# Year 1 Deliverables


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## Caltech


**August 10, 2022**

Presented in CalVision General Meeting

# Overall Plan

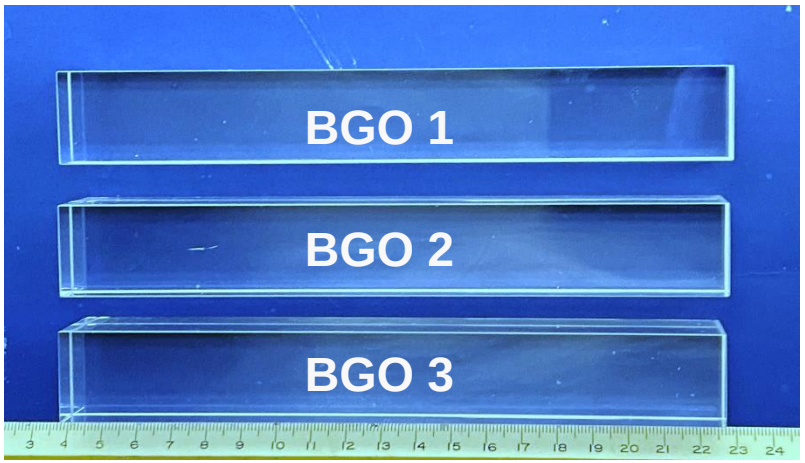
Junjie and his student Yuxiang Guo visited Caltech on March 3 and 4, 2022. Following this visit, we measured three each of BGO and PWO crystals from SIC. Listed below, is our report delivered to Junjie on 4/28/2022.

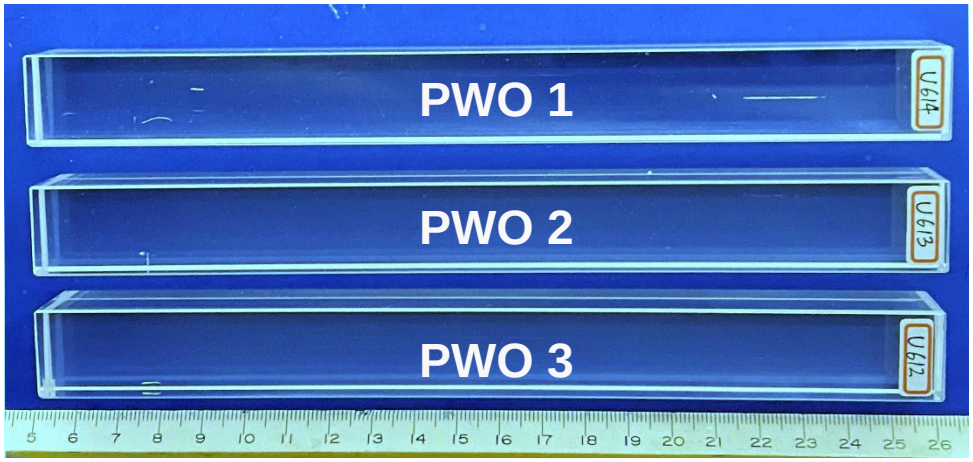
Our plan in the 1st year is to understand current status of inorganic scintillators relevant for the CalVision mission and encourage potential vendors to develop scintillating glass for us.

Characterize small size crystal samples (1.5 $X_0$ cubes) of BGO, BSO, $PbF_2$ and PWO from world-wide producers, such as Crytur and Saint Gobain in Europe and SIC in China etc.

Blue Sky HHCAL: Characterize scintillating glass samples (1.5 $X_0$ cubes) from world-wide producers in the US (Scintilex, AFO and RMD), Europe (Giessen: Czech Precios and German Schott), and China (BGRI, Jinggangshan University etc.).

# Report on BGO and PWO Crystals



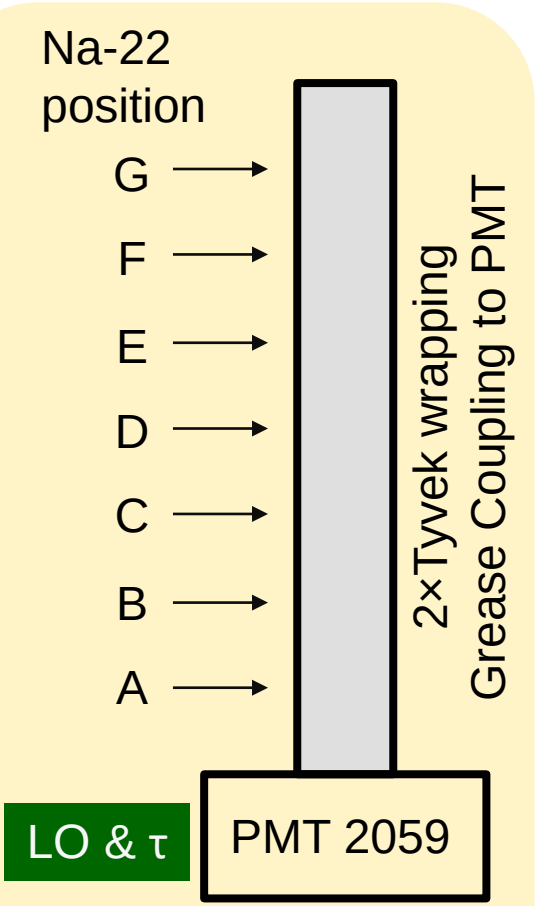




| ID | Dimension ($mm^3$) | # | Polishing |
|---|---|---|---|
| BGO-1,2,3 | 25×25×180 | 3 | All faces |
| PWO-1,2,3 | 20×20×200 | 3 | All faces |
| All samples from U. Michigan received on March 2nd, 2022 (Wednesday) | | | |

## Experiments

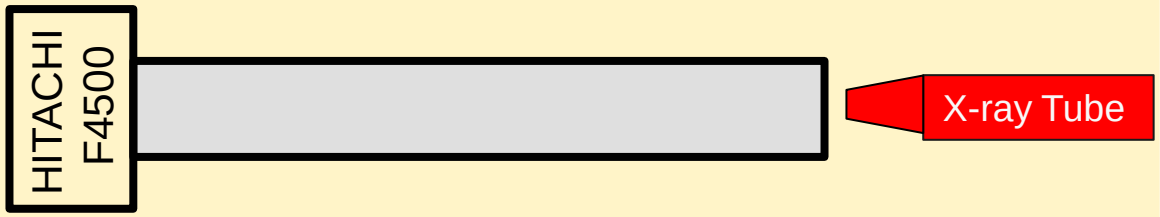
Measured at room temperature: X-ray excited luminescence (XEL), Longitudinal/Transverse transmittance (LT/TT), Emission Weighted Longitudinal transmittance (EWLT), Pulse Height Spectra (PHS), Light Output (LO) & Decay Time (τ), Light Response Uniformity (LRU). Light Yield (LY) with Emission Weighted Quantum Efficiency (EWQE) taken out.

# Measurement Setup




LO & Decay Kinetics: **A**
Pulse Shape: **A**
LRU/PHS: **A-G** (only 200/2,000 ns gate for PWO/BGO)

