# WP12 Innovative RF Technologies

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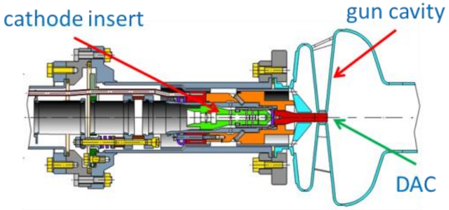
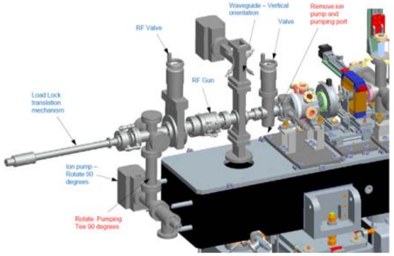
# WP12

# Pushing the Envelope

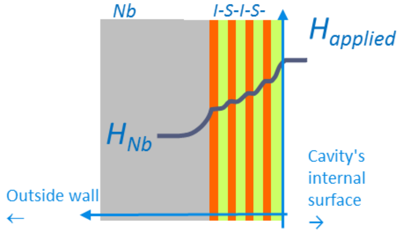
- **Beam Generation:**
  - New photocathodes providing demonstration of highest beam intensities and smallest beam emittances.

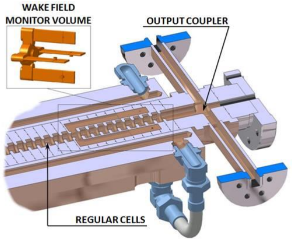


SRF gun cold mass: insert and cavity

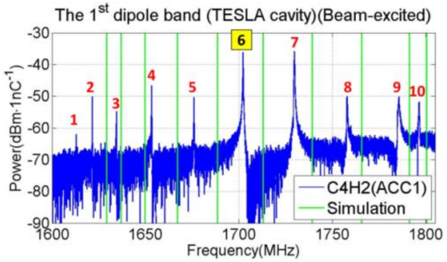


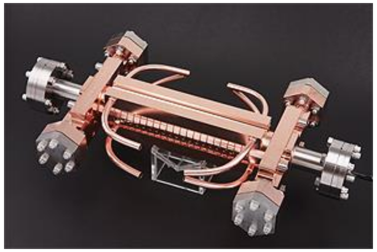
- **Acceleration:**
  - Demonstration of the highest level of acceleration performance.





- **Beam Diagnostics/Control:**
  - Demonstration of high performance and low cost beam position diagnostic.





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

# WP12 Collaborative Team

## SRF Thin Films
C Antoine (CEA)

DE LA RECHERCHE À L'INDUSTRIE cea SACLAY
CERN
HZB Helmholtz Zentrum Berlin
Grenoble INP

## High Gradient NC
W Wuensch (CERN)

DE LA RECHERCHE À L'INDUSTRIE cea SACLAY
LANCASTER UNIVERSITY
PAUL SCHERRER INSTITUT PSI
UPPSALA UNIVERSITET
CERN
MANCHESTER 1824 The University of Manchester
Science & Technology Facilities Council

## SRF HOM Beam Diagnostic
R Jones (Manchester Univ)

DESY
Universität Rostock
MANCHESTER 1824 The University of Manchester

## RF Photocathodes
R Nietubyc (NCBJ)

DESY
HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF
Science & Technology Facilities Council
HZB Helmholtz Zentrum Berlin
ncbj

# 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 reducing accelerator cost and length.

### 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.

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# Task 12.1 Management & Coordination

- Management Team:
    - Peter McIntosh (STFC Daresbury Laboratory)
    - Nicoleta Baboi (DESY)
    - Juliette Plouin (CEA Saclay)
- WP12 Steering Group:
    - Coordinators + Task Leaders.
    - At least 2 x SG meetings per year + telecon meetings amongst Task groups.
- WP12 Annual Review Meeting, rotating amongst collaborating institutes.

# Task 12.1 Management & Coordination

- 1st WP12 Annual Review, hosted at CEA Saclay, April 16-17 2014.
- 29 participants, with all 13 collaborating institutes represented.
- Review material: https://indico.cern.ch/event/301619/

# WP12 Milestones

| | Milestone | Title | Beneficiary | Date | Comments | |
|---|---|---|---|---|---|---|
| **Task 12.2** | MS78 | Characterisation test facility implemented at HZB | HZB | M30 | Facility implemented and validated | |
| | MS84 | Deposition test facility designed at CEA. | CEA | M40 | Facility designed and validated | |
| | MS87 | Fundamental SRF Thin Film physics report | CEA | M48 | Final Activity Report | |
| | MS88 | Report summarising the results obtained in characterising the various new thin film technologies developed, which include both multilayer and monolayer techniques | CEA | M48 | Final Activity Report | |
| **Task 12.3** | MS74 | Design concept RF front end | PSI | M12 | Activity Report | ✓ |
| | MS76 | High power RF components fabricated and tested at low level | CEA | M24 | Prototype completed and validated | |
| | MS77 | Phase stabilisation experiment design | ULANC | M24 | Activity Report | |
| | MS79 | Crab cavity electromagnetic design | ULANC | M30 | Activity Report | |
| | MS81 | RF design CLIC_DDS_B | UNIMAN | M36 | Activity Report. | |
| | MS86 | RF design of fully interleaved structure and CLIC SW study. | UNIMAN | M45 | Activity Report. Concluding final report | |
| **Task 12.4** | MS82 | Completed coupled cavity simulations of 8-cavity module | UNIMAN | M36 | Activity Report | |
| **Task 12.5** | MS73 | Commissioning of the SAPI for operation with metal photocathodes | STFC | M8 | Publication report | ✓ |
| | MS75 | Investigation of quantum yield and energy spectrum of the electrons, emitted from the metal photocathode surface in SAPI | STFC | M18 | Intermediate scientific report | |
| | MS80 | Demonstrated operation of improved deposition system, Pb layers of 1 µm in thickness. | NCBJ | M30 | Report on sample characterisation | |
| | MS83 | Manufacturing and commissioning of the photocathode transport system | STFC | M36 | Technical design report | |
| | MS85 | Investigation of the brightness of different metal photocathodes in a S-band NCRF gun | STFC | M42 | Scientific report | |

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# WP12 Deliverables

| | Deliverable | Title | Beneficiary | Date | Comments |
|---|---|---|---|---|---|
| Task 12.2 | D12.1 | Deposition test facilities implemented and verified at CERN and INPG. | CERN | M18 | Report |
| | D12.5 | First resonator deposited and qualified at CERN. | CERN | M36 | Report |
| | D12.10 | Cavity deposited and qualified at CEA. | CEA | M48 | Report |
| Task 12.3 | D12.2 | Initial progress report of task 12.3. | CERN | M18 | Report |
| | D12.6 | Intermediate progress report of task 12.3. | CERN | M36 | Report |
| | D12.11 | Final report of task 12.3. | CERN | M48 | Report |
| Task 12.4 | D12.3 | Design of electronics for XFEL HOM diagnostics. | DESY | M18 | Report |
| | D12.7 | Completed characterisation of HOMs in the 8-cavity XFEL 3HC module. | UNIMAN | M36 | Report |
| | D12.12 | Report on characterisation of HOMs in XFEL coupled 3HC cryomodule. | UNIMAN | M48 | Report |
| Task 12.5 | D12.4 | Scientific report on photocathode R&D. | STFC | M18 | Report |
| | D12.8 | Optimised procedure for microdorplets flattening with an UV laser. | NCBJ | M36 | Report |
| | D12.9 | Pb/Nb plug photocathodes measurements and characterization. | HZDR | M42 | Report |
| | D12.13 | Results of DAC implementation in SRF guns. | HZB | M48 | Report |

# Task 12.2 SRF Thin Films

**Niobium on copper (µm)**

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

Subtask 1

**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

Subtask 2

**Specific characterization tools needed**

**Better understanding of SRF physics needed**

Subtask 3

**Task 12.2 Coordinator: Claire Antoine (CEA Saclay)**

# Task 12.2 Thin Films

## Why thin films? 2 reasons

**Making cheaper cavities:**

**Bulk like Nb on copper (1-5 µm)**

**Nb : $\lambda$~50 nm => only a few 100s nm of SC necessary**

(the remaining thickness = mechanical support only) **=> Make thin films !**

### Advantages

- Thermal stability (substrate cavity = copper)
- Cost
- Optimization of $R_{BCS}$ possible ($e^-$ mean free path)

### Disadvantages

- Fabrication and surface preparation (at least) as difficult as for bulk
- Superconductivity very sensitive to crystalline quality (lower in thin films for now)

