Light Response Uniformity of SuperB LYSO Crystals with APD Readout

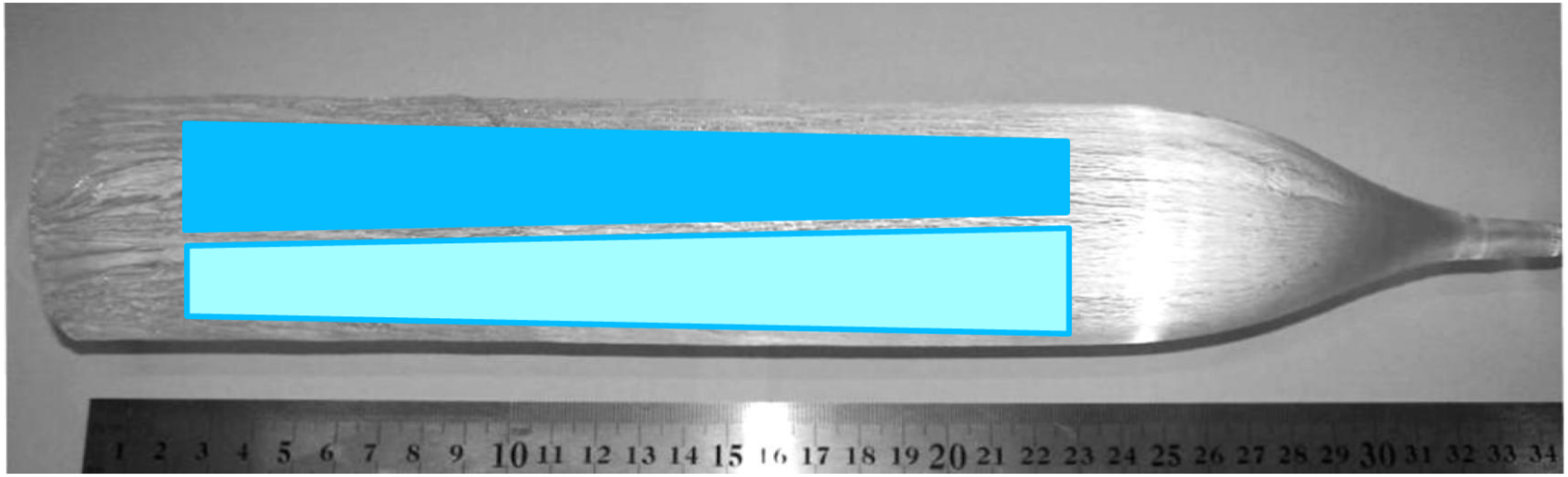
Ren-yuan Zhu

California Institute of Technology

April 4, 2011

Talk at SuperB Workshop (LNF), Frascati

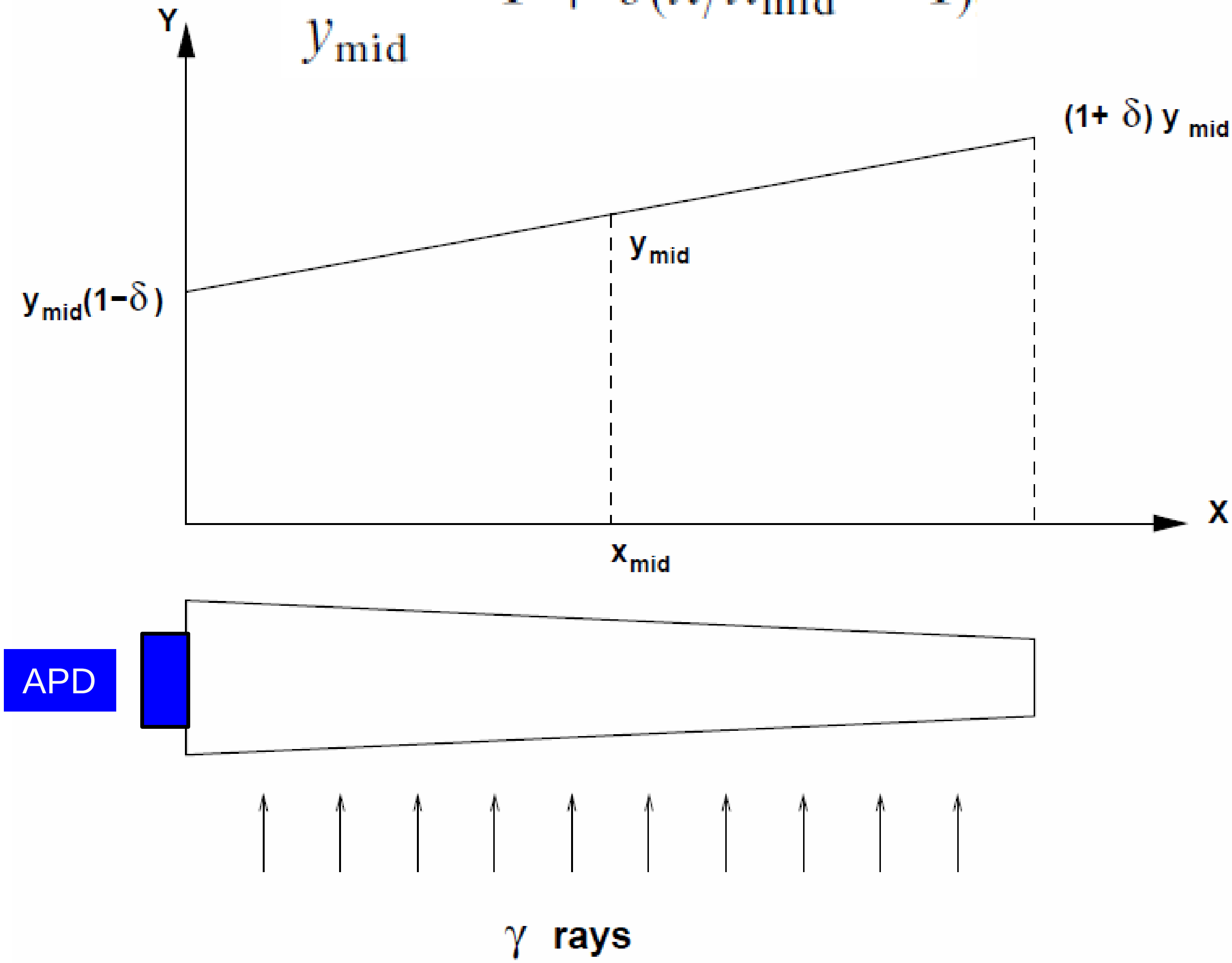
LYSO Crystals for SuperB Test Beam



Φ60 x 250 mm ingots are cut to two 20 cm long crystals for a SuperB beam test at CERN last Fall.

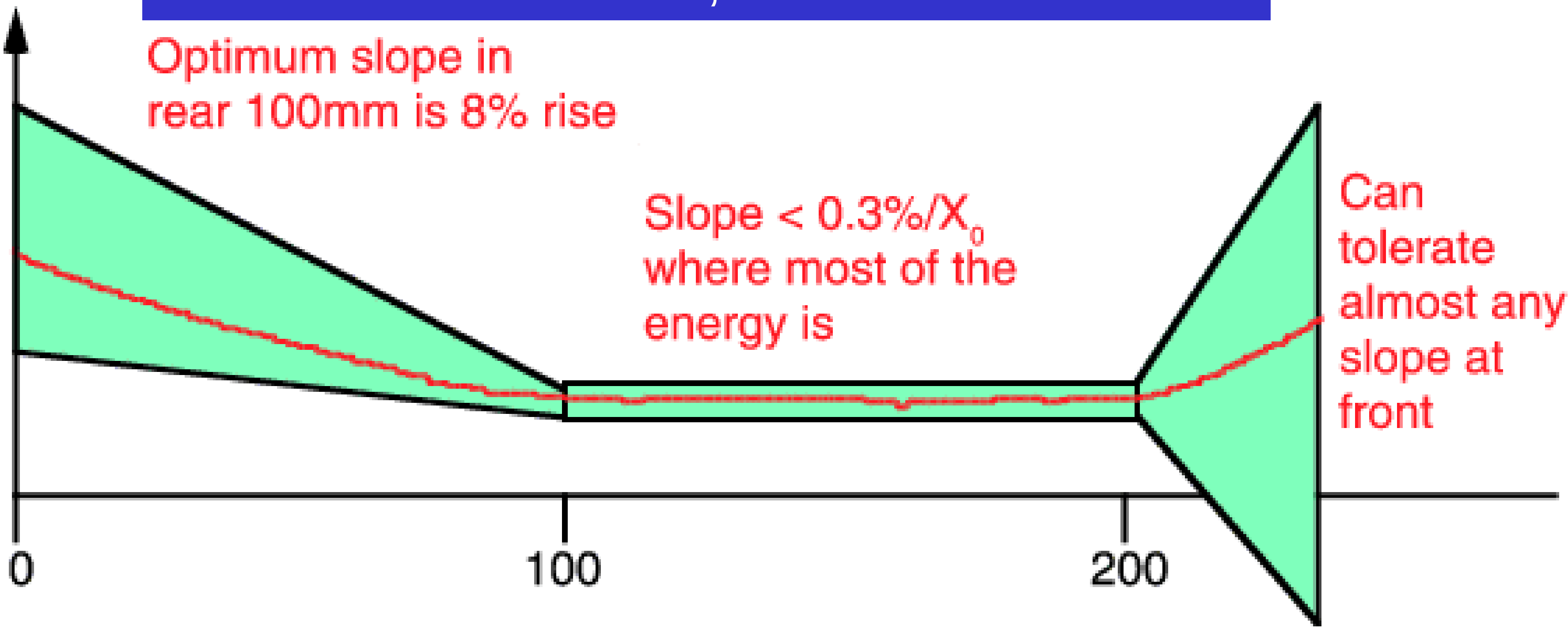
Light Response Non-Uniformity: δ

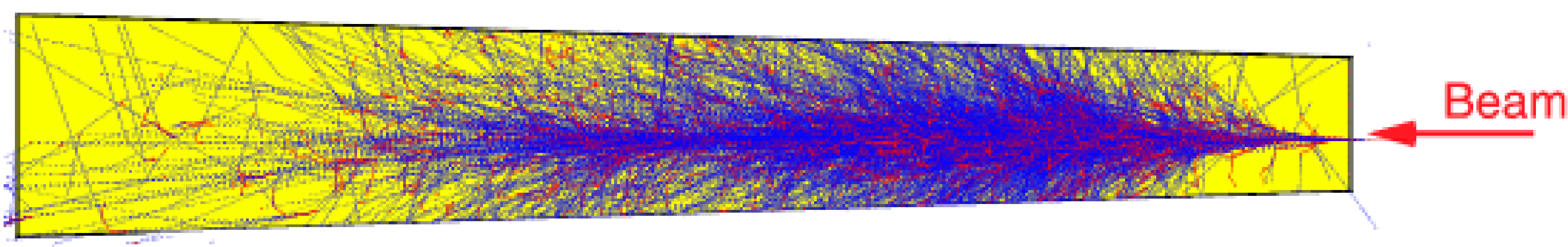
$$\frac{y}{y_{\mathrm{mid}}} = 1 + \delta(x/x_{\mathrm{mid}} - 1)$$



CMS Specification for Uniformity

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





|δ| < 3% & 4% for 18 X_0 (SuperB) & 25X_0 (CMS)

