Updates on the Central TOF System for the CLAS12 detector

First measurements of the timing resolution of fine-mesh Hamamatsu R7761-70 photomultipliers

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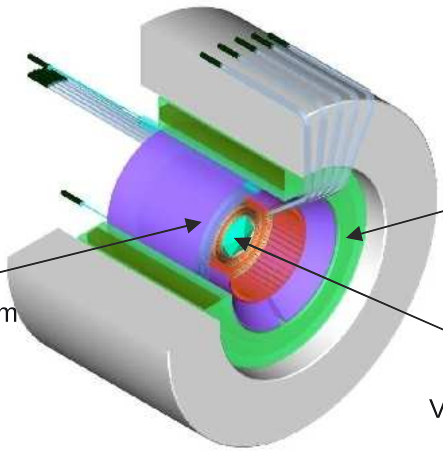
CLAS12 Workshop, JLAB, February 2-3 2007

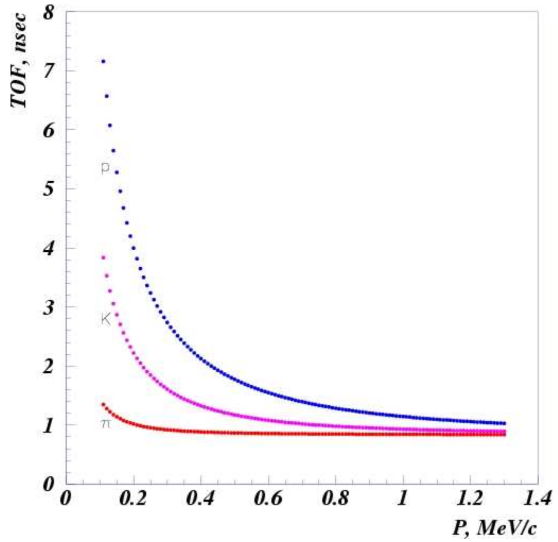
OUTLINE

- Conceptual design and requirements for the Central TOF system
- Method and experimental Setup for the measurements of the PM timing resolution
- Previous results
- Test measurements with Hamamatsu R7761-70 Photomultipliers: choice and first results

What does mean the Central TOF?



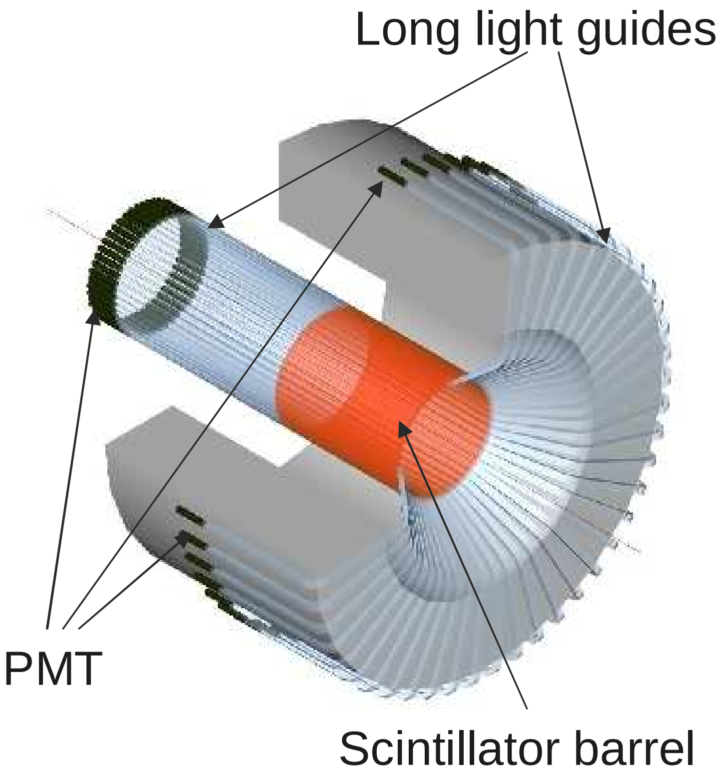
Central Part of CLAS++



Particle Identification of pions, kaons, and protons in the Central Part of TOF System via TOF-momentum Relation

- The main function of the Central TOF detector is the identification of charged particles emitted at central angles 40-130°
- **The design goal is to achieve TOF resolution σ=50 ps.This resolution makes it possible to separate pions from kaons up to 0.64 GeV/c, and pions from protons up to 1.25 GeV/c assuming a ``4σ" cut in time-of-flight between different particles.**

Conceptual Design



The system will operate in the high magnetic field of the solenoid. The magnetic field near the ends of scintillators will be about 1 Tesla and will prevent the use of ordinary PMTs.

