



# **RF**

# **R&D Perspectives in EUCARD-2**

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- This JRA focuses on the development of a range of technical solutions that has the potential to achieve **significant performance increases** in **gradient**, **efficiency** and **beam quality** of RF-based accelerator systems.
- Several novel techniques in the field of normal and superconducting RF technology have been selected, presenting the **highest impact potential** and with the additional benefit of profiting from exchanges and communication between these two distinct communities.
- Main R&D areas encompass:
  - **SRF Thin Films** – C Antoine (CEA Saclay);
  - **High Gradient NC Cavities** – W Wuensch (CERN)
  - **SRF HOM Beam Diagnostics** – R Jones (Manchester University)
  - **RF Photocathodes** – R Nietubyc (NCBJ)

**Big Wins!**

Reducing the footprint, machine energy consumption and overall cost of linear accelerators are of primary importance for all accelerators being developed today.

# EuCARD<sup>2</sup> WP12 Collaborative Team

## RF Photocathodes



HZDR

HELMHOLTZ  
ZENTRUM DRESDEN  
ROSSENDORF

HZB  
Helmholtz  
Zentrum Berlin



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## SRF Thin Films



HZB  
Helmholtz  
Zentrum Berlin



## High Gradient NC



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PSI



MANCHESTER  
1824  
The University  
of Manchester



Science & Technology  
Facilities Council

## SRF HOM Beam Diagnostic



Universität  
Rostock



MANCHESTER  
1824  
The University  
of Manchester

The logo for EuCARD² features a stylized blue and red swoosh with a yellow star above the '2'.

# EuCARD<sup>2</sup> Fundamental Objectives

## 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**.

## SRF Thin Films

Exploitation of new superconducting materials, such as Nb<sub>3</sub>Sn 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**.

## High Gradient NC Cavities

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

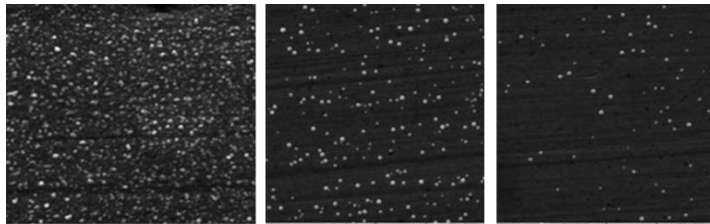
## SRF HOM Beam Diagnostics

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 improving **beam quality** and **stability**.

## Pb surface processing optimisation to reduce a dark current and improve QE

### Pb layer treatment with **EUV radiation**:

- $\lambda = 10 - 70 \text{ nm}$ , 5 ns pulses, rep. 10 Hz
- energy density/pulse  $\approx 30 \text{ mJ/cm}^2$
- penetration depth  $\approx 15 \text{ nm}$



as deposited

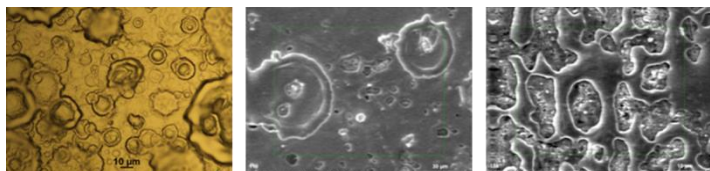
10 pulses

40 pulses

Micro-droplets  
removal

### Pb layer treatment with **pulsed ion beams** from IBIS Rod Plasma Injector:

- Pb/Nb films of thickness  $1 - 20 \mu\text{m}$
- treated with  $1 \mu\text{s}$  Ar ion pulses of  $1 - 6 \text{ J/cm}^2$



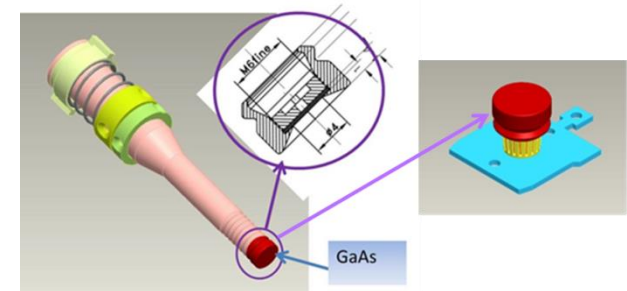
as deposited

2 pulses of  $1.5 \text{ J/cm}^2$

after next pulses of  $1.5 \text{ J/cm}^2$ ;

Melting and recrystallization

### Utilisation of standard photocathode/plug.



Standard *ex-situ* structural and morphological studies with SEM, XRF and XRD

Integrated stand for heat treatment, EUV irradiation and *in-situ* XRF-base purity and thickness diagnostics, QE and DC measurements

Measurements of resonance quality vs  $E_{\text{acc}}$  for electron gun with pure and Pb-coated plug.

