MAX IV Laboratory

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SCN User Meeting

May 2020

Content

- MAX IV Laboratory, Lund University Sweden
- Application description SCN technology at MAX IV Laboratory, Sweden
- MAX IV Laboratory and ScandiNova partnership from 2009 and now..
- Experiences from ScandiNova Modulators (RF Units)
- Conclusions

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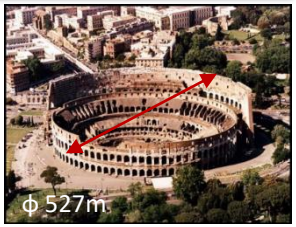
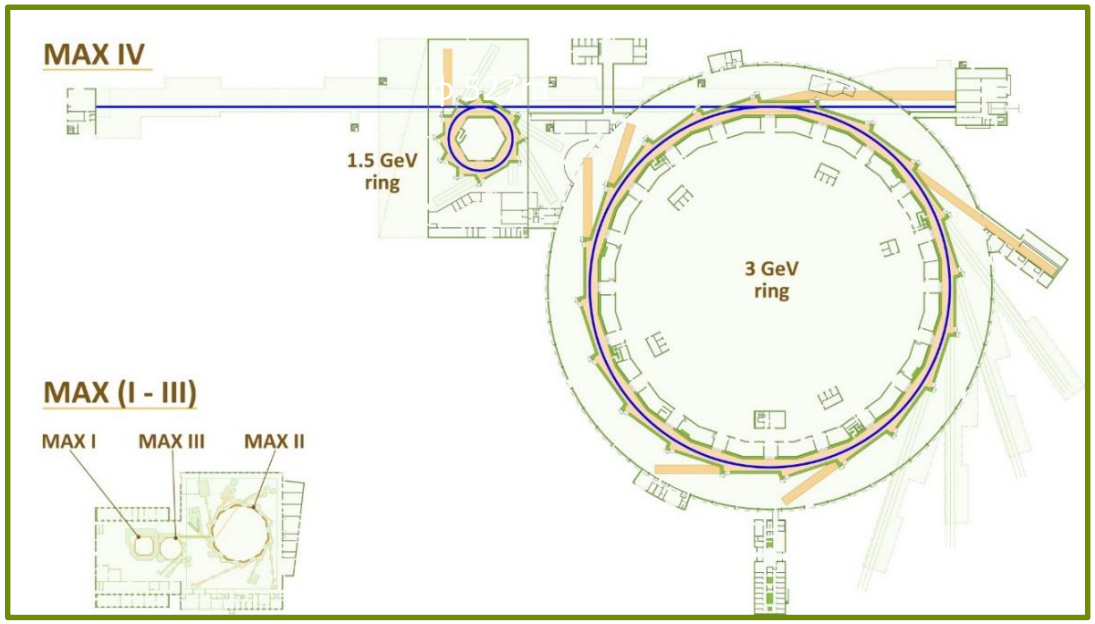
MAX-lab @ MAX IV Laboratory history





1981 - MAX-lab is formed
1986 - First experiments at MAX I
1997 - First experiments at MAX II
2005 – MAX IV Conceptual Design Report
2007 - First experiments at MAX III
2009 - Decision to build MAX IV
2016 - First experiments at MAX IV
2021 - First experiments at Soft X-FEL?

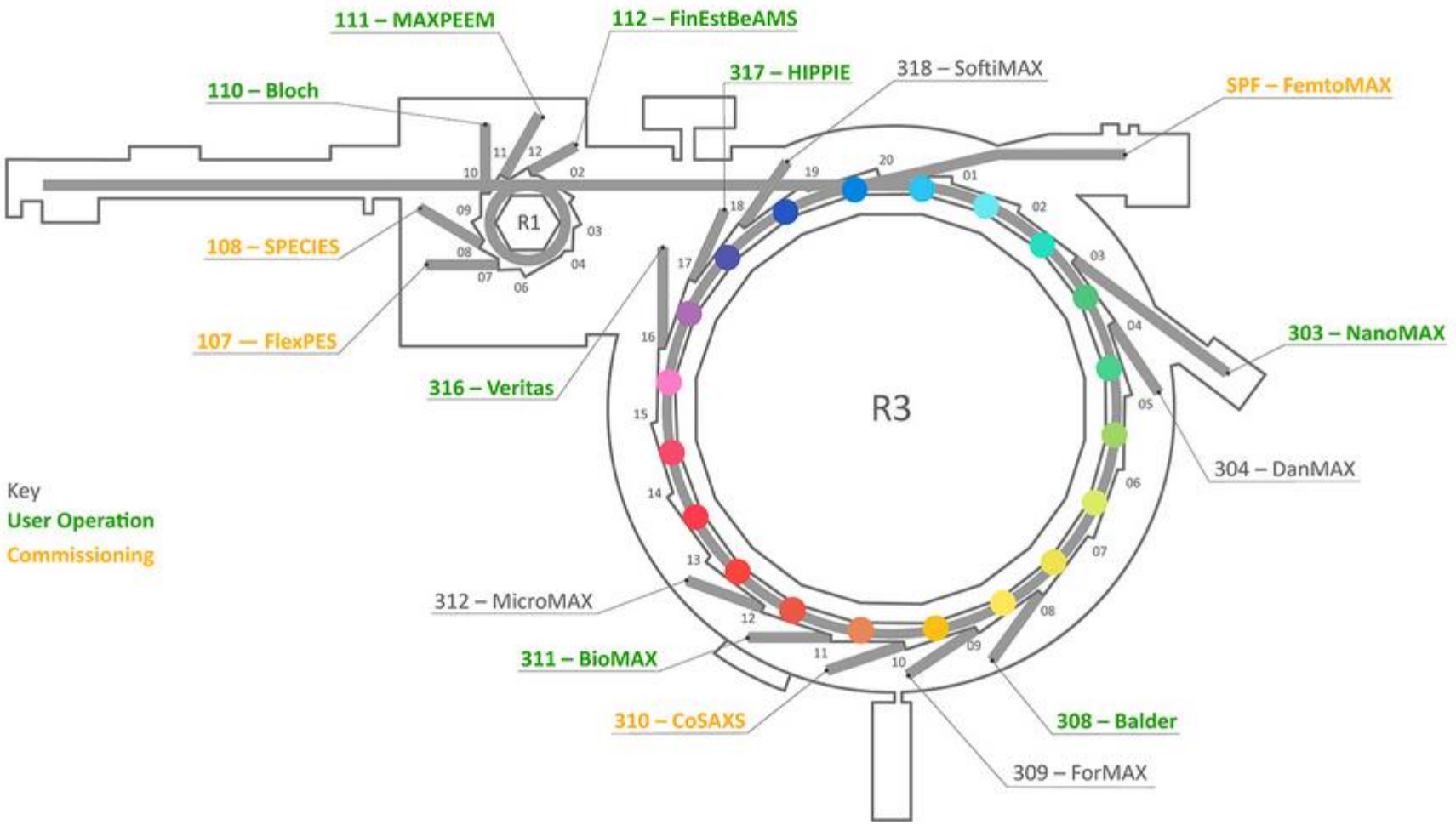
"It's too dangerous not to take the risks"

