Optimizing Scintillation and Light Transmission

for Use in a High Energy Particle Detector

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Abstract

As high levels of precision are needed to analyze particle collisions, it is essential that the Compact Muon Solenoid (CMS) detector incorporate technological advances during current upgrades. The previous setup utilized a 201/204 pair of Eljen Technologies' plastic scintillators (scints) and wavelength shifters (WLSs) which quickly degraded in the high-radiation environment and necessitated disassembly of the detector exterior for replacement. The objectives of this project were to determine Eljen Technologies' plastic scint/WLS combinations optimal for light generation and Eljen Technologies' liquid scint with greatest light generation and least attenuation when used to transmit light in a quartz capillary tube (QCT). Relative light generation abilities of plastic scint/WLS pairs were determined by recording charge on a SiPM resulting from beta-induced output light in a light-tight box and by comparing relative emission intensities of WLSs excited by wavelengths corresponding to scint emission peaks inside a spectrophotometer. Relative light generation and attenuation lengths of QCT-encased liquid scints were determined by measuring current on a photodiode excited by LED light transmitted by the QCT-encased liquid scint. The 205 scint/204 WLS pair resulted in the greatest beta-induced light output while the standard 201 scint/204 WLS pair resulted in the greatest photon-induced light output, and red WLSs may be viable alternatives for long transmission arrangements when paired with the 205 scint. EJ-10A, EJ-11B, and EJ-14A scintillating paints may be useful in liquid-filled QCT arrangements, and it was observed that EJ-309 liquid scint has wavelength shifting ability and may be radiation resistant at doses exceeding 50 Mrad.

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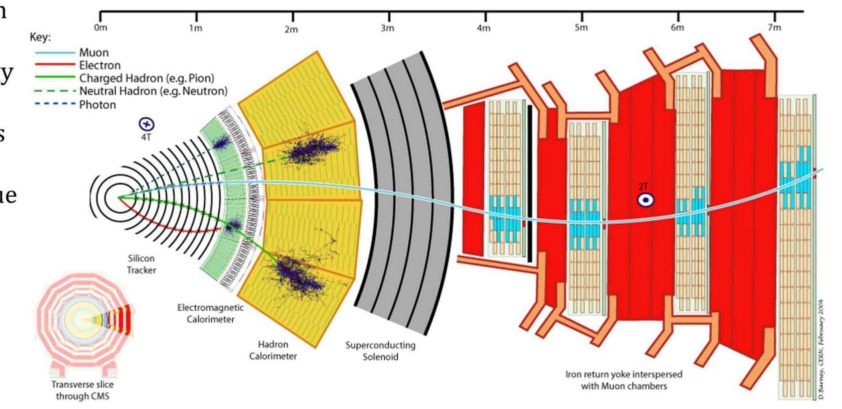
- **Dr. Daniel Karmgard** (University of Notre Dame) – mentoring and use of lab

How it Works

- Like sound in a concert – higher energy → travels to farther levels
- Curvature due to magnetic field used to measure charge-to-mass ratio

