2nd Report on Twenty Mu2e BaF_2 Crystals from SIC

Ren-Yuan Zhu

California Institute of Technology

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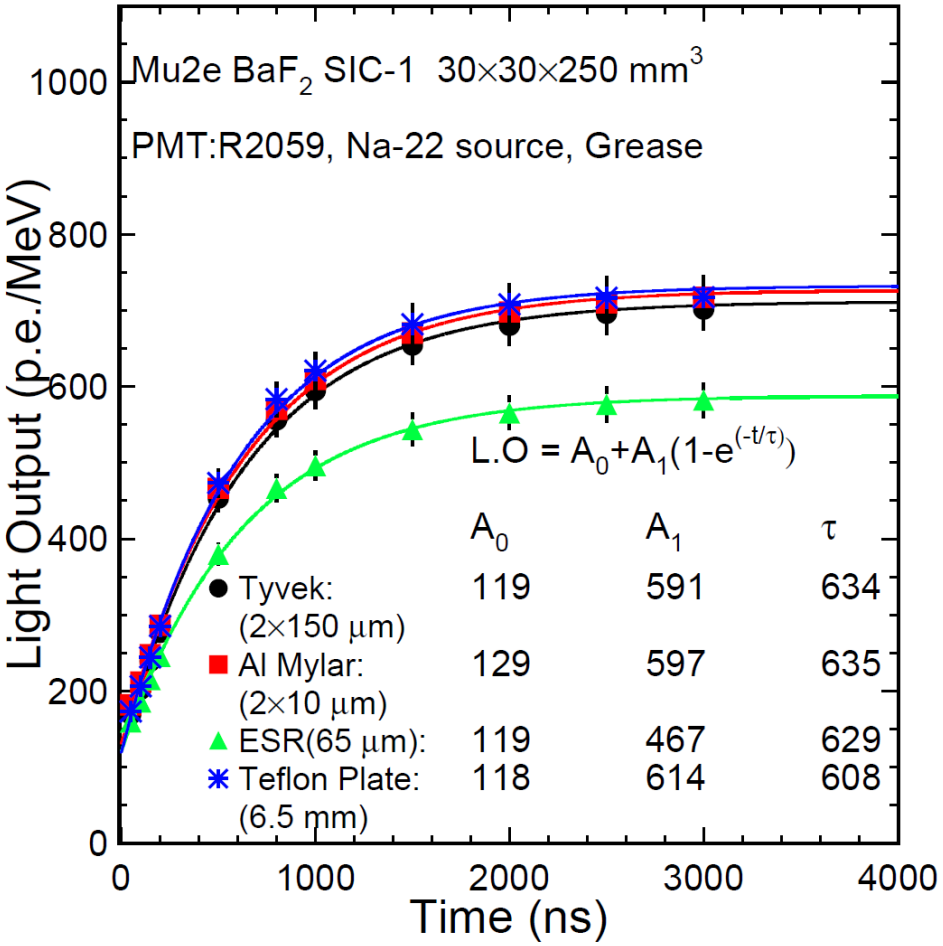
Crystal Samples and Experiment

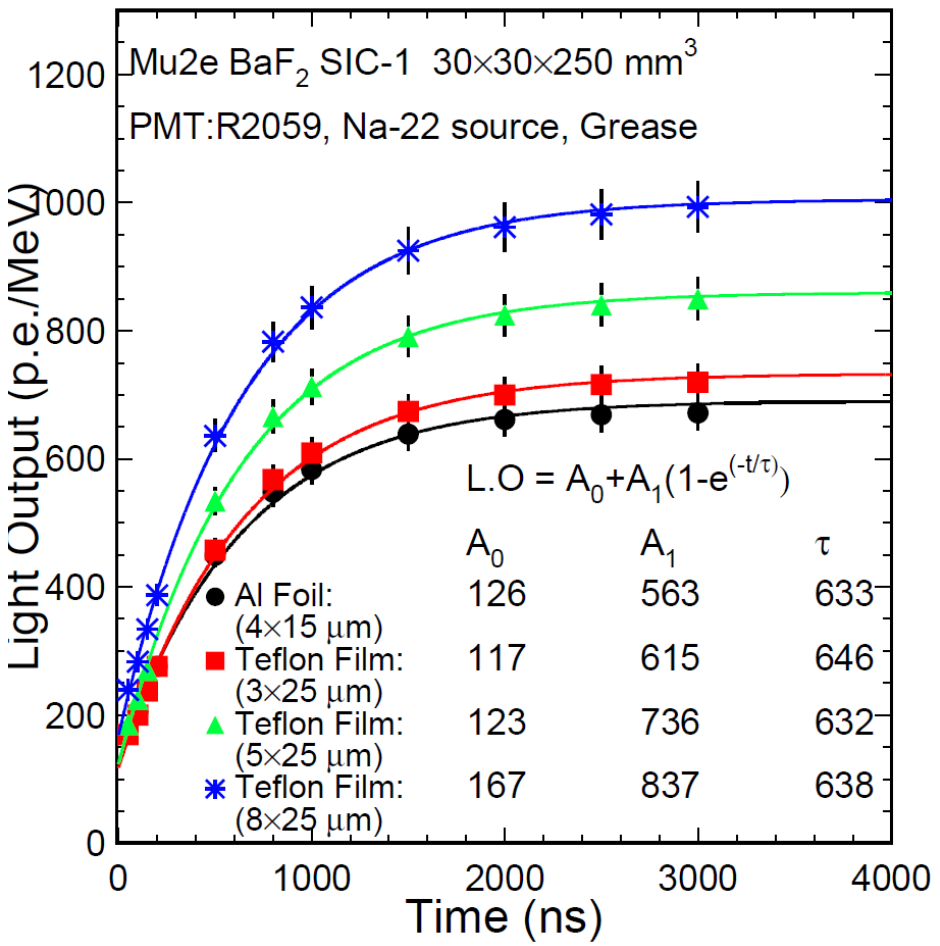
Sample ID	Received Date	Dimension (mm^3)	Total #	Polish
SIC-1,20	4/25/2014	30× 30 × 250	20	Six surfaces

Properties measured: light output, decay kinetics
and light response uniformity for Tyvek and other wrappings

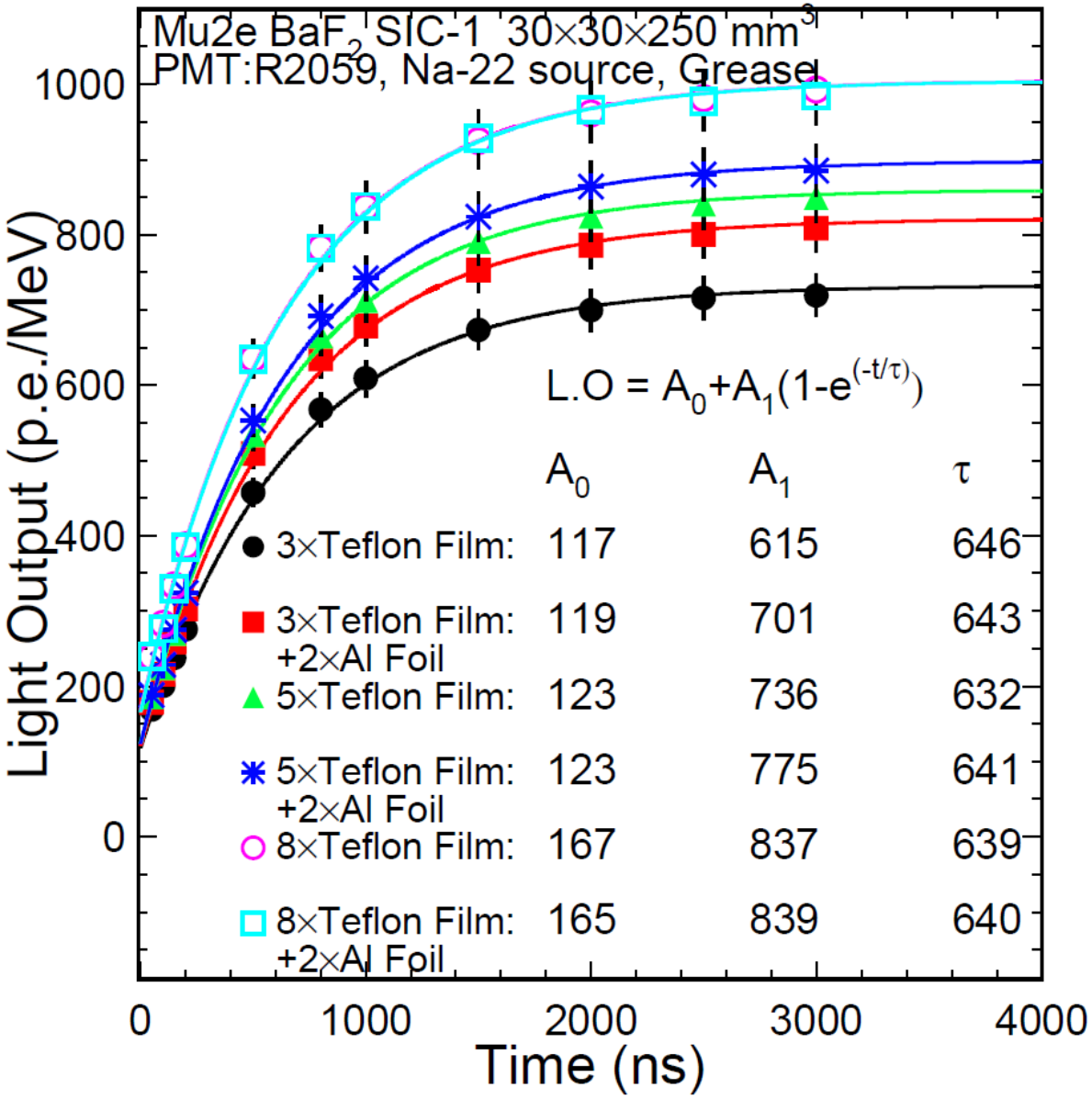
Effect of Crystal Wrapping (I)

The highest LO is observed with 8 layer Teflon wrapping





Effect of Crystal Wrapping (II)



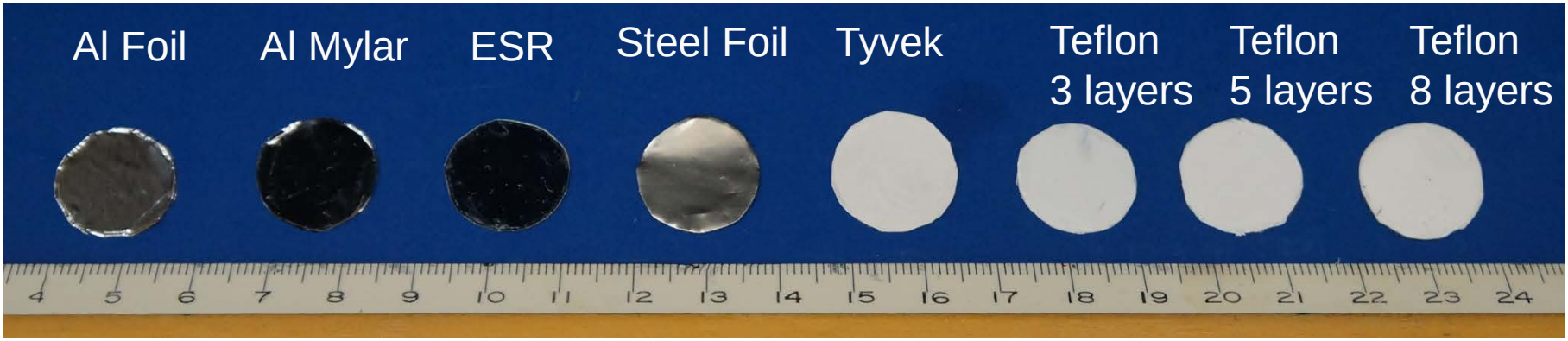
Adding Al foil helps if Teflon layers is less than 8.

Summary: Wrapping Test for SIC-1

	Fast LO (p.e./MeV)	LO: 50 ns (p.e./MeV)	RMS 50 ns (%)	δ_F 50 ns (%/X_0)	R_B 50 ns (%)	Slow LO (p.e./MeV)	LO: 2.5 μs (p.e./MeV)	RMS 2.5 μs (%)	δ_F 2.5 μs (%/X_0)	R_B 2.5 μs (%)
Al Foil (4)	126	131	16.8	-2.0	-44.8	563	579	8.5	-0.3	-25.9
Al Mylar (2)	129	148	10.7	-0.9	-30.4	597	644	5.6	0	-17.3
ESR (2)	119	130	11.0	-1.4	-30.2	467	525	5.0	-0.4	-15.1
Teflon (3)	117	117	21.0	-0.5	-63.5	615	567	12.9	1.2	-43.6
Teflon (3) +Al Foil (2)	119	125	20.4	-0.8	-61.9	701	645	12.2	0.3	-39.0
Teflon (5)	123	135	18.3	-0.9	-53.5	736	706	9.7	0.3	-32.0
Teflon (5) +Al Foil (2)	123	135	17.9	-1.1	-52.8	775	741	13.0	-1.2	-37.6
Teflon (8)	167	172	20.7	-2.0	-58.2	837	788	13.0	-1.2	-37.9
Teflon (8) +Al Foil (2)	165	178	20.6	-2.2	-58.6	839	788	13.1	-1.3	-36.8
Teflon Plate	118	125	18.2	-1.1	-53.1	614	574	12.1	0.5	-39.4
Tyvek (2)	119	130	14.4	-1.6	-39.8	591	586	9.4	-0.1	-29.6

Two layers of Aluminized Mylar seem providing the best uniformity

Reflectance Measurements

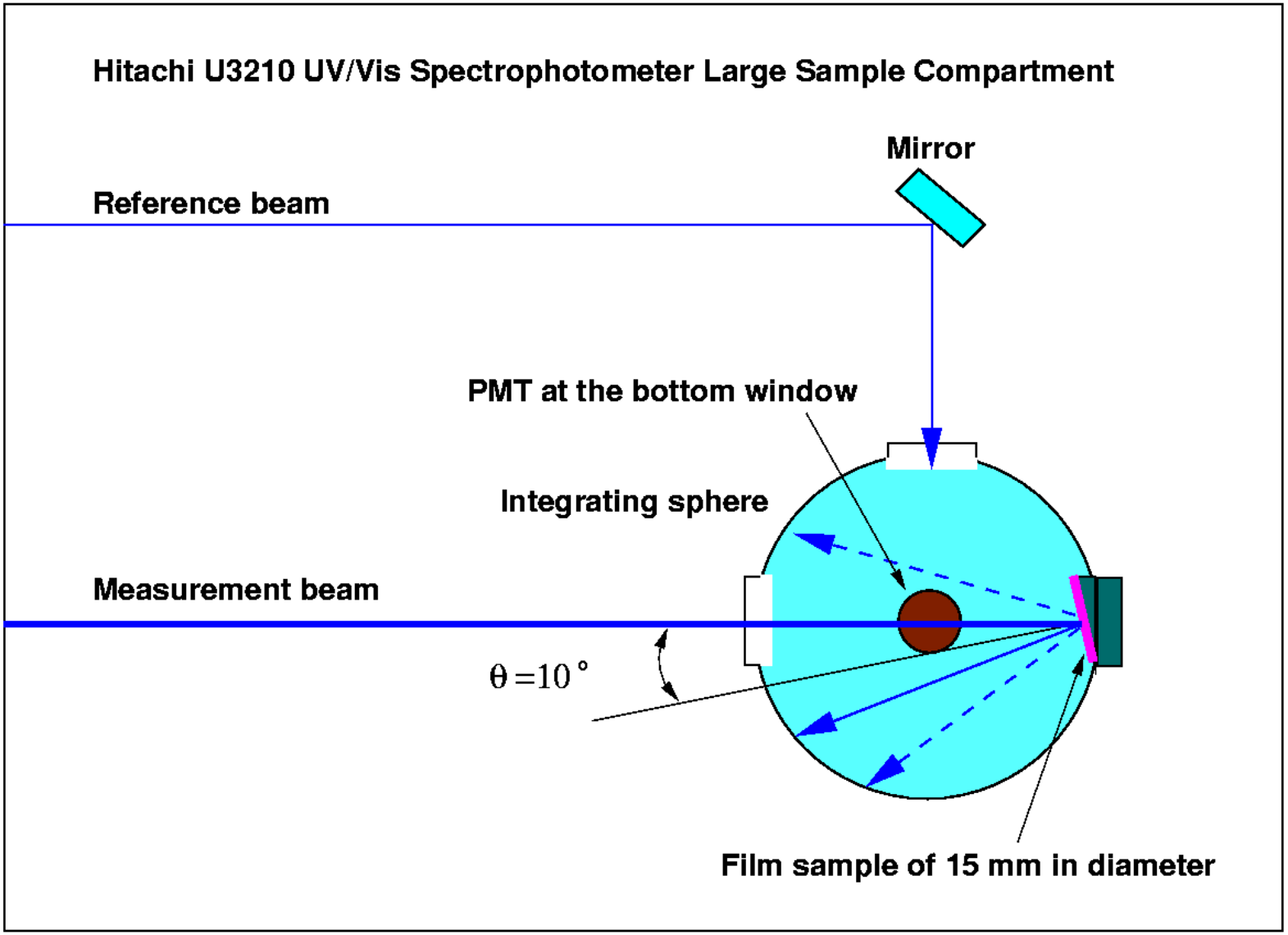


Sample ID	Thickness (μm)
Al Foil	15
Al Mylar	10
ESR	65
Steel Foil	50
Tyvek	150
Teflon ×3	25×3
Teflon ×5	25×5
Teflon ×8	25×8

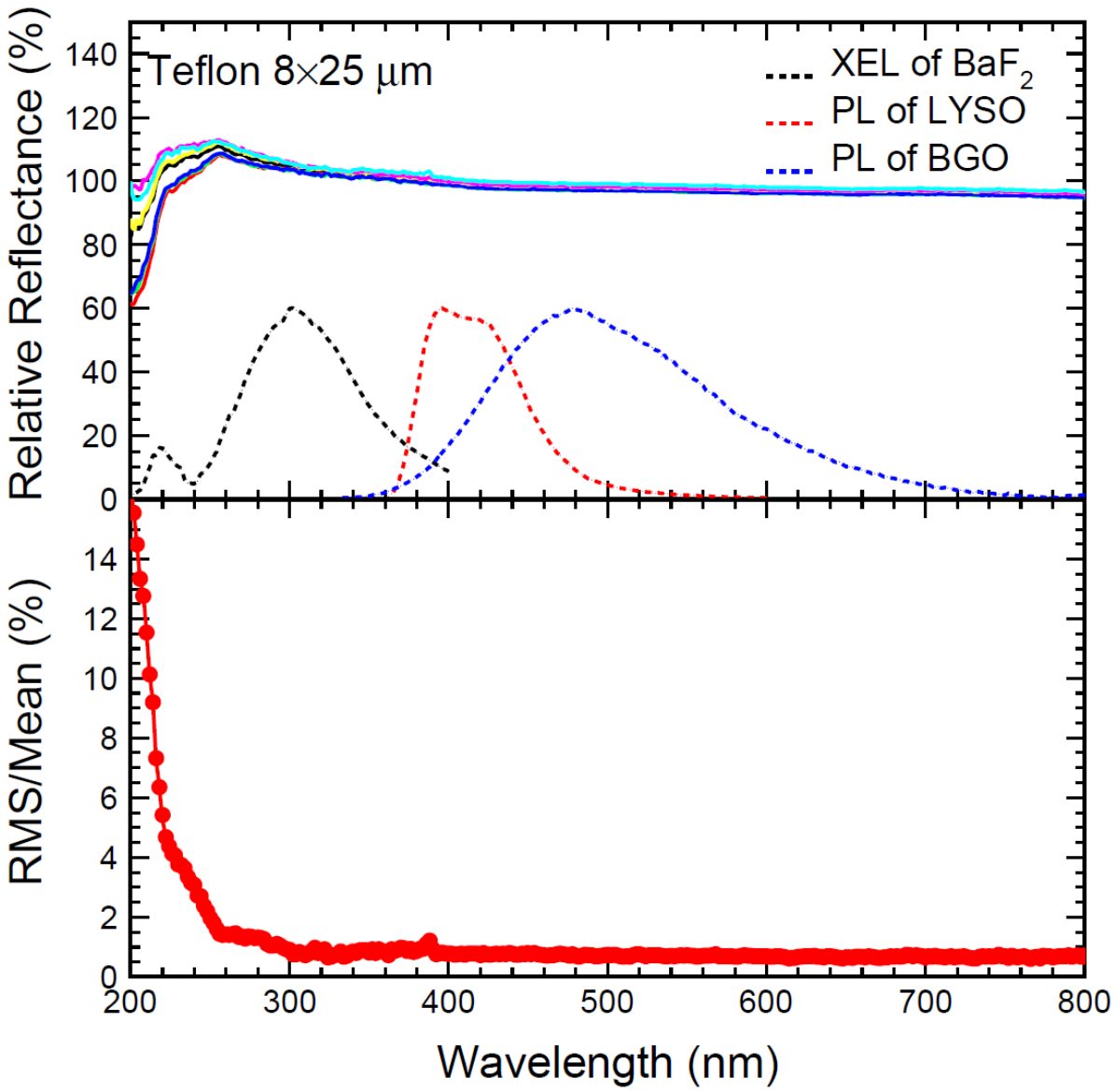
Properties measured at room temperature:

Reflectance as a function of wavelength

Setup for Reflectance Measurement



Systematic Uncertainties



RMS values extracted from ten repeated measurements for 8 layers of Teflon films:

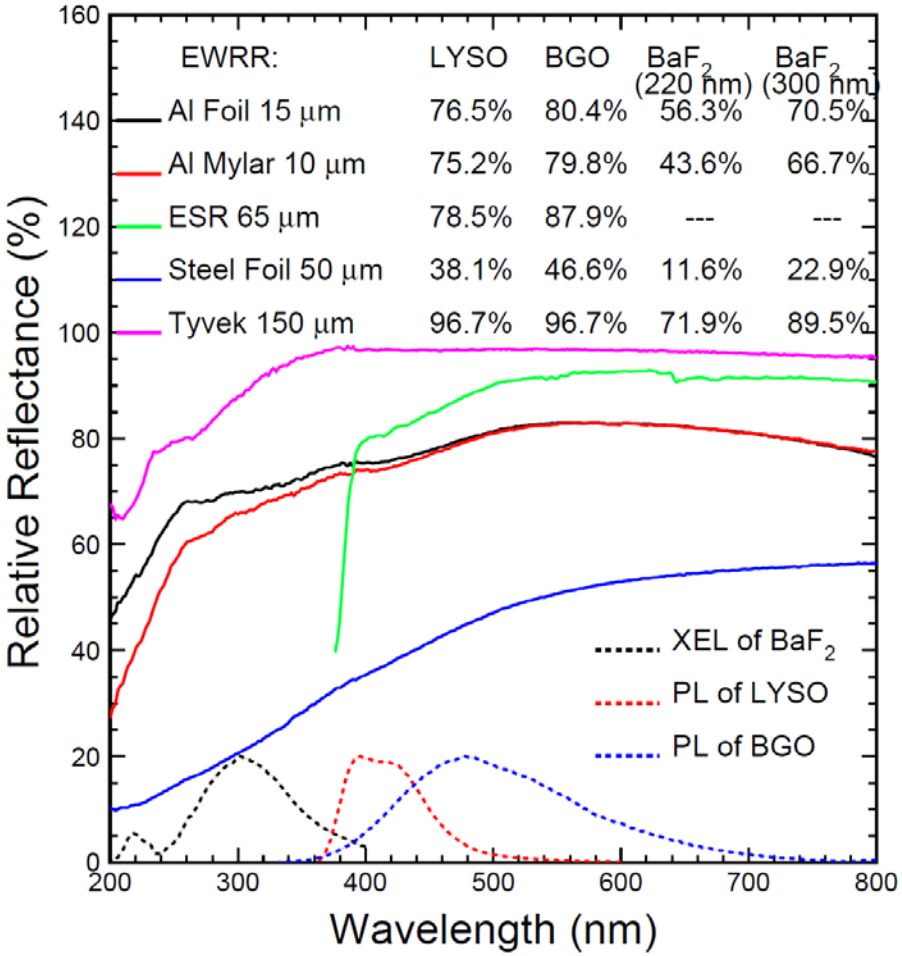
<1% with λ longer than 250 nm; and Up to 15% with λ shorter than 250 nm.

