Soreq

SARAF phase-I beam operation status

Arik Kreisel

September 2014

LINAC14

Outline

- Introduction
- Beam operation
- Problems and solutions (LINAC12 - LINAC14)
  - From pilot beam to full intensity beam
  - Operating the RFQ with a high duty cycle deuteron beam
  - Super conducting cavities
  - Beam dump
  - High power targets
- Physics at SARAF Phase-I
  - Example: $^{nat}Cu(d,x)$ cross section

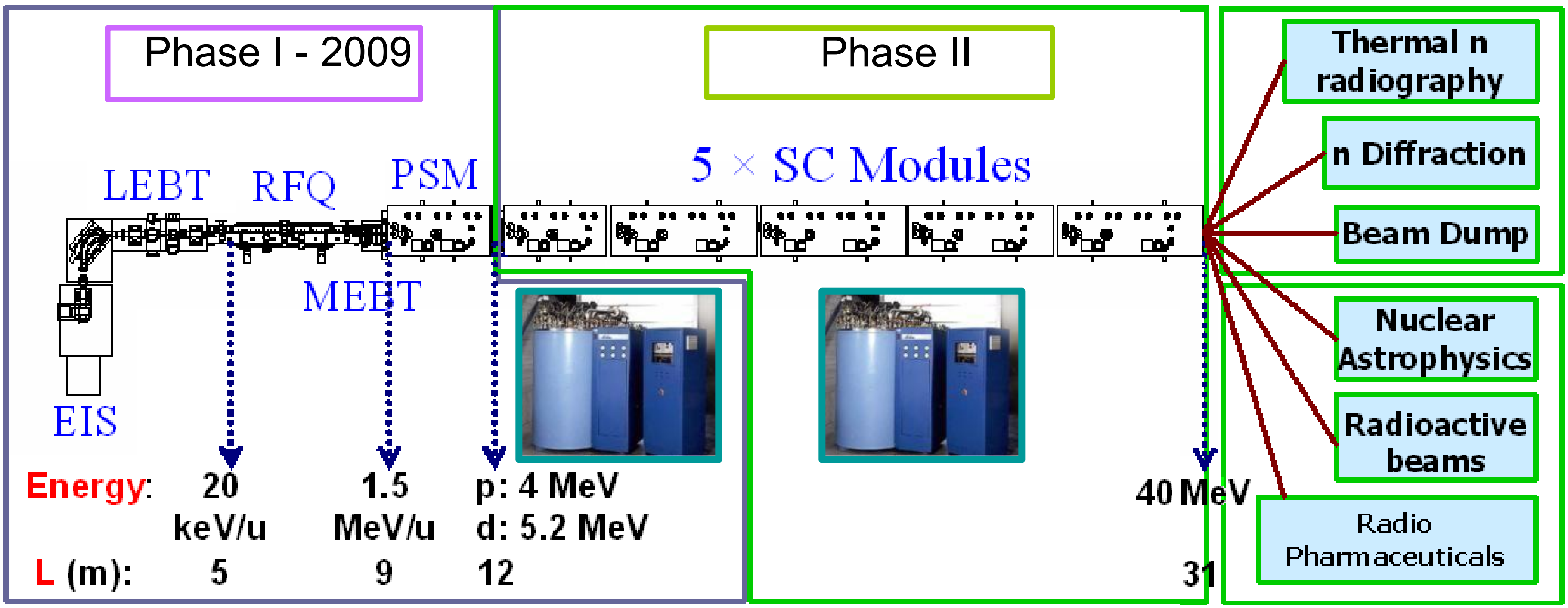
SARAF – Soreq Applied Research Accelerator Facility

- To modernize the source of neutrons at Soreq and extend neutron based research and applications.
- To develop and produce radioisotopes for bio-medical applications.
- To enlarge the experimental nuclear science infrastructure and promote the research in Israel.

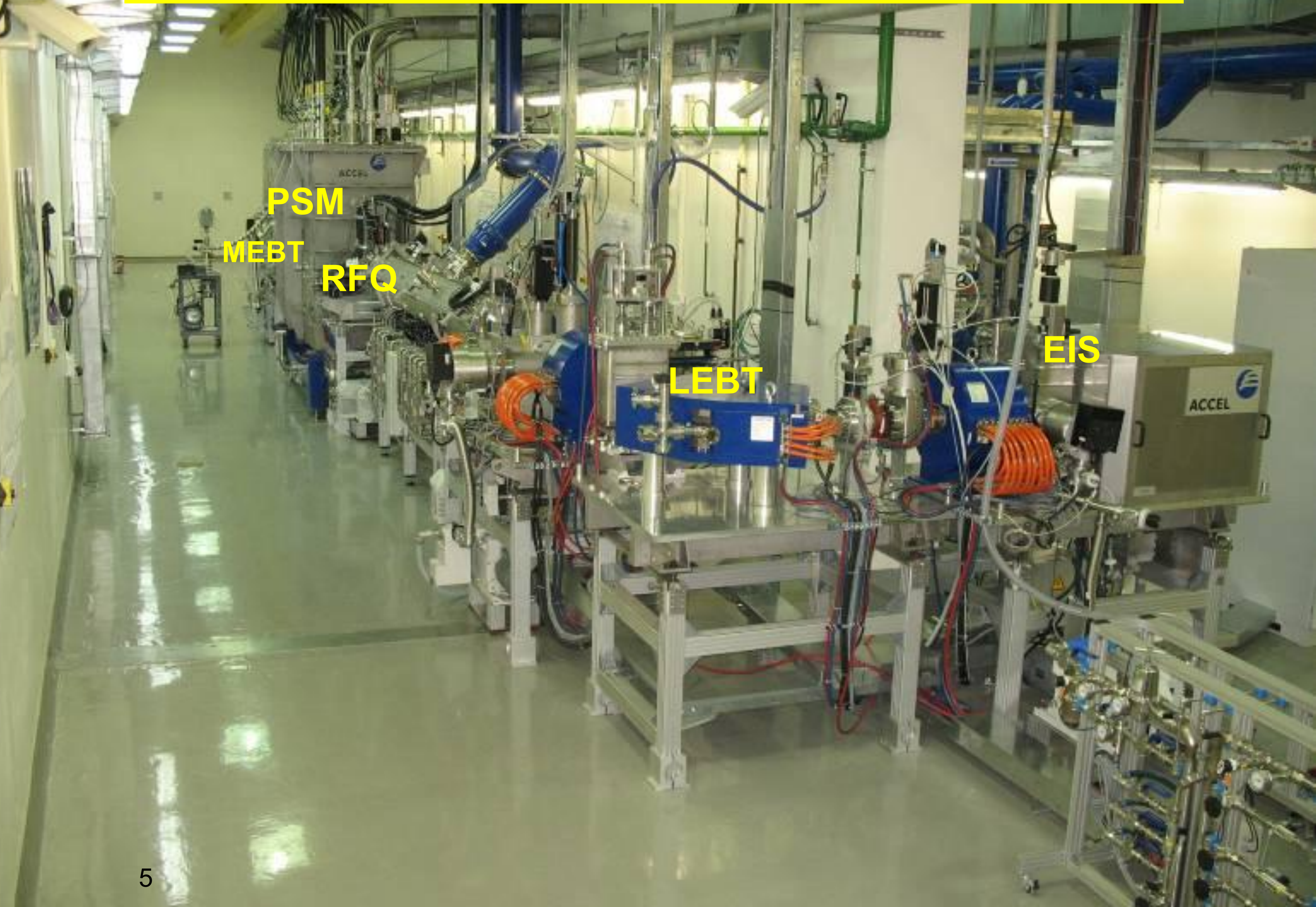
SARAF Accelerator Complex

Parameter	Value	Comment
Ion Species	Protons/Deuterons	M/q ≤ 2
Energy Range	5 – 40 MeV	Variable energy
Current Range	0.04 – 5 mA	CW (and pulsed)
Operation	6000 hours/year	
Reliability	90%	
Maintenance	Hands-On	Very low beam loss

176 MHz



SARAF Phase I – Upstream View



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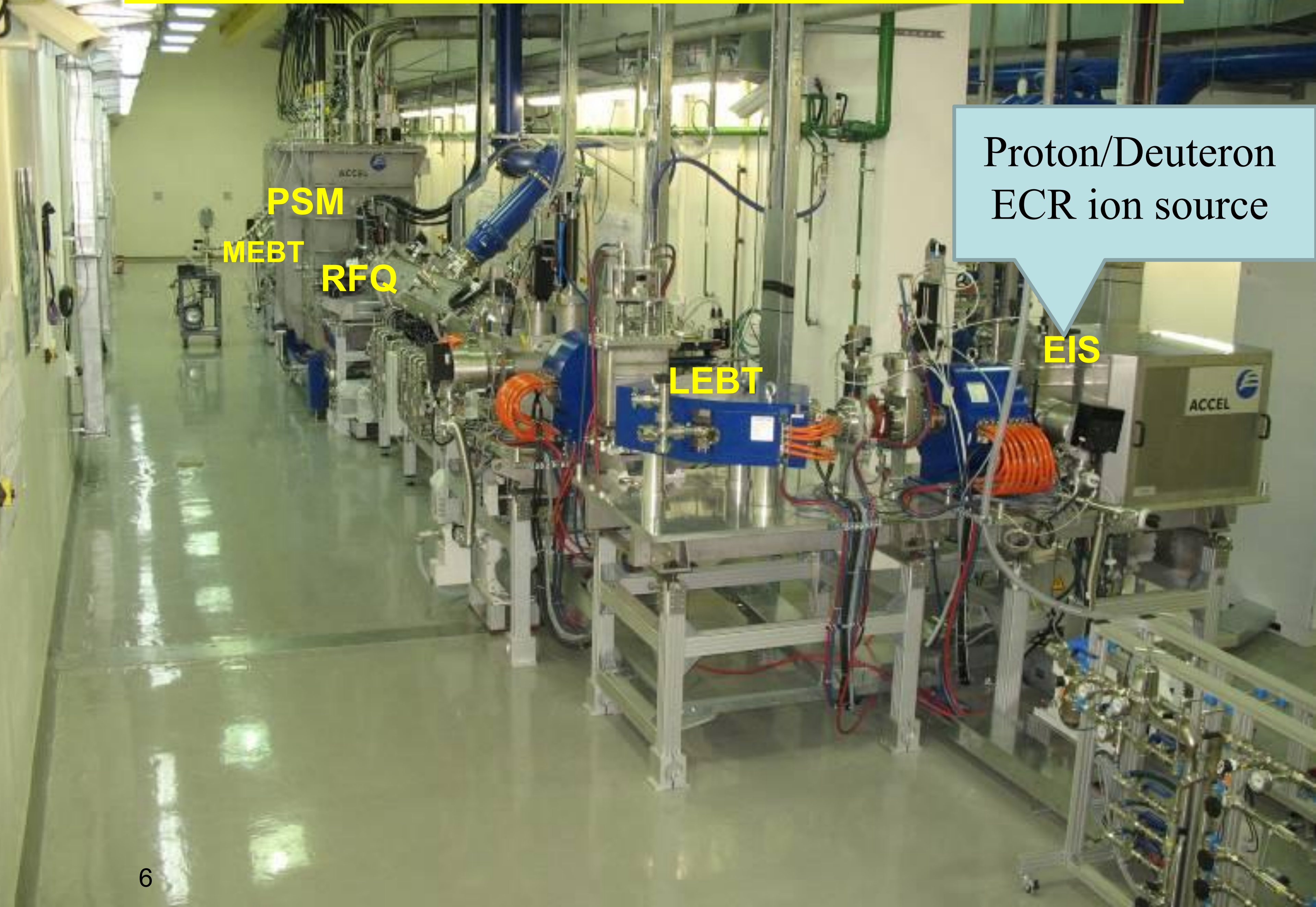

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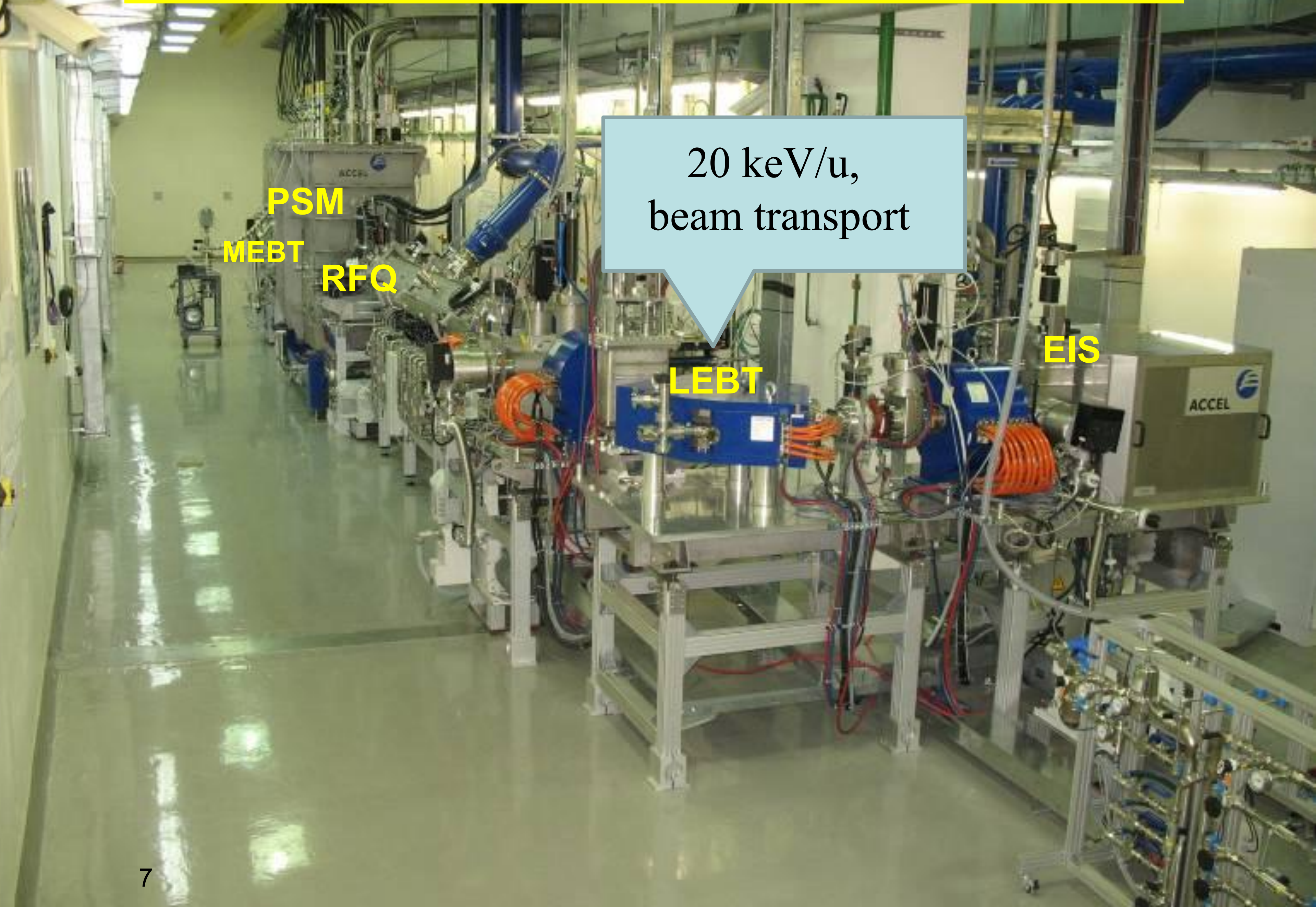

