MAX-IV: Operations and plans

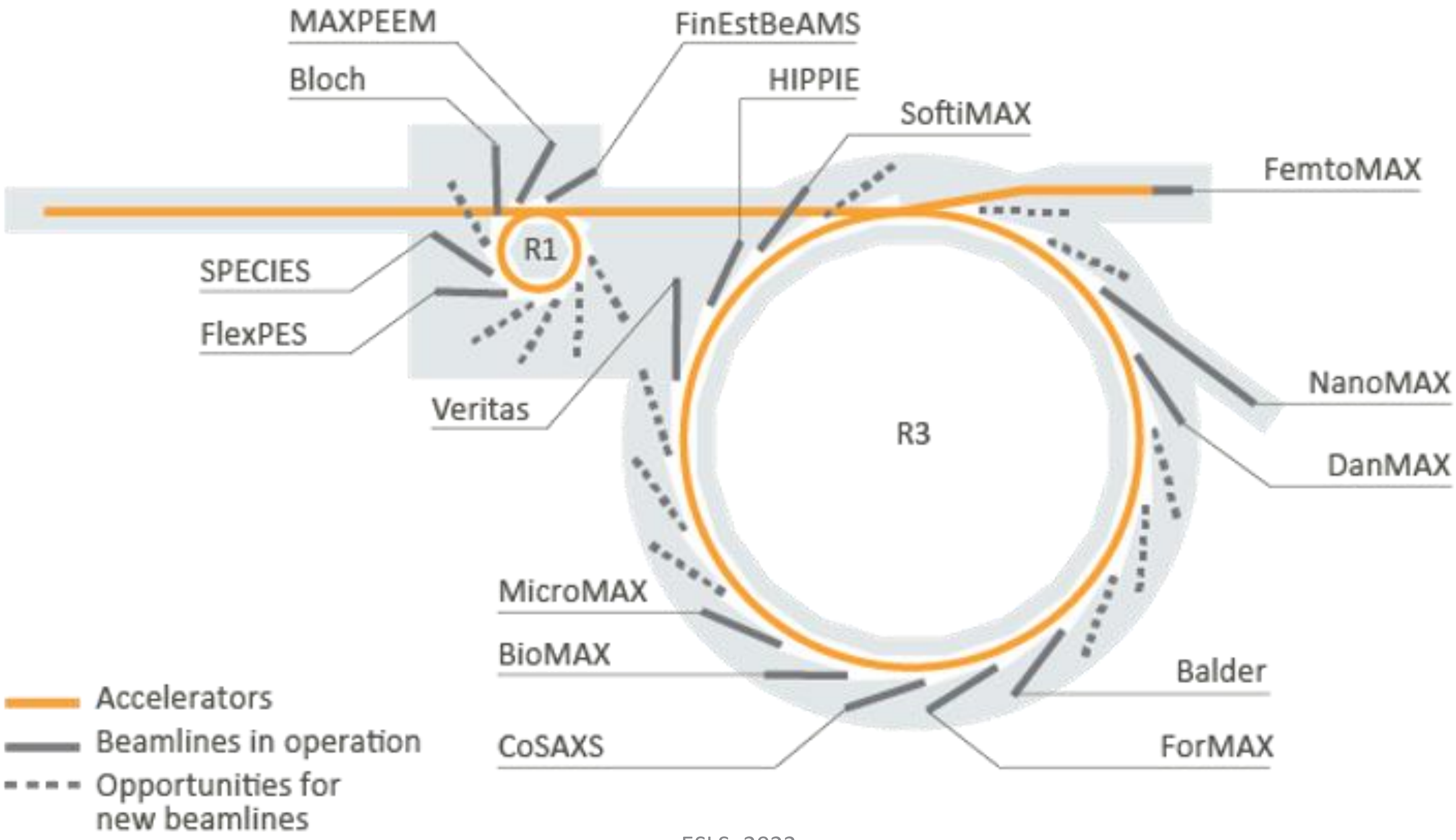
ESLS, 2022

Stephen Molloy
Head of Accelerator Operations

Outline

- Headline statistics
- Highlights
  - Accelerator Reliability Workshop 2024
  - MTBF for linac-based sources
  - Low-emittance lattice for our 3 GeV ring
  - Multipole Injection Kicker for our 1.5 GeV ring
  - "TRIBS"
- Power supply crisis

MAX-IV Facility

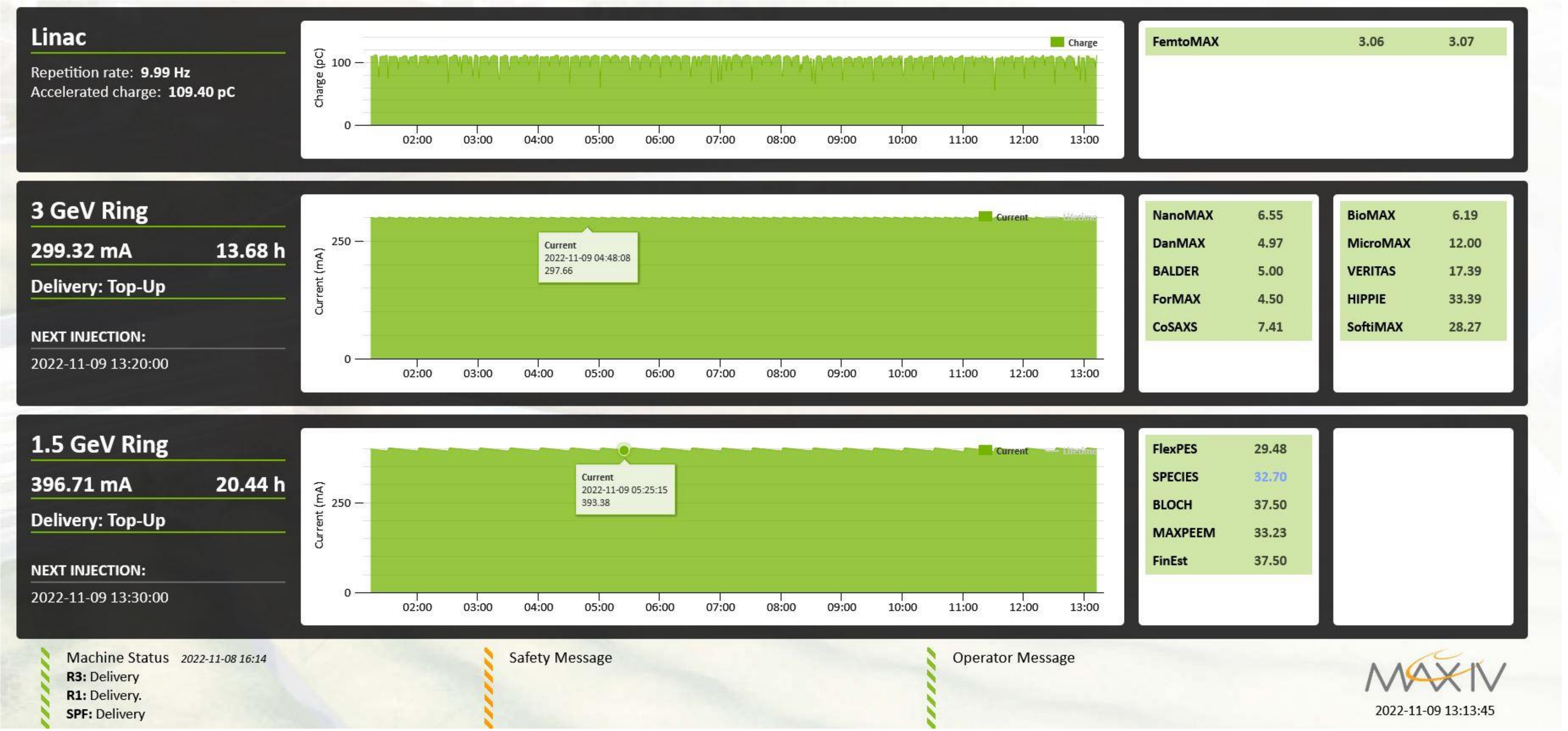


Regular delivery to 16 beamlines

100 pC
10 Hz rep rate

300 mA
Ten-minute top-ups

400 mA
30-minute top-ups



Top-level statistics

- Year to 09/12/2022
  - (Except for the "*Planned*" column)

MTBF = planned / N
MTTR = down / N
Availability = 1 – down/planned

	Delivered	Planned total for 2022	Availability	MTBF	MTTR
3 GeV Ring	4032	4464	98.2%	3.1 days	1.36 hours
1.5 GeV Ring	4240	4848	98.4%	4.1 days	1.62 hours
SPF	3744	4272	96.9%	0.6 days	0.41 hours

MTBF = planned / N
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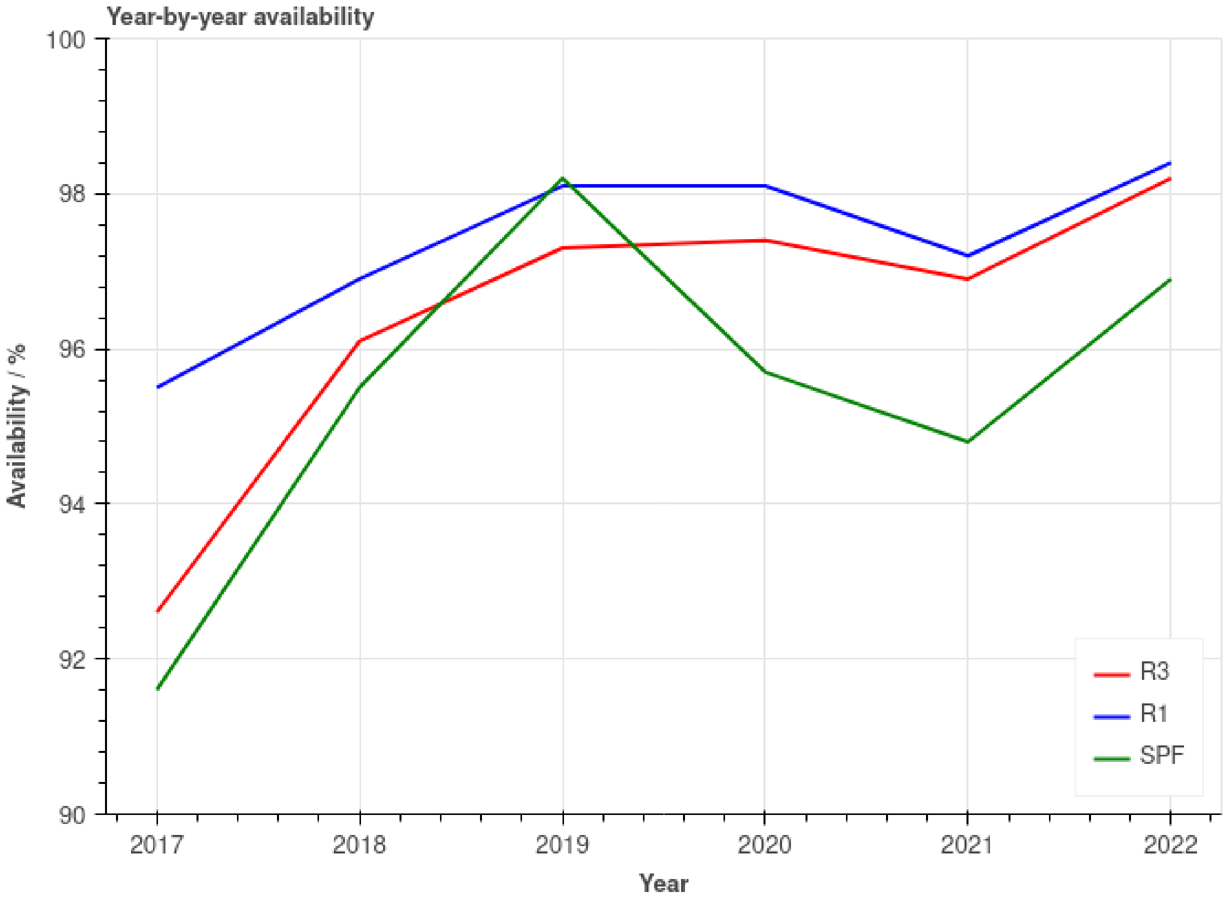
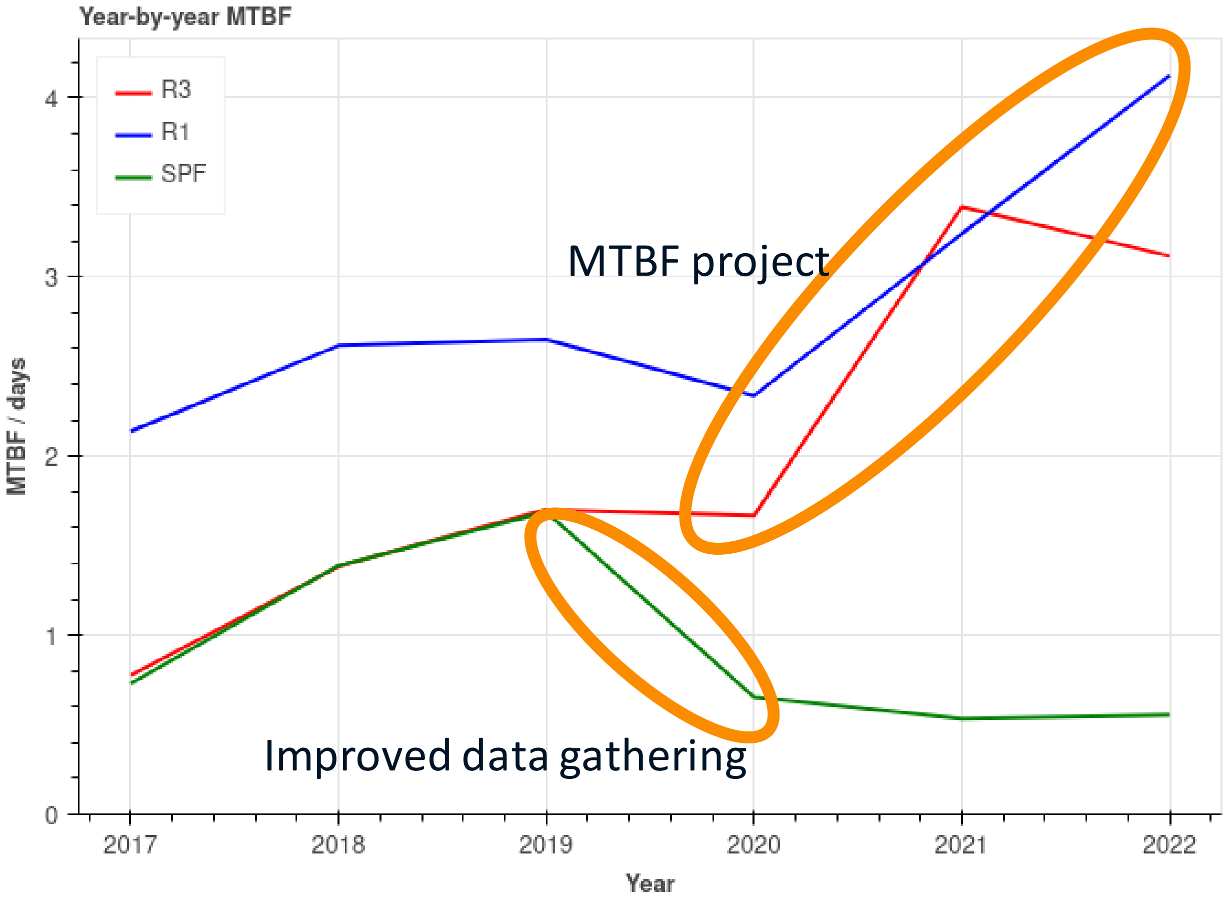
Annual evolution