Conceptual Basis of the MAX IV

- Scientific Case calls for high brightness radiation over a wide spectral and time range: from IR to Hard X-Rays and Short X-Ray Pulses.
- Need for high brightness: low emittance and optimized insertion devices.
- This was hard to achieve in a single machine:
  - higher electron beam energy for harder photons
  - lower electron beam energy for softer photons

- Different machines for different uses:
  - A high energy ring with ultra-low emittance for hard X-ray users.
  - A low energy ring with low emittance for soft radiation users
  - A LINAC based source for generating short pulses and allowing for future development of FEL source.

Actual Beamlines map of the MAX IV

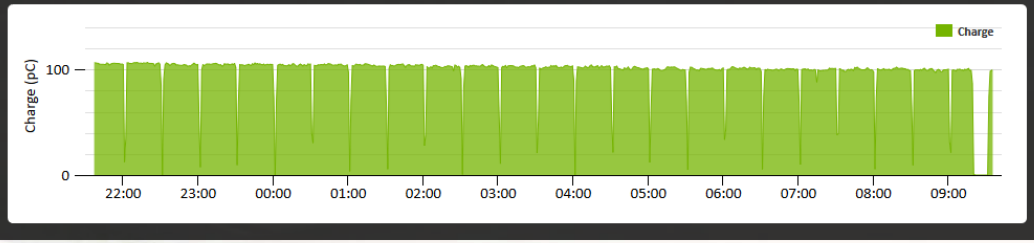


Machine Status MAX IV Laboratory

Linac successfully completed the task for which it was assigned

Linac

Repetition rate: **2 Hz**
Accelerated charge: **97.51 pC**



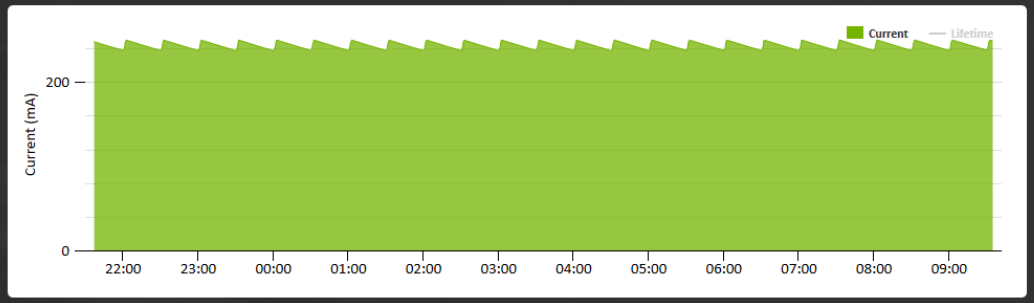
FemtoMAX	5.00	4.96

3 GeV Ring

247.56 mA **9.18 h**

Delivery: Top-Up

NEXT INJECTION:
2019-10-30 10:00:00



NanoMAX	37.32
DanMAX	
BALDER	5.00
CoSAXS	
BioMAX	5.01

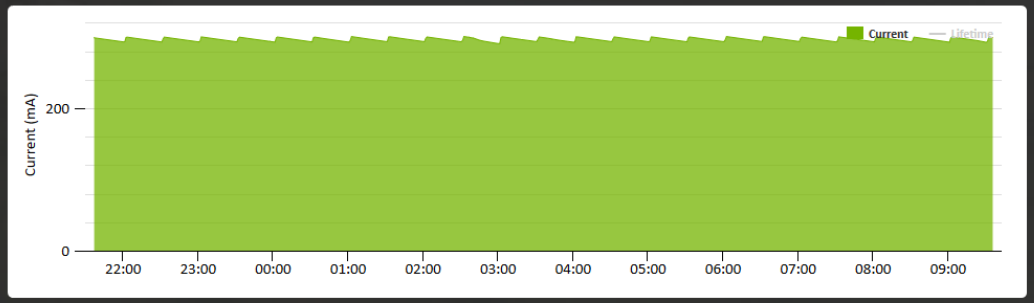
VERITAS	30.00
HIPPIE	36.06
SoftiMAX	

1.5 GeV Ring

298.50 mA **14.67 h**

Delivery: Top-Up

NEXT INJECTION:
2019-10-30 10:00:00



FlexPES	26.49
SPECIES	40.00
BLOCH	26.35
MAXPEEM	30.00
FinEst	50.34

Operator Message *2019-10-29 13:10*
R3: Delivery.
R1: Delivery.
Linac: Ring injections
SPF: Delivery

Safety Message

2019-10-30 09:36:45

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MAX IV Linac

The linear accelerator (Linac) at MAX IV is constructed for injection and top-up to the two storage rings and as a high brightness driver for the Short Pulse Facility. It is also prepared to be used as an injector for a possible future Free Electron Laser. Linac consists of three main hardware parts: RF power, wave guide and accelerator systems. Linac lies in two parallel tunnels: Klystron Gallery and Linac Tunnel:

The RF power system consists by:

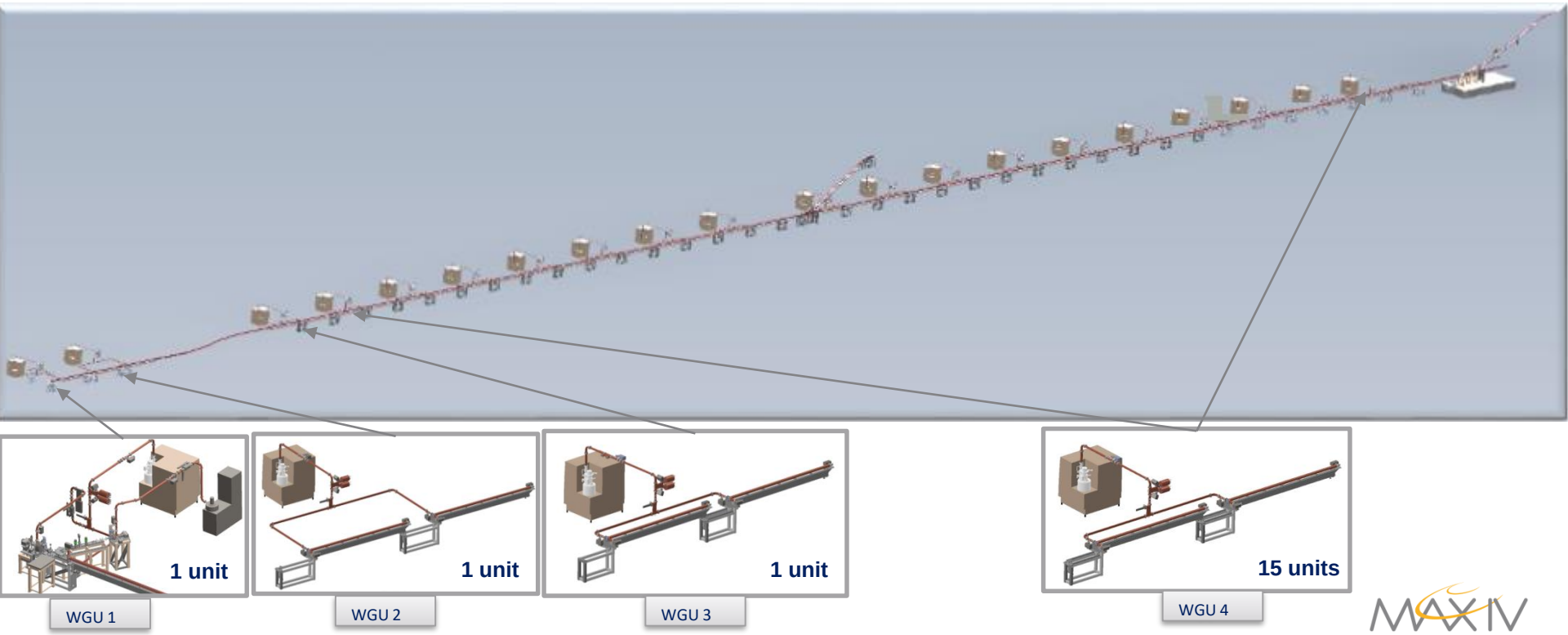
- ¤ 20+1 pcs: RF power units (37MW peak, 4,5usec, 100Hz),
- ¤ 1+1 pc: RF power unit (8MW peak, 3usec, 10Hz),

The wave guide and passive RF compressor:

- ¤ 300 m Wave guide
- ¤ 20+1 pcs: SLED (Q=100000, 4,5usec in, 0,7usec out),

The accelerator system:

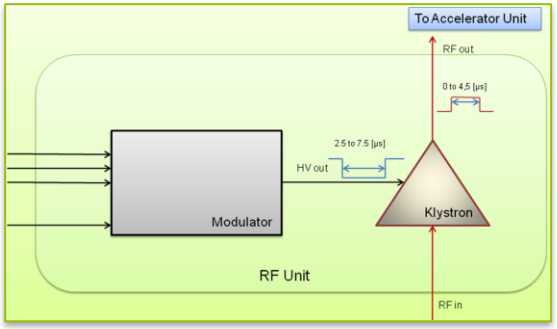
- ¤ 2 pcs: RF Guns (a thermionic and photo-cathode), MAX IV Laboratory
- ¤ 39 pcs: Linac structures (max gradient of acceleration 25MV/M, 5m long)



Klystron gallery

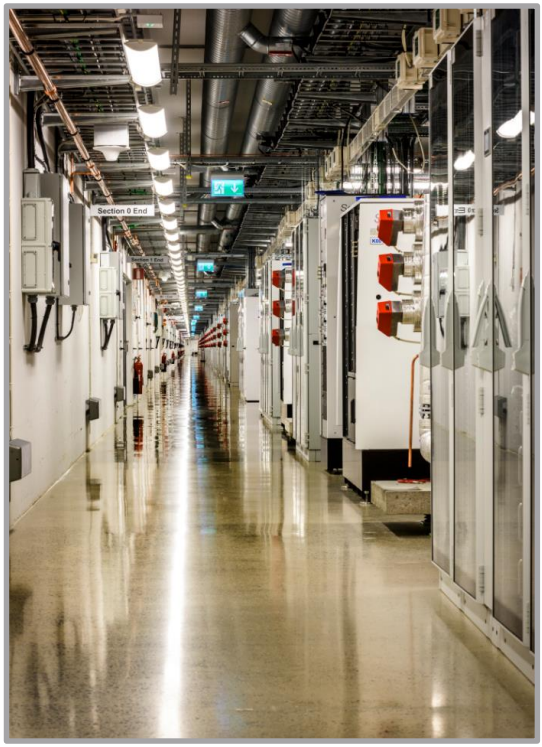
¤ 20 pcs SCN modulator model K2, Toshiba klystrons model E37310
¤ 1pc SCN modulator model K1, Toshiba klystron E37326

In MAX IV Laboratory dictionary:
ScandiNova means modulator and
Canon means klystron



Parameters of model K1 and K2 modulators

Parameters	K1	K2
Peak RF power output [MW]	20	38
Klystron Average RF Power [kW]	0.8	18
Klystron voltage range [kV]	170	300
Klystron current range [A]	140	350
Flat top pulse width variable [µs]	0-3	0-4.5
Voltage Pulse width variable [µs]	1-4	2.5-7
PRF variable [Hz]	0-10	0-100
Flat top ripple or droop [%]	± 1.0	± 1.5
Pulse to pulse amplitude stability [%]	±0.01	< ± 0.01
Pulse to pulse to pulse time jitter [ns]	< ±4	< ±6
Pulse length jitter [ns]	< ±8	< ±8
Modulator Electric efficiency [%]	> 80	> 80



- The modulator model K2, consists of three 25kW High Voltage Power Supplies (CCPS) and seven parallel High Power Switch Units (HPSU).

