PowerMat

Requirements for radiation damage simulations regarding FAIR targets, beam dumps / catchers and previous experiments at GSI

M. Tomut

With input from P. Katrik, H. Weick et al.

Radiation damage in beam dumps and beam catchers

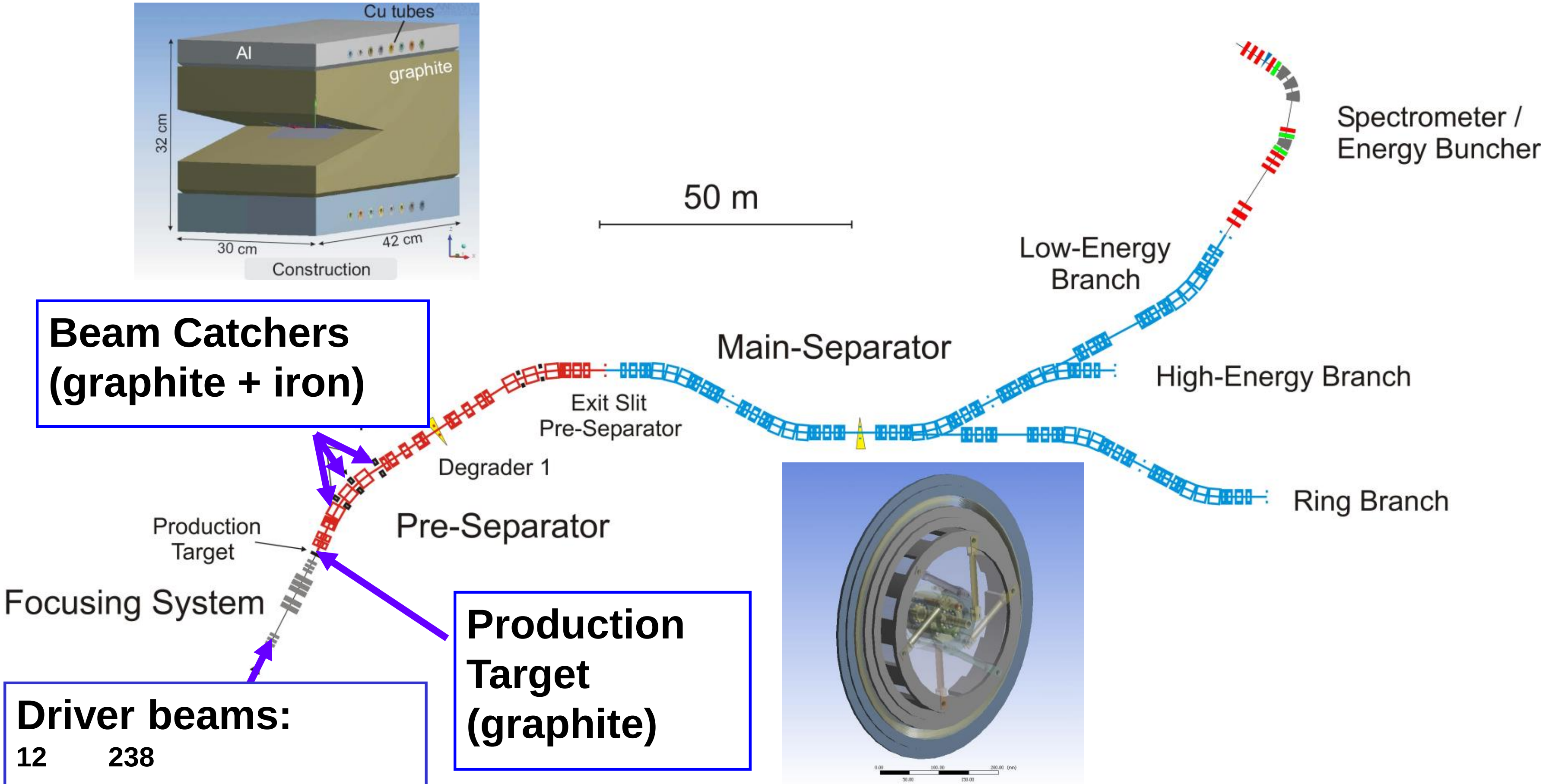
Radiation damage in the carbon part of the beam dump is caused by three mechanisms:

- Elastic collisions of the primary beam, fragments or neutrons with the carbon atoms

- For high linear energy deposition the heating by the electronic energy loss can cause microscopic material transformation and track formation. This happens in graphite above a threshold of dE/dx = 18 keV/nm and will therefore occur only in the Bragg peak close to the end of the range

