The ALS RF systems, upgrades and ALS-U plans

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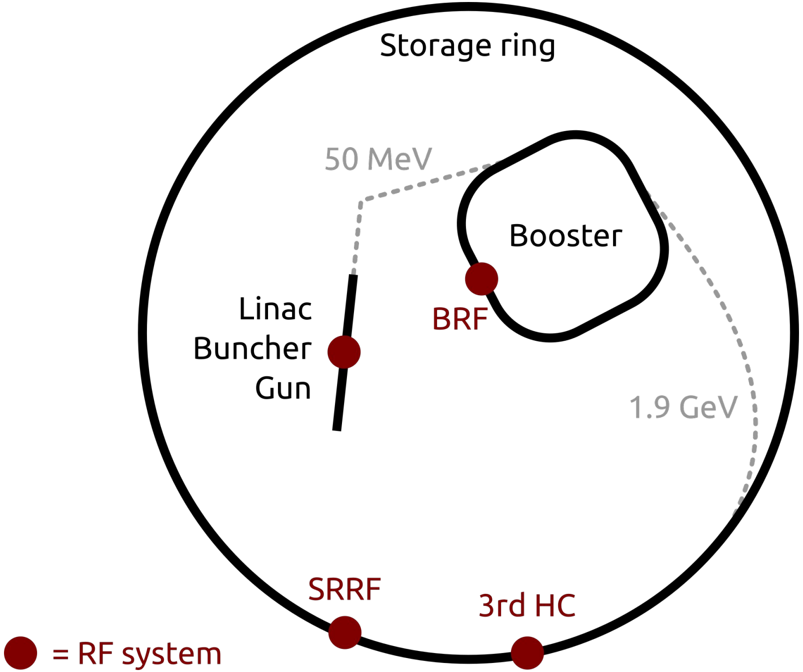
Outline Structure of this talk

- RF systems in the Advanced Light Source **(ALS)**

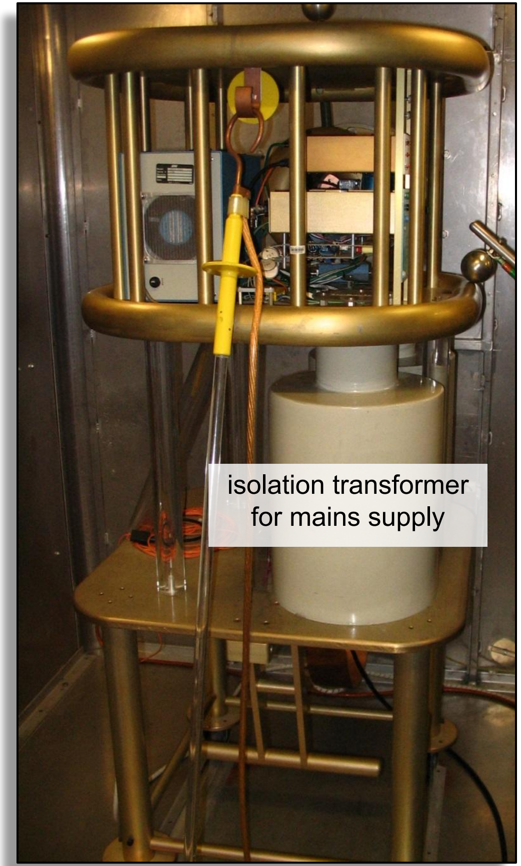
- 2017 - 2018 **work** on the ALS storage ring RF

- Plans for the **ALS-U** RF

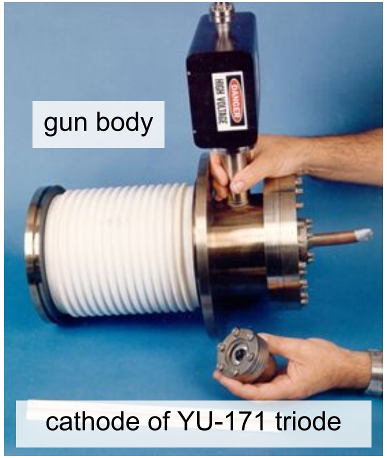
ALS-RF Overview

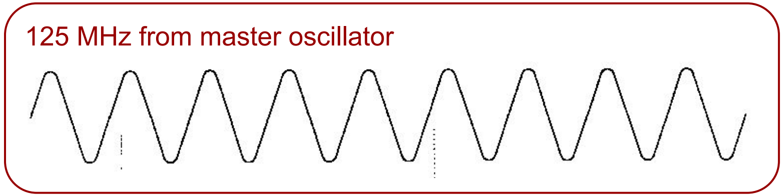


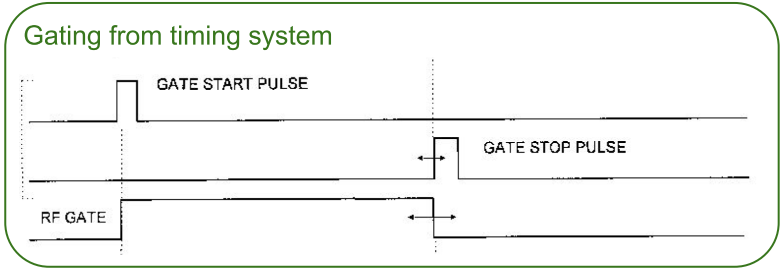
ALS-RF E-Gun

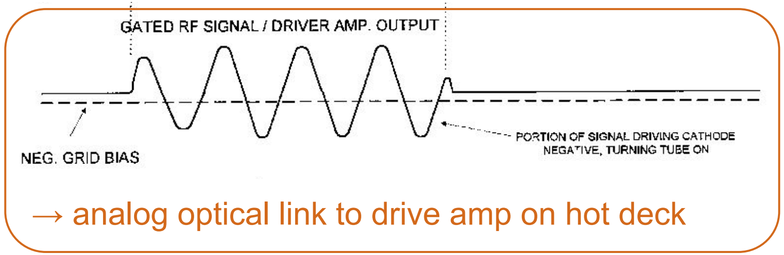


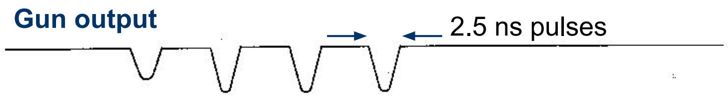
hot deck @ -120 kV
- Heater PS
- Bias PS
- **25 W RF drive amp.** *(ENI 325)*
- Several optical links for control, monitor and RF



