MAX IV Accelerator Operations

ESLS – October 2025

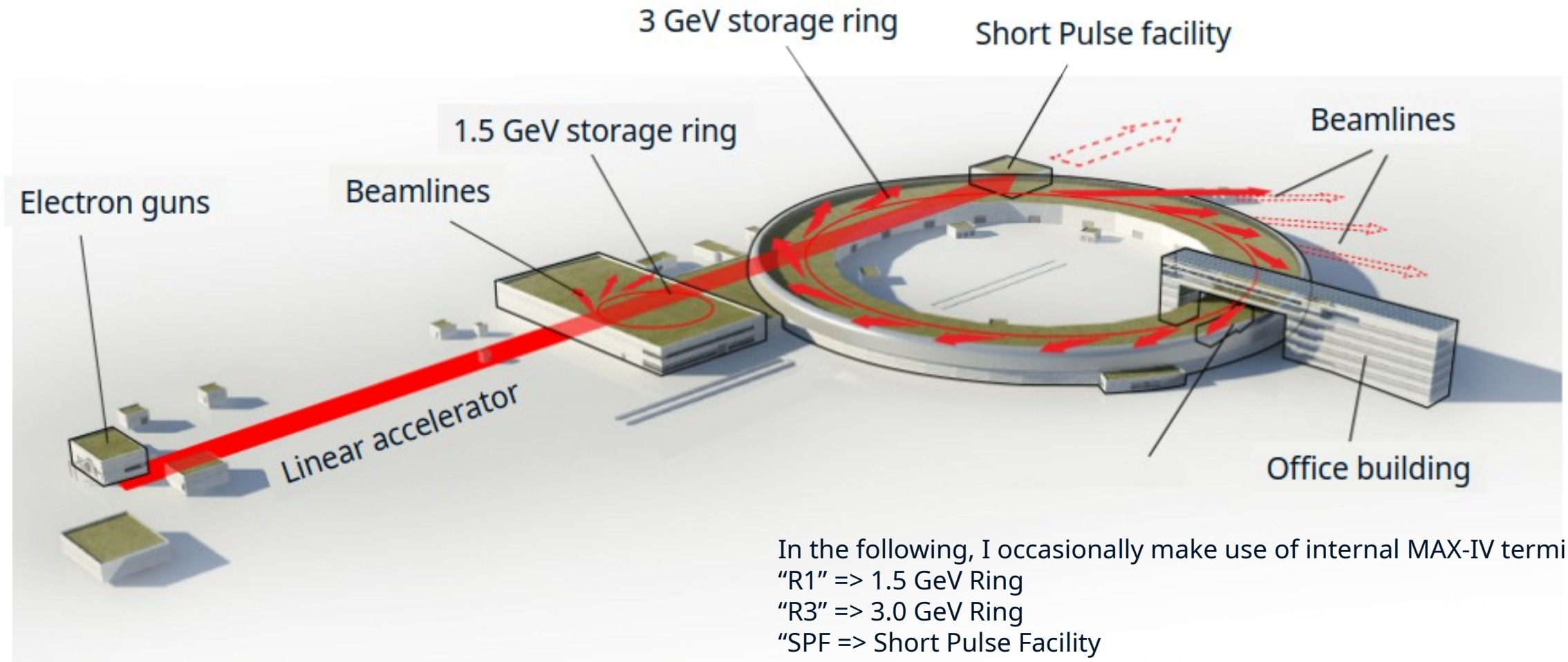
Head of Accelerator Operations, MAX-IV
Stephen Molloy
On behalf of many people

Outline

- Reminder of our facility
- Annual statistics
  - Increased MTTR of our 3.0 GeV ring
- Significant issues
  - Actions being taken to address these
- Future
  - New beamlines
  - MAX 4^{U} upgrade of the 3.0 GeV ring

Image courtesy of Sara Thorin

MAX IV Facility



In the following, I occasionally make use of internal MAX-IV terminology:
“R1” => 1.5 GeV Ring
“R3” => 3.0 GeV Ring
“SPF => Short Pulse Facility

Year-to-date stats

Accelerator	Planned delivery	Total downtime	Uptime	MTTR	MTBF
1.5 GeV Ring	4104 hours	40.2 hours	99.0%	1.75 hours	7.4 days
3.0 GeV Ring	4104 hours	133.5 hours	96.8%	2.90 hours	3.7 days
SPF	3816 hours	103.38 hours	97.3%	0.24 hours	8.8 hours

