LA-UR-17-29066

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Title: Error Budgeting

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Intended for: Report
Web

Issued: 2017-10-04

Error Budgeting

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16 August 2017

Introduction

We calculate opacity from $\kappa(h\nu)=-ln[T(h\nu)]/\rho L$, where $T(h\nu)$ is the transmission for photon energy $h\nu$, ρ is sample density, and L is path length through the sample. The density and path length are measured together by Rutherford backscatter.

According to error propagation $\Delta\kappa = \frac{\partial\kappa}{\partial T}\Delta T + \frac{\partial\kappa}{\partial(\rho L)}\Delta(\rho L)$

We can re-write this in terms of fractional error as $\frac{\Delta\kappa}{\kappa} = \frac{\Delta\ln(T)}{T} + \frac{\Delta(\rho L)}{(\rho L)}$

Transmission itself is calculated from $T=(U-E)/(V-E)=B/B_0$, where B is transmitted backlighter (BL) signal and B_0 is unattenuated backlighter signal. Then $\Delta T/T=\Delta ln(T)=\Delta B/B+\Delta B_0/B_0$, and consequently

$$\frac{\Delta\kappa}{\kappa} = \frac{1}{T}\left(\frac{\Delta B}{B} + \frac{\Delta B_0}{B_0}\right) + \frac{\Delta(\rho L)}{(\rho L)}$$

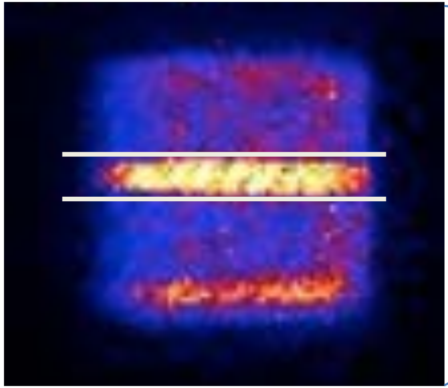
Transmission is measured in the range of $0.2<T<0.6$ so that $1.5<1/T<5$.

Error in ρL

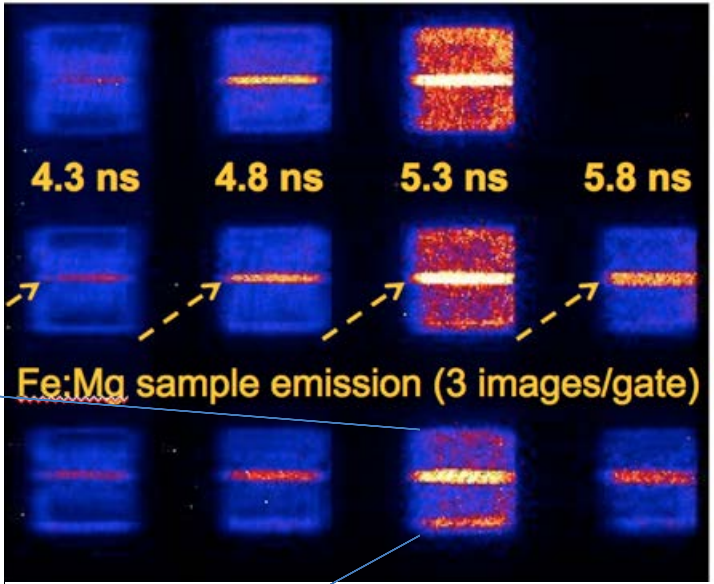
Areal density is measured as a pre-shot characterization of the sample using Rutherford backscatter (RBS). While there are few independent places (LLNL, LANL, Sandia, and K-Tec) that can characterize the sample, our team for variety of reasons uses K-Tec. Based on their study of characterization of opacity foils, the error in areal density is **~20%**. In the future, if it is possible to have more than one independent measurement, then the error can be reduced to possibly ~10%. Igor Usov also thinks that if he can request K-Tec to fine-tune the energy of their RBS source, so that the signals from Fe and Mg are not overlapped, the fitting of the experimental data can be significantly improved. He also mentioned that even for the already characterized samples, the error can be reduced if K-Tec can share their raw data with him so that he can process it with local RUMP code to back out ρL. Overall, Igor said that he is comfortable stating that the error in the areal density is currently ~15%, which can be further reduced with above mentioned strategies.

