A Damage and Recovery Study for Lead Tungstate Crystal Samples from BTCP and SIC

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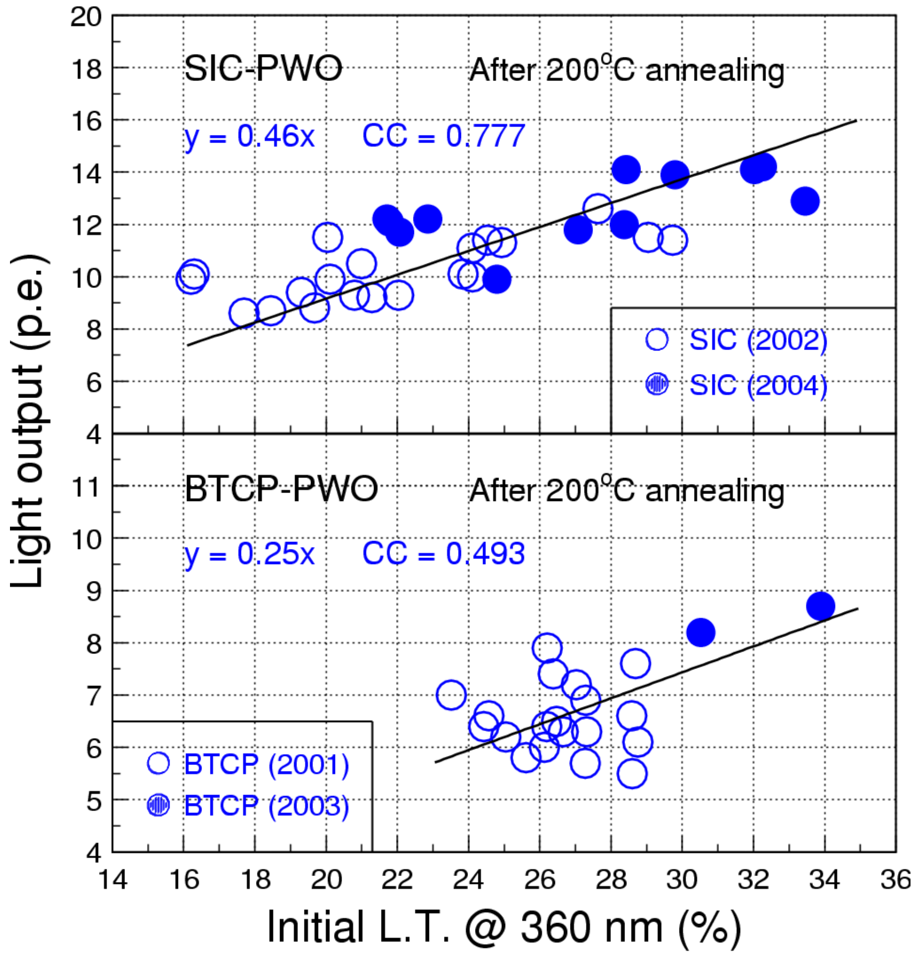
Introduction

- 54 PWO samples were studied at Caltech (32 from SIC and 22 from BTCP). All samples went through 200^{o}C (5 h) thermal annealing followed by γ–ray irradiations at different dose rates until equilibrium.
- Properties measured: transmittance, emission and excitation spectra, light output, decay kinetics, light response uniformity and their degradation, as well as emission weighted radiation induced absorption coefficient (EWRIAC).
- Correlations between measured optical properties and their radiation damage were investigated.
- 2 SIC samples (2570 & 2572) and 2 BTCP 2003 samples (2482 & 2531) went through long term irradiation and recovery cycles @ 100 and 400 rad/h.

Initial LO versus LT @ 360 nm

Correlations observed between Initial LO & initial LT@360 nm

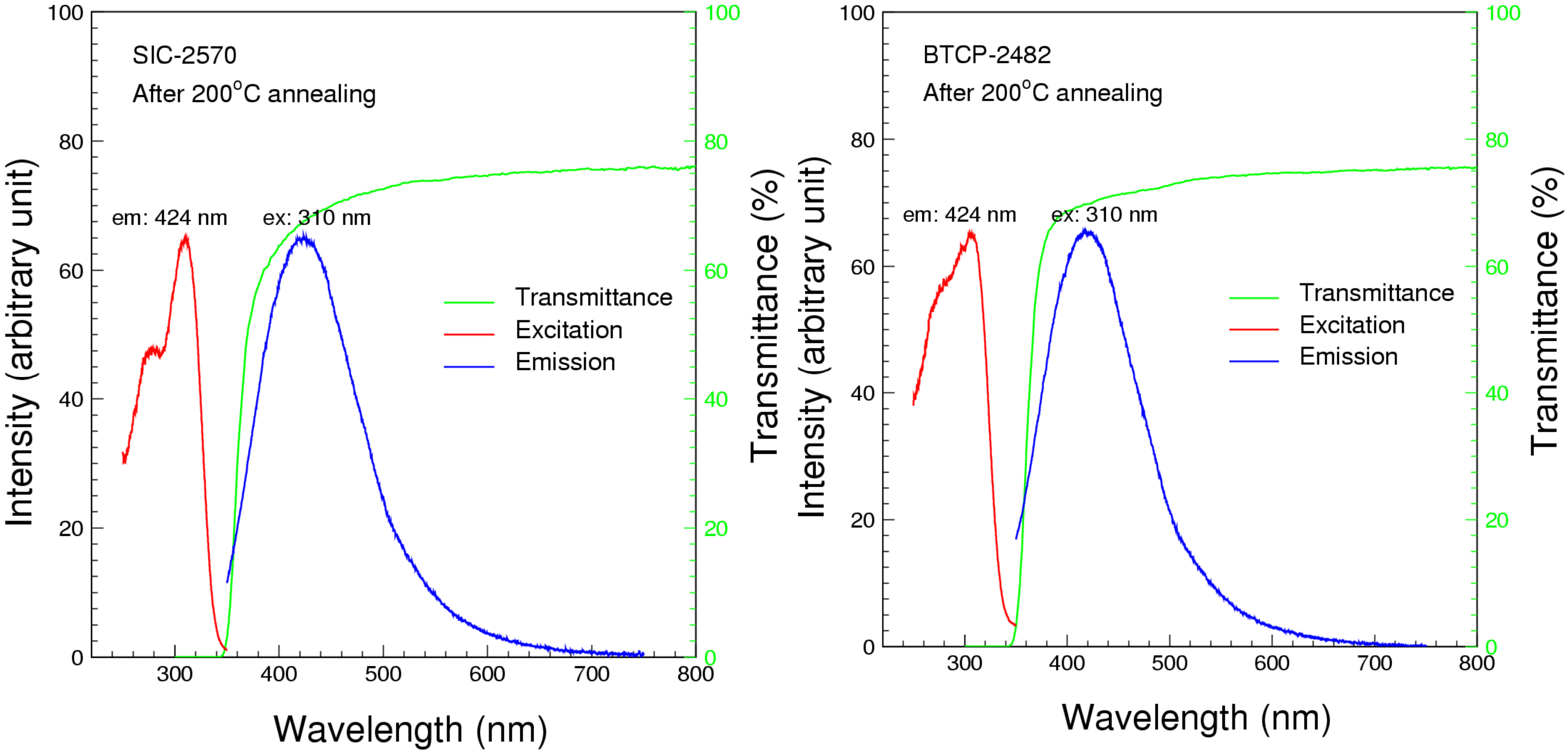


CC, *correlation coefficient*, is a measure of the correlation and defined by:

$$CC = \frac{\sum(x-\overline{x})(y-\overline{y})}{\sqrt{\sum(x-\overline{x})^2\sum(y-\overline{y})^2}}$$

Initial LO versus LT @ 360 nm

A small part of emitted light is self-absorbed



EWRIAC Measured after Irradiations

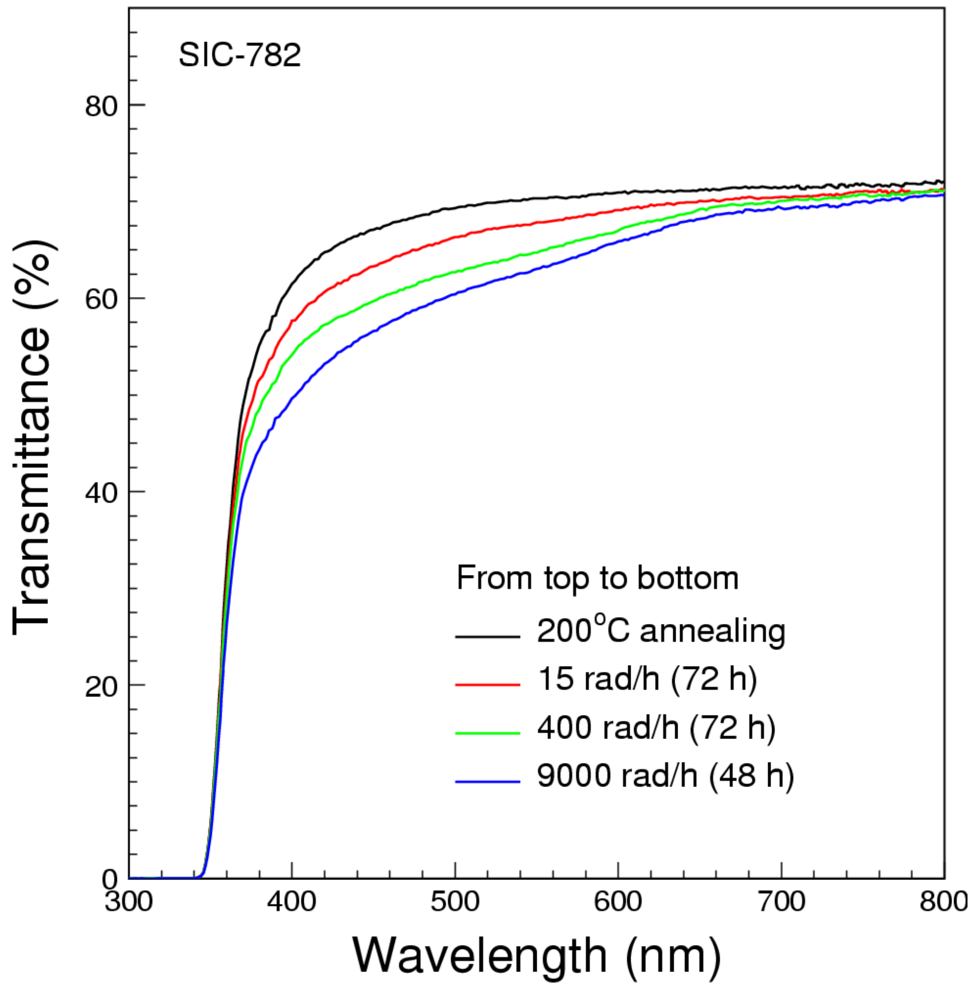
$$Riac = 1/LAL_{equilibrium} - 1/LAL_{before}$$

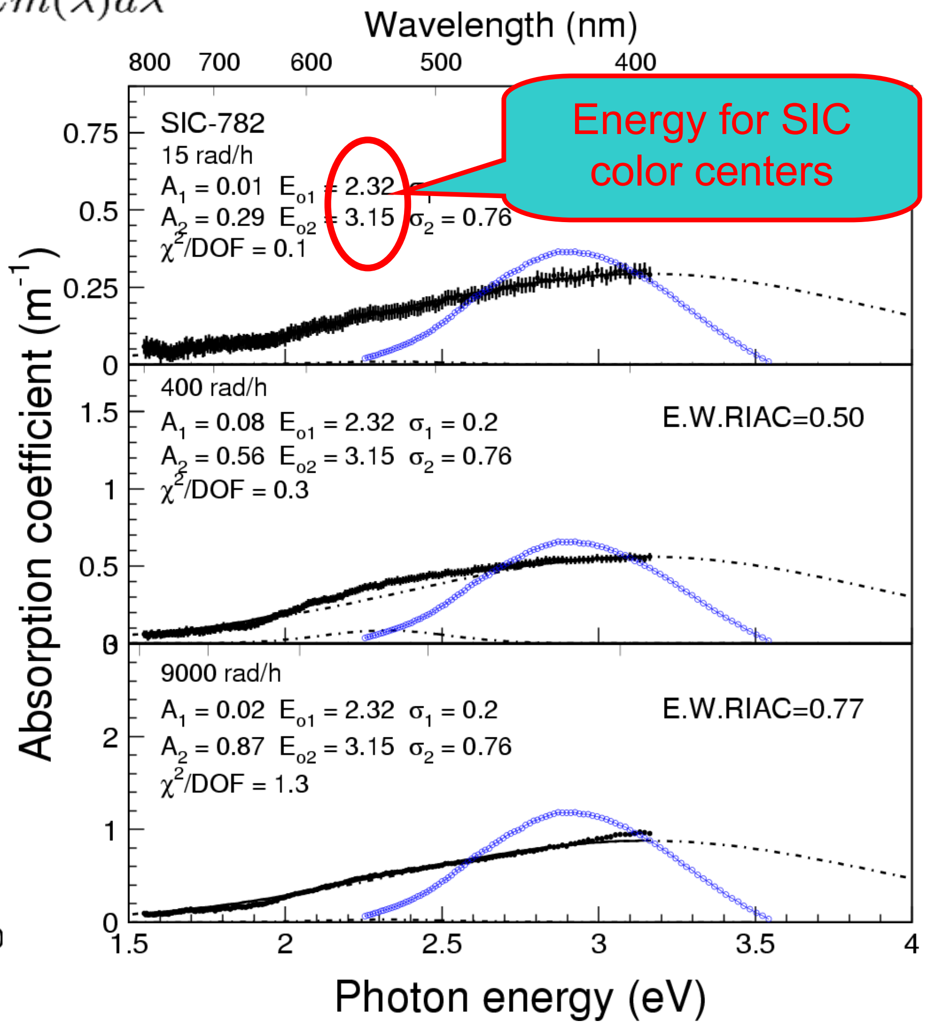
$$T_s = (1-R)^2 + R^2(1-R)^2 + ... = (1-R)/(1+R)$$

$$LAL = \frac{\ell}{\ln\{[T(1-T_s)^2]/[\sqrt{4T_s^4 + T^2(1-T_s^2)^2} - 2T_s^2]\}}$$

$$R = \frac{(n_{crystal} - n_{air})^2}{(n_{crustal} + n_{air})^2}$$

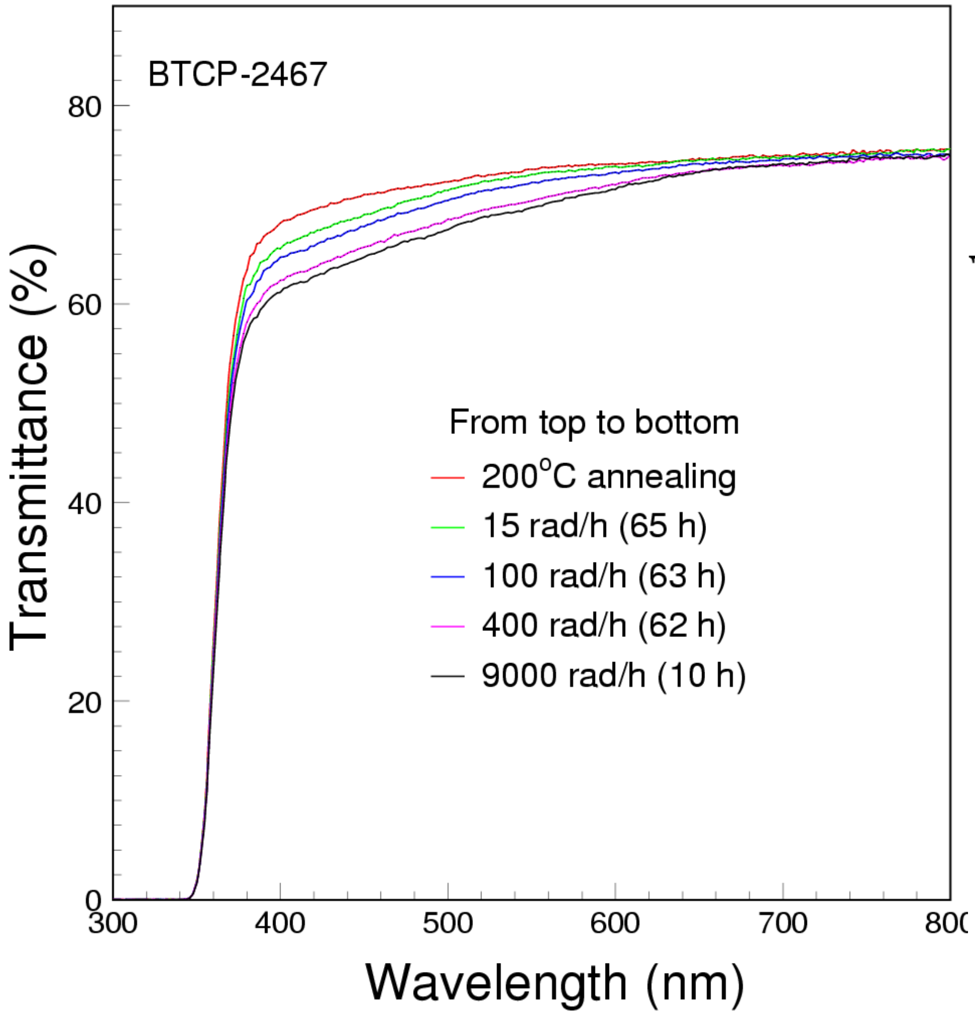
$$EWRIAC = \frac{\int Riac(\lambda)Em(\lambda)d\lambda}{\int Em(\lambda)d\lambda}$$