- Spallation of the nuclides and creation of other chemical elements

Super-FRS Target and Beam Catcher



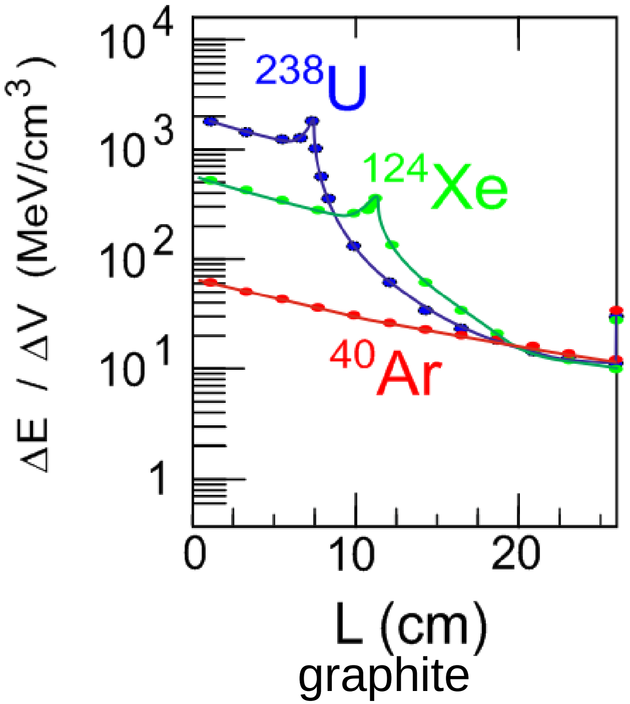
Beam Catchers
(graphite + iron)

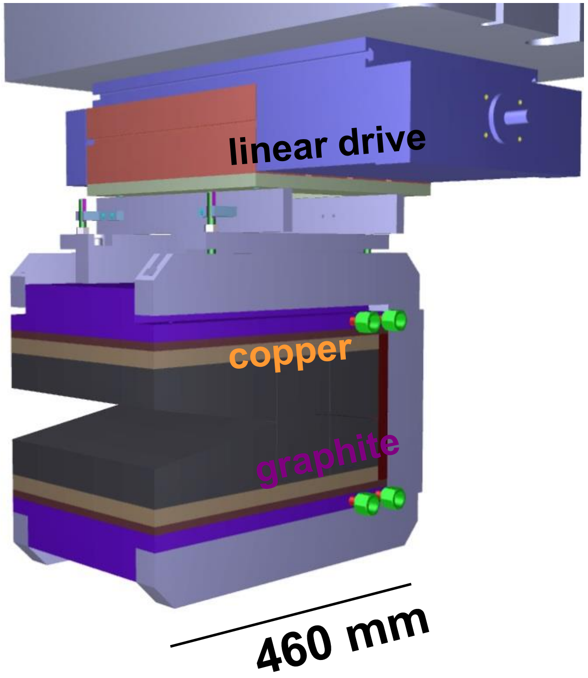
Production
Target
(graphite)

