MeV proton irradiation damage on tungsten

Blisters formation

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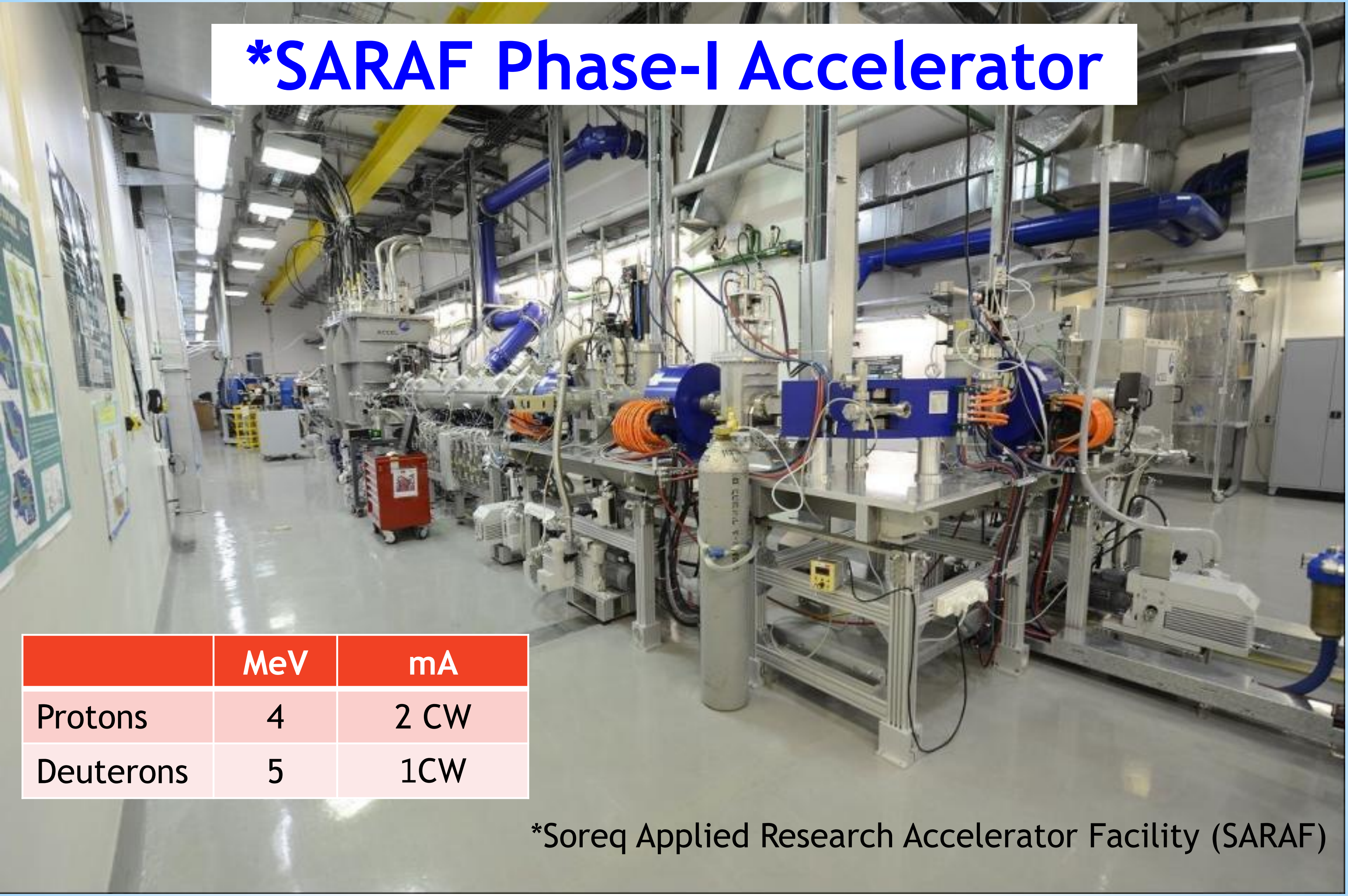
Talk Outline

- √Introduction:
  - √SARAF Accelerator
  - √Tungsten target
- √Research goals
- √Experimental part
- √Irradiation results
- √Discussion
- √Summary
- √Single crystal results

*SARAF Phase-I Accelerator



	MeV	mA
Protons	4	2 CW
Deuterons	5	1CW

*Soreq Applied Research Accelerator Facility (SARAF)

Introduction

Radiation damage from proton irradiation exhibits specific features (H retention):

* Hydride formation
* Embrittlement
* Nucleation and growth of hydrogen blisters

Radiation damage in Tungsten and its alloys:

Increased interest

Choice of tungsten as a structural material in nuclear fusion systems (ITER), and advanced accelerators (ESS).

Exposing it to high flux, low energy proton plasma, high temperature environment and high energy ions.

Introduction- Why W?

