Working Group 1

WG1 Summary & Plan
with Recommendations to the CB

Key Aims for WG1

- Confirm baseline layout for Low/High B sections
  - Performance of the different layout options
  - Stability/repeatability attainable in presence of microphonics, Lorenz detuning, detuned cavities, reflections due to RF distribution component imperfections
  - Difficulties with long waveguides (e.g. for RF Feedbacks)?
- Power Margins needed – identify & quantify definitively – bad/good cavities
- Klystron Modulator specs and design options – HPSPL needs, including space & integration !
- Power Coupler options – existing design & experience, overall review, requirements to get to high power – studies needed, prototyping requirements
- Integration studies, get first version of Klystron Gallery layout / Integration
- Investigate cost-cutting solutions in the RF Power and LLRF systems

List of Presentations

Modulators - Company Presentation SCANDINOVA	Klas Elmquist (*SCANDINOVA SYSTEMS AB*)
Magnetron Power Sources	Amos Dexter (Lancaster U.)
Tuner design and performance	Guillaume Devanz (CEA)
Coupleurs XFEL-Spécifications Techniques et Stratégie Industrielle	Aboud Falou (LAL)
Conditionnement HF des coupleurs TTF-3 et critères XFEL	Lucija Lukovac (LAL)
CEA Saclay Coupler Tests	Guillaume Devanz CEA)
SPL coupler options and integration requirements	Eric Montesinos (CERN)
Development paths for High average RF Power Couplers	Eric Montesinos (CERN)
Lorentz force detuning measurements on the CEA cavity	Daniel Valuch (CERN)
RF simulations	W. Hofle, Mathias Hernandez (CERN)

+ Specialist Input – R. Rimmer, (JLAB) R. Pasquinelli (Fermilab)

Modulators - SCANDINOVA – K. Elmquist

Klystron Modulator Specs

One modulator per klystron, driving 2 cavities

LP-SPL (500 kW on cavity)
flat top: 1.8 ms
rep-rate: 2 Hz
voltage: 110 kV
droop: 5%
power: 3.2-3.4 MW (500 kW per cavity) + margin for splitting and LLRF + 50% klystron efficiency)

HP-SPL (1 MW on cavity)
flat top: <2.1 ms
rep-rate: 50 Hz
voltage: 110 kV
droop: 5%
power: 6.4-6.8 MW (1 MW per cavity + margin for splitting and LLRF + 50% klystron efficiency

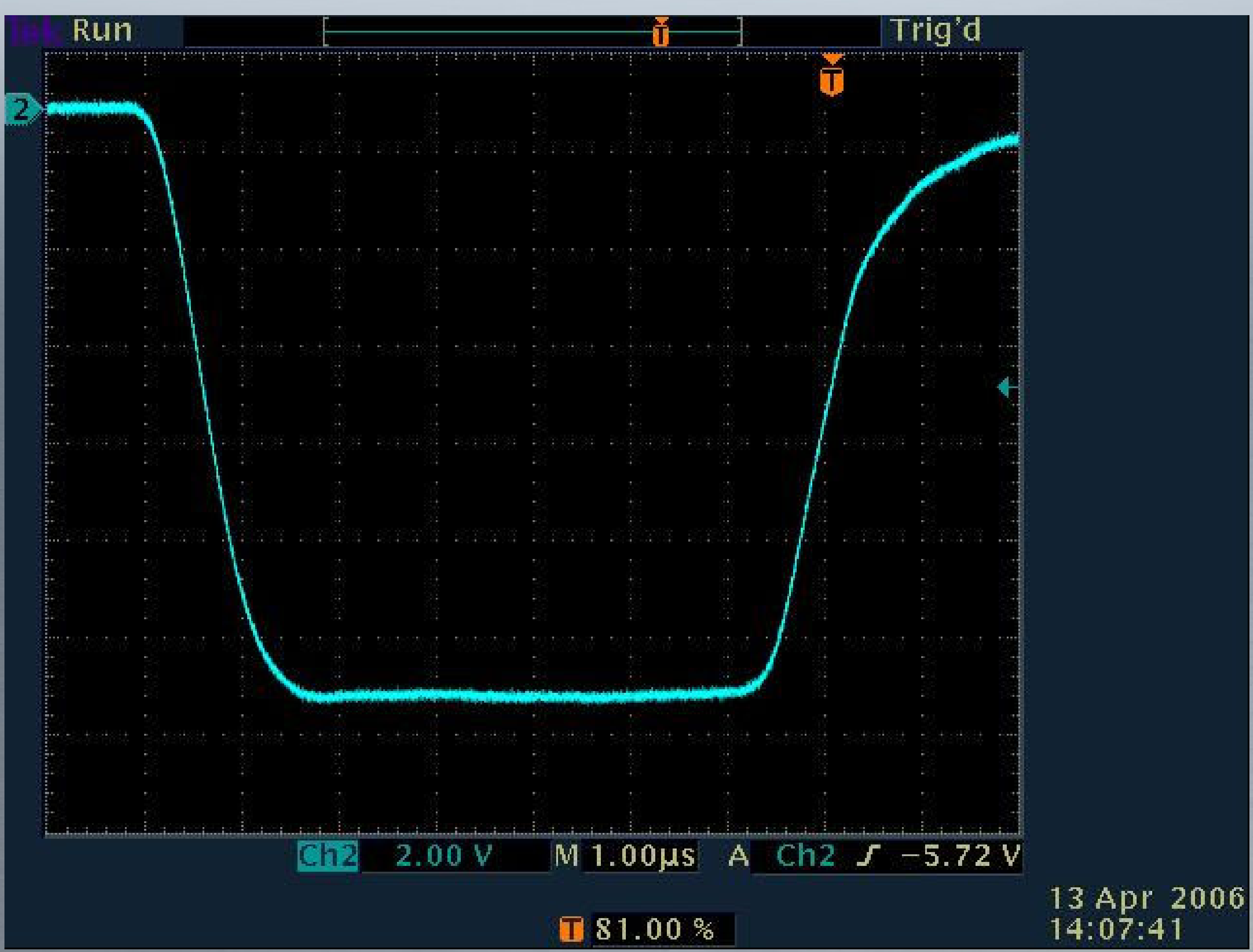
K2-SYSTEM FOR PSI 351kV / 416A

ScandiNova

NEXT

K1-SYSTEM KLYSTRON PULSE 140kV

ScandiNova

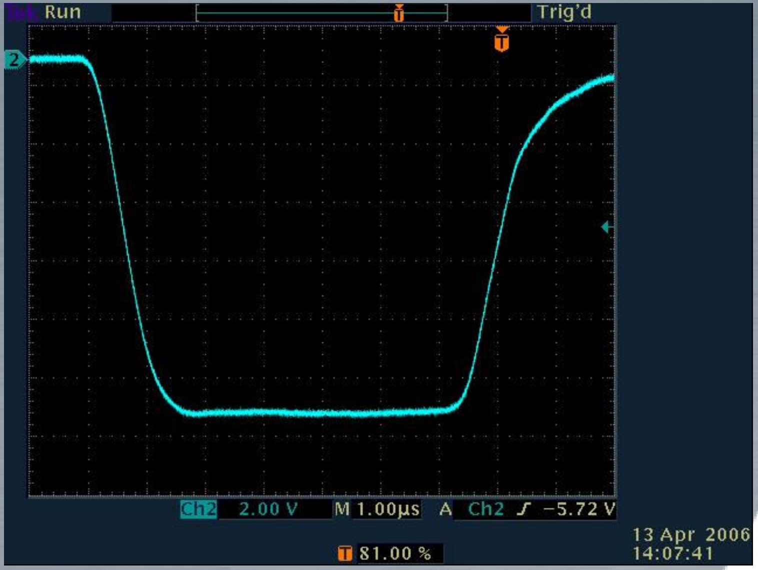


NEXT

ACHIEVED LEVELS

ScandiNova

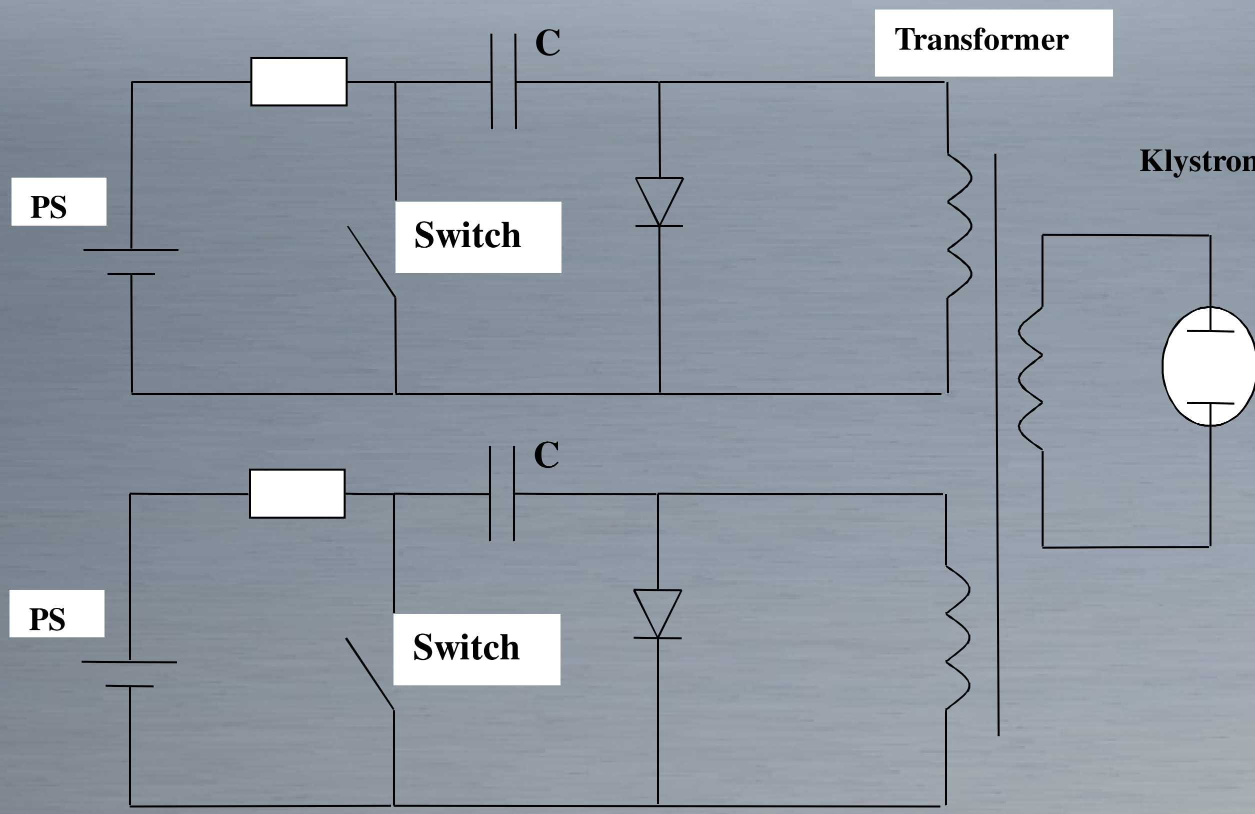
Parameter	Value
Peak Power	147 MW
Average Power	106 kW
Pulse Voltage	507 kV
Pulse Current	4000 A
Pulse length	25 us
Pulse Repetition Rate	1000 Hz
Rise time	286 kV/us
Fall time	280 kV/us
Pulse flatness	± 0.05%
Pulse to Pulse stability	± 0.002%



NEXT

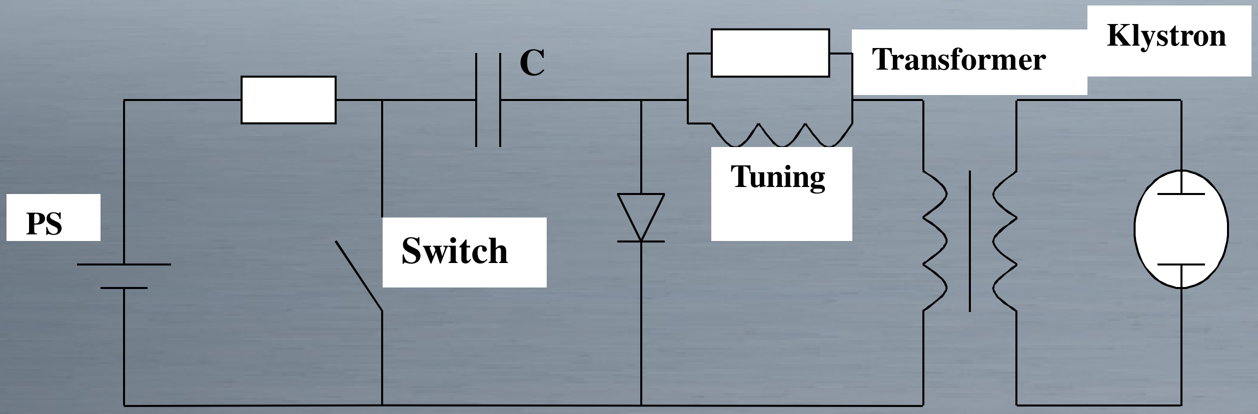
Basic schematic of the Scandinova modulator

N = number of primary circuits
R = Klystron Resistance
N_T= Transformer ratio (Has to be compensated for with **N**)



NEXT

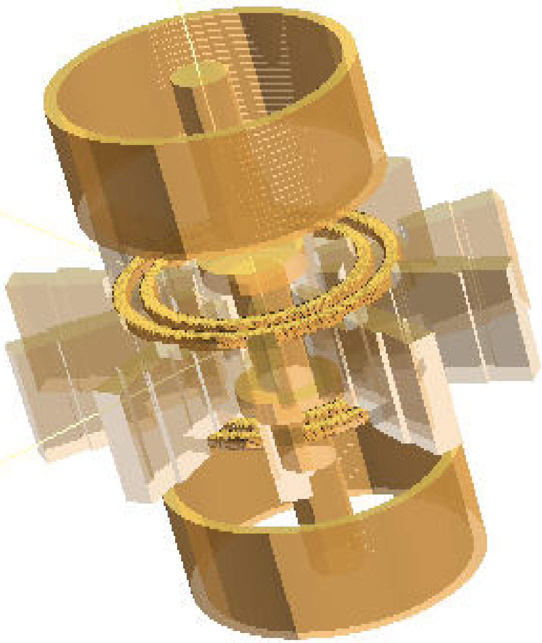
Tuning

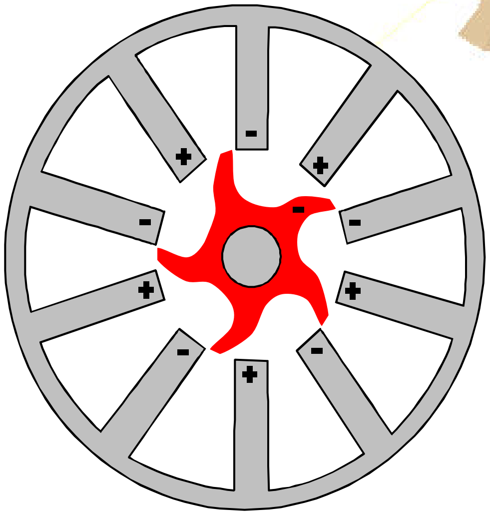


Rt = Tuning resistance
Lt= Tuning inductance

A magnetron solution for SPL?

Amos Dexter, Imran Tahir, Bob Rimmer and Richard Carter





Magnetrons for Accelerators

Single magnetrons 2.856 GHz, 5 MW, 3μs pulse, 200 Hz repetition are used to power linacs for medical and security applications.

Multiple magnetrons have been considered for high energy normal conducting linacs but the injection power needed for an unstabilised magnetron made it uncompetitive with a Klystron.

Overett, T.; Bowles, E.; Remsen, D. B.; Smith, R. E., III; Thomas, G. E. " Phase Locked Magnetrons as Accelerator RF Sources" *PAC* 1987

Benford J., Sze H., Woo W., Smith R., and Harteneck B., "Phase locking of relativistic magnetrons" *Phys. Rev.Lett.*, vol. 62, no. 4, pp. 969, 1989.

Treado T. A., Hansen T. A., and Jenkins D.J. "Power-combining and injection locking magnetrons for accelerator applications," *Proc IEEE Particle Accelerator Conf.,* San Francisco, CA 1991.

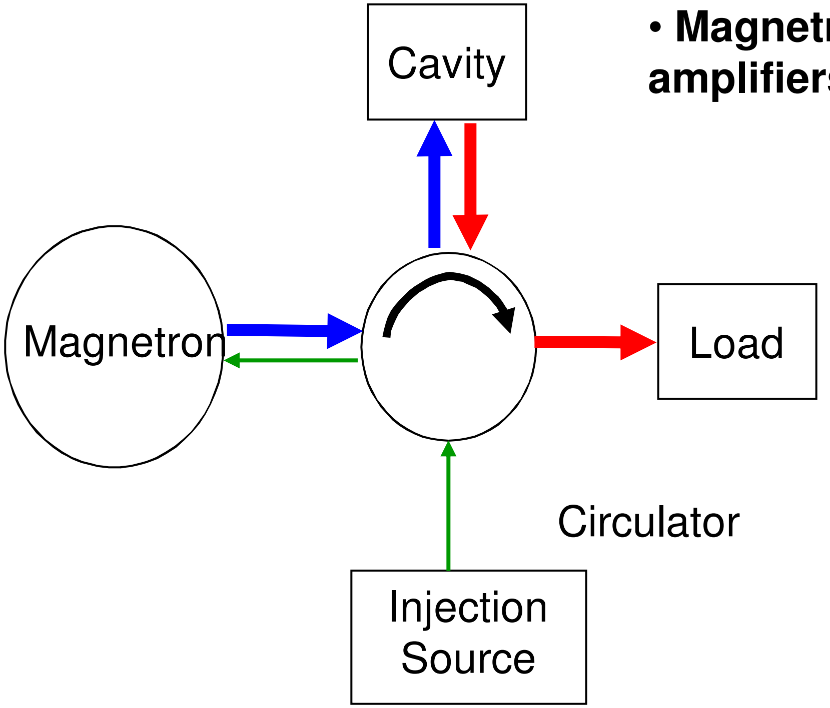
Chen, S. C.; Bekefi, G.; Temkin, R. J. " Injection Locking of a Long-Pulse Relativistic Magnetron" *PAC* 1991

Treado, T. A.; Brown, P. D.; Hansen, T. A.; Aiguier, D. J. " Phase locking of two long-pulse, high-power magnetrons" , *IEEE Trans. Plasma Science,* vol 22, p616-625, 1994

Treado, Todd A.; Brown, Paul D., Aiguier, Darrell "New experimental results at long pulse and high repetition rate, from Varian's phase-locked magnetron array program" Proceedings *Intense Microwave Pulses,* SPIE vol. 1872, July 1993

Courtesy of e2v

The Reflection Amplifier



- **Linacs require accurate phase control**
- **Phase control requires an amplifier**
- **Magnetrons can be operated as reflection amplifiers**

Compared to Klystrons, in general Magnetrons

- are smaller
- more efficient
- can use permanent magnets (at 704 MHz)
- utilise lower d.c. voltage but higher current
- are easier to manufacture

Consequently they are much cheaper to purchase and operate

J. Kline "The magnetron as a negative-resistance amplifier," *IRE Transactions on Electron Devices*, vol. ED-8, Nov 1961

H.L. Thal and R.G. Lock, "Locking of magnetrons by an injected r.f. signal", *IEEE Trans. MTT*, vol. 13, 1965

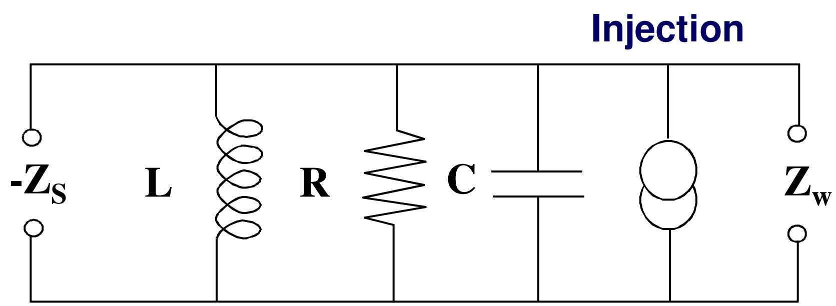
sLHC Adler's Equation for Injection Locking

J.C. Slater "The Phasing of Magnetrons" MIT Technical Report 35, 1947

Shien Chi Chen "Growth and frequency Pushing effects in Relativistic Magnetron Phase – Locking", IEEE Trans. on Plasma Science Vol. 18 No 3. June 1990.

The basic circuit model for the phased locked magnetron is the same as for a cavity

Negative impedance to represent magnetron spokes excitation of the anode. Includes static pushing effects.



Load impedance includes pulling effects.

$$\ddot{V} - \frac{\omega_o}{Q_w}\left(\frac{Z_w}{Z_s} - \frac{Z_w}{R} - 1\right)\dot{V} + \omega_o^2 V = -j\frac{\omega_o\omega_i}{Q_w} V_{inj}\exp(-j\omega_i t)$$

To get Adler's equation set $V(t) = A(t)\exp\{-j(\omega t + \psi(t))\}$

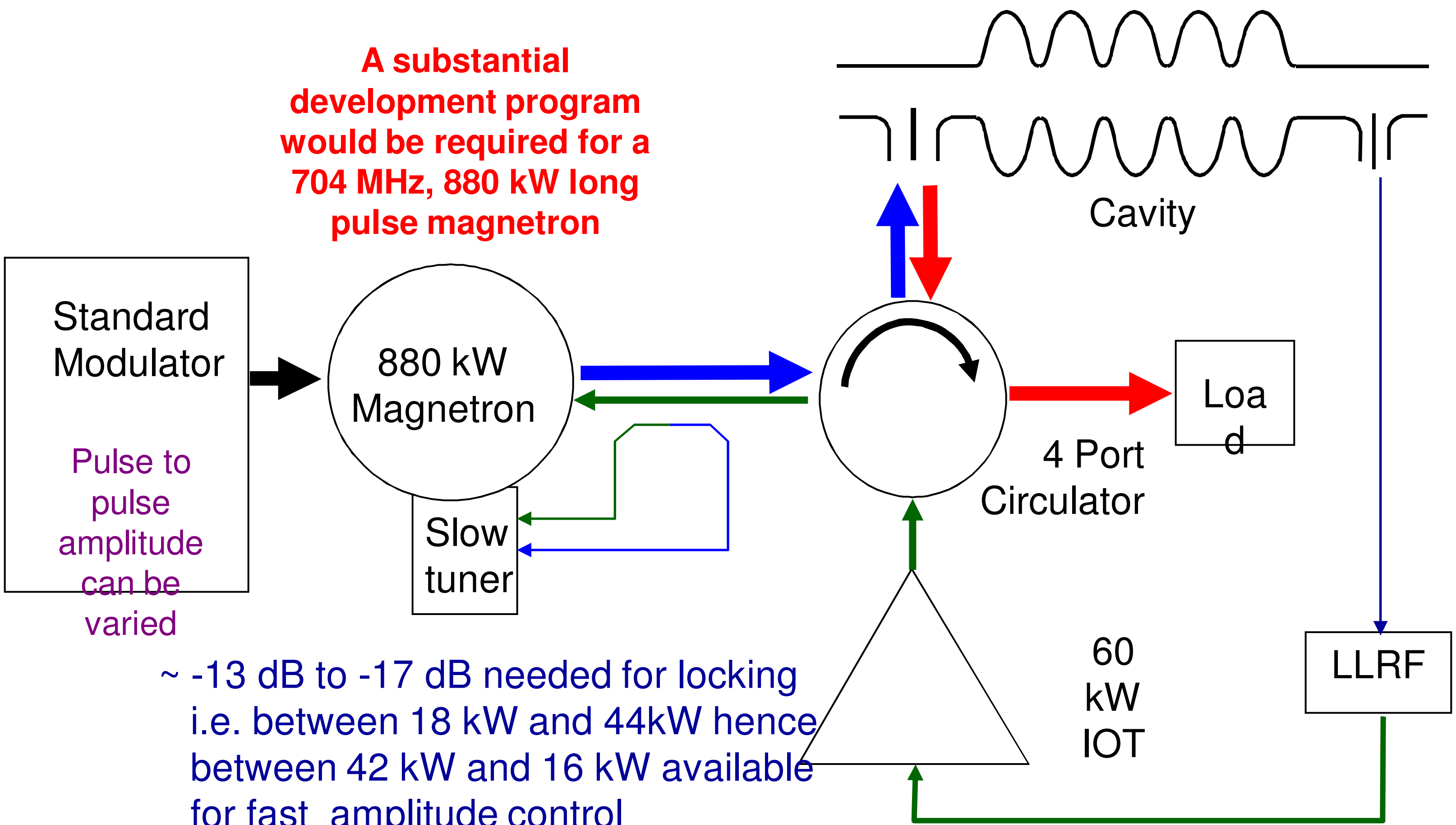
to give

$$\frac{d\psi}{dt} = -\frac{V_{inj}}{V_{RF}}\frac{\omega_o}{2Q_L}\sin\psi + \omega_o - \omega_i$$

Layout using one magnetron per cavity

Permits fast phase control but only slow, full range amplitude control

A substantial development program would be required for a 704 MHz, 880 kW long pulse magnetron

