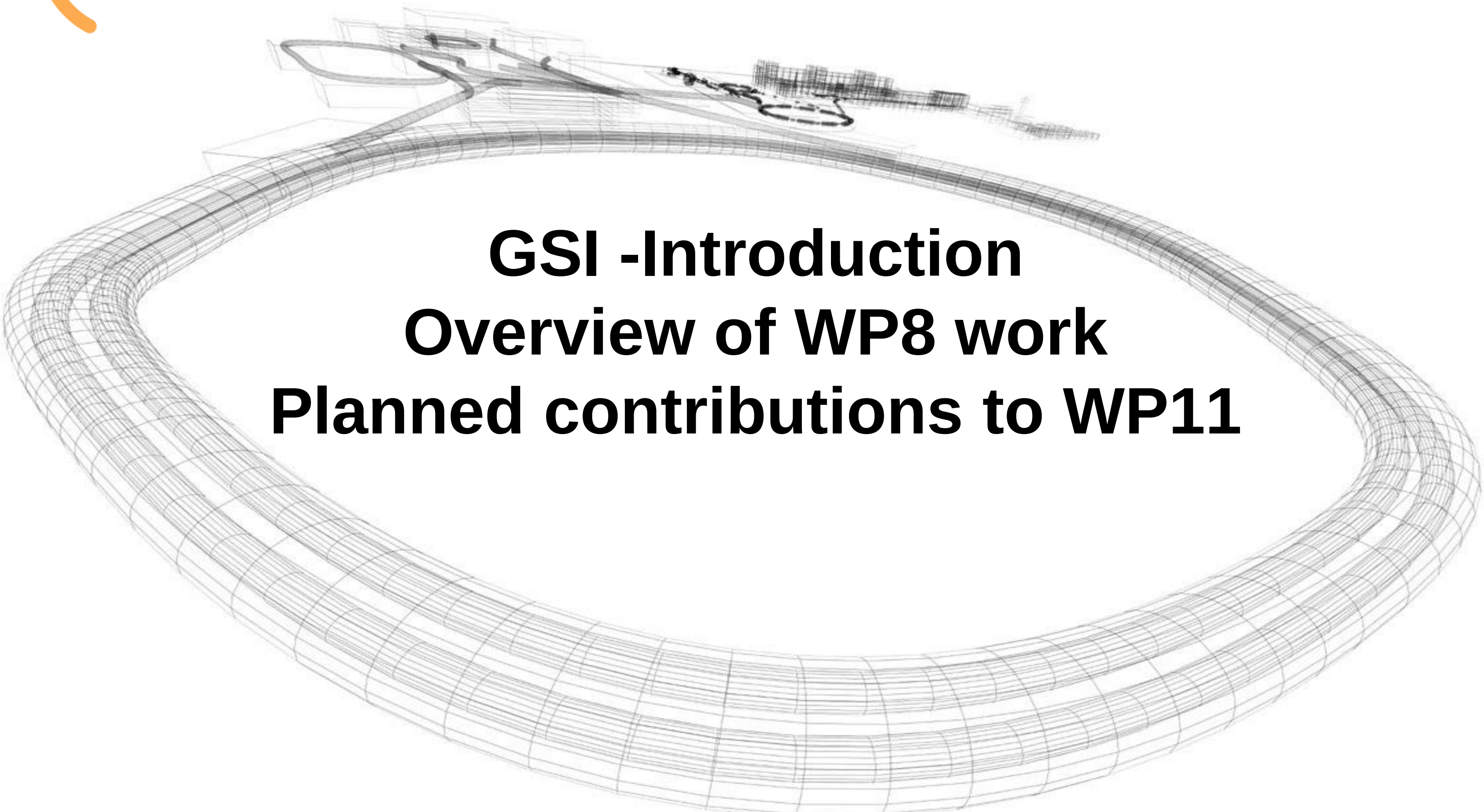


GSI -Introduction
Overview of WP8 work
Planned contributions to WP11

EuCARD2 WP11 (Materials for Collimation) kick-off and tasks meeting

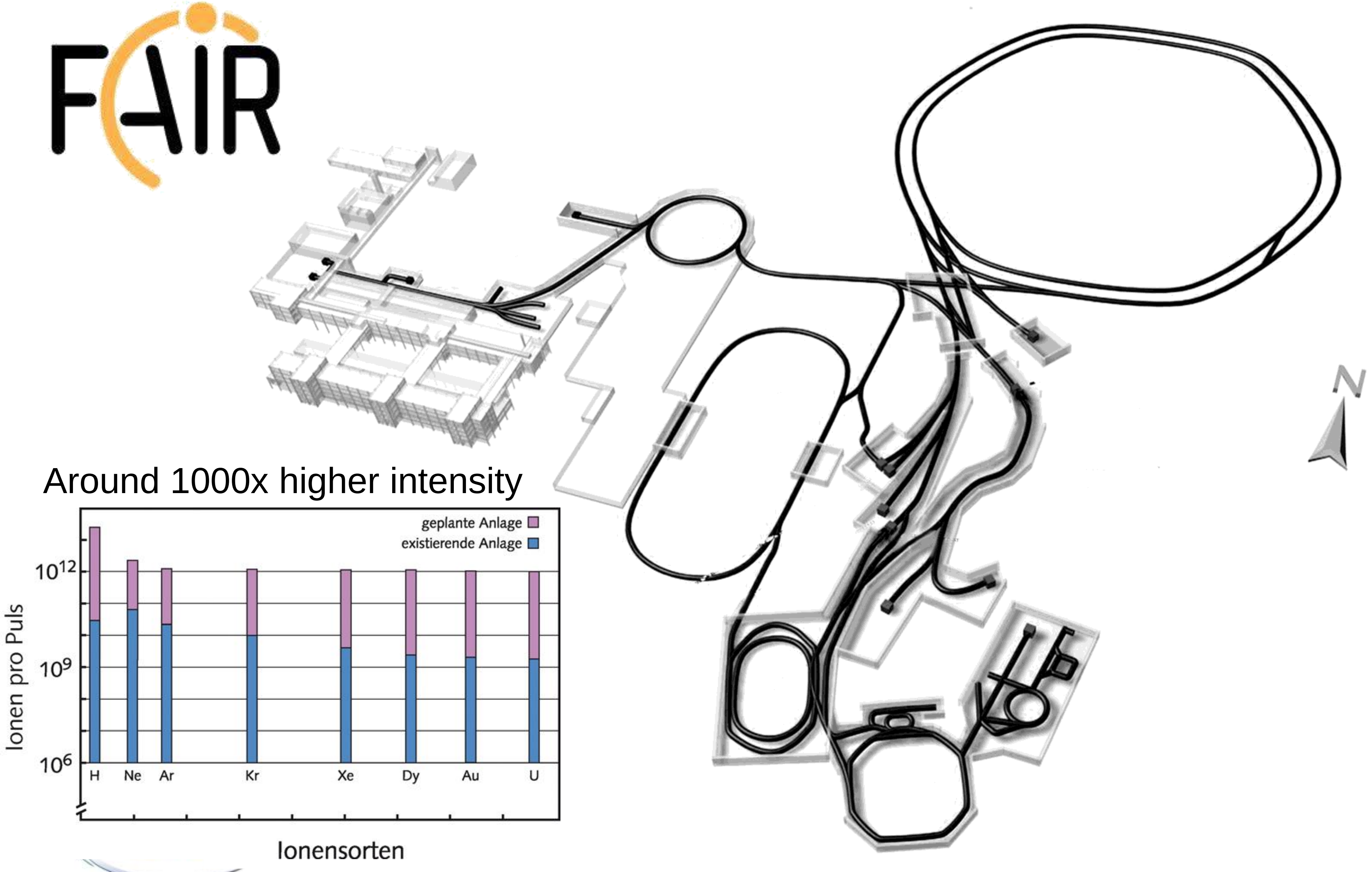
9.12.2013

Marilena Tomut / FAIR@GSI/ BIOMAT

Overview

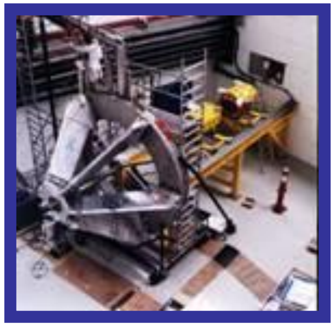
- GSI Research Center for Heavy Ion Physics
- EuCARD WP 8 activities
- Planned activities in EuCARD 2 WP 11

GSI and FAIR



