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# Efficiency measurements of used Nuclear Enterprises-114 PVT plastic scintillator made with a muon telescope - "sandwich test"

Work performed in BNL EDG Lab 2-233

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#### Introduction

A muon telescope setup was used to measure the efficiency of sheets of NE-114 PVT plastic scintillator. 100 scintillators of dimensions ~ 107 cm x 30 cm x 2 cm, donated from Fermilab CDF surplus, will be tested following the procedures outlined here. The scintillators are binge cut to 95 cm long for a cosmic ray detector array. The NE-114 manufacturer specification wavelength of maximum emission is 434 nm. The measurements include different mating techniques between the photomultiplier tube (pmt) and scintillator: an optical-interface pad "silicone cookie" was compression mated, a solid acrylic cookie was mated with optical grease BC-630, versus bonded with optical cement EJ-500. Light reflection measurements were made of the aluminum foil and Tyvek wrapping materials by themselves before wrapping the counters; light transmission tests were conducted for us by Sean Stoll using a Hitachi model 3210 double-beam spectrophotometer, following the procedures outlined in PHENIX Note #245 and #245 Addendum.

## **Summary of results**

The light output from these scintillators from cosmic ray muons produces pulses on an oscilloscope about an order of magnitude lower than other newer and higher quality scintillator counters we have used. However better sanding, polishing, and wrapping methods are now used by the students. The most significant finding is that the discriminator setting is, by far, the most important variable to set properly. Increasing the discriminator threshold from 3 mV to 10 mV lowered the efficiency by 10% to as high as an 80% reduction in efficiency, depending on how far the cosmic ray track was from the pmt. The type of wrapping materials, cookies used, mating whether by compression, grease, or glue, or absence of a cookie all together, only changed the results by about 10-15%; however

## Cookies and wrapping paper

At 430 nm light reflection off one layer all white Tyvek was 90%, two layers 96%, and two layers aluminum foil 86%. The red and blue colored printed letters on the Tyvek reduced reflected light by between 2% to 8% depending on single or double wrapped (Figure A). At 430 nm the light transmission through the newly purchased 6 mm thick silicone cookie, and older used 2mm cookie, were both 92%; the solid acrylic cookie transmitted 89% of the light (Figure B) (test method described in PHENIX Note #245).

#### Scintillator counter discriminator thresholds

For the two small telescoping paddle counters it was determined that a 10 mV discriminator threshold produced the best results; setting the discriminators lower resulted in what appeared to be noise in their 2-fold coincidence rate. The reason we believe this to be noise is the 2-fold rate began to exceed 13 Hz, the expected muon rate, for our paddle sizes, at 1 per cm<sup>2</sup> per minute (Figure 10). However, it is noted here that the dark rate measured from these paddles at operating

voltage was only about 300 Hz each, thus the noise coincidence was not expected to be significant (see the Appendix).

For the NE-114 scintillator counter under test a choice of 3 mV discriminator threshold was determined to work best; Setting the discriminator a few mV higher resulted in a significant reduction in detection rate. This is because the large majority of cosmic ray muons detected with the counter's pmt set at  $10^6$  gain were are about 7 mV in amplitude through 50 Ohms on the oscilloscope. Various charge distributions made from the NE-114 counter, each for 200,000 events, confirmed that the majority of cosmics produce pulses between 5 and 10 mV in amplitude depending on how far from the pmt the muon penetrates the counter (Figures 10 - 19).

## Mating the PMT to NE-114 scintillator

Compression mating the pmt to the scintillator with a new silicone cookie produced the best results. Optically bonding (i.e. gluing) the UVT acrylic cookie to the scintillator was mechanically very sturdy however the light output was significantly less (Figures 16 - 17).

# Efficiency as a function of distance the cosmic ray track is from the PMT

The NE-114 counter s/n 20170710 is 90% efficient across its length of up to 25" which was measured, when its discriminator threshold is set to 3 mV, this drops to only 15% efficient when set to 10mV (Figures 10 - 17).



Figure A: Comparison of light reflection off one and two layers of white Tyvek wrapping paper, and two layers of aluminum foil (the foil is backed with white paper on the backside to reinforce it). Test method described in PHENIX Tech note 245.



Figure B: Light transmission tests through the different cookies: "Acrylic" is the 1 cm thick slotted plastic cookie; "Silicone cookie" is the 2 mm thick, much older and used cookie; "Silicone Cookie #2" is the newly purchased 6mm thick cookie. Test method described in PHENIX Tech note 245.

#### Procedure

Two telescoping scintillator paddles were used, one paddle placed above and the other below the NE114 scintillator under test - a "sandwich-test." Each paddle was compression mated to a pmt. The 2-fold coincidence cosmic ray rate for the paddles was measured simultaneous with the 3-fold coincidence rate. Efficiency was measured at different distances from the pmt-side of the NE-114 scintillator under test:

*Efficiency* (%) = 
$$[3-fold\ coincidence\ rate/2-fold\ coincidence\ rate]\ x\ 100\%$$
 Eq. 1

Each of these variables affected the efficiency results:

- 1. Reflectivity of wrapping material.
- 2. Optical mating between pmt and scintillator.
- 3. Gain of telescoping counters, determined by the HV applied.
- 4. Gain of pmt attached to scintillator under test, determined by the HV applied.
- 5. Discriminator thresholds set for each of the three counters.

The widths of the discriminator outputs were each set to 85 ns; the square wave outputs of the 2fold coincidence unit, and the 3-fold coincidence unit measured to be 40 ns wide. The coincidence rate was not measured as a function of varying discriminator output widths.

## Equipment

#### NE-114 scintillator under test

Two different scintillator plates were tested:

Counter 5 s/n 20170710; dimensions: 90.5cm x 30.3cm x 2cm; wrapped in aluminum foil and later rewrapped with two layers of Tyvek.

Counter 2 s/n 20170713; dimensions: 108cm x 30cm x 2cm; wrapped in one layer of Tyvek.

The same pmt was used, a 2" Hamamatsu H2431-50, s/n AA1071 ("PMT 26").

Measurements made with different mating techniques between PMT & scintillator:

1/16" thick optical interface pad (silicone cookie) compression mated

1 cm thick acrylic cookie (not known if it is UVT), bonded with optical grease BC-630

1 cm thick acrylic cookie (not known if it is UVT), bonded with optical cement EJ-500

#### Two telescoping paddle counters used to sandwich the scintillator under test:

Fermilab Quarknet paddle "counter 1" (marked with red tape); HV set at 720V via a low-to-high voltage converter set at 0.720 V (ratio 1:1000).

Fermilab Quarknet paddle "counter 4" (marked with yellow tape); HV set at 777 V via a low-tohigh voltage converter set at 0.777 V (ratio 1:1000)

Both scintillator paddles are 819 cm<sup>2</sup>, 1 cm thick, EJ-200 PVT plastic wrapped in aluminum foil and black paper; each was compression mated to a SensTech P30CW5 photomultiplier module with Dow Corning optical couplant Q2-3067.

#### **Electronics:**

HV power supply (NIM module, BNL 106900)

Dual Channel Visual Scaler (NIM module, Joerger).

Sixteen channel amplifier model 776 – (NIM module, BNL 13175) - x10 amplifier used.

Six channel discriminator model 711 – (NIM module, BNL 5052).

Quad gate/delay generator model 794 – (NIM module, BNL 20992) – Set to 8.3 s delay.

Multimeter: V&A (VA19).

500 MHz oscilloscope Tektronix DPO 4054 (s/n C022247)



Figure. 1. NIM bin electronic modules used for the experiment.

Fig. 2. Sandwich test setup





Figure. 3. Sandwich test schematic

Figure. 4. Two wrapping techniques for scintillator counter 2 - 20170710



## The outputs of our signals from the various NIM module used in the tests are shown in Figure 5.



#### Figure. 5. NIM electronics signals used

#### **Equipment Adjustments:**

For the measurements an attempt was made to equalize the gain at  $g = 10^6$  on all three counters' pmts. This is discussed immediately below.

#### Power supply setting for PMT Hamamatsu AA1071 mated to NE114 scintillator under test

The pmt used for many tests (s/n AA1071) mated to the scintillator under test was measured to have a gain of  $10^6$  at 2150 V, and it was desired to use an HV set for  $g = 10^6$ . The output of the power supply was measured and the extrapolated results shown in Figure 6 illustrate that at 4.4 knob rotations it is expected to output 2150 V; thus for all the tests with this tube the power supply knob was set to 4.4 rotations for AA1071.



Figure. 6. Power Supply characteristics (BNL 106900)

## Power supply settings for two telescoping paddle counters (AKA "QuarkNet counters")

The two pmts contain an internal LV DC to HV DC converter. The dark rate for each tube was measured as a function of LV shown in Figure 6; the output of each pmt was amplified x10 and then sent into a discriminator set at -30 mV; thus 3 mV is the equivalent lower-threshold for the dark rate plots shown.



