SOREQ

Status of the Phase I of the SARAF Linac

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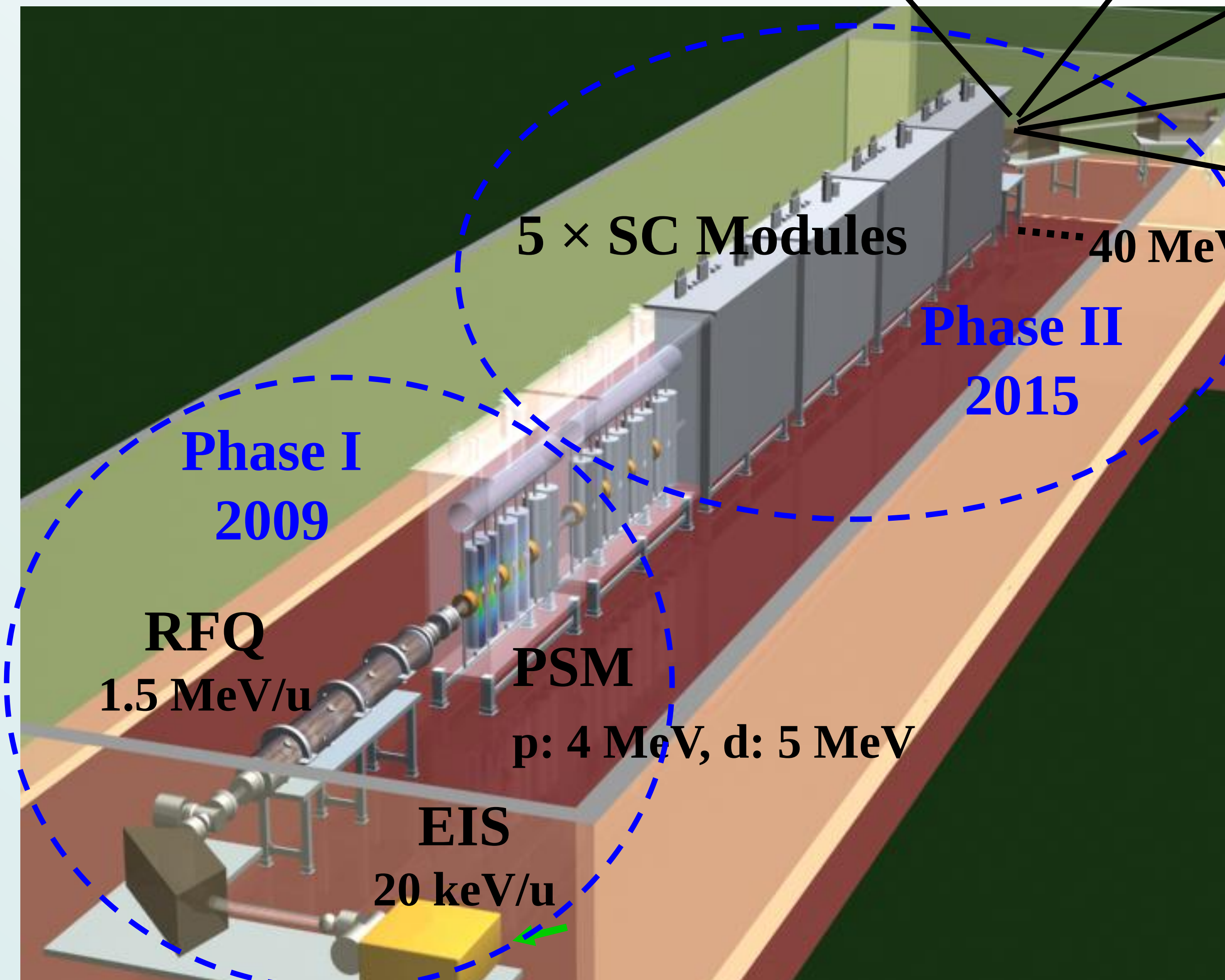
Presentation Outline

- Overview
- SARAF Linac Phase I components
  - ECR ion source + LEBT
  - RFQ
  - Prototype Superconducting Module (PSM)
- Beam operation experience
- Outlook

SARAF LINAC Layout

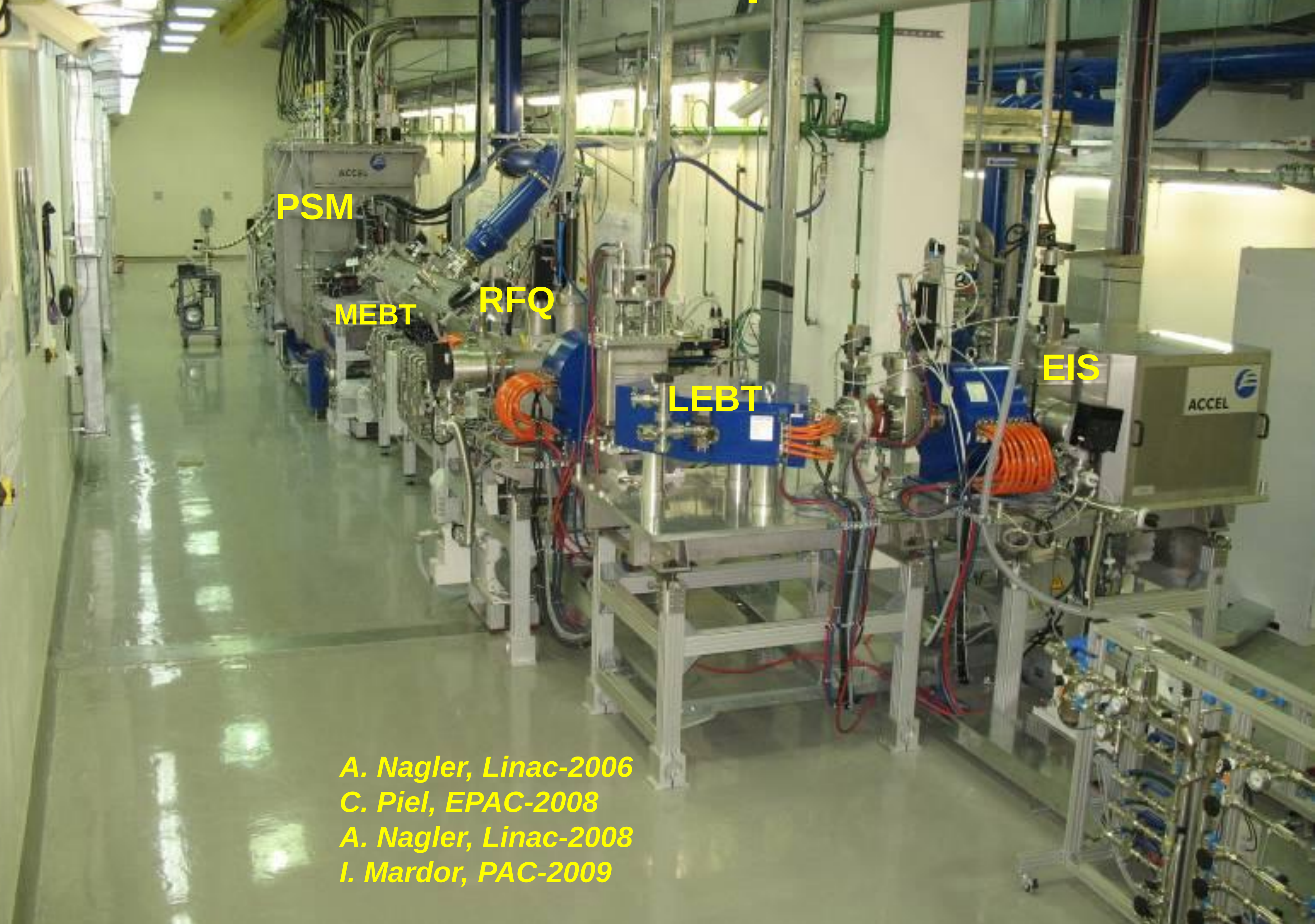


Accelerator Parameters

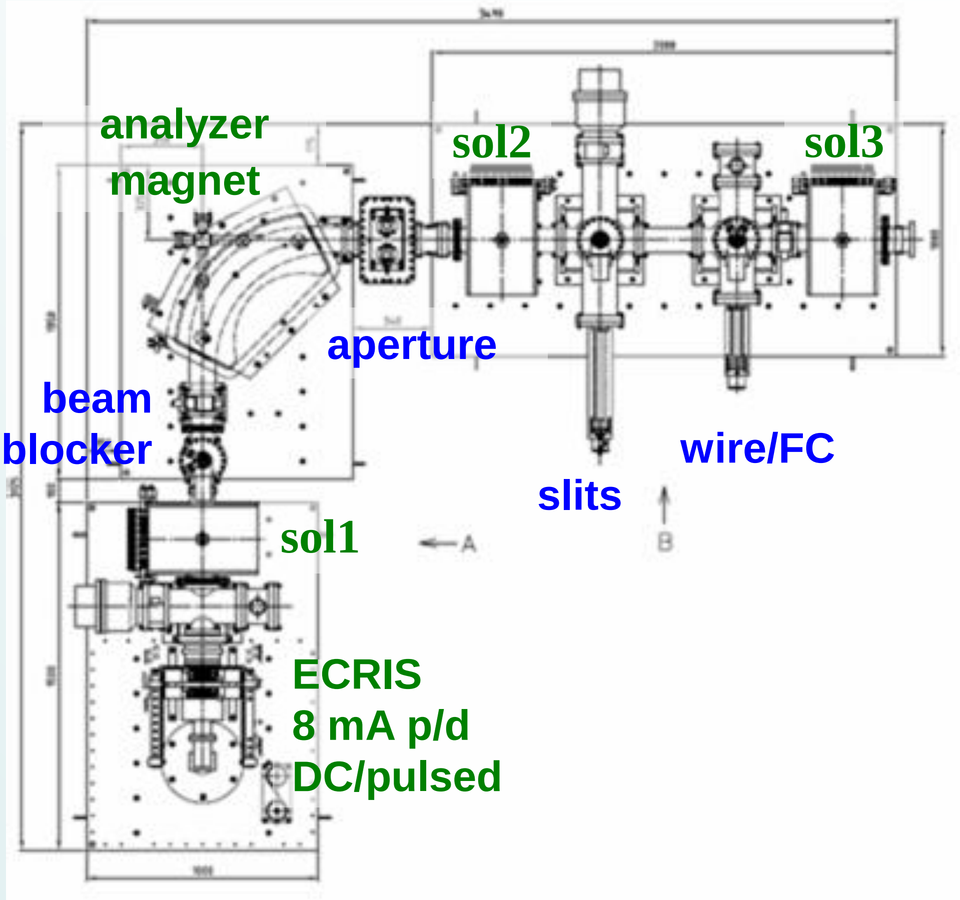
Parameter	Value
Ions	p / d
Energy	5 – 40 MeV
Current	0.04 – 2 mA
Maintenance	Hands-On

•Current upgradeable to 4 mA

SARAF Phase I – Upstream View



ECR/LEBT



Build by RI (ACCEL)