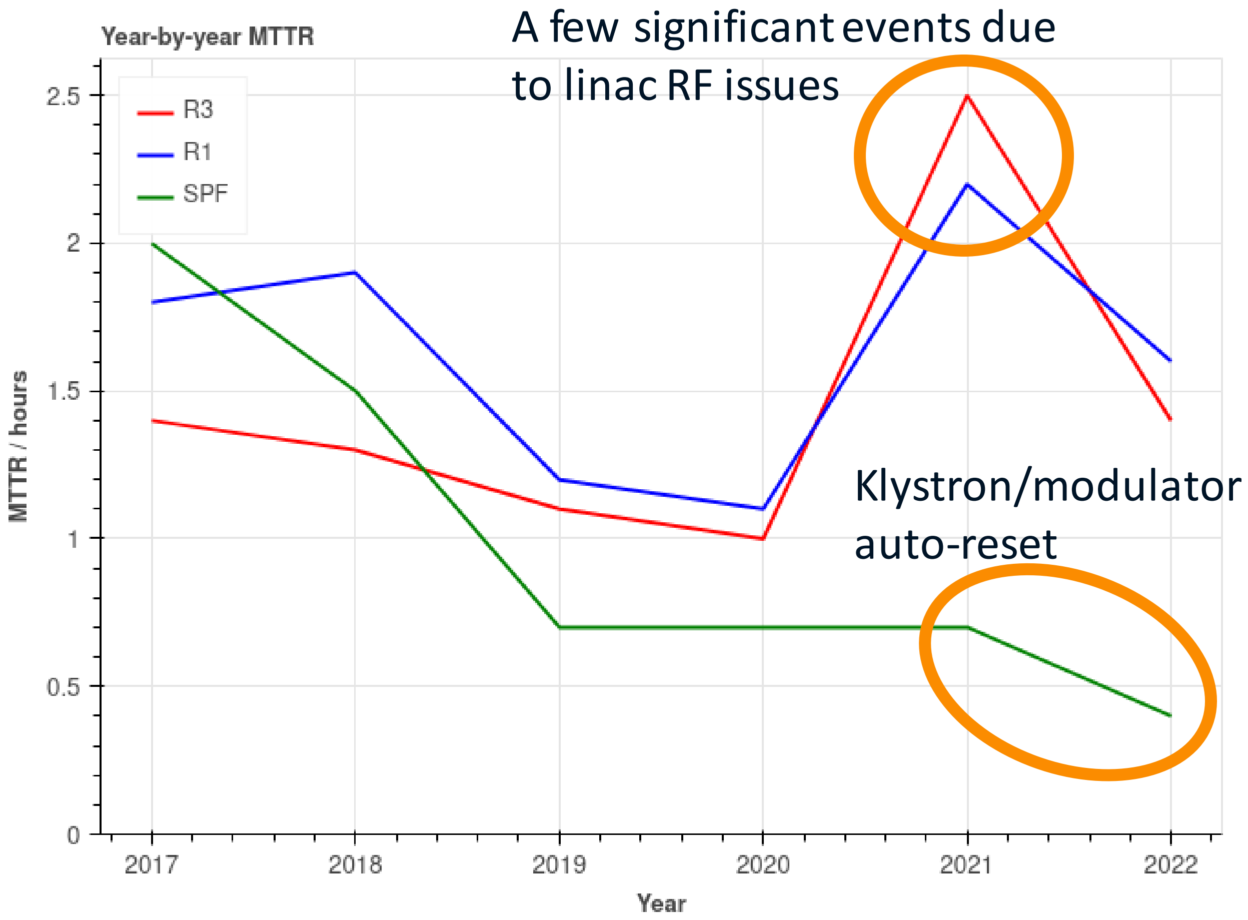


- R3:
  - Upwards trend, interrupted by klystron issues in 2021
- R1:
  - Same upwards trend, with the same interruption
  - Some sign of saturation at ~98%?
- SPF:
  - Improved statistics gathering from 2020
  - This drop is followed by a rise due to better understanding of failures

2022 data is year-to-24/11

Annual evolution





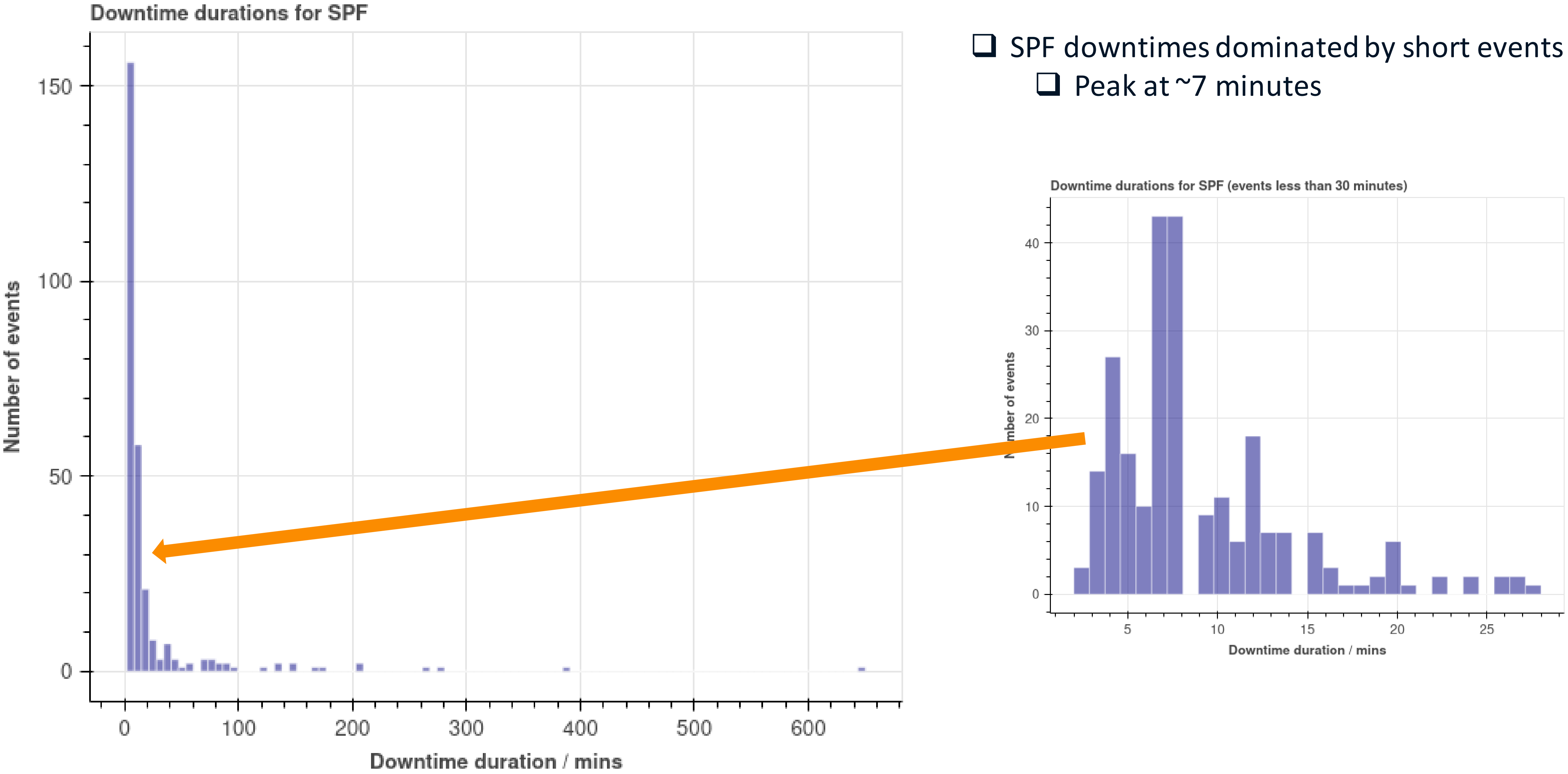
MTBF Project

- Eradicate human error related to the ring-side heat absorber (HA)
  - Automation and Controls Hardware teams completed a project to lock ID motors if:
    - The ringside HA is closed AND
    - The ID is fully open
- Review Machine Protection System (MPS) actions
  - All MPS actions resulted in valves being closed before the heat absorber
    - The beam was then dumped to protect the valves
  - Changed to force HA closed first, then the valves
  - Deployed on all beamlines during pandemic shutdown

Sub-system	MTBF 2020	MTBF 2022
Beamlines	1.0 week	23.8 weeks
Magnets	1.5 weeks	7.9 weeks
RF	1.6 weeks	2.6 weeks
Human error	2.3 weeks	4.8 weeks
Controls	3.3 weeks	11.9 weeks

Short Pulse Facility: MTBF

- ❑ SPF downtimes dominated by short events
  - ❑ Peak at ~7 minutes



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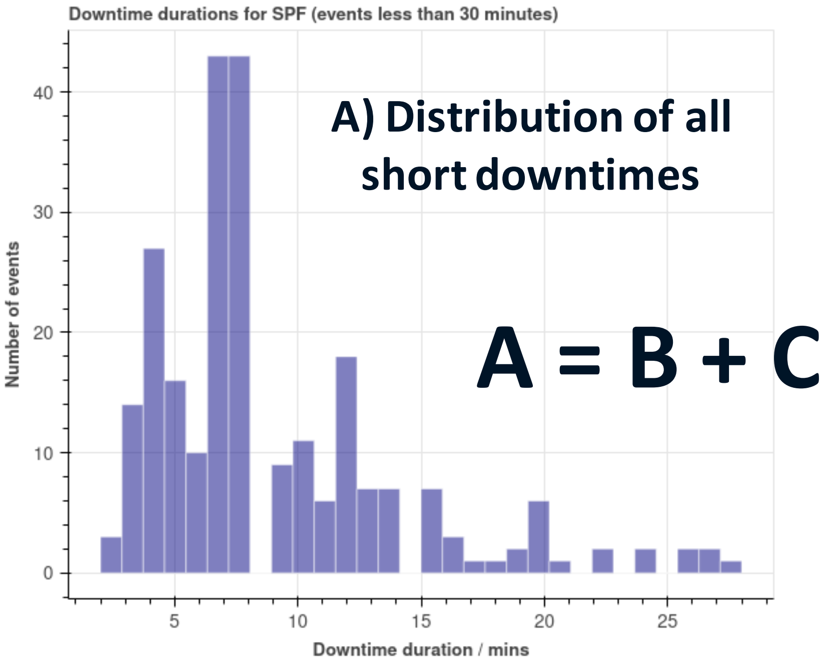
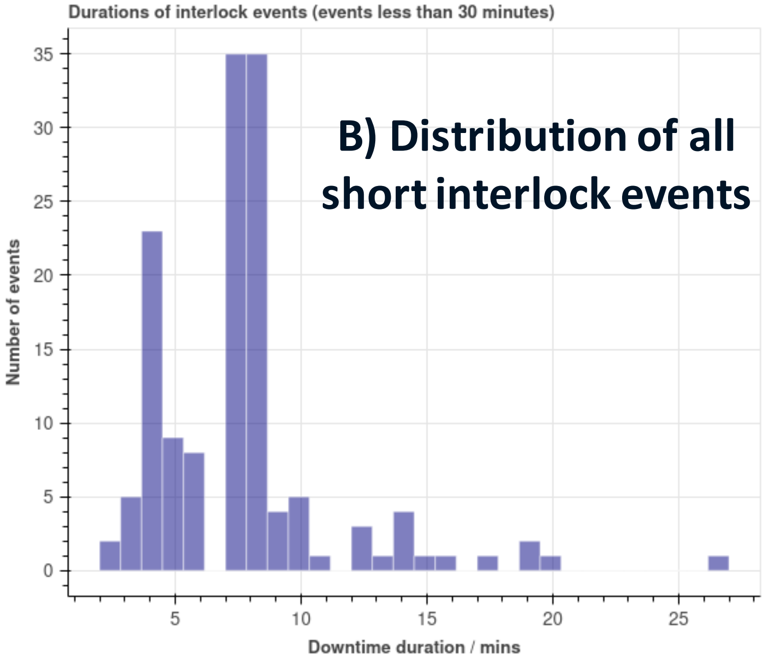
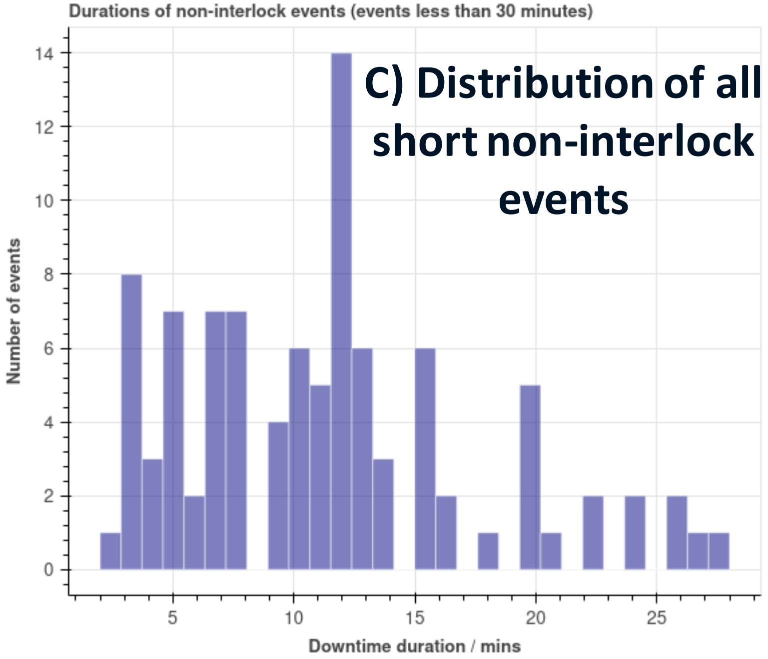