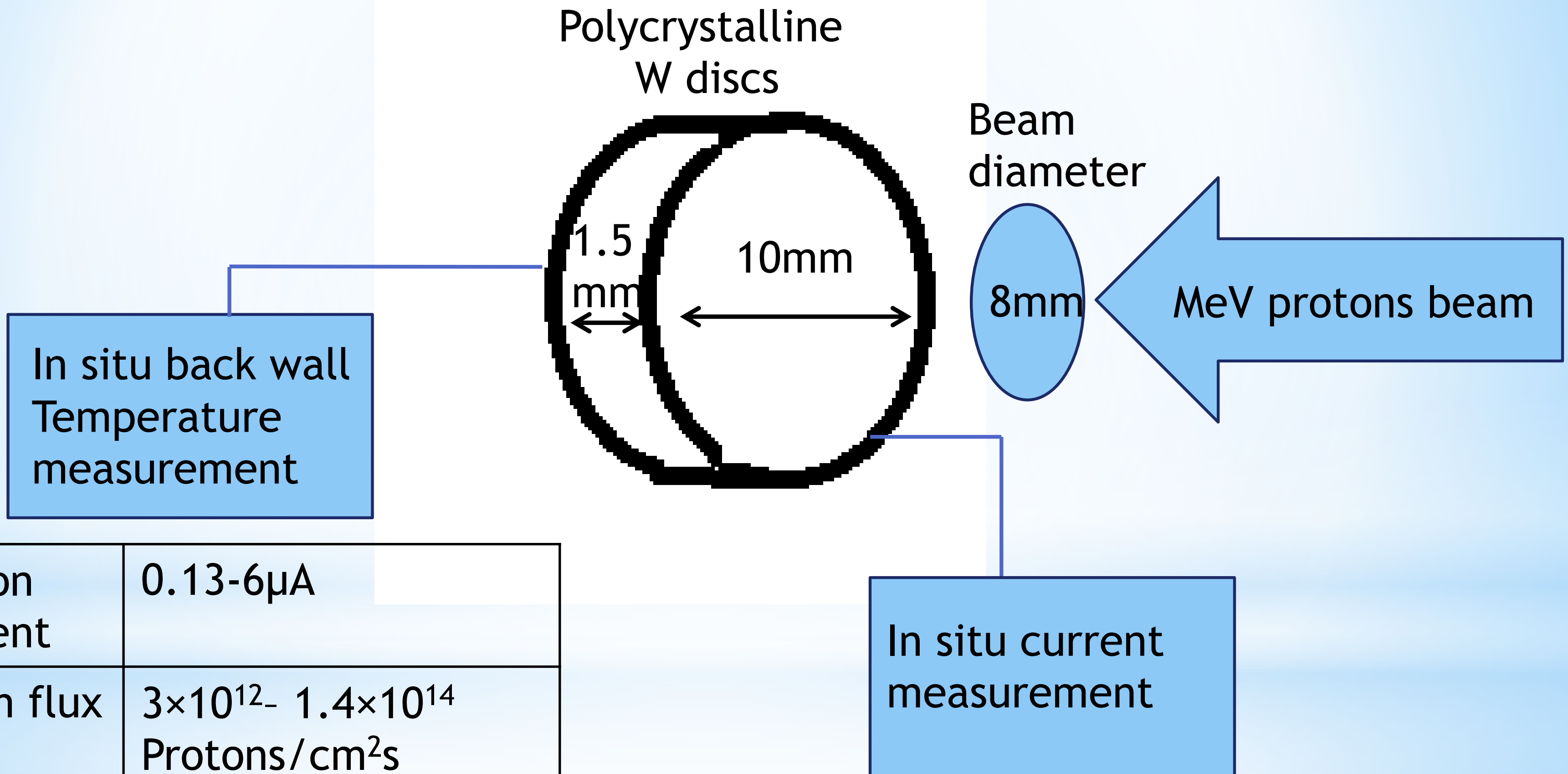
Why Tungsten?

* High Z metal---Low sputtering yield
* Excellent Thermal and Mechanical properties
* Does not create hydrides
* High mobility of H and low solubility---rapid diffusion to surface and evaporation

Nevertheless…
Hydrogen blisters have been identified as a key mode of tungsten degradation under proton irradiation.

Example of Blisters Radiation damage in SARAF beam dump (W)

Experimental



Proton current	0.13-6μA
Beam flux	3×10^{12}– 1.4×10^{14} Protons/cm^{2}s
Total dose	$1.4\text{-}9.5\times10^{17}$ protons/cm^2

keV vs. MeV protons

	keV	MeV
Implantation range	nm scale	Microns scale
Sputtering	Intensive sputtering	Minor sputtering
Irradiation temperature	Low	High
Blister formation critical dose	10^{18}-10^{20} protons/cm^2	**???**

* T affects diffusion processes

Therefore MeV Vs. keV is expected to differ in hydrogen retention, radiation damage evolution and blistering conditions

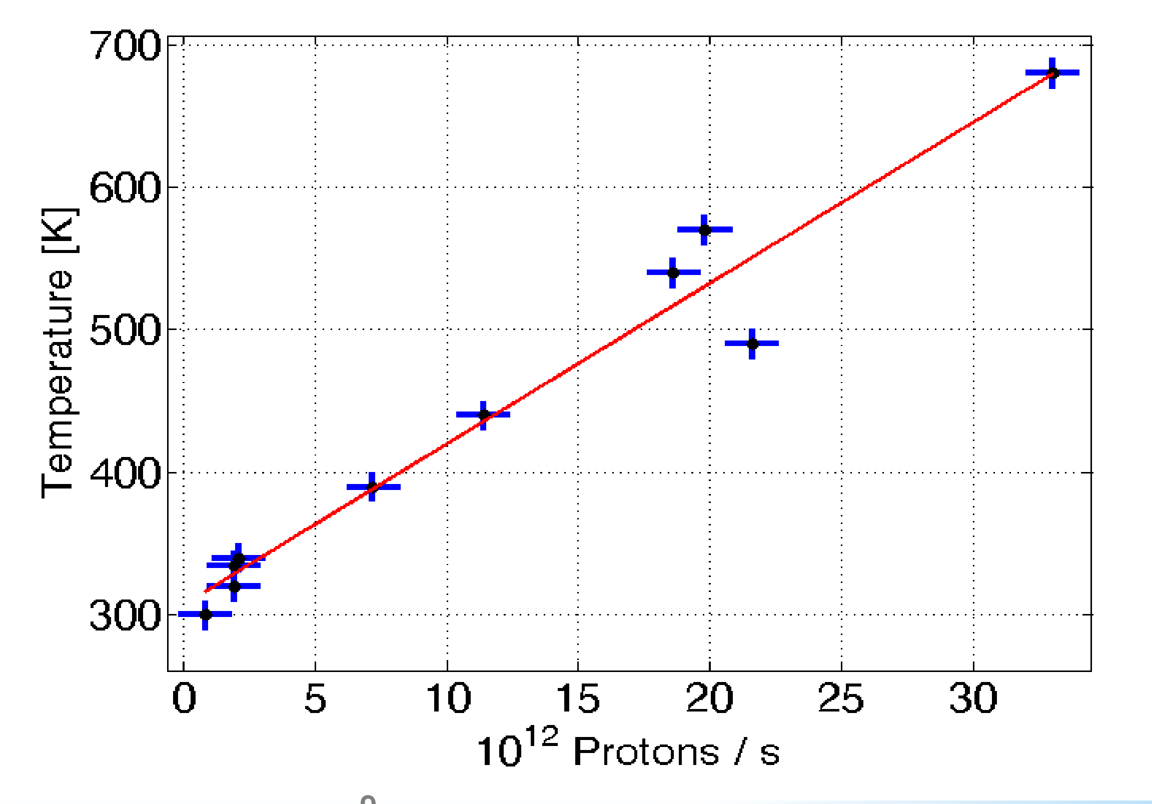
Research goals

* The main goal of this research is to explore the effect of irradiation by high energy protons (MeV's) on blister formation in W.
* At these high energies we expect deeper penetration of the protons in W, greater energy transfer and thus higher temperatures, all of which should affect the nature, density, and evolution of the radiation induced defects in the material.
* In particular, we shall focus on Nucleation and growth of hydrogen blisters, and the material and irradiation parameters controlling them.

