The status of the SARAF phase I linac

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RuPAC 2012, September 2012

Outline

Introduction SARAF Phase I

SARAF components performance/problems

ECR ion source + LEBT
RFQ
Prototype Superconducting Module (PSM)

Beam operations

Summary

SARAF – Soreq Applied Research Accelerator Facility

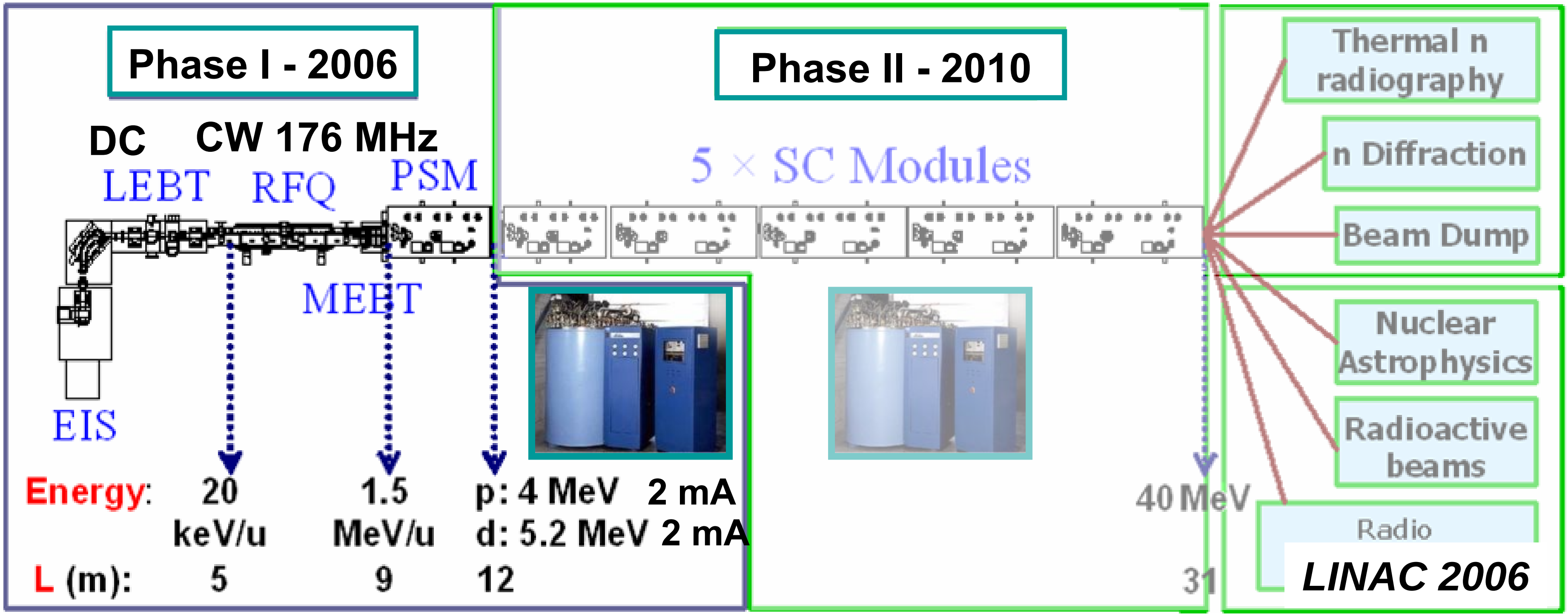
To enlarge the experimental nuclear science infrastructure and promote research in Israel

To develop and produce radioisotopes primarily for bio-medical applications

To modernize the source of neutrons at Soreq and extend neutron based research and applications

To create the field of modern accelerator technology in Israel

SARAF vision in 2006

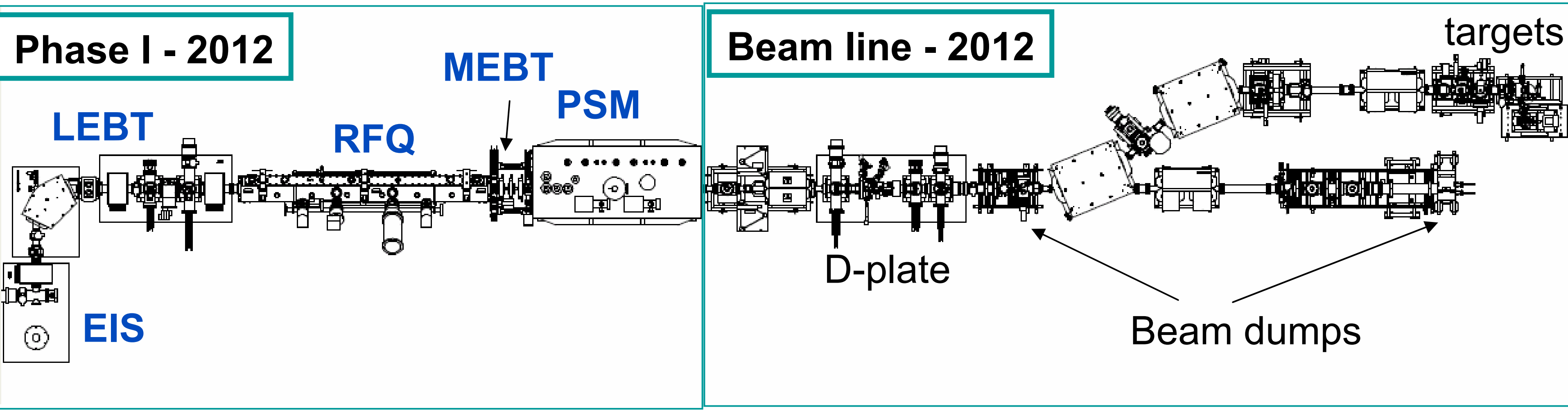


Phase I linac (excluding auxiliaries) was expected to be delivered as a turn-key by the industrial company, Research Instruments, former ACCEL.

Small local group will participate in the Phase I commissioning and will receive adequate training from the industrial partner

Phase II built will be lunched after successful commissioning of Phase I

SARAF today



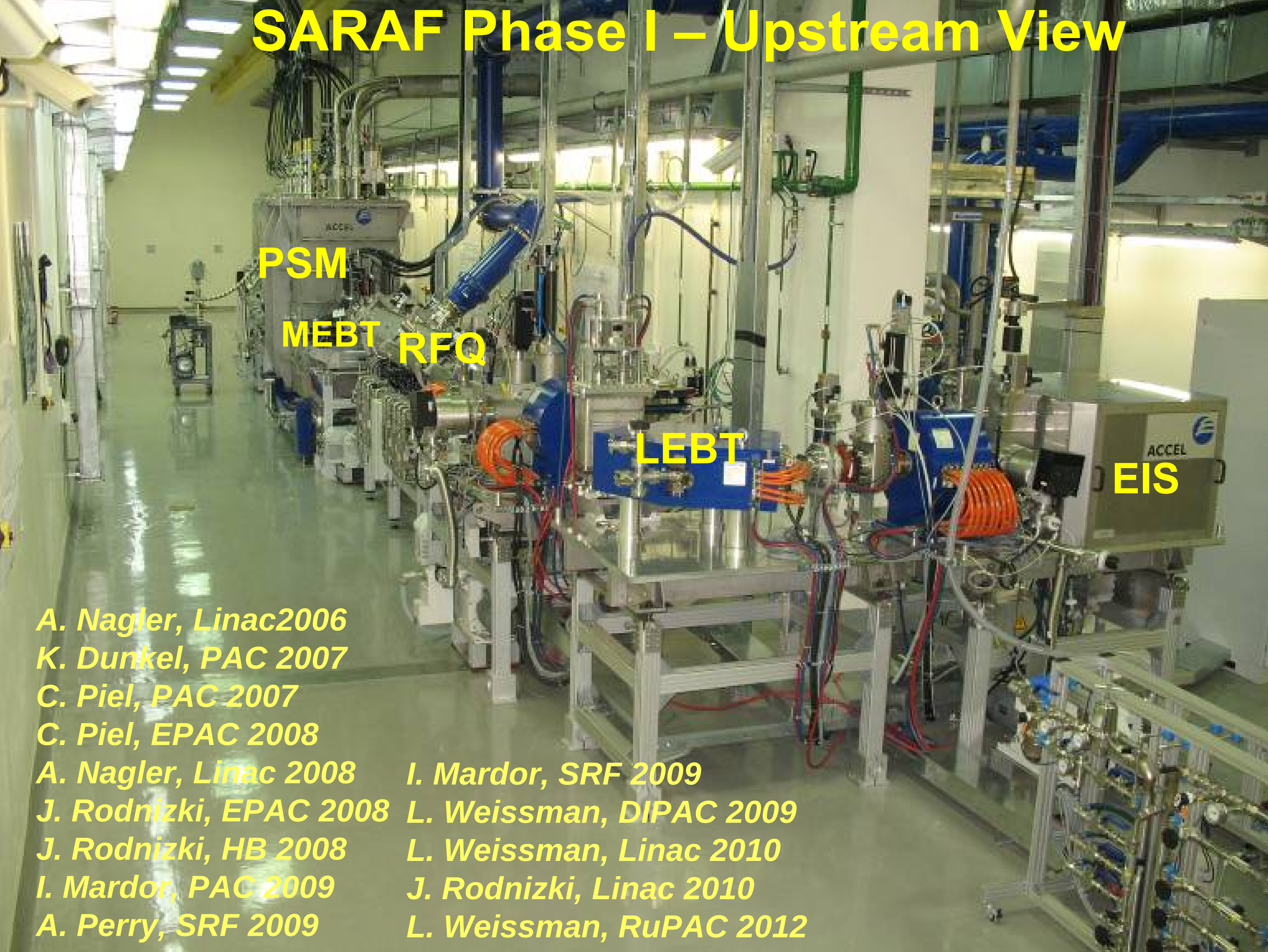
Phase I operational, but not all specifications have been reached

Almost complete decoupling from the former industrial partners. Commissioning and operation by local team. Local team and its expertise has grown considerably

Experiments at the temporary beam line

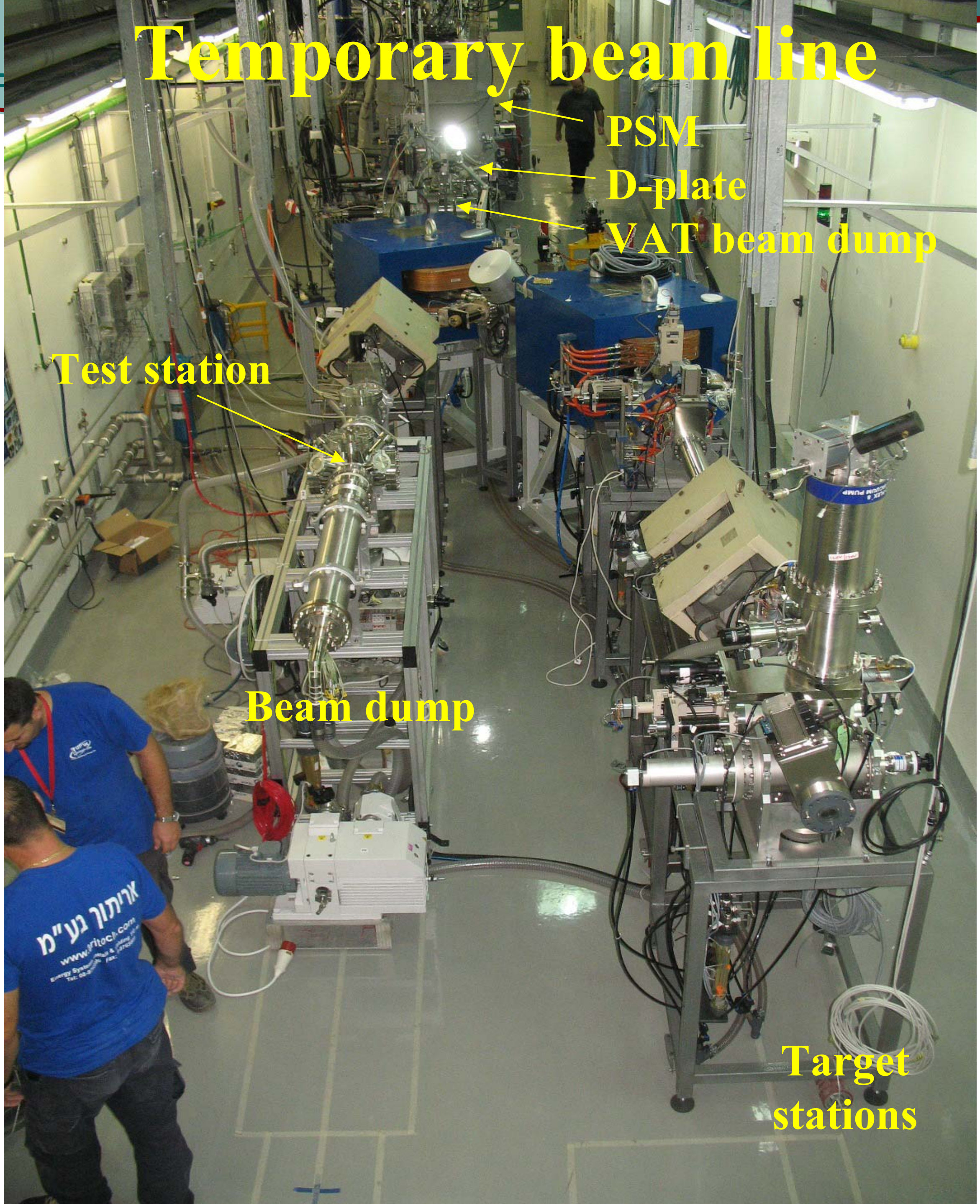
Phase II is under intense discussion

SARAF Phase I – Upstream View



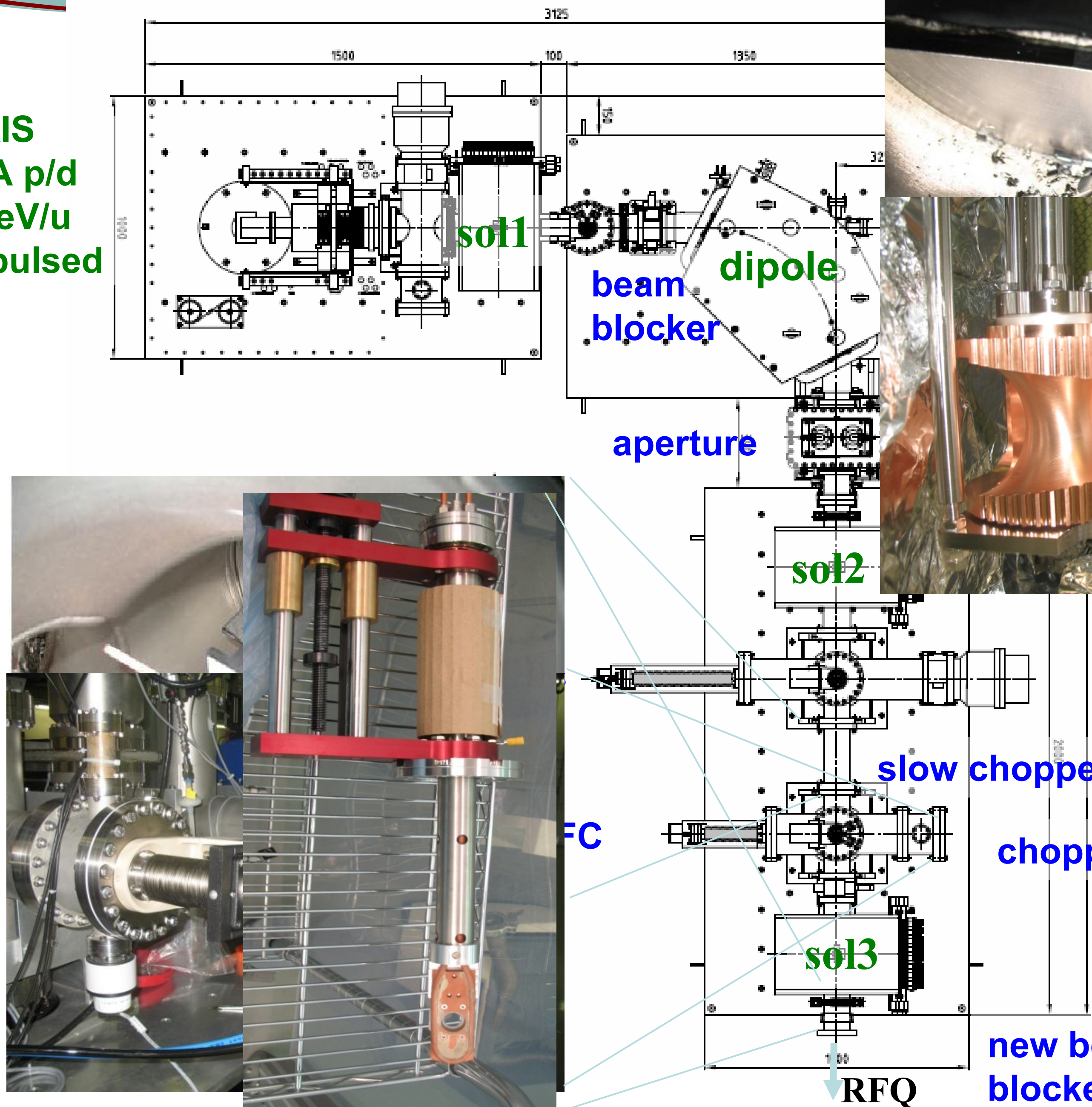
A. Nagler, Linac2006
K. Dunkel, PAC 2007
C. Piel, PAC 2007
C. Piel, EPAC 2008
A. Nagler, Linac 2008
J. Rodnizki, EPAC 2008
J. Rodnizki, HB 2008
I. Mardor, PAC 2009
A. Perry, SRF 2009
I. Mardor, SRF 2009
L. Weissman, DIPAC 2009
L. Weissman, Linac 2010
J. Rodnizki, Linac 2010
L. Weissman, RuPAC 2012

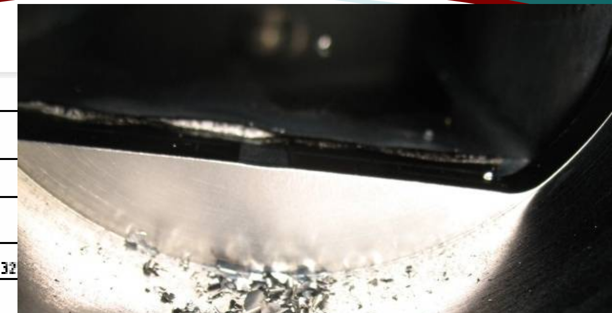
Temporary beam line



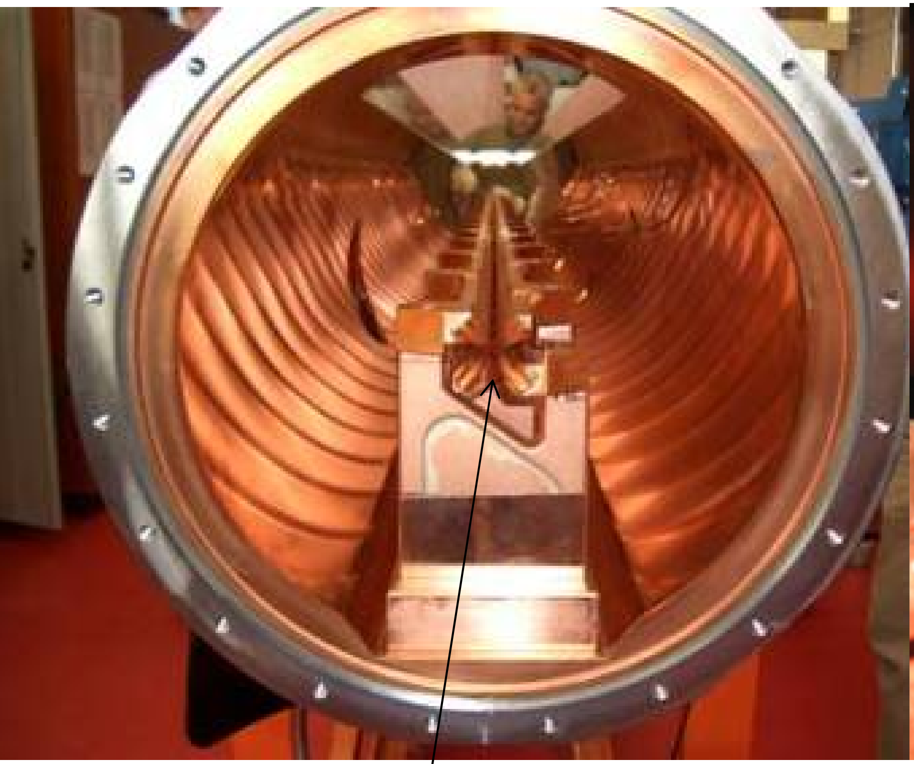
ECR/LEBT

ECRIS
8 mA p/d
20 keV/u
DC/pulsed

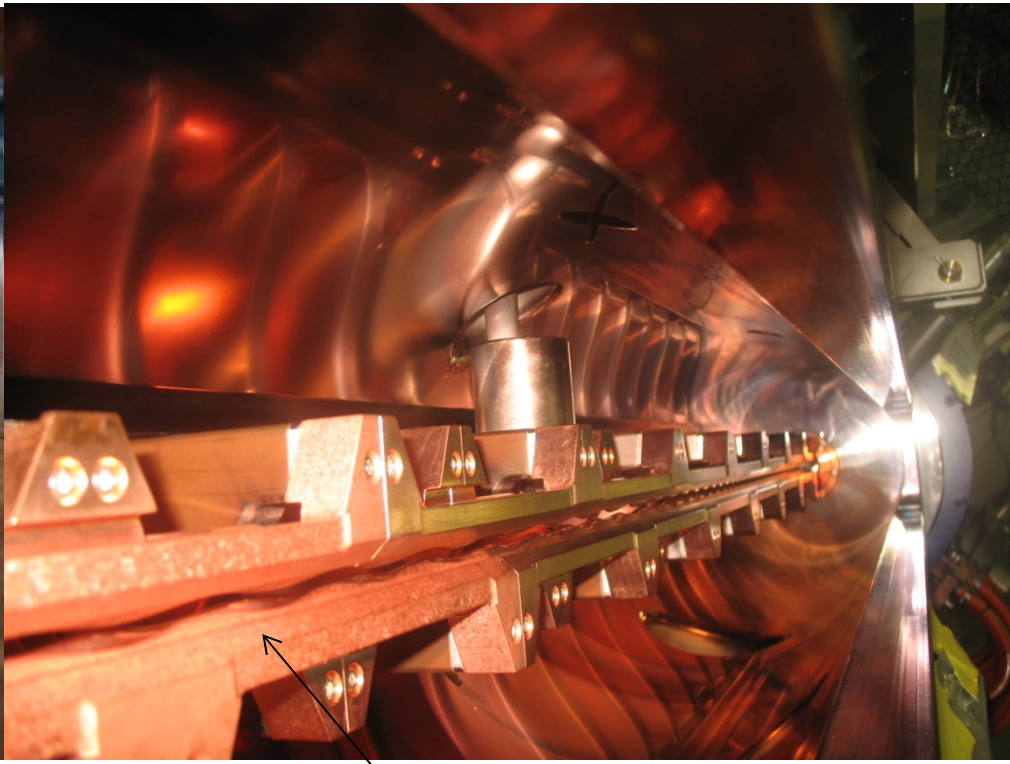




Radio Frequency Quadruple injector



4 rods structure traps and transport the low-energy beam



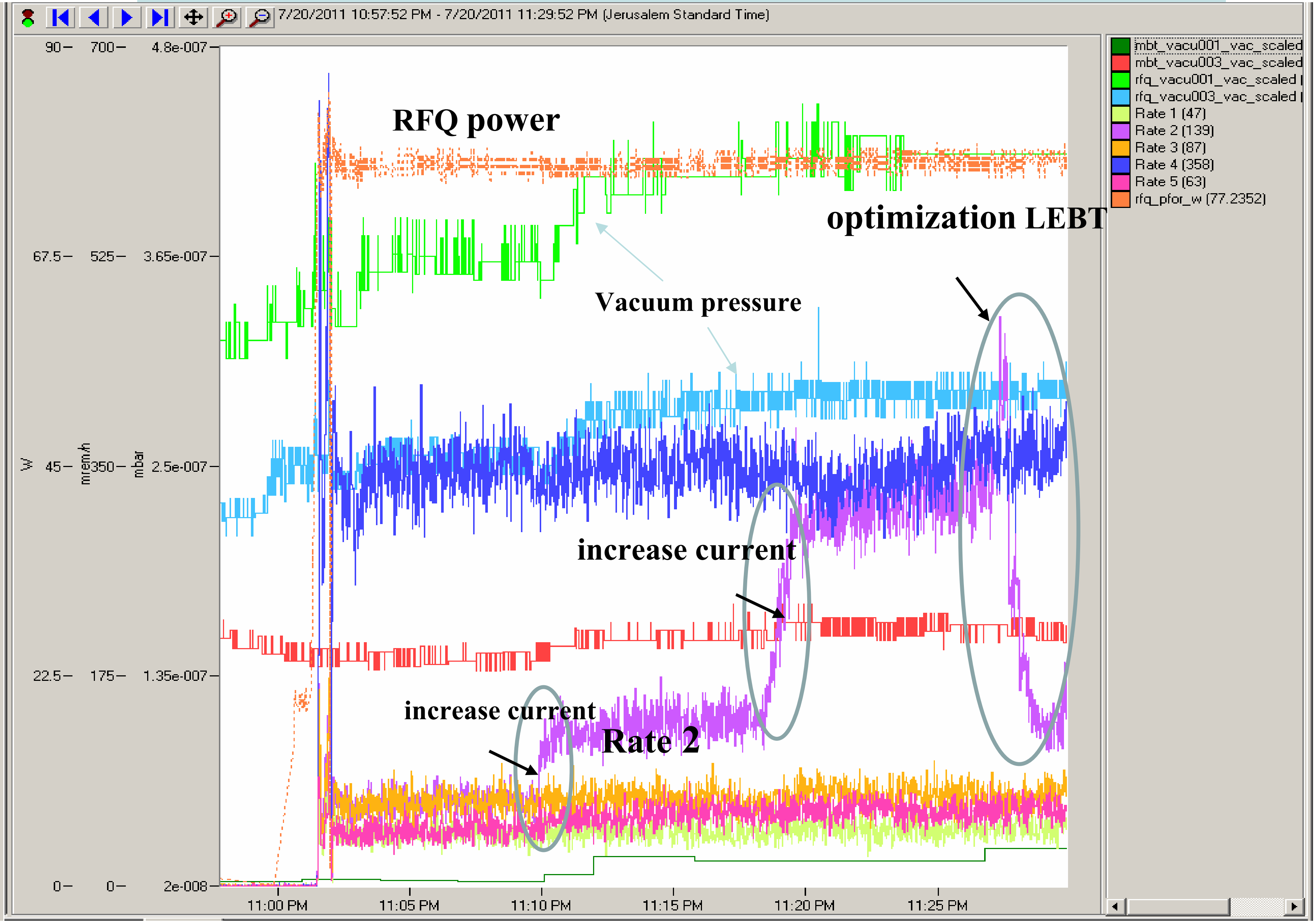
Acceleration and bunching is performed by sophisticated modulation of the rods