- ❑ Short events are dominated by klystron/modulator trips, which are now handled by an **automatic reset system**
  - ❑ Implemented by AccOps
  - ❑ Specified by klys/mod subsystem owner
- ❑ May take up to 10 minutes to complete the reset
  - ❑ Monitoring vacuum, ramping carefully, etc.
  - ❑ Experience showed that **too fast restart may lead to damage to equipment** and decrease overall availability

Accelerator Reliability Workshop

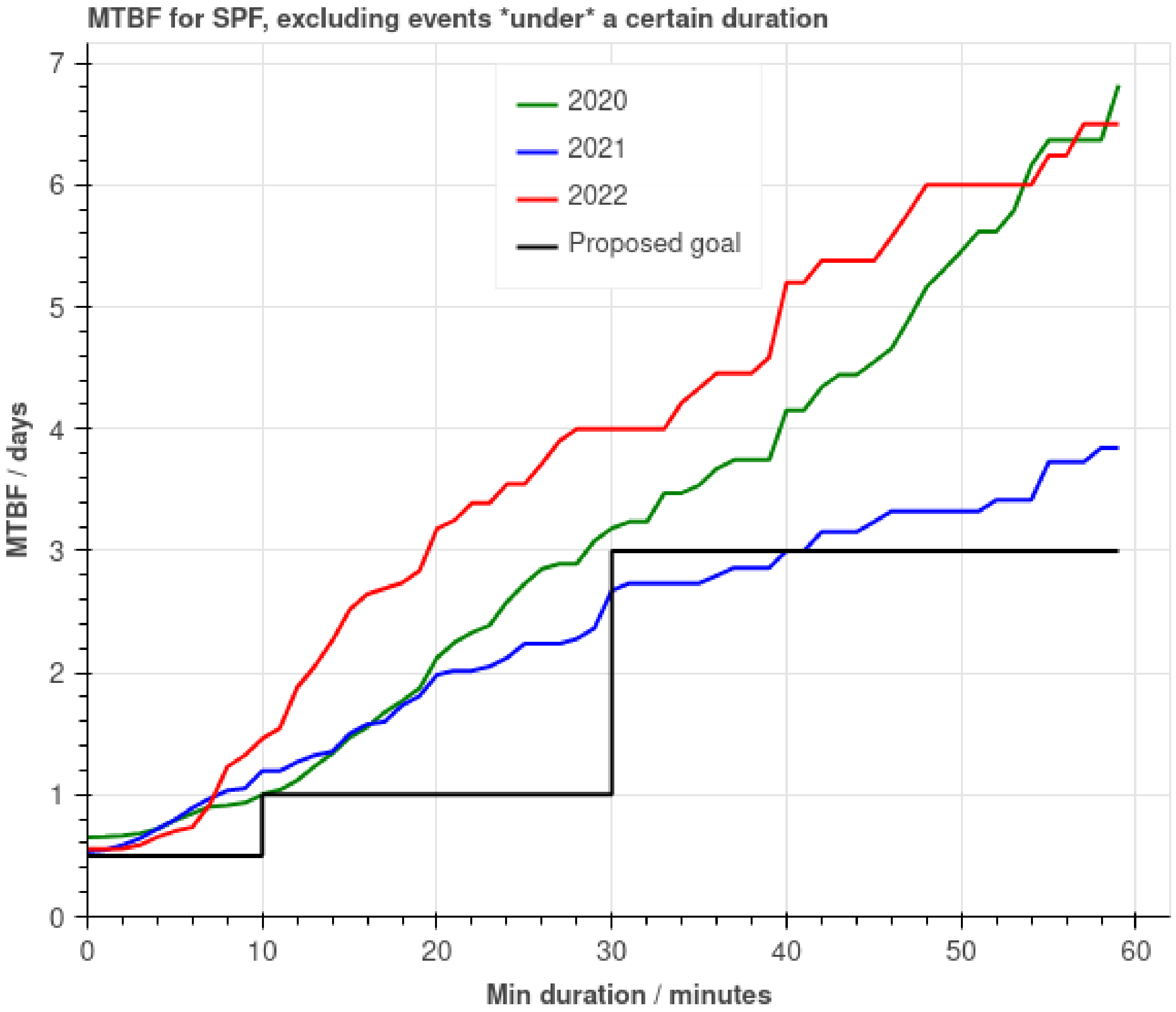
Host status has been awarded jointly to ESS and MAX-IV for 2024

See you in Lund in 2024!

MTBF vs Downtime Duration

- Given the successful experience with auto-restart we believe the present MTBF vs Duration performance is close to optimum.

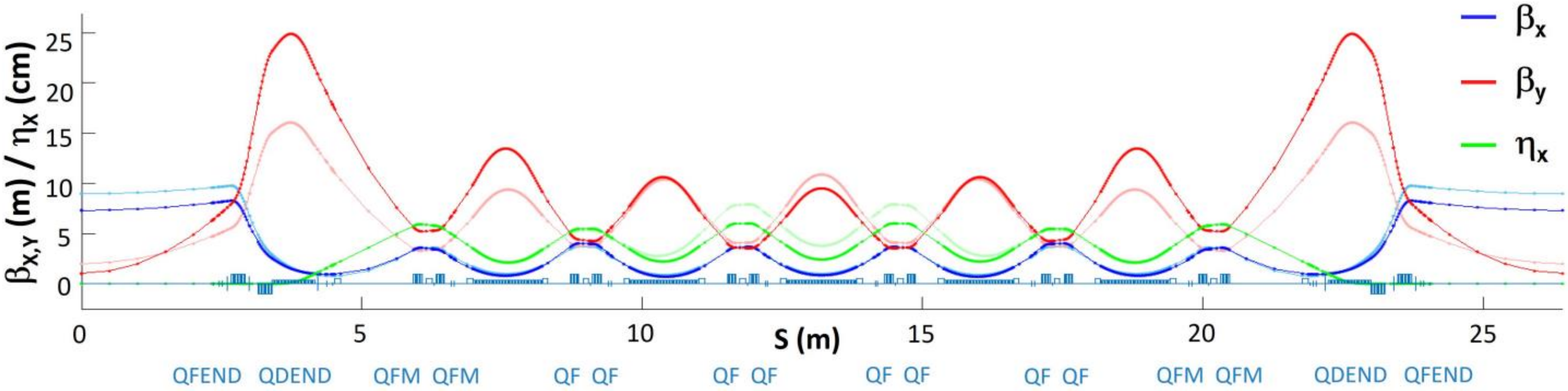
- Other linac-based facilities show similar numbers.



Further studies on the 3 GeV ring lattice for reduced emittance

Slides and data by M. Apollonio

Light colors: Present lattice	*330 pmrad*
Dark colors: Reduced emittance lattice	*270 pmrad*

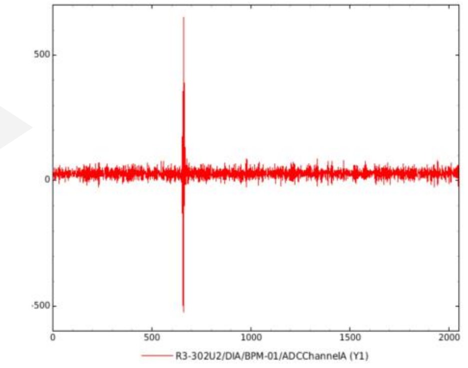


For this, less than 7 % quad strength changes are needed ➔ Magnet iron is untouched

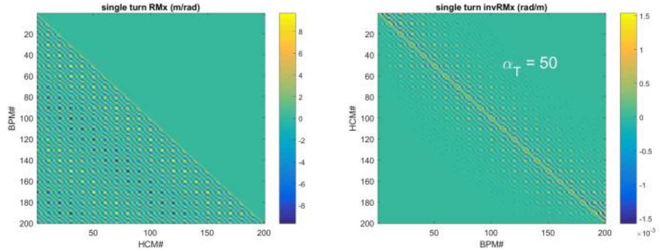
R3	baseline	low-emittance
ϵ (pm rad)	328.18	269.14
ν	(42.20, 16.28)	(44.1997, 14.2793)
ξ (natural)	(-49.98, -50.08)	(-50.72, -76.47)
α_C ($\times 10^6$)	305.97	259.69
$\tau_{x,y,E}$ (ms)	15.7, 29.0, 25.2	16.9, 29.0, 22.7
$\beta_{x,y}^{\text{straight}}$ (m)	9.0, 2.0	7.47, 1.04
brightness increase (%)	-	+22
RF_{height}(1.2 MV) (%)	5.19	5.64

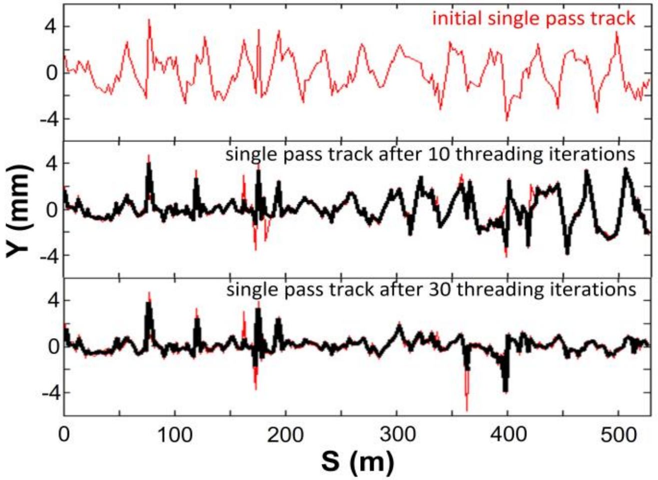
element	baseline	low emittance	Delta
sextupoles	(m^{-3})	(m^{-3})	%
SFi	207.4	212.1	+2.26
SFo	174.0	189.5	+8.91
SFm	170.0	190.5	+11.20
SD	-116.6	-130.2	+11.16
SDend	-170.0	-159.7	-6.05
octupoles	(m^{-4})	(m^{-4})	
OXX	-1649	-3137	+90.23
OXY	3270	2421	-25.96
OYY	-1420	-948	-33.24

1. BPM acquisition **modified** to operate in **single pass mode** with **large S/N ratio**

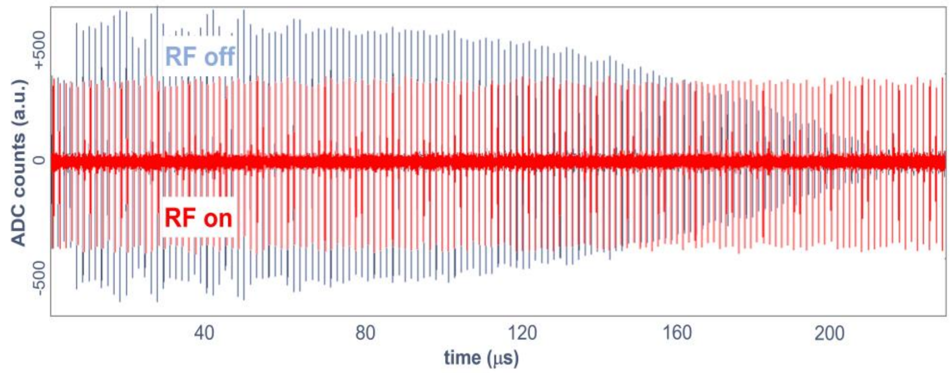


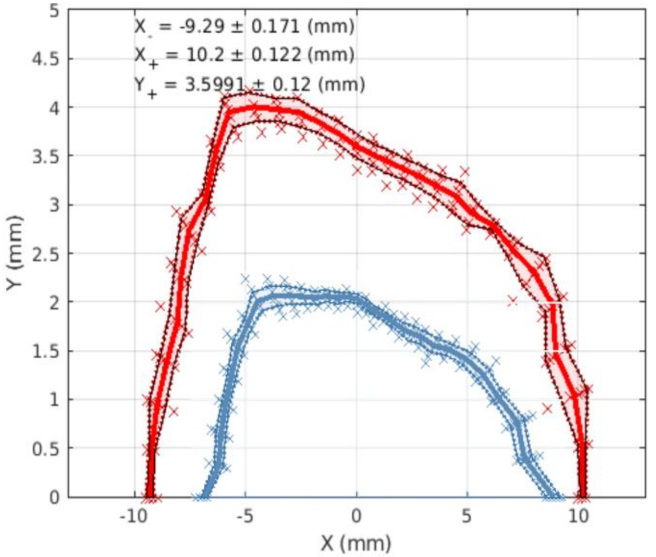
2. Single pass trajectory **response matrix** technique used to **steer the beam** (e.g. trajectory reduction in the V-plane)





