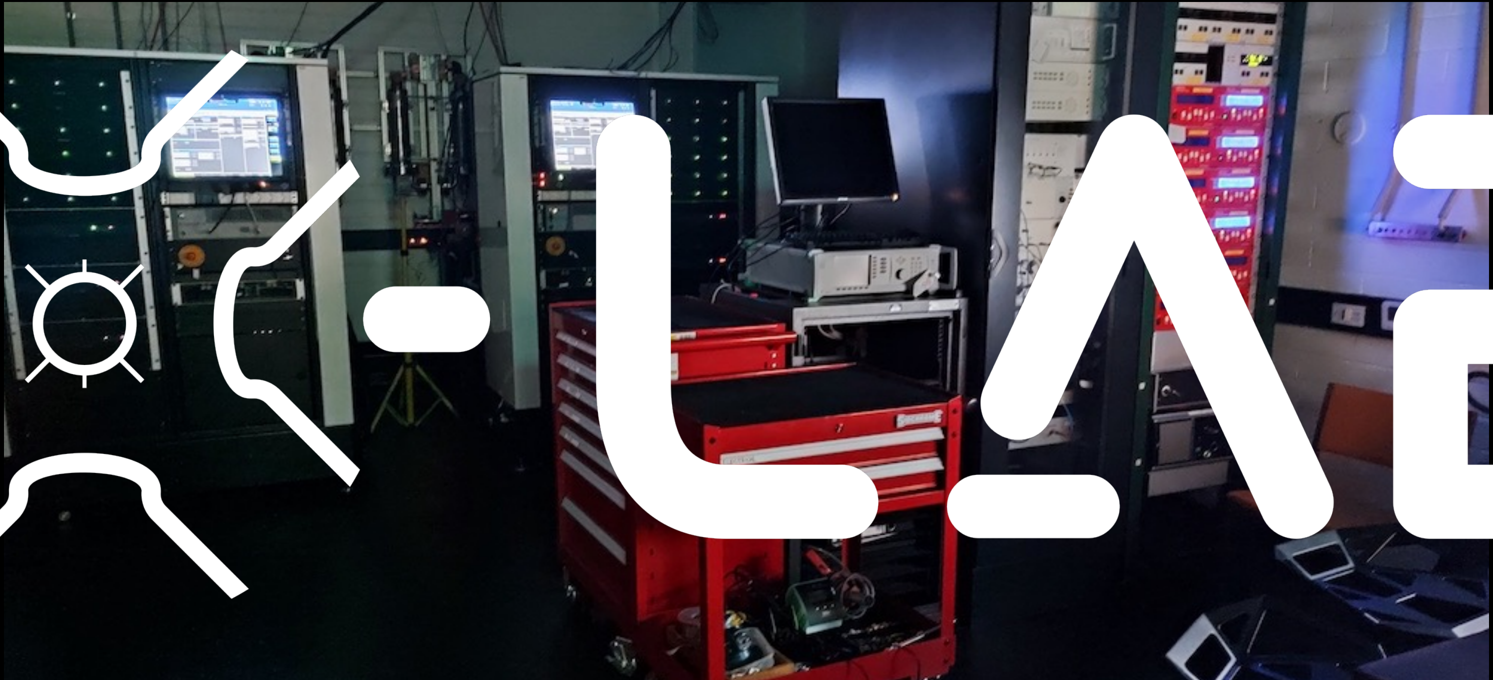
X-LAB: A VERY HIGH-CAPACITY X-BAND RF TEST STAND FACILITY AT THE UNIVERSITY OF MELBOURNE

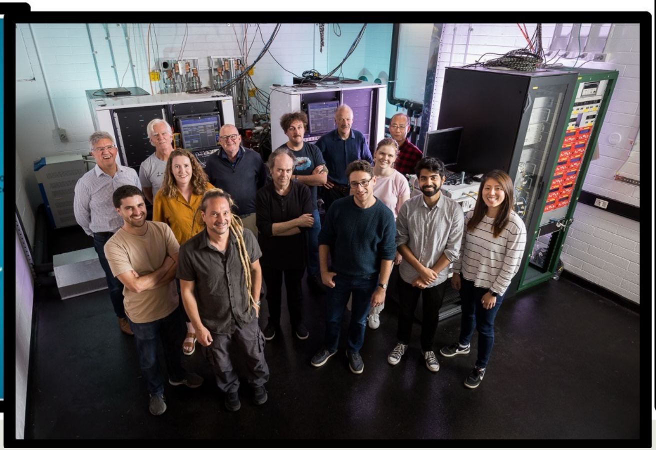


<u>Matteo Volpi</u> on behalf of the X-LAB group:

S. L. Sheehy, P. J. Giansiracusa, R. P. Rassool, G. Taylor, P. Pushkarna, (The University of Melbourne, Melbourne, Victoria), R. Dowd, E. Tan (AS - ANSTO, Clayton), M. Cherrill (University of South Australia), RF CERN group.

X-band Laboratory for Accelerators and Beams (X-LAB)

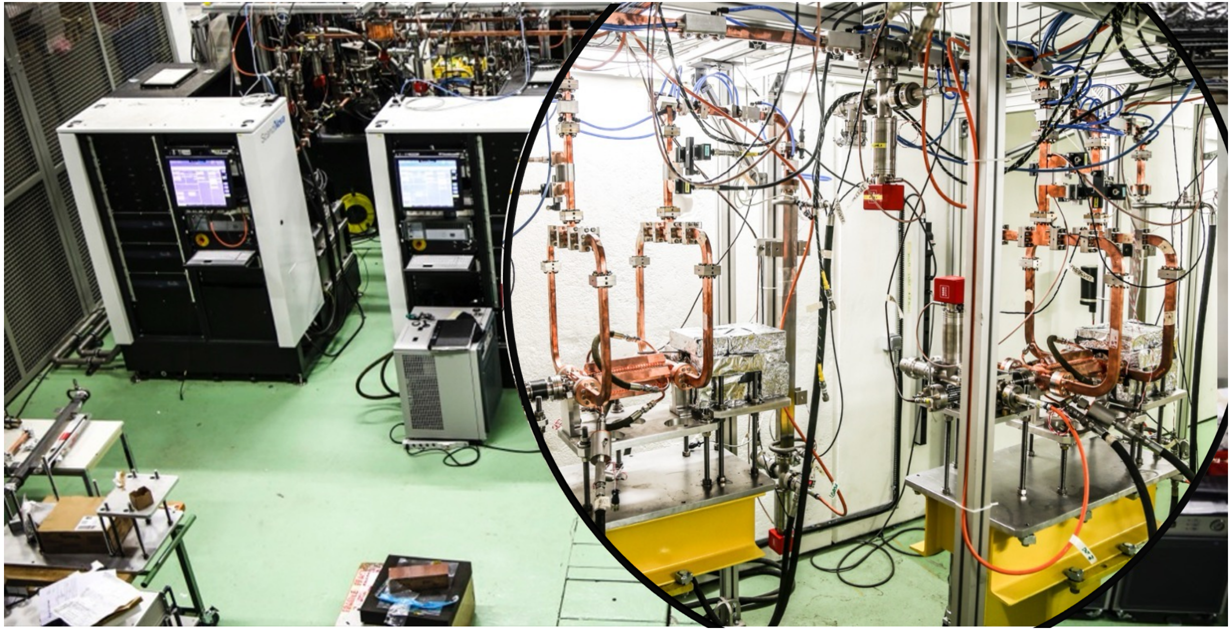
- A new laboratory is currently operational at the University of Melbourne (UoM)
  - This facility represents the first high-power, high-frequency accelerator laboratory in the Southern Hemisphere. It is dedicated to testing high-gradient structure prototypes and RF components for CLIC, as well as engaging in ultra-precision manufacturing.
  - The primary objectives include designing and developing new accelerator technology. This project aims to provide local researchers and students with the opportunity to make significant advances in accelerator design.