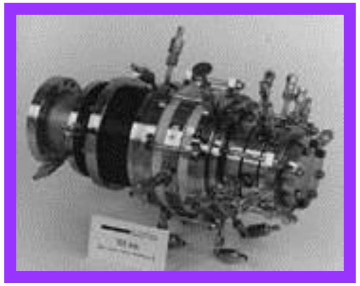
Around 1000x higher intensity

Research Fields at GSI

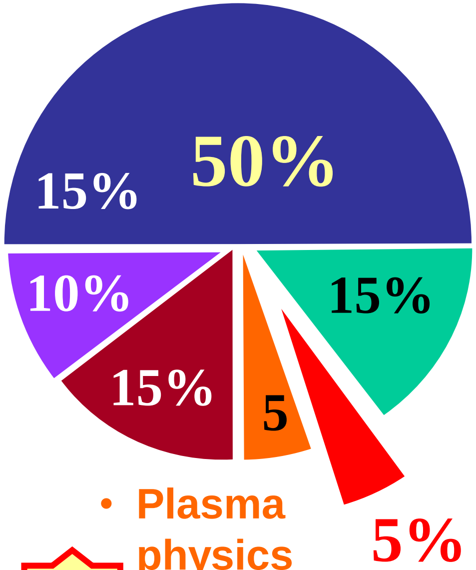


- Compressed & hot nuclear matter

- Superheavy elements
- Nuclei far from stability



- Accelerator & detector development



- Radiobiology
- Tumor therapy

- Plasma physics

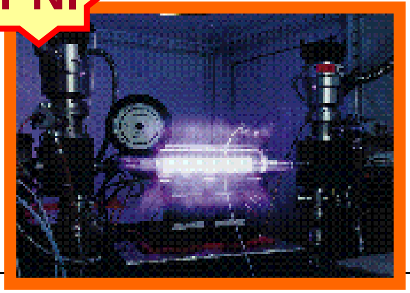
PNI

Materials Research

PNI

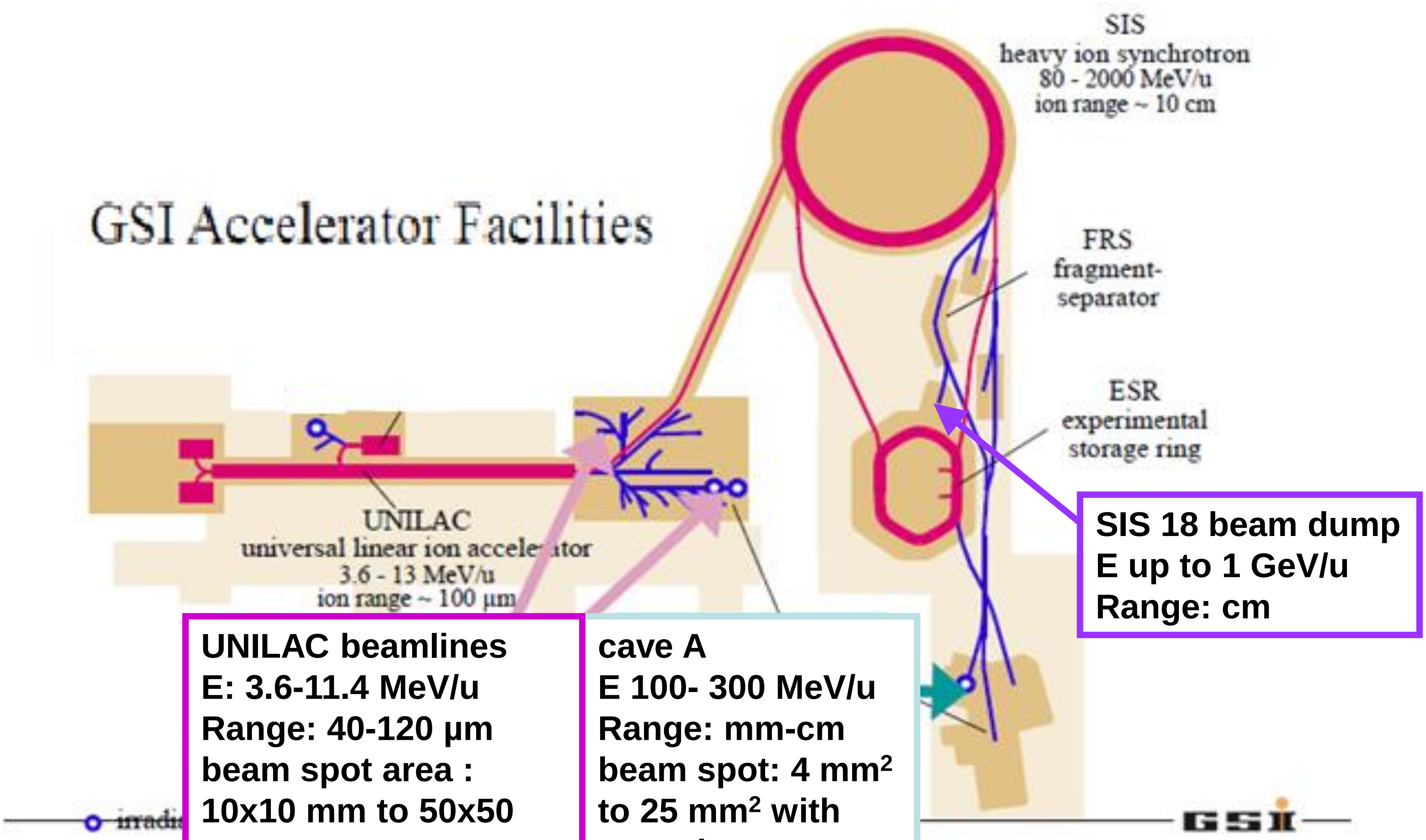
- Atomic physics
- fundamental tests of QED

