First Experience with DELTA's upgraded RF

P. Hartmann
DELTA, TU Dortmund

DELTA parameters:

Beam energy: 550 MeV – 1.5 GeV
Beam current: 130mA @ 1.5GeV
Beam lifetime: 12h @ 130 mA
Availability: 95 %
Operational: 3000 h / year

RF Group:

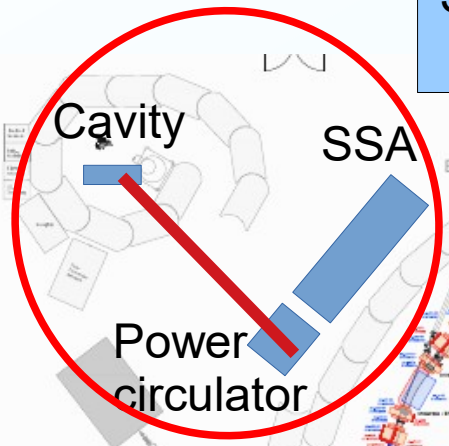
(T. Weis)
P. Hartmann
V. Kniss
(W. Brembt)
(A. Leinweber)

Inhalt

- Überblick Delta + Delta HF
- HF-Truppe
- SSA trips in pulsed mode → Update of all SSA modules by manufacturer
- RF conditioning of EU Cav up to 75 kW, Radiation!
- Installed new 4” cooling water supply line + distribution in SR RF area
- Wasserkühlung DORIS-Schleife
- Waterleak on HOM-Antenna
- Kopplerbrand im Bunker
- PLC BoDo SSA broken → Replaced the same day by manufacturer
- Old glycole dummy loads replaced with DI Water loads
- Glycole water rack removed, frees 4m2 close to cavity
- SMA100A installiert
- Riss der Messchleife + Alba-Design
- Einbau EU-Cavity
- April – July: Betrieb mit EU-Cav. detuned
- Inbetriebnahme ohne LLRF
- Sep.: Installation LLRF + Galil Motor driver
- Oct.: Replacement LLRF
- Synchrotronfrequenz
- Abschätzung versch. Größen
- Betrieb mit einem Cavity
- Betrieb mit 2 Cavities

DELTA's 500 MHz RF systems

New RF system to be commissioned
Solid state amplifier (Cryoelectra, 75 kW)
HOM damped EU-type single-cell cavity



Analog LLRF @ 499,8 MHz
Klystron amplifier YK-1265 (65 kW)
DORIS type single-cell cavity
DESY HOM-Antenna damper

Analog LLRF @ 499,8 MHz
Solid state amplifier (Cryoelectra, 25 kW)
DESY type 3-cell cavity

RF conditioning of EU cavity

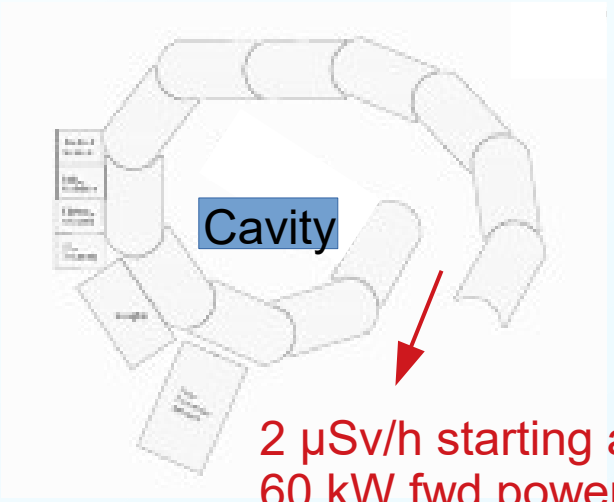
March 2018: Cavity baked at 130°C

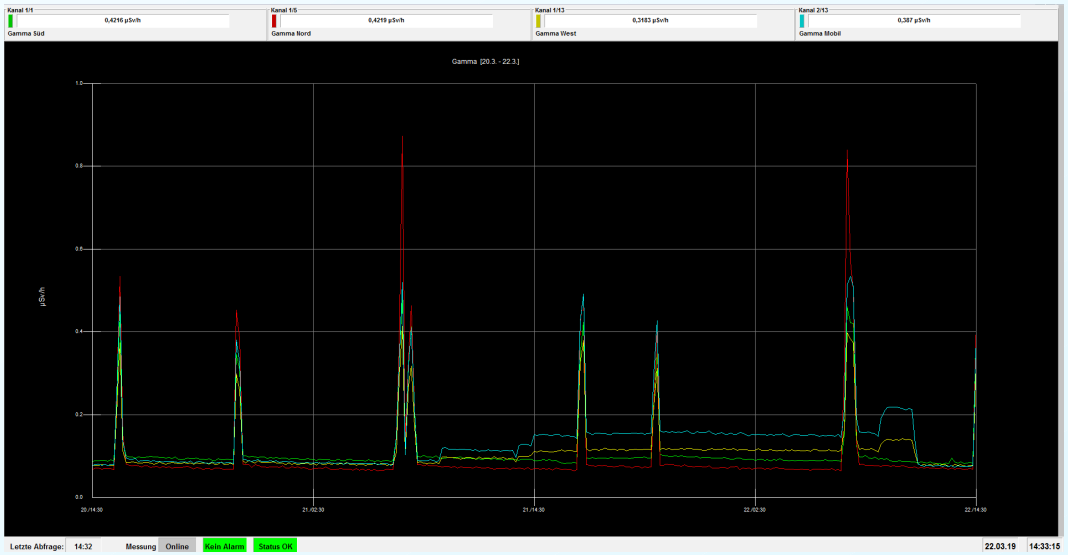
April 2018: Started with CW conditioning to 3 kW, SSA Trips
SSA repair
CW conditioning within 2 days up to 75 kW

