
CERN

Joint Accelerator Performance Workshop 2023

Progress and remaining issues with slow extraction in SPS

JAPW 2023 (15’ + 10’)

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Thanks to SPS OP and all equipment teams

Outline

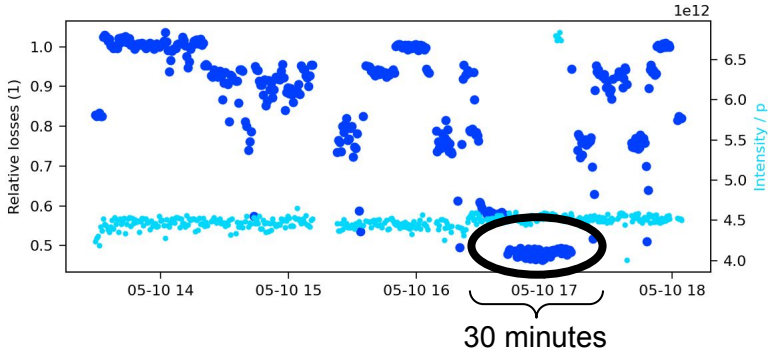
- Crystal-assisted slow extraction
- Losses at TT20 splitters
- Empty bucket channelling (EBC)
- 1 slide, 1 topic

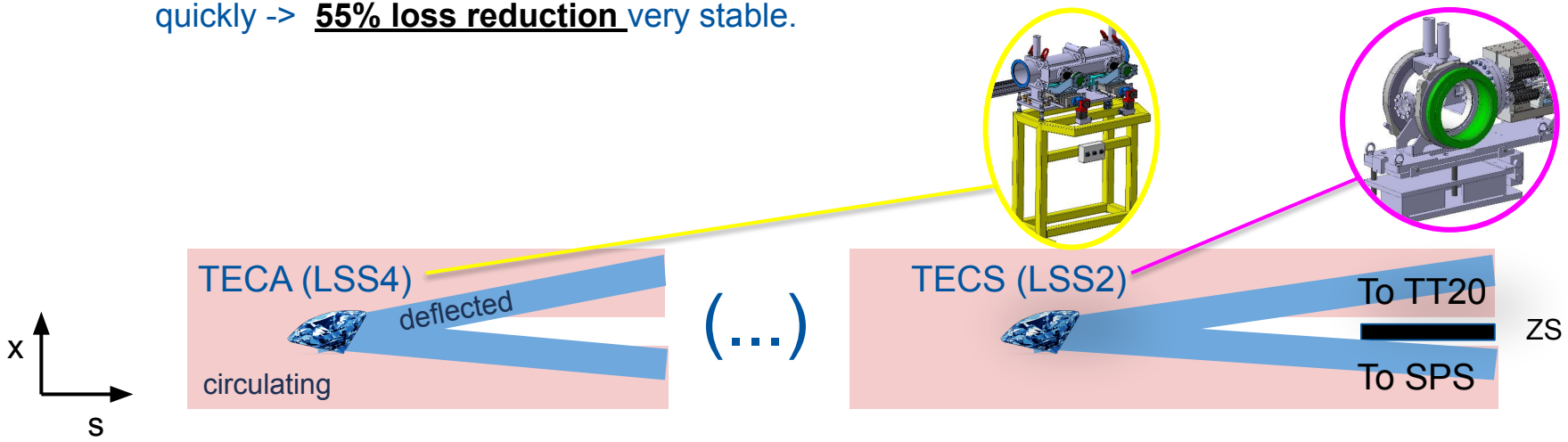
Crystal-assisted slow extraction [1]

Intro

A local (TECS) and non-local (TECA) crystal shadow the electrostatic septum (ZS) during slow extraction. This year, the TECA setup was tested further.

- Shadowing and channeling angle found rather quickly -> **55% loss reduction** very stable.

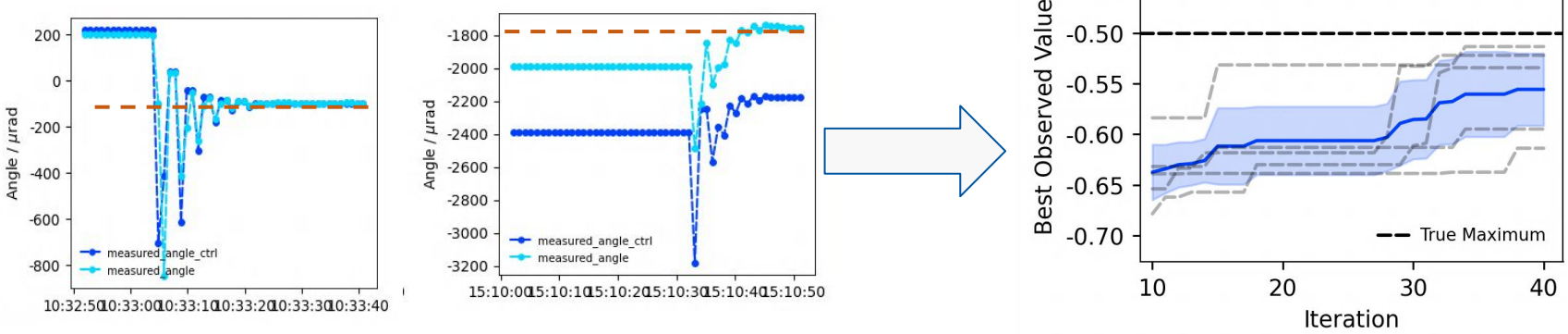




Latest results

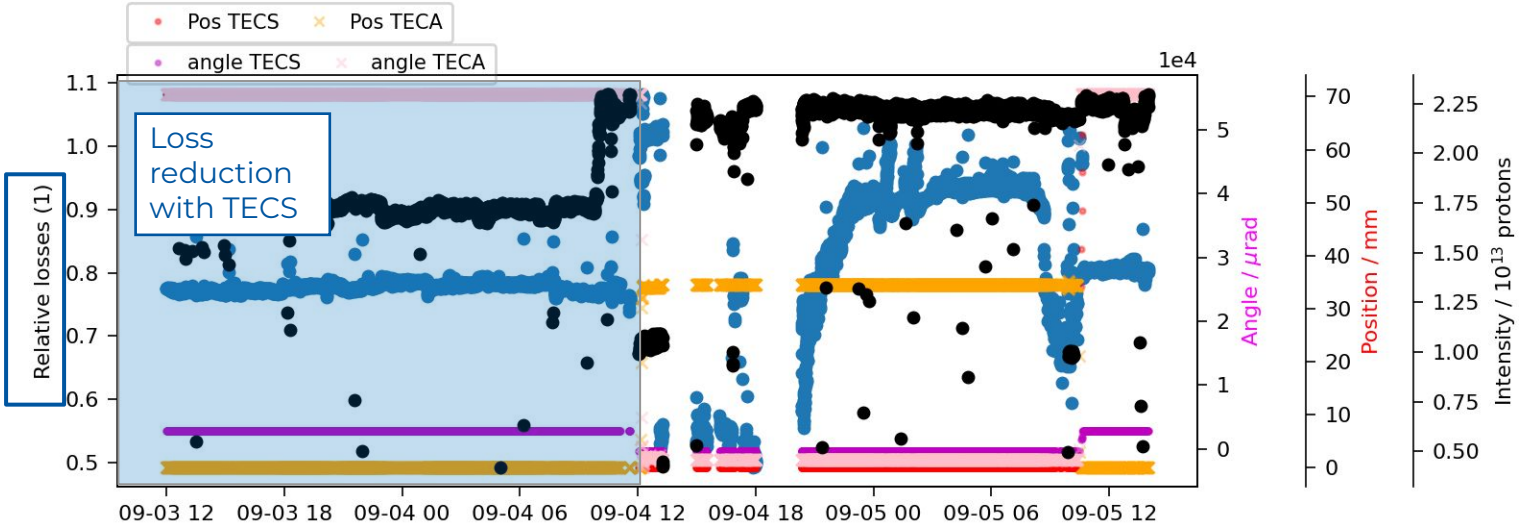
High-level controller implemented, which allows to employ numerical optimisers reliably.

- The absolute position and angle measurements are used via PID controller (limited by the minimum step size of the motor).
- TECA aligned with Bayesian optimisation in <60 cycles (potential to cut in half with surrogate optimisation).



Latest results (ii)

TECA can reduce losses by factor 2 at high intensity, but controller is essential to recover loss reduction after machine stop or supercycle change.



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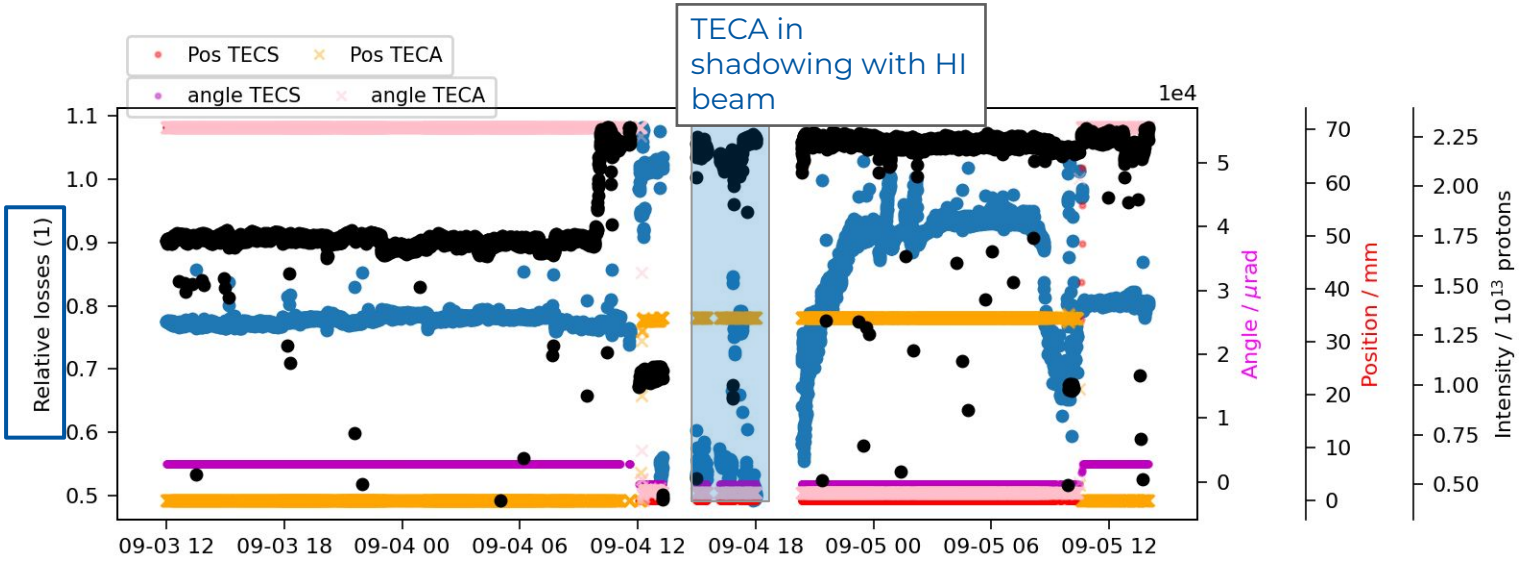