**Overcoming Nb monopoly:**

**$Nb_3Sn$, $MgB_2$, Multilayers…**

### Advantages

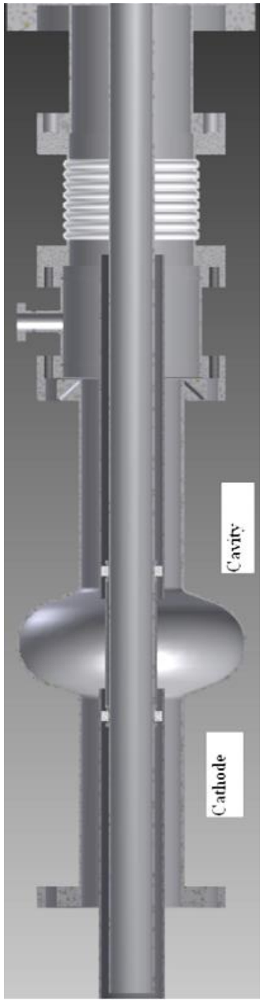
- Can also be deposited onto copper
- Higher Tc => higher Qo
- Higher $H_{SH}$ or $H_{C1}$ => higher accelerating field

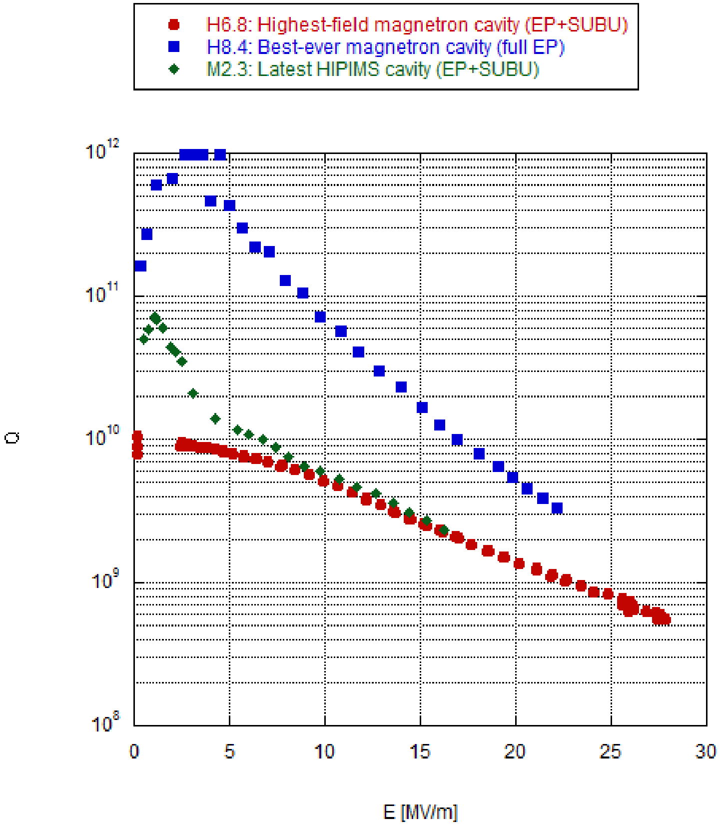
### Disadvantages

- Fabrication and surface preparation (at least) as difficult as for bulk
- Superconductivity very sensitive to crystalline quality (lower in thin films for now)
- **Deposition of innovative materials is very difficult (exact composition + structure)**
- **Theoretical limit ($H_{SH}$ vs $H_{C1}$) still controversial => choice of ideal material !?**

Demonstrate high performance thin films from samples to cavities!

# HIPIMS @ CERN: Bulk-like Thin Films (Subtask 1)

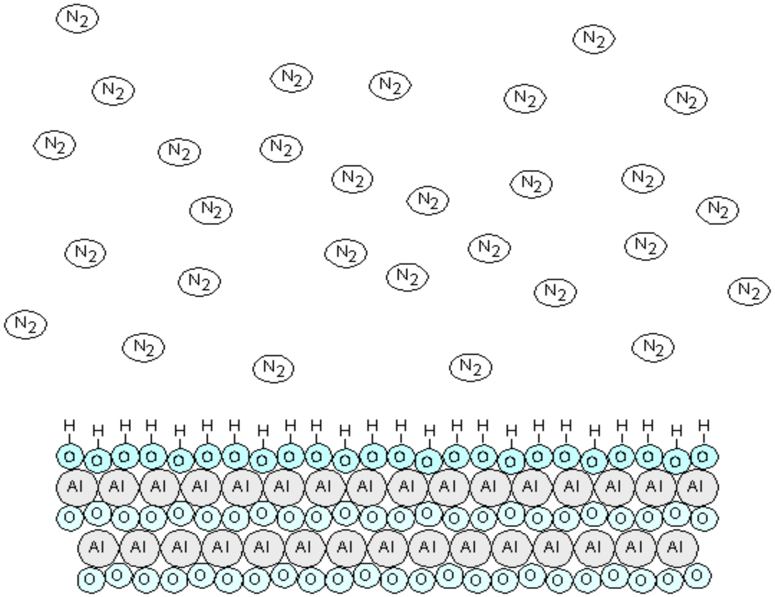




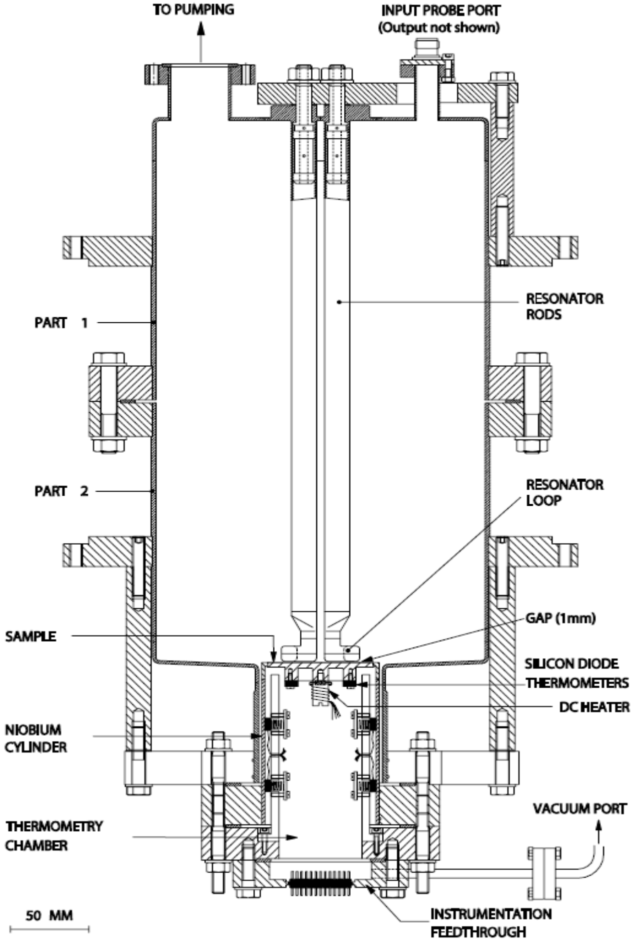
- Reinforced activity w. Sheffield U. to study biased HIPIMS:
  - Study on samples: relationship structure/plasma conditions
  - Two cavities have been coated with HIPIMS. Performance equivalent to the best cavities coated in the past by magnetron.

# CVD/ALD @ Grenoble INP (Subtask 2)

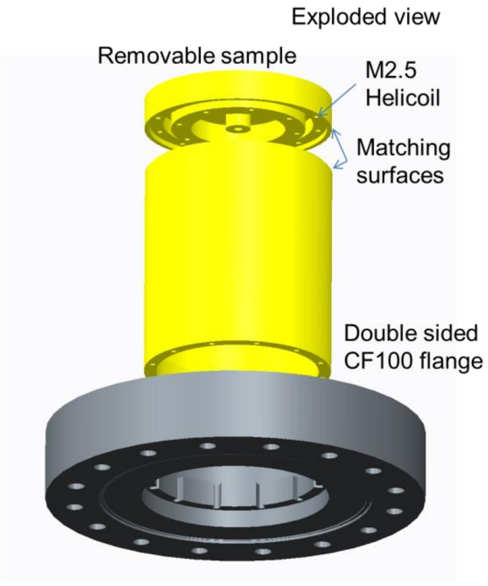
- Received special R&D ALD set-up (March 2014)
  - Preliminary work on CVD deposited NbN performed.
  - Tasked to develop a suitable coordination chemistry for the ALD precursors (+ plasma ALD to help).