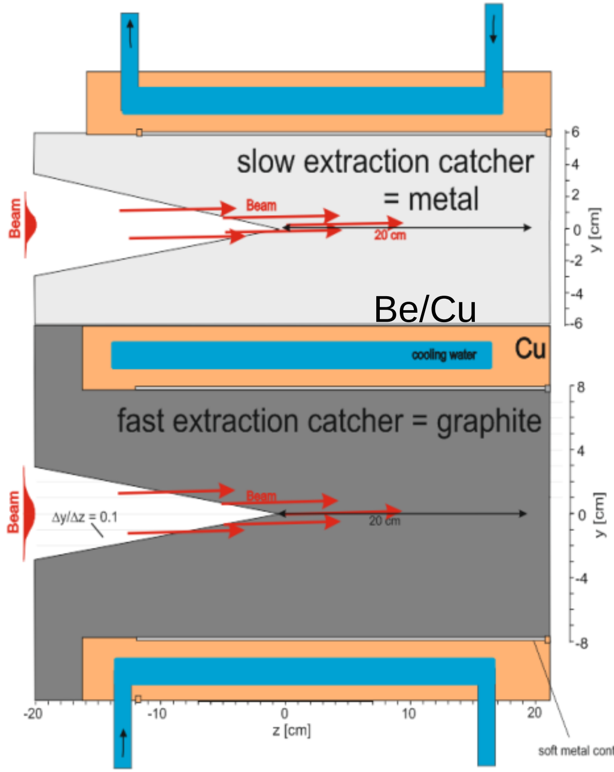
Driver beams:
12 238

1.5 GeV/u

Super-FRS Beam Catcher



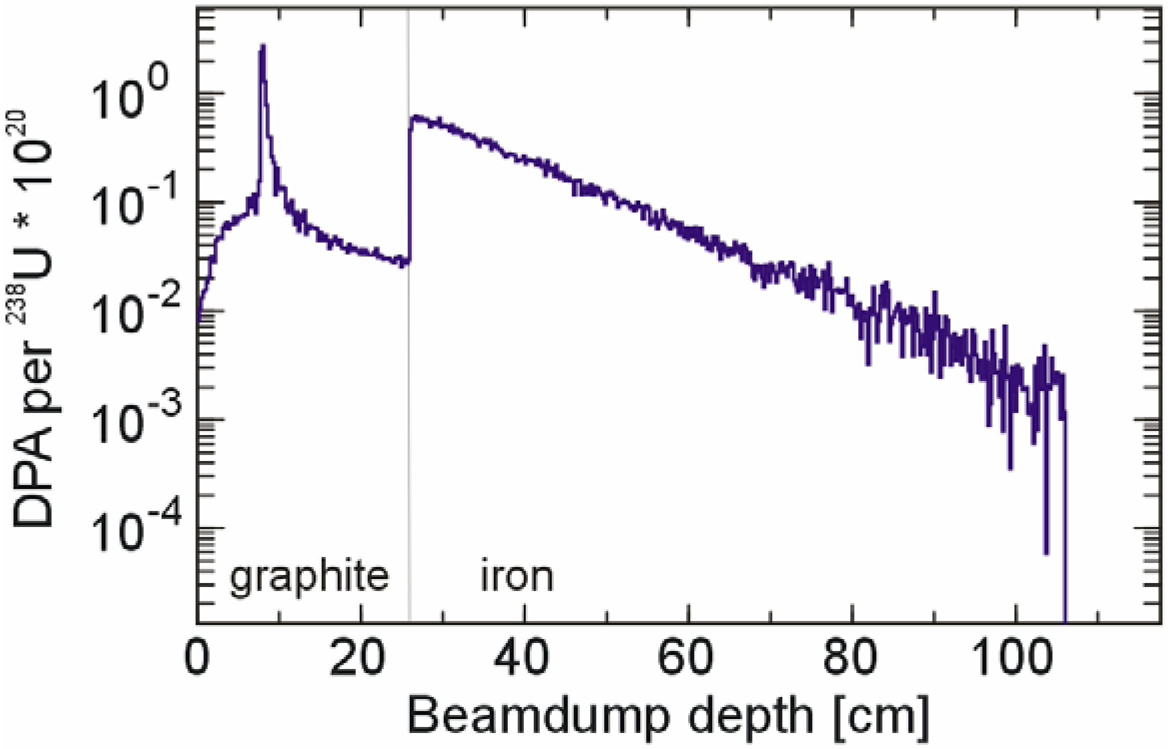




Beam energy: 750 MeV/u.

Courtesy H. Weick

Thermal simulation shows cooling problem with radiation damaged graphite,
λ = 70-40 W/(m K) --> 15 W/(m K),



PHITS simulation of DPAs from elastic collision, all values stay below 1 DPA for the whole lifetime of the device even with full uranium beam intensity over 15 years with 77 days continuous operation in each year . The peak in carbon represents the end of the range near the maximum of nuclear stopping power.

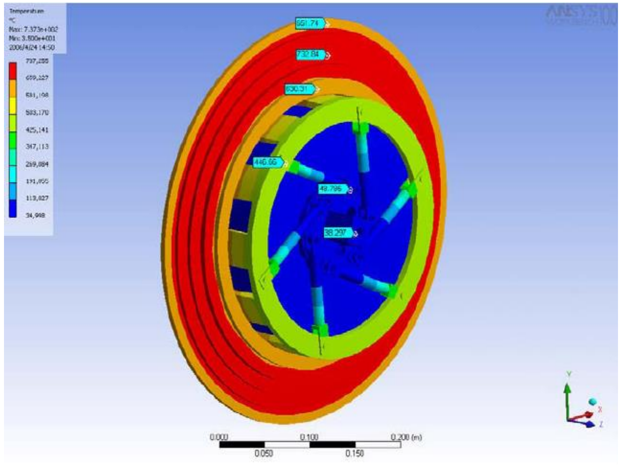
Courtesy H. Weick

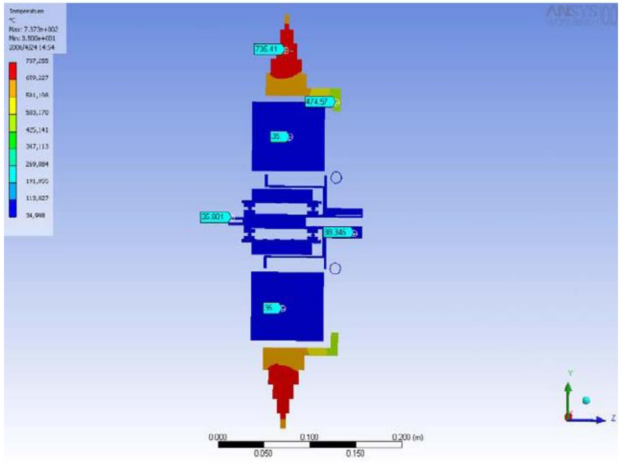
DPA calculation for the Super-FRS graphite target

