High gradient RF testing infrastructure and MgB2 solenoid at CERN

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Muon collider collaboration meeting.

12.10.2022

Outline

Why high gradient?

- Requirements
- Conditioning

Test facilities at CERN

- Xband
- S-band
- Diagnostics
- Conditioning tests
- Other tests
- Superconducting solenoid for Klystron

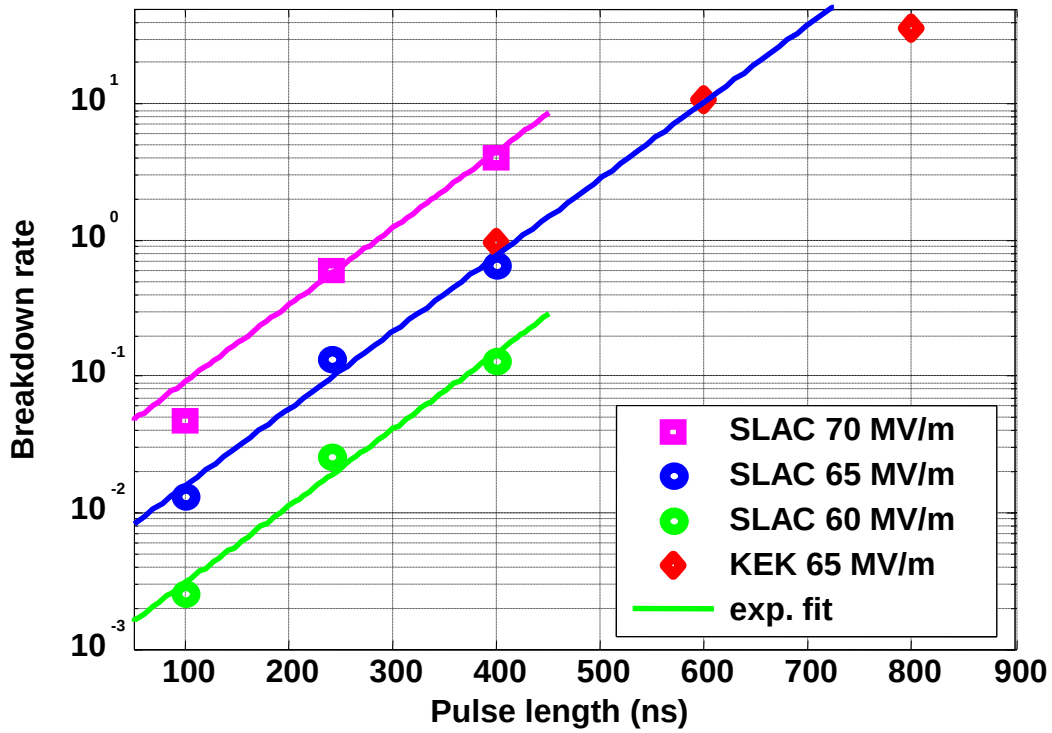
High gradient outside CLIC

Plans and future

Accelerating structure specs

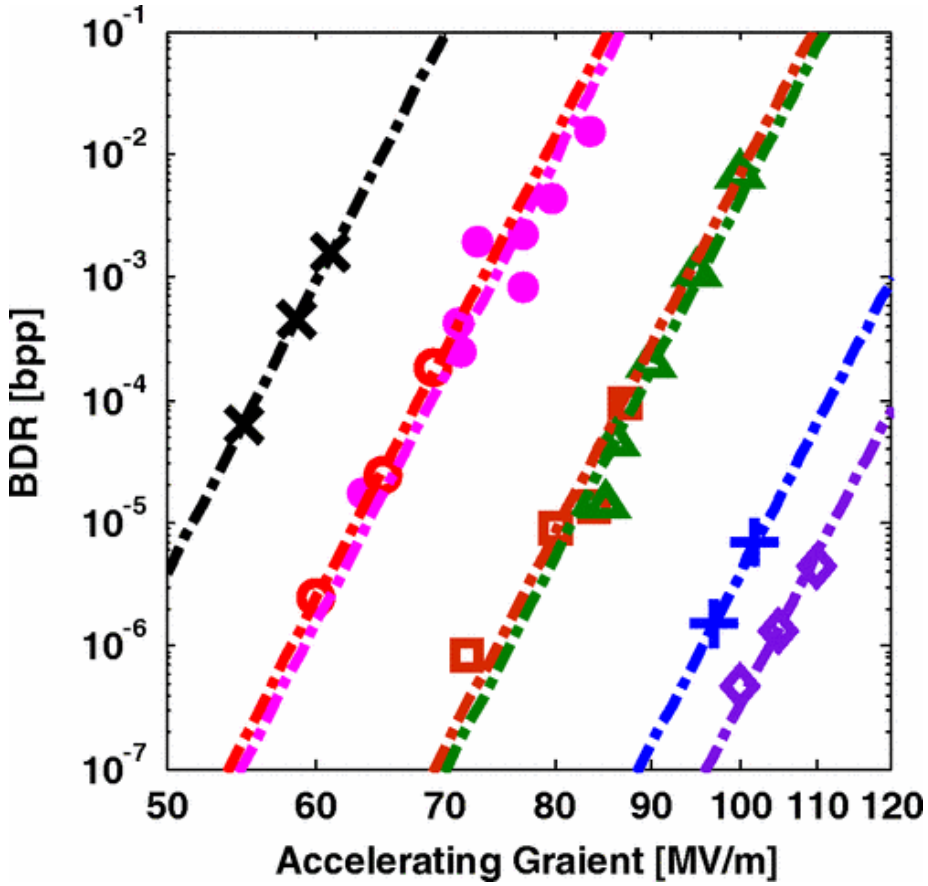
Power and gradient:

1. **100 MV/m** loaded gradient
2. **Less than 3x10^{-7} breakdowns/pulse/m**
3. 240 (full) ns pulse length. 156 ns flat top
4. 12 GHz (X-band)



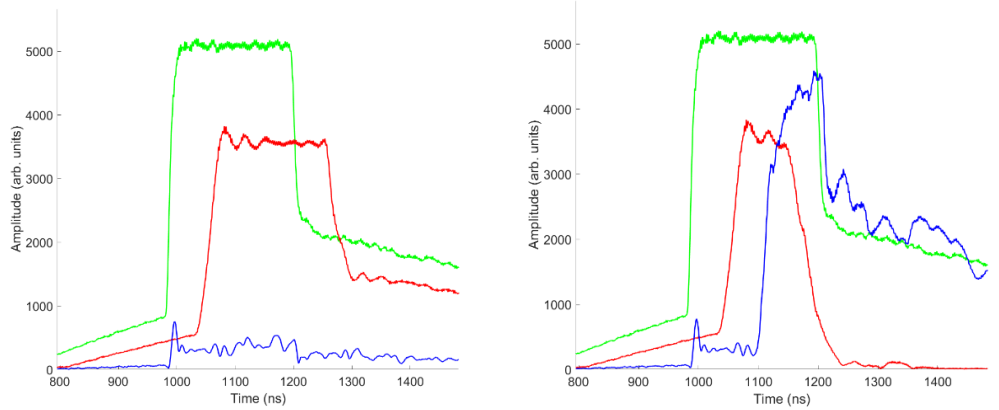
Phys. Rev. Spec. Top. Accel. Beams 12 (2009) 102001

