Status and Development of the ASTRID2 Facility

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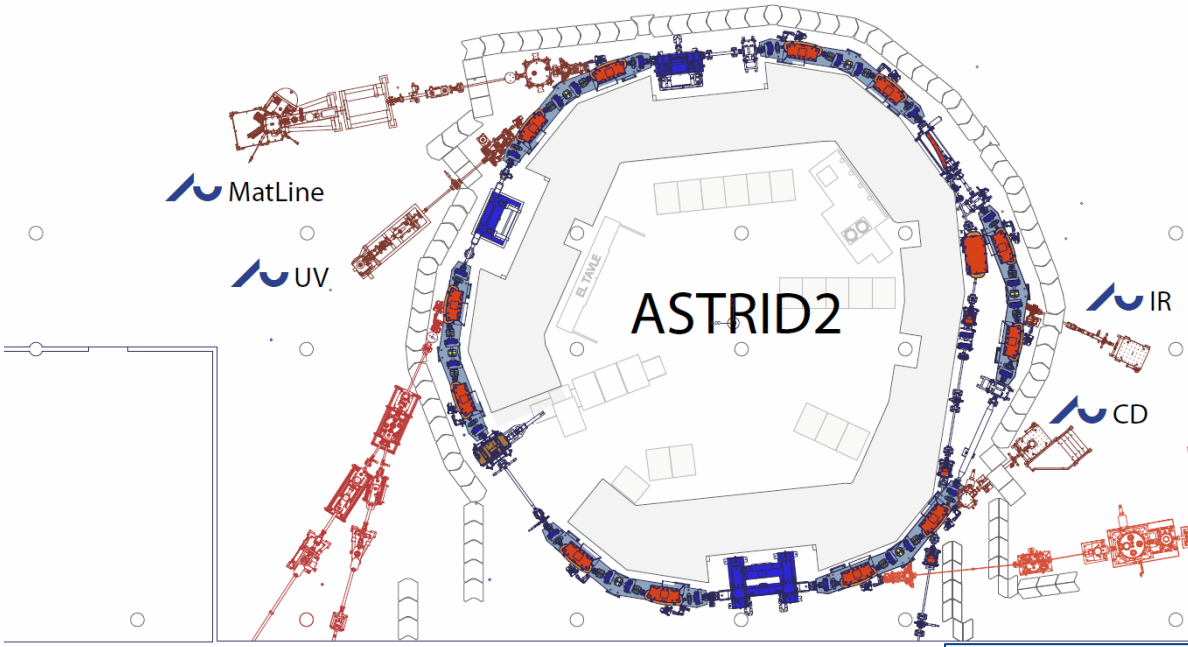
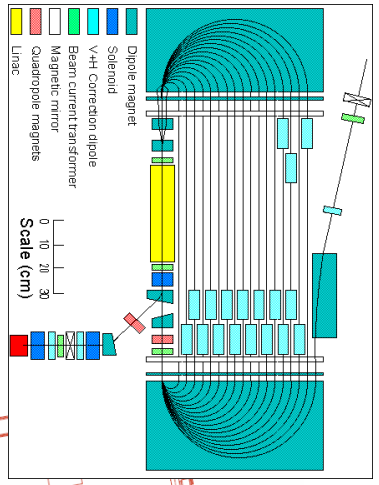
ASTRID2

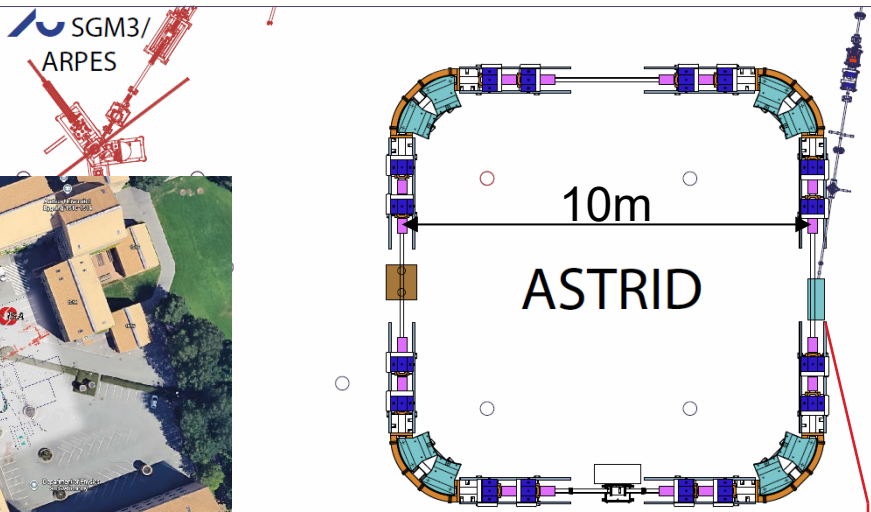
- ASTRID2 is the “new” synchrotron light source in Aarhus, Denmark, since 2013
- ASTRID2 main parameters
  - Electron energy: 580 MeV
  - Emittance: 12 nm
  - Beam Current: 180 mA
  - Circumference: 45.7 m
  - 6-fold symmetry
    - lattice: DBA with 12 combined function dipole magnets
      - Integrated quadrupole gradient
  - 4 straight sections for insertion devices
  - Using ASTRID as booster (full-energy injection)
    - Allows top-up operation

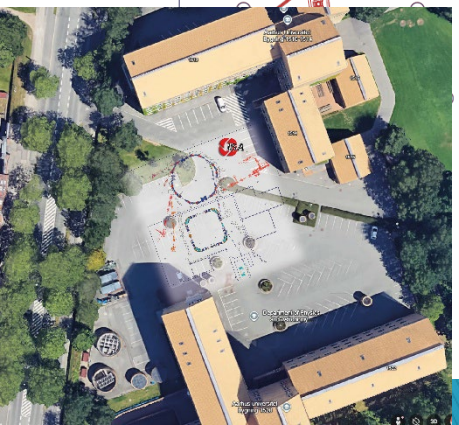
The ASTRID 2 facility



100 MeV Microtron







ASTRID2 main parameters

Circumference	45.71 m
Energy	580 MeV
Current	180 mA
Critical SR energy	257 eV
RF frequency	105 MHz
Harmonic	16
Horiz. emittance	12 nm
#Straight sections	6
Length of straight sections	2.82 m
#ID's	3

Microtron (100MeV)

2025 Schedule

ASTRID2 user

ASTRID2 develop.

ASTRID2 shutdown

Local Users only

A normal User Beam week is from Monday ~12:00 to the following Monday 8:30

31 user weeks / 11 Machine physics weeks / 11 shutdown

2025 Calendar

Schedule - proposed in September 2024.

January		February		March		April		May		June	
W 01		S 01		S 01		T 01		T 01		S 01	
T 02		S 02		S 02		W 02		F 02		M 02	23
F 03	Shutdown	M 03	6	M 03	10	T 03		S 03		T 03	
S 04		T 04		T 04		F 04		S 04		W 04	
S 05		W 05		W 05		S 05		M 05	19	T 05	
M 06	2	T 06		T 06		S 06		T 06		F 06	
T 07		F 07		F 07		M 07	15	W 07		S 07	
W 08	Shutdown	S 08		S 08		T 08		T 08		S 08	
T 09		S 09		S 09		W 09		F 09		M 09	24
F 10		M 10	7	M 10	11	T 10		S 10		T 10	
S 11		T 11	Local users only	T 11		F 11		S 11		W 11	
S 12		W 12	No operator	W 12		S 12		M 12	20	T 12	
M 13	3	T 13	support	T 13		S 13		T 13		F 13	
T 14	Shutdown	F 14		F 14		M 14	16	W 14		S 14	
W 15	Startup	S 15		S 15		T 15		T 15		S 15	
T 16		S 16		S 16		W 16	Shutdown	F 16		M 16	25
F 17		M 17	8	M 17	12	T 17		S 17		T 17	
S 18		T 18		T 18		F 18		S 18		W 18	
S 19		W 19	Machine physics	W 19		S 19		M 19	21	T 19	
M 20	4	T 20		T 20		S 20		T 20		F 20	
T 21		F 21		F 21		M 21	17	W 21	Machine physics	S 21	
W 22	Machine physics	S 22		S 22		T 22		T 22		S 22	
T 23		S 23		S 23		W 23	Shutdown	F 23		M 23	26
F 24		M 24	9	M 24	13	T 24		S 24		T 24	
S 25		T 25		T 25	Machine physics	F 25		S 25		W 25	Machine physics
S 26		W 26		W 26		S 26		M 26	22	T 26	
M 27	5	T 27		T 27		S 27		T 27		F 27	
T 28		F 28		F 28		M 28	18	W 28		S 28	
W 29				S 29		T 29	Startup and	T 29		S 29	
T 30				S 30		W 30	Machine physics	T 30		M 30	27
F 31				M 31	14			S 31			
22	work days excl. 4 Sat.	20	work days excl. 4 Sat.	21	work days excl. 5 Sat.	19	work days excl. 4 Sat.	20	work days excl. 4 Sat.	20	work days excl. 5 Sat.

