Overview and Status of the ASTRID2 RF systems

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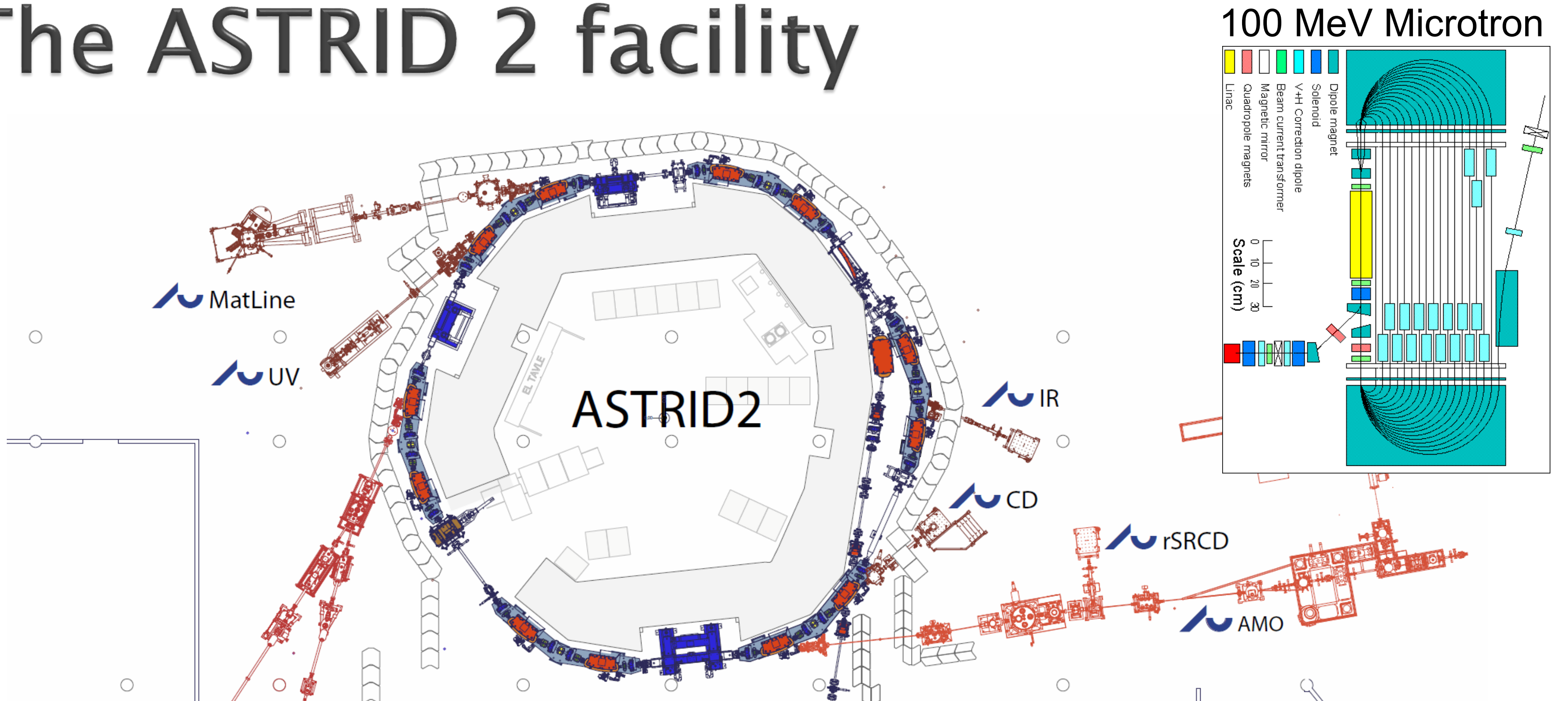
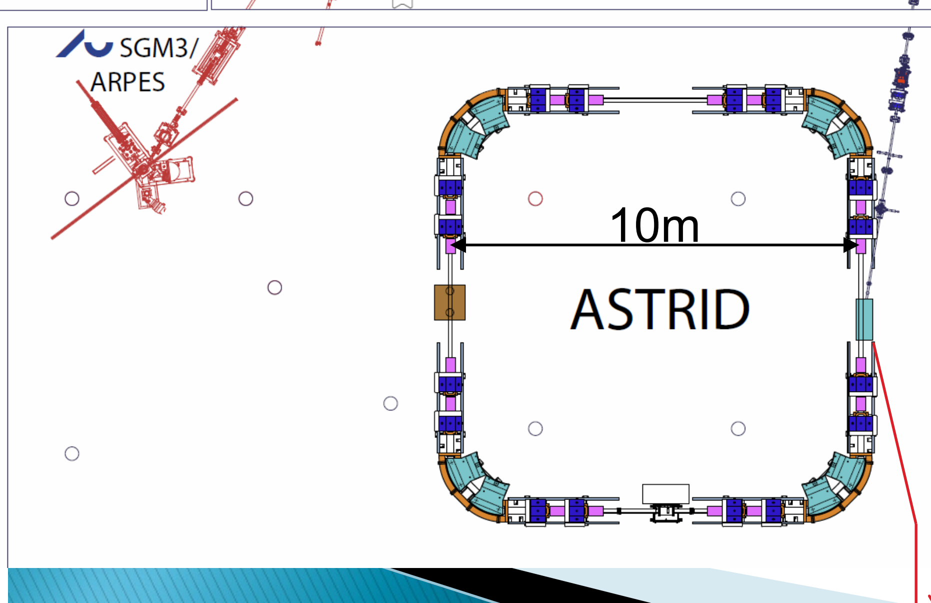
- Reminder
  - ASTRID2 facility overview
  - ASTRID2 RF systems
- New 3 GHz RF system for 100 MeV Microtron
- 3rd harmonic Landau cavity
  - Beam lifetime and beam stability

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



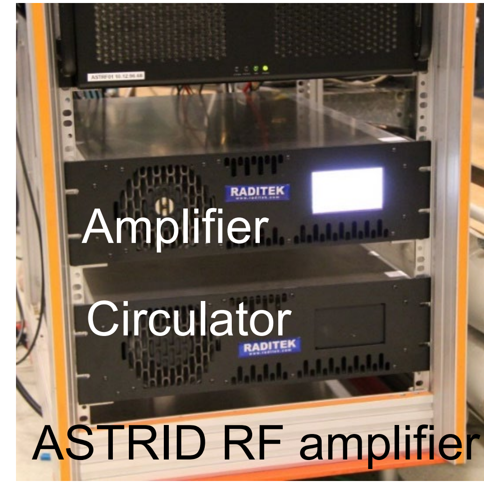


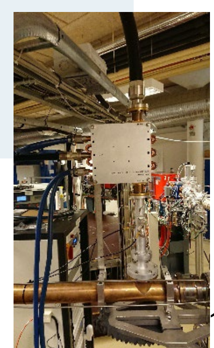
ASTRID2 main parameters

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

ASTRIDx RF parameters

Parameter	ASTRID (booster)	ASTRID2
Frequency	105 MHz	105 MHz
Harmonic	14	16
RF voltage	2 – 40 kV	120 kV
Synchro. freq.	~10 kHz	5-15 kHz
SR power	0 – ~150 W	~1.1 kW
Cavity power	~2 – ~500 W	~4 kW
RF amplifier	~1 kW SSA from Raditek (USA) (but with new amplifier pallets)	8 kW SSA from Tomco (Australia)
Circulator	1 kW avg.	Fwd: 8 kW avg. Refl: 8 kW peak 2 kW avg.