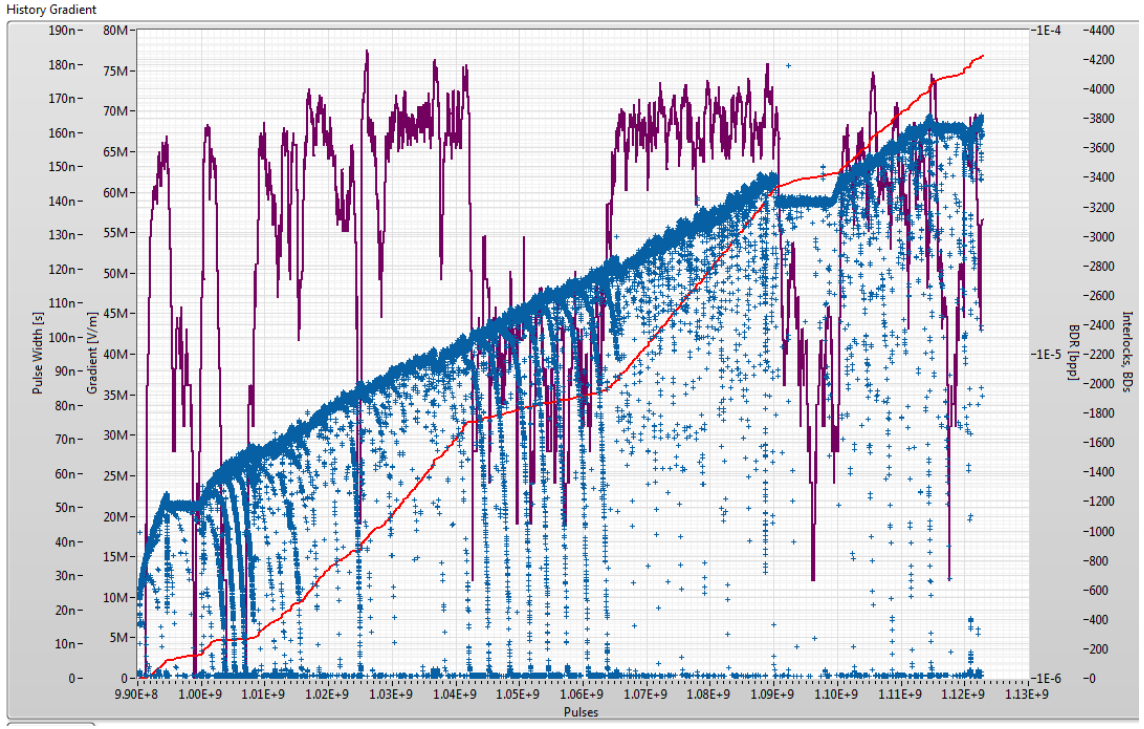
$$BDR \propto E^{30}\,\tau^{5}$$



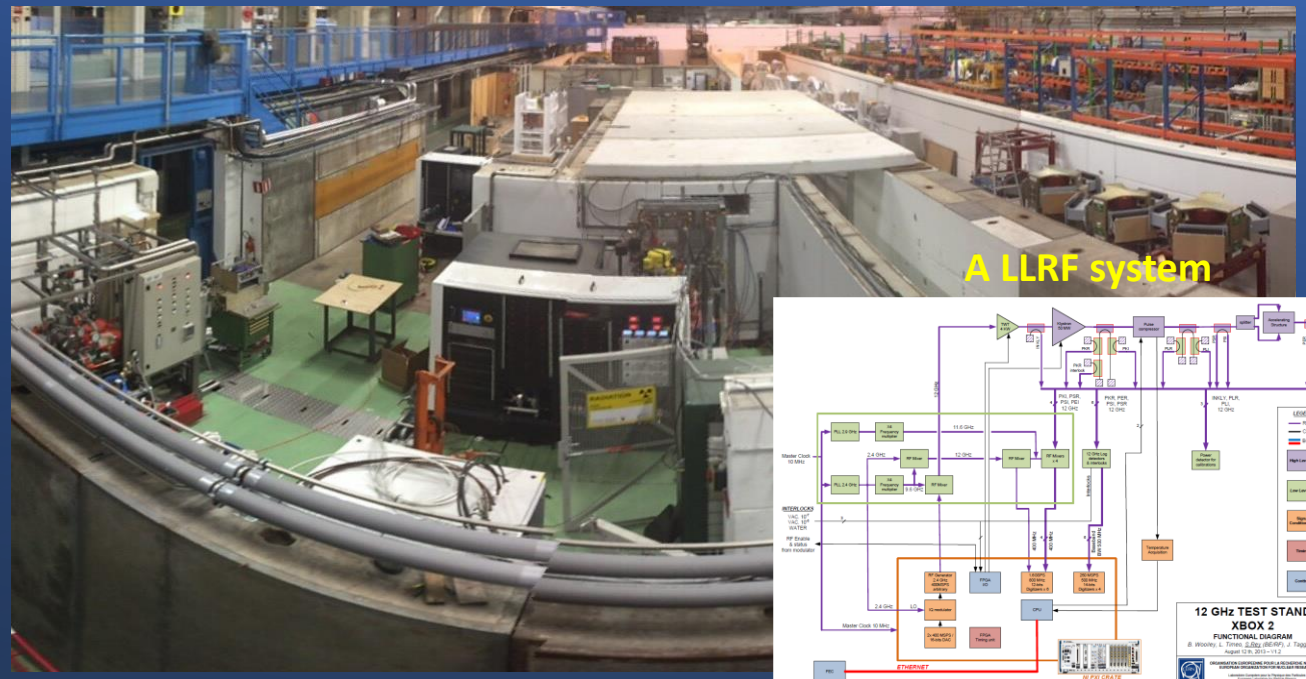
Breakdown and Conditioning

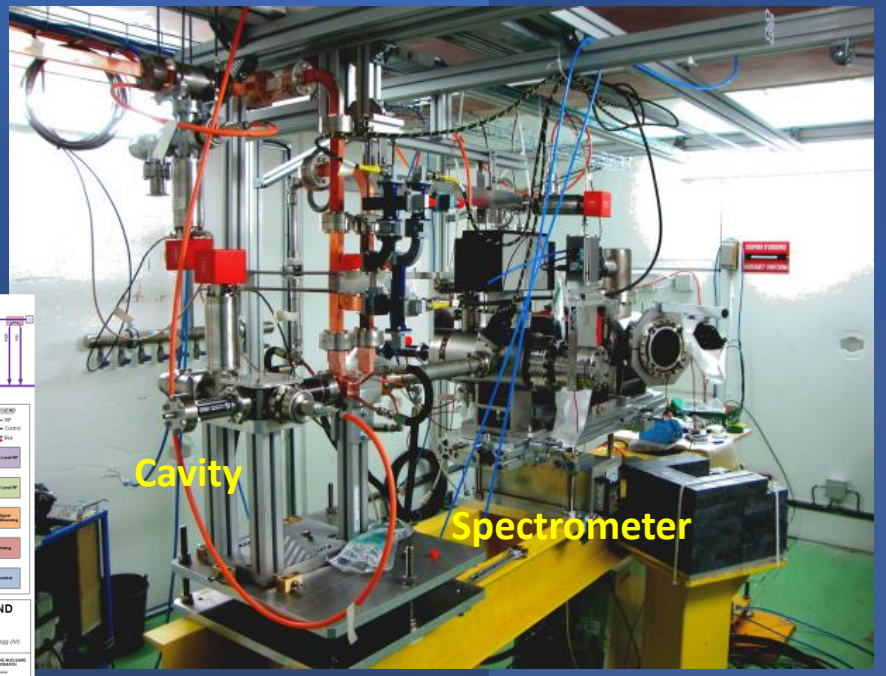
- Very high fields provoke arcing in vacuum and structure damage
- Accelerating structures do not run right away at full specification – pulse length and gradient need to be gradually increased in a process known as conditioning.



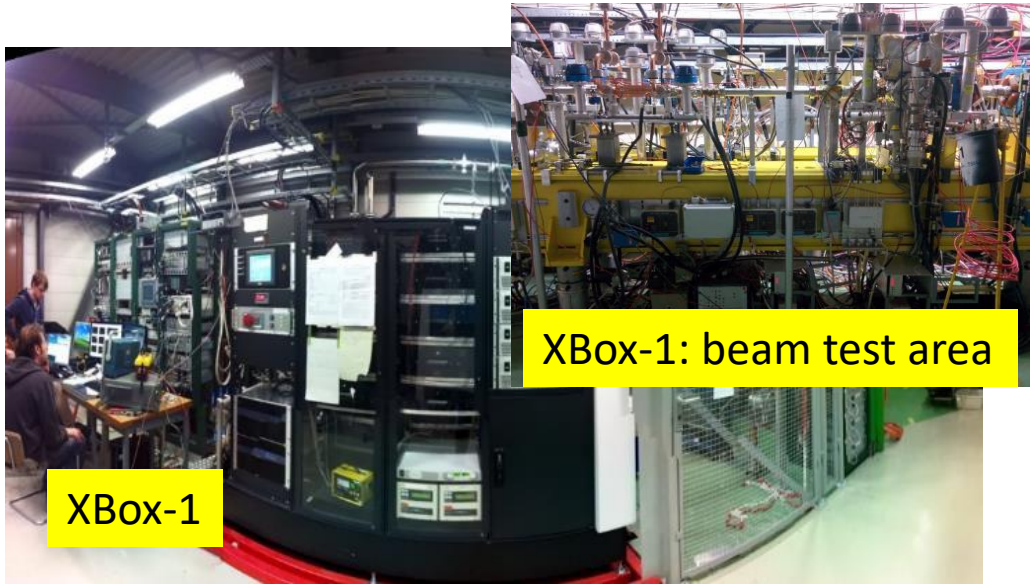


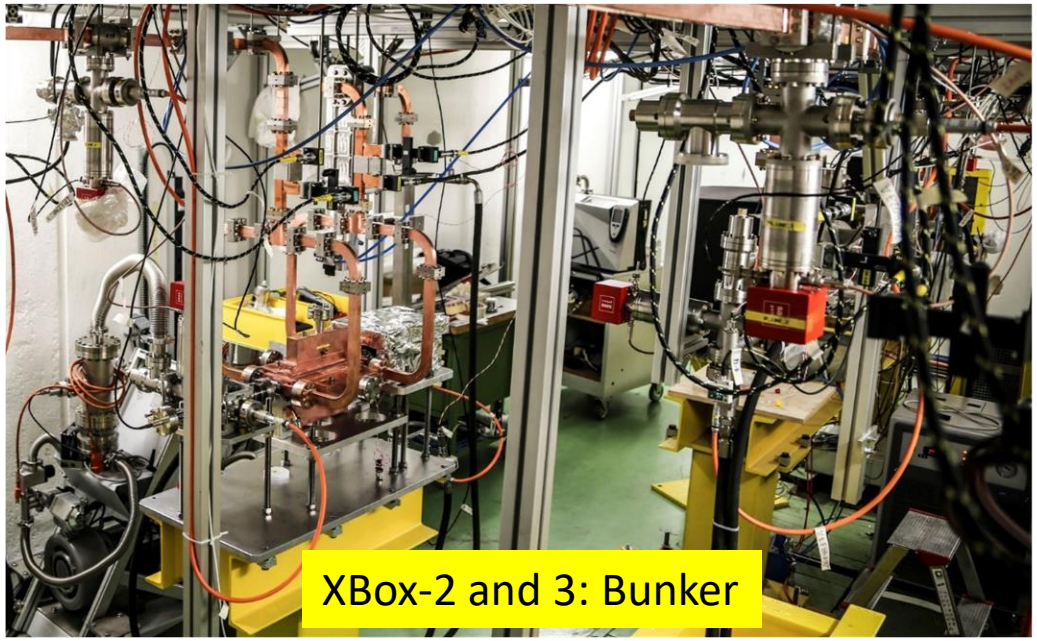
A high gradient test facility

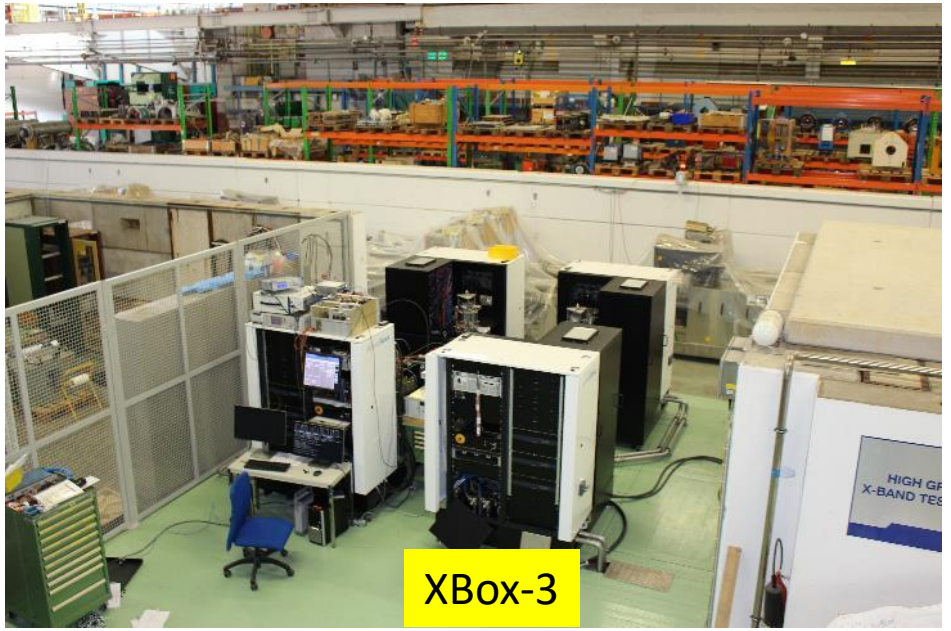




X-band test stands at CERN







Xbox1

- 50 MW/1.5 ms
- 120 MW/250 ns
- 50Hz
- RF signals
- Dark current
- Accurate phase
- Spectrometer
- E-beam capabilities
- Connects to CTF3/CLEAR