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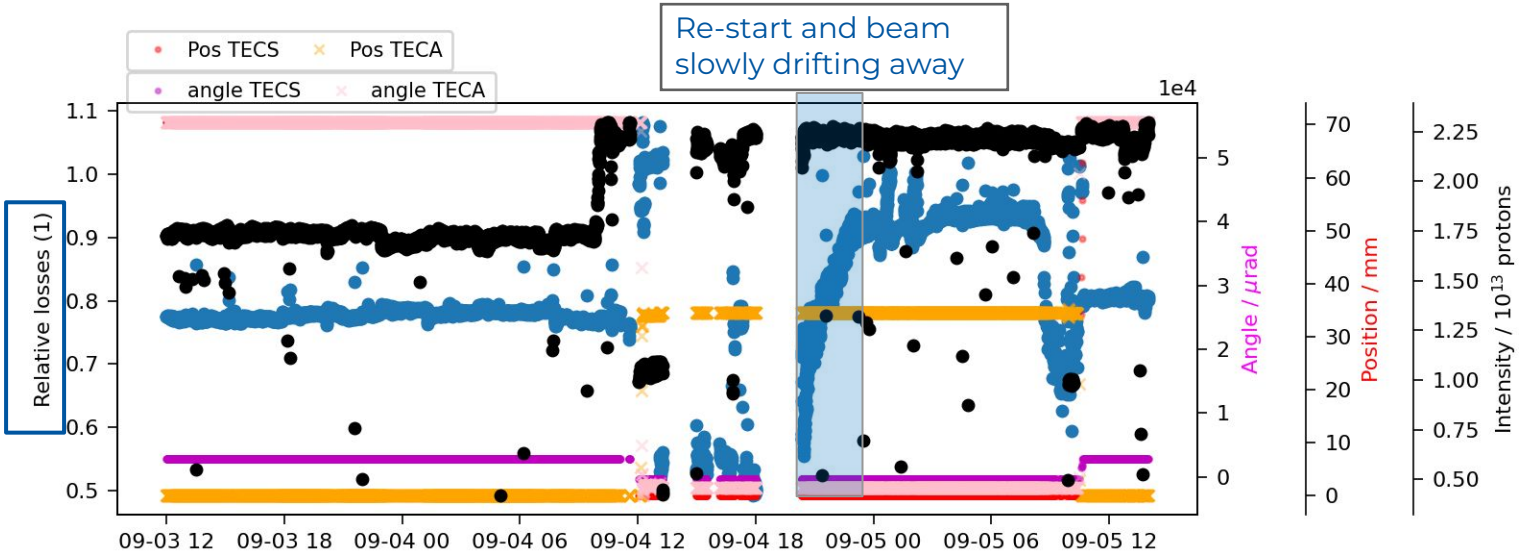


Next steps

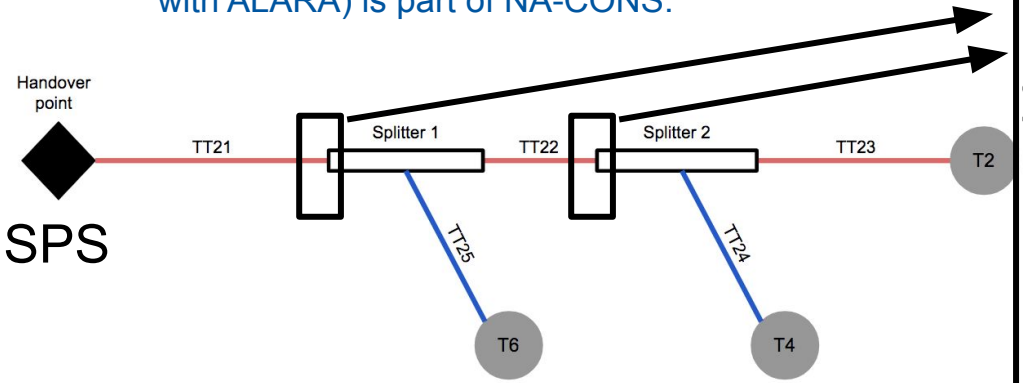
- **Mask probably needed downstream and around TECA.** Activation being studied.
- **TECA** currently running with 0.8 mm thick crystal, **to be replaced with 1.8 mm crystal when available.**
  - Expected loss reduction slightly lower than before due to `sign error' in simulation.
  - DECRYCE project for in-house crystal production collecting specs for optimised TECA [1].
- Discussions on-going to **replace ZS with crystals** [2]. In parallel, **material studies to reduce ZS activation** ongoing [3].

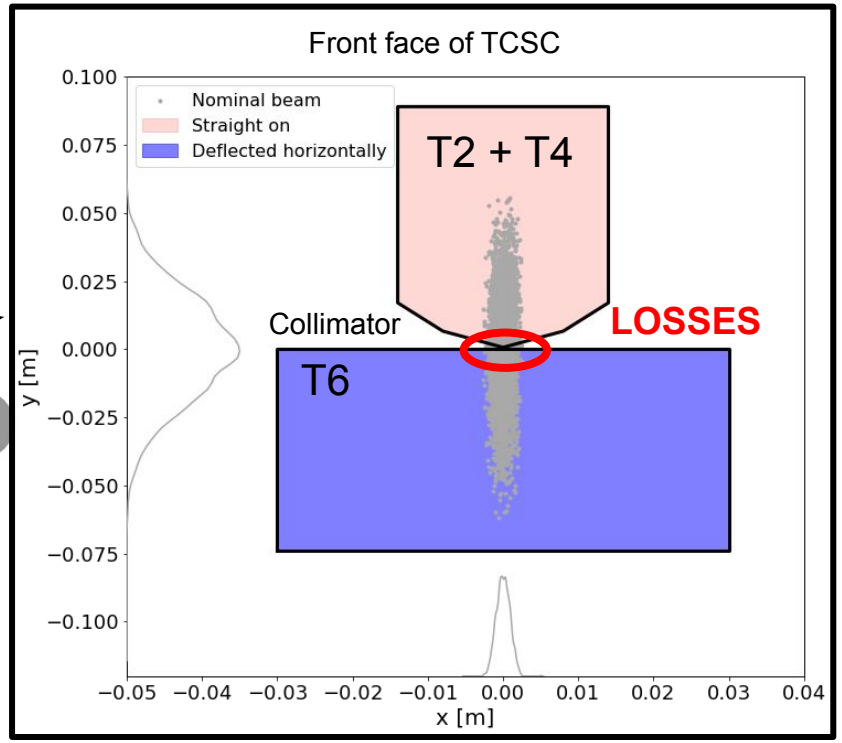
Losses at TT20 splitters

Intro

Two Lambertson septa splitters in TT20 provide simultaneous beam to targets.

- Beam is physically split on TCSC collimator blade.
- Activation is high. New device (more compliant with ALARA) is part of NA-CONS.

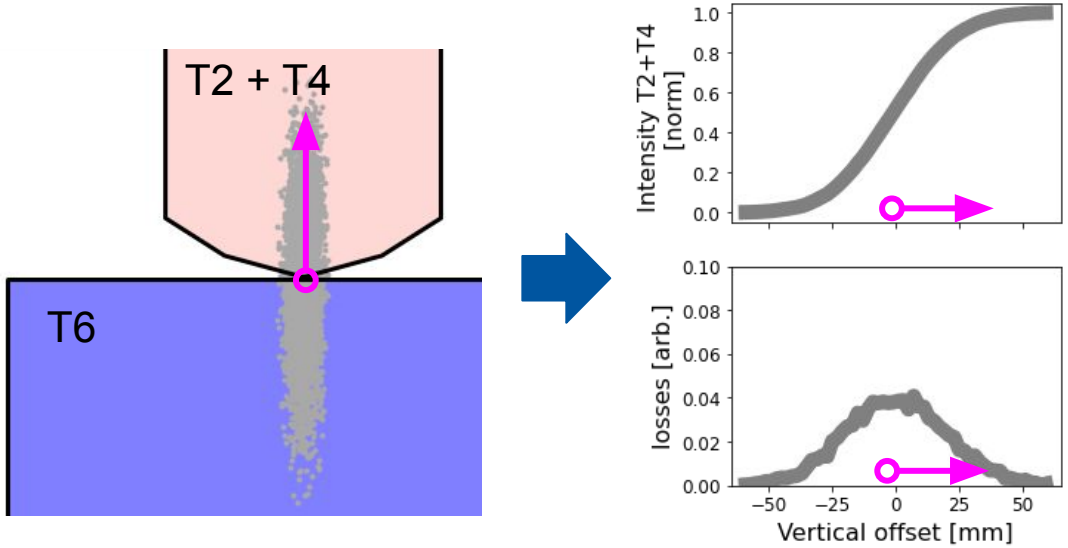




Intensity sharing + vertical emittance

Intensity sharing and vertical emittance determine losses on splitter blade.

- Losses are highest for 50/50 sharing and small v-emittance.



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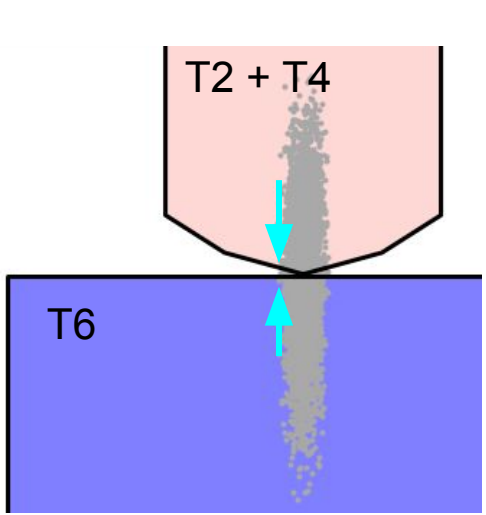
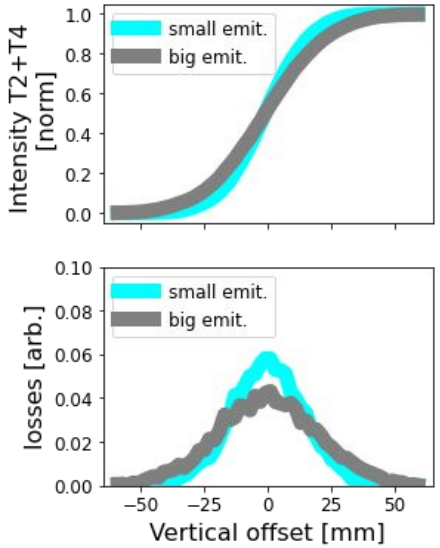
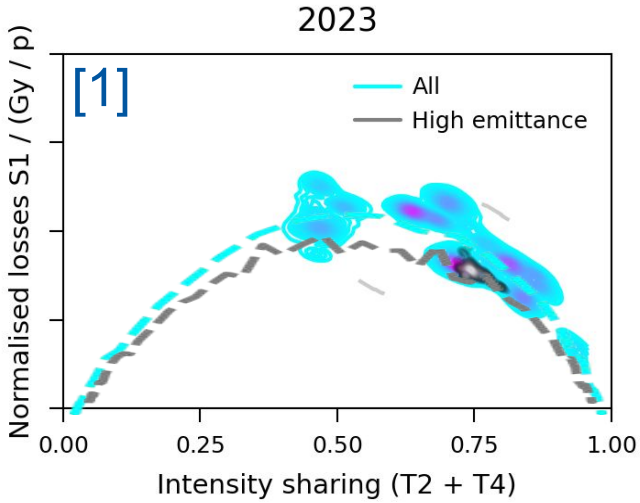