- The modulator K1, consist of one 25kW High Voltage Power Supplies (CCPS) and two parallel High Power Switch Units (HPSU).

Machine Operation Schedule MAX IV Laboratory

Based on MAX IV Laboratory Operation Schedule:

¤ Linac have to be in operation for 45 weeks in year

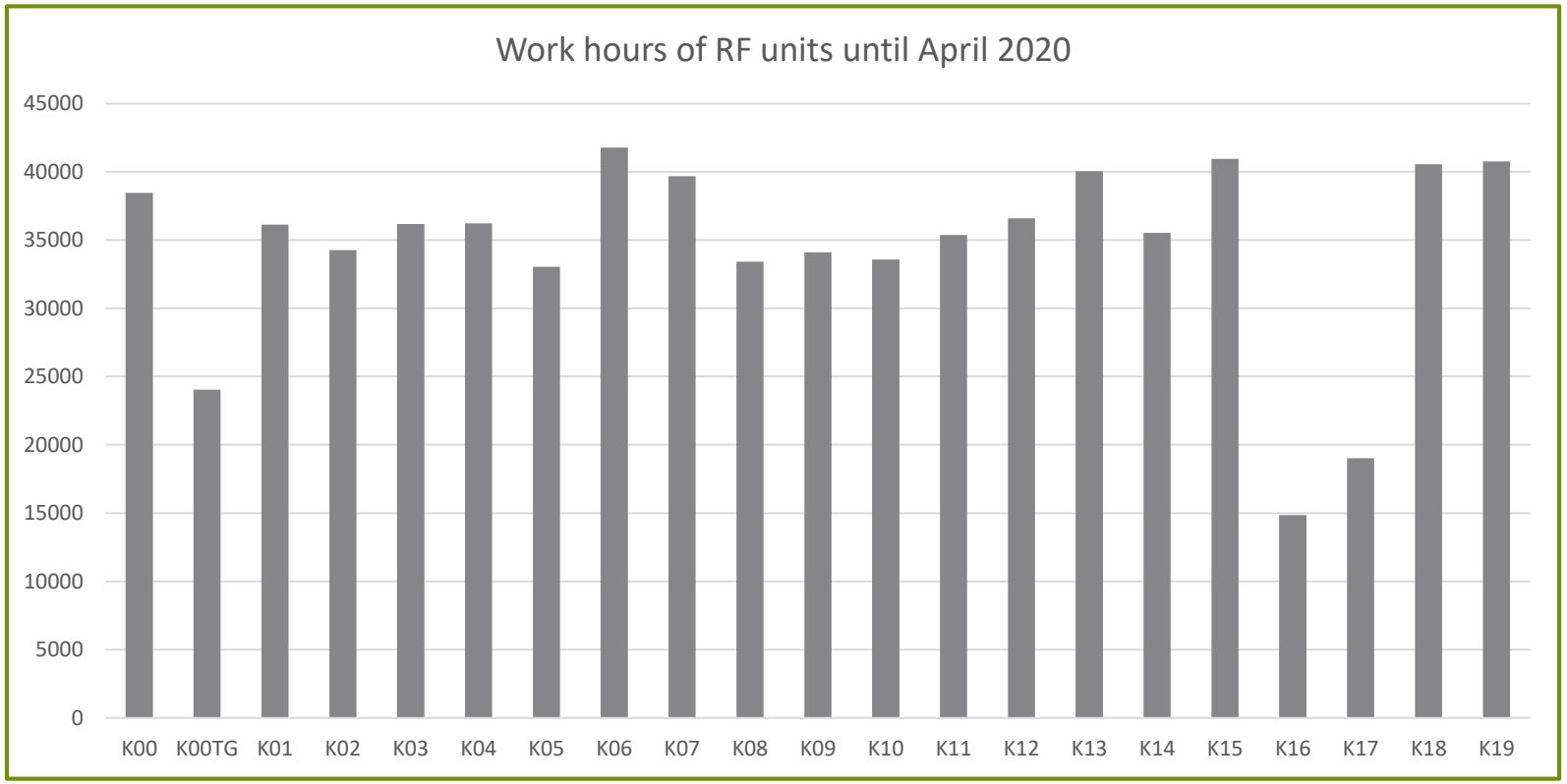
¤ Minimum running hours per week is 168 (18 hours under Monday and 24 hours for the rest 6 days of week)

¤ Linac is running with beam for 7300 hours per year (it means the RF units too are running for the same amount of hours)

