Stripper foil developments at NSCL/MSU

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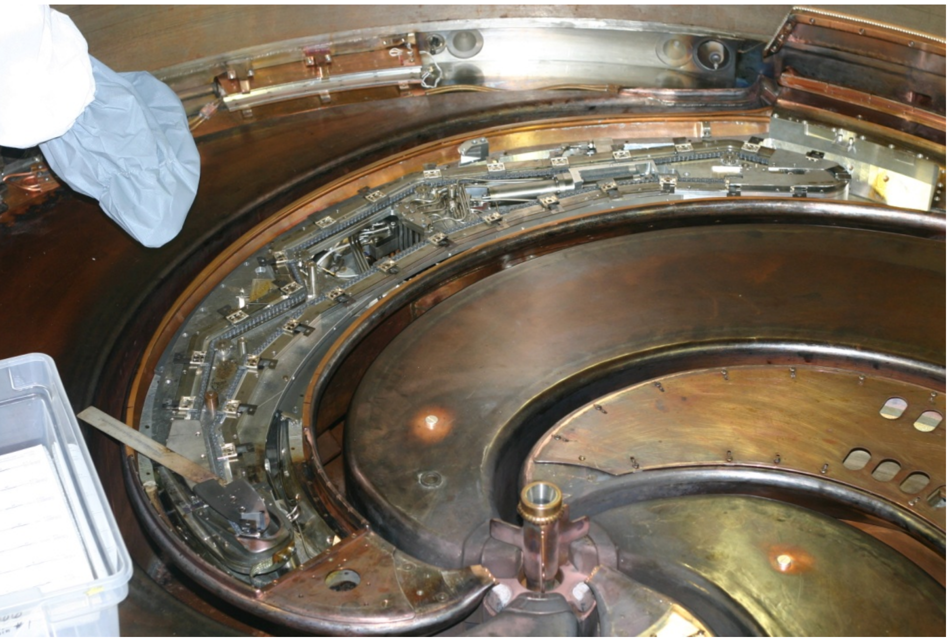
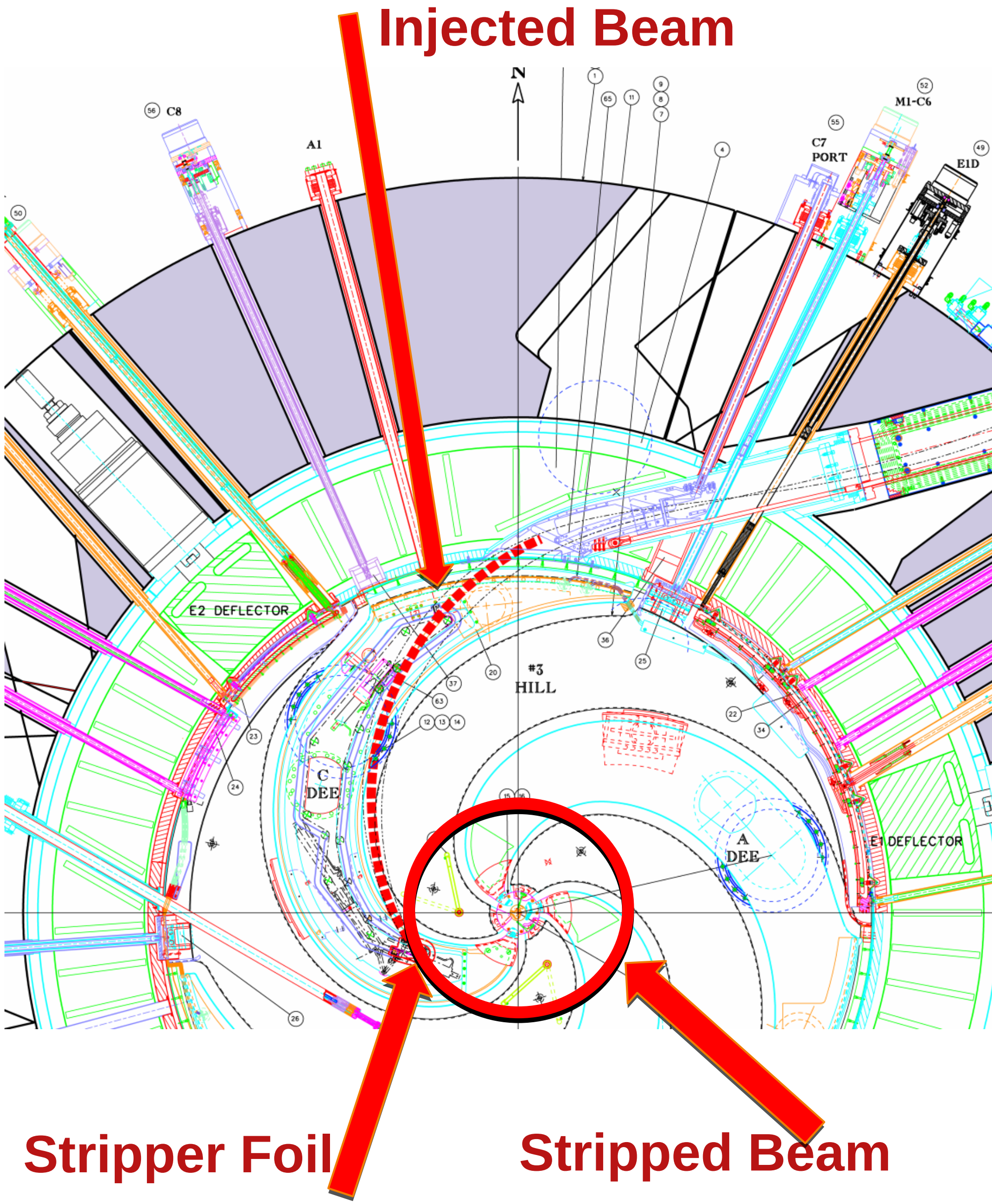
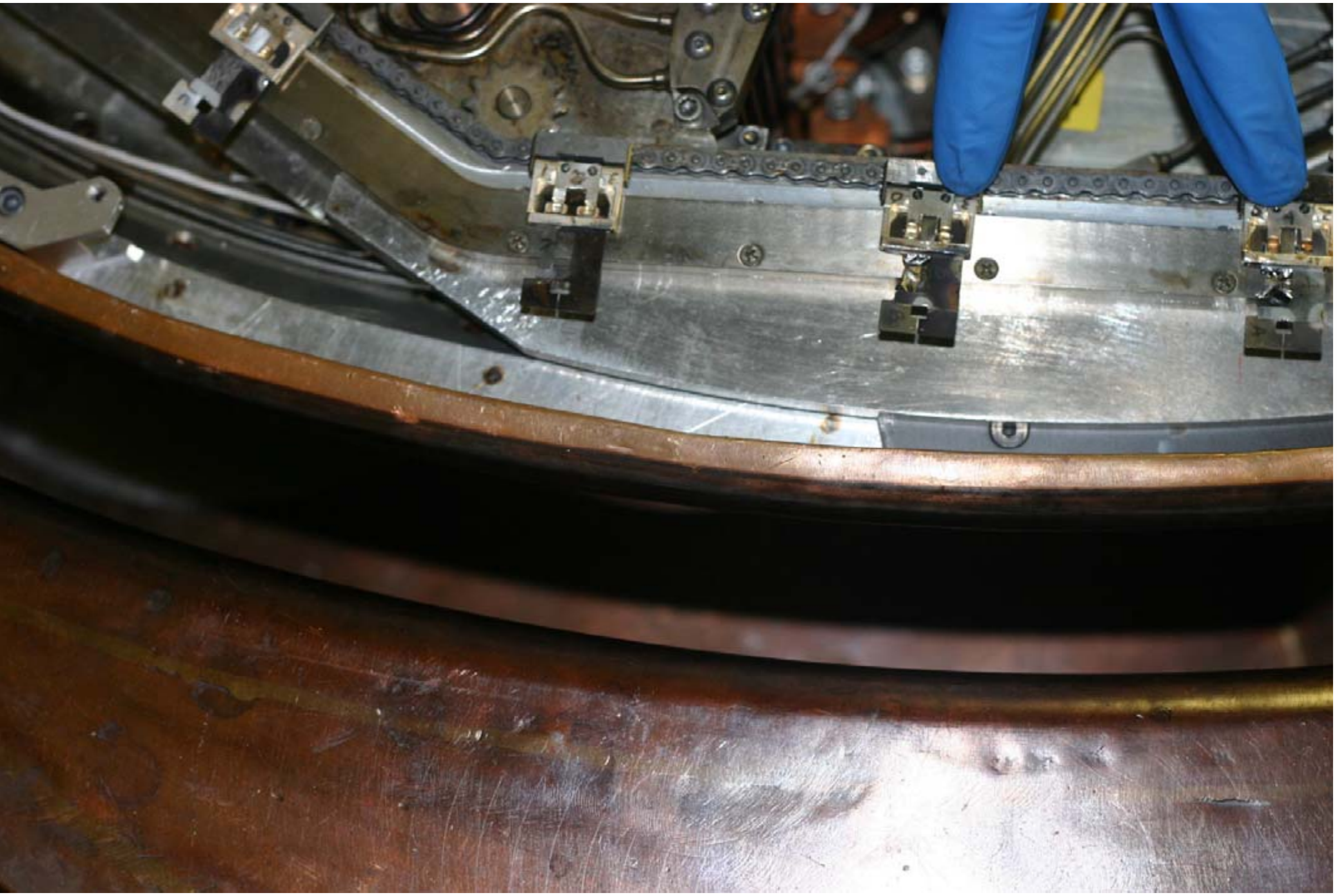
NSCL Stripper System