PNI



more info: http://www.gsi.de

Beamlines for material research irradiation at GSI



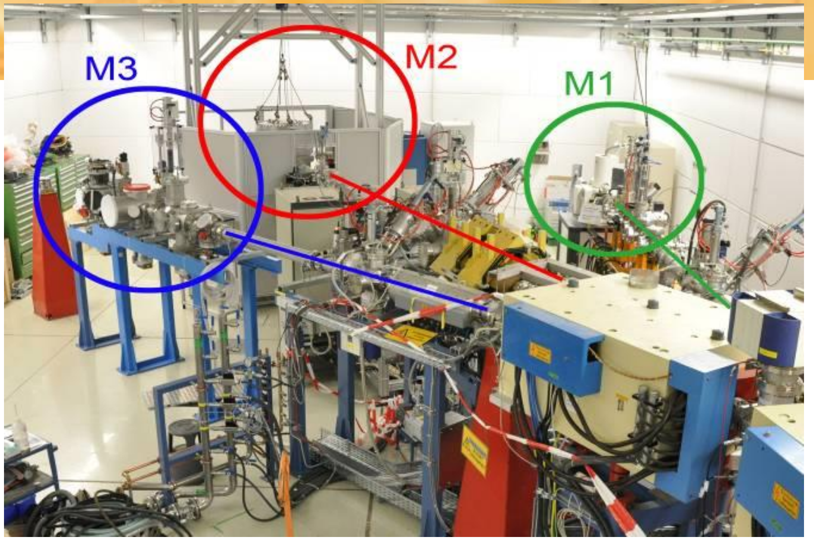
SIS 18 beam dump
E up to 1 GeV/u
Range: cm

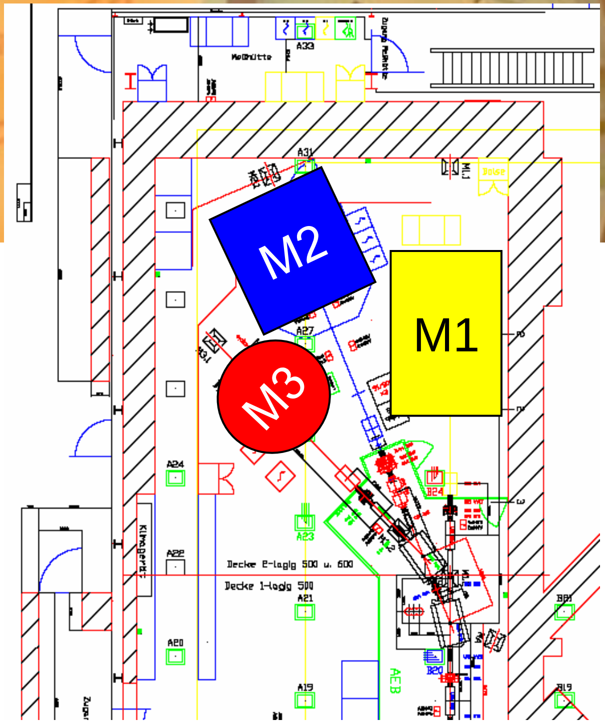
UNILAC beamlines
E: 3.6-11.4 MeV/u
Range: 40-120 µm
beam spot area : 10x10 mm to 50x50 mm

cave A
E 100- 300 MeV/u
Range: mm-cm
beam spot: 4 mm^2 to 25 mm^2 with scanning

New M-Branch (UNILAC)

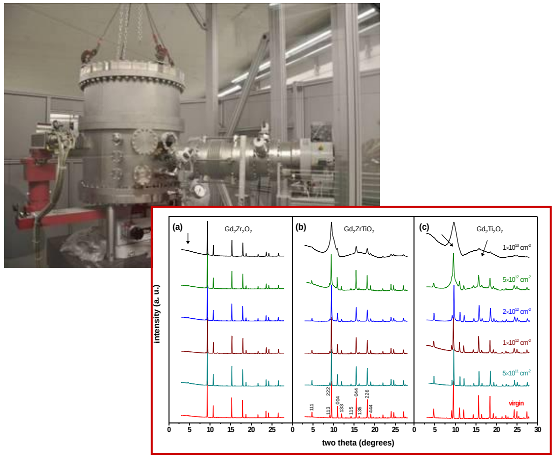
in-situ analysis of ion-irradiated material