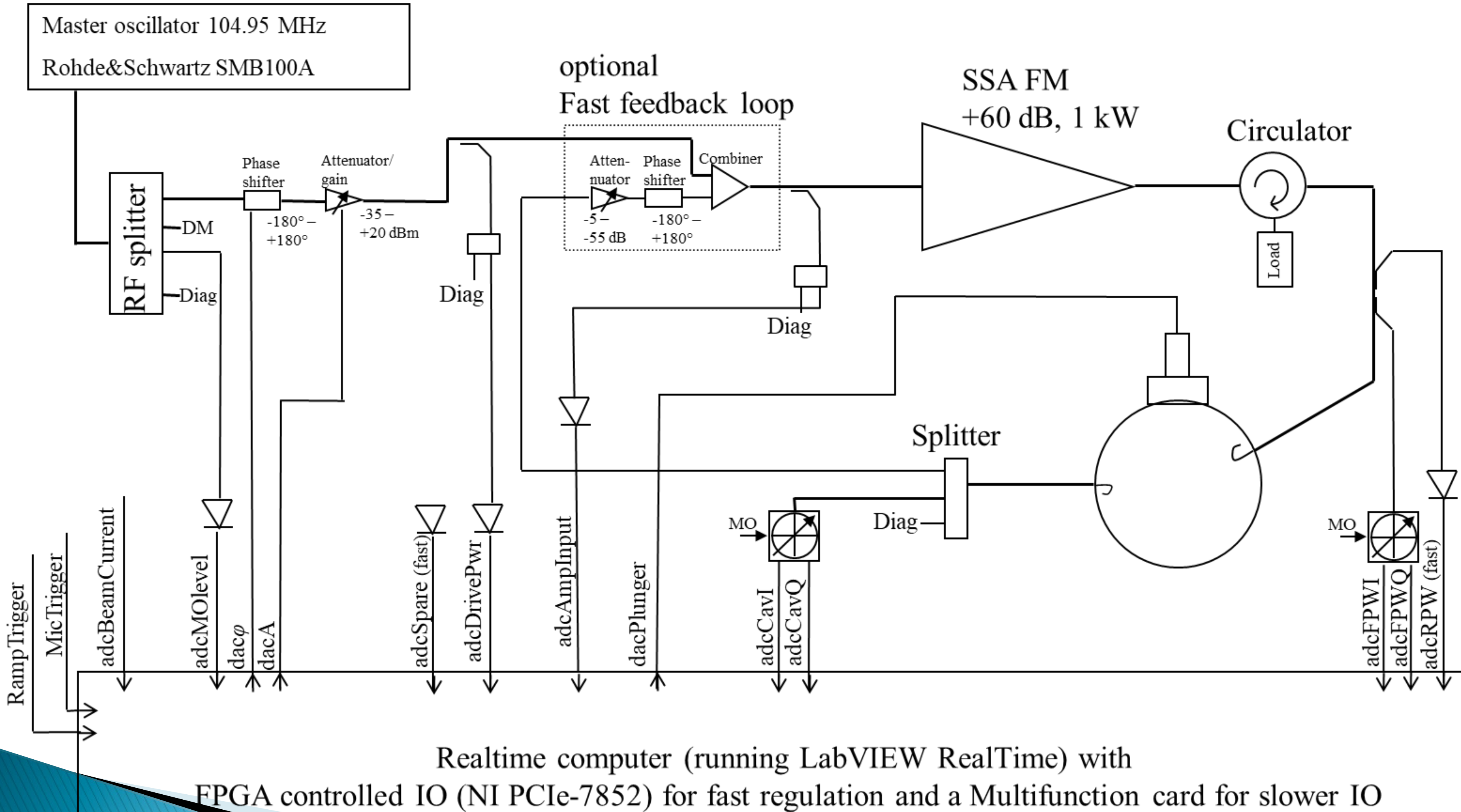


ASTRIDx LLRF

- Since January 2011: New LLRF in operation at ASTRID
  - Same system for ASTRID and ASTRID2
    (except for different tuning control)
- Digital control of baseband signals
  - A computer (PC) running LabVIEW Real-Time with FPGA equipped multifunction card to measure and control the baseband signals
    - NI PCIe-7852R:
      - Virtex 5 FPGA, 8 AI, 750 kS/s/ch, 8 AO, 1 MS/s/ch, 16 bit
  - Detection: IQ demodulators with low pass filter (100 kHz)
      - ±180° phase detection
  - Control: Amplitude and Phase (voltage controlled)
- FPGA (Amplitude Loop): No problems at all
- Real-time (Tuning Loop and Phase Control): A restart is occasional necessary (data acquisition loop stops)
  - Solid State hard disks dies occasional (~5 years)
    - Have (generally) a spare disk ready in the computers which quickly can be switched to
- Very happy with the systems

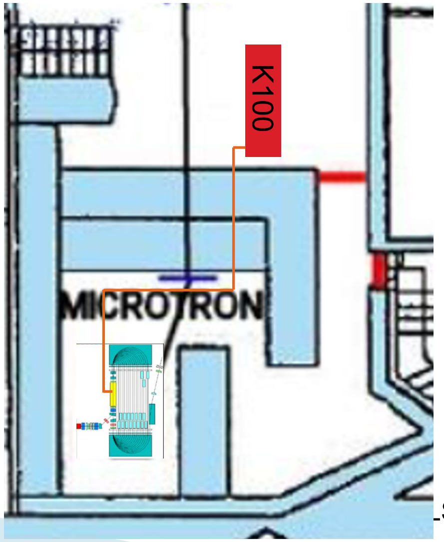
ASTRID LLRF system

IQ for detection, Amplitude and Phase for control



New Microtron modulator

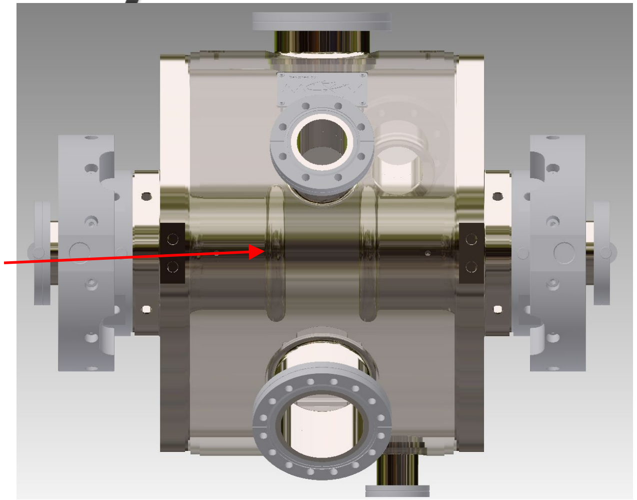
- ScandiNova K100 standard solid-state modulator with Canon E3779,B klystron
  - 3 GHz, 7.5 MW (need ~3.5 MW)
  - ~3 μs pulse length
  - <10 Hz rep. rate (typical < 2 Hz)
  - Has been placed outside Mic. bunker with a new waveguide to the Linac
- Was delivered in September 2022 and installed October-November 2022
  - Has replaced the >30 years old PFN
    - Had one PFN feeding both klystron and e-gun (two transformers in oil-tank)
    - Now have a separate modulator for the e-gun



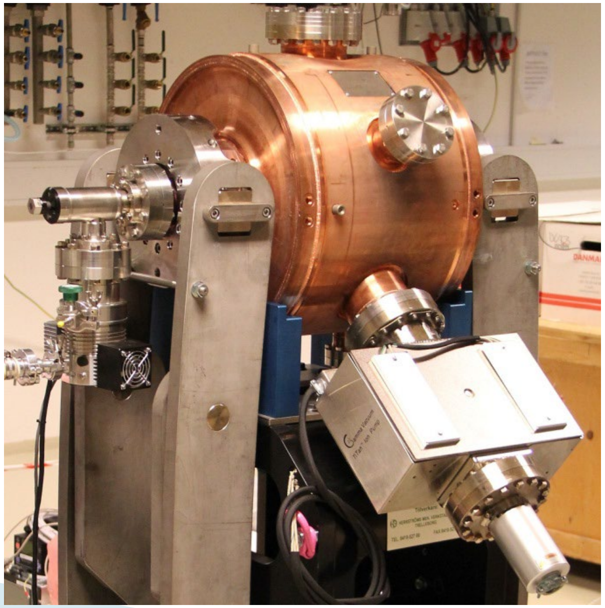
K100 unit

ASTRID2 3rd harm. cavity

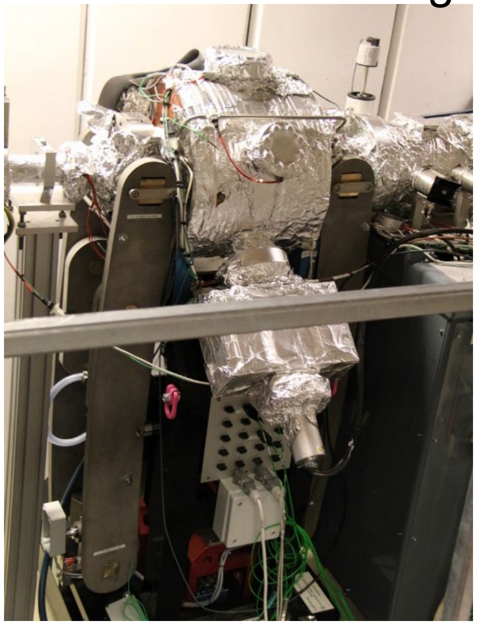
- Copy of MAX IV cavity, except 315 MHz
  - Cavity stub end diameter changed
  - Thanks to Åke and MaxLab
- Installed March 2015
  - Fixed cooling water temperature of ~20°C (at the time)