There are two solutions under consideration:

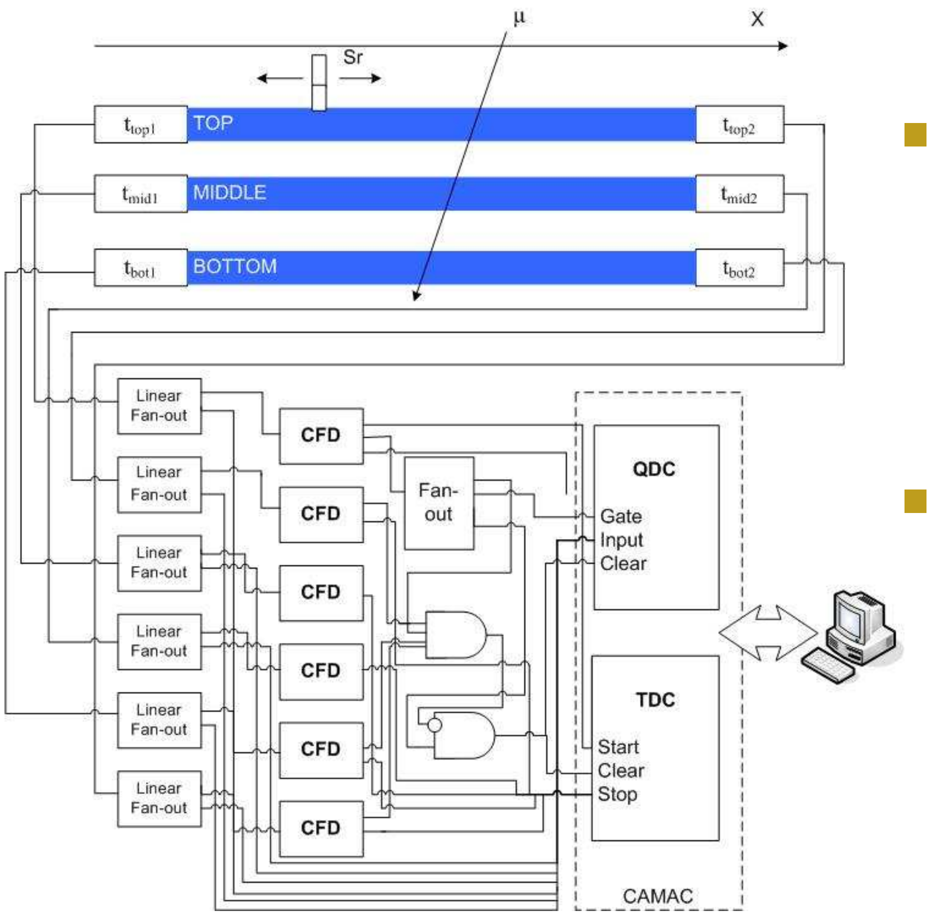
- The use of long light guides, to transport scintillation light out from the region of high magnetic field
- The use of PMs which can operate in the high magnetic field environment

The *TOF* variation is defined by the variations of the timing readouts from PMTs.

$$\sigma TOF = \frac{1}{\sqrt{2}} \sigma t^{2}_{pmt}$$

This relation places the limit of the PMT timing resolution: if the requirements for the *TOF* resolution σ=50 ps, the PMT timing resolution should be ***better than σ=72ps***.

Measurement of the PM timing resolution



- We use cosmic ray muons which are detected in three 30x20x500mm stacked parallel scintillators equipped with 6 PMs
- The PMs signals are digitized by LeCroy 2249A QDCs and their arriving times are measured by LeCroy 2228A TDCs.

How to measure the PMT timing resolution?

Cosmic ray tracking

- We make use of three counters equipped with six identical PMTs. The counters are aligned horizontally and are stacked parallel at equal distance each from the other. The times of scintillations caused by a cosmic-ray muon crossing all three counters (top, middle, and bottom respectively), are defined as:

$$t_{top} = (t_{top1} + t_{top2})/2 + C_1$$

$$t_{middle} = (t_{mid1} + t_{mid2})/2 + C_2$$

$$t_{bottom} = (t_{bot1} + t_{bot2})/2 + C_3$$

- Where t_{top1} ... t_{bot2} are the corresponding TDCs readout values, C_1... C_6 are the calibration constants. The muon looses a small part of its energy/momentum inside the counters. Its velocity remains nearly constant. Therefore

$$t_{middle} = (t_{top} + t_{bottom})/2 + C$$

or

$$\tau = t_{middle} - (t_{top} + t_{bottom})/2 = (t_3 + t_4)/2 - (t_1 + t_2)/4 - (t_5 + t_6)/4 = C$$

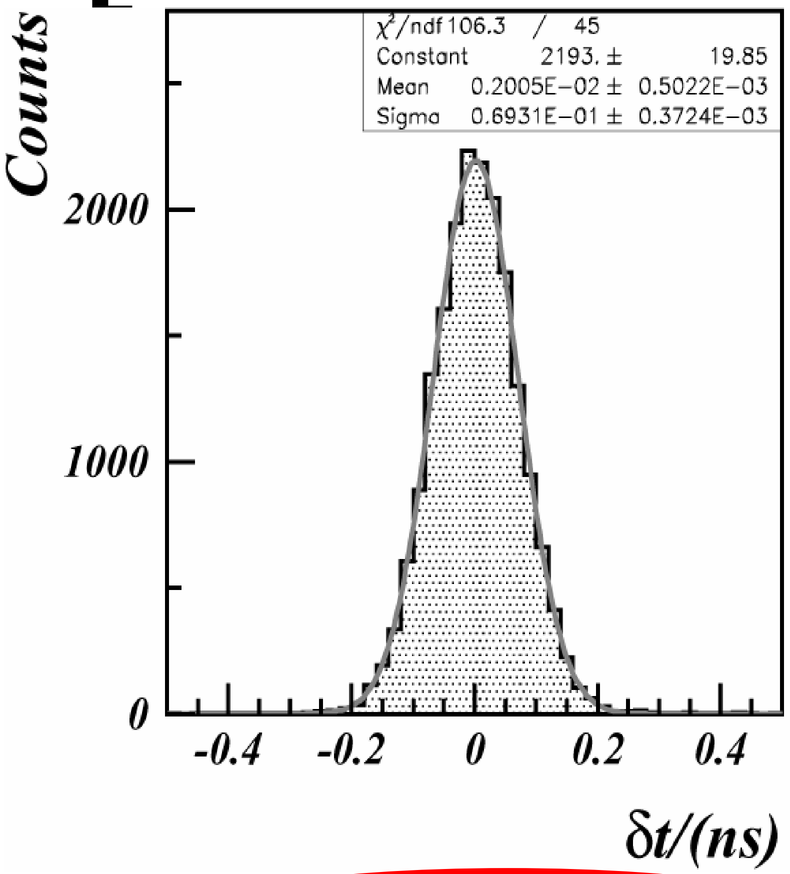
- However, since t_1 ... t_6 are smeared by the PMT resolutions, τ is distributed around some constant value C. Using the variance of τ , one may deduce the average PMT resolution