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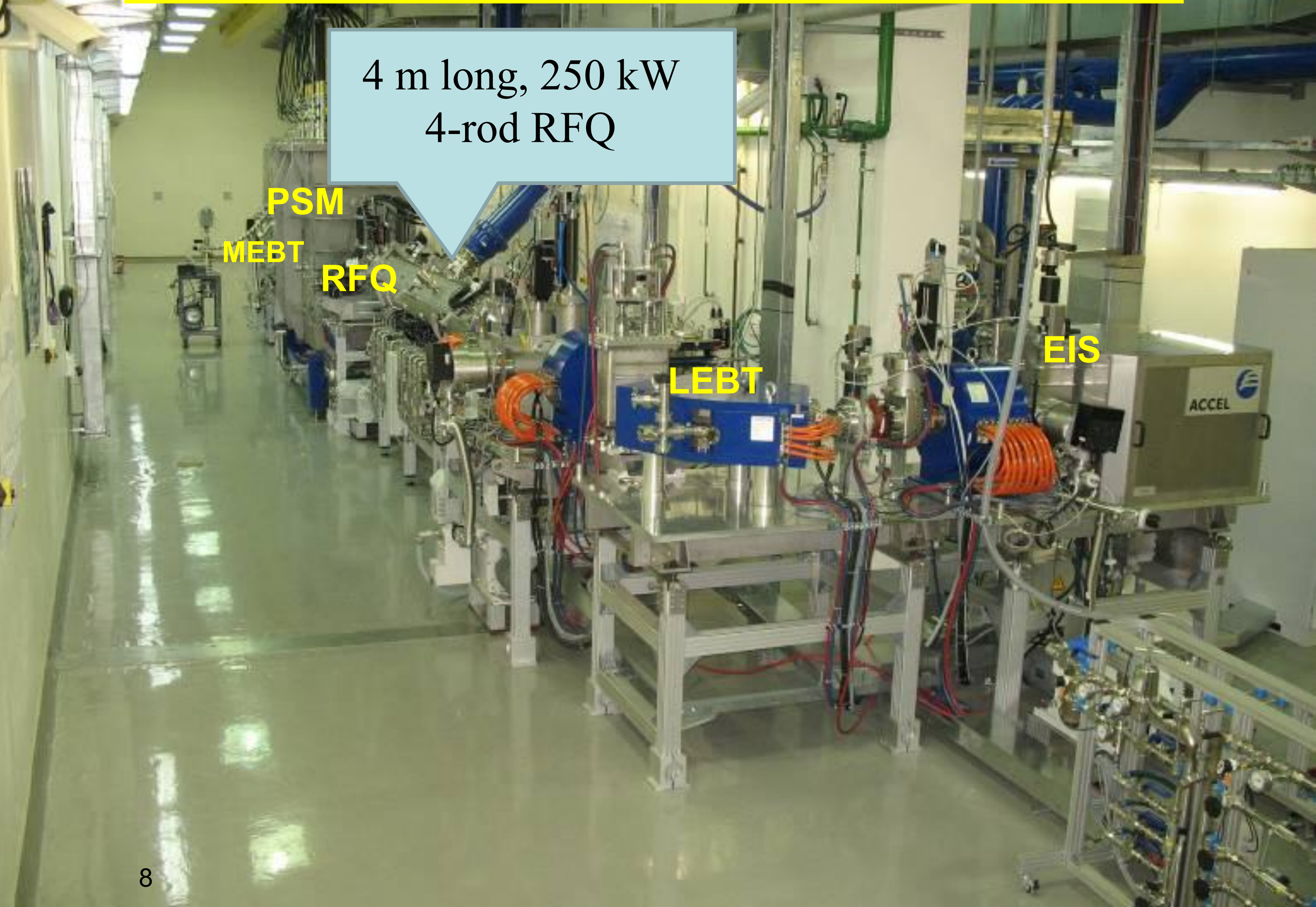

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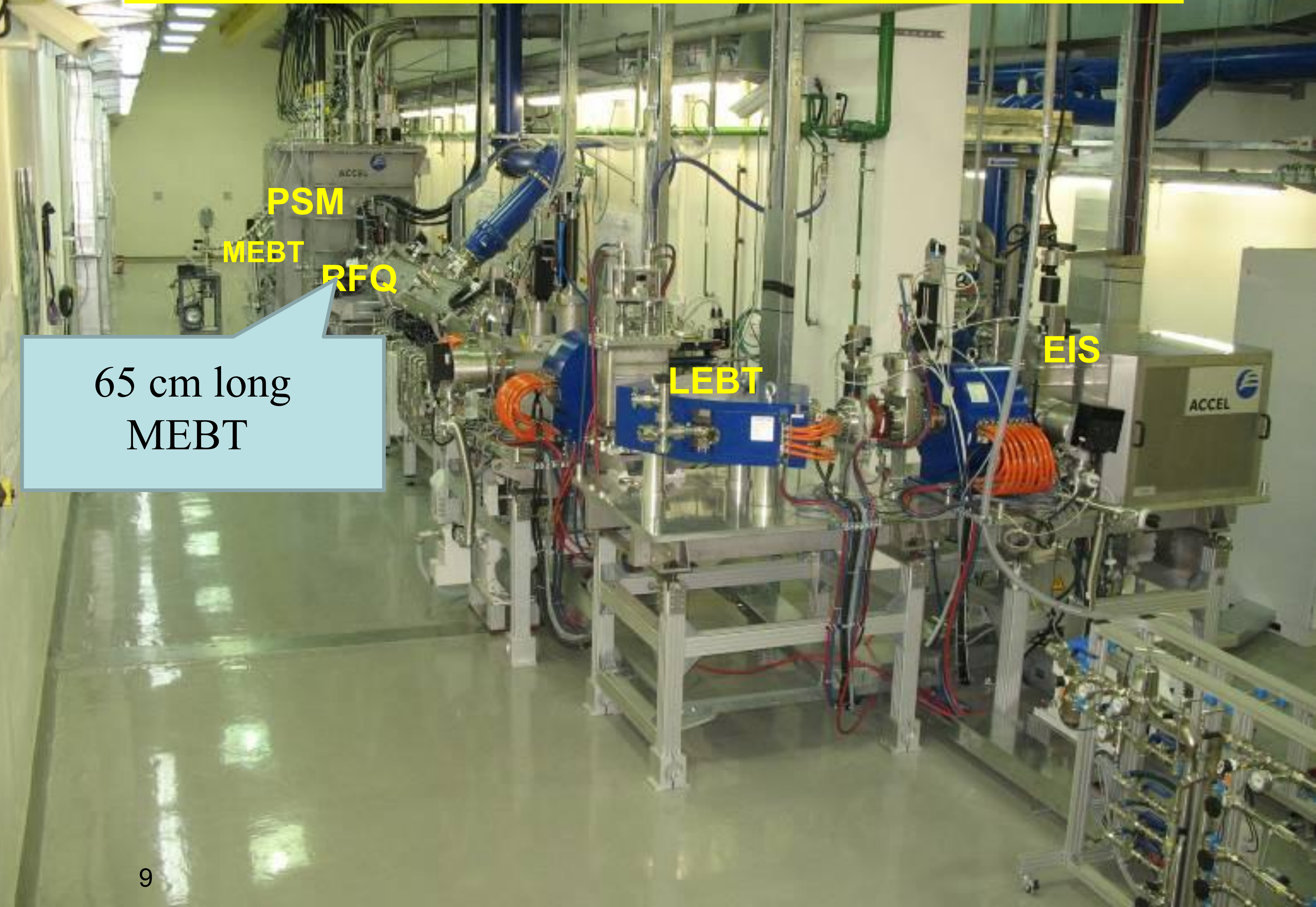
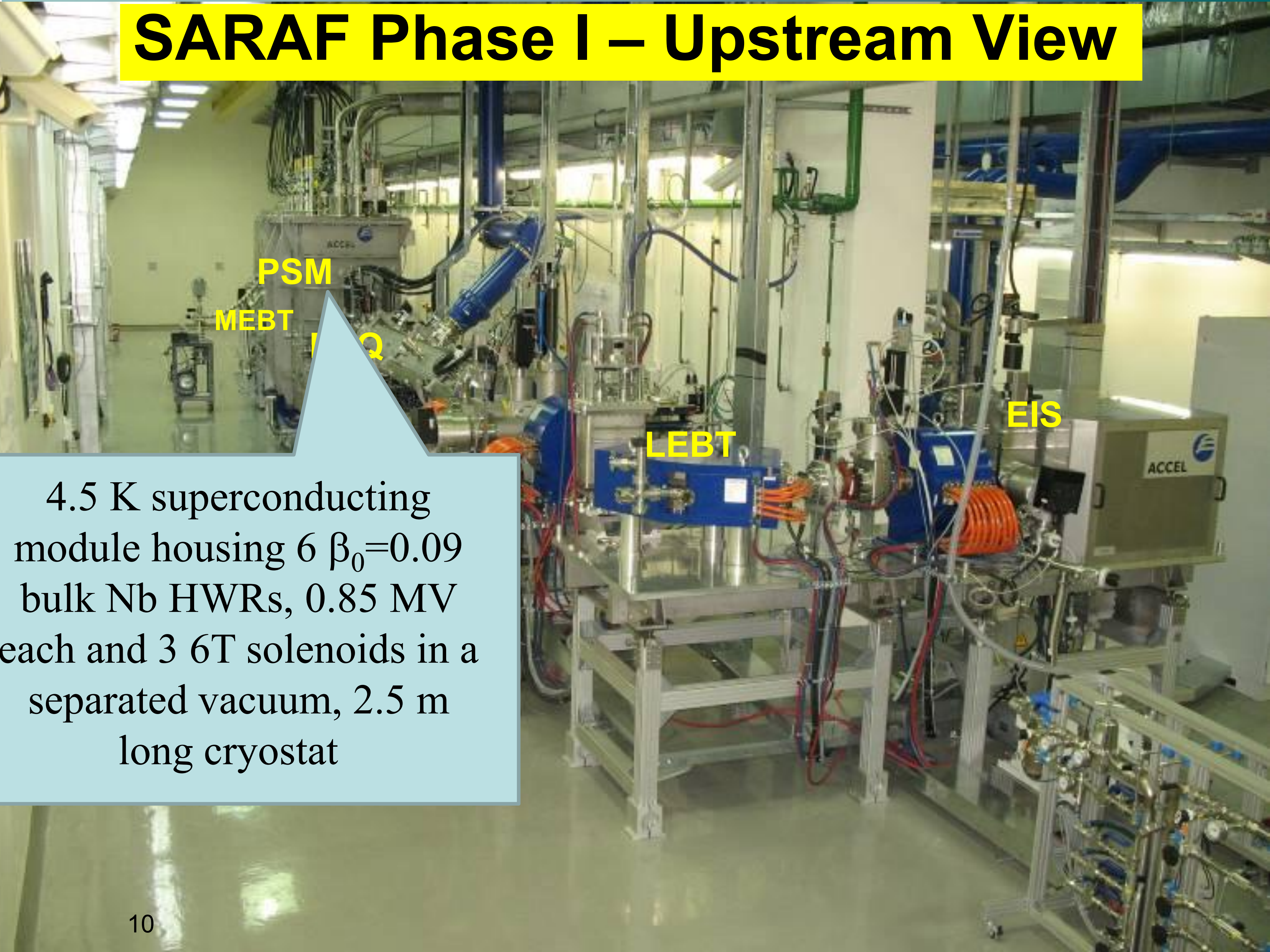


65 cm long MEBT

SARAF Phase I – Upstream View



4.5 K superconducting module housing 6 β_0=0.09 bulk Nb HWRs, 0.85 MV each and 3 6T solenoids in a separated vacuum, 2.5 m long cryostat

2014 Beam Operation

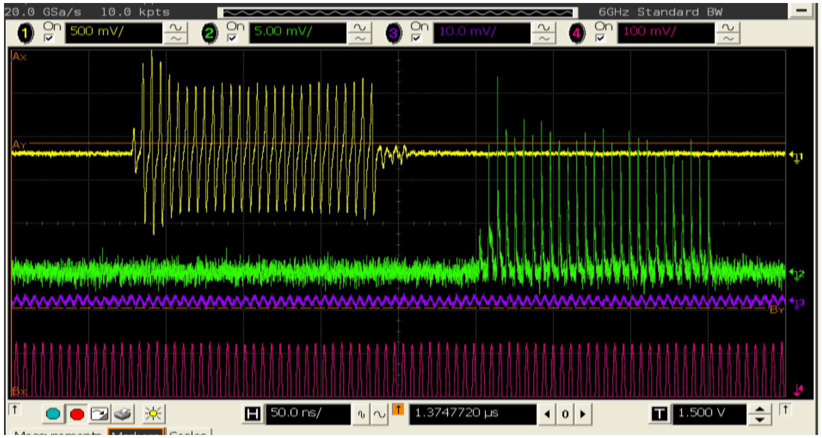
ion	E (MeV)	I (mA)	DC (%)	time (h)	Comments
p	3.6	1.6	100	1	pin beam dump test
p	2.0	2.1	100	4	max. current test
p	1.92	1.5	100	10	LiLiT experiments
p	3.7	0.3	100	50	foil target tests
p	4.0	0.5	160 ns 500 Hz	2	LiLiT 2 MeV neutrons
d	5.6	0.01	1	20	cross section meas.

SARAF phase I - Is a low energy high current operating accelerator

From pilot beam to intense beam

Challenge – At present beam intensity ramping is done by manipulation of LEBT parameters and beam duty cycle is done by pulsing the ion source. Measuring of CW beam profiles with a non-destructive residual gas profiler monitor showed that such a methods lead to variation in the beam optics.

Solution – A beam chopper was introduced at the LEBT and incorporated into the machine safety system. It still needs to be verified that working with the EIS in CW mode and ramping up beam power by changing the chopper duty cycle will lead to a more stable beam and smaller changes in beam optics.



Minimum chopper pulse length of 160 ns as measured by BPM and a FFC

The deflecting electrodes inside the beam line

SPIRAL 2 chopper design: A. Caruso et al. LINAC 2008.
Residual Gas Monitor test: E. Gueroult et al. JINST 2013.

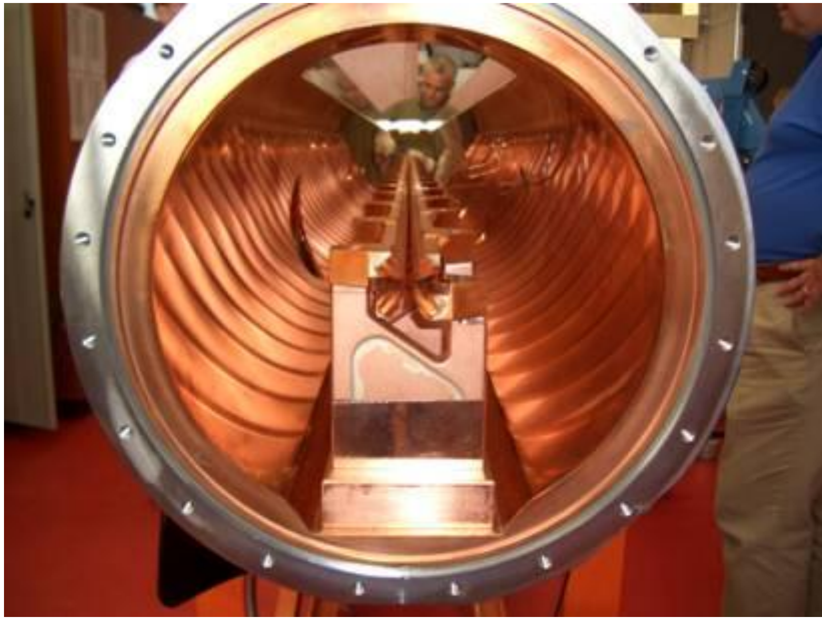
Operating the RFQ with a CW deuteron beam

Challenge – Operating the RFQ in the range of 250-260 kW (65 kV voltage), required for CW deuteron operation.

176 MHz, 65 kW/m, 1.5 MeV/u

Possible solutions –

1. Improve heat removal, vacuum, RF coupling and proceed with aggressive conditioning to enable operation of intense deuteron beam at Phase I;
2. Modify rod structure toward lower energy (1.3 MeV/u 200 kW) with present RFQ; [A. Shor SNRC report #4242 (2013)].

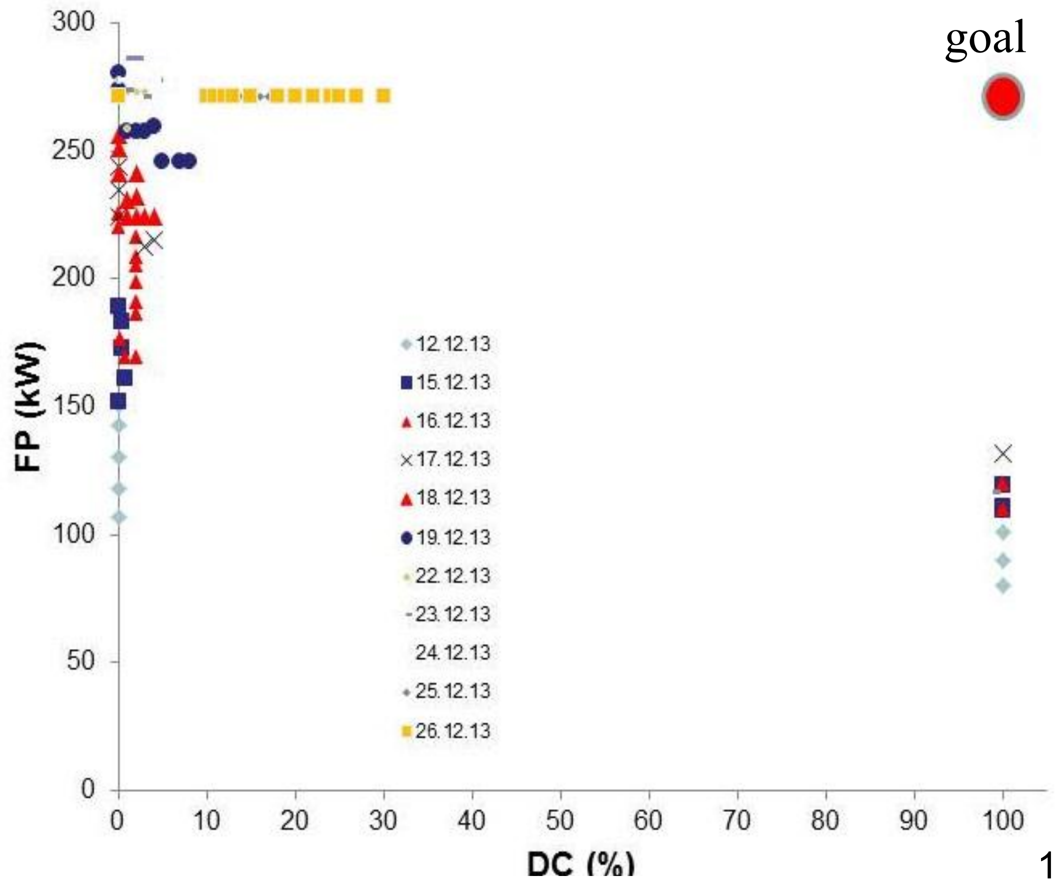


[P. Fischer et al., EPAC06]

RFQ conditioning campaign was started to establish the status of the current RFQ and the feasibility to operate it as is with 250 kW or with modified rods at 180-200 kW.