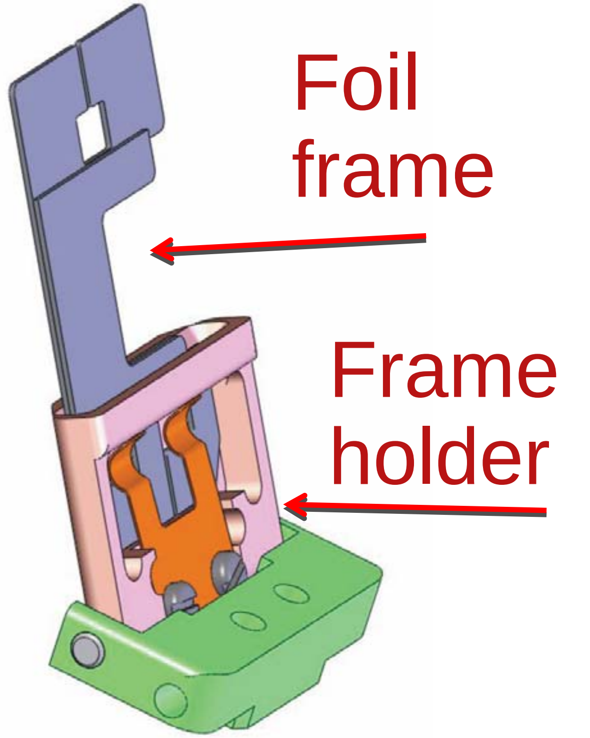
- K500 Injector cyclotron
- K1200 Booster cyclotron
  - Stripping energy ~ 10 MeV/u
  - Bad environment
    - » 5 Tesla magnetic field
    - » Inside the high voltage RF structure
    - » No instrumentation





Foil holders





Foil lifetime observations – Light ions

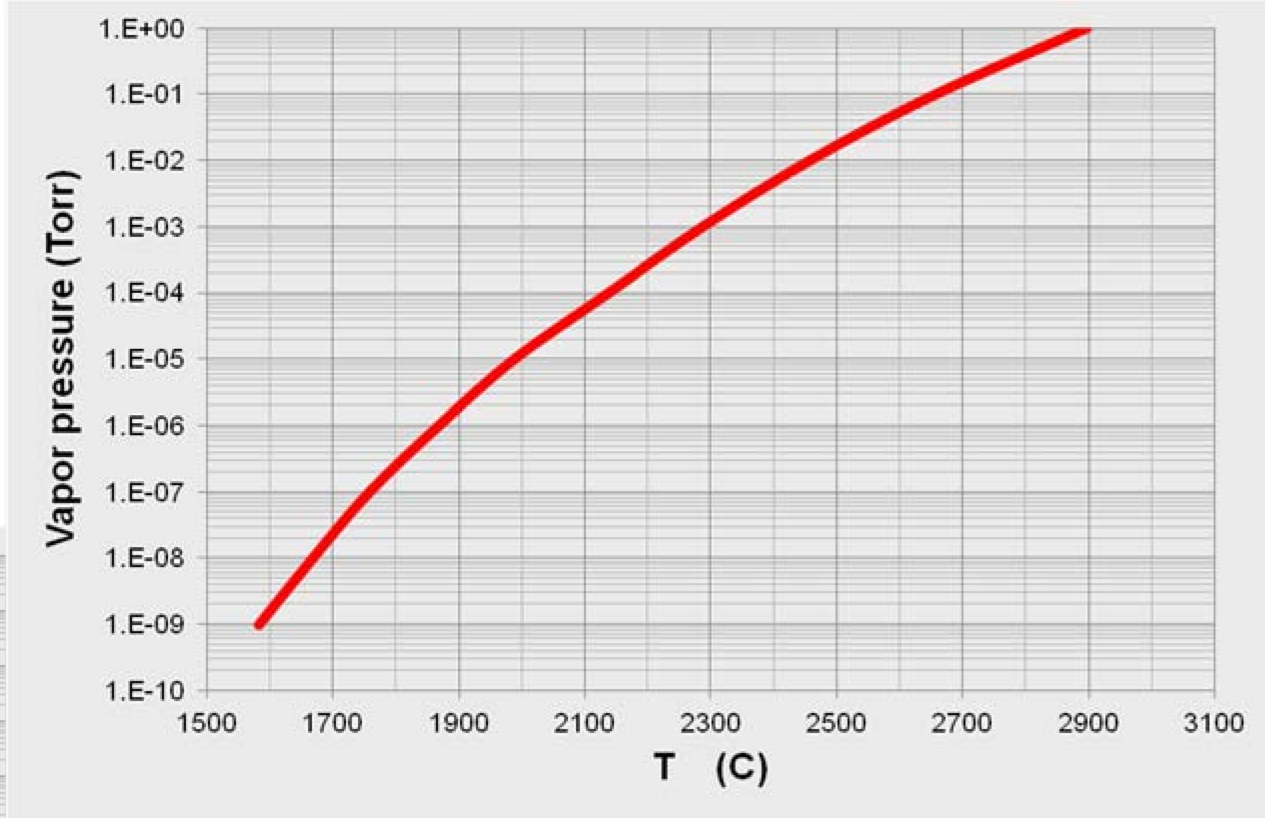
- For lighter ions (< Xe) the observed lifetimes agree reasonable well with the predictions from Baron's formula (1):

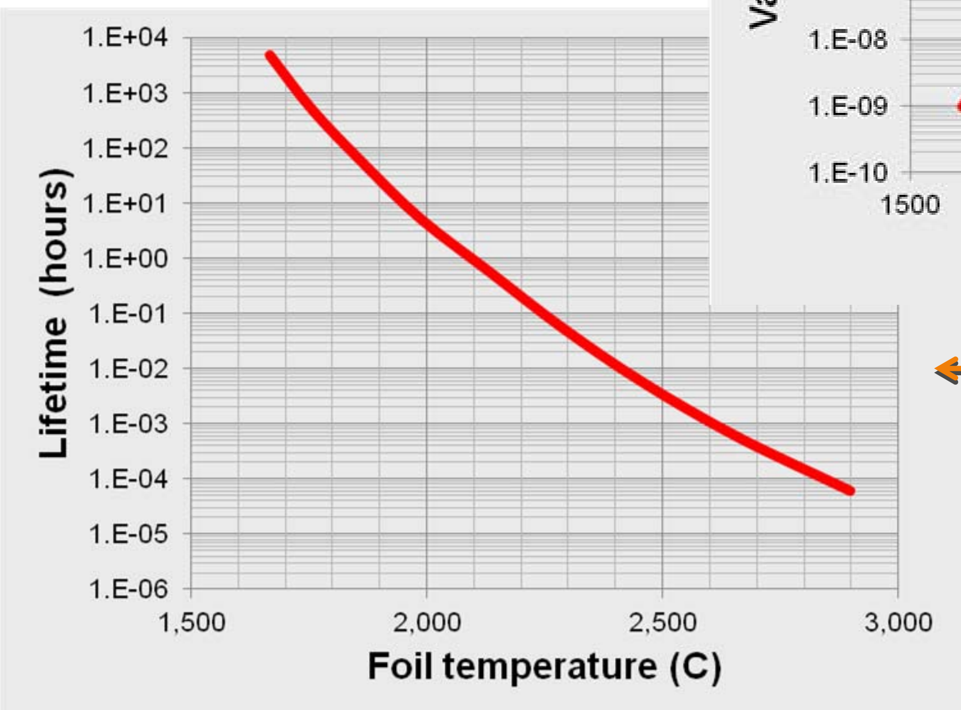
$$T(hours) = 36000 \frac{E/A(MeV/u)}{6{Z_p}^2 j(p\mu A/cm^2)}$$

(1) E. Baron, 8th Intl. Conf. Cyclotrons, IUCF, 1979 p. 2411

What destroys the foils? 1.- Sublimation

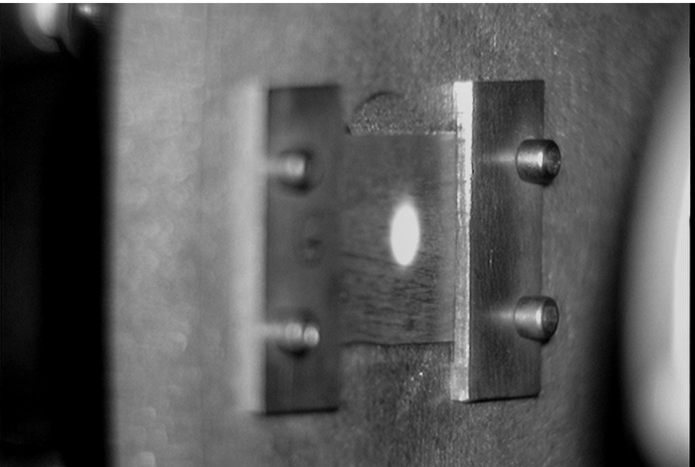
- High temperature
  - Carbon sublimates, thickness changes and charge state distribution shifts toward lower charges.

