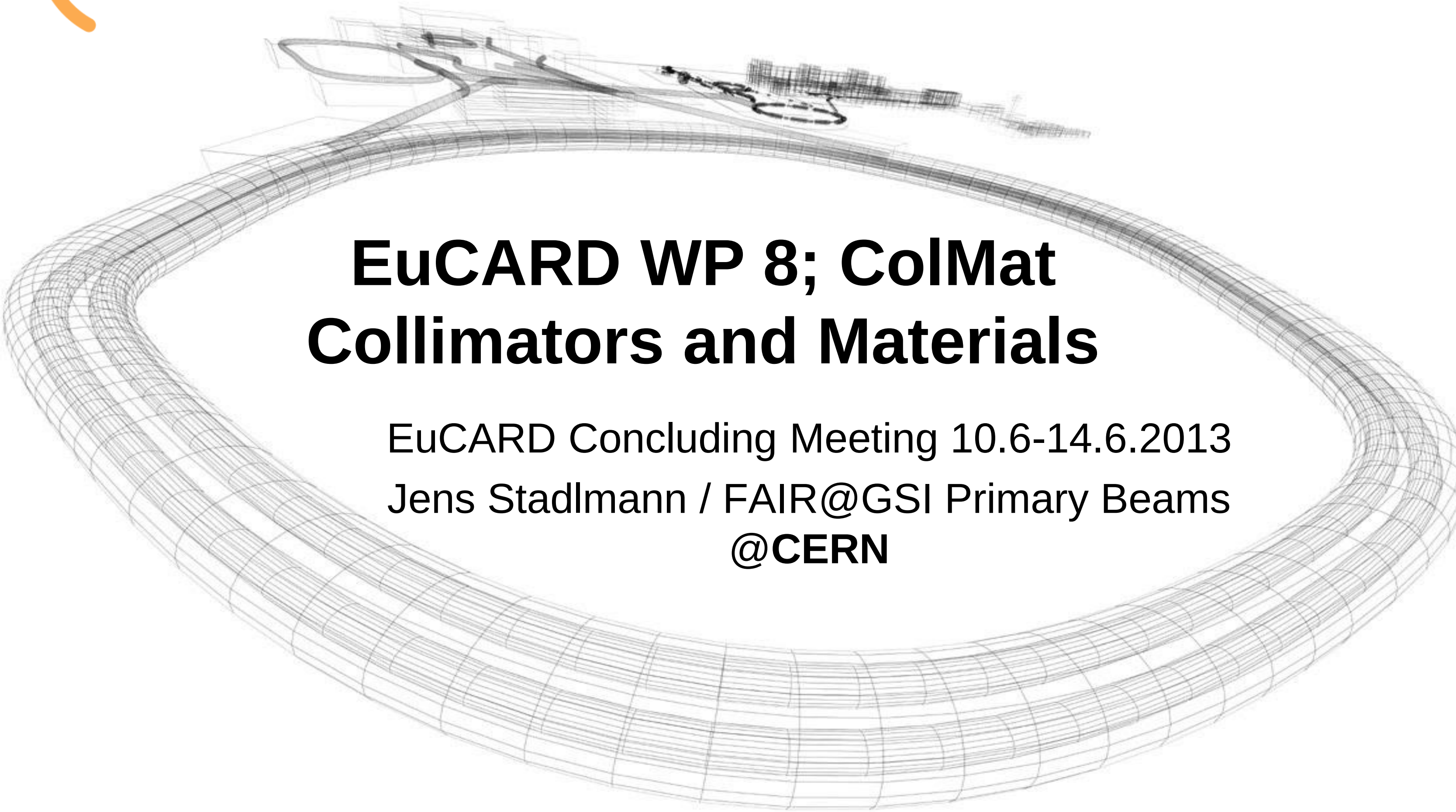


EuCARD WP 8; ColMat
Collimators and Materials

EuCARD Concluding Meeting 10.6-14.6.2013

Jens Stadlmann / FAIR@GSI Primary Beams

@CERN

Overview

- Introduction to WP 8
- Examples of WP 8 activities
- Concluding Summary

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
  ….

- **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

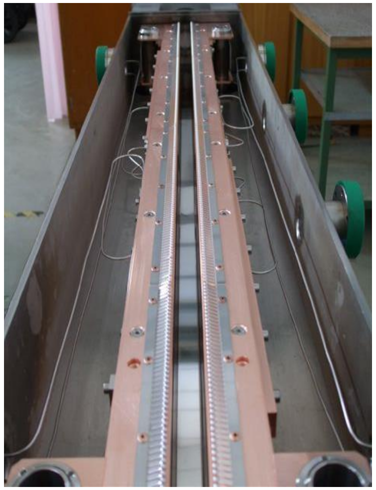
The many topics of WP 8

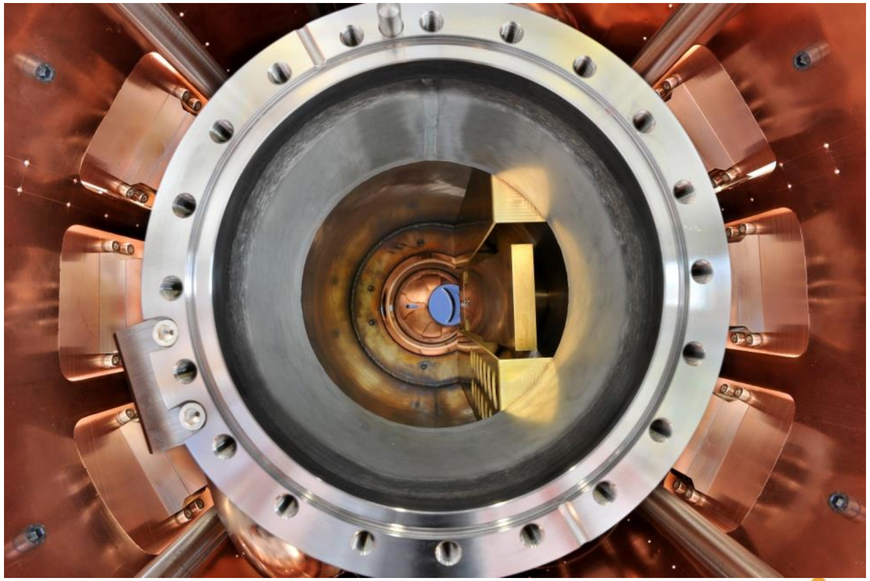
The scope of WP 8 reaches from

- identification of suitable materials for accelerator/collimator design,
- test of material properties,
- simulations of material behavior on beam impact,
- beam simulations and collimator performance to
- actual prototyping an in beam test of collimators for existing and future accelerator facilities.

Status of LHC and FAIR collimator prototypes

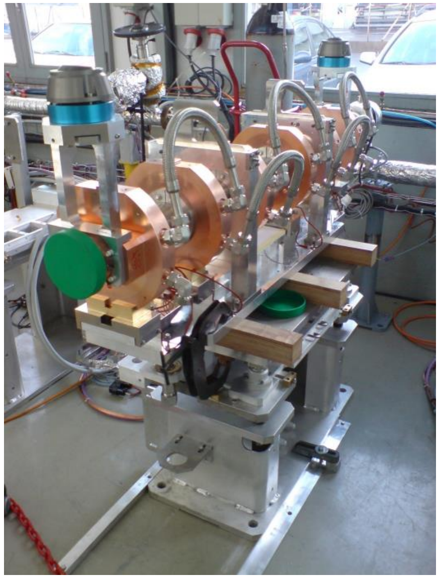
- LHC Phase II collimator
  -> DONE
  (presented 2011/12)
- FAIR cryocatcher
  -> DONE
  (presented 2012)
- Crystal Collimation
  -> DONE
- Some examples of WP8 activities coming up.