Pb/Nb photocathode tests in HZDR SRF gun:

- QE, lifetime, FE, DC and thermal emittance

Generation of high average currents (>100 mA) well above what is currently achievable with high QE multi-alkali photocathodes (*Smedley et al BNL*).

**DAC is a very promising solution!**

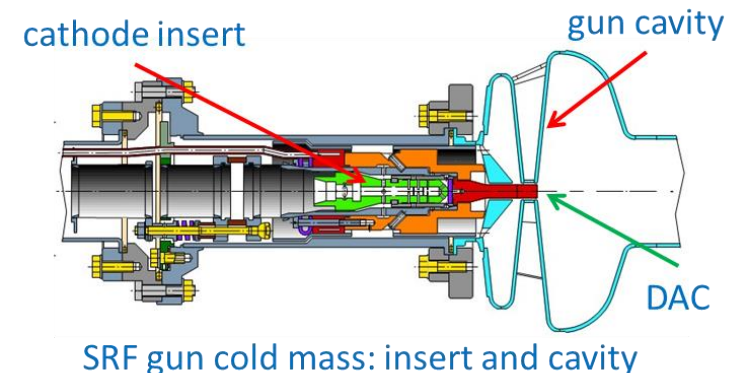
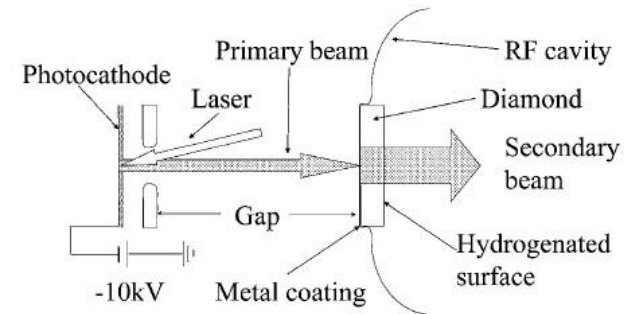
Steps towards DAC at SRF gun:

- Physics and engineering design of a suitable cathode cell which contains the DAC.
- Laboratory tests of beam properties.
- Qualification of DAC in SRF gun at ELBE/HZDR and BERLinPro/HZB

Challenges:

- Operation of DAC inside an SRF gun
- Beam properties (thermal emittance, response time)
- Field emission

Beam Current	Laser	Cathode
Low to medium	UV	Cs <sub>2</sub> Te Pb/Nb
High	green	CsK <sub>2</sub> Sb
Extremely high	green	DAC



# EuCARD<sup>2</sup> Metal Photocathodes

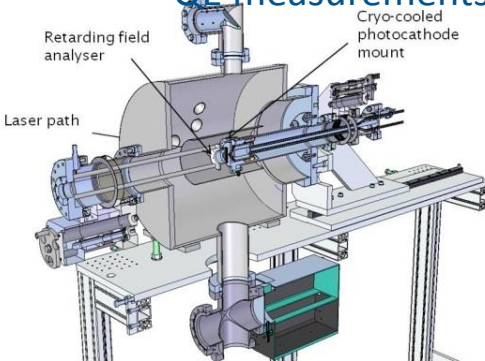
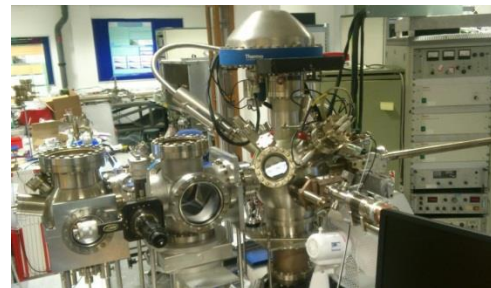
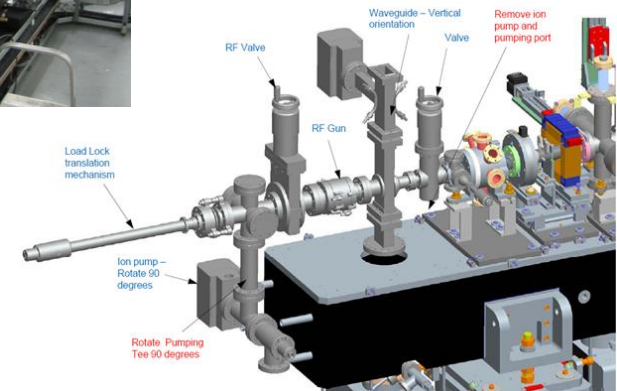
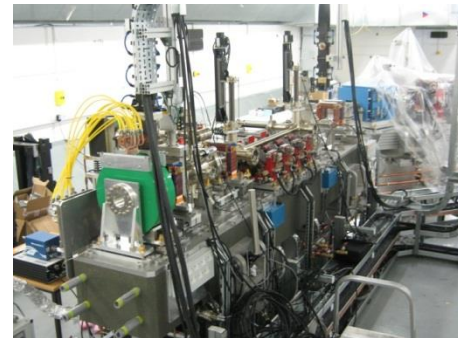
- Metal PC materials (e.g. Ag, Cu, Mg, Nb, Pb, Zr) characterisation and evaluate surface preparation procedures.
- Cathode transfer system to allow rapid evaluation of candidate materials and procedures in the VELA test facility.