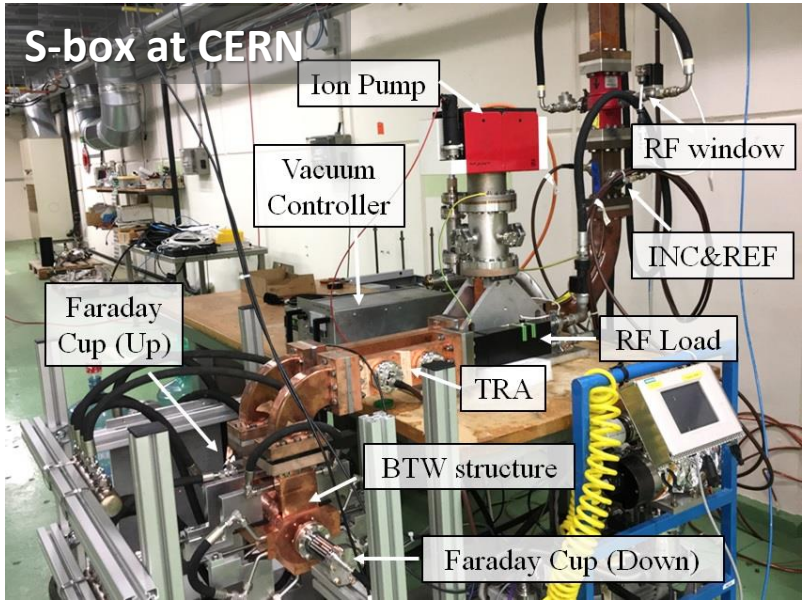
Xbox2

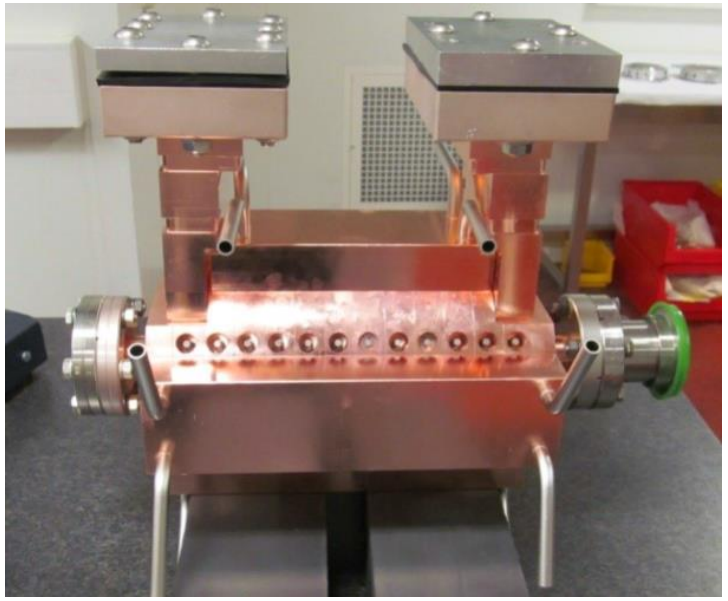
- 50 MW/1.5 ms
- 120 MW/250 ns
- 50Hz
- RF signals
- Dark current
- Accurate phase
- Radiation
- Two DUT feeding with variable power splitting
- Input phase variation

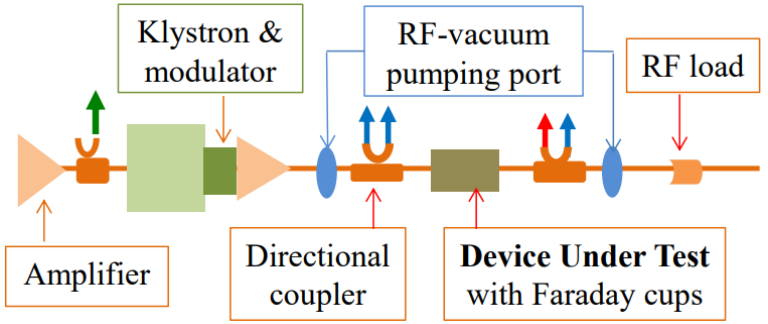
Xbox3

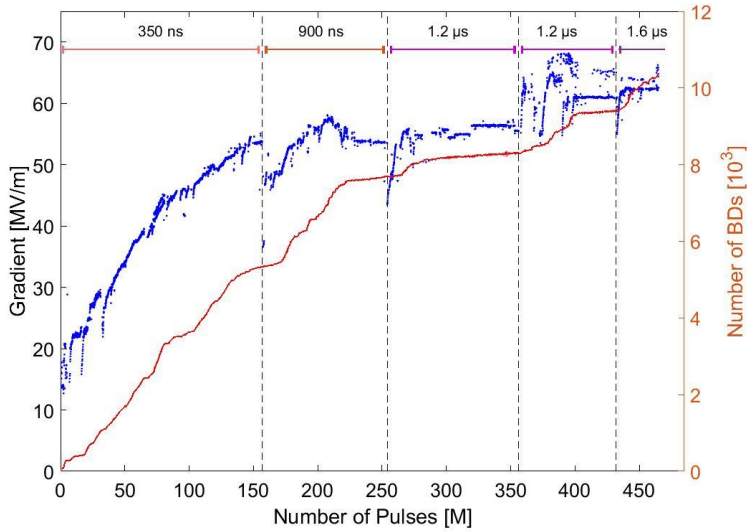
- 6-10 MW/5 ms
- 40-60 MW/100 ns
- Up to 400Hz
- 2 DUT
- RF signals
- Dark current
- Accurate phase
- Radiation monitors