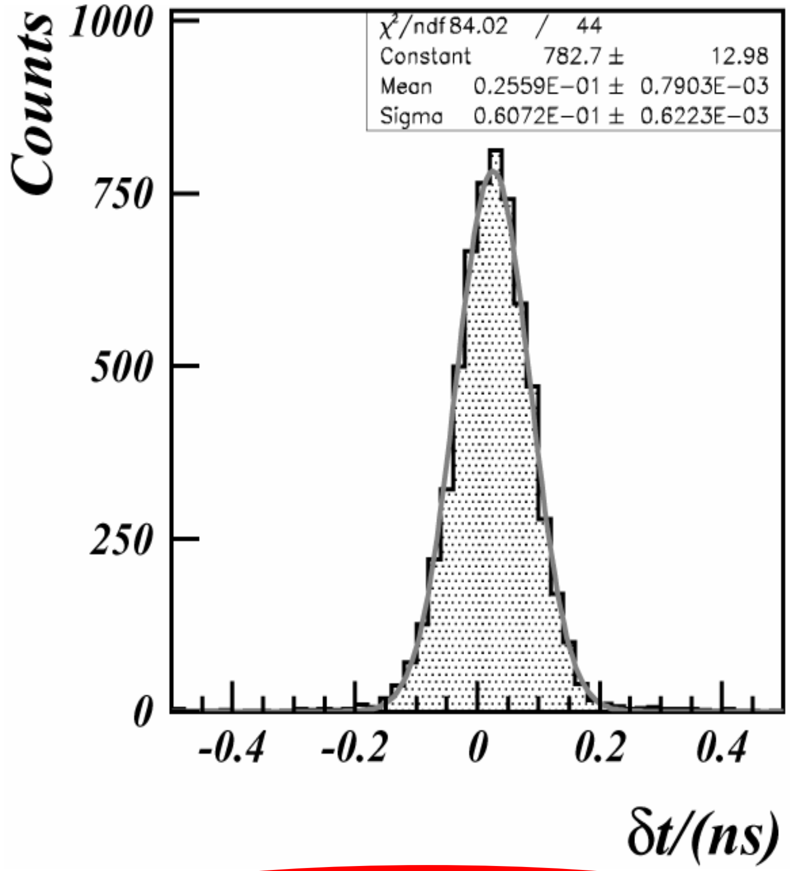
$$\sigma_{PMT} = \frac{2}{\sqrt{3}}\sqrt{\text{var}(\tau)} = \frac{2}{\sqrt{3}}\sigma_\tau$$

- In practice, the PMT resolution is derived from the Gaussian fit of the peak in the measured spectrum of τ.

Reference measurements of σ_{PMT} with prototype scintillator counters and Hamamatsu R2083 PMs

