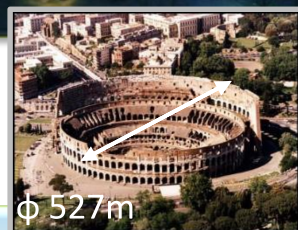
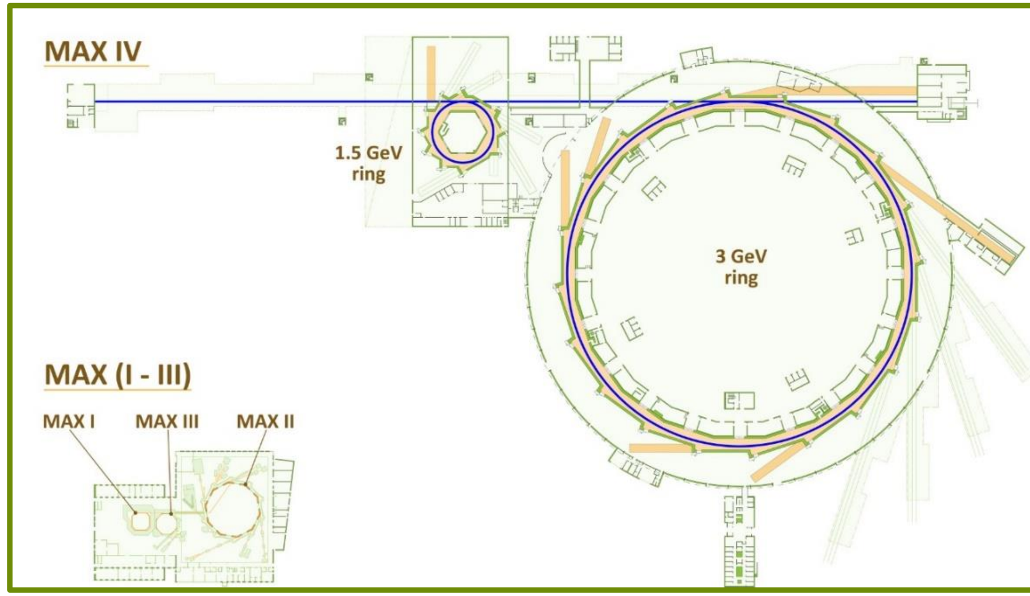
MAX IV Laboratory

RF Power at 3 GeV Linac and Highlights on 1.5 & 3 GeV Rings

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
- 2017 - First experiments at MAX IV
- *2021 - First experiments at Soft X-ray FEL*
- *2027 - First experiments at FEL 2*

Accelerator Road Map

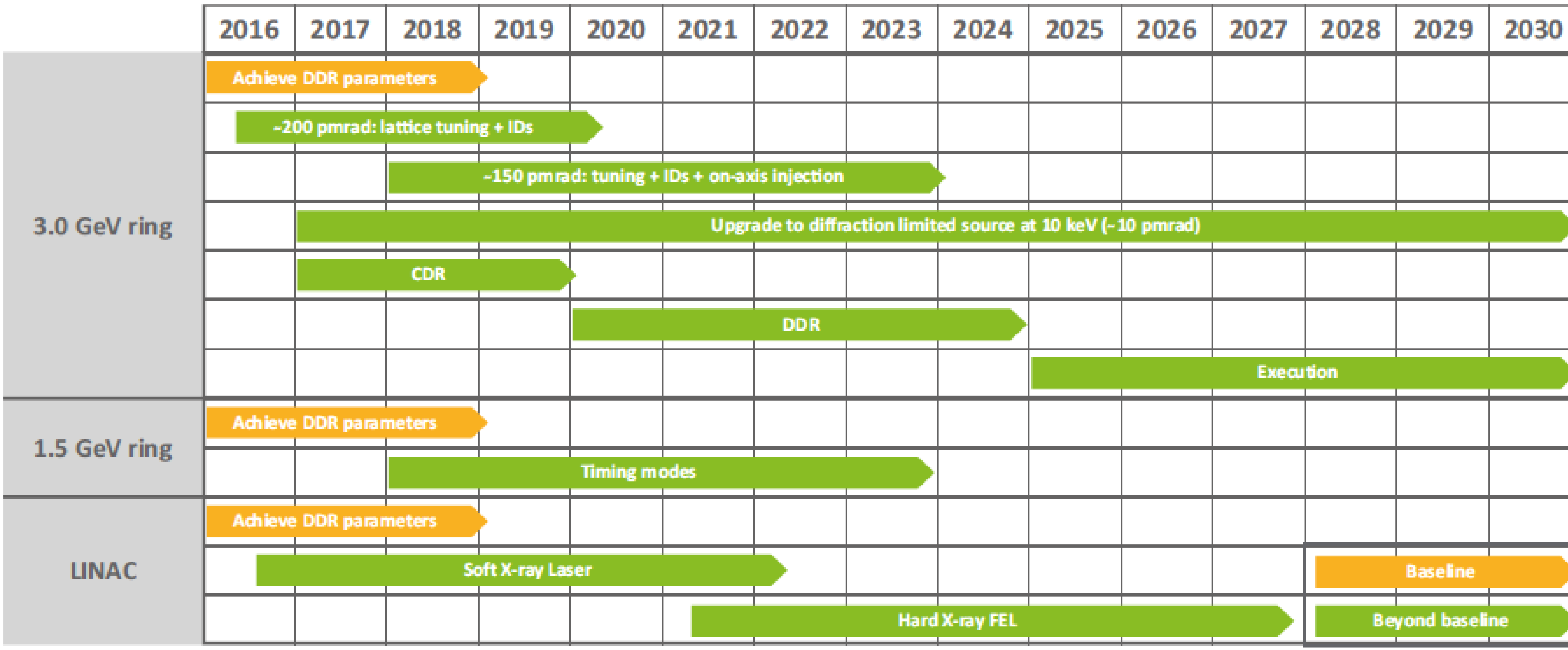


Figure 16. MAX IV Accelerators Roadmap: 2016-2030. Projects included in the base-line design are shown in orange whereas upgrades of the existing accelerators, including a FEL and a complete replacement of the 3 GeV ring are shown in green.

The MAX IV Accelerators

MAX-IV Laboratory Linac live

2011

Contracts were signed for the purchase of RF Units

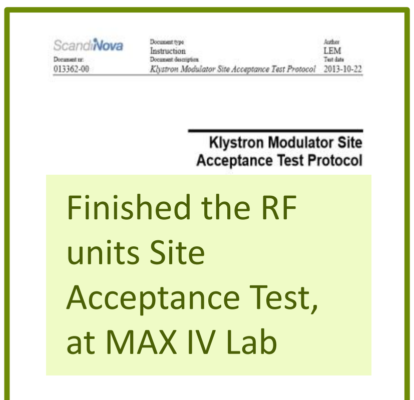
2012

Finished the RF units Factory Acceptance Test, at SCN

2013

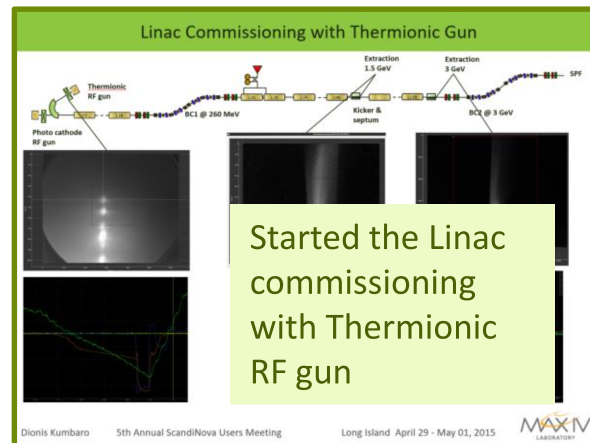
The Linac twin tunnels were ready for RF units installation

2014



Finished the RF units Site Acceptance Test, at MAX IV Lab

2015



Started the Linac commissioning with Thermionic RF gun

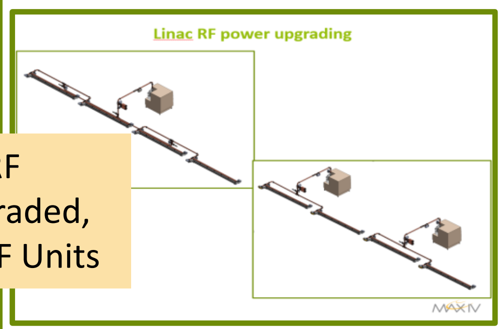
2016


Kungen vid invigningen av MAX IV-laboratoriet

Kungen tillsammans med statsminister Stefan Löfven och direktör Christoph Quitr
laboratoriet, vid invigningen av MAX IV. Foto: Kungahuset.se

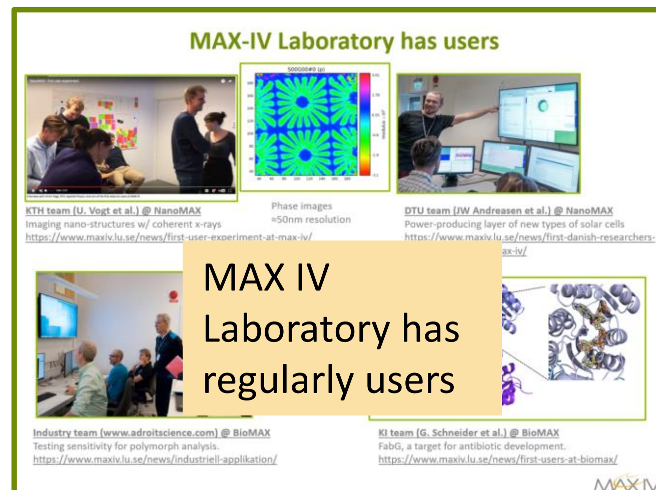
The Official inauguration of MAX IV Laboratory

2017



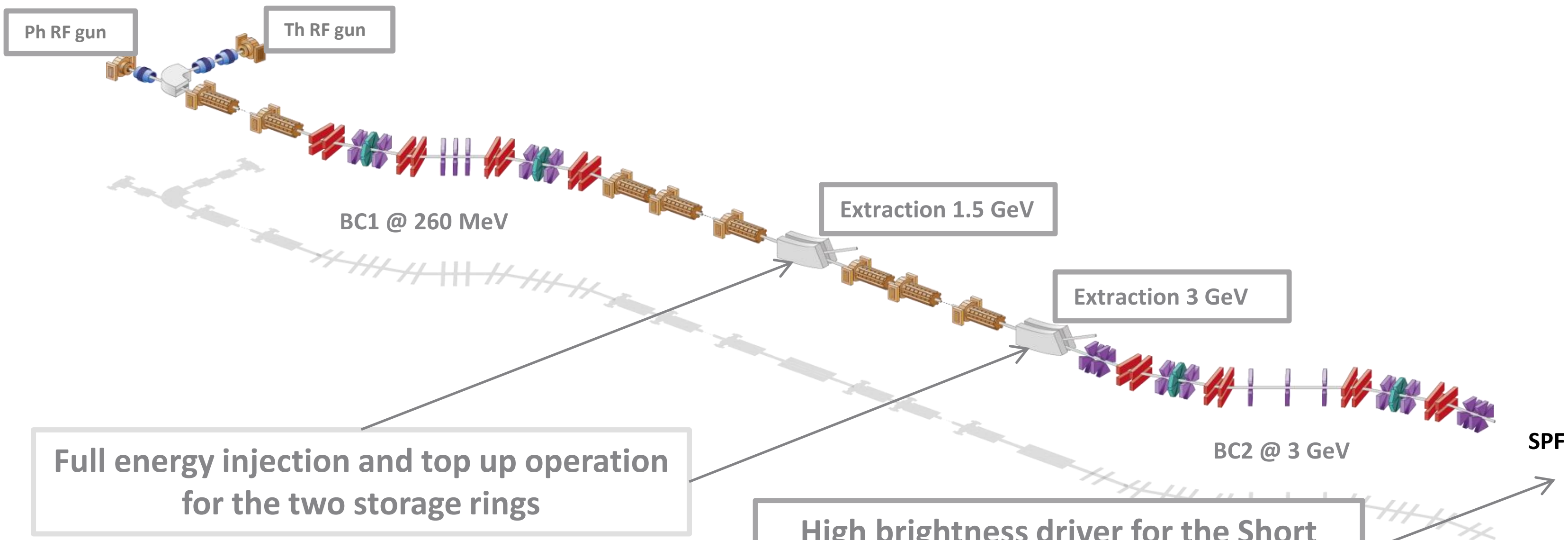
The Linac RF Power upgraded, with two RF Units

2018



MAX IV Laboratory has regularly users

MAX IV Linac overview



Full energy injection and top up operation for the two storage rings

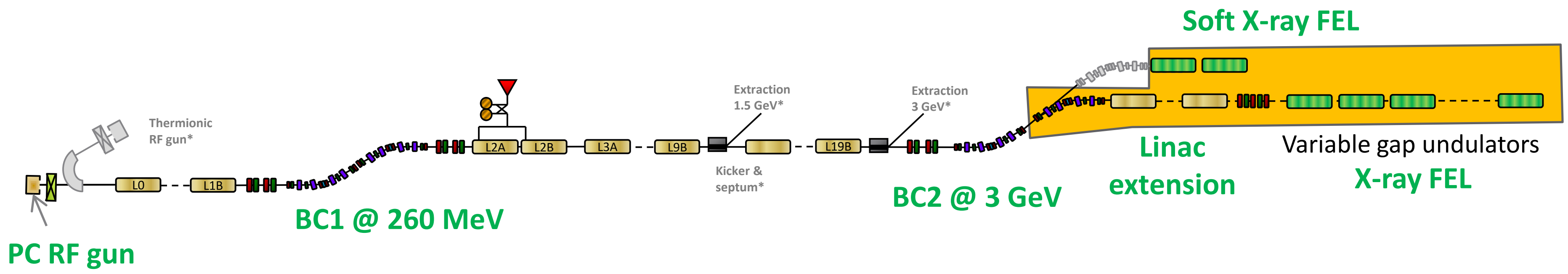
	Design	Currently
Energy	1.5 GeV/ 3GeV	1.5 GeV/ 3GeV
Repetition rate	10 Hz	2 Hz
Charge	0.6-1 nC/shot	0.3 nC/shot
Emittance	10 mm mrad	5 mm mrad
Energy spread	<0.2%	<0.25 %

High brightness driver for the Short Pulse Facility

	Design	Currently
Energy	3GeV	3 GeV
Repetition rate	100 Hz	2 Hz
Charge	100 pC	40-300 pC
Bunch length (rms)	100 fs	3 ps – 50 fs
Emittance	1 mm mrad	1-3 mm mrad
Energy spread	<0.4%	0.05-0.5%

Space for FEL

FEL at MAX IV Laboratory

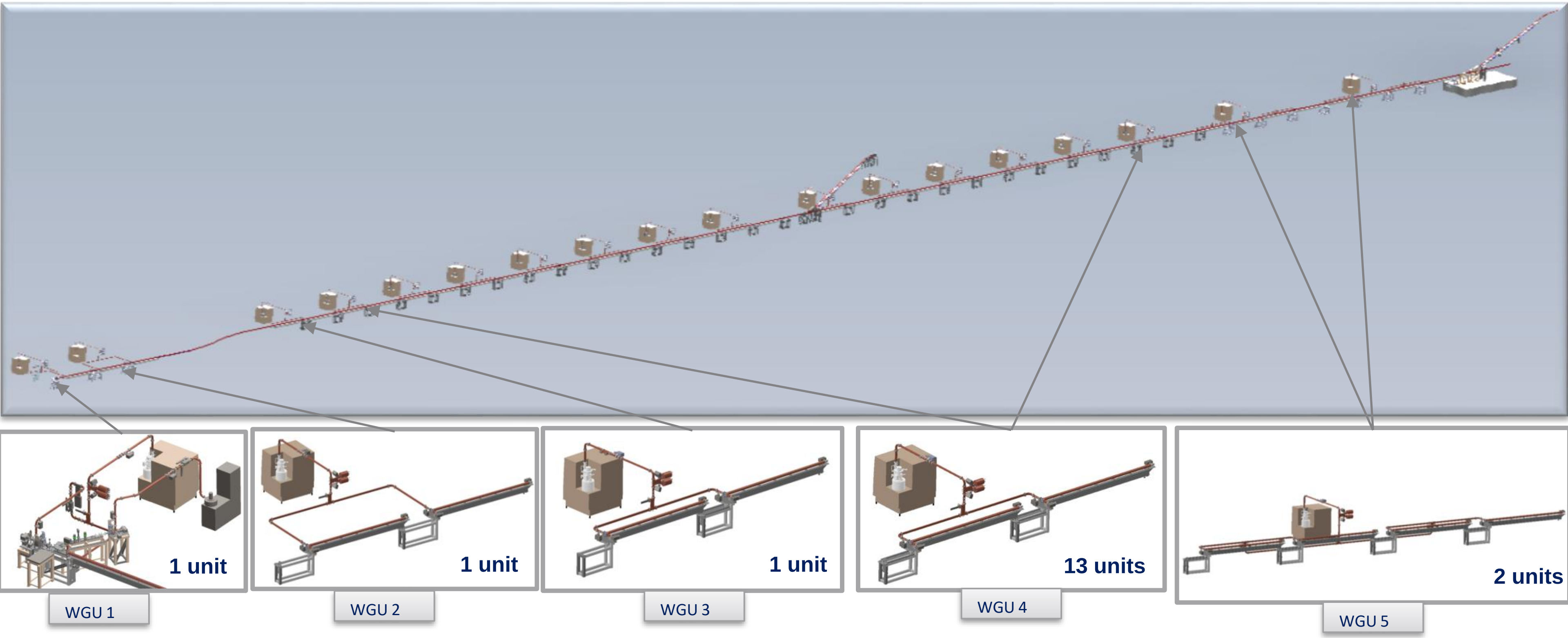


	FEL 1	*FEL 2*
Energy	5 (-6) GeV	2-3 GeV
Wavelength	2-10 Å (1.2-9 keV)	10-50 Å
Flux	10^{12} photons/pulse	
Undulator period	18 mm	
Undulator K-value	1.8-2.1	
Peak current	2-3 kA	
Charge	20-150 pC	
Beta function	7.5 m	
Emittance, norm	0.25-0.4 mm mrad	
Stability, mode control	Self seeding	

Linac configuration before RF Power upgraded

LINAC was build on modules: 5 different models for 18 modules

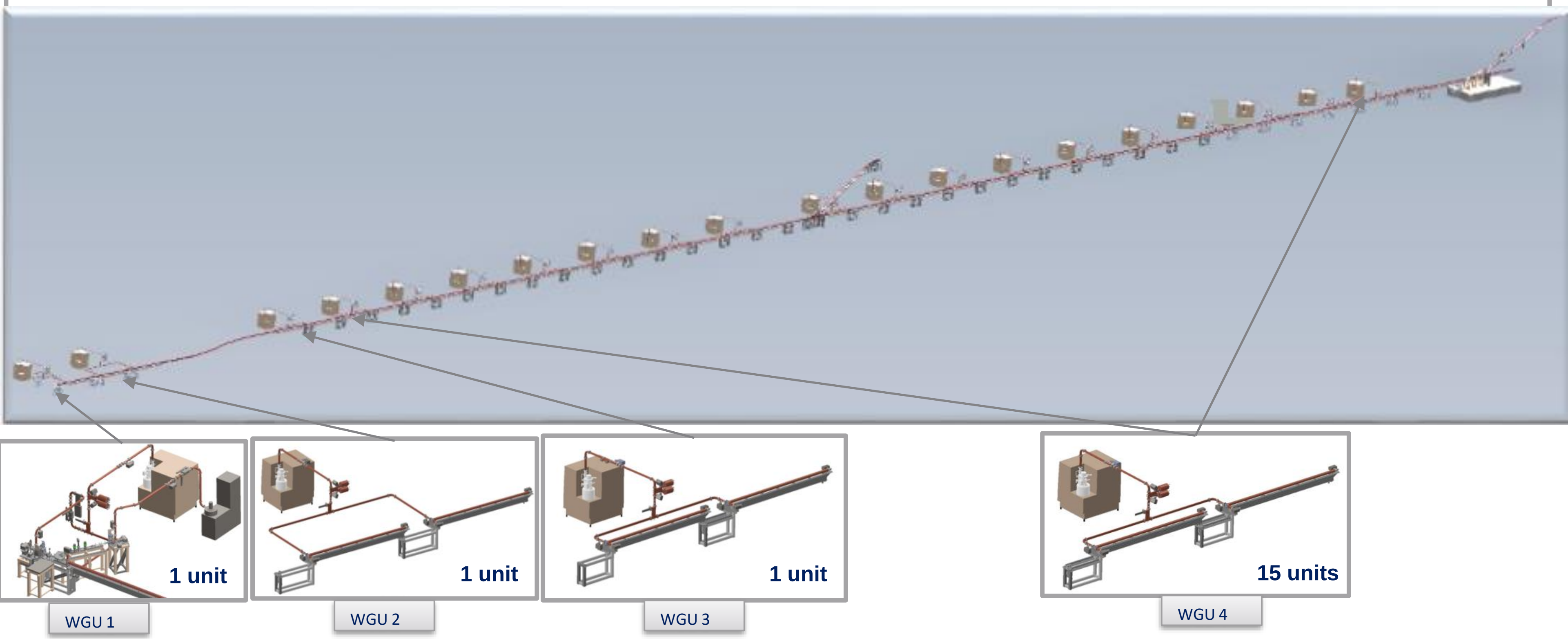
- **18 pcs:** RF power units (37MW peak, 4,5usec, 100Hz), ScandiNova mod & Toshiba klystron
- **1 pc:** RF power unit (8MW peak, 3usec, 10Hz), ScandiNova mod & Toshiba klystron
- **18 pcs:** SLED (Q=100000, 4,5usec in, 0,7usec out), RI
- **2 pcs:** RF guns (a therminioc, second photocathode), MAX IV Laboratory
- **39 pcs:** Linac structures (max gradient of acceleration 25MV/M, 5m long), RI



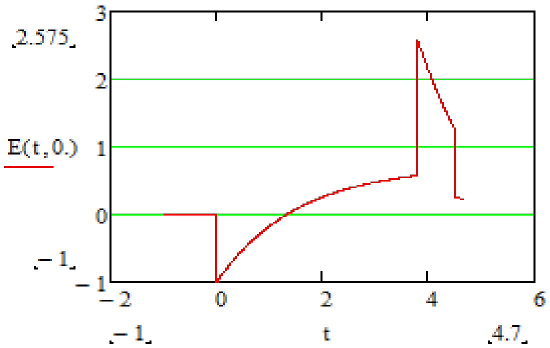
Linac today (upgraded summer 2017)

