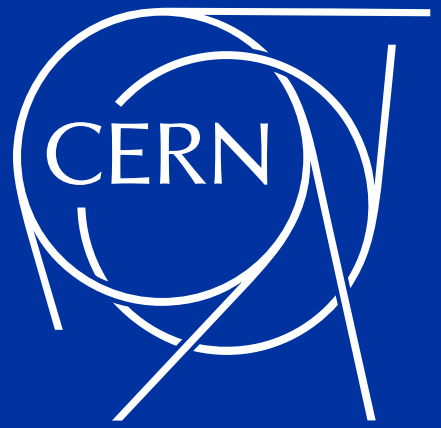


Results of the Linac3 Source Clustering

Max Mihailescu

April 6th, 2020

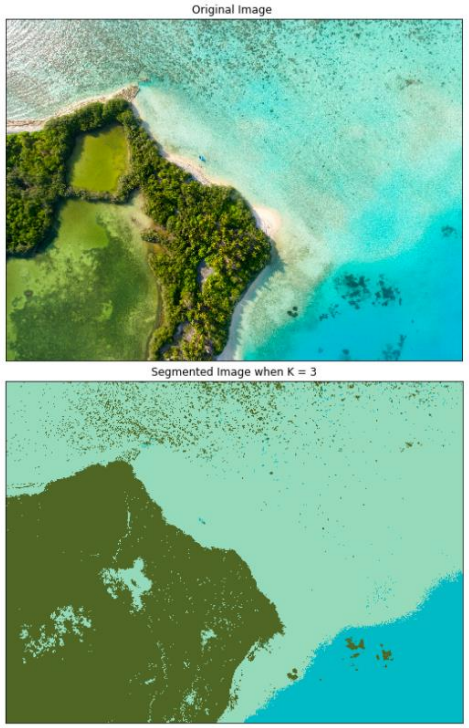
Motivation

- Can an autopilot or automatic source operation support be developed?
- Study on how the source was operated in 2015, 2016 and 2018 (lead periods)
- Did recurring settings exist that could be used as a general rule?
- How was stability linked to different settings?

Clustering can help to answer some of these questions

What is Clustering?

Given a set of data-points, the goal of clustering is to group similar points together and have a high dissimilarity between the groups.



https://towardsdatascience.com/introduction-to-image-segmentation-with-k-means-clustering-83fd0a9e2fc3

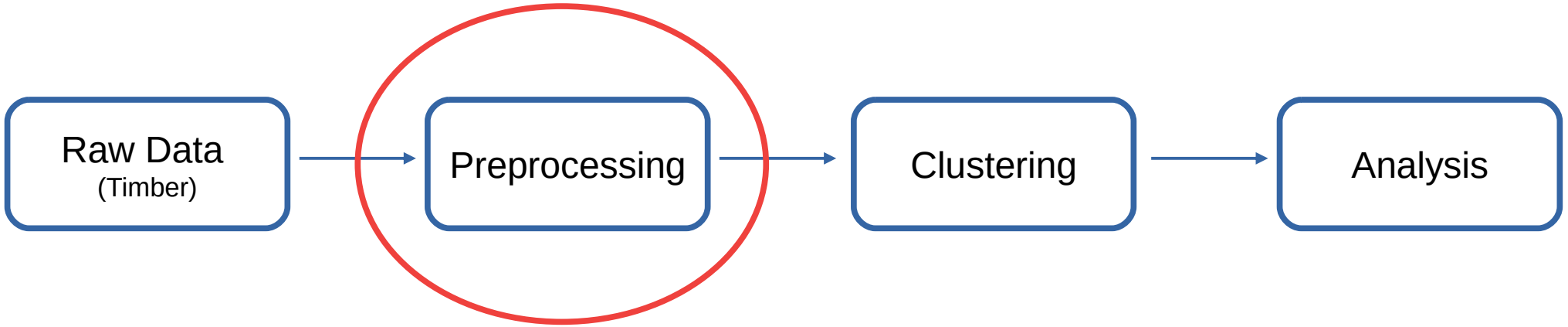
For Linac3: Group together points that represent the same settings of the source.