2 cm vs 3 cm thick



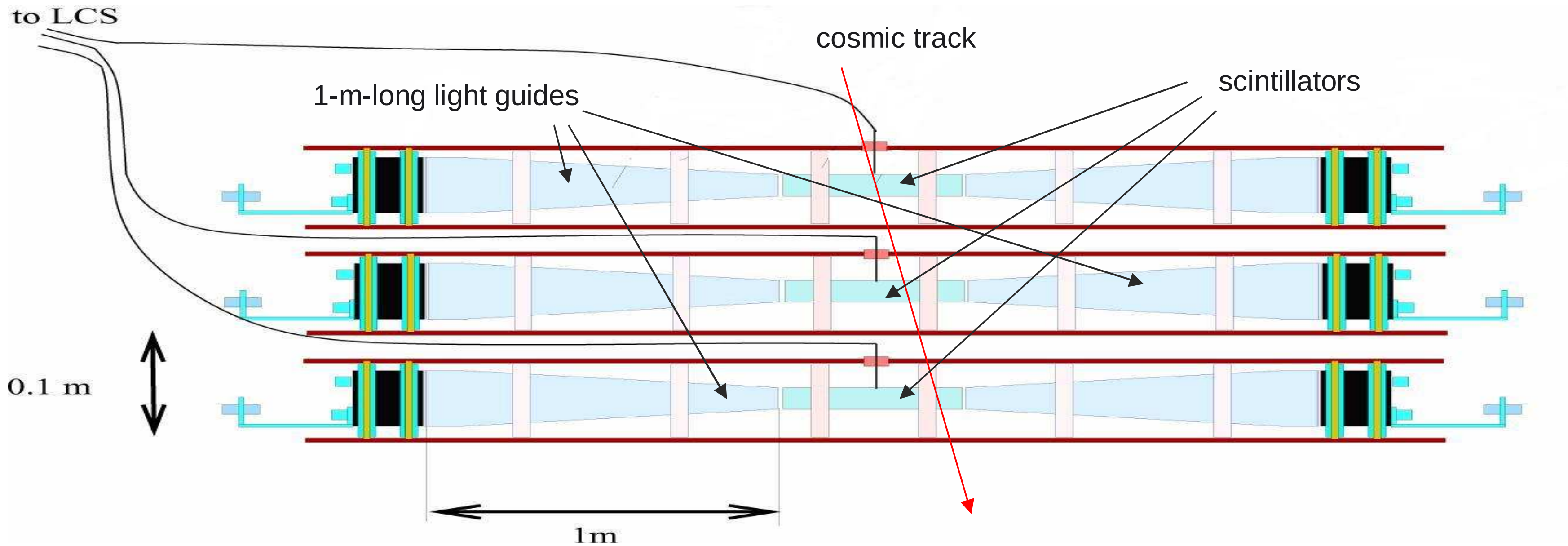


$\sigma = 62.3 \pm 0.4$ ps

$\sigma = 52.0 \pm 0.6$ ps

Measurements with 1m long light guides

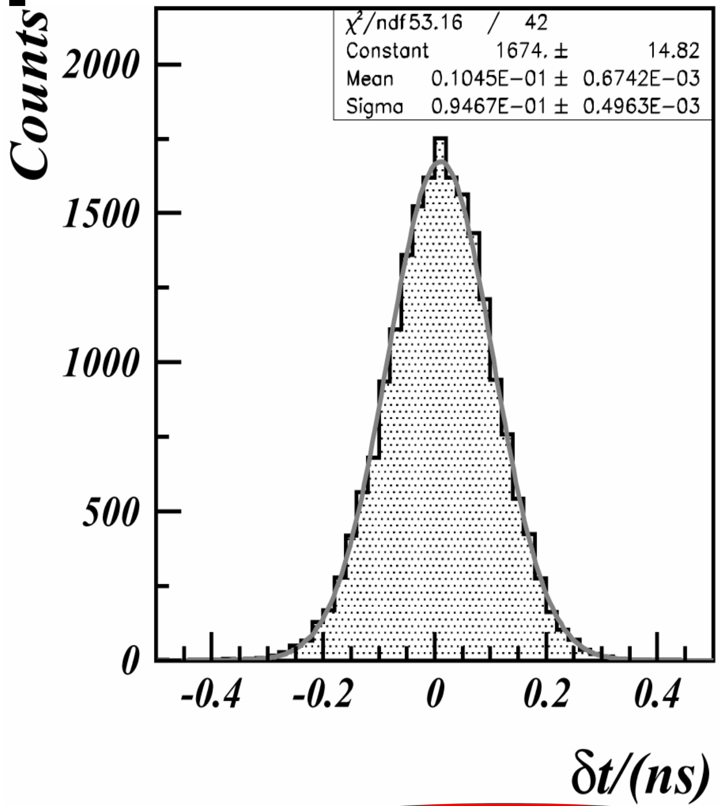
- Ordinary phototubes cannot operate in the high magnetic environment
- One option is to use long light guides, in order to transport scintillation light out from the region of the high magnetic field