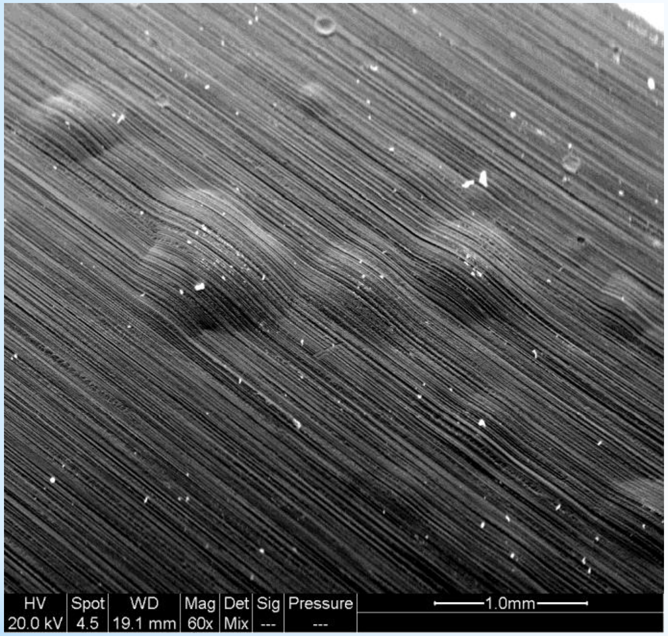
Results - Irradiation T & current

A linear relationship is obtained between the measured temperature and current

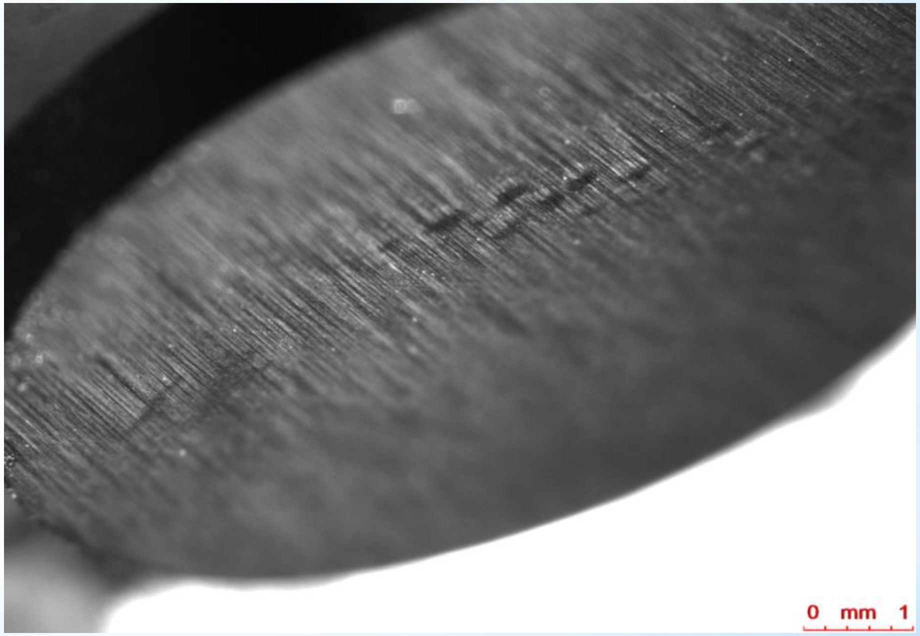
Low scatter - consistency between temperature and flux measurements



Results- blister formation



SEM



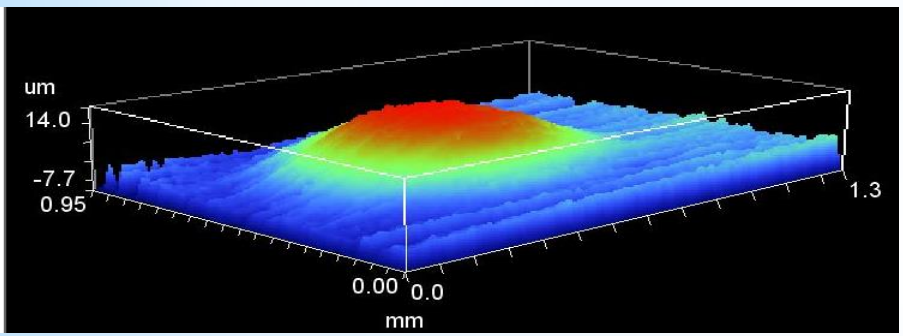
Stereoscope

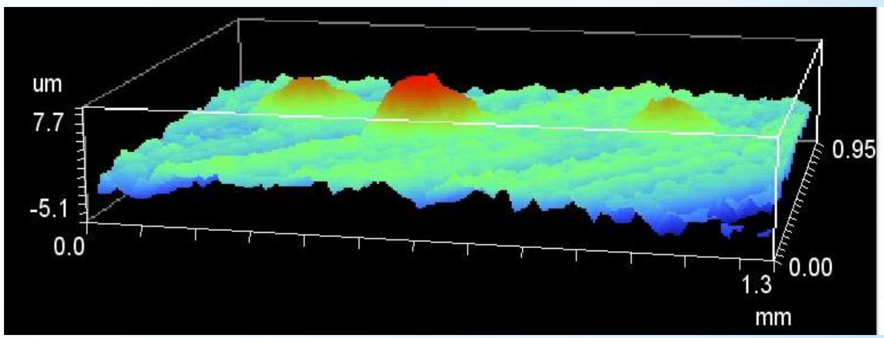
Results- blisters characterization

Each blister was characterized using 3D optical interferometry

Comparison of blisters obtained at samples with same total dose and different irradiation T

