Operational experience with electrostatic septa at CERN

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Outline

- Introduction, ZS general overview
- Operation
- non-straightness investigation
- Improvement for LS3

SPS and ZS general overview

The electrostatic septa ZS are used for the slow extraction from the SPS towards the North Area.

In the framework of the LHC Injector Upgrade (LIU) project, an upgrade of the ZS was decided and aimed at reducing:

- the Break Down rate (increased over the year when the LHC beam circulated in the SPS),
- the vacuum activity in presence of high intensity, high frequency beams (LHC 25ns).

Of note: the 25ns LHC beam is not extracted by the ZS.

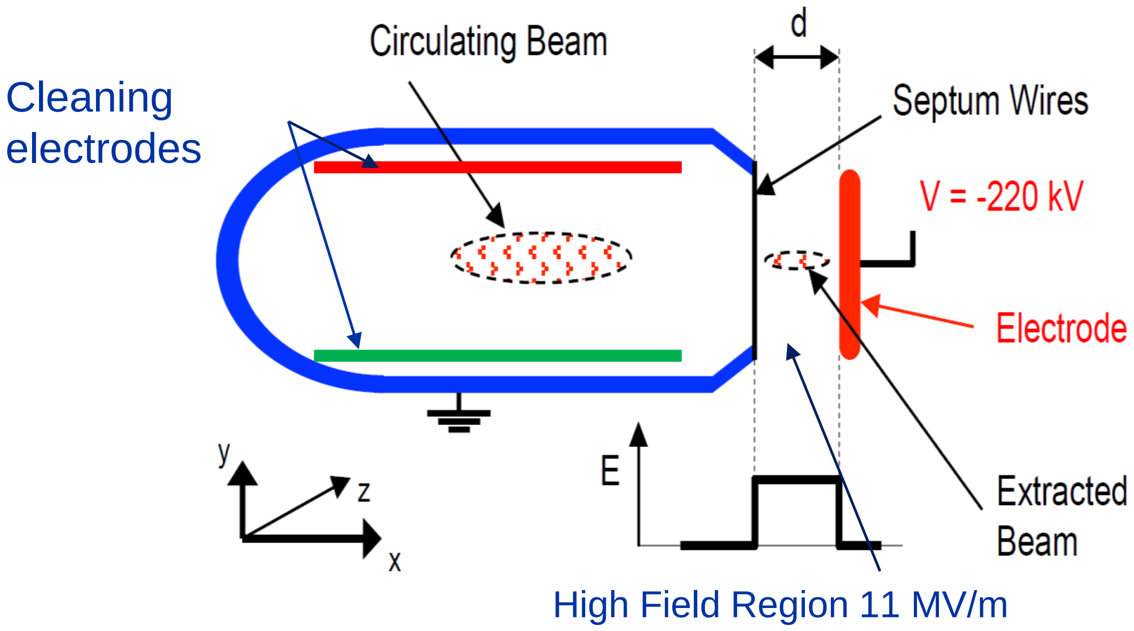
The upgraded ZS were installed in 2020 and operational since 2021.

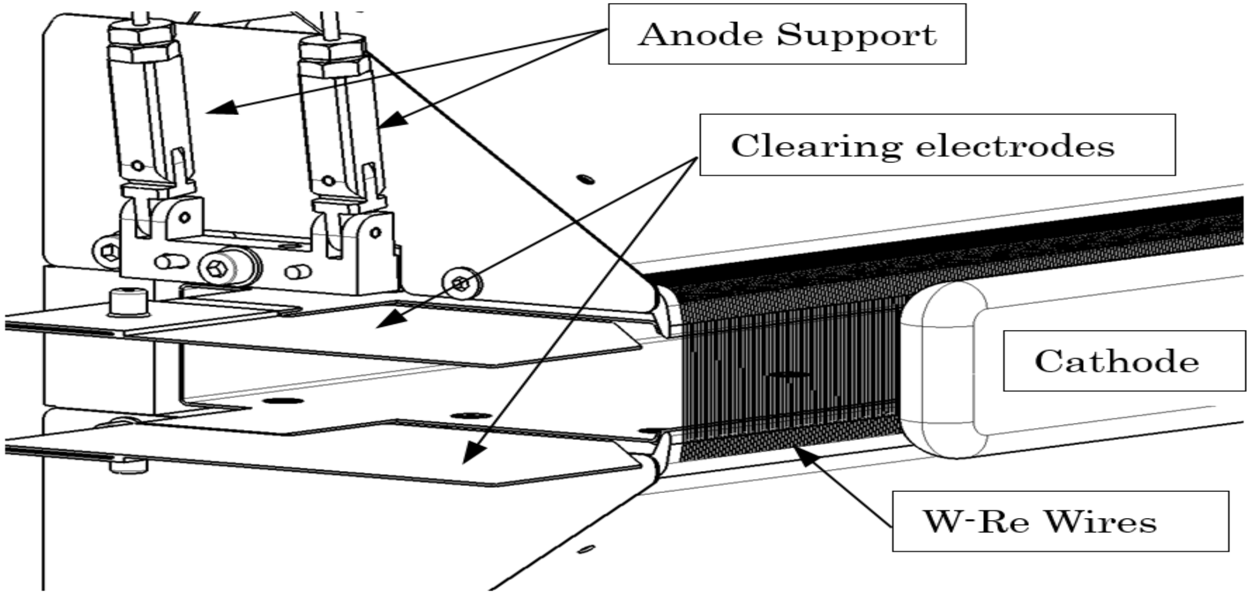
SPS and ZS general overview

The ZS upgrade addressed the challenges holistically with the following measures:

- Increasing the vacuum pumping speed,
- Reducing any possible electron cloud activity,
- Beam impedance reduction:
  - shield the ZS high field area better from the orbiting beam wake fields,
  - reduced the electron cloud activity,
- Anode direct grounding,
- Diagnostics improvements (Cleaning electrode direct voltage measurement).