Apr. - June 2018: 180h of operation, mostly > 30 kW, 40h at 75 kW

Radiation from EU Cavity

During conditioning we encountered up to 2 uSv/h at the door of the bunker, out of direct sight of the cavity, starting at ~60 kW forward power.





Extra lead shielding at the door of the bunker installed in order to suppress radiation level to safe values.

Radiation lowered with time to 2/3 of its initial value after conditioning.

RF conditioning of EU cavity

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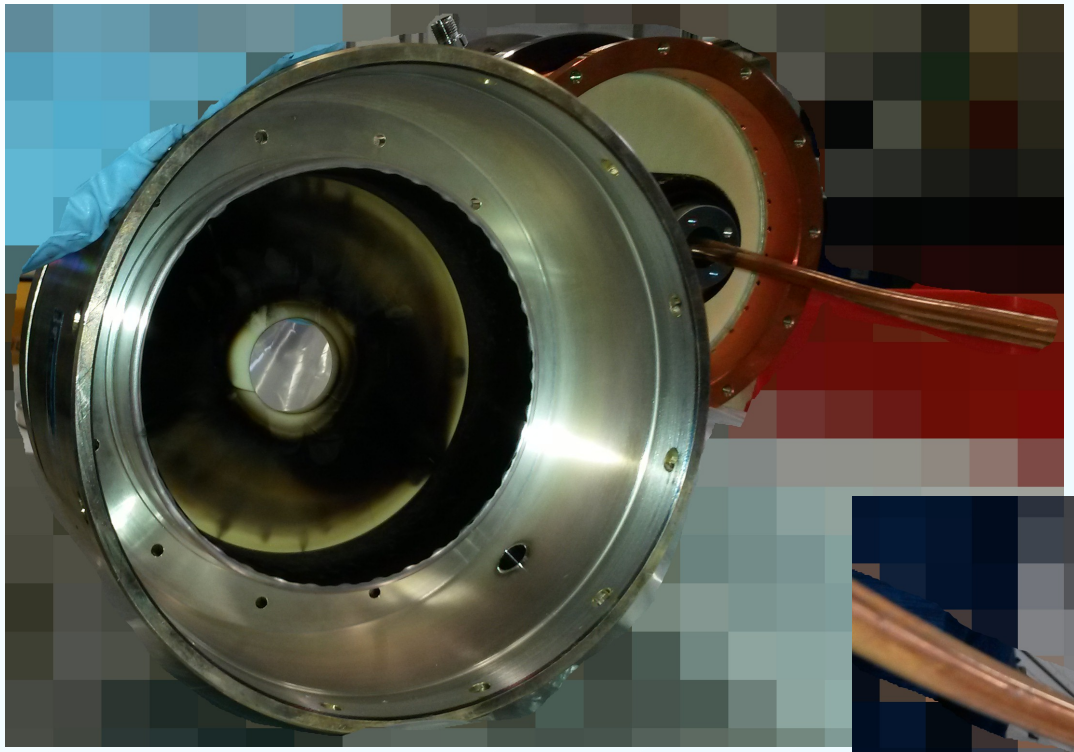
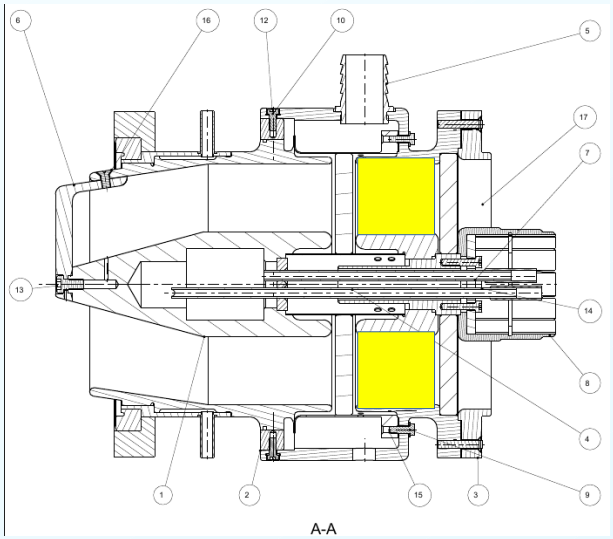
Apr. - June 2018: 180h of operation, mostly > 30 kW, 40h at 75 kW