Before installation



Installed in the ring



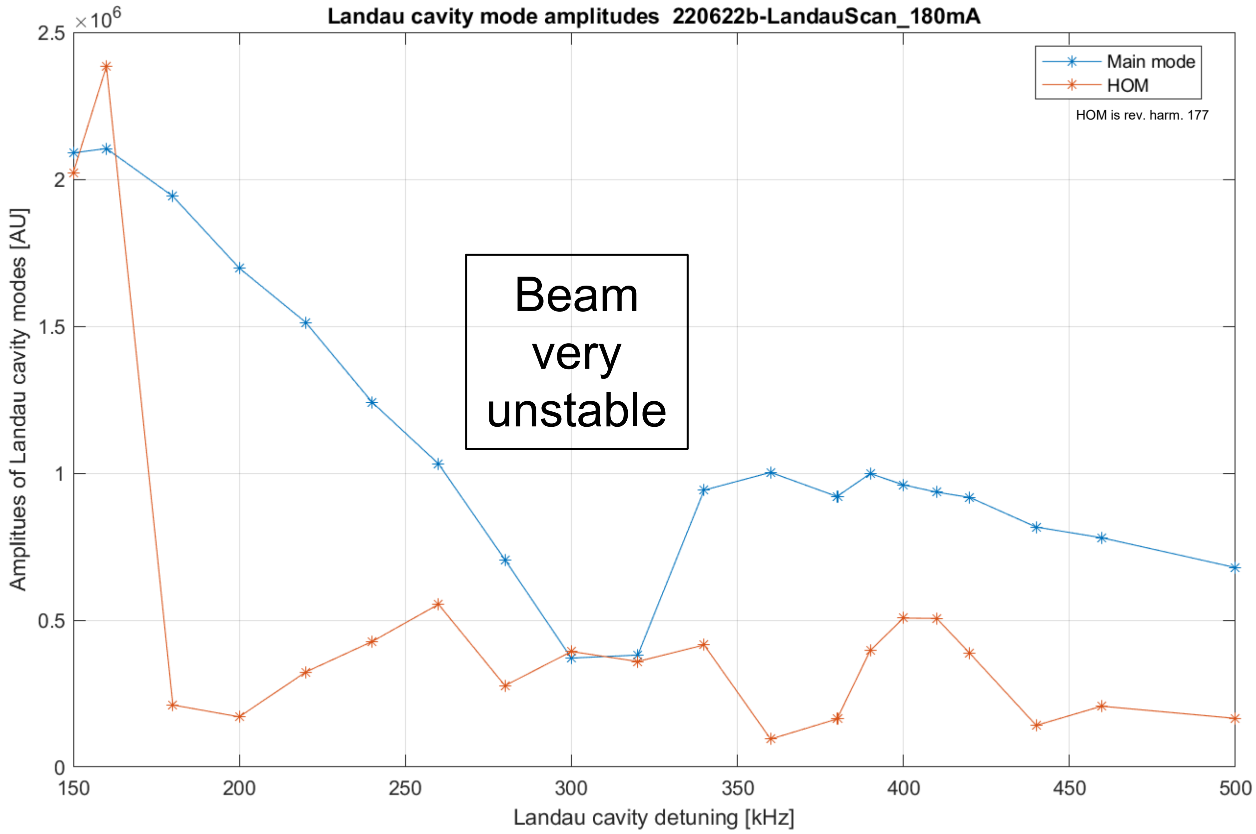
Benefits (at installation time)

- Better lifetime
  - Before: 1.4 h @ 80 mA and 1.0 h @ 120 mA
  - After: 2.0 h @ 80 mA and 1.85 h @ 120 mA
- More stable beam
  - Moved instabilities to higher frequencies
  - SR diagnostic camera (in control room) showed a more stable beam (and happy users)
- Good tuning range is limited
  - Was for long using a detuning of around +400 kHz

    (possible tuning range is ±500 kHz).
    - "Theoretical optimum" (flat potential) should be +160 kHz
  - Large beam instabilies at a detuning of ~300 kHz

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

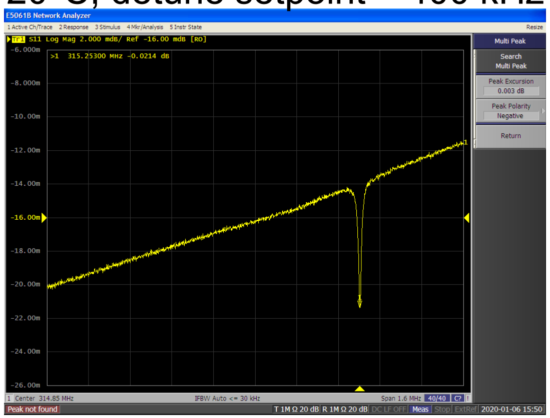


Beam has been accumulated at a cavity detuning of +400 kHz

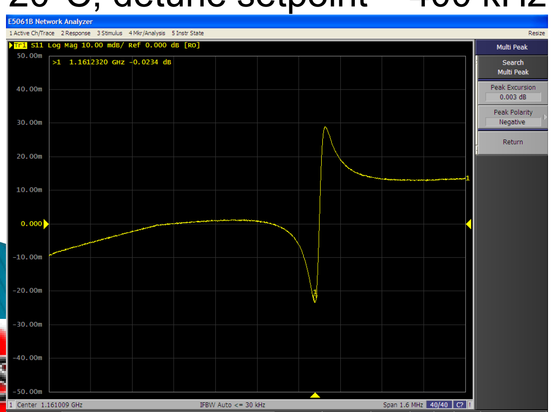
Temperature dependance

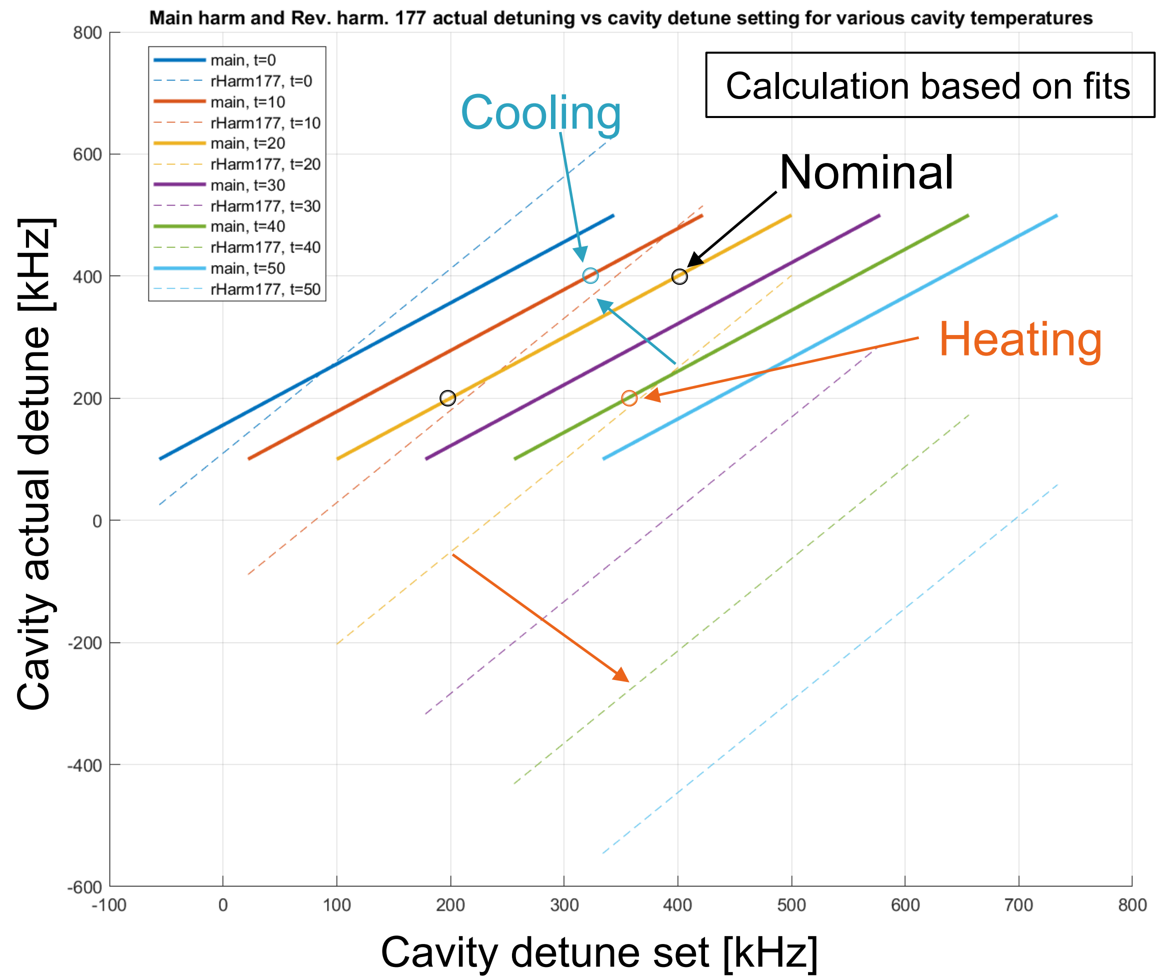
- Have recorded all resonances with a network analyzer for various cavity temperatures (baking the cavity)
- This tells us the resonance is at revolution harmonic 177

Main resonance
20°C, detune setpoint = 400 kHz



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





Increase cavity temperature

- In August 2022, a small (borrowed) cooler/heater (10–40°C) was installed for our 3rd harm. cavity
  - No remote control, temperature stability is ~0.3°C
- By raising the 3rd harm. cavity temperature (above ~30°C) we can operate stable at smaller main resonance detuning ("jumping" below the RevHarm177 resonance)
  - Beam lifetime and/or beam stability is better
    - But keeping good beam stability is not always easy
  - The detuning range with stable beam is (still) rather narrow
  - We often experience an increase in vertical beam size and/or increased jitter in vertical beam size
    - This increase the measurement noise at some of the beamlines
  - Settings depend strongly on cavity temperature, making it difficult to achieve stable beam in Decay mode (where beam induced voltage change)
  - Believe this vertical instability (partly) is caused (or influenced) by ions captured by the beam
    - Should be able to condition this away, and we do see improvements (but slowly)
  - We often see a memory effect
    - Change a parameter to a new value and then back again, does often not restore beam parameters (beam size and beam lifetime)

