficient, and not low light yield. At first number of photoelectrons will be determined by means of LED signal.



MuV initial time resolution

MuV hit time is defined as difference between signal time in MuV and time from Charged Hodoscope. Time resolution for 'bad' counter 1 and typical counter 3, assuming number of fired counters in MuV $n = 1$.

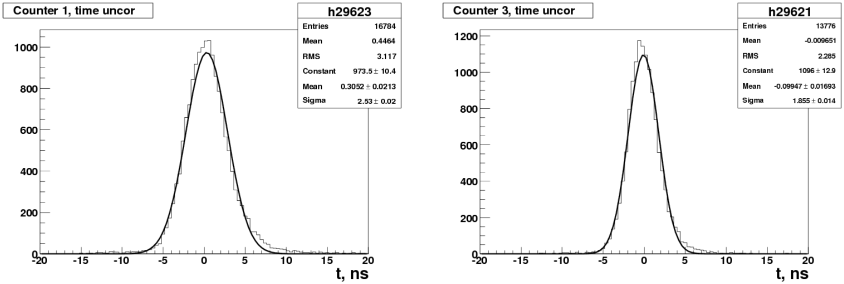
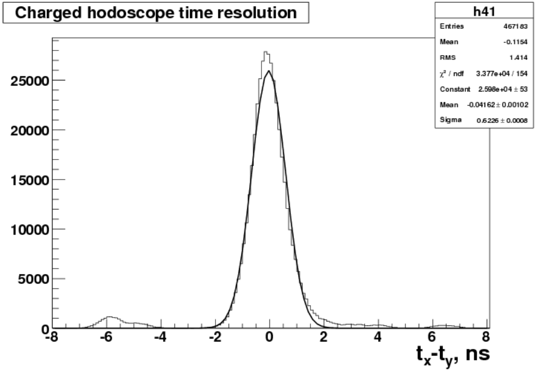


Figure: Counters 1,3

Resolution of charged hodoscope

Time drawn is the difference between times of x and y planes of charged hodoscope.

Time resolution of charged hodoscope determined by this way is 0.62 ns.



Time definition in PMB

We used electronics of Neutral Hodoscope (PMB, 'pipeline memory board') for reading our detector. The signal after shaping is divided into 2 parts:

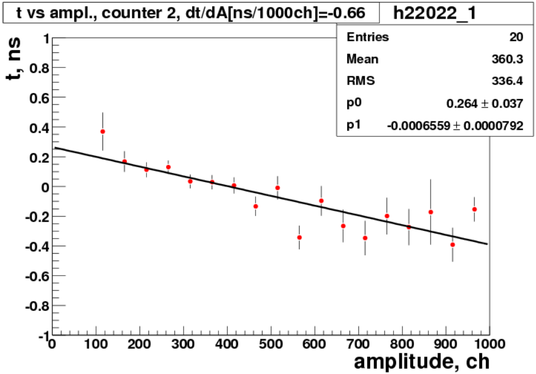
- one is digitized by FADC
- another goes to constant fraction discriminator (**CFD**), which starts *ramp*. Ramp is digitized by 2nd FADC and fitted by straight line, where time is found. This scheme is called *flash TDC*.

Sampling frequency of FADC is 40 MHz.

t(A) dependence

We determined accuracy of CFD, by fitting mean time dependence on amplitude.

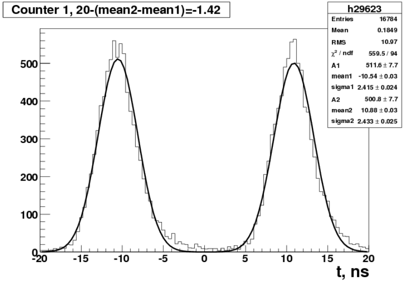
For typical counters mean time dependence on amplitude is $\approx 0.7\ ns/1000\ ch$.

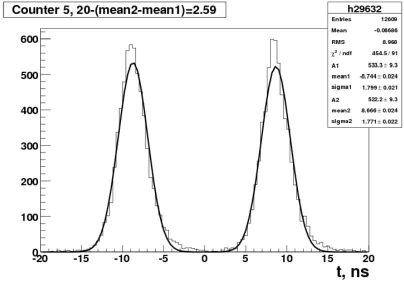


Calibration of up/down ramp

Ramp, started by CFD, has 2 directions: 'up' and 'down'. There is difference between mean times, determined by fitting 'up' and 'down' ramps. Correction is needed to make both mean times equal for each counter.

