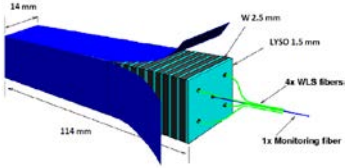

Progress in monitoring LYSO/W Shashlik Calorimeter and Initial consideration for monitoring CeF_3/W Shashlik Calorimeter

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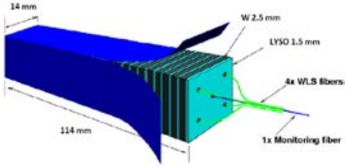
December 10, 2014

Input from: Brad Cox, Bob Hirosky, Sasha Ledovskoy, Francesca Nessi, Harvey Newman, Yasar Onel, Randy Ruchti, Jason Trevor, Sebastian White, Craig Woody, Fan Yang, Liyuan Zhang and Kejun Zhu

Introduction



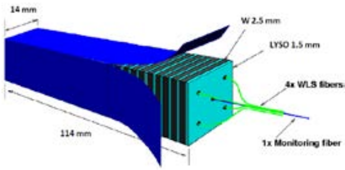
- Because of the severe radiation environment expected at the HL-LHC a light monitoring system is important for keeping intrinsic precision of the proposed LYSO/W Shashlik calorimeter.

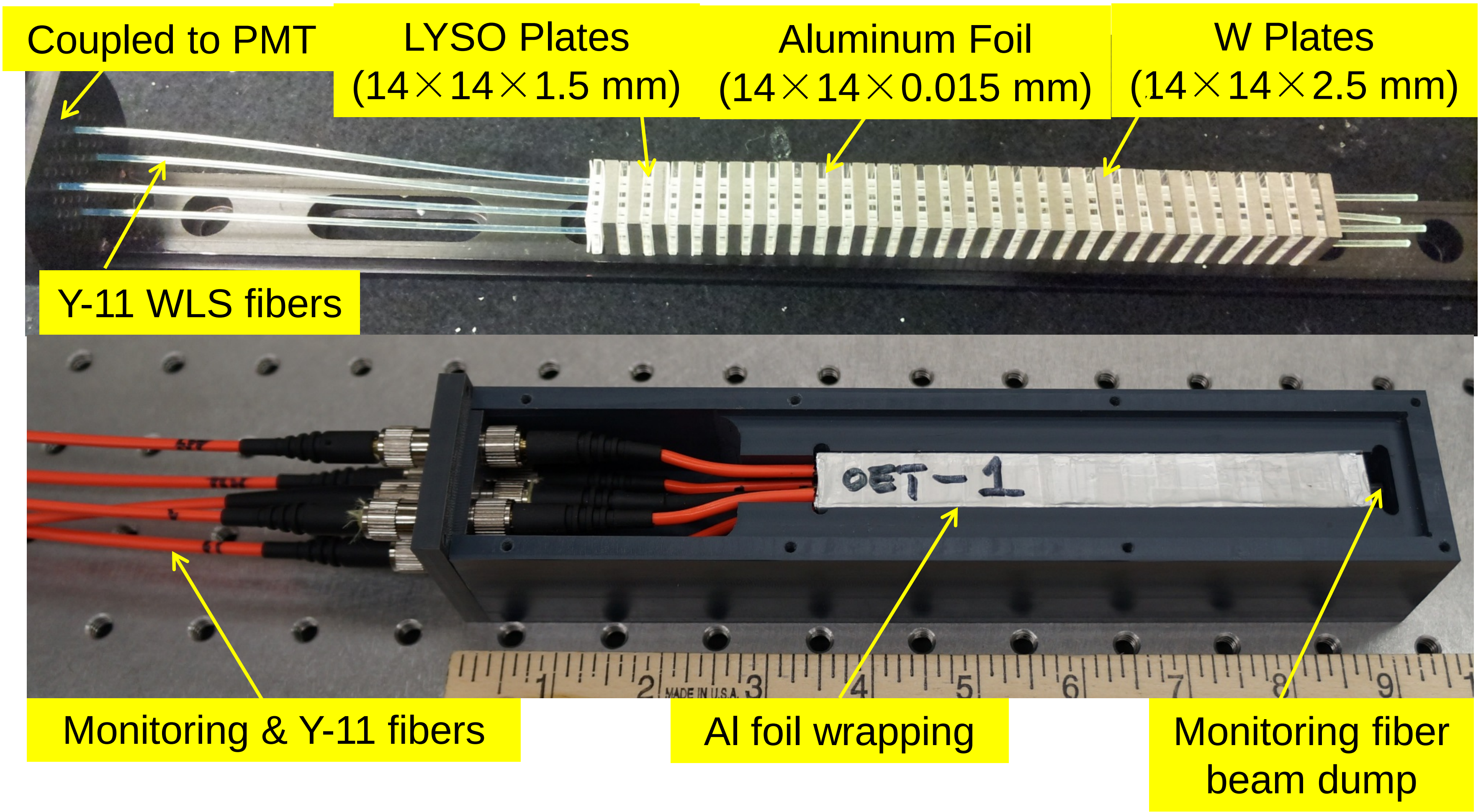
- The required monitoring precision is 0.5% because of the 1% constant term of the energy resolution due to its sampling nature, which is less stringent as compared to the 0.2% required by the PWO ECAL to achieve 0.5% constant term in the energy resolution.

- The required monitoring frequency is much relaxed as compared to the **half hour** for the CMS PWO ECAL:
    - The radiation damage effect in both LYSO crystals and quartz capillaries is much smaller than that in PWO crystals.
    - There is no need to monitor the calorimeter when the beam is off since radiation damage in this calorimeter does not recover.

- Progress has been achieved in monitoring LYSO/W calorimeter. Prototypes were built and tested with LYSO/W/Al Shashlik cells at JPL, and will be tested next week at Los Alamos.

A LYSO/W/Al Shashlik Cell

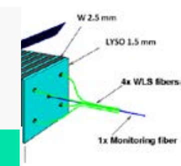




Aluminum foil is used because of its excellent radiation hardness

See: https://indico.cern.ch/event/341217/contribution/7/material/slides/0.pdf

Two LYSO/W Shashlik Cells: 90 Mrad



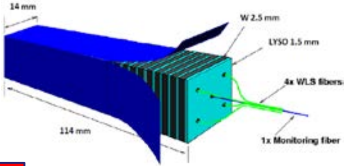
10 Mrad @ 180 krad/h

ID	Dimension (mm)
LYSO OET Plate	14x14x1.5
LYSO SIC Plate	14x14x1.5
LYSO CPI Plate	14x14x2
LYSO CTI L2	25x25x200
BaF2 SIC2012	20x20x250
LYSO SIPAT L2	25x25x200
LYSO SIC L2	25x25x200
LYSO SG L2	25x25x200
BGO SIC2011	25x25x200
BGO NIIC	25x25x200

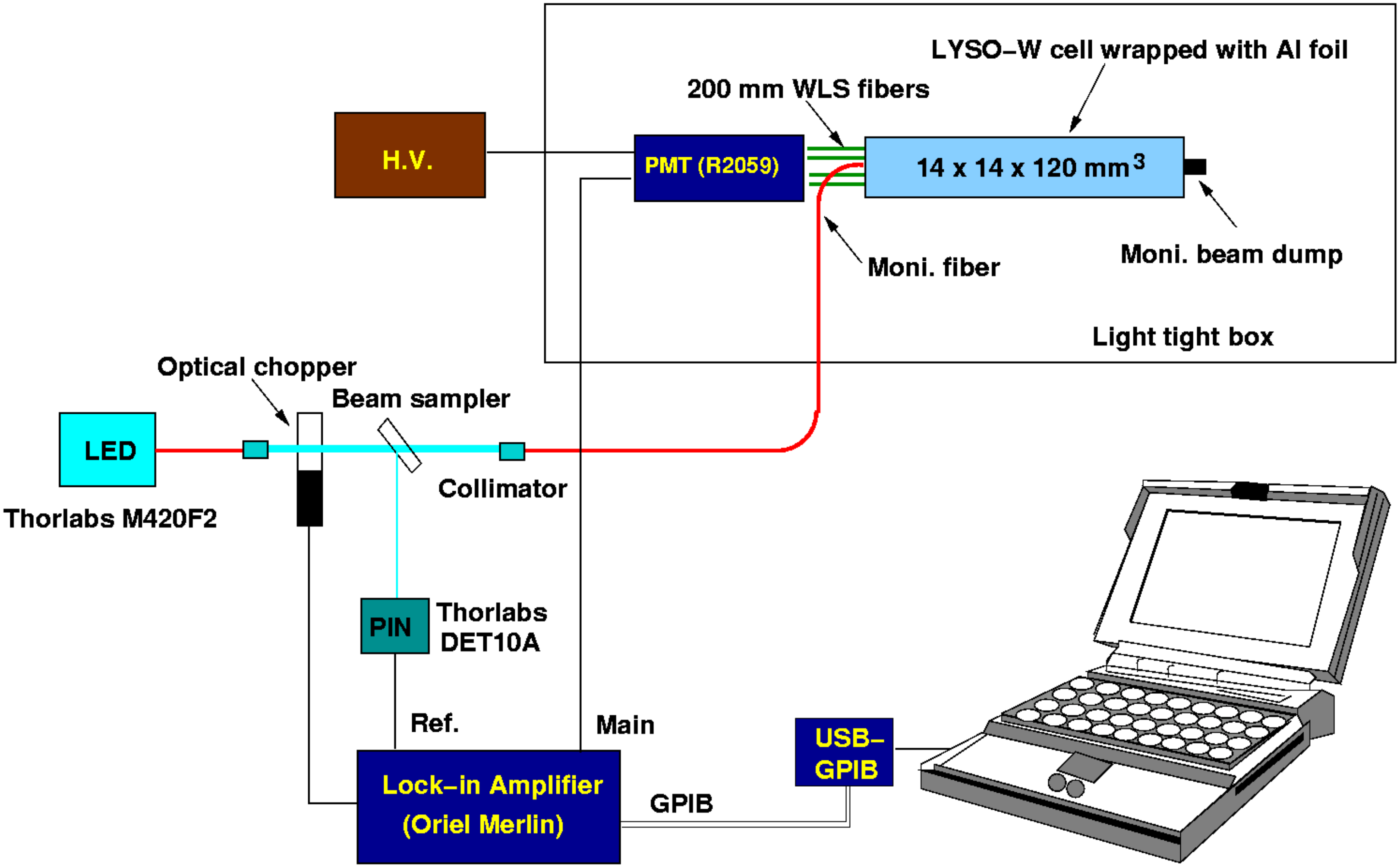
90 Mrad @ 1 Mrad/h

ID	Dimension (mm)
Shashlik (LYSO/W) x 2	**14x14x150**
LYSO OET Plate	14x14x1.5
LYSO SIC Plate	14x14x1.5
LYSO CPI Plate x 2	14x14x2
LYSO CTI L2	25x25x200
BaF2 SIC2012	20x20x250
LYSO SIPAT L2	25x25x200
LYSO SIC L2	25x25x200
LYSO SG L2	25x25x200
BGO SIC2011	25x25x200
BGO NIIC	25x25x200

