Measuring detection efficiency and attenuation length of PVT plastic scintillator for cosmic ray muon detectors

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Abstract:
The performance of NE114 fluorescent PVT plastic scintillator was characterized as a component for cosmic ray muon detectors. Results of this work will be useful in the future project: creating a detector array at campuses of the City University of New York and the State University of New York. The cosmic rays detecting network will be able to gather data from an extensive area and analyze it. Student performed a Sandwich Prototype testing of the scintillator. 100cm x 30cm x 2cm NE114 scintillator was mated to a photomultiplier tube (PMT) and two small QuarkNet scintillators with mated photomultiplier tubes were used to sandwich the scintillator under the test. The apparatus is called "muon telescope." As charged muon particles pass through the scintillator an ionization process produces faint light which is later detected and converted to an electrical signal by the PMT. Performing Sandwich Prototype testing we were able to determine and measure detection efficiency and light absorption characteristics of the NE114 scintillator. In the test setup, 2-fold detection coincidence of two small scintillators and 3-fold detection coincidence of all three scintillators were measured simultaneously. The efficiency is defined as the 3-fold to 2-fold ratio. Efficiency was measured as a function of distance from the PMT mated to the scintillator. The 3-fold to 2-fold coincidence ratio was approximately 90% near the PMT and dropped to 85% at 25 inches. The study indicates that scintillator accuracy is satisfactory and it can be used as a component for cosmic array network.

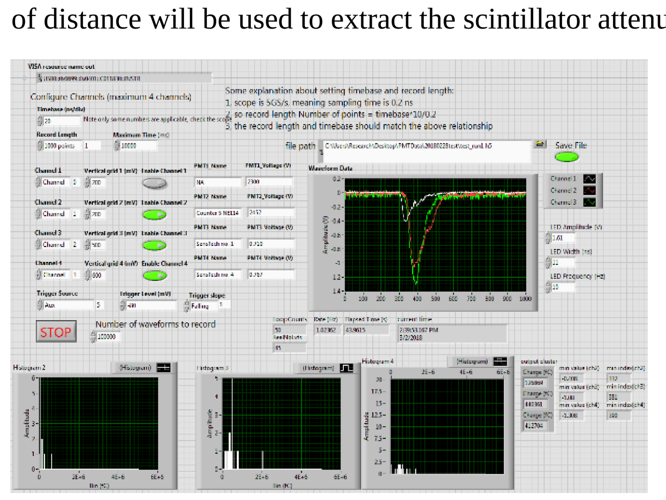
Introduction:
This project is to develop a method to measure the efficiency of large area plastic scintillators and use this method for selecting the best scintillators we have for building cosmic ray shower detector array.
In this work we tested efficiency of two scintillators with some different reflective materials and the results are presented here.

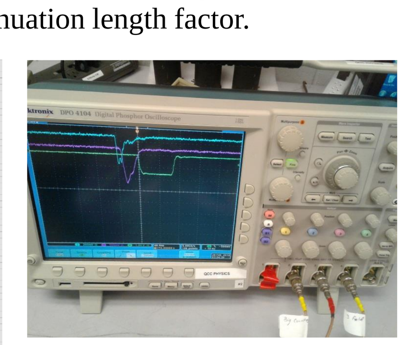
Procedure:
Method of efficiency measurement
There are a list of variables that one should take into consideration performing an experiment. For every experiment there is a minimum set of variables that need to be defined and set constant, student should know what property of the scintillator is tested in advance and decide what variable properties to set constant.
A list of Variables that can be adjusted:

1) **Power supplied to Telescoping counters**
2) **Power supplied to the Photomultiplier tube attached to testing scintillator**
3) **Wrapping method and reflective material**
4) **Optical mating. Photomultiplier tube to scintillator connection technique**
5) **Discrimination threshold value for every sensor**
6) **Light yield/ Attenuation length or scintillator plate material**

To conduct our experiment we will define desired power supply to both telescoping and testing photomultiplier tubes and determine proper discrimination unit threshold values and set these values constant. We also will use one technique of optical mating, and use one scintillator plate to set the attenuation length constant.
With following set up we can test the efficiency of wrapping material by testing the efficiency of the scintillator along its length. To make a decision what reflective material is better we will compare the efficiency results recorded in two cases.