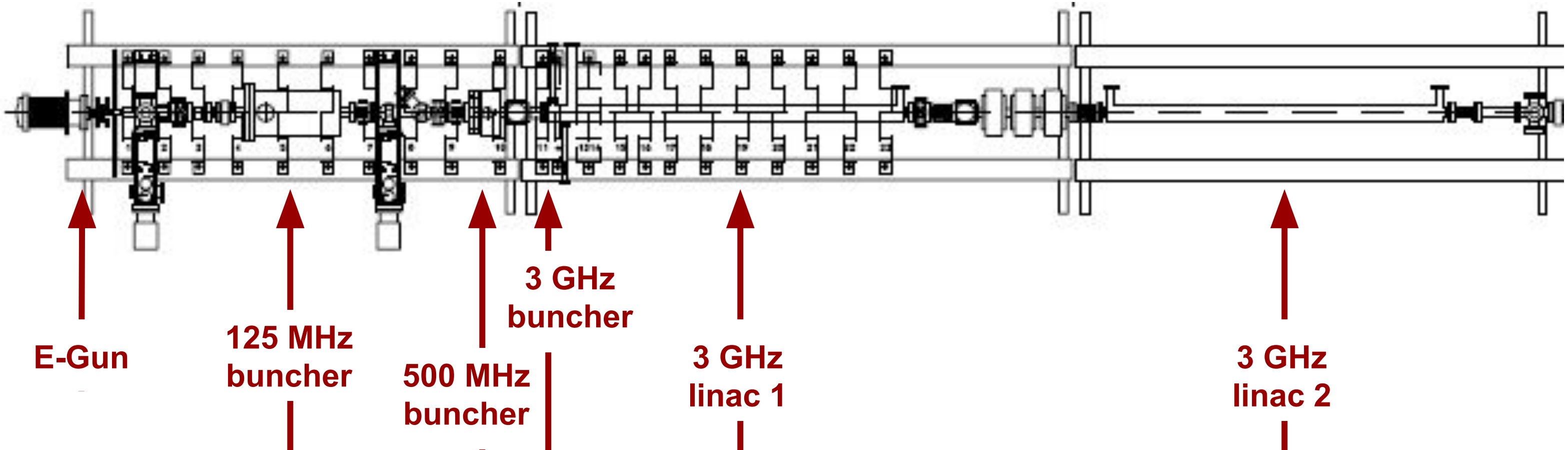






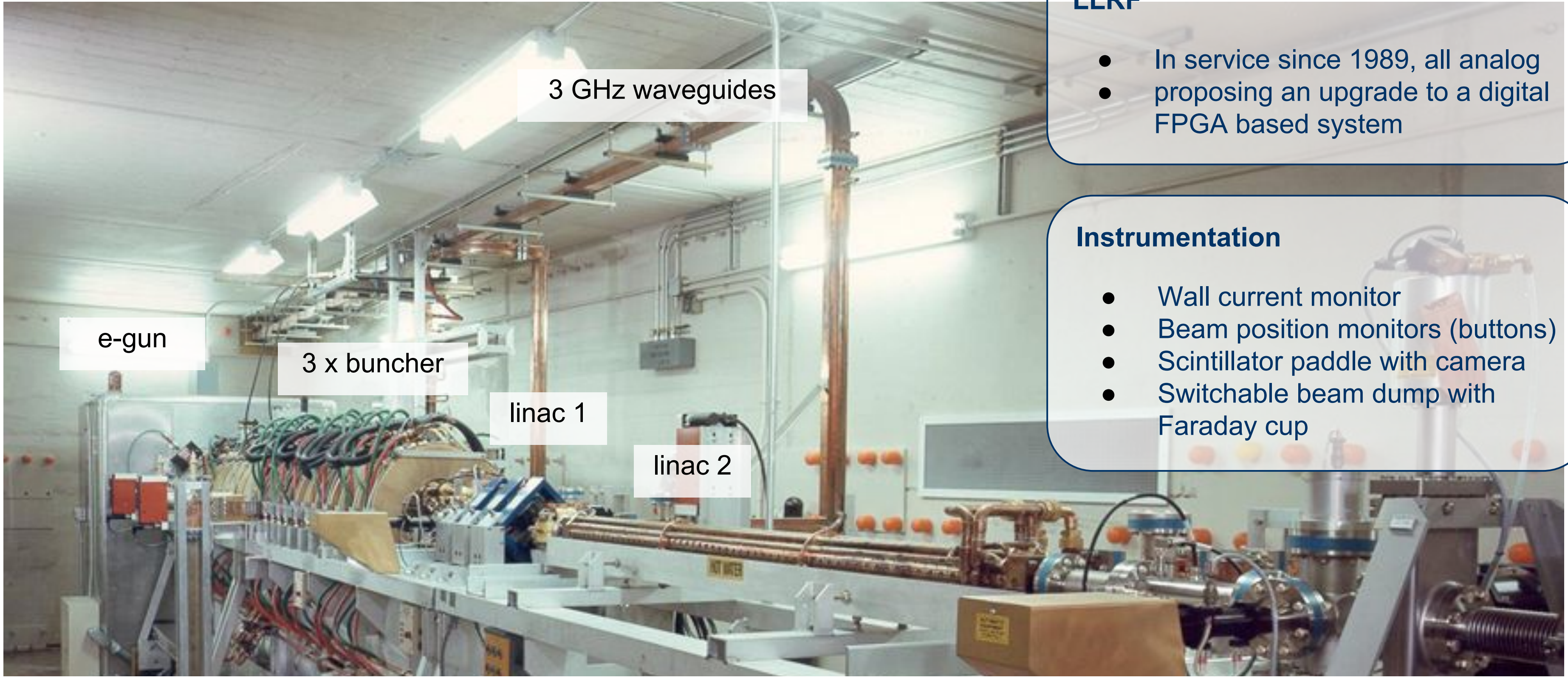


ALS-RF E-Gun & Linac



RF power [kW]		24		18		4000		16000		16000	
Bunch length [ns]	2.50		0.80		0.20		0.02				0.01
Energy [MeV]	0.12								25		50

E-Gun & Linac



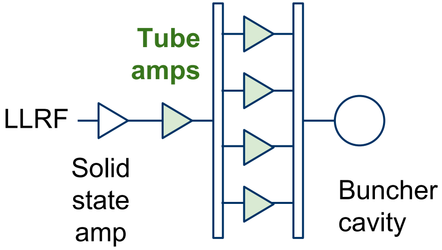
LLRF

- In service since 1989, all analog
- proposing an upgrade to a digital FPGA based system

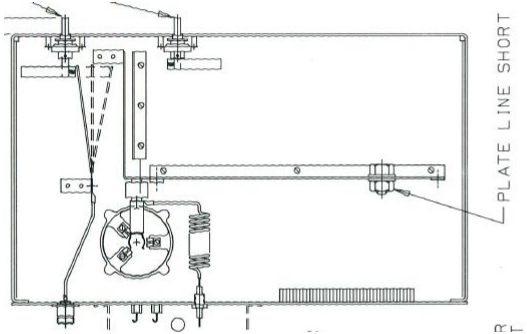
Instrumentation

- Wall current monitor
- Beam position monitors (buttons)
- Scintillator paddle with camera
- Switchable beam dump with Faraday cup

ALS-RF 125 MHz & 500 MHz buncher RF




Eimac CV-2222
125 MHz cavity amplifier



125MHz: 5 x Eimac CV-2222

- P_{out} ~24 kW for ~30 us

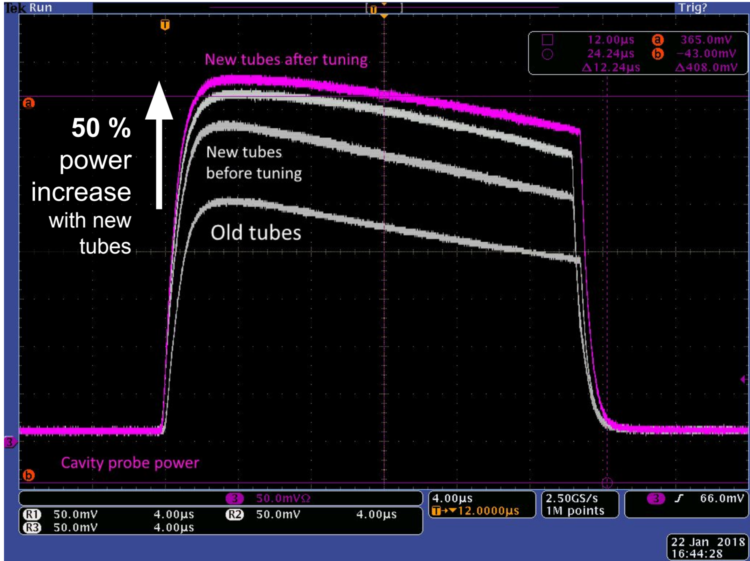
500MHz: 5 x Eimac CV-2404

- P_{out} ~18 kW for ~30 us

2018 Maintenance

- All 10 tubes replaced in 2018
- Sockets cleaned of dust
- All amplifier cavities re-aligned
- 50 % increase in gain & output power


Eimac 3CPX800A7
Lifetime 10-12 years



ALS-RF 3 GHz buncher & linac RF

2 x Thales TV-2002 Klystrons

- 24 MW, 2us, 1 Hz, 50 W avg.
- In service: 1989

Klystron lifetimes [years]

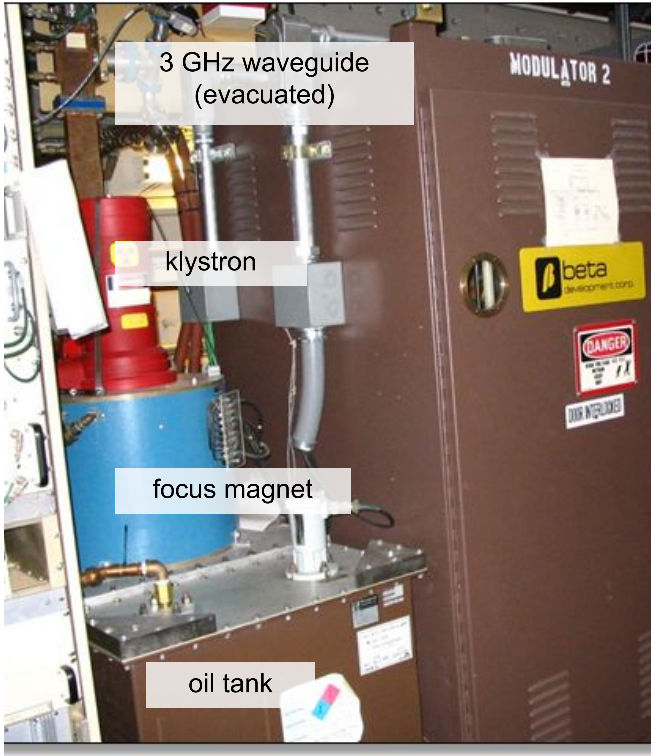
linac 1:		17,	10,	2+
linac 2:	9,	14,	2,	4+

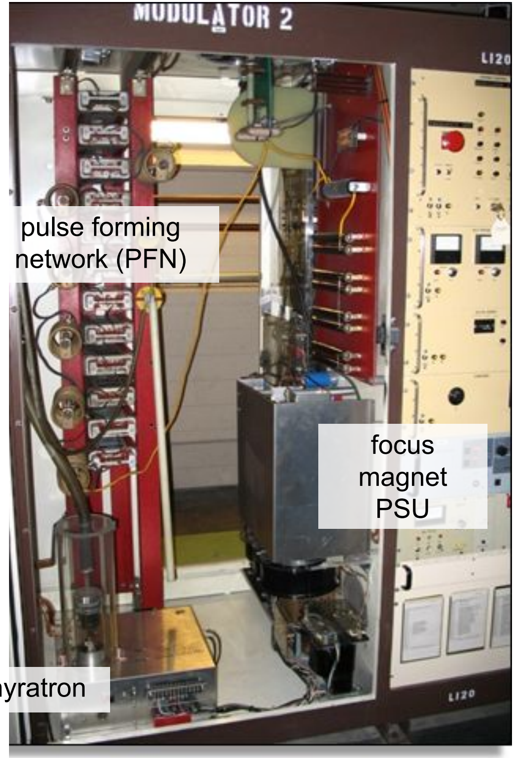
Klystron Failures

- Internal parasitic emission
- Internal arcing
- Low / drifting output power
- 2013: collector water leak, fouled oil, shorted `buck coil` focusing magnet