LINAC is build on modules: 4 different models for 20 modules

- **20 pcs**: RF power units (37MW peak, 4,5usec, 100Hz), ScandiNova mod & Toshiba klystron
- **1 pc**: RF power unit (8MW peak, 3usec, 10Hz), ScandiNova mod & Toshiba klystron
- **20 pcs**: SLED (Q=100000, 4,5usec in, 0,7usec out), RI
- **2 pcs**: RF Guns (a thermionic and photo-cathode), MAX IV Laboratory
- **39 pcs**: Linac structures (max gradient of acceleration 25MV/M, 5m long), RI

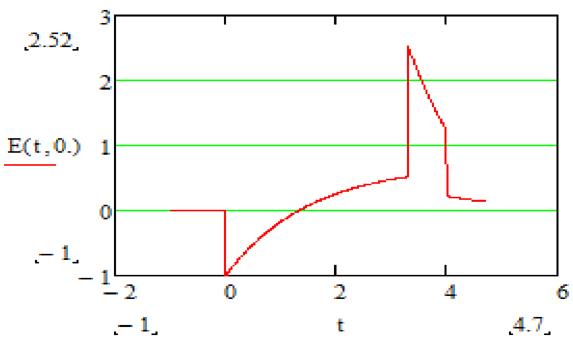


Linac energy adjustment

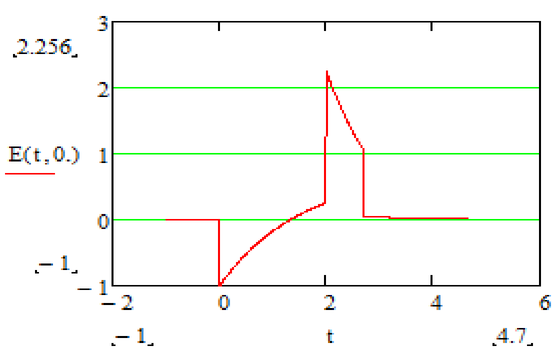


Charging time

3.8 µs



3.3 µs

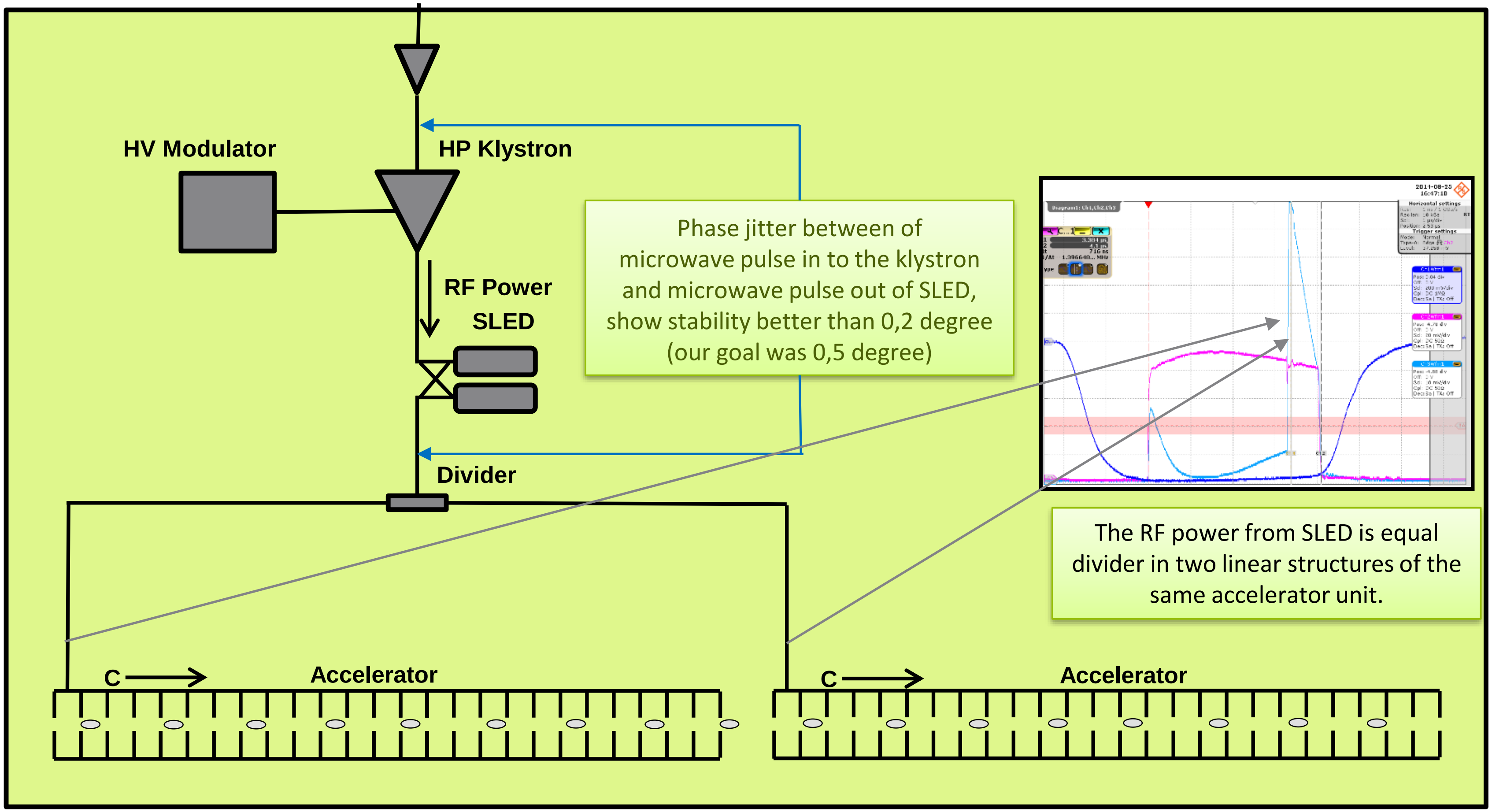


2.0 µs

The klystrons are running at konstant voltage to maintain a constant RF phase at the output. In order to reduce klystron output power variations due to variations in the input power they are run in sturation mode.
The output power from SLED is adjusted by varying the charging time.

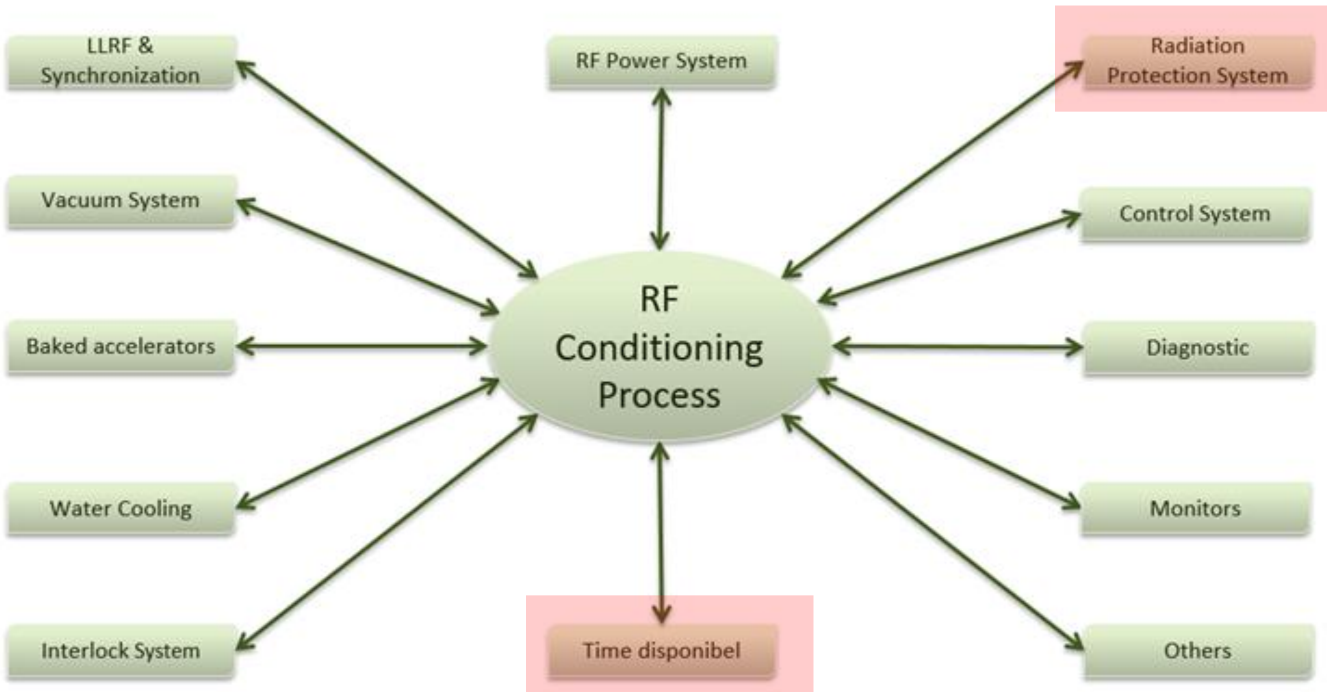
SLED data
β=6
$Q_0=10^5$

Phase jitter & RF Power measurements



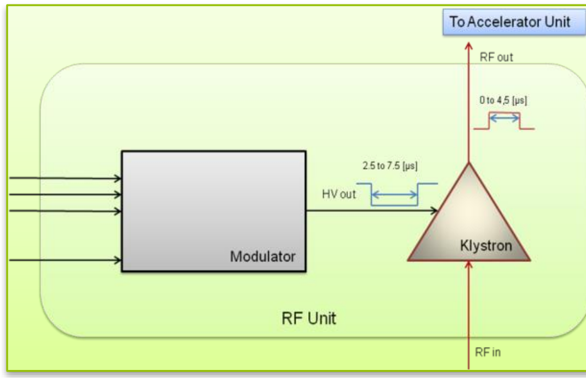
II. RF Conditioning

 # Subsystems and conditions to be satisfied for having successfully completed the conditioning process



Klystron gallery

¤ 20 pcs SCN modulator model K2, S-band Toshiba klystrons model E37310
¤ 2pc SCN modulator model K1, S-band Toshiba klystron E37326

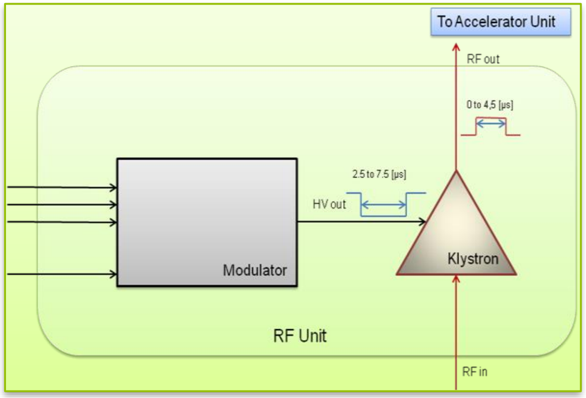


- The modulator K2, have three 25kW High Voltage Power Supplies (HVPS) and seven parallel High Power Switch Units (HPSU).

- The modulator K1, have one 25kW High Voltage Power Supplies (HVPS) and three parallel High Power Switch Units (HPSU).

Modulator

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



- Three principal concepts:
1. Split Core
2. Parallel Switching
3. Pulse to Pulse Control

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

In our case:
- K1 modulator has one HVPS and two parallel switching units.
- K2 modulator has three HVPS and seven parallel switching units.

Klystrons

Klystron E37326 and E37310 parameters

Parameters	E37326	E37310
Frequency [MHz]	2998,5	2998,5
Peak forward beam voltage [kV]	165	295
Peak cathode current [A]	120	345
Peak drive RF power [W]	120	1000
Peak RF output power [MW]	8,5	38
Average RF output power [kW]	10	20
Klystron efficiency [%]	40	40
Pulse width (epy duration) [µs]	7,5	7,5
Pulse width (RF duration) [µs]	5	4,5
Pulse repetition rate [hz]	300	120
Gain (saturation) [dB]	48,0	48,5
Perveance [µP]	1,8	2,2

PULSED KLYSTRON AMPLIFIER E37310

TOSHIBA E37310, S-band high-power pulsed amplifier klystron, is designed for linear accelerators.
The E37310 delivers 37 Mw peak output power with a power gain of more than 48.5 dB and with an efficiency of more than 40%. (*1)

The electron beam is focused with the electromagnet VT-68922.

An "M"-type dispenser cathode with high reliability promises long tube life.

Based on our several years of experience and the generous help of Toshiba, we came to the following explanations and conclusions

Operating principle of klystrons (courtesy Toshiba)

Klystron is a microwave amplifier

Output window

Collector

RF output

Density modulation
(Electron bunching)

RF cavities

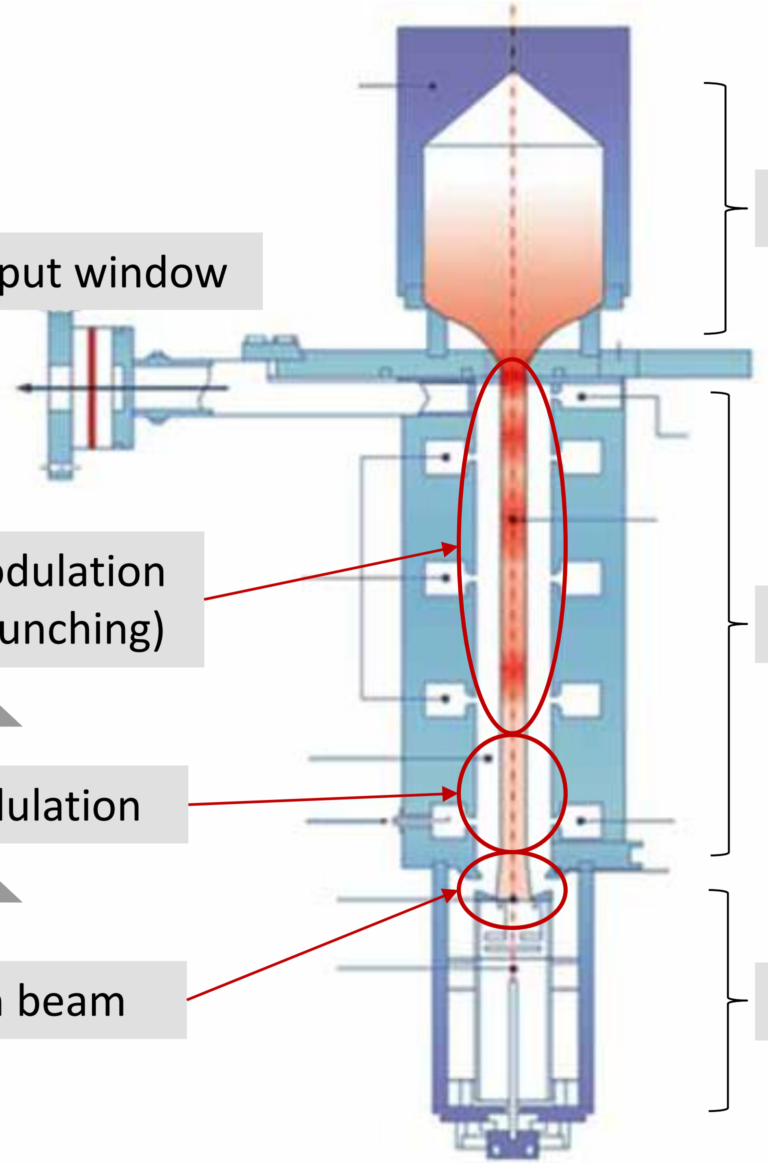
Interaction with RF

Velocity modulation

RF input

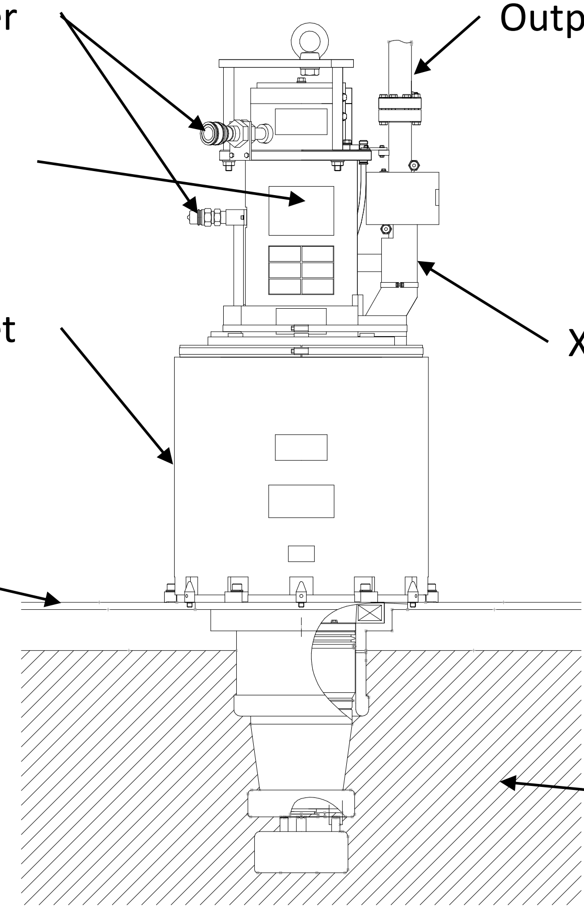
DC electron beam

Electron gun



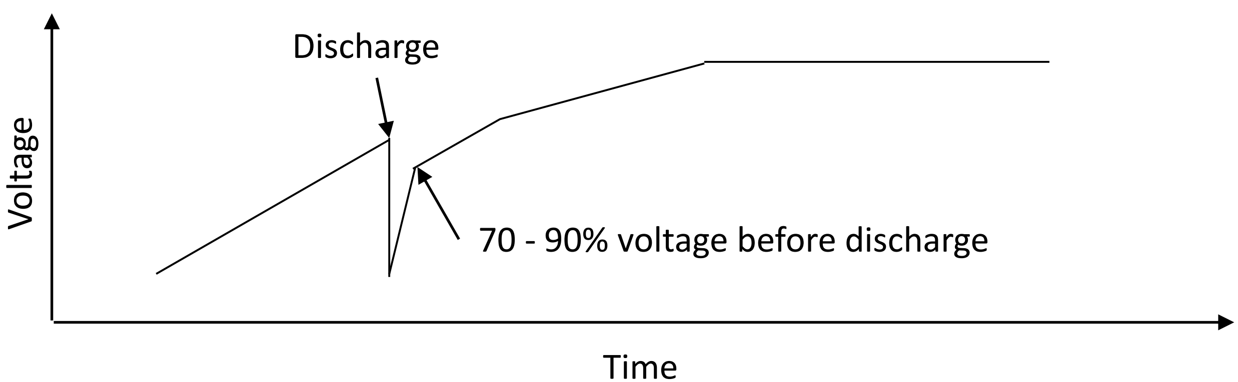
Operating instruction of klystrons

- Installation
  - Oil tank
  - Electromagnet
  - Klystron
  - X-ray shielding
- Connection
  - RF input/output
  - Ion pump
  - Other electricity
  - Cooling water
- Preparation
  - De-gas oil tank
  - Evacuation or pressurize waveguide



Operating instruction of klystrons

- DC startup: conditioning of electron gun
  - Before start operation;
    - Heater warm-up — >1 hour
    - Cooling water flow — The system normally cooled
    - Electromagnet current — Electron beam normally focused
    - Ion pump current — Good vacuum condition
  - High voltage application
    - Increase voltage slowly from low level
    - Avoid large discharge

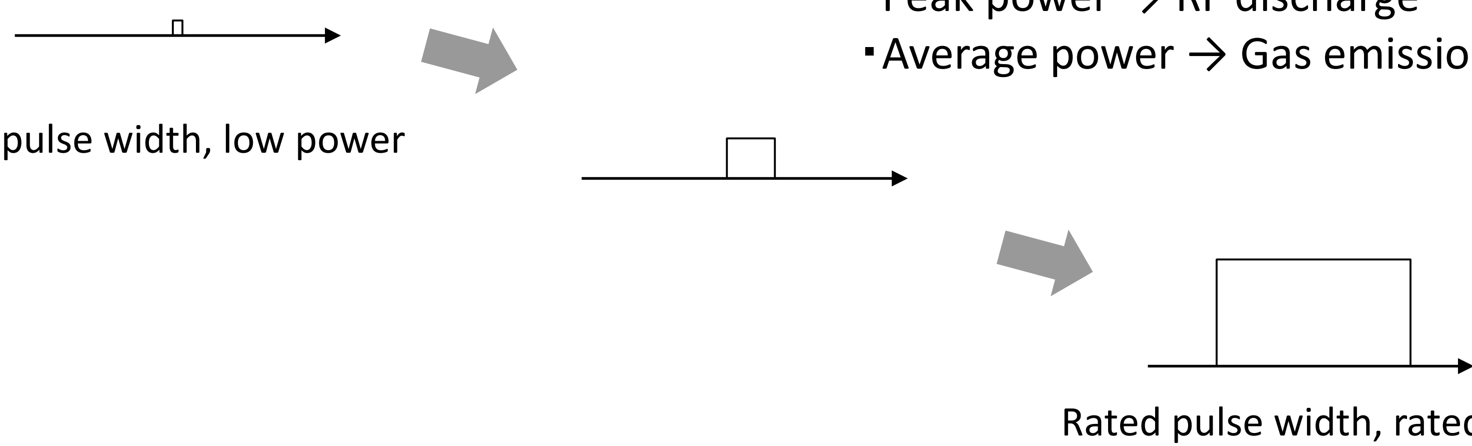


Operating instruction of klystrons

- RF startup: conditioning of RF system
  - Before start operation
    - Waveguide condition
  - RF application
    - Increase RF energy from low level
      - Peak power and average power