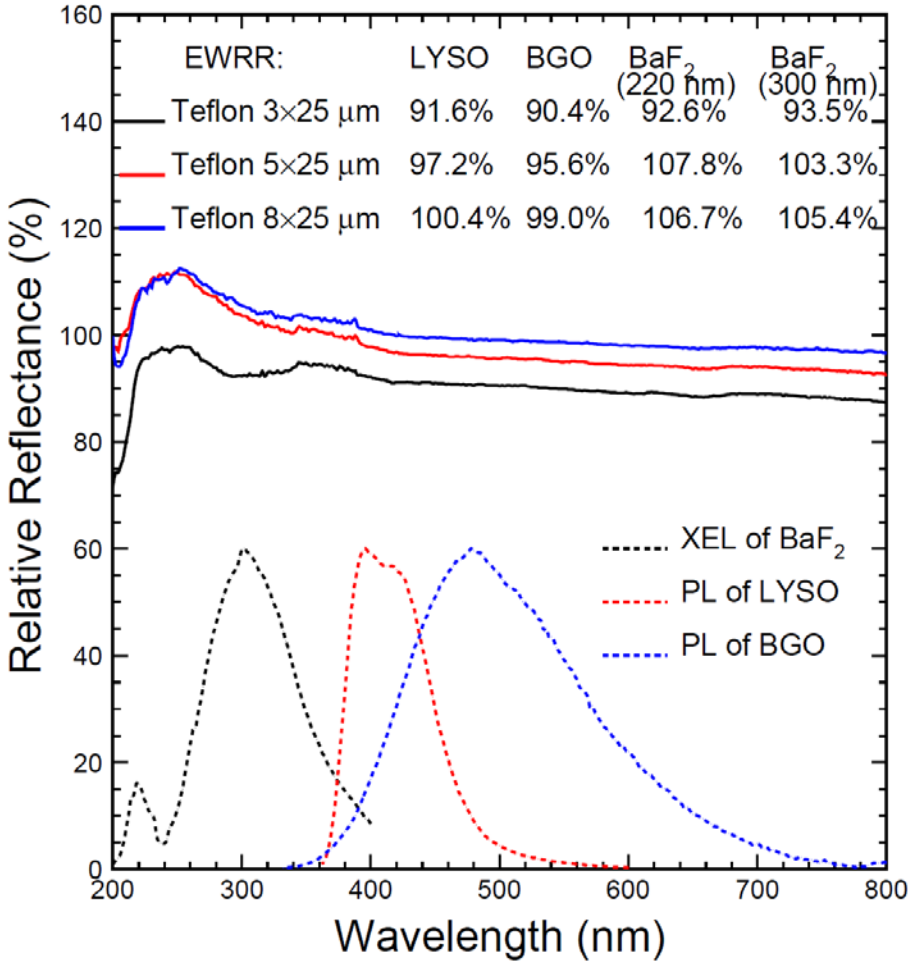
Normalized Reflectance

$BaSO_4$ is the coating material used in the integrating sphere

EWRR : Emission weighted relative reflectance

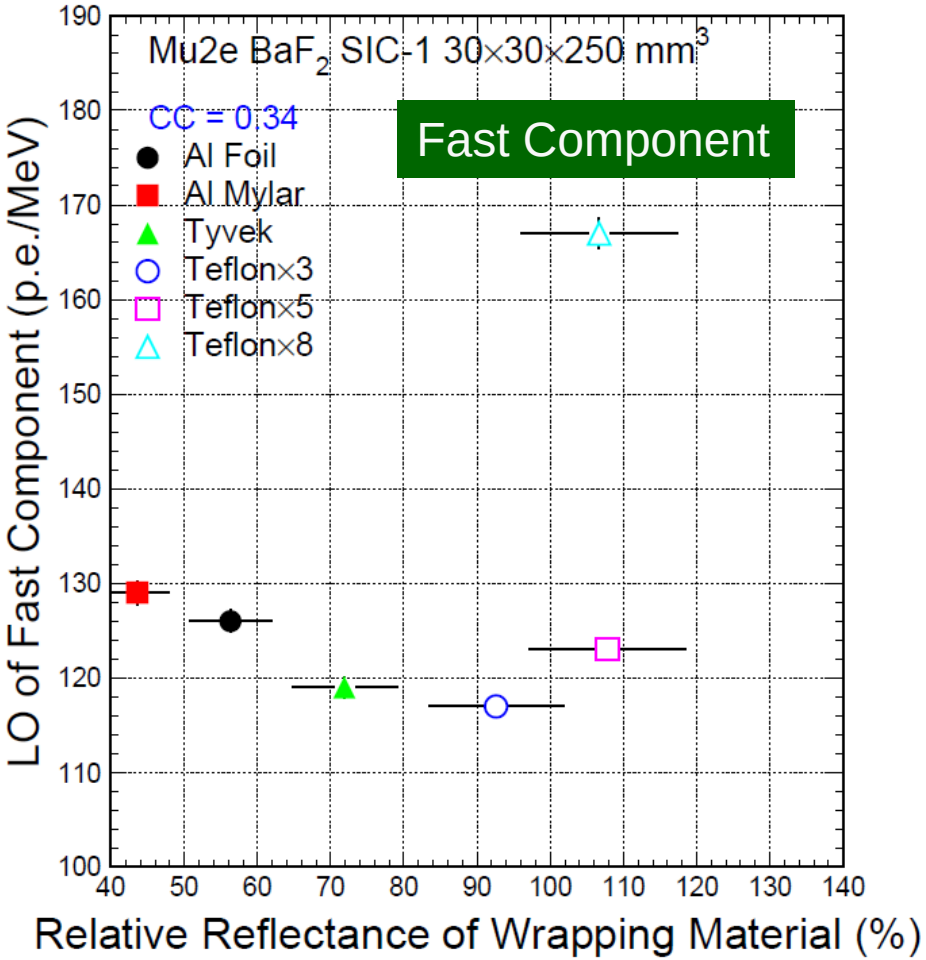
$$EWRR = \int em(\lambda) \cdot reflectance(\lambda) d\lambda / \int em(\lambda) d\lambda$$

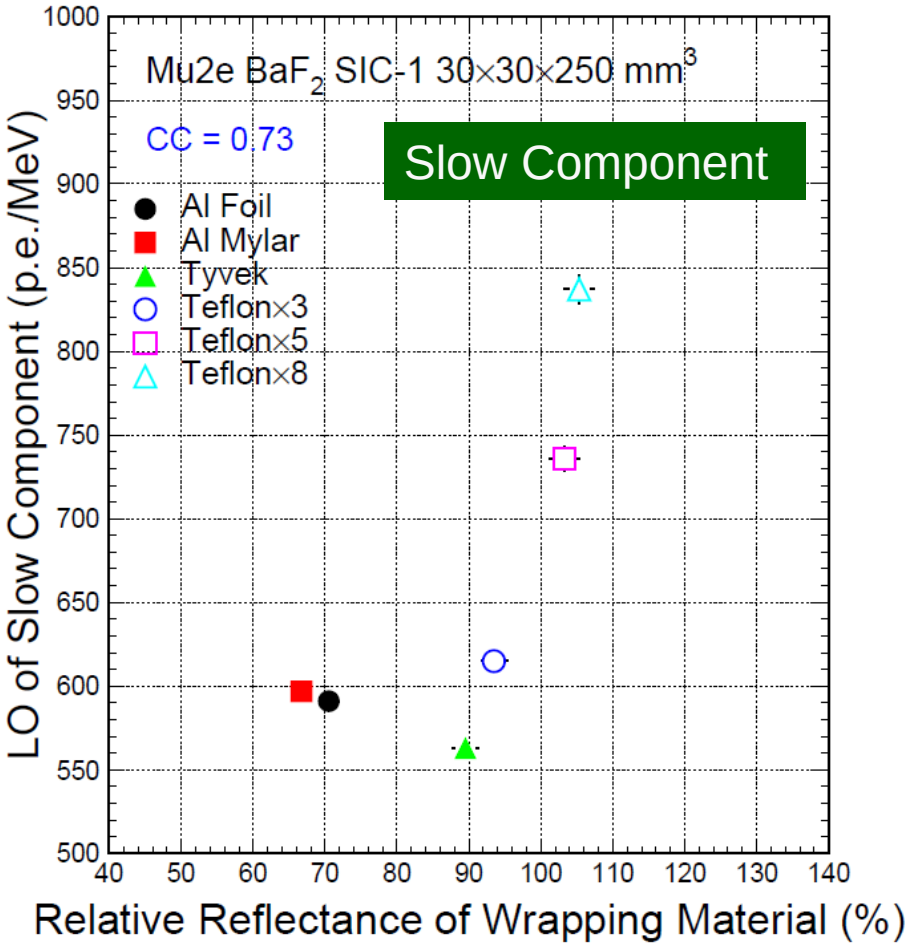




LO versus Reflectance for BaF_2 SIC-1

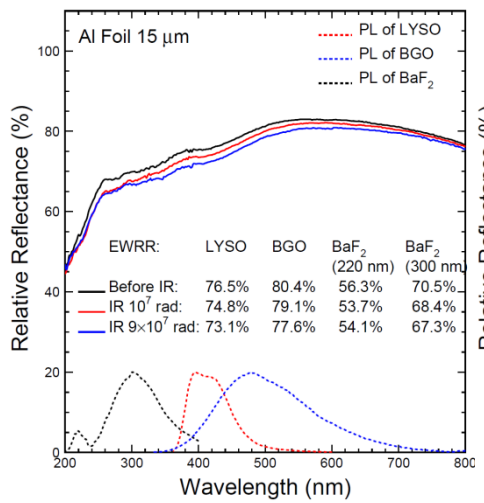
Positive correlations observed

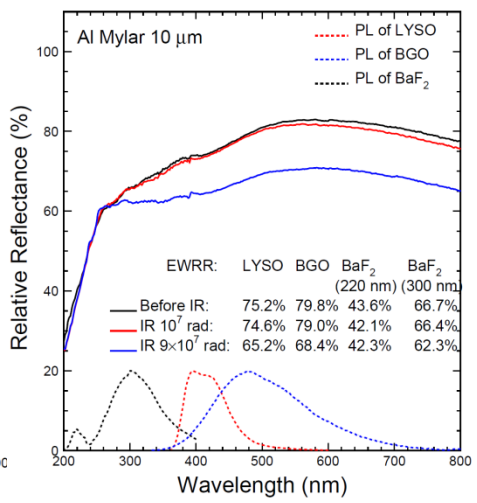


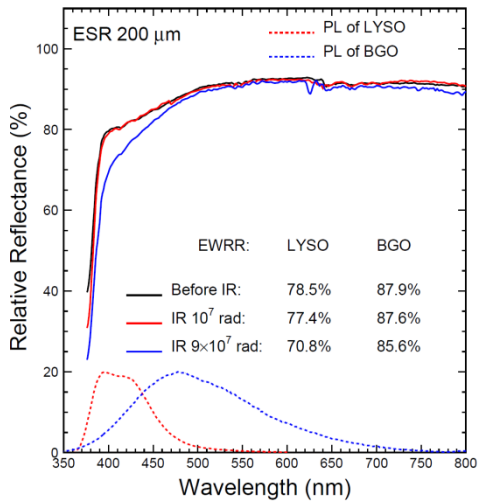


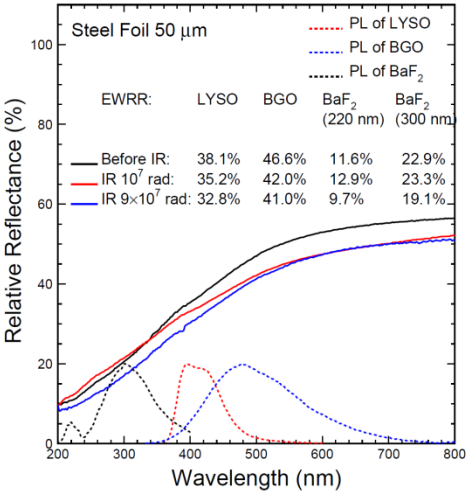
Radiation Damage in Various Reflectors

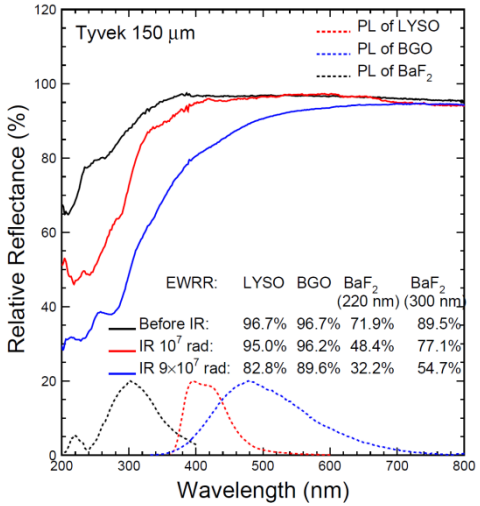
Aluminum foil is the best reflector up to 100 Mrad