At high temperatures smaller blisters are formed





340K
Blister diameter: 700 µm
Height: 14µm

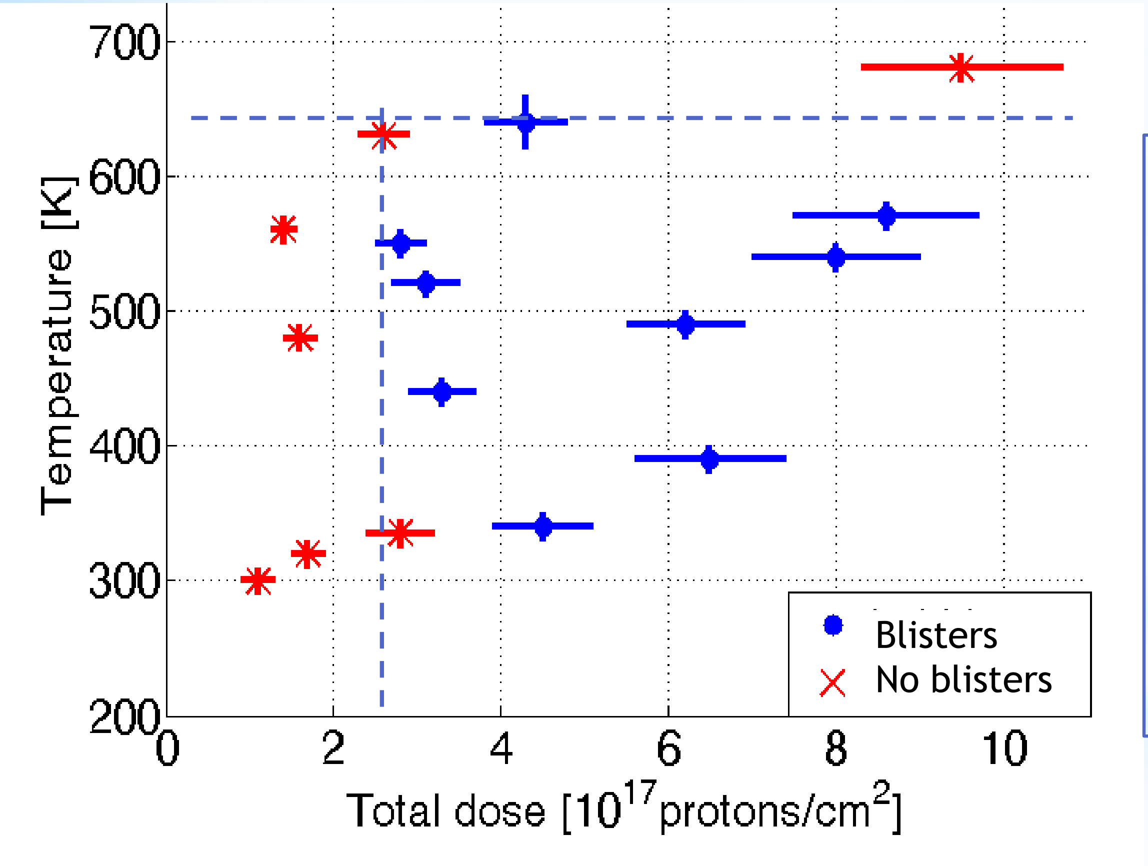
Same total dose
4.4×10^{17} protons/cm^2

640K
Diameters: 150-250µm
Heights: 3.5-6.5 µm

keVs---T increases : Height decreases ; Density decreases
MeVs--T increases: Height decreases; Smaller blisters

Results-Polycrystal W

- Blisters formation as a function of irradiation T and total dose. Dashed lines suggest possible boundaries of blisters formation.



- Critical formation dose **3∘10**^{17} p/cm^2.
- A maximum T for blisters formation - keV protons in W: 700-800K
- Critical formation dose in keV protons: **10^{18}-10^{20}p/cm^2**

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Results- blister characterization

Irradiation parameters	Diameter range	Total dose [ions/ cm^2]	Height range	density
2.2MeVprotons	100-700μm	10^{17}	2-15μm	1-10 blisters per 1 mm^2
keV protons	Typical diameter 0.1-3μm	10^{19}	0.1-0.5μm	~10^6 blisters per 1 mm^2
	Max. diameter of 80μm	10^{21}		

- Blisters from MeV protons obtained at low critical dose and very large

* Enomoto et al. J. Nucl. Mater. 385 (2009) 606.
** Wang et al. J. Nucl. Mater. 299 (2001) 124.