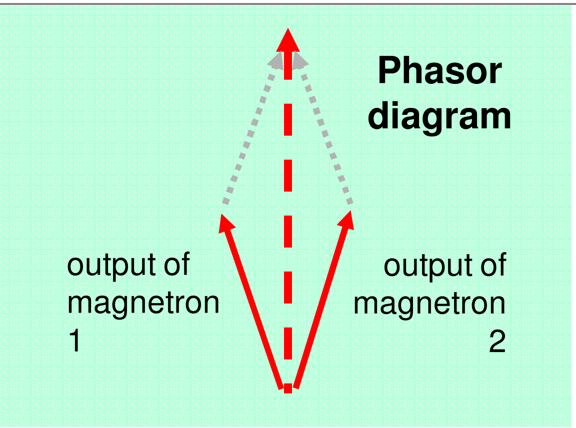


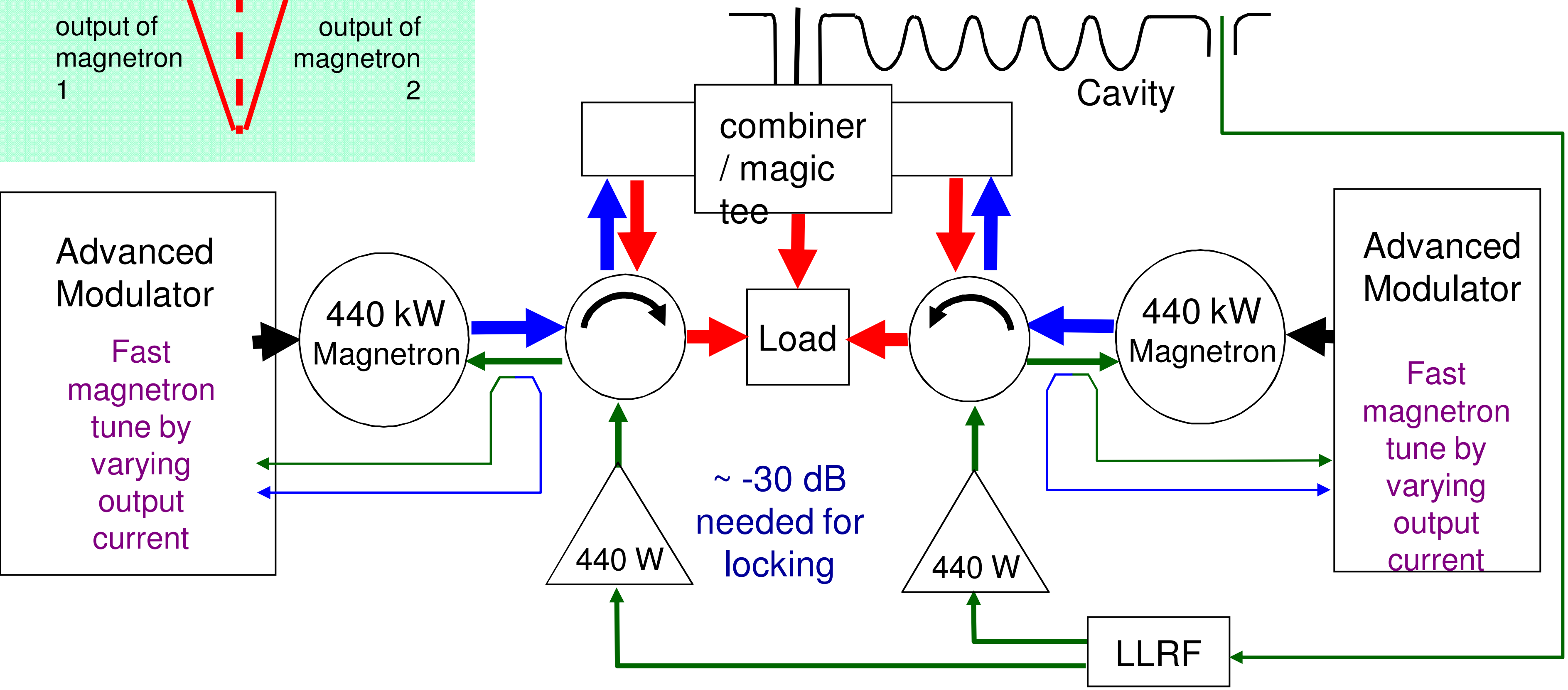
~ -13 dB to -17 dB needed for locking i.e. between 18 kW and 44kW hence between 42 kW and 16 kW available for fast amplitude control

Could fill cavity with IOT then pulse magnetron when beam arrives

Layout using two magnetrons per cavity

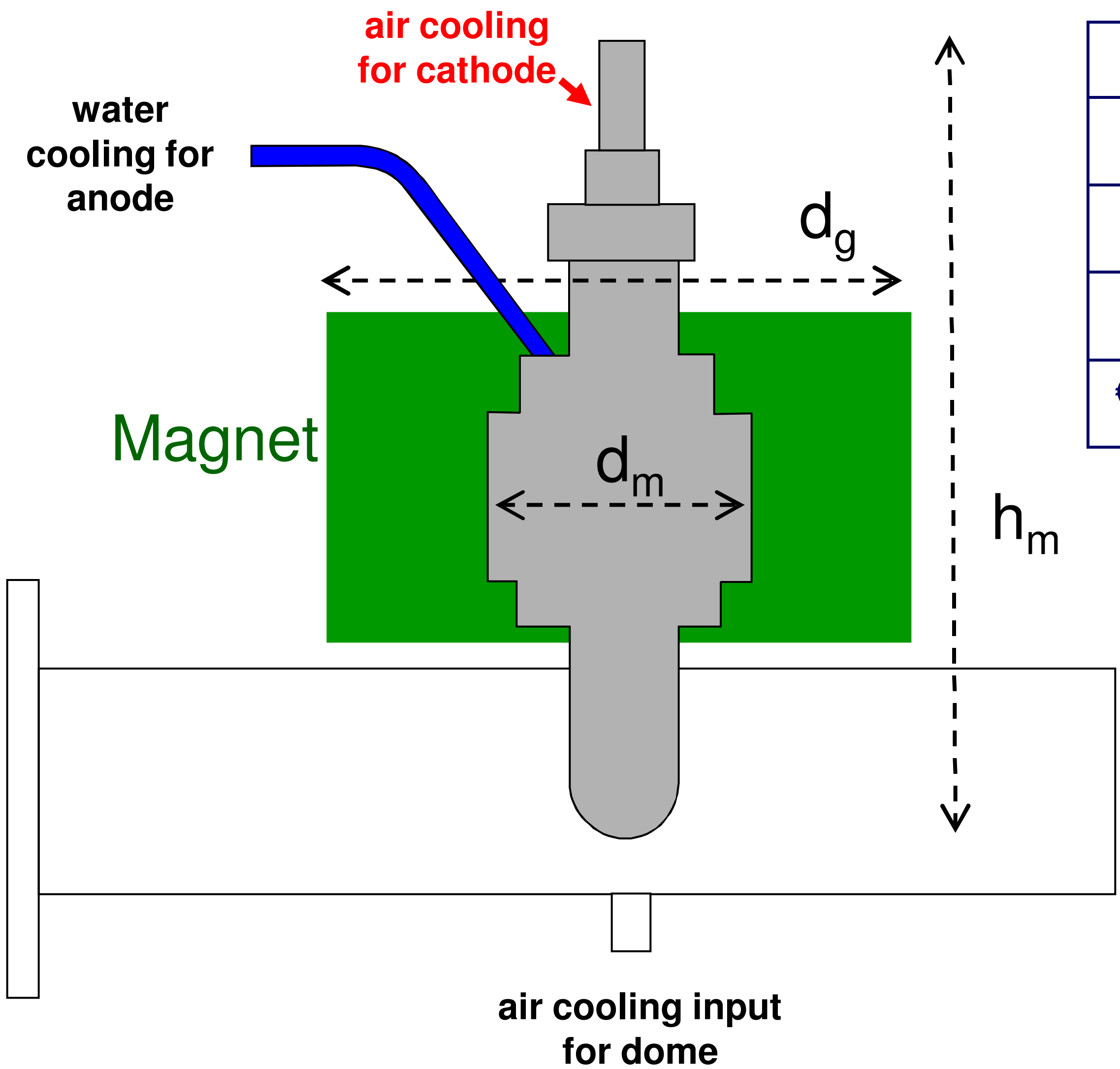
Permits fast full range phase and amplitude control





440 kW Magnetron design is less demanding than 880 kW design reducing cost per kW, and increasing lifetime and reliability.

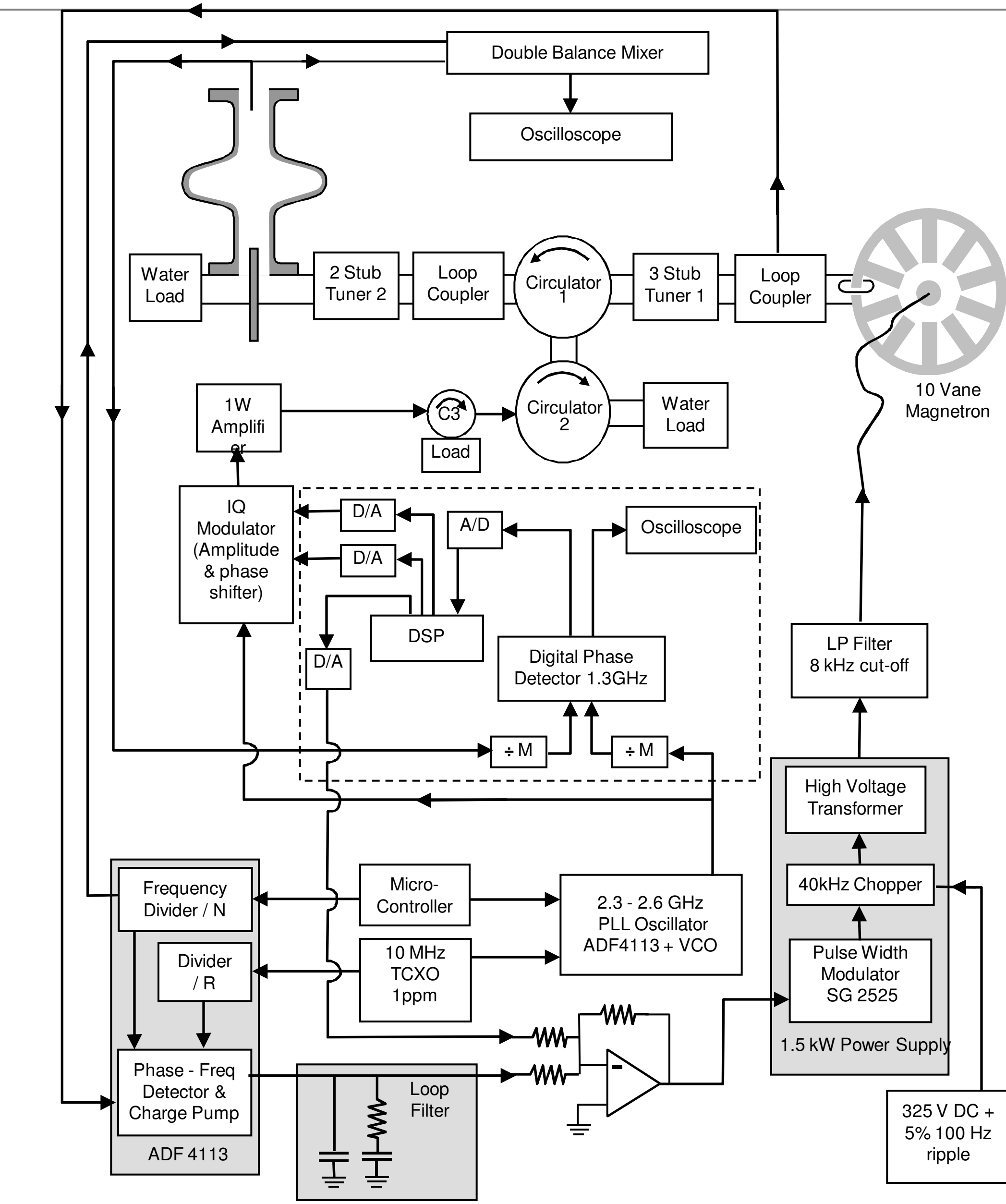
Magnetron Size

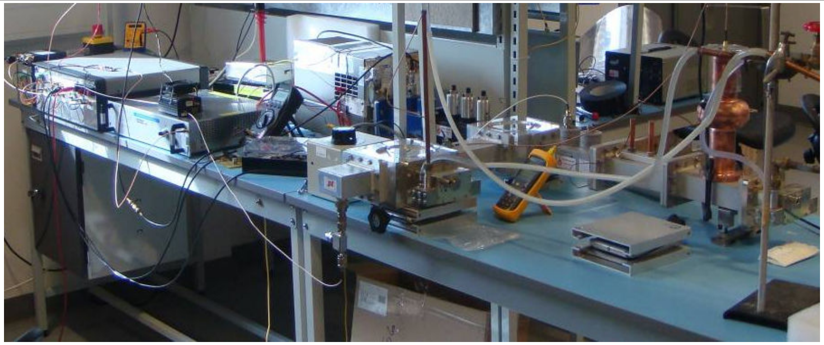


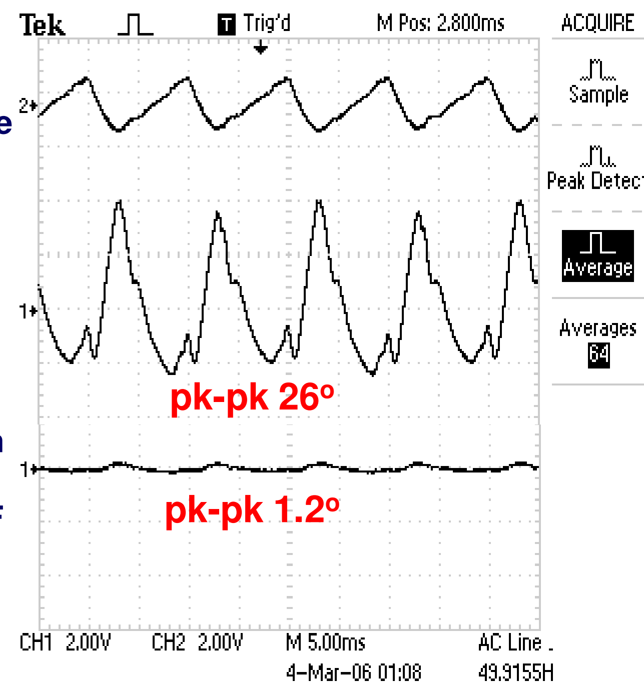
	915 MHz	704 MHz
d_g	325 mm	~ 425 mm
d_m	125 mm	~ 165 mm
h_m	500 mm	~ 650 mm
€ tube	€ 8000	?

If magnetron design is similar to industrial design with similar tolerances and can be made on same production line then cost may not be much more

Experiments at Lancaster







Power supply ripple

Magnetron phase no LLRF

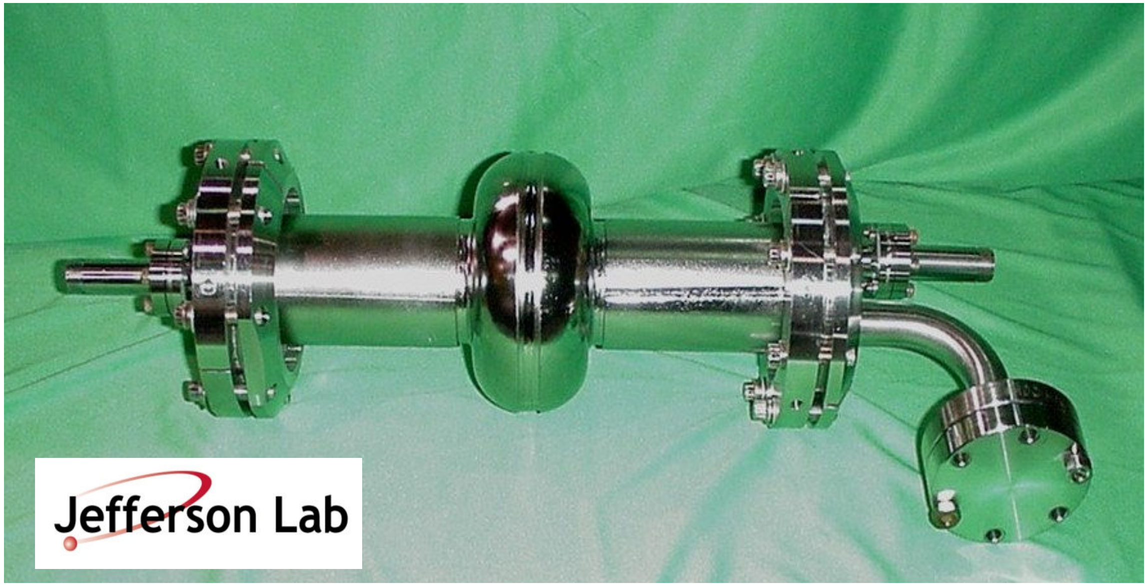
pk-pk 26°

Magnetron phase with LLRF

pk-pk 1.2°

Way Forward

- Commission the development of a 704MHz Magnetron (440kW)
- Procure standard modulator
- Set up test station with IOT as drive amplifier
- Understand locking characteristics of new magnetron
- Commission advanced modulator with in-pulse current control
- Establish minimum locking power
- Establish two magnetron test stand
- Develop LLRF for simultaneous phase and amplitude control



Demonstration of CW 2.45 GHz magnetron driving a specially manufactured superconducting cavity at JLab due later this month should stimulate more interest.

Tuner Design & Performance

G. Devanz (CEA)

Tuning system requirements

Can be corrected with room temperature tuning using plastic deformation:

- Fabrication tolerances
- Main cavity treatments :
  - 800°C heat treatment against Q desease,
  - First heavy chemical treatment (150 to 200 µm)
- Field inbalance between cells

Has to be corrected with the cold tuner:

- The remaining error of the room temperature tuning
- The effect of the last chemical treatments
- The differential shrinkage of materials of the cavity, He vessel and tuner
- He Pressure, Lorentz detuning,

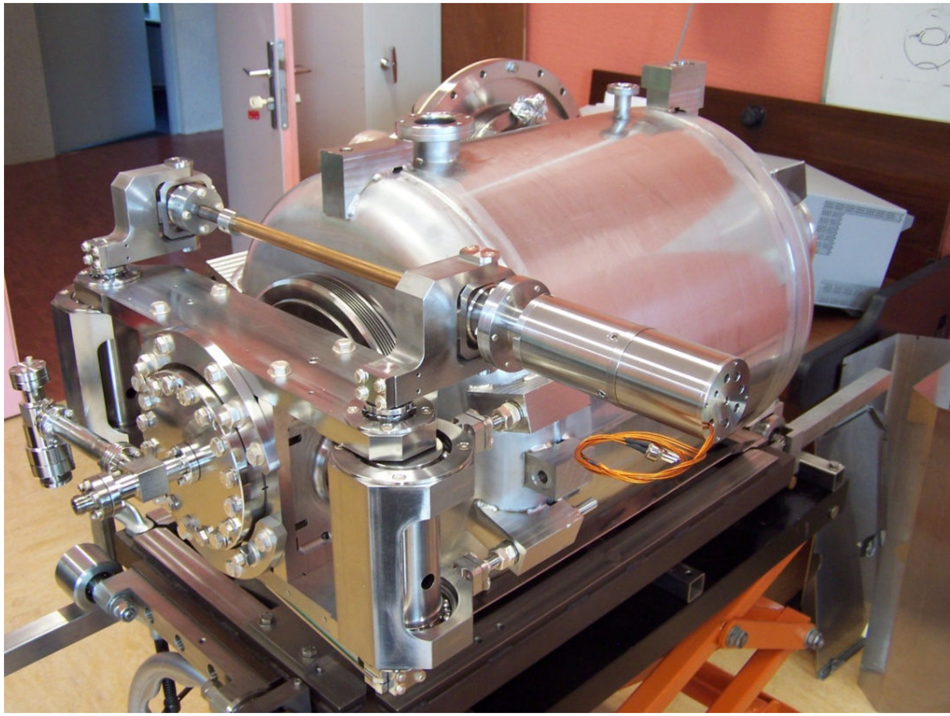
However:

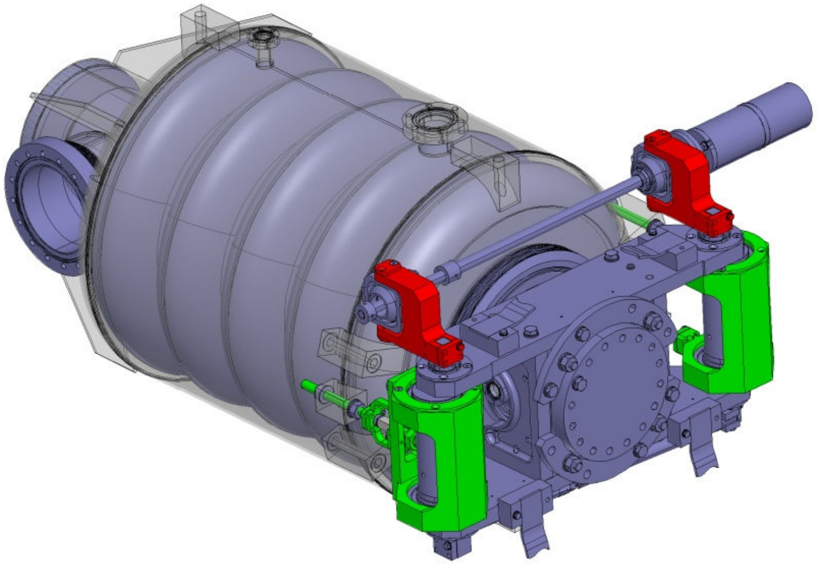
- Last points (diff. Shrinkage) can be taken into account for series cavities after the full test of the first prototype

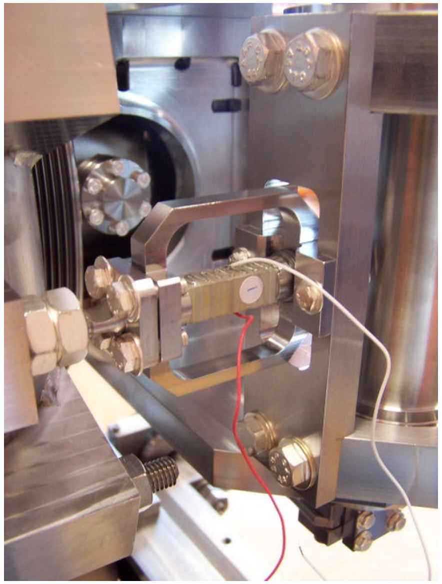
RANGE? (also operation/commissioning of the accelerator)

Saclay piezo tuner for 700MHz cavities

•Slow tuner with symmetric action
• Excentric/lever arm provenSaclay design
• Planetary gear box (3 stages)
• Single NOLIAC 30mm piezo actuator
• Stiffness measured on the tuner pneumatic jack = 35 kN/mm
• Initially developed for the beta=0.5 5-cell cavity

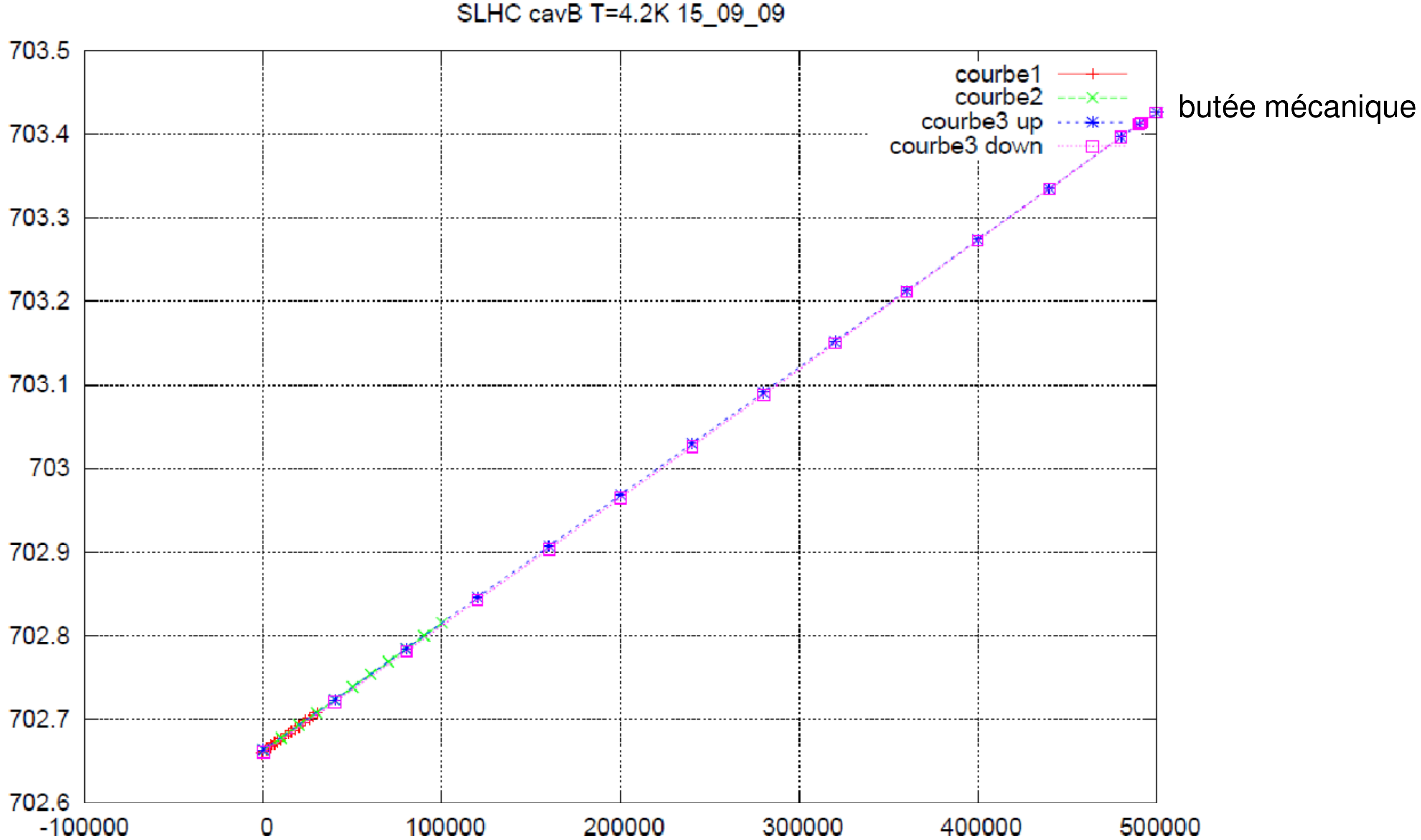






Beta 0.5 cavity tuning

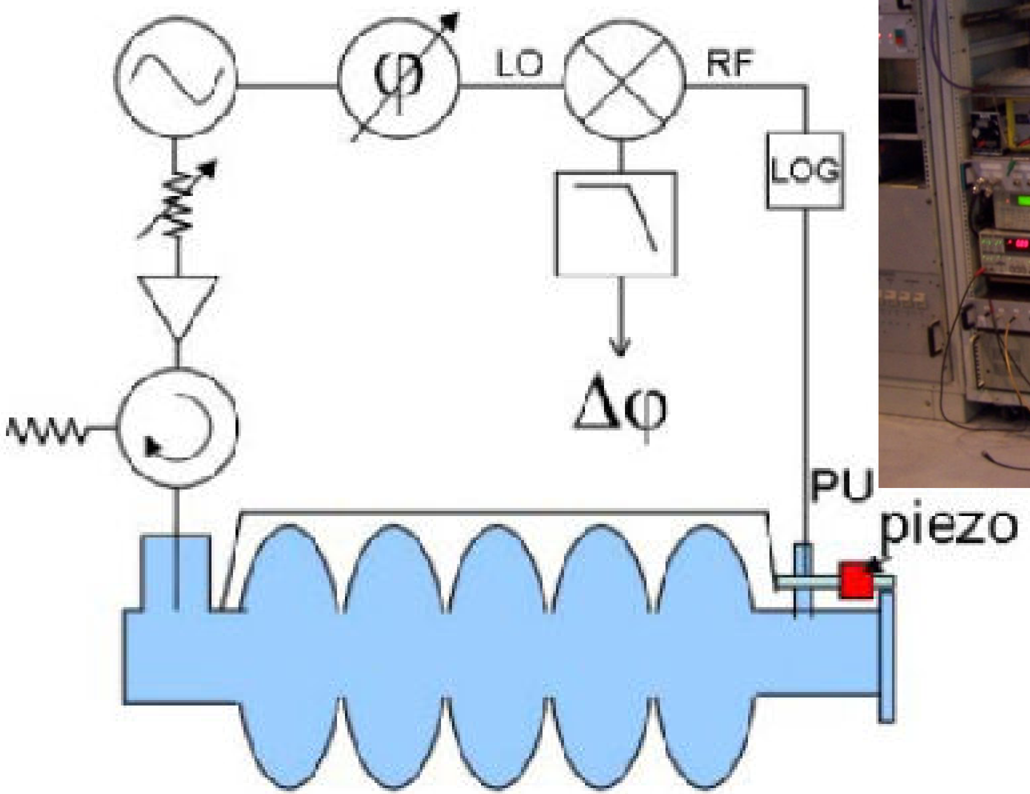
- 4.5 K, amplitude = +760kHz corresponding to 2.5 mm -> would be +400 kHz on SPL beta=1 cavity
- Mechanical hysteresis measurements will be done at 2 K



