EuCARD 2 CEA Saclay proposal

1) Superconducting nanolayers
2) CLIC 12 GHz accelerating structures
3) 704 MHz superconducting cavity, couplers and tuner (+IPN Orsay)

CERN - 21/04/2011

Irfu
cea
saclay

1)

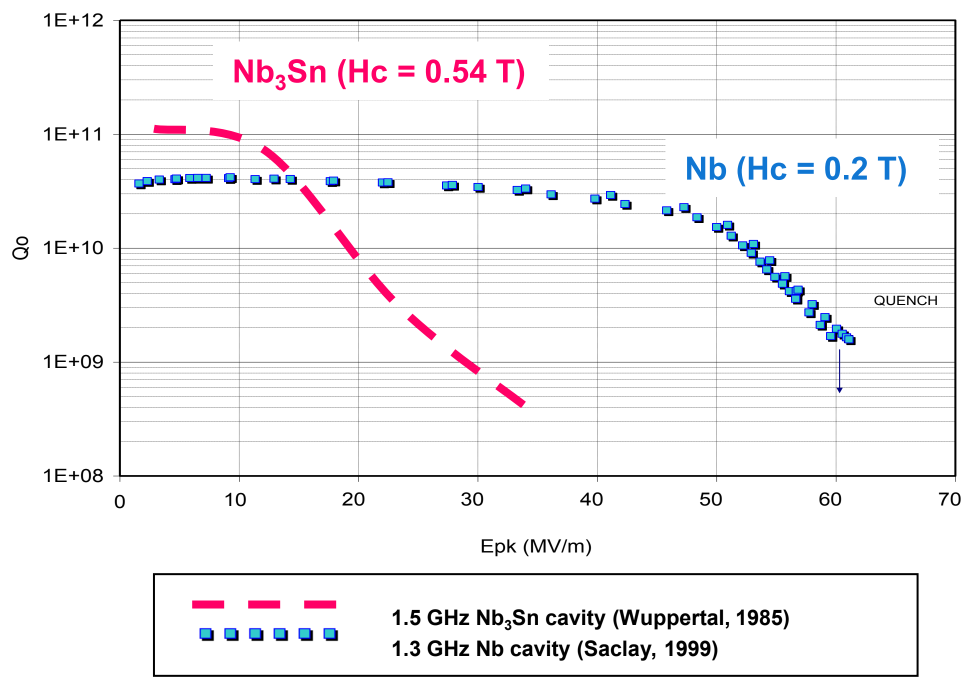
Superconducting Nano-layers : a new family of materials specially adapted to SRF performances

Limits in a RF cavity

Classical theory BCS + RF :

- Magnetic RF field limits E_{acc} : $E_{acc} \propto H^{RF}$
- Phase transition when magnetic H^{RF} ~> H_{SH} *(superheating field)*
- For Nb H_{SH} ~1,2.H_C *(thermodynamic)*
- Higher Tc => higher Hc => higher E_{acc}

But…

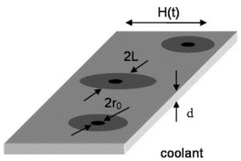


- **Bulk Nb_3Sn cavity : relative failure**
  - High Q_0 @ low field => low surface resistance => good quality material
  - Early Q slope !!!
- **Note :**
  - BCS valid only near T_C , clean limit
  - we work at 2 K + rather dirty limit.
- **BCS model needs to be completed**

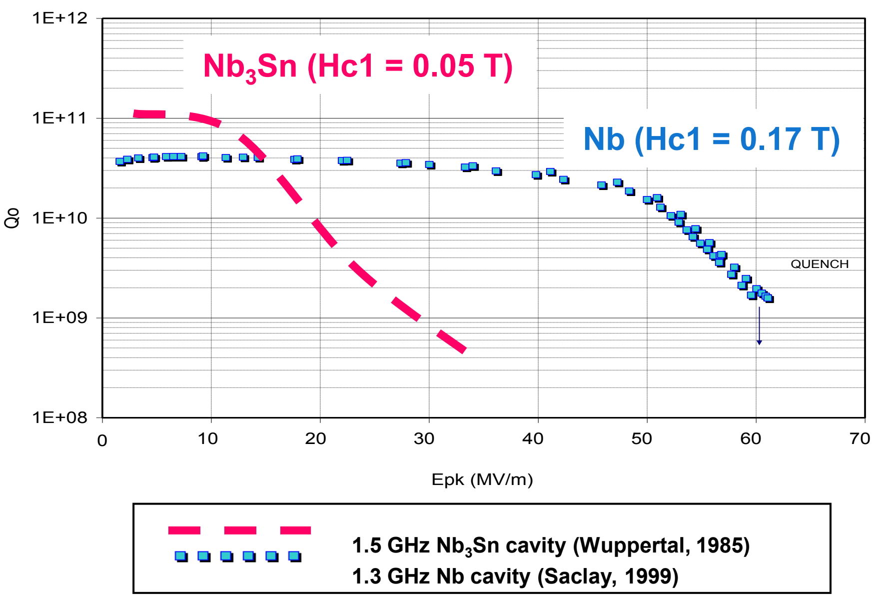
High field dissipations : due to vortices ?

Theoretical Work from Gurevich : temperature correction

Irfu
cea
saclay



- Non linear BCS resistance at high field : quadratic variation of R_{BCS}
- Vortices : normal area ~ some nm can cause “hot spots” ~ 1 cm *(comparable to what is observed on cavities)*
- At high field vortices => thermal dissipation @ vortices => Quench
- **Nb is the best for SRF because it has the highest H_{C1}**, *(prevents vortex penetration)*



- **Nb is close to its ultimate limits** (normal state transition)
- avoiding vortex penetration => keep below H_{C1}
- increasing the field => increase H_{C1}
- “invent” new superconductors with $H_{C1} > H_{C1}^{Nb}$

A. Gurevich, "Multiscale mechanisms of SRF breakdown". Physica C, 2006. 441(1-2): p. 38-43
A. Gurevich, "Enhancement of RF breakdown field of SC by multilayer coating". Appl. Phys.Lett., 2006. 88: p. 12511.
*P. Bauer, et al., "Evidence for non-linear BCS resistance in SRF cavities ". Physica C, 2006. **441**: p. 51–56*

Breaking Niobium monopoly

Overcoming niobium limits (A.Gurevich, 2006) :

- **Keep niobium but shield its surface from RF field to prevent vortex penetration**
- Use nanometric films (w. d < λ) of higher Tc SC :
  => H_{C1} enhancement
- Example :

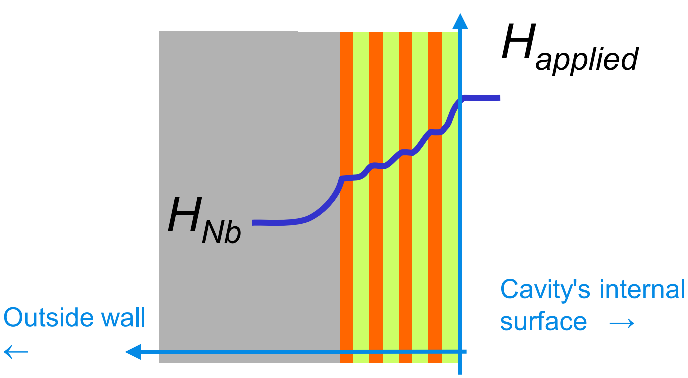
NbN , ξ = 5 nm, λ = 200 nm

Bulk => H_{C1} = **0,02 T**

20 nm film => H'_{C1} = **4,2 T**

x 200

(similar improvement with MgB_2 or Nb_3Sn)



$$H_{Nb} = H_{appl}\, e^{-\frac{Nd}{\lambda}}$$

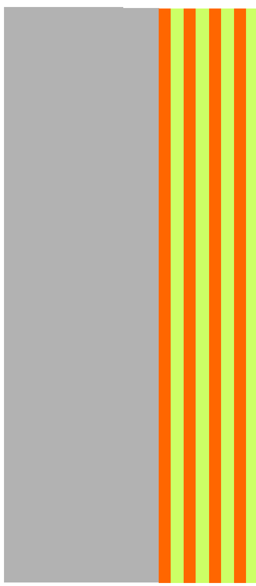
- high H_{C1} => no transition, no vortex in the layer
- applied field is damped by each layer
- insulating layer prevents Josephson coupling between layers
- applied field, i.e. accelerating field can be increased without **high field** dissipation
- thin film w. high Tc => low R_{BCS} at **low field** => higher Q_0

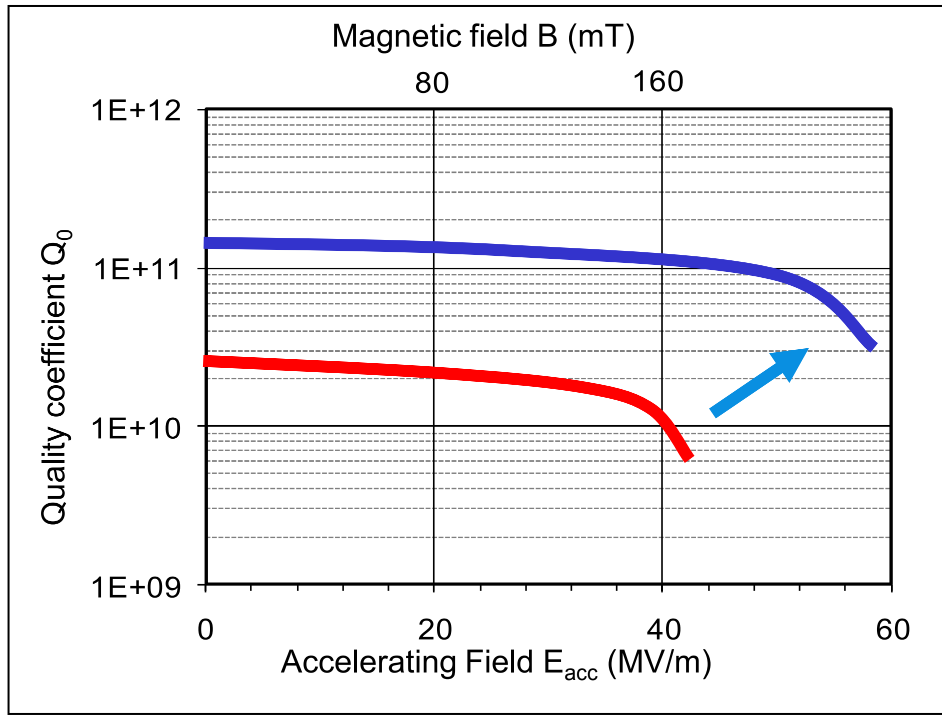
High Tc nanometric SC films : low R_S, high H_{C1}

Irfu cea saclay

- In summary : take a Nb cavity…
- deposit composite nanometric SC (multilayers) inside

Nb / i[illegible]/[illegible] / [illegible] / [illegible]…

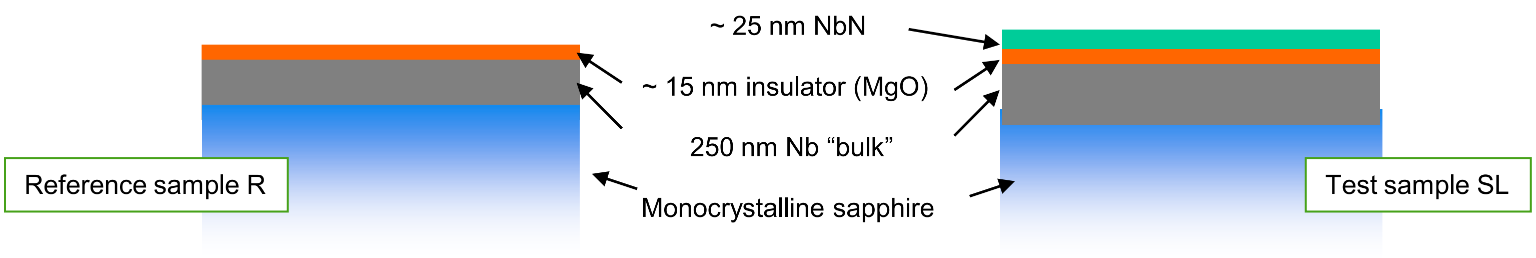


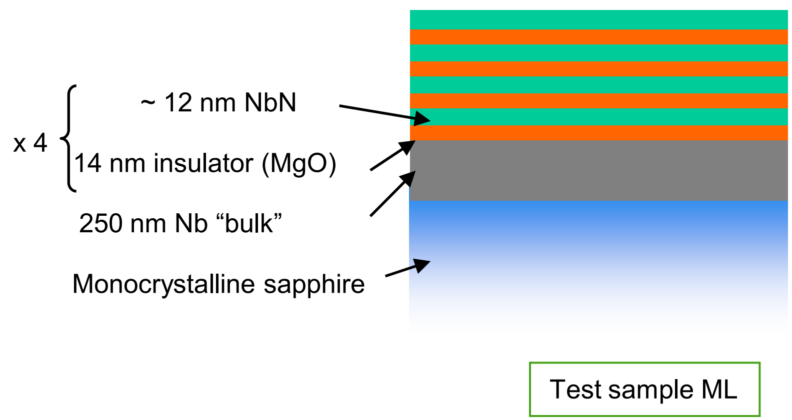


INCREASE E_{acc} AND Q_0 !!!