Summary of SuperB Test Beam Crystals

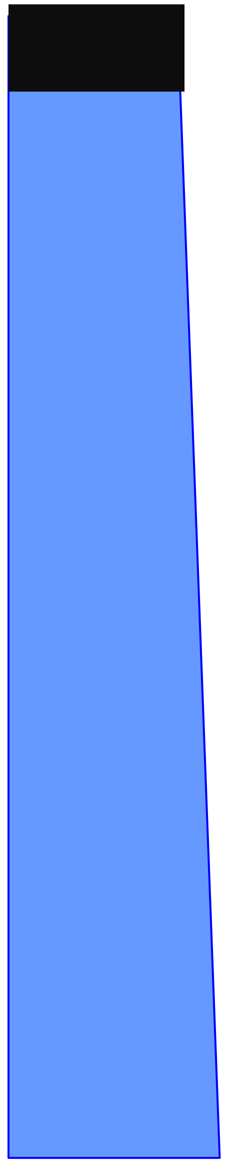
Caltech-ID	Vendor-ID	Test-Beam-Position	Type	LT @ 420 nm (%)	LY, ER & Uniformity by PMT* (% of candel 1), (FWHM, %), (δ, %)	LY, ER & Uniformity by APD (As)* (p.e./MeV), (σ, %), (δ, %) (rms, %)	LY, ER & Uniformity by APD (Uni)* (p.e./MeV), (σ, %), (δ, %) (rms, %)
SIPAT-8			8	57.7	29.3, 13.1, 7.2		
SIPAT-9			8	59.6	32.1, 12.3, -4.5		
SIPAT-10			6	59.3	32.2, 12.3, -6.4		
SIPAT-18		ring 7-3	7	76.0	44.9, 11.0, -7.1	1340, 15.3, 4.8, 2.5	1080, 22.8, 4.2, 2.2
SIPAT-19		ring 7-4	7	70.4	41.3, 11.5, -8.7	1190, 17.3, 3.7, 1.9	1070, 23.0, 0.3, 0.6
SIPAT-23	05_10_16	ring 8-5	8	82.9	48.4, 14.3, 3.1	1480, 16.7, 8.7, 4.4	1040, 23.6, 5.8, 3.0
SIPAT-11	02_08_08	ring 8-3	8	82.3	47.6, 10.7, 5.3	1420, 15.5, 12.9, 6.5	1190, 21.4, 7.2, 3.8
SIPAT-12	02_08_08	ring 8-1	8	82.2	46.5, 10.4, 3.9	1440, 15.1, 14.2, 7.1	1210, 20.7, 10.0, 5.1
SIPAT-13		ring 6-1	6	82.6	52.5, 11.5, 2.7	1440, 14.9, 6.8, 3.6	1220, 20.4, 3.4, 2.0
SIPAT-14		ring 6-2	6	82.7	53.7, 10.9, 3.2	1500, 14.9, 14.4, 7.4	1200, 20.4, 9.0, 4.6
SIPAT-15		ring 6-4	6	80.7	52.8, 10.5, 3.4	1580, 13.7, 11.9, 6.0	1310, 19.1, 6.1, 3.4
SIPAT-16		ring 6-5	6	81.1	51.8, 10.1, -0.8	1570, 13.5, 9.7, 5.0	1100, 19.6, 5.3, 2.7
SIPAT-17		ring 6-3	6	82.1	53.0, 12.2, 3.5	1260, 17.1, 9.8, 4.9	1080, 24.1, 4.9, 2.7
SIPAT-20	07_10_02	ring 7-2	7	79.8	56.4, 10.0, 5.6	1670, 14.6, 8.7, 4.4	1340, 18.2, 5.1, 2.6
SIPAT-21	02_10_23	ring 7-5	7	81.6	48.8, 10.9, 3.0	1550, 15.8, 10.7, 5.6	1190, 20.7, 6.1,3.2
SIPAT-22	07_10_02	ring 7-1	7	81.4	52.6, 11.0, 2.7	1600, 15.2, 9.2, 4.8	1180, 20.3, 5.2, 3.0
SG-S1			8	82.1	52.2, 9.8, 1.0		
SG-S2			8	81.8	54.2, 9.6, 1.4		
SG-S3			9	81.1	56.0, 9.8, 1.0		
SG-S4			9	82	56.5, 9.7, 0.1		
SG-S5			9	82.6	54.5, 9.9, 3.6		
SG-S6			9	81.4	57.6, 9.7, 1.8		
SG-S7			9	80.9	55.2, 9.7, 0.5		
SG-S8			10	82.4	54.3, 9.8, 1.9		
SG-S9			10	82.8	54.1, 9.8, -1.4		
SG-S10			10	81.1	54.3, 9.6, 3.4		
SG-S11			10	82.3	51.6, 10.0, 1.4		
SG-S12			10	81.5	53.4, 10.0, 0.6		
SIC-3			8	80.5	54.8, 10.9, 6.6	1380, 18.0, 15.1, 7.8	1020, 23.8, 10.9, 5.6

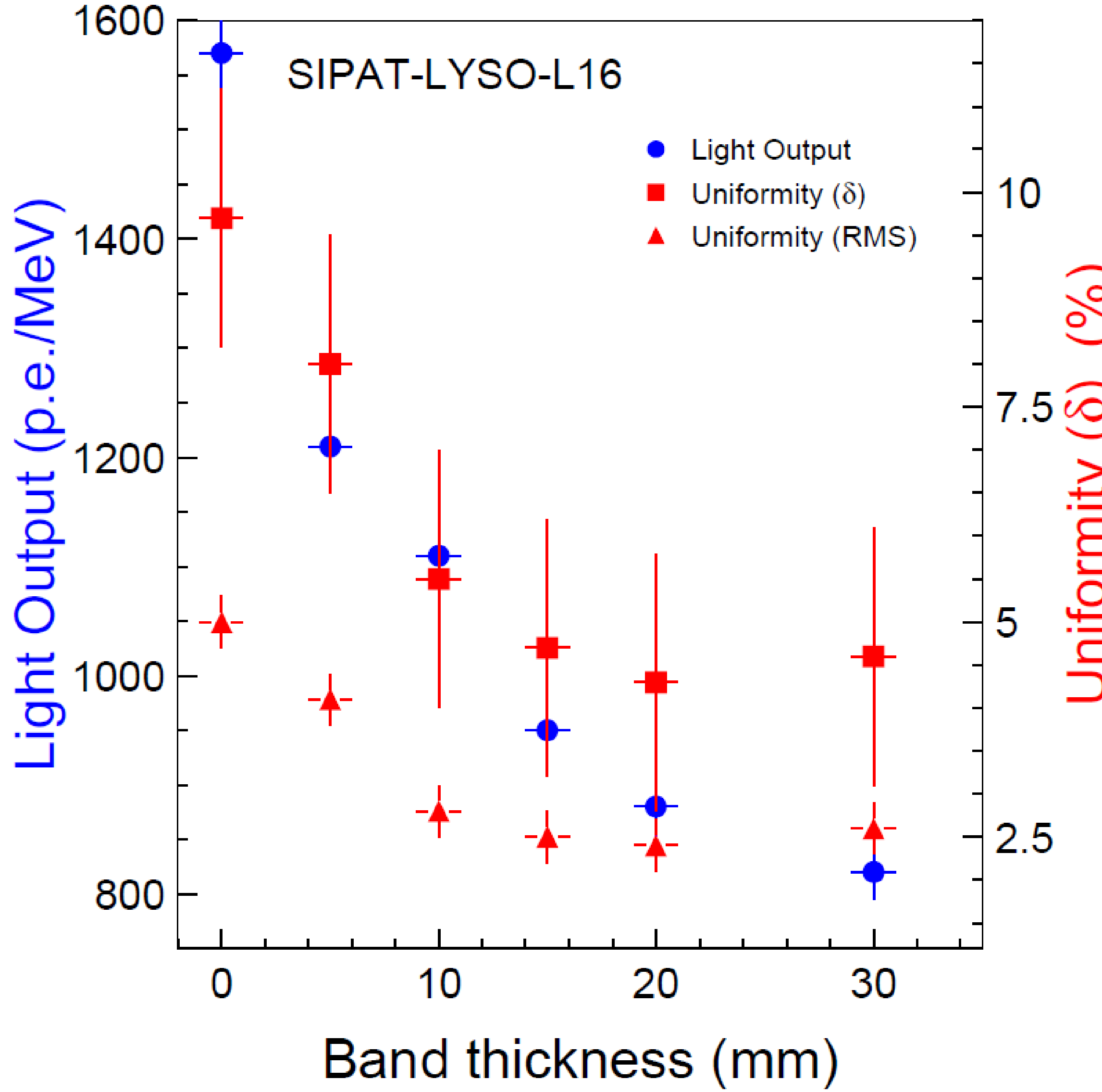
Test beam location is unknown

Will be filled after data taken with Riba cells are analyzed

Uniformization with Black Paint: 5% Possible

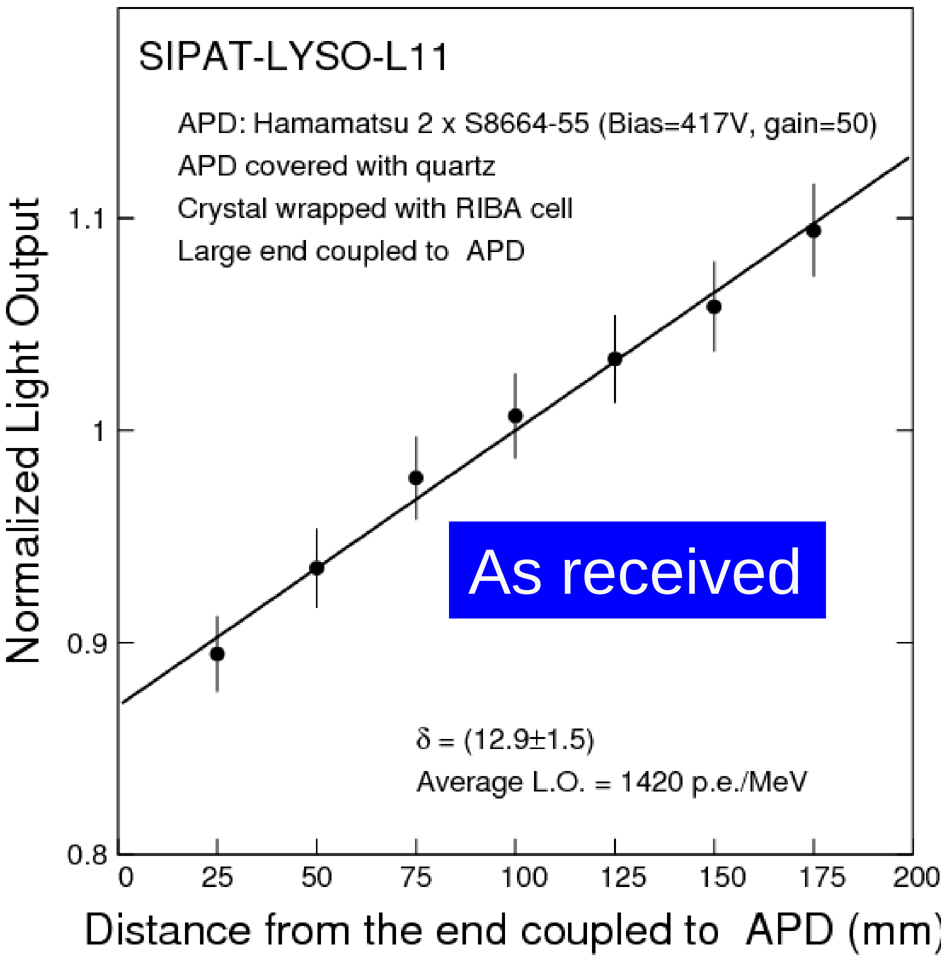
For CERN test beam, a 15 mm wide black band painted at the small end of the smallest side surface effectively reduced the non-uniformity.