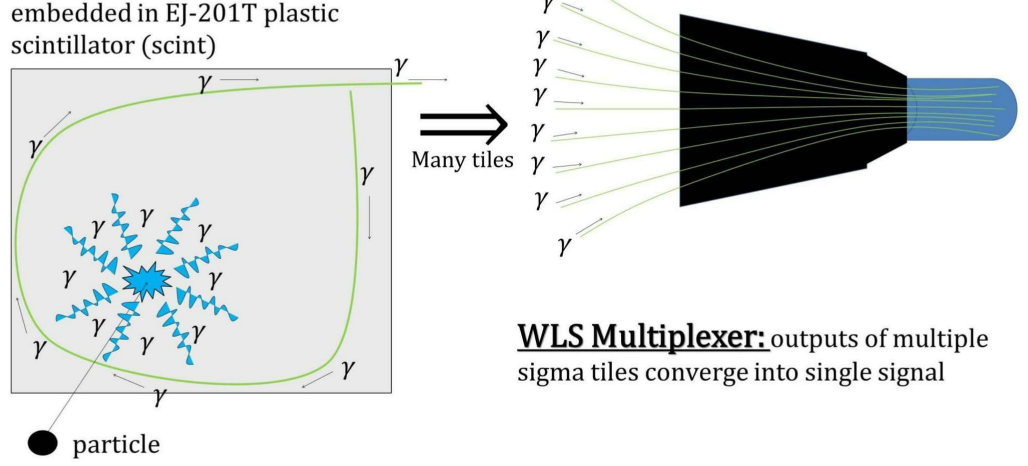


- Scintillating tiles produce light in response to particle influx
- Each tile is associated with an angle and momentum threshold
- Data in the form of light output from scintillating tiles

"The CMS Experiment." *CMS Trieste Group.* INFN Sezione Di Trieste, 26 Sept. 2013. Web. 1 Dec. 2013. <http://cmsweb.ts.infn.it/index.php>.

Light Collection – Current Setup

EJ-204 sigma tile: wavelength shifting (WLS) fiber embedded in EJ-201T plastic scintillator (scint)



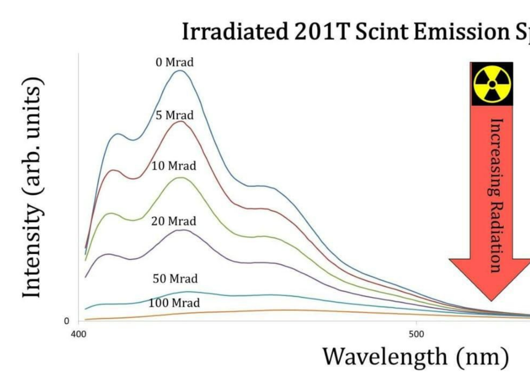
WLS Multiplexer: outputs of multiple sigma tiles converge into single signal

Goals

1. Find Eljen Technologies' plastic scint/WLS combination with greatest initial light output
   - Green WLS
   - Red WLS
2. Find Eljen Technologies' liquid scint that results in greatest light generation and least attenuation in QCT

Problems and Solutions

Light Generation Problem: Radiation Degradation



Scint and WLS plastics exposed to high levels of radiation (as experienced in the CMS detector) have decreased light output and poor signal quality

Note: this graph was generated with the help of Mr. Barry Bambaugh, the lab engineer

Light Generation Solution: Scint/WLS Optimization

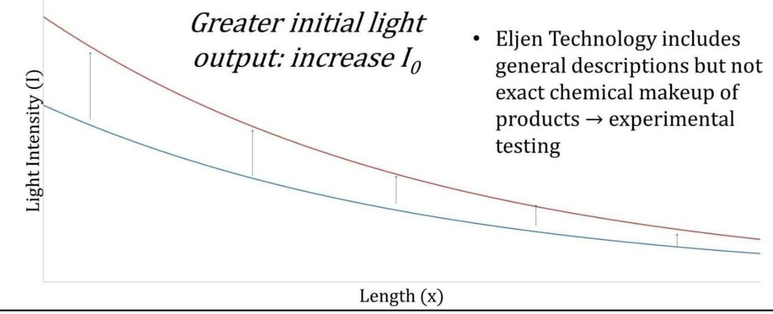
The intensity of light propagating through optical fibers follows the model

$$I = I_0 e^{-x/L}$$

where L is the attenuation length.

