WP12 Innovative RF Technologies

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WP12 Collaborative Team

Task 12.2
SRF Thin Films
C Antoine (CEA)

CEA Saclay, CERN, HZB Helmholtz Zentrum Berlin, Grenoble INP

Task 12.3
High Gradient NC
W Wuensch (CERN)

CEA Saclay, Lancaster University, Paul Scherrer Institut PSI, Uppsala Universitet, ScandiNova 2016, CERN, Manchester 1824 The University of Manchester, Science & Technology Facilities Council, Thales 2015

Task 12.4
SRF HOM Beam Diagnostic
R Jones (Manchester Univ)

DESY, Universität Rostock, Manchester 1824 The University of Manchester

Task 12.5
RF Photocathodes
R Nietubyc (NCBJ)

DESY, HZDR Helmholtz Zentrum Dresden Rossendorf, HZB Helmholtz Zentrum Berlin, NCBJ, Science & Technology Facilities Council

Fundamental Objectives

12.2 Thin Films

Exploitation of new superconducting materials, such as Nb_3Sn and the development of new nano and multi-layer thin films, each anticipated to **break new ground in the performance of SC accelerator cavities**, with the potential of **achieving gradients well beyond present Nb technology**.

12.3 High Gradient NC Cavities

Development of an efficient NC structure **capable of high gradient operation (Eacc > 100 MV/m)** but **free from dangerous wakefield contributions**.

12.4 SRF HOM Beam Diagnostics

Development of electronics for utilising Higher Order Mode (HOM) signals from accelerating cavities for **precision beam position diagnostics in high-energy electron linear accelerators**, with the goal of **substantially improving beam quality**, critical for XFEL applications.

12.5 RF Photocathodes

Development of next generation advanced RF photocathodes, exploring revolutionary production techniques as lead deposition, diamond amplifier cathode and metallic photocathodes, enhancing the **ability to reach fs response time,** for more effective electron beam generation, capture and transport with **high brightness** and **low intrinsic emittance**.

Task 12.2 SRF Thin Films

Niobium on copper (µm)

- After ~ 20 years stagnation : revolutionary deposition techniques (ALD, HIPIMS)
- Great expectations in cost reduction
- Improved performances c.f. bulk Nb

Higher Tc material (µm)

- Based on superheating model (NbN, Nb_3Sn).
- Higher field and Qo expected

Higher Tc material (nm), multilayer

- Based on trapped vortices model (Gurevich)
- Higher field and Qo expected
- Recent experimental evidences

Specific characterization tools needed

Better understanding of SRF physics needed

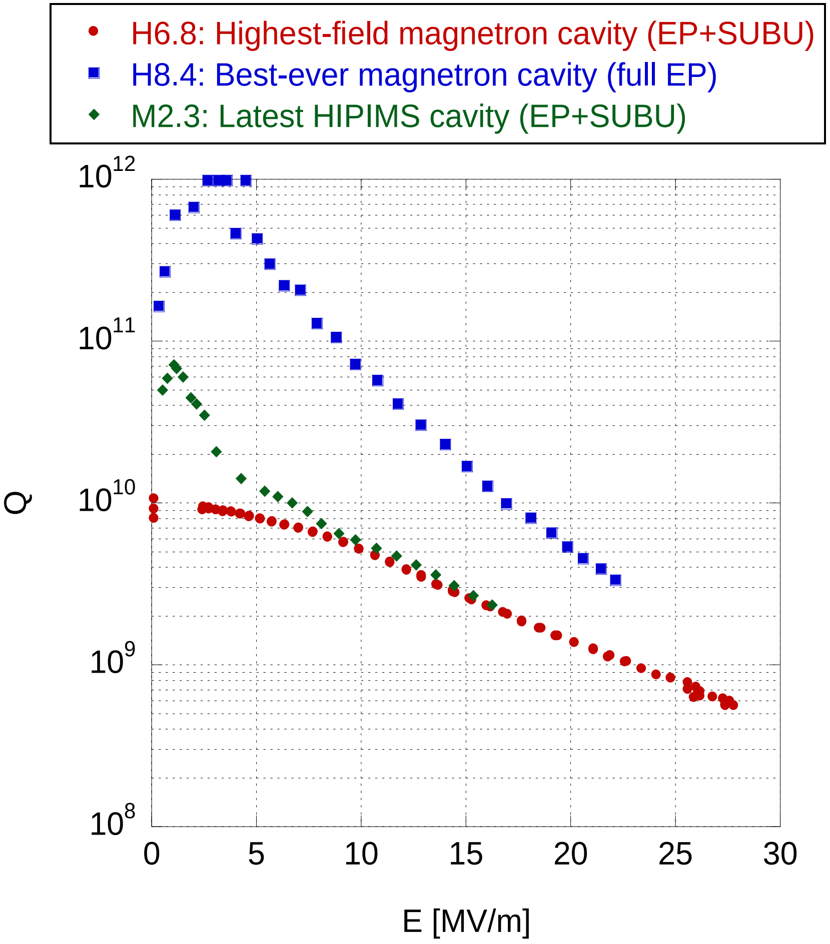
New ARIES JRA on SRF Thin Films, led by Oleg Malyshev (STFC)

Task 12.2 Coordinator: Claire Antoine (CEA Saclay)

HIPIMS @ CERN

HIgh **P**ower **I**mpulse **M**agnetron **S**puttering:

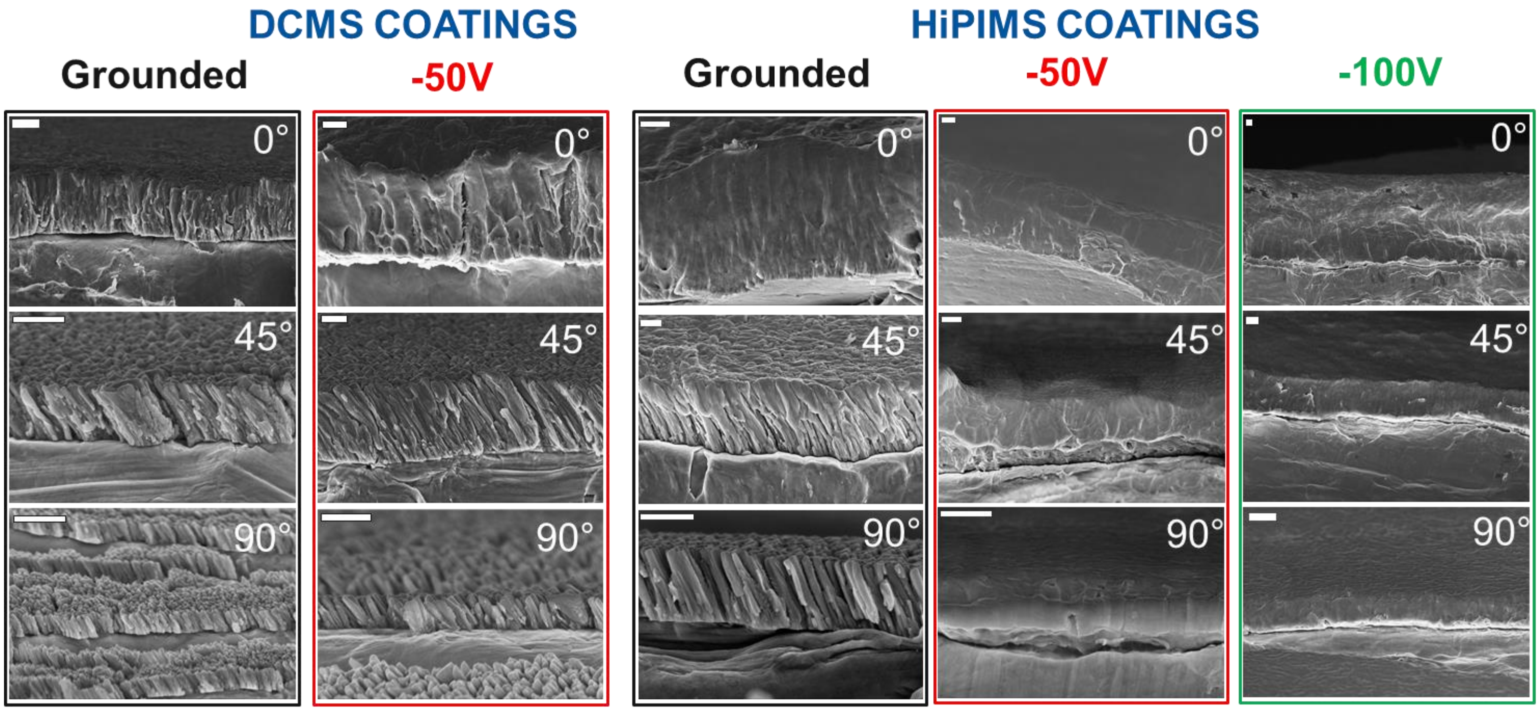
- Pulsed PSU (~100 μs pulses, 1% duty, up to 1 kHz)
- Power density:
  - DC: 12 W/cm² c.f. HiPIMS: ~1 kW/cm²
- Ionization of sputtered species up to 90%
- Better coating conformity
- Lower substrate heating
- Lower coating rate: ions captured at the cathode
- Sensitive to cathode surface (roughness) → arcing



Biased Process:

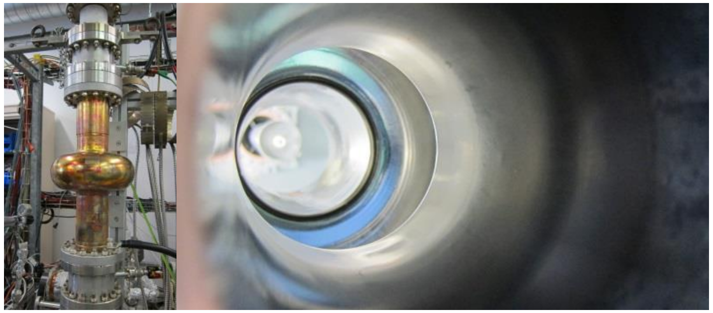
- Three Nb electrodes:
  - Can be used as anode or cathode
- Coating in cut-offs: cavity grounded
- Cell coating: cavity can be biased

Biased HIPIMS

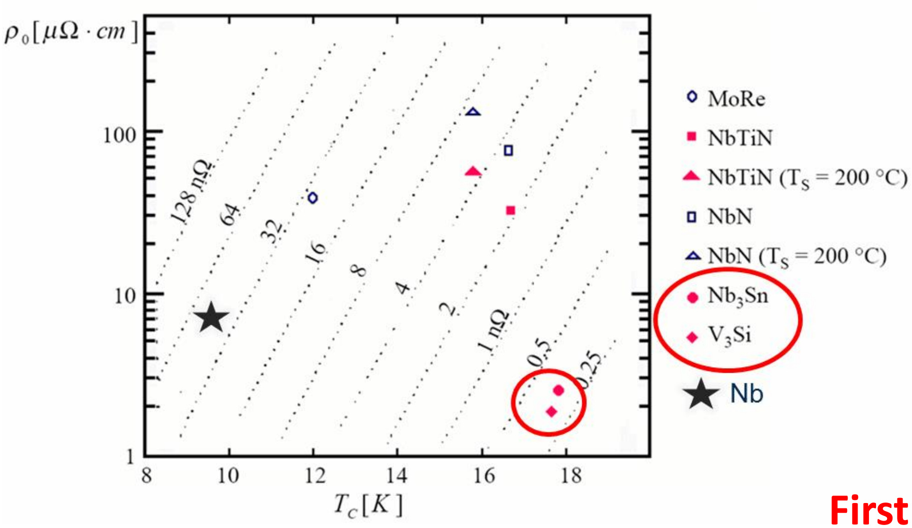


All scale bars are 400µm

- **First 1.3 GHz cavity coated with HiPIMS/-100V bias:**
  - **RF tests underway.**
- Samples FIB preparation and analysis on going :
  - Substrate/Nb layer interface, porosity evaluation…
- New magnetic configurations proposed to enhance Nb ion flux at the substrate.
- **QPR to be used to investigate the superconductive RF properties.**
- Exploration of SC DC properties (magnetometer, T_C …)

