Energy matching

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Outline

- Definition and goals
- Tools to measure energy matching
- Energy matching parameters
- Energy matching procedure
- Energy matching for the future
- Energy matching variation

Definition and goal

- Energy matching “definition”
  - The energy matching is an adjustment of the magnetic bending fields and beam momentum between two consecutives accelerators in a way that guarantees a correct beam transfer between the two machines.

- Why is the beam transfer is better if we have a correct energy matching?
  - The RF capture in the downstream machine will be better because:
    - The synchro loop will only need to be finely tuned, not a big adjustment
    - The mean radial position at the first turn and on the closed orbit will be the same and closed to 0 mm => transverse parameters keep the same value on injection transient.

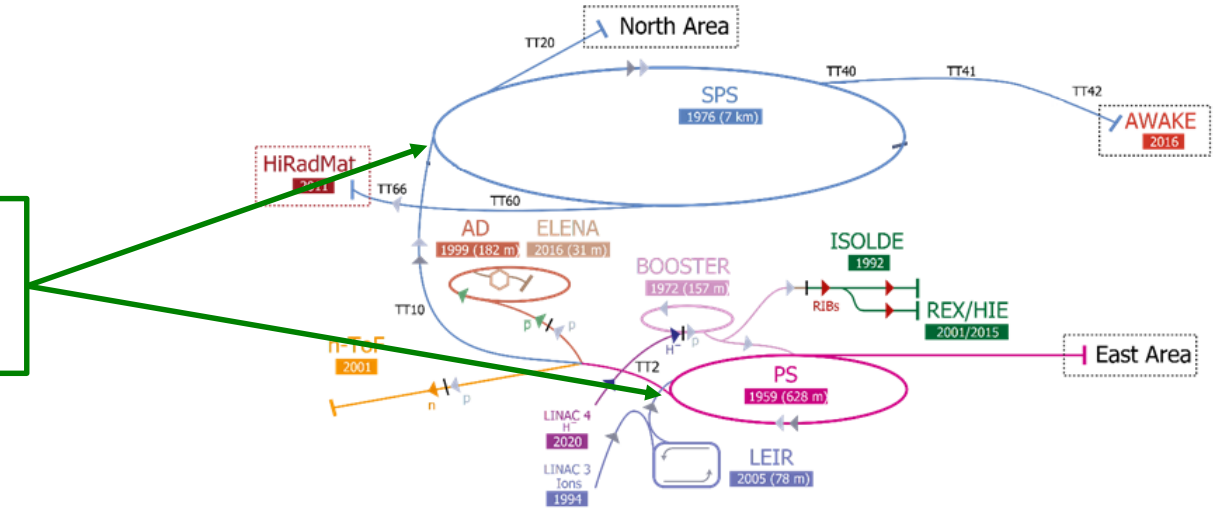
- Equation (frequency error, orbit error and magnetic field correction)
  - $B_{SPS,new} = B_{SPS}\left(1 - \gamma^2 \frac{\Delta f}{f} - \left(\gamma^2 - \gamma_{T_{SPS}}^2\right)\frac{\Delta R}{R_{SPS}}\right)$
  - $B_{PS,new} = B_{PS}\left(1 - \left(\gamma^2 - \gamma_{T_{PS}}^2\right)\left(\frac{\Delta f}{f} - \frac{\Delta R}{R_{SPS}}\right)\right)$

Tools to measure energy matching

- How we can see if energy matching is correct?
  - With this list of observables on the downstream machine
    - Mean Horizontal position on first turn
    - Mean Horizontal position of the closed orbit between 50 and 300ms
    - Average position H on injection plateau
    - RF synchro loop error
    - Mountain range with RF off
    - Fast BCT with RF off
    - Upcoming tomoscope as in PS with RF off

All these displays give the same information

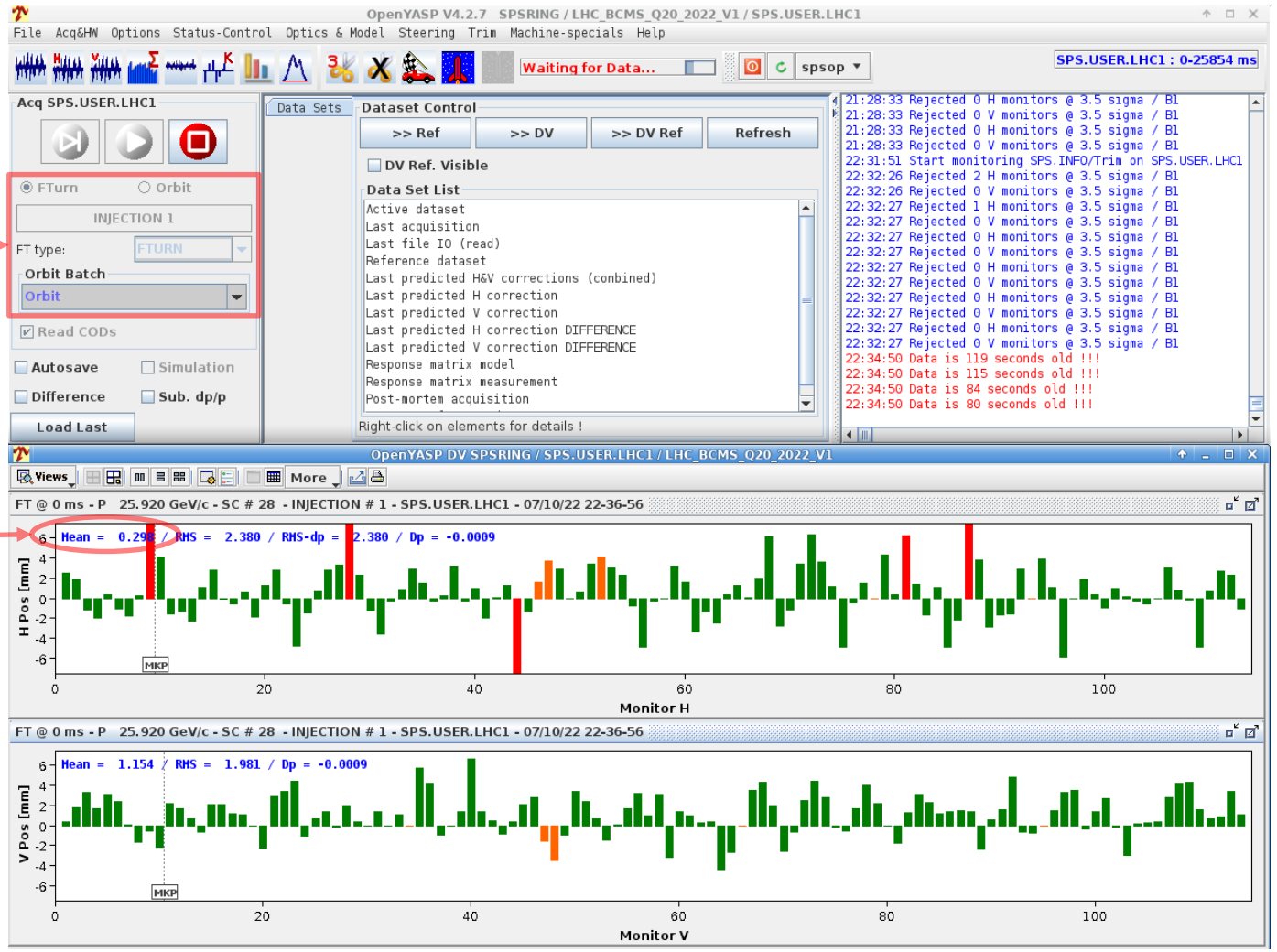
SPS Energy matching consists of adjusting beam momentum and magnetic field at PS extraction and at SPS injection