S-band test stand



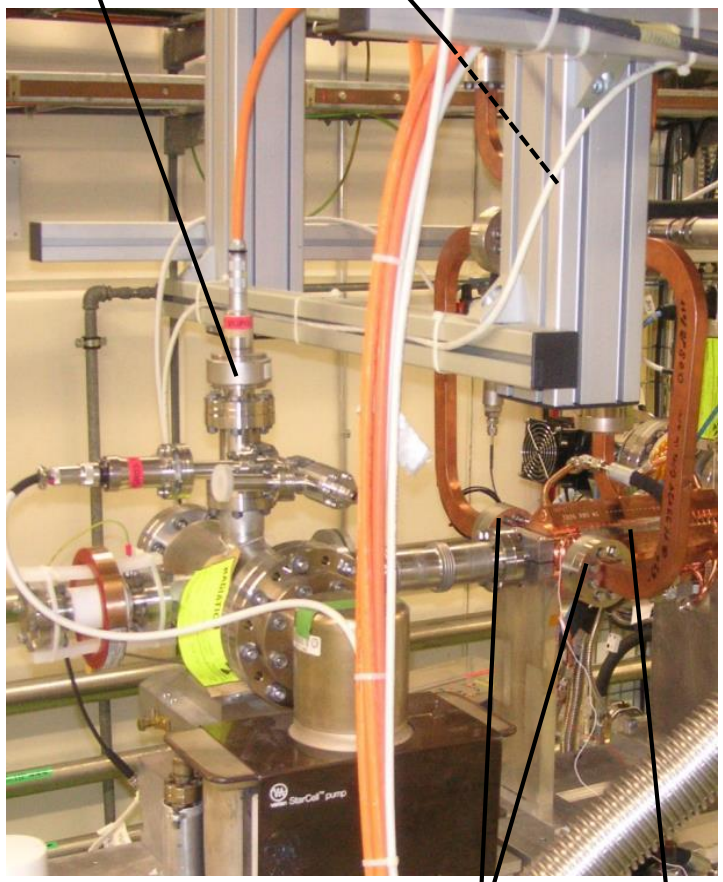


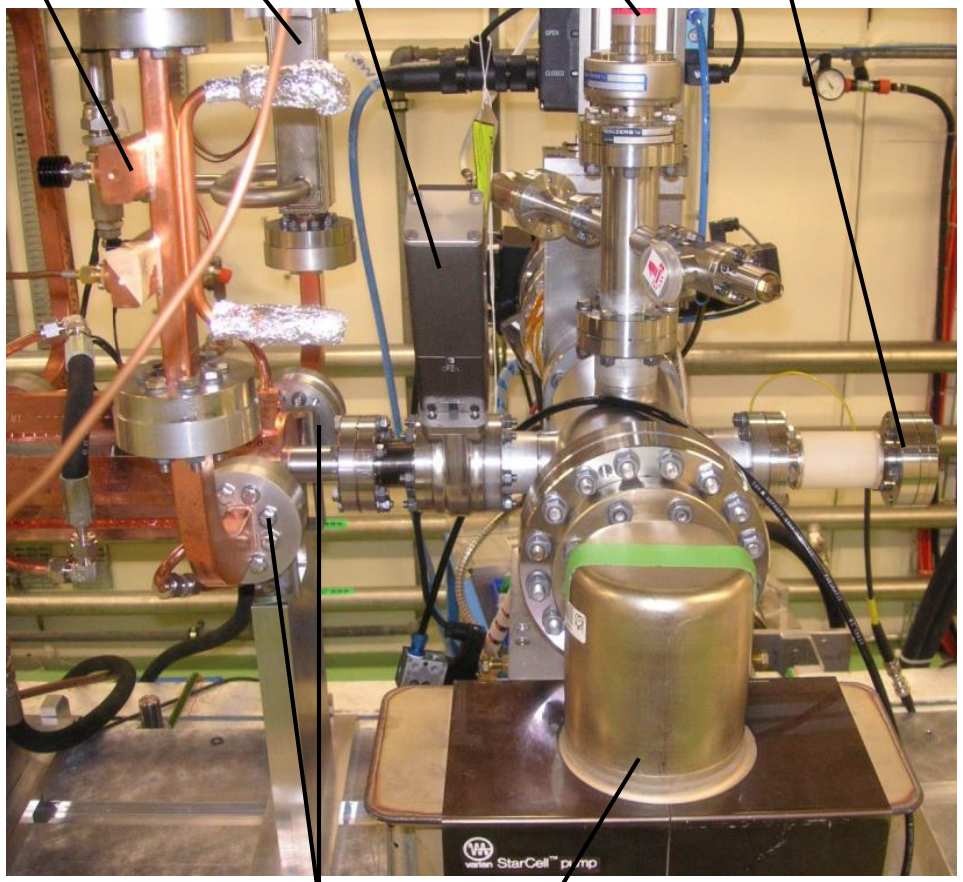




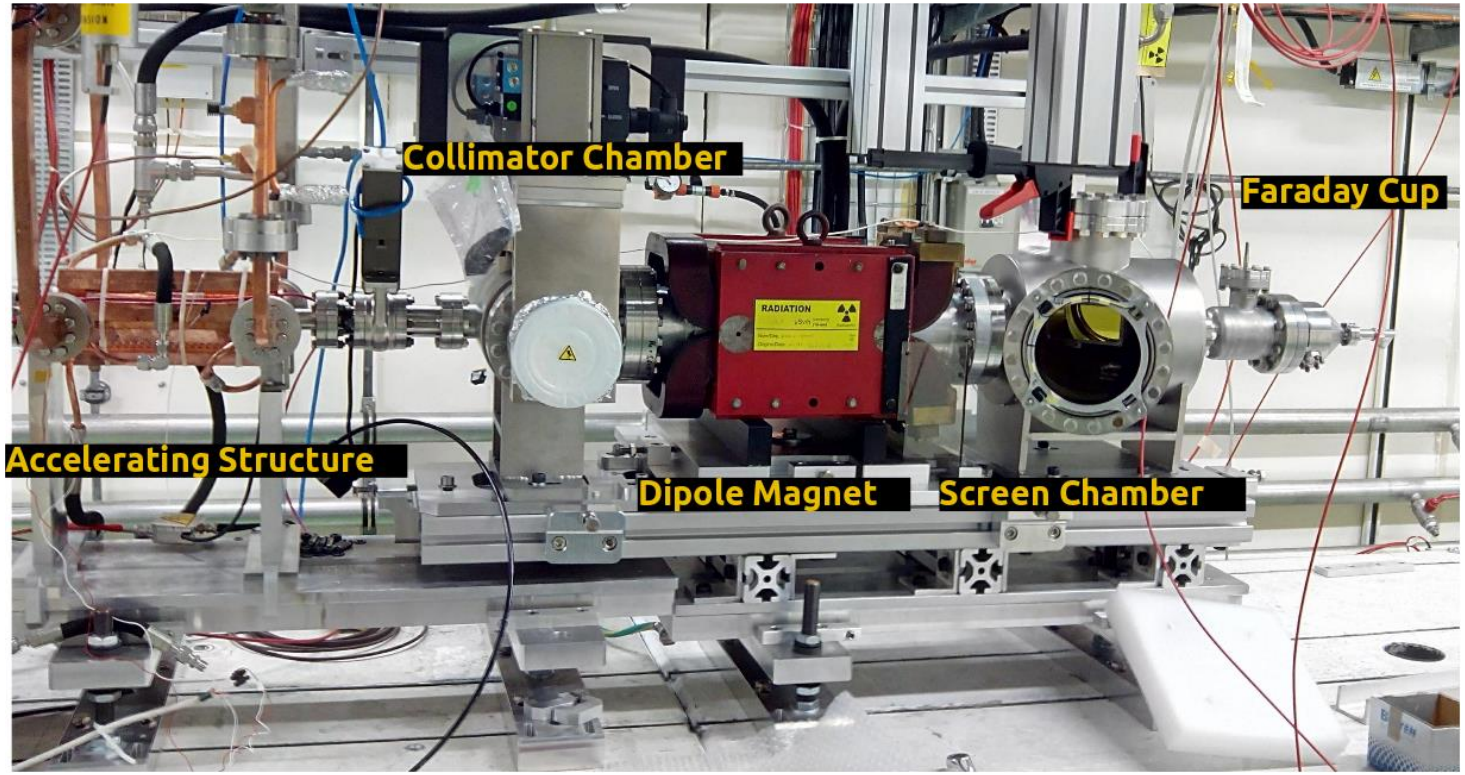
- 3 Ghz, 1.5 ms 45 MW, 10 Hz. SW and TWT
- Tested two generations of medical structure (Back Travelling Wave Structure) developped in collaboration with KT
- Aim at testing PRObe Structure also medical application in collaboration with Lancaster University
- Currently conditioning a S-band gun

