Use of BLM sensor to compute lifetime

Summary

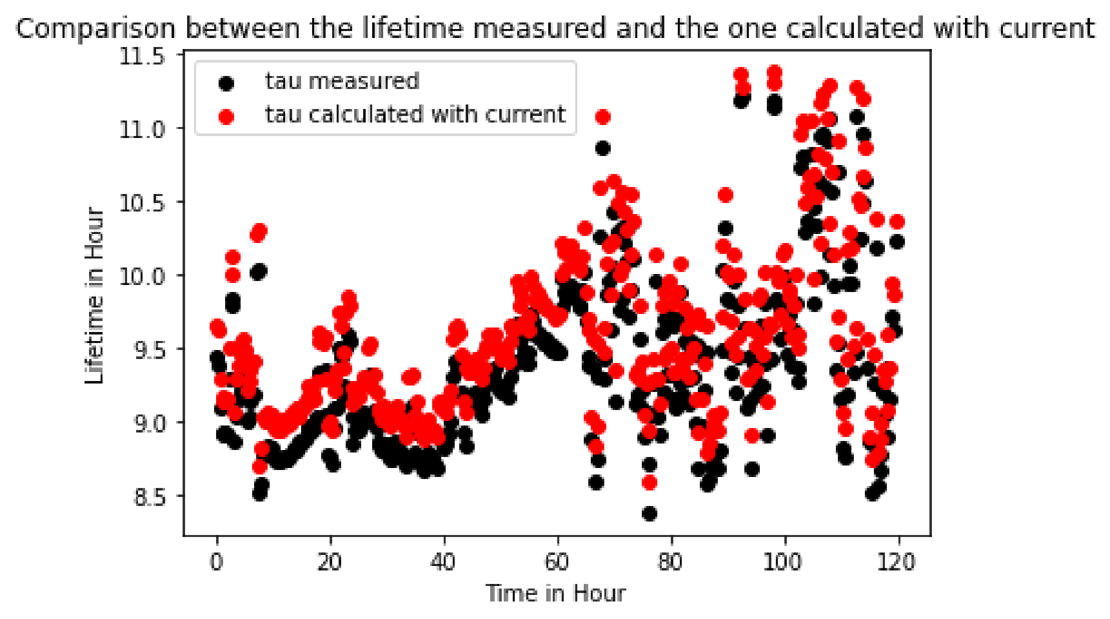
- I) Introduction
- II) How the lifetime is currently calculated
- III) Noise analysis
- IV) Changing Chromaticity
- V) Computing lifetime during user-operation
- VI)Touschek and gas scattering lifetime
- VII) Uncertainties
- VIII)Conclusion

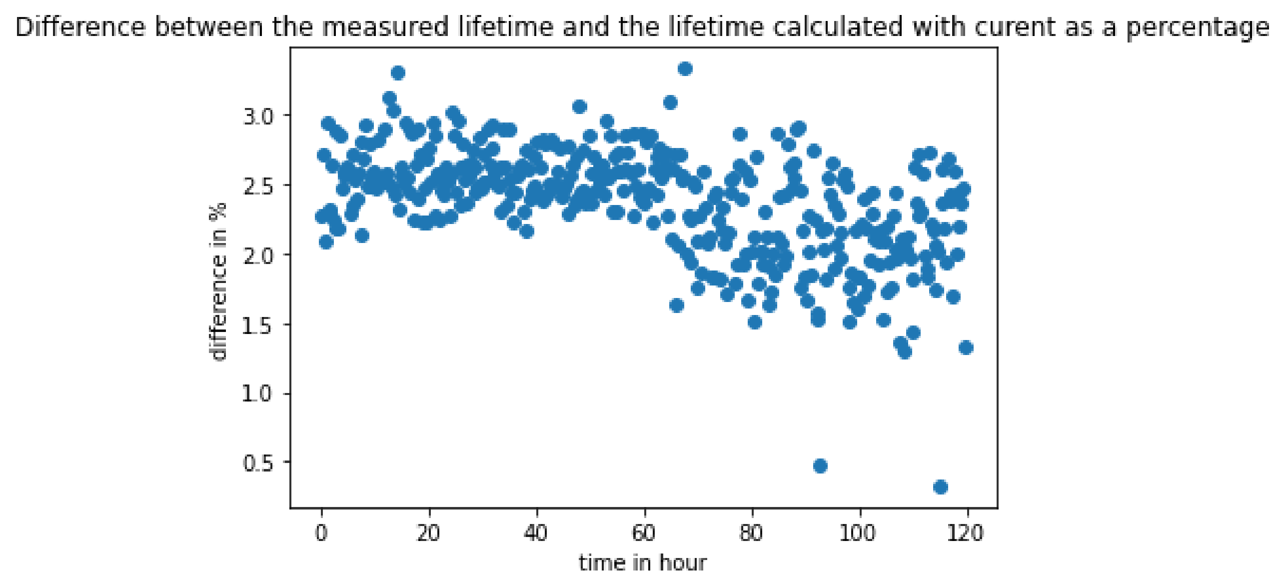
I) Goals of my internship

- **Understanding** how the BLM sensors work
- Find a way to **compute lifetime** with BLM sensors
- Compute **Touschek lifetime and gas scattering lifetime** at SLS during user-operation