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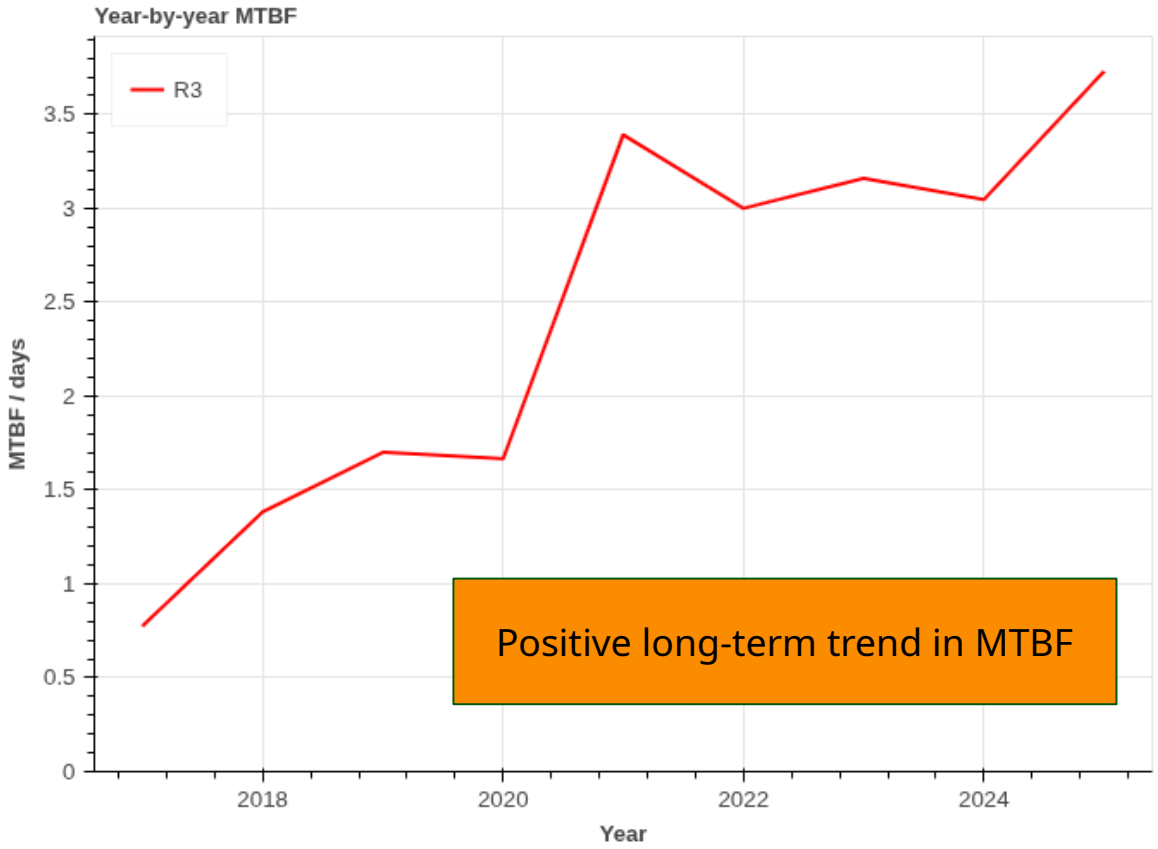
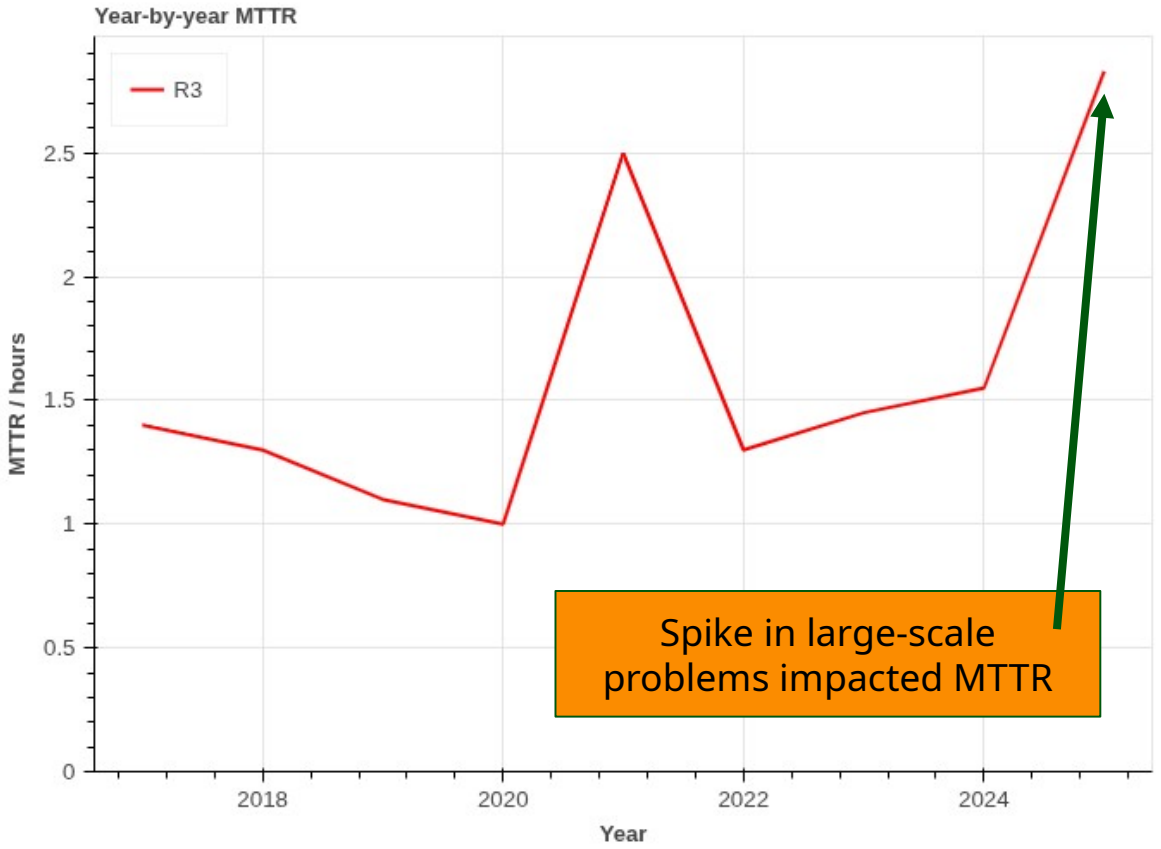
What happened here?