The gain functions for these two pmts mated to the paddle counters were not measured beforehand; in an attempt to set their gain to about 10<sup>6</sup> their LV was adjusted such that their lowest amplitude dark pulses measured ~ 1 mV through a 50  $\Omega$  load on an oscilloscope. 1 mV was chosen for the following reason: the pmt pulses are near triangular with area *A*, thus when a single photoelectron is emitted from the cathode, if gain is set at 10<sup>6</sup>, then for a pmt pulse of width  $\Delta T \sim 20$  ns, the expected peak voltage is estimated to be about 0.8 mV. We adjusted the supplied power by looking at the signals on the oscilloscope shown in Fig. 7:

PMT pulse area 
$$A = \frac{1}{2}\Delta T \cdot V_{\text{peak}} = \Sigma V_i \Delta t = \Sigma (I_i R) \Delta t = \Sigma \left(\frac{Q_i}{\Delta t_i} R\right) \Delta t = R Q_{\text{pulse}}$$
  
$$V_{\text{peak}} = \frac{2R}{\Delta T} Q_{\text{pulse}} = \frac{2R}{\Delta T} ge = \frac{2(50\Omega)}{20x10^{-9}\text{s}} (1.6x10^{-19}\text{C})g = 0.8 \text{ mV}$$

Fig. 7. Oscilloscope (Tektronix DPO 4054) showing typical 1 mV dark pulse noise from telescoping counter for HV set to 10E6 gain



Figure 8 shows a low voltage divider circuit which was used to adjust the voltage as needed to the two paddle counters.

# Fig. 8. Power Distribution Unit (PDU).





## Results

The cosmic ray muon detection efficiency of our scintillator under test is defined here as (3-fold coincidence rate) / (2-fold coincidence rate). Thus, efficiency here is relative to the two paddle counters. Efficiency was measured over different variables. Figures 10 and 11 show efficiency as a function of discriminator thresholds for all three counters in the muon telescope. When the paddle counters are set at a discriminator setting of about 10 mV the efficiency plateaus.

Figure. 10. Efficiency as a function of discriminator threshold settings for the three counters in the telescope. The 3 mV and 9 mV "series" refers to the discriminator settings for the NE-114 scintillator under test. The x-axis is the discriminator threshold for the two paddle counters. (Foil and black paper wrapping, Scintillator plate used was NE-114, 20170710, Data table 3).



#### **Comparing wrapping techniques**

The goal is to determine the most efficient way of wrapping scintillator plates. Some photons are traveling along the scintillator plate, with an angle, which makes it possible for them to escape the plate and never be detected by the photomultiplier tube. Our objective is to reflect these photons back. We will compare two wrapping techniques for the same scintillator plate. First when wrapped in foil and paper, second when wrapped in two Tyvek layers. There are different types of reflecting materials and we ought to determine the efficiency of every one of them

We conducted experiments with two different sets of discrimination thresholds. First test with (10, 10, 3) mV for telescoping counters and testing counter accordingly. Second test with (10, 10, 10) mV for telescoping counters and testing counter accordingly.

The same scintillator, but different wrapping did not change the efficiency.

Figure. 11. Efficiency along the distance of Scintillator plate NE-114, 20170710 wrapped with foil and black paper. Data Table 4



Figure. 12. Efficiency along the distance of Scintillator plate NE-114, 20170710 wrapped with two layers of Tyvek. Data Table 6



Figure. 13. Efficiency along the distance of Scintillator plate NE-114, 20170713 wrapped one layer Tyvek wrapping. Data Table 5



Figures 14 a and b: Comparing results for two wrapping techniques applied to one scintillator plate, NE-114, 20170710.





Figure. 15. Comparing results for two wrapping techniques applied to one scintillator plate, NE-114, 20170710 and 20170713.

This graph is for deeper research purpose, there are two variables different in the setup: scintillator and wrapping but Comparing two scintillators with a similar wrapping technique we have notice that the second scintillator is more efficient.



## Measuring efficiency for different pmt mating techniques

In this experiment, we tested four mating techniques with scintillator plate s/n 20170713:

- 1) Silicone cookie (1/16") placed in between photomultiplier tube and scintillator
- 2) Acrylic cookie and optical grease applied on both sides of the cookie
- 3) Acrylic cookie and optical grease applied between cookie and photomultiplier tube and optical cement applied between cookie and scintillator
- 4) Acrylic cookie and optical cement applied on both sides of the cookie

Figure. 16. Mating Techniques Graph. Scintillator plate NE-114, 20170713, wrapped with one layer Tyvek. 10, 10, 10 mV thresholds.



Figure. 17. Mating Techniques Graph. Scintillator plate NE-114, 20170713, wrapped with one layer Tyvek. 10, 10, 3 mV thresholds.



#### Additional tests:

- It was determined after some of our measurements that a strip of Tyvek reflecting material was missing in a ~ 1 inch border around where the pmt mates to the scintillator; the gap was later closed with Tyvek and tests repeated resulting in a 10% higher efficiency.
- 2) Measurements were made with and without white Teflon reflective plumbing tape wrapped around the perimeter of the acrylic cookie, no difference in efficiency was measured.

#### Tests of different mating of the pmt to the scintillator

In the following part of the experiment, we tested five mating techniques with scintillator plate s/n 20170710:

- 1) Light guide, Silicone cookie (1/4in)
- 2) Light guide, Silicone cookie (1/16in)
- 3) Light guide, no cookie
- 4) Silicone cookie (1/4in)

#### 5) No adaptor in mating junction

Figures 18 a and b: Mating Techniques Graph. Scintillator plate NE-114, 20170710, wrapped with two layer Tyvek. 10, 10, 3 mV thresholds. Data table 7





Figures 19 a and b: Mating Techniques Graph. Scintillator plate NE-114, 20170710, wrapped with two layer Tyvek. 10, 10, 10 mV thresholds. Data table 7





## Appendix

#### Calculating false coincidence rate probability:

The probability of 2-fold and 3-fold coincidences occurring from the dark noise rate was estimated using the formulas below, and not expected to be significant. The two paddle counters' pmts noise single rates were measured at about 300 Hz each while at operating voltage with a 3 mV discriminator threshold; the NE-114 counter pmt noise rate was measured at 4500 Hz at operating voltage and a 3 mV discriminator threshold.



# Data tables:

## Data table 1

		Re		Yellow c	ounter			
voltage (V)			counts	rate	voltage (V)	rate (Hz)		
0.605	471	436	438	420	419	53	0.656	55
0.55	203	173	186	192	195	23	0.7	96
0.585	330	352	335	331	324	40	0.733	177
0.59	371	340	393	354	381	44	0.744	214
0.701	2219	2170	2353	2301	2370	275	0.777	362
0.675	1561	1621	1559	1613	1556	191		
0.69	1939	2018	1982	2087	1916	240		
0.72	2726	2813	2860	2843	2848	340		

I want to meas	sure effi. f	unction of	threshold	of the big	PMT								
I will be chang	ing a thres	hold for bi	ig PMT										
Threshold for	small pmt	s is fixed a	t 8 (mV) ec	quivailance	e voltage								
blue=0.593V	Ye	ellow=0.77	7V								rate (Hz)		
eqv thrshld (mV)		2	fold count	S				Bfold count	S		2 fold	3 fold	effi.
2	36	25	30	36	30	33	22	26	32	27	3.783133	3.37349	89%
3	34	28	30	38	39	31	21	23	31	44	4.072289	3.61446	89%
4	27	25	39	37	31	24	20	35	30	27	3.831325	3.27711	86%
5	30	37	31	33	24	25	29	19	27	19	3.734940	2.86747	77%
6	32	37	39	36	37	18	24	24	21	23	4.361446	2.65060	61%
7	22	37	33	34	26	13	23	13	20	8	3.662651	1.85542	51%
8	33	29	37	44	22	14	13	11	21	7	3.975904	1.59036	40%