December 2013 RFQ conditioning campaign

- Several improvements were performed in order to bring the RFQ to its specified power [L. Weissman et al. JINST T05004 (2014)], however:
- The fact that the RFQ was not operated at the deuterons field for two years resulted in deterioration of its performance
- The rod structure and the coupler ceramics were cleaned and maintenance on the RFQ-RF amplifier was performed before the campaign
- It was still extremely difficult to raise the field up to deuteron operation level. It took a week (50 net hours) to reach the required field value even for the shortest RF pulses.
- After the breakthrough, progress was quite fast, and 30% duty cycle was reached within three days



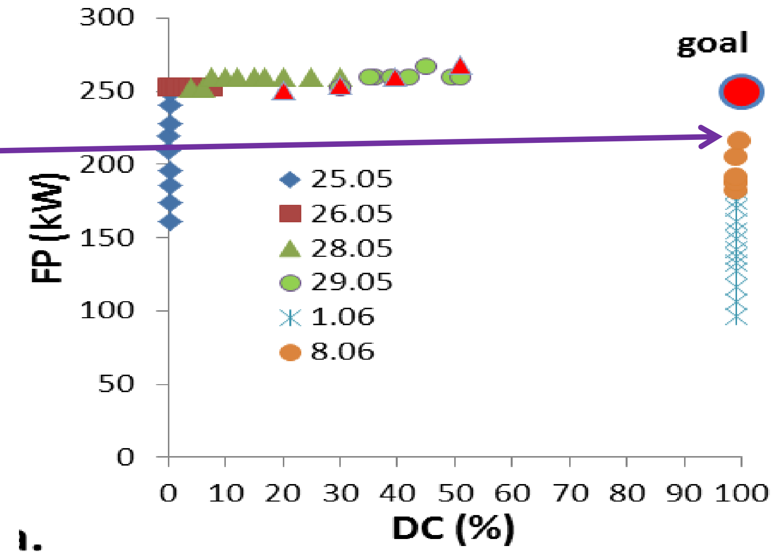
May-June 2014 RFQ conditioning campaign

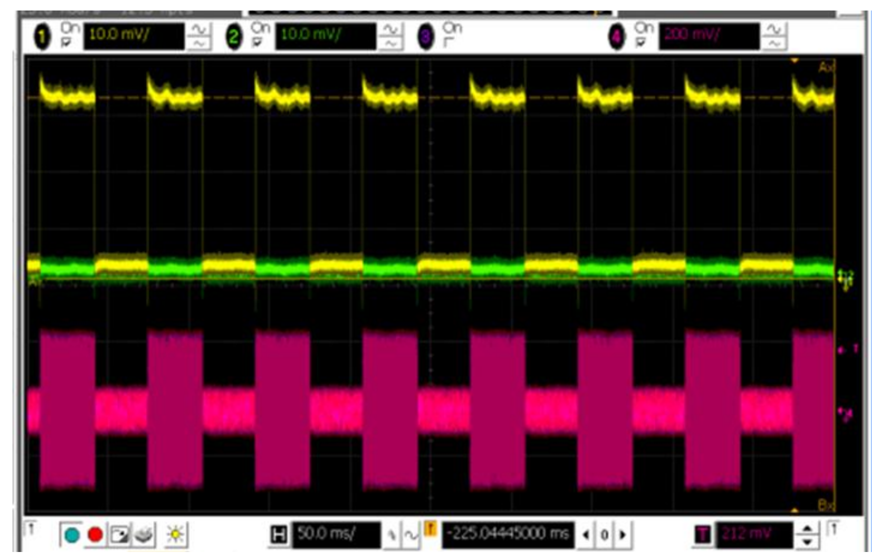
- The main objective of the campaign, to demonstrate RFQ operation in the range of 180-200 kW CW, was achieved.

- The emphasis in the campaign was on safe RFQ operation in order not to disrupt the accelerator schedule. As a result, the conditioning campaign was not as “aggressive” as it could have been.

- Record levels of RFQ operation (250 kW at 50 % DC and 200 kW CW) were achieved in a relatively short time

- Average time of operation without trip at 250 kW, 50 % and 20% duty cycle, were 10-15 min and 2-3 hours, respectively .The RFQ stability improved with continuation of the campaign.





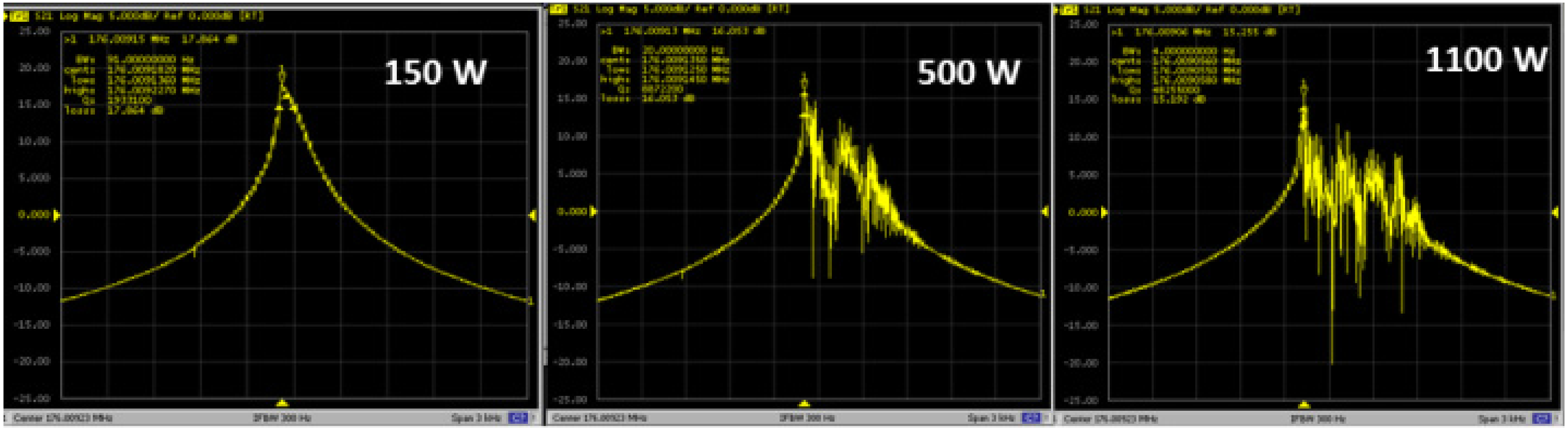
A scope screenshot of the RFQ signals during operation at 250 kW, 50 % duty cycle

The Superconducting cavities sensitivity

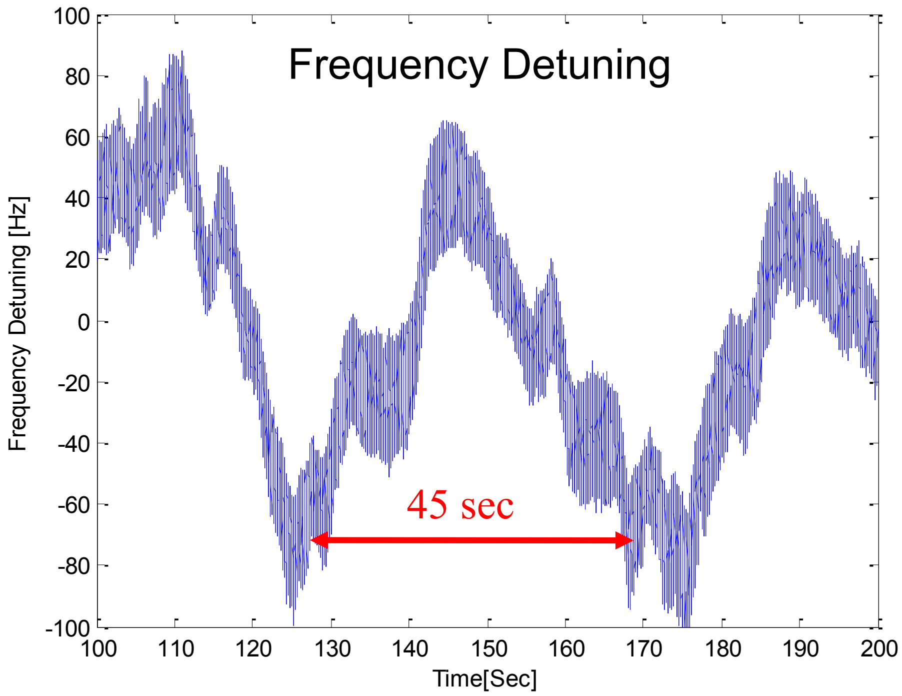
The main problem of the SARAF Phase-I superconducting cavities is their susceptibility to mechanical deformation:

- The cavities are sensitive to fluctuations in the Liquid He pressure (60 Hz/mbar compared to the designed value 15 Hz/mbar). The ±1.5 mbar pressure variation of the cryogenic system is manifested by frequency detuning that exceeds the cavities loaded bandwidth of 130 Hz.

- The cavities are sensitive to Lorentz detuning. Intense ponderomotive oscillations appear at certain power on the high frequency side. These oscillations hinder locking of the cavities at high RF power values.



Improving cavity rigidity

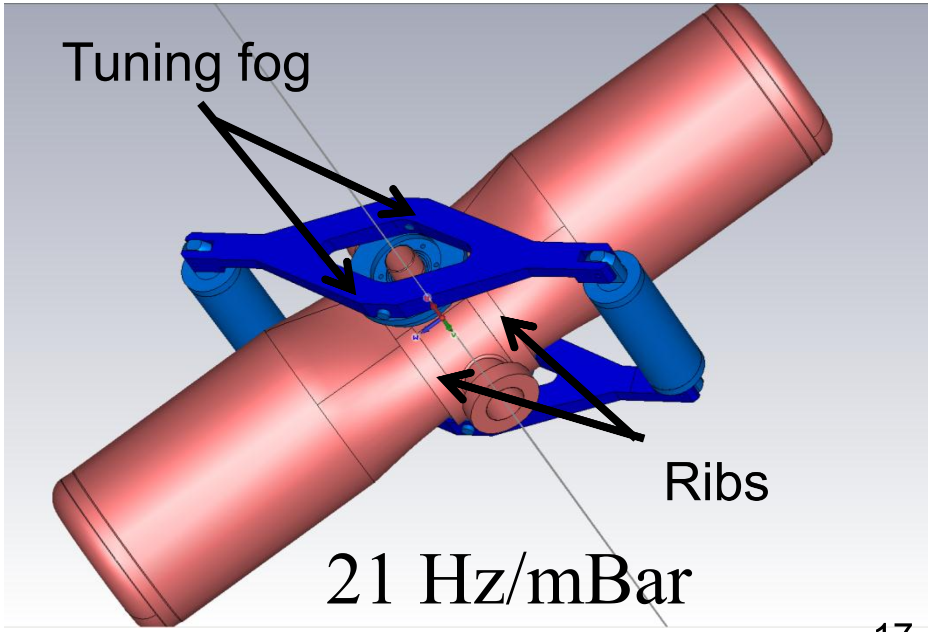


🡐 Measured sensitivity of 60 Hz/mBar

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

[L. Weissman LINAC 2010]

Suggested solution - Increase the rigidity of the tuning fog and add ribs at the vicinity of the beam line. This should reduce the sensitivity of the HWR to helium pressure by a factor of ~3



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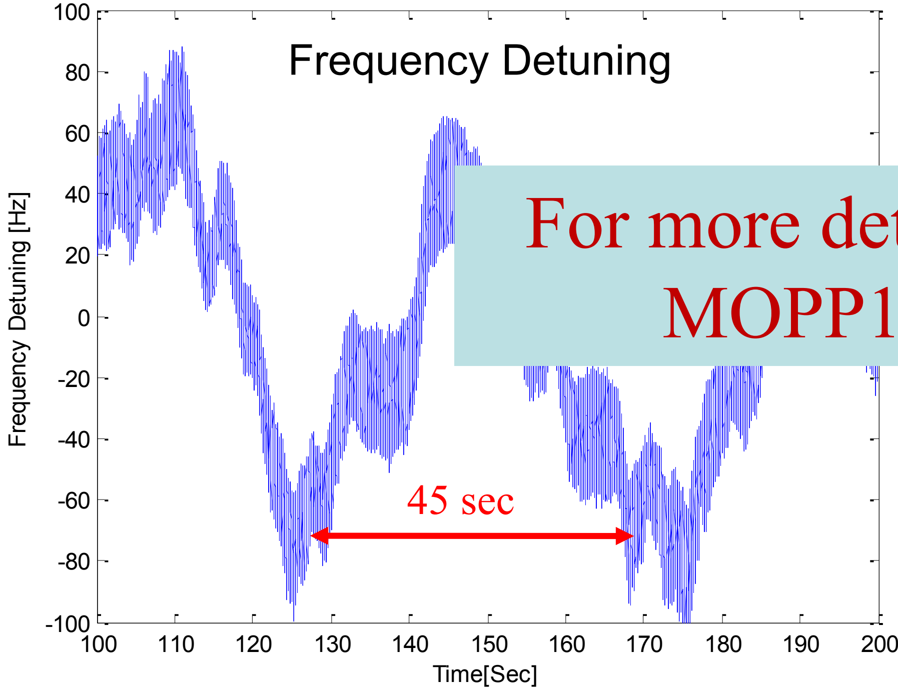

For more details please visit poster MOPP134 by J. Rodnizki

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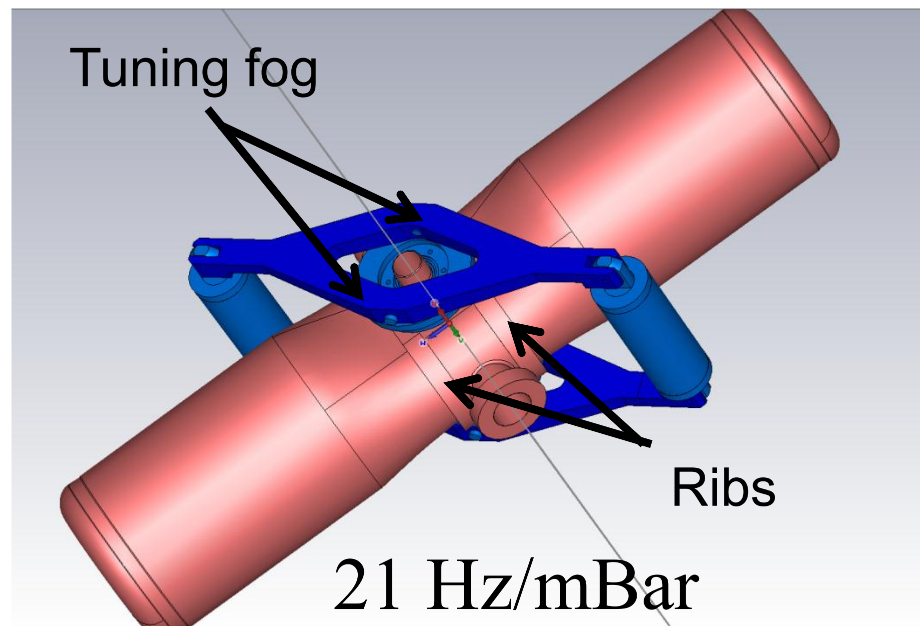