Conditioning factor

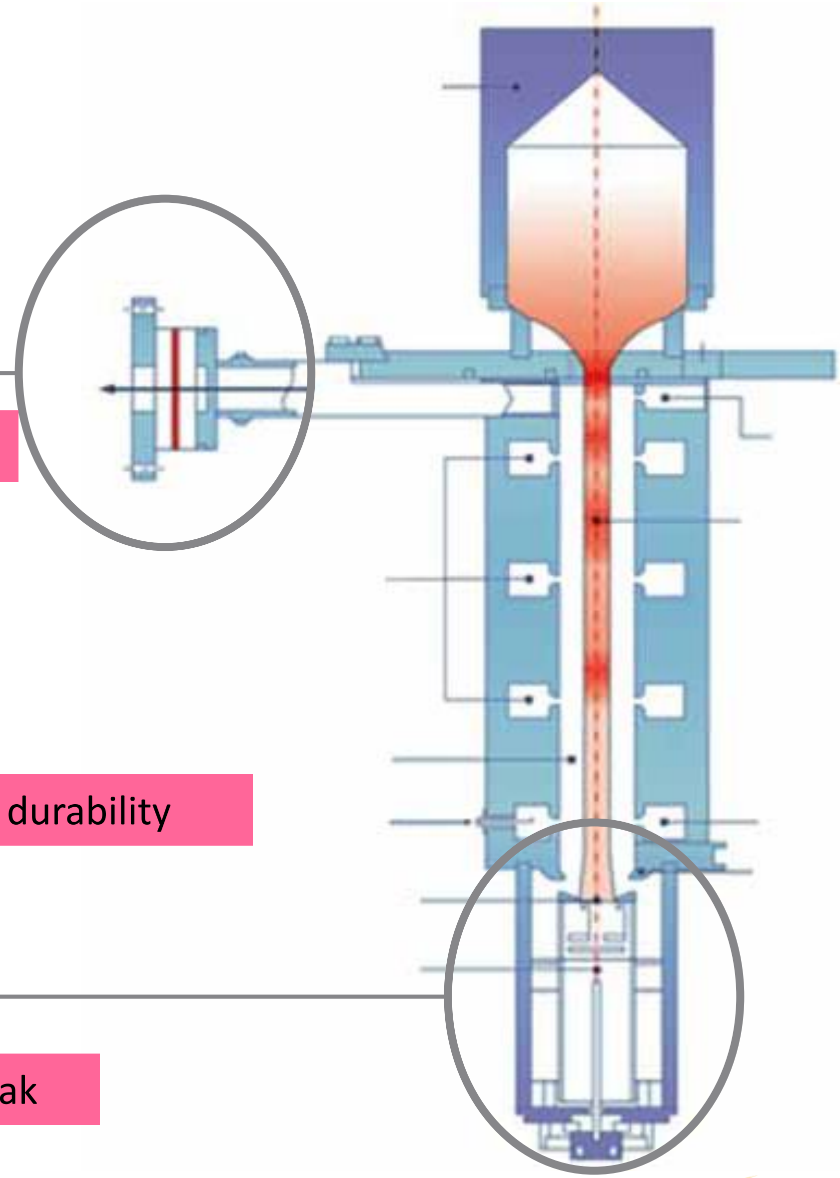
- Pulse width → Multipactor
- Peak power → RF discharge
- Average power → Gas emission



Weak parts of klystrons

Weak parts and major failure modes

Output window



1. Thermal load
2. High electric field strength

→Window ceramic leak

Electron gun

Large energy of discharge

→Degradation of high voltage durability

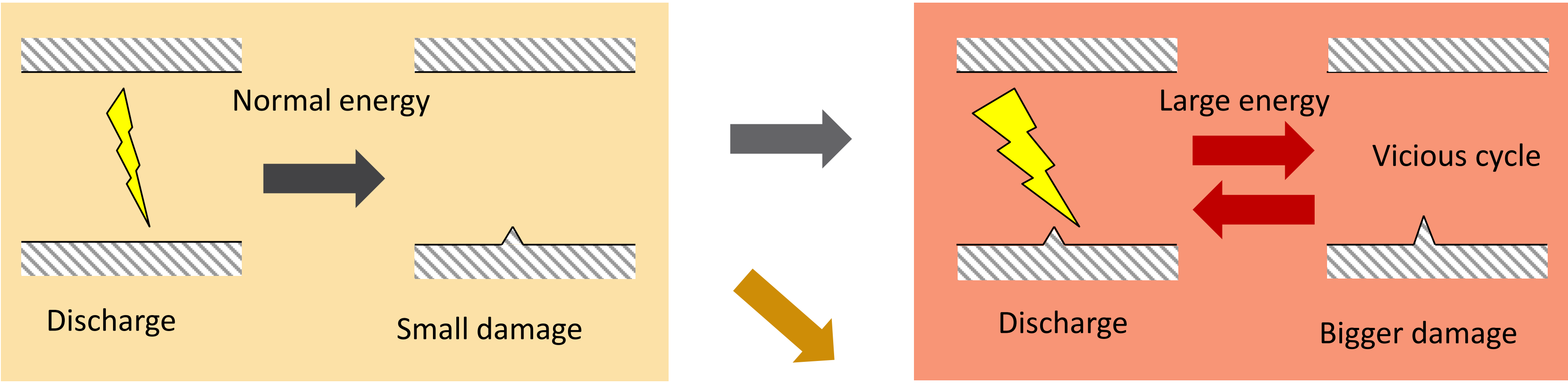
Gun ceramic

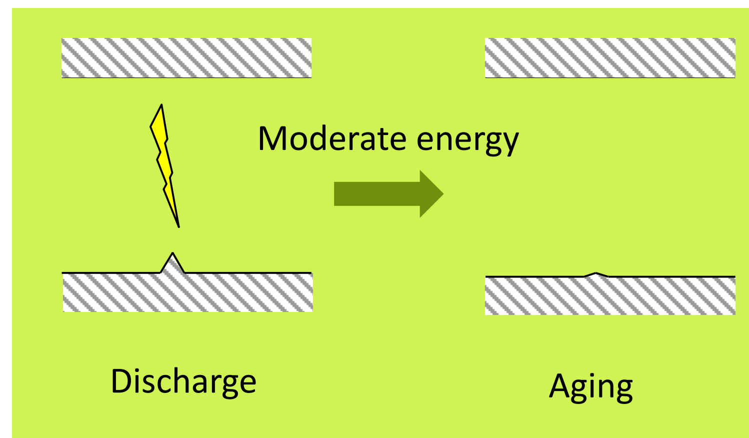
Creeping discharge or partial charging

→Gun ceramic leak

Electron gun failure

- Degradation of high voltage durability





- Gun ceramic leak

Creeping discharge
Partial charging

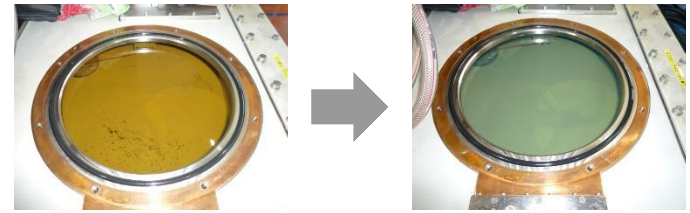
Damage on ceramic

Damaged gun ceramic

Courtesy Toshiba

Electron gun protection

Remove the causes of discharge



Dust or soil in the insulation oil
Check the oil quality periodically

Bubbles in the insulation oil
De-gas the oil tank

Dust or stains on the electron gun ceramic
Cover the ceramic by plastic bag during storage

Interlocks

Beam current monitor
Beam current increases during arcing.

Ion pump current monitor
Arcing cause gas emission.

Interlock recommendation (factory setting)

__Several J__ of discharge energy
→ Depends on:
- Beam energy
- Electron gun size
- Operation mode (CW or pulse)

Courtesy Toshiba

Output window failure

Even though the design key point have been:

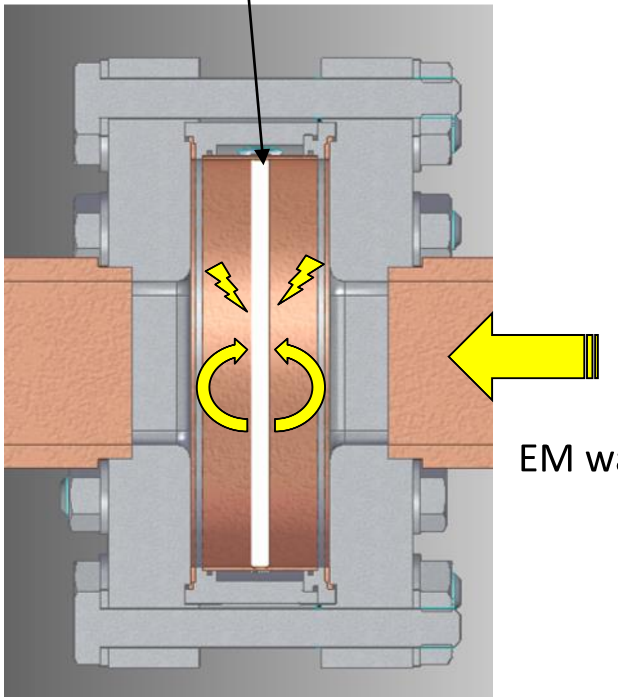
1. Peak power durability (electric field)
   - Vacuum or SF6 condition
   - Multipactor suppression TiN coating

2. Average power durability (thermal)
   - Low tanδ material
   - Water cooling

RF discharge on ceramic surface created by:
- VSWR degradation
- Multipactor
- Bad waveguide condition
- Dust or soil (had a greater weight in our case)

These discharge gives the window thermal stress which caused the cracks on it

Broken window



How Klystron conditioning goes:

- In factory Conditioning and Testing flow
  - SK: spot knocking
  - DC aging: Static electric field conditioning
  - RF aging: RF electric field conditioning
  - Testing: Confirm all parameters satisfy the specification

- In MAX IV Laboratory
  - DC aging: Static electric field conditioning
  - RF aging: RF electric field conditioning

How Klystron conditioning goes in factory

①DC aging

Enhance high voltage durability of electron gun

Aging of collector

Important interlocks

Ion pump current of klystron

Beam current

Take 1 or 2 days

②RF aging

Aging of RF components

Waveguide

Output window

Other RF components

Important interlocks

Waveguide pressure

VSWR

Take 1 or 3 weeks

How Klystron conditioning goes in MAX IV

①DC aging

Enhance high voltage durability of electron gun, began with very short pulses and increase the HV more than 20% of nominal value.

Take 8 to 24 hours

Important interlocks

- Ion pump current of klystron
- Beam current

②RF aging

Aging of RF components

- Waveguide
- Output window
- Other RF components

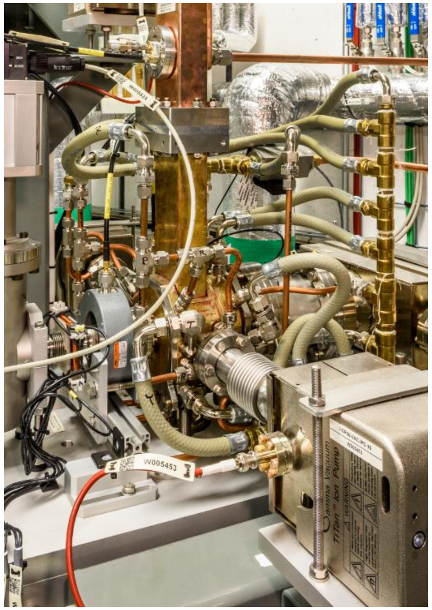
Take 1 or 2 days

Important interlocks

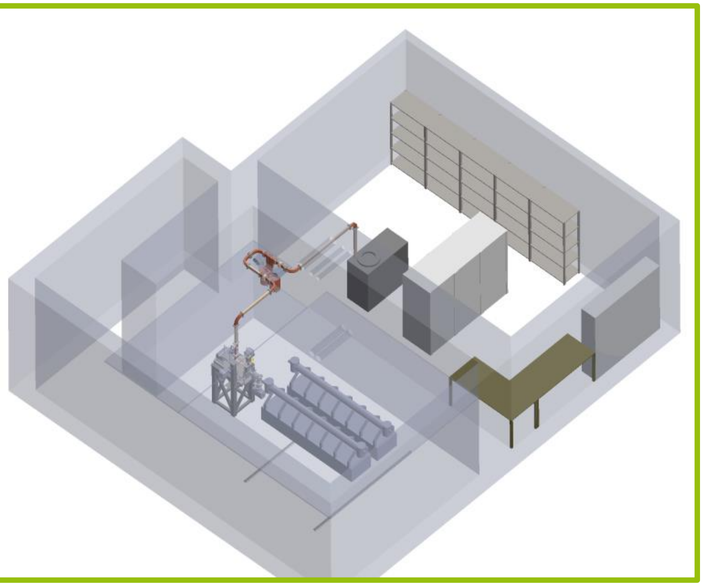
- Waveguide pressure
- VSWR (Reflected Power)

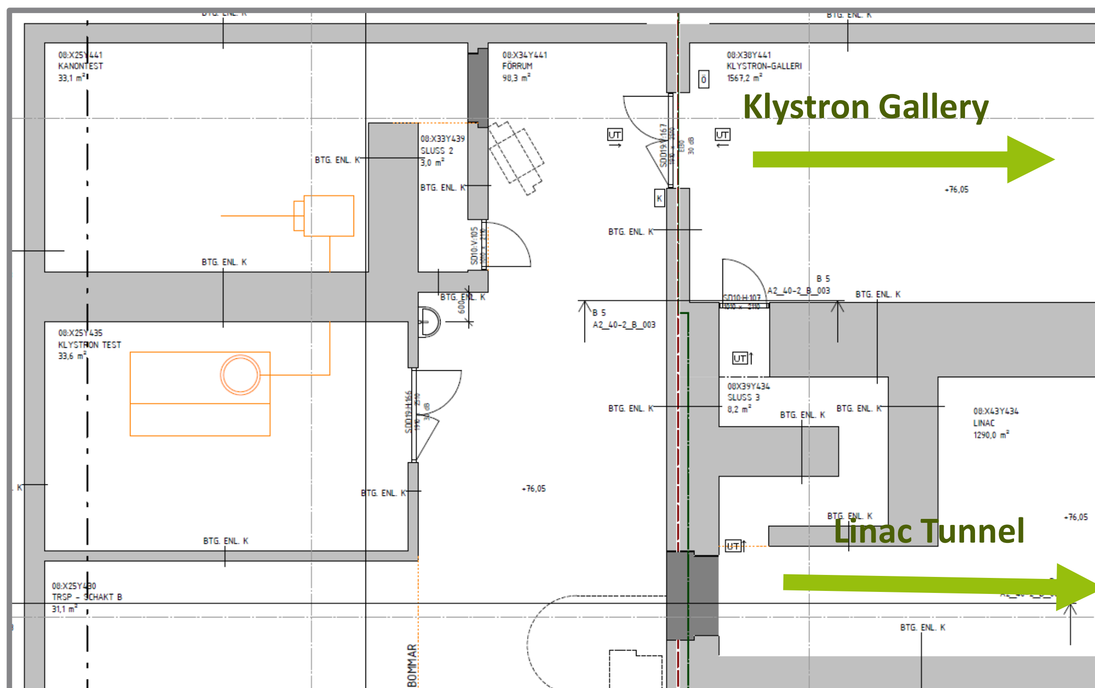
Linac tunnel

39 pcs linear accelerator structures 5.2m (156 cells) from RI,
39 pcs RF power compressor (SLED) from RI
2 RF Guns (home-made)
2 electron bunch compressor



Location of Gun test facility

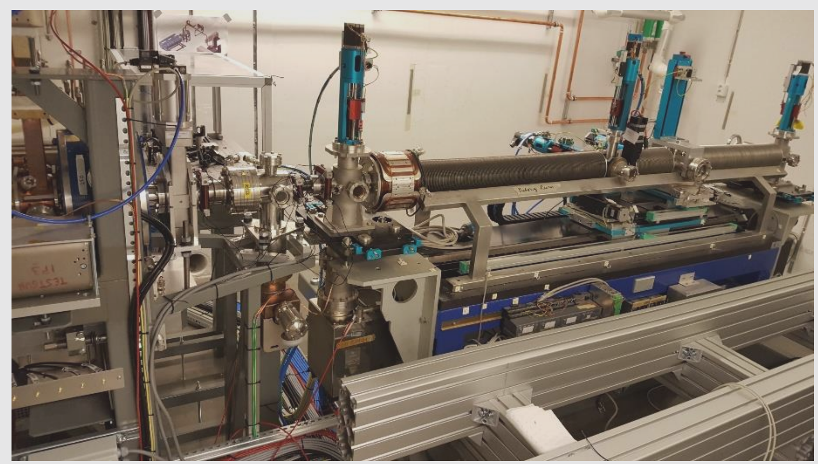




MAX IV Gun test Facility

Klystron room

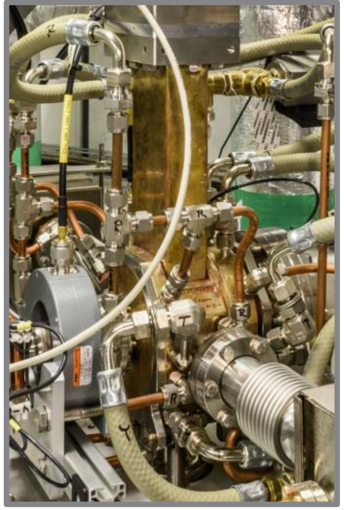
Gun room



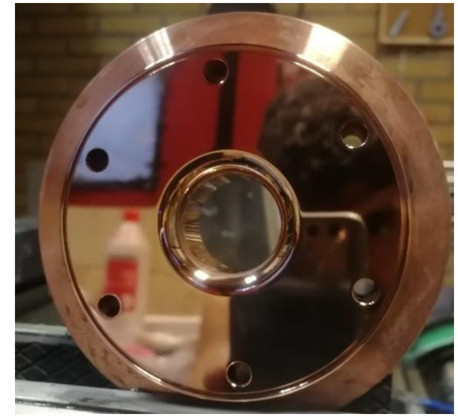
MAX IV - Thermionic RF Guns

Retired Thermionic RF Gun
Located: Musem

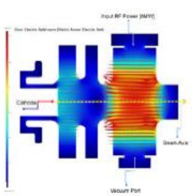
Today Thermionic RF Gun
Located: Installed in Linac



Next Thermionic RF Gun
Located: ”Hot spare”

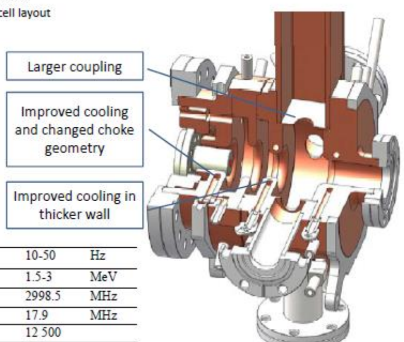


Thermionic RF gun

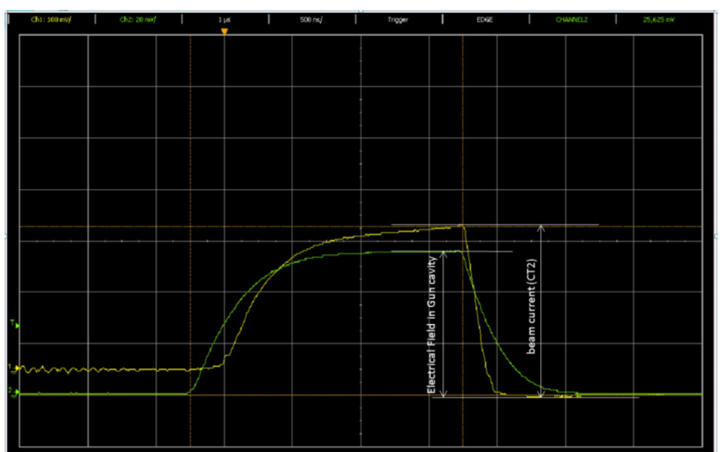


Field and cell layout

This gun builds on the existing thermionic RF gun in operation at MAX-lab. It is improved for higher coupling, better cooling and lower surface field densities (increased radiia on apertures).
The improved structure is in production.
The cathode is standard BaO.

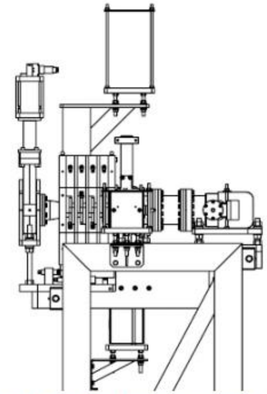


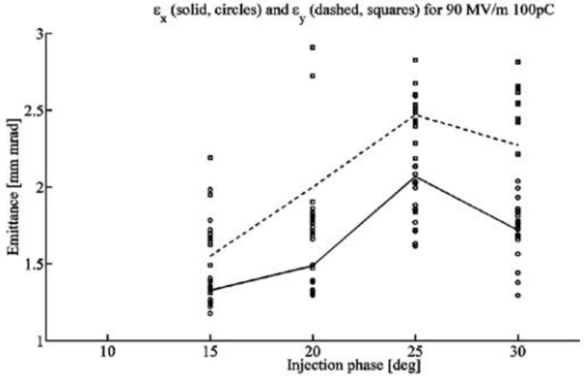
Rep rate	10-50	Hz
Energy	1.5-3	MeV
Frequency	2998.5	MHz
Mode separation	17.9	MHz
Q	12 500	
Coupling	1.85	

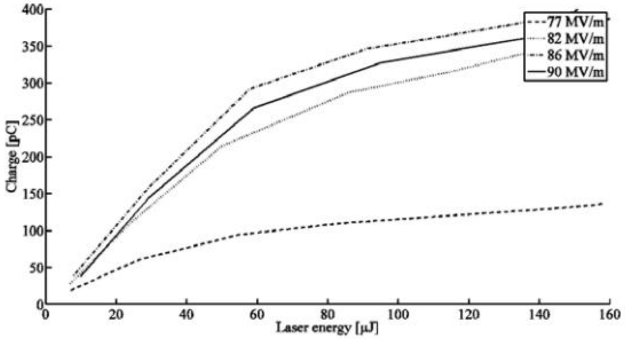


MAX IV - Photocathode RF Gun

- 1.6 cell UCLA-type RF gun
- Copper cathode
- 10 Hz/100Hz
- SLED
- Ti-sapphire laser, 263 nm
- Commissioned and tested at MAX-lab
    - < 1.5 mm mrad @ 100 pC
    - 4.2 MeV @ 90 MeV/m cathode field
    - Quantum efficiency $2 \cdot 10^{-5}$
- Installed at the MAX IV linac
- Commissioning late 2014

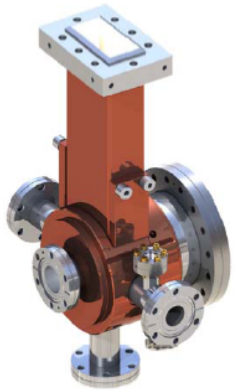






MAX IV - Photocathode RF Gun

Photo cathode RF gun

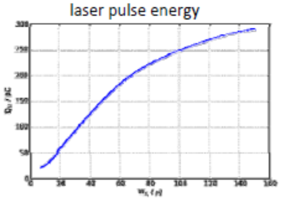


The photo cathode RF guns are built with the experience of the Fermi@ELETTRA gun previously tested at MAX-lab. A first structure has been operated up to 3.3 MeV electron energy (kinetic).

A quantum efficiency of 1.5 10^{-5} for the Cu cathode has been measured. Saturation of the emitted charge (see fig) was seen already above 50 mJ laser energy, which is partly due to the small laser spot size (0.4 mm RMS).