Next steps

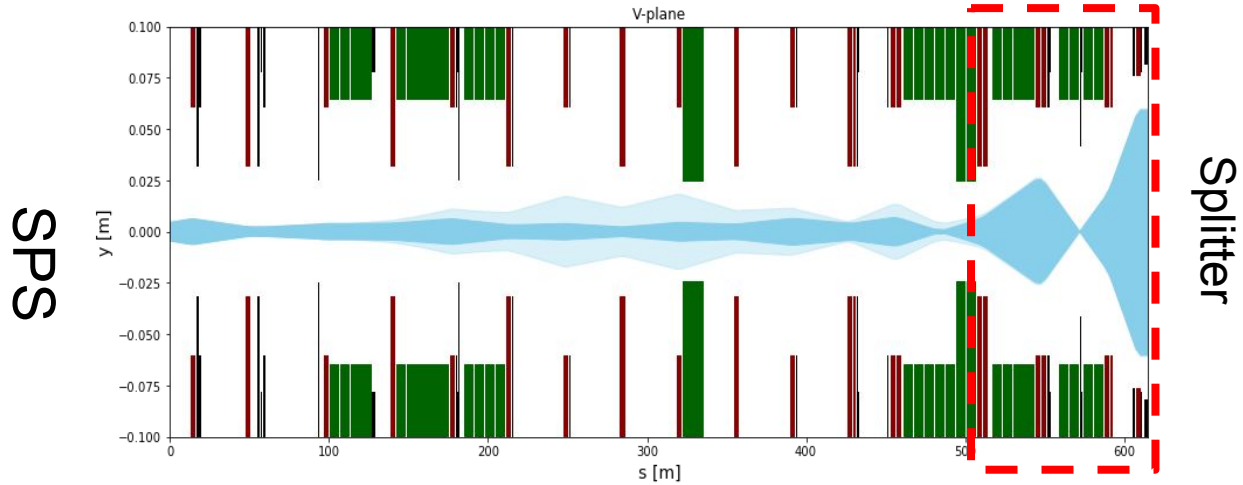
This topic has been comprehensively covered in the past [1]. The **vertical emittance should be made large at the PSB** (at least 4 mm.mrad).

- Already agreed at SPS-MPC and IPP in 2022: no request should be made by SPS to make it smaller.
- The increase of SPS losses at injection energy is small, and is far outweighed by the loss reduction at 400 GeV at the splitter [1, 2].
- R&D studies ongoing to decouple splitter losses from PSB emittance.

R&D: Optics studies

An alternative is to adapt the optics in TT20 to accommodate all v-emittances.

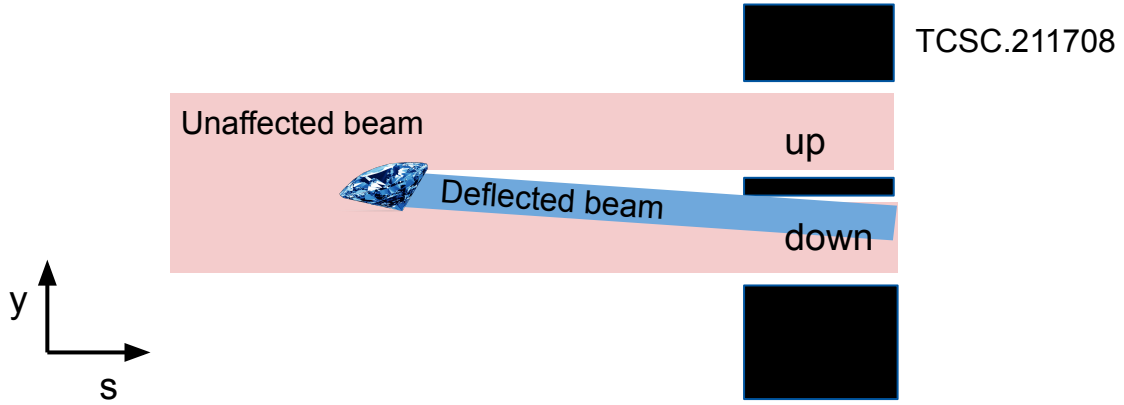
- Requires very good understanding of transfer line optics (quads near splitter must be strongly powered).
- Time to be requested in 2024 to investigate this topic during commissioning and/or MD.



R&D: Crystal shadowing of splitter

In the future, the splitter blade could be shadowed by a crystal, as done for the ZS (but in v-plane)

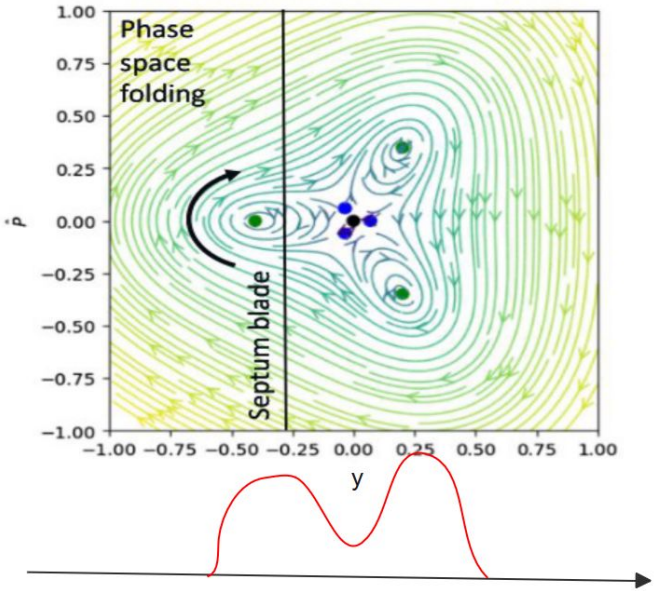
- ~25% loss reduction expected with same crystal as those we have in the SPS (TECS/TECA).
- Discussions ongoing with STI to specify technical details, location and optimised crystal parameters.



R&D: Non-linear folding

Non-linear folding being pursued for loss reduction both at the ZS and at the splitters.

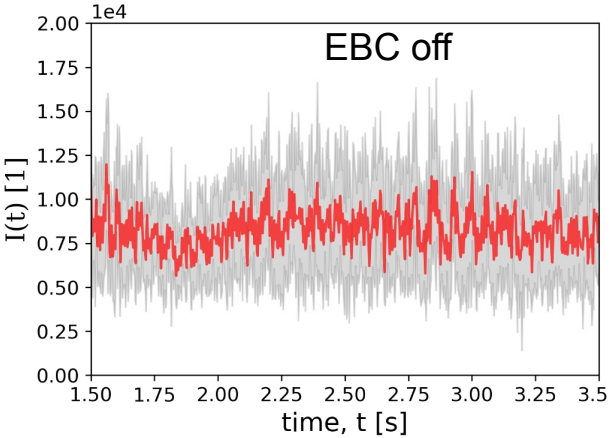
- Octupole folding for **ZS loss reduction already demonstrated** in the past (MD time to be requested in 2024 to follow this up) [1].
- **Similar strategies can be used for splitter**:
  - Deplete core of vertical distribution inside SPS.
  - Deform distribution in transfer line [2].
  - PhD student will start in ABT in 2024, with synergies with Machine Learning topics.

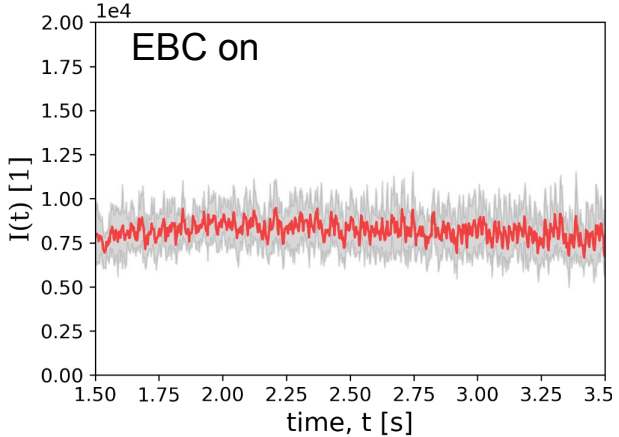


Empty-bucket channelling

Intro

Empty-bucket channelling (EBC) is an RF manipulation pursued in the SPS due to difficulties to suppress 100Hz spill ripple*.



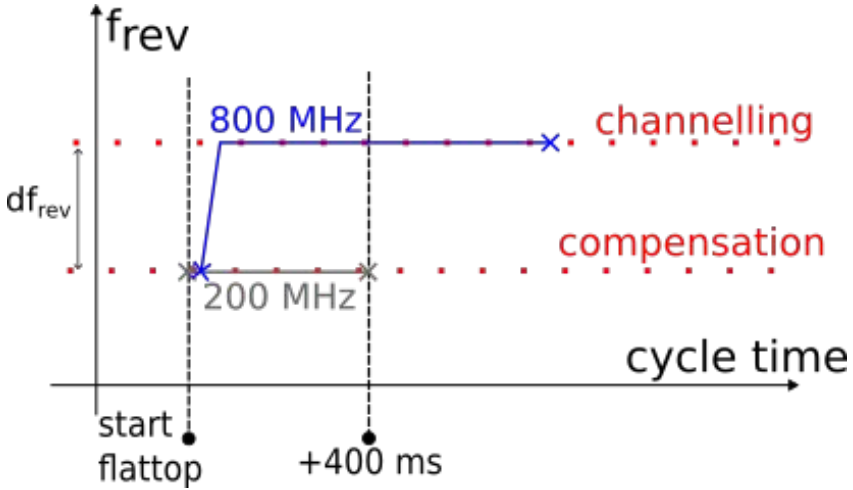


[1] Cappi and Steinbach
*SPS power-converter analysis provided in later slide

New RF feature

In 2023, new RF feature implemented to add frequency offset between 200MHz and 800MHz frequency programs at SFT flattop.

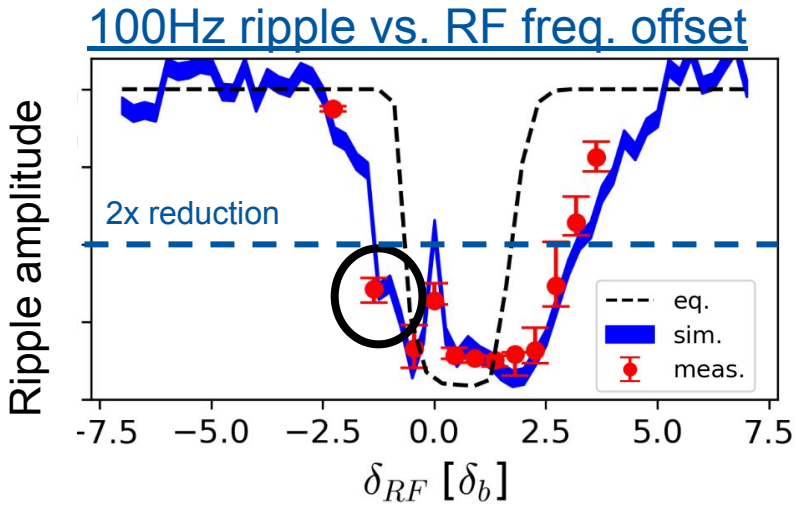
- In 2022, EBC with 800MHz cav. was in conflict with 200MHz compensation during SFT extraction. RF team exploited slip-stacking controls to solve issue [1].



[1] EDMS 2874819

MDs (2023)

- May-Aug 2023: Test of new RF feature + benchmarking on modelling tools [1].
- **Stable configuration** found that suppresses 100 Hz ripple: compatible with crystal, 50-100Hz controllers and Autospill.



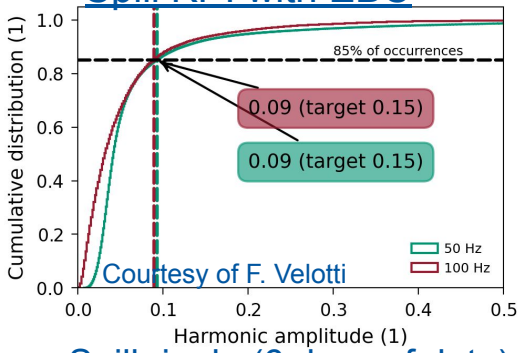
Operational implementation

Aug 2023: EBC is put in operation. Running successfully until end of proton run.