Greater initial light output: increase I_0

- Find scint/WLS pair that generates the most light
- Eljen Technology includes general descriptions but not exact chemical makeup of products → experimental testing



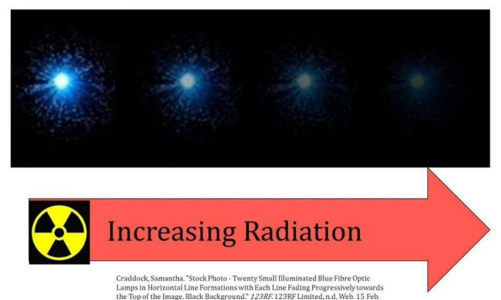
The plastic scintillators

and the plastic wavelength shifters

in UV light

Light Transmission Problem: Radiation Degradation

- Optical fibers darken with increasing radiation, thus increasing light attenuation
- Degradation is roughly linear until fiber becomes dysfunctional



Craddock, Samantha. "Stock Photo - Twenty Small Illuminated Blue Fibre Optic Lamps in Horizontal Line Formations with Each Line Fading Progressively towards the Top of the Image. Black Background." *123RF.* 123RF Limited, n.d. Web. 15 Feb. 2013.

Light Transmission Solution: Scintillation/Transmission of Red Light

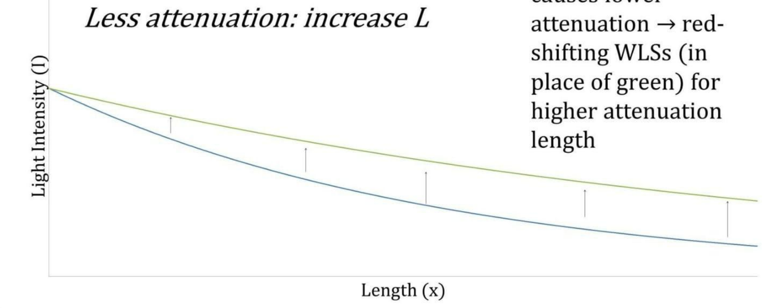
The intensity of light propagating through optical fibers follows the model

$$I = I_0 e^{-x/L}$$

where L is the attenuation length.

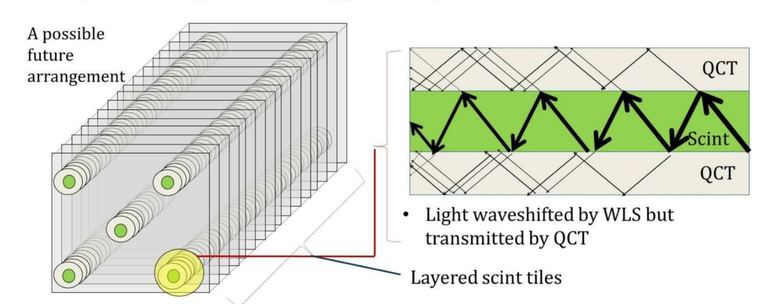
Less attenuation: increase L

- Lower frequency causes lower attenuation → red-shifting WLSs (in place of green) for higher attenuation length

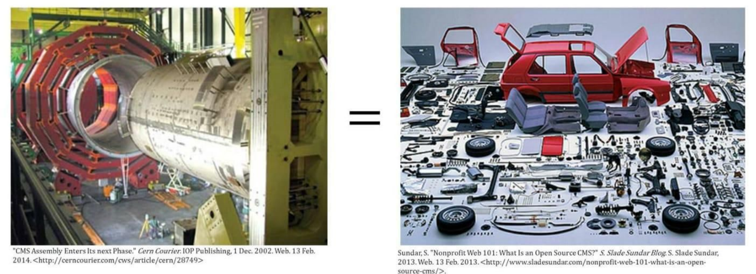


Light Transmission Solution: Rad-hard QCTs and Scintillating Paint

- Quartz capillary tubes can transmit light and have a higher resistance to radiation than do WLS fibers
- Eljen Technologies scintillating paints may reduce attenuation



Maintenance Problem

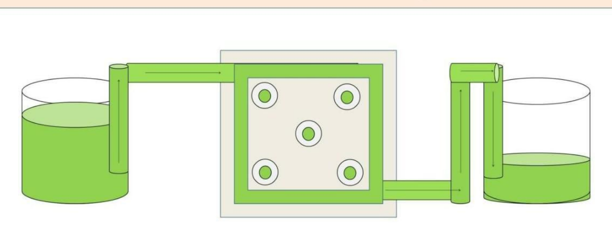


"CMS Assembly Enters its next Phase." *Cern Courier.* IOP Publishing, 1 Dec. 2002. Web. 13 Feb. 2014. <http://cerncourier.com/cws/article/cern/28749>.