Features
- Gas Voltage
- Bias Disc Voltage
- RF Power
- Solenoid Currents (Inj./Central/Ext.)
- HT Current

Additional
- Oven Power
- BCT25

Time information is lost!

Overview of the process



- **Removal of time periods without interest**
  - Source off or no beam (BCT05)
- **Two regimes: Stable vs unstable source (measured at BCT25)**
  - Lower bound for output current (15µA)
  - Upper bound for standard deviation (ca. 5-10% from mean)

Demonstration

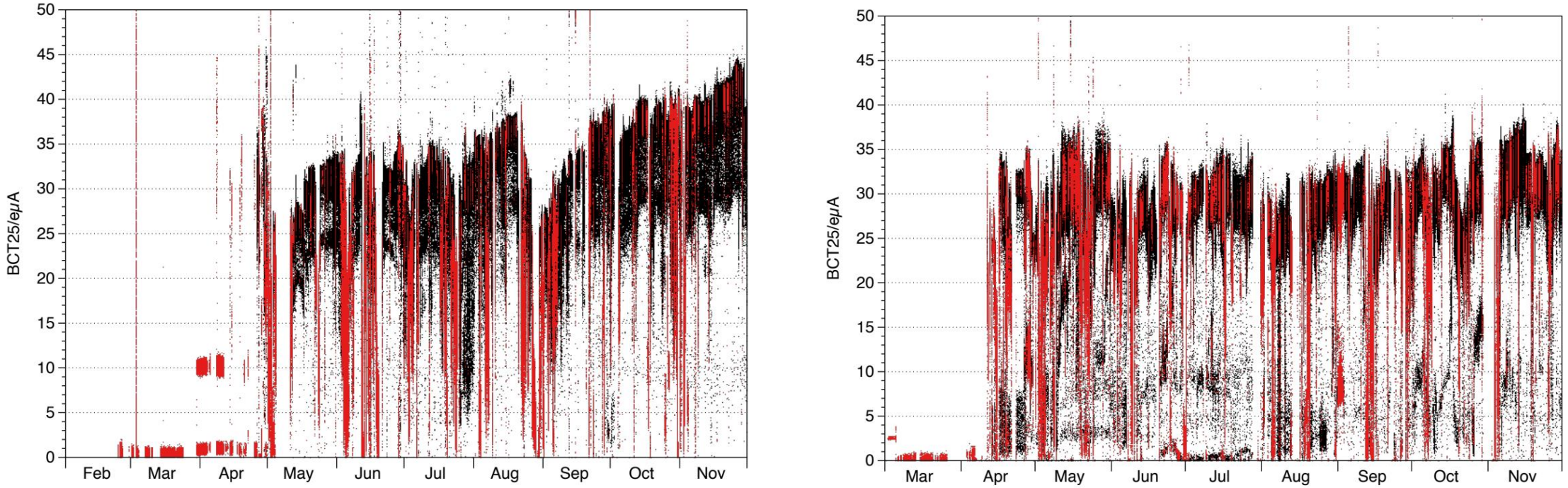


Figure: Yearliy plot of BCT25 with unstable periods in red (2016, left compared to 2018, right)

In total the source was running stable…

…62.8% of the time in 2015. …70% in 2016. ….68% in 2018.