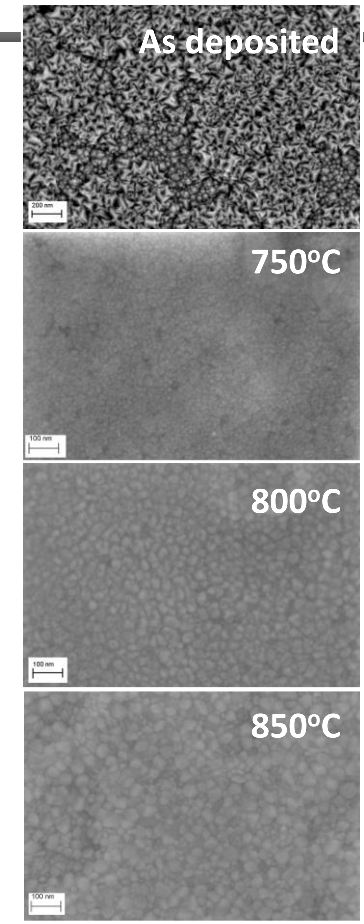


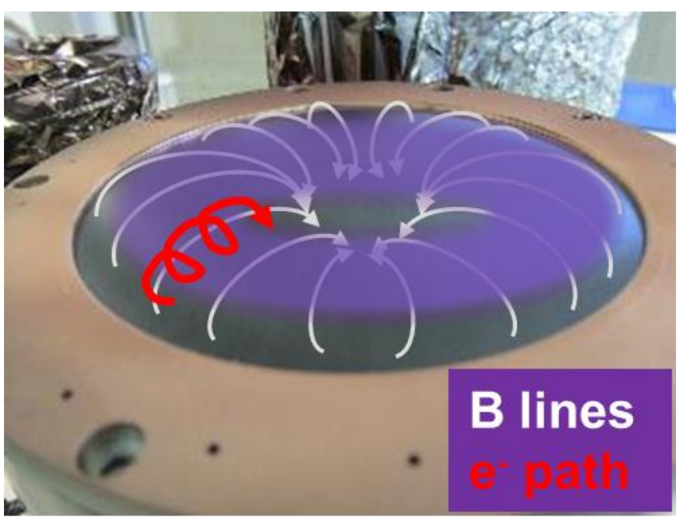
Nb_3Sn (A15) @ CERN



Alternative SC materials:

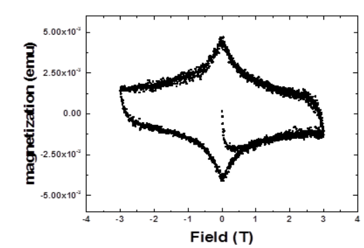
- "High" T_C
- Low resistivity
- Low surface resistance
- Single SC gap
- Remain SC in high B-fields





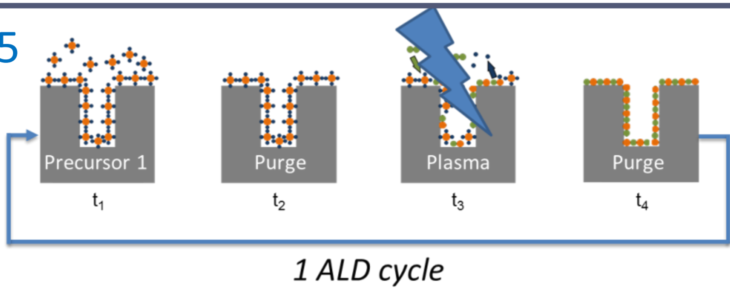
First HT magnetron deposition:

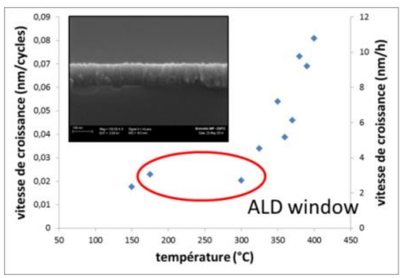
- As deposited layer: nanocrystal but mainly amorphous.
- After annealing: A15 phase obtained even after annealing at low temperature.
- DC measurement confirms the superconducting phase retained.
- Strong hysteresis suggests flux pinning.

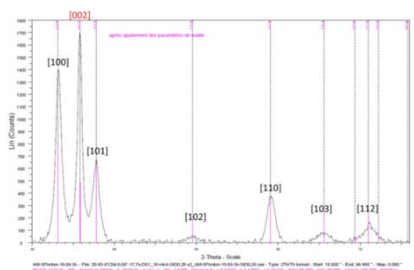


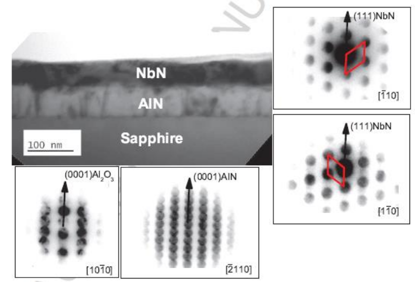
ALD @ INP-Grenoble

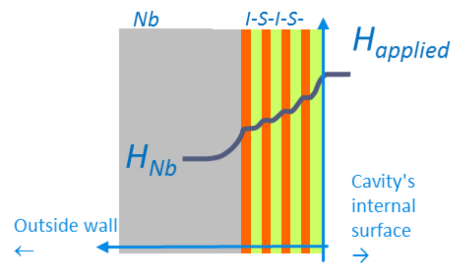
Apr 2015

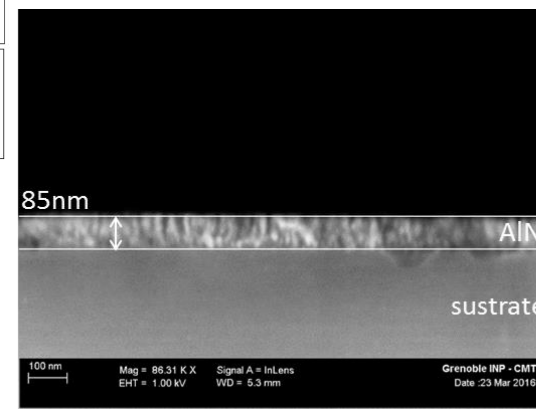






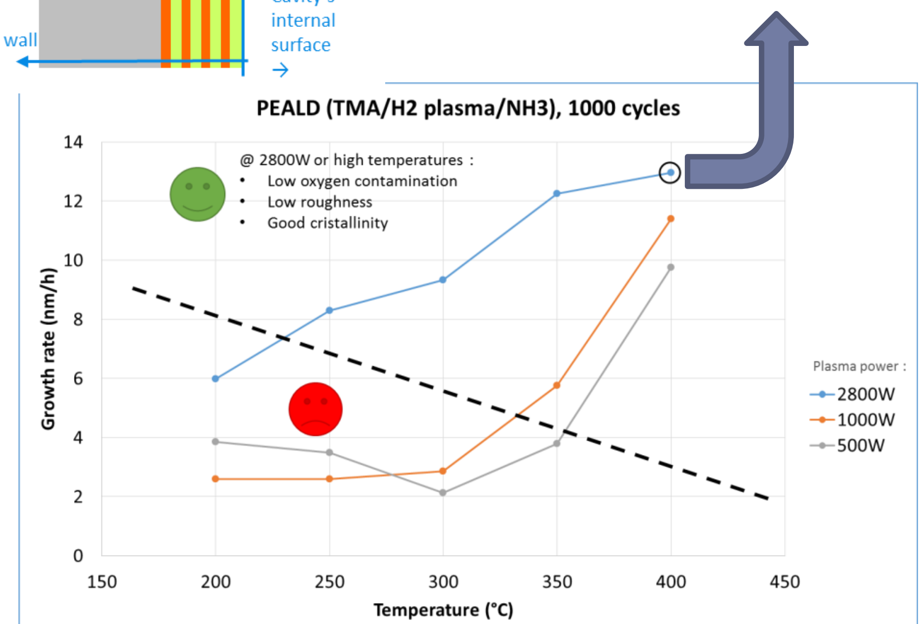


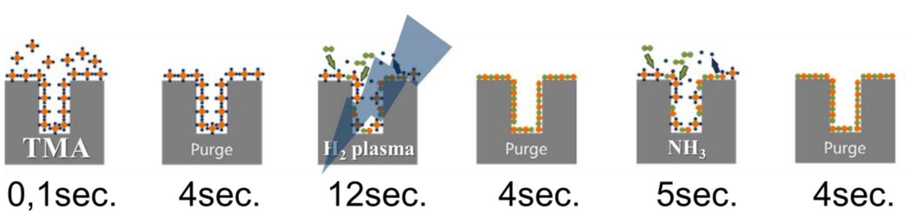




AlN deposition:

- Most common settings in plasma ALD:
  - Al source : TMA (Tri-Methyl Aluminium)
  - N source : NH3 **plasma**
  - Temperature : 350°C





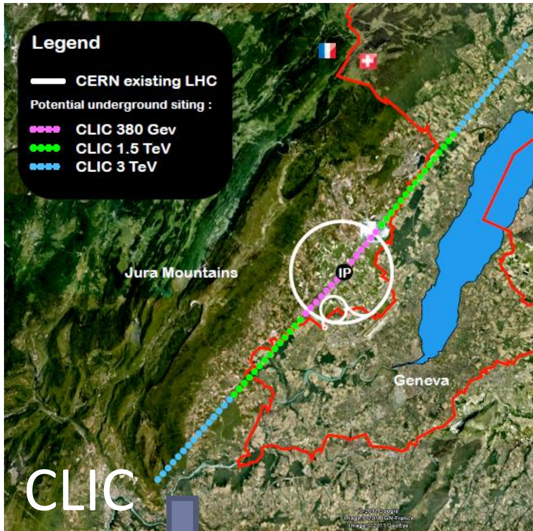
Task 12.3 High Gradient Normal Conducting

- Where are we going with X-band and high-gradients?

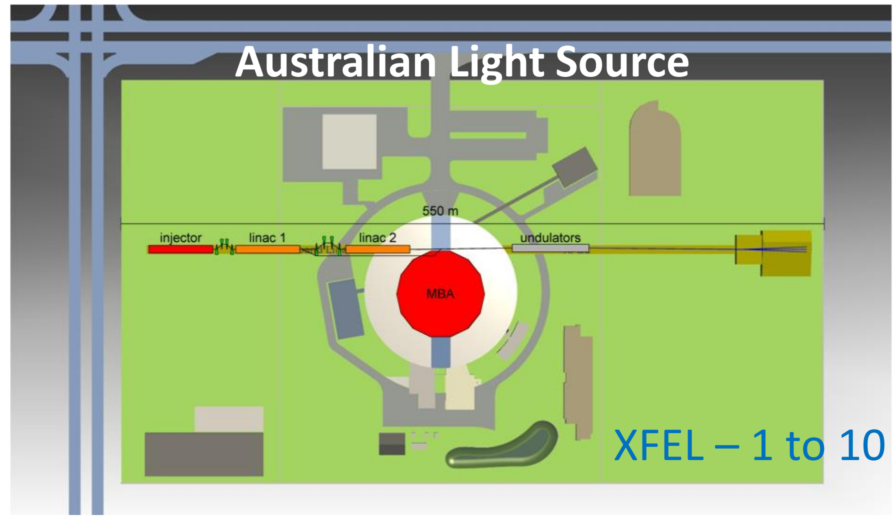
- Deepen the technological base:
  - New high efficiency X-band klystron design from CEA
  - WFM instrumentation and electronics from PSI
  - Flexible modulator development from UU
- Broaden the use in accelerators:
  - Crab cavity/deflector development from Lancaster Univ & STFC
- New applications:
  - Medical linacs
  - XFELs

Task 12.3 Coordinator: Walter Wuensch (CERN)