Sundar, S. "Nonprofit Web 101: What Is an Open Source CMS?" *S. Slade Sundar Blog.* S. Slade Sundar, 2013. Web. 13 Feb. 2013. <http://www.sladesundar.com/nonprofit-web-101-what-is-an-open-source-cms/>.

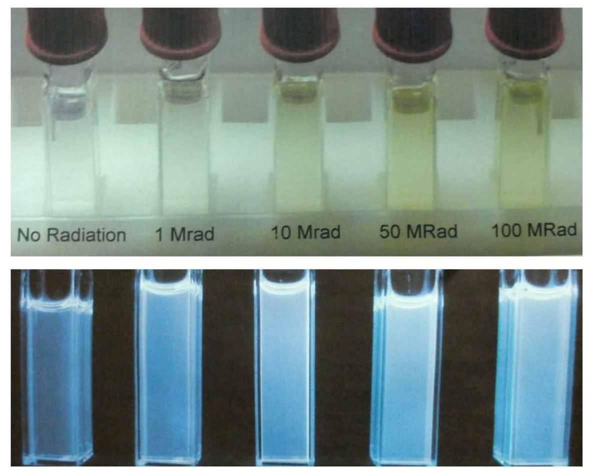
Replacement of radiation-damaged plastics requires disassembly of detector exterior

Maintenance Solution: Liquid Scintillator



- Liquid-filled scintillating tiles could be periodically replaced via fluid pumps
- No detector disassembly

Irradiated EJ-309…



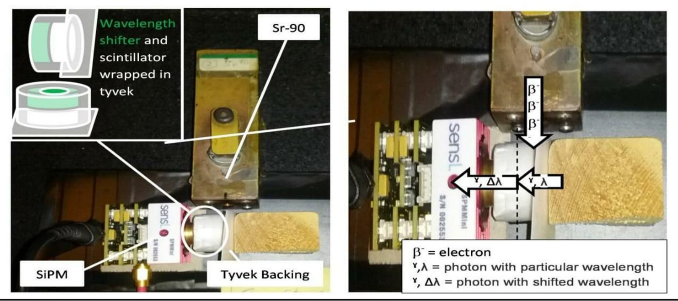
in room light

in UV light

Procedures and Data

Plastic Combo Testing: Beta Source

- Event: electron from beta emitter causes scint to emit light, which is waveshifted by WLS and detected by SiPM inside light-tight box
- Scint/WLS combinations compared by analyzing light intensity histograms



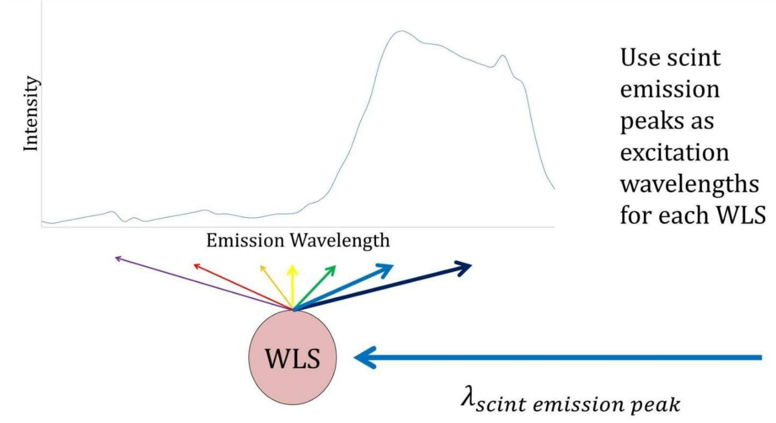
Data: Light Tight Box Trials (Plastic Scint/WLS Optmization and Red WLS Testing)