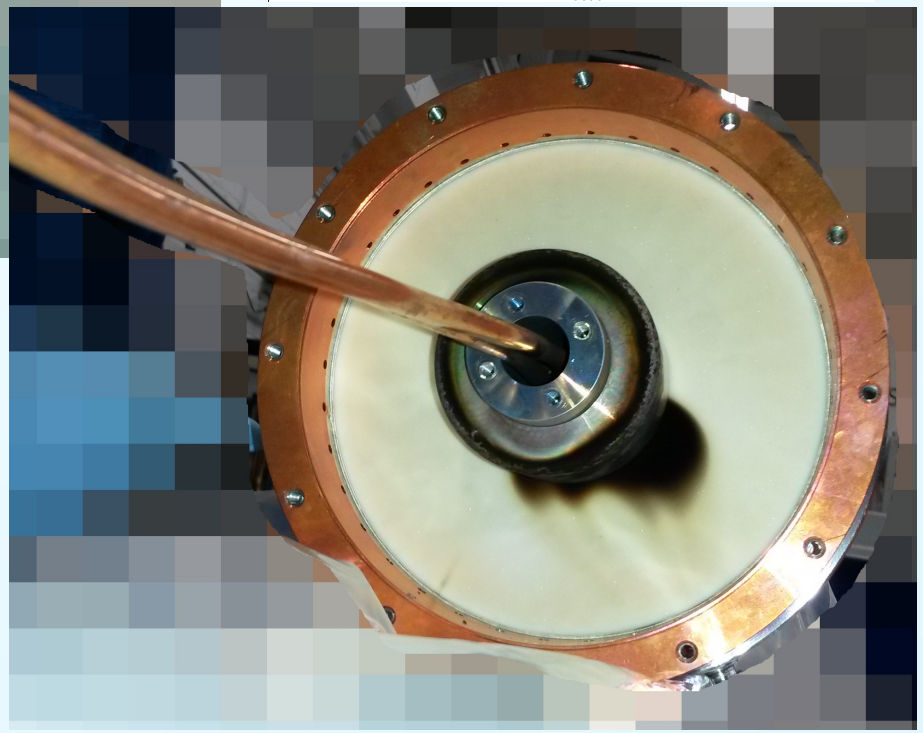
Jul-Aug 2018: Vacuum opened, no re-baking

Sep 2018: Vacuum window cracked at 24 kW CW during re-conditioning

Sep. 2018: Broken power coupler (EU)

