# Increasing the light yield for scintillation strips with WLS fiber embedded into the co-extruded hole.


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3 October 2016 г




Montenegro, Budva, Becici
2 – 8 October 2016 (Europe/Podgorica)
Hotel Splendid, Conference Hall

NEW TRENDS
IN HIGH-ENERGY PHYSICS

# INTRODUCTION

- Detectors based on extruded scintillation bars (strip) are widely used in HEP experiments, in particular, in most neutrino experiments and will be used in incoming experiments.
- Usually, strips have a rectangular or triangular shape in cross section and a length in a few meters: 8 m (MINOS), 7 m (Mu2e), 6 m (OPERA), 3.5 m (MINERvA) and 3 m (T2K). They are co-extruded with groove(s) or hole(s).
- Very high efficiency (better than 99.999%) of scintillation counters is required in some HEP experiments, for instance, in Mu2e . An amount of photons collected on PD is a crucial to achieve high efficiency of such detectors.
- One of an efficient method of increase light yield in system «scintillation strip with co-extruded hole + WLS fiber» is the addition of an optical filler in the space between the strip and the fiber with refractive index close to the scint. material.

This work is devoted to finding a suitable filler, and use it in long strips.

Light yield change was measured in two ways:
- using an absolute calibrating method under irradiation by cosmic muons;
- direct measurement of the PMT's anode current using rad. sources .

# Motivation

- ***the fibers glued into the strip holes could give up to 90-100% more light compare to the fibers in the air filled holes*** (see "Extruded Plastic Scintillator for MINERvA" Anna Pla-Dalmau, Alan D. Bross, Victor V. Rykalin and Brian M. Wood)
- for long counters (several meters) fiber gluing inside hole is the difficult technical challenge due to limited lifetime of adhesive solution
- it make sense to fill the hole around fiber with some low viscosity filler
- the optimal refractive index of the filler would be in the range between 1.6 (polystyrene) and 1.4 (external fiber cladding)
- the filler would be chemical inactive and would have rad. hardness not less than strip and fiber

# STEP 1 What fillers have we chosen?


**Medical glicerin**
(from farmacy)
glycerol/water proportion 86/100
(43% solution).

dynamic viscosity ~20 mPa*s

refractive index (20 C) = 1.38818

used in optical devices


**Ultra-low viscosity UV adhesive** “SPECTRUM-K-59EN”
(produced in Nizhny Novgorod)

This is the photo curable composition, hardening by UV (365 nm)

dynamic viscosity (25 $^0$C) = 20 mPa*s

refractive index (20 $^0$C) = 1,46

used to glue glasses with transparent transition

**Low molecular weight viscous rubber** “SKTN-MED mark E” without hardener
(produced in St. Petersburg)

dynamic viscosity = 10 Pa*s
(like a fresh honey)

refractive index (20 $^0$C) = 1.606

used in medical and optical equipment

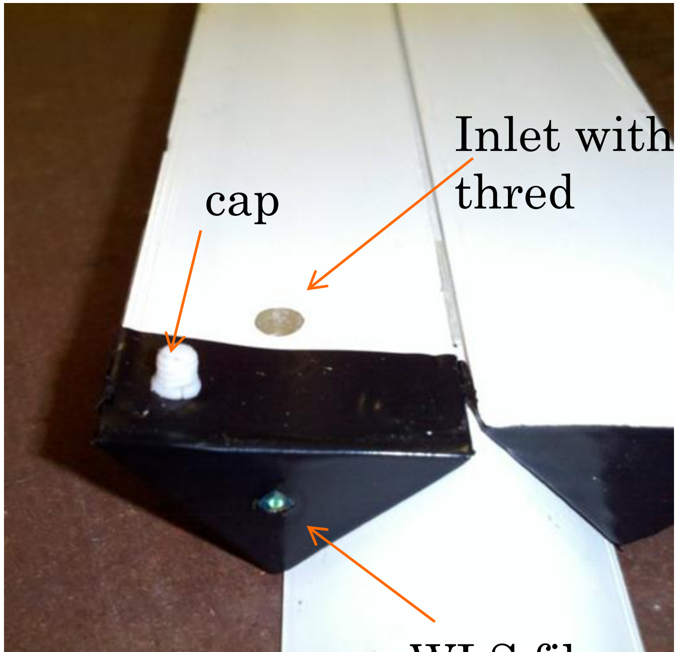

**Distilled water**

dynamic viscosity (20 $^0$C) = 1,002 mPa*s

refractive index (20 $^0$C) = 1,3330

as reference sample

# WHAT DID WE USE?




Scint. strip with triangular cross-section and $TiO_2$ shell (PS(base) dopped 2%PTP(activator) and 0.02%POPOP(shifter)) with a longitudinal hole (diam. 2.6 mm). Produced by * ISMA. The ends polished and mirrored

Strip's geometry:

Base: 33 mm
Height: 17 mm
Length: 500 mm

WLS fiber Kuraray Y11 (200ppm)
Polystyrene core n = 1.59
an inner shell is PMMA** n = 1.49
An outer shell is fluorinated PMMA n = 1.42

For pumping liquids the threaded holes were prepared and plastic caps to them. In the case of viscous rubber, we didn't use the caps. Just added a small drop of hardener.