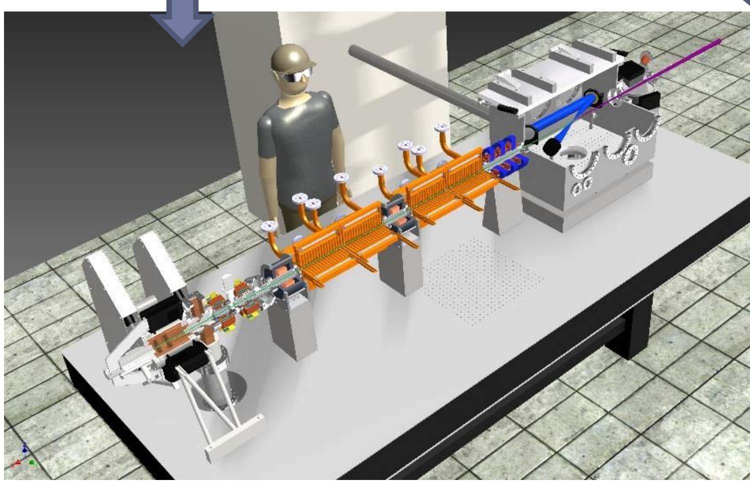
Applications of X-band Technology



CLIC



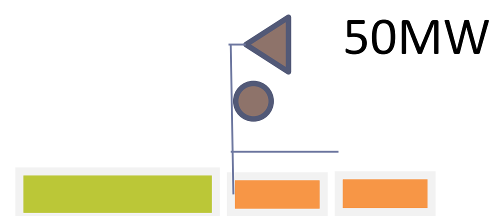
XFEL – 1 to 10 GeV



Smart*Light, NL

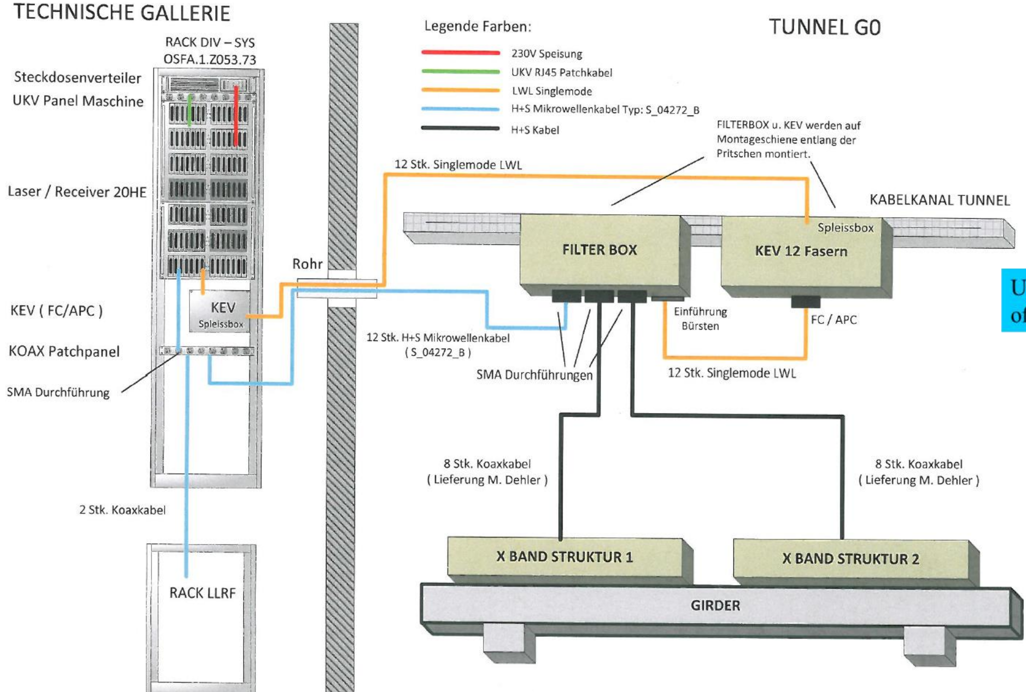
Compact Compton source
few 10s MeV

Thompson/Compton
source – few 100s MeV

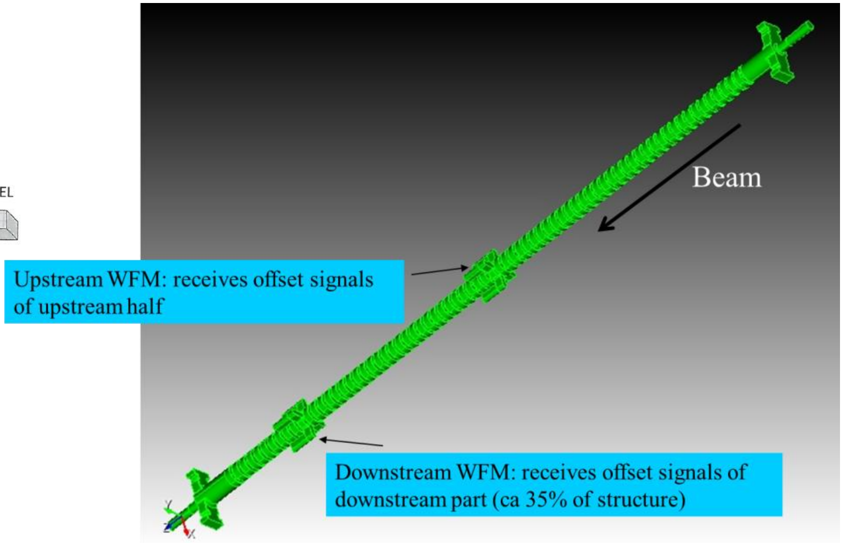


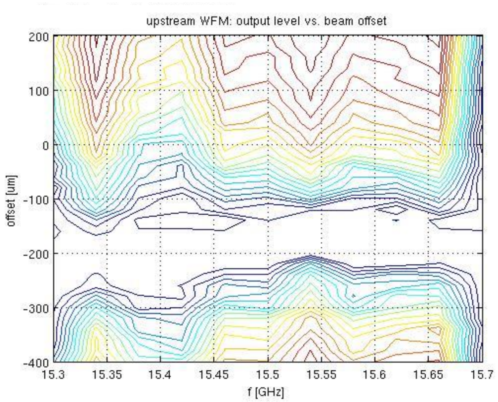
Tsinghua, China

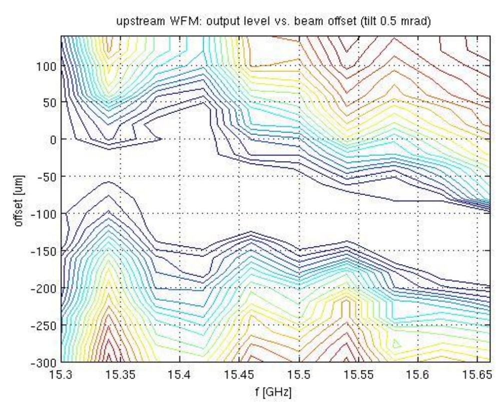
Wakefield Monitors @ PSI



Prinziplayout Wake Field Monitore SwissFEL



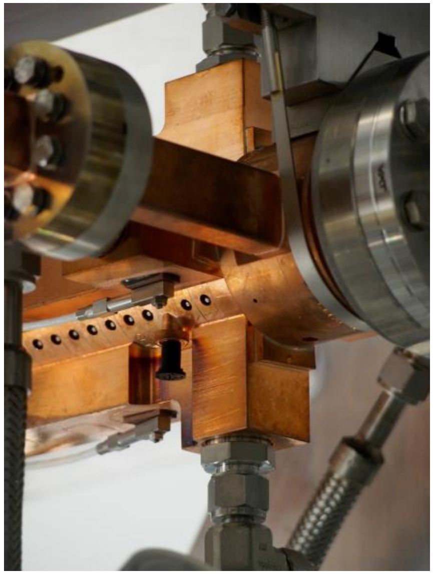


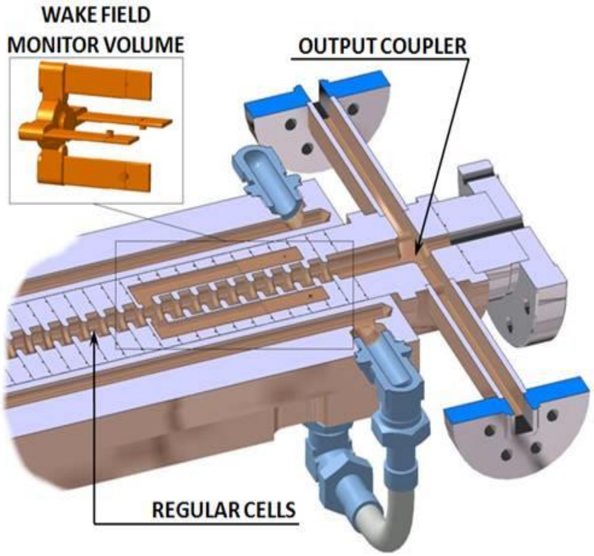


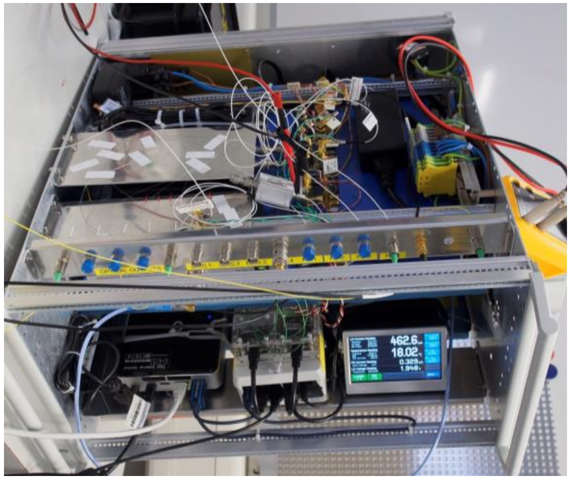
- Constant gradient X-band Structure:
  - dipole band spread out in frequency.
- Frequency of interaction correlated with position inside structure:
  - Low-f upstream, high-f downstream
- Dipole modes don't extend over full length of structure
- Big Advantage:
  - Spectrum contains information about tilt and internal misalignments (72 cavity BPMs!)

Minimum WFM signal ⇒ minimum emittance dilution!

SwissFEL WFM Testing



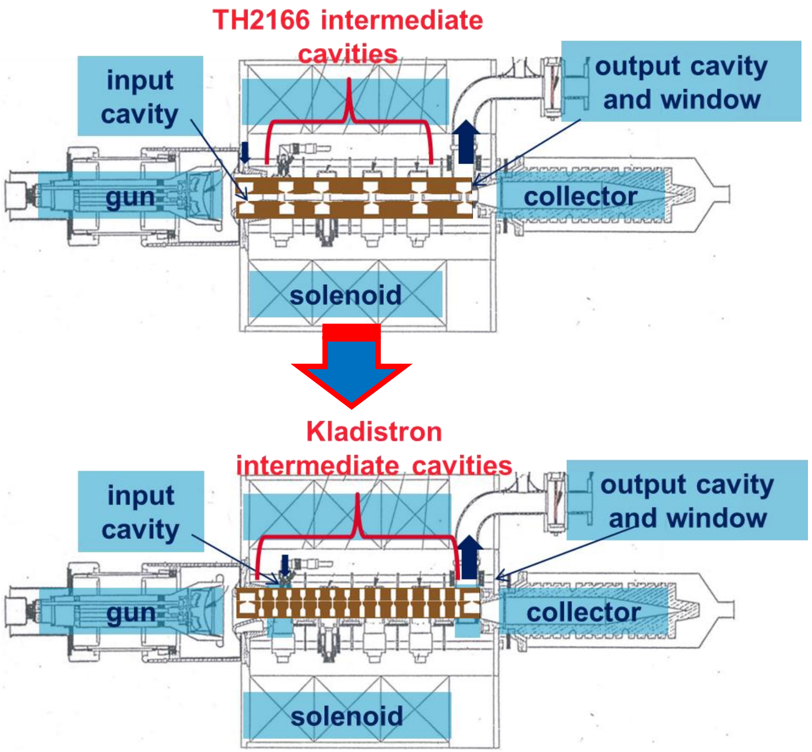


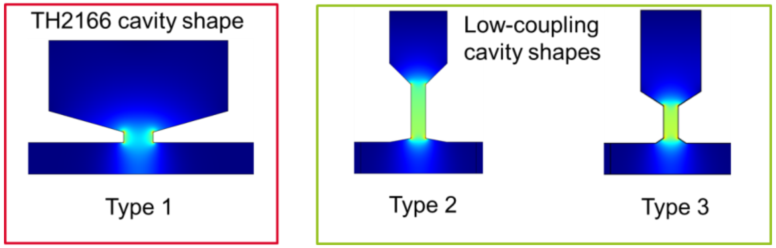


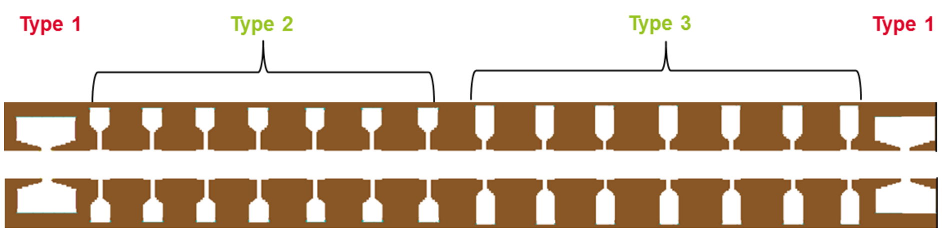
- 14 μm measurement resolution achieved on SwissFEL test facility.
- Noise contributions being mimimised to improve measurement resolution:
    - Carrier, thermal, shot and Johnson.
- **Tests expected to start on SwissFEL injector in Jun16.**