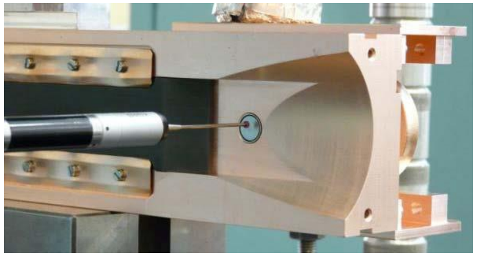


Beam and halo modeling for LHC

- Simulations and beam measurements on beam halo were performed, aimed to improve the performance of the actual LHC collimation system and to support its upgrade.
- Some of the many topics include combined betatron and momentum cleaning, misalignment studies and non linear collimation.
- Calculations done with combination from MAD-X + SixTrack + FLUKA
- Studies continued over the whole project.



Passive absorber, straight section point 3



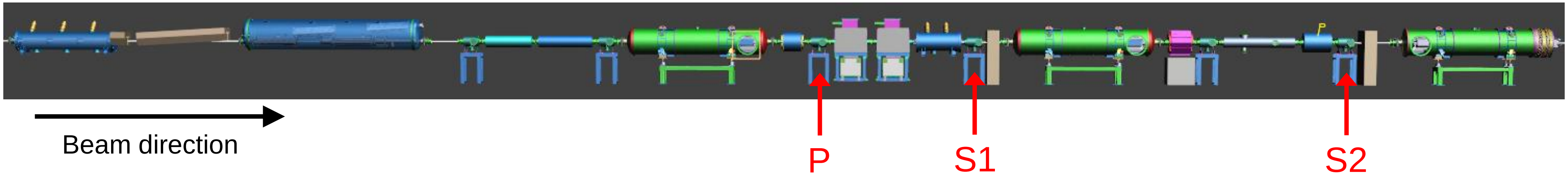
BPM button in collimator allows precise adjustment

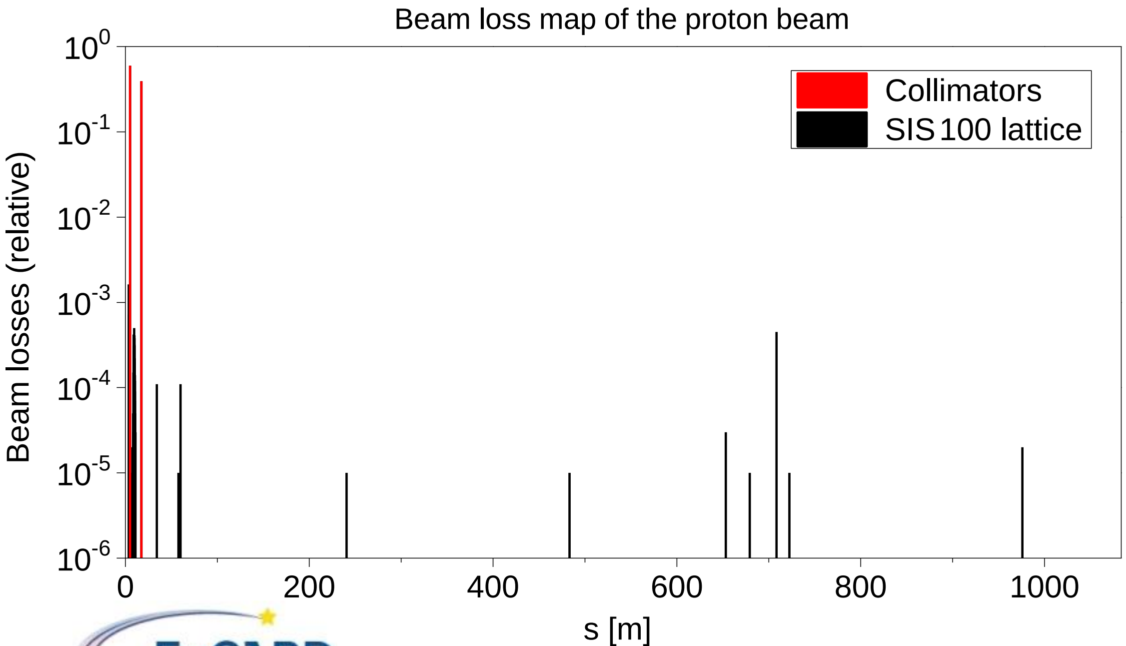
Halo collimation system in SIS 100

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

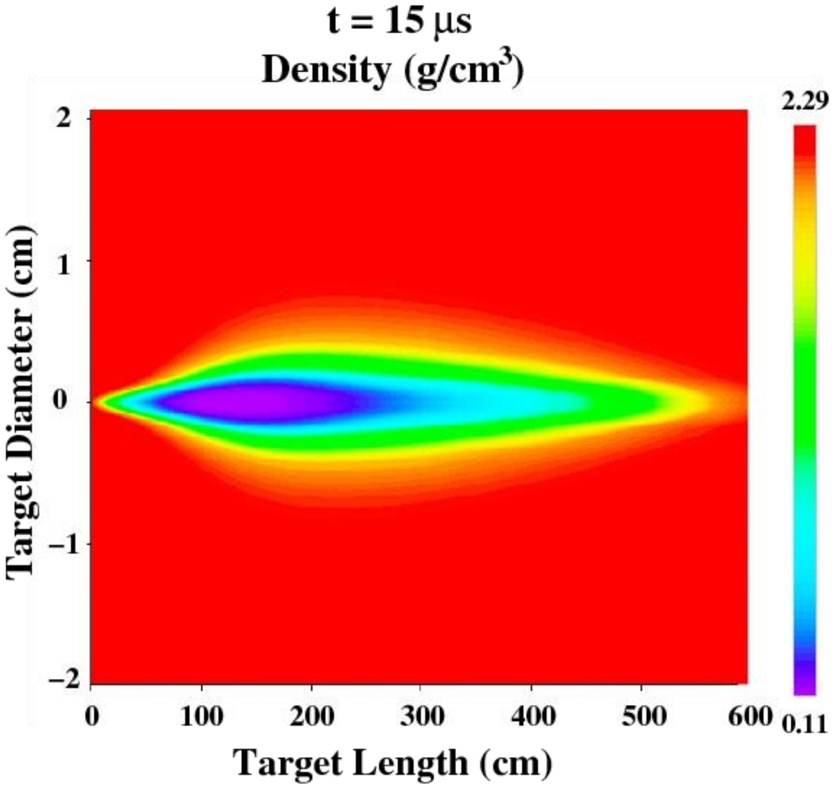
Collimation efficiency (protons): ~ 99 %

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.

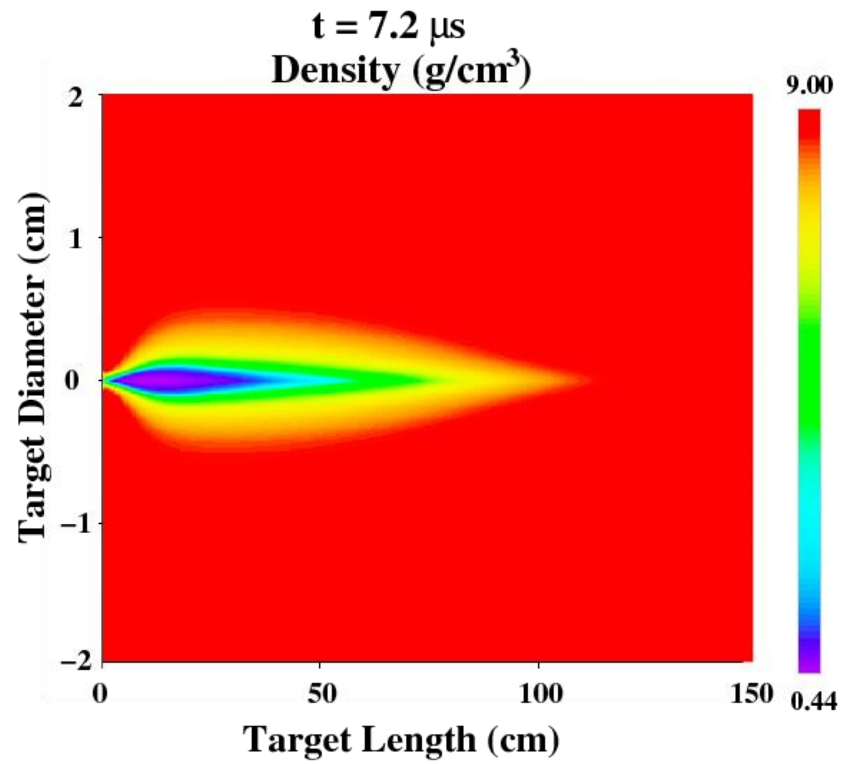


Full impact LHC beam on solid carbon cylinder
„N.A. Tahir et al.,
PRSTAB 15 (2012) 051003"