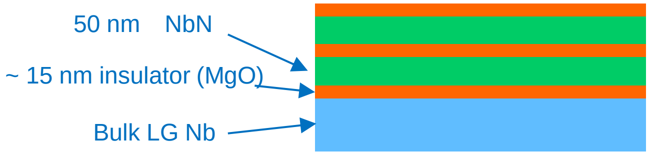
# "Sample Cavity" @ HZB (Subtask 3)

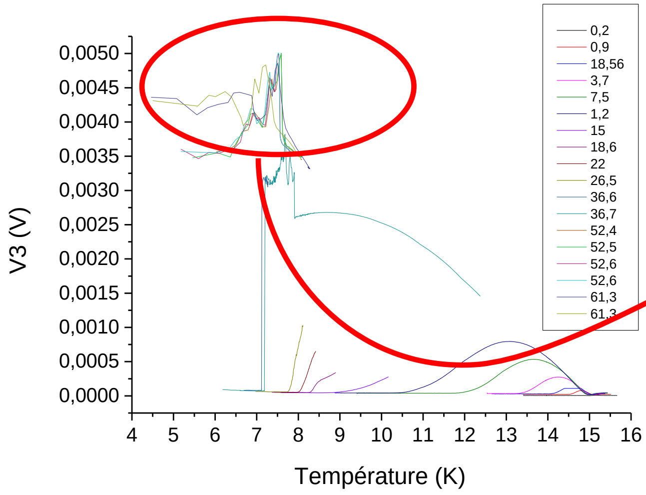


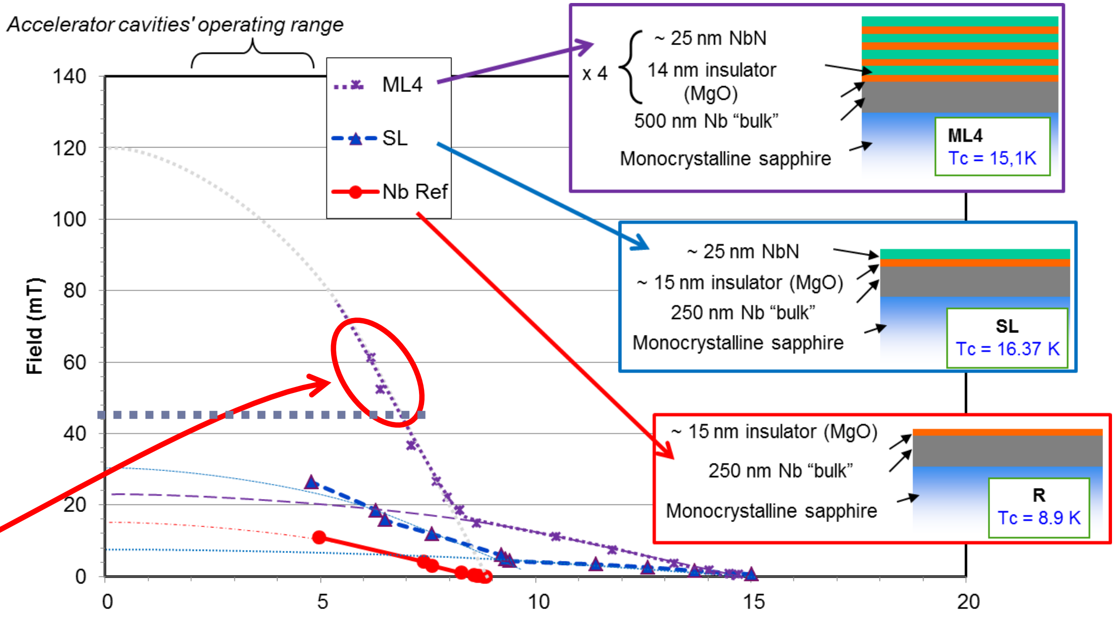
- Quadrupole resonator developed at HZB:
  - Quadrupole resonator close to final fabrication (presently BCP at JLAB).
  - Special vertical cryostat and RF test stand under assembly.
- Design of a special sample holder for small flat sample underway:
  - Will allow RF testing of small flat sample 1.3 GHz and lower ω, medium magnetic field.

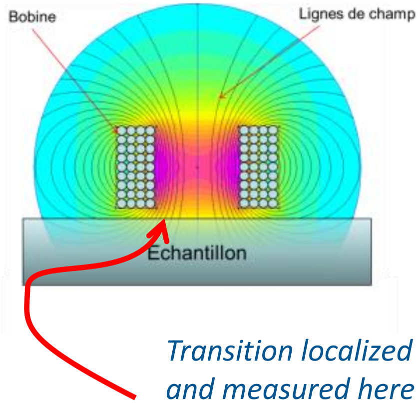


# Magnetometry @ Saclay (Subtask 3)









*Transition localized and measured here*

- Allowed to evidence magnetic screening of single and multilayers:
  - Transition at 38 mT => need to develop smaller coil design.
  - Strong indication that $R_{BCS}$ is improved with ML.

# Task 12.3 High Gradient Normal Conducting

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

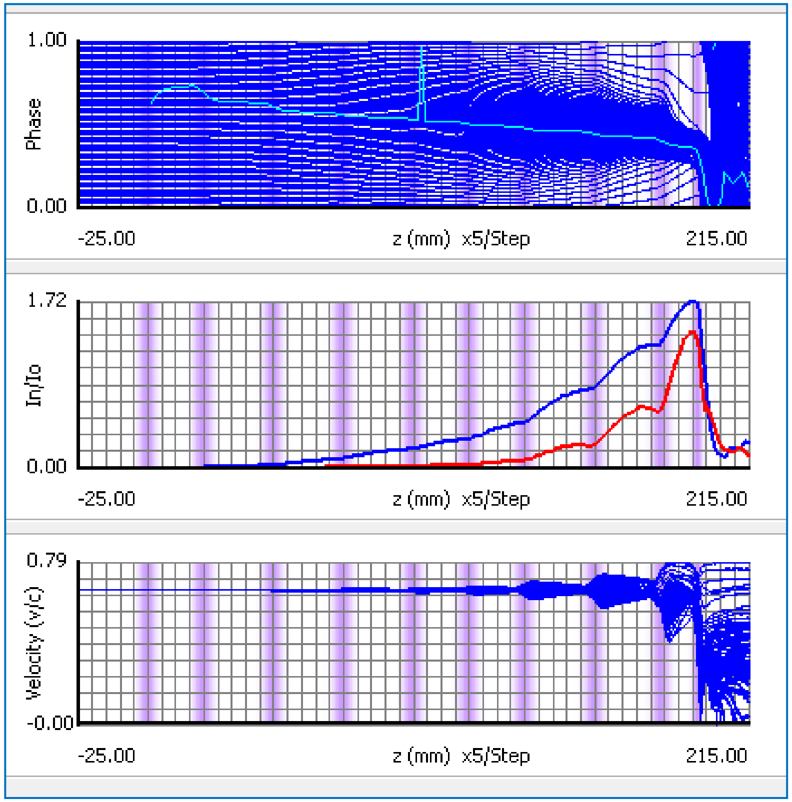
- Deepen the technological base:
  - New X-band klystron design from SACLAY
  - Instrumentation and electronics from PSI
  - Test-stand optimization from Uppsala Univ
  - Alternative design of HOM suppression from Manchester Univ
- Broaden the use in accelerators:
  - Crab cavity/deflector development from Lancaster Univ & STFC
- New applications:
  - Medical linacs
  - XFELs

**Task 12.3 Coordinator: Walter Wuensch (CERN)**

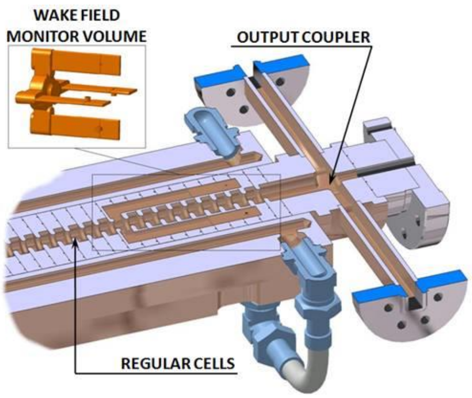
# Towards Higher Klystron Efficiencies @ CEA

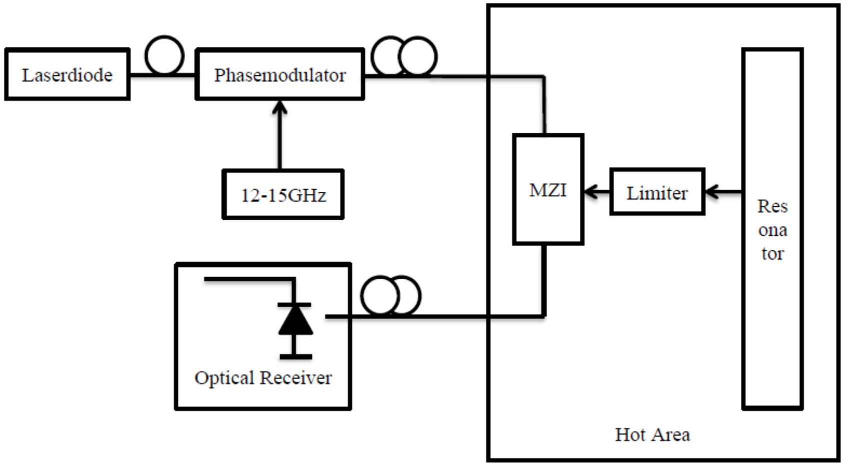
- X-Band Klystron R&D:
  - The approach is to bunch the beam with a large number of small kicks instead of a small number of larger kicks.

