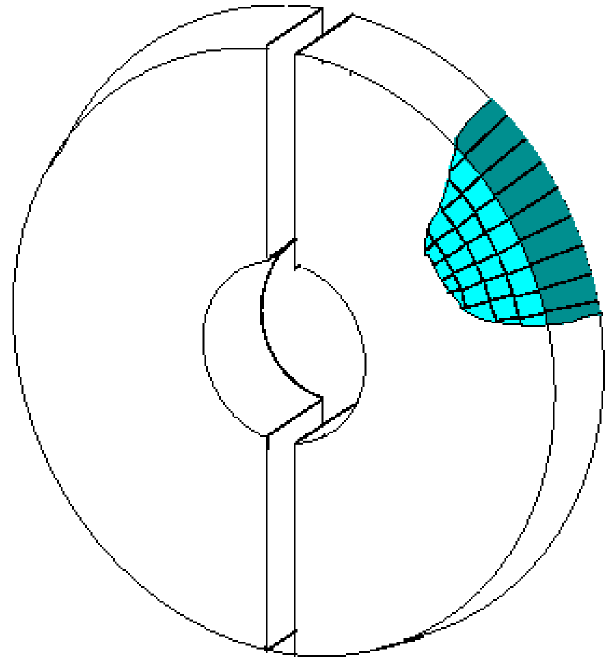
Investigation on GSO:Ce Crystals

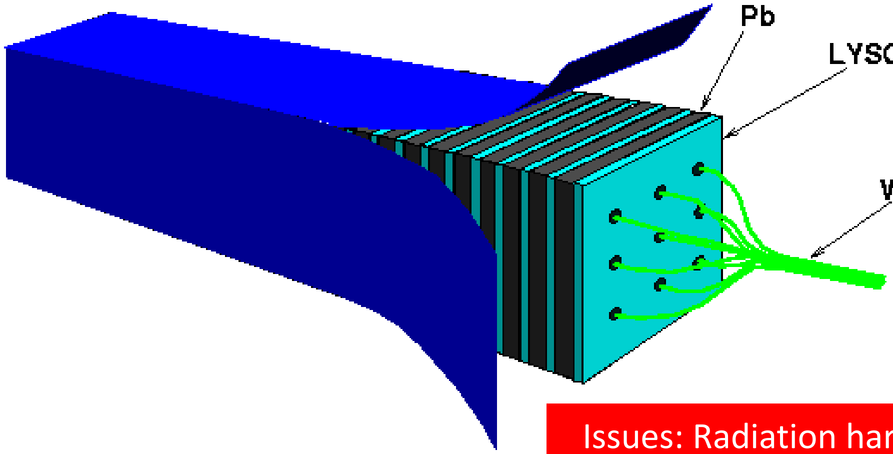
Ren-Yuan Zhu

California Institute of Technology

October 30, 2012

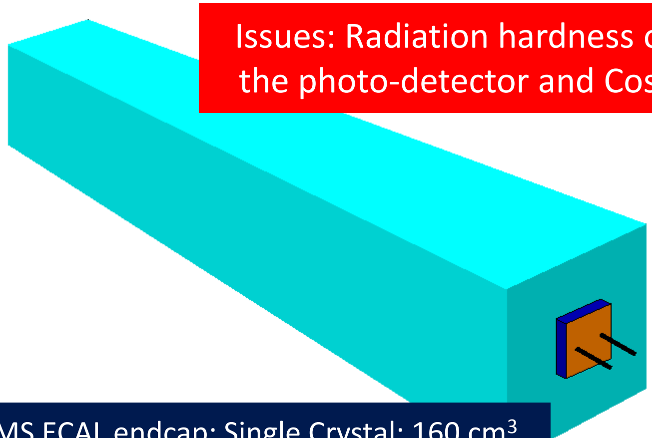
CMS Forward Calorimeter Upgrade

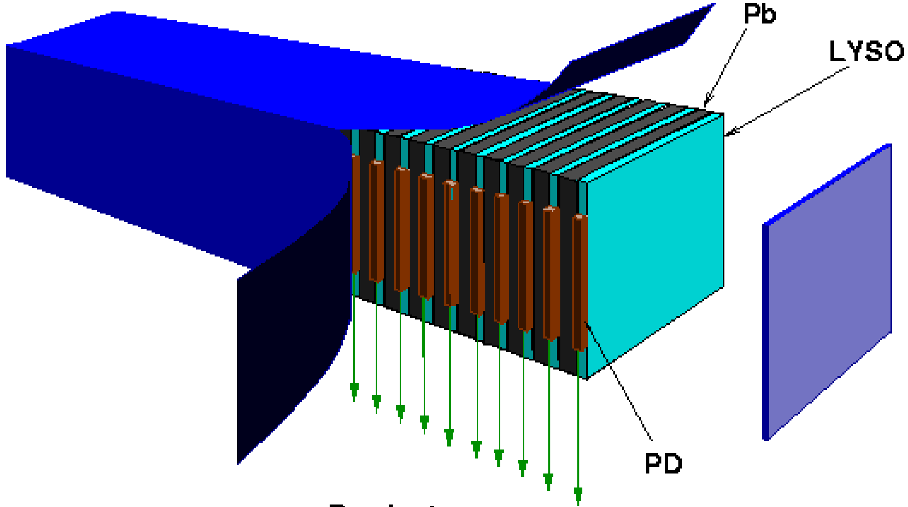




Issues: Radiation hardness of photo-detector and WLS fiber

Issues: Radiation hardness of the photo-detector and Cost





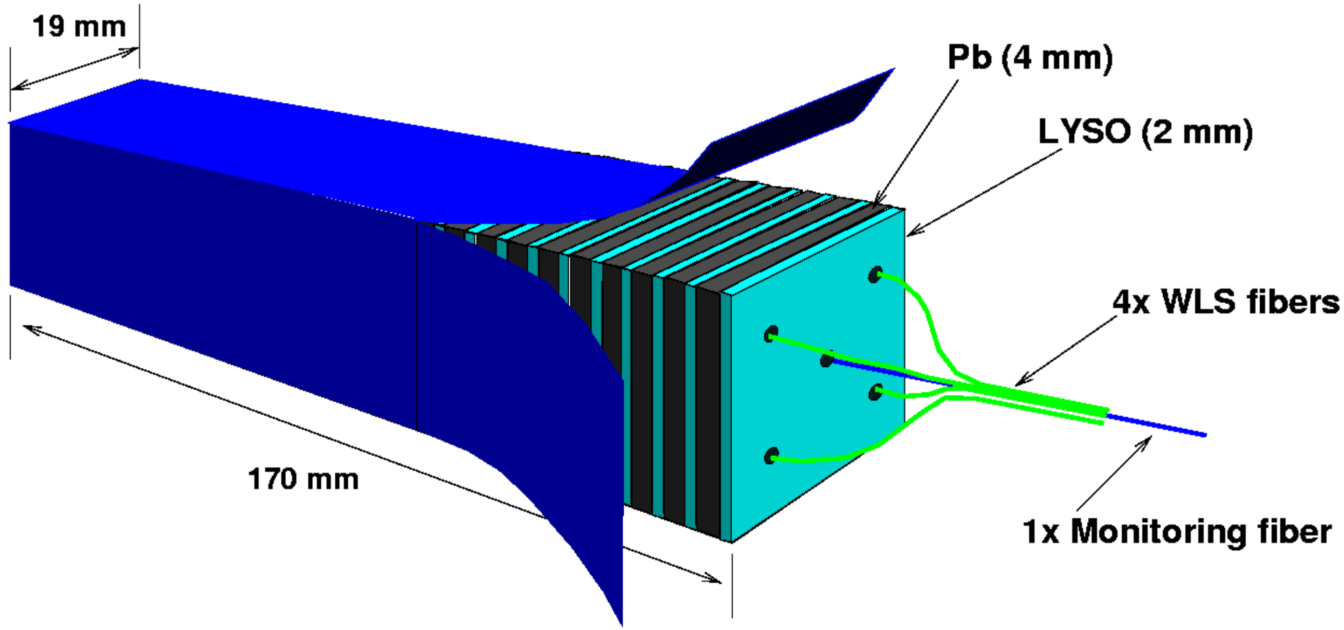
Issue: Radiation hardness of the photo-detector

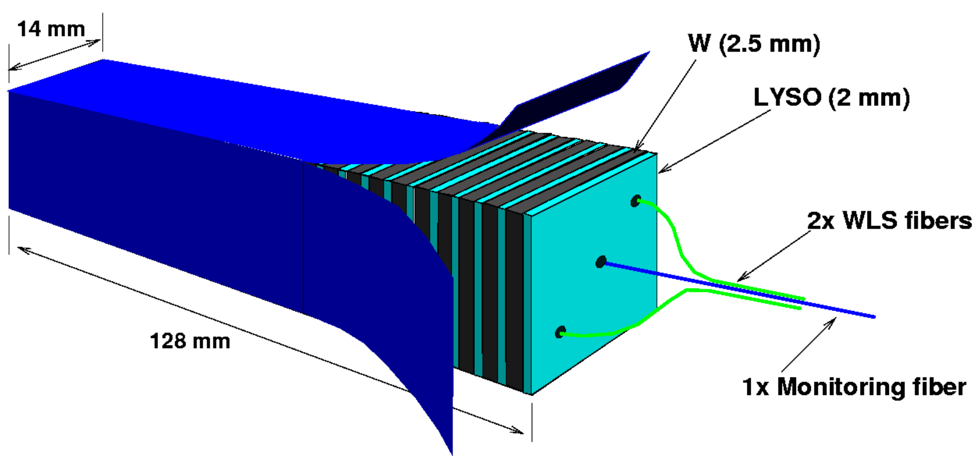
CMS ECAL endcap: Single Crystal: 160 cm^3
Total number: 16,000 Total Volume: 2.5 m^3
Expected Crystal Cost: ~$60M@$25/cc

