TRIUMF
CANADA'S NATIONAL LABORATORY FOR PARTICLE AND NUCLEAR PHYSICS

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TRIUMF Extraction Foil Developments and Contamination Reduction

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- Foil and Frame Developments
- Contamination Reduction
- Conclusions

LABORATOIRE NATIONAL CANADIEN POUR LA RECHERCHE EN PHYSIQUE NUCLÉAIRE ET EN PHYSIQUE DES PARTICULES

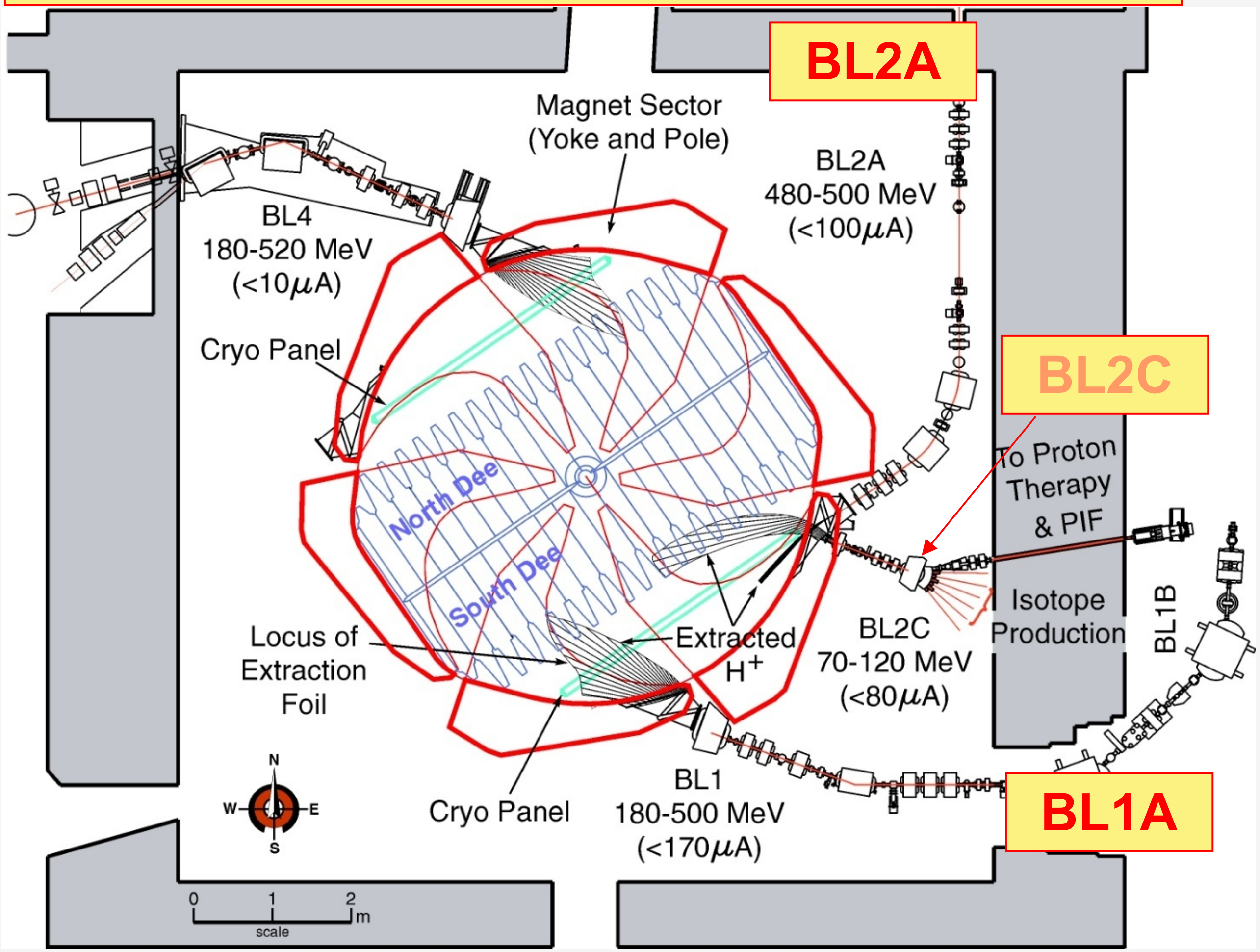
Propriété d'un consortium d'universités canadiennes, géré en co-entreprise à partir d'une contribution administrée par le Conseil national de recherches Canada

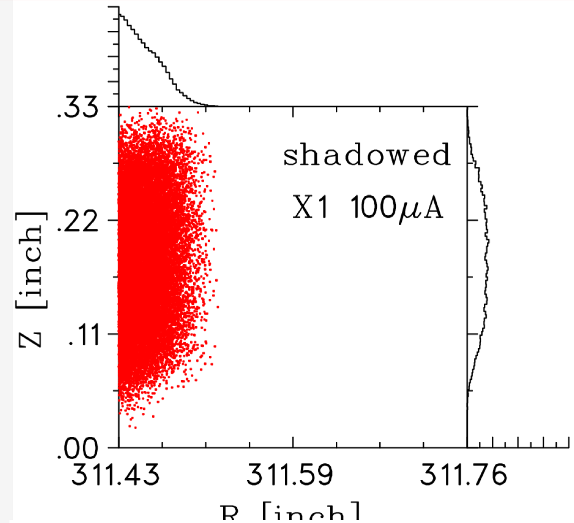
TRIUMF 500 MeV H^- Cyclotron

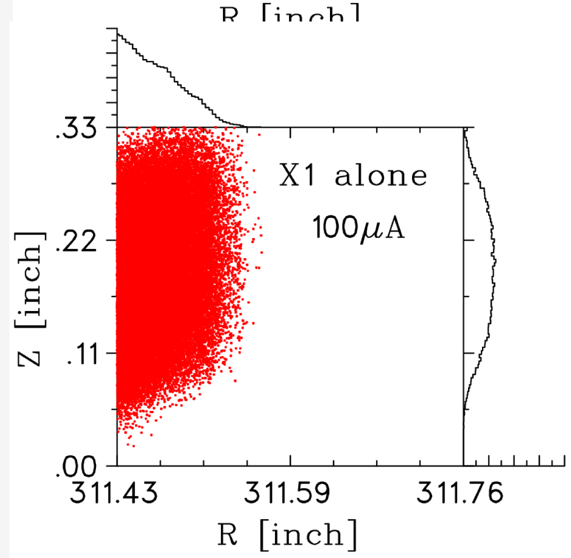
Using stripping extraction

Beam density on foils in radial shadow is 40% higher than in single extraction case