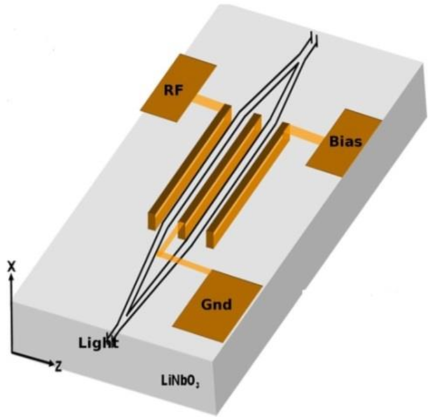
| Name | Numbers of Cavities | R/Q [Ohm] | TTF | Efficiency | Overall Length [mm] |
|---|---|---|---|---|---|
| AK10-2 | 10 | 20 to 50 | 0.683 | 67.2 % | 197 |
| AK14-1 | 14 | 20 | 0.683 | 68.5 % | 221 |
| AK20-3 | 20 | 27.4 | 0.688 | 74 % | 285 |
| AK20 | 20 | 12 | 0.72 | 78 % | 285 |



# Wakefield Monitor (WFM) Concept @ PSI



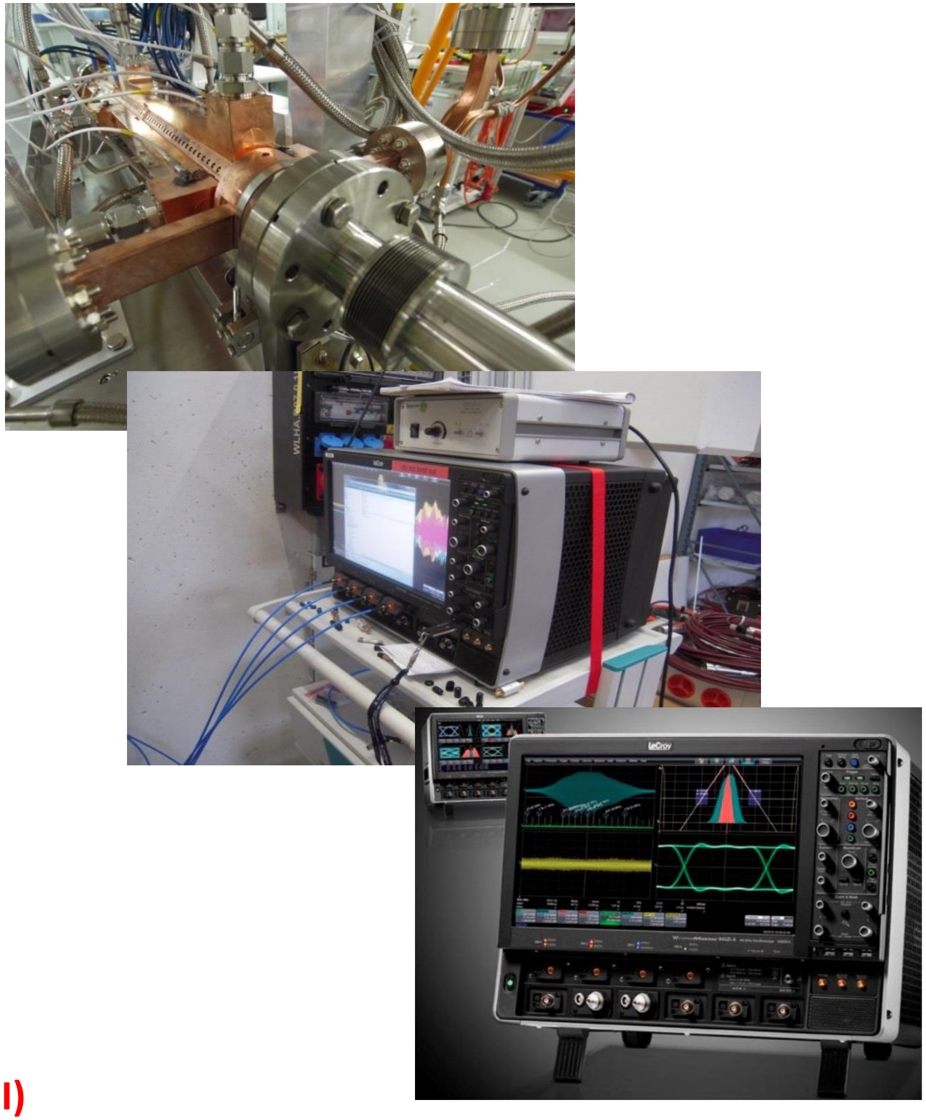

Laserdiode
Phasemodulator
12-15GHz
MZI
Limiter
Resonator
Optical Receiver
Hot Area



- WFM DC optical signal from laser diode gets modulated with local oscillator at 12-15 GHz:
  - 2nd modulation of optical carrier by WFM signals via MZI type electro optical modulator – WFM signals get optically up/down converted by LO frequency.
  - Photo diode converts down converted WFM pulse back into electrical signal.
  - Not shown: analog electrical post processing, 3 paths:
    - Logarithmic amplifier (-60dBm sens., 70 dB dyn. range) to give ‘operator signal’
    - Fast high sensitive tunnel diode detector (-80 dBm TSS, 1V/uW) for structure straightness
    - Raw PD output – ‘expert’ signal’

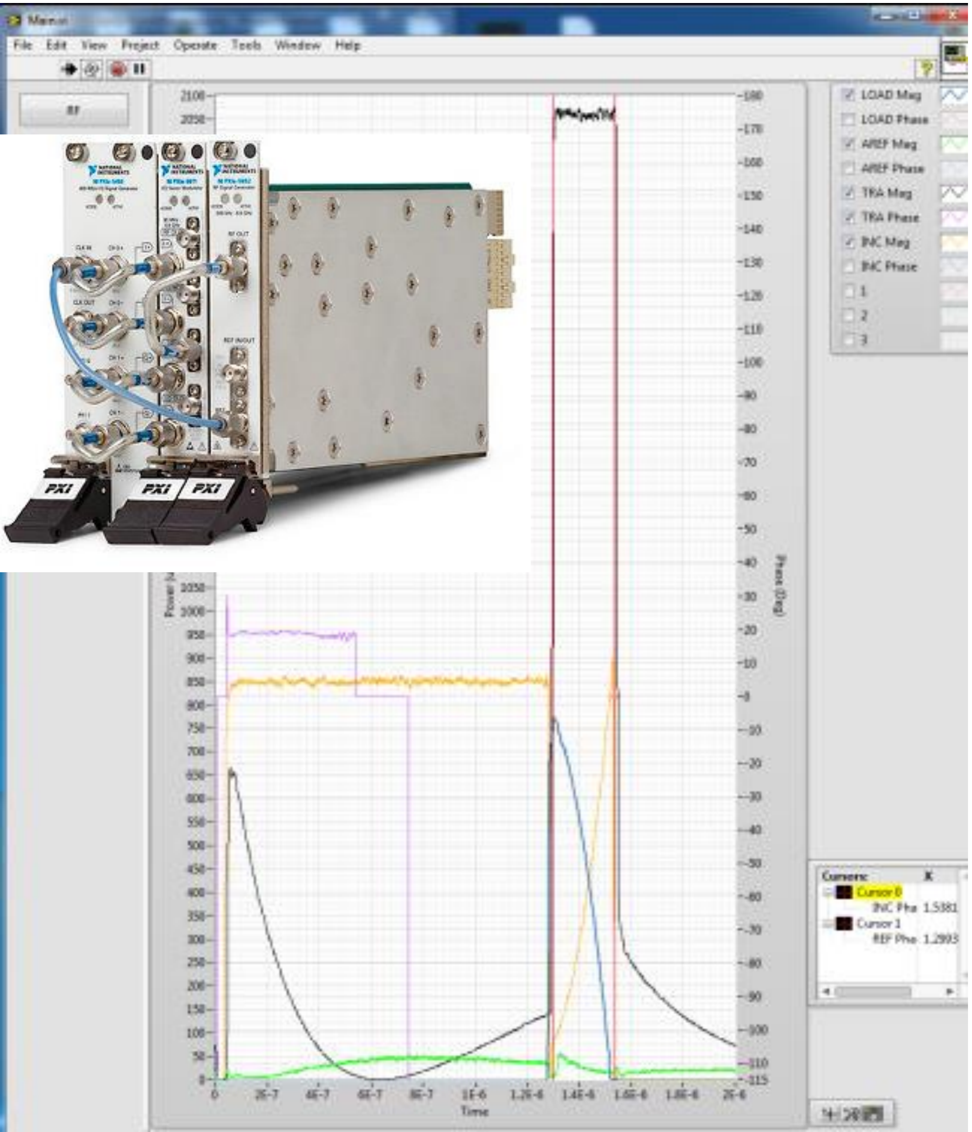
# WFM Characterisation with Beam @ PSI

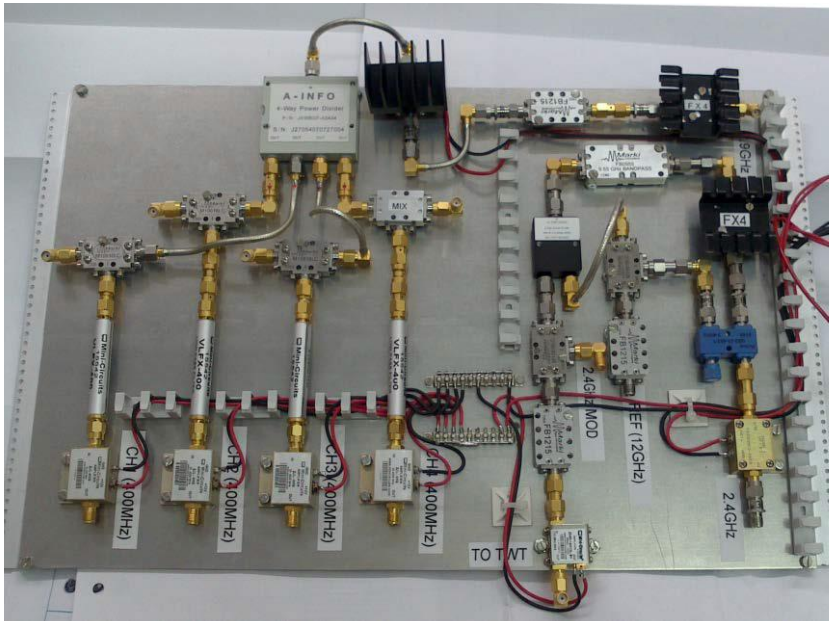
- Beam set to golden orbit.
- Structure moved (instead of beam) using the mechanical mover system to have clear picture of emittance dilution.
- Questions:
  - Leakage of klystron power into monitors.
  - Wide bandwidth response.
  - Any longitudinal bands visible (as indication of internal tolerances)?
  - Compare emittance dilution to optimum WFM alignment.