Crystal Cost: <$10M

Shashlik Cells with Pb/W Absorbers

R.-Y. Zhu, presented in the Forward Calorimetry Task Force meeting on 8/30/2012

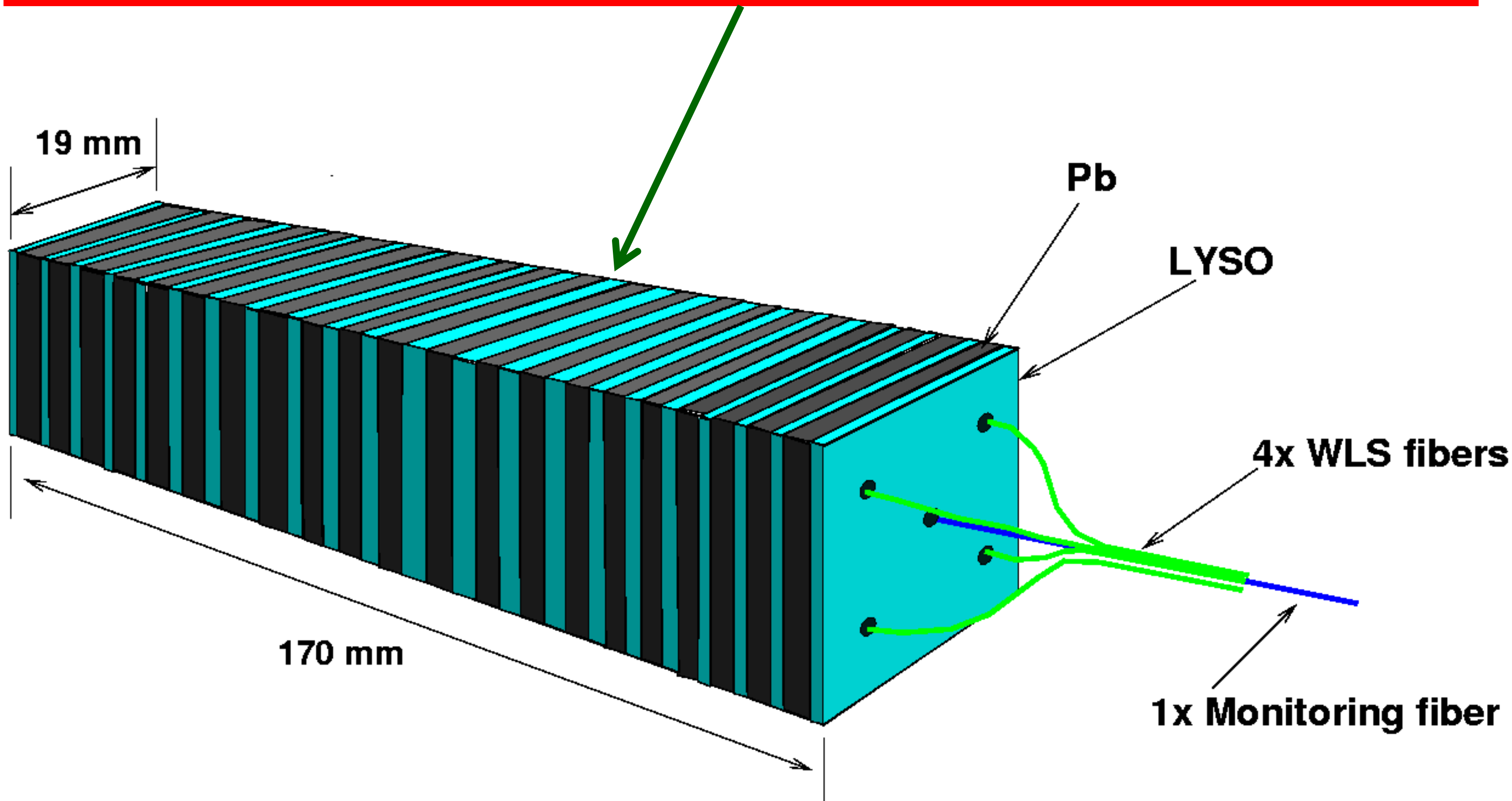




It is interesting to see what is the energy resolution and the photon angular resolution with longitudinal segmentation.

Another Option: Varied Sampling

The thickness of crystal plates may be adjusted according to the longitudinal shower profile without cost increase. An optimized sampling with varied crystal plate thickness may provide a better resolution for photons and electrons, but...



Presented in the Forward Calorimetry Task Force meeting on 8/30/2012

Crystals Options

While LSO/LYSO might be seen as the only scintillating crystal which might survive the sever radiation environment expected at HL-LHC, many fast crystals may be considered as candidates of the active material for a sampling calorimeter option. This is due to the fact that the consequence of radiation induced absorption is much reduced because of the short light path for the sampling option. To avoid calibration difficulty, however, damage recovery, which leads a dose rate dependent damage, is not preferred.

Other Fast Crystal Candidates

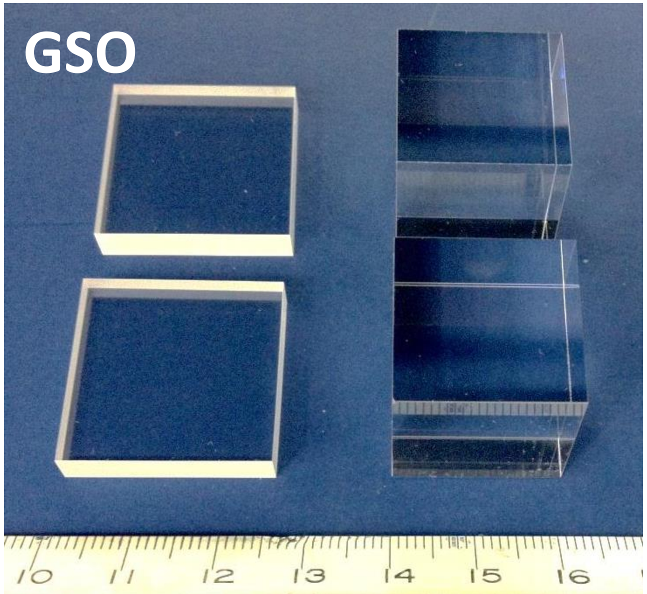
R.-Y. Zhu, Talk in CMS Forward Calorimetry Task Force Meeting, CERN, June 27, 2012

	LSO/LYSO	GSO[1]	YSO[1]	CsI	BaF_2	CeF_3	$CeBr_3$[2]	$LaCl_3$	$LaBr_3$	Plastic scintillator (BC 404)[3]
Density (g/cm^3)	7.40	6.71	4.54	4.51	4.89	6.16	5.23	3.86	5.29	1.03
Melting point (°C)	2050	1950	1980	621	1280	1460	722	858	783	70[#]
Radiation Length (cm)	1.14	1.38	3.04	1.86	2.03	1.70	1.96	2.81	1.88	42.54
Molière Radius (cm)	2.07	2.23	2.87	3.57	3.10	2.41	2.97	3.71	2.85	9.59
Interaction Length (cm)	20.9	22.2	27.3	39.3	30.7	23.2	31.5	37.6	30.4	78.8
Z value	64.8	57.9	33.3	54.0	51.6	50.8	45.6	47.3	45.6	-
dE/dX (MeV/cm)	9.55	8.88	6.70	5.56	6.52	8.42	6.65	5.27	6.90	2.02
Emission Peak[a] (nm)	420	430	420	420 310	300 220	340 300	371	335	356	408
Refractive Index[b]	1.82	1.85	1.80	1.95	1.50	1.62	1.9	1.9	1.9	1.58
Relative Light Yield[a,c]	100	35	40	4.2 1.3	42 4.8	8.6	141	15 49	153	35
Decay Time[a] (ns)	40	65	70	30 6	650 0.9	30	17	570 24	20	1.8
d(LY)/dT[d] (%/°C)	-0.2	-0.7	-0.3	-1.4	-1.9 0.1	~0	-0.1	0.1	0.2	~0

a. Top line: slow component, bottom line: fast component.
b. At the wavelength of the emission maximum.
c. Relative light yield normalized to the light yield of LSO
d. At room temperature (20°C)
#. Softening point

1. N. Tsuchida et al *Nucl. Instrum. Methods Phys. Res. A*, 385 (1997) 290-298
http://www.hitachi-chem.co.jp/english/products/cc/017.html
2. W. Drozdowski et al. *IEEE TRANS. NUCL. SCI*, VOL.55, NO.3 (2008) 1391-1396
Chenliang Li et al, *Solid State Commun*, Volume 144, Issues 5–6 (2007),220–224
http://scintillator.lbl.gov/
3. http://www.detectors.saint-gobain.com/Plastic-Scintillator.aspx
http://pdg.lbl.gov/2008/AtomicNuclearProperties/HTML_PAGES/216.html

