Development of BaF_2 Crystals for Future HEP Experiments at the Intensity Frontiers

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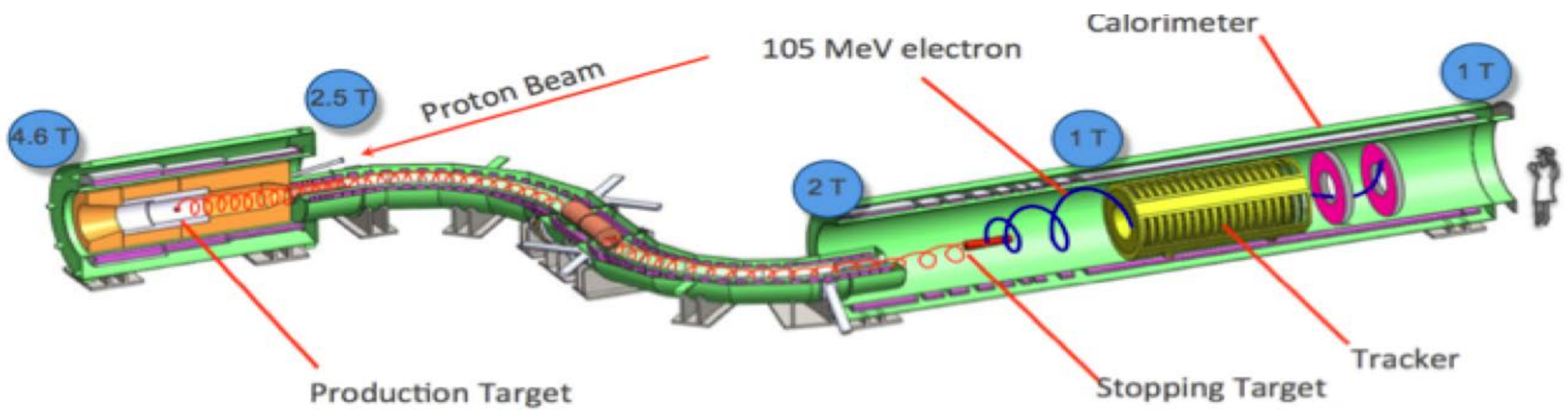
Introduction

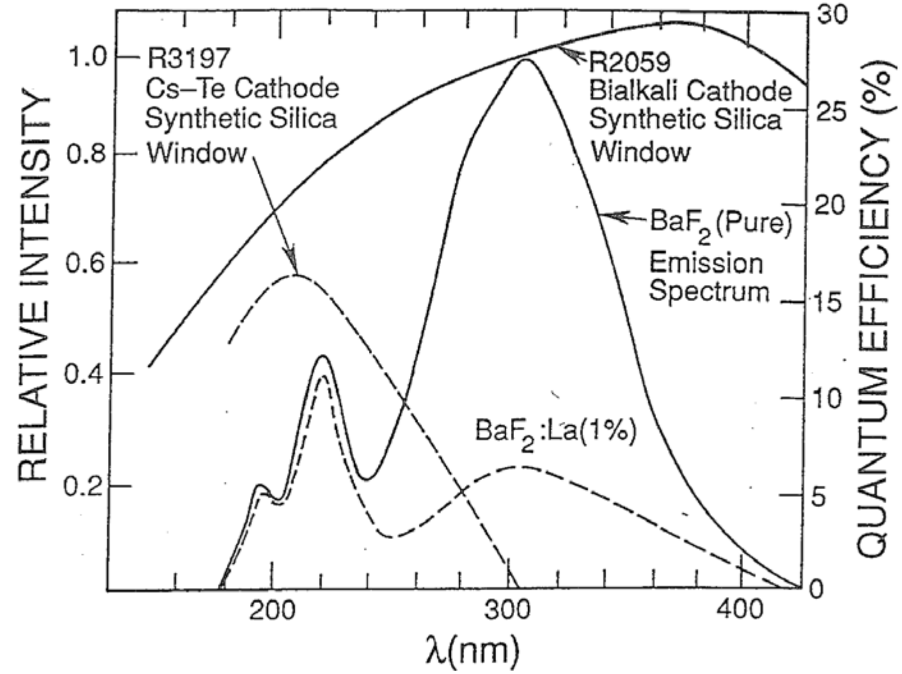
- Mu2e-I is building a CsI calorimeter, which has 30 ns fast scintillation and survives up to 100 krad. A radiation level beyond 100 krad, however, is expected by Mu2e-II.
- With sub-ns fast scintillation and excellent radiation hardness up to 120 Mrad, BaF_2 promises a very fast and stable calorimeter for Mu2e-II.
- There are several approaches to handle the 600 ns slow scintillation in BaF_2: solar-blind photodetector and selective doping etc. We report here an exercise of selective doping.

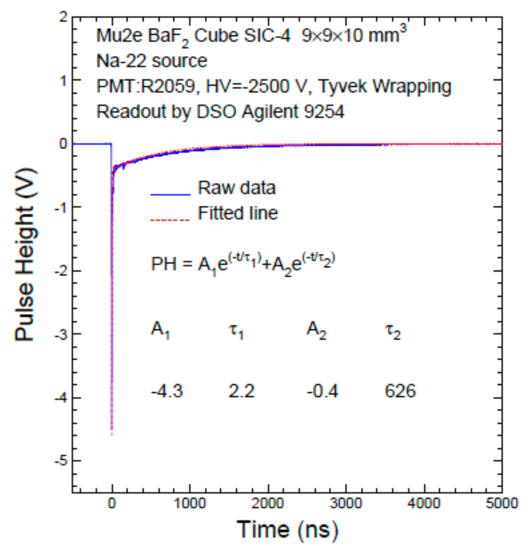


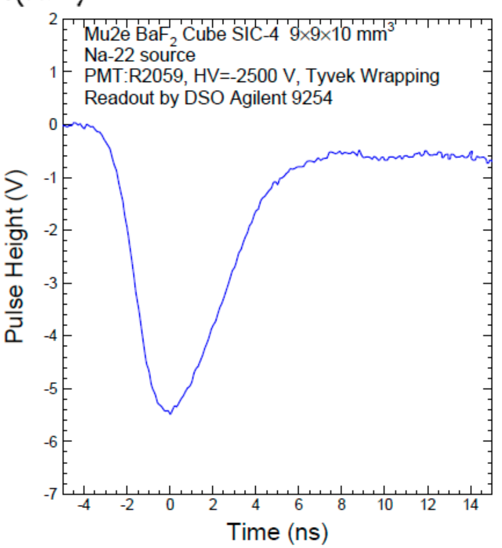
Why BaF_2?

"On Quality Requirements to the Barium Fluoride-Crystals" *NIMA* **340** (1994) 442-457

BaF_2 has a very fast scintillation component at 220 nm with sub-ns decay time, which provides a good foundation for a very fast calorimetry to face the challenge of the unprecedented high event rate expected in future HEP experiments at the intensity frontier.