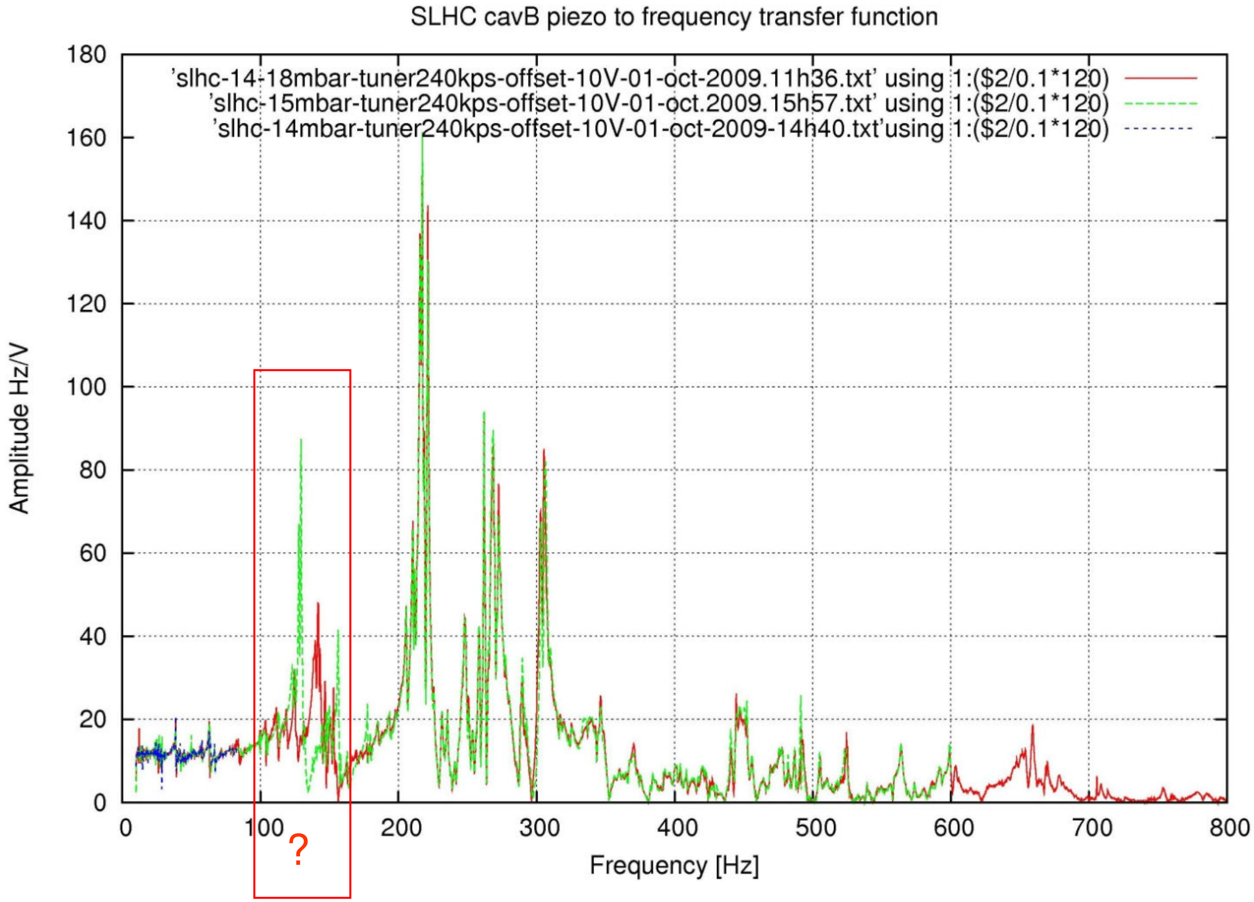
G. Devanz CEA-Saclay, SPL 3rd coll. meeting

Irfu cea saclay

Transfer function measurements



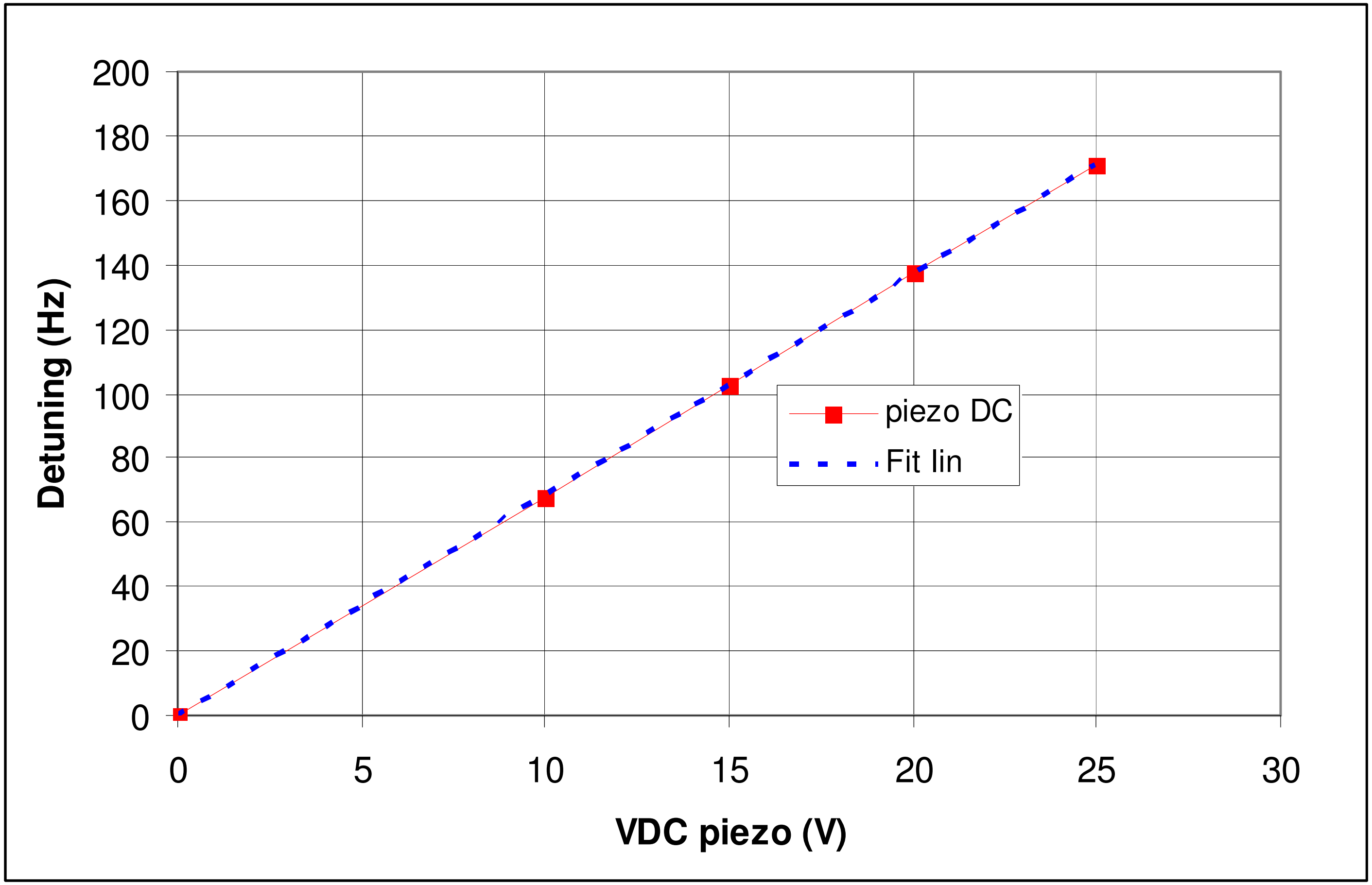
Transfer function measurements



Phase demodulation measurements at 1.8K in Cryholab
TF piezo drive voltage -> cavity detuning can be used to identify the mecanical modes of the system, especially modes generating most detuning (220 Hz)
Reproductible measurements except in the 100-160 Hz range (why?)

Fcav=703 MHz, far from tuner neutral point

Piezo detuning (DC)



measured at 1.8 K (main tuner parts at 20 K)
piezo 44V for 1 μm elongation of the cavity (~2 μm for the piezo actuator)
Maximum detuning measured at 150V DC = +1 kHz

Conclusion

- Piezo tuner is working as expected
- Caracterization of the cavity is going on
- Lorentz Force Detuning compensation not yet tested, will be done with the fixed and modified HPVS, with long pulses 2ms, 50 Hz
- Preliminary compensation tests with 2 ms, 5 Hz are foreseen in the upcoming weeks
- The CERN crate is working now as an fast IQ acquisition system, will be used as the piezo controler, and ultimately a adaptive feed-forward for LFD compensation could be implemented.

Power Couplers - Presentations

- Coupleurs XFEL - A. Falou (LAL)
- Conditionnement Coupleurs TTF-3 - L. Lukovac (LAL)
- CEA Coupler Tests – G. Devanz (CEA)
- SPL Coupler Options Integration - E. Montesinos (CERN)
- Development of High av. power Couplers - E. Montesinos (CERN)

SPL 3rd Collaboration Meeting
(CERN/ from 11 to 13 November 2009)

Aboud Falou (LAL-Orsay)

XFEL Power Couplers 1.3GHz

Technical Specification & Industrial Strategy

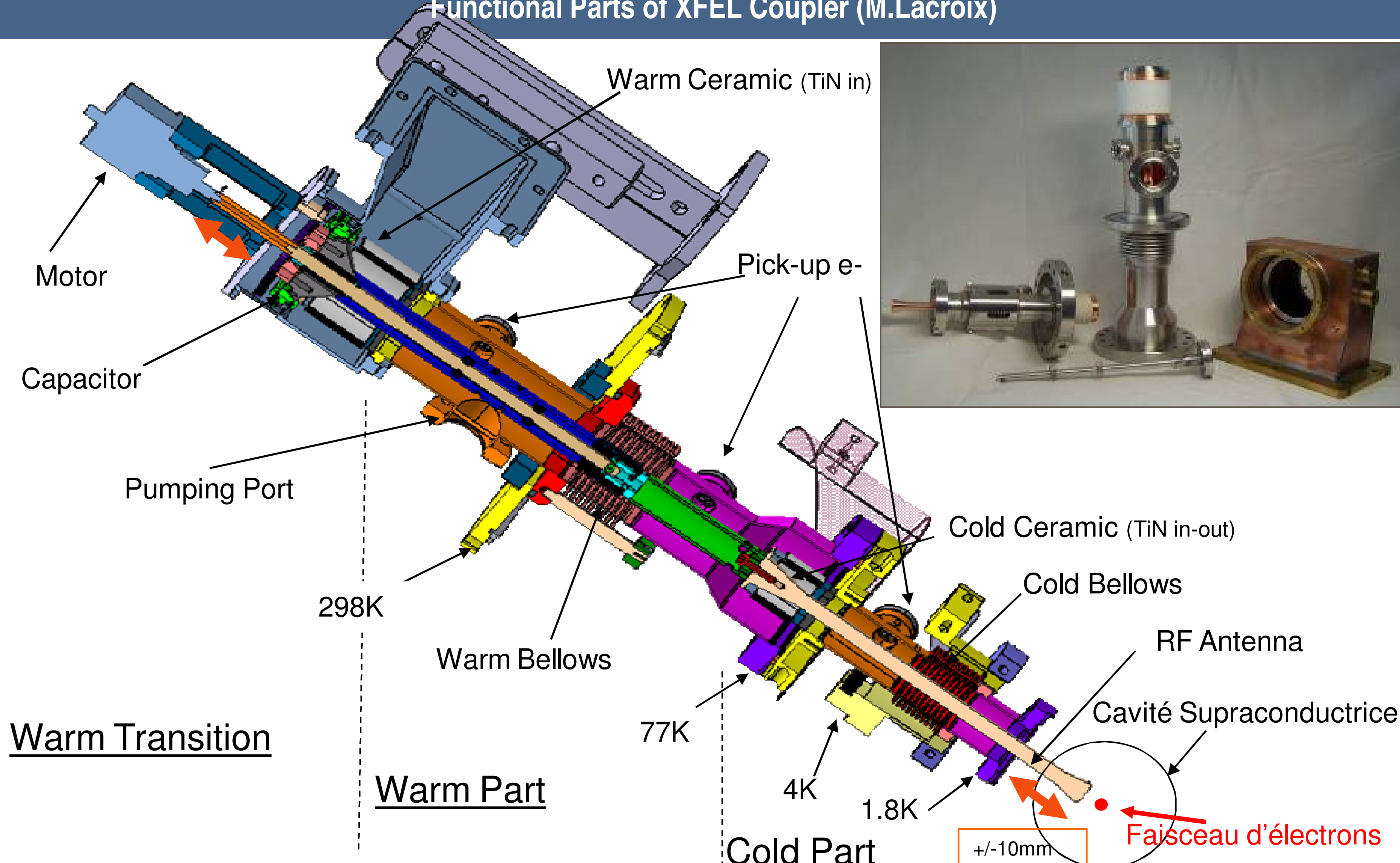
LAL contribution to XFEL linac at DESY

SOMMARY

- Power Couplers main components & technical performance
- Interfaces with cryomodule & string cavities
- Industrial studies & coupler prototypes
- RF contact evaluation
- Market Strategy for mass production (Technical Specifications)
- Manufacturing Sequence & Transport/Storage logistic
- Time schedule 2009/2012

XFEL RF Couplers/ from R&D to Mass Production

Functional Parts of XFEL Coupler (M.Lacroix)



XFEL RF Couplers/ from R&D to Mass Production

Major non conformities (TTF-3 Inspections)

- SS welding performance (full penetration, roughness & seam flatness at RF side).
- Cupper/ceramic brazing (tensile resistance, tightness, metallic projections).
- TiN & Cu surface coating (matrix adhesion, thickness control, roughness, boundary lines).
- Final ‘welding’ assembly (alignment of in/out conductors, penetration, metallic projections).
- Cleaning procedures, difficult access to residual particles.
- Wave Guide Boxes soldering (lack or excess of metal, acid discoloration).
- RF contact between Wave Guide Box & coupler flanges (misalignment, sparks).
- Translation mechanism of RF antenna (alignment, mechanical constraints).
- Bolting dysfunction under UHV environment (grippage).

. Brazing final assembly, 2 proto Feb 2008 from Toshiba

- Cleaning non conformity, couplers complete dismounting at LAL, fully cleaning up, drying and remounting.
- Automatic RF processing failed, many vacuum interlocks. RF manual processing was successful.
- Possible failure reasons: High T°C TiN cycles, Hollow antenna.

. EB weld final assembly, 2 proto March 2008 from Accel

- Cleaning non conformity, back to the company and fully cleaned up.
- Automatic RF processing successful, few interlocks.
- RF contact failed during sweeps (capacitor springs assembly).

. EB weld final assembly, 2 from Thales (Tin & Cr2O3)

- Automatic RF processing successful, few interlocks.
- RF contact identical to TTF-3 design.

. EB weld final assembly, many TTF-3 couplers from CPI

- Automatic RF processing successful, few interlocks.
- Engineering non conformance during visual inspections.
- Couplers under operation at FLASH experiment.

XFEL RF Couplers/ from R&D to Mass Production

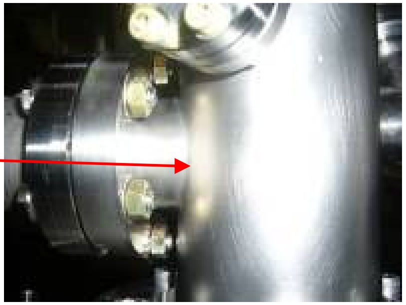
Industrial Studies/ Accepted & rejected proposals {manufacturing techniques}

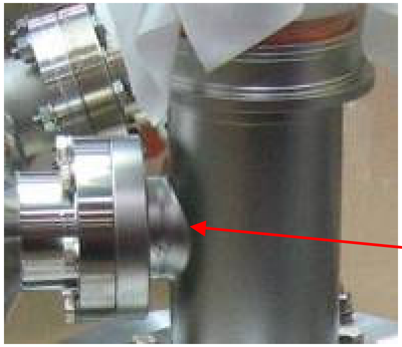
Single Block Machining,

Non optimized cost

Forming by Deep drawing, recommended

Saddle weld, not recommended





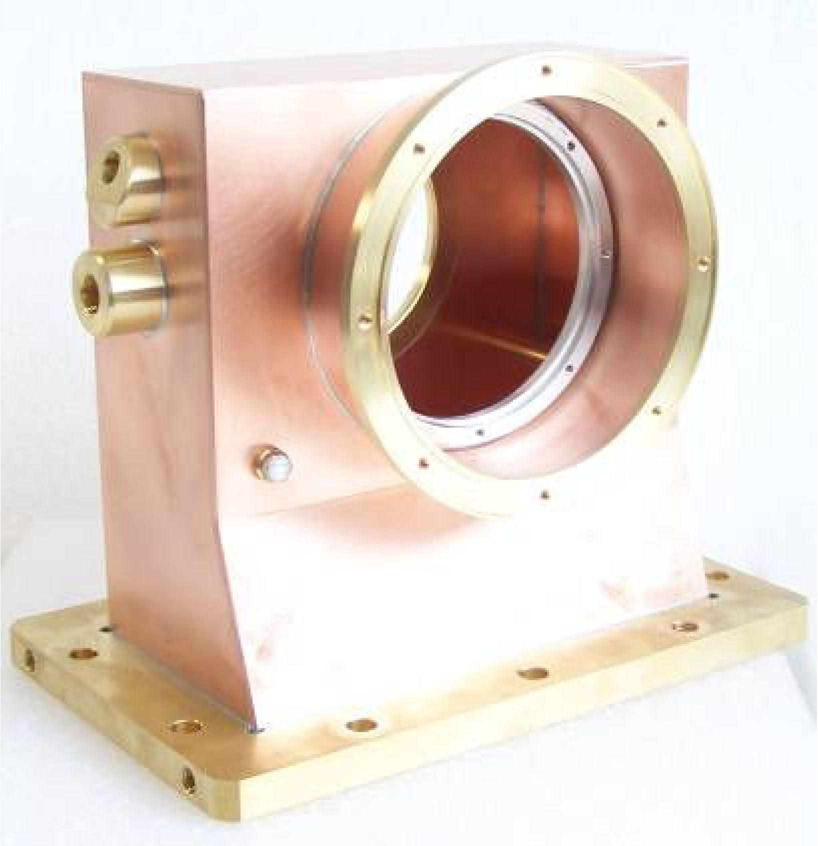
Pull out + circular weld

Smooth RF surface

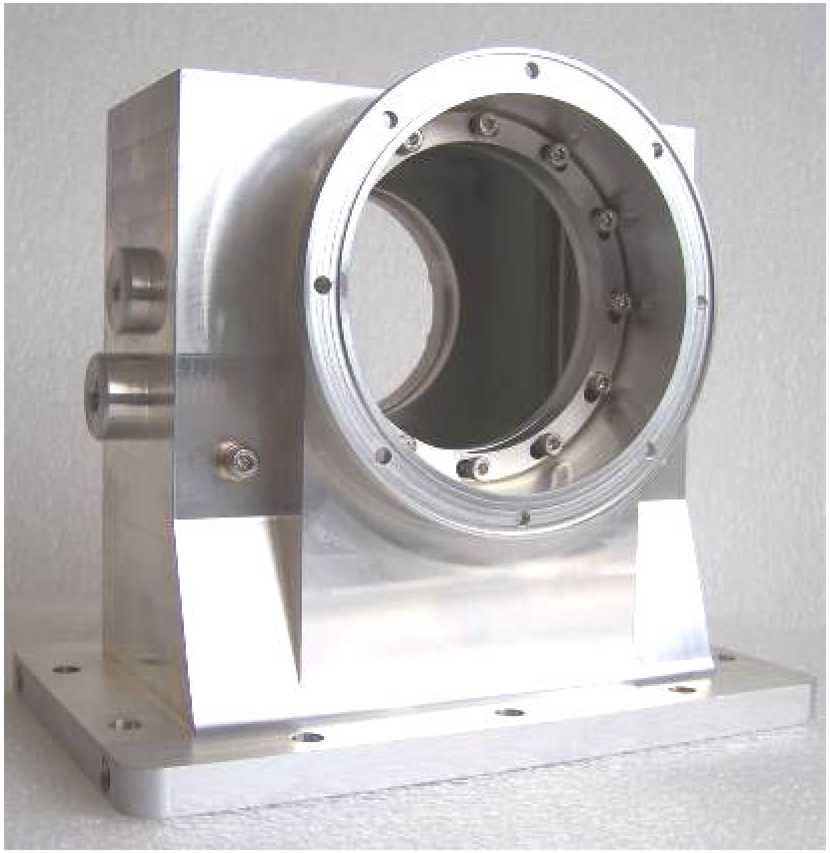
Final brazed assembly, not accepted to prevent TiN coating

Final EB or TIG weld, recommended.

Industrial Studies/ Accepted & rejected proposals {Wave Guide Box}



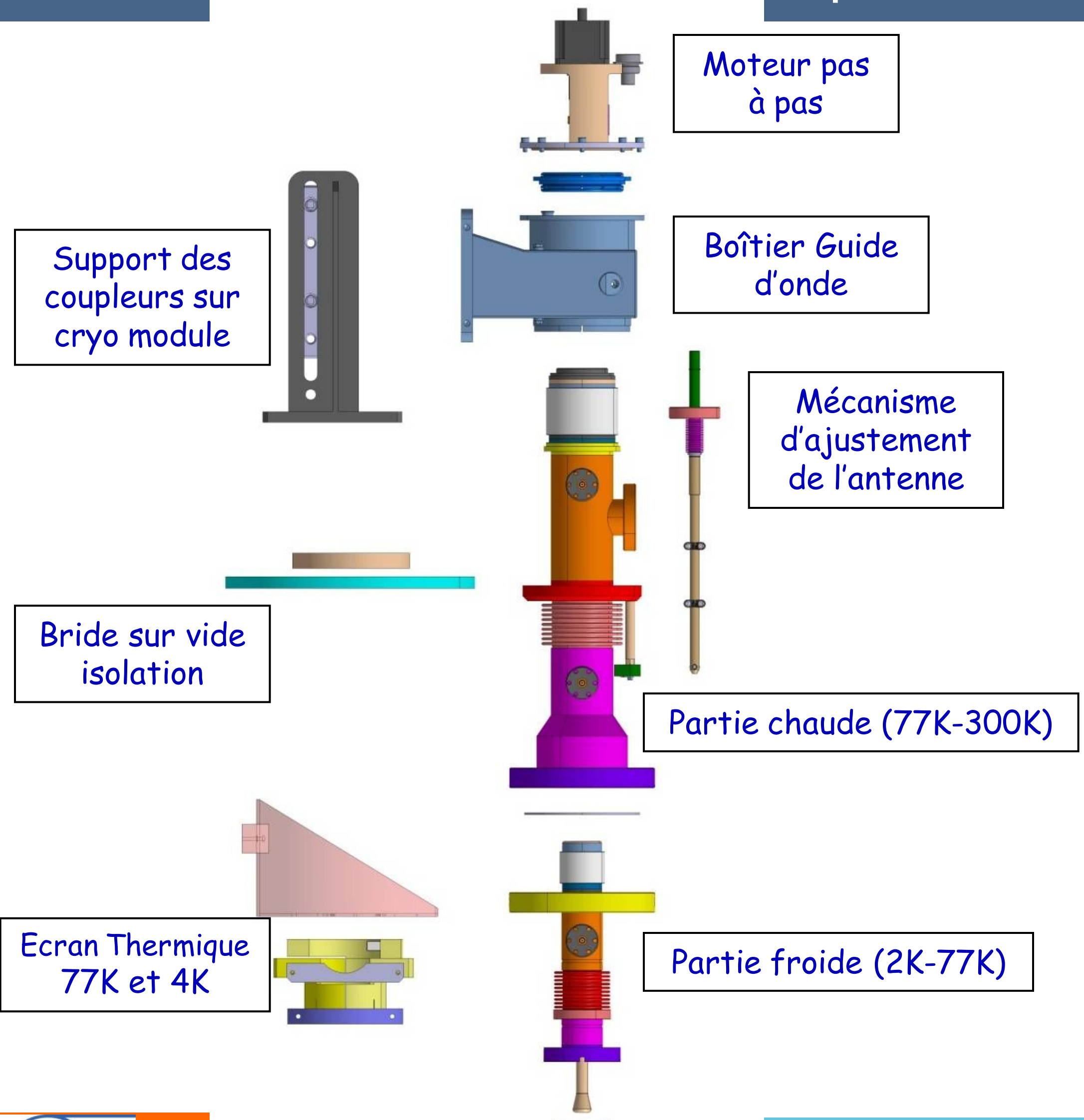
Boîtier guide d'ondes: la conception d'origine TTF-3 est un assemblage brasé de pièces cuivre, laiton et acier inoxydable. La membrane Cu donne la flexibilité pour le contact RF.