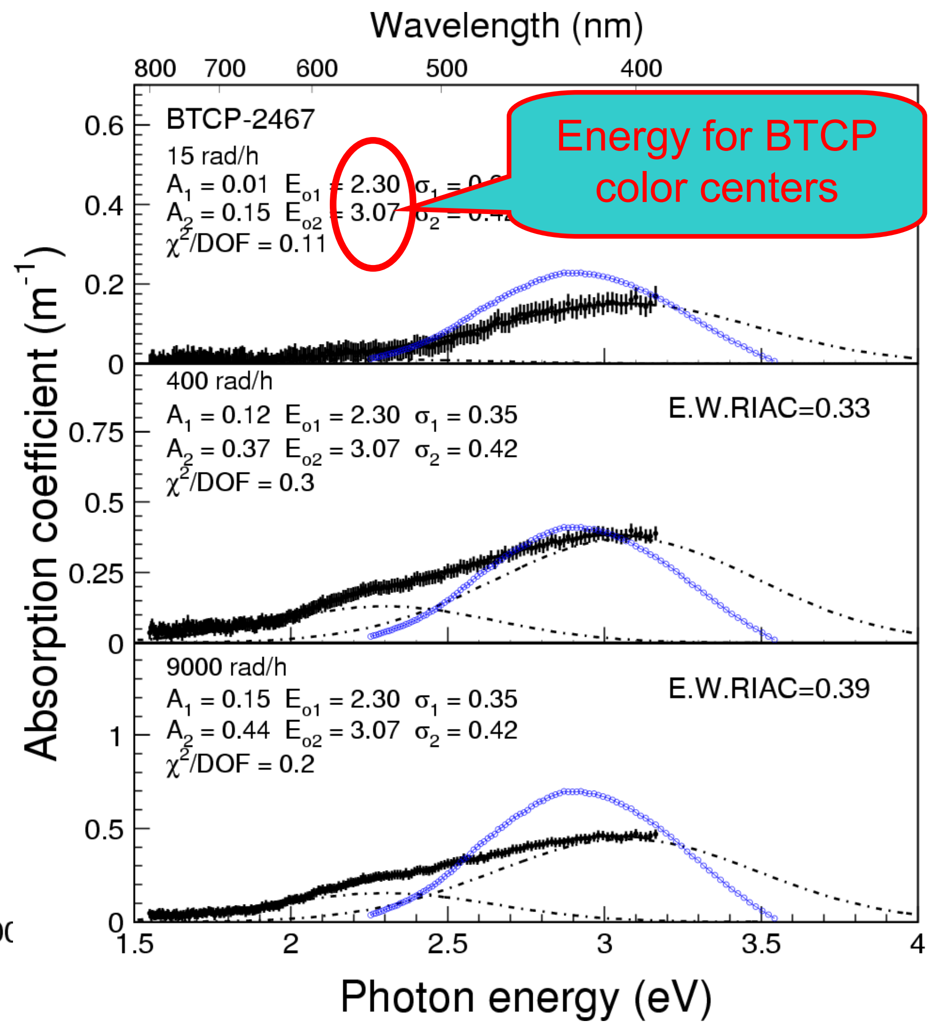




EWRIAC Measured after Irradiations

Both BTCP and SIC samples have two radiation induced color centers off emission peak, but SIC centers are deeper



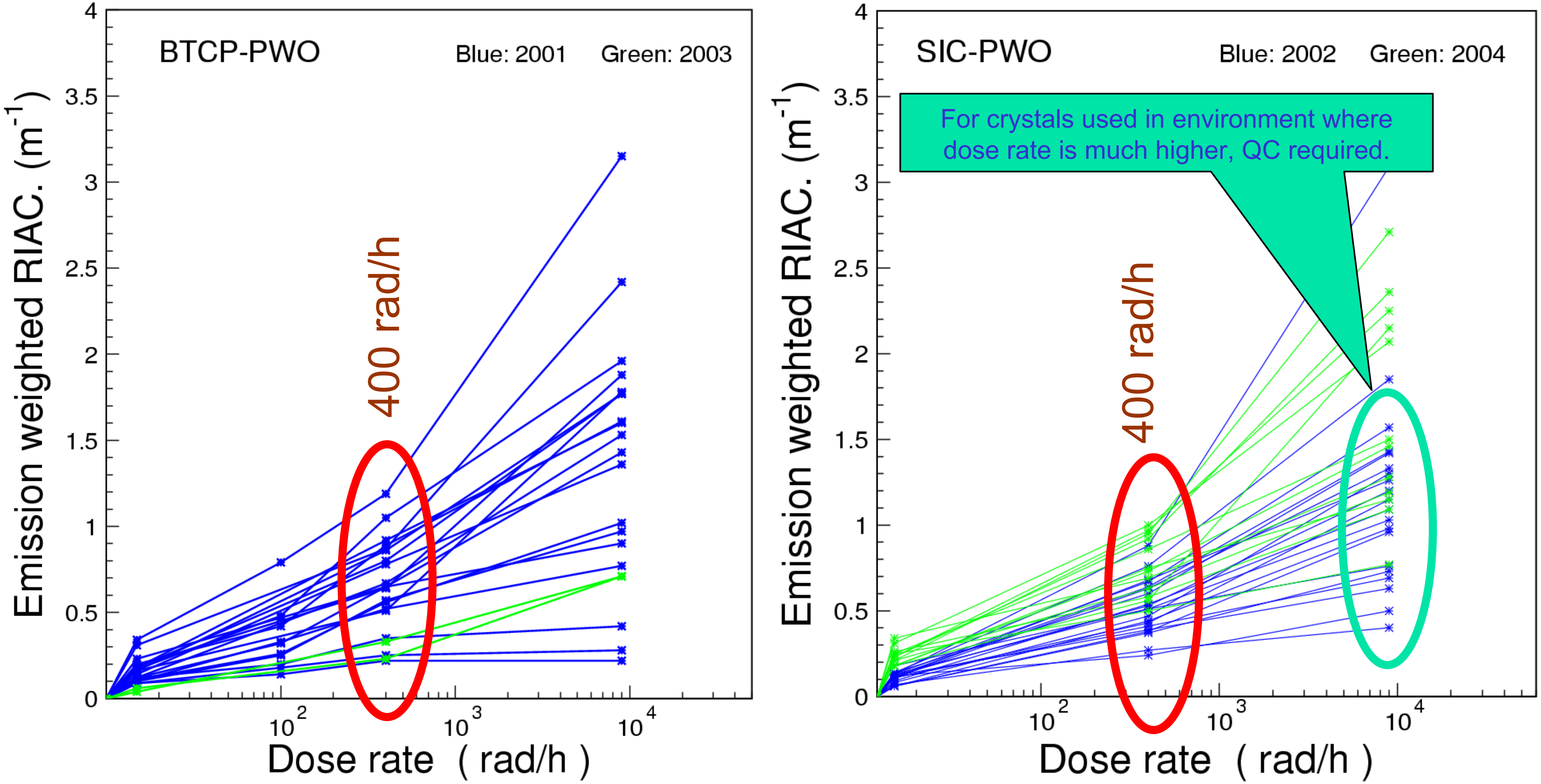


Emission Weighted RIAC

All samples: EWRIAC < 1 m^{-1} up to 400 rad/h

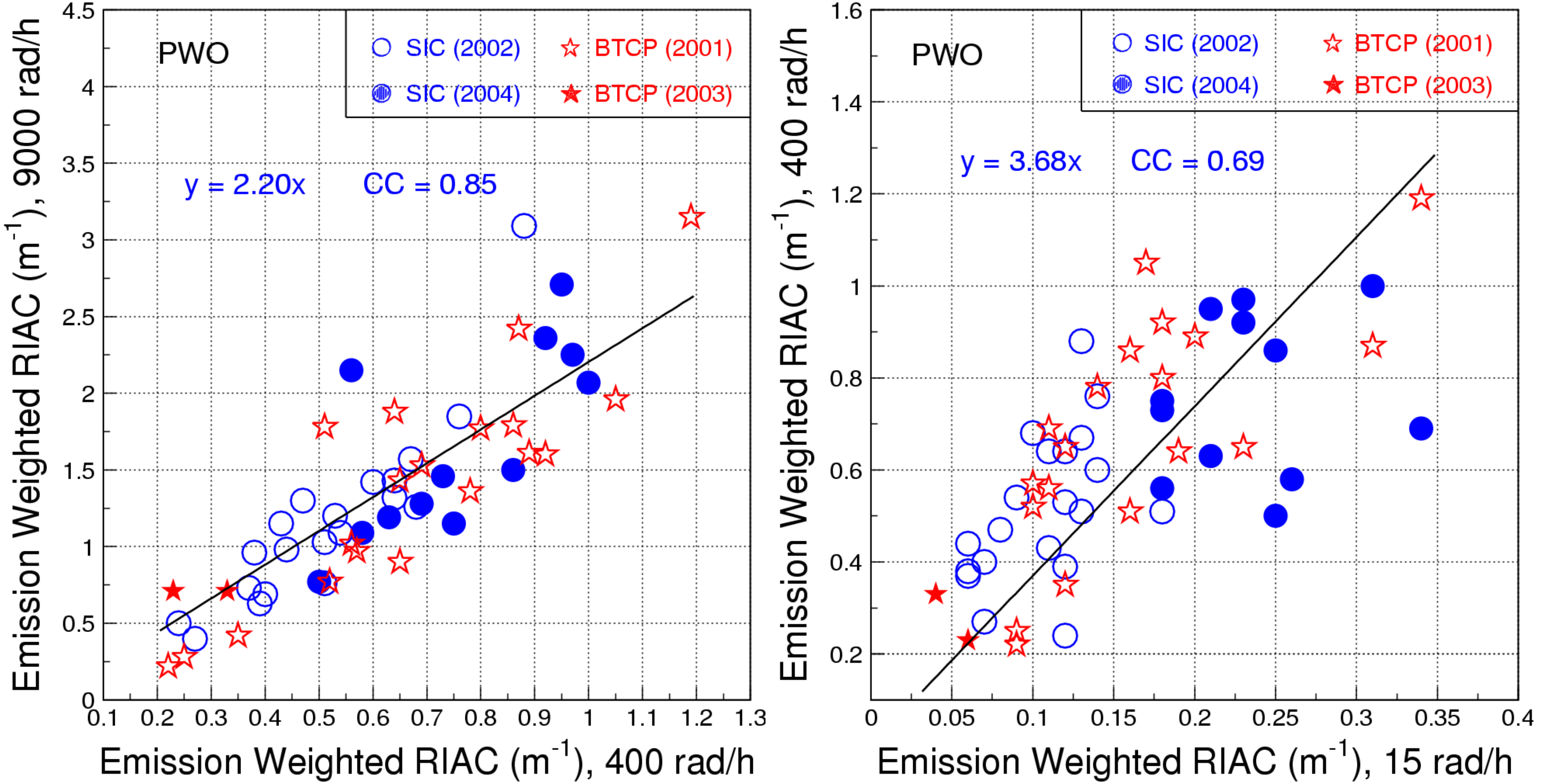
CMS expects: 15 rad/h @ barrel and 400 rad/h @ endcaps

Rigorous QC required to qualify endcap crystals for SLHC



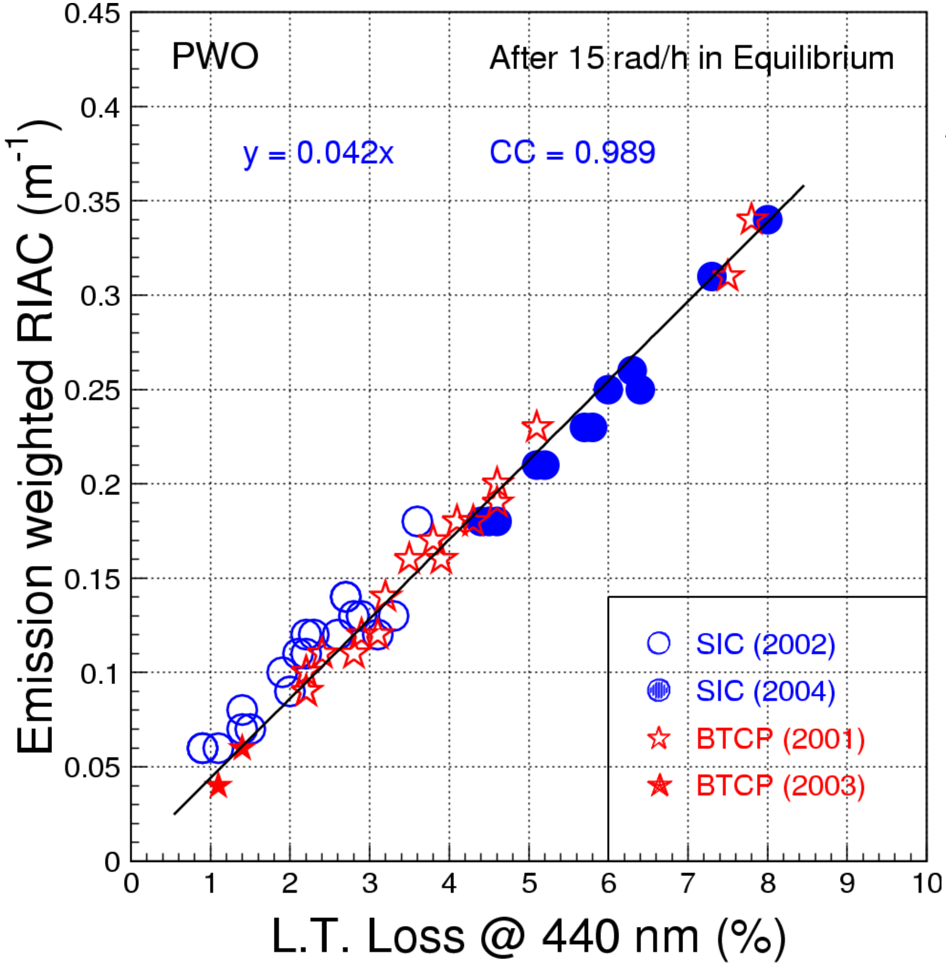
EWRIAC at Different Dose Rates

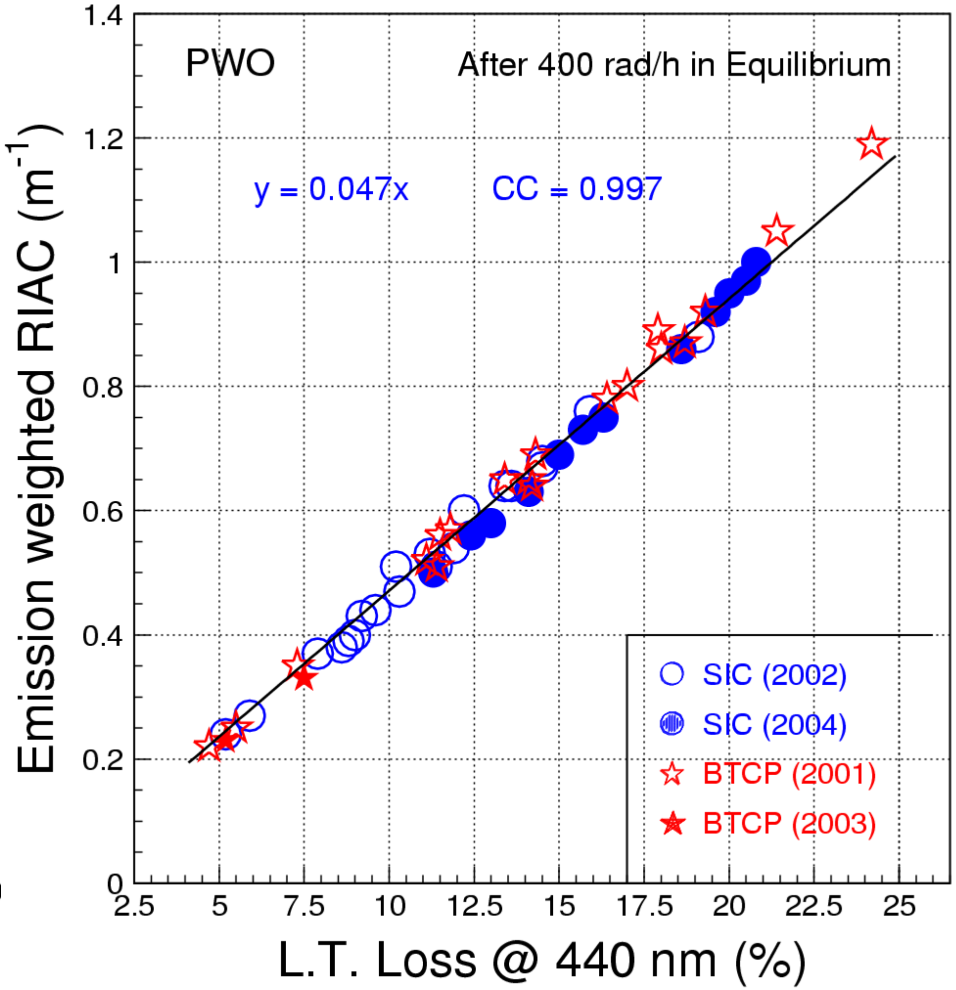
Correlations is weaker at lower dose rates because of different initial status (preexisting absorption)