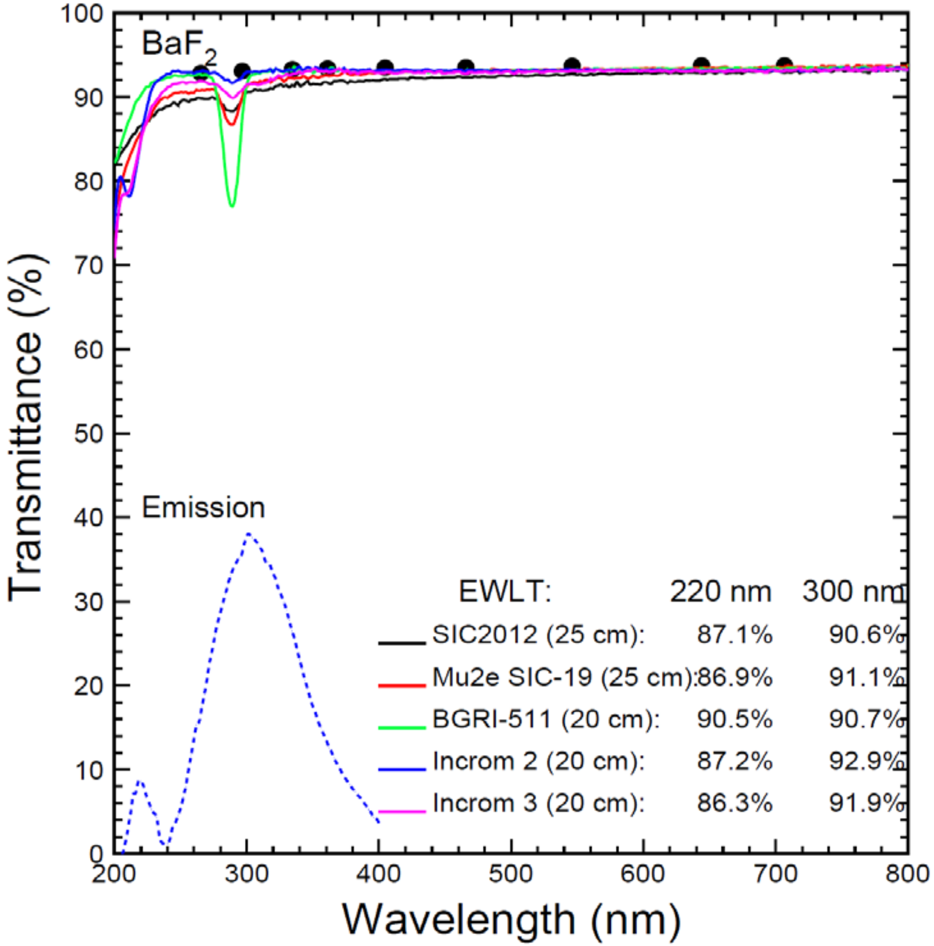


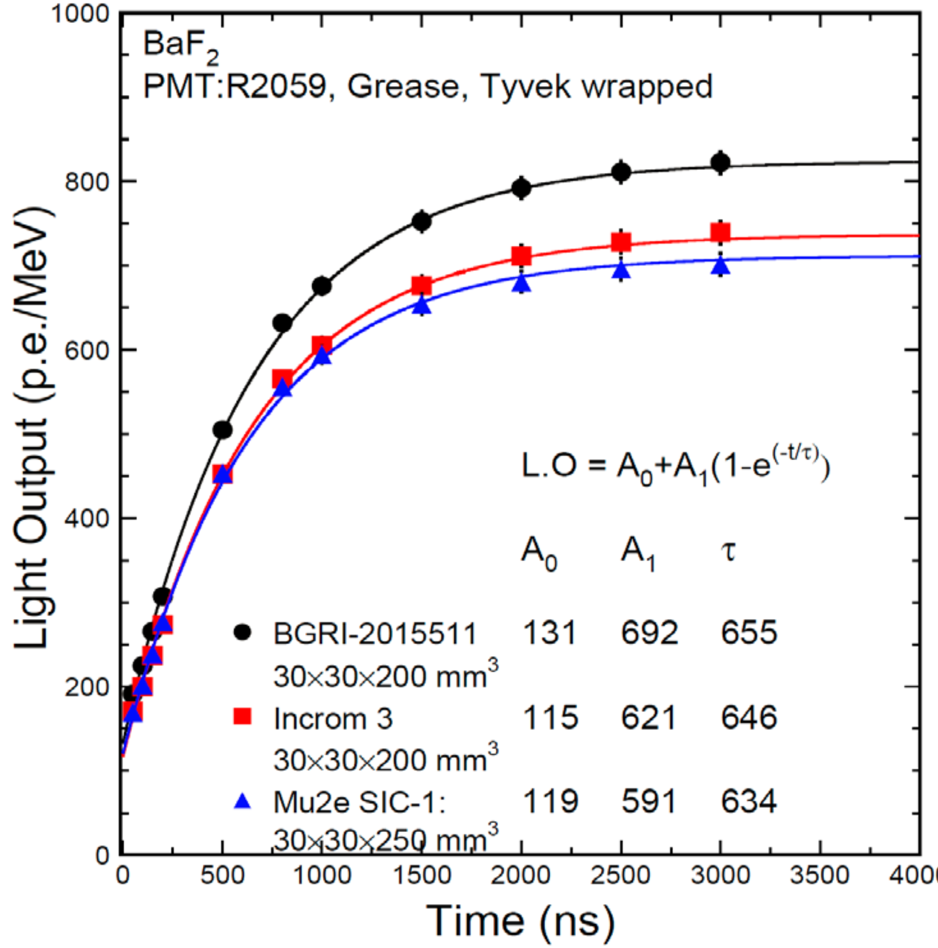




Properties of 20 cm BaF_2

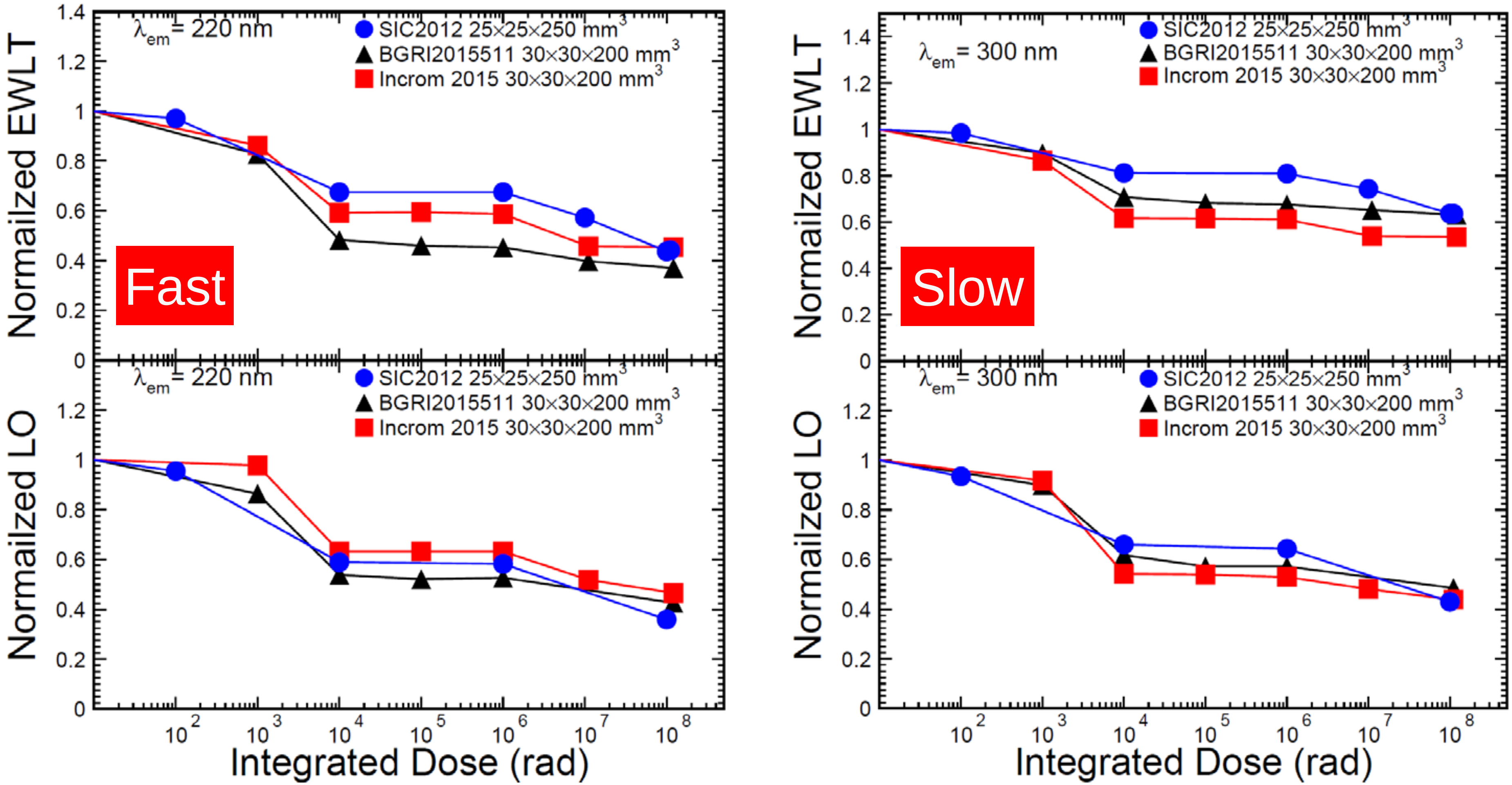
Large BaF_2 crystals from three vendors show comparable performance





Radiation Hardness of BaF_2

40%/45% light output after 120 Mrad for the fast/slow component
Crystals from three vendors have similar radiation hardness



The Issue of Slow Component

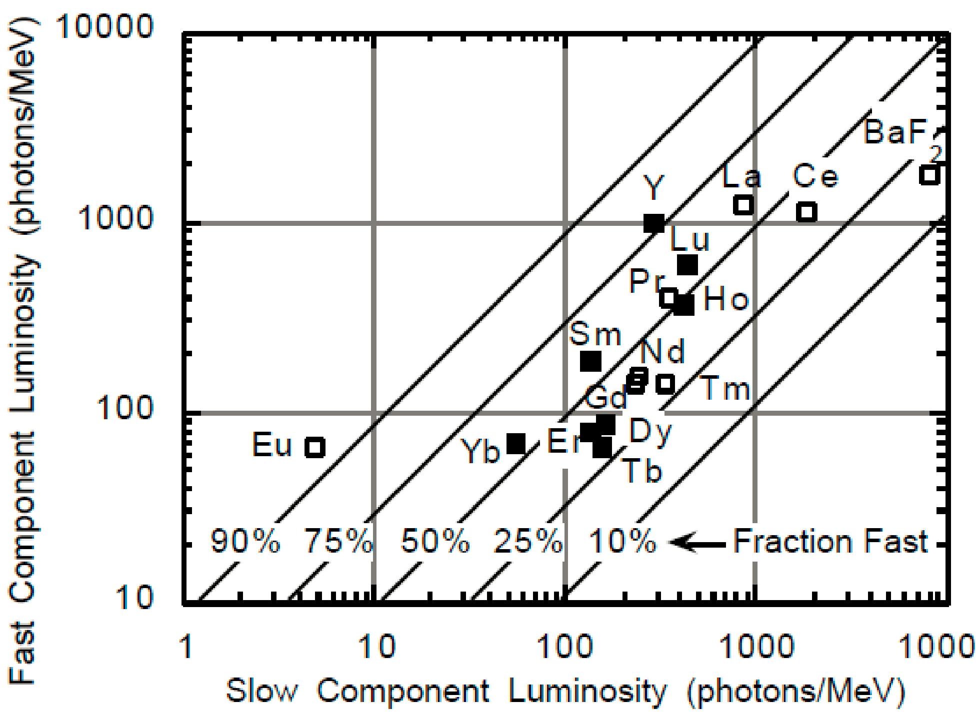
- BaF_2 has a slow scintillation component at 300 nm with 600 ns decay time, which is a factor of five in intensity as compared to the fast component. It causes pile up noise.
- Approaches being pursued:
  - Solar blind photo-detector sensitive to 220 nm, not 300 nm: Si APD with interference filter and vacuum photo-detector with solar-blind cathode.
  - Crystal development by selective doping: Ce/La/Y has been successfully implemented at BGRI and SICCAS.
- The fast light in BaF_2 is of general interest for a large community beyond the HEP, e.g. GHz X-ray imaging.