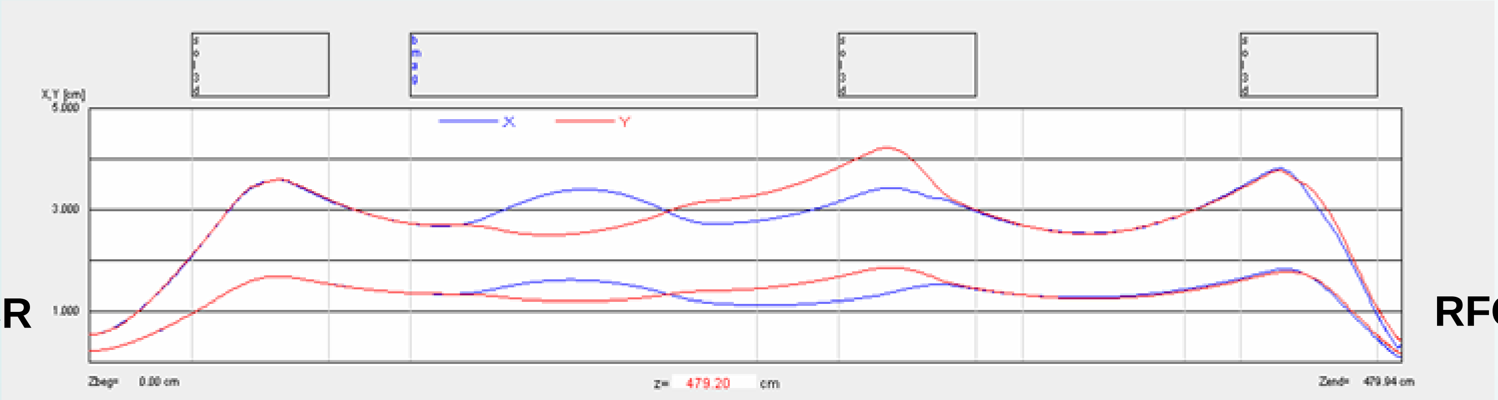
K. Dunkel PAC 2007

See poster TUP74

L. Weissman et al.

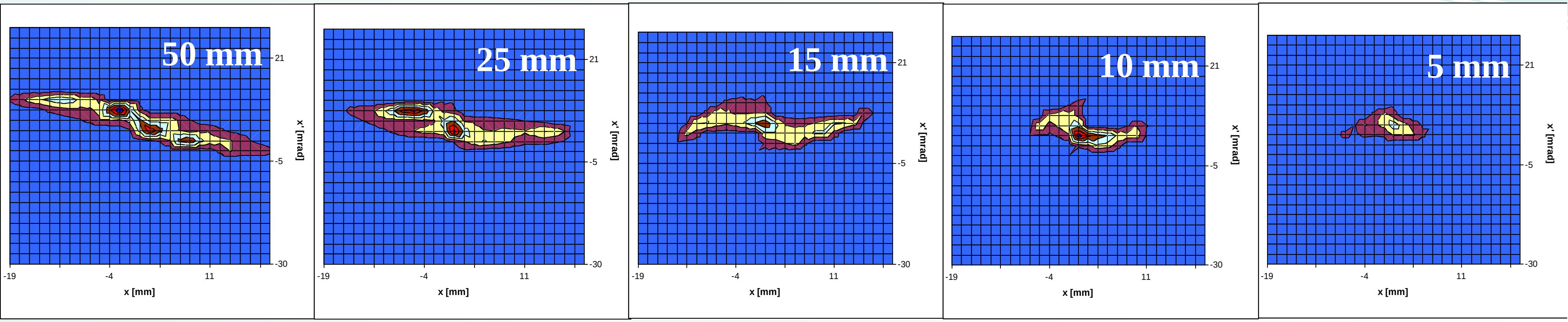
5 mA proton beam optics

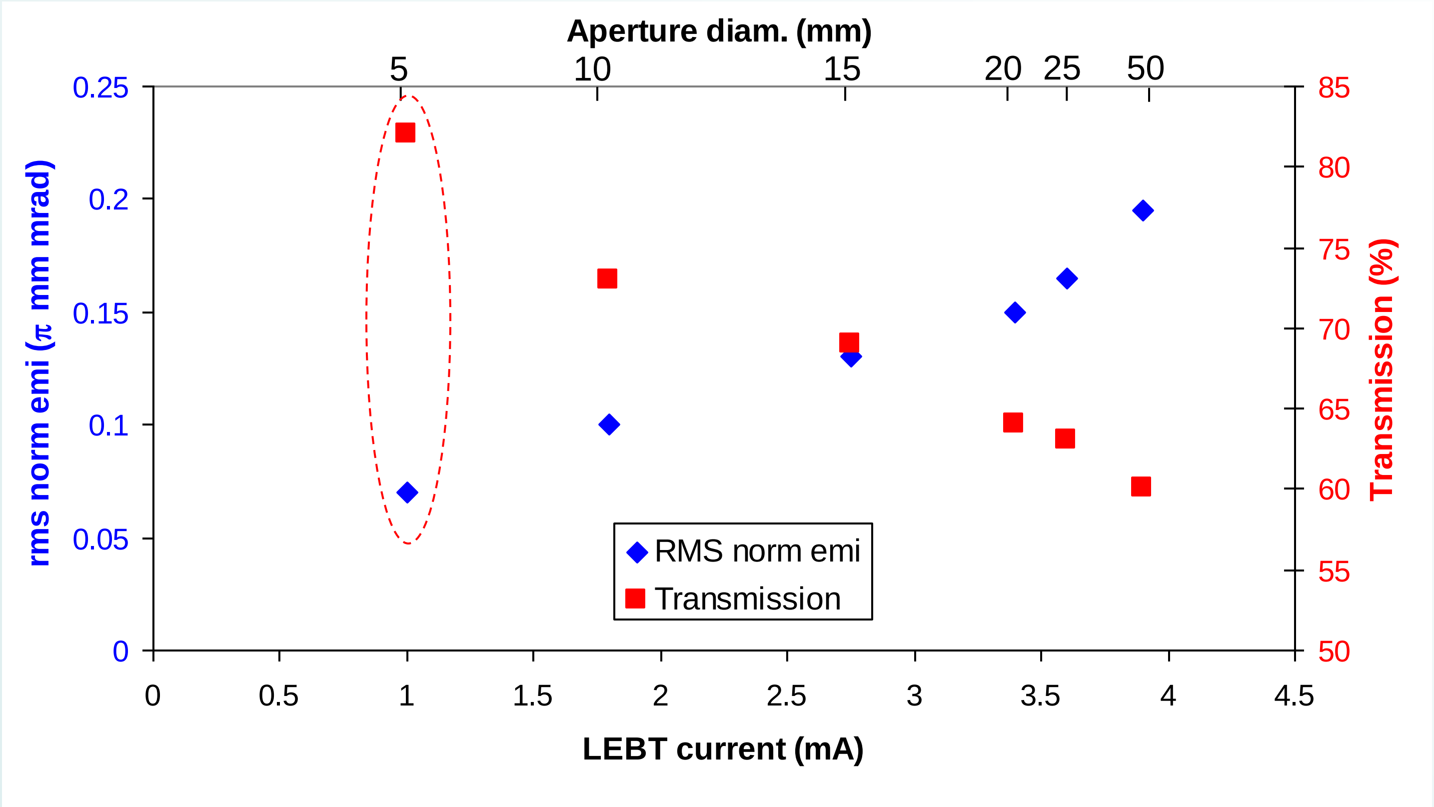
Large beam minimize space charge (TRACK)



LEBT aperture

Manipulating beam size, current and emittance using the LEBT aperture





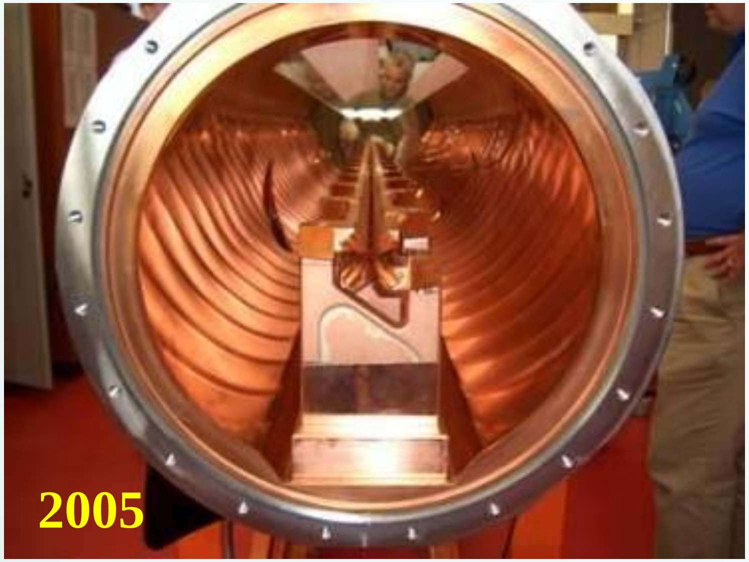
176 MHz 4-Rod CW RFQ

RFQ Beam Properties		
Beam Parameter	**Protons**	**Deuterons**
Energy (MeV)	1.5 (1.5)	3.0 (3.0)
Maximal current [mA]	4.0 (CW) (4.0)	2.5 (10^{-2}) (4.0)
Transverse emittance, r.m.s., normalized, 100% [π·mm·mrad] (0.5 mA, closed LEBT aperture)	0.17 (0.30)	0.16 (0.30)
(4.0 mA, open LEBT aperture)	0.25 / 0.29 (0.30)	NM
Longitudinal emittance, r.m.s., [π·keV·deg/u] (3.0 mA/0.4 mA)	90 (120)	200 (120)
Transmission [%] (0.5 mA)	80 (90)	NM
(2.0 mA)	70 (90)	NM
(4.0 mA)	65 (90)	70 (90)

RF Conditioning Status	
Input Power [kW]	**Duration [hrs]**
190 (CW)	12
210 (CW)	2
240 (CW)	0.5
260 (DC = 80%)	0.5

Deuteron CW operation requires conditioning up to 260 kW (65 kV)

Power density: average ~ 25 W/cm^2



RFQ conditioning campaigns

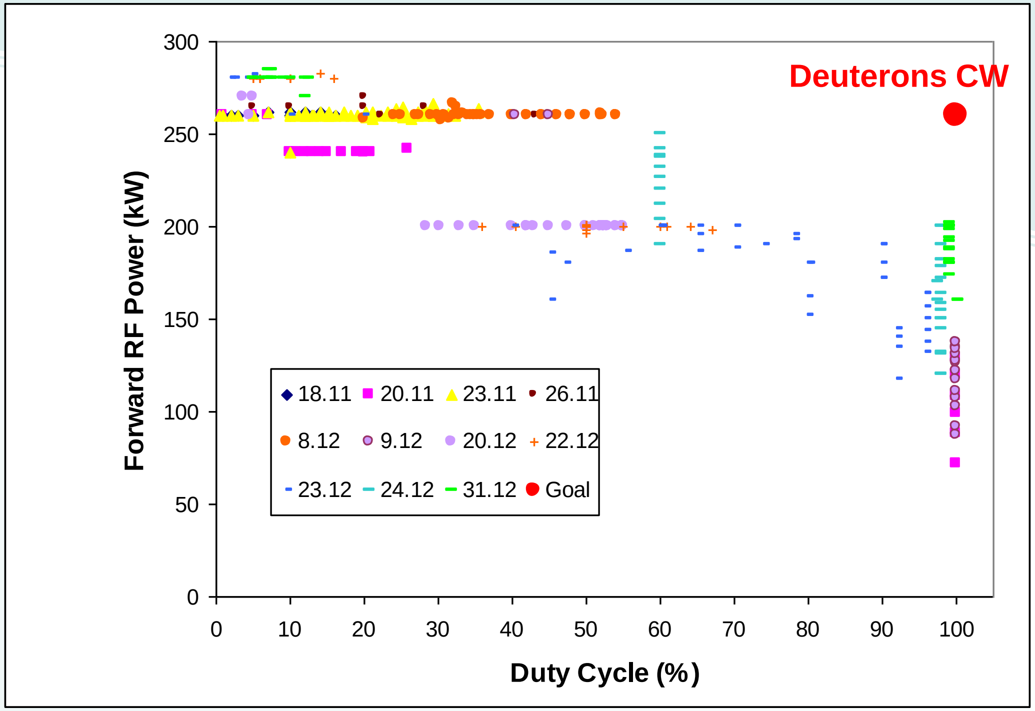
The objective of the RFQ conditioning (260 kW CW) has not been achieved yet

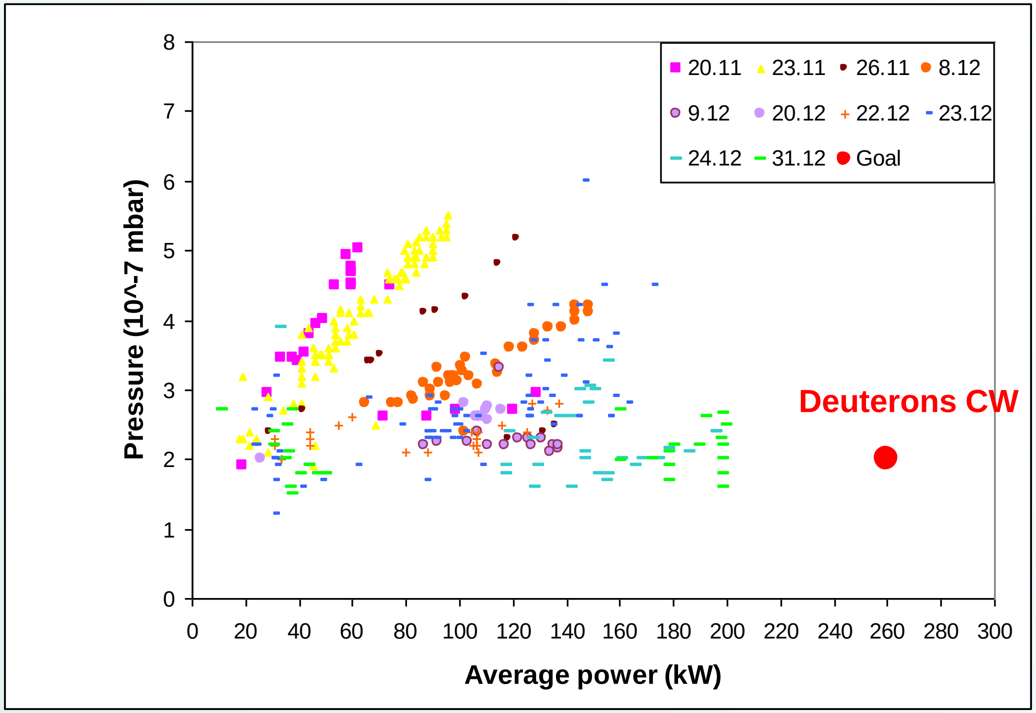
Example: campaign end 2009

RFQ issues which prevented reaching deuteron CW power:

- Arching from back side of rods
- Melted tuning plates
- Melted plungers
- Broken RF fingers
- Warming of end flanges
- Burning O-rings
- …

See poster TUP095 J. Rodnizki et al.

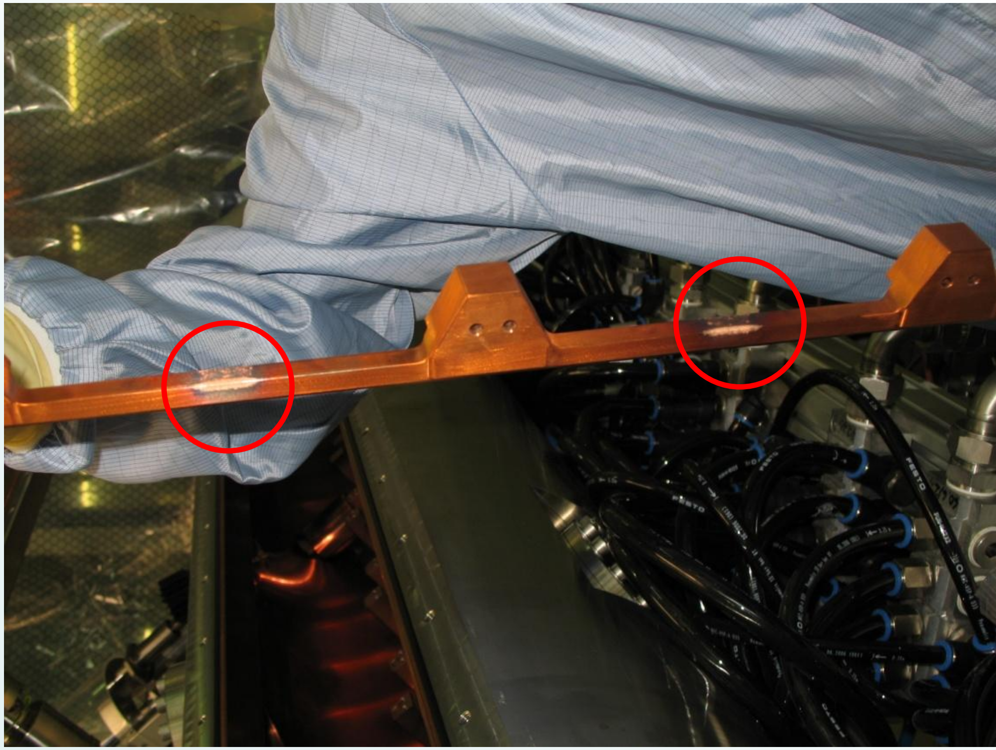




Discharge between the rods and stems

Non-linearity of voltage response,
High x-ray background

Discharge between back of the rods and stems

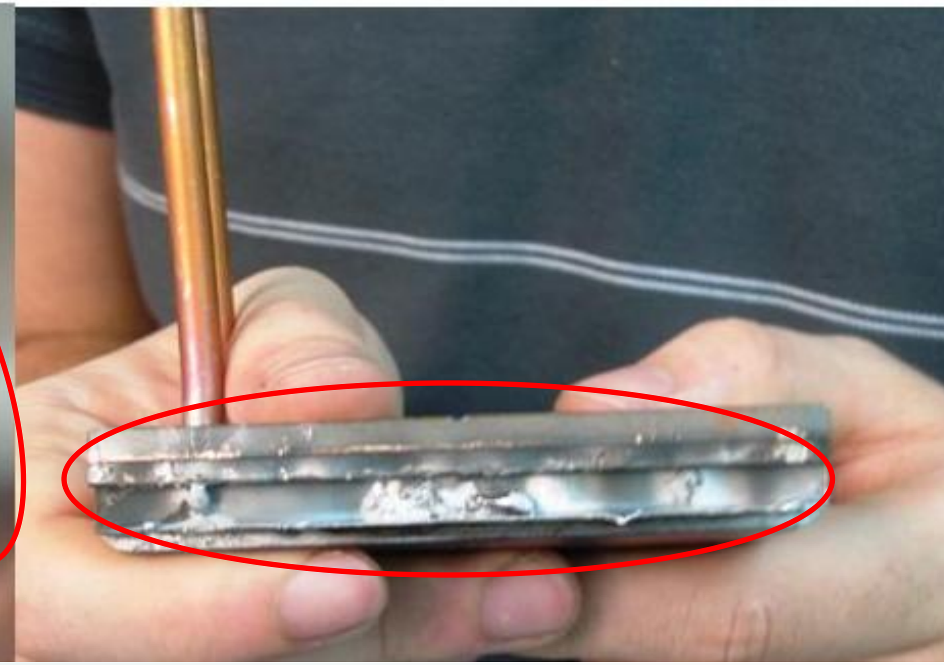


In spring 2009 the rods were modified locally to reduce the parasitic fields.

This solved the problem of discharge.

However, field realignment was required (later in the talk).