EWRIAC versus δ LT/LT

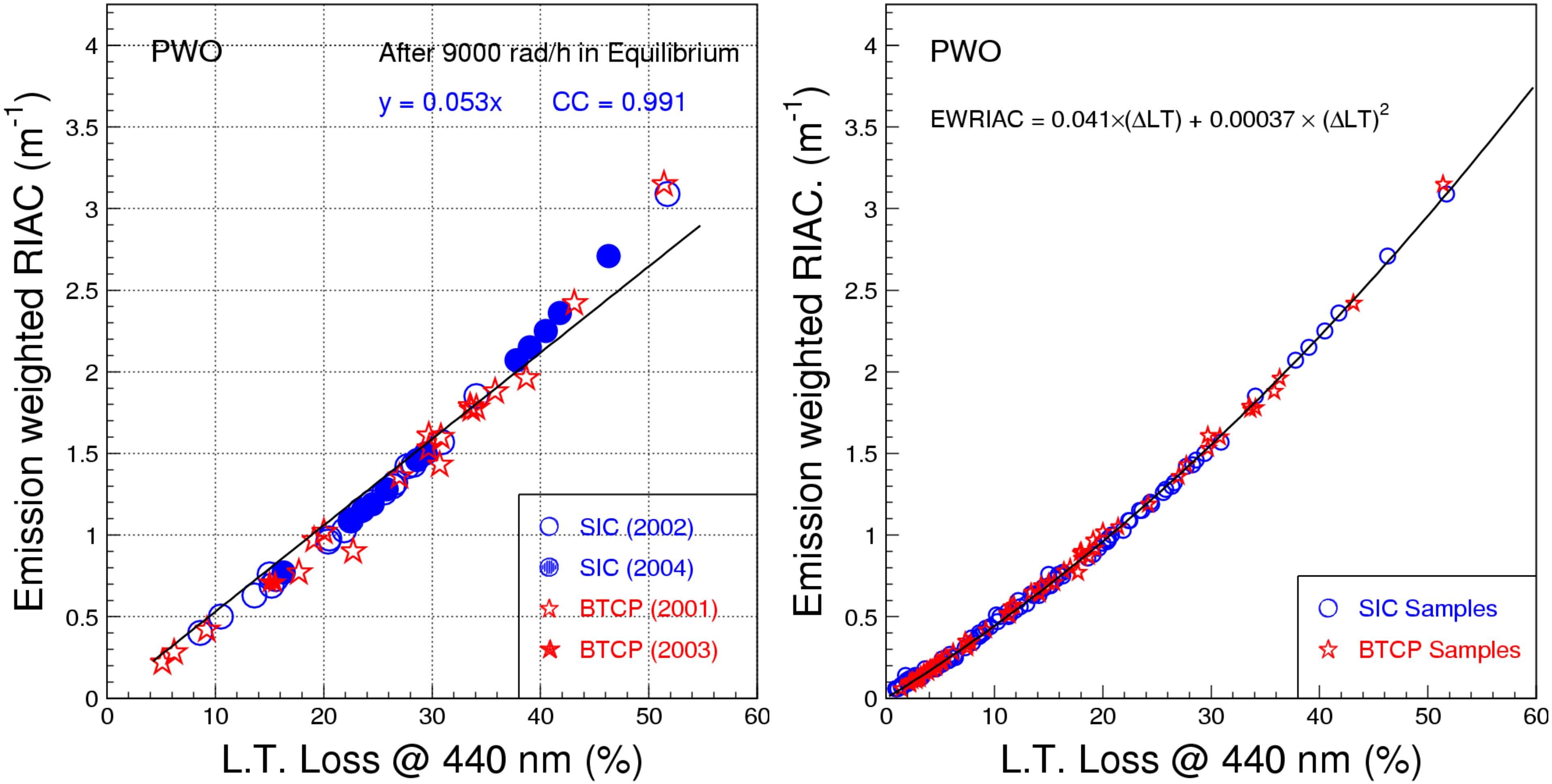
Linear correlation exists between EWRIAC and LT loss @ 440 nm at low dose rate





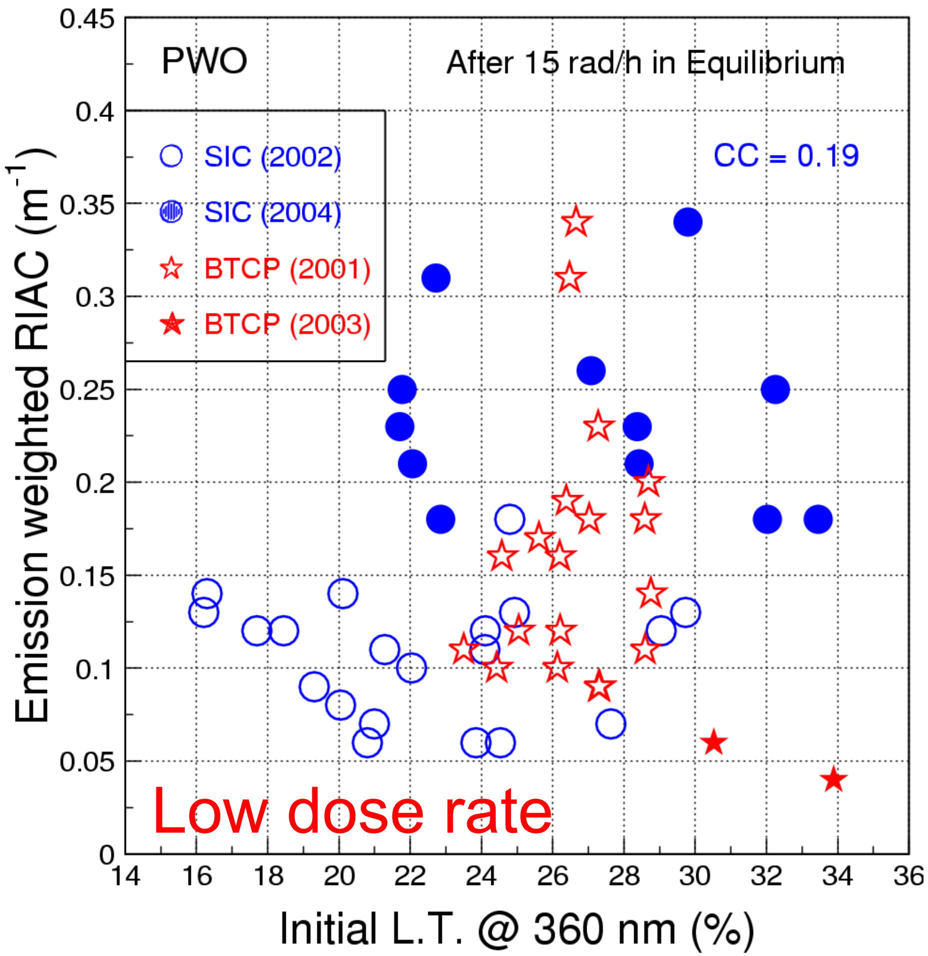
EWRIAC versus δ LT/LT

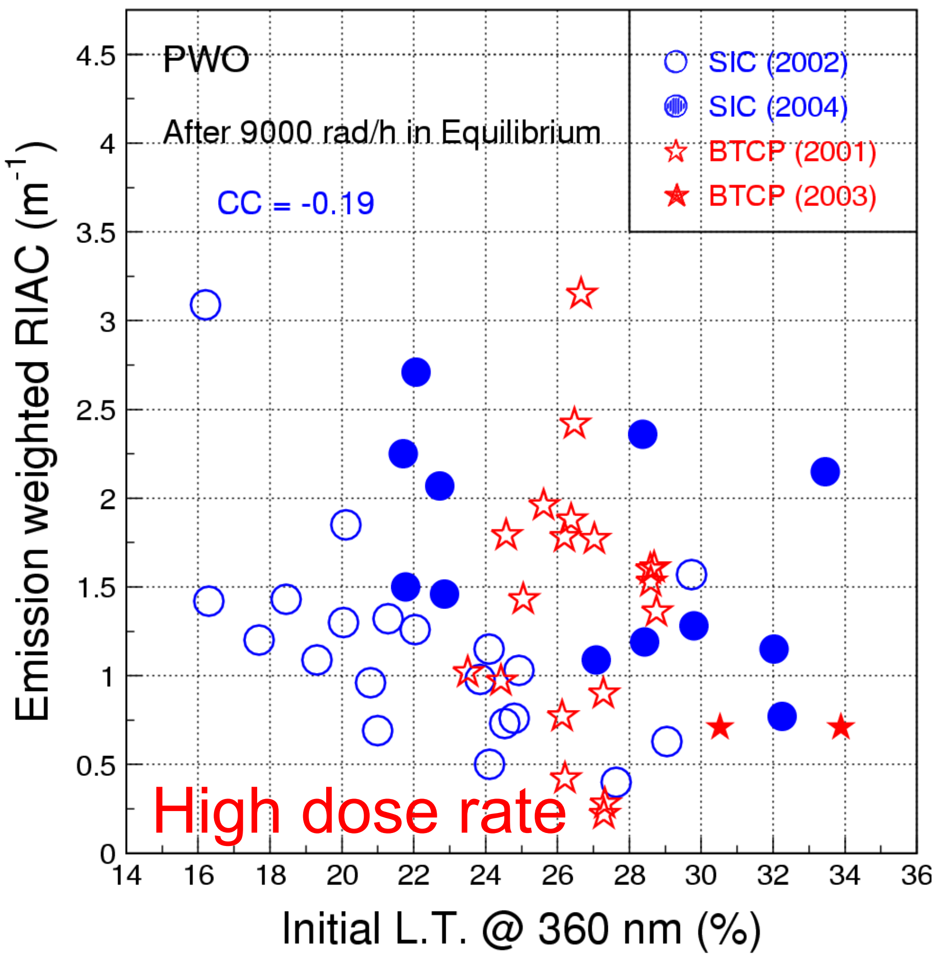
At high dose rate it is no longer linear. All BTCP/SIC data, however, are consistent with a 2nd order polynomial



EWRIAC versus Initial LT

No correlation between EWRIAC & Initial L.T.