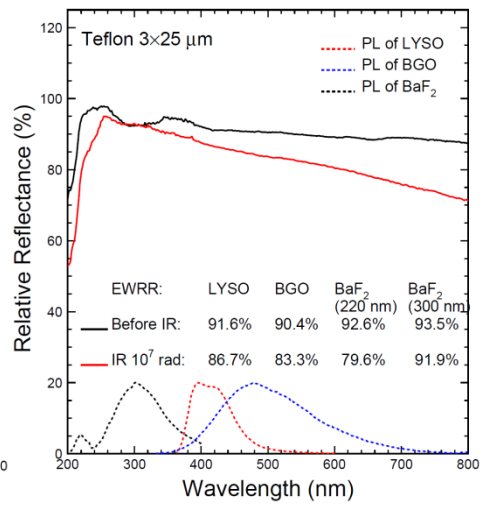


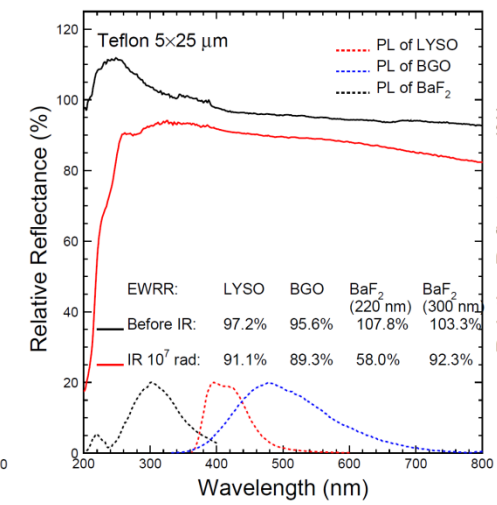


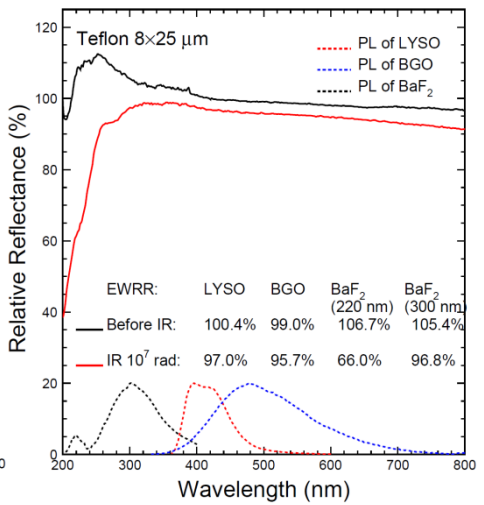






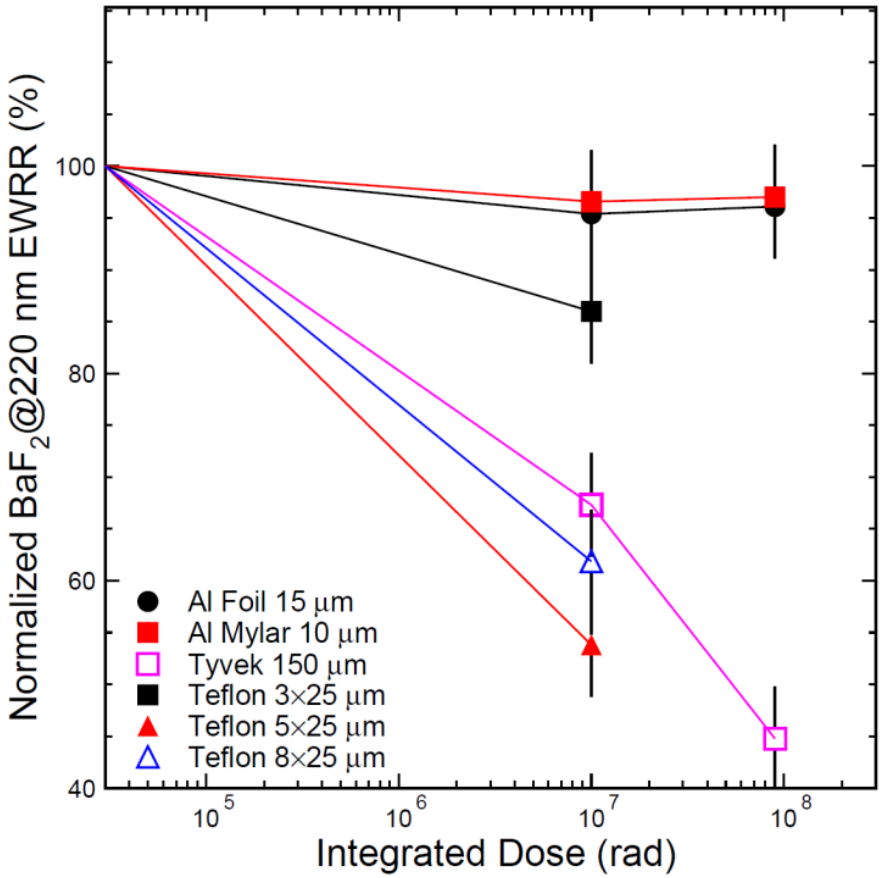




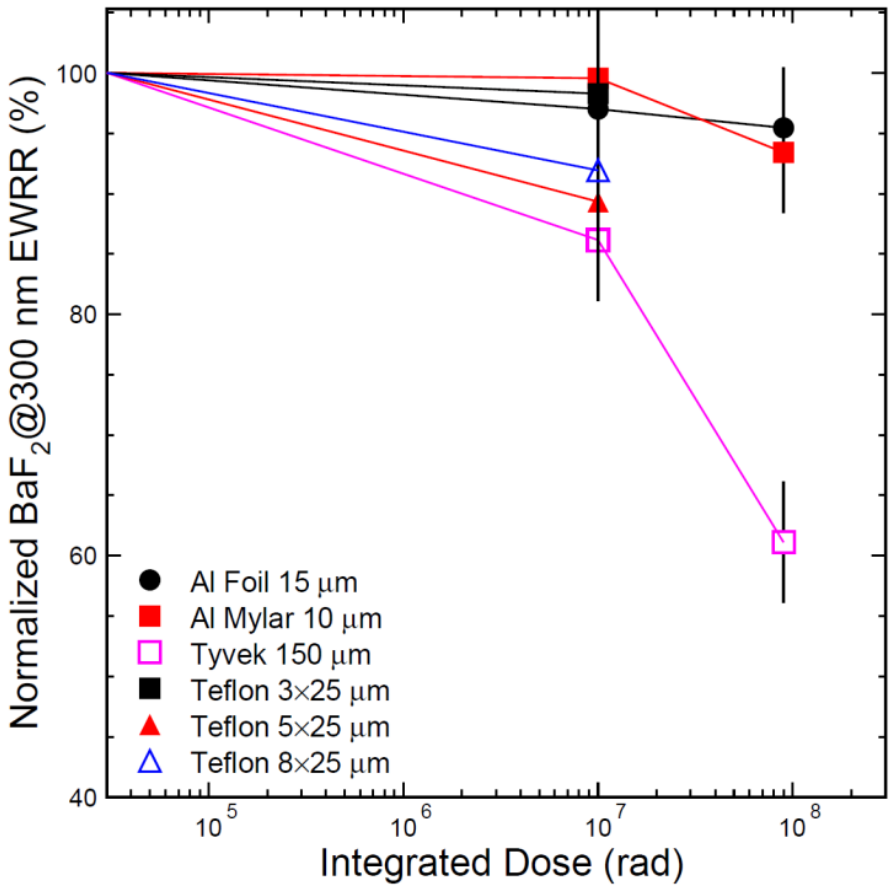


Radiation Damage in Wrapping Materials

Al foil is radiation hard up to 100 Mrad for BaF_2

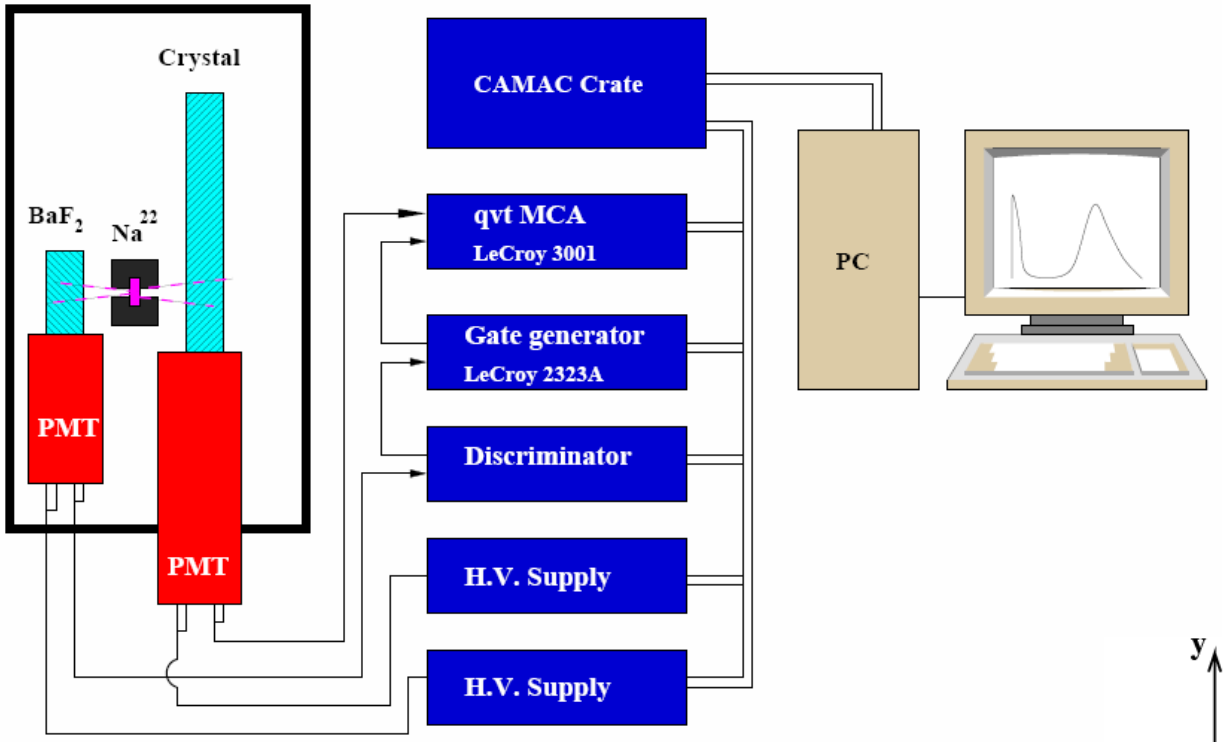


Fast Component



Slow Component

Light Response Uniformity

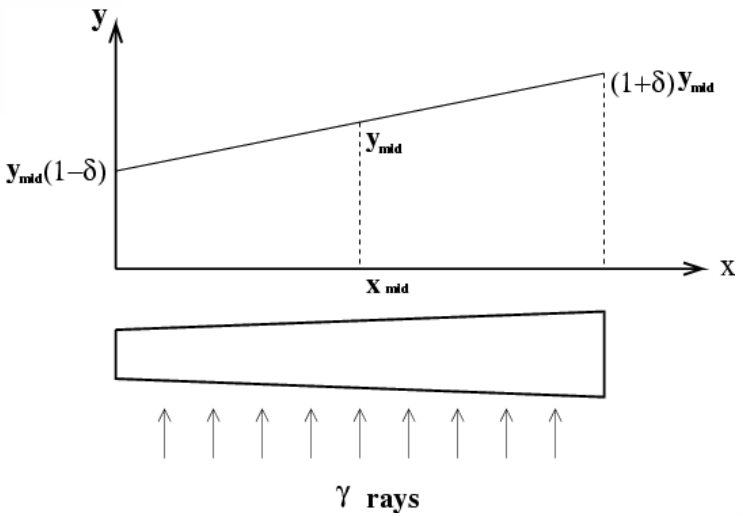


Crystals wrapped with two layers of Tyvek (2 x 150 μm)

One end coupled to

Hamamatsu R2059 PMT
With DC-200 grease coupling

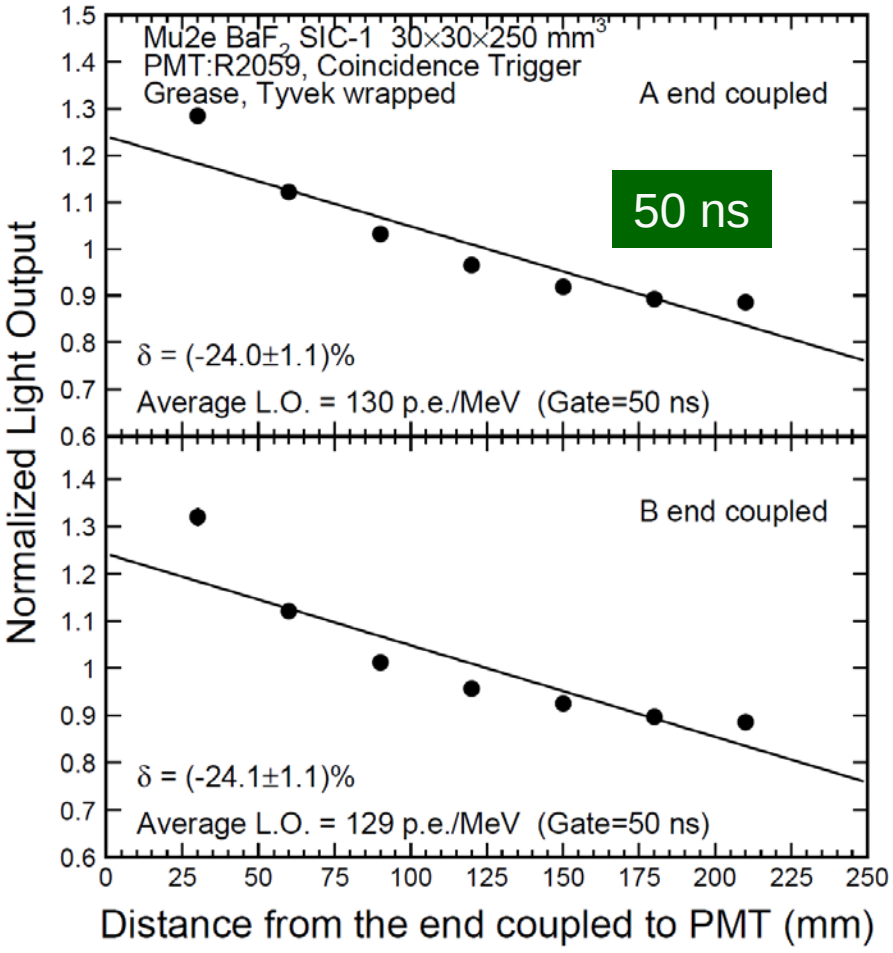
50 ns and 2.5 μs gate
Coincidence trigger from
a Na-22 source

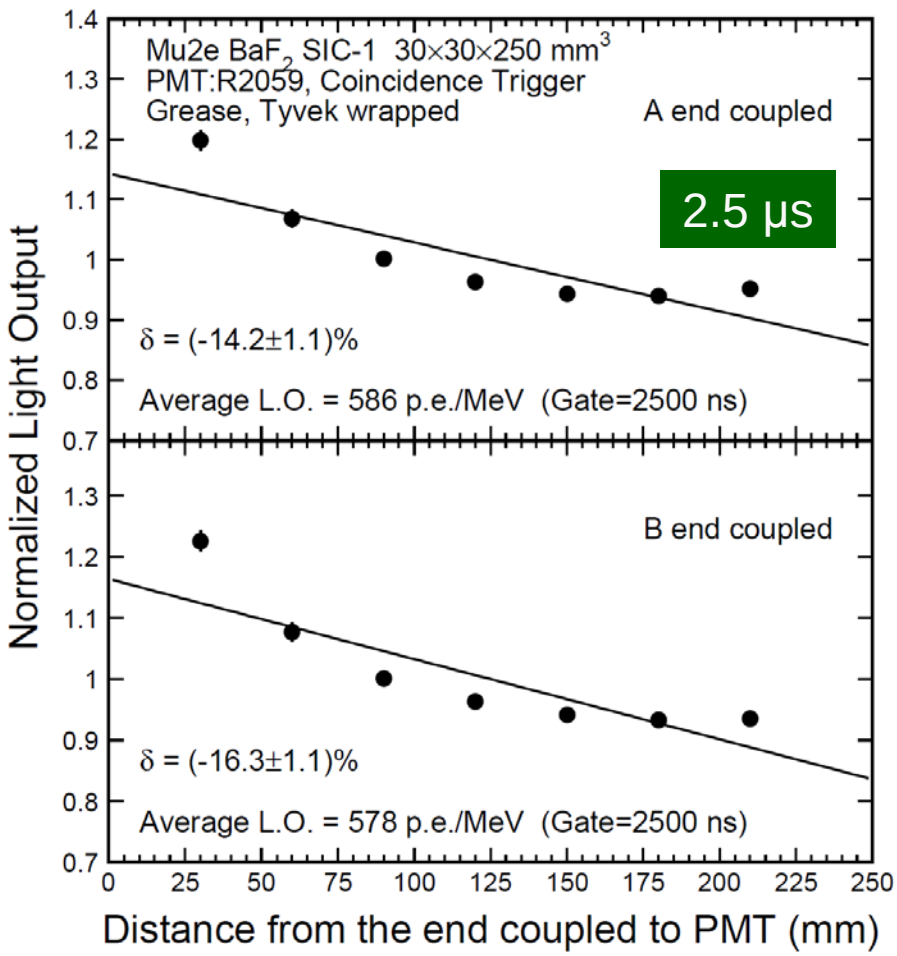


Light output and FWHM energy resolution (see report dated 6/25/14) are measured at seven points along the crystal

No Difference between Coupling Ends

SIC1: No difference with alternative ends coupled to the PMT

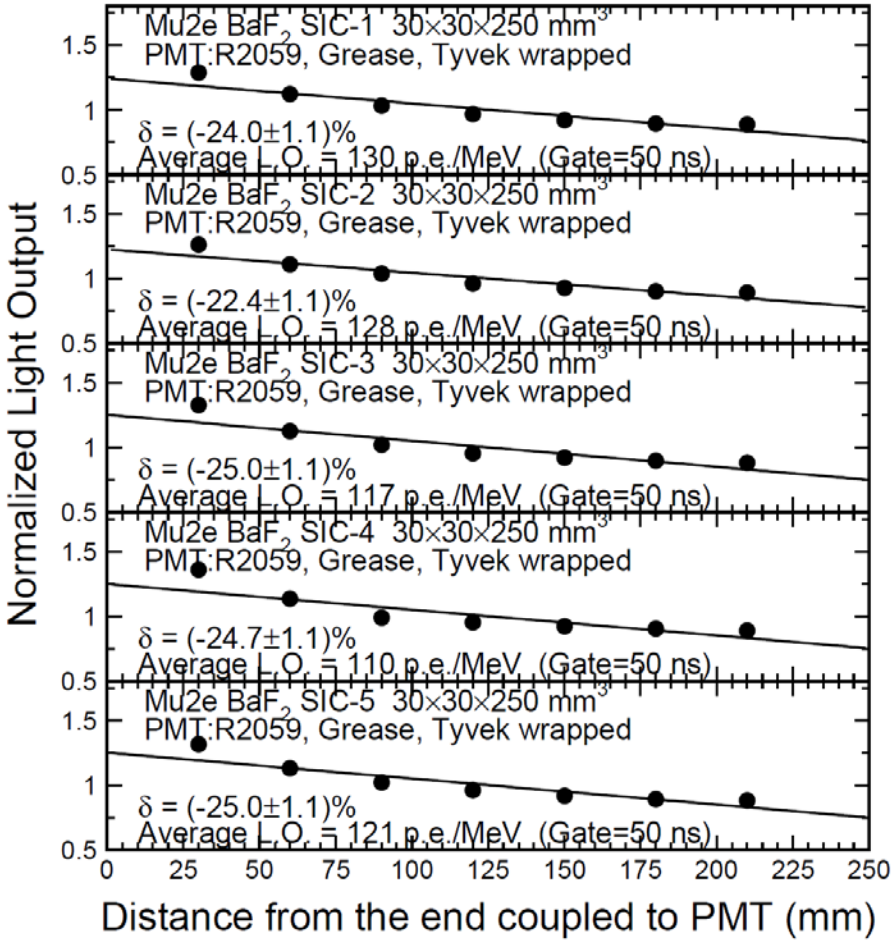


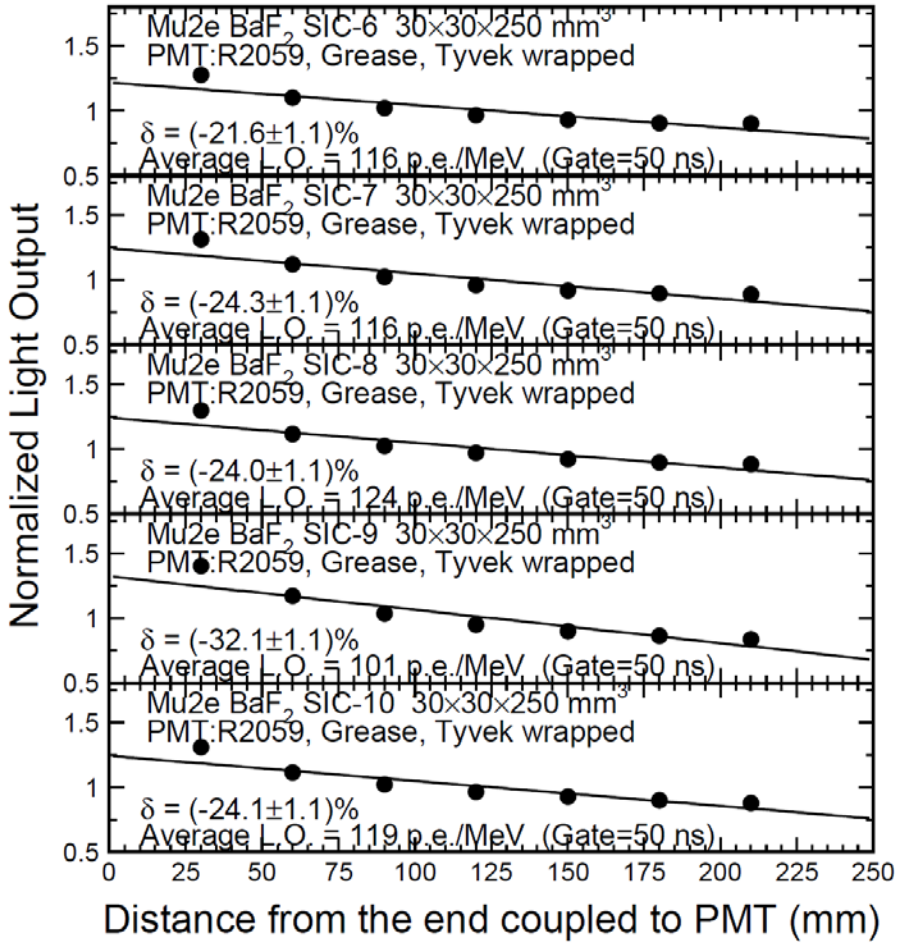


Intrinsic scintillation production is uniform

LRU and LO of No.1-10 (Tyvek)

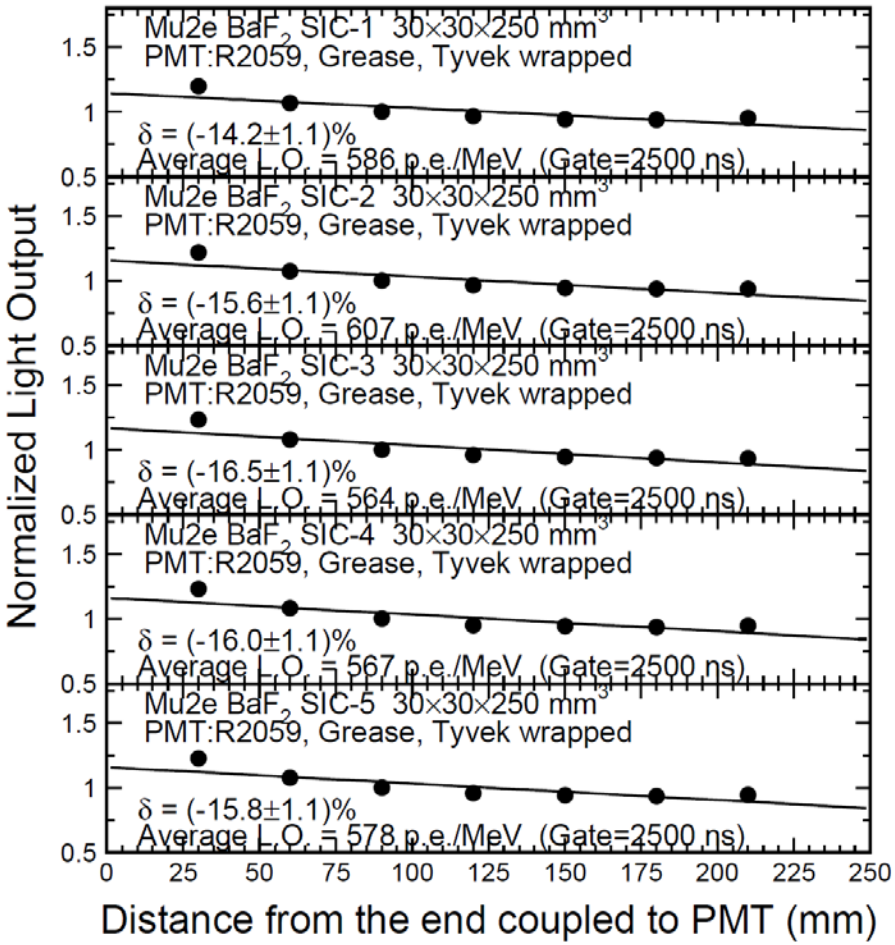
50 ns

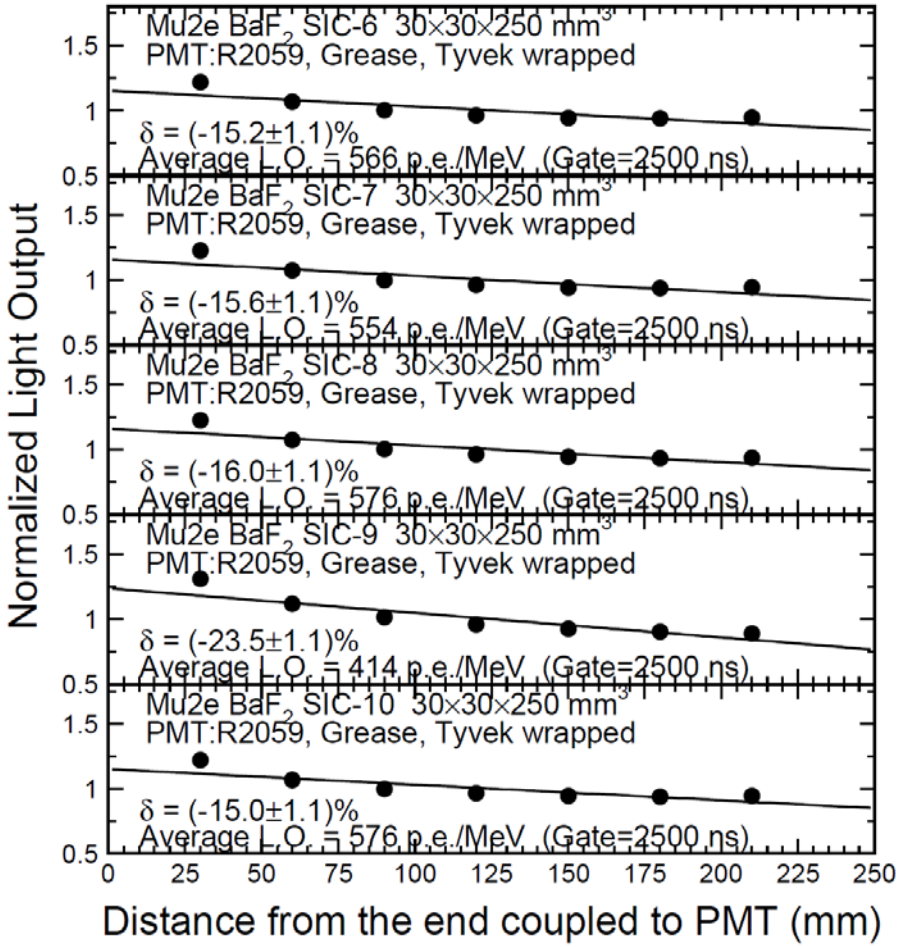




LRU and LO of No.1-10 (Tyvek)