Delivered up to 320µA for production over the last 10 yrs: 140µA(BL1A) + 100µA(BL2A) + 80µA(BL2C)

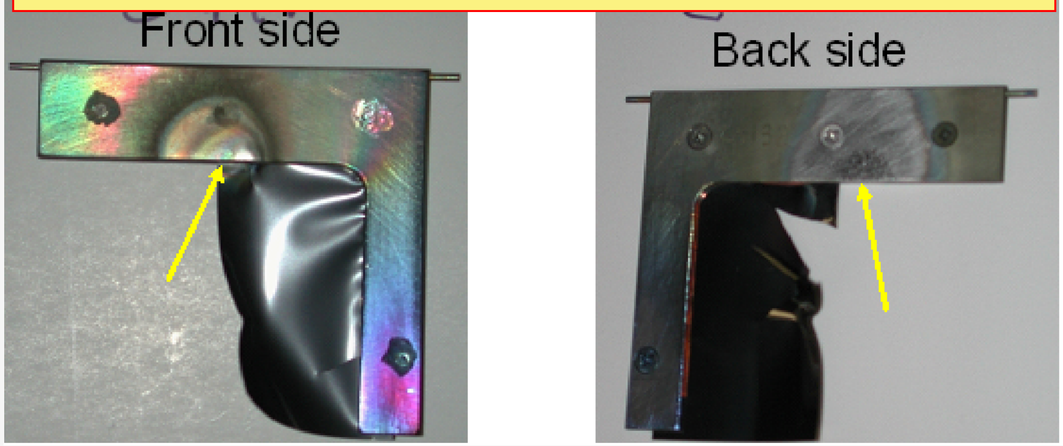






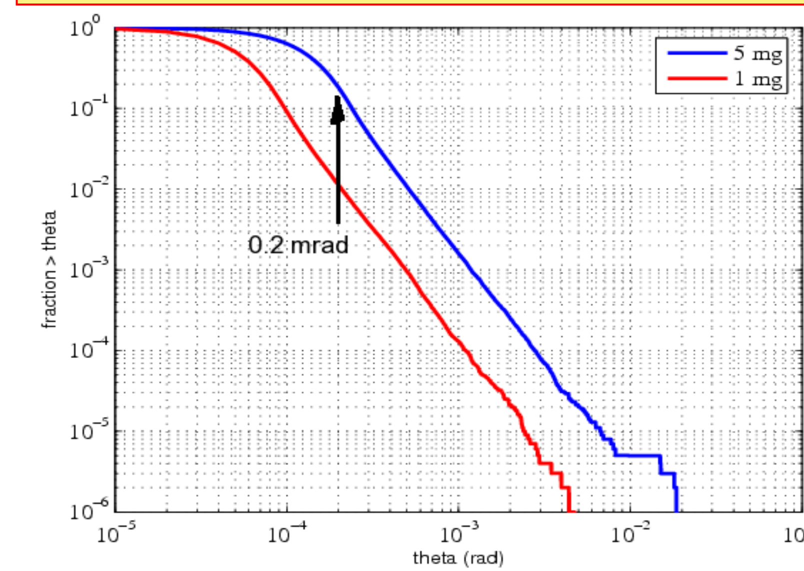
Failure Modes and Activation Issues

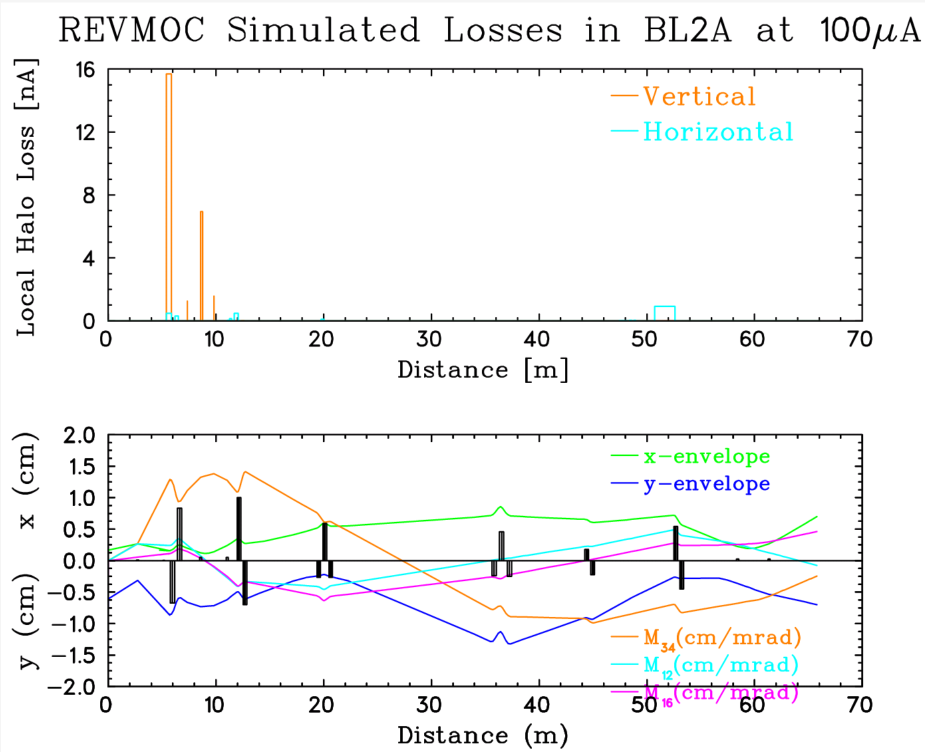
Frame over-heated, foil warped and cracked



- The ^{7}Be contamination has in the past decade been observed near the main extraction stripper;
- Stripping foils warped or even broke after an accumulation of 60mA-hrs, which could take three to five weeks.

