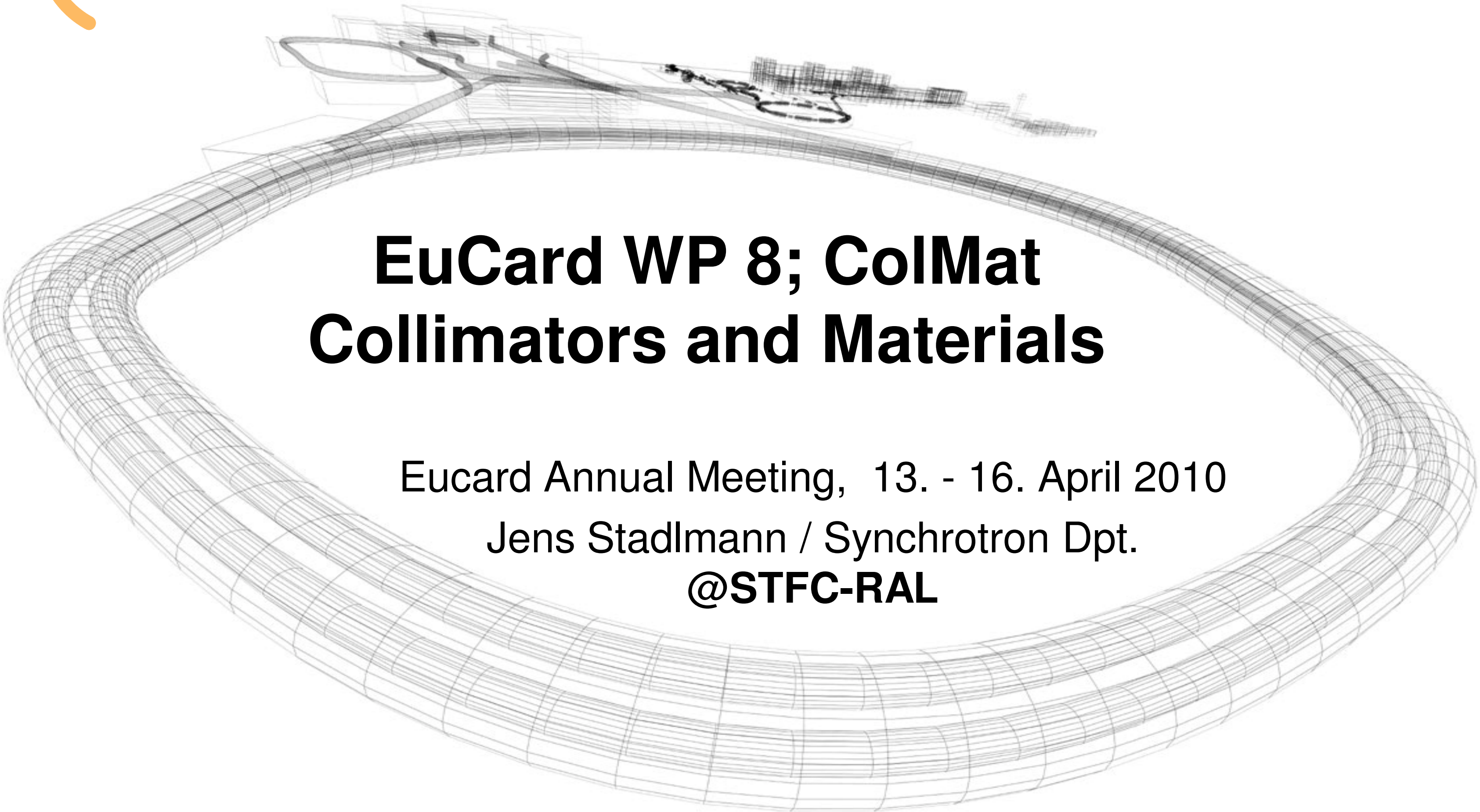


EuCard WP 8; ColMat
Collimators and Materials

Eucard Annual Meeting, 13. - 16. April 2010

Jens Stadlmann / Synchrotron Dpt.
@STFC-RAL

Overview

- Introduction to WP 8
- Examples and first result from some Tasks
- Summary and Outlook