Times for 'up' and 'down' ramp are moved apart for 20 ns interval and fitted. Difference between 20 ns and real interval is time definition error:

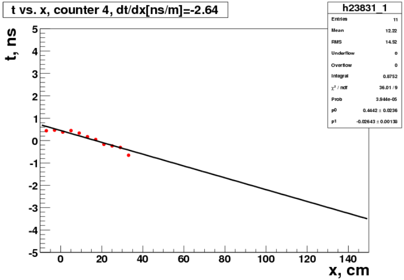


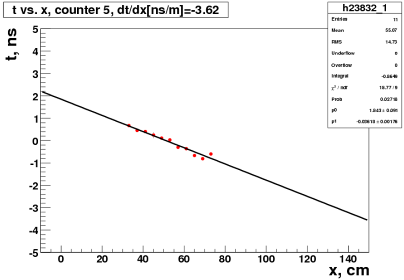


For instance, error reaches 1.4 ns for counter 1 and 2.6 ns for counter 5.

t(x) dependence

Dependence t on x for counters 4–5:





For most counters (except 1) $dt/dx \approx 3\ ns/m$. This behaviour is caused by

- reflections of light in scintillation pad $20x20\ cm^2$
- reflection of light by the mirror at the end of WLS-fiber

Time resolution with differrent corrections

Corrections: t(A), ramp, σ of charged hodoscope.

$$\sigma^2_{full} = \sigma^2_{own} + \sigma^2_{t(A)} + \sigma^2_{ramp} + \sigma^2_{Ch.Hod.}$$

The resolution σ_{own} also includes dependence $t(x)$, but it can not be excluded in trigger.

Time resolution, corrected by $t(A)$ and ramp, is near 1.85 *ns* for most counters except 1st, and **1.75 ns** if corrected by time resolution of Charged hodoscope.

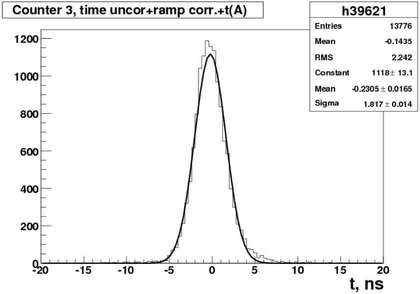


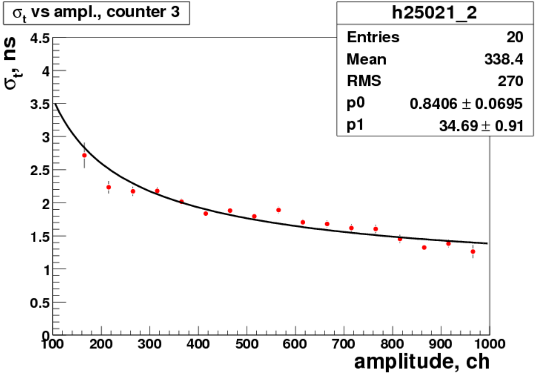
Figure: Counter 3

Best possible resolution

Assuming that time resolution depends on light yield as $1/\sqrt{N_{ph.e.}}$, we fitted dependence σ_t on amplitude A with function $\sigma_t = \sqrt{p_0^2 + p_1^2/A}$, so we can obtain the best possible resolution for our construction p_0 is equal ≈ 0.8 *ns* and 0.6 *ns* if corrected by $\sigma_{Ch.hod}$.

Then we can predict dependence σ_t on $N_{ph.e.}$:

light yield	σ, *ns*
present	1.75
2 times more	1.2
4 times more	0.9



Trigger L0 requirements for MuV time resolution

Assuming, that muon veto should suppress muon background by a factor of 10 or 100, we'll choose **Veto time interval** $\delta = 2 \times 1.64\,\sigma$ or $2 \times 2.58\,\sigma$ accordingly (if time resolutions is distributed as gauss). Dead time depends on muon rate: **dead time** is $1 - e^{-\delta r}$. Muon rate at MuV is usually reported to be $r = 9.2$ MHz. Direct calculation — summing rates, given in "TURTLE-HI" files from N. Doble — gives $r = 20\ MHz$.