¤ The klystron filament is ON for 7600 hours

Week	Start date	LINAC	R1 (1.5 GeV)	R3 (3 GeV)
31	July 29, 2019	Shutdown	Shutdown	Shutdown
32	August 5	Shutdown	Shutdown	Shutdown
33	August 12	Startup	Startup	Shutdown
34	August 19	Delivery to Rings	Delivery to beamlines	Shutdown
35	August 26	Delivery to Rings	Delivery to beamlines	Shutdown
36	September 2	Delivery to Rings	Delivery to beamlines	Startup
37	September 9	Delivery to Rings	Delivery to beamlines	Startup
38	September 16	Startup	Delivery to beamlines	Delivery to beamlines
39	September 23	Delivery to SPF & Rings	Delivery to beamlines	Delivery to beamlines
40	September 30	Delivery to SPF & Rings	Delivery to beamlines	Delivery to beamlines
41	October 7	Delivery to SPF & Rings	Delivery to beamlines	Delivery to beamlines
42	October 14	Delivery to SPF & Rings (reduced)	Delivery to beamlines	Accelerator Commissioning
43	October 21	Accelerator Commissioning	Delivery to beamlines	Delivery to beamlines
44	October 28	Delivery to SPF & Rings	Delivery to beamlines	Delivery to beamlines
45	November 4	Delivery to SPF & Rings	Delivery to beamlines	Delivery to beamlines
46	November 11	Delivery to SPF & Rings	Delivery to beamlines	Delivery to beamlines
47	November 18	Delivery to SPF & Rings	Delivery to beamlines	Delivery to beamlines
48	November 25	Delivery to SPF & Rings	Delivery to beamlines	Delivery to beamlines
49	December 2	Delivery to SPF & Rings	Accelerator Commissioning	Delivery to beamlines
50	December 9	Delivery to SPF & Rings	Accelerator Commissioning	Delivery to beamlines
51	December 16	Accelerator Commissioning (reduced)	Accelerator Commissioning	Accelerator Commissioning
52	December 23	RF Conditioning	RF Conditioning	RF Conditioning
1	December 30	RF Conditioning	RF Conditioning	RF Conditioning
2	January 6, 2020	Shutdown	Shutdown	Shutdown
3	January 13	Startup	Startup	Startup
4	January 20	Accelerator Commissioning (reduced)	Accelerator Commissioning	Accelerator Commissioning
5	January 27	Startup	Delivery to beamlines	Accelerator Commissioning
6	February 3	Delivery to SPF & Rings	Delivery to beamlines	Accelerator Commissioning
7	February 10	Delivery to SPF & Rings	Delivery to beamlines	Delivery to beamlines
8	February 17	Delivery to SPF & Rings	Delivery to beamlines	Delivery to beamlines
9	February 24	Accelerator Commissioning	Delivery to beamlines	Delivery to beamlines
10	March 2	Delivery to SPF & Rings	Delivery to beamlines	Delivery to beamlines
11	March 9	Delivery to SPF & Rings	Delivery to beamlines	Delivery to beamlines
12	March 16	Delivery to SPF & Rings	Delivery to beamlines	Delivery to beamlines
13	March 23	Accelerator Commissioning (reduced)	Accelerator Commissioning	Delivery to beamlines
14	March 30	Delivery to SPF & Rings	Delivery to beamlines	Delivery to beamlines
15	April 6	Delivery to SPF & Rings	Delivery to beamlines	Delivery to beamlines
16	April 13	Accelerator Commissioning (reduced)	Delivery to beamlines	Accelerator Commissioning
17	April 20	Delivery to SPF & Rings	Delivery to beamlines	Delivery to beamlines
18	April 27	Delivery to SPF & Rings	Delivery to beamlines	Delivery to beamlines
19	May 4	Startup	Startup	Startup
20	May 11	Radiological Survey	Radiological Survey	Radiological Survey
21	May 18	Radiological Survey	Radiological Survey	Radiological Survey
22	May 25	Startup	Delivery to beamlines	Delivery to beamlines
23	June 1	Delivery to SPF & Rings	Delivery to beamlines	Delivery to beamlines
24	June 8	Delivery to SPF (reduced) & Rings	Accelerator Commissioning	Delivery to beamlines
25	June 15	Delivery to SPF & Rings	Delivery to beamlines	Delivery to beamlines
26	June 22	Delivery to SPF & Rings	Delivery to beamlines	Delivery to beamlines
27	June 29	Delivery to SPF & Rings	Delivery to beamlines	Delivery to beamlines
28	July 6	Delivery to SPF & Rings	Delivery to beamlines	Delivery to beamlines
29	July 13	Shutdown	Shutdown	Shutdown
30	July 20	Shutdown	Shutdown	Shutdown
31	July 27	Shutdown	Shutdown	Shutdown
32	August 3	Shutdown	Shutdown	Shutdown
33	August 10	Shutdown	Shutdown	Shutdown