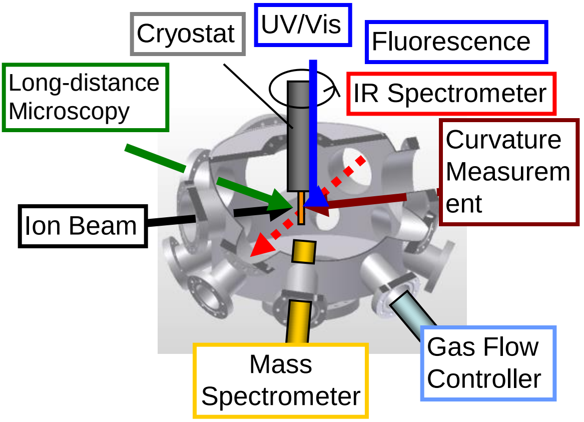


M1
Electron Microscopy

M2
4-circle X-Ray Diffraction



M3
On-line Spectroscopy



Cryostat

UV/Vis

Fluorescence

Long-distance Microscopy

IR Spectrometer

Curvature Measurement

Ion Beam

Mass Spectrometer

Gas Flow Controller

in collaboration of Univ. Darmstadt, Dresden, Göttingen, Heidelberg, Jena, Stuttgart, and HZB

GSI participiption in WP 8 Tasks

- **8.1** Coordination and Communication

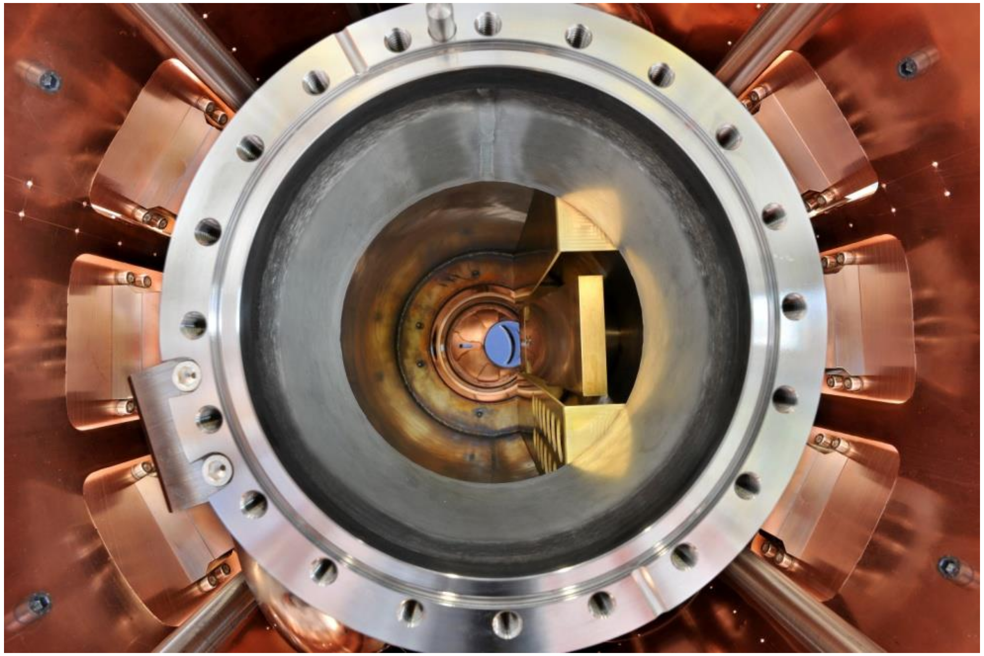
- **8.2** Modeling & Material Tests for Hadron Beams
  1. Halo studies and beam modeling
  2. Energy deposition calculations and tests
  3. Materials and thermal shock waves
  4. Radiation damage and activation studies
  ….

- **8.3** Collimator Prototyping & Tests for Hadron Beams
  1. Prototyping, laboratory tests and beam tests of room-temperature collimators (LHC type)
  2. Prototyping of cryogenic collimators (FAIR type)
  3. Crystal collimation

