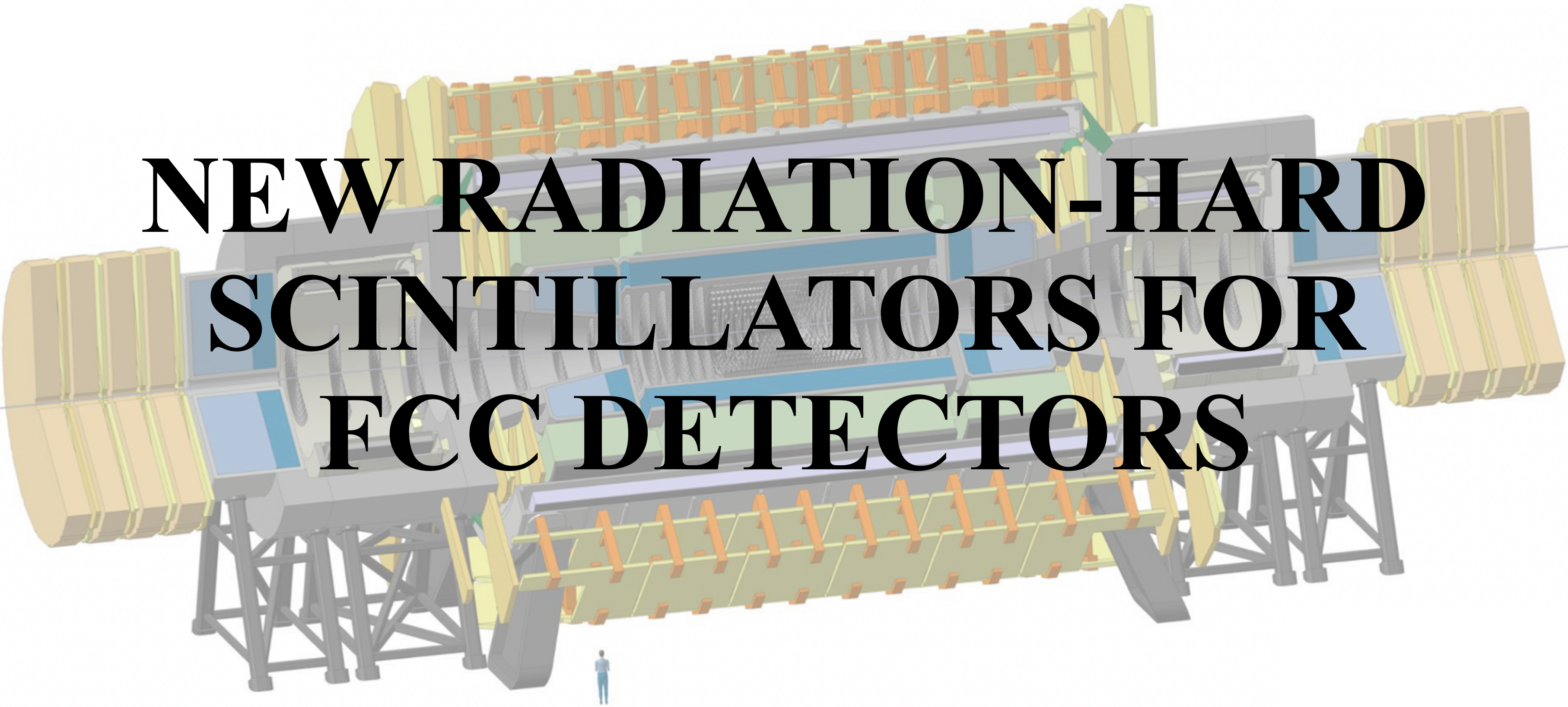


NEW RADIATION-HARD SCINTILLATORS FOR FCC DETECTORS

Burak Bilki, Yasar Onel

EPS-HEP Conference 2021

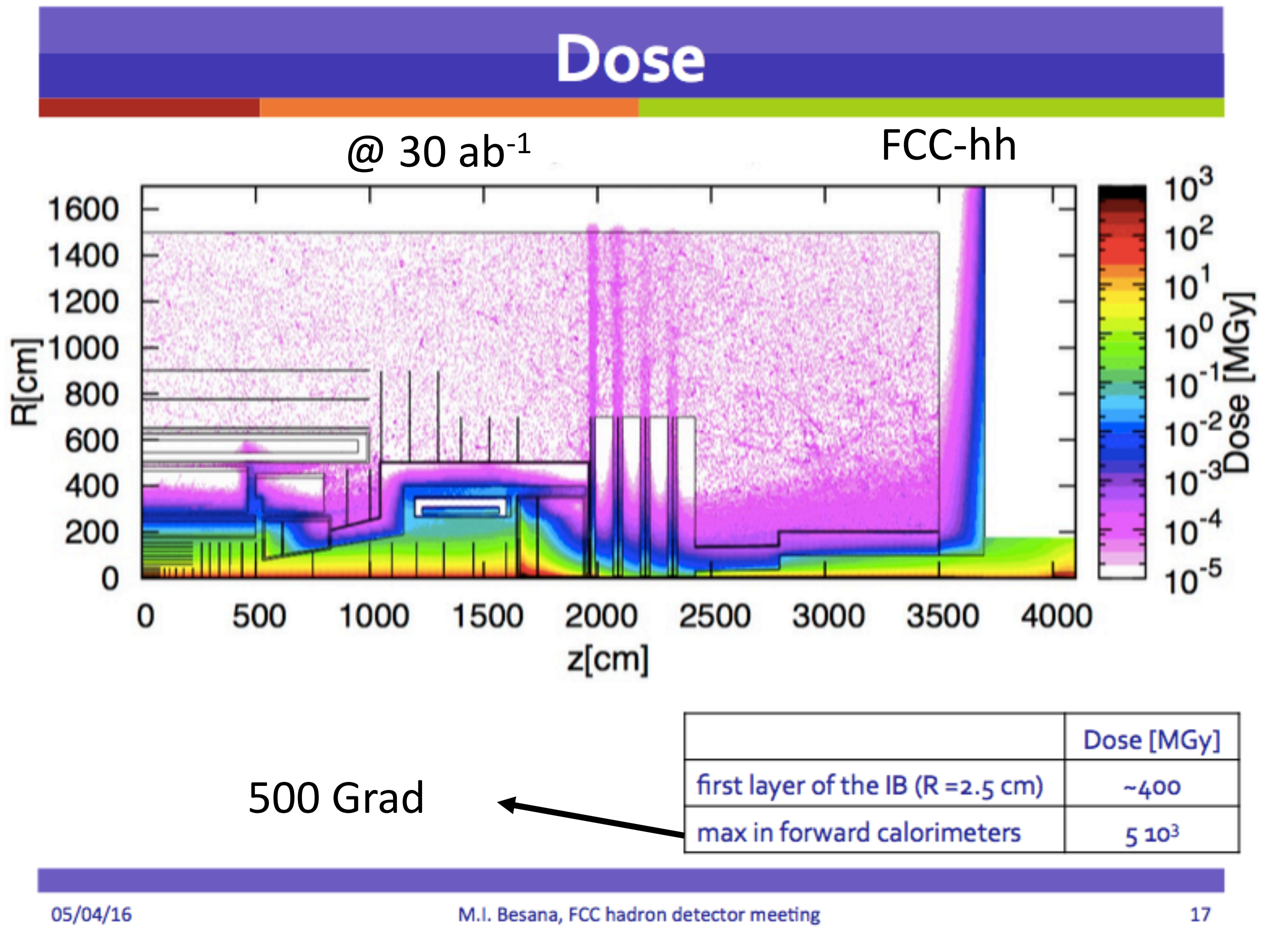
Motivation for Radiation-Hard Scintillator and WLS Fiber Development

Future and upgrade colliders impose unprecedented challenges on the radiation-hardness of the active media of the calorimeters.

Scintillators play a central role as the active medium of calorimeters.