built by NTG

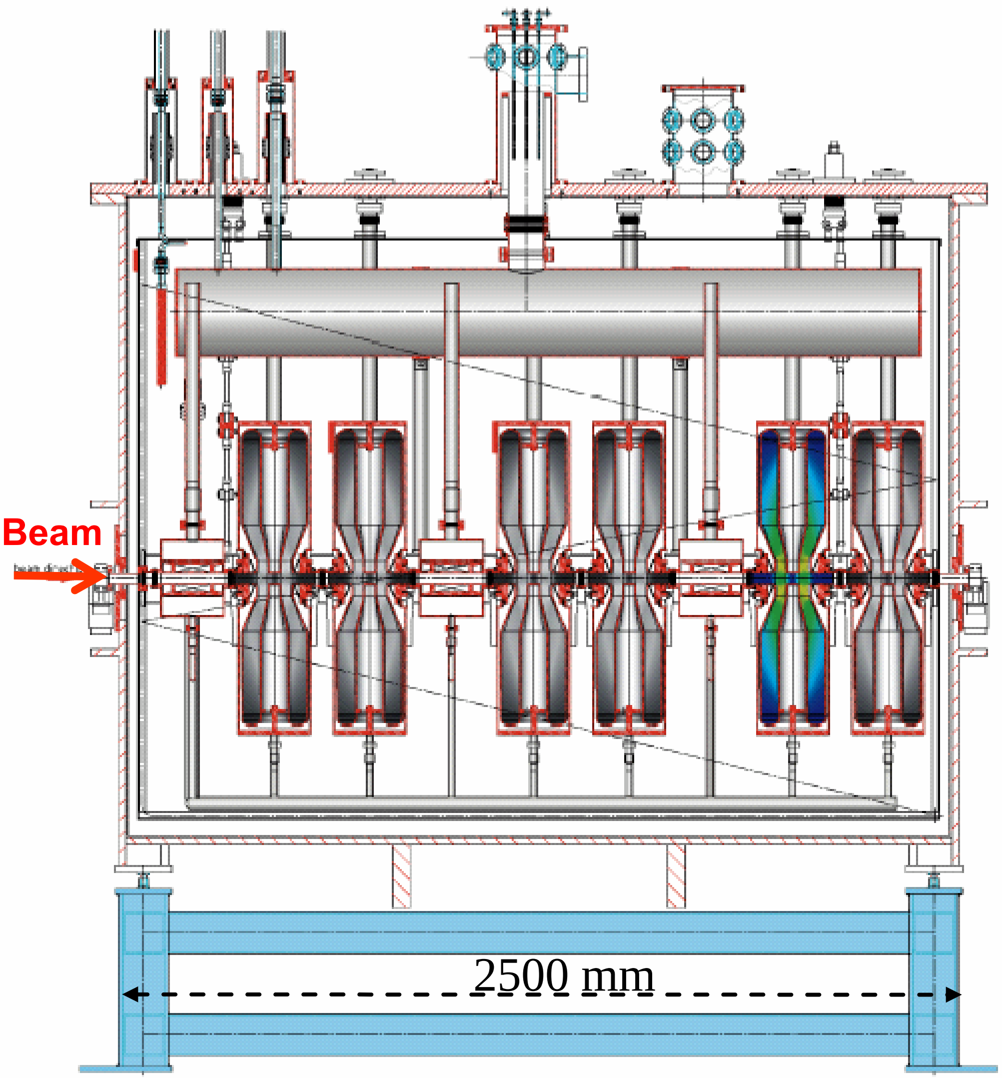
RFQ works, but ….

Stable operation of deuterons only at low DC(<10%)

Insight into beam loss in RFQ



Prototype Super conducting Module (PSM)

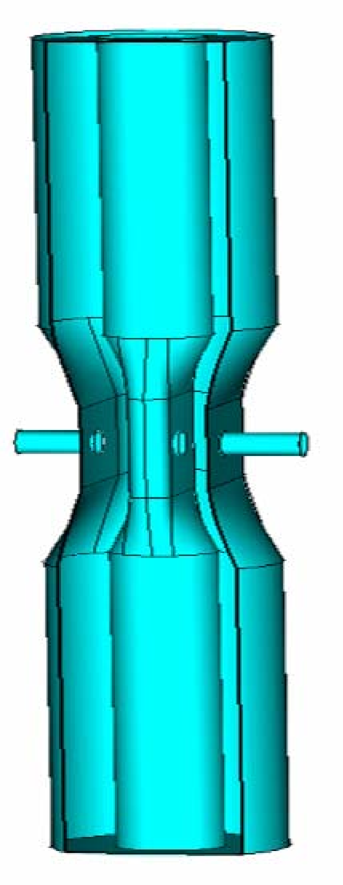


M. Pekeler, LINAC 2006

- Houses 6 x 176 MHz HWR (Half Wave Resonator) and 3 SC 6T
- Accelerates protons and deuterons from 1.5 MeV/u to 4 and 5 MeV
- Very compact design in longitudinal direction
- Cavity vacuum and insulation vacuum separated

Routinely works with new 4 kW amplifiers
[I. Fishman et al. LINAC!2]

HWR – parameters



Frequency	176 MHz
Geom. β	0.09
$L_{acc}=\beta\lambda$	0.15 m
E_{acc} V_{acc}	5.5 MV/m 840 kV
$Q_0@E_{acc}$	$>4.7\times10^8$
Q_{ext} Loaded BW	$\sim1.3\times10^6$ ~130 Hz
Cryo load	< 10 W $@E_{max}$

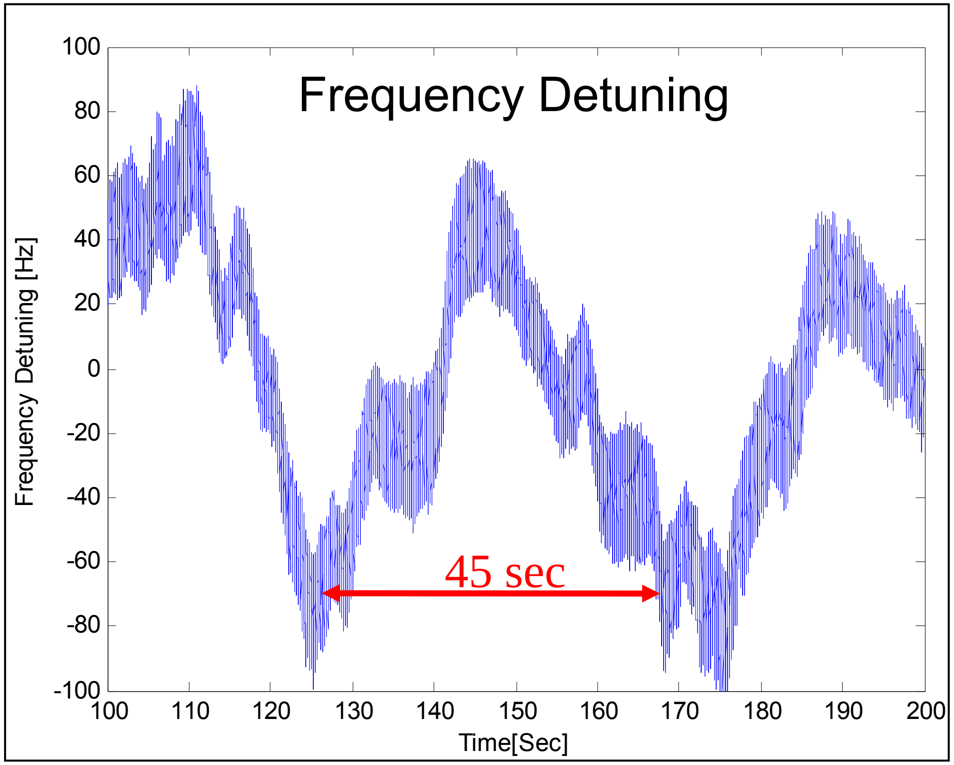
The main goal of the Prototype cryomodule is demonstration of acceleration of high current (> 1mA) CW proton(deuteron) beams to variable energy up to 4(5.5) MeV

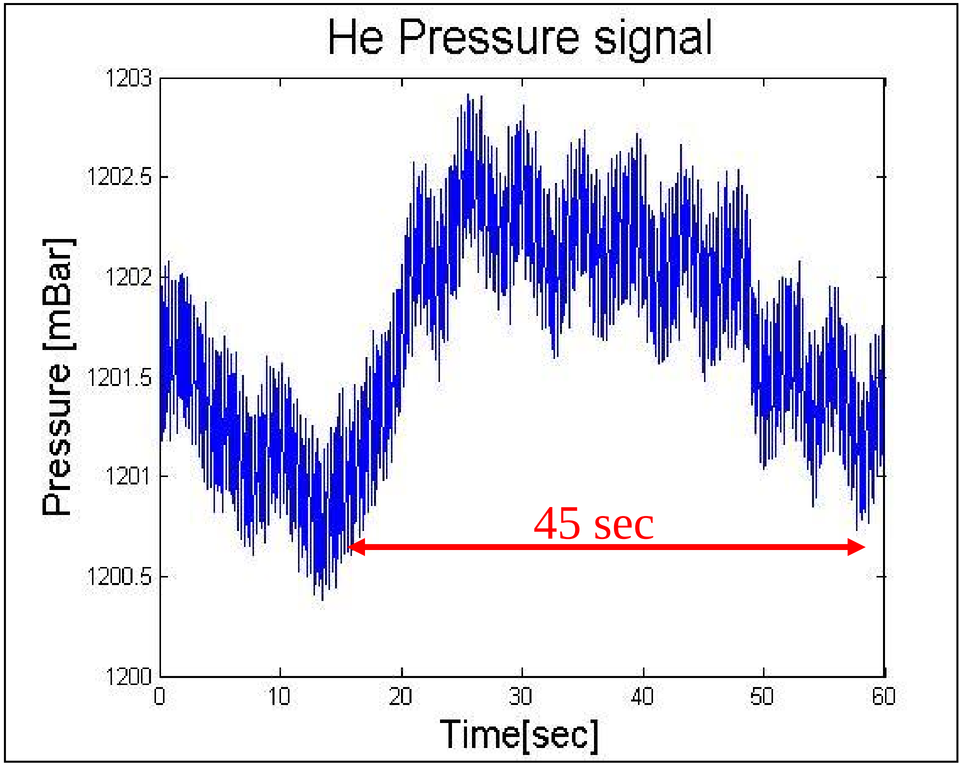
HWR Microphonics measurements

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

Detuning signal is dominated by the Helium pressure drift

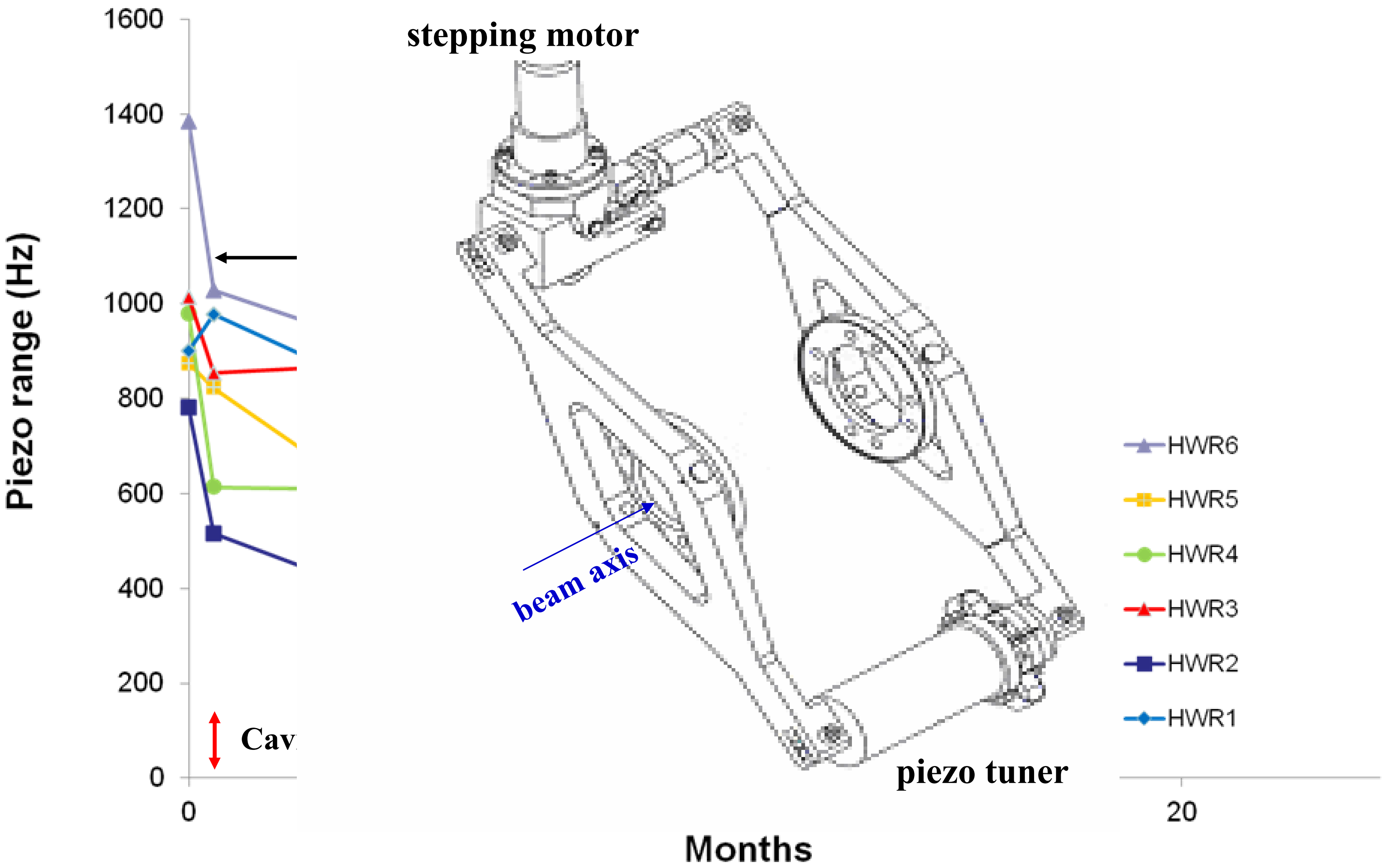
Detuning sometimes exceeds +/-200 Hz (~ +/-2 BW)



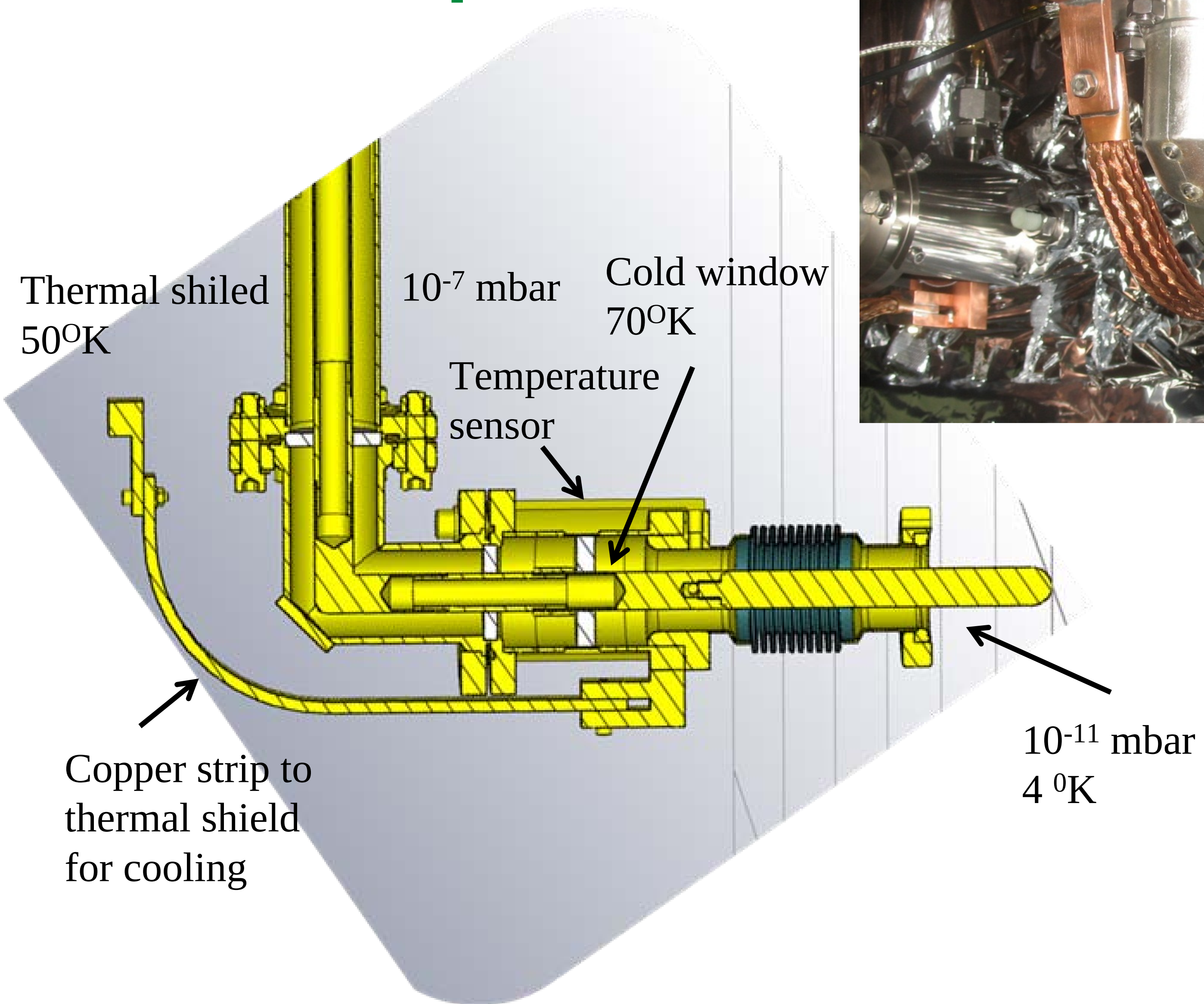


* Performed in collaboration with J.Delayen and K. Davis (JLab)