Different operation modes

- Dependent of cavity temperature we have different modes:

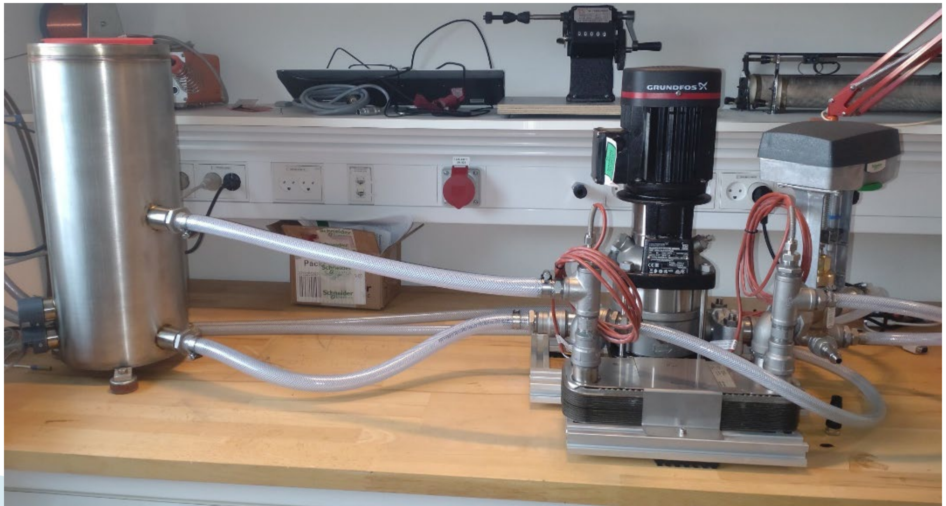
Cav. temp.	Cav. detuning	Beam lifetime	Horizontal beam size at dipoles
~20°C	~400 kHz	1.5-2.0 h	Large and noisy
40°C	~185 kHz	~5 h	Large and noisy
38°C	~185 kHz	1.5-2.0 h	Small and stable

  - 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)

- 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

Future developments

- We expect vertical stability to improve with time due to (vacuum) conditioning
  - Better vacuum => less ions captured by the beam
- We are presently building a new cooling water system for the 3rd harmonic Landau cavity
  - Better temperature stability (<0.1°C)
  - Remote control
    - Easier to try new settings (temperature scans)
    - Can change setpoint for instance as beam current changes
  - Expect (hope) to commission the system in December
- Build a (vertical) Bunch-by-Bunch feedback system ??
  - This will be a large project for us



New cooler system on the test bench in the lab

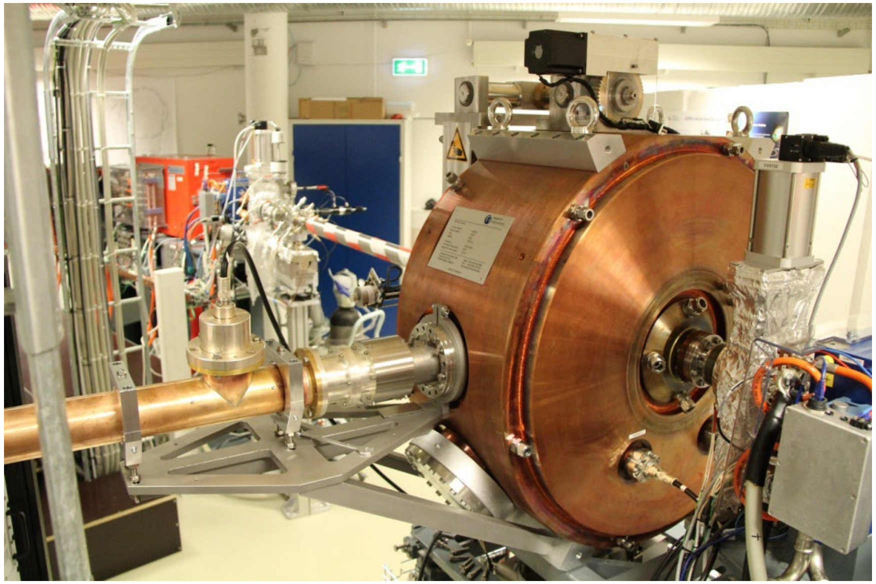
Thank you for your attention

Extra (spare) slides

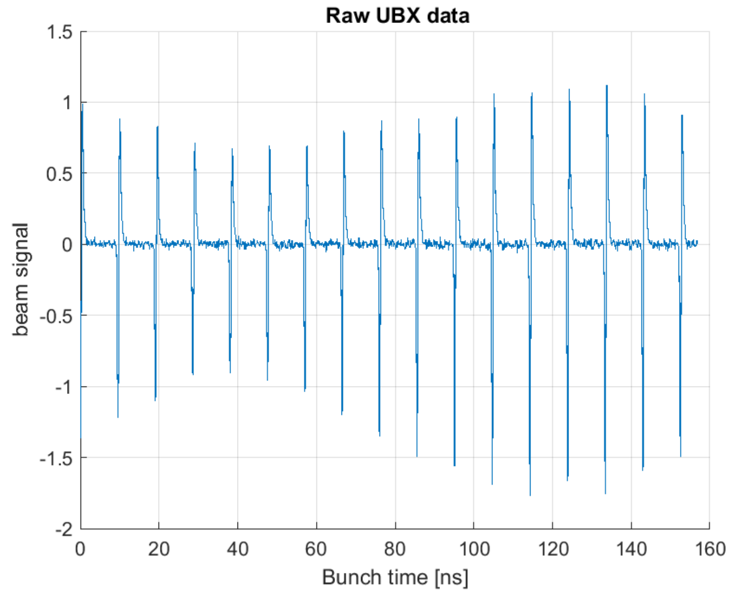
ASTRID2 Cavity

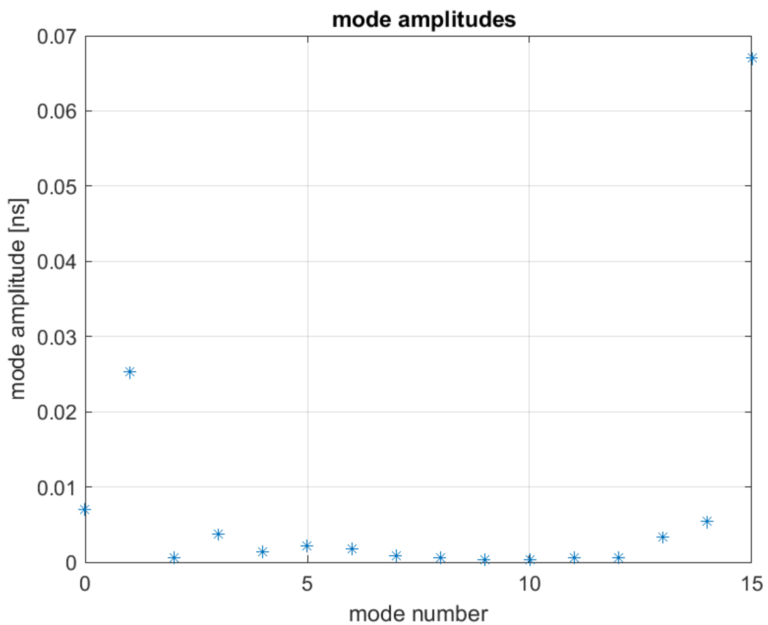
- Basically, the same as MAX IV cavities
  - Built by RI (RF design by MaxLab)
- Has been conditioned to ~150 kV (~5 kW)
  - No problems seen
- Usual operate at 120 kV (~3.5 kW)

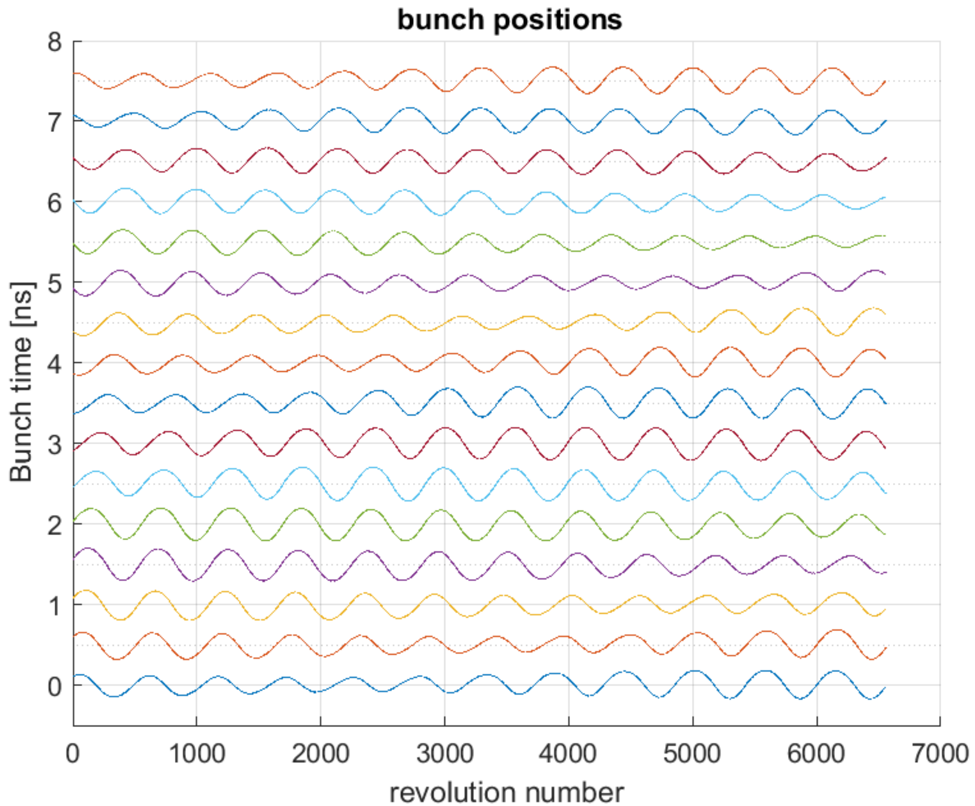
- Have a 315 MHz Landau cavity (also from RI and based on MaxLab design).
  - Installed March 2015