Trigger counters based on the SiPM SensL 3x3mm2. There are analog and digital outputs. The size of the scintillator – 2 cm3. Power +/-5V and -35V.

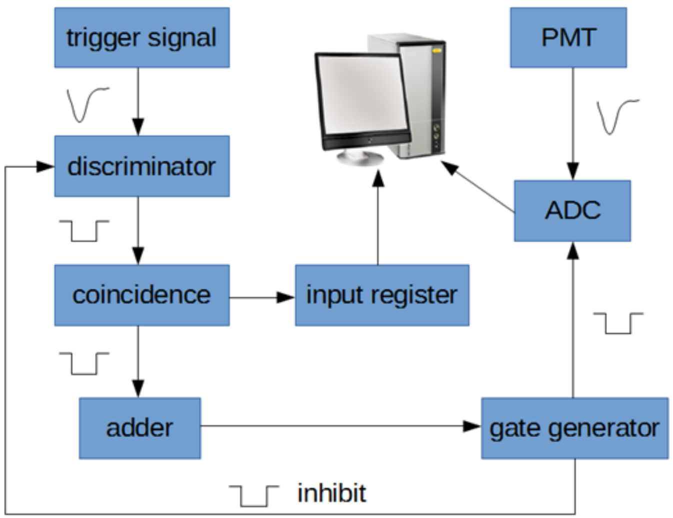
* ISMA – Institute for Scintillation Materials, Kharkiv, Ukraine