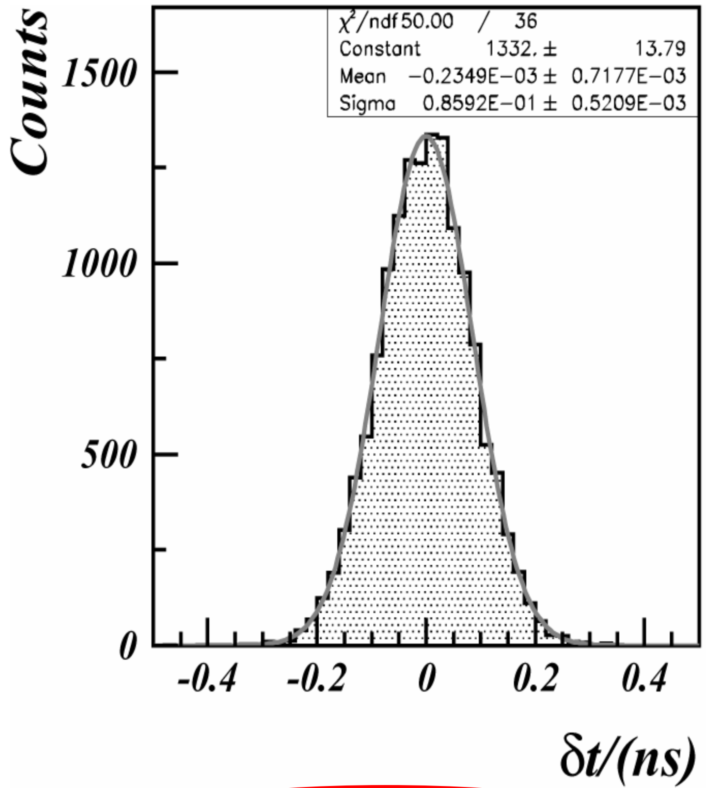


Setup of 3 proto-counters with 1m-long light guides

σ_{PMT} with 1m-long light guides

2 cm vs 3 cm





σ = 93.2±2.5 ps

σ = 83.6±0.6 ps

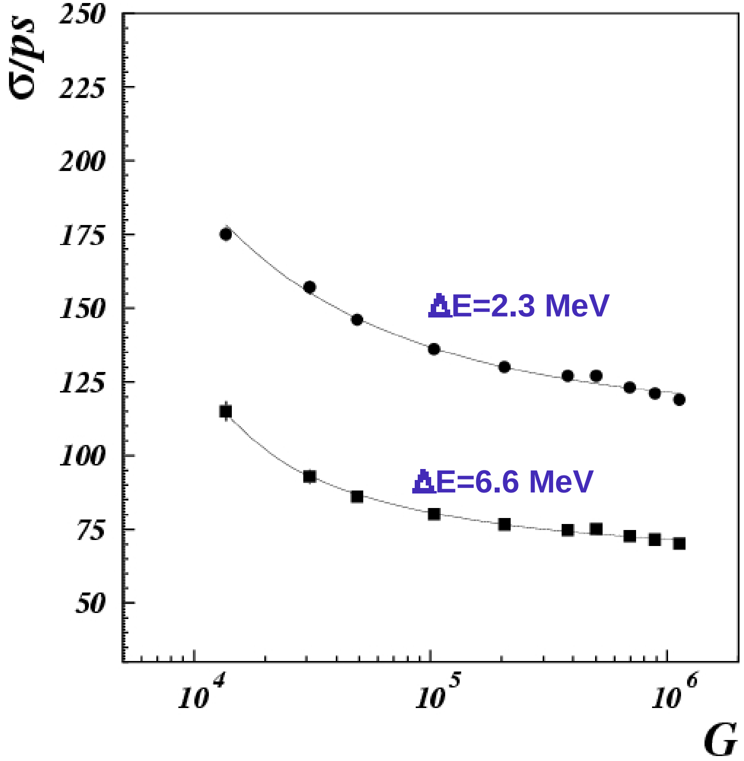
=>Significant deterioration

Measurements with Burle85011 singlet

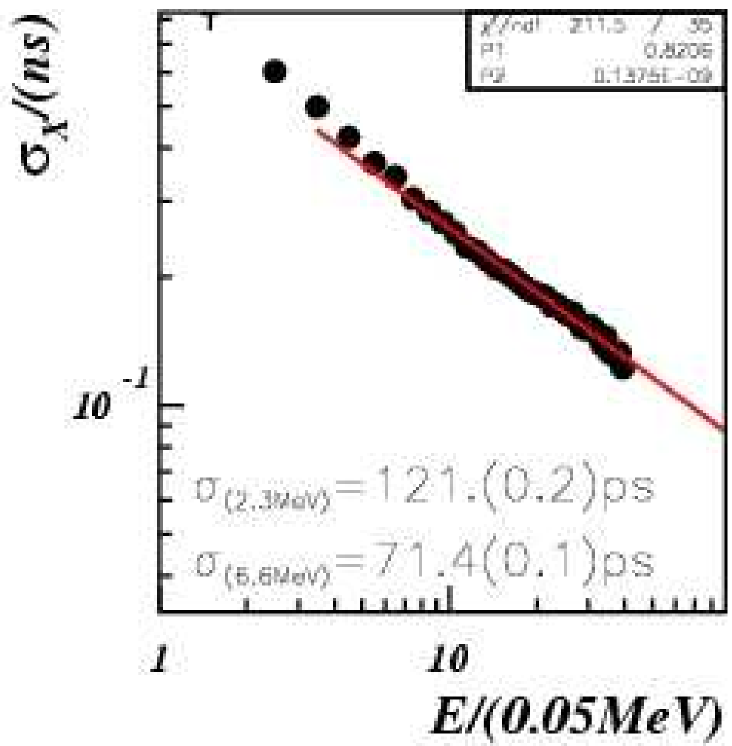
- New assembly of Burle85011 PMT with ``on-board" preamplifier and high-voltage divider was designed at JLB for these measurements;
- Time resolution depends on gain. At ultimate gain of $G=0.89 \times 10^6$ it was obtained as 71.4ps for $\Delta E=6.6$ MeV signals. At $G= 0.5 \times 10^5$ time resolution is 86 ps for $\Delta E=6.6$ MeV.
- Maximum operational count rate at $G=0.89 \times 10^6$ is limited to 10^5 Hz.

At maximum gain MCP cannot operate normally at higher count rate.

Measurement with Burle85011 singlet



Dependence of time resolition on gain



Dependence of time resolution at maximum gain on the signal amplitude

First measurements with Fine Mesh Hamamatsu R7761-70 Photomultipliers

The result shown below are preliminary

Why Hamamatsu R7761-70?

- Fine mesh Photomultipliers have been designed to operate in the high-magnetic field environment. Their dynode system is made of the ladder of fine grade mesh at certain potentials.