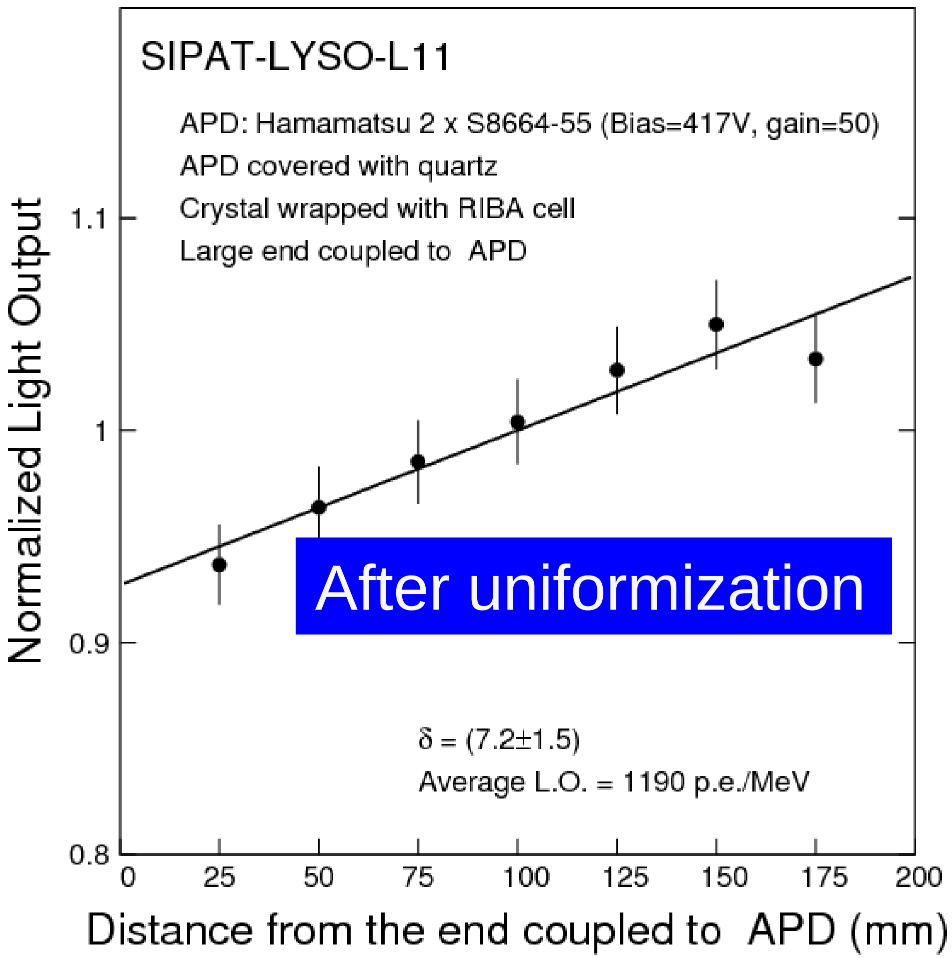




Uniformization: SIPAT-11

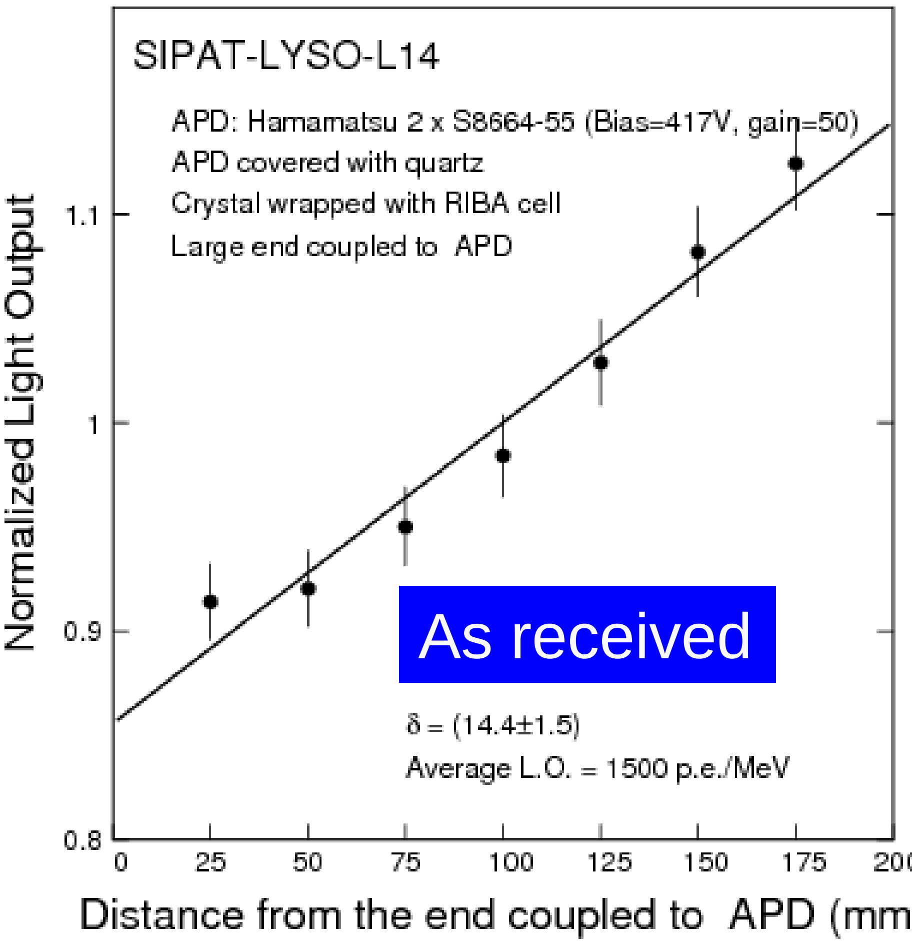
Non-uniformity reduced from 12.9% to 7.2%

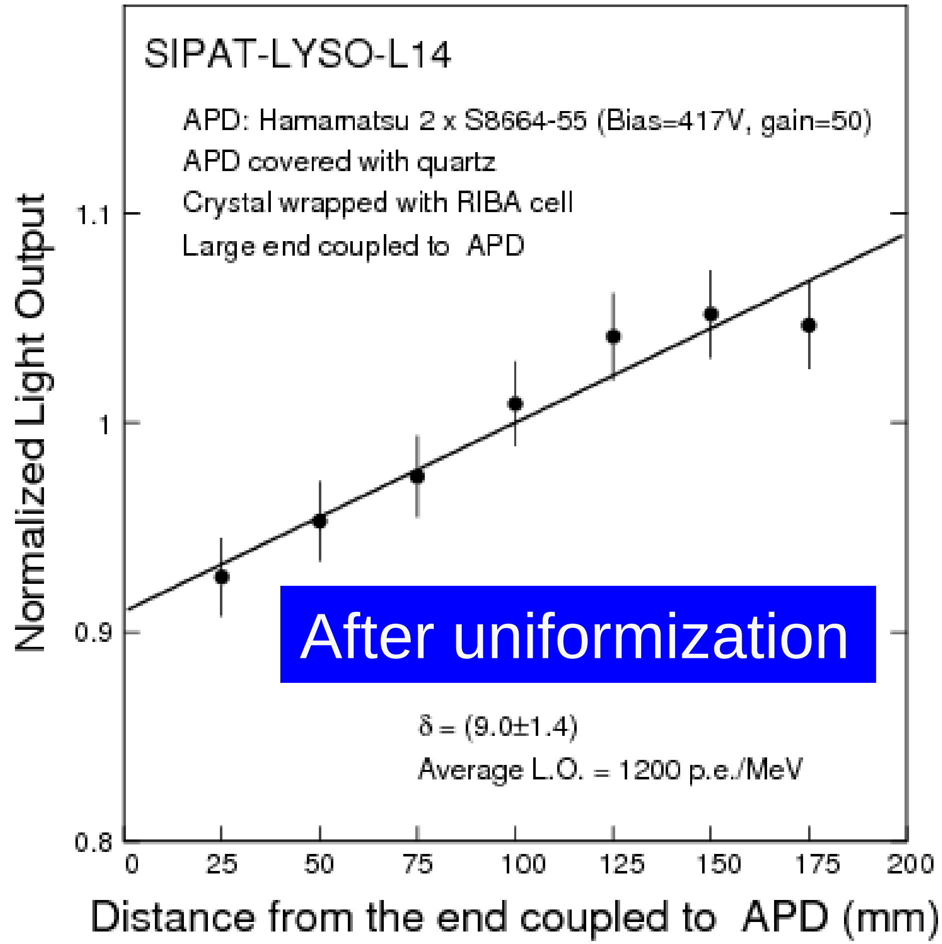




Uniformization: SIPAT-14

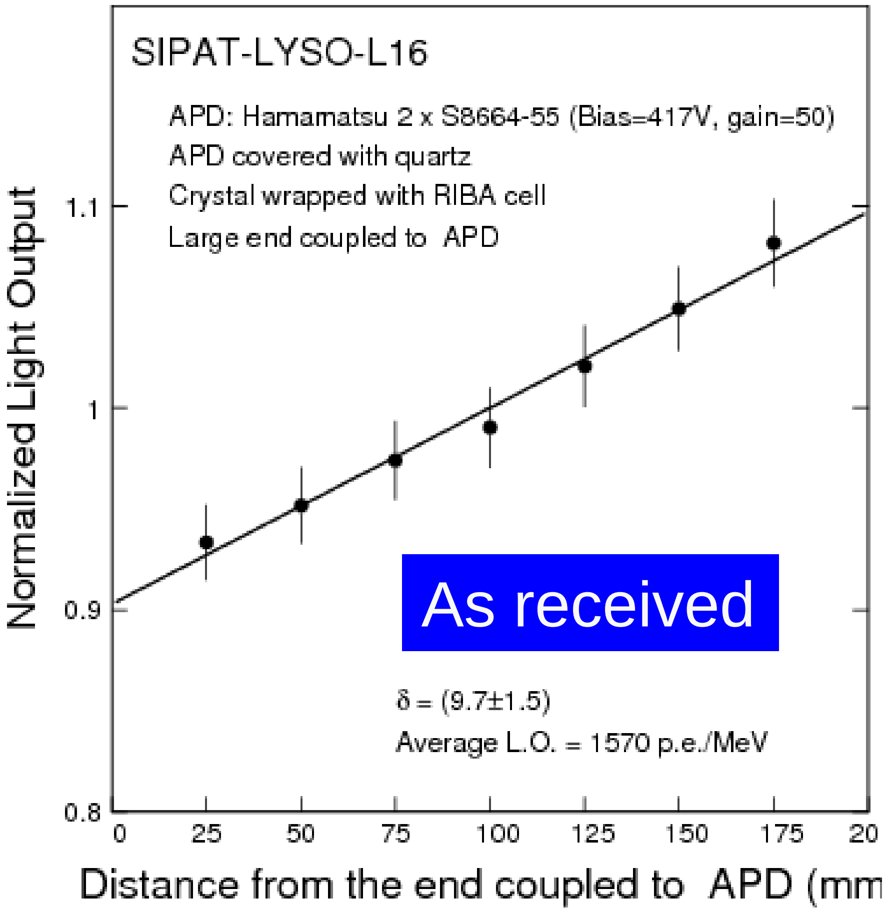
Non-uniformity reduced from 14.4% to 9.0%

