TIPP'17

THE UNIVERSITY OF IOWA

DEVELOPMENT OF RADIATION-HARD SCINTILLATORS AND WAVELENGTH-SHIFTING FIBERS

Fairfield UNIVERSITY

Burak Bilki

Y. Onel, E. Tiras, J. Wetzel, D. Winn

BEYKENT UNIVERSITY ISTANBUL 1997

COE COLLEGE 1851

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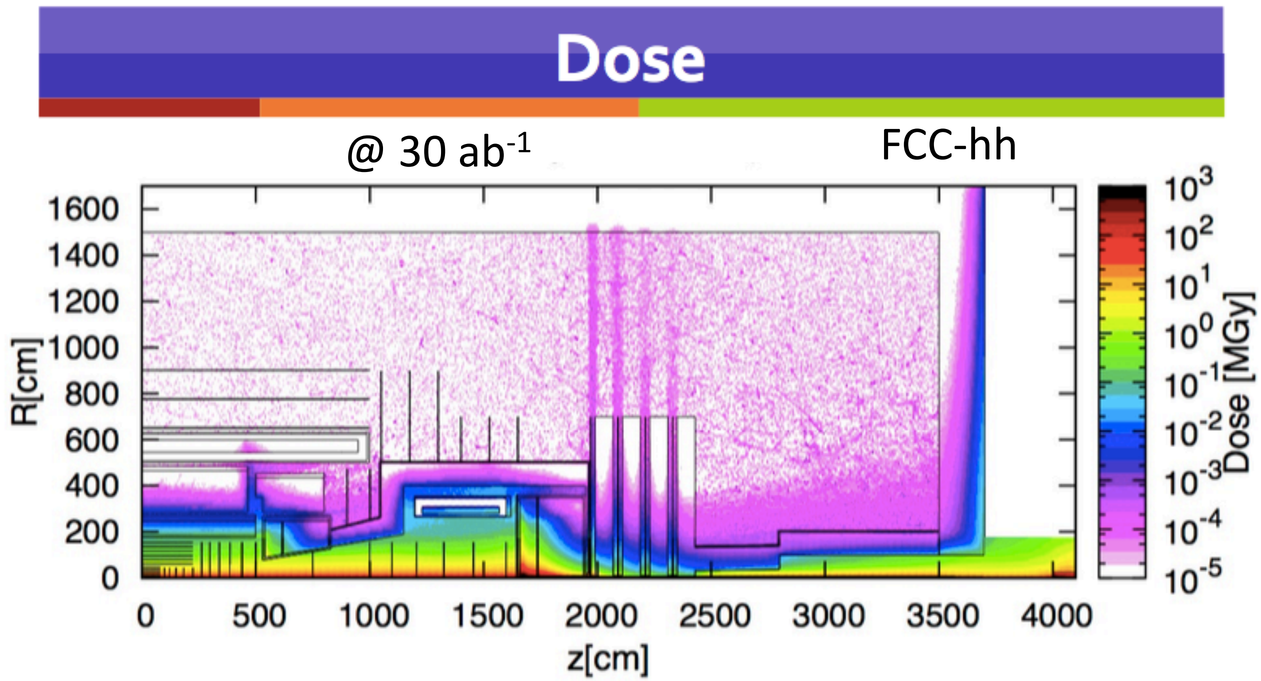
Motivation for Radiation-Hard Scintillator and WLS Fiber Development

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?

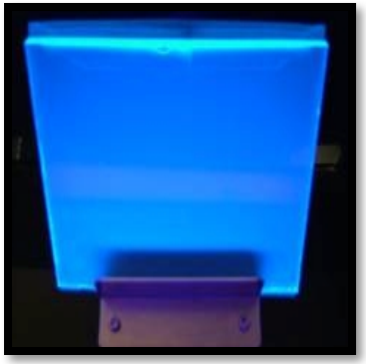
- ✓ Compact
- ✓ High light yield
- ✓ High resolution
- ✓ Radiation resistant
- ✓ Fast
- ✓ Cost effective scintillators.

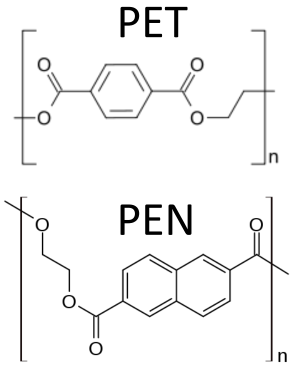


500 Grad ←

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

Intrinsically Rad-Hard Scintillators

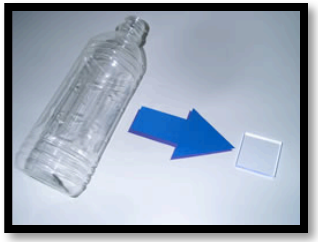




Commercially Available Scintillating Materials:

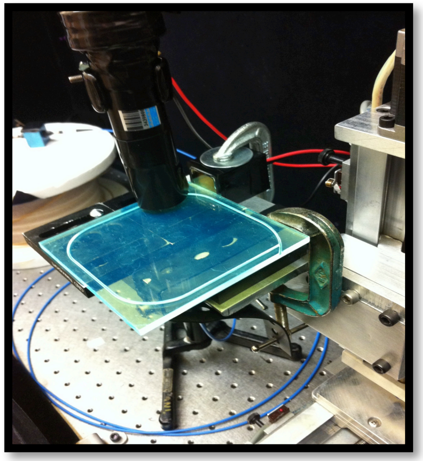
- Polyethylene Naphthalate (PEN)
- Polyethylene Terephthalate (PET)

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 Rad-Hard Scintillators

HEM/ESR: sub-µm film stack of Poly(Ethylene-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.

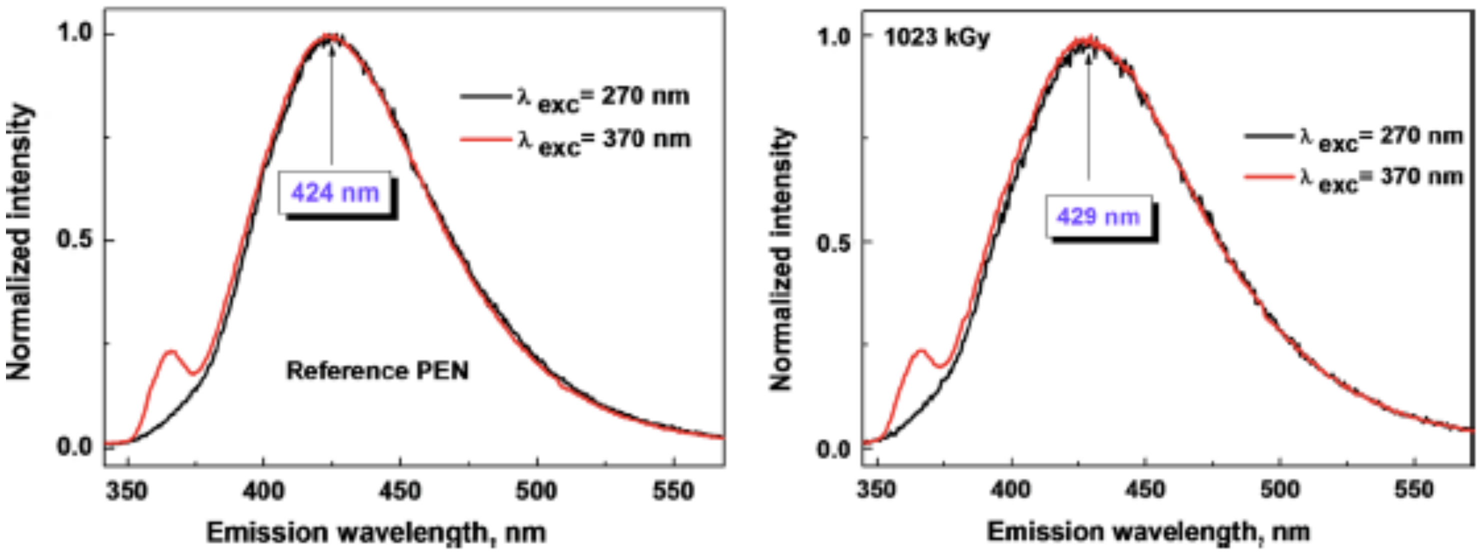
Material	Polyethylene naphthalate	Organic scintillator (ref. [14])	Plastic bottle (ref. [13])
Supplier	Teijin Chemicals	Saint-Gobain	Teijin Chemicals
Base	$(C_{14}H_{10}O_4)_n$	$(C_9H_{10})_n$	$(C_{10}H_8O_4)_n$
Density	$1.33\,g/cm^3$	$1.03\,g/cm^3$	$1.33\,g/cm^3$
Refractive index	1.65	1.58	1.64
Light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