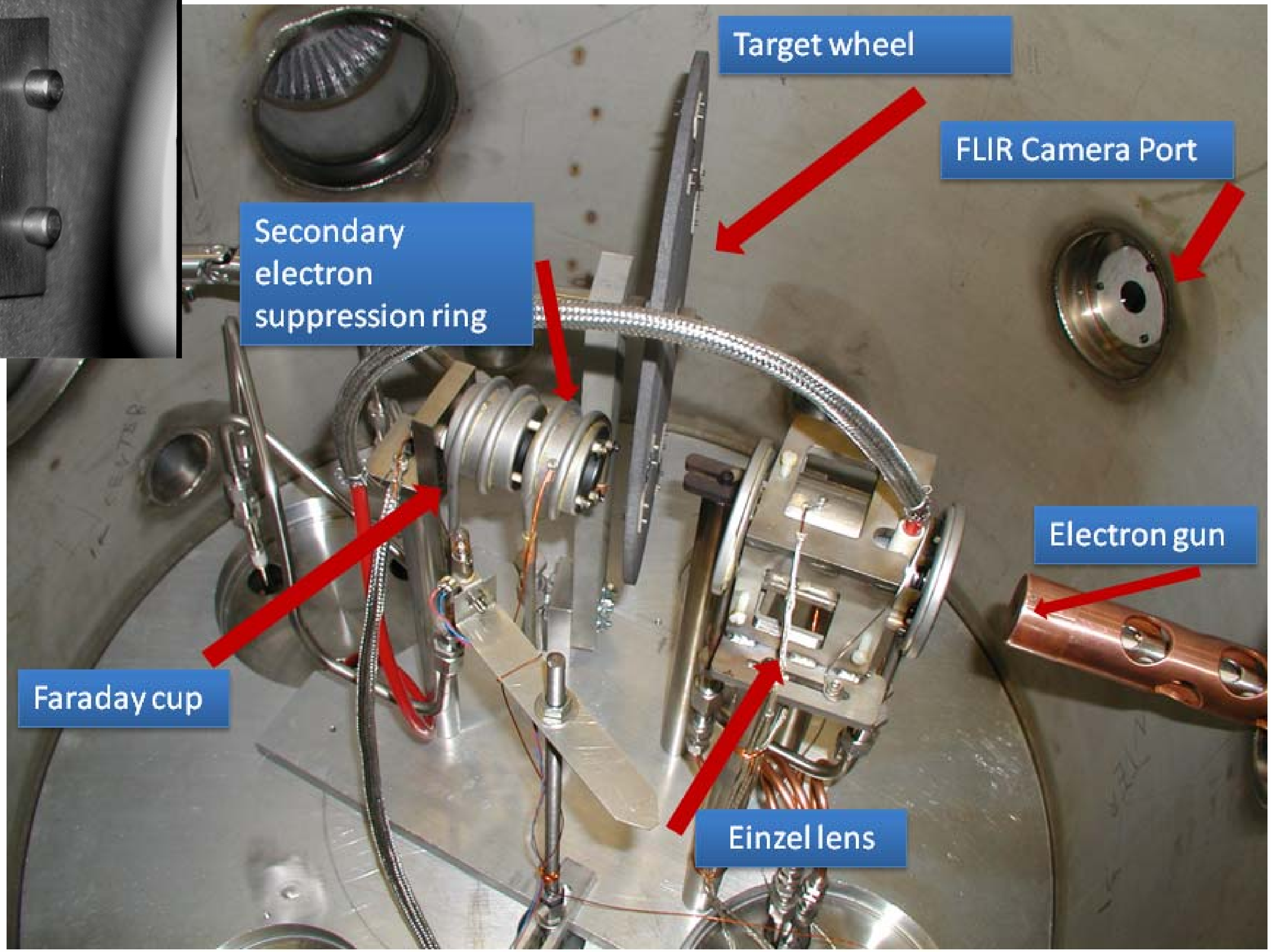




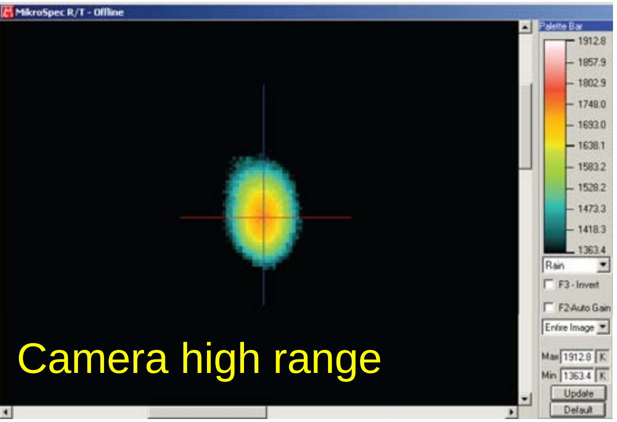
Lifetime defined as reaching 20% change in thickness for a 500 μg/cm^2 foil