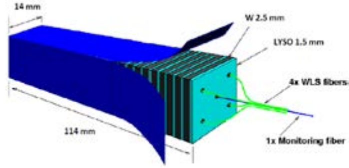
Monitoring LYSO/W/Al/Y-11Cell



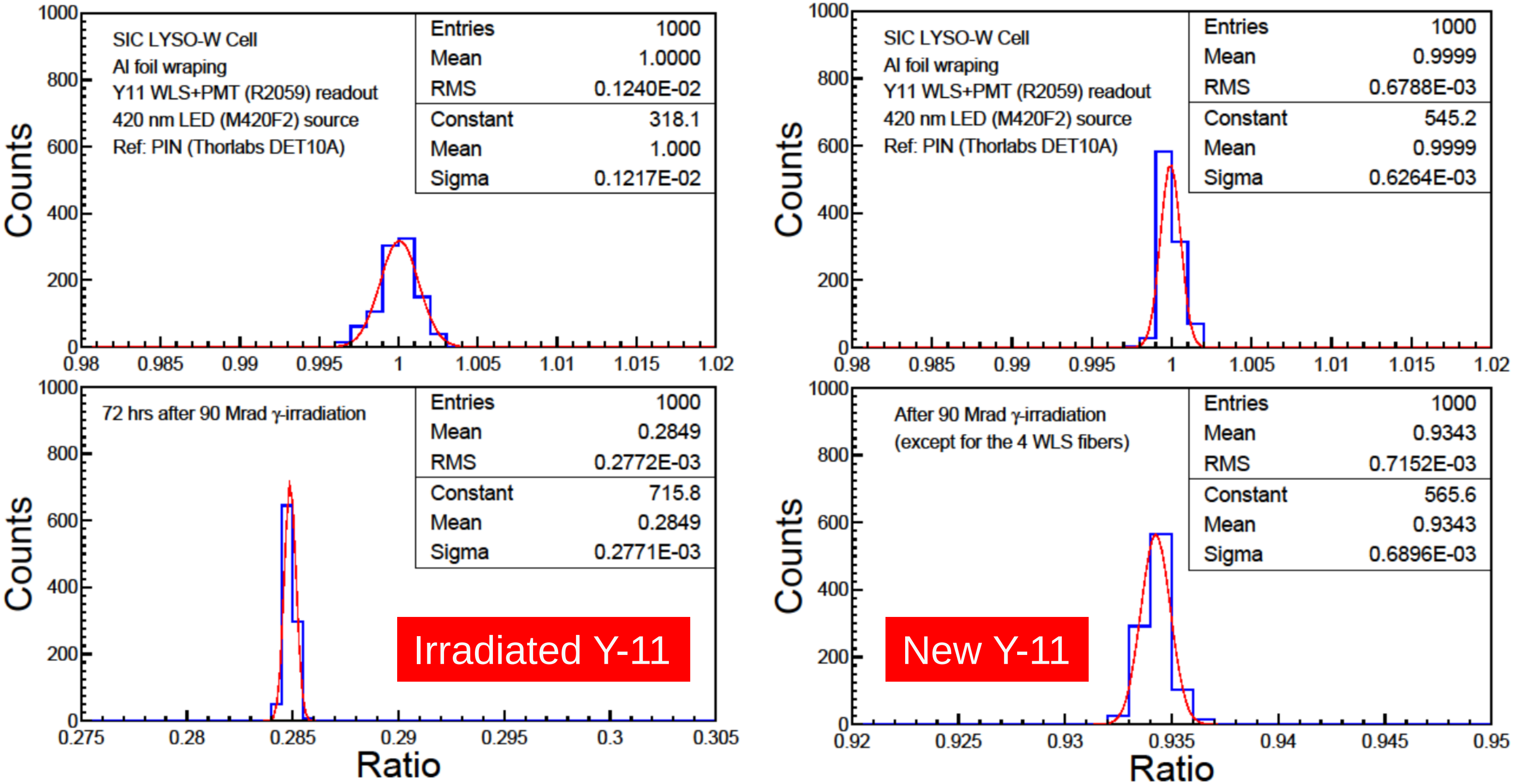
Data taken ~72 h after 90 Mrad @ 1 Mrad/h
Systematic uncertainty: 1%, 3% with fibers replaced



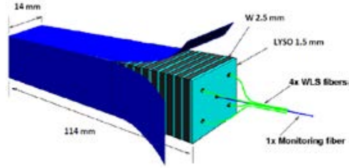
SIC LYSO/W/Al/Y-11



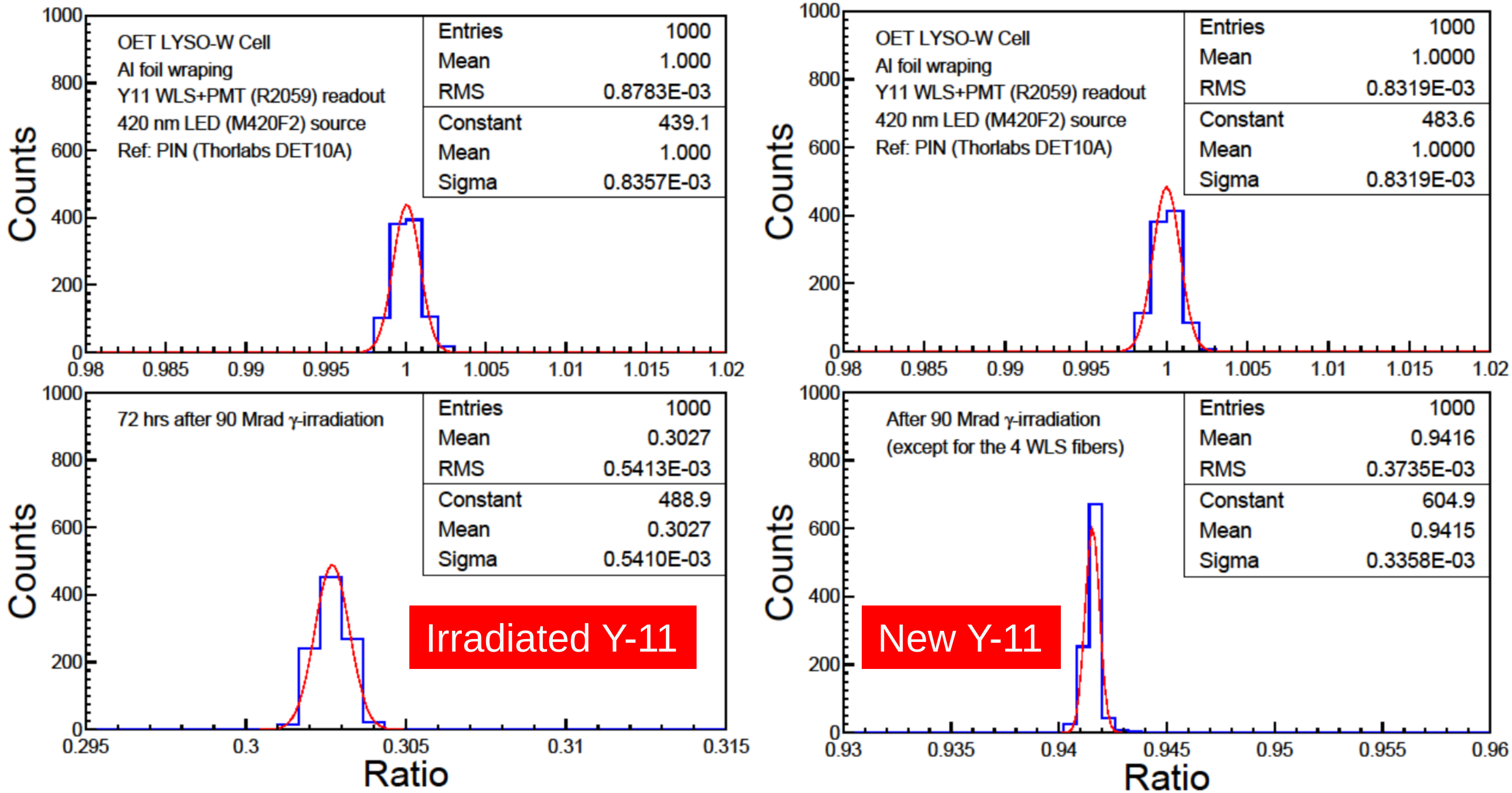
72/7% loss after 90 Mrad @ 1 Mrad/h with irradiated/replaced Y-11



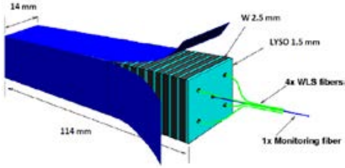
OET LYSO/W/Al/Y-11



70/6% loss after 90 Mrad @ 1 Mrad/h with irradiated/replaced Y-11



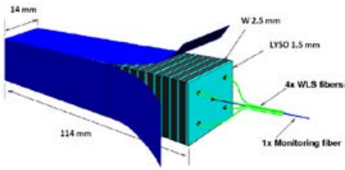
Summary of LYSO/W/Al/Y-11



LYSO/W/Al Cell	WLS Fibers	LED Response (%)
SIC-C1, 90 Mrad	Y-11 Irradiated	29 ± 1
SIC-C1, 90 Mrad	Y-11 Replaced	93 ± 3
OET-C1, 90 Mrad	Y-11 Irradiated	30 ± 1
OET-C1, 90 Mrad	Y-11 Replaced	94 ± 3

- Consistent degradation was found in LYSO/W/Al Shashlik cells constructed by using LYSO plates from SIC and OET.
- After replacing damaged Y-11 fibers with non-irradiated ones the net damage in LYSO/W/Al cells after 90 Mrad @ 1 Mrad/h is measured to be 7%, indicating less than 1%/year caused by ionization dose.
- Combined with the excellent radiation hardness of quartz capillaries, damage at this level is easy to be followed by a light monitoring system *in situ* at the HL-LHC. Will look hadrons at Los Alamos.