DK Holiday | Astrid2 Shutdown | Machine Physics | MP/Local Users only | All other weeks are ASTRID2 user beam time

2025 Calendar

Proposed schedule for 2nd half of the year

July		August		September		October		November		December	
T 01		F 01		M 01	36	W 01	Shutdown	S 01		M 01	49
W 02		S 02		T 02		T 02		S 02		T 02	
T 03		S 03		W 03	Machine physics	F 03		M 03	45	W 03	
F 04		M 04	32	T 04		S 04		T 04	Machine physics	T 04	
S 05		T 05		F 05		S 05		W 05		F 05	
S 06		W 06	Startup and	S 06		M 06	41	T 06		S 06	
M 07	28	T 07	machine physics	S 07		T 07		F 07		S 07	
T 08		F 08		M 08	37	W 08		S 08		M 08	50
W 09		S 09		T 09		T 09		S 09		T 09	
T 10		S 10		W 10		F 10		M 10	46	W 10	
F 11		M 11	33	T 11		S 11		T 11		T 11	
S 12		T 12		F 12		S 12		W 12		F 12	
S 13		W 13		S 13		M 13	42	T 13		S 13	
M 14	29	T 14		S 14		T 14	Local users only	F 14		S 14	
T 15		F 15		M 15	38	W 15	No operator	S 15		M 15	51
W 16	Shutdown	S 16		T 16		T 16	support	S 16		T 16	
T 17		S 17		W 17		F 17		M 17	47	W 17	Machine physics
F 18		M 18	34	T 18		S 18		T 18		T 18	
S 19		T 19		F 19		S 19		W 19		F 19	
S 20		W 20		S 20		M 20	43	T 20		S 20	
M 21	30	T 21		S 21		T 21		F 21		S 21	
T 22		F 22		M 22	39	W 22		S 22		M 22	52
W 23	Shutdown	S 23		T 23		T 23		S 23		T 23	Shutdown
T 24		S 24		W 24		F 24		M 24	48	W 24	
F 25		M 25	35	T 25		S 25		T 25		T 25	
S 26		T 26		F 26		S 26		W 26		F 26	
S 27		W 27		S 27		M 27	44	T 27		S 27	
M 28	31	T 28		S 28		T 28		F 28		S 28	
T 29		F 29		M 29	40	W 29		S 29		M 29	1
W 30	Shutdown	S 30		T 30		T 30		S 30		T 30	
T 31		S 31				F 31				W 31	
23	work days excl. 4 Sat.	21	work days excl. 4 Sat.	22	work days excl. 5 Sat.	23	work days excl. 4 Sat.	20	work days excl. 4 Sat.	19	work days excl. 5 Sat.

DK Holiday | Astrid2 Shutdown | Machine Physics | MP/Local Users only | All other weeks are ASTRID2 user beam time

2026 (proposed)

34 user weeks / 11 MP weeks / 6 shutdw

2026 Calendar

Schedule - preliminary 2025

January		February		March		April		May		June	
T 01		S 01		S 01		W 01		F 01		M 01	23
F 02	Shutdown	M 02	6	M 02	10	T 02		S 02		T 02	
S 03		T 03		T 03		F 03		S 03		W 03	
S 04		W 04		W 04		S 04		M 04	19	T 04	
M 05	2	T 05		T 05		S 05		T 05		F 05	
T 06		F 06		F 06		M 06	15	W 06		S 06	
W 07		S 07		S 07		T 07		T 07		S 07	
T 08	Shutdown	S 08		S 08		W 08	Startup and	F 08		M 08	24
F 09		M 09	7	M 09	11	T 09	Machine physics	S 09		T 09	
S 10		T 10	Local users only	F 10		S 10		S 10		W 10	
S 11		W 11	No operator	W 11	Machine physics	S 11		M 11	20	T 11	
M 12	3	T 12	support	T 12		S 12		T 12	Machine physics	F 12	
T 13		F 13		F 13		M 13	16	W 13		S 13	
W 14	Machine physics	S 14		S 14		T 14		T 14		S 14	
T 15		S 15		S 15		W 15		F 15		M 15	25
F 16		M 16	8	M 16	12	T 16		S 16		T 16	
S 17		T 17		F 17		S 17		S 17		W 17	Machine physics
S 18		W 18	Machine physics	S 18		M 18	21	T 18		F 18	
M 19	4	T 19		S 19		T 19	Local users only	F 19		S 19	
T 20		F 20		M 20	17	W 20	No operator	S 20		S 20	
W 21		S 21		T 21		T 21	support	S 21		M 21	26
T 22		S 22		W 22		F 22		S 22		T 22	
F 23		M 23	9	T 23		S 23		M 23	22	T 23	
S 24		T 24		F 24		S 24		T 24		W 24	
S 25		W 25		S 25		M 25	18	W 27		S 27	
M 26	5	T 26		S 26		T 26		T 28		S 28	
T 27		F 27		M 27	18	W 27		F 29		M 29	27
W 28		S 28		T 28		T 28		S 30		T 30	
T 29				W 29		F 29		S 31			
F 30				M 30	14	S 30					
S 31				T 31							
21	work days excl. 4 Sat.	20	work days excl. 4 Sat.	22	work days excl. 5 Sat.	19	work days excl. 4 Sat.	21	work days excl. 4 Sat.	21	work days excl. 5 Sat.

DK Holiday | Astrid2 Shutdown | Machine Physics | MP/Local Users only | All other weeks are ASTRID2 user beam time

2026 Calendar

Proposed schedule for 2nd half of the year

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W 01		S 01		T 01		T 01		S 01		T 01	
T 02		S 02		W 02		F 02		M 02	45	W 02	
F 03		M 03	32	T 03	Machine physics	S 03		T 03		T 03	
S 04		T 04		F 04		S 04		W 04		F 04	
S 05		W 05	Startup and	S 05		M 05	41	T 05		S 05	
M 06	28	T 06	machine physics	S 06		T 06	Machine physics	F 06		S 06	
T 07		F 07		M 07	37	W 07		S 07		M 07	50
W 08		S 08		T 08		T 08		S 08		T 08	
T 09		S 09		W 09		F 09		M 09	46	W 09	
F 10		M 10	33	T 10		S 10		T 10		T 10	
S 11		T 11		F 11		S 11		W 11	Machine physics	F 11	
S 12		W 12		S 12		M 12	42	T 12		S 12	
M 13	29	T 13		S 13		T 13	Local users only	F 13		S 13	
T 14		F 14		M 14	38	W 14	No operator	S 14		M 14	51
W 15	Shutdown	S 15		T 15		T 15	support	S 15		T 15	
T 16		S 16		W 16		F 16		M 16	47	W 16	Machine physics
F 17		M 17	34	T 17		S 17		T 17		T 17	
S 18		T 18		F 18		S 18		W 18		F 18	
S 19		W 19		S 19		M 19	43	T 19		S 19	
M 20	30	T 20		S 20		T 20		F 20		S 20	
T 21		F 21		M 21	39	W 21		S 21		M 21	52
W 22	Shutdown	S 22		T 22		T 22		S 22		T 22	
T 23		S 23		W 23		F 23		M 23	48	W 23	Shutdown
F 24		M 24	35	T 24		S 24		T 24		T 24	
S 25		T 25		F 25		S 25		W 25		F 25	
S 26		W 26		S 26		M 26	44	T 26		S 26	
M 27	31	T 27		S 27		T 27		F 27		S 27	
T 28		F 28		M 28	40	W 28		S 28		M 28	53
W 29	Shutdown	S 29		T 29		T 29		S 29		T 29	
T 30		S 30		W 30		F 30		S 30		W 30	
T 31		M 31	36			S 31				T 31	
23	work days excl. 4 Sat.	21	work days excl. 4 Sat.	22	work days excl. 5 Sat.	21	work days excl. 4 Sat.	19	work days excl. 4 Sat.	19	work days excl. 5 Sat.