Burning of tuning plates

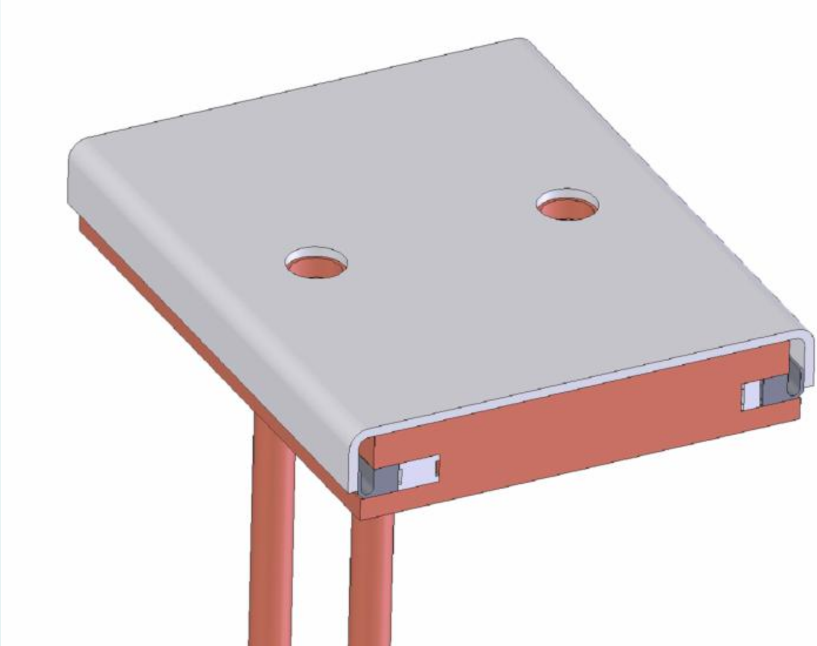


Contact springs of tuning plates were burned twice

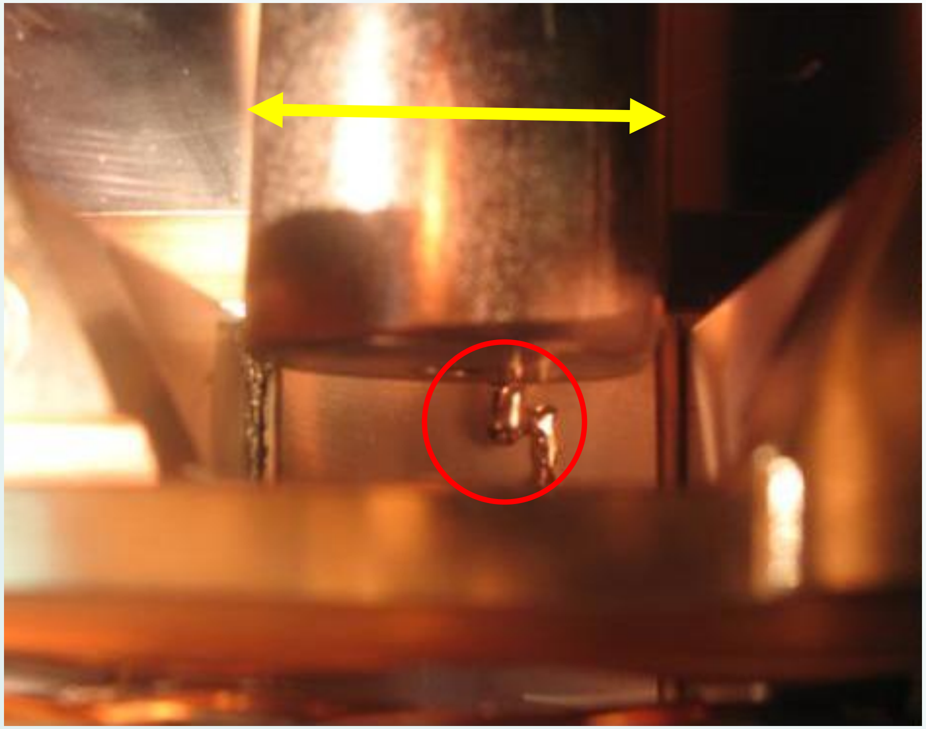
<u>New design</u> :

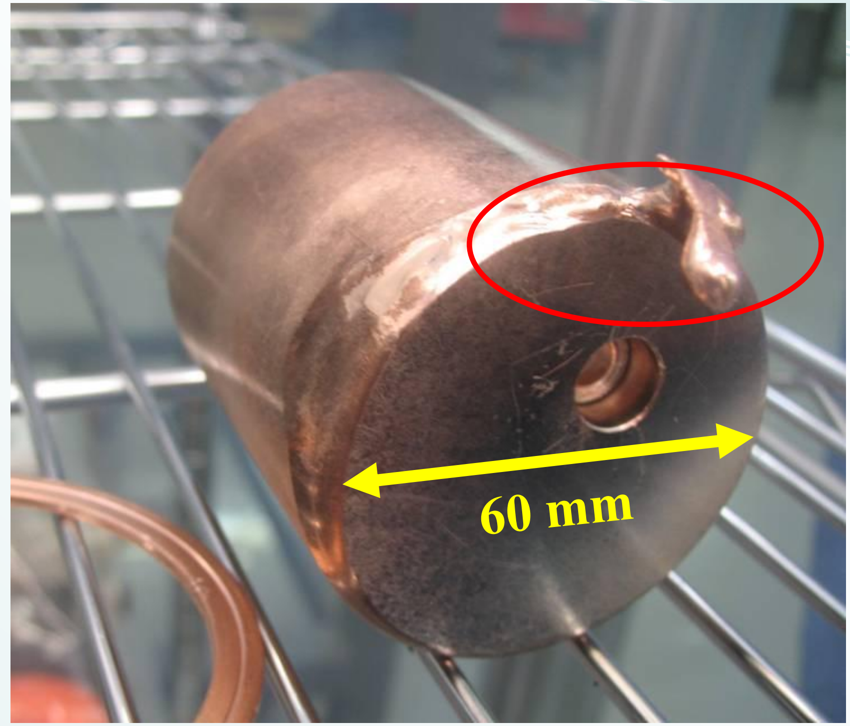
massive silver plate for better current and thermal conductivity,

mechanical contact with stems by a splint system



Melting of plunger electrode



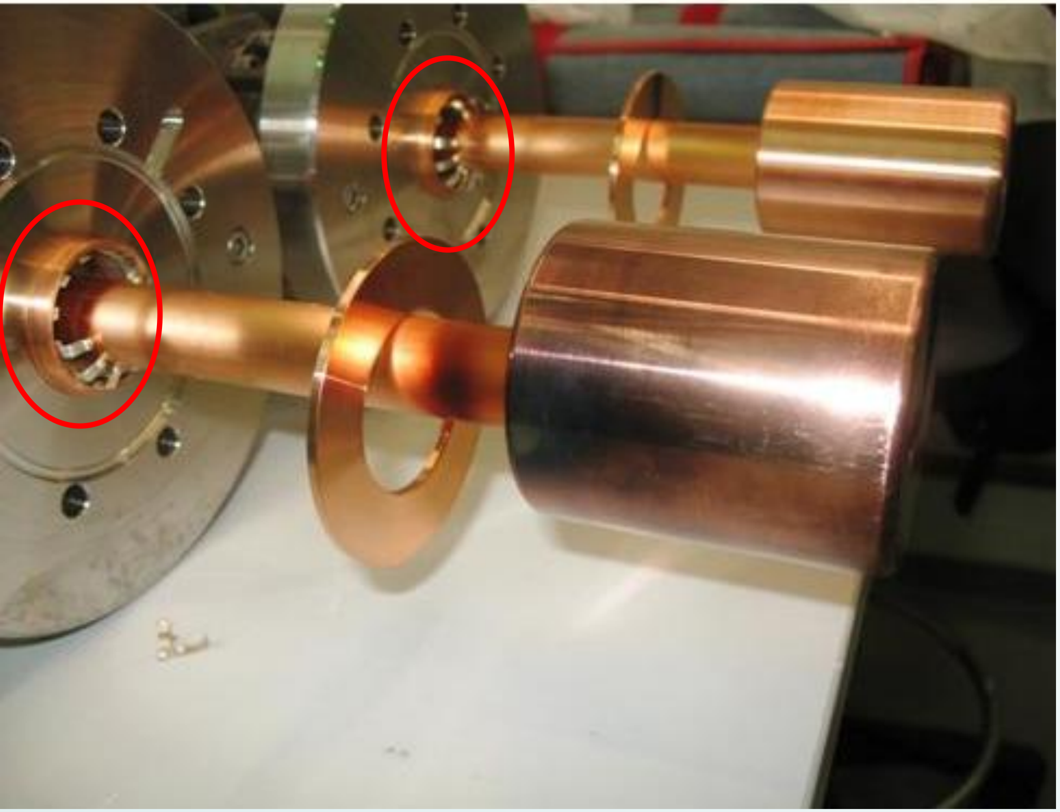


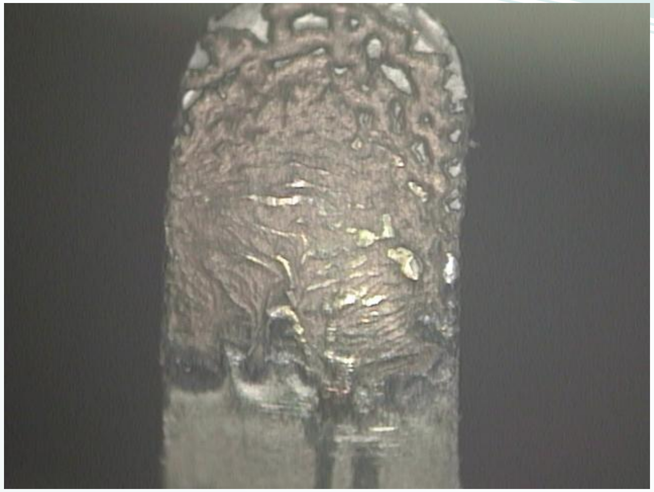
The low-energy plunger electrode has been melted.
It was verified that this was not due to a resonance phenomenon.

<u>New design</u>:

plunger was reduced by size (twice less thermal load),
cooling capacity was improved (the plunger and cooling shaft made from one block)

Plungers RF sliding contacts





Cu/Be silver plated

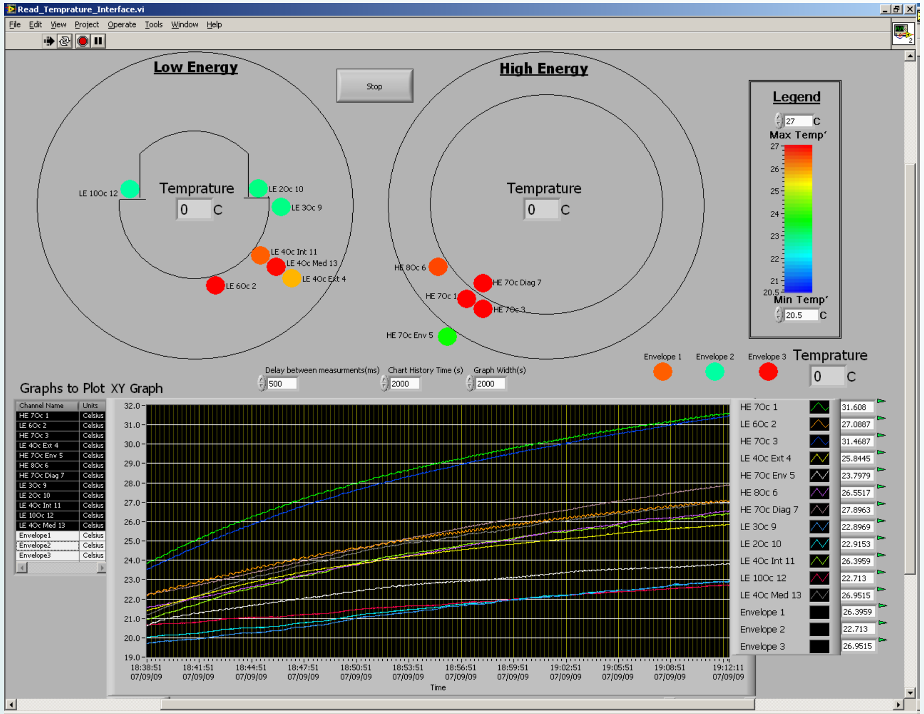
Broken and deformed RF fingers of the plunger sliding contacts.
The sign analysis of the finger surface showed melting signs.

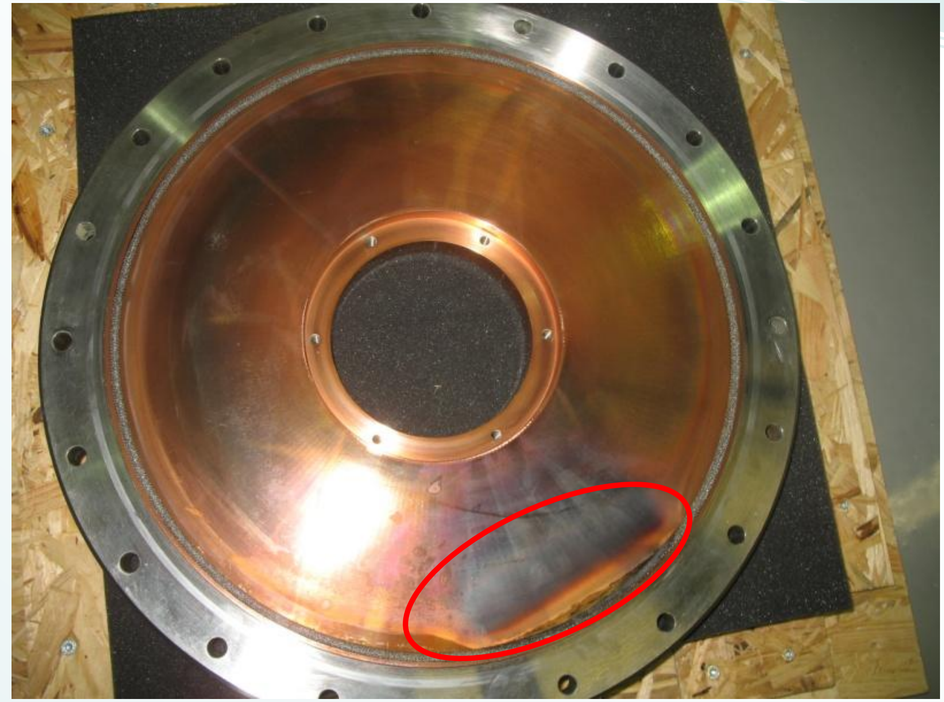
New design :

- new type of RF contact with more rigid fingers
- shafts plated by rhodium to avoid cold welding
- rigid alignment of the plunger providing uniform contact pressure

Heating of end flanges

SOREQ





Heating of RFQ end flanges (not water cooled).
Coloration of flanges was observed.