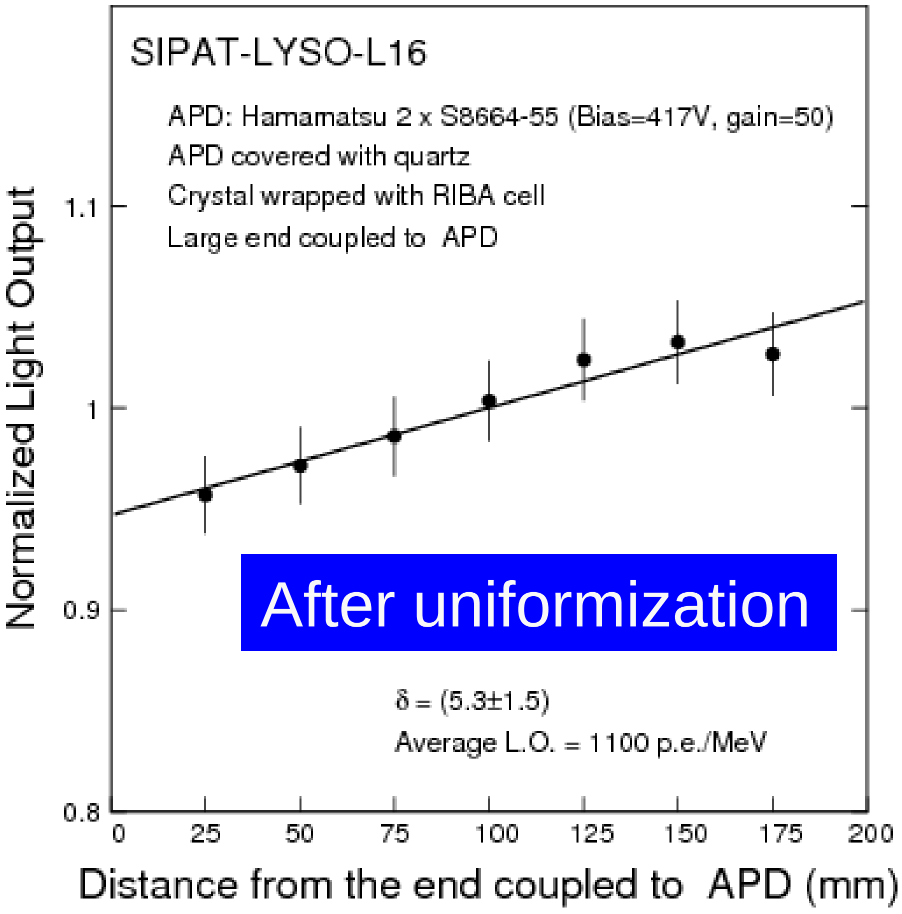




Uniformization: SIPAT-16

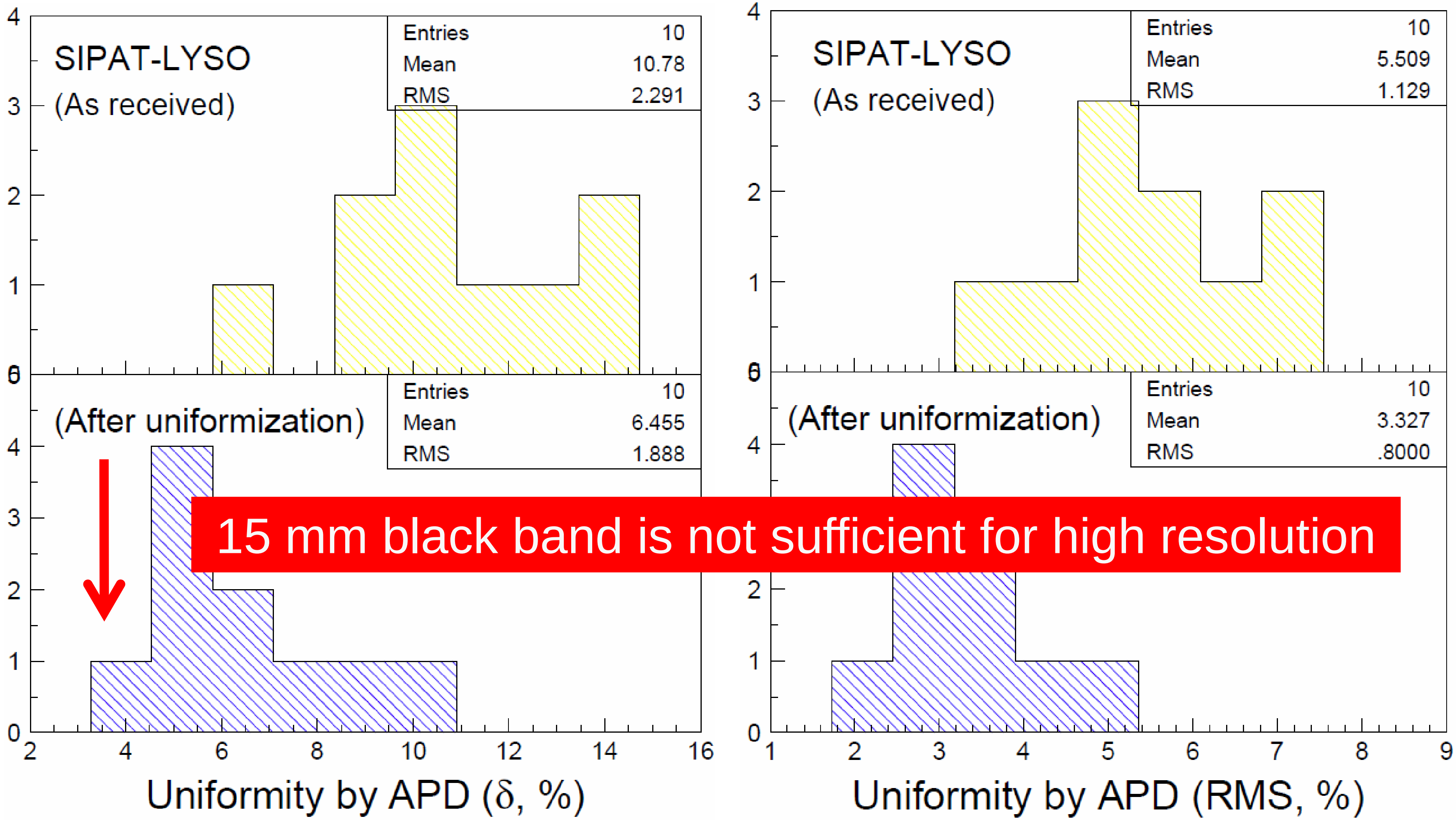
Non-uniformity reduced from 9.7% to 5.3%





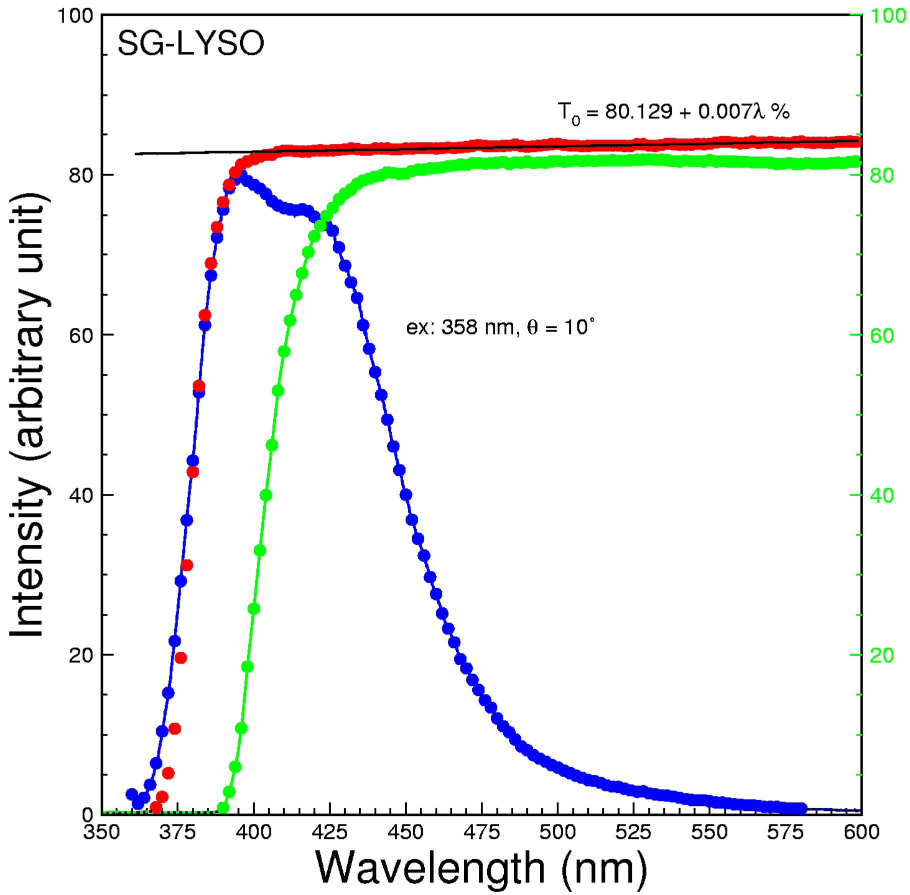
Distribution of Non-Uniformity

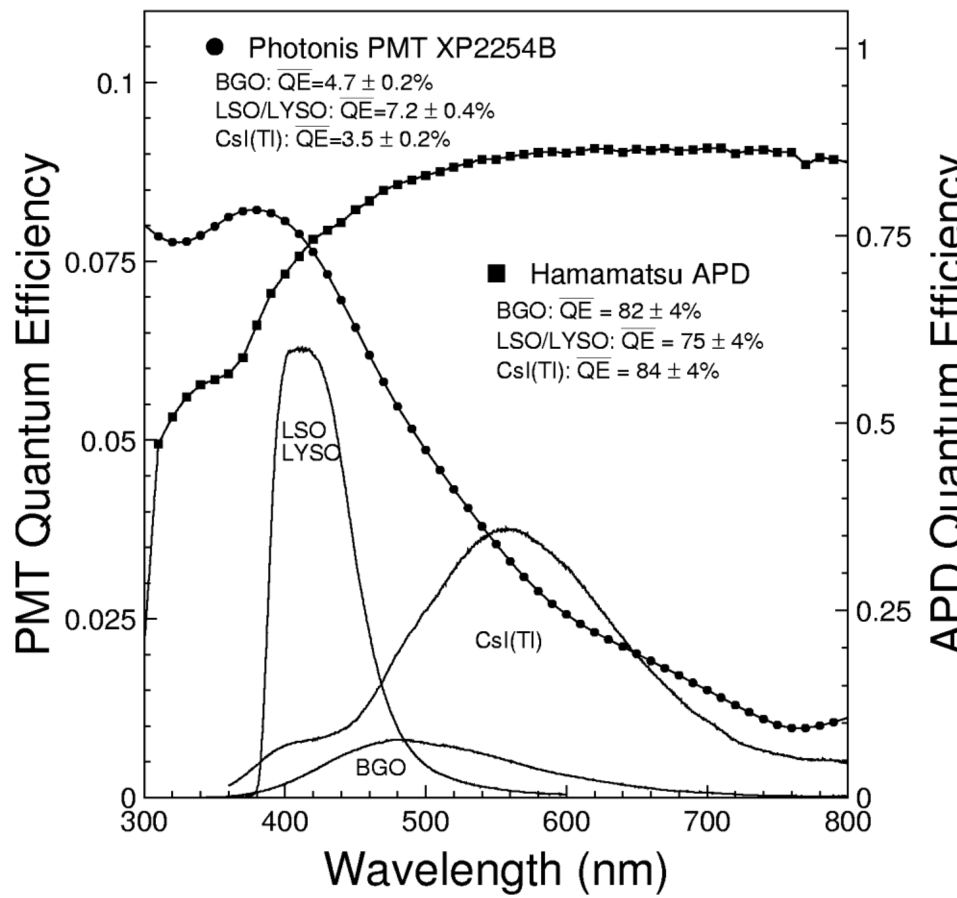
Non-uniformity reduced from 10.8% and 5.5% to 6.5% and 3.3% for δ and rms respectively



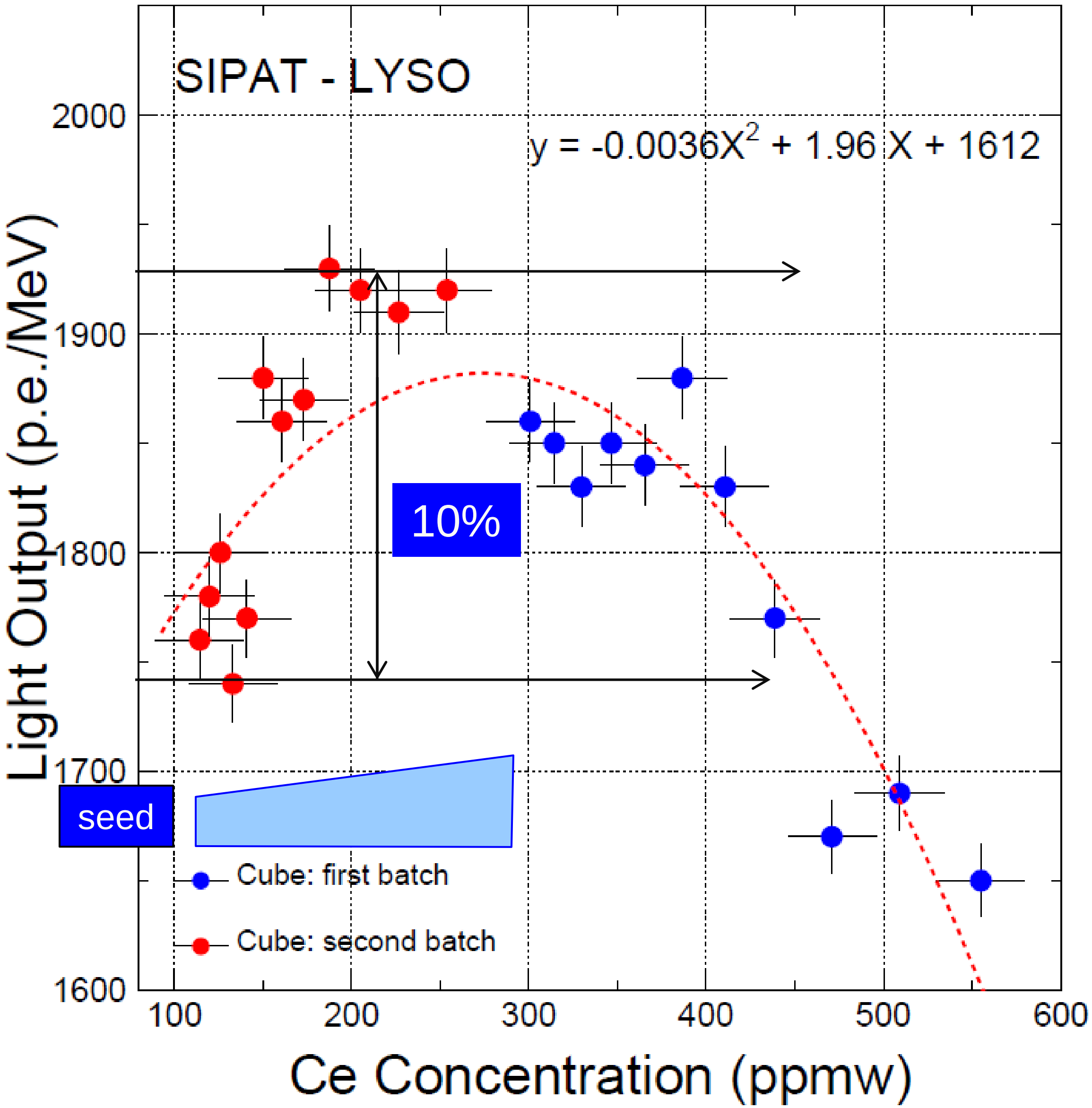
Effect of Self-absorption

It is well known that part of the emission light is absorbed in the crystal: self-absorption.