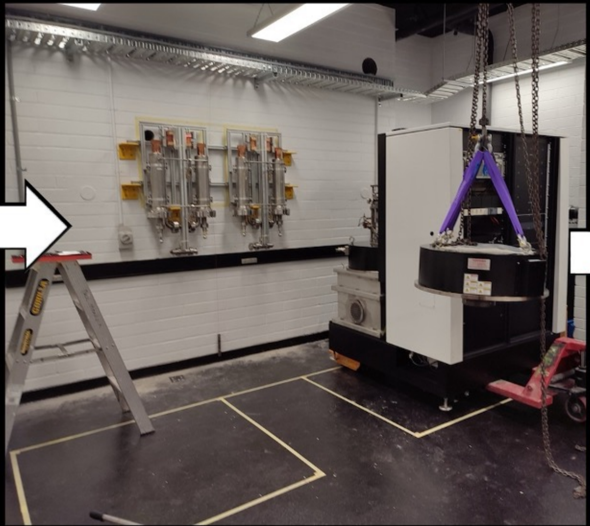
CERN layout before the shipping

At the heart of the project is the CERN X-band **(~12GHz)** high power equipment including modulator and klystron (left) feeding RF power to two copper accelerating structures (right).

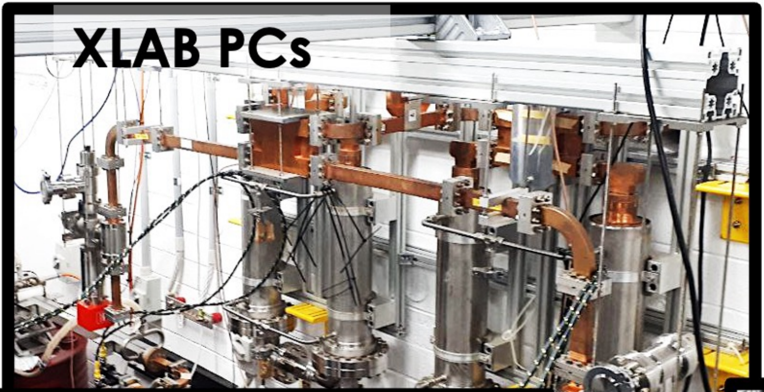
- Half of CERN Xbox-3 has been brought to Australia
- Reassembled in the old Betatron Bunker in the School of Physics at the University of Melbourne
- 2x 6 MW 12GHz Klystrons + Modulators operating in tandem to feed 2 test stands
- 400Hz repetition rate