Mean position H on first turn

Steering configuration to read the first turn

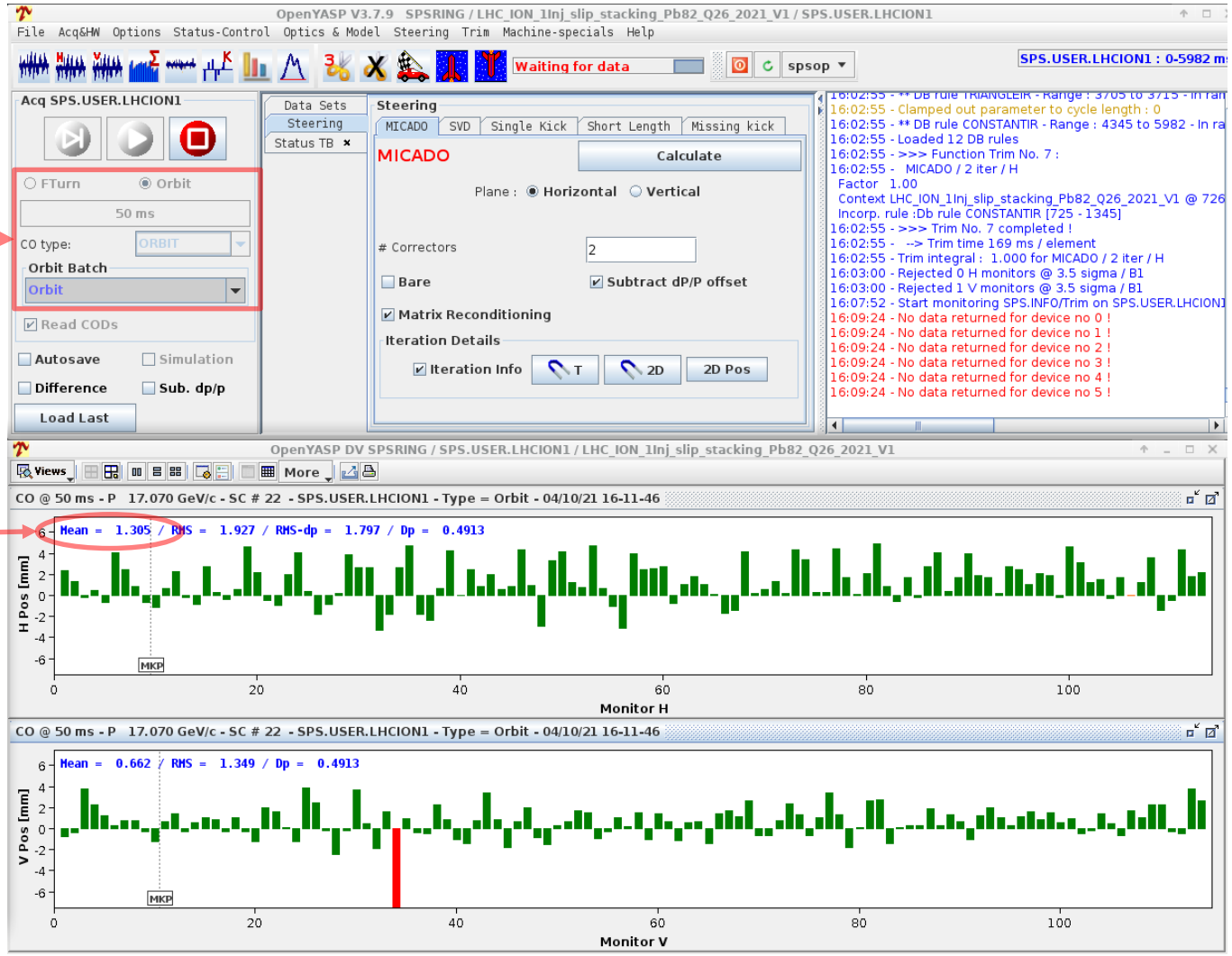
Mean H position corresponds to the extraction energy from upstream accelerator



Mean position H on closed orbit (50, 300ms)

Steering configuration to read the closed orbit at 50ms

Mean H position corresponds to energy set on the downstream accelerator

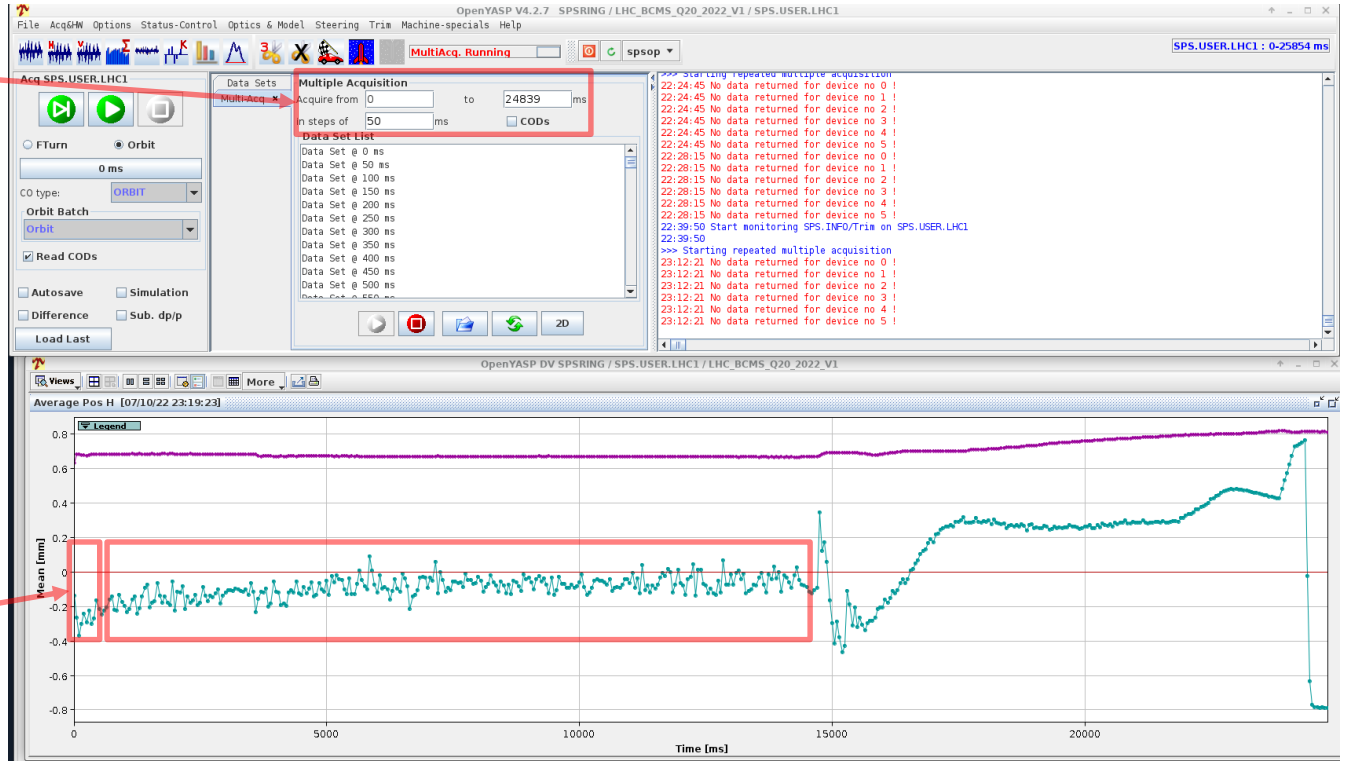


Average position H on injection plateau

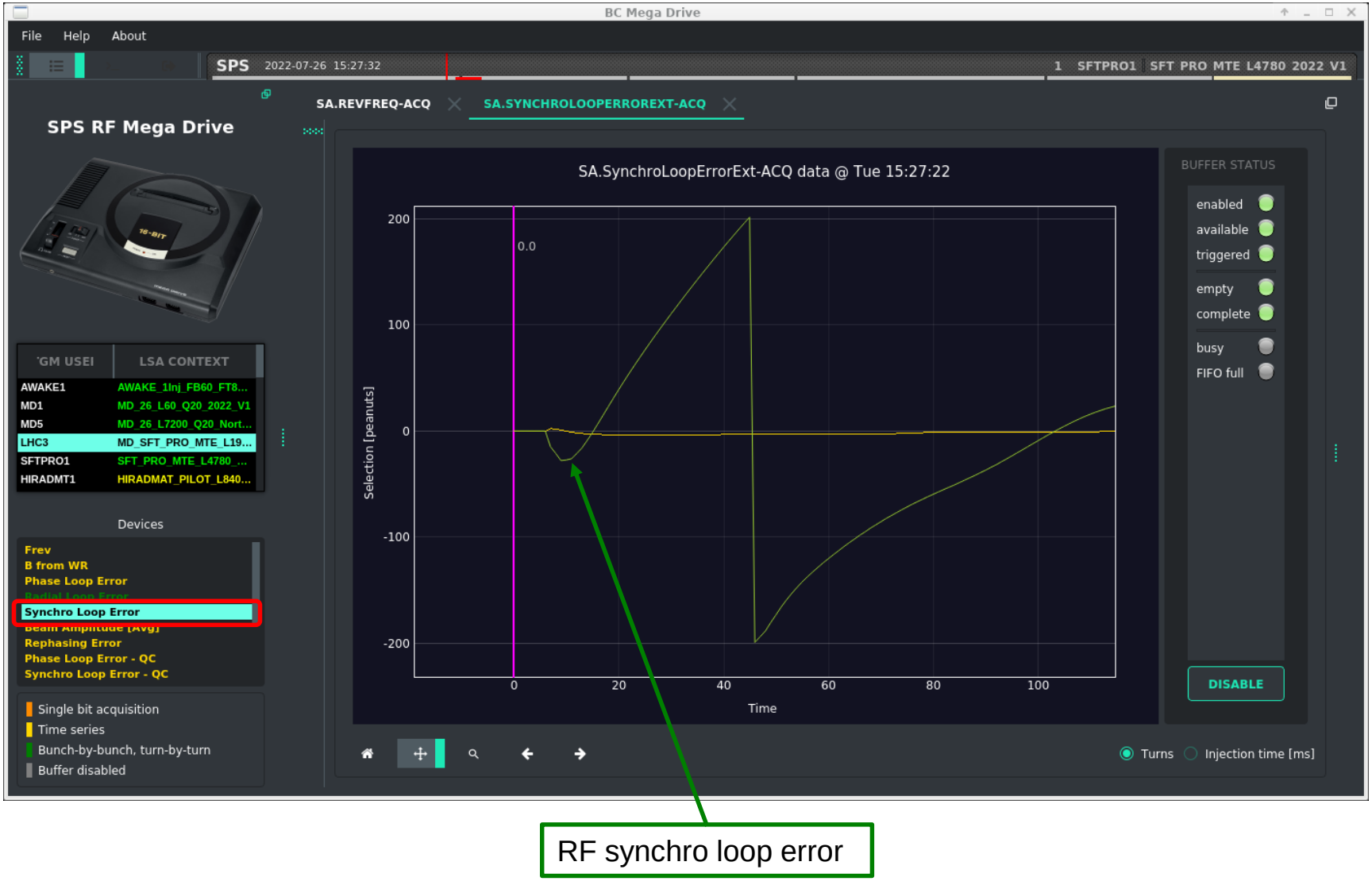
Steering configuration to read the average of the closed orbit with multiple acquisition

Average H position on flat bottom.
First part: the energy matching is correct.