Boîtier guide d'ondes: Usinage sur CN d'un bloc massif d'aluminium exempt de soudures et brasures. Variante possible pour la production de série si le contact RF ne nécessite pas de flexibilité.

XFEL RF Couplers/ from R&D to Mass Production

Séquences de Fabrication



- Spécification Matière et Approvisionnement
- Mise en forme, usinages, soudages, brazages
- Dégraissage, Nettoyage
- Fenêtres Céramique + TiN
- Soudage sous-ensembles
- Contrôle Qualité, Test He et mesures géométriques
- Nettoyage final, étuvage comptage des particules
- Assemblage final parties chaude, froide et cavité
- Emballage, transport LAL
  CP sous vide, WP sous N2

XFEL RF Couplers/ from R&D to Mass Production

Planning 2009-2012

Item	Resources
Rédaction du CCTP et des documents associés {Nomenclature + dossier de plans, Spécifications de Controle/Qualité, conditionnement HF}	Equipe Technique
Rédaction du CCAP et des documents administratifs relatifs au marché	LAL & DDA du CNRS
Traduction français→anglais des documents du marché	**Externe**
PRR {Revue de lancement de l'appel d'offre}	**ET & groupe de revue**
Lancement de l'appel d'offre/ Reception des offres techniques-commerciales	DDA du CNRS
Analyse des offres, consultation et audit des candidats, selection des deux firmes A & B (ou du consortium)	Commission du marché
Revue de contrat avec le partenaire XFEL-DESY	ET & groupe de revue
Derniers examens administratifs et fiscaux, notification des contrats	**DDA du CNRS**
Réception/Analyse du dossier de management & de production des firmes (organigramme, plan qualité, LOFC, planning de fabrication et de livraison...)	Contractants A & B Equipe Technique.
Spécification & Appro matière, outil industriel (salle blanches, postes de soudage, de brasage, dépôts Cu et TiN, nettoyage, étuvage, pompage UHV}	Contractants A & B
Production présérie de 2x12 unités {amélioration de l'outil industriel, inspection par le représentant LAL} livraison par paire & dossier qualité	**Contractants A & B, {représentant LAL}**
Montée progressive de la production, ~2x3x8 coupleurs {8/ mois/ contractant} Approbation de l'outil industriel et de l'inspection + recette technique	Contractants A & B, {représentant LAL}
Livraison régulière de 2x16 coupleurs par mois. Conditionnement HF au LAL et préparation livraison à l'IRFU de 2x4 coupleurs par semaine	Equipe Technique LAL

2009
- CCTP/CCAP début (Avril) →
- Revue de projet IN2P3 (06/Juillet) →
- CCTP/CCAP fin (Dec) →

2010
- CEC/PRR (Janvier) →
- Appel d'offre (Fevrier) →
- Notification marché Avril →
- Préséries {2x12 unités} →

2011
- Fin Préséries →
- Montée progressive →

2012
- Régime nominal 2x4 unités par semaine

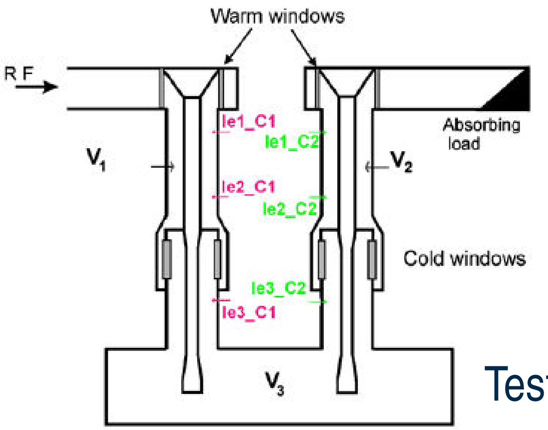
3rd SPL Collaboration Meeting
(CERN, 12 November 2009)

Lucija Lukovac (LAL)

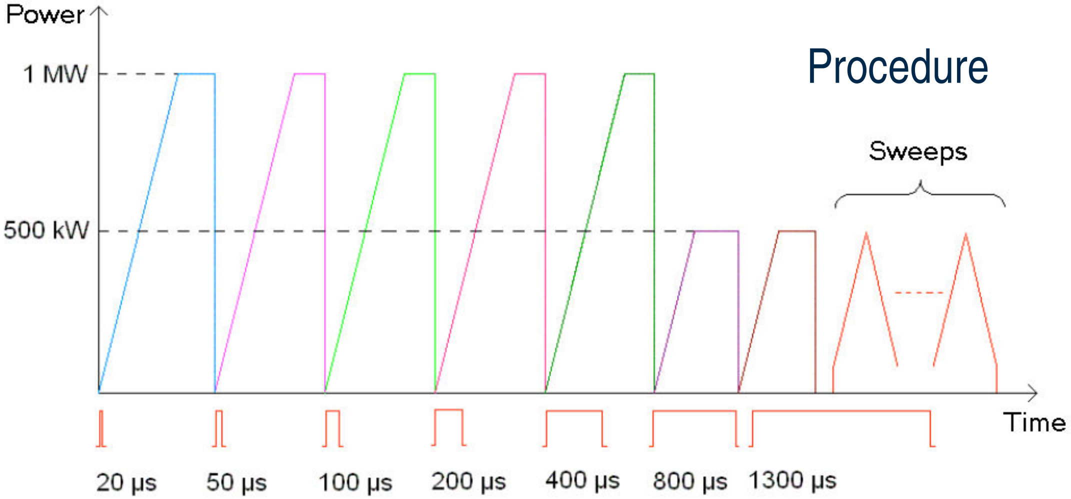
RF Conditioning of TTF3 Input Power Couplers & Acceptance Criteria for XFEL

CNRS IN2P3 Les deux infinis · Université Paris-Sud 11 · LAL Laboratoire de l'Accélérateur Linéaire · DESY · Helmholtz Association · European XFEL

Warm test stand : travelling wave mode @ LAL



Test stand



Control parameters

Vacuum	1st threshold (↓ 0.1 dB)	$2 \cdot 10^{-7}$ mbar
Vacuum	2nd threshold (↓ 0.4 dB)	$4 \cdot 10^{-7}$ mbar
Vacuum	IL	10-6 mbar
e- current IL		5 mA
Light IL		1 lux
Ceramic temperature IL		85° C
WG arc IL		If any
Repetition rate		2 Hz
Control loop duration ↑ 0.1 dB		30 s

Cryomodule - reconditioning : standing wave mode @ DESY

Off resonance = Warm test stand

On resonance 20 µs -> 200 µs Pmax = 1 MW

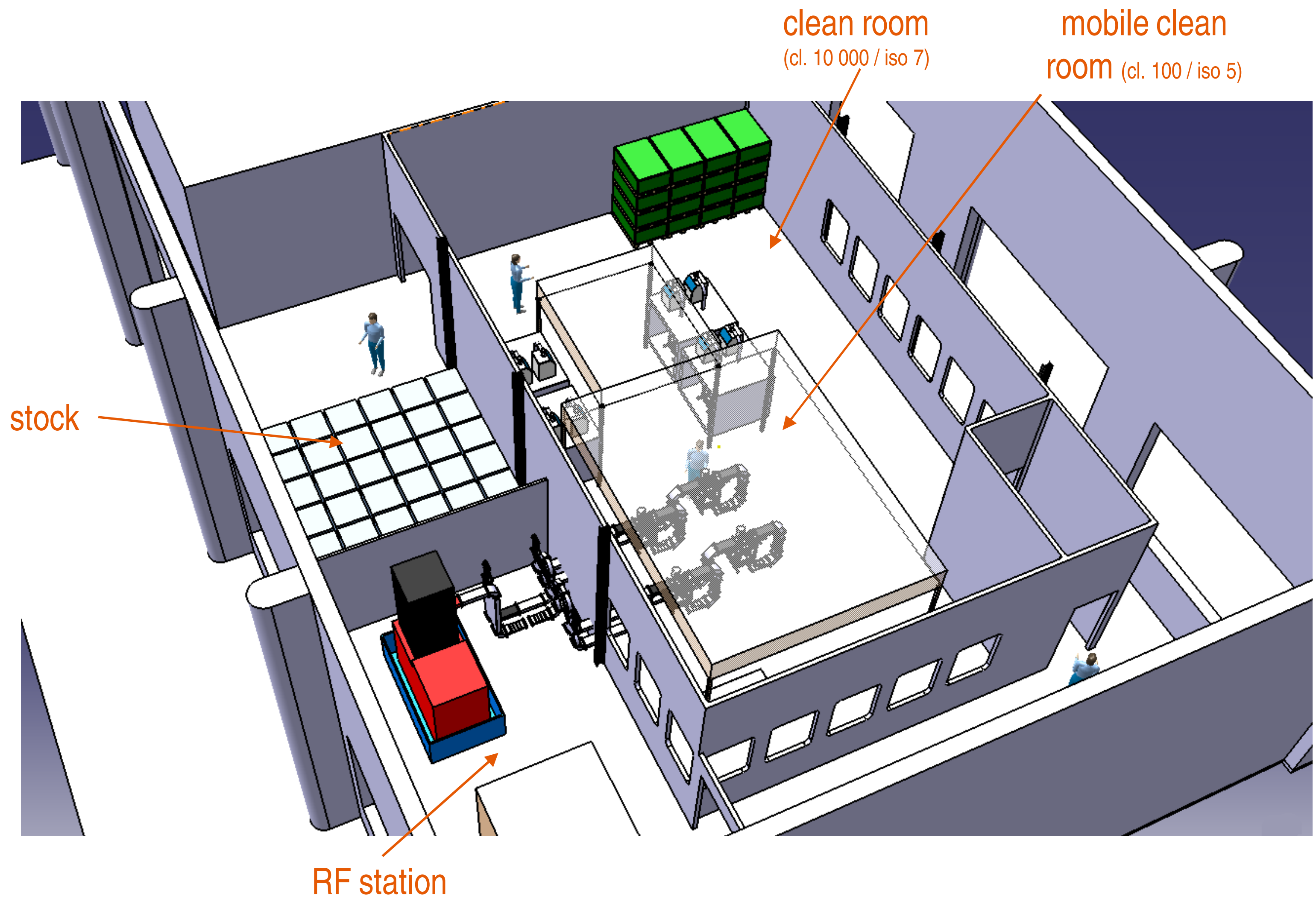
400 µs Pmax = 330 kW

500 µs flat top + flat top 100 µs, 200 µs, 400 µs, 800 µs Pmax = 250 kW

sweeps 500 µs + flat top 800 µs

Acceptance criteria for XFEL power couplers

Conditioning : Infrastructure



Managed by E. Genesseau (LAL)

Conditioning : lessons learned from TTF3 couplers

Cleaning & Assembly

- Class 10 clean room
- US bath cleaning with detergent + high temperature
- Drying with filtered N2 and under laminar flux
- **Particle count**
- **Leak test**

Cleaning & assembly procedure @LAL ⇨

Nouvelle procédure montage conditionnement.doc Date : 07/01/2009

Etape 4	Comptage de particules / pré assemblage des parties froides / étuvage

Classe 10

Préparation

S'assurer que la bouteille d'azote à l'extérieur de la salle blanche est ouverte et réglée sur 4 bars.

Matériel nécessaire

Les pièces de l'étape précédente

Tâches

Noter les références du montage

Contrôle visuel :
- Refaire un contrôle visuel des pièces lavées

Contrôle de particules des parties froides :
- Souffler les parties froides avec l'azote ionisé, capteur de particules en face (Position 1)
- Lancer l'acquisition du compteur de particules
- Si au bout d'une minute il compte moins de 10 particules de taille >0.3 µm, la partie contrôlée est considérée comme propre dans le cas contraire, le compteur relance un cycle de mesure.
- Si au bout de 9 cycles, il compte toujours plus de 10 particules de taille >0.3 µm, la pièce contrôlée sera alors considérée comme sale et elle devra être re-nettoyée.
- Recommencer les étapes précédentes pour les 3 positions suivantes :

- Imprimer le ticket de comptage
- Contrôler de la même façon la seconde partie froide

Contrôle de particules de la transition de test :
- Placer les tiges filetées sur la transition de test capotée

Attention : L'opérateur doit être placé à l'opposé du port de pompage
- Faire le contrôle de particule de la transition dans les 2 positions suivantes

Rédigé par : M Lacroix 10 / 58

To be performed by the manufacturer !

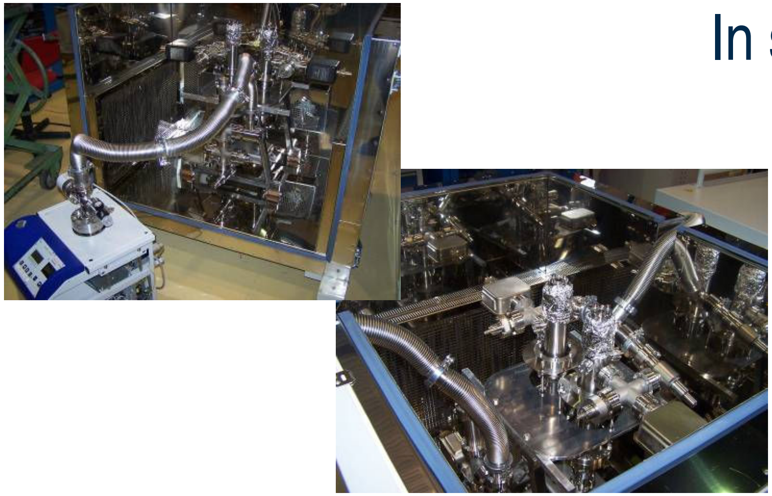
Follow the procedure

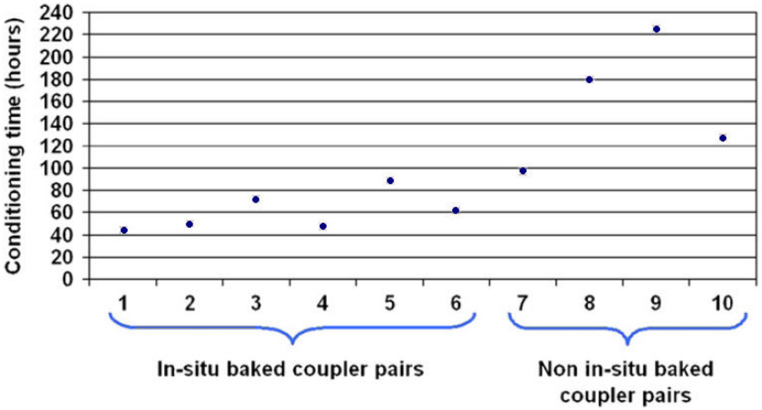
M. Lacroix et al., LAL internal report

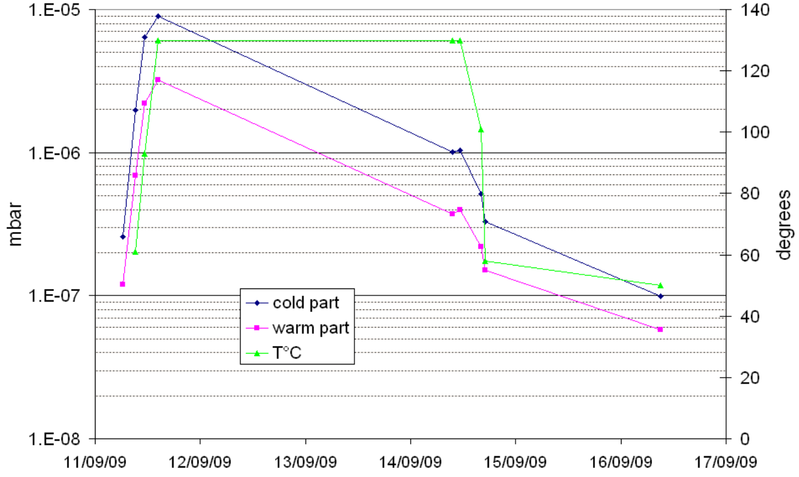
Acceptance criteria for XFEL power couplers

Conditioning : lessons learned from TTF3 couplers

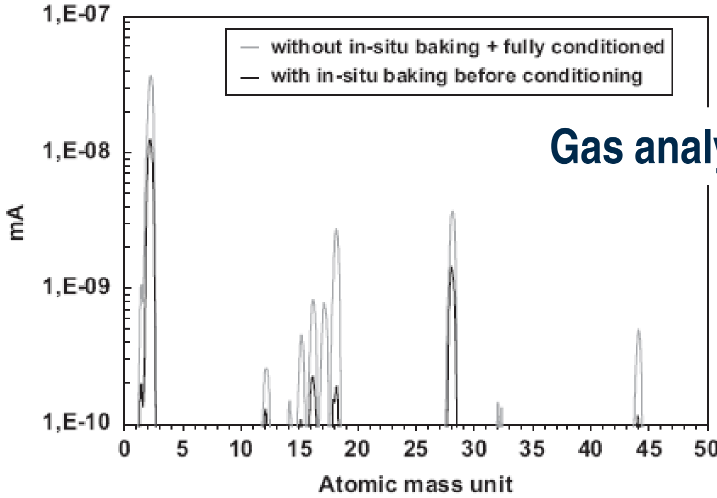
In situ baking







Gas analysis



H. Jenhani et al., NIM A 595 (2008)

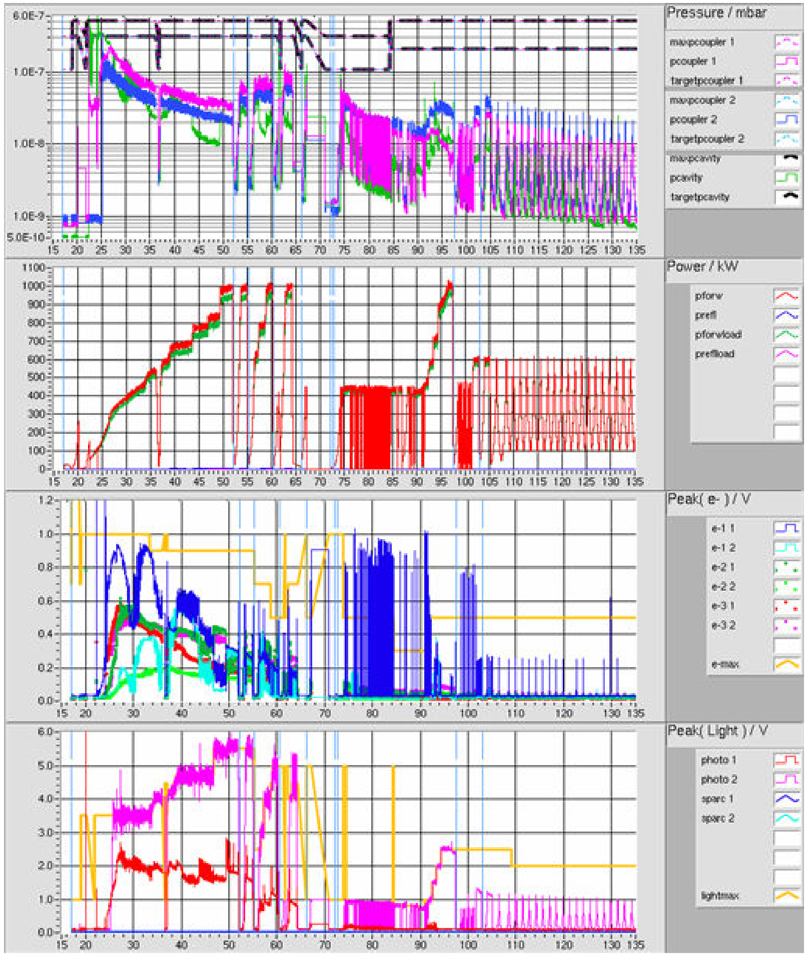
Acceptance criteria for XFEL power couplers

Accepting a coupler : good or excellent?

- *Mechanical : dimensions, visual inspection*
- *Material tests (TiN & Cu coatings)*

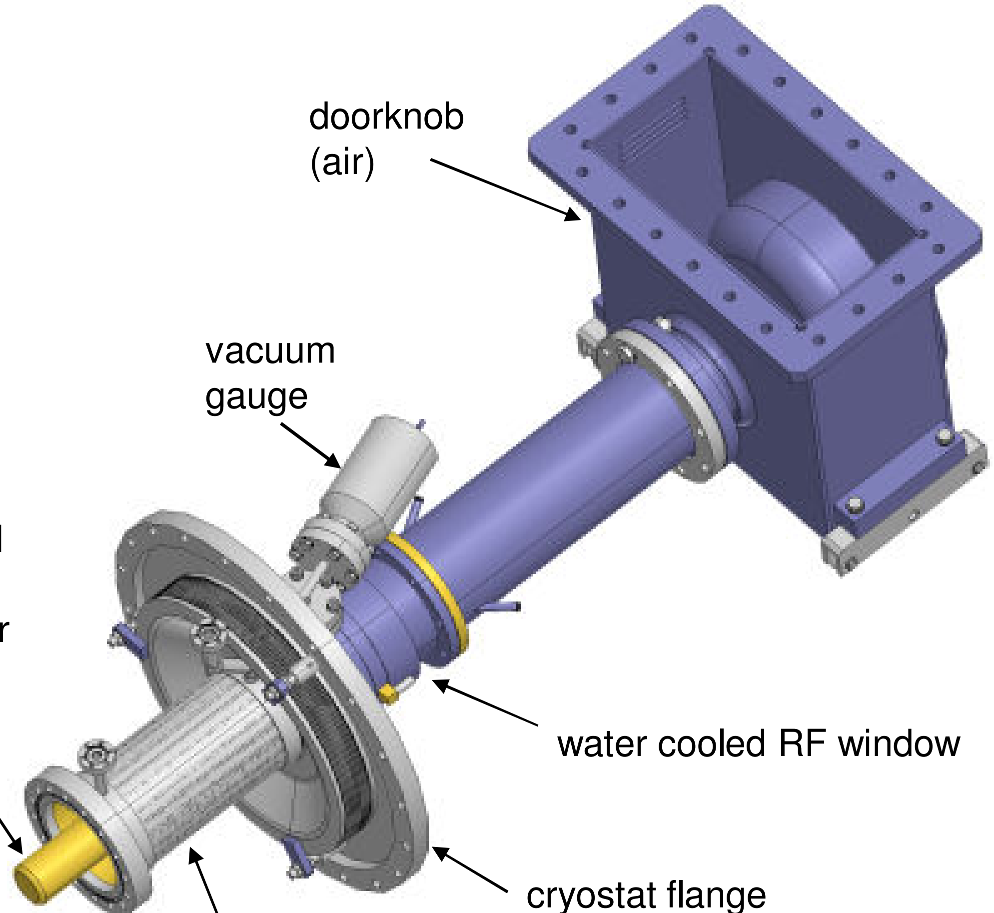
- Following the cleaning and assembly procedure
- Particle count
- Leak tests
- In situ baking gas analysis
- **Time needed to achieve given power level**
- **Total conditioning time => excellence**
- **Number of interlocks => refusal**