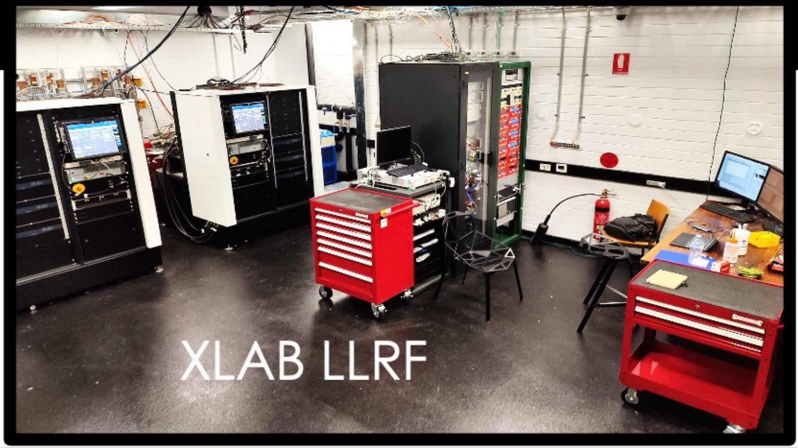


XLAB layout history



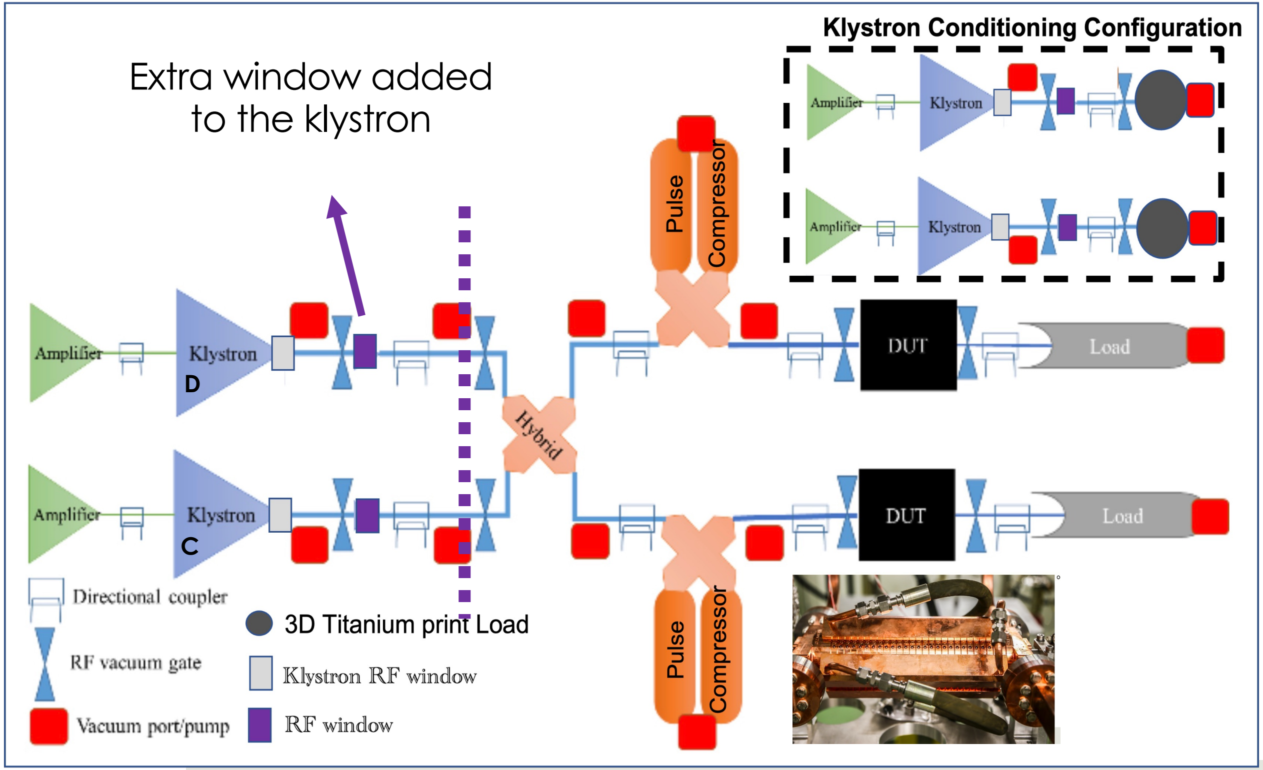
XLAB today

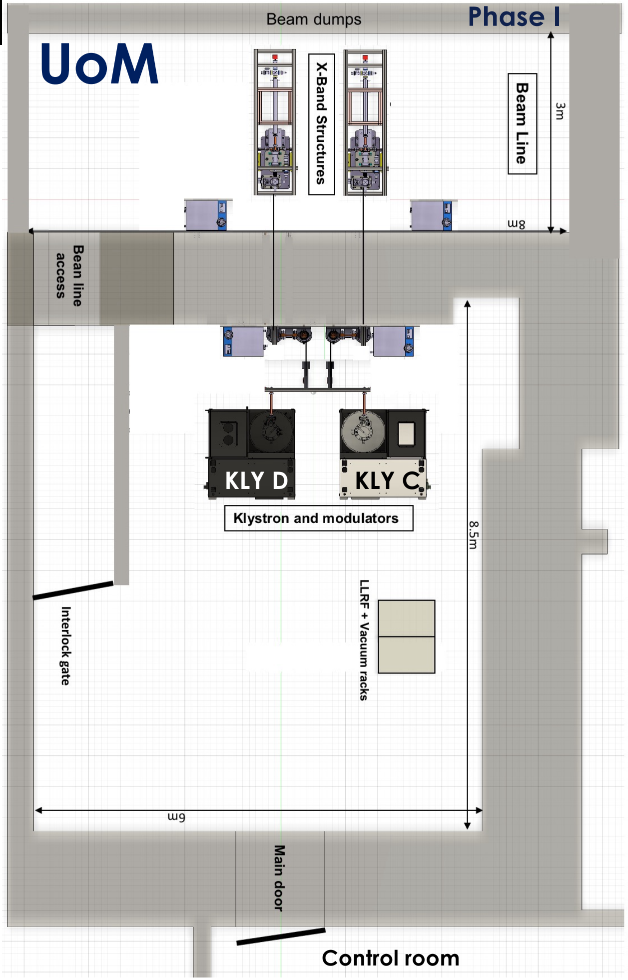




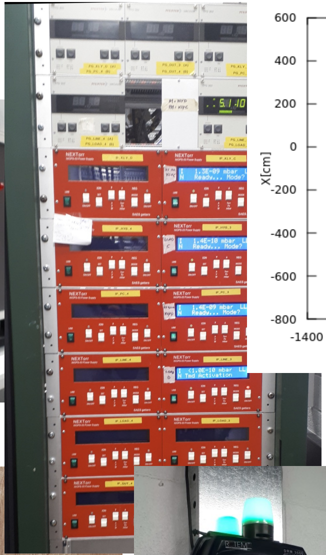
MeL-BOX Layout

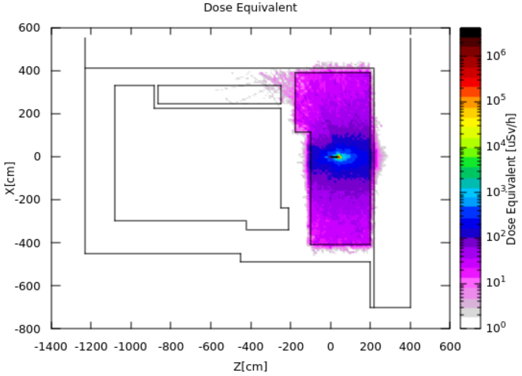
Schematic of the X-lab setup for experimental structure testing and conditioning CLIC prototype structures.

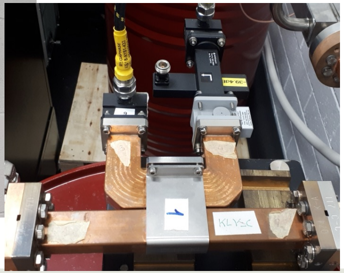




Interlock System - Triggers







- Radiation monitors
- RF reflections
- High vacuum activity
- Open doors
- Key-based interlock the system cannot be started if the tunnels are open
- E-Stop
- Temperature
- Chillers/flow meter

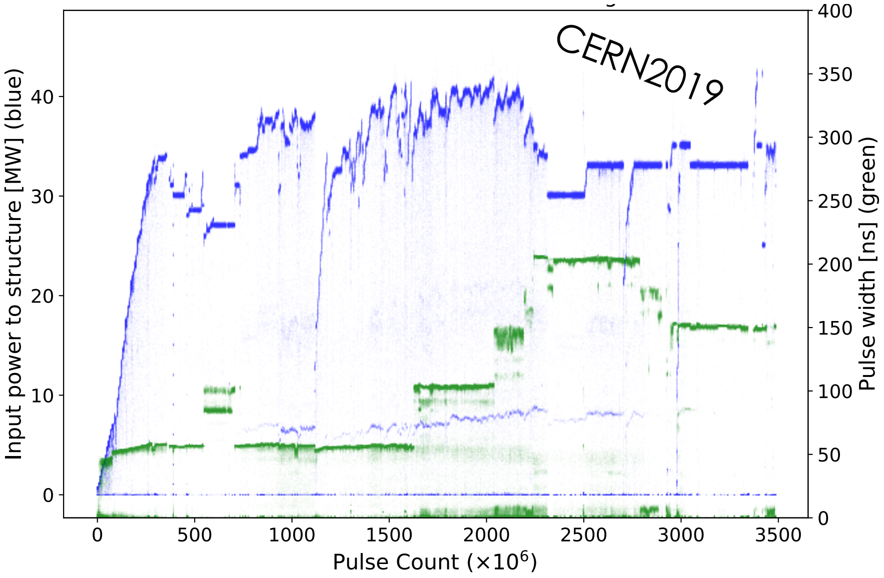
CLIC prototype structure conditioning and more..

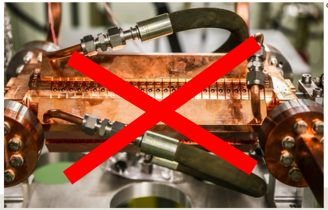
- Each RF breakdown causes a destructive sideways kick to the particle bunches. **This is why accelerating structures are conditioned** - or 'broken in' - before operation.

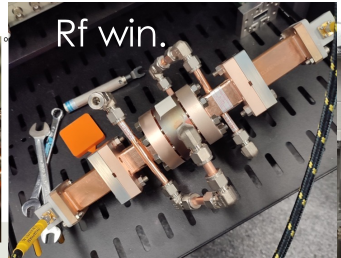
- The process of conditioning requires a variation of input pulses as gradient and pulse width to ensure reliability of operation to attain the lowest possible breakdown rate.

- **Before** installing the structures, we are conditioning the lines. **Main components:**
  - **RF windows**
  - **Pulse Compressor (PC)**
  - **Stainless steel loads**

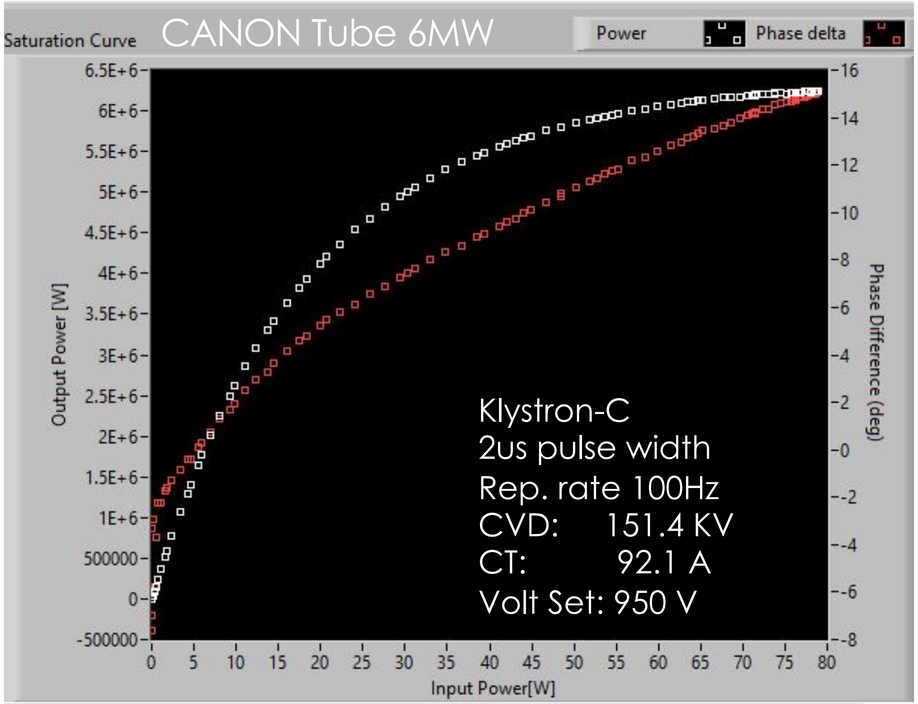
TD24 structure so far reached 40.45 MW (97.9 MV/m)