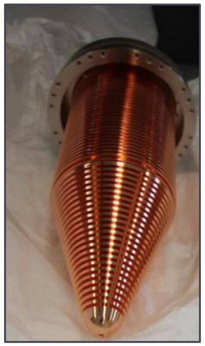
High Efficiency ‘Kladistron’ @ CEA

- The approach is to adiabatically bunch the beam with a large number of small kicks instead of a small number of larger kicks:
  - Benchmark simulation tools
  - Build technology demonstrator
- **2015: New collaboration with Thales!**
  - **Part funding Phd student with CEA.**









See Franck Peauger (CEA) talk later today

Flexible Modulator @ UU

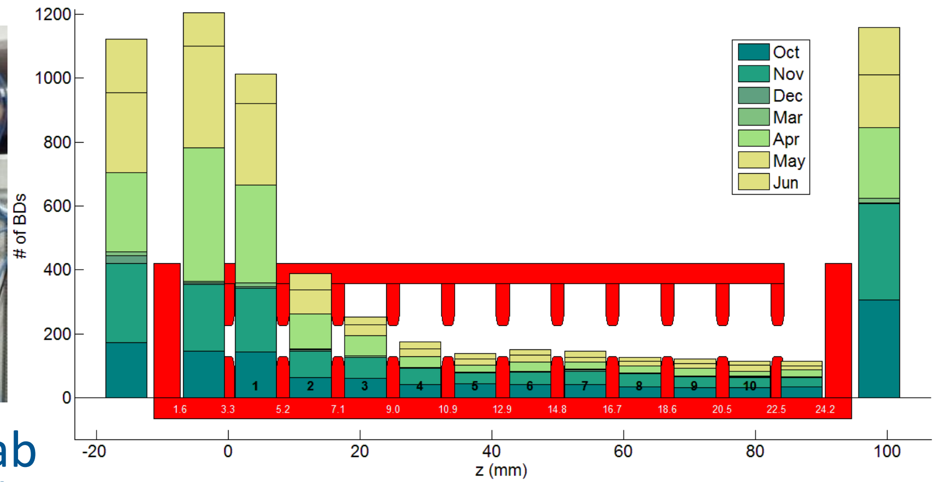
CPI VKX-8311A

Thales TH2100C

- Upsalla University formed **new collaboration with Scandinova**.
- To develop a flexible modulator platform design:
  - Able to support ~25% adjustment in klystron voltage and perveance.
  - Define modulator component specifications to provide necessary variability.
- Focusing on S and X-band klystron compatibility.

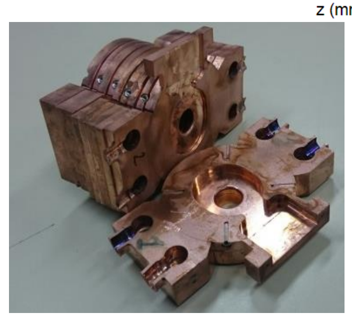
Klystron	Frequency (MHz)	Voltage (kV)	Current (A)	Pmax (MW)	Pavg (kW)
CPI VKX-8311A	11994	410	310	50	5
Thales TH2100C	2998	304	335	45	20

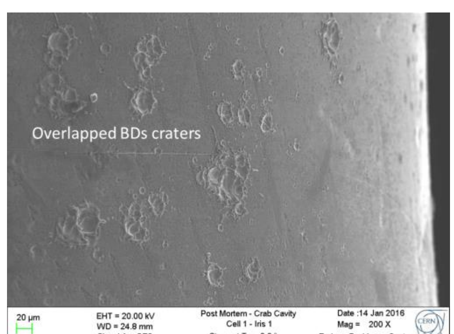
ULAN Crab Cavity Testing @ CERN

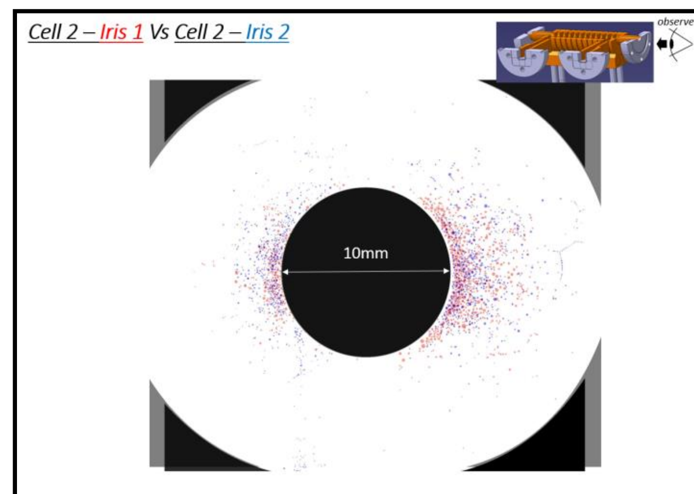


Monograph on CLIC Crab Cavity Being prepared B Woolley (ULAN/CERN)

- First UK ‘un-damped’ crab cavity successfully tuned:
  - XBOX2 test stand @ CERN used for high power breakdown tests.
- Apr15: Conditioned to 30 MW of input power – twice the design gradient!
- Breakdown analysis performed to assess limitation locations.







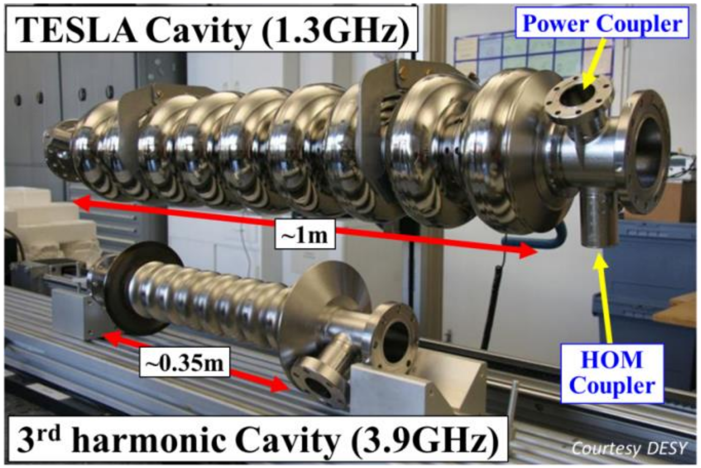
See Ben Woolley (ULAN/CERN) talk this morning

Task 12.4 SRF HOM Diagnostics

Overall Objective:

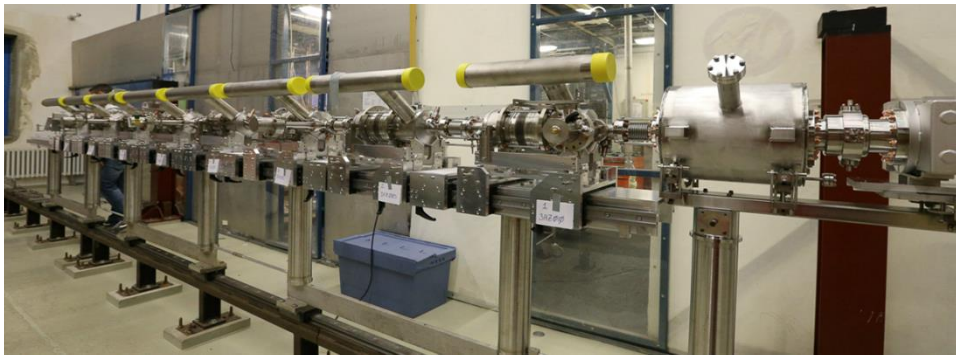
- Develop system which can be used to monitor HOM spectra to:
  - Characterise beam phase (wrt RF) and position within both 1.3 GHz and 3.9 GHz XFEL cavities.
  - Provides information for remote structure alignment.

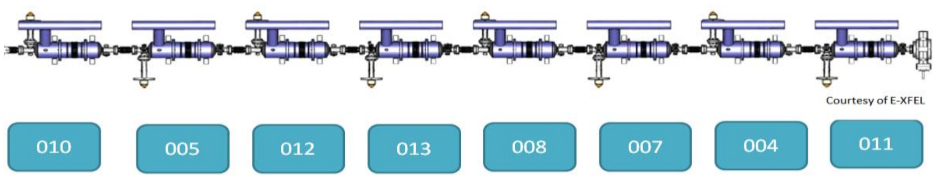
- HOM-BPM (DESY)
  - Electronics development and experimental characterisation.
- HOM-CD (UNIMAN)
  - Cavity Diagnostics – EM simulations of FLASH and XFEL modes.
- HOM-GD (Rostock)
  - Geometric Dependencies – Long cavity string determination using concatenation processes.



Task 12.4 Coordinator: Roger Jones (Manchester Univ)

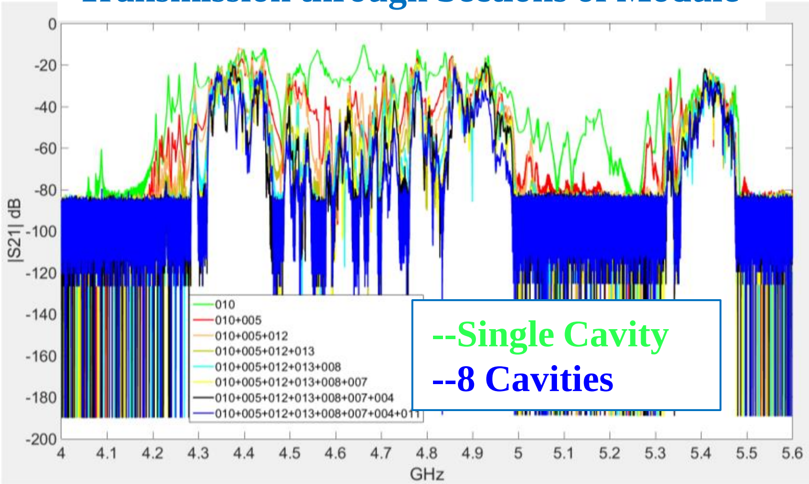
XFEL 3.9 GHz HOM Measurements @ DESY



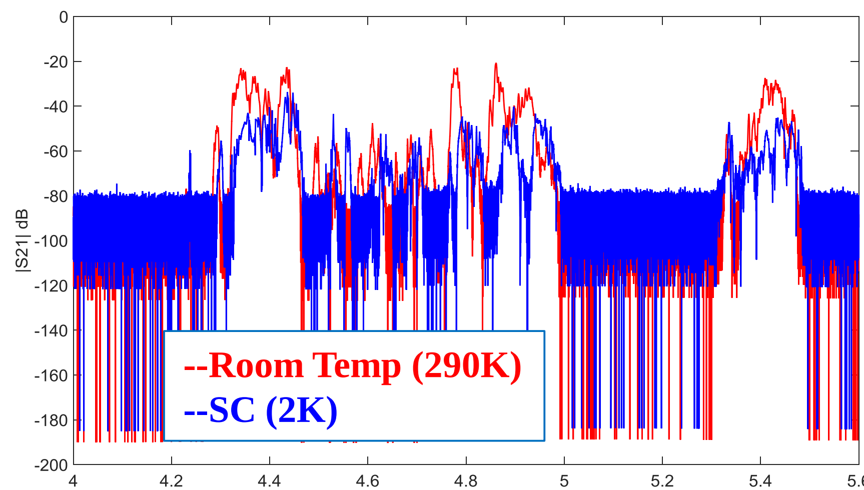


- First transmission measurements performed at 2 K for complete 3.9 GHz (8-cavity) cryomodule.
- Dense spectrum of coupled modes.