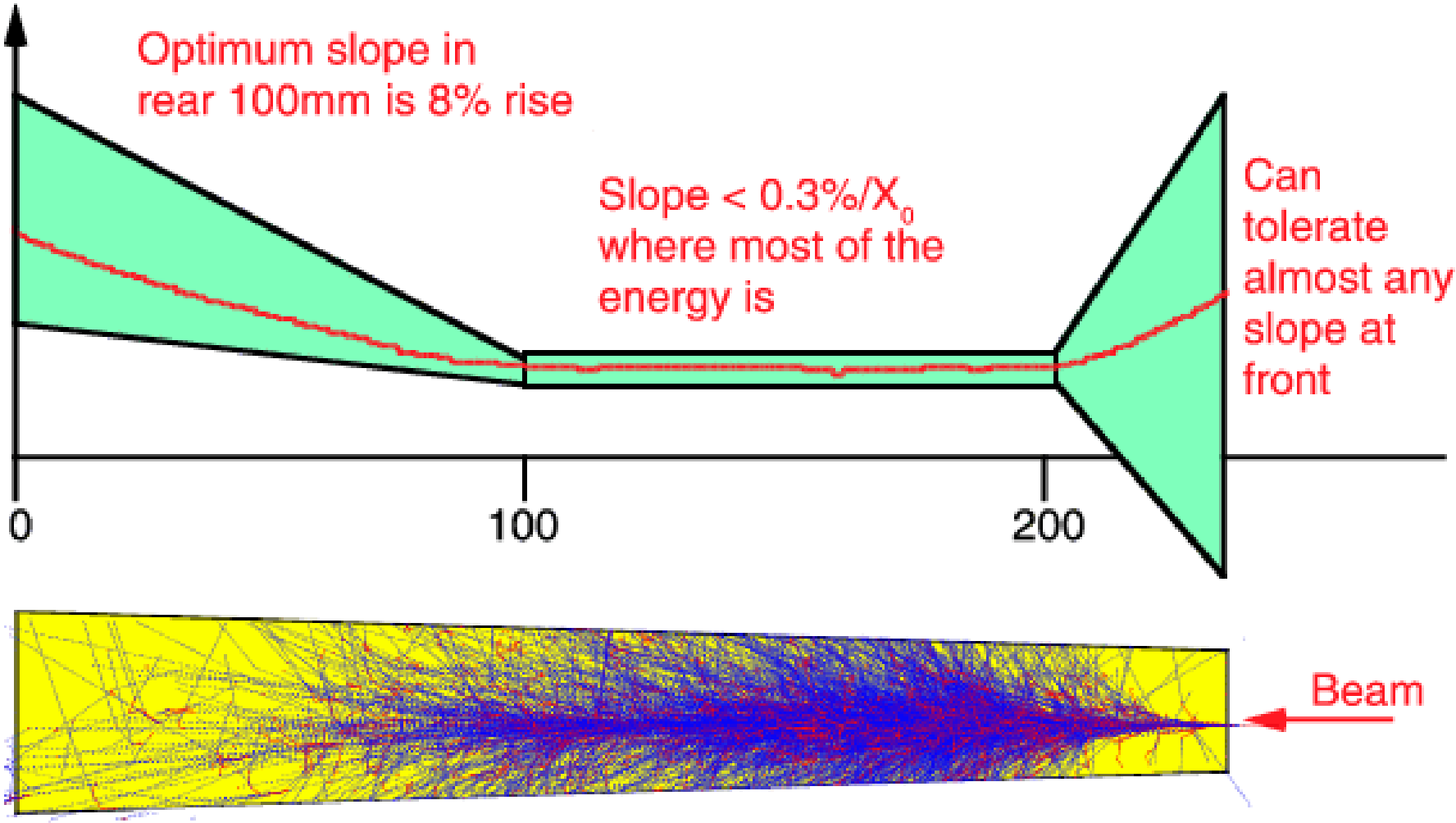
2.5 μs



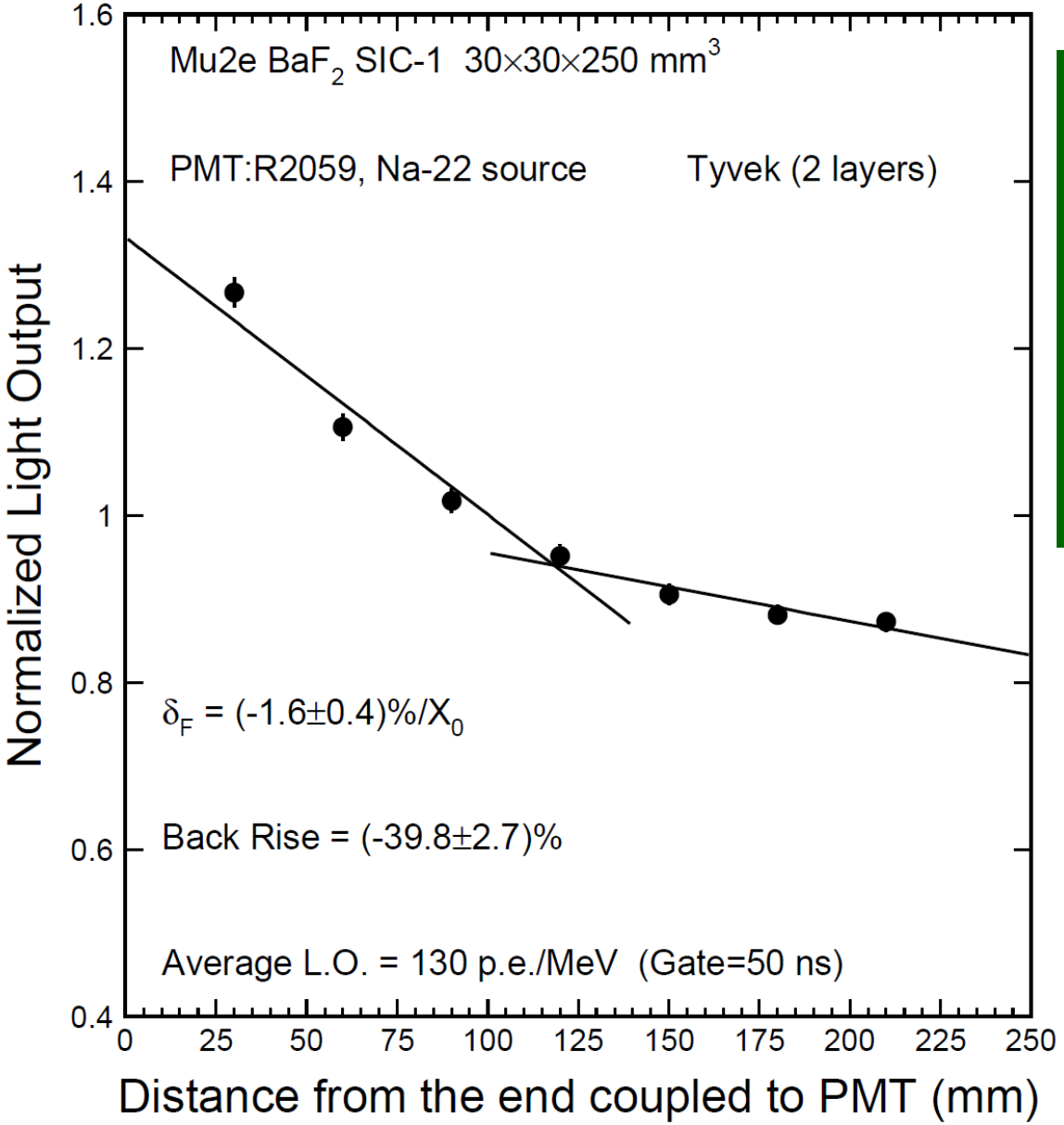


CMS Uniformity Specification

D. Graham & C. Seez, CMS Note 1996-002



Front Slope and Back Rise



First four points and last four points were fit to

$Y = a + b \times x$ and

$Y = c + d \times x$

respectively.

$$Front\ Slope$$

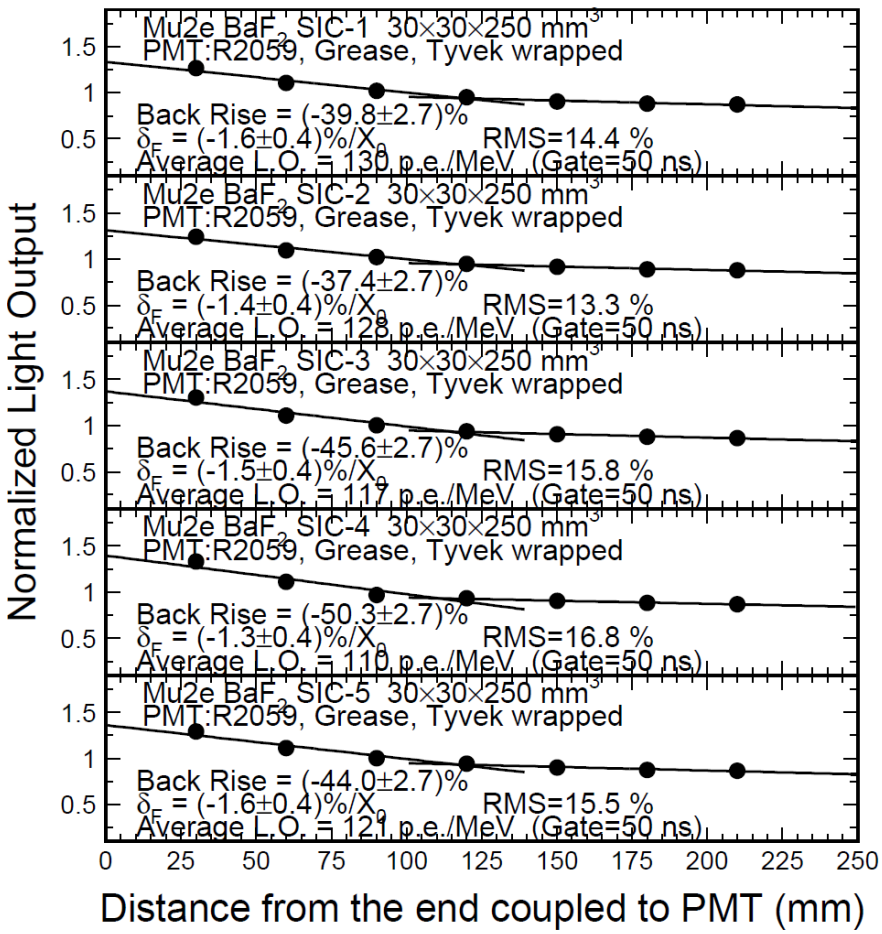
$$\delta_F = d \times 20.3\ mm$$

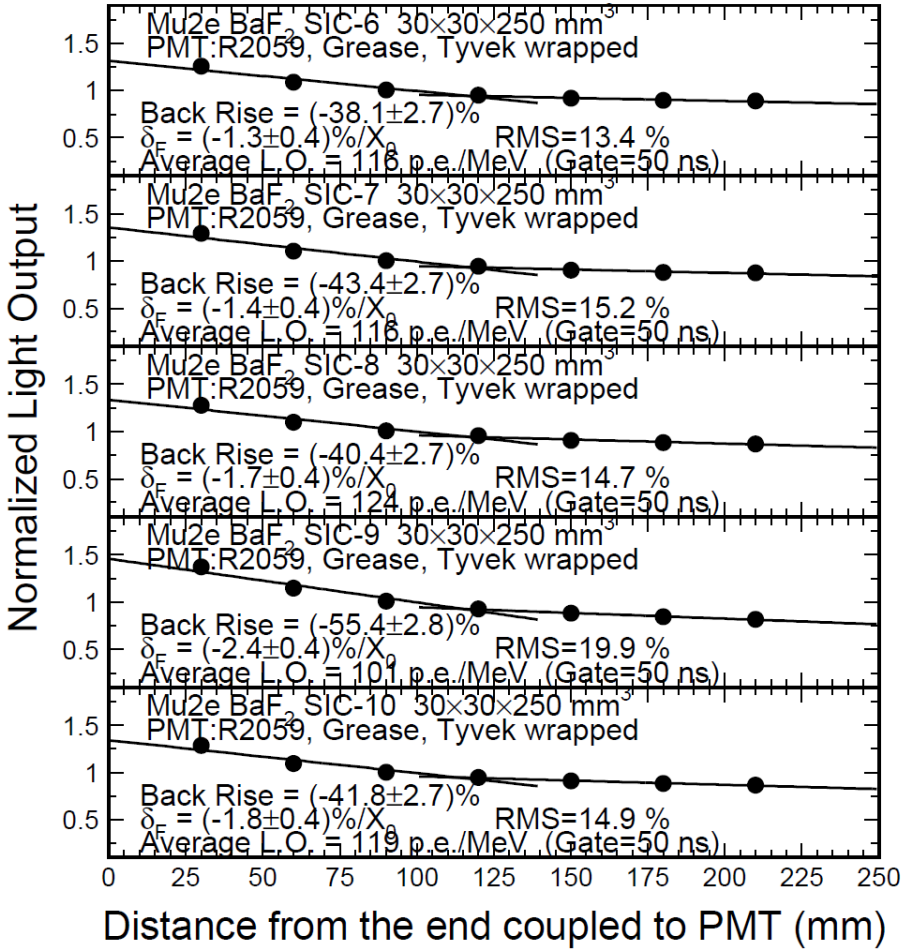
$$Back\ Rise$$

$$R_B = b \times 120\ mm$$

Front Slope & Back Rise: No.1-10 (Tyvek)

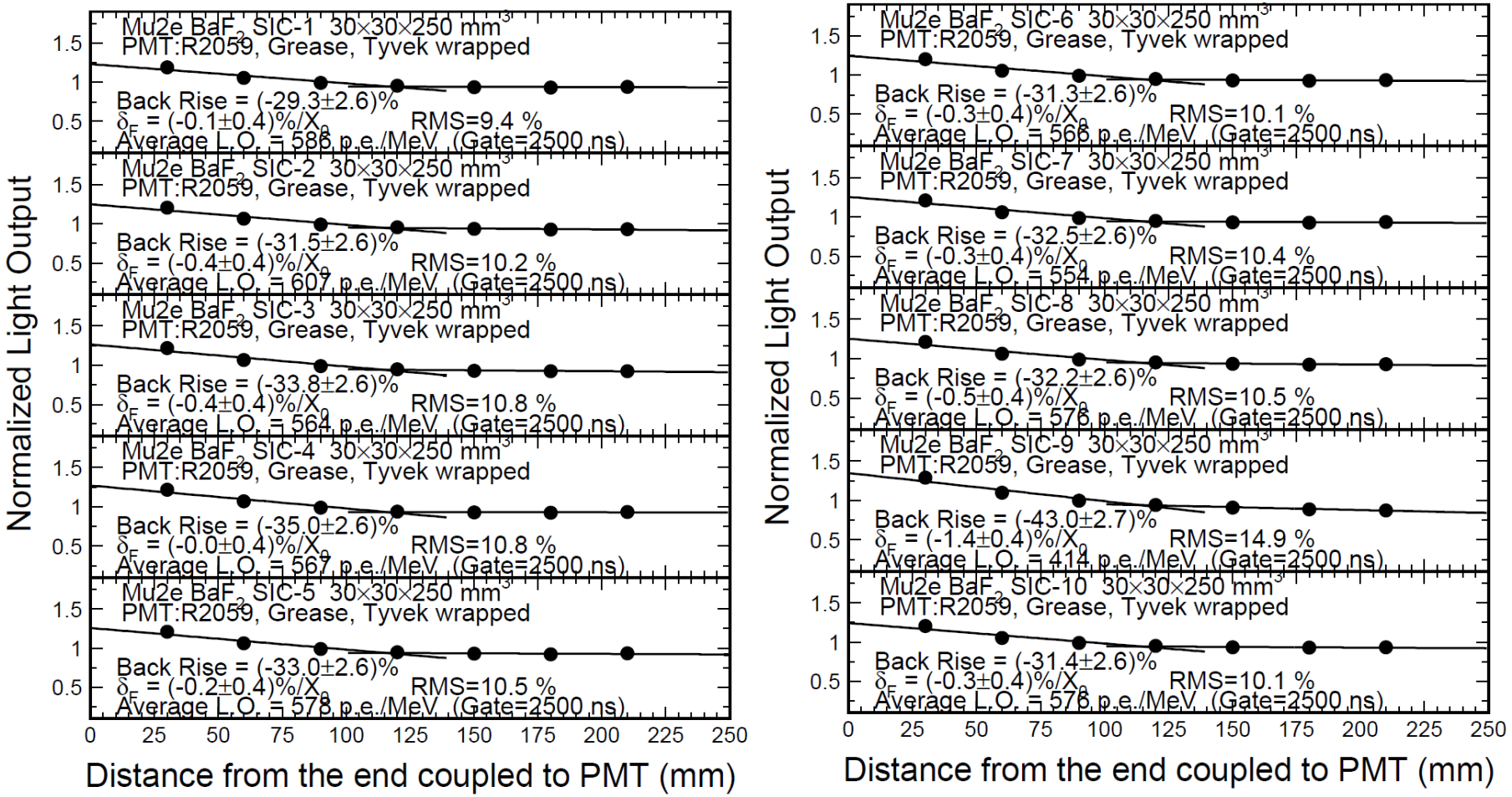
50 ns





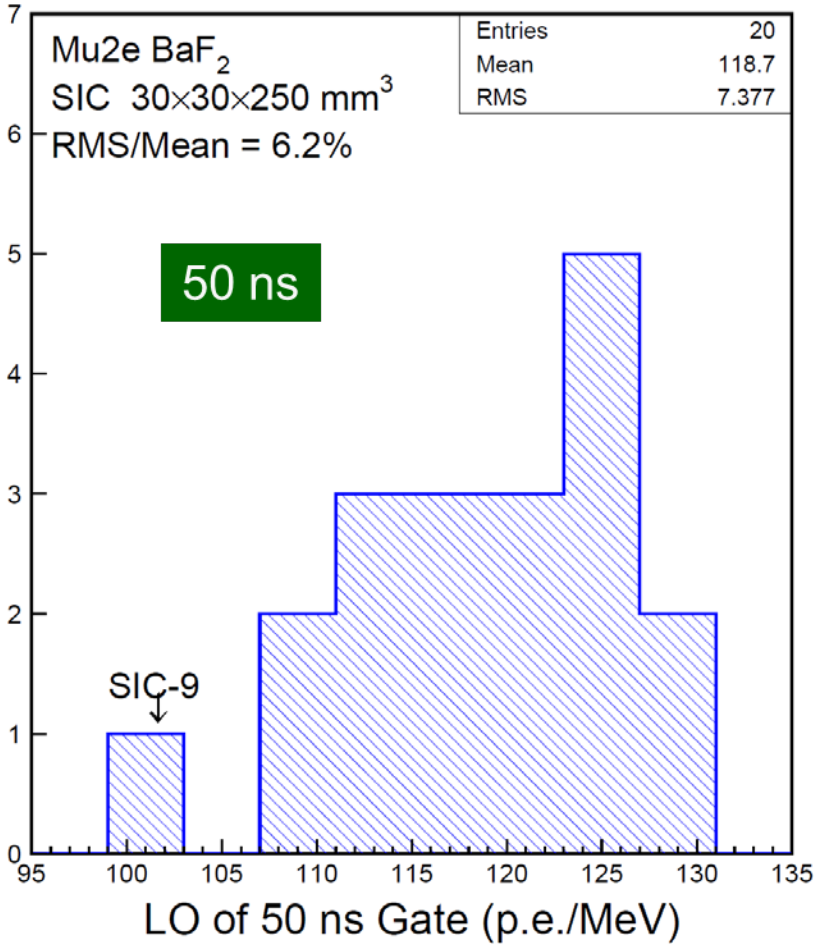
Front Slope & Back Rise: No.1-10 (Tyvek)