Simulation of hydrodynamic tunneling II
+ Experiments at HiRadMat using 440 GeV SPS protons

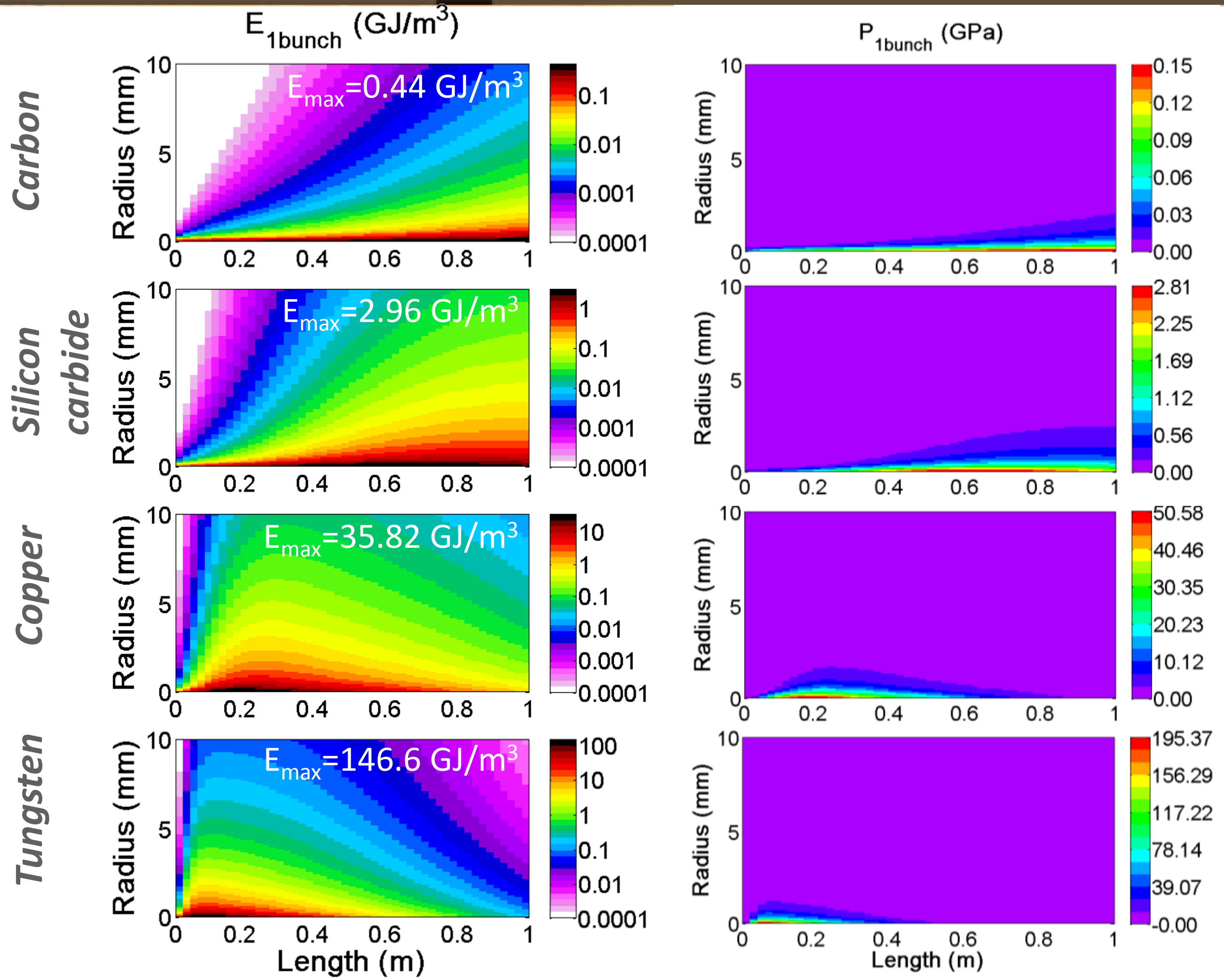
- To validate “hydrodynamic tunneling” in LHC simulations, experiments were done at the HiRadMat using th SPS 440 GeV protons
[“*J. Blanco Sancho et al., Proc. IPAC 2013, Shanghai”].*
- Extensive simulations were done using FLUKA and BIG2 iteratively to design these experiments.
- SPS beam with 244 bunches,
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“

Example: Comparison between different materials



One 7 TeV protons bunch 1.15×10^{11} protons

The proton energy loss and the maximum position is strongly "material" dependent

A beam of LHC has 2808 bunches!
362 MJ energy/beam sufficient to melt 500 kg copper

MERLIN simulations in WP8

Rob Appleby, Adina Toader, Maurizio Serluca, James Molson (Manchester)
Roger Barlow, Haroon Rafique (Huddersfield)

MERLIN: a modern, flexible C++ library for accelerator simulations.

The groups is:

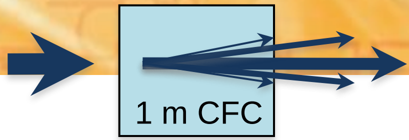
•Checking LHC collimation results obtained using sixtrack. Comparing loss maps.

• Improving the models of elastic and diffractive scattering in collimators with assistance from friendly theoretician Sandy Donnachie. At last, a use for the Pomeron!

• Obtaining large increases in computation speed using multiple cores

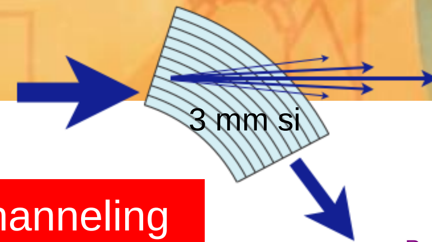
• Maintaining and updating the Merlin code on the SourceForge repository

Crystal assisted collimation



amorphous

$\langle\theta\rangle_{MCS} \cong 3.6\mu rad$ @ 7 TeV

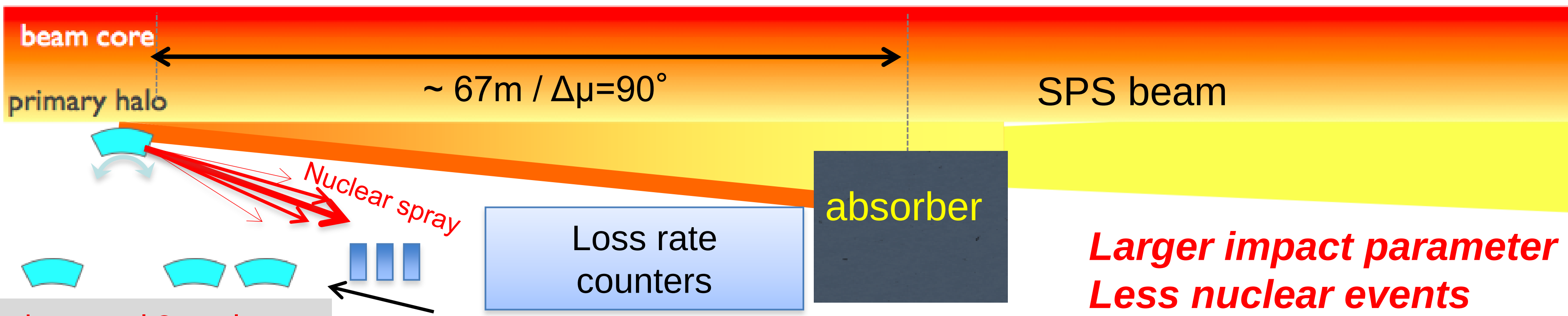


$\theta_{ch} \cong \alpha_{bending}$

channeling

$\theta_{optimal\ @7TeV} \cong 40\ \mu rad$

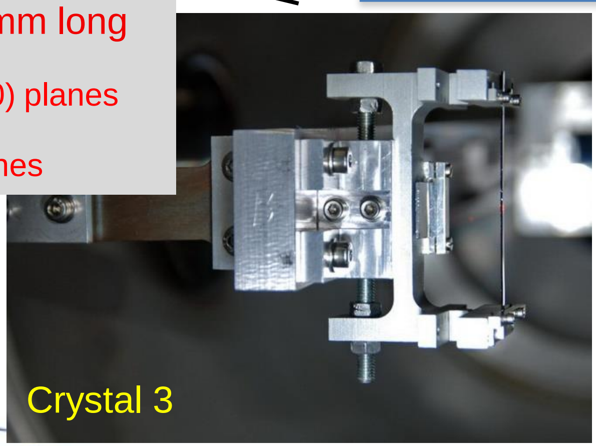
R. W. Assmann, S. Redaelli, W. Scandale, "Optics study for a possible crystal-based collimation system for the LHC", EPAC 06