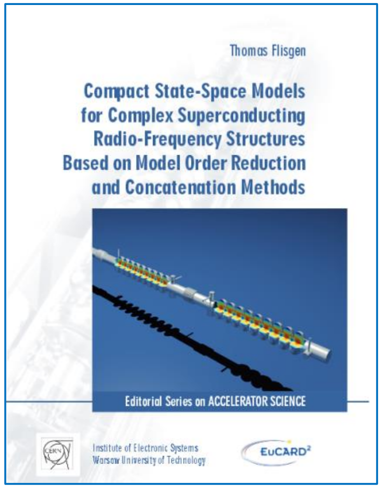
Transmission through Sections of Module



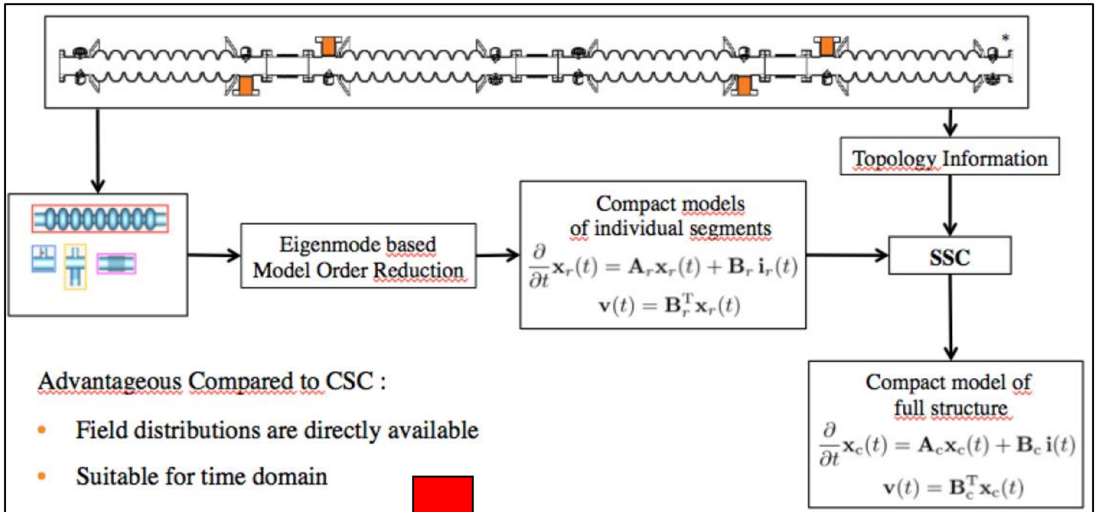
Transmission through Complete Module



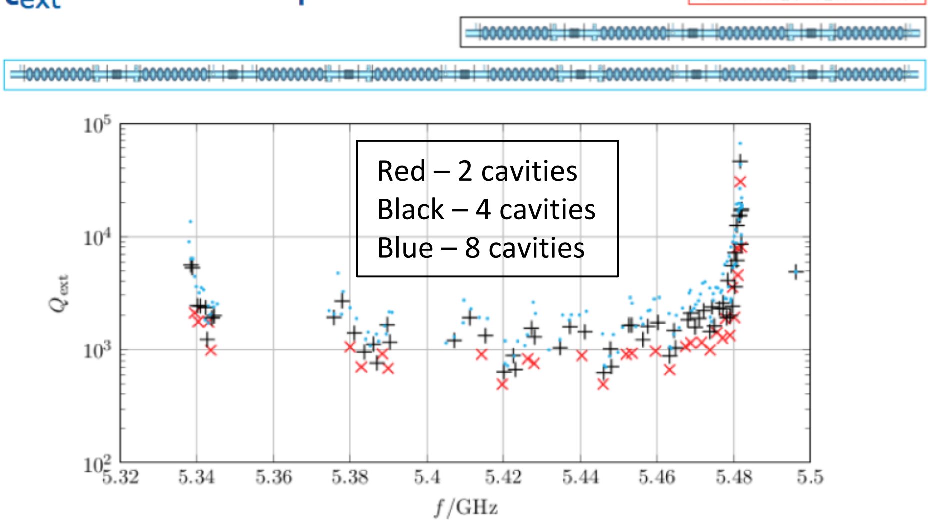
HOM Simulations @ UROS

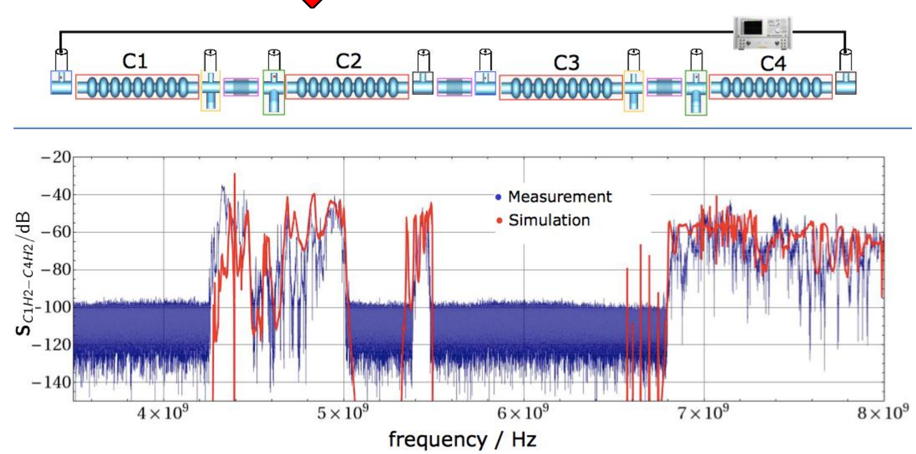


T Flisgen (UROS)

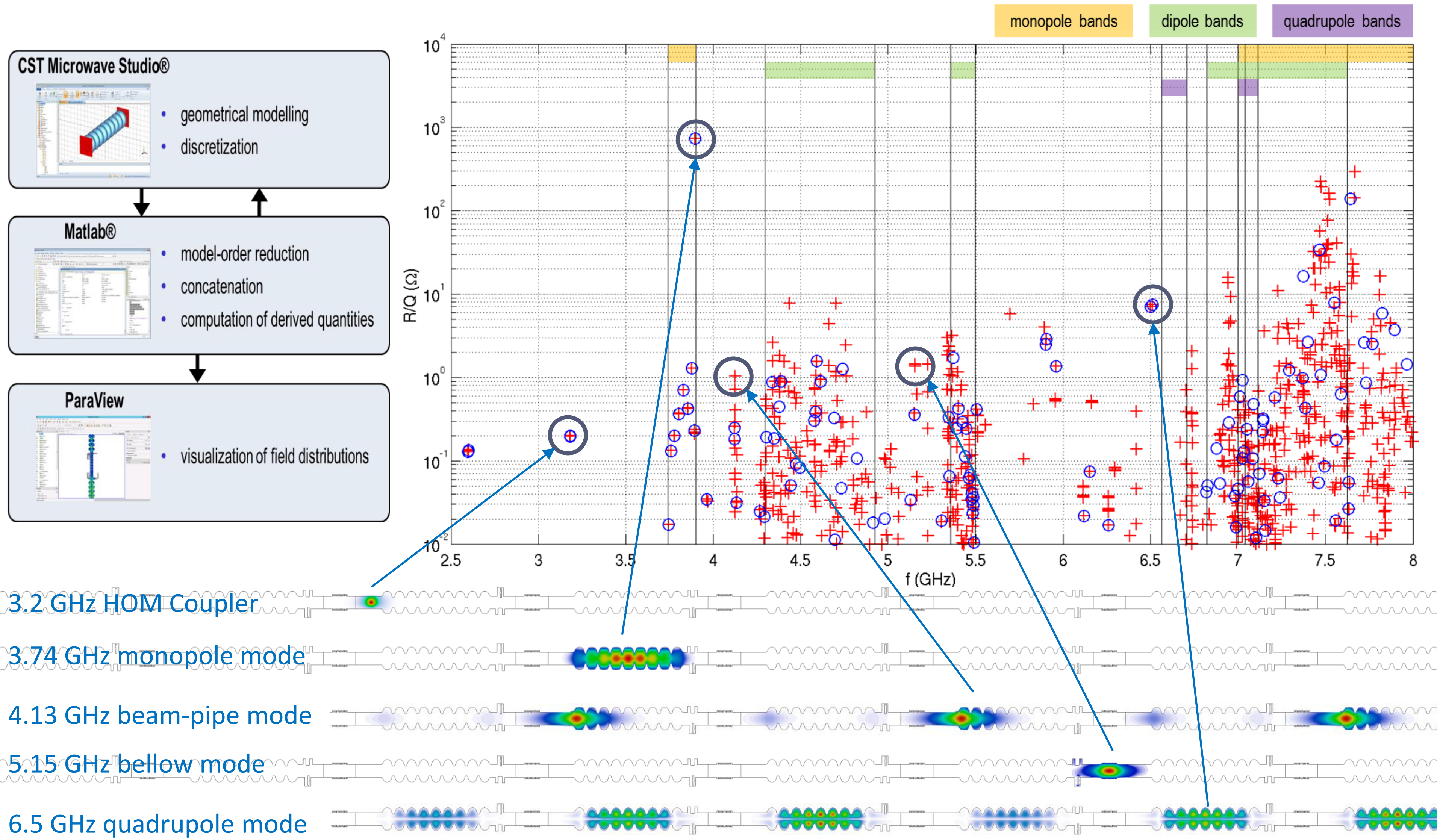


Q_{ext} of 2nd Monopole Band

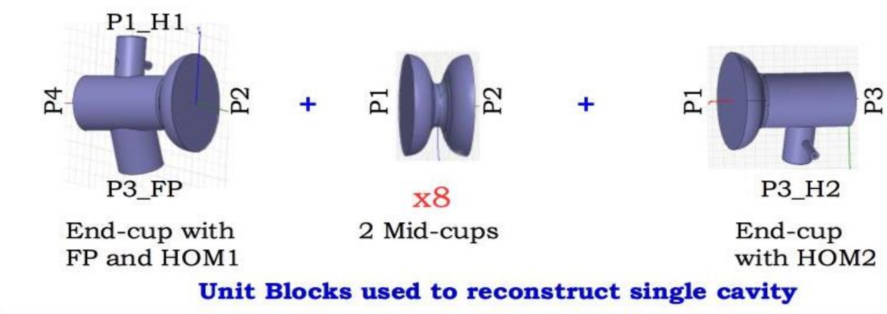


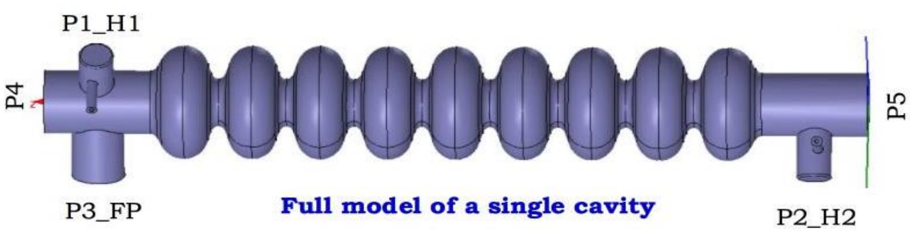


3.9 GHz 8-cavity Chain Analysis

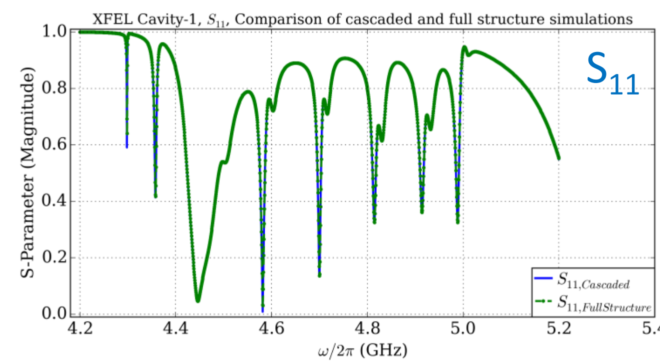


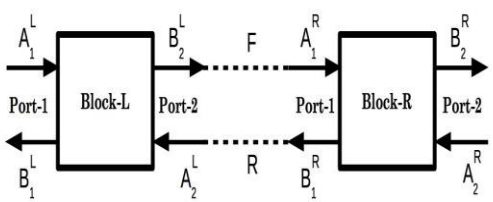
Generalised Scattering Matrix (GSM) Analysis @ UMAN





- S-parameters of each block simulated separately, and cascaded to reconstruct the large structure.
- Smaller structure can be simulated with higher accuracy, in shorter time duration.
- Significant computation time reduction for long cavity chain simulations.