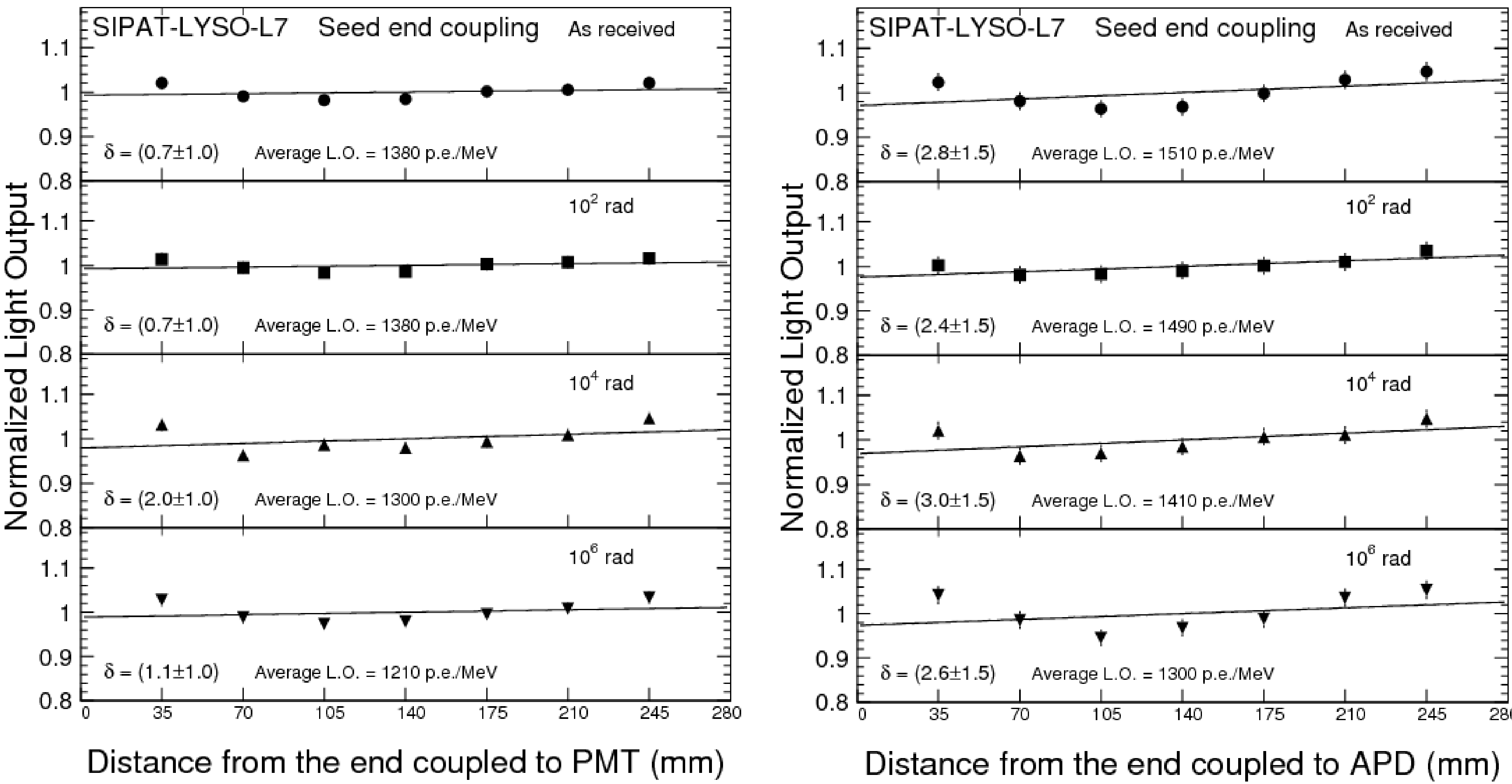
Effect of Cerium Segregation



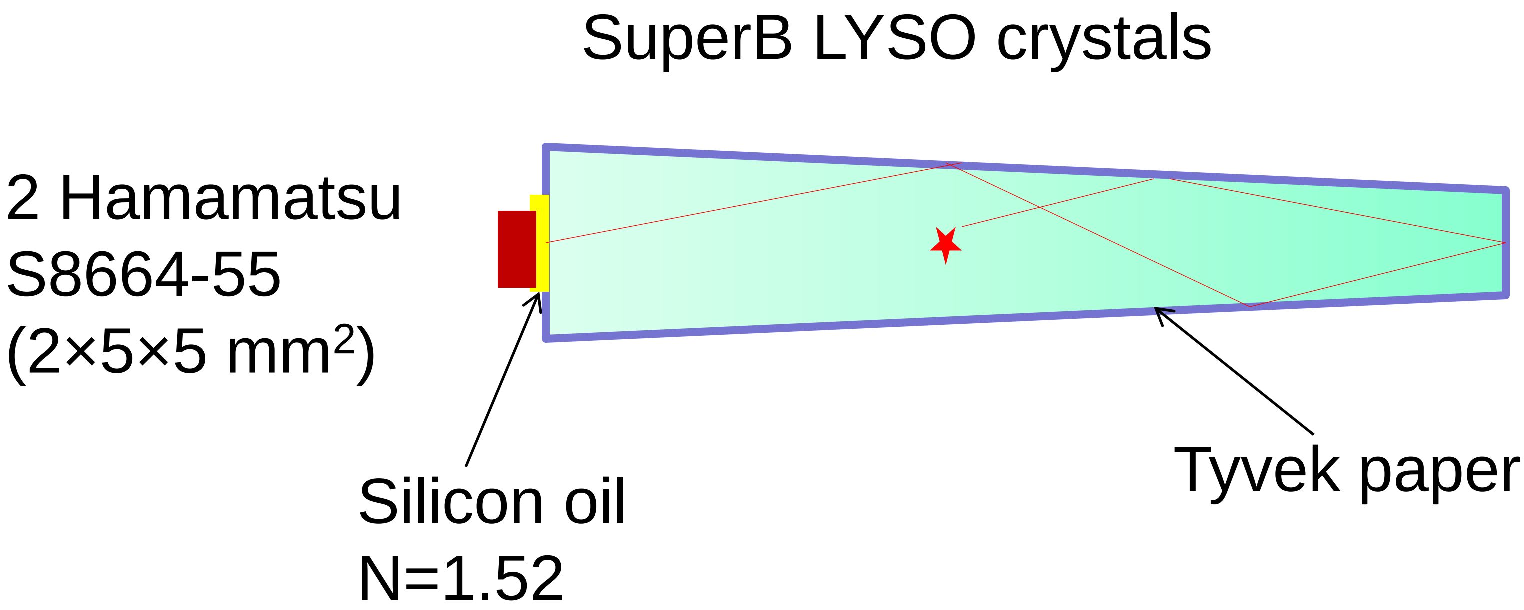
It is also known that cerium concentration along long LYSO crystals is not uniform, causing non-uniformity up to 10% at two ends, indicating up to 5% variation in δ is possible because of cerium segregation.

Good Uniformity for Rectangular Crystals

^{137}Cs γ-rays up to 1 Mrad @ 7.5k rad/h: 12 ~14% loss
Light response uniformity (δ<3%) maintained for PMT/APD

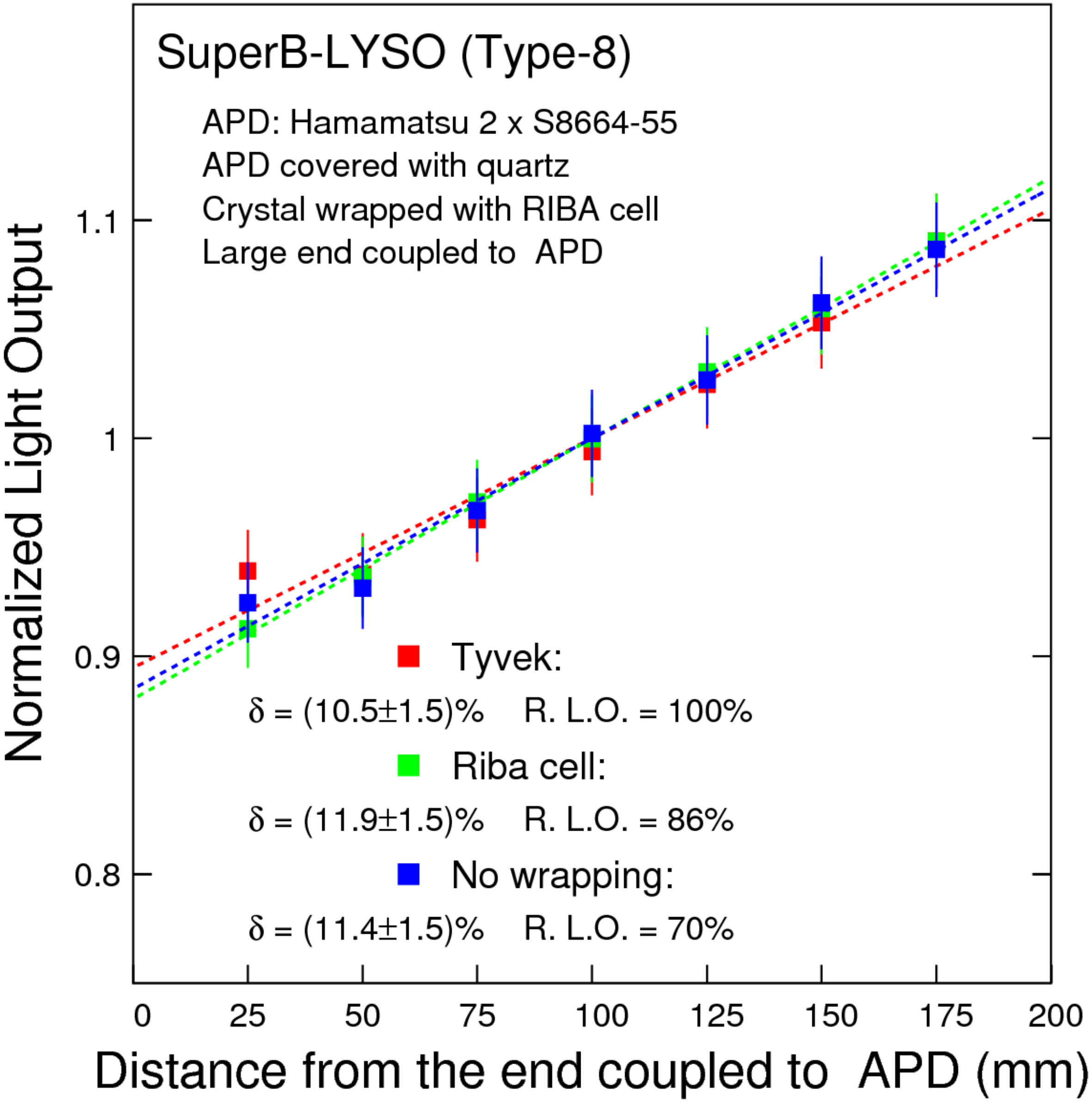


Ray-Tracing Simulation "set-up"