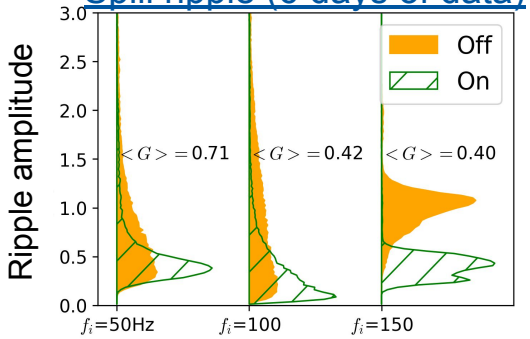
- In combination with Adaptive Bayesian Optimisation (See Michael's talk [1]), **we reach the SPS spill-quality KPIs** [2].
- **No need for explicit alignment**: tune adjustment performed by operators also aligns EBC.
- Suppresses all low-frequency ripple (50, 100, 150 Hz…)

Next step is to implement EBC monitoring tool via UCAP node to facilitate operation and post-mortem analysis.

Spill KPI with EBC



Spill ripple (6 days of data)



[1] M. Schenk (JAPW 2023)
[2] V. Kain (IPP 2023)

1 slide, 1 topic

R&D: Spill quality

The Spill Optimisation for eXperiments working group will discuss NA experimental requirements and KPIs in 2024. Progress in 2023/24:

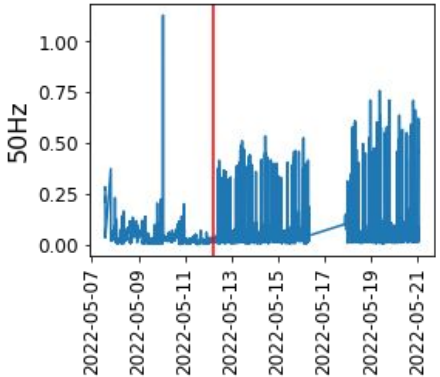
- RF team optimised phase jump and bunch rotation -> increased dpp by ~15% [1].
- New RF technique to tailor momentum spread already demonstrated in PS in 2023 [2] (See Eliott's talk [3]). Time to be requested for MD in SPS.
- Use of longitudinal and transverse noise to improve spill quality (first being investigated in the PS).

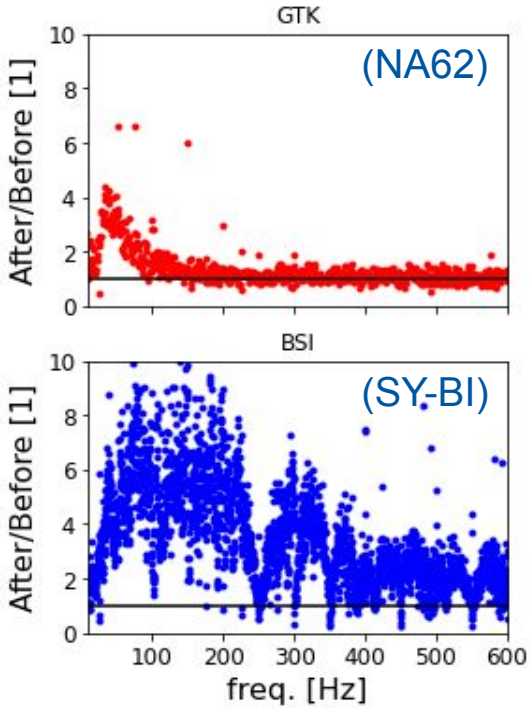
[1] O. Naumenko (MPC 2023)
[2] P. Arrutia et al (NIMMA 2022)
[3] E. Johnson (JAPW 2023)

SPS power-converter analysis

Low-frequency spill quality suddenly got worse at 9:34 12/5/2022. Investigations launched to find root cause [1].

- Comprehensive analysis of power converters but no smoking gun found: **request to characterise measurement noise when magnets are off.**
- Spill monitor (BSI) differs from NA62 detector (GTK) when comparing spectra before and after 12/5/2022 -> **Second spill monitor needed on ATS side (OTR PMT).**





Summary

Non-local crystal shadowing:

- **2x loss reduction** shown during high-intensity operational test.
- **Improved controls and reduced setup** time with optimisers.
- **Shielding** may be needed.

Losses in TT20 splitter:

- **Can be reduced with high v-emittance from PSB** (and constant optimisation of splitter losses).
- Future strategies: optics change, crystals, non-linear folding.

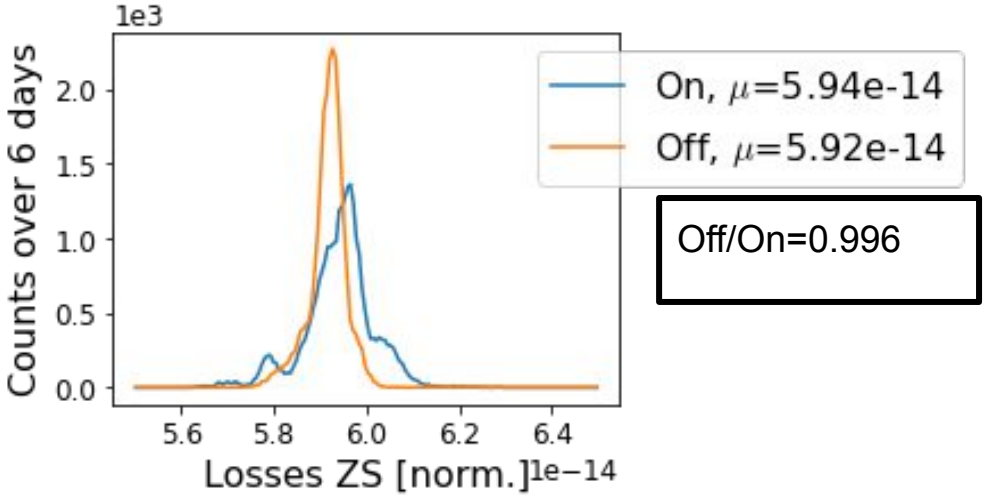
Empty-bucket channelling:

- **Operational**, without need for re-alignment.
- Tools for monitoring and further optimisation to be studied.

Extra slides

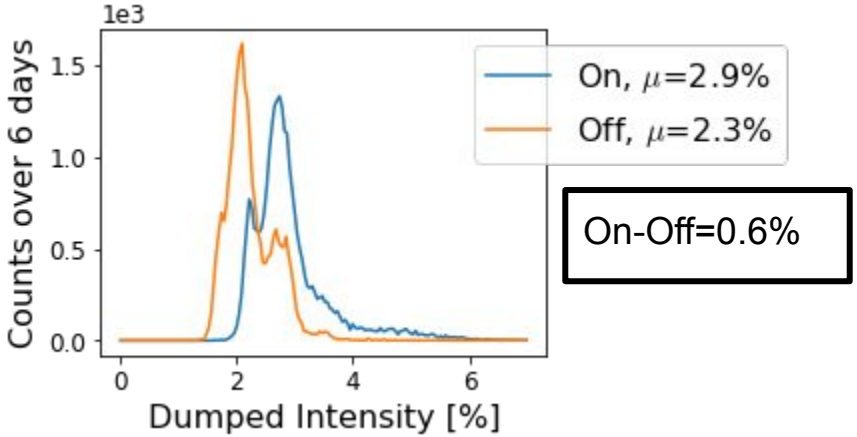
Beam Loss EBC

Beam loss on ZS practically identical.



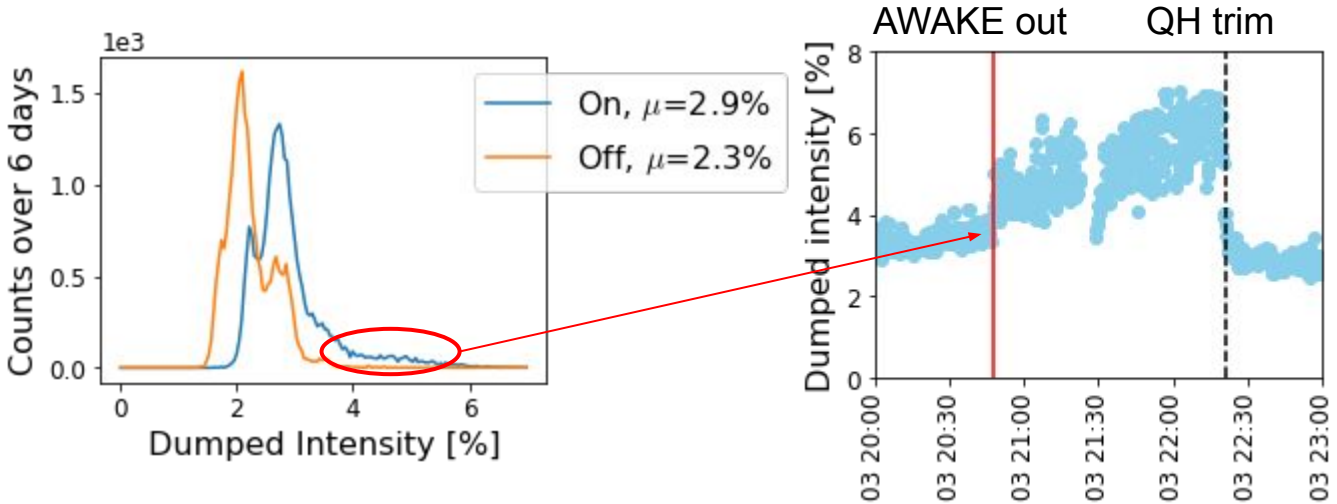
Dumped Intensity EBC

- Small increase in dumped intensity, to be expected from beam dynamics.
- Important: this beam is not lost on aperture. It stays in the ring until dump.