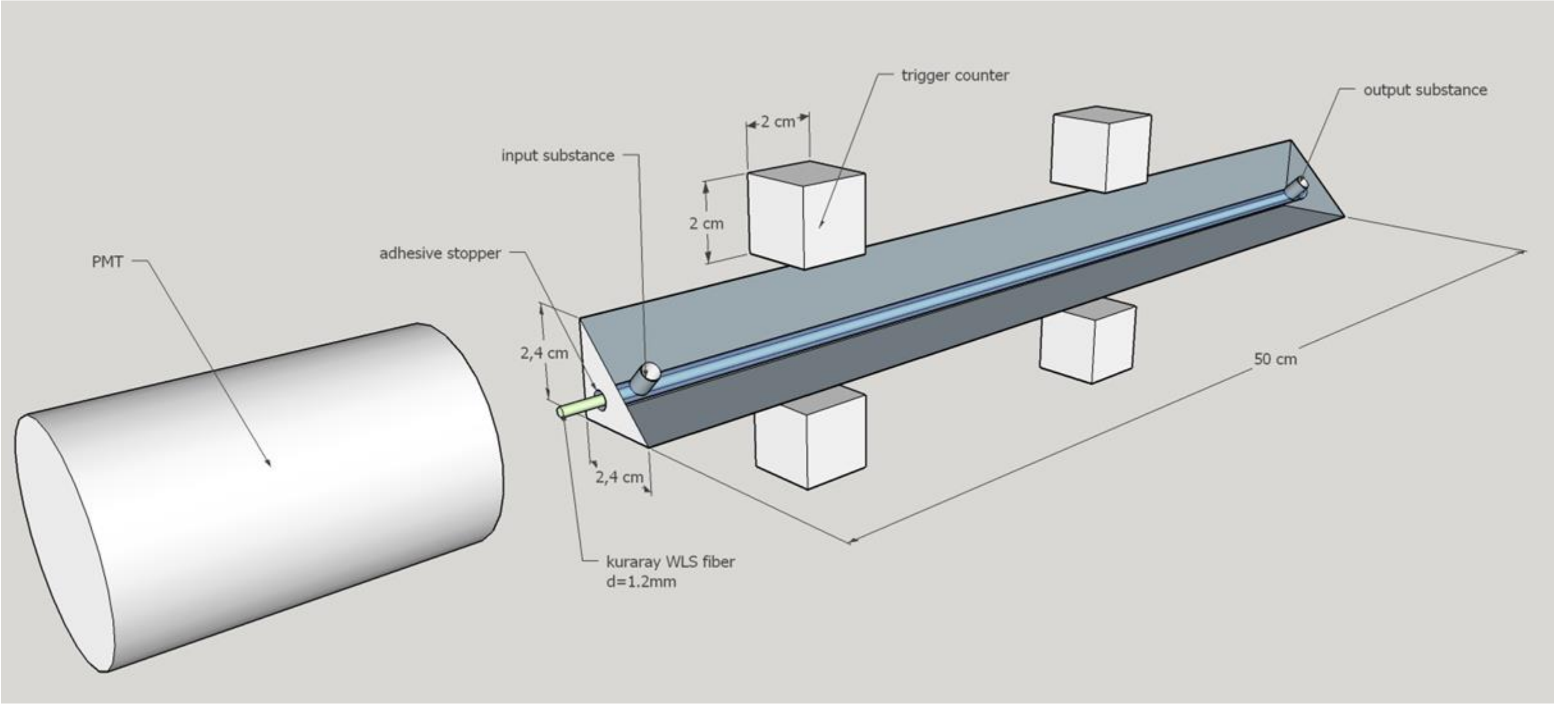
**polymethylmethacrylate

# TEST CONDITIONS

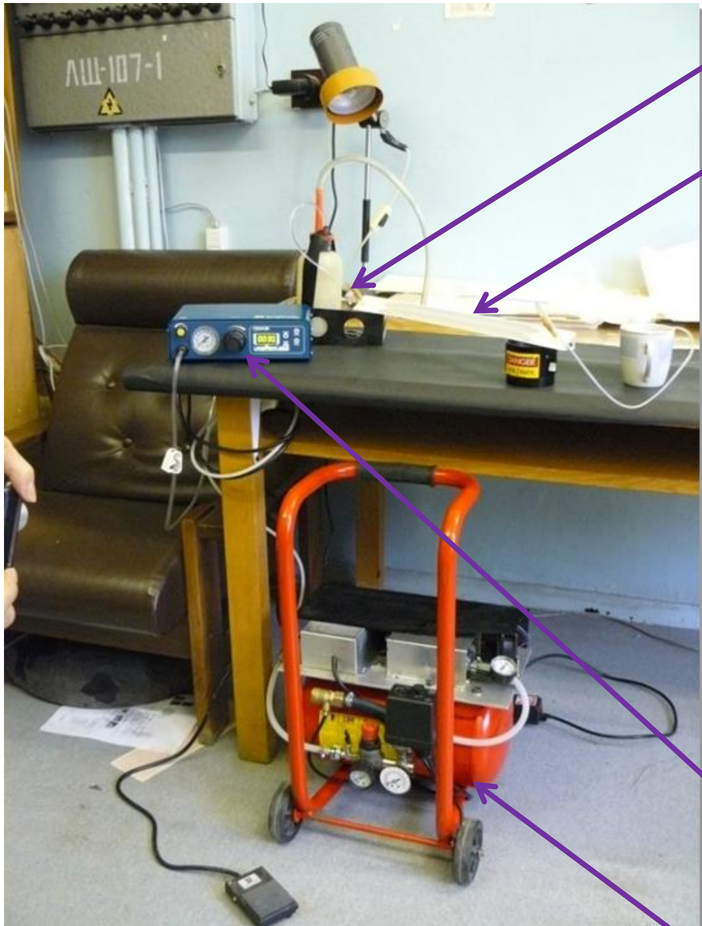
- Measurements were carried out by comparing the light yield of the same strips, dry and filled with a certain substance;
- Light was collected from fiber only (Kuraray Y11, 200 ppt). The ends were mirrored and isolated from the outer light by black cover;
- The WLS fiber was fixed with adhesive on both sides;
- Substances were inserted in two ways. In the case of liquids with low viscosity, the liquid was injected using a syringe. We used an air compressor and dispenser for viscous rubber;
- PMT EMI 9814B was used, HV=2000V. Two pairs of trigger counters were also used;
- An absolute calibration method was applied to calculate the light yield in ph.e. (Bellamy at al. Absolute calibration and monitoring of a spectrometric channel using a photomultiplier, NiMA 1994 V.339 P.468-476).