I want to m	neasure eff	i. As a fun	ction of th	reshold of	the small s	scintillators	5						
set large so	cintilator eo	quivalenc	e threshold	d 3 mV									
Threshold	for small so	intillators	s is changir	ıg									
red=0.720\	/ \	ellow=0.7	777V								rate (Hz)		
equivalen		2	fold count	S			3	fold count	S		2 fold	3 fold	effi.
3	70	76	79	105	82	30	25	35	41	36	10	4	41%
4	86	56	69	70	65	43	29	32	36	36	8	4	51%
5	58	47	59	53	47	38	33	33	33	25	6	4	61%
6	34	50	48	38	40	25	43	32	31	32	5	4	78%
7	41	35	29	42	52	34	27	26	35	47	5	4	85%
8	38	33	39	32	29	35	28	34	31	26	4	4	90%
q	37	41	30	28	37	34	40	36	27	20	4	4	94%
10	27	26	25	20	26	10	-+0	22	27	22			01%
10	22	30	20	10	30	19	21	33	17	33	4	4 7 2	0.20/
11	55	50	50	10	50	52	51	55	17	27	4	3	9270
I want to m	neasure eff	i. As a fun	ction of th	reshold of	the small s	scintillators	5						
set large so	cintilator ec	quivalence	e threshold	d 4 mV									
Threshold	for small so	intillators	s is changir	ıg									
red=0.720\	/ \	/ellow=0.	777V								rate (Hz)		
equivalen		2	fold count	S			3	fold count	S		2 fold	3 fold	effi.
3	63	64	85	79	70	25	30	38	27	28	9	4	41%
4	69	76	70	70	59	35	40	35	29	26	8	4	48%
5	38	49	41	58	46	26	33	27	37	31	6	4	66%
6	52	28	42	48	39	41	23	27	37	31	5	4	76%
7	29	33	40	41	30	28	27	30	33	24	4	3	82%
8	40	29	21	30	35	32	23	19	29	28	4	3	85%
9	31	32	30	36	36	29	31	28	29	32	4	4	90%
10	37	37	27	28	42	32	34	22	27	39	4	4	90%
11	30	38	38	32	31	28	35	36	29	29	۵	4	93%
			50							=5			5070
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l want to m set large sc Threshold red=0.720V equivalen 3 4 5 6 7 8 9 9 10 11	neasure eff cintilator ec for small sc / Y 93 66 61 40 36 32 45 34 38	i. As a fun quivalence intillators (ellow=0. 2 71 64 59 36 35 34 40 39 35	ction of th e threshold s is changir 777V fold count 60 58 49 48 42 37 38 37 30	reshold of d 9 mV lg s 65 60 52 44 35 33 26 36 27	the small s 105 84 60 49 36 31 39 29 31	30 26 29 24 27 22 32 26 28	3 27 24 28 18 20 27 34 33 29	fold count 20 18 20 35 30 31 32 28 21	s 15 26 27 26 19 20 18 27 20	31 29 23 28 25 23 28 22 22 22	rate (Hz) 2 fold 9 8 7 5 4 4 4 5 4 4 4	3 fold 3 3 3 3 3 3 3 3 3 3 3	effi. 31% 37% 45% 60% 66% 74% 77% 78% 75%
I want to m set large so Threshold red=0.720V equivalen 3 4 5 6 7 8 9 10 11 11	93 66 61 40 36 32 45 34 38 measure eff	i. As a fun quivalence intillators (ellow=0. 2 71 64 59 36 35 34 40 39 35 As a fun	ction of th e threshold s is changir 777V fold count 60 58 49 48 42 37 38 37 30 ction of th	reshold of d 9 mV lg s 65 60 52 44 35 33 26 36 27 reshold of	the small s 105 84 60 49 36 31 39 29 31 the small s	30 26 29 24 27 22 32 26 28 scintillators	3 27 24 28 18 20 27 34 33 29 5	fold count 20 18 20 35 30 31 32 28 21	s 15 26 27 26 19 20 18 27 20	31 29 23 28 25 23 28 22 22 22	rate (Hz) 2 fold 9 8 7 5 4 4 4 5 4 4 4	3 fold 3 3 3 3 3 3 3 3 3 3 3 3 3 3	effi. 31% 37% 45% 60% 66% 74% 77% 78% 75%
I want to m set large sc Threshold red=0.720V equivalen 3 4 5 6 7 8 9 10 11 1 I want to m set large sc	neasure eff cintilator ec for small sc / Y 93 66 61 40 36 32 45 34 38 measure eff cintilator ec	i. As a fun quivalence intillators (ellow=0.7 2 71 64 59 36 35 34 40 39 35 40 39 35 40 39 35	ction of th e threshold s is changir 777V fold count 60 58 49 48 42 37 38 37 30 ction of th e threshold	reshold of d 9 mV ng s 65 60 52 44 35 33 26 36 27 reshold of d 15 mV	the small s 105 84 60 49 36 31 39 29 31 the small s	30 26 29 24 27 22 32 26 28 scintillators	3 27 24 28 18 20 27 34 33 29 5	fold count 20 18 20 35 30 31 32 28 21	s 15 26 27 26 19 20 18 27 20	31 29 23 28 25 23 28 22 22 22	rate (Hz) 2 fold 9 8 7 5 4 4 4 5 4 4 4	3 fold 3 3 3 3 3 3 3 3 3 3 3 3 3	effi. 31% 37% 45% 60% 66% 74% 77% 78% 75%
I want to m set large sc Threshold red=0.720V equivalen 3 4 5 6 7 8 9 10 11 11 I want to m set large sc Threshold	neasure eff cintilator ec for small sc / Y 93 66 61 40 36 32 45 34 38 measure eff cintilator ec for small sc	i. As a fun quivalence intillators (ellow=0.7 2 71 64 59 36 35 34 40 39 35 i. As a fun quivalence intillators	iction of th e threshold is is changir 777V fold count 60 58 49 48 42 37 38 37 30 iction of th e threshold is is changir	reshold of d 9 mV ng s 65 60 52 44 35 33 26 36 27 reshold of d 15 mV	the small s	30 26 29 24 27 22 32 26 28 scintillators	3 27 24 28 18 20 27 34 33 29 5	fold count 20 18 20 35 30 31 32 28 21	s 15 26 27 26 19 20 18 27 20	31 29 23 28 25 23 28 22 22 22	rate (Hz) 2 fold 9 8 7 5 4 4 5 4 4 5 4 4	3 fold 3 3 3 3 3 3 3 3 3 3 3 3 3	effi. 31% 37% 45% 60% 66% 74% 77% 78% 75%
I want to m set large sc Threshold red=0.720V equivalen 3 4 5 6 7 8 9 10 11 11 I want to m set large sc Threshold red=0.720V	neasure eff cintilator ec for small sc /	i. As a fun quivalence intillators (ellow=0.7 2 71 64 59 36 35 34 40 39 35 i. As a fun quivalence cintillators (ellow=0.7	iction of th e threshold is is changir 777V fold count 60 58 49 48 42 37 38 37 38 37 30 iction of th e threshold is is changir 777V	reshold of d 9 mV lg s 65 60 52 44 35 33 26 36 27 reshold of d 15 mV	the small s	30 26 29 24 27 22 32 26 28 scintillators	3 27 24 28 18 20 27 34 33 29 5	fold count 20 18 20 35 30 31 32 28 21	s 15 26 27 26 19 20 18 20 18 27 20	31 29 23 28 25 23 28 22 22 22	rate (Hz) 2 fold 9 8 7 5 4 4 5 4 4 5 4 4 5 7 7 5 7 7 5	3 fold 3 3 3 3 3 3 3 3 3 3 3 3 3	effi. 31% 37% 45% 60% 66% 74% 77% 78% 75%
I want to m set large sc Threshold red=0.720V equivalen 3 4 5 6 7 8 9 10 11 I want to m set large sc Threshold red=0.720V equivalen	neasure eff for small sc / Y 93 66 61 40 36 32 45 34 38 neasure eff cintilator ec for small sc / Y	i. As a fun quivalence intillators (ellow=0.7 2 71 64 59 36 35 34 40 39 35 i. As a fun quivalence cintillators (ellow=0.7 2	iction of th e threshold is is changir 777V fold count 60 58 49 48 42 37 38 37 30 ction of th e threshold is is changir 777V fold count	reshold of d 9 mV lg s 65 60 52 44 35 33 26 36 27 reshold of d 15 mV lg s	the small s	30 26 29 24 27 22 32 26 28 scintillators	3 27 24 28 18 20 27 34 33 29 5 5	fold count 20 18 20 35 30 31 32 28 21	s 15 26 27 26 19 20 18 27 20 18 27 20	31 29 23 28 25 23 28 22 22 22	rate (Hz) 2 fold 9 8 7 5 4 4 5 4 4 5 4 4 5 7 7 5 7 4 7 5 2 4 2 fold	3 fold 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3	effi. 31% 37% 45% 60% 66% 74% 77% 78% 75%
I want to m set large sc Threshold red=0.720V equivalen 3 4 5 6 7 8 9 10 11 11 I want to m set large sc Threshold red=0.720V equivalen 3	neasure eff cintilator ec for small sc /	i. As a fun quivalence intillators (ellow=0.7 2 71 64 59 36 35 34 40 39 35 i. As a fun quivalence cintillators (ellow=0.7 2 79	ction of th e threshold s is changir 777V fold count 60 58 49 48 42 37 38 37 38 37 30 ction of th e threshold s is changir 777V fold count 116	reshold of d 9 mV lg s 65 60 52 44 35 33 26 36 27 reshold of d 15 mV lg s 5	the small s	30 26 29 24 27 22 32 26 28 scintillators	3 27 24 28 18 20 27 34 33 29 5 5 5	fold count 20 18 20 35 30 31 32 28 21 	s 15 26 27 26 19 20 18 20 18 27 20 	31 29 23 28 25 23 28 22 22 22	rate (Hz) 2 fold 9 8 7 5 4 4 4 5 4 4 5 4 4 5 7 7 5 1 4 7 5 1 1 1	3 fold 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3	effi. 31% 37% 45% 60% 66% 74% 77% 78% 75% 75%
I want to m set large sc Threshold red=0.720V equivalen 3 4 5 6 7 8 9 10 11 1 I want to m set large sc Threshold red=0.720V equivalen 3 4	neasure eff for small sc / Y 93 66 61 40 36 32 45 34 38 neasure eff for small sc / Y 81 61	i. As a fun quivalence intillators (ellow=0.7 2 71 64 59 36 35 34 40 39 35 i. As a fun quivalence cintillators (ellow=0.7 2 79 61	ction of th e threshold s is changir 777V fold count 60 58 49 48 42 37 38 37 38 37 30 ction of th e threshold s is changir 777V fold count 116 91	reshold of d 9 mV lg s 65 60 52 44 33 26 36 27 reshold of d 15 mV lg s 78 78	the small s	30 26 29 24 27 22 32 26 28 scintillators	5 3 27 24 28 18 20 27 34 33 29 5 5 5 5 5	fold count 20 18 20 35 30 31 32 28 21 	s 15 26 27 26 19 20 18 20 18 27 20 	31 29 23 28 25 23 28 22 22 22 22 22 22 22 22 22 22 22 22	rate (Hz) 2 fold 9 8 7 5 4 4 5 4 4 5 4 4 5 7 7 5 1 4 9 8 7 7 5 1 1 1 8	3 fold 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3	effi. 31% 37% 45% 60% 66% 74% 77% 78% 75% 75%