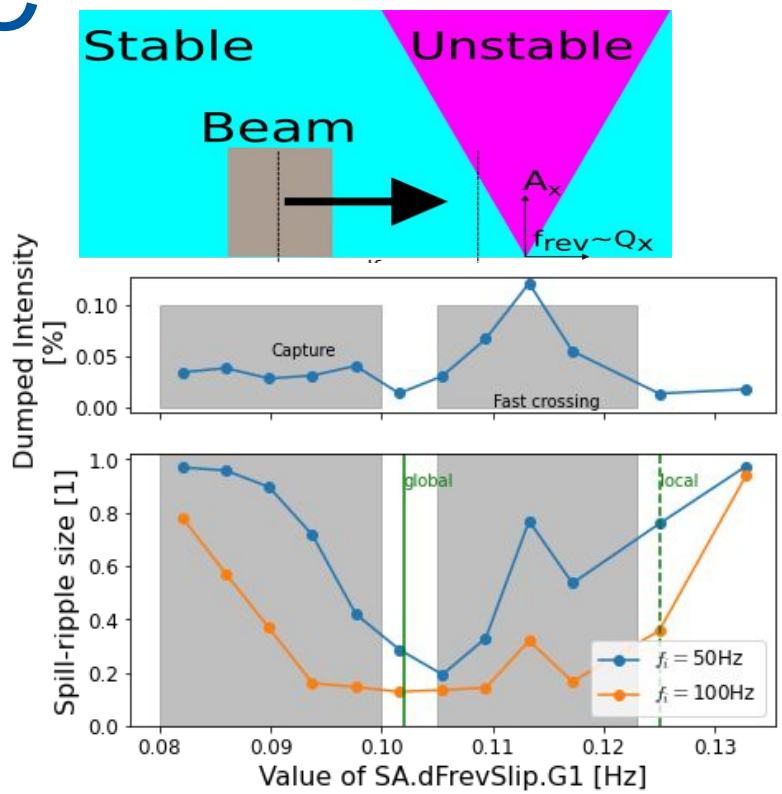
Supercycle change EBC

- Supercycle change -> hysteresis -> extraction starts later -> more dumped intensity
- With EBC, the empty-bucket also shifts and slightly aggravates this effect
- QH correction restores both `start extraction' and `empty-bucket misalignment'



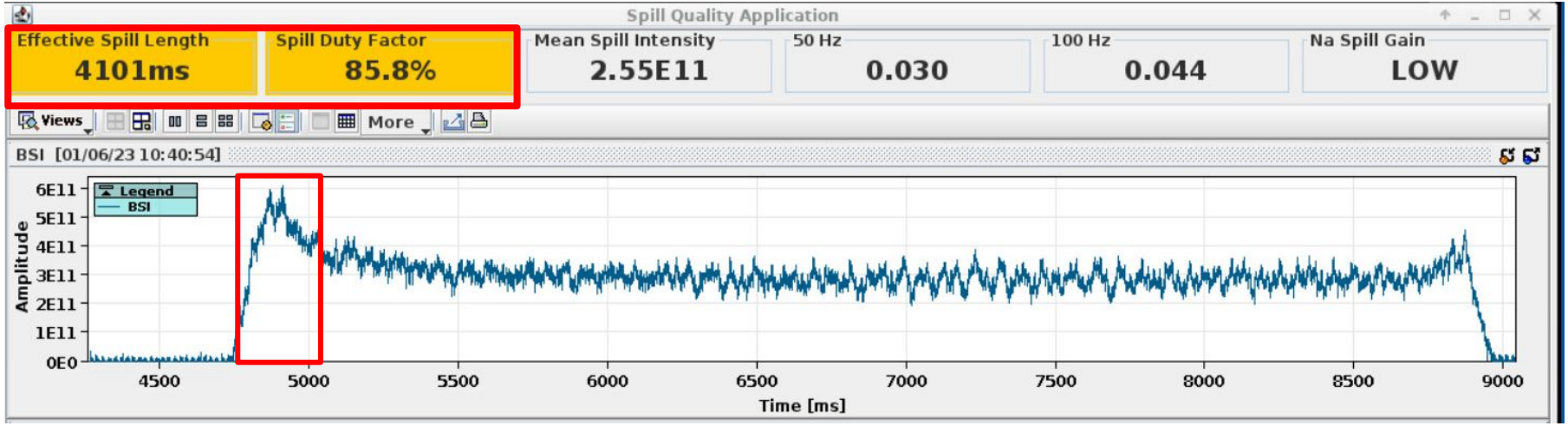
Working points EBC

- The empty bucket may be situated between the beam and the resonance for maximal suppression (global)
- The empty bucket channelling may be situated on the other side of the resonance and still achieve good suppression (local)
- Local configuration is more robust, with smaller chance of perturbing waiting stack and spill macro-structure



2023: Global optimum EBC

Spill was slightly too short and had bump in the beginning.
Also suppresses 20Hz and lower
Beam loss needs to be assessed



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Empty-bucket channelling:

- **Operational**, without need for re-alignment.
- Tools for monitoring and further optimisation to be studied.

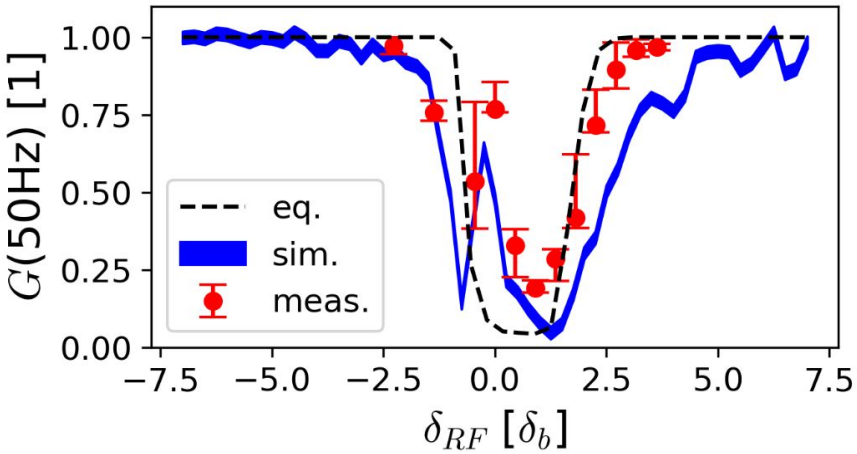
During the year…

At JAPW

Empty-bucket channelling

[1] Courtesy of A. Lu

EBC scan


1.00
0.75
0.50
0.25
0.00
$G(50\text{Hz})$ [1]
eq.
sim.
meas.
−7.5
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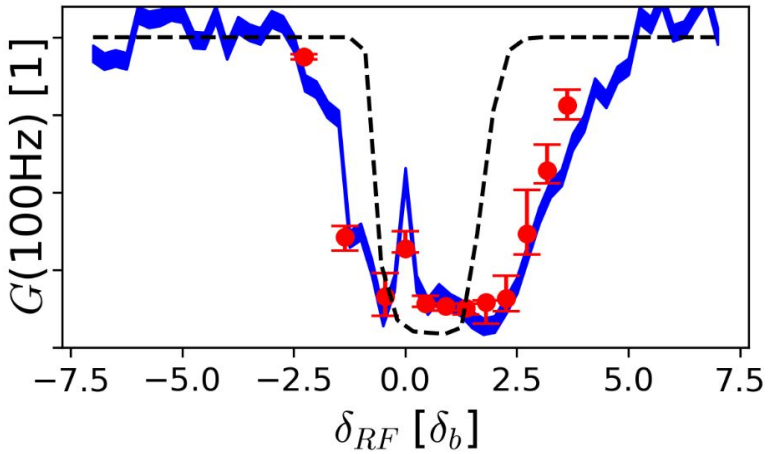
δ_{RF} [δ_b]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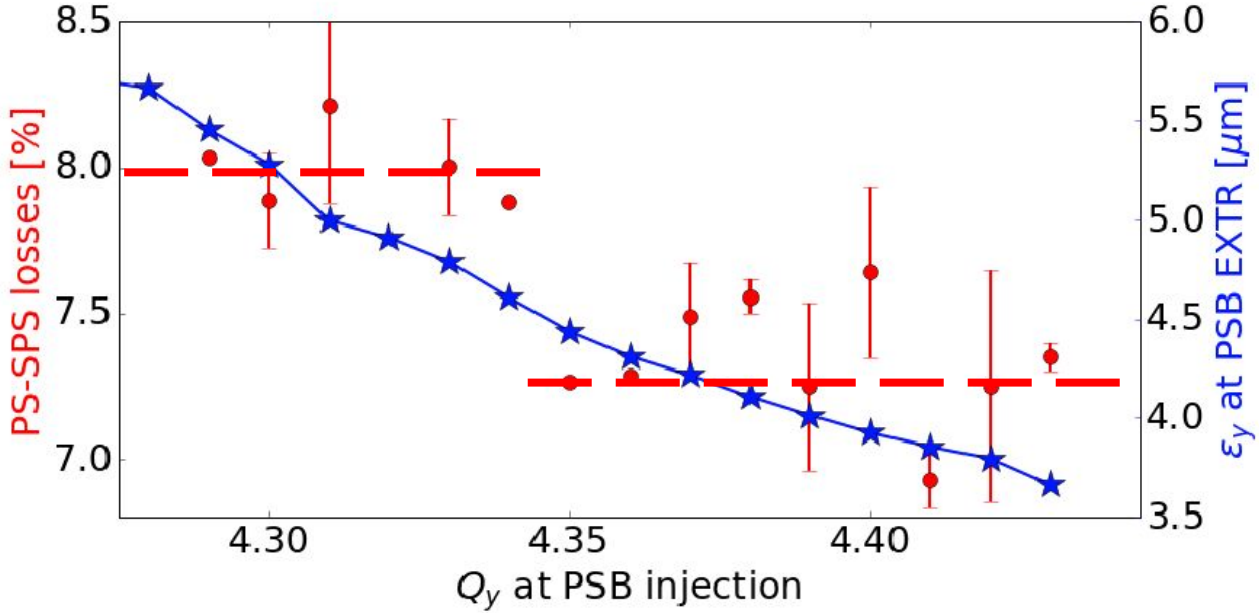
Losses v emittance PS-SPS



Tirsi (IPP 2023)

Crystal assisted slow extraction in the SPS – update

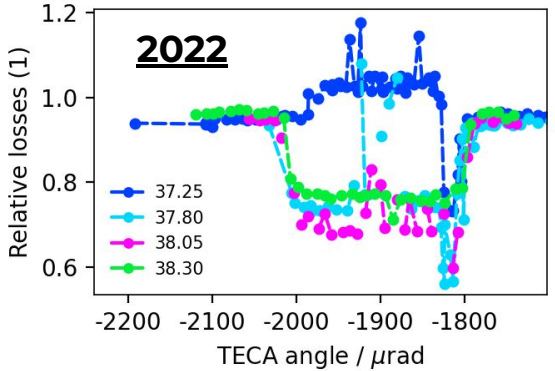
F. M. Velotti, M. Fraser

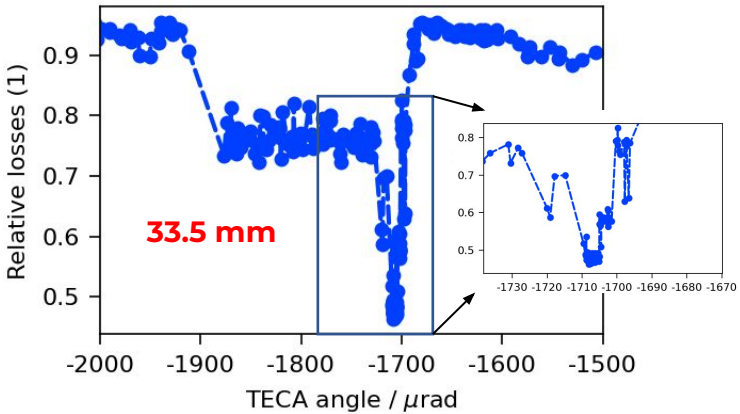
Crystals in the SPS – plan from last report

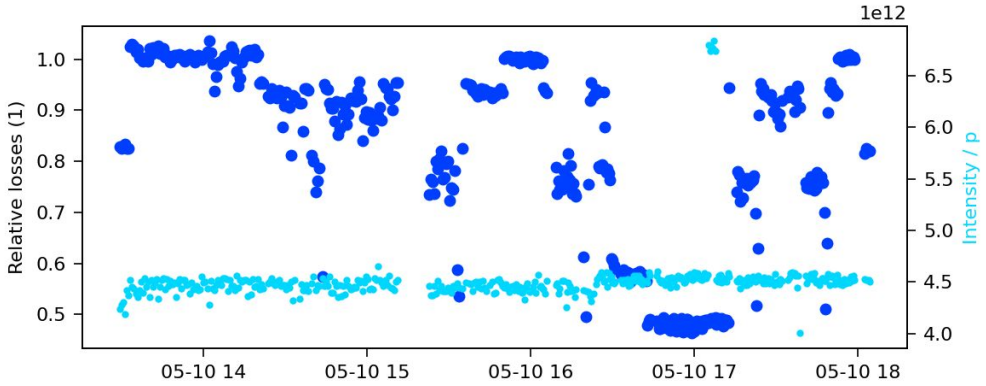
- DECRYCE project looking at produce crystal in-house
  - Collecting specs now provided for optimized TECA
  - Still missing full parameter set: max deflection angle, range…
- Non-local shadowing:
  - Simulations to quantify expected activation of LSS4 input for RP to plan operational test
  - Depending on results, design mask for TECA
  - When 1.8 mm crystal available, install in TECA gonio and re-evaluate
- Studies carried out (Pablo) to test crystal to shadow splitter blade ~25% loss reduction expected with same crystal as those we have in the SPS (TECS/TECA)
  - Need to find space in TT20 – investigation ongoing
  - Need then to define timeline, funds…STI will provide initial estimates
- Studies for ZS replacement by crystal to get started:
  - Discussions have started on a roadmap to the future…