Larger impact parameter
Less nuclear events
Less impedance

Strip crystal 2mm long

- Bent along (110) planes
- Equidistant planes



Strip crystal manufactured in INFN Ferrara

Mechanical holder to impart proper curvature (~150 mrad)

Installed in SPS and tested

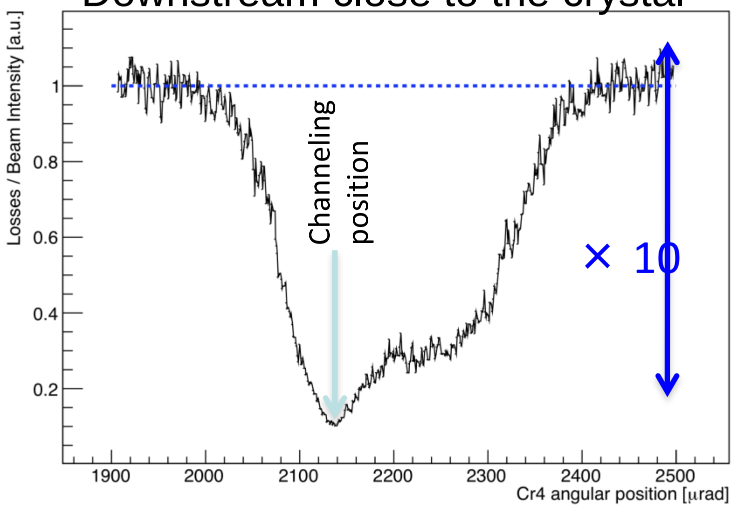
Reduction of secondary interaction

- Crystal acting as primary aperture
- Crystal rotated in a continuous scan
- Reduction of recorded secondary interaction close to crystal in channeling condition.

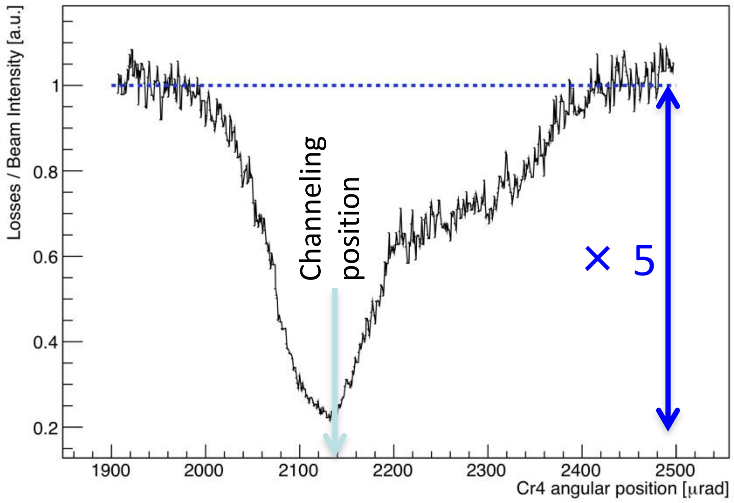
- Off-momentum particles produced in the secondary absorber.
- Intercepted with scatterer in a dispersive area
- Observed a substantial reduction.

Tests done with 120 GeV proton beam and Pb ion beam, similar results

Downstream close to the crystal



in a dispersive area

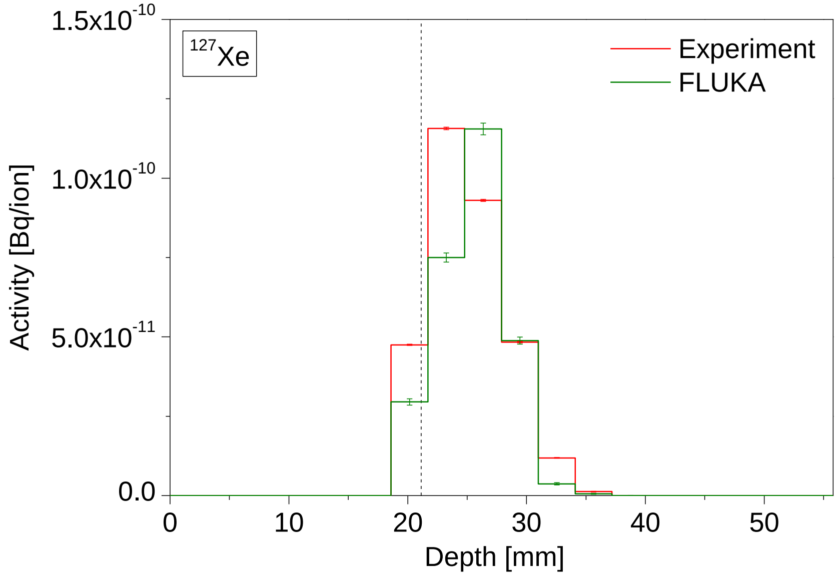


Residual activation of collimator materials

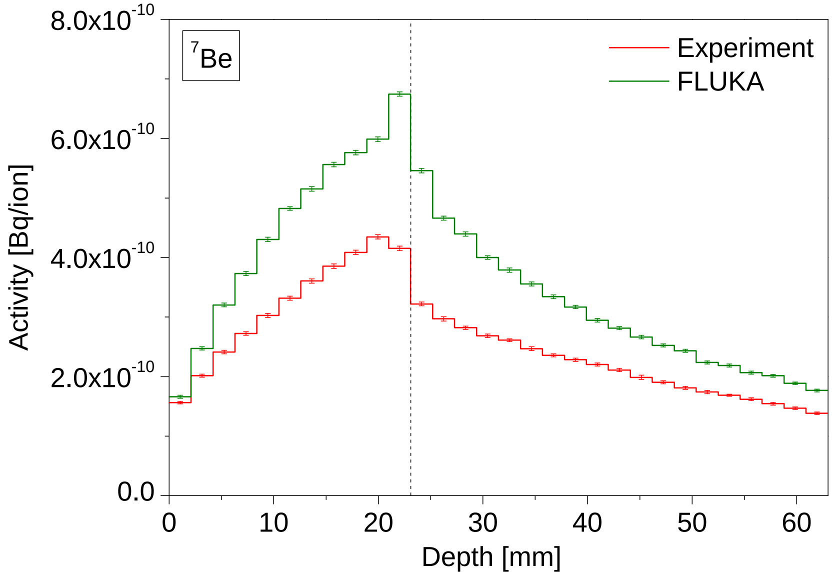
Topics:

- 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

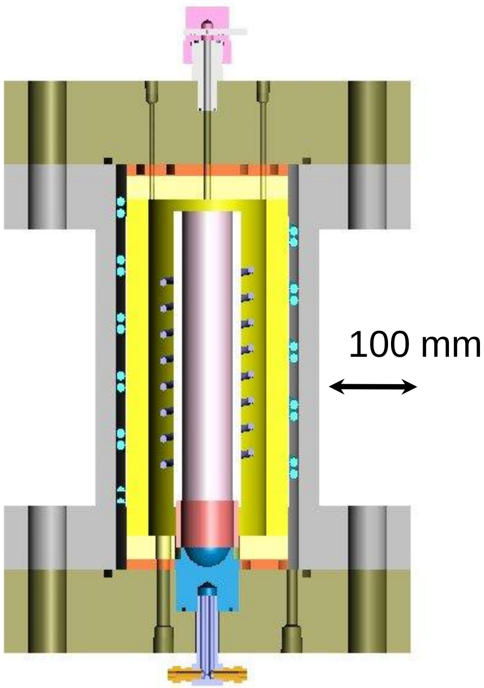


Target material: graphite
Beam species: ^{181}Ta ions
Beam energy: 500 MeV/u



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

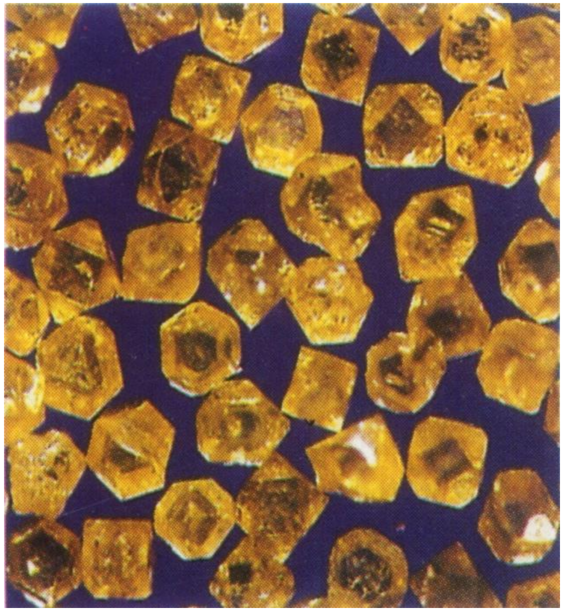
Diamond Metal Composite Materials



• Cold wall vessel
(250 bar, 200°C)
Inner side of the wall in contact with a water cooled heat shield

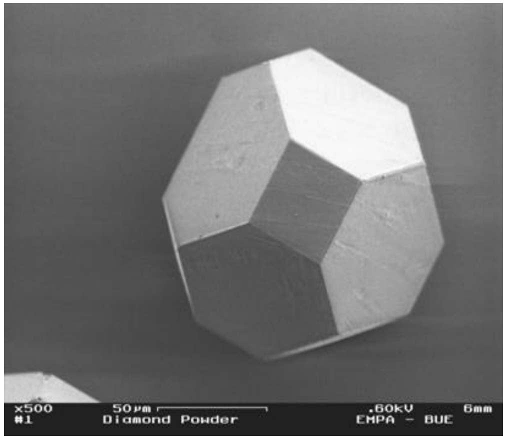
• Induction heating
(using a graphite susceptor)

• primary vacuum pump
(0.1 mbar)



Selected Diamond Grid

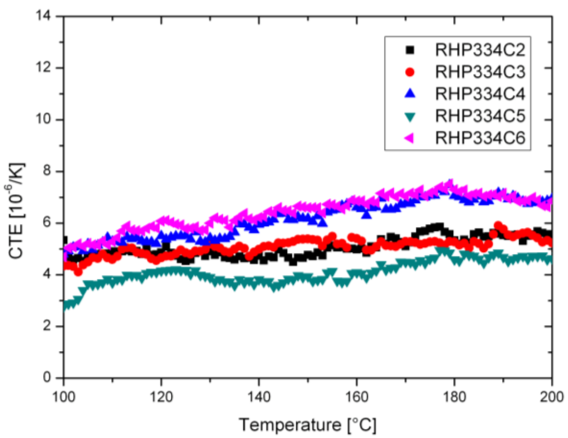
- Mono-crystalline diamond
- Low nitrogen level
- Relatively large size (>100µm)



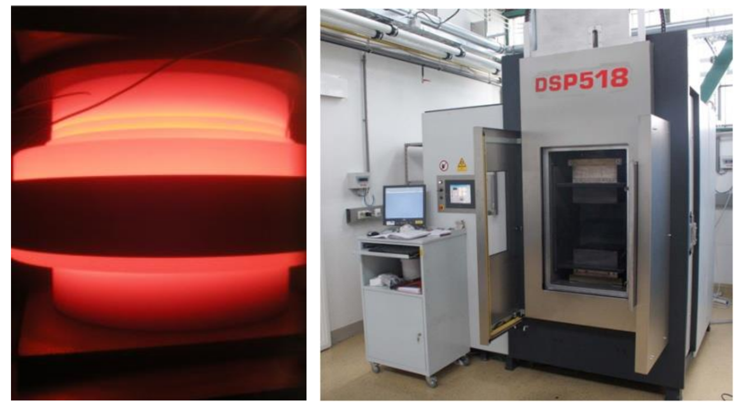
Résistance et Ténacité

HIGHLIGHTS RHP-TECHNOLOGY (DIACOOL MATERIAL)

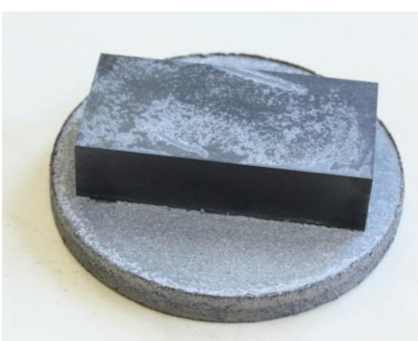
- Copper-Diamond Composite Material available for large size (a)
- Rapid Hot Pressing for optimized manufacturing (b)
- Direct bonding to SiC tiles (c)
- Samples for HiRadMat and BNL experiments (d)



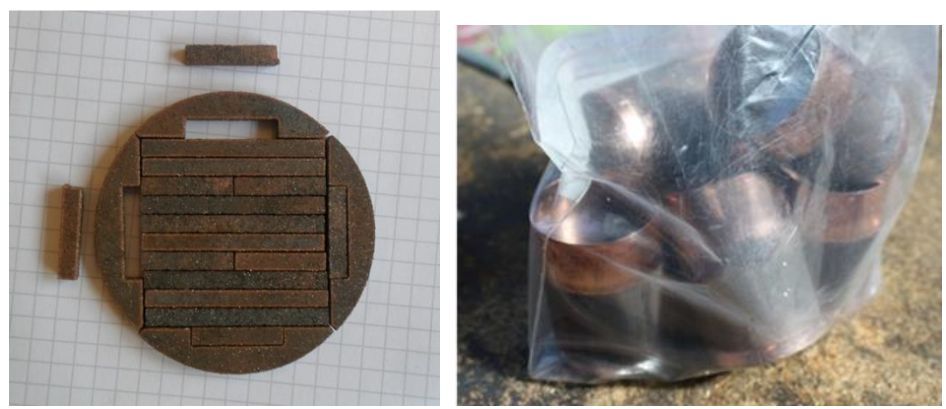
(a)



(b)



(c)



(d)

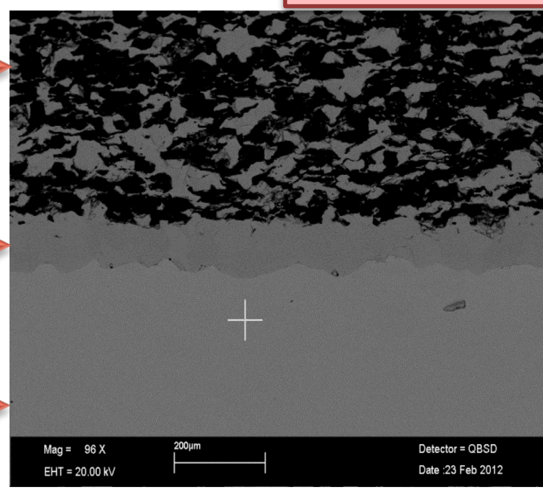
- **Metal Matrix Composites (MMC)** for advanced thermal management materials combine properties of Diamond or Graphite (high ***k***, low ρ and low ***CTE***) with those of Metals (**strength**, γ, etc.)
- Most promising material seems to be **Molybdenum-Graphite (MoGr), coated with Mo to increase the surface electrical conductivity**
- R&D and characterization ongoing → effects of radiation being studied at BNL