WP 8 Tasks

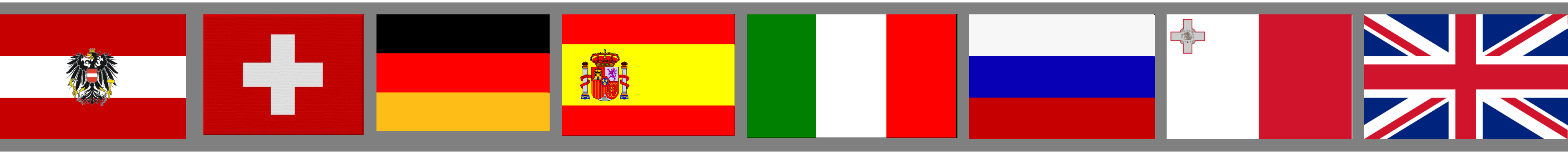
- **8.1** Coordination and Communication

- **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)

Participants in WP 8 Task

- AIT
  (Austrian Institute of Technology)
- CERN
  (European Organization of Nuclear Reserach)
- EPFL
  (Ecole Polytechnique Fédérale de Lausanne)
- GSI
  (Helmholtzzentrum für Schwerionenforschung Darmstadt)
- IFIC
  (Instituto de Física Corpuscular, Valencia)
- INFN
  (Istituto Nazionale di Fisica Nucleare)
- Kurchatov Institute
  (Moscow)
- Malta University
- Lancaster & Manchester University
- Politecnico di Torino
- RHUL
  (Royal Holloway University of London)
- and further "sub"-collaborations: i.g. BNL, FNAL and SLAC ...



The many topics of WP 8

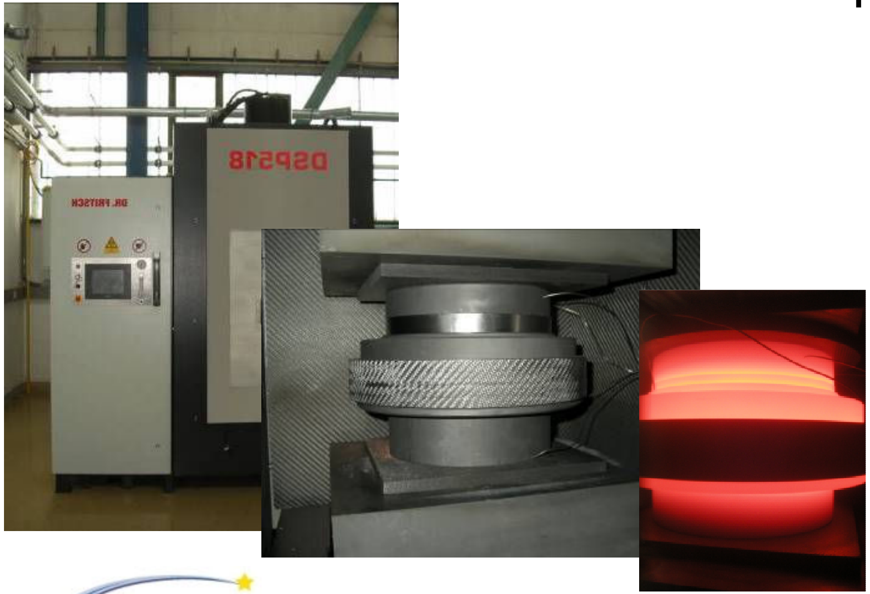
The scope of the WP reaches from

- 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.