**MS74 Design Concept for RF Front End, M Dehler (PSI)**

# Crab Cavity Synchronisation on @ Lancaster Univ

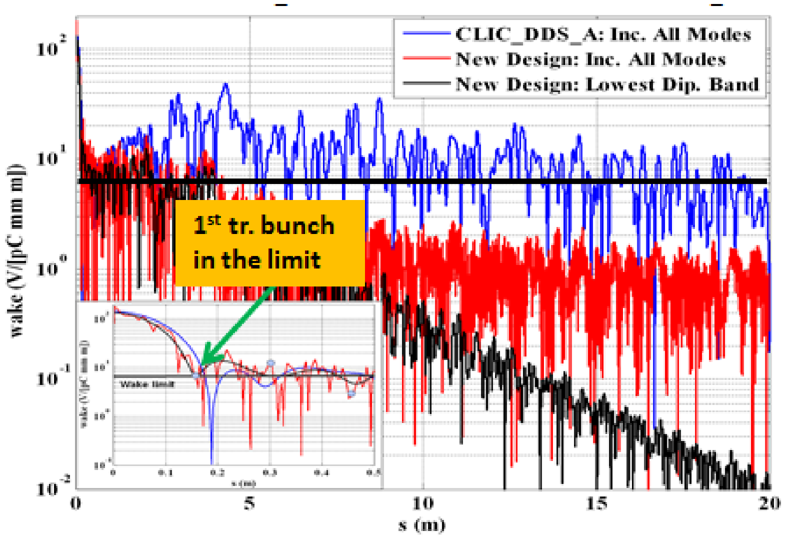


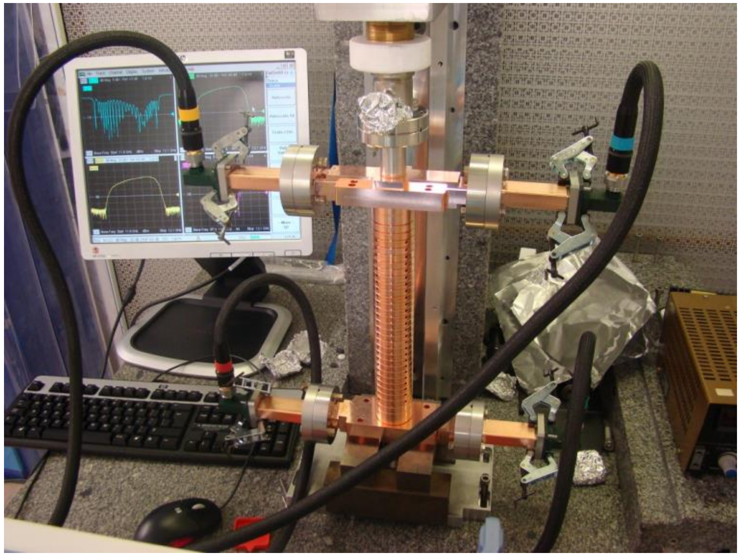


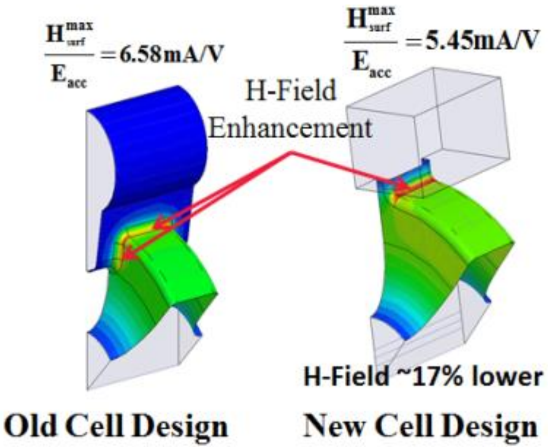
Developments include:

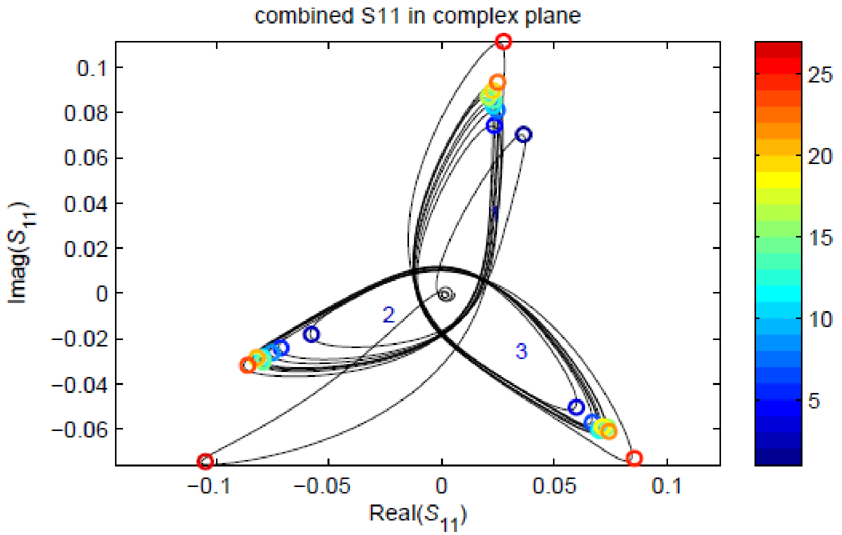
- FPGA demodulation; potentially give a spare channel (4ch+1ref → 5ch + internal ref).
- Phase feedback control to keep the pulse compressor’s output pulse flat during temperature fluctuations (±1°C tested stable on XBOX2 @ CERN).

# DDS Cavity Tuning @ Manchester Univ









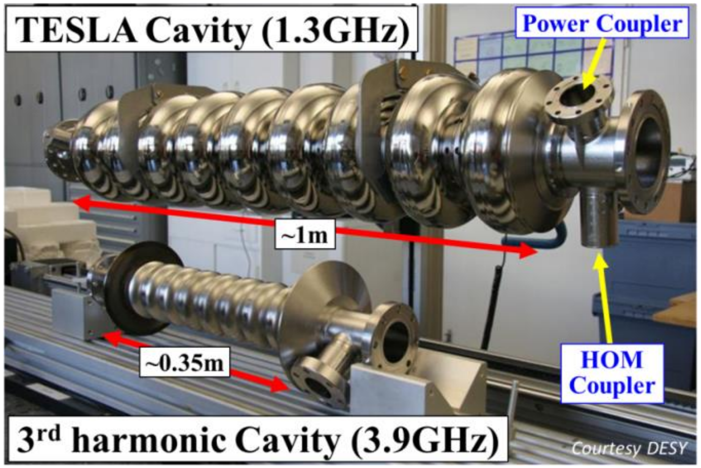
Cavity to be tested at CERN in late 2014.