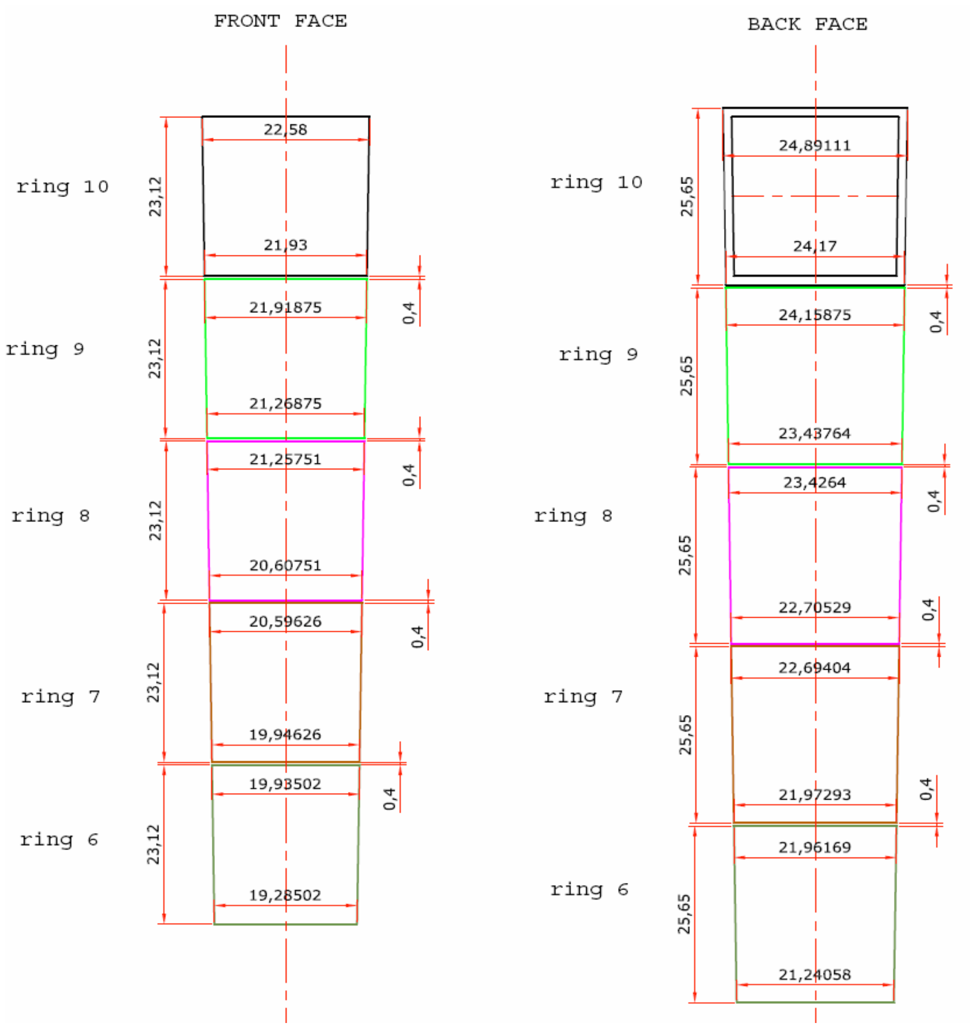
The simulation package was developed in early eighties, and was used for the L3 BGO and CMS PWO crystals.

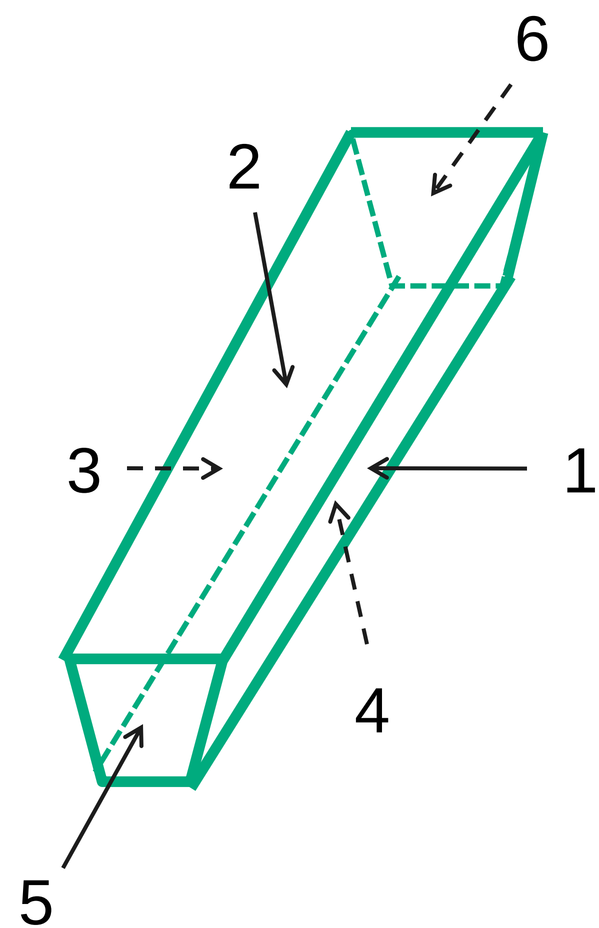
Minor Wrapping Effect



While wrapping affects overall light output, its effect on uniformity is minor

Dimensions and Surface Definition





Light Response Uniformity

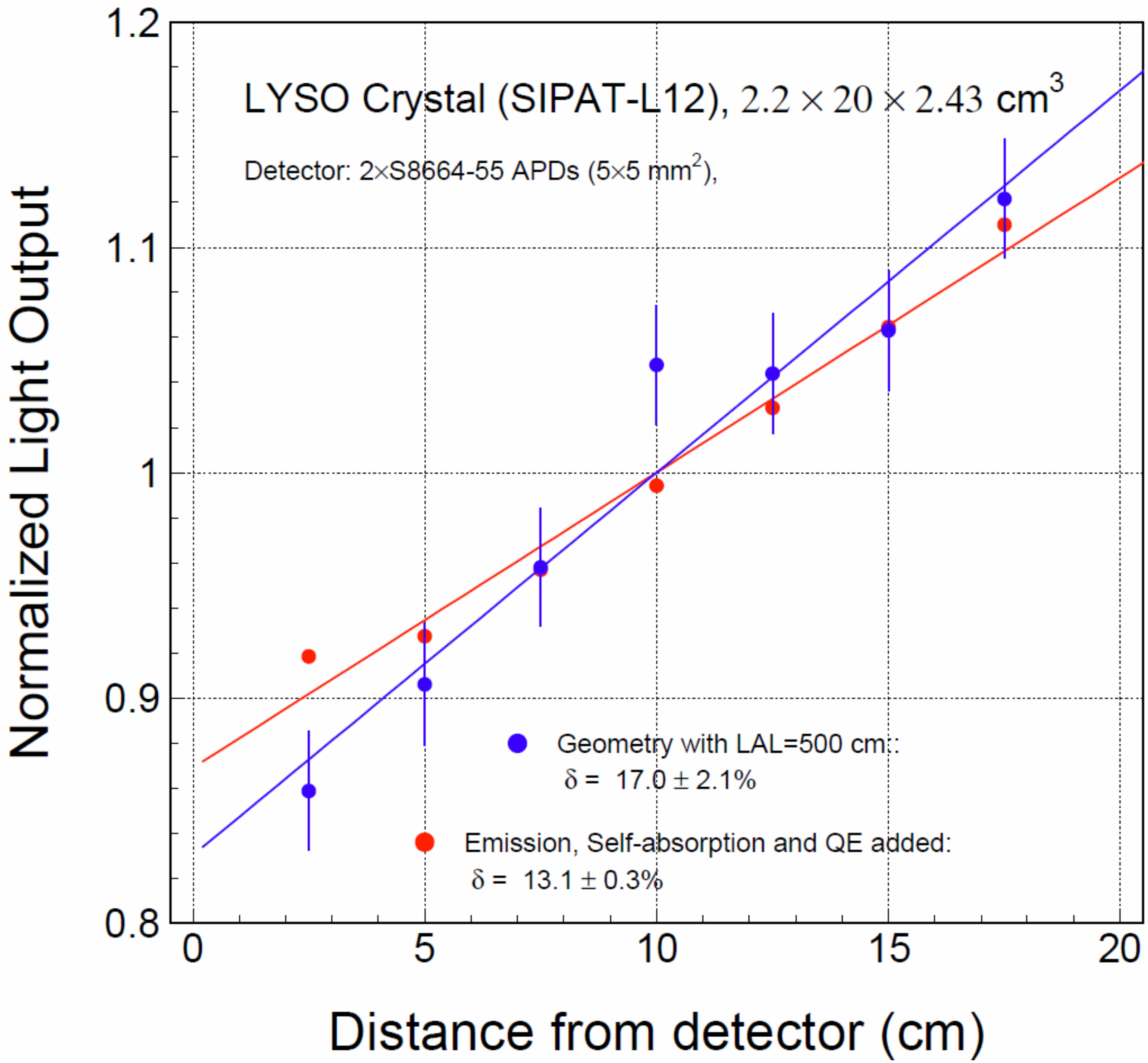
$$LO(z) = LY(z)\int Em(\lambda)LCE(\lambda, z)QE(\lambda)d\lambda$$

PMT / APD

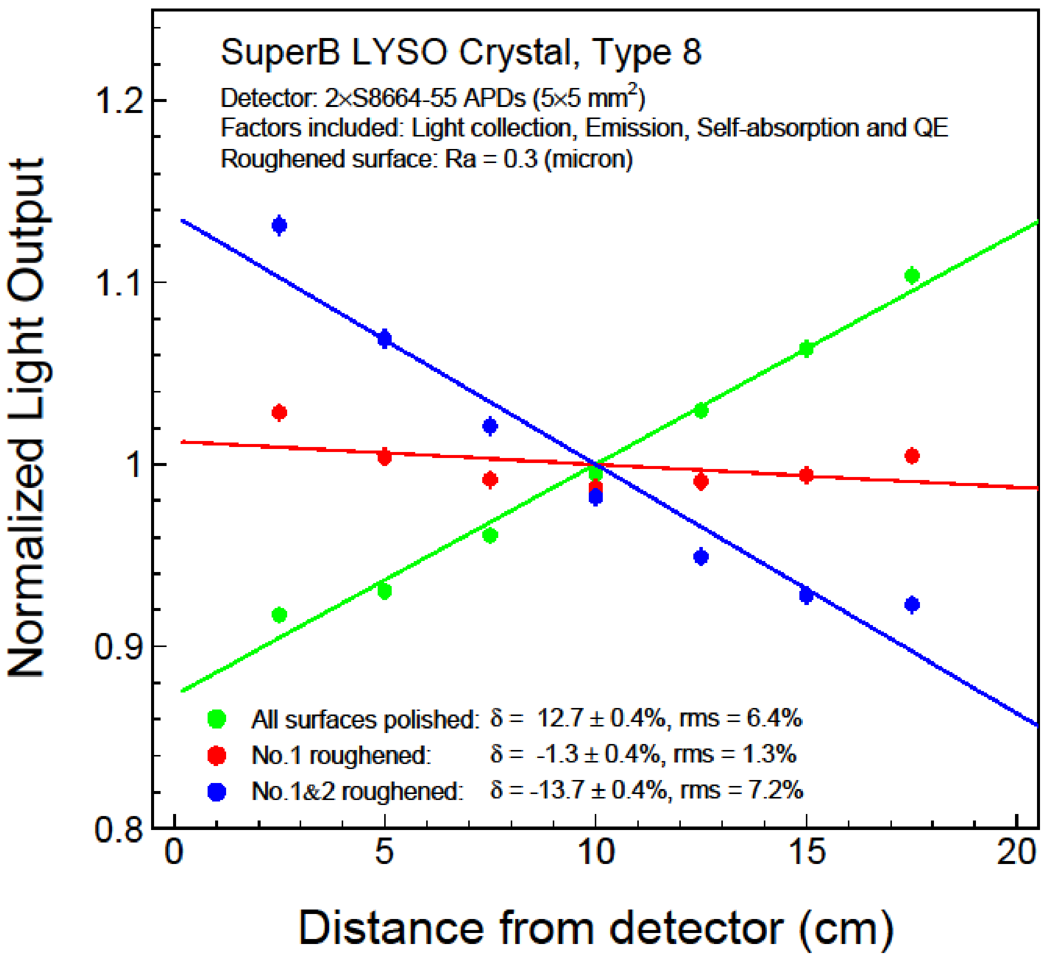
- LY(z): light yield at different longitudinal position,
- Em(λ): emission spectrum,
- LCE(λ,z): light collection efficiency,
- QE(λ): quantum efficiency of APDs.