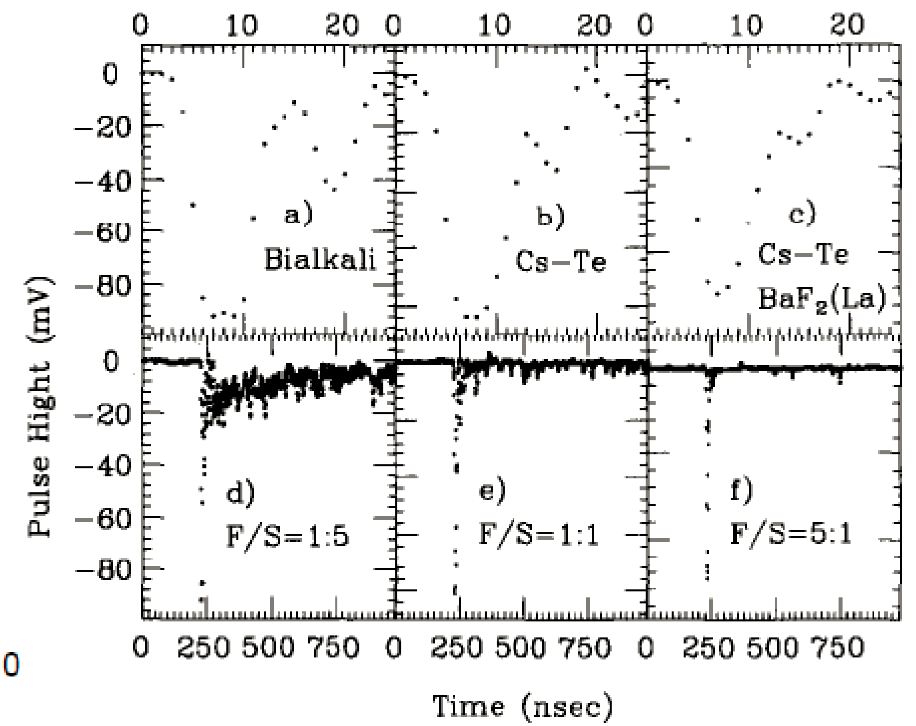
Slow Suppression

RE doping and solar-blind photodetector are effective in improving F/S

B.P. SOBOLEV et al., "SUPPRESSION OF BaF2 SLOW COMPONENT OF X-RAY LUMINESCENCE IN NON-STOICHIOMETRIC Ba0.9R0.1F2 CRYSTALS (R=RARE EARTH ELEMENT)," *Proceedings of The Material Research Society: Scintillator and Phosphor Materials,* pp. 277-283, 1994.

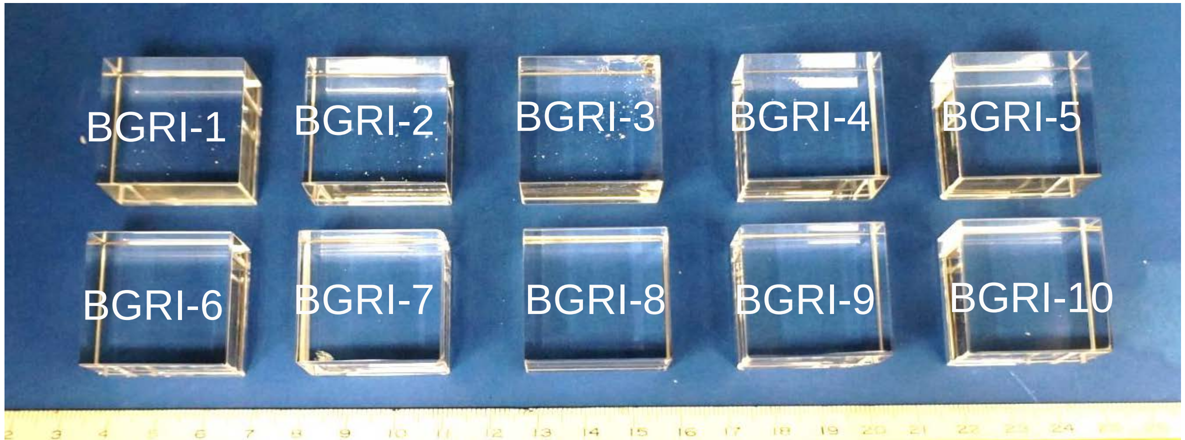
Z. Y. Wei, R. Y. Zhu, H. Newman, and Z. W. Yin, "Light Yield and Surface-Treatment of Barium Fluoride-Crystals," *Nucl Instrum Meth B,* vol. 61, pp. 61-66, Jul 1991.

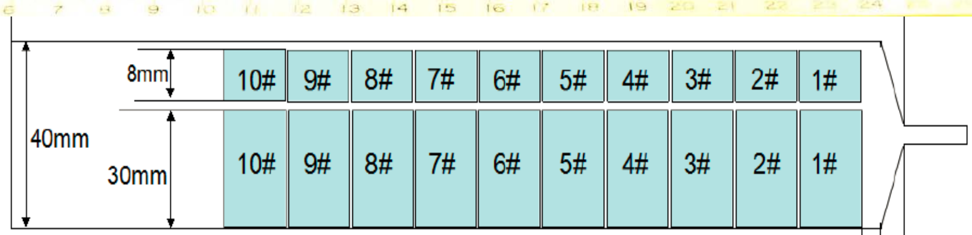


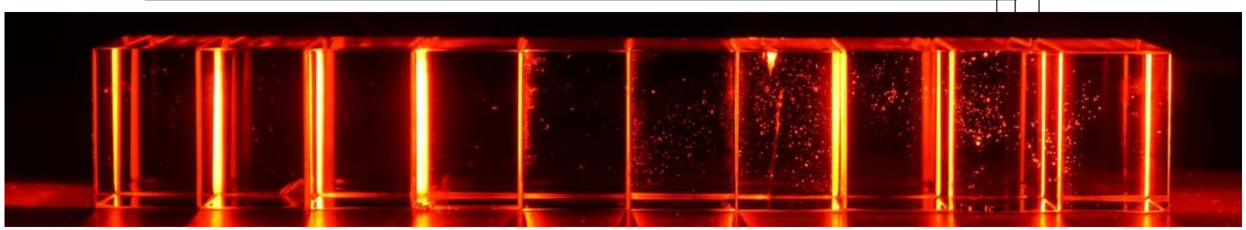


La/Ce Co-Doped BaF_2 Samples from BGRI

1% La
100 ppm Ce







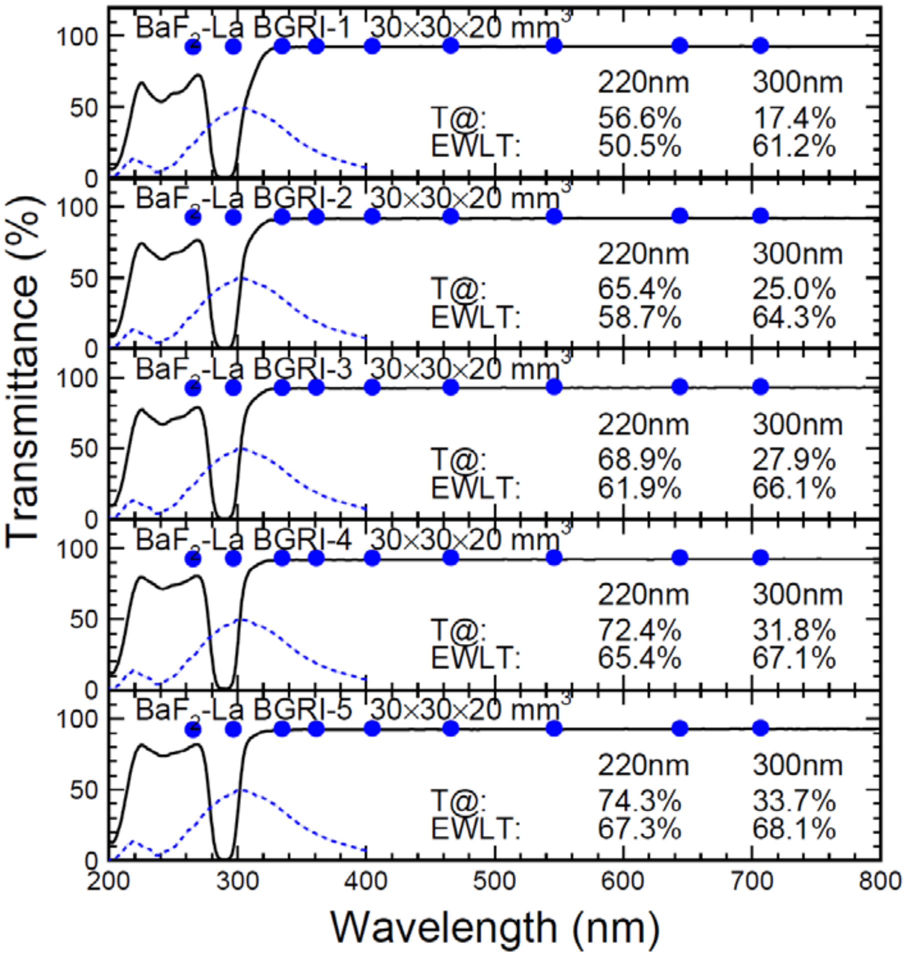
ID	Dimension (mm³)	Polishing
BaF_2-La/Ce BGRI-1,10	30x30x20	All faces