Intrinsically Rad-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 60Co 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.*

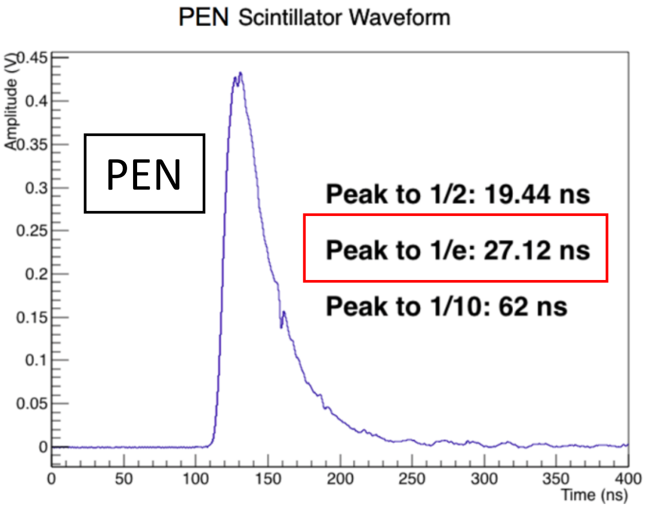


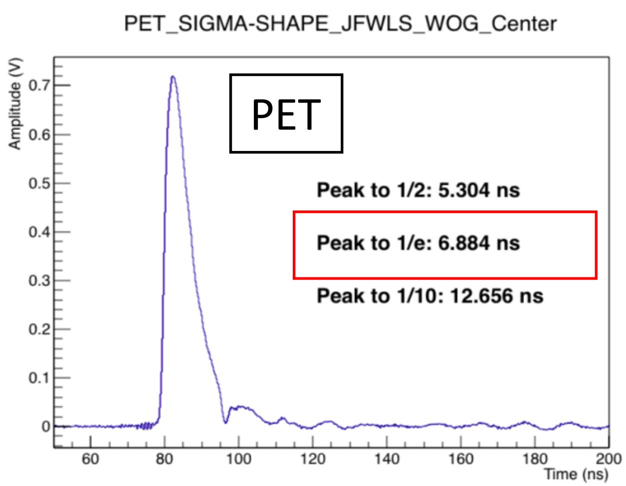
PL intensity at peak maximum (relative units) versus irradiation dose.

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

Laboratory Measurements

Timing



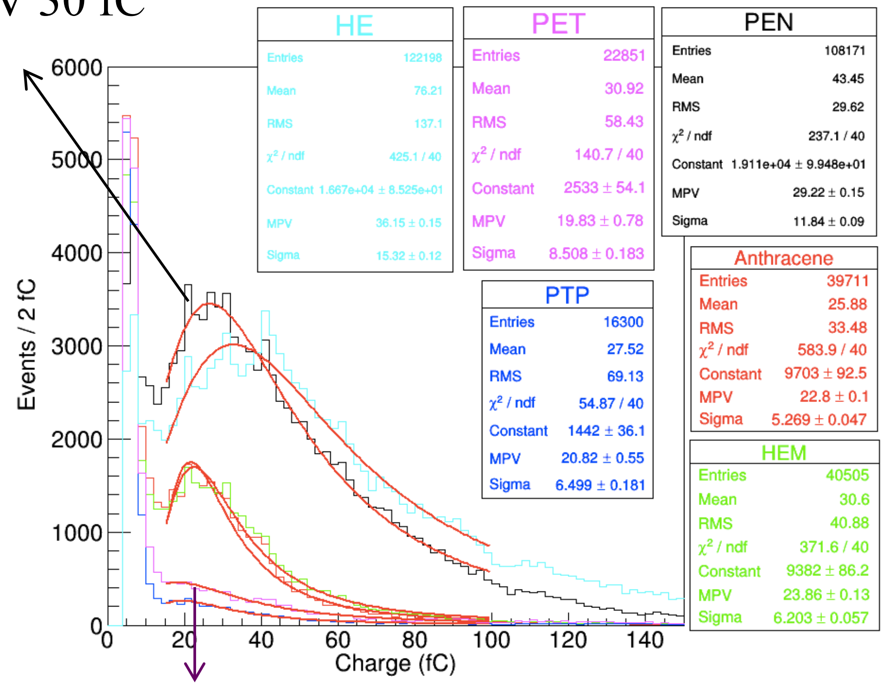


Beam Test Results

Light Yield

150 GeV muons @ CERN

PEN → Light yield MPV 30 fC

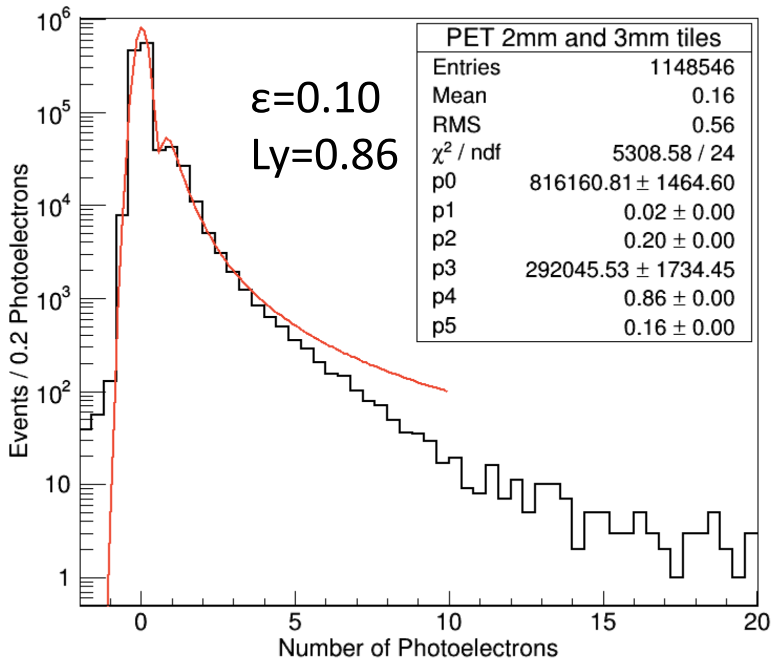


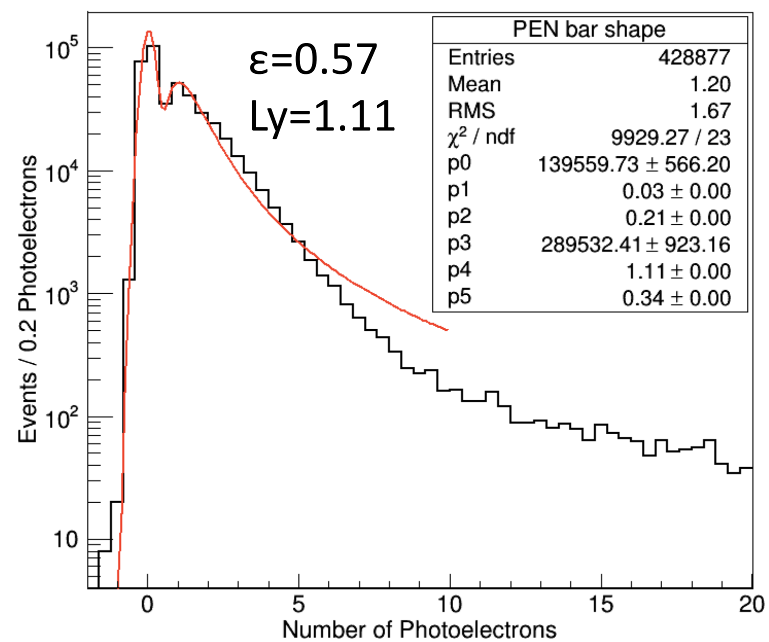
PET → Light yield MPV 20 fC

- 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.

PEN Performance in Beam Measurements

We tested 2 - 4 mm thick PEN and PET tiles read out with green wavelength shifting fibers with 150 GeV muons.