Electrostatic septum layout





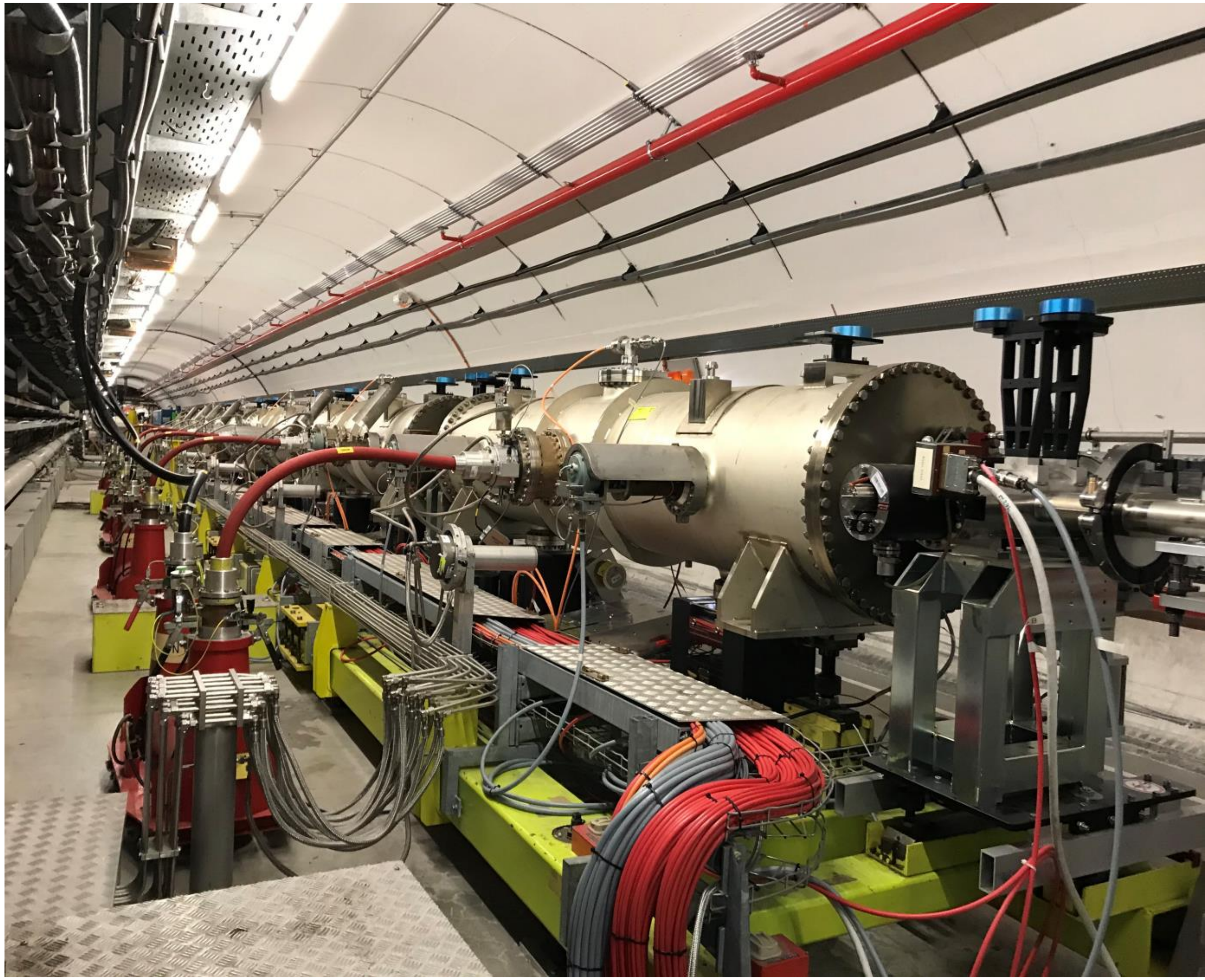
SPS ZS Layout

- **5 ZS installed of each 3.0 m long**
- **Individual anode positioning range**

  +/- 2 mm
- **Individual cathode displacement range**

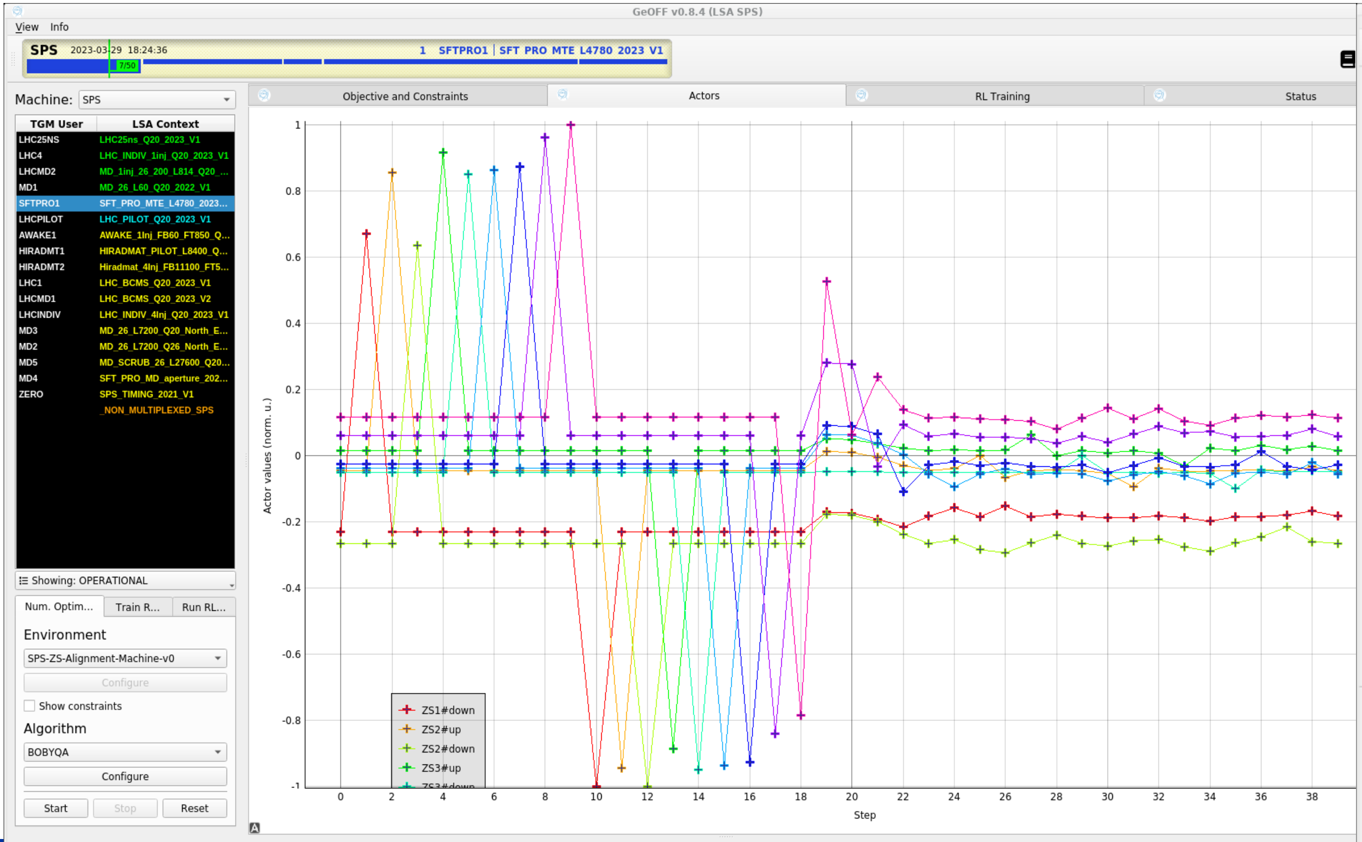
  17- 40 mm
- **Common HV generator** 0 - 300 kV
- **Individual clearing electrode power supplies**

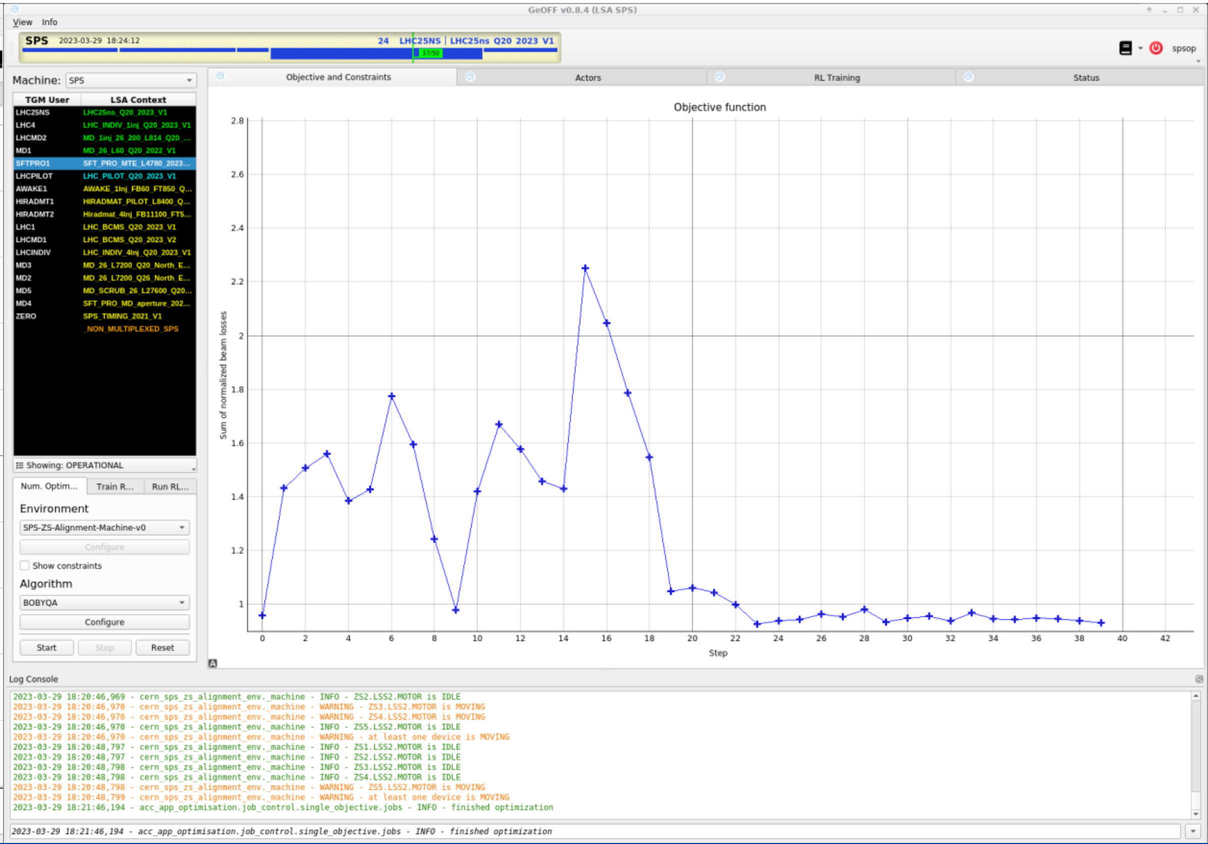
  0 - 10 kV
- **Nominal operational Field** 11 MV/m
- **All 5 ZS installed on a common motorised girder . Displacement range** +/- 30 mm.