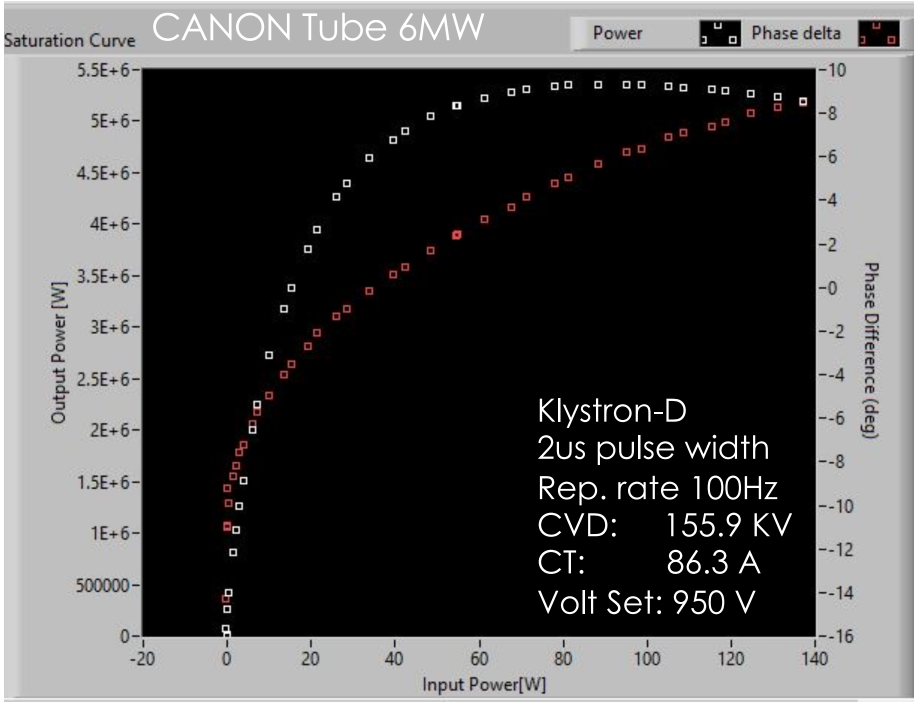






Klystron and RF window conditioning-Gain curves

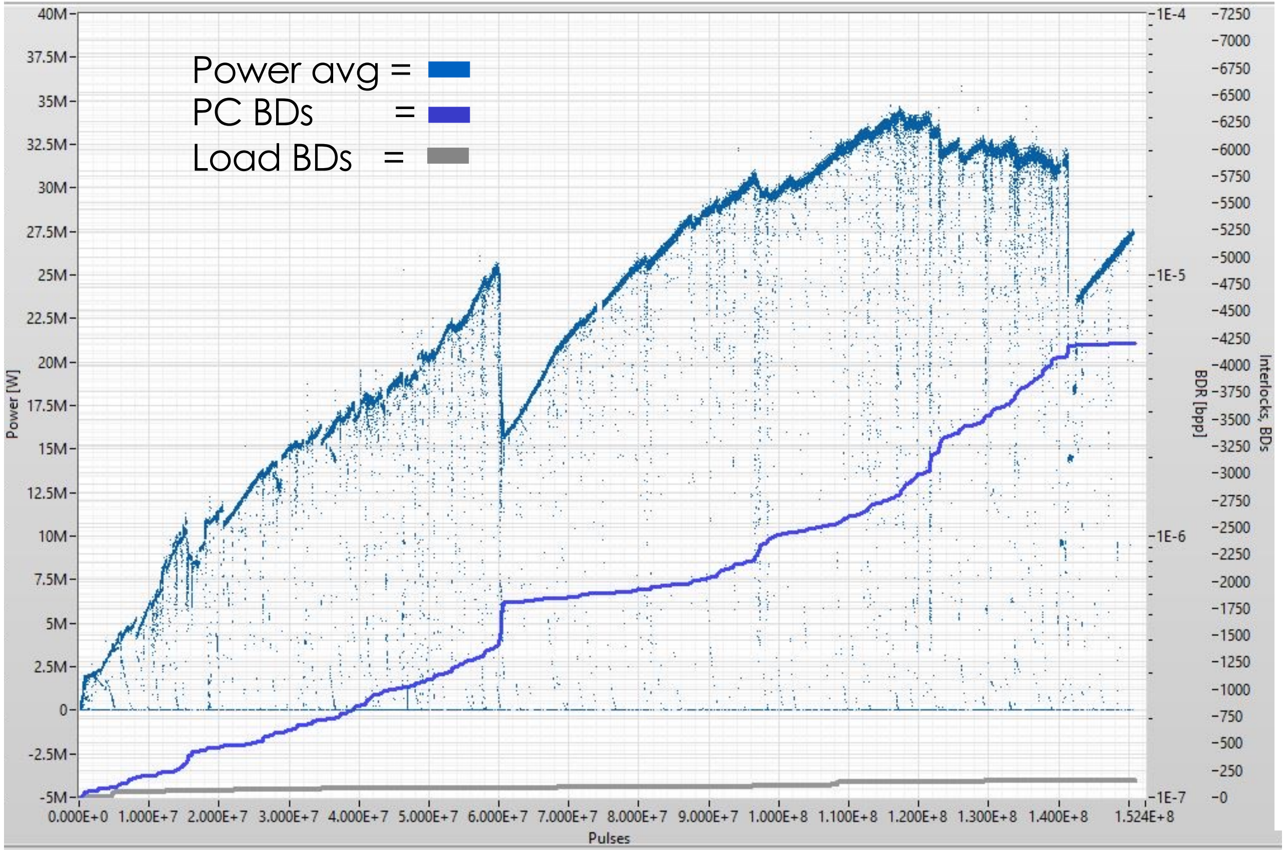




NOTE: The new **RF windows** installed after the klystron have also been conditioned. We encountered some issues with one of them during the power ramping conditioning algorithm. By using the **'pulse length rise'** instead of the power, we were able to recover the window.