Error in ρL

Apart from the errors in the initial characterization of the sample, there are errors associated with the assumption that the foil is undergoing mainly 1D expansion and therefore $\rho L \sim const$. Equatorial views during May 2017 shots did not show significant distortions in the foil. In Ted Perry's view, the RBS errors are significantly larger and the assumption of 1D expansion is valid. To quantify the error associated with this assumption, we need to measure thickness profiles across the sample and evaluate their variation.



Rectangular Fe:Mg sample self-emission



Preliminary: At 4.8 ns, expansion = 63 microns → $n_e = 5.6\times10^{21}/cm^3$

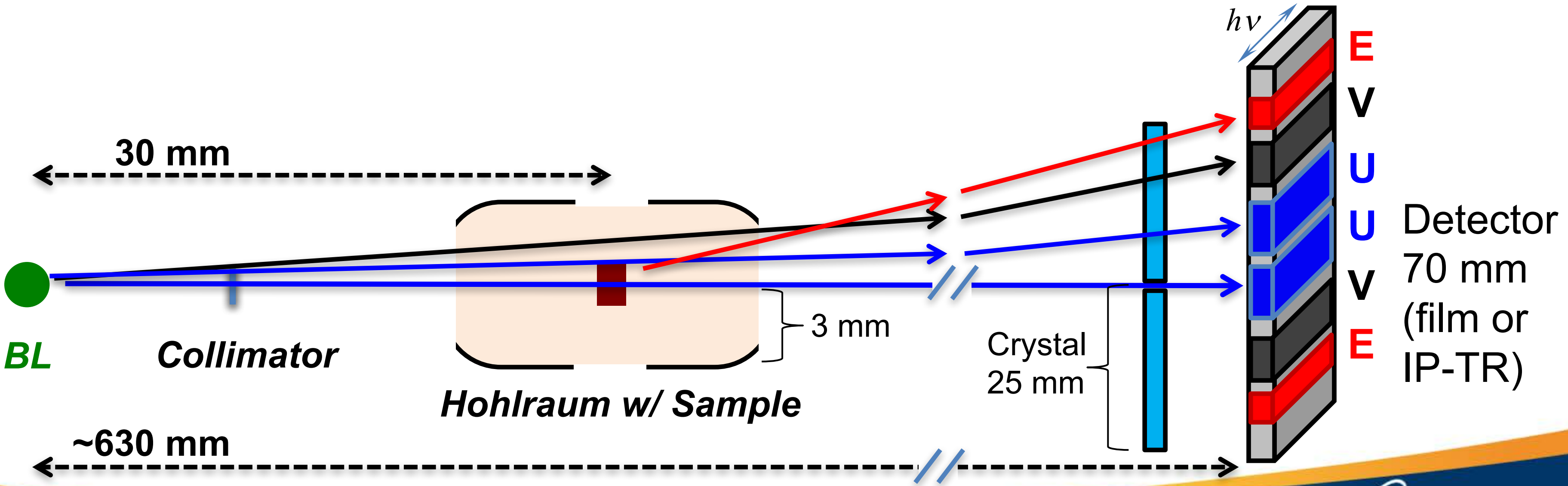
Error in Backlighter

After my discussions with Ted Perry, I believe our present understanding of quantitative errors in both of the backlighter signals is limited. Ted said that in his opinion relative errors in the un-attenuated and transmitted BL signals are on the order of 5% or less. However, he freely confesses that currently he does not have any quantitative proof of this. As such, in the following, I will discuss our qualitative understanding of errors, their origin and possible strategies to quantify them.

Perhaps the easiest error to quantify is the resolution of the spectrometer, $\Delta(h\nu)/(h\nu)$, which is 2.5×10^{-2} for the image plate and 1.25×10^{-2} for the film. However, it is not simple to incorporate this into the error of the BL. My opinion is that this provides one of the smallest contributions to the error in BL signal. If we were inclined to do so, one way to confirm this would be to perform two identical shots, one with image plate and one with film. I assume some features would be missing from the image plate but not the film. Quantifying these differences can help us understand the relative contribution of the spectrometer resolution to the error in BL signal and opacity in general.