Block diagram of the data acquisition system



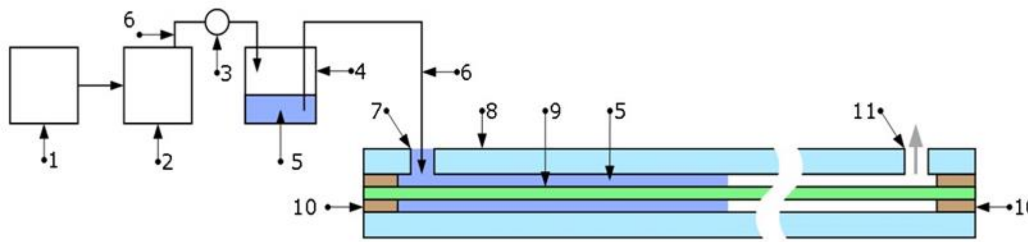



# INJECTION METHOD FOR VISCOUS RUBBER




a vessel with rubber

scint. strip



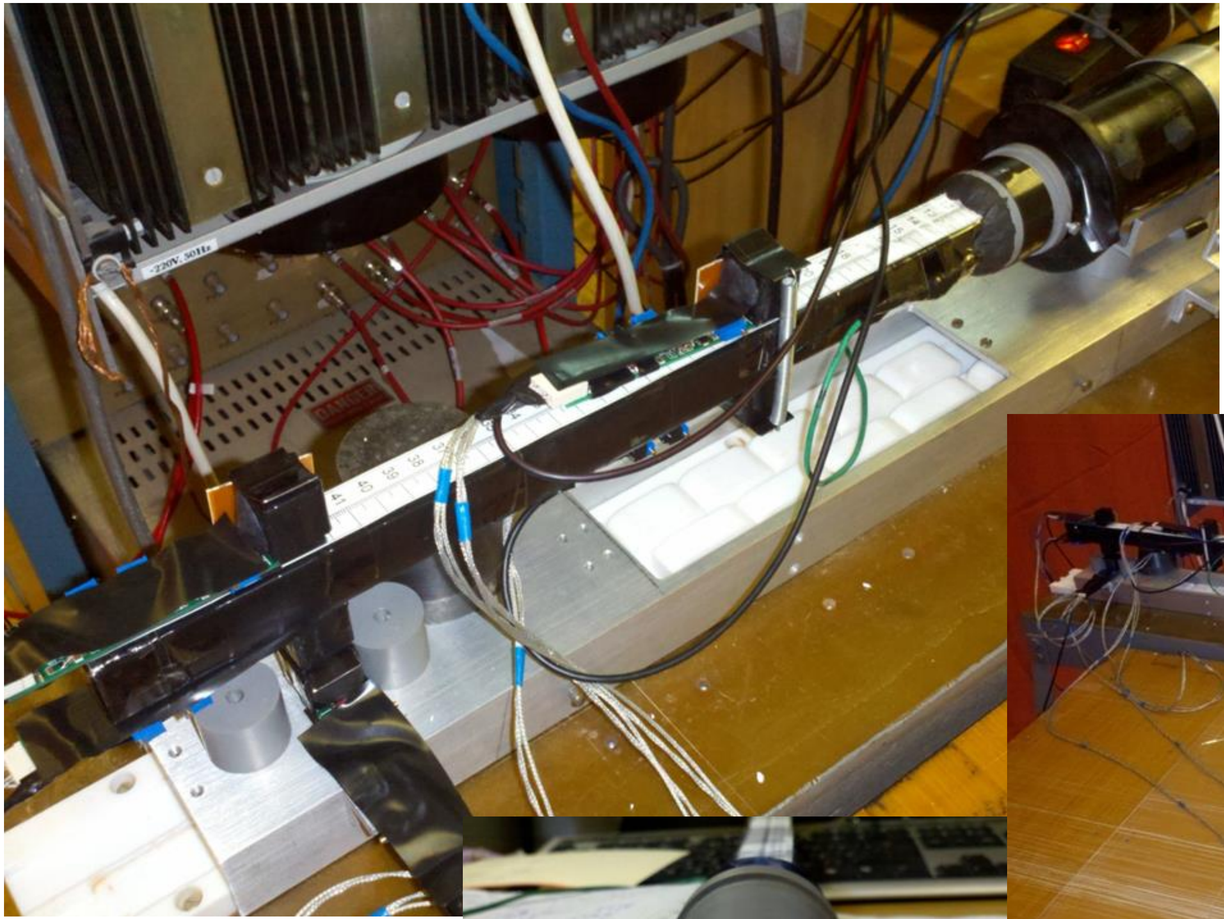

(1) air compressor; (2) SL101N digital Liquid Dispenser;
(3) manometer; (4) special vessel with filler; (5) filler;
(6) polyvinylchloride tube; (7) inlet for filling; (8) strip;
(9) WLS fiber; (10) sealing; (11) exhaust outlet for extracting air.

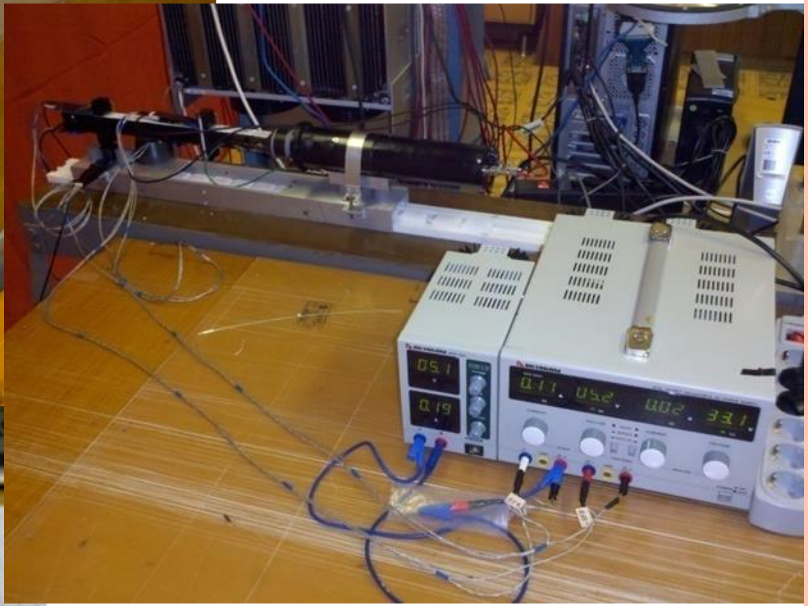
dispenser for maintaining constant pressure

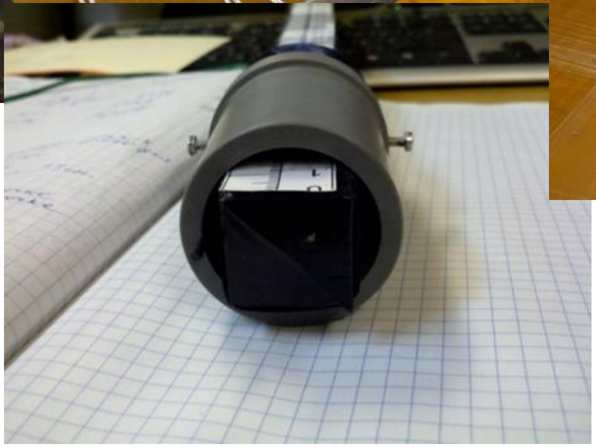
air compressor

## For visual inspection of the filling process (the presence of air bubbles), the titanium oxide layer was removed from the sample