# 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.



Courtesy DESY

**Task 12.4 Coordinator: Roger Jones (Manchester Univ)**

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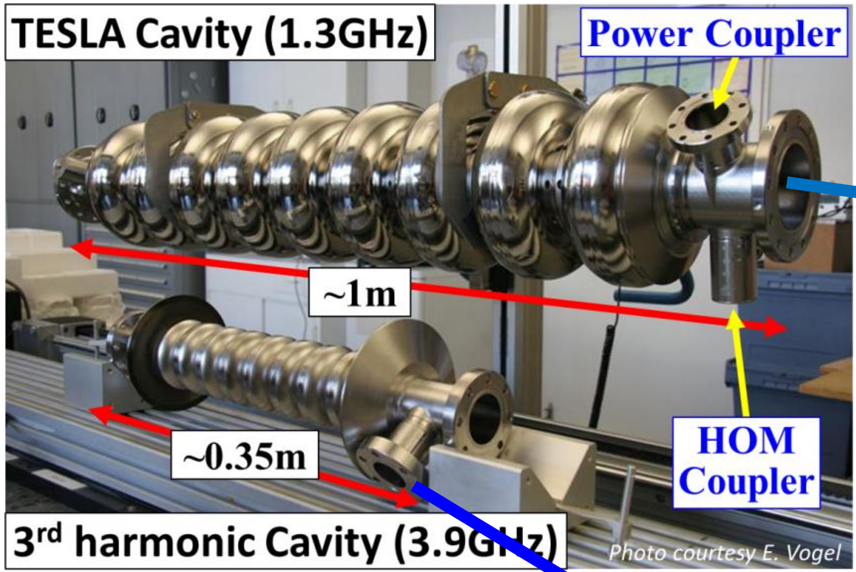
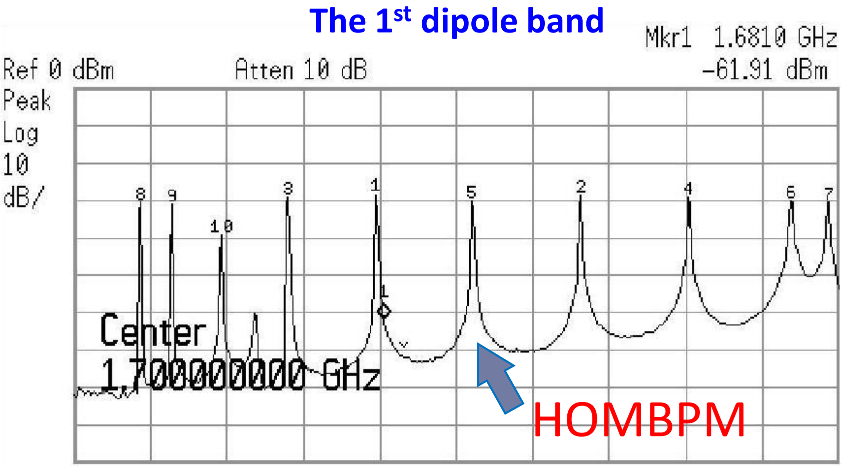
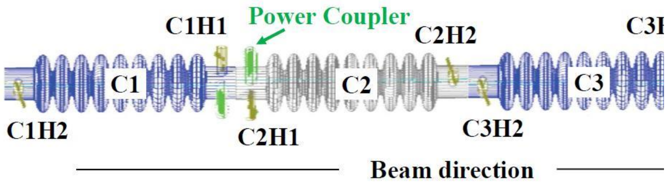
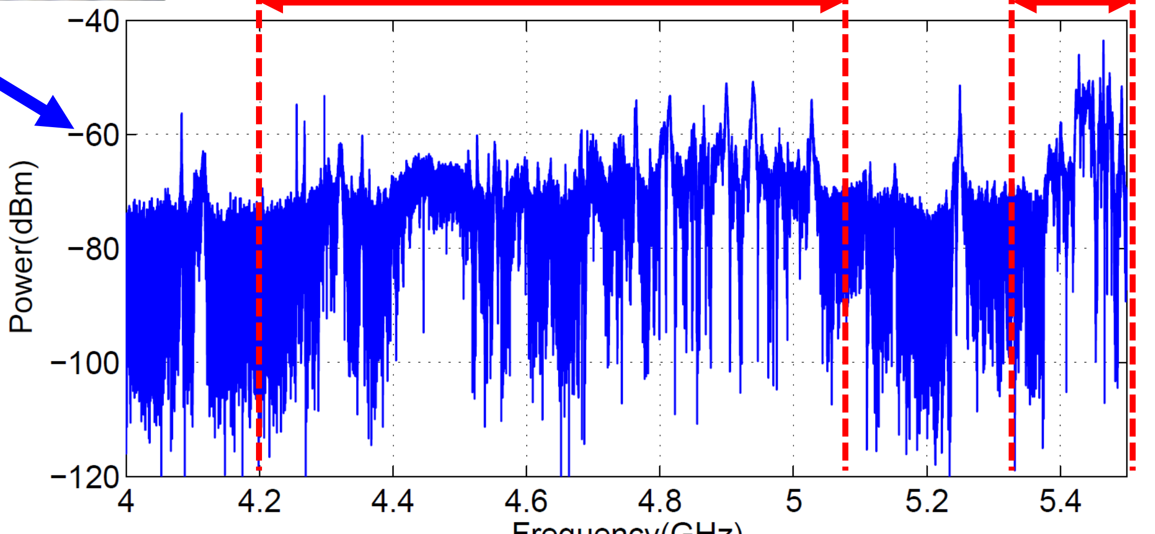
# FLASH HOM Characterisation @ DESY



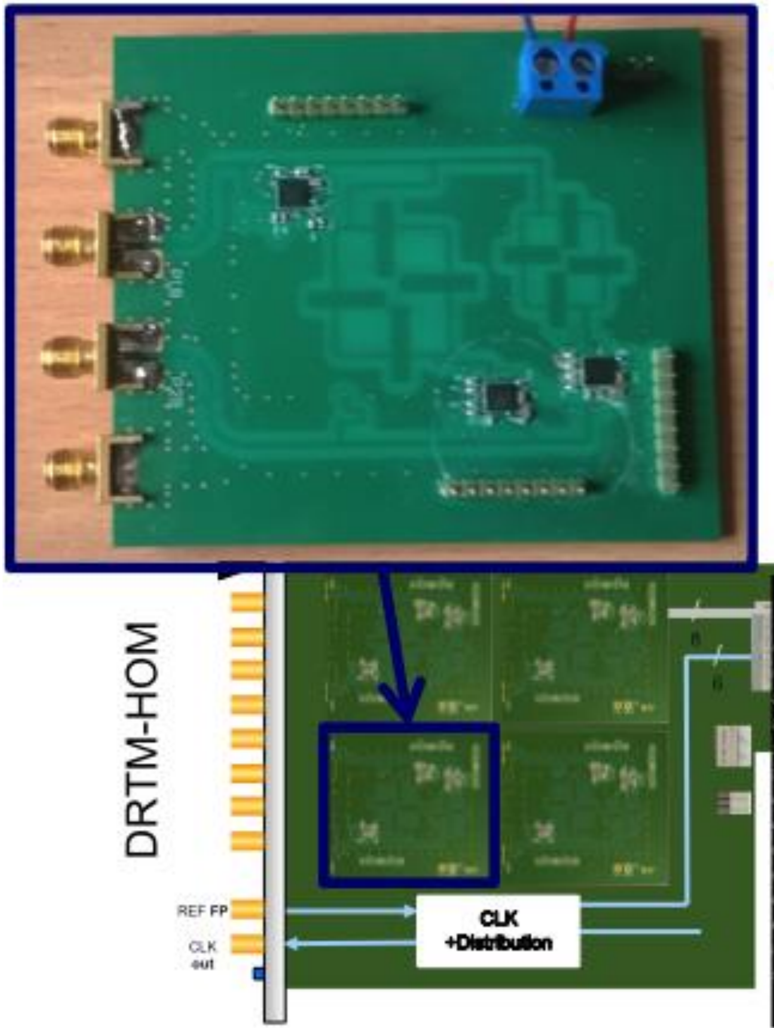


Coupled cavities

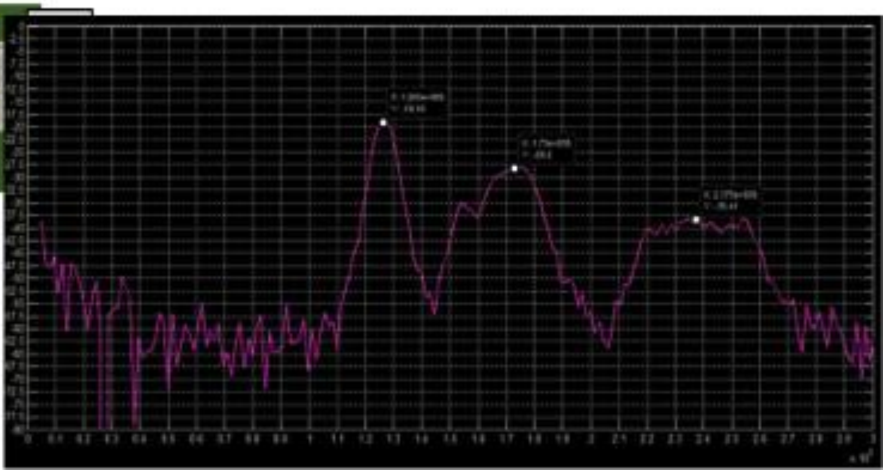




# 1.3 GHz Upgraded XFEL Electronics @ DESY



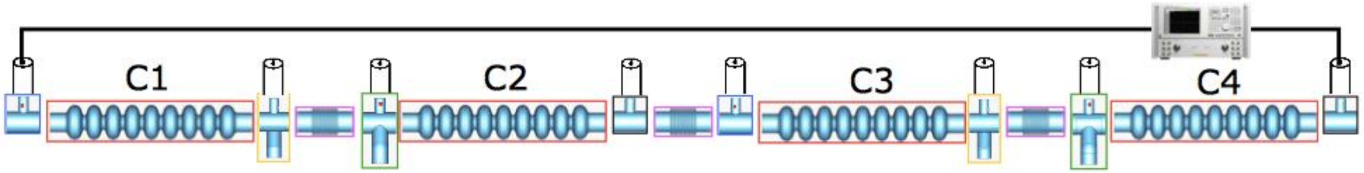
- Filter test board
  - two filters, one on each side
  - each for 3 frequencies (1.3/1.7/2.4)
- Example measurement
  - Attenuation settings: -8dB @1.3 GHz, -16db @ 1.7 GHz, -24dB @dB
  - The filter should be tuned and then implemented in an 8 channel RTM