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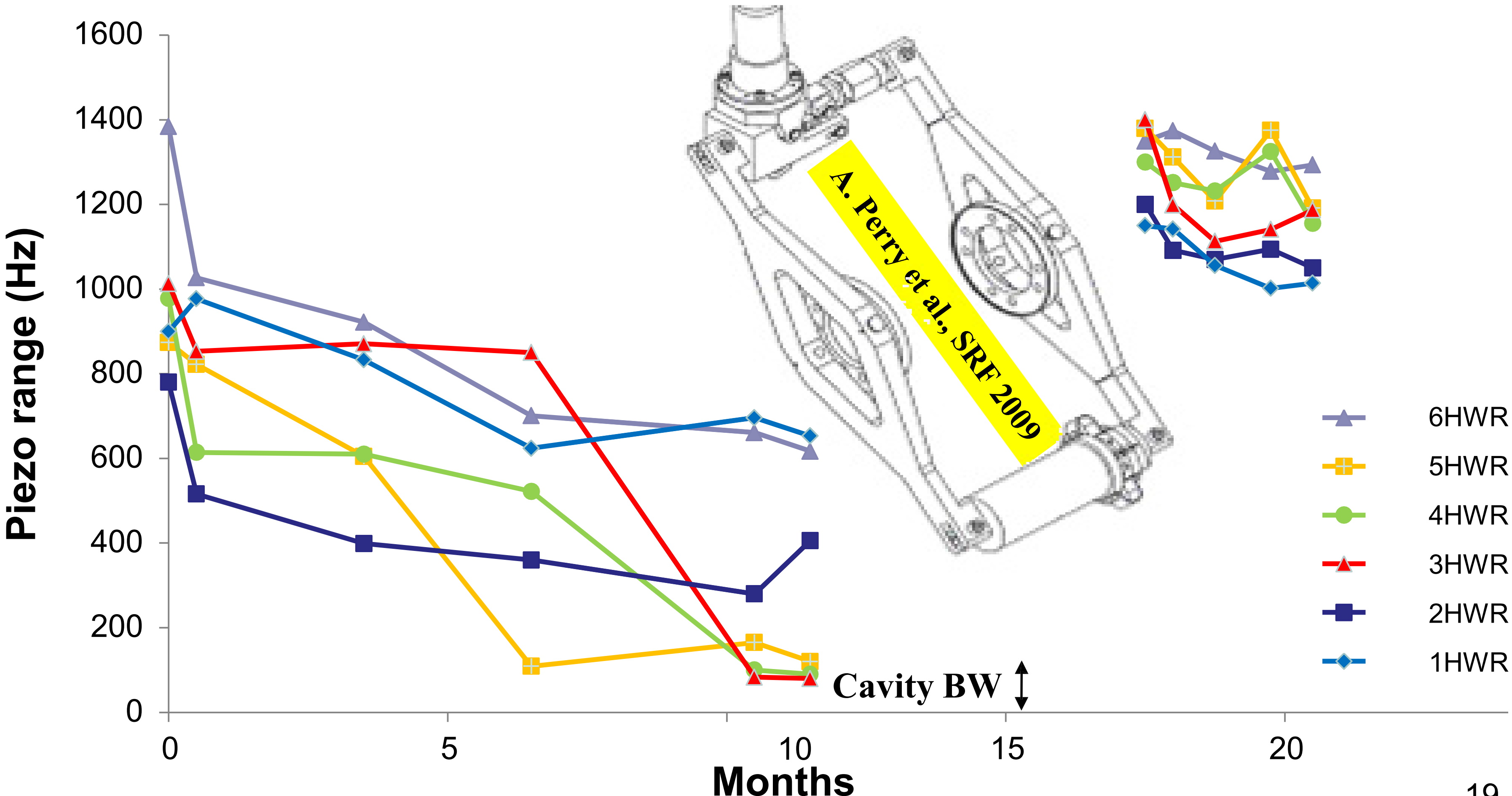
Follow up On

Deterioration of the Piezo tuners problem

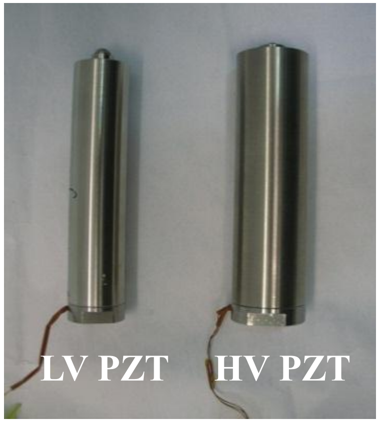
presented by D. Berkovits LINAC 2012

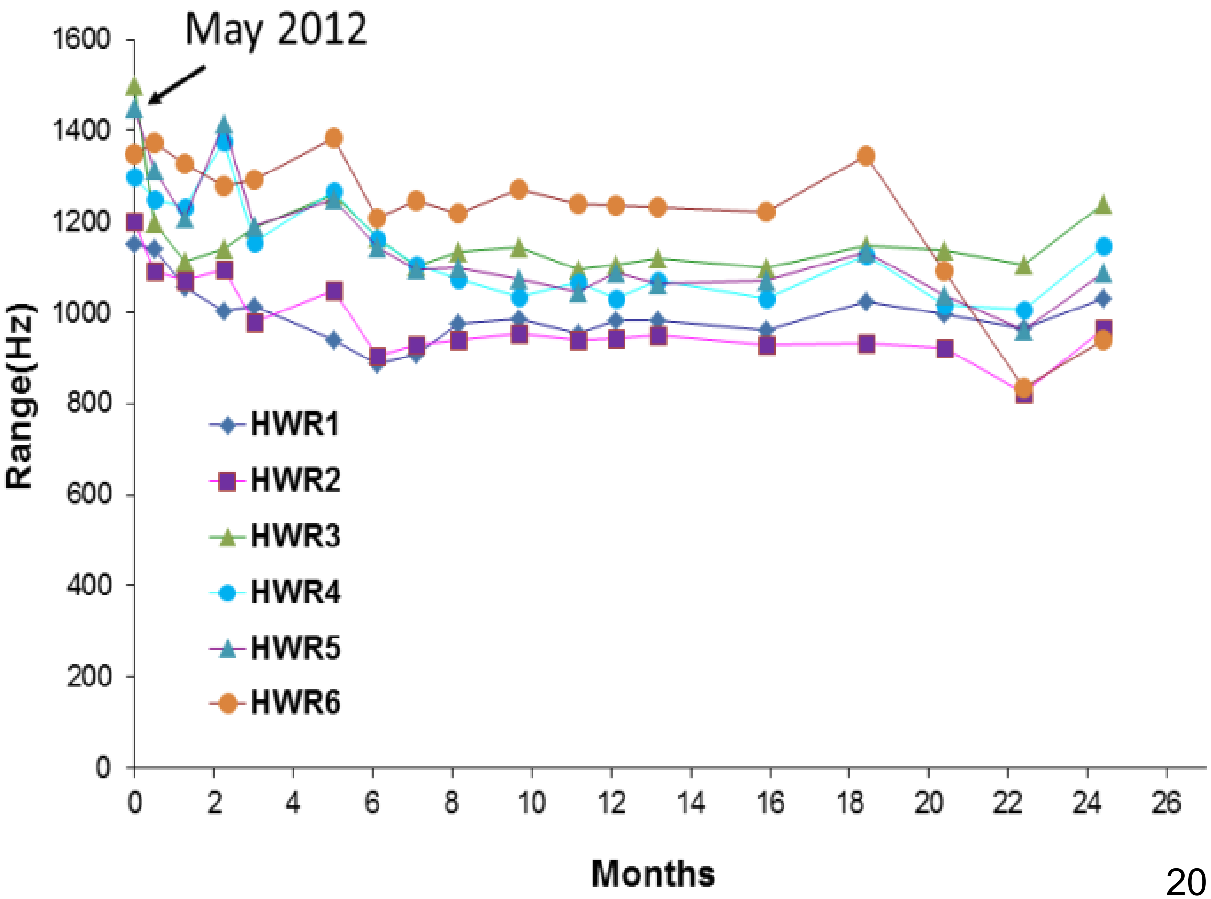


Solution follow up from LINAC12

- During the 2012 winter-spring maintenance period, the tuners were replaced by another type of piezo activators (Pst1000), which operate at higher voltage and have superior mechanical strength.

- The tuning ranges of the new piezos are measured regularly since May 2012. So far, no significant degradation of the tuning ranges has been observed.

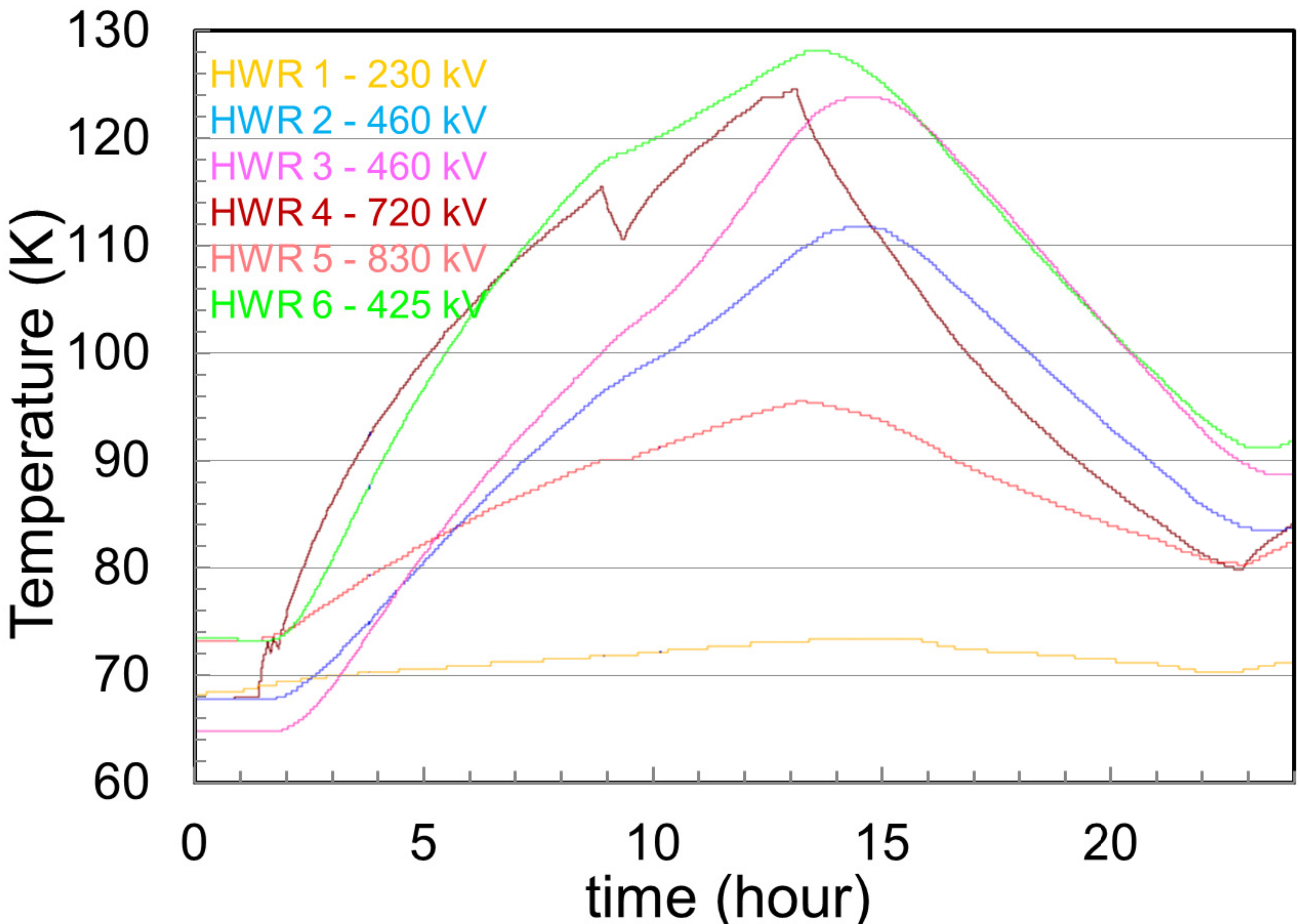




Follow up On

Couplers heating problem

presented by D. Berkovits LINAC 2012



Follow up On
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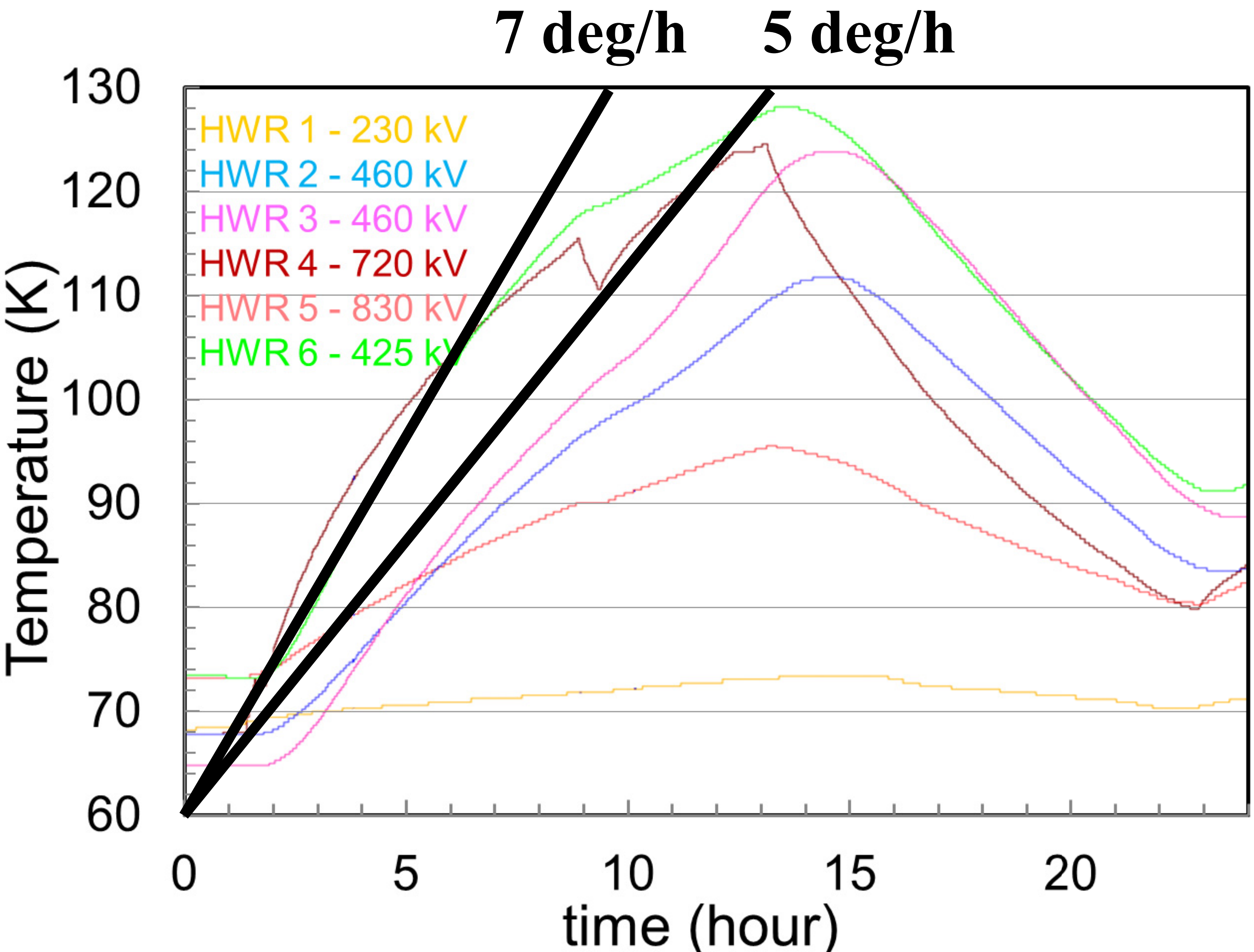
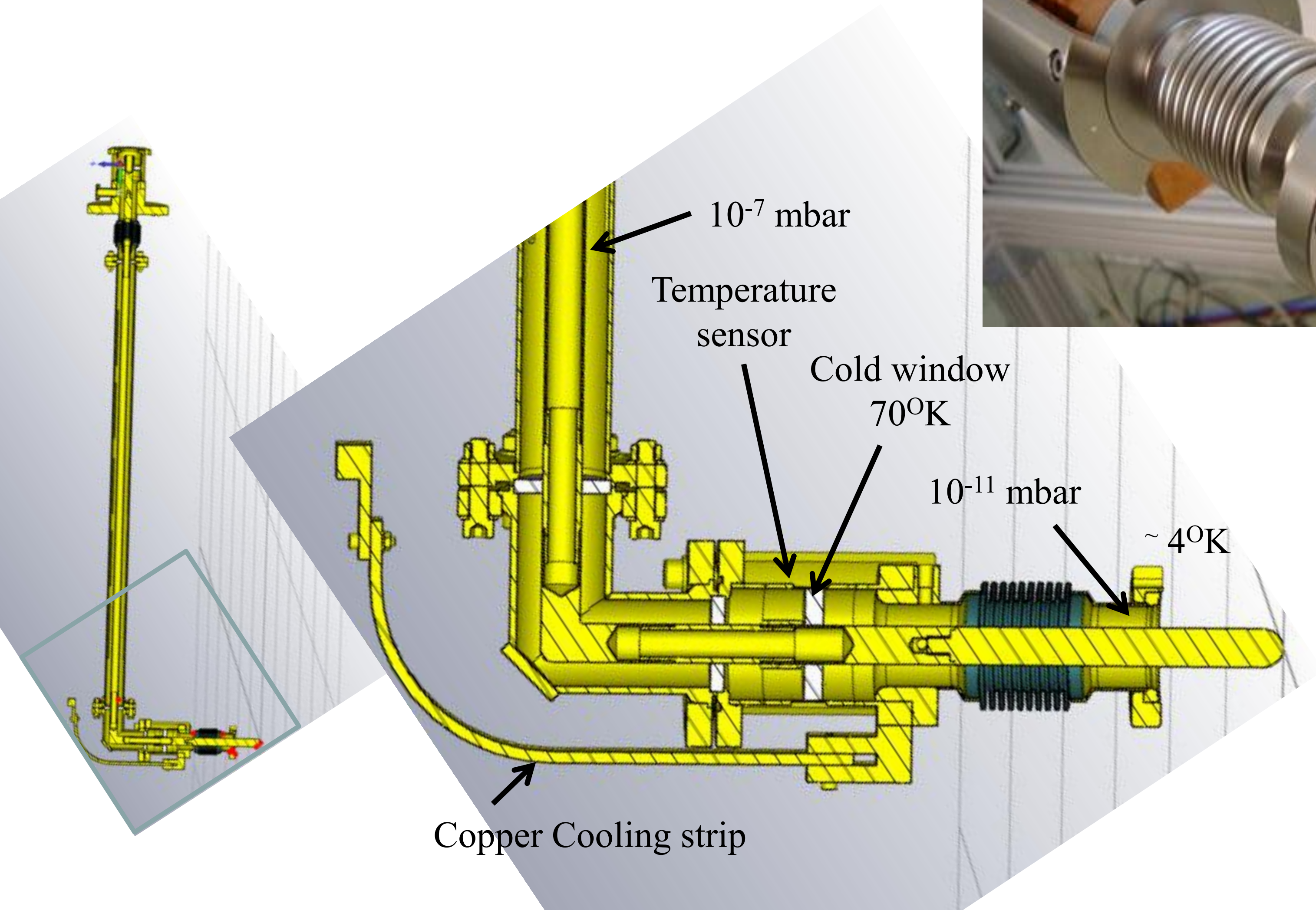
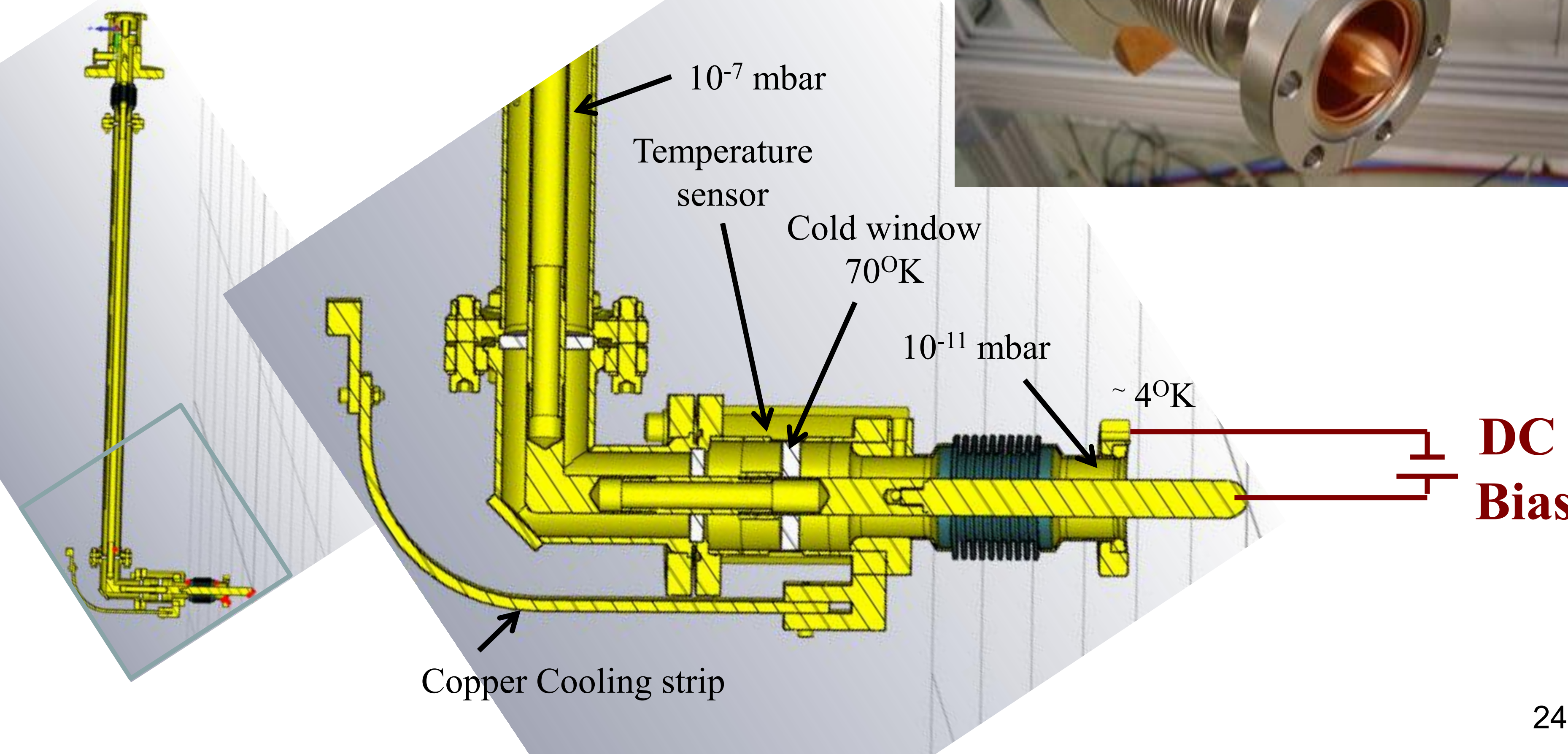