MD Results - recap

- Quick cycle set up
  - New cycle: copy from last year
  - Bump put on after orbit flattening at flat top 30 mm (margin)
  - Extraction with 4e12 ppp
- First AM scan to find shadowing position
- Large angular scan around the proposed angle
  - Shadowing and CH angle found rather quickly **55% loss reduction!!**
  - Increase in losses seen right at the end of TT24 (basically at T4 target when in CH) with dedicated ECN3 (unsplit) optics
- Stability in shadowing: run for about half an hour in shadowing
  - Loss reduction very stable

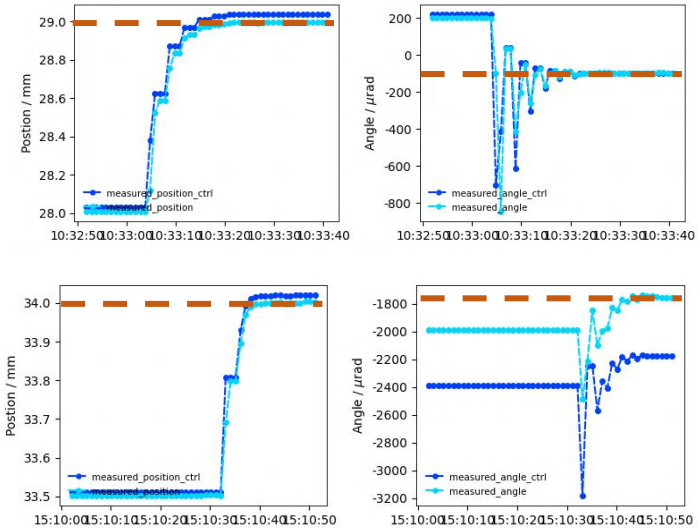


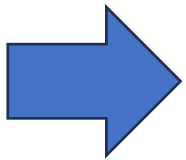


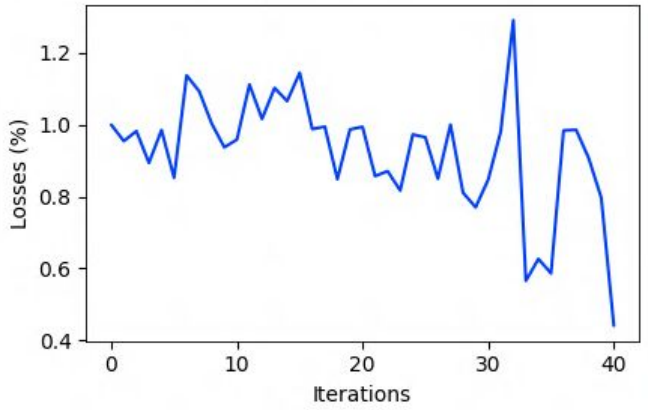


Latest results

- High level controller (simple PID) developed and test during MDs in August
  - We could control the TECA using its LVDT (absolute position and angle measurement) instead of motor control not affected anymore by non-reproducibility of position and angle of the crystal
  - It allows to properly use numerical optimizers (see example with Bayesian optimizer)



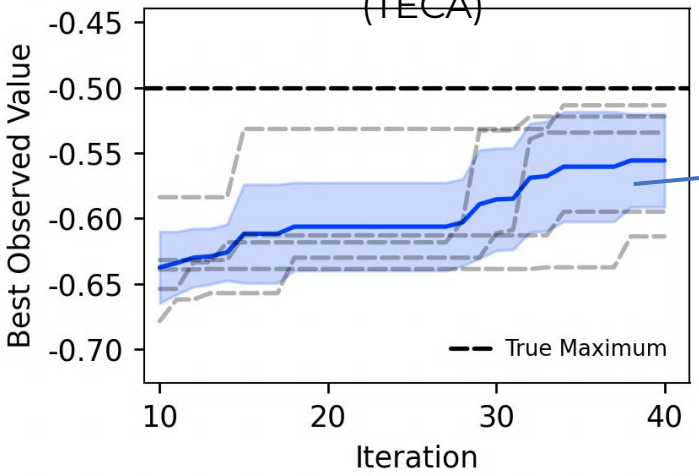




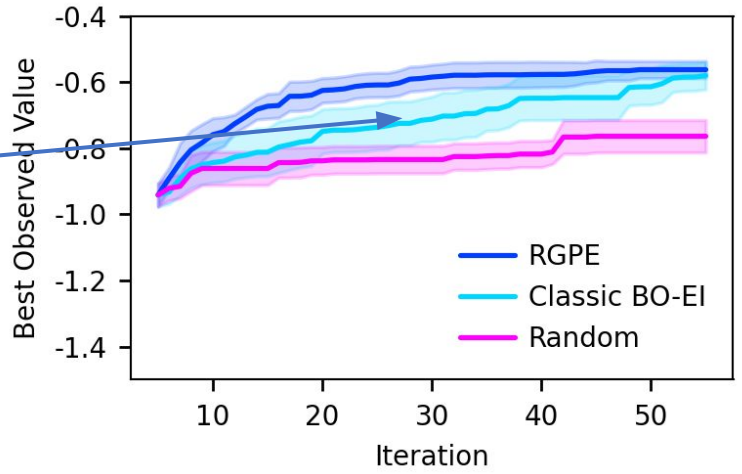
Latest results

- Bayesian optimisation for TECA alignment tested in simulations and MD
  □ we can align TECA via BO in < 60 cycles
  - Very reproducible and robust
  - Only issue is the minimum step size the crystal can do □ this is one of the main bottleneck at the moment
  - Tools ready to test surrogate optimisation (RGPE) in the machine – for now only simulations but potential to halve number of cycles needed to align the crystal

Real machine data (TECA)



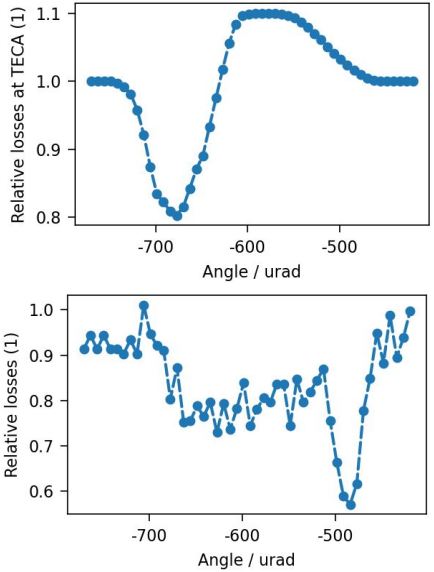
Simulations (TECS)

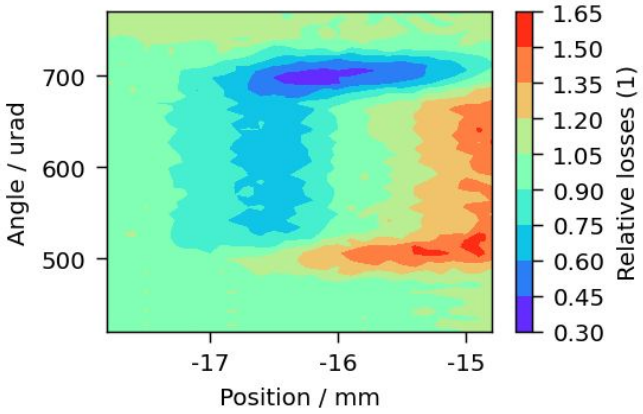


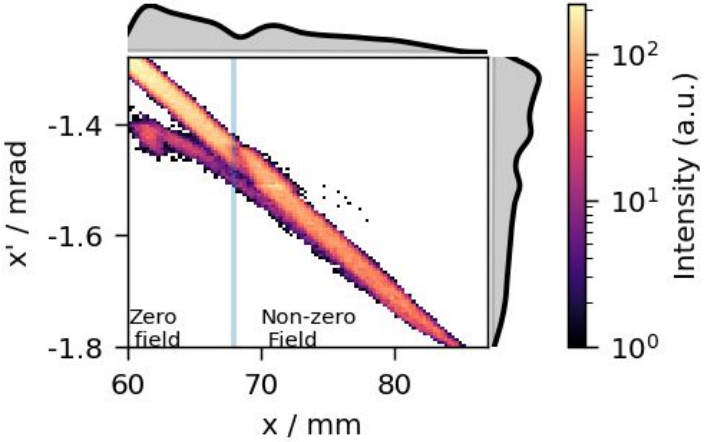
Latest results

→ Simulations updated as sign error found in description of the crystal agree very well with data now

- Drawback: max x3 loss reduction achievable and need to orient crystal towards the outside of the machine – full study still pending
- Now we can describe accurately loss patter expected at TECA location during scans



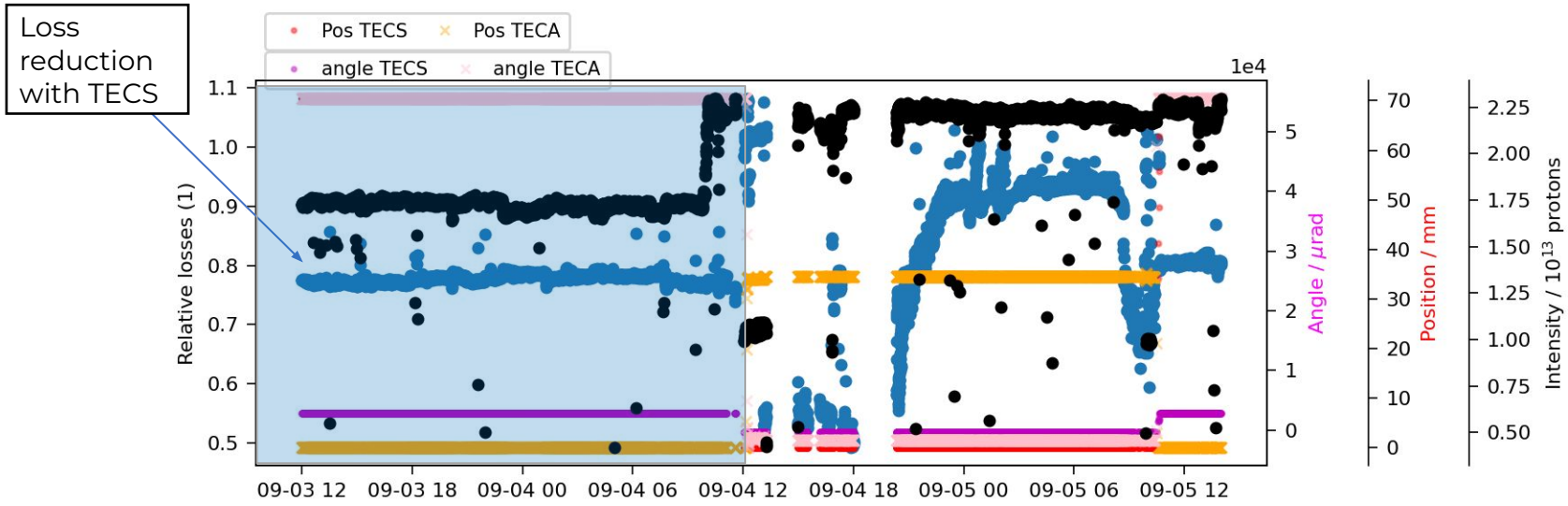




Latest results

→ Operational test carried out very important results:

- TECA can reduce losses x2 in this configuration also with high intensity
- Loss reduction is not resilient to machine stops or changes
  - Major difference before and after long stop for MKDH cable replacement
  - The good news is that the beam “drifts away”, hence we could catch this with “simple” feed-forward controller!