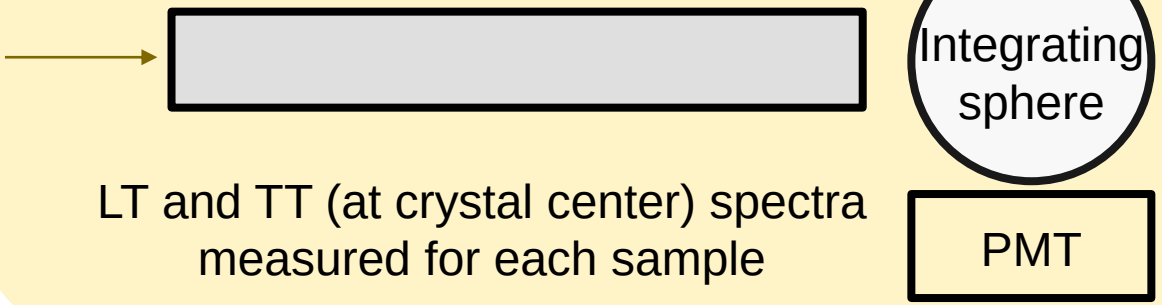
## X-ray excited luminescence




XEL spectrum measured for each sample
With no wrapping and air gap coupling

## Transmittance

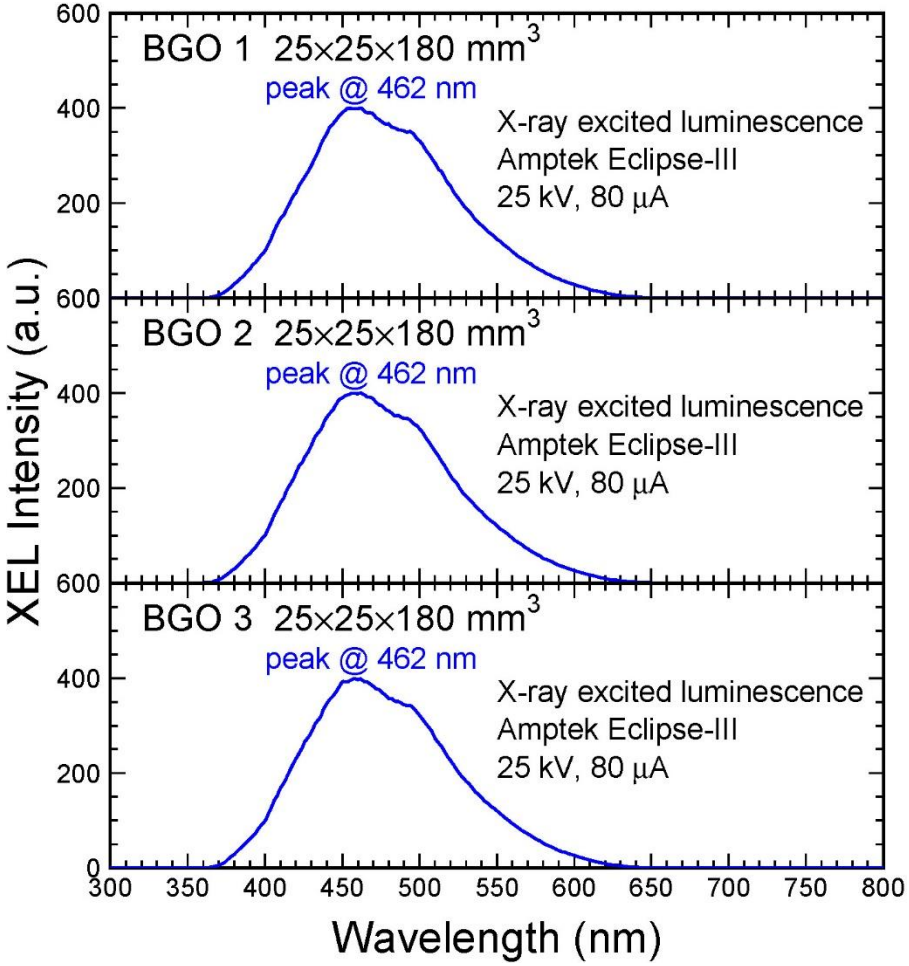
HITACHI 3210

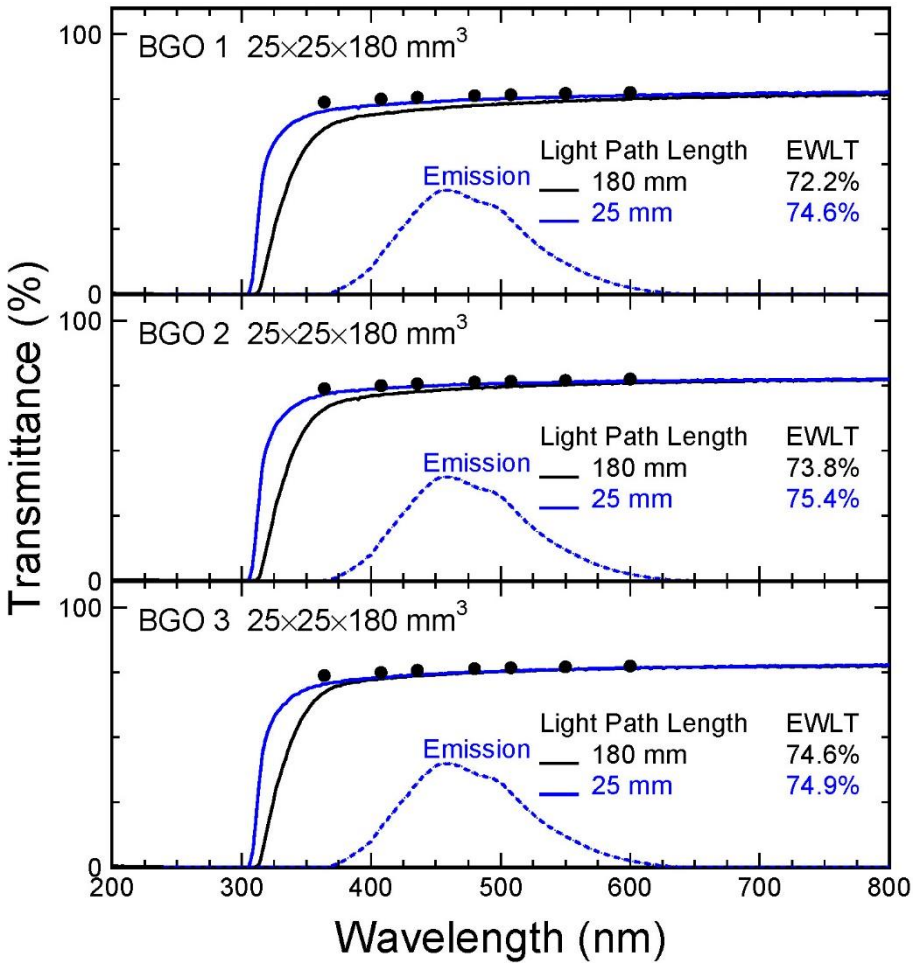



LT and TT (at crystal center) spectra measured for each sample

# XEL and LT Spectra, TT and EWLT: BGO

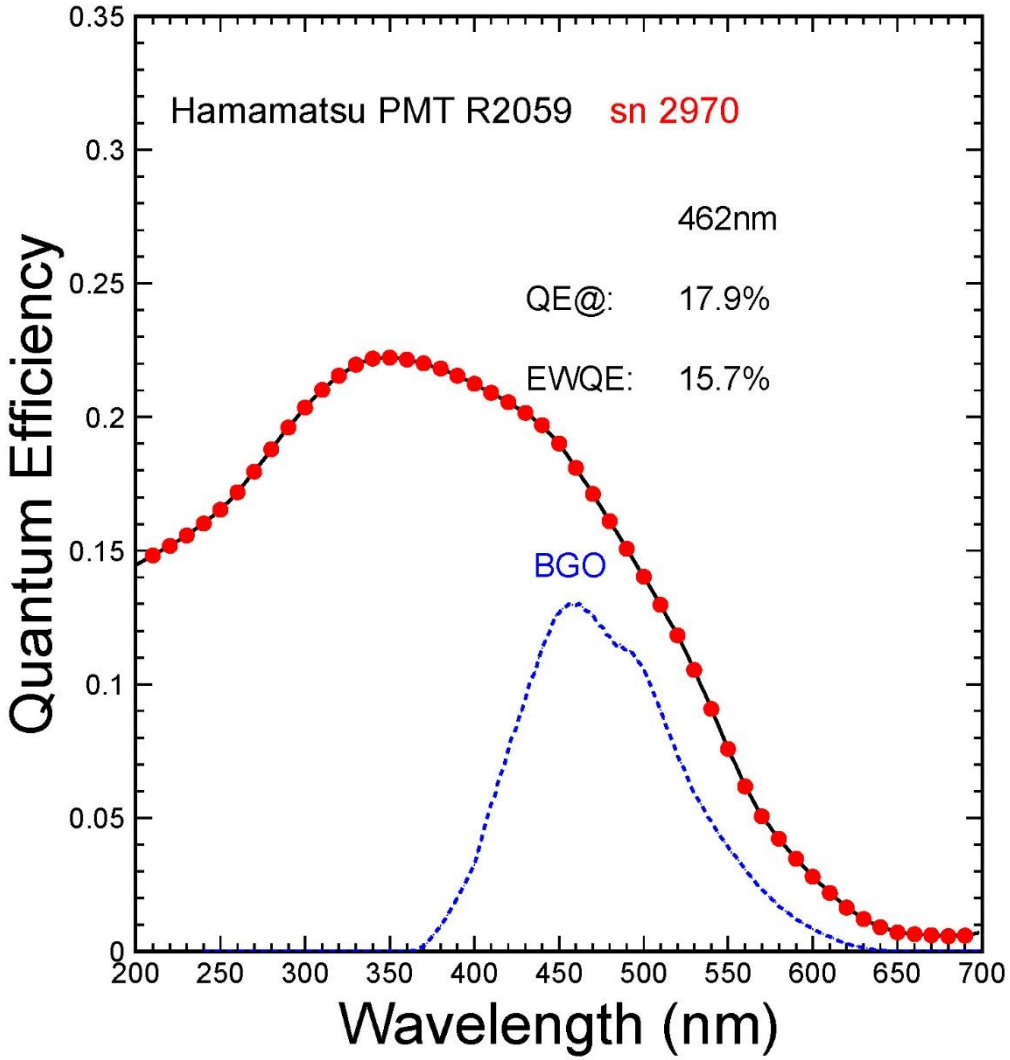
XEL peaked at ~462 nm
TT measured at the crystal center