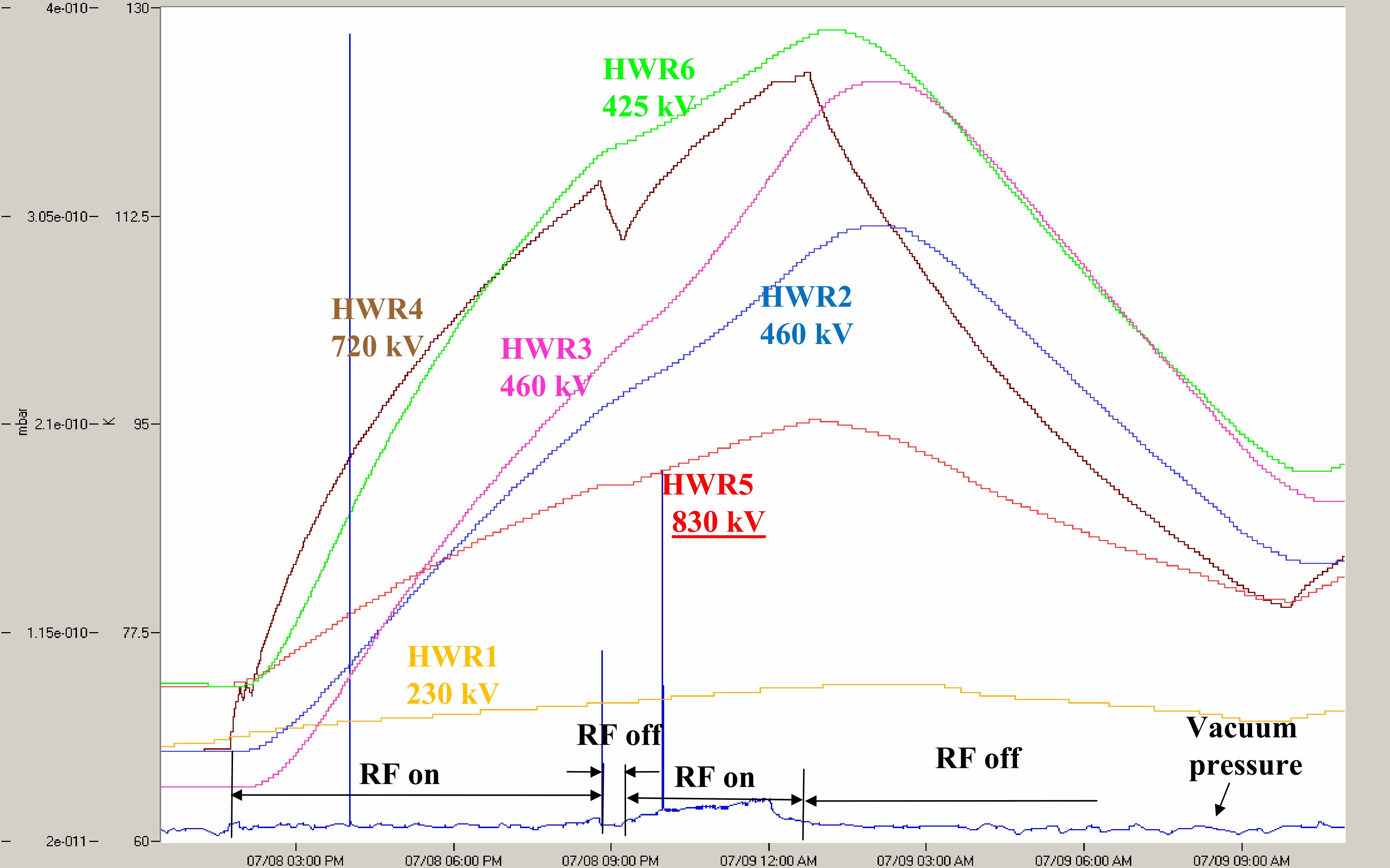
Deterioration of piezo ranges



RF couplers

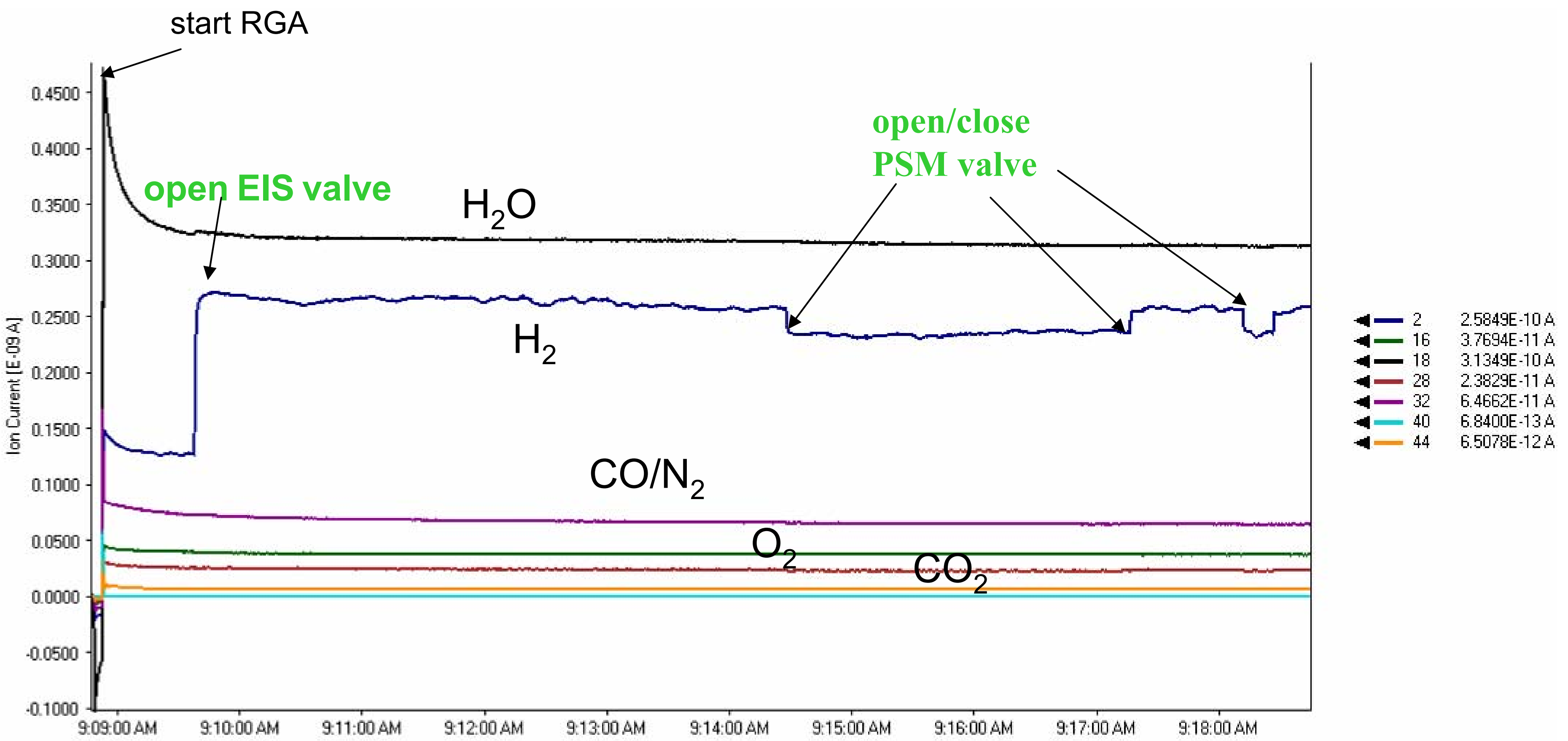

Thermal shiled
50^{O}K
10^{-7} mbar
Cold window
70^{O}K
Temperature
sensor
Copper strip to
thermal shield
for cooling
10^{-11} mbar
4 ^{0}K

Coupler warming up during operation (set for 3.9 MeV)



Warming couplers is the main limiting factor for the acceleration field values .
The warming effect differs for different couplers

Hydrogen diffusion along the accelerator



Significant increase of the hydrogen pressure after starting the ion source: hydrogen diffuses all way through the accelerator till the cryo module entrance

Opening the PSM valve slightly reduces hydrogen pressure: the cryomodule efficiently pumps hydrogen

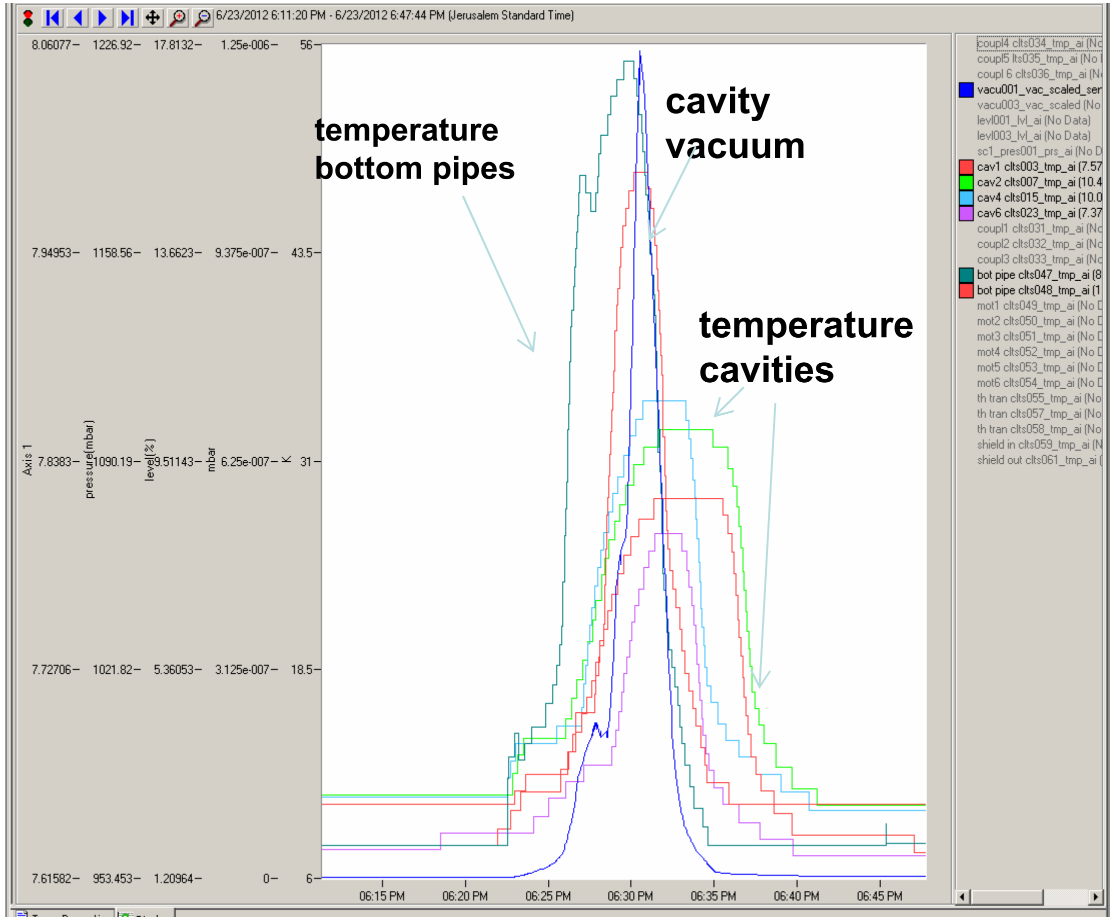
We have to improve hydrogen pumping in EIS/LEBT area

Hydrogen built up in cryomodule

The build up of hydrogen on the cryogenic surfaces at the entrance to the module.

During full or partial warm up intense hydrogen sublimation takes place at the temperatures higher than 20 K.

Such massive sublimation and consequent absorption may result in redistribution of hydrogen over more sensitive cryosurfaces of cavities which would lead to deterioration in cavity performance.



We plan to improve hydrogen pumping capacity in the region of EIS (powerful ark pump) and MEBT (new chamber&getter pump)

Summary on Phase I status

1. **EIS/LEBT: preforms OK**

   Improve hydrogen pumping capacity
   Bring chopper to routing operation
   Beam optics study

2. **RFQ : major alignment problems were solved in 2010**

   Return to conditioning campaign to achieve CW for deuterons
   If not successful consider major modification or even replacement

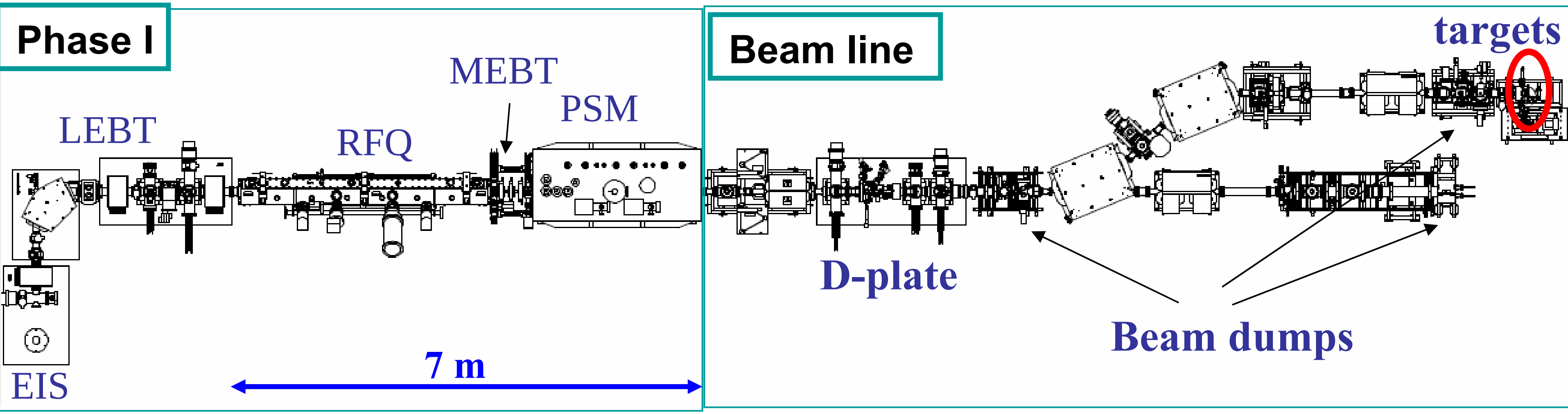
3. **MEBT: introduction of beam scrapper improved beam operation**

   Improve hydrogen pumping capacity

4. **PSM: introduction new 4 kW RF amplifiers and new HV piezo tuners improved performance**

   Understanding and improving the RF coupler performance
   Improving the couplers cooling
   Stiffening cavities

Beam optics study



Tune of the accelerator and the beam line is done with pulsed beam. Different diagnostics instrumentation used for tuning require different pulsed beams parameters (duty cycle and beam intensity). Furthermore when CW beam is operated its intensity varies within a factor ~100.

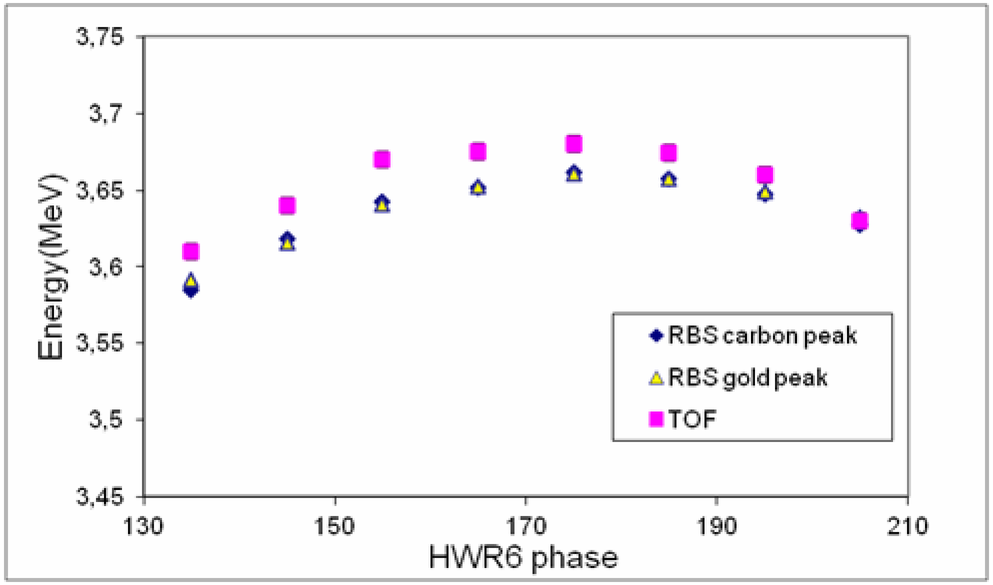
The questions asked by the accelerator users:

How well does tune performed with pulsed beam work for CW beam?

How robust is a tune for the whole range of beam intensity (0.01-1 mA)?

How sensitive is a tune for variation of optics parameters in the front-end?

Phasing of the cavities



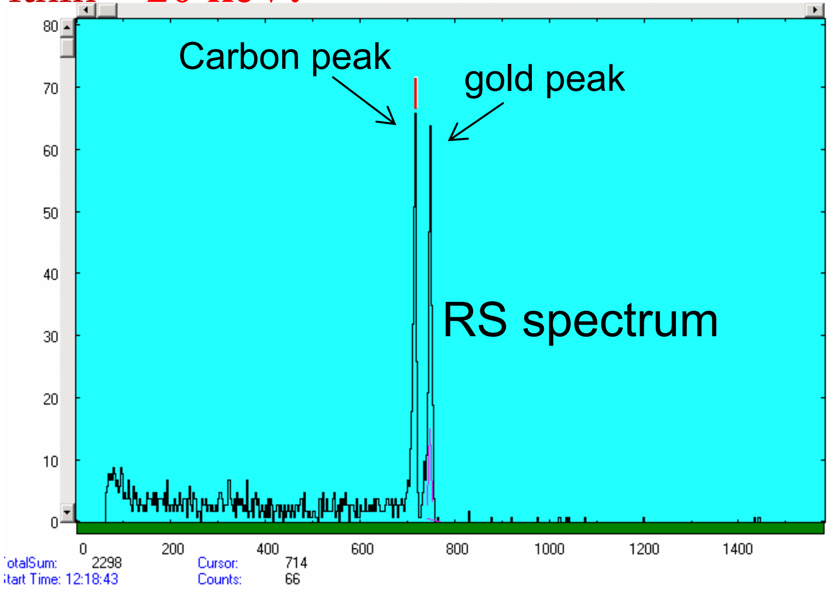
Two methods are used for phasing:

1.Non-destructive TOF that requires high beam intensity ~ **1 mA**
2.Destructive, Rutherford scattering (RS), which requires low intensity ~ a **few μA**

Two orders difference in the beam intensity; the results of TOF and RS are consistent within ~ **20 keV.**

For RS we had thick carbon backing which allowed for measurement of two scattering peaks.

The main sources of systematic errors are error in energy calibration of the Si detector and uncertainties in the target thickness.



Varying beam intensity by LEBT parameters

Use of a quartz viewer allows for fast study of influence of the front end parameters on the beam optics just before the target.

Opening of the LEBT aperture is shown.

5 mm

10 mm

20 mm

30 mm

50 mm

Changing current on the 1st LEBT solenoid.

64 A

62 A

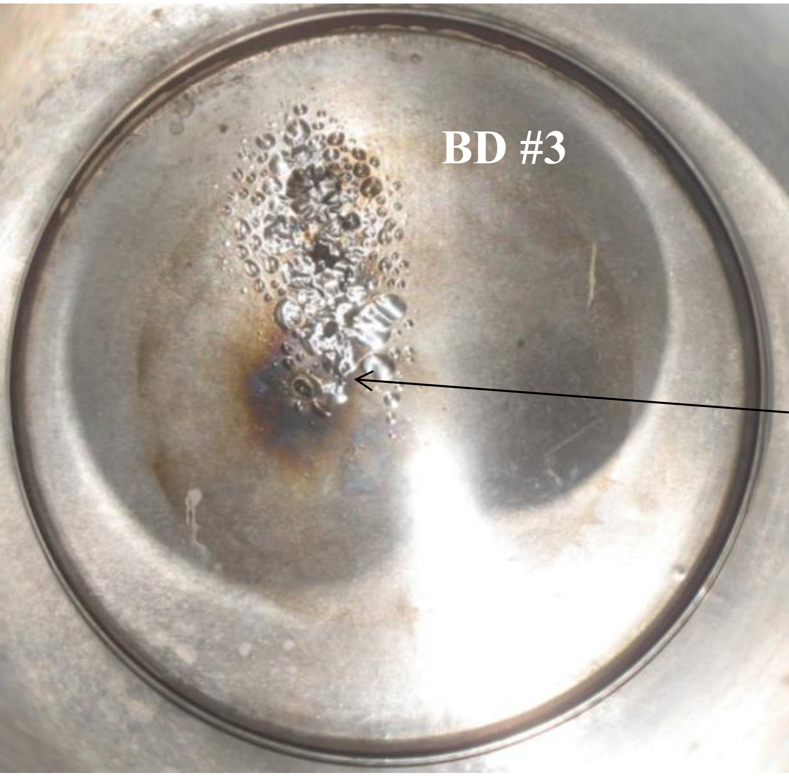
60 A

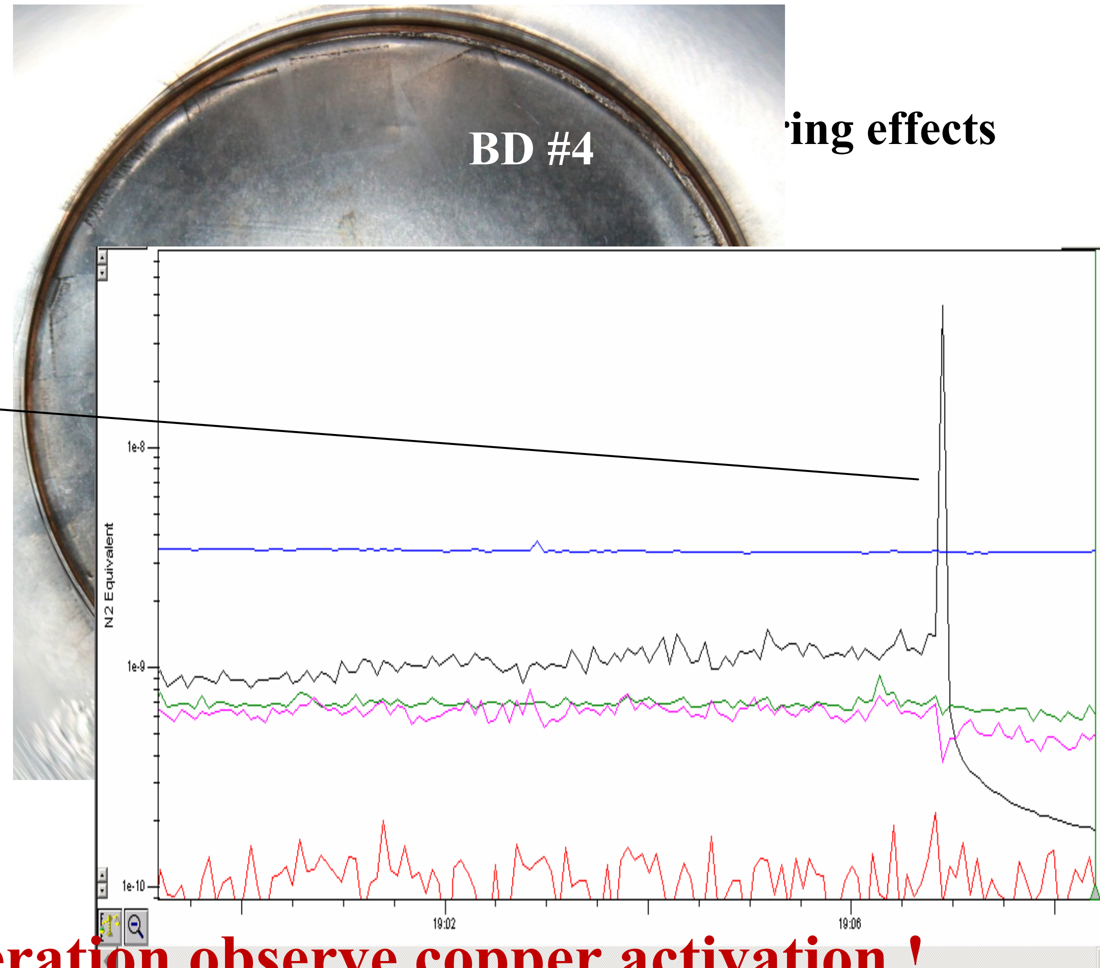
58 A

Varying the LEBT aperture and the LEBT 1st solenoid is used to vary the beam intensity within a factor 100. In the first order the beam position on target does not change with varying these parameters.

Experience with the Tungsten Beam dump

The beam dump 50 micron Tungsten sheet fused to a water cooled cooper plate.
Up to 10 MeV, no activation low neutron radiation is expected.





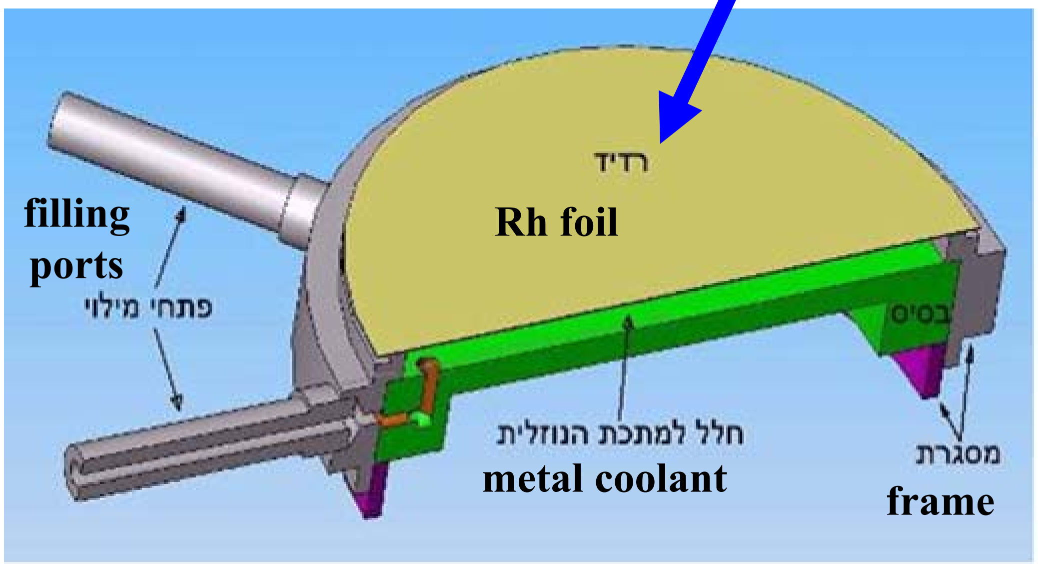
ing effects

After many hours of operation observe copper activation !