BCT41 intensities during stable operation

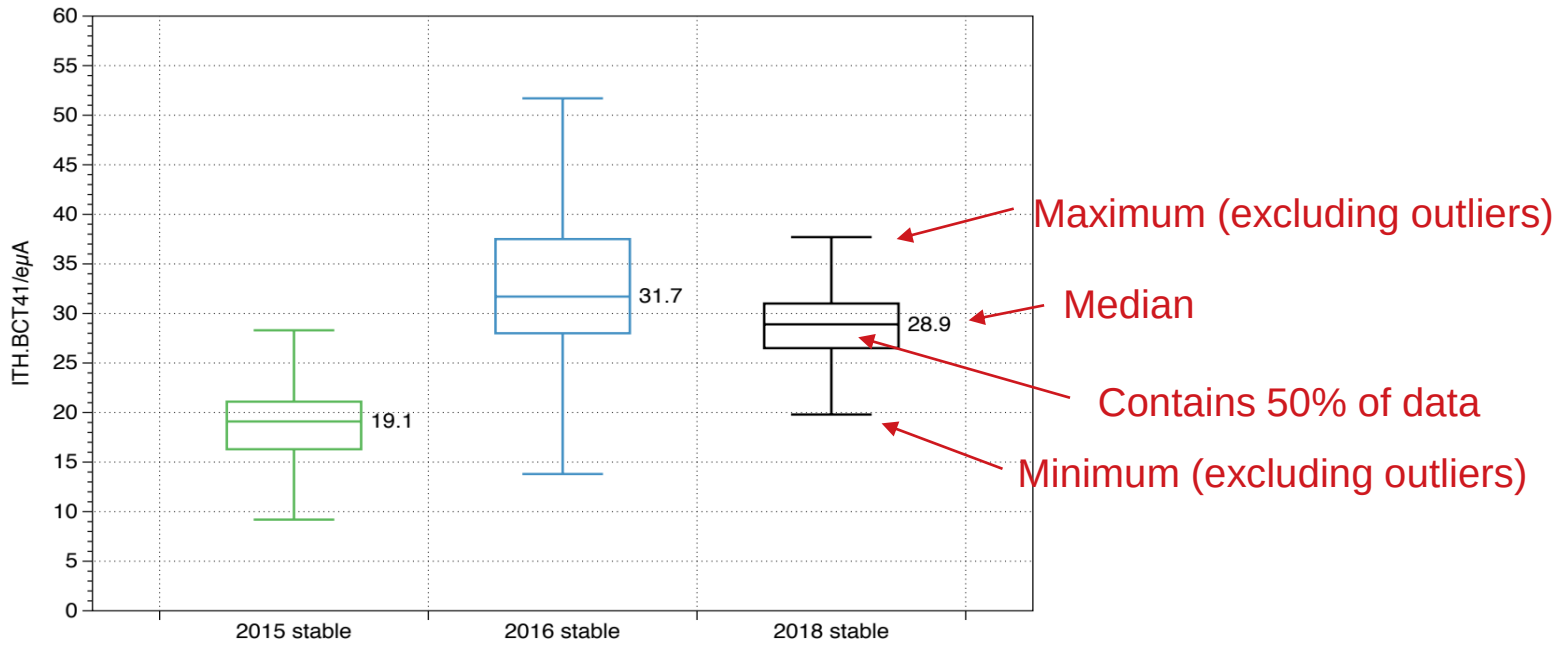


Figure: Boxplots for BCT41 current during the stable periods of the three years

- Different intensities where reached during the three years
- Highest intensity in 2016