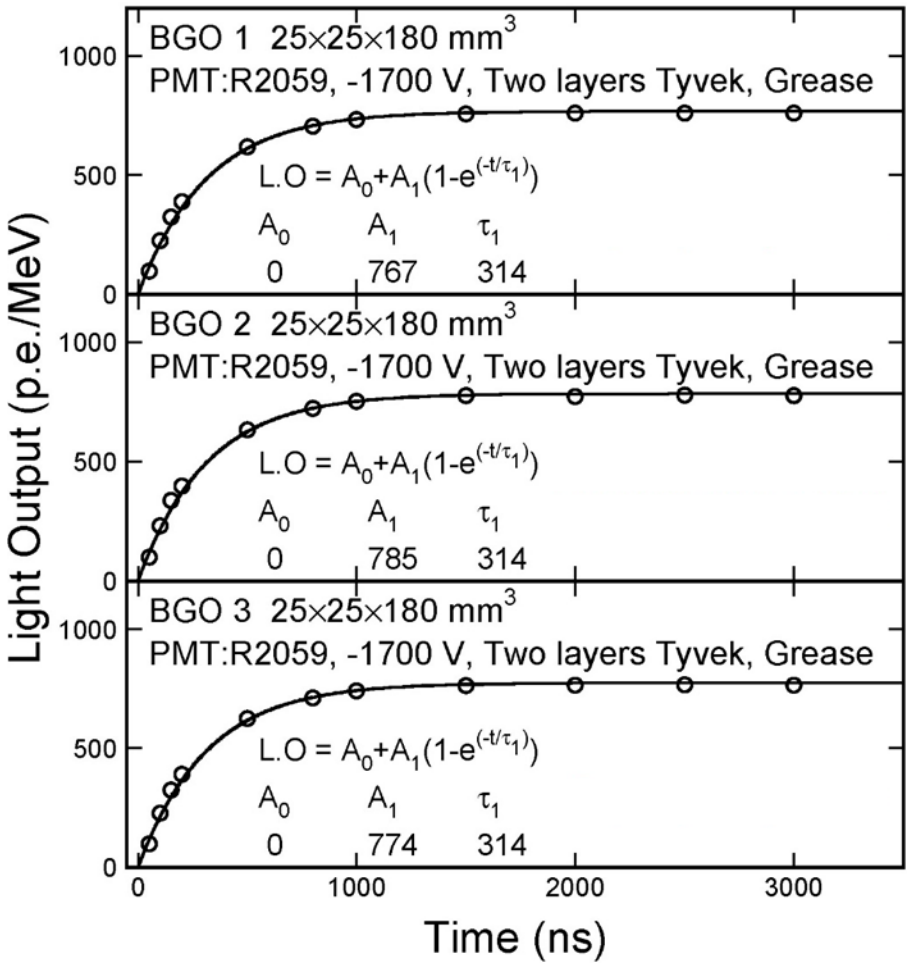
# EWQE: BGO

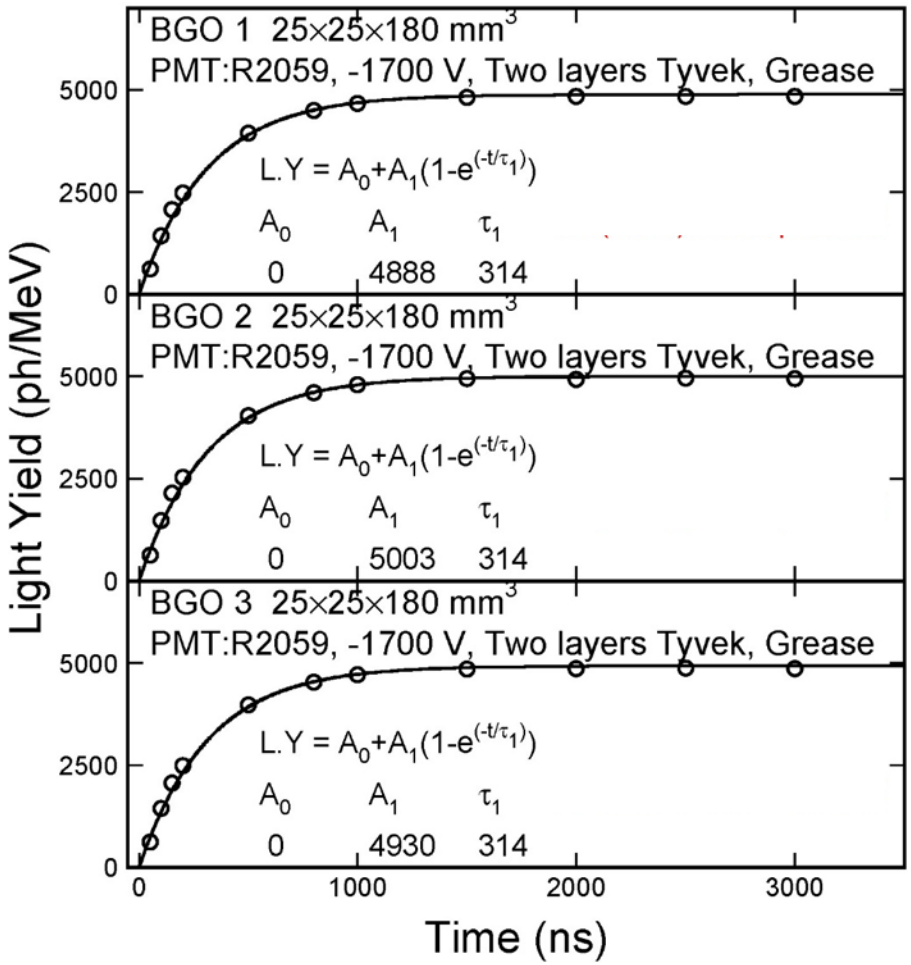
EWQE of 15.7% used to convert light output (LO) in p.e./MeV to light yield (LY) in photons/MeV. Both are sample/wrapping/ coupling dependent.



# LO/LY and Decay Kinetics: BGO

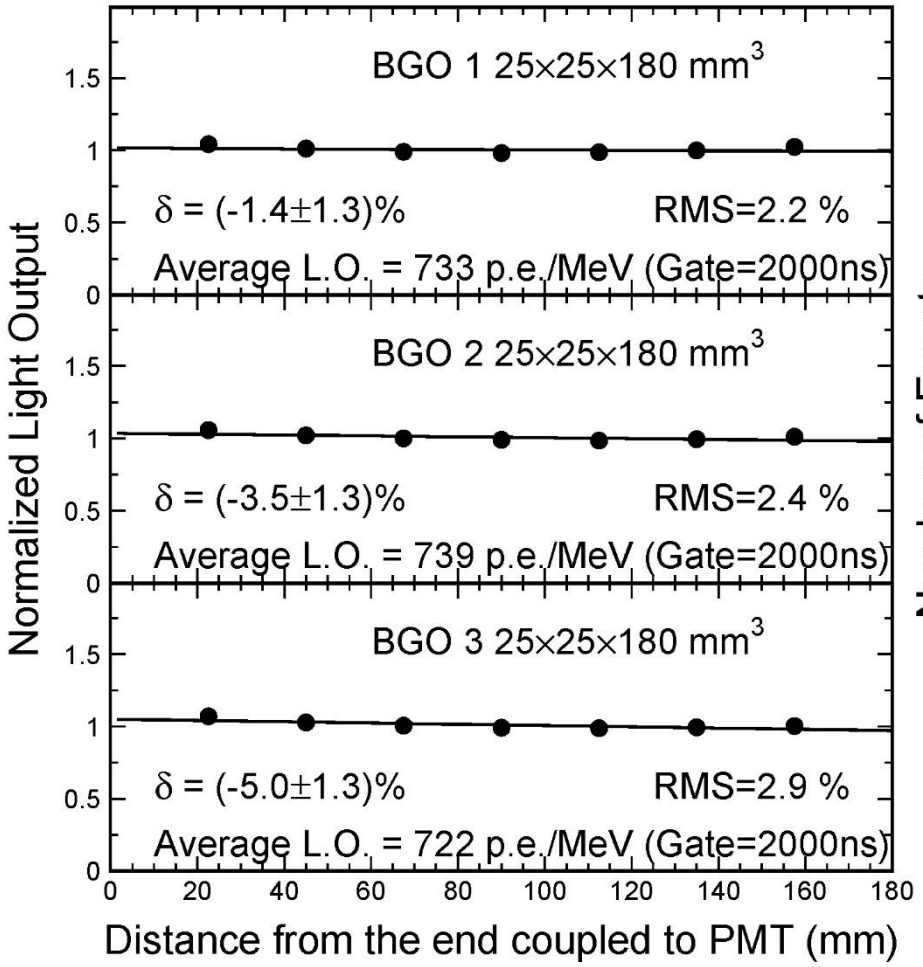
BGO shows 314 ns decay time with LO and LY of 775 p.e./MeV and 4,940 ph/MeV in 2,000 ns