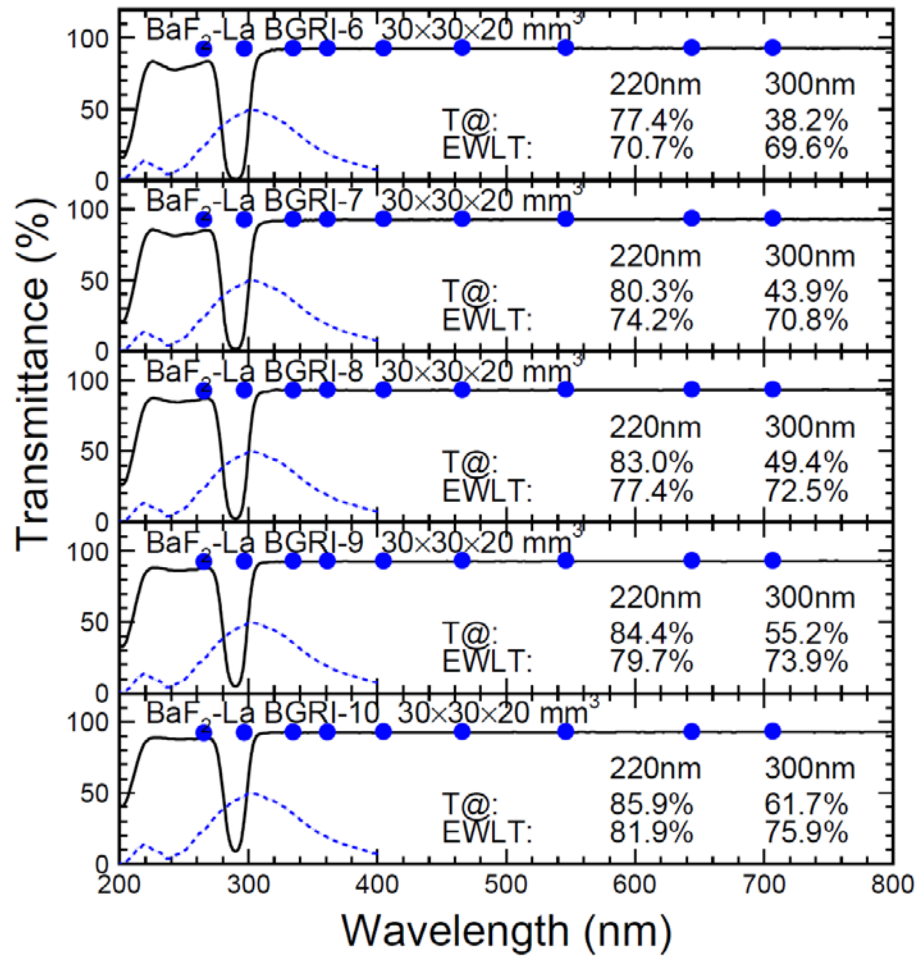
Experiments

- Properties measured: Transmittance, Light Output and Decay Kinetics

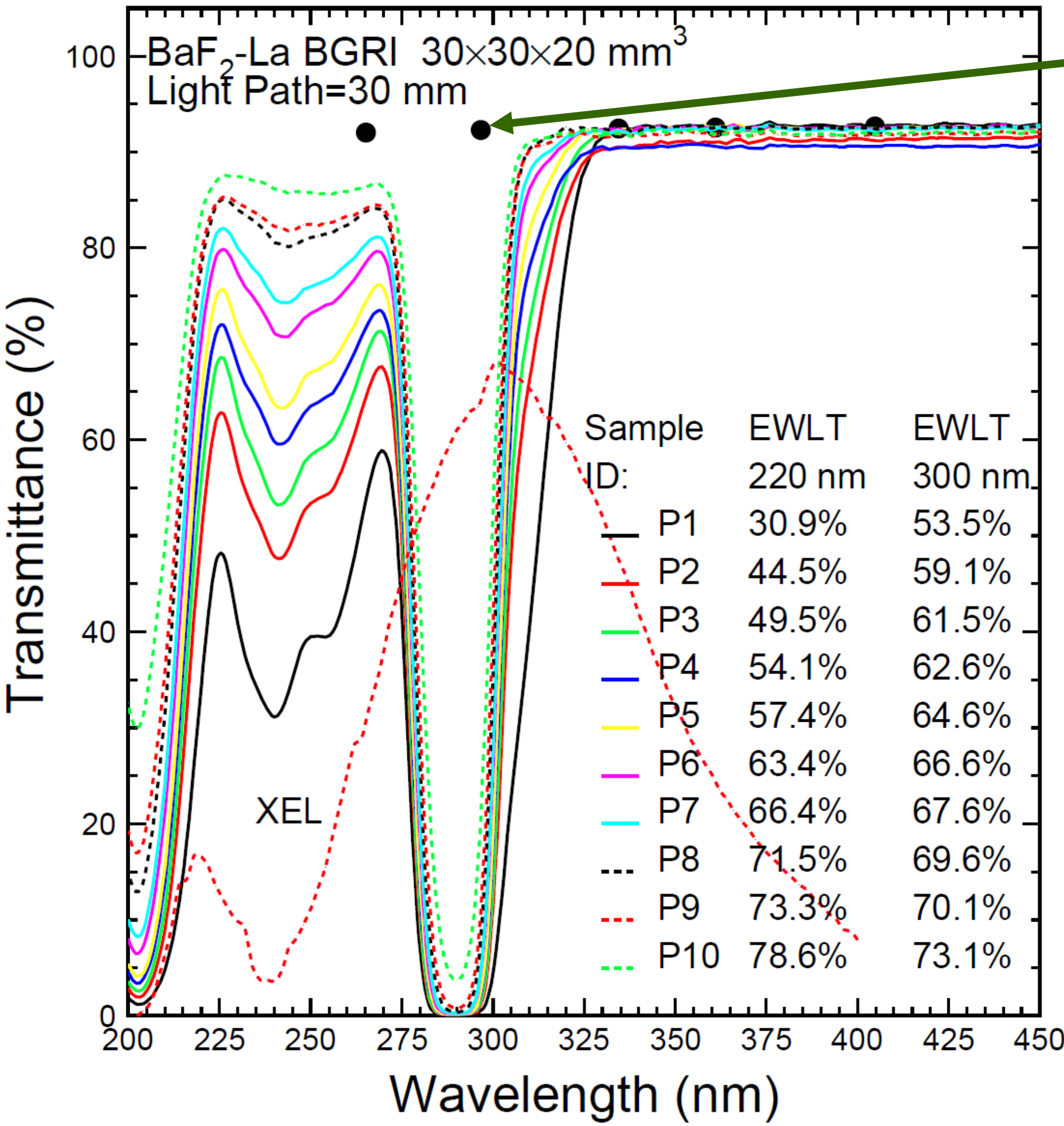
Transmittance Along 2 cm Path

Absorption bands at 203/290 nm observed





La/Ce Induced Absorption Bands

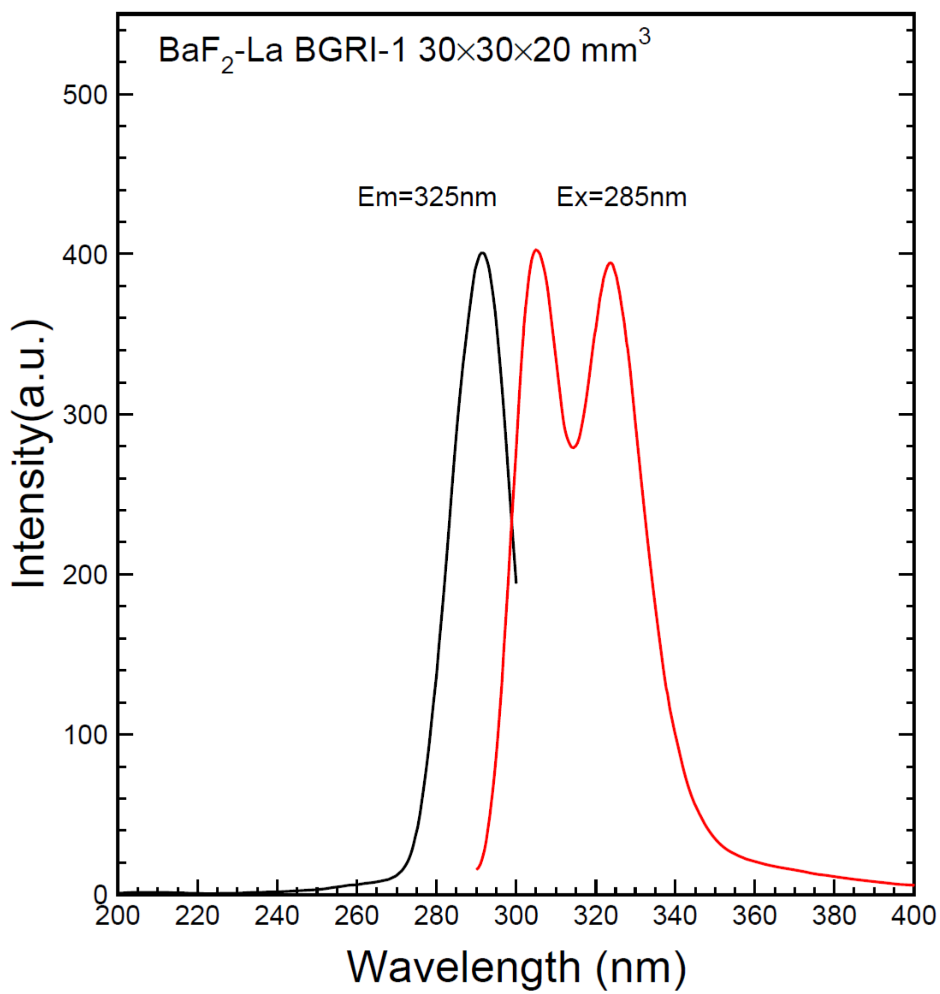


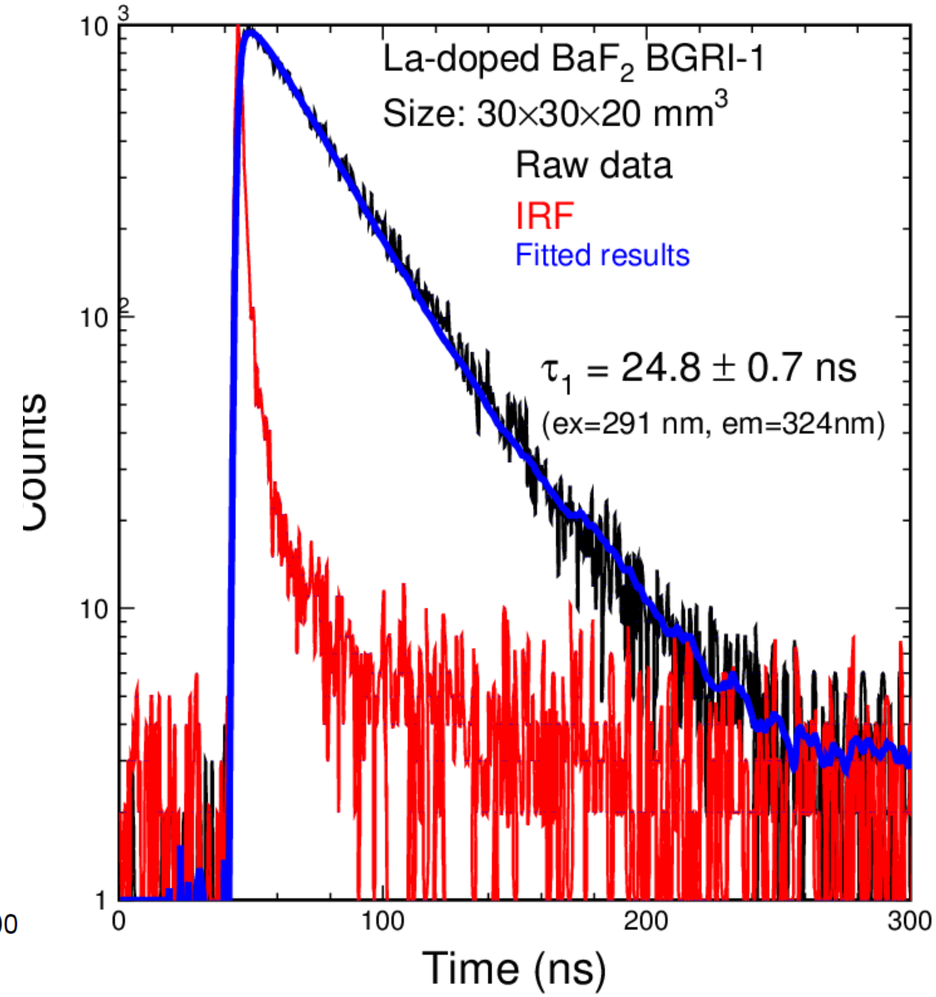
Ce doping induces an absorption band at 290 nm, which reduces the slow component, and improves the overall Fast/Slow ratio.