Example 1a: Cu-Diamond Material

- Manufacturing of Cu-Dia using two different alloying elements/coatings using conventional hot pressing technology
- Thermal cycling tests of materials with 50 vol% (CTE/diffusivity)
- Mould design for a Cu-Dia tile of 320mmx80mm
- First tests and assessment of temperature profile using this mold in combination with direct hot pressing

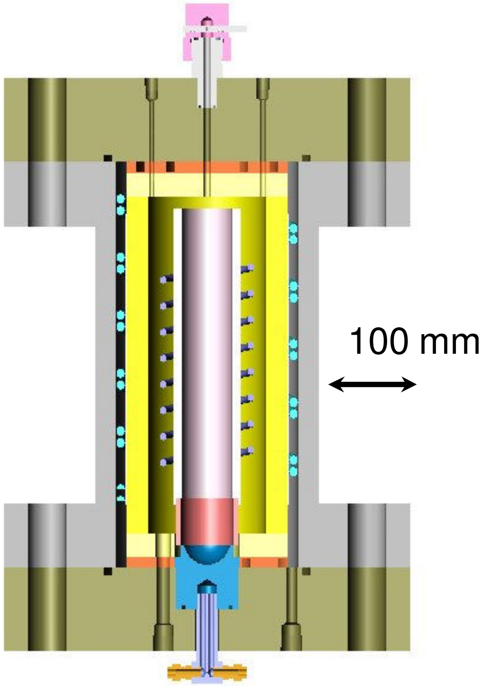
AUSTRIAN INSTITUTE OF TECHNOLOGY
TOMORROW TODAY



Direct heated hot pressing hotpressing:

- Heating rate: up to 400 K/min
- Max. temperature: 2.400°C
- Cycle time: < 1 hour

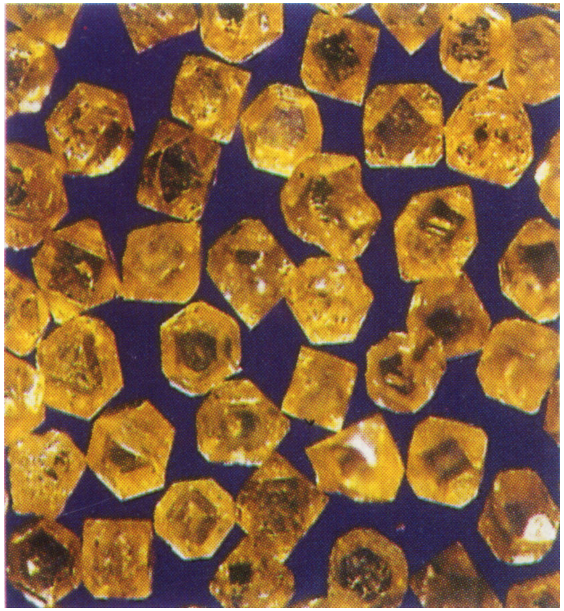
Example 1b:
Diamond Composite Material



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

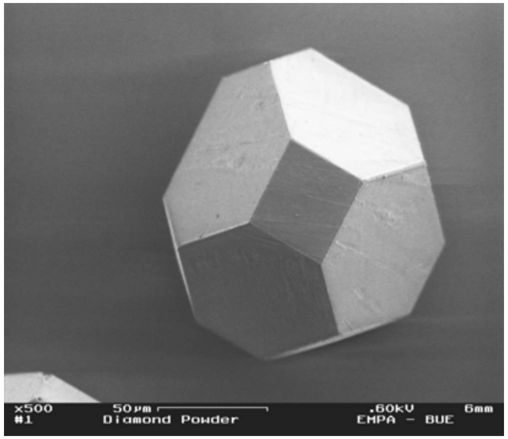
- Induction heating
(using a graphite susceptor)

- primary vacuum pump
(0.1 mbar)