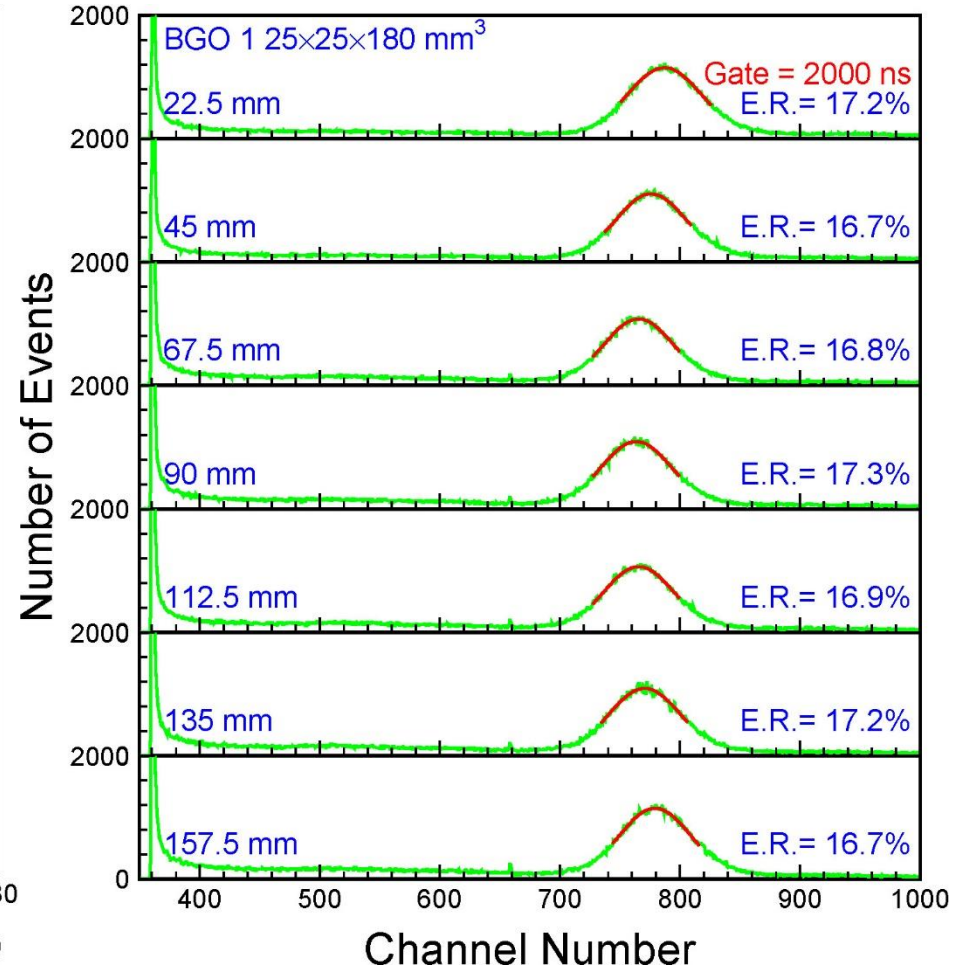


# LRU: All Three and PHS: BGO-1

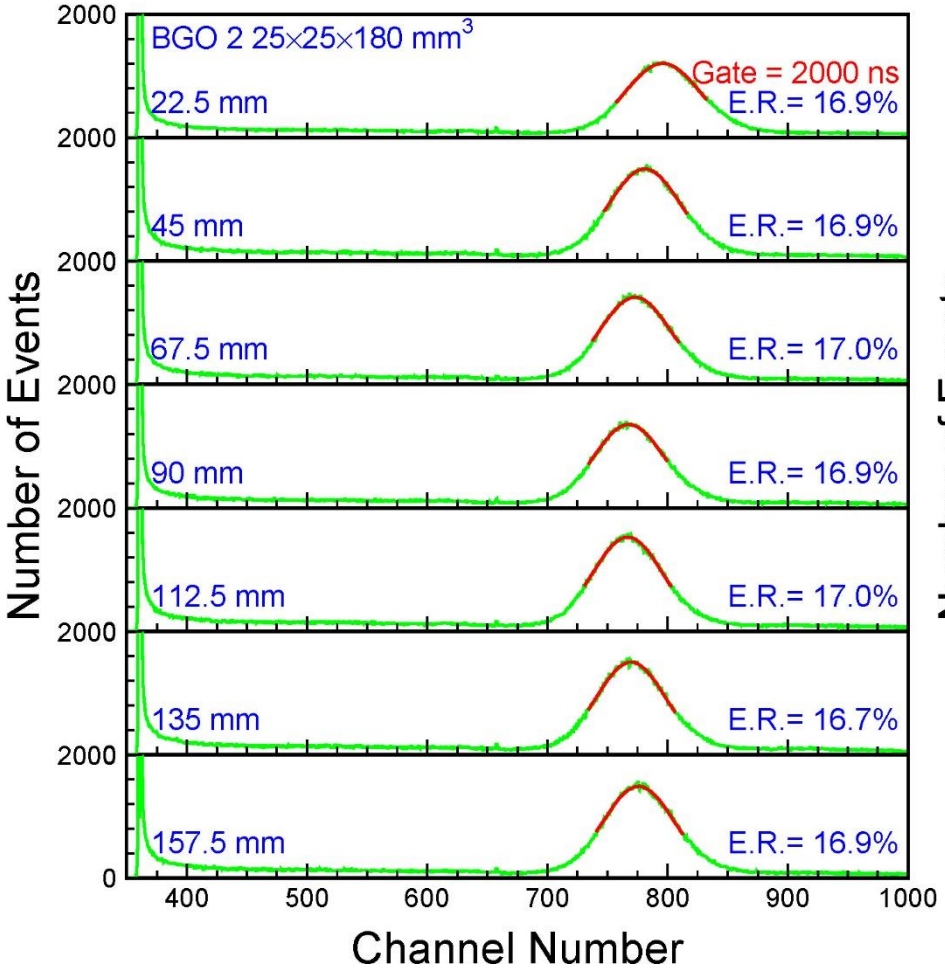
BGO 1/2/3 shows LRU rms of 2.2%/2.4%/2.9%
average LO: 733/739/722 p.e./MeV for BGO-1/2/3