The intensities of both absorption bands weakened from the seed to the tail because of the large segregation coefficient of La and Ce in BaF_2

Ce Emission in La/Ce Co-Doped BaF_2

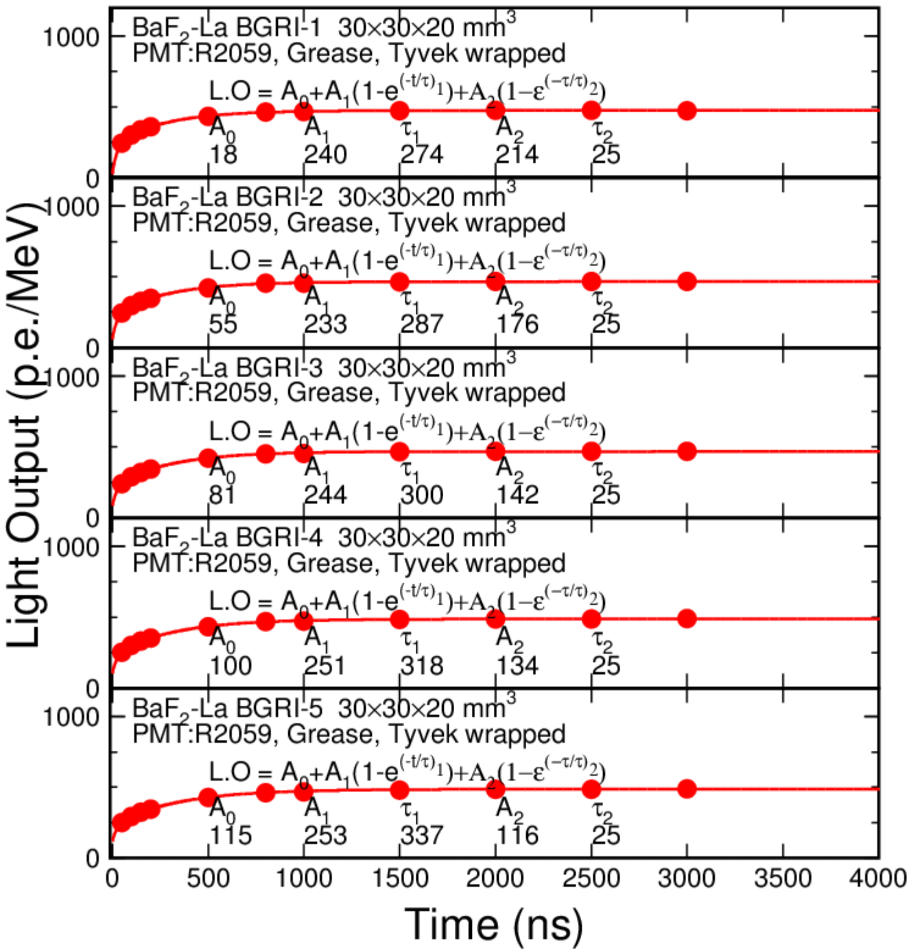
Ce emission is observed in La/Ce Co- doped BaF_2 samples

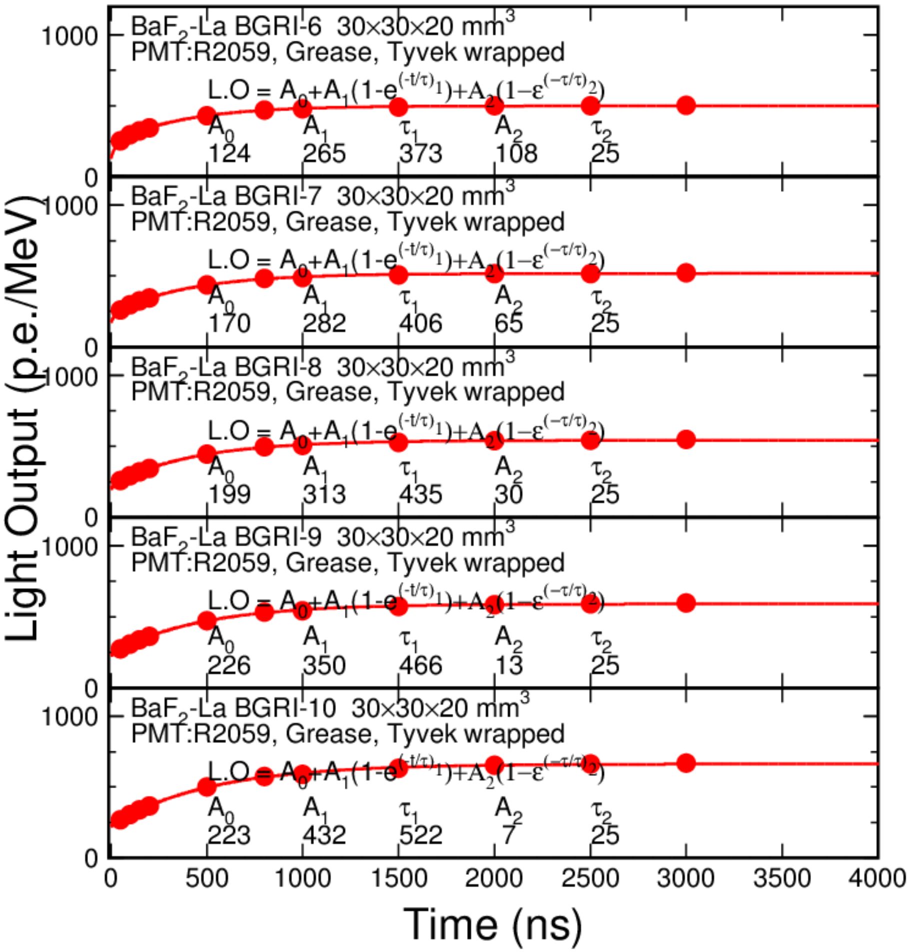




Decay Kinetics: La/Ce Co-Doped BaF_2

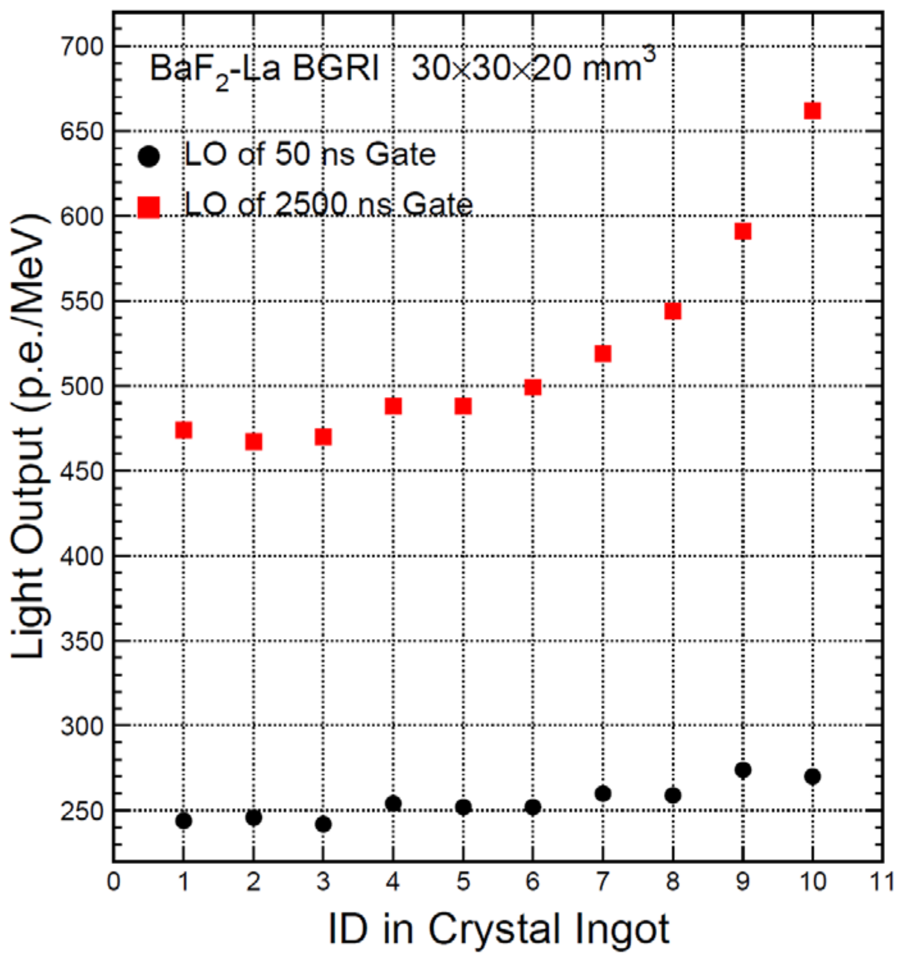
Decay kinetics was fit to three components to accommodate Ce emission
The decay time of slow component decreases with doping