Quartz Capillary Damage

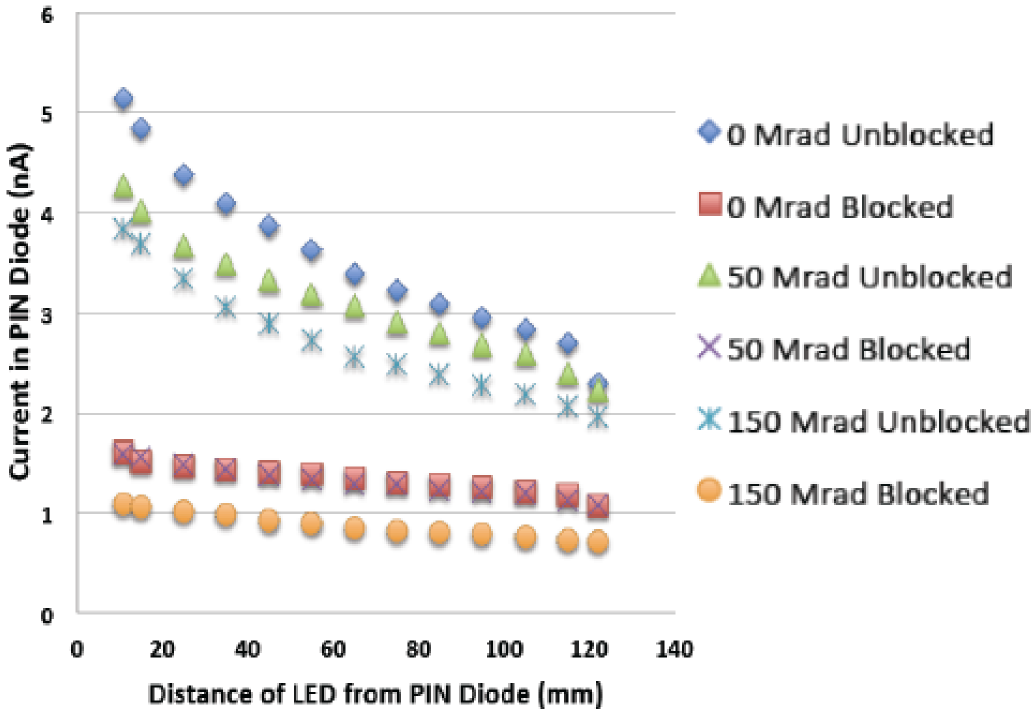


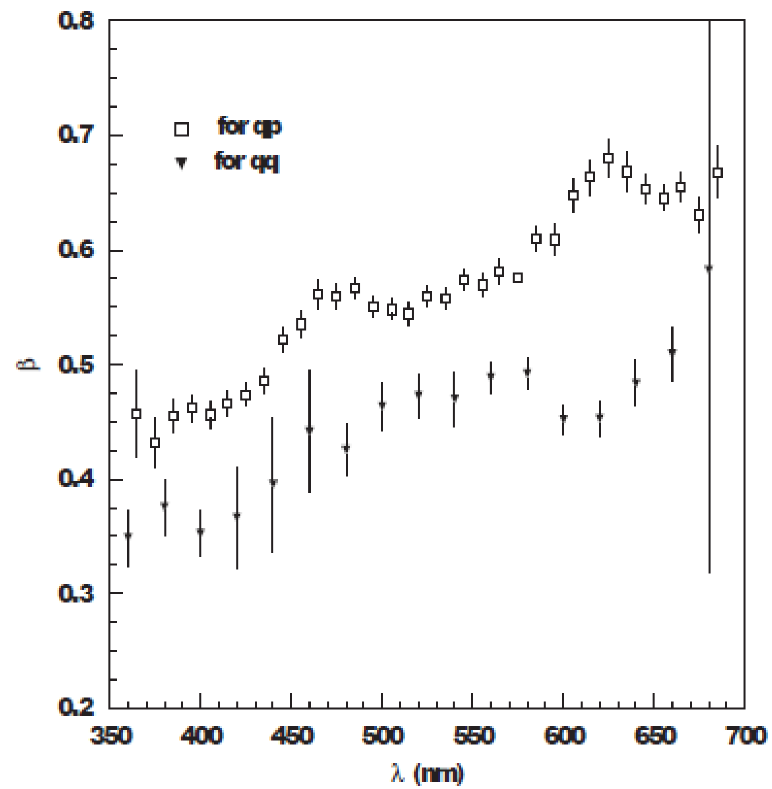
Liquid WLS: No damage up to 50 Mrad
See Tommaso's talk for the details

Induced μ in Quartz Fiber
NIM A585 (2008) 20-27

$$\mu_{\mathrm{IND}}(\lambda) = \frac{1}{4.343} \cdot \alpha(\lambda) \cdot \left(\frac{D}{100}\right)^{\beta(\lambda)}$$

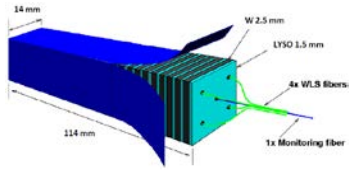
Study of Light Collection from Capillaries as a function of irradiation (gammas)

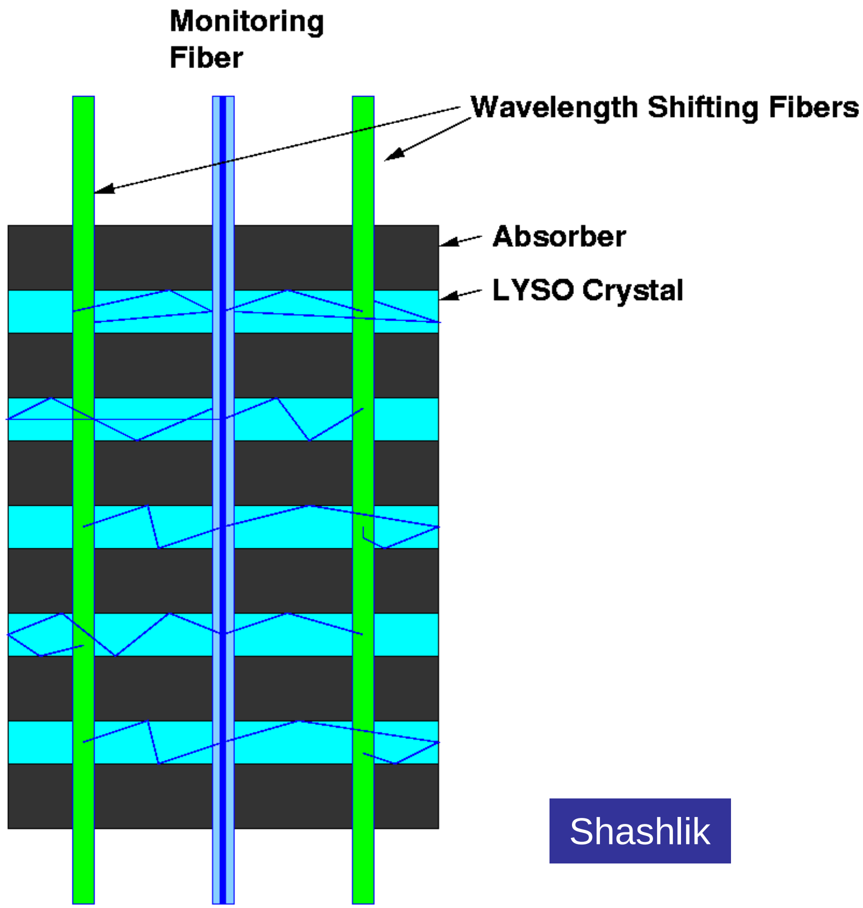




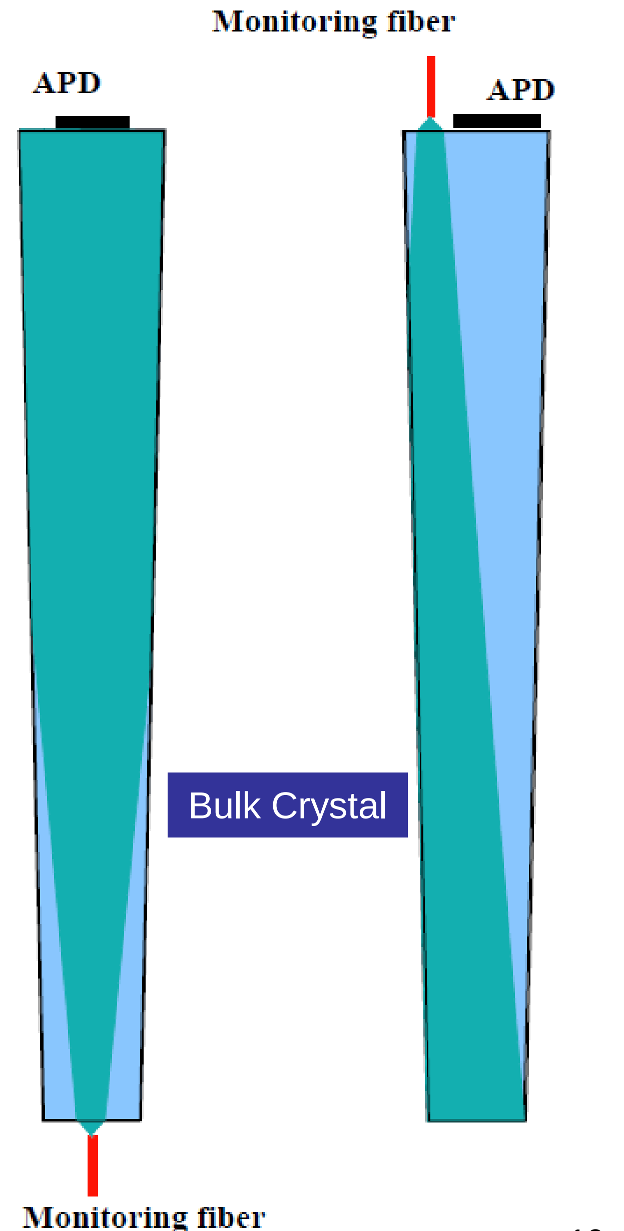
The overall induced μ after 150 Mrad is 0.8 and 0.5 /m at 500 and 430 nm respectively, corresponding to 10% loss in light output or 1%/year