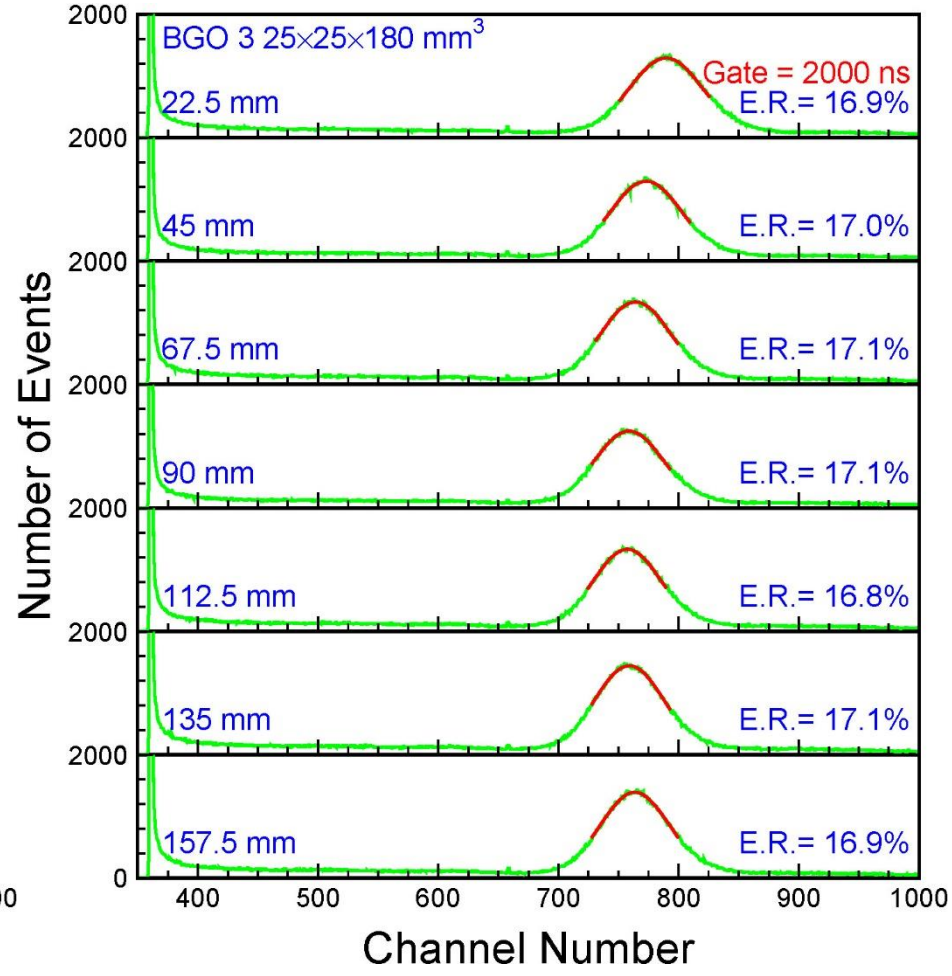


# PHS: BGO-2,3

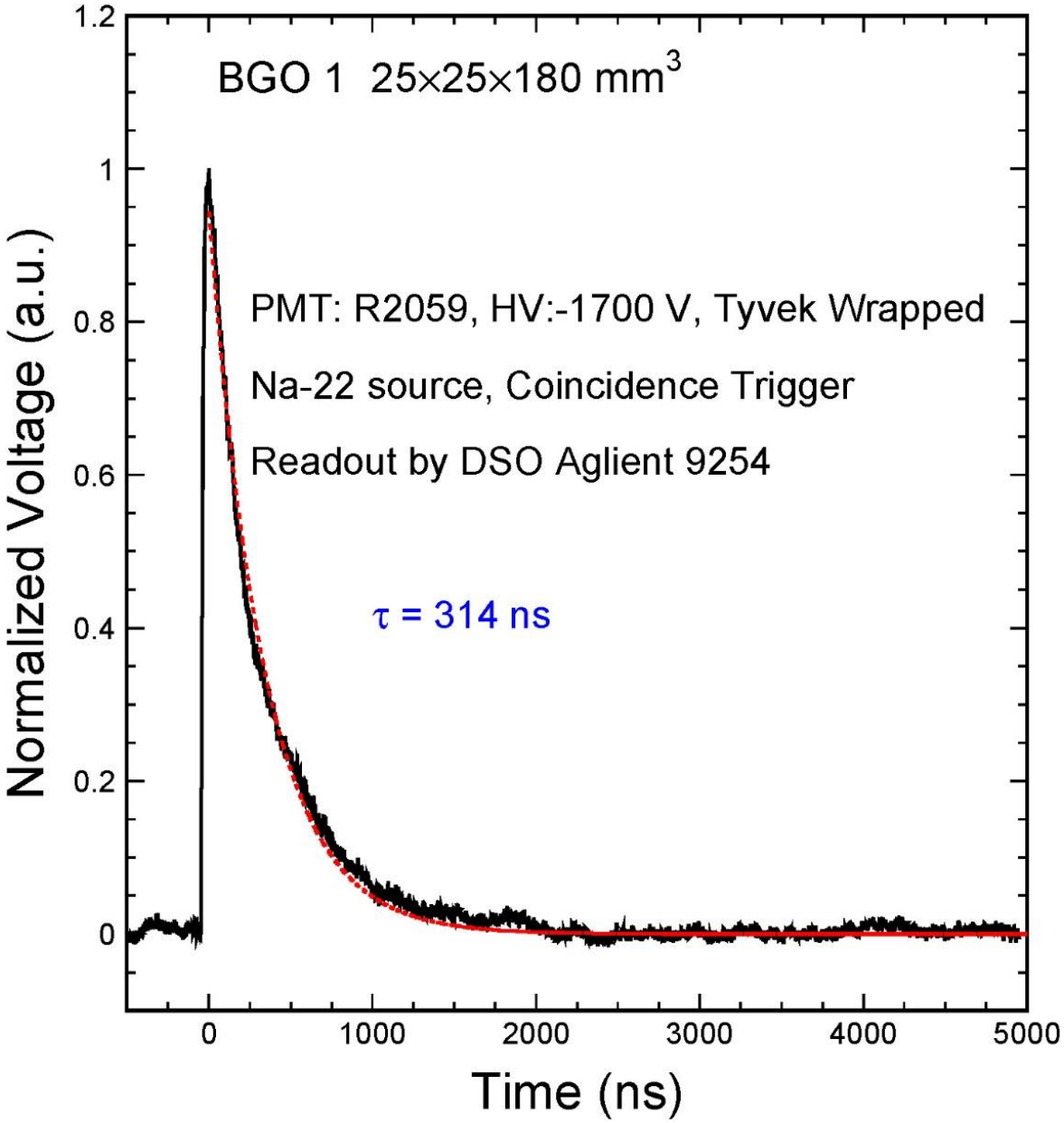
BGO 2 shows the highest light output and the best energy resolution