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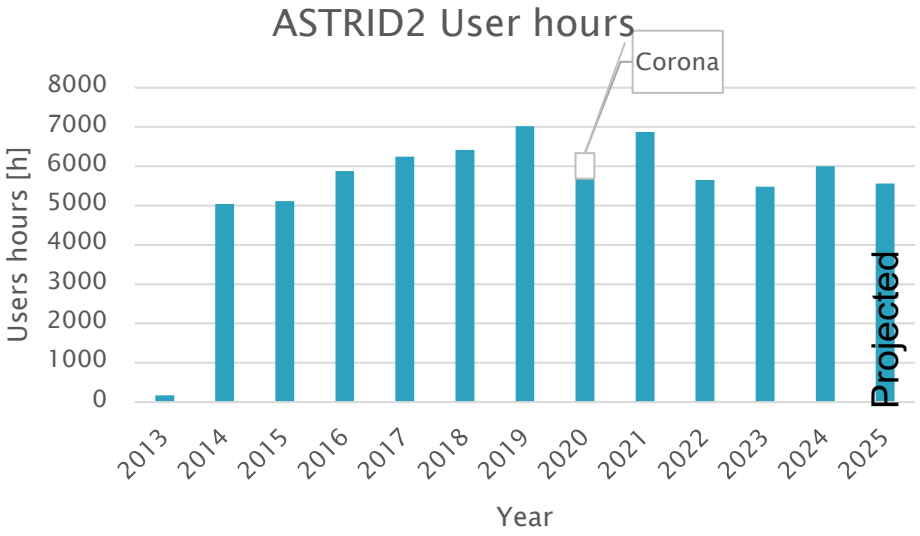
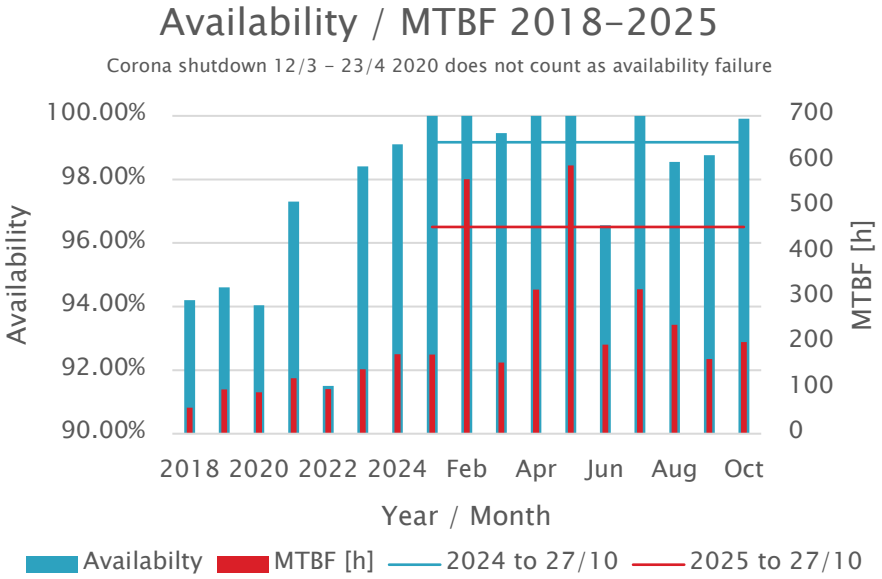
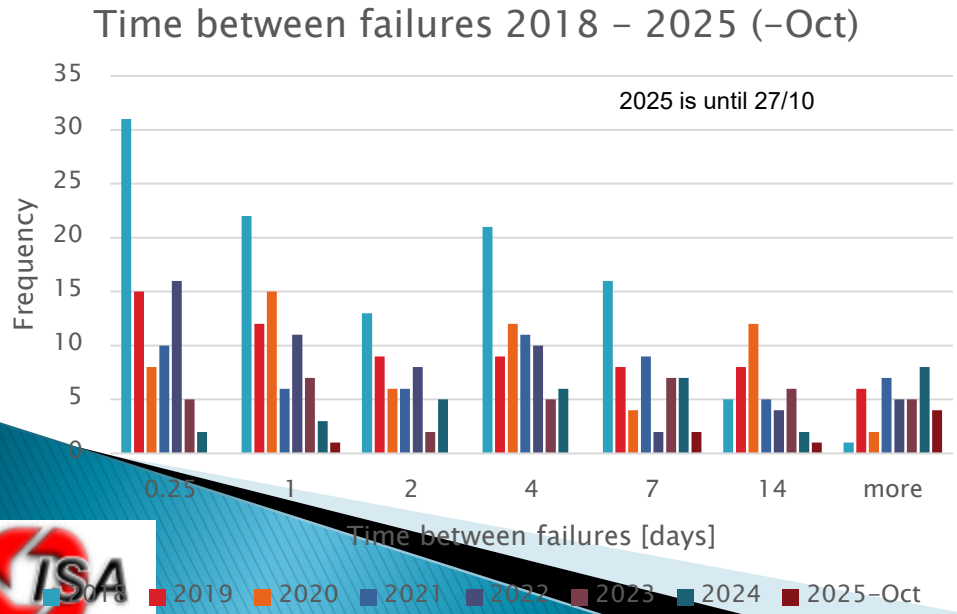
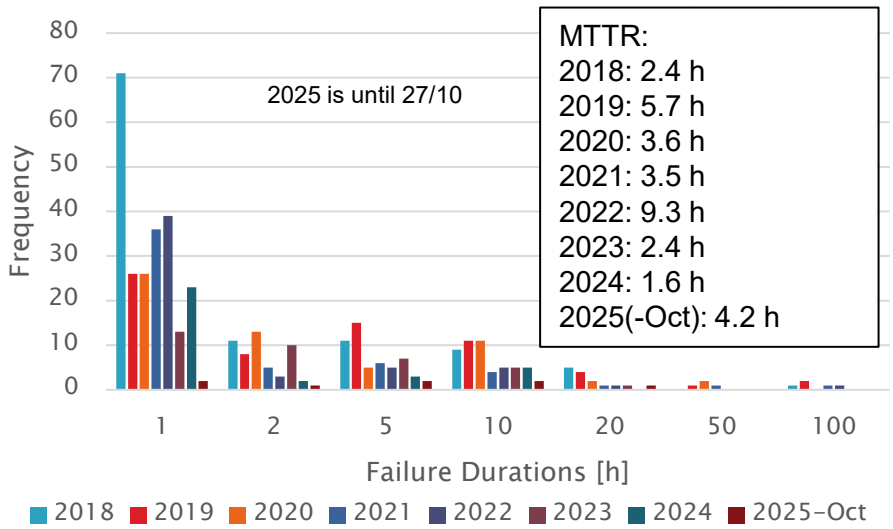
User hours and reliability