Scan and alignment optimisation [1]

- During routine operation, a regular loss scan is performed,
- The improved anode motorization works very well, however, the installed potentiometers need regular cleaning after a period of nonoperation,
- At the beginning of the run, all anodes were set to the mid-position.





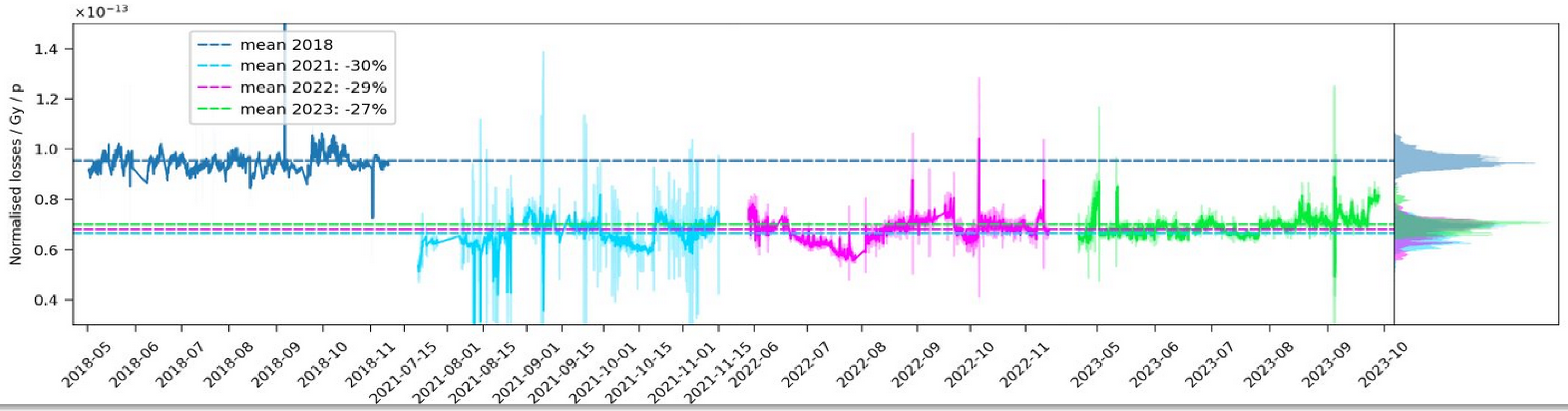
Crystal [2]

Routine operation with local shadowing

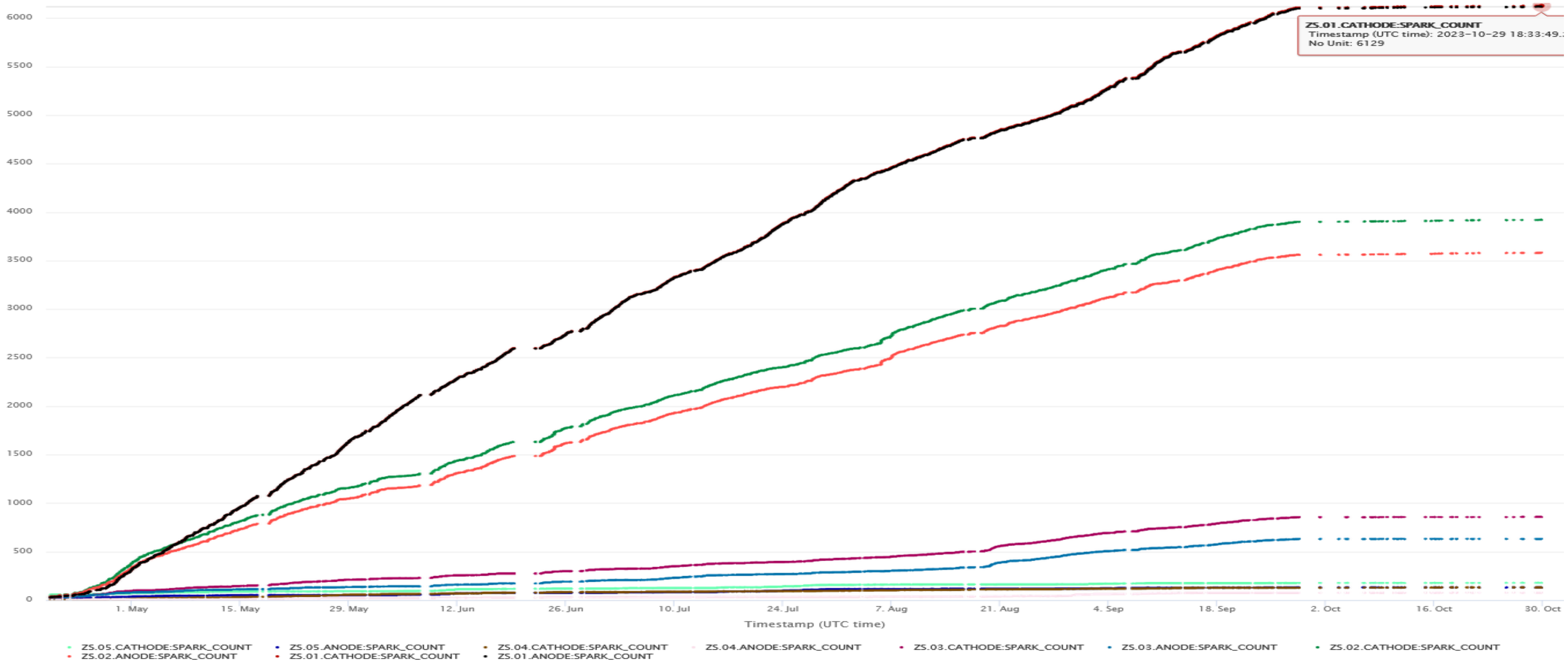
→Since 2021, TECS (local crystal) in operation in VR with intensities [1e13, 4e13] protons per extraction