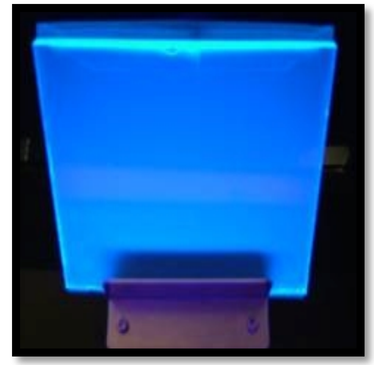
What are we looking for?

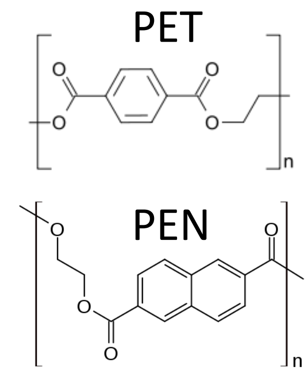
- ✓ Compact
- ✓ High light yield
- ✓ High resolution
- ✓ Radiation resistant
- ✓ Fast
- ✓ Cost effective scintillators.



	Dose [MGy]
first layer of the IB (R =2.5 cm)	~400
max in forward calorimeters	5 10^3

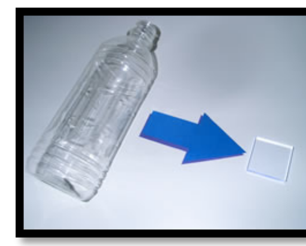
Intrinsically Radiation-Hard Scintillators





Commercially Available Scintillating Materials:

- Polyethylene Naphthalate (PEN)
- Polyethylene Terephthalate (PET)

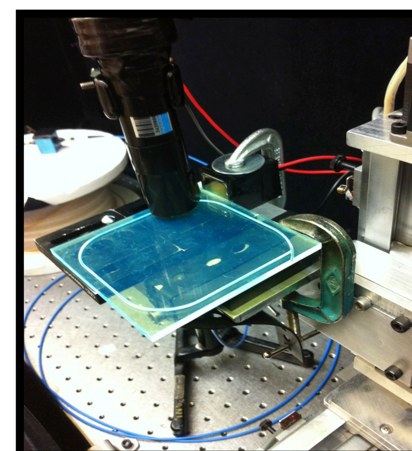


PEN:

✓ Intrinsic blue scintillation (425 nm)

PET:

✓ A common type polymer
✓ Plastic bottles and as a substrate in thin film solar cells.
✓ Emission spectrum of PET peaks at 385 nm [Nakamura, 2013]



Intrinsically Radiation-Hard Scintillators

HEM/ESR: sub-µm film stack of PolyEthylene-2,6-Naphthalate (PEN), polyester, polyethylene terephthalate (PET): ***intrinsic blue scintillation!***

425 nm; 10,500 photons/MeV; ….

epl A LETTERS JOURNAL EXPLORING THE FRONTIERS OF PHYSICS

July 2011

EPL, 95 (2011) 22001 www.epljournal.org
doi: 10.1209/0295-5075/95/22001

Evidence of deep-blue photon emission at high efficiency by common plastic

H. NAKAMURA[1,2(a)], Y. SHIRAKAWA[2], S. TAKAHASHI[1] and H. SHIMIZU[3]

Table 1: Properties of the three samples used in the present study.

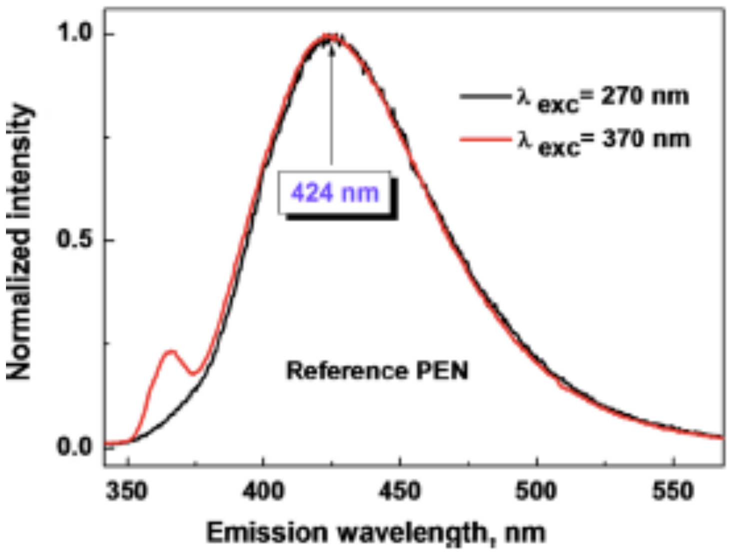
Material	Polyethylene naphthalate	Organic scintillator (ref. [14])	Plastic bottle (ref. [13])
Supplier	Teijin Chemicals	Saint-Gobain	Teijin Chemicals
Base	$(C_{14}H_{10}O_4)_n$	$(C_9H_{10})_n$	$(C_{10}H_8O_4)_n$
Density	$1.33\,g/cm^3$	$1.03\,g/cm^3$	$1.33\,g/cm^3$
Refractive index	1.65	1.58	1.64
Light output	∼ 10500 photon/MeV	10000 photon/MeV	∼ 2200 photon/MeV
Wavelength max. emission	425 nm	425 nm	380 nm

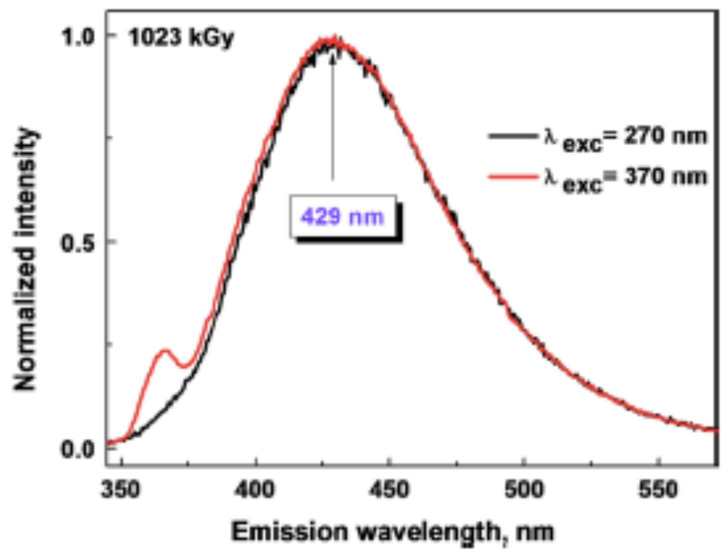
Intrinsically Radiation-Hard Scintillators - PEN

100 MRad (1 MGy) Radiation Resistance!

N. Belkahlaa et al., *Space charge, conduction and photoluminescence measurements in gamma irradiated poly (ethylene-2,6-naphthalate)* Rad. Physics & Chem, V101, August 2014

Abstract: *Polyethylene naphthalate (PEN) thin films were subjected to gamma rays at different doses and changes in both the dielectric and photophysical properties were investigated. Samples were irradiated in air at room temperature by means of a ^{60}Co gamma source at a dose rate of ~31 Gy/min. Total doses of 650 kGy(344 h) & 1023 kGy(550 h) were adopted. The high radiation resistance of PEN film is highlighted.*