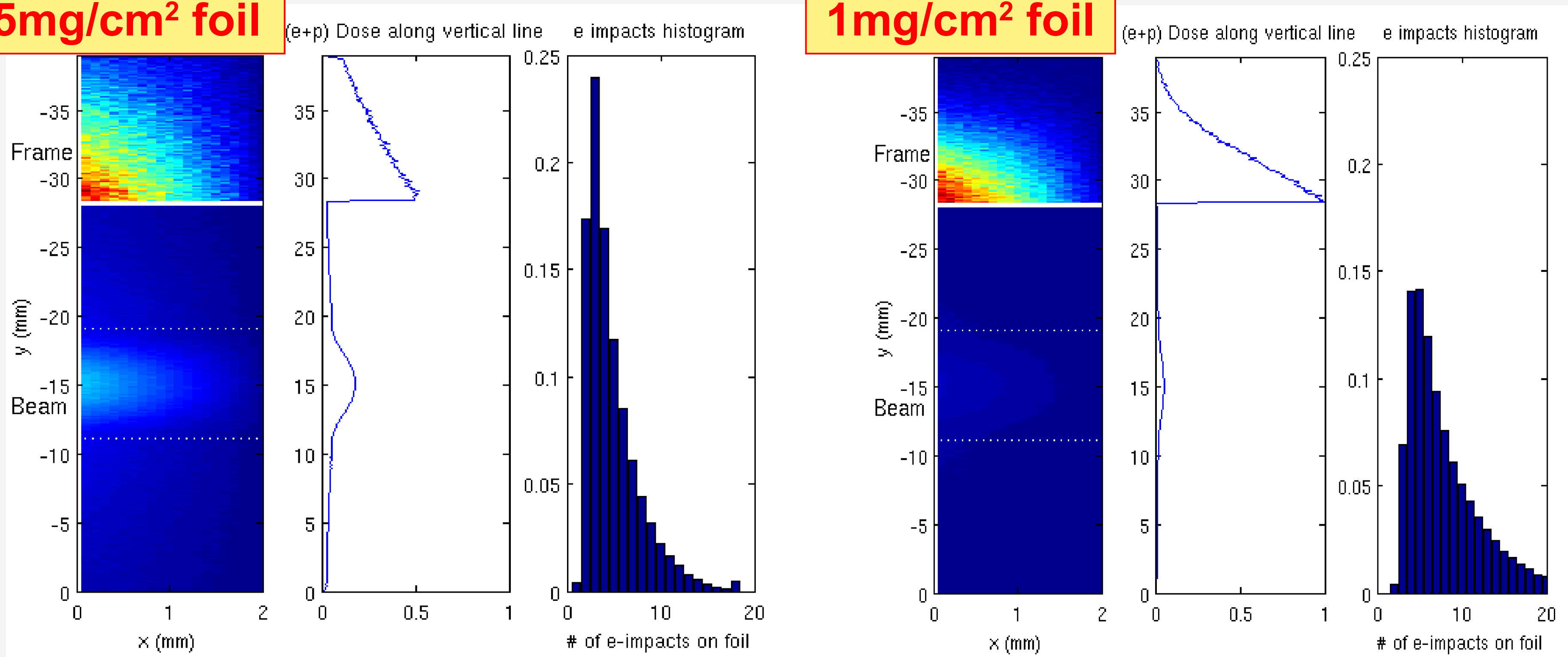
With 5mg/cm^2 foil, over 6x10^{-5} particles have angle >3.3 mrad, these are outside 4" beam pipe as R_{12} reaches ~1.5 cm/mrad at max.





Electron Heating Simulations

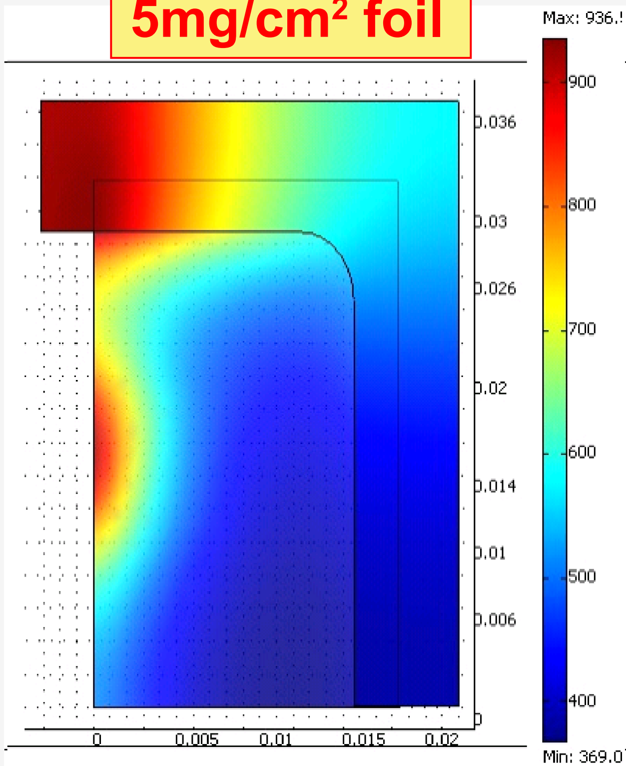
5mg/cm² foil | **1mg/cm² foil**



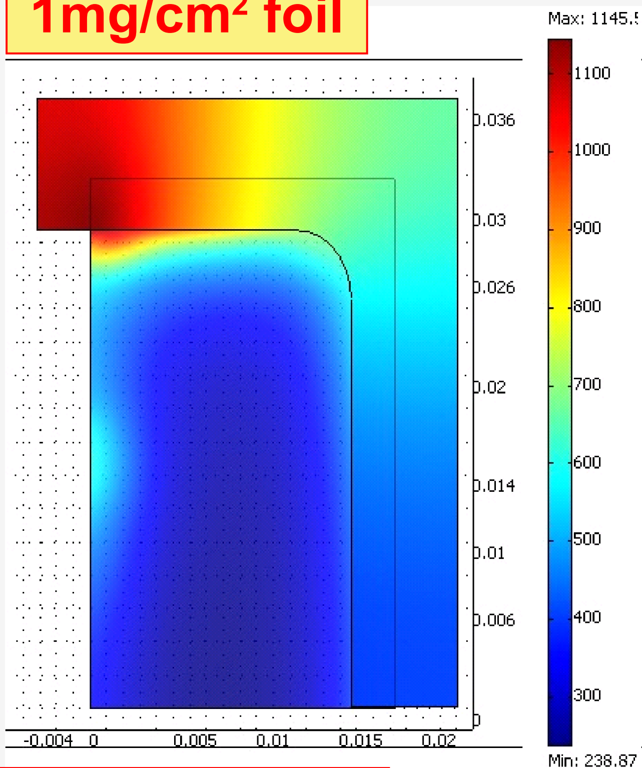
- Stripped electrons pass through the foil;and then spiral around the magnetic field and cross the foil repeatedly. At every crossing, the electrons lose energy longitudinally and scatter transversely. Electrons that migrate upward sufficiently to reach the foil frame are stopped there, depositing all remaining energy. Protons pass only once through foil or frame.
- The dose maximum is not in the foil but in the frame. This is because scattering dominates over straggling; roughly half of electrons reach the frame before they have lost any significant amount of energy, especially for thin foils; the other half are lost off the bottom.
- The thinner the foil, the fewer energy deposited at the proton spot where ^{7}Be isotopes are created.