→Consistent ~30% loss reduction: crystal 2/3 and new ZS 1/3

→Clearly visible in residual activation measurements of the area



ZS break down count evolution 2023

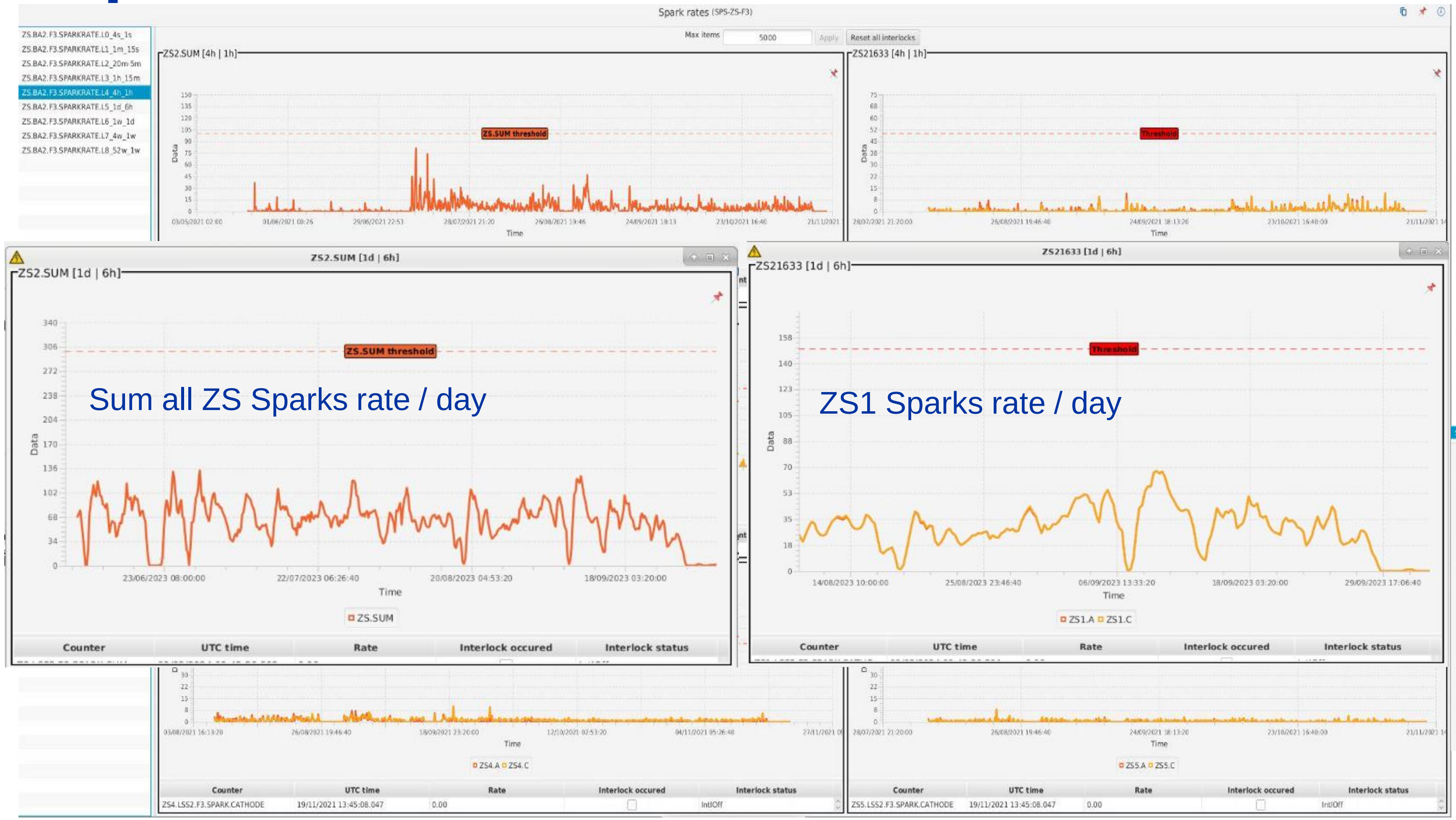


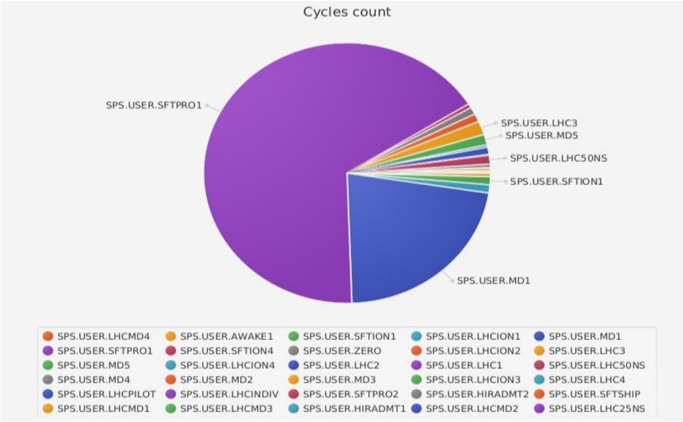
Cathode & Itrap top electrode Spark Counts

Compared to ZS before upgrade, the total spark count has been reduced, especially the number of high spark rates. Although the beams are not identical (now use the crystal upstream of the ZS), we tend to believe this is at least partly due to the upgrade.

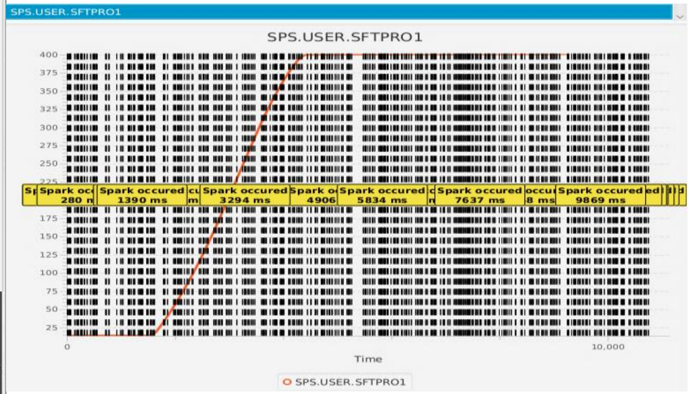
The favoured hypothesis is that the loss reduction contributes partially to the spark rate reduction.

Spark rate over the time





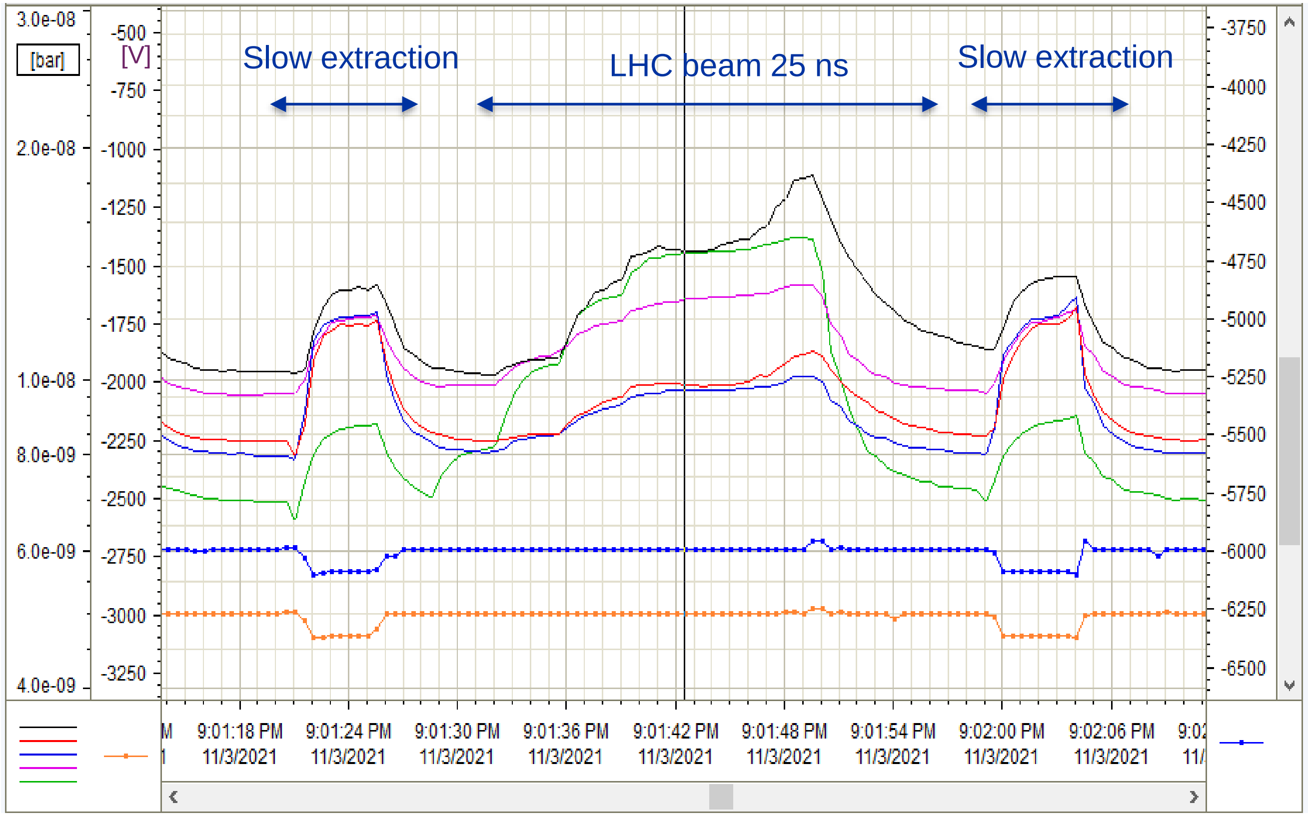
Sparks occurs mainly during SFTPRO cycles