- **ESCALABII and Multi-probe surface analysis:**

- Compositional and chemical analysis
- Surface roughness evaluation
- Work function measurement
- Quantum efficiency measurements

- **Transverse Energy Spread Spectrometer (TESS) for:**

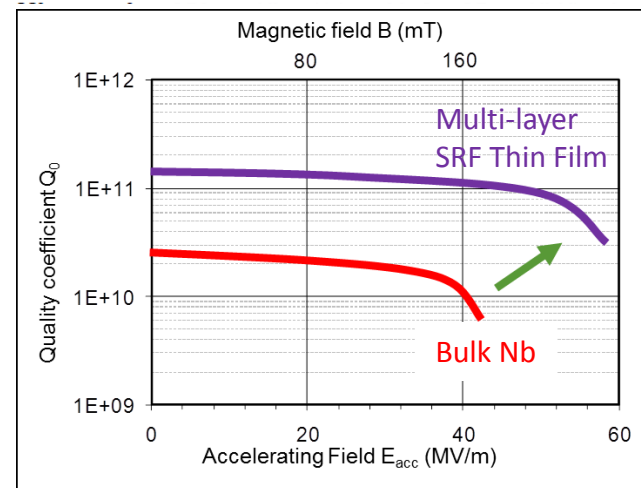
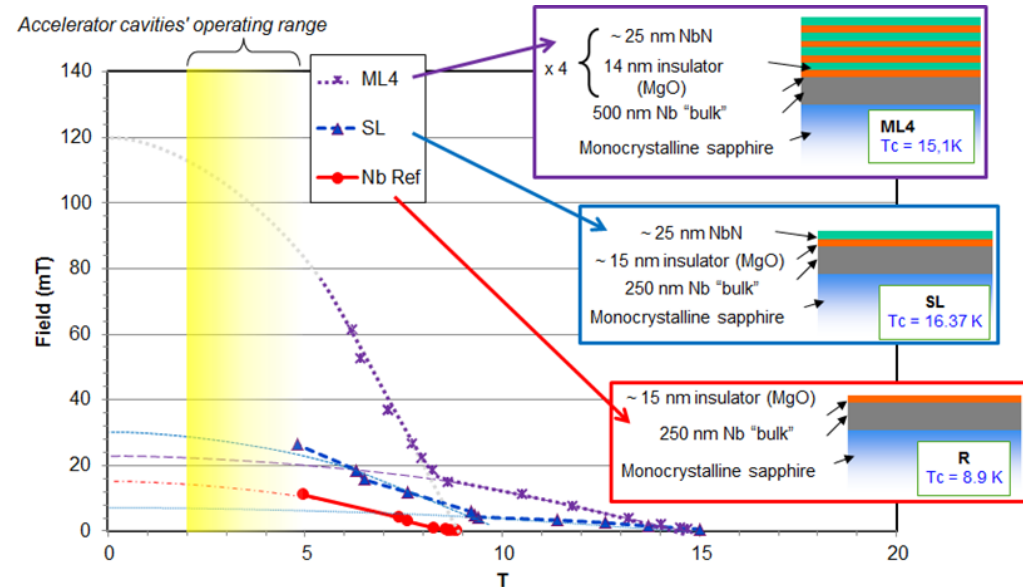
- Transverse emittance measurements
- QE measurements



- Improve cathode QE and reduce emittance, providing high brightness beams for future FEL applications.