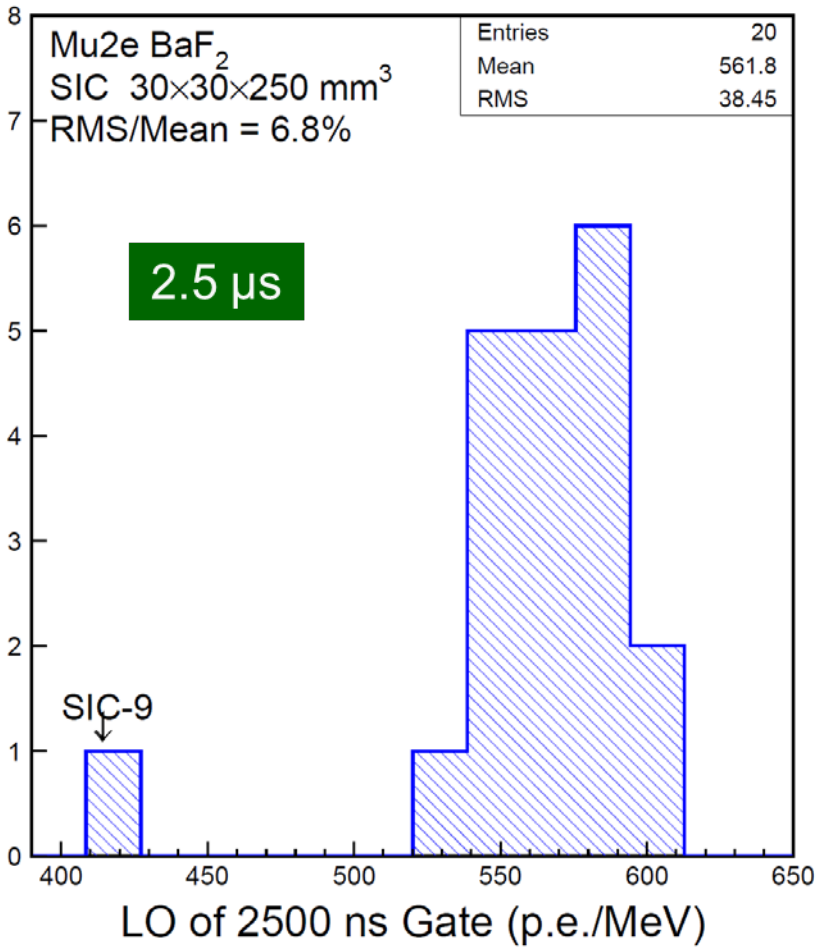
2.5 μs



Summary of Light Output

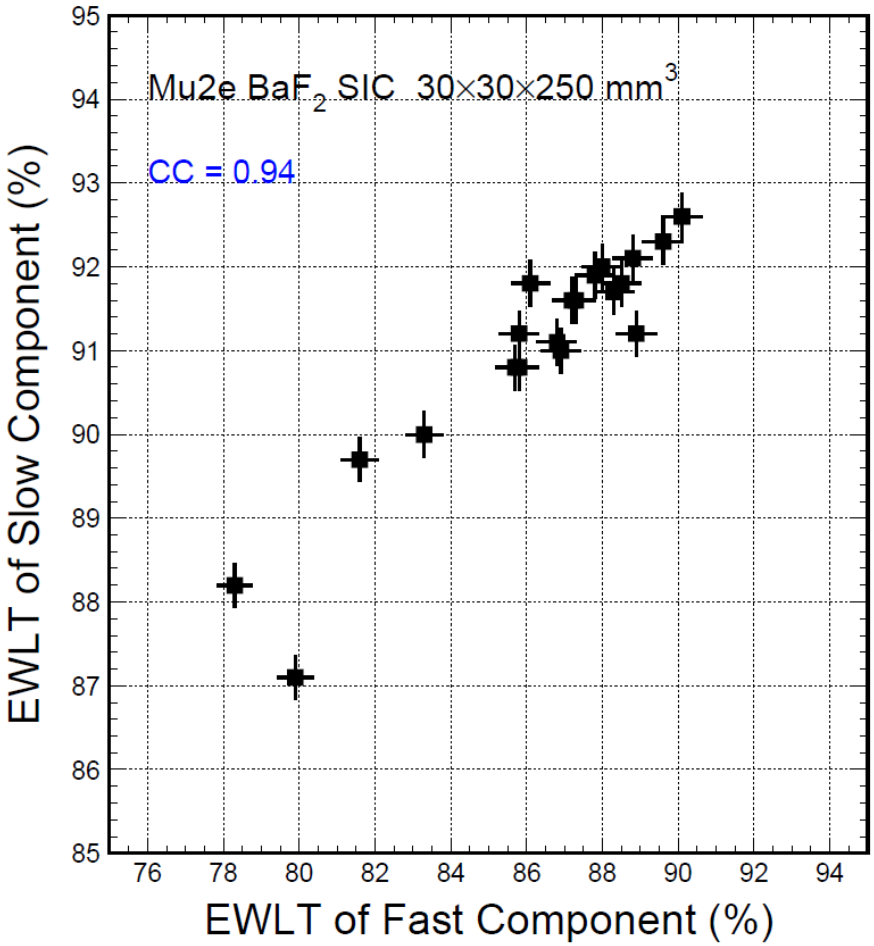
Consistent with LO obtained by fitting decay kinetics