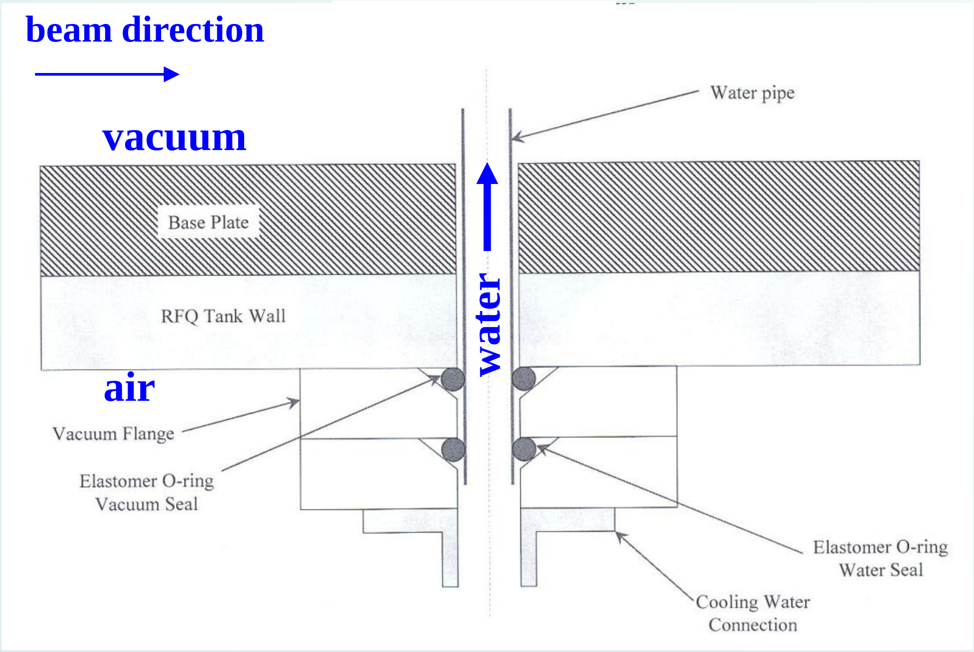
<u>New design</u>:

efficient water cooling
improved RF contact between the flanges and the base plate

Failure of vacuum seals

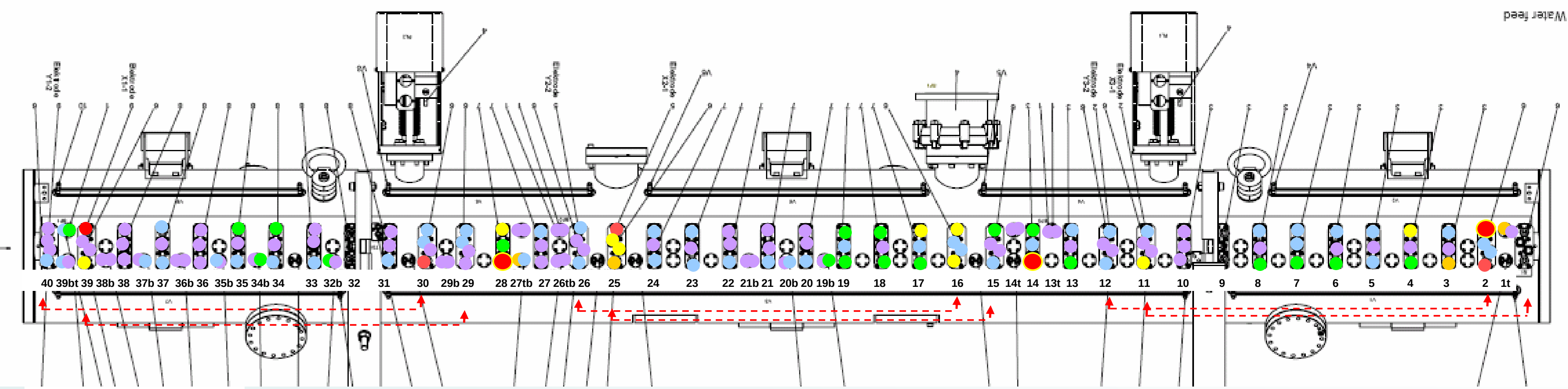
Several times vacuum failure occurs during conditioning

Damaged vacuum or water o-rings



This probably happens due to discharges of RF field leaked along cooling tubes

RF mapping of cooling channels

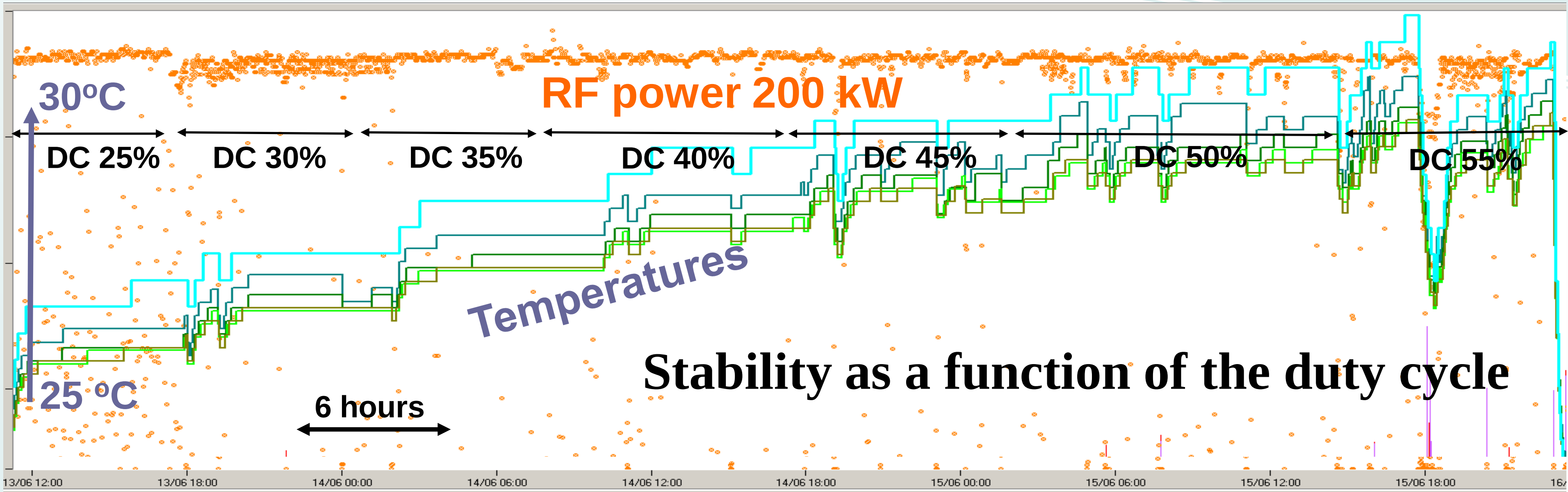


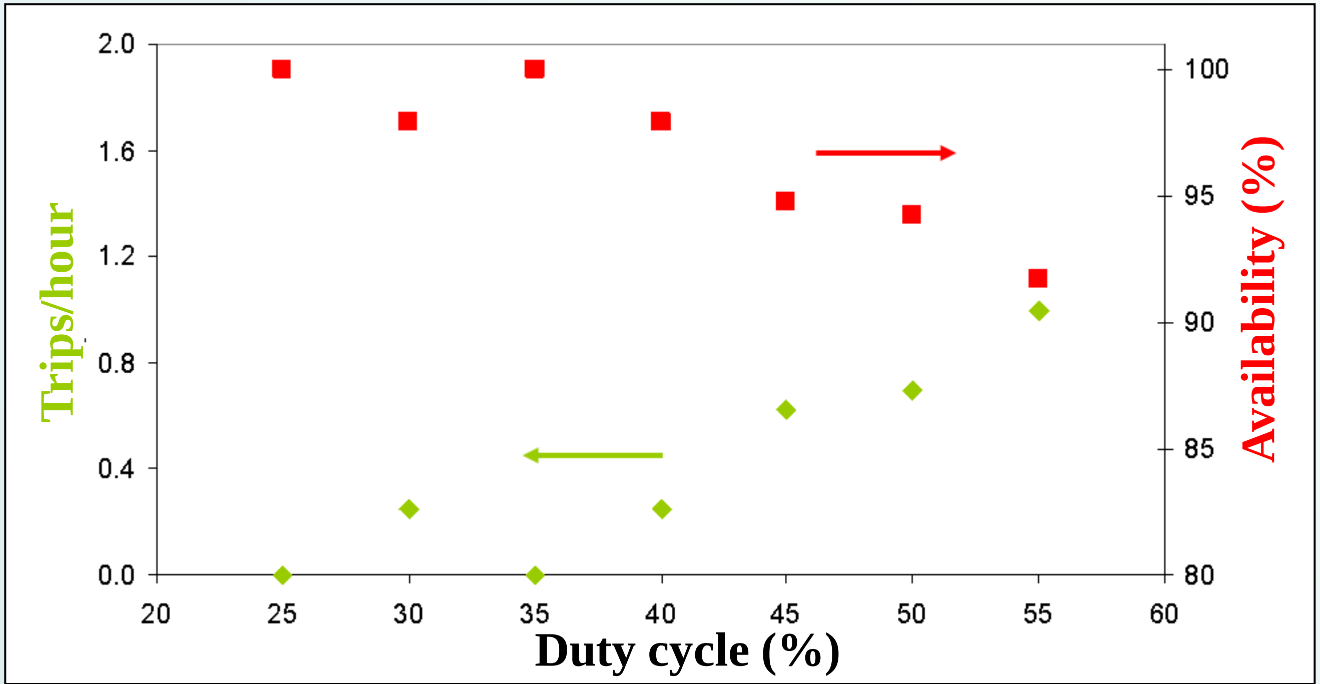
- <150 mV
- 150 -300 mV
- 300-450 mV
- 450-600 mV
- 600-750 mV
- 750-1000 mV
- >1000 mV

RF hot spots were observed by mapping RF fields (200 W) on the cooling channels .
In many cases these positions corresponded to the failed o-rings.

Solutions for better RF contact, not implemented yet.

RFQ stability/availability



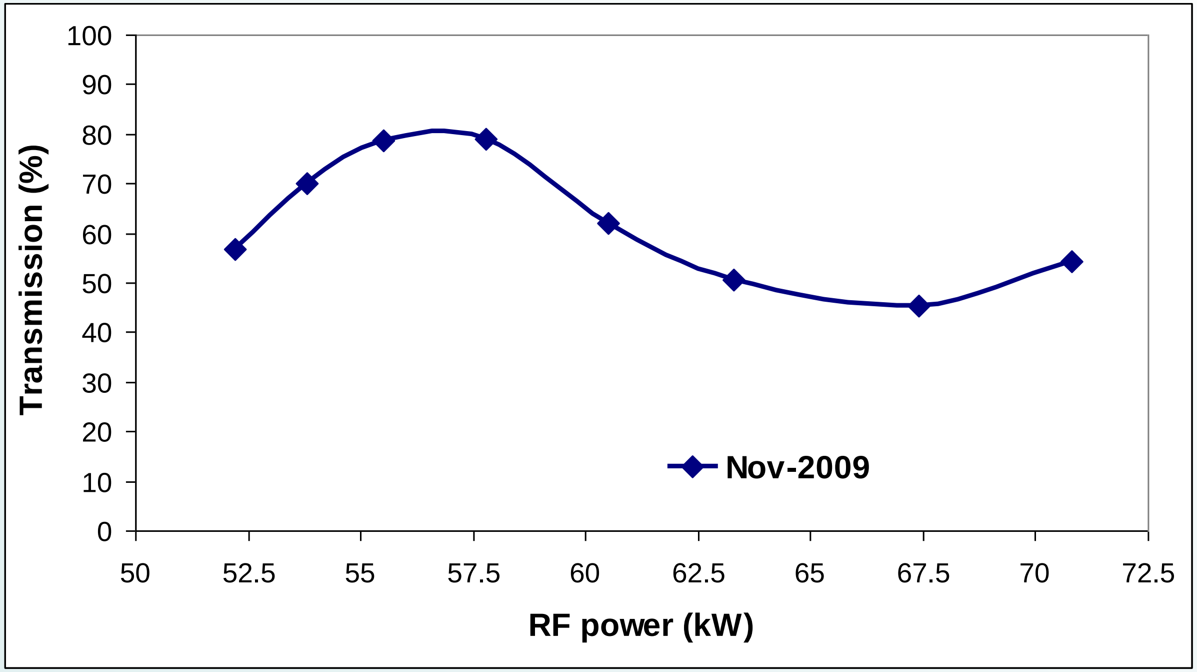


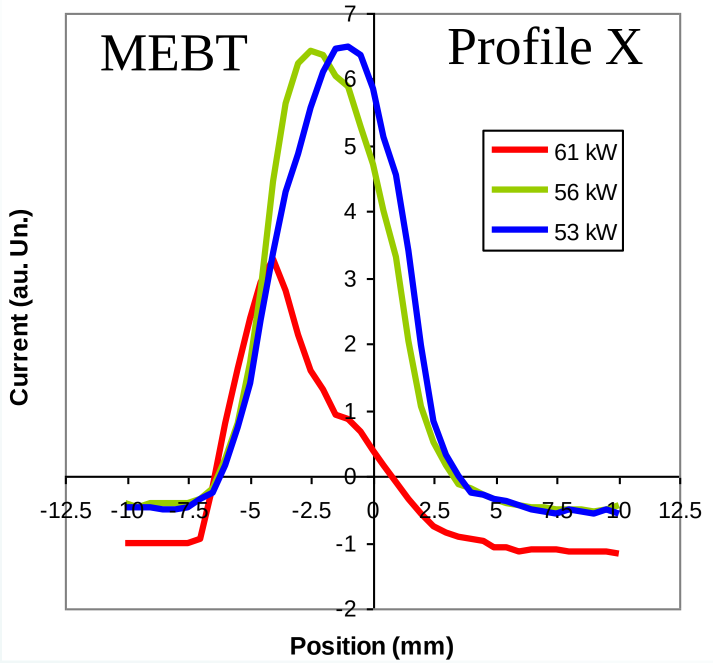
RFQ Conditioning Summary

- The objective to condition RFQ to CW deuteron operation powers is NOT achieved yet

- Next steps to improve RF performance
  - Redesign and replace water flanges to solve the vacuum seals problem
  - Improve vacuum systems: additional pumps, centralized oil free backing
  - Further improvement of the RFQ cooling
  - Additional diagnostics for RF conditioning (more vacuum gauges, RGA, x-ray mapping, etc.)

RFQ beam steering effects



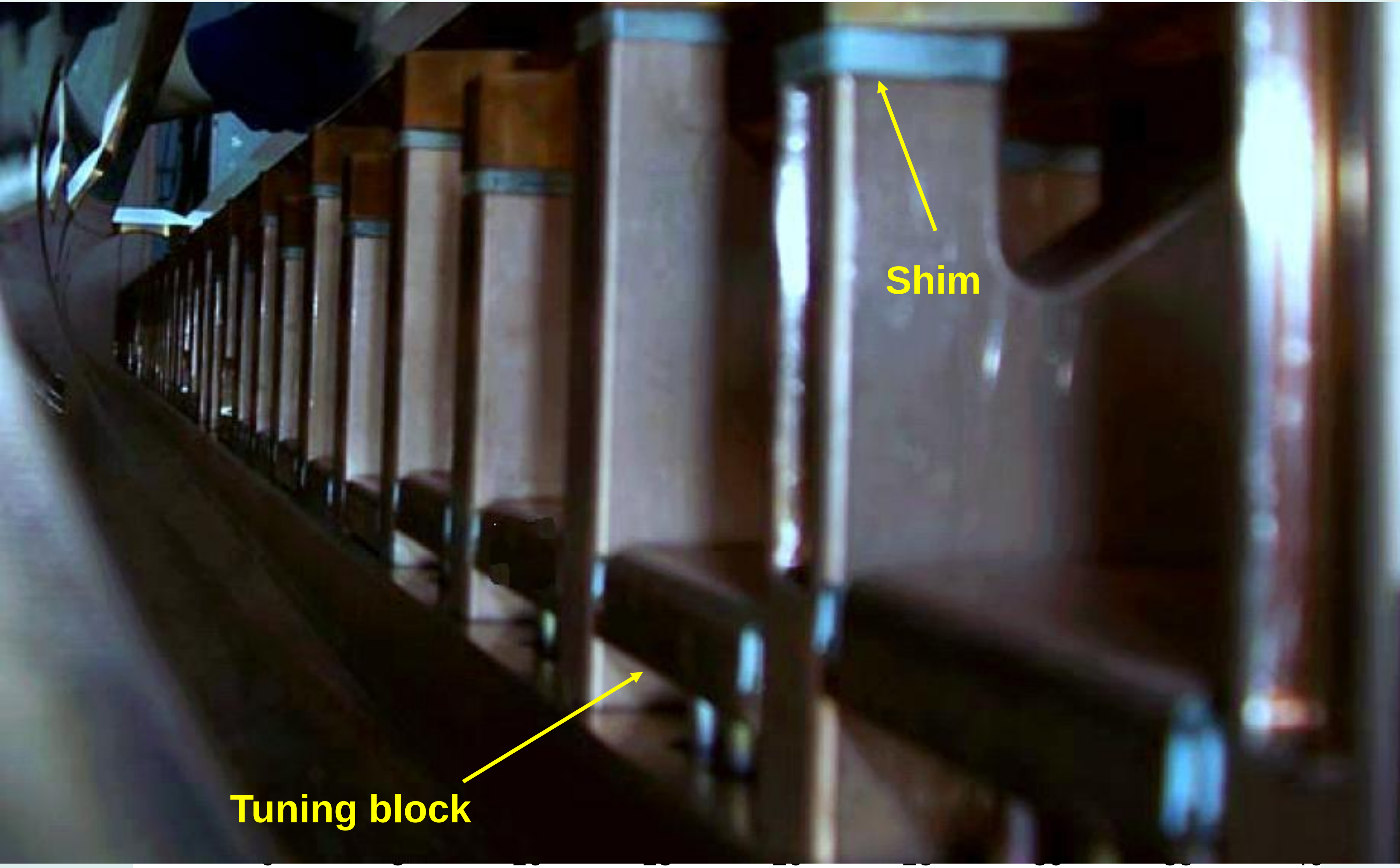


Observed strong dependence of the overall transmission and beam profiles on the RFQ forward power.