Temperature Calculations

5mg/cm² foil



1mg/cm² foil



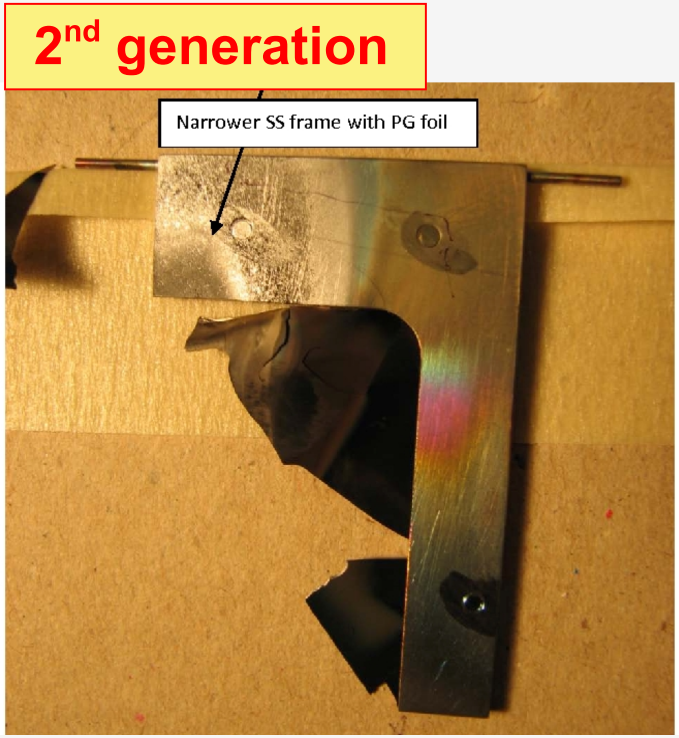
Max. temperature ((in °C) on the foil at beam spot vs. foil and frame materials

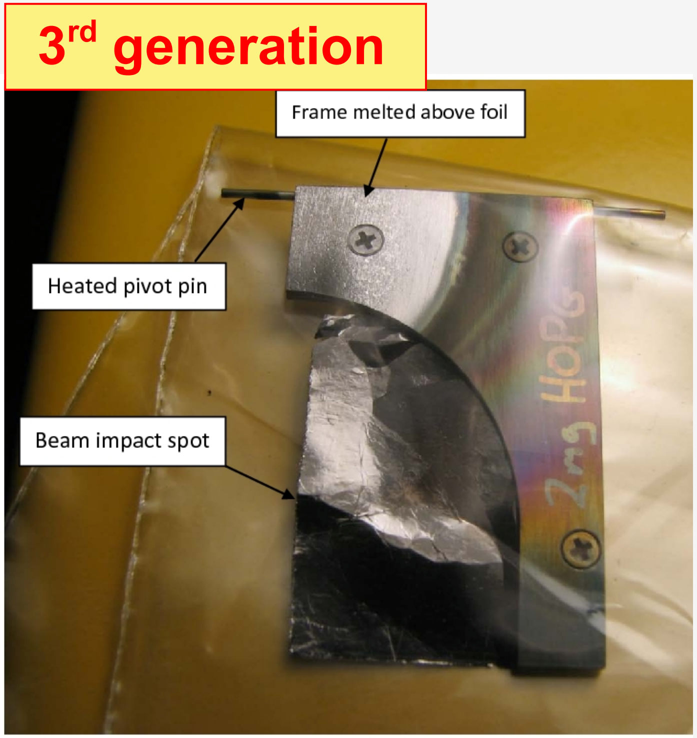
	PG		HOPG	
	Foil	Frame	Foil	Frame
SS304	780	1092	630	1045
Tantalum	780	940	640	900
Molybdenum	780	850	640	810
Tungsten	780	840	640	800

- Thicker foil results in higher temperature on the foil at location of beam spot where the protons create ^{7}Be. Since lower foil temperature reduces the amount of ^{7}Be released, it was decided to reduce the foil thickness to ≤2mg/cm² .
- With HOPG, the foil temperature is lower by 140 °C than with PG. With Ta frame, the frame maximum temper. is lower by 150 °C than with SS304; for Mo or W, the frame temper. is even lower. These results contributed to the decision to employ HOPG for the foil and Ta for the frame.

Foil and Frame Developments

A number of changes were made over the years to reduce the temperature rise on the foil and frame