GSO:Ce Samples from HITACHI

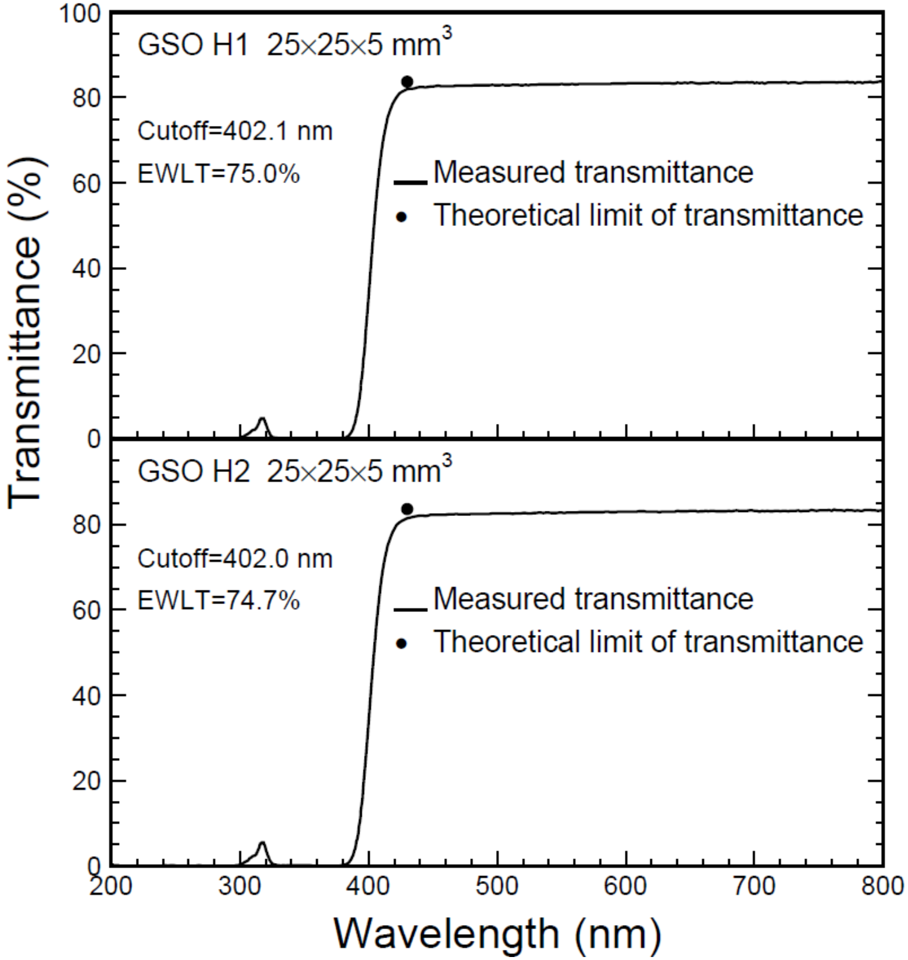


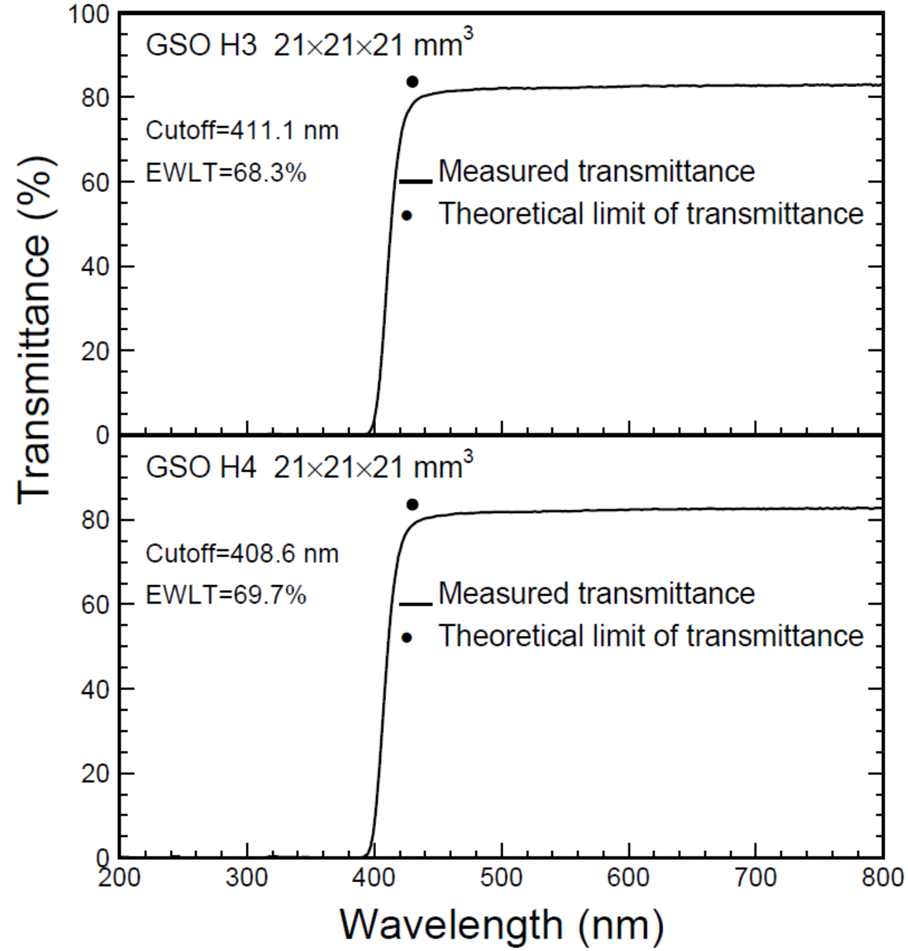
Sample ID	Received Date	Dimension	Polish
GSO H1	8/21/2012	25×25×5 mm^3	Two faces (25×25 mm^2 faces)
GSO H2	8/21/2012	25×25×5 mm^3	Two faces (25×25 mm^2 faces)
GSO H3	8/21/2012	21×21×21 mm^3	Six faces
GSO H4	8/21/2012	21×21×21 mm^3	Six faces

Experiments

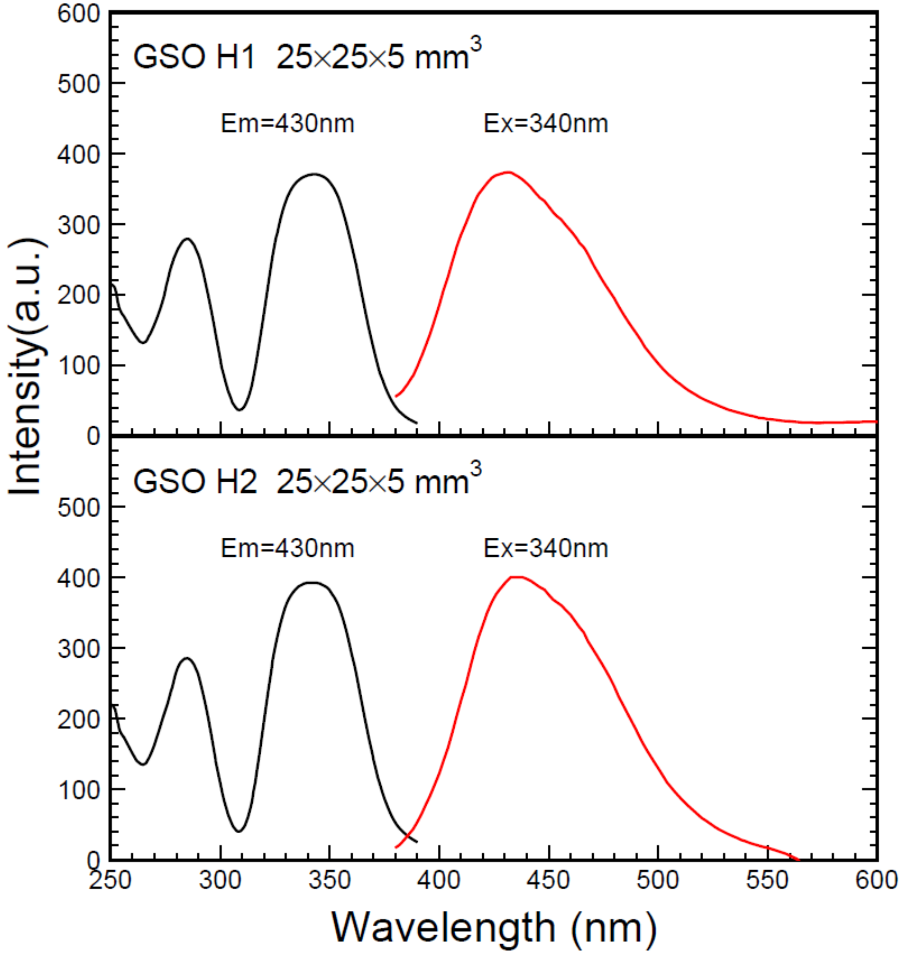
- All samples annealed at 300℃ (600 minutes)
- Optical properties: Transmittance and Photo-Luminescence
- Light Output (LO), Pulse Height Spectrum (PHS) and Uniformity measured by R1306 PMT with a grease coupling and using a Cs-137 source.