Modulator Failures

- Thyratron CX-1666
- HV Caps
- HVPS & Cable





Replacement of PFN type modulator by a solid state type funded for FY18/19

Linac RF HV breakdowns

2018
frequent (every few days) modulator trips

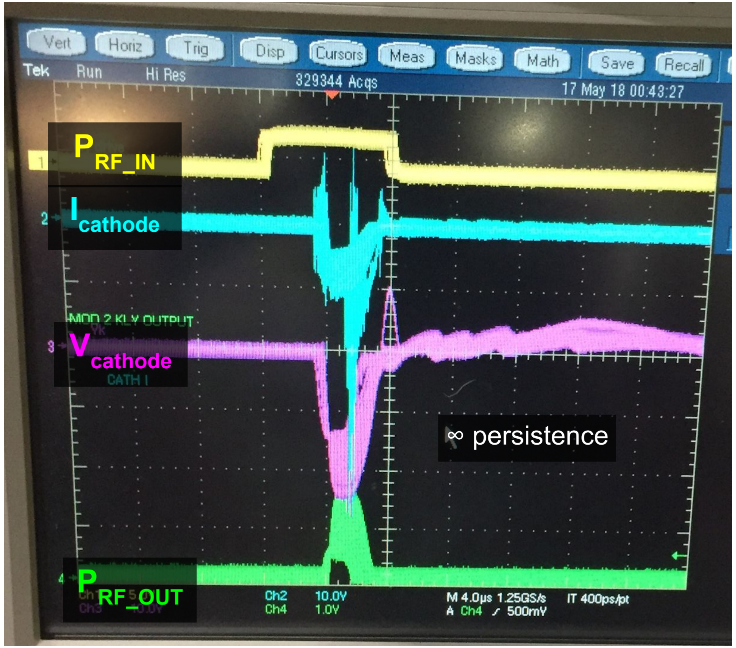
suspected arcing in the klystron

oil shows signs of **degradation**, oil processing equipment on order

… might need to replace the tube soon

Normal HV / RF pulsing

Pulses with suspected arcing



500 MHz booster RF

Commercial IOT Based Broadcast TV Transmitter

Nominal operating parameters

- V_k = 32 kV
- I_k = 2.8 A
- Eff = 60 %
- Gain = 23 dB
- P_{out} = 54 kW

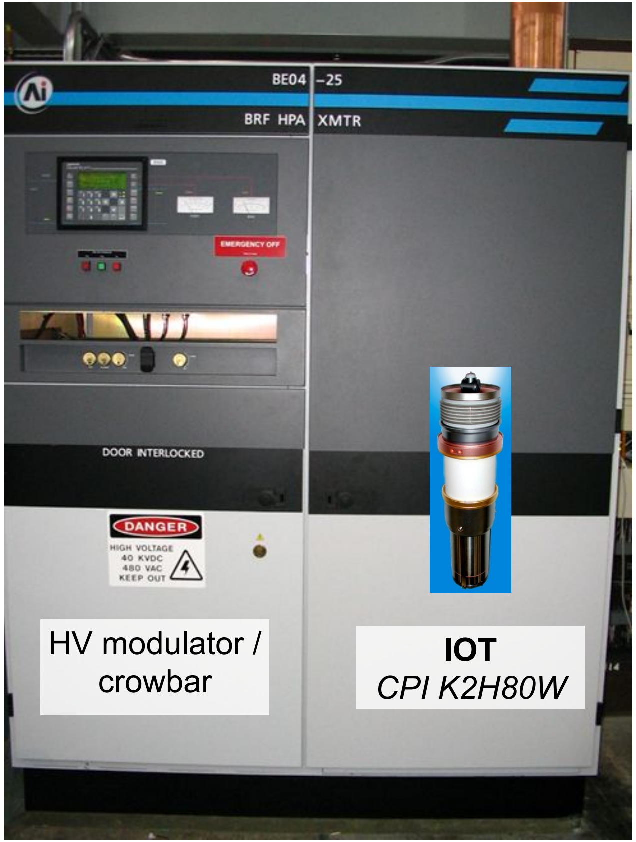
IOT lifetimes

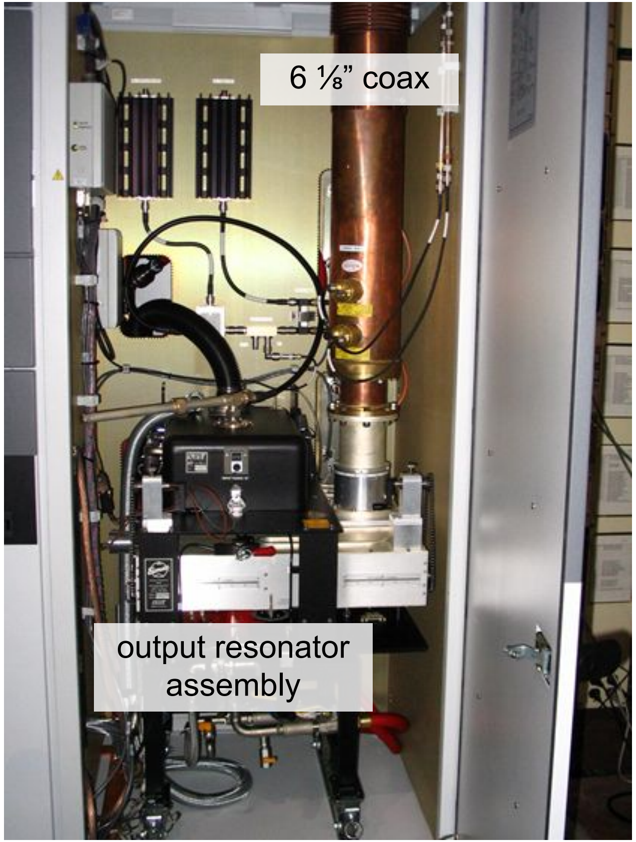
#1: 3 yrs failed due to poisoned cathode from HV cable fault

#2: 9+ yrs

Failures

- Grid Bias PS
- HV Cable fault
  (due to RF standing wave)
- HV Isolation Transformer
- Thyratron
- 2018: resistor went open circuit in analog LLRF system





ALS-RF Storage ring RF

Klystron Operating Parameters

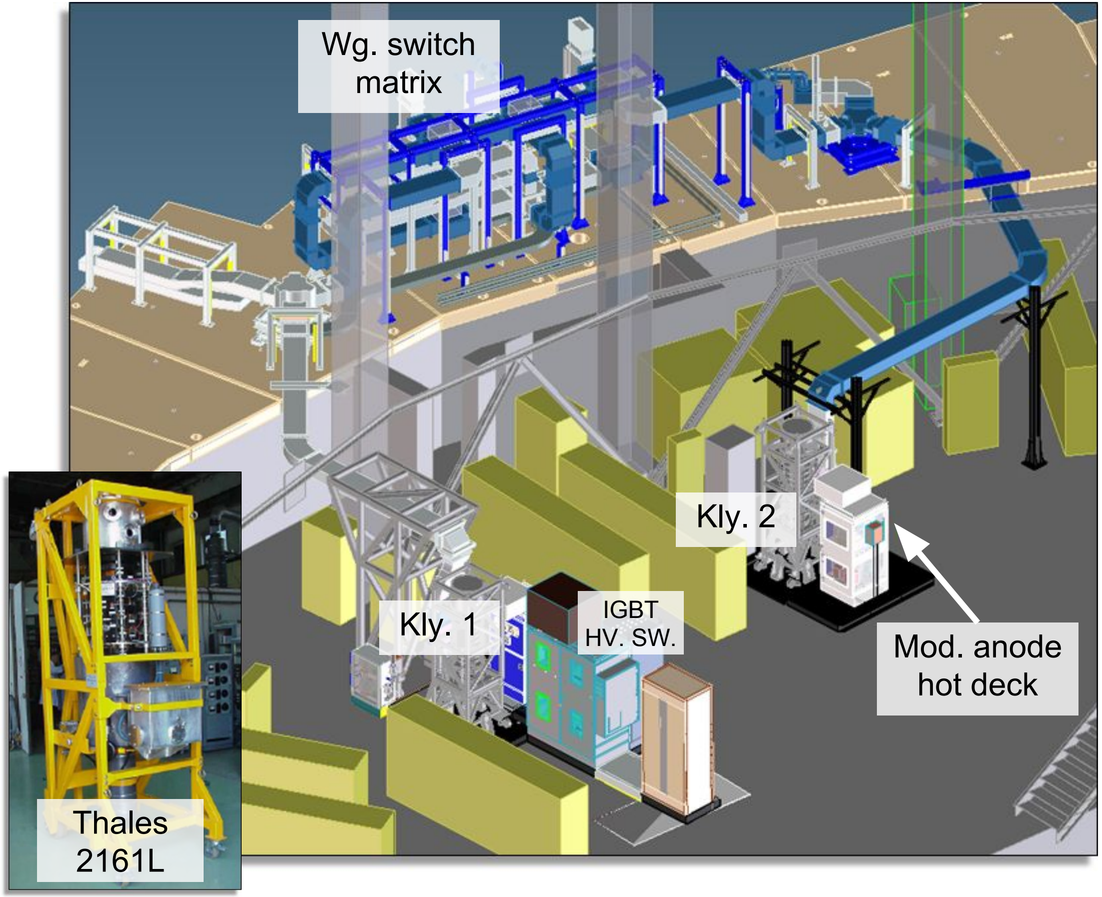
V_k = -53.1 kV I_k = 9.55 A
V_a = 32.8 kV I_a = 1.6 mA
Eff = 51.53%   Gain = 41.41 dB
μP = 1.61   RF Output = 261.7 kW