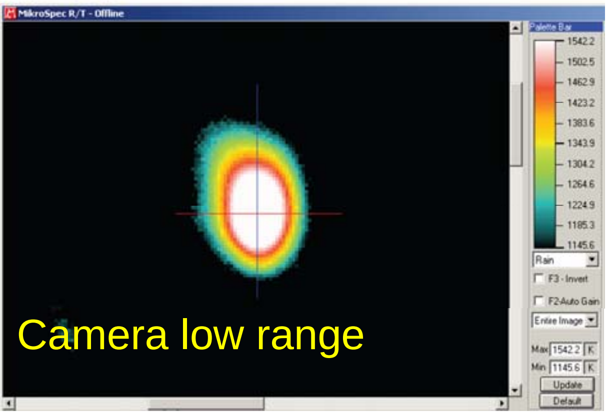
Stripper foil test chamber

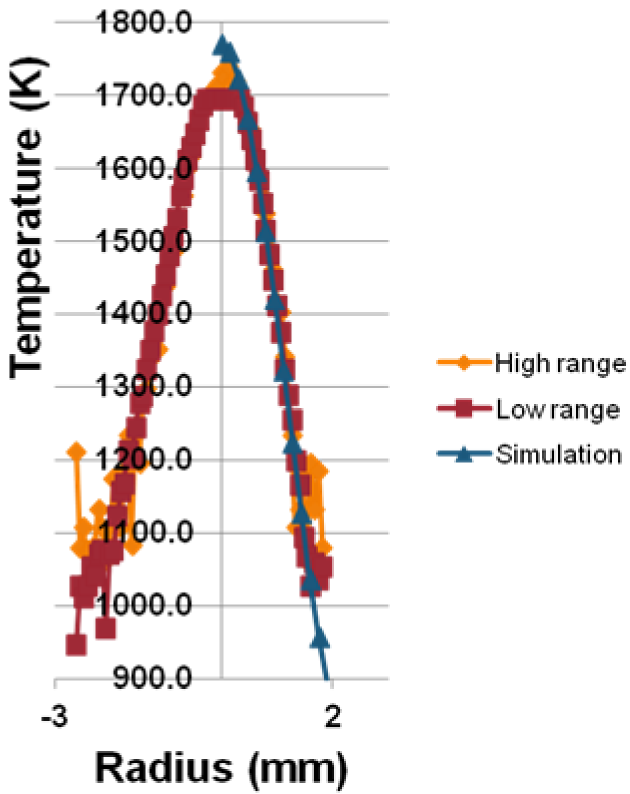


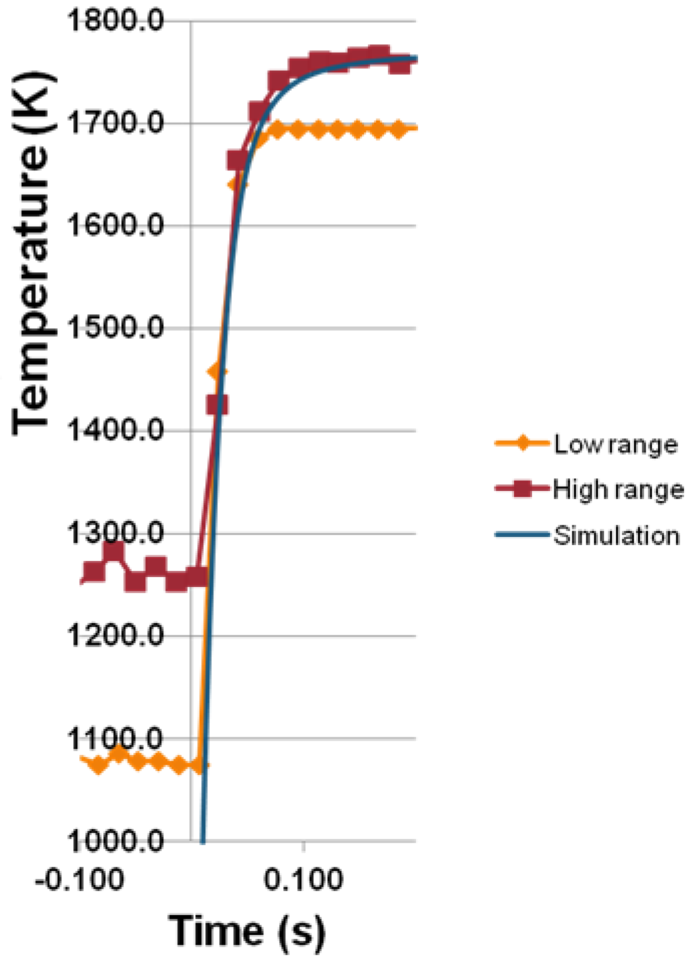


Static Electron Beam Spot on Carbon Foil



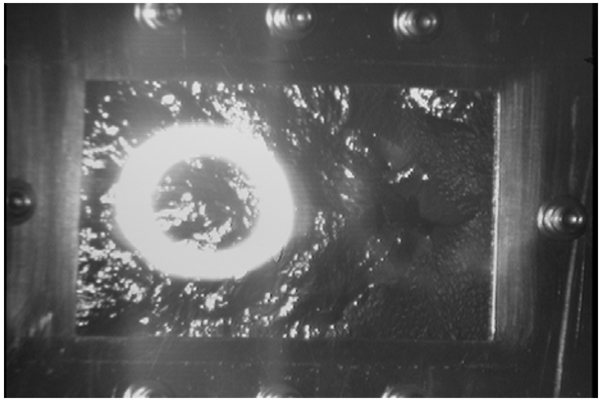


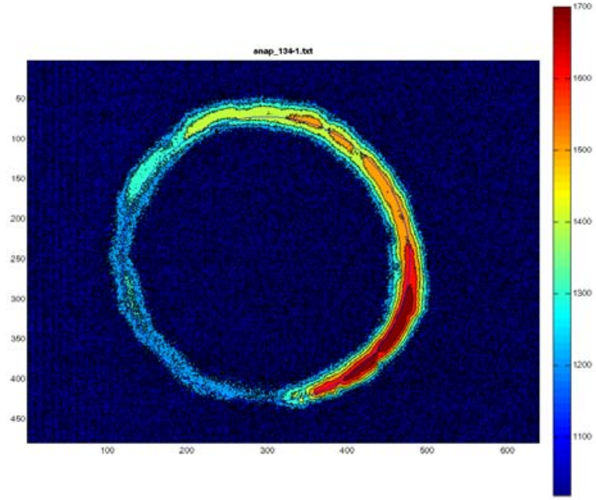




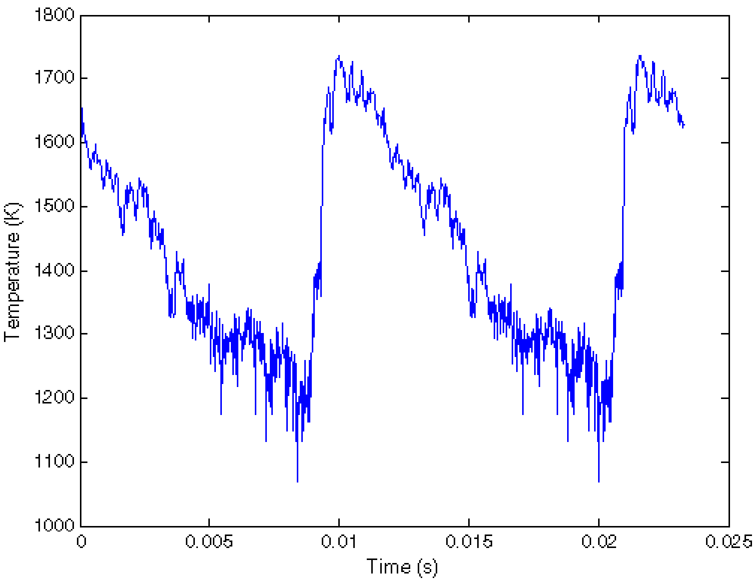
- We can reproduce the temperature measurements for $\varepsilon = 0.4$

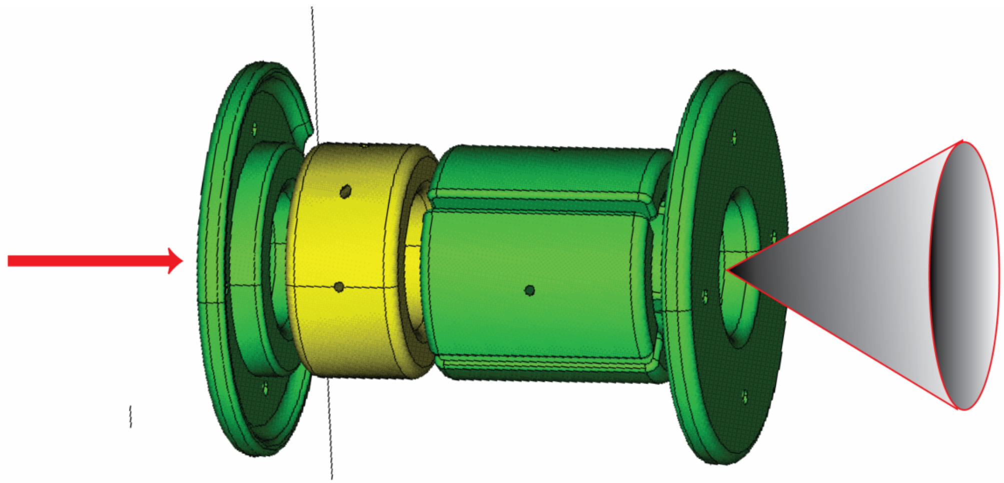
Rotating Beam on Carbon Foils (86 Hz, 33W)





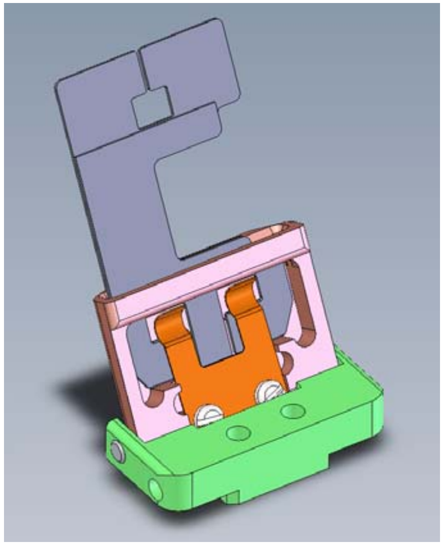
Electron gun beam on a foil from MicroMatter (500 μg/cm² foil)

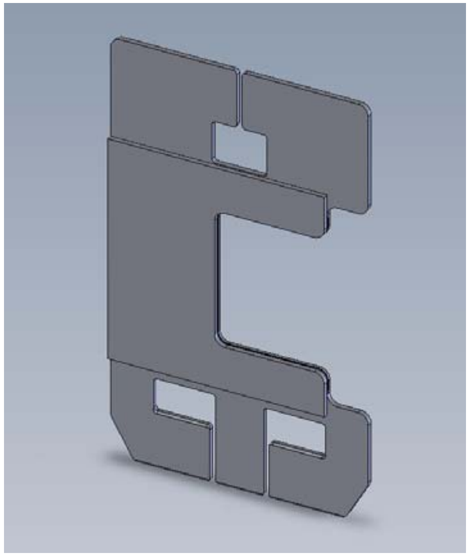




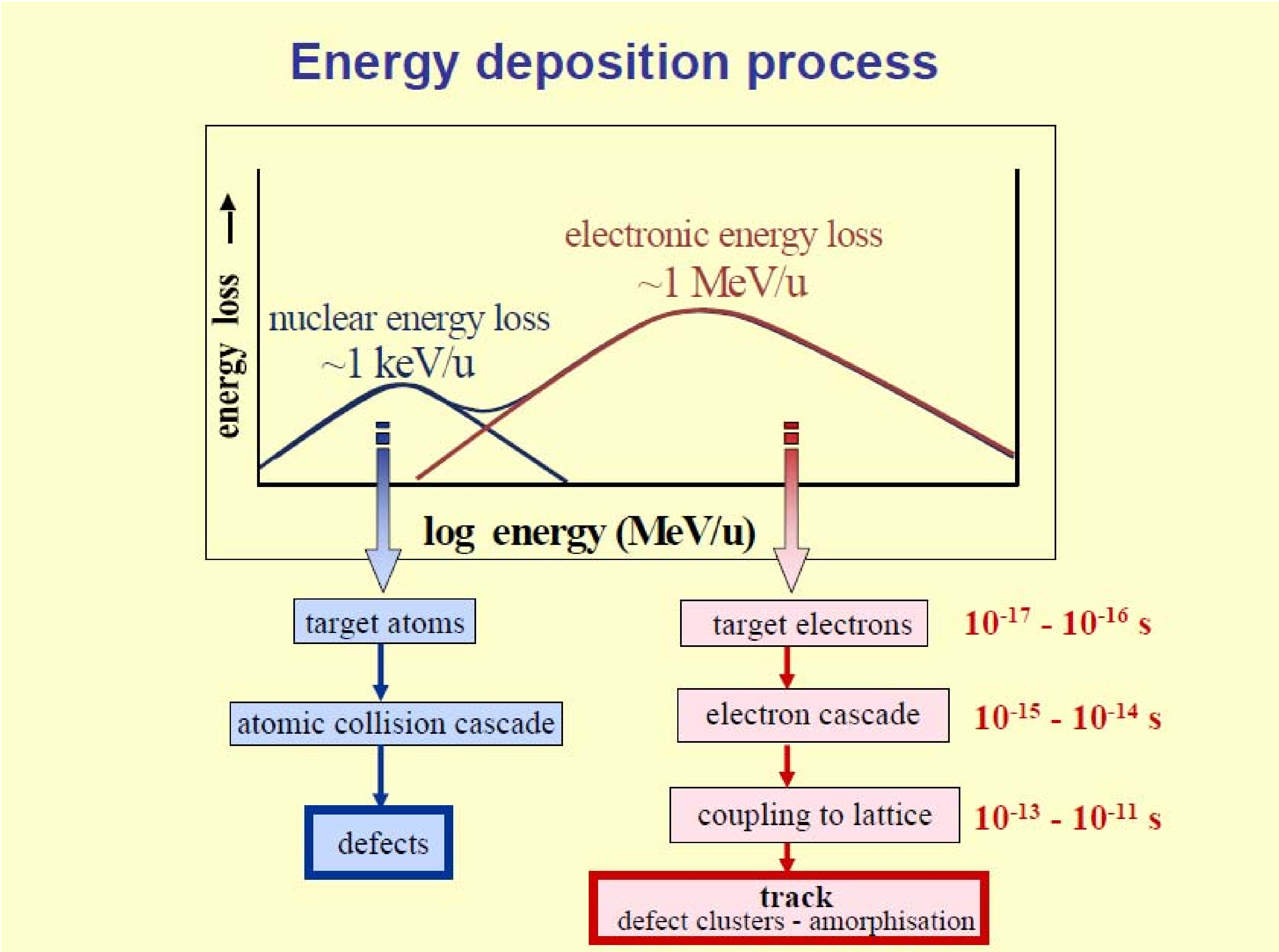
Foil holder with pocket

- It is common to see foils that develop a tear. They appear to be under tension.
- In previous tests with thicker foils outside the cyclotron we succeeded in extending the foil life by “floating” it inside a pocket and allowing it to move.
- The same idea was applied in these frames shown here with graphene foils.
- These foils “wrinkled” but did not tear.
- We plan on pursuing this idea.