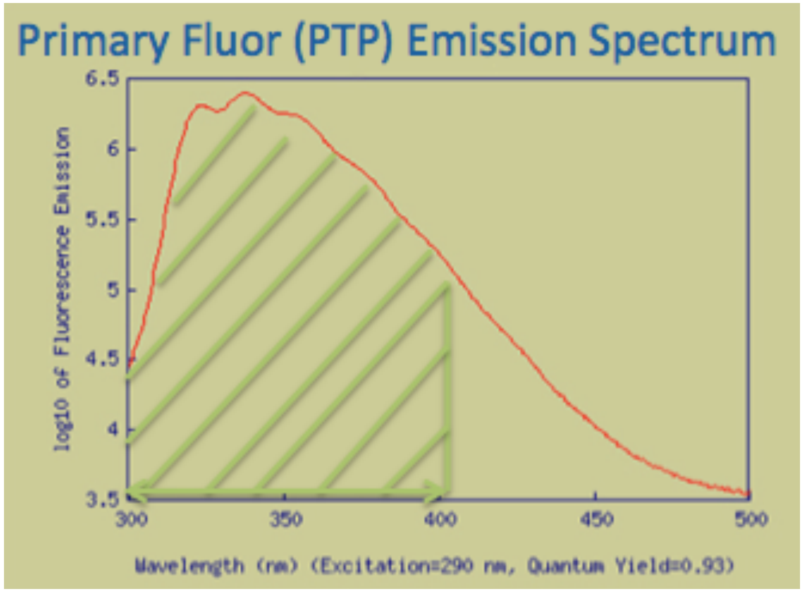


New SiX Scintillators

- 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.



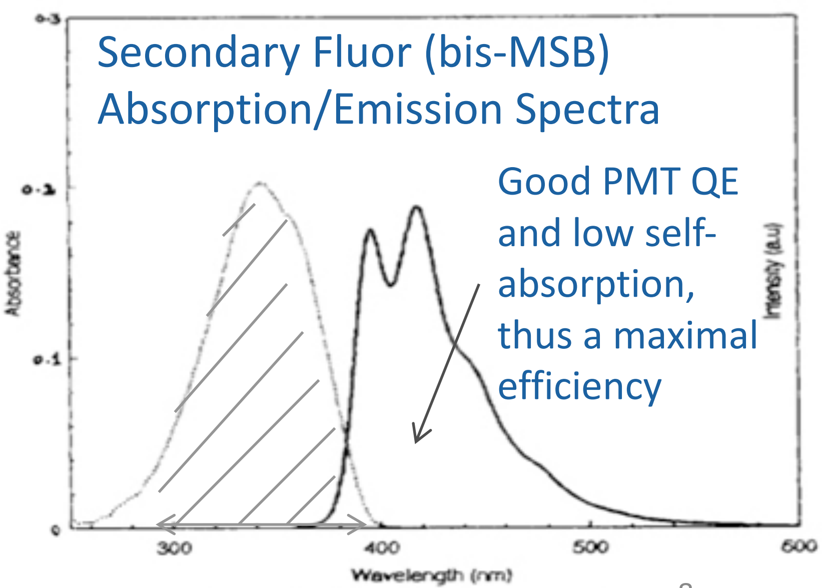
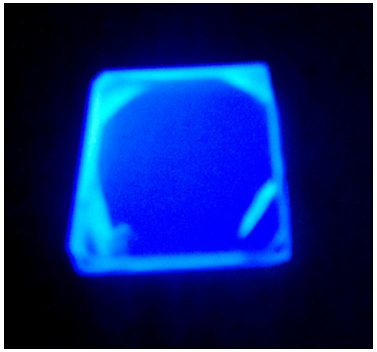
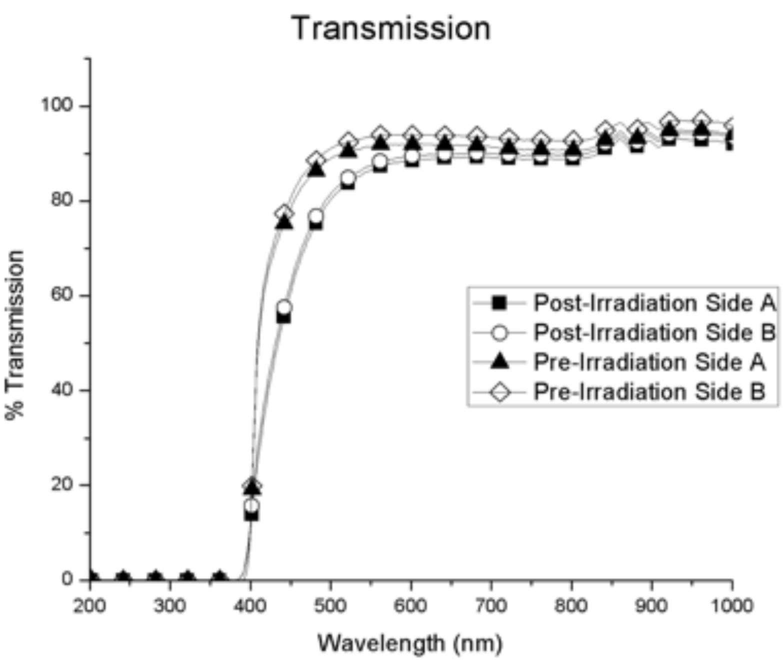


Fig. 1. Absorption (· · ·) and emission (— —)