3. (RF off) **substantial increase** in n. of. turns, (RF on) **full capture**

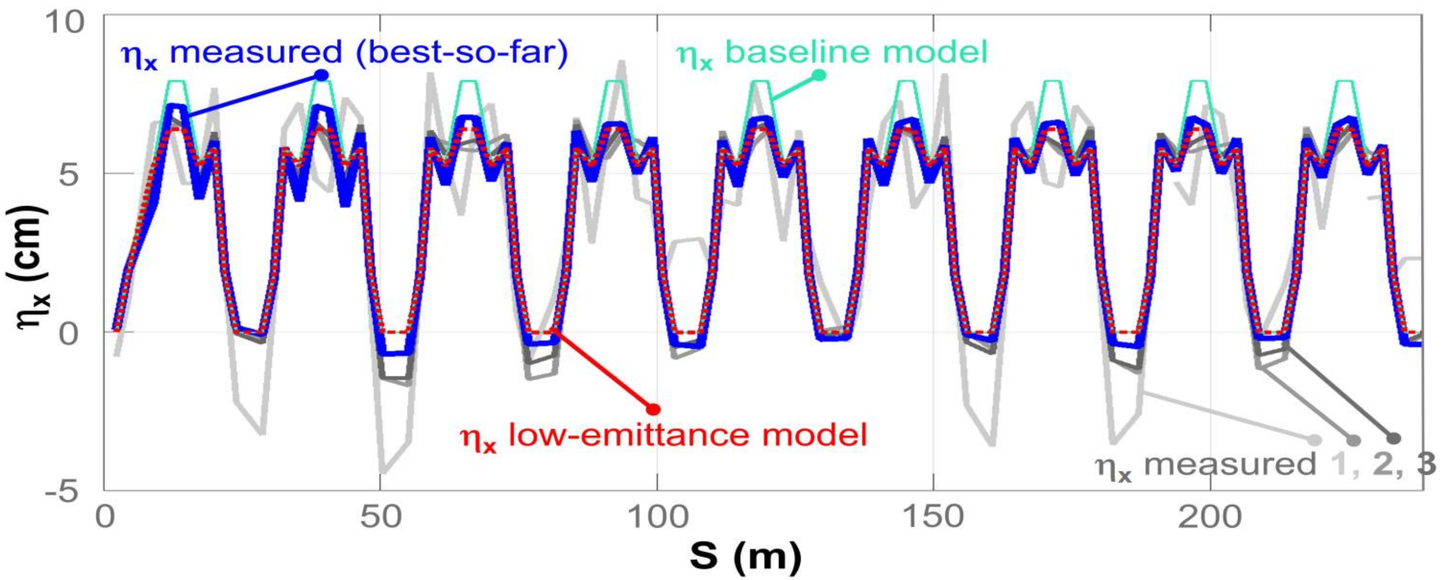


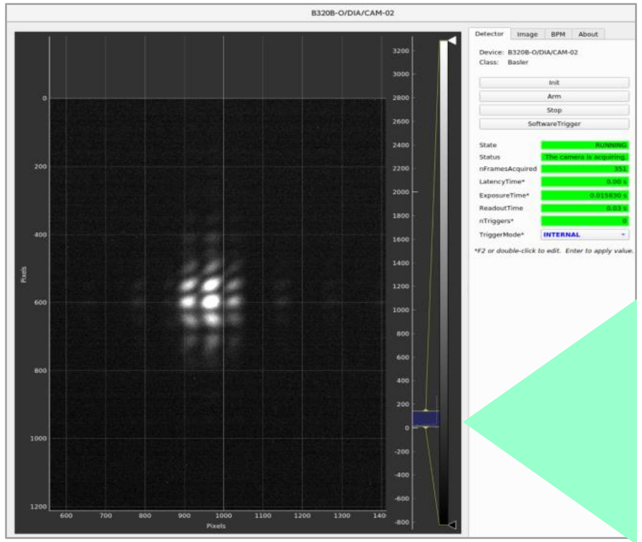


4.a Linear Optics can be characterized even with a current of **250 uA** only …

4.b ... several iterations of Linear Optics Corrections:

- residual **beta-beat** from **50% to 13%**
- **horizontal dispersion** gradually moves towards **low-emittance model**



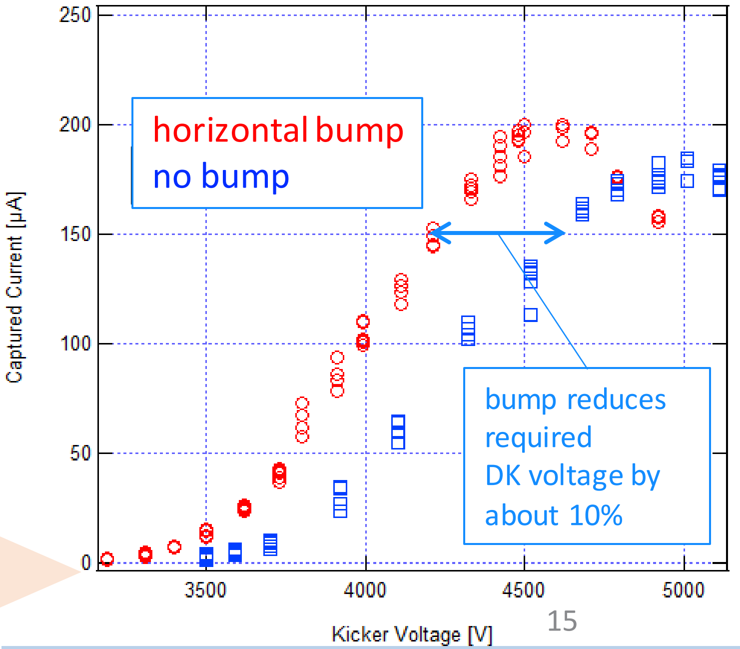


5. preliminary emittance measurement (NO systematic uncertainty!)

σ_x = 20.37 ± 0.32 μm (measured, 50 samples)
β_x = 1.354m (considering LOCO **residual beta-beating of -4.1%**
$\eta_x \approx$ -5.3mm @dipole source (**measured)**
δ_E = 0.073% (**theoretical** value)
$\varepsilon_x \approx (\sigma_x^2 - (\eta_x\ \delta)^2)/\beta_x$ = **295 ± 10 pm rad** (only statistical fluctuations)

PRESENT STATUS - issues

- **Stacking** (accumulation) still impossible with present Dipole Kicker injection scheme indicating a **smaller than expected Dynamic Aperture**. Work in progress to overcome this problem
- Tune scans, on-line optimisations, **introduction of bumps** explored to try and reduce the gap between stored and injected beam acceptance



Multipole Injection Kicker (MIK) for 1.5 GeV ring at MAX IV
(Slide courtesy of Alexey Vorozhtsov)

- ❑ Top-up injection of the e-beam into the storage ring without disturbances on a stored beam
- ❑ Implemented in 3.0 GeV ring(2017), SOLEIL- MAX IV collaboration.

<u>MIK R3:</u> Pulse duration=**3.5 µs@10Hz**, Imax=7 kA@Umax=15 kV, Xinj=-4.66 mm, α=-1.176 mrad (BL=-11.7 mTm)

- ❑ Similar system for 1.5 GeV ring, but is more challenging than for 3.0 GeV due to shorter pulse duration of **1.28 µs**
  - Initial requirements (from design early design studies):

    Xinj=-5.4 mm(MIK at the positon of Dipole kicker)

    α=2.4 mrad (BL=12.0 mTm), **Imax=5 kA@Umax=24 kV**
  - Updated requirements (new design study in 2021):

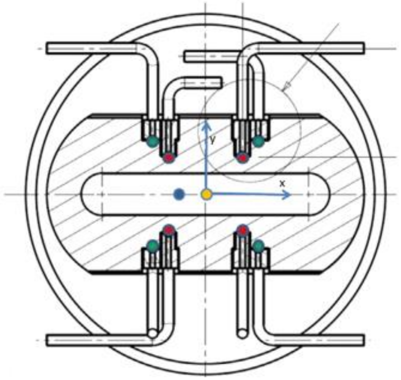
MIK is shifted by 931 mm Downstream

<u>One of the options:</u> **I=2.3 kA @U=11 kV**

I. Xinj=-8.6 mm(1st kick), α=2.75 mrad

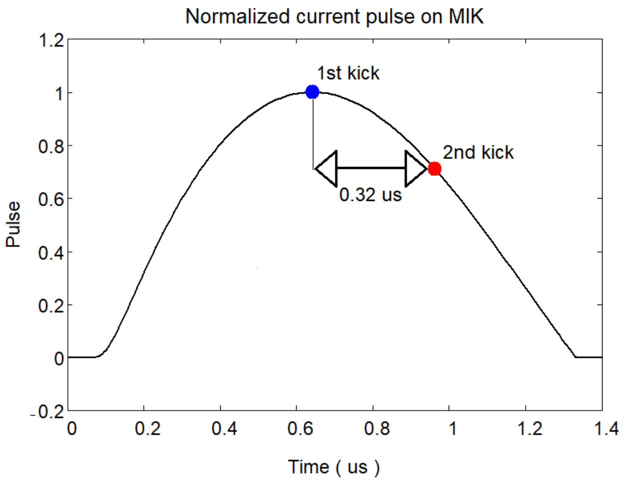
II. Xinj=5.6 mm (2nd kick), α=-0.854 mrad

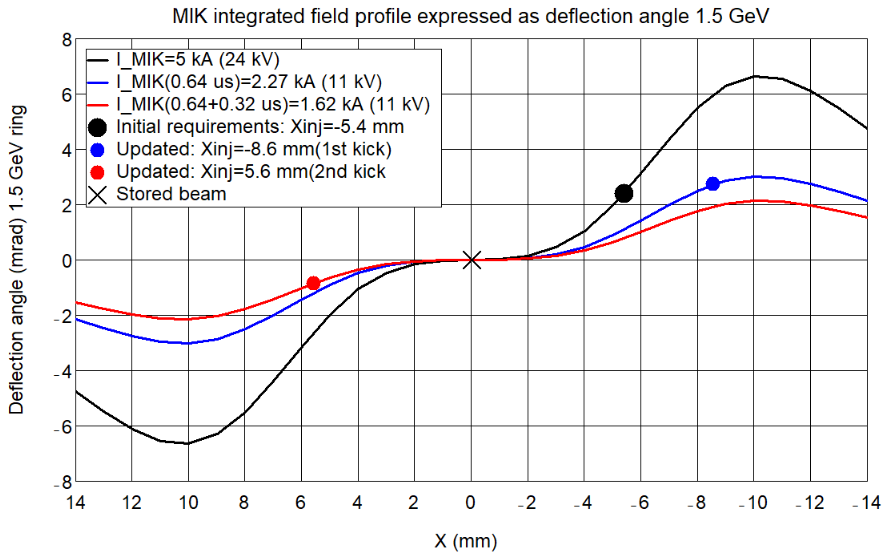
courtesy of Marco Apollonio



MIK cross-section:

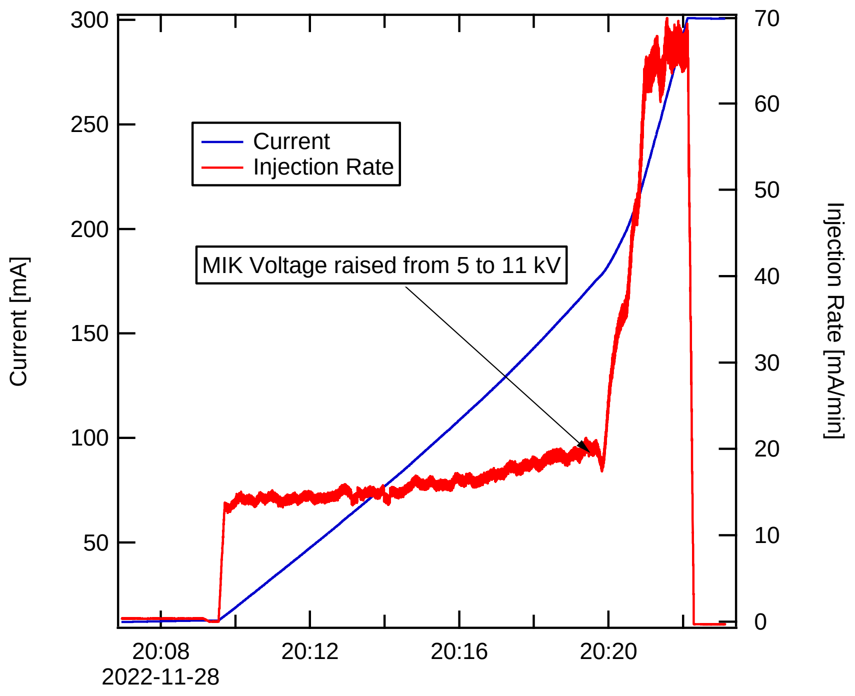
8 copper rods form the octupole field.