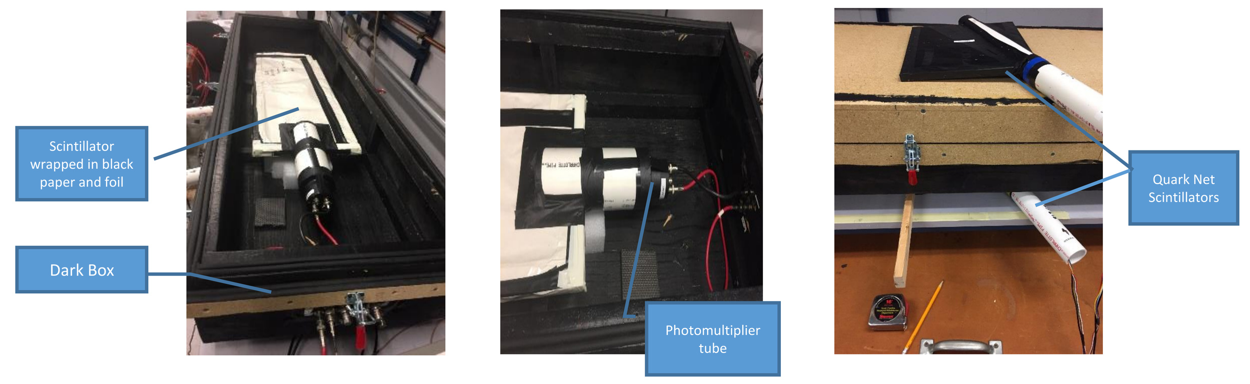
Attenuation length measurement setup:
Using NIM electronic modules the three PMT signals from the muon telescope were amplified x10, passed through a voltage discriminator, and connected to a logic AND gate which selected 3-fold coincidence events. The output of the AND gate triggered a DPO4104 oscilloscope which recorded all 3 PMT waveforms; a computer running a LabVIEW program acquired the oscilloscope waveforms for analysis.
Figure: LabVIEW interface for data acquisition:
A LabVIEW program was created to acquire and analyze the cosmic ray measurement data from an oscilloscope connected to the NE-114 scintillator counter under test. Since the rate at which LabVIEW acquires the waveforms is not synchronized with the rate of cosmic ray events, the program was designed to keep only 3-fold triggered events. The measured PMT signals are waveforms of voltage vs. time. The program integrates the voltage under each signal pulse, converts it to units of charge, and fills a charge distribution. The cosmic ray charge distribution is expected to be a Landau distribution. Next we will fit this charge distribution and extract the peak charge from the fit. Charge measurements will be made at different distances from the PMT along the scintillator, and the measured charge as a function of distance will be used to extract the scintillator attenuation length factor.



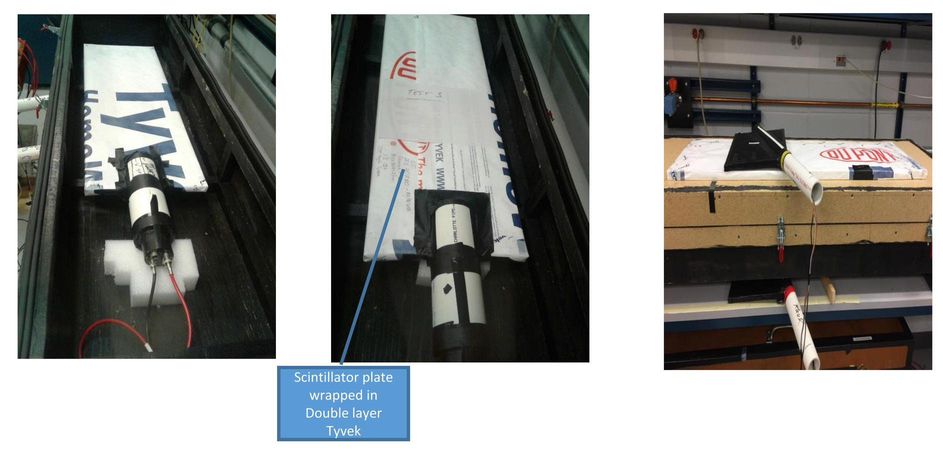


Efficiency Measurement Method:

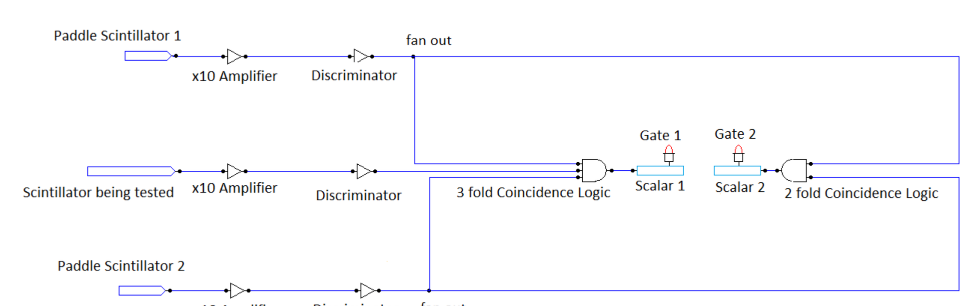
NE114 plastic scintillator under test in a muon telescope setup
Black paper and foil wrapping

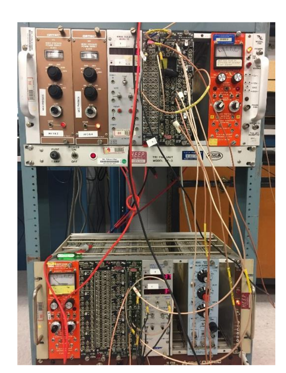


NE114 plastic scintillator under test in a muon telescope setup
Double layer Tyvek wrapping



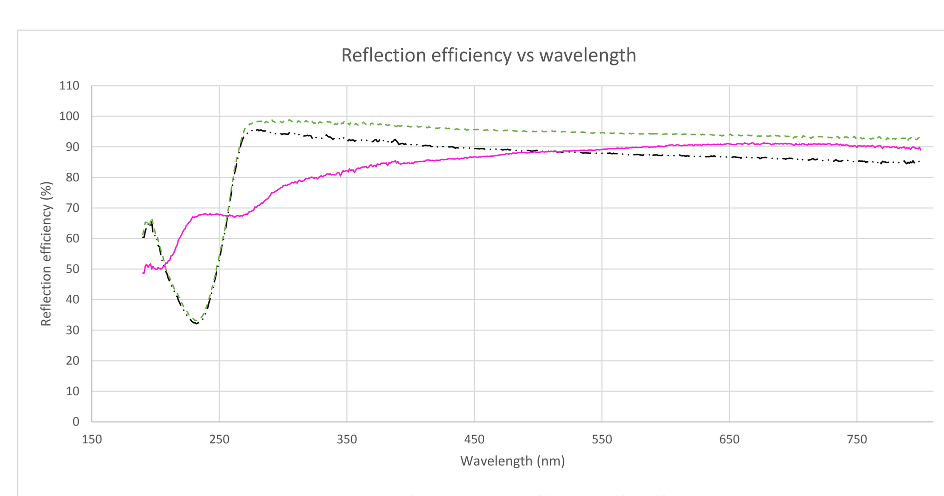
Muon telescope Block diagram (NIM electronics)





NIM bin setup used:
Power supply (BNL 106900)
Dual Channel Visual Scaler (Joerger).
Sixteen channel amplifier (model 776) – (BNL 13175) - *Set to 10x amplification.*
Six channel discriminator (model 711) – (BNL 5052).
Quad gate/delay generator (model 794) – (BNL 20992) – *Set to 8.3(s) delay.*
Multimeter: Fluke 8022B (QCC- PHY 4713).

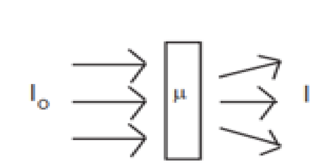
Reflectivity tests for aluminum foil and Tyvek industrial wrap



Photons are absorbed in matter by statistical processes that lead to an exponential absorption that is a function of position.