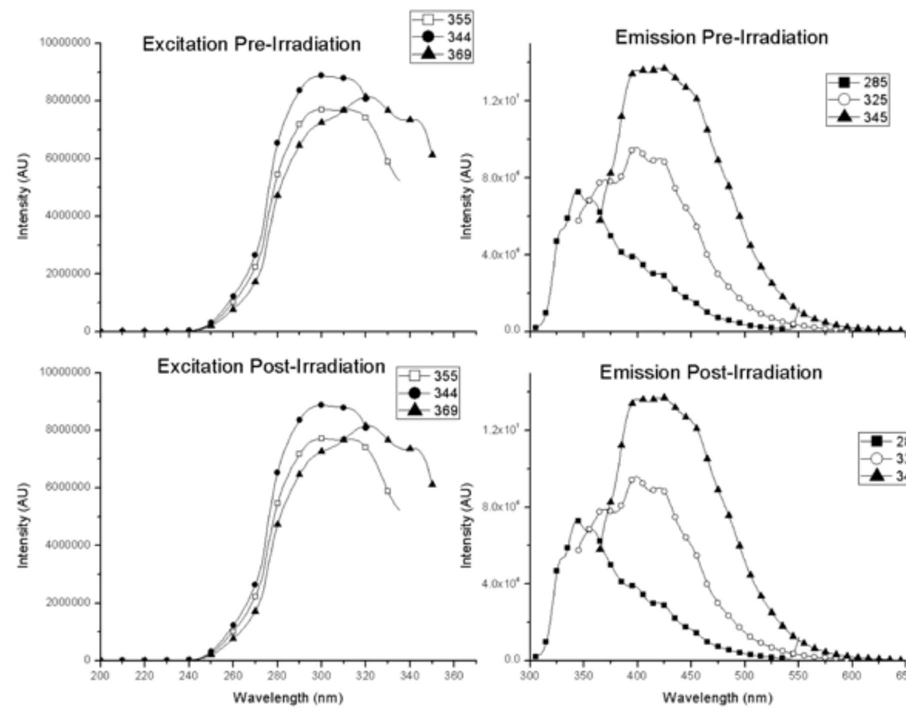


New SiX Scintillators

Lose only 7 % transmission after 40 Mrad proton radiation

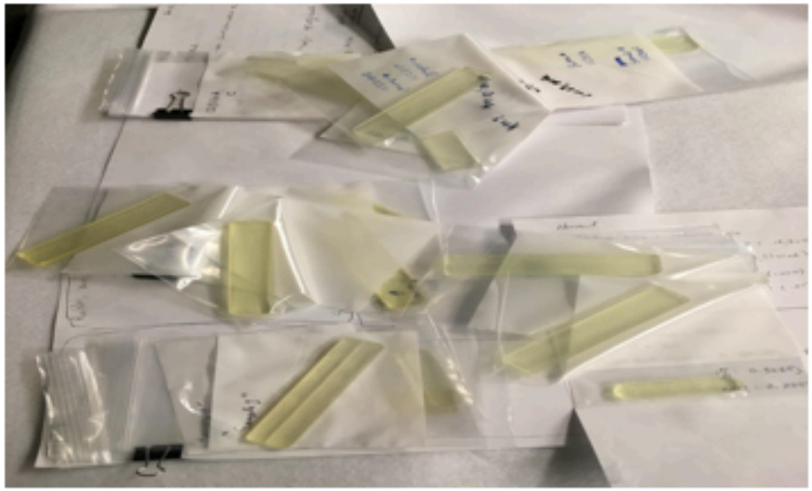


Almost no change on emission and absorption after irradiation

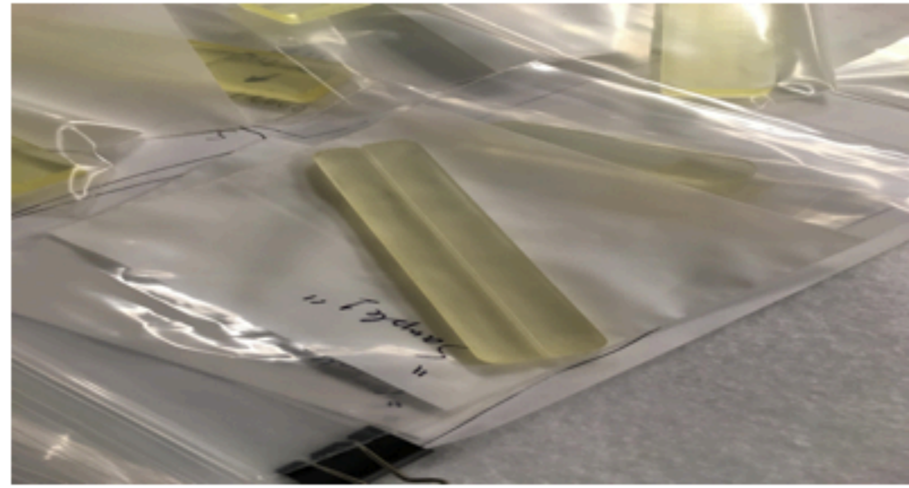


SiX Production

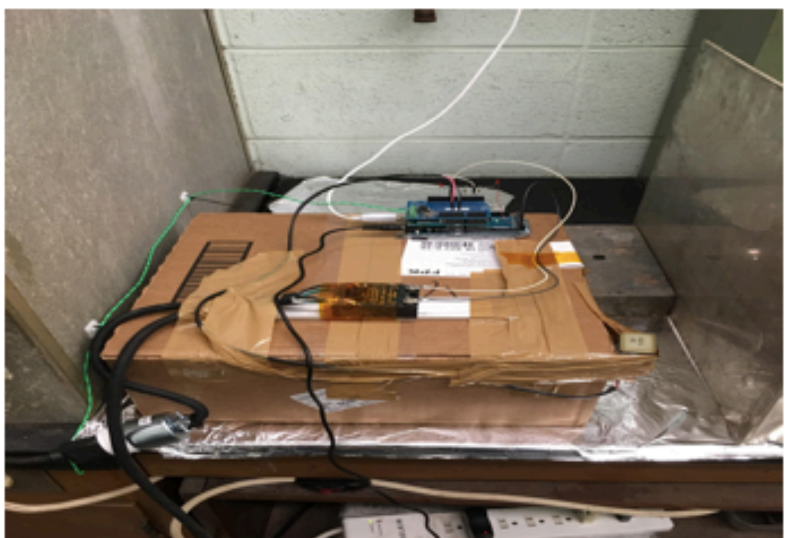
Finger Tiles



Grooved Tiles



Control Circuits



Modified Owen

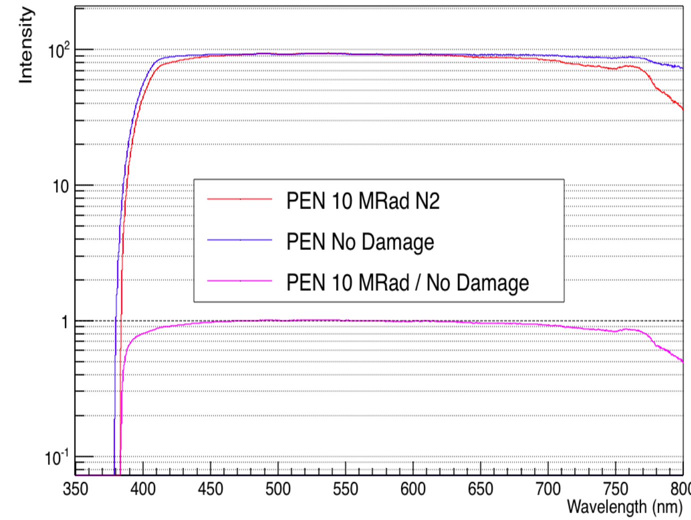
PEN Radiation Damage Studies (MSU)

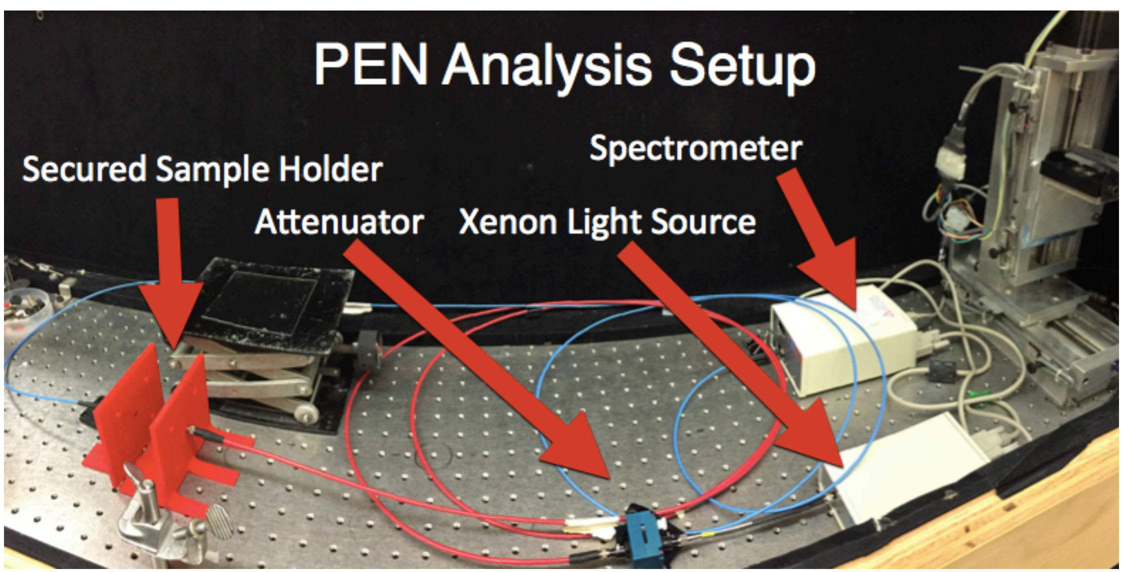
Facilities:
- National Superconducting Cyclotron Laboratory
- Used ^{60}Co, 1.33 MeV Gammas

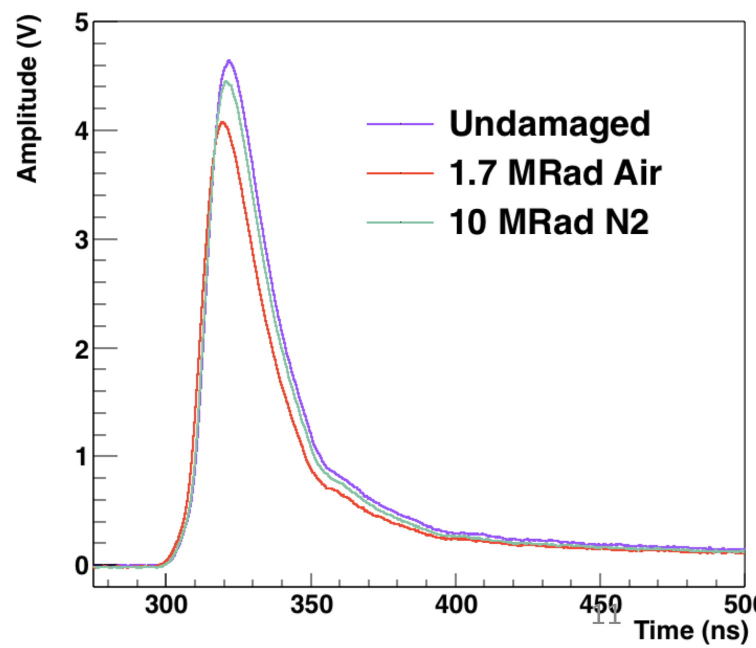
Two Samples:
- 1.7 MRad in Air
- 10 MRad in N_2