3.0 GeV ring


Year-by-year MTBF
R3
MTBF / days
Year
0
0.5
1
1.5
2
2.5
3
3.5
2018
2020
2022
2024
Positive long-term trend in MTBF


Year-by-year MTTR
R3
MTTR / hours
Year
0
0.5
1
1.5
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2018
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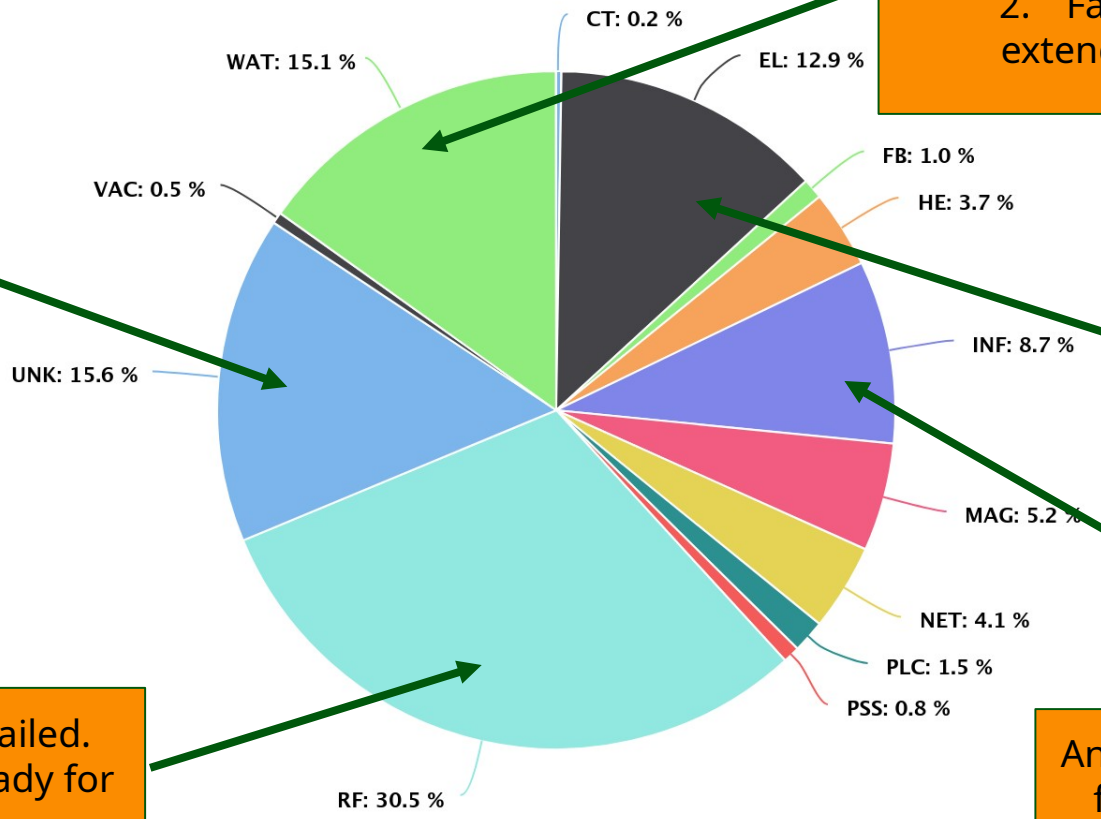
2022
2024
Spike in large-scale problems impacted MTTR

3.0 GeV Ring: Downtime codes

1. Water leak in magnet circuit caused during electrical work on a maintenance day. Lessons-learned resulted in replanning.
2. Failure of thermoswitches. Downtime extended due to difficulty in determining the cause.

A recent issue whereby we have a dump with no clear cause followed by significant issues reinjecting. Under investigation this week.