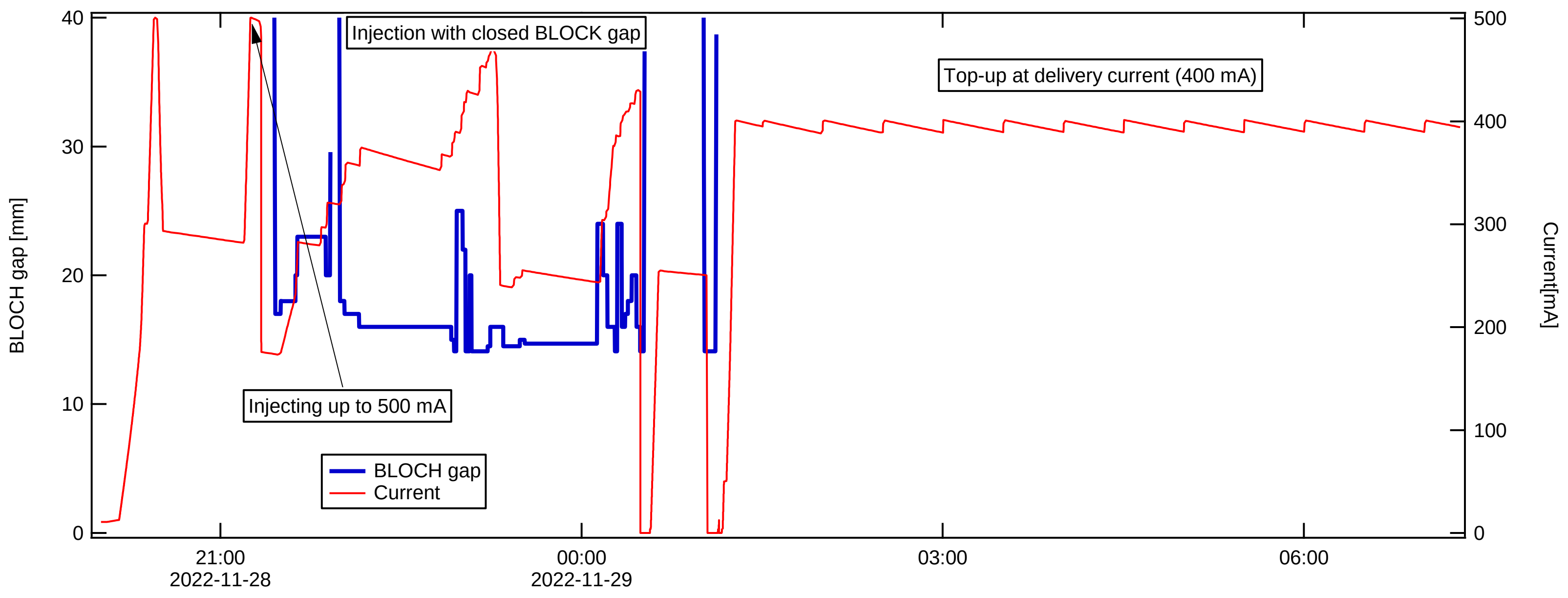




First Results with Beam

First Injection – Better performance than with dipole kicker



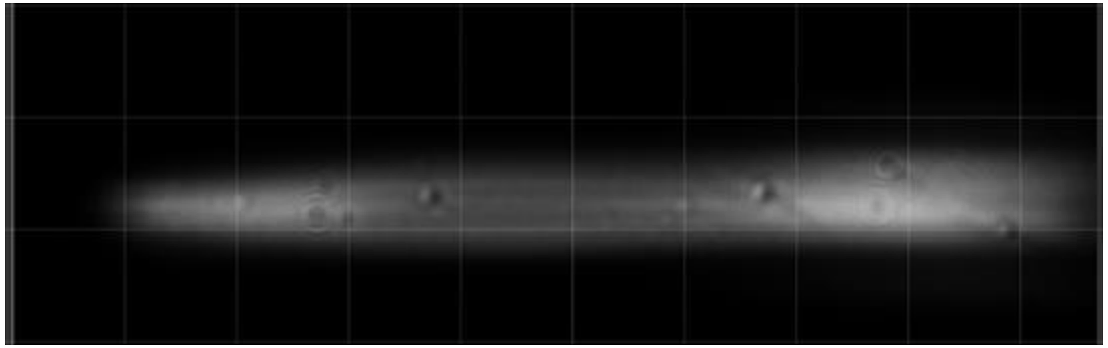


Pictures by Pedro Fernandes Tavares

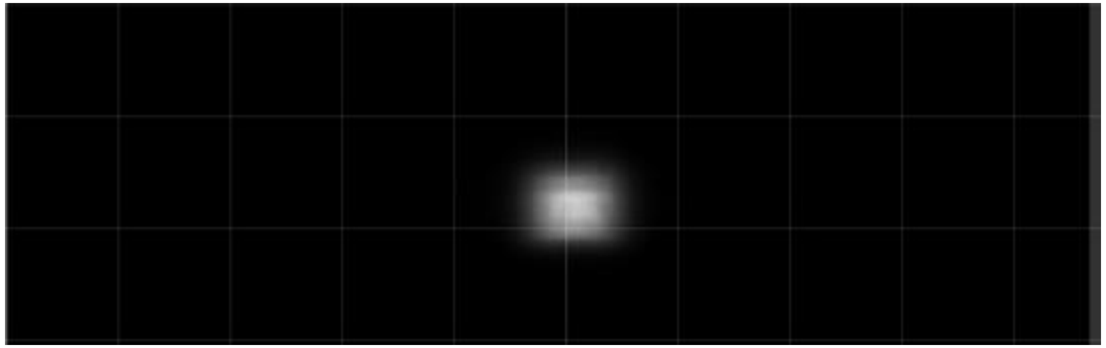
First Results with Beam

Perturbations to the stored beam

Dipole Kicker



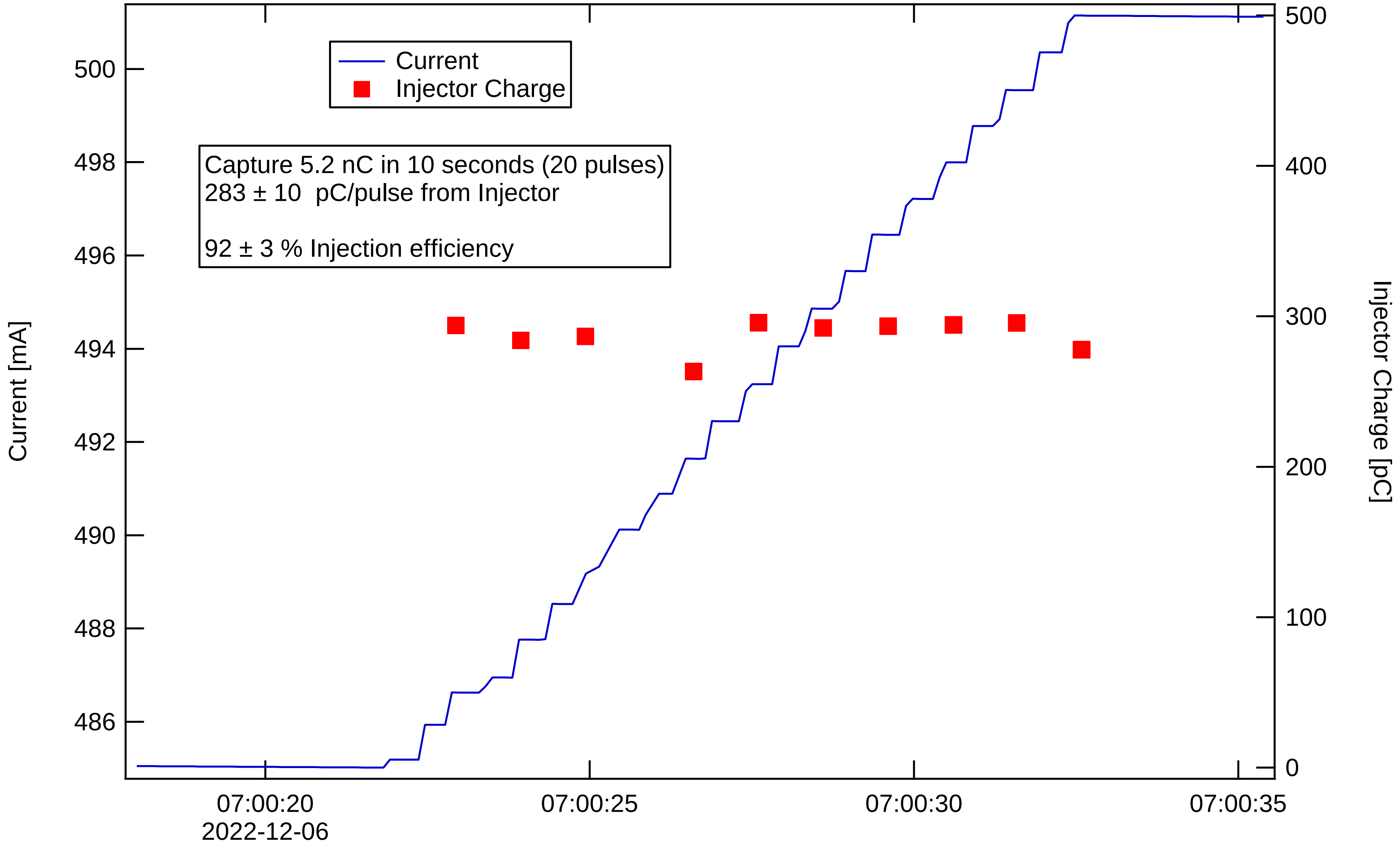
MIK



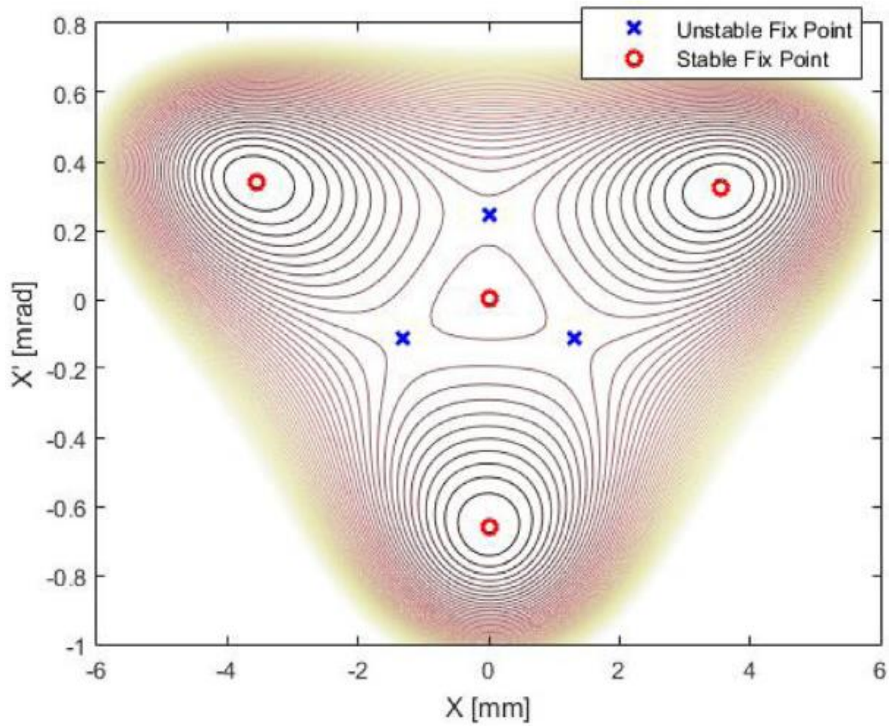
horizontal beam size:
150 µm(MIK is ON) ~10 times less than for the conventional dipole kicker

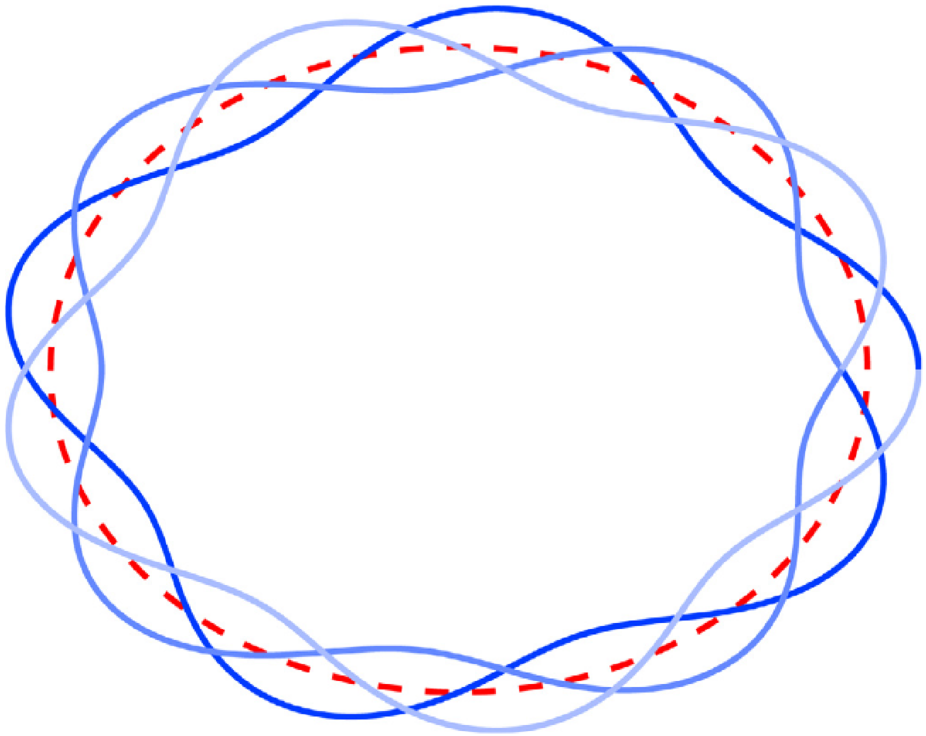
Pictures by Jonas Breunlin and Åke Andersson

Injection Efficiency



Transverse Resonance Island Buckets (TRIBS)





- ❑ "Studies on Transverse Resonance Island Buckets in third and fourth generation synchrotron light sources"
  - ❑ David Olsson, Åke Andersson
  - ❑ Nuclear Inst. and Methods in Physics Research, A 1017 (2021) 165802