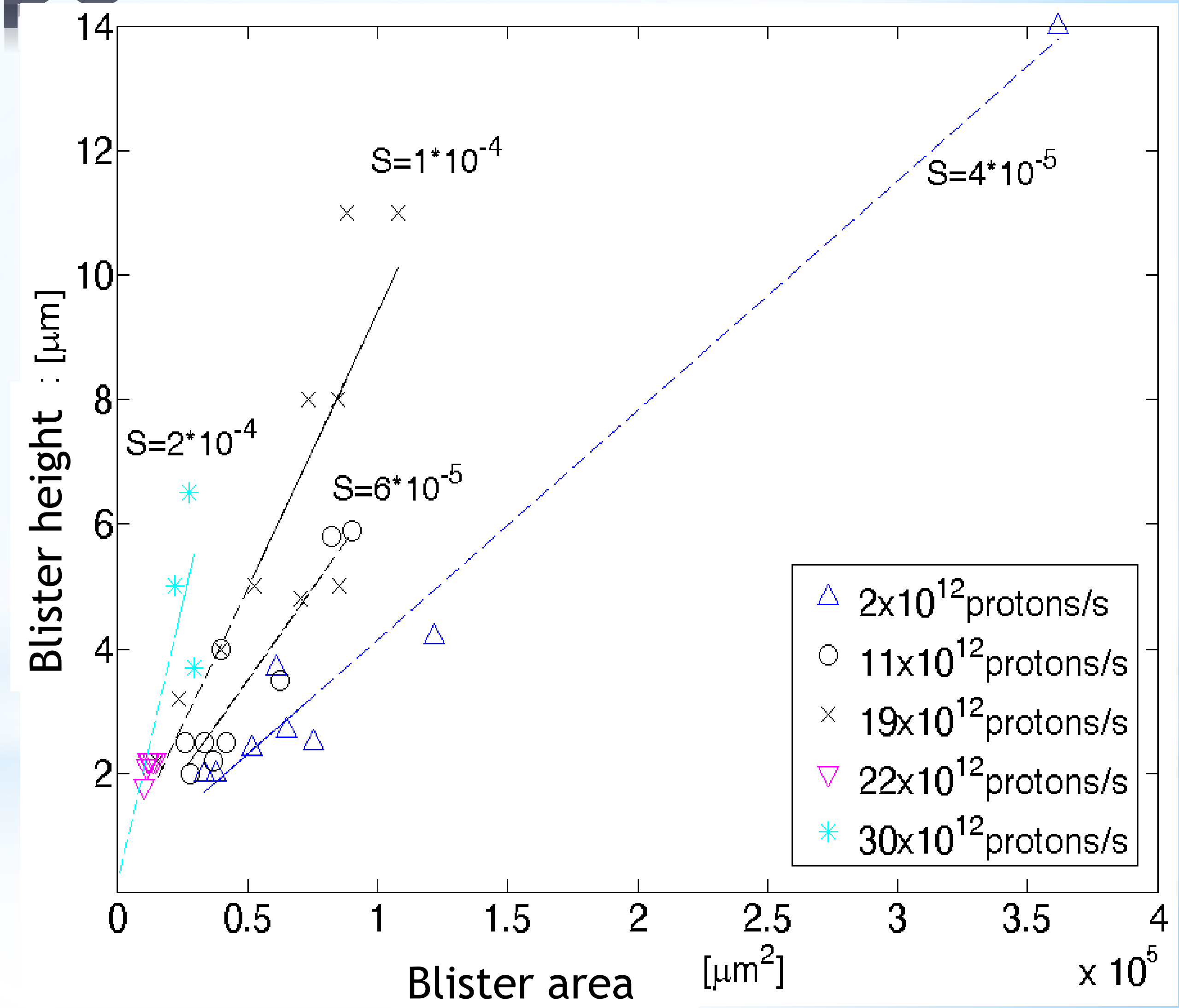
Low critical dose-Discussion

We suggest that the lower critical dose for blister formation in MeV is an outcome of the bulk implantation, far from the surface.

* In MeVs :
  * Hydrogen implanted far from the surface- Decreased H reaches the surface.
  * Decreased recombination of other defects with surface, increases the density of possible traps of H.
  * Decreased sputtering- increases the retained H.

Results - Effect of flux\T on blister shape

* Flux increases, ratio of blister height to area increases
* It could be that larger fluxes\temperatures contribute to higher stresses, allowing smaller area of blisters to elevate the cap.



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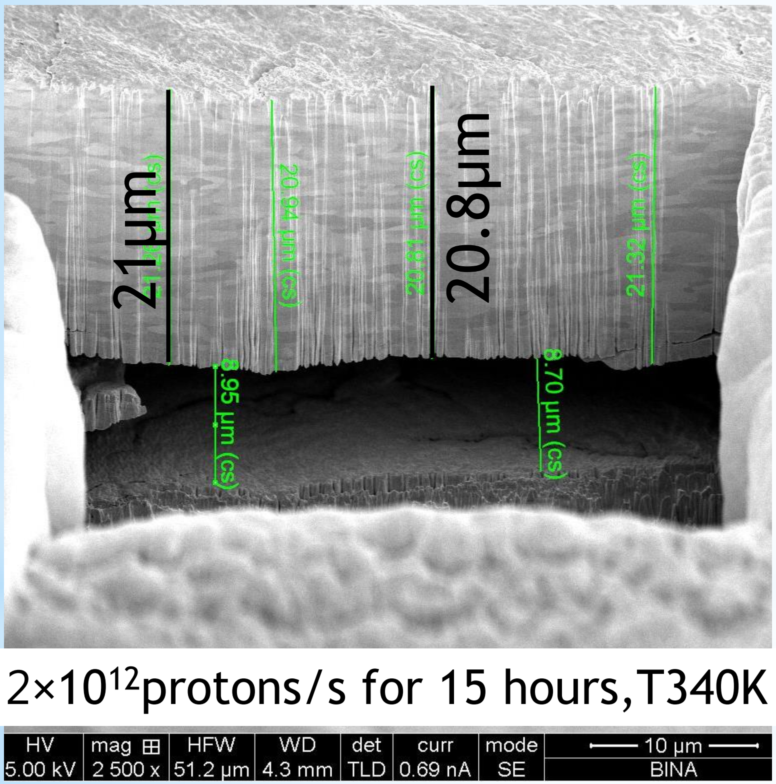
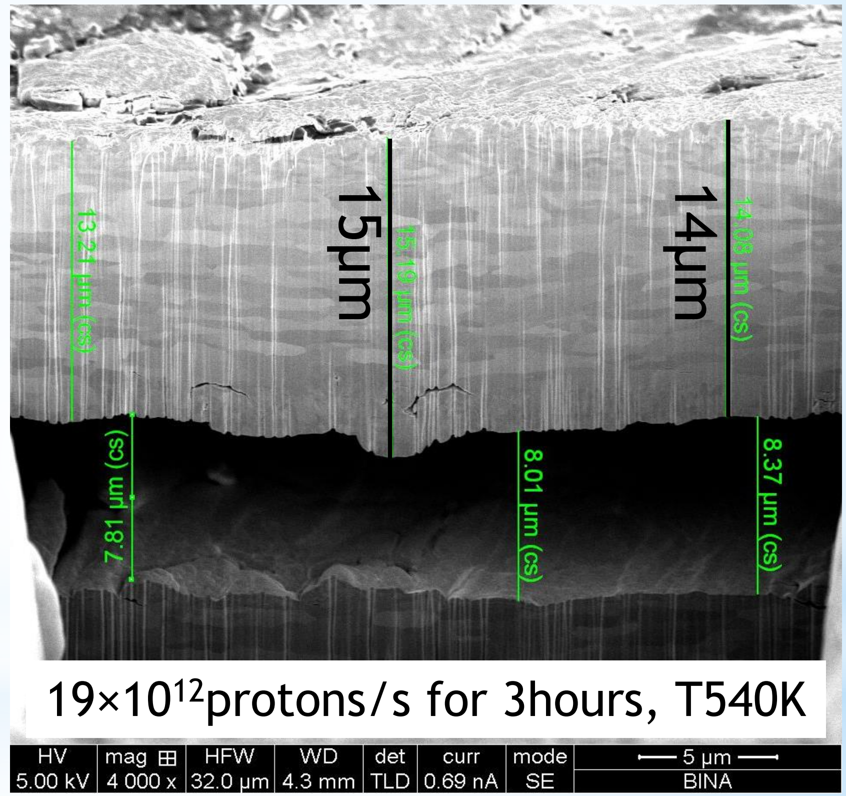
Results- single blister characterization