This Function is normally written as:

$$I = I_o e^{-\mu x}$$



Where:

I_o= the number of photons of a certain energy incident or entering the sheet of material,

x = the thickness of the sheet,

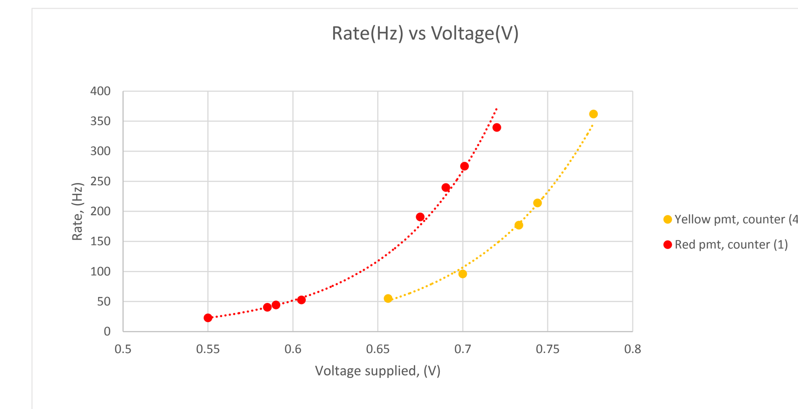
I = the number of photons that have passed through a layer of thickness x,

μ = the linear attenuation coefficient for the material.

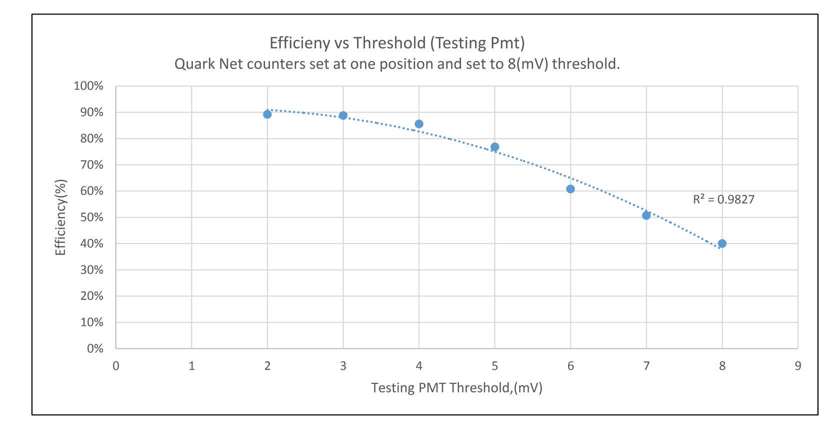
The photons that do not get through have interacted within the sheet of material and are either absorbed or scattered. In this case, photons have interacted in the sheet.

Setup description:

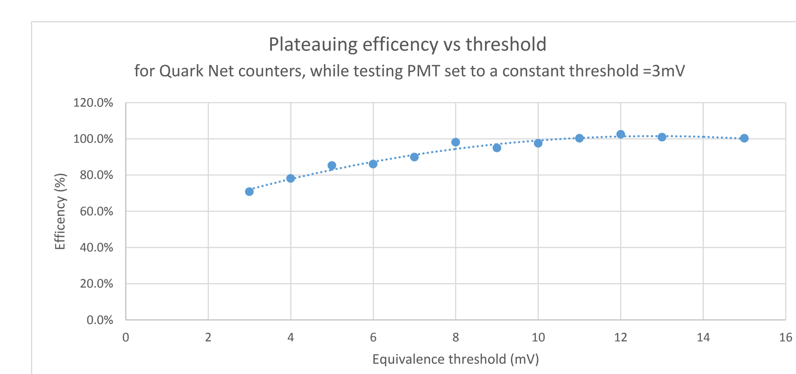
Photomultiplier tube dark rate measurements vs. operating voltage :
Results are shown for an H2431 PMT and two SensTech pmts. Ideally we want to know the exact gain function for each photomultiplier tube, because it is important to set counters to the same signal amplification.