II) How the lifetime is currently calculated

$$\tau = -\frac{I}{\frac{dI}{dt}}$$

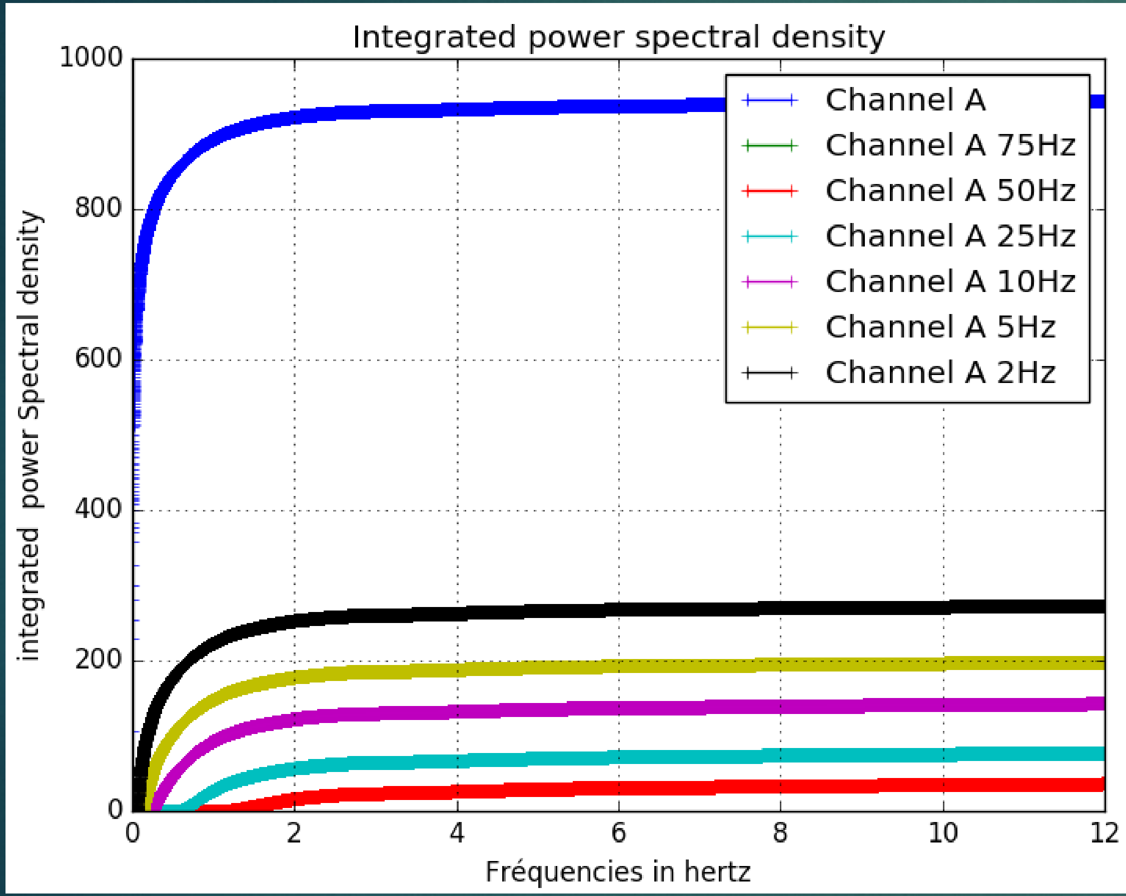


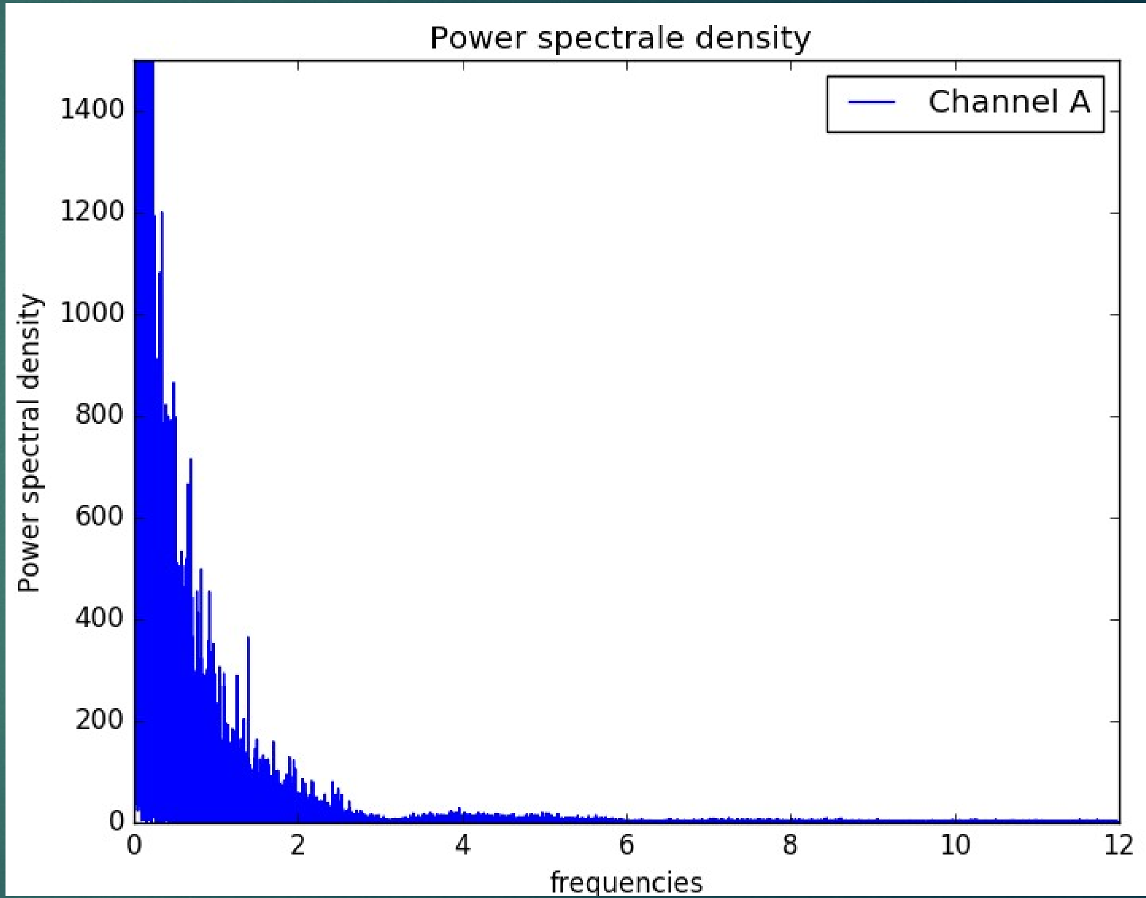


Comparison between lifetime calculated with PCT reading and lifetime calculated by EPICS.