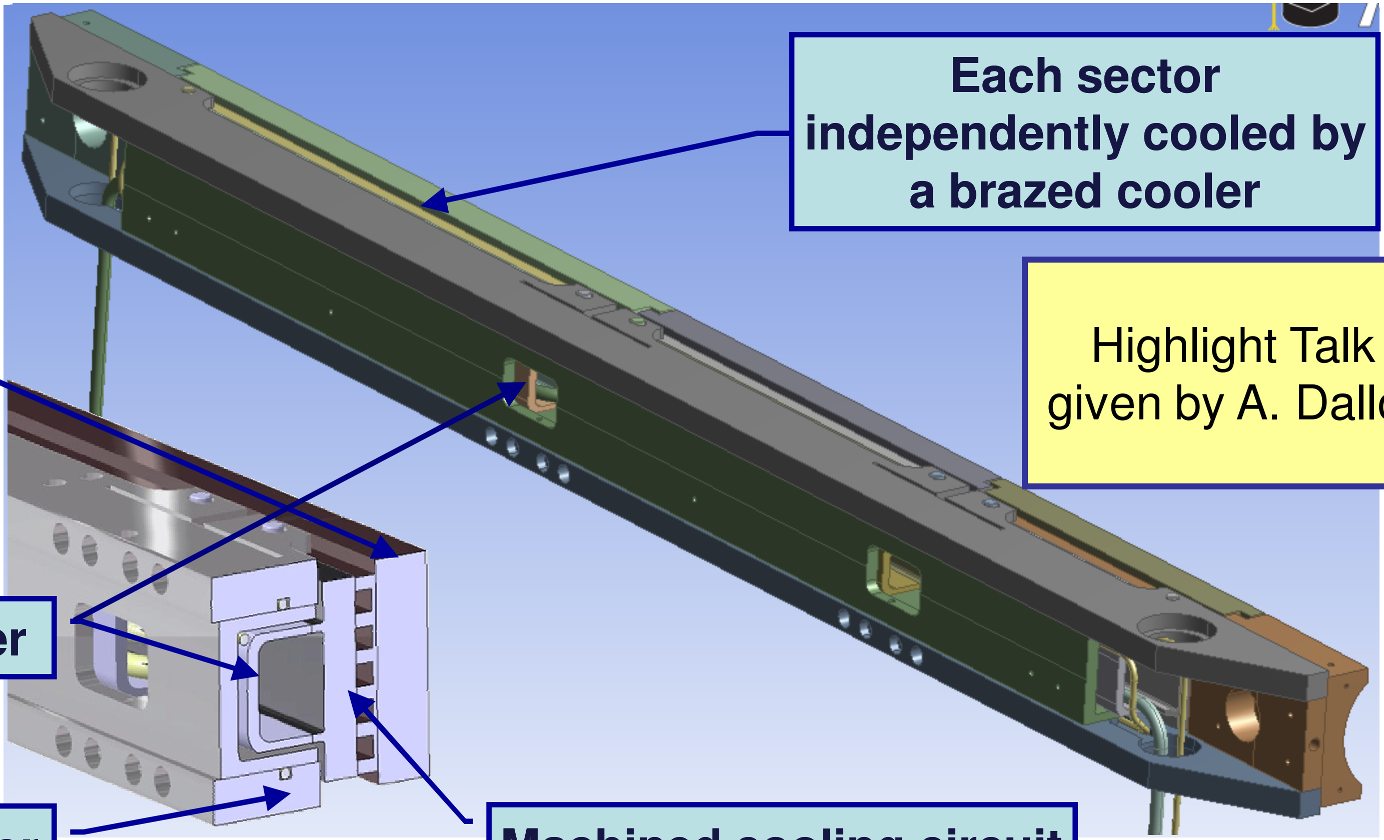
Selected Diamond Grid

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



Example 2a: LHC Phase II Collimator

Jaw with 3 Segments on 2 intermediate adjustable support.
Modular design allowing choice of alternative materials