Such strong effects were not observed before the modifications made in the RFQ in the first half of 2009

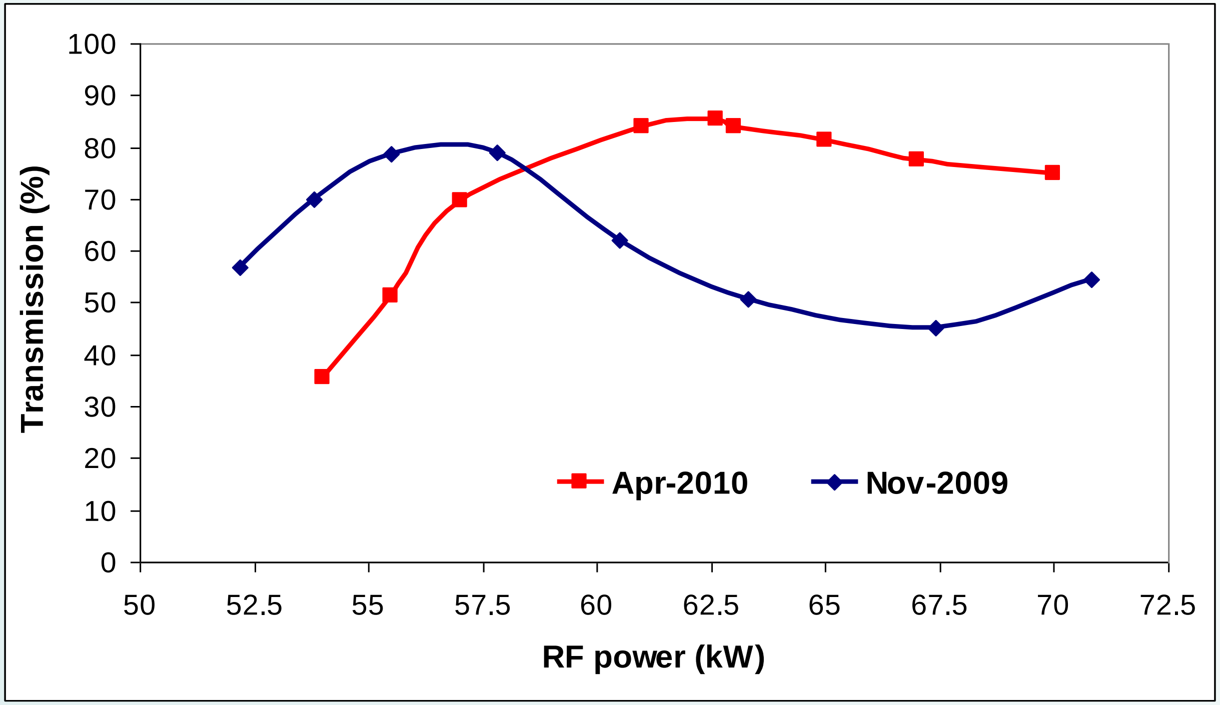
RFQ field homogeneity

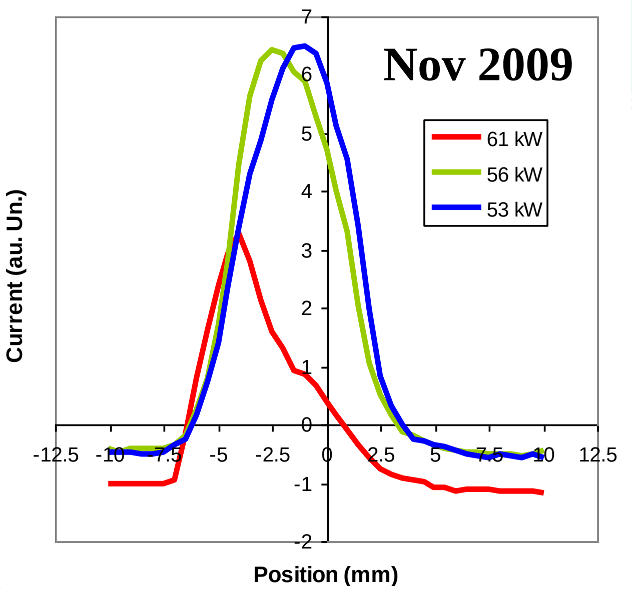
March 2010:

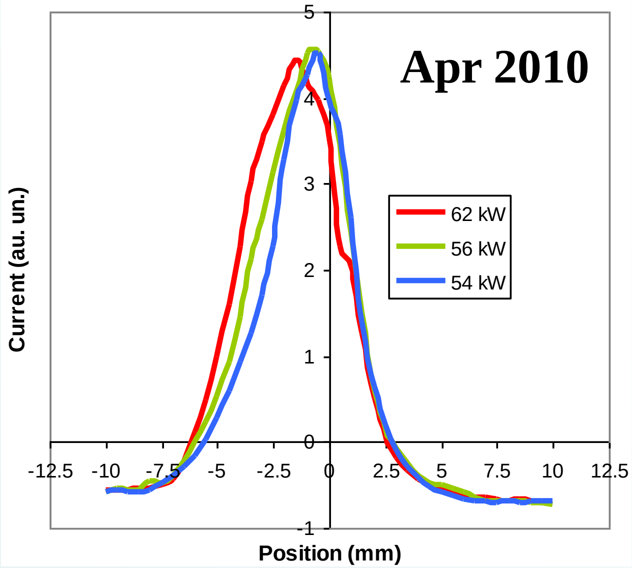


Stem no

RFQ steering effects







After improving field homogeneity observe much smaller RFQ power effects

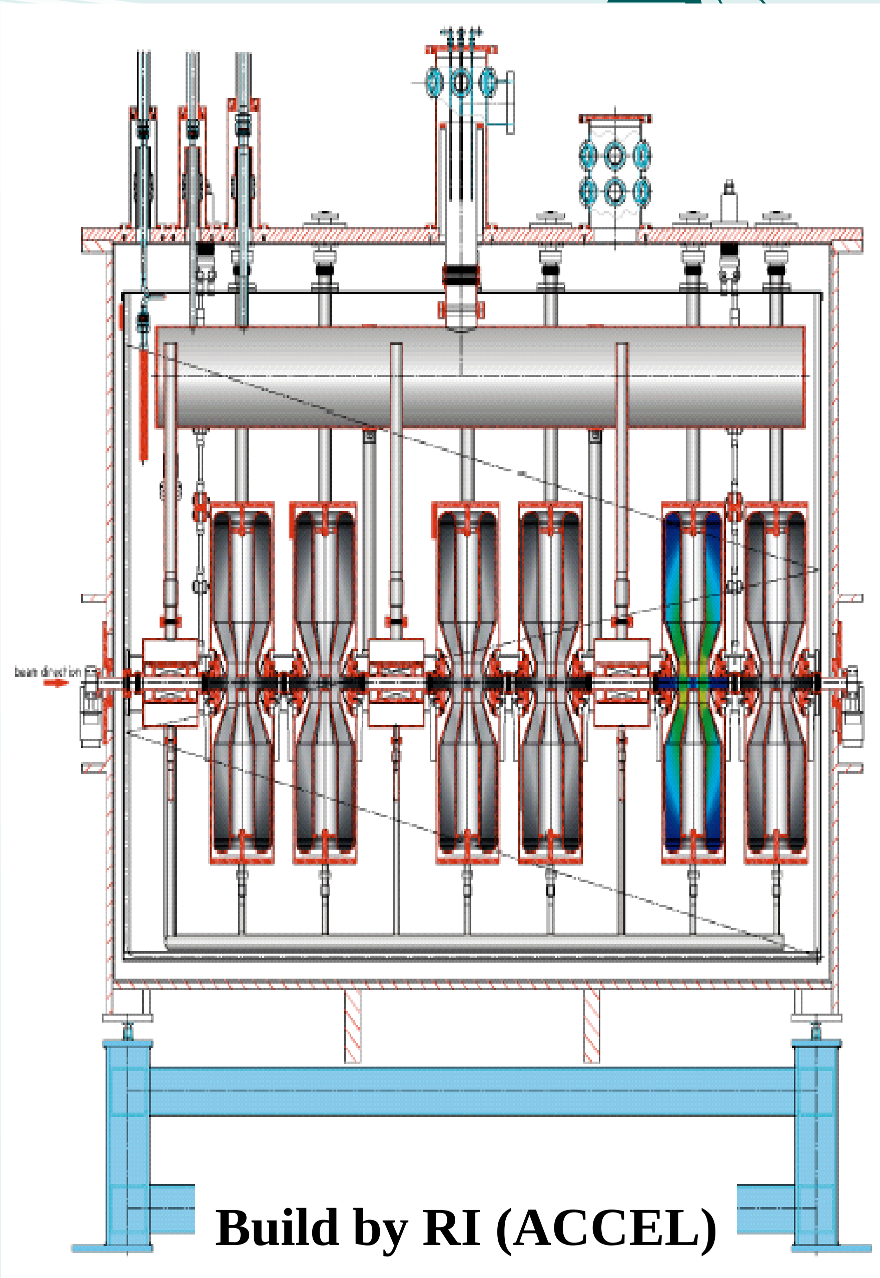
We plan further improvements of rods alignment
(with help of our colleagues from the optics department)

Prototype Superconductive Module

SOREQ

- The cryomodule houses six SC HWR cavities and three SC solenoids
- Separate beam and insulation vacuum
- Operating temperature 4.2°K
- six 2 kW solid state amplifiers
- Designed to accelerate 2 mA protons or deuterons beams

HWR Parameters	
Frequency	176 MHz
Optimal β (protons)	0.09
$L_{acc}=\beta\lambda$	0.15 m
ΔV @ E_{peak}	840 kV @ 25 MV/m
Q_0@E_{peak}	$>4.7\times10^8$
Cryogenic load	< 70 W
Q_{ext} Loaded BW	$\sim1.3\times10^6$ ~130 Hz



Build by RI (ACCEL)

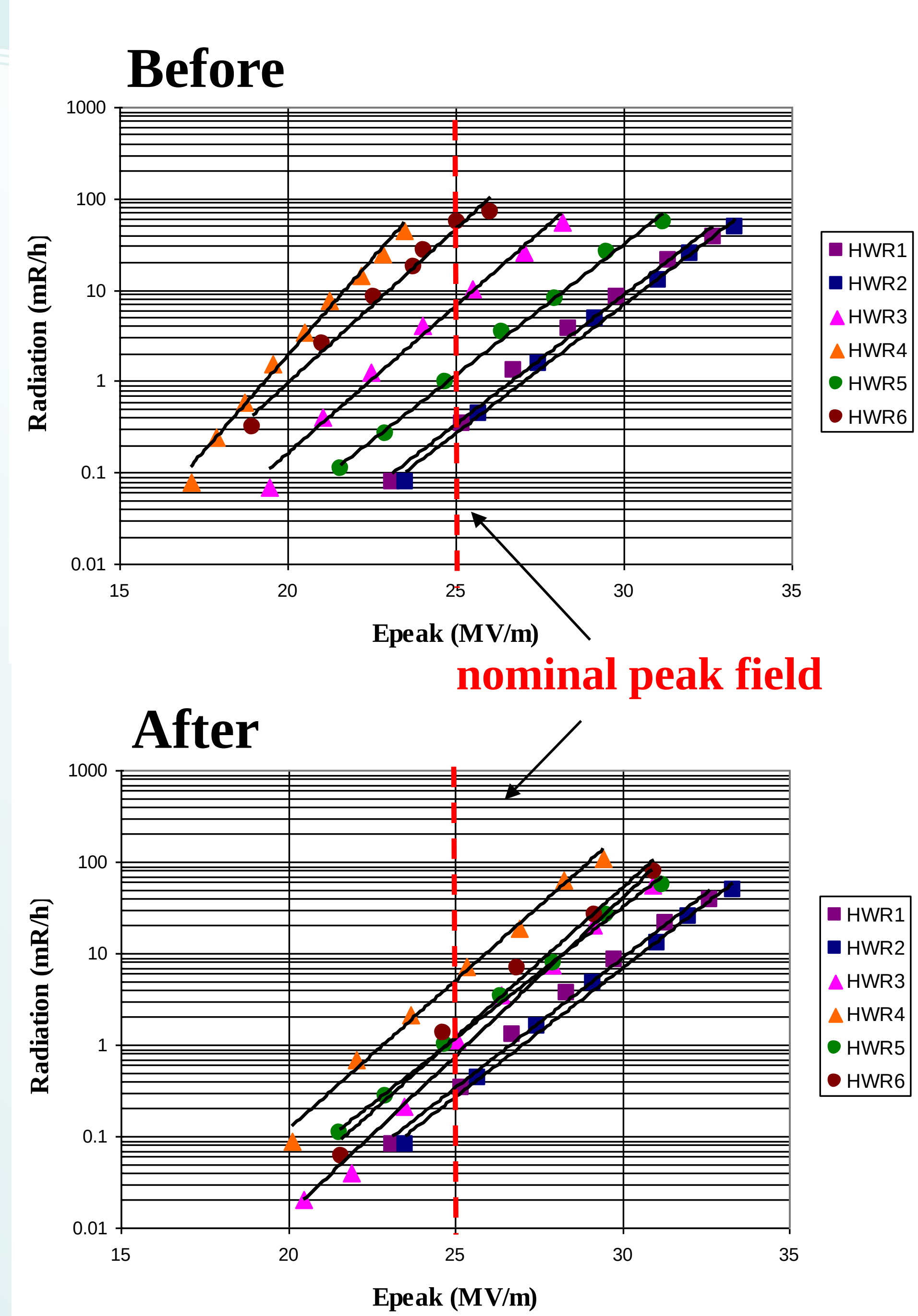
M. Pekeler, LINAC 2006

PSM commissioning

Helium processing :
99.9999% purity,
4 10^{-5} mbar
up to 43 MV/m 10% DC

Reduced field emission from the cavities and allowed stable operation at the nominal fields.

However, simultaneous operation of all cavities at the nominal field was not achieved for long period.