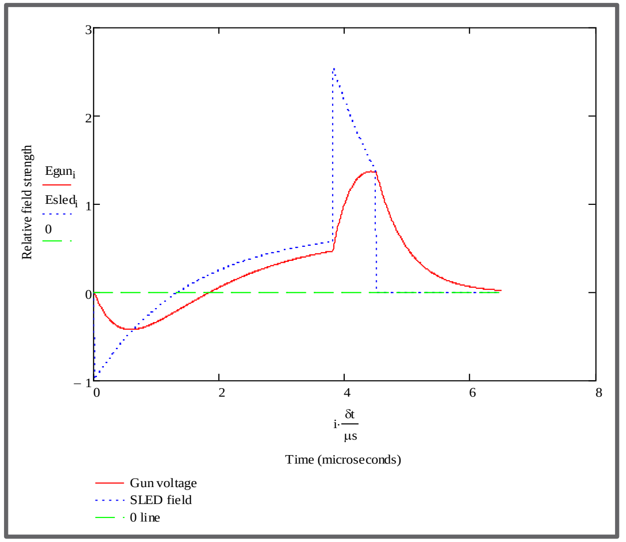
The coupling of the tested structure was 1.45 which is not enough for the short pulses from the SLED system. Thus a gun with coupling >1.85 is in production.

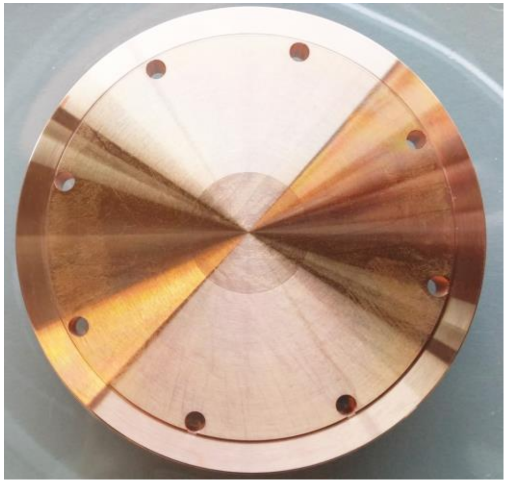
Charge as a function of laser pulse energy



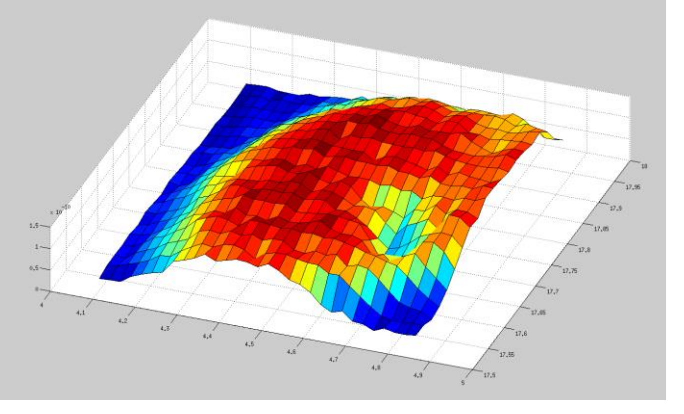
Rep rate	10-100	Hz (design)
Energy	~4	MeV (design)
Frequency	2998.5	MHz
Mode separation	14.3	MHz
Q	12 150	
Coupling	1.76	

- Applied SLED RF power pulse on photocathode RF Gun, released 4,6 times less heating than 3 μs rectangular pulse for a given gun field





- Charge map from current operation cathode, axis are motor positions. The hole in the charge positions. The hole in the charge corresponds to the ”normal” position of the laser



Cathodes and cathode preparation

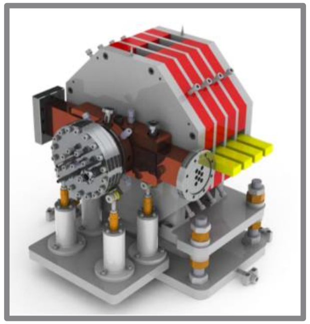
- Cathode material is copper, there is currently one cathode in operation and one in the test stand.
- The cathode in operation is in gun ”one”, and was in test bed before moved into operation. QE was measured to 2.2·10-5.
- The cathode for the test stand was baked and transported in protected atmosphere, QE around 2·10-5 . No significant difference of QE before and after baking.
- Operational cathode machined in-house. Some issues with hot spots and uneven emission.
- Test stand cathode machined externally, still emission hot spots.

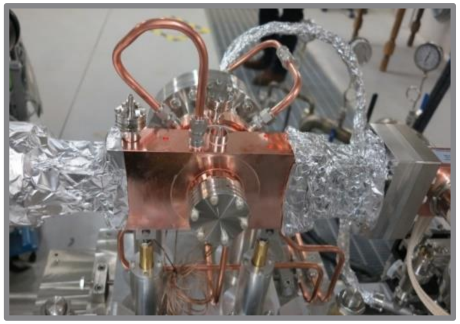
Courtesy J. Andersson

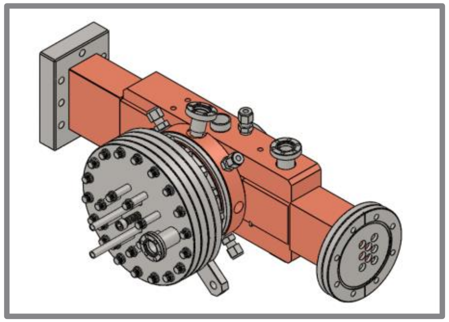
MAX IV

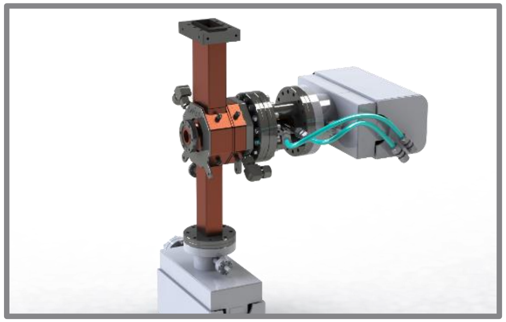
MAX IV – Next Photocathode RF Gun

- This 100 Hz Radiabeam/SLAC/UCLA gun will be gun ”three”.
- Some modifications in-house for manufacture.
- Produced during Q1-Q2 2019
- It will use copper cathode
- Investigate possibility to test Mg cathode

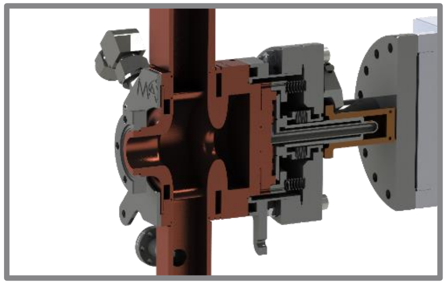


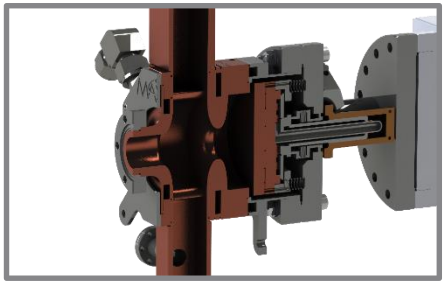






❑ Adapted to be mounted directly on site, replacing the old one

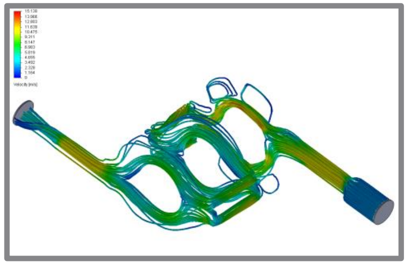
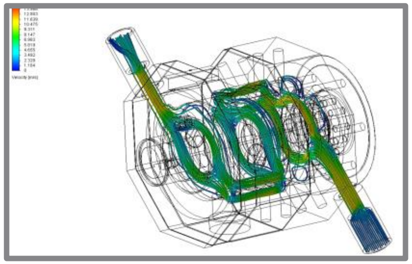




MAX IV

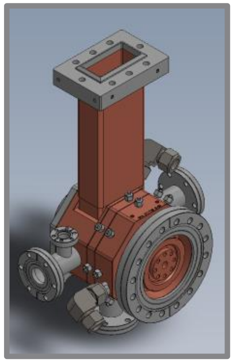
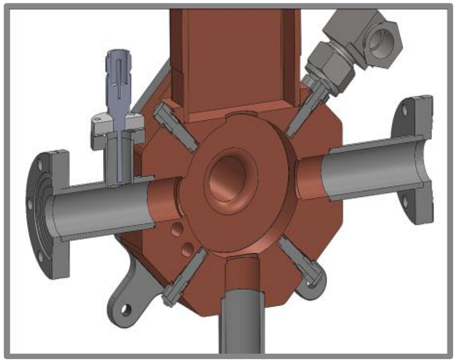
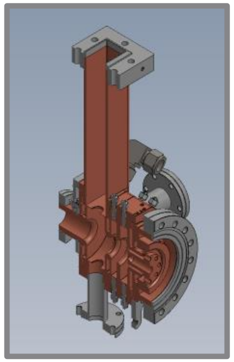
RF Gun technology improvements

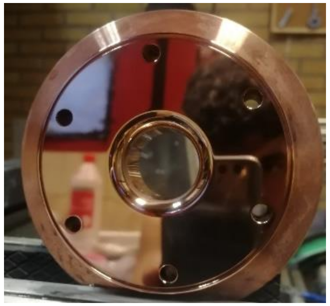
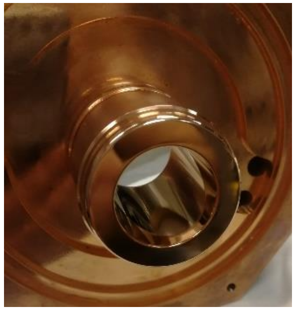
- ❑ RF Gun cooling system improved, higher volume and flow of water

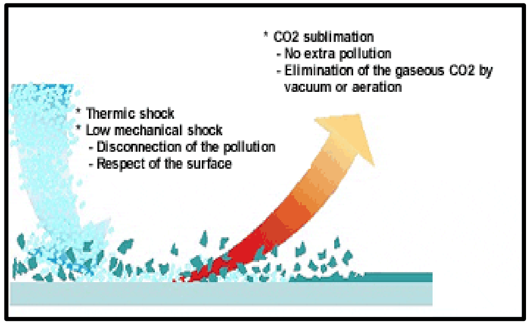



- ❑ Diamond polishing all internal site of RF Gun

- ❑ Adjusting the RF Guns resonance frequency cavities with tuning screws

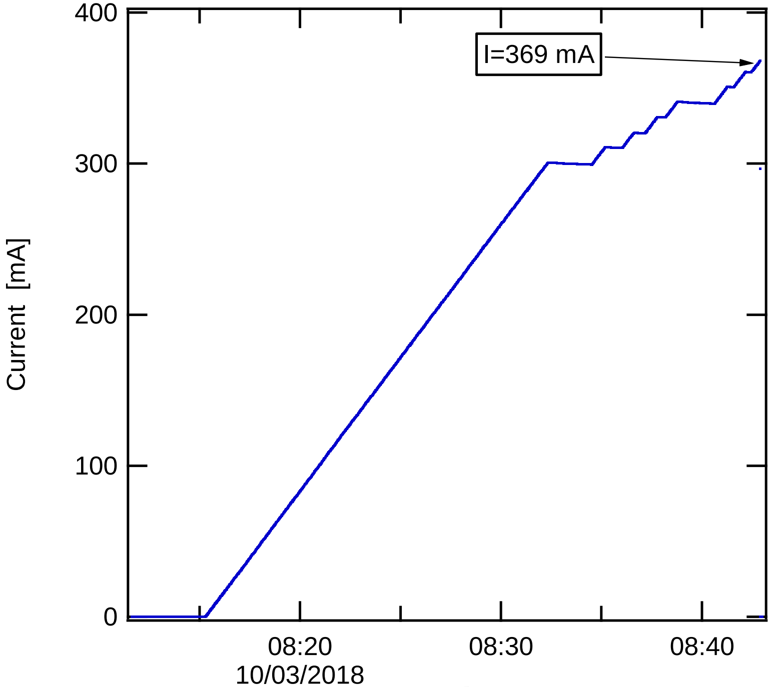
❑ **Dry Ice Blasting** has three collaborating active principles:

1. The low temperature of the blasting medium cools the part and unwanted particles. Due to different thermal expansion coefficients of them, easily unwanted particles moving way.
2. The **kinetic energy of the particles** leads to a mechanical treatment of the surface material, reduce the material (copper) peaks (low hardness of the blasting material provides a low-damage handling of the surface or substrate)
3. Thanks to **sublimation of dry ice** at room temperature, the sudden increase of volume by the factor 600 when the particles hit the surface to be processed, it makes to have a **smooth surface** material.

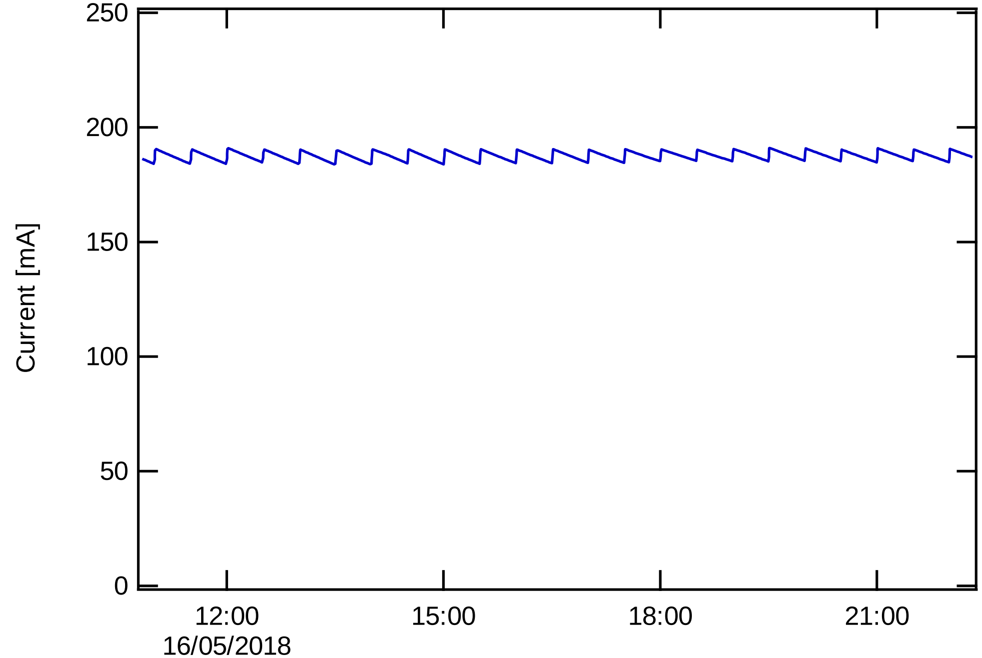
3 GeV Ring Highlights (courtesy Pedro F. Tavares)

Stored Beam Current & Top-up

Max: **369 mA**



Routine delivery to beamlines: **190 mA in top-up**



Path to 500 mA

- ❑ Remaining chamber hot spots adressed (2018 SD): **Done**
- ❑ Further cavity conditioning Ongoing
- ❑ Reinstallation of the 6th cavity Planned for 2019
- ❑ Coupling adjustment in all cavities **Done**
- ❑ RF power upgrade (from 60 to 120 kW per station) Ongoing

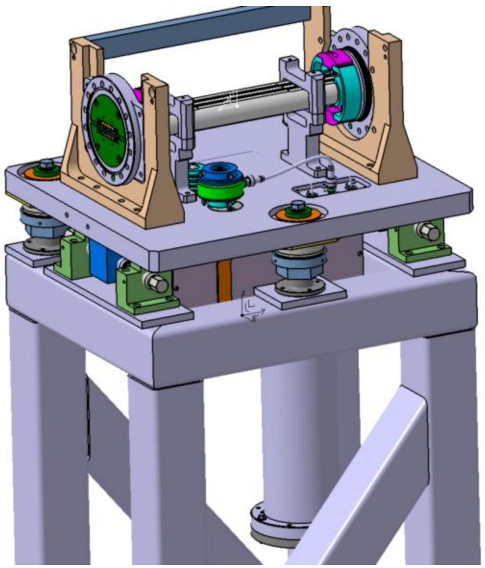
Courtesy Pedro Tavares

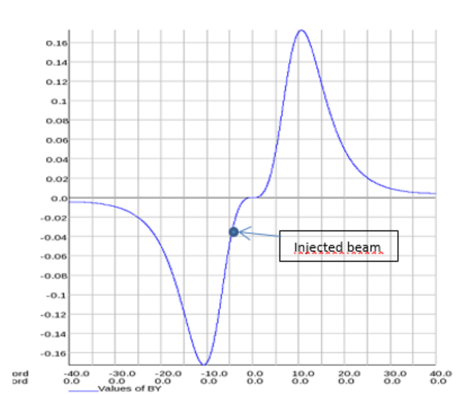
MAX IV

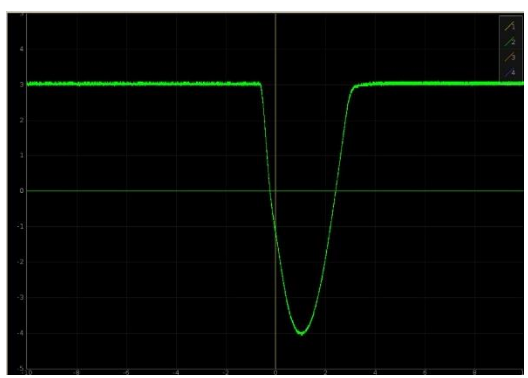
3 GeV Ring Highlights

Multipole Injection Kicker (MIK)

- Objective: achieve near transparent top-up injection.
- Joint project with **SOLEIL** based on original concept from **BESSY**.
- **First prototype** installed in the 2017 shutdown.
- Injection with MIK (up to 300 mA) demonstrated.
- Perturbation to the stored beam reduced by a factor ~60.

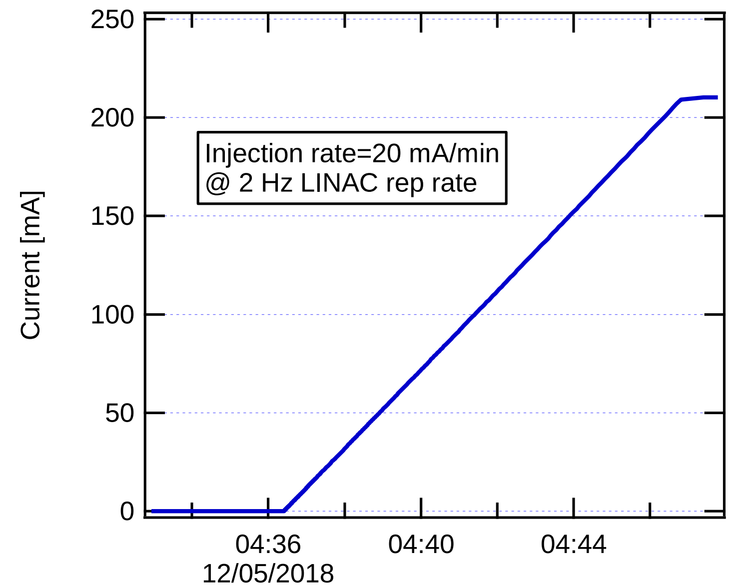






Drawings by SOLEIL
P.Lebasque
P.Alexandre

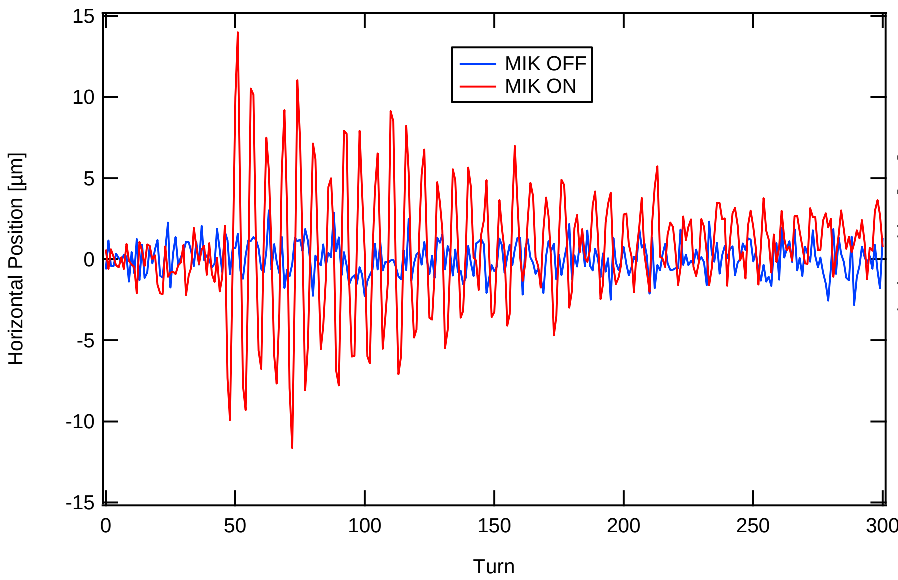
Injection with the MIK



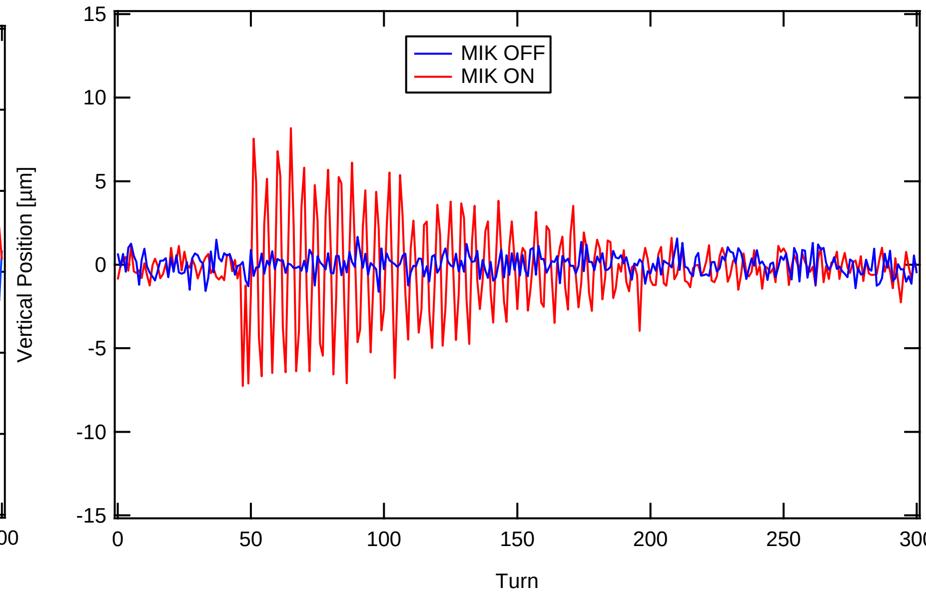
3 GeV Ring Highlights

Residual Orbit Perturbations

- Store 10 consecutive bunches
- Scan of stored beam position at the MIK
- Amplitudes measured from Turn-By-Turn libera data stream
- One BPM at $\beta_x = 9.6\ m\ \beta_y = 4.80\ m$
- Amplitudes scaled to centre of long straigt where $\beta_x = 9.0\ m\ \beta_y = 2.0\ m$