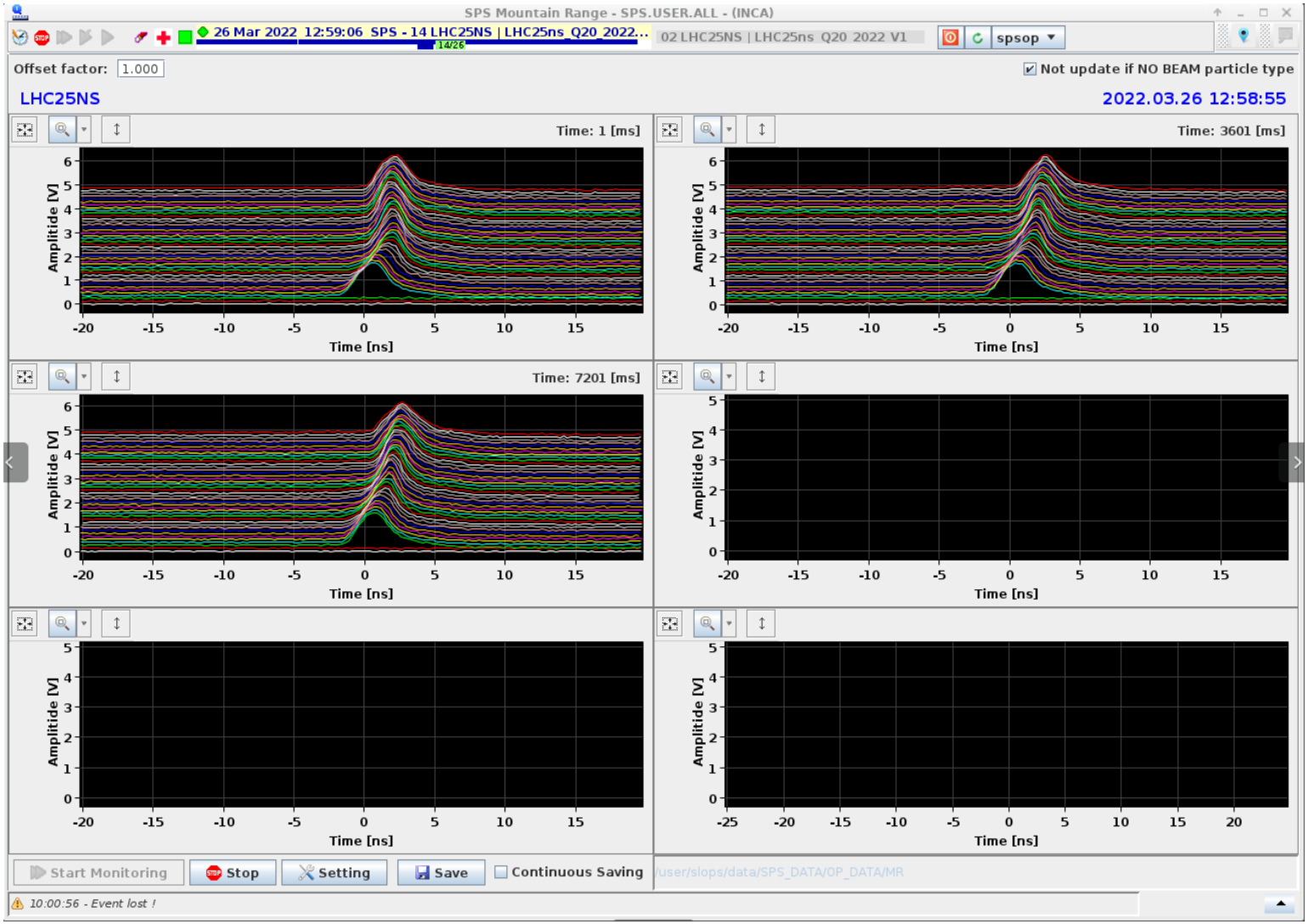
Second part: the closed orbit is correctly centered with the help of the momentum correction to compensate the hysteresis