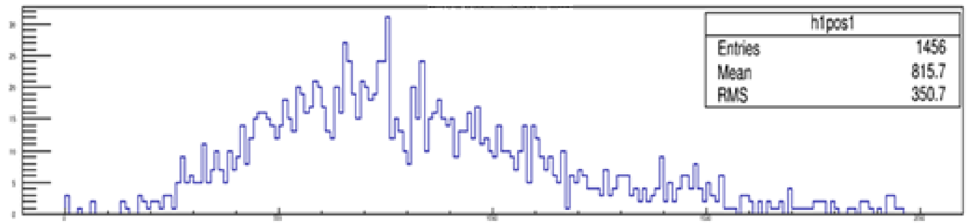
# Test Area (Lab. of Nuclear Problems, DUBNA)



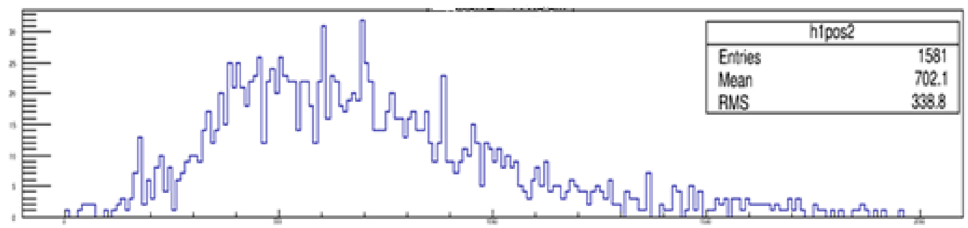




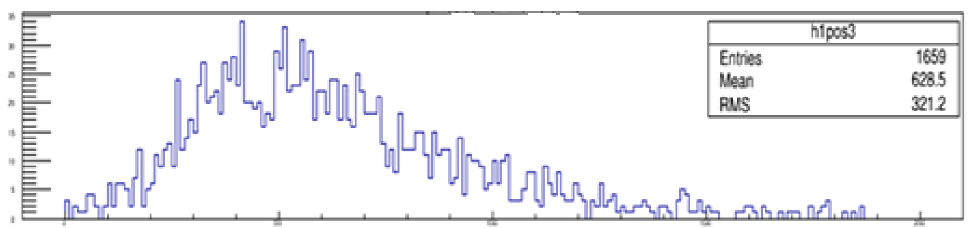
# Examples of cosmic muon spectra for our strip filled with water in relation to distance from PMT