First exp. results on high quality model samples

- Choice of NbN:
  - ML structure = close to Josephson junction preparation (SC/insulator compatibility)
  - Use of asserted techniques for superconducting electronics circuits preparation:
    - Magnetron sputtering
    - Flat monocrystalline substrates

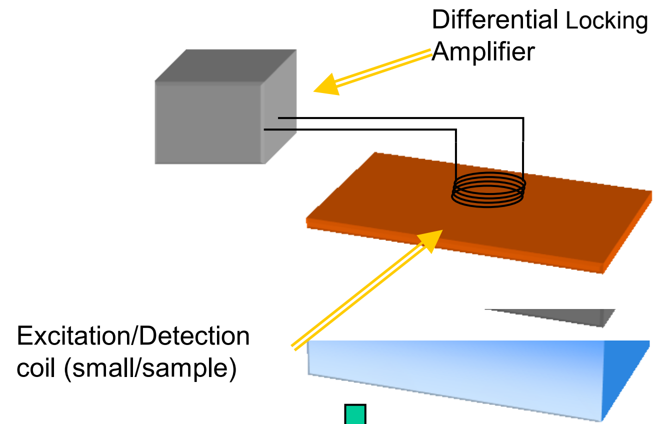


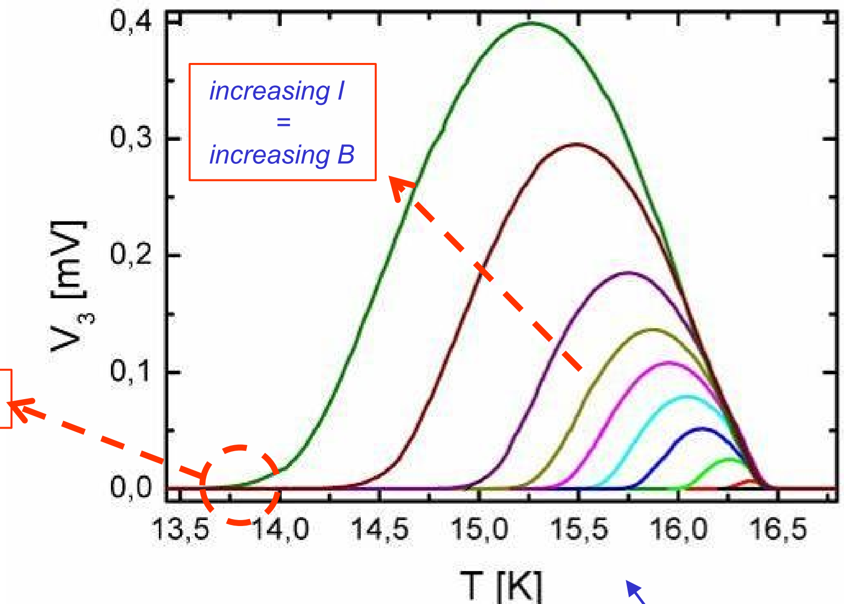


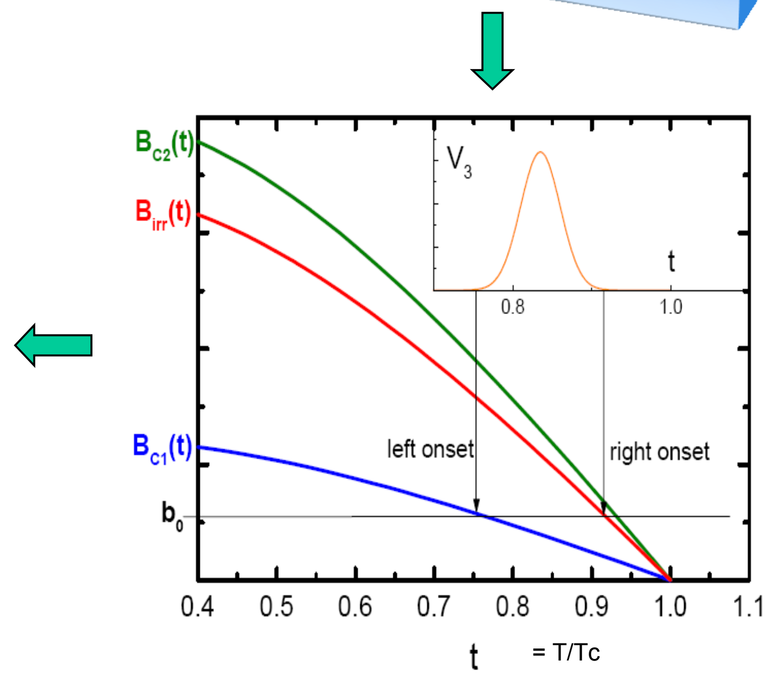
Collaboration with J.C. Villégier, CEA-Inac / Grenoble

Local magnetometry (1)

- 3^{rd} harmonic measurement, collaboration INFM Napoli
  - local measurement :
    sample size >> excitation/measuring coil
  - perpendicular field ∃ @ Napoli
    (// field underdevelopment @ Saclay)
  - $b_0\cos(\omega\tau)$ applied in the coil
  - temperature ramp
  - third harmonic signal appears @ B_{C1}

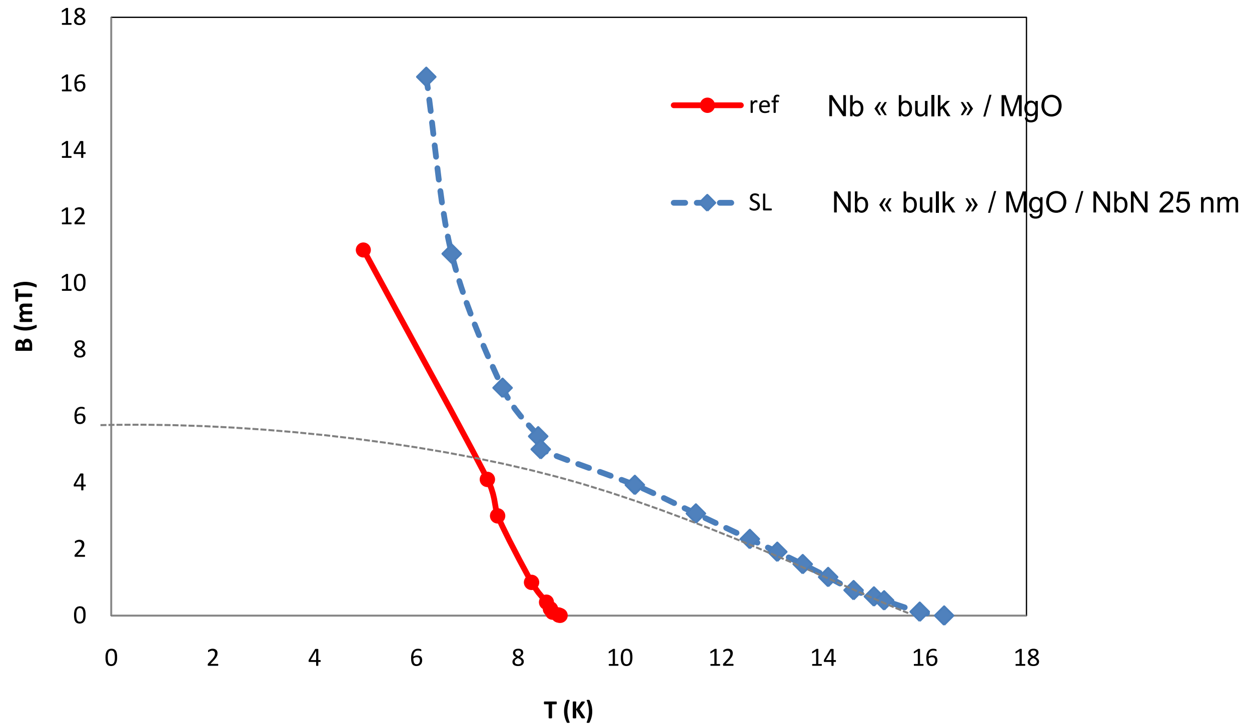






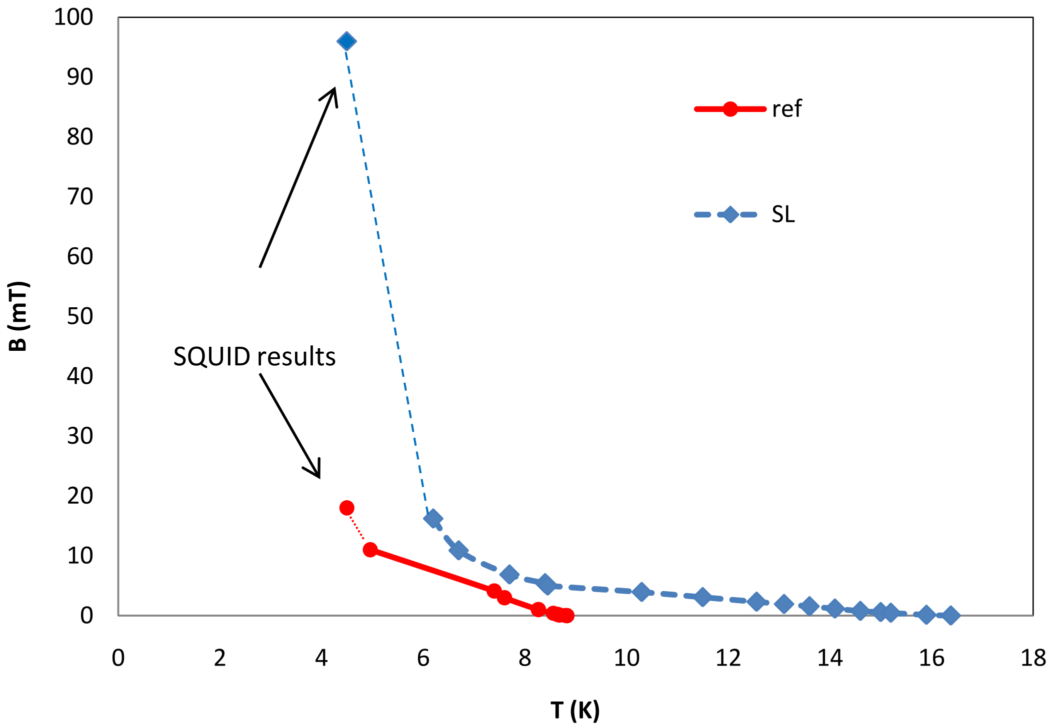
Sample SL : third harmonic signal for various b0

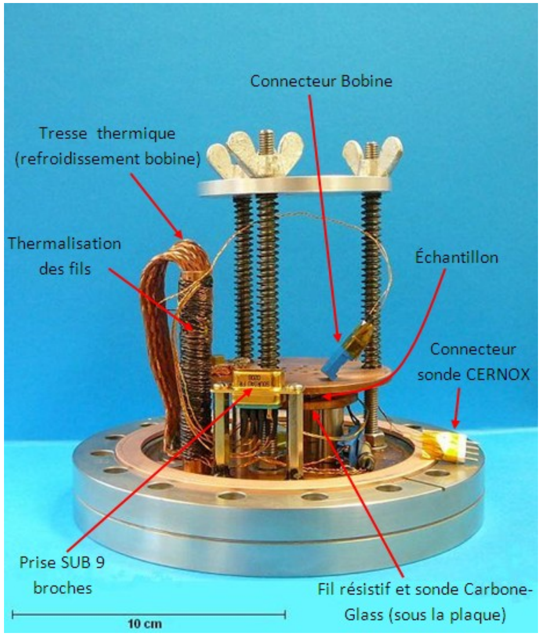
Local magnetometry (2)



- **SL sample :** 250 nm Nb + 14 nm MgO + 25 nm NbN
- 8.90K < Tp° < 16K : behavior ~ NbN alone
- Tp°< 8.90K, i.e. when Nb substrate is SC , **=> B_{C1}^{SL} >> B_{C1}^{Nb}**

Local magnetometry + SQUID measurement @ 4,5K





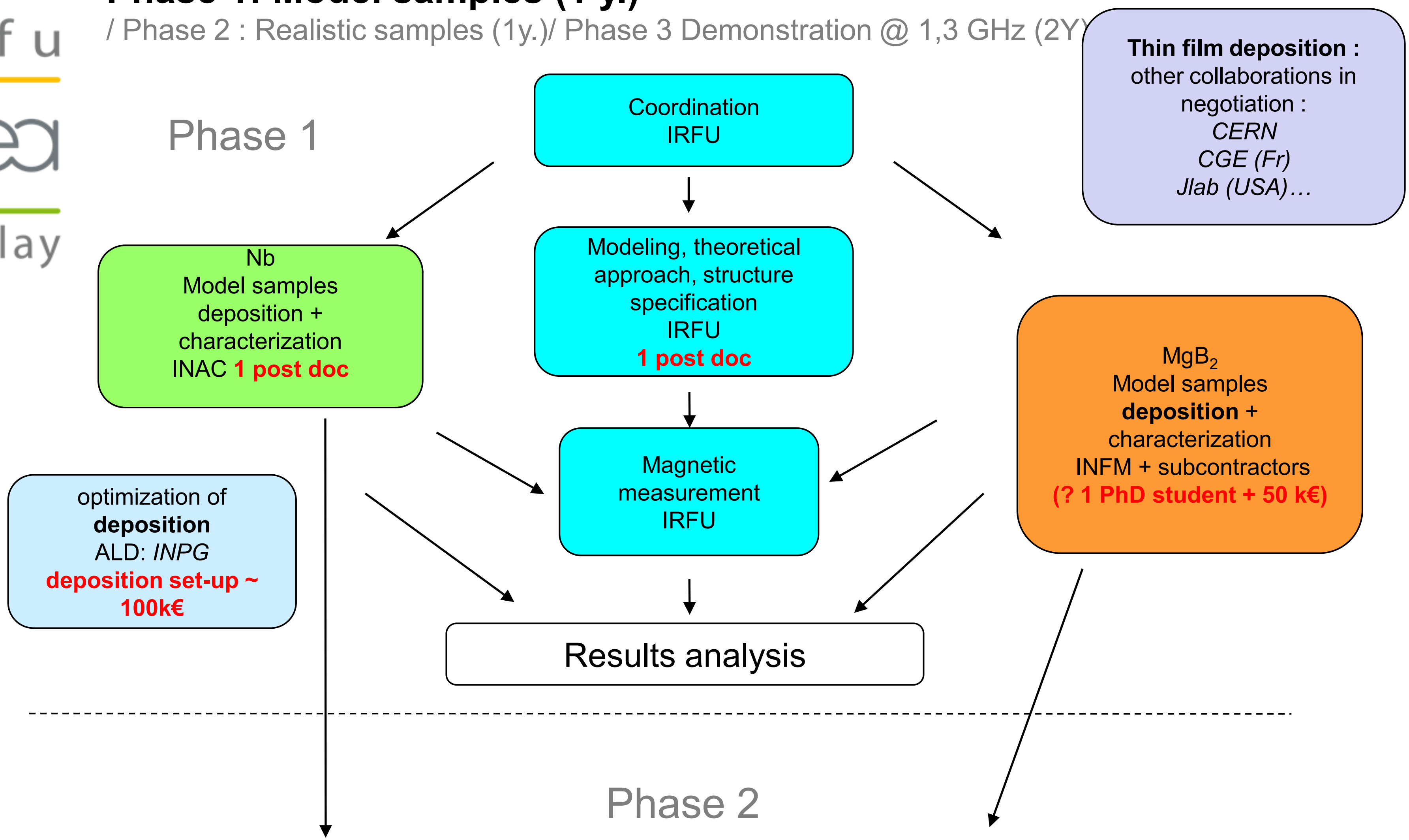
2k, 200 mT local magnetometer under development @ Saclay

- **SL sample :** 250 nm Nb + 14 nm MgO + 25 nm NbN
- Tp°< 8.90K, i.e. when Nb substrate is SC , **=> $B_{C1}^{SL} >> B_{C1}^{Nb}$**
- **Need to extend measure @ higher field and lower temperature**

What is needed (1)?

Phase 1: Model samples (1 y.)

/ Phase 2 : Realistic samples (1y.)/ Phase 3 Demonstration @ 1,3 GHz (2Y)



What is needed (2)?