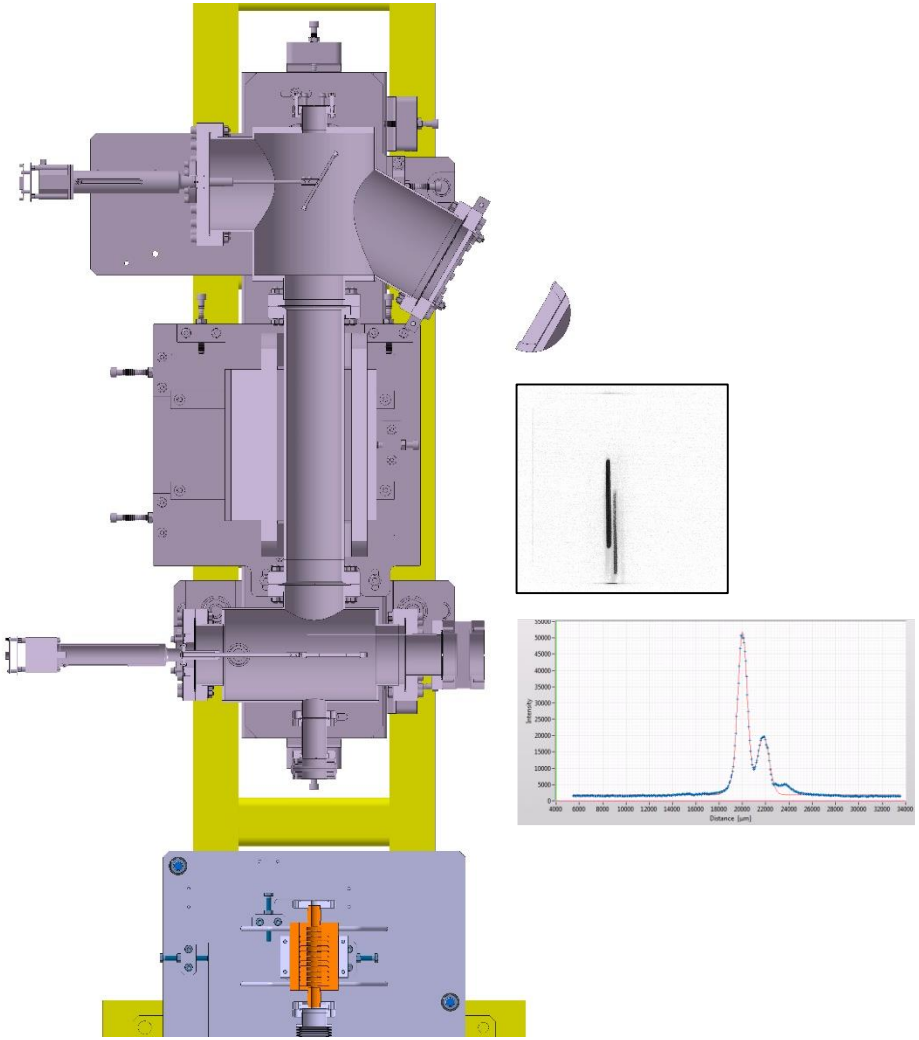
Accelerating Structure Diagnostics





Diagnostics: Spectrometer

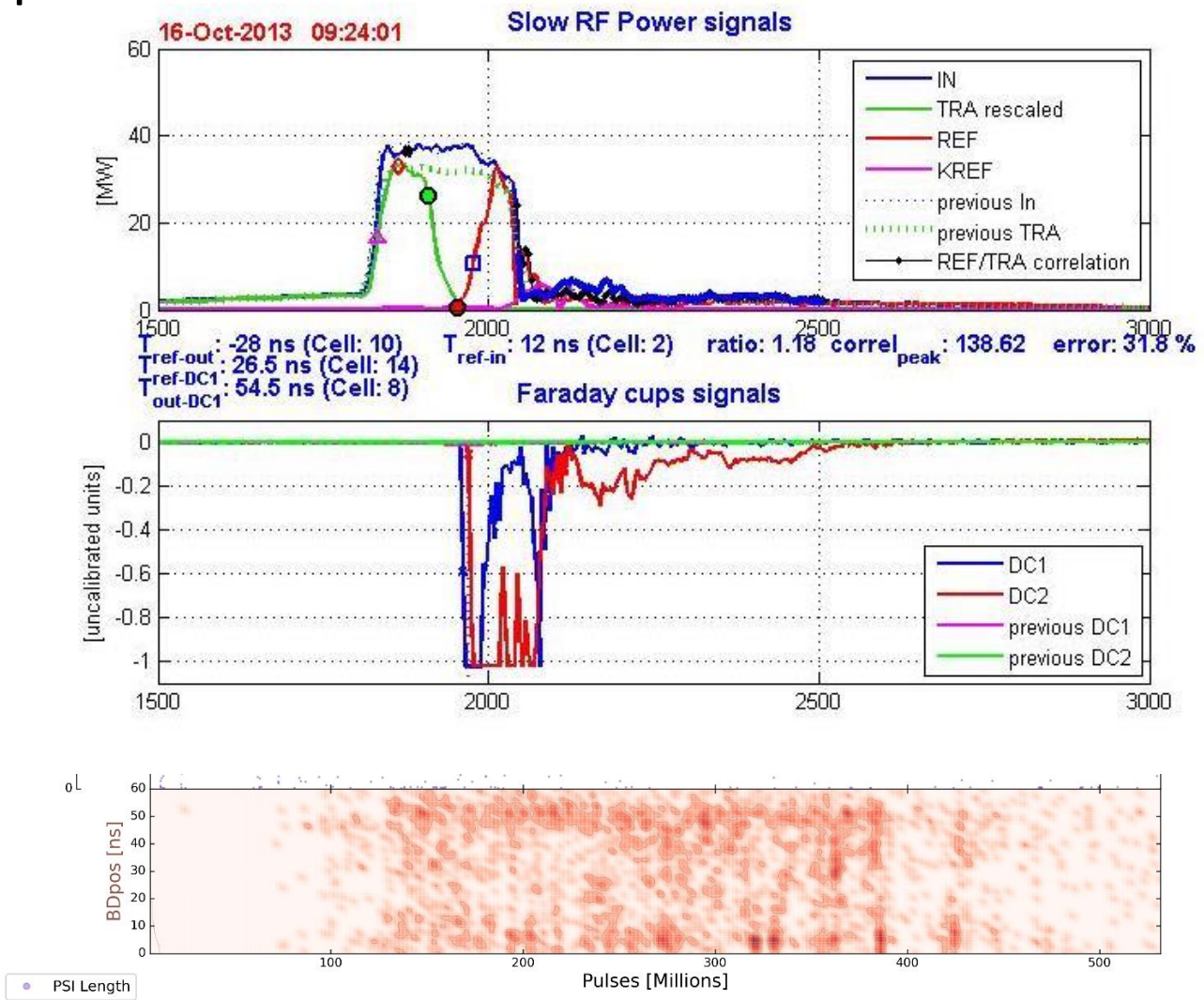




- Maximum electron energy < 20MeV
- Real energy spread (single slit) 10-25%
- Full energy coverage through a magnetic field scan
- System under commissioning. Interesting data at B. Woolley presentation

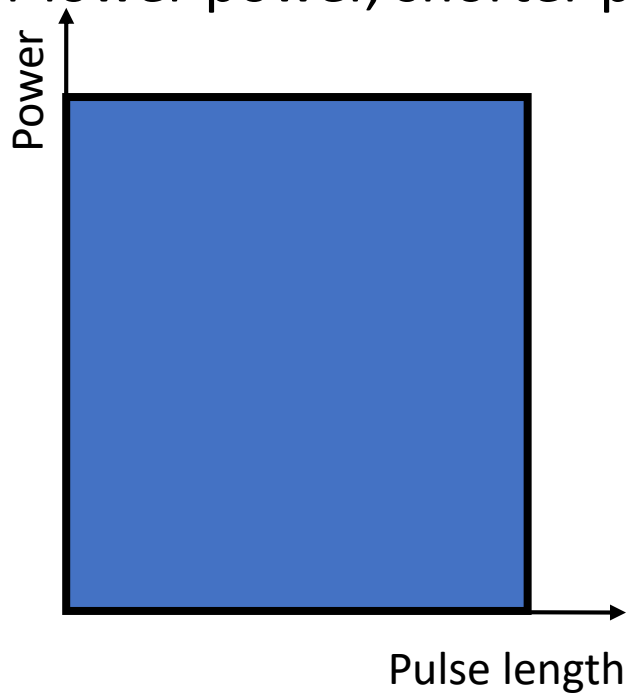
BD Detection: Breakdown

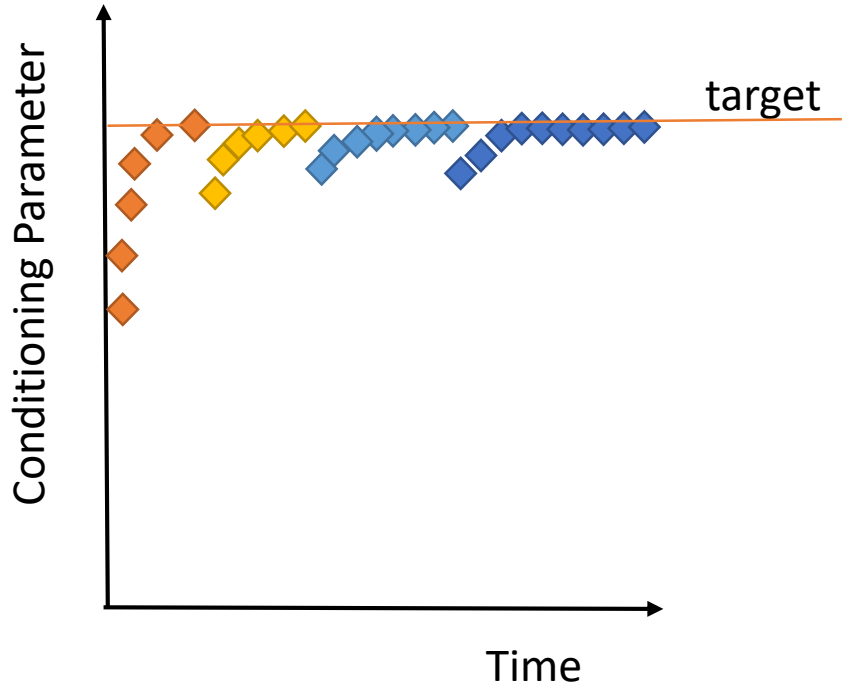
- Transmitted pulse drops as the arc is established.
- Reflected power increases to the same order as the incident pulse.
- Faraday cup voltages are saturated: 100-1000x increase in charge emitted.
- We can use the difference in time between the transmitted power falling and the reflected power increasing to find the BD cell location.
- The phase of the reflected signal is used to pinpoint cell location.



Operation: Conditioning

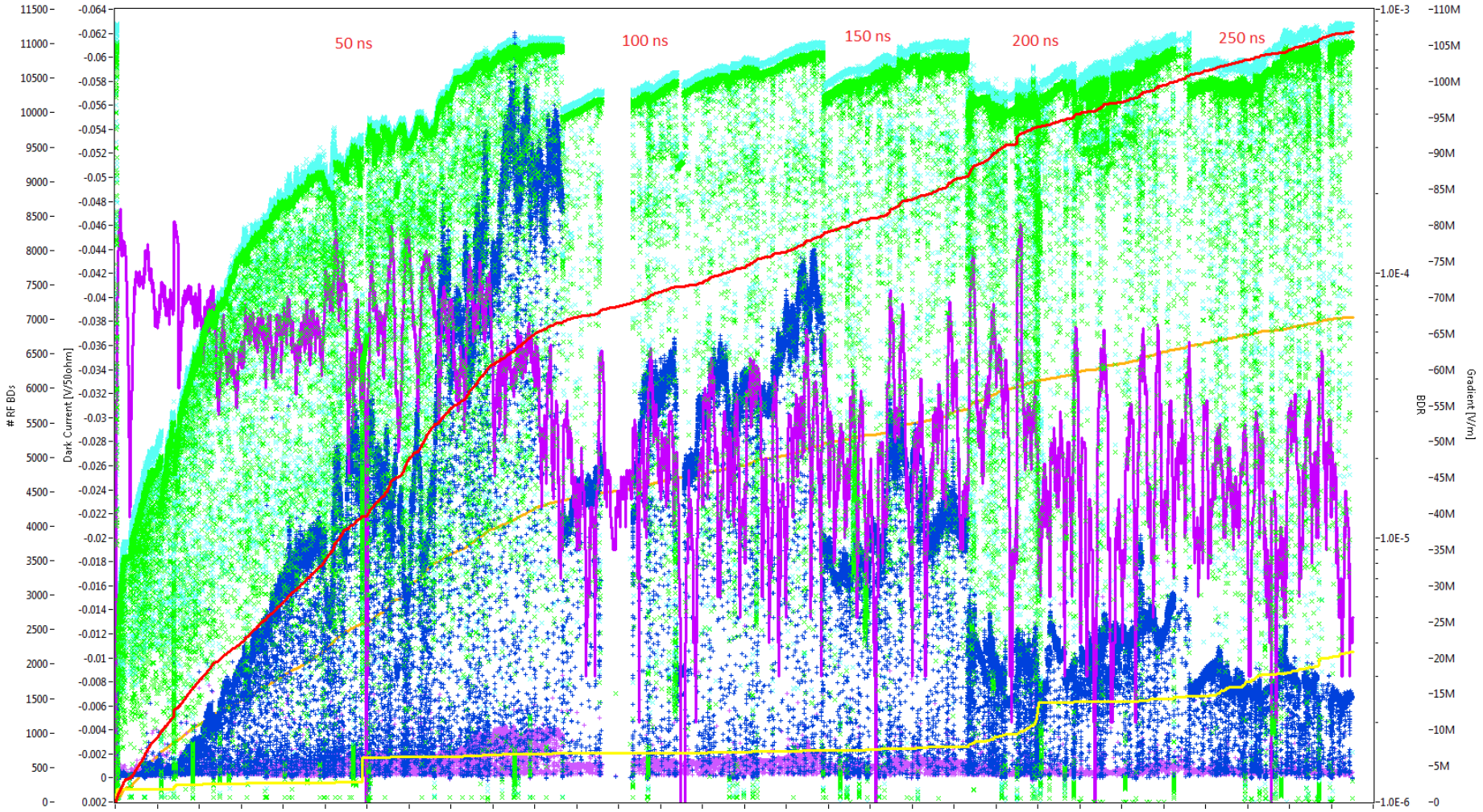
- The final pulse length and power is defined for each structure
- Conditioning algorithm sets a target value for vacuum level (network conditioning) or BDR (structures)
- Real conditioning speed follows a complicated algorithm and is a function of the state of the DUT.
  - Faster for lower power, shorter pulses or conditioned structures