Example of radioisotopes production

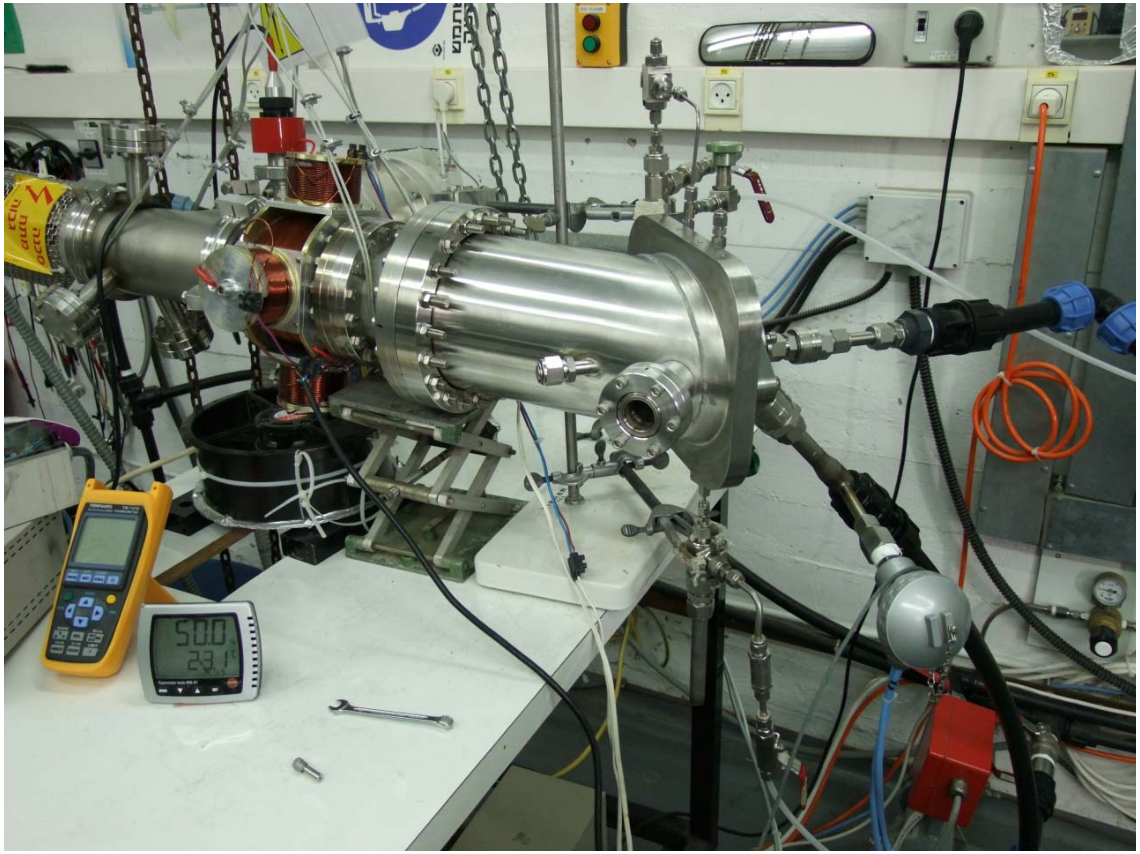
103 Pd production via $^{103}Rh(d,2n)^{103}Pd$ reaction

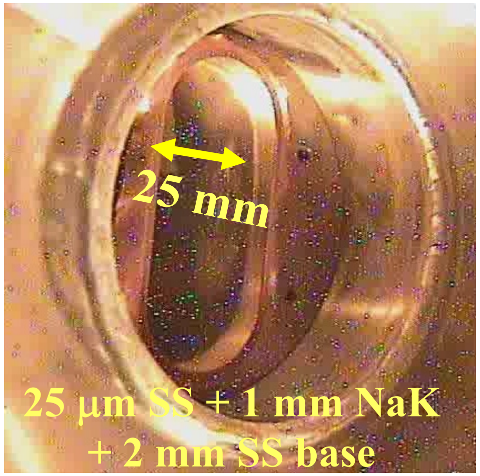
deuteron beam

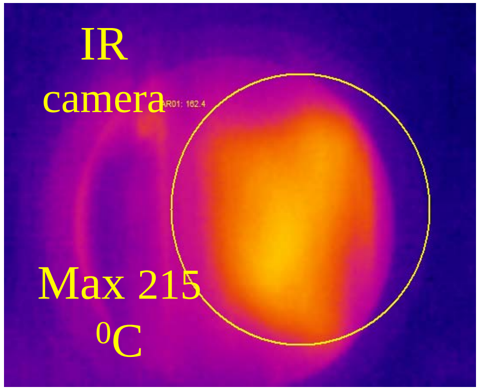


I. Silverman et al., NIM B261, 747-750 (2007)

Prototype capsule test



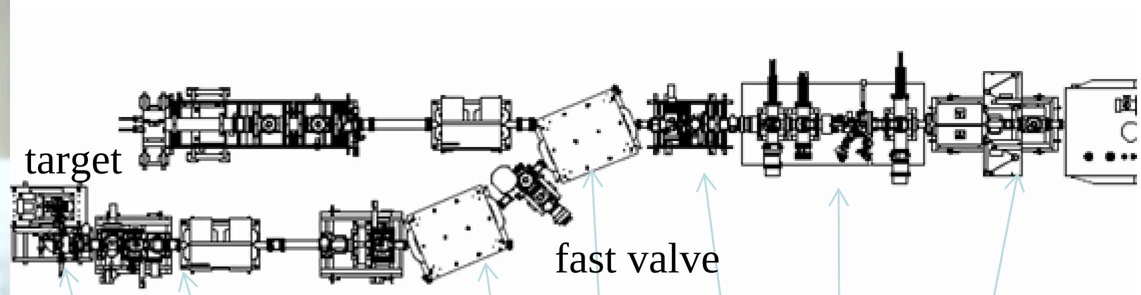


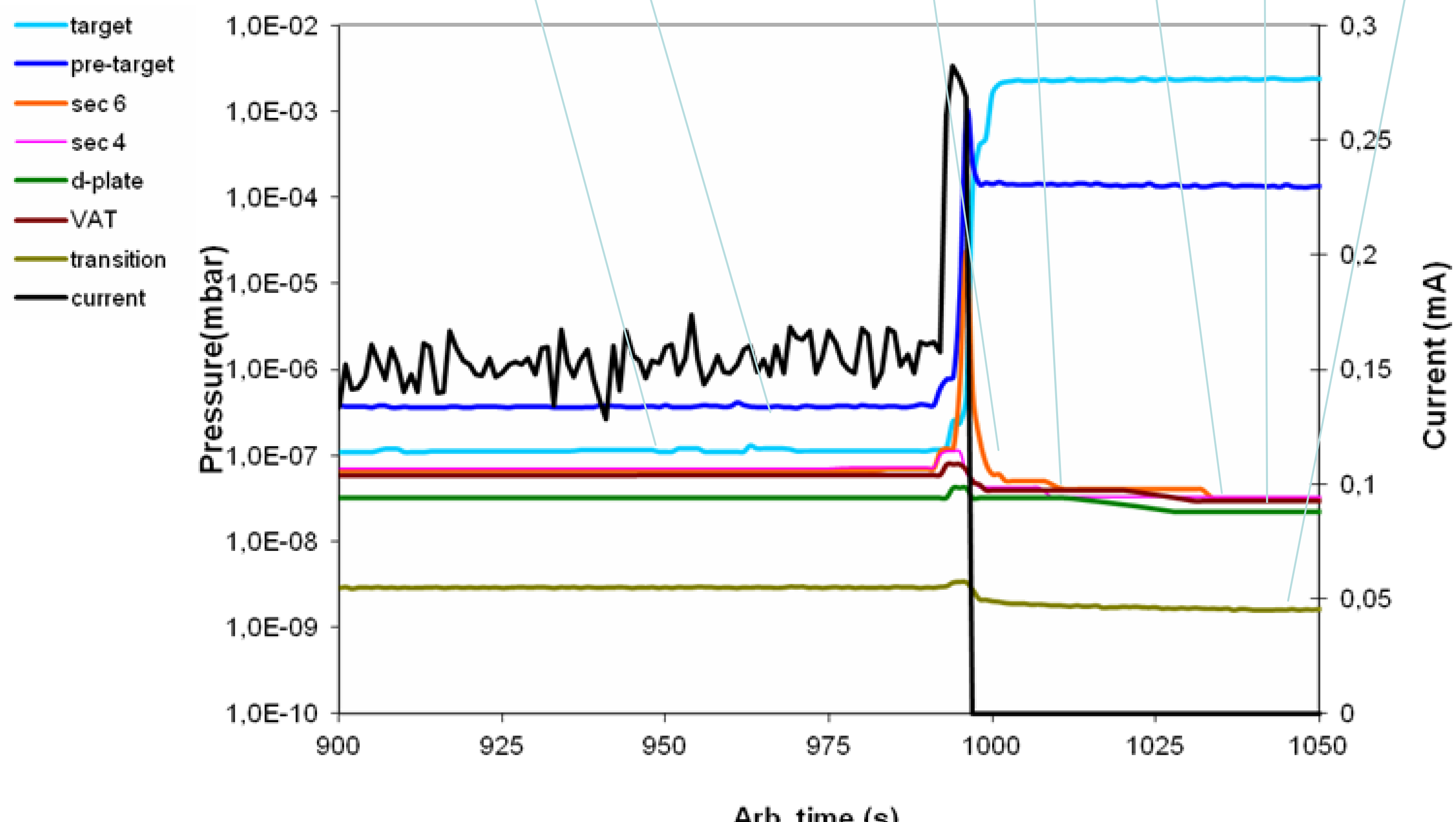


Ido Silverman et al

25 micron stainless steel foil cooled by liquid 1 mm metal NaK , base cooled by water
Maximum ever applied power ~ 1 kW
Stable operation ~ 400 W

Vacuum protection





The accelerator vacuum protection worked well during the tests

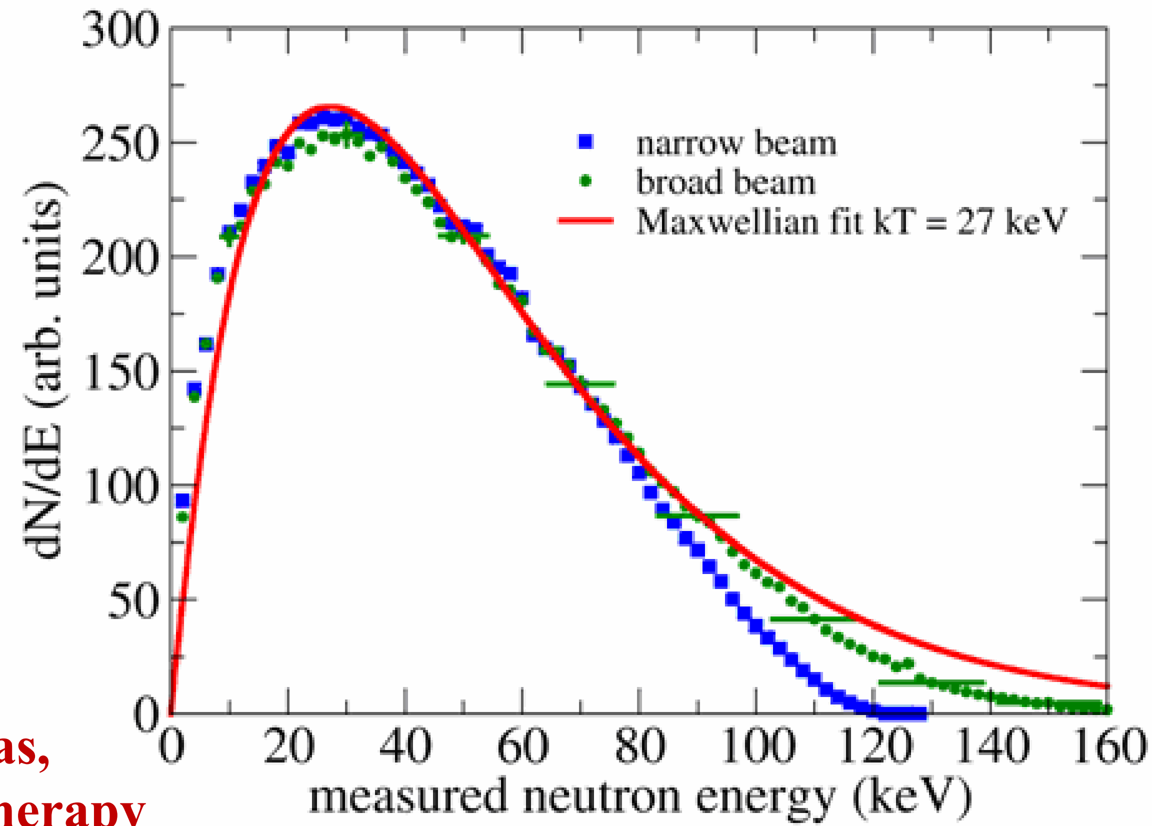
Protons on Li target

$^{7}Li(p,n)^{7}Be$

$E_{threshhold}$=1.88 MeV

Application of protons at ~ 1.92 MeV produce spectrum similar to a Maxwelian distribution at ~ kT=30 keV

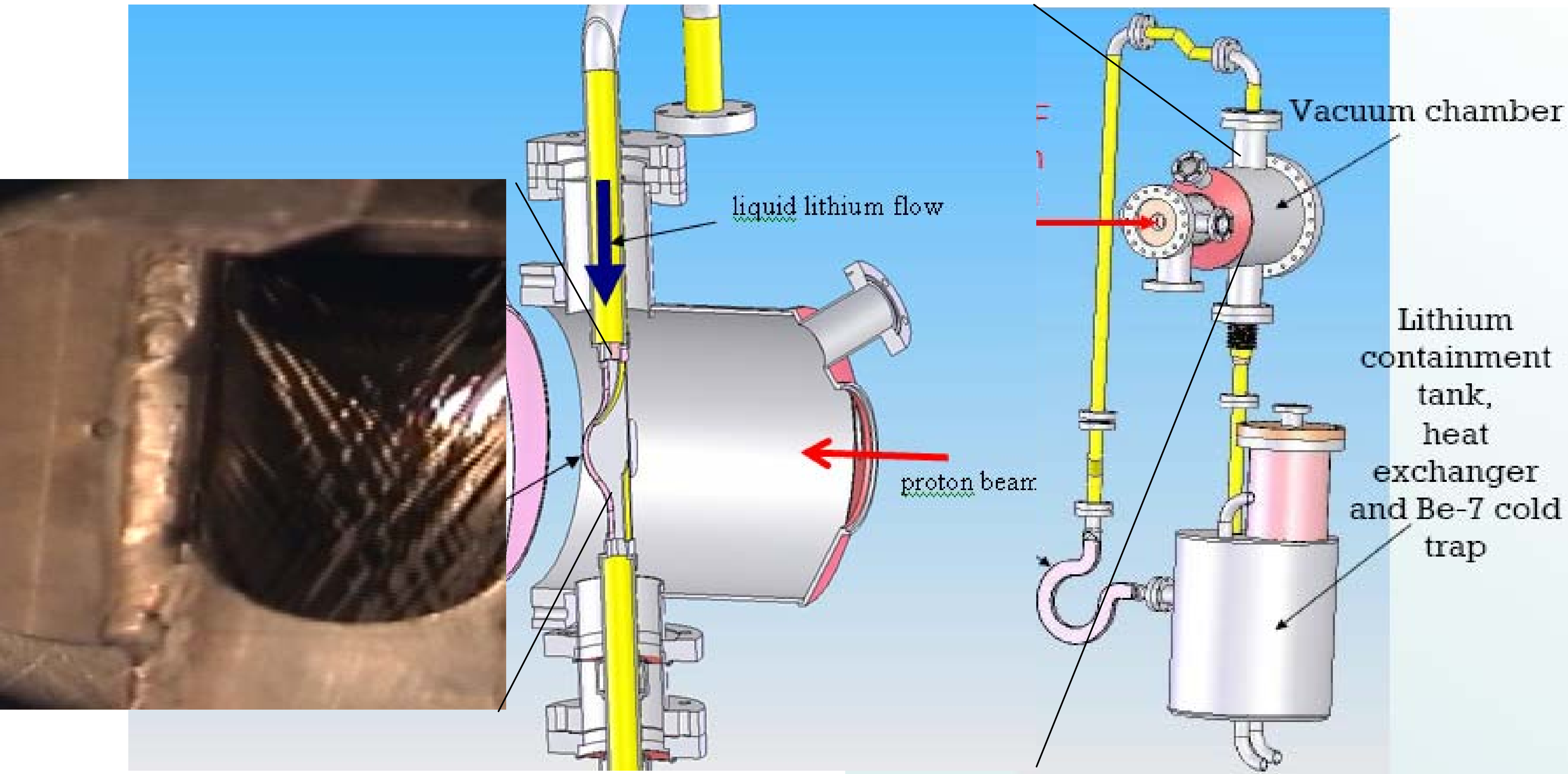
This distribution mimics stellar neutron spectrum, and can be used for astrophysics research, as well as, for Boron Neutron Capture Therapy (BNCT)



M. Paul et al

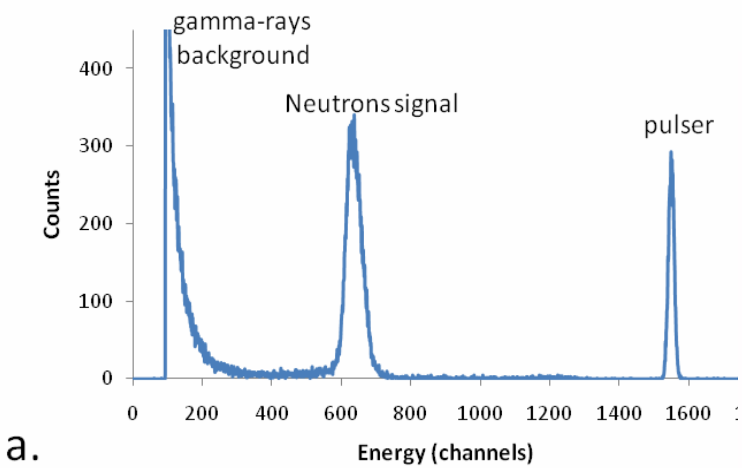
Liquid Li target (LILIT)

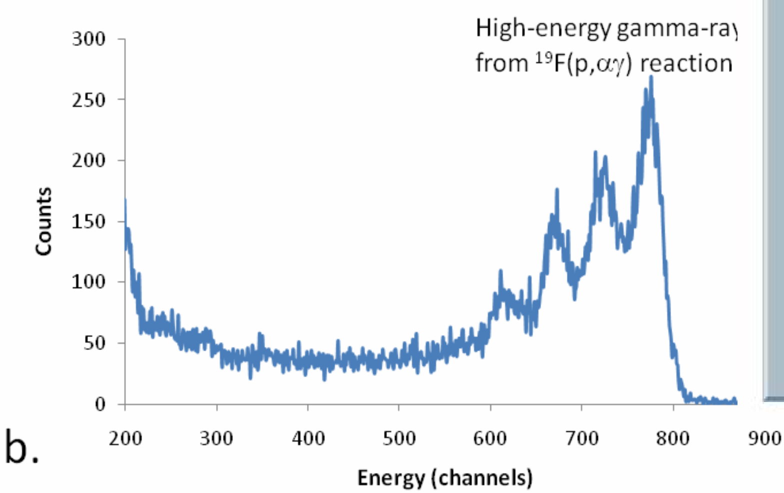
Jet: 18 mm x 1.5 mm.
Lithium velocity: 20 m/s.
Wall assisted lithium jet