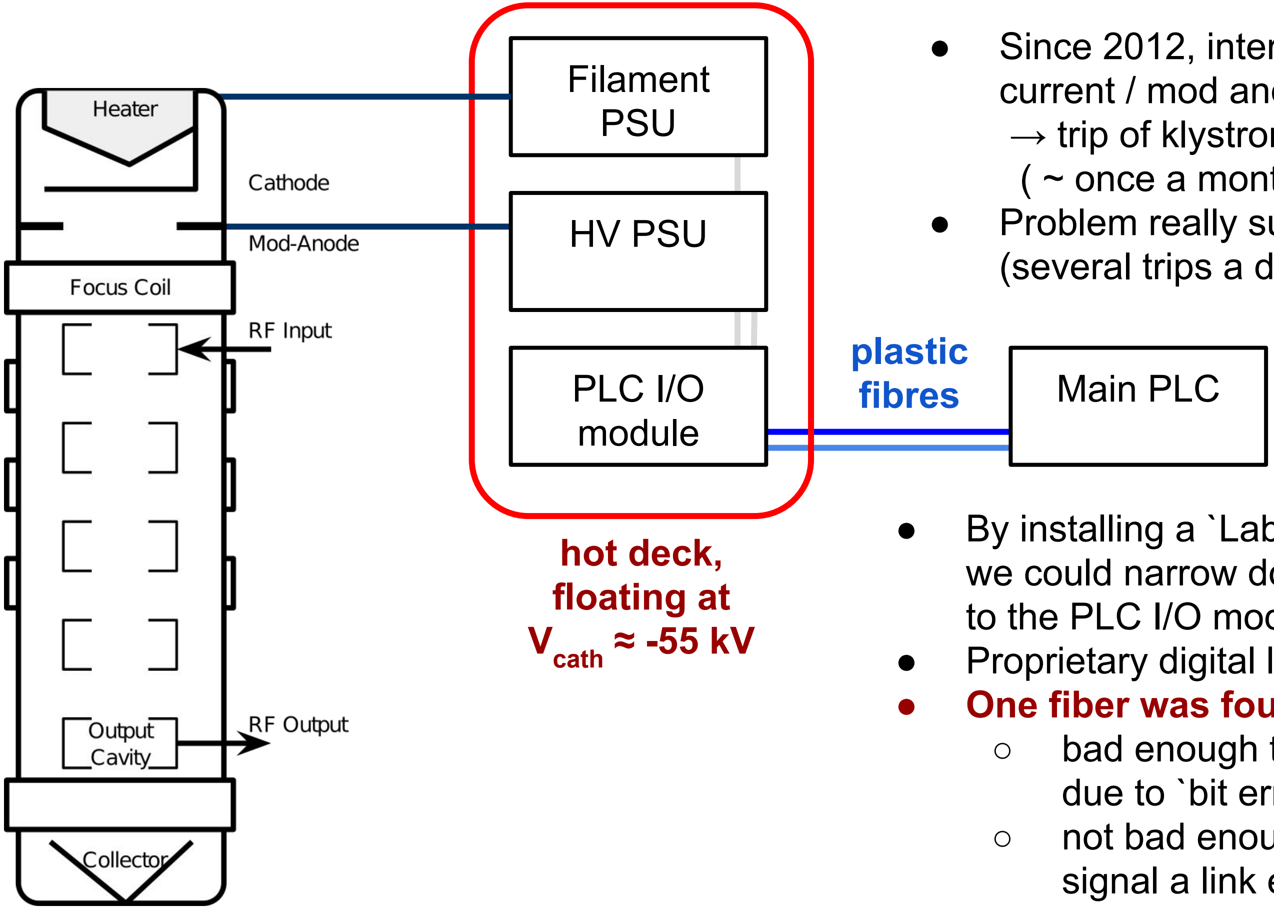
RF system

- Operational since 2012
- Nominal RF output power ~260 kW with a single klystron (500 mA, nominal ID gap)
- In 2019: ~360 kW max. with 2 klystrons

Issues

- HV filter capacitor degradation
- Arc detectors not reliable (due to ionizing radiation!)
- Mod anode control system ...





- Since 2012, intermittent loss of filament current / mod anode voltage → trip of klystron interlock system (~ once a month)
- Problem really surfaced in 2017 (several trips a day!)

- By installing a \`Lab-Jack\` DAQ module we could narrow down the faulty behavior to the PLC I/O module
- Proprietary digital link over plastic fibres
- **One fiber was found partly damaged**
  - bad enough to cause I/O glitches due to \`bit errors\`
  - not bad enough for the PLC to signal a link error