Phase 1: Model sample (1 y.) **/ Phase 2 : Realistic samples (1y.)**
/ Phase 3 Demonstration @ 1,3 GHz

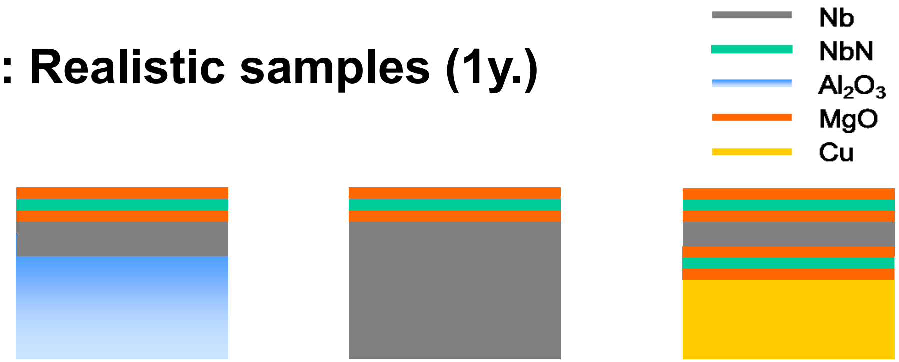
Sample deposition:
Sputtering
ALD
Hollocathode
HIPIMS….

Magnetic measurement IRFU

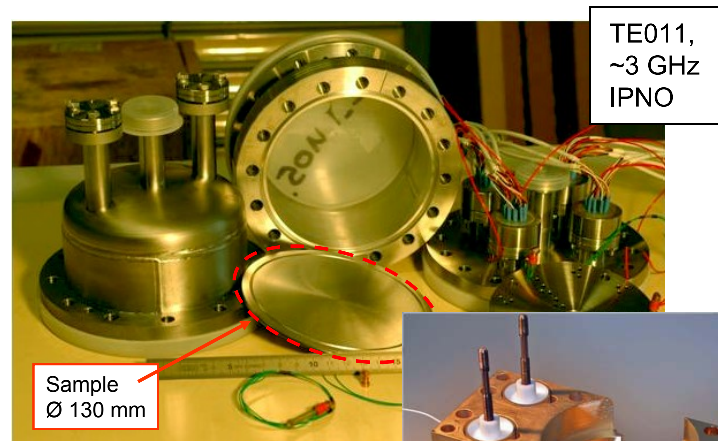
Sample cavities tests IPNO/LKB

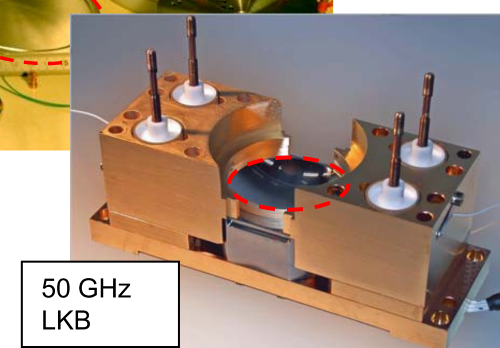
Results analysis
Selection of deposition technique

Phase 3



ML on mono-crystalline saphire → ML on mono- And poly-crystalline niobium → Complex structures on copper





“sample” cavities

Existing set-ups : small improvement investments (< 50k€)

What is needed (3)?

Phase 1: Model sample (1 y.) / Phase 2 : Realistic samples (1y.)

/ Phase 3 Demonstration @ 1,3 GHz

cavity set up design

↓

cavity set up construction
Sub contract

Typically 100 k€

↓

Cavity deposition
IRFU

↓

RF measurement
IRFU

↓

DEMONSTRATION !

- Design must be chosen after comparison of performances on samples deposited with various deposition techniques
- Measurement on 1,3 GHz will achieve a demonstration of feasibility

1.3 GHz
Irfu

Summary

- 4 years program
- 3 labs in the task and possibly up to 5 labs

Manpower	80 p.m 3 yr postdoc
Equipment + Consumable + Subcontracting	480 k€
Other costs	15 k€

Conclusions & perspectives:

- If theoretical approach from Gurevich gets confirmed

MULTILAYERS = only way to go beyond Nb !!!!

- Main challenge : thin film deposition inside cavities

- They are recent promising developments in deposition techniques *(ALD, HIPIMS…)* => collab^{n} with materials labs.

- Multilayers can be deposited inside existing cavities => upgrade of existing facilities

- Improvement expected for **E_{acc}** AND **Q_0** : all SRF application can benefit from this technology !

2)

CLIC X-band accelerating structure R&D

F. Peauger

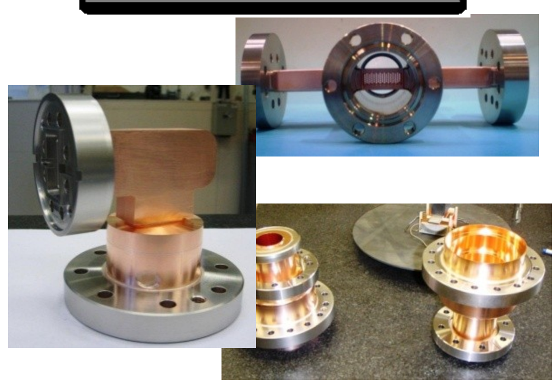
21th April 2011

Context of the X-band activities at CEA Saclay

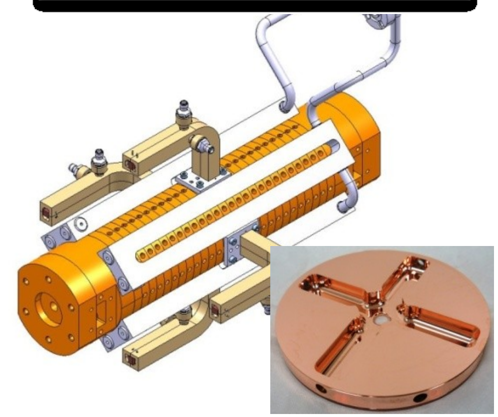
- CEA entered in the CLIC collaboration with the construction of the Probe Beam Linac CALIFES in CTF3 (in 2005)
- Exceptional contribution of France to CERN
  - ➢ CTF3 contributions:
    - ✓ HV modulator and RF components for the CERN klystron test stand and TBL line
    - ✓ Accelerating structures for the Two Beam Test Stand
  - ➢ Period : 2008 – 2012, Budget = 1 M€ - 48 persons-months (p.m.)

HV Modulator

RF Components



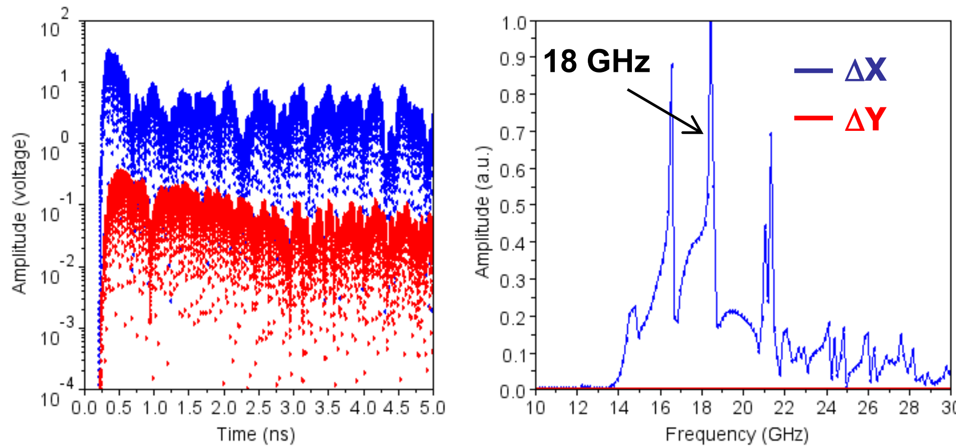
Accelerating structures (fabrication in progress)

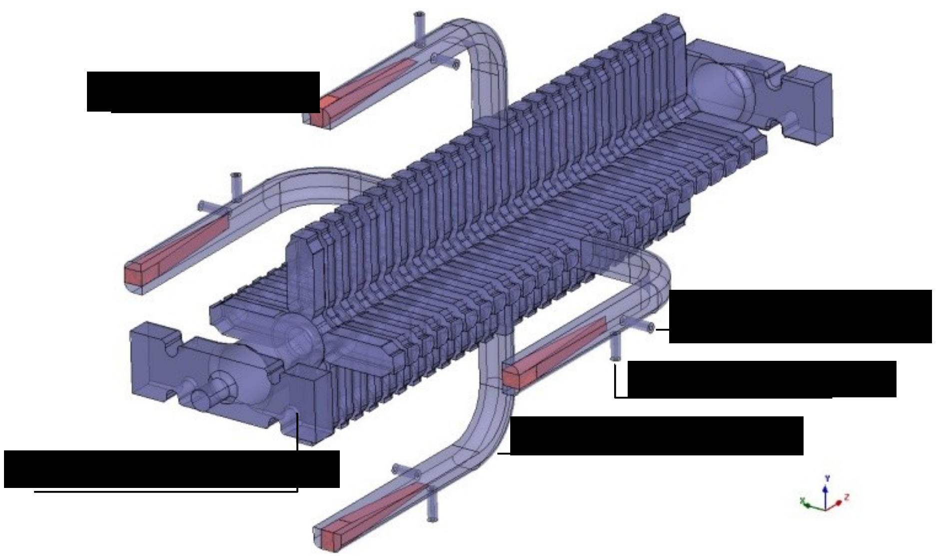


Wakefield monitor development for CLIC accelerating structures

- ➢ Wakefield Monitors = Beam Position Monitors integrated to the accelerating structures
- ➢ Allows beam-based alignment of structures to remove wakefield effects and emittance growth
- ➢ Emittance growth very well improved by aligning the structure to an accuracy of **5 µm**

GdfidL simulation of TM modes, beam offset δx = 1 mm





Accelerating Structure features :

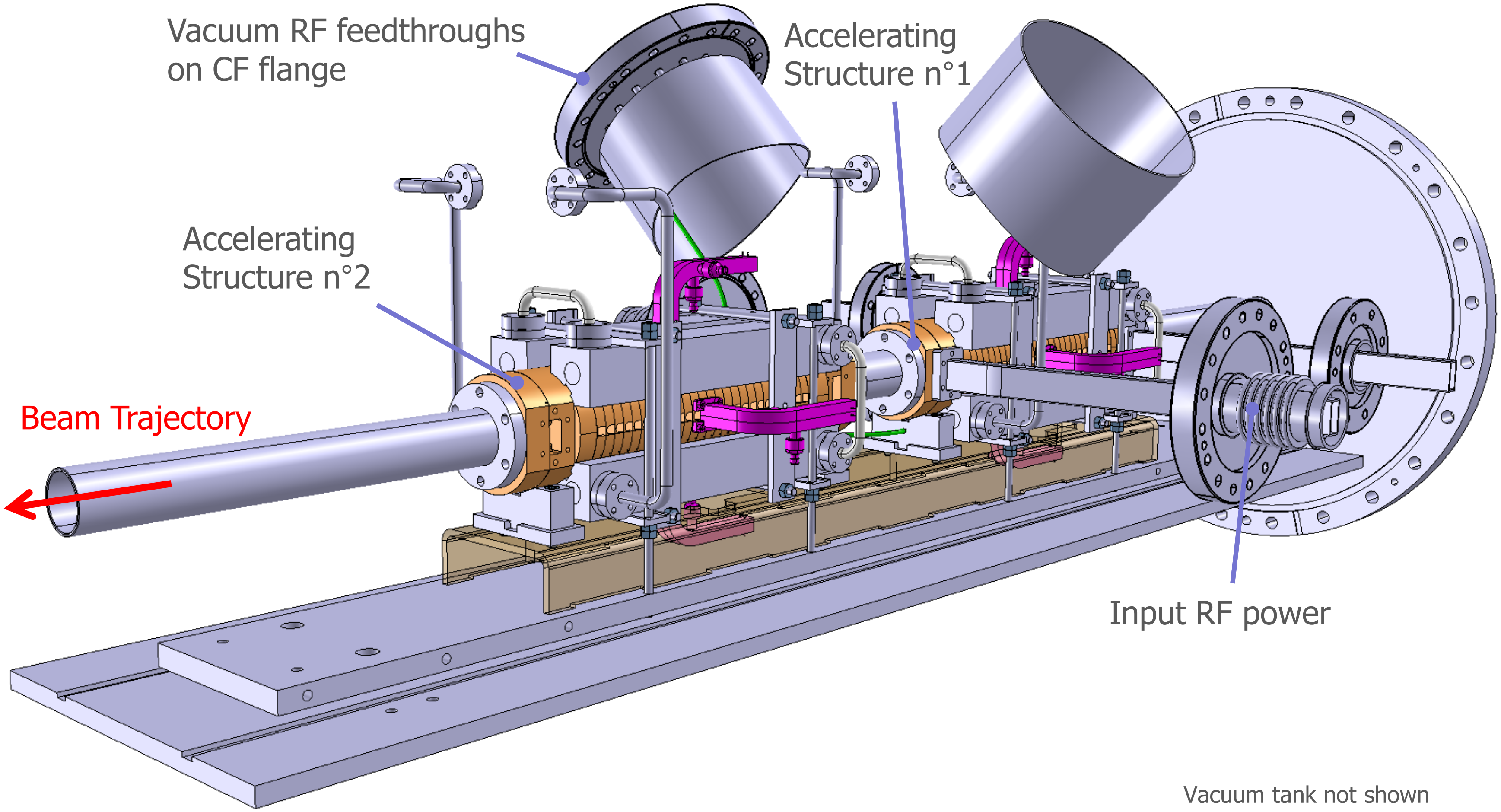
- ➢ TD24 (CERN design) without RF absorbers
- ➢ 100 MV/m accelerating gradient
- ➢ 24 tapered cells with $2\pi/3$ phase advance at 12 GHz with mean aperture of 5.5 mm
- ➢ dipole mode above 16 GHz

WFM features :

- ➢ WFM = Two coaxial rf pick-ups on the middle cell damping wg
  - on large side wg for TM-like modes
  - on small side wg TE-like modes