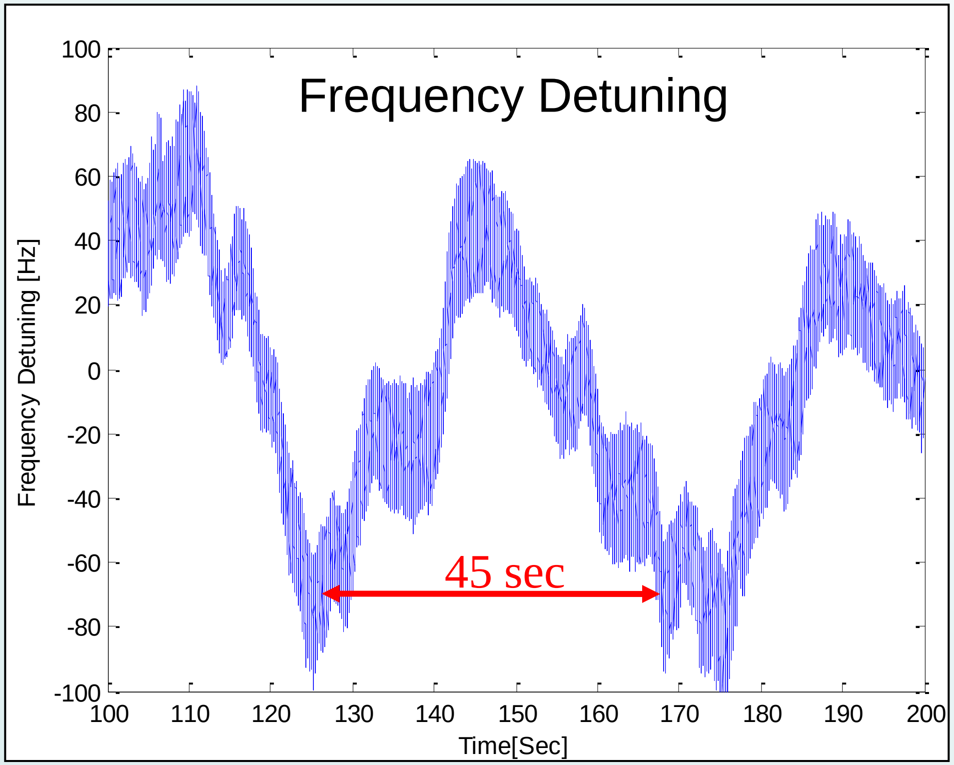
A. Perry, SRF2009

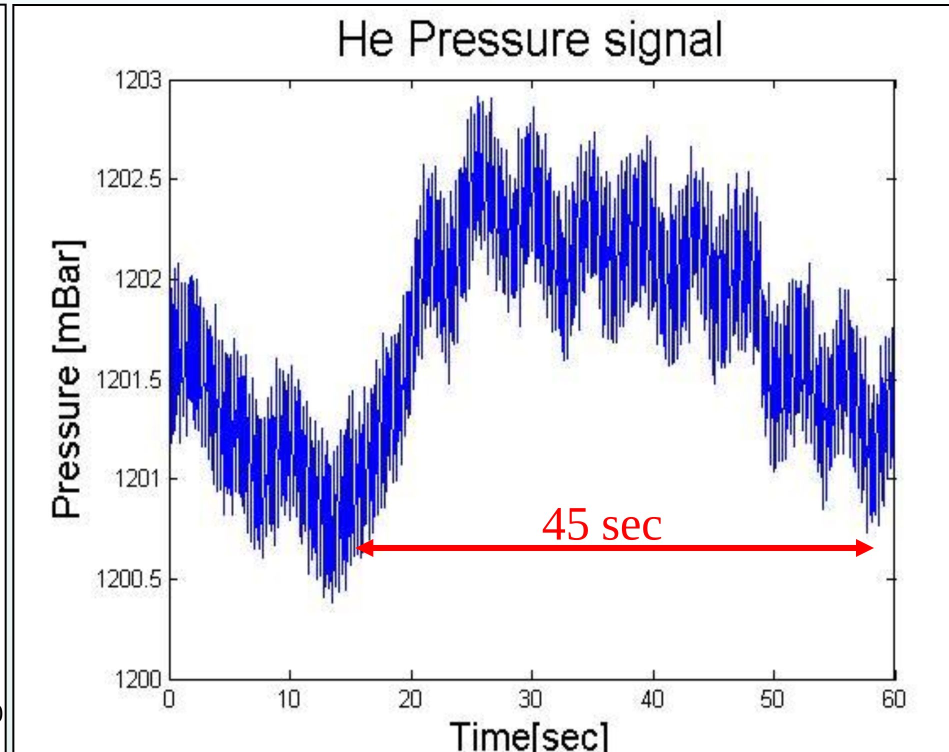
HWR Microphonics measurements*

HWRs are extremely sensitive to LHe pressure fluctuations (60 Hz/mbar)

Detuning signal is dominated by the Helium pressure drift

Detuning sometimes exceeds +/-200 Hz (~ +/-2 BW).

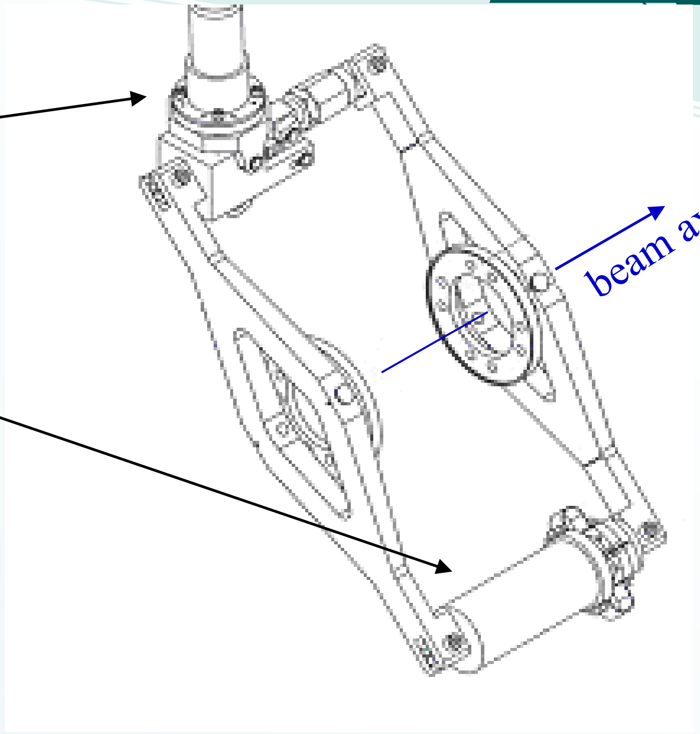




* Performed in collaboration with J.Delayen and K. Davis (JLab)

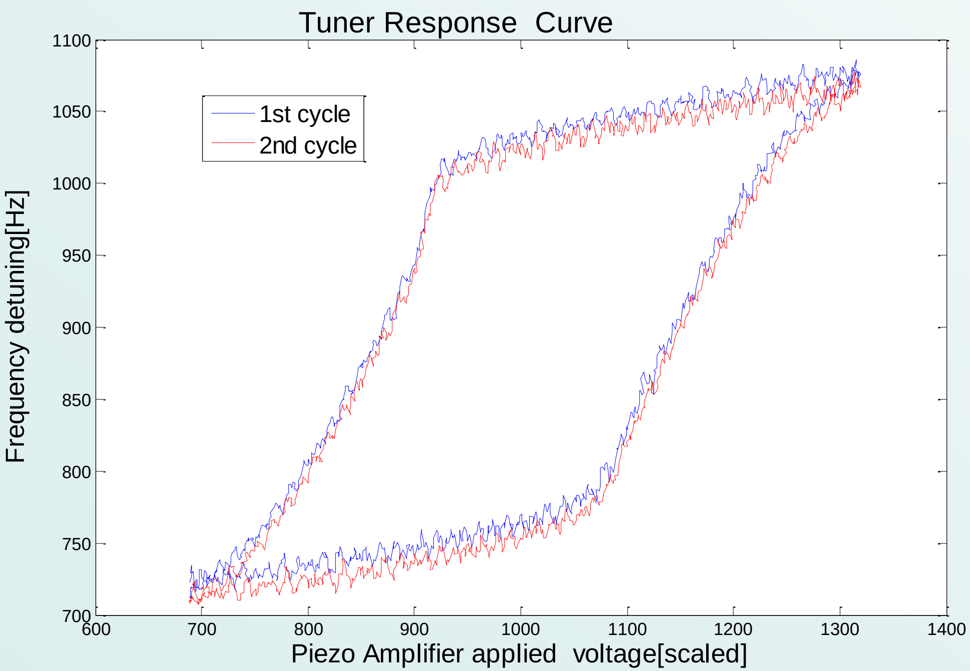
HWR Tune*

<u>**Stepper motor**</u> **is used for coarse tuning.**
Stepper motor movement induces instabilities and is therefore disabled during RF operation



<u>**Piezoelectric actuator**</u> **provides fine tuning of the resonance frequency**

Range reduction of the piezoelectric elements Were subsequently replaced



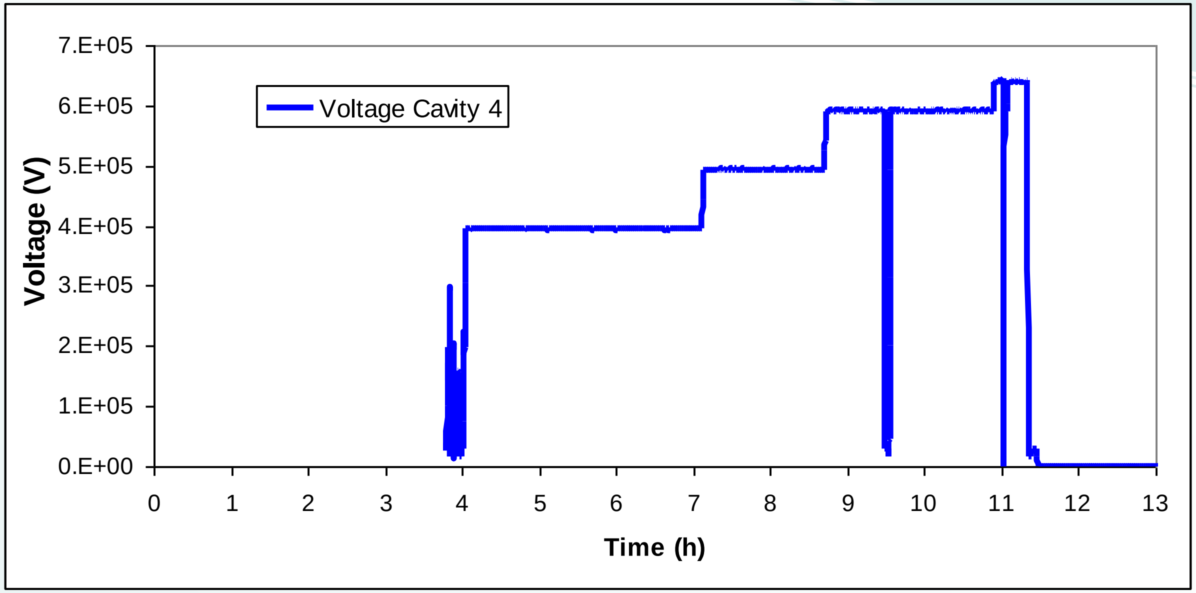
Response of the fine tuner is **highly non-linear**.

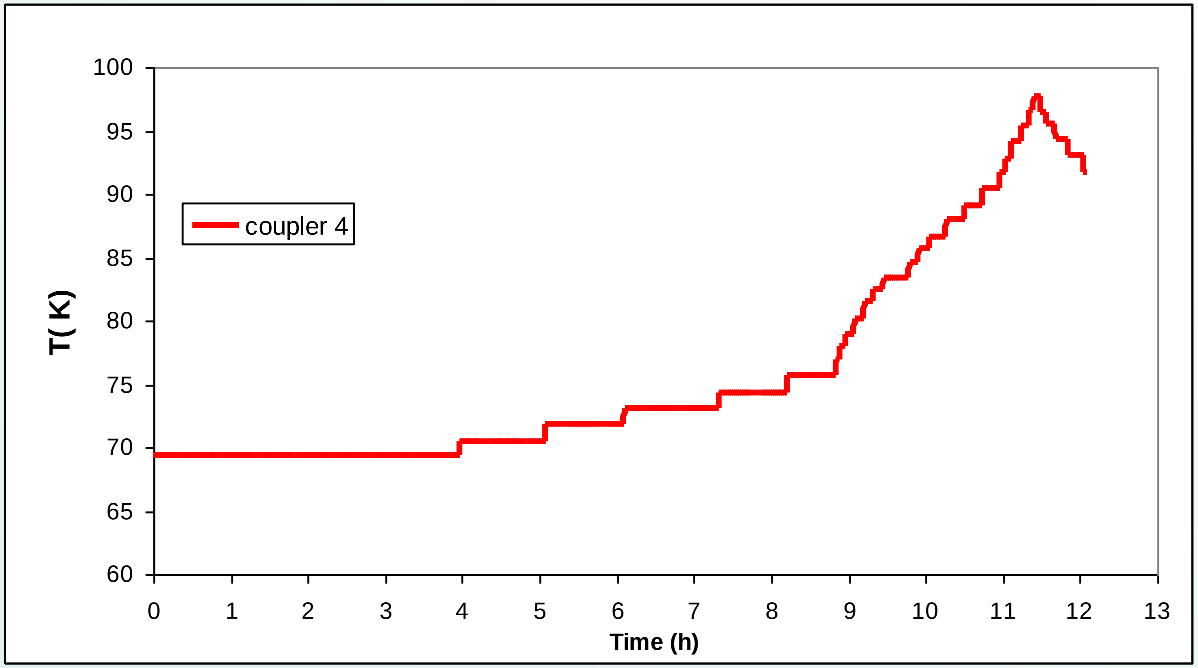
* Performed in collaboration with J.Delayen and K. Davis (JLab)

HWR Couplers temperature

During operation significant heating of coupler #4 was observed

Operation of cavity 4 is therefore limited to ~500 kV to avoid overheating



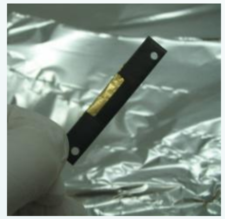


PSM Status

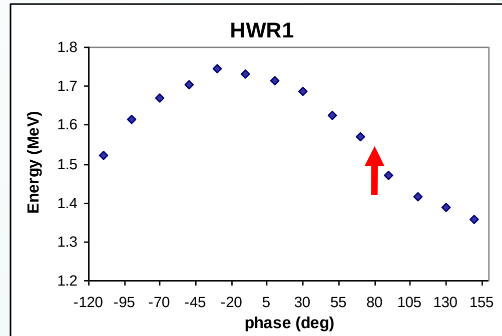
- **Reached stable long-term only at <u>60-70%</u> of nominal gradients :**
  - high-sensitivity to helium pressure fluctuations
  - problems with tuner response
  - warming up of some couplers
- **Work on implementing a new tuner control algorithm on a NI – CRIO FPGA core – improve the response time and account for the hard nonlinearities.**
- **Upgrade of 2 kW amplifiers to <u>4.0 kW</u> to provide additional RF power required for high current field stabilization.**

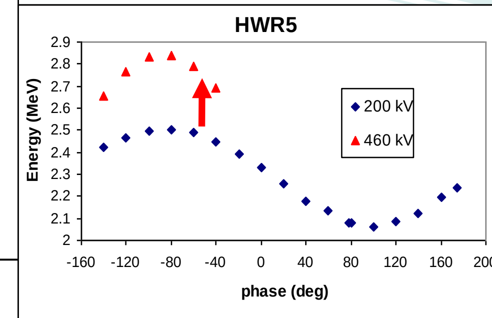
Phasing cavities for pulsed beams

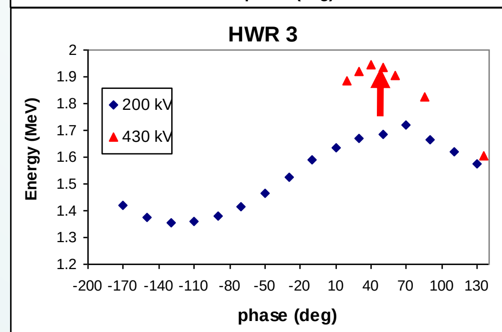
Example of phasing cavities for proton beam
Use low beam DC (10^{-2} %)
RFQ - 100 % (protons),
a few % (deuterons)

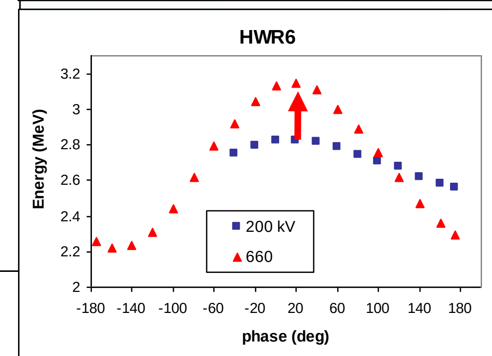


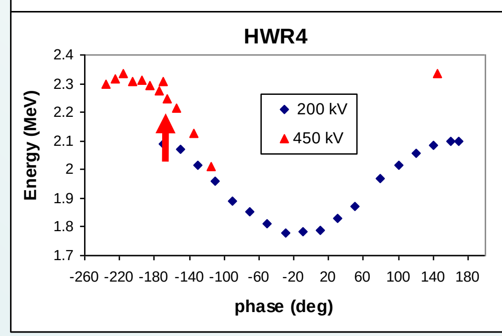
Measure energy of the protons scattered on a 0.3 mg/cm^2 gold foil as a function of the cavities voltages/phases