	Undamaged	10 MRad N2	1.7 MRad Air
Integral (300-450 ns)	**20208**	**19012**	**17311**
Relative % (damaged / Undamaged)	**100%**	**94.1%**	**85.7%**

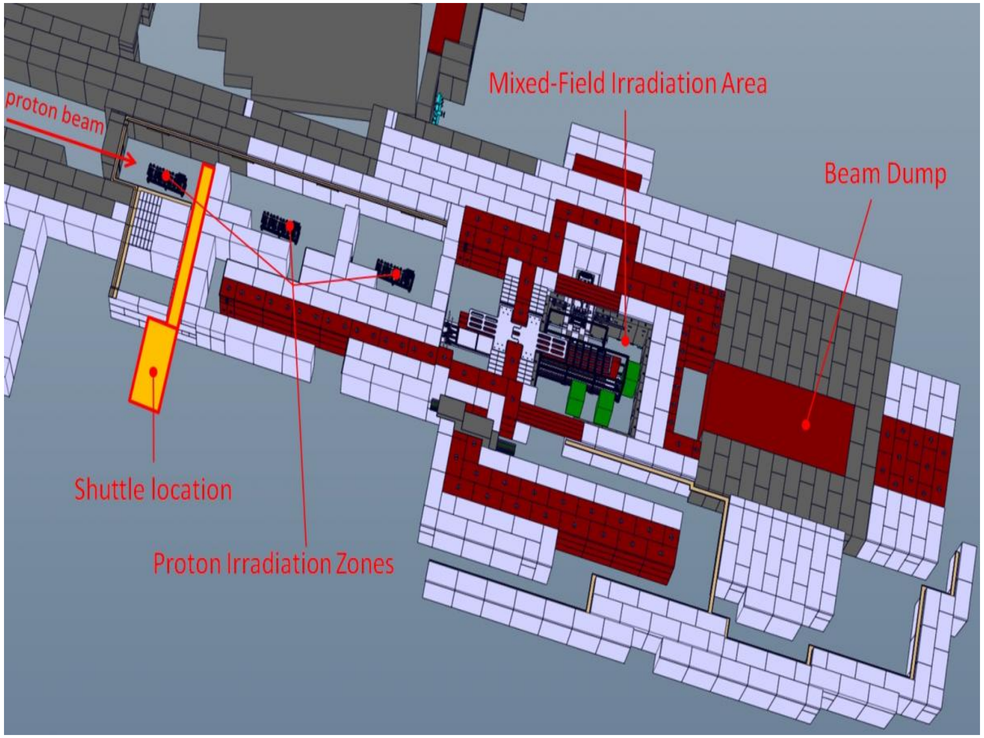
Transmission







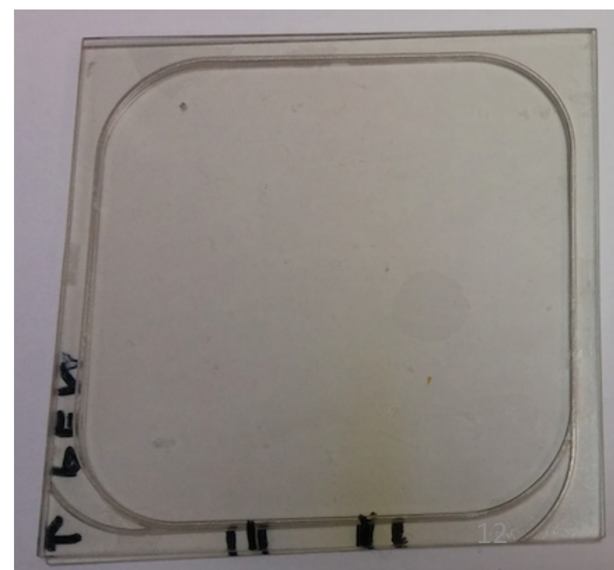
IRRAD facility at CERN PS



- 10 x 10 cm PEN tile was placed in the PS accelerator IRRAD area .
- First batch – perpendicular to the beam direction. Three different positions were selected to expose to protons
- Second batch – tilted ~30 degrees to beam direction – three different position were exposed to the proton beam
- Samples were irradiated during one week. In average 30 Mrad was absorbed per spot

24 GeV protons ,
beam spot (FWHM) 15x15 mm^2
proton flux - ~$6x10^9$ p cm^{-2} s^{-1}

➔ 75% loss at 40 Mrad.



Radiation Damage Studies (Iowa)

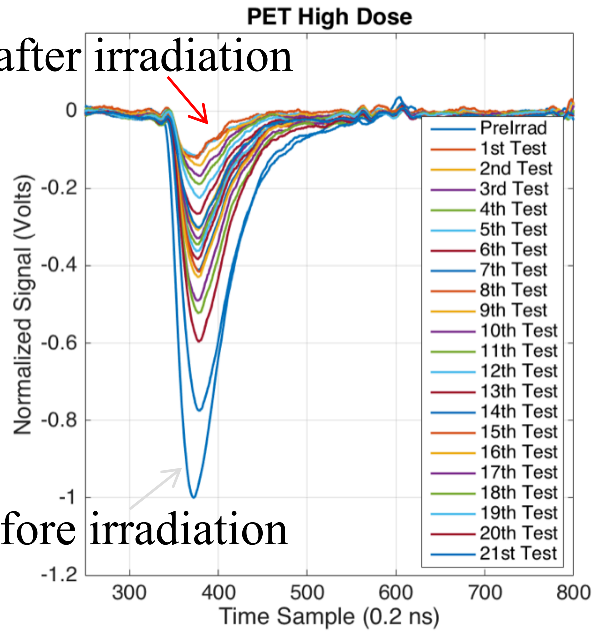
We irradiated scintillator samples with using ^{137}Cs gamma source at Iowa Rad Core