Example of refused coupler



704 MHz -1 MW power coupler
G. Devanz

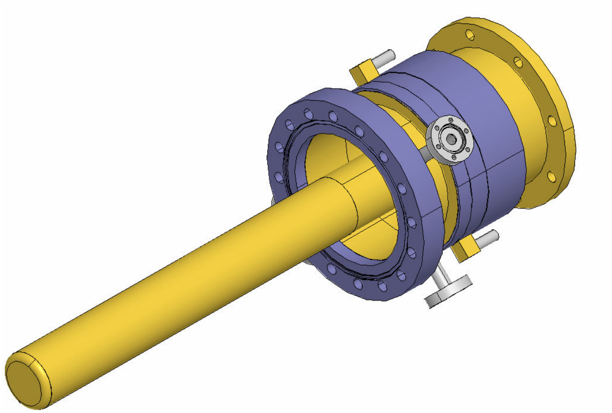
100 mm diameter
50 Ω



Designed for 1MW, 10%DC

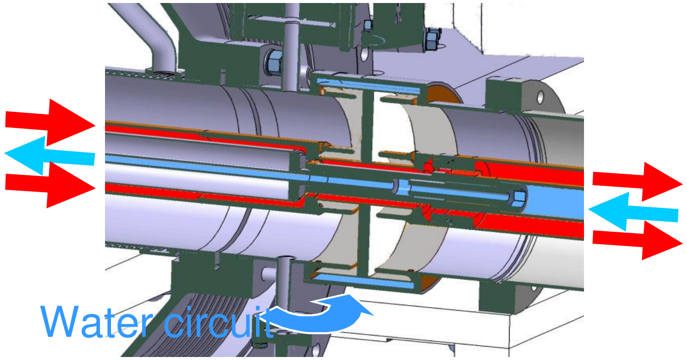
Coupler - window

- KEK like design , disk window matched with chokes
- water cooling of the antena and the internal braze of the ceramic



internal conductor dissipation
for 100kW average incident power

	P int (W)	dens. int (W/m²)
TW	100	870
SW	200	1740



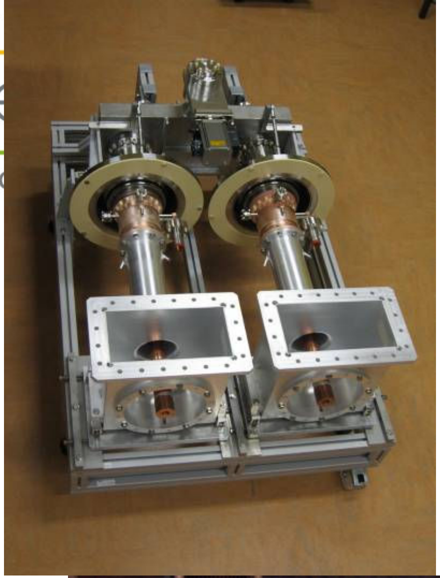
Coupler & stand preparation

- parts ultrasound cleaning, high purity water rinsing
- assembly in clean room (couplers+coupling box)
- couplers always handled in vertical position
- clean room compatible handling tools
- rail and cart system to move heavy parts
- 200℃ 48h in-situ baking of the vacuum parts

Irfu
cea
saclay

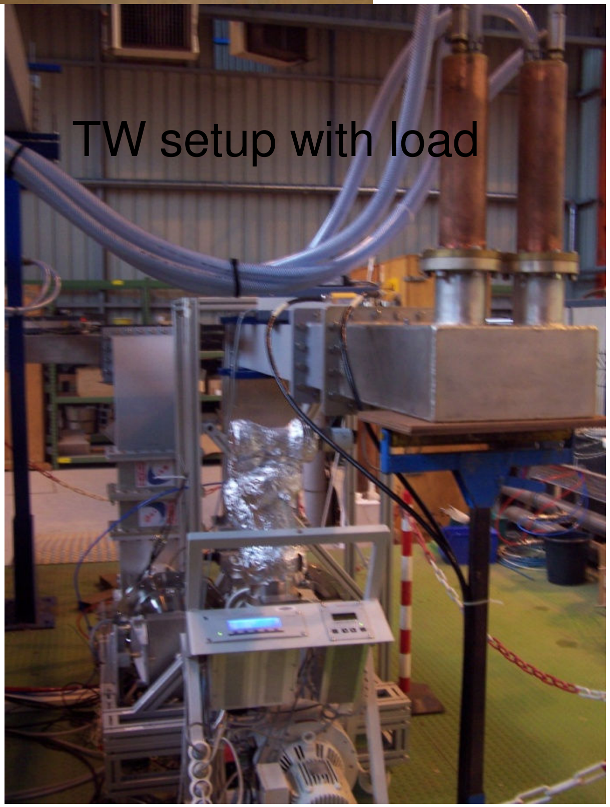
Assembly of the couplers in class 10 clean room



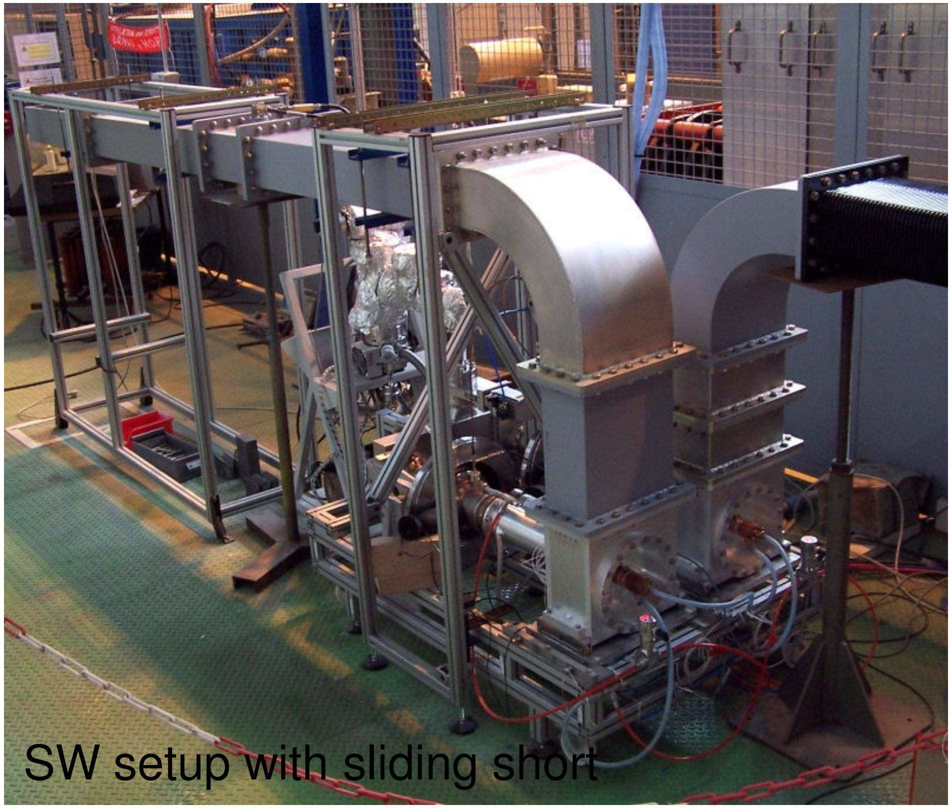



704 MHz coupler test stand

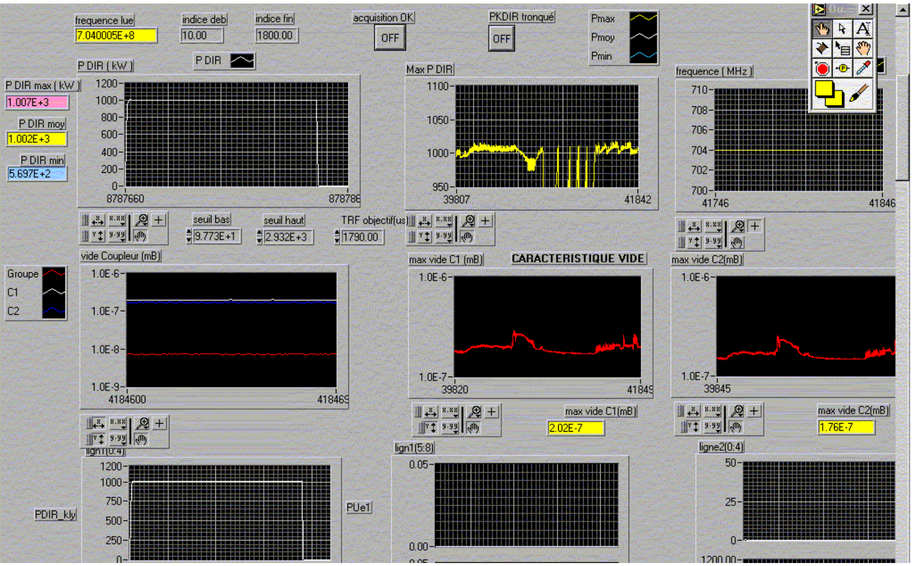
Couplers are conditioned in horizontal position
RF power source : 1 MW klystron 2ms 50Hz
Pulsed HV power supply : 110 kV 2.5 A HVPS and modulator
Circulator commissioned with full reflected power, all phases
Oil-free pumping (high pressure turbomolecular+scroll pump)

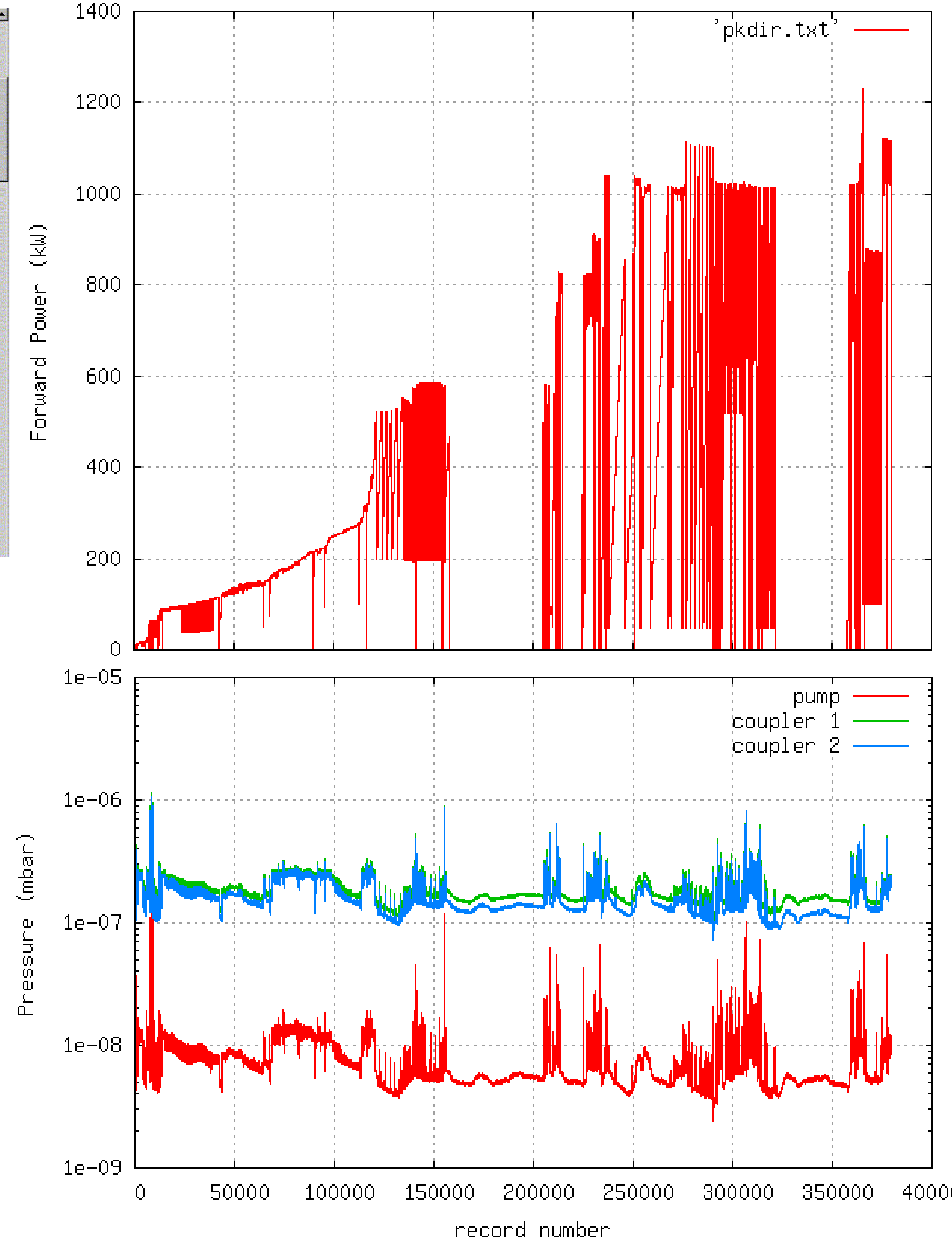


Fully functional test stand



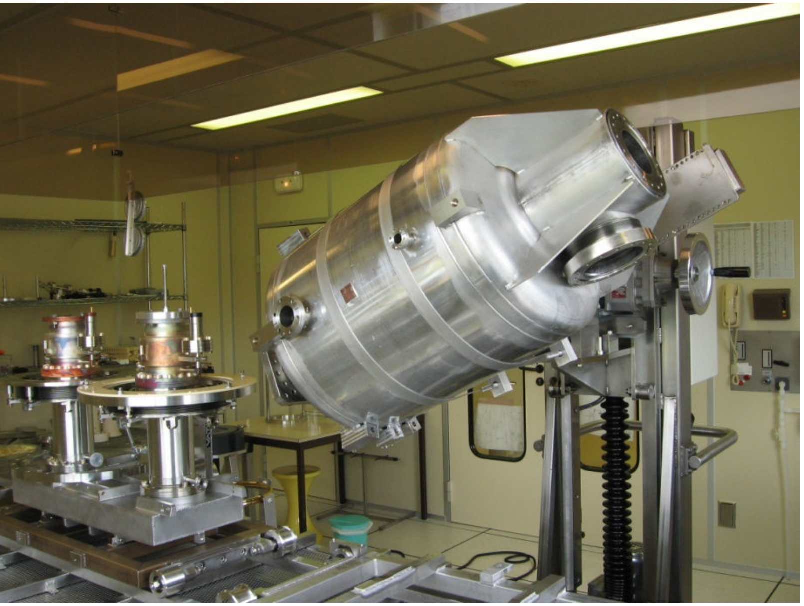
Coupler conditioning



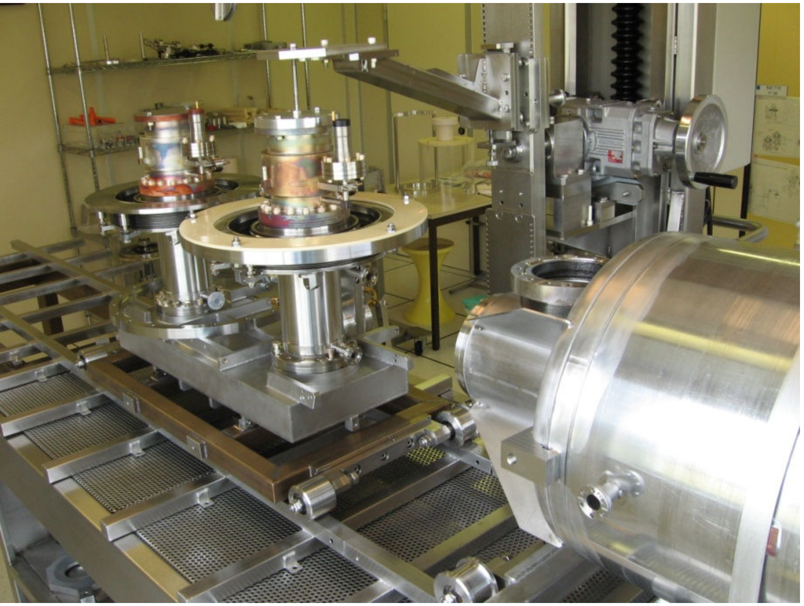


- Maximum en TW 1.2 MW peak @10% DC
- Total duration. 300h
- SW conditioning stopped due to HVPS failure in march09, then had to proceed with the coupler installation on the test SC cavity
- Repair of the 110kV 2.5A still going on, coming back end of november
- Othe HVPS were available at the lab to operate with a lower duty cycle.