I want to m set large sc Threshold red=0.720V equivalen 3 4 5 6 7 8 9 10 11 11 I want to m set large sc Threshold red=0.720V equivalen 3 4 5	neasure eff for small sc / Y 93 66 61 40 36 32 45 34 38 neasure eff cintilator ec for small sc / Y 81 61 28	i. As a fun quivalence intillators /ellow=0.7 2 71 64 59 36 35 34 40 39 35 i. As a fun quivalence intillators /ellow=0.7 2 79 61	iction of th e threshold is is changir 777V fold count 60 58 49 48 42 37 38 37 38 37 30 ction of th e threshold is is changir 777V fold count 116 91 61	reshold of d 9 mV lg s 65 60 52 44 33 26 33 26 36 27 reshold of d 15 mV lg s 78 78 59	the small s	30 26 29 24 27 22 32 26 28 scintillators	5 3 27 24 28 18 20 27 34 33 29 5 5 5 5 5 5 5 5	fold count 20 18 20 35 30 31 32 28 21 fold count 25 19 17	s 15 26 27 26 19 20 18 20 18 27 20 5 5 3 13 14 20	31 29 23 28 25 23 28 22 22 22 22 22 22 22 22 22 22 22 22	rate (Hz) 2 fold 9 8 7 5 4 4 4 5 4 4 5 4 4 5 7 7 7 5 2 fold 11 8 7	3 fold 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 2 3 5 1 0 4 2 2 2 2 2 2 2	effi. 31% 37% 45% 60% 66% 74% 77% 78% 75% 75% 75% 75% 75% 75%
I want to m set large sc Threshold red=0.720V equivalen 3 4 5 6 7 8 9 10 11 11 I want to m set large sc Threshold red=0.720V equivalen 3 4 5 6	neasure eff for small sc / Y 93 66 61 40 36 32 45 34 38 neasure eff cintilator ec for small sc / Y 81 61 28 56	i. As a fun quivalence intillators /ellow=0.7 2 71 64 59 36 35 34 40 39 35 34 40 39 35 . As a fun quivalence intillators /ellow=0.7 2 79 61 58	iction of th e threshold is is changir 777V fold count 60 58 49 48 42 37 38 37 30 iction of th e threshold is is changir 777V fold count 116 91 61	reshold of d 9 mV lg s 65 60 52 44 33 26 33 26 36 27 reshold of d 15 mV lg s 78 78 75 59 27	the small s	30 26 29 24 27 22 32 26 28 5cintillators 5cintillators 8 13 20 8	3 27 24 28 18 20 27 34 33 29 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	fold count 20 18 20 35 30 31 32 28 21 	s 15 26 27 26 19 20 18 27 20 20 5 5 3 13 14 20 5	31 29 23 28 25 23 28 22 22 22 22 22 22 22 22 22 22 22 22	rate (Hz) 2 fold 9 8 7 5 4 4 4 5 4 4 4 5 4 4 5 2 fold 7 2 fold 11 8 7 7	3 fold 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3	effi. 31% 37% 45% 60% 66% 74% 77% 78% 75% 75% 75% 75% 28% 24% 28% 21%
I want to m set large sc Threshold red=0.720V equivalen 3 4 5 6 7 8 9 10 11 11 I want to m set large sc Threshold red=0.720V equivalen 3 4 5 6	neasure eff for small sc / Y 93 66 61 40 36 32 45 34 38 neasure eff cintilator ec for small sc / Y 81 61 28 56 28	i. As a fun quivalence intillators /ellow=0.7 2 71 64 59 36 35 34 40 39 35 34 40 39 35 . As a fun quivalence intillators /ellow=0.7 2 79 61 58 47	iction of the e threshold is is changir 777V fold count 60 58 49 48 42 37 38 37 30 iction of th e threshold is is changir 777V fold count 116 91 61 35	reshold of d 9 mV bg s 65 60 52 44 33 26 33 26 36 27 reshold of d 15 mV bg s 78 78 75 59 37	the small s	30 26 29 24 27 22 32 26 28 5cintillators 5cintillators 8 13 20 8 17	3 27 24 28 18 20 27 34 33 29 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	fold count 20 18 20 35 30 31 32 28 21 5 6 10 5 10 17 11	s 15 26 27 26 19 20 18 27 20 20 5 3 3 13 14 20 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	31 29 23 28 25 23 28 22 22 22 22 22 22 22 22 22 22 22 22	rate (Hz) 2 fold 9 8 7 5 4 4 4 5 4 4 4 5 4 4 2 5 4 4 2 5 1 1 1 8 7 7 5 7 7	3 fold 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3	effi. 31% 37% 45% 60% 66% 74% 77% 78% 75% 75% 75% 75% 24% 24% 28% 231%
I want to m set large sc Threshold red=0.720V equivalen 3 4 5 6 7 8 9 10 11 11 I want to m set large sc Threshold red=0.720V equivalen 3 4 5 6 7	neasure eff for small sc /	i. As a fun quivalence intillators /ellow=0.7 2 71 64 59 36 35 34 40 39 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 35 34 35 35 34 40 35 35 35 34 40 35 35 35 35 35 34 40 35 35 35 35 34 40 35 35 35 35 36 35 36 36 37 37 37 35 35 36 37 37 37 37 37 37 37 37 37 37 37 37 37	iction of the e threshold is is changir 777V fold count 60 58 49 48 42 37 38 37 30 ction of th e threshold is changir 777V fold count 116 91 61 35 32	reshold of d 9 mV bg s 65 60 52 44 33 26 33 26 33 26 36 27 reshold of d 15 mV bg s 5 78 78 75 59 37 43	the small s 105 84 60 49 36 31 39 29 31 the small s 10 52 70 47 70 47	30 26 29 24 27 22 32 26 28 5cintillators 5cintillators 8 13 20 8 17 15	3 27 24 28 18 20 27 34 33 29 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	fold count 20 18 20 35 30 31 32 28 21 5 6 19 17 11 11	s 15 26 27 26 19 20 18 20 18 27 20 5 3 3 14 20 12 5 5	31 29 23 28 25 23 28 22 22 22 22 22 22 22 22 22 22 22 22	rate (Hz) 2 fold 9 8 7 5 4 4 4 4 5 4 4 4 5 4 4 2 fold 11 2 fold 11 8 7 5 5 5 5	3 fold 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3	effi. 31% 37% 45% 60% 66% 74% 77% 78% 75% 75% 75% 75% 24% 28% 31% 33%
I want to m set large so Threshold red=0.720V equivalen 3 4 5 6 7 7 8 9 10 11 I want to m set large so Threshold red=0.720V equivalen 3 4 5 6 7 8 9 10 11	neasure eff for small sc /	i. As a fun quivalence intillators /ellow=0.7 2 71 64 59 36 35 34 40 39 35 34 40 39 35 34 40 39 35 34 40 39 35 34 40 39 35 34 40 39 35 34 40 39 35 34 40 39 35 34 40 39 35 34 40 39 35 34 40 39 35 34 40 39 35 34 40 39 35 34 40 39 35 34 40 39 35 34 40 39 35 34 40 39 35 34 40 39 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 40 35 35 34 34 35 35 34 40 35 35 36 36 37 37 37 37 37 37 37 37 37 37 37 37 37	iction of the e threshold is is changir 777V fold count 60 58 49 48 42 37 38 37 30 iction of th e threshold is is changir 777V fold count 116 91 61 35 32 45	reshold of d 9 mV bg s 65 60 52 44 33 26 33 26 33 26 33 26 36 27 78 59 59 37 43 41	the small s 105 84 60 49 36 31 39 29 31 the small s 41 52 70 47 37 41	30 26 29 24 27 22 32 26 28 5cintillators 5cintillators 8 13 20 8 17 15	3 27 24 28 18 20 27 34 33 29 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	fold count 20 18 20 35 30 31 32 28 21 5 6 19 17 11 11 11 11 11	s 15 26 27 26 19 20 18 20 18 27 20 18 20 18 27 20 11 20 12 5 17	31 29 23 28 25 23 28 22 22 22 22 22 22 22 22 22 22 22 22	rate (Hz) 2 fold 9 8 7 5 4 4 4 4 5 4 4 4 5 4 4 4 2 5 4 4 1 1 2 fold 11 1 8 7 5 5 5 5 5	3 fold 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3	effi. 31% 37% 45% 60% 66% 74% 77% 78% 75% 75% 75% 78% 75% 24% 28% 31% 33% 45%
I want to m set large so Threshold red=0.720V equivalen 3 4 5 6 7 8 9 10 11 1 I want to m set large so Threshold red=0.720V equivalen 3 4 5 6 7 7 8 9 10 11	heasure eff for small sc /	i. As a fun quivalence cintillators (ellow=0. 2 71 64 59 36 35 34 40 39 35 34 40 39 35	iction of the e threshold is is changir 777V fold count 60 58 49 48 42 37 38 37 30 iction of th e threshold is changir 777V fold count 116 91 61 35 32 45 33	reshold of d 9 mV yg s 65 60 52 44 33 26 33 26 36 27 reshold of d 15 mV yg s reshold of d 15 mV yg s 78 78 75 59 37 43 41 41	the small s 105 84 60 49 36 31 39 29 31 the small s the small s 94 52 70 47 37 41 31	30 26 29 24 27 22 32 26 28 5cintillators 5cintillators 8 13 20 8 17 15 12 16	3 27 24 28 18 20 27 34 33 29 	fold count 20 18 20 35 30 31 32 28 21 5 6 10 17 11 11 11 11 11 11	s 15 26 27 26 19 20 18 20 18 27 20 30 31 4 20 12 5 17 15 5	31 29 23 28 25 23 28 22 22 22 22 22 22 22 22 22 22 22 22	rate (Hz) 2 fold 9 8 7 5 4 4 4 4 5 4 4 4 4 5 2 fold 11 8 7 5 5 5 5 5 5	3 fold 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3	effi. 31% 37% 45% 60% 66% 74% 77% 78% 75% 75% 75% 24% 28% 31% 33% 45% 43%
I want to m set large so Threshold red=0.720V equivalen 3 4 5 6 7 8 9 10 11 1 I want to m set large so Threshold red=0.720V equivalen 3 4 5 6 7 7 8 9 10 11	heasure eff cintilator ec for small sc /	i. As a fun quivalence cintillators (ellow=0. 2 71 64 59 36 35 34 40 39 35 34 40 39 35 (As a fun quivalence cintillators (ellow=0. 2 79 61 58 47 56 30 22 28	iction of the e threshold is is changir 777V fold count 60 58 49 48 42 37 38 37 30 	reshold of d 9 mV yg s 65 60 52 44 33 26 33 26 36 27 reshold of d 15 mV yg s 78 78 78 78 78 79 37 43 41 41 41	the small s 105 84 60 49 36 31 39 29 31 the small s the small s 94 52 70 47 37 41 31 31 34	30 26 29 24 27 22 32 26 28 5 cintillators 5 cintillators 8 13 20 8 17 15 12 16 8 8	3 27 24 28 18 20 27 34 33 29 	fold count 20 18 20 35 30 31 32 28 21 5 6 6 7 11 11 11 11 11 11 11 11 11 11 11 11 1	s 15 26 27 26 19 20 18 20 18 27 20 5 3 13 14 20 12 5 17 15 13	31 29 23 28 25 23 28 22 22 22 22 22 22 22 22 22 22 22 22	rate (Hz) 2 fold 9 8 7 5 4 4 4 4 5 4 4 4 5 4 4 2 fold 11 8 7 5 5 5 5 5 4 4	3 fold 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3	effi. 31% 37% 45% 60% 66% 74% 78% 75% 66% 74% 28% 31% 33% 45% 43% 40%