Uniformity of Self-Emission Signal

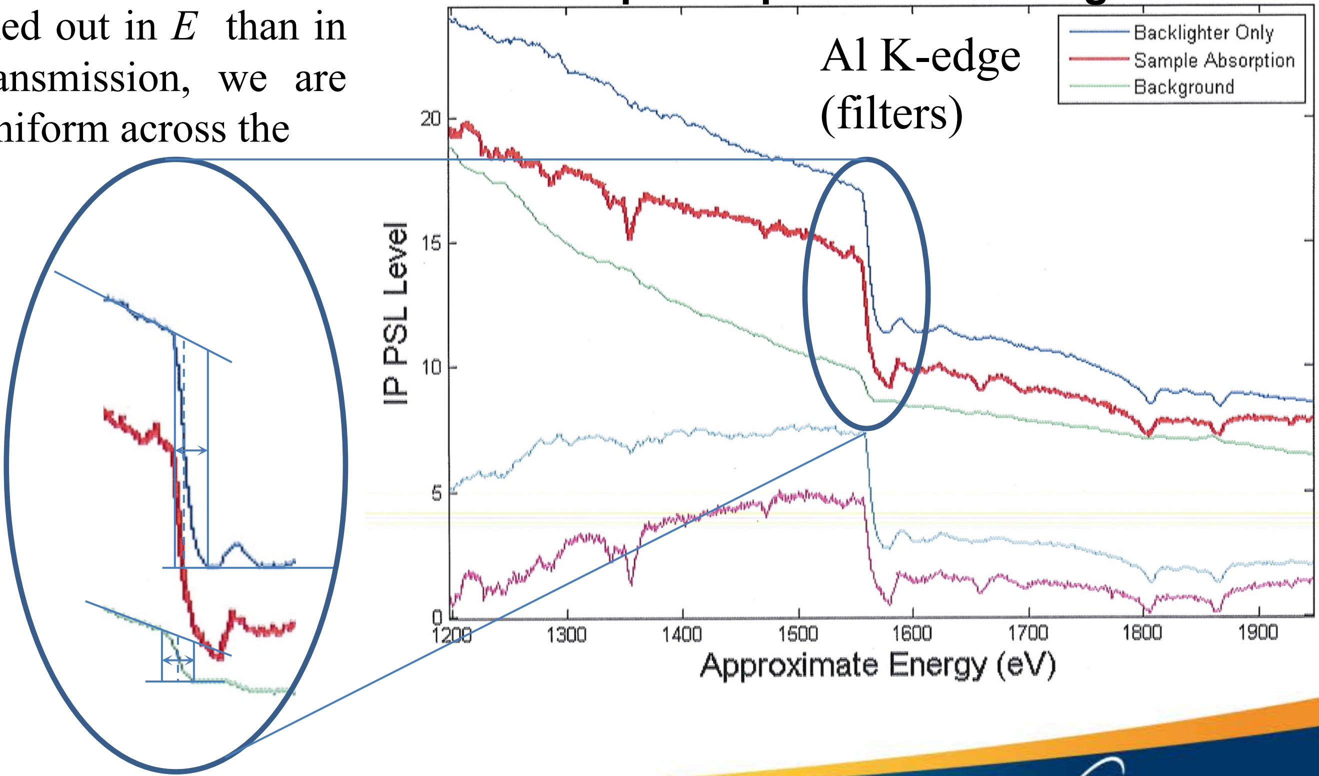
Both, the un-attenuated $V=B_0+E$, and transmitted, $U=B+E$, backlighter signals are measured together with the self-emission, E, coming from the sample, where E depends on the sample and hohlraum plasma conditions. To calculate the transmission, self-emission signal, which is assumed to be uniform in the spatial direction, is subtracted from the un-attenuated and transmitted signals.