Moving average to smooth the lifetime calculated with PCT reading

III) Background Noise Analysis



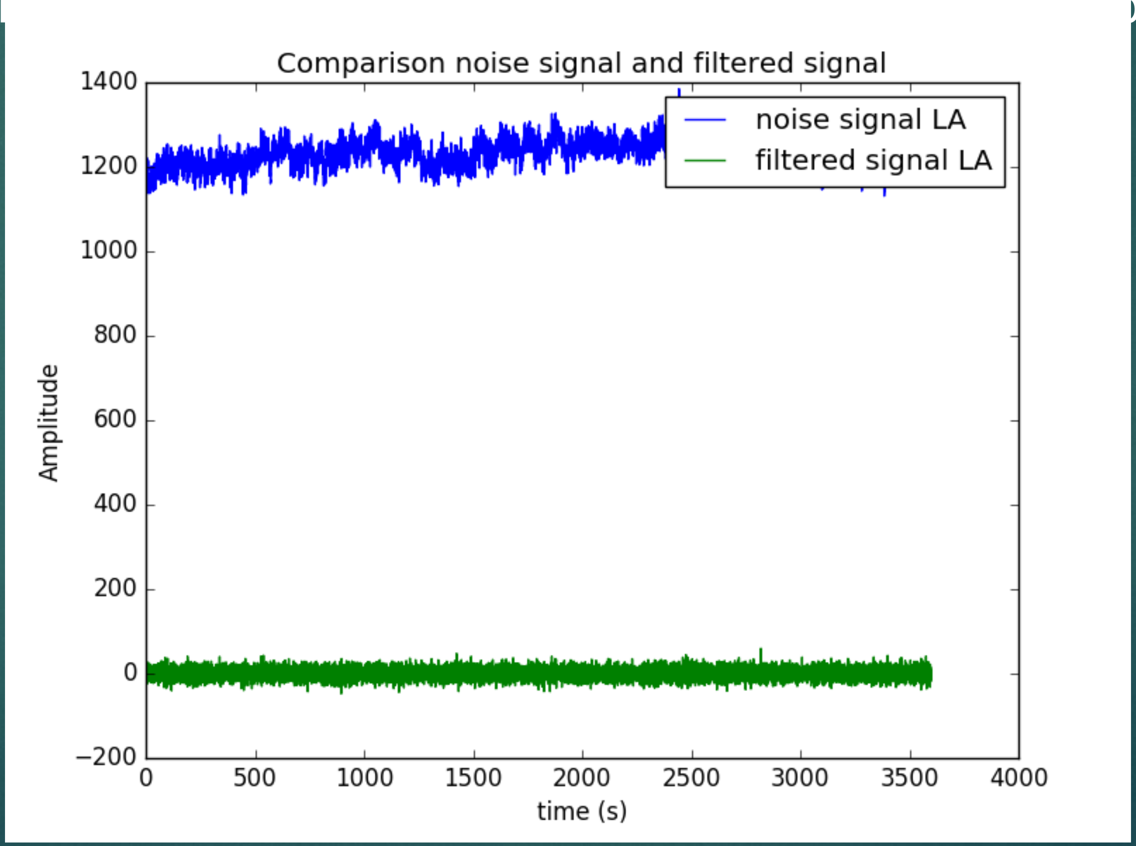


Noise only at low frequency more than 75% of noise deleted with a high pass of cutting frequency of 2Hz

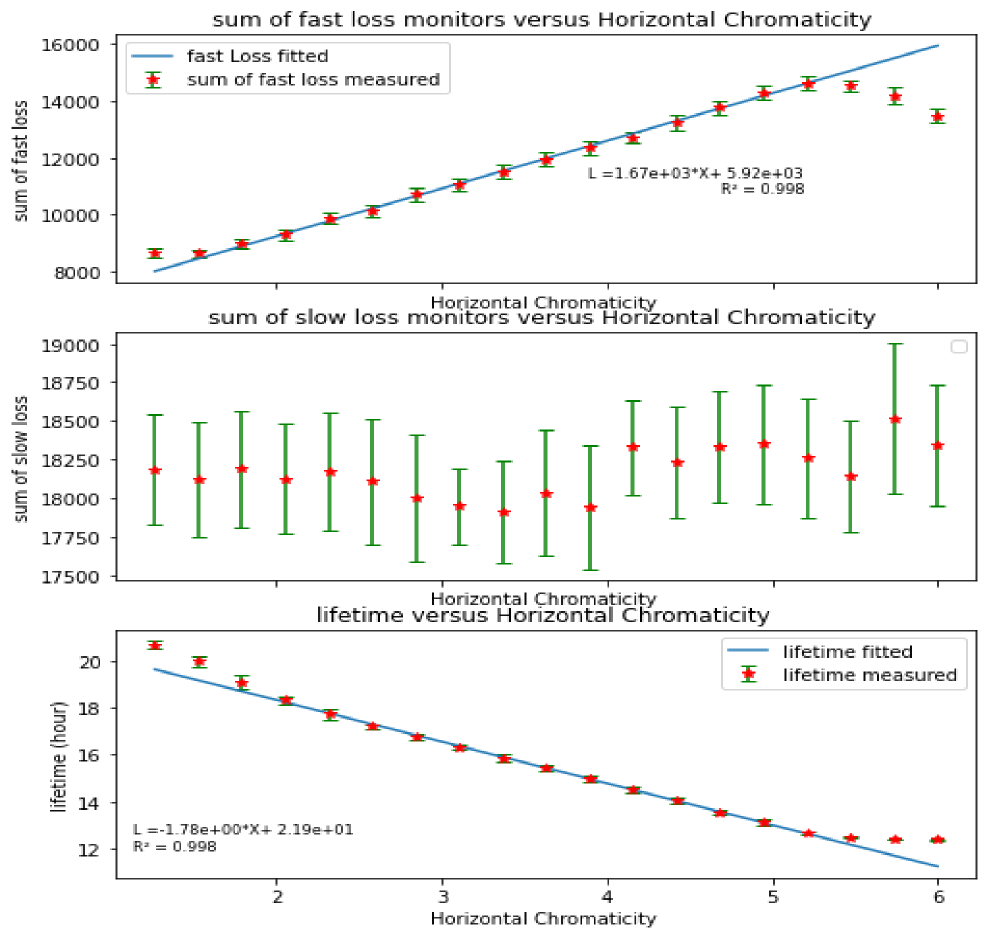
III) Filtering the signal

Why ? To make sure sampling rate didn't affect the previous measure.

How ? Filtering the background noise signal with high-pass of cutting frequency fc=10Hz



IV) First measurement: Change of horizontal chromaticity



Linear range is range of stability.

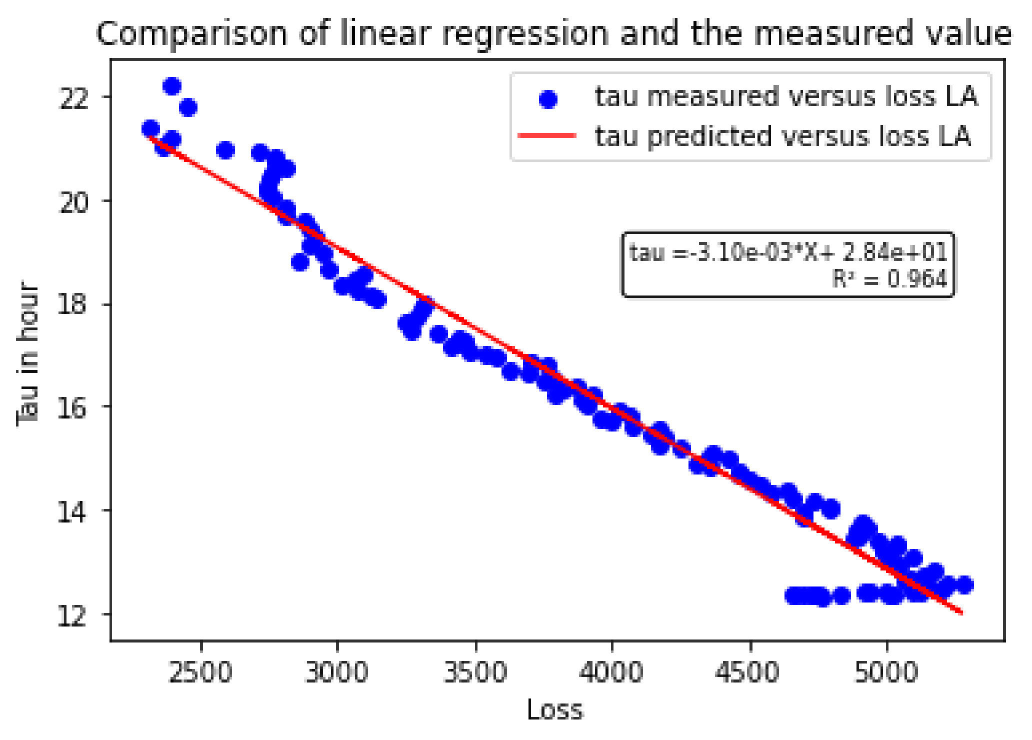
	Horizontal Chromaticity	slow loss monitor	Fast Loss monitor	Lifetime	Current
0	6	18300	13500	12.4	152
1	5.74	18500	14200	12.4	152
2	5.47	18100	14500	12.5	151
3	5.21	18300	14600	12.7	151
4	4.95	18400	14300	13.1	151
5	4.68	18300	13800	13.5	151
6	4.42	18200	13200	14	151
7	4.16	18300	12700	14.5	151
8	3.89	17900	12300	15	151
9	3.63	18000	11900	15.4	151
10	3.37	17900	11500	15.9	151
11	3.11	17900	11100	16.3	151
12	2.84	18000	10700	16.8	151
13	2.58	18100	10100	17.2	151
14	2.32	18200	9870	17.7	151
15	2.05	18100	9300	18.3	150
16	1.79	18200	9000	19.1	150
17	1.53	18100	8640	20	150
18	1.26	18200	8680	20.7	150