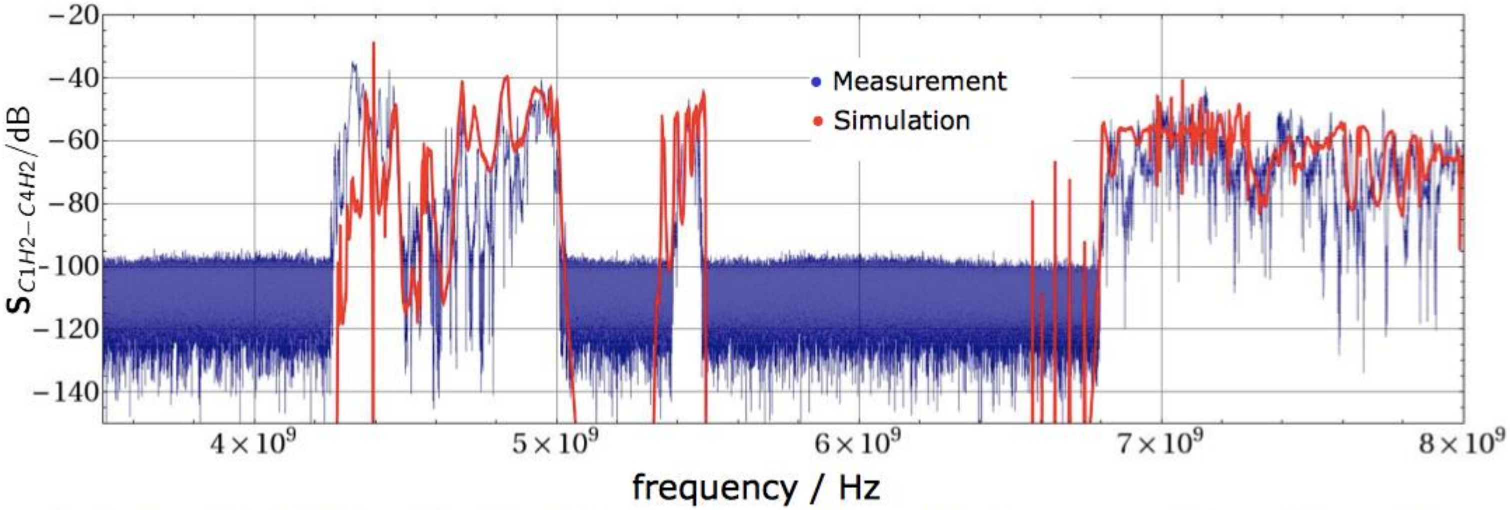


**Highlight Talk: HOM Based Beam Diagnostics: From FLASH to XFEL, Nicoleta Baboi (DESY)**

# 3.9 GHz HOM Analysis @ Rostock Univ

- Using concatenation transmission techniques to simulate complete FLASH module ACC39 is possible to:
  - Accurately compute cavity section.
  - Concatenate for complete module – significantly reduces CPU overhead.





T. Flisgen, H.-W. Glock, P. Zhang, I. R. R. Shinton, N. Baboi, R. M. Jones, and U. van Rienen: "Scattering parameters of the 3.9 GHz accelerating module in a free-electron laser linac: A rigorous comparison between simulations and measurements", Phys. Rev. ST Accel. Beams, 17:022003, February 2014

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# Task 12.5 RF Photocathodes

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

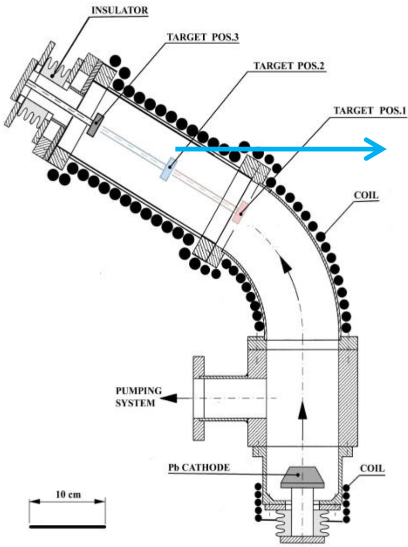
**Actions and institutions:**

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

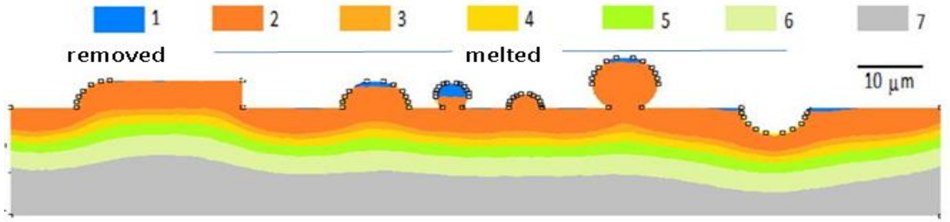
**Task 12.5 Coordinator: Robert Nietubyc (NCBJ)**

# Pb Photocathode Surface Preparation @ NCBJ

UHV arc Pb deposition with $30^0$ angular filter, extended plasma duct and movable, negatively biased target. Optimization of target position has been performed to reach a flat layer at sufficient deposition rate.



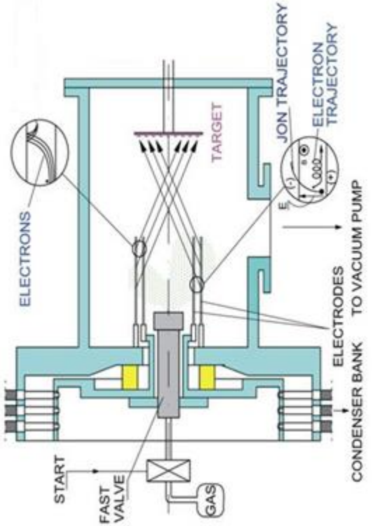
Deposition time 800 s
5 particles/$\text{mm}^{2,}$
10 μm < droplet size < 20 μm

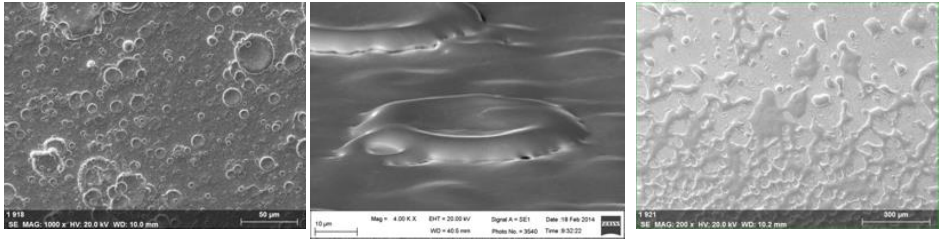


Heat transfer evaluation:

- single 3 J/cm$^2$ pulse removes lead from droplets but not from the flat surface
- melts about 10 μm in depth

Rod Plasma Injector IBIS:
Remelting and flattening of extrusions on the surface of a Pb layer with low-fluency 1.5 J/cm$^2$ ion pulses is effective only for extrusion smaller than ≈ 20 μm