An example cluster

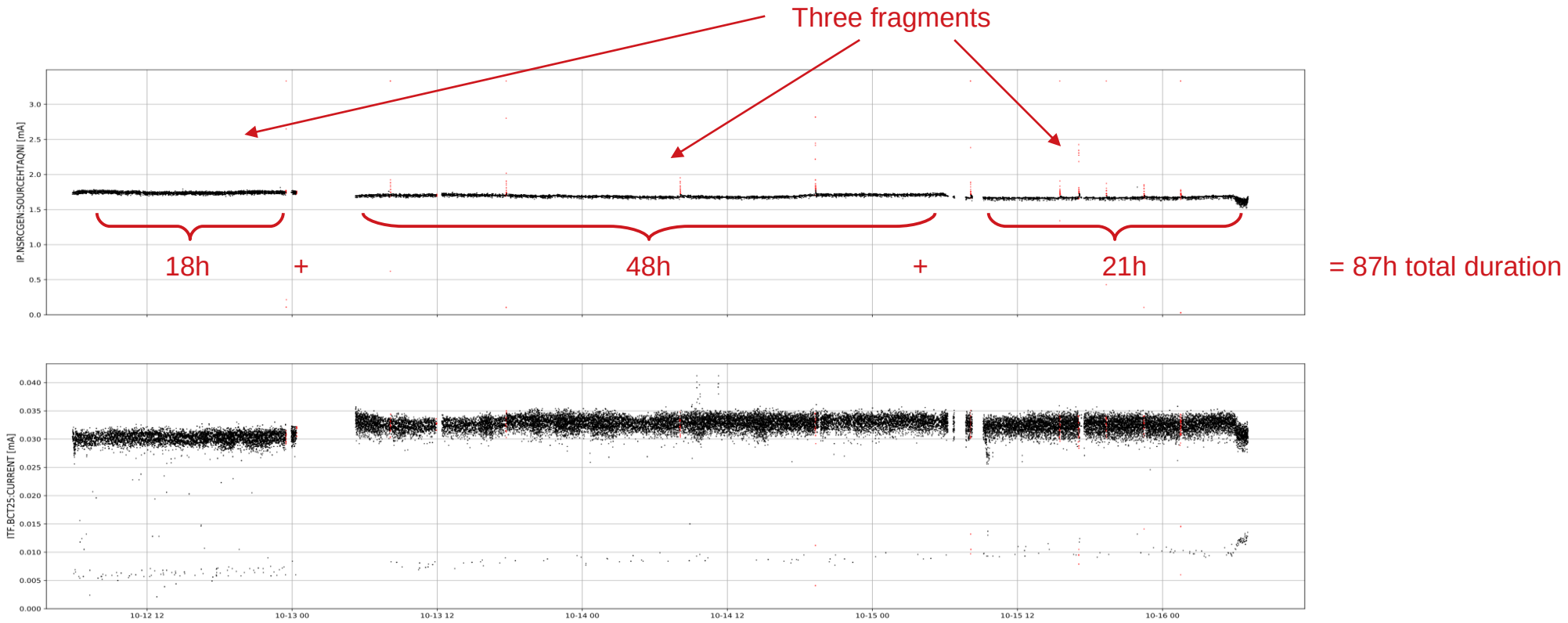


Figure: One of the longest clusters of 2018

A lot of variability within a year

Parameter	Median (% std)			
Bias Disc [V]	-305 (0.3)	-299 (0.2)	-297 (0.0)	-340 (0.1)
Gas [V]	9.92 (0.0)	9.92 (0.0)	9.92 (0.0)	9.93 (0.0)
Oven [W]	20.8 (8.7)	21.4 (7.6)	9.7 (5.4)	10.4 (4.3)
RF [W]	1903 (0.9)	1883 (0.2)	1879 (0.1)	1997 (0.01)
Inj. Solenoid [A]	1180 (0.6)	1220 (0.3)	1250 (0.0)	1230 (0.0)
Cen. Sol. [A]	150 (0.2)	180 (0.0)	175 (0.0)	220 (0.0)
Ext. Solenoid [A]	1259 (0.0)	1259 (0.0)	1259 (0.0)	1249 (0.0)
HT current [mA]	1.92 (1.4)	1.86 (9.0)	1.0 (1.9)	2.15 (1.3)
BCT25 [µA]	35 (5.8)	38 (3.5)	40 (3.8)	30 (10.2)