- **Niobium on copper ( $\mu\text{m}$ ):**
  - After  $\sim 20$  years stagnation
  - New revolutionary deposition techniques developed:
    - HIPIMS, CVD, ALD
  - Great expectations in cost reduction
  - Improved performances c.f. bulk Nb
- **Higher  $T_c$  material ( $\mu\text{m}$ ):**
  - Based on superheating model.
  - Higher field and  $Q_0$  expected
- **Higher  $T_c$  material (nm), multilayer:**
  - Trapped vortex model (Gurevich)
  - Higher field and  $Q_0$  expected
  - $\sim 200 \times H_{c1}$  predicted
- **Specific characterization tools needed.**
- **Better understanding of SRF physics needed.**

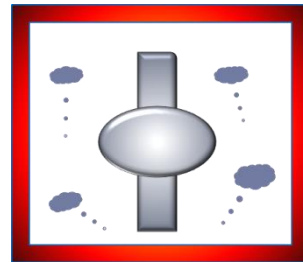
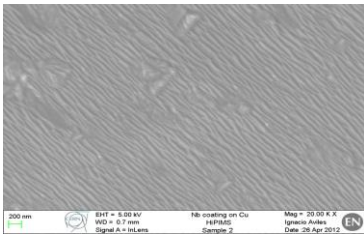
See C. Antoine (CEA) talk this afternoon



**Fundamental Goal!**

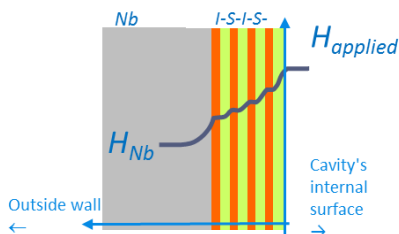
## CERN:

- **HIPIMS:** Energetic deposition => better film microstructure (bulk-like, high RRR)
- **Nb<sub>3</sub>Sn:** Development of a thermal deposition set up.



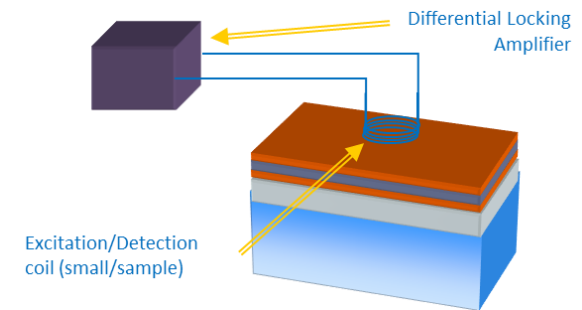
## INP Grenoble:

- Superconducting heterostructure deposition – CVD & ALD techniques.
- ALD utilised to develop multilayer NbN/insulator/NbN coatings.



## CEA Saclay:

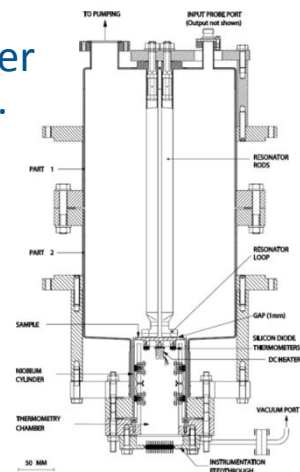
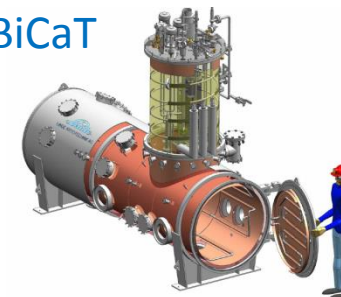
- Optimisation of multi-layers.
- Thin layers ( $d \sim \lambda$ ) have higher  $H_{C1}$
- Measure  $H_{C1}$  using magnetometry.



## HZB-Berlin:

- Build an optimised RF testing resonator.
- $R_s$  vs  $B$  characterisation.
- Investigate samples under external magnetic fields.