ALS-RF Storage ring RF

Wg. Switch Matrix

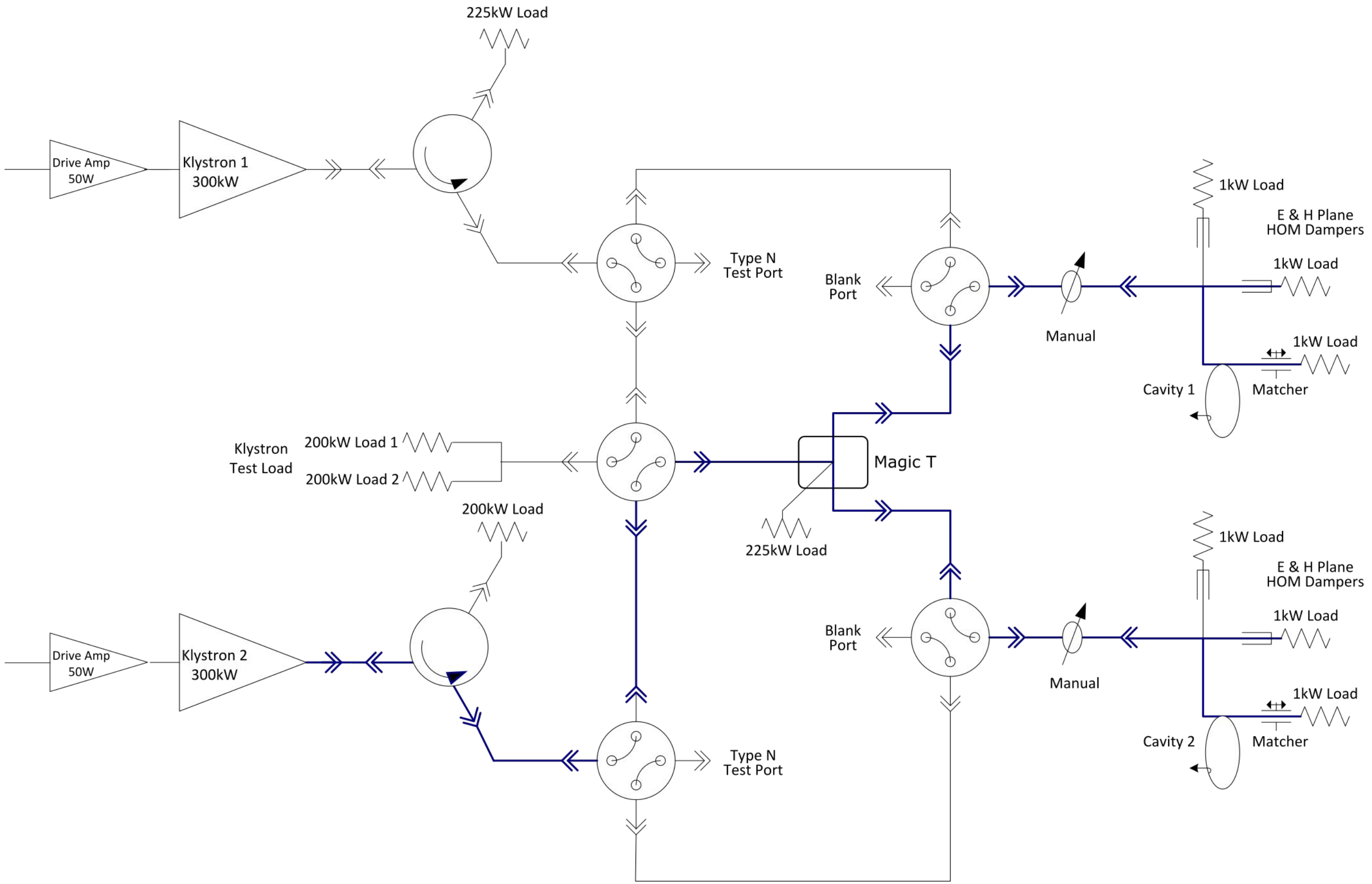
- Provides operational redundancy

Operating modes

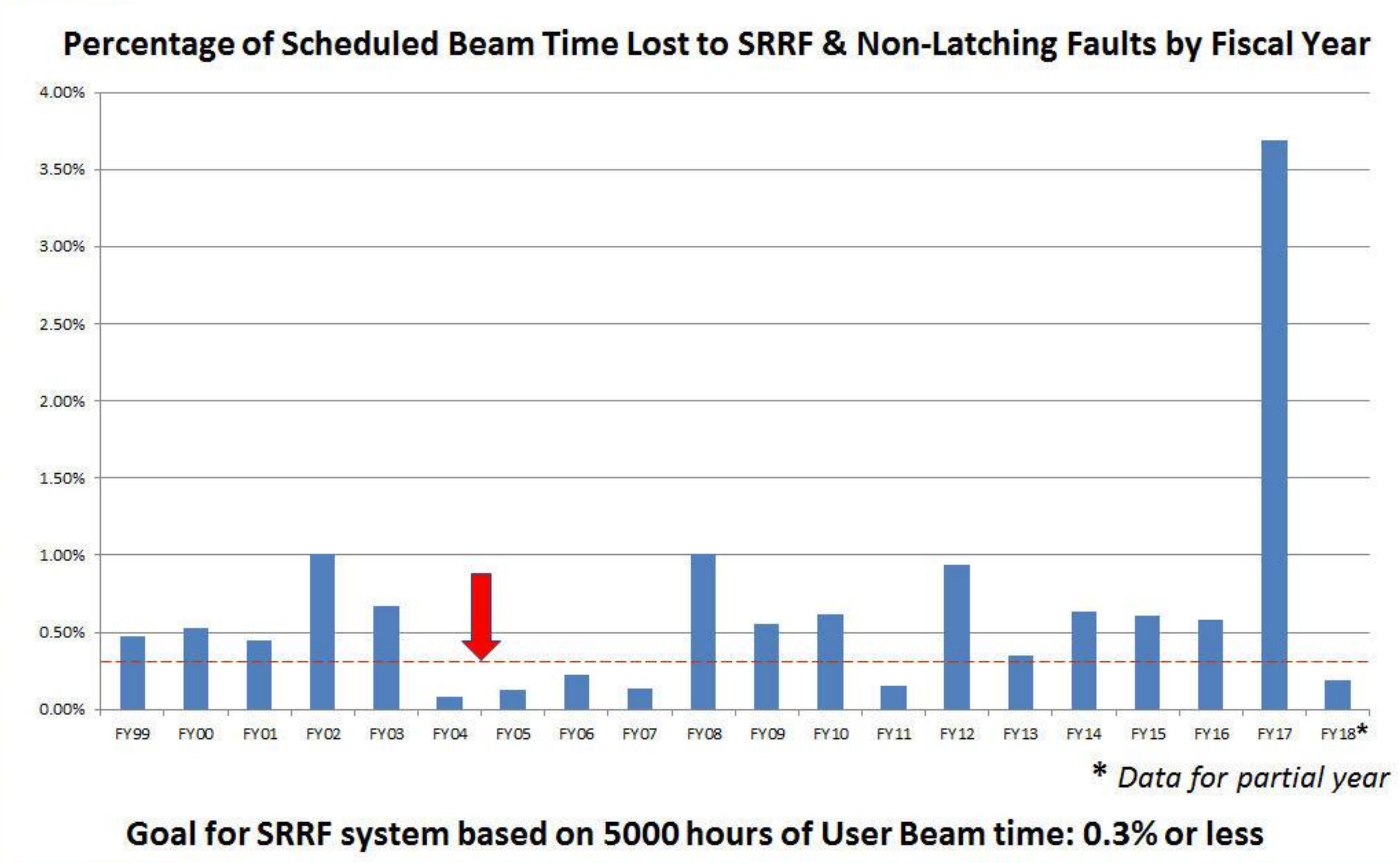
- Kly. 1 or 2 single drive (shown)
- Dual drive
- Dummy load drive
- Cavity to test port for VNA meas.

Current state

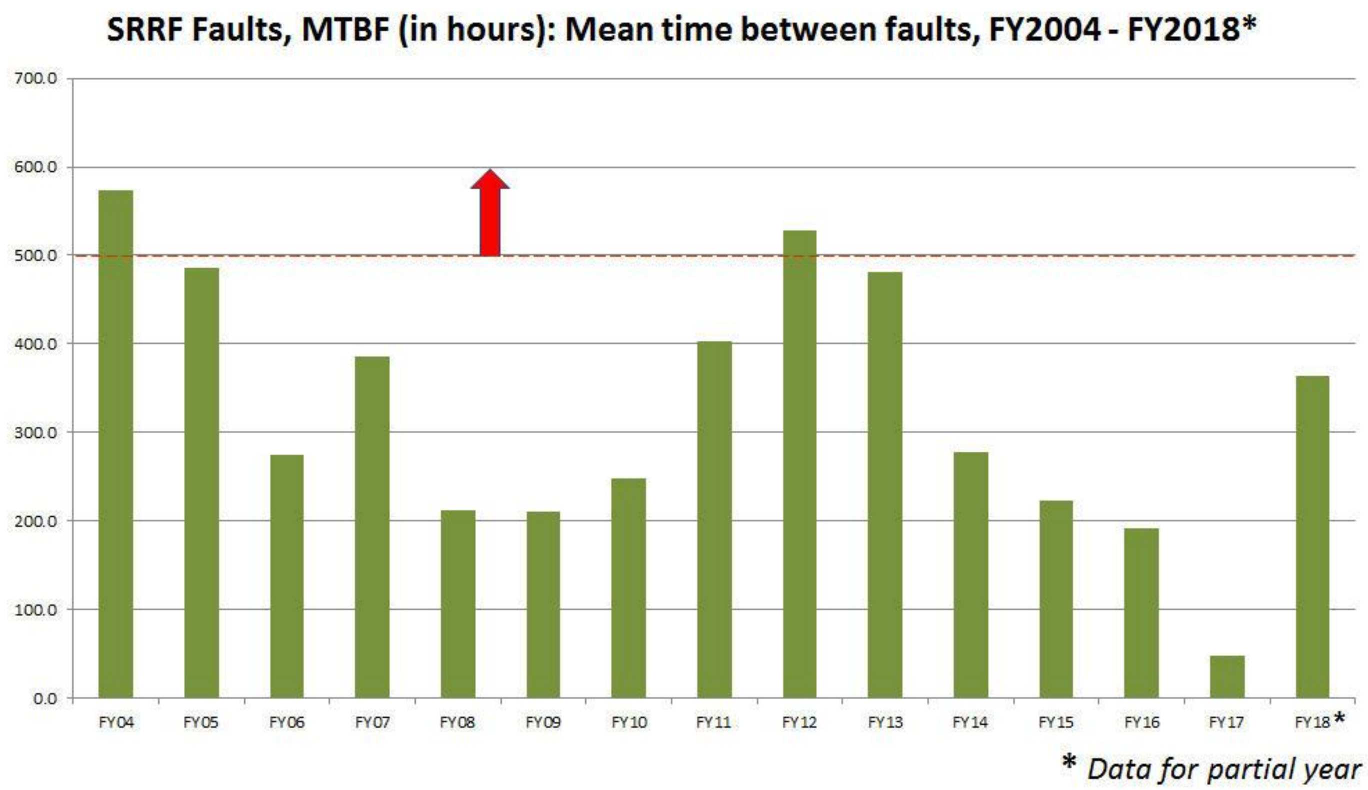
- Wg. switches locked in place as shown
- 2019: finish work on control / interlock system for full 2 klystron operation