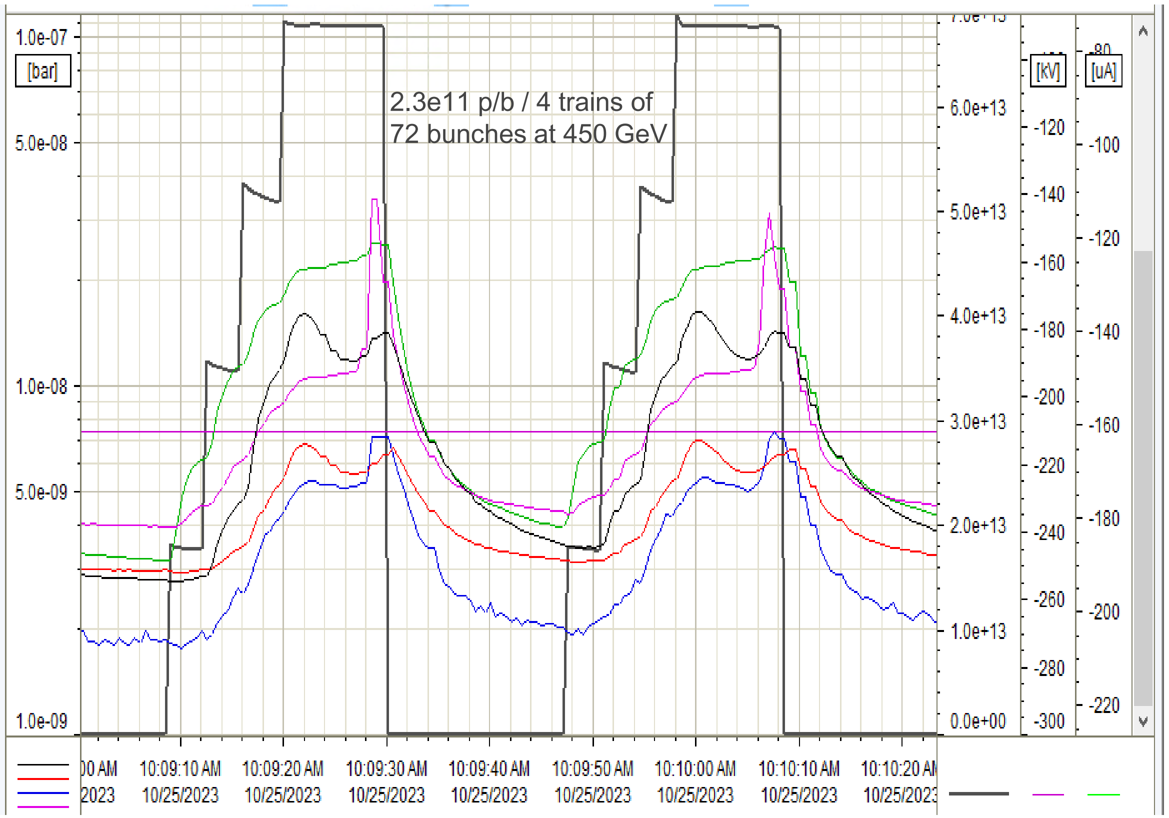


Sparks homogeneously distributed during cycle

2 interlocks from spark monitoring system in 2023 (max rate / 1hour).

Clearing electrode voltage monitoring





Vacuum Zs1-5 | U monitoring Zs1- Itrap Top | U monitoring Zs1-Itrap Bot | Vacuum Zs1-5 | Beam intensity

- Ion Trap voltage measurement stable during LHC high intensity beam,
- Electron cloud vacuum spikes still present, but without reaching vacuum interlock level,
- With the improved diagnostics, the electrode voltage can now be measurement directly on the electrodes and variations were observed.

Anode straightness investigation [3]

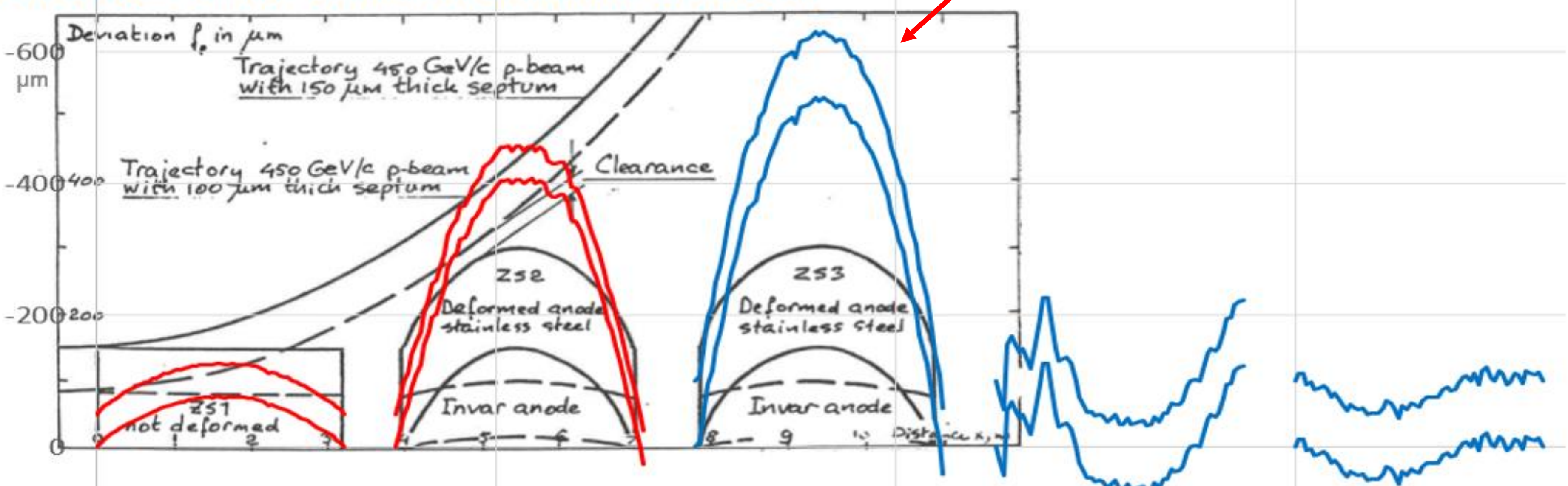
Anode straightness

EX channel is composed of

- 2 * Ø 60 µm wire ZS INVAR
- 1 * Ø 100 µm ZS INVAR
- 2 * Ø 100 µm ZS Stainless steel

INVAR chosen for low coefficient of thermal expansion

~500 µm deformation!!!