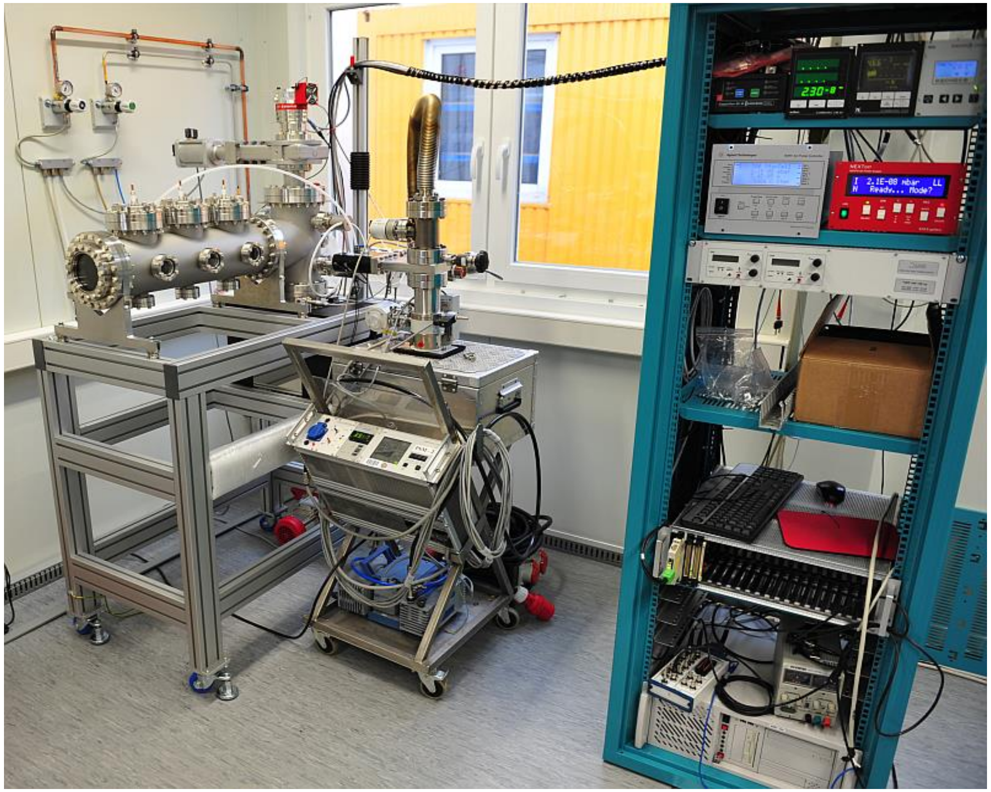




# Field Emission Setup @ HZB

## Emission measurements:

- $E = 10^7$ V/m achieved, eventually planned $2.5 \times 10^7$ V/m, $p = 10^{-10}$ mbar.
- Integral current emitted from the samples by Keithley 6514
- Emitter distribution over the surface by CCD with a resolution of about 4 µm achieved.

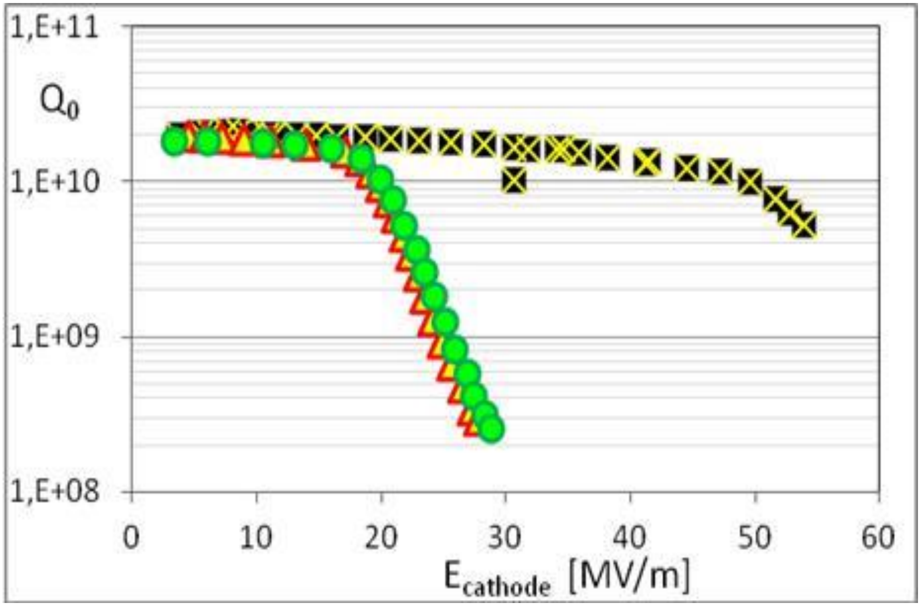


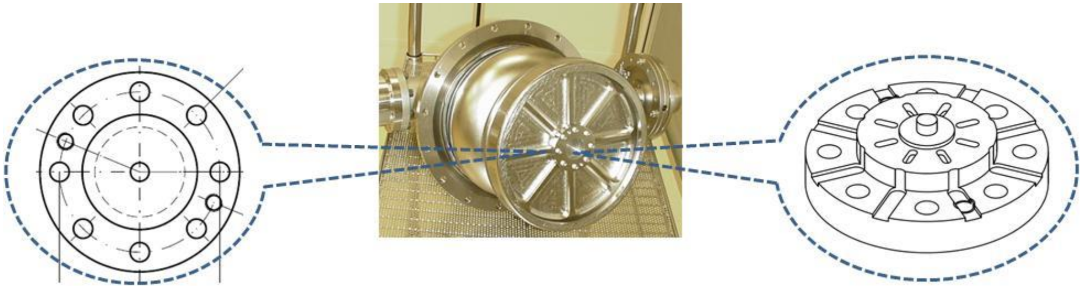
## Mo substrates measurements:

- No field emission was observed at a field gradient of 10 MV/m.
- The next step will be further commissioning of the system with DFEA cathodes, multi-alkali photocathode substrates and increasing the gradient up to 20 MV/m and test with photocathode substrates.

# E-Gun and PC Plug Optimisation @ DESY/HZDR/NCBJ

- A 1.6-cell gun has been designed & fabricated (EUCARD).
- Two baseline tests were performed with cathode made of pure Nb. The results (yellow triangles and green circles on the chart) are not as good as results obtained previously in JLab (black squares on the chart).
- The main reason of the difference is insufficient cooling of the plug during present measurements.
- The modified plug with additional channels and holes for better helium circulation is in fabrication.



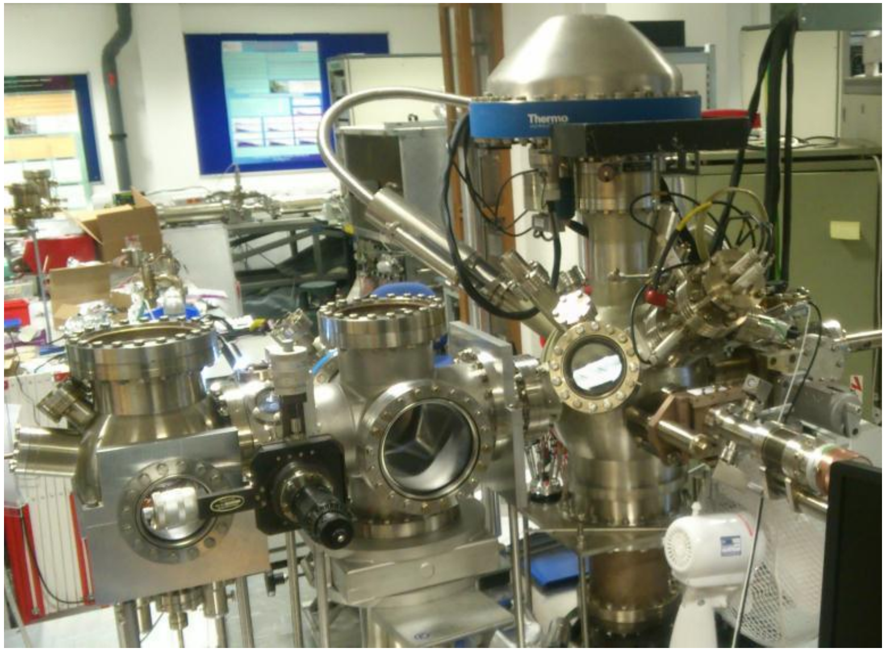


Present plug without cooling channels

Modified plug with cooling channels

# Metal Photocathode Research @ STFC

- A multi-chamber UHV system has been constructed and equipped with:
  - Electron energy analyser and X-ray gun provide (XPS) capability, used to evaluate both composition and chemical state of material species at the PC surface.
  - Atomic force microscopy (AFM) to provide detailed topographical information (surface roughness).
  - Low Energy Electron Diffraction (LEED) for characterising the surface order in single crystal samples.
- In addition, on a separate chamber:
  - QE measurements
  - Kelvin probe work function measurements



**MS73 Commissioning of the SAPI for Operation with Metal Photocathodes, T Noakes (STFC)**

# WP12 Conclusions

Technical Achievements:

- Task 12.2 SRF Thin Films
  - First multi-layer deposition results look extremely promising.
  - High-Q, low-field performance demonstrated with HIPIMS.
  - Quadrupole resonator designed, fabricated and undergoing tests.
- Task 12.3 High Gradient NC
  - DDS X-band structure fabricated, tuned and awaiting HP tests.
  - First high-resolution, WFM electronics designed and qualified. (**MS74**)
  - CLIC crab cavity synchronisation system implemented and undergoing tests @ XBOX2.
- Task 12.4 SRF HOM Diagnostics
  - 1.3 GHz HOM BPM and Phase Monitor electronics designed, fabricated and awaiting beam tests on FLASH.
- Task 12.5 RF Photocathodes
  - Polished Nb plugs prepared by HZDR and Pb coated by NCBJ.
  - ‘Bare’ Plug tests performed at DESY – awaiting coated plug implementation and tests.

New Infrastructures Implemented:

- Task 12.2 SRF Thin Films
  - New ALD infrastructure implemented at INP-Grenoble – well ahead of schedule!
- Task 12.5 RF Photocathodes
  - New field emission laboratory installed @ HZB.
  - New SAPI analysis infrastructure implemented at STFC Daresbsury Laboratory. (**MS73**)
  - New arc/plasma deposition/preparation system implemented at NCBJ.

# Thank You

The WP12 Innovative RF Team

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