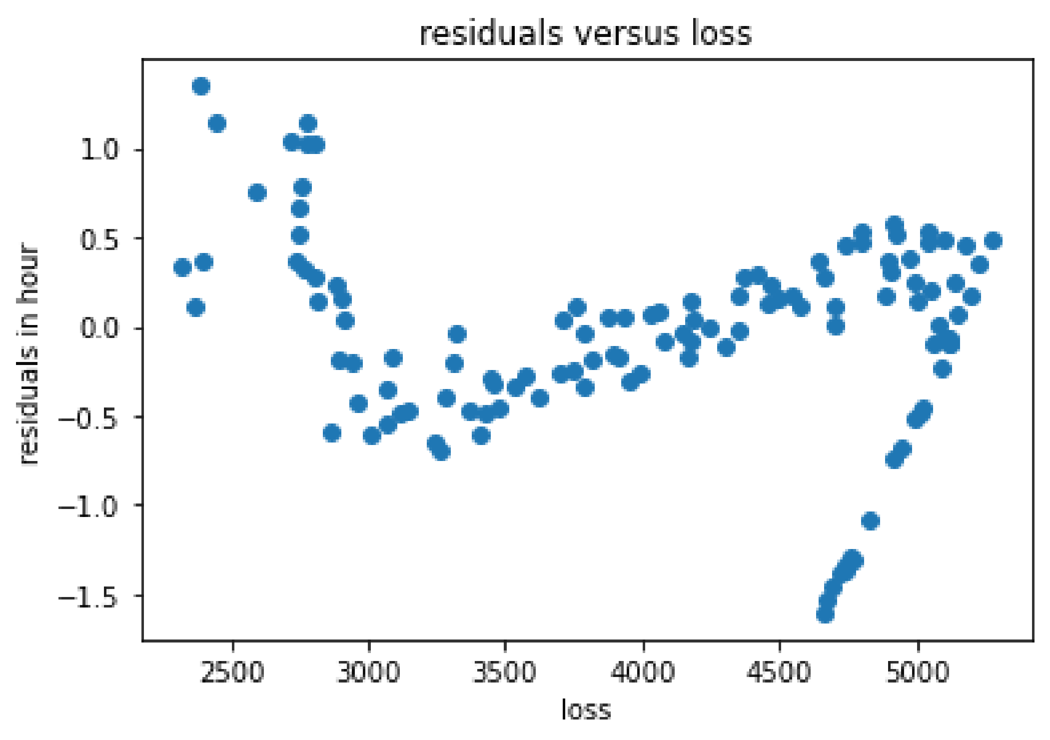
For a chromaticity of 3.11 lifetime increase of 4h
Chromaticity is not optimised

IV) Fit of lifetime with beam loss monitor

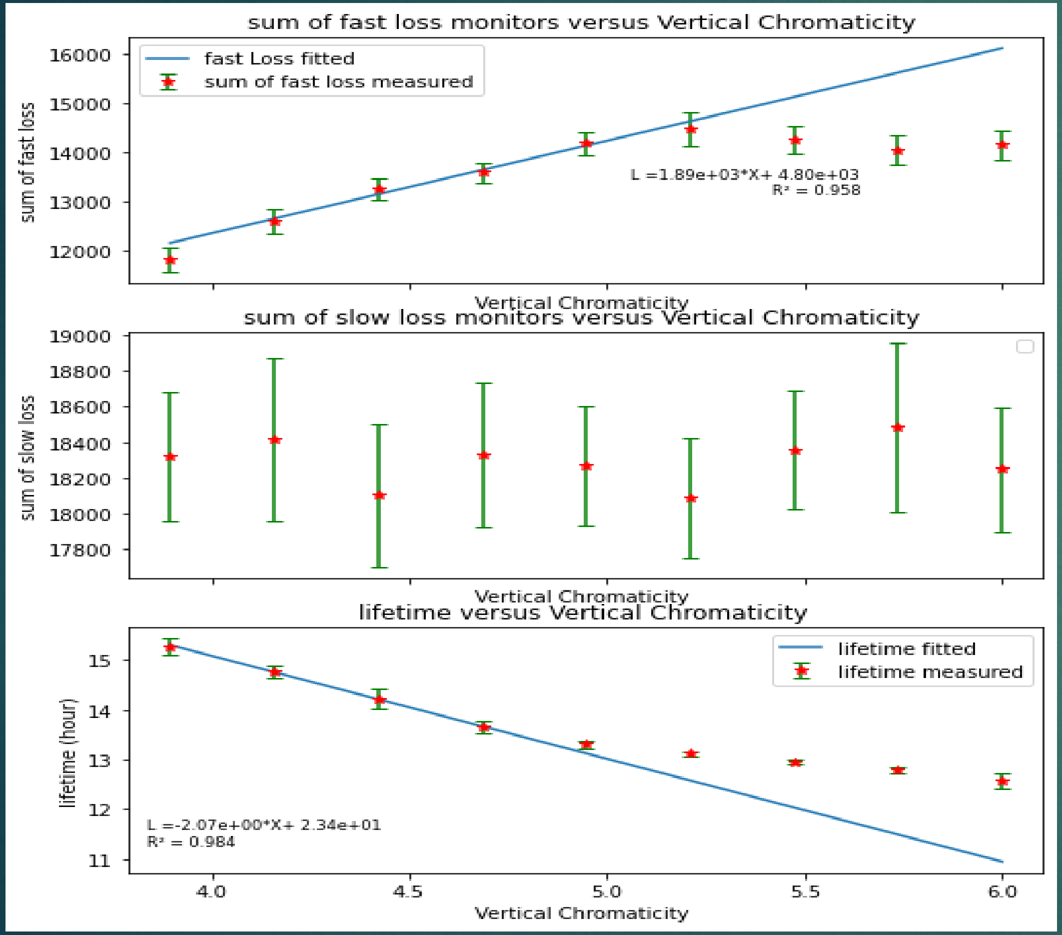
Fast loss monitor are better correlated on this measurement:

R^2=0.96





IV) Second Measurement: Change of vertical chromaticity



	Vertical Chromaticity	slow loss monitor	Fast Loss monitor	Lifetime	Current
0	6	18200	14100	12.6	152
1	5.74	18500	14000	12.8	152
2	5.47	18400	14300	13	152
3	5.21	18100	14500	13.1	152
4	4.95	18300	14200	13.3	151
5	4.68	18300	13600	13.7	151
6	4.42	18100	13200	14.2	151
7	4.16	18400	12600	14.8	151
8	3.89	18300	11800	15.3	151