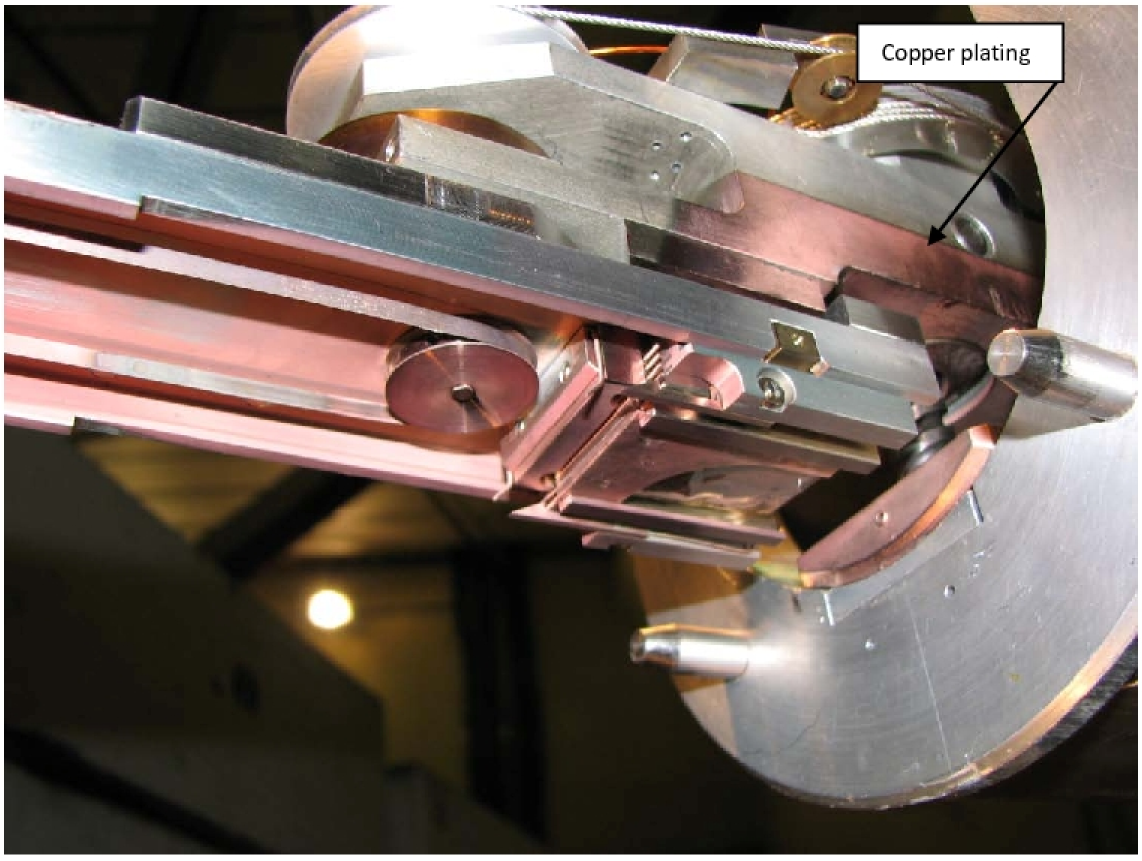




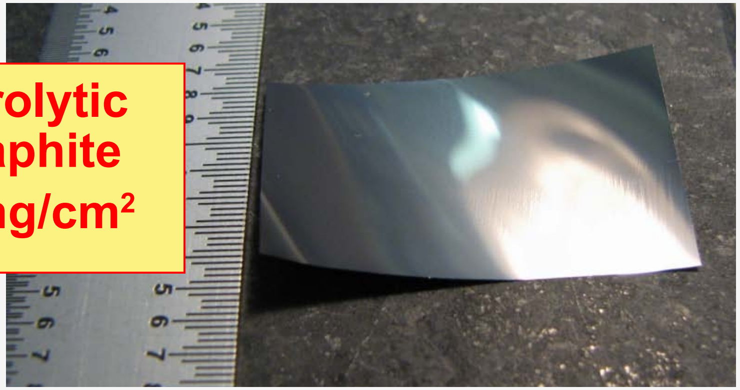
- The first attempt made was using a narrower frame while the material remained stainless steel (the 2nd generation). Still, the frame became thermally damaged and the foil was broken.
- For the 3rd generation, a larger radius was used for the frame inside corner to try to reduce the stresses on the foil material (HOPG). This was marginally successful, but the frame still suffered some damage.

Foil and Frame Developments-cont'd

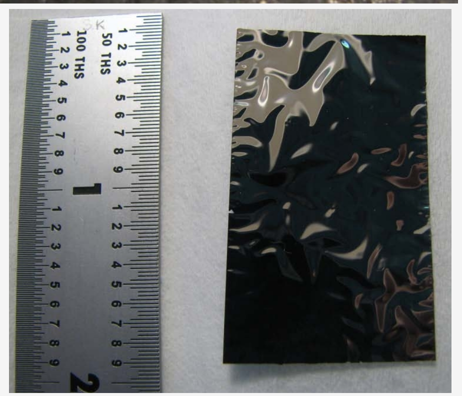
- Also, a copper frame assembly was experimented with the same shape as the 3rd generation frame, but it yielded disastrous outcome: the frame was partially melted and copper was deposited on the probe arm and surrounding parts.



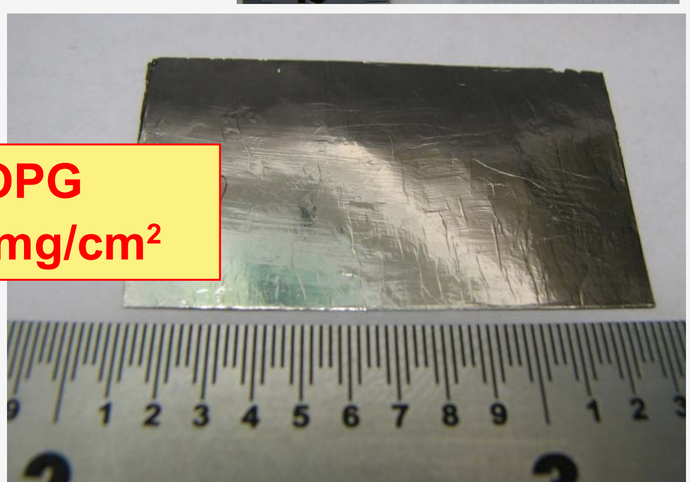
Foil and Frame Developments-cont'd



Pyrolytic graphite
2.5mg/cm²



Diamond foil
1-2 mg/cm²



HOPG
1.5-2.5mg/cm²

- Pyrolytic graphite of 5 mg/cm² was used until 2006. Thinner PG of 2.5mg/cm² was used in the years 2007 and 2008, and did increase the foil life but only marginally.
- Diamond foil was tried but proved to be no more reliable than the lighter PG. It was also brittle and hard to mount in the foil assembly.
- Finally from 2009 to the present, highly oriented pyrolytic graphite(HOPG) was used. This foil material has been extremely reliable, and is now used for high current extraction on all extraction probes.