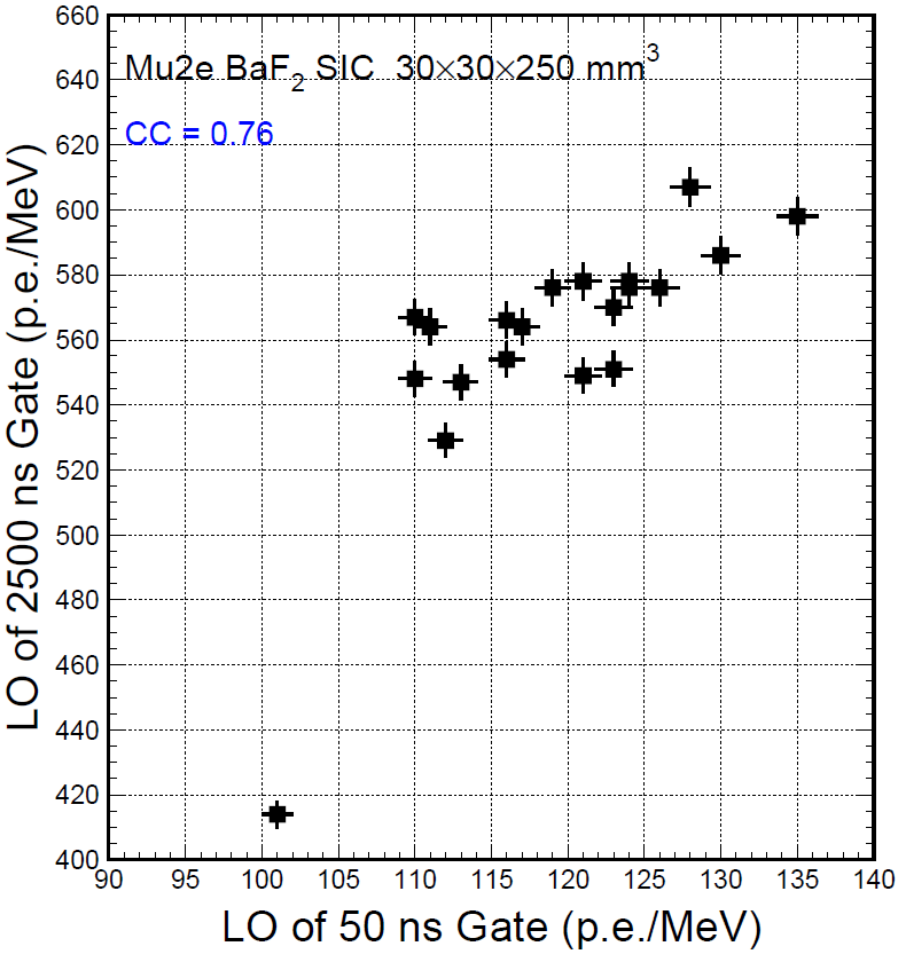




Correlations between Slow & Fast Components

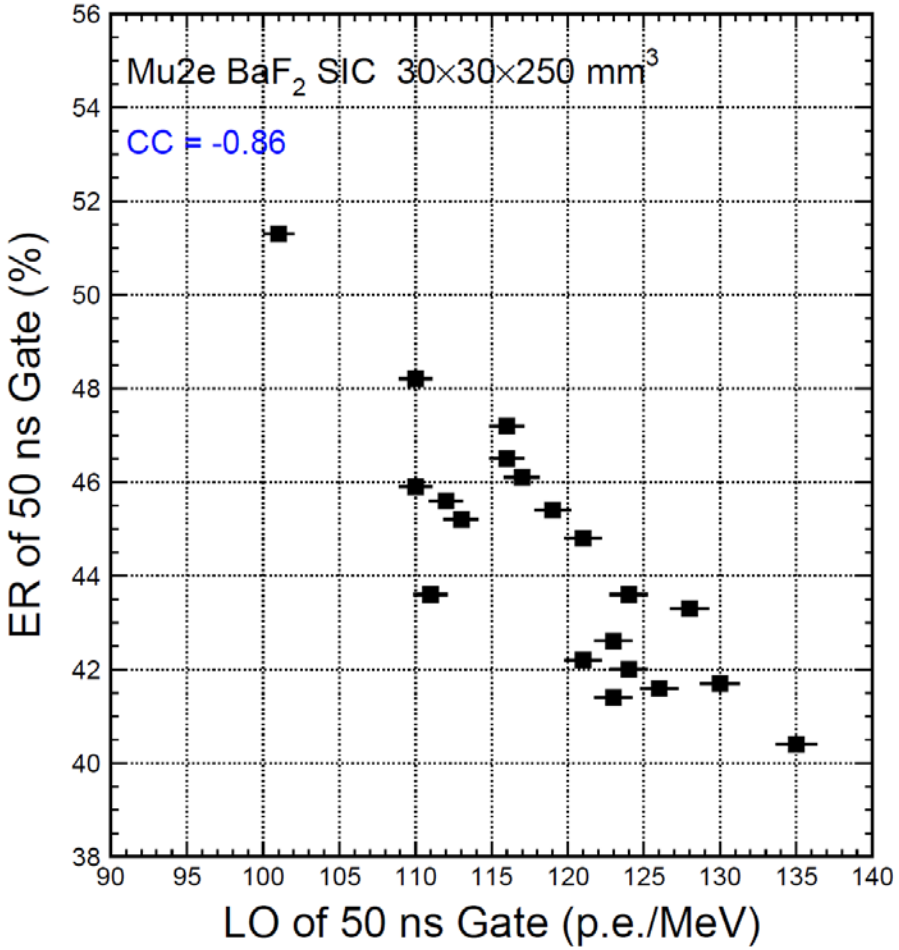
Positive correlations observed

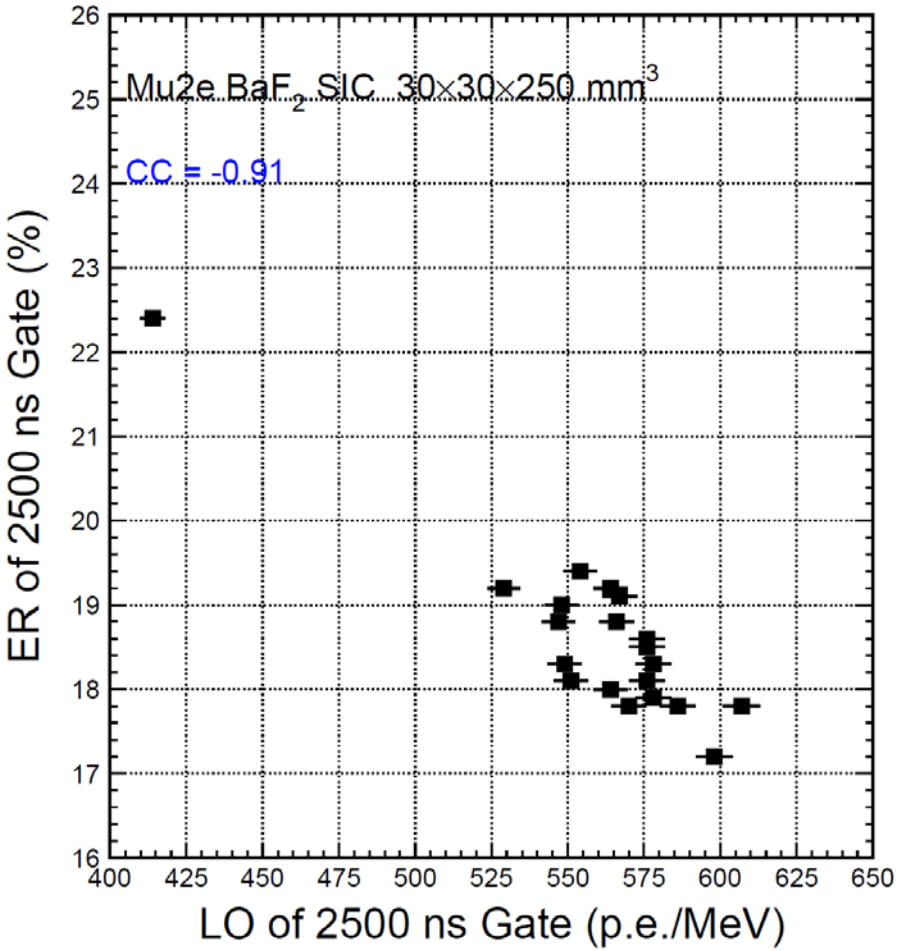




Correlations between ER and LO

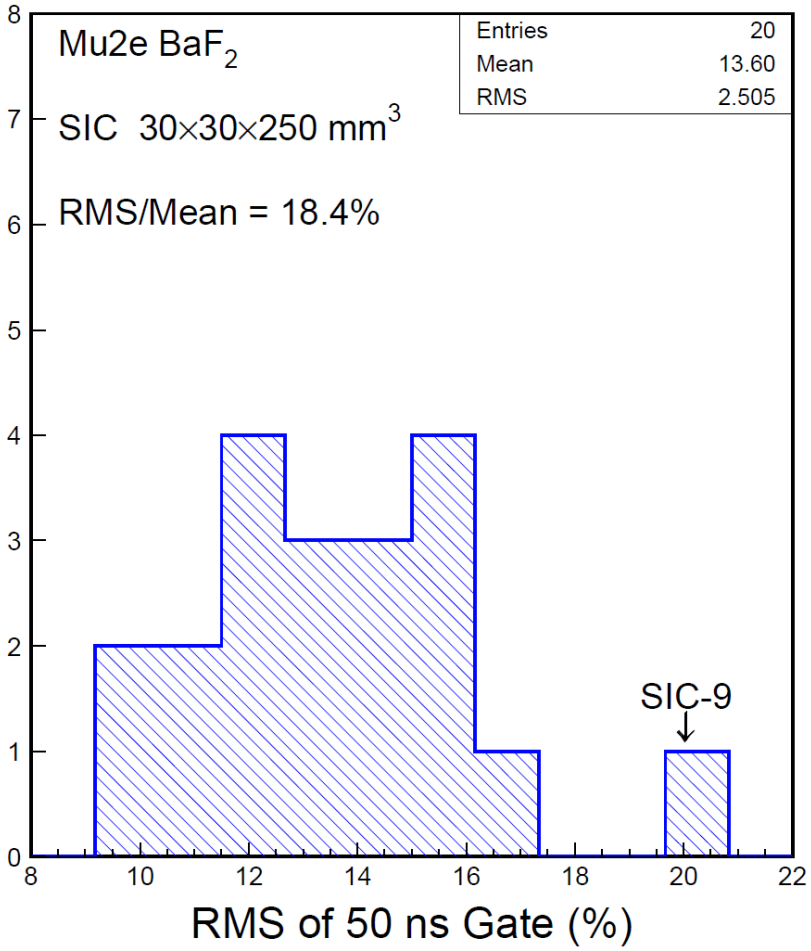
Negative correlations observed

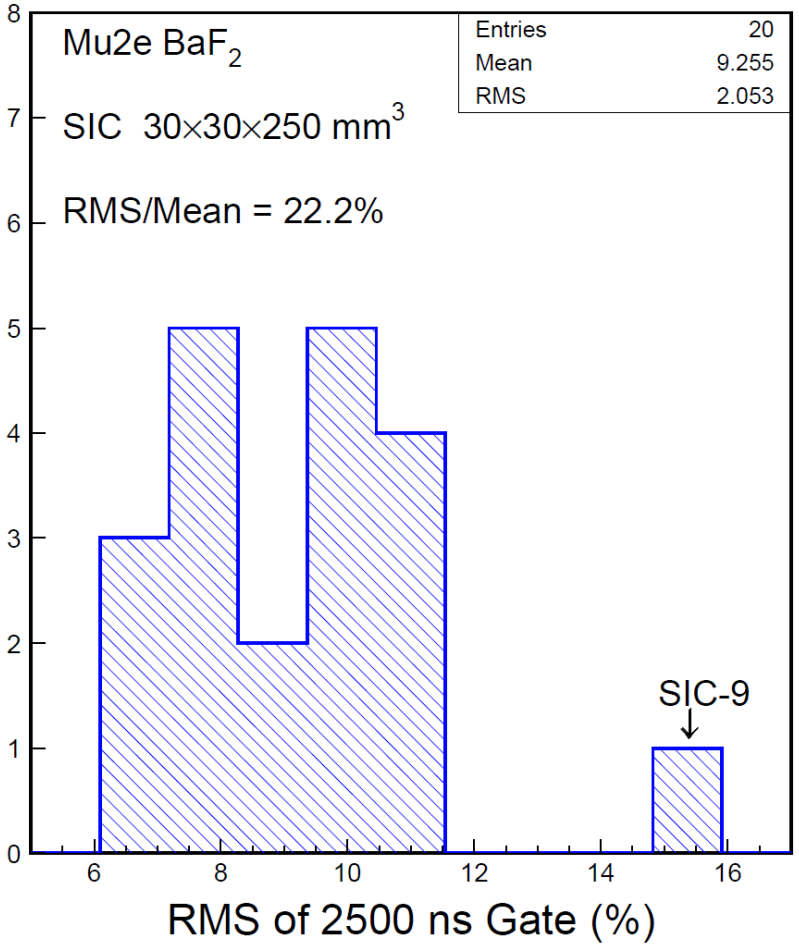




Summary of RMS of LO Measured @ 7 Points

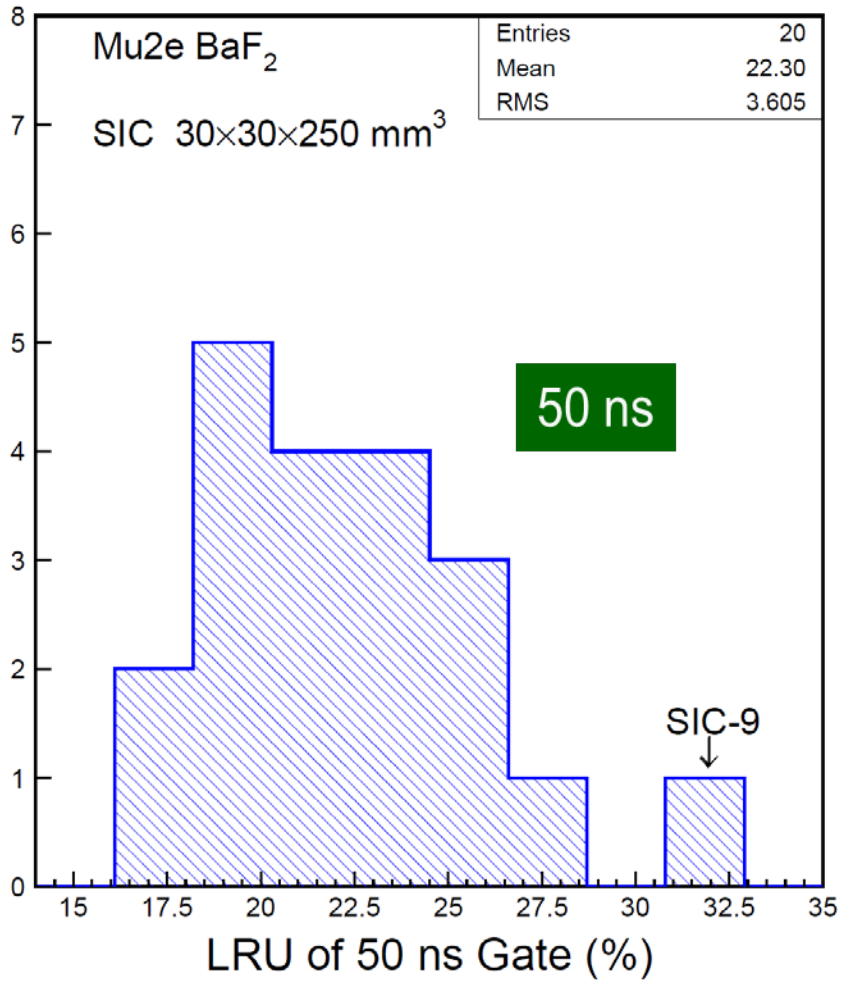
14/9% observed for 50 ns/2.5 μs gate

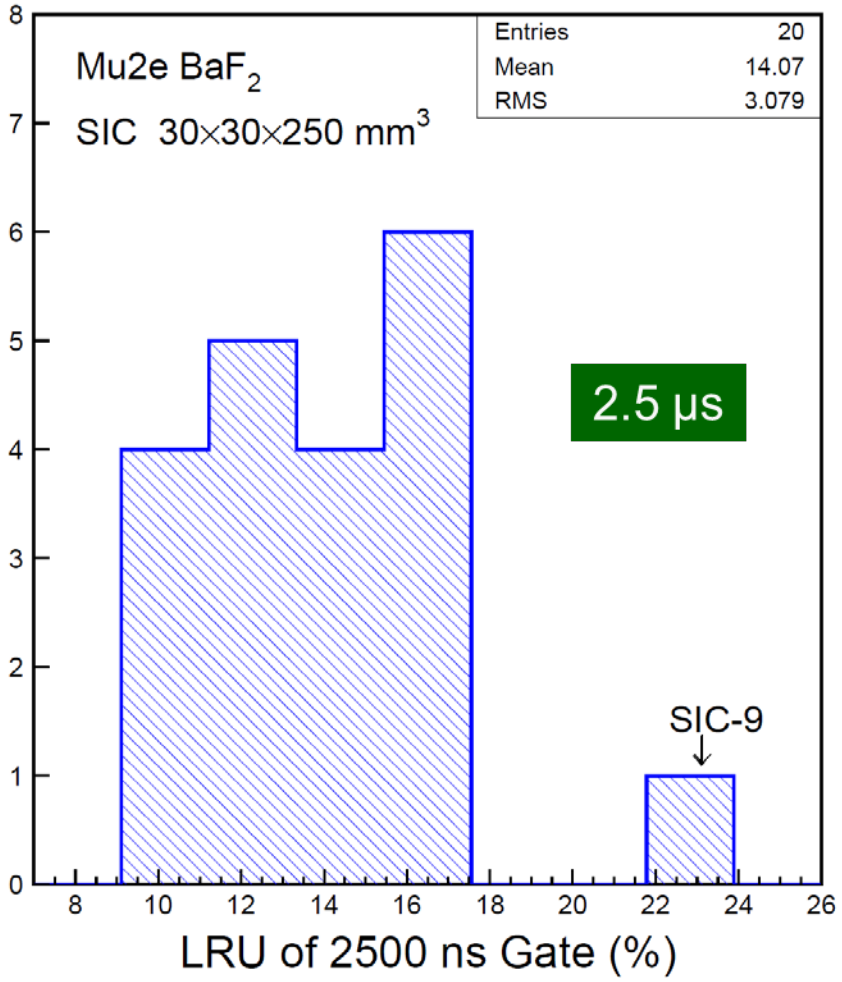




Summary of Light Response Uniformity

22/14% negative slope observed for 50 ns/2.5 μs gate

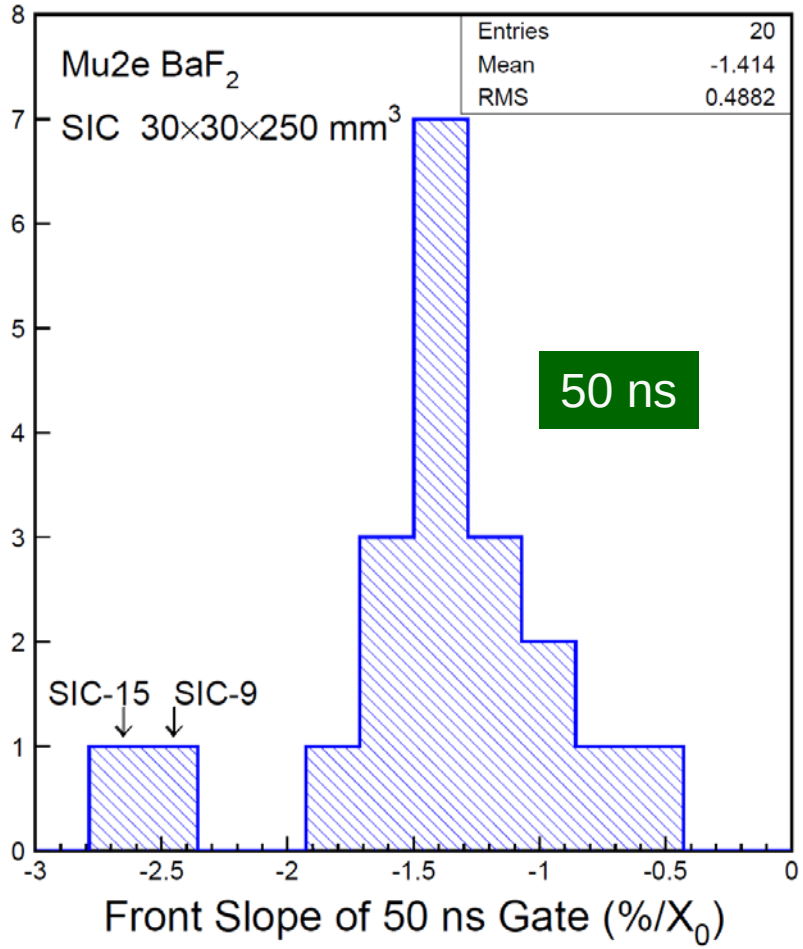


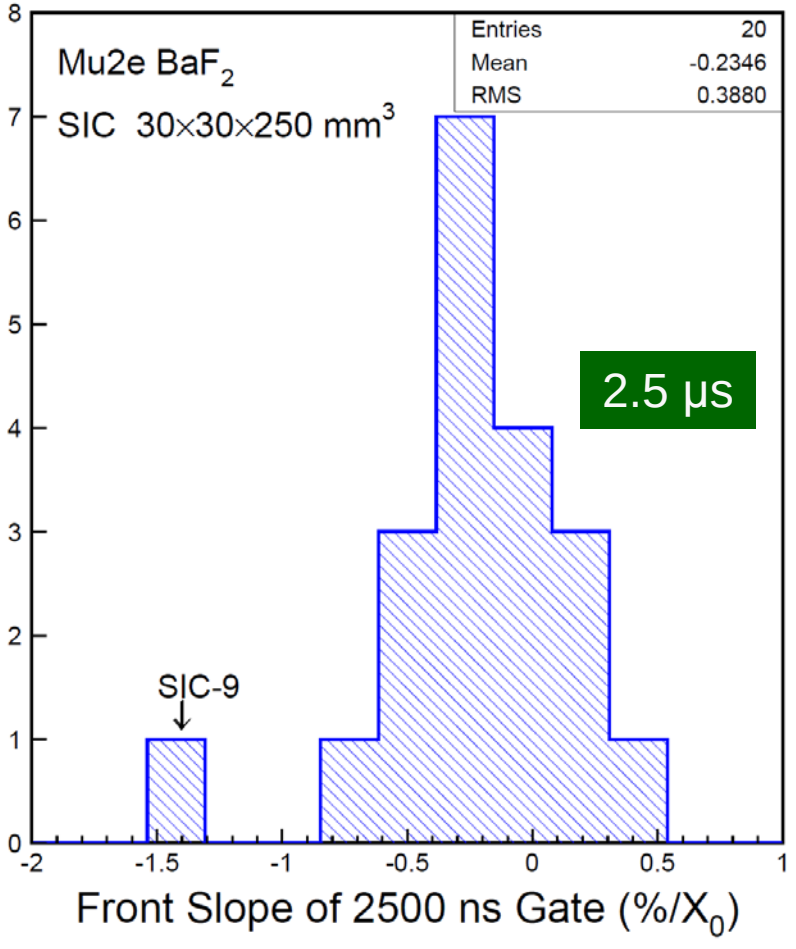


A consequence of UV absorption

Summary of Front Slope (Tyvek)

1.4% & 0.2% per X_0 observed for fast & slow components

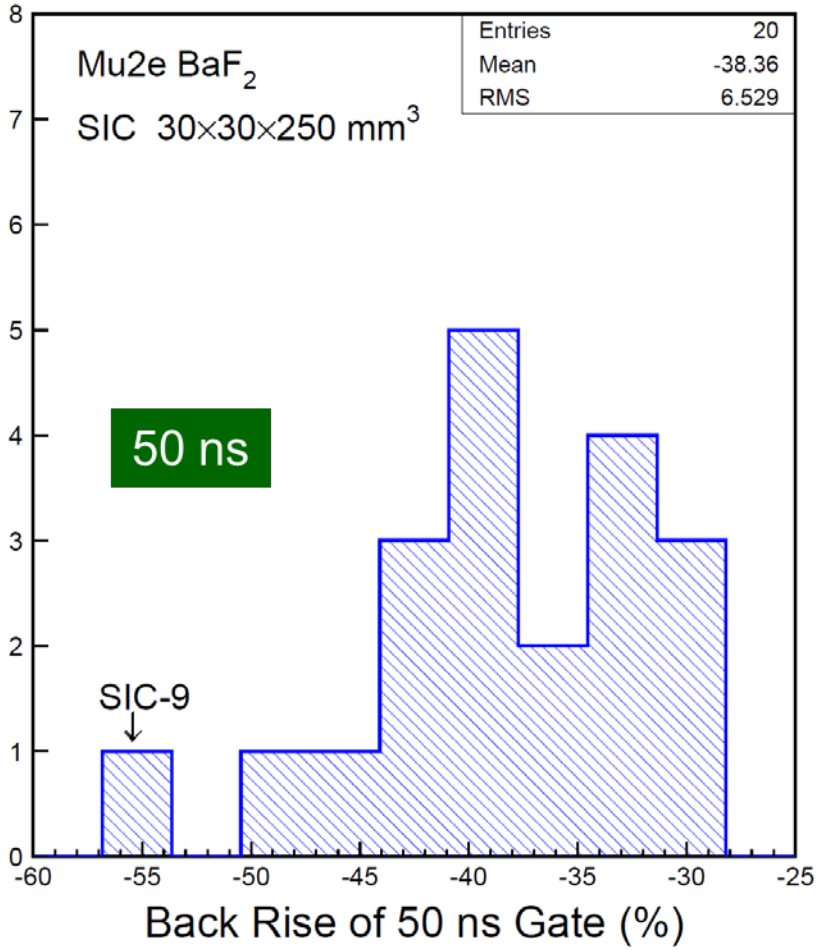


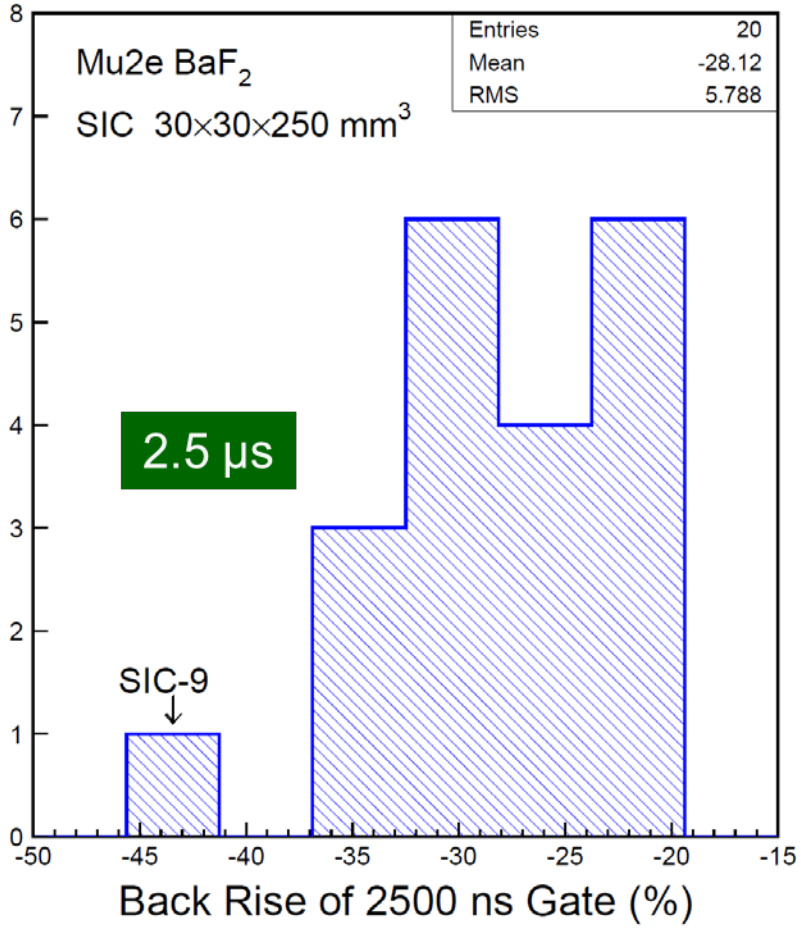


Simulation is needed to understand the consequence

Summary of Back Rise (Tyvek)

38% and 28% observed for fast and slow components





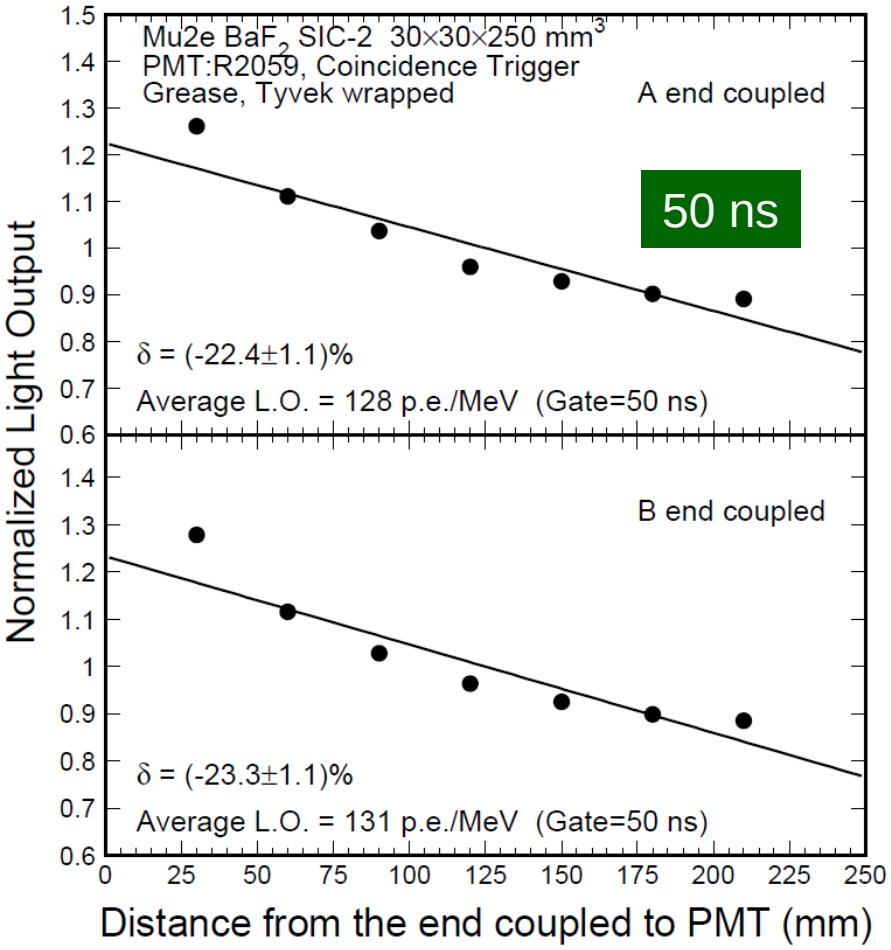
Simulation is needed to understand the consequence

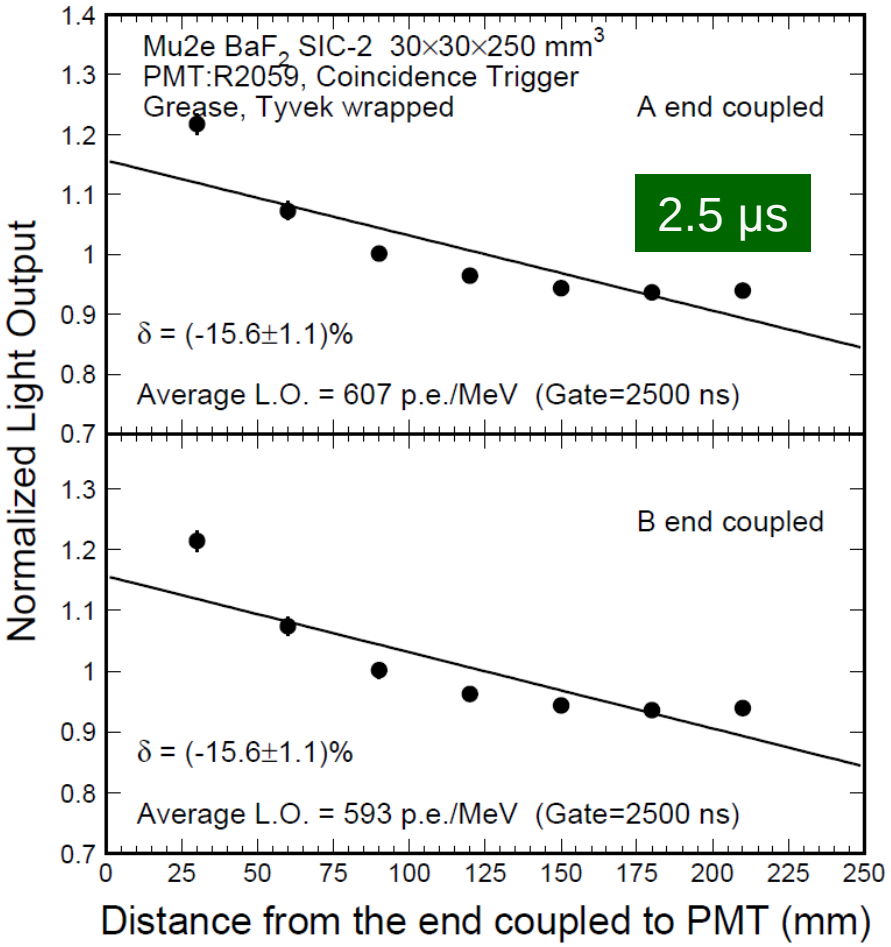
Summary

- Crystal SIC-1 was measured with different wrappings:
  - Light output of BaF_2 crystals depends on crystal wrapping. Eight layers of PTFE Teflon film (8 x 25 μm) show the best light output, followed by two layers of aluminized Mylar (2 x 10 μm), four layers of Al foil (4 x 15 μm) and two layers of Tyvek paper (2 x 150 μm 1056D). Additional Al foil helps if Teflon layers are less than 8.
  - Positive correlations are observed between the BaF_2 light output and the measured reflectance of wrapping materials.
  - Al foil is radiation hard up to 100 Mrad.
- Light response uniformity was measured for all twenty BaF_2 crystals wrapped with two layers of Tyvek paper:
  - No change of LRU when the crystal end coupled to PMT is altered.
  - An overall negative slope of 22% &14% (rms of 14% & 9%) was observed for 50 ns & 2.5 μs gate, indicating absorption dominance of the UV light.
  - An alternative fit with two segments shows 1.4%/X_0 & 0.2%/X_0 slope in the front 13 cm and 38% & 28% rise in the back 12 cm for 50 ns & 2.5 μs gate.

No Difference between Coupling Ends

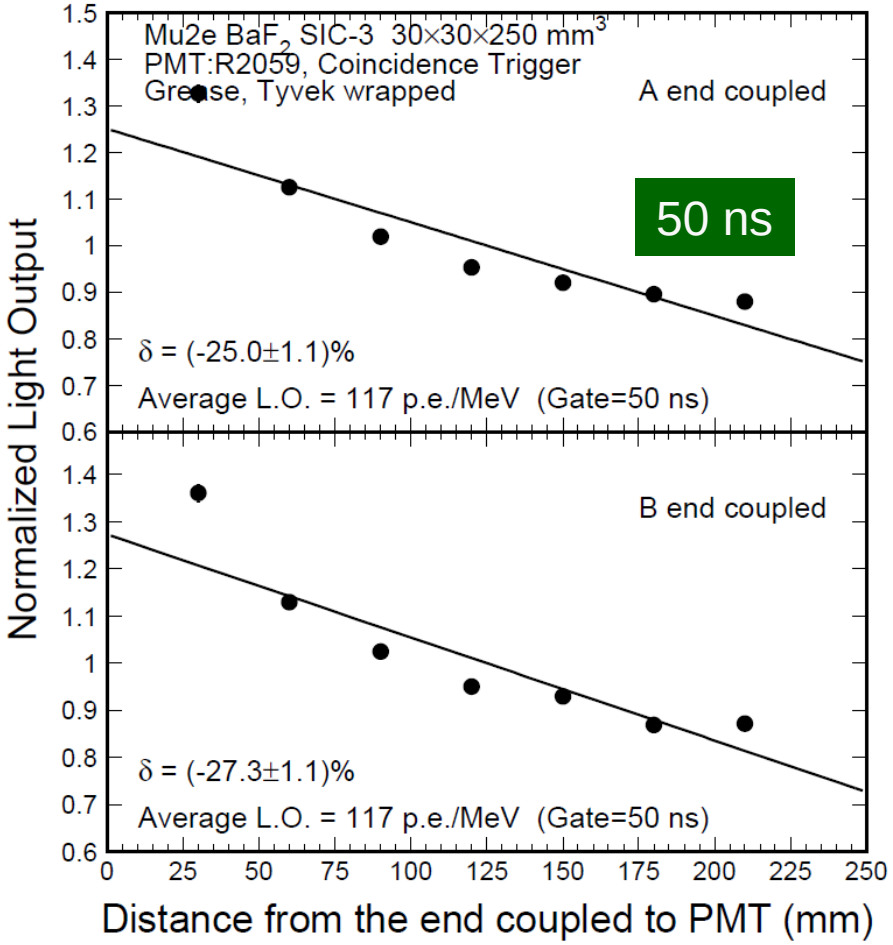
SIC2: No difference with alternative ends coupled to the PMT