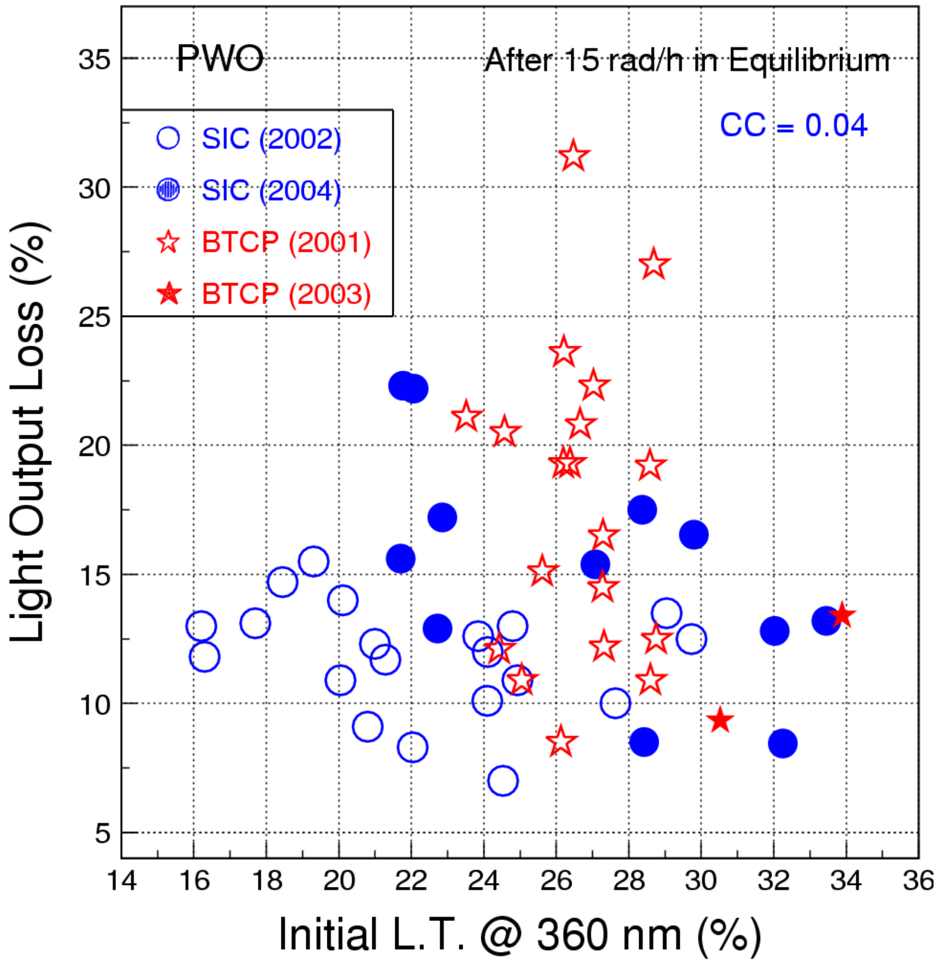


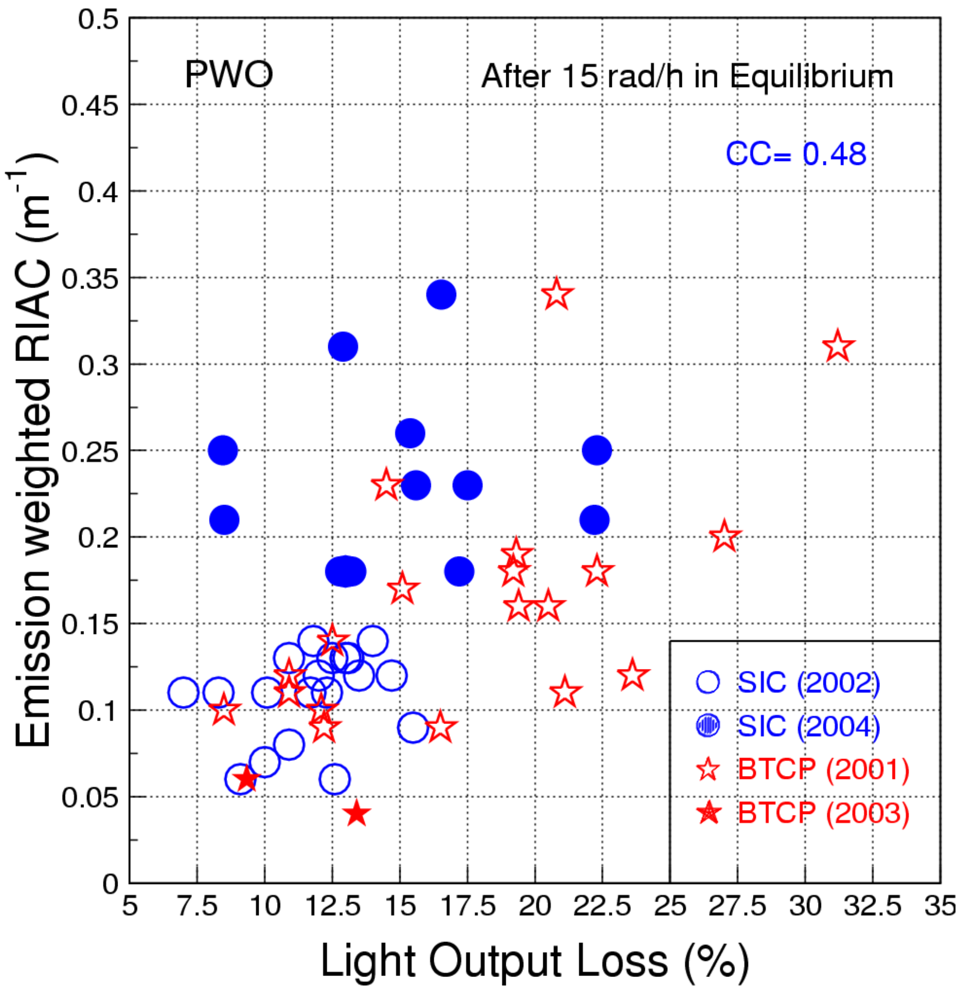


δLO/LO versus Initial LT and EWRIAC

No correlation between δLO/LO and Initial LT

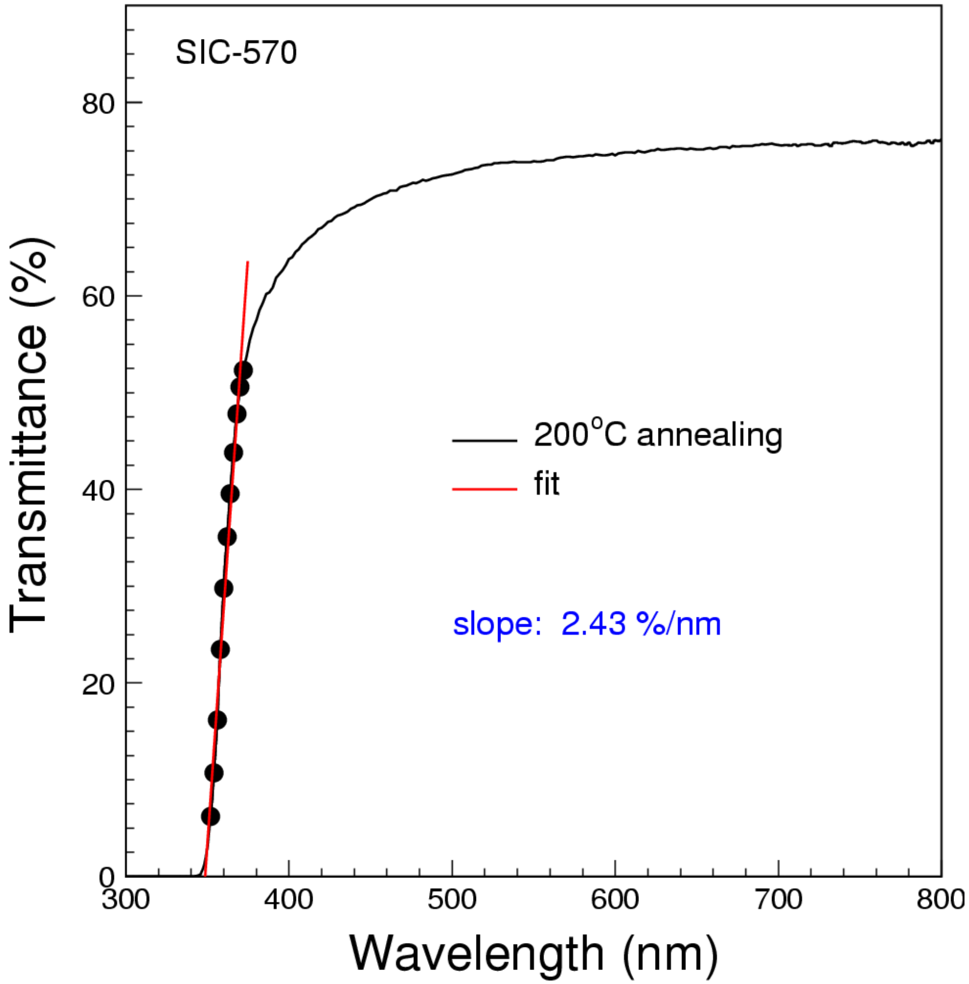
Weak (0.48) correlation between δLO/LO and EWRIAC





Fit Slope for the Initial LT Data

Fit region for BTCP samples: 350 -- 370 nm ("a" axis)
for SIC samples: 352 -- 372 nm ("c" axis)

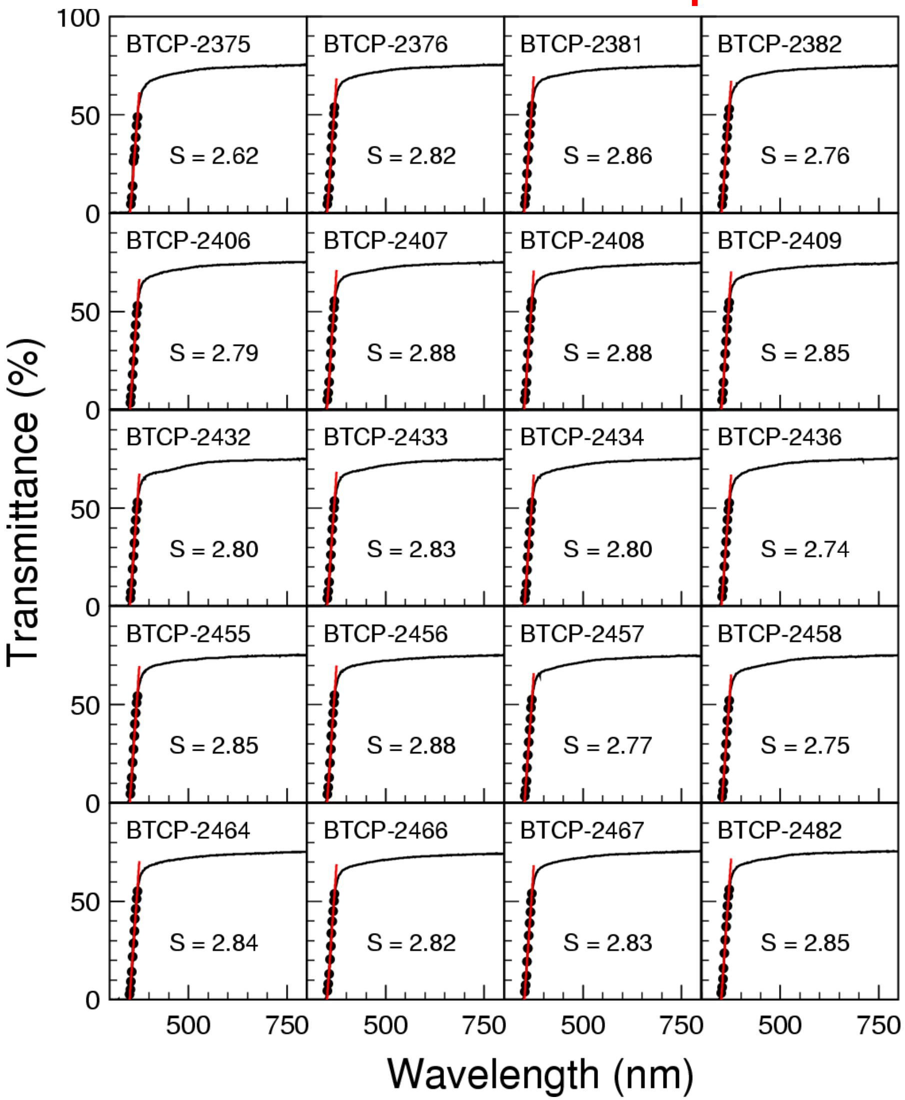


Slope of absorption edge for PWO crystals:

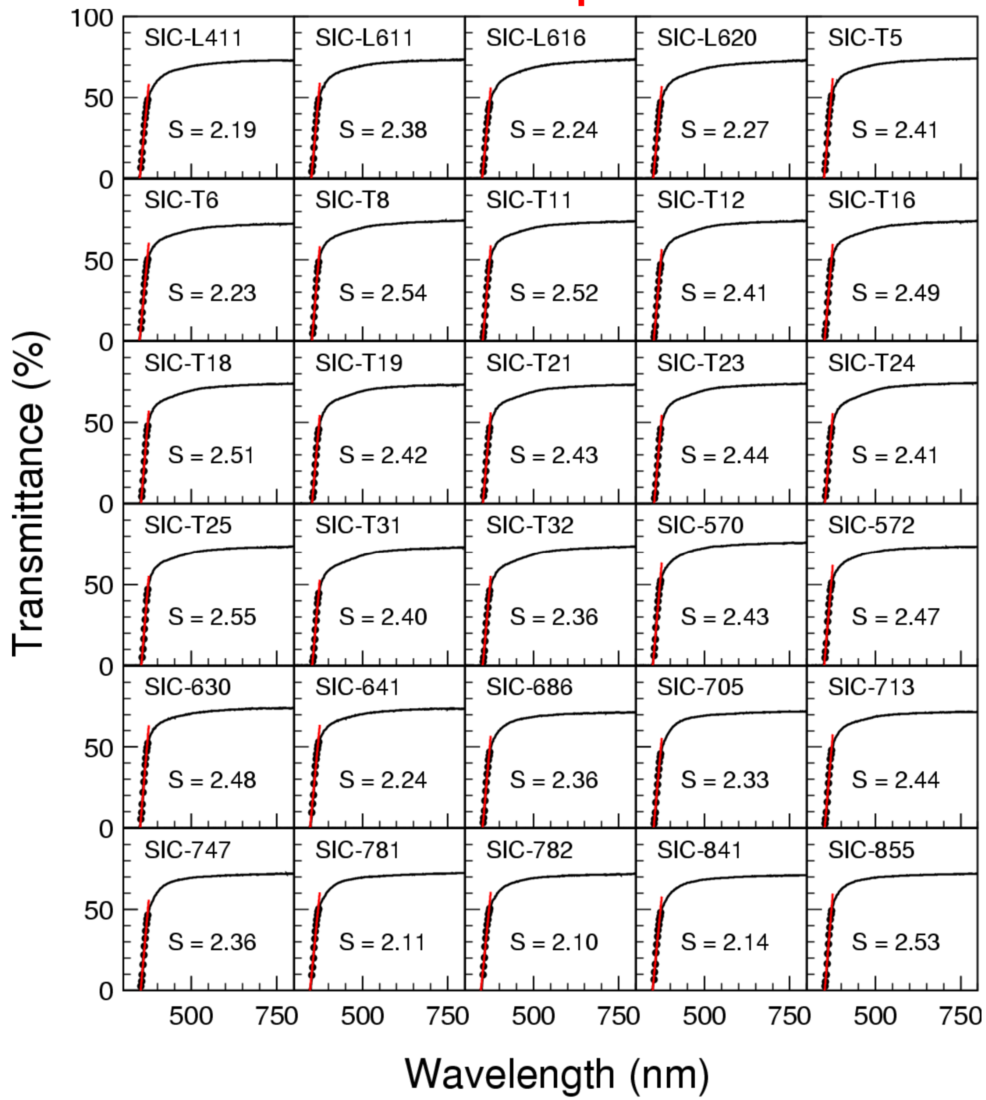
$$Slope = \frac{T_b - T_a}{\lambda_b - \lambda_a}$$