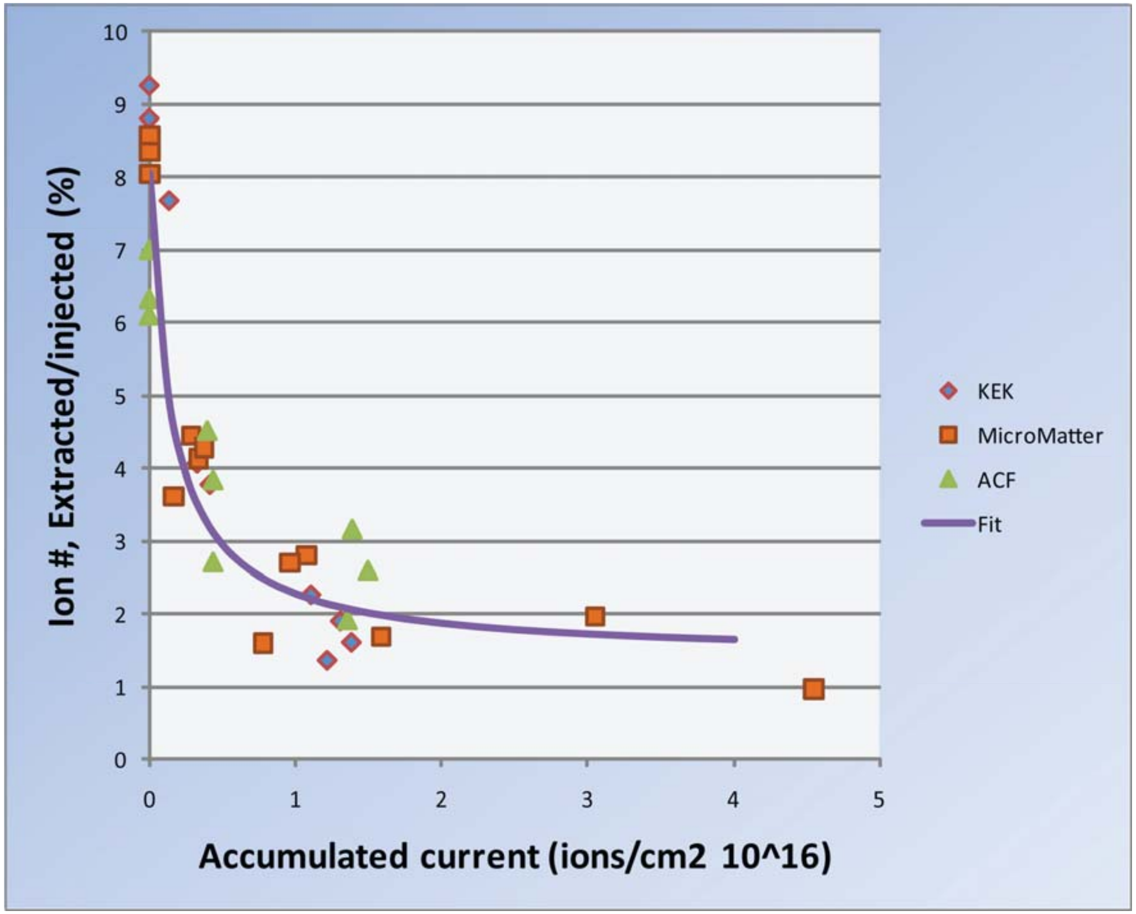


What destroys the foils? 2.- Radiation damage



Christina Trautmann, Gesellschaft für Schwerionenforschung (GSI) Darmstadt, Germany

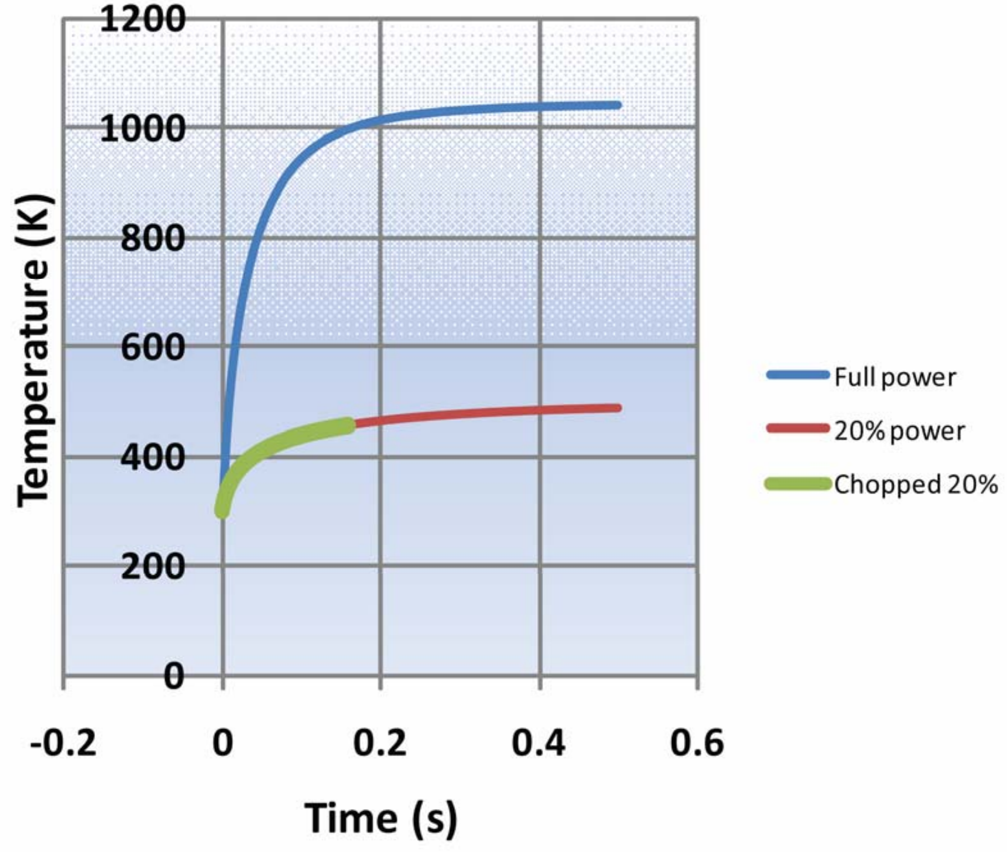
Foil performance decay with 8.1 MeV/u Pb ions



- Experiment performed in the K1200 cyclotron (27+→63+)
- Significant decay observed at 10^{14} ions in 4 mm^2 in the cyclotron test = 2.5 10^{15} ions/cm^2
- Not practical to use at the present time.
- We need to study temperature dependence. Is there annealing?

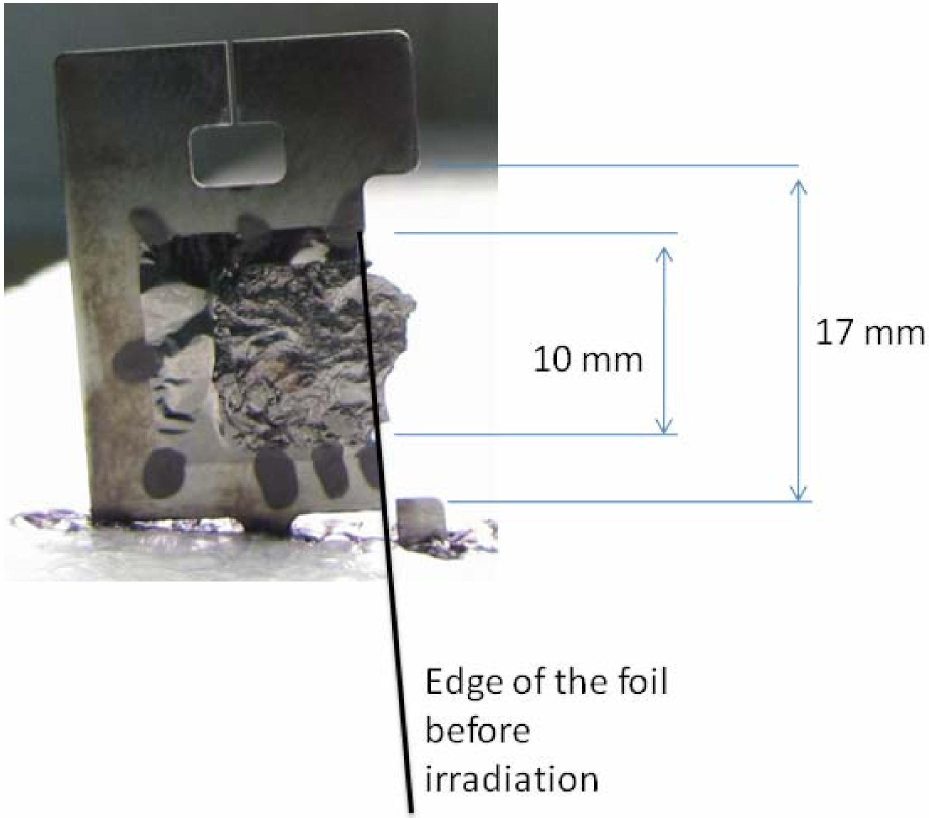
What was the temperature during the Pb test?

- Full power deposited on foil = 0.72 W (1.4% of beam power)
- Beam power applied in stages using a chopper (2kHz)
  - 20%
  - 50%
  - 100%
- Even at full power (100 %) the temperature barely exceeds 1000 degrees K.
- Sublimation effects should be minimal.