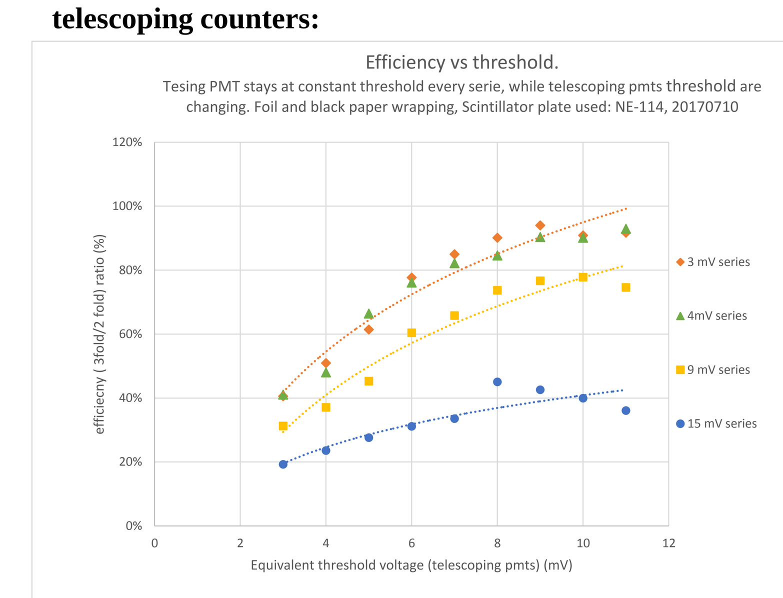
NE114 Scintillator efficiency vs. Testing Photomultiplier tube threshold:
Three (mV) equivalence threshold for PMT attached to testing scintillator determined to be suitable for experiment. Increasing Threshold after this point leads to the loss of muon signal.



NE114 Scintillator efficiency vs. telescoping signal threshold:
The NE114 scintillator plateaus at about 95% efficient when the telescoping counters' signal threshold is set at about 8mV; measurements were made about 5 inches from the PMT on the NE114 counter

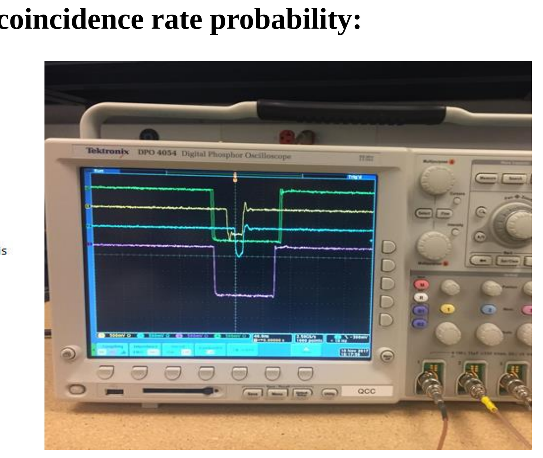


Efficiency vs. threshold for NE114 counter and telescoping counters:



Calculating False coincidence rate probability:

- Green and Purple graphs represent discriminator unit signals for two small muon detectors the width of the gate approximately 85(ns) and an amplitude is 1.5 (V)
- Yellow and blue graphs represent the width of 2 fold and 3 fold coincidence signals after coincidence unit.



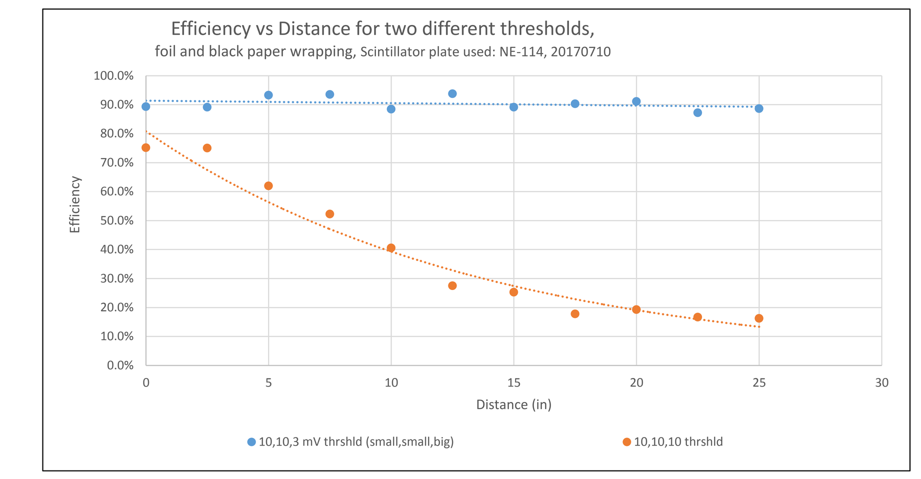
Gate Width
Voltage
Random "noise" pulses