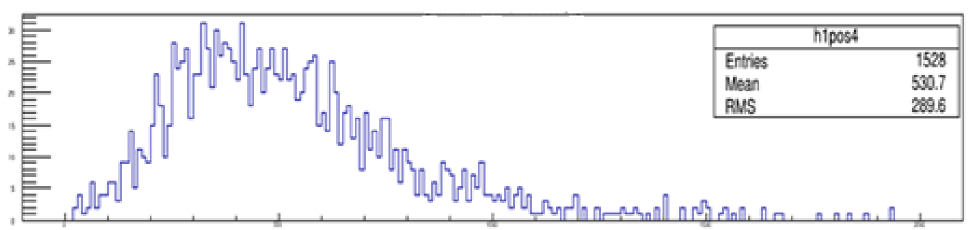

13 cm




23 cm



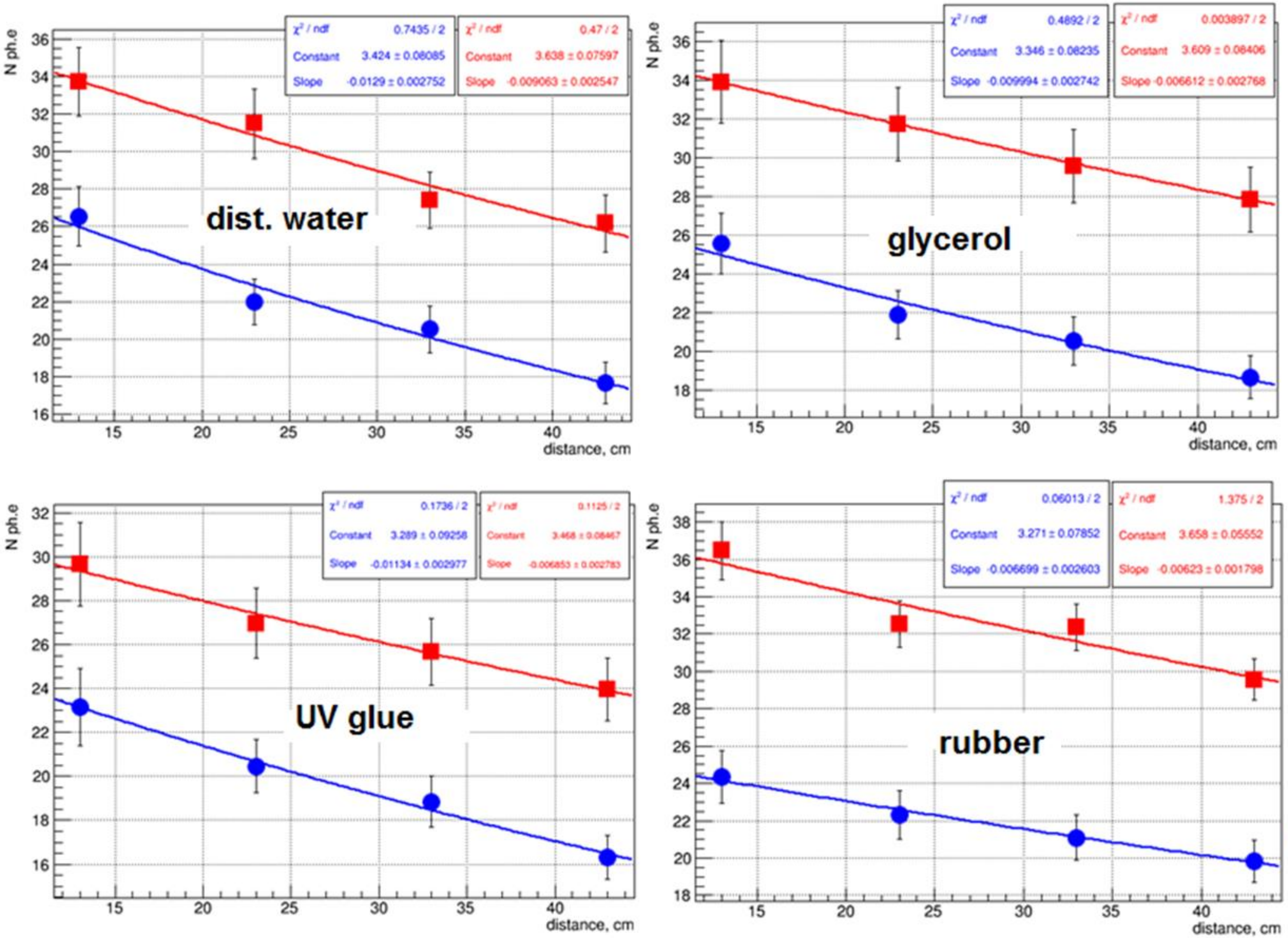

33 cm




43 cm

# Results (0.5 m strips)

blue – dry mode  red – with filler




Fit function  $f(x)=\exp(p_0 + p_1 * x)$

# TABLES:

*refractive index of polystyrene 1.59
an outer shell of WLS fiber n = 1.42

| characteristics | dist. water | med.glycerin | rubber | UV adhes. |
|---|---|---|---|---|
| refractive index | 1.3333 | 1.38818 | 1.606 | 1.46 |
| dynamic viscosity, mPa*s | 1.002 | 20 | >10000 | 20 |
| method of pumping | manual | manual | mechanical | manual |
| time of pumping | >1 min | 1-3 min | 30 min | 1-3 min |
| in/out holes for pumping | screw-thread + cap | screw-thread + cap | no screw-thread, no cap | screw-thread + cap |
| cost in $, 100 ml | 0.07 | 0.5 | 3 | ~ 5 - 7 |

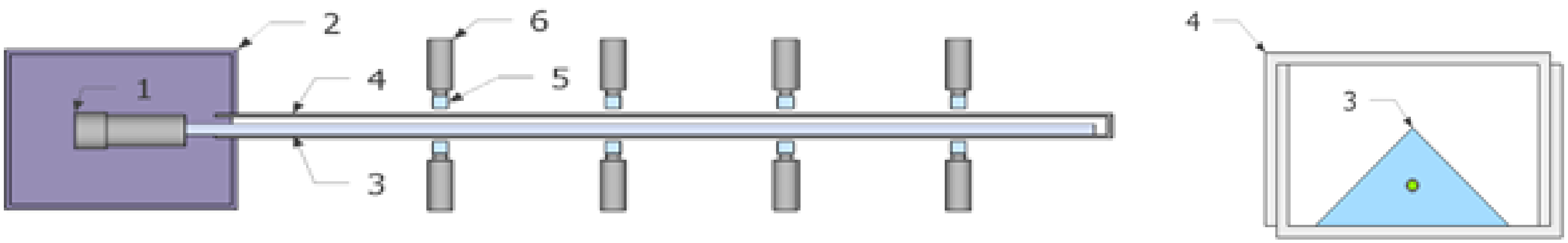
## The increase of light yield

| distance to PMT (cm) | dist. water, % | med.glicerin, % | rubber, % | UV adhes,% |
|---|---|---|---|---|
| 13 | 27 ± 10 | 33 ± 11 | 50 ± 11 | 28 ± 10 |
| 23 | 43 ± 13 | 45 ± 13 | 46 ± 10 | 32 ± 11 |
| 33 | 34 ± 11 | 44 ± 13 | 53 ± 11 | 36 ± 12 |
| 43 | 48 ± 13 | 49 ± 13 | 49 ± 10 | 47 ± 13 |
| mean | 38 ± 6 | 43 ± 6 | 50 ± 5 | 36 ± 6 |