FIB cross section of blisters



2×10^{12}protons/s for 15 hours,T340K



19×10^{12}protons/s for 3hours, T540K

protons stopping range for 2.2MeV protons is 16.4±2.2μm (TRIM)

The cap of the blisters is within several microns of the stopping range

Summary and conclusions

1. Poly crystalline W samples were irradiated by 2.2 MeV protons, at a novel regime not explored previously.
2. Large, well developed blisters were obtained at sub critical dose (**$3 \circ 10^{17}$** p/cm^2)
3. We correlate it to the bulk implantation, far from the surface.
4. We saw an effect of the irradiation flux\temperature on blisters dimensions.
5. The blister cap was found to be within several microns with stopping range

Single crystal- High T results

* W single crystals (110) irradiated by 2.2MeV protons at SARAF
* Critical blisters formation dose increases to ~**$4X10^{18}$P/cm^2**

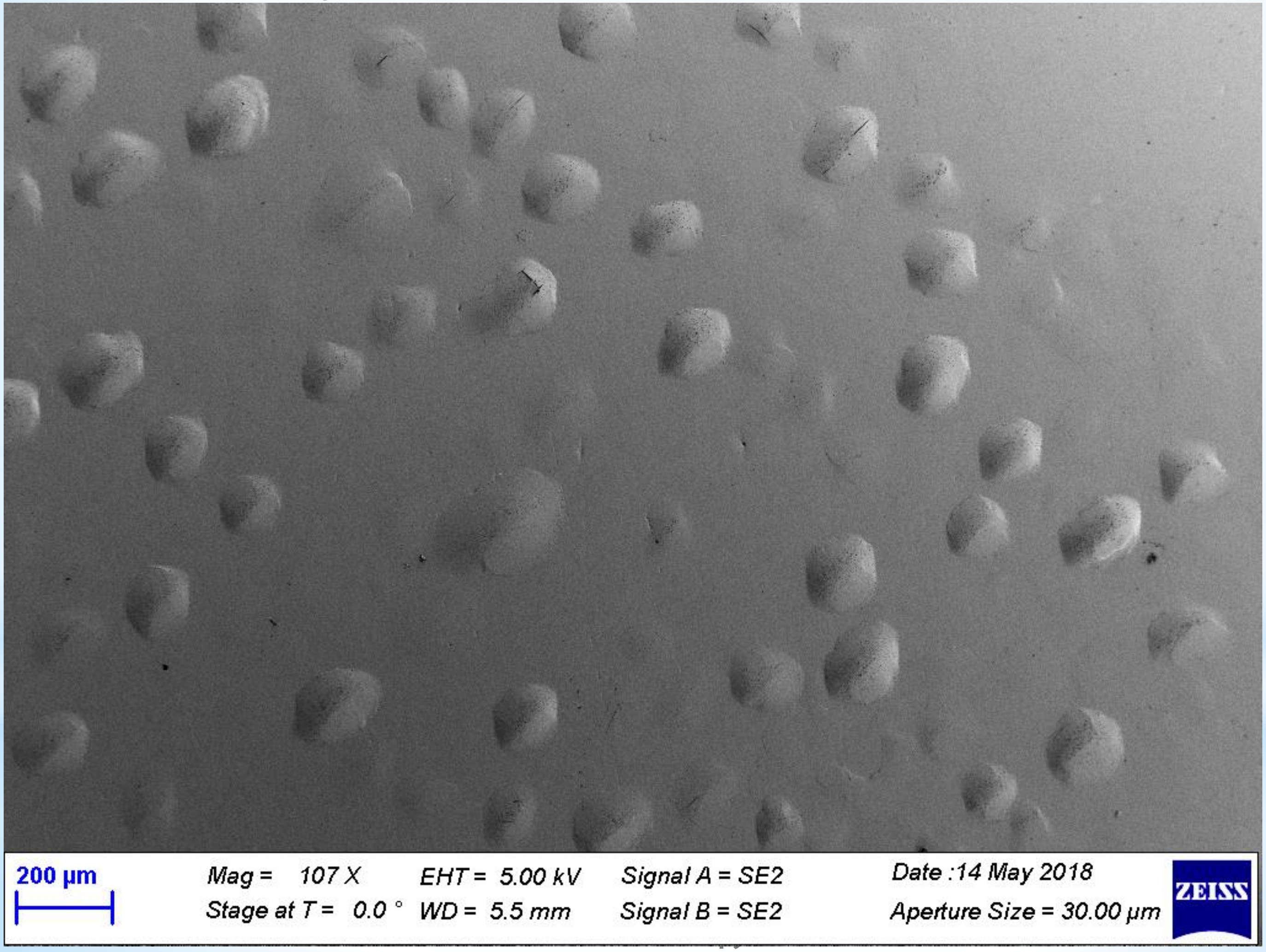
	2.2MeV			1.5keV	
	PC	SC		PC	SC
Critical dose[P/cm^2]	$3\circ10^{17}$	$4X10^{18}$		10^{18}-10^{20}	10^{19}
Blisters diameter[μm]	120-700	50-80	120-180	0.1-3	1
Blisters Height	2-15μm	50-200nm	1-10μm	200-700nm	150-500nm

Due to higher critical total dose in SC, Temperature controlled experiments are needed to reach the critical dose at reasonable time.