} **Hybrid HEM modes in the cell generated by an offset beam**

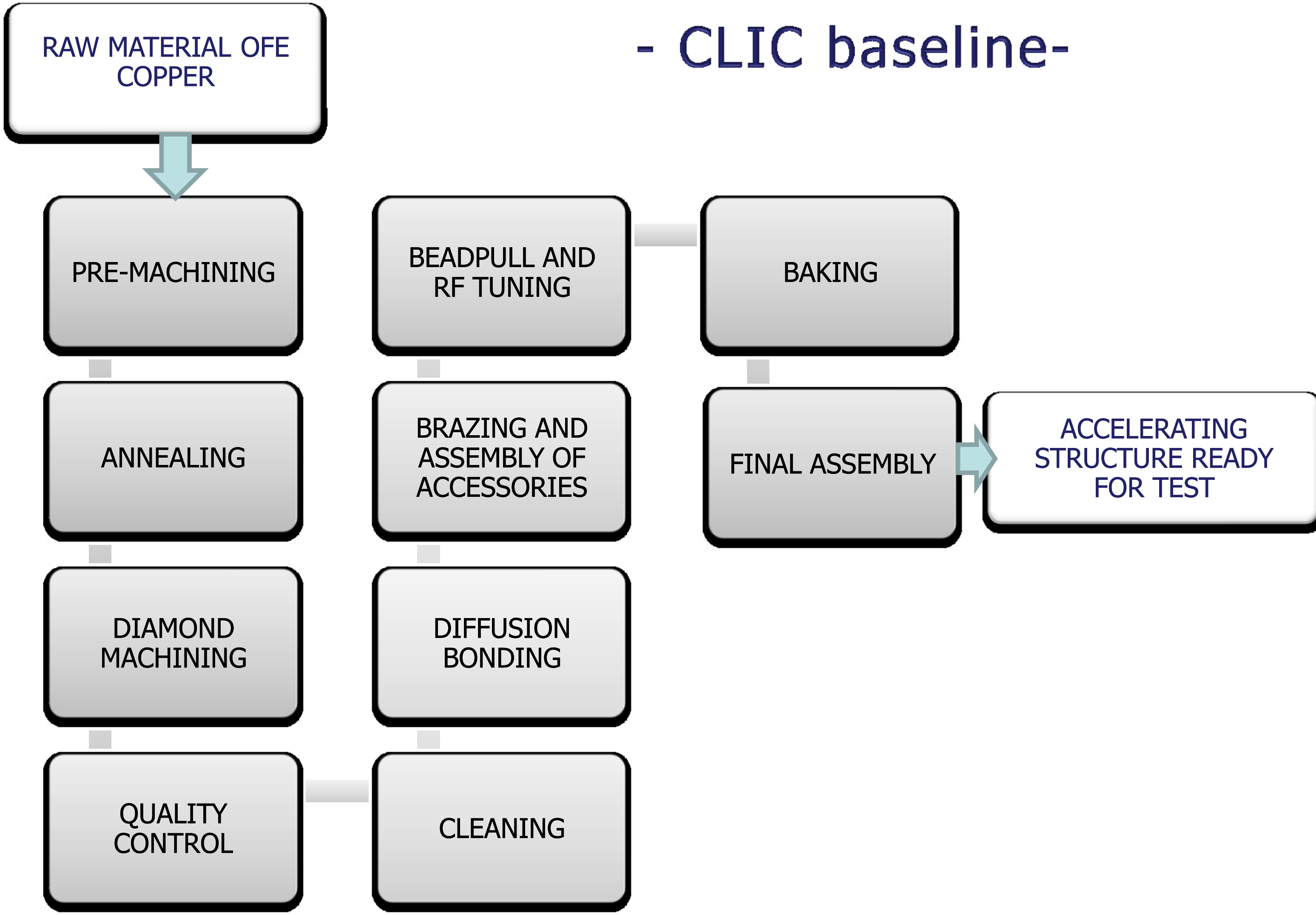
Integration in the Two Beam Test Stand in CTF3



☞ Installation in 2011

Fabrication process of X band structures

- CLIC baseline-



☞ Fabrication of three structures in progress in collaboration with CERN

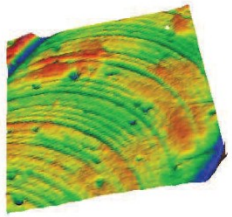
Industrial partner for ultra-precision machining

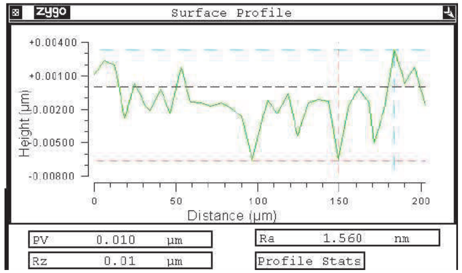
- Tolerance = 2.5 µm
- Surface roughness = 25 nm
- Flatness = 2 µm

- Large investment of our supplier :
  - Machining equipment:
    - ✓ 1 nm programming resolution
    - ✓ hydrostatic oil bearing slides
    - ✓ linear motors
    - ✓ thermal stabilization at +/- 0.05°C

  - Interferometers for roughness and flatness control without contact

- Cutting tools:
  - Monocristal diamond for milling and turning





Surface roughness of 1.5 nm achieved

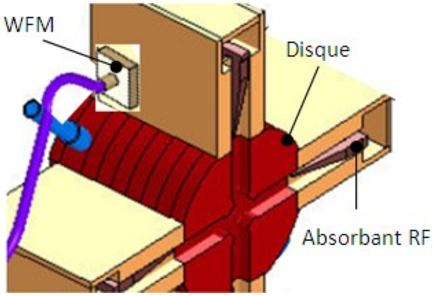
Why an R&D on X band structures ?

X band technology becomes more and more attractive :

- CLIC main linac frequency
- Growing interest for FEL and compact light sources (PSI, ELETTRA, Univ. Groningen, SLAC, LANL, LLNL…)

But :

- Few statistic results ,100 MV/m demonstrated on few structures only,
- Surface damages still present, even with good breakdown rate
- Some breakdown theories exists, but no clear experimental demonstration
- Very difficult to fabricate
  - Tight tolerances
  - Few industrial capabilities: fabrication costs and delays are high
- Full feature not tested yet (HOM absorbers, wakemonitors, etc…)



CERN design example

1. Design, fabrication and test of "12 GHz prototype structures "
   - As close as possible to the CLIC requirements
     100 MV/m, TW with low vg, HOM damping with RF absorbers
     compact couplers, WFM, vacuum tightness and cooling circuits
     (80-90 % already designed by CERN)
   - Short structures could help for the statistic demontration (reduced nb of cells)
2. Alternative material configurations, fabrication process and preparation techniques
   - Use of large grain copper to reduce atomic diffusion and breakdown probability (or mixed grain sized ?)
3. Bead pull measurement test bench at CEA Saclay
   - Fundamental mode tuning and HEM modes measurement for wakefield monitors
4. "Mid power" test bench at CEA Saclay
   - ~ tens of kW peak power with TWT and pulse compressor
   - Multipactor study in rf absorbers and WFM
   - Preparation of the structures for high power tests (pre-processing?)

The 12 GHz Power station project at CEA Saclay

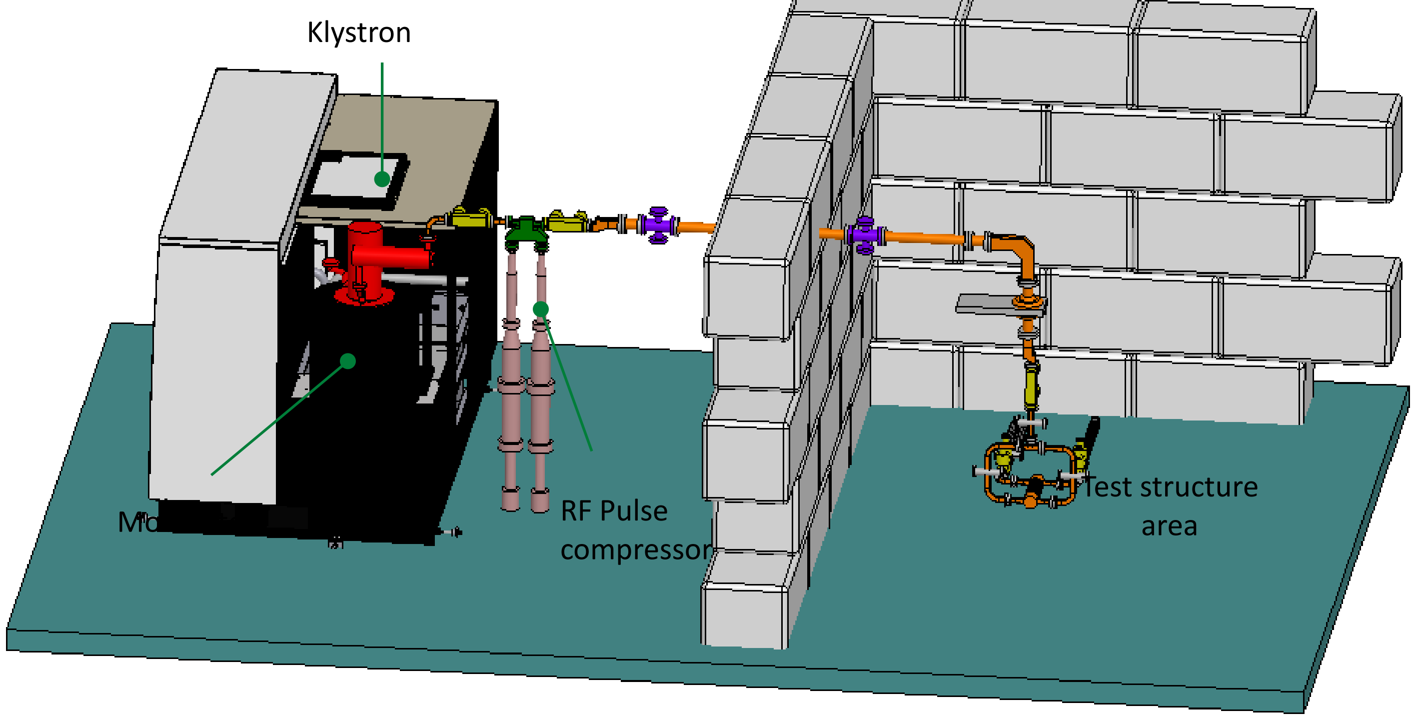
- Independant operation to CTF3
- Proximity with chemical lab and clean room

__Main features:__

- Modulator HT 430 kV
- Klystron 50 MW – 1.5 µs
- RF Pulse compressor SLED
- LLRF with fast phase modulation

__Specifications :__

RF Frequency:	12 GHz
Peak power:	120 MW
Pulse length:	300 ns
Repetition rate:	50 Hz



☞ Ressources of this project not asked in Eucard 2

Budget, schedule and collaborations

Rough schedule:

- Year 1-2 : Design and manufacture of the structures, test bench study and construction
- Year 3-4 : High power tests of the structures

Possible collaborations:

- CERN for structure design, fabrication and high power testing
- PSI for high power testing ?
- Cockcroft Institute ?

Cost estimation:

1) Structure fabrication and testing and alternative fab. Process (4 structures at 80 k€ + 30 k€ accessories)	20 p.m.	350 k€ *
2) Bead pull test bench	10 p.m.	30 k€
3) « Mid power » test bench	15 p.m.	85 k€
TOTAL	**45 p.m.**	**465 k€**

* not include high power tests costs

3)

Development of critical components for high power accelerators

CEA Saclay proposals for 704 MHz cavity and couplers

G. Devanz – S. Chel

21th April 2011

Introduction

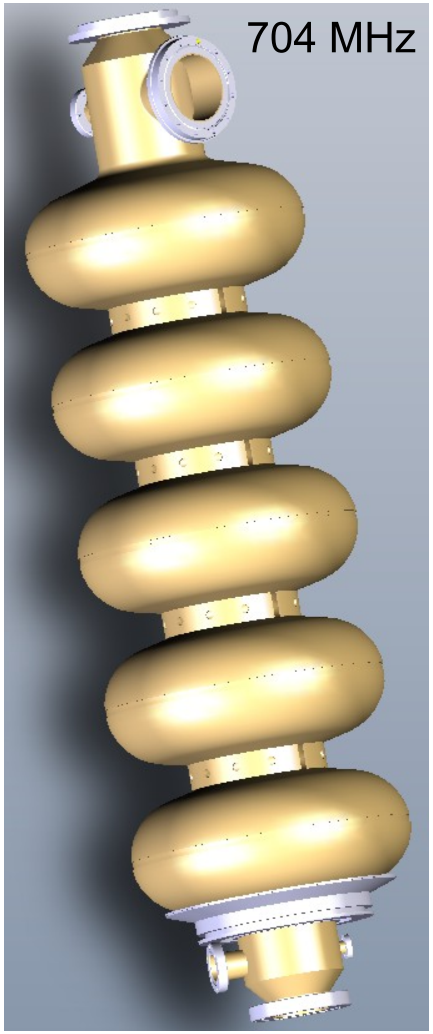
Several laboratories are involved in programs aiming at designing and prototyping sc cavities and components for high intensity proton linacs (SPL, ESS, MYRRHA, …)

R&D programmes already supported such developments, in particular in the frame of CARE (FP6) and EuCARD (FP7). Progress done on several critical components makes them available for European Research Infrastructures which are now in construction.

We propose to proceed with the same spirit in order to increase the performances of some components and to make them fit with future linac design and/or parameters.

irfu cea saclay

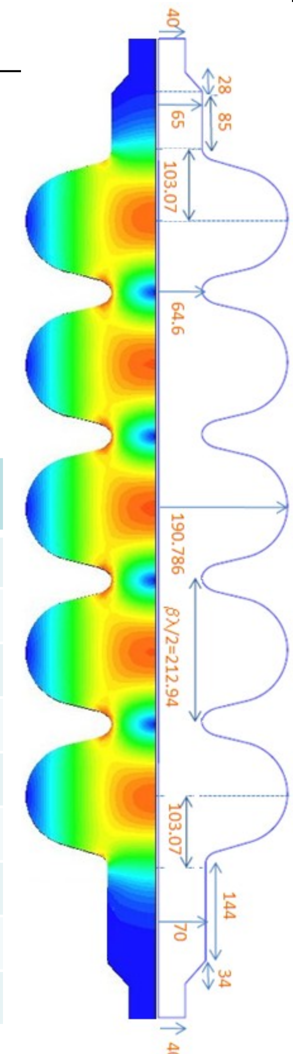
High beta cavity development in EuCARD



Achievements in FP7-EuCARD:
Optimized RF and mechanical design of a 704 MHz β=1 elliptical sc cavity
Fabrication and test in Vertical cryostat of cavity

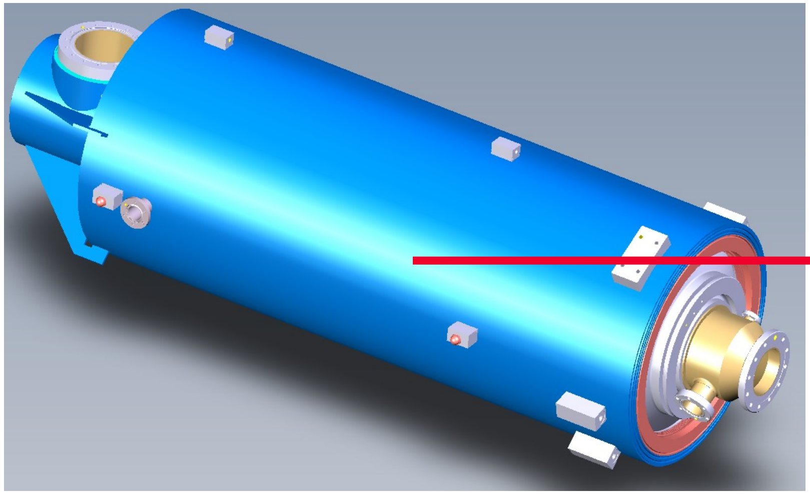
- ☑ assymetric cavity
  - beam tube Ø140 mm with a Ø100 mm port for power coupler
  - beam tube Ø130 mm with a Ø10 mm port for pick-up probe
- ☑ stiffening rings between adjacent cells
- ☑ each beam tube equipped with one Ø40 mm HOM port