Downtime: If current goes below 90% of top-up set current

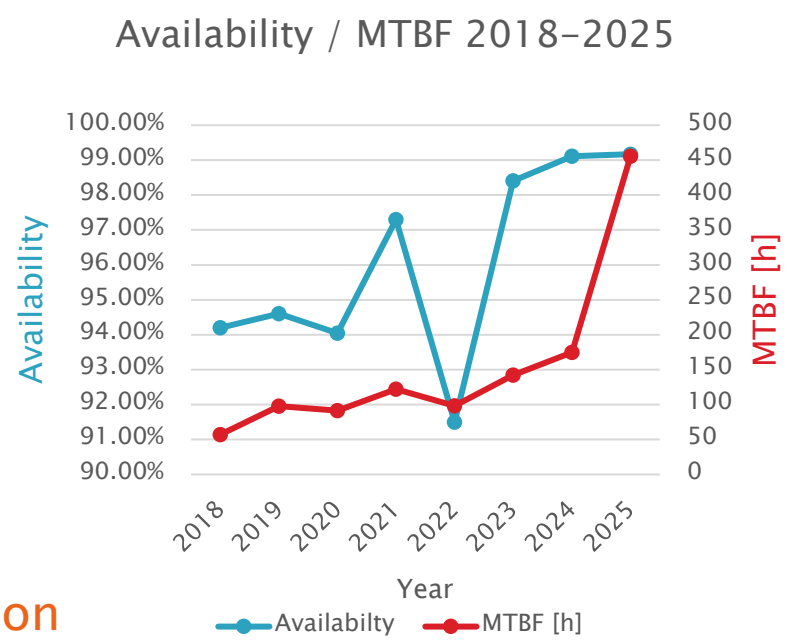








Failures

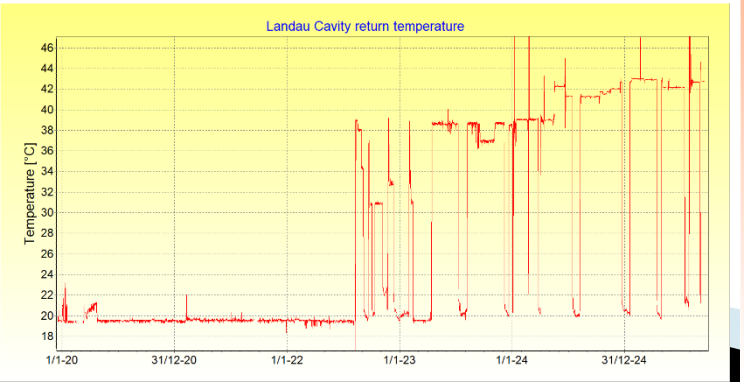


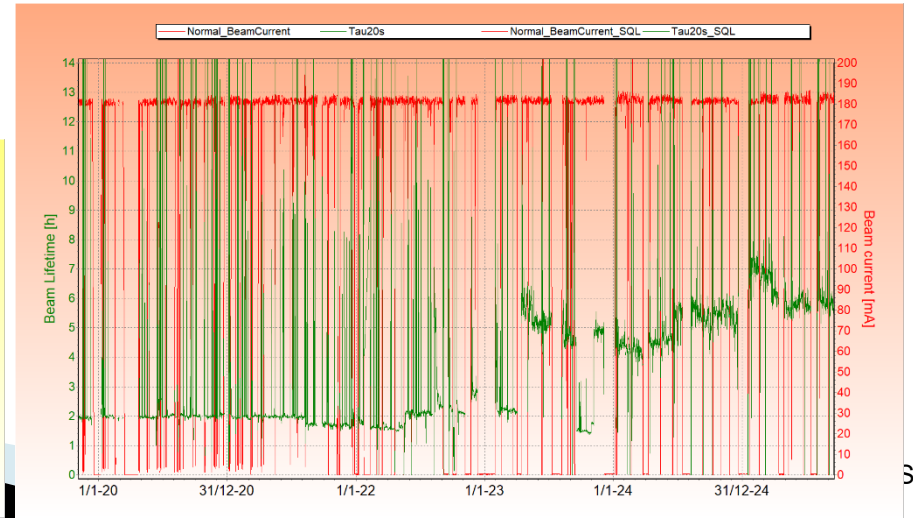
- 2025 has been a good year (so far)
  - Again, high Availability and MTBF
  - No real large and "catastrophic" events
- June 12th: Microtron
  - Failure of Turbo Pump controller
  - 17 h lost because of failure late afternoon
- Aug. 28th: Microtron
  - A "jump" in settings following a spark in the Linac
  - 7 h lost because of night
- Sep. 11th: ASTRID
  - Failure of vacuum interlock power supply
  - 6 h lost because of night
- Plus, several other smaller failures

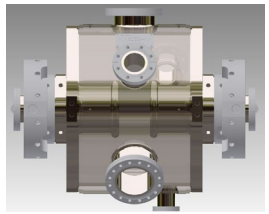
Note:
No operator or technician on call during evenings, nights and weekends

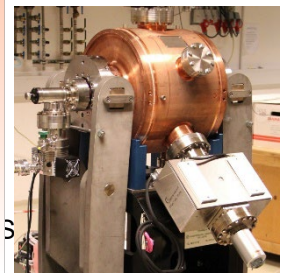
3rd harm. Landau cavity

- As reported earlier we have the last ~3 years operated our 3rd harmonic Landau cavity at an elevated temperature (around 40-45°C)
  - The higher temperature changes the frequency of a Higher Order Mode, so we can achieve a smaller detuning of the main mode, giving a better beam lifetime
- Quite a bit of work has been put into finding optimum fill pattern, cavity temperature and detuning, which maximizes beam lifetime, and provide a stable beam vertically and horizontally
  - These settings has evolved over time, because vacuum has changed (improved). The low beam energy makes us sensitive to ion captures.