FAIR collimator prototype

FAIR cryocatcher

Cryocollimator prototype built and successfully tested in SIS 18

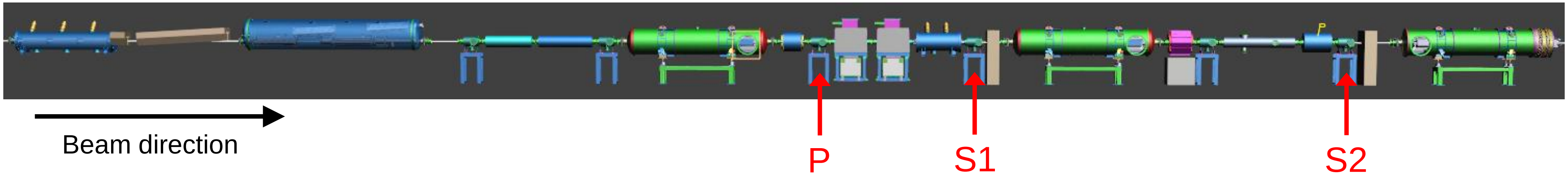


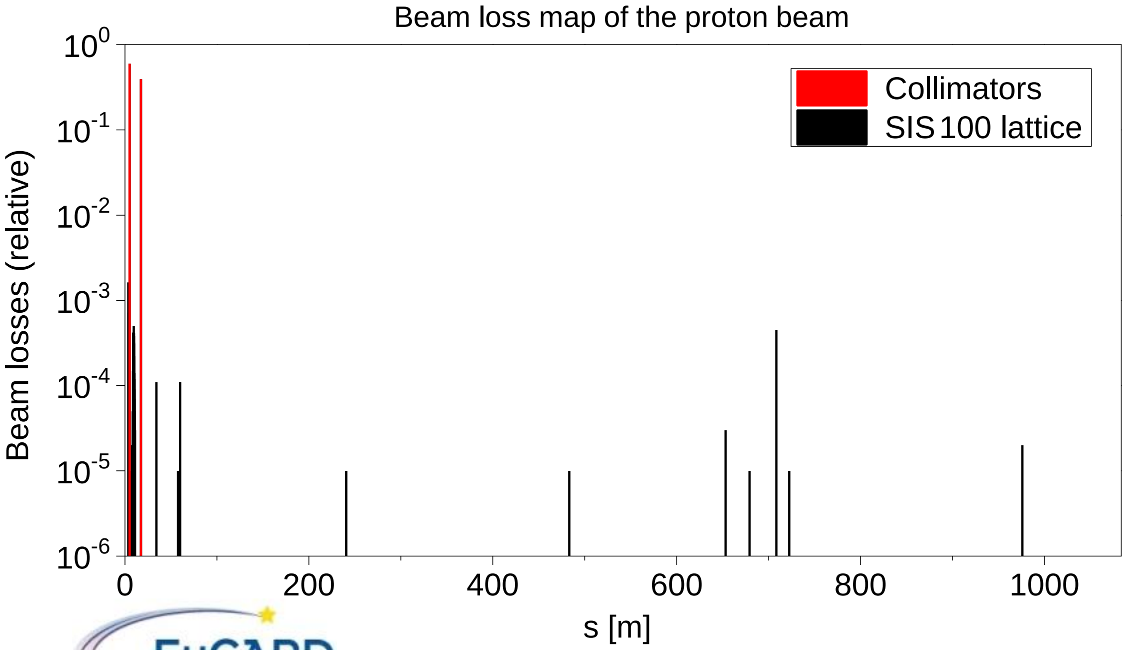
Halo collimation system in SIS 100

Two-stage betatron collimation concept

Location: Sector 1, straight section (SIS100 → SIS300 transfer)

P – primary collimator
S1 – 1. secondary collimator
S2 – 2. secondary collimator





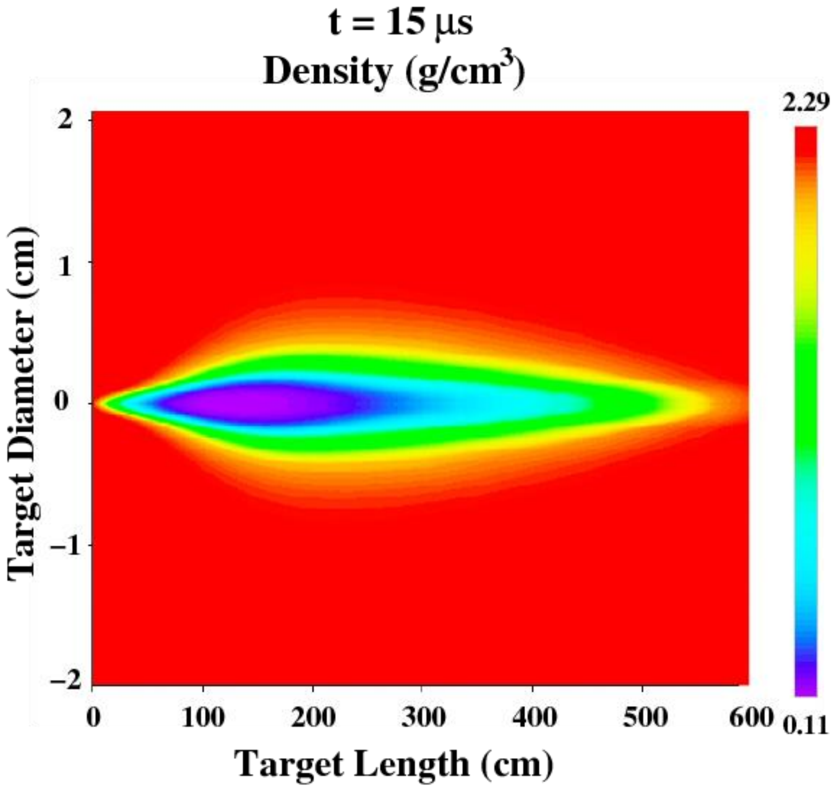
Particle tracking: MADX code
Material interaction: FLUKA code
Statistics: 100 000 particles

Collimation efficiency (protons): ~ 99 %
Collimation efficiency (^{40}Ar ions): ~ 85 %

Simulation of hydrodynamic tunneling I

- One LHC beam, 7 TeV, protons, nominal bunch intensity = 1.15×10^{11}, 2808 bunches, pulse length = 89 µs, beam size σ = 0.2 mm.
- Solid carbon cylinder, L = 6 m, r = 5 cm.
- Energy loss code FLUKA and 2D hydro code Big2 are run iteratively using a step of 2.5 µs.
- In 15 µs the beam penetrates up to 6 m, in 89 µs the penetration depth is 25 m.
- In a static model (no hydro) the beam and the shower penetrates up to only 4 m.

"Hydrodynamic Tunneling"
is therefore not neglectable and important.



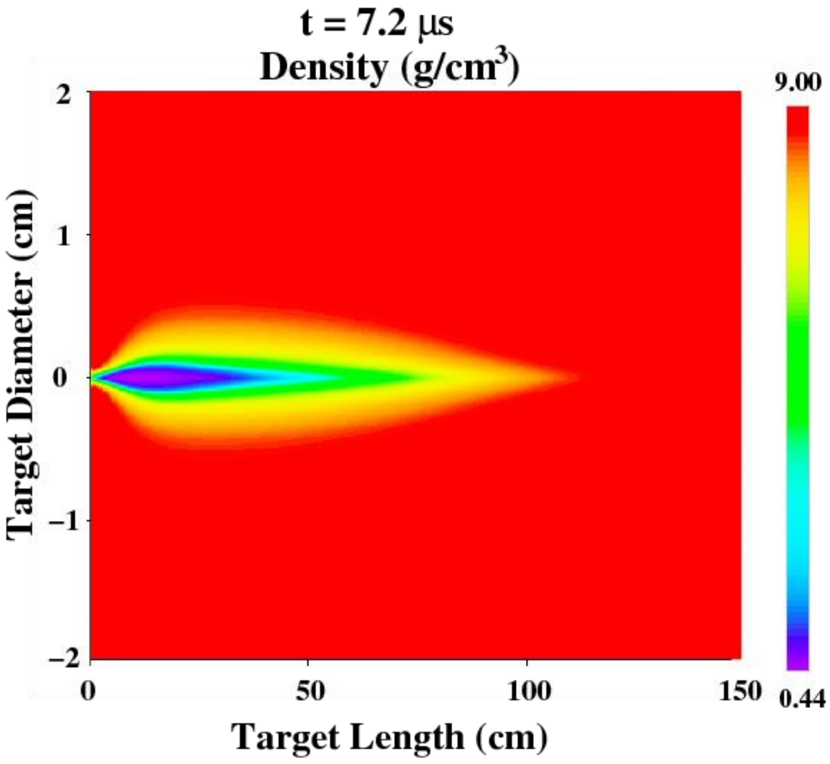
Full impact LHC beam on solid carbon cylinder
„N.A. Tahir et al.,
PRSTAB 15 (2012) 051003"

Simulation of hydrodynamic tunneling II

+ Experiments at HiRadMat using 440 GeV SPS protons

- To validate “hydrodynamic tunneling” in LHC simulations, experiments were done at the HiRadMat using th SPS 440 GeV protons
  [“*J. Blanco Sancho et al., Proc. IPAC 2013, Shanghai”].*
- Extensive simulations were done using FLUKA and BIG2 iteratively to design these experiments.
- SPS beam with 244 bunches,
  7.2 μs, σ = 0.2 mm.
- Solid copper cylinder, L = 1.5 m, r = 5 cm facial irradiation on left face.