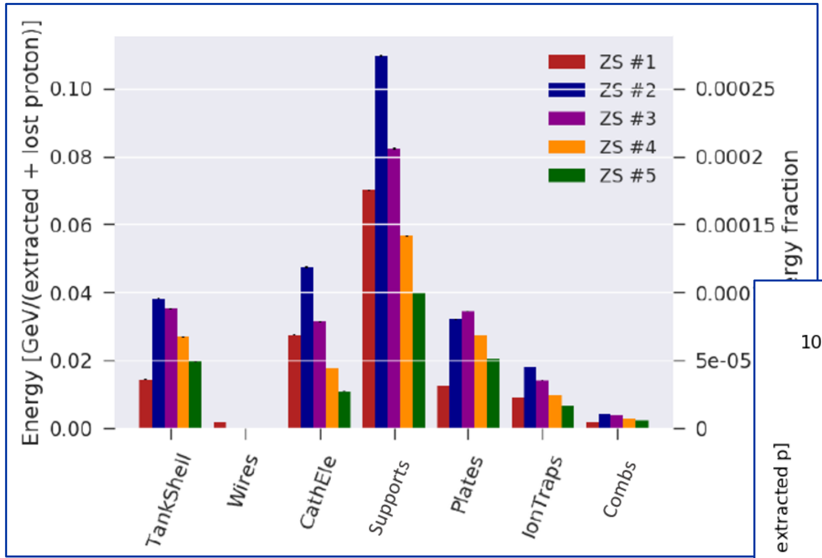


ZS1-2 anode straightness measurement results wire Ø 60 µm

ZS3-5 anode straightness measurement results wire Ø 100 µm

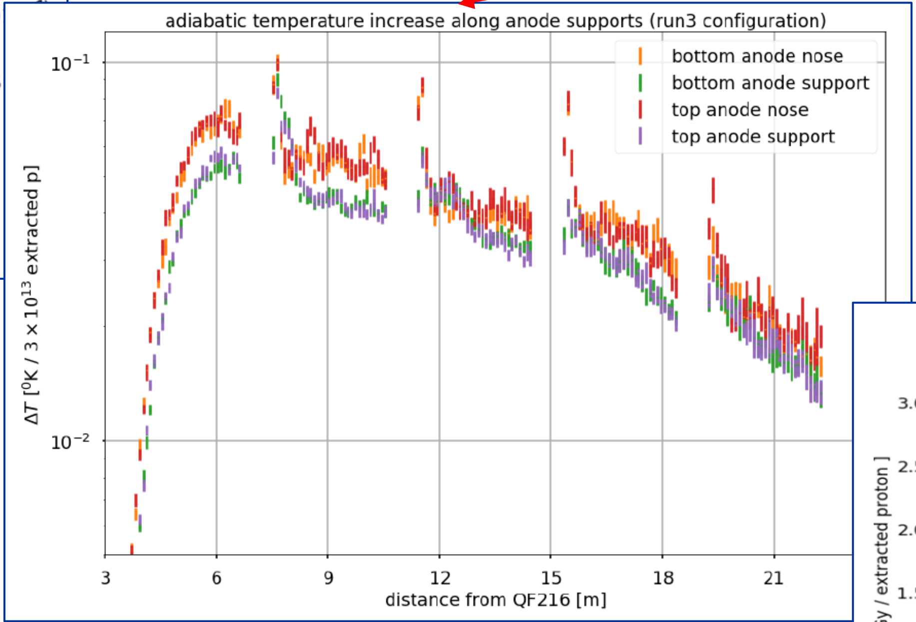
27 January 2022 B.Balhan, KEK/J-PARC SX workshop 11

Activation study in FLUKA [4]