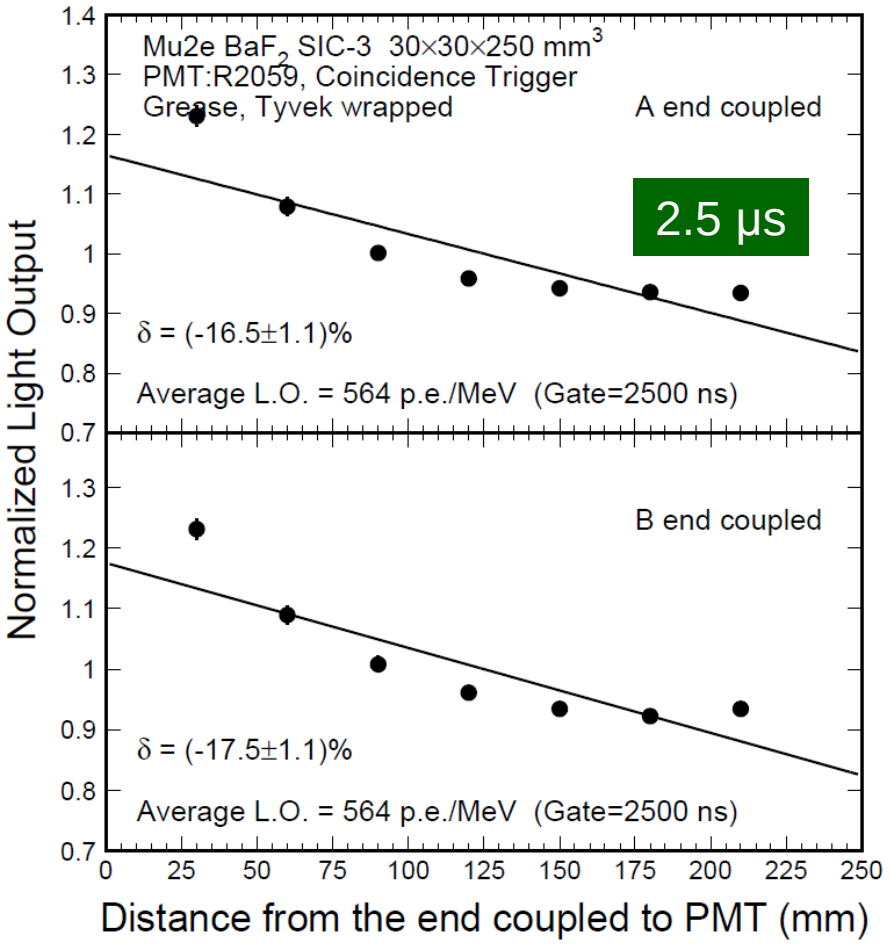




No Difference between Coupling Ends

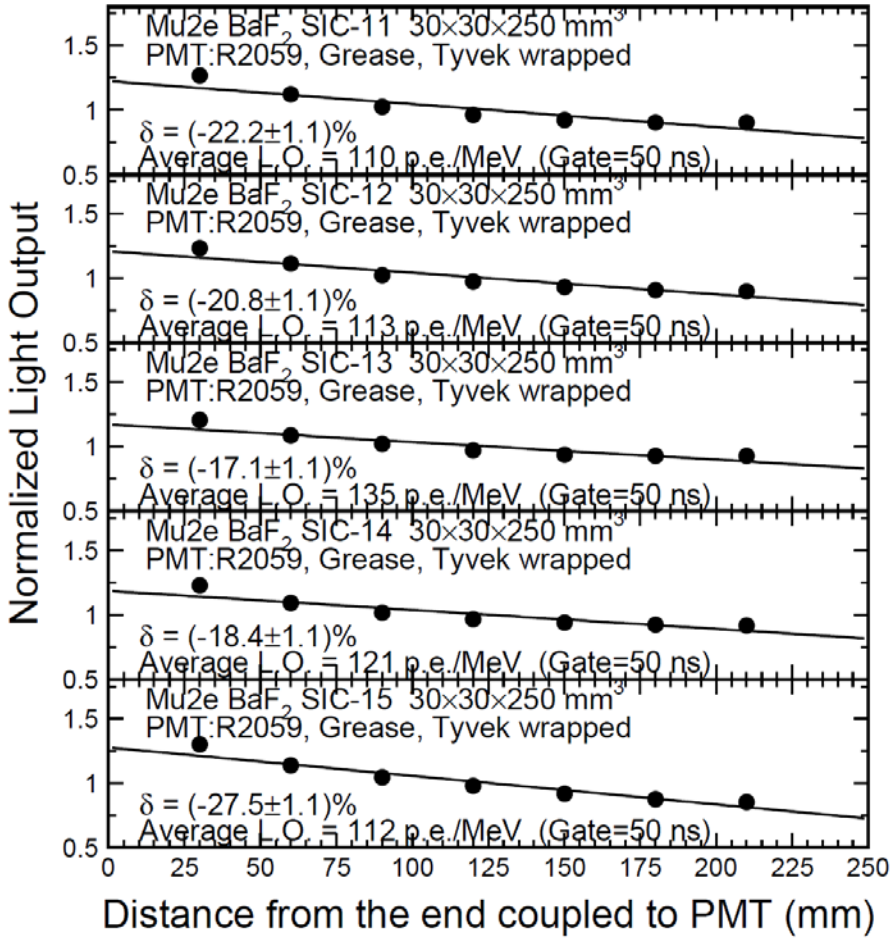
SIC3: No difference with alternative ends coupled to the PMT

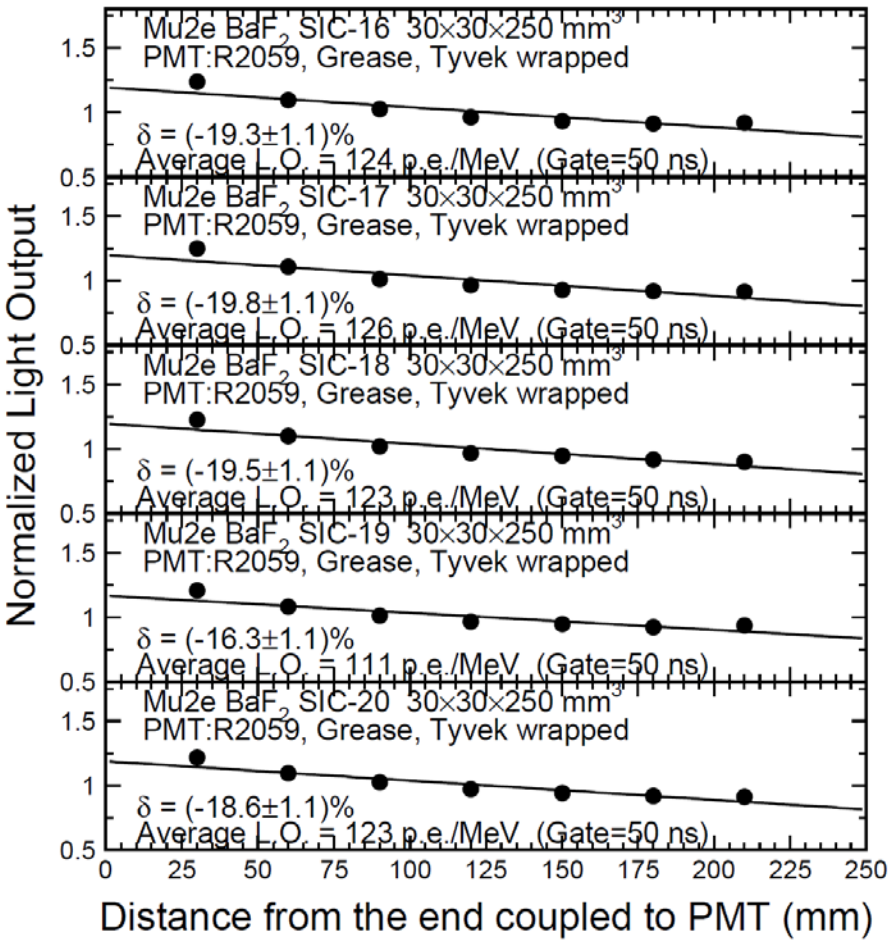




LRU and LO of No.11-20 (Tyvek)

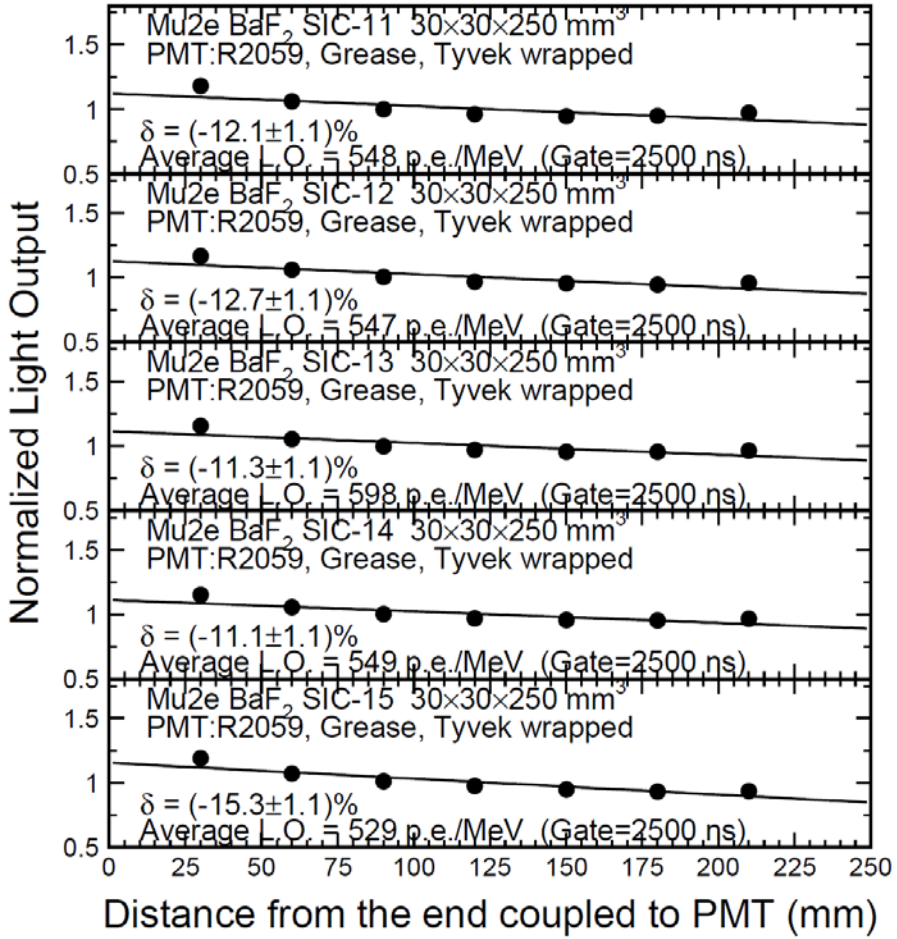
50 ns

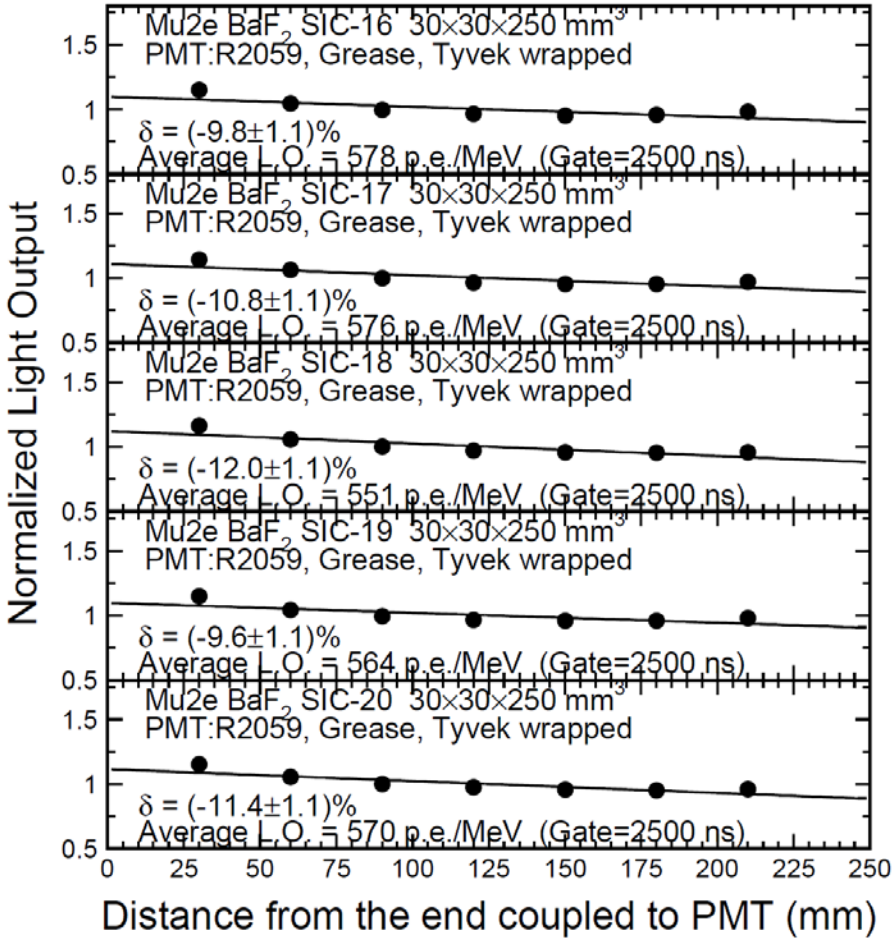




LRU and LO of No.11-20 (Tyvek)

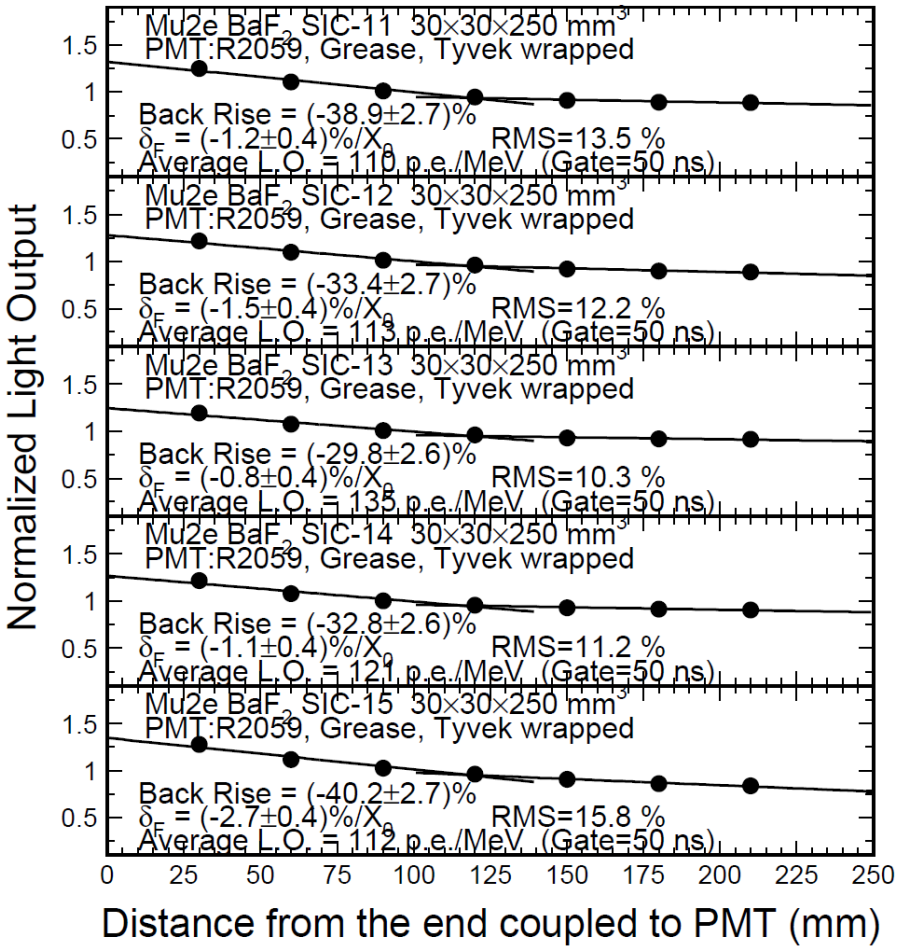
2.5 μs

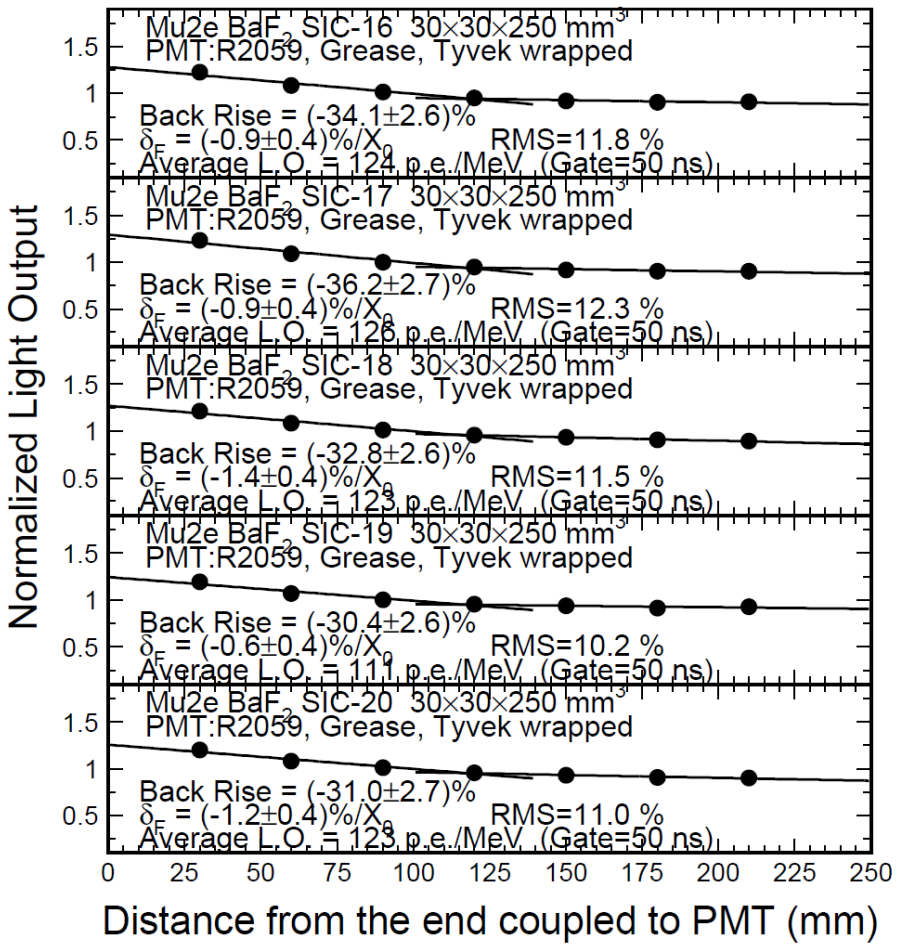




Front Slope & Back Rise: No.11-20 (Tyvek)

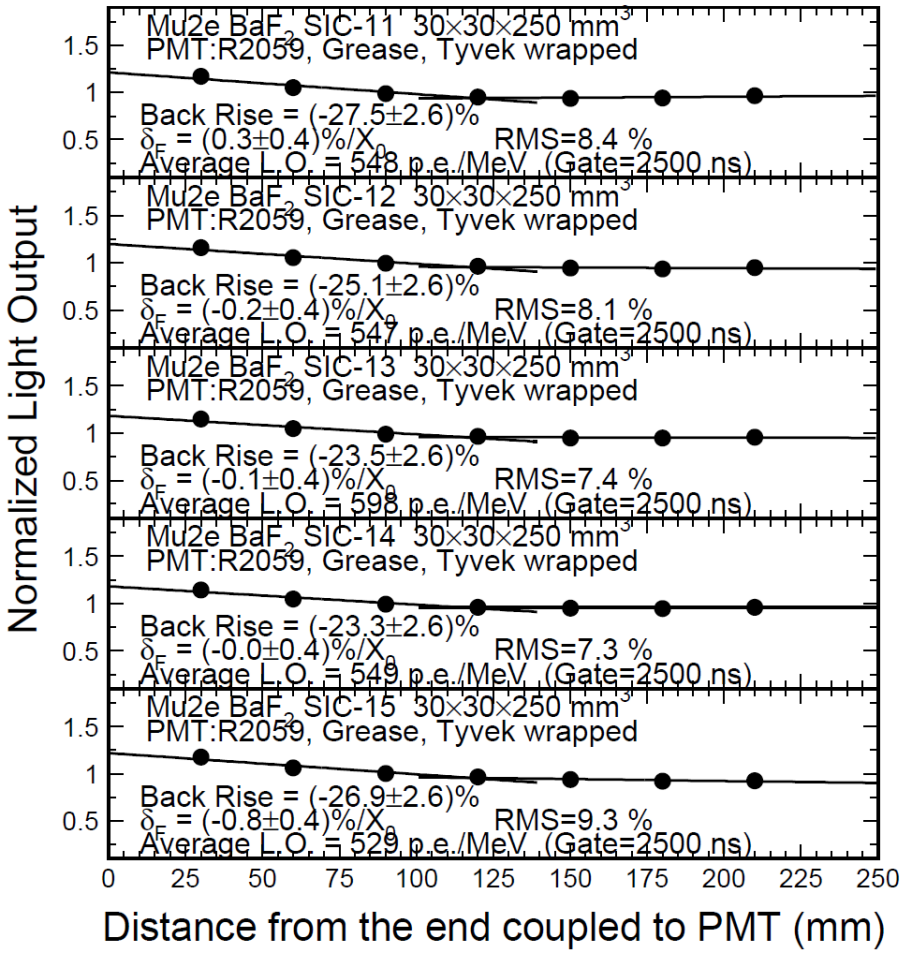
50 ns

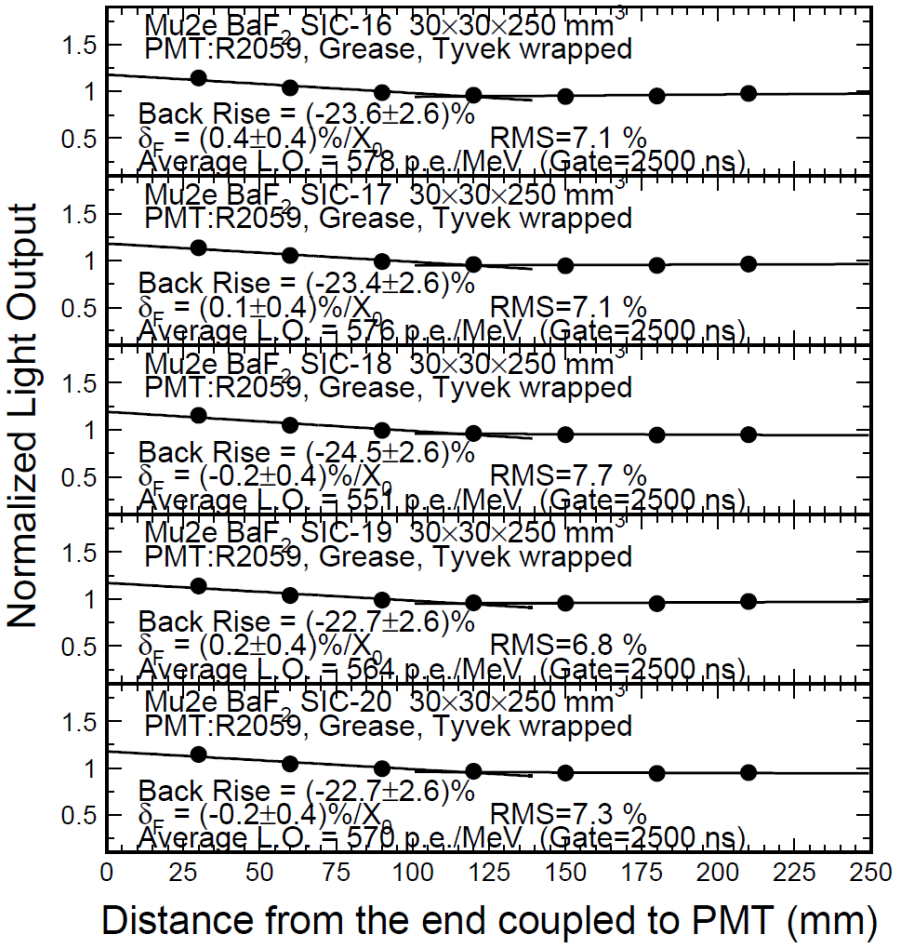




Front Slope & Back Rise: No.11-20 (Tyvek)