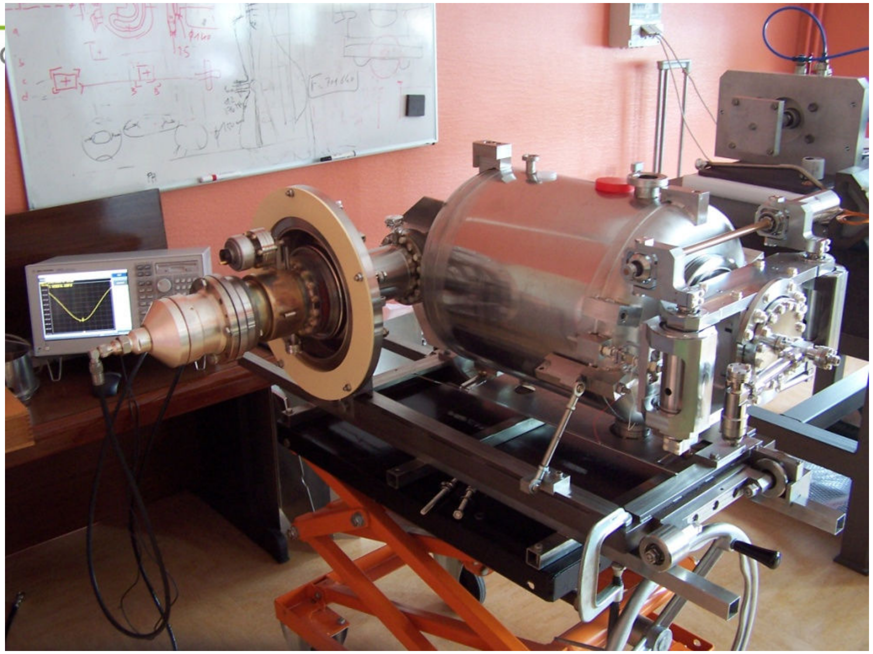
Coupler transfer on the test cavity

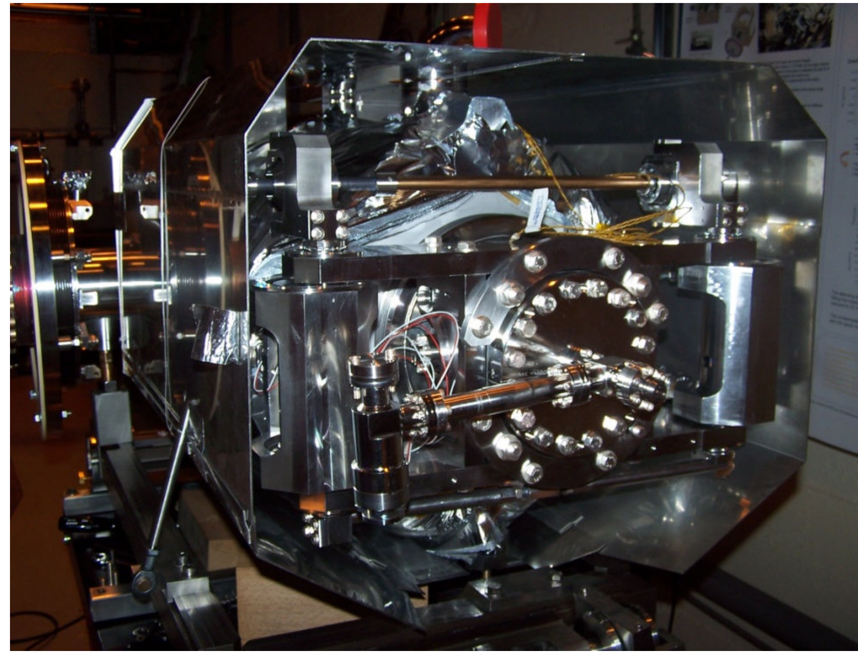


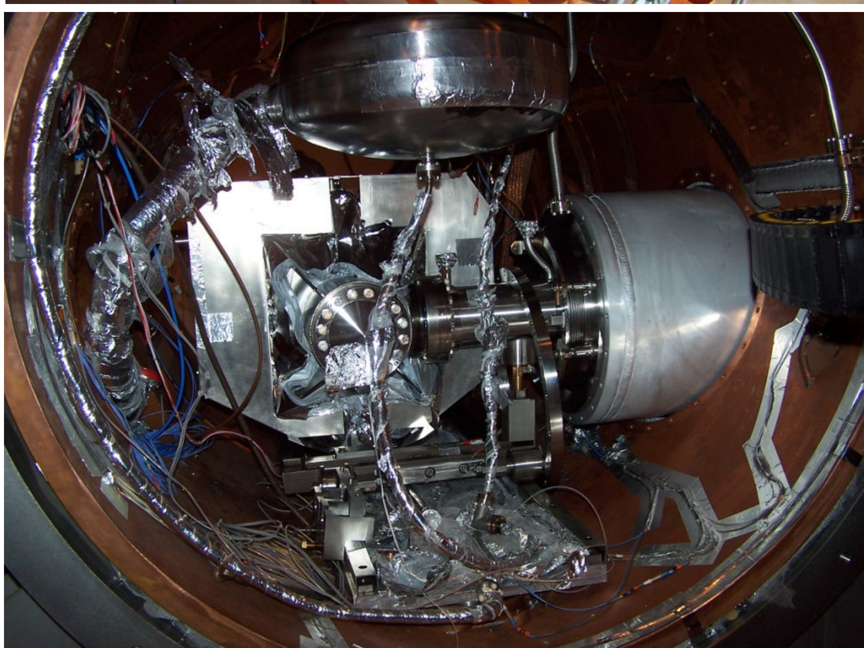
In class 10 clean room

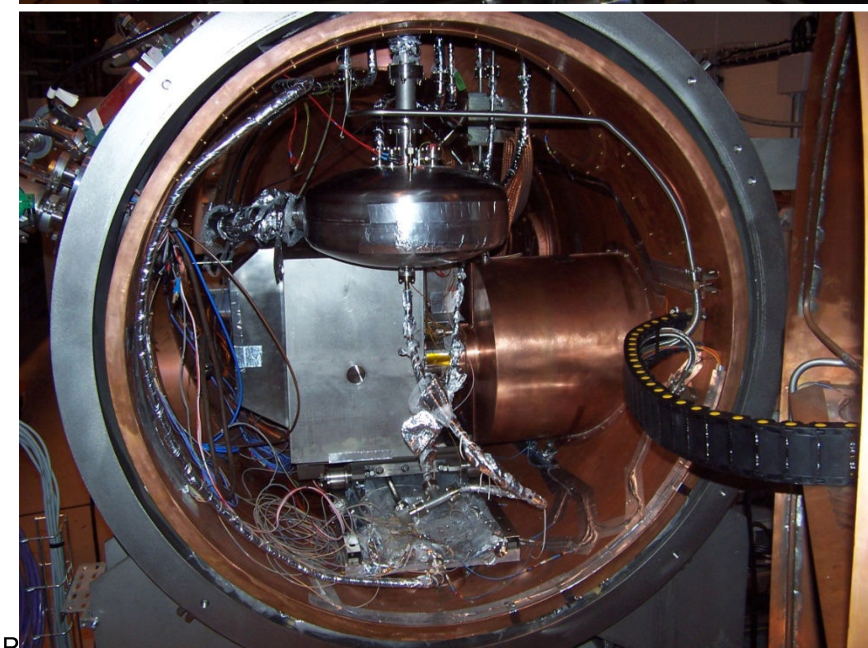


Cryholab configuration for pulsed tests



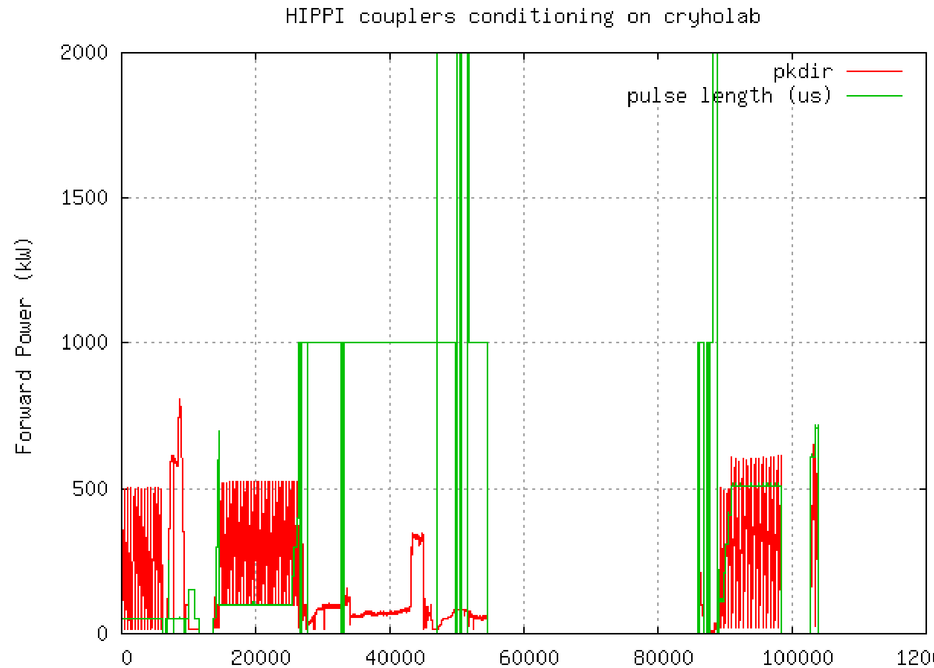


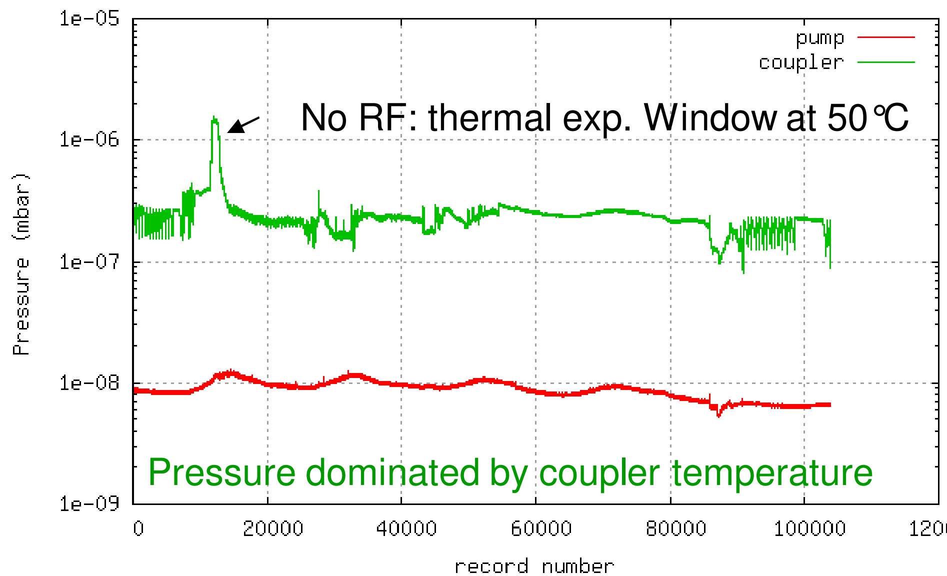




Conditioning on cavity

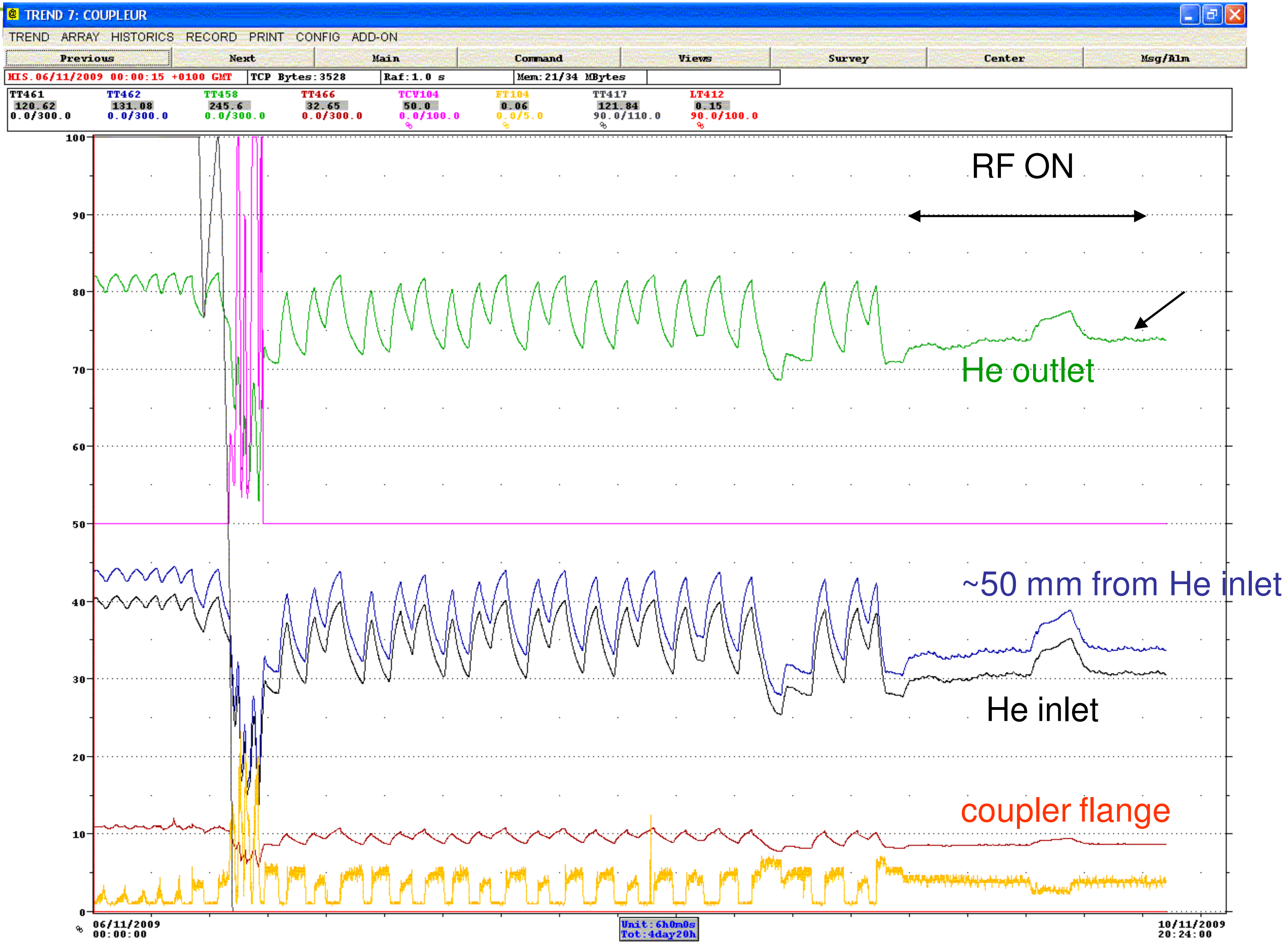
- No conditioning done at room temperature on cavity
- Cool down of Cryholab with only the vacuum part of the coupler assembled to monitor the cavity displacement, only 0.1 mm at the level of the coupler window
- Assembly of doorknob and coaxial extension of the coupler.
- Conditioning with reduced duty cycle (spare HV power supply) in full reflection (detuned cavity)
    - start with 100 µs pulses 5 Hz ramping power from 20 to 500 kW
    - increase pulse length up to 1 ms, same power ramping :
- conditioning with the cavity/ klystron tuned at 703 MHz, 1.8 K
    - 1ms pulses : up to 80 kW (too much Lorentz detuning on the cavity without compensation)
    - 2ms pulses: 240kW/80kW
- This week : resume of the pulsed tests after cryogenics and HPVS downtime
- Run with detuned cavity going on now 700 µs, 600kW, 5Hz Monday, the coupler is conditioned, no more activity





Downtime due to HVPS failure mainly

Thermal behavior



Conclusion

- Couplers performed as expected on the test stand achieving 1.2 MW peak,120kW average
- After installation on the beta 0.5 cavity in the horizontal test cryostat Cryholab, very small amount of conditioning was necessary to operate in full reflection, well above the necessary power for cavity operation
- Cryo operation was done using a reduced duty cycle (most of the time 1ms pulses at 5Hz) due to main HVPS failure, and the use of a lower spec'd spare HVPS
- Higher average power test will be resumed as soon as we install the main HPVS again in december

- One water leak occurred on the air side due to a misalignment of the inner conductor of the doorknob extension. Most probable scenario: gap between conductors->arcing->arc through the gasket drills a hole-> water leak. This can be avoided with a modification of the dual water/RF connection, the vertical position of the coupler and a shorter doorknob extension.
- Downtime due to High Voltage Power Supplies failure mainly

High average power couplers

SPL possible designs

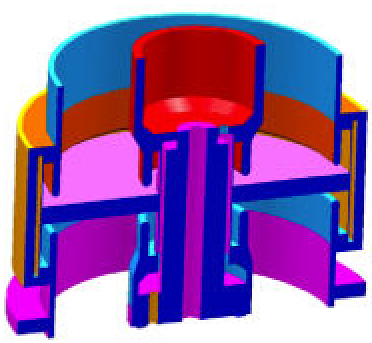
SPL requirements

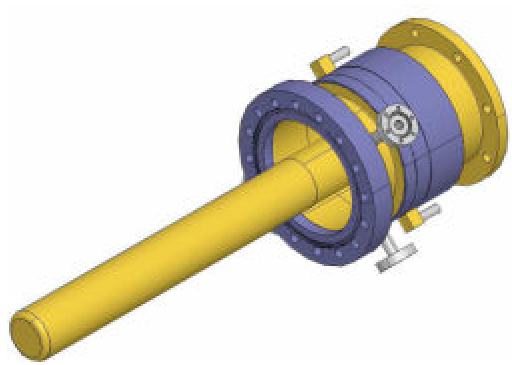
f_0	704.4 MHz
Low Power SPL	2.5 kW average 600 kW pulsed 0.4 + 1.2 + 0.4 = 2.0 ms 2 Hz (500 ms)
High Power SPL	100 kW average 1000 kW pulsed 0.4 + 1.2 + 0.4 = 2.0 ms 50 Hz (20 ms)
Cavity design gradient	19-25 MV/m
Q_{ext} of input coupler	$1 \cdot 10^6$ for LP-SPL and HP-SPL
Input line Ø	100 / 43.5 mm = 50 Ω
Waveguides	WR 1150

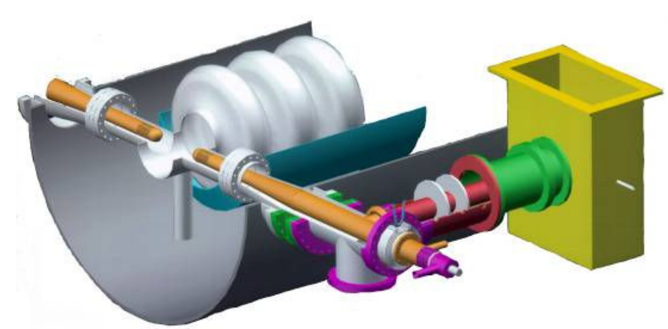
Source : https://twiki.cern.ch/twiki/bin/view/SPL/SplWeb

Coaxial Disk windows

Coupler	Frequency [MHz]	Average Power [kW]	Peak power [kW]	# in operation or constructed
APT	700	1000	1000	2
SPS	200	550	800	16
KEKB	509	300	1420	8
CEA-HIPPI	704	120	1200	2
IHEP	500	150	270	2
JPARK	972	30	2200	23
SNS	805	78	2000	93

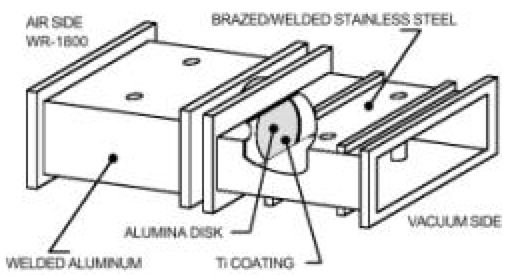


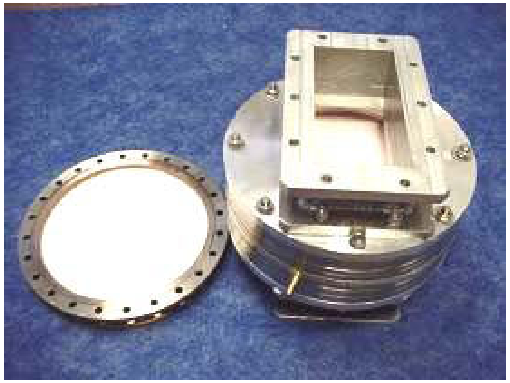


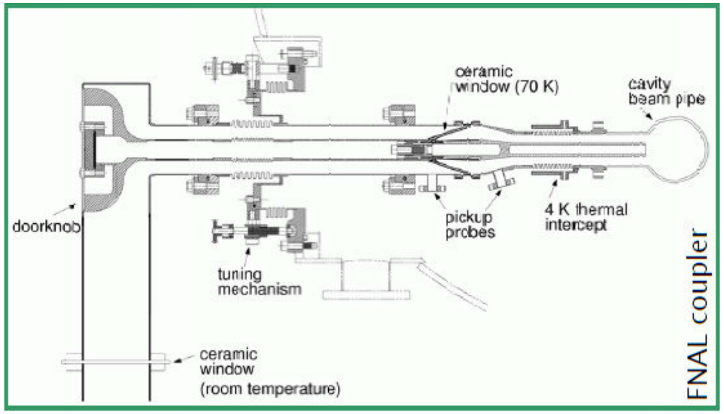


Waveguide windows

Coupler	Frequency [MHz]	Average Power [kW]	Peak power [kW]	# in operation or constructed
SPS	801	225	225 (more ?)	8
Cornell	500	350	350	4
FNAL / TTF II	1300	4.5	1000	32

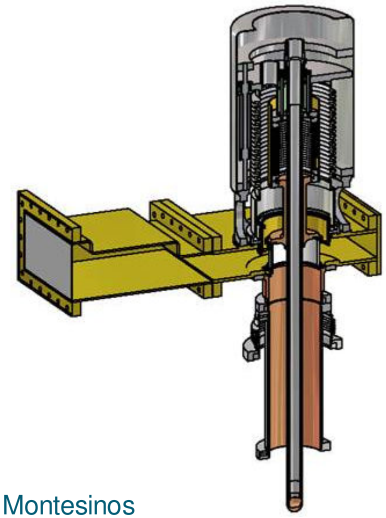


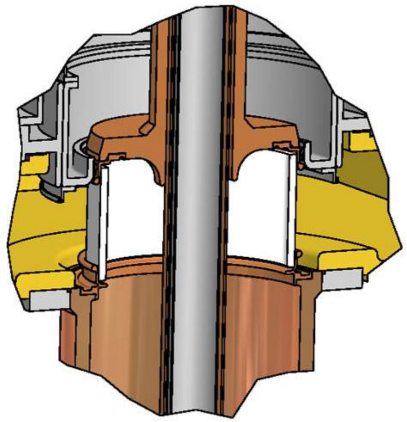


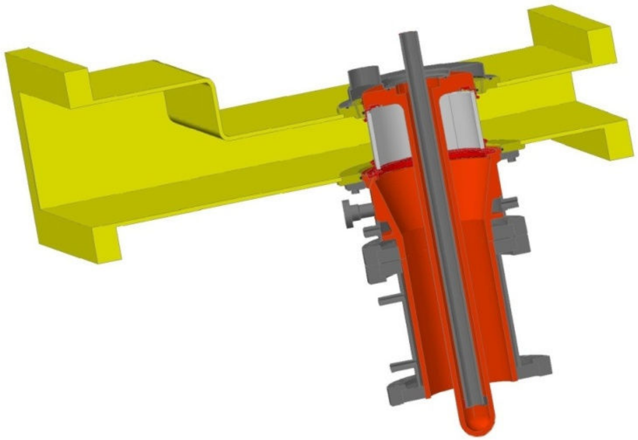


One cylindrical window

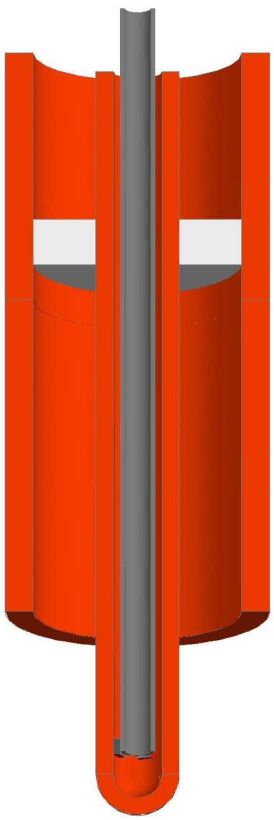
Coupler	Frequency [MHz]	Average Power [kW]	Peak power [kW]	# in operation or constructed
ESRF / Soleil	352	550 sw cw	Under construction	64
LHC	400	550 sw cw, (i.e 2200 tw cw)	i.e. 2200 tw cw	16
LEP	352	550 tw cw	565 tw cw	252
SPS (1976-2000)	200	375	500	16





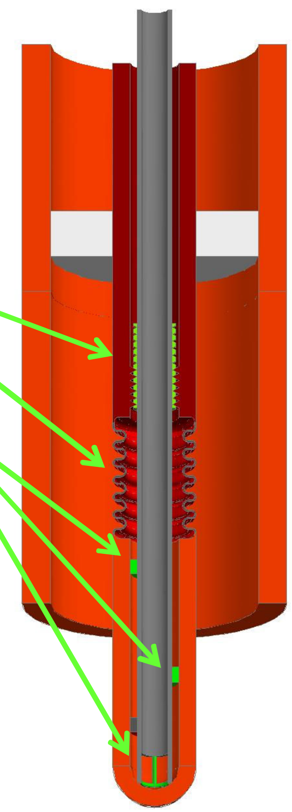


Fixed versus Adjustable coupler



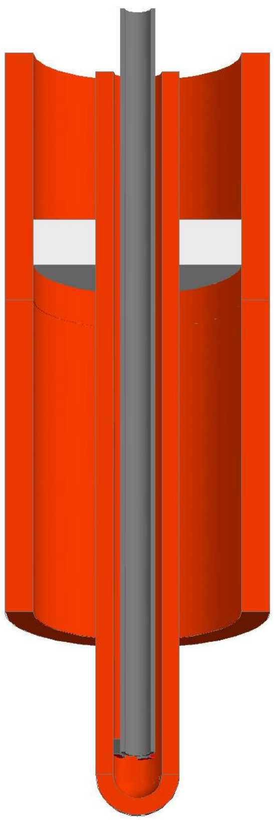
Disk window - fixed coupler

- An adjustable coupler is not a variable coupler (only few mm of fine coarse)
- However, in addition to the already complex line :
  - Moving system not stressing the ceramic
  - Below, more EB welding
  - Alignment system to keep the bottom part of the antenna at the right place under the below
- This will :
  - increase the complexity
  - Increase the number of mechanical operations
  - Increase the risk of pollution of the coupler
  - Increase the risk of vacuum leak
  - Subsequently increase the total price



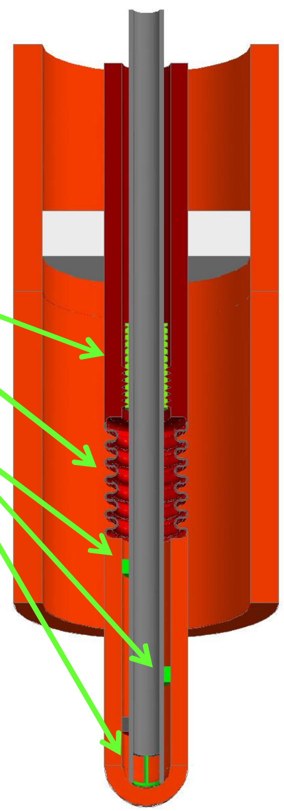
Disk window - adjustable coupler

Fixed versus Adjustable coupler



Disk window - fixed coupler

- An adjustable coupler is not a variable coupler (only few mm of fine coarse)
- However, in addition to the already complex line :
  - Moving system not stressing the ceramic
  - Below, more EB welding
  - Alignment system to keep the bottom part of the antenna at the right place under the below
- This will :
  - increase the complexity
  - Increase the number of mechanical operations
  - Increase the risk of pollution of the coupler
  - Increase the risk of vacuum leak
  - Subsequently increase the total price

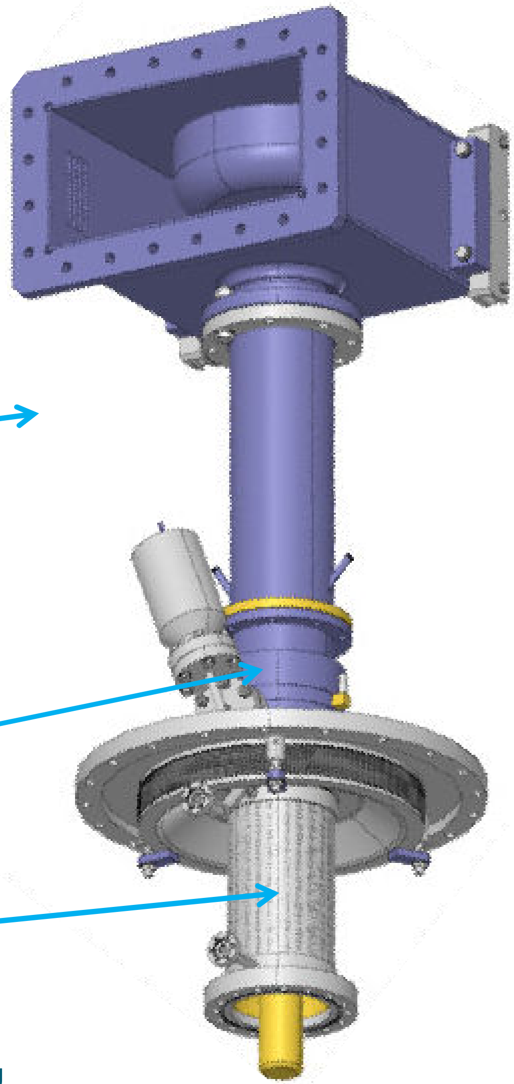


Disk window - adjustable coupler

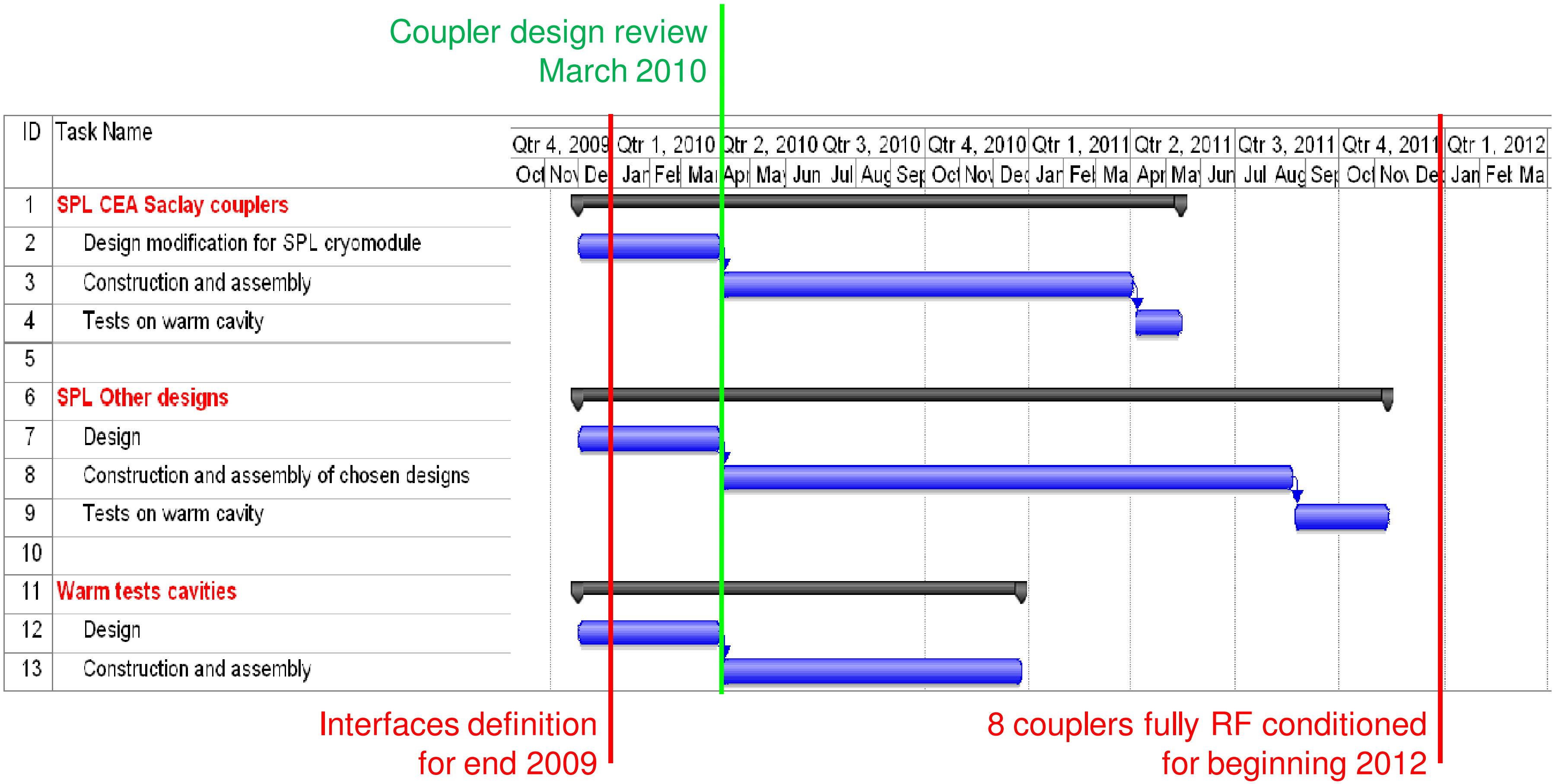
Proposed design

Coupler Working Group's conclusions:

- For mechanical reasons, easier to have the coupler mounted vertically, less stress to the antenna
- Preferably above the cavity, allows a good access, also the preferred solution for the tunnel integration
- Access from the bottom is less convenient for work with the air side and for connecting the waveguides
- Only one ceramic (very important impact onto the cavity assembly process)
- To ensure the thermal transition, a double walled tube will be connected between the cavity and the cryomodule (as already experienced with LHC, CEA Saclay)



Draft time table



SPL main power coupler

integration requirements

Cryomodule connectivity

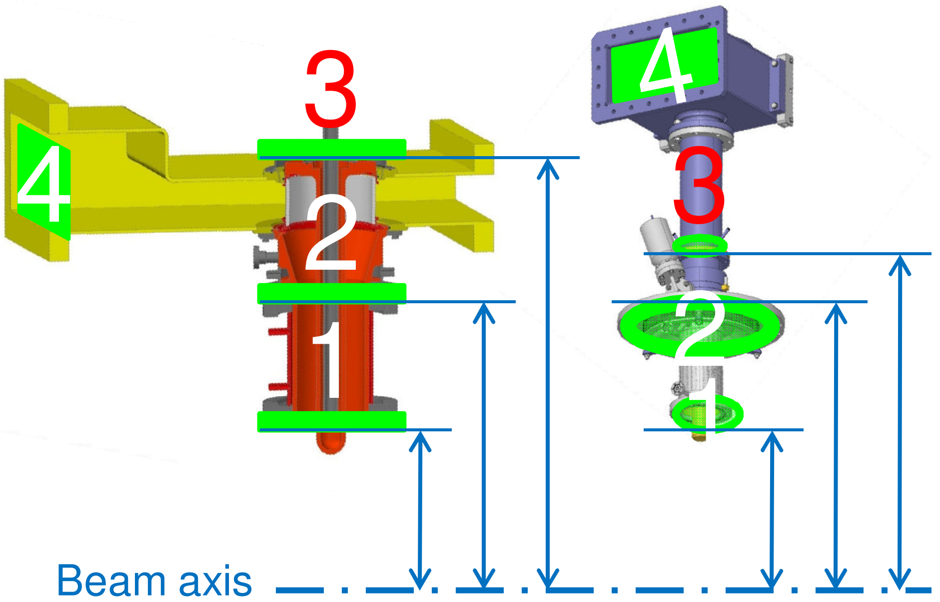
- Prior to all that process, including the design of the coupler, the main interfaces still have to be decided as soon as possible:

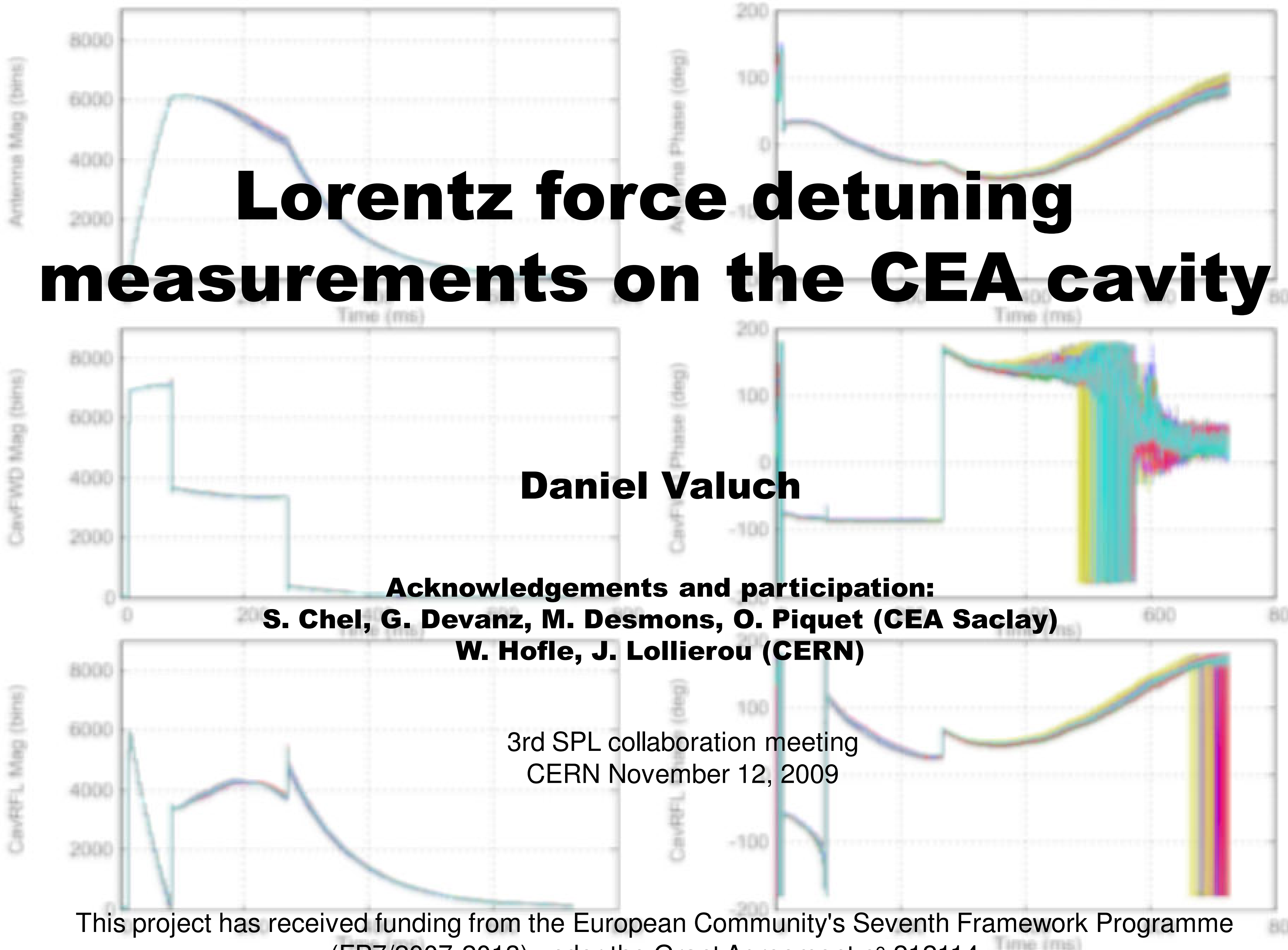
  1/ Cavity flange, lower part of the double walled tube

  2/ Cryostat flange, upper part of the double walled tube

  3/ Total height of the coupler for cryomodule integration

  4/ Waveguide flange, will impact on the waveguide distribution, and will define the needed supporting tool





Lorentz force detuning measurements on the CEA cavity

Daniel Valuch

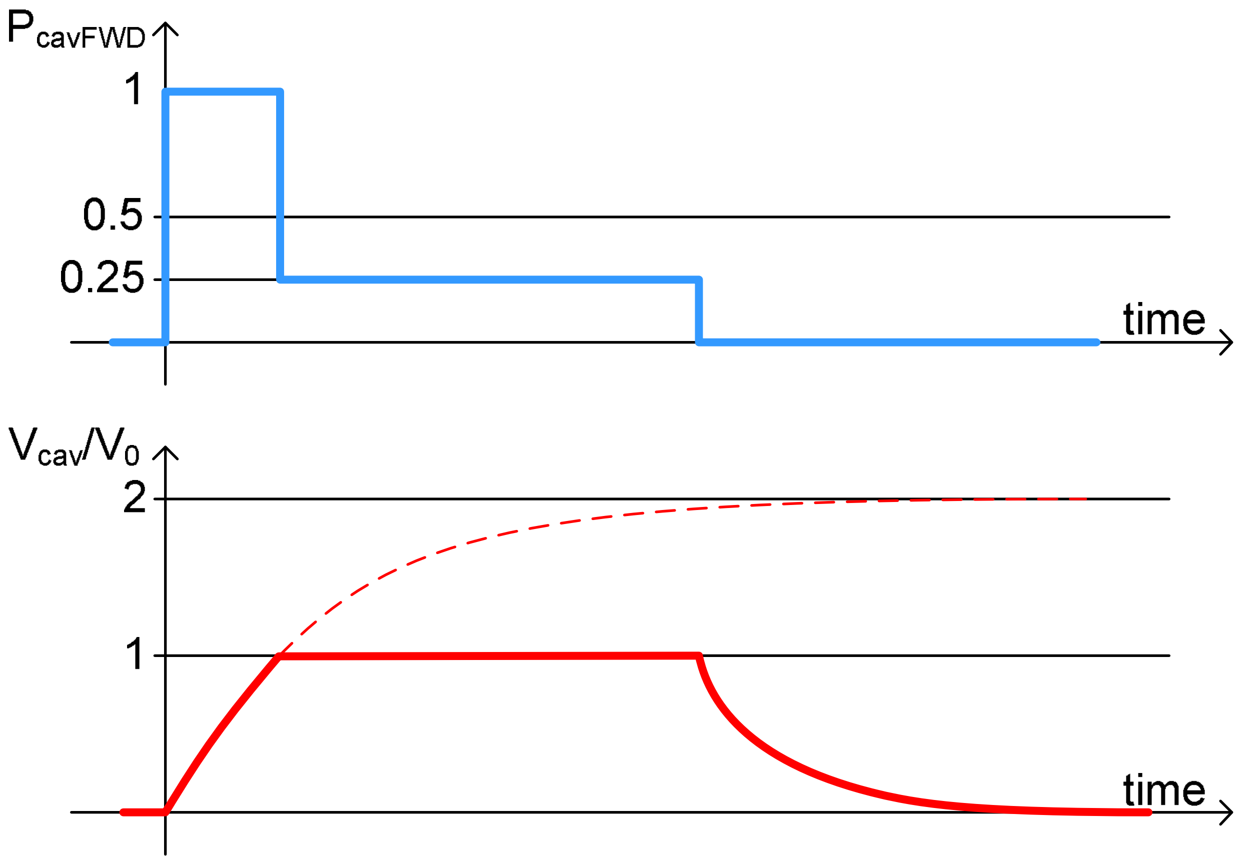
Acknowledgements and participation:
S. Chel, G. Devanz, M. Desmons, O. Piquet (CEA Saclay)
W. Hofle, J. Lollierou (CERN)

3rd SPL collaboration meeting
CERN November 12, 2009

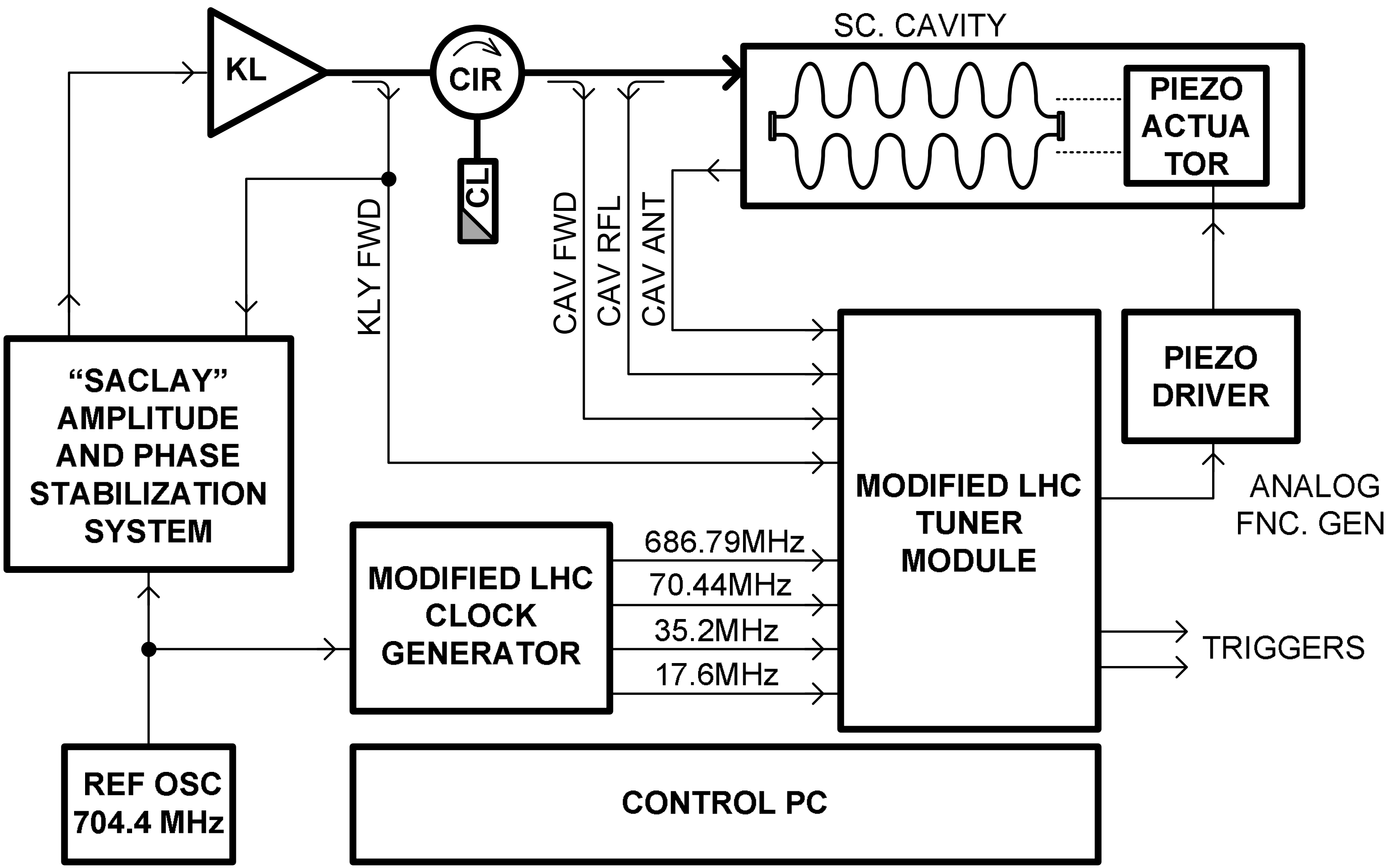
This project has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreement nº 212114

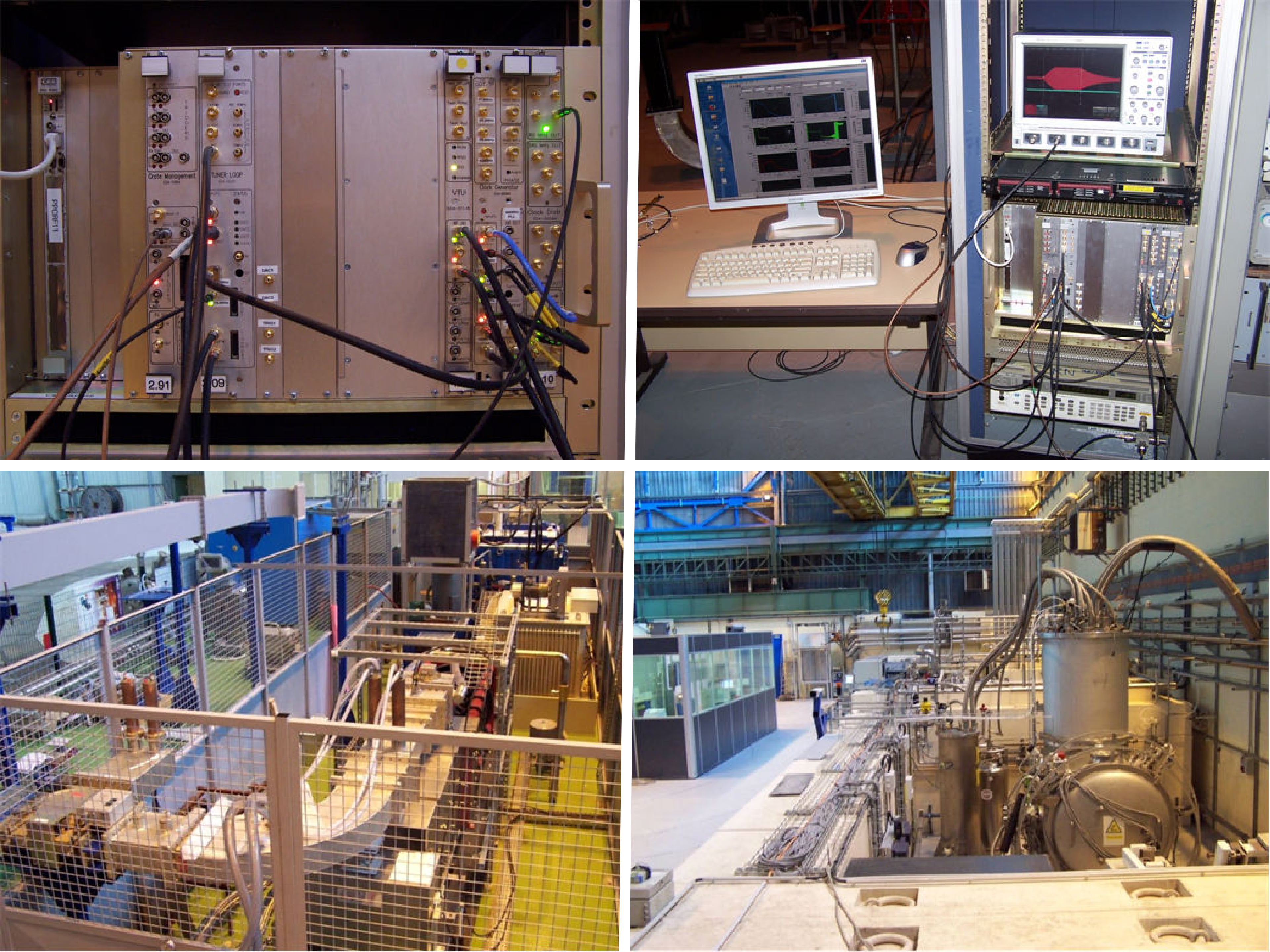
Typical waveforms

- Cavity filling transient with “simulated” beam



Measurement setup

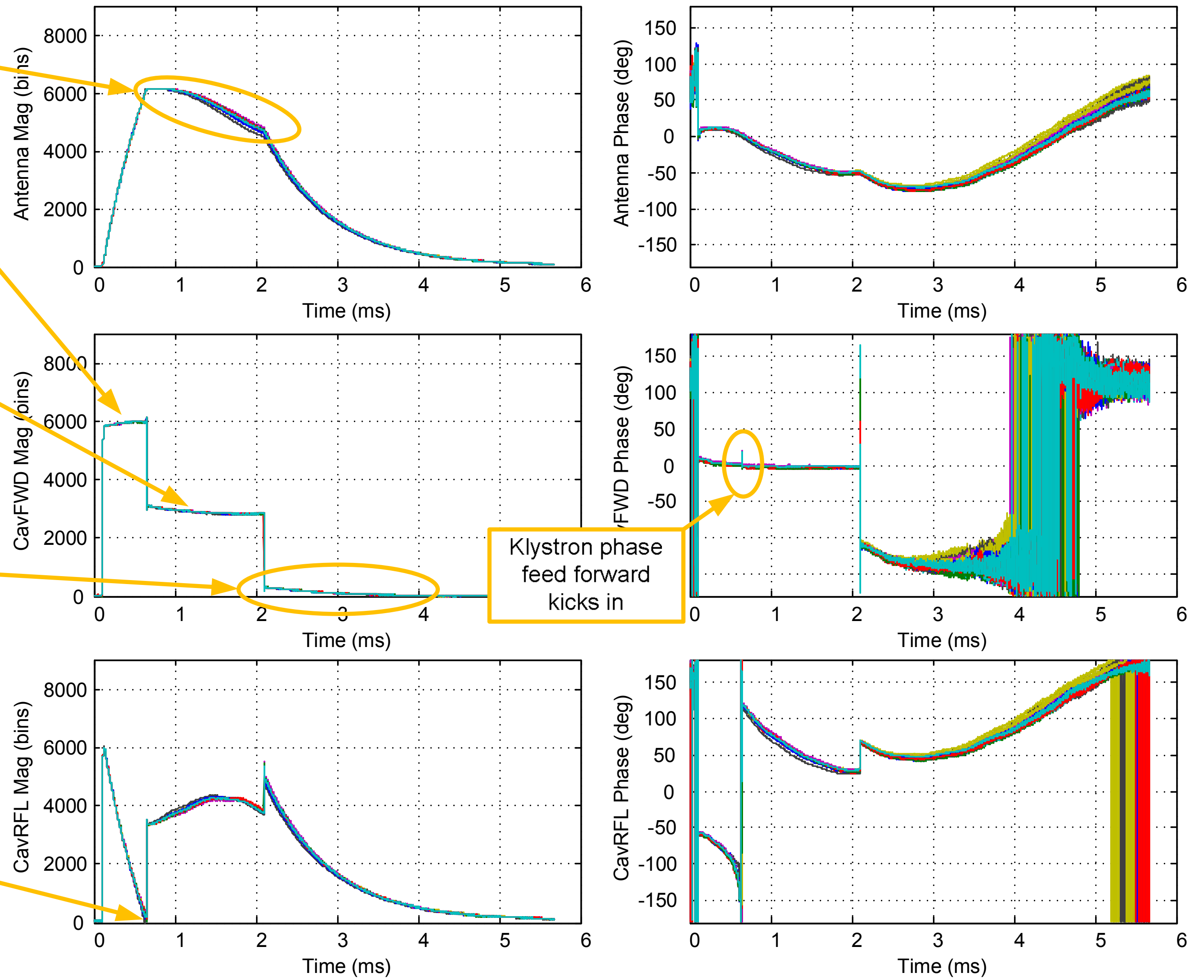




Crate Management
TUNER LOOP
VTU
Clock Generator
2.91

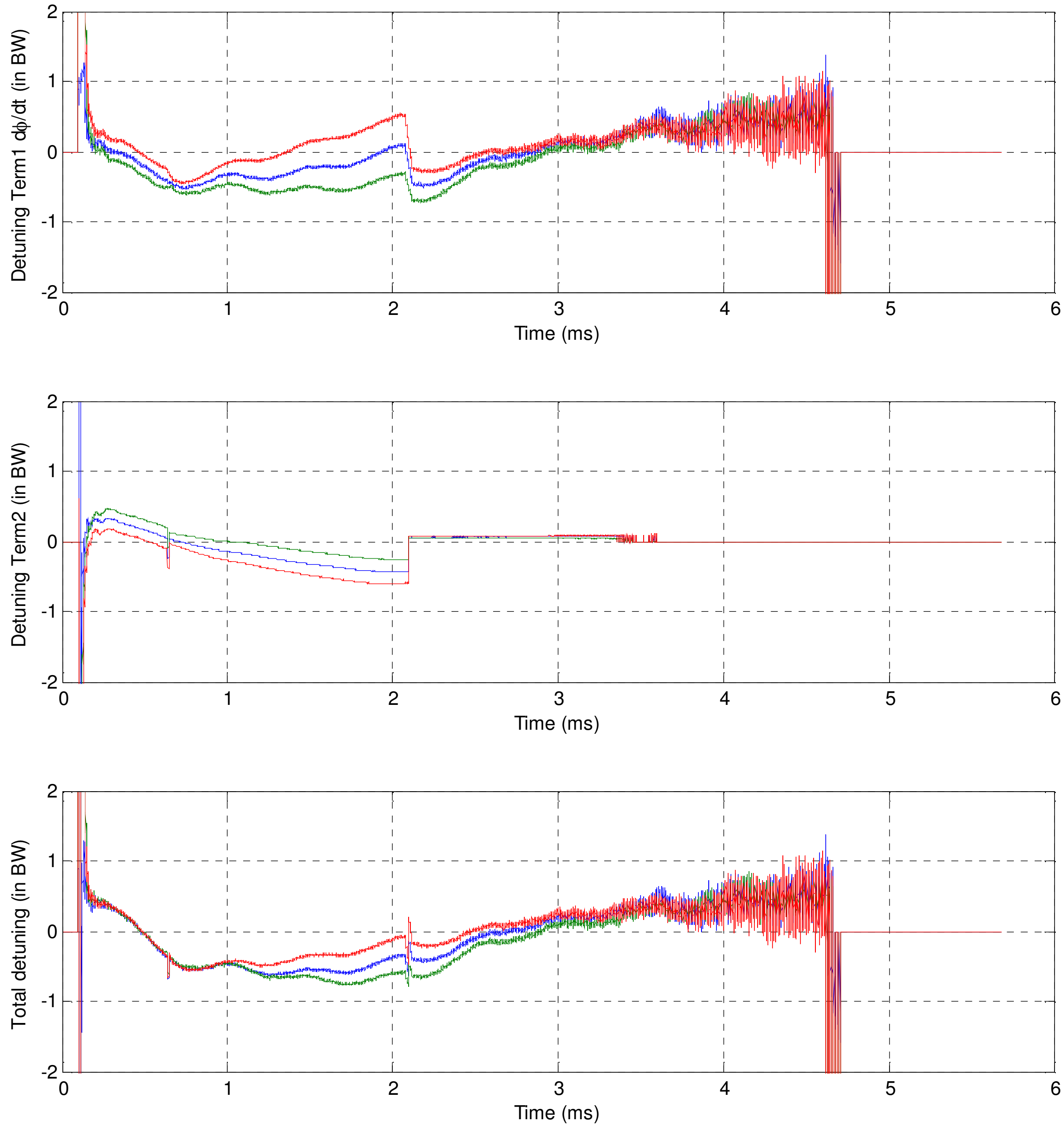
Preliminary results

- Acquired c[illegible] a typical li[illegible] pulse
- The beam was simulated by lowering the forward po[illegible] nominal
- A set c[illegible] measurements showing pulse reproducibility



Preliminary results

- Calculated cavity detuning during the setting up process
- The cavity was deliberately detuned by known amount to verify the calibration and calculations



Conclusions and following actions

- Low power measurements:
  - Characterize cavity microphonics
  - Excitation by piezo to measure mechanical resonant modes of the cavity (f_{mech} and Q_{mech})
  - Excitation by piezo to get realistic model parameters for the compensation system (delay, tuning range etc.)
  - Find optimal piezo drive pulse shape (amplitude, delay, function, observe and mitigate resonant build-up of detuning from pulse-to-pulse)
  - Find optimal control algorithm to drive the piezo tuner

Conclusions and following actions

- High power measurements:
  - Measure and quantify dynamics of the cavity in a pulsed environment
  - Measure the mechanical mode damping times (2 Hz vs. 50 Hz operation)
  - Measure the klystron and cavity behaviour with full length, full power RF pulses
  - Quantify reproducibility of the klystron pulses
  - Quantify reproducibility of the cavity field pulses (feed-back vs. feed-forward compensation, how fast etc.)