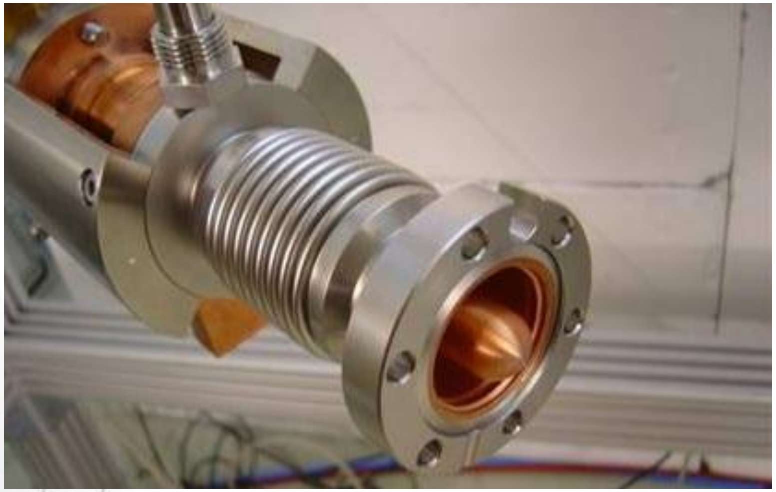
cause of heating: inside coupler multipacting



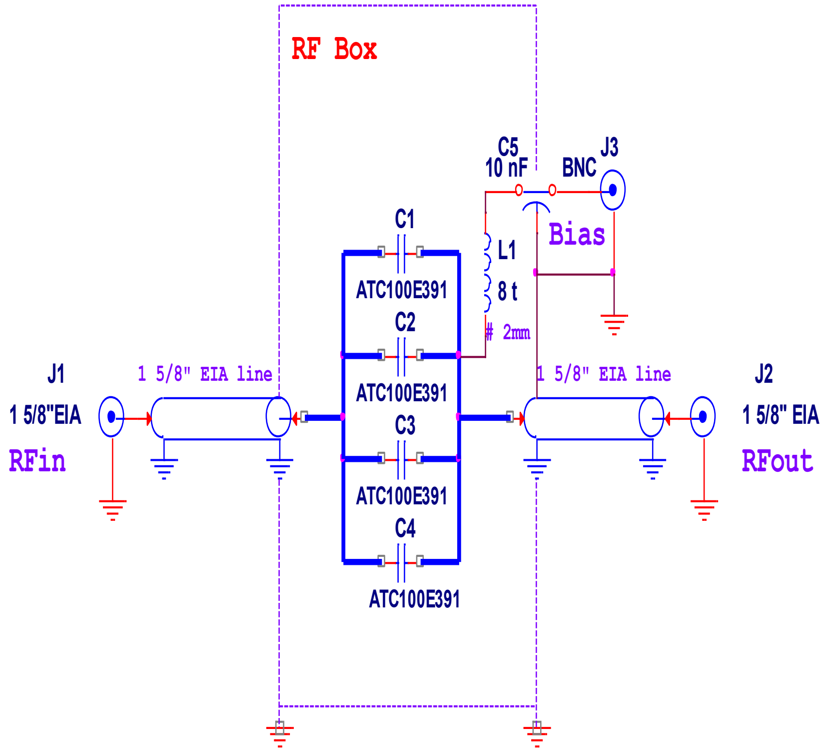
cause of heating: inside coupler multipacting

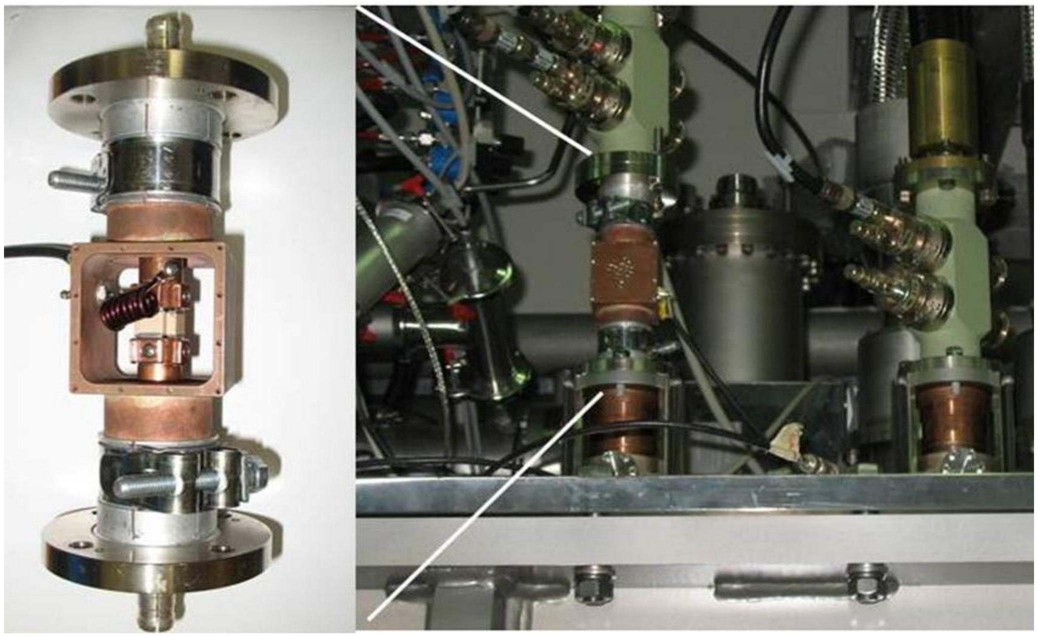
Solution - a DC bias voltage between the inner and outer conductors of the coupler





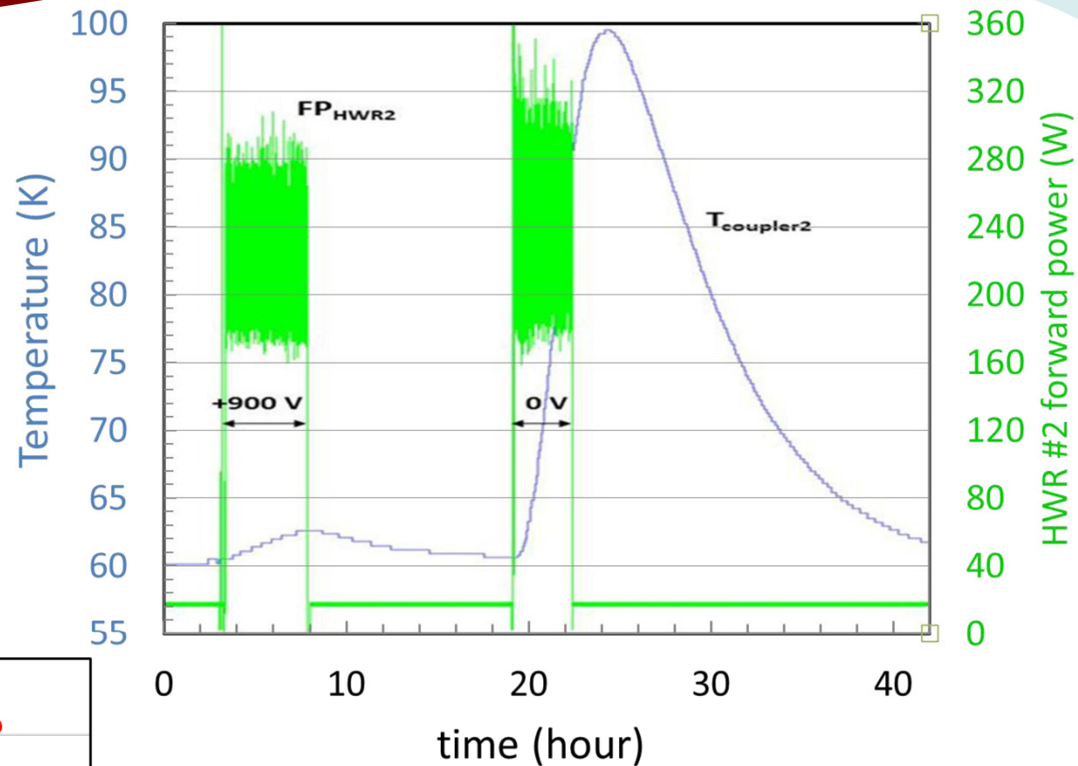
Implementation - DC bias-T element

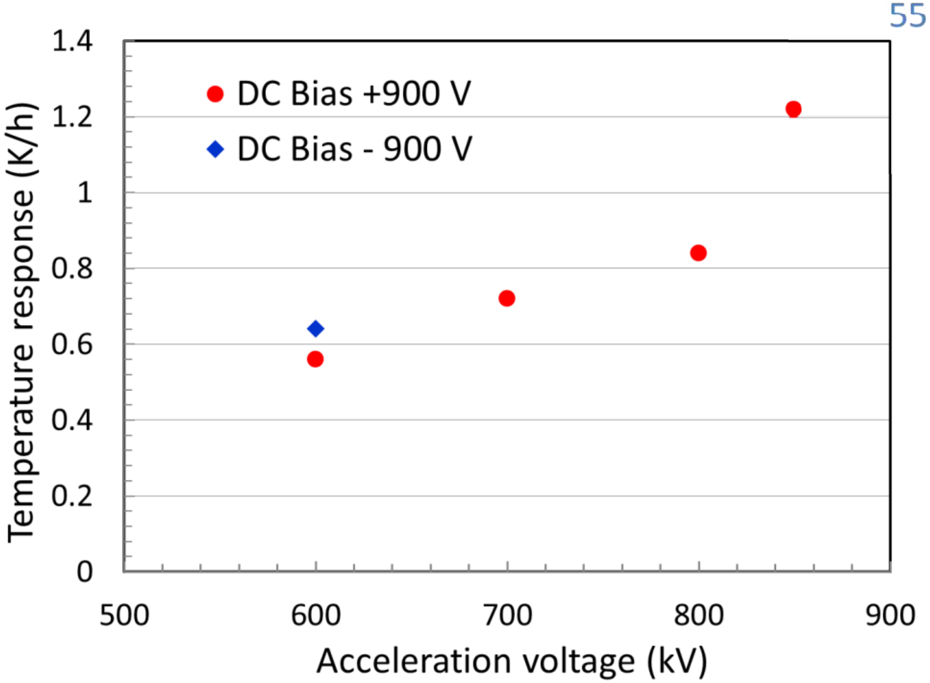




For full details please visit poster THPP132
by Boaz Kaizer on Thursday, 16:00-18:00, poster session

DC Bias-T test

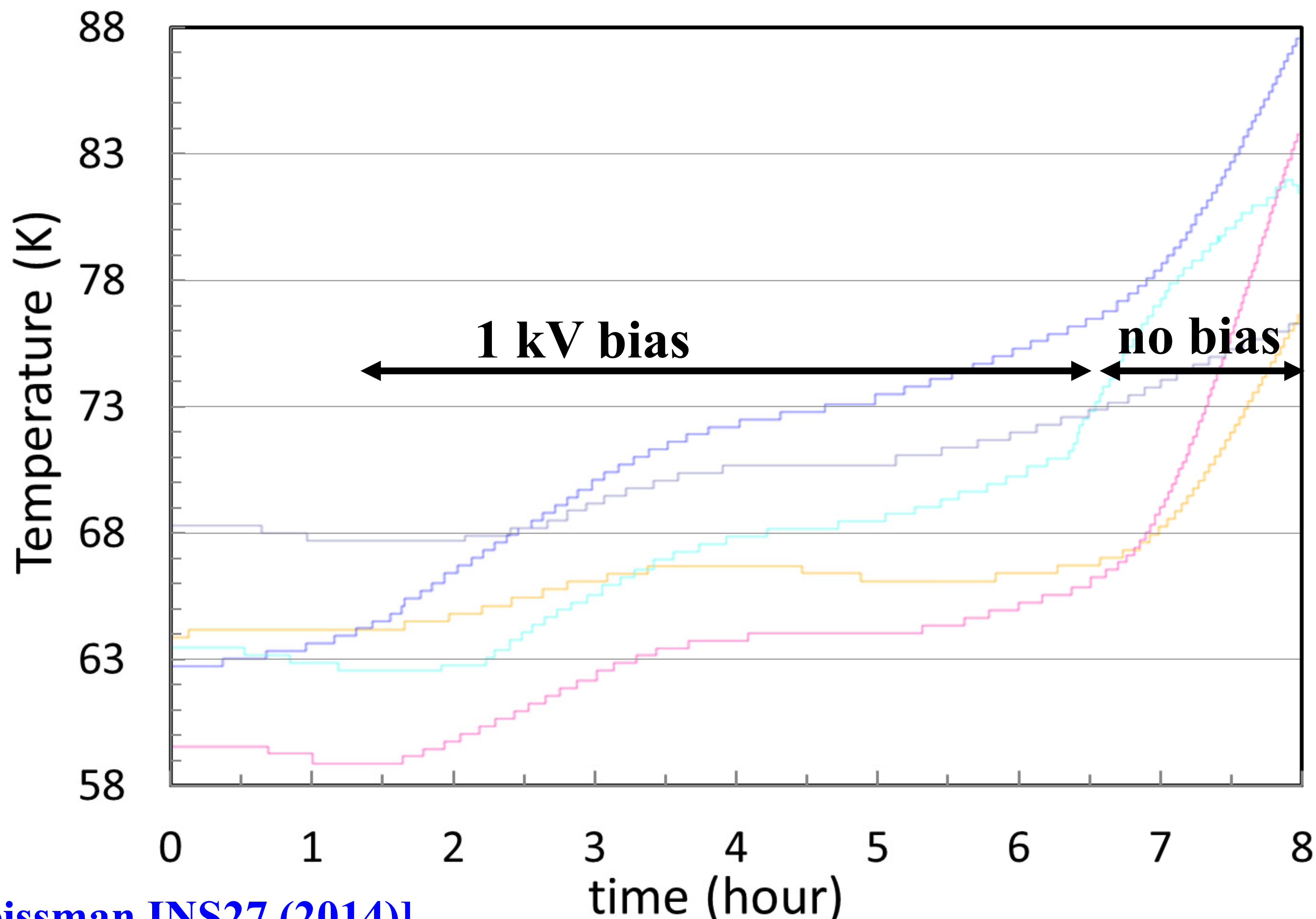




At 600 kV (240 W forward power) acceleration voltage:
Without bias - 10 K/h
With 900 V bias - 0.6 K/h