Horizontal = $\pm 13\ \mu m$

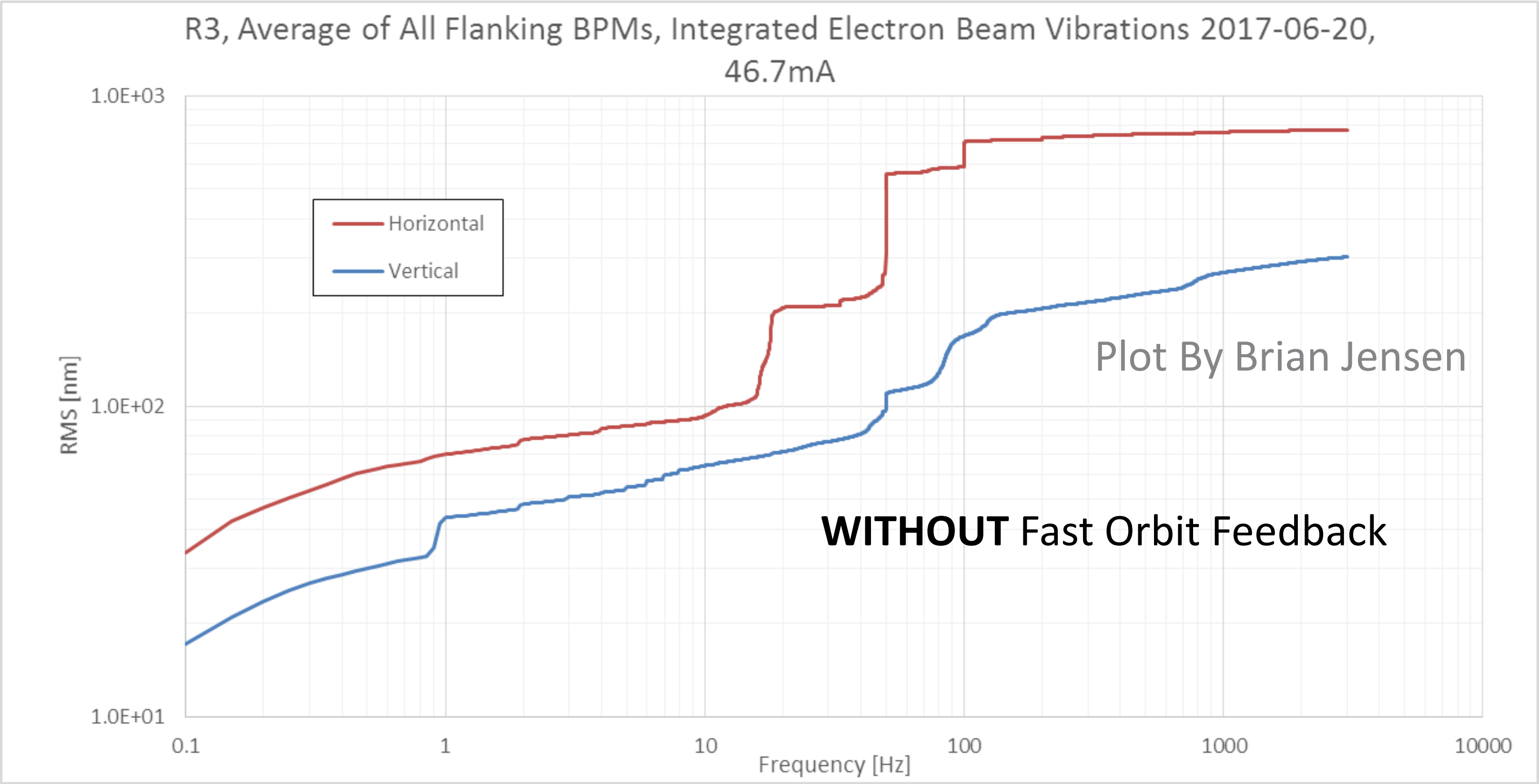


Vertical = $\pm 8\ \mu m$

MAX IV

3 GeV Ring Highlights

Orbit Stability



Integrated up to 100 Hz

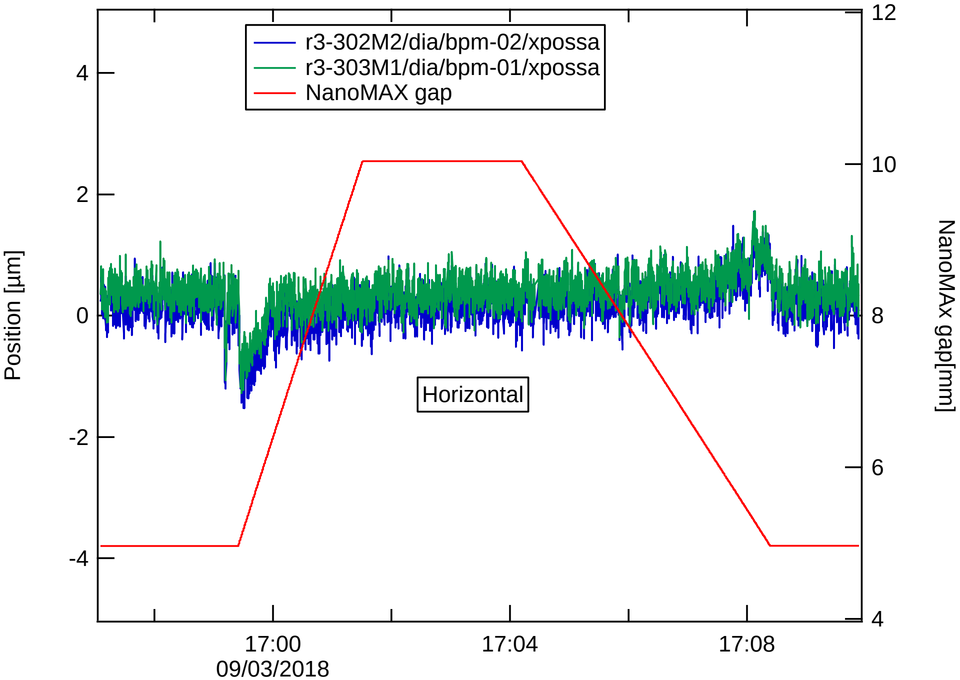
- ❑ Horizontal RMS < 710 nm ~ 1.3 % of RMS beam size at BPM position
- ❑ Vertical RMS < 170 nm ~ 5.5 % of RMS beam size at BPM Position

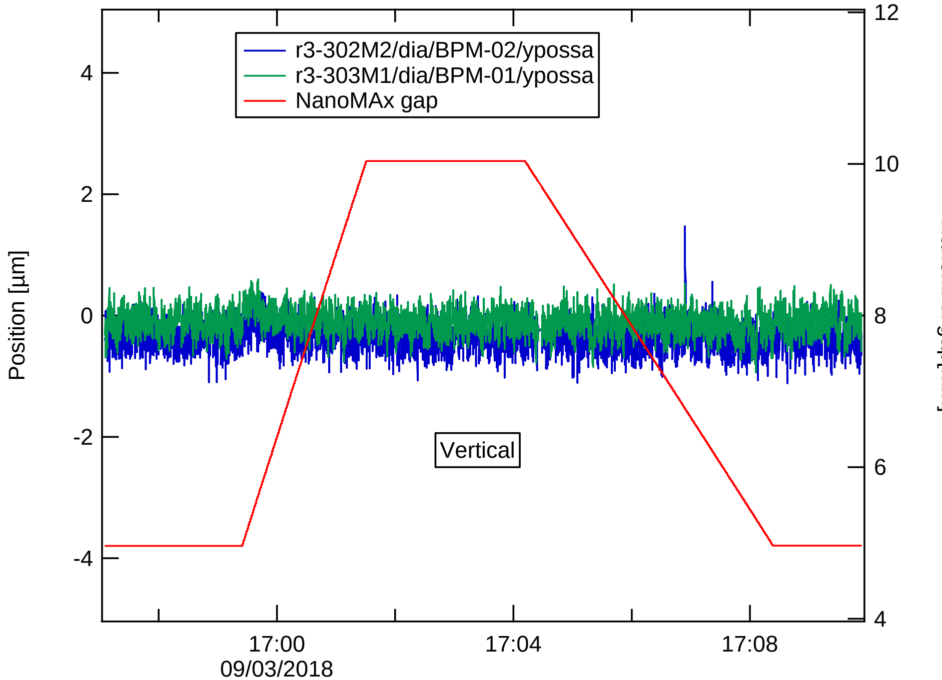
MAX IV

3 GeV Ring Highlights

Faster orbit feedback

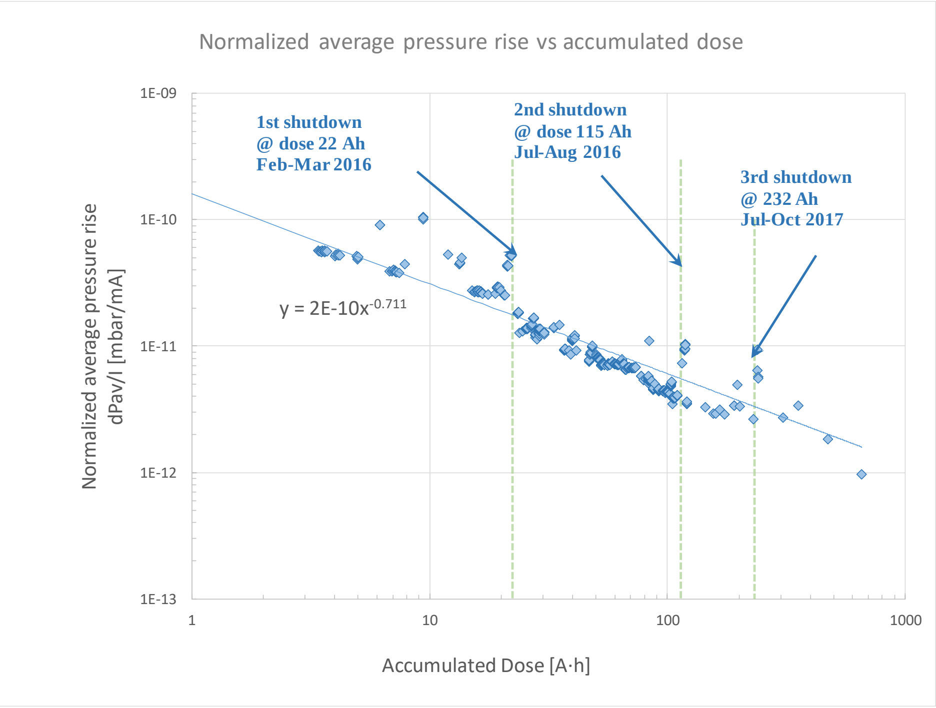
- Previous implementation (Matlab script) limited to 0.25 Hz.
- New tango device has been run at up to 2 Hz
- Goal is to reach 10 Hz

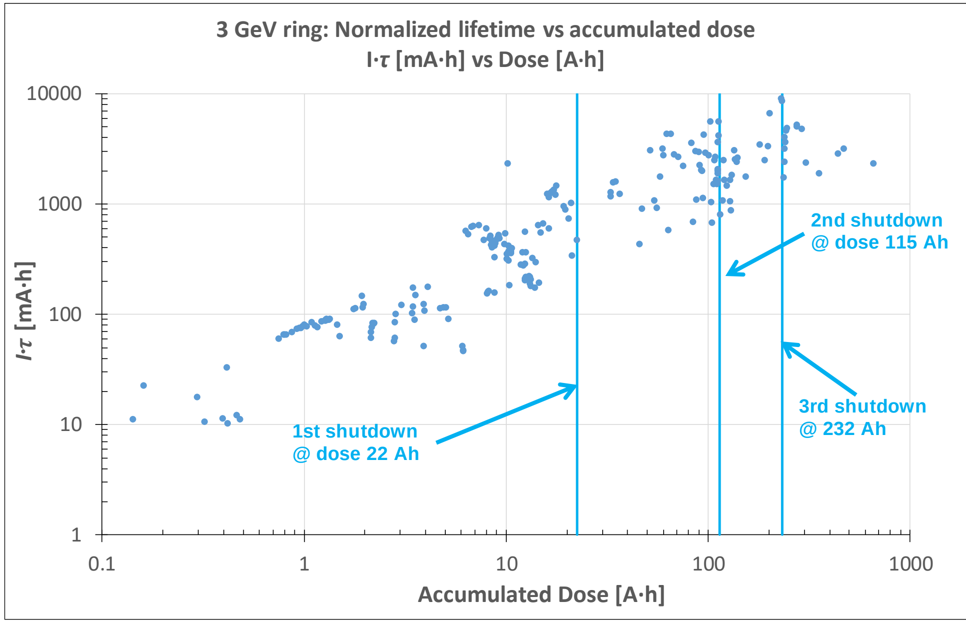




3 GeV Ring Highlights

Vacuum Evolution





Plots by Eshraq Al-Dmour

3 GeV Ring Highlights

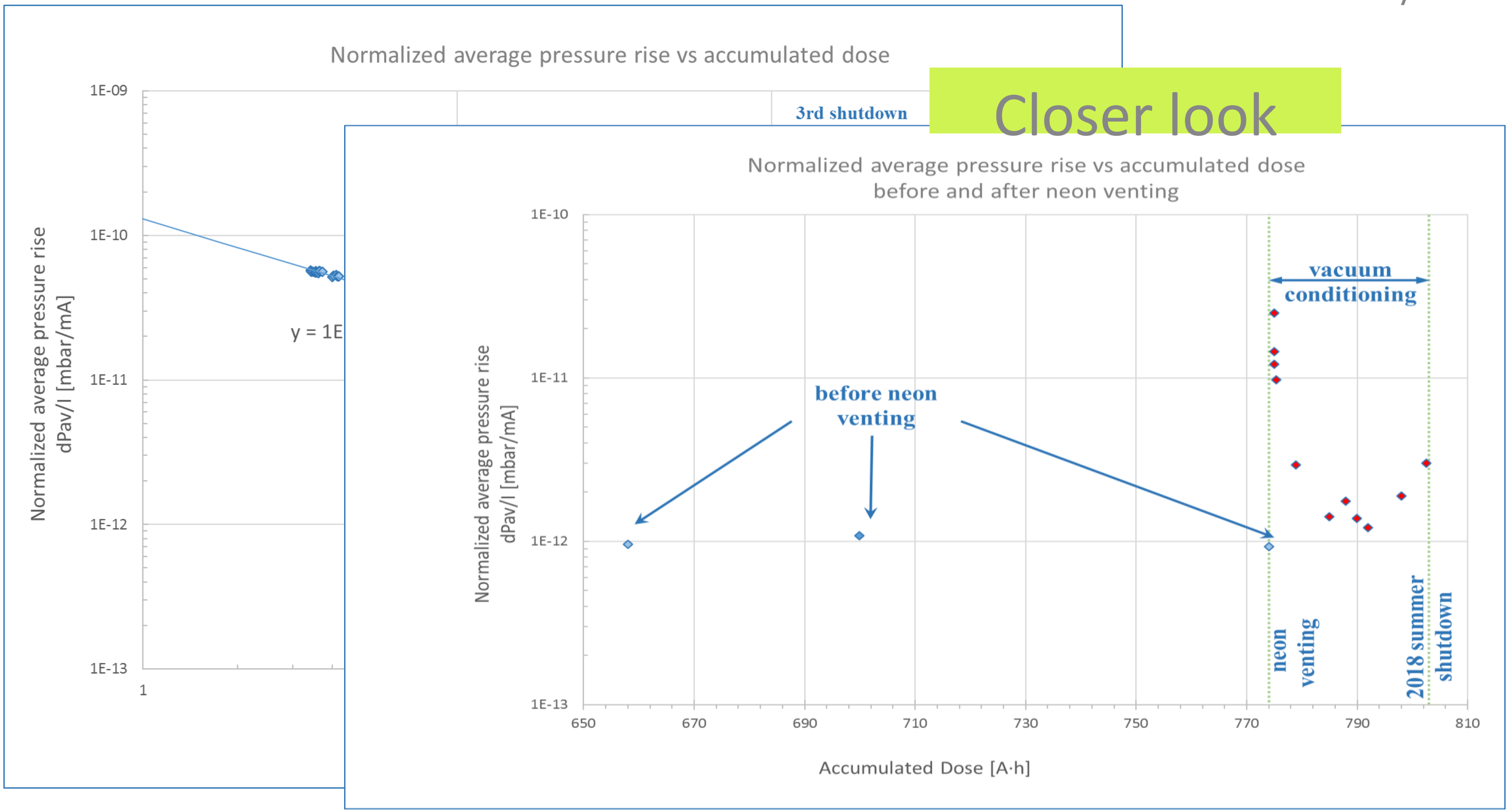
Neon Venting in the 3 GeV Ring

- A conventional vacuum intervention in R3 takes 2-3 weeks due to the need to reactivate the NEG coating.
- In the 2018 summer shutdown, we tested a new procedure (developed originally at CERN) in which
  - the chambers are vented with ultra-pure neon gas (instead of nitrogen).
  - The time the chamber remains open is minimized by careful planning of the intervention.
  - The chamber is pumped down **WITHOUT** reactivation (i.e., no baking at ~200 °C)
- This reduces the intervention time to just a few days.
- The big question was: **how does the vacuum pressure and beam lifetime recover after such an intervention ?**

3 GeV Ring Highlights

Vacuum conditioning after neon venting intervention.

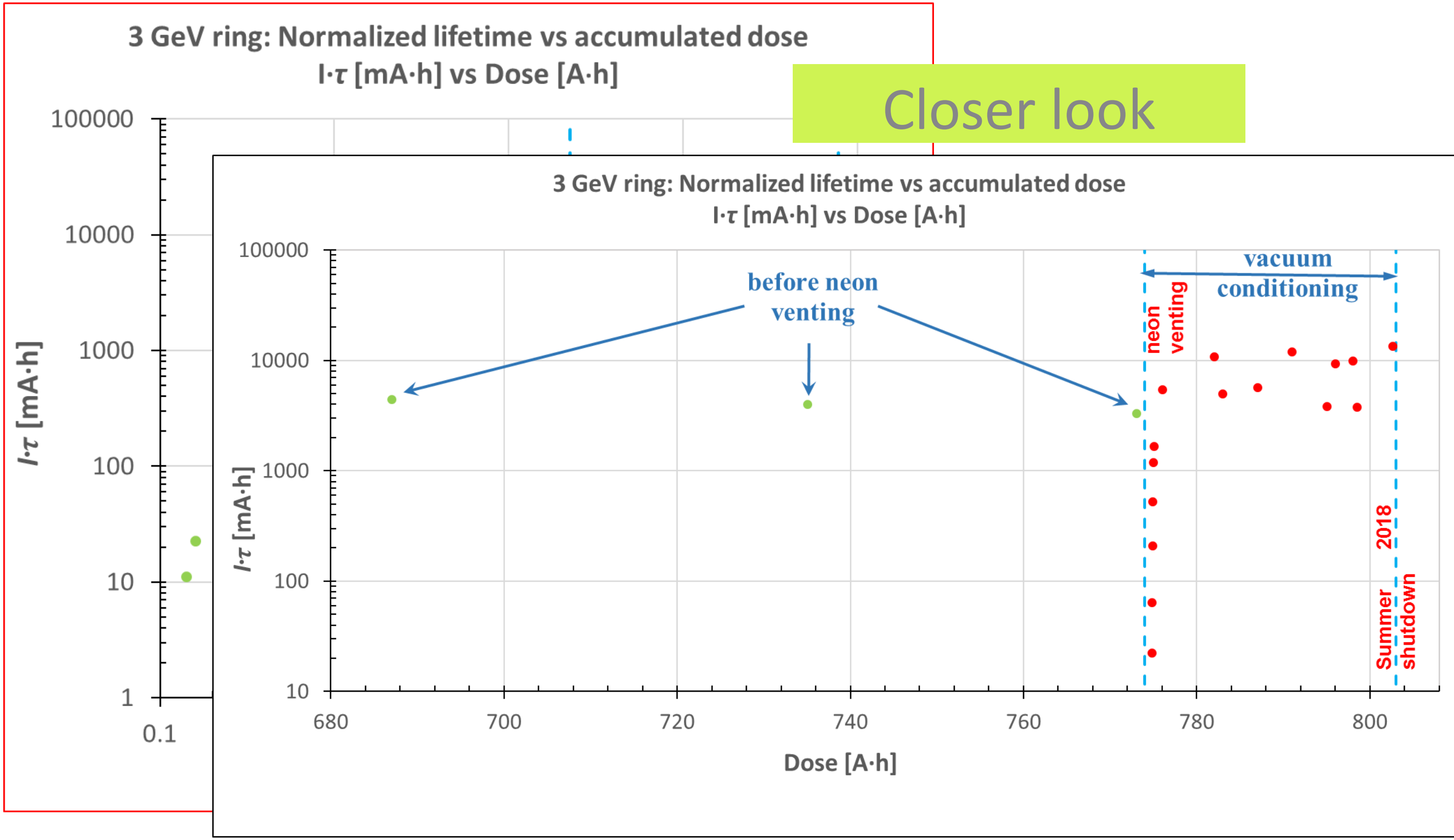
Slide by E. Al Dmour



The average pressure recovered after around 18Ah, highest pressure readings were close to the areas were we have exchanged the vacuum chambers.