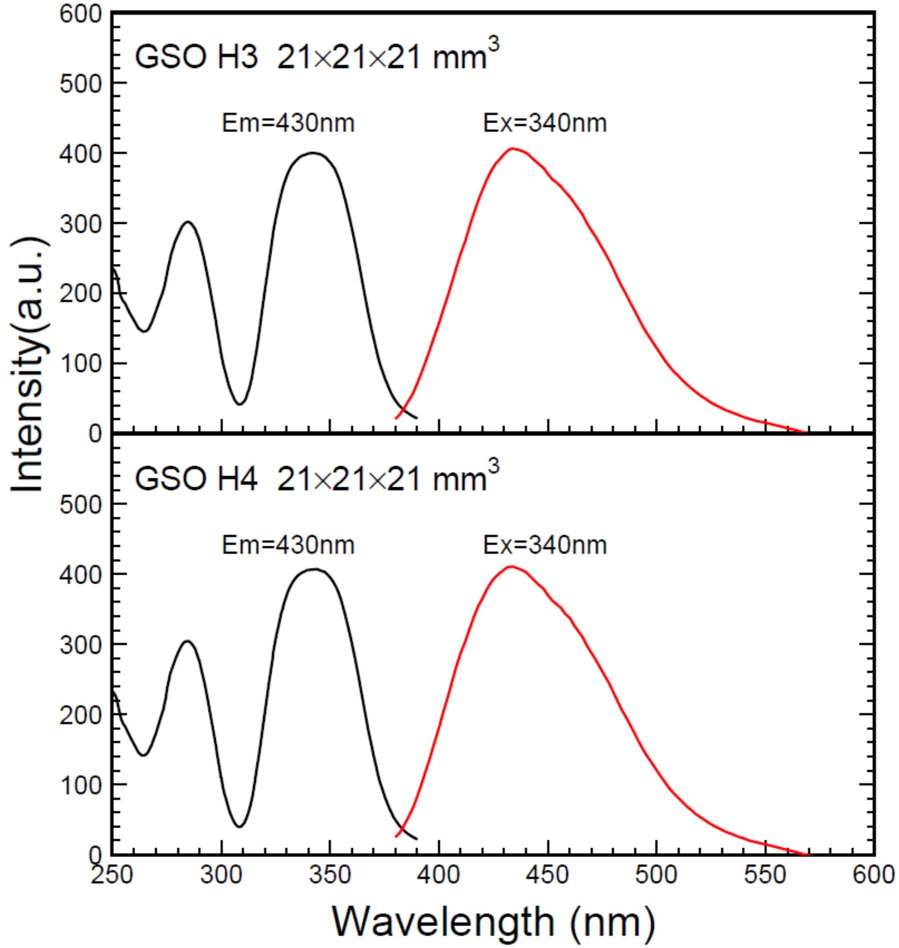
GSO:Ce Transmittance



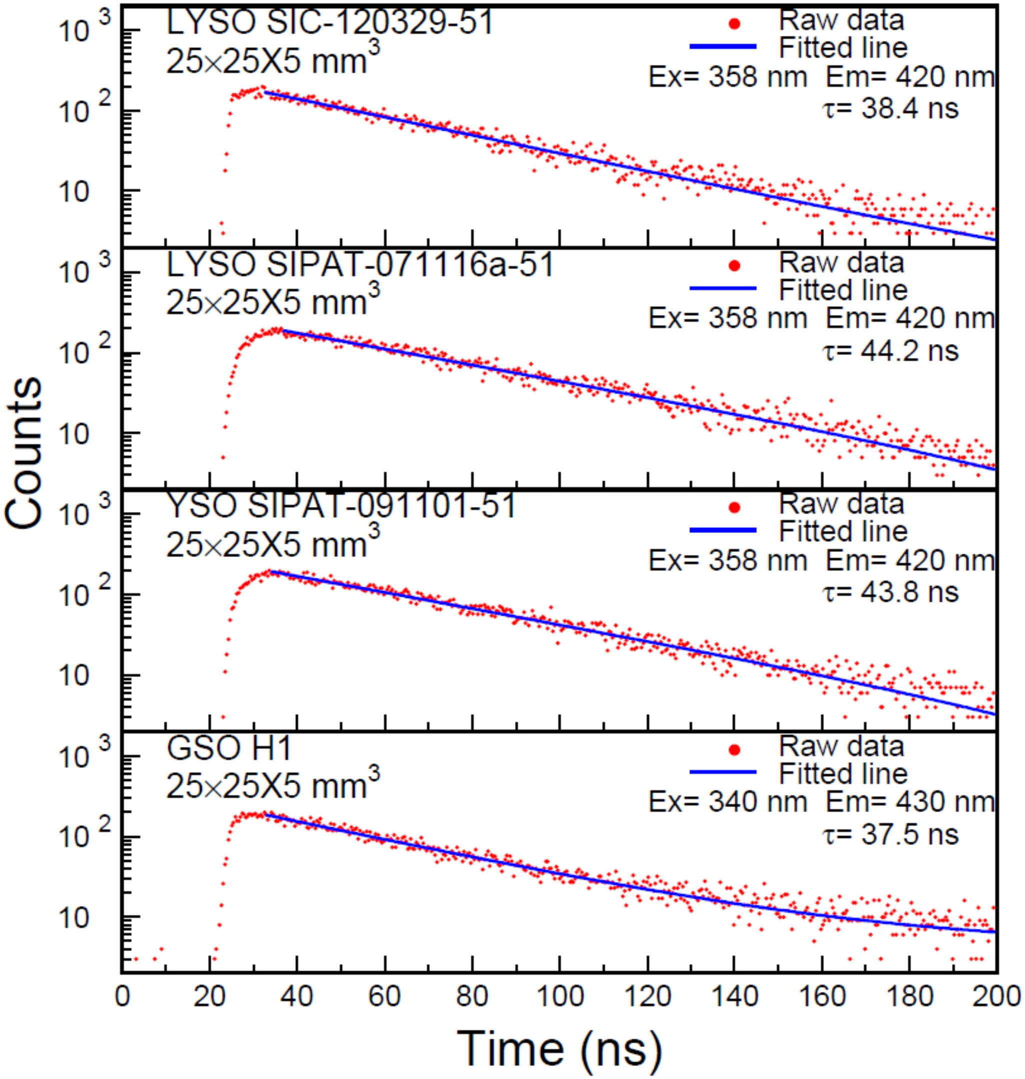


GSO:Ce Photo-Luminescence





GSO:Ce Decay Time



Measured with Edinburgh FLS920 Fluorescence Spectrometer

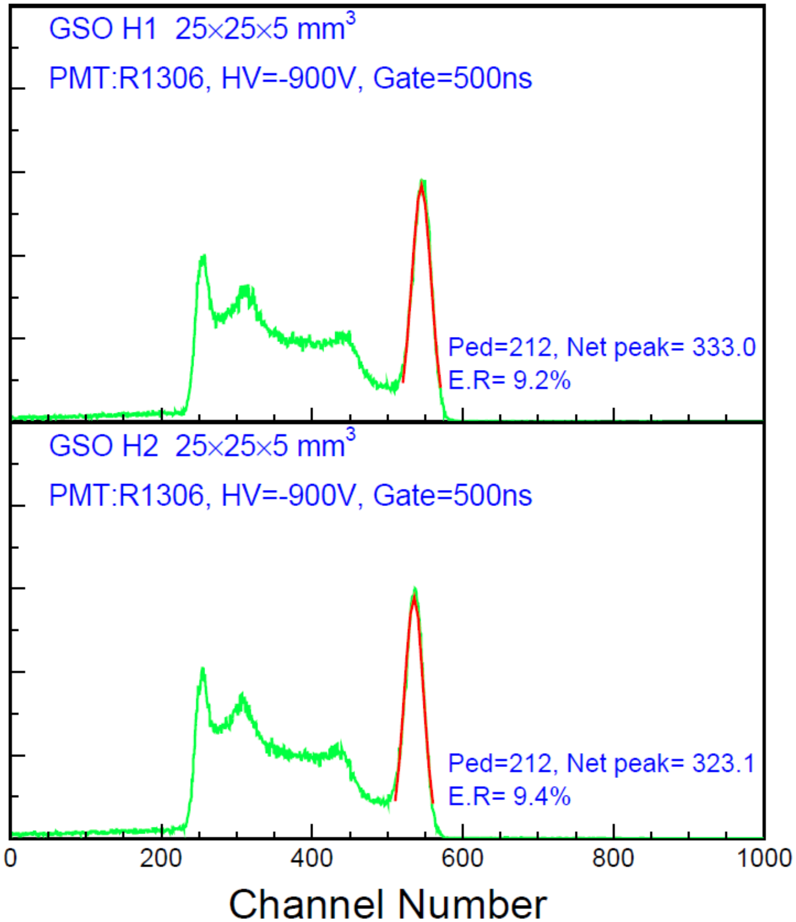
Fitting function:

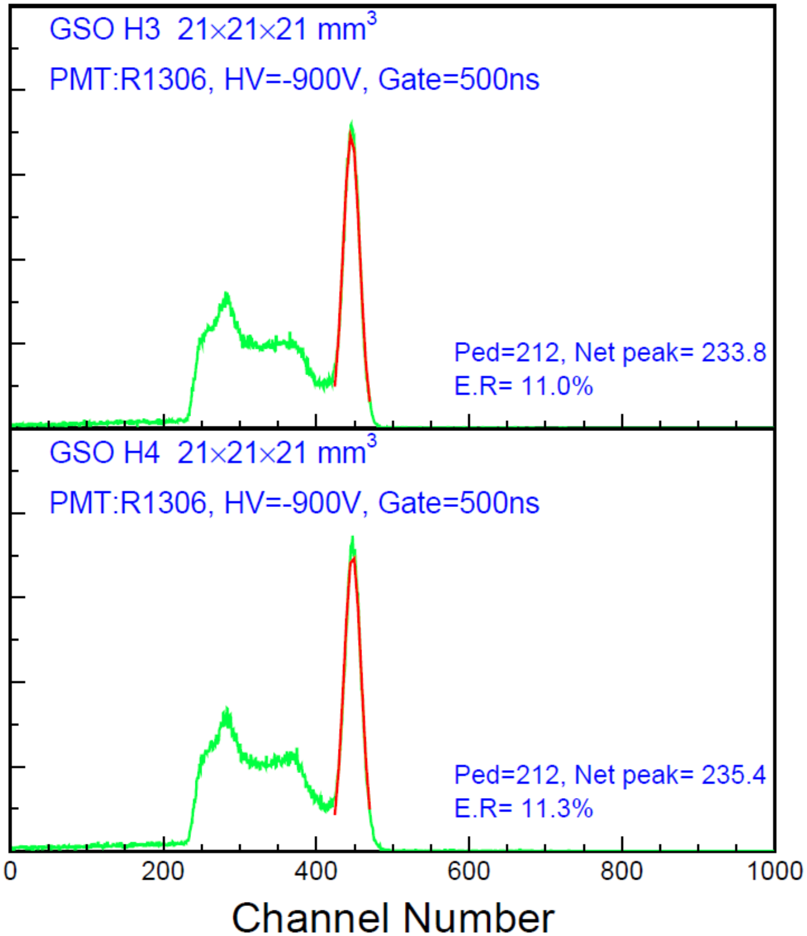
$$R(t) = B_1 \exp\left\{-\frac{t}{\tau_1}\right\}$$

Excited with eV Photons: 40 ns

GSO:Ce Pulse Height Spectra

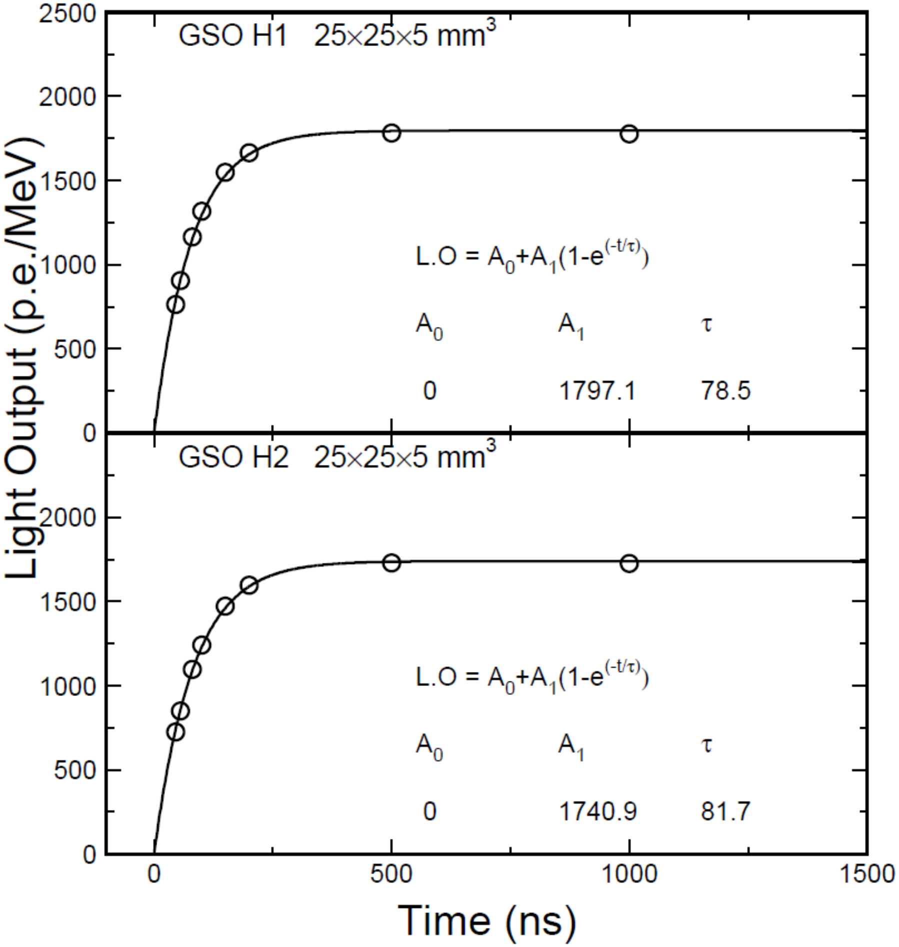
Excellent energy resolution, compatible with LSO/LYSO