Slope Fits for BTCP and SIC Samples

20 BTCP Samples

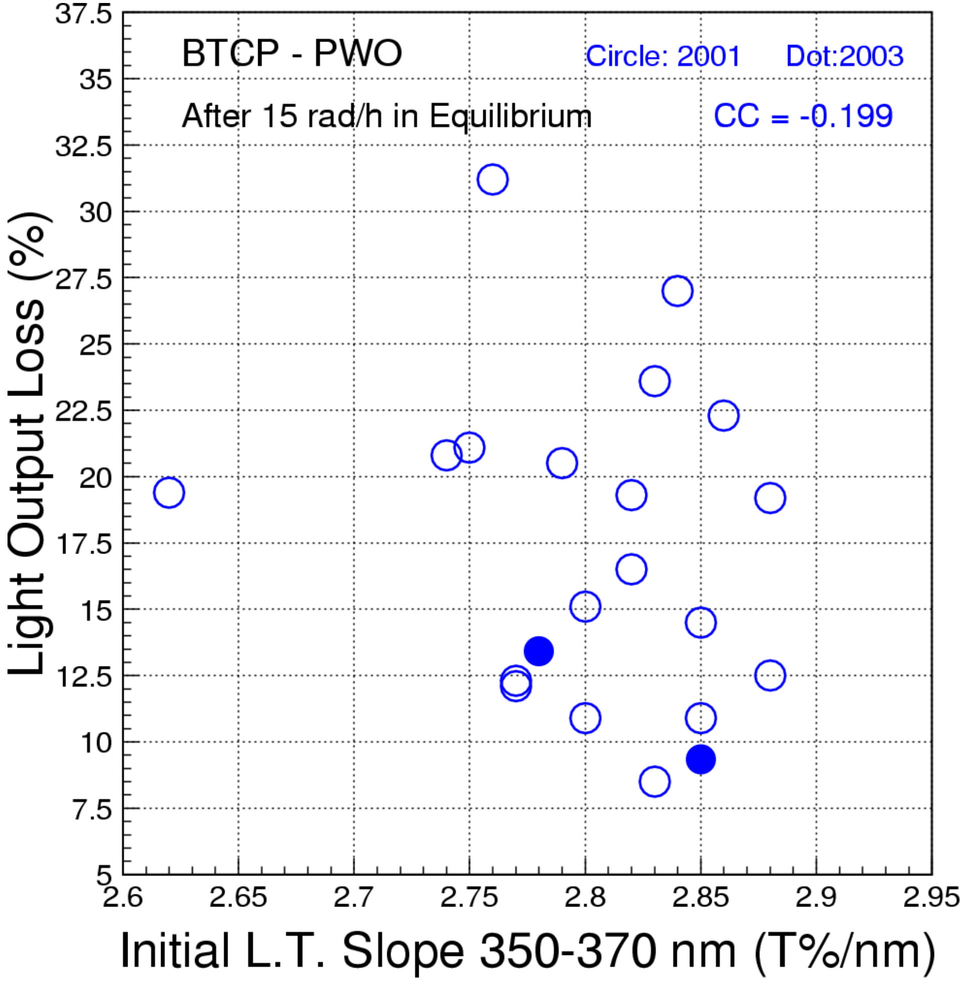


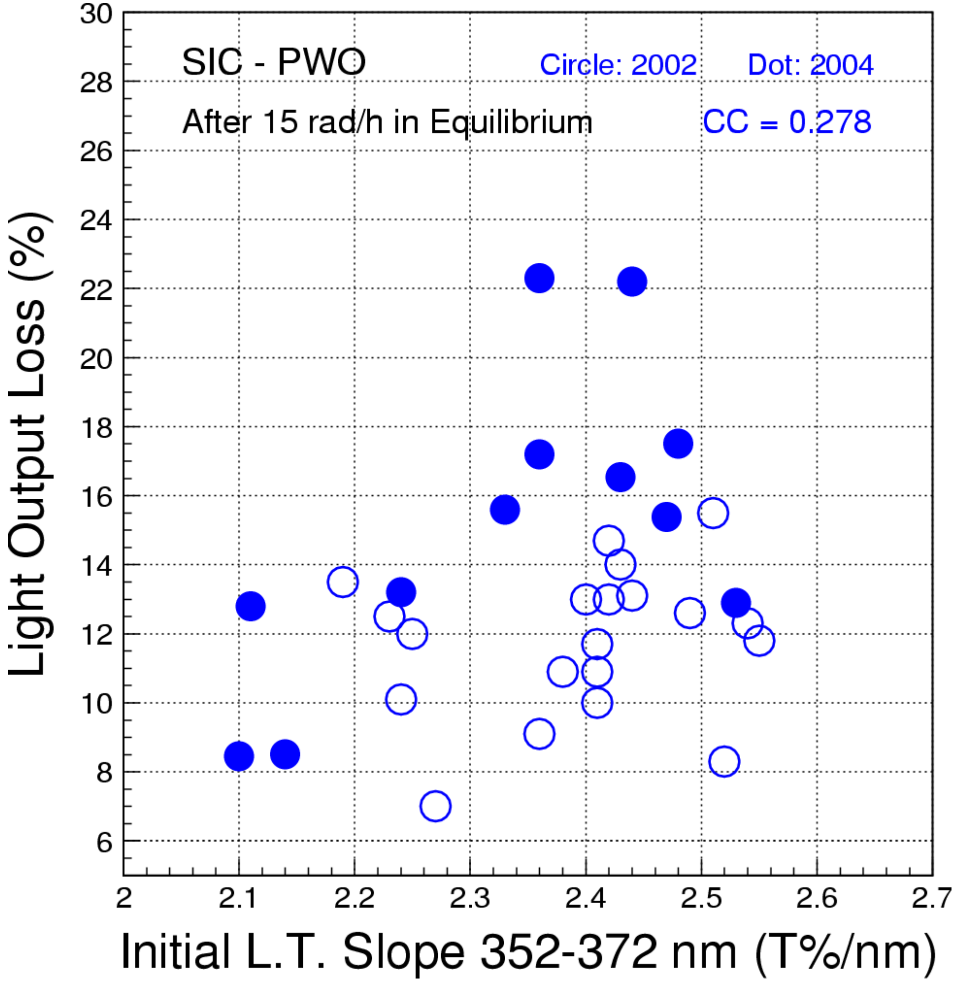
30 SIC Samples



δLO/LO @ 15 rad/h versus Slope

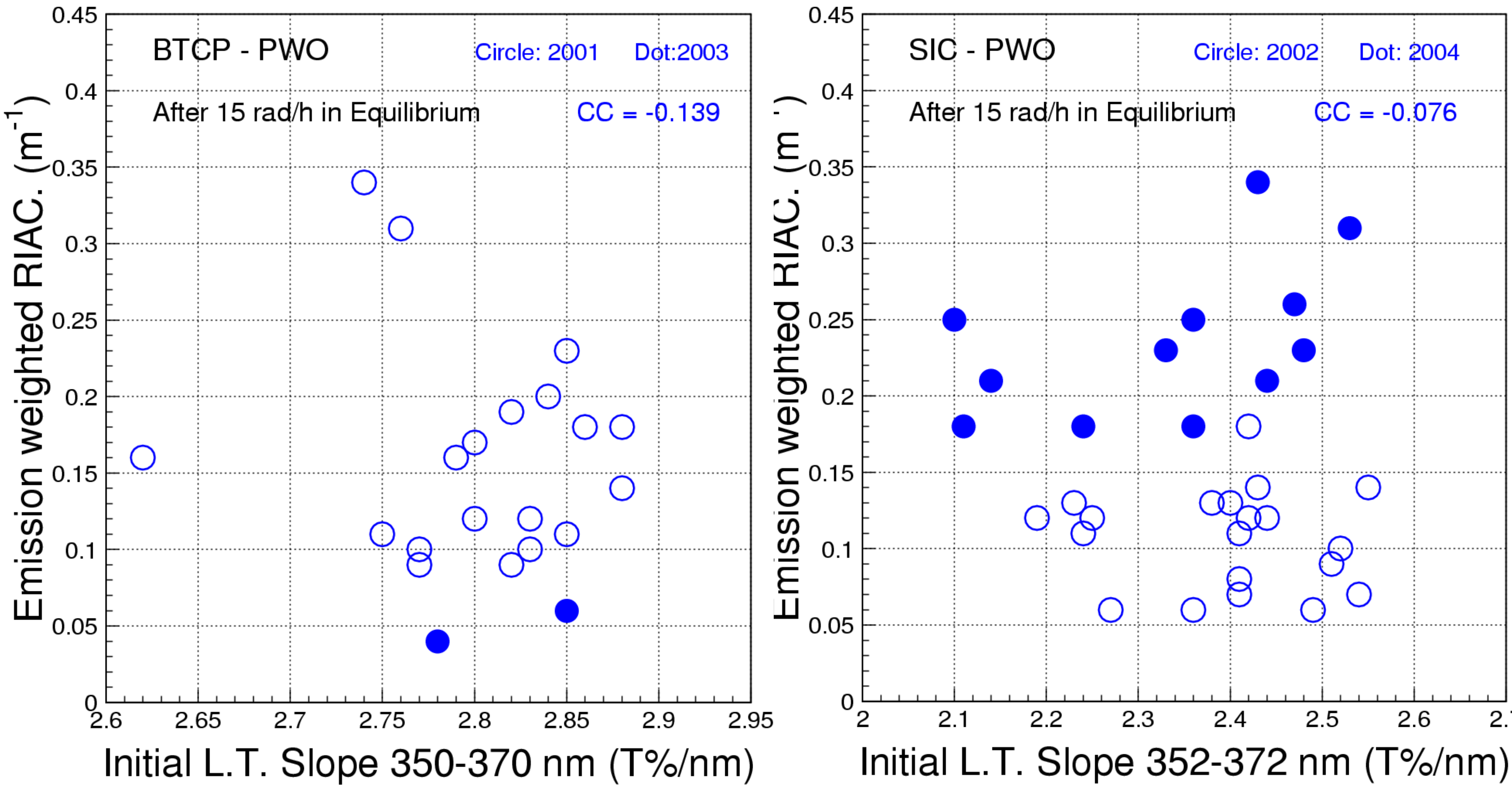
No correlation: Slope of initial LT is not correlated to the light output loss





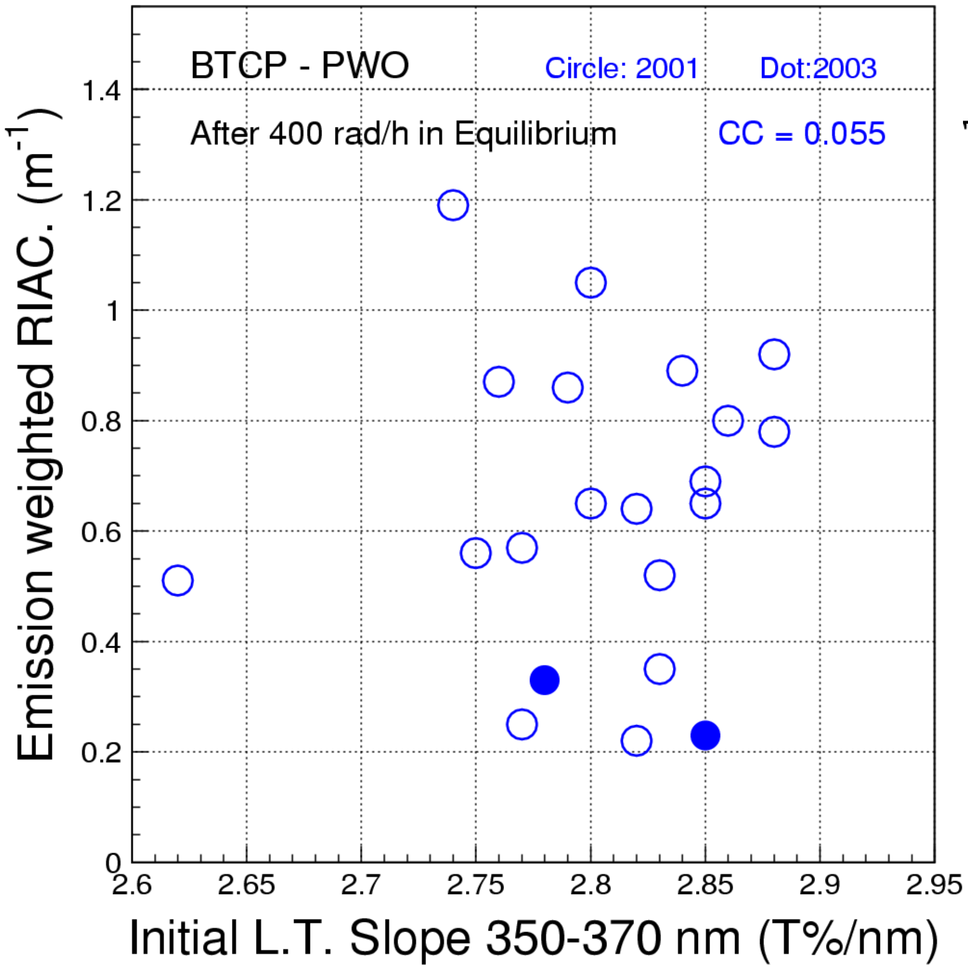
EWRIAC @ 15 rad/h versus Slope

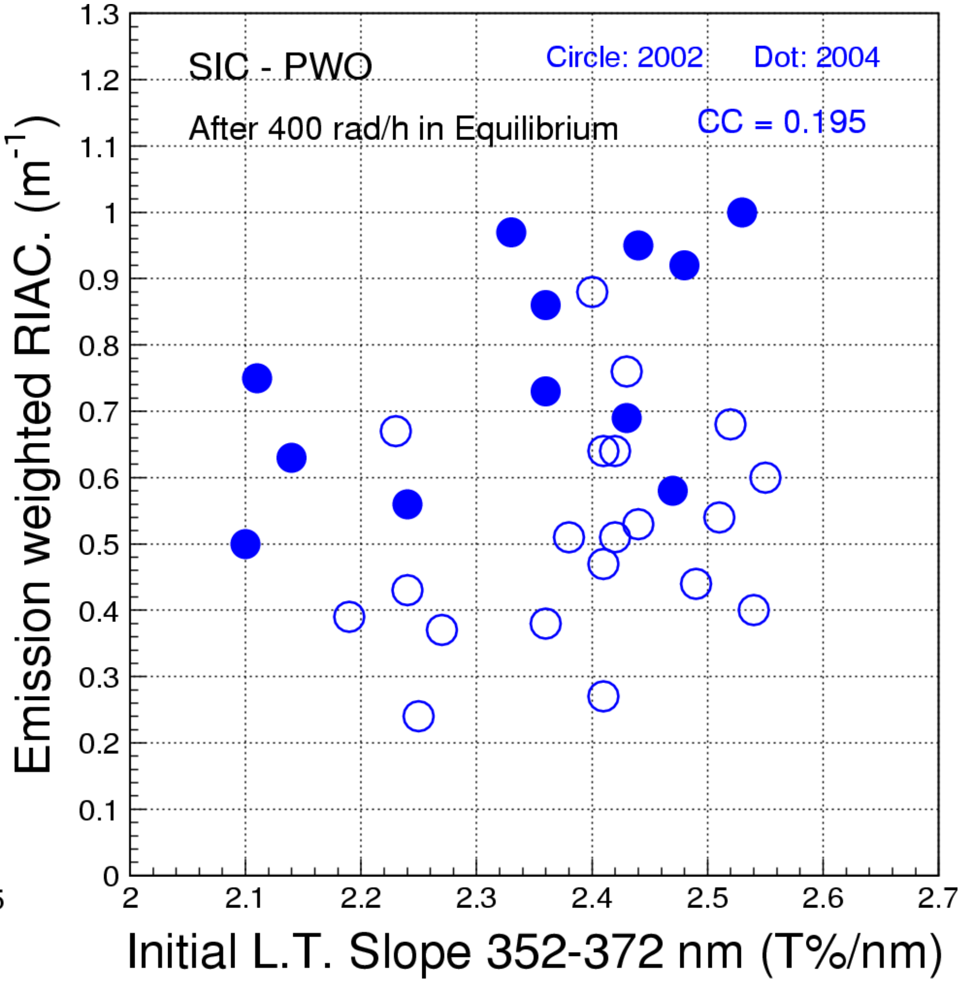
No correlation: Slope of initial LT is not correlated to the radiation induced absorption



EWRIAC @ 400 rad/h versus Slope

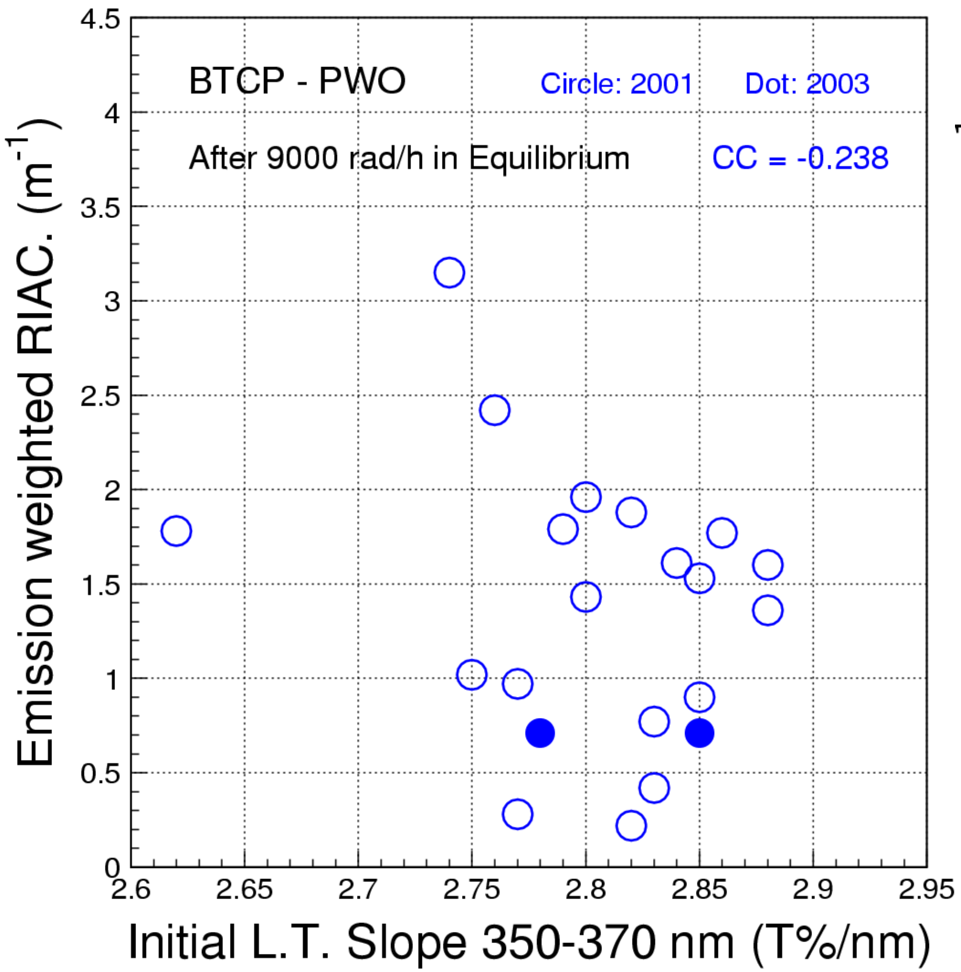
No correlation: Slope of initial LT is not correlated to the radiation induced absorption