Each sector independently cooled by a brazed cooler

Highlight Talk was given by A. Dallocchio

Jaw

Jaw - Stiffener

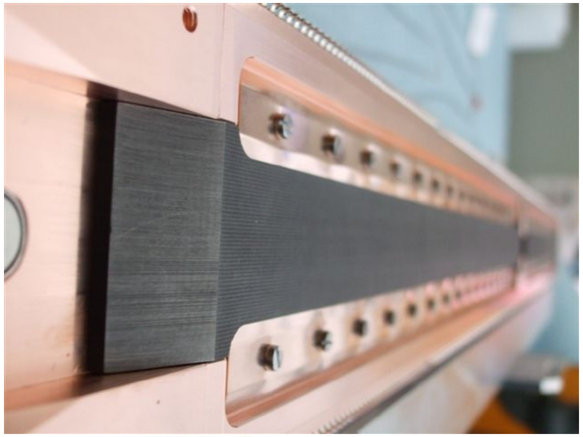
Back - Stiffener

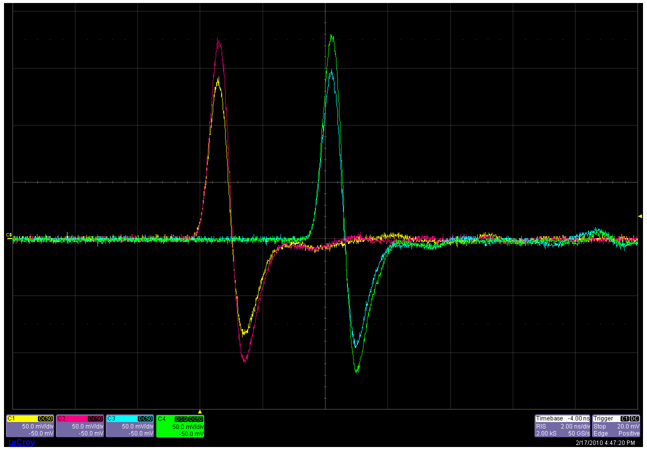
Machined cooling circuit with brazed covers

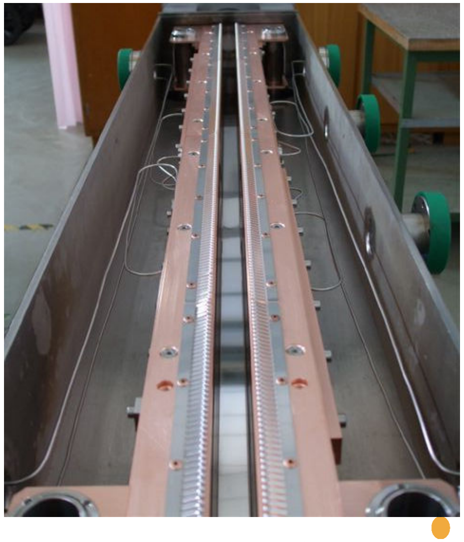
Example 2b: LHC Phase II Collimator

Present Status:

- **Design of collimator jaws very advanced.**
- **BPM prototype manufactured, installed, under test.**
- **New full Phase II prototype under manufacturing.**
- **Material R&D program in progress**







Example 3:
Halo studies and beam modelling

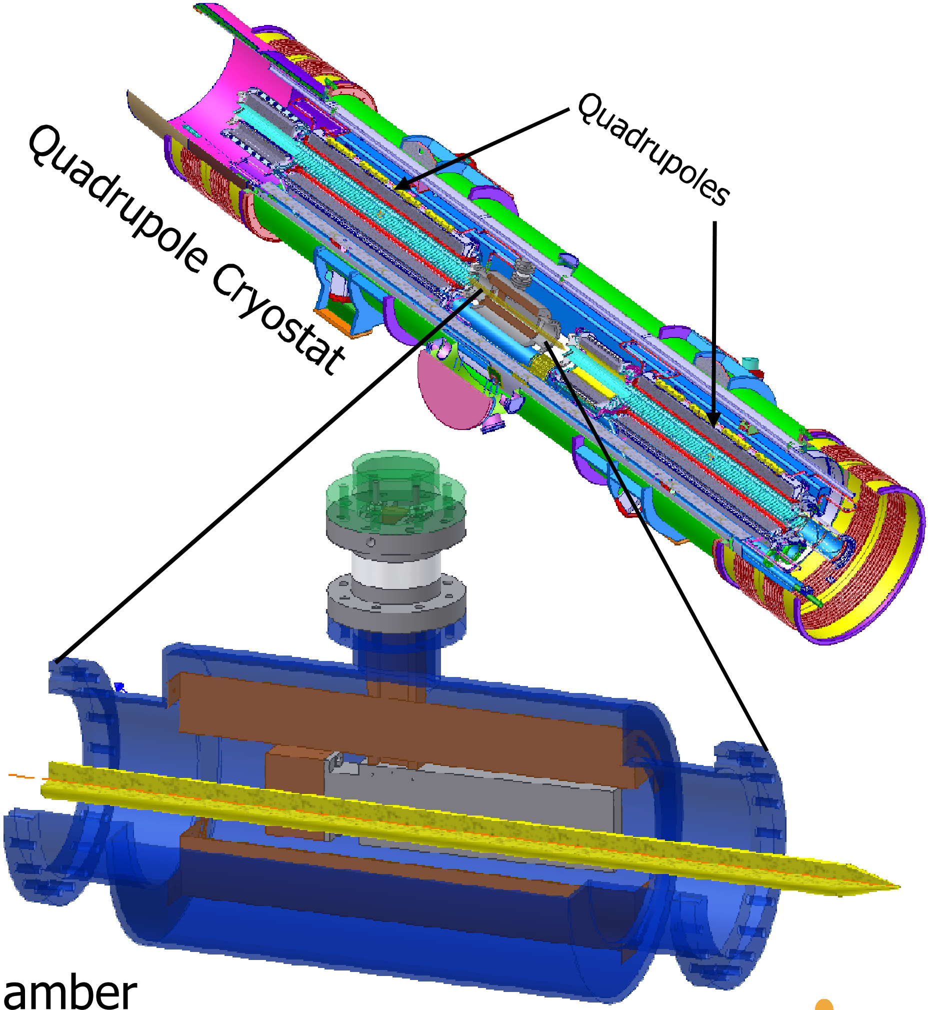
- Simulations and beam measurements on beam halo, intensity reach, collimation efficiency and upgrades.
- Modelling and simulation of the LHC collimation system to identify the nature, magnitude on location and beam losses, intensity reach and collimation efficiency in the different LHC future scenarios.
- Beam measurement of the beam losses, beam halo and intensity limits.
- Study of innovative collimation upgrades, like *non-linear collimation system* or *crystal collimators*.