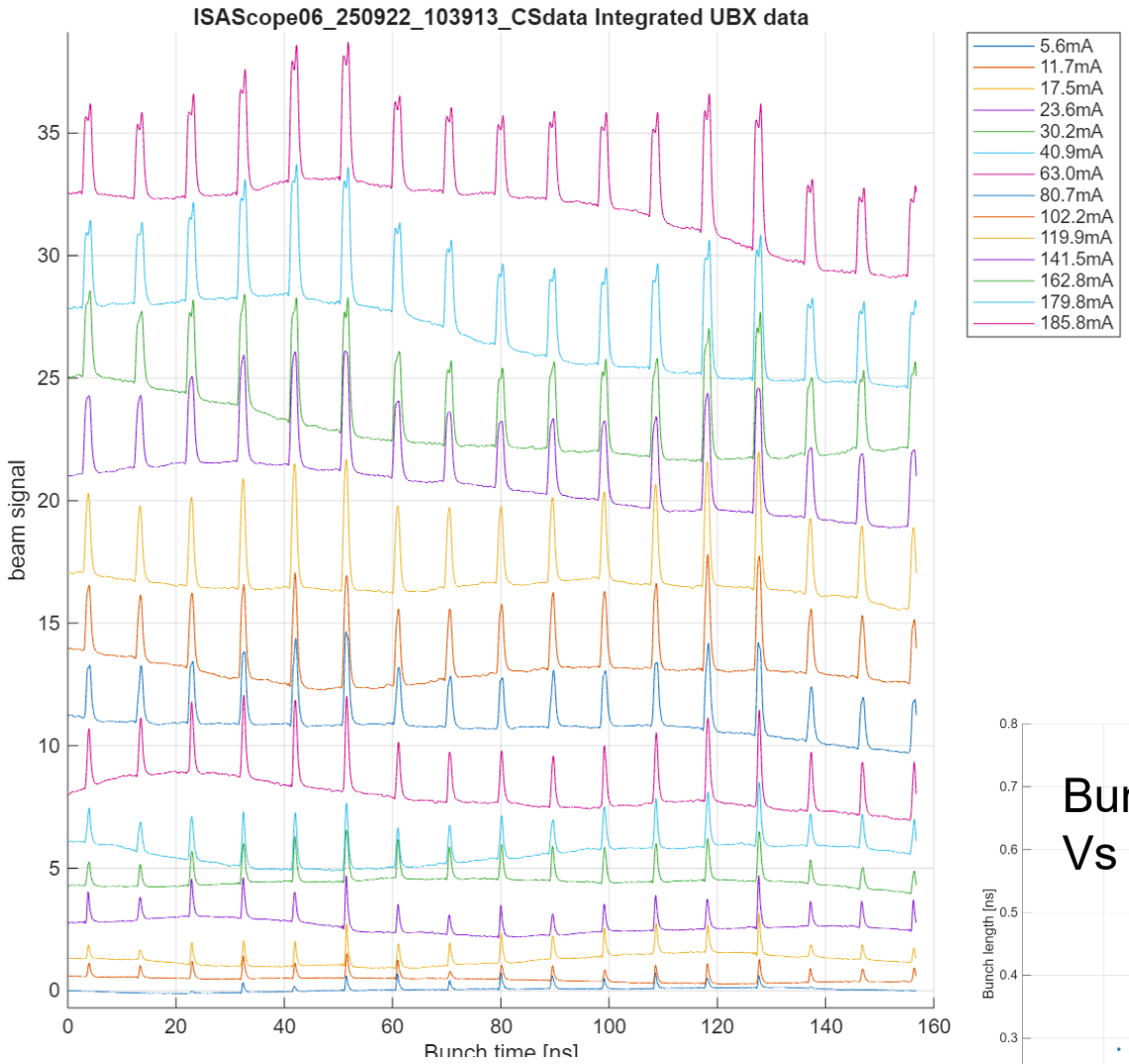




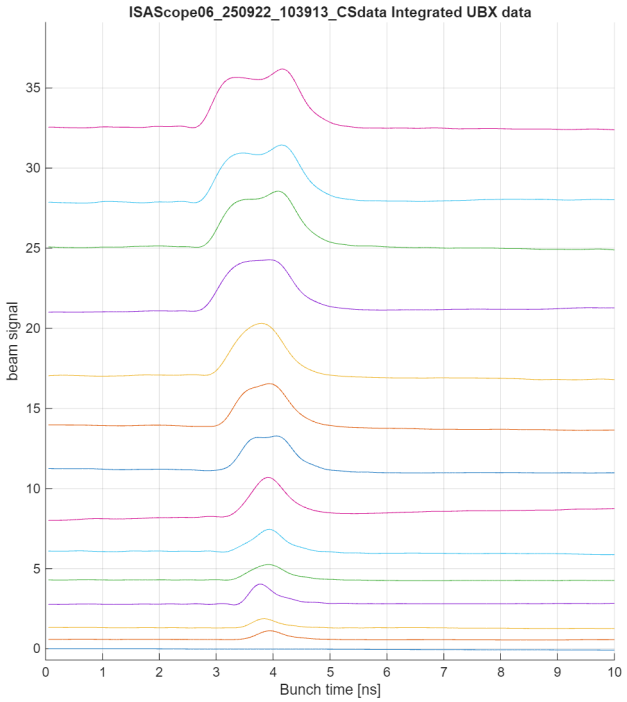


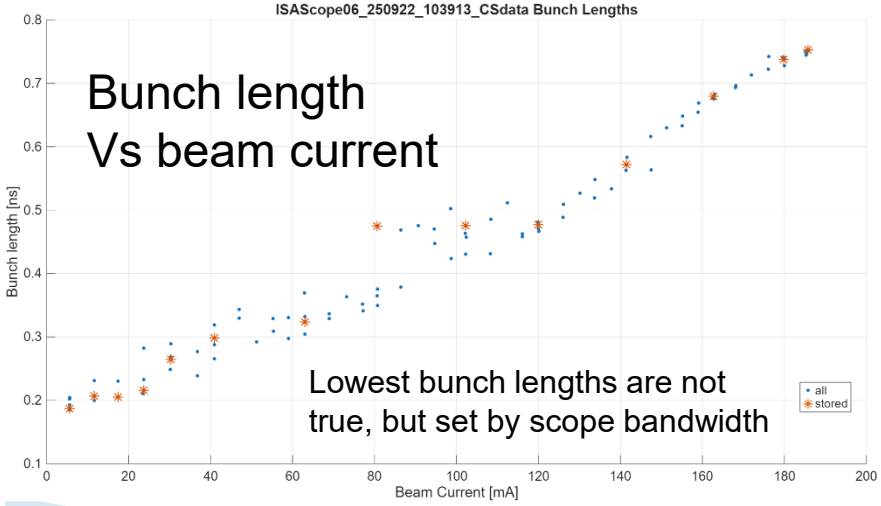
Beam profiles as function of beam current

All 16 bunches (one revolution)



One bunch





Bunch length
Vs beam current

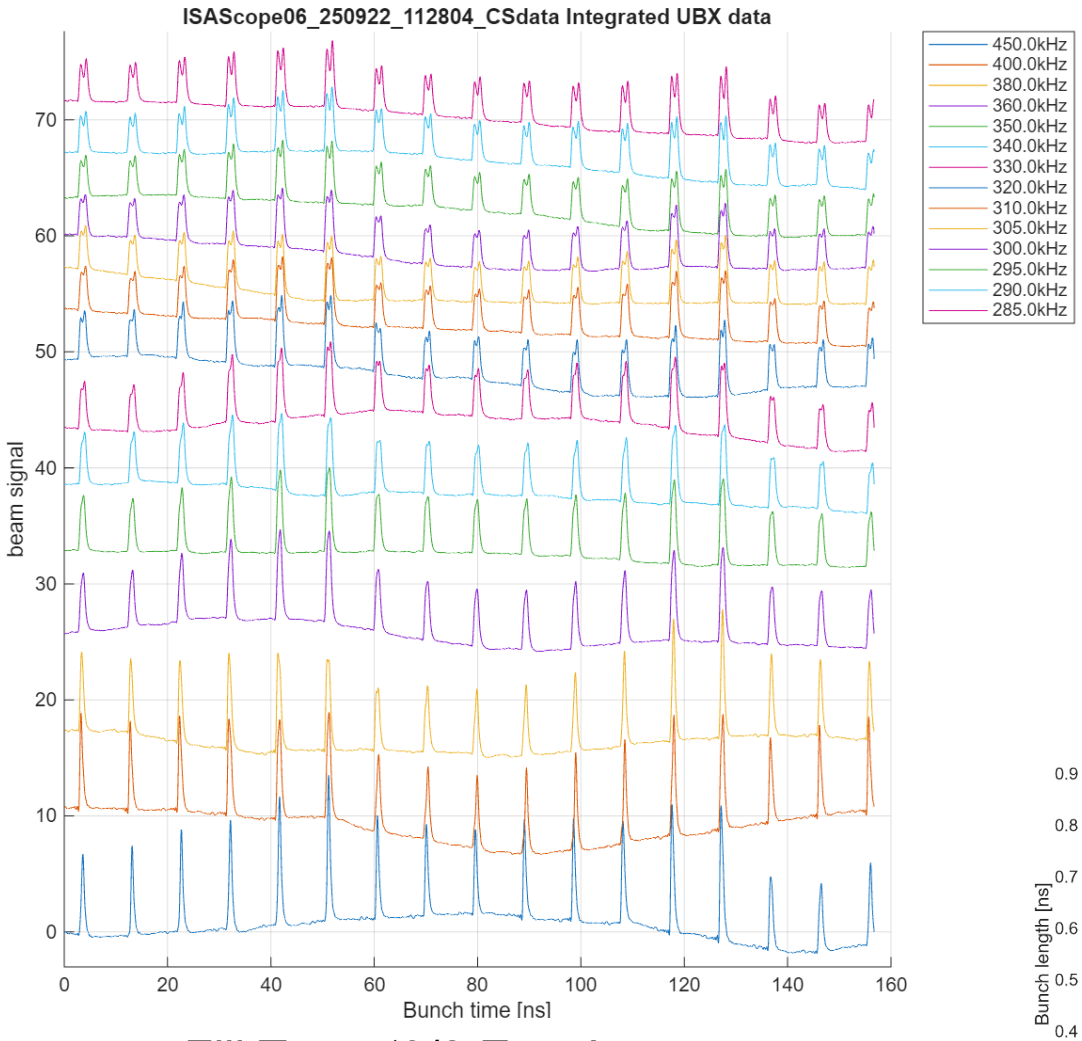
Lowest bunch lengths are not true, but set by scope bandwidth

Fill Type: '0/8 Even'

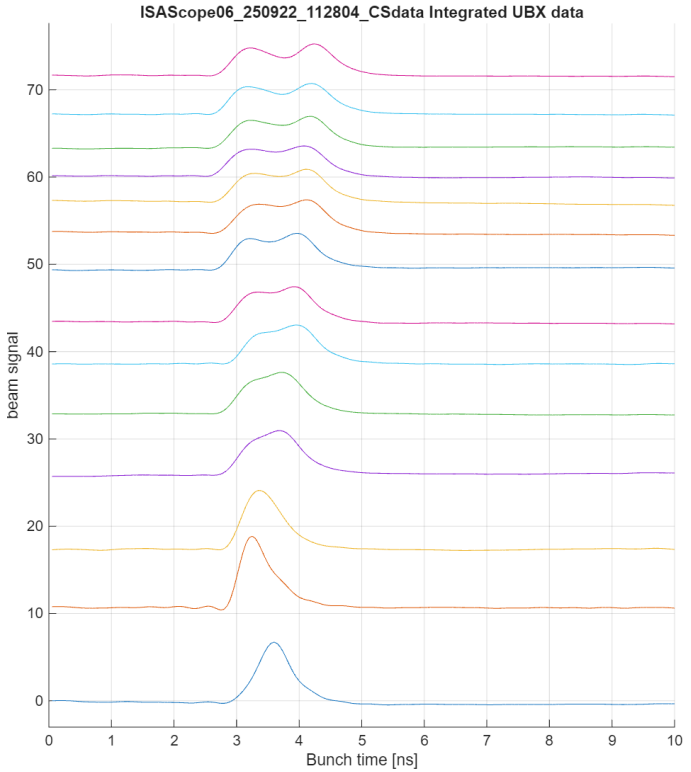
Detuning: 304 kHz (setpoint),
corresponding to 113 kHz actual

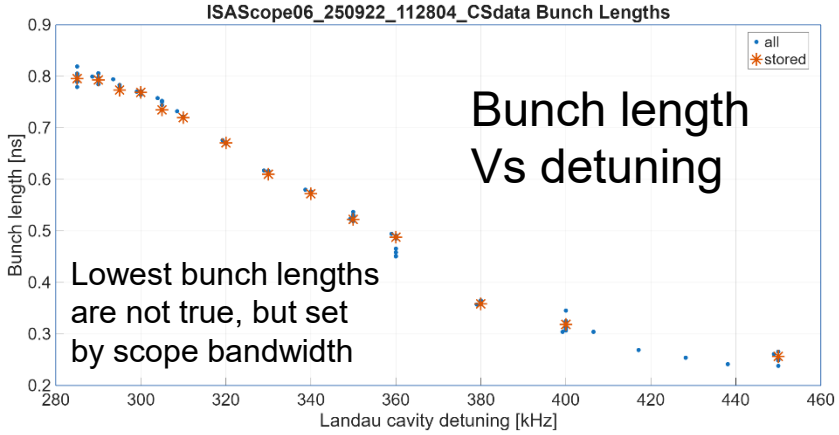
Beam profiles as function of cavity detuning