SRRF Reliability - Beam time lost

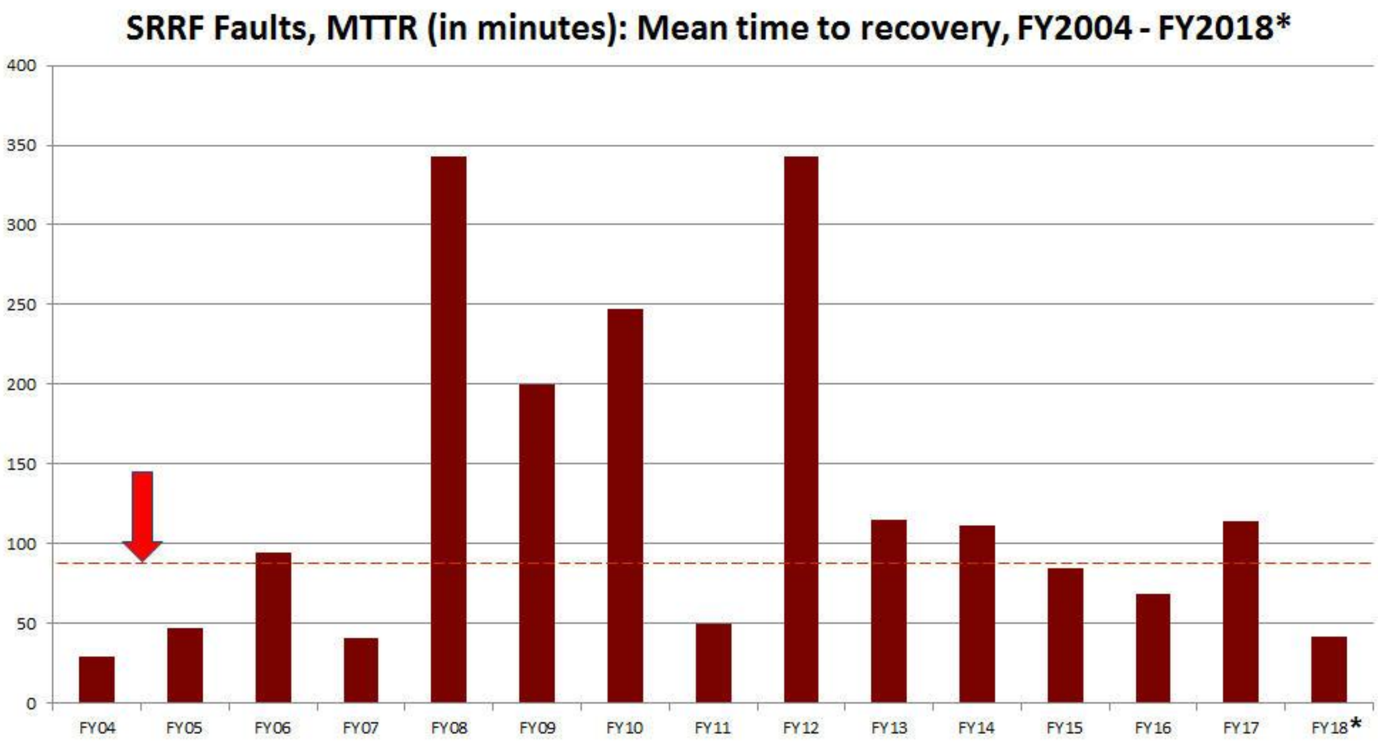


SRRF Reliability - Mean time between faults



Goal for SRRF system based on 5000 hours of User Beam time: 500 hrs or greater

SRRF Reliability - Mean time to recovery

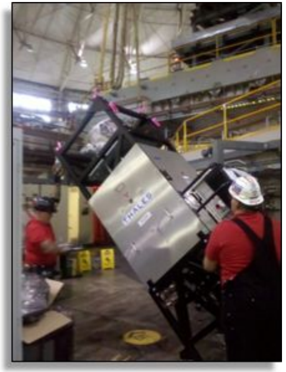


** Data for partial year*

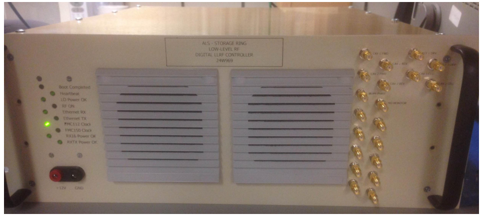
Goal for SRRF system based on 5000 hours of User Beam time: 90 min or less

SR-RF upgrades Timeline

- **2012** – Established **Klystron** site #2
- **2013** – New **HVDC** power supply
- **2014** – Installed **IGBT** based **disconnect** switch
- **2016** – Finished waveguide **switch-matrix**
- **2017** – Commissioned **digital LLRF** system
- **2018** – RF **phase noise** improvements
- **2019** – Full **2 Klystron** operation







SR-RF upgrades Digital LLRF

Hardware

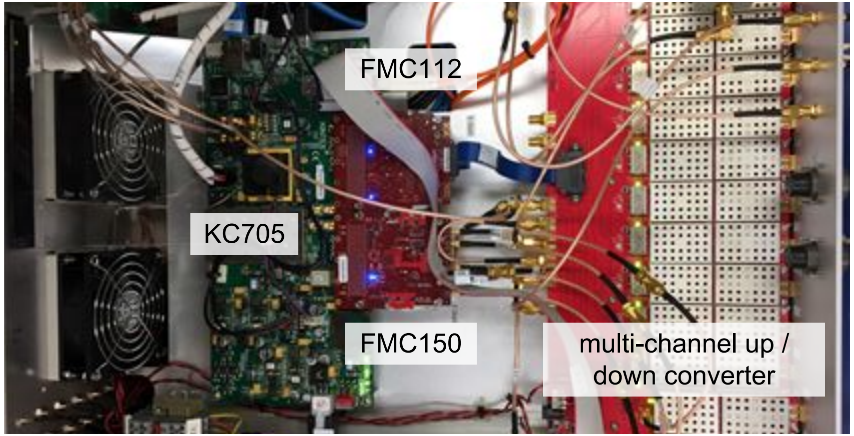
- Xilinx **KC705** eval. board (Kintex 7) +
  ADC & DAC daughter boards by 4DSP
- Custom made 500 MHz **up / down converter** board

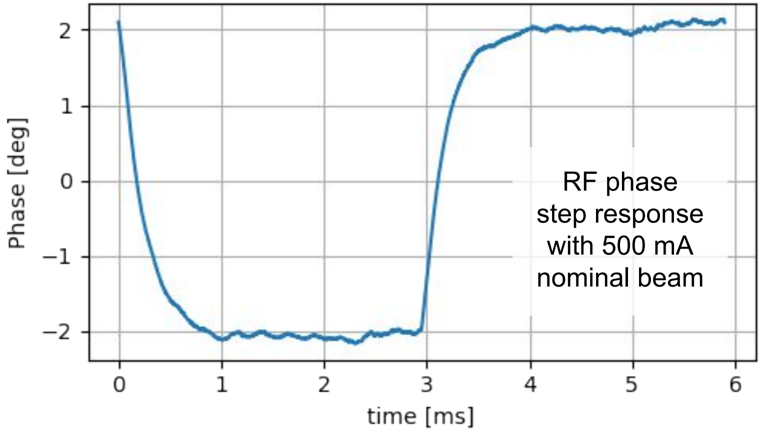
Features

- Scalable, distributed design,
  ≤ 42 input / output channels with ≤ 60 MHz bandwidth
- 1.45 µs interlock latency
- Non - IQ sampling
- Managed through gigabit ethernet interface
- Epics integration / python expert GUI
- Open Source! Code available on github

In progress

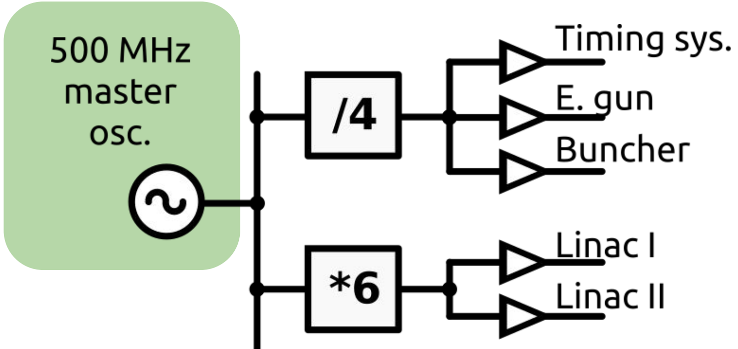
- Narrow-band network analyzer feature
- System-on-a-chip for initialization & housekeeping
- Timing system integration (Micro-research Finland)
- SRRF loop optimization
  (avoid `fighting` with ALS longitudinal feedback)