Table: Four biggest clusters of 2016, stable operation

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Two examples

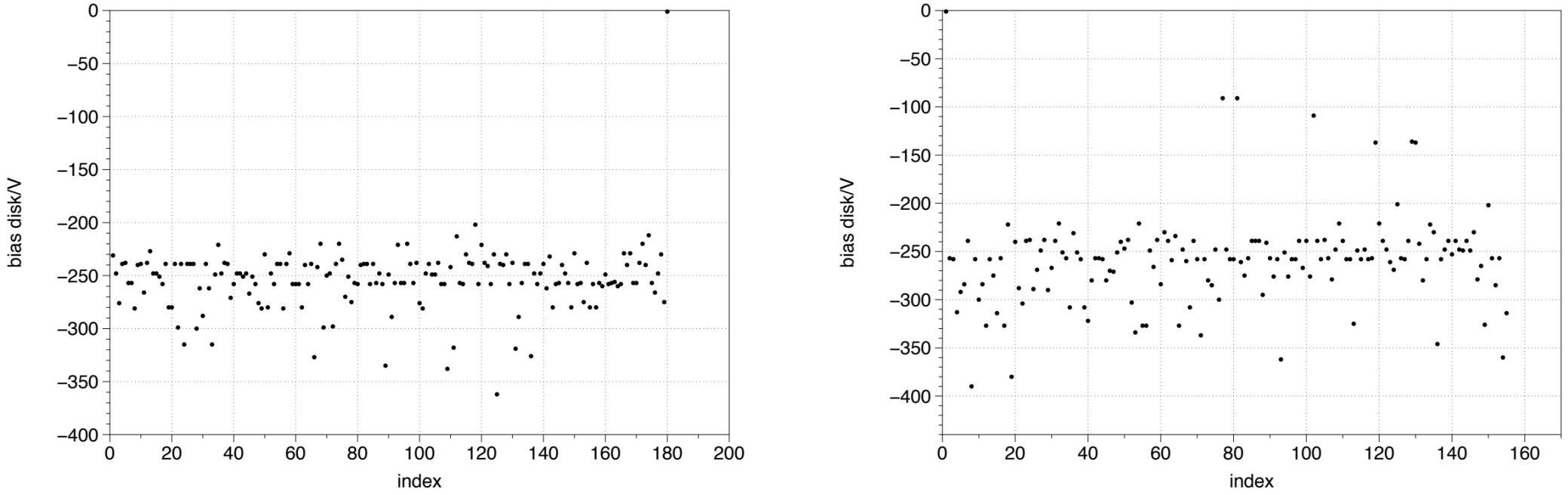


Figure: Bias Disc in 2018 (stable, left vs unstable, right), sorted by total cluster duration (longest at lower index)

Two examples

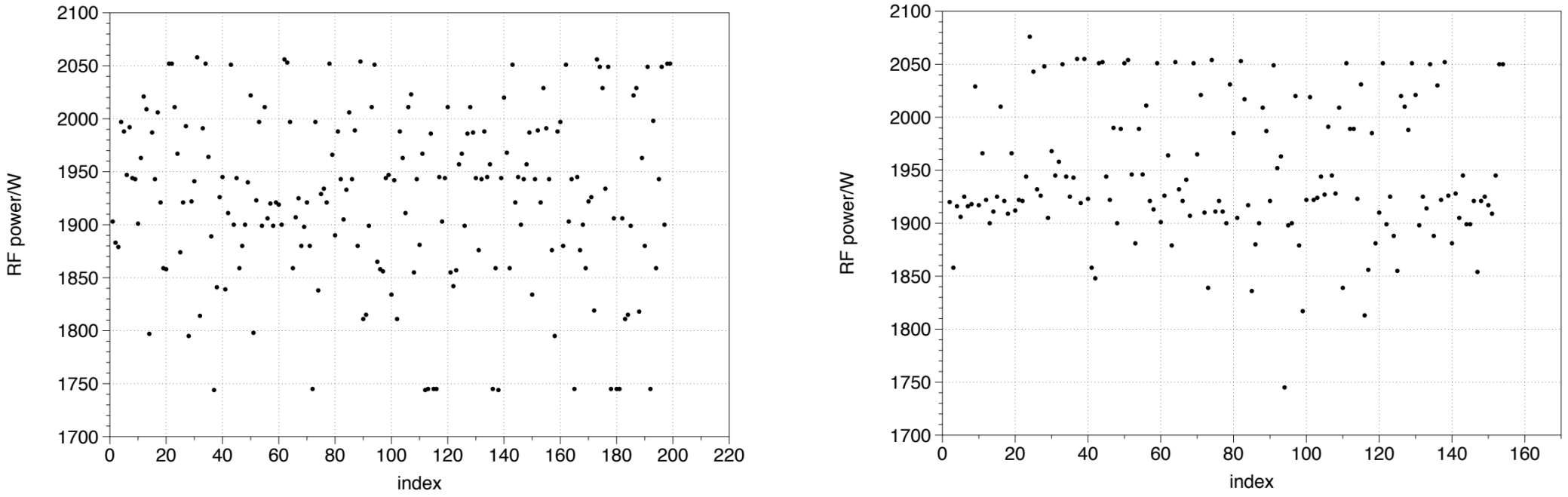


Figure: RF in 2016 (stable, left vs unstable, right), sorted by total cluster duration (longest at lower index)