Final settings for 3.1 MeV

Cavity	Set Voltag	Real Voltage	Set Phase	Sync Phase
HWR1	120 kV	150 kV	80	-95
HWR2	off	off	off	off
HWR3	*430 kV*	600 Kv	40	0
HWR4	490 kV	500 kV	-170	-35
HWR5	400 kV	500 kV	-50	-30
HWR6	660 kV	500 kV	20	0

Beam Dynamics calculations J. Rodnizki

L. Weissman, DIPAC2009

The highest beam energies for low DC beam:
Protons – **3.7** MeV
Deuterons – **4.3** MeV

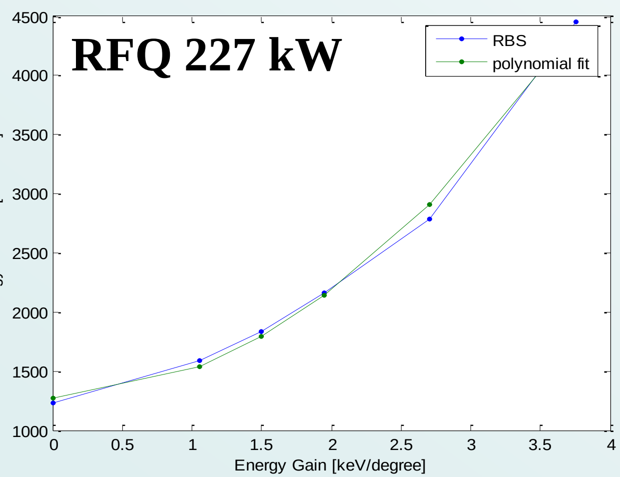
RFQ Longitudinal emittance measurement

Example : Deuteron beam

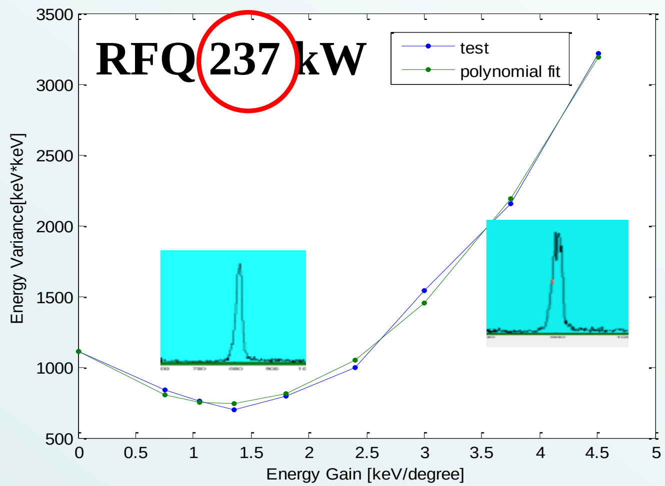
RFQ + 1st cavity

The cavity was set to -90° (bunching mode) and its voltage is varied

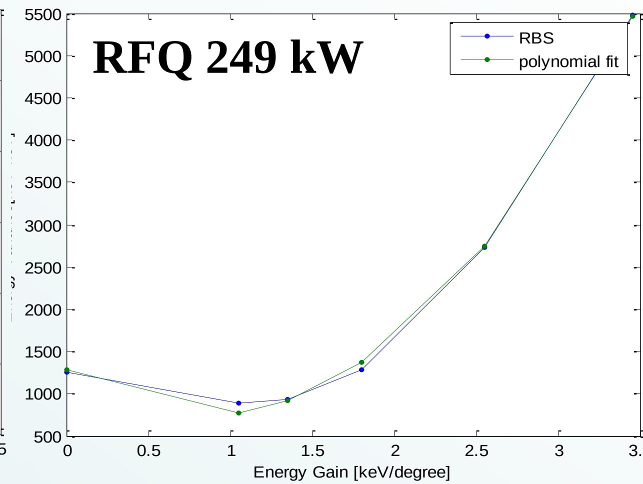
Evaluation of longitudinal emittance via measuring energy width of the peak as a function of the cavity voltage



Long. Emittance
260 π deg keV/u



Long. Emittance
210 π deg keV/u



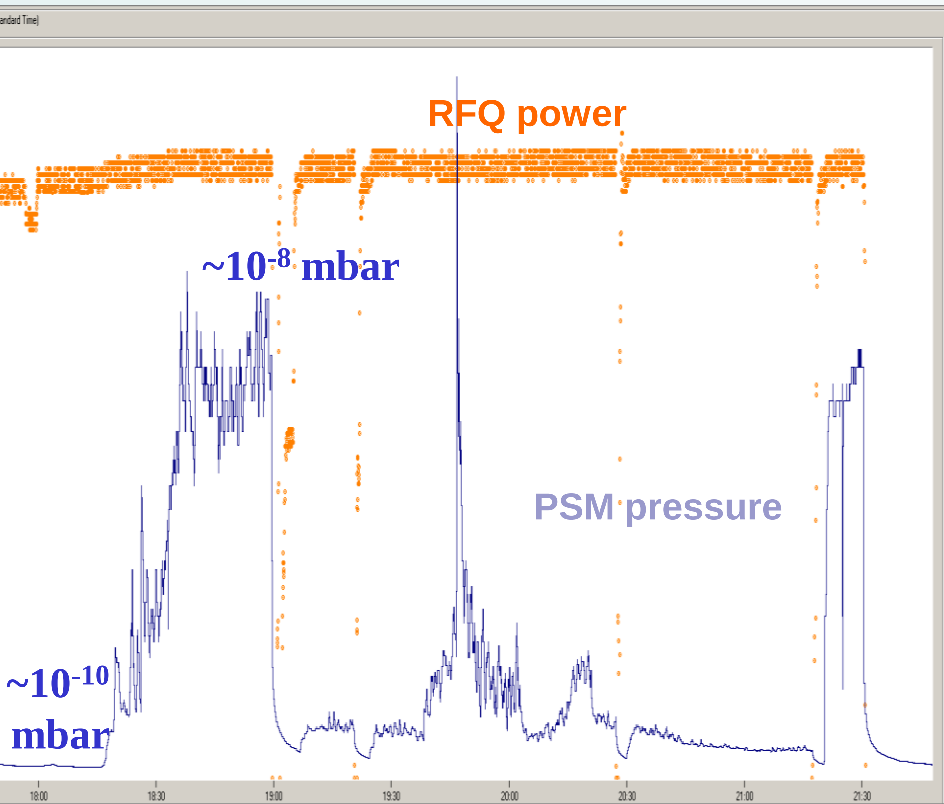
Long. Emittance
365 π deg keV/u

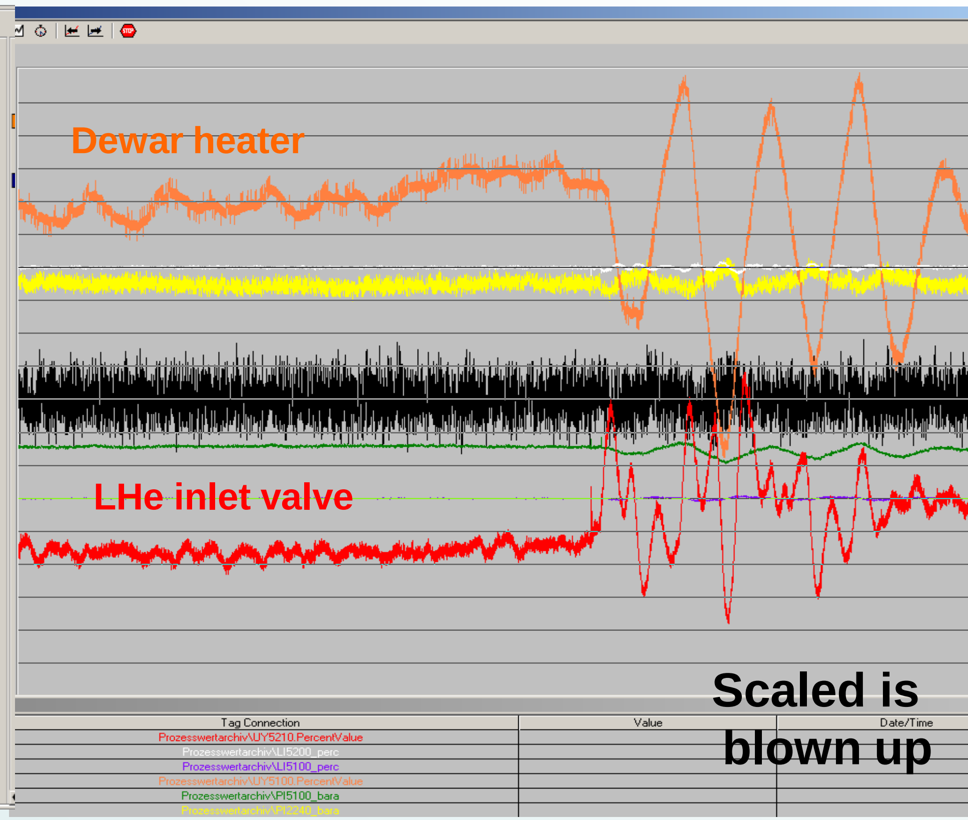
See poster TUP091, J. Rodnizki et al

CW beam: vacuum/cryogenics effects

First attempts to conduct ~ mA CW
strong effects in the PSM vacuum and in the cryogenics

In this example 1 mA beam is conducted through the cryomodule without acceleration and some optics parameters were varied (<u>RFQ power, MEBT steers</u>).





CW beam (continued)

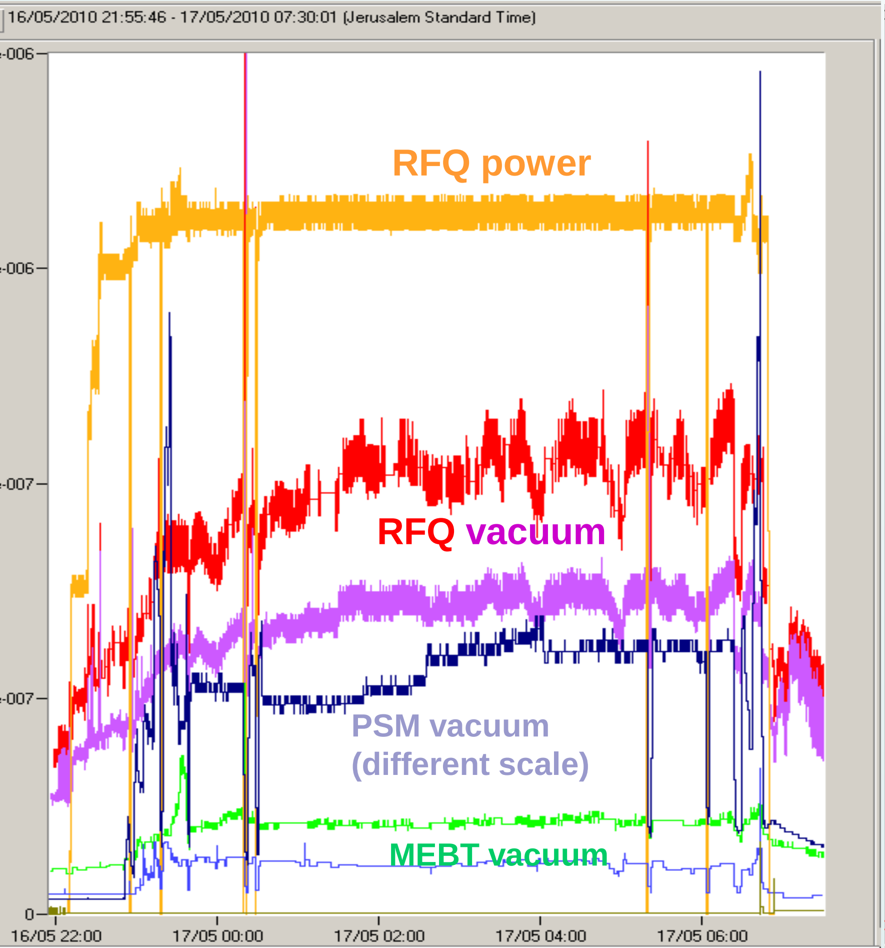
Otimizing RFQ power and MEBT steering to minimize beam-induced effects

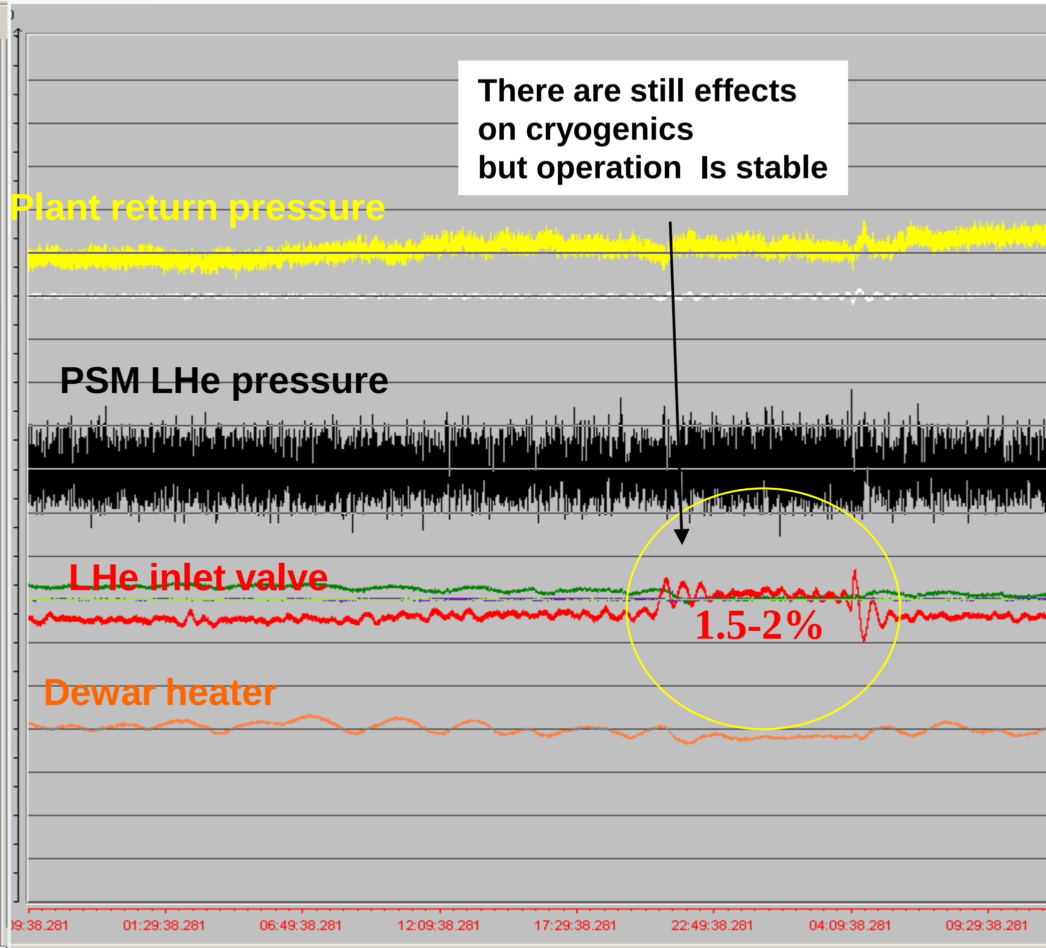
Managed to achieve stable operation for CW beam

In this example, 1-1.3 mA 1.5 MeV drifted through the cryomodule.