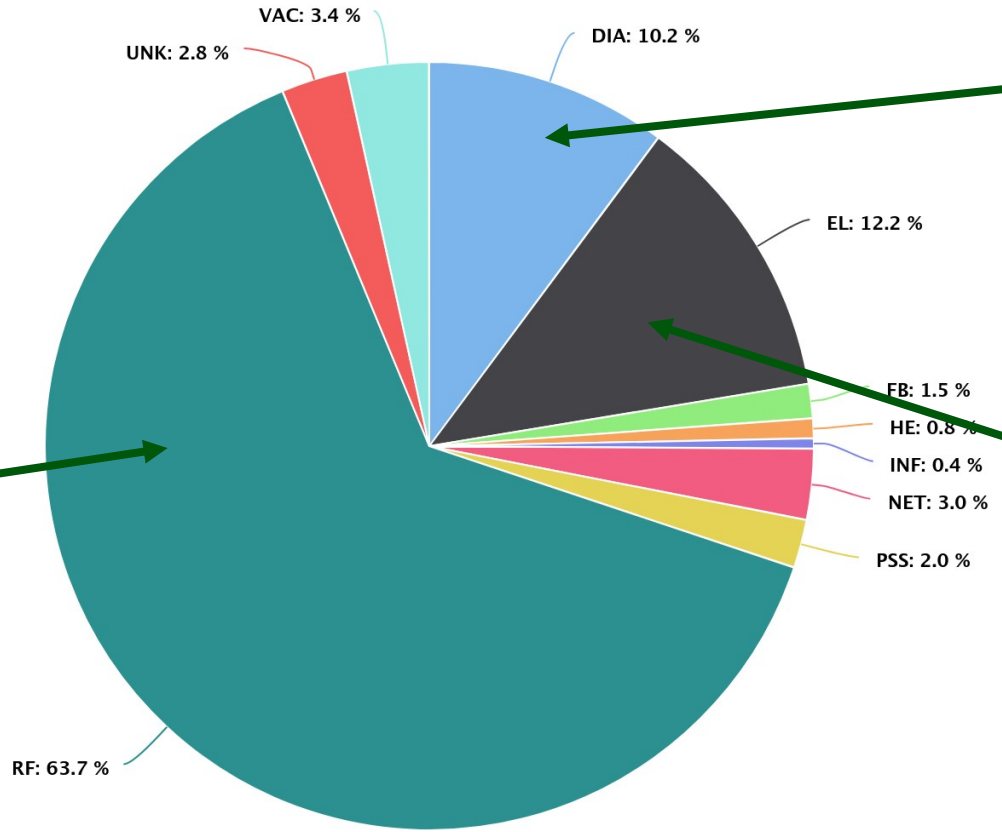


Power loss to a critical cabinet with network switches. Old UPS batteries to blame. Labwide inventory of UPS's being gathered. Some other issues relating to magnet power supplies.

Klystron for the thermionicgun failed. Photocathode gun was not yet ready for use as a replacement.
Significant progress has been made in this since then.

An unannounced change in the pressure from our cooling provider resulted in repeated RF failures.
Robust discussions underway with supplier

Causes of downtime: 1.5 GeV ring

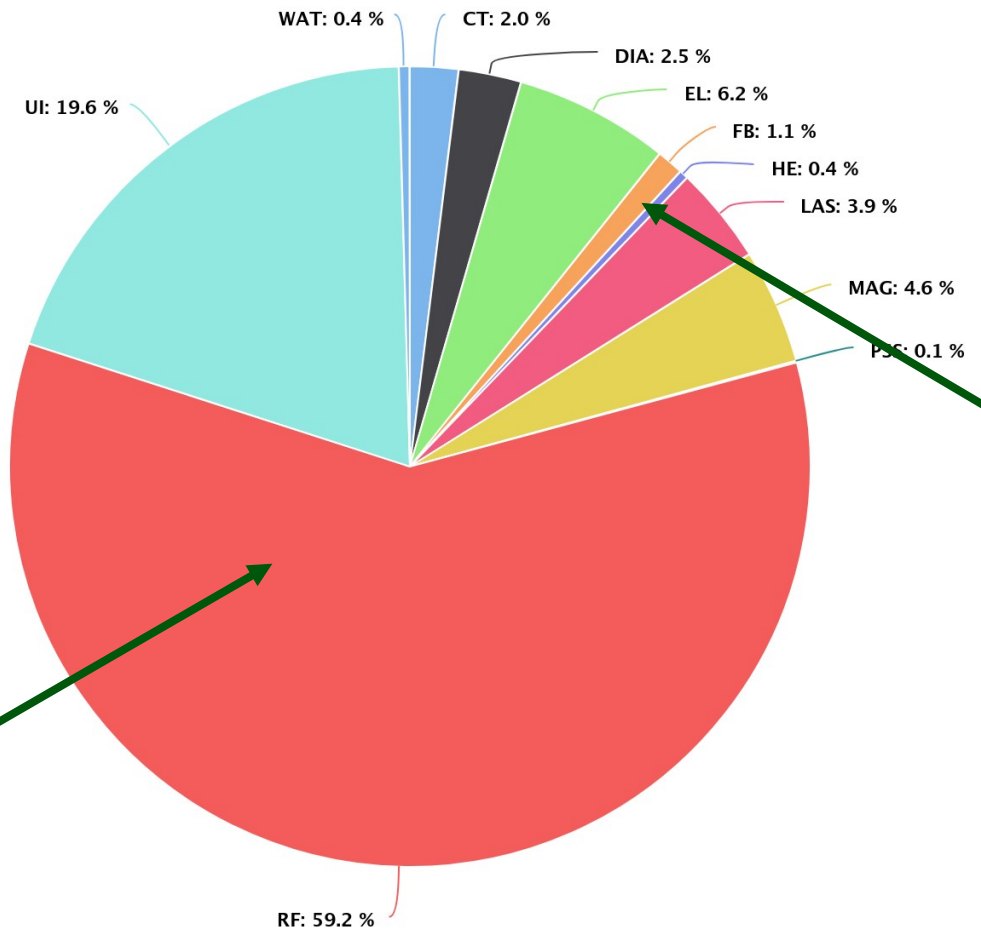


Failure of controls for BPMs in one achromat.

Klystron for the thermionic gun failed.
Beam was not lost, but decayed below the downtime-limit.
Photocathode gun was not yet ready for use as a replacement.
Significant progress has been made in this since then.

Power loss to a critical cabinet with network switches. Old UPS batteries to blame.
Labwide inventory of UPS's being gathered.

Causes of downtime: SPF



UI ("unscheduled injection") occurs due to recovery from beam-losses in the rings.

Power loss to a critical cabinet with network switches. Old UPS batteries to blame.
Labwide inventory of UPS's being gathered.

Klystron for the thermionic gun failed.
No delivery due to ongoing efforts to use photocathode gun for ring injection.