.. and also between the years

- **Similar result when comparing the different years**
  - Settings were very different in 2015, 2016 and 2017
- **Instabilities did not show any correlation with parameters**
  - Same settings could have lead to a stable or an unstable source
  - Neither linear regression nor SVMs (support vector machines) found any general rules

Results regarding setting duration

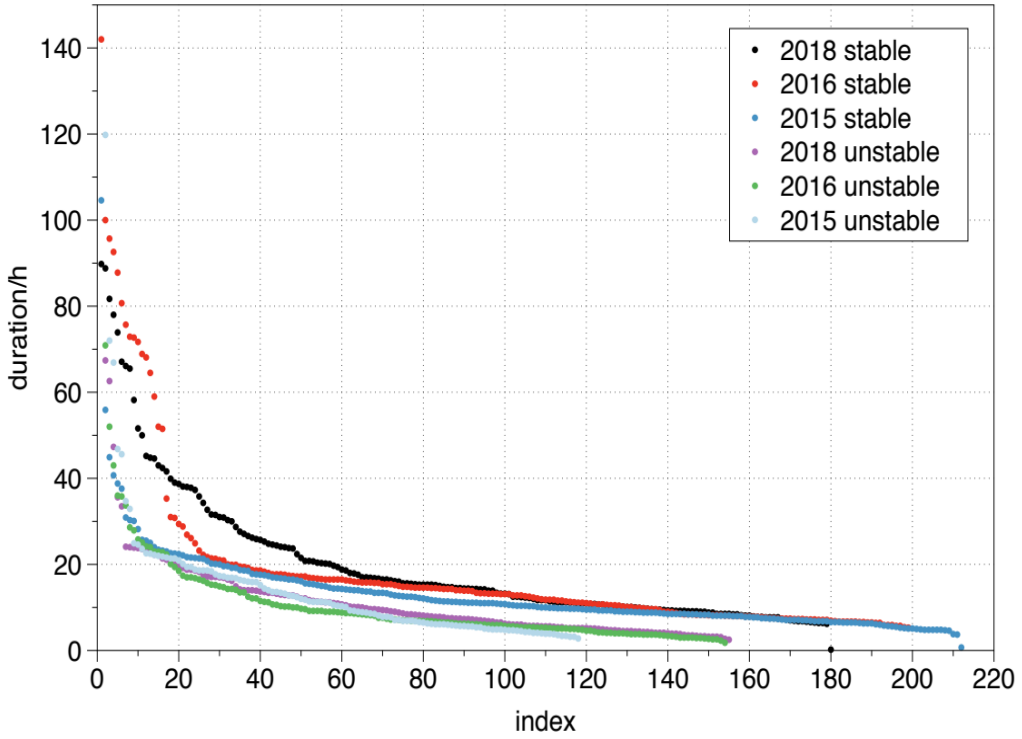