Line3- history plot

Conditioning limited by the Pulse Compressor breakdowns

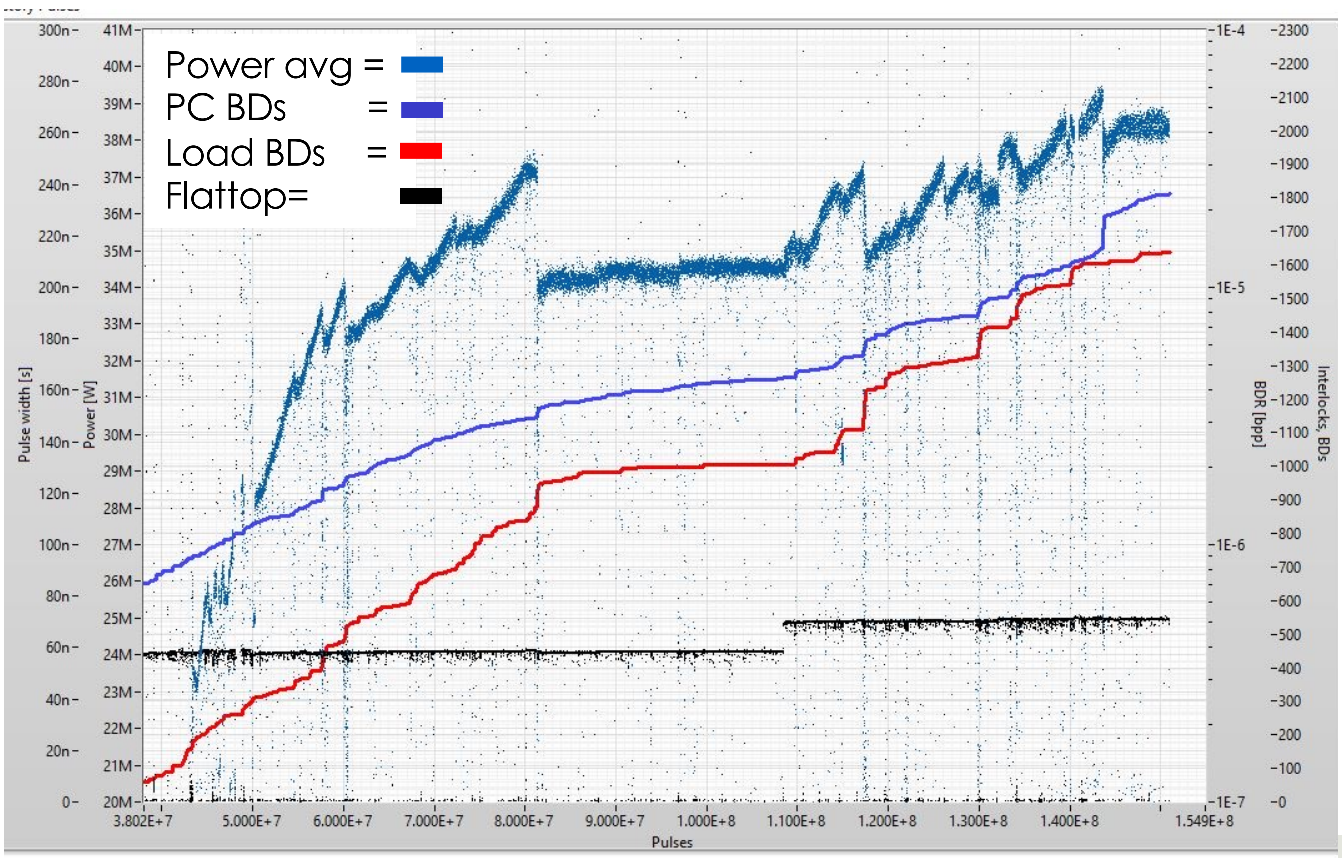


Peak Power ~34MW
1.8 us pulse width
60 ns flat-top
100Hz repetition rate
PC BDR limit threshold 5x5E^{-5}
~4000 BDs

We are aware of the problem and already have a solution that needs to be implemented as soon as possible.

Line4- history plot

Pulse Compressor and load breakdowns



Peak Power ~40MW
2 us pulse width
70 ns flattop
100Hz
BDR threshold 5x5E-5
PC4 BDs ~2000

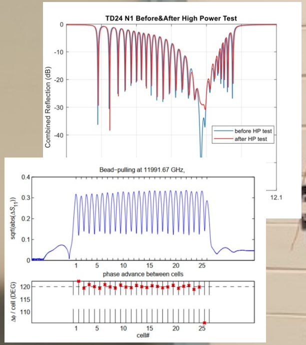
Conditioning summary

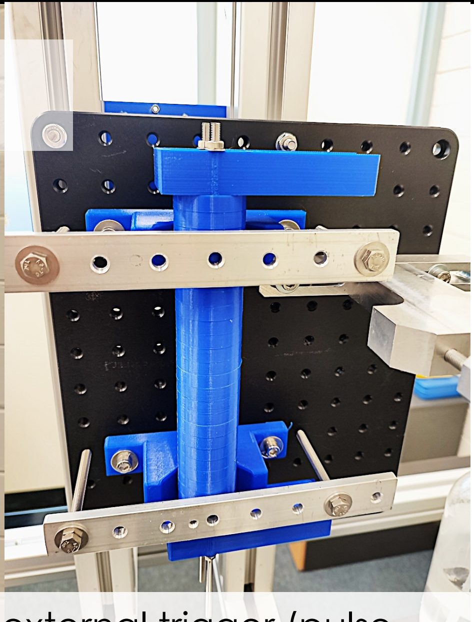
Component	Pulse Width	Peak Power [MW]	Max Rep. Rate [Hz]	NOTE
KlyC	2 us	6.2	100	
KlyD	2 us	5.5	100	“Old” klystron
RF window - C	2 us	6.2	100	“Pulse length ramping” conditioning
RF window - D	2 us	5.5	100	
PC-3	1.8 us	34	100	Breakdown -> new cup required
PC-4	2 us	40	100	Conditioning going on
LOAD 3	1.8us	34	100	Conditioning limited by PC-3 BDs
LOAD 4	1.8us	40	100	Conditioning going on

Nex steps and long-term goals

Bead pull setup

- **Check and tune the two TD24 structures (if required).**

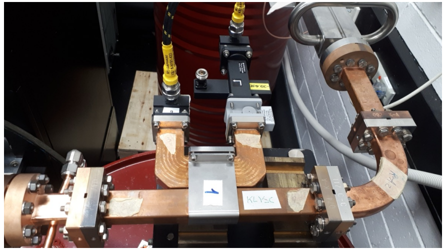




- VNA + external trigger (pulse generator)
- Step motor controlled by an Arduino (triggered)
- Fishing wire alignment
- Temperature control (chiller)
- Nitrogen system

Diagnostic Systems

- Directional couplers
- Faraday cups – RadiaBeam 35 MeV

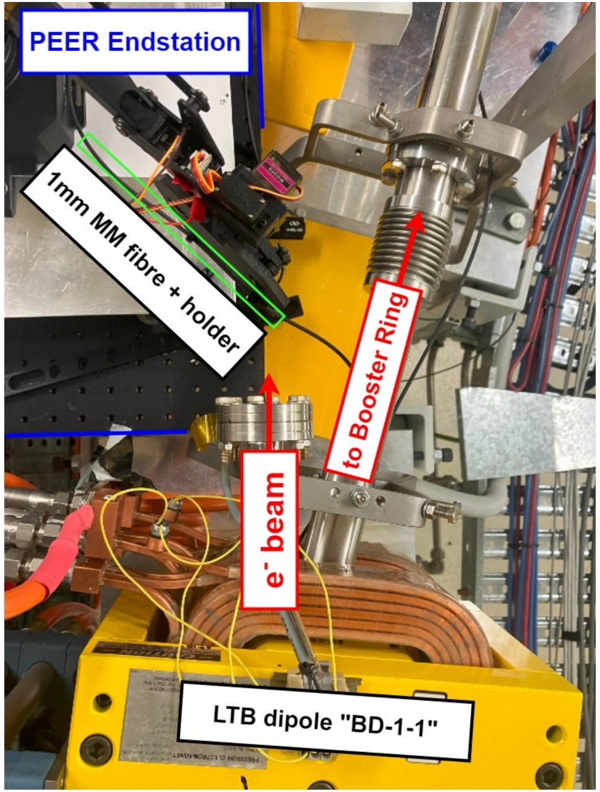


- BLMs
  - Optical fibre – 1 mm quartz fibre with Sens l/Hamamatsu SPMs
  - Scintillator Based – Libera BLM
  - PIN diodes