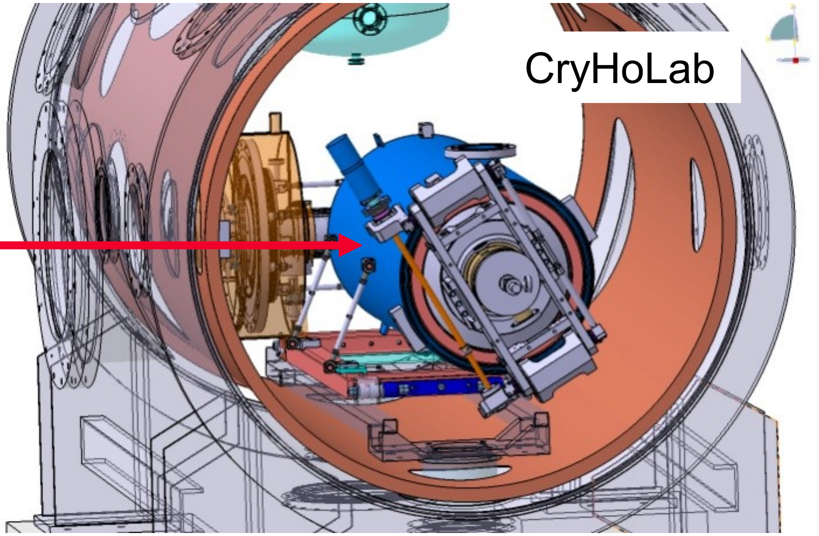
	SPL	Tesla	HIPPI
Number of cells	**5**	9	5
Frequency [MHz]	**704.4**	1300	704.4
Beta	**1**	1	0.47
Bpk/Eacc [mT/(MV/m)]	**4.20**	4.26	5.59
Epk/Eacc	**1.99**	2	3.36
G [Ω]	**270**	270	161
Cell to cell coupling [%]	**1.92**	1.87	1.35
r/Q [Ω]	**566**	1036	173
Lacc = Ngap.β.λ/2 [m]	**1.065**	1.038	0.5

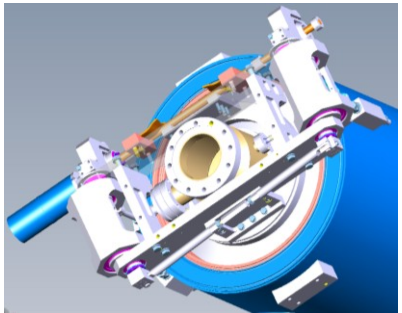


Helium tanks for 704 MHz $\beta=1$ cavities

The prototype fits on our frames for surface preparation (BCP, VEP, HPR) and test in vertical cryostat
In order to be able to perform qualification tests in **horizontal cryostat CryHoLab**, this prototype can be equipped with tuner, coupler, He tank, …







- power coupler port cooled by LHe
- interfaces for lateral frequency tuner ready (similar to Saclay IV)
- Helium tank made of Ti

High beta cavity characterization

First proposal for EuCARD2 : completion of RF tests in CryHoLab

- **Several components will be ready in 2013 (tuner, support, He tank)**
- **Cryo and RF test stand already qualified**
- **Magnetic shielding still to be studied and fabricated**

- **Qualification of the Helium tank design ; cryogenic behavior ; freq. tuner and LFD**

SPL and ESS requirements

SPL beam parameters (for neutrinos and RIB programs)		
	Option 1	Option 2
Energy (GeV)	2.5 or 5	2.5 and 5
Beam power (MW)	2.25 (2.5 GeV) or 4.5 (5 GeV)	5 (2.5 GeV) and 4 (5 GeV)
Rep. frequency (Hz)	50	50
Av. Pulse current (mA)	20	40
Pulse duration (ms)	0.9	1 (2.5 GeV) + 0.4 (5 GeV)
Protons/pulse (x 10^{14})	1.1	2 (2.5 GeV) + 1 (5 GeV)

ESS Beam parameters (to be confirmed)		
	Nominal	Upgrade
Energy (GeV)	2.5	2.5
Beam power (MW)	5	7.5
Rep. frequency (Hz)	20	20
Av. Pulse current (mA)	50	75
Pulse duration (ms)	2	2

With our set of cavity and beam parameters:
SPL: $Q_{ex,opt}$ = **1.2 e6** and $P_{beam} = P_{in,max}$ = **1.03 MW**
ESS: $Q_{ex,opt}$ = **6 e5** and $P_{beam} = P_{in,max}$ = **0.8 to 1.2 MW**

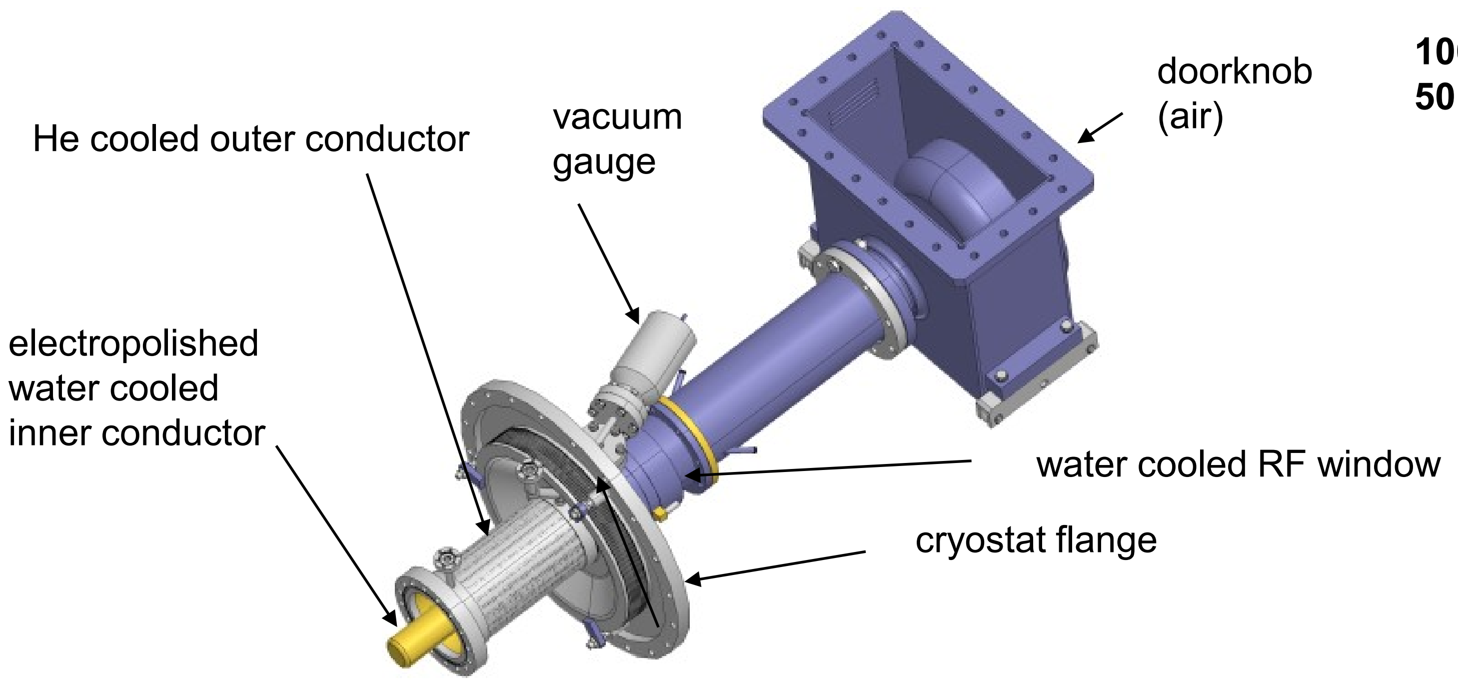
→ Typical RF power in the MW range
From recommandations of RF experts, following tests are required:
- 2 MW peak power with a limited pulse length
- nominal peak power with the nominal average power

Power couplers for 704 MHz sc cavities

Coupler developments:

In the previous FP6/HIPPI program, we started the development of a high power coupler operating in pulsed mode

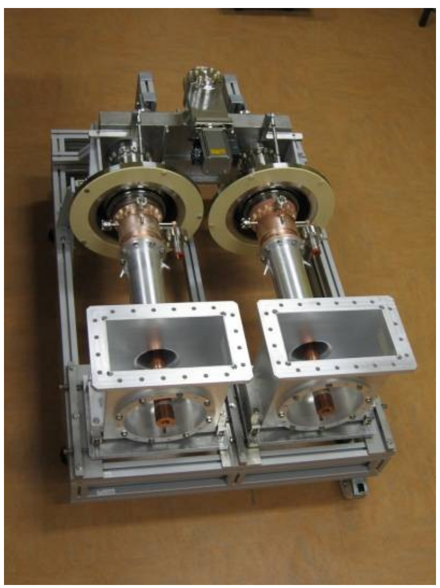
G. Devanz designed most of the critical parts (doorknob, window, LHe and water cooling circuits, …) for 1 MW at 10% duty cycle required for operation of high intensity proton linacs

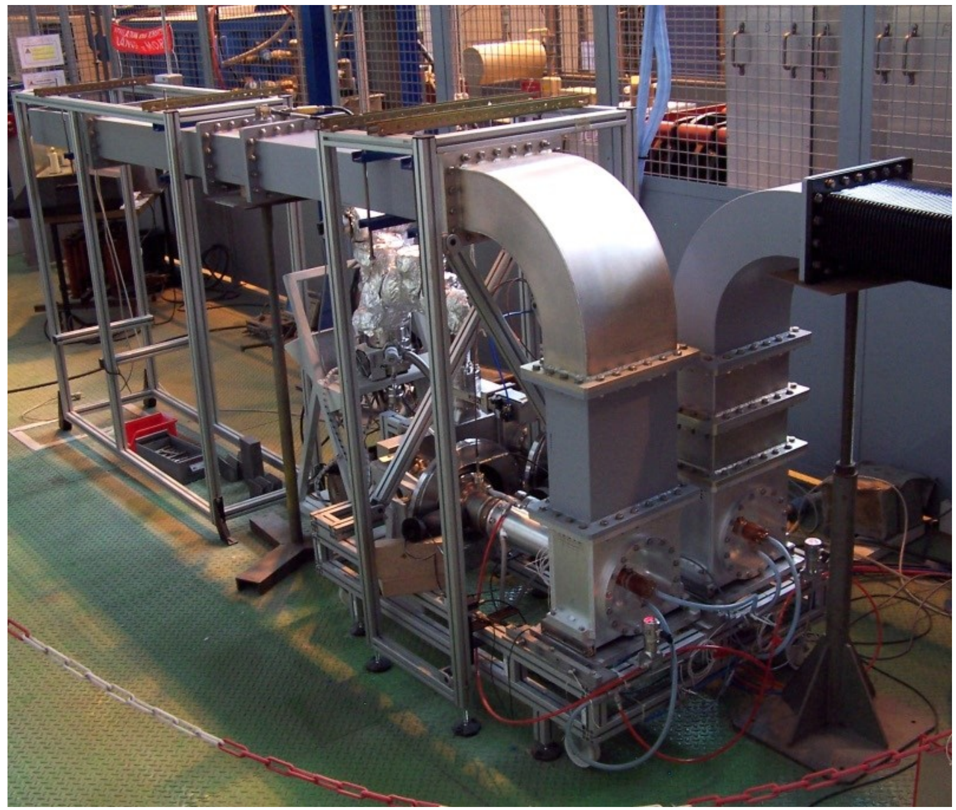


100 mm diameter
50 Ω impedance

704 MHz coupler test stand at RT

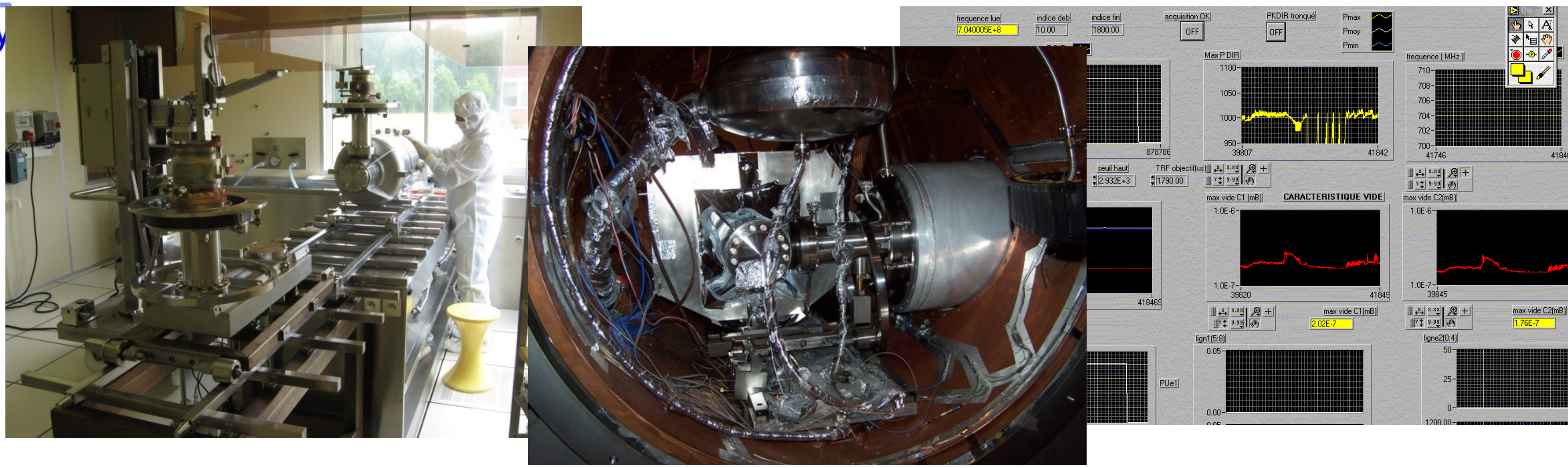
Coupler assembly in Clean Room
Coupler processing in horizontal position





Two couplers successfully processed at RT
up to 1.2 MW peak @10% DC in TW for 300hrs