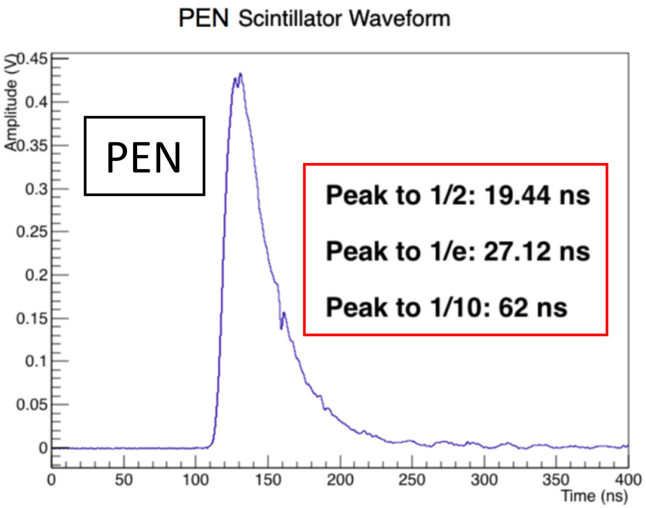


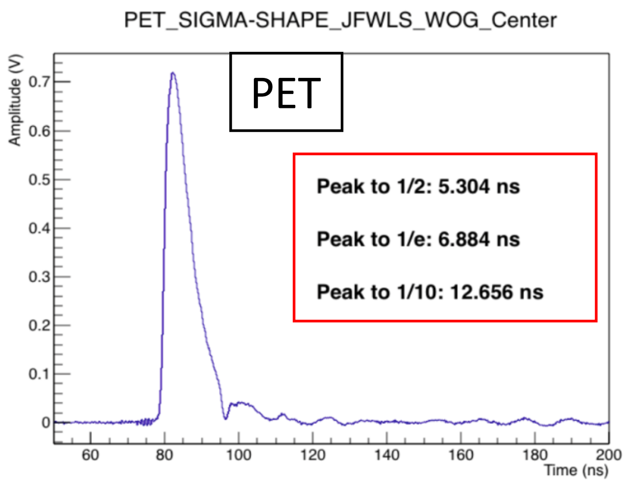


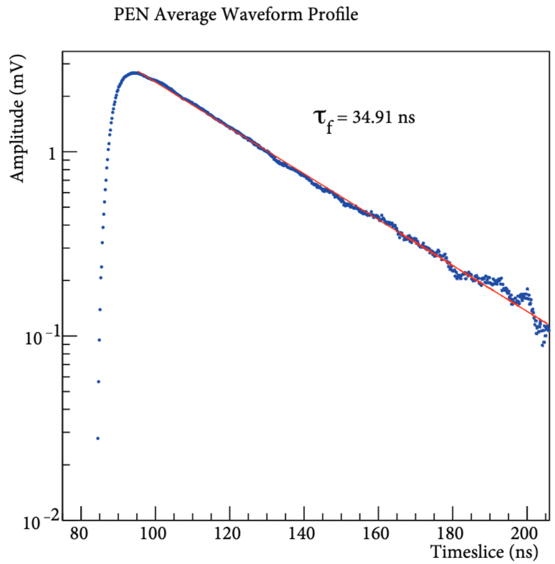
PL intensity at peak maximum (relative units) versus irradiation dose.

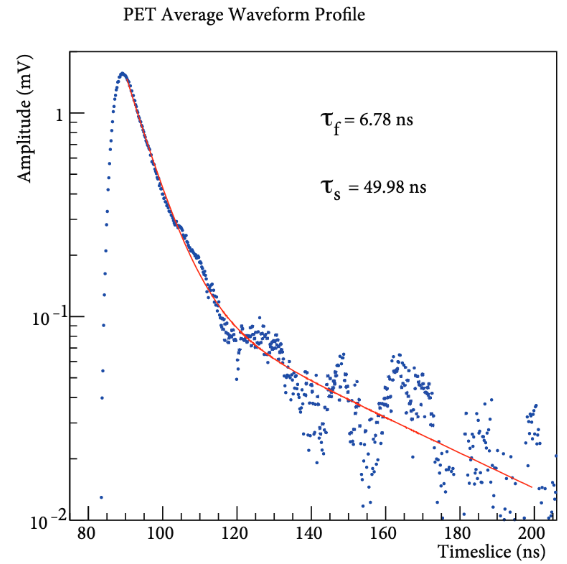
Excitation wavelength	Reference-PEN	650 kGy	1023 kGy
λ_e = 270 nm	1	0.98	0.95
λ_e = 370 nm	1	0.98	0.96

PEN/PET Scintillation Time Constants









Measurements with 337 nm pulsed Nitrogen laser :

PEN: 27.12 ns
PET: 6.88 ns

Measurements with 120 GeV protons of FTBF:

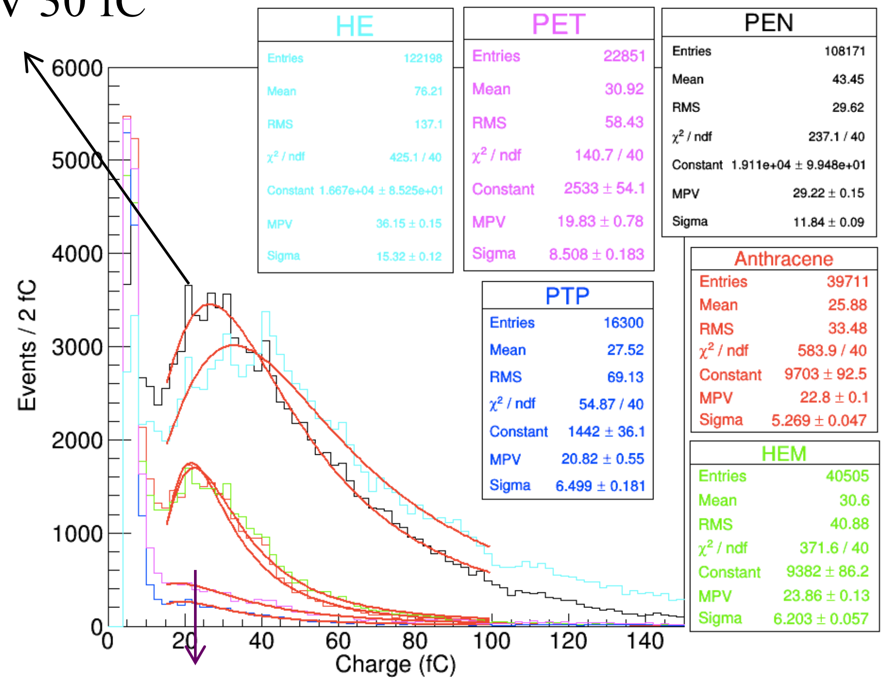
PEN: 34.91 ± 0.08 ns
PET: 6.78 ± 0.07 ns

PET has two time constants (fast and slow)