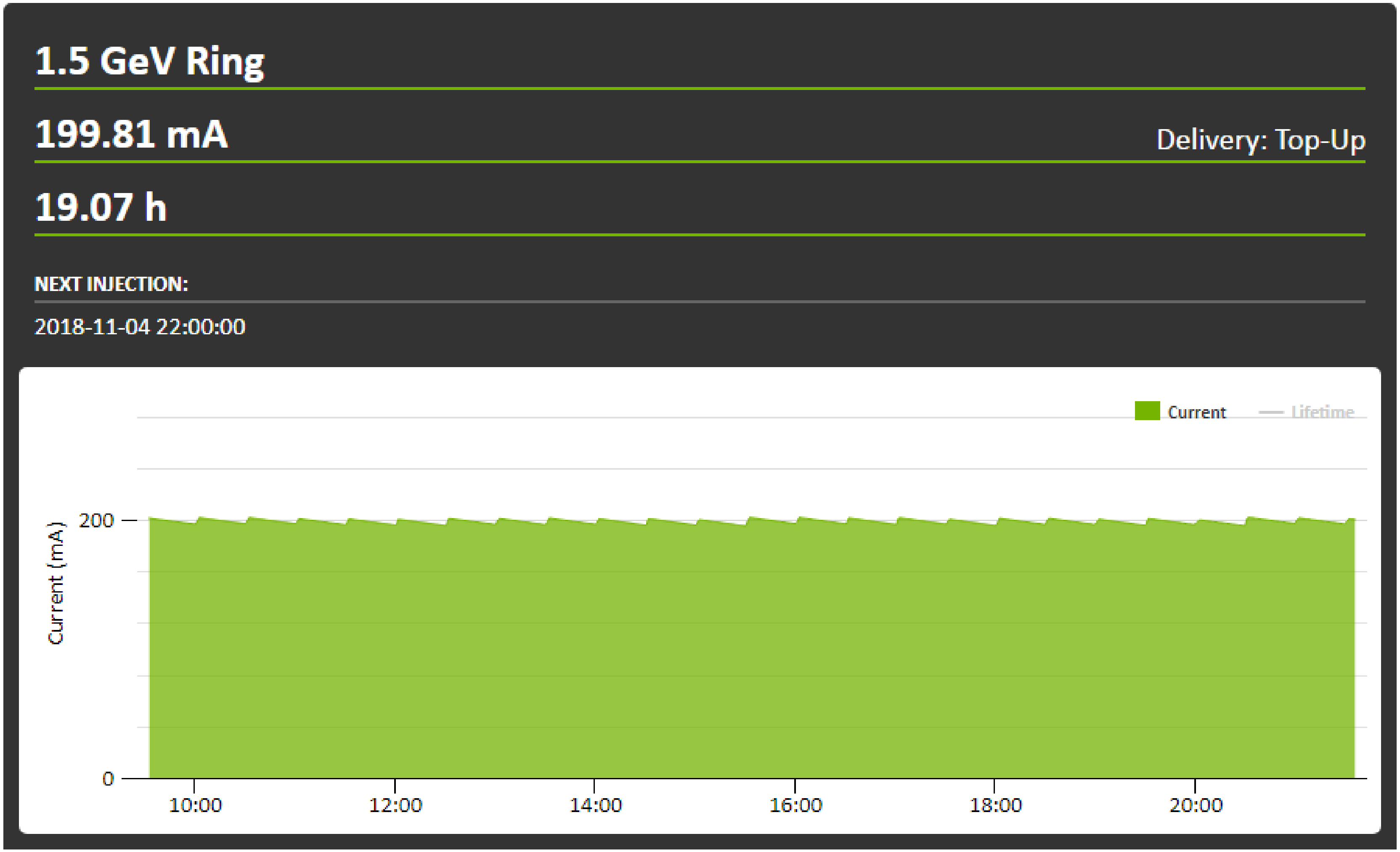
3 GeV Ring Highlights

Life time after neon venting



1,5 GeV Ring Highlights (courtesy Åke Andersson)

Current Delivery



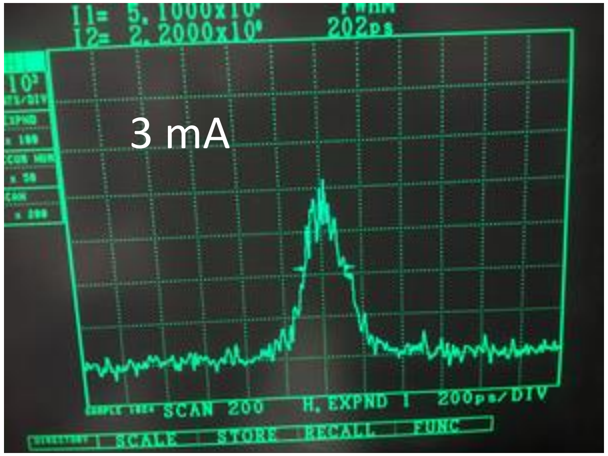
1,5 GeV Ring Highlights

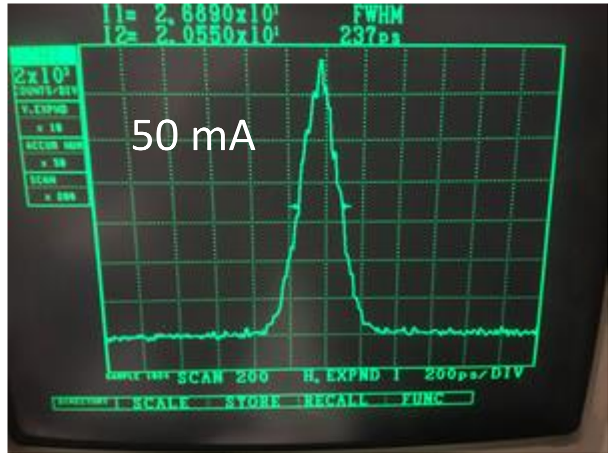
RF straight section

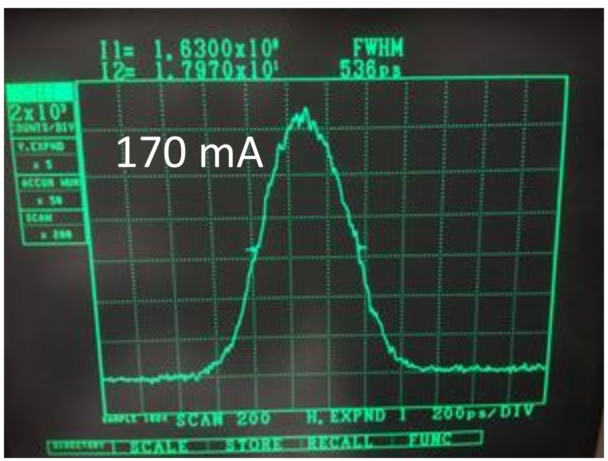
A_ε = 3.7 %
f_s = 6.8 kHz

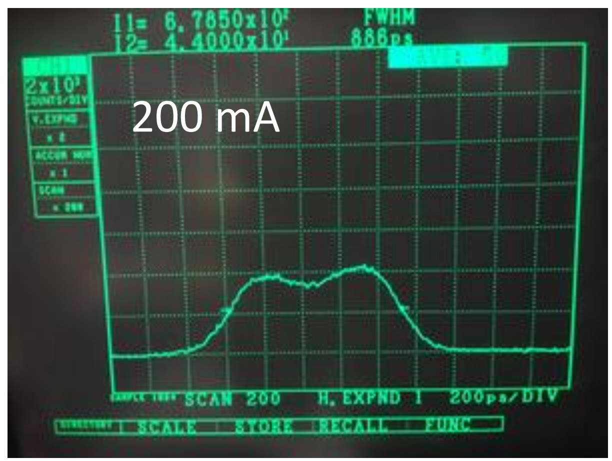
1,5 GeV Ring Highlights

Bunch lengthening for fixed HHC detuning









I [mA]	FWHM [ps]
3	202
50	237
170	530
180	680
200	900

Un-stable region from 60 to 130 mA.

Theory:
125 ps @ 0 mA
800 ps @ 200mA

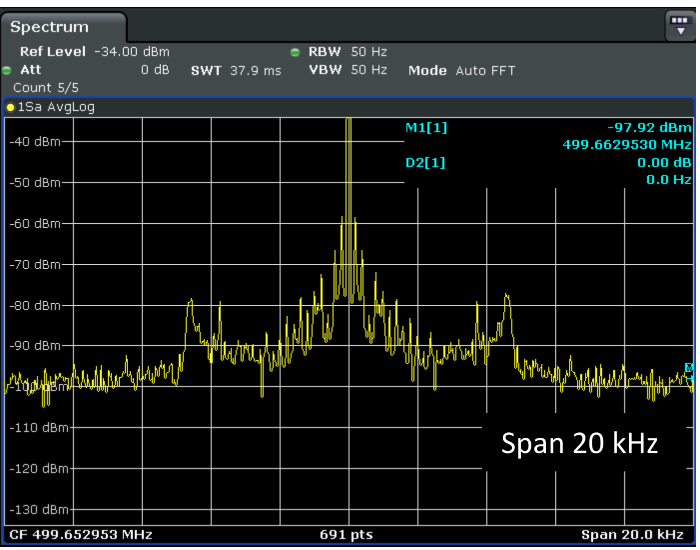
Data by David Olsson and Per Lilja

MAX IV

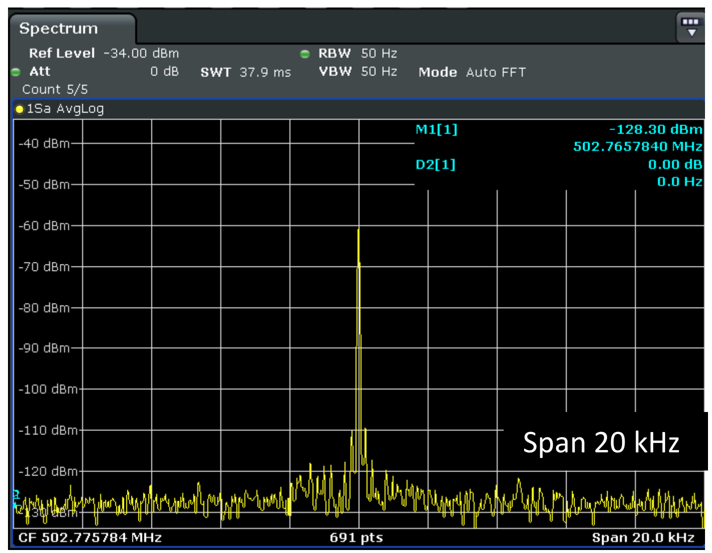
1,5 GeV Ring Highlights

HHC bunch lengthening

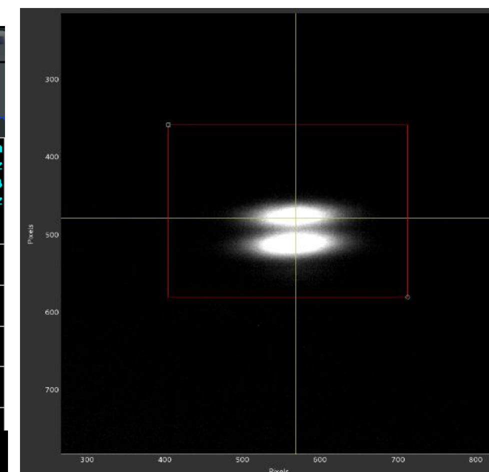
- **With HCs** an evenly filled bunch train stays stable in all three planes, without the use of the BbB feedback system, from around 130mA and upwards.
- **”Auto-tuning”** is applied to the HCs, for maintaining the ~80 kV.



Mode 0



Mode 1 ……. Mode n

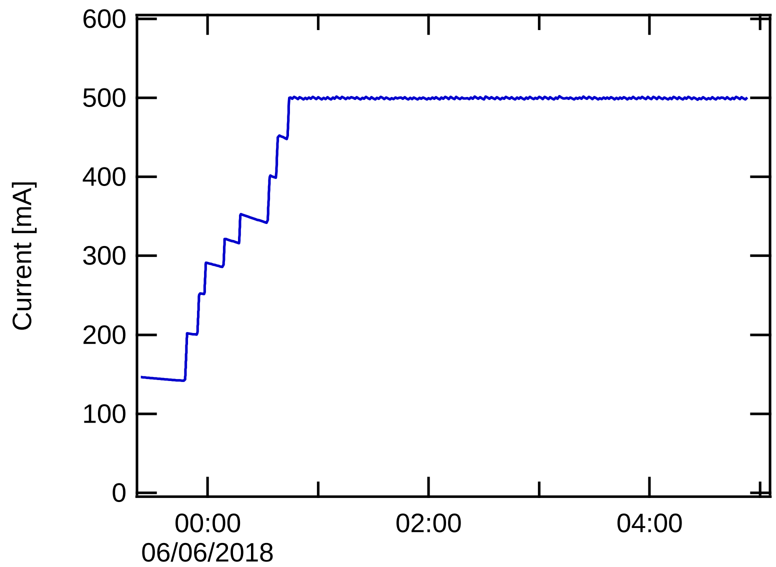


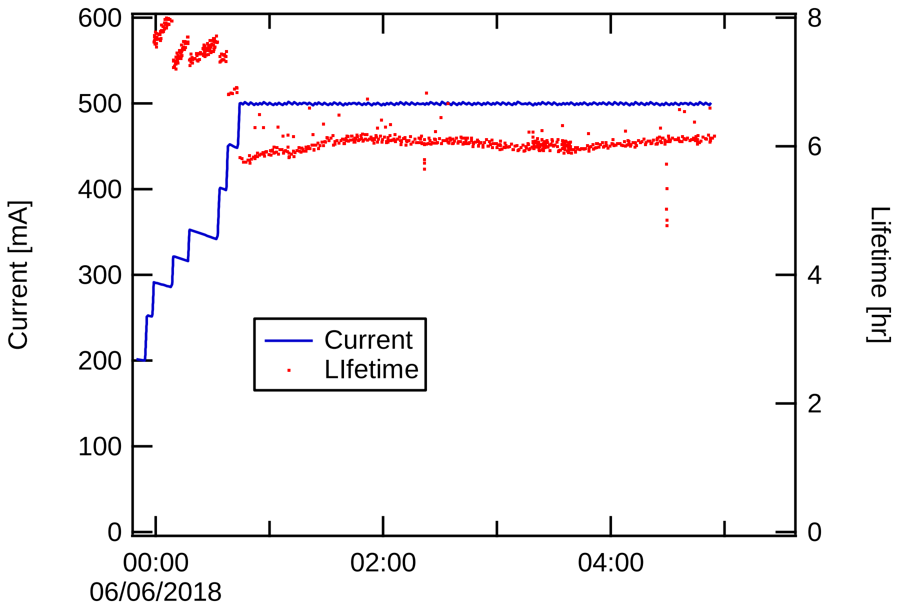
Courtesy Robin Svärd & Mathias Brandin

1,5 GeV Ring Highlights

Off delivery time

500 mA in top-up mode during acc. dev. shift.





Night Tuesday 5th to Wednesday 6th of June 2018.

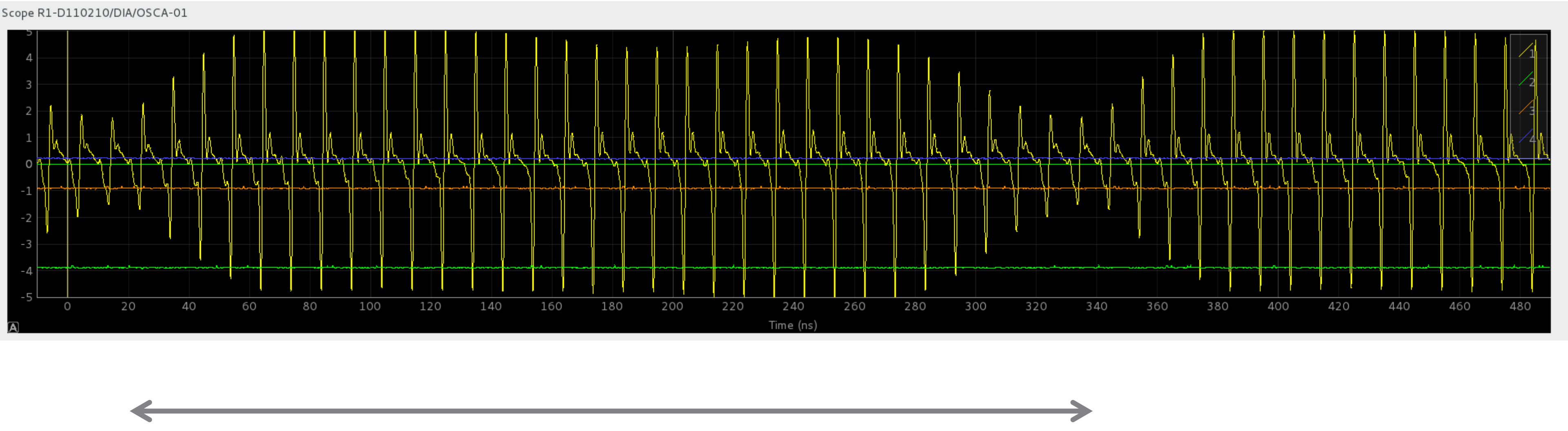
I*Tau = 3 Ah @ 500 mA

(Design is 5 Ah @ 500 mA)

1,5 GeV Ring Highlights

Fill Pattern @ 500 mA

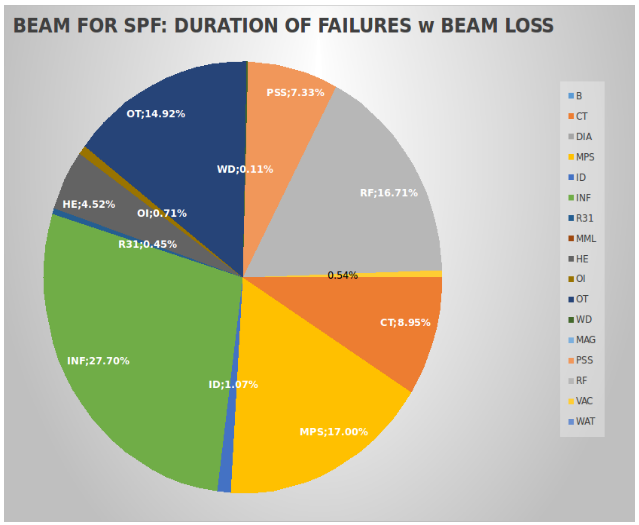
- Around 400 mA the beam goes unstable vertically. We counteract by an uneven filling pattern.

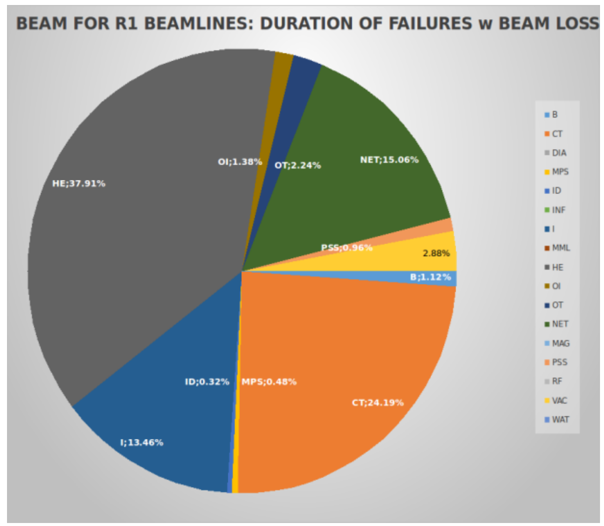


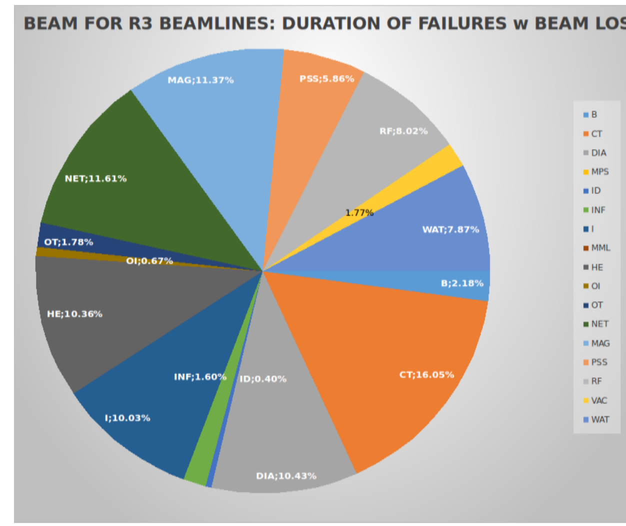
One turn (32 buckets)

Accelerator Operations Summary

- Accelerator Operations Statistics January -June 2018.