Including Self-Absorption Effect

The tapered geometry leads an optical focusing effect of 17%. Including self-absorption and QE reduces non-uniformity from to 13%.

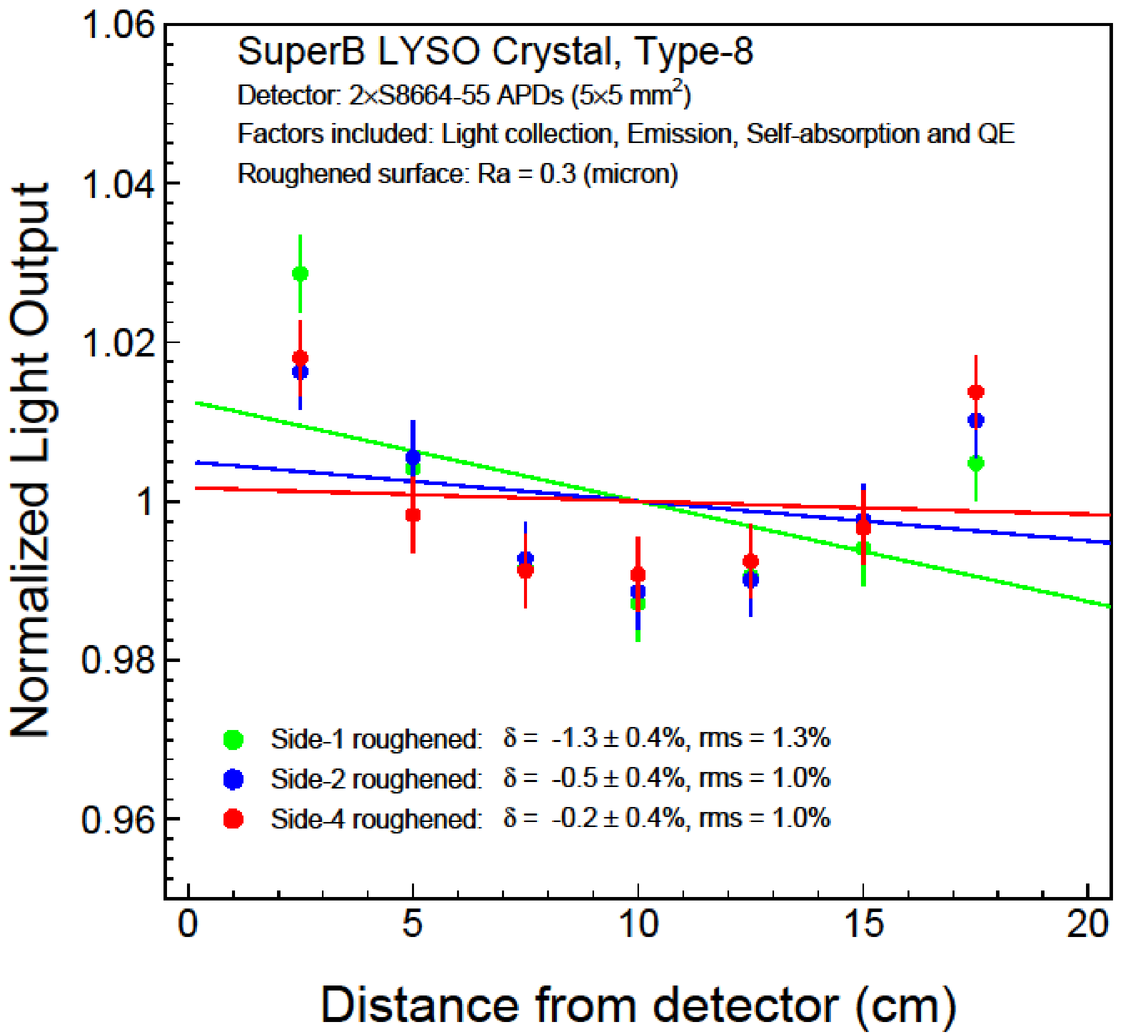


Polished and Roughened Surfaces



- The optical focusing, effect dominates non-uniformity: δ is about 13% for all polished surfaces.
- Roughened surface(s) can compensate the optical focusing effect.
- The best result is achieved by roughening only one side surface.

Which Side Surface?

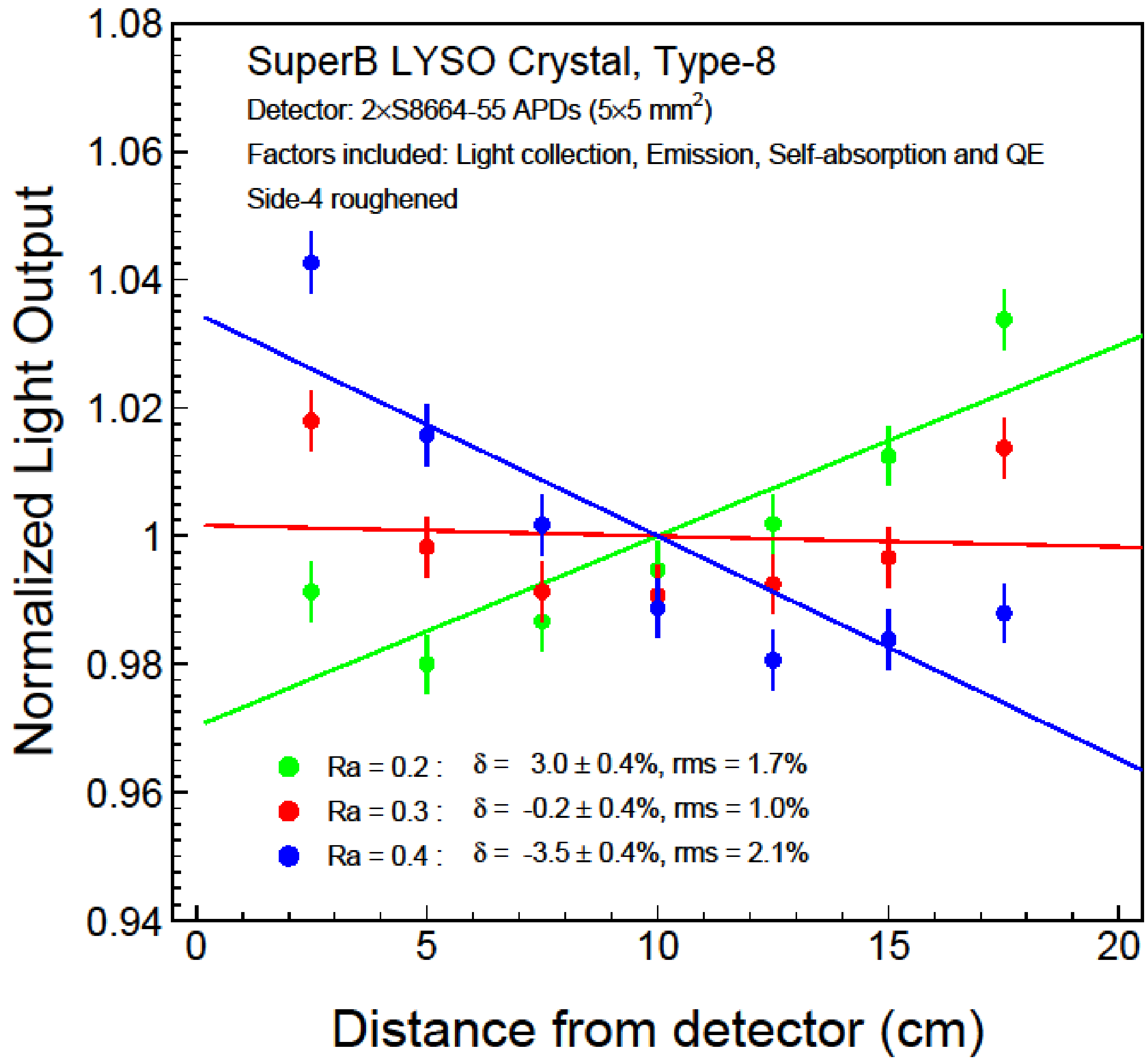


For the type-8 crystal with R_a=0.3 roughening surface 4 (the smallest side surface) provides the best uniformity.

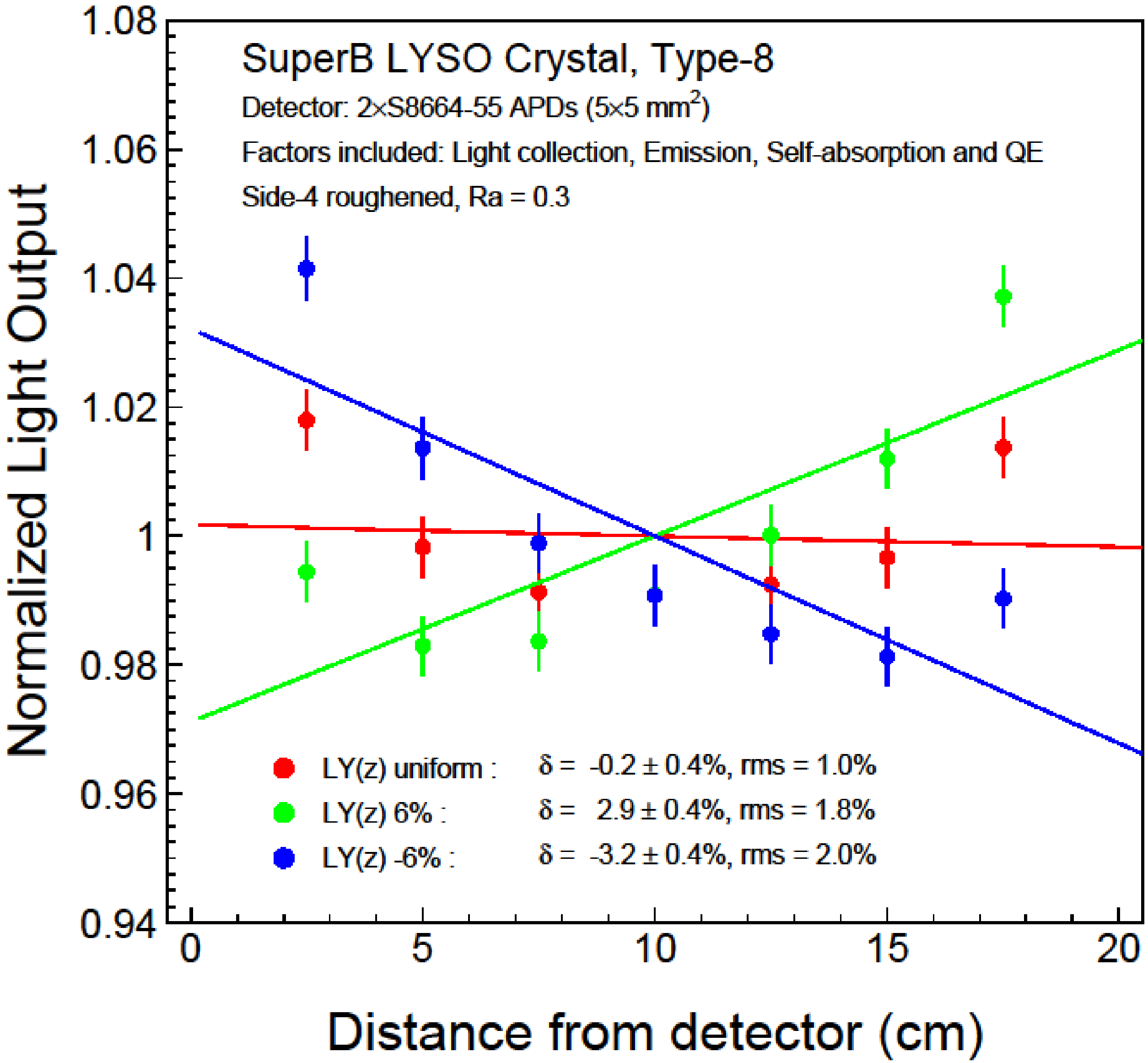
How Rough it Should Be?