Chromaticity may be not optimised
Avoiding instability at 400mA is harder

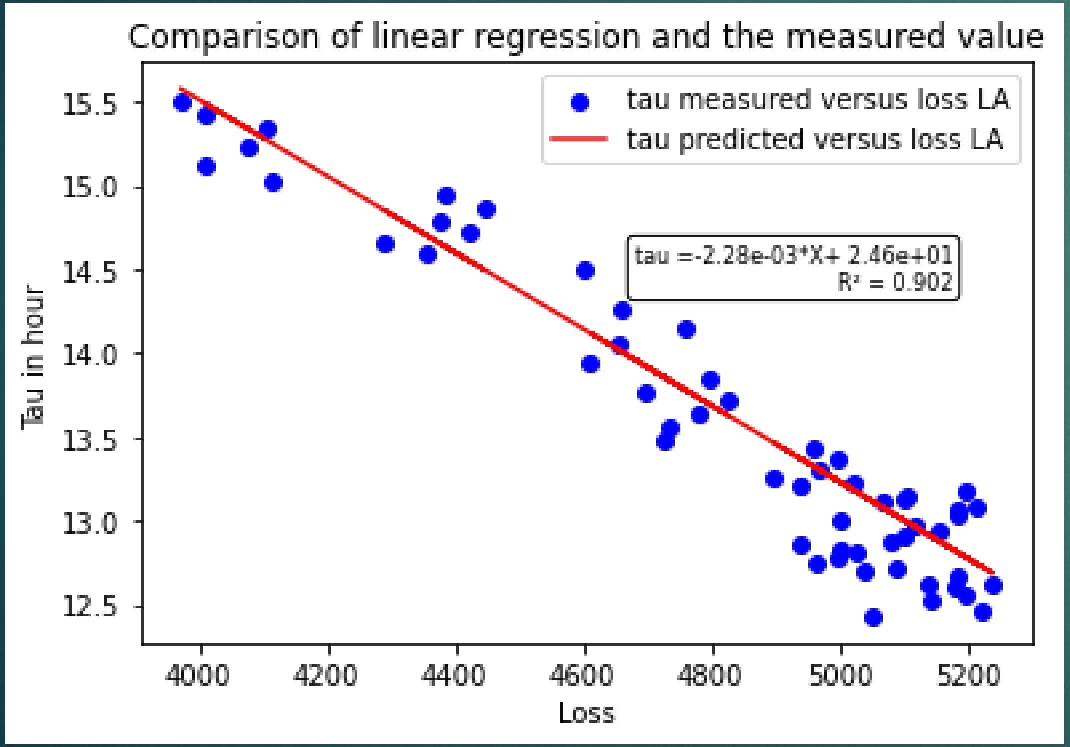
Range of stability finer

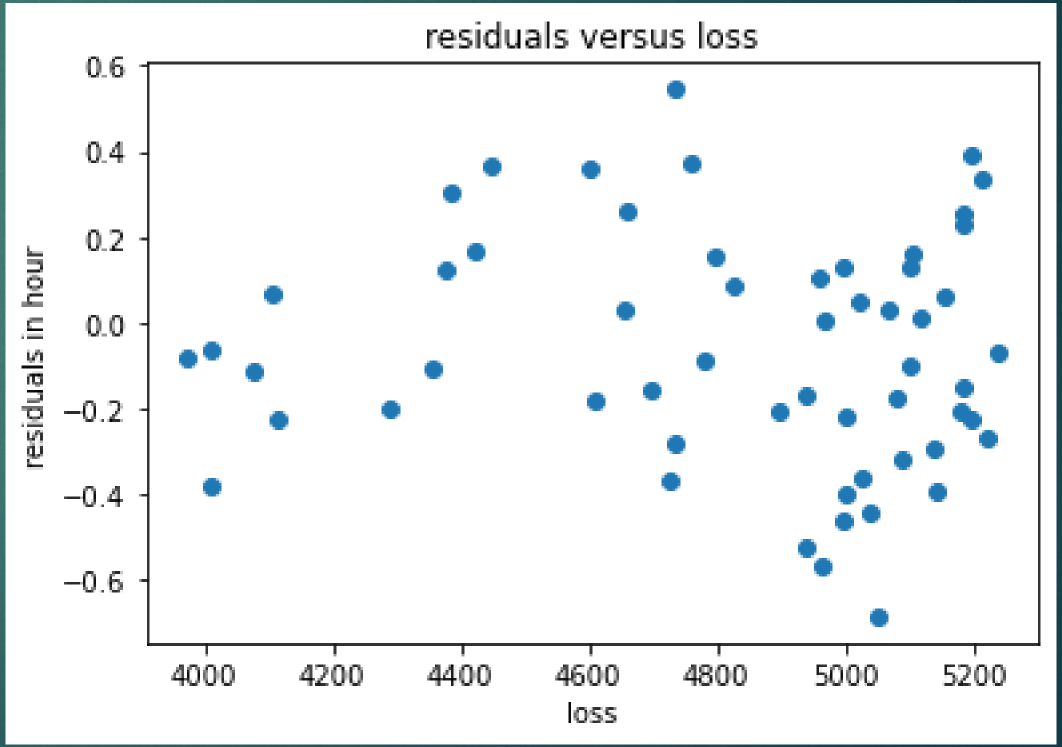
IV) Fit of lifetime with beam loss monitor