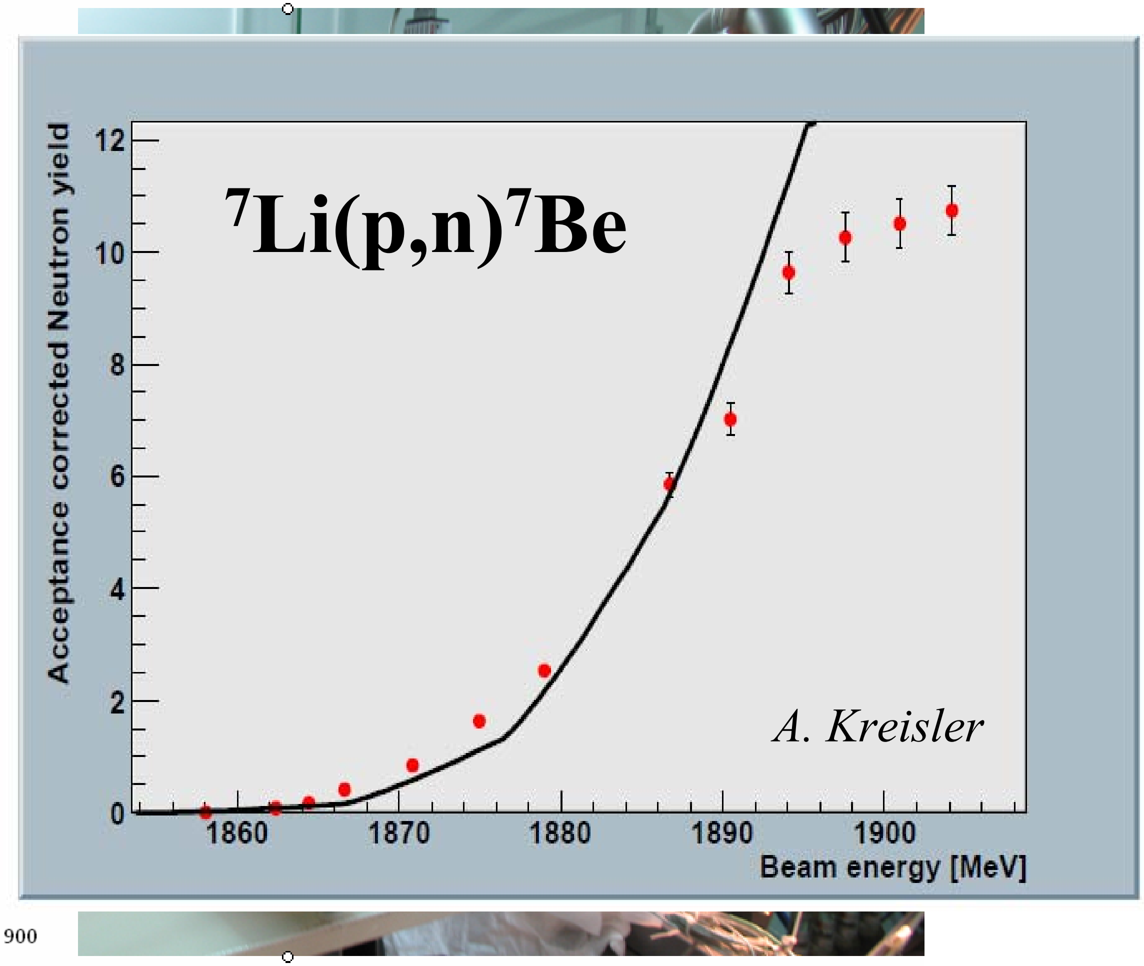


A. Arenshtam, D. Kijel et al

First tests: Solid Lithium Target

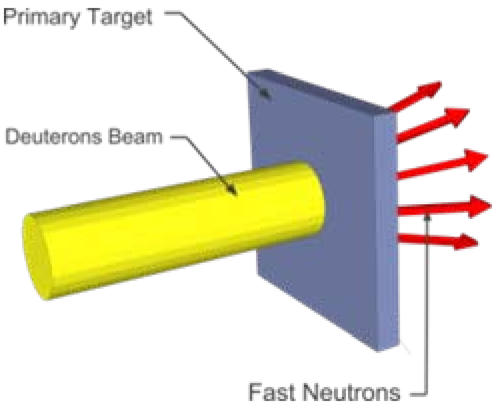






G. Feinberg PhD thesis

n spectrum of d-Li with 40 MeV



$4 \cdot 10^{14}$ n/sec/mA

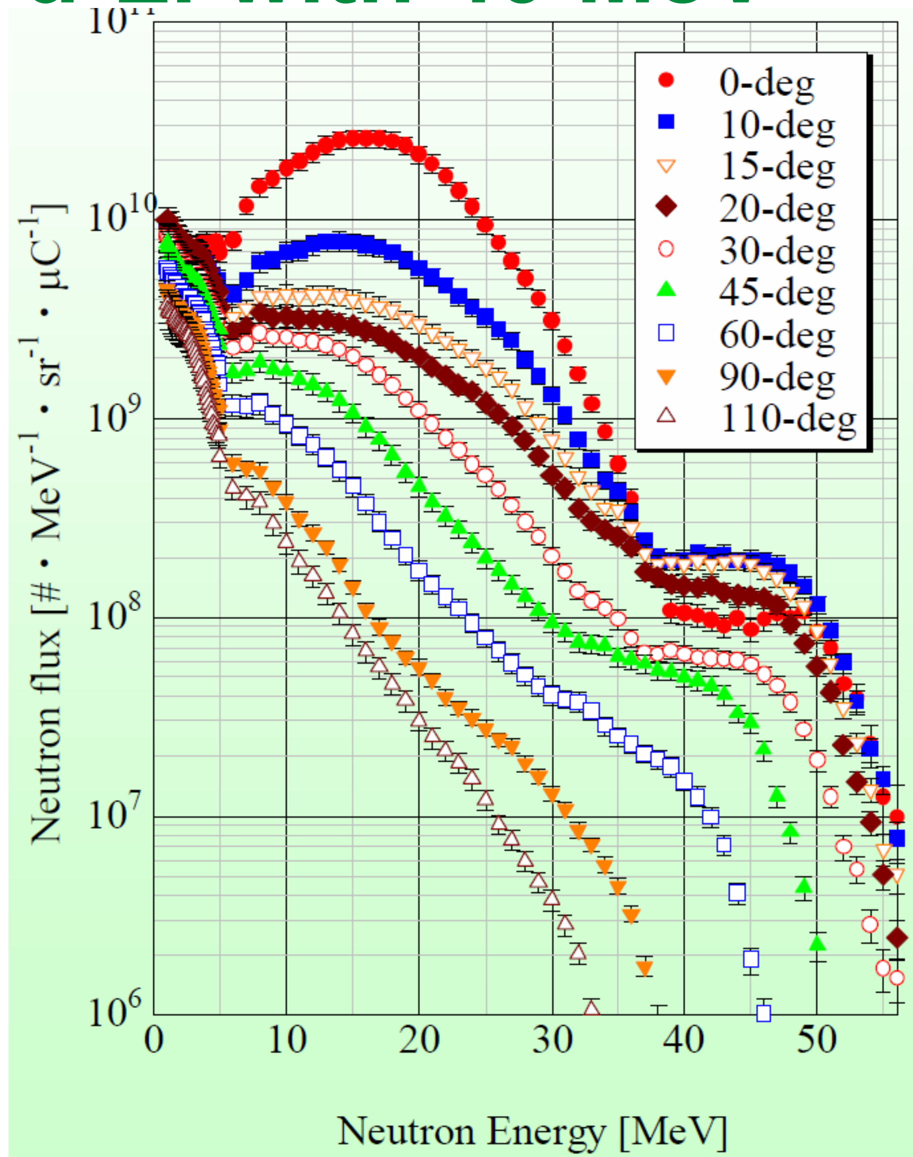
<En> = 15 MeV

IFMIF: 40 MeV, 250 mA Lithium Converter

Spiral2: 40 MeV, 5 mA Graphite converter

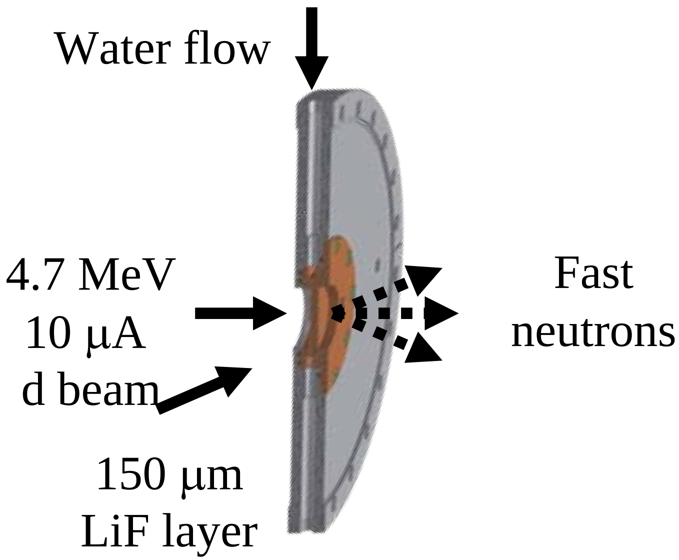
SARAF: 40 MeV , 5 mA Lithium Converter

Other possible converters: Beryllium, Water, Heavy water

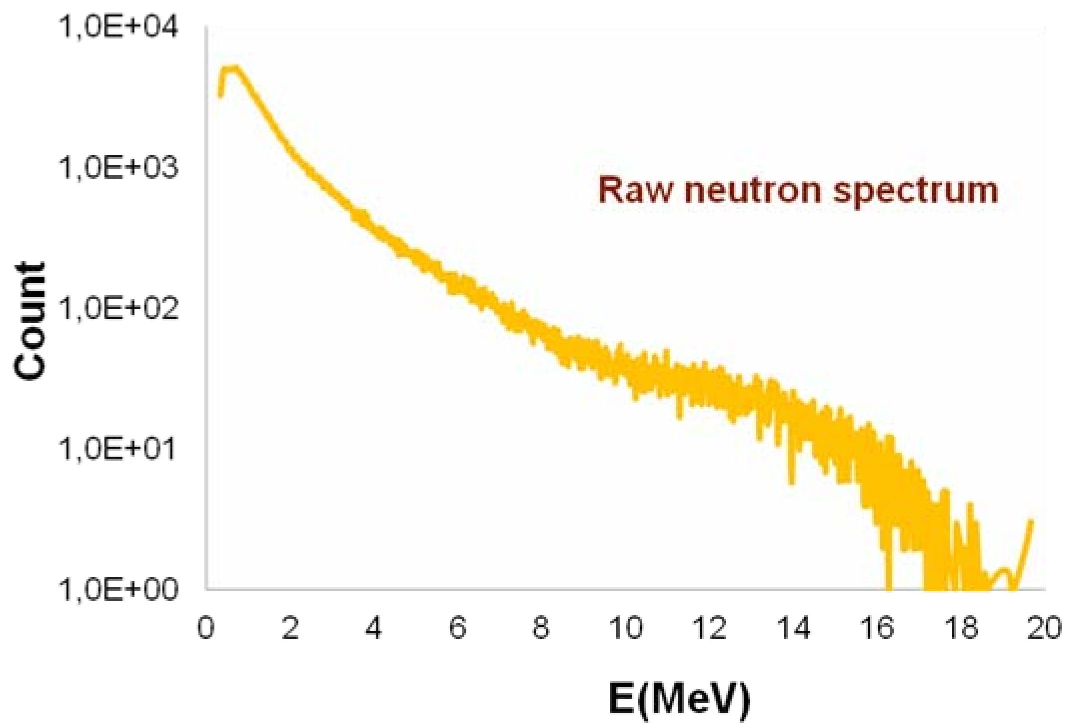


M. Hagiwara *et al. Fus. Sci. Tech.*, **48** (2005)

First experience with accelerated deuterons



10^9 n/sec
Isotropic distribution
Fast neutrons up to 20 MeV



T. Hirsh PhD. Thesis

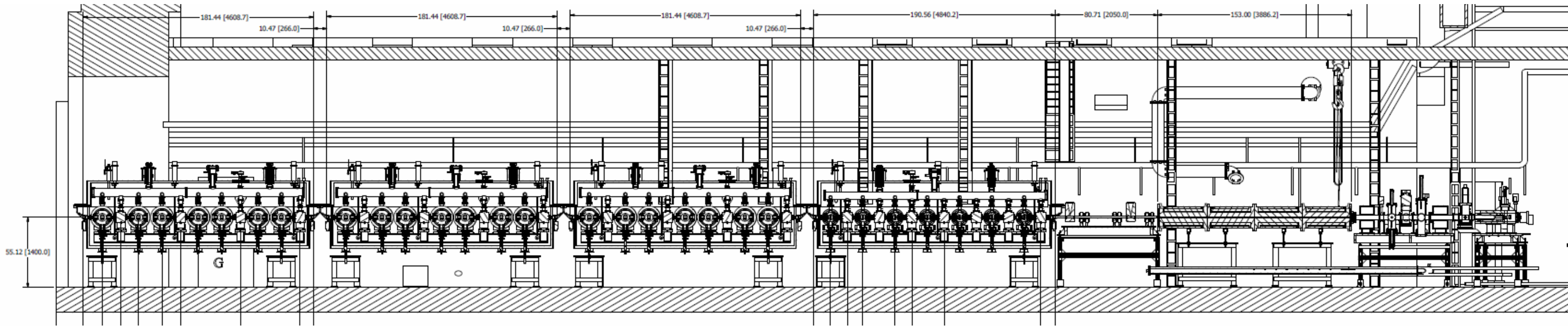
Summary

There are still many problems at Phase I of SARAF.The local team works hard to solve them.

Beam operation in 2011-12 showed that SARAF even at Phase I has potential to become an user facility with broad scope of the applications

Conceptual design of Phase II is done

Phase II,ANL conceptual design (2012)



- The ion source and LEBT are in the original position
- New (RFQ) MEBT and superconducting linac
- 176 MHz β=0.09 and β=0.16 Half Wave Resonators
- Total superconducting linac = 19.47 m
- 7 low-β HWR operating at 1 MV and 21 high-β HWR operating at 2 MV
  - Beam dynamics study at **[B. Mustapha *et al.* IPAC12, J. Rodnizki *et al.* LINAC12]**
- Total (static and dynamic) power dissipation ~ 350 W @4K

P. Ostroumov *et al.* LINAC12

People involved in accelerator &experiments

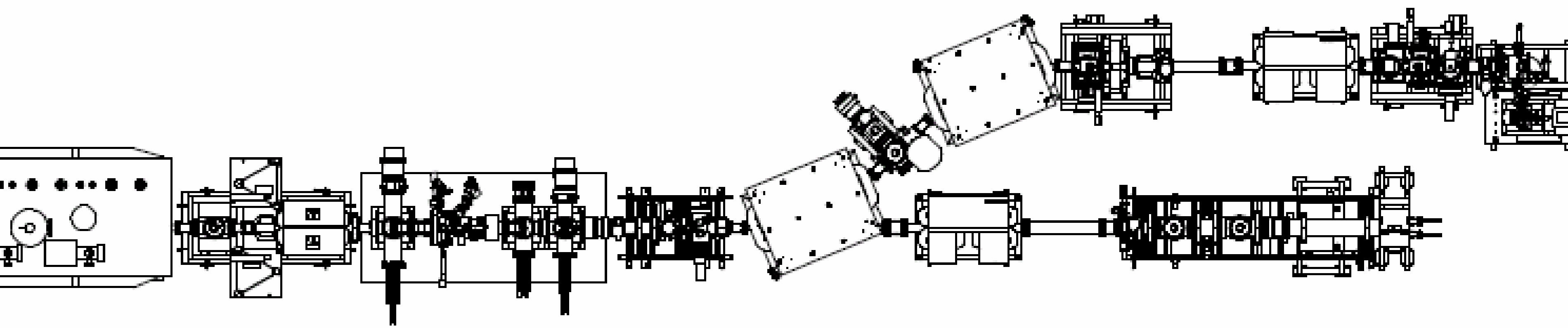
(including students, consulters and partially affiliated personal) :

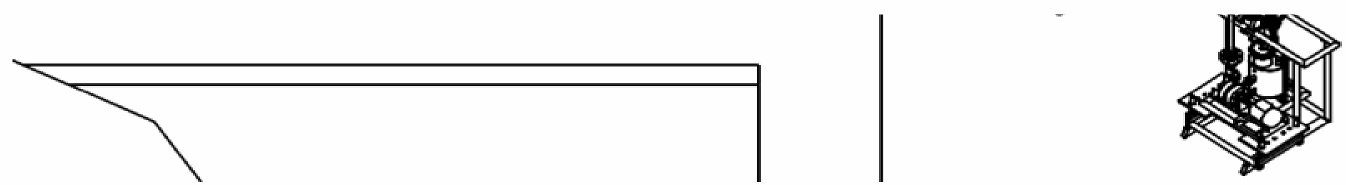
D. Berkovits, A. Arenshtam, Y. Ben-Aliz, Y. Buzaglo, O. Dudovich,Y. Eisen, I. Eliyahu, G. Finberg, I. Fishman, I. Gavish, I. Gertz, A. Grin, S. Halfon, D. Har-Even, Y. Haruvi, D. Hirshman, T. Hirsh, T. Horovits, B. Keizer, A. Kreisel, D. Kijel, G. Lempert, Y. Luner, A. Perry, E. Reinfeld, J.Rodnizki, G. Shimel, A. Shor, I. Silverman, E. Zemach, L. Weissman.

Phase I commissioning,
accelerator operation,
maintenance of the accelerator,
maintenance beam line,
maintenance the infrastructure,
users support,
preparation to Phase II

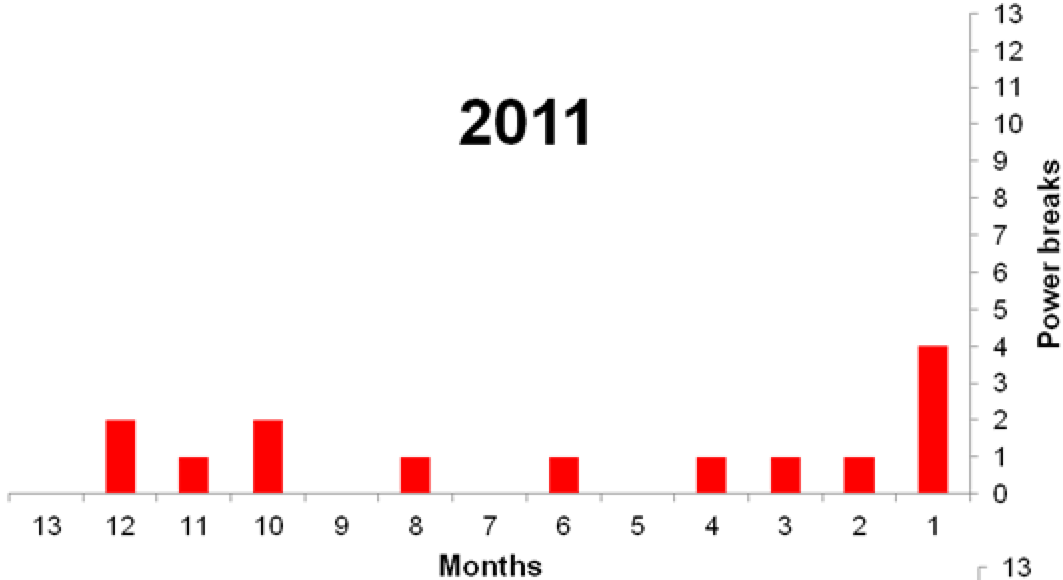
~ 20 persons

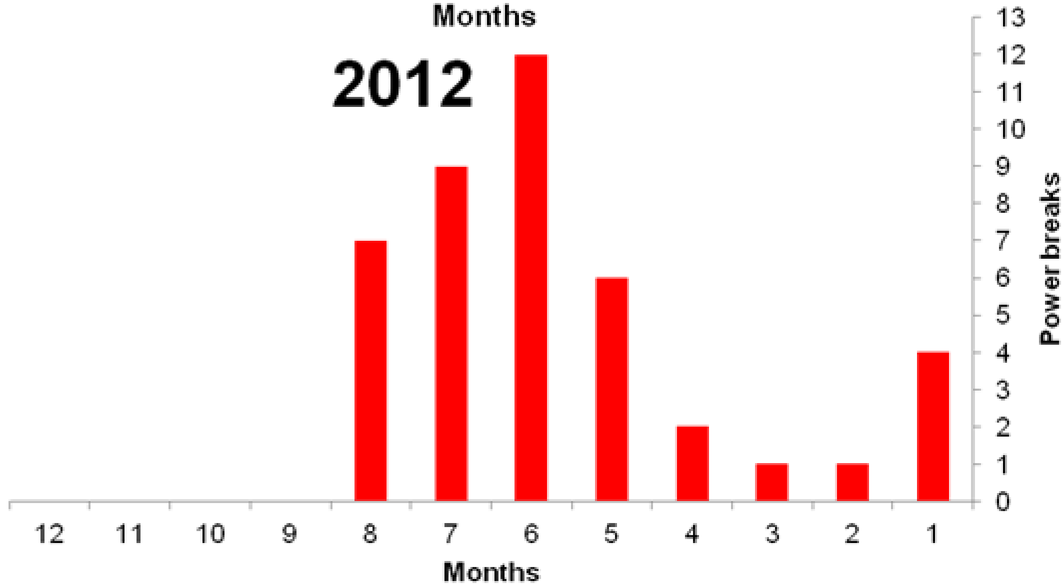
Temporary beam line





Quality of electricity





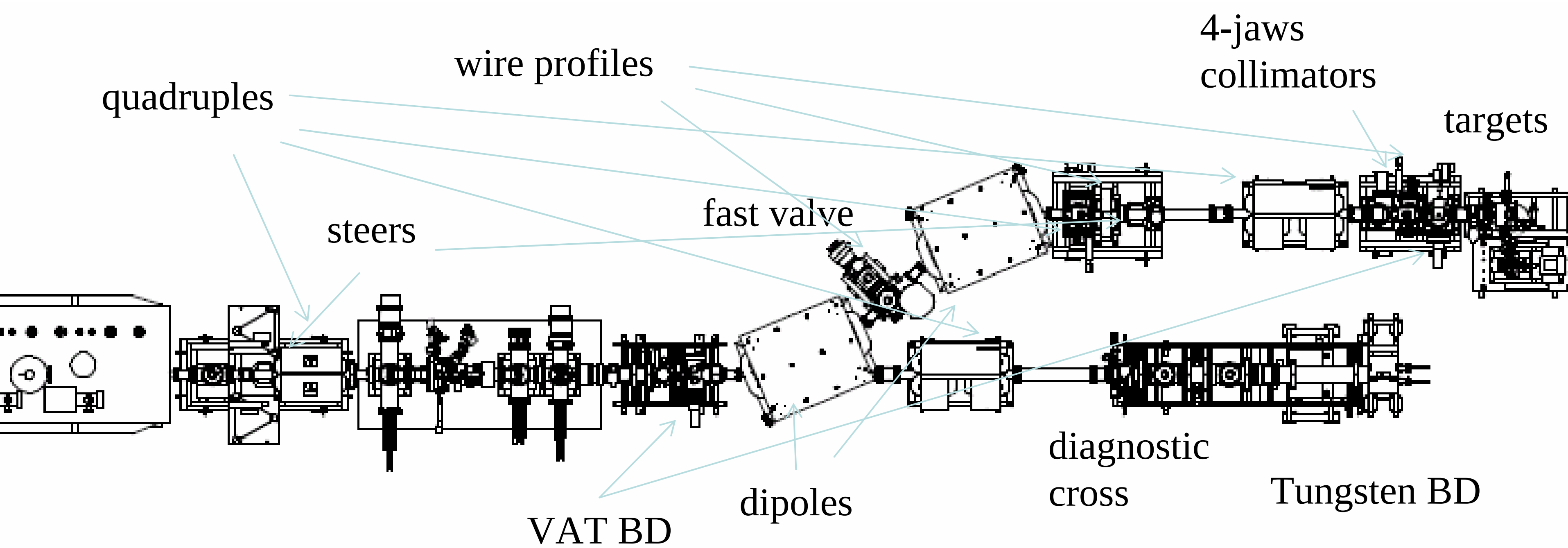
Funds for upgrade of the facility UPS.
New UPS operational in early 2013

Some slides

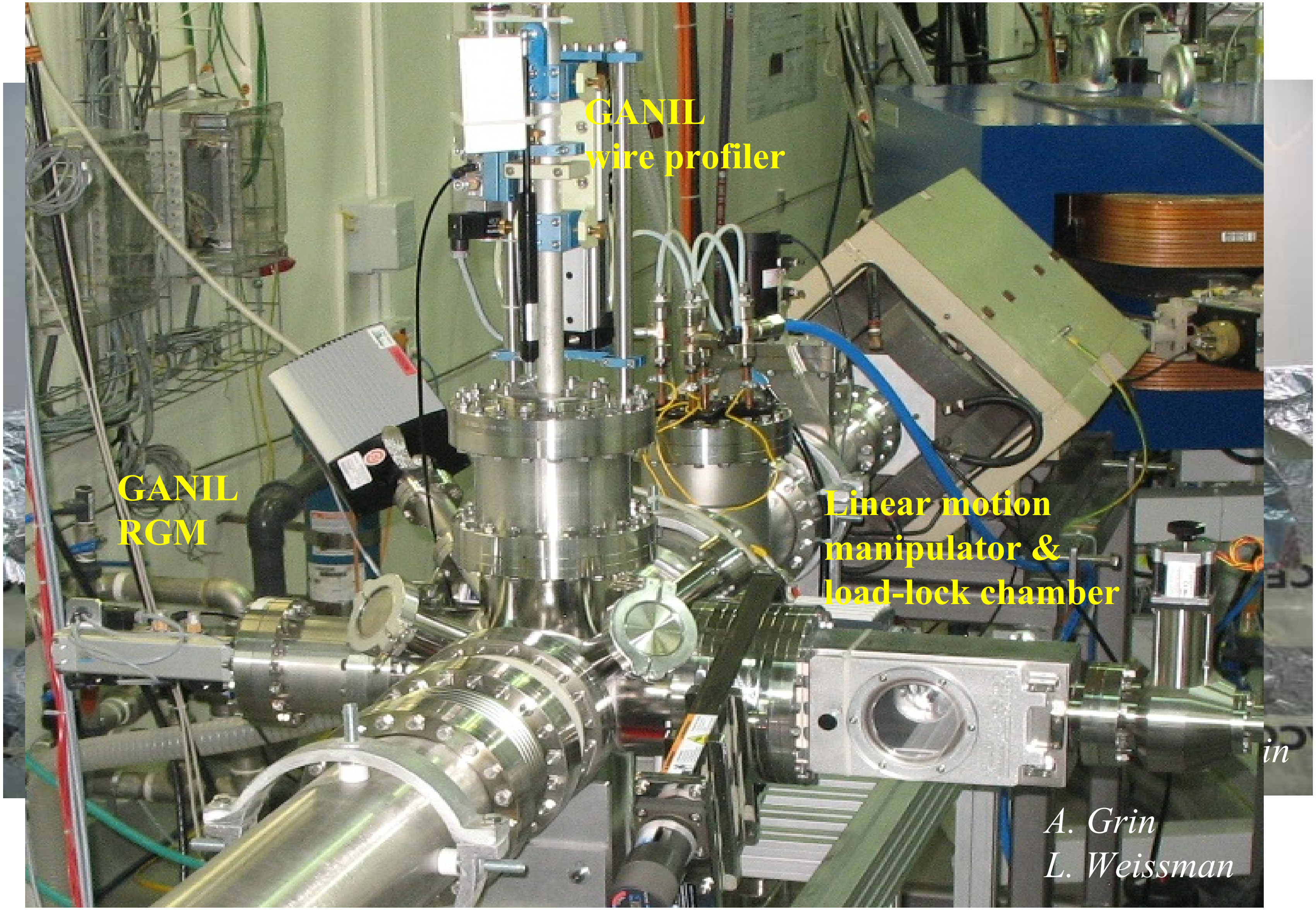
Beam operation of Phase I. Temporary beam line.