Graphite wheel cooled only by radiation

- 5 concentric graphite rings, 16 mm wide
- thicknesses of 1, 2.5, 4, 6 and 8 g/cm^2
- beam parameters:

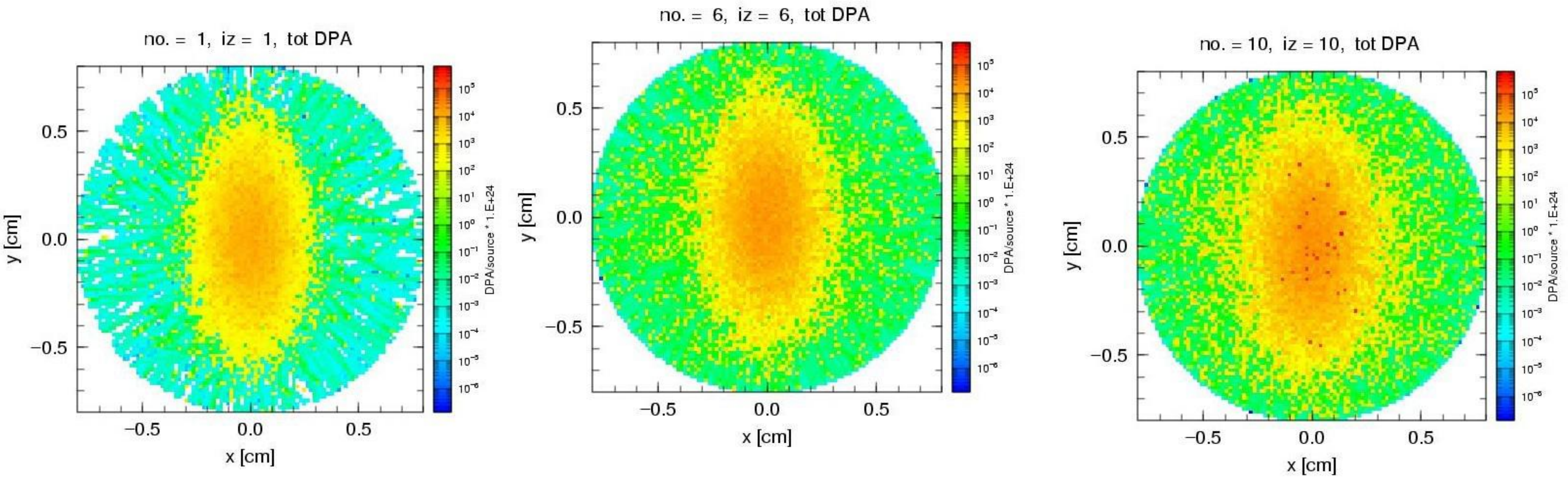
1. Slow extraction mode:
   - extraction time ~1s; 10^{12} ions/cycle
   - beam energies: 1 GeV/u.
   - beam spot: two-dimensional Gaussian with $\sigma_x = 1$ mm and $\sigma_y = 2$ mm
   - ions fluence per year: 10^{17} ions/cm^2 (assuming an annual accumulation of 10^7 pulses)
   - The temperature distribution for the worst case (10^{12} ions/spill, 1 GeV/u ^{238}U on the 4 g/cm2 ring) The target layer is heated to a maximum temperature of 750 ºC
2. Fast extraction mode:
   - 10^{12} ions extracted within 50 ns





B. Achenbach

DPA calculation for the Super-FRS graphite target



max DPA/source~ 4x10^{-19}
DPA/ year ~ 4 x 10^{-3}
H prod ~ 50 appm/year (diffuses out)
He prod ~ 5 appm/year
(high enthalpy of solution, can reach very high concentration in material - accumulates in bubbles)