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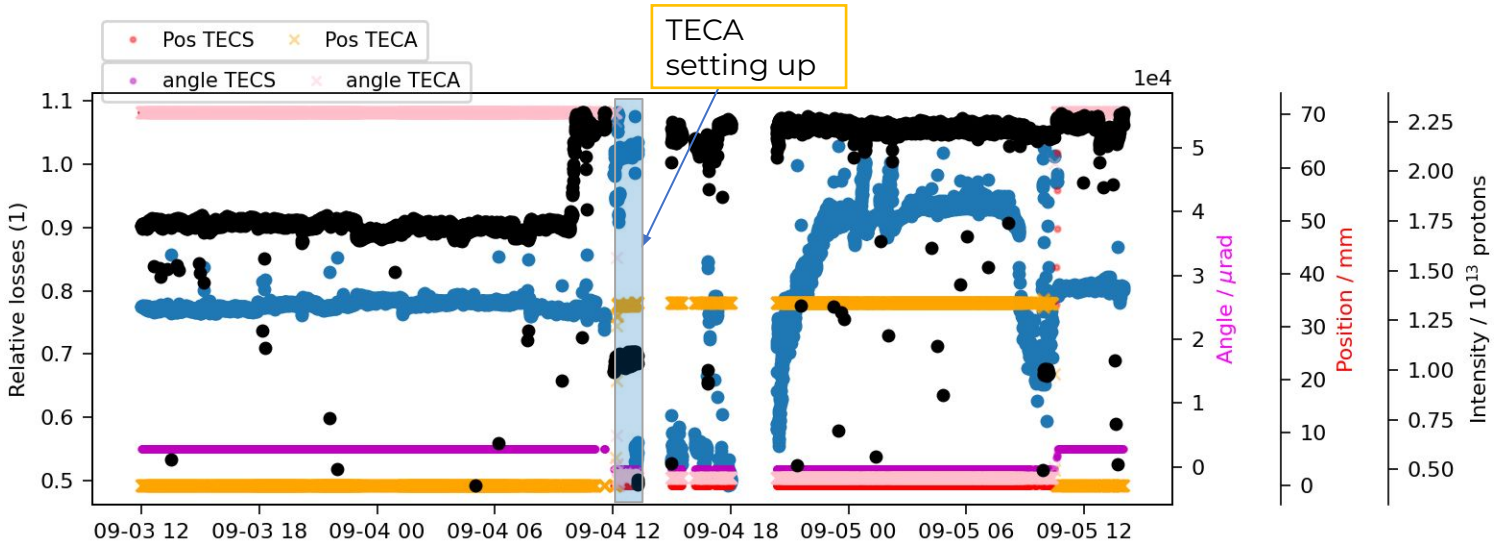

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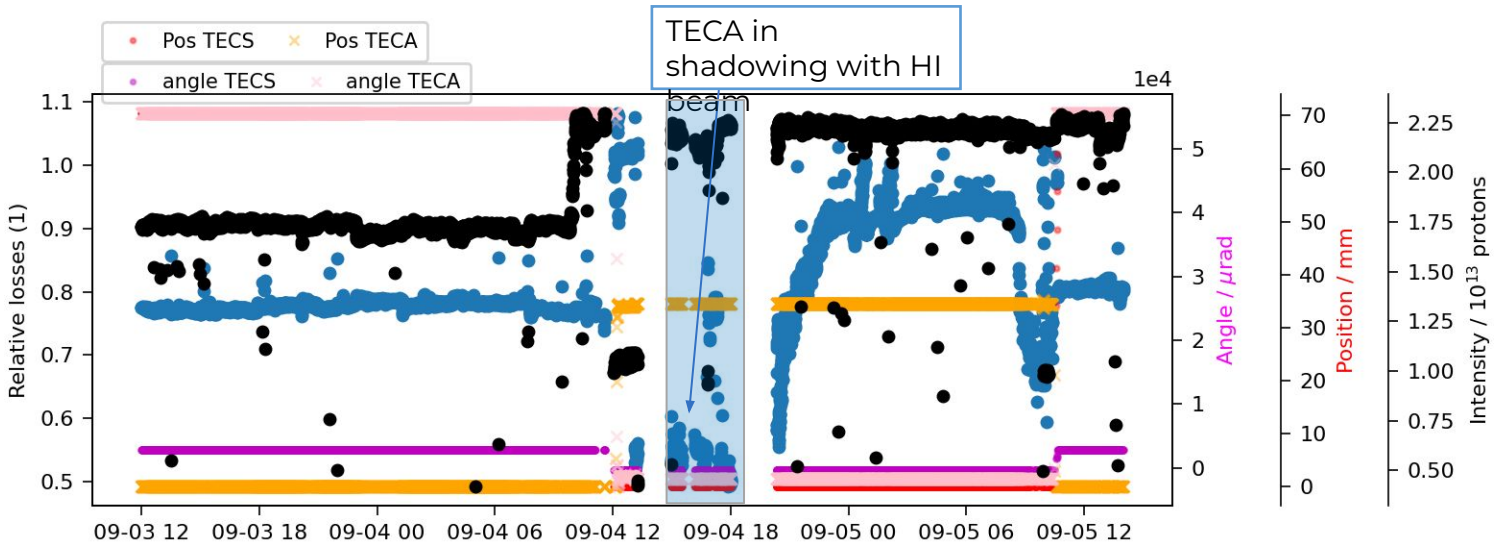

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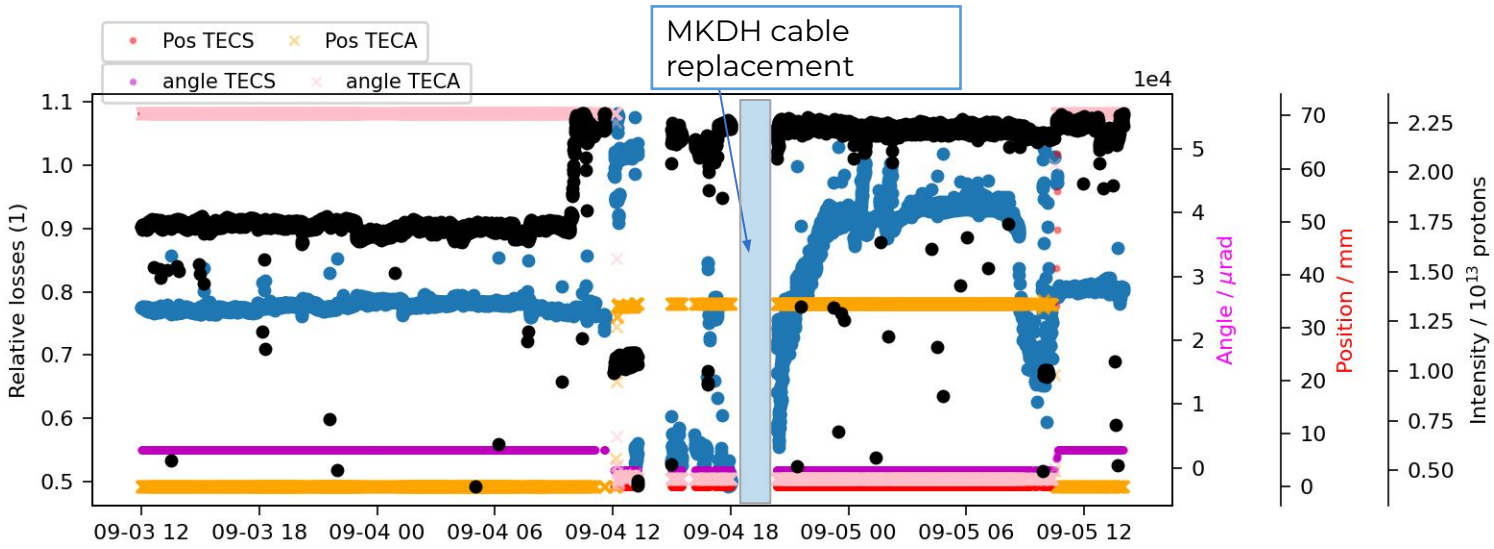

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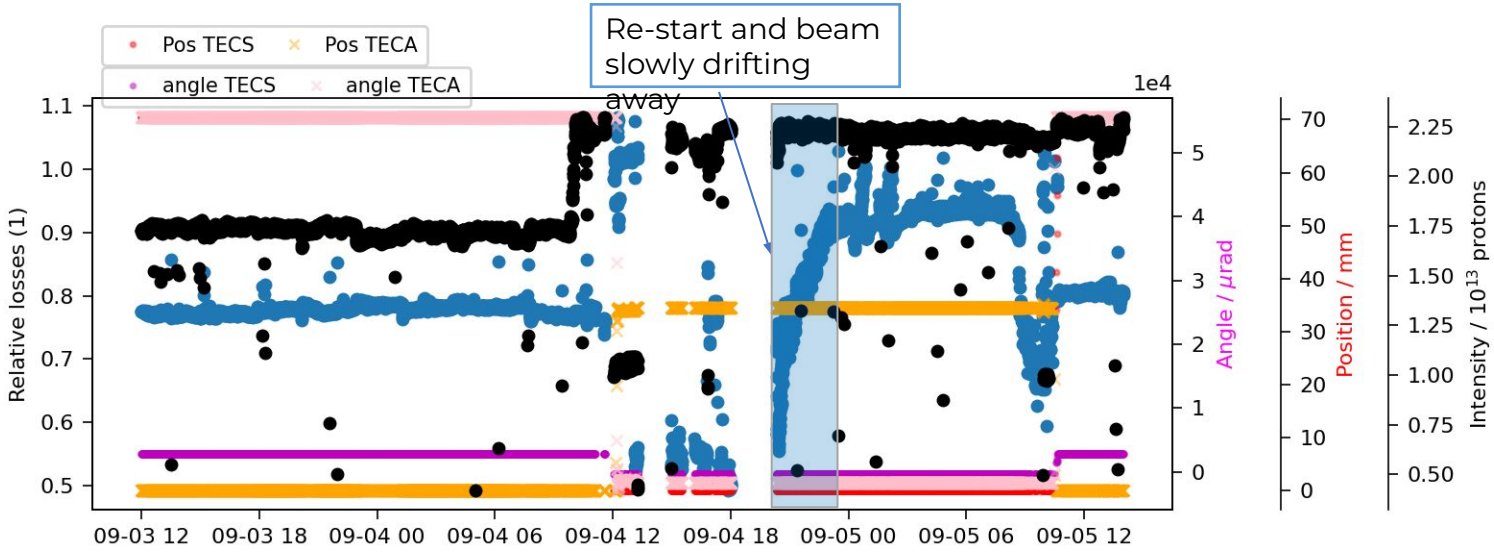