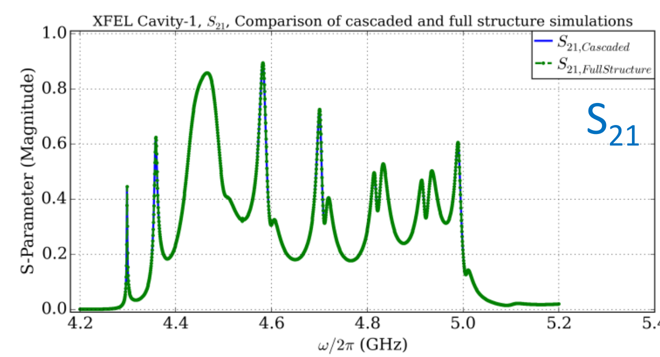


$$S_{11}^{LR} = S_{11}^{L} + S_{12}^{L}\left[I - S_{11}^{R}S_{22}^{L}\right]^{-1} S_{11}^{R}S_{21}^{L}$$

$$S_{12}^{LR} = S_{12}^{L}\left[I - S_{11}^{R}S_{22}^{L}\right]^{-1} S_{12}^{R}$$

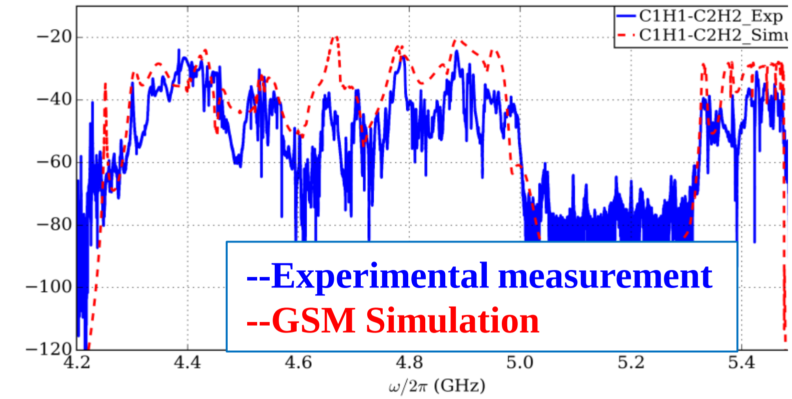
$$S_{21}^{LR} = S_{21}^{R}\left[I - S_{22}^{L}S_{11}^{R}\right]^{-1} S_{21}^{L}$$

$$S_{22}^{LR} = S_{22}^{R} + S_{21}^{R}\left[I - S_{22}^{L}S_{11}^{R}\right]^{-1} S_{22}^{L}S_{12}^{R}$$

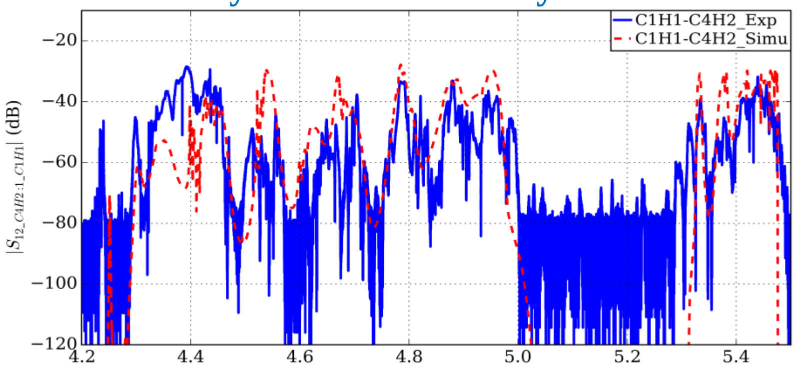


EuCARD² GSM Measurement Comparison

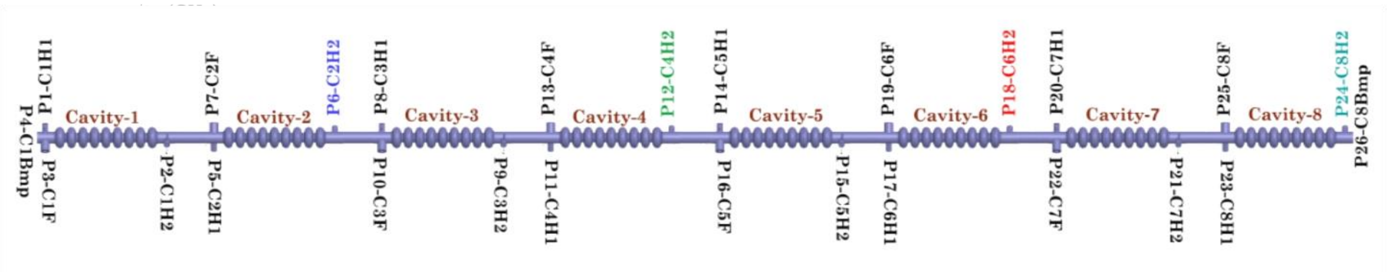
Cavity-1 HOM1 to Cavity-2 HOM2



Cavity-1 HOM1 to Cavity-4 HOM2



- First comparison of HOM spectrum from 8 cavity module AH1 at 2K.
- In this initial simulation some parameters were modified to aid comparison:
  - bellows excluded to enable rapid calculation.
  - attenuation in cables, transitions etc accounted for by rescaling ordinate.
- Beam pipe reflections accounted for by 45 MHz & 25 MHz rescaling of 1st and 2nd bands.



Task 12.5 RF Photocathodes

- Material R&D for advanced photo cathodes for NC RF guns.
- Evaluate Pb photocathode deposition for improved performance of SRF guns.
- Characterise and optimise performance of Diamond Amplifier Cathode solutions for SRF guns.

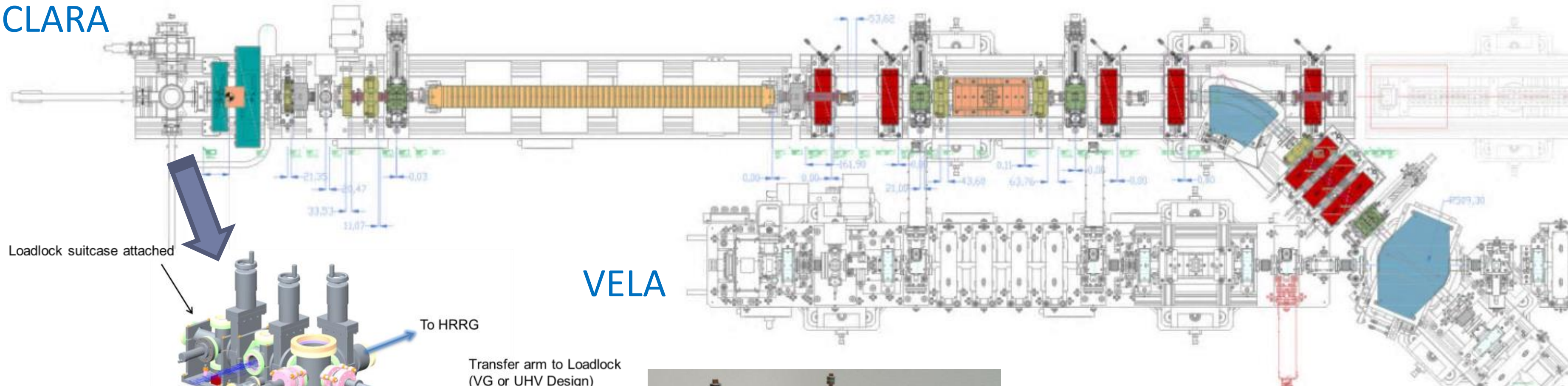
Actions and institutions:

• SAPI commissioning and photocathodes characterisation	**STFC**
• Pb photocathodes: deposition improvement, post-deposition treatment, Q and QE measurements	**NCBJ, DESY, HZDR**
• DAC photocathodes	**HZDR, HZB**

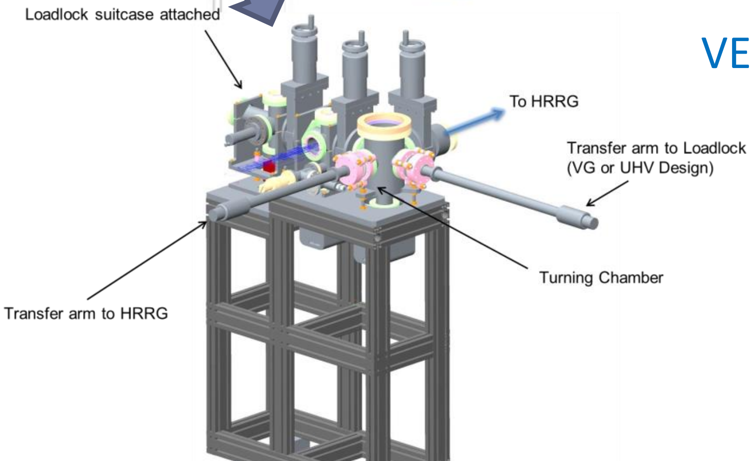
Task 12.5 Coordinator: Robert Nietubyc (NCBJ)

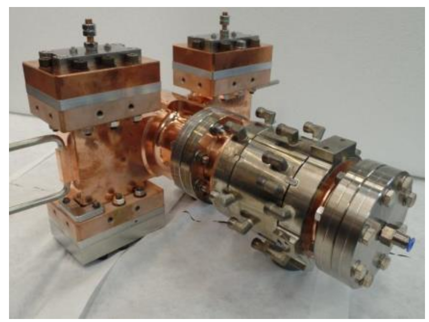
New VELA/CLARA Photocathode Transport System @ STFC

CLARA

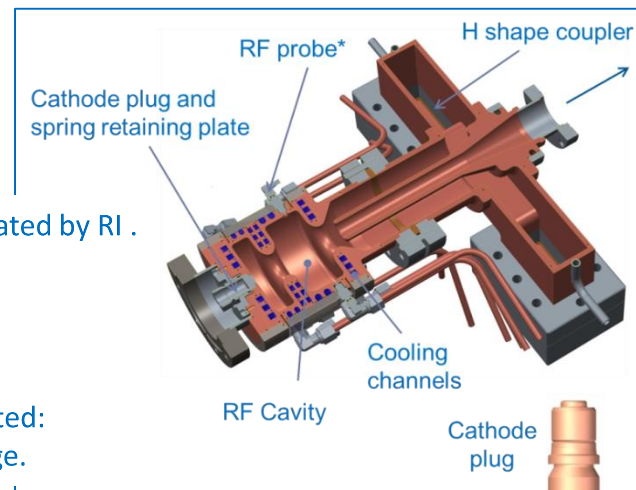


VELA





New 400 Hz RF-Gun



Phase 1 parameters:

Max Energy	~50 MeV
Max Charge	250 pC
Norm. Emitt.	<1 mm mrad
Min Bunch Length	50fs (rms), (10 MeV)
Max Peak Current	2 kA
Bunches/RF pulse	1
Pulse Rep Rate	10 Hz* (400Hz upgrade)

*RF Gun provided by Strathclyde University

- 1.5 cell S-band with RF probe fabricated by RI .
- Max. gradient:
  - 120 MV/m @ 100 Hz or
  - 100 MV/m @ 400 Hz
  - 10 kW cooling capacity
- Vacuum load lock system incorporated:
  - easy photo-cathode exchange.