Qualification of 700 MHz – 1 MW coupler at cold



- Assembly of one coupler on HIPPI cavity (700 MHz, β=0.5) in ISO4 CR, and installation in test cryostat CryHoLab
- Only short time of RF processing in full reflection was necessary to reach high power levels
- Cavity (off resonance) and coupler operation at 1MW full duty cycle for several hours
- Efficient counter-flow GHe cooling of the coupler leading to limited heat transfer to the LHe bath

Qualification of 704 MHz power coupler on sc cavity at 2 K operated at P_{peak} = 1.1 MW with t_{pulse} = 2 ms and freq = 50Hz

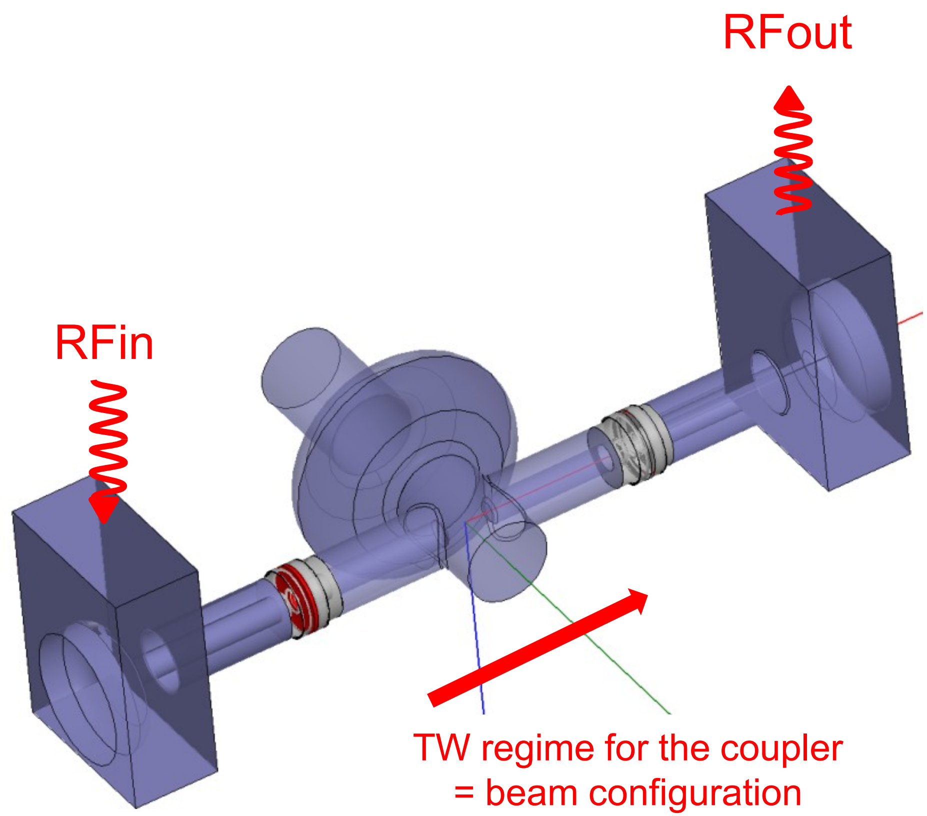
2-ports SC cavity for coupler qualification in TW

In the previous test: coupler tested with a "off resonance" cavity (open circuit)

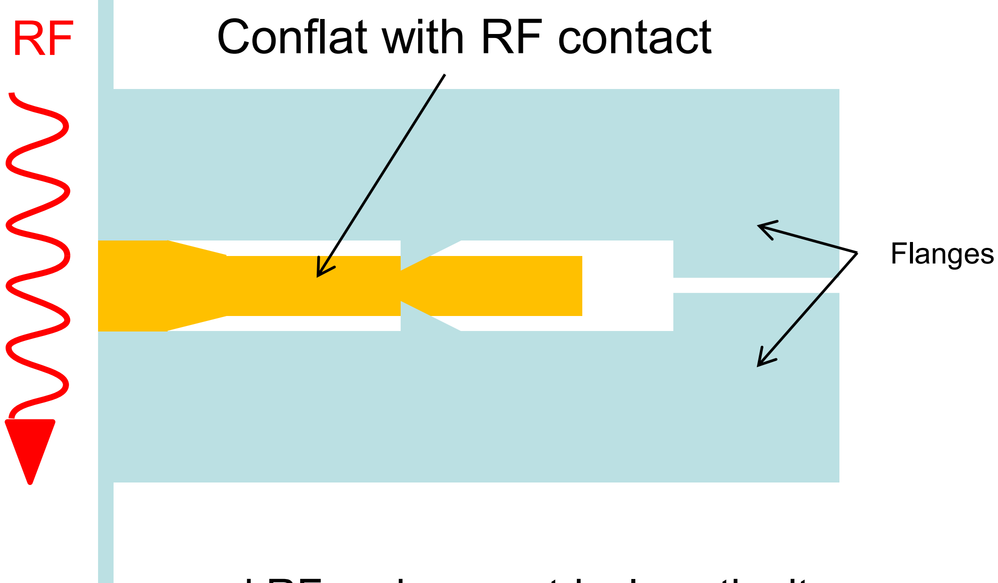
⇨ Coupler tested in a standing wave regime:
- Spatially fixed field extrema
- Not easy to sweep along the coax

In order to test the coupler in a beam configuration, i.e. all the RF is absorbed by the beam and the coupler is working on a travelling wave regime (TW), we use a 2-port cavity

This superconductive cavity would allow tests at 2 K in CryHoLab

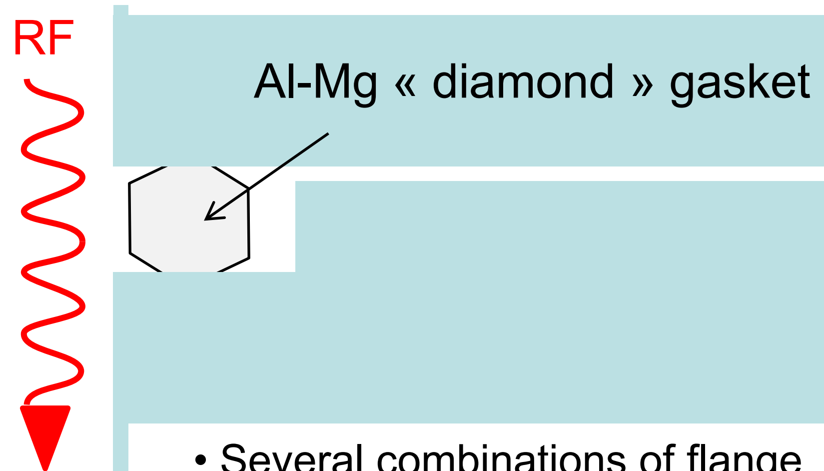


RF vacuum gaskets for couplers

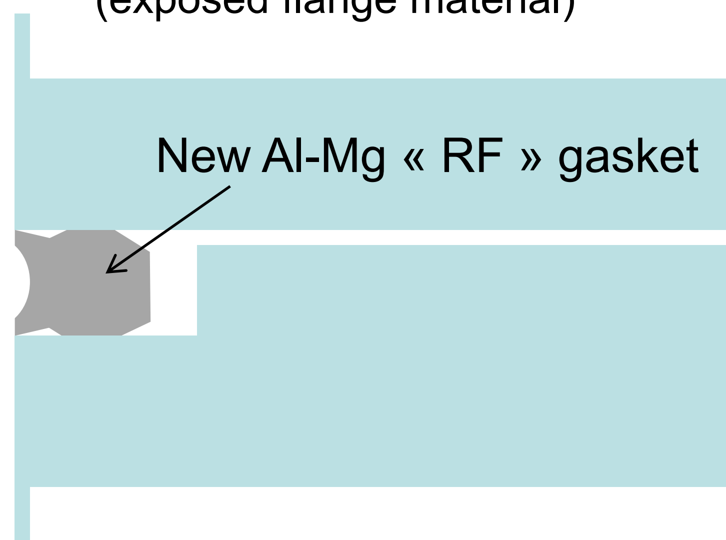


• good RF and geometrical continuity
• Large diameters ~100 mm: only stainless steel flanges

Optimization of Al-Mg gasket for RF
New gasket profiles
Need prototypes and tests



• Several combinations of flange materials possible (NbTi+NbTi, NbTi+SS, …)
• RF boundary not optimized (exposed flange material)



Qualification of 700 MHz – 1 MW coupler at 4 K

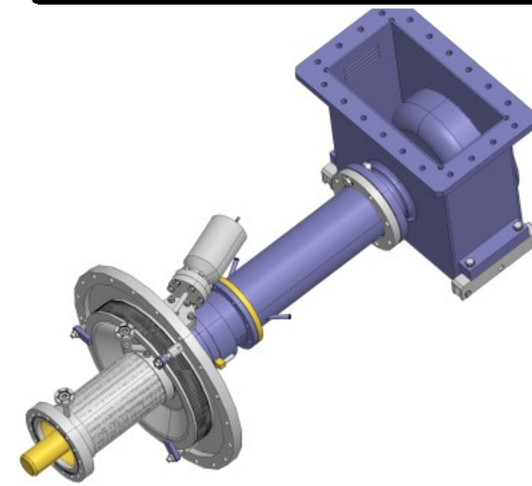
<u>Second proposal for EuCARD2 :</u>

a) power tests of 704 MHz couplers in full TW mode at 1 MW

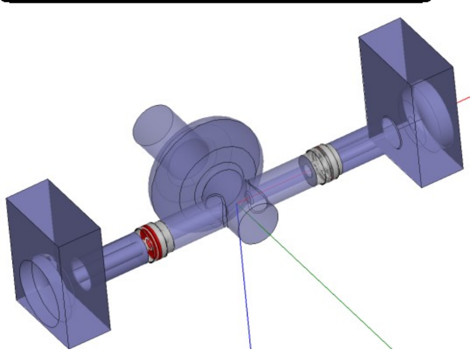
- **optimization of some coupler parts (DoorKnob, RF gaskets, ???)**
- **fabrication of a pair of couplers**
- **design and fabrication of a 2-ports cavity**
- **qualification tests in CryHolab**

b) power tests of 704 MHz couplers in full TW mode at 2 MW

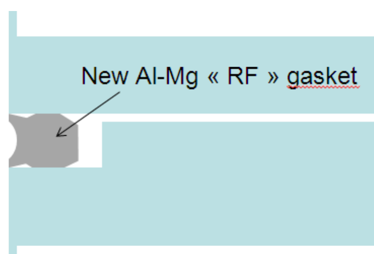
704 MHz – MW(s) coupler



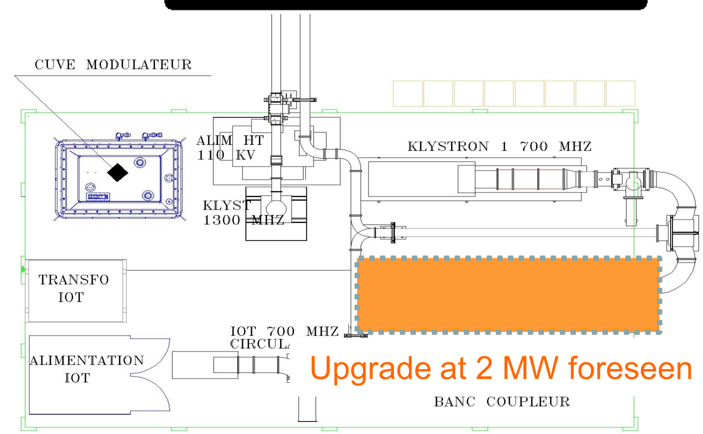
2-ports SC cavity



Vacuum RF flange



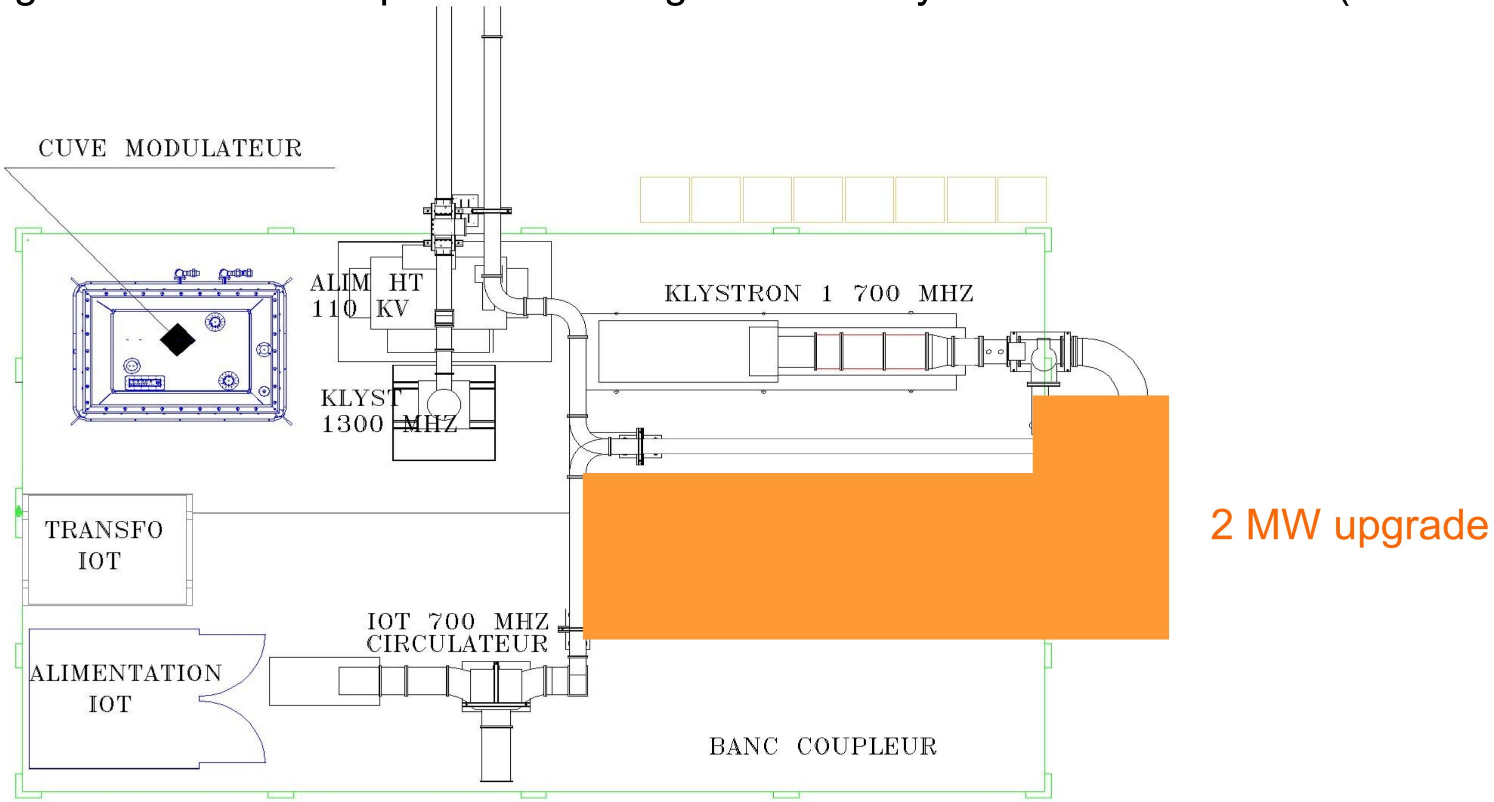
704 MHz Power Station



Power test stand: 2 MW upgrade

The SUPRAtech platform at Saclay is equipped with a 704 MHz power station with a single klystron delivering a maximum of 1 MW maximum peak power and 100 kW average.