Plastic Scintillator/Wavelength Shifter Combination Distributions (Pedestal)

		Mean				67%				95%				99%				Endpoint			
		201	205	206	208	201	205	206	208	201	205	206	208	201	205	206	208	201	205	206	208
Green WLS	204	117	255	111	85	142	288	134	101	270	432	258	205	348	518	335	272	582	778	575	486
Red WLSs	209	52	162	41	34	60	169	48	39	114	217	92	78	154	254	126	112	308	397	266	242
	210	49	164	41	34	57	164	48	39	111	224	94	79	151	265	130	113	301	419	269	241
	224	59	167	48	36	68	175	57	42	129	226	106	79	172	262	143	108	327	394	269	204
	225	58	169	50	38	68	178	59	45	131	230	109	84	176	269	146	113	330	403	272	217

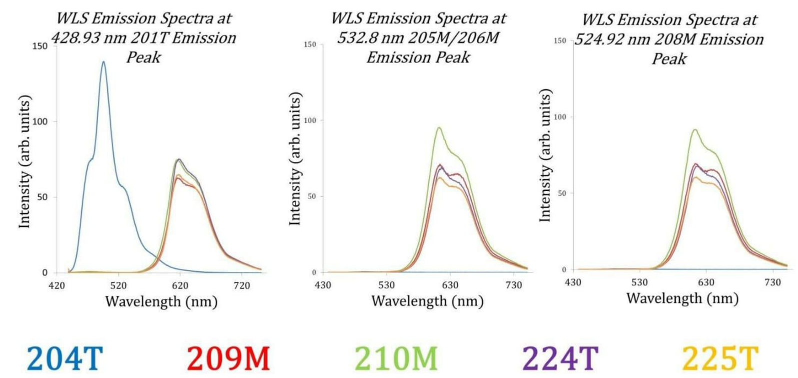
- Intensity distribution lengths for each scint-WLS pair
- Green represents broad distribution; red represents narrow distribution (unrelated to WLS color)
- Scints on horizontal axis; WLSs on vertical axis

Plastic ComboTesting: Spectrophotometer

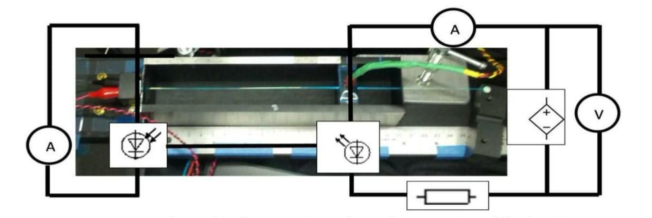


Use scint emission peaks as excitation wavelengths for each WLS

Data: Spectrophotometer



Liquid Testing: LED Light Transmission



Measure current across photodiode at various lengths on paint-filled QCT inside light-tight box to calculate:

- Relative initial intensities
- Attenuation lengths

Data: LED Light Transmission

	I_0	L_0	I_0 % change per Mrad	L_0 % change per Mrad
EJ-10A	9.11	500	1.15	-0.65
EJ-10B	4.51	167	0.51	-0.41
EJ-11A	7.06	500	1.19	-0.82
EJ-11B	5.09	200	0.80	-0.52
EJ-12A	4.91	200	0.78	-0.53
EJ-12B	3.71	111	0.87	-0.02
EJ-14A	5.41	250	1.02	-0.53
EJ-14B	1.35	200	0.35	-0.24
EJ-15A	3.86	250	1.04	-0.56
EJ-15B	0.47	167	0.33	-0.07
EJ-309	0.97	250	1.92	-0.60

- For each scintillating paint in the leftmost column: I_0 represents initial intensity at 0 Mrad, L_0 is attenuation length at 0 Mrad
- Relative characteristics: Green represents strong, red represents poor

Results – Plastic Combo Testing

Beta Source Testing

Greatest light output for a plastic scint/WLS combination with

- Green WLS: **205 scint/204 WLS** combination.
- Red WLS: **all red WLSs** were comparable when combined with the **205 scint** .