Fast loss monitor are better correlated on this measurement

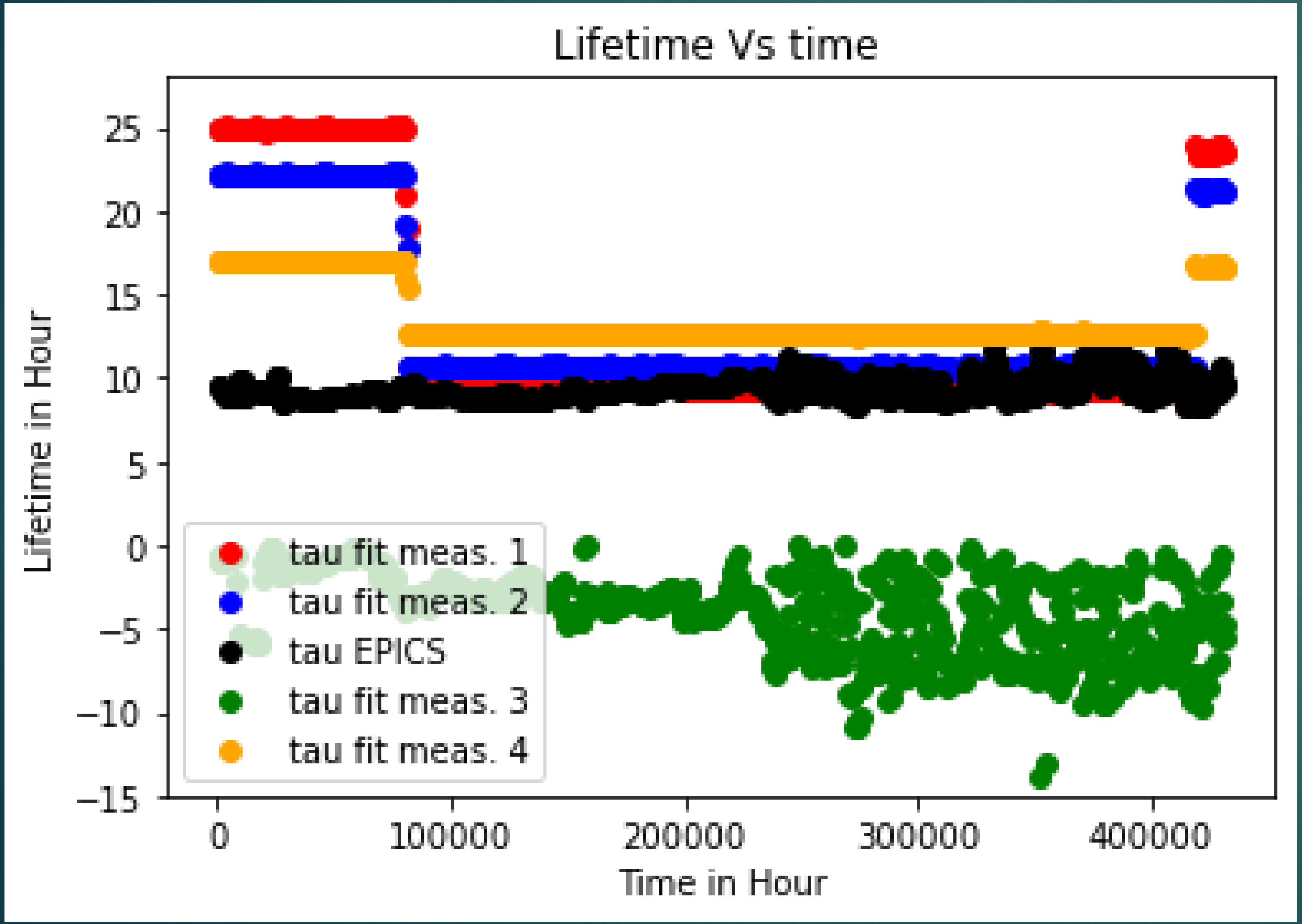
R^2=0,9

Bigger uncertainties and lower R^2 due to more instabilities for vertical chromaticity





V) Test of these fits on data acquired passively



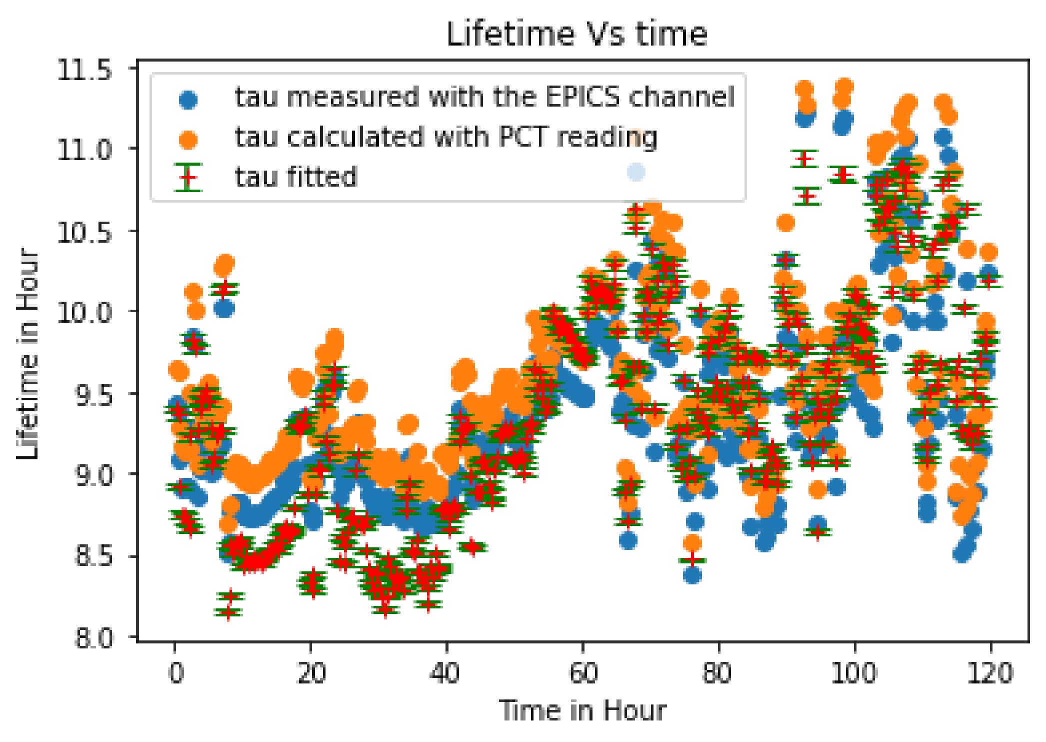
Fits are not working on nominal data:

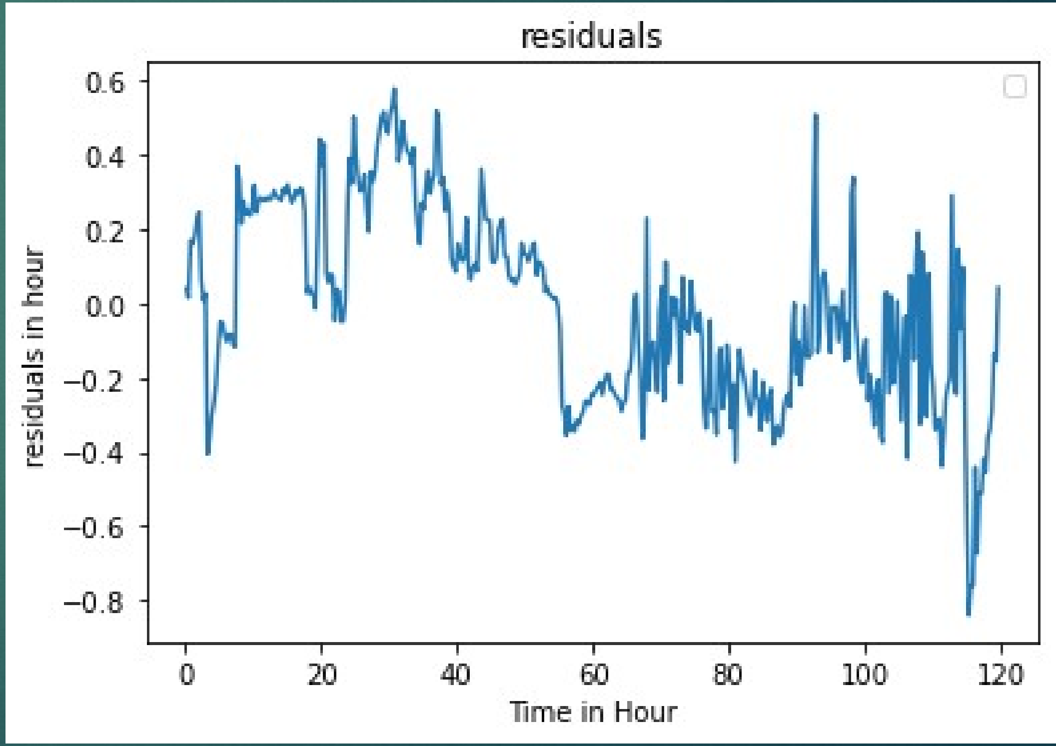
- To sensitive to changes of sensors values
- Not giving the correct value most of the time