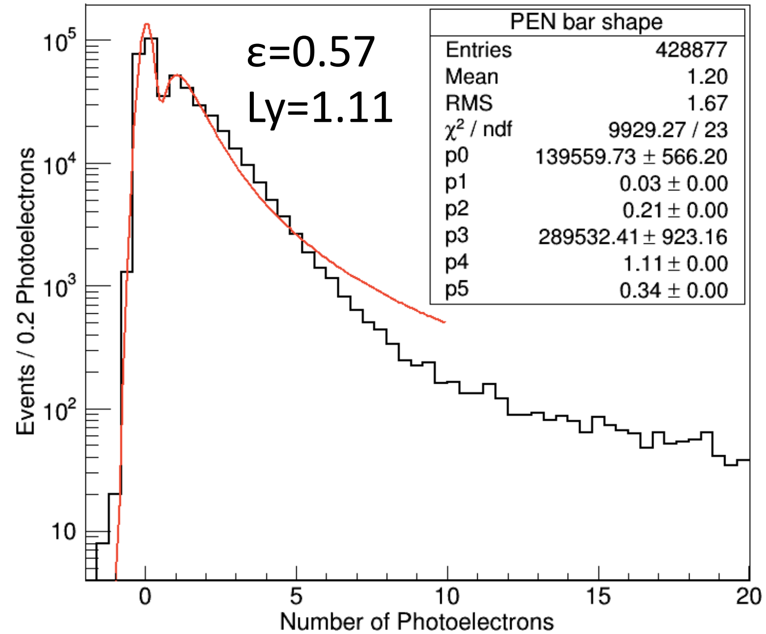
PEN/PET Light Yield

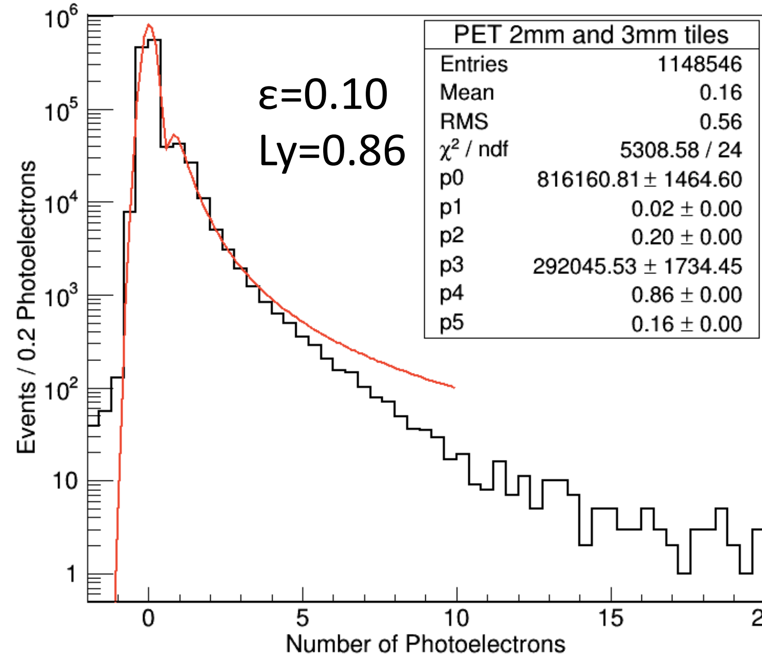
PEN → Light yield MPV 30 fC

150 GeV muons @ CERN



PET → Light yield MPV 20 fC





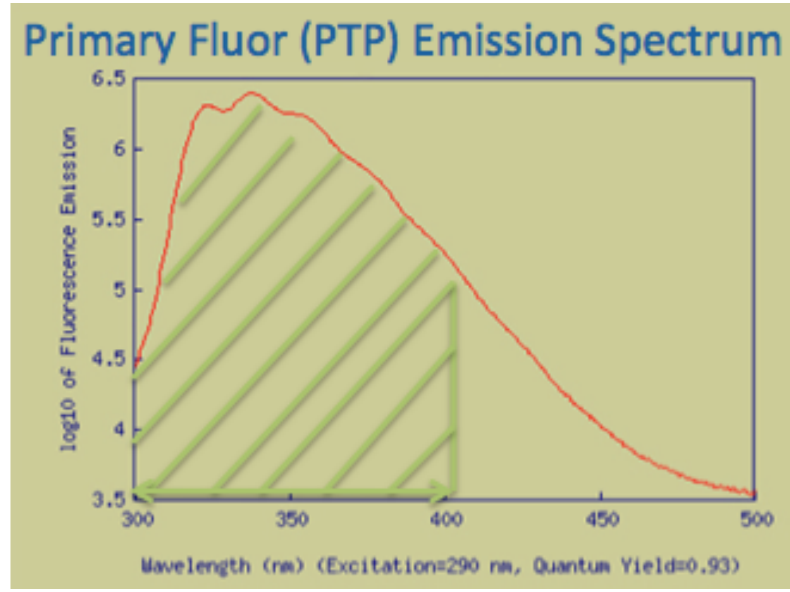
- PET is faster but emits less light. PEN is radiation resistant up to 10 Mrad and it has a significant light yield but it is too slow.

New SiX Scintillators

- The scintillators have a base material, primary fluor, and secondary fluor.

- The main scintillation comes from the primary fluor.

- The secondary fluor, or waveshifter, absorbs the primary's emissions and re-emits to a wavelength that is desirable for optimum efficiency.



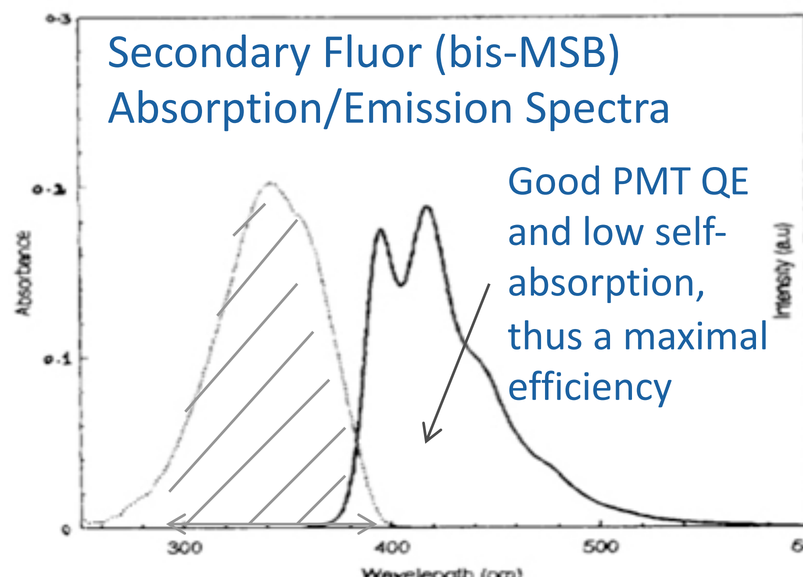
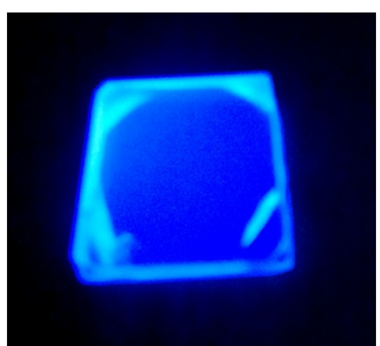
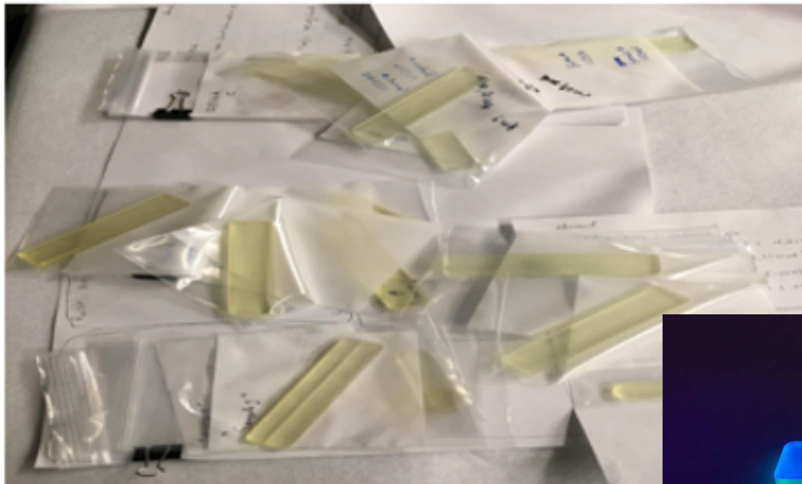


Fig. 1. Absorption (· · ·) and emission (— —)