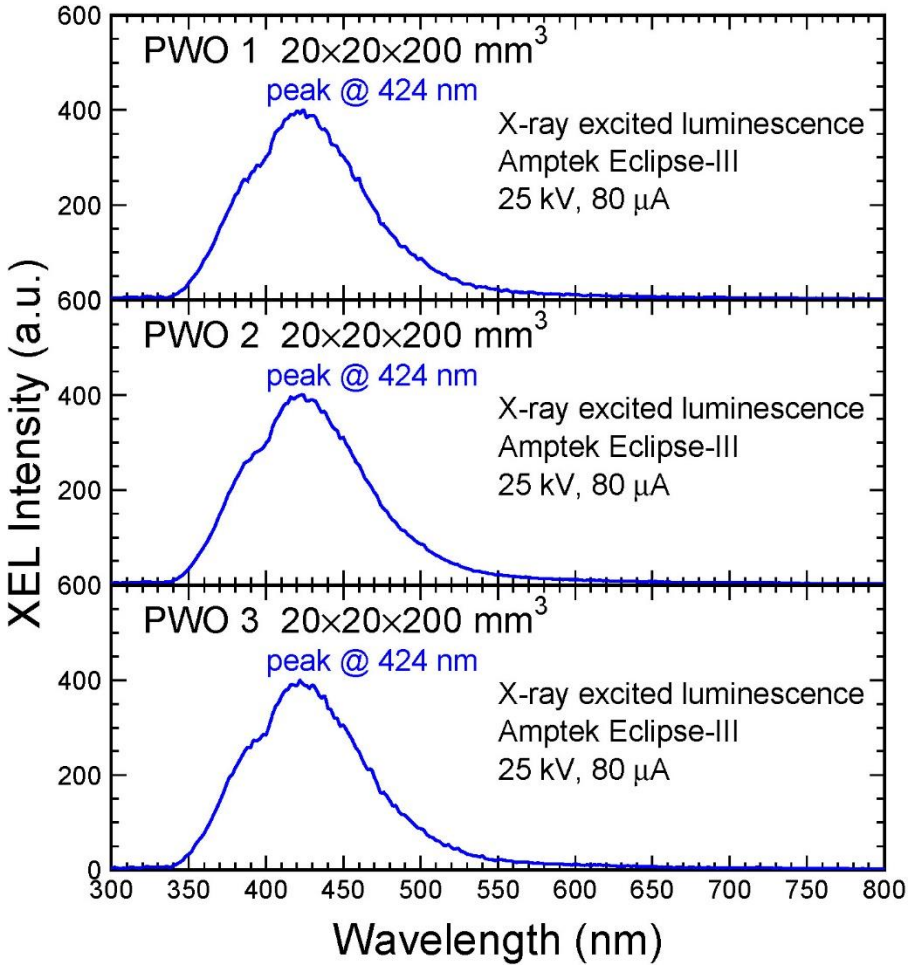
# Pulse Shape Measured by DSO: BGO

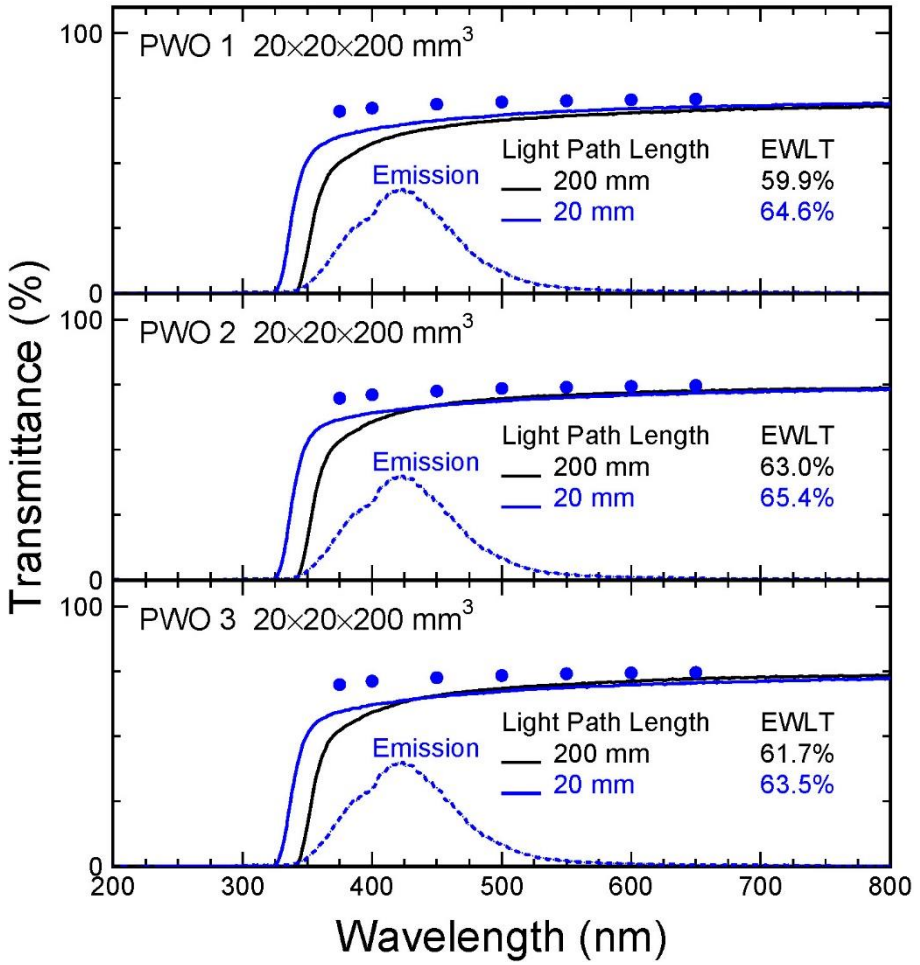
Decay time of 314 ns observed



# XEL and LT Spectra, TT and EWLT: PWO

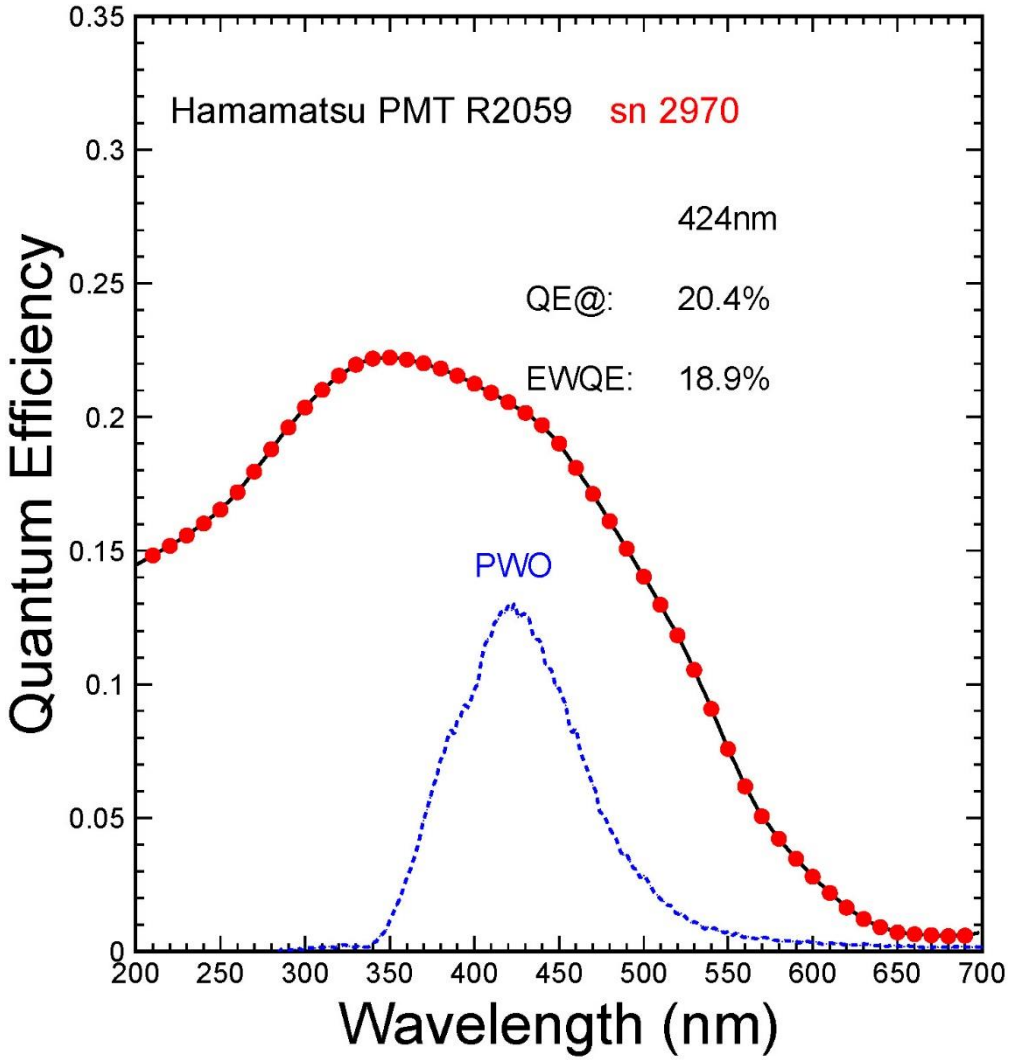
XEL peaked at ~424 nm
TT measured at the crystal center



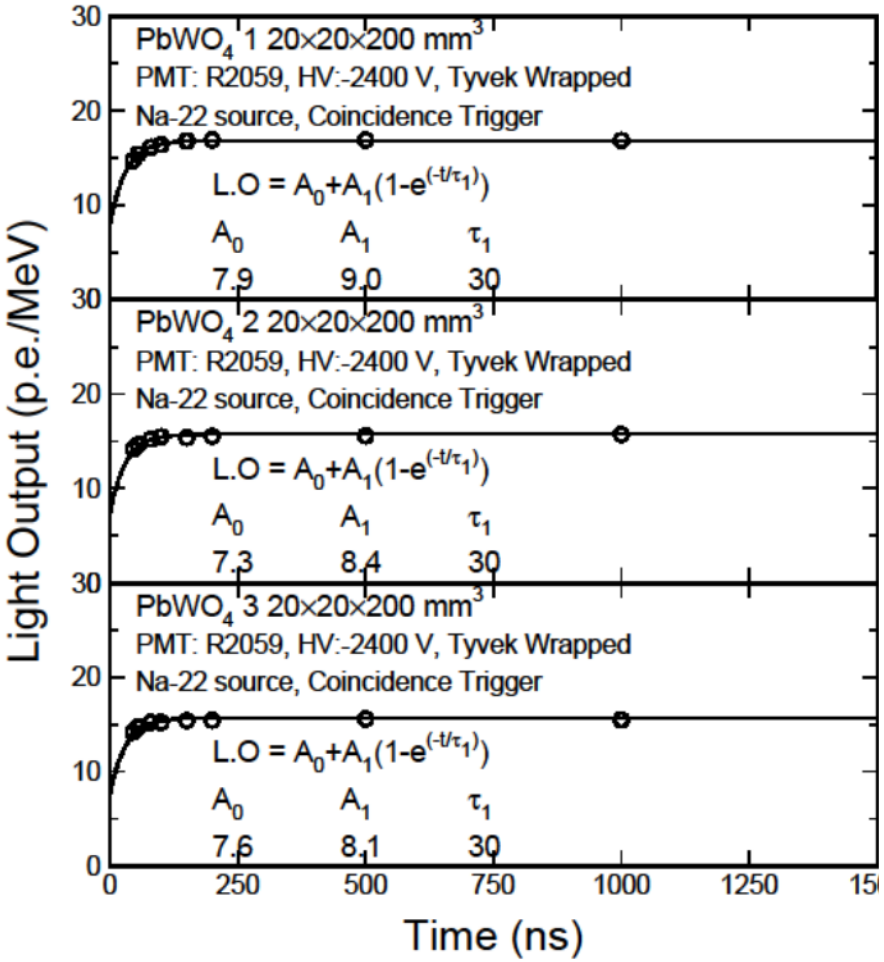
# EWQE: PWO

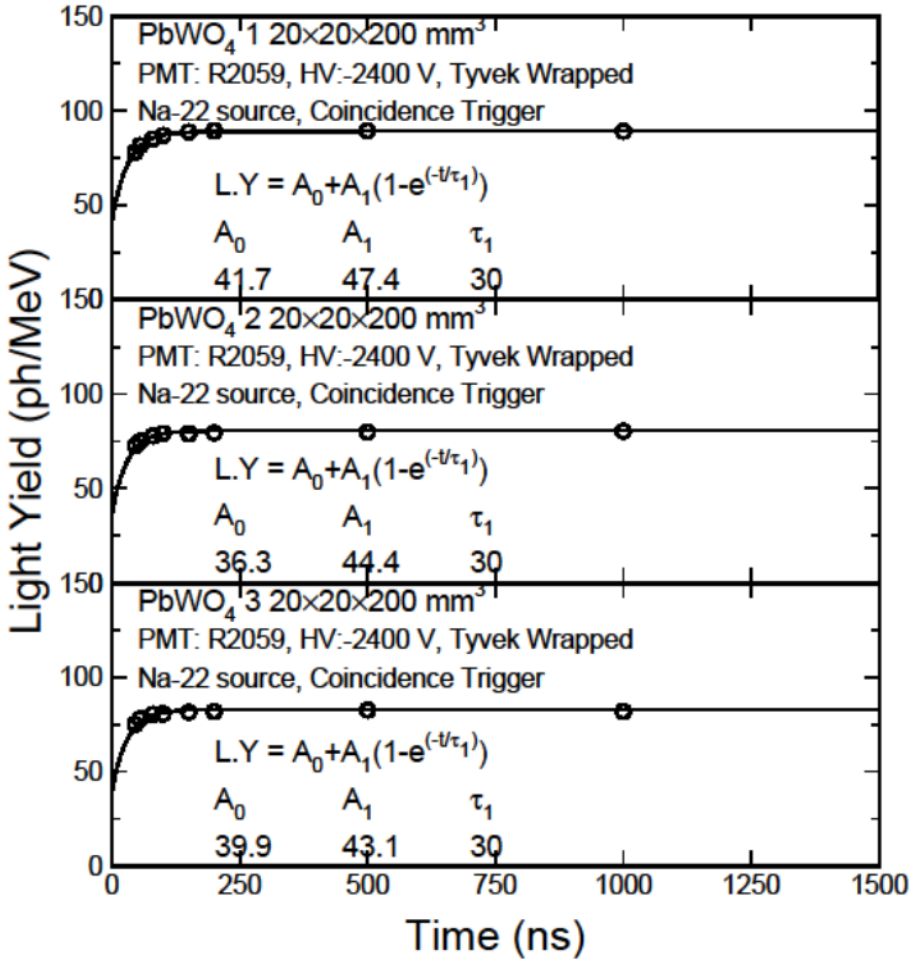
EWQE of 18.9% used to convert light output (LO) in p.e./MeV to light yield (LY) in photons/MeV. Both are sample/wrapping/ coupling dependent.