V) How to compute lifetime during user-operation

Slow loss monitor after the undulator are better correlated during user operation

$$\tau = 12.39 \pm 0.005 - (0.163 \pm 0.001) * \frac{CMOS1L11}{I}$$





V) How the data is processed

The dataset used for this fit contained **785586 elements**. Data processing needed to improve the quality of the fit:

- Deleting every value for which the derivative of PCT reading is positive. To **delete injection**
- Deleting all the values for which the lifetime calculated by the EPICS channel is the same.
- A **moving average** to smooth the signal of the sensors.
- **Normalization** by PCT reading

At the end the dataset contained **737 elements**

VI) How to compute gas scattering lifetime and Touschek lifetime

- Plug a signal generator at the **Tune frequency** to the multibunch feedback to increase the beam size

- Fit inverse lifetime with beamsize to **compute lifetime for infinite beamsiz**e

- At beam size lifetime is **only gas scattering**

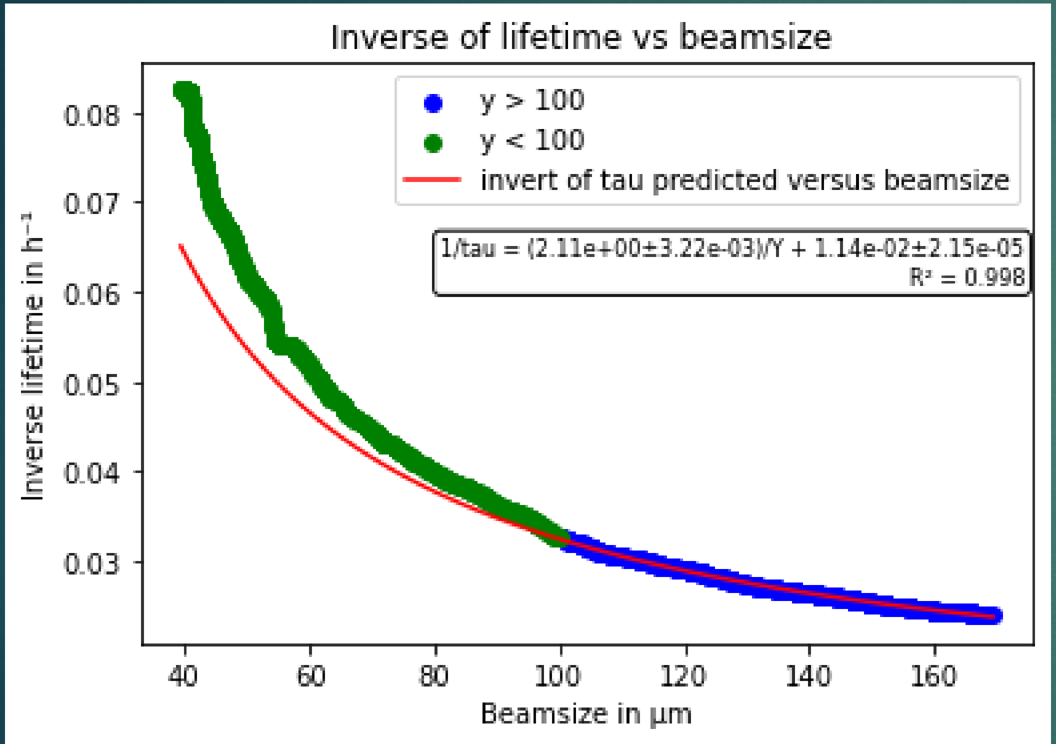
- Using equation bellow to compute **Touschek lifetime**

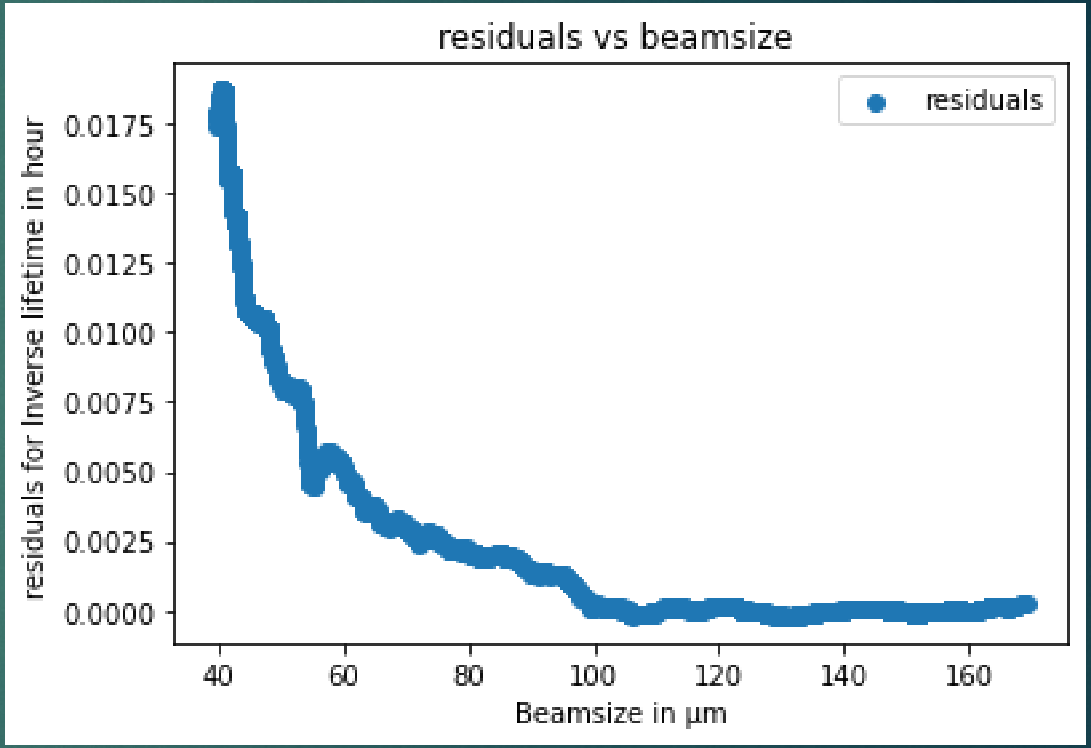
$$\frac{1}{\tau} = \frac{1}{\tau_{tousch}} + \frac{1}{\tau_{gas}}$$

VI) Inverse lifetime versus beam size

$$\frac{1}{\tau} = 1.14 * 10^{-2} \pm 2.14 * 10^{-5} + \frac{2.113 \pm 3.22 * 10^{-3}}{Y}$$