The R_a matters.

A variation of 0.1 in R_a causes a 3% variation in δ.



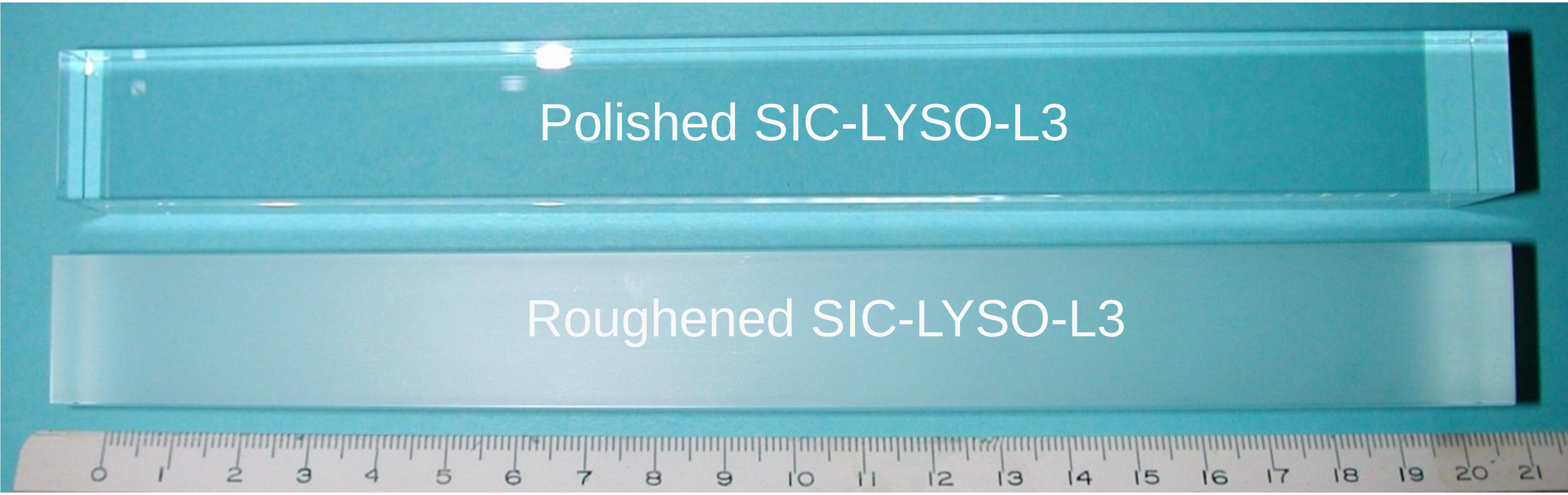
Introducing Longitudinal LY Variation



A light yield variation of 6% causes a 3% variation in δ.

Real Exercise: Roughening SIC-LYSO-L3

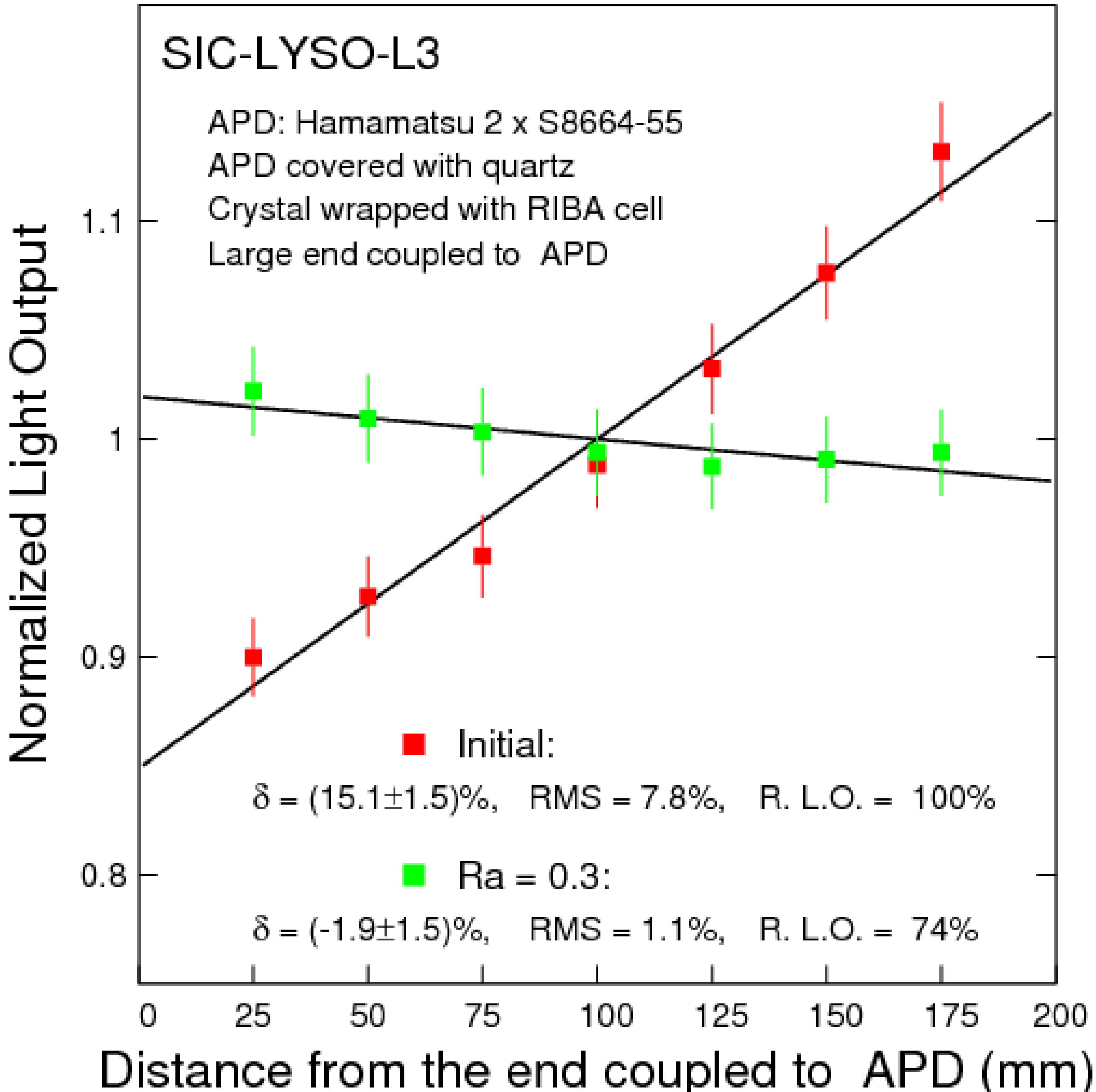
The smallest side surface of SIC-LYSO-L3 was roughened to Ra = 0.3 at SIC via a two step process



1st: lapped to Ra = 0.5 by using 11 μm Al_2O_3 powder for 10 min with 2.5 kg weight.
2nd: lapped to Ra = 0.3 by using 6.5 μm SiC powder for 3 min with 1.5 kg weight.

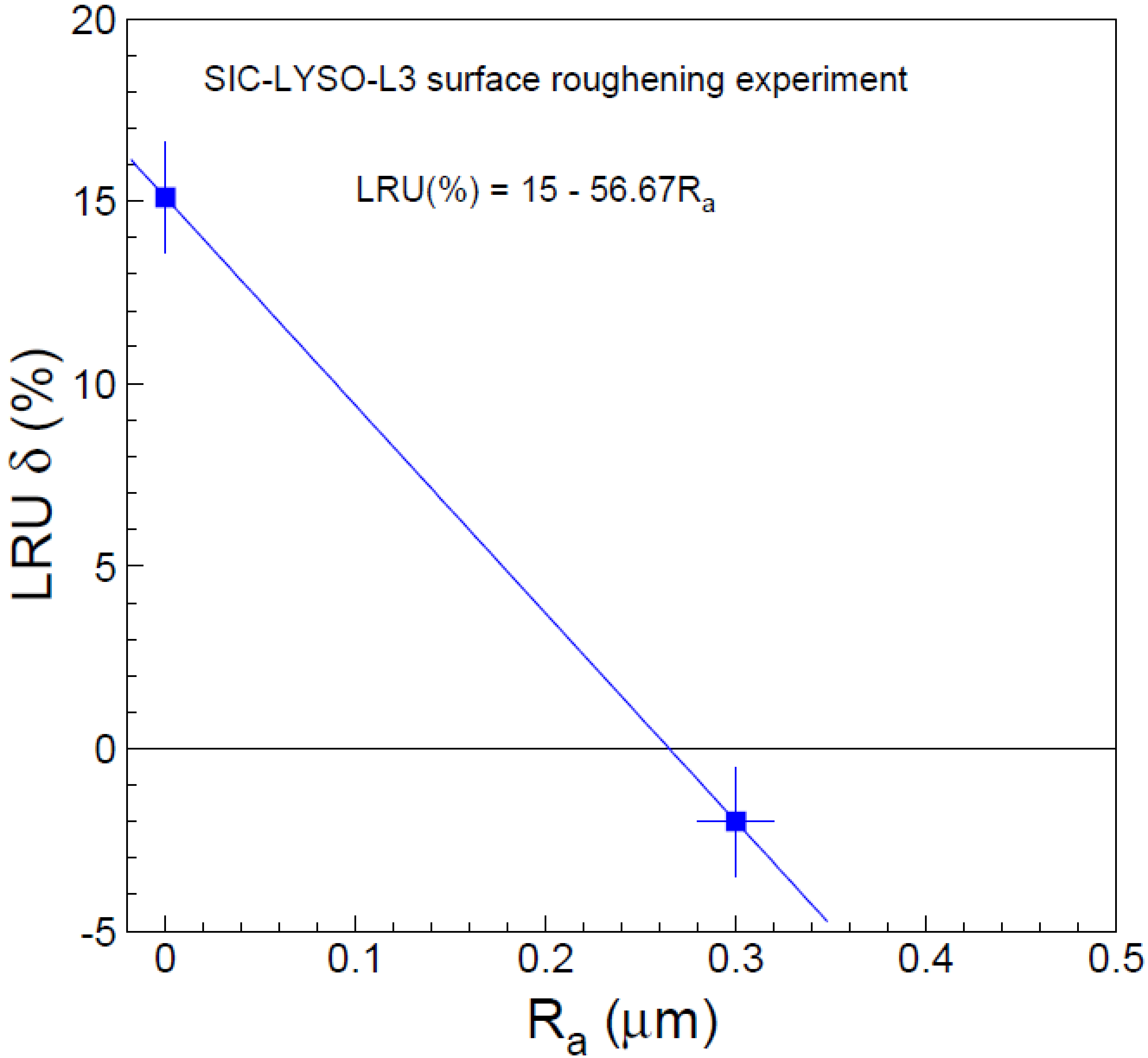
Relative Light Output & Uniformity

Ra = 0.3 uniformize this crystal to < 2%. Ra = 0.25 seems the best for this sample.



Roughness Required to Uniformize SIC-L3

Assuming a linearity Ra = 0.26 is the best. Additional measurements are needed to define the best Ra values for each crystal based upon measured δ. This will take some time.



Summary

The light response uniformity of long tapered LYSO crystals suffer from effects caused by (1) self-absorption and (2) cerium segregation and (3) optical focusing.

Uniformization with 15 mm black paint at the small end on the smallest side surface reduces the non-uniformity from 10.8% to 6.5% for SuperB crystals. This level of uniformity, however, is not sufficient.

Uniformization with roughening one side surface to a designed roughness is expected to reduce the non-uniformity to less than 3%, so that crystal resolution would not be compromised.

All crystals will be uniformized after the Frascati test beam.

Status of Test Beam Crystals

Following the decision on Frascati test beam ten SIPAT crystals and all APDs were shipped to Perugia on 3/25.

Riba cells for type 9 and 10 were received on 3/29. All twelve Saint-Gobain crystals were measured with Riba cells, and were shipped to Perugia on 4/1. Light output and uniformity data with Riba cells are being analyzed.

Three SIPAT crystals (18, 19 and 23), which do not meet specifications, were returned to SIPAT in January. SIPAT will deliver three replacement crystals on 4/15.

SIC will deliver two type 7 crystals on 4/10. Together with SIC-LYSO-L3. Three SIC LYSO crystals should be available for the Frascati test beam in May.