All 16 bunches (one revolution)



One bunch





Fill Type: ‘0/8 Even’

Nominal detuning: 304 kHz (setpoint)
corresponding to 113 kHz actual

A possible new EPU undulator for ASTRID2

- PSI has offered us one of their old UE54 Apple-II
  - They have another two UE56 for sale
- Fits our need very nicely, and we have applied for money to buy and install it
  - Waiting for an answer
- It will be some work to do lattice compensation for it
  - If anyone has some tips, I would like to hear

	UE54	Units
Units available	1	-
Gap range	16-100	mm
Shift range	+/- 27	mm
Number of shift axes	2	-
Total Length	2070	mm
Number of periods	32	-
Kx	2.7	-
Ky	4.00	-
Polarization	All elliptical Linear 0-90 deg	-

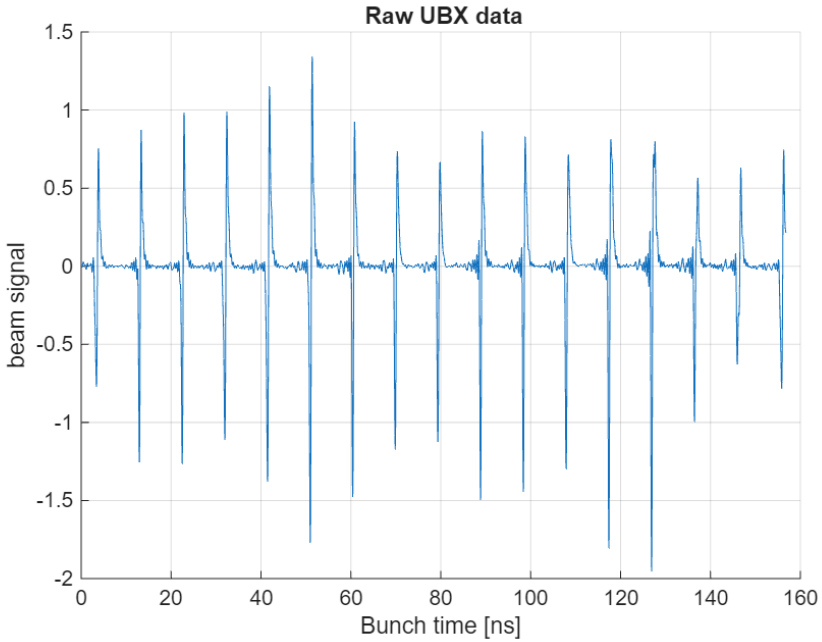
Thank you for your attention

LEGO model of ASTRID2 by Nykola Jones:

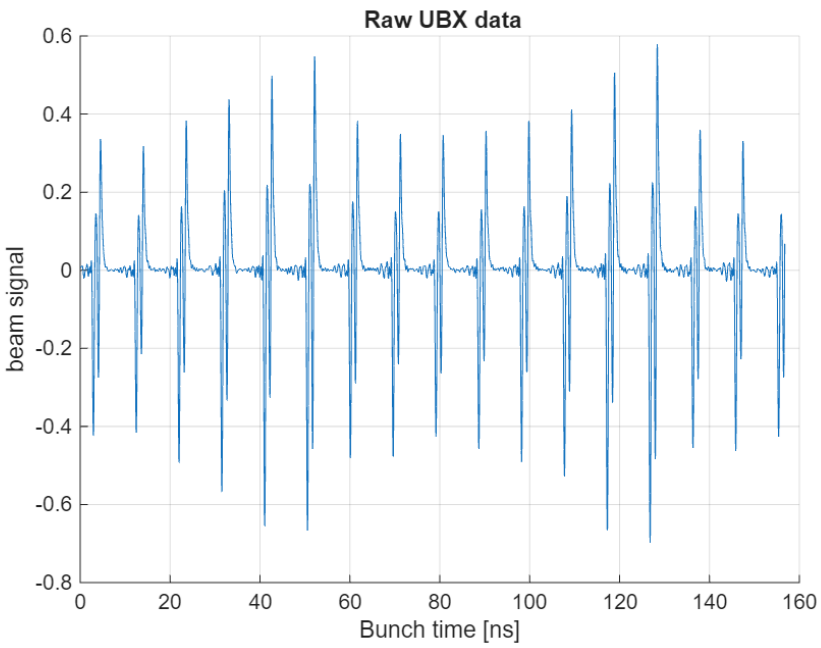
Spare slides

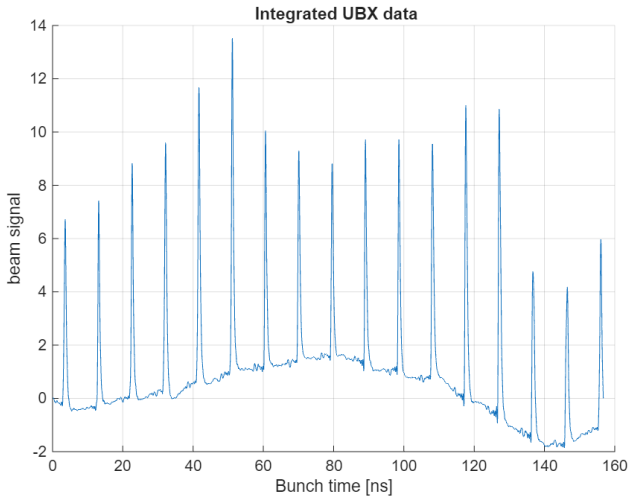
Raw Beam profiles (cavity detuning scan)

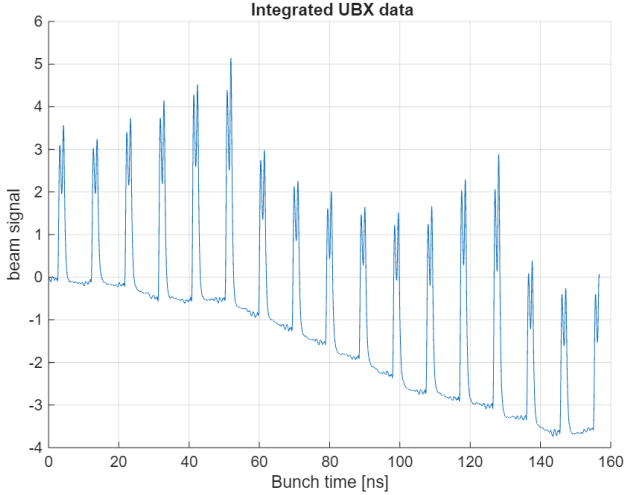
400 kHz detune (181 mA)



285 kHz detune (184 mA)



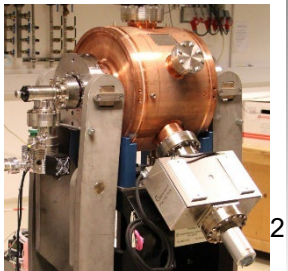


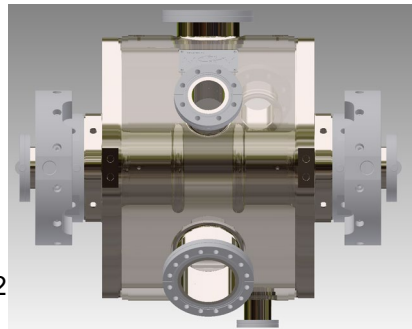


ASTRID2 Layout

3rd harm. Landau cavity

- As reported earlier we have the last ~2 years started to operate our 3rd harmonic Landau cavity at an elevated temperature (35-40°C)
  - Allows to detune a Higher Order Mode, so we can achieve a smaller detuning of the main mode, giving a better beam lifetime
- At higher temperatures, we often saw an increase and a variation in vertical beam size
  - Believe it was ions captured by the beam, and we believe this mostly has condition away. But it has taken a long time.
  - We have, however, also introduced some variation in bunch filling (partial gap)
- To circumvent the changing vertical beam size, we implemented a feedback on a skew quadrupole to control the vertical beam size
  - Can now maintain the vertical beam size to within less than 1 μm (out of 140 μm), which is more than sufficient for our users
  - Note that undulator gap changes also (earlier) affected vertical beam size