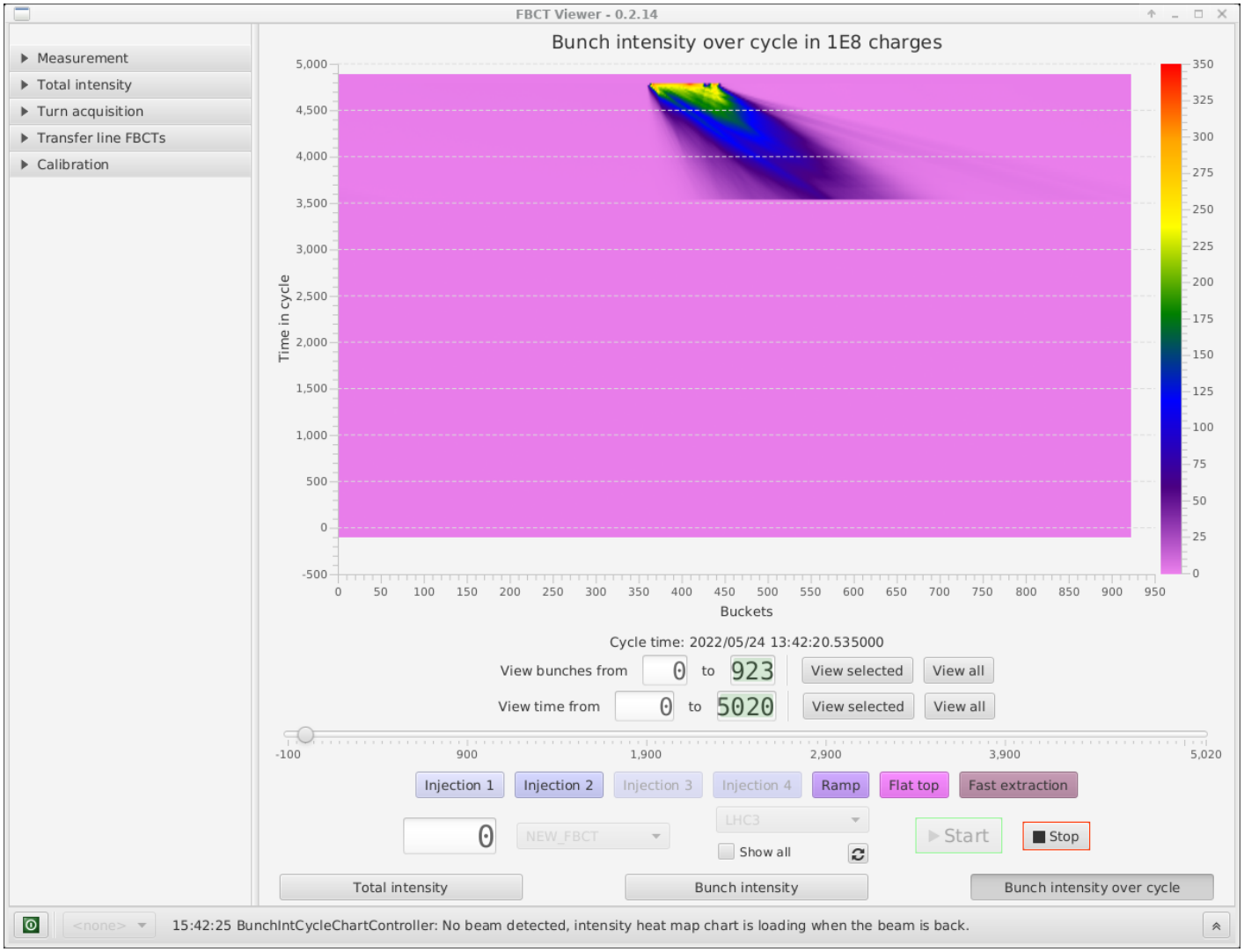
RF synchro loop error



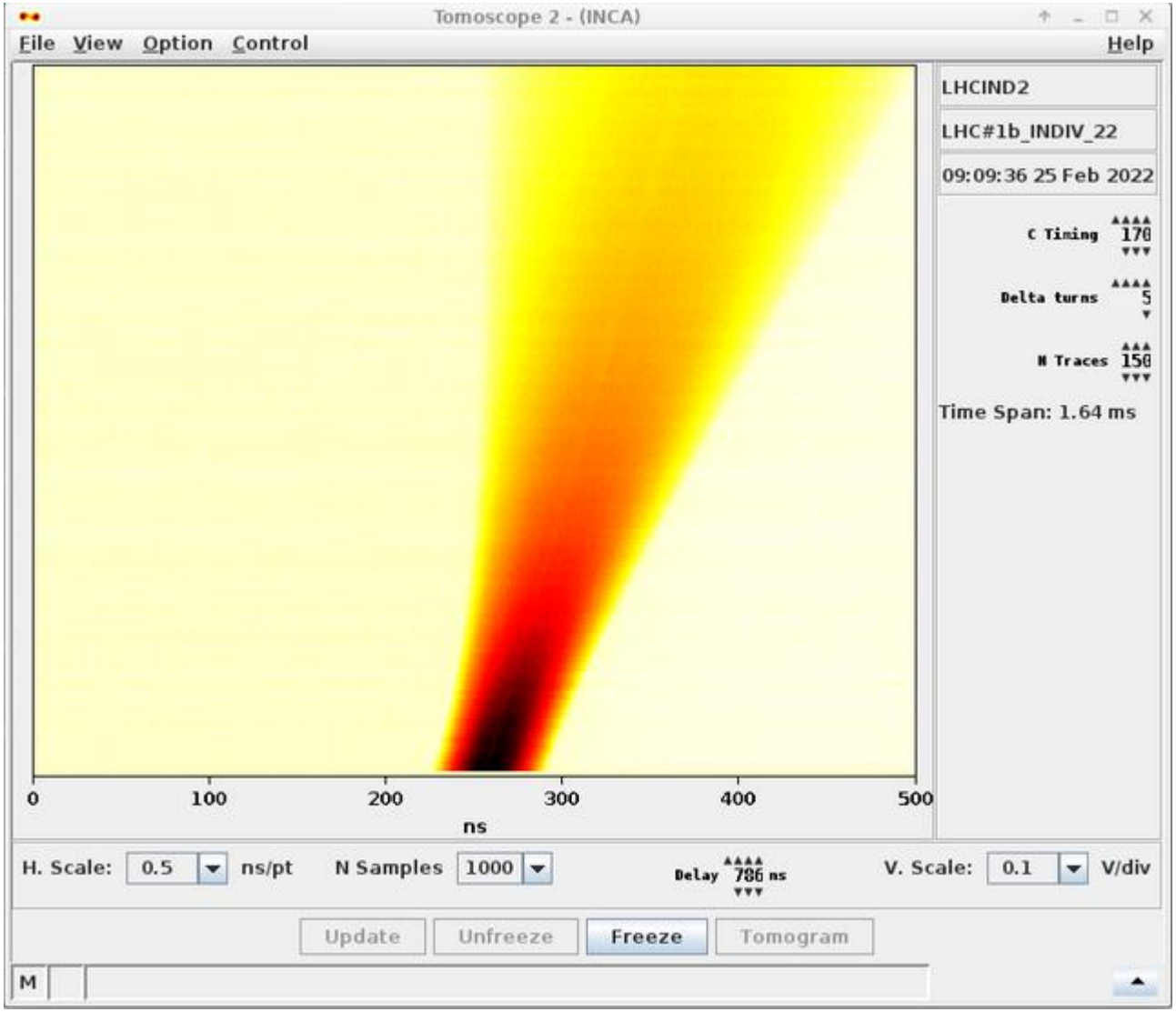
Mountain range



Fast BCT with RF off



PS Tomoscope with RF off



Parameters to adjust

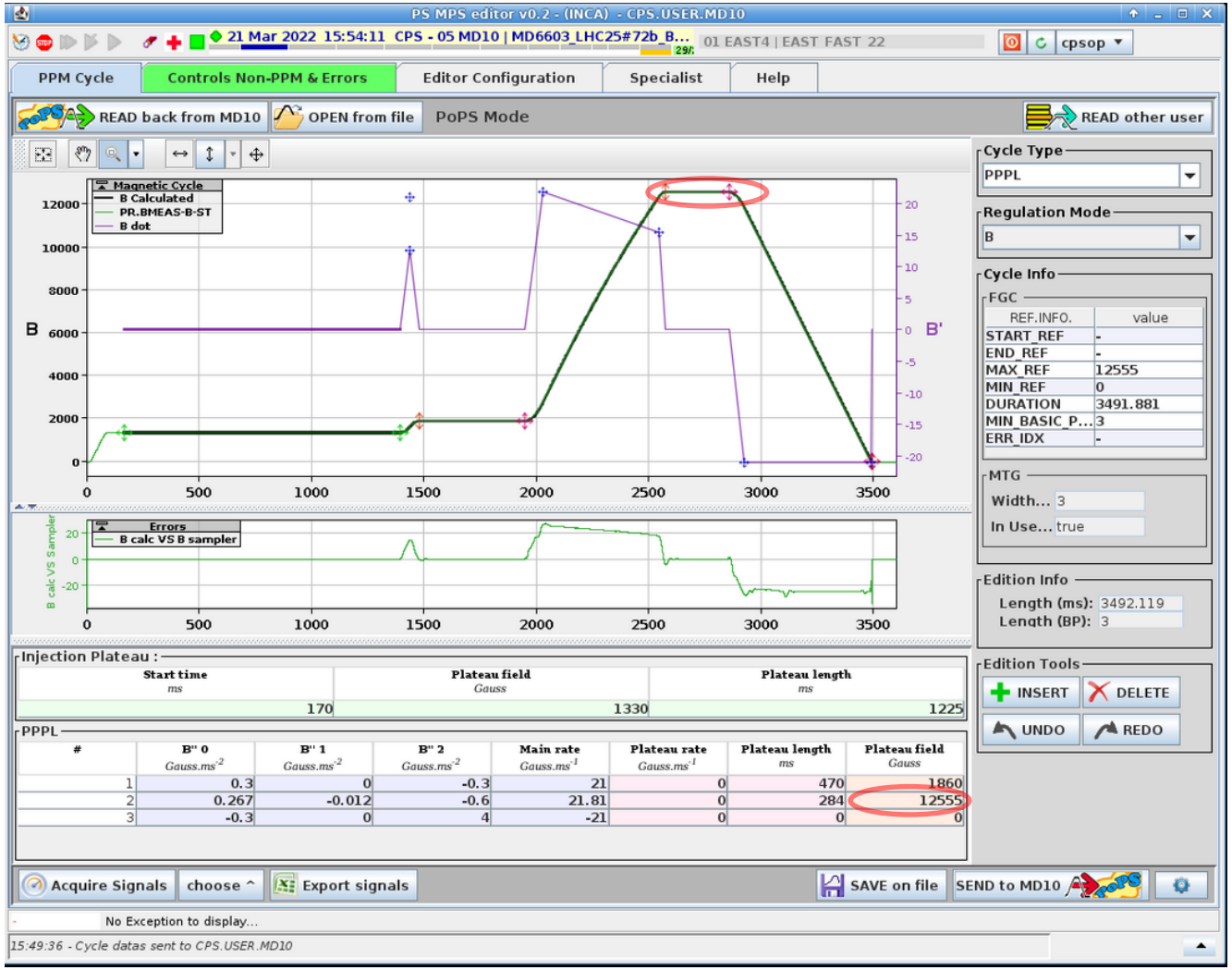
- PS settings
  - Extraction magnetic field
  - Rpos (radial placing at PS extraction)
    - Synchro cavities
      - SFTPRO: 200MHz to have a good structure on MTE beam (it change the energy)
      - LHC beams: 40 MHz rebucketing (it change the energy)

- SPS settings
  - **B0 (formerly Bfield) which is the injection frequency we send to PS**
  - IMains correction on injection plateau (Momentum)
  - SPSBeam/Momentum to compensate magnetic hysteresis along injection plateau (set when the energy matching is done)

- for LHC (proton, ion) and SFTION: procedure not to touch B0
  - “fixed frequency transfer”: 200.264 MHz
- SFTPRO: legacy procedure not to touch PS, but to change transfer frequency
  - will try and proceed as with LHC beams, at fixed frequency: 199.948 MHz

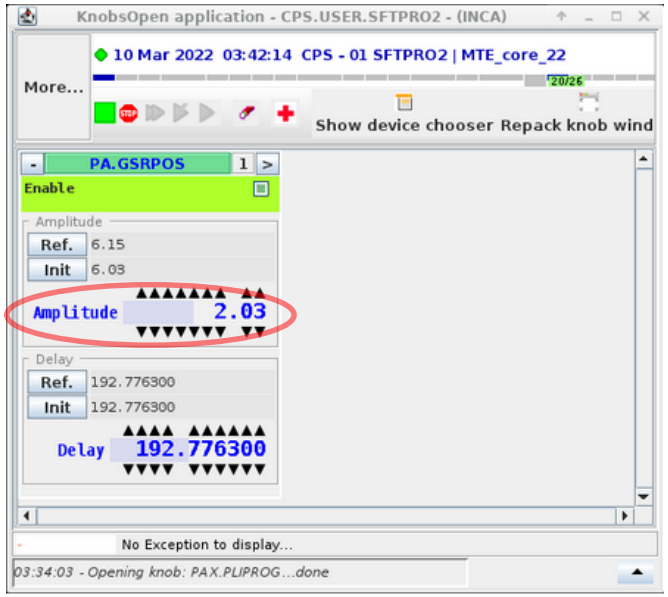
PS settings

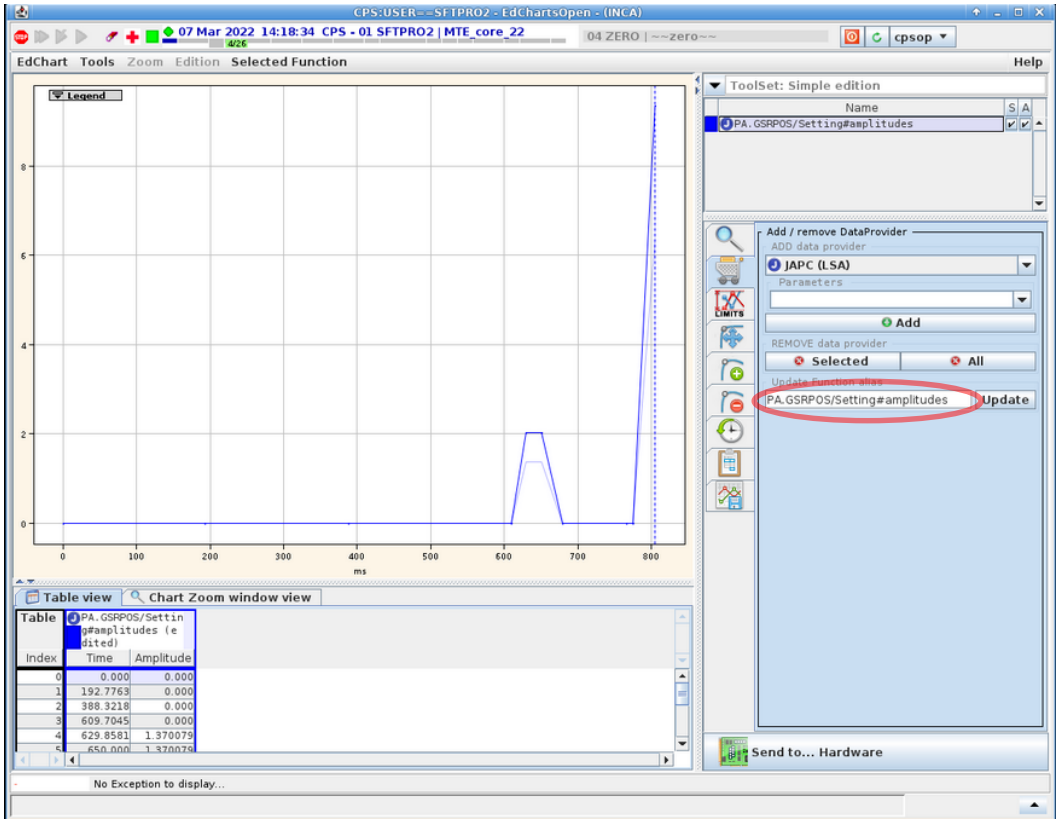
- Extraction magnetic field (in Gauss)