Work hours of RF Units



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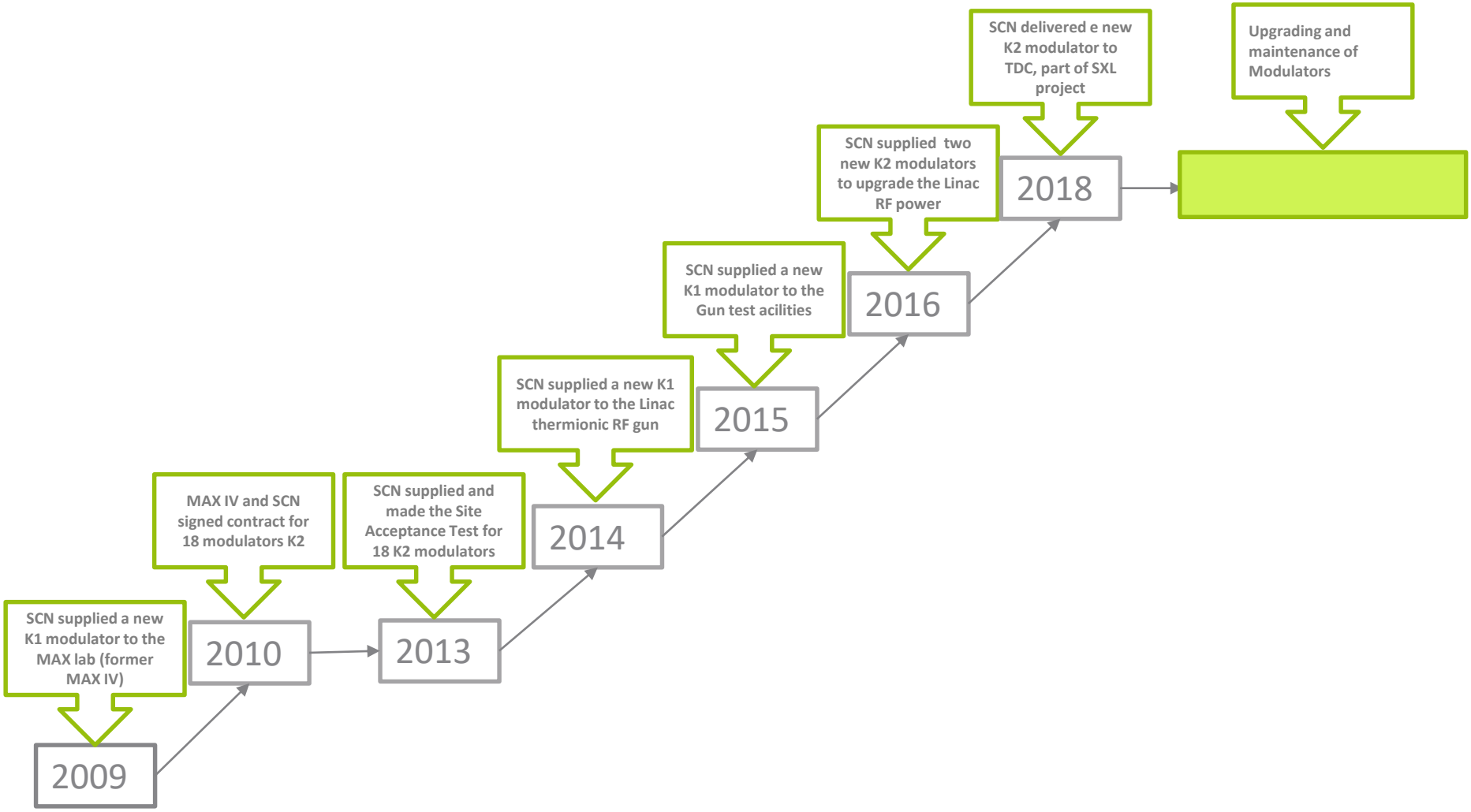
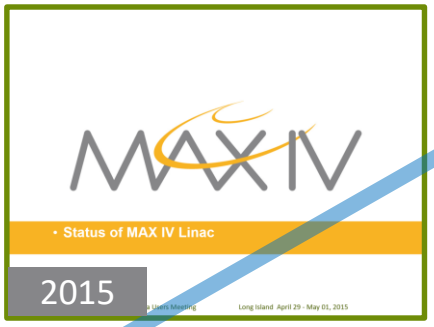
Cooperation and collaboration

Moments to mention in the collaboration of the MAX IV laboratory and the ScandiNova



MAX IV Laboratory & ScnadiNova User Meetings



Problems and solutions on RF Units

Below is a list of problems and solutions we have encountered with RF units from the beginning:

1. Transport damaged klystrons, which are favored by the klystron's position during transport (they were transported vertically with a very high center of gravity from the ground, as the lead used in their cocktail was very heavy.

2. Lack of conditioning for some klystrons

3. Klystron RF window problem, in some klystrons those without taking proper care during the assembly with waveguides, the dust part was deposited on the window surface, which unduly damaged the surface. (the orientation on vertical position of window is helping this too)

4. On the modulator, using the extended USB memory for some manufactured device routines, it helped got many false alarms and stops of modulators. Moving these drive routines into the hard disk made us get rid of them the noise.

5. I beginning we had problem oil filters electrical motors. The electric motor bearings of these pumps were of poor quality, so this made some pumps irreparably damaged. We changed all of the bearings of all pumps and never had a problem since that.

6. We were not satisfied with the solution made of the control and protection of oil cooling electrical motor (the alarm system did not signal when the motor has not feet with electrical power, but only when they had high temperature). In two cases these motors did not worked (there was no power supply) and not generate any interlocks. In agreement with SCN we are improving this, with a new supplement control.

6. The IGBT maximum current level of interlocks were to low, which artificially increase the false IGBT over-current alarms. In agreement with SCN, we increase this level for all IGBT-s and as a result the number of this type of alarm is significantly reduced.

7. Measuring the micro-perveances of the klystrons revealed another phenomenon, in our modulators we did not read the current and the high voltage correctly, they were saturated and showed of almost constant perveances for a whole year. After the new calibration of klystron current and voltage the micro-perveances measurements are going well.

8. After more than 7 years that the modulators in MAX IV are in operation for 24 \ 7, for the third time we dictate that a PS break down, and stop running the modulator and all Linac stops.
In agreement with SCN, we are changing all these old power supplies with a new and better performance to prevent an unwanted Linac stop.

9. The existing ion pumps high voltage power supplies, does not meet our needs for information on the vacuum condition inside the klystron, especially when we have activity (we are pretty blind in this regard). Therefore it is planned to replace them with those that inform in detail about the change of vacuum inside of klystron.

Summery of Linac interlocks during 2019

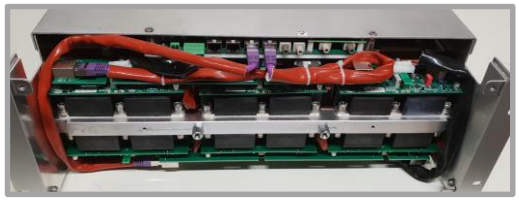
Modulator	Trig (Vac)	IGBT	Main Water	Flow	AvgPwr	Reflected	Current	Switch	Oil	Vacuum	Other
I-K00	35	0	0	5	0	0	1	0	0	0	48
I-K00 TG	35	2	3	0	0	0	0	0	0	0	1
I-K01	16	3	0	4	0	0	0	0	0	0	1
I-K02	0	3	1	2	0	0	0	0	0	0	1
I-K03	7	**7**	0	3	0	0	0	0	0	0	3
I-K04	0	1	0	3	0	0	0	0	0	0	2
I-K05	0	4	0	4	0	0	0	0	0	0	3
I-K06	0	3	0	5	0	0	0	1	0	0	2
I-K07	0	3	0	3	0	0	0	0	0	0	2
I-K08	1	2	2	1	0	0	0	0	0	0	5
I-K09	2	2	0	4	0	0	0	3	0	0	2
I-K10	0	1	0	5	0	0	0	1	0	0	2
I-K11	2	0	0	4	0	0	0	0	0	0	4
I-K12	2	0	3	3	0	0	0	0	0	0	2
I-K13	2	1	0	10	0	0	0	0	0	0	1
I-K14	0	0	1	2	0	0	0	0	0	0	6
I-K15	0	4	2	1	0	0	1	0	0	0	2
I-K16	3	2	0	3	0	0	0	6	0	0	5
I-K17	16	0	3	0	0	0	0	0	0	0	2
I-K18	5	0	0	3	0	0	0	0	0	0	2
I-K19	6	0	0	3	0	1	0	0	0	0	3