Molybdenum-Graphite

Core:
1 MS/m

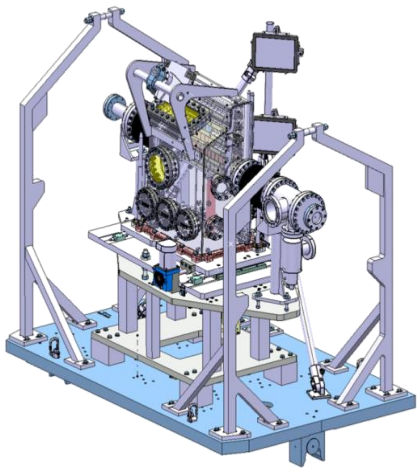
Carbide layer:
1.5 MS/m

Mo Sheet:
18 MS/m



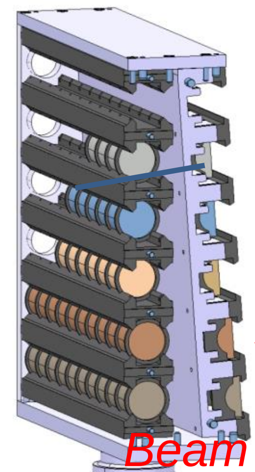
Experimental tests: HRMT14

- Beam impact tests on **novel materials** currently under development for Phase II Collimators: Inermet180, Molybdenum, Glidcop, MoCuCD, CuCD, MoGR



Medium Intensity (Type 1 samples):

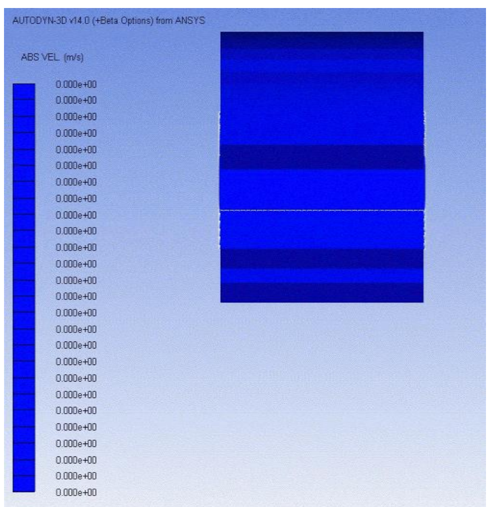
- Strain measurements on sample outer surface;
- Radial velocity measurements (LDV);
- Temperature measurements;
- Sound measurements.

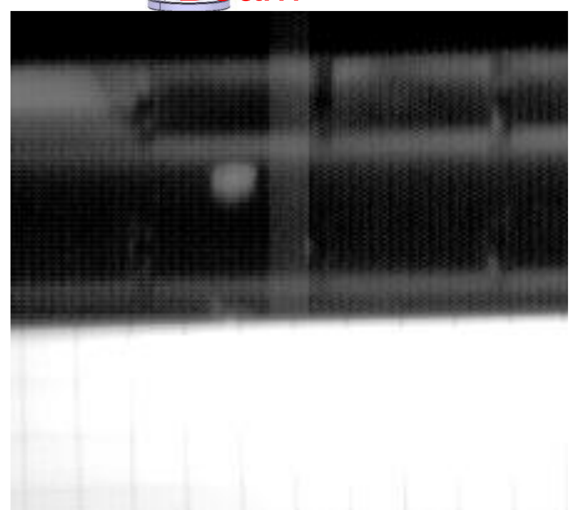


High Intensity (Type 2 samples):

- Strain measurements on sample outer surface;
- Fast speed camera to capture fragment front formation and propagation;
- Temperature measurements;
- Sound measurements.

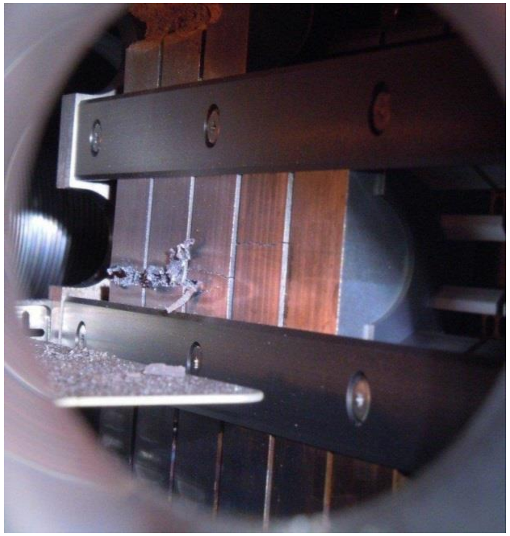
Beam



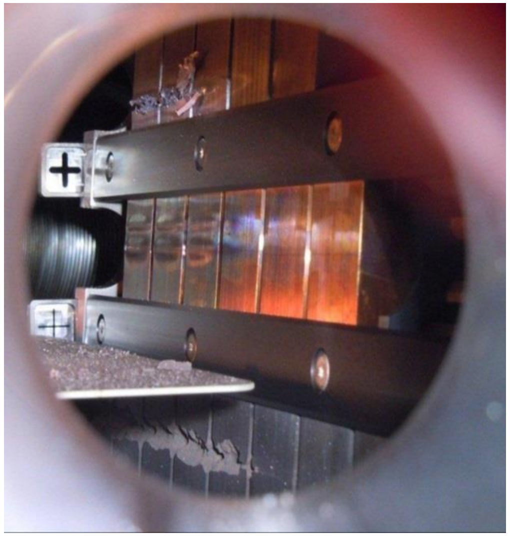


Inermet : comparison Autodyn (SPH) between simulation and experiment

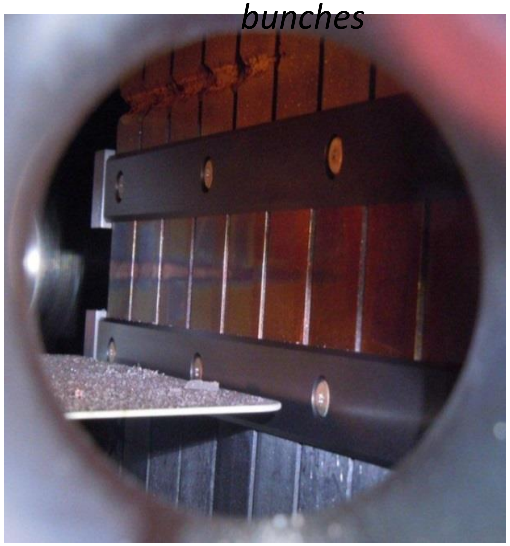
Inermet 180, 72 bunches



Molybdenum, 72 & 144 bunches



Glidcop, 72 bunches (2 x)



Copper-Diamond 144 bunches

Molybdenum-Copper-Diamond 144 bunches

Molybdenum-Graphite (3 grades) 144 bunches

Experimental and theoretical studies of the effects of irradiation on Cu-Diamond composites

The theoretical and experimental characterization of radiation damage to composite materials is difficult at best. Several tests and first theoretical studies on changes after radiation in Cu-Diamond materials have been performed including:

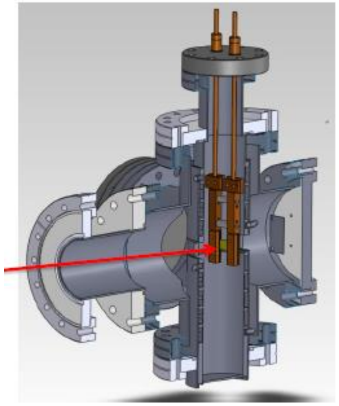
1. radiation-induced deformation (radiation swelling)
2. radioactive isotope composition
3. thermal expansion coefficient
4. temperature conductivity in Cu-Diamond
5. dependence of specific heat
6. change of electrical resistivity
7. mechanical properties and Joung’s modulus changes

National Research Center” Kurchatov Institute”

Diamond composite materials in ColMat

- We started out with questions about basic properties like "can we actually make them in sufficient size".
- Material characterizations: Mechanical, irradiation...
- Handling of the composite materials in simulations
- The workpackage extended it's reach from metal – diamond to metal – graphite and general composite materials towards EuCARD².