I want to r	measure e	ffi. As a fur	nction of di	stance alo	ng a big sc	intillator							
set large s	scintilator	equivalenc	e threshol	d 3 mV									
Threshold	for small	scintillator	= 10mV										
Red=0.720	V	Yellow=0.	777V			rate (Hz)							
Distance	2 fold cou	nts				3fold cour	nts				Average 2	Average 3	effi.
0	35	26	44	36	37	32	22	40	31	34	35.6	31.8	89.3%
2.5	33	36	39	42	34	29	29	37	38	31	36.8	32.8	89.1%
5	36	45	32	28	37	33	44	28	27	34	35.6	33.2	93.3%
7.5	35	38	37	29	46	33	37	33	26	44	37	34.6	93.5%
10	35	38	37	39	33	31	35	32	34	29	36.4	32.2	88.5%
12.5	41	24	39	42	31	39	21	38	39	29	35.4	33.2	93.8%
15	36	33	39	48	28	35	30	34	39	26	36.8	32.8	89.1%
17.5	28	36	44	30	37	24	31	39	28	36	35	31.6	90.3%
20	34	27	32	35	29	32	24	28	33	26	31.4	28.6	91.1%
22.5	32	30	23	45	34	28	24	20	40	31	32.8	28.6	87.2%
25	30	48	38	37	32	29	43	34	32	26	37	32.8	88.6%
I want to r	measure e	ffi. As a fur	nction of di	stance alo	ng a big sc	intillator							
set large s	cintilator	equivalenc	e threshol	d 10 mV									
Threshold	for small	scintillator	= 10mV										
Red=0.720	)V	Yellow=0.	777V			rate (Hz)							
Distance	2 fold cou	nts				3fold cour	nts				Average 2	Average 3	effi.
0	27	37	24	42	31	21	26	17	32	25	32.2	24.2	75.2%
2.5	40	39	25	19	41	29	27	19	15	33	32.8	24.6	75.0%
5	33	37	22	42	29	11	26	15	28	21	32.6	20.2	62.0%
7.5	38	38	35	36	29	23	24	15	18	12	35.2	18.4	52.3%
10	34	41	31	33	36	13	19	16	10	13	35	14.2	40.6%
12.5	38	40	29	27	37	11	10	10	8	8	34.2	9.4	27.5%
15	42	29	31	43	37	14	5	8	8	11	36.4	9.2	25.3%
17.5	29	36	27	39	38	7	7	4	7	5	33.8	6	17.8%
20	33	41	28	27	37	8	9	4	3	8	33.2	6.4	19.3%
22.5	30	29	34	23	34	5	5	5	3	7	30	5	16.7%
25	32	45	40	36	32	4	8	6	9	3	37	6	16.2%