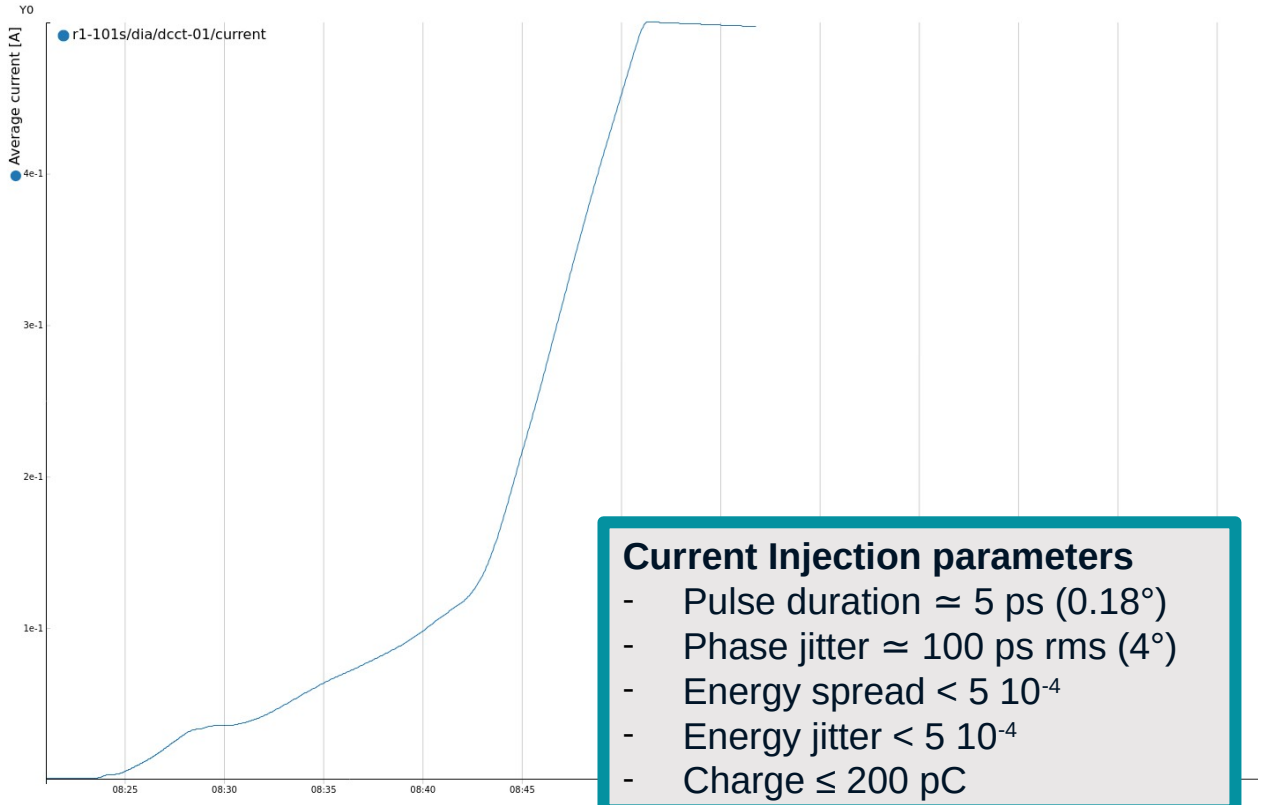
Responses to main downtime causes

- A recent issue whereby we have a dump with no clear cause followed by significant issues reinjecting.
  - Under investigation this week.
- Klystron for the thermionic gun failed.
  - Photogun being prepared as a functional backup solution.
- Water leak in magnet circuit caused during electrical work on a maintenance day.
  - Lessons-learned resulted in replanning.
- Power loss to a critical cabinet with network switches. Old UPS batteries to blame.
  - Lab-wide inventory of UPS's being gathered.
- An unannounced change in the pressure from our cooling provider resulted in repeated RF failures.
  - Robust discussions underway with supplier

Experimental demonstration of photo gun injection

Results from 29/9:
- PG injection in R1
- 140 mA/min
- 190 pC per shot @ 10 Hz

- Injection from the photo gun has been demonstrated in both rings; work in progress
- Photo-gun injection is a backup in case of thermionic gun problems
- So far tested with off-axis injection only
- Plans to test on-axis off-phase during fall



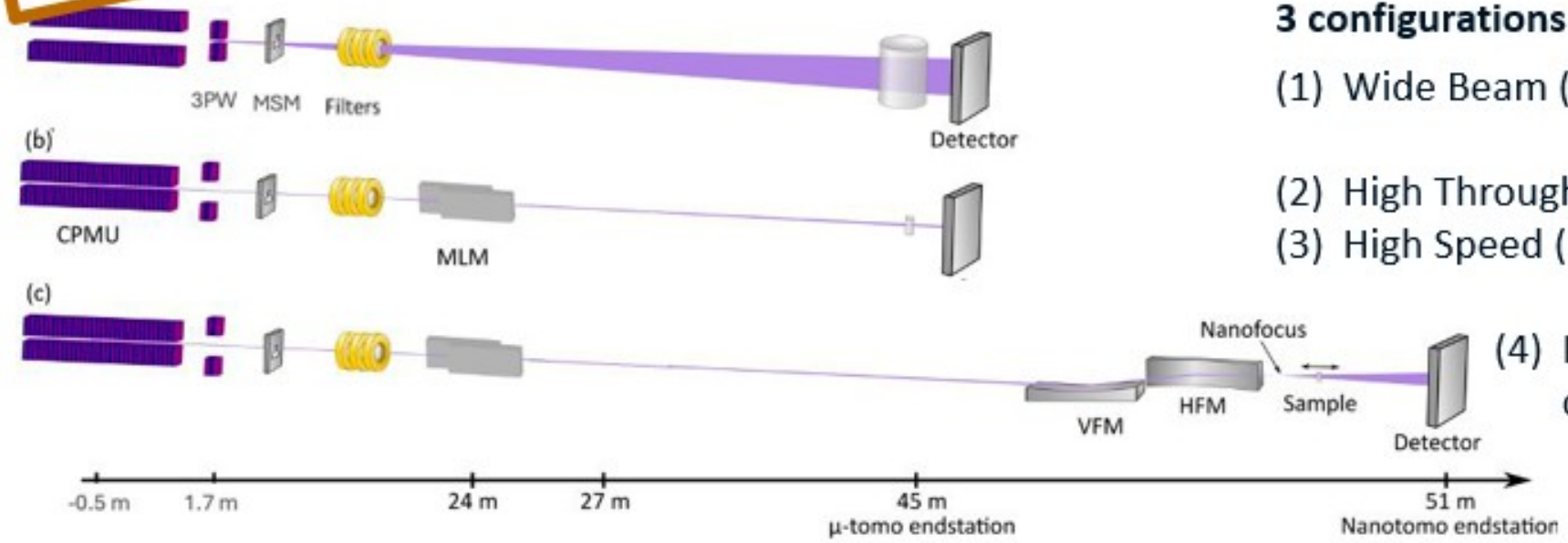
Current Injection parameters
- Pulse duration ≃ 5 ps (0.18°)
- Phase jitter ≃ 100 ps rms (4°)
- Energy spread < 5 10^{-4}
- Energy jitter < 5 10^{-4}
- Charge ≤ 200 pC