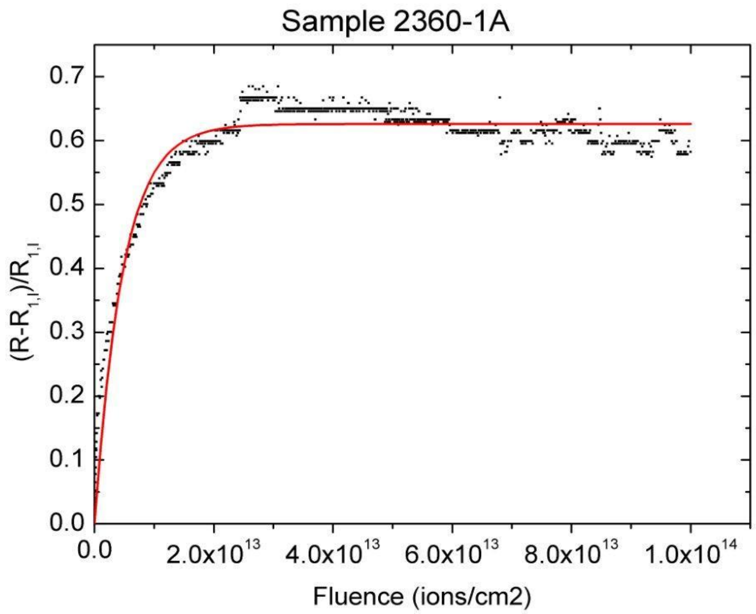
Online measurements of heavy Ion-induced electrical resistivity increase of graphite



Collaboration with MSU

Experimental set-up M3 / UNILAC GSI

Irradiation conditions:
ions / energy: ^{197}Au, 8.6 MeV/u
beam intensity: up to $5x10^{10}$ i/cm^2s
dose: up to 10^{15} i/cm^2



Direct impact model fit:

- Poisson Law

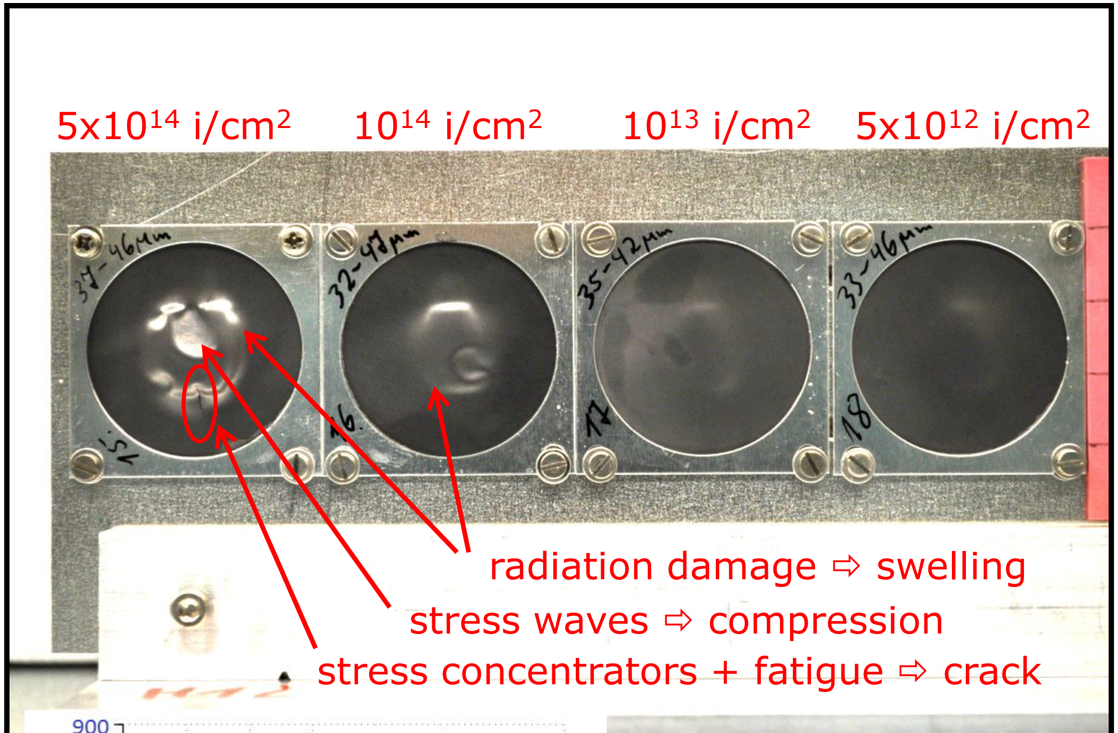
$$\frac{\Delta R}{R} = \left(\frac{\Delta R}{R}\right)_{Sat} \left(1 - e^{-\sigma_a \Phi}\right)$$

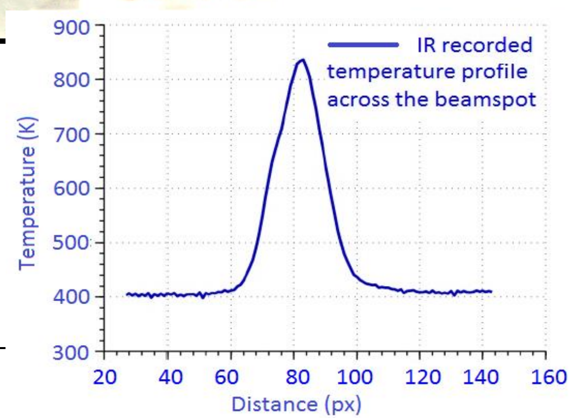
Damage cross section:

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

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

Experiment





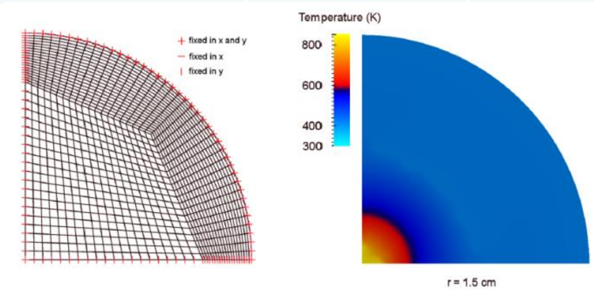
^{238}U, 4,8 MeV/u

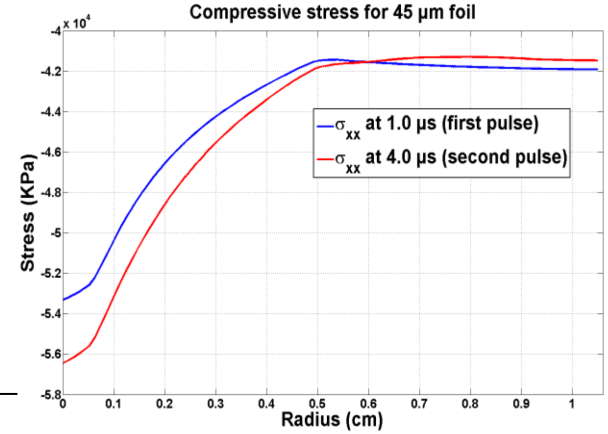
1.5 x10^{10} i/pulse

150 µs, 1 Hz

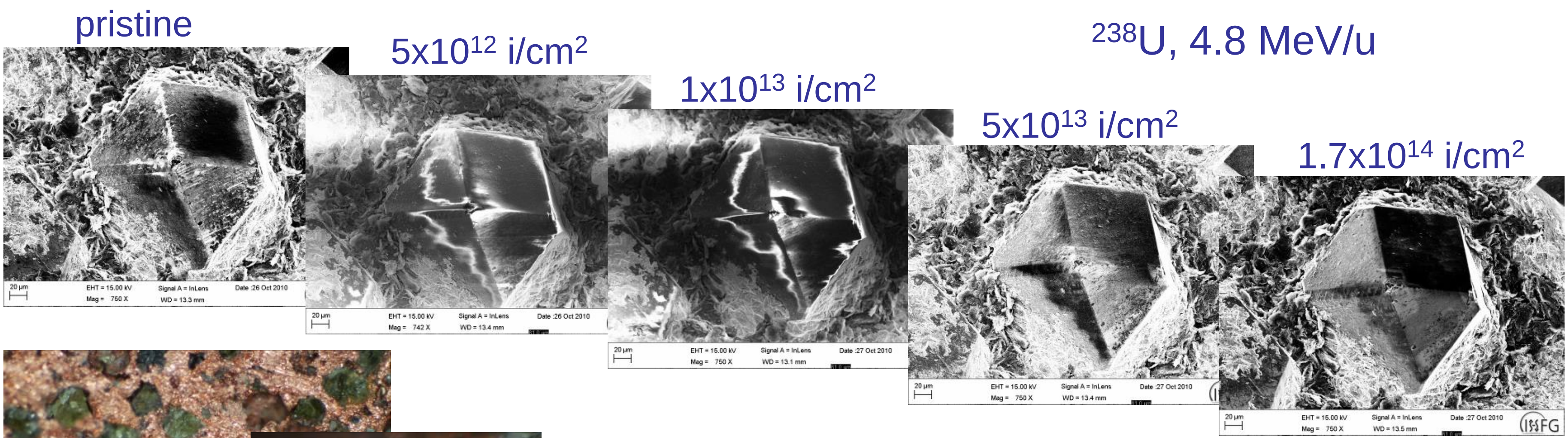
FEM simulations

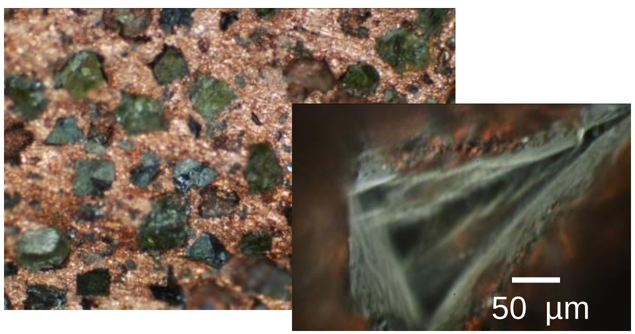
Graphite target / Pulse structure	Maximum compressive stress (MPa)	Maximum tensile stress (MPa)
45 µm (single pulse)	-53.3	0.5
45 µm (double pulse)	- 56.4	0.7



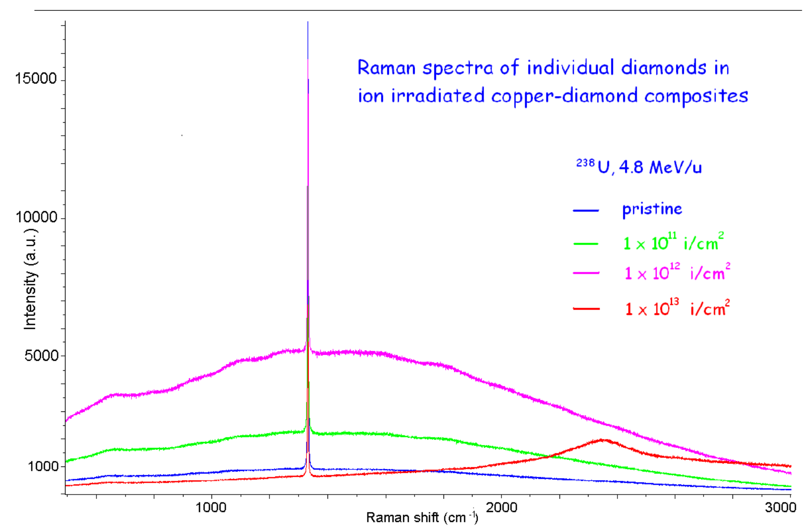


In situ SEM monitoring of heavy ion irradiation effects in novel copper-diamond composites



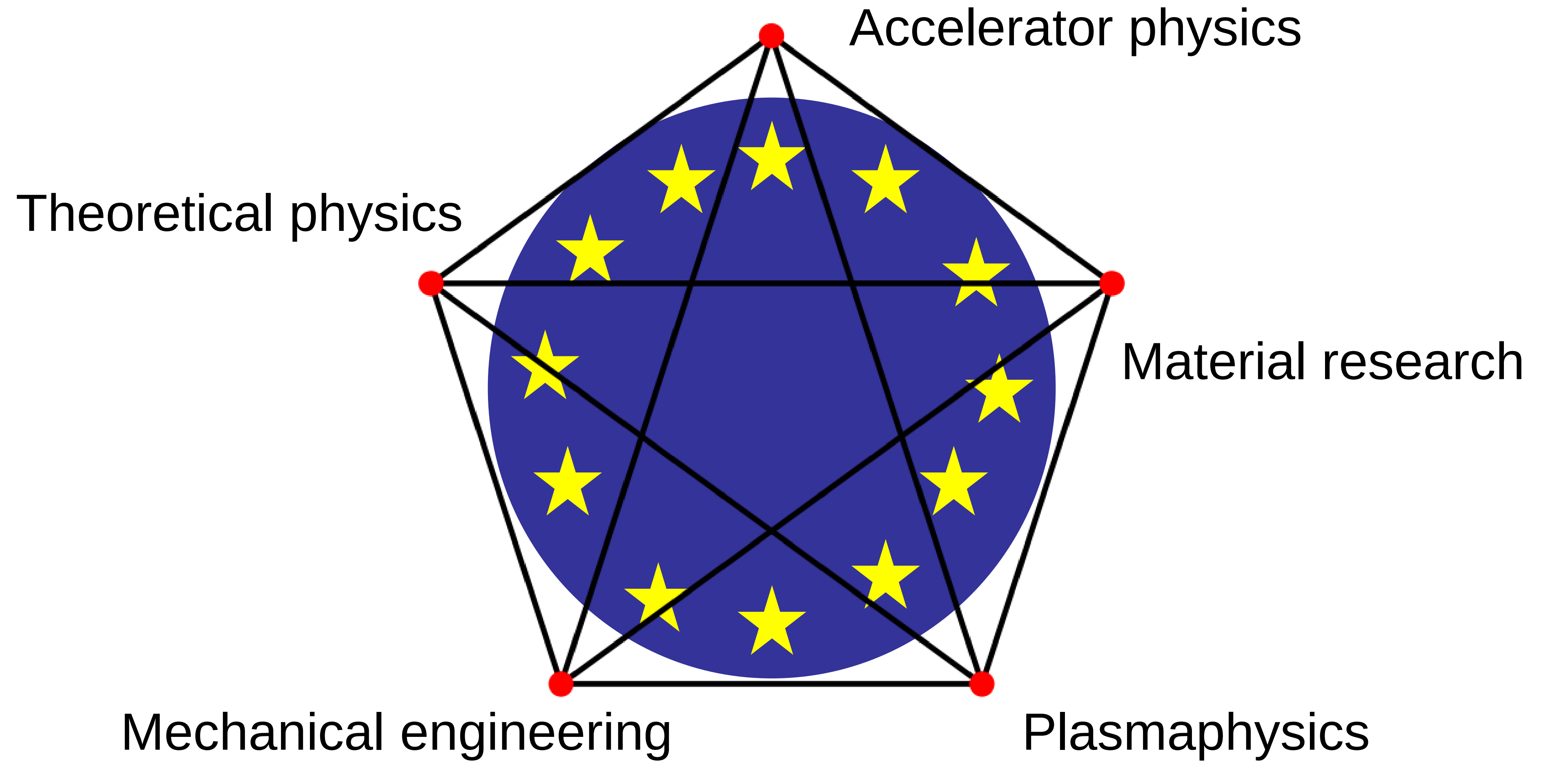


Diamond



- 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

Bonds formed by materials and collimators



Interdisciplinary collaborations between labs have been established

Conclusion

- All major deliverables and milestones could be reached. The report is the last missing objective.
- Beside the excellent results obtained by the many participants many really new interdisciplinary collaborations have been formed.

We want to thank all our collaborators for their outstanding work which made WP8 a major success. We hope the many collaborations formed will be continued beyond EuCARD. Ralph & Jens