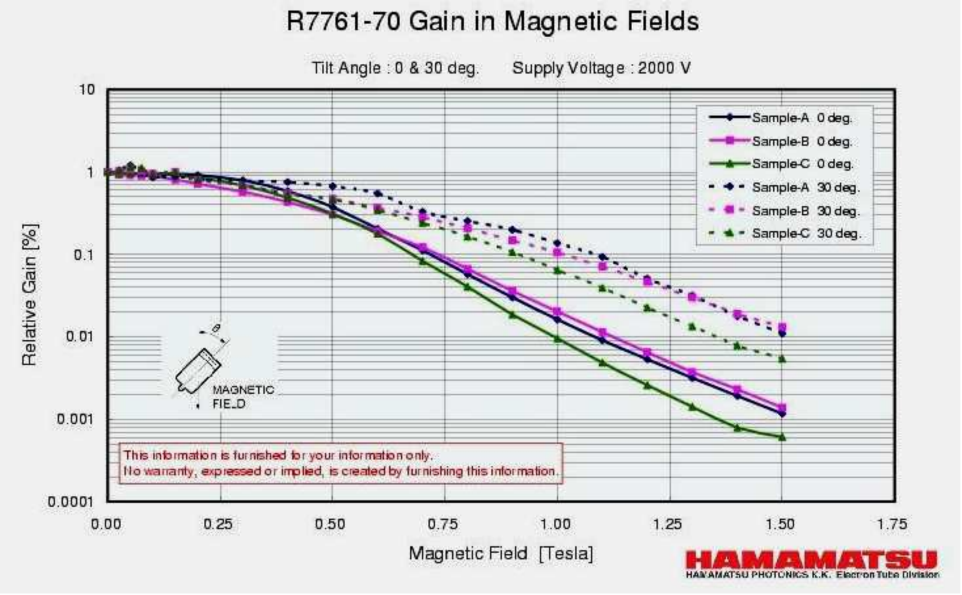
Comparison of properties of R2083 and Fine mesh PMTs

#	Phototyube (type)	Dynode System	Photocathode diameter (mm)	Photocathode Type	Anode Sensetivity (typical) (A/Lm)	Anode Pulse Rise Time (ns)	Electron Transit Time (ns)	Transit Tame Spread (ns)
1	**R2083**	**ordinary**	**39**	**Bialkali**	**200**	**0.7**	**16**	**0.37**
2	R5505-70	fine mesh	17.5	Bialkali	40	2.1	5.6	0.35
3	**R7761-70**	**fine mesh**	**27**	**Bialkali**	**800**	**2.5**	**7.5**	**0.35**
4	R5924-70	fine mesh	39	Bialkali	700	2.5	9.5	0.44
5	R6504-70	fine mesh	51	Bialkali	700	2.7	11	0.47

Why Hamamatsu R7761-70?

Hamamatsu R7761-70 photomultipliers have been chosen because

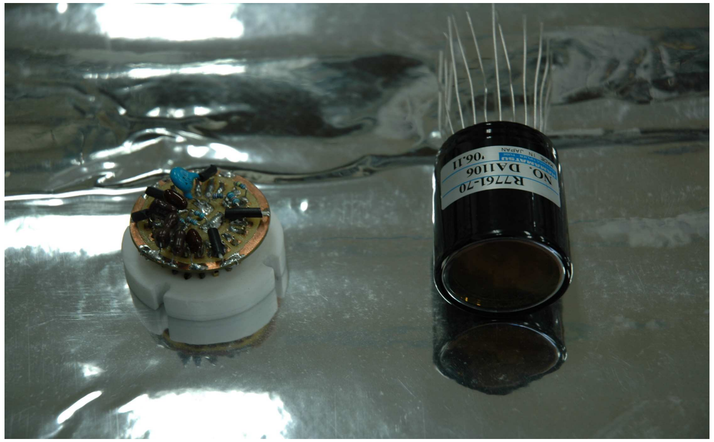
- Their resistance to magnetic field
- Good timing performance: transit time spread is even better than for R2083
- Geometrical dimensions
- High gain
- Relatively low price



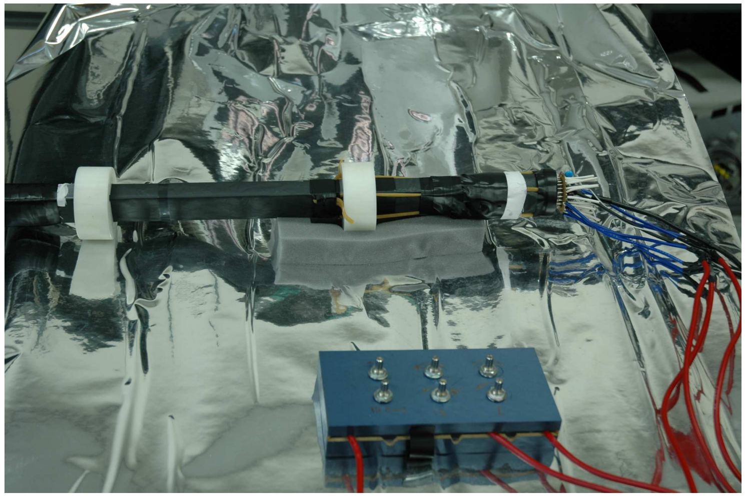
Voltage Divider

We have developed our voltage divider which was optimized for the timing performance.

In difference from the Hamamatsu voltage divider, our divider uses negative HV. It was optimized for the best timing performance.