1.4 Mrad and 14 Mrad

Initial damage

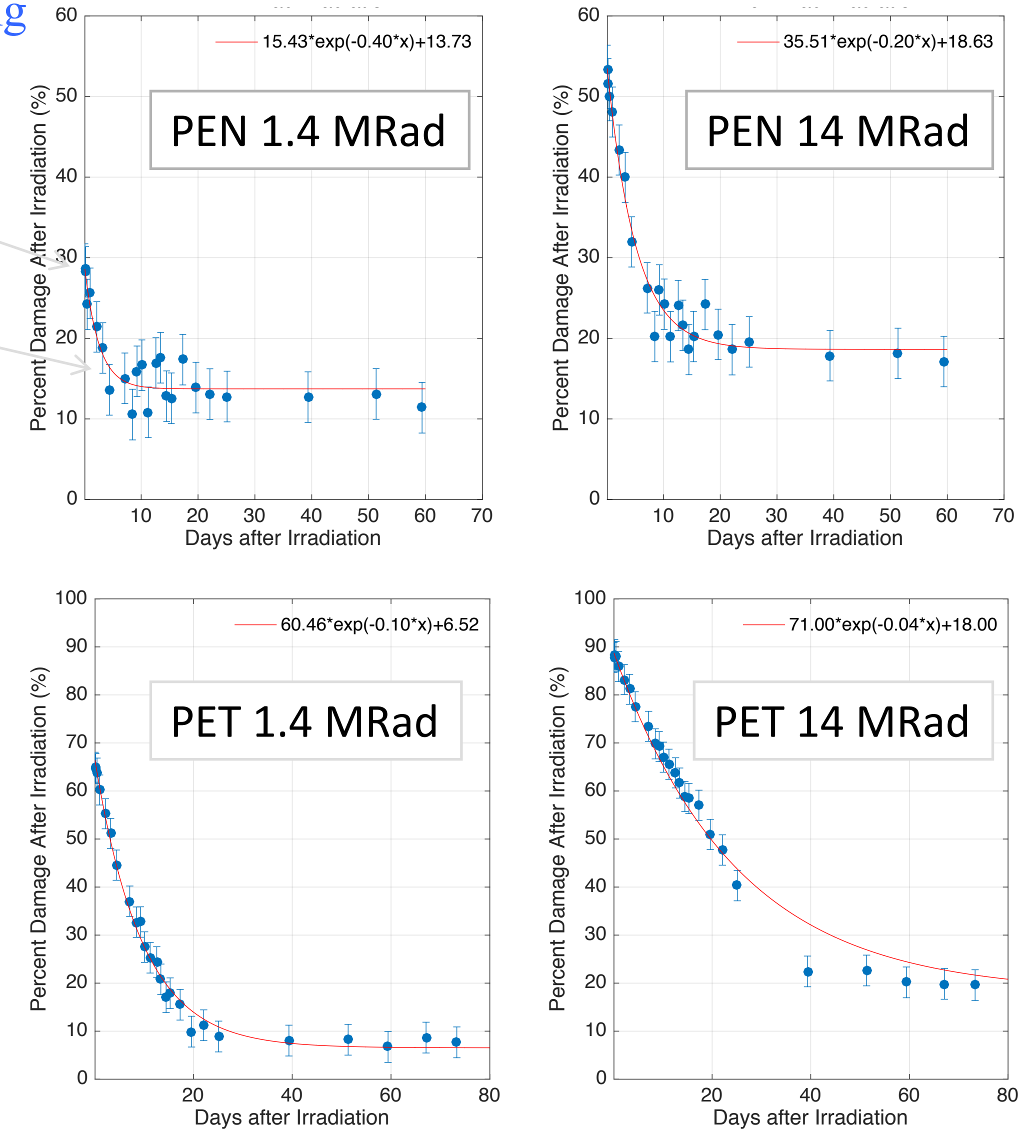
Permanent damage - plateau

Right after irradiation



Before irradiation

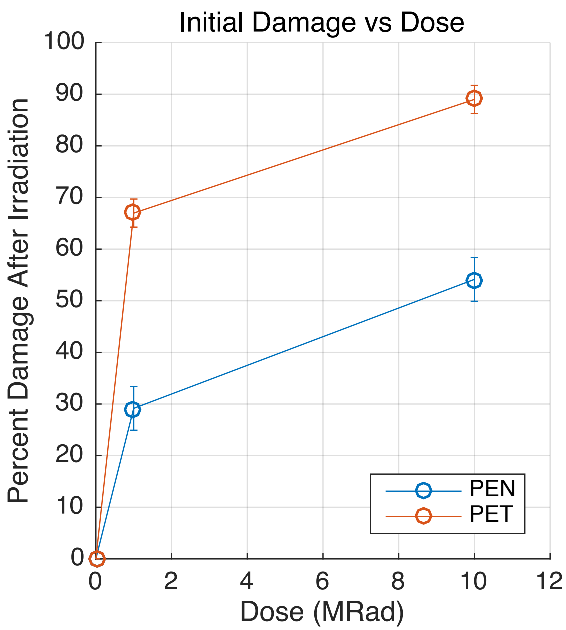
- Damage was calculated in terms of light yield



JINST 11, P08023, 2016

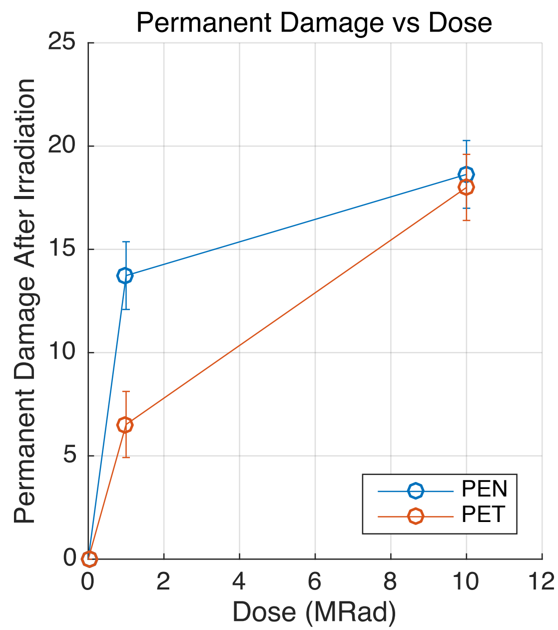
Summary of irradiation results

Initial damage



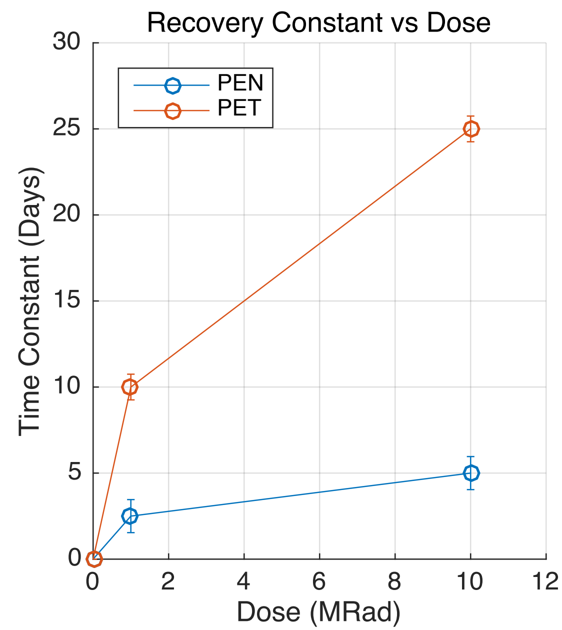
- PET was damaged more than PEN initially

Permanent damage



- Permanent damage was same at 14 MRad

Time for Recovery



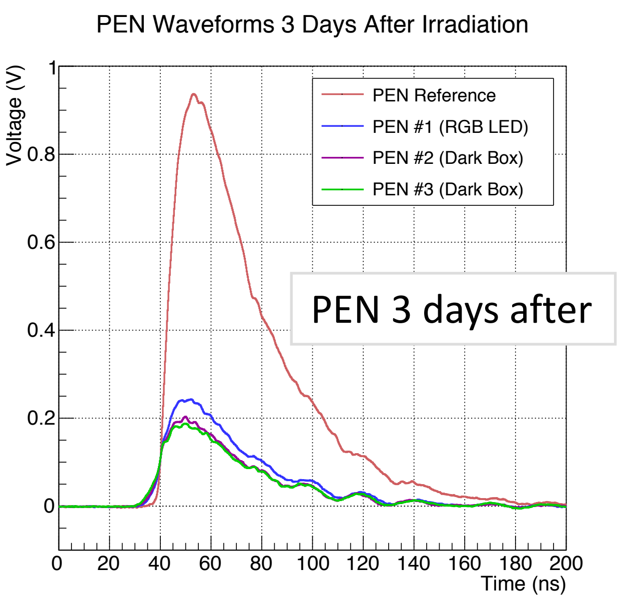
- PEN was recovered in 5 days only and PET in 25 days – so slow

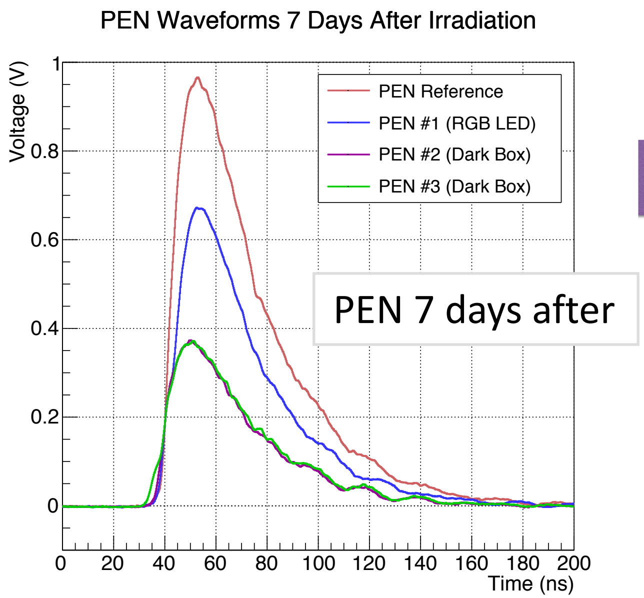
JINST 11, P08023, 2016

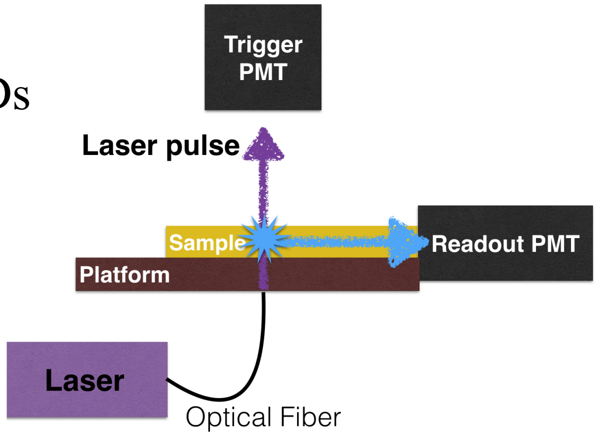
LED Stimulated Recovery

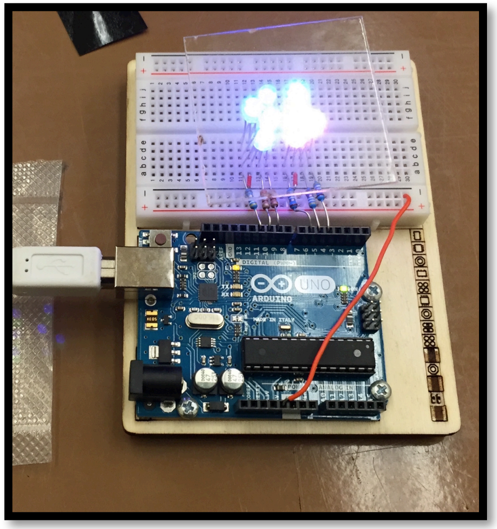
Can we stimulate the recovery of scintillators damaged from radiation?