Radiation Damage Estimate with Neutrons

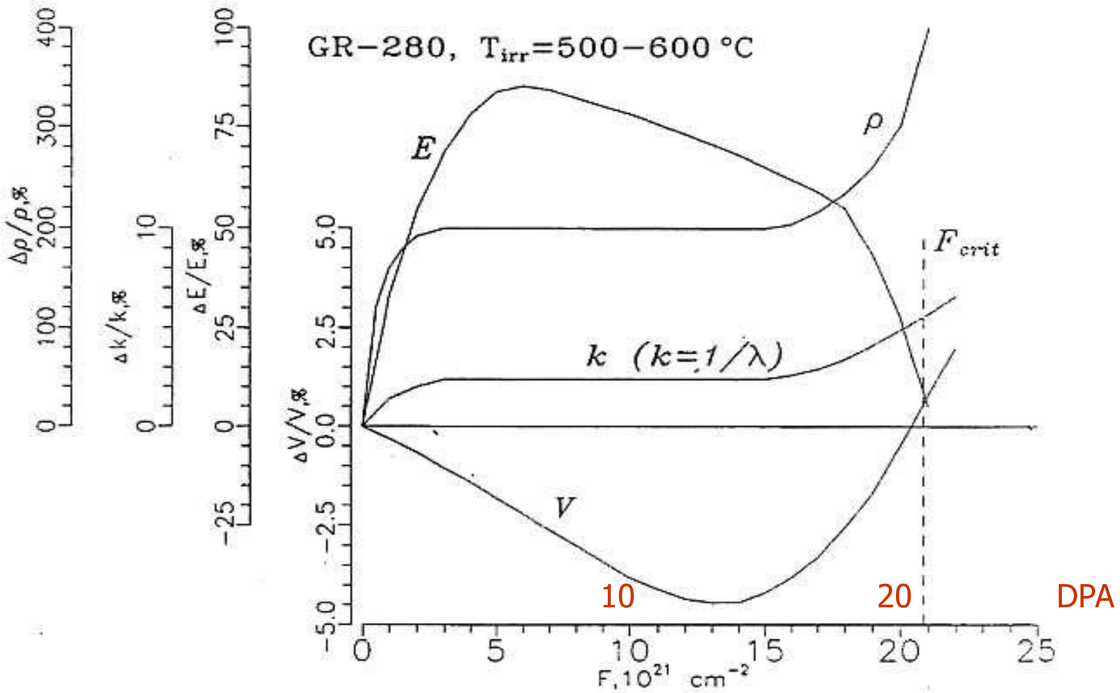


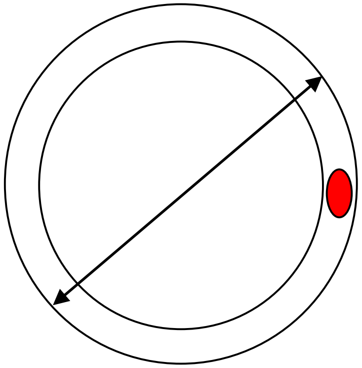
Fig.1. Determination of critical value of neutron fluence for graphite and changing of its physical properties under irradiation.
V − volume changing; E − elastic modulus; k − thermal resistance;
ρ − electrical resistance.

Radiation Damage and Life-time Evaluation of RBMK Graphite Stack, *XA9642904*,

P.A.Platonov, O.K.Chugunov, V.N.Manevsky, V.I.Karpukhin, Russian Research Center Kurchatov Institute

How long will the Super-FRS graphite target last: low extraction

- **10^{13} tracks/cm^2 is a critical density of ion tracks:**
  - **high values of swelling and induced stresses which are relaxed through crack formation**



Fluence/puls = 10^{12} / A ring =$1.11*10^{10}$ i/ cm^2

Fluence /year = 10^7pulses/year x fluence/puls ~ 10^{17} i/cm^2

Heavy ion track yield at Super-FRS energies of primary beam and target temperatures

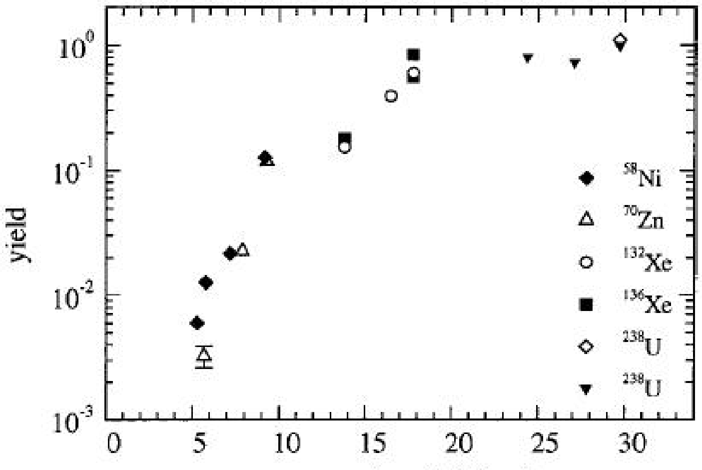
- **Track yield is highly reduced at high ion energy and target temperature (*Liu et al, PRB 64 (2001) 184115)***

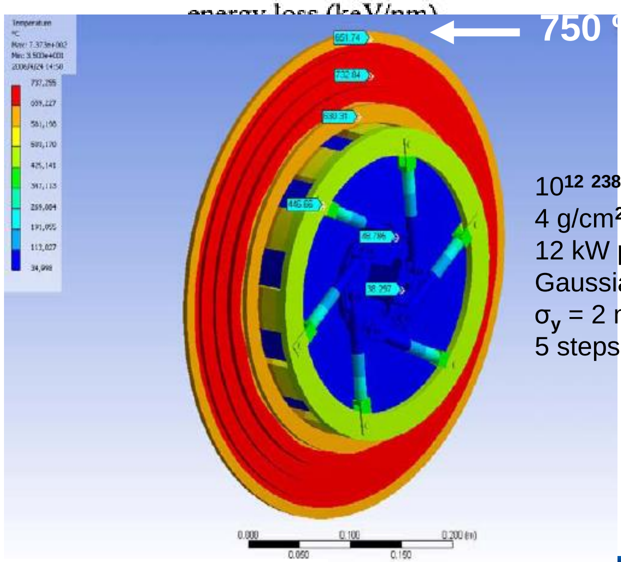
- **10^{-3} efficiency of track formation at Super-FRS energies**