I want to r	measure eff	i. As a func	tion of dis	tance along	g a big scir	ntillator										
set large s	cintilator er	quivalence	threshold	3 mV												
Threshold	for small sc	intillators	= 10mV					_					Standard	Standard		
Red=0.720	JV	Yellow=0.	777V			rate (Hz)							Deviation	Deviation	Error	
Distance	2 fold coun	ts				3fold count	ίS				Average 2	Average 3	2 fold	3 fold	propagation	effi.
0	41	35	34	43	38	38	28	30	38	35	38.2	33.8	3.834058	4.604346	15.0%	88.5%
5	29	37	29	29	29	27	35	28	29	29	30.6	29.6	3.577709	3.130495	15.3%	96.7%
10	41	36	24	27	34	36	34	22	27	32	32.4	30.2	6.8775	5.674504	26.4%	93.2%
15	38	39	39	32	32	. 36	33	35	27	26	36	31.4	3.674235	4.615192	15.6%	87.2%
20	33	35	33	37	36	28	30	30	34	32	34.8	30.8	1.788854	2.280351	8.0%	88.5%
25	43	21	34	33	45	27	14	22	24	32	35.2	23.8	9.549869	6.648308	26.3%	67.6%
30	42	33	41	32	38	29	28	34	21	34	37.2	29.2	4.549725	5.357238	17.3%	78.5%
I want to r set large s Threshold Red=0.720 Distance	neasure eff cintilator ec l for small sc DV 2 fold coun	i. As a func quivalence cintillators Yellow=0.	tion of dist threshold = 10mV 777V	tance along 10 mV	; a big scir	rate (Hz)					Average 2	Average 3	Standard Deviation	Standard Deviation 3 fold	Error	effi.
0	21010 0001	3	37	32	42	31010 200110	.3	30	25	38	35.6	30.8	4 159327	4 658326	16 5%	86.5%
5	33	35	31	35	37	30	34	30	34	36	33.0	32.8	2 683282	2 683282	11 1%	97.0%
10	32	33	31	41	38	2 29	37	28	40	36	35.0	32.0	4 301163	2.003202	18.4%	94.3%
15	36	47	26	30	31	25	41	22		28	34	30.4	8 093207	7 569676	30.8%	89.4%
20	27		26	35	37	25	31	20	27	28	33	26.2	6 204837	4.086563	19.4%	79.4%
25	38		45	28	26	23	24	37	18	20	33.6	25.2	7 829432	7 463243	28.3%	75.0%
30	29	38	36	42	36	19	24	25	31	26	36.2	23.2	4 711688	4 582576	15.7%	71.8%
				72		1.5				20	30.2		4.711000	4.302373	13.776	/1.0/0
I want to r	neasure eff	i. As a func	tion of dis	tance along	g a big scir	ntillator										
set large s	cintilator eq	quivalence	threshold	15 mV											ļ!	
Threshold	for small sc	intillators	= 10mV										Standard	Standard		
Red=0.720	JV	Yellow=0.7	177V			rate (Hz)							Deviation	Deviation	Error	
Distance	2 fold coun	ts				3fold count	čS				Average 2	Average 3	2 fold	3 fold	propagation	effi.
0	44	35	27	30	41	. 28	21	14	15	22	35.4	20	7.162402	5.700877	19.7%	56.5%
5	27	38	37	30	21	10	21	22	7	5	30.6	13	7.092249	7.968689	27.8%	42.5%
10	34	30	31	29	30	3	5	4	4	9	30.8	5	1.923538	2.345208	7.7%	16.2%
15	44	34	41	30	43	, 3	3	6	1	4	38.4	3.4	6.107373	1.81659	4.9%	8.9%
20	23	33	40	34	38	, 1	2	2	2	2	33.6	1.8	6.580274	0.447214	1.7%	5.4%
25	34	36	30	30	40	ı 1	1	1	1	5	34	1.8	4.242641	1.788854	5.3%	5.3%
30	37	35	42	31	33	3	2	1	1	1	35.6	1.6	4.219005	0.894427	2.6%	4.5%