Monitoring with Light Pulses



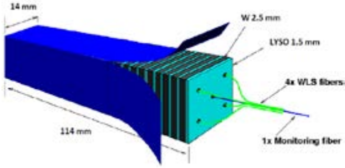


Shashlik

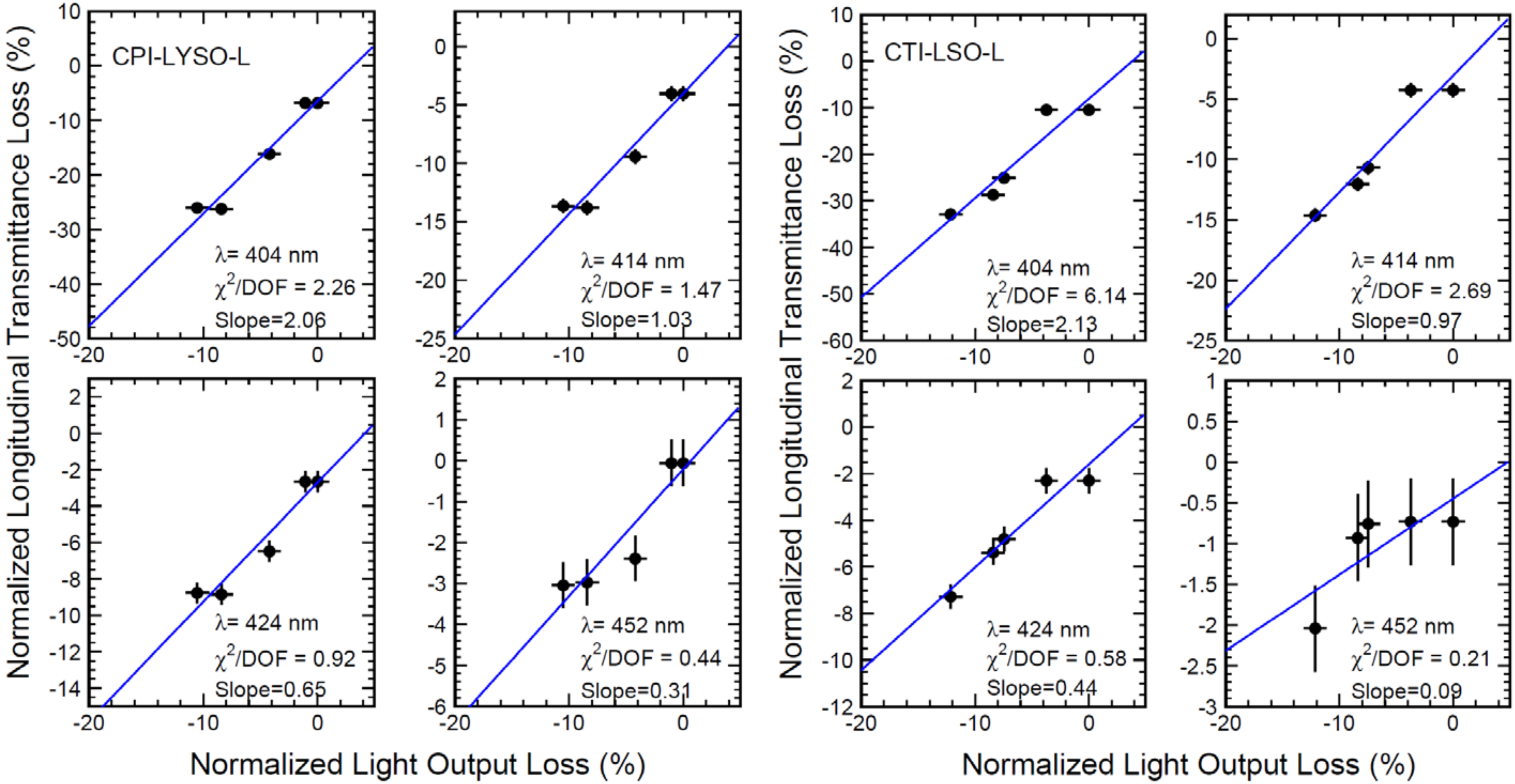


Light pulses with a wavelength close to the emission peak would be effective to monitor variations of crystal transparency.

δLT vs. δLO for 20 cm LYSO

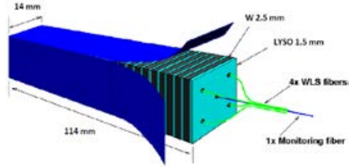


Fitting function: $\frac{LT_{IR}-LT_0}{LT_0} = Slope \times \frac{LO_{IR}-LO_0}{LO_0}$

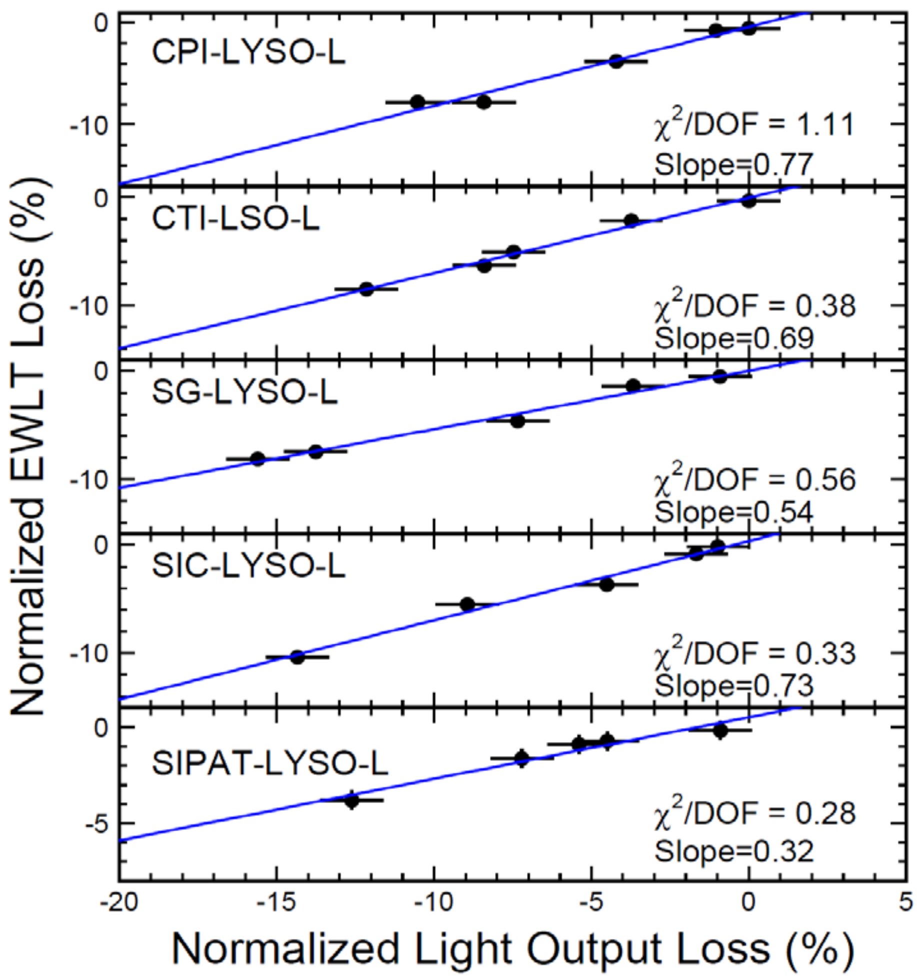


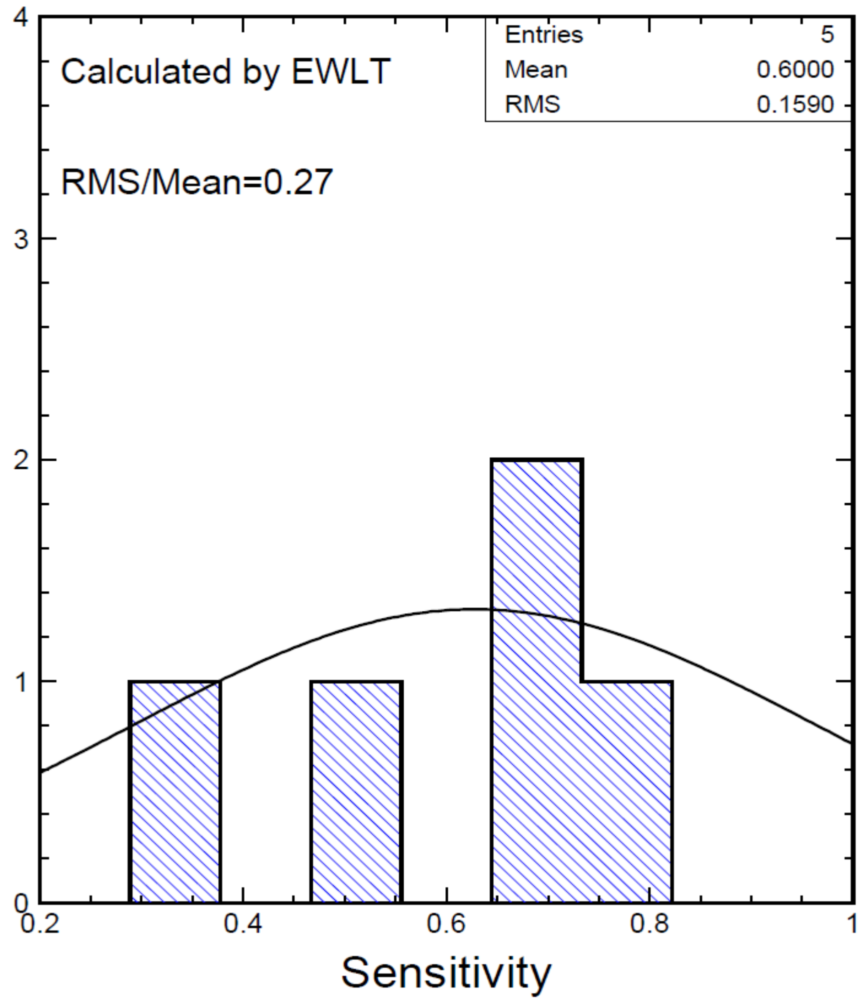
The slope represents the monitoring sensitivity at a particular wavelength