# STEP 2

- Once study of light yield for short strips with different fillers in has been performed, we decided to switch focus on study of light yield for 2m long strip filled by rubber CKTN-MED(E)
- WLS fiber coupling quality with PMT window has been improved to avoid the effect of additional light from the scintillator passing fiber.
- we used the same injection method and acquisition system as before

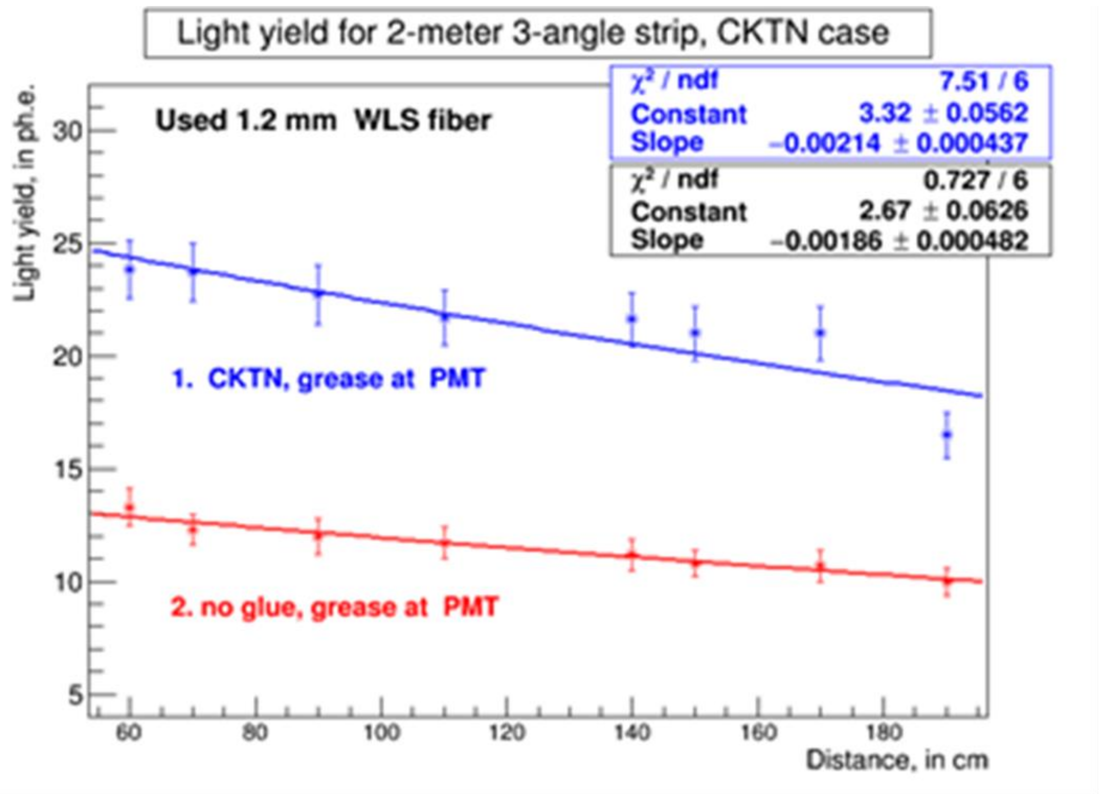
# Scheme of experimental setup




PMT EMI9814B (1) in black box (2), strip (3) in light isolated Al tube (4),

4 pairs of trigger scintillation counters 20x25x30 mm (6) with PMT FEU 85 (5).

# light collected from the 2 m long scint strip



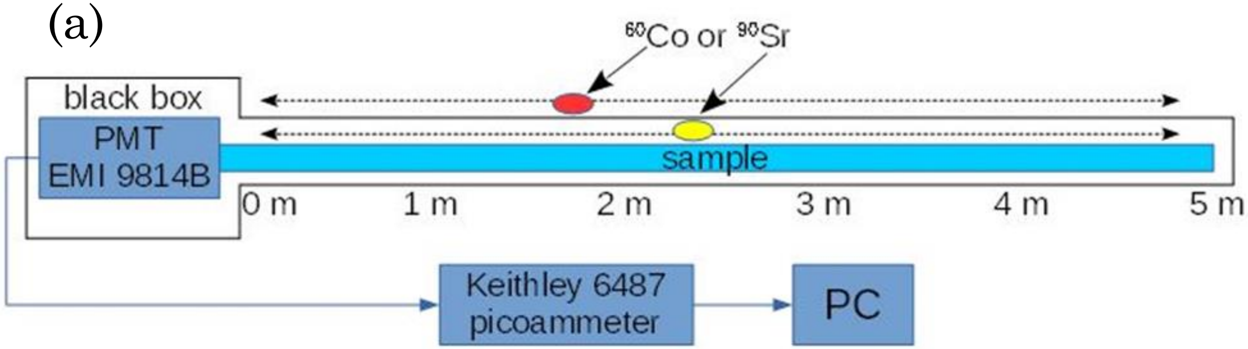

Light yield collection for the strip filled by CKTN-MED(E) with 1.2 mm WLS fiber is higher by **factor 1.8** than light yield for "dry" strip with same other conditions