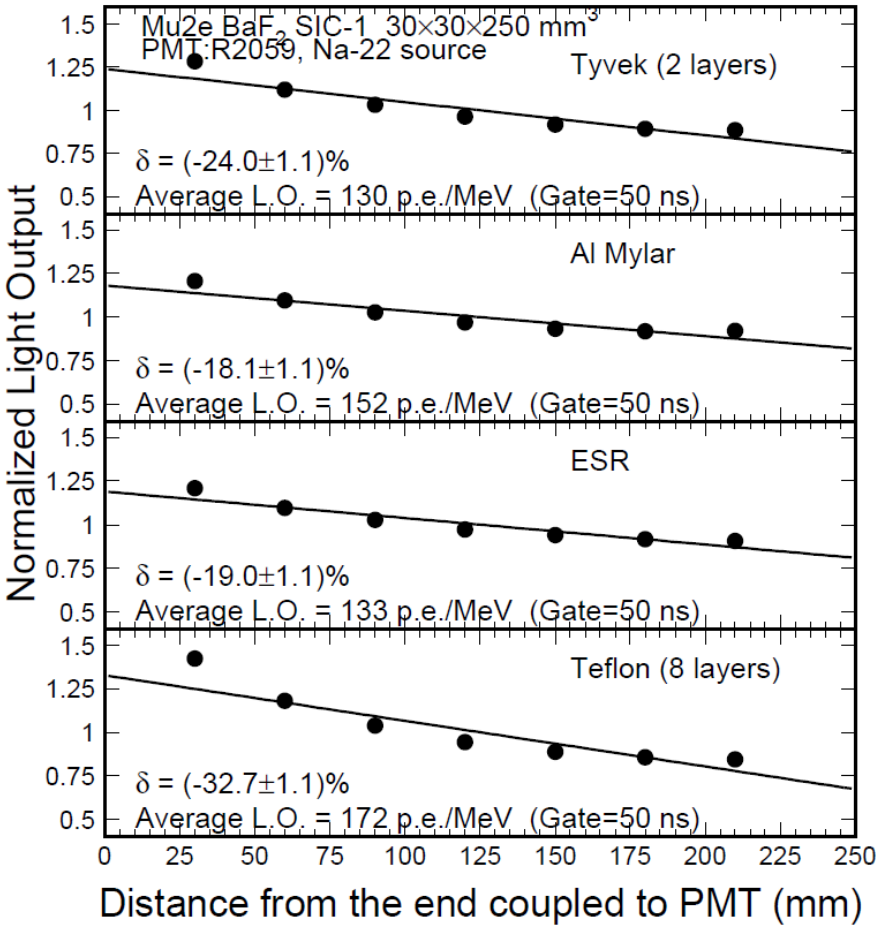
2.5 μs

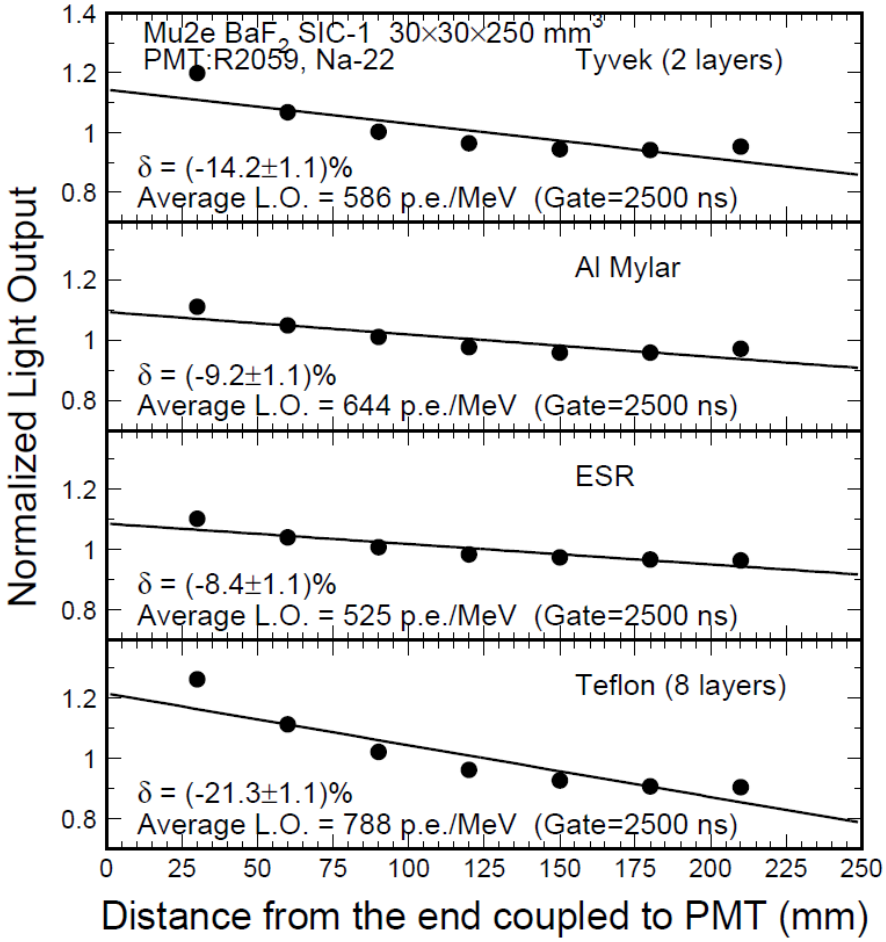




LRU of Different Wrapping

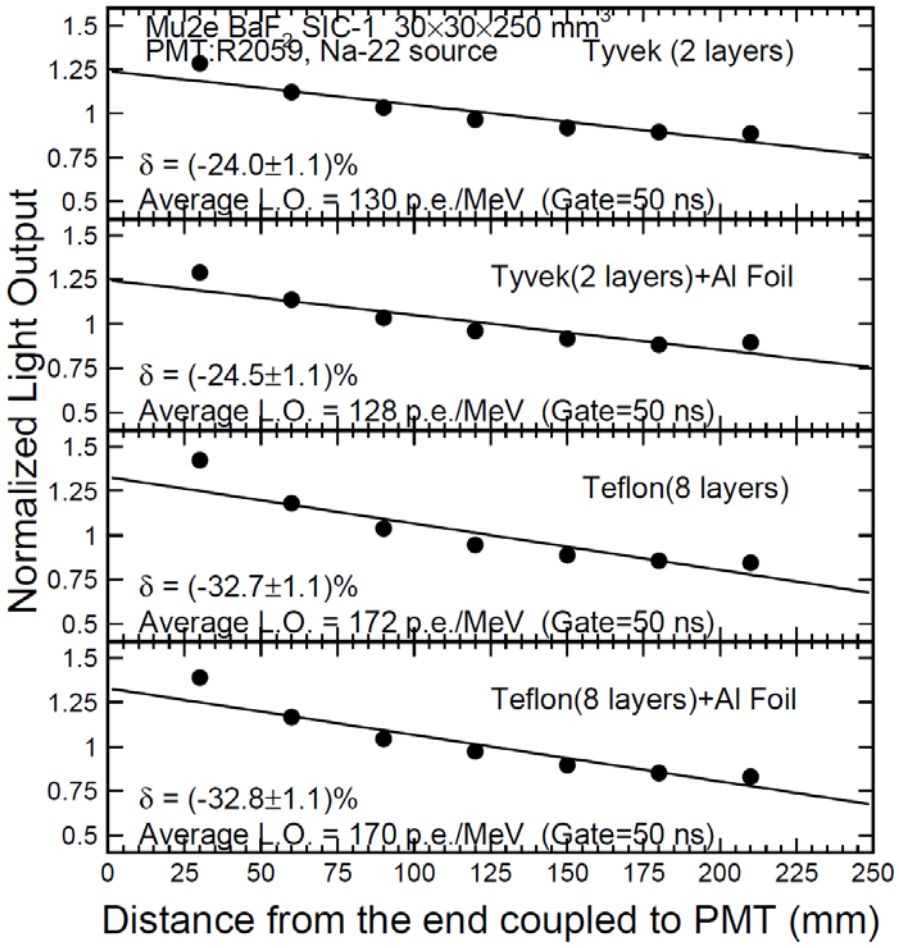
The best LRU is observed in the crystal wrapped with Al Mylar or ESR.

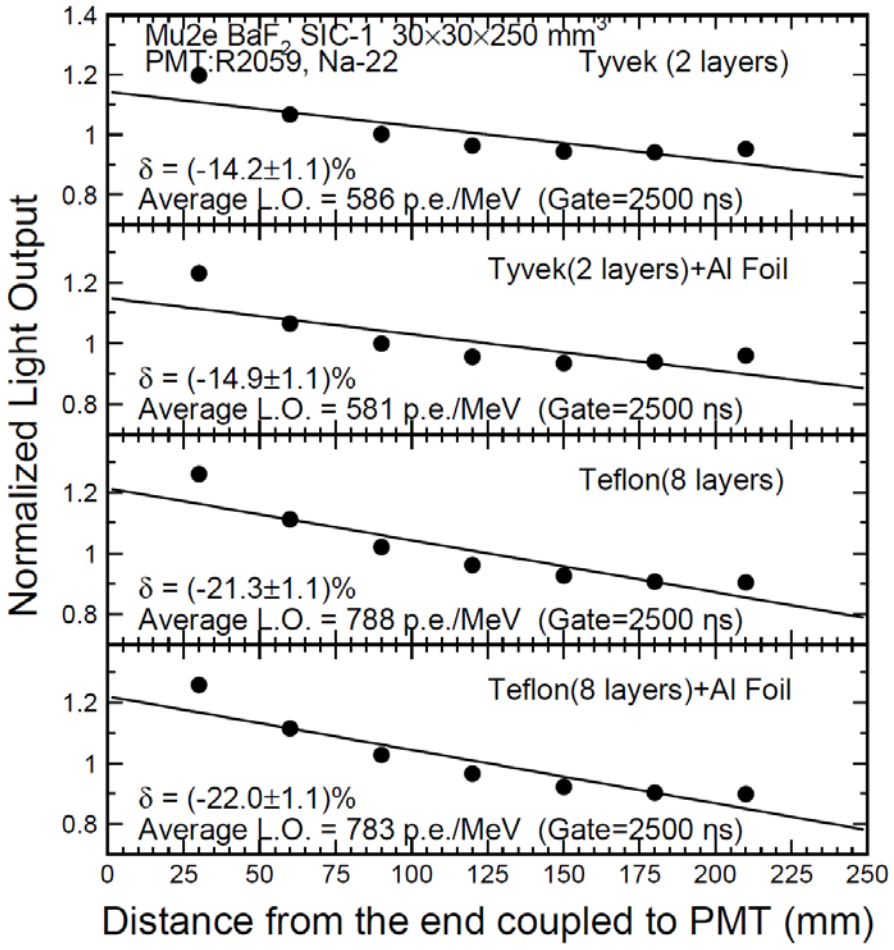




LRU of Different Wrapping

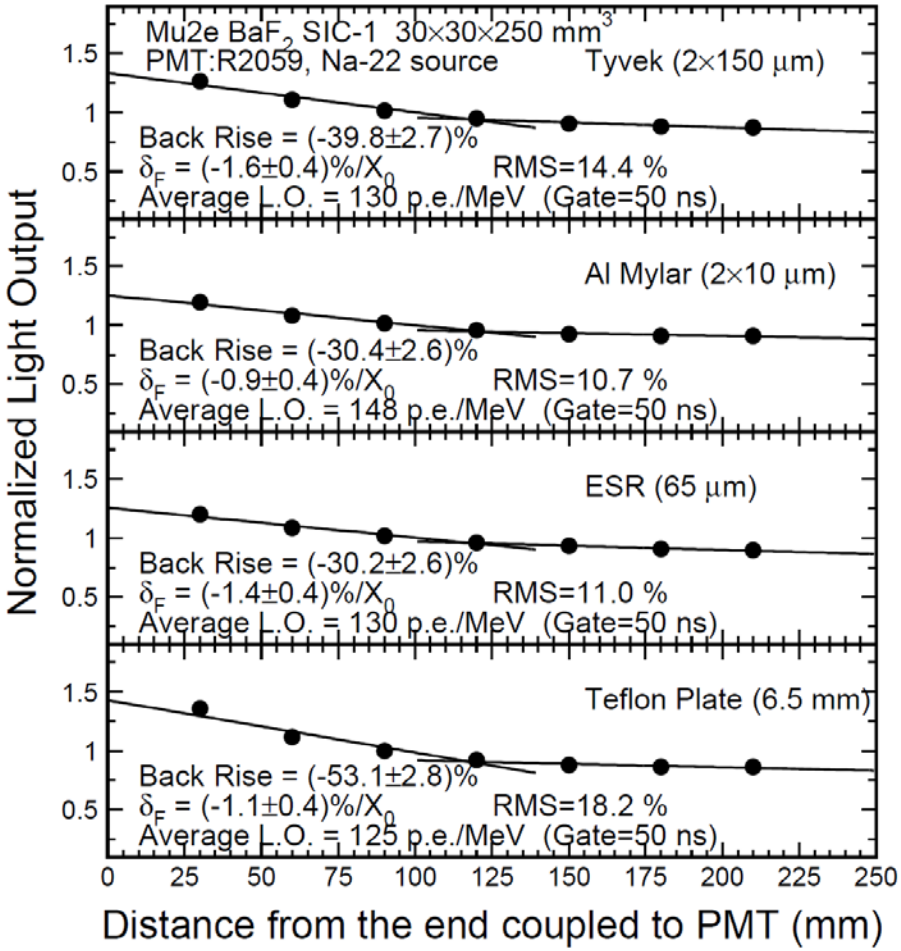
The additional Al foil does not affect the LO and LRU.

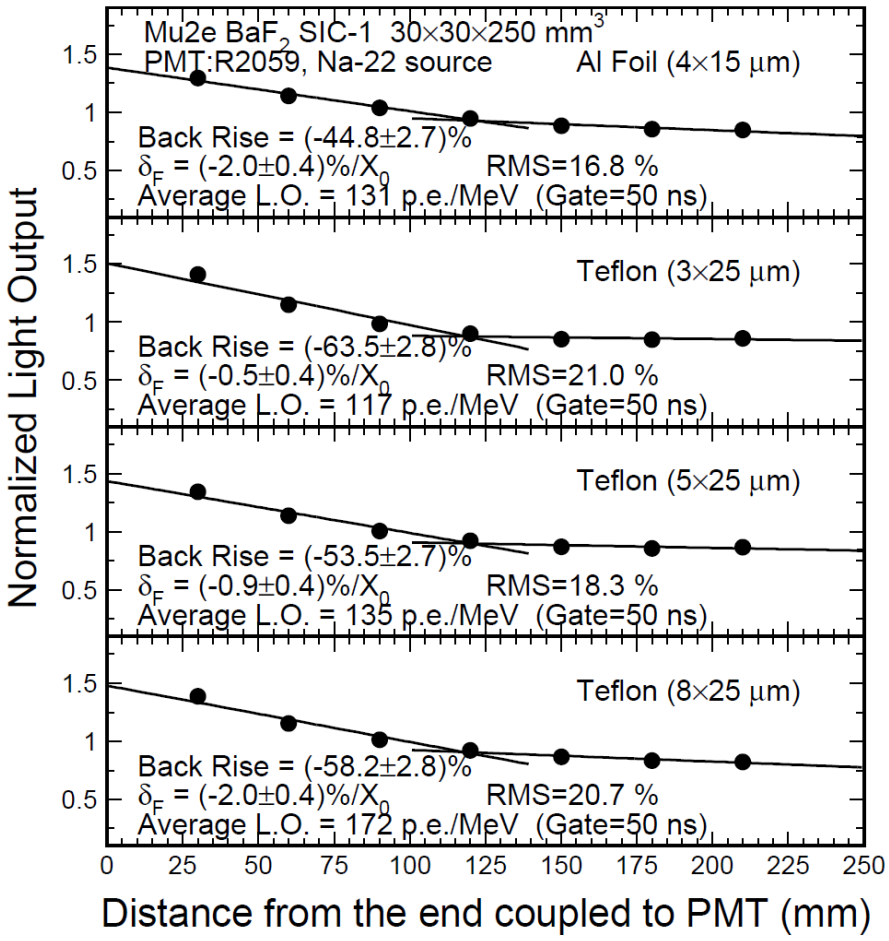




Front Slope and Back Rise of Different Wrapping

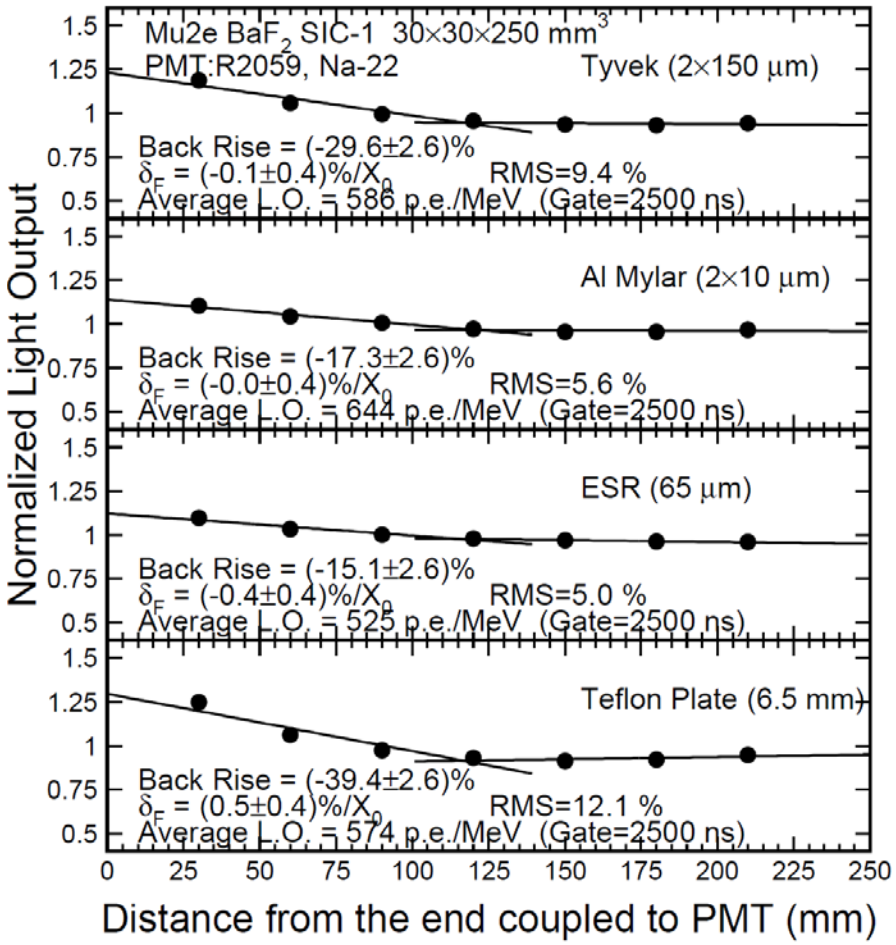
50 ns

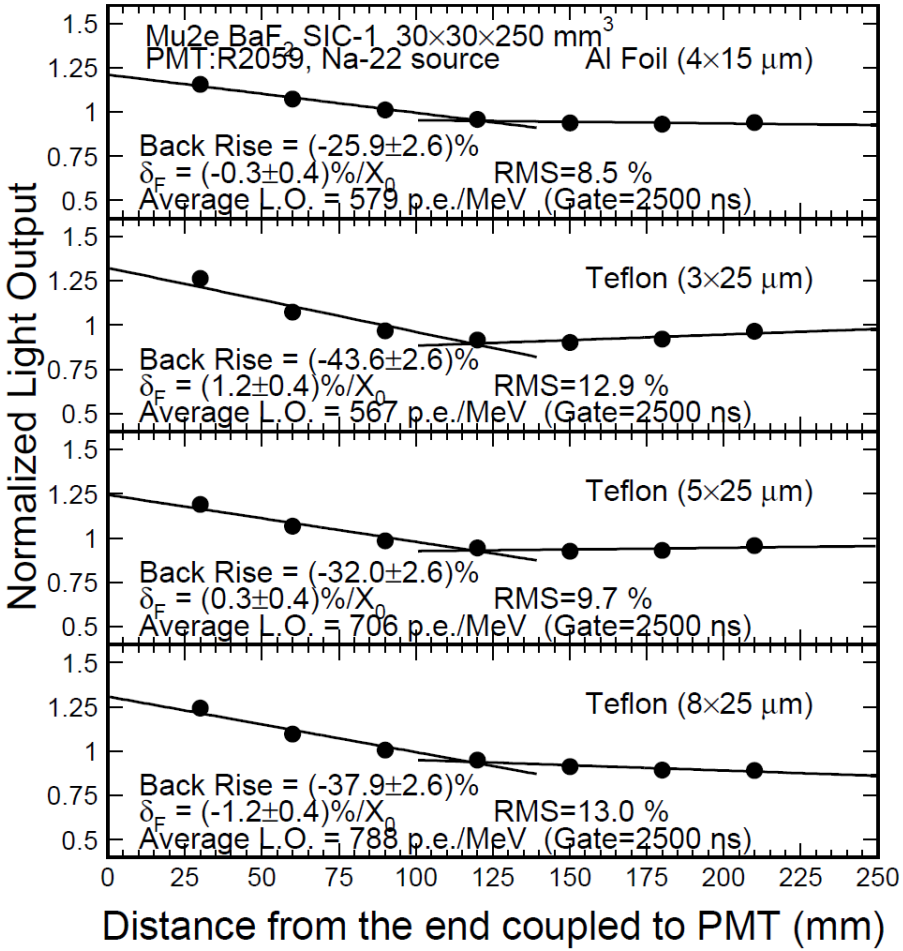




Front Slope and Back Rise for Different Wrapping

2.5 μs





Front Slope & Back Rise for Different Teflon Layers