Uniformity of Self-Emission Signal

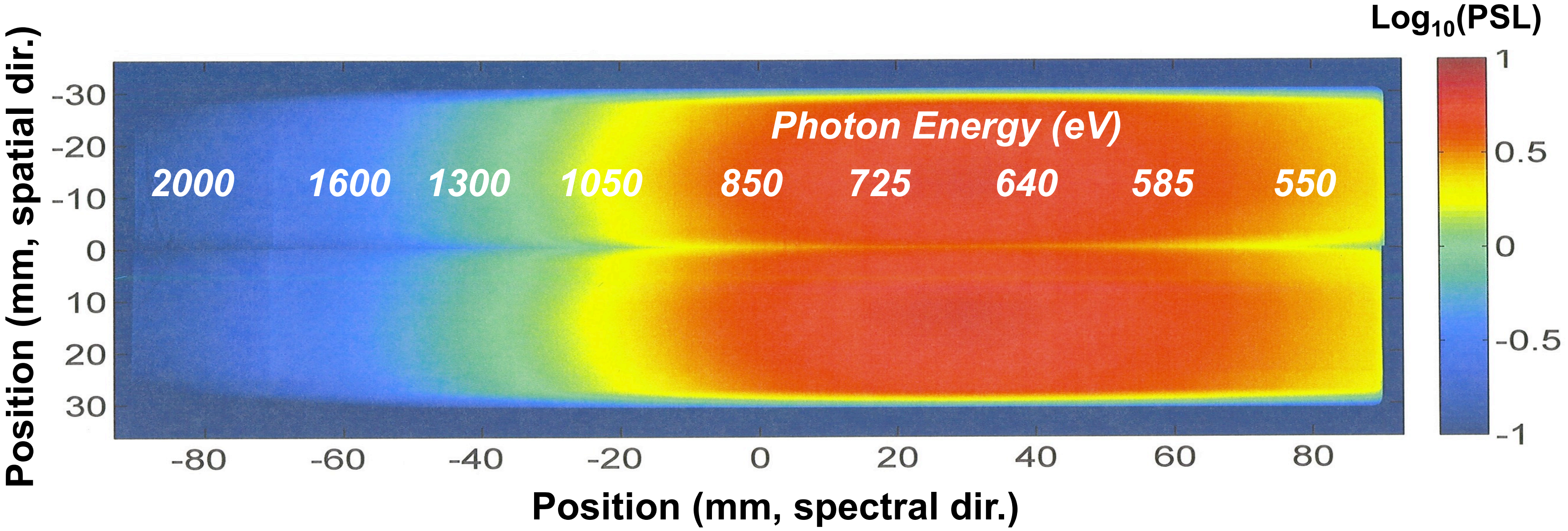
Ted Perry mentioned that features (such as Al K-edge) appear to be more washed out in E than in U. In our calculation of transmission, we are assuming that the E signal is uniform across the detector. The question is, how realistic is this assumption? I have recommended to have a dedicated hohlraum + sample only shot to assess the validity of this assumption.

Absorption spectrum from Mg K-shell



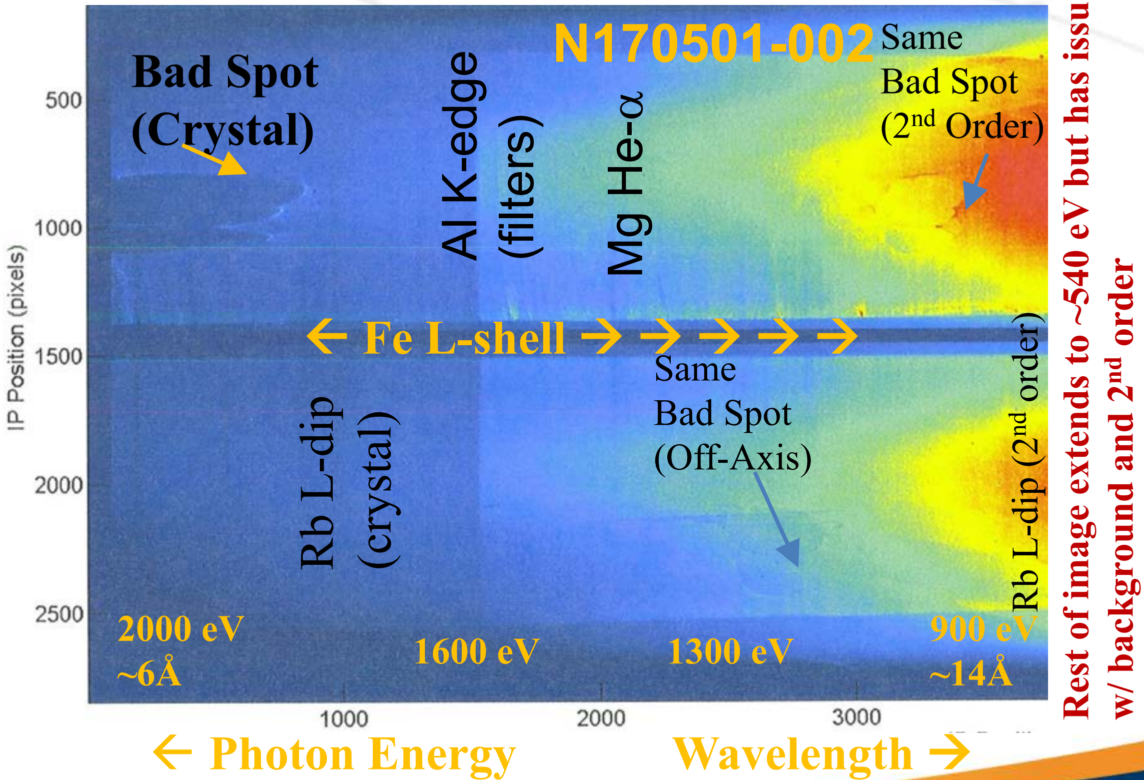
Uniformity of Un-Attenuated Backlighter Signal