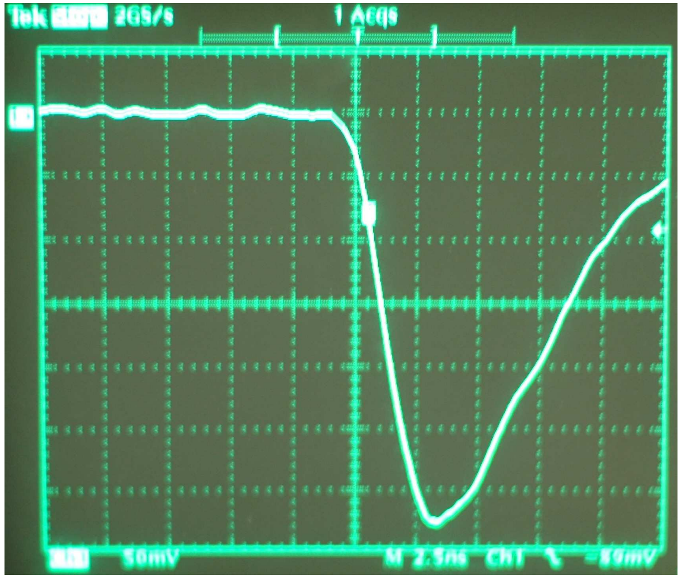


Voltage divider for R7761-70 (on the left) developed and manufactured at KNU, and R7761-70 PMT (on the right)

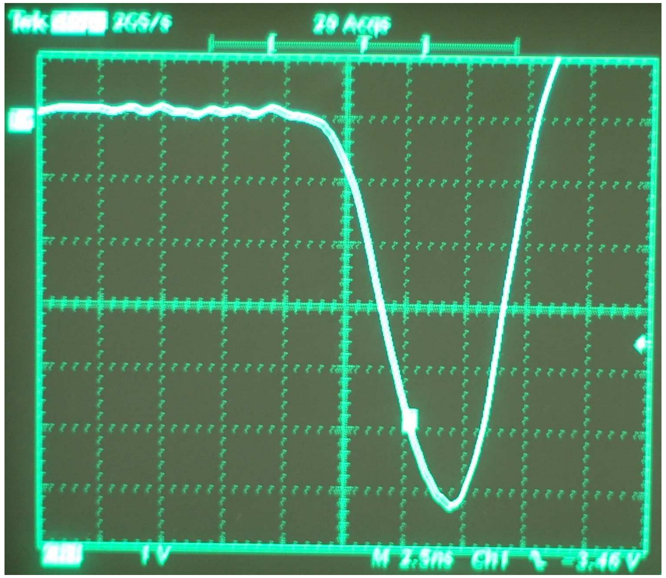


Experimental setup for optimization of potentials at the dynode system, in order to achieve the best timing performance.

R7761-70 and R2083 anode pulses



R2083

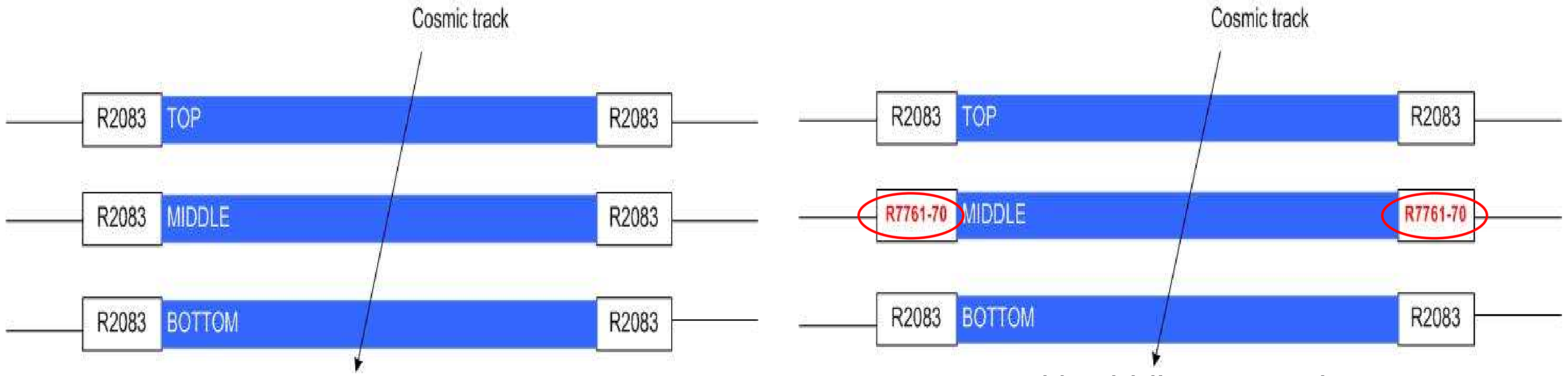


R7761-70

Typical anode pulses corresponding to a cosmic muon event in the 3cm thick scintillator counter.

- HV to R7761-70 : 2100V (max 2300V); HV to R2083 : 2500V (max 2800V)
- Rise time is ~3.2nsec for R7761-70 and ~2nsec for R2083
- R7761-70 provides much higher pulse height (~5V/50Ohm). This preserves the possibility to use these PMTs in the high-magnetic field with significant reduction of gain.