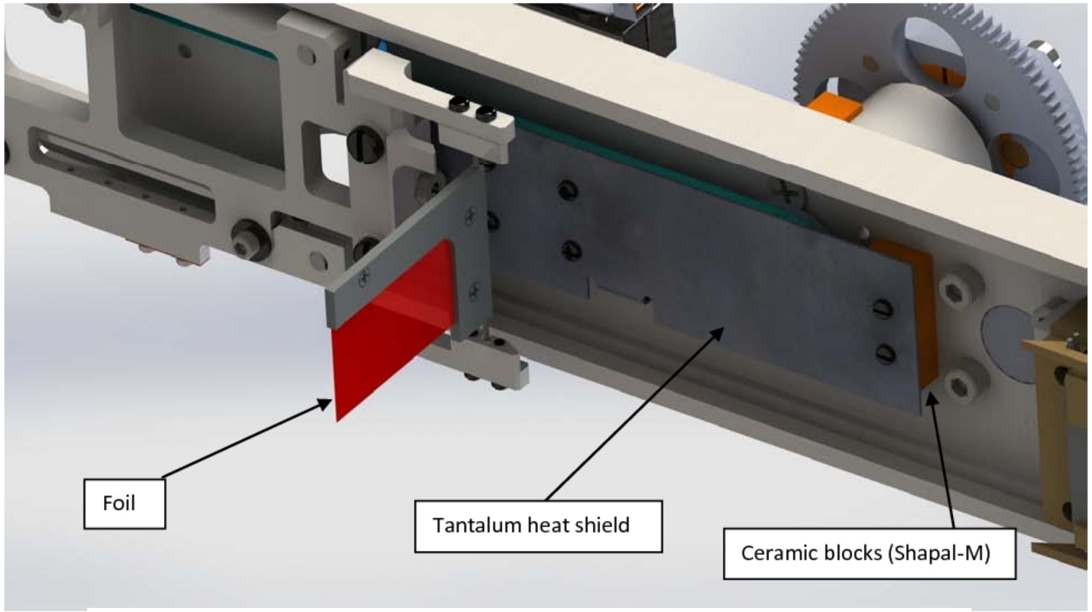
Foil and Frame Developments – cont'd

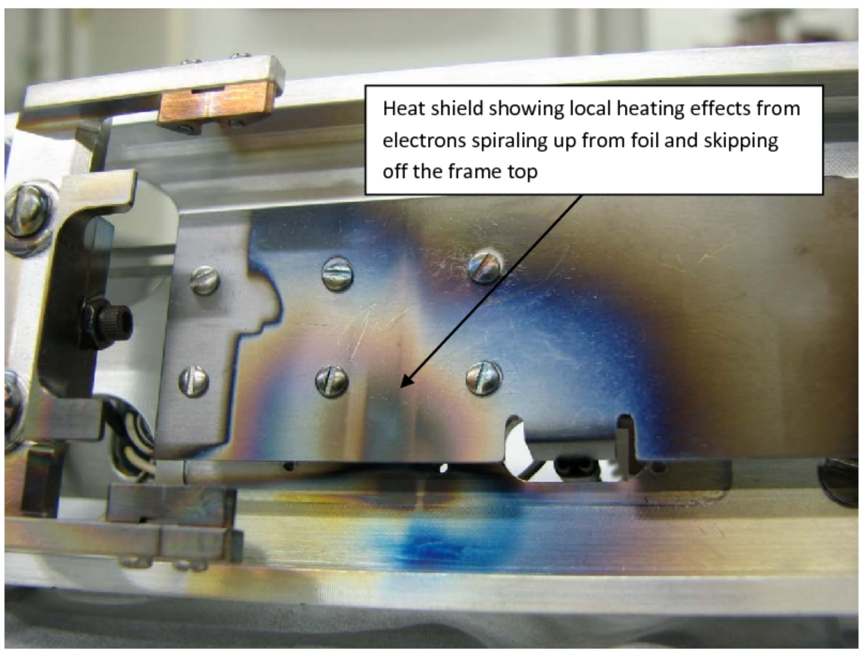
4th Generation (brand new)

A used one (accumalated 176 mA-hr)

- The frame material was changed to Ta in 2009 with a thin copper cushion sandwiched between the plates and foil to relive the stress of the foil.
- The large corner radius was kept to better support the foil and reduce any stresses on it.
- The frame over-heating and damage issue has disappeared. The foil life time increased dramatically, with a record set in 2010 of 253 mA-hr accumulated in 17 weeks. This was 4 times longer than the typical foil life using the 5mg/cm^2 PG foil and a stainless steel frame. Also, all indications were that it was still in good operational condition, and swiping did not show any ^{7}Be contamination at the probe.

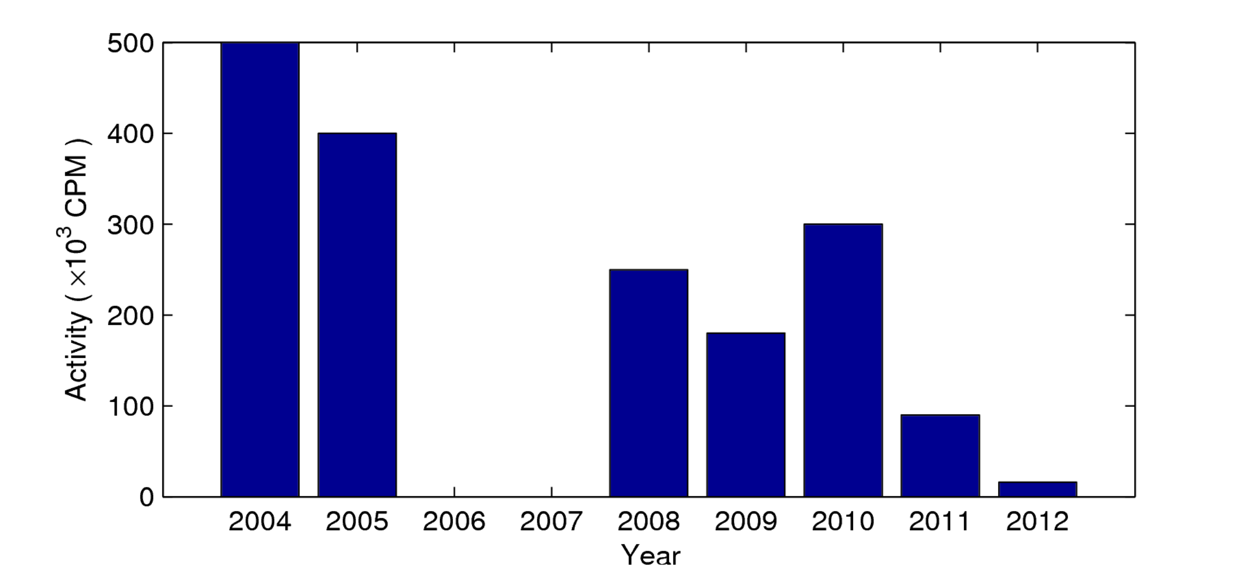
Additional Heat Shield





- In order to minimize heating to the Mo tape which drives the trolley along the probe arm, a Tantalum shield, mounted on a ceramic (Shapal-M) blocks, was installed to absorb and spread out the heat from the electrons skipped above the foil frame. Also, a current signal is taken from this plate.

Tank Contamination Reduction



- Since the 2004 year-end shutdown, ^{7}Be contamination has been discovered in the vicinity of the main extraction foil (1A). With the use of the thin, higher quality HOPG foil and Tantalum frame of improved geometry, the foil heating is reduced and this retains the ^{7}Be inside the foil material instead of contaminating the surrounding environment.
- The tank contamination level surveyed around the 1A foil has been reduced by a factor of 5 to 10 in 2012.
- Should be mentioned that in 2012 the beam spot on 1A foil was lowered by roughly 6mm.

