ISBN: 978-3-95450-210-3 doi:10.18429/JACoW-FEL2019-WEP034

CHARACTERIZATION OF FEL SPECTRA USING SPECIFIC FIGURES OF MERIT

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ABSTRACT

There is an increasing demand from the user community for high quality FEL radiation. The spectrum of this radiation can prove to be a useful tool in characterizing the FEL process. Starting from a tool initially developed at FERMI we extend its capabilities to be able to analyze the modal components of the FEL spectrum. In this paper we will describe and compare two different figures of merit and offer initial bench-marking with respect to classic figure of merit for spectra such as FWHM and RMS.

INTRODUCTION

It is a common practice to optimize the setup of the FEL by looking at the spectrum of the radiation. However in order to have any type of automation procedure feeding back on this measurement, a simple figure of merit is needed. This can help not only in automation of the optimization procedure but also in removing biases that a human inevitably has while looking at a spectrum. Important work regarding FEL optimization procedure has been carried out at FERMI FEL as presented in [1].

With this in mind we sought out to create such a figure of merit. The real time acquisition system used at FERMI FEL, REALTA , is capable of using real time scans of numerous hardware components. Along with an offline data analysis software, PyDart, provides a strong tool in characterizing the machine, both software tools are described in [2]. The initial goal of the project was to create a few figures of merit (from here on out referred to as *fom*) that can better characterize the "*goodness*" of a spectrum. The main addition to the capabilities of PyDart was the decomposition into spectral components by identifying the different peaks in the spectra.

PEAK DETECTION WORK-FLOW AND CAPABILITIES

The peak detection algorithm is a more complex version of scipy's find peaks routine [3] with the added ability to not only detect peaks but also valleys and even find peaks that do not have a prominence but manifest as a shoulder, see Figure 1.

The work-flow is structured as follows:

1. Subtracting a linear background from the Spectrum
2. Evaluate the background in terms of height periodicity and prominence

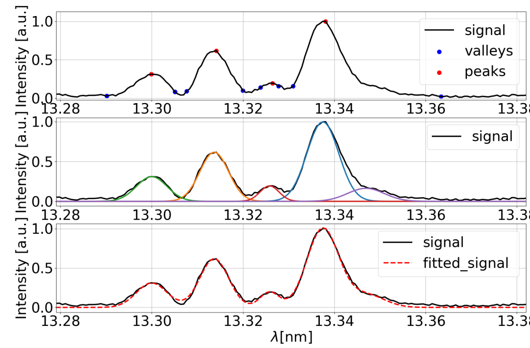

Figure 1: Illustration of work-flow : finding peaks and valleys (top) fitting (mid and bottom). Spectra supplied by Fermi.

3. Find all peaks that Are several times higher that the background, Have a prominence much higher that the background,Are separated from other peaks by n times the peak separation in the background Figure 1 (top).
4. Find the corresponding valleys to the peaks 1 (top).
5. Fit Gaussian functions to the region of interest defined by the peaks and valleys.
6. Calculate goodness of fit Figure 1 (bottom).

For a more comprehensive explanation of the working of the algorithm refer to [4].

FIGURES OF MERIT

In this section we will go through the *fom* to be able to understand their individual strengths and weaknesses. For the present analysis we have chosen a total of 6 *fom* but the list is by no means exhaustive with more work still remaining to be done.

- **Intensity** : the total intensity contained in a spectrum
- **FWHM** : width of the spectrum at half of the maximum intensity
- **Sigma 0** : the weighted RMS of the spectrum with respect to the weighted mean position
- **W of 80 %** : the minimum continuous width over which 80% of the intensity is located
- **A ratio** : the ratio between the area of the highest peak found by gaussian fitting to the total Intensity
- **Multi G sig** : the sigma of the highest peak fond by gaussian fit

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ANALYSIS

All the spectral analysis was done using PyDart that takes a real time acquisition file as input. This file contains spectral and actuator information and to this file PyDart appends the results of the analysis. The spectra we analyzed were taken among many the spectra acquired during the Echo Enabled Harmonic Generation (EEHG) setup of FEL2. This paper is not meant to give estimates of the performance or quality of the spectra for FERMI FEL2 operating in EEHG mode.

As a first step in the analysis we test the *fom* with a *scanfile*. In this case we use a file where the seed delay line was scanned. This provides a clear trend for the FEL process efficiency and a good baseline to test for our *fom*. In Figure 2 we can see that all the *fom* detect the region where the actuator scan produces the best FEL output. As an observation we could state that among the *fom* plotted **A ratio** shows some sensitivity in the highest intensity region.