Operation was stable for longer than 6.5 hours and

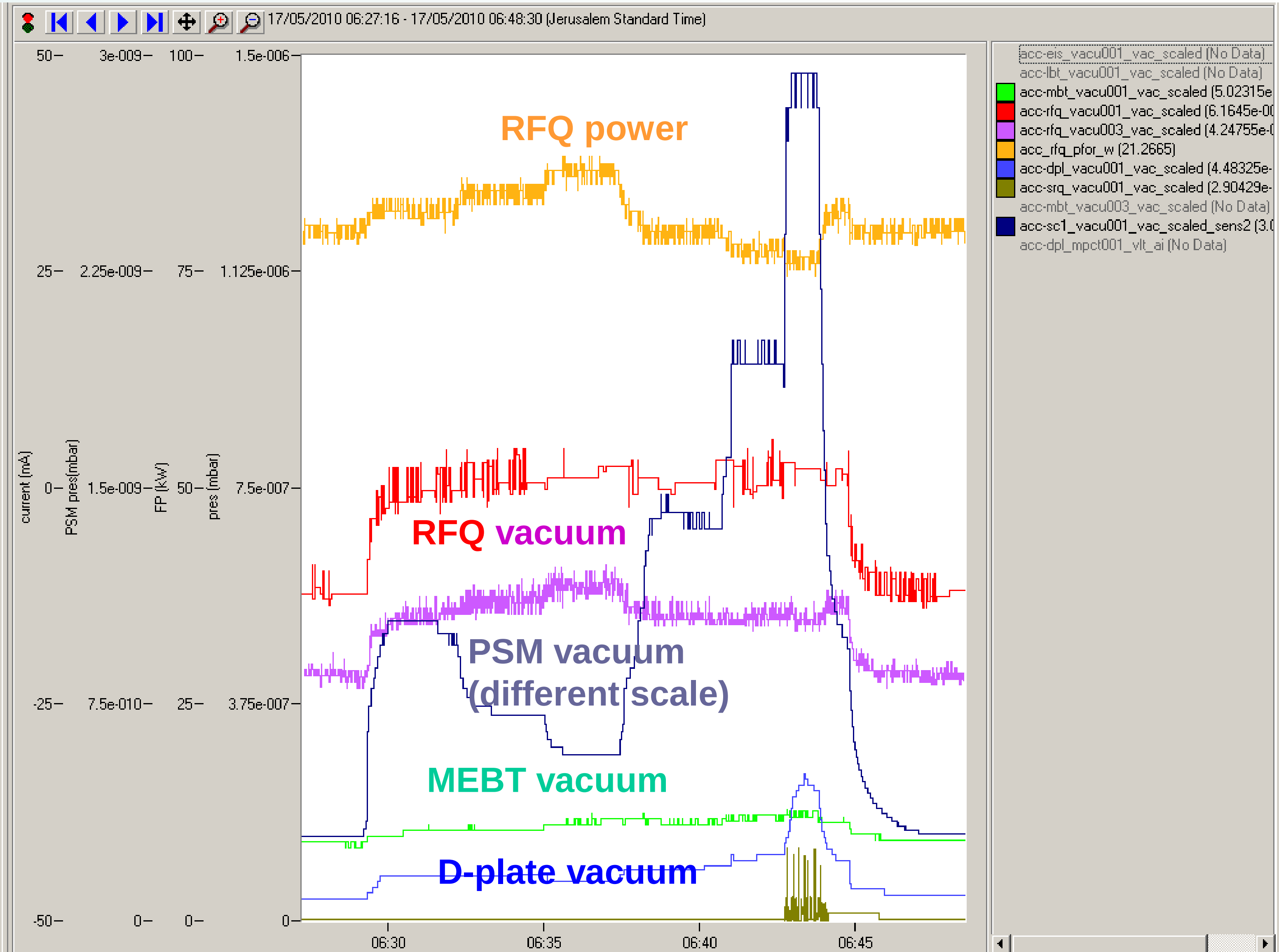
Operation was repeated during the two consequent days





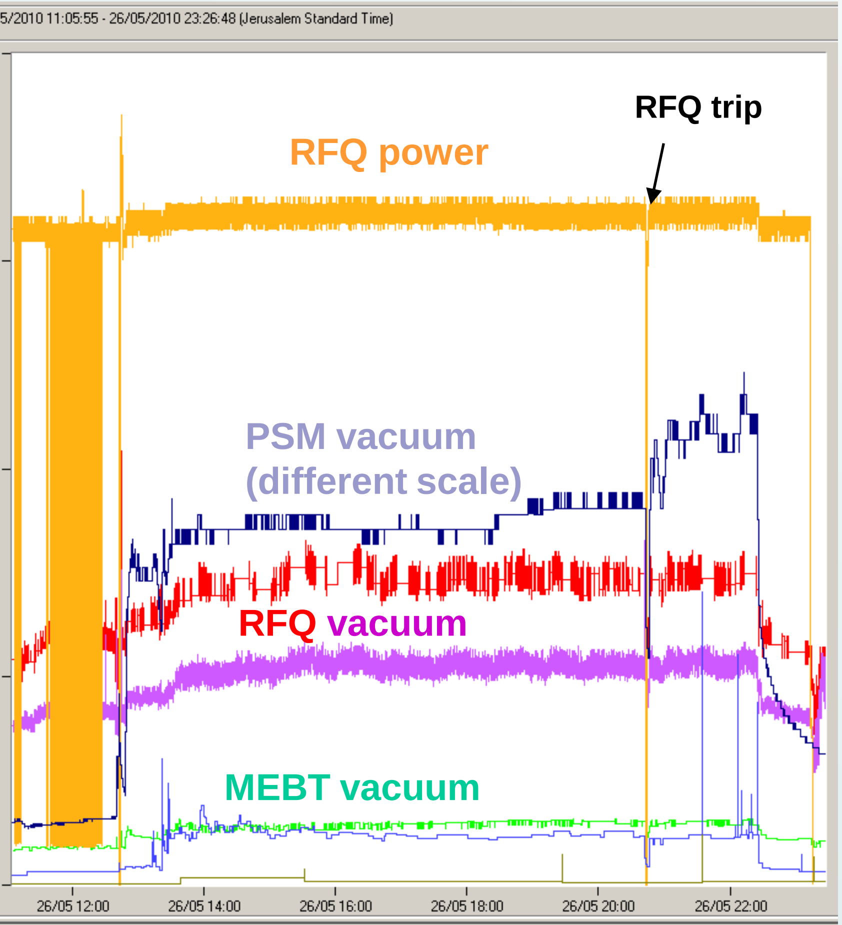
CW beam (continued)

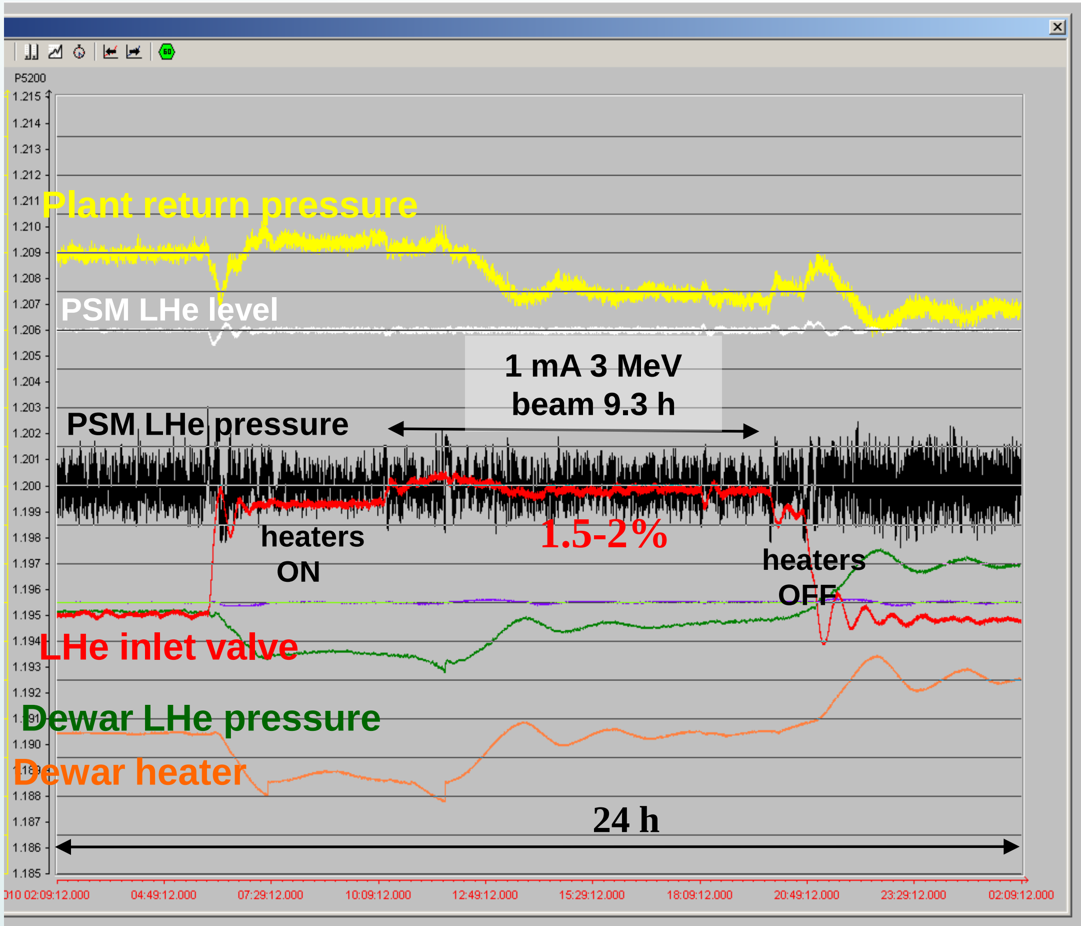
The effects of vary RFQ power on vacuum in the accelerator are observed



CW beam (continued)

In this example:
Operation of ~1 mA, ~3 MeV accelerated proton beam.
Operation was stable for more than 9 hours.
Only one RFQ trip. Return to operation within minutes.
Effect on cryogenics is similar to 1.5 MeV beam.
So, probably, the loss of 2-3 μA happens at the entrance of the cryomodule.
Plan to introduce a beam scrapper in MEBT





Phase I Beam Operation Summary

HWR #	Low DC Proton 3.7 MeV		Low DC Deuteron 4.3 MeV		CW (1 mA) Proton 3.1 MeV	
	Voltage [kV]	E_{acc} MV/m	Voltage [kV]	E_{acc} MV/m	Voltage [kV]	E_{acc} MV/m
1	150	1	290	1.9	150	1
3	630	4	590	3.9	560	3.7
4	550	3.7	500	3.3	400	2.7
5	550	3.7	500	3.3	550	3.7
6	900	5.9	500	3.3	520	3.5

$L_{acc}=\beta\lambda$

Nominal voltage:
840 kV

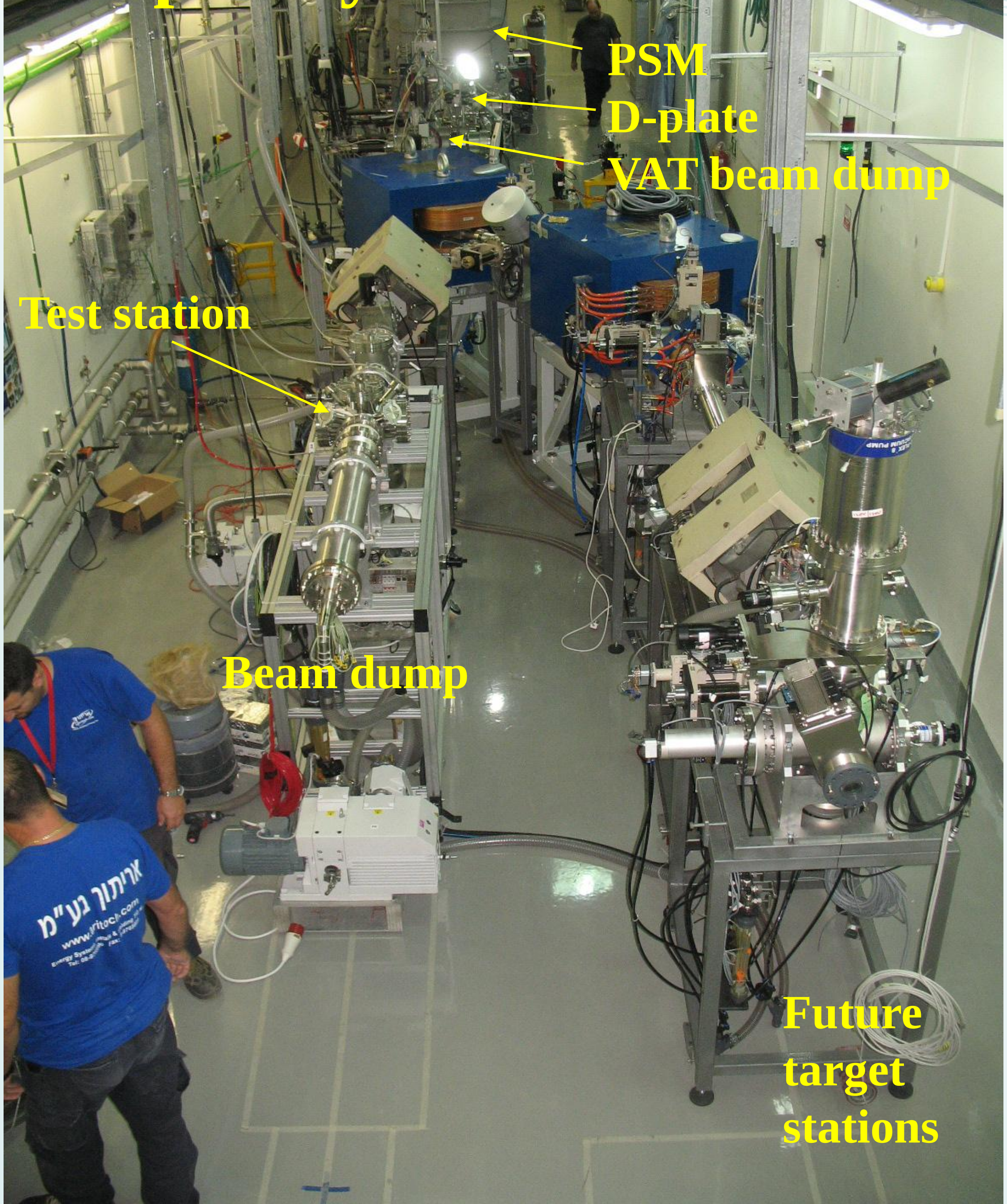
- **Cavities 1 is used for bunching; cavity 2 is used as a drift**
- **Operation at higher gradients is still limited by instabilities**
- **Beam induced effects**

Summary and Outlook

- First proton and deuteron beams were accelerated by a HWR based SC Linac
- Proton and Deuteron **low duty cycle** beams were accelerated up to **3.7 MeV** and **4.3 MeV**
- Protons **CW ~1 mA** beams accelerated up to **3.1 MeV**
- Phase I is still in its commissioning stage.
  1. Actions to improve beam operation :
     - RFQ alignment
     - MEBT scrapper
     - Upgrade of tuners control and cavities amplifiers
  2. CW Deuteron operation has not been achieved yet
- Design of Phase II is underway

Temporary beam line

SOREQ



Temporary beam line is being commissioned in the accelerator tunnel

Pilot project. Several beam lines will be built for the Phase II

The first experiments in material science and astrophysics

The first experiments should take place until the end of the year

People involved

SARAF team (including students, advisers and partially affiliated personal) :
A. Nagler , I. Mardor, D. Berkovits, A. Abramson , A. Arenshtam, Y. Askenazi, B. Bazak (until 2009), Y. Ben-Aliz, Y. Buzaglo, O. Dudovich, Y.Eisen, I. Eliyahu, G. Finberg, I. Fishman, I. Gertz, A. Grin, S. Halfon, D. Har-Even, D. Hirshman, T. Hirsh, A. Kreisel, D. Kijel, G. Lempert, A. Perry, R. Raizman (until 2010), E. Reinfeld, J. Rodnizki, A. Shor, I. Silverman, B. Vainas, L. Weissman, Y. Yanay (until 2009).

Red font : persons who joined recently

RI&Varian /(former ACCEL):
H. Vogel, Ch. Piel, K, Dunkel, P. Von Stain, M. Pekeler, F. Kremer, D. Trompetter, many mechanical and electrical engineers and technicians

Cryoelectra :
B. Aminov, N. Pupeter, …

NTG/ Frankfurt Univ:
A. Bechtold, Ph. Fischer, A. Schempp, J. Hauser