[J. Rodnizki SRF 2013]
[B. Kaizer LINAC 2014]

RF couplers temperature with Bias-T



[L. Weissman INS27 (2014)]

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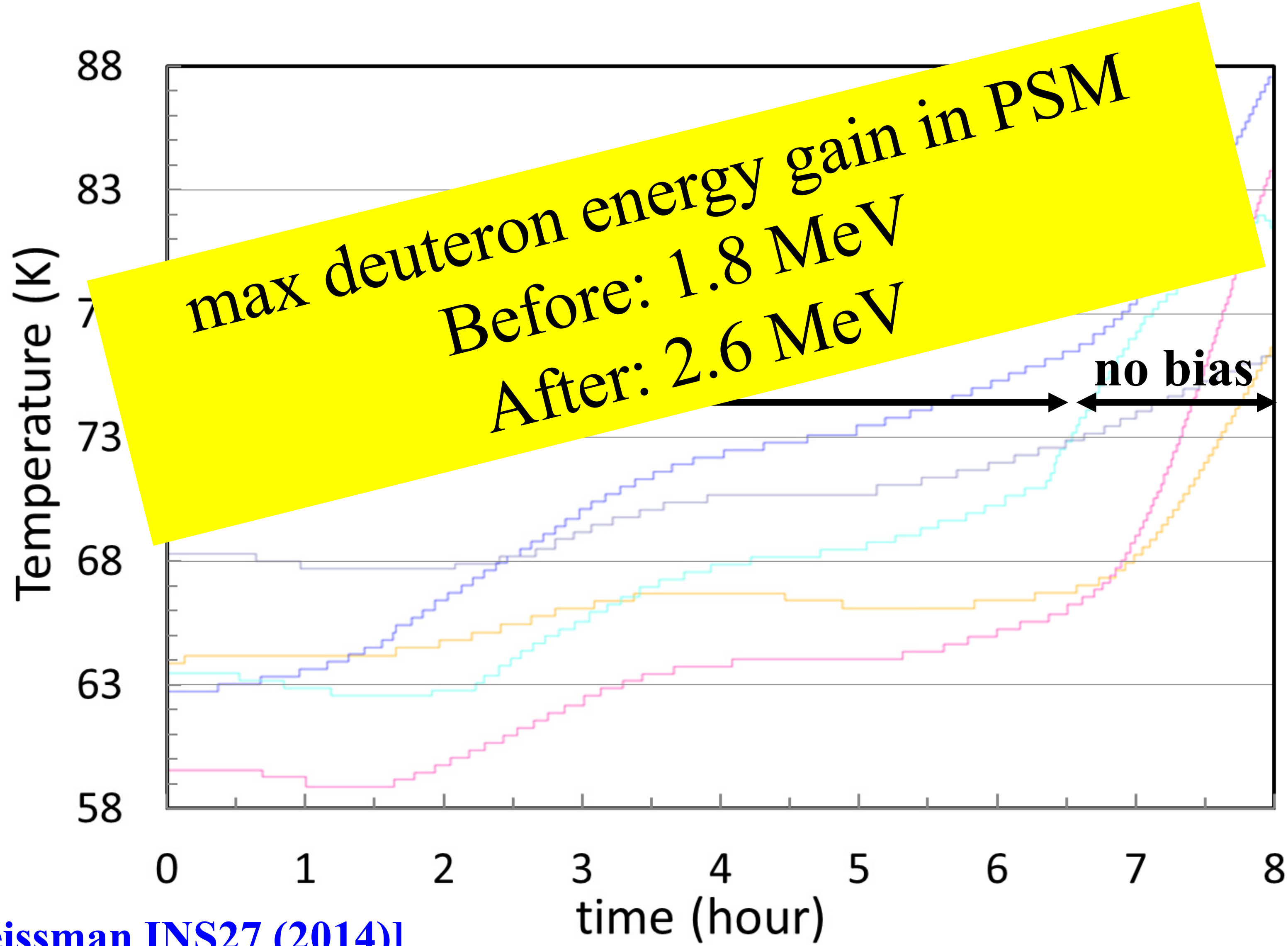
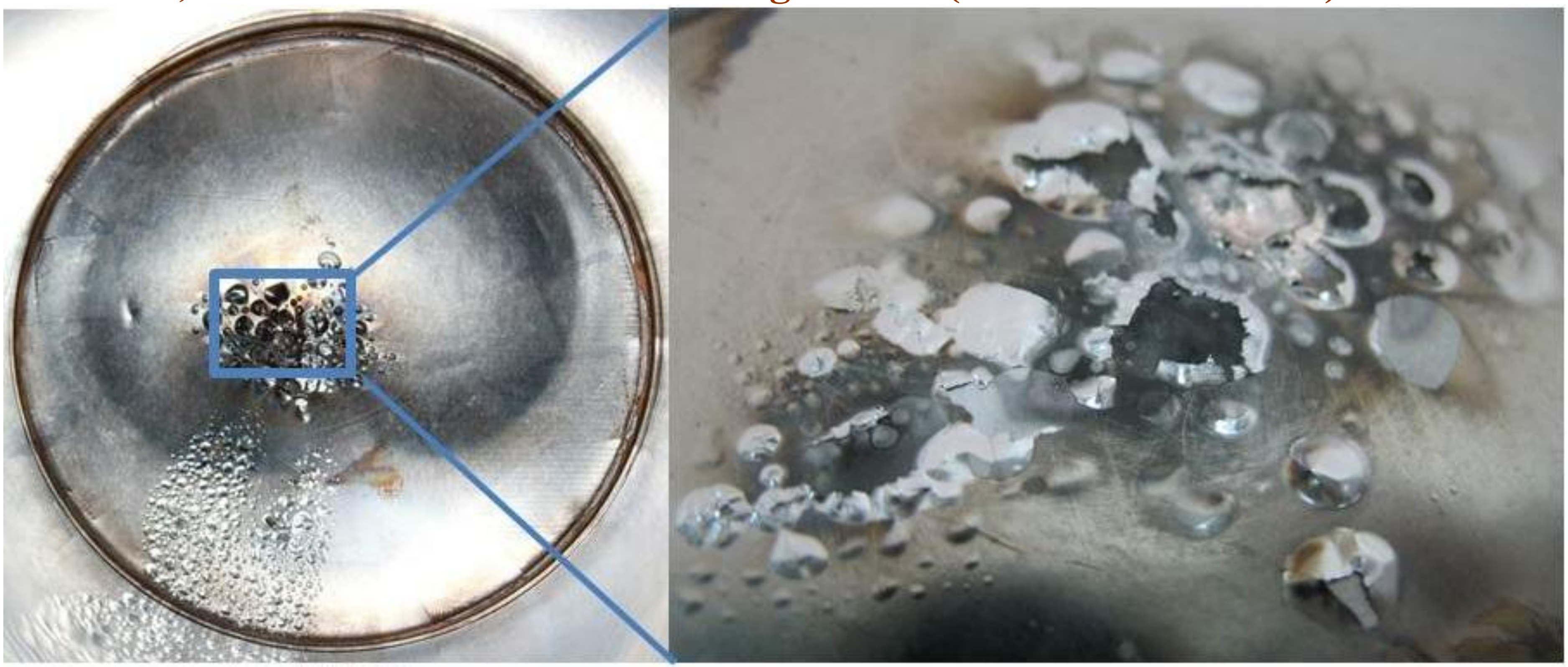


[L. Weissman INS27 (2014)]

Tungsten beam dump blistering problem

The 250 micron Tungsten sheet fused to a water cooled cooper plate beam dump exhibits remarkably low prompt and residual radiation at phase I beam energies. However, it suffers from severe blistering effects. (Generation 2 and 3).



150 mm

[L. Weissman RuPAC 2012]

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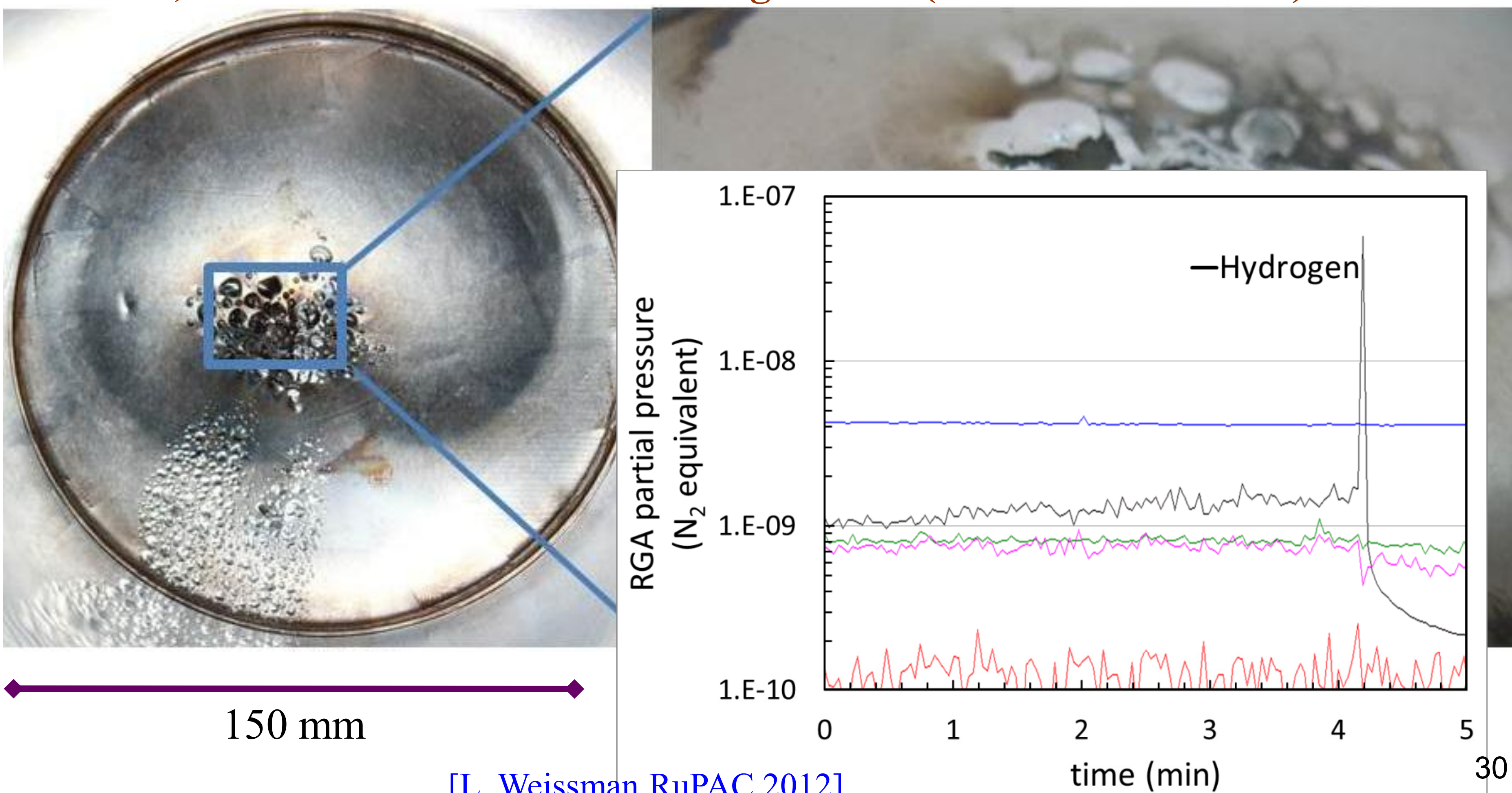


150 mm

[L. Weissman RuPAC 2012]

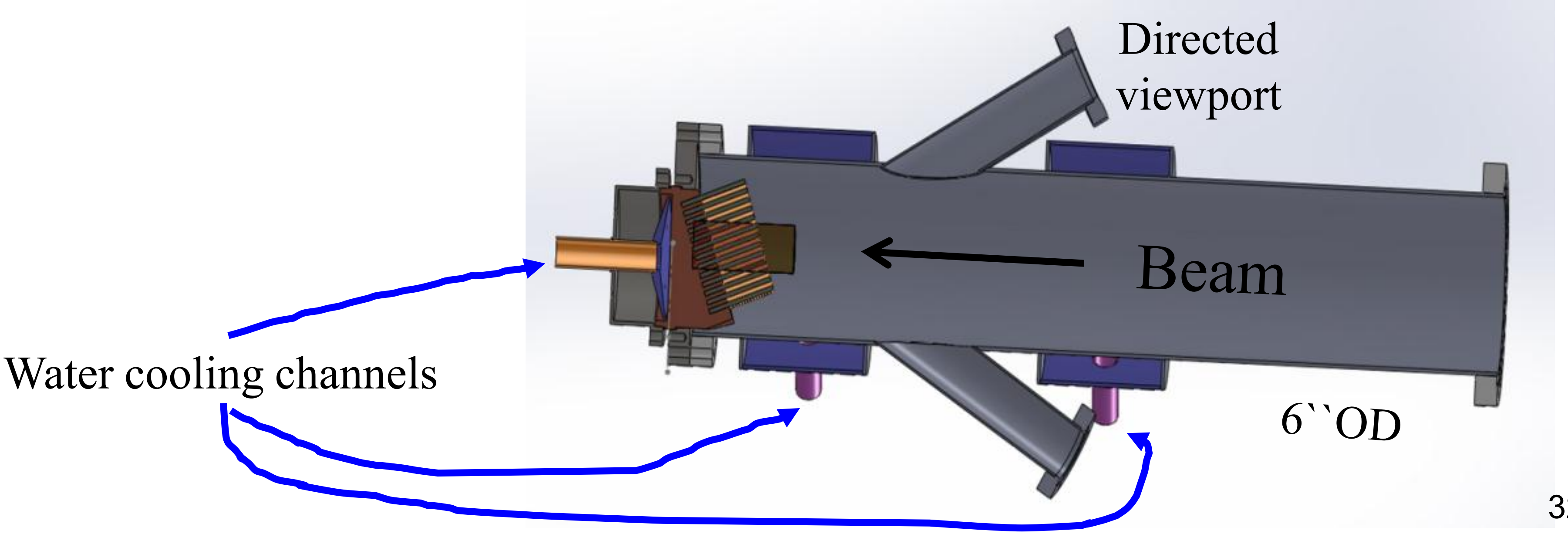
Alternative porous heavy metal beam dump

- A desirable moveable beam dump should enable long and reliable operation of the accelerator at the highest beam power, with minimal prompt and residual radiation

- A similar beam dump (generation 4), made of copper free heavy metal instead of pure tungsten with high porosity of the heavy metal solved the blistering problem. Up to 4 kW of beam intensity was applied on this dump for many hours. The beam dump did not exhibit any blistering. Long term operation of this beam dump still leads to severe activation due to low-Z metal content in heavy metal.