EuCARD² VELA/CLARA Photo-cathodes

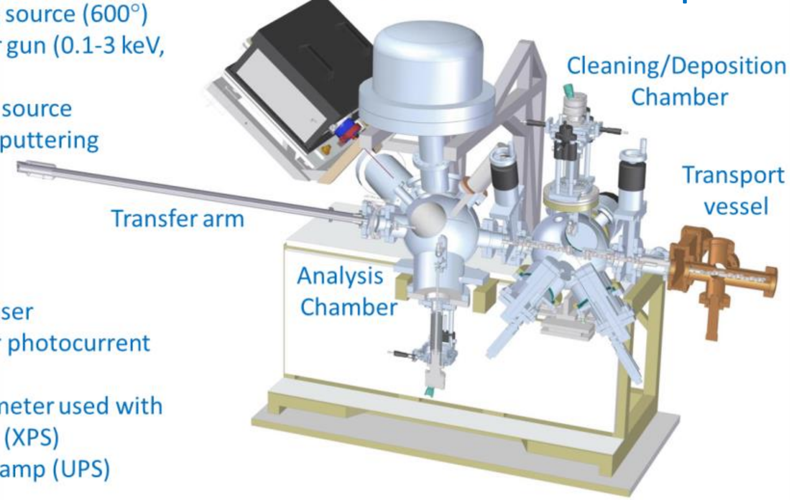
Metal Photocathodes:

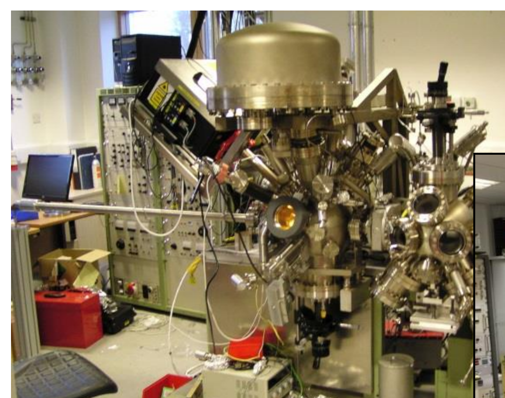
- Pc-plug based on FNAL/INFN/DESY design with reduced 10 mm tip.
- R&D program started on metal photocathodes to develop high quantum efficiency, with bulk and thin films.
- Research facility with extensive analytical instrumentation set up:
  - Photocathode transport systems compatible with other laboratories.
  - Photocathode Preparation and Characterisation Facility dedicated for VELA/CLARA operational photocathodes.

Apr'15

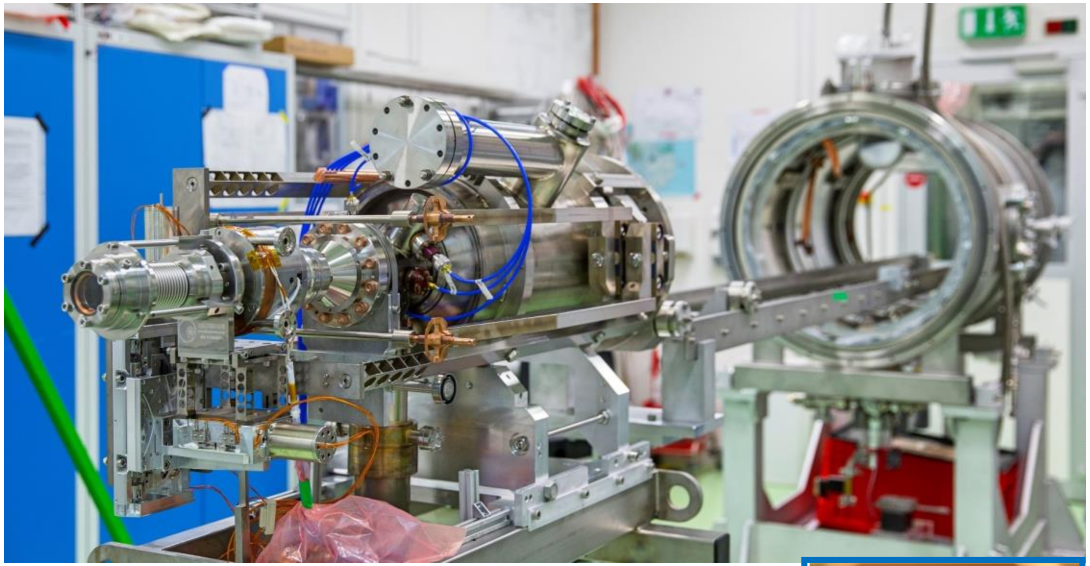
Cleaning/Deposition Chamber:
- Radiative heating source (600°)
- Argon ion sputter gun (0.1-3 keV, 15 μA)
- Atomic hydrogen source
- Two magnetron sputtering
- sources

Analysis Chamber:
- UV 266 nm CW laser
- Pico-ammeter for photocurrent measurement
- Electron spectrometer used with
  - X-ray source (XPS)
  - Ultra-violet lamp (UPS)



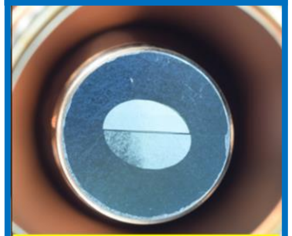


Mg Photo-cathodes @ HZDR



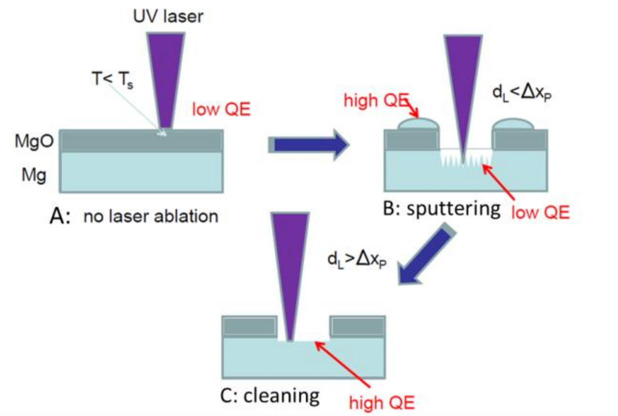
Metal (polycrystalline)	QE (%)	ϕ (eV)
Cu	10^{-6} - 10^{-5}	4.6
Mg	10^{-6} - 10^{-4}	3.6
Mo	10^{-6}	4.5
Nb	10^{-6}	4.3
Pb	10^{-6}	4.25

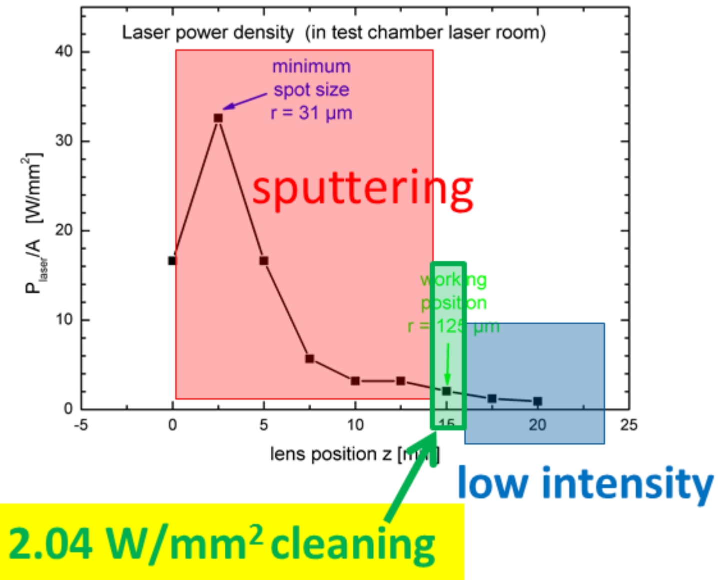
2015.12.7 Mg ~ 10^{-5}



2016.03.05 Mg ~ 10^{-3}

Laser cleaning PC surface





Mg photocathode in SRF gun-II

QE increased 2 orders of magnitude

- Removal of the surface contamination (MgO, ϕ: 4.2eV)
- Plasma enhanced photoemission due to roughness (nm level)*

Experiment very repeatable

Cleaned Mg is very sensitive

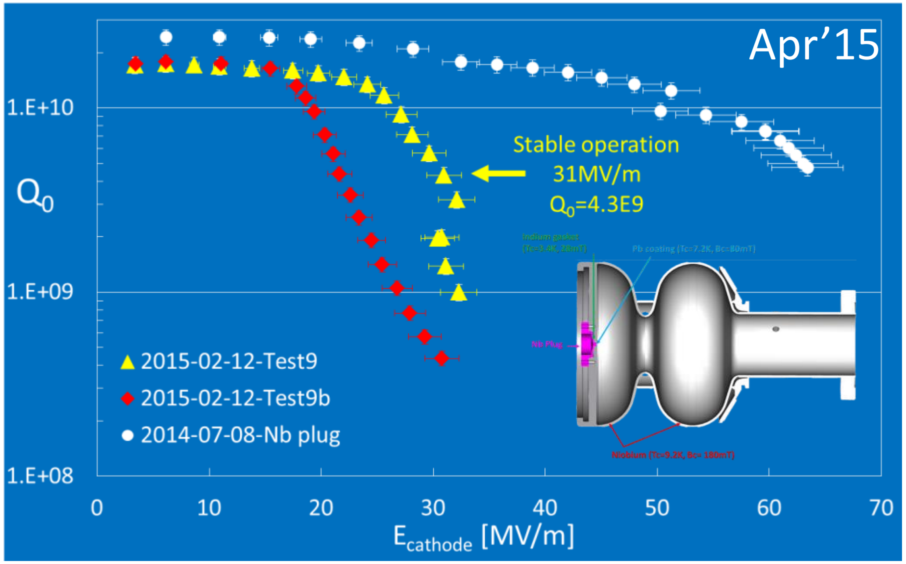
- stable in 10^{-9} mbar
- 10^{-8}mbar, loses 60% of QE in the 1st day

Effect of surface change

- Reduced work function
- Reduced thermal emittance
- Reduced dark current

*Qian, H. J. et al., Applied Physics Letters, 97, 253504 (2010)

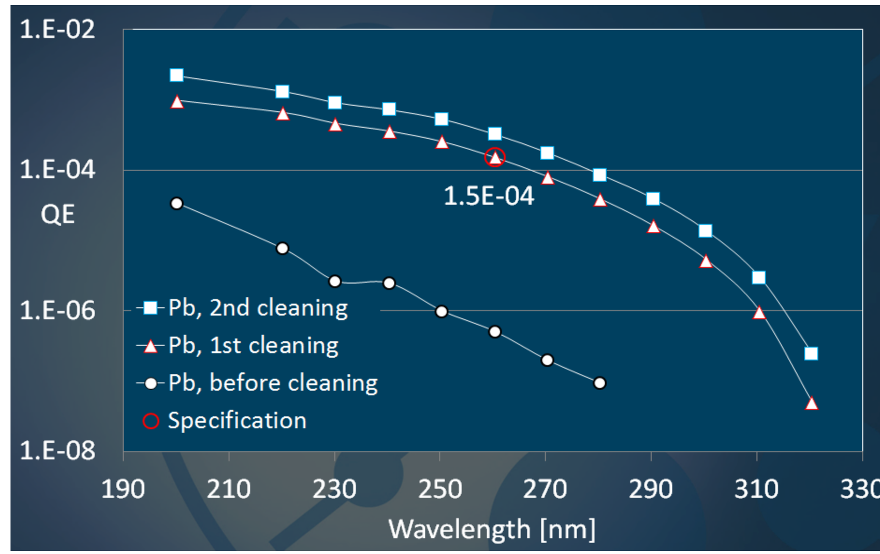
EuCARD² Pb PC Developments @ NCBJ

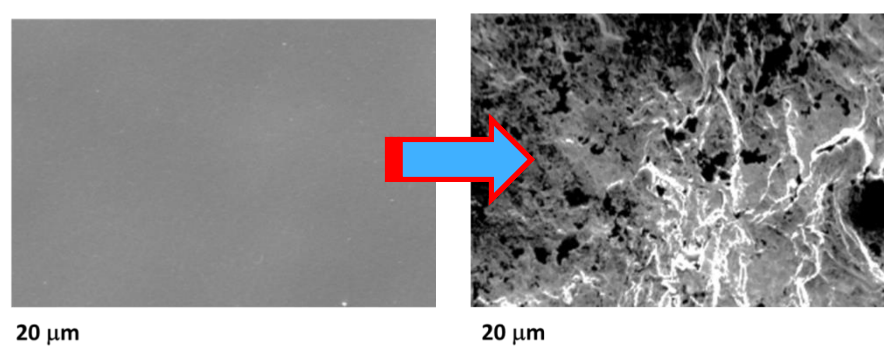


<10 µm Pb surface roughness PC - DESY/NCBJ

- Plasma irradiation leaves Pb surface smooth (<10 µm achieved).
- Laser treatment increases the QE a lot.
- This is accompanied with roughening the surface.