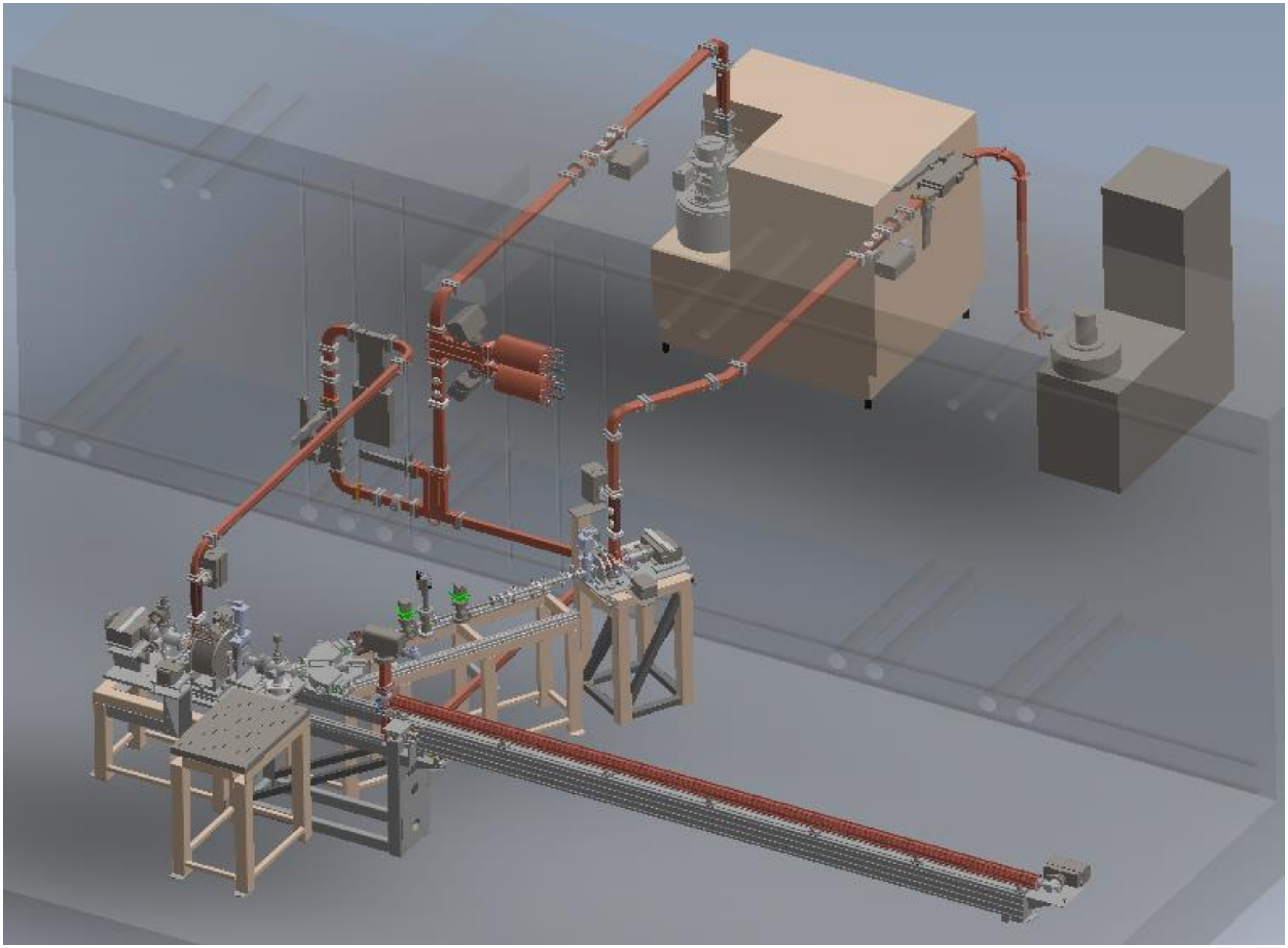


		SPF	R1(1,5GeV)	R3(3GeV)
1	Delivery Days	71	85	113
2	Availability	91.0%	96.2%	96.9%

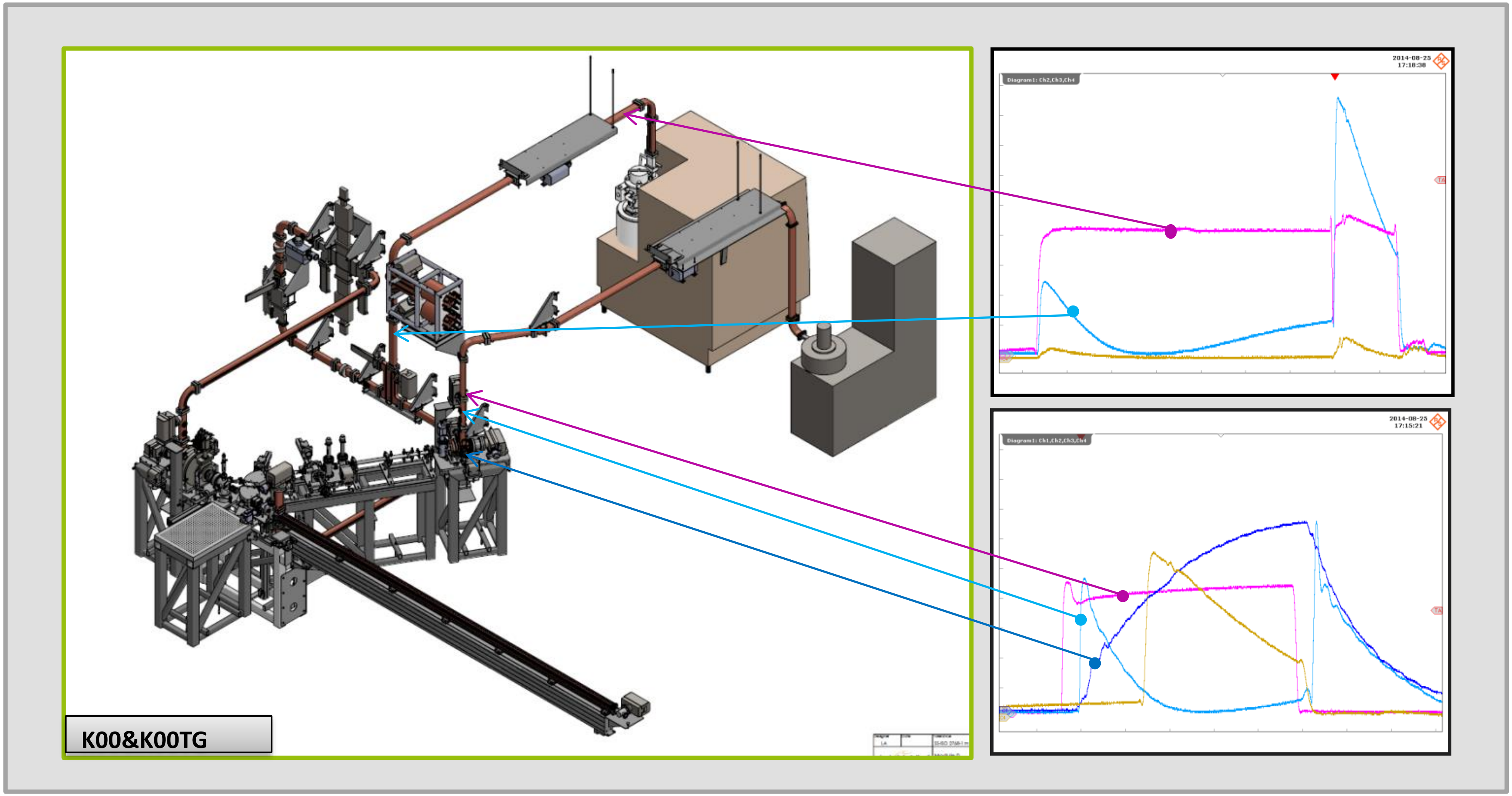
MAX IV Laboratory

Thank You!!

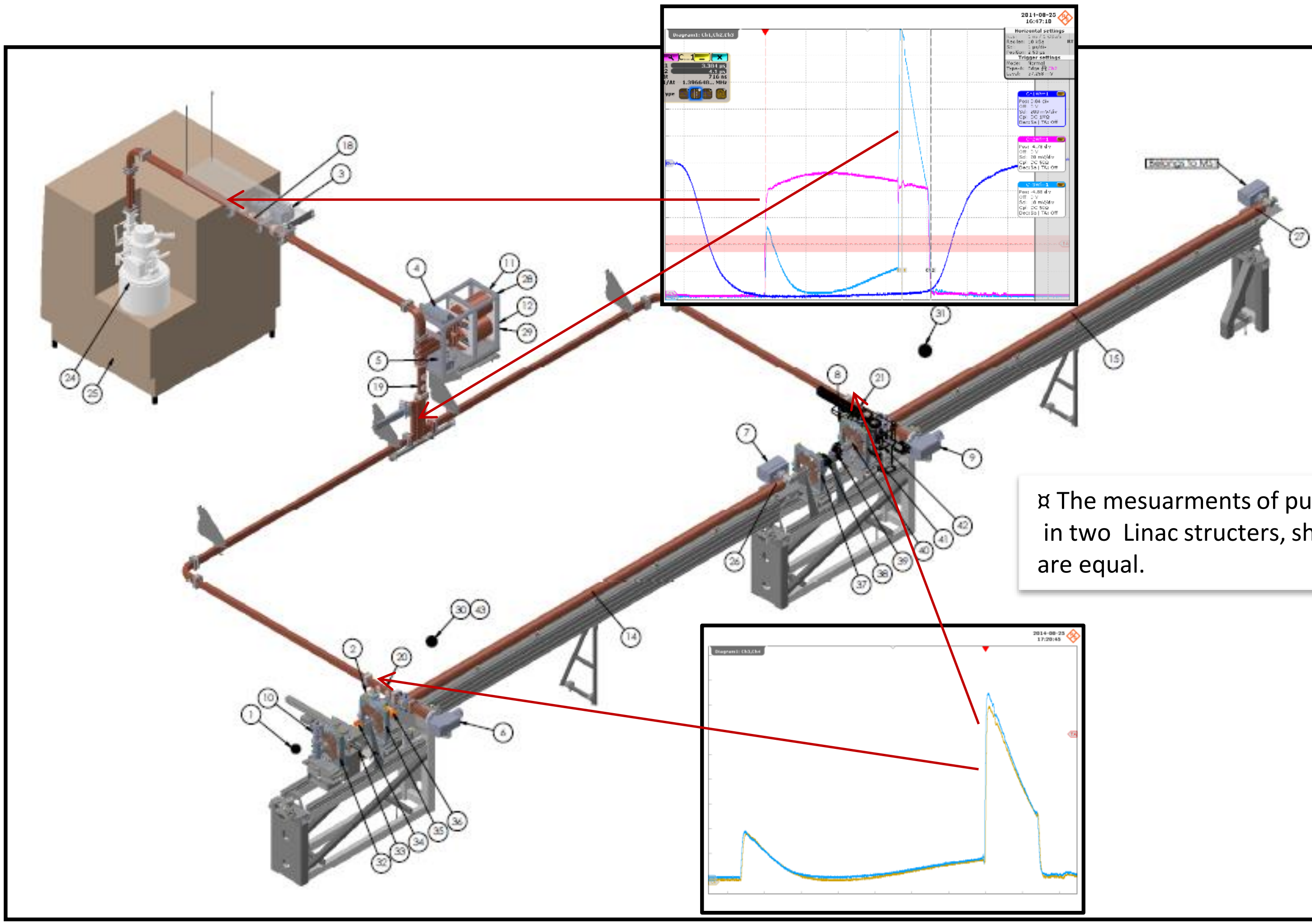
Accelerator Units K00+K00TG



Accelerator Units K00+K00TG



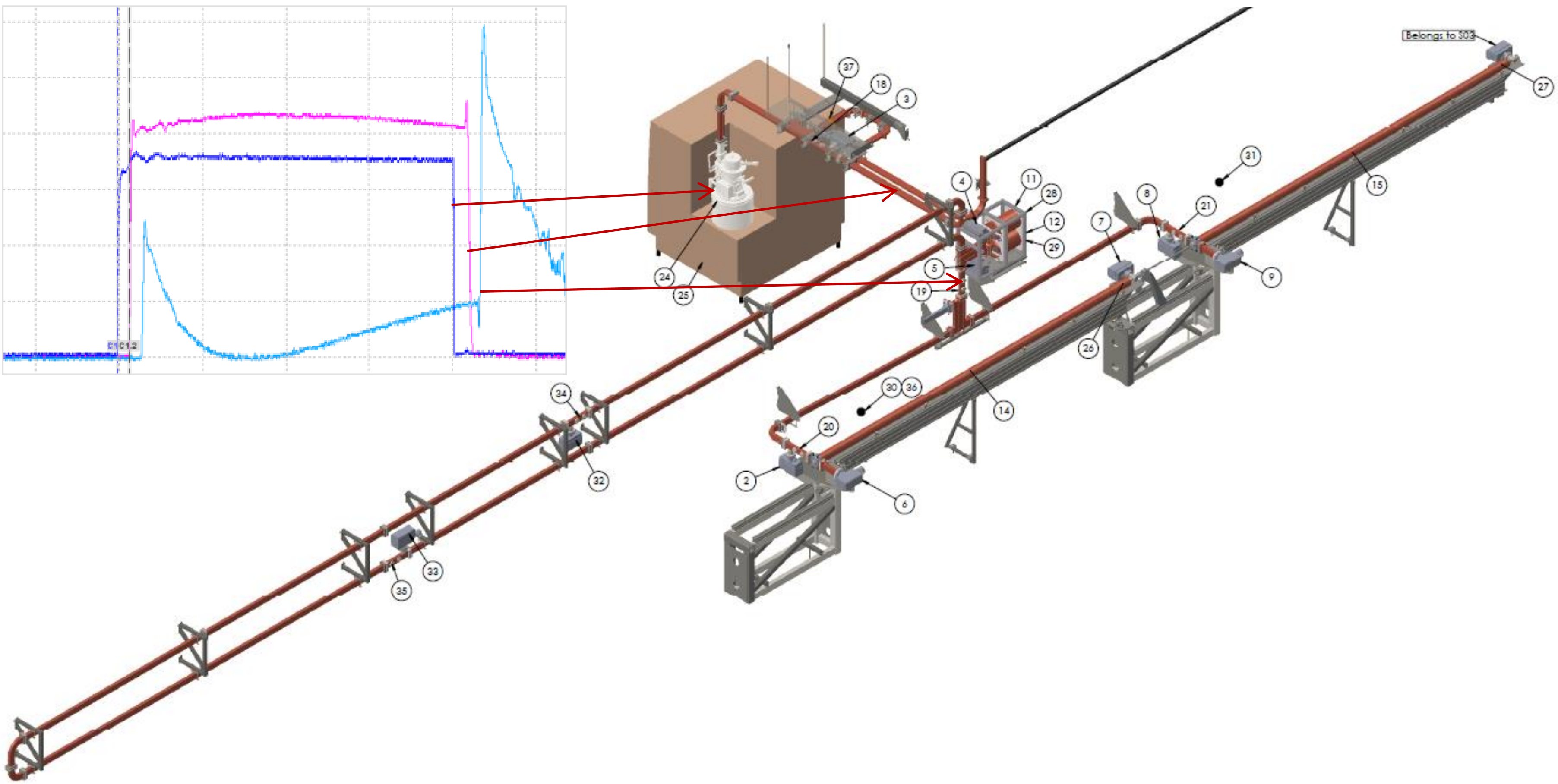
Accelerator Unit K01



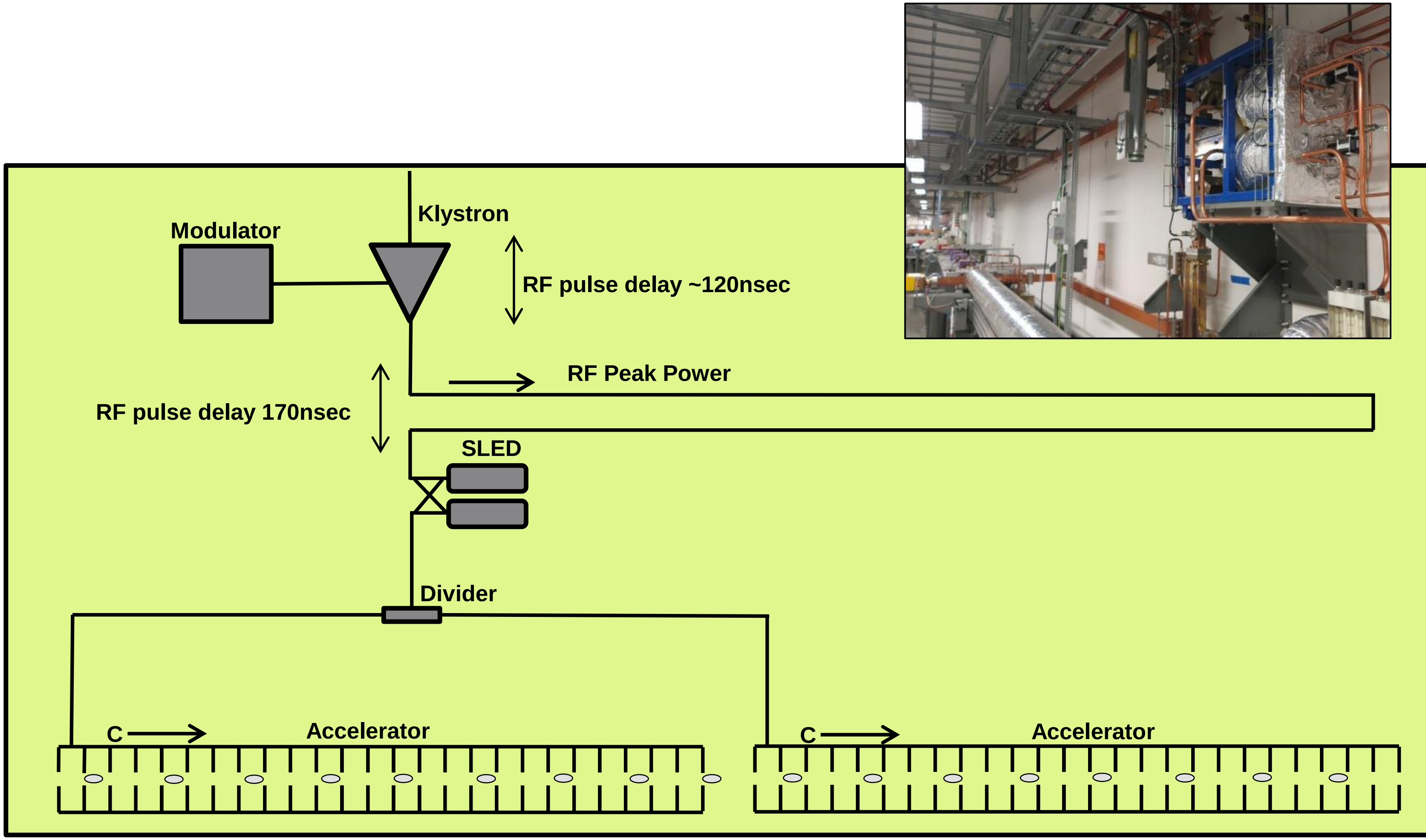
¤ The mesuarments of pulsed RF power in two Linac structers, shows that they are equal.

Accelerator Unit K02

To utilize the RF power produced by K02 to feed both the structure accelerator and the main driver, the RF effect on the path of the structures will be delayed longer than the time taken for electrons to pass the distance from the first cavity to the cavity the last of the klystron (the bunch electron time in klystron was circa 120ns, we delayed the RF power pulse with 170 ns)

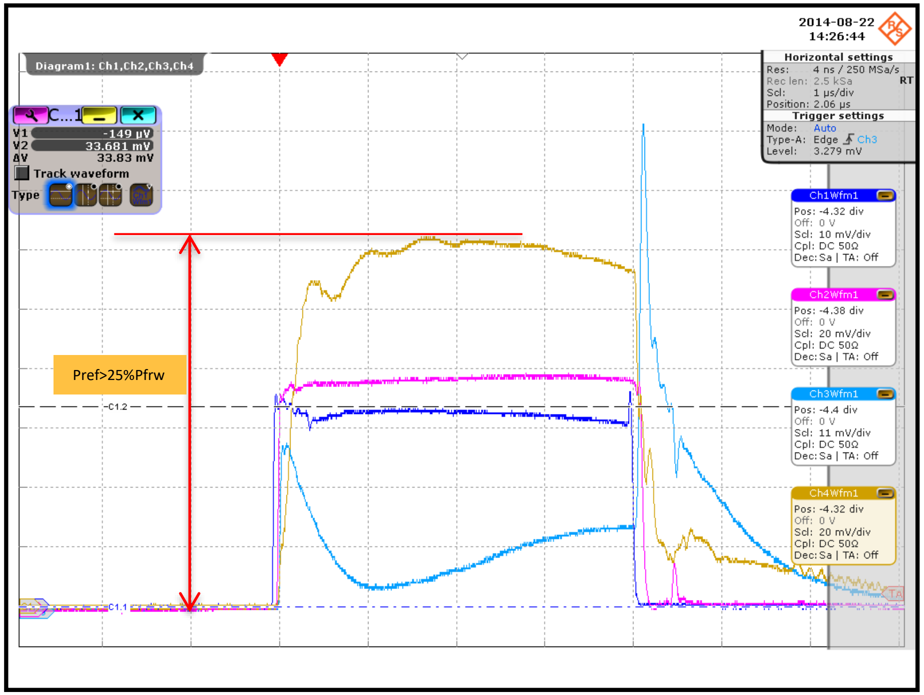


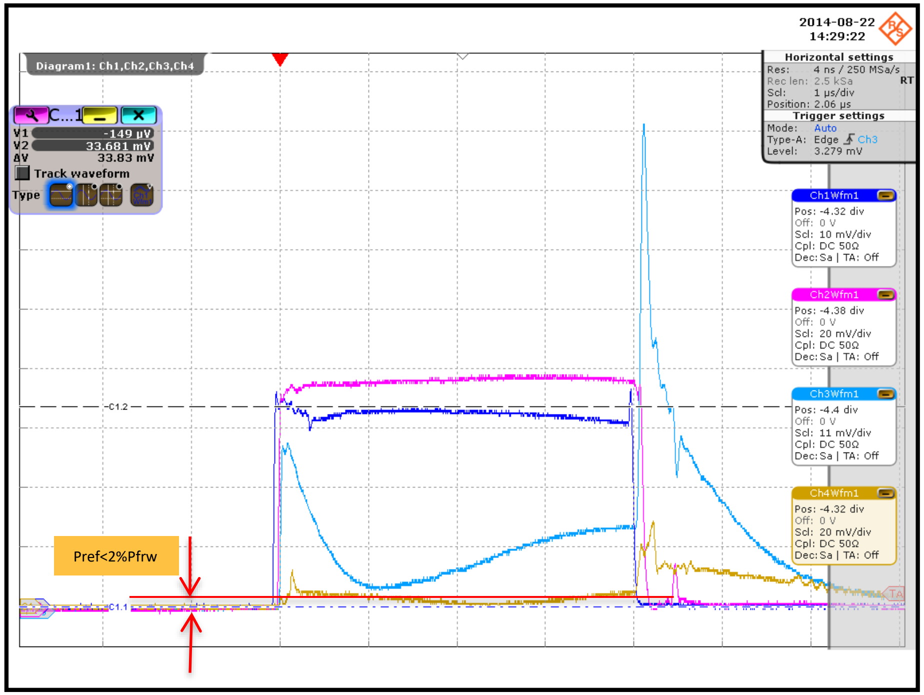
Accelerator Unit K02



RF high harmonics (f=n*3GHz)

¤ The following images give an illustration of how is changing the RF reflected power level with and without 3GHz band filter (orange color curves)



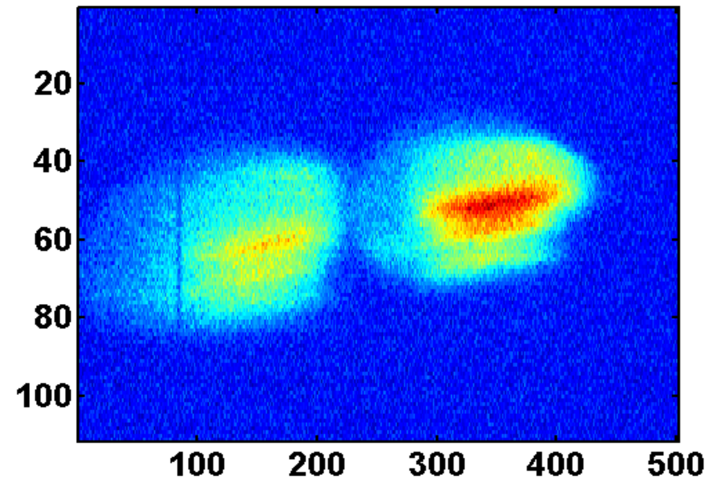


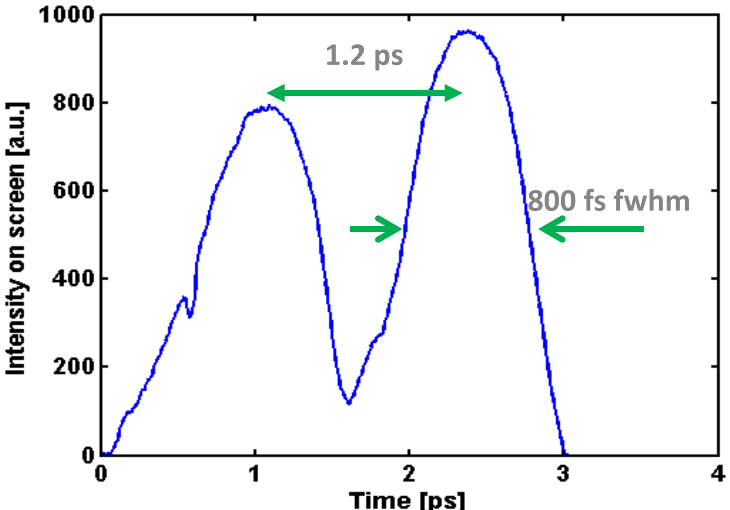
MAX IV Linac accelerator section

All linear accelerator structures are magnetic field isolated and also together with RF compressors (SLEDs) are thermal insulated.