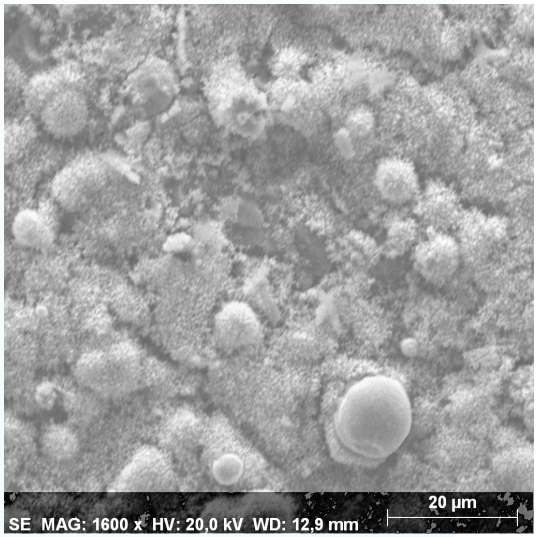


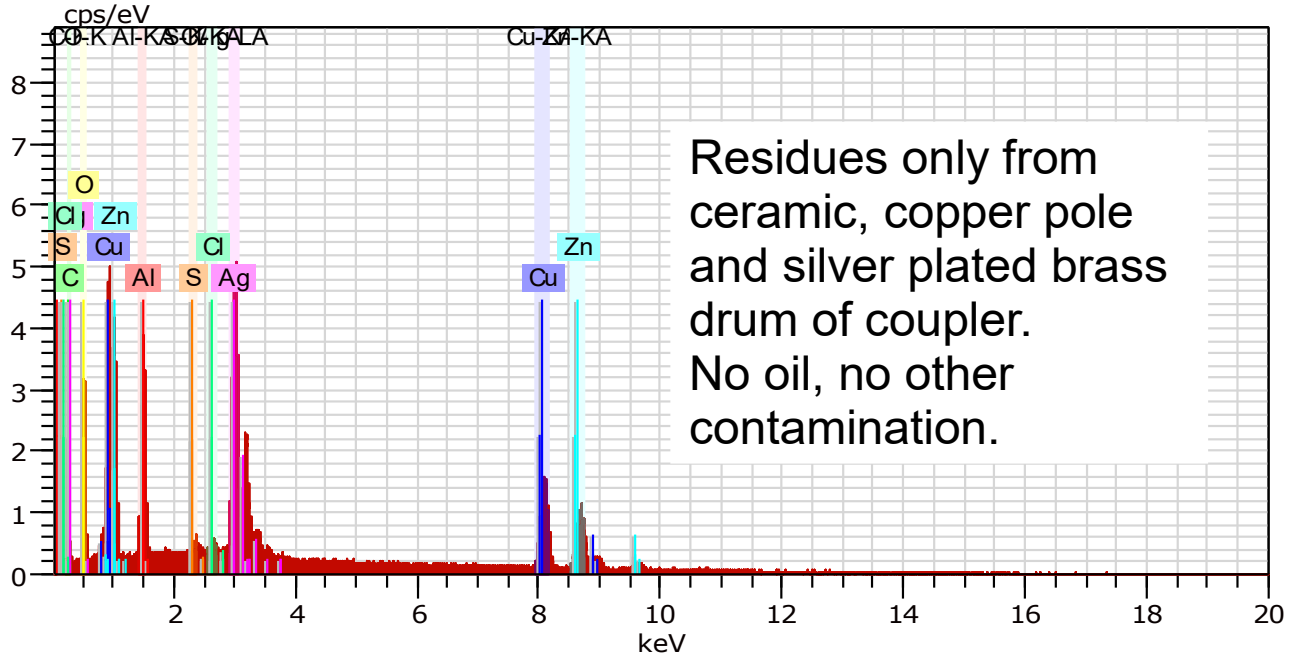




Continuous arcing in the air vented region between the vacuum window and the center plate outside the vacuum eventually broke the vacuum window. Arcing was not detected because of the reflected power interlock being too slow.

Broken power coupler





Sincere thanks to A. von Bohlen, ISAS, Dortmund for doing the analysis.

The cause for the arcing was presumably a particle from the 1m long rubber air hose between the particle filter and the coupler. This kind of particles were found in the air filter.

Remedies:
- Replaced rubber hose with hose having a smoother surface on the inside.
- Installed fast reflected power interlock.

Sincere thanks to V. Dürr and W. Anders from HZB for lending out a spare coupler.

RF conditioning of EU cavity

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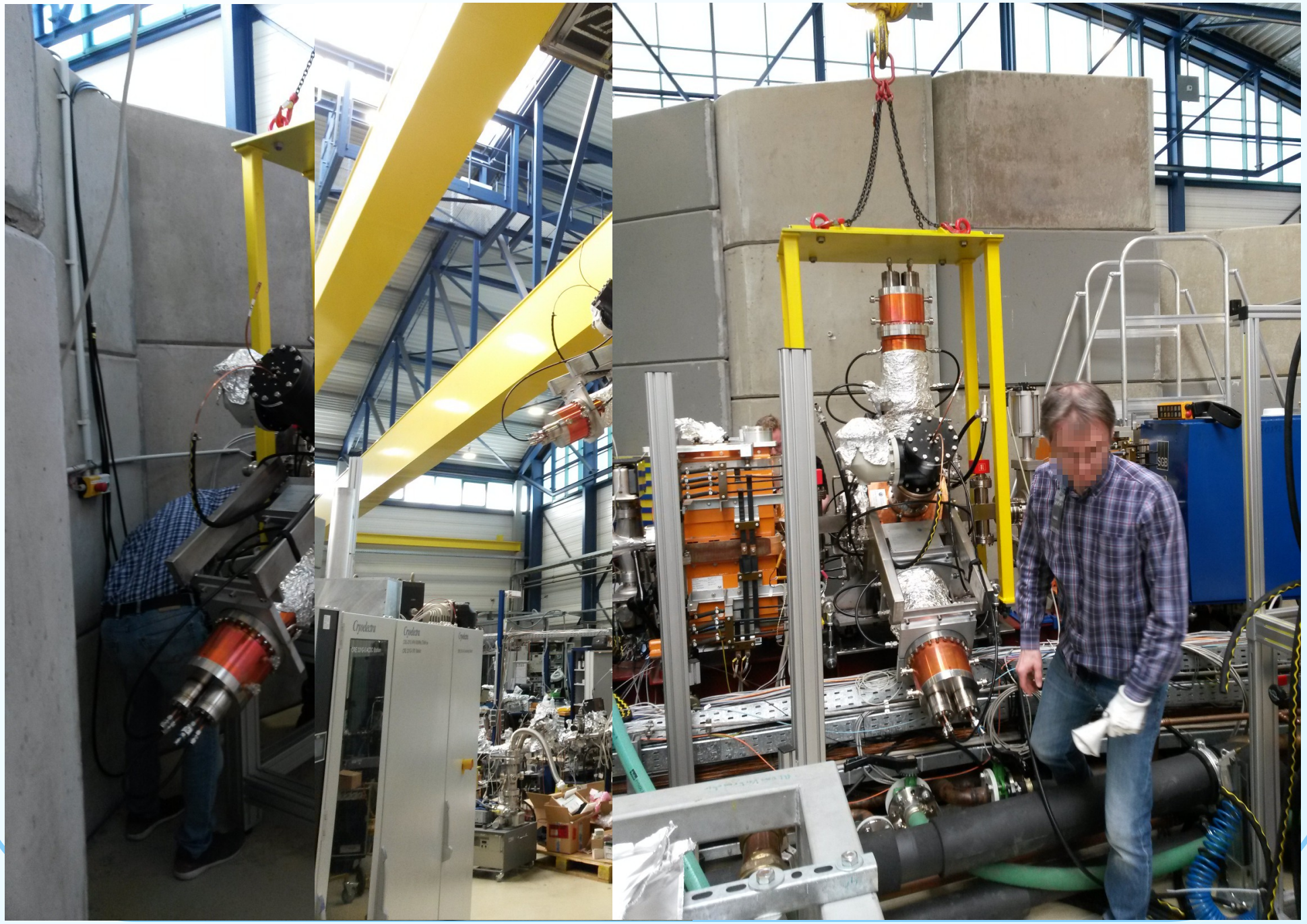
April 2018:	Started with CW conditioning to 3 kW, SSA Trips SSA repair CW conditioning within 2 days up to 75 kW
Apr. - June 2018:	180h of operation, mostly > 30 kW, 40h at 75 kW
Jul-Aug 2018:	Vacuum opened, no re-baking
Sep 2018:	Vacuum window cracked at 24 kW CW during re-conditioning
Jan 2019:	Power coupler replaced with coupler from HZB
March 2019:	Fast reflected power interlock, new air hose. Very slow pulsed conditioning to 60 kW followed by CW conditioning to 75 kW