- Vacuum Gauges
- Very few channels remain on the NI-PXI
- Increasing diagnostic capacity, parallel system with faster digitizers
  - Max Sample Rate 10GS/s
  - Resolution 12 bits

Novel diagnostics using Cherenkov radiation

- Transport of radiation to detector challenging
  - Optical fibres enable transport under geometric constraints
- CR intensity in fibres proportional to incident charge
  - Already employed as distributed Beam Loss Monitors
- Explore application to
  - longitudinal diagnostics
  - breakdown science
  - and bunch profile reconstruction

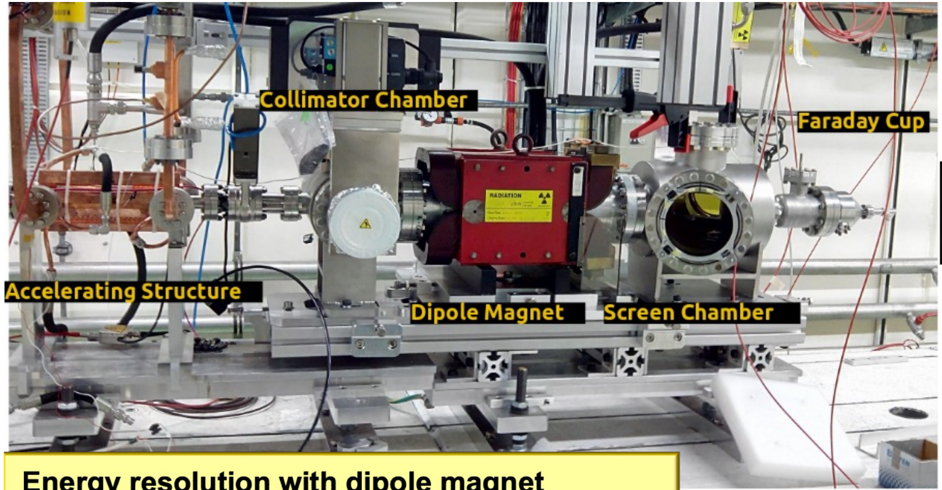


Paarangat Pushkarna, PhD student & AS - ANSTO

Spectrometer

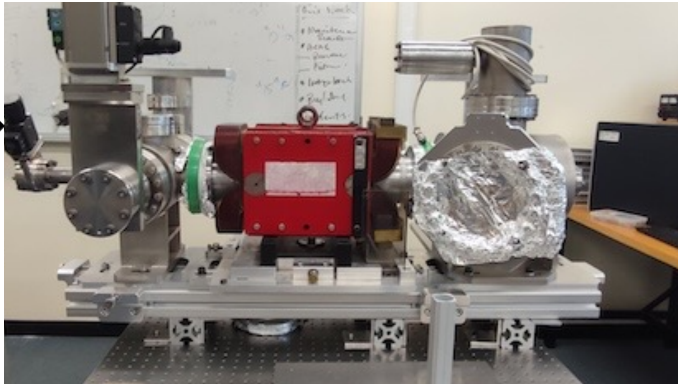
Uppsala/CLIC X-band Spectrometer (UCXS)

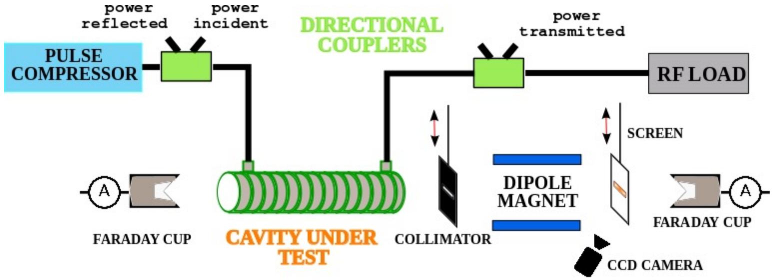
Spectrometer was installed at "XBox1" 12GHz 50 MW test stand @CERN



Energy resolution with dipole magnet
Maximum expected electron energy ~20MeV
Rel. energy spread (single slit) 10% - 25%
Full energy coverage with magnetic field scan

Started the reassembling in MELBOURNE





- BD event analysis
  - Position: transversal and longitudinal
  - Energy

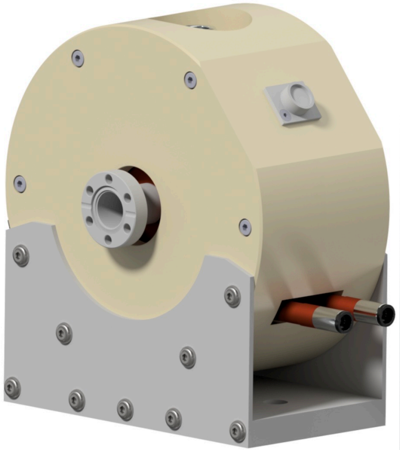
Marek Jacewicz and Uppsala accelerator group

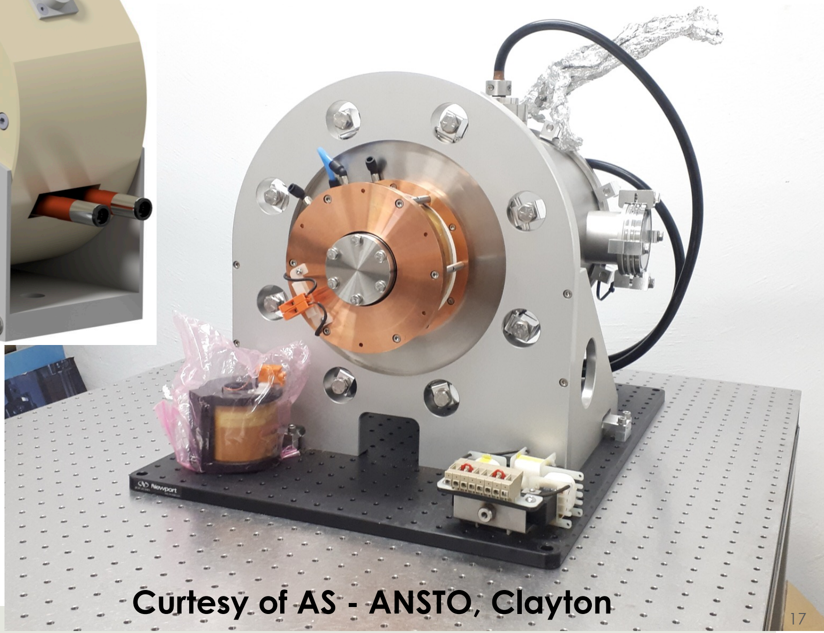
The Future of XLAB – Accelerator Physics Lab