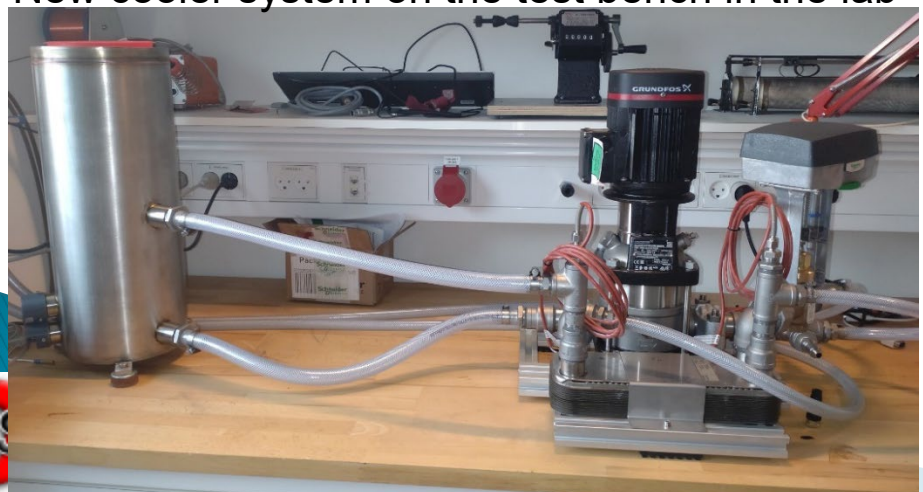




New cooler

- In January 2024 we commissioned a new home-made cooling water system for the 3rd harmonic Landau cavity
  - Increased temperature range (~20°C to 70°C)
  - Good temperature stability (<0.1°C)
    - The water in the cooler system is stable within ~±0.01°C in normal user mode (Topup)
  - Remote control
    - Easier to try new settings (automated temperature scans)
- Now operating at 43.75°C and have a beam lifetime of ~5.5 h
  - Beam lifetime before raising Landau cavity temperature was ~2.0 h
- Rather pleased with the system

New cooler system on the test bench in the lab



New cooler system at the ring

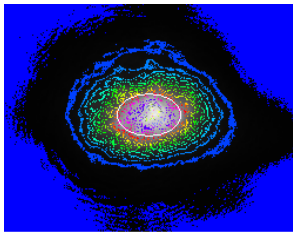
Different operation modes

- Dependent of cavity temperature we have different “modes”:

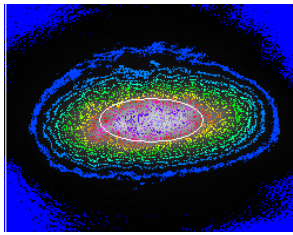
Cav. temp.	Cav. detuning	Beam lifetime	Horizontal beam size in dipoles
~20°C	~400 kHz	1.5–2.0 h	Large and noisy
38°C	~185 kHz	1.5–2.0 h	Small and stable
40°C	~185 kHz	~5 h	Large and noisy

- Note that the horizontal beam size and jitter in the dipoles is (mostly) determined by longitudinal oscillations and variations (there is dispersion in the dipoles)

38°C



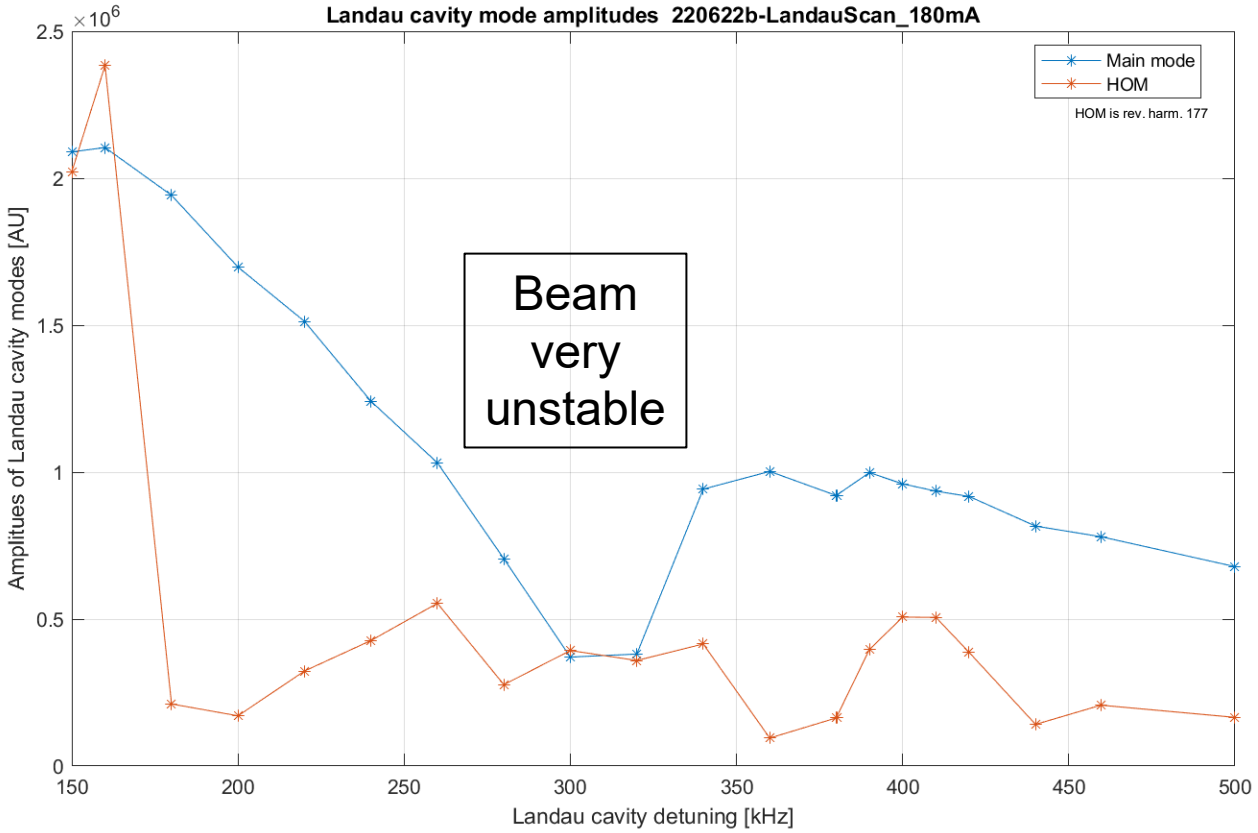
40°C



- For the “hot” cavity we have had varying trouble with stability of the vertical beam size
- The stability of the horizontal (and longitudinal) dimension is not so important for our beam lines (most have horizontal slits)
- Vertical beam size (and thereby beam lifetime) can be varied by changing skew quadrupoles (change the coupling)

Cavity detuning scan

- With the cavity at 20°C, we see a strong dip in amplitude of the fundamental around a detuning of ~300 kHz, and the beam becomes very unstable