The Tungsten Pin Beam dump

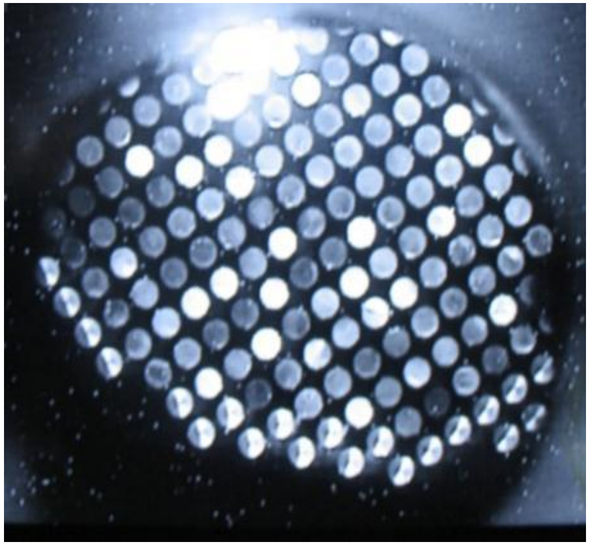
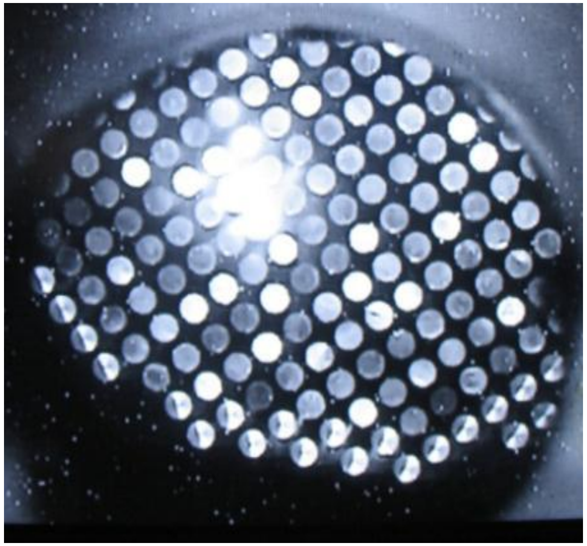
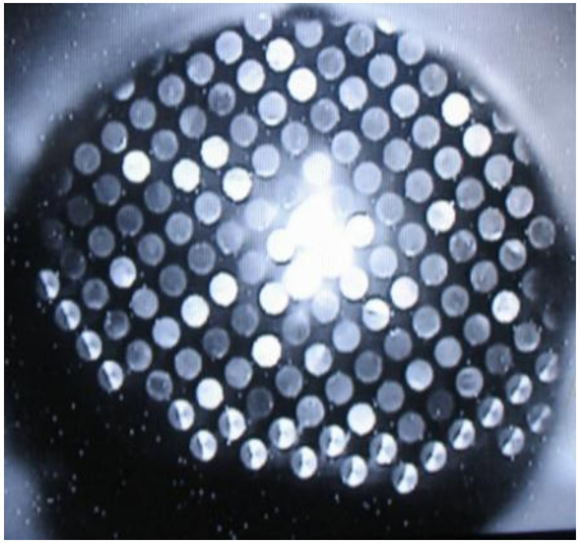
- The current SARAF beam dump (generation 5) is made from tungsten pins inserted in a water cooled copper block. The pins are arranged in such a way that beam does not impinge on the copper. The absorbed beam power is irradiated by the hot pins and reabsorbed by the water cooled environment. This beam dump is designed for up to 20 kW of beam power. It is not susceptible to blistering due to efficient diffusion of hydrogen from the hot directed pins.



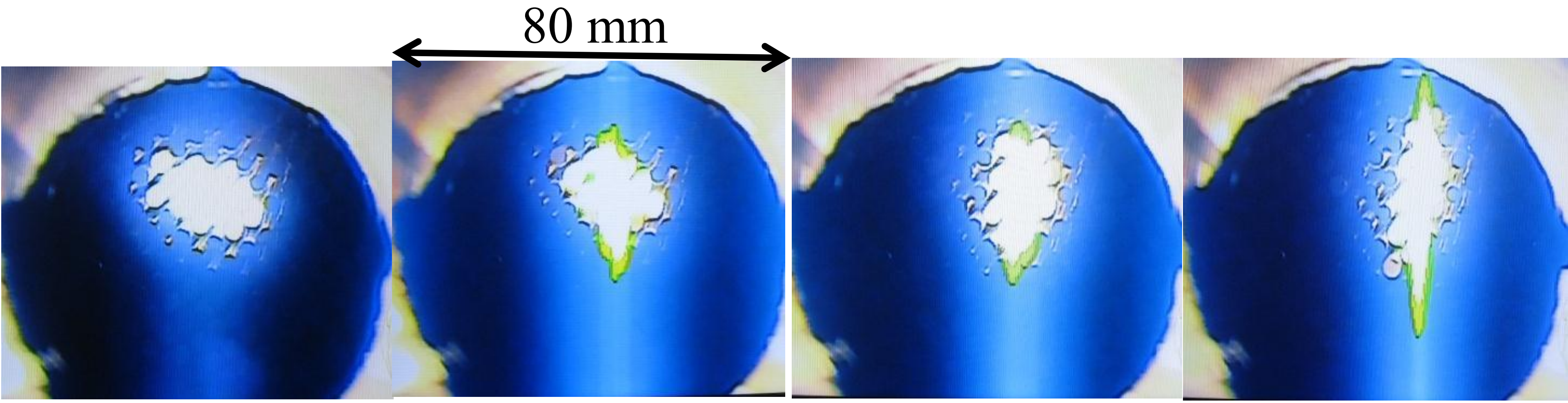
Testing the Tungsten Pin Beam dump

- 2 kW of beam energy was successfully applied to this beam dump prototype [A. Arenshtam JINST 2013]

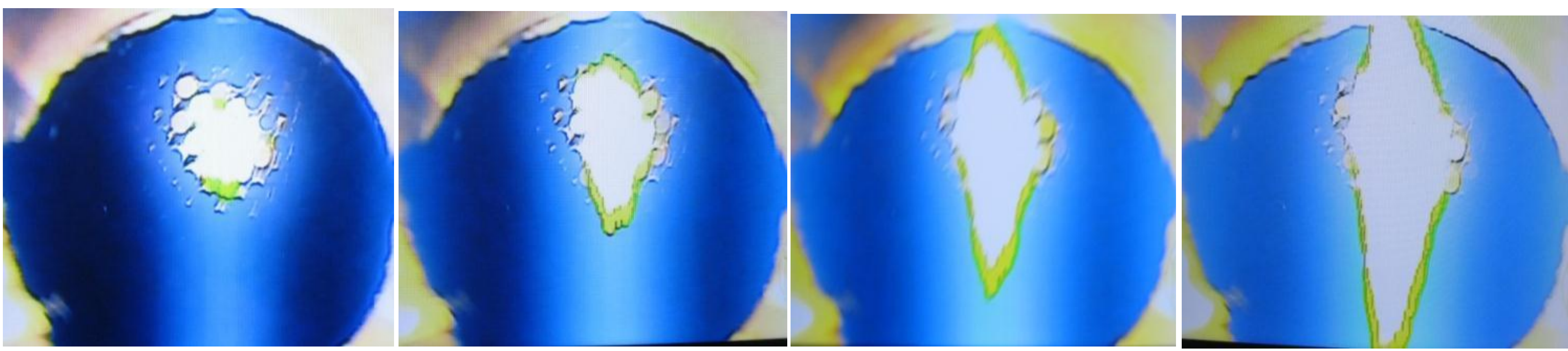
- The first version of a 80 mm diameter pins dump was tested at SARAF with 5.7 kW, 3.6 MeV protons. It emitted lower gamma radiation relative to the previous beam dump and low neutrons radiation (~ 10 mrem/h at one meter distance from the dump) was measured. The heat from the pins, which is irradiated in visible light, enables this beam dump to serve for beam visualisation

Operating with the Tungsten Pin Beam dump



Varying quads while observing 0.3 mA beam (0.65 kW)



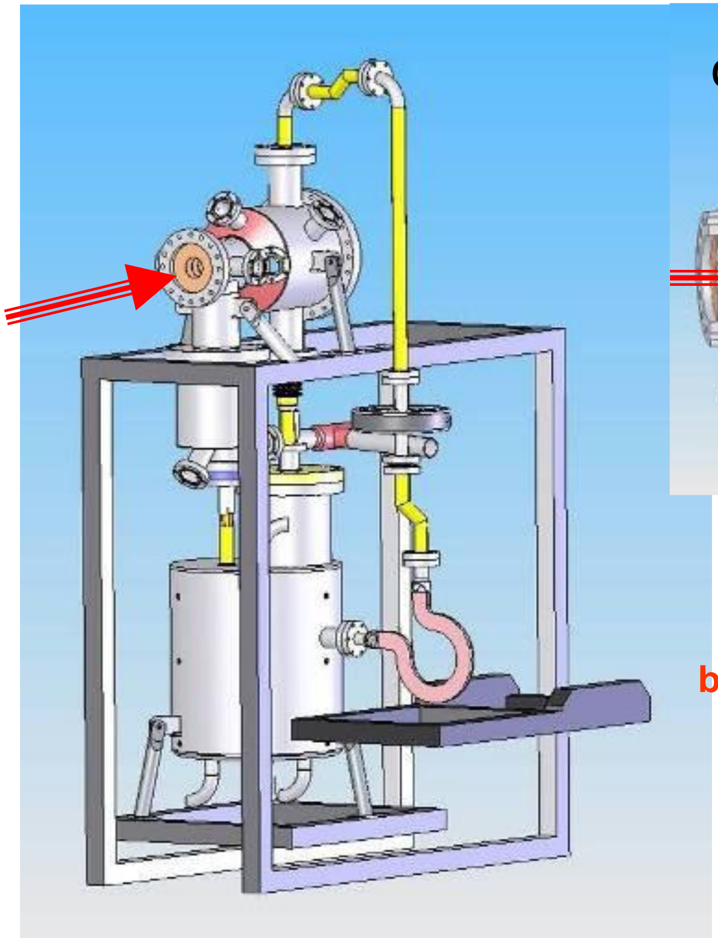
Ramping up the current

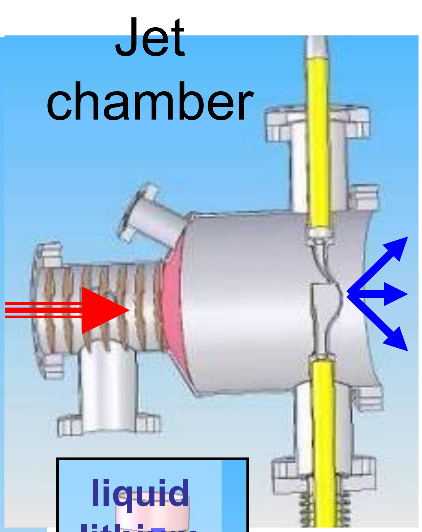
0.2 mA 0.4 mA 0.8 mA 1 mA

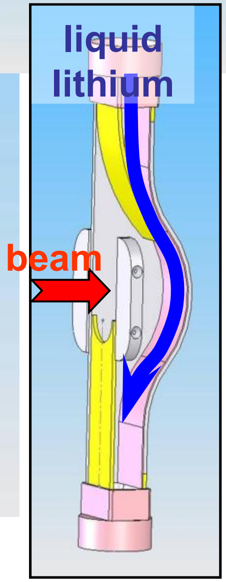
Requirements from a strong neutron source from a low energy beam

- Intense neutron source at low energies means high current
- At low energy the target has to be in the accelerator vacuum
- That means difficult heat removal
- The SARAF solution is a Liquid Lithium jet Target (LiLiT) $^{7}Li(p,n)$

[S. Halfon RSI 2014]







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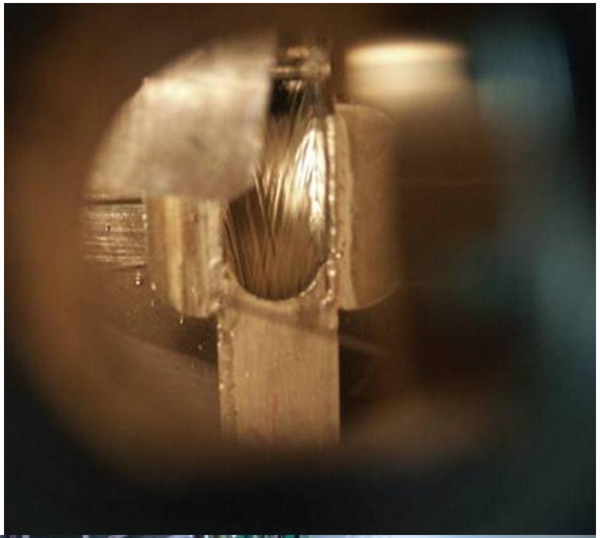
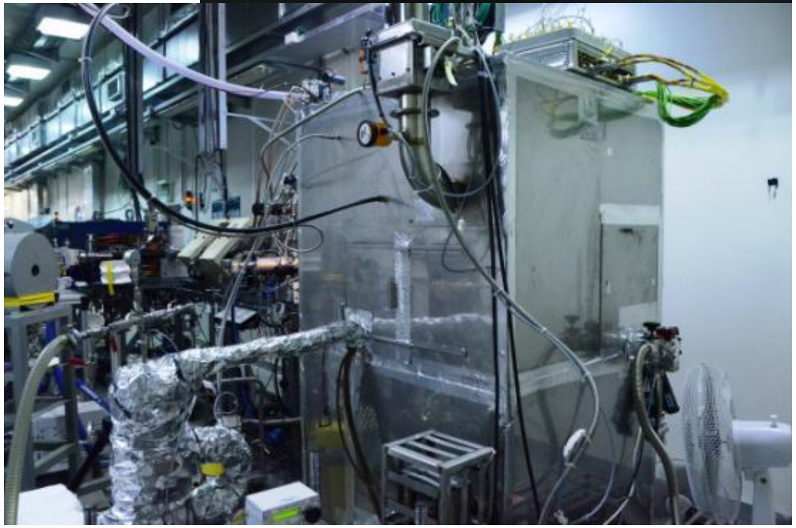
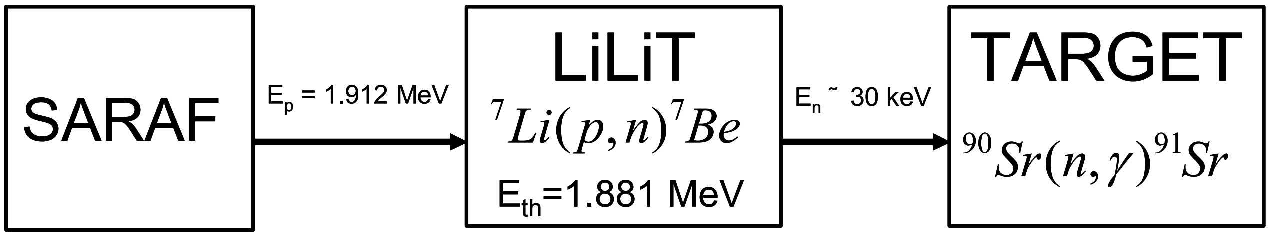
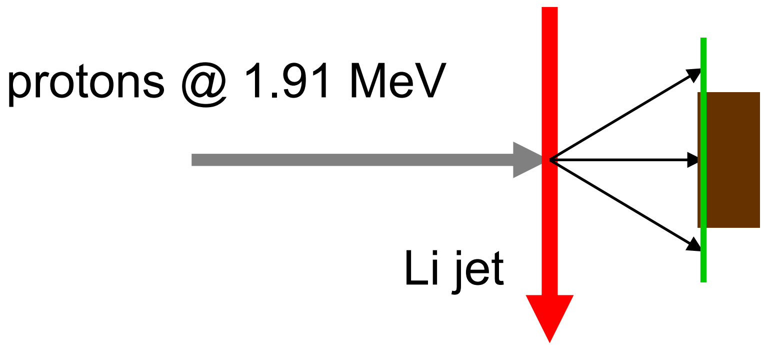
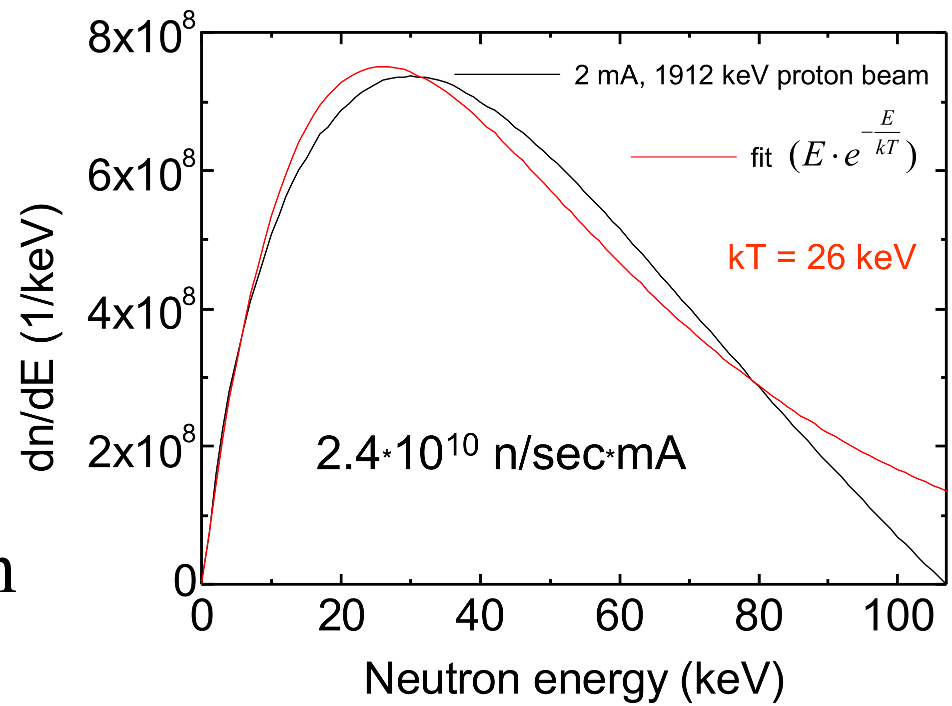