- Build on the RF test stand
- Develop hands-on skills in accelerator systems

- Compression cavity
  - DRX Works
  - 3GHz

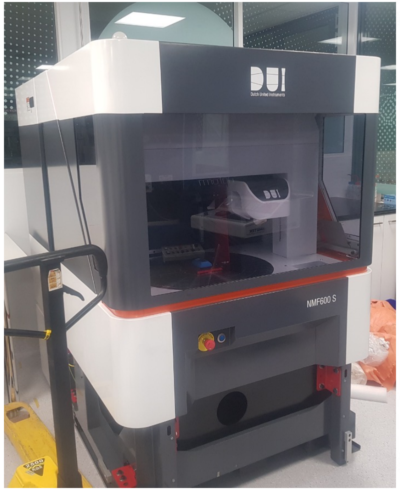
- Electron Gun
  - DRX Works
  - 100 kV Photogun
  - 12.3 MV/m
  - Copper cathode
  - Illumination with a 1μJ 266 nm 1fs laser pulse can produce 1 pC electron bunches
  - Looking for advice on a suitable laser





Local Manufacturing

- **Australian National Fabrication Facility (ANFF): manufactured a W90 to waveguide adaptor**
  - "This project has been a good chance to review some of our processes and equipment gaps."
- They have been using monocrystal diamond tooling
  - surface roughness ~Ra 7nm (best measured so far)
  - tolerances within 1µm
- Be able to make a disc? Not sure, but that our overall aim for the future is to have that capability.
  - They are refurbishing the space for the new equipment.
  - New diamond turning machine
  - **Advanced milling training courses**



Specification

ANFF-SA were tasked to fabricate 1 W90 adaptor flange from 316LN to drawing specification 2021 052 F P001.

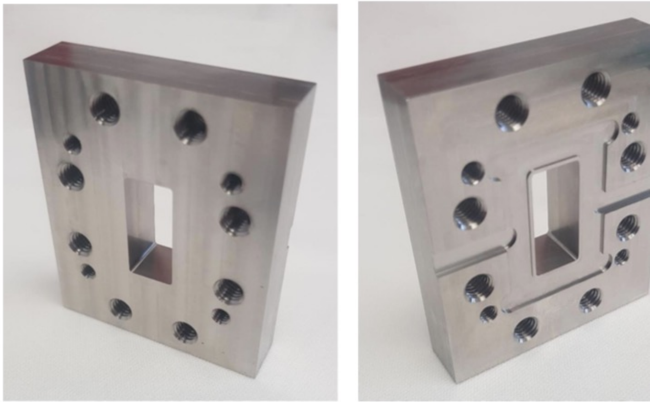


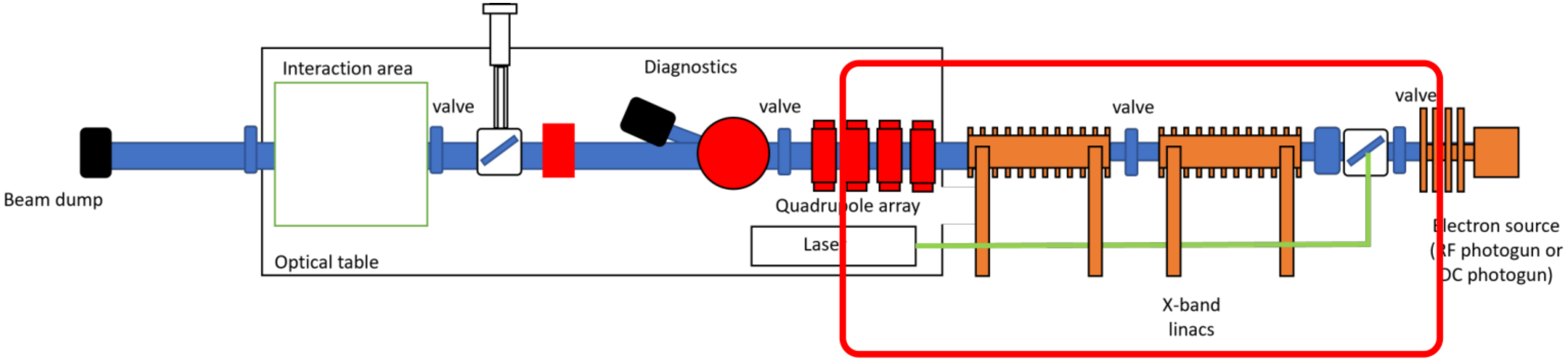
Fig 1. Images of finished part (front and back).

Conclusion and future plan

- An X-band test stand has been commissioned at the University of Melbourne (UoM) to serve as the central infrastructure for further development in the new X-LAB.
- Both lines have almost been fully conditioned. The next step is to start conditioning the structures.
- Diagnostic beam systems are currently under development.
- You are welcome to visit the facility! Help and support are more than welcome!

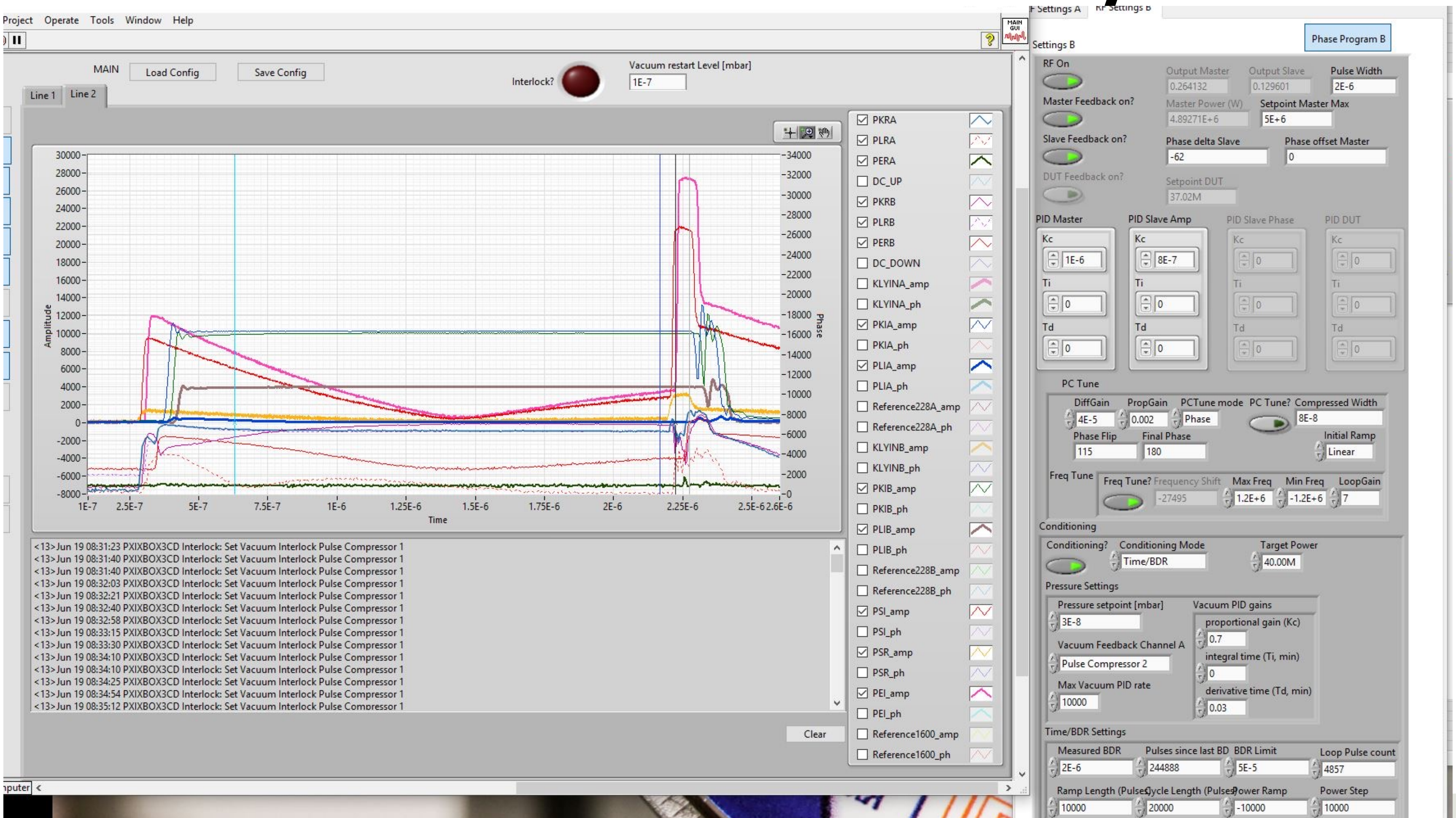
Beamline

- Build on the RF test stand
- Develop hands-on skills in accelerator systems



S. Williams (2023). *Simulations of a compact beamline utilising high gradient X-band RF accelerating cavities at the University of Melbourne X-LAB* [PhD Thesis]. The University of Melbourne