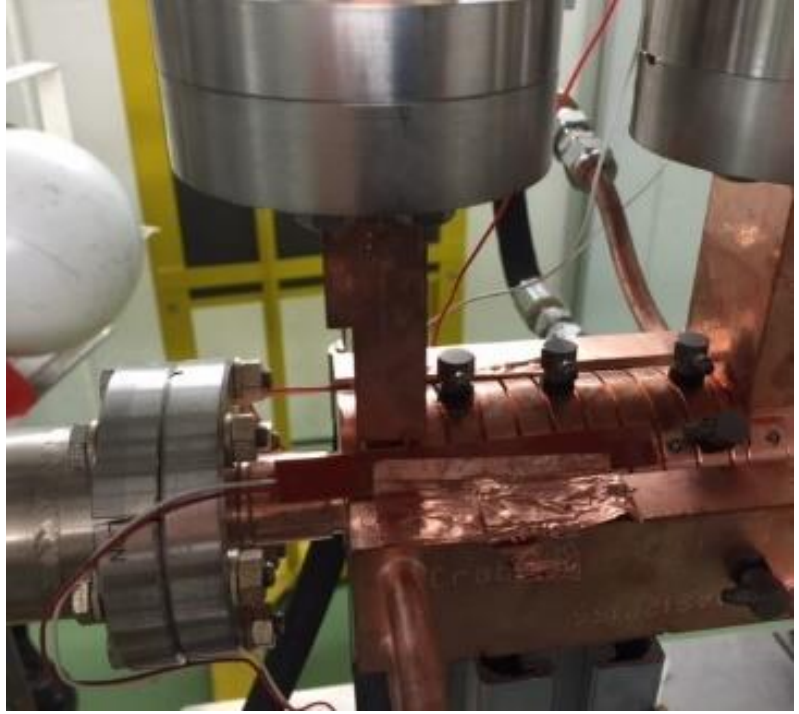
Typical conditioning history

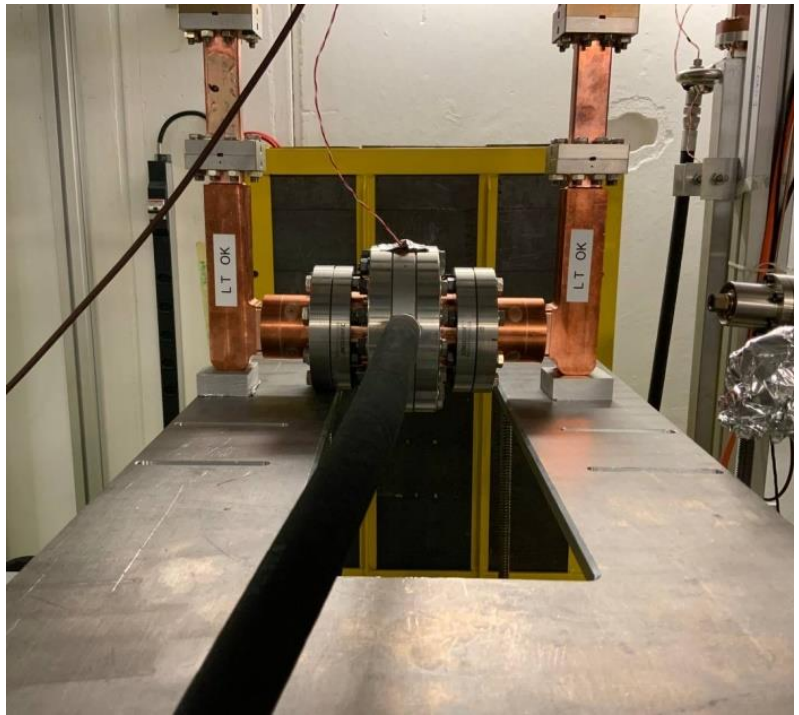
- Millions of pulses
- Months of testing
- BDR decreases with conditioning
- Measured at 10^{-5} and extrapolated to 10^{-7}

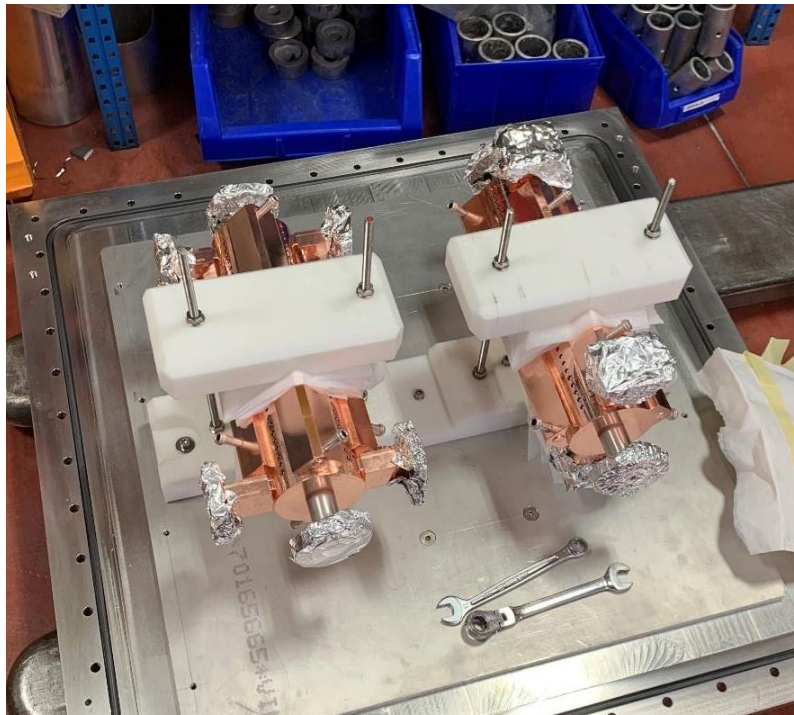


Tests history

- CLIC prototypes
- High gradient prototypes made by other institutes
- Deflector cavities for diagnostics
- Crab cavities
- Prototypes for medical treatment (TERA, Christie)
- *RFQ2 (352 MHz)*
- X-band components
  - Loads, phase shifter, power splitter, windows

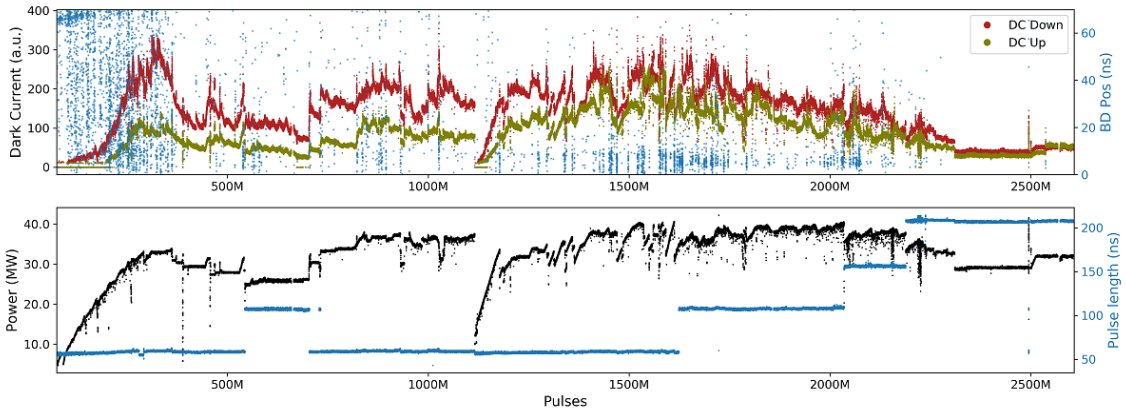


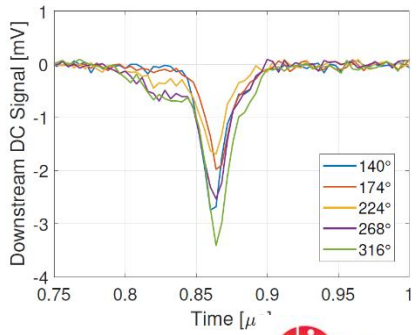


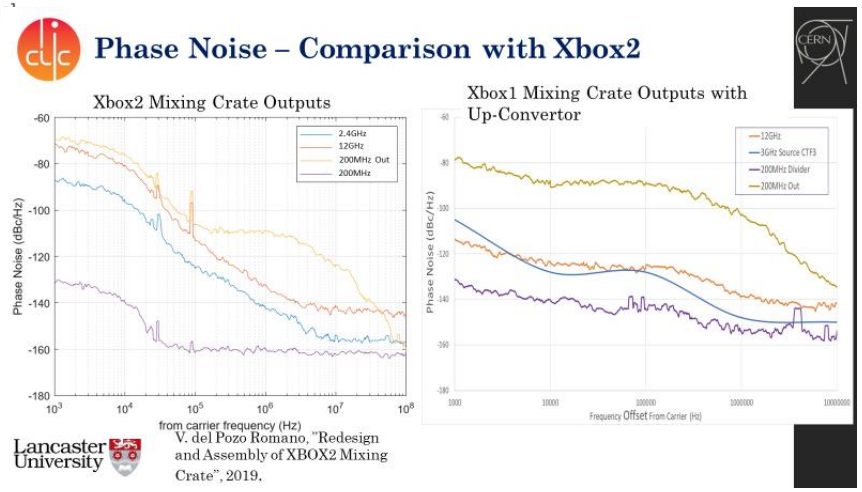


Other tests

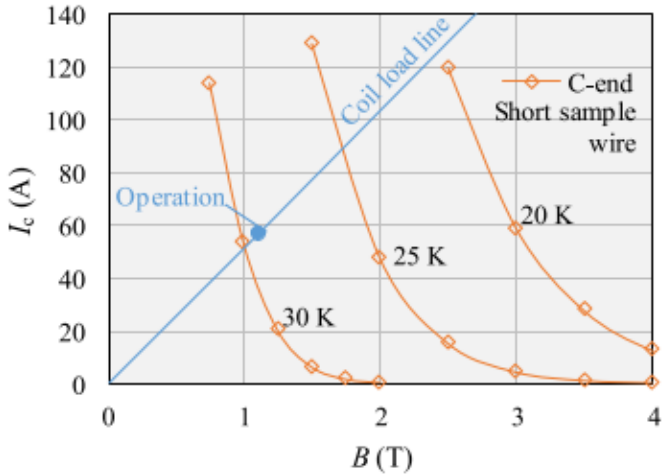
- Dark current and radiation
- Phase measurements and crab cavities synchronization
- RF gun (S-band)
- High Efficiency klystrons tests
- Superconducting solenoid