The rate of noise depends on the voltage applied to the photomultiplier tubes – Higher voltage produces more random pulses.
– Rate on channel 1 is R_1
– Rate on channel 2 is R_2
– Accidental rate when channel 1 fires first: R_1R_2*w
– Accidental rate when channel 2 fires first: R_2 R_1*w
– Total accidental rate: 2 R_1R_2*w= 2*300*300*85*(10^-9)= 0.0153
– Three-fold accidental rate: $R_1R_2R_3$*w^2 =4500*300*300*85*85*(10^-9)^2= 3*(10^-6).

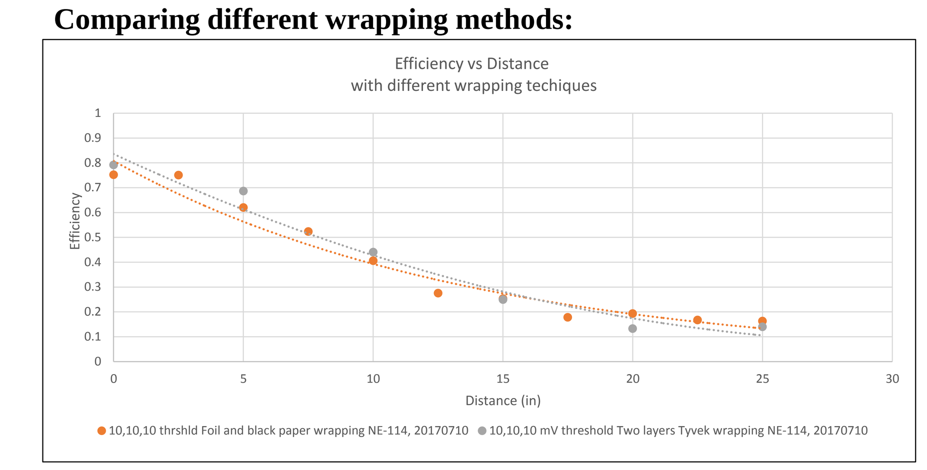
– Gate width was set to 85 ns for all three discriminators.
– Accounts for different lengths of cables, different "transit times" in photomultiplier tubes.

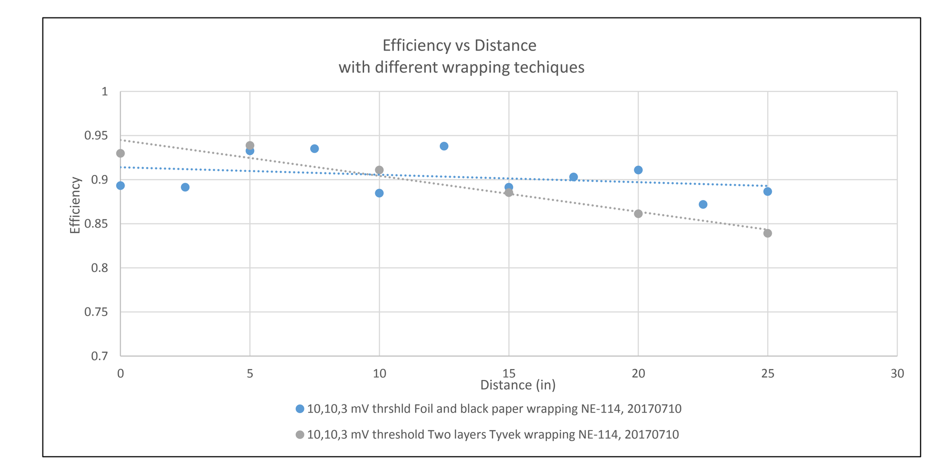
Results and conclusions:

Efficiency vs. distance from the PMT for different signal thresholds
Testing the first scintillator:
The NE114 counter is about 90% efficient across its length when its signal threshold is set low to 3 mV

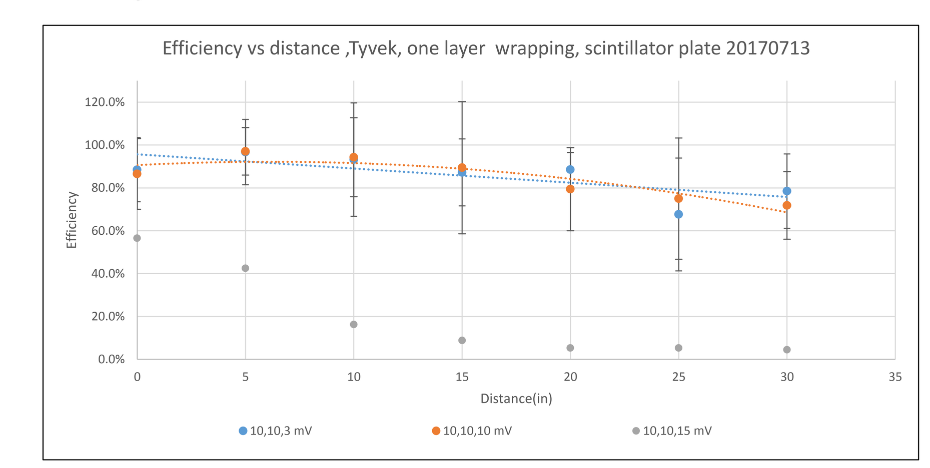


Comparing different wrapping methods:

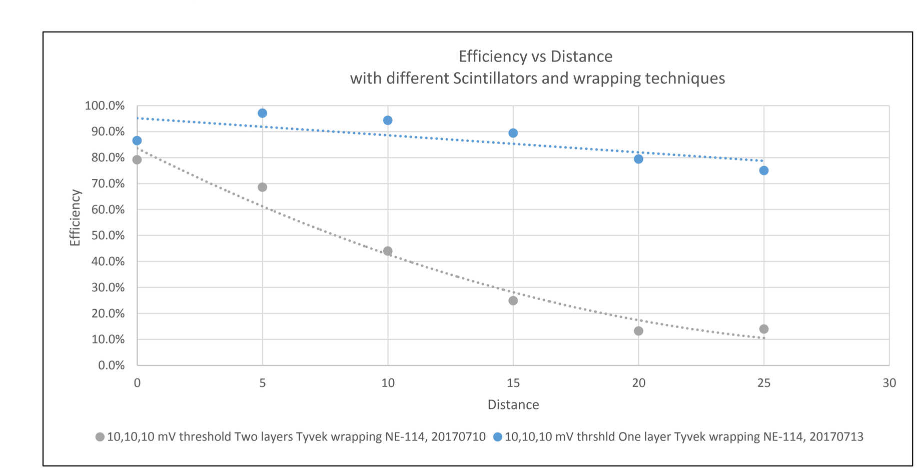




Efficiency vs. Distance from the PMT for different signal thresholds
Testing the second scintillator:



Efficiency vs. Distance
Comparing two scintillator plates:



Conclusions:

- We have developed a working procedure of measuring plastic scintillators efficiency and uniformity by selecting cosmic rays with a so-called muon telescope.
- Using the method of efficiency measurement we were able to see that black paper and foil has the same reflective property as Double Tyvek.
- We also compared and noticed a sufficient difference in efficiency between two scintillator plates. We have to look into this to see and define the reason why one scintillator plate is more efficient then another. It could be several reasons: cracks or fractures, grinding finish or light absorption characteristics.
- With our method of efficiency measurement we will be able to perform and learn other properties of the scintillator plates which will be used and applied in later projects.

Future plans:
We have developed a method to roughly measure attenuation length and light yield of scintillators. We are going to apply this method to a few scintillators.
We plan to do a batch measurements and select the best scintillators for the cosmic ray shower detector array.