LCBI, 180 mA, Landau cav. at 20°C, detune 400 kHz

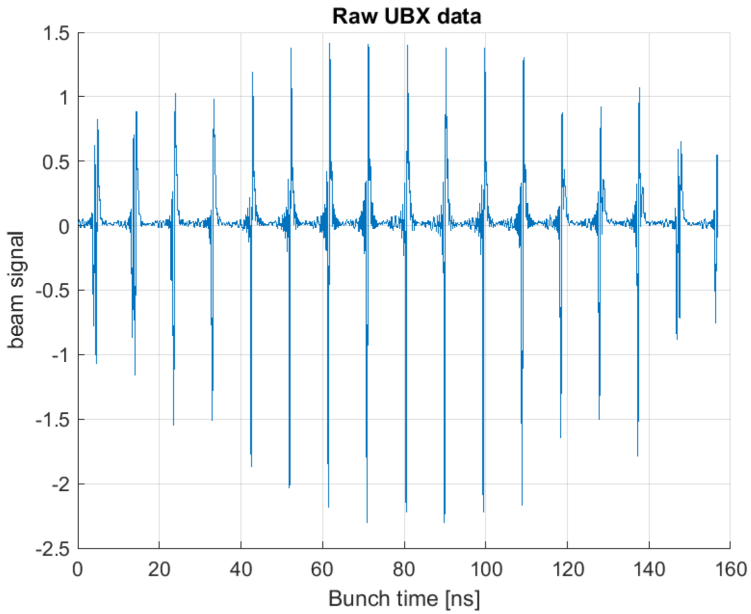


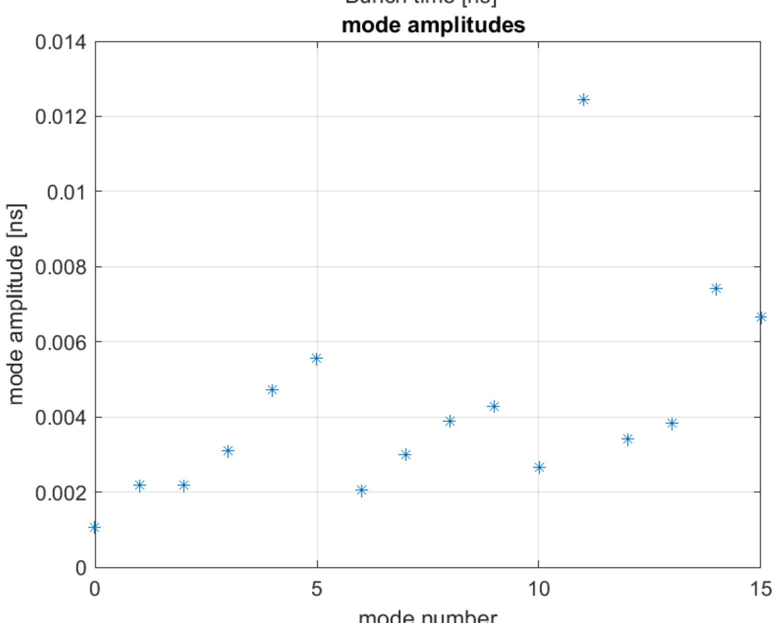


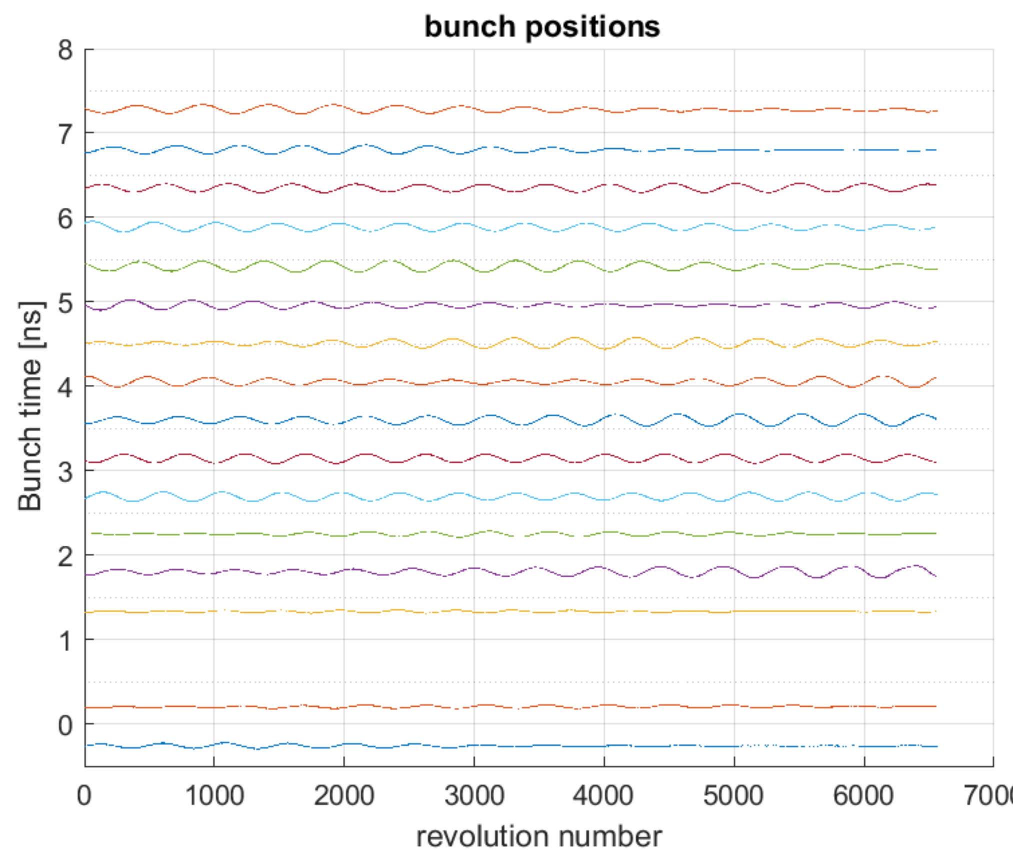


220624c-BeamAccumAtLandau400kHz

LCBI, 180 mA, Landau cav. at 30°C, detune set 320 kHz (actual 240 kHz)







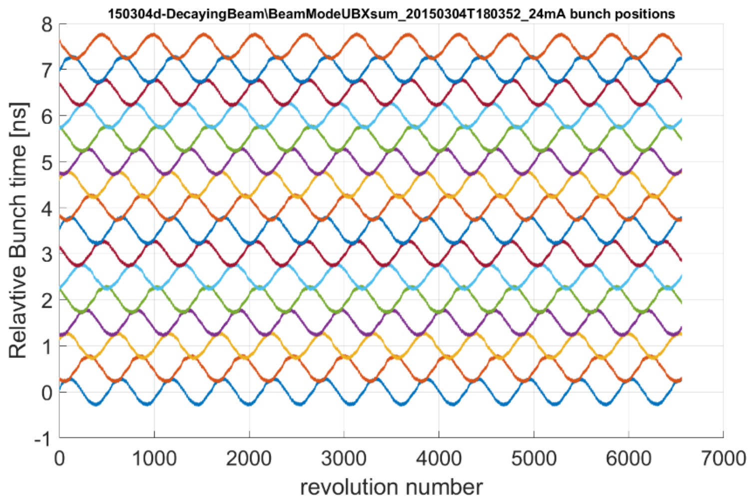
220925d-BeamAccumAtLandau320kHz30degC

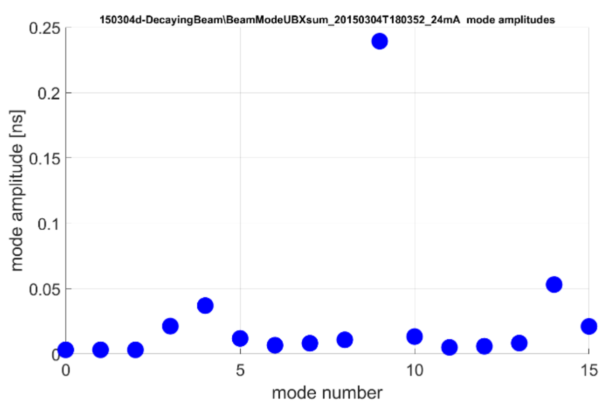
LCBI

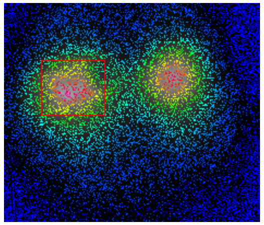
- After installation of 3rd cavity Longitudinal Coupled Bunch Instability (LCBI) mode spectra changed