SPL
LLRF simulations
Feasibility and constraints for operation with more than one cavity per klystron
Power overhead

Wolfgang Hofle

Acknowledgements and Participation:
S. Chel, G. Devanz, M. Desmons, O. Piquet (CEA Saclay)
M. Hernandez Flano, J. Lollierou, D. Valuch (FB section)
O. Brunner, E. Ciapala, F. Gerigk, J.Tuckmantel

This project has received funding from the European Community's Seventh Framework Programe (FP7/2007-2013) under the Grant Agreement nº212114

SPL parameters

SPL cavities and frequency: 704.4 MHz, cooling @ 2K He-II

Low energy part : β=0.65, 5–cell cavities, 6 cavities/cryostat,
60 cavities, R/Q = 320 Ω_{linac}
1 klystron / cavity → likely baseline

High energy part: β=1, 5-cell cavities, 8 cavities/cryostat,
160 for 4 GeV (200 for 5 GeV) cavities, R/Q = 525 Ω_{linac}
One 1.x MW klystron for 2 cavities (LPSPL)
One 1.x MW klystron for 1 cavity (HPSPL)
One ~5.5MW klystron per 4 cavities (previous)

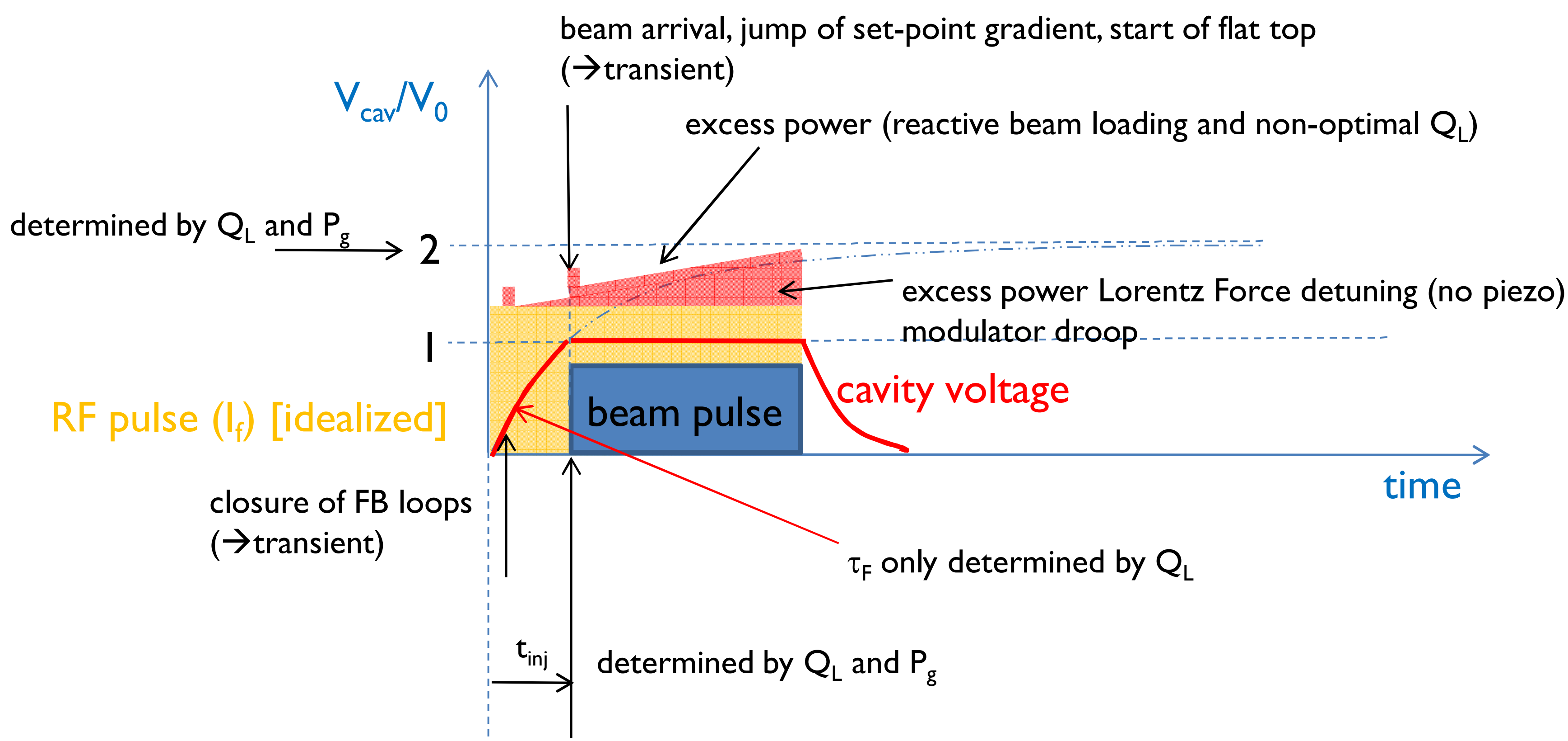
SPL requirement: for β=1 → 25 MV/m
Stability: 0.5% and 0.5 degrees for V_{acc} during beam pulse

LPSPL:	4 GeV	2 Hz	1.2 ms beam pulse	20 mA beam current (DC)
HPSPL:	5 GeV	50 Hz	0.4 ms / 1.2 ms beam pulse	40 mA beam current (DC)

Cavity loaded Q ~ 10^6 HPSLP: ppm change of beam pulse length ??
Fixed coupler position optimized for 40 mA operation, will give reflection @ 20 mA
ϕ_s=15 degrees

Principle of pulsed operation

SPL (with beam)



sLHC

Parameters for 20 mA operation, with optimized coupling for zero reflected power during 40 mA beam pulse (1)

frequency:	704.4 MHz
accelerating gradient of β=1 cavities:	25 MV/m
length of cavity L=$\beta 5\lambda/2$:	1.06 m
cavity accelerating voltage for β=1	26.5 MV
synchronous phase angle ϕ_s	15 degrees

power delivered to beam $P_b = I_b \cdot V_{acc} \cdot \cos\varphi_s = 512\ \text{kW}$

chosen (optimal value for 40 mA) $Q_{ext} \approx Q_L = 1.3064 \times 10^6$

reflected current in steady state with beam $I_r = \frac{V_{acc}}{(R/Q)} \frac{1}{Q_{ext}} - I_b \cos\varphi_s = 19.3\ \text{mA}$

reflected power in steady state with beam $P_{refl} = \frac{1}{4}(R/Q) \cdot Q_{ext} \cdot |I_r|^2 = 64\ \text{kW}$

forward current in steady state with beam $I_f = \frac{V_{acc}}{(R/Q)} \frac{1}{Q_{ext}} + I_b \cos\varphi_s = 58.0\ \text{mA}$

forward power in steady state $P_{fwd} = \frac{1}{4}(R/Q) \cdot Q_{ext} \cdot |I_f|^2 = 576\ \text{kW}$

Parameters for 20 mA operation, with optimized coupling for zero reflected power during 40 mA beam pulse (3)

2) 576 kW $V_\infty = V_{\mathrm{fwd}} + V_{\mathrm{refl}} = 2\sqrt{P_{\mathrm{fwd}} Q_{\mathrm{L}} (R/Q)} \approx 49.73\ \mathrm{MV} \approx 1.5 \times V_0$

$$V(t) \approx \frac{3}{2} V_0 \left(1 - e^{-t/2\tau_{\mathrm{F}}}\right) \to V_0 \qquad \frac{1}{3} \approx e^{-t_{\mathrm{inj}}/2\tau_{\mathrm{F}}}$$

$$t_{\mathrm{inj}} \approx 2\tau_{\mathrm{F,40\,mA,opt}} \ln 3 \approx 1.099 \times \tau_{\mathrm{F,40\,mA,opt}} \approx 0.648\ \mathrm{ms}$$

compared to 40 mA opt. $t_{\mathrm{inj}} = 2\tau_{\mathrm{F,\,40mA,opt}} \ln 2 \approx 1.386 \times \tau_{\mathrm{F,40\,mA,opt}} \approx 0.4092\ \mathrm{ms}$

20 mA opt. $t_{\mathrm{inj}} = 2\tau_{\mathrm{F,20mA,opt}} \ln 2 \approx 1.386 \times \tau_{\mathrm{F,20\,mA,opt}} \approx 0.8184\ \mathrm{ms}$

$Q_{\mathrm{ext}} \approx Q_{\mathrm{L}} = 1.3064 \times 10^6$

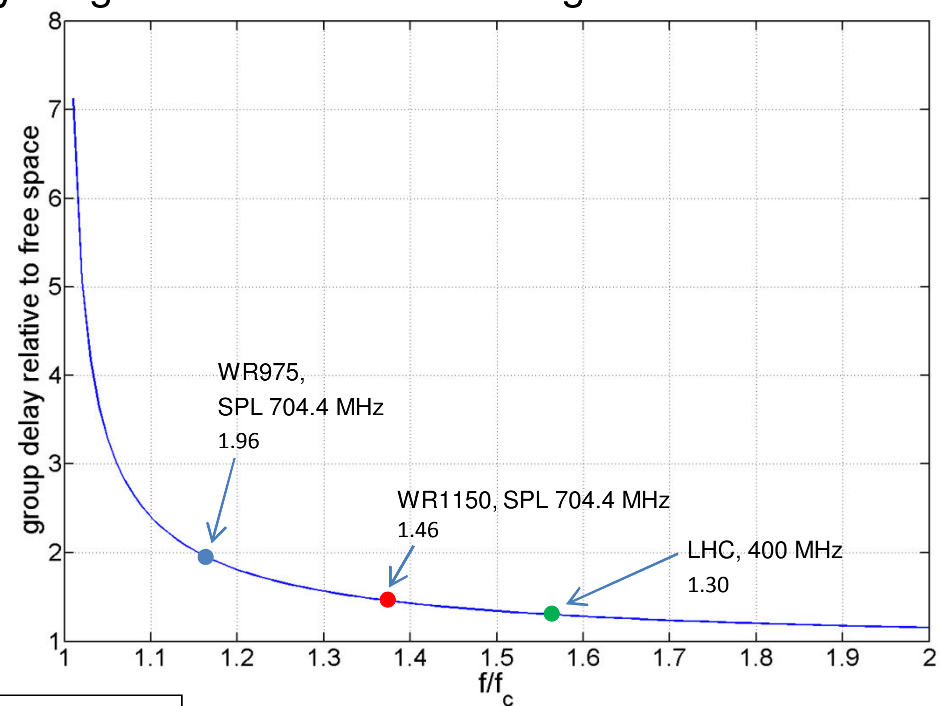
- $t_{\mathrm{inj}} = 0.648\ \mathrm{ms}$ — 0.576 MW, 2 cavities → 1.152 MW
- $t_{\mathrm{inj}} = 0.4092\ \mathrm{ms}$ — 1.024 MW, 1 cavity → 1.024 MW

12.5 % more power required for two cavities / klystron due to non optimal Q_{ext}

Waveguide group delay

The maximum frequency range in which a rectangular wave guide supports the propagation of only one mode is one octave

To obtain this maximum frequency range the width of the wave guide has to be at least a factor 2 of its height



The propagation constant is

$$\beta(\omega) = \frac{2\pi \cdot f}{c}\sqrt{1-\left(\frac{f_c}{f}\right)^2}$$

The group delay is

$$\tau_g = \frac{L/c}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$$

	WR-975	WR-1150	LHC (WR-2300)
cut-off in MHz	605	513	257
group delay (rel to free space)	1.96	1.46	1.3
group delay (rel to WR-975)	1	0.74	0.66
rel cross section	1	1.18	2.36
cross section for 200 waveguides (full height, in m**2), net	6.16	7.27	15.54

multiply by a factor 3-5 for required space

Group delay budget (tentative)

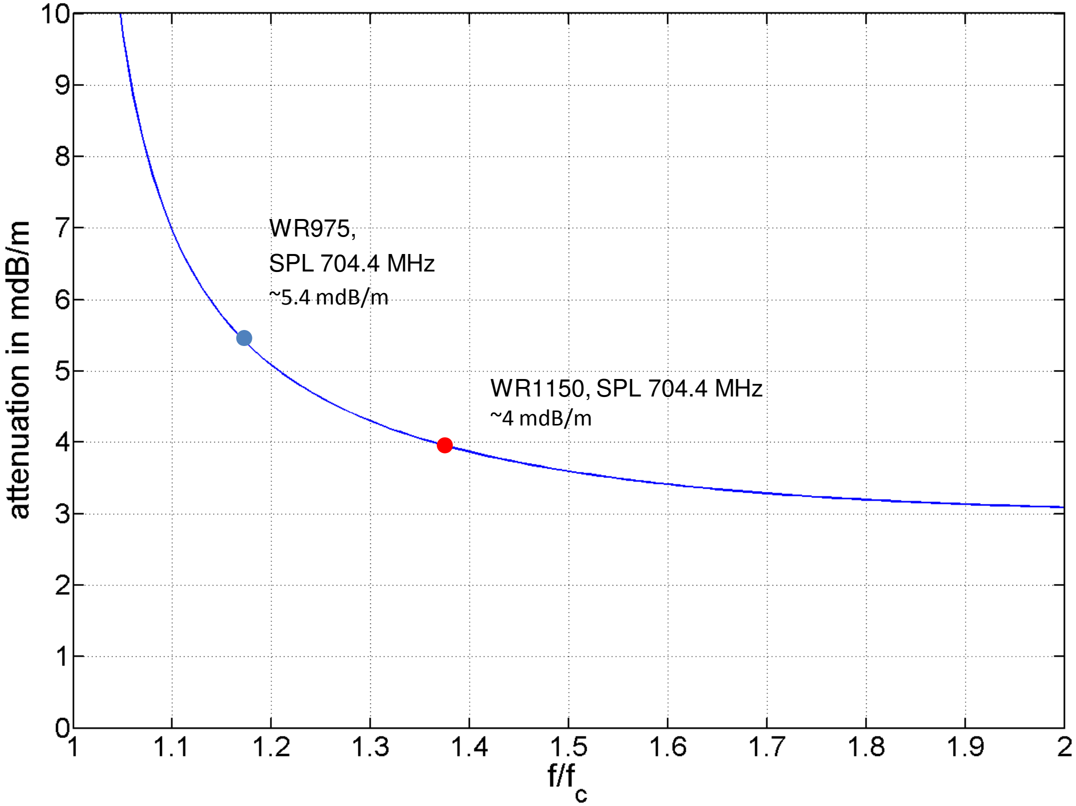
klystron:	250 ns ?
80 m waveguides (WR-1150)	360 ns (WR-1150)
80 m cabling (0.9 velocity factor)	270 ns
driver amplifier	40 ns
waveguide components (circulator etc.)	40 ns ?
local cabling (LLRF to klystrons etc.)	50 ns
LLRF latency	250 ns ?
total:	1260 ns
part related to 80 m distance (surface to underground)	630 ns (50 %)
savings 60 m → 15 m (2nd tunnel)	510 ns (40 %)

80 m seems ok (feedback does not need high bandwidth)

unknown, details to be studied: beam transients, chopping, HV ripple sLHC

Waveguide attenuation

From the attenuation point of view it is also better to stay away from the cut-off frequency, i.e. $f/f_c > 1.5$



Fundamental mode in full-height rectangular waveguide (Al 37.7×10^6 $1/\Omega$m)
AL alloys, Al Mg Si 0.5 → 35 % to 45 % higher losses !

Power budget (very tentative)

power minimum two cavities / klystron	1152 kW
reactive beam loading reserve	20 kW
detuning res. (Lorentz Force + micr.ph.)	20 kW ?
transients for loops	50 kW
variation in Q_L	15 kW ?
variation in cavity parameters	15 kW ?
beam current fluctuations	40 kW ?
power at cavity input:	1302 kW ?

1532/1152 = 1.33

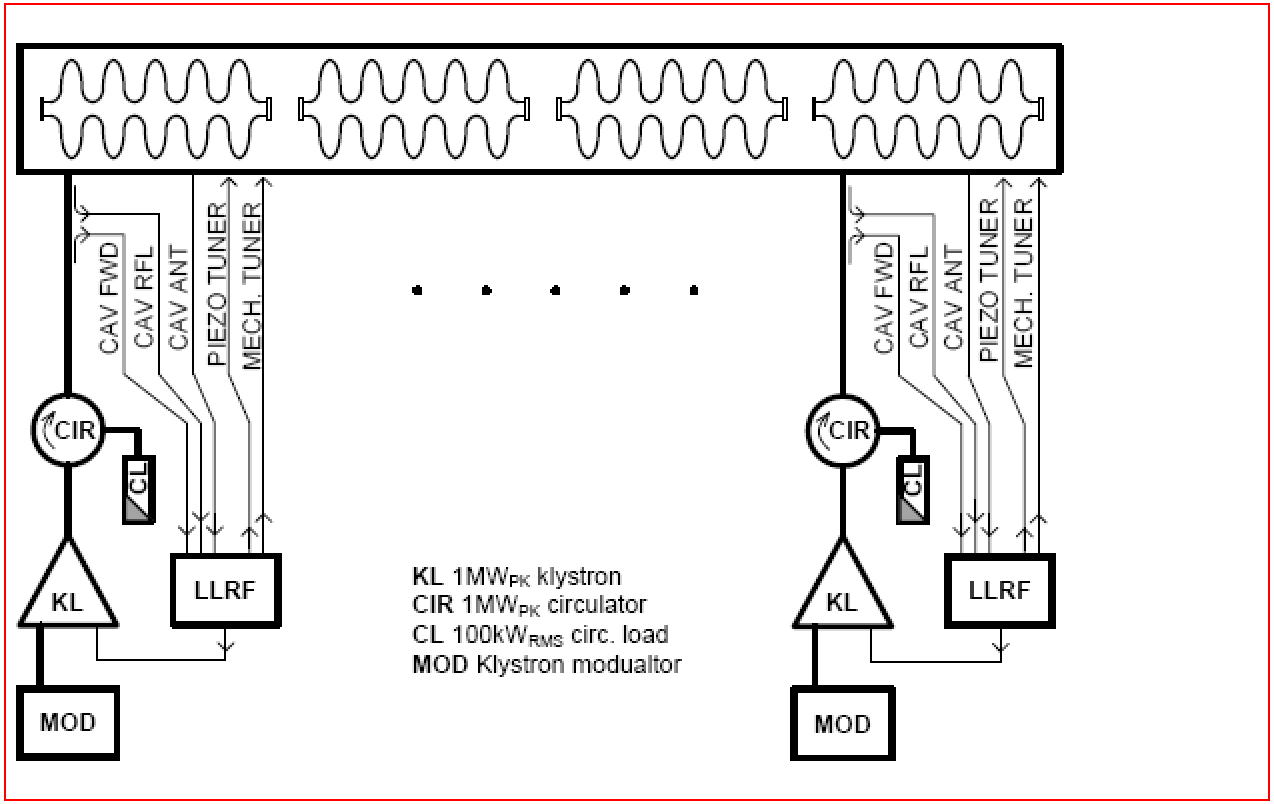
from klystron:	100%
end of life klystron reserve	0%
unusable (last 3%)	3%
waveguide losses	7% (more ?)
circulator losses	3%
reserve for imperfect matching	0% ?
ripple and noise due to HV	3% ?

→ 85%

klystron peak (saturated) power: 1532 kW → no reserve for unforeseen items
How much we need to stay away from klystron saturation – depends on klystron characteristics

Need simulations to better quantify these needs (see presentation by M. Hernandez)

Many possible Layouts, final for high energy part of HPSPL ?



1 klystron per cavity: individual control possible without RF vector modulator

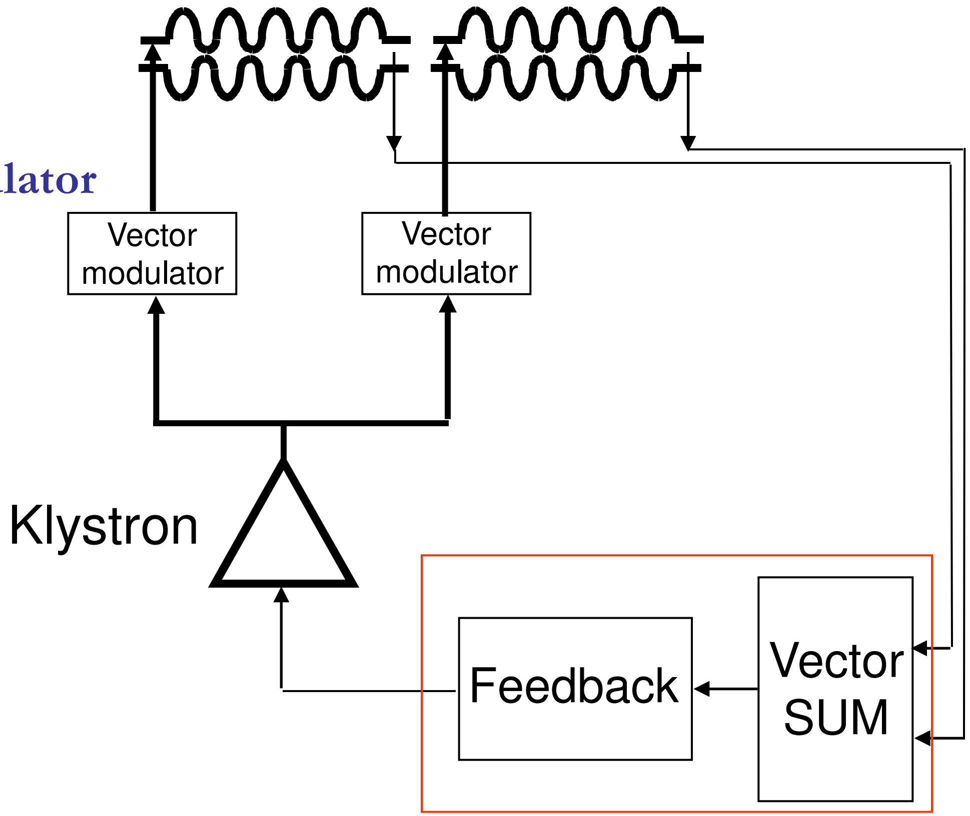
Disadvantage: Many klystrons required

Advantage: Easiest for control, considered adopted solution for low energy part

In this case and all following cases we assume individual Lorentz-force detuning compensation with a fixed pulse on the piezo or an adaptive feedforward (pulse-to-pulse)

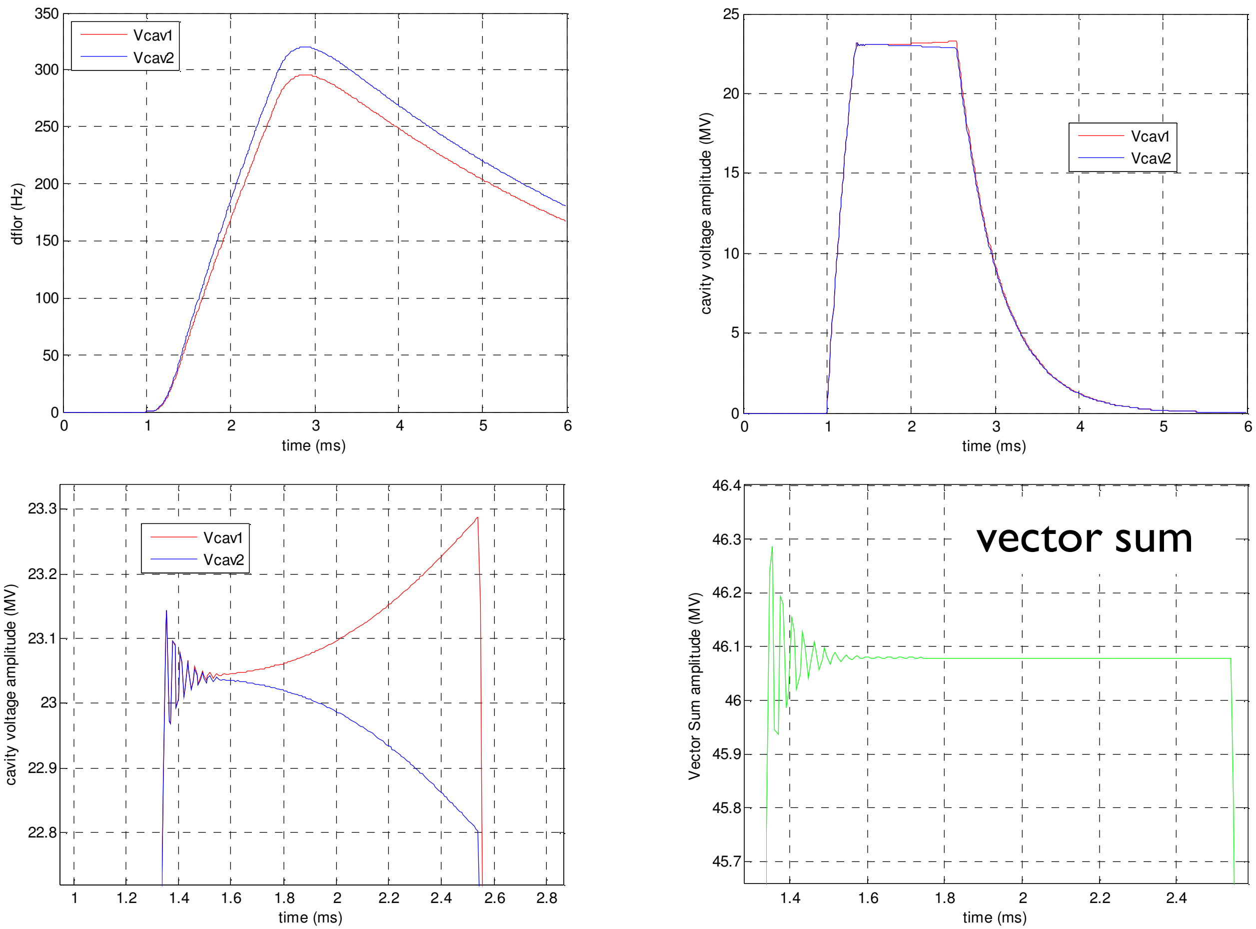
Many possible Layouts, initial for high energy part of LPSPL ?

optional
RF vector modulator



This case was analysed, see O. Piquet, CEA Saclay, simulation, LLRF09 workshop and presentation by M. Hernandez Flano

Two cavities per klystron high energy part of LPSPL



10% variation in Lorentz Force detuning

$K_{L,1}$=-2.0 Hz/(MV/m)^2

$K_{L,2}$=-2.2 Hz/(MV/m)^2

PI FB controller

5 μs delay in FB loop

loop closed at start of beam pulse

O. Piquet, CEA Saclay, simulation, LLRF09 workshop

Modelling - M. Hernandez Flano

- Matlab Simulink Modelling started
- Feedback and cavity simulations done
- Will be expended to include LFD, Mechanical resonances, waveguide elements.

Conclusions

- Baseline layout for Low/High B sections decided:
  * 1.5 MW klystron for 2 cavities in High B LPSPL
  * Single lower power source (IOT?) in Low B section
  * Individual klystron per cavity in HPSPL High B (Integration must allow this..)
- No difficulties with long WR1150 waveguides (80m)
- Studies nevertheless need continue on stability/repeatability attainable in presence of microphonics, Lorenz detuning, detuned cavities, reflections due to RF distribution component imperfections etc.
- Power coupler experience from CEA, LAL & CERN is very valuable, synergy & common experience.
  => Final designs to be studied at March Workshop
- Magnetron development work to be followed up
- Construction of test area in SM18 for RF power and cavity work

(Details to be elaborated shortly after the workshop)

Issues arising during the meeting

- Need for adjustable coupler
- Positioning of coupler (Top / Bottom)
- Can we get a ‘compact modulator’ for HPSPL ?

Thanks to all the speakers

and to the participants for all the valuable feedback