An upgrade is foreseen up to 2 MW using a second klystron + RF combiner (2013 – 2014)



☞ Ressources of this upgrade not asked in Eucard 2

Budget Estimation (CEA Saclay)

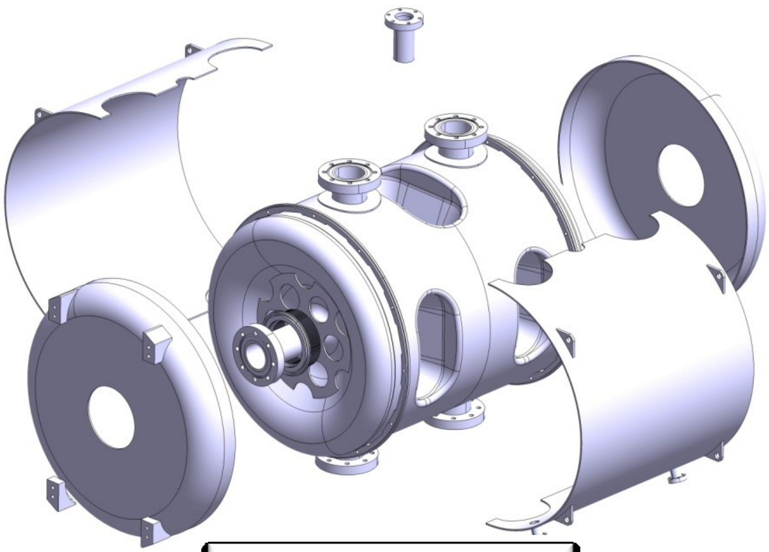
Task 1: 700MHz b=1 test of fully equipped cavity in CryHoLab (2014)	Integration in Cryholab (flanges, cryo tubes, …)	2 p.m.	8 k€
	Design & fab. of mag. shielding	3 p.m.	27 k€
	RF tests assuming availability of power couplers (consumables)	9 p.m.	50 k€
Task 2: development of multiMW - 700MHz power coupler (2014 - 2016)	Optimisation of RF gaskets (mechanical and thermal calculations, instrumentation, leak tests @ cold, power tests at RT)	9 p.m +1yr postdoc	45 k€
	Fabrication and processing of multi-MW power couplers	8 p.m +1yr postdoc	200 k€
	Test at cold in TW mode (similar to operation with beam) of power couplers (including 2-ports sc cavity and consumables)	10 p.m +0.5yr postdoc	140 k€
	Test at 2 MW (missing RF components + consumables)	3 p.m +0.5yr postdoc	45 k€
TOTAL		**44 p.m +3yr postdoc**	**515 k€**

Development of critical components for high power accelerators

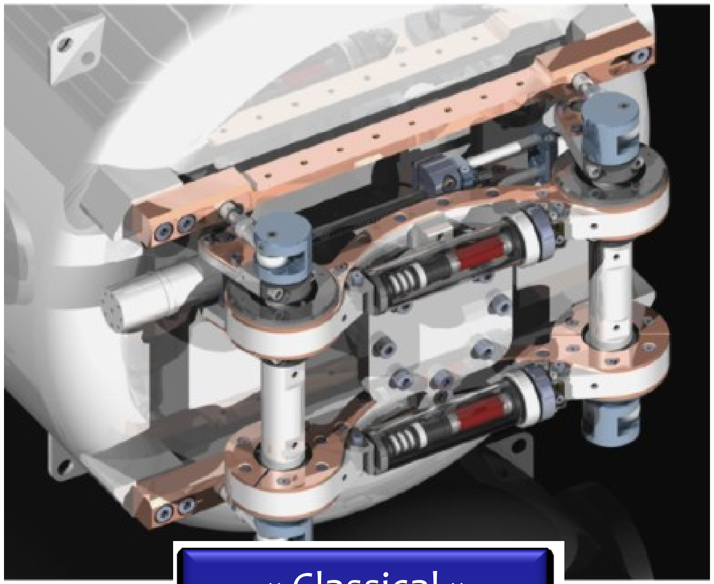
IPN-Orsay proposal for 352 MHz freq tuner

New tuning system for Spoke cavity

- GOAL: study, fabrication and test at cold temperature of an innovative tuning system for multi-gaps Spoke cavity in pulsed regime.



352 MHz, beta 0.30, Triple Spoke

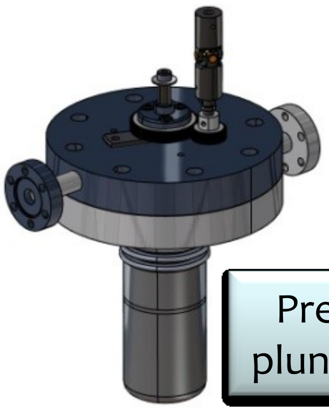


« Classical » tuning system by deformation

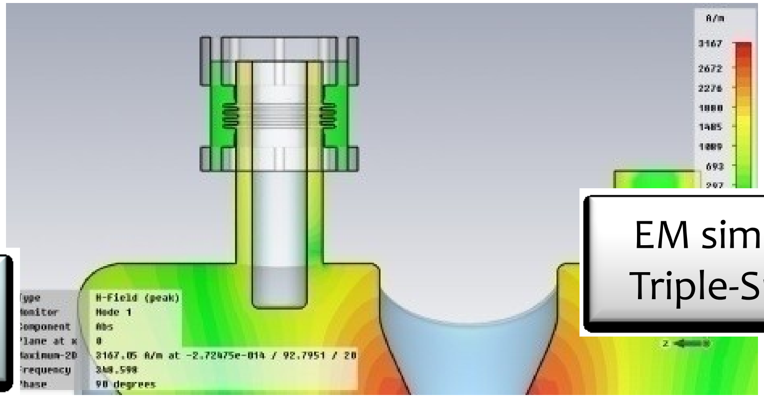
New tuning system for Spoke cavity

- PROBLEMS:
  - In pulsed operation → need to increase cavity stiffness to compensate for the Lorentz forces detuning
  - Applied forces on the cavity become relatively high
  - Tuning system becomes bulky and shows thermal gradients

- IDEA: Develop a tuning system WITHOUT deforming the cavity body → use of a superconducting plunger

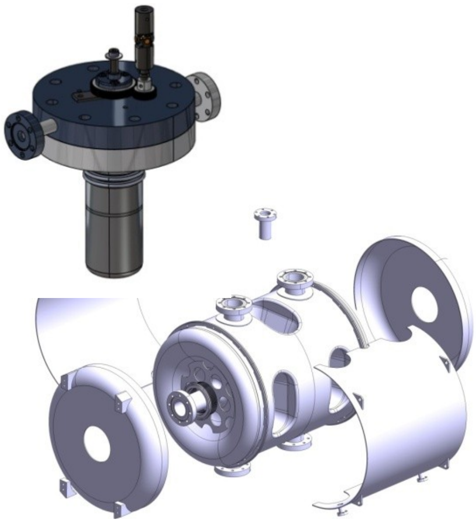


Preliminary study of a plunger for Spoke cavity

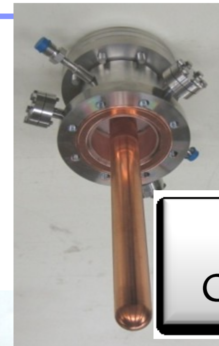


EM simulations on Triple-Spoke cavity

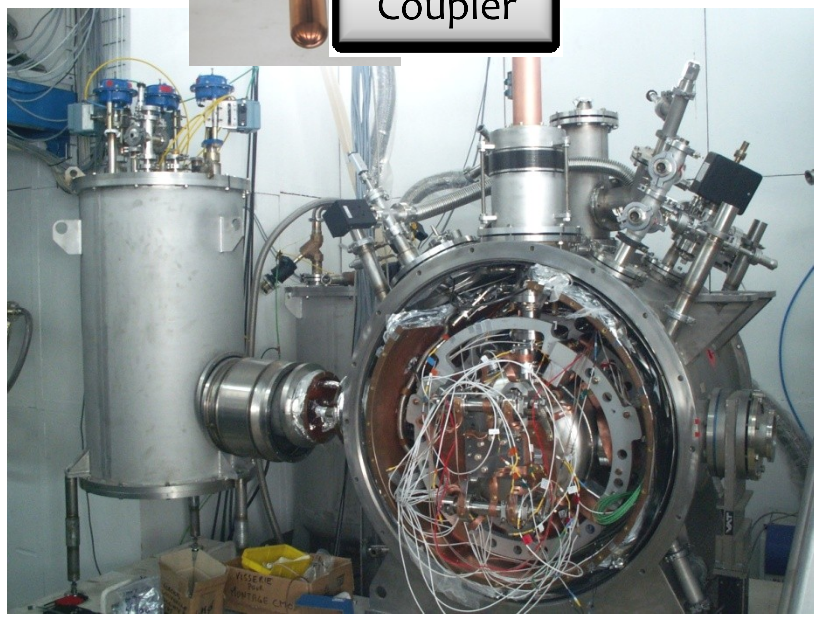
IPN Orsay proposal for Spoke cavity tuner



Plunger + Triple-Spoke cavity



RF Coupler



RF amplifier

Third proposal for EuCARD2 :

Design and fabrication of a new frequency tuner
Study of LFD compensation with tests at cold with existing RF coupler

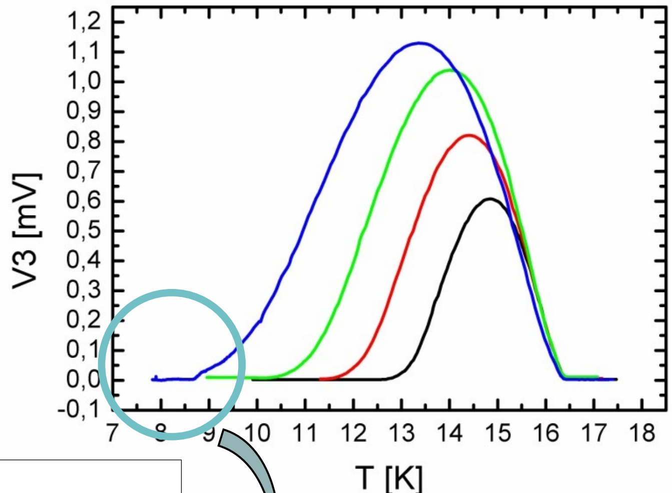
Budget Estimation (IPN Orsay)

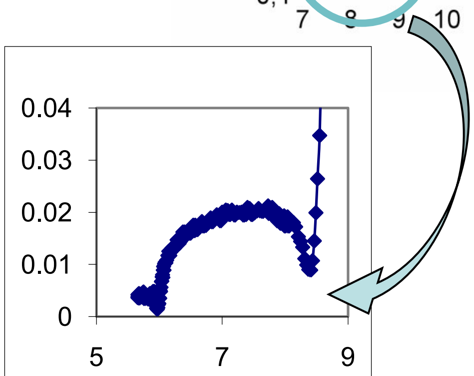
<u>Task 3:</u> ***development of plunger tuner for spoke cavities*** **(2014-2015)**	Design & fab. of tuner	4 p.m. +0.6y postdoc	20 k€
	Mechanical tests Cold tests	2 p.m. +0.4y postdoc	8 k€

Compléments

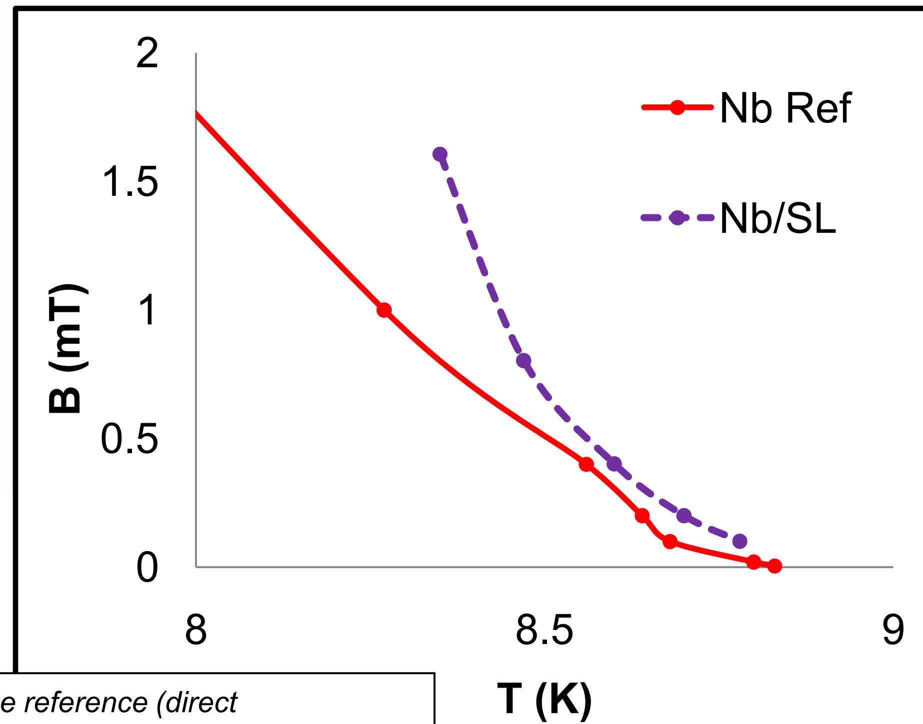
Local magnetometry (4)

- Sample SL : small Nb signal @ ~Tc^{Nb} : Nb is sensed through the NbN layer !
- Since the Nb layer feels a field attenuated by the NbN layer, the apparent transition field is higher.
- This curve provides a direct measurement of the attenuation of the field due to the NbN layer



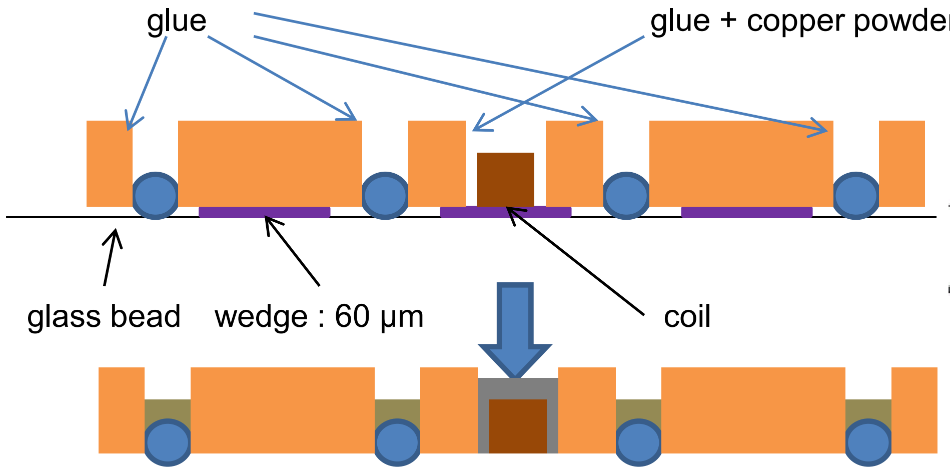


$$H_{Nb} = H_{appl}\, e^{-\frac{Nd}{\lambda}}$$



B_{C1} curves for Niobium in the reference (direct measurement) and in SL (under the NbN layer).