- **10^{-3} efficiency of track formation at temperatures above 800 K *(J.Liu et al./ NIM B 245 (2006) 126-129)***

- **estimation of the track density/ year in the Super-FRS target:**

☞10^{11} tracks/cm^2





750 °

10^{12} ^{238}U/s
4 g/cm^2 C target
12 kW power
Gaussian vertical profile,
σ_y = 2 mm
5 steps (1 – 8 g/cm^2)

B. Achenbach,
ANSYS workbench

M.Tomut, GSI

Radiation Damage

(discussion at WP11 annual meeting ‘14)

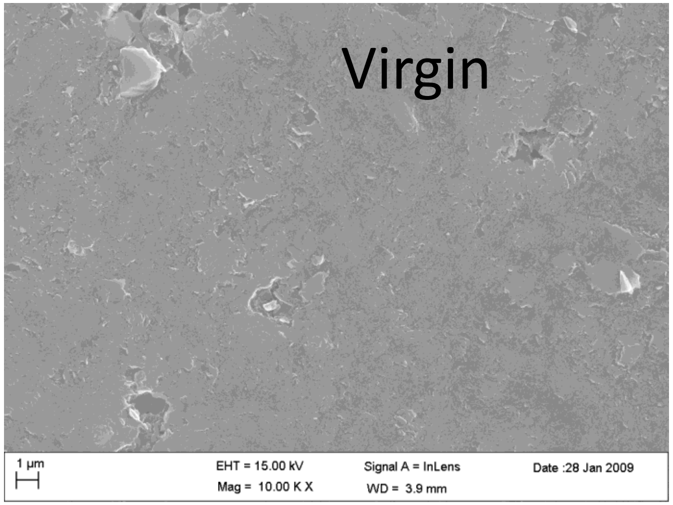
- Parameters to account for damage are:
  - Displacement Per Atom
  - He/H transmutation (especially for high energetic particles);
  - Electronic stopping (presently taken into account only as temperature increase, could produce damage – DPA – in non-metallic materials);

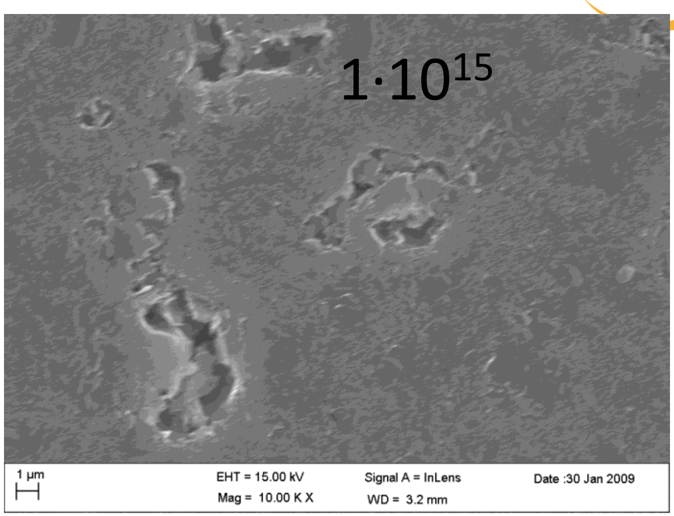
- Damage correlation between different types of irradiations (projectile and energy) should take into account:
  - Primary recoil energy spectra;
  - Displacement dose rate, DPA/s;
  - Transmutation production rates, He/DPA and H/DPA;
  - Kinetics of irradiation-induced defect production and accumulation behaviour due to pulsed irradiation.
  - Production of single point defects and defect clusters.