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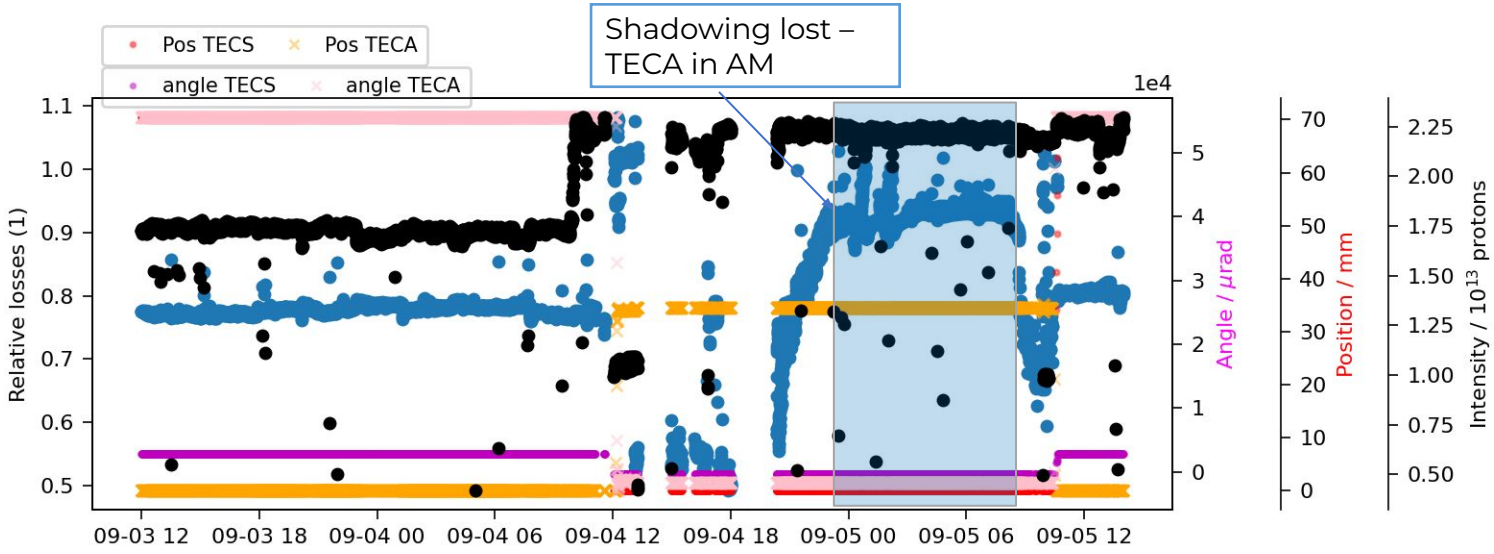

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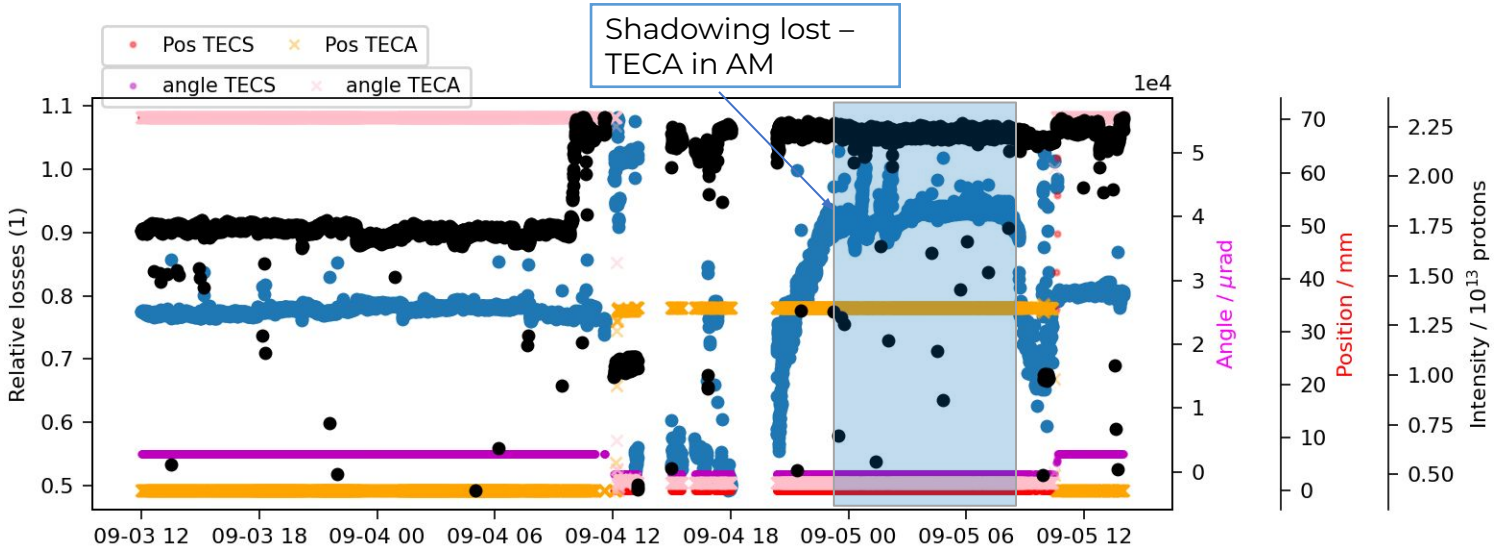

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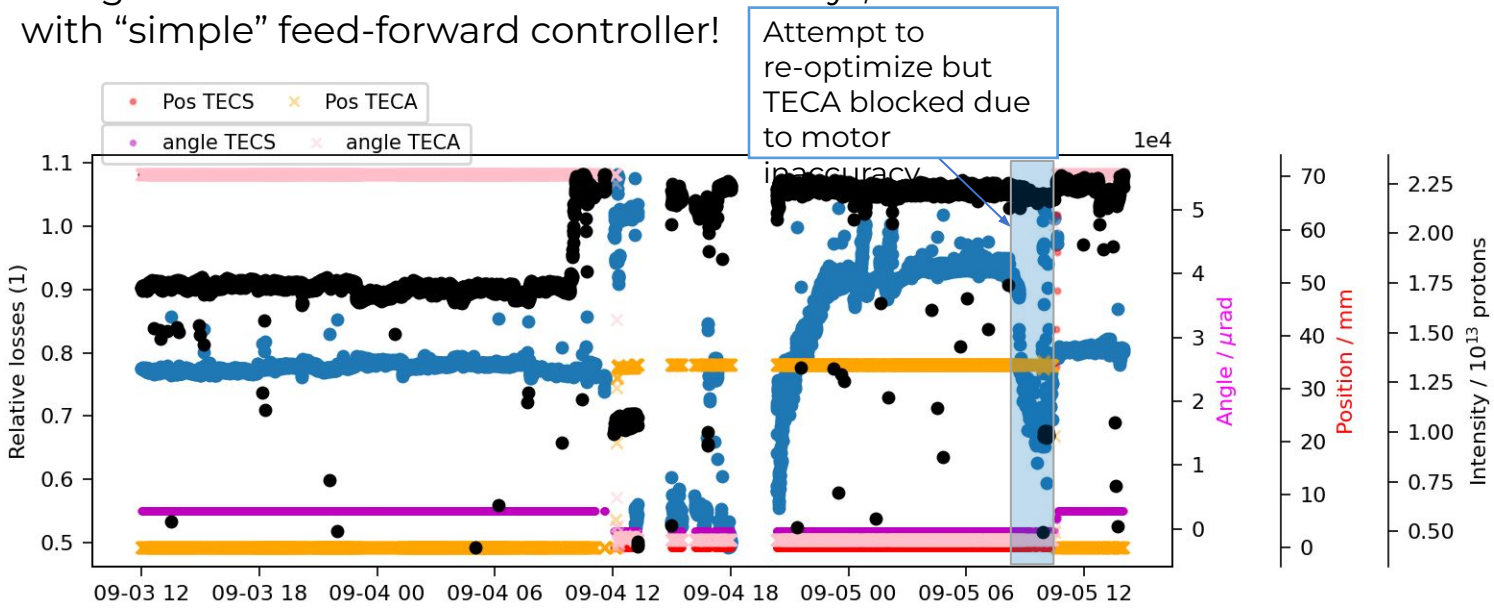

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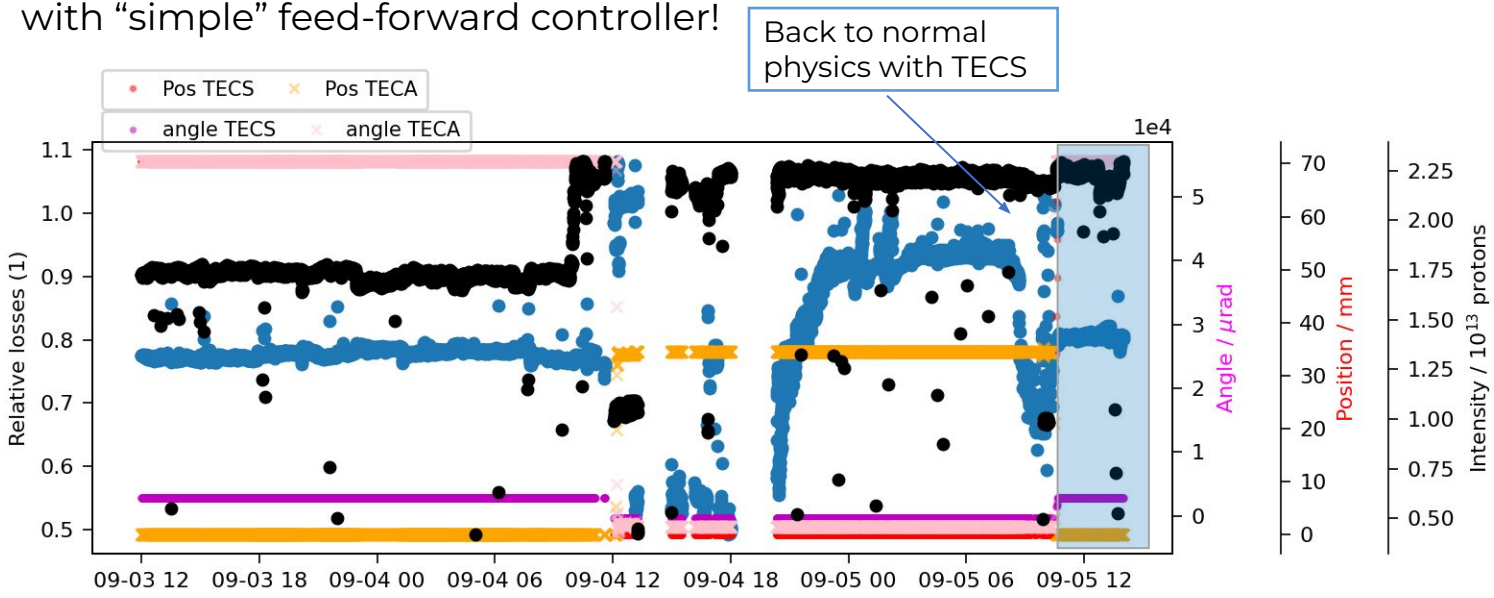

Summary

- Good and not-so-good news from both machine tests and simulations
- Much better understanding of the performance reach of the principle and limitation of HW and controls
- High-level controller showed that we need it to use optimizers only efficient way to use crystals (see also LHC experience with ions…)
- We absolutely need a controller on the crystal to operate in CH – machine is not stable enough!
- Performance reach with single crystal seems closer to x3…we need something else to get to x4!


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