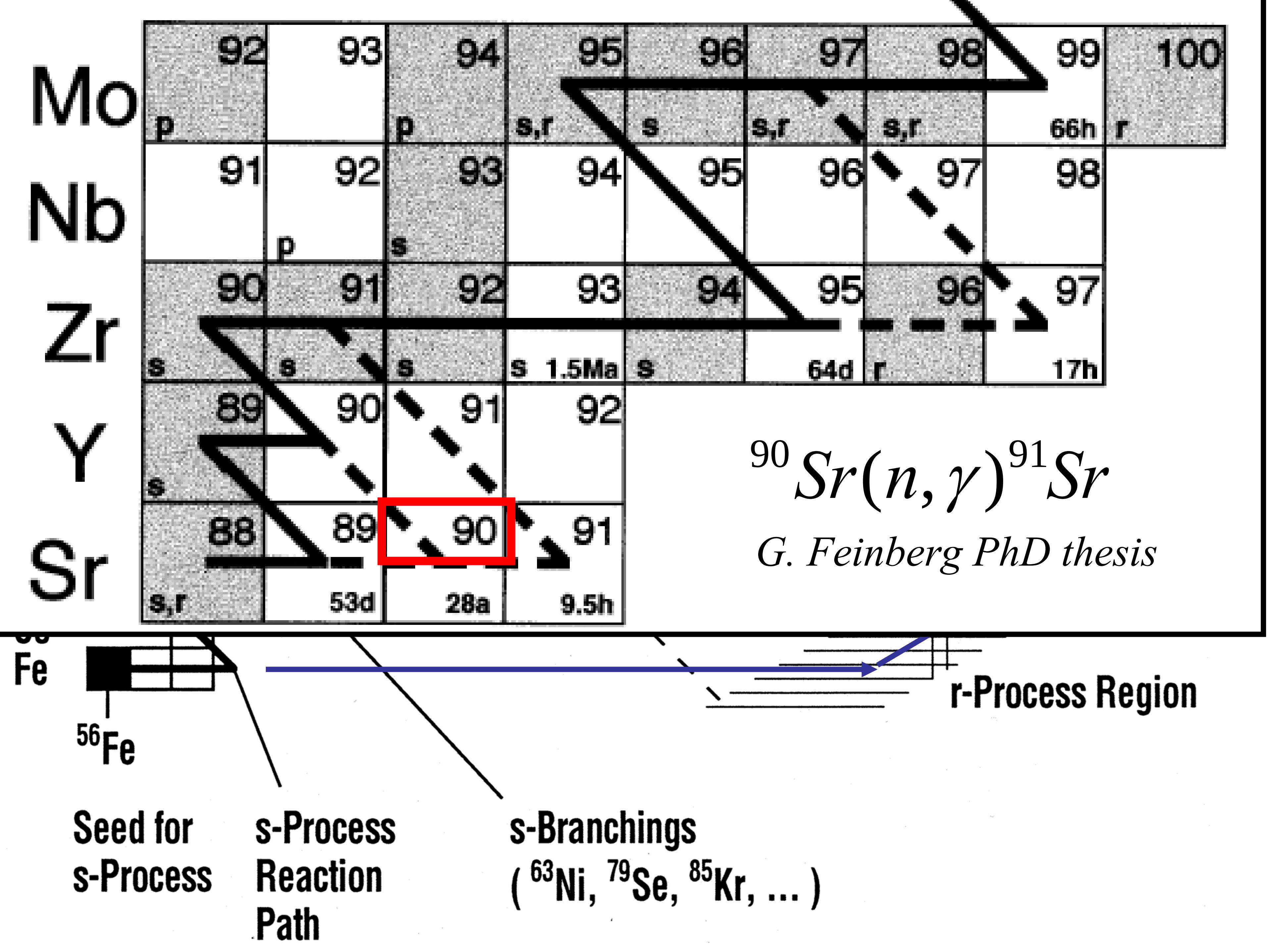
Very strong demand for the beam time

Some research can be done only at Phase I energies during the time window before the Phase II installation.



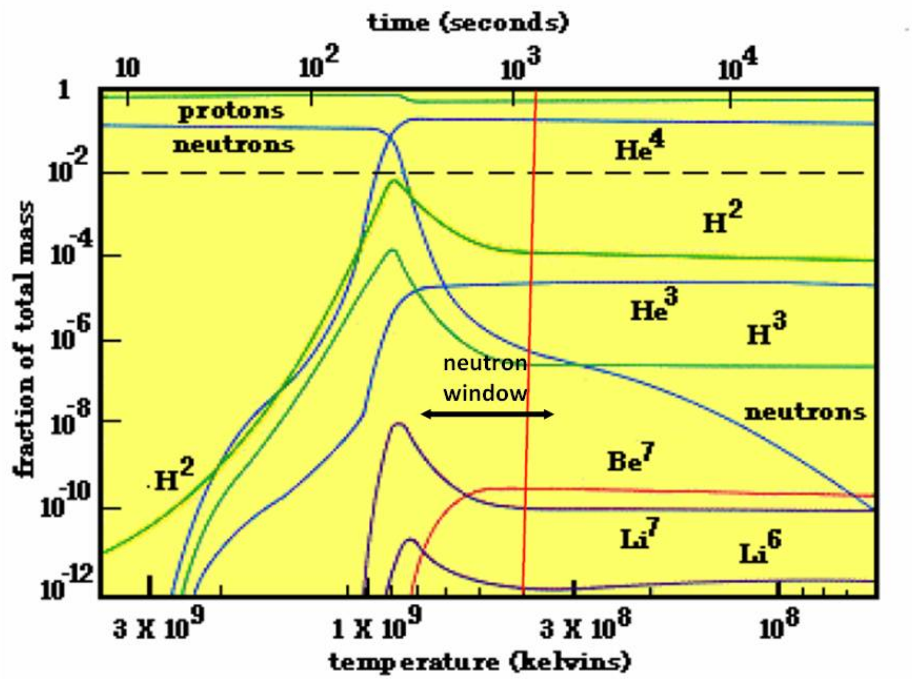
Developments on the BD line

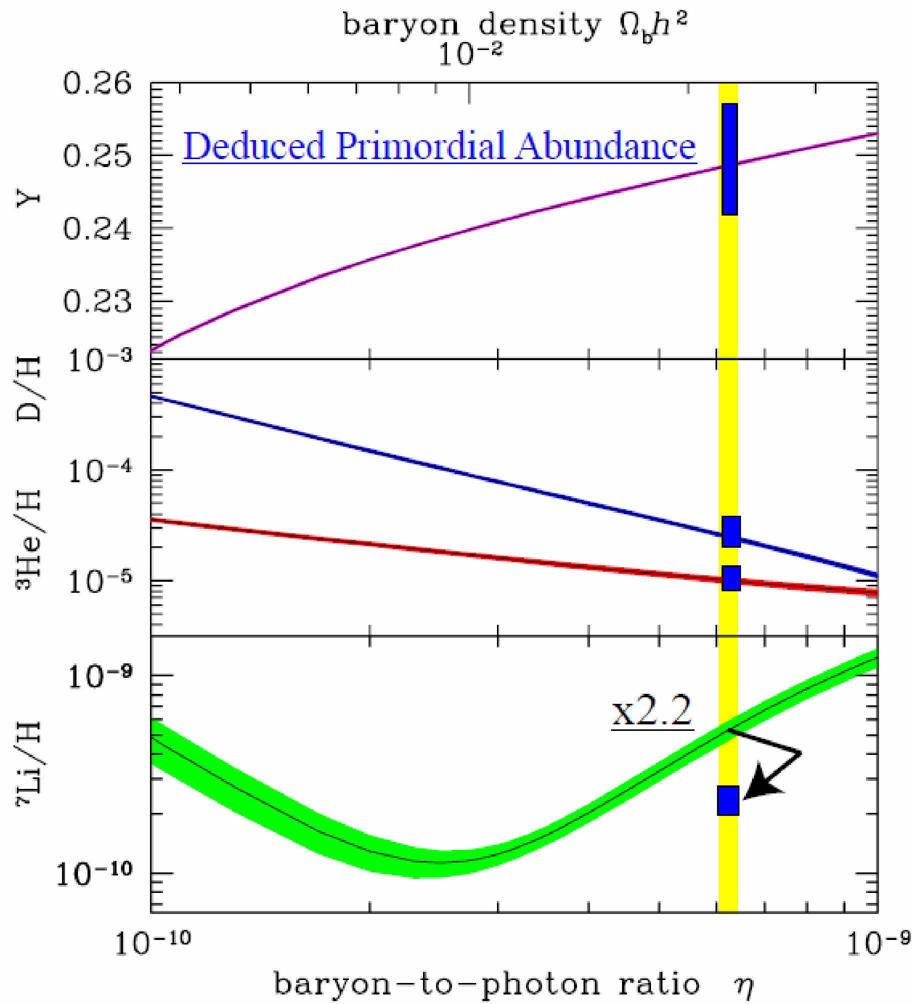




Mo
Nb
Zr
Y
Sr
53d
28a
9.5h
1.5Ma
64d
17h
66h
$^{90}Sr(n,\gamma)^{91}Sr$
G. Feinberg PhD thesis
Fe
^{56}Fe
r-Process Region
Seed for s-Process
s-Process Reaction Path
s-Branchings (^{63}Ni, ^{79}Se, ^{85}Kr, …)

Big Bang Li production problem

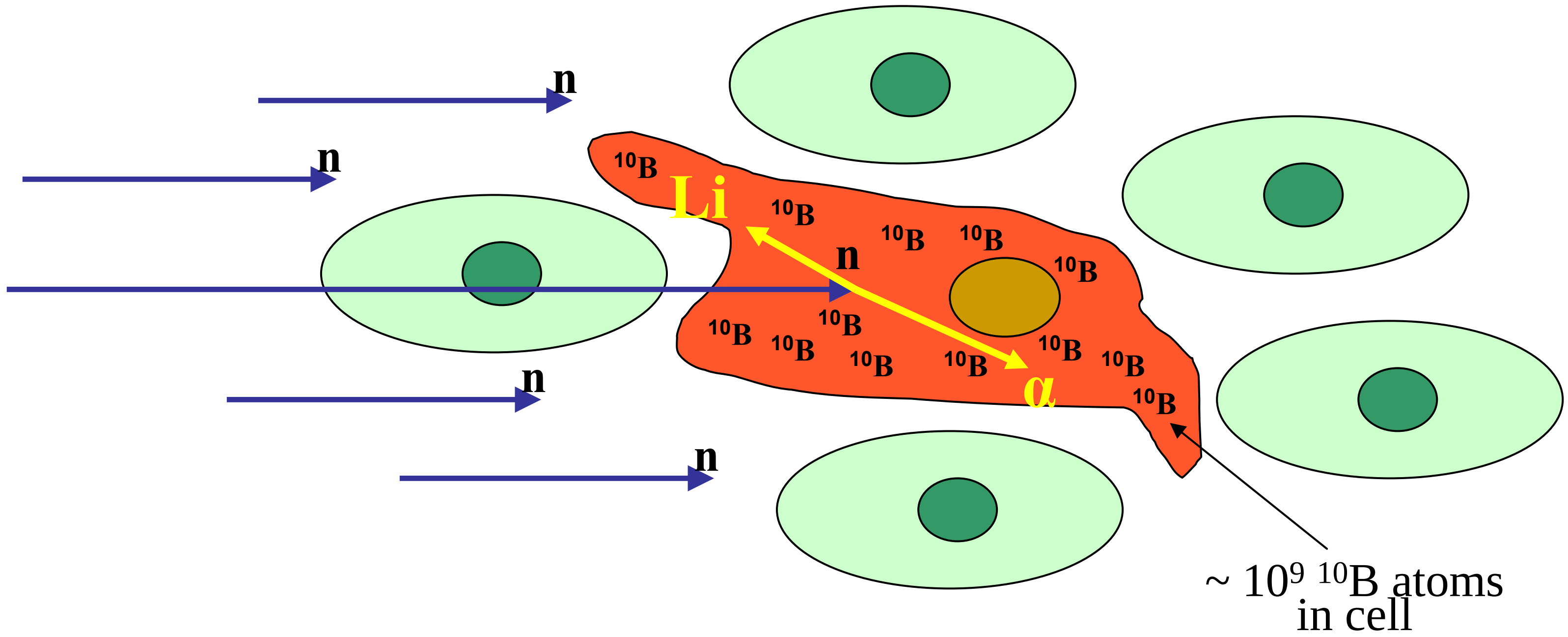




Measure destruction rate of ^{7}Be via the **^{7}Be(n,α)α** reaction

M. Gai et al

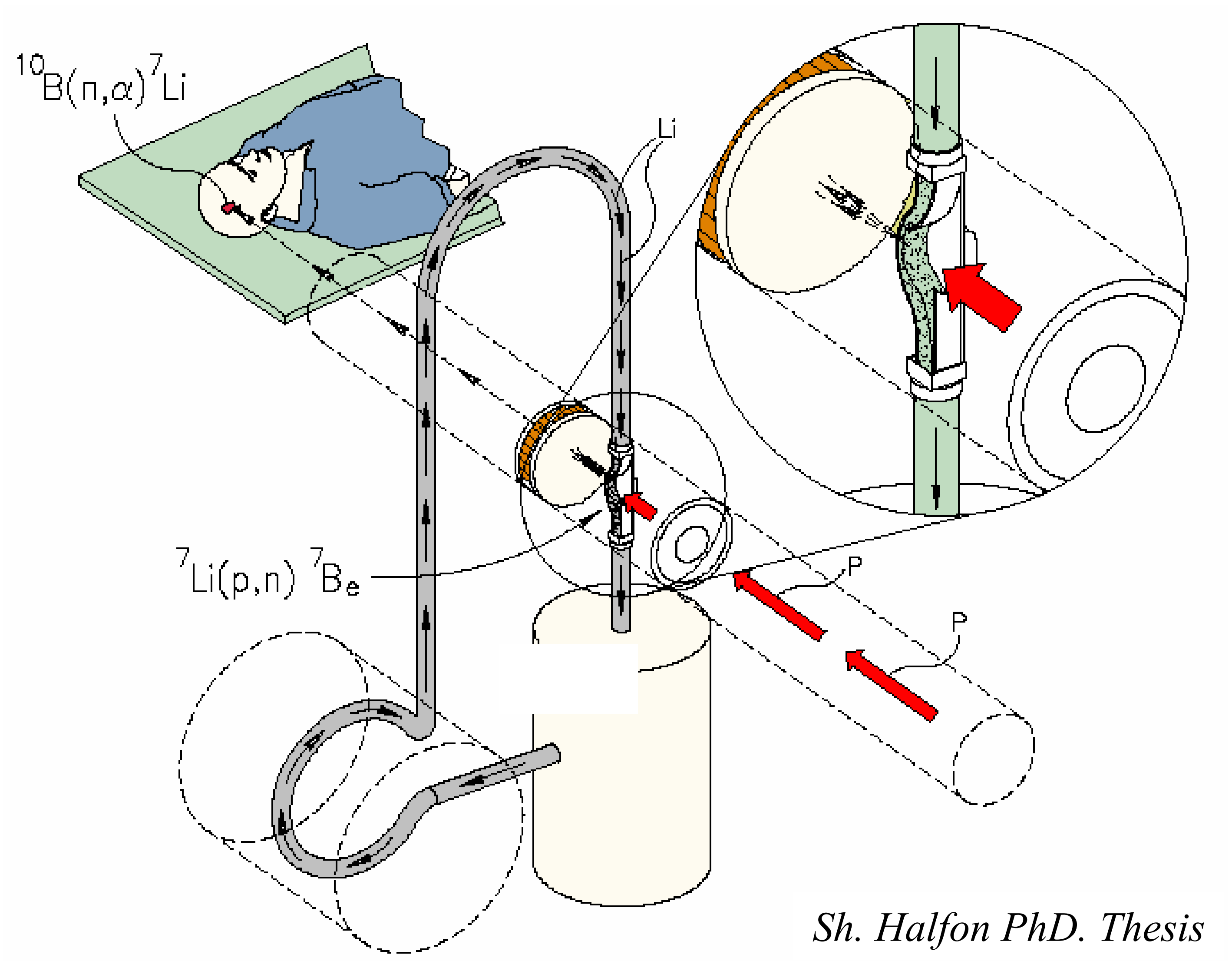
Boron Neutron Capture Therapy



1. Selectively deliver ^{10}B to the tumor cells.
2. Irradiate the target region with neutrons.
3. The short range of the $^{10}B(n,\alpha)^{7}Li$ reaction product, 5-8 μm in tissue, restrict the dose to the boron loaded area.

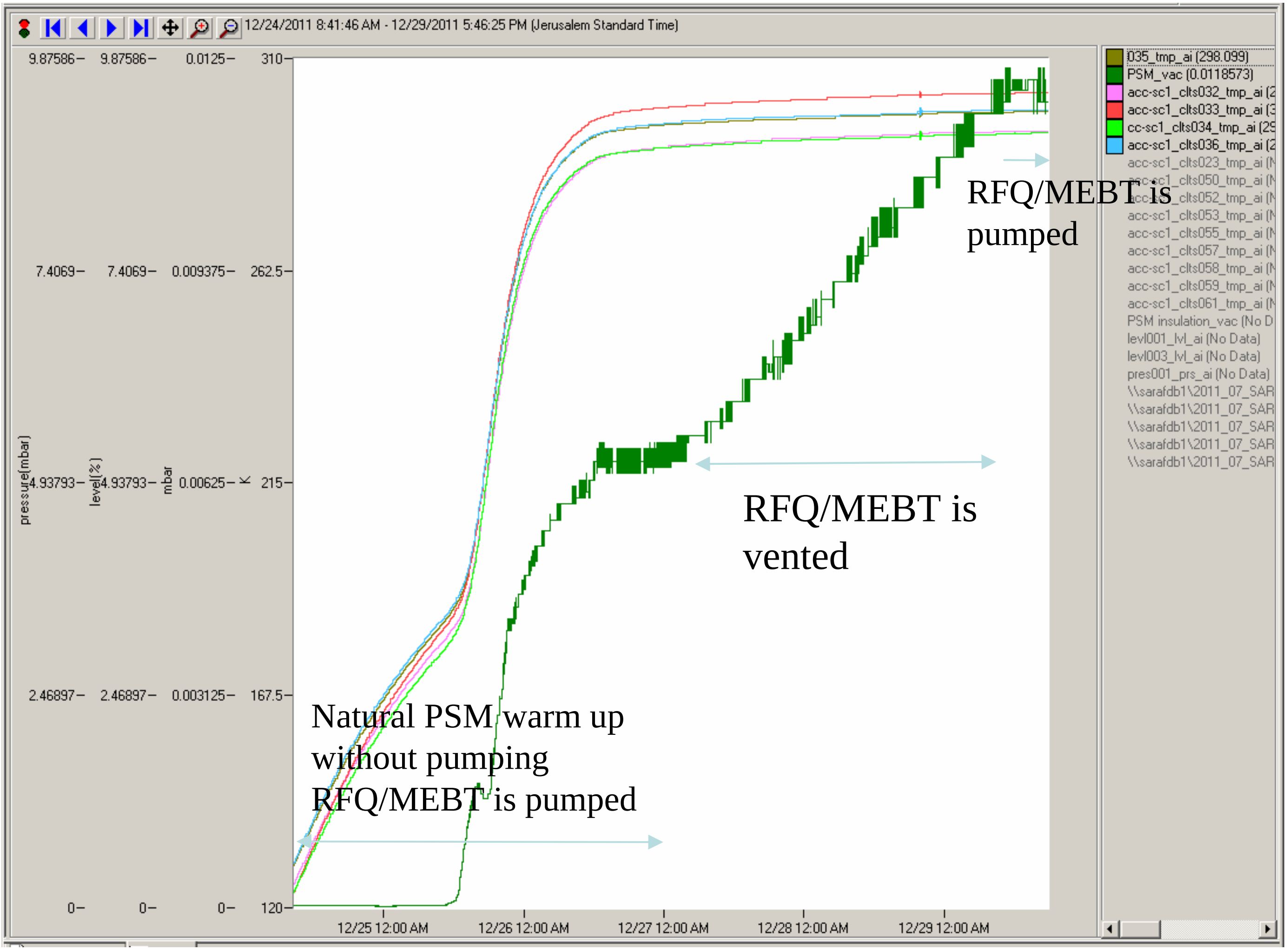
Locher G. L., Biological effects and therapeutic possibilities of neutrons, Am. J. Roentgenol, 36, 1-13, 1936.

Boron Neutron Capture Therapy



Sh. Halfon PhD. Thesis

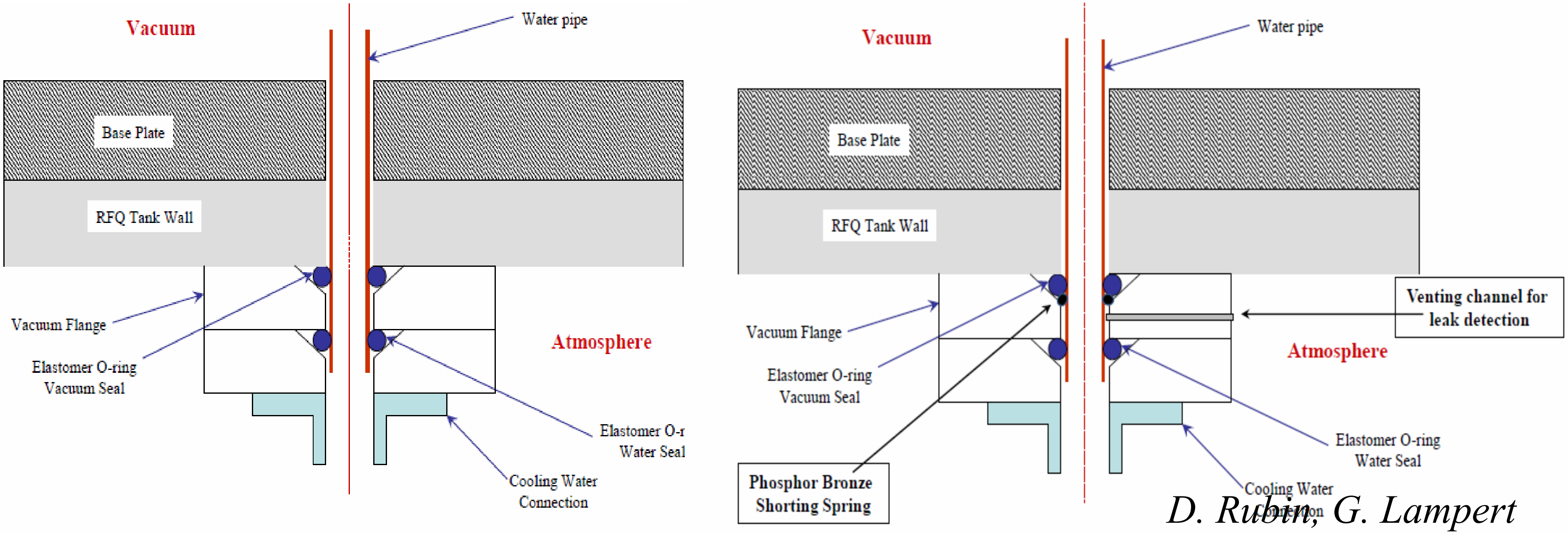
MEBT/PSM valve



Leak rate through the valve is ~ **3 10^{-6}** l mbar/s when RFQ is vented

As the consequence RFQ has to be pumped while the PSM is cold

Replacement of vacuum flanges



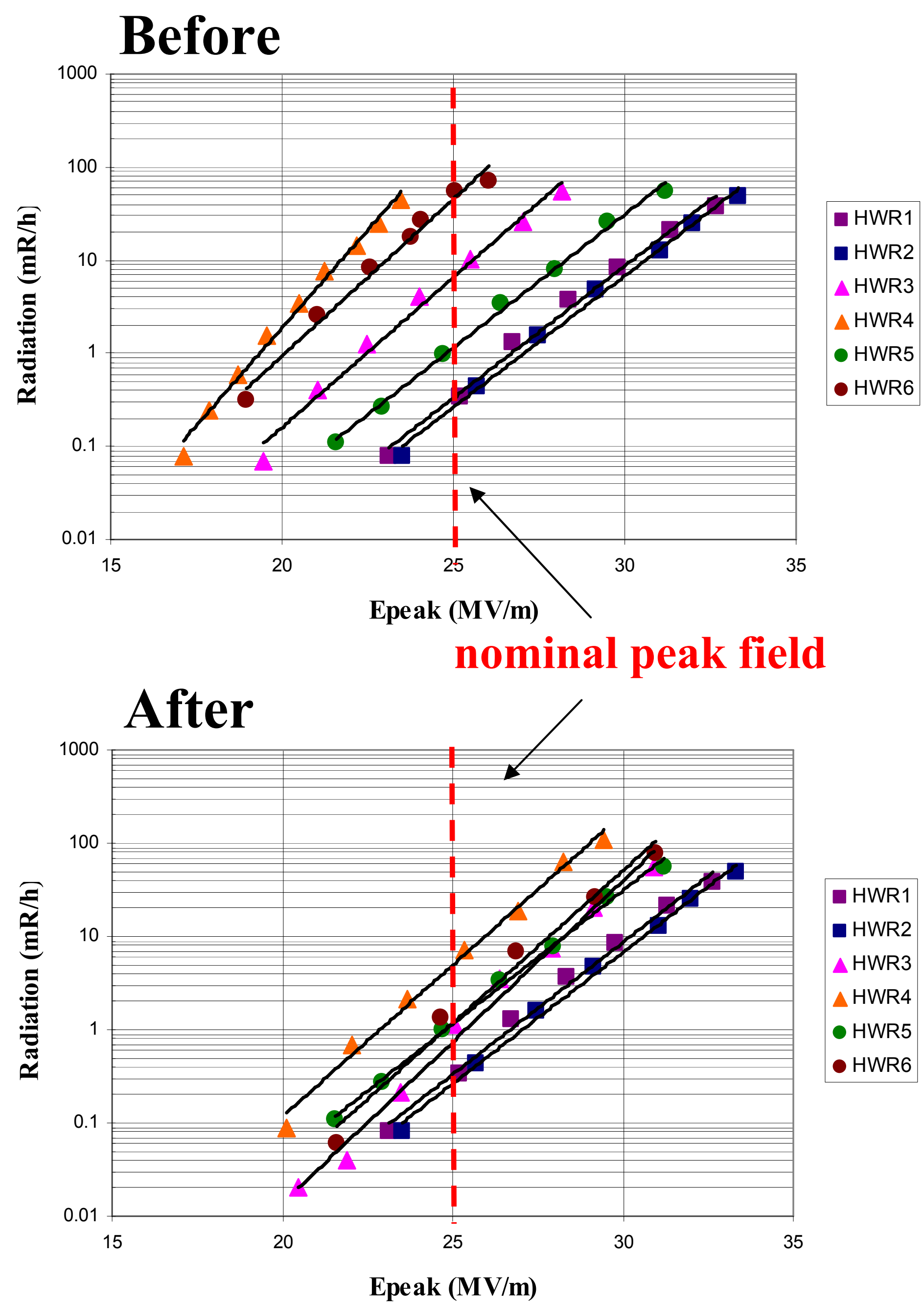
D. Rubin, G. Lampert

He processing

Helium processing :