Figure: Cluster durations throughout the years

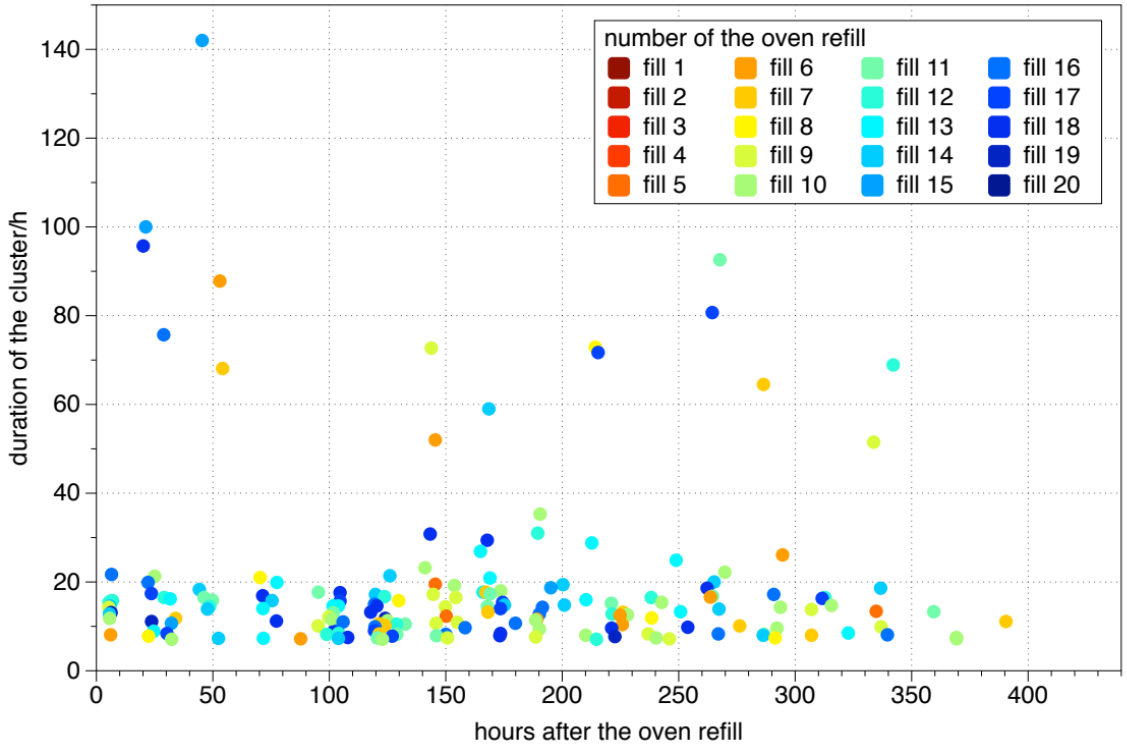


Figure: Duration of the clusters in relation to last ofen refill (2016)

- No single setting was used for a long time (Total operation ~6000h)
- Setting duration did not depend on the “when?” after a refill

Did the source take off where it left after a refill?

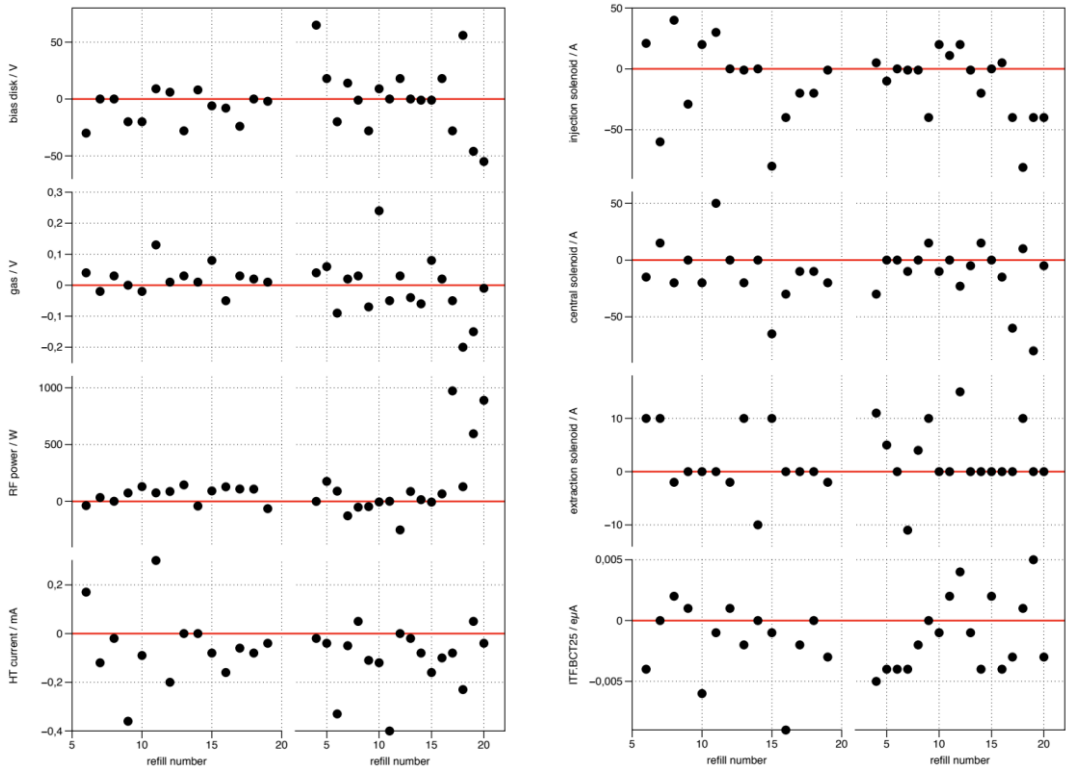


Figure: Difference of parameters after/before refill. 2016 (left) vs 2018 (right)