SEM photographs of foil before irradiation

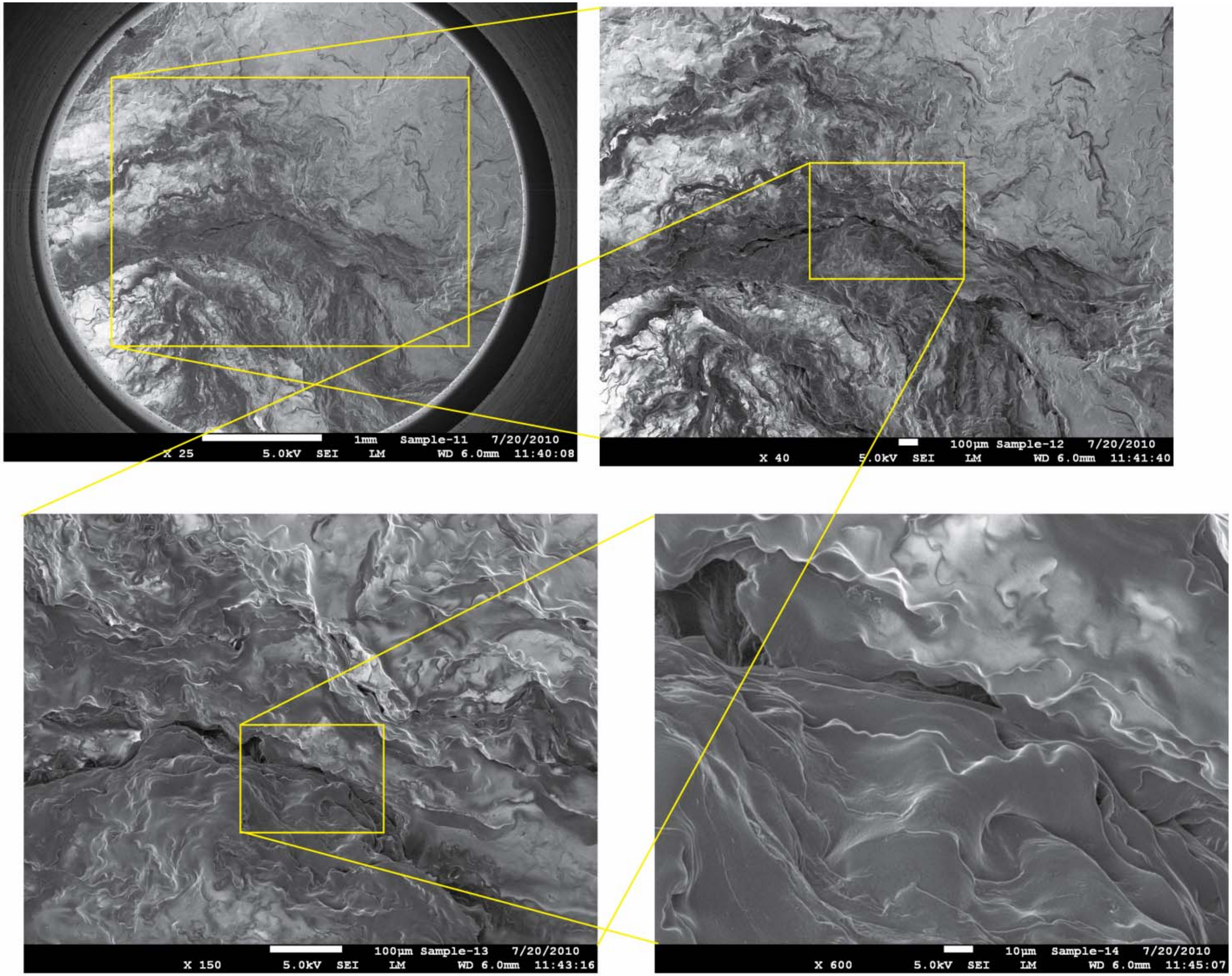
8.1 MeV/u Pb Beam on Carbon Foils at NSCL/MSU



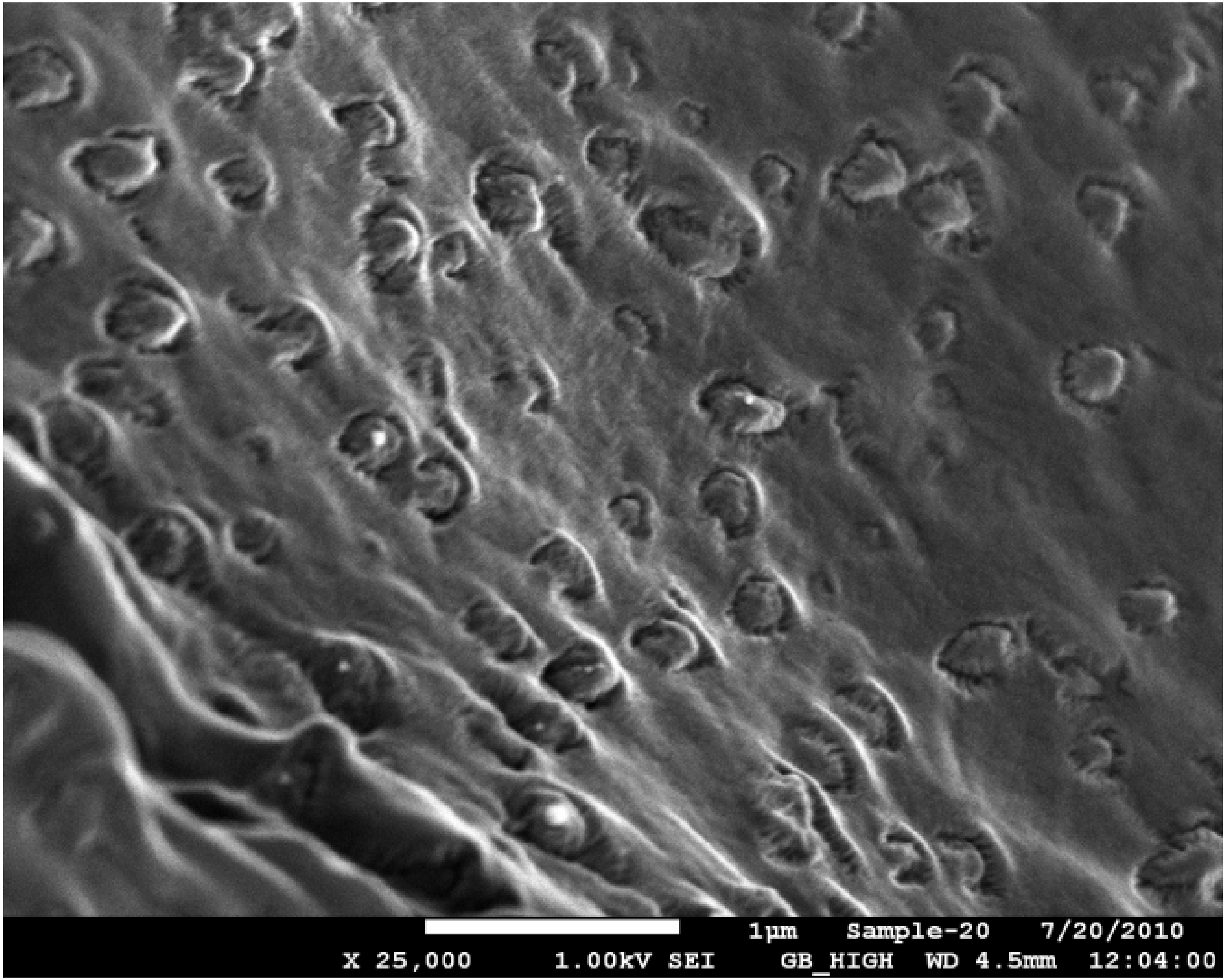
Empty frame
on mm paper

Foil thinning displaces the peak of the stripped beam charge distribution toward lower charge states. Foil thickness measured with α source.