Future:
New beamlines
MAX4^{U} upgrade

A hard X-ray tomography imaging beamline supporting materials science for sustainabili

Funding decision by WISE and Knut and Alice Wallenberg Foundation in June 2025:
200 MSEK for TomoWISE (including 15 MSEK for CDR and TDR)

Dina Carbone
Scientific lead



3 configurations and 4 main operation modes:

(1) Wide Beam (WB) for the study of large samples,

(2) High Throughput (HT) tomographic microscopy*
(3) High Speed (HS) for capturing dynamic processes

(4) High Resolution (HR) for nano-characterisation

(*standard operating mode at TomoWISE)

Opportunities with a MedMAX beamline

- Exploiting the high MAX IV brilliance for optimal trade-off in imaging
- Access to 0.1–1 µm resolution range – zooming in/out from the organ level to sub-cellular 3D imaging
- Dynamic studies – capturing fast biological processes in living organisms at one micrometre spatial resolution in 3D
- Big potential for research collaborations with the on-site Comparative Medicine Unit
- Large potential synergies with ongoing activities in imaging in the Greater Copenhagen area
- MedMAX now in the TDR phase

Arash Panahifar
Scientific lead

MAX 4^{U}: A surgical upgrade

- ❑ Emittance $\lesssim$ **100 pmrad.**
- ❑ Energy : 3 GeV
- ❑ Keep shielding wall
- ❑ Keep light source positions
- ❑ Keep injector - accumulation
- ❑ Limited dark period
- ❑ Cost-effective
- ❑ Realizable until the early part of the next decade

ID	Beamline	Potential Gain	Gain Description	Type	Technique
Undulator	NanoMAX	7x	Higher coherent flux	A	Nano (XRD+XRF), CDI, Ptycho.
	DanMAX	5x	More flux in focused beam. Higher coherence.	B, C	μ(XRD+XRF) PC-μCT
	SINCRYS	2x	More flux, tighter focus	B	SC-XRD
	TomoWise-U	2-3x	Higher resolution in nano-CT. Higher coherence.	C	PC-μCT nano-CT
	ForMAX	3-9x	More flux, tighter focus. Higher coherence.	B, C	Scanning SAXS/WAXS, SAXS-CT
	CoSAXS	2-3x	More parallel beam	C	SAXS/WAXS
	BioMAX	2-3x	More flux, tighter focus	B	MX
	MicroMAX	5x	More flux, tighter focus	A, B	MX
	Veritas	1-1.5x	Smaller horizontal focus	A	RIXS
	Hippie	3x	More flux in focussed beam	A	AP-XPS AP-XAS
	SoftiMAX	2x	Higher coherent flux	A	Ptycho., CDI, STXM
Wiggler	TomoWISE-W	n.a.	Wiggler source is unaffected by MAX 4^{U}: **same performance as now.**	n.a.	μCT
	BALDER				XAS, XES, XRD

Two paths:

- "Absolute Requirement": AR lattice
  - Lattice that **meets** all MAX 4U requirements at the lowest possible cost.
- "Stretch Goal": SG lattice
  - Lattice that **surpasses** the MAX 4U emittance requirement accepting an increase in cost.