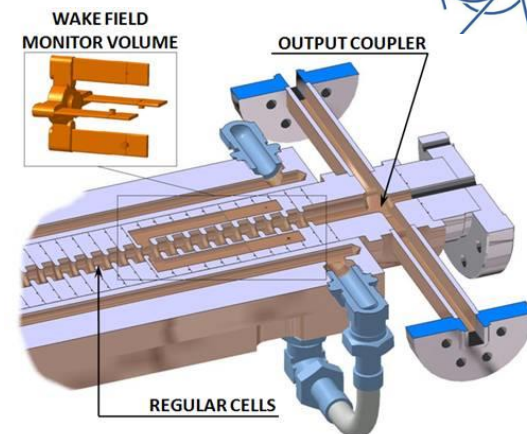
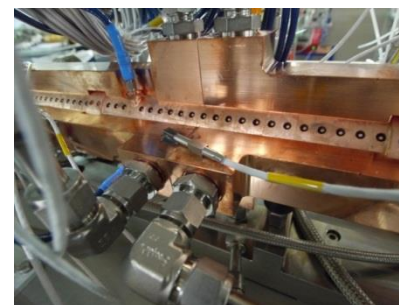
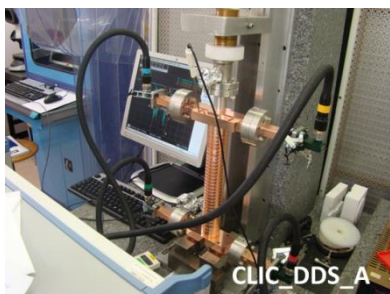
## HoBiCaT



# EuCARD<sup>2</sup> Wakefield Management

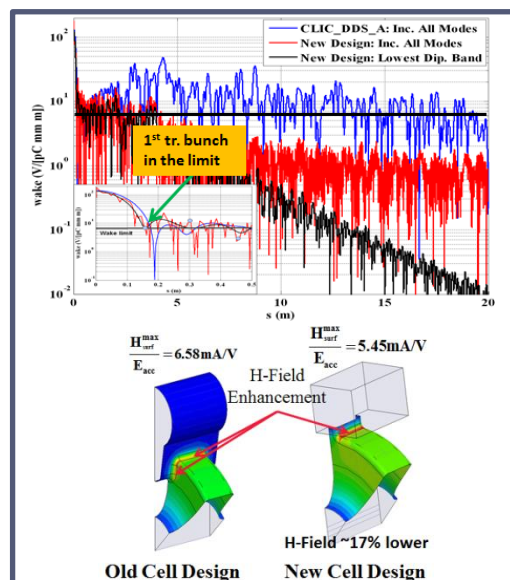
## CLIC Damped Detuned Structure (DDS) wakefield suppression:

- Strong detuning to provide moderate damping.
- Incorporation of damping manifolds, interleaving neighbouring cell modes.
- Assess perturbation sources (frequency errors, misalignment...) by means of combined RF (GdfidL) and beam dynamics (PLACET) simulations.
- Fabricate and test a prototype damped DDS structure.