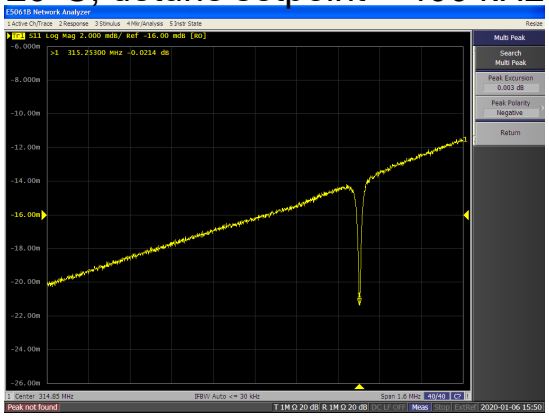


Beam has been accumulated at a cavity detuning of +400 kHz

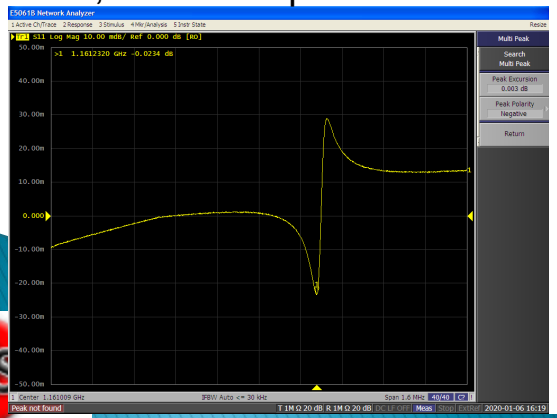
Temperature dependance

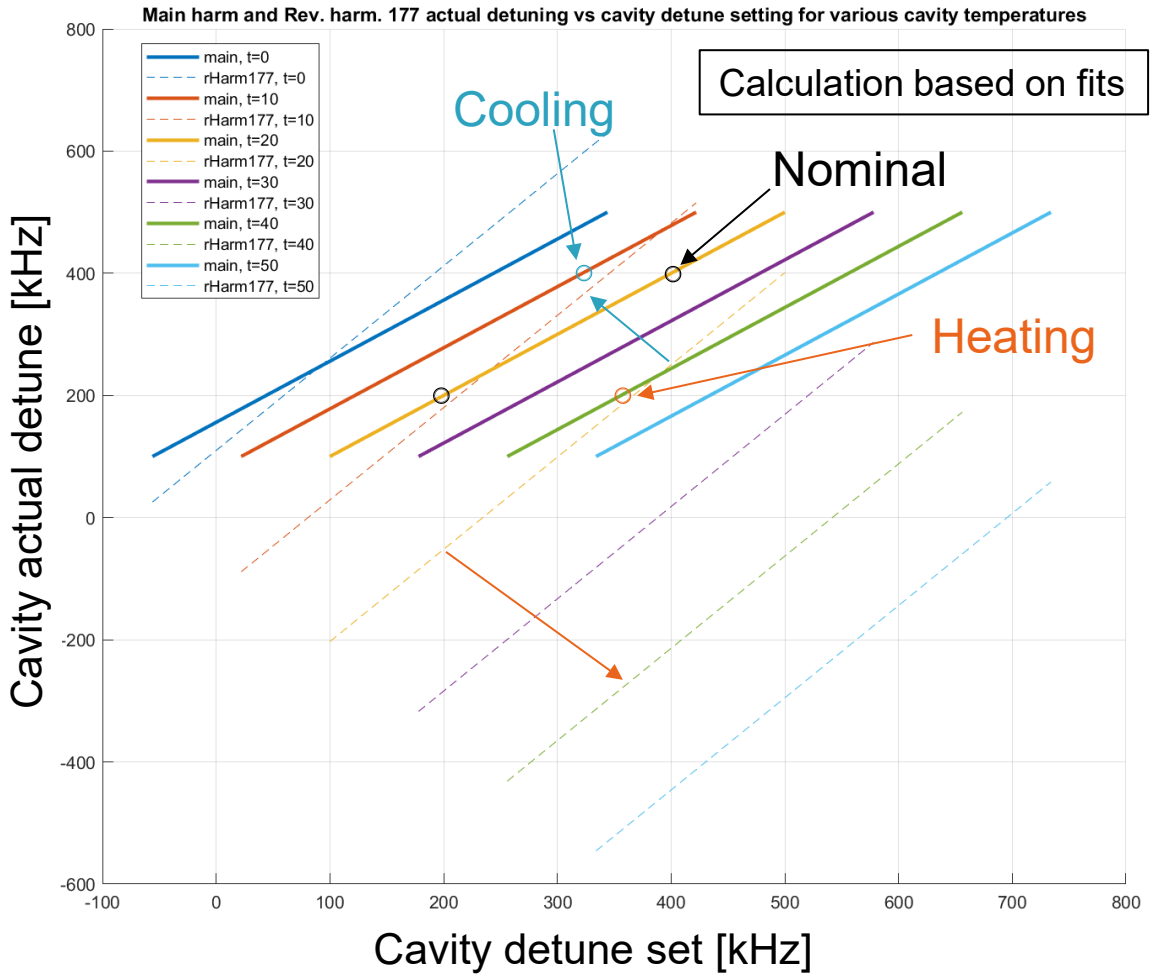
- Have recorded all resonances with a network analyzer for various cavity temperatures (baking the cavity)
- This tells us the resonance is at revolution harmonic 177

Main resonance
20°C, detune setpoint = 400 kHz



Rev. Harm. 177
20°C, detune setpoint = 400 kHz

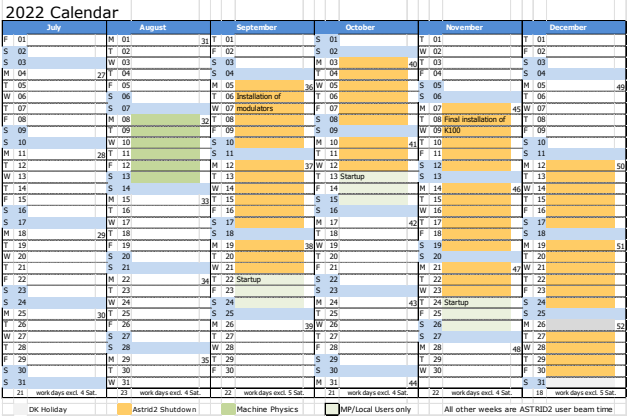




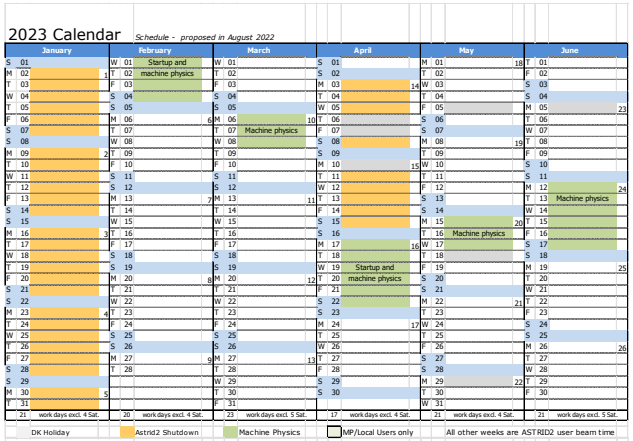
Energy Savings

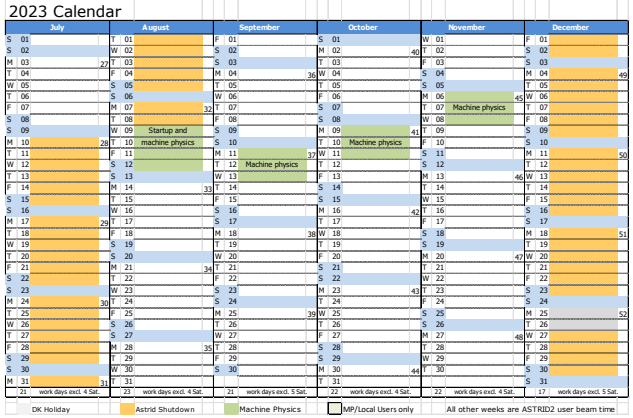
- Reduction in operation:
  - 2022 (Sep–Dec): 50%
  - 2023: 25%
  - 2024: 10%

2022

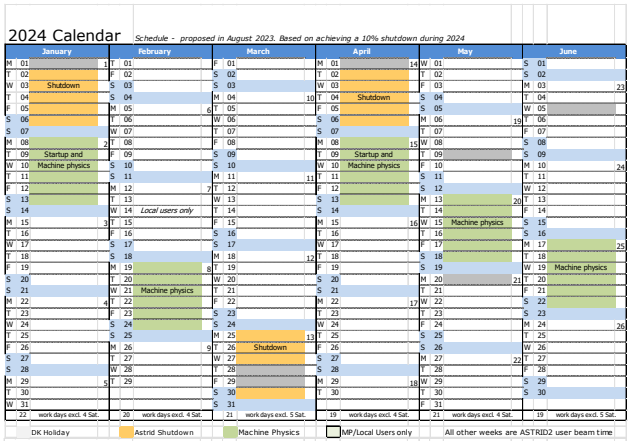


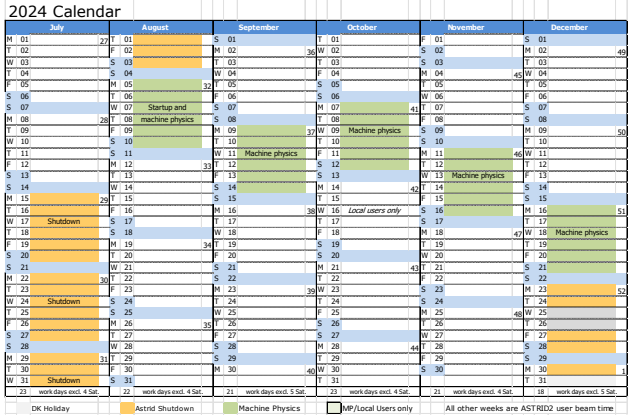
2023





2024





ASTRID2 user

ASTRID2 develop.

ASTRID2 shutdown

Automations/ErrorFix

- Since we have no dedicated operators, we have for long been automating operation
  - Until recently this has been done by the accelerator physicists
- Have now been more formalized by controls group
  - System to coordinate the recovery from several failures
- ErrorFix: Recover operation in case of failures
  - ASTRID main power supplies (AC voltage errors (brownouts))
  - Microtron vacuum valves
  - Microtron main dipole supply spike detection
    - A mains brownout sometimes “tilts” the power supply, and the magnet then needs a “wash”
  - ASTRID2 main power supplies
  - …
  -
- Note the ring staff is only
  - 2 accelerator physicists/operators
  - 1 controls person
  - 1 beamline scientist helping with ring operation (as backup)