# STEP 3

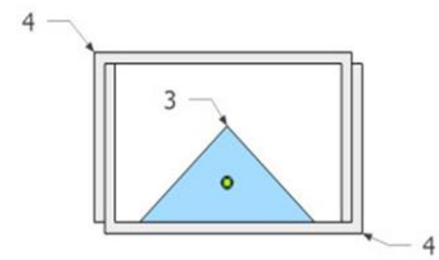
- The third stage is the using 5-meter strip samples and other measurement method (see next slide)
- We used the same filler (rubber CKTN-MED(E)) and test setup for long strips

# Experimental setup

(a)




(b)



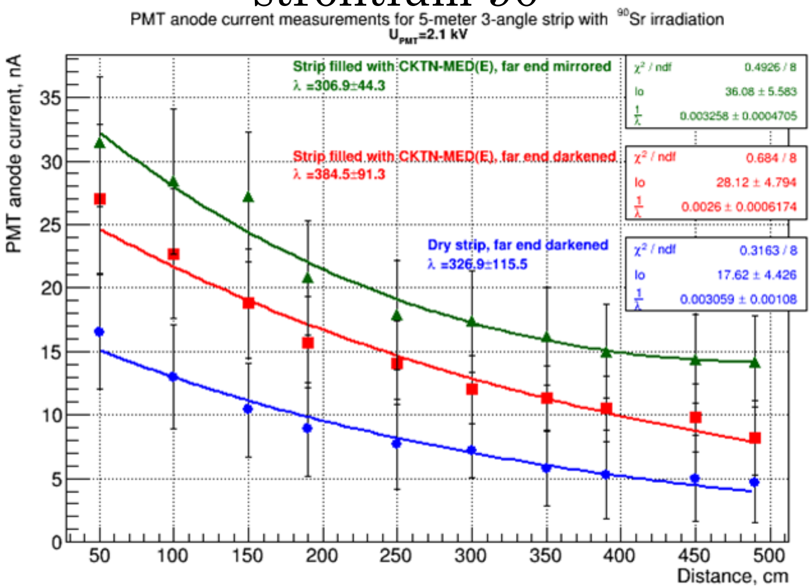

(c)

(d)

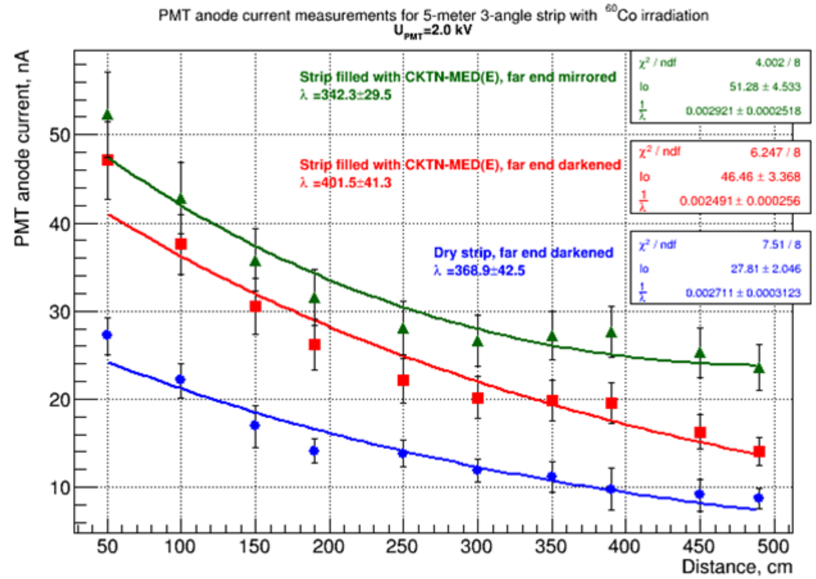
(a) Layout of the experimental setup;
(b) cross section of the light-proof Al U-channels with a strip inside;
(c) general view;
(d) moving platform with radiactive source.

# PMT anode current measurement as a function of the distance from the PMT photocathode with $^{60}Co$ and $^{90}Sr$ irradiation for the 5 meter scint strip

## strontium 90




## cobalt 60




- BLUE and RED fit function $I = I_0 e^{(-x/\lambda)}$ GREEN fit function $I = I_0 \left(e^{(-x/\lambda)} + e^{(x-2L/\lambda)}\right)$
- $\lambda$ – technical attenuation length (TAL); x – distance along the strip;

I – anode current in nA, $I_0$ – calculated anode current at $x_0$; L – length of the strip in cm.

- Light collected from the strip filled with rubber CKTN-MED(E) in average is **1.8 times** higher than the “dry” strip

# Conclusion

- Using low viscous liquids and viscous adhesive without a hardener in order to increase a light yield is a good alternative gluing of fibers, which is particulary problematic for long scintillation strips;

- The special technique of filling the viscous rubber tested on short strip samples is applicable to fill the 2 and 5-meter strips;

- Filling of the strip hole with the rubber SKTN-MED(E) increases the light yield ~ 80%;

- Results obtained with the rad sources and picoammeter readout are consistent with measurements employing cosmic muons;

- The fillers could be especially useful in the case of long counters (3-6 meters) with one end fiber readout;

Thank you for your attention