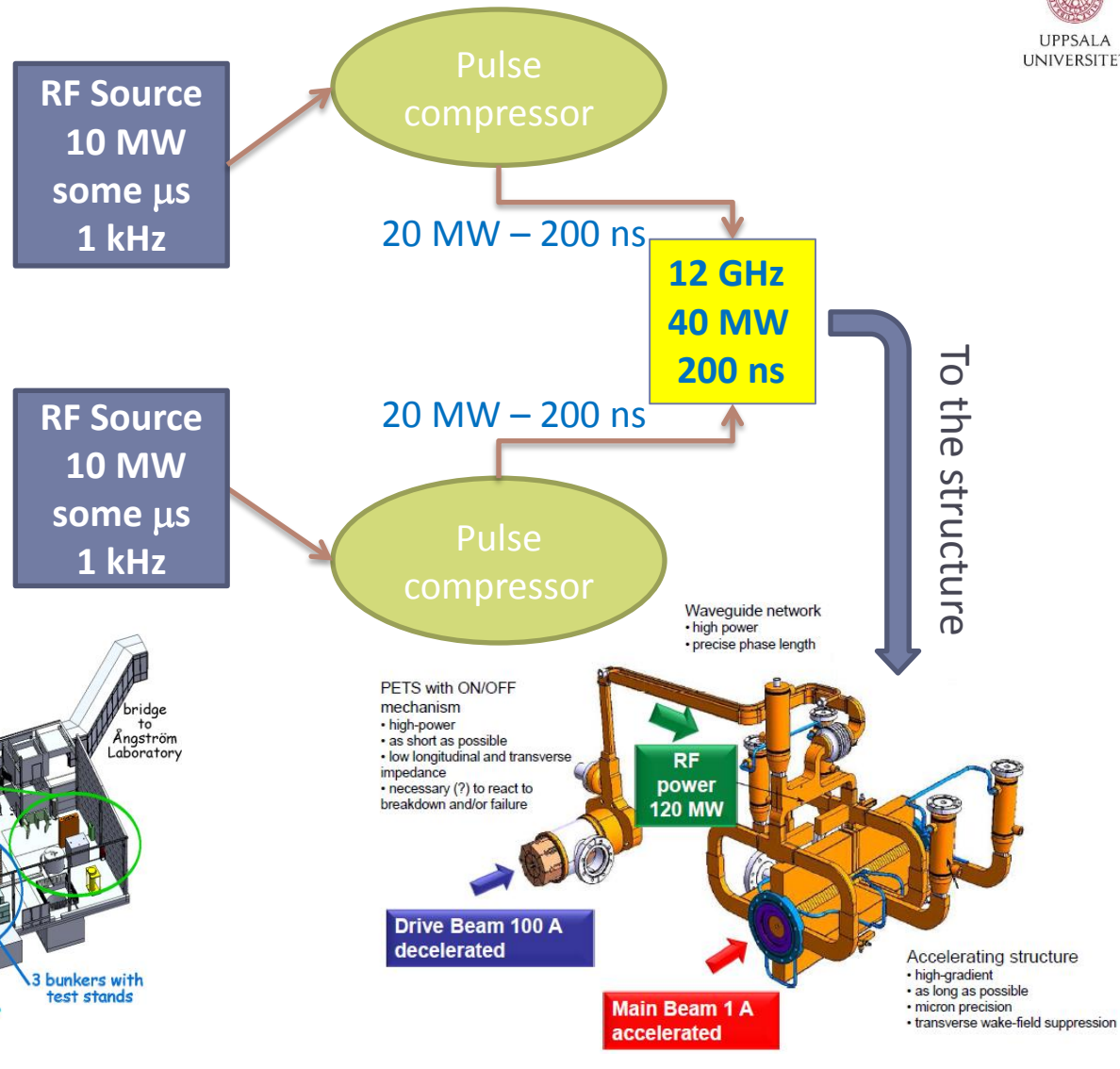


## Wakefield Monitor:

- Develop wide-band (2 GHz) front-end electronics for CLIC and SwissFEL.
- Optimize signal/noise to reach theoretical  $\mu\text{m}$ -scale resolution.
- Allow for spectral analysis to extract information about higher order misalignments (pitch, roll, bend), whilst also giving simple 'operator' signal.
- Evaluating classical RF style option versus Electro-Optical approach with promising properties with respect to radiation damage, electromagnetic interference and bandwidth.



- Develop **affordable** and **reliable** technical design for **RF testing** of CLIC X-band accelerating structures:
  - Modest power klystron used in 'cluster' configuration.
  - Pulse compressor optimisation.
  - Prototype and testing of sub-components.





# EuCARD<sup>2</sup> CLIC Crab Cavity System

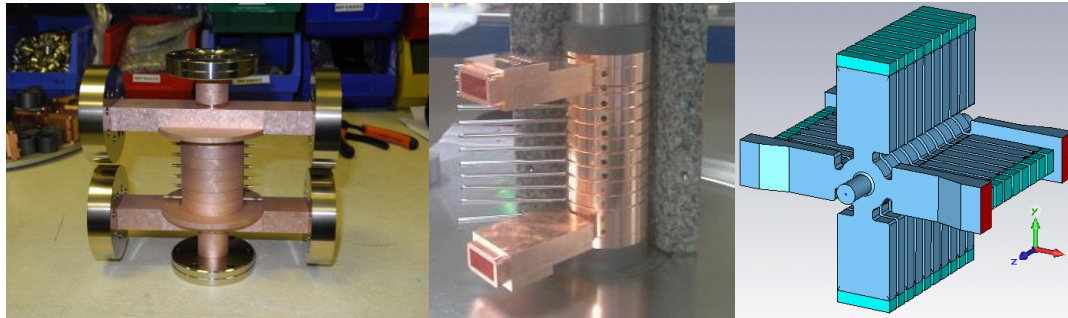


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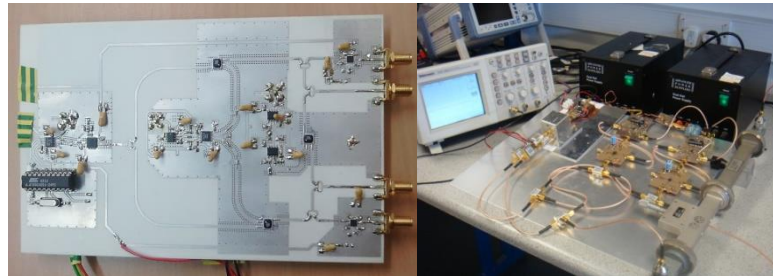
LANCASTER  
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To complete the design, evaluation and high gradient testing of a CLIC crab cavity.  
Complete the testing of the cavities developed pre-EUCARD2 and the development of a new 'fully-damped' cavity solution.