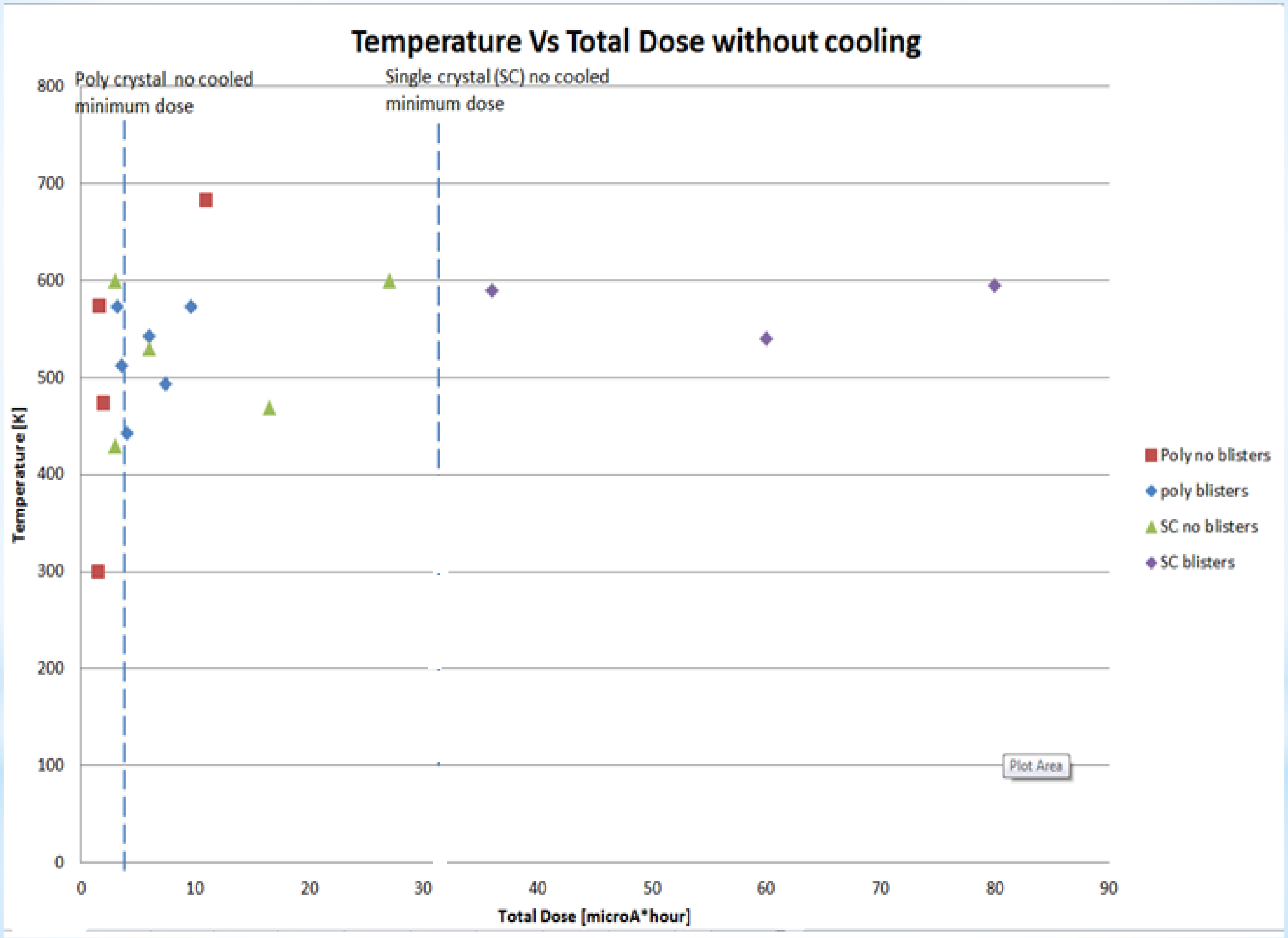
* Enomoto et al. J. Nucl. Mater. 385 (2009) 606.
** Wang et al. J. Nucl. Mater. 299 (2001) 124.