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







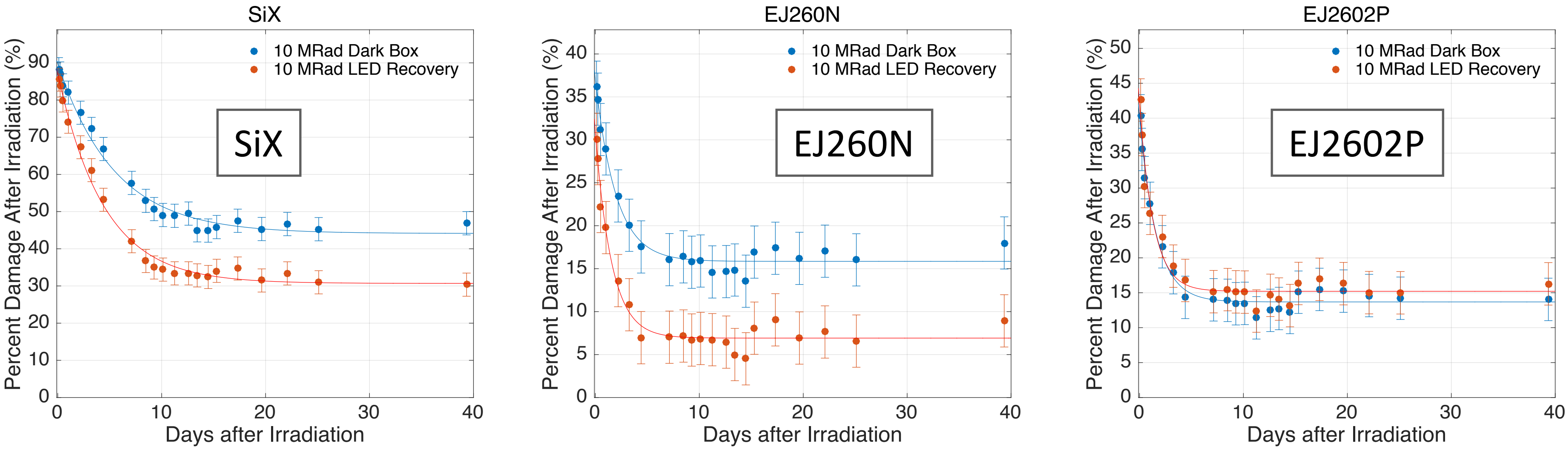


Different Materials:

- 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.

NIM B395, 13, 2017

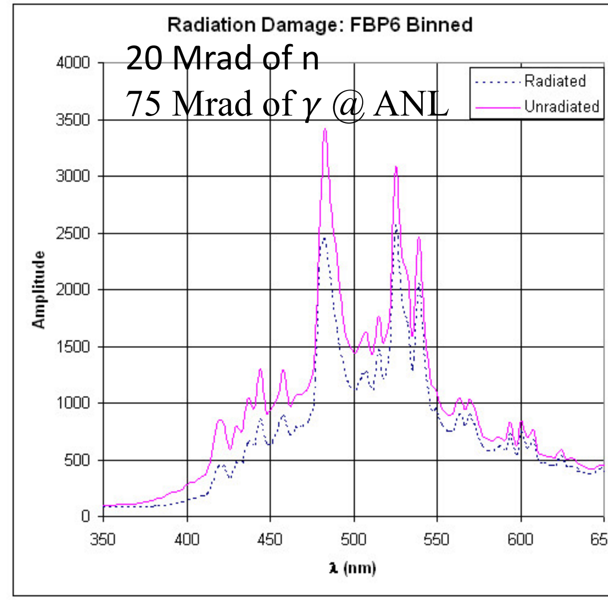
Quartz with Thin Film Coating

Quartz alone is extremely radiation-hard but only a Čerenkov radiator ➔ very small amount of directional light

➔ Quartz plates coated with organic/inorganic scintillators/wavelength shifters ~ scintillators

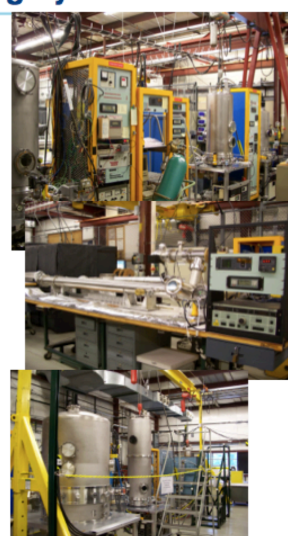
Scintillator/WLS Films on Quartz Tiles

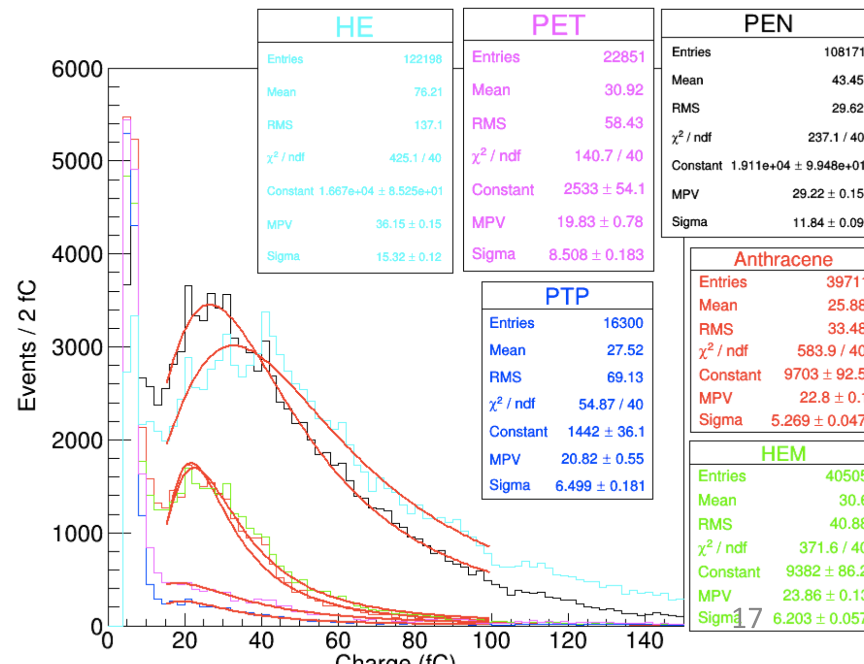
- **Ptp, anthracene**
- **ZnO:Ga; CsI; CeBr3 – emissions 375-450 nm; T<17ns**
- **CsI and CeBr3 will be protected with an over-deposited quartz film ≥50 nm thick.**



Fermilab's THIN FILM Facility Coating Systems at Lab 7

- 2 Bell Jar sputtering systems
  - Al, Ag, Au, Cr, Cu, Ir, Ni, PtIr, Ti, ZnO2-Ga
- 2 tube sputtering systems-dedicated to 99.999% pure aluminum sputtering
  - Optical fiber mirroring
- 1 Bell Jar system for resistive evaporation
  - Al, Ag, Au, Cr, Cu, Al & MgF2 surface mirrors, Ni, NiCr, TiN
- 1 Pyrex Bell Jar system for resistive evaporation-dedicated to Scintillator and WLS materials
  - pTp, TPB, POPOP, Cesium Iodide, Anthracene, Bis-MSB, Cerium(III) bromide
- 1 Tall Bell Jar system (17"dia x 70"tall) designed for resistive evaporation with rotating motor at 45° and 6 rpm speeds
  - NiCr "electroding" of MCPs
  - Distance from boat to substrate is 34"
- 1 Large Bell Jar (34.5" ID x 50.5" tall)
  - Resistive setup currently