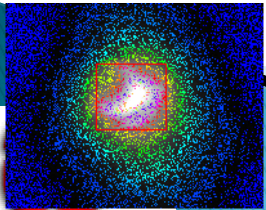
Relative bunch time [ns]
measured with fast oscilloscope

Before Landau cavity (24 mA)
Dominant mode: 9

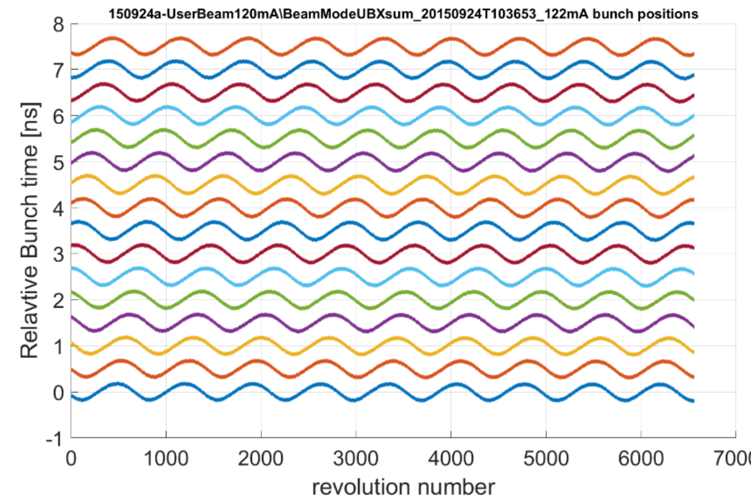


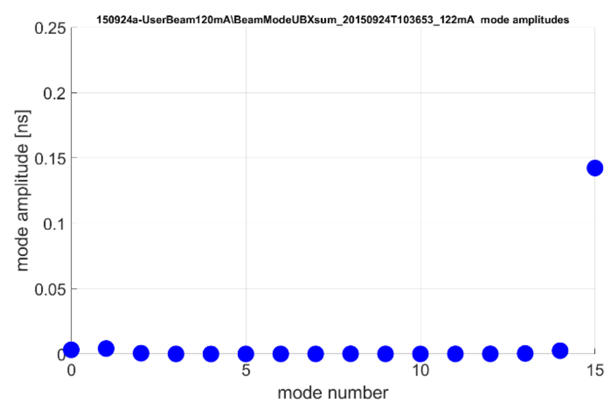


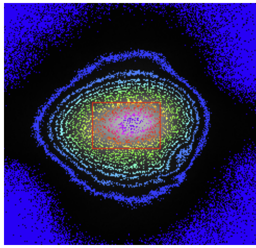




With Landau cavity (120 mA)
Dominant mode: 15

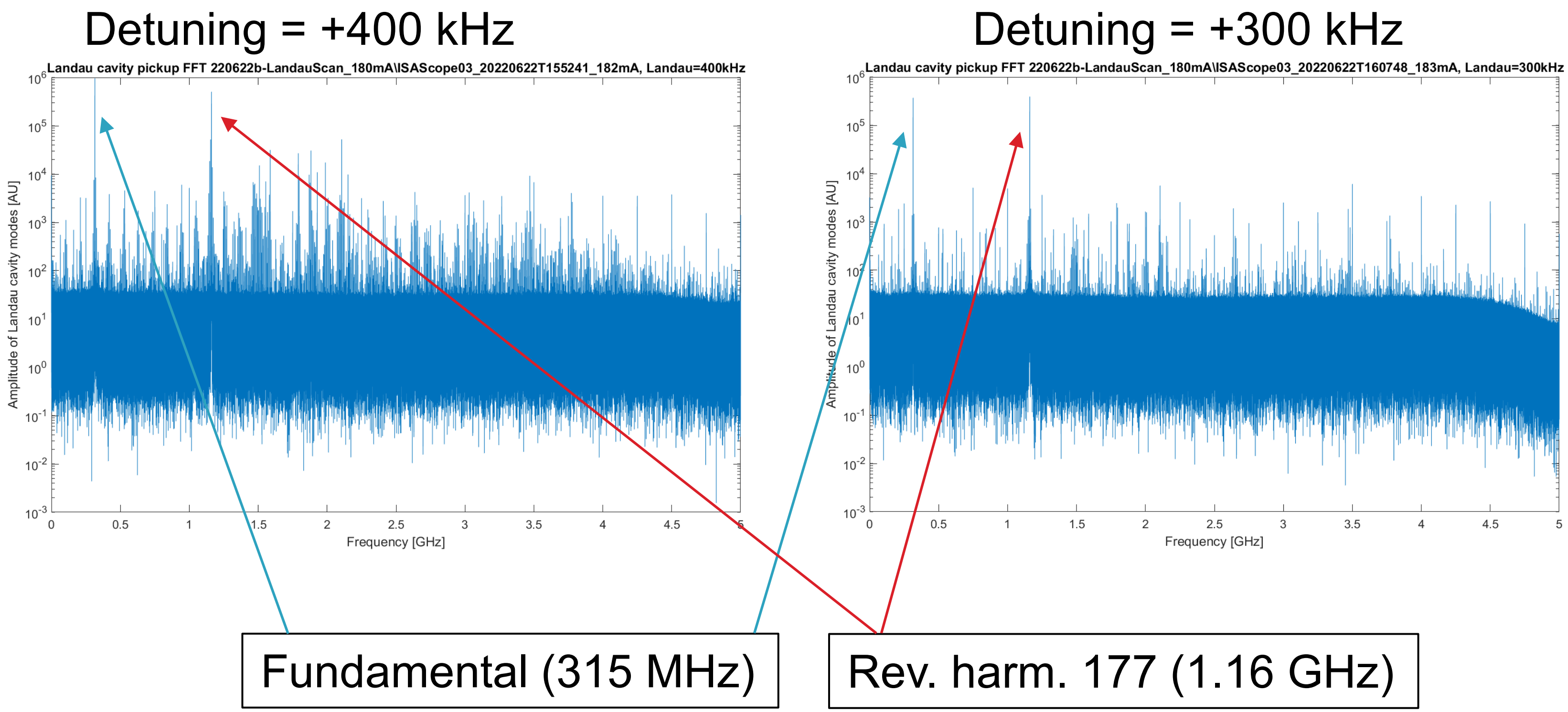






Strong HOM at rev. harm. 177

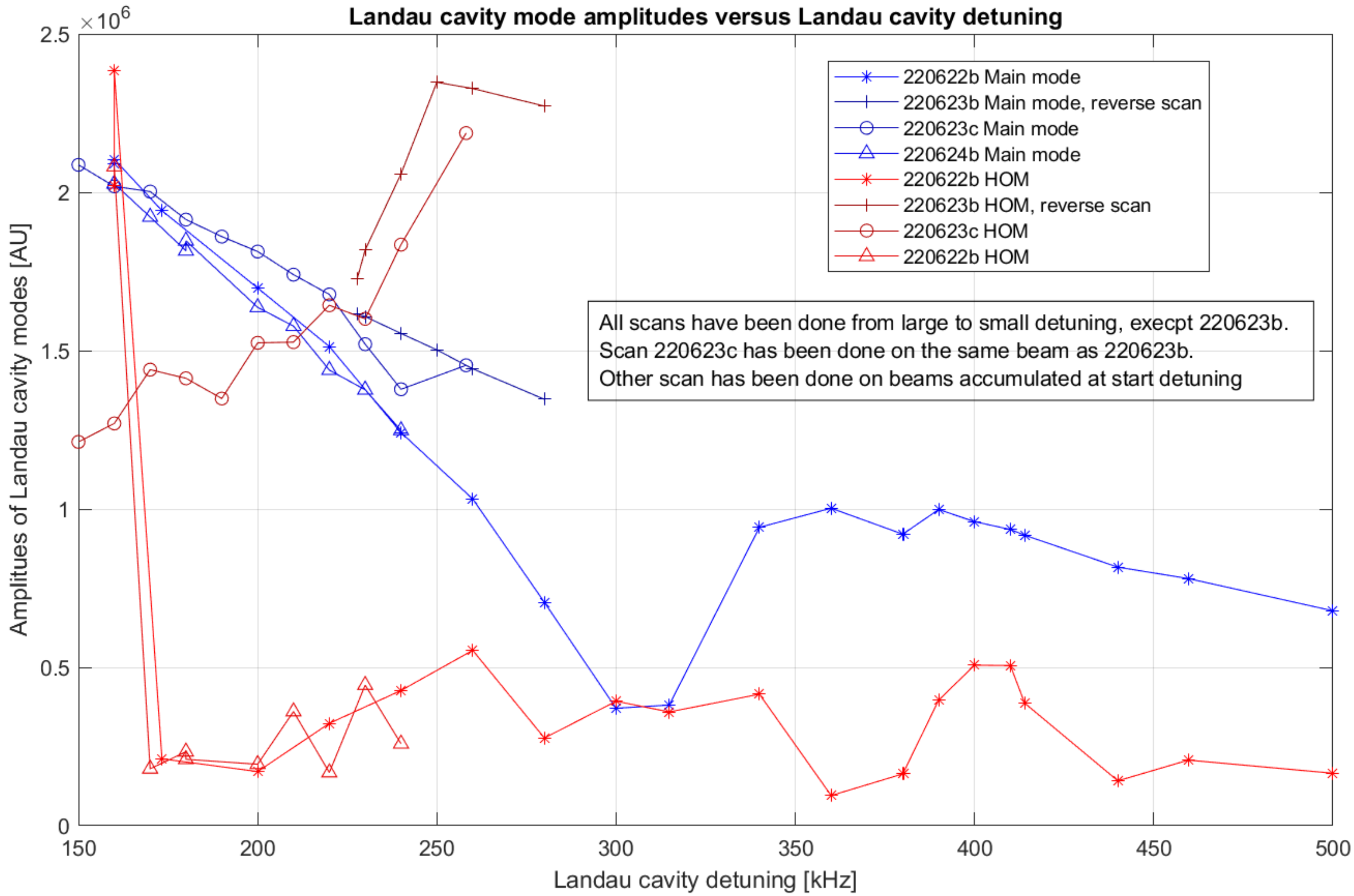
- Direct sampling of Landau cavity pickup signal with (fast) scope and then FFT