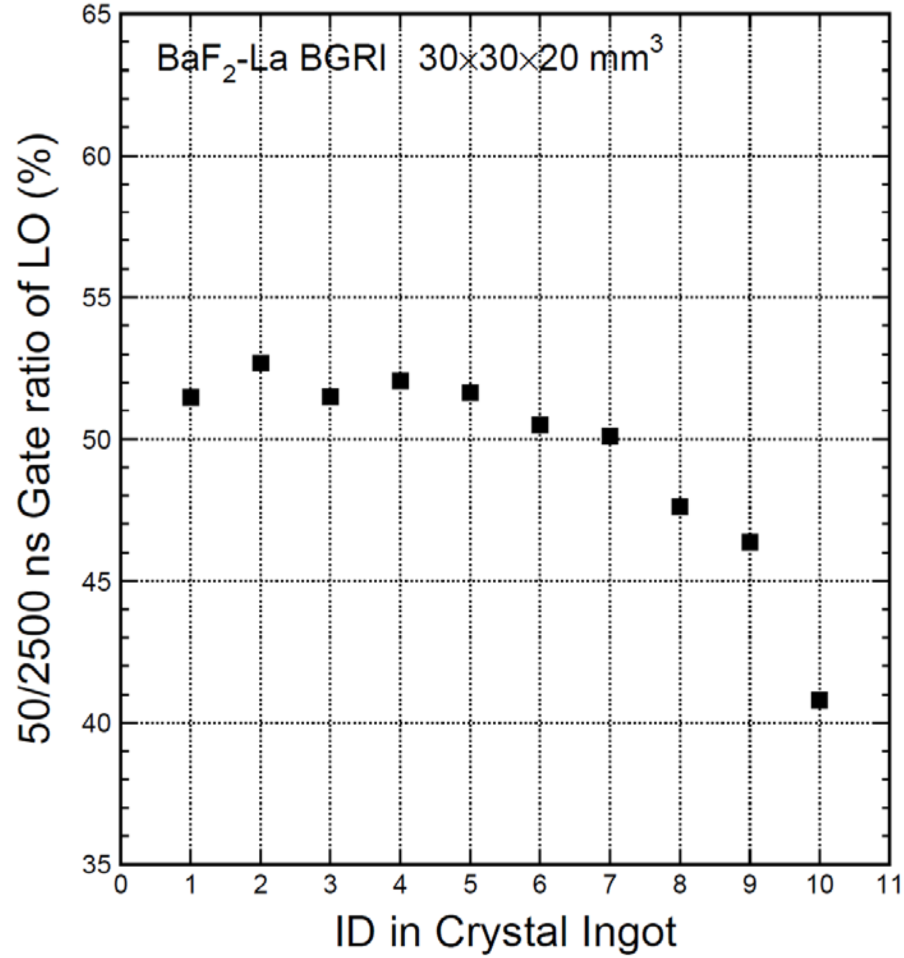




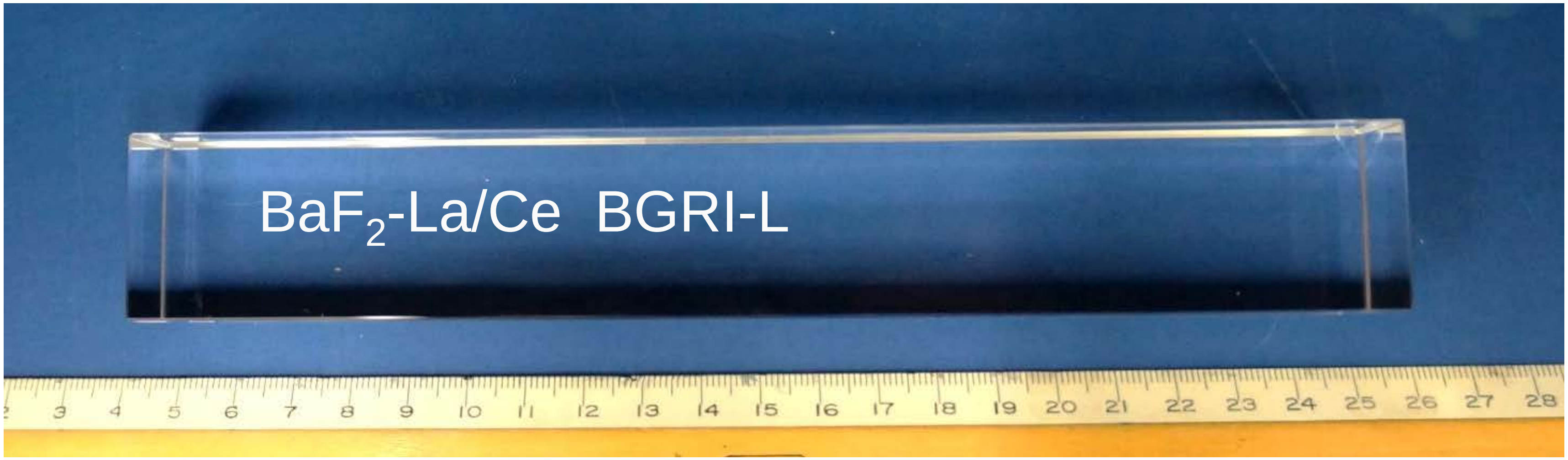
Light Output and 50/2500 ns Ratio

The largest 50/2500 ns ratio observed at the seed end





La/Ce Co-Doped 20 cm BaF_2 from BGRI



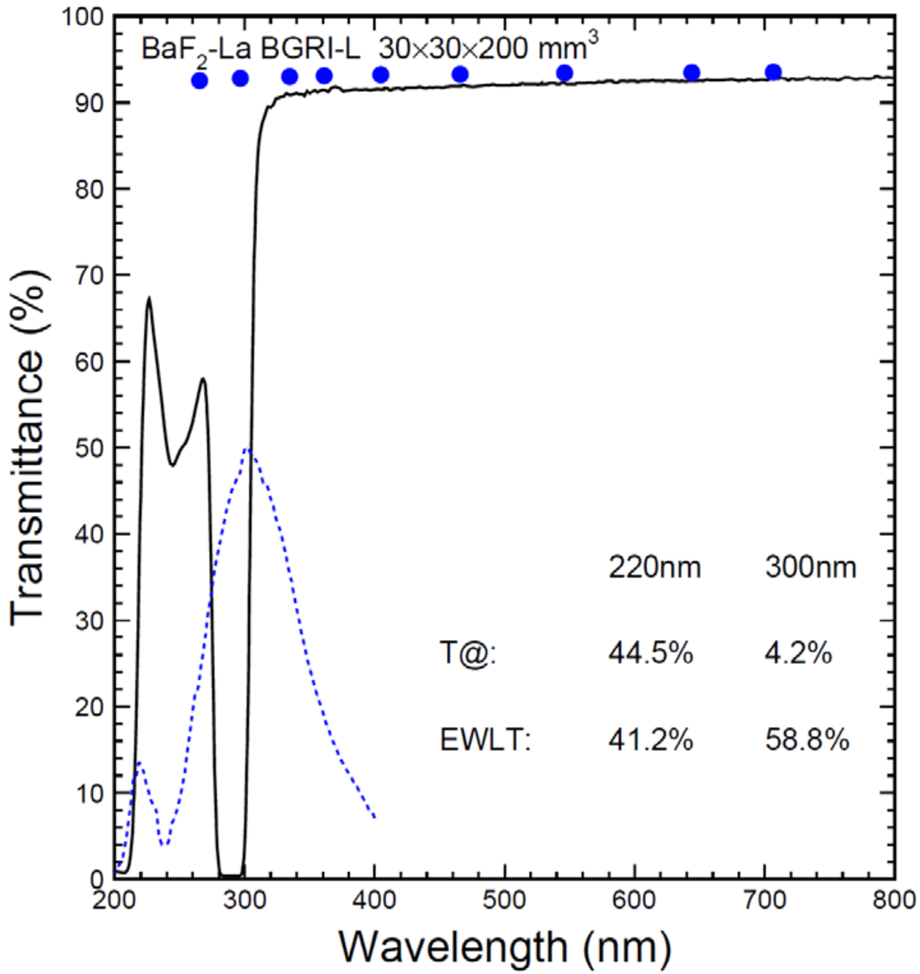
ID	Dimension (mm^3)	Polishing
BaF_2-La BGRI-L	30x30x200	All faces