PS settings

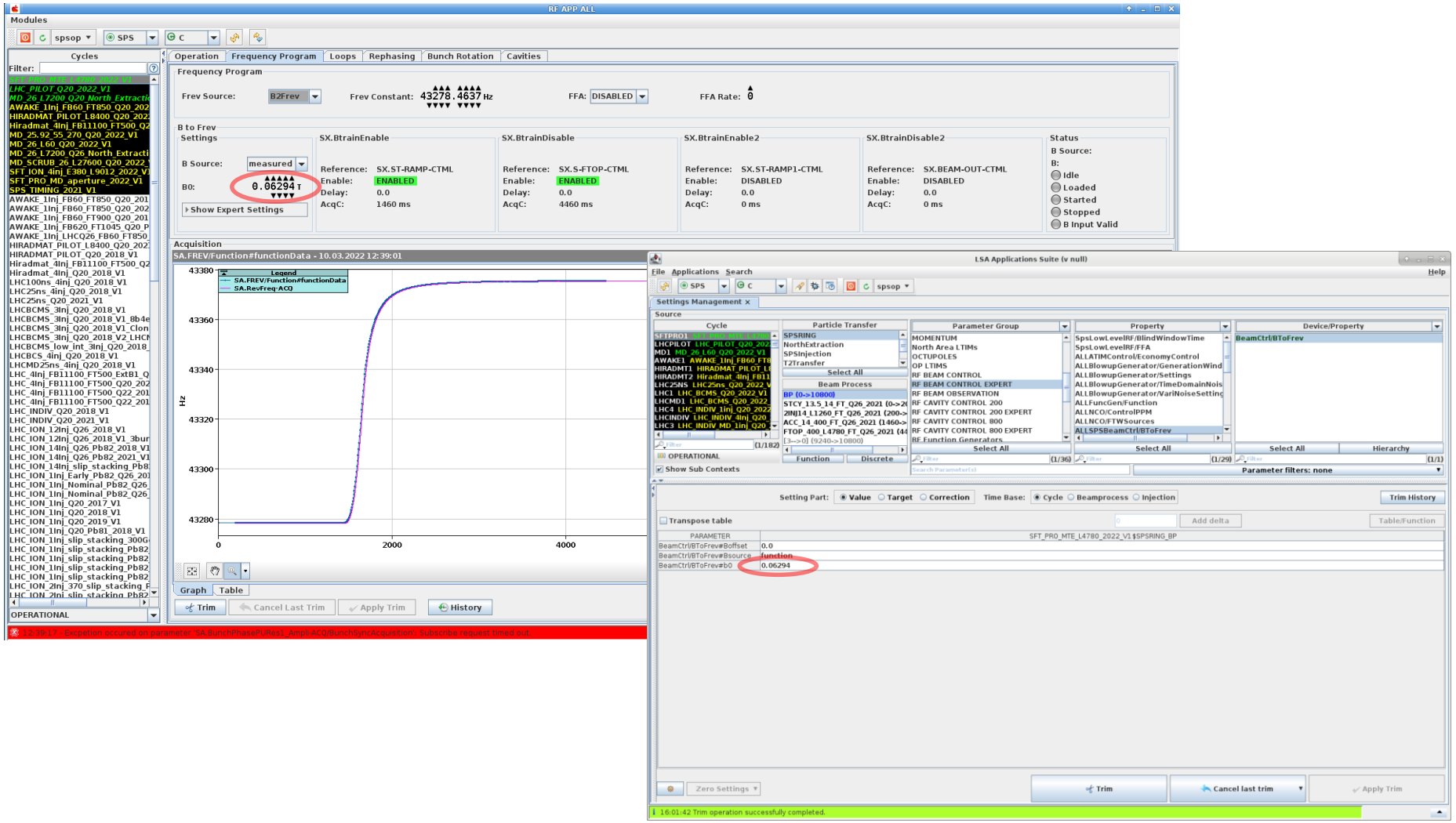
- Rpos (radial placing at PS extraction)
  - Used by PS RF expert