Astrophysics nucleo-synthesis



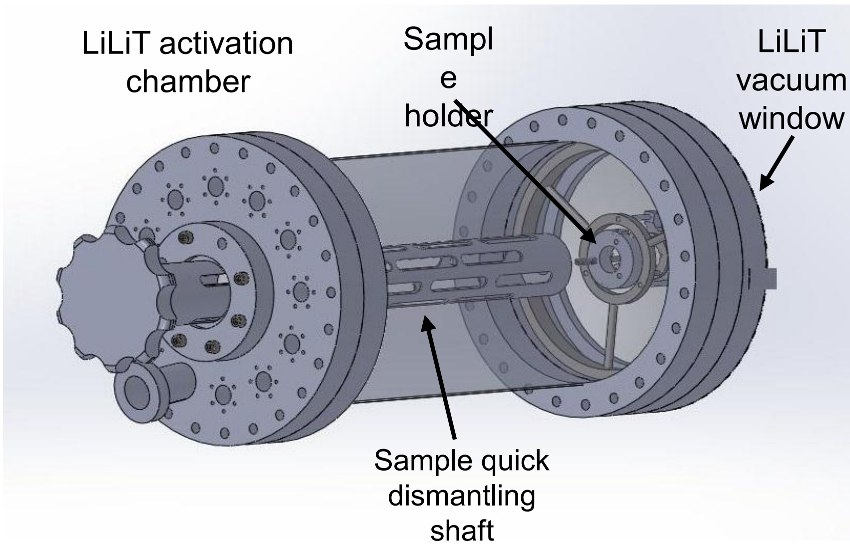


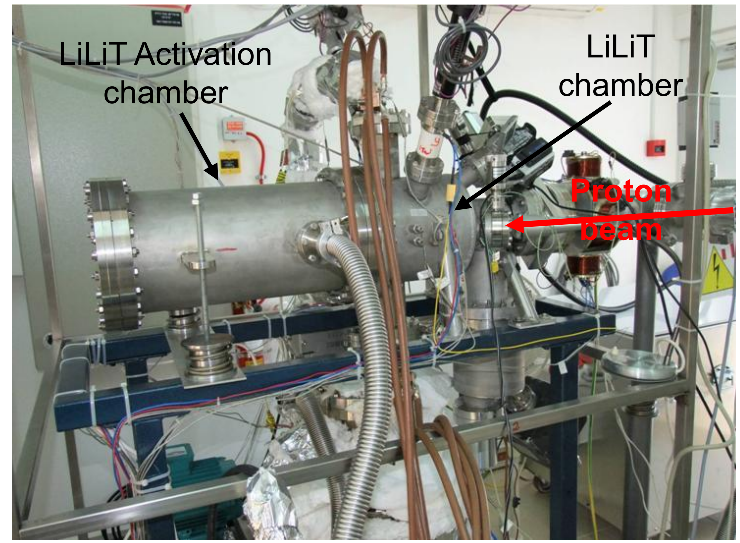


creates in lab stellar neutron spectra with T=300 million degrees ~ kT = 25 keV neutron flux approaching ~10^{11} n/sec

[G. Feinberg et al., Nucl Phys A827(2009)]

Nuclear astrophysics – XS measurement at SARAF





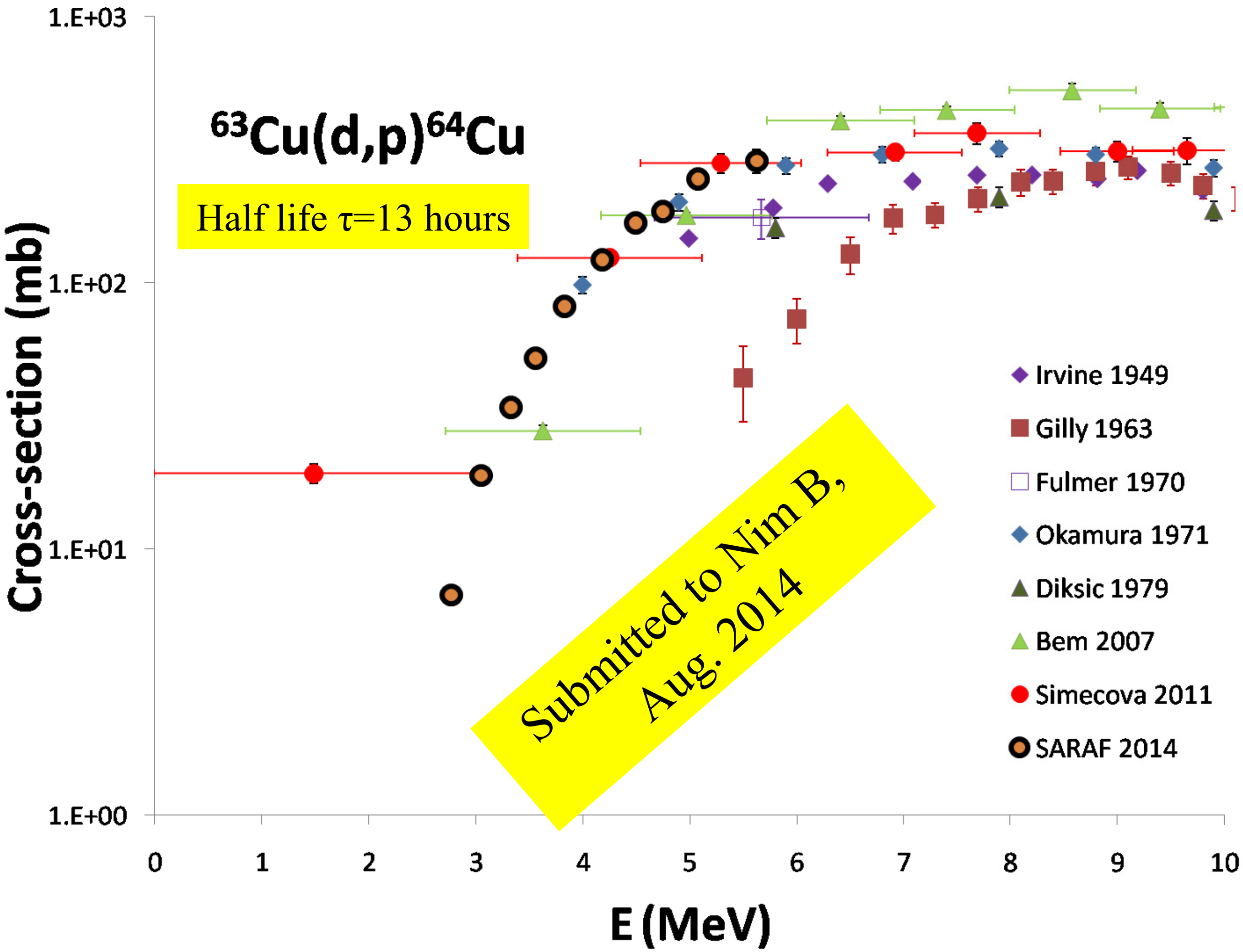
	(n,γ) MACS at 30 keV (mb)						
Target Isotope	This work	KADoNiS v0.3					
		Toukan 1990	Wyrick 1983	Musgrove 1978	Boldeman 1976	Macklin 1967	Recommended
^{94}Zr	28.9 ± 1.3	26.1 ± 1.0	25 ± 4	33 ± 5	26.6 ± 3	-	26 ± 1
^{96}Zr	13.3 ± 1.1	10.7 ± 0.5	12 ± 1	-	-	41 ± 12	10.7 ± 0.5

[G. Feinberg INS27 (2014)]

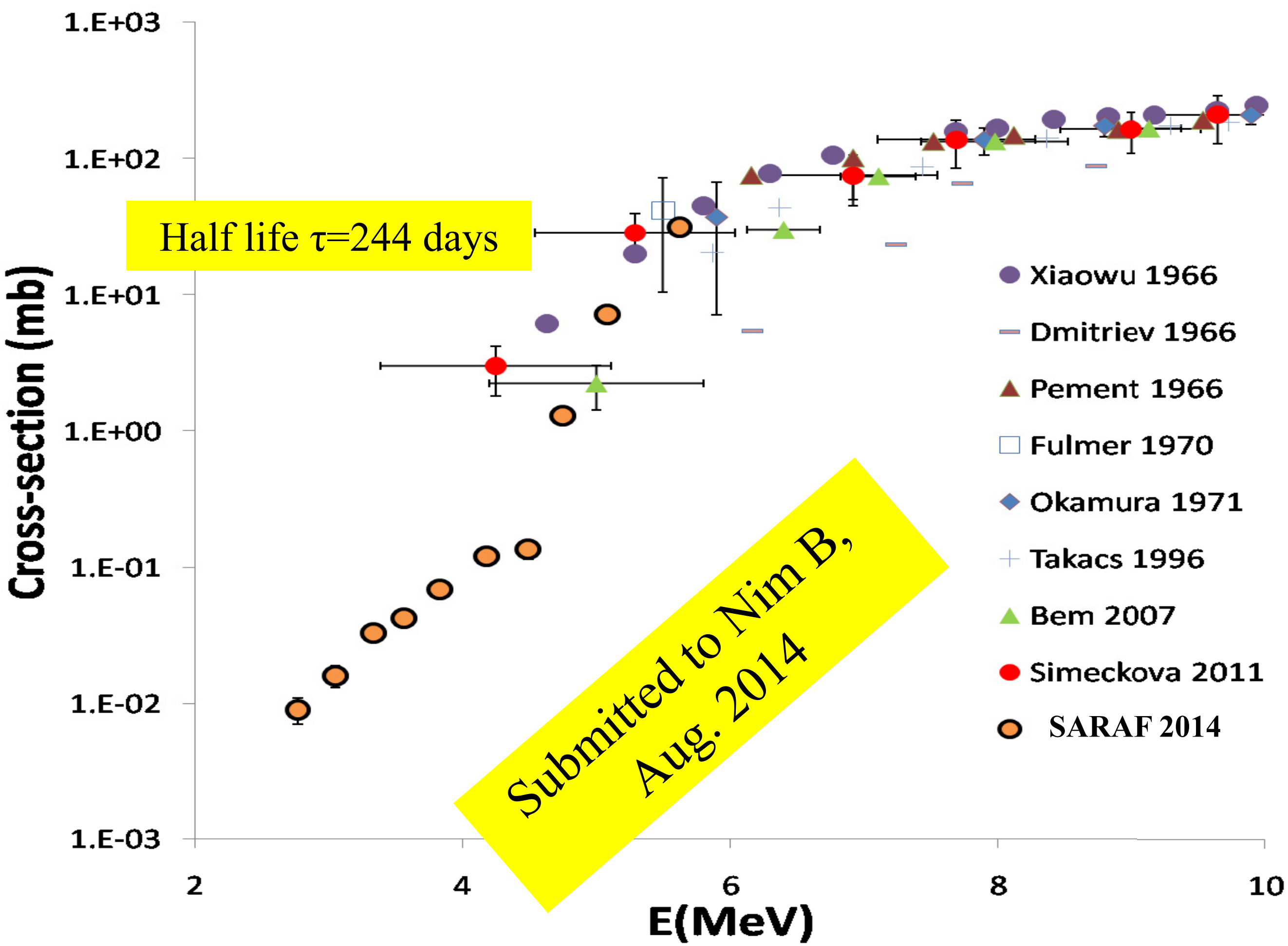
Physics at SARAF – deuterons on copper

- Activation of natural copper by deuterons at energy of a few MeV is of the special interest, as Radio Frequency Quadrupole (RFQ) injectors consist of copper electrodes
- Although the nuclear cross-section is low, beam loss in this accelerator component is expected to be high compared to that of the superconducting LINAC
- For example, in the IFMIF RFQ, deuteron beam losses in the energy ranges of 3-4 MeV and 4-5 MeV are expected to be as high as 0.2 mA and 0.1 mA, respectively [S. Simakov, Fus. Eng, and Des. (2008)]
- For d+Cu cross section measurements ten values of deuteron energy from 2.77 MeV to 5.62 MeV were used in irradiations. The lowest deuteron energy was achieved by setting the second cavity at a deceleration phase

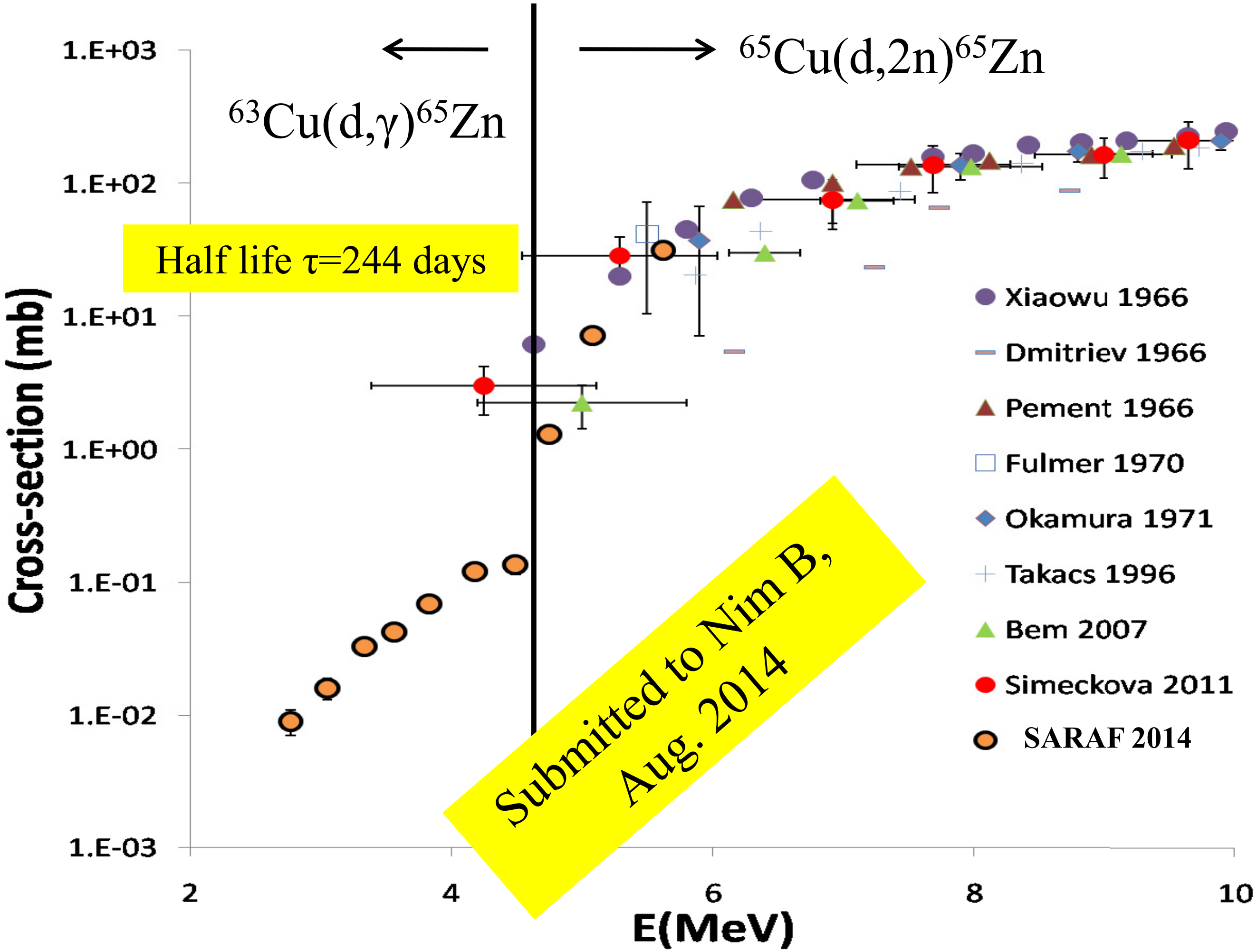
$^{63}Cu(d,p)^{64}Cu$ measurement at SARAF



Physics at SARAF - $^{nat}Cu(d,x)^{65}Zn$



Physics at SARAF - $^{nat}Cu(d,x)^{65}Zn$



Summary

- Significant progress at SARAF phase-I was achieved recently, while overcoming hurdles and bridging gaps of knowledge.
- Beam operation using the chopper installed in the LEBT and integrated into the machine safety is now being tested
- Operation of RFQ at deuteron duty cycle of 50% at 250 kW and with 200 kW CW was demonstrated.
- New DC bias elements were connected to the coupler, which significantly reduced coupler heating due to multipacting
- A new tungsten pin beam dump was installed and tested
- The LiLiT target was installed, operated and first scientific experiments were performed
- A program for measuring deuteron-induced cross-section was launched

THANK YOU!

- A. Kreisel, L. Weissman, A. Arenshtam, Y. Ben Aliz, D. Berkovits, Y. Buzaglo, O. Dudovich, Y. Eisen, I. Eliyahu, G. Feinberg, I. Fishman, I. Gertz, A. Grin, S. Halfon, Y. Haruvy, T. Hirsh, D. Hirschmann, Z. Horvitz, B. Kaizer, D. Kijel, Y. Luner, I. Mor, J. Rodnizki, G. Shimel, A. Shor, I. Silverman, D. Vartsky and E. Zemach

ion	E (MeV)	I (mA)	DC (%)	time (h)	Comments
p	3.6	1.6	100	1	pin beam dump test
p	2.0	2.1	100	4	max. current test
p	1.92	1.5	100	10	LiLiT experiments
p	3.7	0.3	100	50	foil target tests
p	4.0	0.5	160 ns 500 Hz	2	LiLiT 2 MeV neutrons
d	5.6	0.01	1	20	cross section meas.