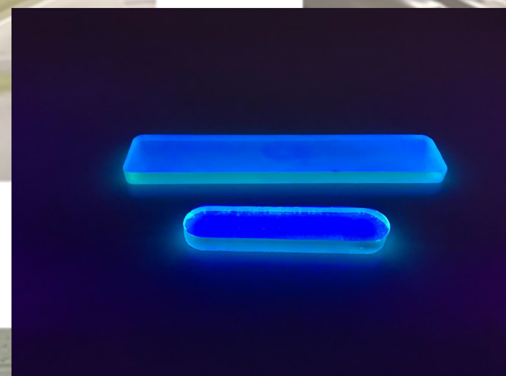


SiX Production

Finger Tiles



Grooved Tiles



Modified Oven

Control Circuits

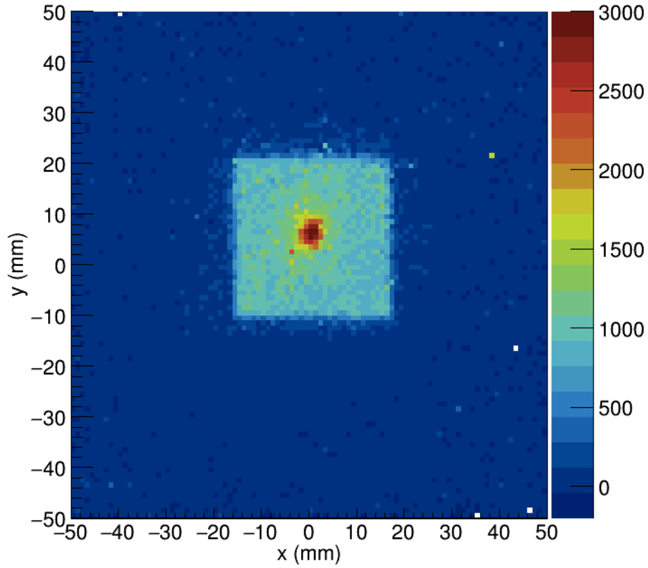
SiX in Test Beam

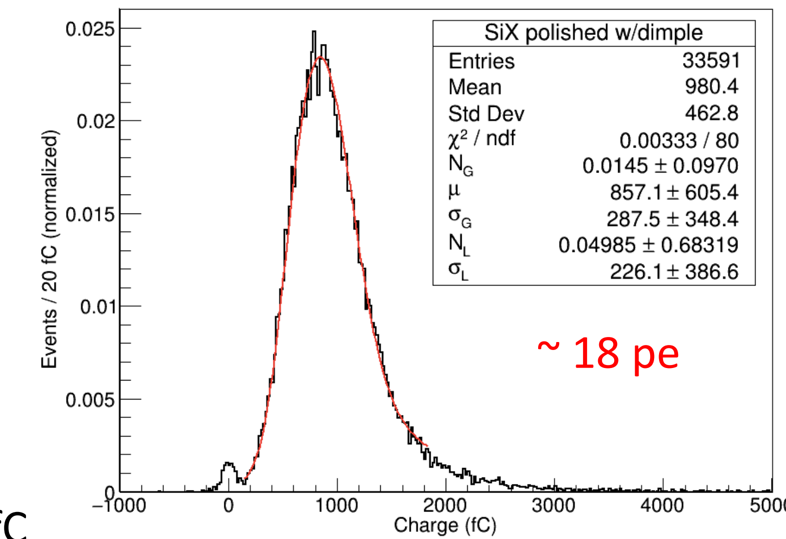
Scintillator-X response to 150 GeV muons

SiPM directly coupled to dimple (Hamamatsu S12572-010)

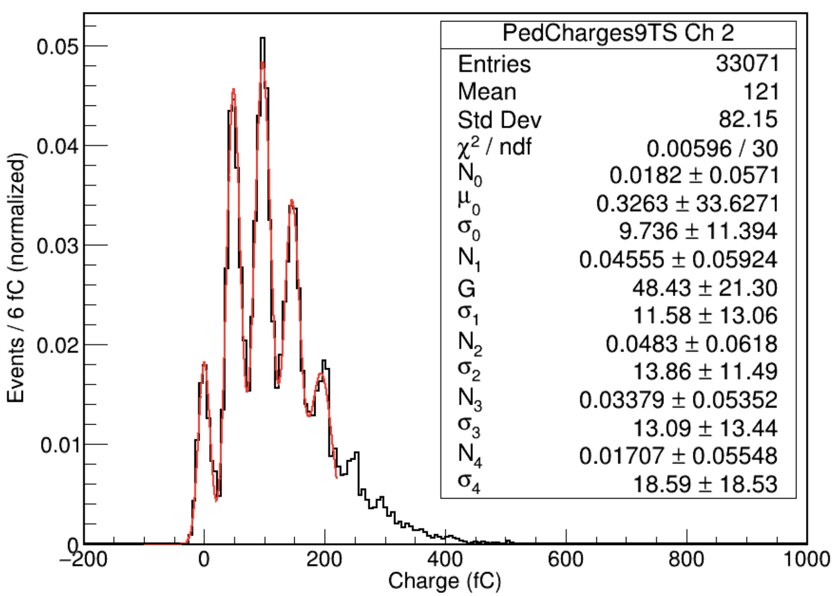
Tile size 3 cm x 3 cm x 5 mm

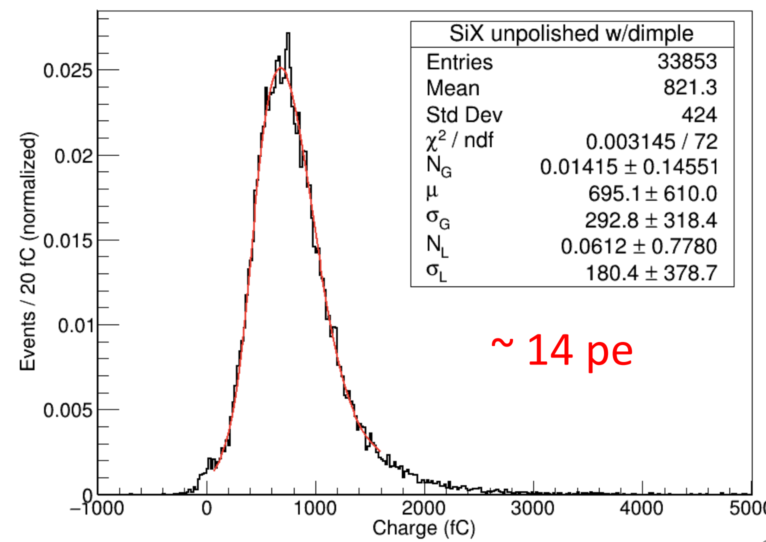
Select the muons passing through the tile and 1 mm away from the SiPM