Beam penetration in static model up to 85 cm, in dynamic case =120 cm. “Hydrodynamic Tunneling” predicted.



Simulations of hydrodynamic tunneling experiments at HiRadMat facilty using 440 GeV SPS Protons

„N.A. Tahir et al.,High Energy Density Phys. 9 (2013) 269“

Residual activation of collimator materials

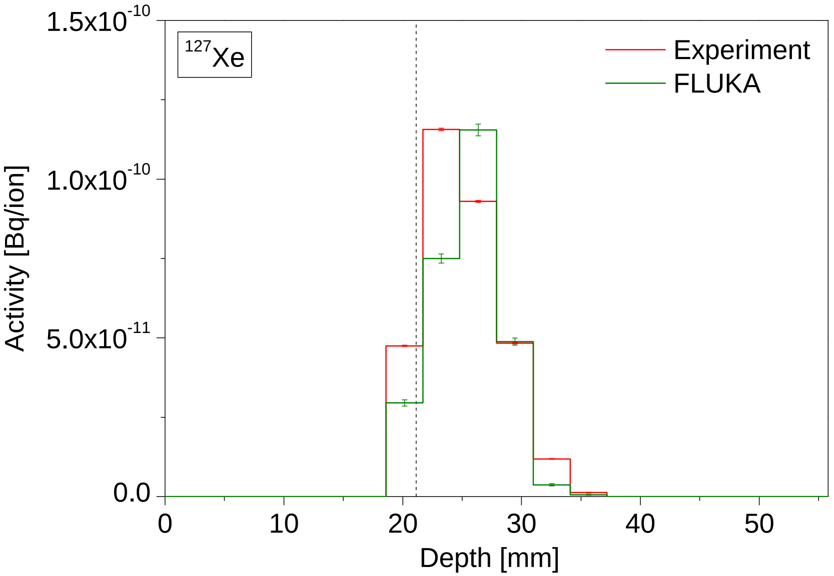
Topics:

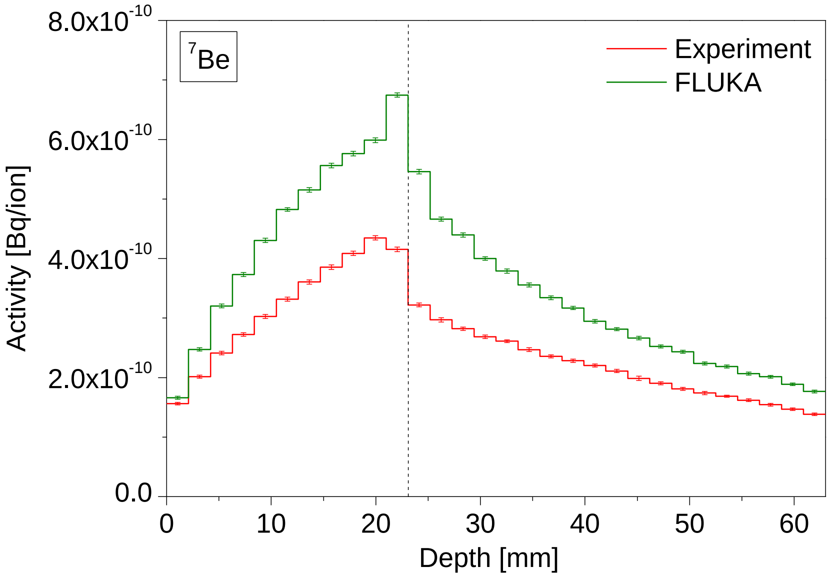
- Experiments – irradiation of the collimator materials by heavy ions, gamma spectroscopy analysis
- FLUKA simulations – validation of the code using the experimental data
- Depth profiles (depth distribution) of the residual activity in the targets

---

Target material: carbon-composite AC150
Beam species: ^{238}U ions
Beam energy: 500 MeV/u

Target material: graphite
Beam species: ^{181}Ta ions
Beam energy: 500 MeV/u



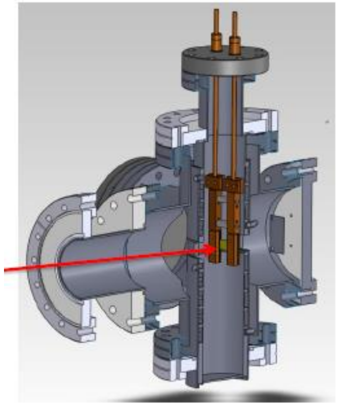


Identified isotopes (only gamma emitters) – 1. target-nuclei fragments (only ^{7}Be)
– 2. projectile fragments (from ^{46}Sc to ^{237}U)

Experimental studies of radiation damage effects on carbon and Cu-Diamond collimator materials

- radiation-induced dimensional changes of graphite
- mechanical properties and Young’s modulus changes in irradiated graphite and CFC
- fluence dependence of electrical resistivity of irradiated graphite
- fatigue behaviour of irradiated graphite
- in-situ montoring of structural changes in ion-irradiated Cu-diamond composite materials