SEM photographs of Pb irradiated foil, beam area

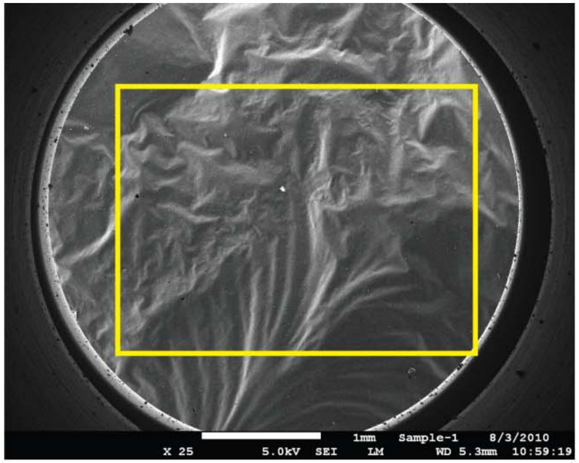


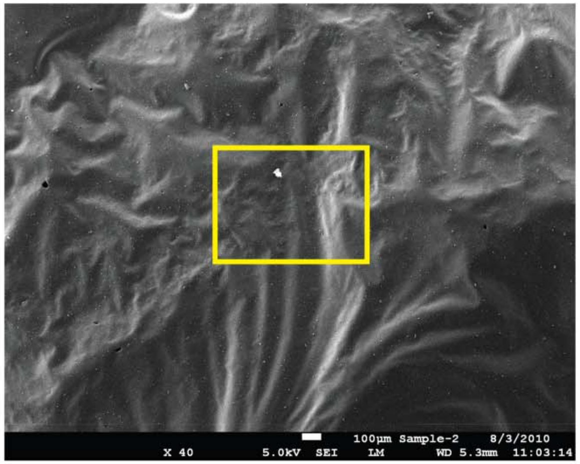
SEM of the beam irradiated area

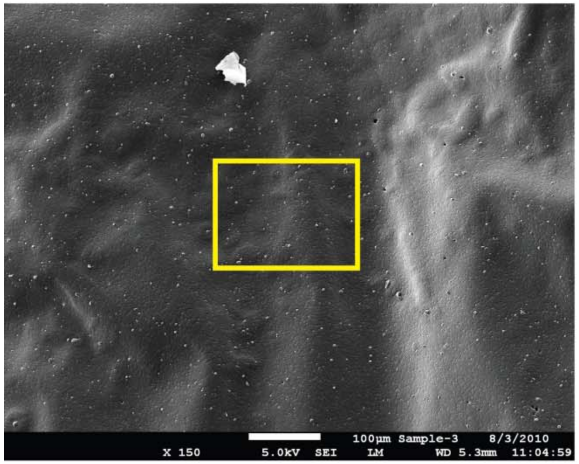


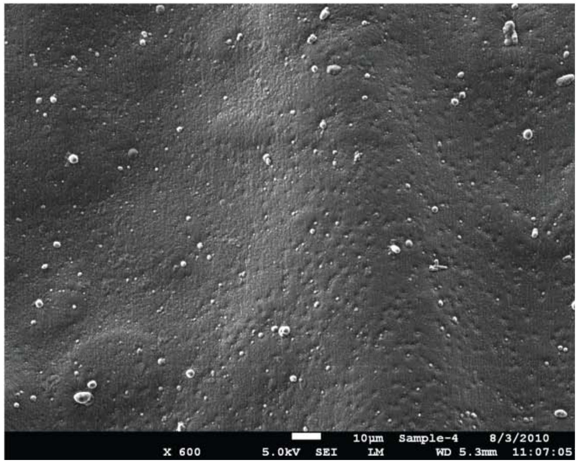
SEM photos of MicroMatter foils heated with e-gun

- These foils were heated to temperatures around 1700-2000 deg. K
- Although they wrinkled immediately the structure is quite different from the foils exposed to the Pb beam.



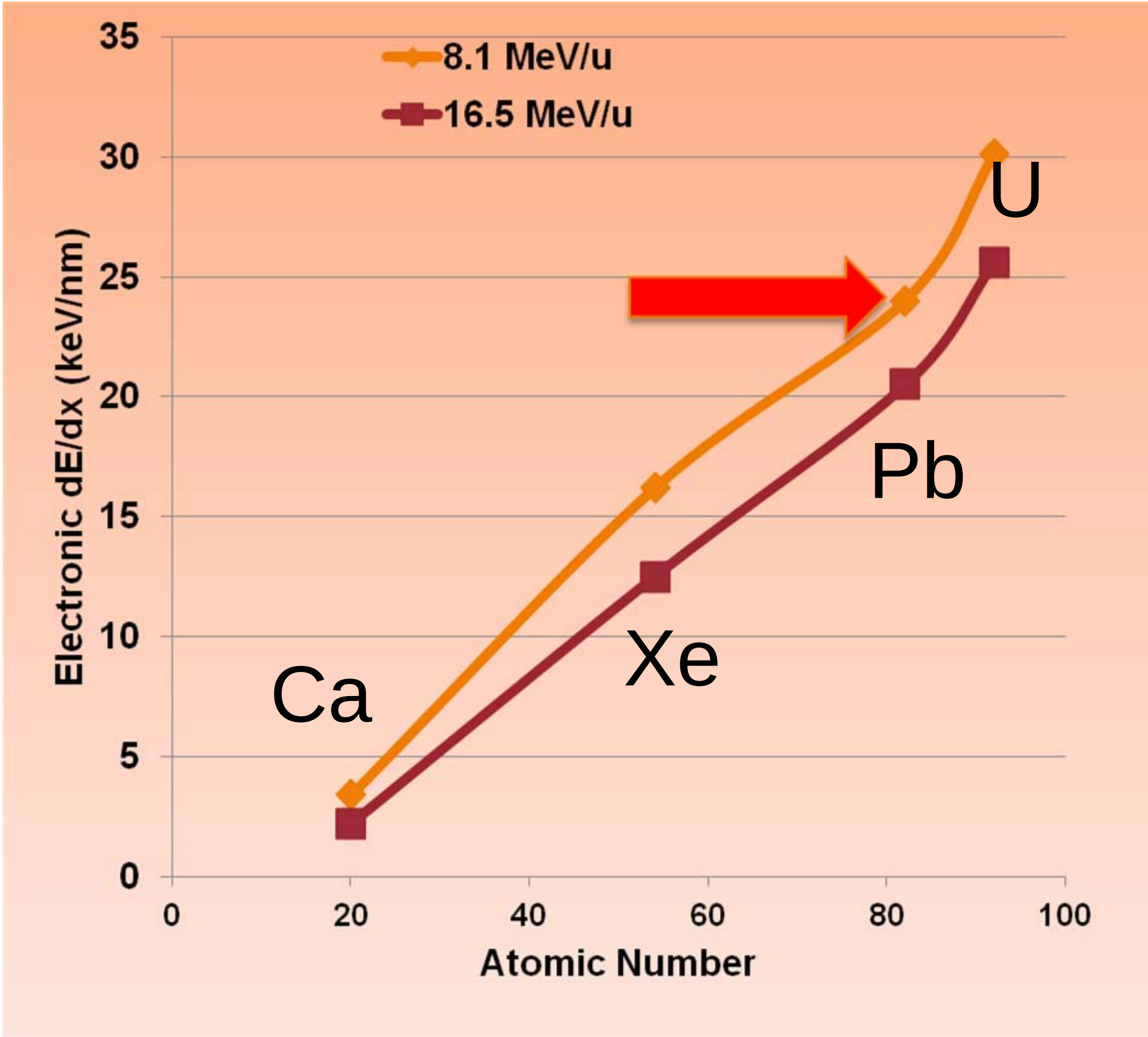






Ion hammering effect?

- Transverse growth and longitudinal thinning compatible with "Ion hammering" as proposed by Klaumunzer
- What is the ***threshold*** dE/dex?
- Which material, appropriate for a stripper, has the largest threshold value?



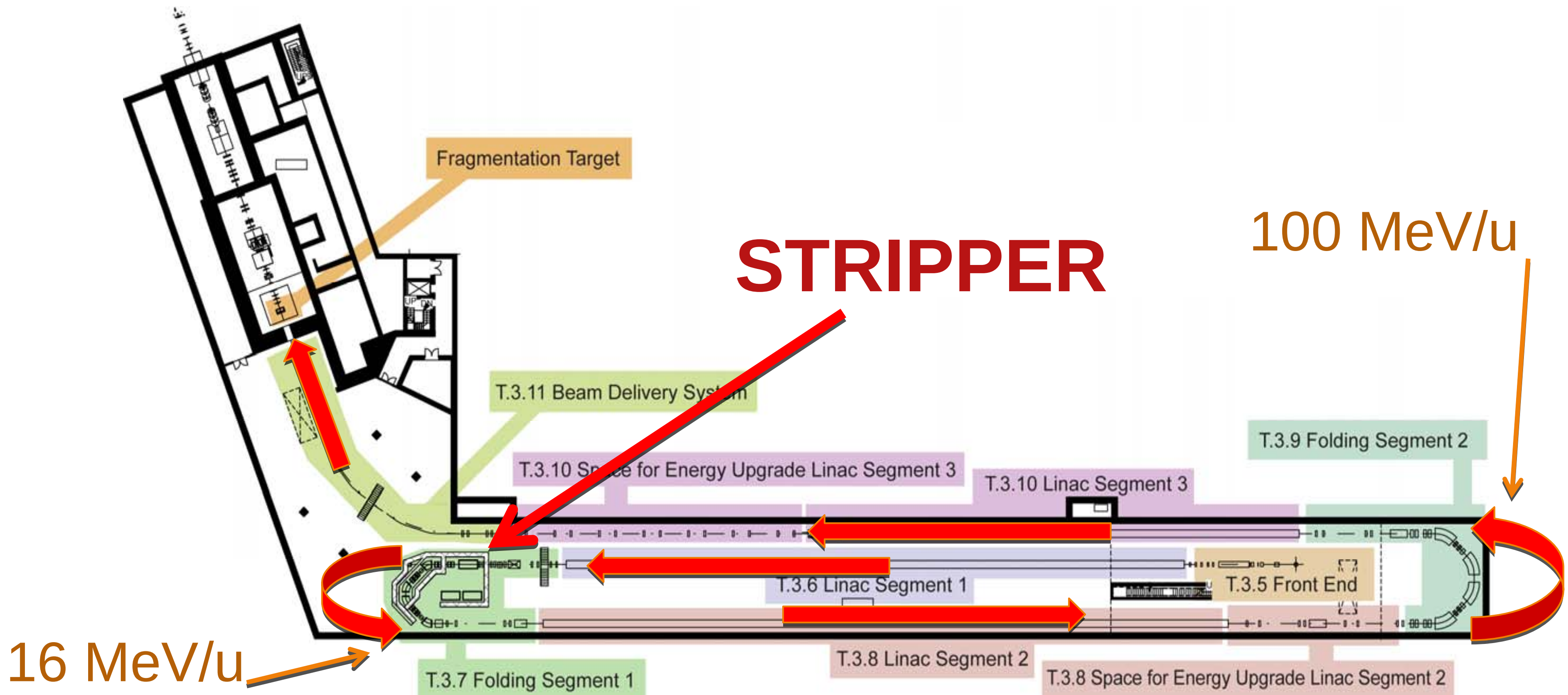
A. Benyagoub and S. Klaumunzer, Radiation Effects and Defects in Solids, 1993, vol. 126, pp. 105-110

Status

- We believe that we understand the thermal behavior of the foils.
- The mechanical stresses are significant and depend on the projectiles
- The heavier ions produce an expansion of the foils in the transverse plane and a thinning in the beam direction
- As the foils become thinner the charge state distribution shifts toward lower charge states and the output from the cyclotron decreases very fast
- An interpretation of this thinning is compatible with the “ion hammering” effect.
- We do not have a good way of running intense beams of U yet.