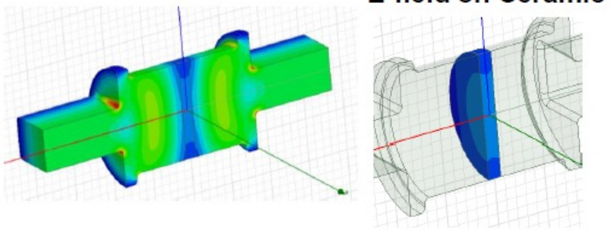
MEL-BOX Line4 GUI



X-band High Power RF Window

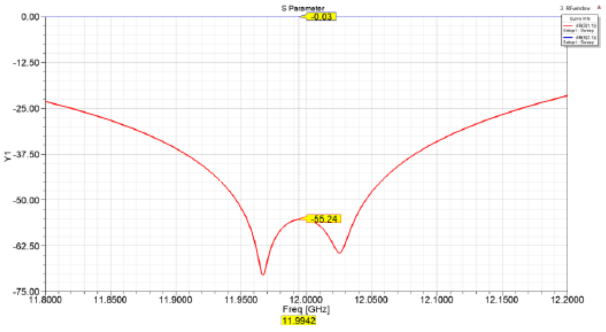
- Compact RF window with TW in ceramic was designed at CERN to decrease the electric field strength on ceramic. At Canon, it is now commercialized as a separate RF device.
- VNA measurements before installation
  - S_{11} ; S_{22}~-30 dB attenuation
  - S_{12} ~ 0.05 dB transmission
- Vacuum test : ~10^{-10} mbar

E-field　　E-field on Ceramic

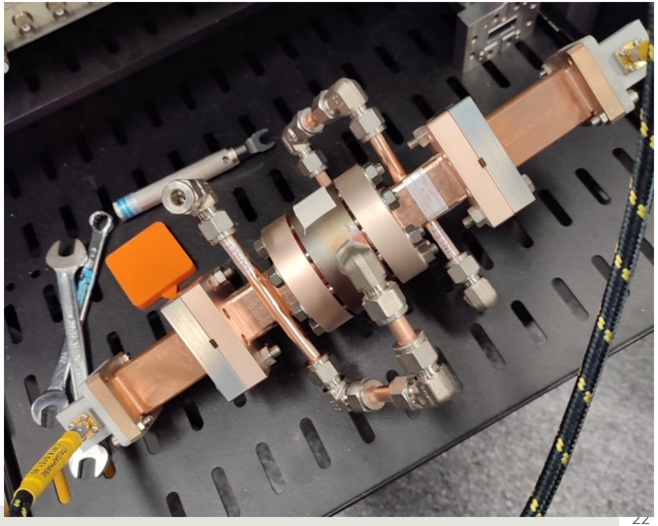


CANON specification	Value	Units
f_0	11.9942	GHz
P_{IN}	10	MW
Material	Al_2O_3	
Relative Permittivity	9.8	
Dielectric Loss Tangent	0.002	
s_{11}	-55	dB
s_{21}	-0.03	dB
$E_{Max\ Ceramic}$	3.9	MV/m

Bandwidth



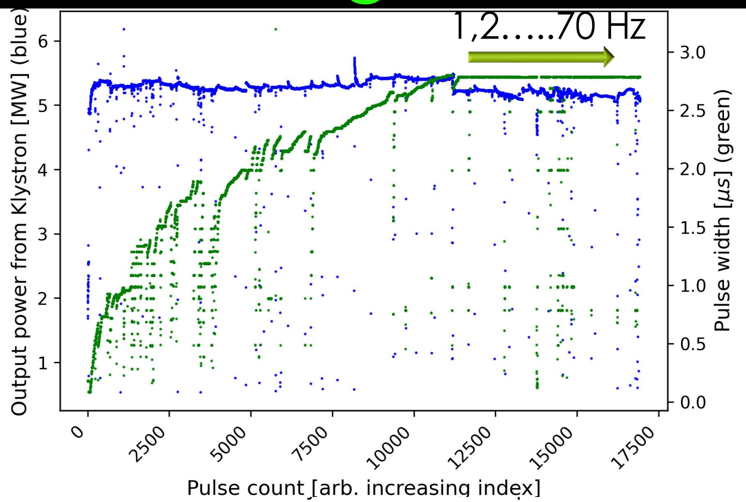
RF Parameters at f_0 = 11.9942 GHz

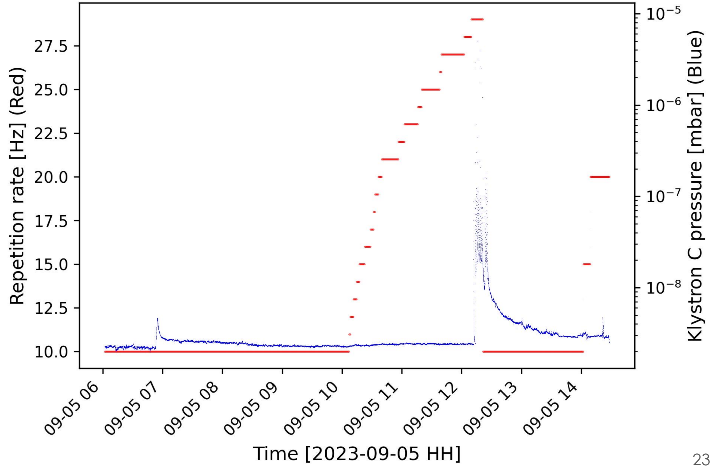


“Pulse length” line C conditioning

- To address such surfaces, we recondition the RF circuit using the following steps:
  1. Reduce the pulse length to a level that allows for continuous high-power operation without frequent breakdowns at **10 Hz** (e.g., 0.3 µs). Also, decrease the pulse repetition rate since the vacuum pressure remains high after breakdown and takes time to decrease.
  2. Maintain conditioning for 30 minutes.
  3. **Increase the pulse length** by 0.1 µs and continue conditioning for 5 minutes. In our case, we use approximately a 20 ns step.
  4. Repeat step 3 until the pulse length reaches the same value as before this procedure.

- Gradually increase the pulse repetition rate (e.g., 1 Hz per minute). Conditioning is in progress, and vacuum tests confirm that the windows aren’t broken.





Cherenkov signal improvement studies

- Propagation in fibre distorts CR signal
- Using multimode fibres increases signal
  - But introduces modal dispersion
- Vary beam incidence angle to improve intensity
- Examine dispersion compensation techniques
- Seek an intensity vs dispersion trade-off