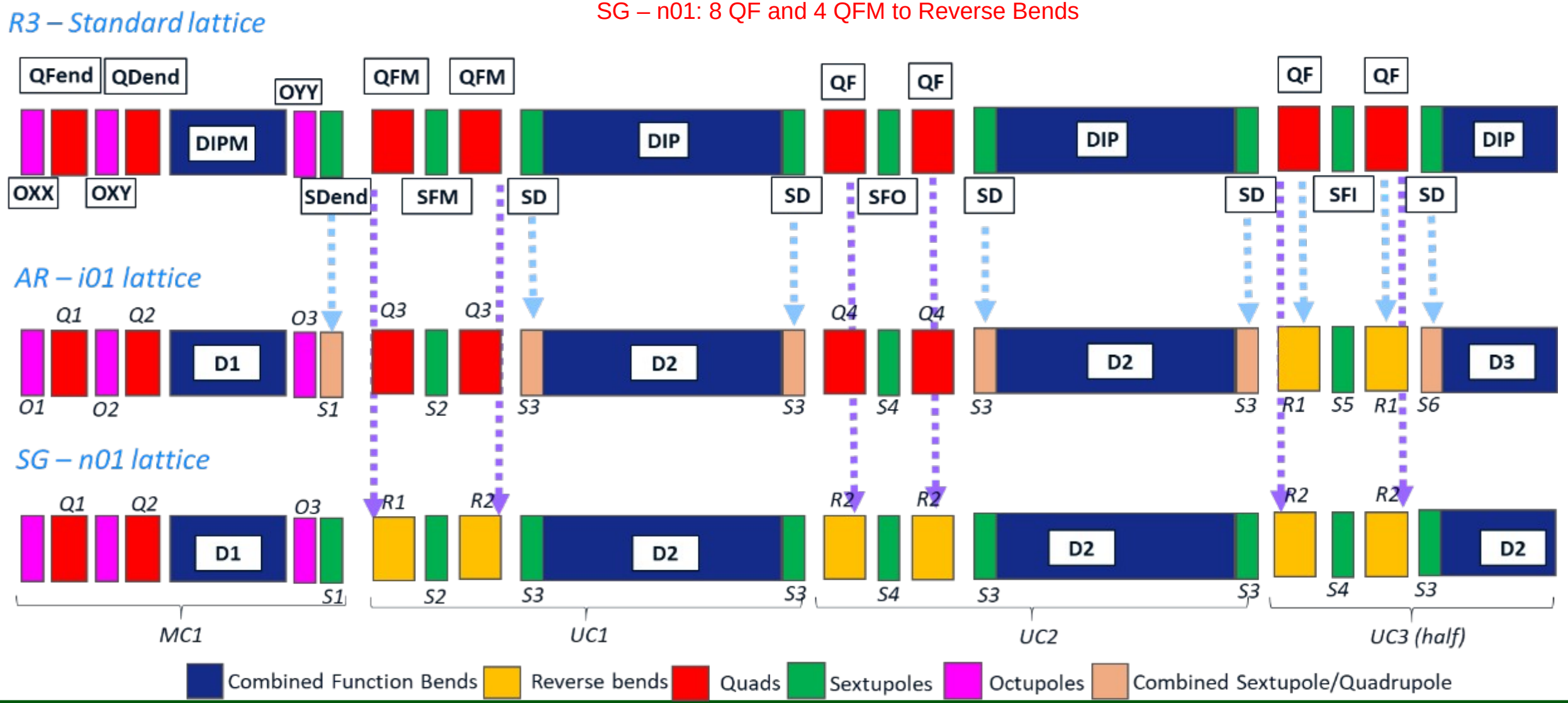
Two lattice designs

	R3 (as designed)	AR (i01-04-01-01)	SG (n01-01-01-01)	Units
Natural Emittance	328	95	65	pm rad
Natural Energy spread	7.69	7.55	8.46	10^{-4}
β∈@ long straights (x/y)	9.0 / 2.0	6.8 / 3.3	4.2 / 4.4	m
Natural Bunch length	8.8	6.7	5.7	mm
Betatron tunes (x/y)	42.20, 16.28	55.28, 16.20	58.29, 17.15	
Natural chromaticity per achromat	-2.50, -2.51	-4.46, -2.83	-4.87, -2.88	
Corrected chromaticity	+1, +1	+2, +2	+2, +2	
Momentum compaction factor	[3.06, 1.63, 15.8]	[0.944, 2.92, -4.49]	[0.54, 3.63, -4.47]	10^{-4}
Total abs. deflection angle	360	395	442	deg
M1 block deflection angle	1.50	1.50	1.29	deg
Max. orbit shift	0	8.8	21.3	mm
Radio-frequency change	0	-1.91	0	kHz
Energy loss per turn	364	414	474	keV
Damping times (H/ V/ L)	15.73 / 29.05 /25.19	14.75 / 25.51 / 20.08	11.44 / 22.29 / 21.18	ms

R3 Standard Lattice Vs MAX 4^{U} Lattices

Slide by A. Sharma

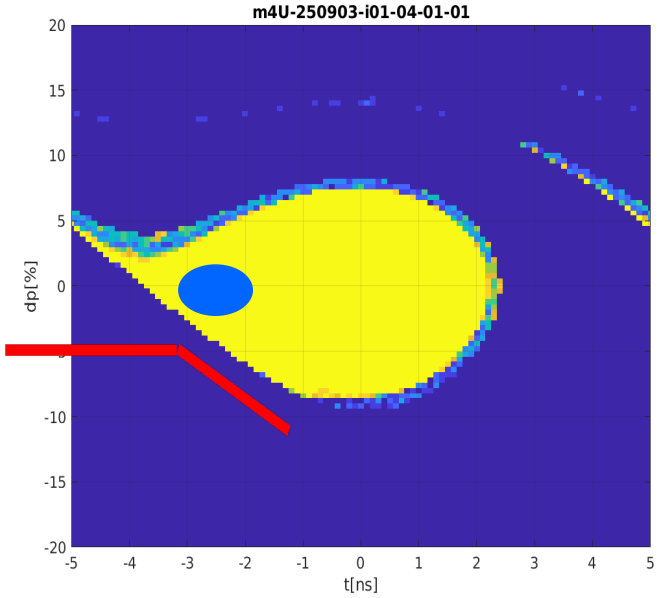
AR – i01: 4 QF to RB, 12 Sextupoles changed to combined function
SG – n01: 8 QF and 4 QFM to Reverse Bends