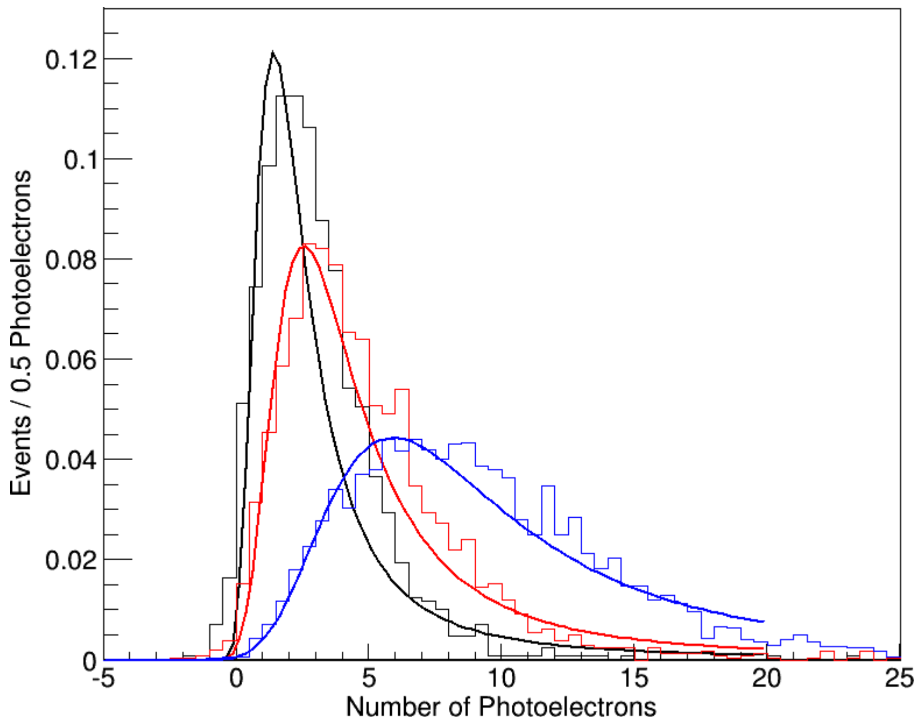
Gain ~ 50 fC





Fit to a Gaussian + Landau

Clean Quartz Tiles

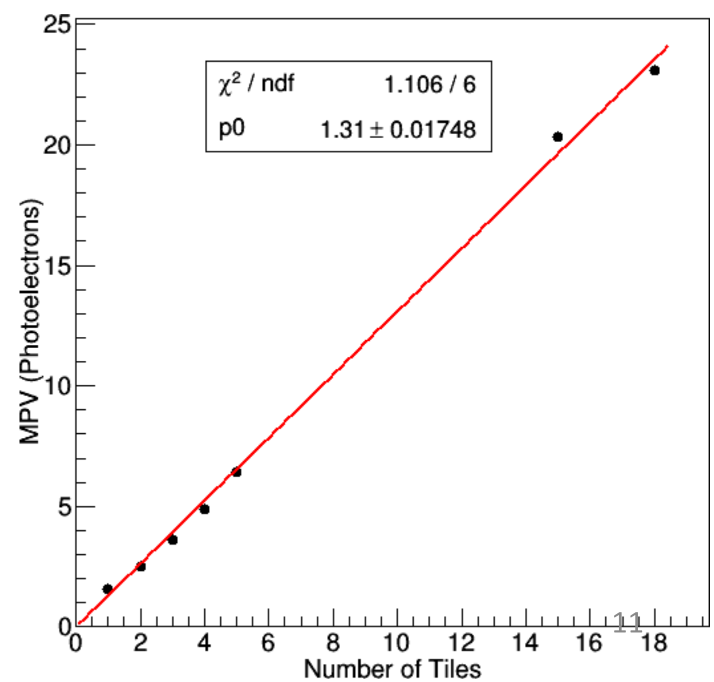


Hamamatsu R7600U-200 PMTs directly coupled to the edge of a combination of 1 mm clean quartz tiles

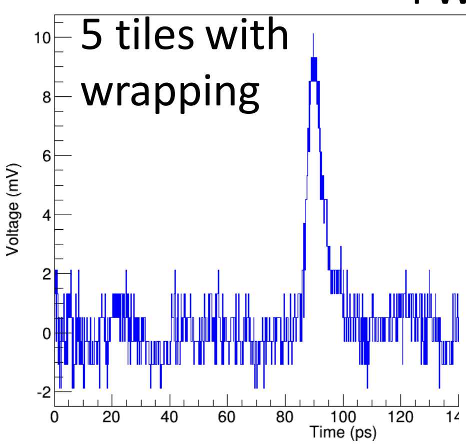
Single tile with reflective wrapping

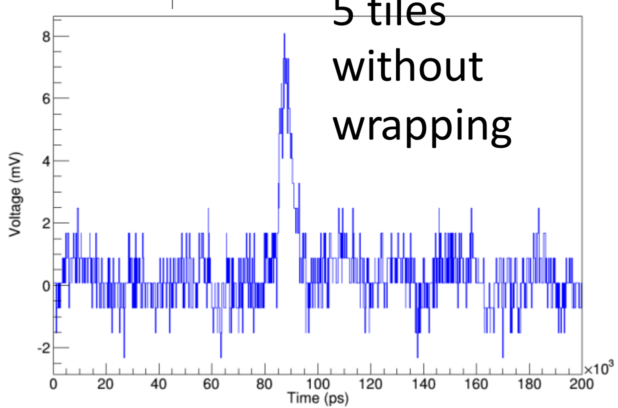
5 tiles with no wrapping

5 tiles with individual reflective wrappings



FW @ 1/10 ~ 10 ns





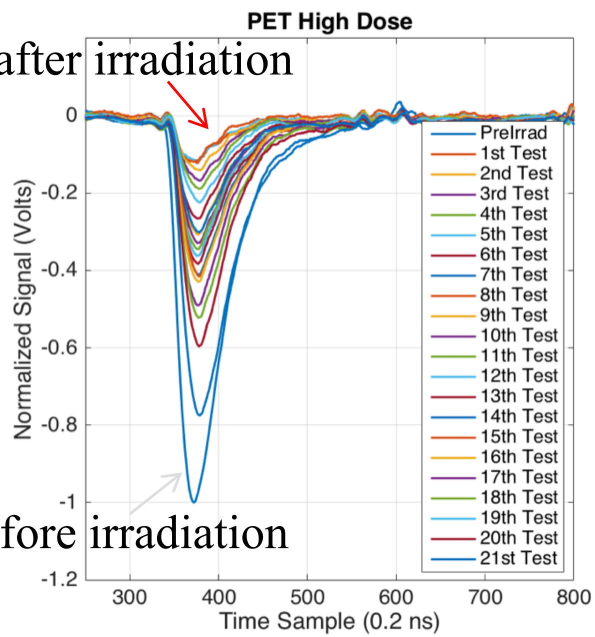
Radiation Damage and Recovery Mechanisms – PEN/PET

We irradiated scintillator samples with ^{137}Cs gamma source at Iowa Rad Core Facility to 1.4 Mrad and 14 Mrad