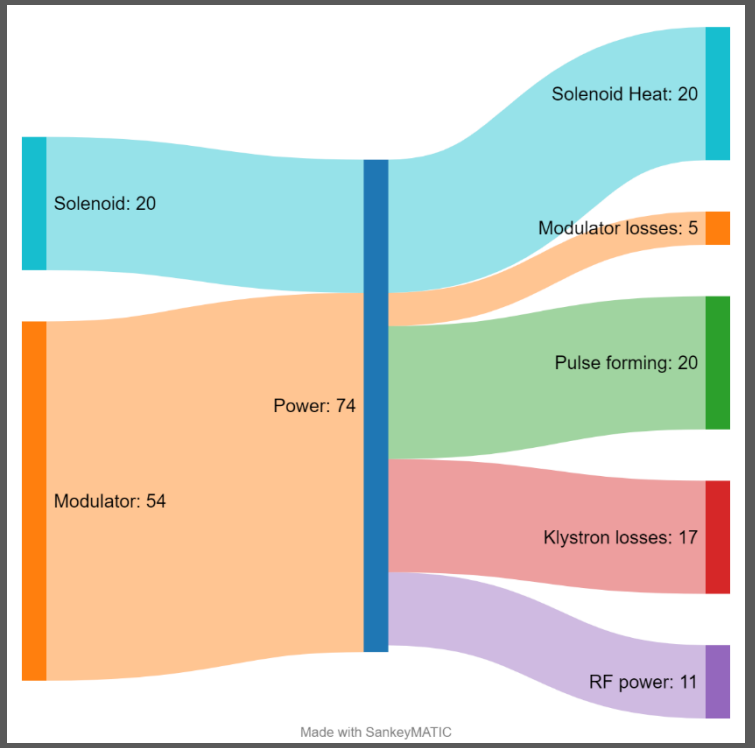


Super conducting solenoid for VKX-8311 in Xbox2

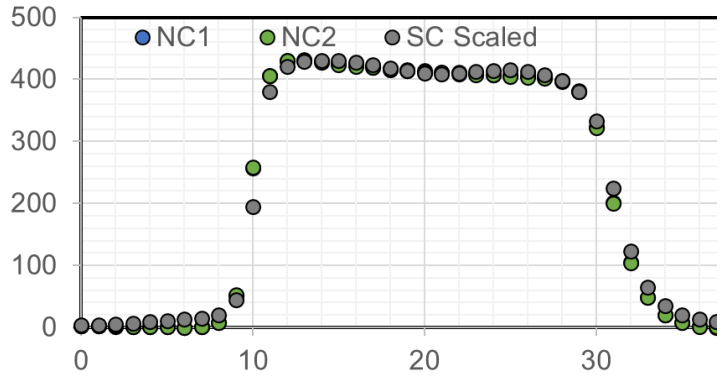


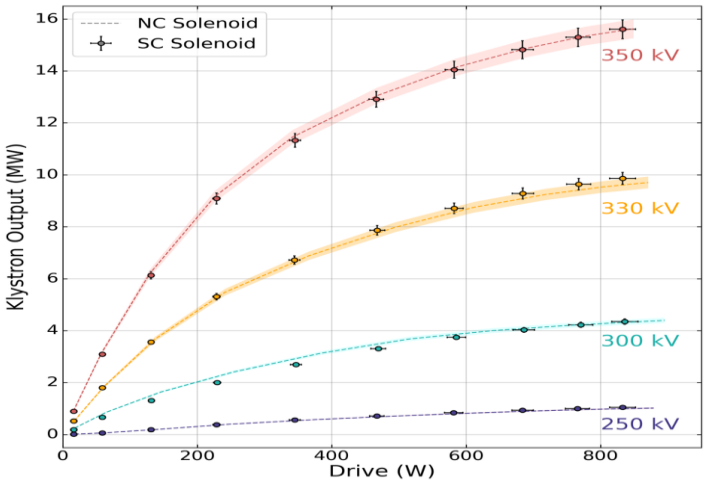
Superconductor	MgB2	
Maximum B field	0.8	T
Current	57.1	A
Inductance	7.3	H
Max. field in coil	1.06	T
Operating temperature	<20	K
Stored energy	11.8	kJ
Weight	600	Kg
AC plug power	<3	kW

- Initiative of A. Yamamoto
- Manufactured by Hitachi in collaboration with KEK
- Significant energy savings in a pulsed system

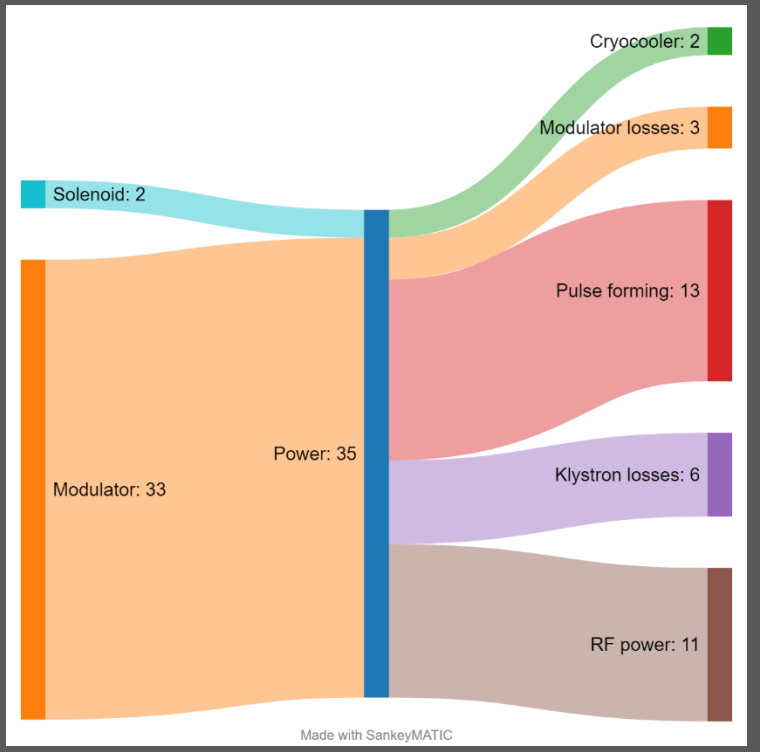


MgB2 SC solenoid for VKX-8311 in Xbox2



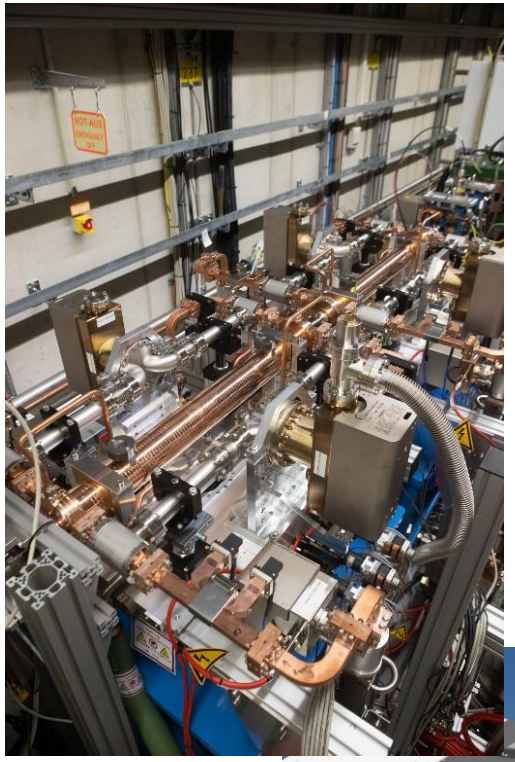


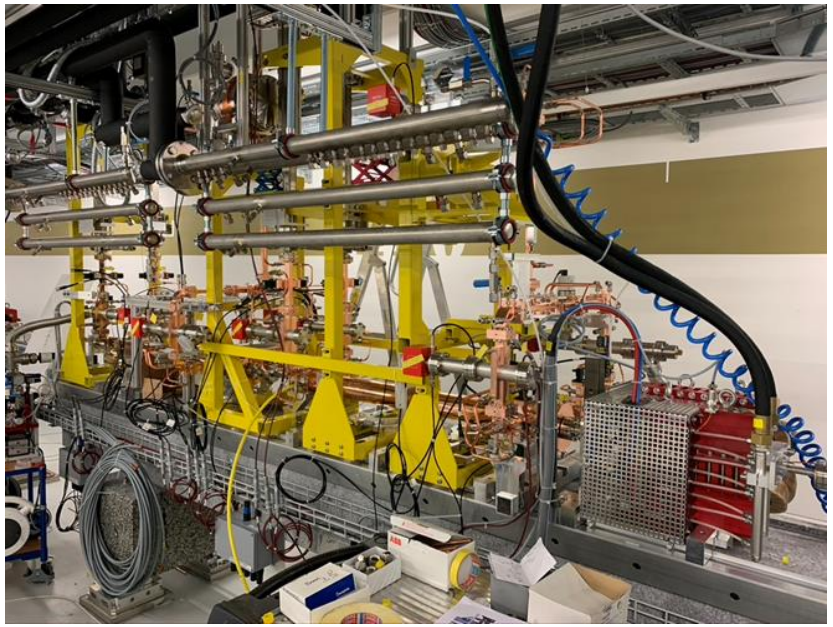
- Tests at CERN Dec 2020 and spring 2022
  - Cooling and powering
  - Magnetic measurements
  - Gain curves
- Operational in the Xbox2