Linac RF Units Downtime

The main contribution of Linac RF Units downtime are:

- the damage of switch units (exactly one type of electronic component get broken)
- the klystron lose the conditioning (it was new installed klystron but had been stored for quite some years.

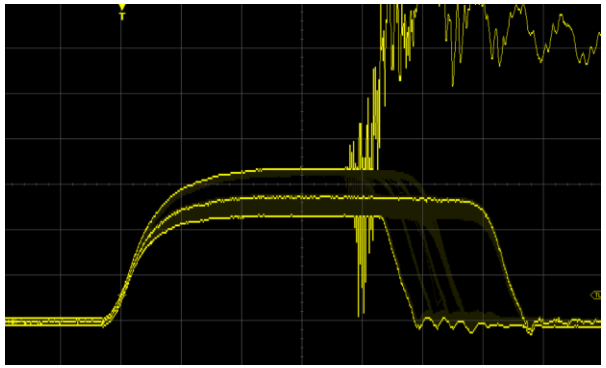
To re-establish a RF Unit after IGBT's defect requires at least 4 hours of intensive maintenance work



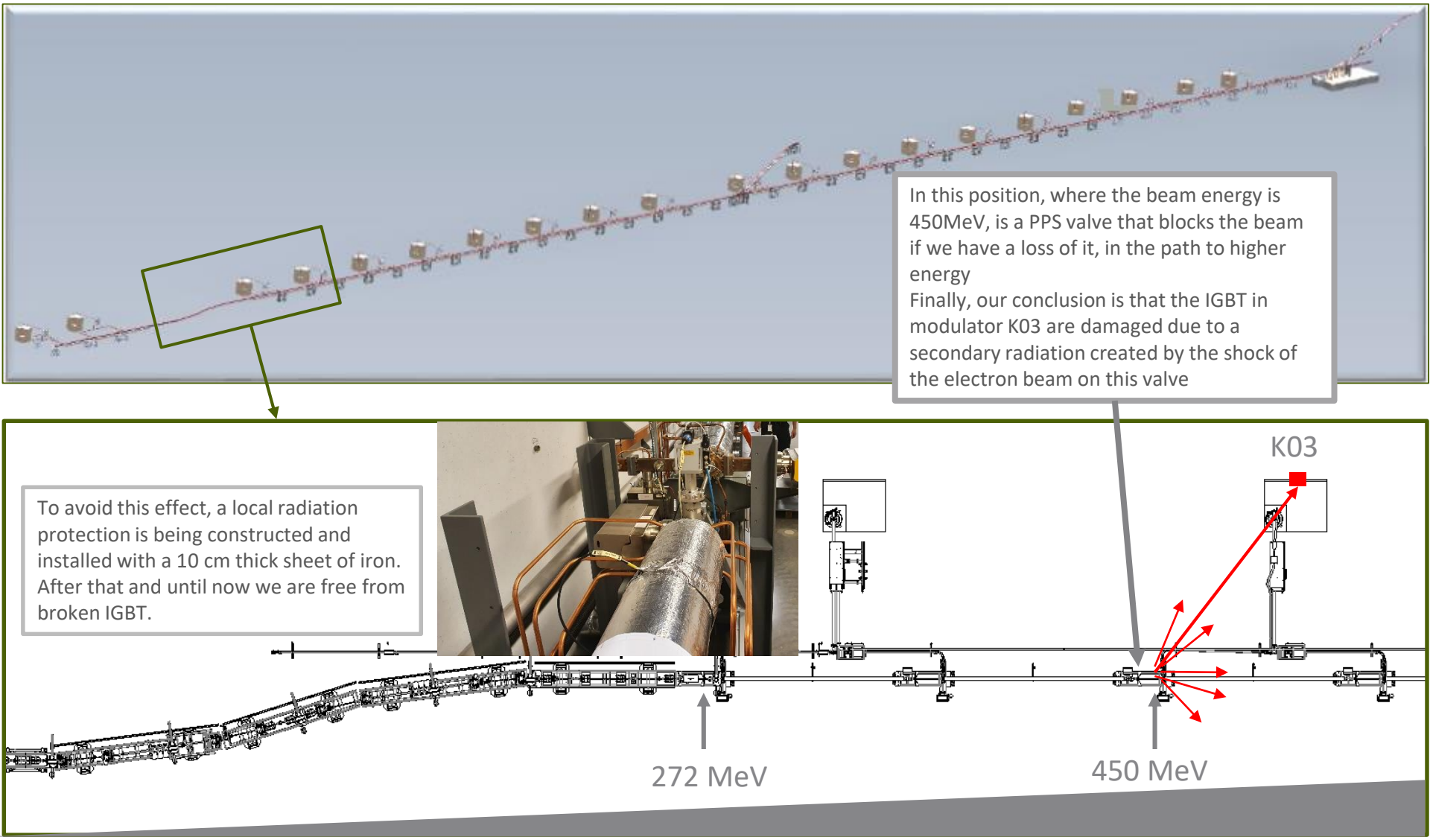
21 K02 x 7 HVSU = 147 x 6 = 882 IGBT's
21 K02 x 3 HVPS = 63 x 6 = 378 IGBT's
2 K01 x 3 HVSU = 6 x 6 = 36 IBGT's
2 K01 x 1 HVPS = 2 x 6 = 12 IGBT's