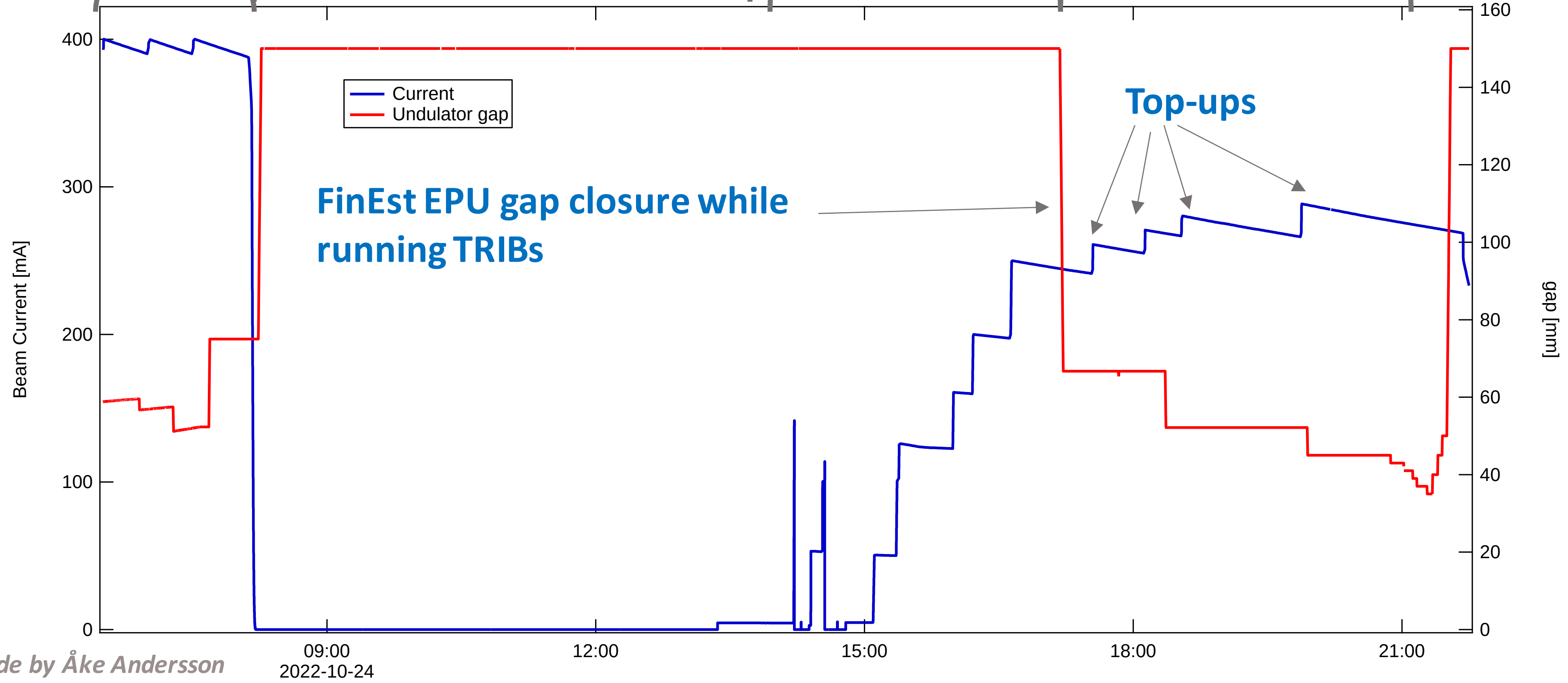
TRIBs

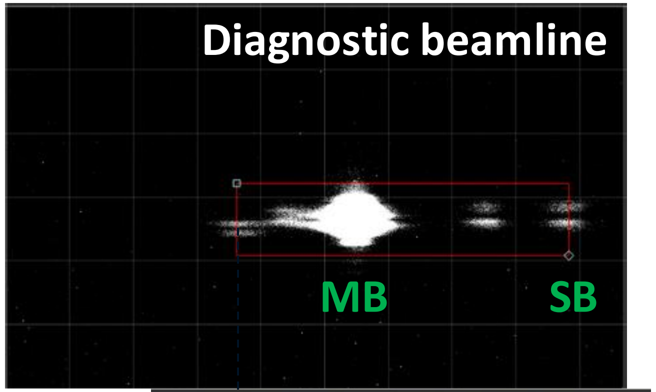
Usual MB delivery, 400 mA

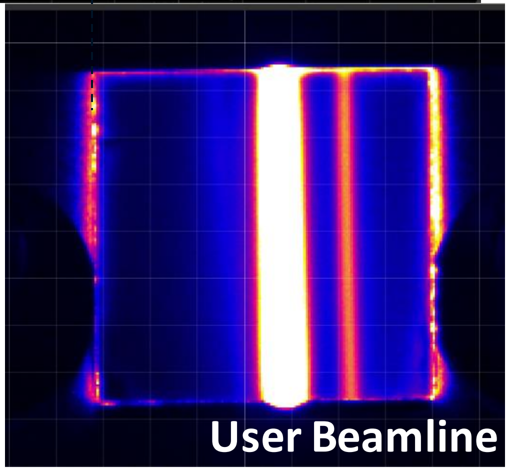
Open tunnel maintenance

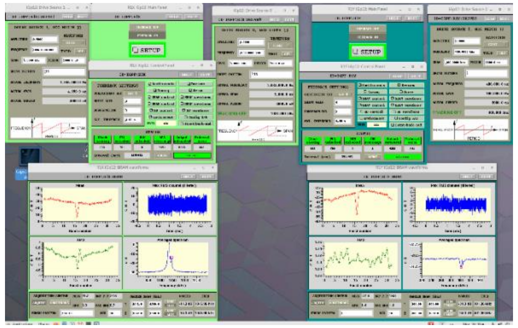
Setup for **Simultaneous SB & MB**

Test **with SB** BLs incl. **top-ups, 280 mA (MB BLs could not join)**









BbB-system tuning

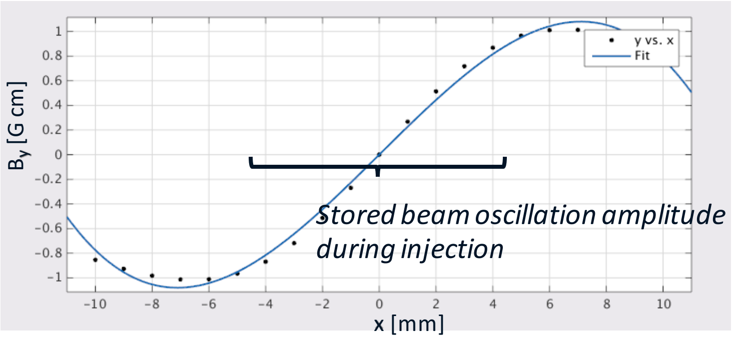
Slide by Åke Andersson

Active shims

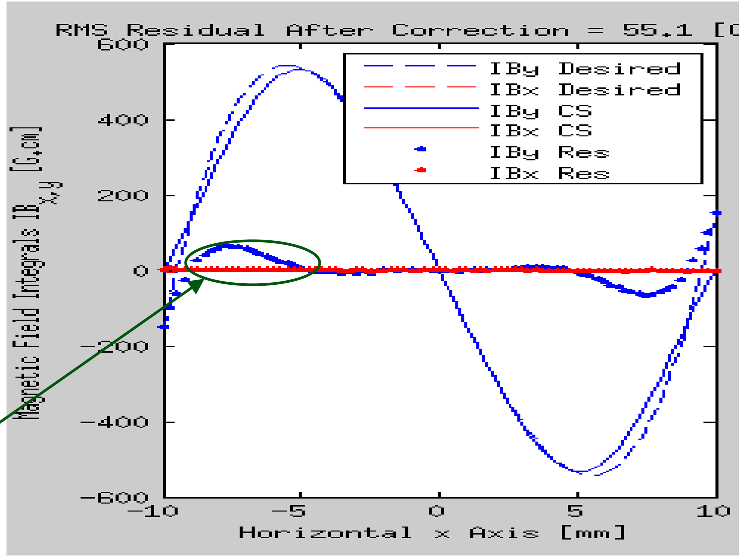
Main aim: make the ID transparent up to the oscillation amplitude of the stored beam during injection

Rough empirical method used to produce the active shim FF table:

1. Campaign of response matrix measurements done for gaps and phases
2. Fit model representation of ID via LOCO in each point to obtain integrated k and k_s
3. For simplicity obtain approximate octupole field in each point via a static octupole-to-quadrupole field ratio, determined in a few points by restoring bare lattice ADTS.
4. Compute active shim currents to produce the inverted field profile (genetic optimizer used for first attempts)

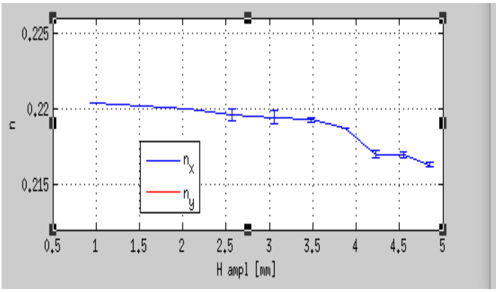


FinEst kick map $B_y(x)$ @ 20 mm gap, vertical pol.

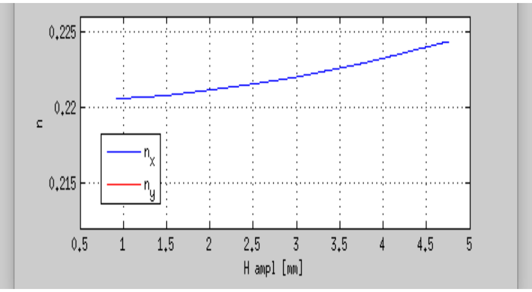


Discrepancy due to strip current limits. Heavy weighting on central region ensures gradient well corrected (verified in follow-up LOCO campaigns)

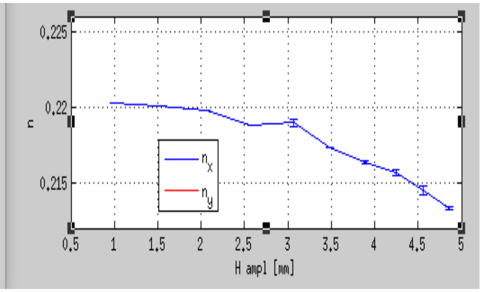
Active shim strip currents calculated to generate inverse of ID integrated field



Bare lattice hor. ADTS



FinEst @ 25 mm gap, ver. pol. No compensation



FinEst @ 25 mm gap, ver. pol. Compensation active

Most extreme gaps/phases will require additional help from ring magnets even for the gradient… Not yet implemented!

MAX IV

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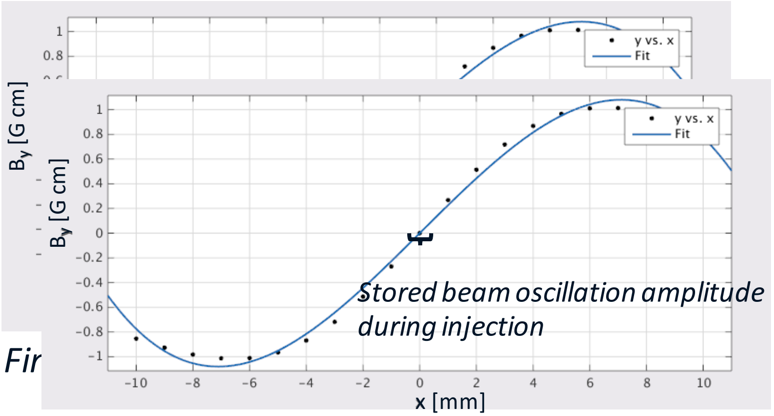

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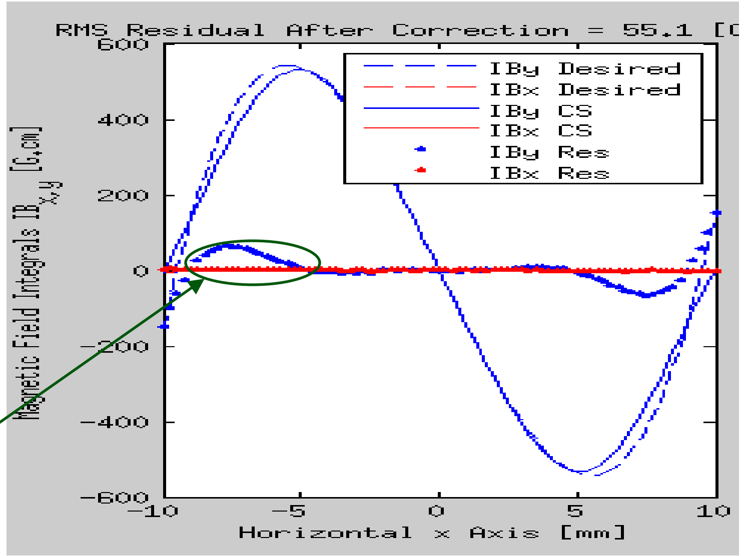

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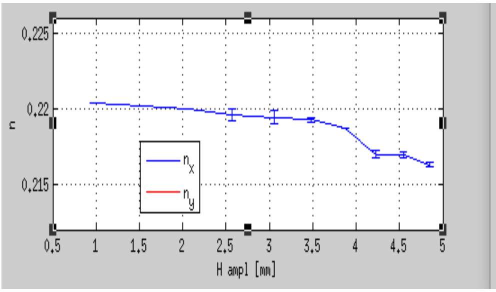

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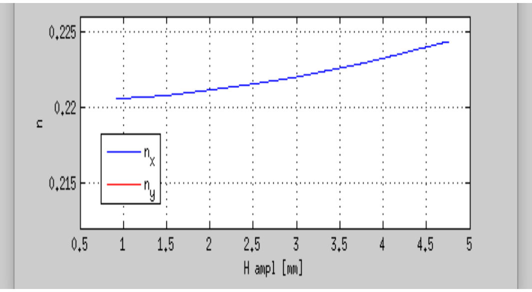
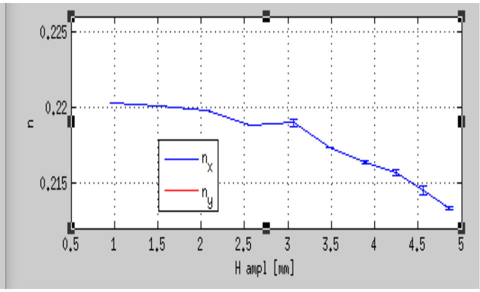


FinEst @ 25 mm gap, ver. pol. No compensation

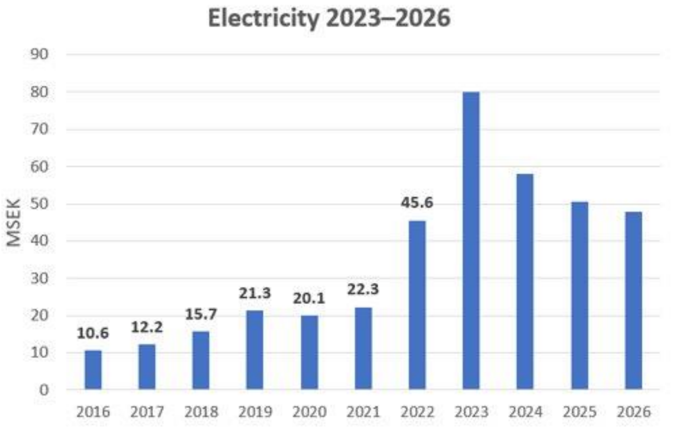


FinEst @ 25 mm gap, ver. pol. Compensation active

Most extreme gaps/phases will require additional help from ring magnets even for the gradient… Not yet implemented!