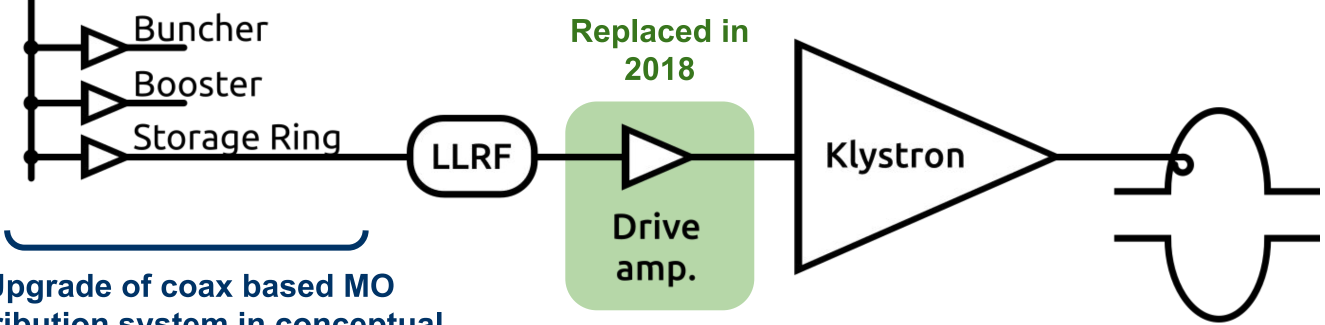




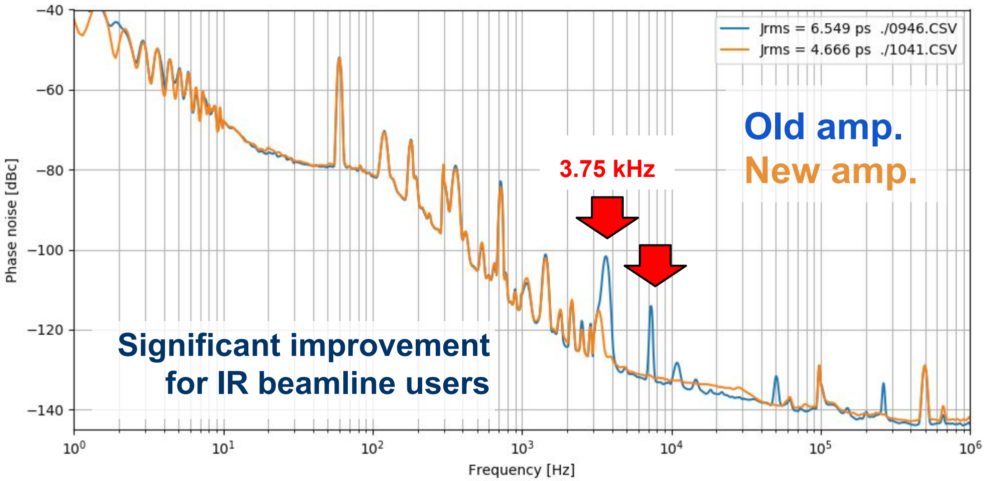
SR-RF upgrades Phase noise hunting

MO replacement selected & ordered





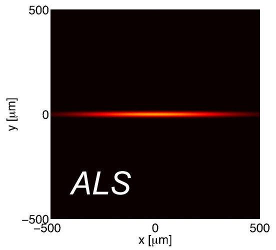
Upgrade of coax based MO distribution system in conceptual design stage

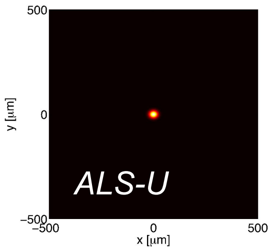


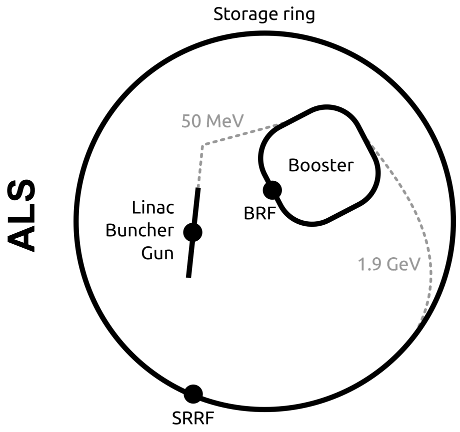
ALS-U Plans Overview

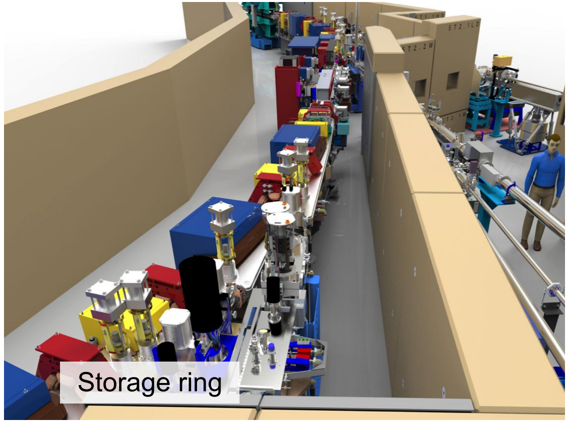
- **> 100 fold** increase in soft x-ray **brightness**
- Requires **new lattice** in the storage ring, diffraction limited emittance
- Unique: **on axis swap out injection** to satisfy the smaller dynamic apertures of the new lattice
- New **accumulator** ring for topping-up the swapped-out bunch train

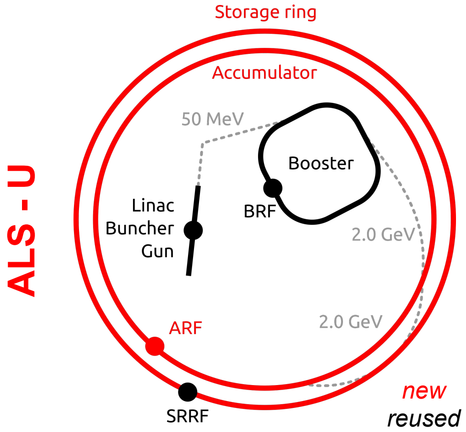
Beam profile

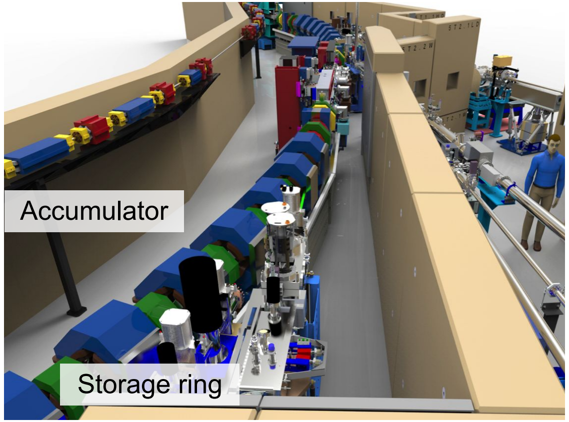










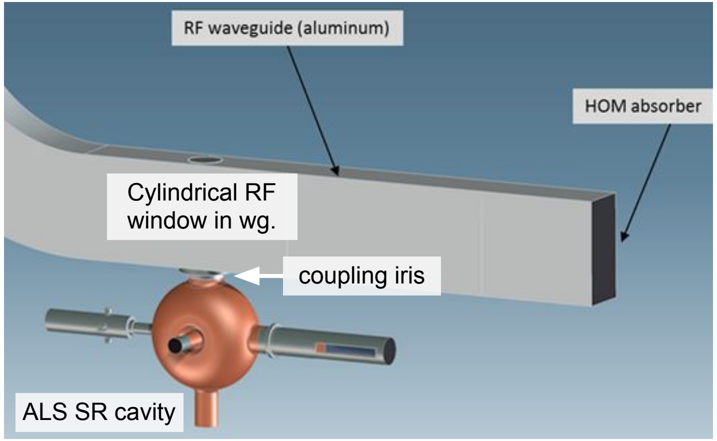


ALS-U Plans Cavities

Storage ring

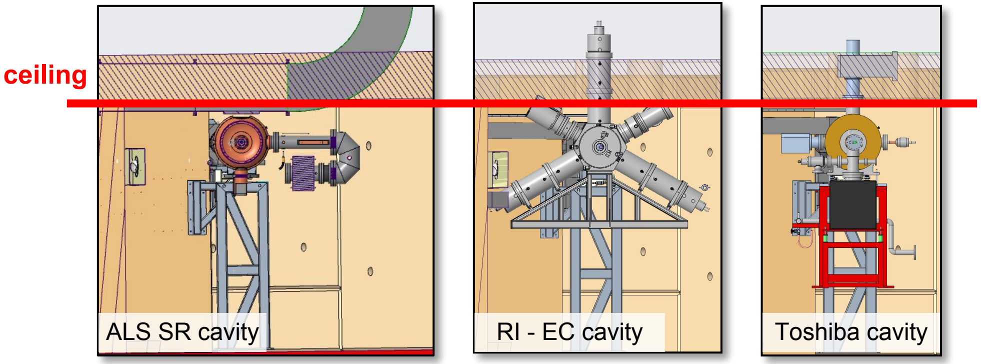
There is a real chance of reusing the existing 500 MHz ALS RF system + cavity

- **But** optimum coupling factor ~10, existing coupler only achieves < 3.2
- **Option 1** live with reflected RF power (and larger electricity bill)
- **Option 2** develop a new RF coupler
- Simulation work in progress



Accumulator

- Severe space constraints
  → will need to modify the concrete shielding
- Exploring existing cavity options
  - ALS SRRF cavity
  - Research Instruments - EC "Dampy" cavity
  - Toshiba ASP cavity
- RF Performance & Cooling:
  RI & Toshiba have no big differences
- Fit: Toshiba cavity would be a leading candidate if coupler coaxial section is extendable. NDA?