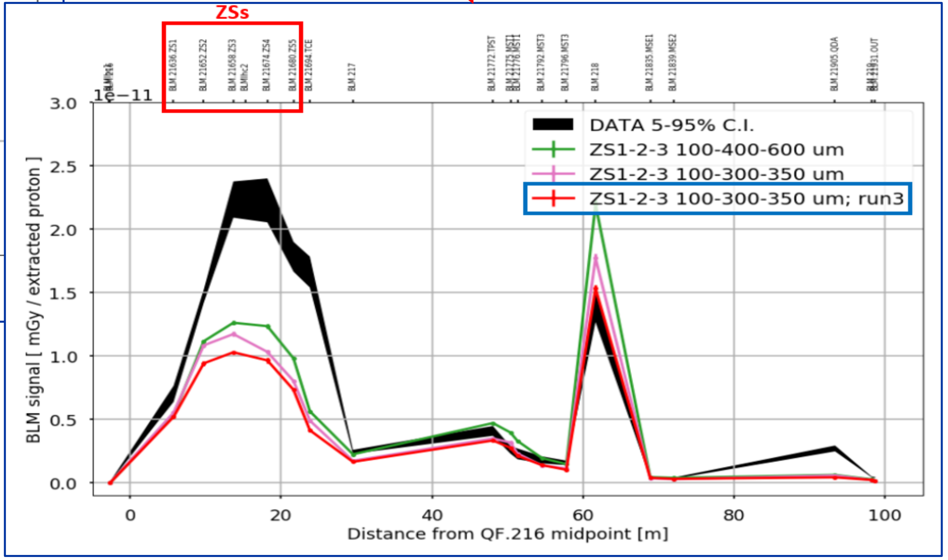


ZS2 anode support is the most activated component

Mis-match



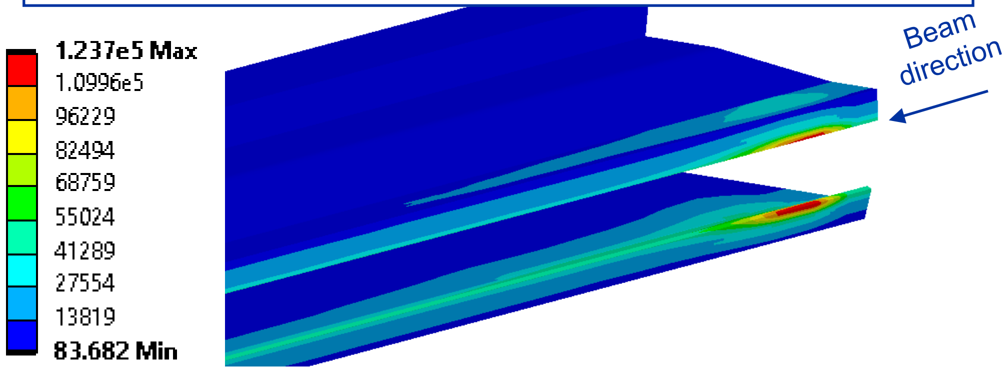
Highest thermal gradient for the ZS1



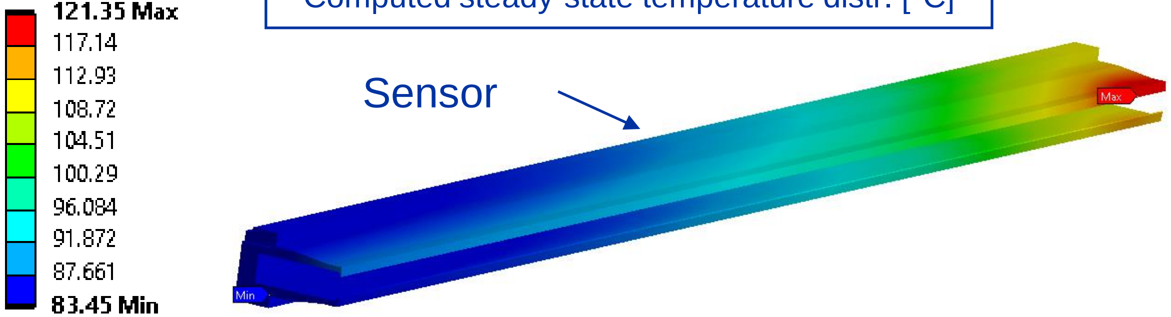
BLM data → reduction factor 2-2.5

Anode temperature distribution in ANSYS

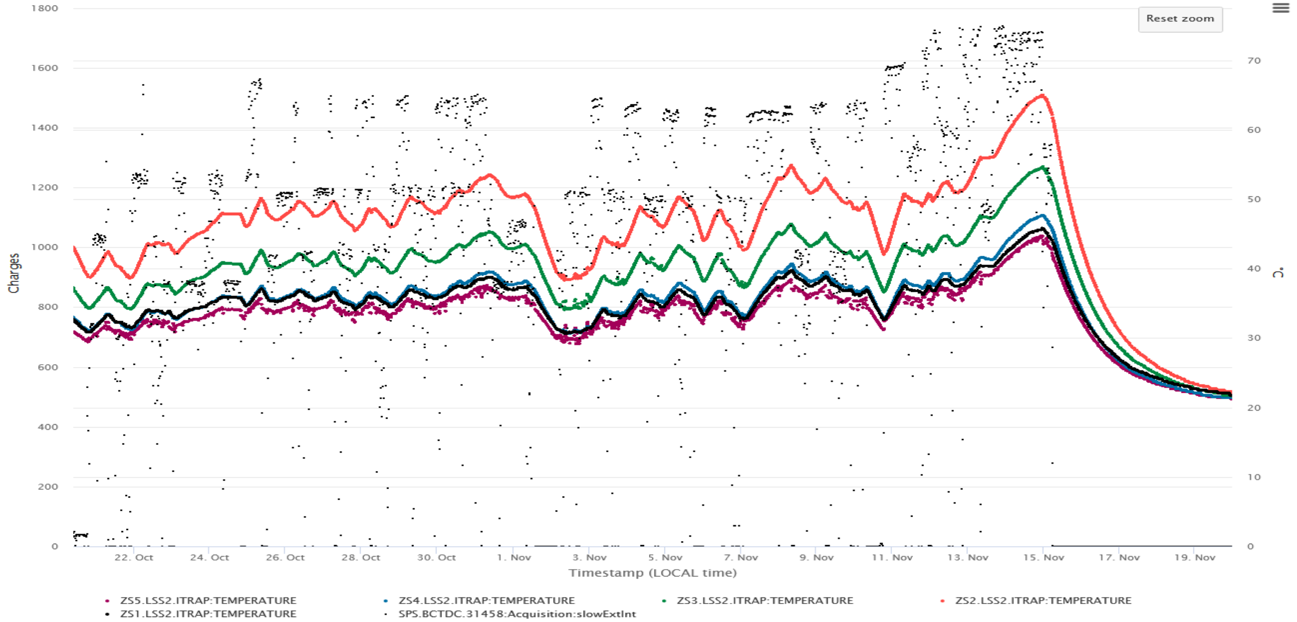
ZS2 Fluka Energy Deposition imported in Ansys $[W/m^3]$
(single extraction)



Computed steady-state temperature distr. [°C]



- **Installed thermal sensor** incapable to measure a gradient,
- **Backward deformation** in steady-state conditions → $CTE_{st.steel>} CTE_{Invar}$
- A **transient effect** could clarify the observations → Energy deposition concentrated at tip during extraction
- Measured temperature did not yet reach a stable equilibrium.

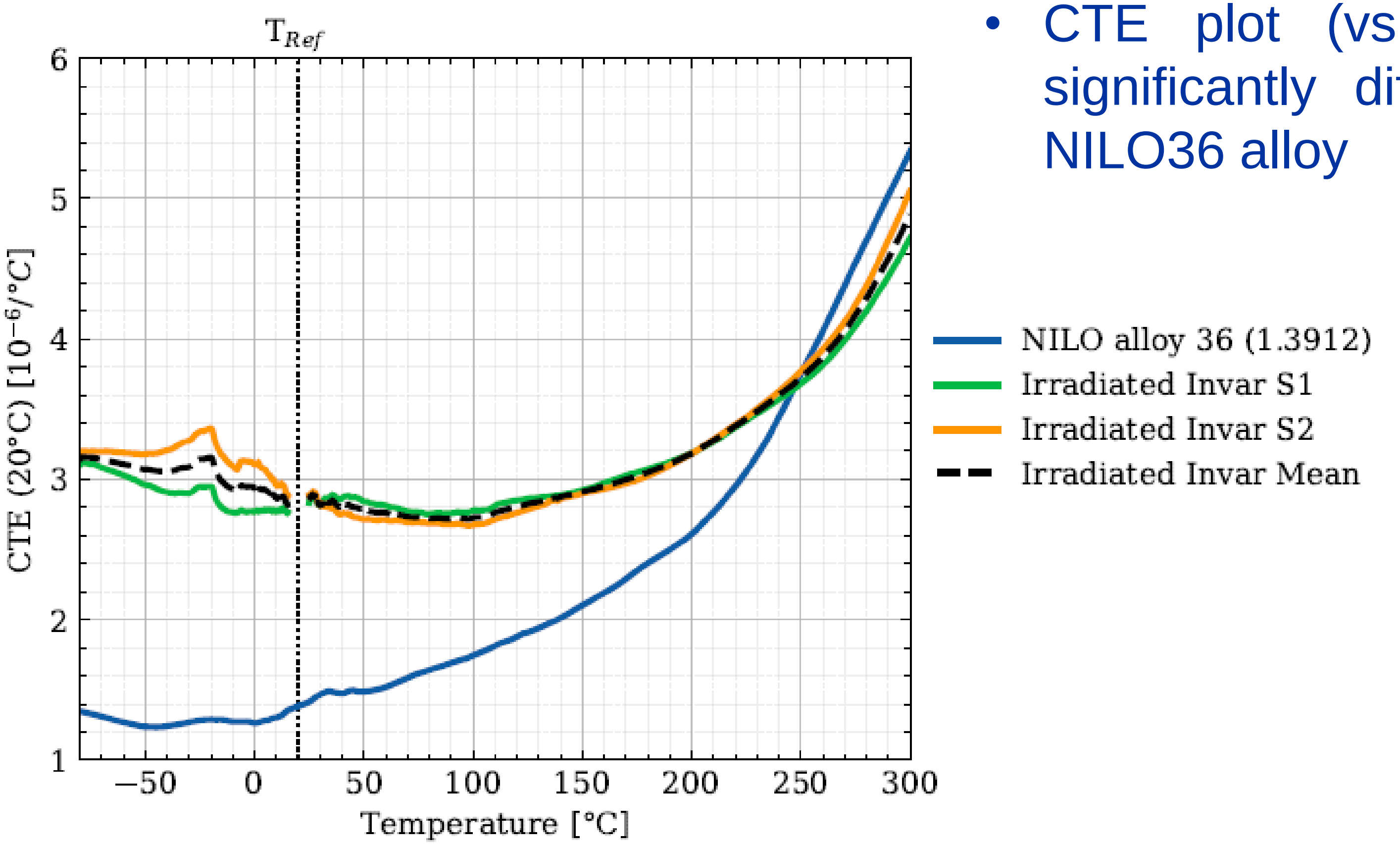


Anode temperature measurement ZS1-5 (midpoints)

Anode support straightness variation

- Computed static-deformations in nominal condition (no beam impact) → Max vertical sag = 1.33 mm (with ϕ100 µm W26Re wires strung on anode support),
- Simulation confirmed anode straightness deformation < 20 µm,
- Max. stress induced by beam energy deposition cannot explain the plastic deformation observed on ZS,
- Measured vertical sag about 40% larger than value from FEA (plastic deformation)→ Invar material properties not stable over time (aging, beam impact, radiation..?).

CTE measurements on irradiated Invar samples



- Samples have been taken on existing Invar Anode
- CTE plot (vs. temperature) of the used Invar is significantly different than the CTE of the standard NILO36 alloy

Anode straightness variation on ZS2 [5]

The observed plastic anode deformation cannot be explained by the computed stresses, which all remain below the plastic deformation limit.

Possibly, the anode straightness deformation is higher in-beam than measured in the lab,

→ would be good if this could be monitored on-line.