Similar question can be asked about BL signal. We already have the data from our October BL characterization shot. Its analysis, particularly in regards to signal uniformity in the spatial direction, can help us quantify the error associated this assumption. Ted also pointed out that the point source approximation is valid more for the BL than for the sample. Based on the geometry, in my opinion, it is a small factor.



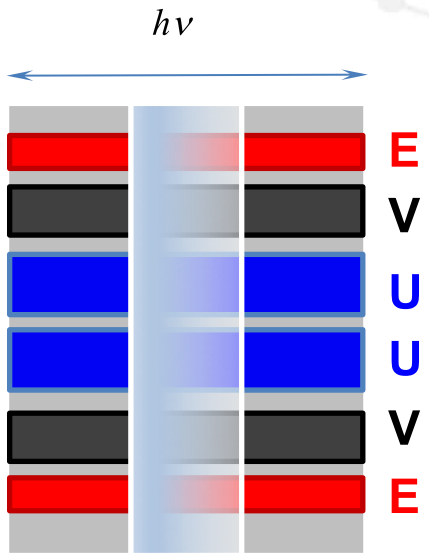
Hard X-Ray Contamination

OpSpec is currently vulnerable to hard x-rays (> 10 keV) scattered from aluminum alloy crystal substrate, while x-rays with lower energies are heavily attenuated by the RbAP crystal material. Our current understanding is that the substrate includes micro-grains of crystalline Al which diffract hard x-rays due to crystal planes with 2D spacing of ~4Å. This hard x-ray background is only seen on shots where backlighter is fired so the assumption is that it comes from the backlighter.



Uniformity of Hard X-Ray Contamination

There are several steps that were undertaken to reduce background levels, such as the use of Cu collimator, CH mount, and fine-tuning of BL pulse shape. We are also working on theoretical model to improve the accuracy of background subtraction. In addition, Ted has mentioned that with the use of film, one can employ double-layer, which will only capture hard x-ray background contribution and allow for its accurate subtraction. In the mean time, based on the acquired data we can assess the uniformity of hard x-rays. Since the current assumption is that x-ray background contamination comes from the backlighter, analyzing BL characterization shot for signal uniformity can quantify this relative error. If the background is fairly uniform across the spatial direction then most of its contribution will be subtracted in transmission calculation:



$$T=(U\text{-}E)/(V\text{-}E)=[(U_0+HXRC)-(E_0+HXRC)]/[(V_0+HXRC)-(E_0+HXRC)].$$

We do, however, need to be mindful of the fact that error in measurement is also a function of intensity.

Current Conclusions

Our goal is to measure opacity to within 10%. In order to achieve this, the error in areal density cannot exceed 10% and if we assume that the error in the un-attenuated BL is on the same order as the transmitted BL signal then each of them cannot exceed 3%.

Presently, the error in $\rho L \sim const$ is on the order of 15-20% and has to be reduced by a factor of 1.5-2. This can be achieved by a number of ways. In the order of increasing difficulty: 1. re-analyzing raw RBS data with local RUMP code, that Igor Usov thinks is more accurate, 2. working closely with K-Tec to fine-tune their RBS energy source, and 3. using multiple venues to characterize the sample.

Currently, our understanding of errors in BL signal is less advanced than that of the areal density. Ted readily admits that his assessment of $\Delta B/B \sim 5\%$ is presently not substantiated. There are several issues that need to be addressed in assessing the errors in BL signals, in particular hard x-ray background contamination, spatial uniformity of BL and SE signals. Currently, there are steps in place to work on the first one. Based on the BL characterization shot data, the signal seems to be fairly uniform, but this needs to be quantified. Examining May shots data, albeit to my untrained eye, it seems that it is less uniform in the spatial direction. This makes me question the uniformity assumption of the SE signal. We can advance our level of understanding by performing a SE-dedicated shot that will assess the levels of SE-signal variation across the film.