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Conclusions

- Through the electron heating simulations and the temperature calculations, we gained a better understanding of the problems that we had in the past with the extraction probes and foils and frames. We became aware that it was the over-heating of the frame due to the stripped electrons scattering vertically upwards along the magnetic field lines.
- The high temperature caused problems such as the ^{7}Be contamination, foils cracking and warping, and occasional mechanical malfunction of the probe.
- For mitigation,highly-orientated pyrolytic graphite is now used as stripping material, mounted in a tantalum frame with a thin copper cushion. Additional heat relief features were introduced in the mechanism of the extraction probe.
- These changes have resulted in foil lifetimes extended from the typical 60mA-hr to 250mA-hr for the 1A foil, operating at 140 μA and 480MeV with negligible release of ^{7}Be contamination.
- Also, these improvements have resulted in improved beam quality and stability; the amount of beam spill monitor trips has been significantly reduced.

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Thank You

For listening ...

But especially, the great success achieved in the developments of extraction probes and stripping foils was credited to the Diagnostics group and Beam Physics group.

Also, thank S. Kellog for prividing the photos.

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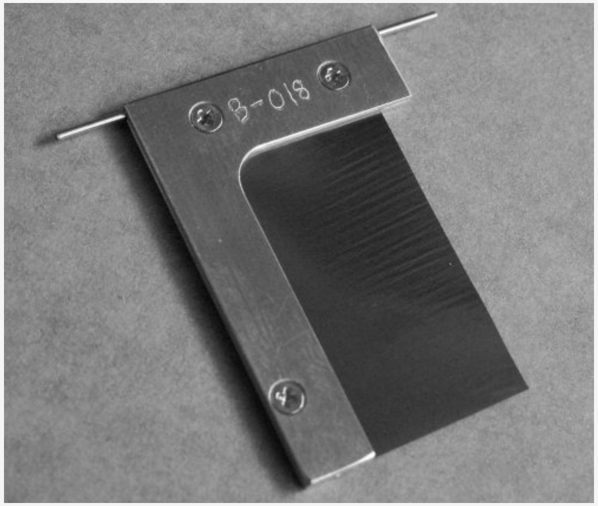
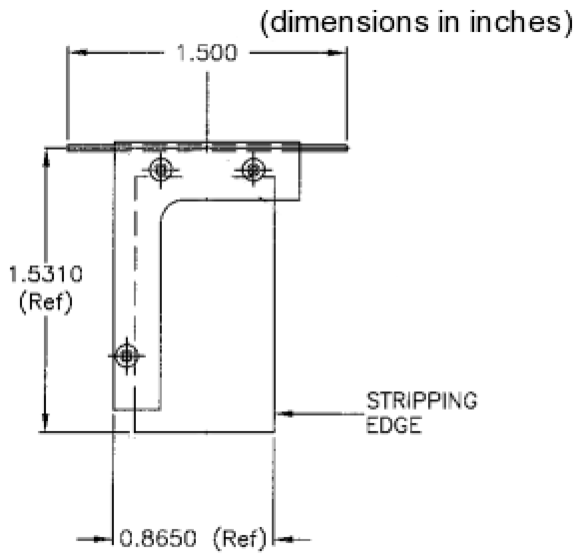
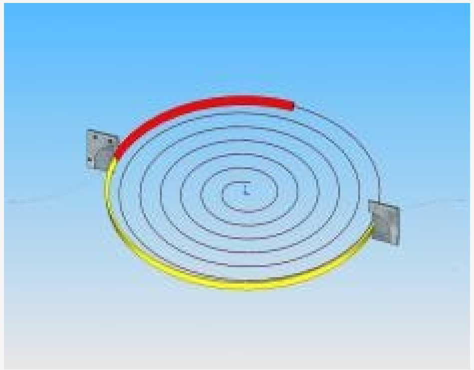
Foil Drawing