Beam has been accumulated at a cavity detuning of +400 kHz and a cavity temperature of ~20°C

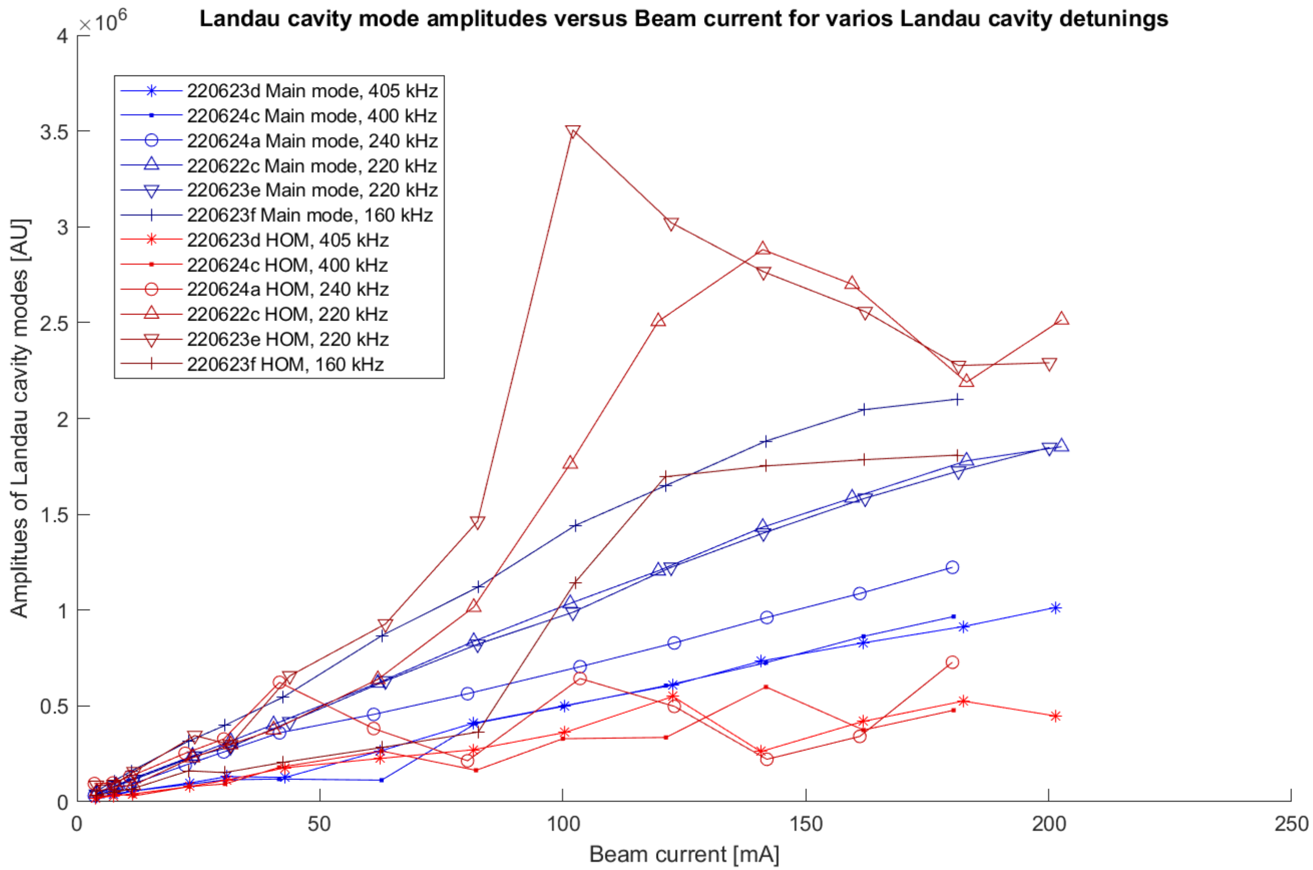
Accumulate at various detuning's

- Cavity behavior depends on “history”



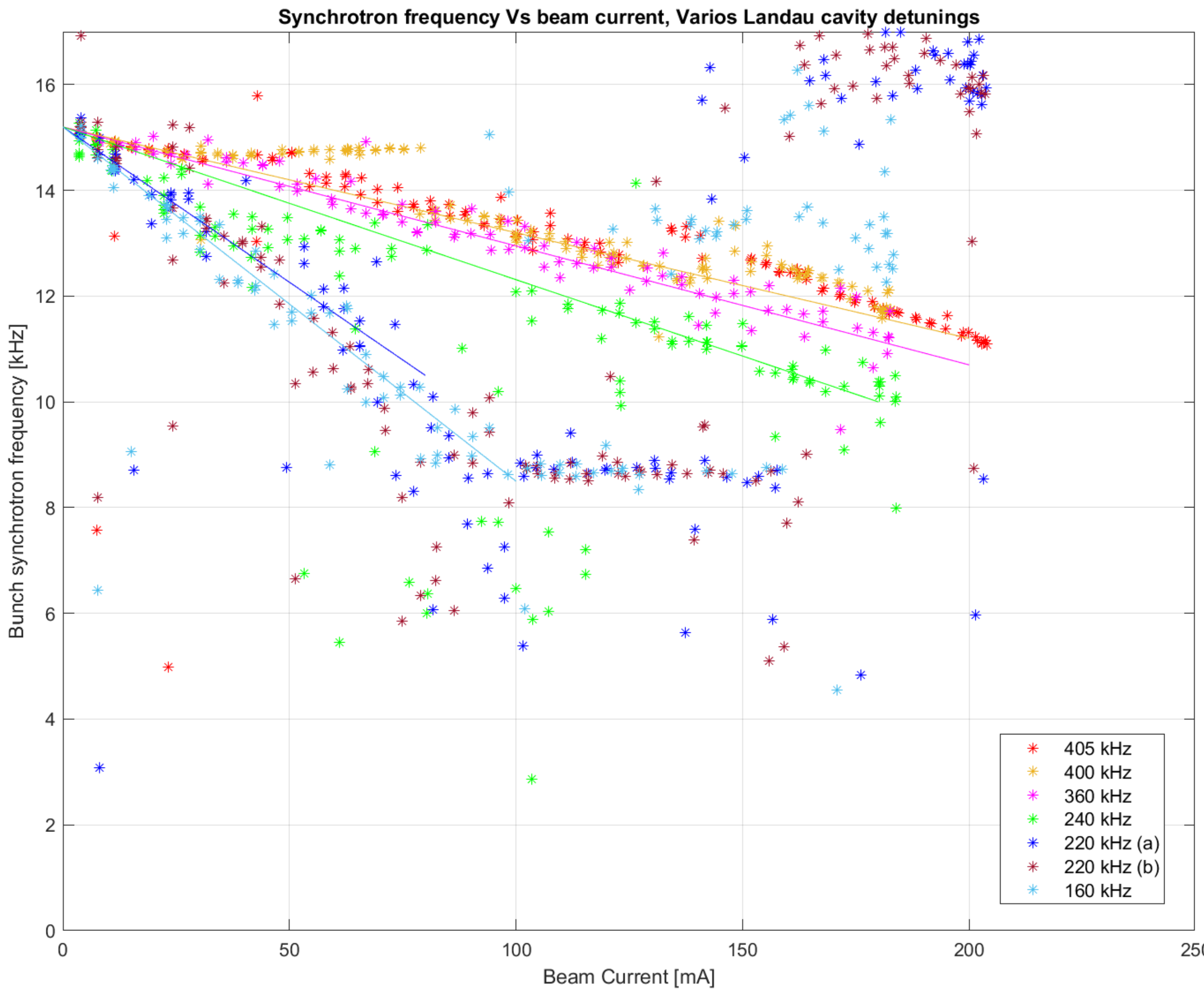
Beam accumulation

- Cavity amplitudes as function of beam current
  - Amplitude of fundamental (blue) increases as detuning is lowered
  - But amplitude of RevHarm177 (red) are more irregular, but with a tendency that smaller detuning give much more amplitude of harmonic