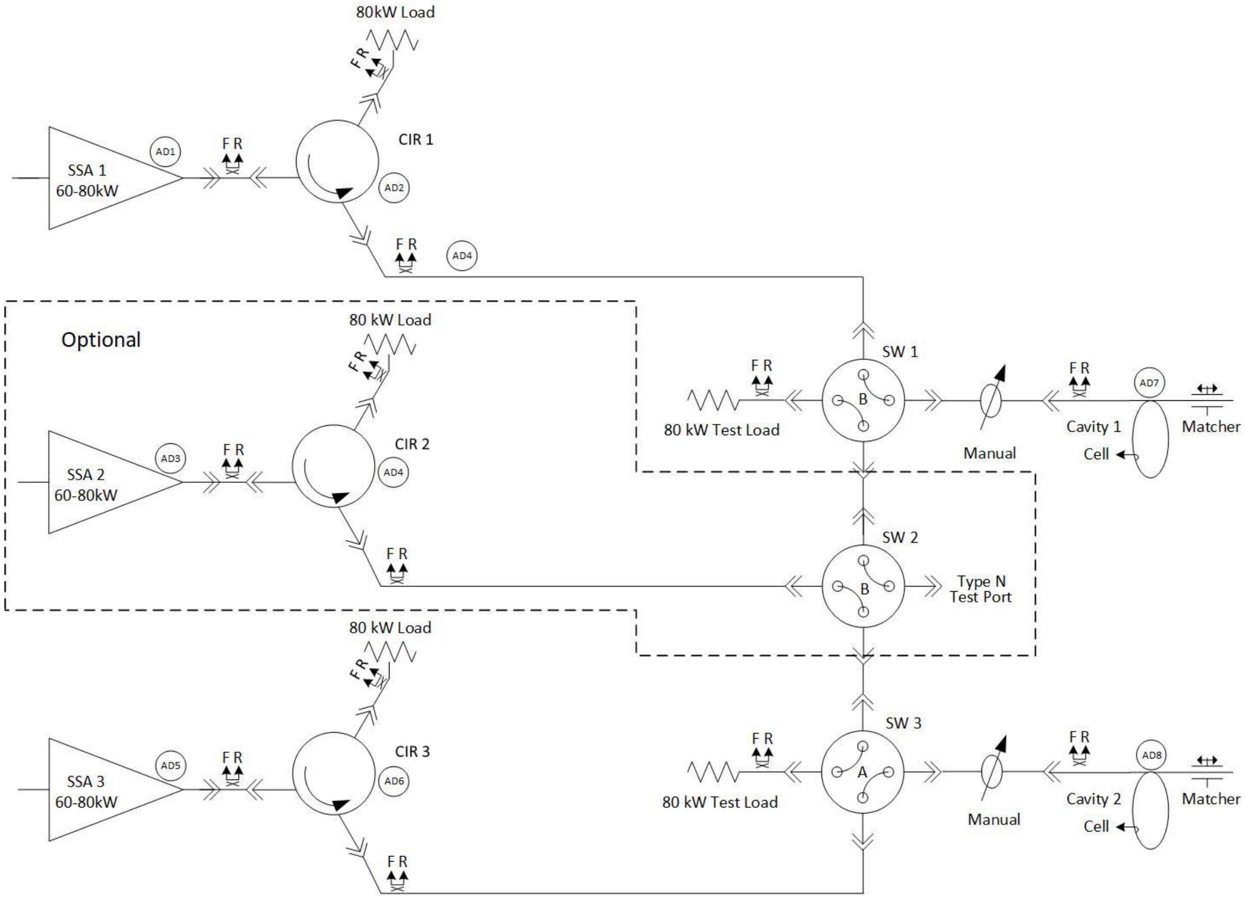


ALS-U Plans Accumulator RF

- **2 amplifiers**
  (one for each cavity)

- optional:
  3rd amplifier to improve reliability (might not be needed with SSAs)

- simplified switch matrix



ALS-U Plans   Accumulator RF

Major specs.

CW output power [kW]	60 - 80
Frequency [MHz]	499.6
1 dB bandwidth [MHz]	> 4

Additionally, we would like

- High Reliability / Fault Tolerance: continue to operate with N failed transistors, amp. modules or power supplies (PS)
- Maintenance: modular design, dripless quick disconnects, hot-swappable DC PS
- Fail-Safe Controls & Interlocks

→ can be met by commercial SSA's

Example: VHF solid state amplifier for the LCLS-II Gun B collaboration

See poster by K. Baptiste on Thursday

Booster IGBT magic-smoke was released

Booster Bend Magnets
- 1 cycle per second
- 1.2 MJ capacitor bank for energy storage between cycles

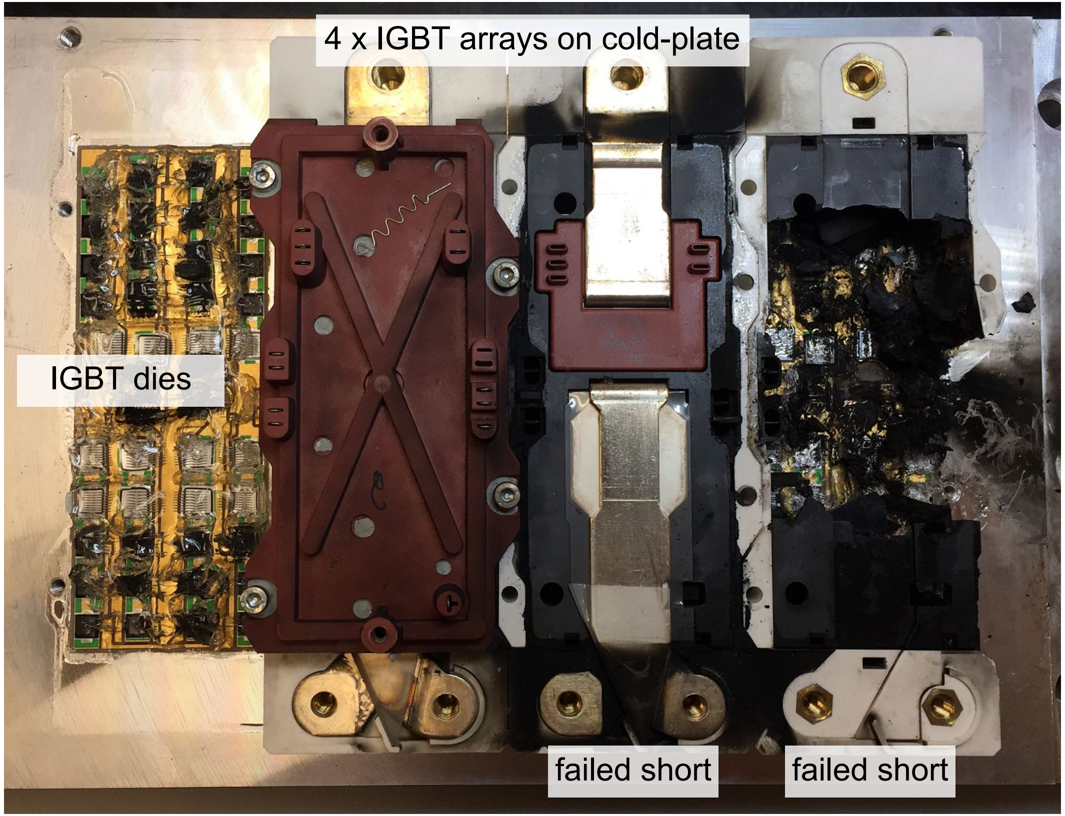
Power converter
- based on Semikron IGBT bridge modules
- rated 1.7 kV, 2.4 kA, switches @ 2 kHz

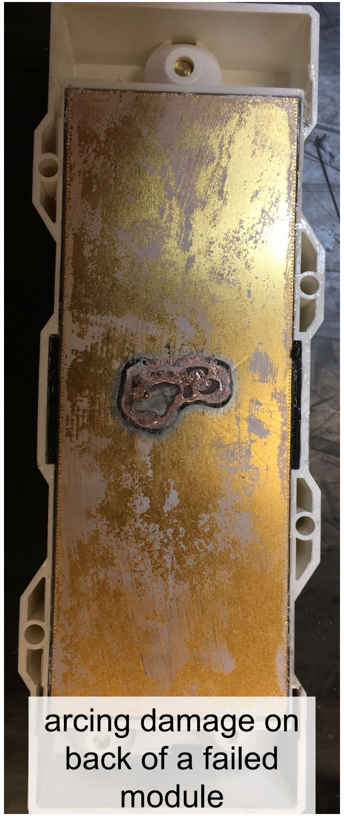
11. April 2018
- upper half-bridge switch failed closed during its conduction period, root cause not clear
- short across the DC bus in the next half-cycle
- IGBT module went through **rapid unscheduled disassembly**
- 12 x 100 A fuses blew in the cap. bank and prevented worse
- replacing IGBT module and a DC bus filtering cap. allowed us to start back up

Capacitor bank

failed IGBT module

Booster IGBT magic-smoke was released





Summary

- The injector and its RF systems will still be needed for a long time. Legacy systems are being replaced step by step. (S-Band PFN modulators, analog LLRF, etc.)
- Storage ring RF system upgrade very close to completion (Outstanding: Arc detector issues, control and interlock integration for second klystron)
- There’s a good chance we will need a new solid state amplifier + cavity for the ALS-U accumulator ring soon

Thank you!

ALS-RF Booster cavity

Center Frequency	499.64 MHz
Harmonic #	125
Peak acc. voltage (@ 66 kW)	813 kV
Beam current (multibunch)	4 mA
Synch. rad. loss (dipoles)	5 kW
Shunt imp. (ZT^2)	5 MΩ
RF power required *beam loading + cavity loss + return loss + transmission loss*	54 kW
RF power installed	80 kW