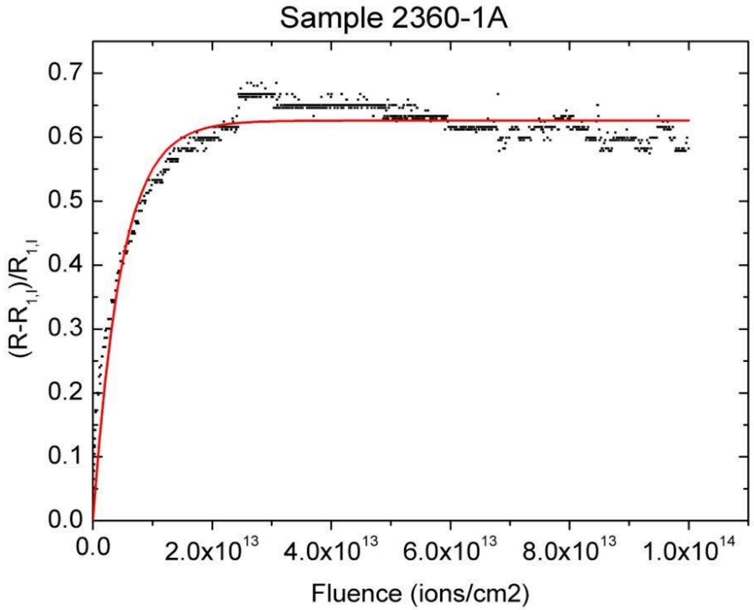
Online measurements of heavy Ion-induced electrical resistivity increase of graphite



Collaboration with MSU

Experimental set-up M3 / UNILAC GSI

Irradiation conditions:
ions / energy: ^{197}Au, 8.6 MeV/u
beam intensity: up to 5×10^{10} i/cm^{2}s
dose: up to 10^{15} i/cm^2



Direct impact model fit:

- Poisson Law

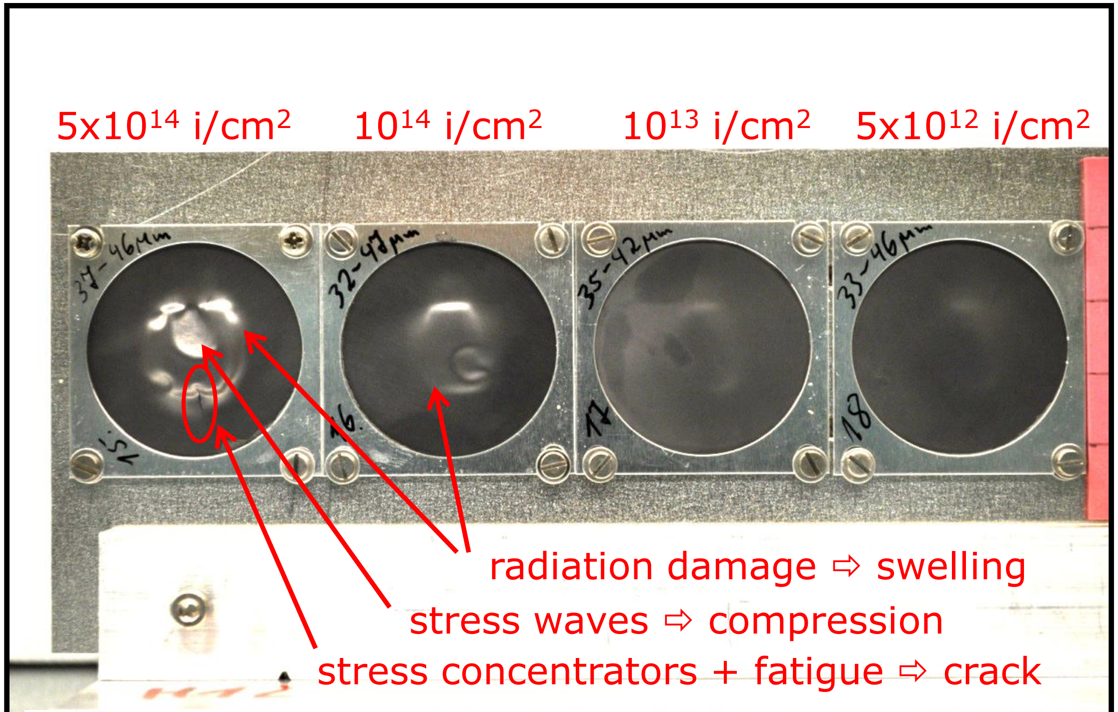
$$\frac{\Delta R}{R} = \left(\frac{\Delta R}{R}\right)_{Sat} \left(1 - e^{-\sigma_a \Phi}\right)$$

Damage cross section:

$\sigma_a = 6.0 \times 10^{-14}$ cm^{-2}

Failure of graphite exposed to pulsed ^{238}U beam

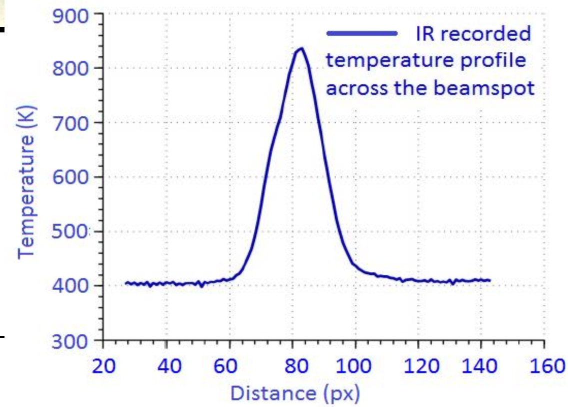
Experiment



radiation damage ⇨ swelling

stress waves ⇨ compression

stress concentrators + fatigue ⇨ crack



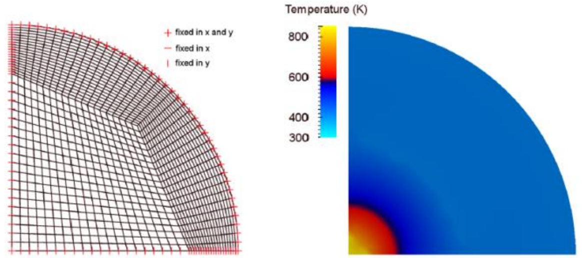
^{238}U, 4,8 MeV/u

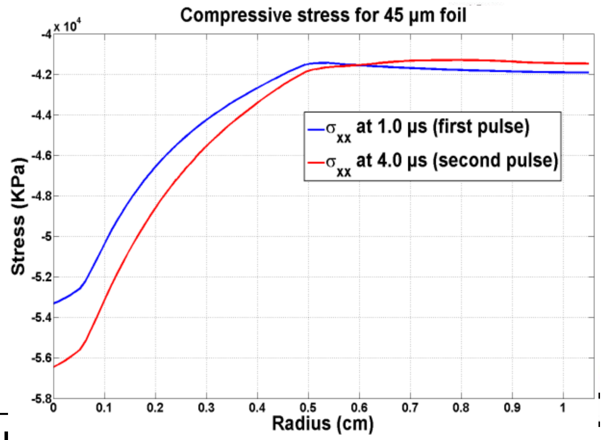
1.5 x10^{10} i/pulse

150 μs, 1 Hz

FEM simulations

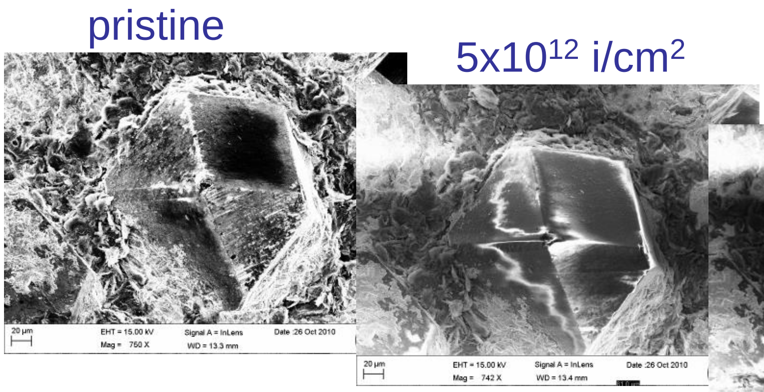
Graphite target / Pulse structure	Maximum compressive stress (MPa)	Maximum tensile stress (MPa)
45 μm (single pulse)	-53.3	0.5
45 μm (double pulse)	- 56.4	0.7

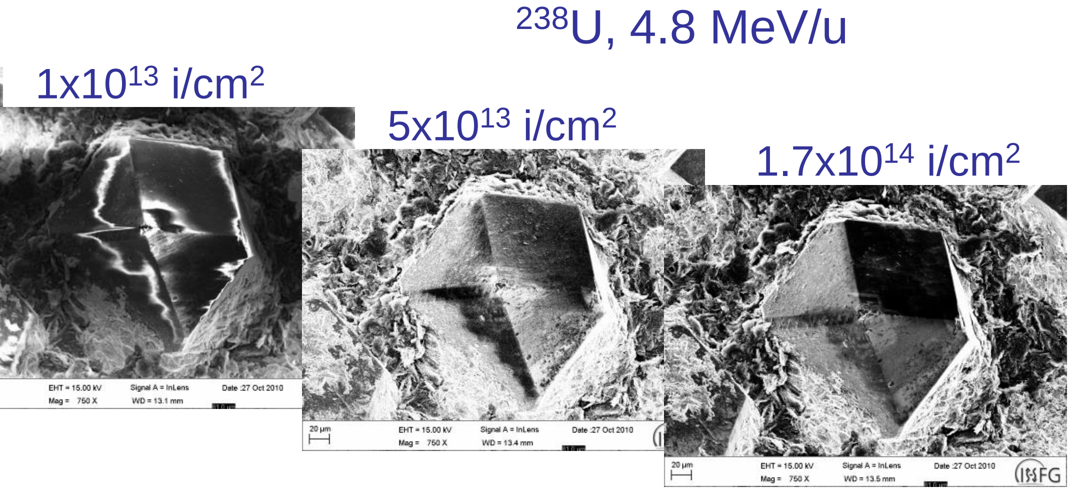


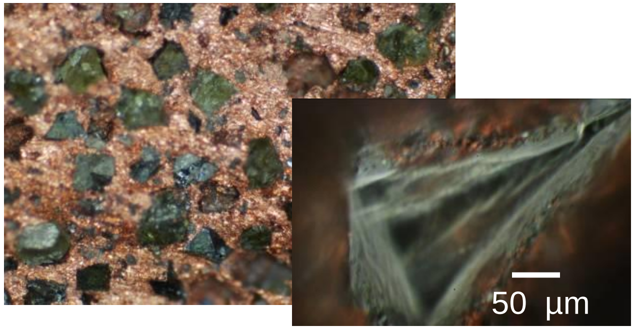


M.Tomut, GSI

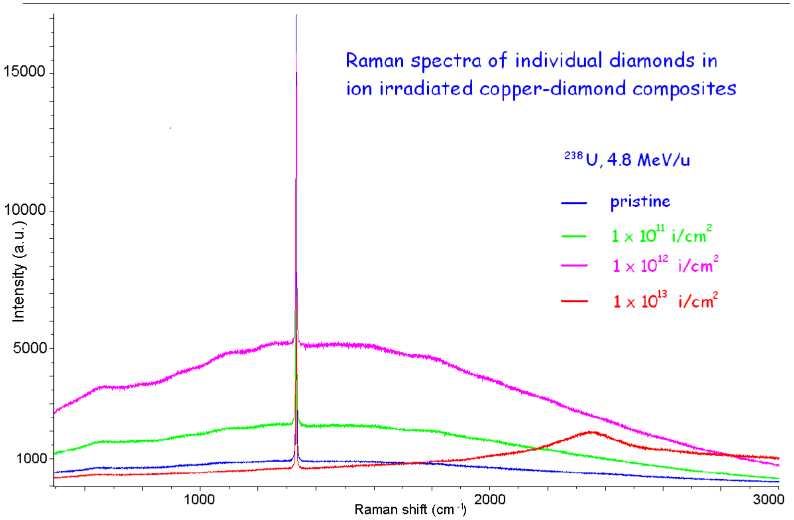
In situ SEM monitoring of heavy ion irradiation effects in novel copper-diamond composites







Diamond



- In-situ- SEM during ion irradiation shows:
  - no detachment or cracks at interfaces
  - charge trapping at ion induced defects in diamonds
- Off-line Raman spectroscopy shows:
  - increasing luminescence background due to ion-induced optical active defects
  - thermal conductivity degradation of irr. diamonds

M.Tomut, GSI

Planned activities in WP 11 Advanced collimator materials

Material irradiation and radiation damage characterization in situ and off-line:

- online IR monitoring (bulk and interfaces)
- fatigue studies with: Impact nanoindentation, pulsed ion beams, ns pulse laser generated proton beams
- characterization of mechanical properties degradation as a function of dose using micro- and nanoindentation: hardness, Young modulus, impact resistance, fatigue behaviour, creep
- other in situ possibilities still open
- spall strength studies of single component and model composite materials in ultrafast experiment, using the the Petawatt laser at GSI
- continuation of hydrodynamic tunneling simulations