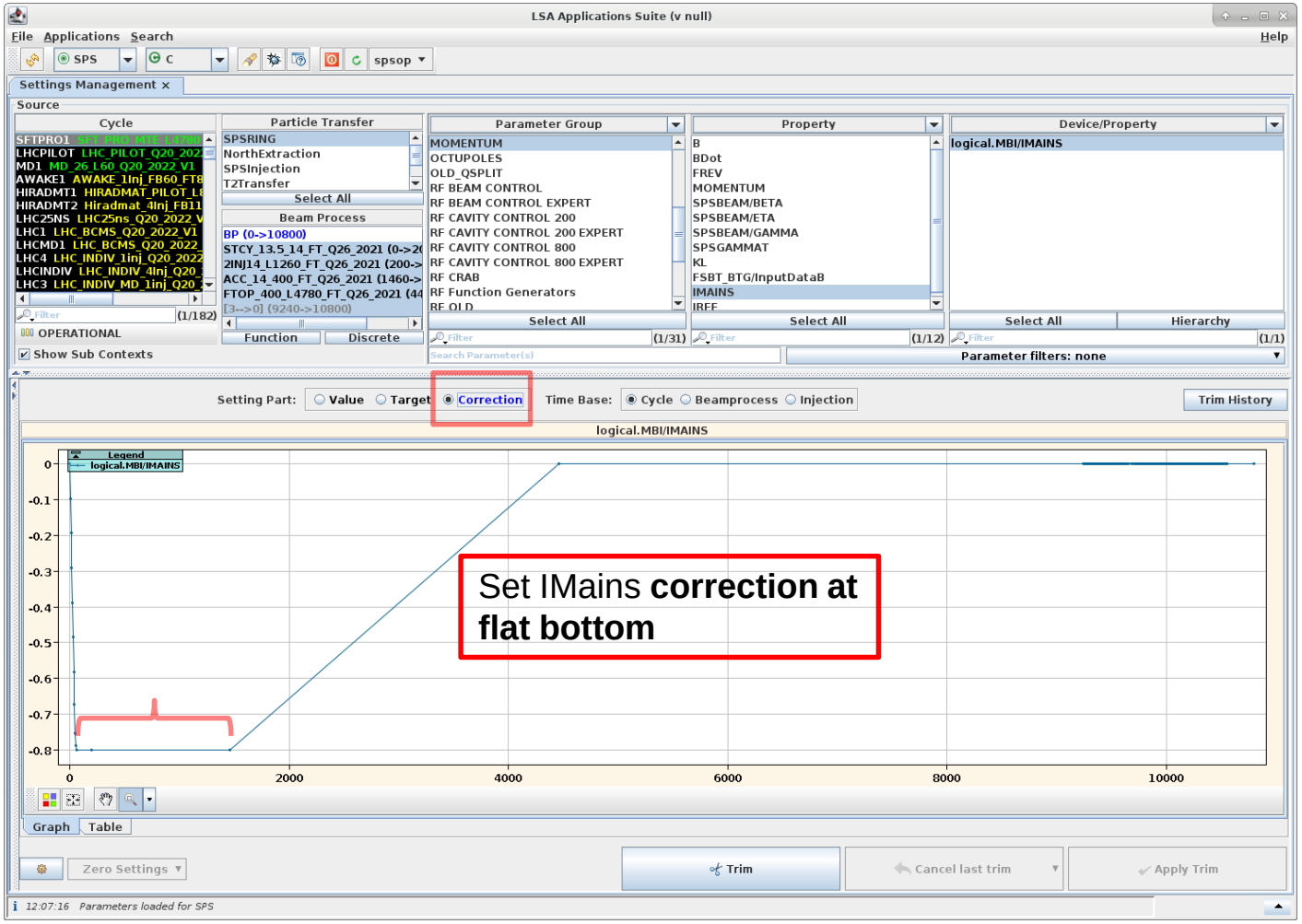
SPS settings

- B0 (formerly Bfield) which is the injection frequency we send to PS



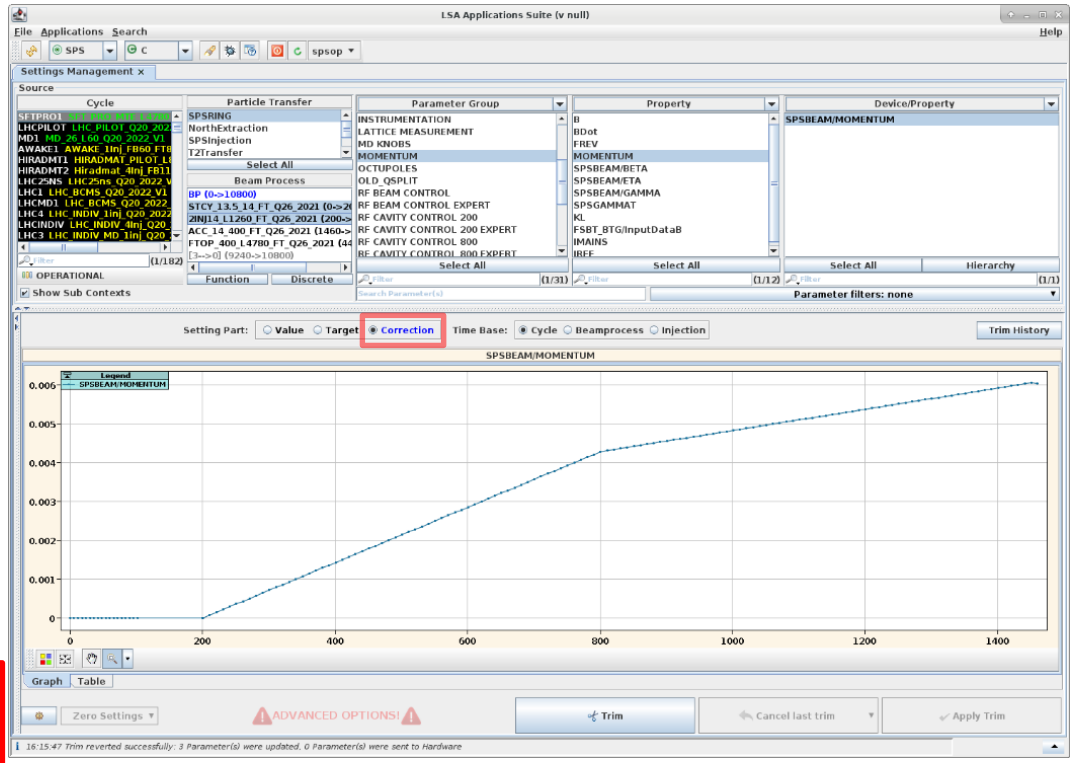
SPS settings

- IMains correction on injection plateau (Momentum)
  - SFTPRO generally negative and LHC positive

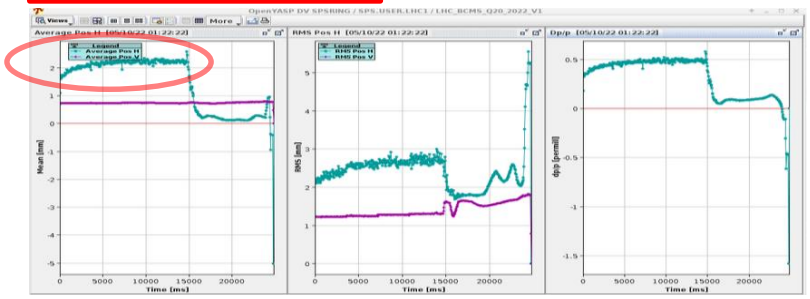


SPS settings

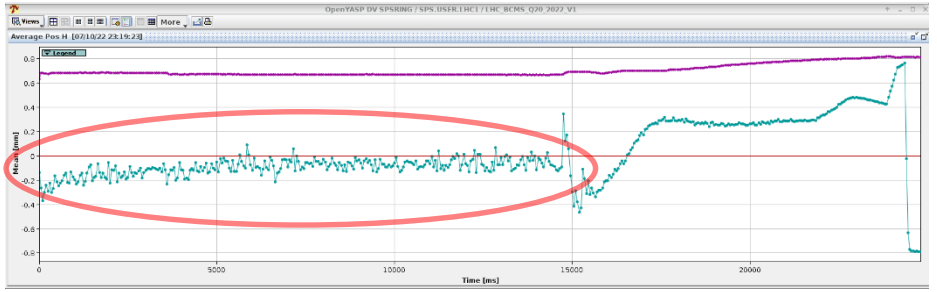
- SPSBeam/Momentum correction
  - compensate magnetic hysteresis along injection plateau (flattening)



Before momentum correction



After momentum correction



Energy matching procedure

- **SFTPRO**
  - *Legacy procedure not to touch PS, but to change transfer frequency*
    - *We used B0 to changed the injection frequency send to the PS*
    - *IMains corr at Flat bottom (+/- 1.5A by step of 0.2A)*
  - Now we try with fixed frequency transfer: ~199.948 MHz => B0 ≈ 0.0631056
  - Parameters used to do the energy matching at fixed frequency
    - Extraction field at PS (normally +/- 30 Gauss by step of 5 Gauss)
    - Rpos (radial placing at PS extraction) synchro cavities 200MHz set by PS expert to have 200 MHz structure on MTE beam (it change the energy)
    - SPS IMains corr at Flat bottom (+/- 1.5A by step of 0.2A)
- **LHC (proton, ion) and SFTION**
  - Fixed frequency transfer: ~200.264 MHz => B0 ≈ 0.11691
  - Parameters used to do the energy matching
    - **Never used B0 to change the injection frequency send to the PS**
    - Extraction field at PS (normally +/- 30 Gauss by step of 5 Gauss)
    - Rpos (radial placing at PS extraction) synchro cavities 40 MHz rebucketing (it change the energy)
    - SPS IMains corr at Flat bottom (+/- 1.5A by step of 0.2A)

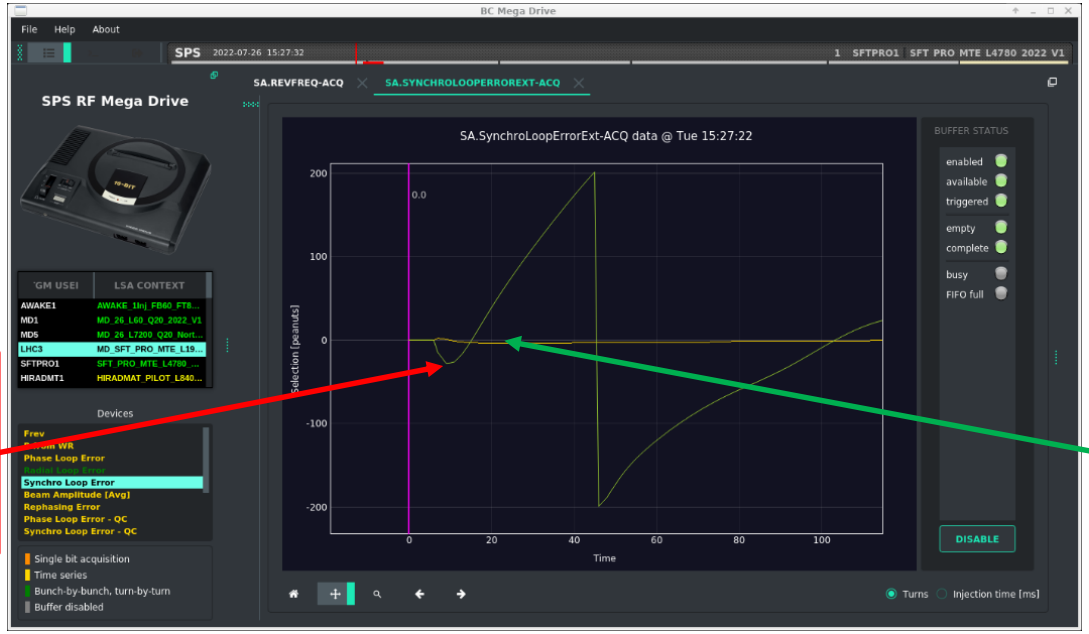
Energy matching procedure

- **SFTPRO, LHC (proton, ion) and SFTION**
  - **Reminder**
    - The mean horizontal position of the first turn corresponds to the energy at the extraction of the PS
    - The mean horizontal position of the closed orbit from ~50 to 300 ms corresponds to the energy set in the SPS
    - On the scope the synchro loop error corresponds of the mismatch energy between PS and SPS
  - Set B0 to obtain the fixed frequency
  - The goal is to vary different parameters listed in the previous slide so that the mean horizontal position of the first turn is equal to the mean horizontal position of the closed orbit and should tend to 0
  - When the beam is injected, each parameter adjustment will be step by step, otherwise you will lose the beam

Energy matching procedure

- For all beam types
  - It will be necessary to do several iterations to bring the mean horizontal position of the first turn and of the closed orbit towards 0 mm
  - Careful when you will set the IMains correction as you will have to adjust the tune to follow otherwise you may loose the beam
  - Once you are satisfied with the mean value of the first turn and closed orbit you should see the effect on the various applications (RF synchro loop error, Steering)