# LO/LY and Decay Kinetics: PWO

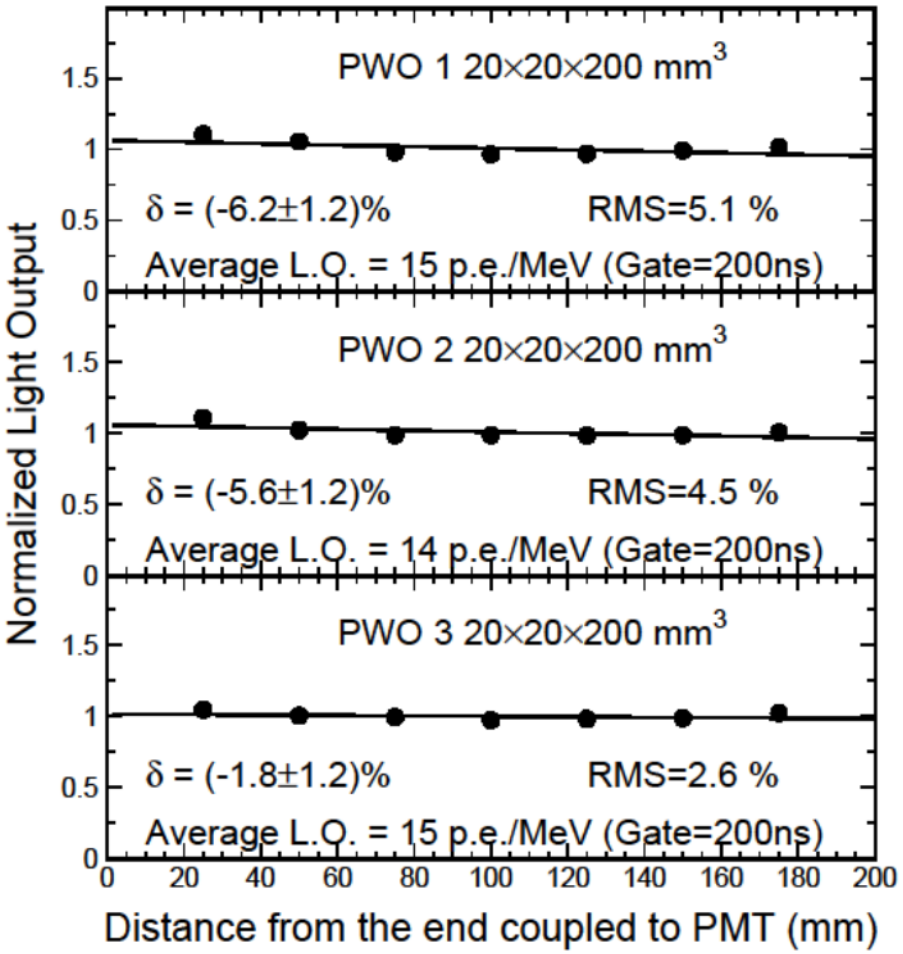
PWO shows a fast light and a slow light of 30 ns decay with LO and LY of 15 p.e./MeV and 79 ph/MeV in 200 ns

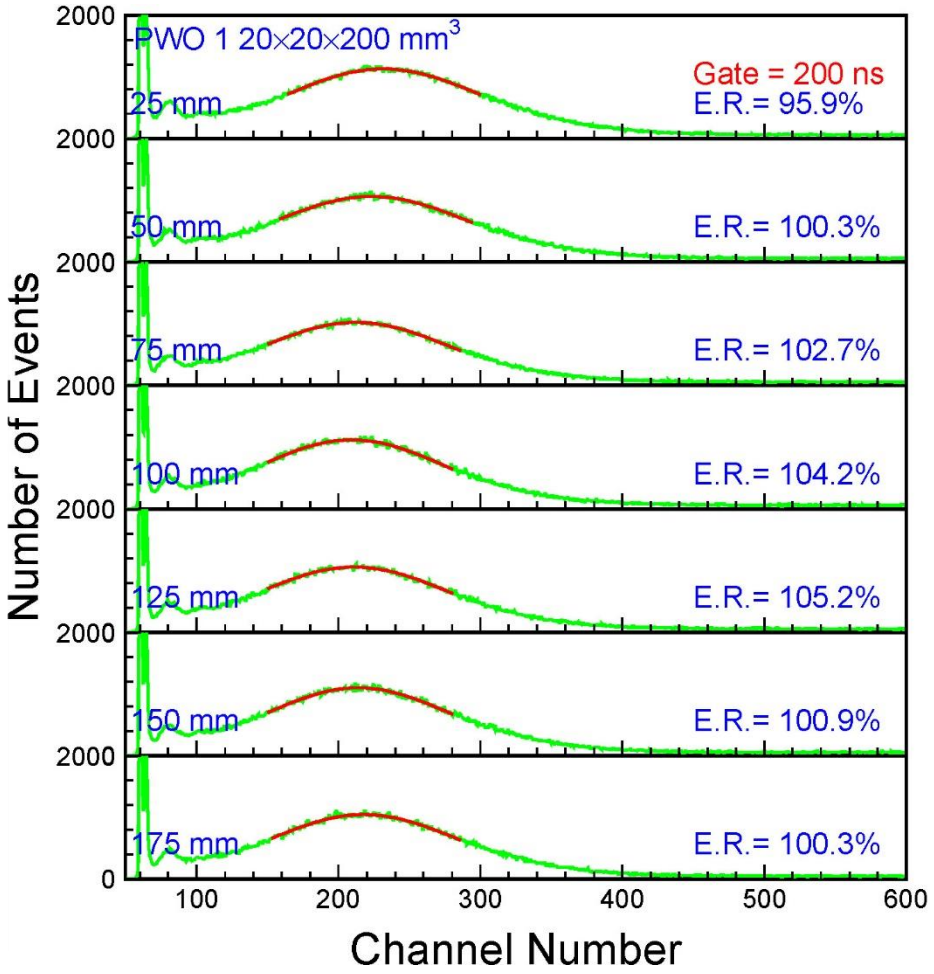


# LRU: All Three and PHS: PWO-1

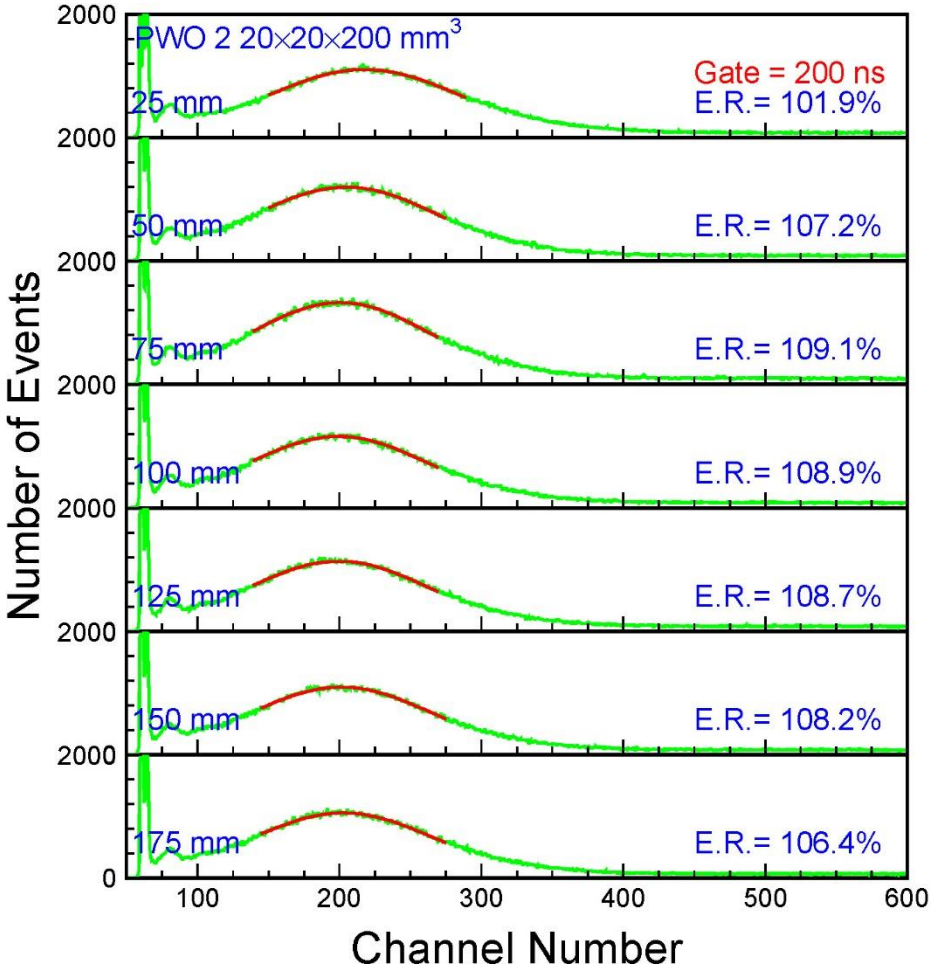
PWO 1/2/3 shows LRU rms of 5.1%/4.5%/2.6%
Average LO: 15/14/15 p.e./MeV for PWO-1/2/3