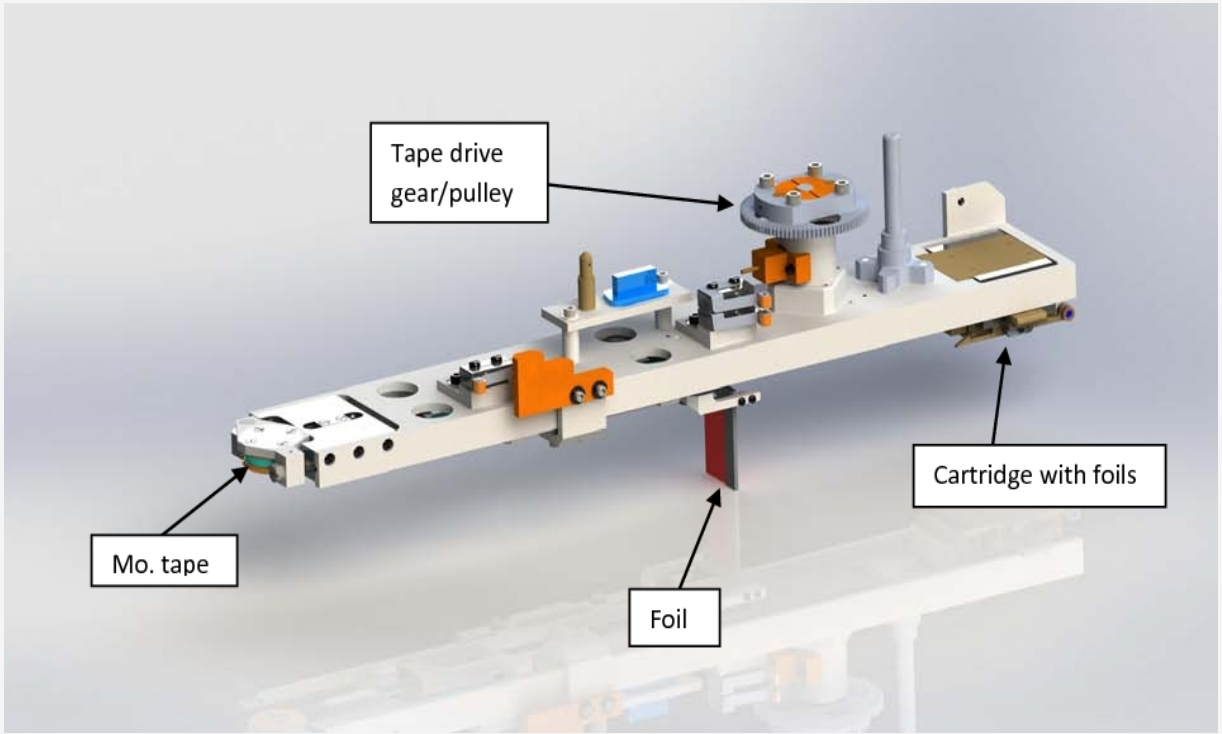




Radial Shadow

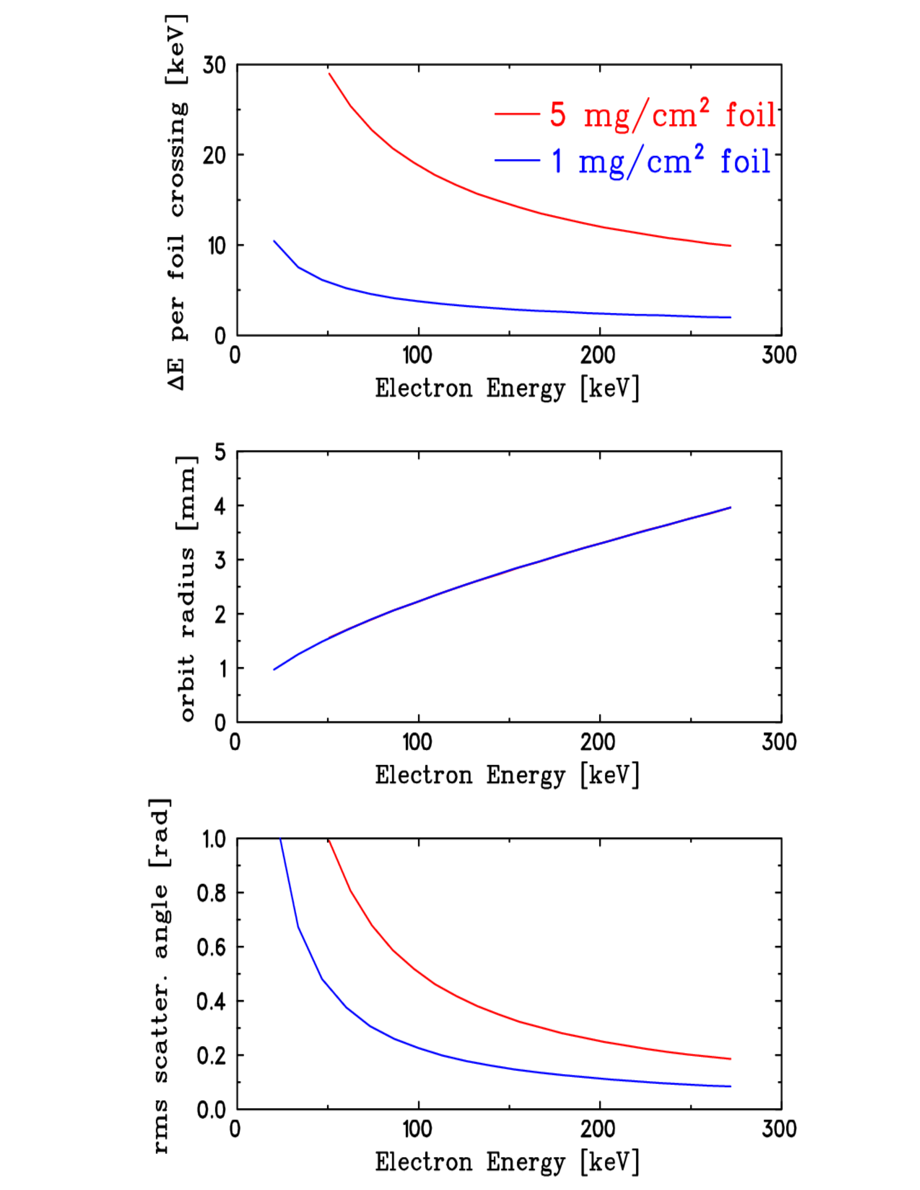


Extraction Probe

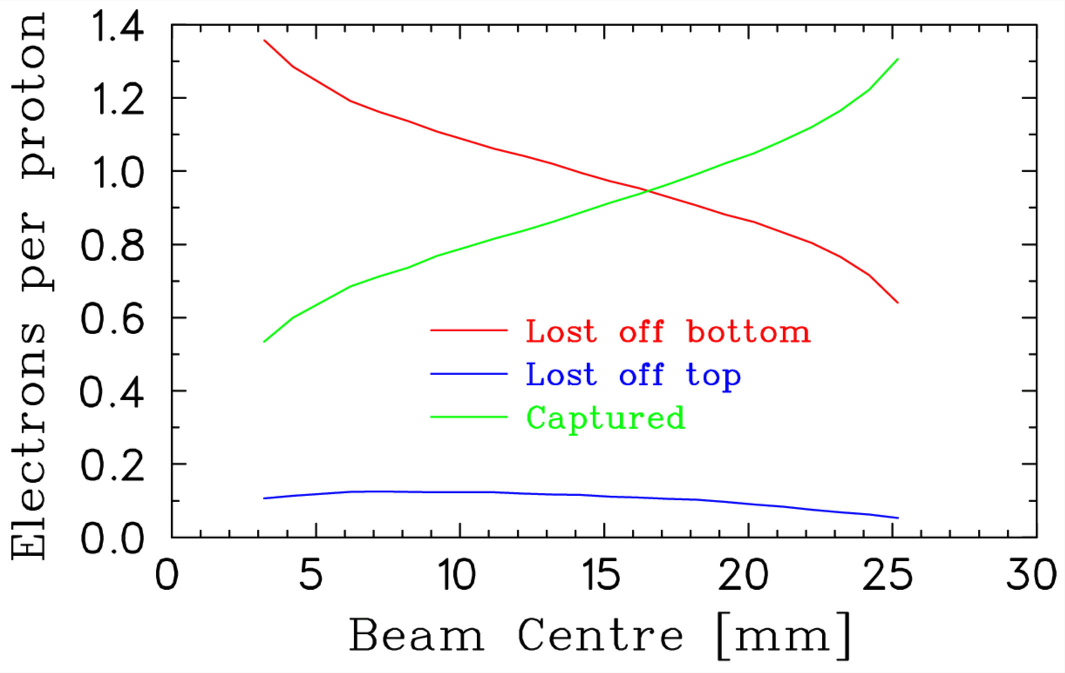


- The probe member extends into the tank. A cartridge, containing up to six foils, is mounted in the arm.
- Foils are picked up from the cartridge by a trolley which travels along the probe arm, driven by Molybdenum tape.
- After use the foil can be dropped remotely, inside the cyclotron, and the next foil in the stack picked up.

Electron Energy Loss and Scattering



Electron Capture



- Less than 2 electrons per proton would show up on the extraction probe current measurement; for most cases, even less than 1 electron per proton would be captured, as the beam is often nearer the bottom edge than the top. This means that that over half the electrons are lost off the bottom, and of those ones travelling upward, some even skip over the frame. Even when the beam is almost hitting the frame, only 1.3 electrons per proton are captured, while 0.65 escape off the bottom, 0.05 off the top. The top skipping ones will hit the heat shield.