Total **1308** IGBT's

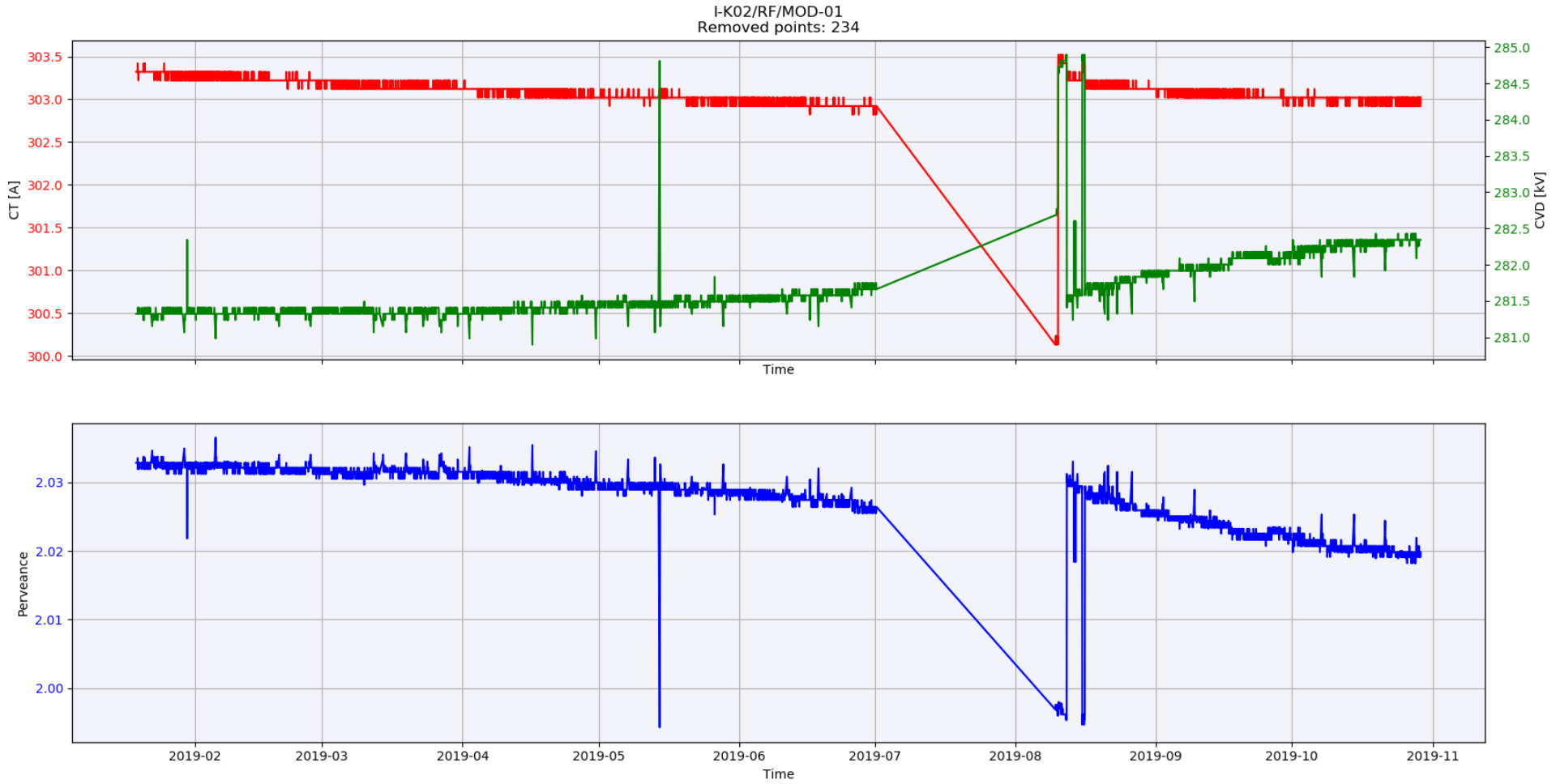
To re-establish a RF Unit after Klystron's defect requires at least 48 to 72 hours of intensive high voltage and high PRF conditioning process



Broken down component



Micro perveance development of K02



Content

- MAX IV Laboratory, Lund University Sweden
- What next? (MAX IV Laboratory)
- Installation and commissioning
- RF units and issues (four years experience)
- Conclusions

Conclusions

- We can not avoid having technical problems; doesn't mater how much you invest and how well a Linac will be built, it is impossible to have zero technical problems and shortcomings. But we can and have improved a lot to:
  - Avoid working under **high psychological pressure**, which has significantly reduced errors and increased the quality of repair.
  - Keep very **good relation and cooperation with manufactory companies** (in this case with SCN and Canon), we see these companies as part of our team.
  - S**horten as much as possible time** to restore the RF unit after having technical issues. Except for the replacement of a klystron, the repair time and put on operation an RF unit does not exceed 4 hours. Klystron exchanged can take 6-8 hours if the klystron is already conditioned or 24 hours if not.
  - **Preventive maintenance**, it is payed very much attention on this. During the planed shut down period of time we prepared a detailed plan what to control and substitute for preventive maintenance
  - **Sufficient qualified personal** and ongoing qualification for the maintenance. It has become clear in defect and critical situations, who should deal with this problem and what to do.
  - **Spare parts and insure a qualified assistance**, our goal is to have all spare parts possible needed for the RF unit maintenance. The most sensitive and difficult thing is to plan to have spare klystrons. It is a potential risk for us to face a critical situation "ketchup effect" when 18 klystrons work more than 40,000 hours, and it is not known how long they will work.
  - **Sufficient budget** for spare parts and repair assistance. RF units (modulator and klystron) having klystron component as consumable part, our goal is to keep the annual maintenance budget no less than 3% of the initial investment of them.
  - To facilitate **successful management** of difficult technical situations. All the spare parts are stored in rooms that are housed in the klystron gallery. Easily access to them and have prepared accessories that facilitate the work of transporting and mounting heavy parts of the modulator

……sometime small invention does great work

Klystron's conservation and transport in klystron gallery.

Thank You!!