Monitoring Sensitivity with EWLT

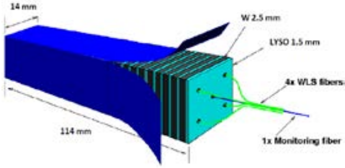


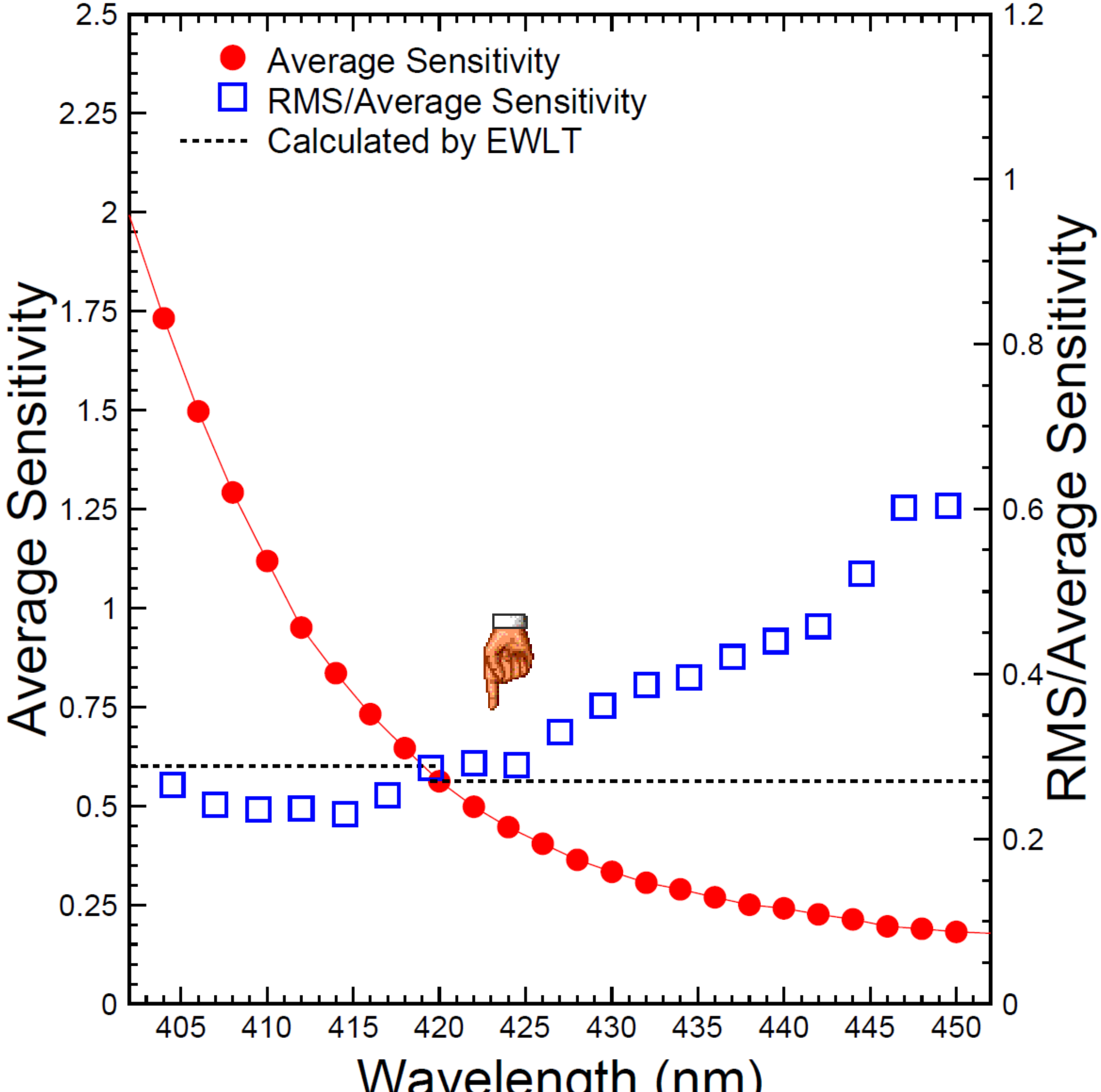
EWLT representing monitoring with excitation (PHENIX)





Choice of Monitoring Wavelength



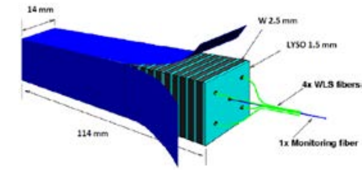


Consistent monitoring sensitivity is observed for both the EWLT and the wavelength close to the emission peak: 425 nm.

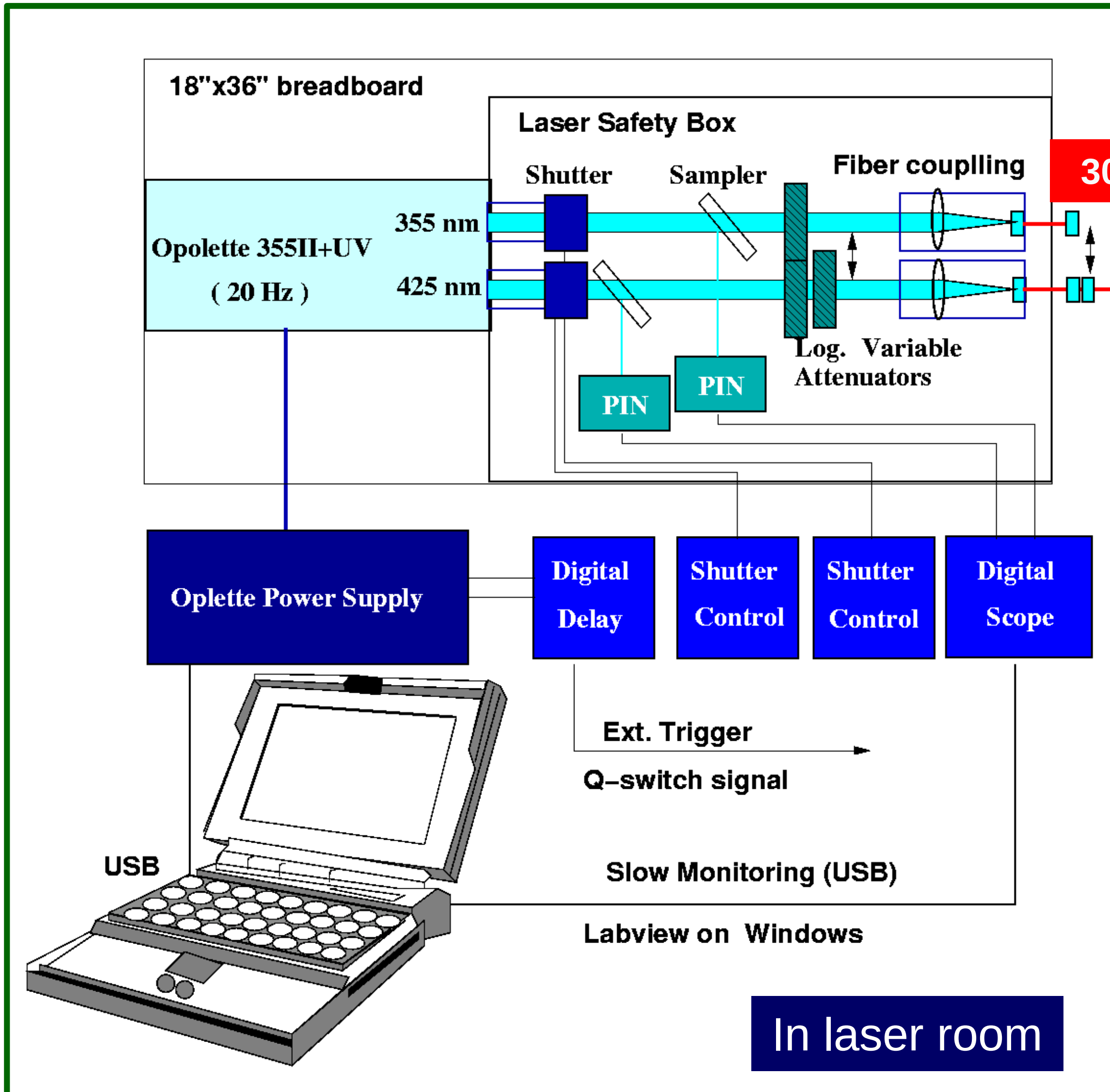
Consistent divergence is also observed between the EWLT and 425 nm for LYSO crystals from five vendors.

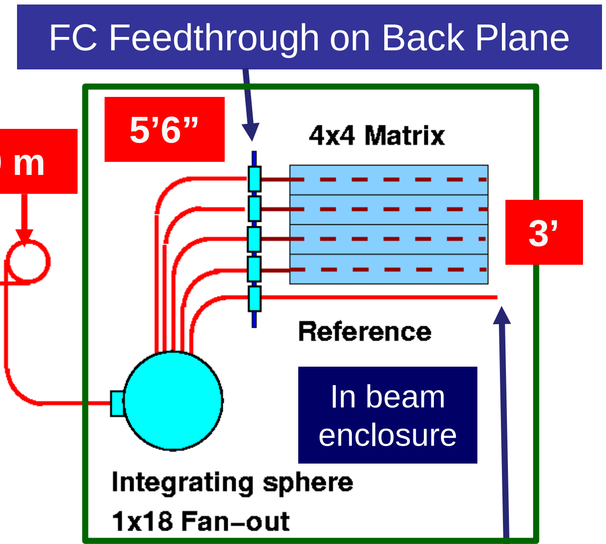
It is possible to use excitation at 355 nm, where cost-effective high power DPSS lasers are commercially available.