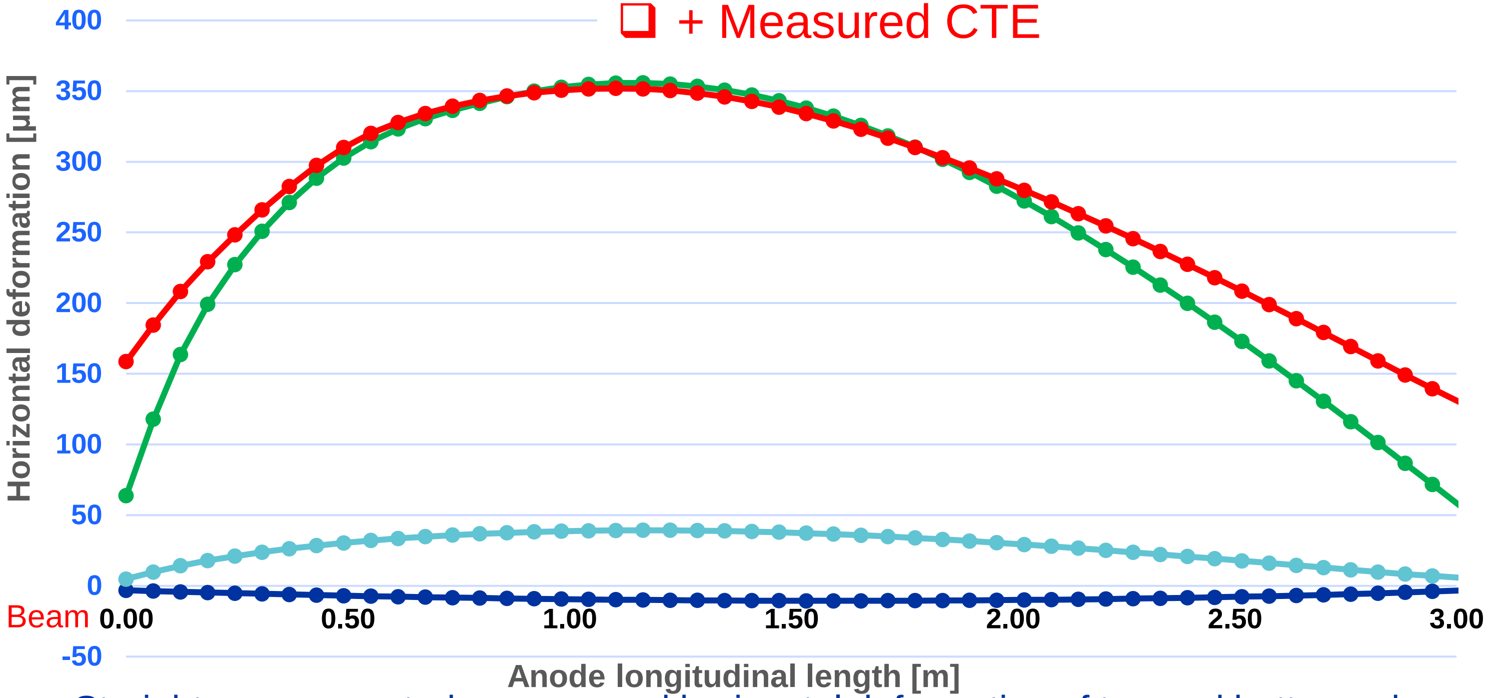
If an elastic deformation is confirmed, Invar is not effective ?

→ could consider anode cooling and/or low-Z anode.

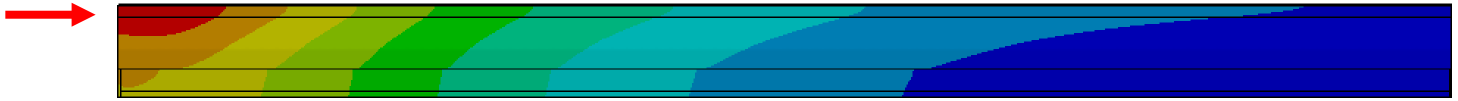
Thermal gradients expected to be higher during **transient** → larger thermal-deformations.

Legend:

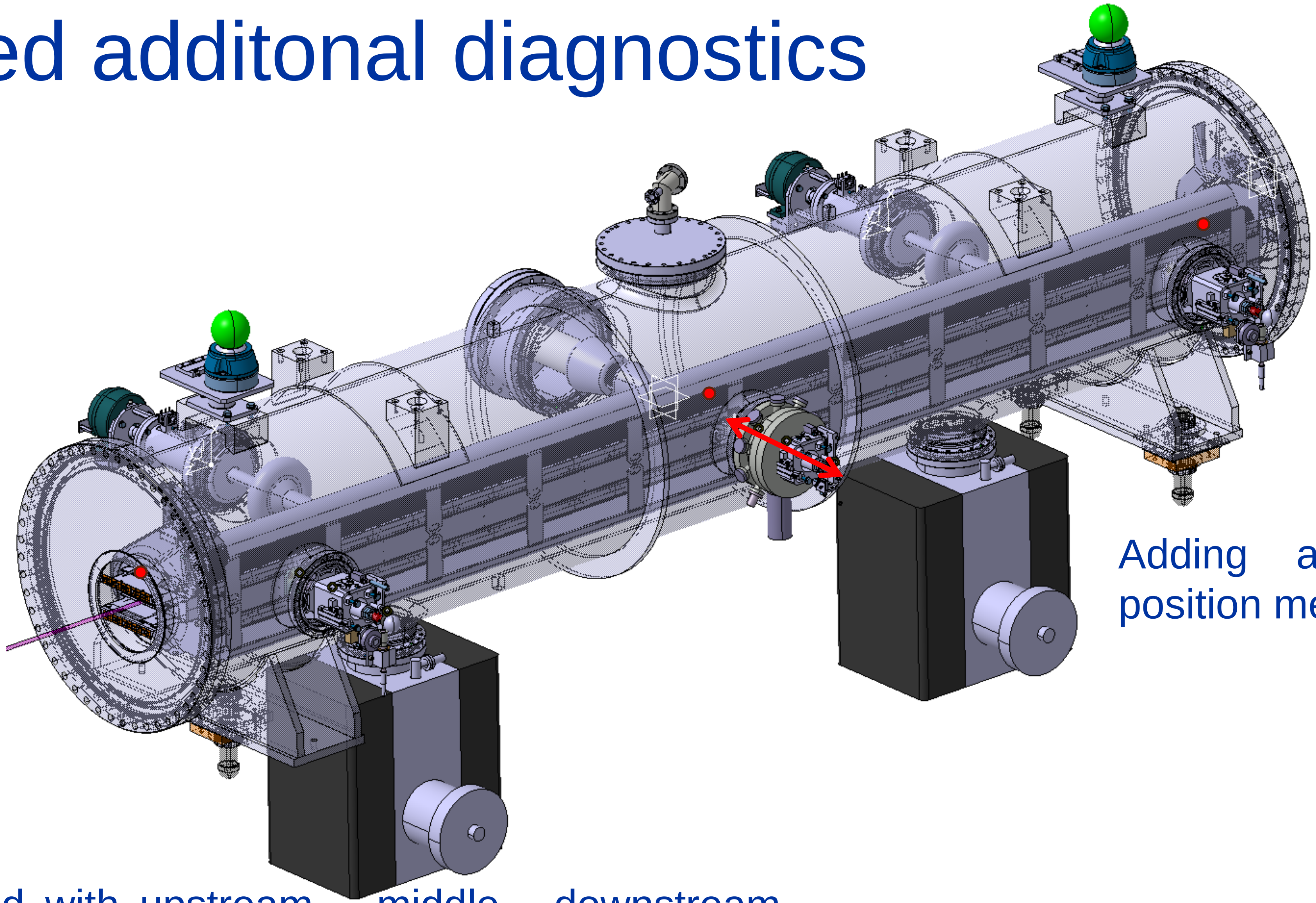
- ❑ Static loads (self-weight + wires effect)
- ❑ + Computed FLUKA Energy Deposition
- ❑ FLUKA ED x 2.5 (BLM data)
- ❑ + Measured CTE



Straightness computed as averaged horizontal deformation of top and bottom edge



Proposed additonal diagnostics



Adding an intermediate position measurement

Anode equipped with upstream – middle - downstream temperature sensors

Outlook

Next long stop (LS3) planned for 2026-2027. The following works are scheduled:

- SPS LSS2 full re-cabling campaign (irradiated cable replacement control/power),
- Global equipment removal for ALARA considerations,
- Propose to use this opportunity to install Low-Z ZS [6]:
  - intermediate positioning measurement (evolution of straightness of new machined Invar anodes)
  - add Upstream and Downstream temperature sensors to determine real temperature and gradient
- Improve conditioning process using Machine Learning,
- New main HV generator (SF6 elimination).

References:

[1] Routine operation plot from CERN Op logbook F.Velotti .

[2] Crystal shadowing F.Velotti 5th Slow extraction Workshop TFZ Wiener Neustadt

[3] Summary of recent investigations on ZS anode straightness B.Balhan SLAWG #56

[4] Estimate of temperature profile along ZS anodes from FLUKA simulations SLAWG #58

[5] low-Z SPS electrostatic septa F.Pirozzi ABTEF aug 23

[6] Development of Low-Z septa for CERN's future FT programme F.Lackner 5th Slow extraction Workshop TFZ Wiener Neustadt

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