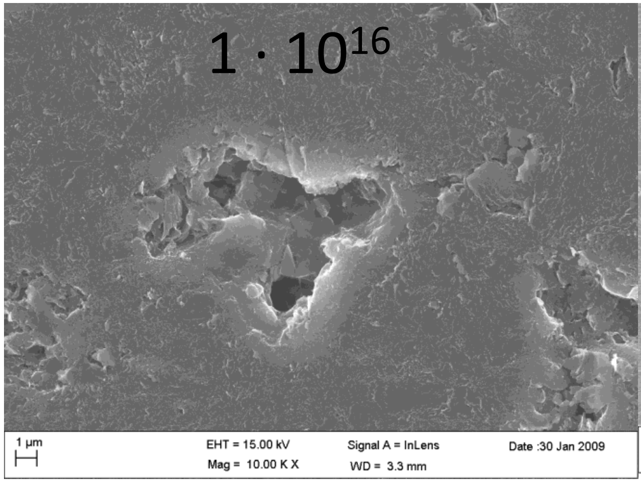
→ Extrapolating from ion to high energetic protons challenging

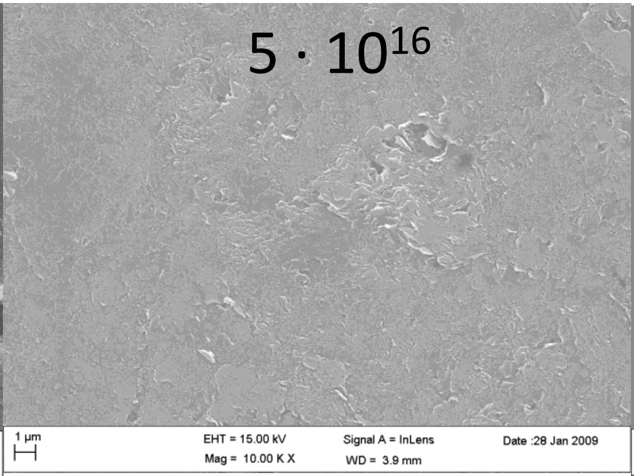
He implantation experiments

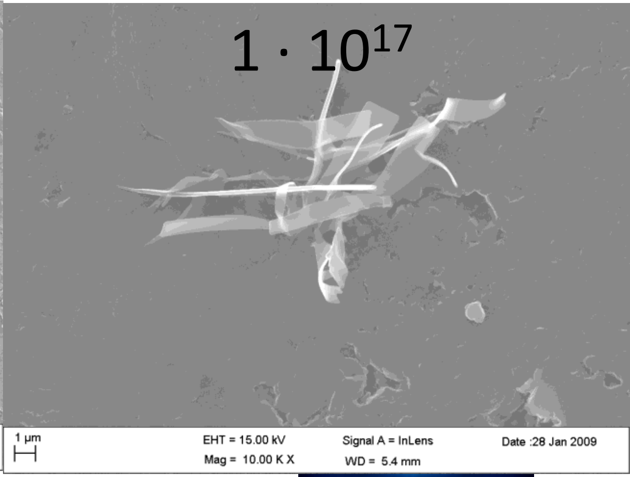
Morphology evolution with He$^+$ fluence