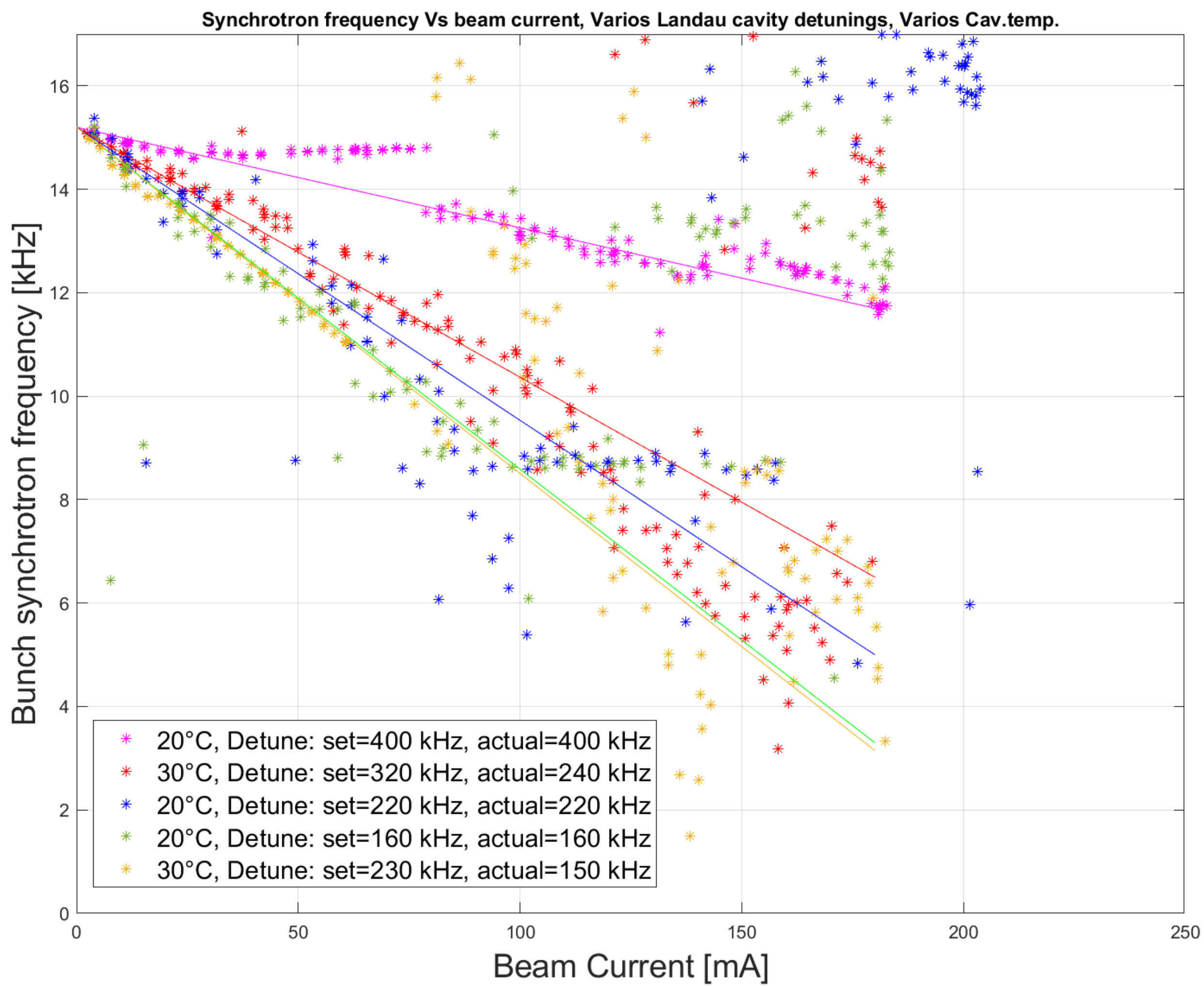
Synchrotron frequency

- Synchrotron frequency gives a measure of total voltage seen by the beam (or rather slope around synchronous point)



Sync. freq. vary cav. temperature

- Synchrotron frequency measurements are consistent for various cavity temperatures



New ASTRID RF power amp.

- 1 kW Solid State from Raditek Inc.
  - Replaces the ~25 year old 8 kW tetrode amplifier
- Saves electrical power
  - Idle power consumption:
    - Tetrode: ~7 kW
    - Raditek: ~150 W

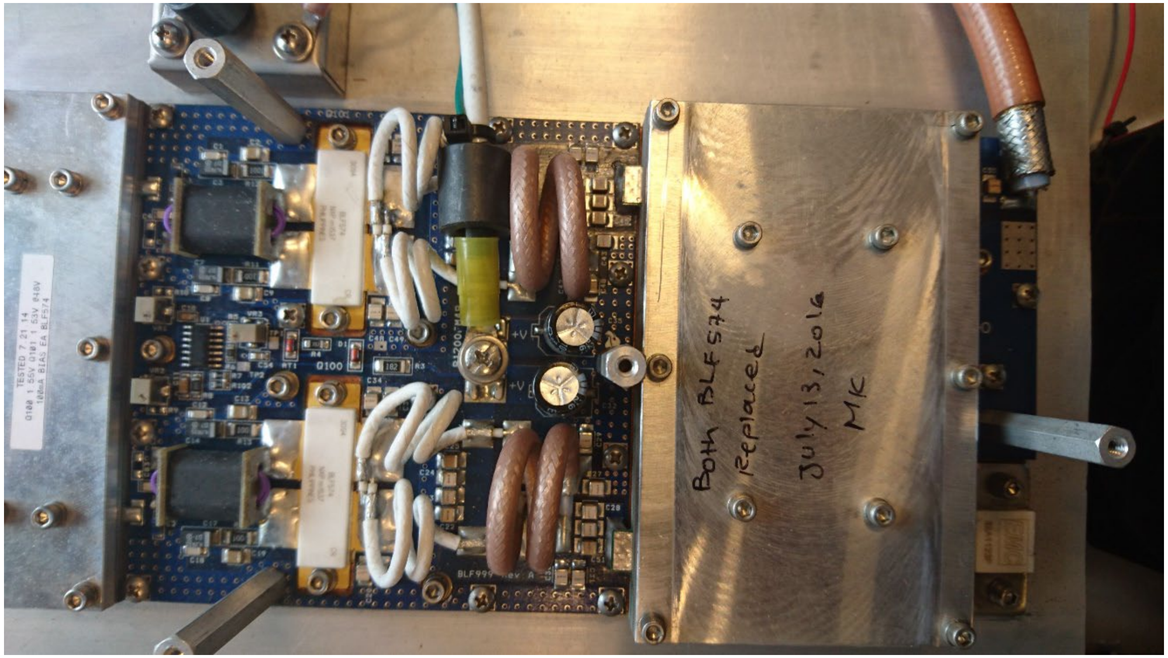
Amplifier

Circulator

Old amplifier

New ASTRID RF power amp.

- 1 kW power module:



- Commercial FM module

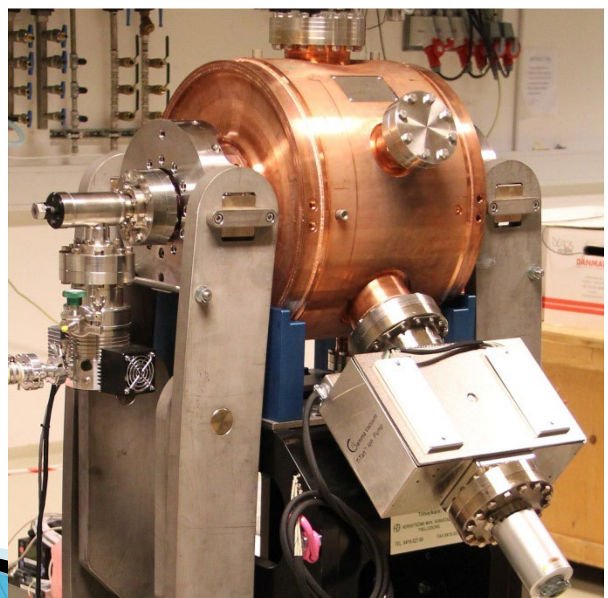
Amplifier

Circulator

ASTRID2 Layout

Landau cavity

- Installed March 2015
- Prebaked (130°C)
- Preconditioned with 100 W (~20 kV)
  - Multipactoring around 10 W (200 V)



Installed in the ring