An Opolette Laser Based Monitoring System



Used in LYSO/W Shashlik beam test at Fermilab

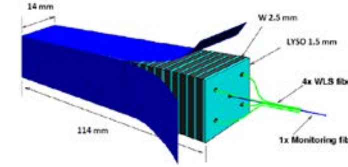




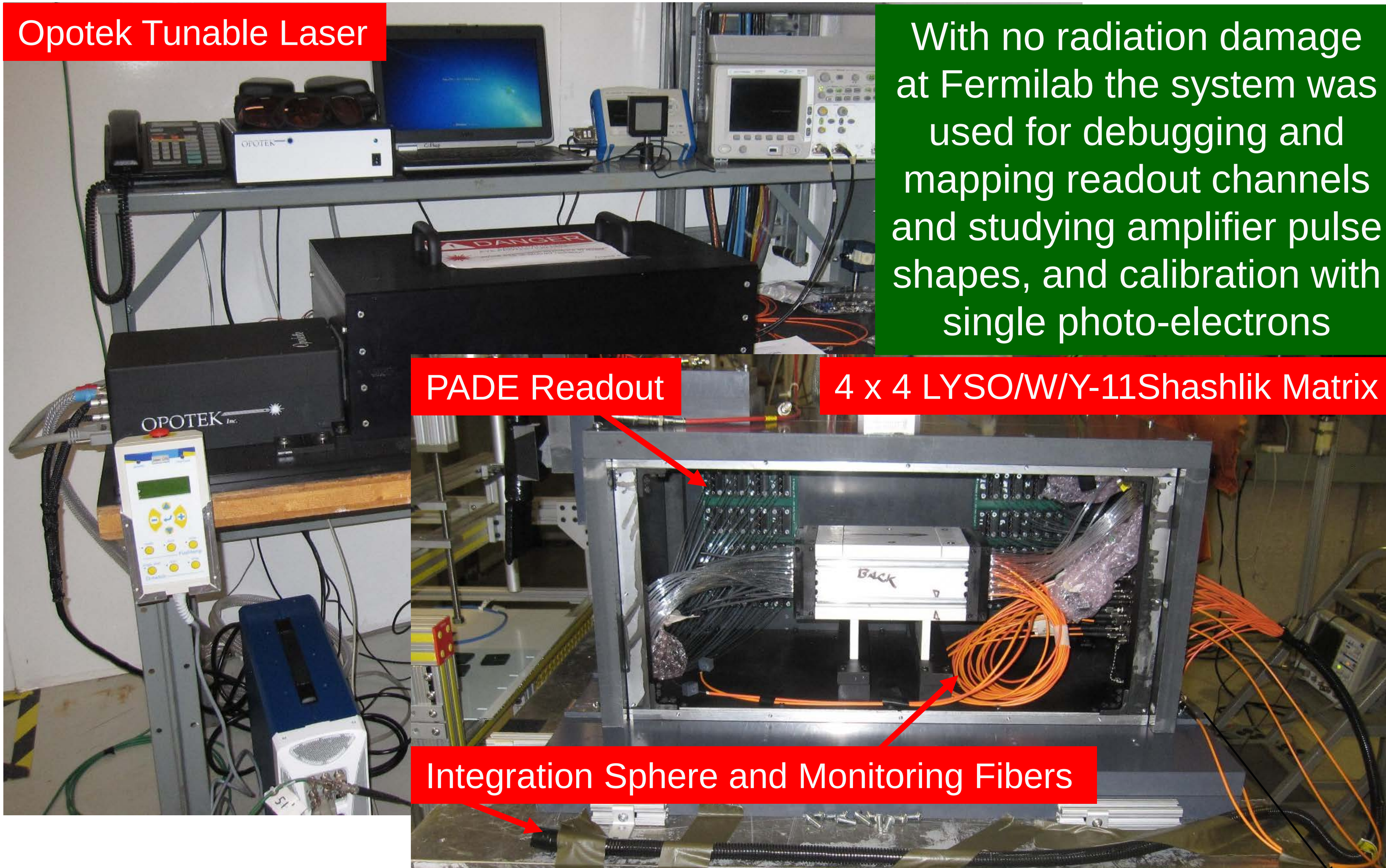
The same photo-detector and electronics with neutral density attenuator for the reference

Caltech *July 10, 2014*

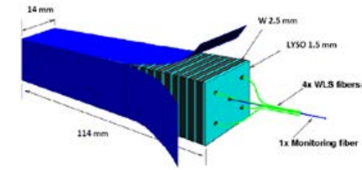
Monitoring System at Fermilab



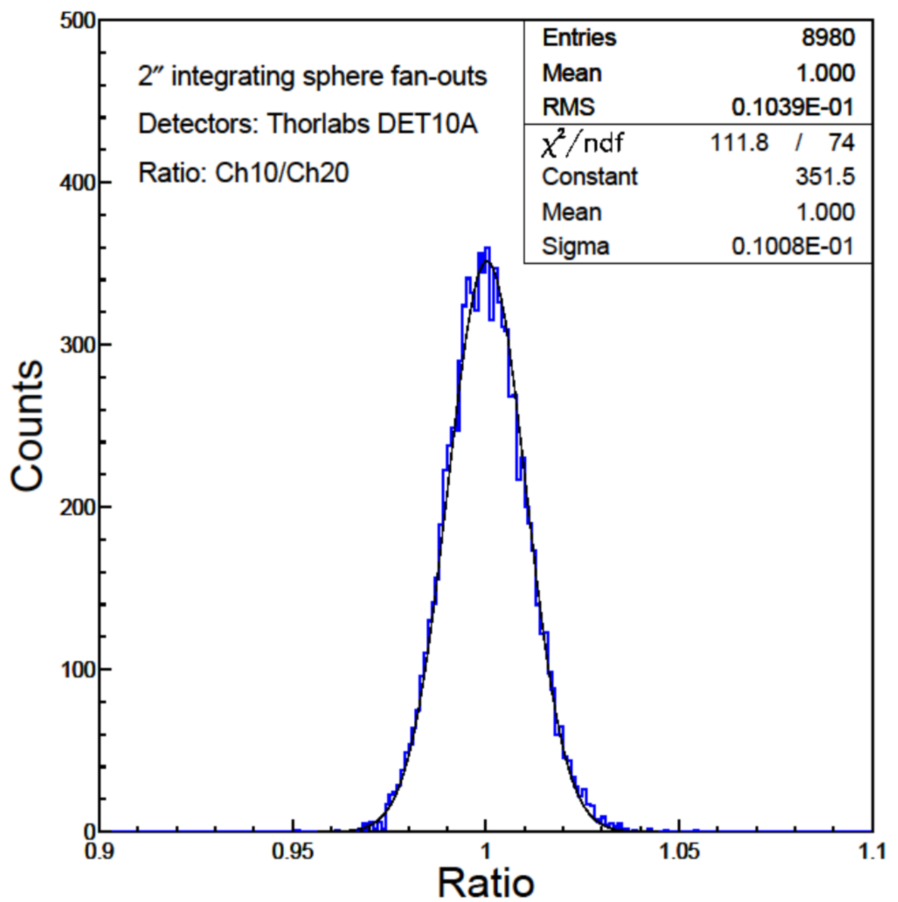
With no radiation damage at Fermilab the system was used for debugging and mapping readout channels and studying amplifier pulse shapes, and calibration with single photo-electrons