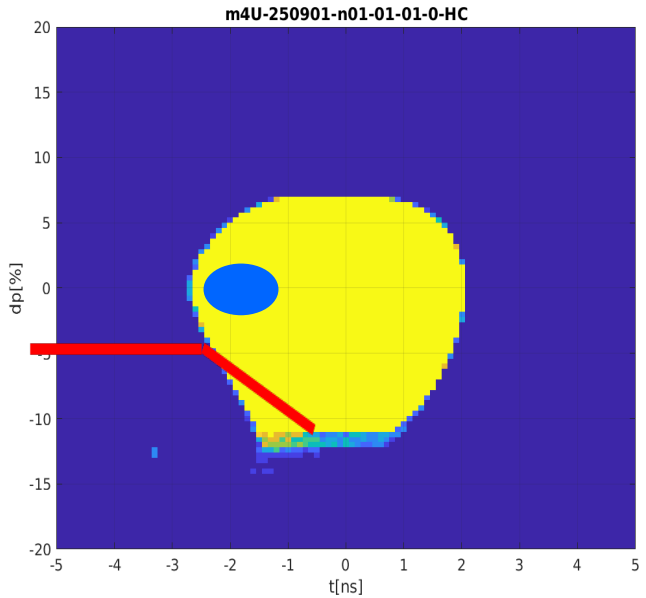
Off-phase, on-axis injection Schemes

- Our injector (full-energy linac) and low (100 MHz) ring RF frequency puts us in a privileged position to implement these schemes
- This approach
  - Allows advanced IDs with small horizontal gap.
  - Improves top-up transparency.
  - Eases accumulation into lattices with small dynamic aperture.

AR AT2 6D tracking, including errors



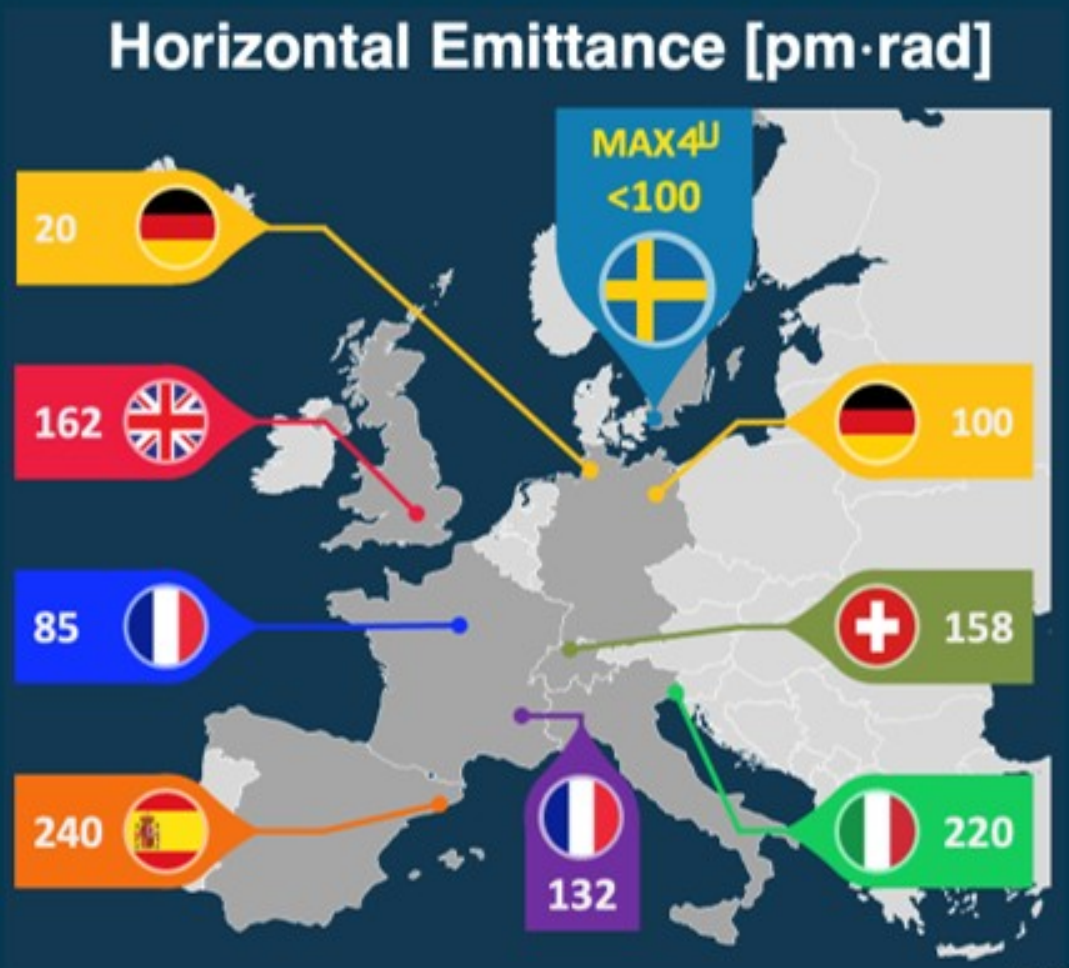
SG AT2 6D tracking, including errors, 3rd Harmonic Cavity



MAX 4U

Securing leadership, excellence, resilience, and relevance of Swedish research with X-rays for the next decades

A *"surgical"* upgrade of our 3GeV ring
from 328 to below 100 pm·rad



c/o A.ROBERT

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