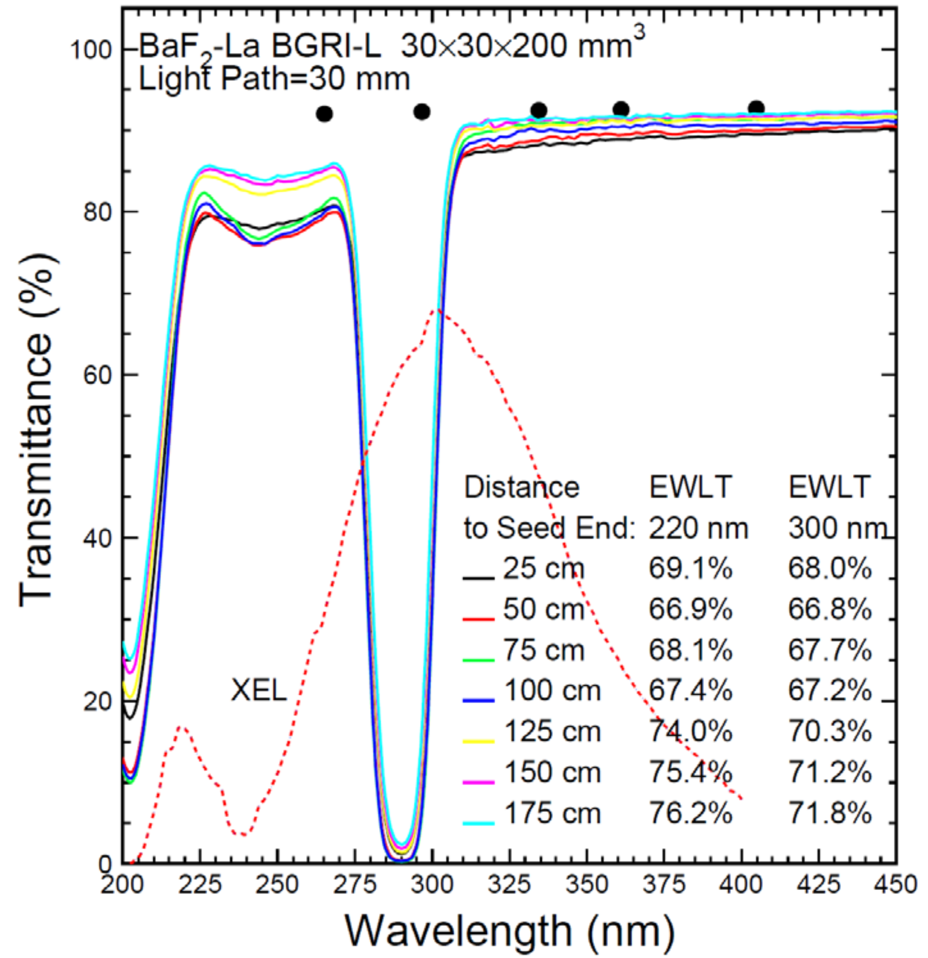
Experiments

- Properties measured at room temperature : Transmittance, LO and Decay Kinetics

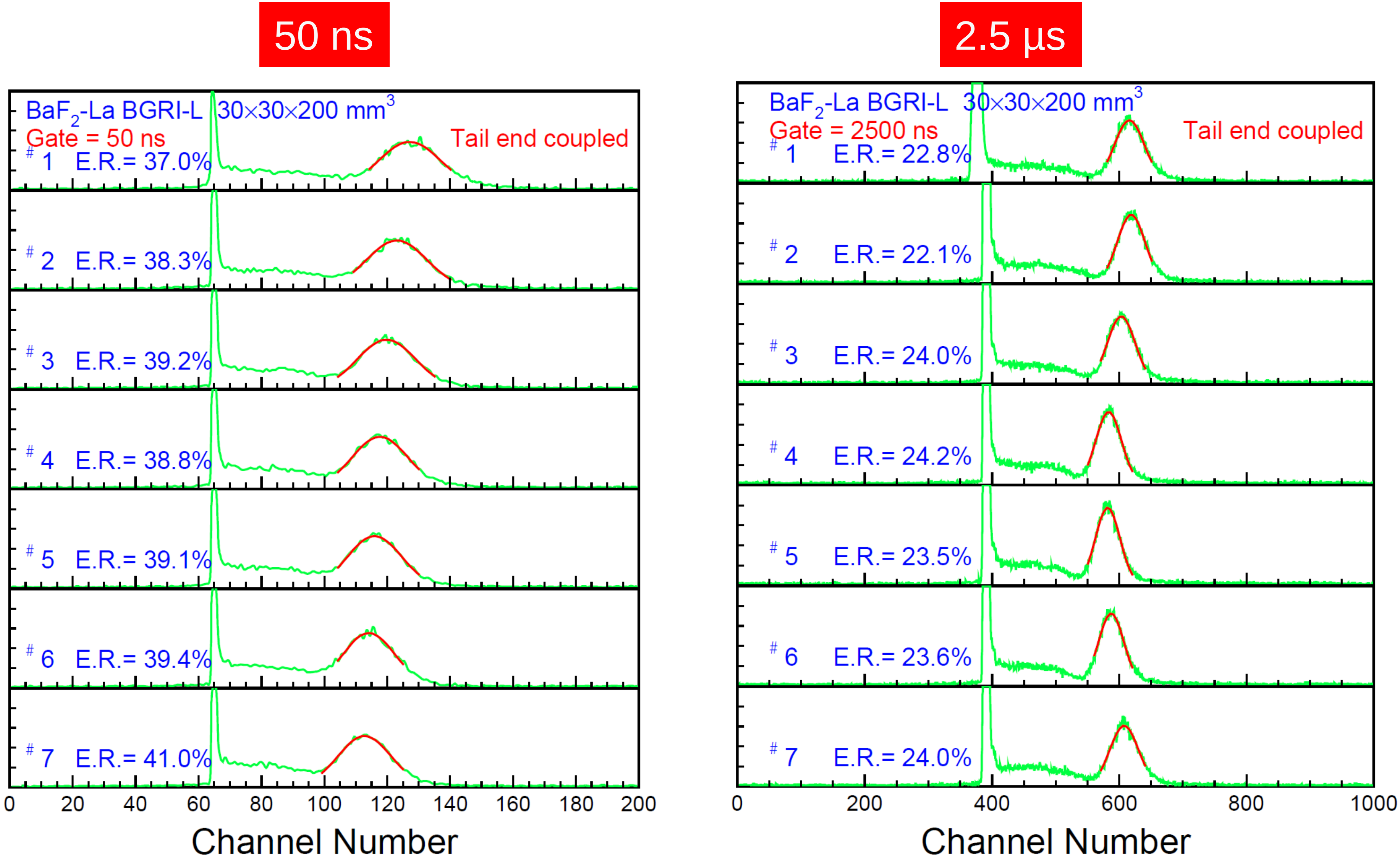
Longitudinal and Transverse Transmittance

Longitudinal transmittance approaches the theoretical limit, indicating good optical quality. Transverse transmittance consistent with 2 cm samples

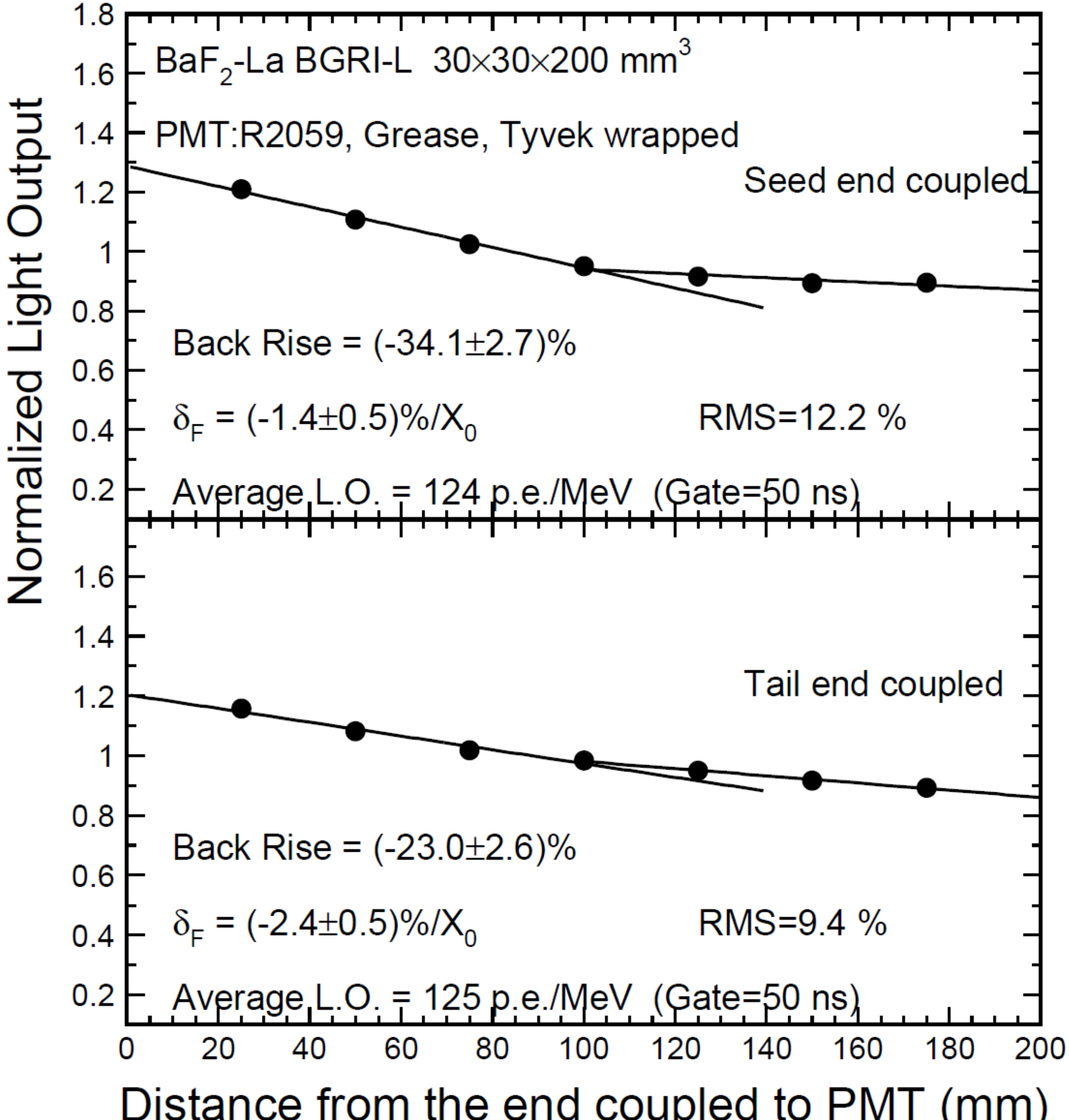




PHS: BGRI BaF_2:La/Ce



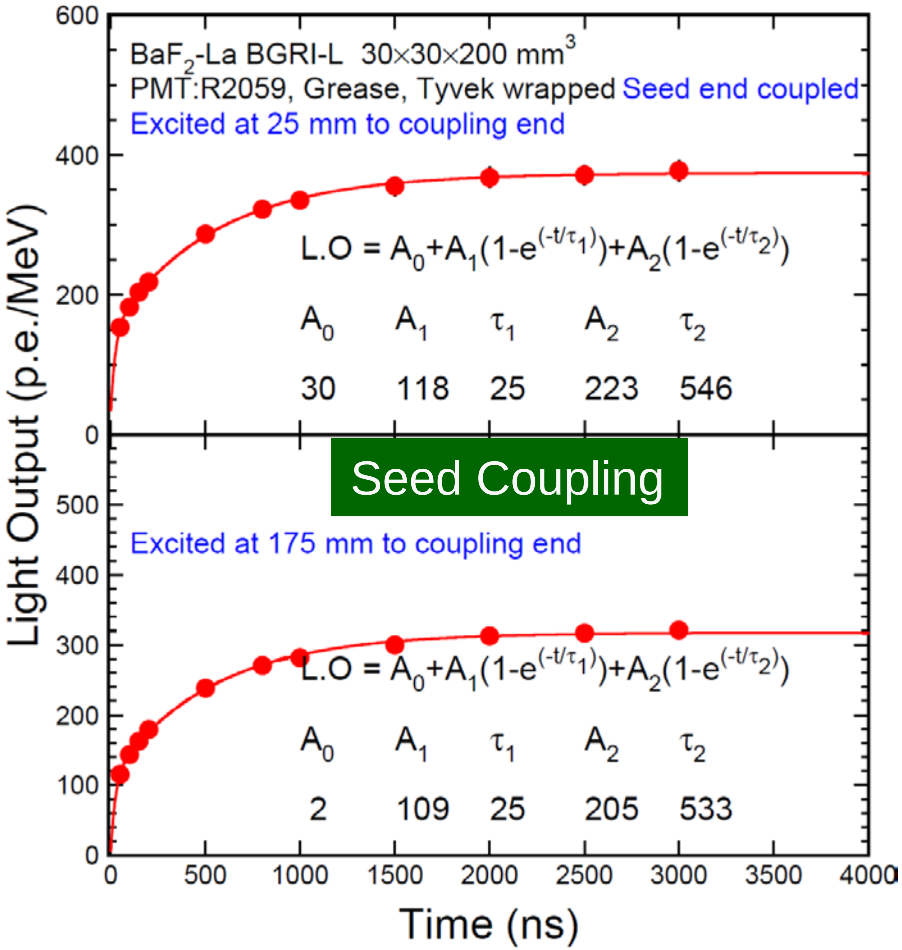
Light Response Uniformity: BGRI BaF_2:La/Ce