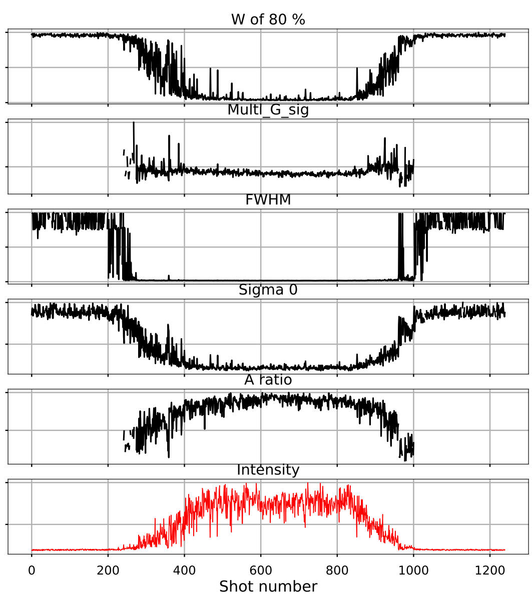


Figure 2: Different *fom* trends for spectra obtained during an actuator scan.

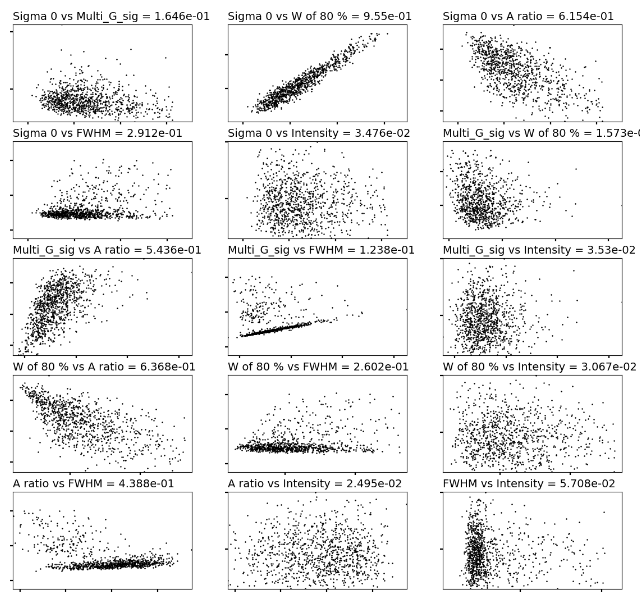
Correlation

There is no pre-existing, objective way of determining how "*good*" a spectrum is, so we try to gauge which ones are the best by correlating them with each other so that we have more confidence in *fom* with high degree of correlation. If two *fom* are highly correlated it is probable that they will find the same spectra as being the best. We define the correlation between two *fom* as in equation 1. To be able to compare *fom* fairly, we take the absolute value of the correlation, for single peak clean spectra there should be an inverse correlation between intensity and width related *fom*. Furthermore, for each *fom* we only take values that are within 3 standard deviations of the mean and for each correlation we use only those shots that both *fom* satisfy this condition.

$$Cor_{x,y} = \frac{(\sum(x_i - \bar{x})(y_i - \bar{y}))}{\sqrt{\sum(x_i - \bar{x})^2}\sqrt{\sum(x_i - \bar{x})^2}} \quad (1)$$

In Figure 3 we plot all the *fom* with respect to each other for another 1000+ shot file with real time acquisition i.e. no parameter was scanned. Several features of this figure stand out :

- The best single correlation is between **Sigma 0** and **W of 80 %**.
- The **Intensity** has the worst correlation with all the other *fom*.
- At a closer look one can find that **A ratio** has the best cumulative correlation with **W of 80 %** a close second.



Cumulative Correlation

A ratio	0.398	**W of 80 %**	0.335
Sigma	0 0.312	**FWHM**	0.2131
Multi G sig	0.144	**Intensity**	0.0186

Figure 3: Comparison between the different fom correlation (top figures) and a cumulative correlation for each one (bottom table).

Sorting Spectra by fom

Having created an initial hierarchy of the *fom* we test the top two (**A ratio** and **W 80 %**) to see how well they sort the spectra. In addition we prepare a compounded *fom*, **mix fom** = $\frac{\textbf{Multi G sig}}{\textbf{Intensity}}$ and complete the selection with **Intensity**.