I want to	measure ef	fi. As a fun	ction of di	stance alon	g a big sci	ntillator										
set large s	scintilator e	quivalence	e threshold	d 3 mV												
Threshold	I for small s	cintillator	= 10mV										Standard	Standard		
Red=0.720	)V	Yellow=0.7	777V			rate (Hz)							Deviation	Deviation	Error	
Distance	2 fold cour	nts				3fold cour	nts				Average 2	Average 3	2 fold	3 fold	propagation	effi.
0	34	38	43	42	28	33	33	39	41	26	37	34.4	6.164414	5.899152	22.2%	93.0%
5	37	23	36	24	27	36	21	34	22	25	29.4	27.6	6.655825	6.94982	31.8%	93.9%
10	40	26	23	27	41	36	25	23	22	37	31.4	28.6	8.443933	7.300685	33.8%	91.1%
15	29	35	25	34	34	27	33	21	29	29	31.4	27.8	4.27785	4.38178	18.4%	88.5%
20	39	39	29	39	27	37	33	23	34	22	34.6	29.8	6.0663	6.83374	24.9%	86.1%
25	37	43	37	44	38	31	34	32	39	31	39.8	33.4	3.420526	3.361547	11.1%	83.9%
	1															
			1													
I want to I	neasure ef	fi. As a fun	ction of di	stance alon	g a big sci	ntillator										
I want to i set large s	measure ef	fi. As a fun quivalence	ction of dis	stance alon 13 mV	ıg a big sci	ntillator										
l want to i set large s Threshold	measure ef scintilator e for small s	fi. As a fun quivalence cintillator:	ction of di e threshold = 10mV	stance alon d 3 mV	ıg a big sci	ntillator							Ctoodord	Ctondord		
l want to i set large s Threshold Red=0.720	measure ef scintilator e I for small s )V	fi. As a fun quivalence cintillator Yellow=0.7	ction of di e threshold = 10mV 777V	stance alon d 3 mV	ıg a big sci	ntillator rate (Hz)							Standard Deviation	Standard Deviation	Frror	
l want to i set large s Threshold Red=0.720 Distance	measure ef scintilator e I for small s IV 2 fold cour	fi. As a fun quivalence cintillator Yellow=0.7 nts	ction of di e threshold = 10mV 777V	stance alon d 3 mV	ıg a big sci	ntillator rate (Hz) 3fold cour					Average 2	Average 3	Standard Deviation 2 fold	Standard Deviation 3 fold	Error propagation	effi.
l want to i set large s Threshold Red=0.720 Distance 0	measure ef scintilator e I for small s V 2 fold cour 25	fi. As a fun quivalence cintillator Yellow=0.7 nts 51	ction of di e threshold = 10mV 777V 31	stance alon d 3 mV 28	ıg a big sci	ntillator rate (Hz) 3fold cour 22	1ts 38		22	23	Average 2 32.6	Average 3	Standard Deviation 2 fold 10.50238	Standard Deviation 3 fold 6.870226	Error propagation 33.1%	effi. 79.1%
l want to i set large s Threshold Red=0.720 Distance 0 5	measure ef scintilator e I for small s XV 2 fold cour 25 23	fi. As a fun quivalence cintillator Yellow=0.7 nts 51 34	ction of di e threshold = 10mV 777V 31 32	stance alon d 3 mV 28 31	ig a big sci 28 39	ntillator rate (Hz) 3fold cour 22 16	1ts 38 23	   21	22	23 27	Average 2 32.6 31.8	Average 3 25.8 21.8	Standard Deviation 2 fold 10.50238 5.80517	Standard Deviation 3 fold 6.870226 3.962323	Error propagation 33.1% 17.7%	effi. 79.1% 68.6%
l want to i set large s Threshold Red=0.720 Distance 0 5 10	measure ef scintilator e I for small s DV 2 fold cour 25 23 43	fi. As a fun quivalenco cintillator Yellow=0.1 nts 51 34 35	iction of di e threshold = 10mV 777V 31 32 42	stance alon d 3 mV 28 31 38	ıg a big sci 28 39 33	ntillator rate (Hz) 3fold cour 22 16 22	1ts 38 23 13	 24 21 15	22 22 22 16	23 27 18	Average 2 32.6 31.8 38.2	Average 3 25.8 21.8 16.8	Standard Deviation 2 fold 10.50238 5.80517 4.32435	Standard Deviation 3 fold 6.870226 3.962323 3.420526	Error propagation 33.1% 17.7% 10.2%	effi. 79.1% 68.6% 44.0%
I want to i set large s Threshold Red=0.720 Distance 0 5 10 10	measure ef scintilator e I for small s DV 2 fold cour 25 23 43 40	fi. As a fun quivalence cintillator Yellow=0.7 nts 51 34 35 41	action of di e threshold = 10mV 777V 31 32 42 34	stance alon d 3 mV 28 31 38 43	ıg a big sci 28 39 33 35	ntillator rate (Hz) 3fold cour 22 16 22 10	nts 38 23 13 14	24 21 15 8	22 22 22 16 8	23 27 18 8	Average 2 32.6 31.8 38.2 38.6	Average 3 25.8 21.8 16.8 9.6	Standard Deviation 2 fold 10.50238 5.80517 4.32435 3.911521	Standard Deviation 3 fold 6.870226 3.962323 3.420526 2.607681	Error propagation 33.1% 17.7% 10.2% 7.2%	effi. 79.1% 68.6% 44.0% 24.9%
I want to r set large s Threshold Red=0.720 Distance 0 5 10 10 15 20	measure ef scintilator e I for small s DV 2 fold cour 25 23 43 40 40	fi. As a fun equivalence cintillator Yellow=0. nts 51 34 35 41 38	action of di e threshold = 10mV 777V 31 32 42 34 26	stance alon d 3 mV 28 31 38 43 34	ng a big sci 28 39 33 35 29	ntillator rate (Hz) 3fold cour 22 16 22 10 5	nts 38 23 13 14 4	24 21 15 8 1	22 22 22 16 8 5	23 27 18 8 7	Average 2 32.6 31.8 38.2 38.6 33.4	Average 3 25.8 21.8 16.8 9.6 4.4	Standard Deviation 2 fold 10.50238 5.80517 4.32435 3.911521 5.899152	Standard Deviation 3 fold 6.870226 3.962323 3.420526 2.607681 2.19089	Error propagation 33.1% 17.7% 10.2% 7.2% 7.0%	effi. 79.1% 68.6% 44.0% 24.9% 13.2%