Storage Ring Infrastructure Upgrades

- Replaced all glycol based dummy loads with DI water loads
- Removed glycol water rack → frees 4m^2 in cavity area
- Installed new 4 inch cooling water supply line + distributor to cavity area
- Designed and built fast interlock electronics for EU cavity
- Designed and built water cooler with 13 interlocked DI water supply lines for EU cavity
- Reconfigured personal safety scheme
- Installed new RF Master with ‘phase continuous frequency shift’ (Rohde & Schwarz)
- Built 2-axis plunger motor driver based on Galil DMC-21x2 board

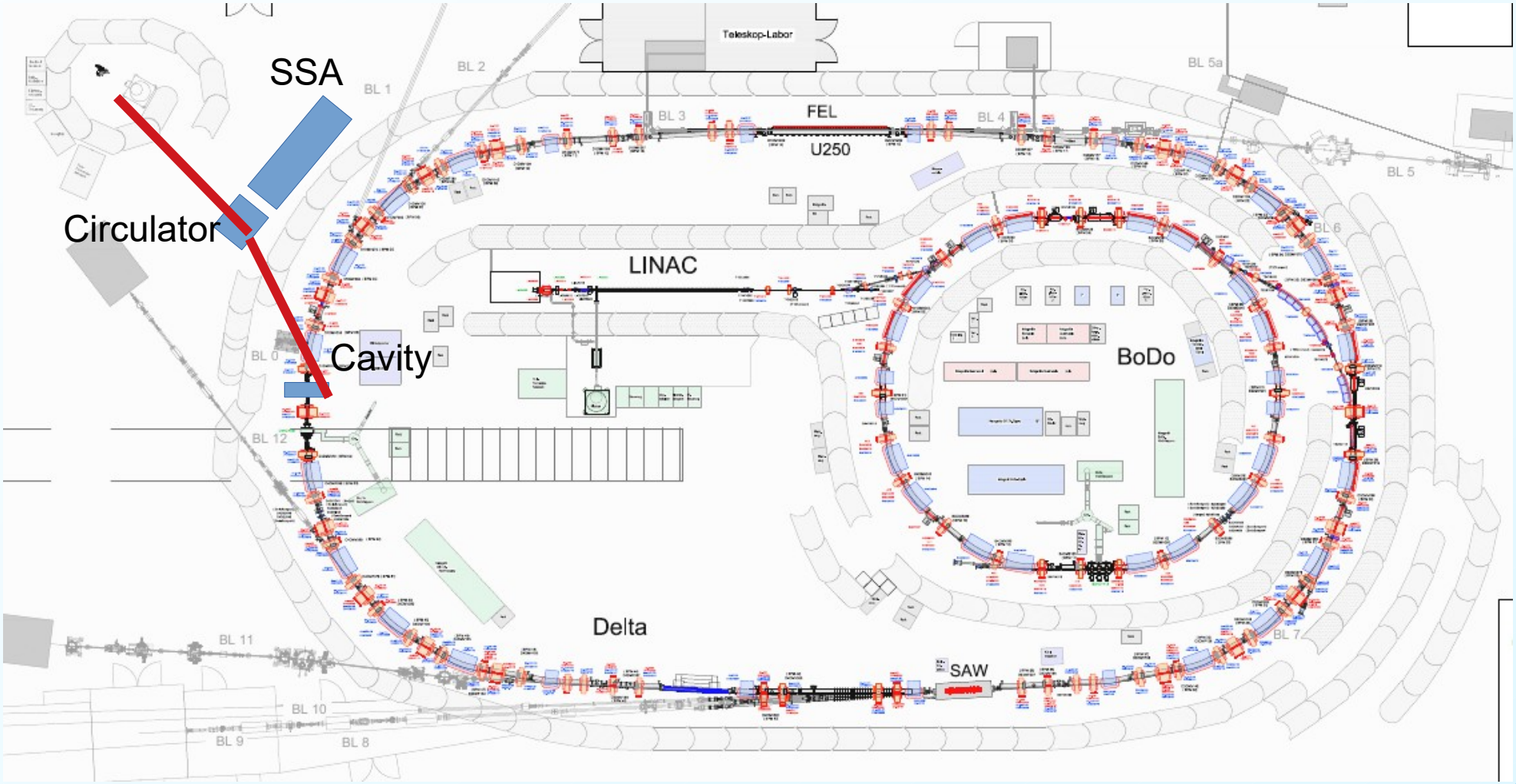
April 2019: SR Installation of cavity



Storage Ring Operation

Apr. 2019:	Installation of EU cavity in storage ring
Apr. 2019 – Jul. 2019:	Single cavity operation with active DORIS cavity and passive (detuned) EU cavity
Jul. 2019:	Installation of 6 1/8” koaxial tube