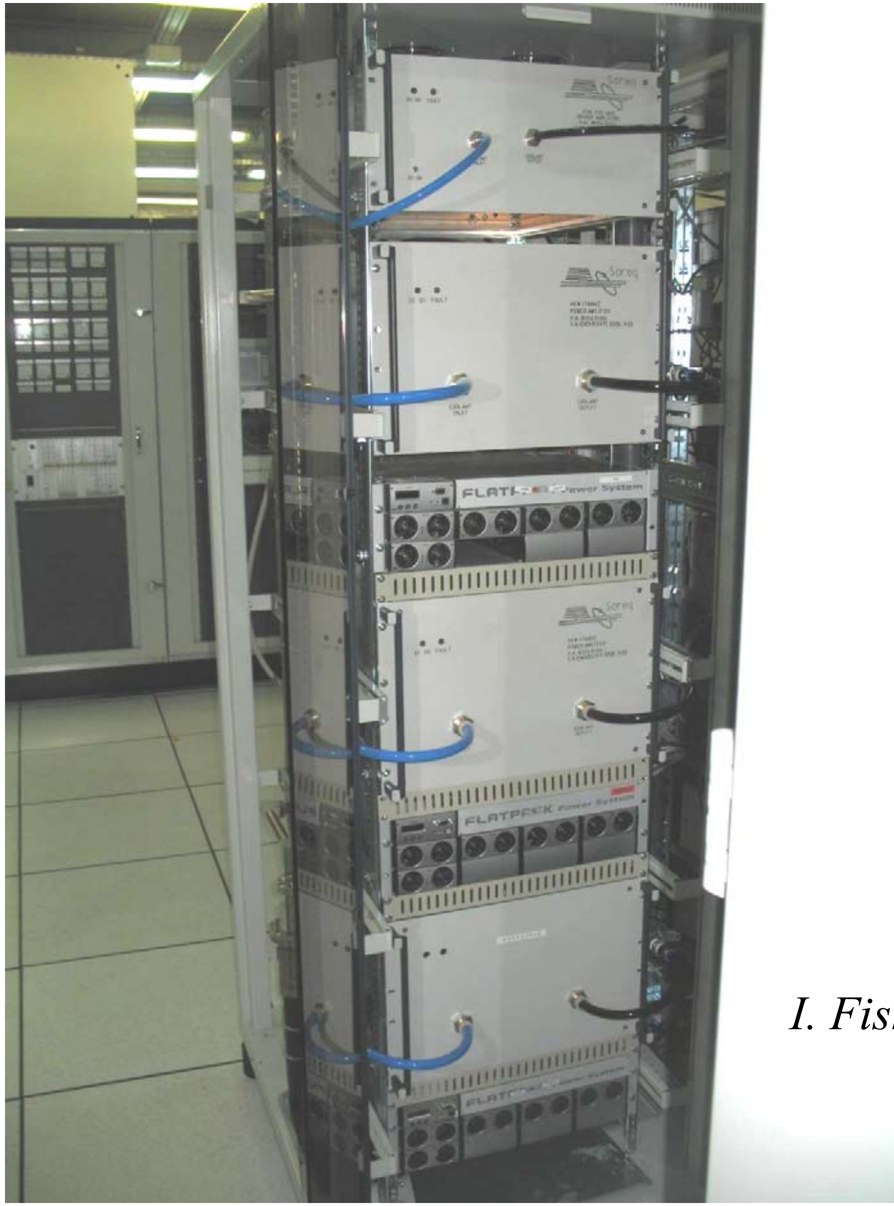
99.9999% purity, 4 10^{-5} mbar

up to 43 MV/m 10% DC



A. Perry et al, SRF2009

4 kW RF power supplies



I. Fishman, Tuesday discussion

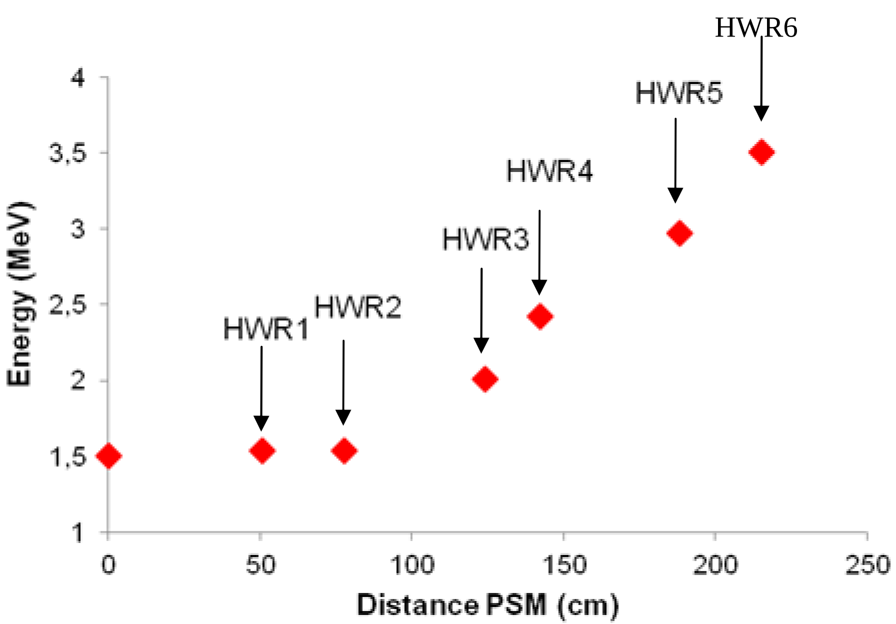
Accelerator tunes

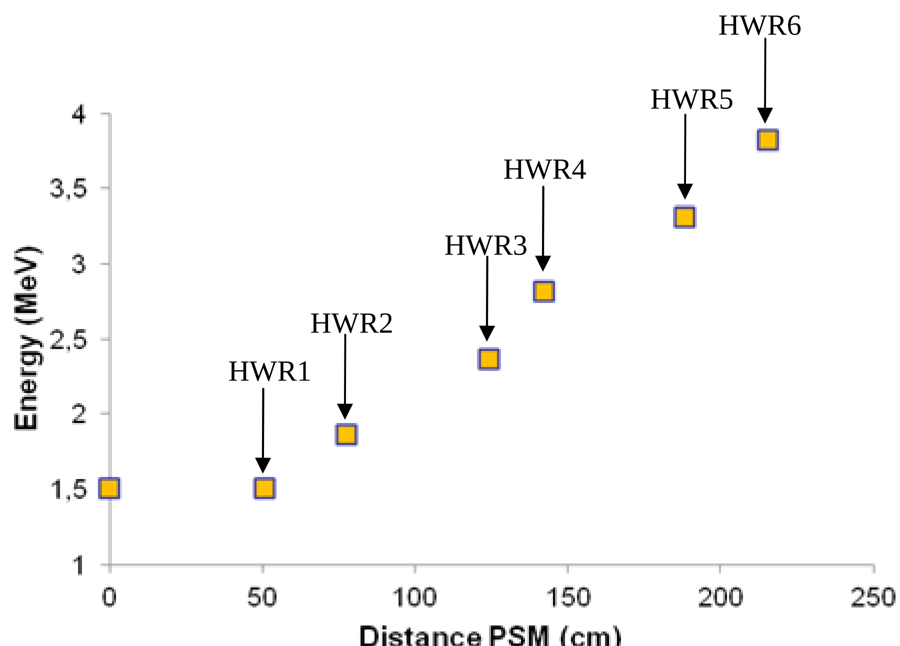
Type 1

Cavity	Acceleration voltage (kV)	Phase (deg)	Energy (MeV)
HWR 1	213	-90	1.536
HWR 2	**0**	**0**	**1.536**
HWR 3	646	-10	2.003
HWR 4	493	-15	2.416
HWR 5	**697**	**-35**	**2.971**
HWR 6	544	-10	3.501

Type 2

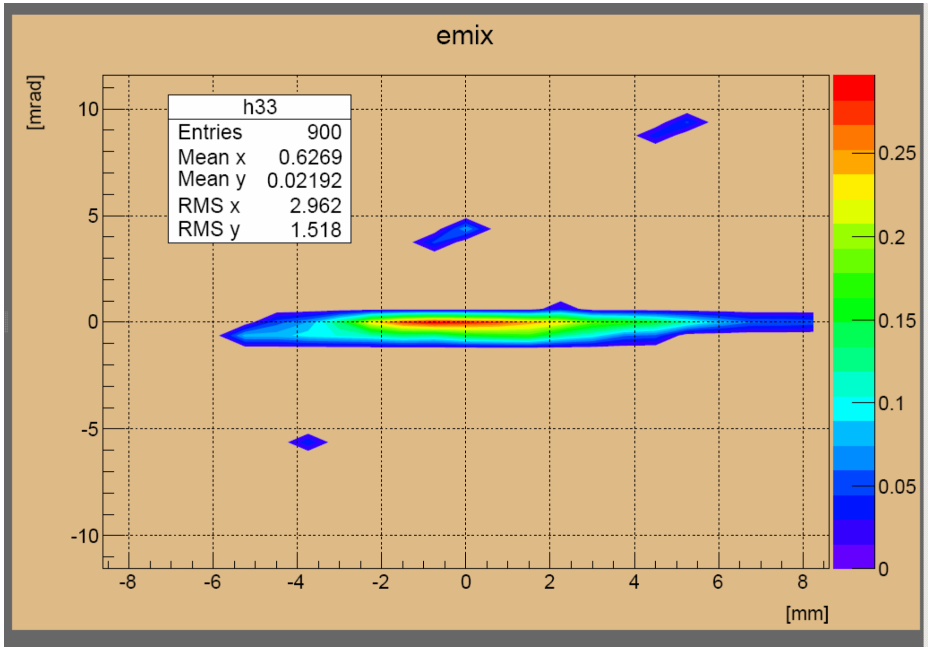
Cavity	Acceleration voltage (kV)	Phase (deg)	Energy (MeV)
HWR 1	212	-95	1.5
HWR 2	**552**	**30**	**1.86**
HWR 3	646	-25	2.36
HWR 4	493	-10	2.81
HWR 5	**552**	**-10**	**3.31**
HWR 6	544	-20	3.82

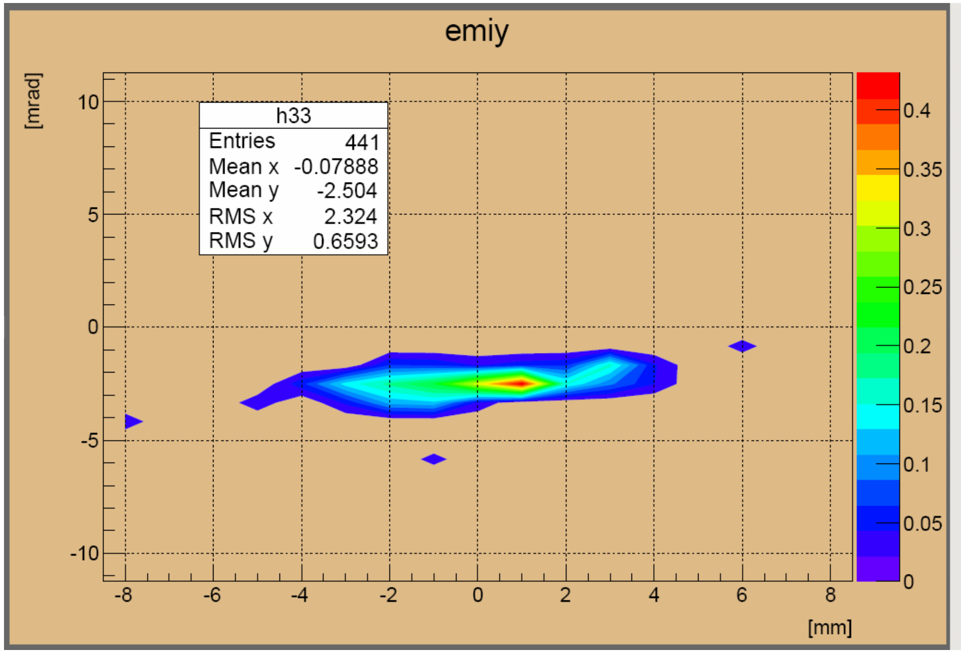




from Arik Kreisel

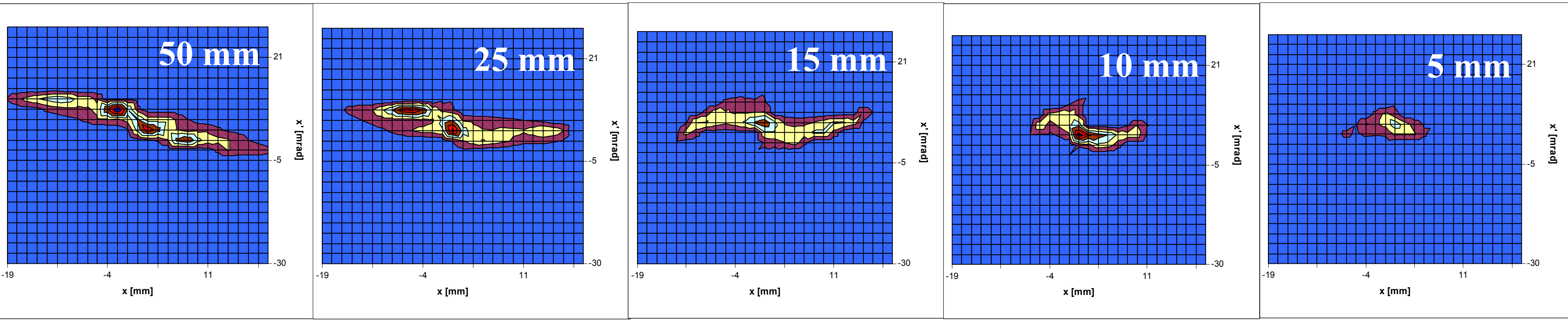
Emittance 3.7 MeV

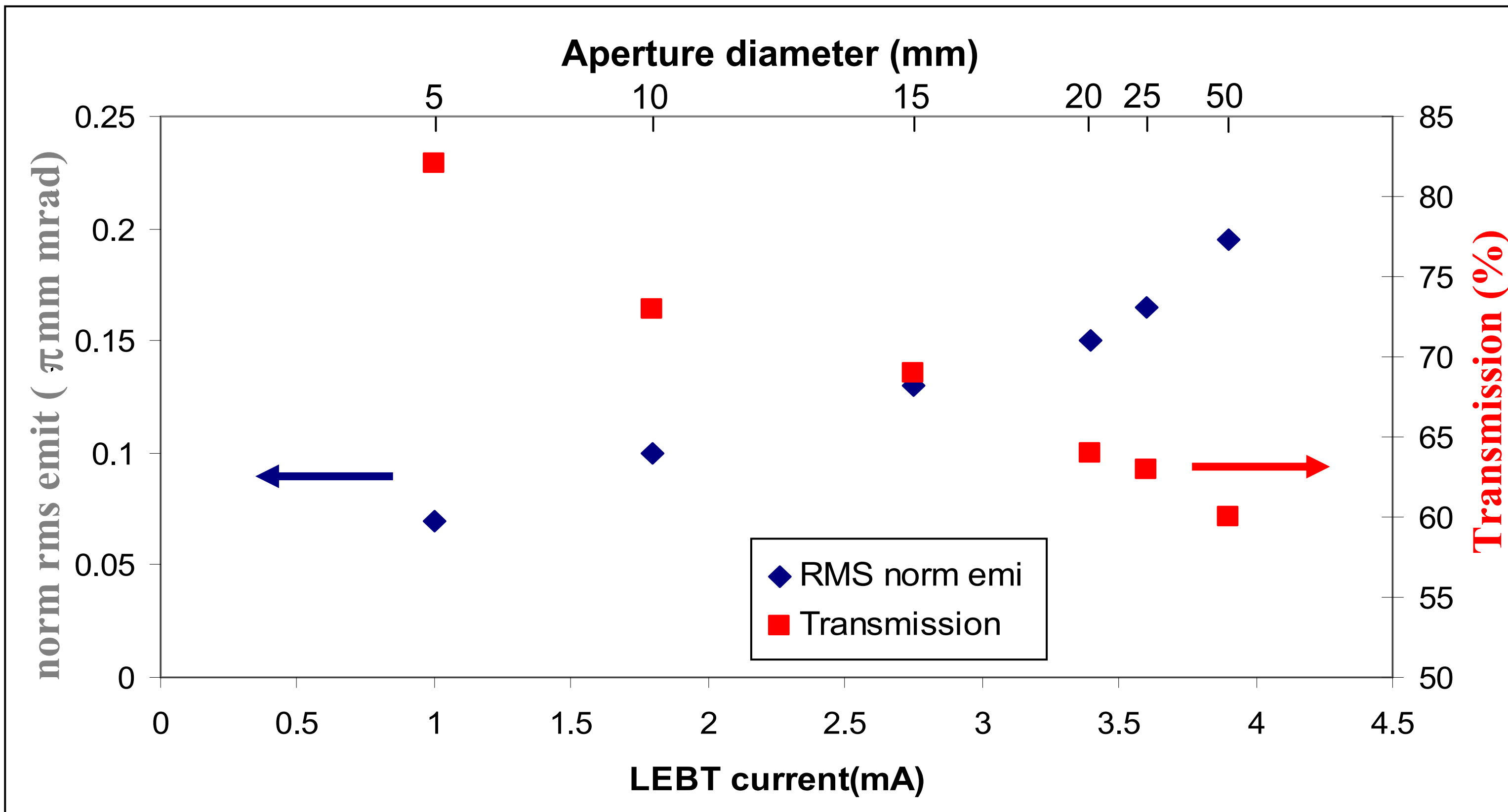




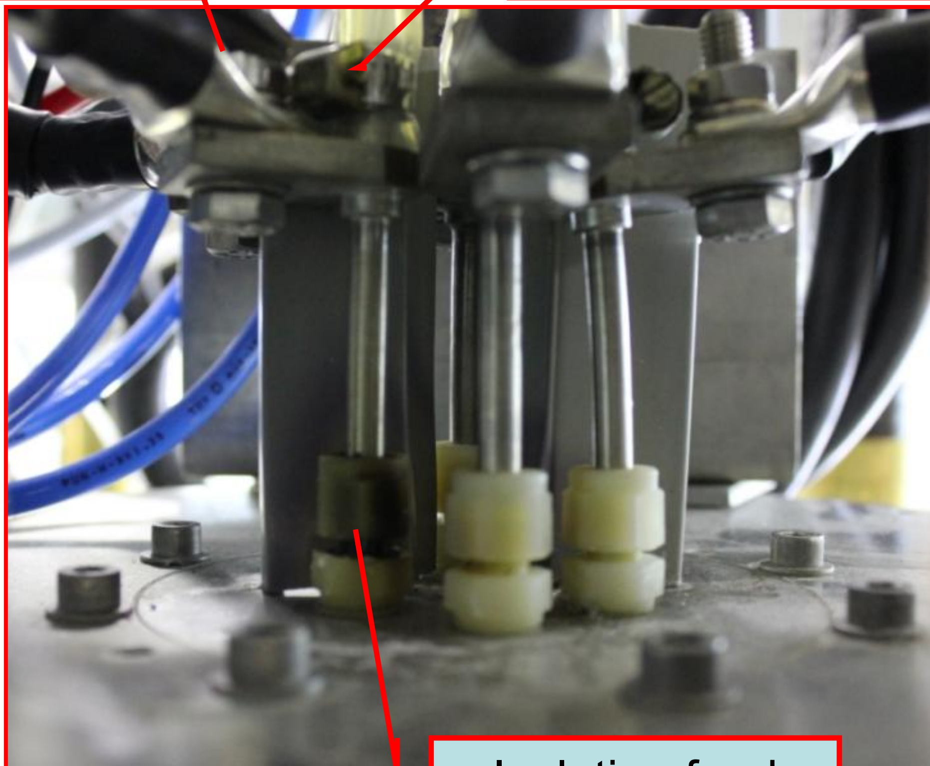
LEBT aperture

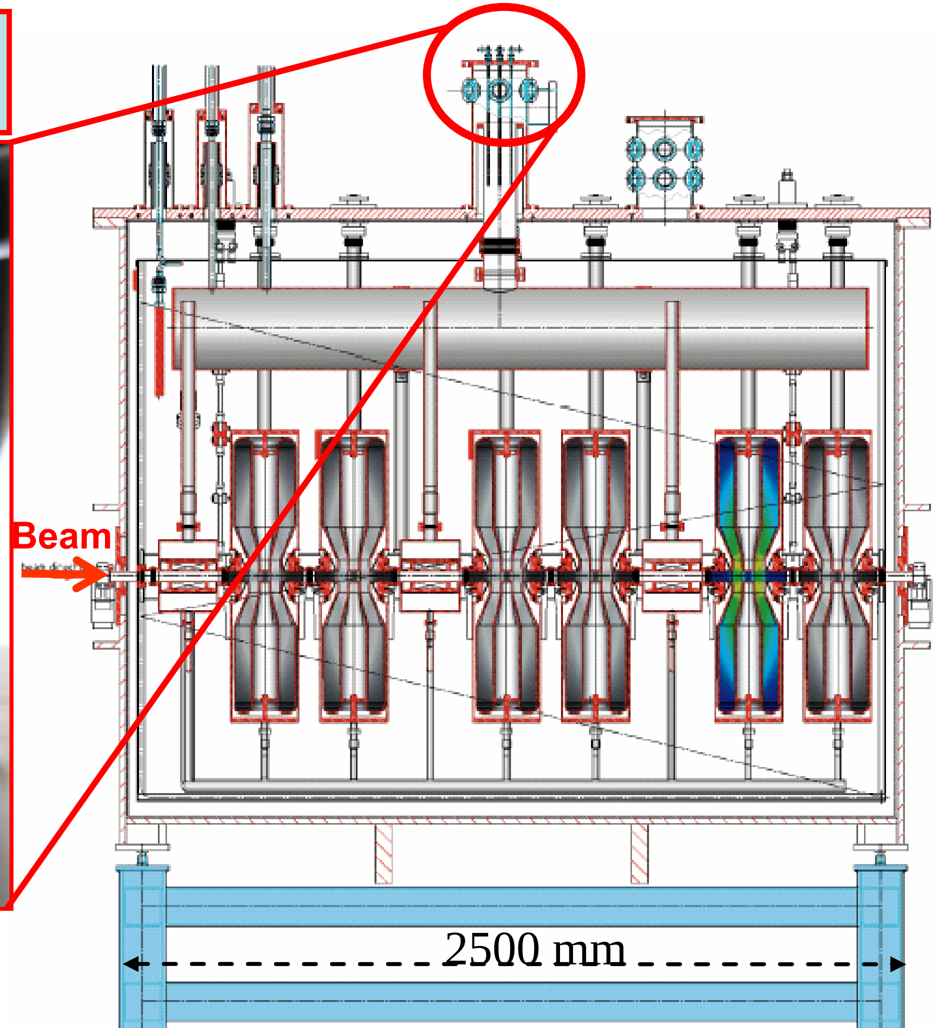
Manipulating beam size, current and emittance using the LEBT aperture





SC solenoid current lead leak

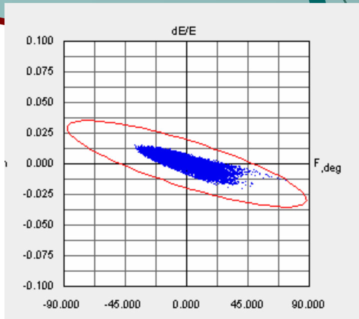




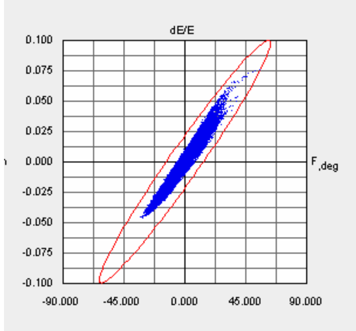
M. Pekeler, LINAC 2006

Longitudinal phase space

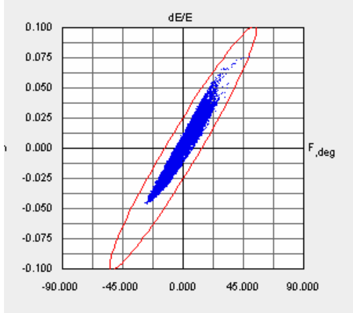
Beam Dynamics



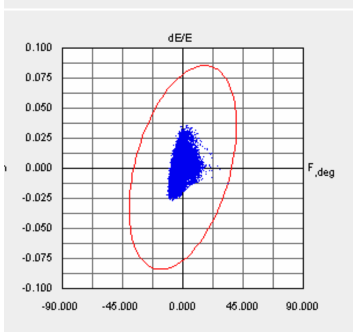
HWR1 entrance: First cavity is used as a buncher.