Adjustment of coil distance



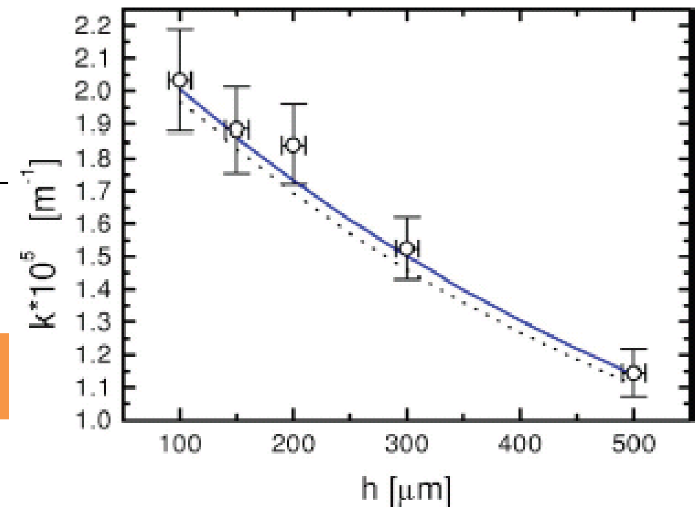


FIG. 5. Determination of the scaling factor k vs the sample-coil distance h. The continuous and the dashed lines represent the behavior expected for the discrete and the continuous models, respectively. The open circles represent the k values experimentally evaluated.

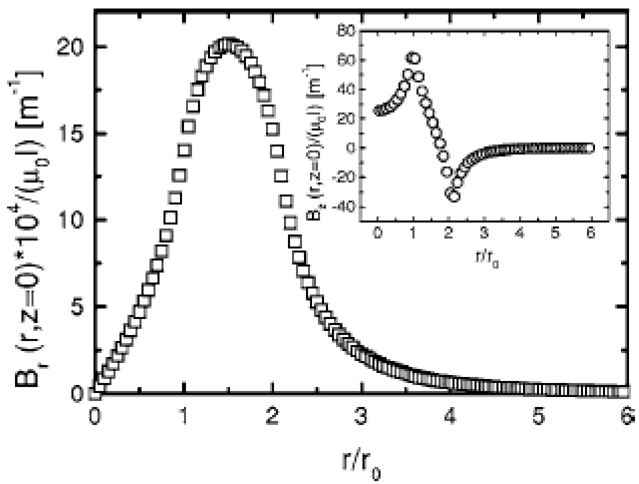
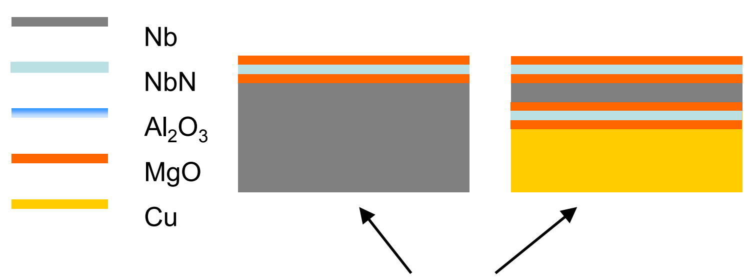


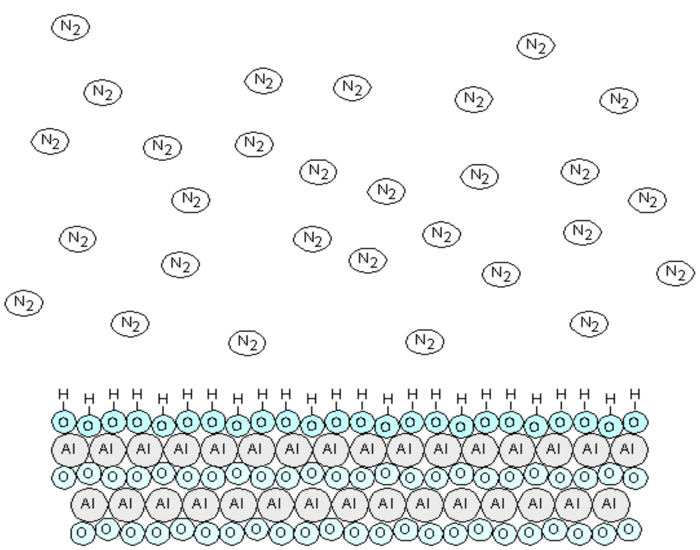
FIG. 4. Radial component of the total induction field (open squares) for a multiturn coil. In the inset the result for the normal component (open circles) is shown. Both components have been calculated at the sample surface as a function of r/r_0.

Multilayers optimization

- SC structure optimization
- Deposition techniques optimization
  - Magnetron sputtering *Inac (Grenoble),*
  - Atomic Layer Deposition *INP (Grenoble)*



Metallic substrates more realistic):

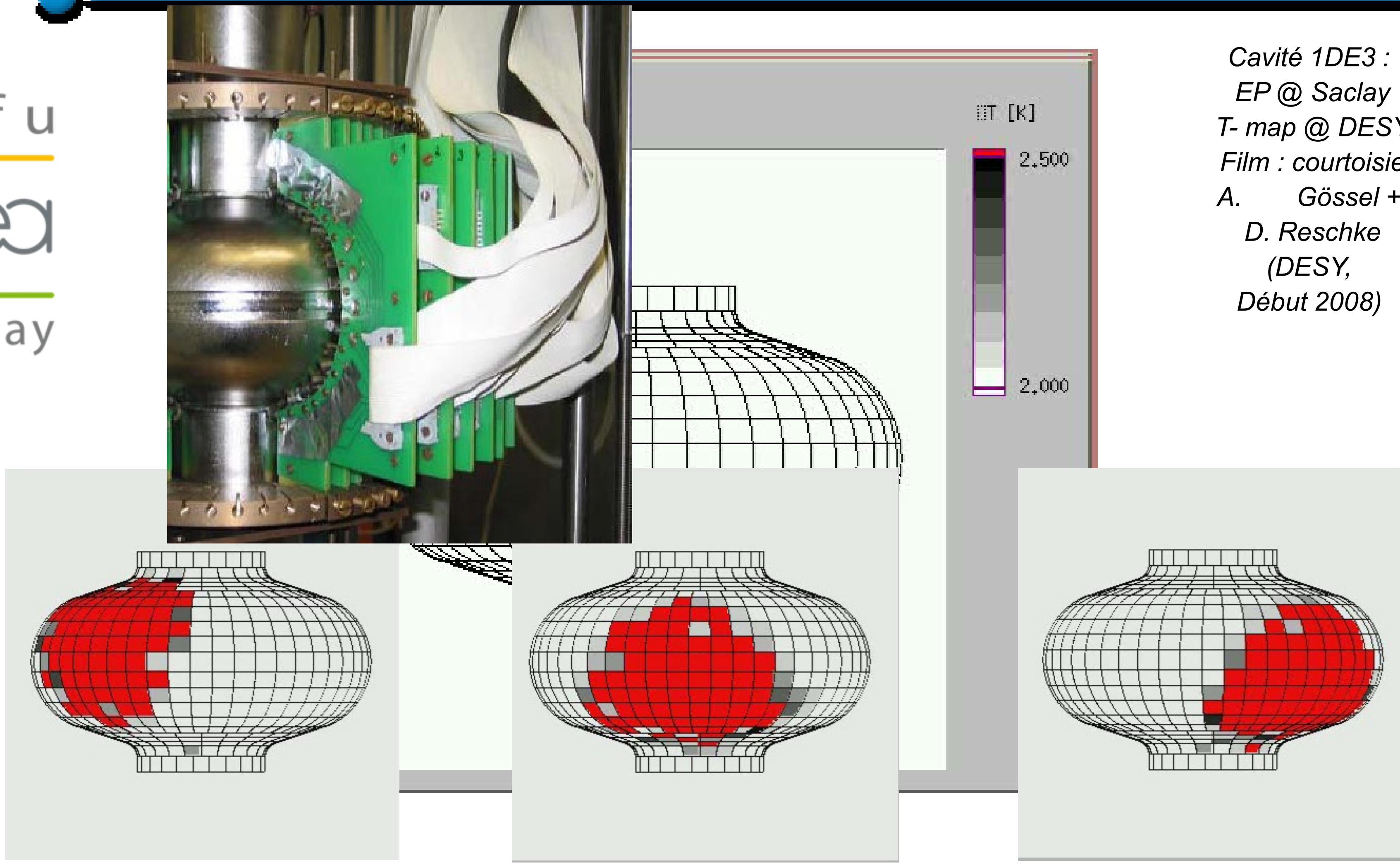


From samples to cavities :

- ALD involves the use of a pair of reagents
- Application of this AB Scheme
  - Reforms a new surface
  - Adds precisely 1 monolayer
- Viscous flow (~1 Torr) allows rapid growth
- No line of site requirements

- **=> uniform layers, larges surfaces, well adapted to complex shapes : cavities!**
- **up grade of existing cavities ?**

Bulk Nb ultimate limits : not far from here !



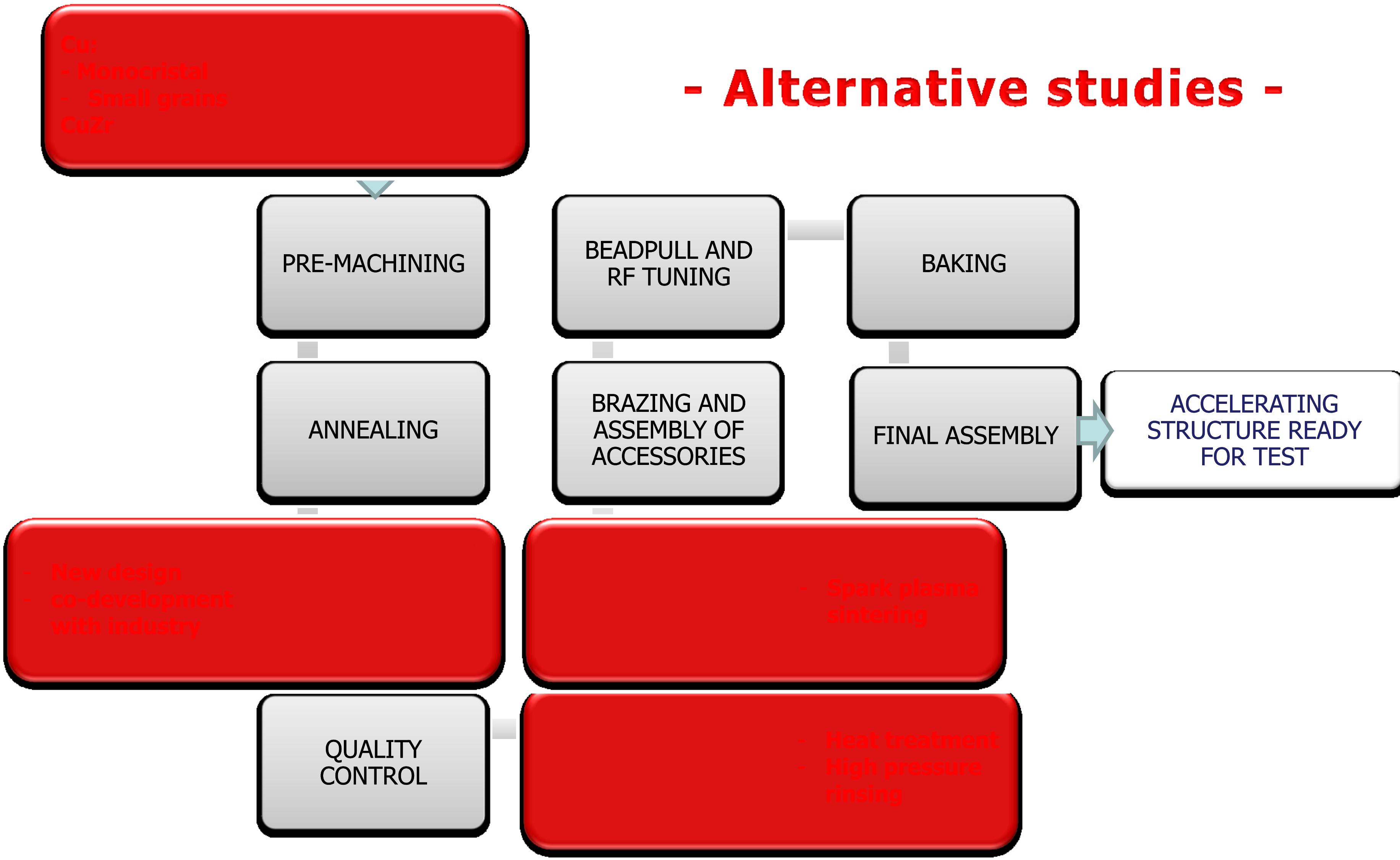
Cavité 1DE3 : EP @ Saclay T- map @ DESY Film : courtoisie A. Gössel + D. Reschke (DESY, Début 2008)

The hot spot is not localized : the material is ~ equivalent at each location
=> cavity not limited /local defect, but by material properties ?

Rappels sur les principaux supras

Matériau	T_C (K)	ρ_n (μWcm)	H_C (Tesla)*	H_{C1} (Tesla)*	H_{C2} (Tesla)*	λ_L (nm)*	Type
Pb	7,1		0,08	n.a.	n.a.	48	I
Nb	**9,22**	**2**	**0,2**	**0,17**	**0,4**	**40**	II
Mo_3Re	15		0,43	0,03	3,5	140	II
NbN	17	70	0,23	0,02	15	200	II
V_3Si	17						II
NbTiN	17,5	35		0,03		151	II
Nb_3Sn	18,3	20	0,54	0,05	30	85	II
Mg_2B_2	40		0,43	0,03	3,5	140	II-2gaps
YBCO	93		1,4	0,01	100	150	d-wave

Fabrication process of X band structures



52