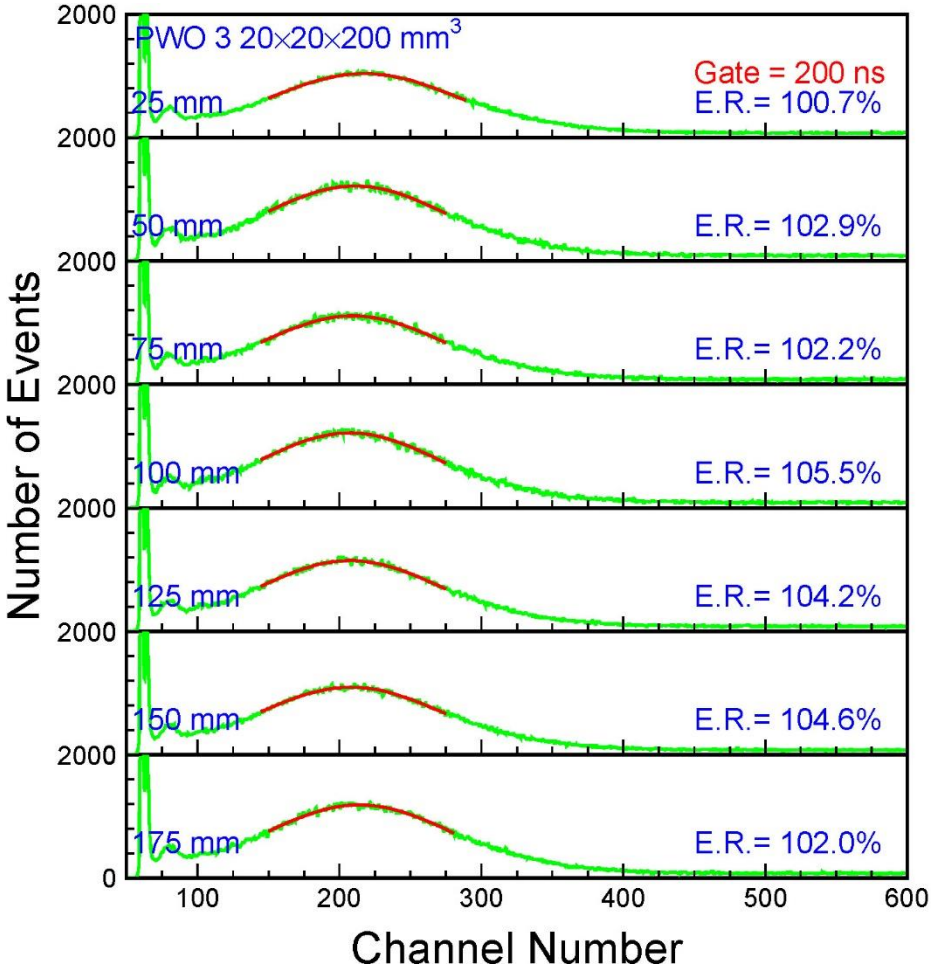


# PHS: PWO-2,3

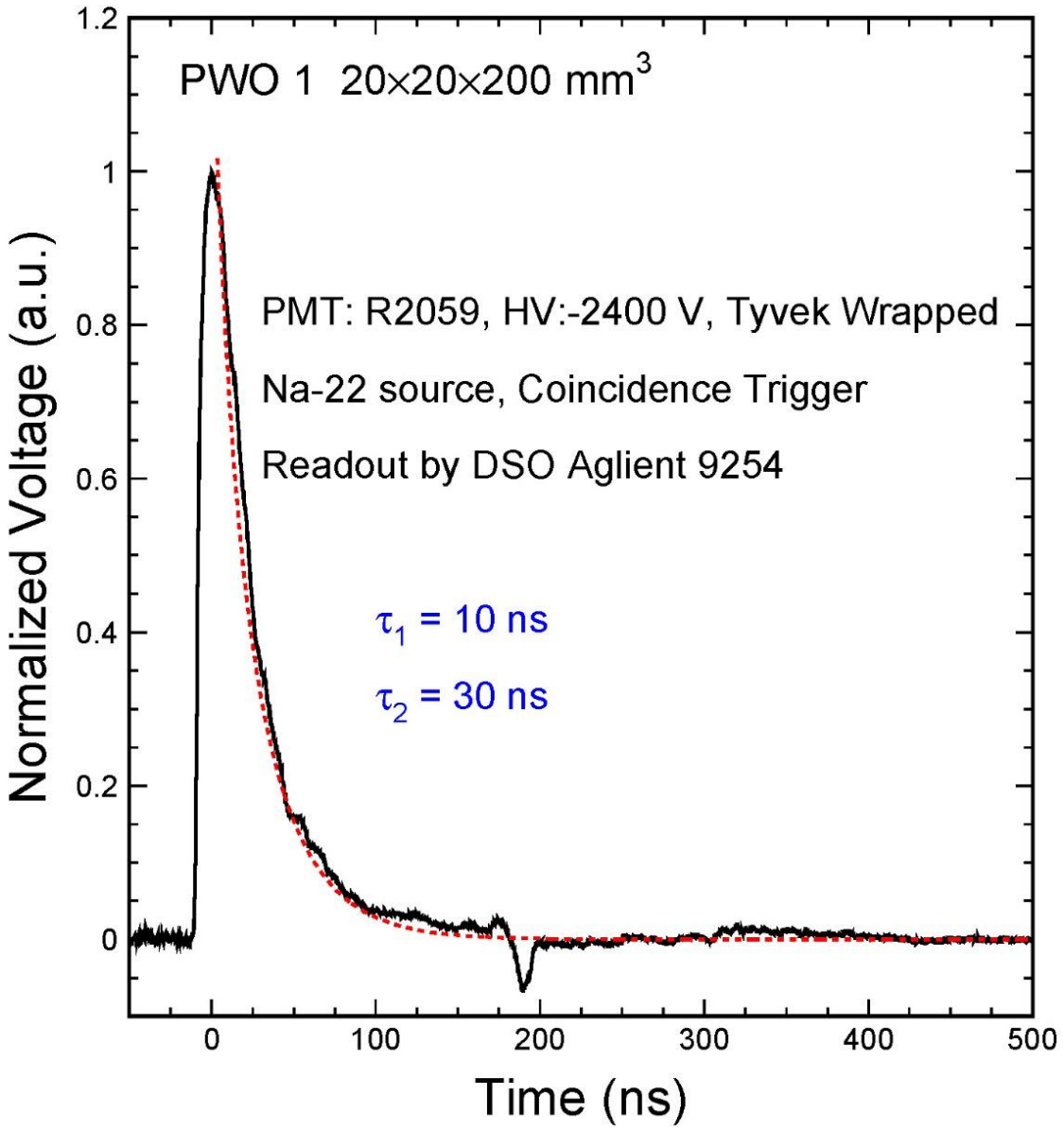
PWO 1 shows the highest light output and the best energy resolution



# Pulse Shape Measured by DSO: PWO

Two decay time of 10 and 30 ns observed



# Summary: EWLT, LO, ER and LRU

LO & ER: Average of 7 points with 2,000/200 ns gate for BGO/PWO

| BGO | EWLT (%) | Light Output (p.e./MeV) | Energy Resolution (%) | Light Response Uniformity (%) |
|---|---|---|---|---|
| BGO-1 | 72.2 | 733 | 17.0 | 2.2 |
| BGO-2 | 73.8 | 739 | 16.9 | 2.4 |
| BGO-3 | 74.6 | 722 | 17.0 | 2.9 |
| Ave | 73.5 | 731 | 17.0 | 2.5 |
| rms/Ave (%) | 1.4 | 1.0 | 0.2 | 12 |

| PWO | EWLT (%) | Light Output (p.e./MeV) | Energy Resolution (%) | Light Response Uniformity (%) |
|---|---|---|---|---|
| PWO-1 | 59.9 | 15 | 101.4 | 5.1 |
| PWO-2 | 63.0 | 14 | 107.2 | 4.5 |
| PWO-3 | 61.7 | 15 | 103.2 | 2.6 |
| Ave | 61.5 | 15 | 103.9 | 4.1 |
| rms/Ave (%) | 2.1 | 3.9 | 2.4 | 26 |

# Summary

Three each BGO and PWO crystals of 18 and 20 cm long respectively were received from University of Michigan. Their XEL, LT, TT and PHS spectra, EWQE, LO, LY, τ and LRU were measured at Caltech HEP Crystal Lab.

BGO/PWO show consistent XEL peaked at 462/424 nm.

BGO/PWO crystals show average 731/15 p.e./MeV and 4,660/79 photons/MeV after taking out EWQE values of 15.7%/18.9%. While BGO crystals show a single decay time of 314 ns, PWO crystals show two components with decay time of 10 and 30 ns.

Three BGO samples show a much better consistency than three PWO samples.

Acknowledgements: DOE HEP Award DE-SC0011925