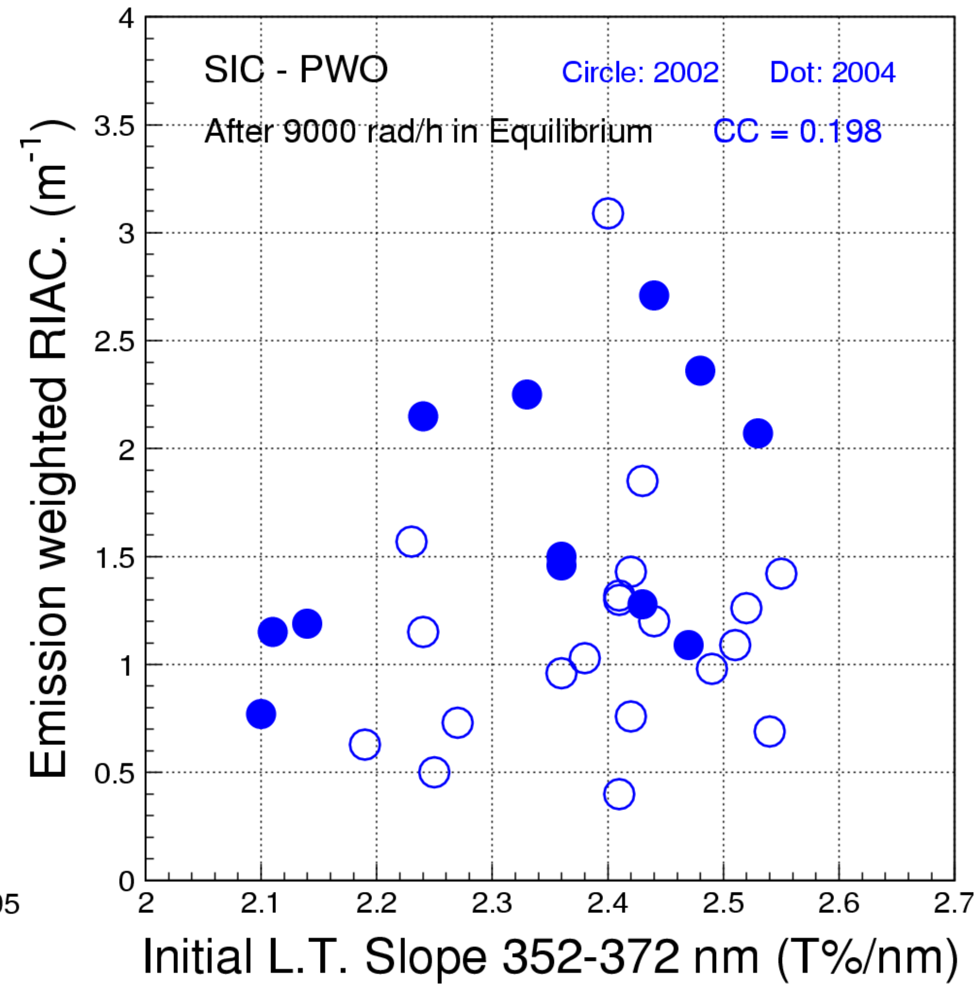




EWRIAC @ 9 krad/h versus Slope

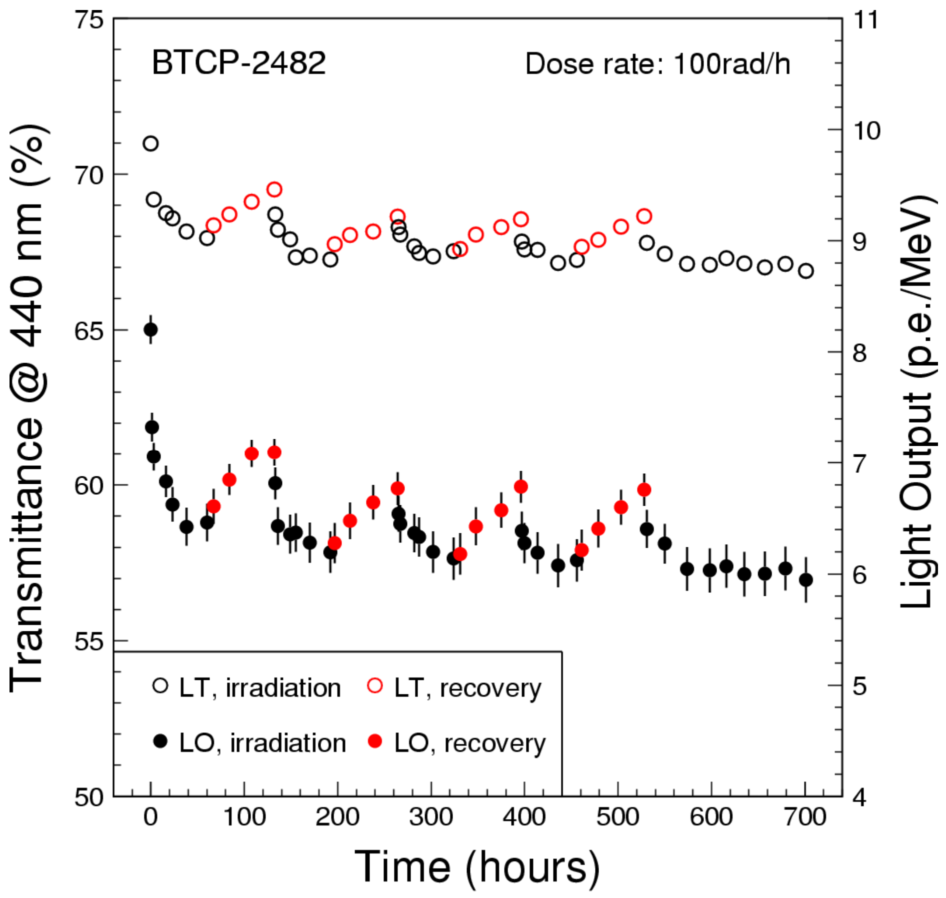
No correlation: Slope of initial LT is not correlated to the radiation induced absorption