First attempt at double bunches

- Compressed only in BC1
- Same method as previous slide to measure
- Two electron bunches within one RF-bucket
- First attempt, used only the crystals in the laser pulse stretcher to achieve two laser pulses.
- Only lightly compressed

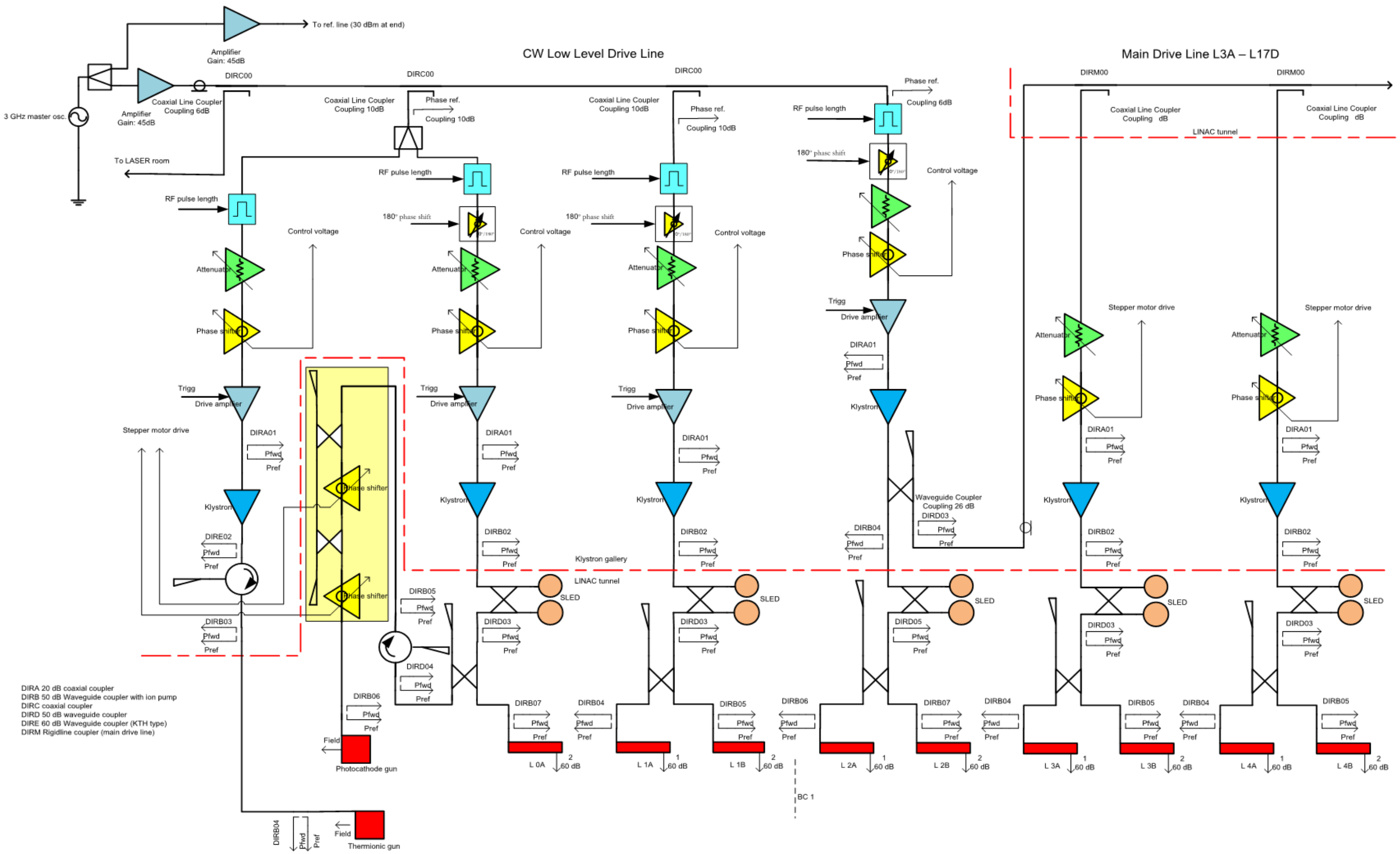




Linac Low Level RF Power (LLRF from K00 to K04)

¤ The linac consists of two parallel tunnels with 1.5 m concret in between. The wave velocity in an air-filled transmission lines is almost the same as the speed of the electrons in the linac.

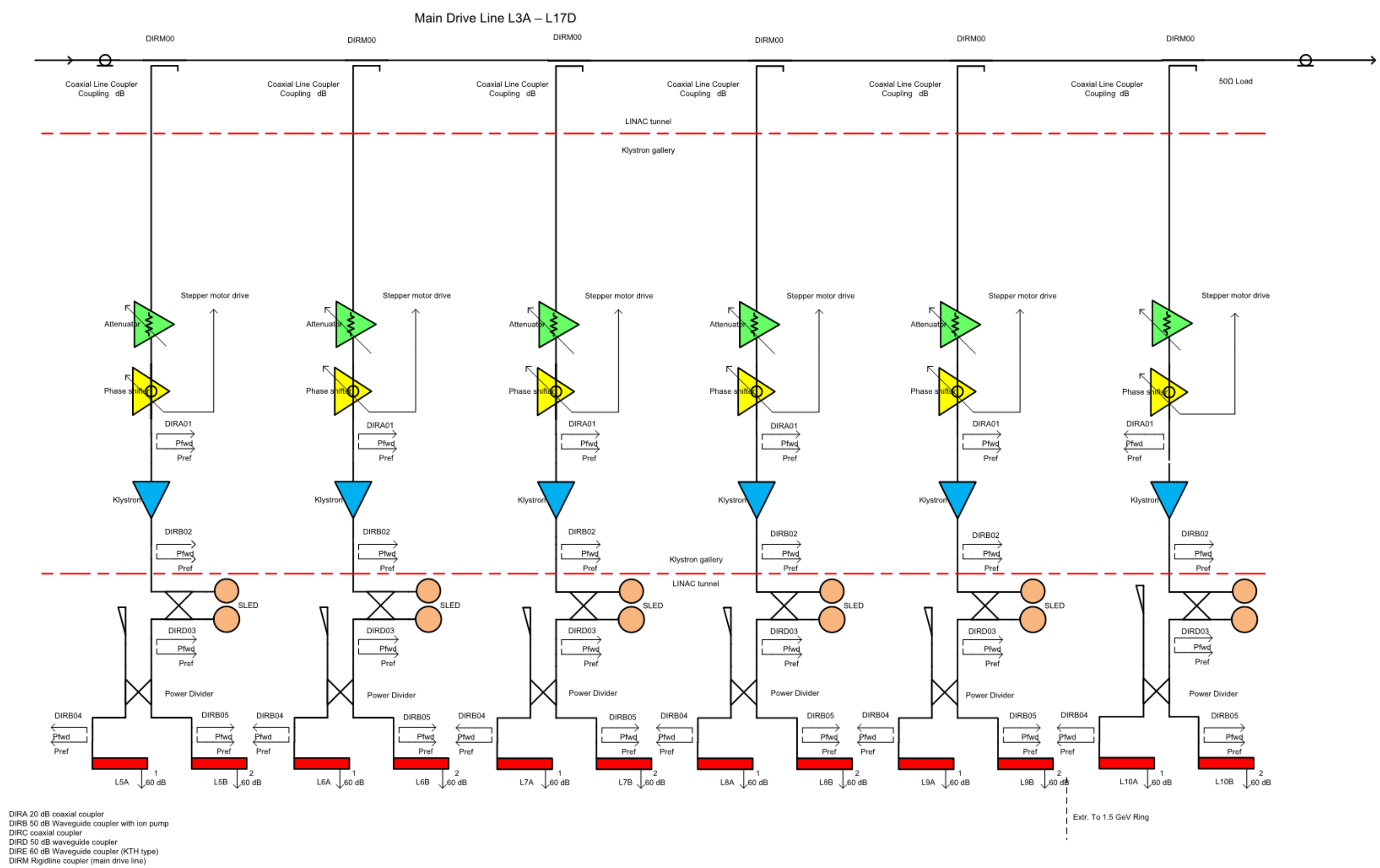
¤ Length variations of the linac tunnel due to e.g. seasonal outside temperature variations will automatically be compensated, since the MDL, consisting of a rigid 1 5/8" coaxial transmission line with sliding joints, also will follow this length variations.



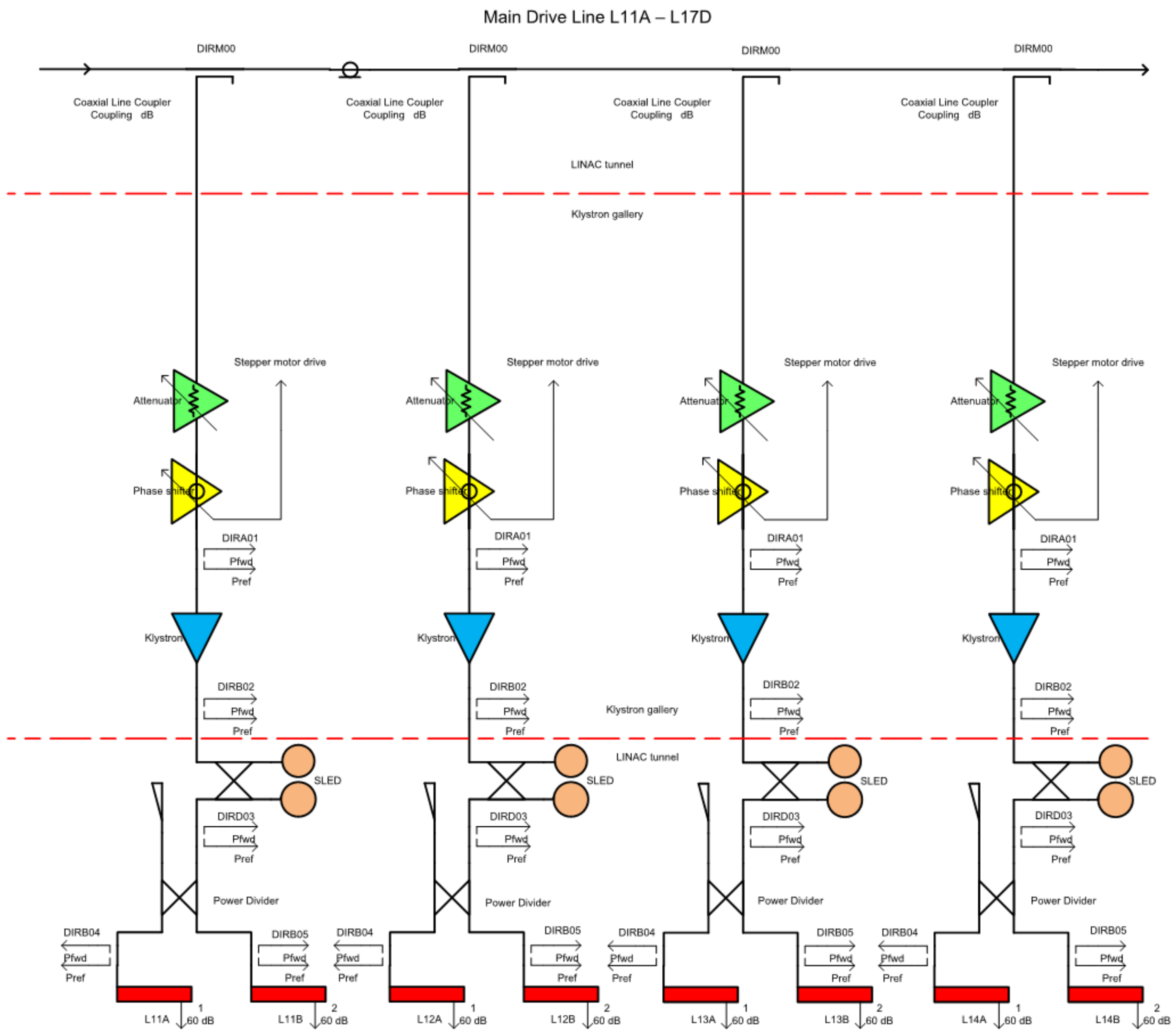
Linac Low Level RF Power (LLRF from K05 to K10)

¤ Main Drive Line (MDL) feeding 17 klystrons with low RF power.

¤ Random voltage and phase variationstions are reduced by one over the square root of the number of klystrons

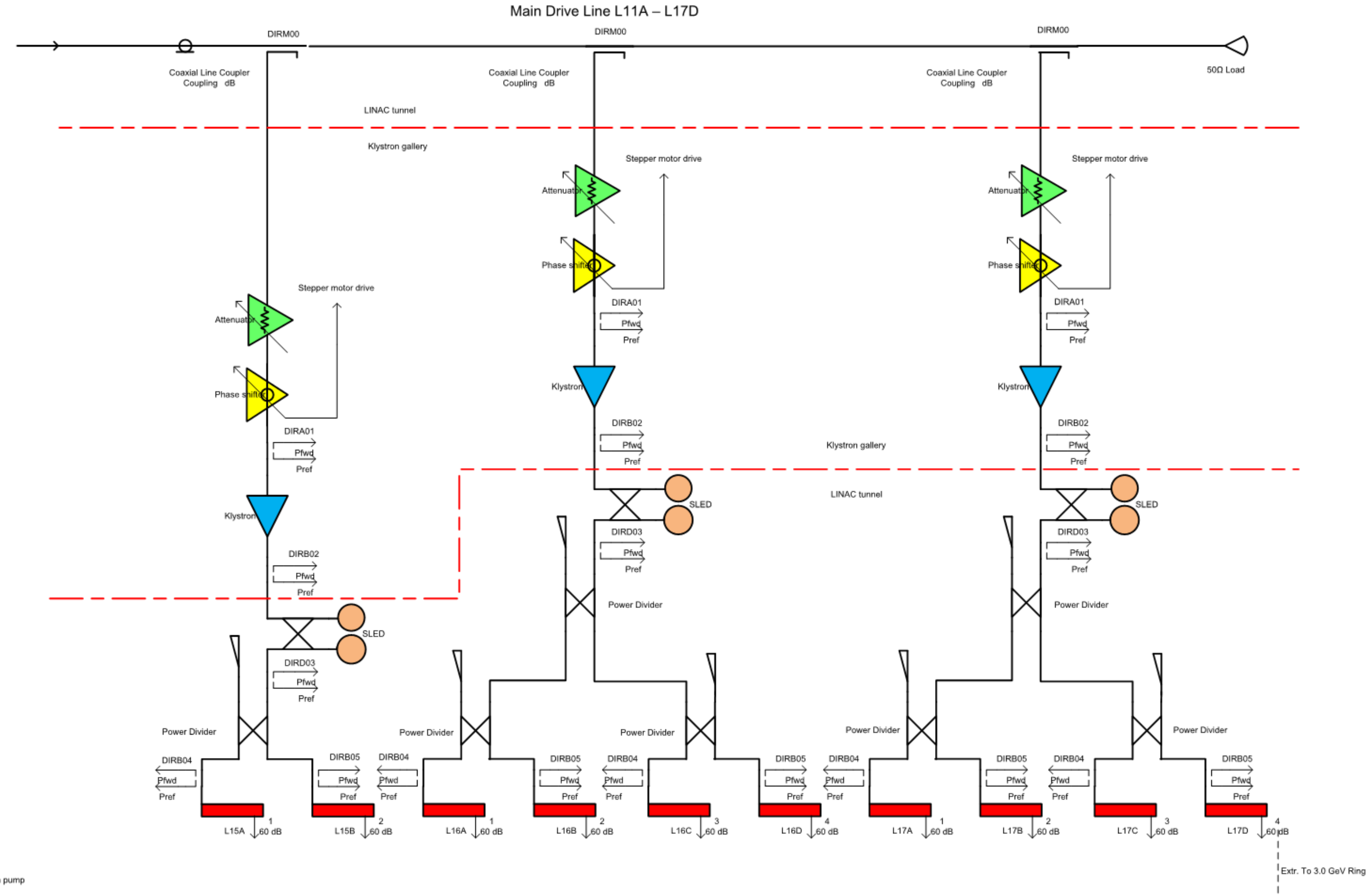


Linac Low Level RF Power (LLRF from K11 to K14)



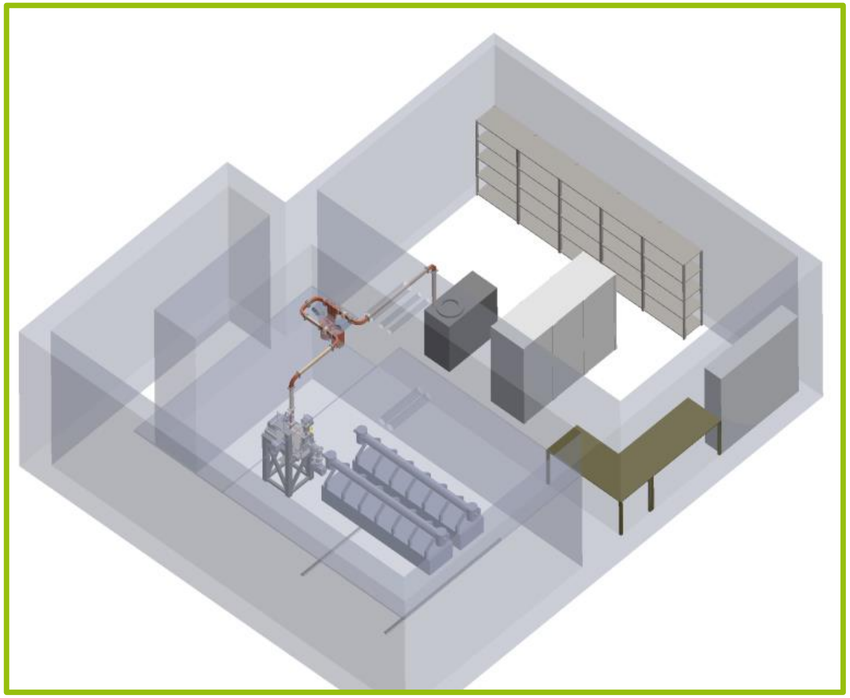
DIRA 20 dB coaxial coupler
DIRB 50 dB Waveguide coupler with ion pump
DIRC coaxial coupler
DIRD 50 dB waveguide coupler
DIRE 60 dB Waveguide coupler (KTH type)
DIRM Rigidline coupler (main drive line)

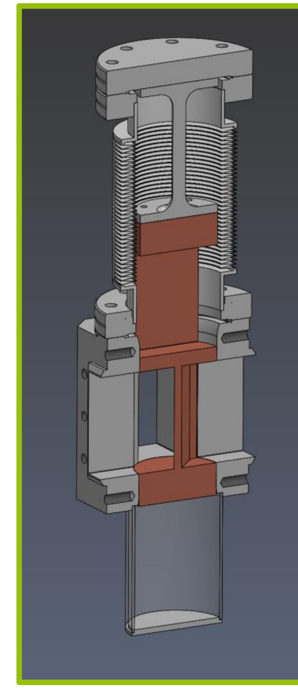
Linac Low Level RF Power (LLRF from K15 to K19)



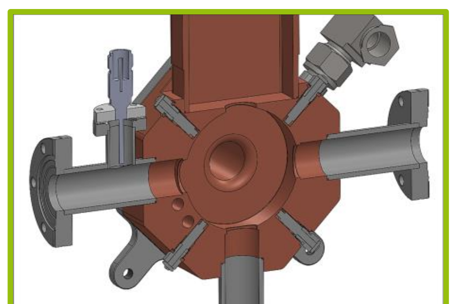
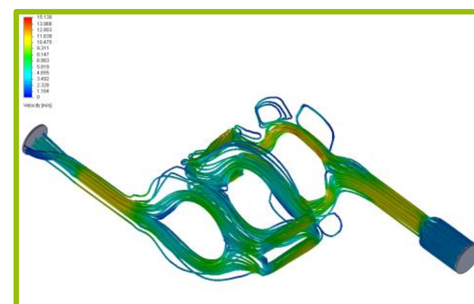
DIRA 20 dB coaxial coupler
DIRB 50 dB Waveguide coupler with ion pump
DIRC coaxial coupler
DIRD 50 dB waveguide coupler
DIRE 60 dB Waveguide coupler (KTH type)
DIRM Rigidline coupler (main drive line)

RF power test facility





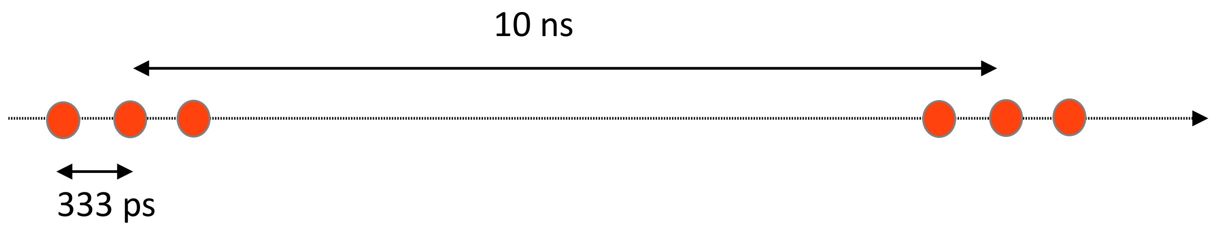
- Under construction
- Preliminary first results by the end of this year
- RF conditioning
- Experiments, tests, optimization for RF guns
- New developments

Kicker system

•The thermionic gun will only be used for ring injections.
•The bunches are leaving the gun with a period of 333 ps (3 GHz).
•Storage ring cavities are operating at 100 MHz.

Injection bunch train structure
•A bunch train should consist of 3 bunches, appearing with a period of 10 ns (100 MHz).
•10 bunch trains during one LINAC shot.



- Has two identical vertical kickers.
- The kickers consist of a 15 cm long stripline pair with a characteristic impedance of 50 Ω for odd TEM modes.
- Both electrodes are fed by RF
- An aperture is located downstream. The unwanted bunches will be dumped here.
- The aperture can be adjusted so the wanted bunches pass a 1 mm hole, a 2 mm hole, or over an edge.

MAX IV

Kicker set-up