- Recent laser cleaning tests at BNL for Pb PC.



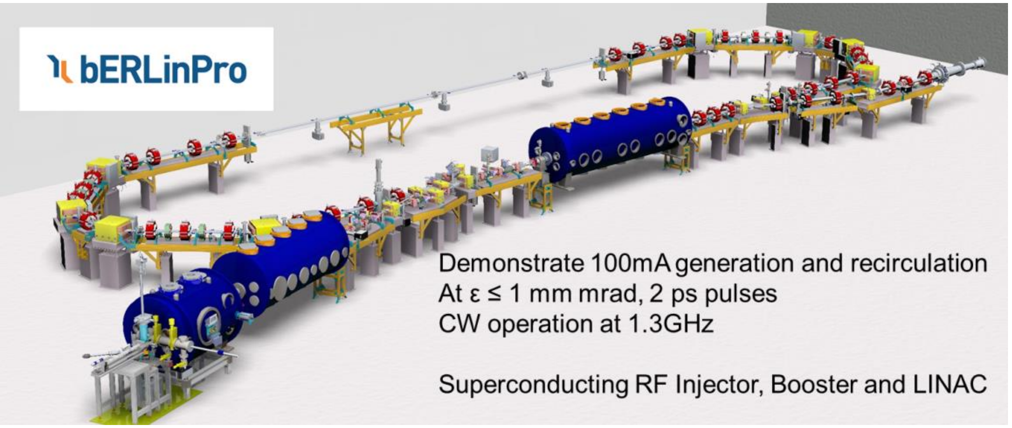


Laser Cleaning and QE Measurement System @ NCBJ

- Anode holder with an optical fiber and mirror
- Faraday cup for breakdown measurements
- Sample holder rotates for laser cleaning
- Distance between sample and anode can be adjusted with accuracy of 0.25 mm
- HV pulse is 12.5 kV during 1ms $\Rightarrow$ 50 MV/m

- Xe lamp 150 W $\Rightarrow$ 0.5 W in 200 – 210 nm
- Czerny-Terner monochromator
- Optical fiber
- Picoamperometer, measures above 10 pA
- Nd:YAG laser, 2nd harmonic: 25 mJ/pulse, 20 Hz, 10 ns
- Turbo and scroll-pumps give 10^{-7} mbar

Alkali PC Activities @ HZB

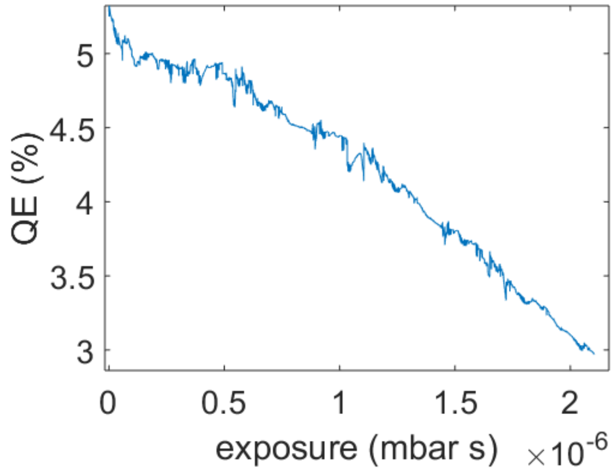


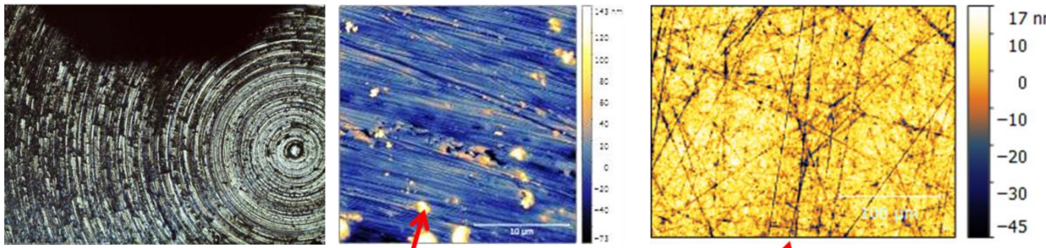
PC Plugs

Ø 10 mm x 6 mm from Mo or Cu rods machined to roughness Ra = 10 µm:

- **Mo** from sintered material polished samples have roughness ~ 8nm rms
- **Cu** from OFHC copper 20nm rms roughness after polishing

- $Cs_{2.7}K_{1.7}Sb$ composition after Cs deposition
- All Sb reacted, Alkali rich surface
- **5.2% QE demonstrated**



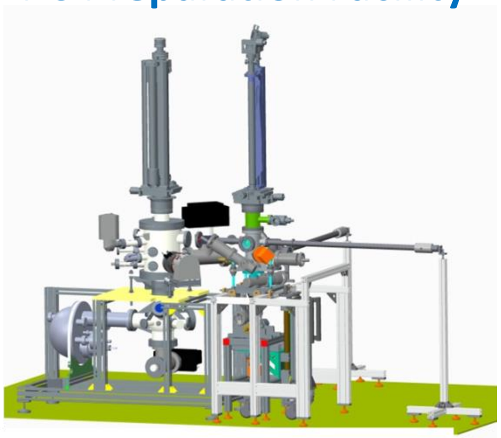


Protrusions in the AFM images for Mo and Cu

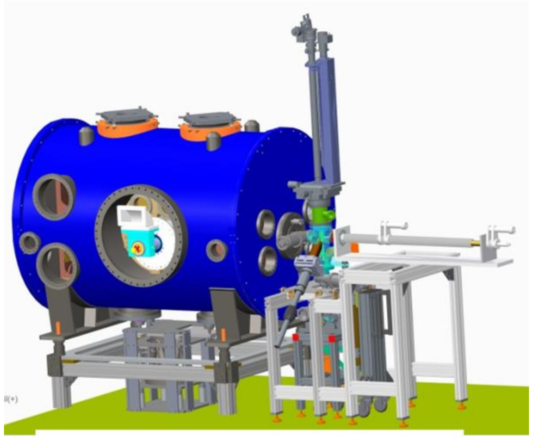
White light interferometry of Mo samples shows scratches, boundaries

PC Preparation/Implementation and DAC @ HZB

PC Preparation Facility



Transfer System #1 at Prep Chamber



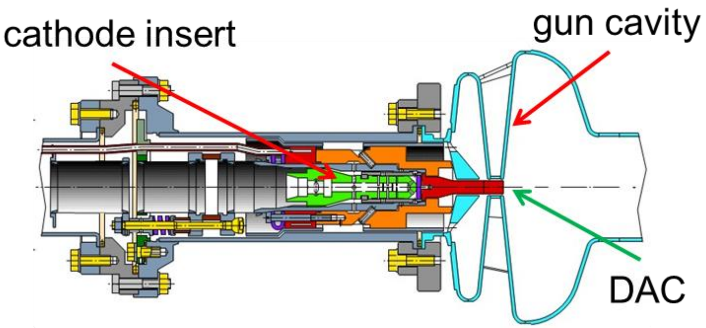
Transfer System #2 at Gun Module

Cathodes must be stored and handled in < 10^{-10} mbar UHV.

- Vacuum suitcase is available. Vacuum ~ $1*10^{-11}$ mbar.
- Stability with NEG + getter pump is good for >3 months.
- Cleaning and assembly in ISO 5 clean room conditions.

- Transfer system 1 is being comissioned.
- Transfer system 2 engineering done, parts are manufactured.

Diamond Amplifier Cathodes



SRF gun cold mass: insert and cavity

Challenges:

- Operation inside a SRF gun.
- Beam properties (thermal emittance, response time) .
- Unwanted beam production, field emission.

Steps towards a DAC in an SRF gun

- Collaboration with BNL.
- Physics and engineering design of a suitable cathode cell which contains the DAC.
- Laboratory tests on wanted and unwanted beam properties.
- Engineering design for operation of DAC in SRF gun at ELBE/HZDR and BERLinPro/HZB.

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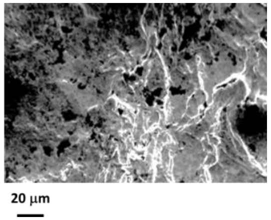
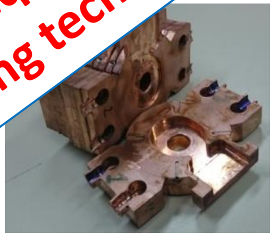
WP12 Plans for the Final Year

- Task 12.2 SRF Thin Films:
  - Validate 1.3 GHz HIPIMS bias deposition.
  - Demonstrate multi-layer ALD deposition.
  - Qualify HT Nb_3Sn deposition in QPR cavity at CERN.
  - **Unequivocally validate break-though performance for a thin-film SRF cavity.**
- Task 12.3 Normal Conducting High Gradient:
  - **Beam validation of X-band WFM on SwissFEL.**
  - **High efficiency Kladistron to be built and tested with industry.**
  - **Flexible klystron modulator design to be developed with industry.**
  - **Damped X-band crab cavity to be fabricated and tested.**
- Task 12.4 SRF HOM Diagnostics:
  - XFEL 3.9 GHz HOM electronics to be tested with cryomodule @ 2 K.
  - Refined SSC and GSM analysis to improve measurement correlation.
  - **Validate long-chain cavity modelling against XFEL cold tests with optimised HOM electronics.**
- Task 12.5 RF Photo-cathodes
  - **Validation of high QE metal PC on CLARA for low current applications.**
  - **Optimised Pb PC deposition tested in SRF cavity to high performance at DESY and HZDR for medium current applications.**
  - **DAC PC demonstration in SRF gun at HZB and HZDR for high current applications.**

WP12
Pushing the Envelope

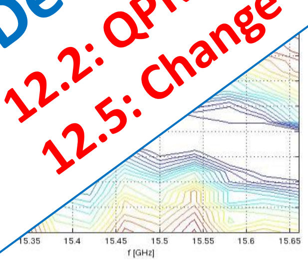
- **Beam Generation:**
  - New photocathodes providing demonstration of highest beam intensities and smallest beam emittances.
- **Acceleration:**
  - Demonstration of the highest level of acceleration performance.
- **Beam Diagnostics/Control:**
  - Demonstration of high performance and low cost beam position diagnostic.

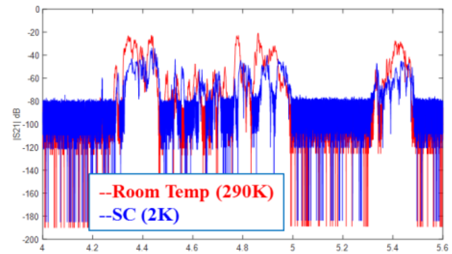


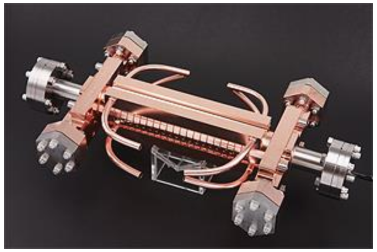


10/11 Milestones completed:
- 12.3: Change in DDS structure optimisation priority

6/8 Deliverables completed:
- 12.2: QPR hardware failure requiring repair
- 12.5: Change in laser cleaning technology







Integrated and balanced programme encompassing high performance capabilities across both SC and NC technologies.

Many Thanks

The WP12 Innovative RF Team

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