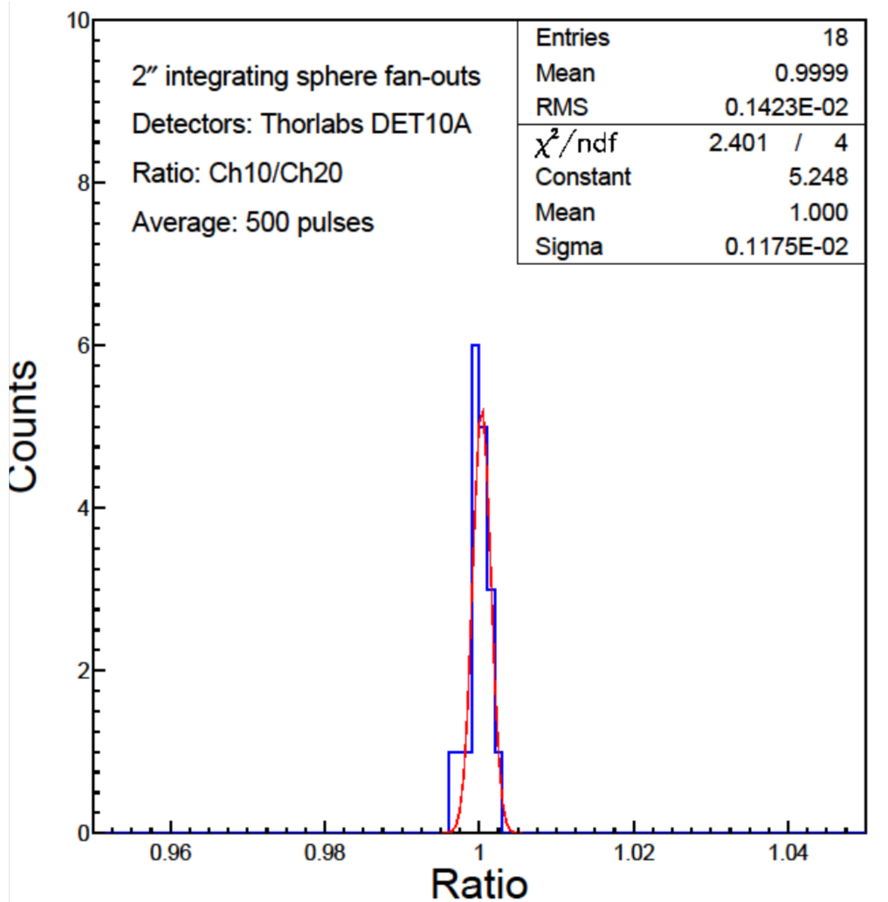


Monitoring Precision

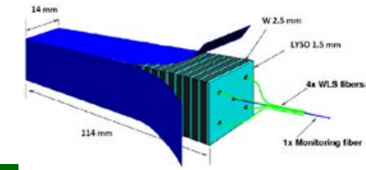


Pulse to pulse monitoring precision: 1%
0.1% reached with average of 500 pulses

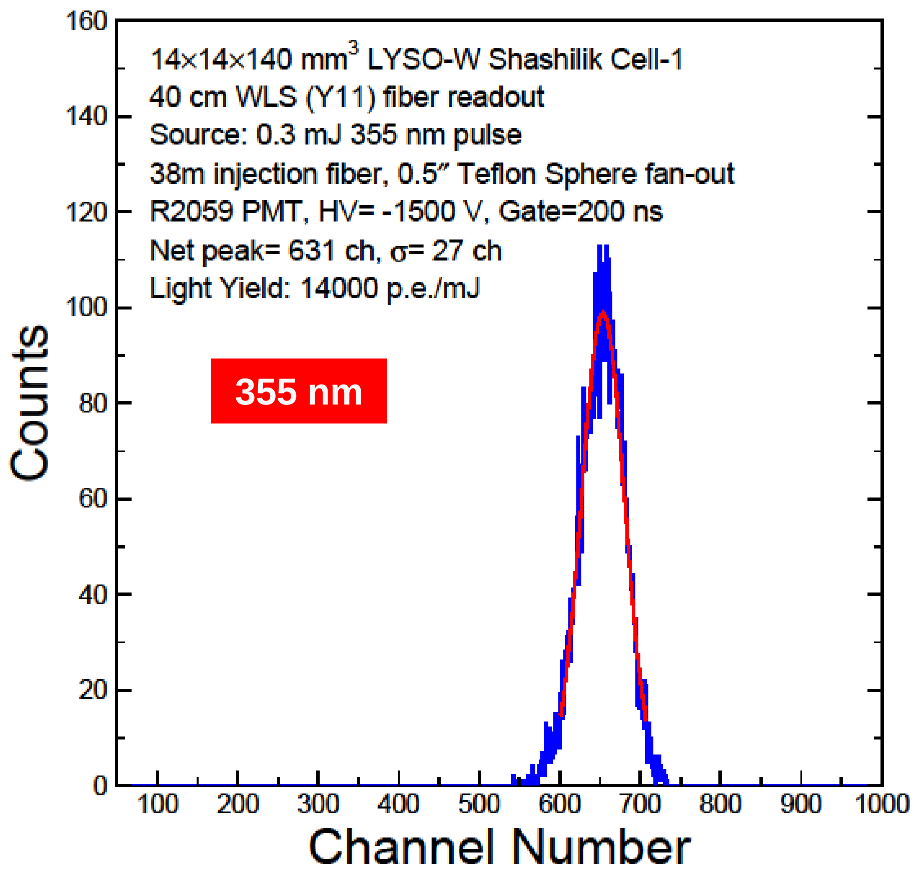


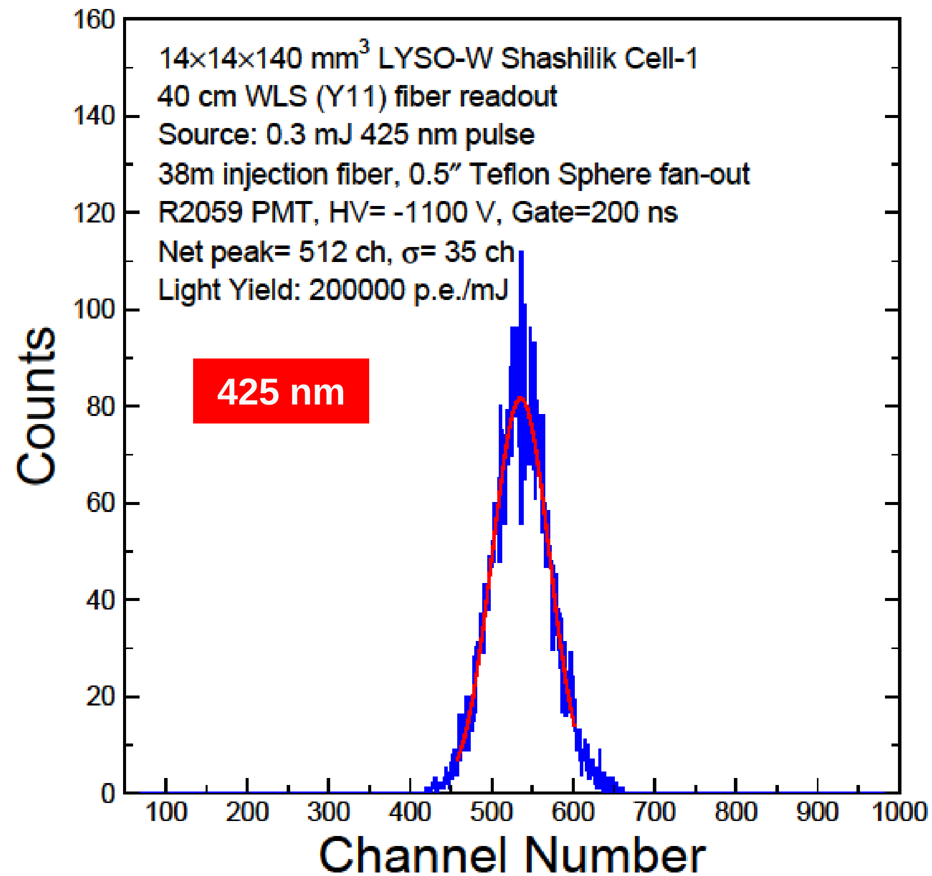


Dynamic Range with Quartz Fiber Leakage



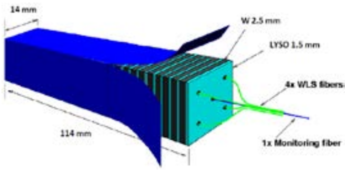
355 nm: 14,000 p.e./mJ, corresponding to 2.5 GeV/mJ
425 nm: 200,000 p.e./mJ, corresponding to 36.5 GeV/mJ



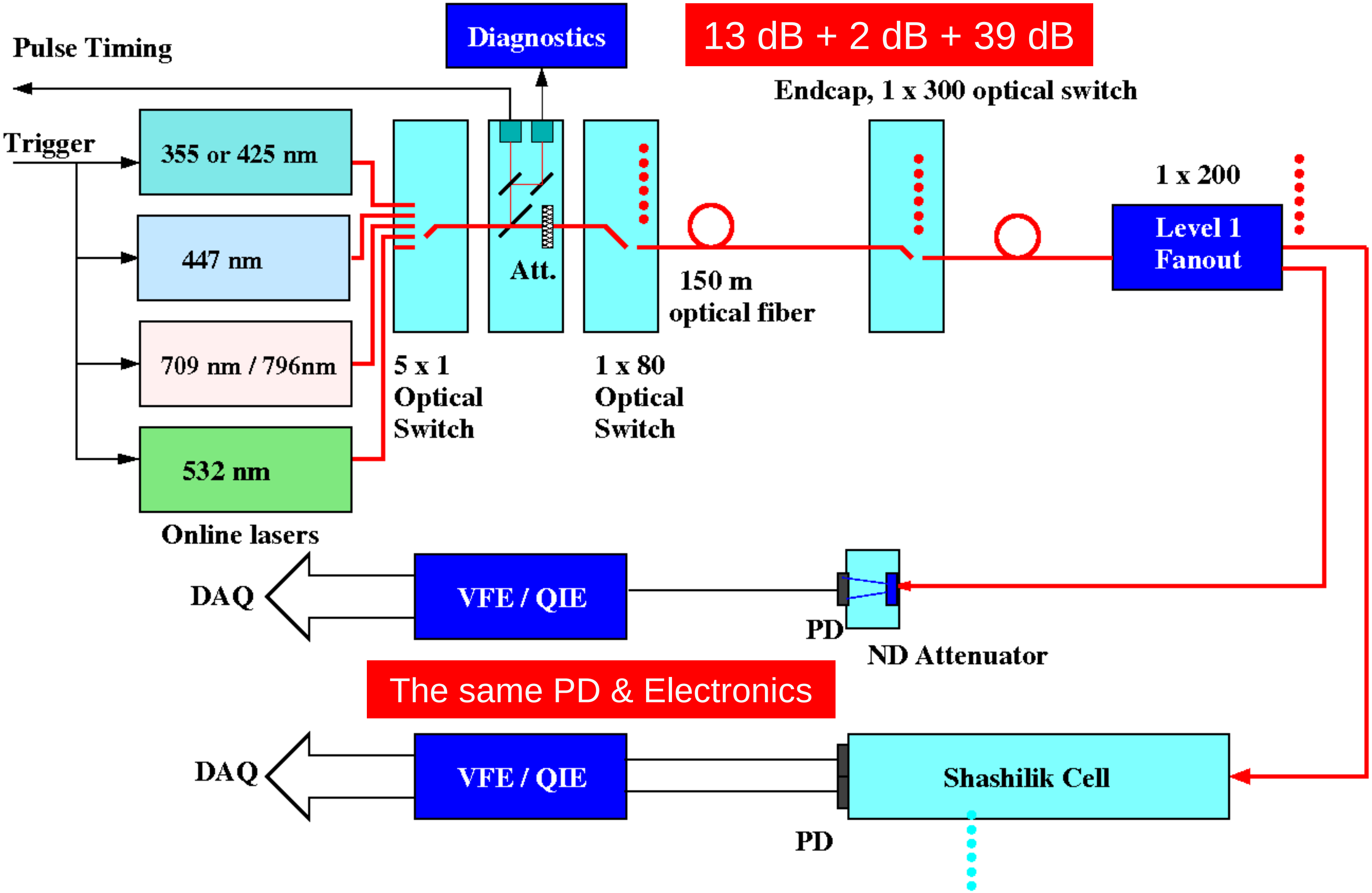


A factor of 15 lower dynamic range for 355 nm caused by excitation and attenuation
Commercial DPSS lasers @ 355 nm have pulse energy of 15 times of the blue

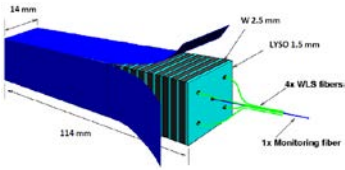
A Preliminary Design



Fast/slow scan for PWO barrel and LYSO endcaps



Monitoring CeF_3 Shashlik

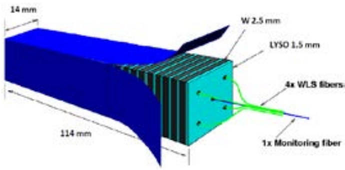


CeF_3 has an emission centered at 340 nm, so lasers at 355 nm may also be used for CeF_3 transparency monitoring.

There are also frequency quadrupled laser at 256 nm which matches well the excitation wavelength of CeF_3 so can be used to monitoring both excitation and transmission processes.

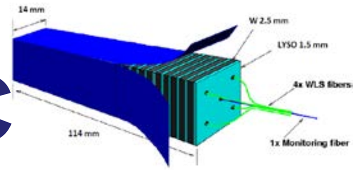
Monitoring a CeF_3/W Shashlik calorimeter thus follows a similar approach as the LYSO/W Shashlik calorimeter discussed above.

Summary



- A light monitoring system is important for keeping precision of the proposed LYSO/W Shashlik calorimeter.
- The required monitoring precision is 0.5%.
- Because of small damage level and no damage recovery the required monitoring frequency for the proposed LYSO/W/Capillary Shashlik calorimeter is much lower than the ½ hour required for the CMS PWO ECAL.
- The monitoring wavelength for LYSO is 425 nm for transparency and 355 nm for both excitation and transparency.
- A higher monitoring dynamic range may be achieved by a lower monitoring frequency.
- R&D Issues for the monitoring system:
  - Effective leaky fibers;
  - Efficient level 1 split; and
  - Radiation hardness of monitoring components.