Coaxial tube installation



Storage Ring Operation

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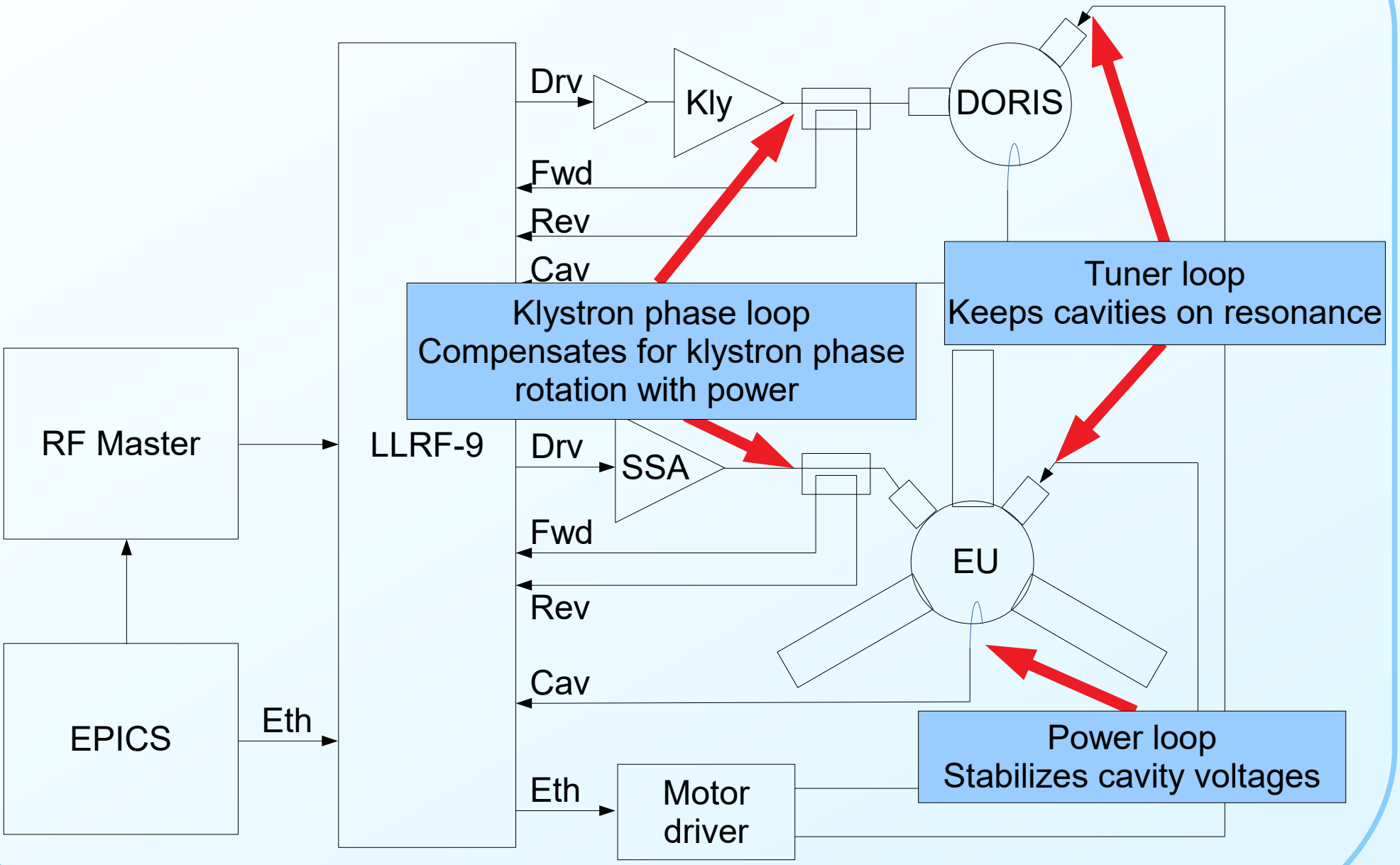
Jul. 2019:	Installation of 6 1/8” koaxial tube
Aug. 2019 – Sep. 2019:	Single cavity operation with active EU cavity and passive (detuned) DORIS cavity
Sep. 2019:	Installation of new Digital Low Level RF (Dimtel)
Ever since:	Dual cavity operation

Sep. 2019: Digital Low Level RF



Digital Low Level RF

New cooling water distribution

New cooling water supply line

Power levels

Vacuum gauges

Dimtel LLRF-9

2-axis motor controller

Klystron pre-amplifier

Interlock plc

Arc detector electronics and premagnetization

Failiures and Disasters

Apr. 2018: Storage ring SSA interlocks above 3kW, burned submodule connectors
→ manufacturer reworked all modules

Sep. 2018: power coupler of EU cavity arced, RF window cracked
→ replaced with HZB coupler

Oct. 2018: No water flow through center rod of DORIS power coupler
→ coupler replaced with spare

Apr. 2019: Water leak on HOM damper (DORIS)
→ removed HOM damper

Leaking HOM damper (DORIS)

Incident: Vacuum pressure increase in RF area.
No leak found with He leak search.
No leak found with He immediately after blowing water out of the cooling tubes.
Leak found after blowing air through the water tubes for ~2 hours
→ Sudden vacuum pressure increase by 2 orders of magnitude.