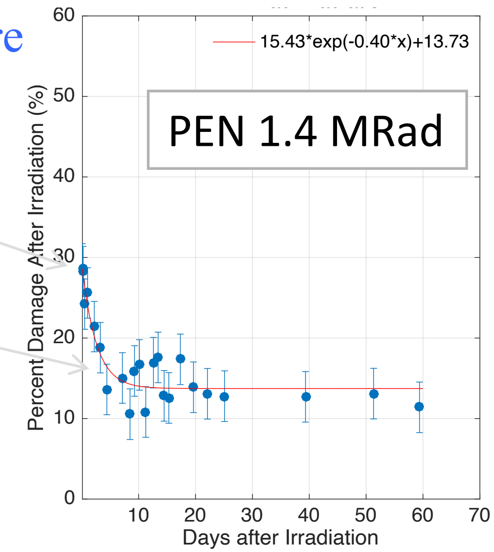
Initial damage

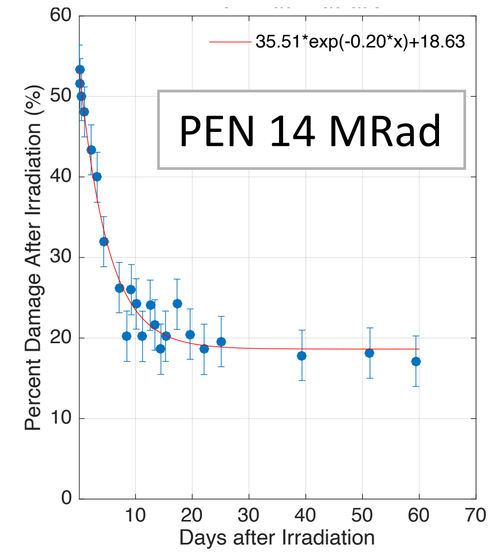
Permanent damage - plateau

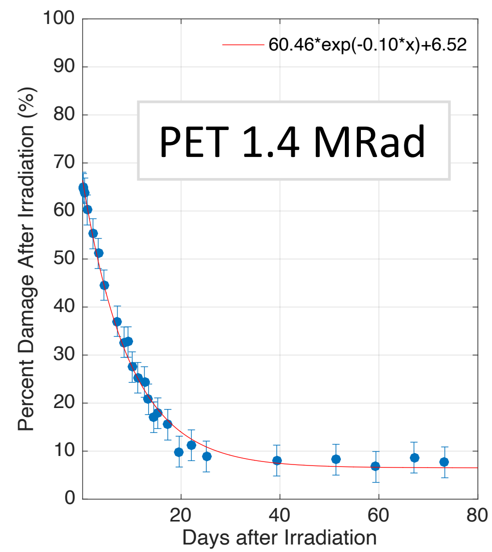
Right after irradiation

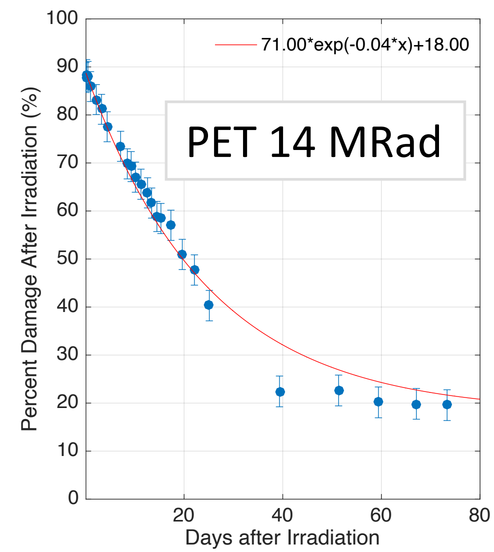


Before irradiation







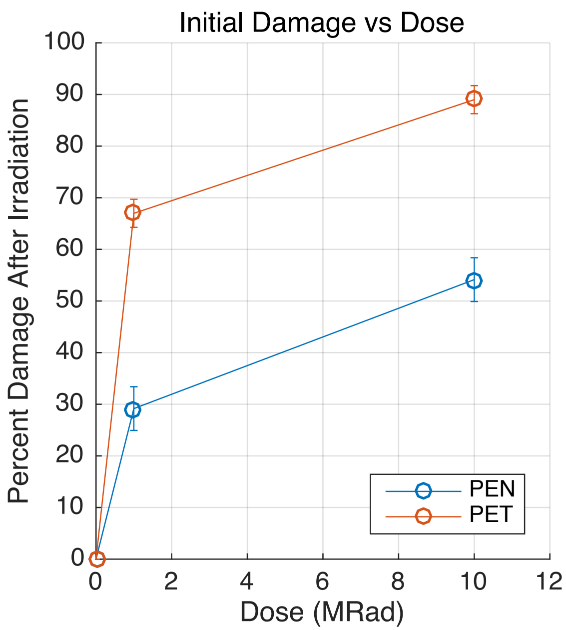


- Damage was calculated in terms of light yield

JINST 11, P08023, 2016

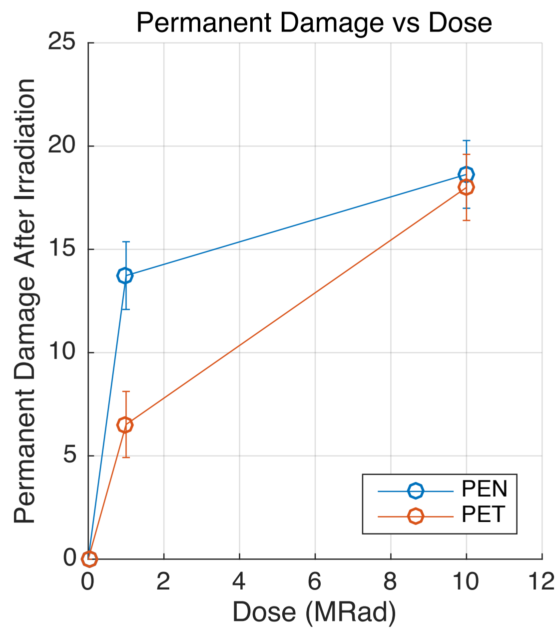
Radiation Damage and Recovery Mechanisms – PEN/PET

Initial damage



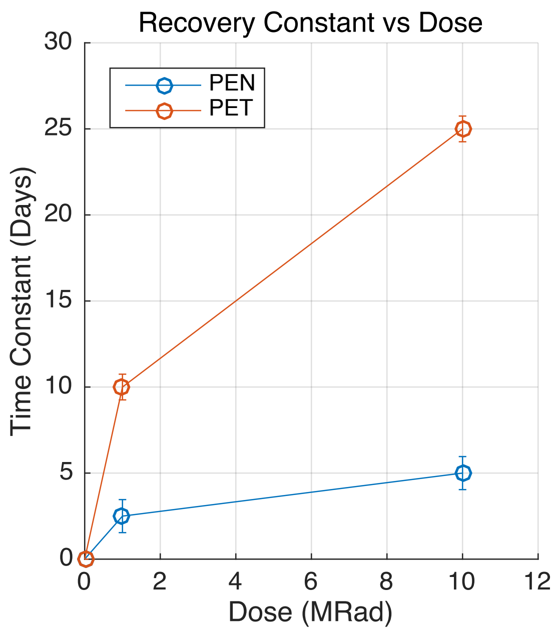
- PET was damaged more than PEN initially

Permanent damage



- Permanent damage was the same at 14 MRad

Time for Recovery



- PEN recovered in 5 days only and PET in 25 days – so slow

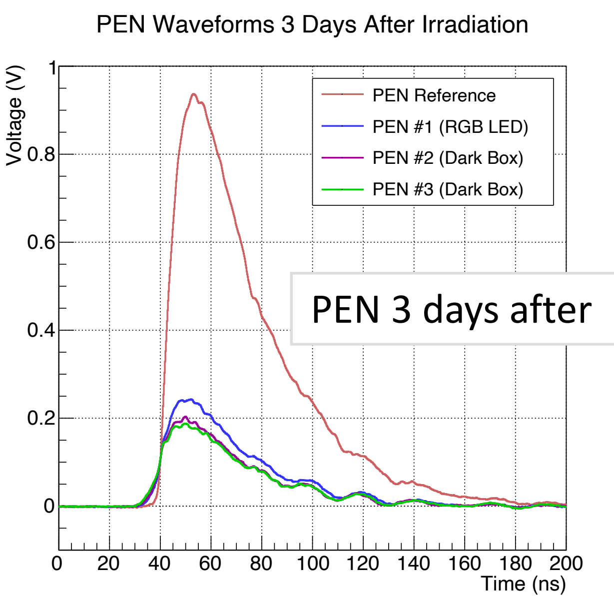
Natural recovery under dark condition.

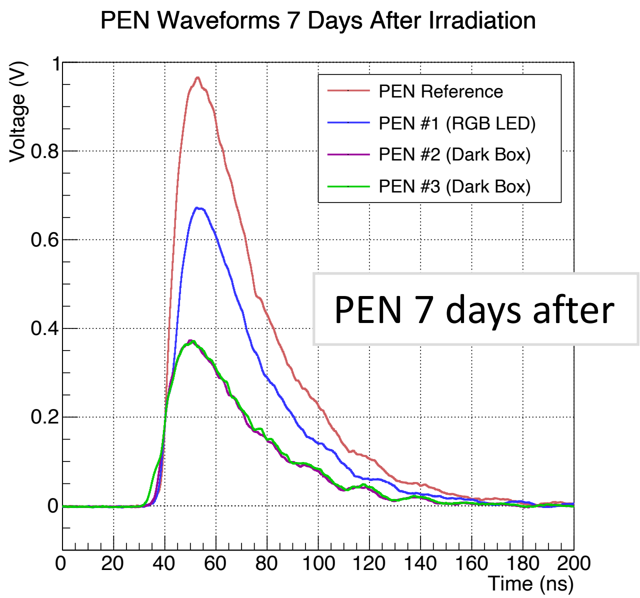
JINST 11, P08023, 2016

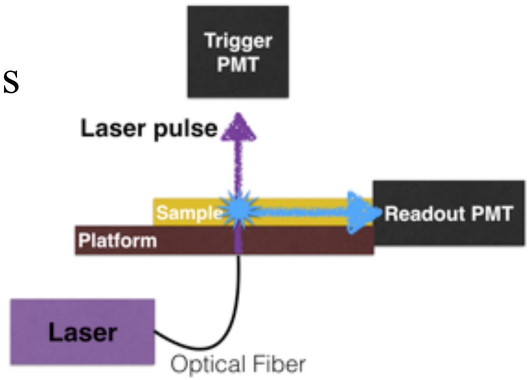
LED Stimulated Recovery

Can we stimulate the recovery of scintillators damaged from radiation?