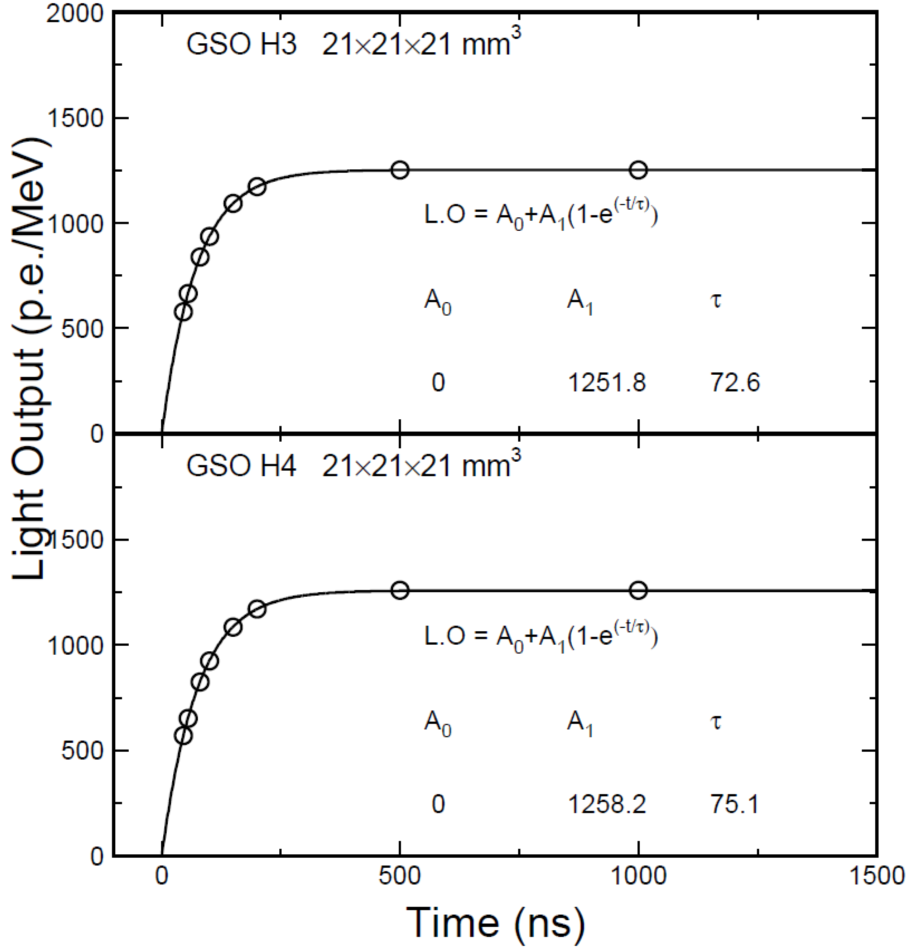




GSO:Ce Decay kinetics

Measured with Cs-137 Gamma-rays: 80 ns

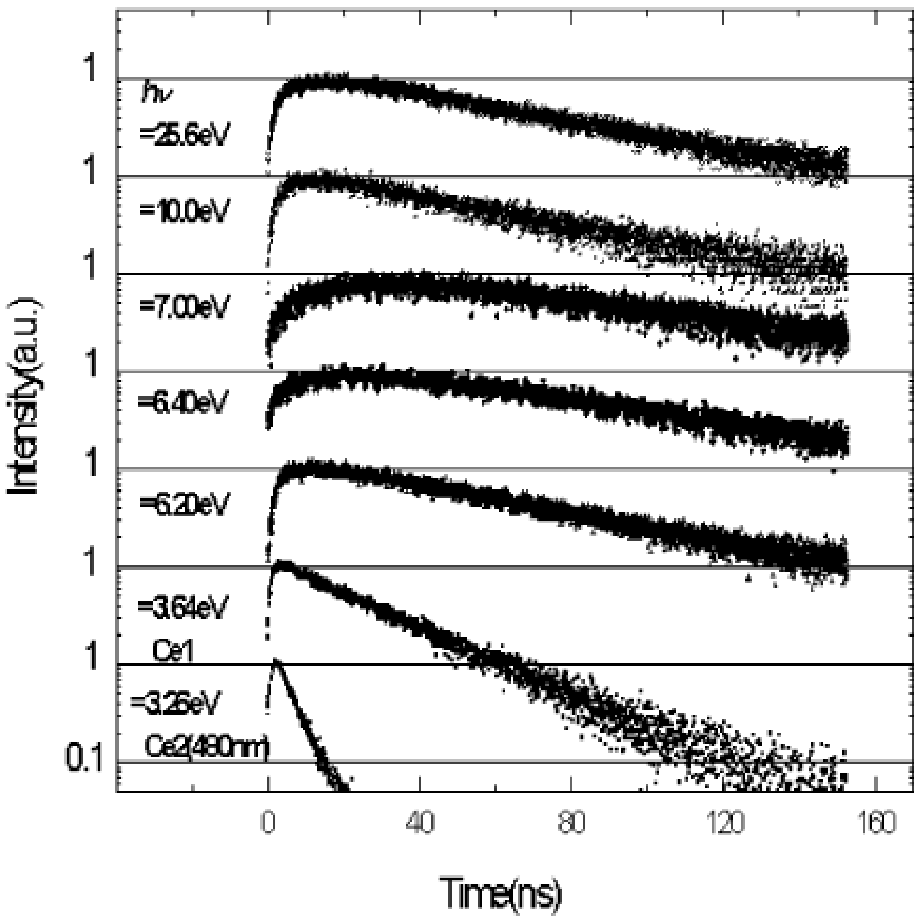


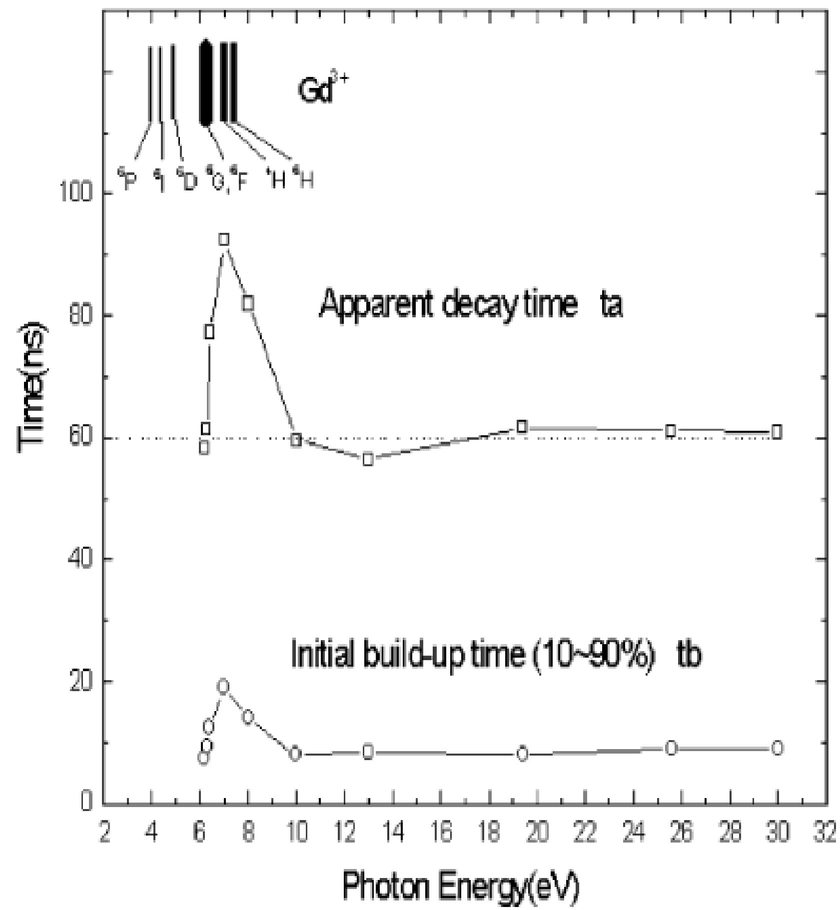


GSO:Ce Scintillation Decay Time

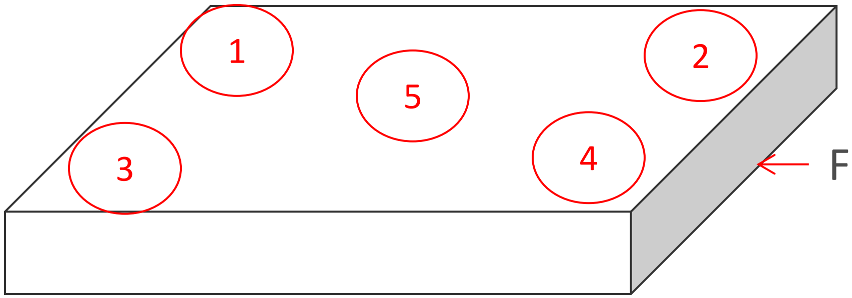
S. Shimizu et al, NIM A486, 2002, 490

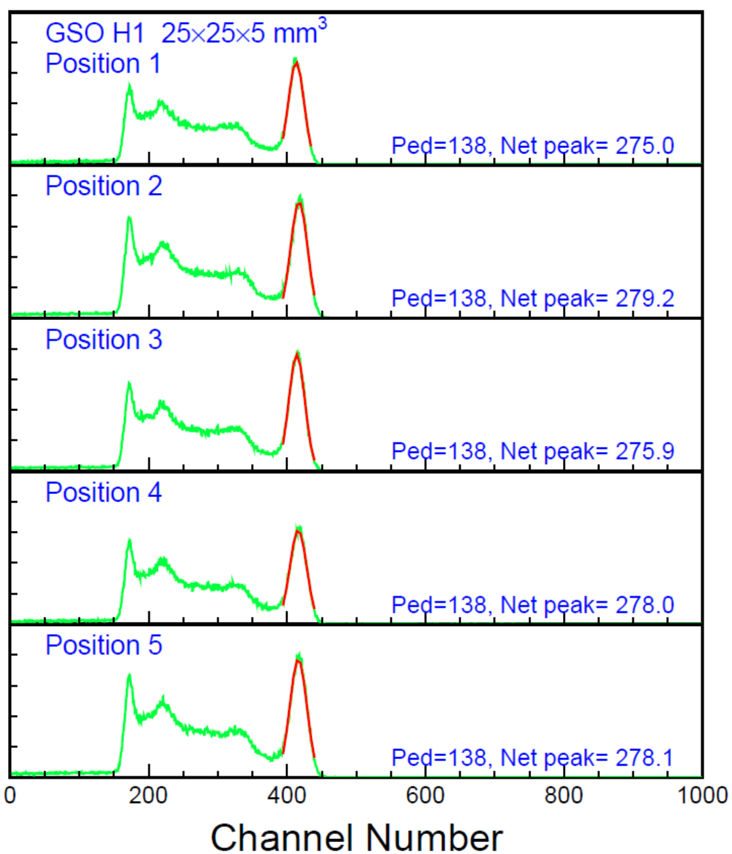
Decay time found as a function of excitation energy