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Jul. 2019: Microleak on cavity probe window (EU)
→ installed ALBA's in-vacuum design

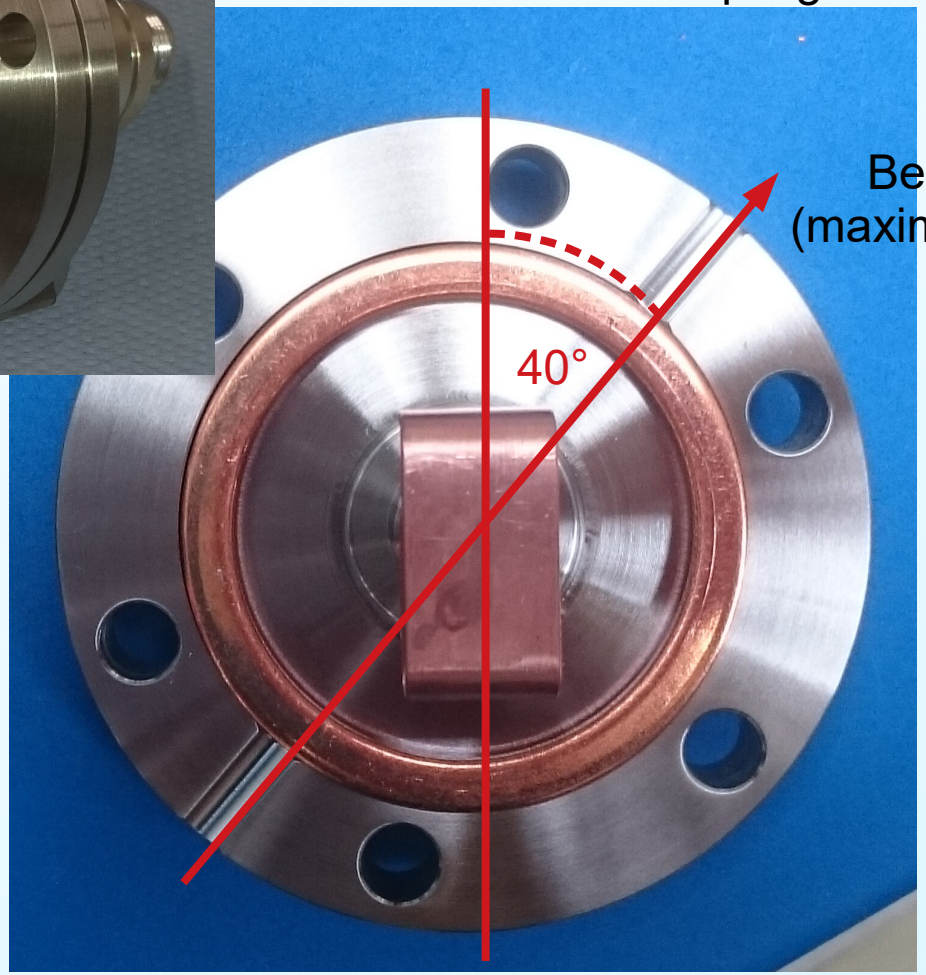
Broken cavity probe (EU)

Old style cavity probe

Micro leak

ALBA design (in-vacuum)

-50.3 dB coupling



Sincere thanks to A. Salom
and F. Perez from ALBA/CELLS

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→ removed HOM damper

Jul. 2019: Microleak on cavity probe window (EU)
→ installed ALBA's in-vacuum design

Aug. 2019: Booster SSA PLC broke
→ same day repair by manufacturer

Oct 2019: Continuous beam trips due to malfunctioning LLRF
→ installed spare LLRF from KARA

Digital Low Level RF

Single cavity operation, analog LLRF

Removal of analog LLRF, Installation of digital LLRF

Commissioning of digital LLRF

Dual Cavity operation

Digital LLRF failiure

Installed KARA LLRF

Dual Cavity operation

ESLS-RF

Sincere thanks to M. Schuh and KARA team for quick and un-bureaucratic help !