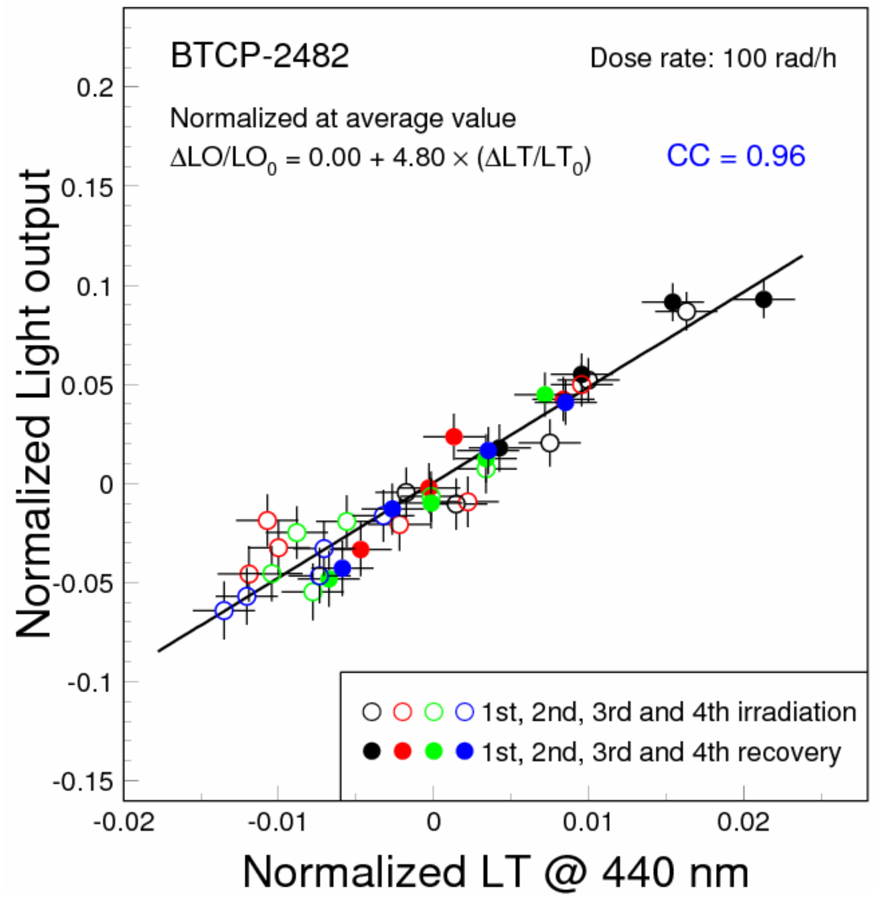




δLO/LO versus δLT/LT @ 100 rad/h

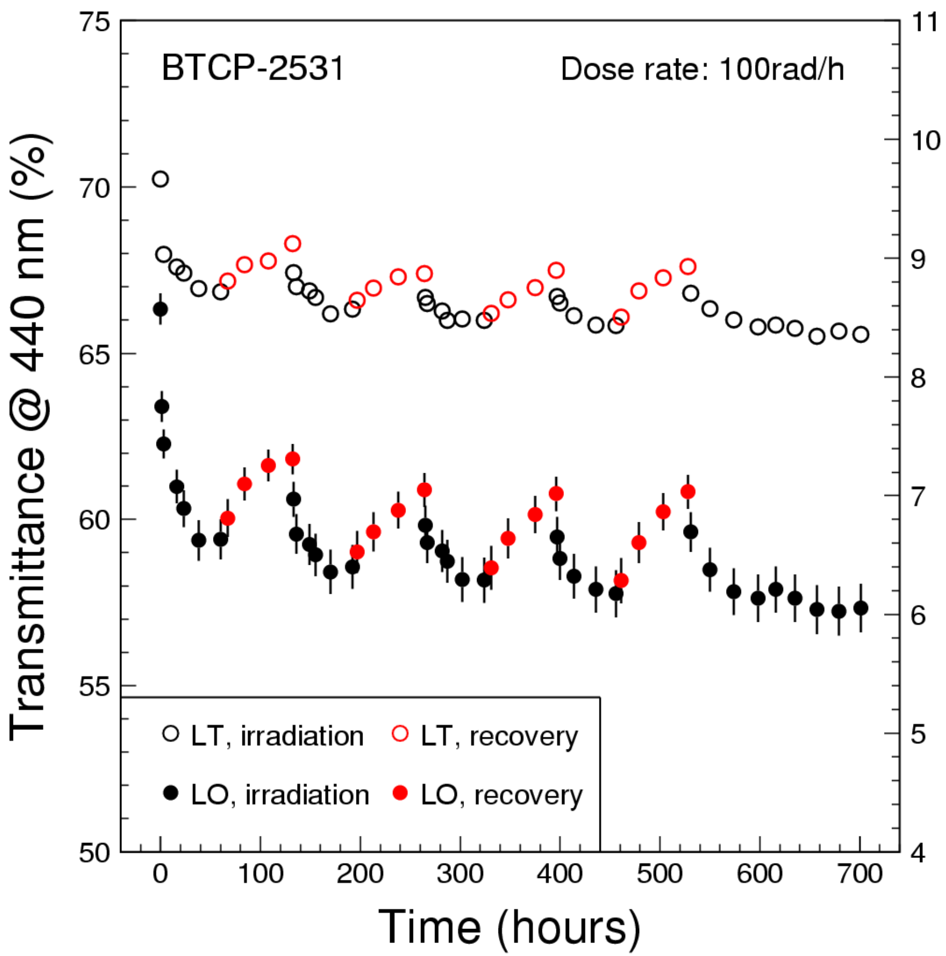
Strong correlation: Slope = 4.80

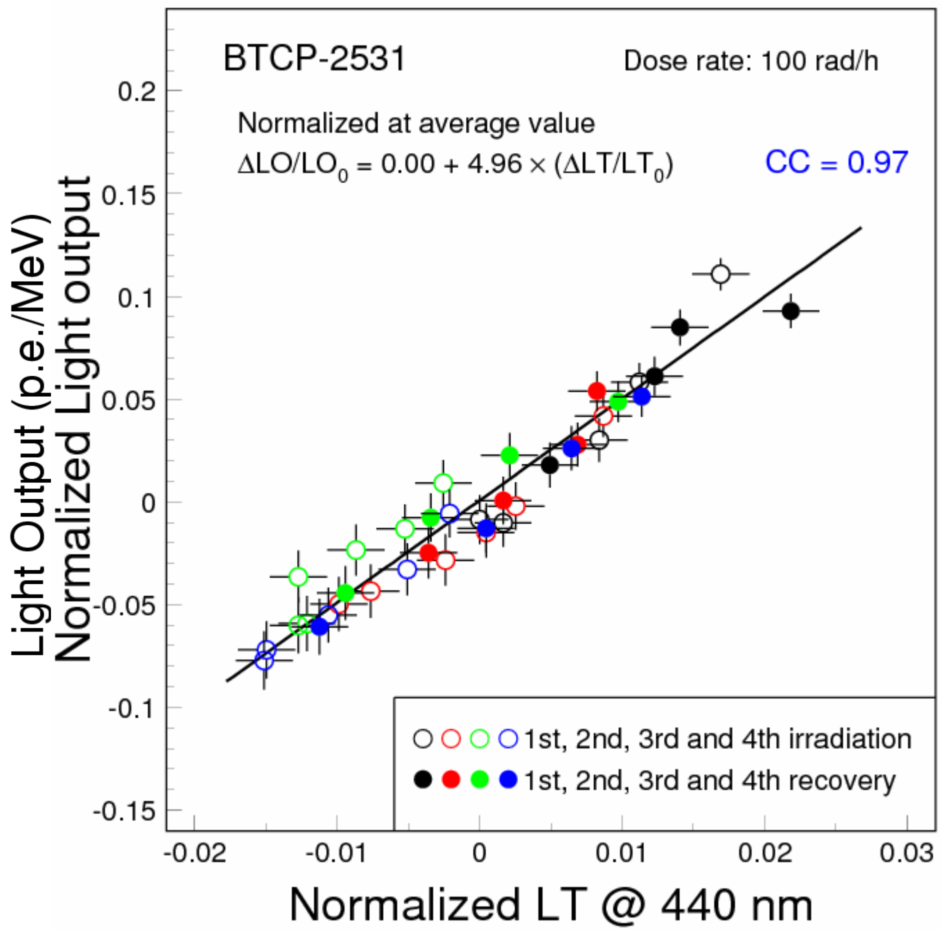




δLO/LO versus δLT/LT @ 100 rad/h

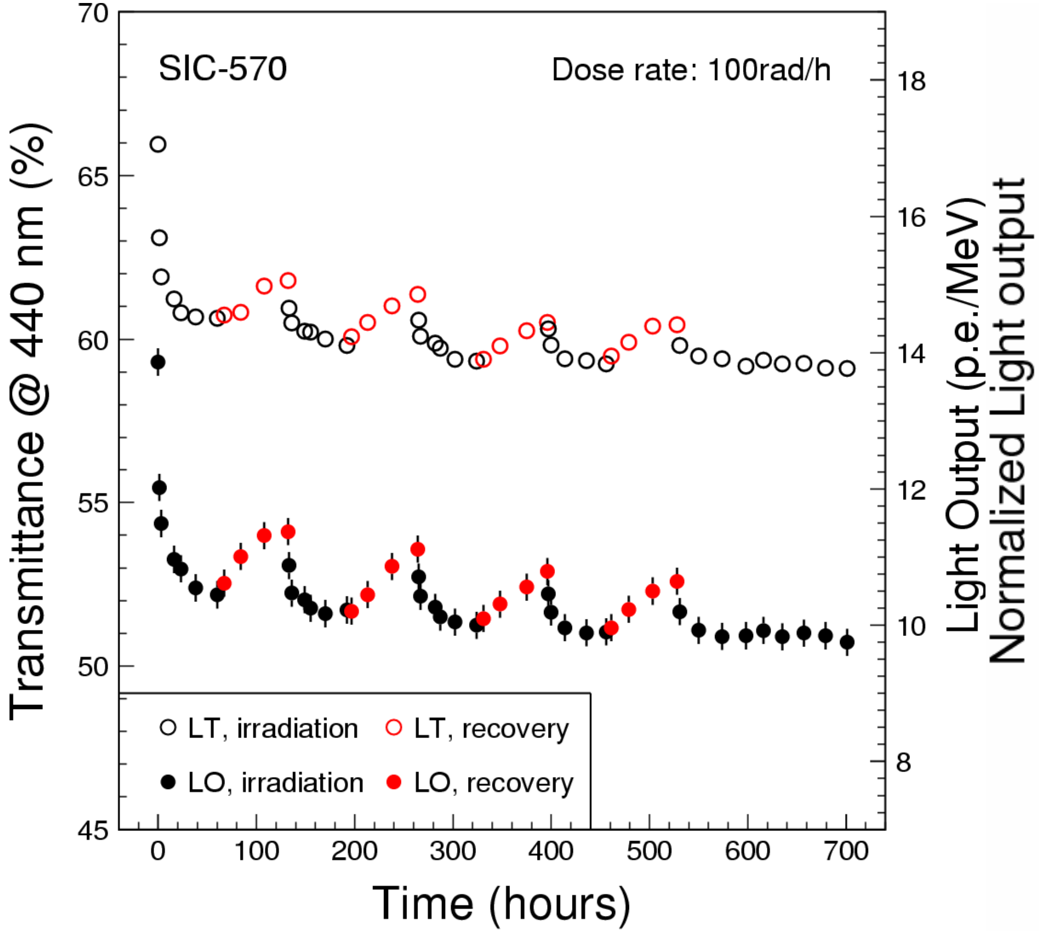
Strong correlation: Slope = 4.96

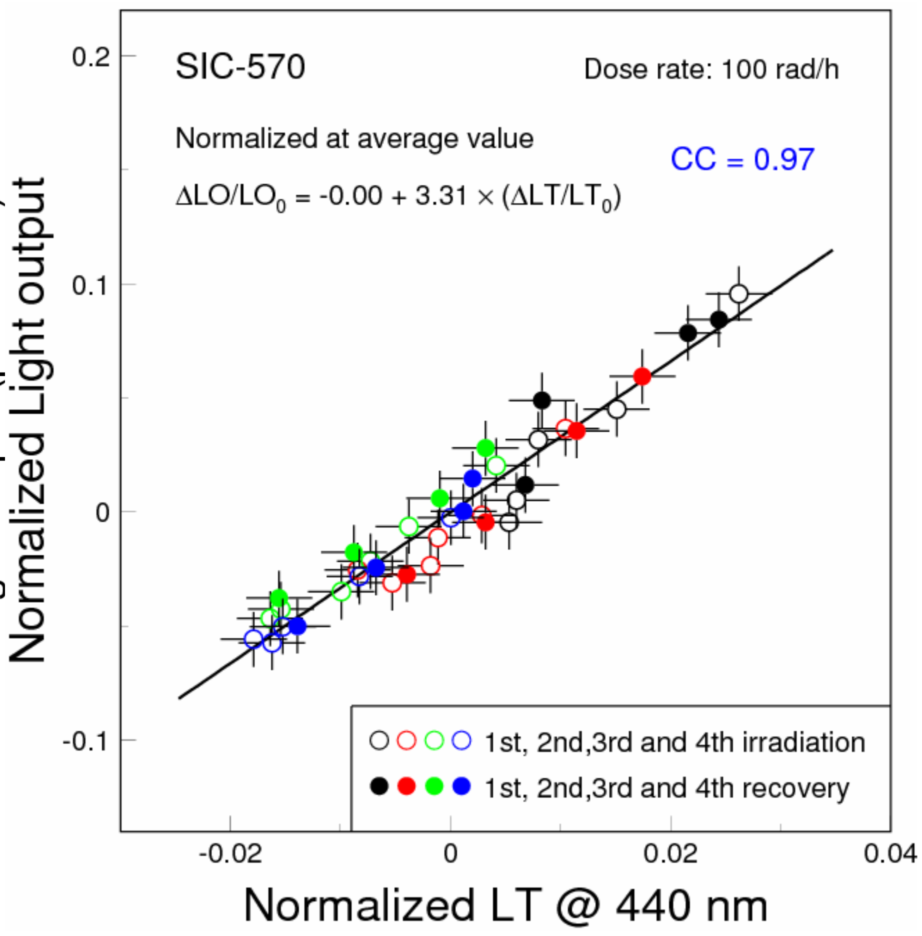




δLO/LO versus δLT/LT @ 100 rad/h

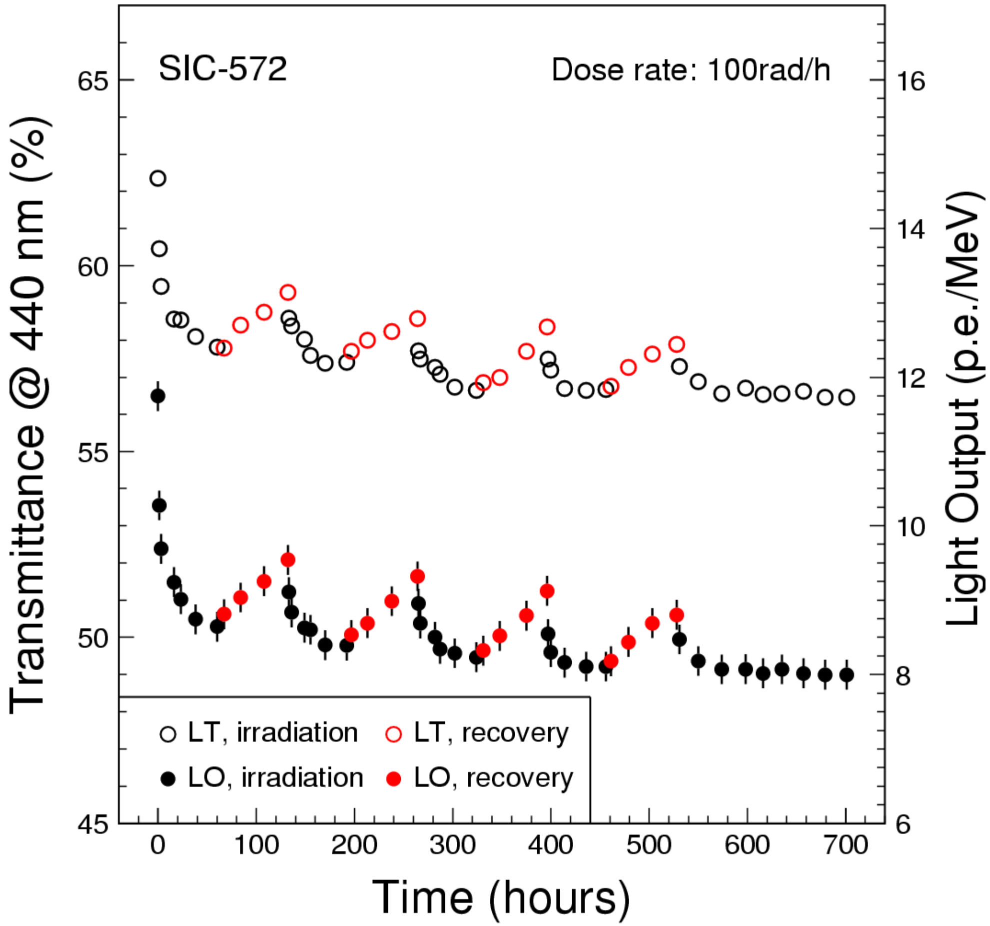
Strong correlation: Slope = 3.31

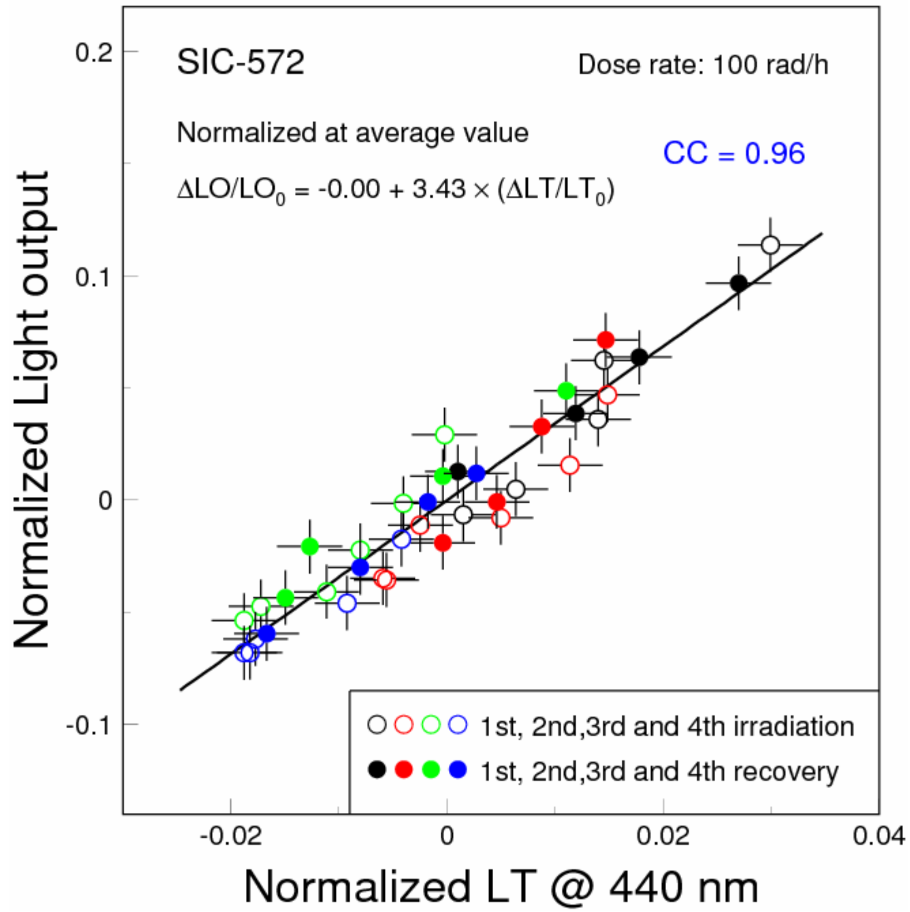




δLO/LO versus δLT/LT @ 100 rad/h

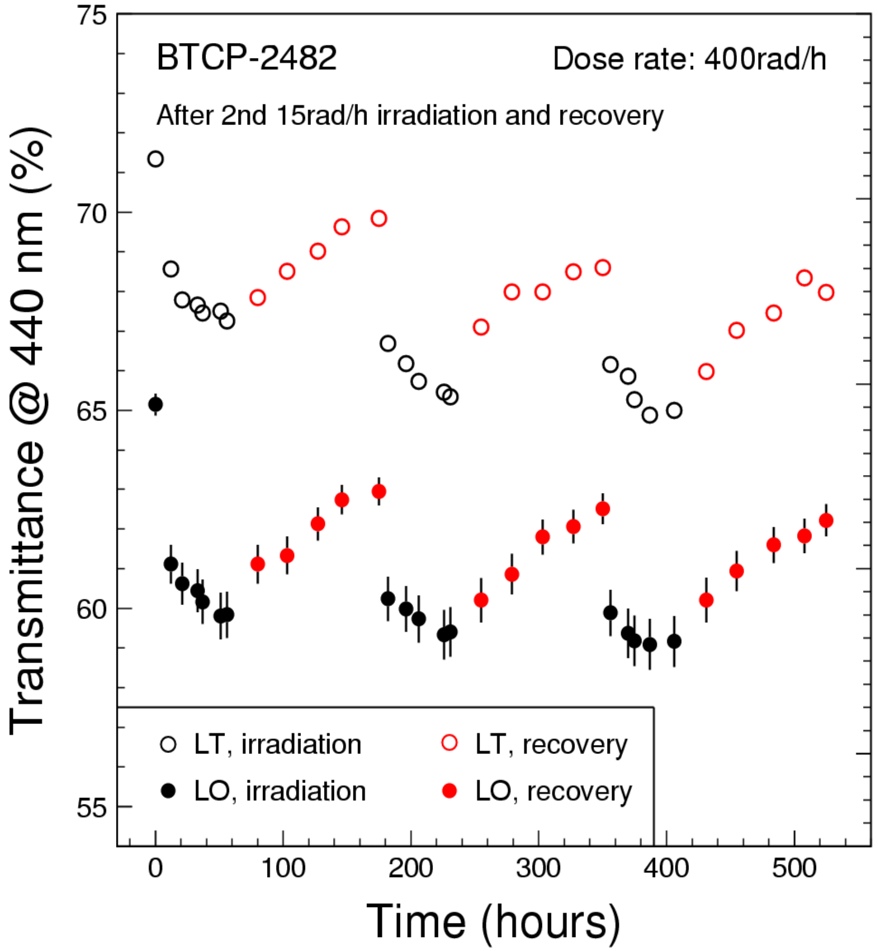
Strong correlation: Slope = 3.43

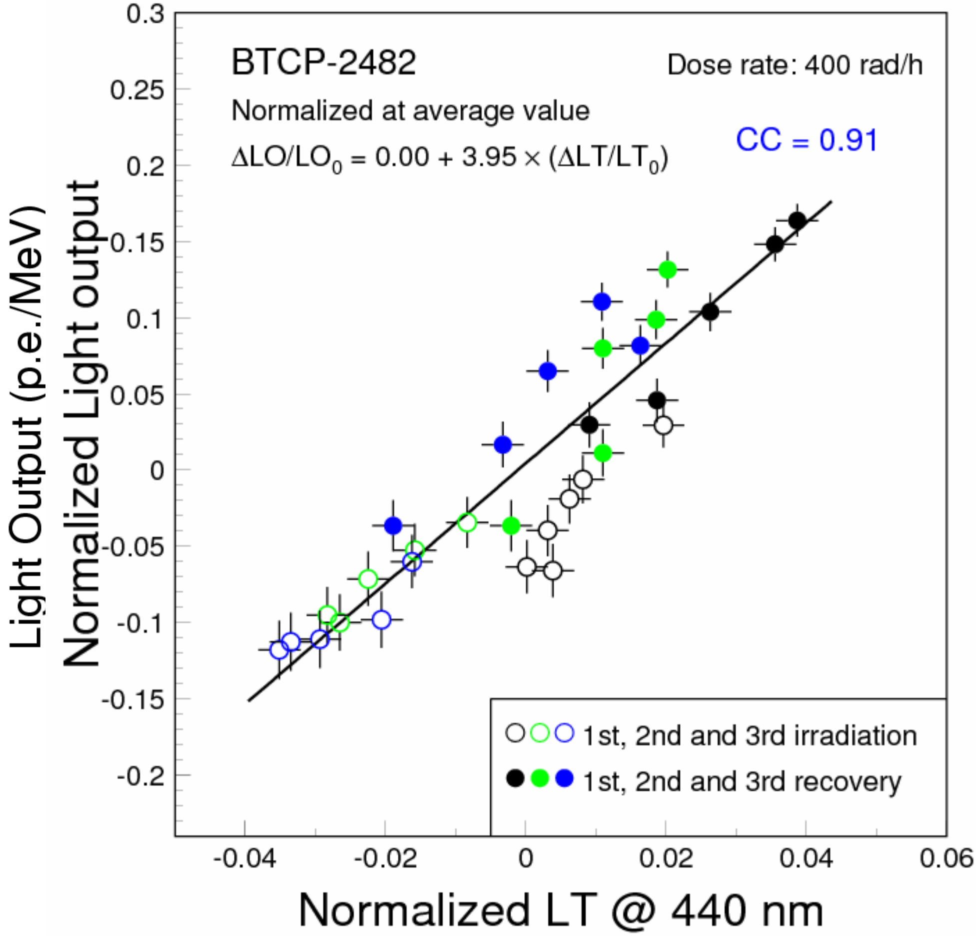




δLO/LO versus δLT/LT @ 400 rad/h

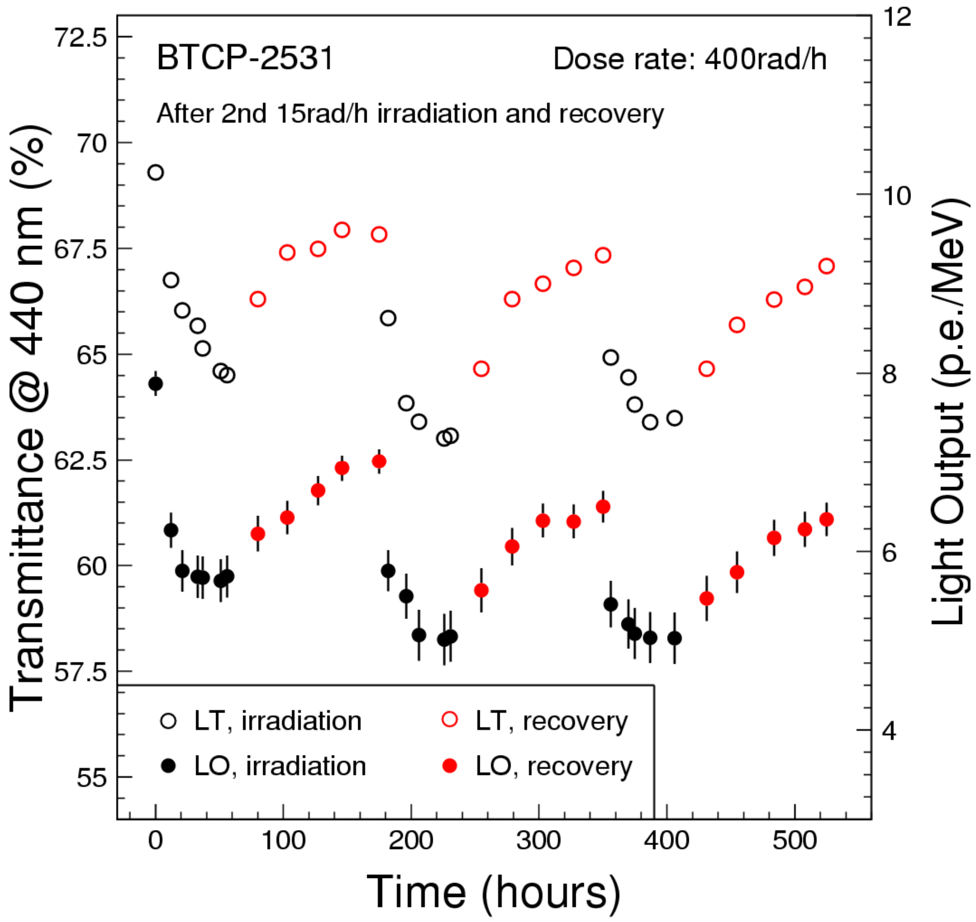
Strong correlation: Slope = 3.95

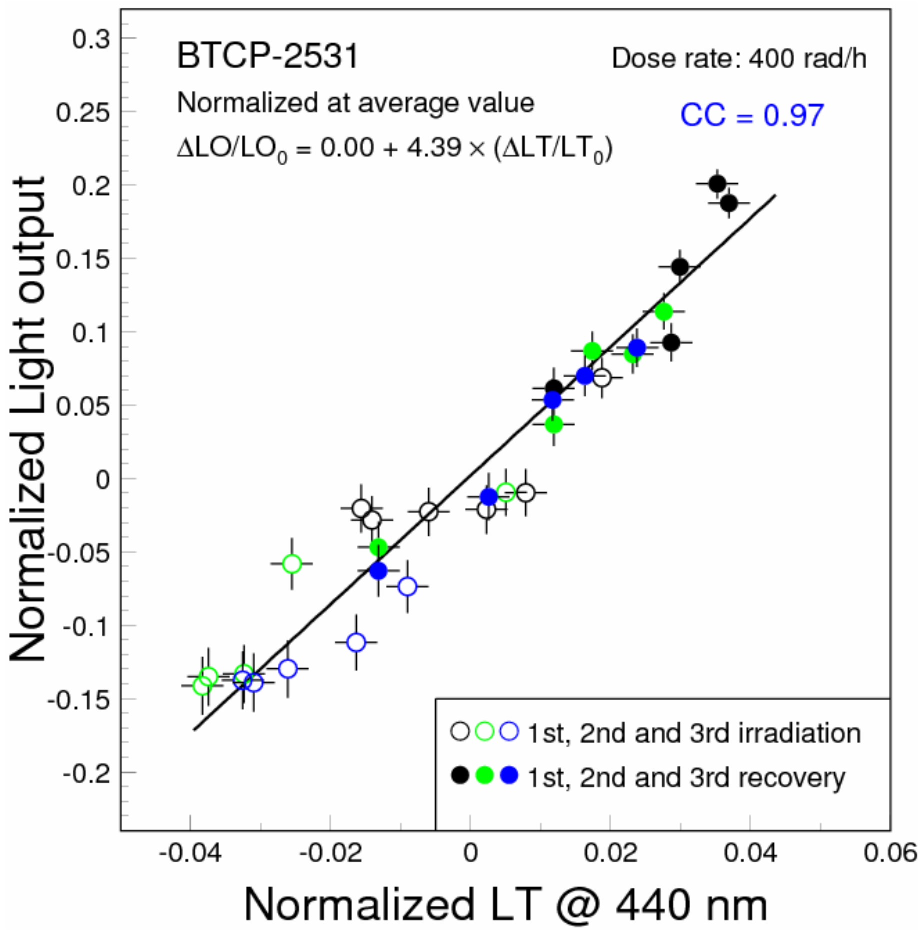




δLO/LO versus δLT/LT @ 400 rad/h

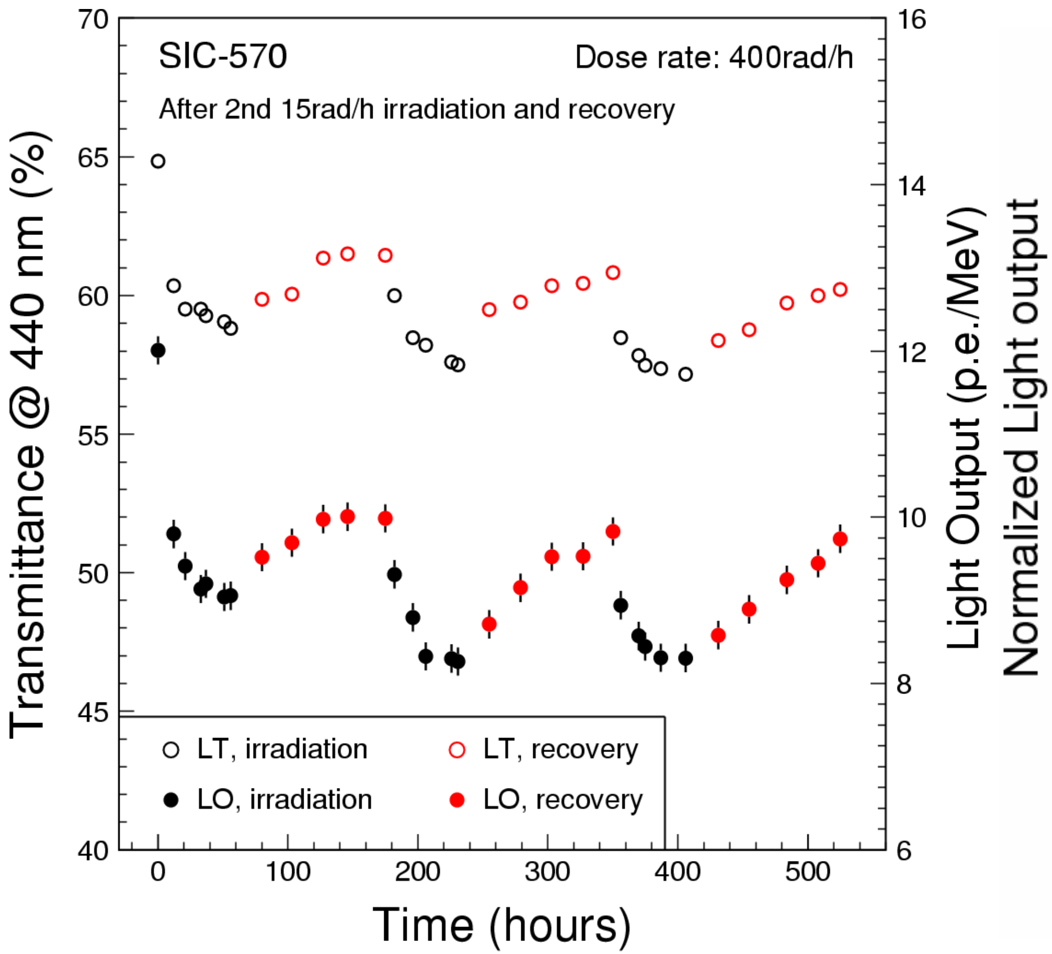
Strong correlation: Slope = 4.39

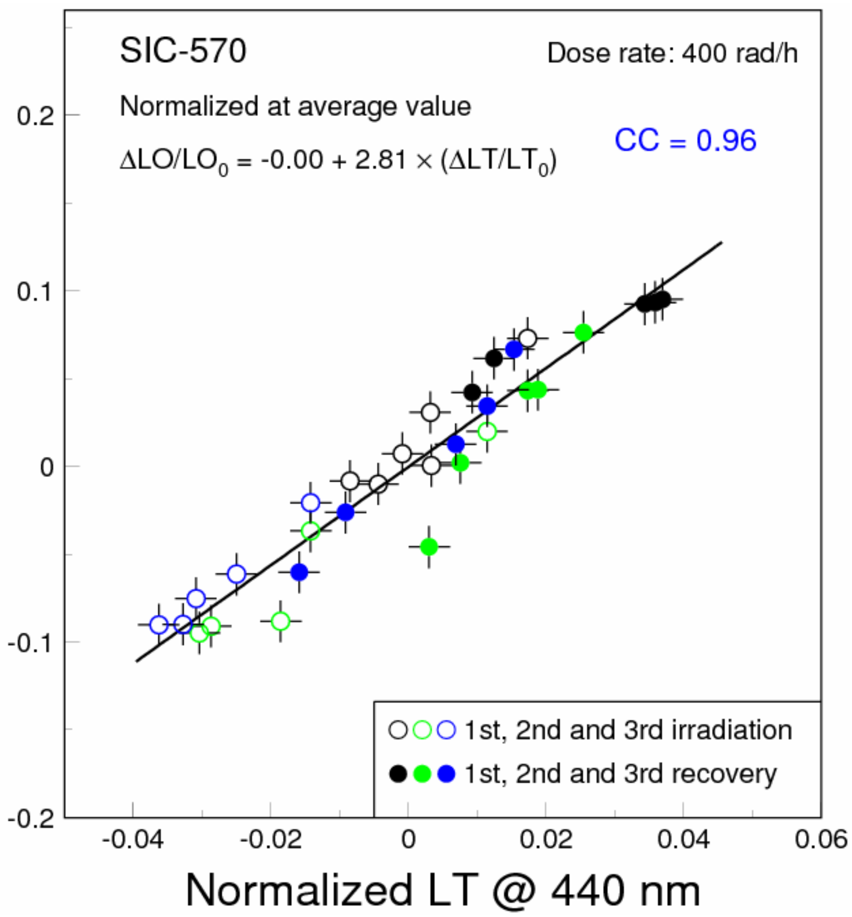




δLO/LO versus δLT/LT @ 400 rad/h

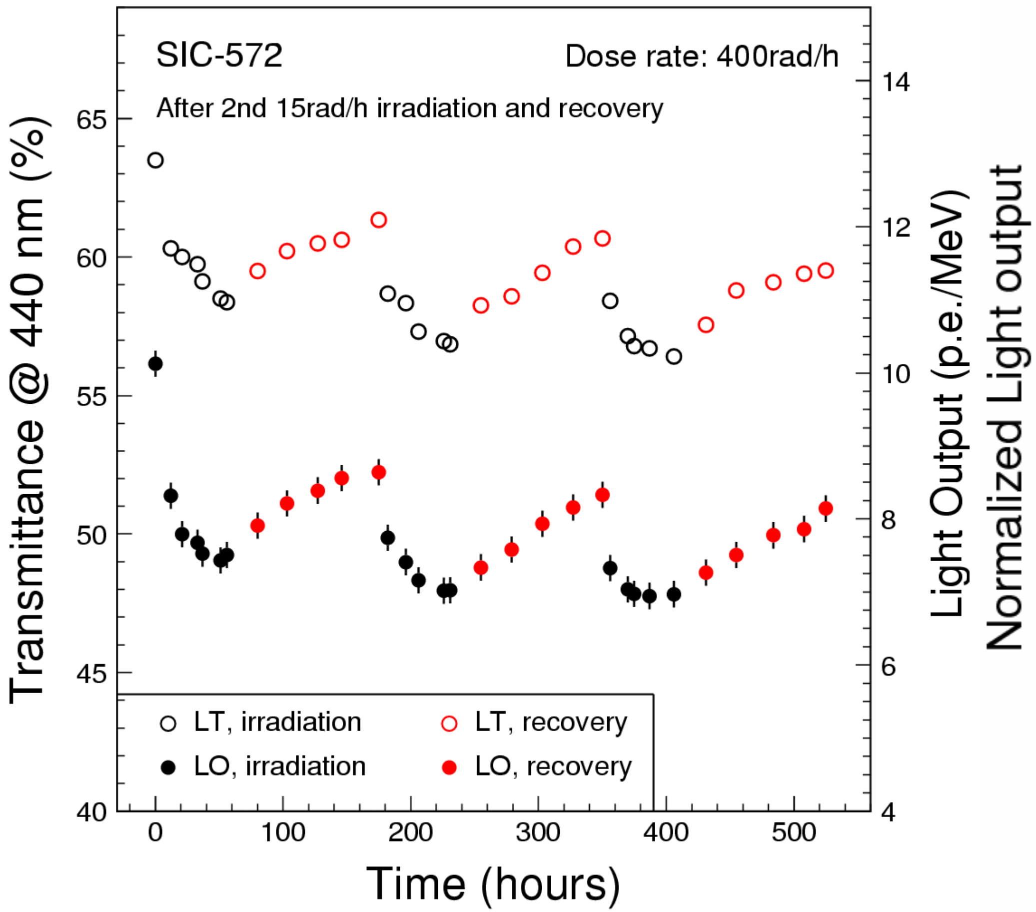
Strong correlation: Slope = 2.81

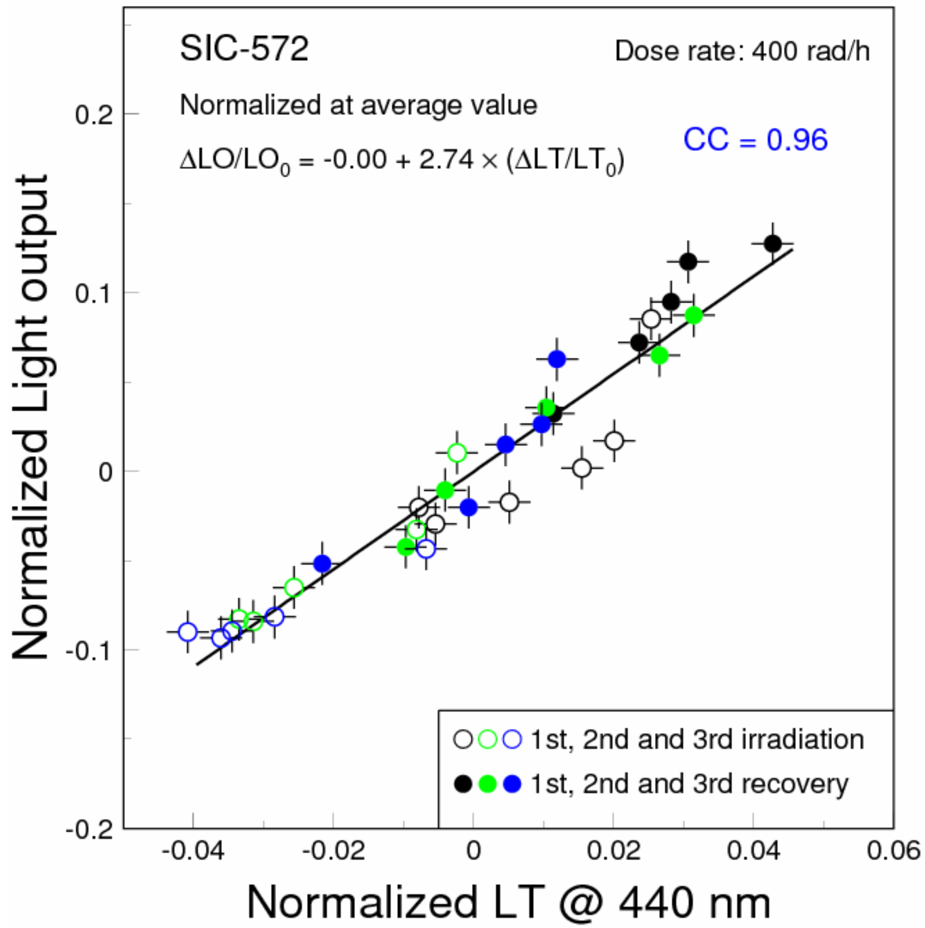




δLO/LO versus δLT/LT @ 400 rad/h

Strong correlation: Slope = 2.74





Summary

- A correlation between the initial LO and the initial LT @ 360 nm is observed, which may be caused by self-absorption.
- A correlation between the EWRIAC measured at different dose rates is observed, which is weaker at lower dose rates because of the preexisting absorption.
- No correlation observed between the initial LT, or the slope of crystals' initial LT around the band edge, and its radiation hardness for both BTCP and SIC samples, indicating no correlation between the preexisting absorption and the radiation induced absorption.
- δLO/LO versus δLT/LT @ 440 nm follow the same slope in multiple damage and recovery cycles, indicating that the LO variation can be corrected by using the variation of the transmittance even in a severe radiation environment with a dose rate of 400 rad/h.
- The slope of δLO/LO versus δLT/LT @ 440 nm, obtained with a linear fit, however, is damage level dependent, indicating a necessity of extracting it *in situ* from the data.

Transmittance anisotropy of PWO