HWR1 exit: Forward protons are now less energetic.



HWR2 entrerance: Only 5 cm drift from HWR1. Forward protons are still less energetic.



HWR2 exit: In order to accelerate without increasing ΔE, it is necessary to work at a positive phase in HWR2.

Protons 0.2 mA

Component	Acceleration voltage kV	Phase	Energy MeV
HWR 1	229	-90	1.52
HWR 2	459	30	1.81
HWR 3	459	-30	2.14
HWR 4	722	-20	2.76
HWR 5	833	-20	3.52
HWR 6	425	-10	3.93

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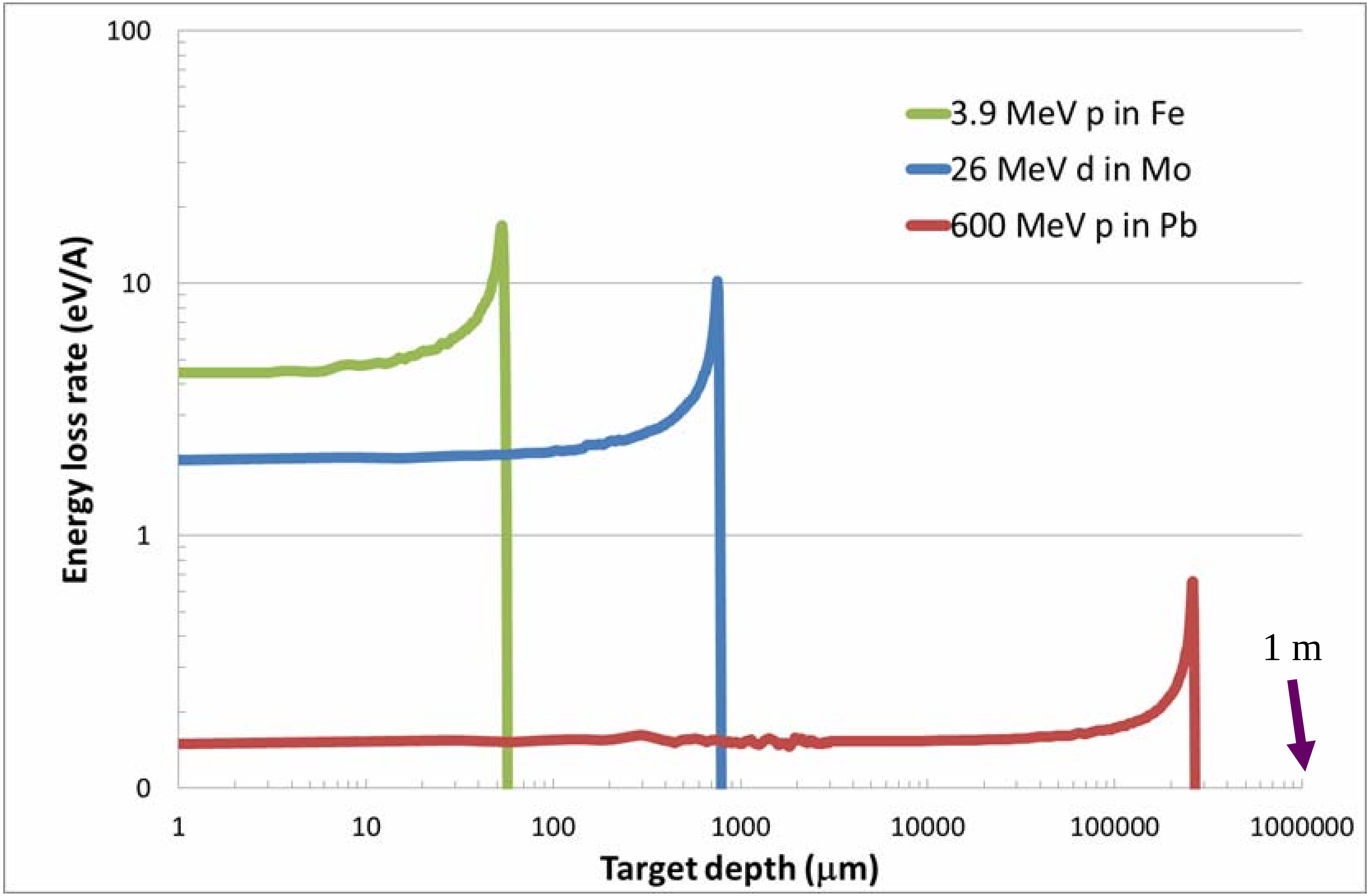
Projectile in target power density



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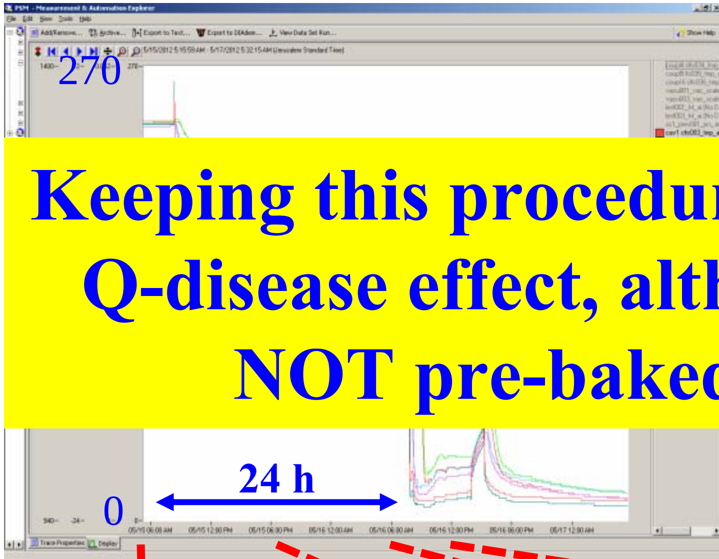
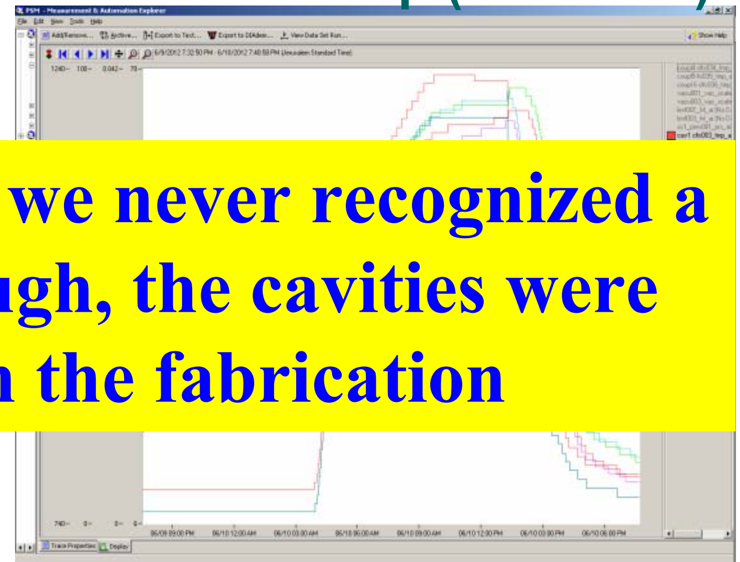
PSM cooling process

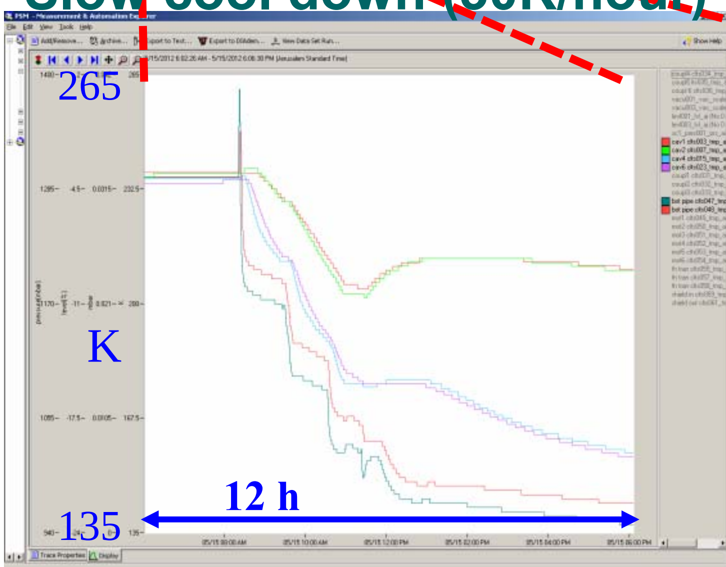


Natural warm up (10K/hour)

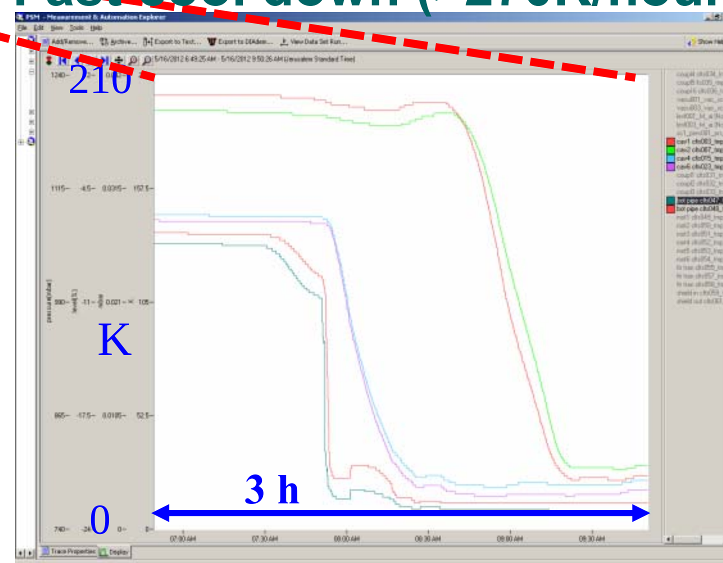


Keeping this procedure, we never recognized a Q-disease effect, although, the cavities were NOT pre-baked in the fabrication

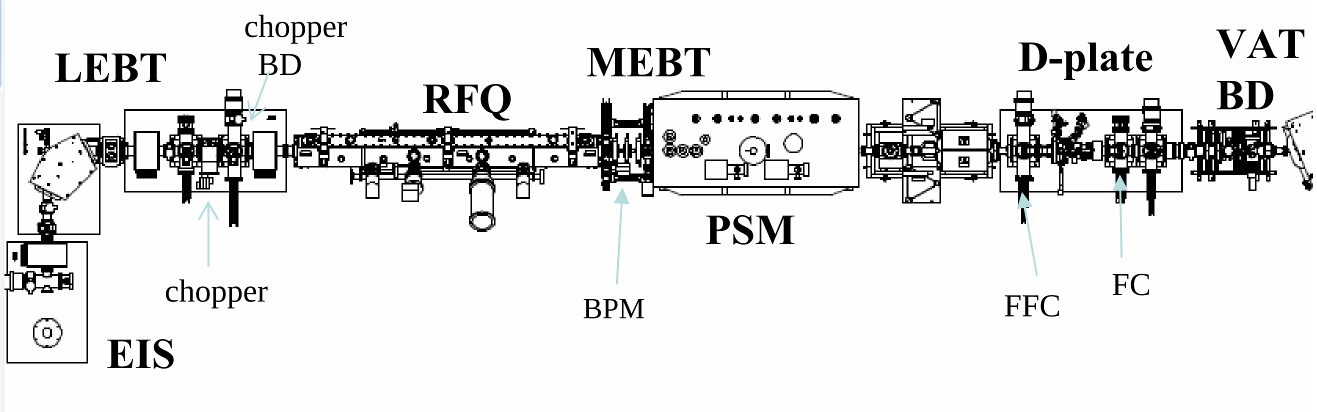
Slow cool down (30K/hour)

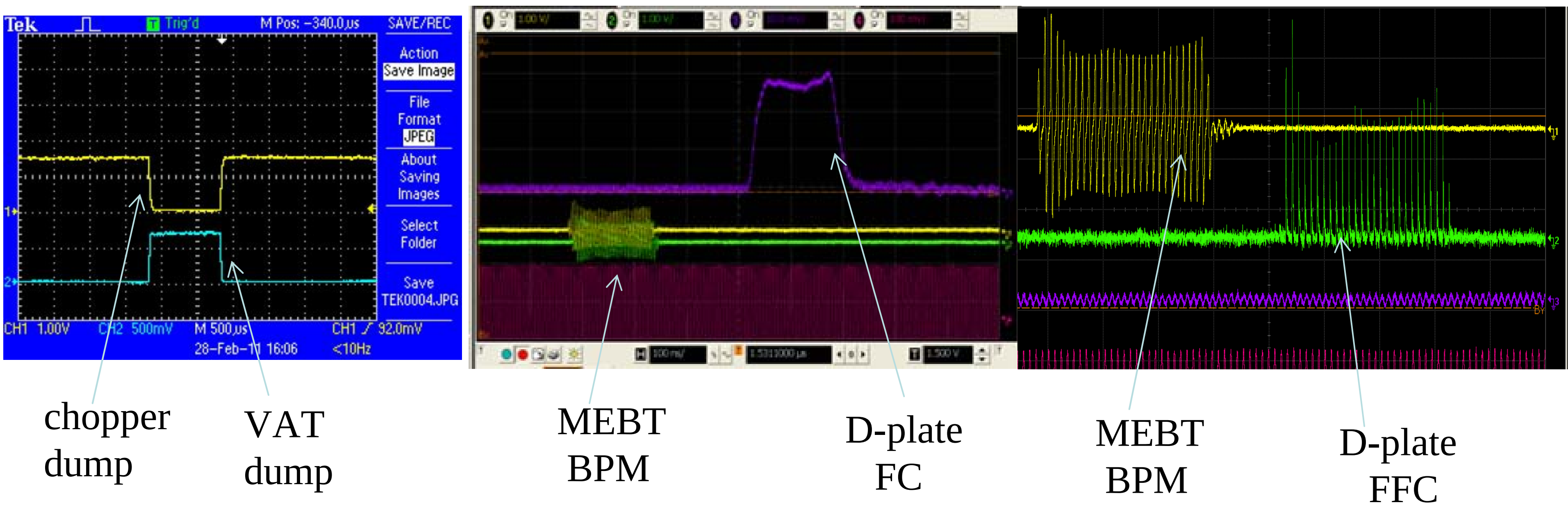


Fast cool down (>270K/hour)



Acceleration of chopped beam

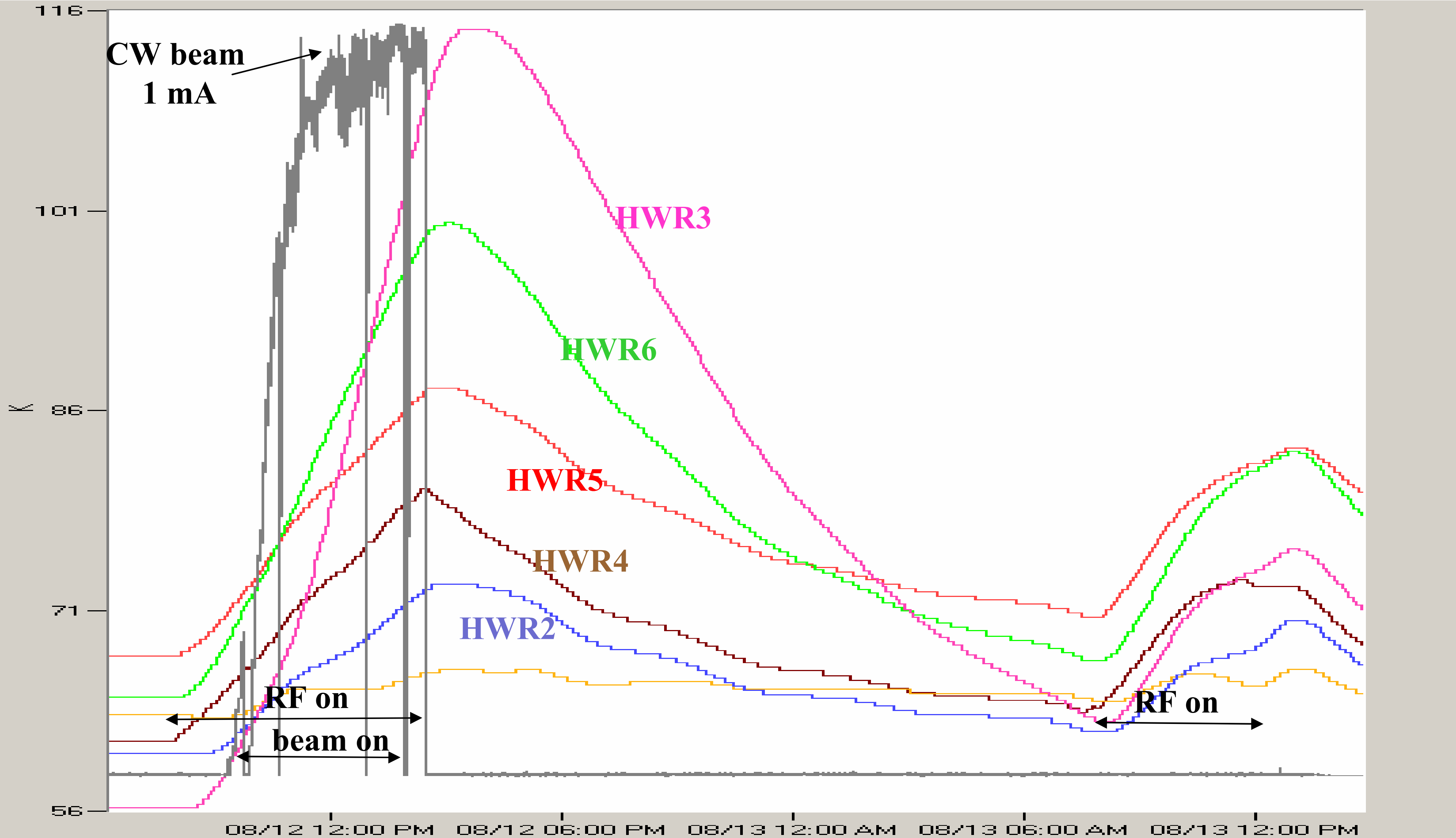




The next steps:

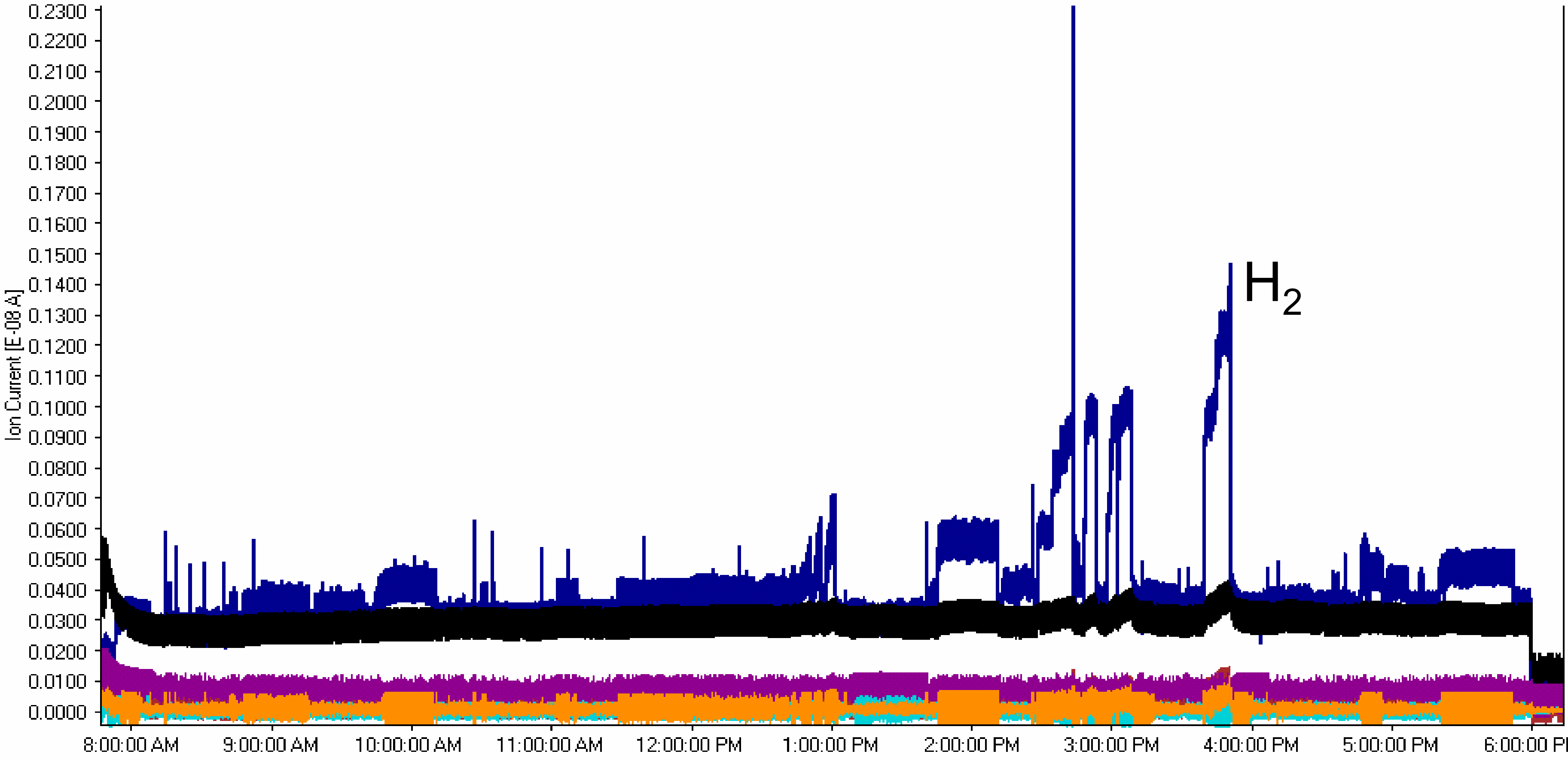
- **Integration of the chopper into machine safety**
- **Beam studies**
- **Routing use**

Coupler warming up, dependence on beam current



Warming rate changes while operating intense current (especially coupler #3)
Understanding of the coupler warming and improvement in their performance is in progress

MEBT beam blocker/collimator



During beam operation the collimator cuts the tails of the beam (~few %) which improves the stability of the cavity operation). The scrapped protons diffuse from collimator surface which leads to increase of the hydrogen partial pressure during beam operation. It is likely that the most of that hydrogen molecules end up on the cryo surfaces at the entrance of the module.

We have to improve pumping speed in MEBT area