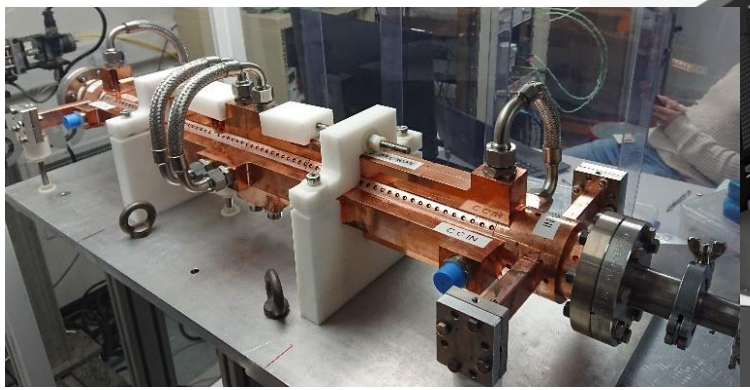


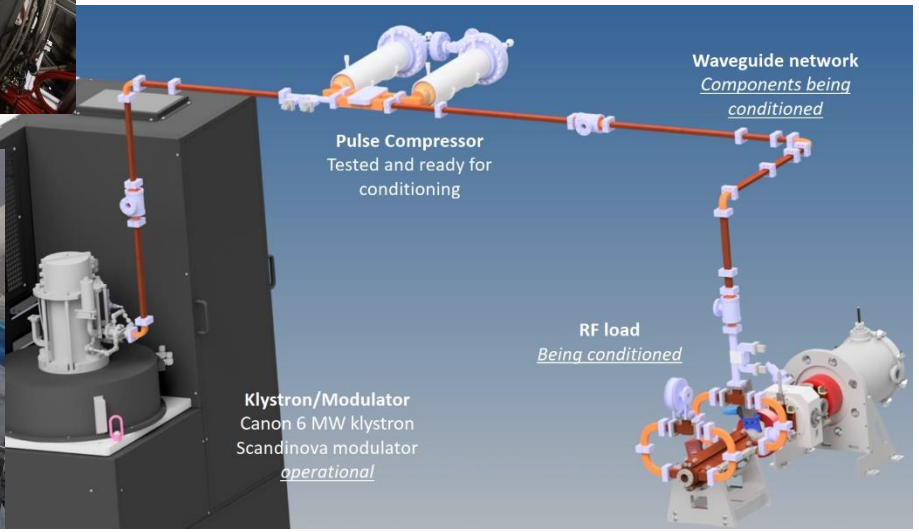
Other projects using high gradient. Beam facilities

- TU Eindhoven: SMART*LIGHT, ICS
- Tsinghua: VIGAS, ICS
- CERN: AWAKE electron injector
- INFN Frascati: EuPRAXIA@SPARC_LAB, accelerator
- DESY: SINBAD/ARES, deflector
- CHUV/CERN: DEFT, medical accelerator
- Daresbury: CLARA, linearizer
- Trieste: FERMI energy upgrade



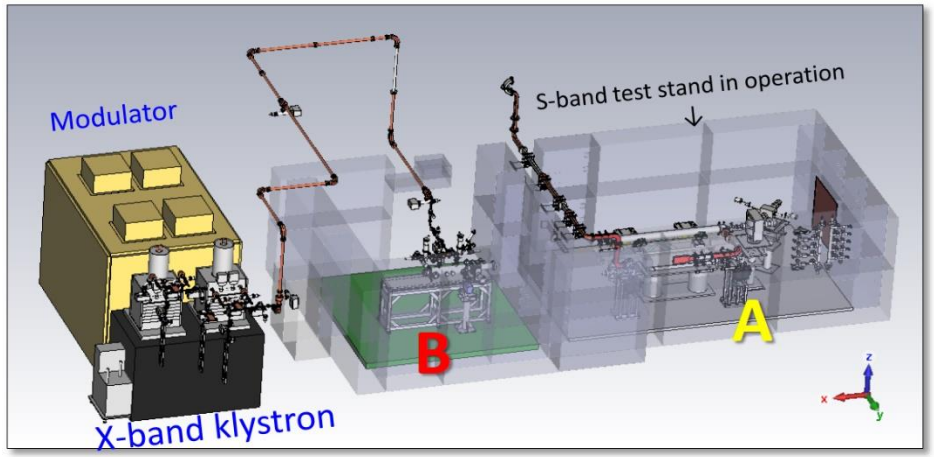


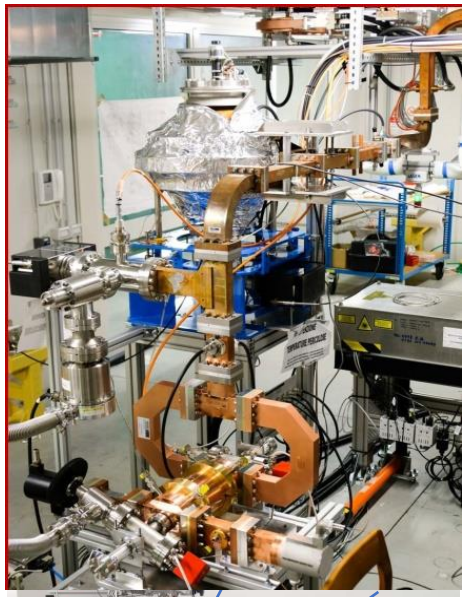




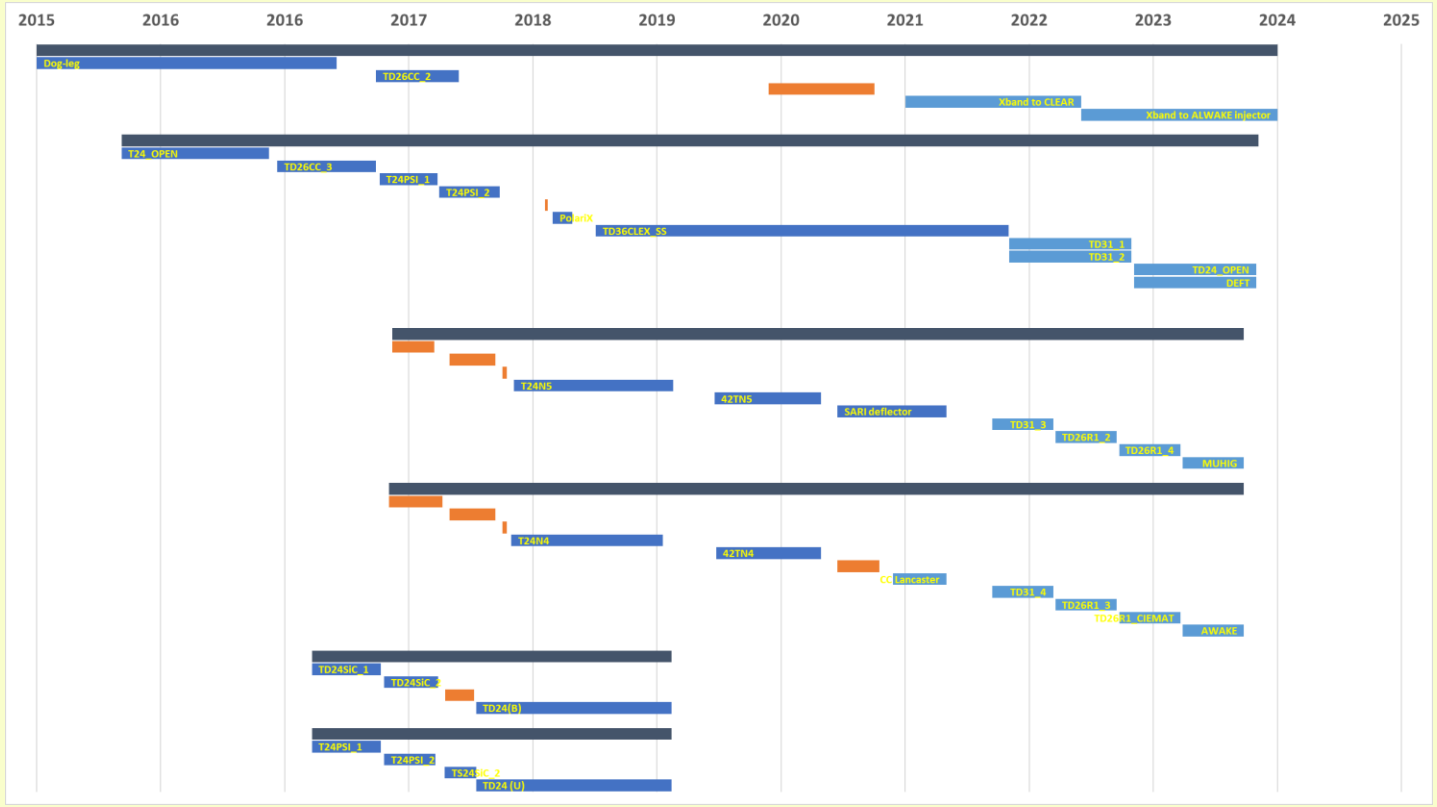
Other NC high gradient test facilities

- KEK: NEXTEF
- CERN: XBox-2,3 and Sbox
- Tsinghua: TPot
- Valencia: IFIC VBox
- Trieste: FRMI S-Band
- SLAC: Cryo-systems
- LANL: CERF-NM
- INFN Frascati: TEX
- Melbourne: AusBox





Plans and future



- CLIC prototypes for a 380 GeV Klystron-based machine brazed
- CompactLight prototype as part of IFAST project
- First prototype for FLASH therapy DEFT
- *Medical imaging and treatement cavity (3Ghz) PROBE*
- UK X-band prototype for demostration of technology transfer (MUHiG)
- Xband structures for AWAKE

Summary

- High gradient test facilities are operating since 2010 at CERN
- 3 test benches in X-band and 1 in S-band have been progressively installed and commissioned until 2017
- Quite complex system
- Improved stability and diagnostics
- Large operating flexibility
  - Different DUTs but also different programs
- CERN collaborating with external laboratories for the installation of similar infrastructure
- Extensive past and future testing program
- We also have test benches for power purposes at 352, 400, 1000 MHz

Thanks!

To a **REALLY LARGE TEAM** of very motivated young (and no so young) students, fellows, technicians, engineers, visitors, managers, companies and collaborators

International workshop on Breakdown Science and High Gradient Technology (series)