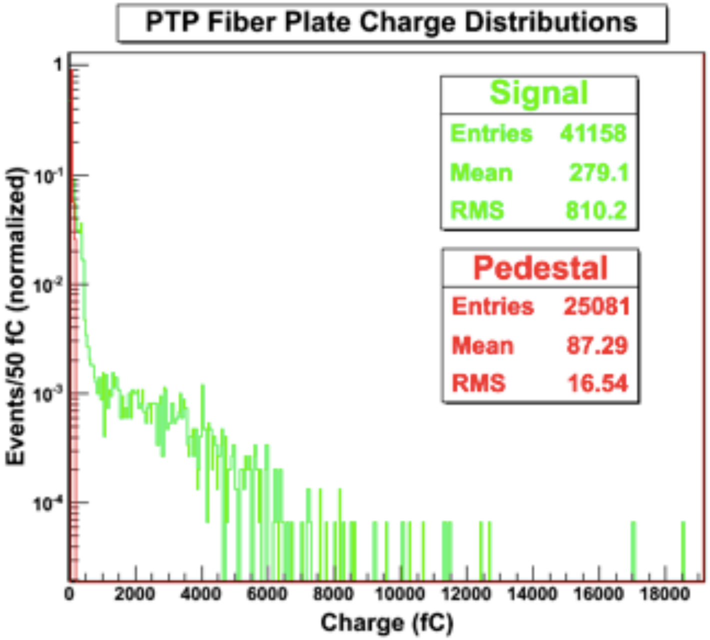


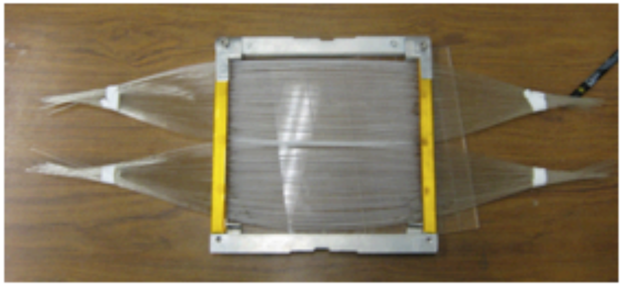


Radiation-Hard WLS Fibers

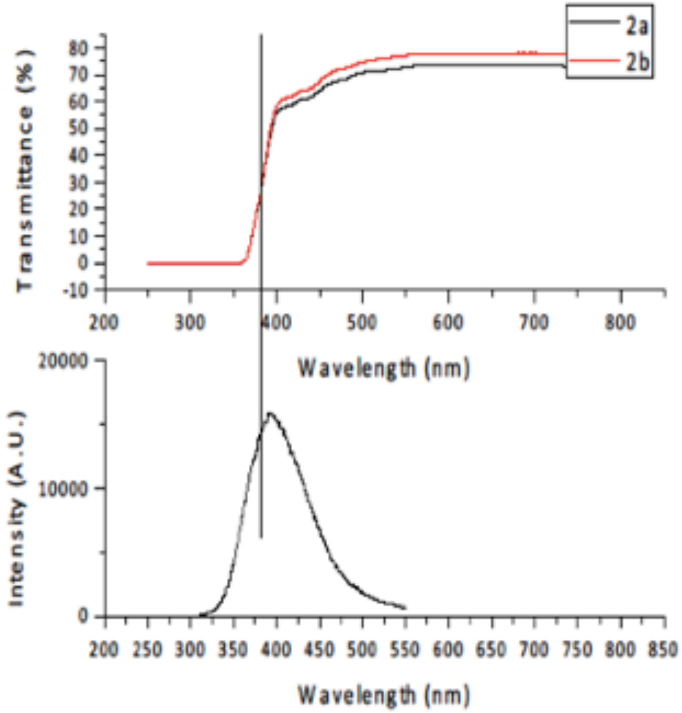
[1] Quartz rods with surface coating
[2] Capillaries
[3] Doped quartz rods

[1] Quartz Fibers with pTp Coating





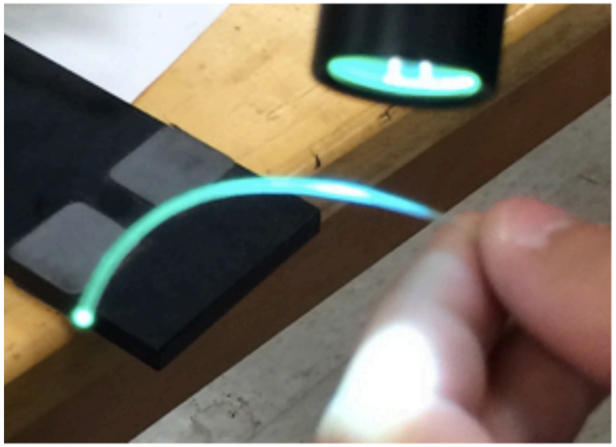
[3] Cerium-doped Scintillating Glasses



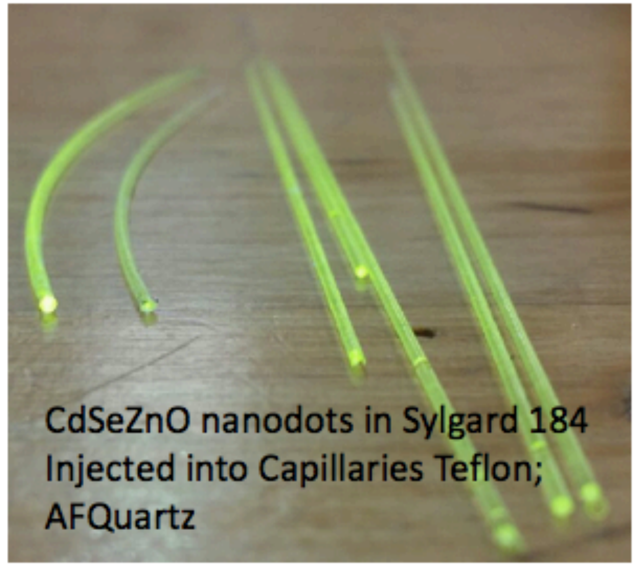
Radiation-Hard WLS Fibers

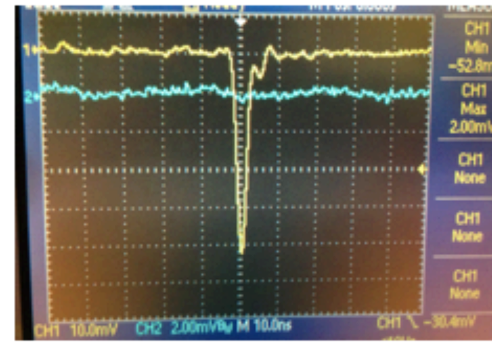
1 Quartz rods with surface coating
2 Capillaries
3 Doped quartz rods

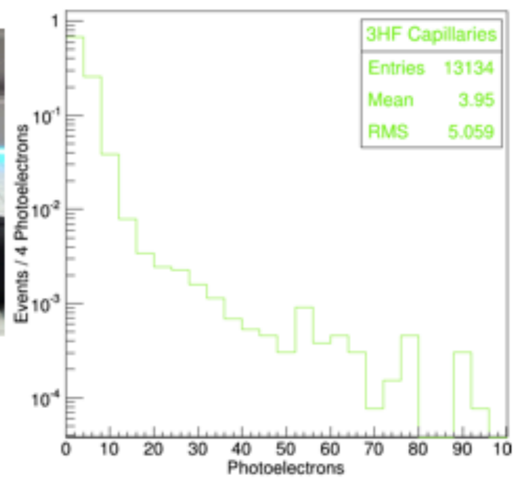
3HF+Meltmount injected
TeflonAF 800µm ID



3HF Core Quartz WLS Capillaries







Expected Anthracene Fiber Pulse:

~200 KeV/mm x 0.25mm x 40 photons/KeV x 2% transmission x 20% QE ~ 8 p.e.

Typical Observed Pulse:

~ 8-9 p.e.

Conclusions

- The options of intrinsically radiation-hard scintillators is being expanded with the addition of Scintillator-X. Different combinations e.g. PEN+PET and different variants of Scintillator-X can be probed.

- Quartz is extremely radiation-hard. With the correct combination of coating and readout, it can be the optimal option for forward region in all collider experiments. Coating is a relatively easy process nowadays. We need to probe different types of coatings and also their mixtures.

- Radiation-hard wavelength shifting fibers need to be studied in further detail. Need more and realistically sized samples tested in actual calorimeter environments.