To understand and measure long-term phase stability in high power RF distribution and use this to develop an appropriate distribution scheme for the CLIC crab cavity system.

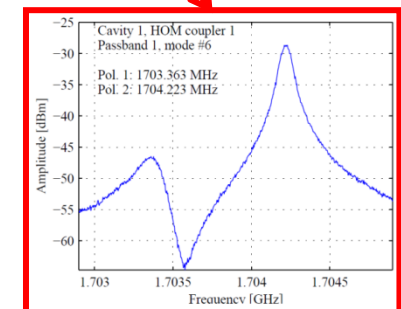
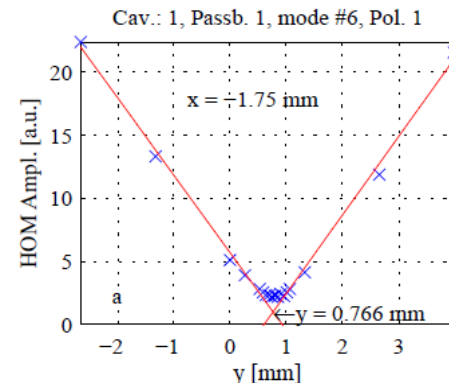
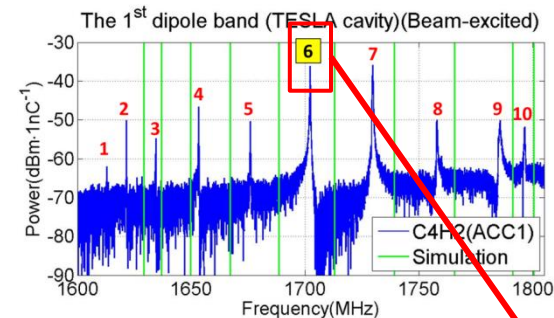
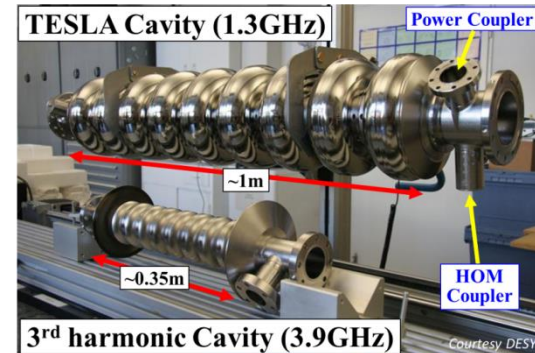


## HOM-based beam diagnostics for XFEL:

- Reduced emittance dilution from transverse wakefields.
- Direct, on-line measurement of beam phase wrt RF phase.
- Align beam on cavity axis.
- Measure beam position intrinsically.
- Measure cavity alignment within cryo-module.

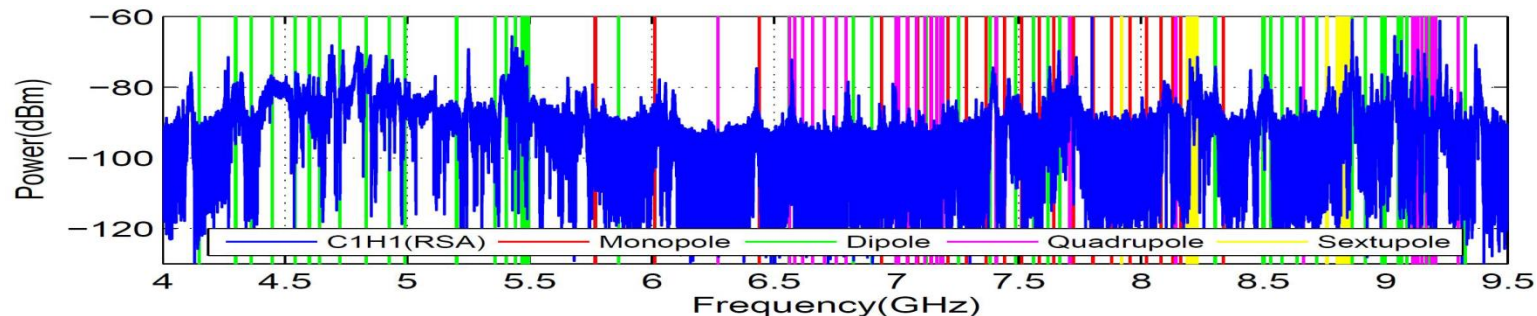
## HOMBPM-electronics built for 1.3 GHz cavities in FLASH (SLAC, DESY):

- Use 1 dipole mode at 1.7 GHz.
- Used as operator tool for beam alignment.
- Used for measurement of cavity alignment.
- Demonstrated use as BPM:
  - 10  $\mu\text{m}$  rms resolution.
- Difficulty:
  - Instability of calibration into BPM-signals (phase or frequency drifts?).