							Light guide	, Silicone d	cookie 1/4"							
I want to	measure e	ffi. As a fi	inction of	distance alo	ng a big sc	intillator										
set large s	scintilator	equivaler	ce thresh	old 3 mV												
Threshold	d for small	scintillato	r = 10mV										Standard	Standard		
Red=0.720	0V	Yellow=	).777V			rate (Hz)							Deviation	Deviation	Frror	
Distance	2 fold cou	unts				3fold cour	nts				Average 2	Average 3	2 fold	3 fold	propagation	effi.
0	2	7 2	9	23 25	22	21	21	16	19	14	25.2	18.2	2.863564	3.114482	14.8%	72.2%
5	33	3 2	5	51 41	37	30	25	44	38	36	37.4	34.6	9.633276	7.334848	30.9%	92.5%
10	2	7 3	1	30 32	36	27	31	27	30	30	31.2	29	3.271085	1.870829	11.4%	92.9%
15	43	3 2	6	37 30	28	42	25	32	29	24	32.8	30.4	7.049823	7.231874	29.7%	92.7%
20	35	5 4	2	1 30	42	32	39	37	27	39	38	34.8	5.338539	5.215362	18.8%	91.6%
25	3	5 4	0	32 28	41	. 33	36	28	25	38	35.2	32	5.449771	5.43139	20.9%	90.9%
I want to	measure e	ffi. As a fi	inction of	distance alo	ng a big sc	intillator										
set large	scintilator	equivaler	ce thresh	old 10 mV												
Threshold	for small	scintillato	r = 10 mV													
Red=0.720	ov	Yellow=	).777V			rate (Hz)							Standard	Standard	_	
Distance	2 fold co	ints				3fold cour	nts				Average 2	Average 3	2 fold	3 fold	Error	effi
0	21010 000	; 3	9	18 37	40	23	27	28	28	29	37.8	27	1 973538	2 345208	7 2%	71.4%
5	3	1 7	3	14 39	40	32	30	41	33	39	38.2	35	4 658326	4 743416	16.7%	91.6%
10	29	2 7	0	23 30	20	32	26	28	35	26	33.6	30.6	4.050520	5 5/0775	21.0%	01 1%
10	20	2	с .	20 42	20	25	20	20	24	20	22.4	27.0	E 272E71	1 060765	10.6%	02 20/
20	2	7 3	7	22	21	23	22	23	34	23	23.4	27.0	2 760200	2 646017	14.7%	03.2/0
20	2		2	-0 -36	32	16	32	20	23	30	32.0	27.0	10 54000	5.040917	20.40/	64.1/0 CF F9/
25	20	2	3	50 36	33	16	15	31	24	24	33.6	22	10.54988	6.595453	28.4%	65.5%
							Light g	uide, No c	cookie			,,				-
I want to	measure e	ffi. As a fi	inction of	distance alo	ng a big sc	intillator										
set large s	scintilator	equivaler	ce thresh	old 3 mV												
Threshold	d for small	scintillato	r = 10mV										Standard	Standard		
Red=0.720	0V	Yellow=	).777V			rate (Hz)							Deviation	Deviation	Frror	
Distance	2 fold cou	unts				3fold cour	nts				Average 2	Average 3	2 fold	3 fold	propagation	effi.
0	34	1 4	1	38 21	23	25	30	24	15	16	31.4	22	8.961027	6.363961	28.5%	70.1%
5	32	2 3	8	36 38	35	31	34	32	34	30	35.8	32.2	2.48998	1.788854	8.0%	89.9%
10	39	9 4	0	26 29	41	. 37	37	24	28	40	35	33.2	6.964194	6.83374	27.2%	94.9%
15	3	5 4	9	10 43	41	33	47	38	37	38	41.6	38.6	5.07937	5,128353	16.7%	92.8%
20	33	2 3	2	27 26	41	31	30	24	23	30	32	29.4	6	6.426508	26.5%	91.9%
25	30	,	2	20	37	37	27	24	39	29	35.2	32.7	4 969909	5 403702	20.5%	91.5%
I want to	measure e	ffi. As a fi	inction of	distance alo	ng a big sc	intillator										
set large	scintilator	equivaler	ce thresh	old 10 mV												
Threshold	d for small	scintillato	r = 10mV													
Red=0.720	0V	Yellow=	).777V			rate (Hz)							Standard	Standard		
Distance	2 fold co	ints				3fold cour	nts				Average 2	Average 3	2 fold	3 fold	Error	effi
0	210101000	1 7	4	17 37	34	15	25	32	25	21	35.2	23.6	8 228001	6 228965	23.6%	67.0%
5	2	2 7	1	27 36	36	26	23	32	32	33	31.2	20.0	5 215362	1 138/68	23.070	07.0%
10	20		1	01 20	47	20	23	32	10	20	31.2	20.2	7 9102	7 220020	21.1/0	01 10/
10		5 4 5 7	1	20	47	29	34	20	19	30	30	29.2	7.61025	7.526026	20.9%	61.1%
15			5 C	27 32	44	10	15	1/		50	52.0	20.4	0.400529	5.94156	24.1%	02.2%
20	2	/ 3	ь с	28 20	3/	8	15	/	/	15	29.6	10.4	7.021396	4.219005	16.5%	35.1%
25	30	2	6	35 30	36	10	5	3	6	8	32.6	6.4	4.449/19	2.701851	8.7%	19.6%
						Ligh	ntguide, (1	/16in) sili	cone cook	e.		,	-			-
I want to	measure e	ffi. As a fi	inction of	distance alo	ng a big sc	intillator										
set large s	scintilator	equivaler	ce thresh	old 3 mV												
Threshold	d for small	scintillato	r = 10mV										Standard	Standard		
Red=0.720	ov	Yellow=	).777V			rate (Hz)							Deviation	Deviation	Error	
Distance	2 fold cou	unts				3fold cour	nts				Average 2	Average 3	2 fold	3 fold	propagation	effi.
0	39	Э З	9	38 38	35	27	30	21	28	29	37.8	27	1.643168	3.535534	9.9%	71.4%
5	20	5 2	9	10 28	24	31	27	35	26	19	31.4	27.6	6.465292	5.98331	26.3%	87.9%
10	5 50	2 3	5	34 24	34	21	33	30	22	33	30	27.8	5.958188	5.890671	26.9%	92.7%
15	23	, u					-									
	23	, 3 1 3	0	30 35	33	32	29	29	31	33	32.4	30.8	2.302173	1.788854	8.7%	95.1%
20	23 34 34 32	, 3 1 3 9 2	0	30 35 28 37	33	32	29	29 25	31 34	33 32	32.4 30.4	30.8	2.302173	1.788854	8.7% 22.5%	95.1% 92.1%
20	23 34 32 30 29 30	) 3 1 3 9 2	0 4	30 35 28 37 27 32	33 34 27	32 27 28	29 22 30	29 25 27	31 34 30	33 32 26	32.4 30.4 29.8	30.8 28 28 2	2.302173 5.128353 2 774887	1.788854 4.949747 1.788854	8.7% 22.5% 10.7%	95.1% 92.1% 94.6%
20 25	23 34 29 30	i 3 2 2 3 3	0 4 3	30         35           28         37           27         32	33 34 27	32 27 28	29 22 30	29 25 27	31 34 30	33 32 26	32.4 30.4 29.8	30.8 28 28.2	2.302173 5.128353 2.774887	1.788854 4.949747 1.788854	8.7% 22.5% 10.7%	95.1% 92.1% 94.6%
20 25	23 34 29 30 30	1 3 2 2 ) 3	0 4 3	30 35 28 37 27 32	33 34 27	32 27 28	29 22 30	29 25 27	31 34 30	33 32 26	32.4 30.4 29.8	30.8 28 28.2	2.302173 5.128353 2.774887	1.788854 4.949747 1.788854	8.7% 22.5% 10.7%	95.1% 92.1% 94.6%
20 25 I want to r	measure e	1 3 9 2 0 3	0 4 3 Inction of	30 35 28 37 27 32 distance alo	33 34 27 ng a big sc	32 27 28 intillator	29 22 30	29 25 27	31 34 30	33 32 26	32.4 30.4 29.8	30.8 28 28.2	2.302173 5.128353 2.774887	1.788854 4.949747 1.788854	8.7% 22.5% 10.7%	95.1% 92.1% 94.6%
20 25 I want to i set large s	measure e	ffi. As a fu	0 4 3 Inction of ice thresh	30 35 28 37 27 32 distance alo old 10 mV	33 34 27 ng a big sc	32 27 28 intillator	29 22 30	29 25 27	31 34 30	33 32 26	32.4 30.4 29.8	30.8 28 28.2	2.302173 5.128353 2.774887	1.788854 4.949747 1.788854	8.7% 22.5% 10.7%	95.1% 92.1% 94.6%
20 25 I want to i set large s Threshold	measure e scintilator	iffi. As a fu	0 4 3 inction of ice thresh ir = 10mV	80 35 28 37 27 32 distance alo old 10 mV	33 34 27 ng a big sc	32 27 28 intillator	29 22 30	29 25 27	31 34 30	33 32 26	32.4 30.4 29.8	30.8 28 28.2	2.302173 5.128353 2.774887 Standard	1.788854 4.949747 1.788854 Standard	8.7% 22.5% 10.7%	95.1% 92.1% 94.6%
20 25 I want to i set large s Threshold Red=0.720	measure e scintilator	ffi. As a fu equivaler scintillato	0 4 3 inction of ice thresh ir = 10mV 0.777V	30         35           28         37           27         32           distance aloo         old 10 mV	33 34 27 ng a big sc	intillator	29 22 30	29 25 27	31 34 30	33 32 26	32.4 30.4 29.8	30.8 28 28.2	2.302173 5.128353 2.774887 Standard Deviation	1.788854 4.949747 1.788854 Standard Deviation	8.7% 22.5% 10.7% Error	95.1% 92.1% 94.6%
20 25 I want to i set large s Threshold Red=0.720 Distance	measure e scintilator d for small	ffi. As a fu equivaler scintillato Yellow=	0 4 3 Inction of ice thresh in = 10mV 0.777V	30 35 28 37 27 32 distance alo old 10 mV	33 34 27 ng a big sc	32 27 28 intillator rate (Hz) 3fold cour	29 22 30	29 25 27	31 34 30	33 32 26	32.4 30.4 29.8 Average 2	30.8 28 28.2	2.302173 5.128353 2.774887 Standard Deviation 2 fold	1.788854 4.949747 1.788854 Standard Deviation 3 fold	8.7% 22.5% 10.7% Error propagation	95.1% 92.1% 94.6% effi.
20 25 I want to i set large s Threshold Red=0.720 Distance 0	measure e scintilator d for small 0V 2 fold cou	ffi. As a fu equivaler scintillato Yellow= unts 5 2	0 4 3 Inction of ice thresh rr = 10mV 0.777V	30 35 28 37 27 32 distance alo old 10 mV 27 36	33 34 27 ng a big sc 25	32 27 28 intillator rate (Hz) 3fold cour 24	29 22 30 nts 14	29 25 27 27 27	31 34 30 	33 32 26 20	32.4 30.4 29.8 Average 2 28.8	30.8 28 28.2 28.2 28.2 28.2 28.2 28.2 28.	2.302173 5.128353 2.774887 Standard Deviation 2 fold 7.049823	1.788854 4.949747 1.788854 Standard Deviation 3 fold 6.204837	8.7% 22.5% 10.7% Error propagation 28.5%	95.1% 92.1% 94.6% effi. 76.4%
20 25 I want to I set large s Threshold Red=0.720 Distance 0 5	2: 34 2: 36 36 36 36 36 36 36 36 36 36 36 36 36	ffi. As a fu equivaler scintillato Yellow= unts 5 2 5 3	0 4 3 inction of ice thresh r = 10mV 0.777V 0 8	30 35 28 37 27 32 distance alo old 10 mV 27 36 31 44	33 34 27 ng a big sc 25 29	32 27 28 intillator rate (Hz) 3fold cour 24 34	29 22 30 nts 14 35	29 25 27 27 21 29	31 34 30 30 31 42	33 32 26 20 20 25	32.4 30.4 29.8 Average 2 28.8 35.6	30.8 28 28.2 Average 3 22 33	2.302173 5.128353 2.774887 Standard Deviation 2 fold 7.049823 5.94138	1.788854 4.949747 1.788854 Standard Deviation 3 fold 6.204837 6.442049	8.7% 22.5% 10.7% Error propagation 28.5% 23.8%	95.1% 92.1% 94.6% effi. 76.4% 92.7%
20 25 I want to I set large s Threshold Red=0.720 Distance 0 5 10	2 3 3 4 3 4 3 4 3 4 3 4 4 4 4 4 4 4 4 4	ffi. As a fu equivaler scintillato Yellow= 5 3 5 3	0 4 3 3 ce thresh r = 10mV 0.777V 0 8 1	30         35           88         37           27         32           distance aloo         old 10 mV           27         36           31         44           34         32	33 34 27 ng a big sc 25 29 27	32 27 28 intillator rate (Hz) 3fold cour 24 34 32	29 22 30 nts 14 35 30	29 25 27 27 21 29 31	31 34 30 30 31 42 29	33 32 26 20 20 25 24	32.4 30.4 29.8 Average 2 28.8 35.6 32	30.8 28 28.2 Average 3 22 33 29.2	2.302173 5.128353 2.774887 2.774887 Deviation 2 fold 7.049823 5.94138 3.391165	1.788854 4.949747 1.788854 Standard Deviation 3 fold 6.204837 6.442049 3.114482	8.7% 22.5% 10.7% Error propagation 28.5% 23.8% 13.7%	95.1% 92.1% 94.6% effi. 76.4% 92.7% 91.3%
20 25 I want to i set large s Thresholc Red=0.720 Distance 0 5 10 10	33           33           33           22           33           34           35           36           37           38           38           38           38           38           38           38           38           38           38	i         3           i         3           j         2           j         3           iffi. As a full         equivaler           scintillato         Yellow=           unts         5         2           j         3         3           j         3         3           j         3         3	0 4 3 	30         35           88         37           27         32           distance alo         35           old 10 mV         32           27         36           31         44           34         32           30         35	33 34 27 ng a big sc 25 29 27 43	32 27 28 intillator rate (Hz) 3fold cour 24 34 34 32 21	29 22 30 hts 14 35 30 27	29 25 27 27 21 29 31 33	31 34 30 	33 32 26 20 20 25 24 34	32.4 30.4 29.8 Average 2 28.8 35.6 32 35.2	30.8 28 28.2 Average 3 22 33 29.2 28.8	2.302173 5.128353 2.774887 2.77487 2.7747	1.788854 4.949747 1.788854 Standard Deviation 3 fold 6.204837 6.442049 3.114482 5.215362	8.7% 22.5% 10.7% propagation 28.5% 23.8% 13.7% 21.2%	95.1% 92.1% 94.6% effi. 76.4% 92.7% 91.3% 81.8%
20 25 I want to i set large s Threshold Red=0.720 Distance 0 5 10 15 20	333           333           333           223           333           233           333           measure escintilator           1 for small           0V           2 fold cou           333           333           333           333           333           333           2223	i         3           i         3           j         2           j         3           iffi. As a fut         equivaler           scintillato         Yellow=           ints         5           j         3           j         3	0 4 3 mction of ce thresh r = 10mV 0.777V 0 8 1 1 4	30         35           88         37           27         32           Image: state sta	33 34 27 ng a big sc 25 29 27 43 35	32 27 28 intillator 3fold cour 24 34 32 21 22	29 22 30 hts 14 35 30 27 18	29 25 27 27 21 29 31 33 24	31 34 30 30 30 31 42 29 29 29 28	33 32 26 20 20 25 24 34 34	32.4 30.4 29.8 Average 2 28.8 35.6 32 35.2 34	30.8 28 28.2 Average 3 22 33 29.2 28.8 23.8	2.302173 5.128353 2.774887 2.774887 2.774887 Standard Deviation 2.fold 7.049823 5.94138 3.391165 6.496153 7.968689	1.788854 4.949747 1.788854 Deviation 3 fold 6.204837 6.442049 3.114482 5.215362 4.024922	8.7% 22.5% 10.7% propagation 28.5% 23.8% 13.7% 21.2% 20.2%	95.1% 92.1% 94.6% effi. 76.4% 92.7% 91.3% 81.8% 70.0%

#### Conclusions:

- We have developed a working procedure with a muon telescope (aka Sandwich Prototype Testing) of measuring plastic scintillators' efficiency.
- We concluded that black paper and foil wrapping have the similar reflection percent as Tyvek.
- We compared results for different scintillator plates. We have to look into this further to determine why one scintillator plate is more efficient then another. It could be several reasons: crazing, sanding and polishing methods, or light absorption characteristics.
- The new silicone cookie is the most efficient method in mating a photomultiplier tube to a plastic scintillator. However the acrylic cookie optically glued from both sides provides the best mechanical stability.

#### Future plans:

• With a developed method we will measure attenuation length and light yield of scintillators. We are going to apply this method to select the best scintillators for the cosmic ray shower detector array.