Single crystal- High T results

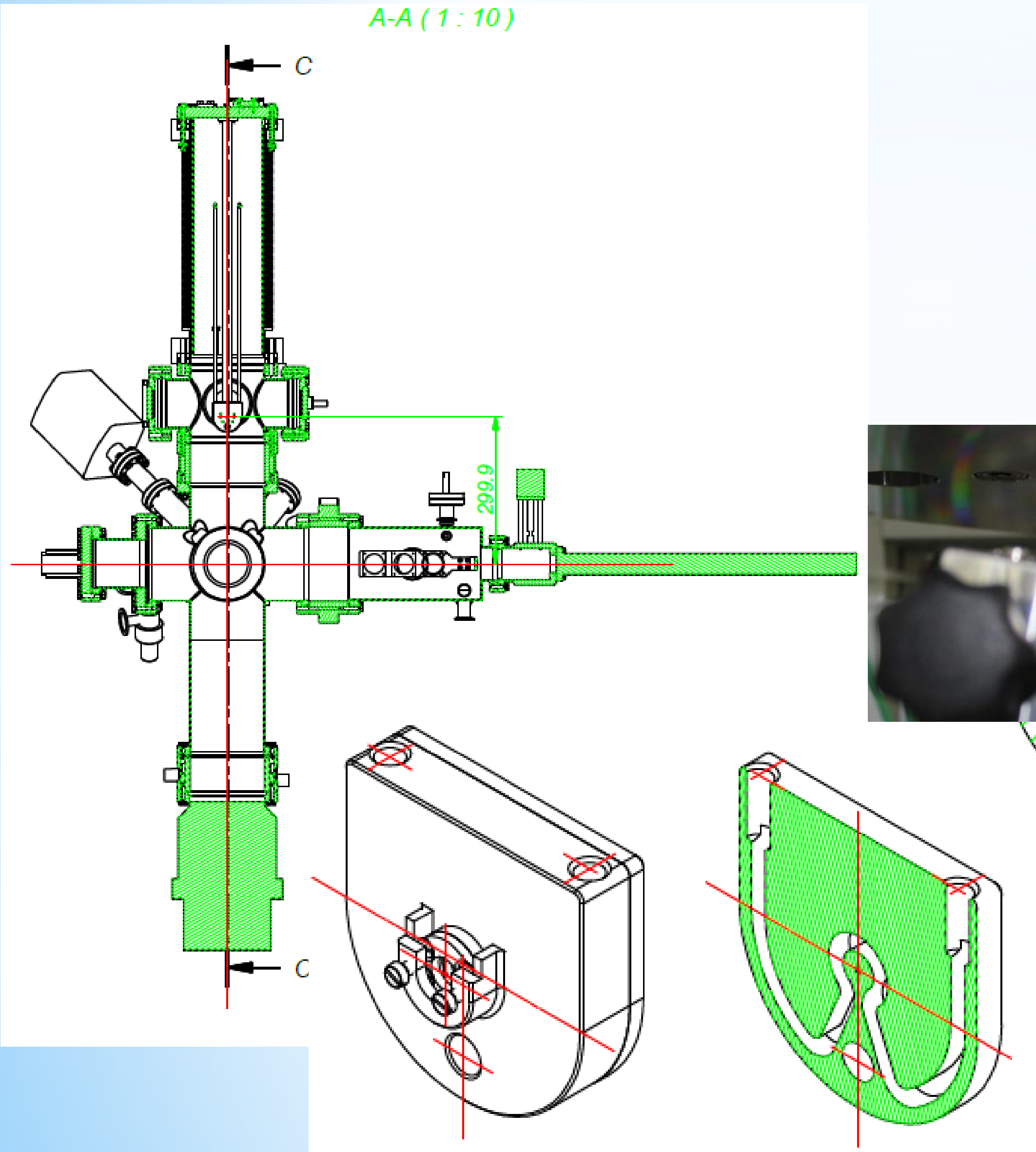
High total dose irradiation

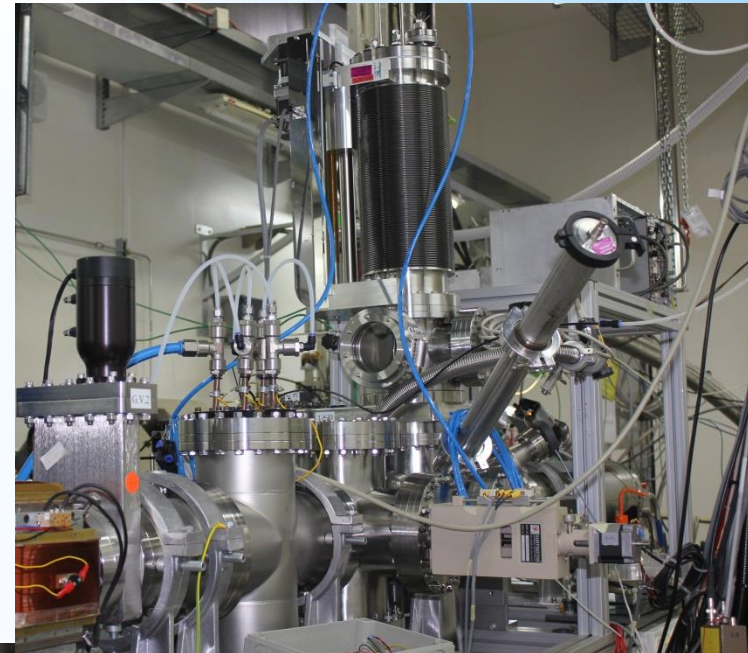


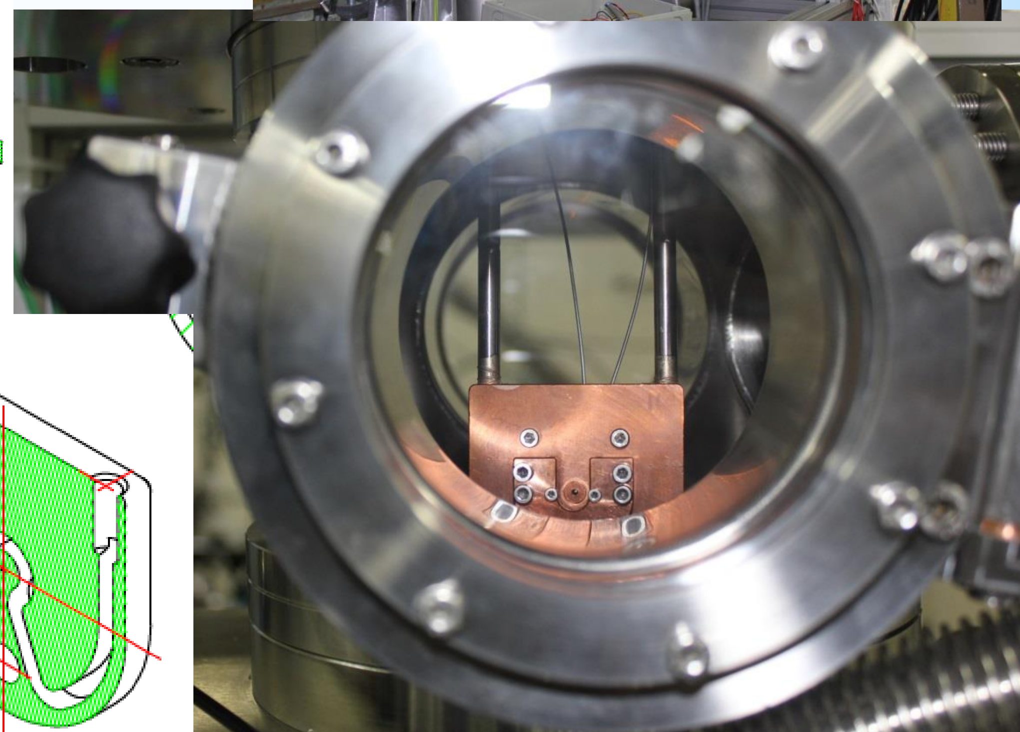
Single crystal- High T results



Cooled Target Cell







Results from the cooled target experiments are being analyzed these days,

Please stay tuned…

Special Thanks

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