# 3.9 GHz System R&D

- HOMBPM-Electronics for 3.9 GHz cavities in FLASH (EuCARD):
  - Due to higher frequency and 4-cavity coupling, use bands of modes instead of single modes:
    - Coupling modes around 5.4 GHz for high resolution
    - Trapped modes around 9 GHz for localized measurement
    - ~20  $\mu\text{m}$  rms positional resolution achieved



- 3.9 GHz cavities in the European XFEL vs. FLASH:
  - **Significantly more challenging** (8 coupled cavities c.f. 4) and higher frequency (4.5 MHz beam repetition rate c.f. 1 MHz)
  - **Demands extensive theoretical and experimental studies**

The logo for EuCARD² features a stylized yellow star above the text "EuCARD²". The text is in a bold, blue, sans-serif font. To the left of the text is a graphic consisting of several overlapping, curved lines in shades of blue and grey, suggesting a particle path or a dynamic system.

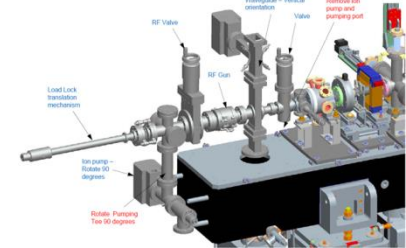
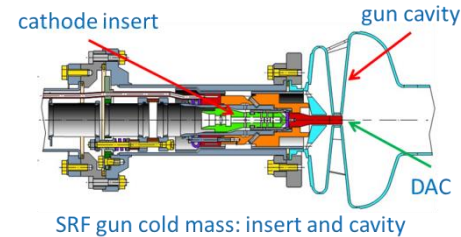
# EuCARD<sup>2</sup> Infrastructure Benefits

- **SRF Photocathodes:**
  - HZDR - ELBE
  - HZB - Hobicat – BerlinPro
  - VELA
- **SRF Thin Films:**
  - Materials analysis infrastructure at CEA, HZB and INPG
  - Sputtering facility at CERN
- **High Gradient NC:**
  - SwissFEL
  - CTF3
  - HP test benches at CERN, CEA and Uppsala Univ.
- **SRF HOM Diagnostics:**
  - FLASH and XFEL

# Conclusions: Pushing the Envelope

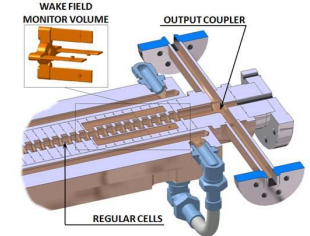
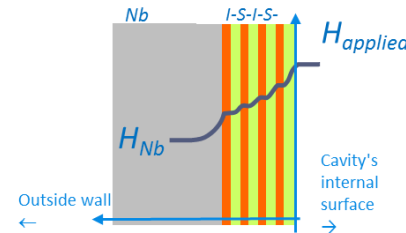
- Beam Generation:**

- New photocathodes providing demonstration of highest beam intensities and smallest beam emittances.



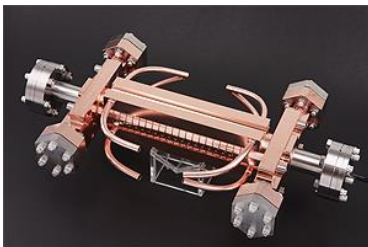
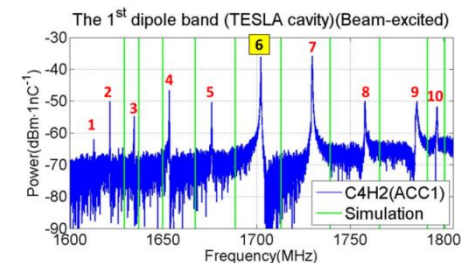
- Acceleration:**

- Demonstration of the highest level of acceleration performance.



- Beam Diagnostics/Control:**

- Demonstration of high performance and low cost beam position diagnostic.



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