Power supply crisis

- ❑ Two separate crises unfolding simultaneously
  - ❑ Power supply limitations in southern Sweden
    - ❑National authority may issue an alert to a period of high risk to the grid
    - ❑During such a period MAX-IV will cease operations:
      - ❑Reduce consumption to a level consistent with office work
      - ❑Protect equipment that could be damaged by a sudden loss of power
  - ❑ Significantly increased costs
    - ❑ Power and building rental
    - ❑ Budgets have been tightened significantly throughout the lab
    - ❑ Top-level budget approved for 2023 allows operation as planned



Summary

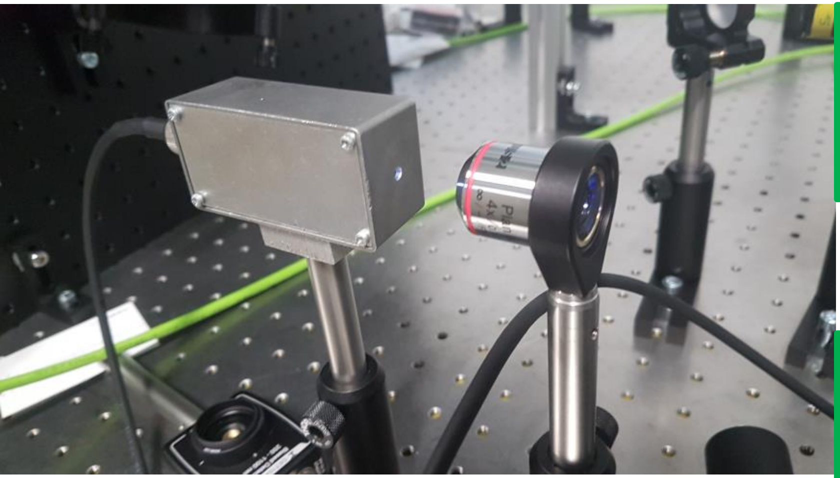
- Continued improvement in understanding of failures is reflected in the delivery statistics
  - >98% for the rings, ~97% for the linac-based source
  - MTBF of 3 days for the large ring, and 4 days for the small
- Several highlights were reported
  - Low emittance lattice
  - Multipole injection kicker
  - TRIBS
- Power supply will remain a significant issue throughout the winter

Backup Slides

H'light: Filling Pattern Monitor & Feedback device

Work by
A. Johansson (oper's)
J. Breunlin
F. Cullinan

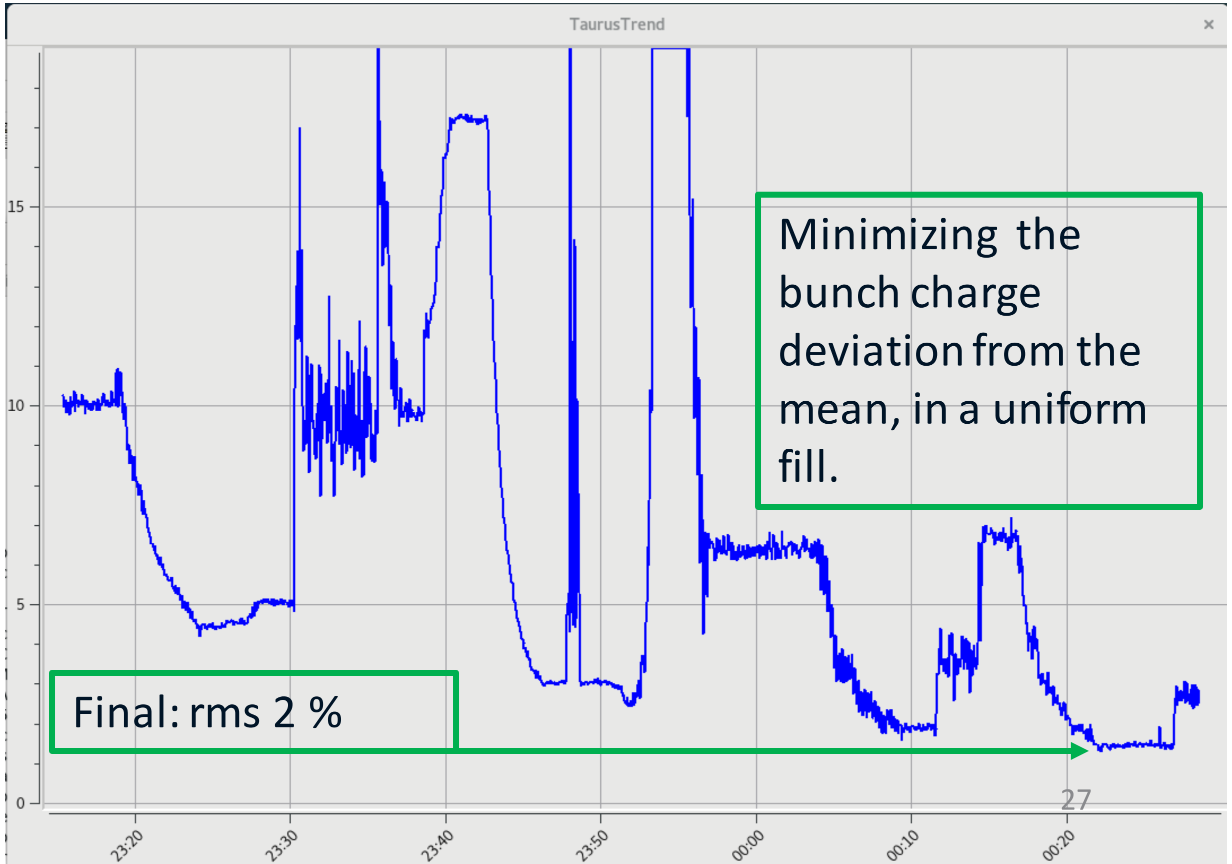
Photon based diagnostics



Evaluating different **photo diodes**

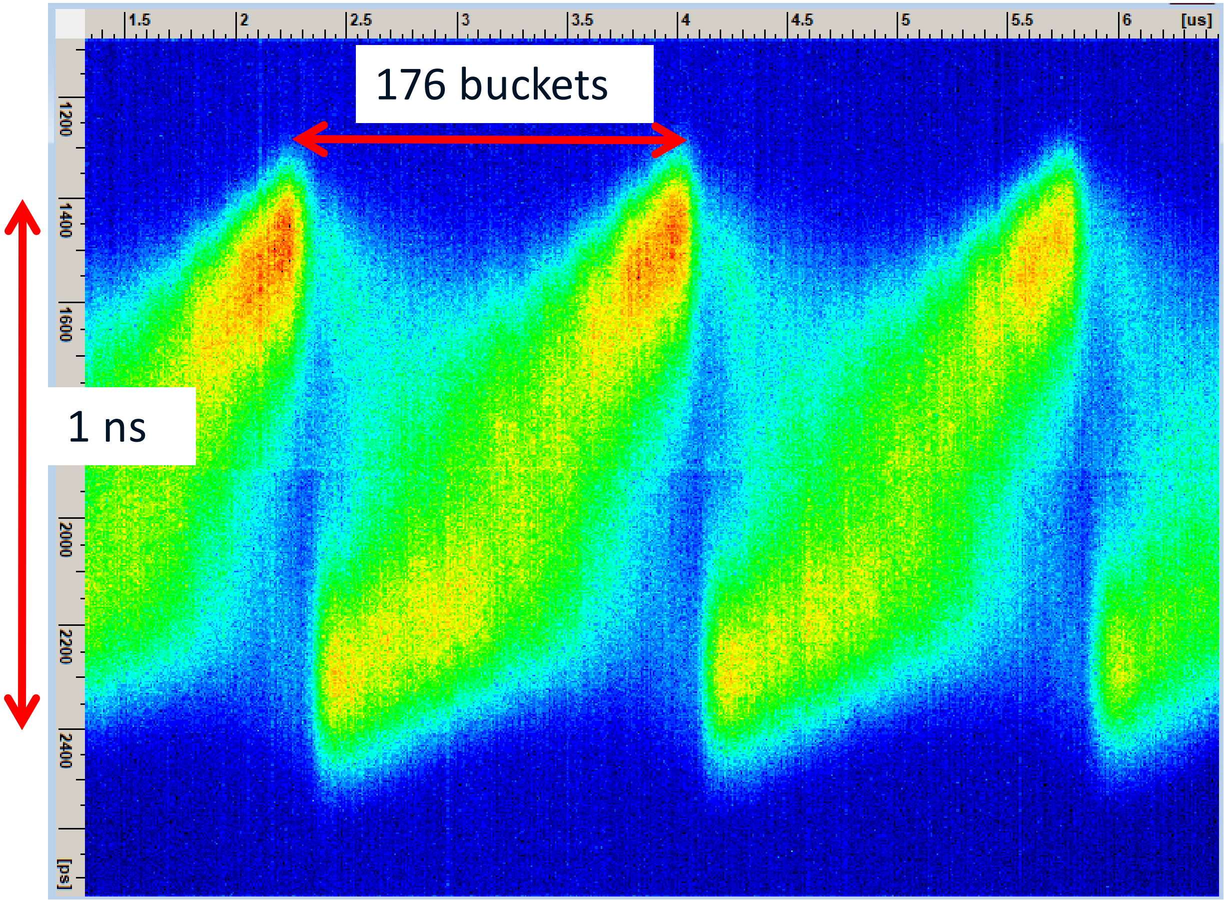
Evaluating different oscilloscopes

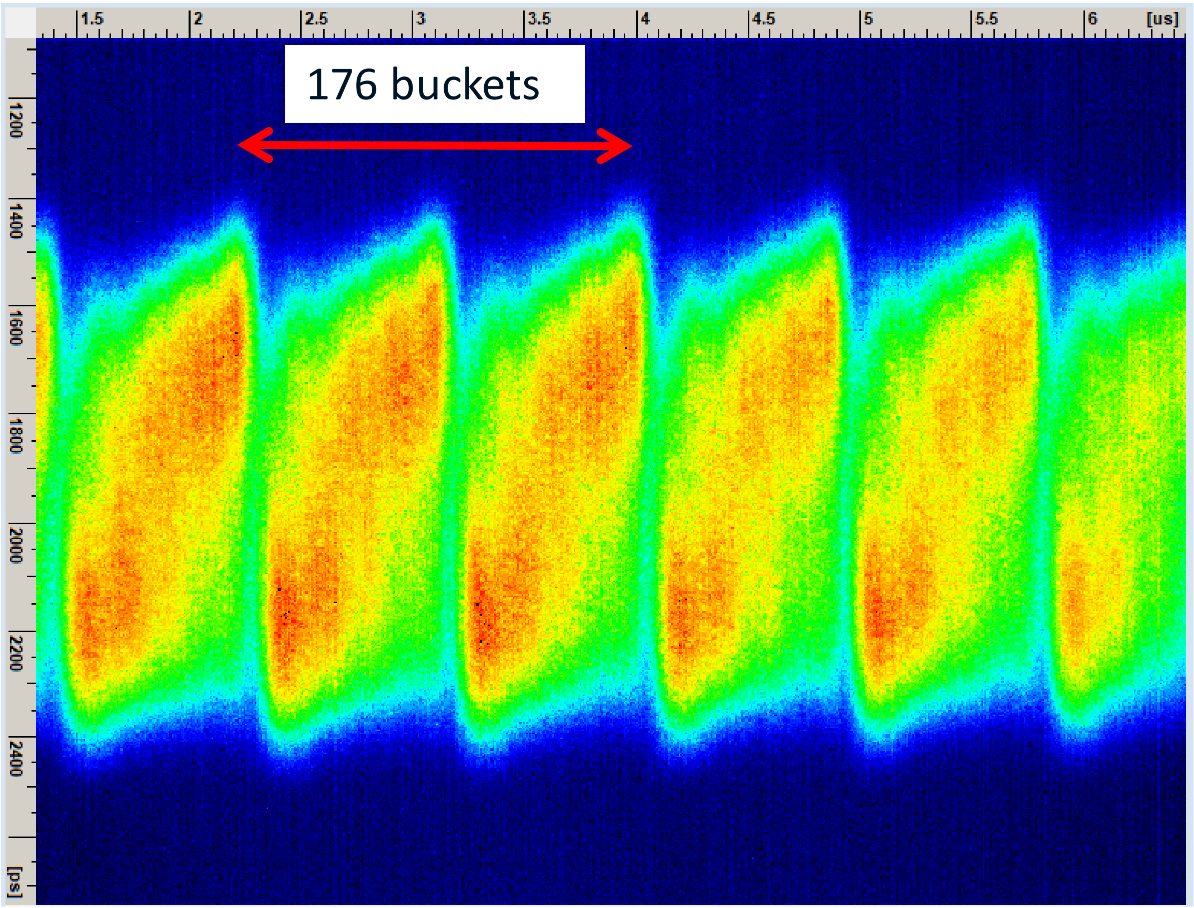
Evaluating different settings of a FB device, which predicts where to place the injected charge



H'light: Filling Pattern Monitor & Feedback device

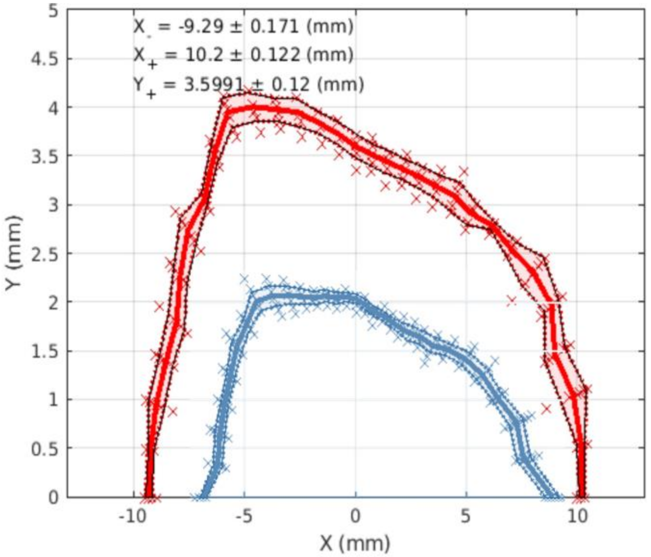
- ❑ Starting from the uniform fill, we create one, two or several bunch trains per turn
- ❑ With several trains, the non-uniform beam loading effect diminishes
- ❑ Might be beneficial for future more efficient bunch lengthening