Measurements of R7761-70 timing resolution



a) 6 R2083 PMs

b) Middle counter is

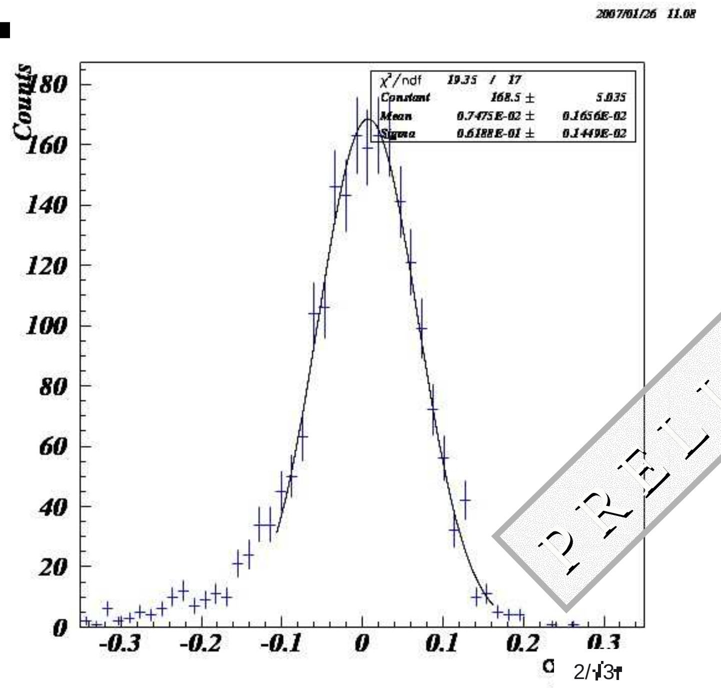
Viewed by R7761-70

- We use the triplet of scintillation counter and the cosmic-ray method
- Two alternative measurements:

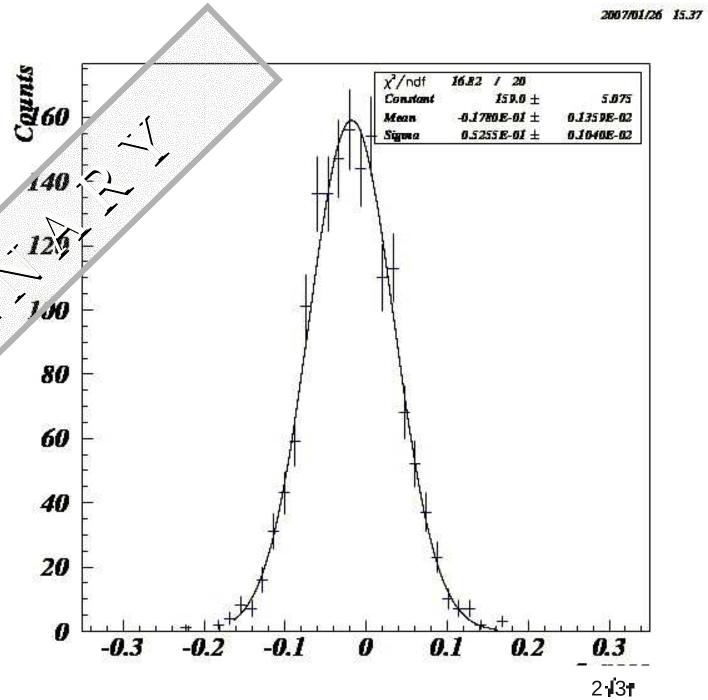
a) using 6 PMs - R2083 ;

b) using the middle counter equipped with two R7761-70 PMs

First results



4*R2083+2*R7761-70



6*R2083

Average σ_{PMT} obtained with the middle counter viewed with two R7761-70 is **62** psec. σ_{PMT} obtained with six R2083 PMs is **53** psec.

Estimate of R7761-70 timing resolution

$$\sigma_{PMT} \sim \sigma(\tau) = \sigma\left[\frac{1}{2}(t_{middle1} + t_{middle2}) - \frac{1}{4}(t_{top1} + t_{top2} + t_{bot1} + t_{bot2})\right]$$

$$\sigma^2(\tau) \sim 2\sigma^2_{PMTmiddle} + \sigma^2_{PMTtop} + \sigma^2_{PMTbot}$$

where σ_{PMT_middle}, σ_{PMT_top}, and σ_{PMT_bot} denote the timing resolutions of the photomultipliers which view the middle, top, and bottom counters respectively.

$$\frac{\sigma^2{}_{(R7761\&R2083)}}{\sigma^2{}_{(R2083)}} = \left(\frac{62}{53}\right)^2 = \frac{\sigma^2_{R7761} + \sigma^2_{R2083}}{2\sigma^2_{R2083}}$$

Preliminary:

$\sigma_{R7761\text{-}70} \leq$ 72 psec

Some remarks regarding our measurements

- The photocathode diameter of R7761-70 is 27mm. R7761-70 covers only 85% of the 2x3cm^2 surface of the scintillator counter. Therefore only 85% of scintillation light has been collected.
- In first measurements we had to use relatively low HV=1800V, to reduce pulse height.
- The anode rise time of R7761-70 is 3.5 nsec. In comparison with R2083 we have observed an additional “time walk”. At this time we used a rather primitive correction.

Therefore there are sources for further improvements!

Which TOF resolution one may expect with R7761-70?

Our present (preliminary) estimate

$$\sigma_{TOF} = \frac{1}{\sqrt{2}} \sigma_{PMT} \leq 50\, p\sec$$

Our expectation for $\sigma_{R7761\text{-}70}$ is 60-65 psec. This corresponds to σ_{TOF}~ 43-46 psec.

An open question is how the R7761-70 timing resolution depends on magnetic field.

No information available => Special measurements are needed.

Conclusions

☞ We report on the first measurements with R7761-70 fine-mesh photomultipliers. The measured timing resolution encourage these PMTs in the Central TOF System.

☞ Further study of the R7761-70 properties in magnetic field is needed for the final decision.

☞ Possible design of the Central TOF system might be a barrel made of scintillator bars viewed by R7761-70 PMTs directly or through short light guides.