RF Synchro loop error

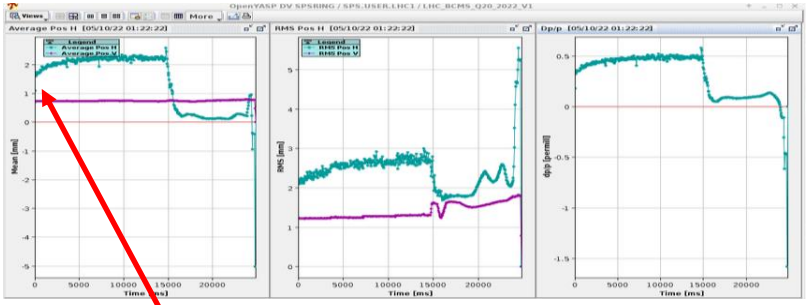


Not Match
RF synchro loop, unstable energy not matched

Match
RF loop stable, energy matching improving

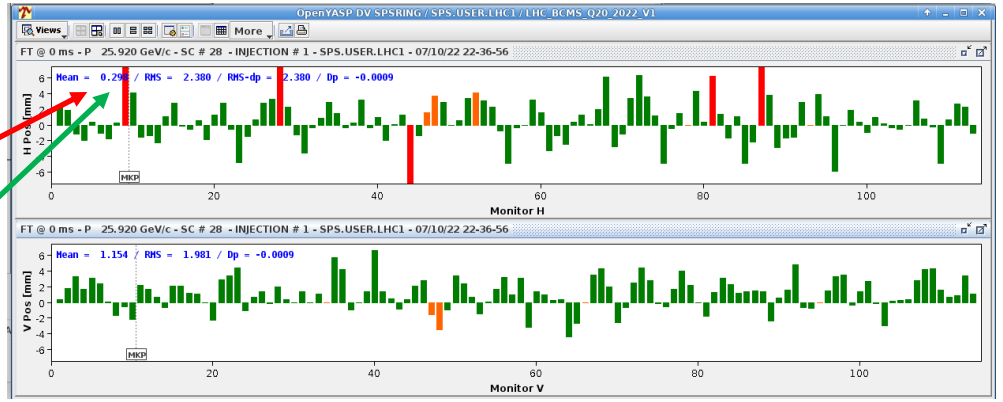
Energy matching procedure

Steering: Average closed orbit before energy matching



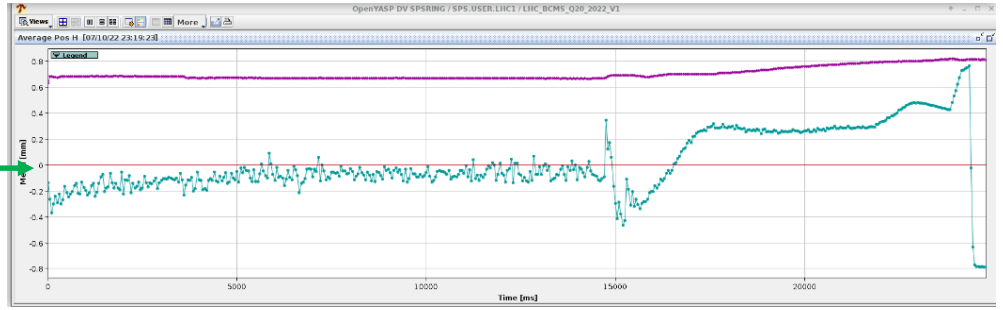
Not Match
at 50 ms the mean H position (~1.5mm) is not the same as the first turn (~0.3mm) and the closed orbit is not centered

Steering: First turn



Steering: Average closed orbit after energy matching

Match
at 50 ms the mean H position is the same as the first turn (~0.3mm) and the closed orbit is centered

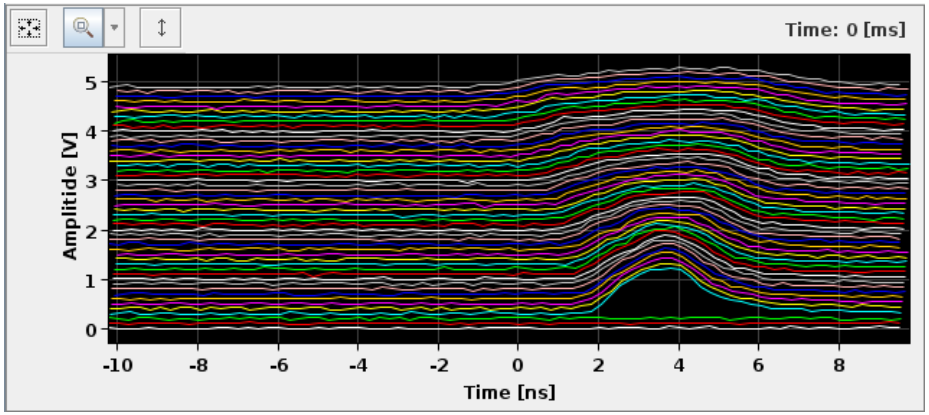


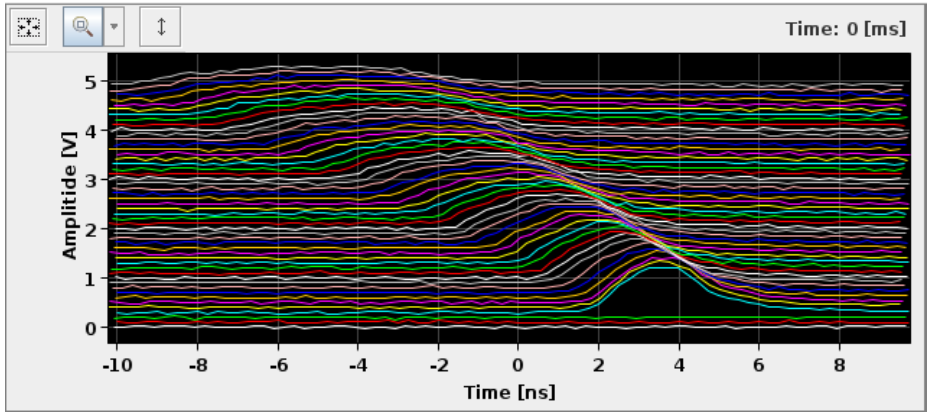
Energy matching procedure

- To check if the energy matching is correct you can switch off the RF cavities and watch the mountain range, fast bct or tomoscope.
    - On the mountain range you should see no slippage after injection

RF off no slippage
Energy matching correct

RF off slippage
Energy matching not correct

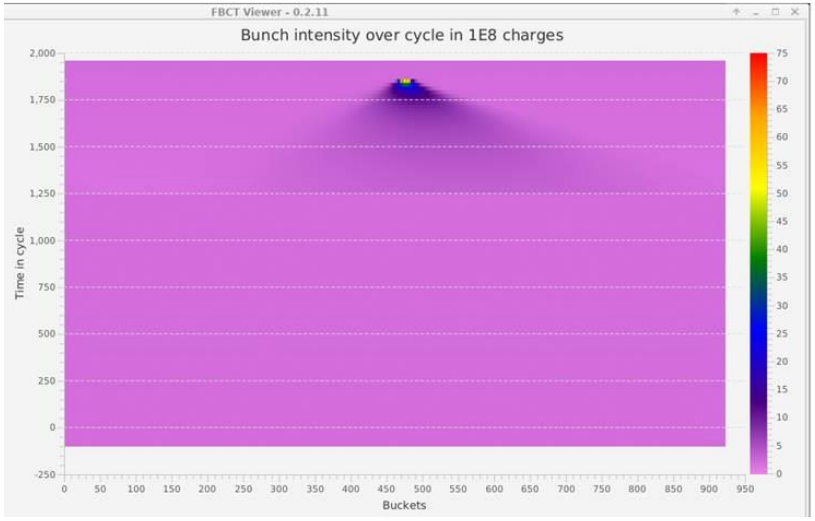




Energy matching procedure

- For all beam types
  - On the FBCT you should see no slippage after the injection

RF off no slippage
Energy matching correct

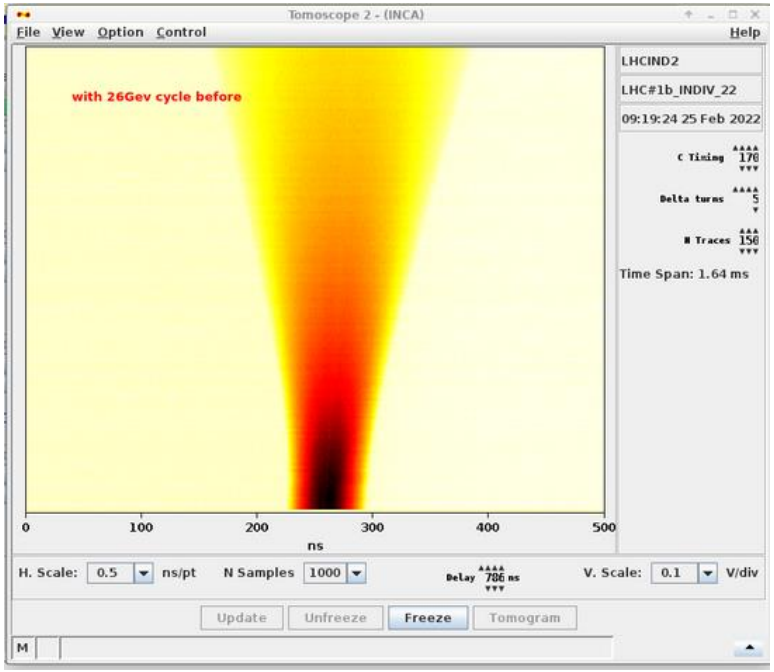


RF off slippage
Energy matching not correct

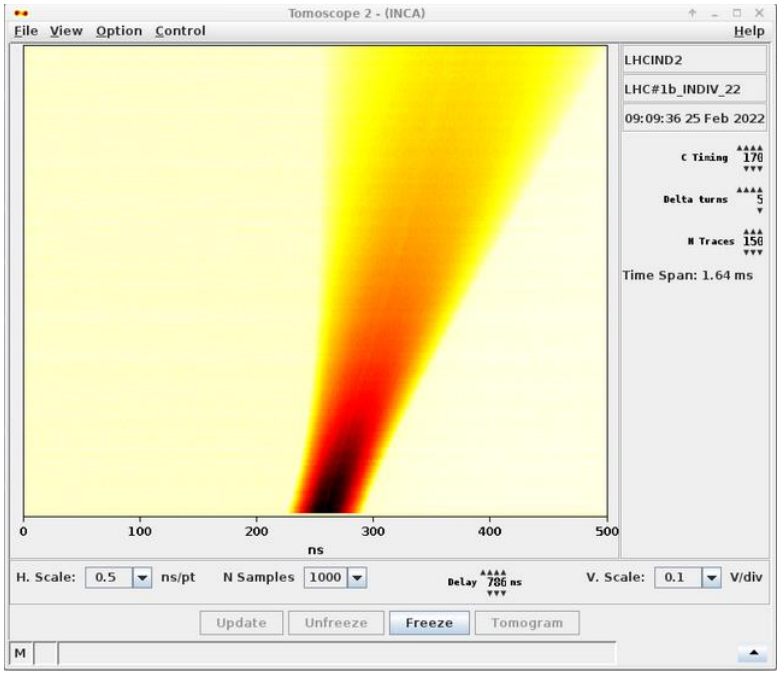
Energy matching procedure

- For all beam types
  - On the tomoscope you should see no slippage after the injection