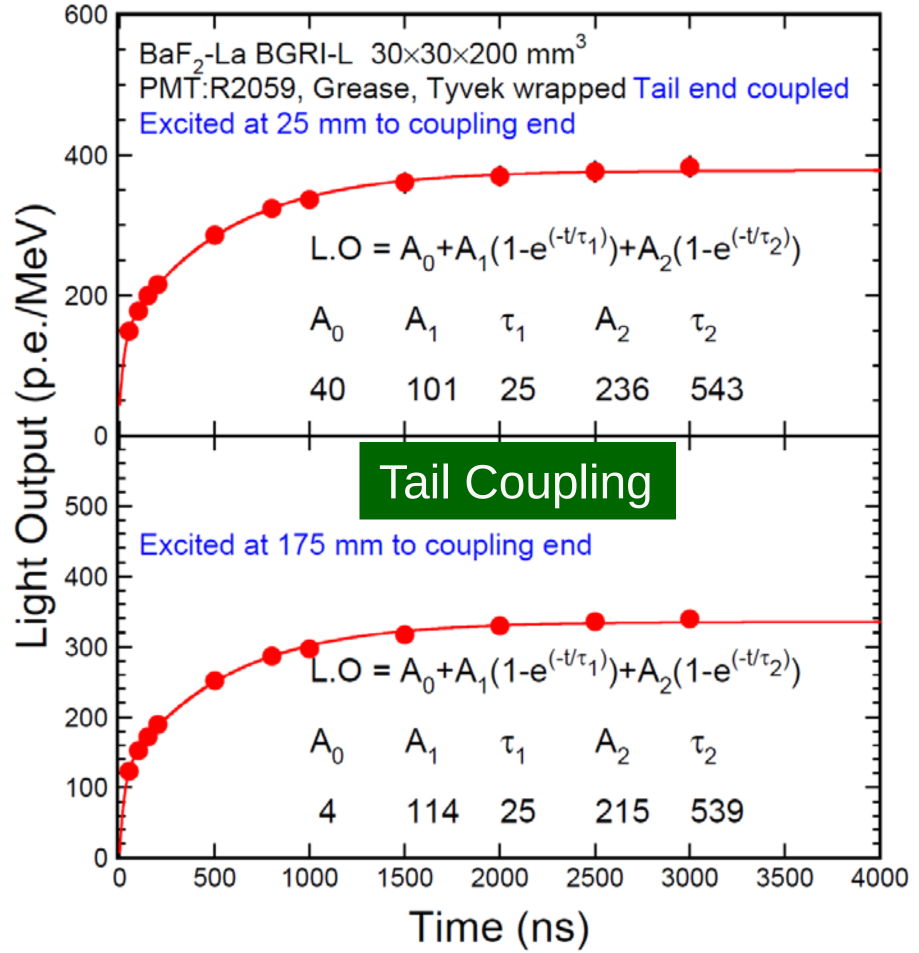


La/Ce Co-doped 20 cm long BaF_2 crystal shows good light response uniformity.

Decay Kinetics of BGRI BaF_2:La/Ce

Both decay time and LO of slow component decrease with doping

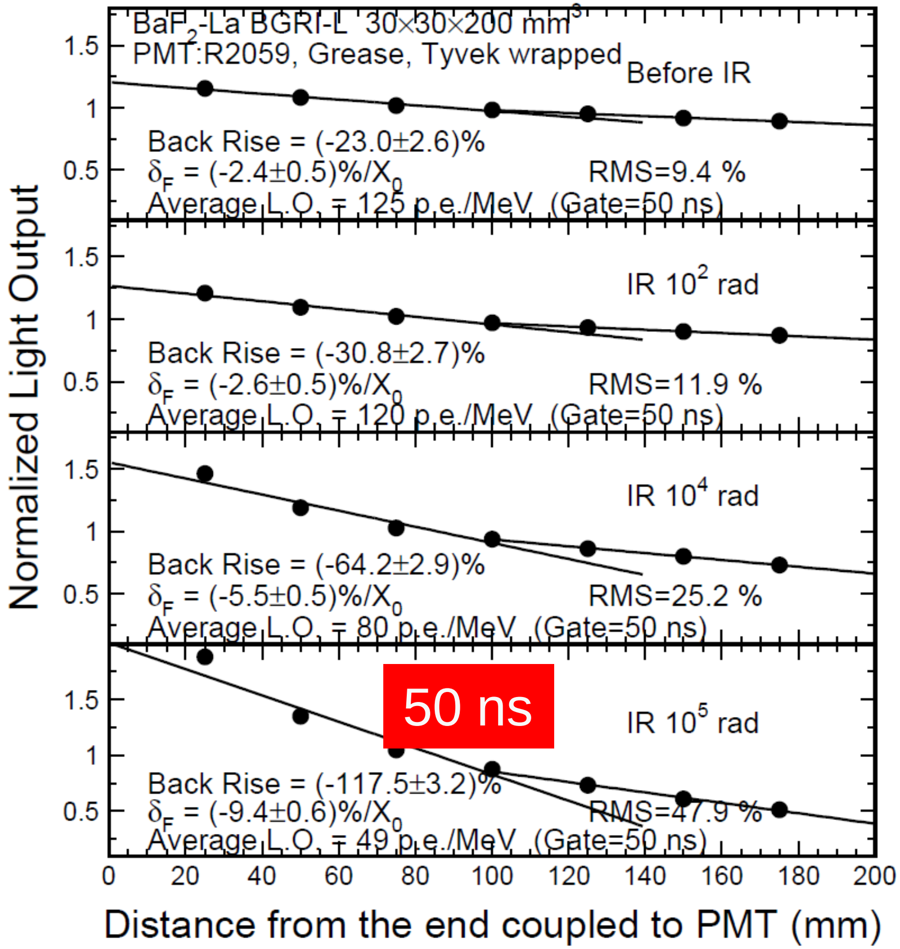


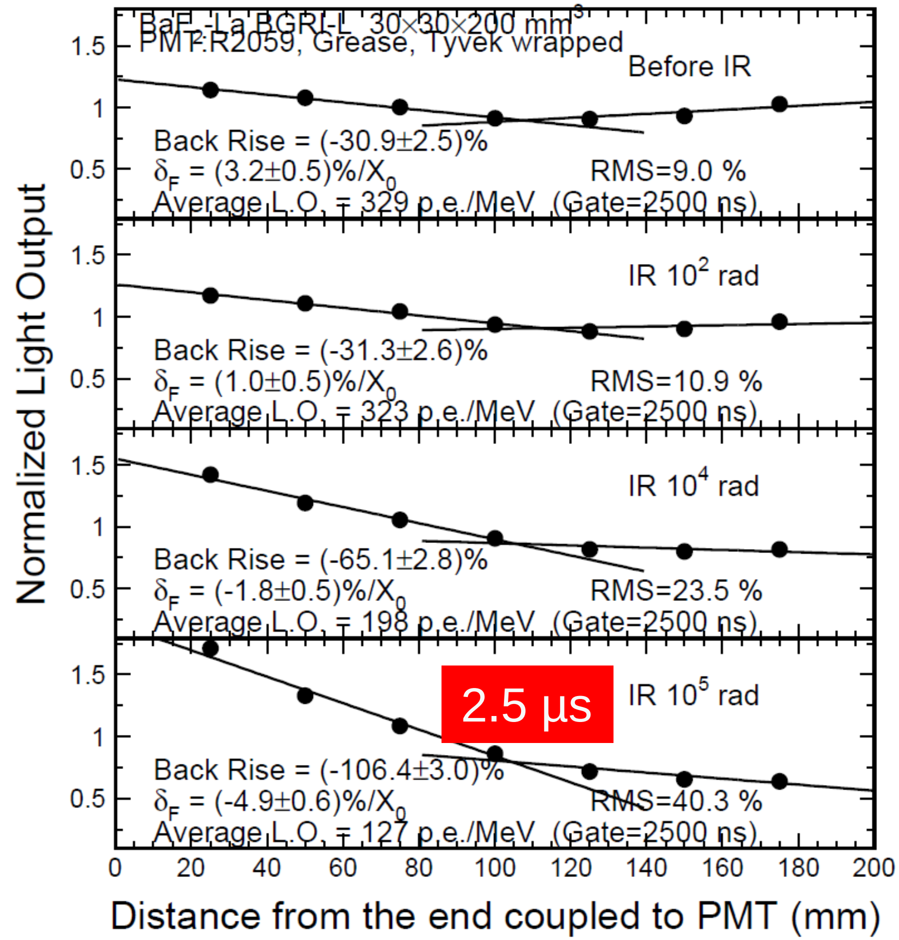


Consist F/S ratio after switching the coupling end

Radiation Damage: BGRI BaF_2:La/Ce

This La doped BaF_2 crystal is radiation hard up to 10 krad





Summary

- Commercially available BaF_2 crystals provide sufficient fast light with sub-ns decay time and excellent radiation hardness up to 120 Mrad. They promise a very fast and stable calorimeter in a severe radiation environment.
- The issue of BaF_2 crystal's slow scintillation light with 600 ns decay time can be handled by several approaches: photo-detector and crystals.
- Work on La/Ce co-doping in BaF_2 crystals started last Fall. The 1st 20 cm long sample with La/Ce cooping shows the overall F/S ratio increased from 1:5 to 1:2 with good initial light response uniformity. Their radiation hardness, however, need further investigation.