Below we assume $r = 20\ MHz$.

σ, *ns*	Veto time interval, ns	**dead time** if s=10	**dead time** if s=100
1.75	5.7	10.8%	**16.5**%
1.2	3.9	7.6%	11.6%
0.9	3.0	5.7%	8.9%

Below we assume $r = 9.2\ MHz$.

σ, *ns*	Veto time interval, ns	**dead time** if s=10	**dead time** if s=100
1.75	5.7	5.1%	8.0%
1.2	3.9	3.6%	5.5%
0.9	3.0	2.7%	4.2%

Inefficiency due to high rates

Since PMT can't register signals that are more frequent than 1 per 10 ns, high rates per channel will increase inefficiency of detector.

$$ineff = 1 - e^{-\tau r} \approx \tau r, \quad \tau = 10\ ns.$$

When $r = 1\ MHz$, $ineff = 1\%$. But we suppose achieve efficiency not less than 99%.

That is why muons rates for each channel should be essentially less than $r = 1\ MHz$.

This fact should be taken into account for plans of both current detector modernizaton and alternate detector design.

The expected muon rates (according to "TURTLE-HI" files of N. Doble) to pads for current detector design [kHz]:

range	0–40 cm	40–80 cm	80–120 cm
0–40 cm	3385.2	1016.3	325.3
40–80 cm	1183.4	411.5	188.0
80–120 cm	427.7	177.4	18.2

Suggestions on improvement for current detector design

- glueing WLS fibers into grooves for better optical contact **done for 4 pads now**
- change PMTs from russian FEU-85 to Hammamatsu R7899–20 **done**
- new reflection surface (Tyvek paper instead of aluminium foil) **partially done!**
- selection of WLS fibers & scintillator plates

According to our estimations, current changes can increase mean light yield at least by a factor of 2, therefore improve time resolution to 1.2 ns. The rate for 1st pad (near beam) is expected to be 3.4 Mhz. We suppose divide this pad to 3 pads of 20x20 cm^2, that will have 1.4, 1.4, 0.5 Mhz rate.

It was reported according to some tests that changing PMT from russian FEU to Hammamatsu improves time resolution by a factor of 2.

In June 2009 we performed a comparison between PMTs to predict effect due to the change of FEU-85 to Hammamatsu. The comparison was made using cosmical rays signal in scintillator sample (such as in HAC).

Measured time resolution is **2.5 ns** for FEU-85 and **2.0 ns** for Hammamatsu, e.g. **20%** better.

Possibility of using another detector design

Since results with current time resolution are not fully satisfactory, we consider possibility of using detector with other design:

- Strips hodoscope with meantimer (2 PMTs reading from both ends): 5, 10, 20 *cm* width, for example; it will be analogous to hodoscopes currently used in NA48/NA62 detector;
- Pad hodoscope (with size of pad $20 \times 20\ cm^2$), each pad is read by 1 PMT;
- Possibly most easy: make meantimer for our pad detector to exclude coordinate dependence in time resolution (idea of Rainer Wanke)

Preferred variant is the strip hodoscope with meantimer. It can provide resolution much better than 1 ns.

Strip detector proposal

According to calculation of rates based on "TURTLE-HI" files [N. Doble] we choose preliminary configuration of the hodoscope with meantimer:

- $7 \times 2 \times 2$ strips of 5 cm width and 120 cm length (in central region); marked by 'h' below
- 3×2 strips of 5 cm width and 240 cm length
- 3×2 strips of 10 cm width and 240 cm length
- 2×2 strips of 20 cm width and 240 cm length

Corresponding number of PMTs: 44 (for full area 240x240 cm^2).
The muon rates expected for strips of this design (from center to edge):

width[cm]:	h5	h5	h5	h5	h5	h5	h5	5	5	5
rate[kHz]:	749	507	515	484	516	403	340	486	374	349
width[cm]:	10	10	10	20	20					
rate[kHz]:	531	490	297	522	240					