RF off no slippage
Energy matching correct



RF off slippage
Energy matching not correct



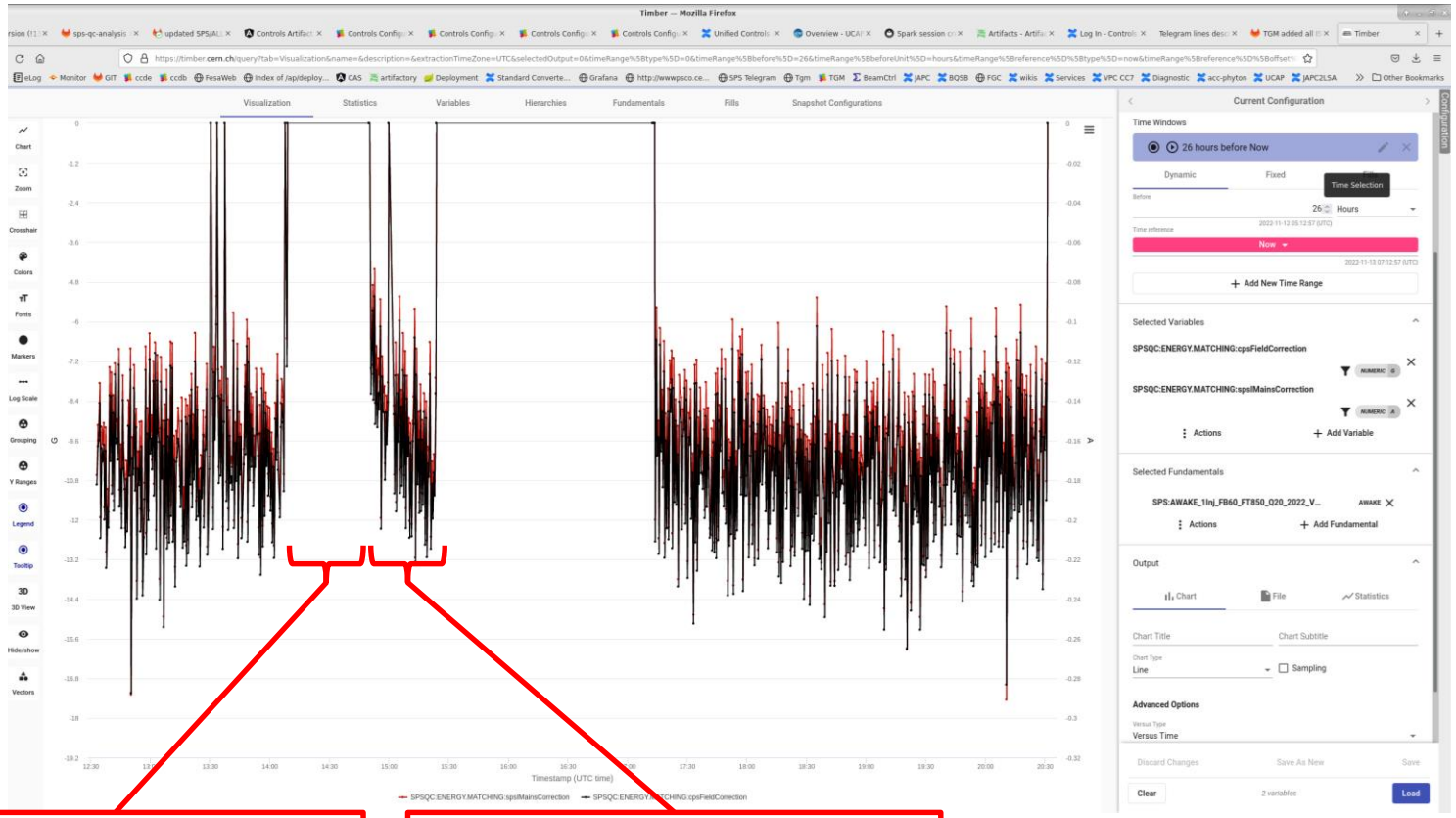
Energy matching for the future

- Until now we did the energy matching by hand and it work well
  - For the future we will have an algorithm based upon aforementioned procedure to do the energy matching in semi-automatic mode

  - Corrections will propose according to logged measurements (proof of principle validated in MD. Algorithm and data collection in SPS QC since end of 2022 (FF) proposed corrections already in NXCALS for end of 2022

Energy matching variation

- Correlation with Mains magnet start from a long stop
  - Not a problem because the beam accept this little change

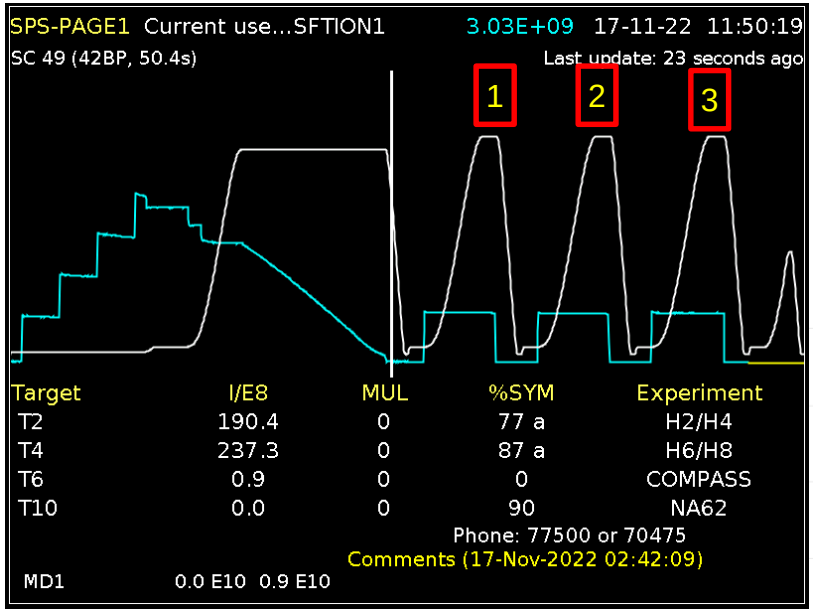


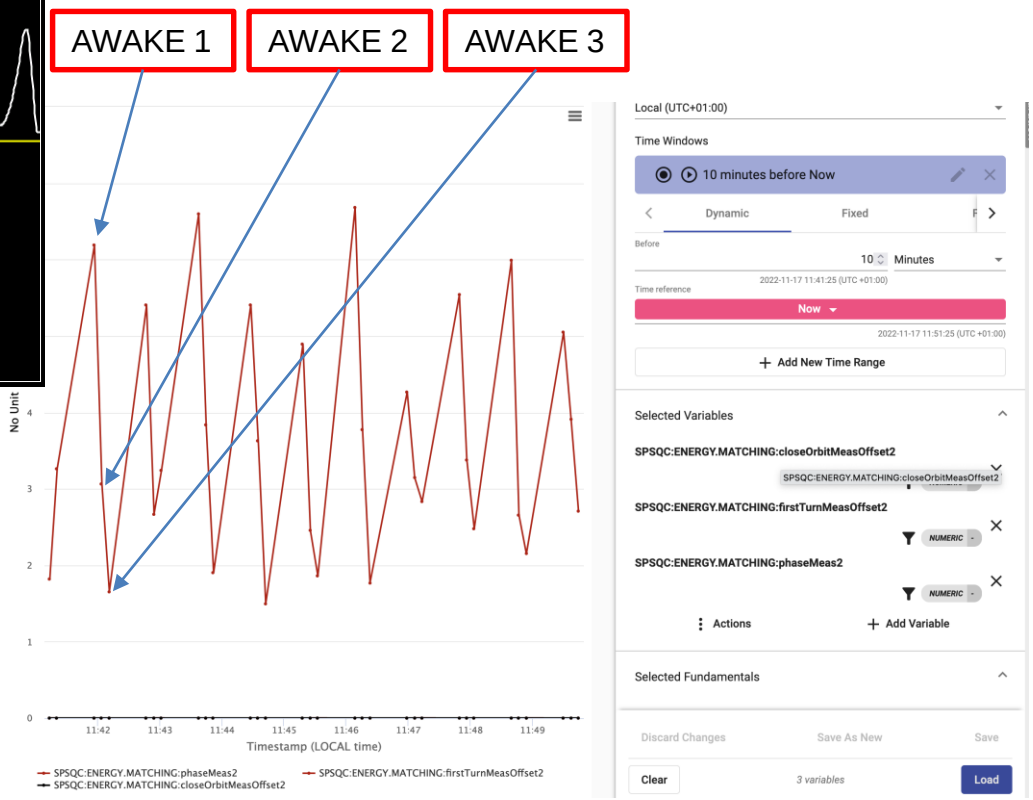
MPS has stopped for ~1h00, the temperature has cooled down

MPS back with beam we can see the change of energy matching

Energy matching variation

- For the AWAKE cycle we see a correlation of the energy matching and its place in the super cycle





Thanks for your attention