$R^2 = 0.998$





Fit done for large beam size only 100µm to 170µm

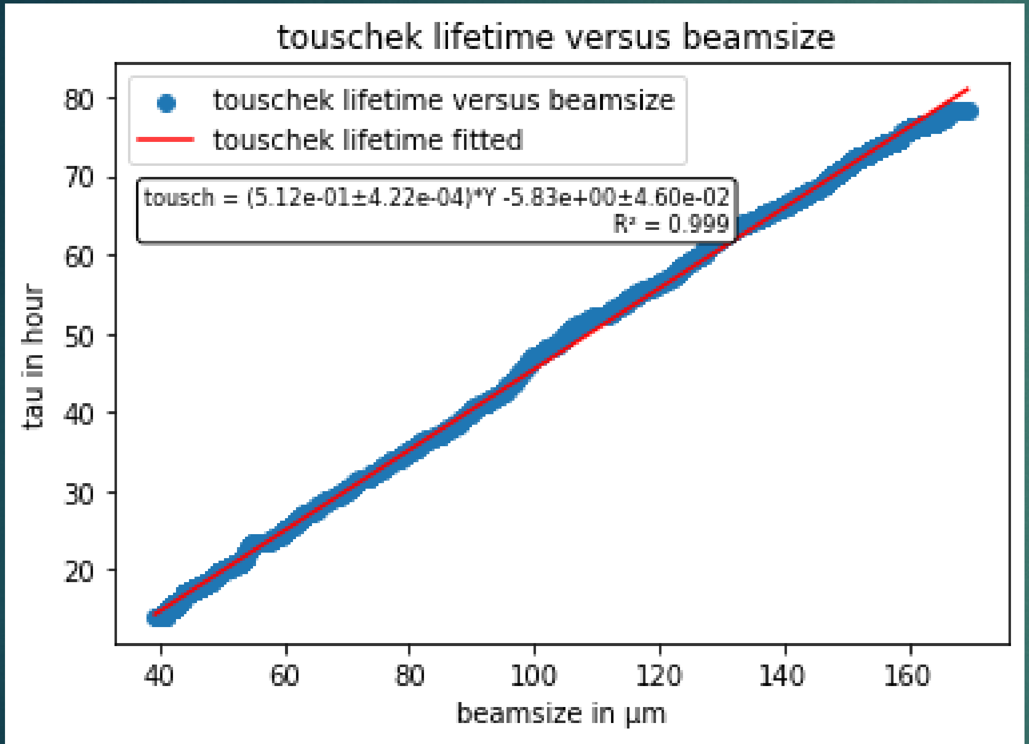
Well distributed residuals

$$\tau_{gas} = 88.1\,h \pm 0.3\,h$$

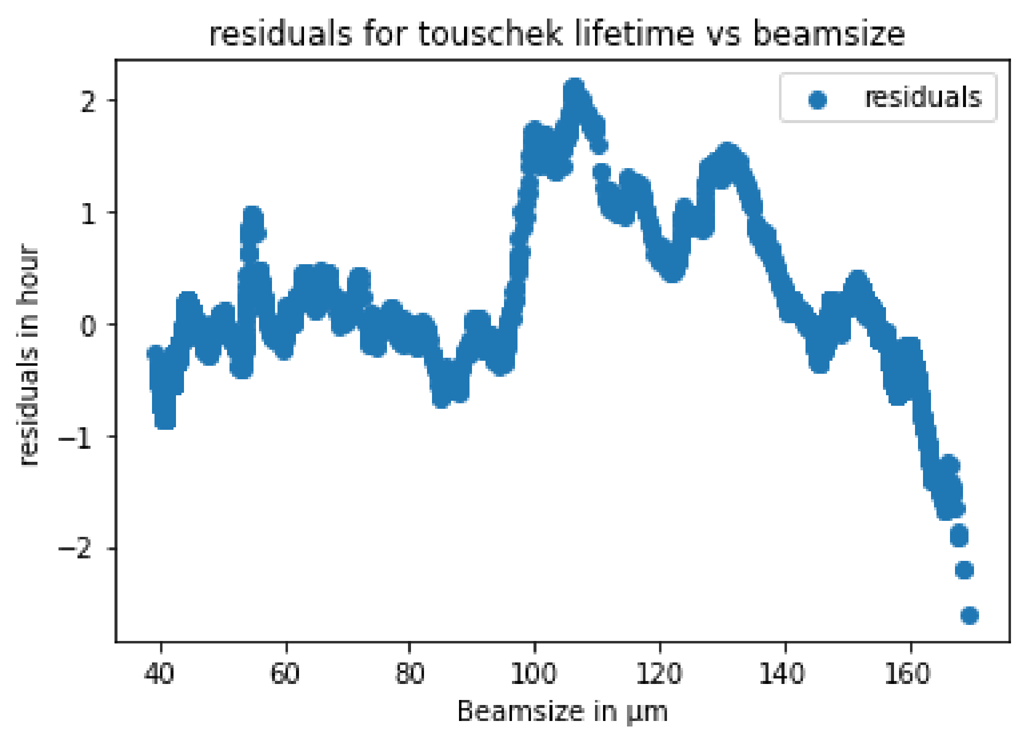
VI) Touschek lifetime versus beam size

$$\tau_{tousch} = (5.12 * 10^{-1} \pm 4.22 * 10^{-4}) * Y - 5.83 \pm 4.60 * 10^{-2}$$

R^2=0.999



Satisfaying fit !



Well distributed residuals

nominal Touschek lifetime is calculated for a forward power of 0 in the multi-bunch feedback

$$\tau_{Tousch_{nom}} = 14.052\,h \pm 0.008\,h$$

VII)The bootstrapp method for uncertainties

- **Bootstrap method**: Creating multiple new training datasets by randomly selecting observations with replacement from the original dataset.
- "With replacement" means selected observations remain in the original dataset, **allowing possible repeated selection**.
- Each new dataset is used to fit a **linear regression model**, similar to the original dataset.
- Repeating this process **10,000 times** generates a distribution of regression coefficients and intercepts, estimating uncertainties in the original regression model.

```
for i in range(n_iterations):
    # Bootstrap sampling of data
    x_boot, y_boot = resample(x_train, y_train)
    # Create a linear regression model and train it on the
      sampled data
    model = LinearRegression()
    model.fit(x_boot, y_boot)
    # Save the sampled regression coefficients
    coef_samples[i] = model.coef_
    # Make predictions on the sampled test data
    y_pred_samples[i] = model.predict(x_test)
    intercept_samples[i] = model.intercept_

# Calculate uncertainty on regression coefficients
coef_std = 2 * np.std(coef_samples, axis=0)
intercept_std = 2 * np.std(intercept_samples)
```

VIII) Conclusion

- The fast loss monitor are better to compute lifetime during experiments and the slow ones during user operation

- The **chromaticity may be not optimized** at SLS and could be lowered to increase lifetime if we stay in the stable range of chromaticity

- Loss monitors don’t behave in the same way during normal operation and experiments

- To compute lifetime with a loss monitor more precisely it is necessary to **normalize loss by beam current.**

- At SLS, the Touschek lifetime during normal operation is **14h** and the gas scattering lifetime is **88h**

VIII) Further steps to improve this study

- **Repeat measurement** of change of horizontal chromaticity at the nominal beam current to find the optimized chromaticity of the machine

- **Repeat measurement** of lifetime versus beam size with a wider range of beam sizes to have a more precise value of gas scattering lifetime.

Special thanks

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