Virgin

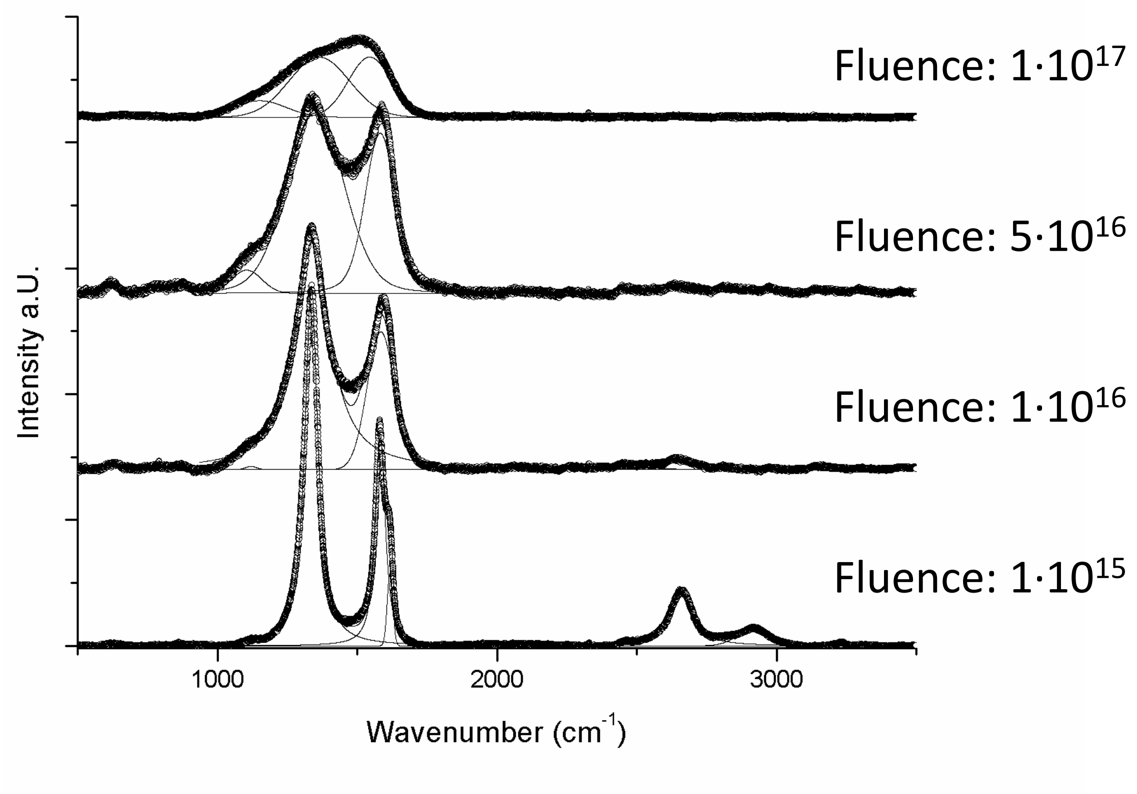

$1{\cdot}10^{15}$

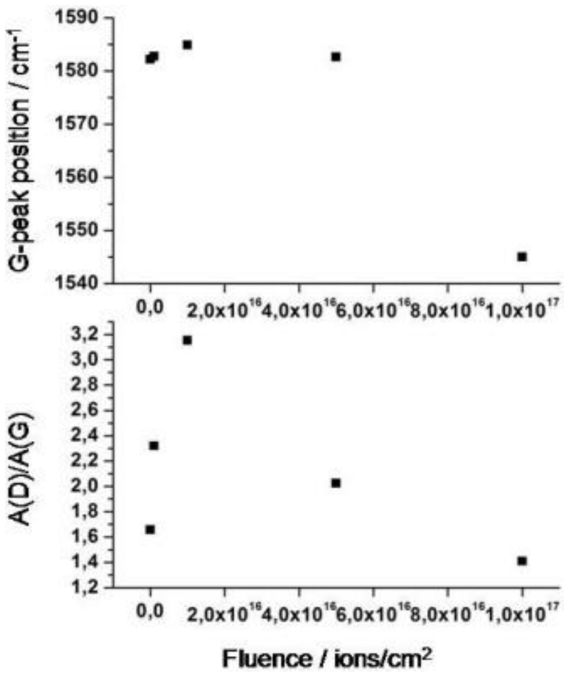

$1 \cdot 10^{16}$


$5 \cdot 10^{16}$


$1 \cdot 10^{17}$

Raman spectra of graphite irradiated with 100keV He^+-ions





- G-peak shifts first to higher then to lower wavenumbers
- Increase of D-peak to G-peak ratio followed by decrease of this ratio

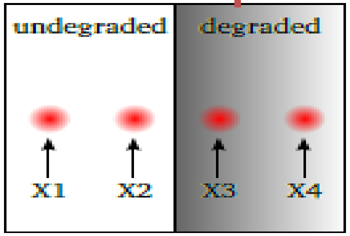
Experiments at GSI for dpa calculations

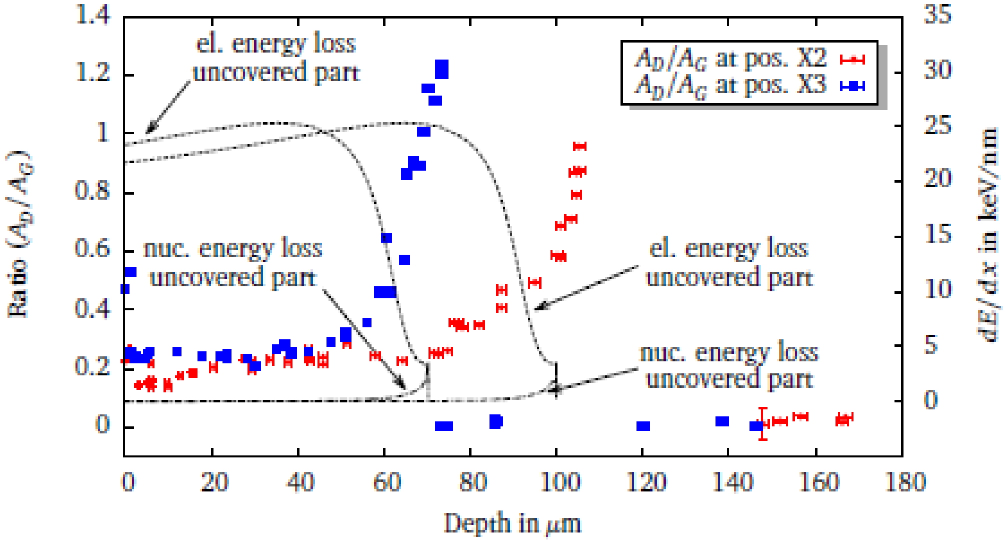
Ion: C, Ca, Sm, Au and U
Energy : 4.8 MeV/u
Material:
graphite 1.8 g/cm^3
MoGr 2.6 g/cm^3

dpa/ primary
as a function of depth

^{197}Au, 11.1 MeV/u

Sample





Damage evolution with depth