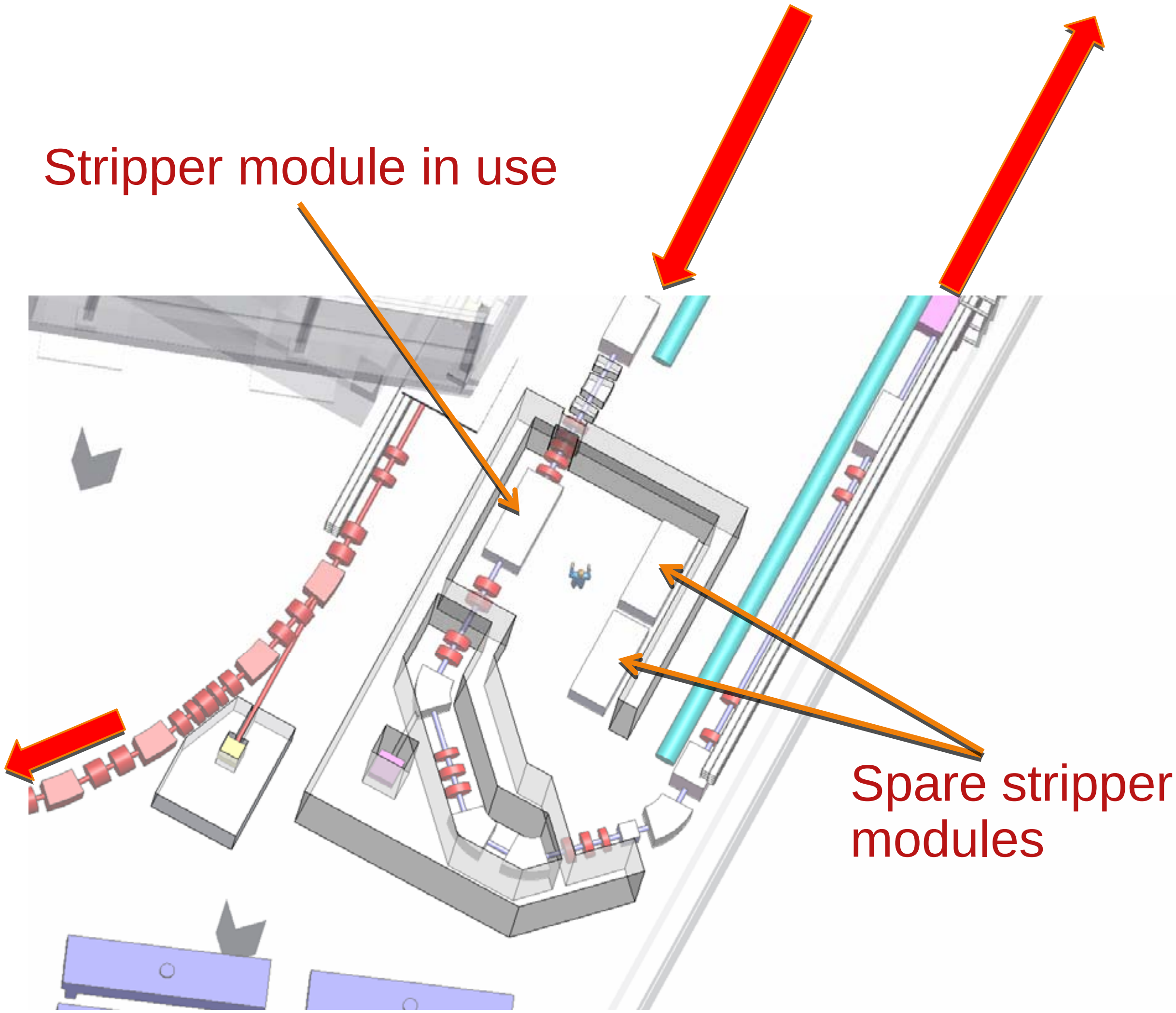
What is FRIB?

- **Facility for Rare Isotope Beams**
- 400 kW E/A > 200 MeV/u   Superconducting Linac Driver
- ~ 40 kW beam @ 16.5 MeV/u at stripper
- Multiple charge acceleration (for $U^{33+,34+}$ before stripper)

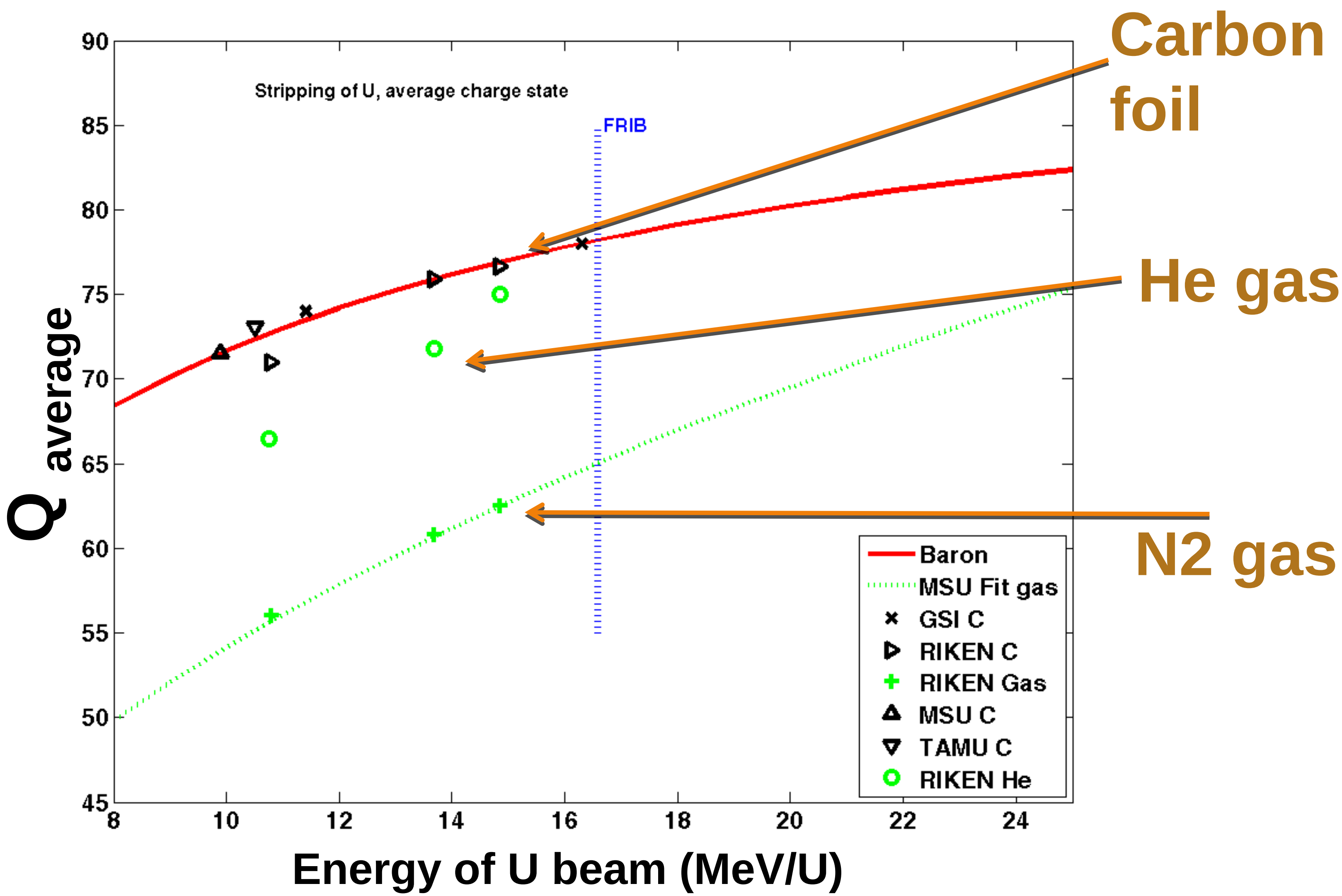


FRIB Stripper

- A slot length of 2.5 m has been reserved in the first bend for the stripper system. It is compatible with all the alternatives being explored.
- The energy spread should be small to reduce the beam losses downstream, i.e. small thickness variations (±10%).
- The floor plan will allow the storage of two extra stripper modules that can be moved into operations in a short time



Charge State for Different Stripper Alternatives



Technical Alternatives

- **Solid carbon based foil** (high charge state, simple system)
  - Baseline design
  - Thermal-mechanical issues studied at NSCL/MSU
  - Radiation damage issues studied at NSCL/MSU and RIKEN
  - R&D established that this is not a viable alternative
- **Liquid lithium** (high charge state)
  - Film thickness and stability studied at ANL
- **Gas stripper with differential pumping** (lower charge state, long lifetime)
  - Studied at RIKEN and NSCL/MSU
- **Gas stripper with plasma windows** (high charge state if He confinement is successful)
  - Studied at BNL and NSCL/MSU
- **Plasma stripper** (potential for high charge state)
  - Studied at BNL. Stability and <Q> to be determined
- Selection of preferred option done by November 2011, consistent with cryoplant order date

Acknowledgements

- NSCL operators (specially R. Rensock and S. Krause)
- J. Oliva, D. Ipple and T. Xu for their mechanical design help with the electron gun test chamber.
- RIKEN personnel (specially H. Okuno, H. Kuboki and H. Hasebe)

• For FRIB work:

- C. Reed and collaborators from ANL for their liquid lithium work
- A. Hershcovitch and P. Thieberger from BNL for the plasma windows work

- ***Thank you for your attention***

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