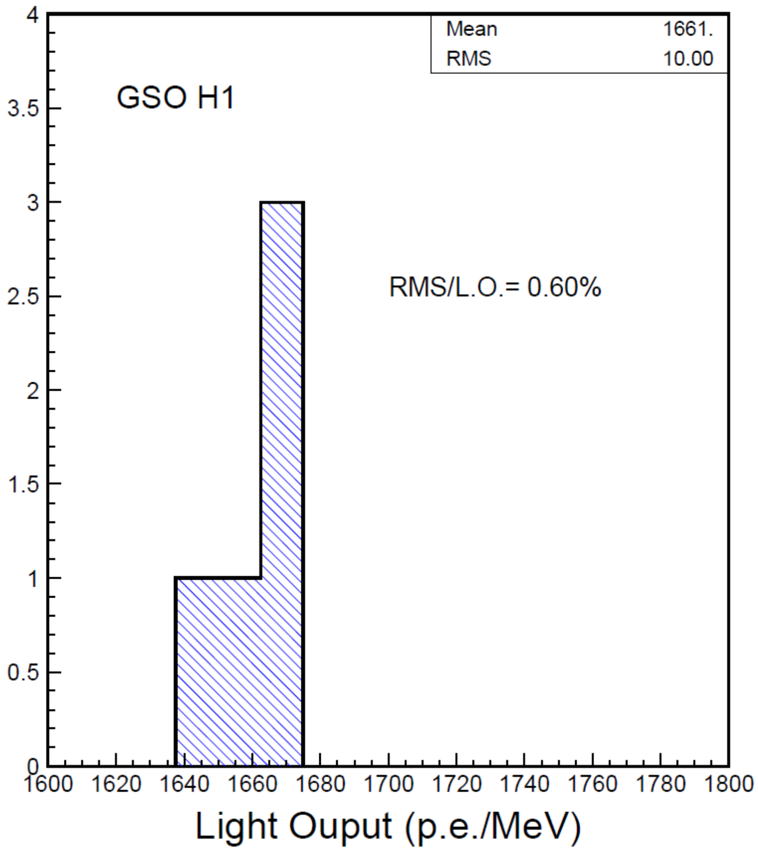




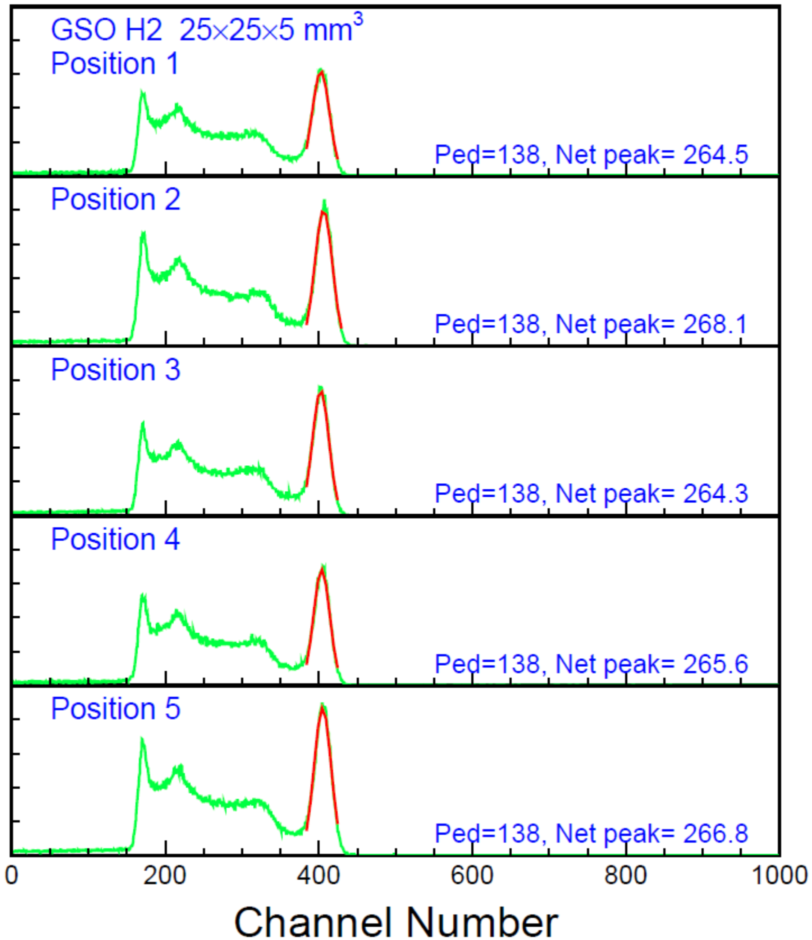
GSO:Ce Plate Response Uniformity

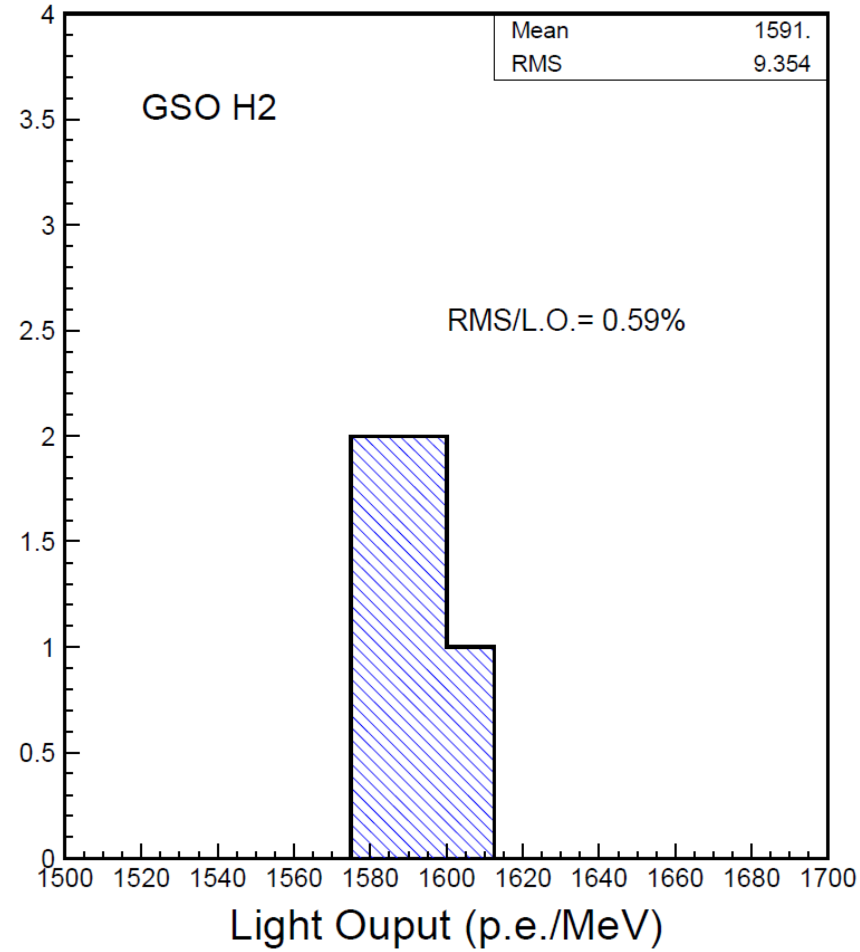






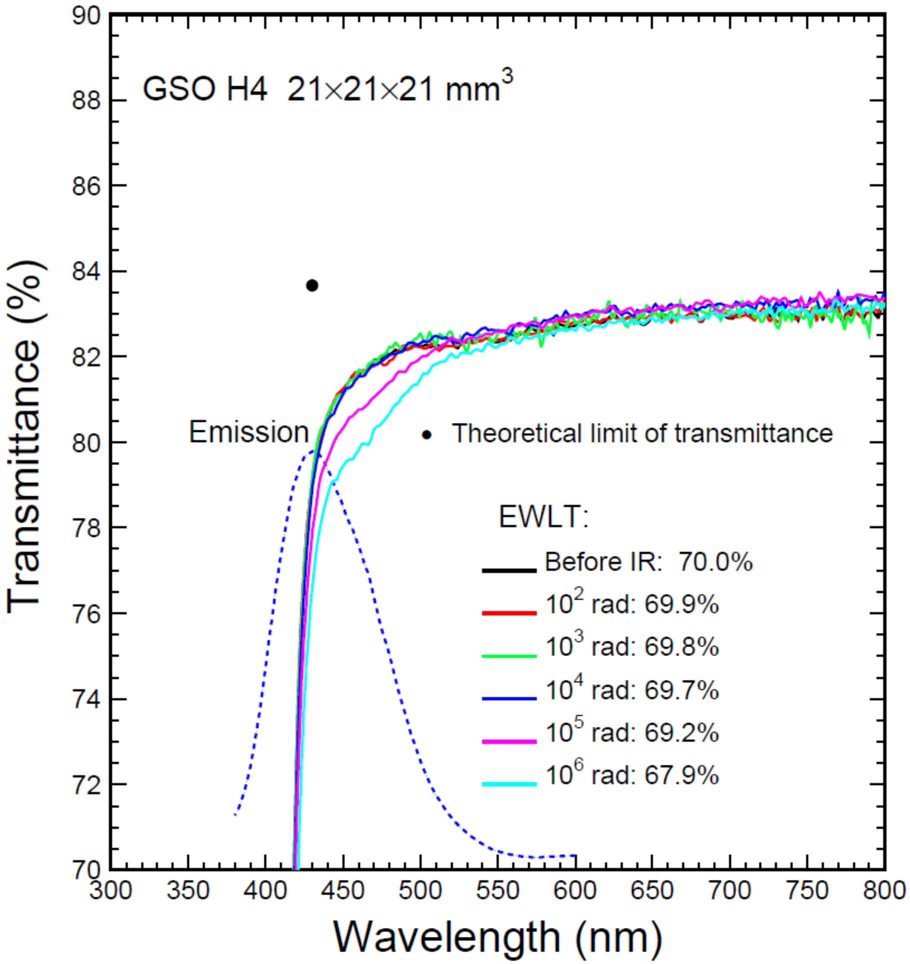
GSO:Ce Plate Response Uniformity

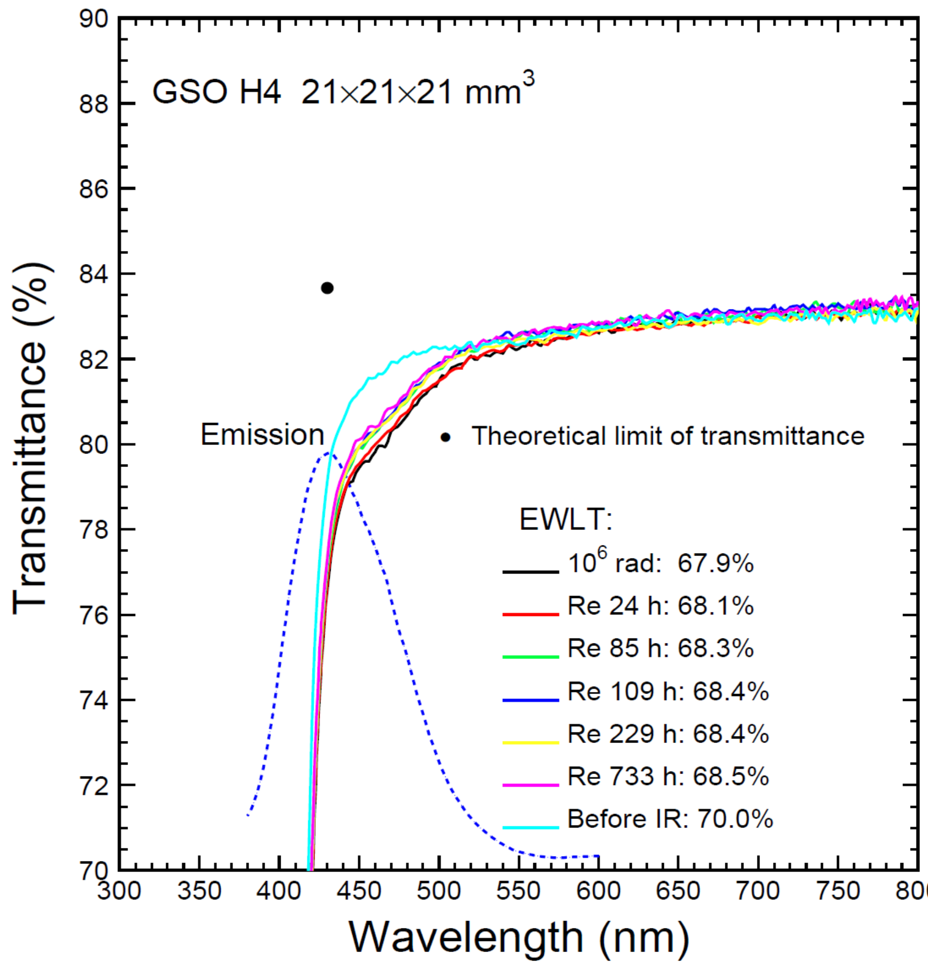




GSO:Ce LT Damage/Recovery

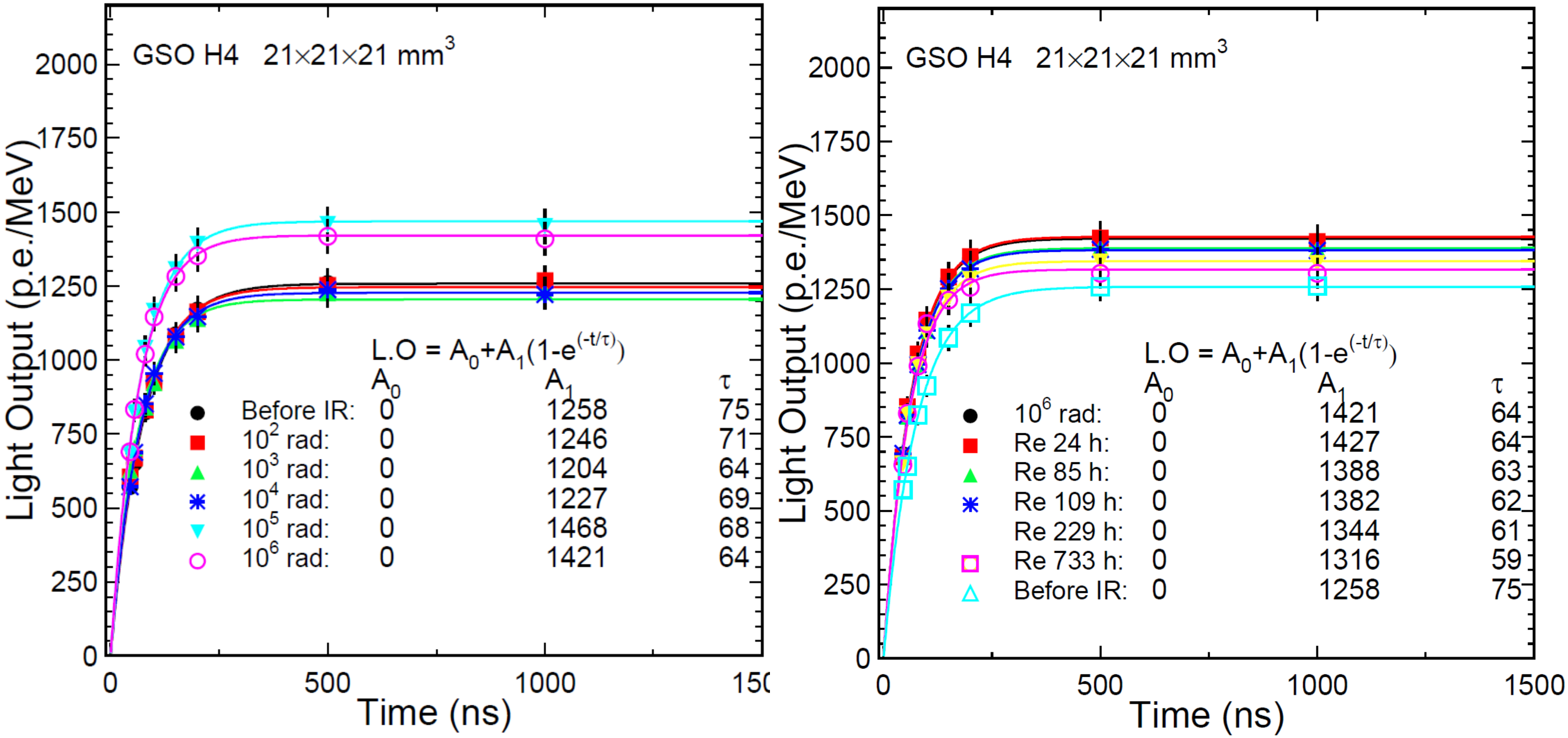
Damage in transmittance is small (3%) up to 1 Mrad
Recovery observed, indicating a dose rate dependent damage



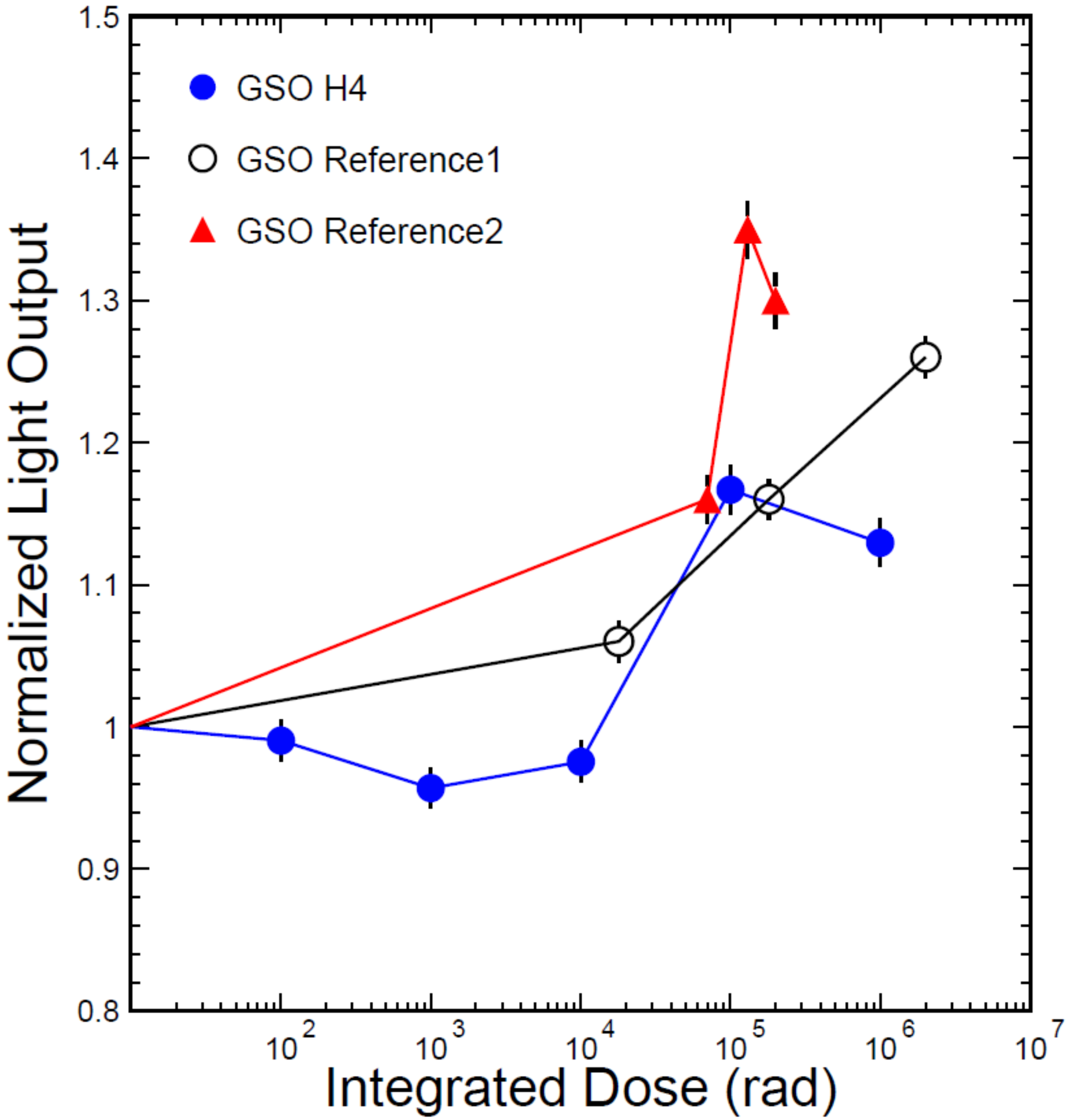


GSO:Ce LO Damage/Recovery

Damage in light output is large (>10%) up to 1 Mrad
Irregular behavior in LO under radiation is observed



GSO:Ce Irregular Behavior of LO



Ref 1: K. Kawade et al., JINST, 6, T09004, 2011.

Ref 2: Tanaka et al., NIM A404, 283-294, 1998

Summary of GSO:Ce

Vender	Crystal	Cutoff (nm)	EWLT (%)	τ (ns)	LO (p.e./MeV)	E.R. (%)	Uniformity RMS/L.O. (%)
HITACHI	GSO H1	402.1	75.0	78.5	1797.1	9.2	0.60
	GSO H2	402.0	74.7	81.7	1740.9	9.4	0.59
	GSO H3	411.1	68.3	72.6	1251.8	11.0	-
	GSO H4	408.6	69.7	75.1	1258.2	11.3	-

Following issues are observed in GSO:Ce, based on which GSO:Ce is not our candidate for the sampling option.

- Gadolinium has high neutron x-section, and is an expansive material similar to lutetium. Hitachi is a single vendor.
- Its light yield/decay is half/double as compared to LSO/LYSO.
- While radiation damage in transmittance is small, irregular behavior was observed in LO variation under irradiation by us and others. Recovery is also observed, so expect instability.