- Significant changes when comparing last stable interval before and first one after refill
- Source requires adjustments after new lead is filled in

Analysis of the HT breakdown rate

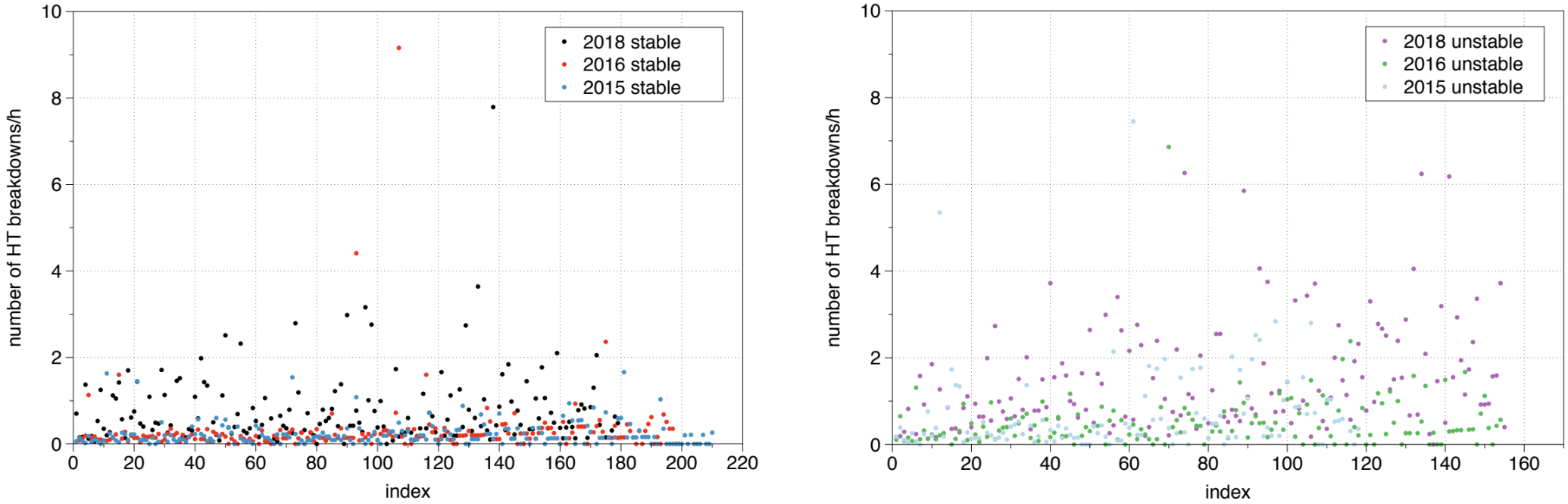


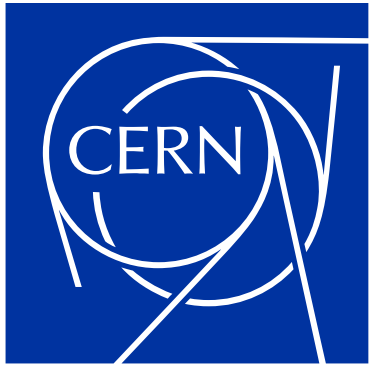
Figure: Number of HT breakdowns per cluster (stable periods, left compared to unstable periods, right)

- Slightly higher breakdown rate when the source was unstable
- No indication that certain settings lead to more breakdowns found

Conclusion and outlook

- Behavior of source and operations is very complex
- Many relationships are not well understood yet
- No quantitative results could be yet established

- Time dependency was not taken into account
- Important features of the source could be missing (Plasma Temperature, ...)


CERN

For Linac 4 (LBE run 2019)

- Source, Dump and Einzel voltage constant (as expected?)
- Lot of variation of the RF forward power and e/H ratio
- Two regimes of LEBT vacuum
- More and shorter clusters than with Linac3
  - More tuning?
  - More data?
  - Algorithm settings more sensible?