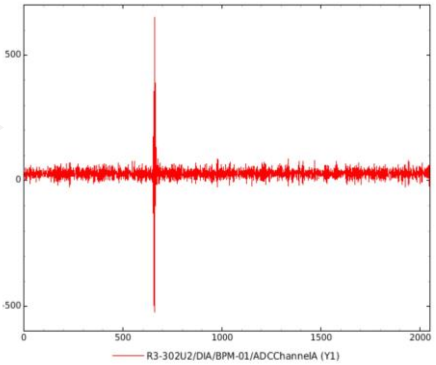


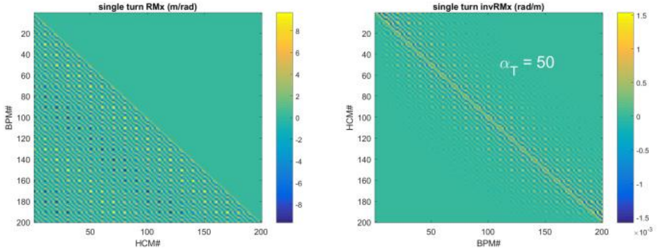
R3	baseline	low-emittance
ϵ (pm rad)	328.18	269.14
ν	(42.20, 16.28)	(44.1997, 14.2793)
ξ (natural)	(-49.98, -50.08)	(-50.72, -76.47)
α_C ($\times 10^6$)	305.97	259.69
$\tau_{x,y,E}$ (ms)	15.7, 29.0, 25.2	16.9, 29.0, 22.7
$\beta^{\text{straight}}_{x,y}$ (m)	9.0, 2.0	7.47, 1.04
brightness increase (%)	-	+22
RF_{height}(1.2 MV) (%)	5.19	5.64

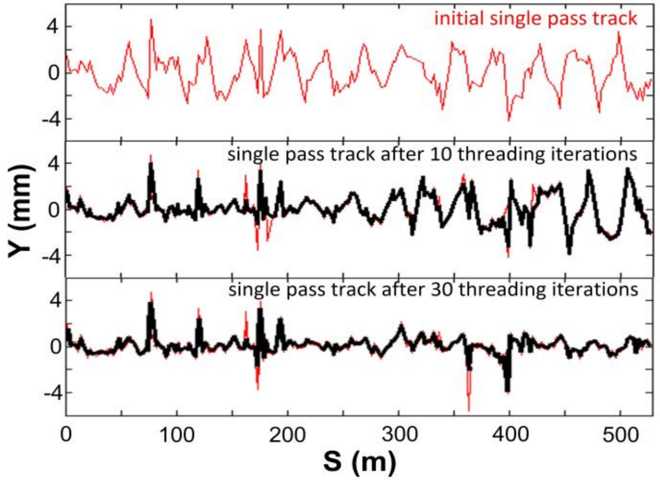
element	baseline	low emittance	Delta
sextupoles	(m^{-3})	(m^{-3})	%
SFi	207.4	212.1	+2.26
SFo	174.0	189.5	+8.91
SFm	170.0	190.5	+11.20
SD	-116.6	-130.2	+11.16
SDend	-170.0	-159.7	-6.05
octupoles	(m^{-4})	(m^{-4})	
OXX	-1649	-3137	+90.23
OXY	3270	2421	-25.96
OYY	-1420	-948	-33.24



1. BPM acquisition **modified** to operate in **single pass mode** with **large S/N ratio**

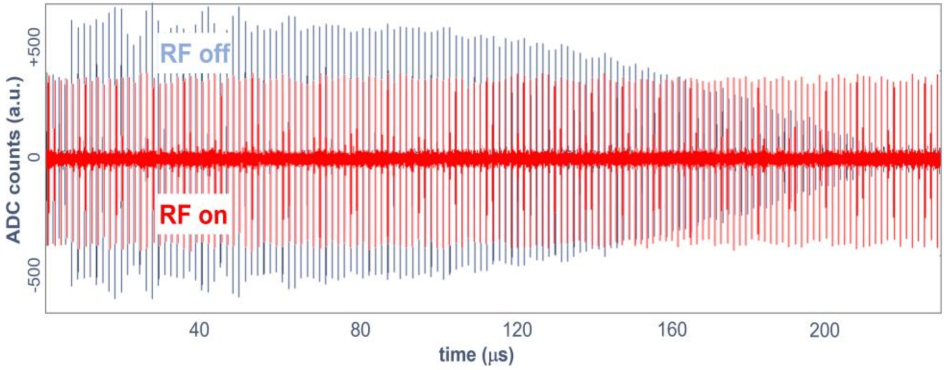






2. Single pass trajectory **response matrix** technique used to **steer the beam** (e.g. trajectory reduction in the V-plane)

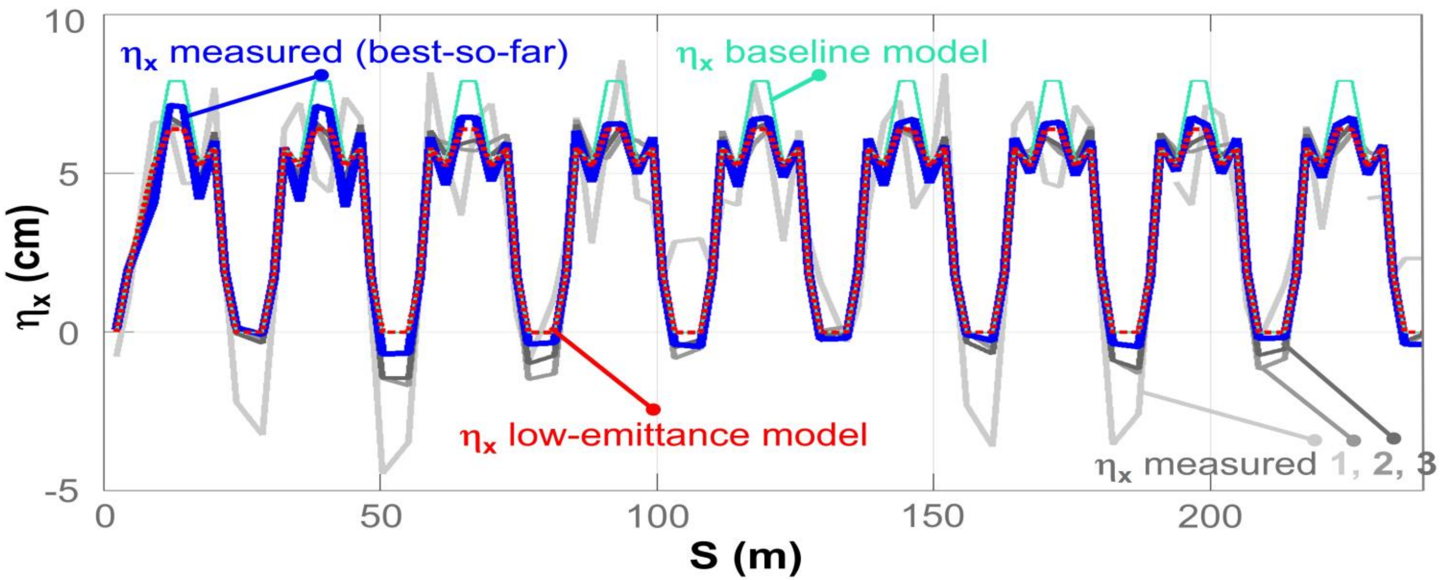
3. (RF off) **substantial increase** in n. of. turns, (RF on) **full capture**

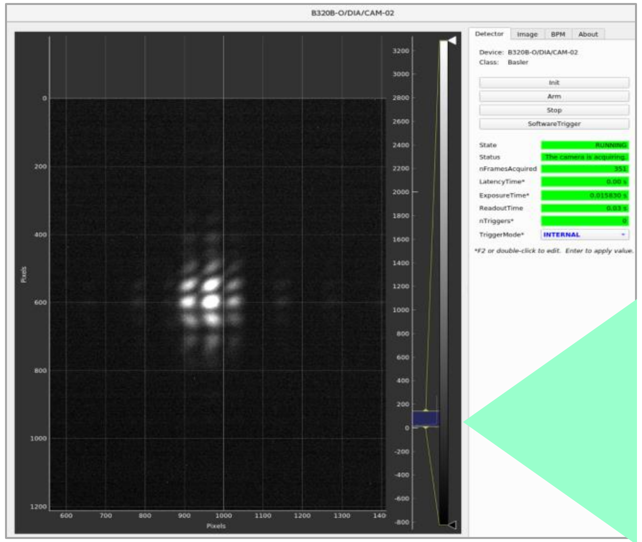


4.a Linear Optics can be characterized even with a current of **250 uA** only …

4.b ... several iterations of Linear Optics Corrections:

- residual **beta-beat** from **50% to 13%**
- **horizontal dispersion** gradually moves towards **low-emittance model**



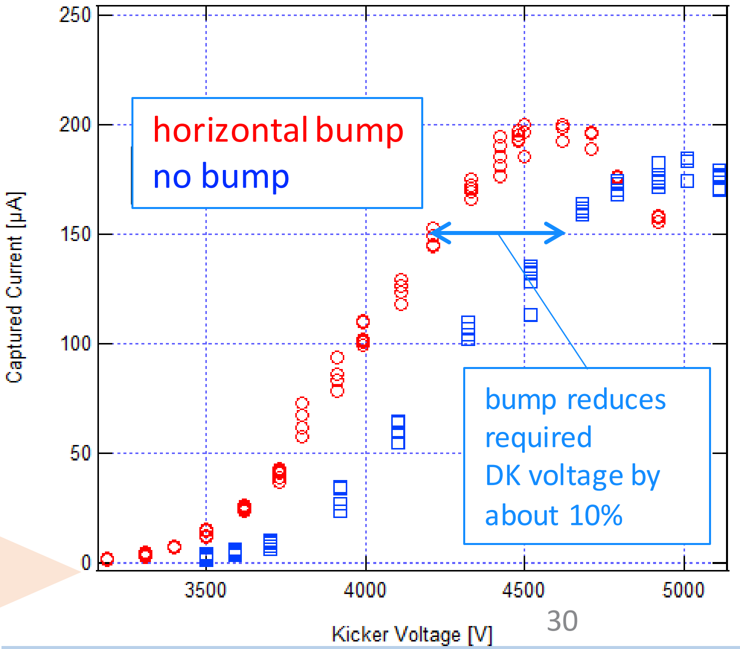


5. preliminary emittance measurement (NO systematic uncertainty!)

$\sigma_x = 20.37 \pm 0.32\ \mu m$ (measured, 50 samples)
$\beta_x = 1.354m$ (considering LOCO **residual beta-beating of -4.1%**
$\eta_x \approx -5.3mm$ @dipole source (**measured**)
$\delta_E = 0.073\%$ (**theoretical** value)
$\varepsilon_x \approx (\sigma_x^2 - (\eta_x\ \delta)^2)/\beta_x =$ **295 ± 10 pm rad** (only statistical fluctuations)

PRESENT STATUS - issues

- **Stacking** (accumulation) still impossible with present Dipole Kicker injection scheme indicating a **smaller than expected Dynamic Aperture**. Work in progress to overcome this problem
- Tune scans, on-line optimisations, **introduction of bumps** explored to try and reduce the gap between stored and injected beam acceptance

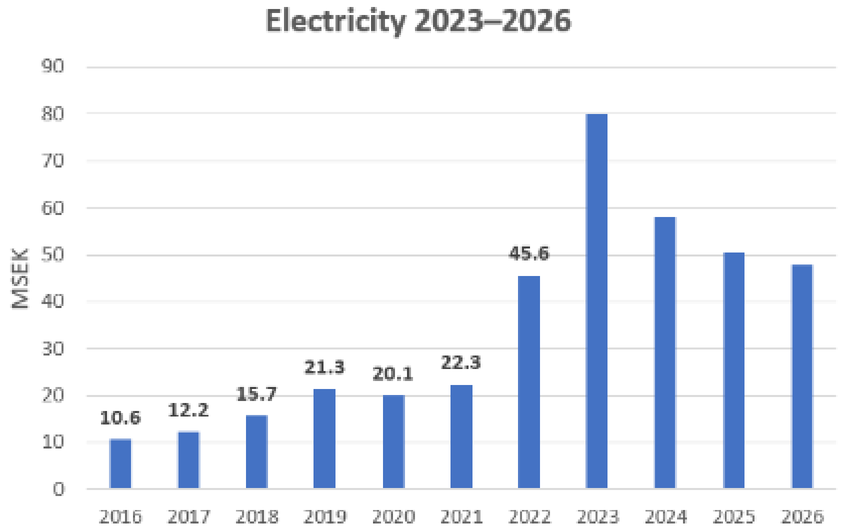


Further Short-Term Energy Efficiency Enhancement Measures

- ❑Replacement of lighting in the experimental hall
- ❑Change of average temperature in offices, common areas
- ❑Relaxation of temperature control tolerances in non-critical areas (e.g. **not** accelerator tunnels or beamline hutches).
- ❑General energy saving culture

Electricity Costs and Accelerator Operations

- ❑Preparedness for several scenarios
  - ❑Total/Partial Cuts
    - ❑Identify minimum needed for critical systems.
  - ❑Reduction of yearly consumption
    - ❑**Extended shutdowns**
    - ❑**Avoid frequent stops**



Consequences and Risk mitigation of loss of Electrical Power at the MAX IV campus	Document location -	MAX IV
Prepared by Stephen Molloy (Head of Accelerator Operations)	Date 2022-09-12	Revision 01
Approved by Pedro F. Tavares (Accelerator Director)	Date 2022-09-13	Page 1 (6)

Reviewed by	Date
Yngve Cerenius	2022-09-21

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