Spectrophotometer Testing

Greatest light output for a plastic scint/WLS combination with

- Green WLS: **201 scint/204 WLS** pair. All other pairs resulted in minimal light output.
- Red WLS: **210 WLS** had comparable emission intensities with **205, 206, and 208 scint** emission peaks.

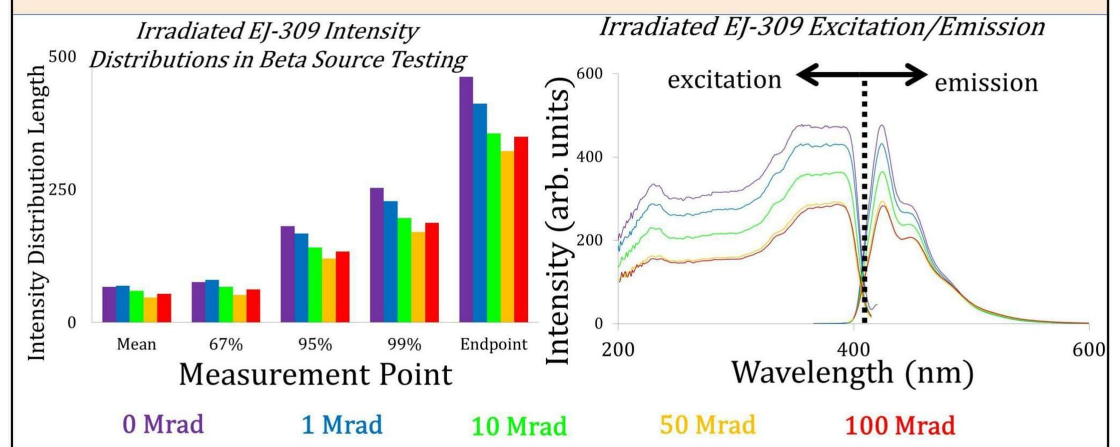
Results – Liquid Scint Testing

All intensities tended to increase with increasing radiation.

The most favorable scintillating paints were

- **EJ-10A**: good initial intensity and attenuation length but poor change in attenuation length
- **EJ-11B and EJ-12B**: average initial intensity, attenuation length, and change in attenuation length
- **EJ-14A**: above average initial intensity and attenuation length and average change in attenuation length

Interesting finding - Liquid Scintillator



- Distribution length tends to *decrease* with increasing radiation of *less than 50 Mrad*
- However, distribution length *increases* from *50 Mrad to 100 Mrad*

Discussion

- **205 scint/204 WLS pair** had **broader length distributions** than all others, including standard 201 scint/204 WLS pair
- Combinations with **red WLSs had narrower** (by approximately 1/2) **distributions** than did the standard green WLS 204
- **Red WLSs may be a viable alternative** for long arrangements when used with the 205 scint
- **EJ-10A, EJ-11B, EJ-12B, and EJ-14A scintillating paints** may be useful in a liquid-filled QCT arrangement for light transmission in the CMS detector
- EJ-309 **liquid scintillator may have higher scintillation ability at high radiation levels**
- Surprising characteristic of the EJ-309 **liquid scintillator: wavelength shifting** ability

Conclusion

- The **205 scint/204 WLS may be superior** to the standard 201 scint/204 WLS that has previously been used in the CMS detector
- Due to their higher attenuation lengths, **red WLSs paired with 205 scint may be a viable alternative to green WLSs** for long optical fiber arrangements.
- **EJ-10A, EJ-11B, EJ-12B, and EJ-14A scintillating paints** may be useful in a liquid-filled QCT arrangement for light transmission in the CMS detector
- EJ-309 liquid scintillator may be worthy of further investigation