✓ By using an array of tri-color red, blue, green (RGB) LEDs





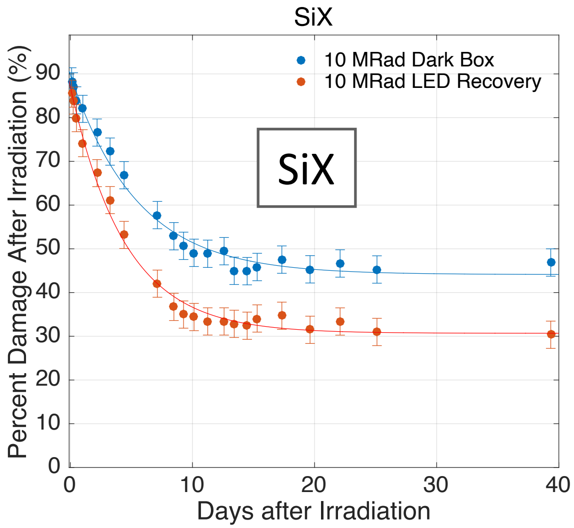


Different Materials:

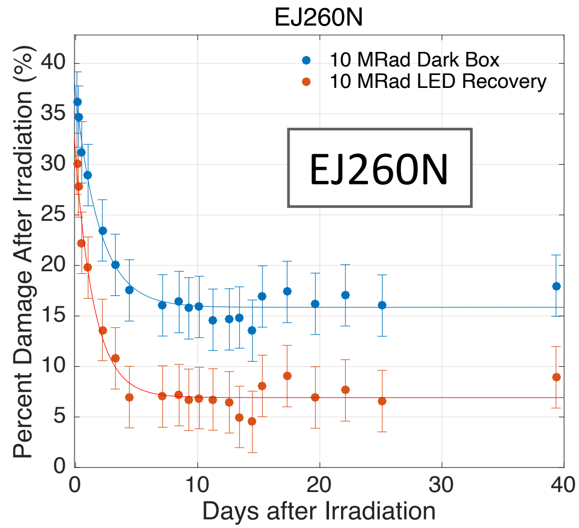
- Eljen brand EJ-260 (N) and overdoped version EJ2P.
- Lab produced plastic scintillator (SiX)

NIM B395, 13, 2017

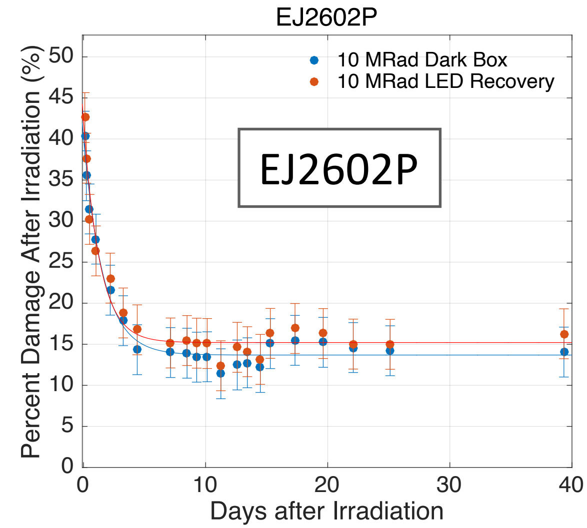
LED Stimulated Recovery



Blue emission



Green emission



Green emission

Tile	'a', Total Recovery	'c', Permanent Damage
SiX RGB	56.3 ± 2.4%	30.7 ± 1.6%
SiX dark box	45.7 ± 2.5%	44.1 ± 1.9%
EJN RGB	24.0 ± 2.2%	6.92 ± 0.7%
EJN dark box	21.1 ± 1.8%	15.9 ± 0.6%
EJ2P RGB	26.9 ± 3.1%	15.2 ± 0.9%
EJ2P dark box	26.5 ± 2.2%	13.7 ± 0.7%

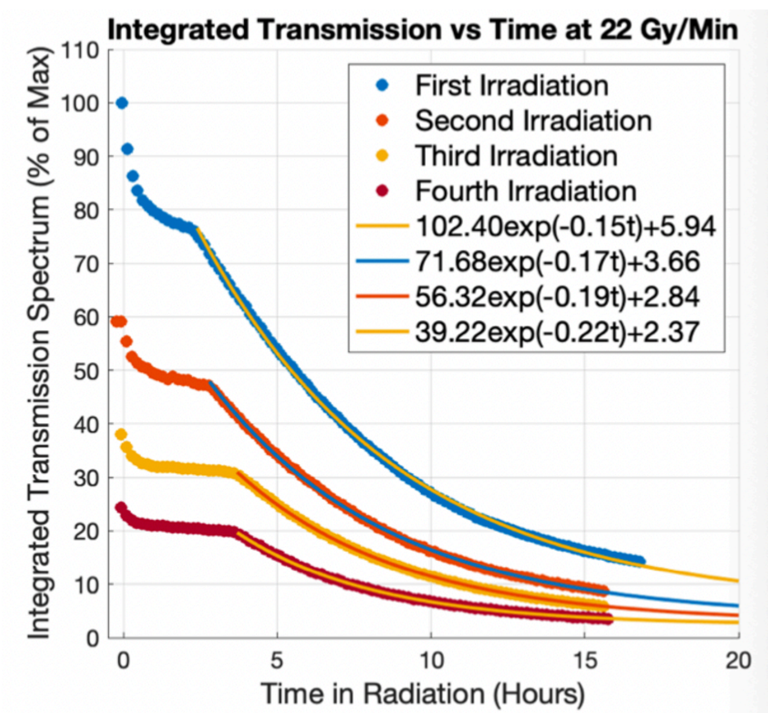
- SiX showed significant effect, the sample on RGB LED recovering 10% more and faster (4.5 vs 5.5 days)
- Neither EJN and EJ2P showed significant effect.
- 'Blue' scintillators respond to color spectrum but 'green' scintillators are affected very little.

Very useful to implement on the on-detector electronics!

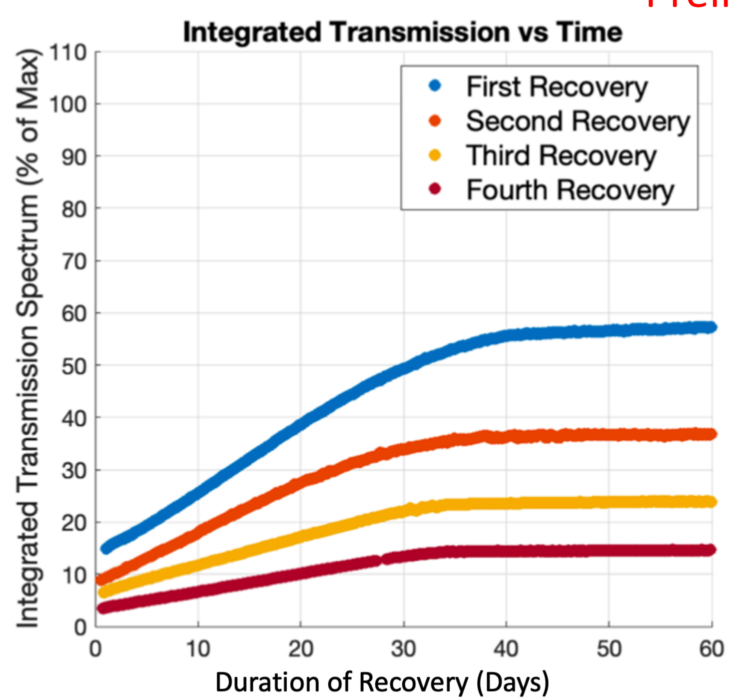
NIM B395, 13, 2017

In-Situ Measurement of Radiation Damage and Recovery in Scintillating Fibers

We successively irradiated three different scintillating fibers with emission spectra centers at blue, green and orange regions of the visible spectrum, with ^{137}Cs Gamma source at the University of Iowa RadCore Facility. The dose rate for the irradiations was kept constant at 22 Gy/min. In between irradiations, the fibers were left in dark for recovery. Results for blue fiber are shown.



Preliminary



Conclusions

- The options of intrinsically radiation-hard scintillators are being expanded with the addition of Scintillator-X. Different variants of Scintillator-X should be probed.

- For any new candidate for a future implementation, detailed radiation damage and recovery studies should be performed (the effects of dose rate, total dose, temperature, recovery, etc.).

- LED-stimulated recovery is a proven method for recovery from radiation damage. The implementation with the on-detector electronics is trivial nowadays. The recovery mechanisms should be systematically studied for optimal implementation.