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LLRF calibration check with beam

Synchrotron frequency : $f_S = f_{rev}\sqrt{\frac{\alpha h}{2\pi}\frac{e U_C}{E}\sin(\phi_S)}$, $\sin(\phi_S) = \sqrt{1-\left(\frac{U_{rev}}{U_C}\right)^2}$

$$U_C = \sqrt{\underbrace{\left(\frac{2\pi E}{f_{rev}^2\,\alpha\,h\,e}\right)^2}_{k} f_S^4 + U_{rev}^2}$$

Reference parameters :

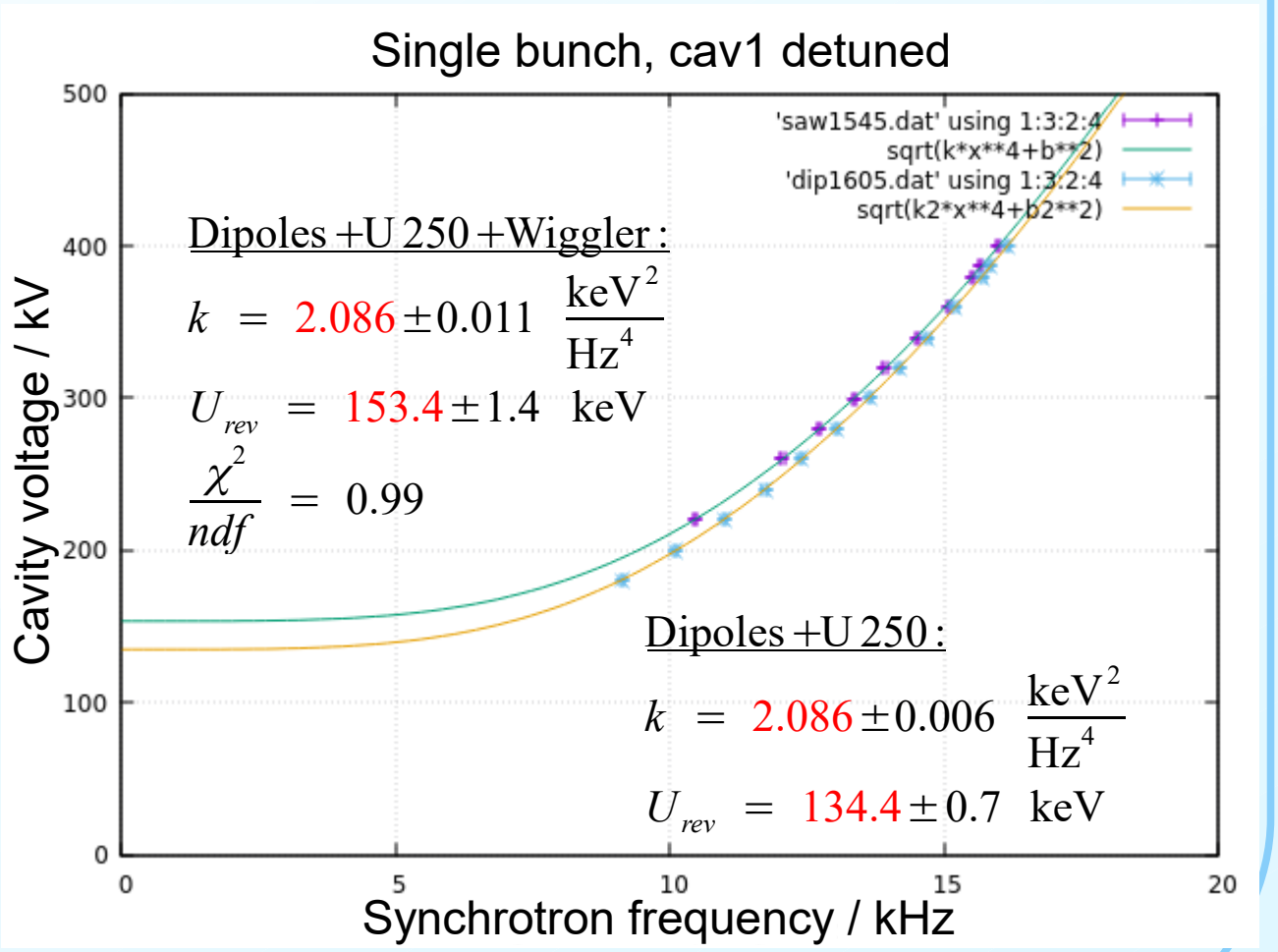
$(E = 1492\,\text{MeV}, \alpha = 0.0050)$

$\rightarrow k^{calc} = 2.076 \ \frac{\text{keV}^2}{\text{Hz}^4}$

Calculated and from Simulation:

$U_{rev}^{Dipoles+U250+Wiggler} = 150$ keV

$U_{rev}^{Dipoles+U250} = 128$ keV



Summary

- Smooth upgrade (for users) from single cavity to dual cavity operation
- Users suffered 2 weeks from lower lifetime after cavity installation and 4 days from frequent beam trips due to LLRF failure
- LLRF in combination with BBB feedback is an excellent tool for beam diagnostics
- Dual cavity operation led to an increased injection efficiency and a better lifetime
- Phase modulation not yet implemented (lifetime increase: 2h)
- Basic functionality fine, still open questions, minor bugs need reworking
- Many things still to do: System optimization, documentation, ...

Acknowledgements

Vadim Kniss, RF Engineer @ DELTA

DELTA Team

University electronics workshop

University mech. workshop

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W. Anders, V. Dürr, HBZ (BESSY)

A. Salom, ALBA

M. Schuh + KARA Team (KIT)

Thank you
for your attention