Expected Radiation at HL-LHC



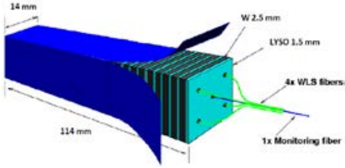
CMS Radiation	LHC (10^{34} cm^{-2}s^{-1}, 500 fb^{-1})		HL-LHC (5×10^{34} cm^{-2}s^{-1}, 3000 fb^{-1})	
	Barrel (max)	Endcap (max)	Barrel (max)	Endcap (max)
Absorbed dose (rad)	**3.50E+05**	**2.10E+07**	2.10E+06	1.26E+08
Dose rate (rad/h)	25	1512	126	7560
Fast neutrons fluence (E>100KeV, cm^{-2})	**3.00E+13**	**8.00E+14**	1.80E+14	4.80E+15
Fast neutrons flux (E>100KeV, cm^{-2}s^{-1})	6.00E+05	1.60E+07	3.00E+06	8.00E+07
Charged hadrons fluence (cm^{-2})	**4.00E+11**	**5.00E+13**	2.40E+12	3.00E+14
Charged hadrons flux (cm^{-2}s^{-1})	8.00E+03	1.00E+06	4.00E+04	5.00E+06

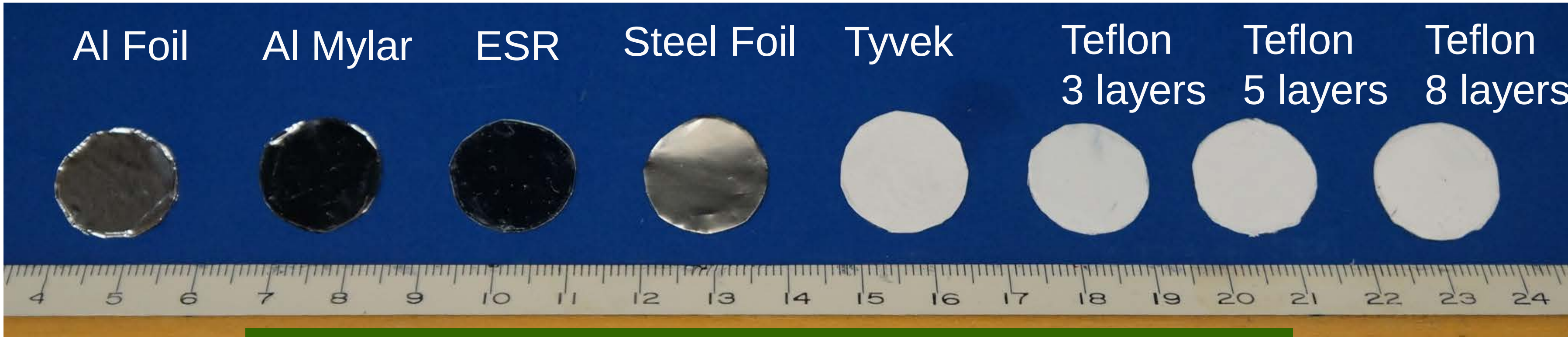
ɣ-rays: Up to 130 Mrad at 7.6 krad/h;

Fast Neutrons: Up to 5 x 10^{15} n/cm^2 at 8 x 10^7 n/cm^2/s;

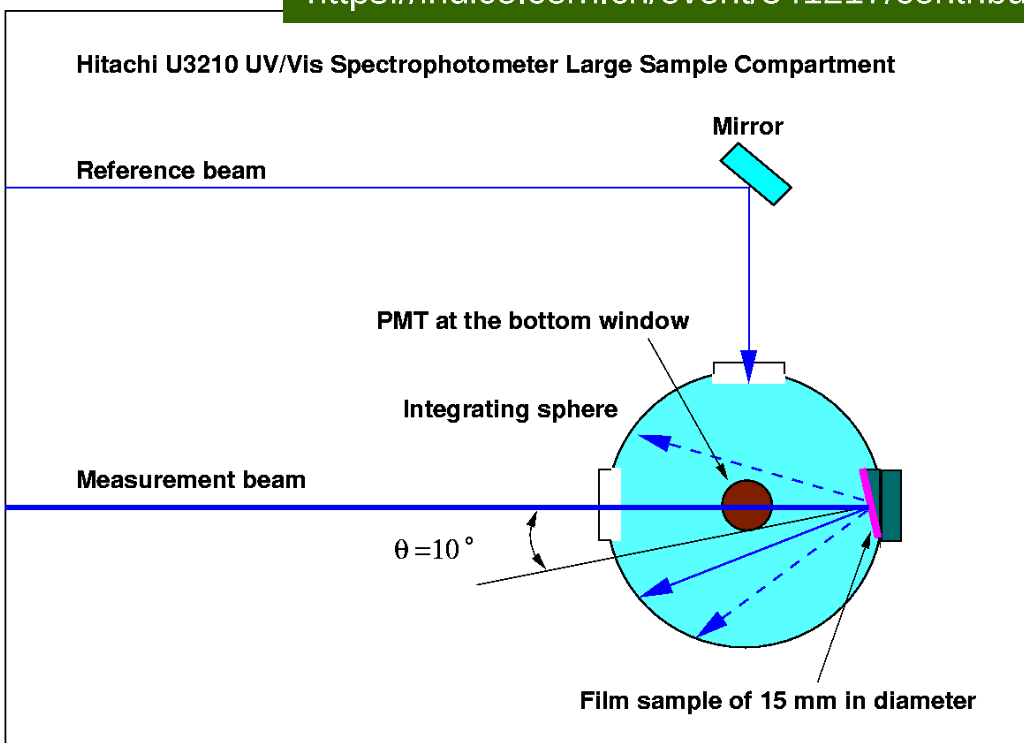
Charged hadrons: Up to 3 x 10^{14} p/cm^2 at 5 x 10^6 p/cm^2/s.

Wrapping Materials



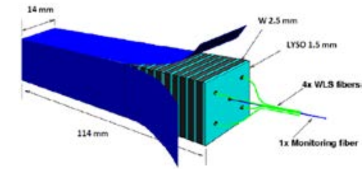


https://indico.cern.ch/event/341217/contribution/7/material/slides/0.pdf



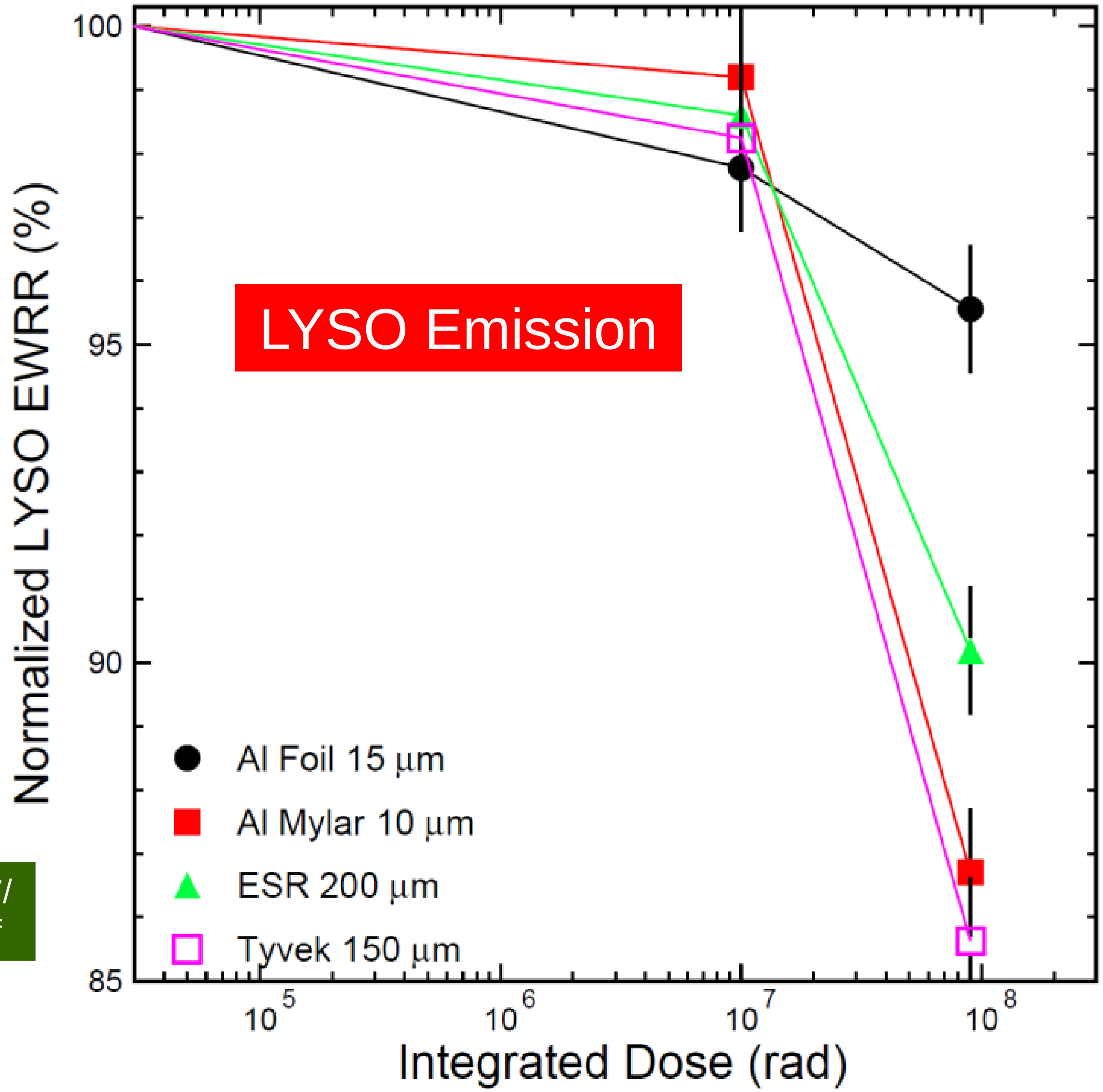
Sample ID	Thickness (μm)
Al Foil	15
Al Mylar	10
ESR	65
Steel Foil	50
Tyvek	150
Teflon ×3	25×3
Teflon ×5	25×5
Teflon ×8	25×8

ɣ-ray Induced Damage in Wrapping

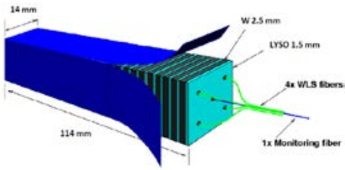


After 90 Mrad 15 μm thick Al foil is the most stable reflector.

https://indico.cern.ch/event/341217/contribution/7/material/slides/0.pdf



Existing ECAL Monitoring System



Two DP2 lasers to guarantee 100% availability of 447 nm