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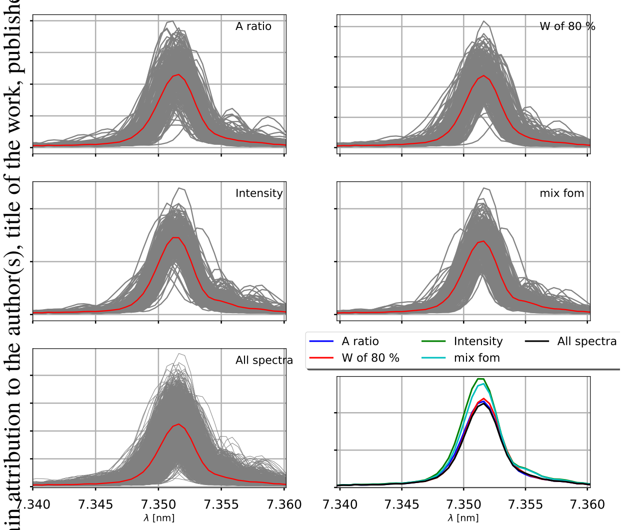

Figure 4: Comparison between the different fom for "not so good" spectra. Top 20 % of spectra as sorted by **A ratio** (top left), **W of 80%** (top right), **Intensity** (middle left), **mix fom** (middle right). 100% of the spectra (bottom left). Average of spectra for each *fom* and for the full selection.

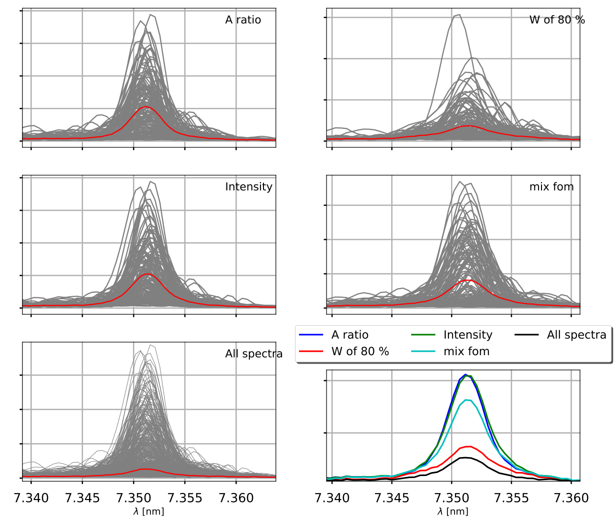

Figure 5: Comparison between the different fom for "not so good" spectra. Top 20 % of spectra as sorted by **A ratio** (top left), **W of 80%** (top right), **Intensity** (middle left), **mix fom** (middle right). 100% of the spectra (bottom left). Average of spectra for each *fom* and for the full selection.

In Figure 4 and 5 we plot the top 20 % , according to each *fom*. Each plot contains the individual top spectra in grey and the average of them in red. The comparison is done in the bottom right plot where the averages are plotted. We use a real time acquisition containing mostly single spike spectra and to show how each *fom* sorts relatively clean spectra (Figure 4. By choosing a file in which the second dispersive section of the EEHG scheme is scanned we illustrate the capabilities of each *fom* to sort though irregular spectra that some have multiple peaks.

The first thing to observe in Figure 4 is that the **Intensity** sorting gives the highest average even though the **mix fom** has a similar height, with a slightly narrower average peak. Secondly, all of the *fom* are better than the total average however the top performing ones in terms of correlation, **A ratio** and **W of 80 %**, are the worst at sorting among the four presented here. In Figure 5 the **Intensity** again shows great results with **A ratio** being only marginally better. The **W 0f 80 %** being the worst out of the *fom*. One might be inclined to speculate that **A ratio** chooses more narrow spectra, just by eye, but we would need an objective function to estimate this before making any claims.

A peculiar detail that might help in the future development of the code is the fact that even though **Intensity** is the least correlated of the *fom* it performs exceedingly well at sorting. It may be possible to take advantage of this fact and force some dependency of the rest of *fom* with respect to **Intensity** as we have seen with the **mix fom**.

CONCLUSIONS AND OUTLOOK

The *fom* analyzed here manage to find cleaner spectra and show reasonably good correlation among themselves. The **mix fom** performed well I believe largely due to it's dependency on *Intensity*. A deeper understanding of the fitting process' efficiency and weaknesses is needed to further optimize *fom* such as **A ratio**.

Speculating, we can infer that among the reasons that **A ratio** and **w of 80 %** are not finding the highest intensity spectra consistently is that they are always scaled with the total intensity. Another improvement might be that in the definition of **A ratio** we should take into account the background level since the total Intensity has a larger contribution from the background than the largest peak.

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ISBN: 978-3-95450-210-3 doi:10.18429/JACoW-FEL2019-WEP034

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