More details presented as part of highlight talk by A. Rossi

Example 4: Cryocollimator for FAIR

- Tendering process is prepared.
- An experimental area with helium supply for the tests has been identified. An old vacuum chamber is available. Test will be done under realistic conditions with SIS18 beam.
- Plan is to have first test beam on the collimator 2011.

Highlight Talk was given by P. Spiller

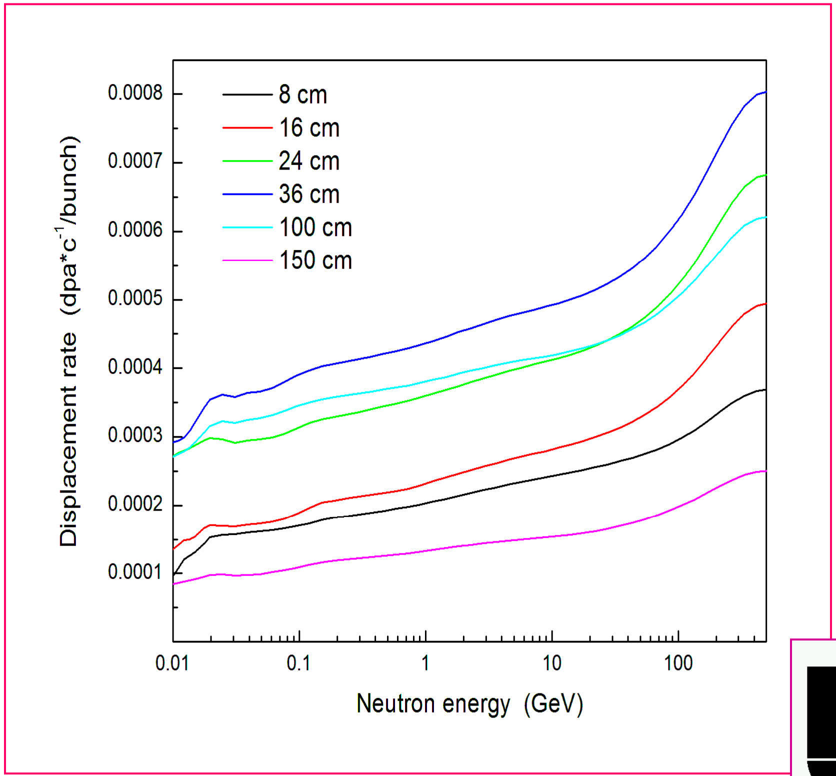


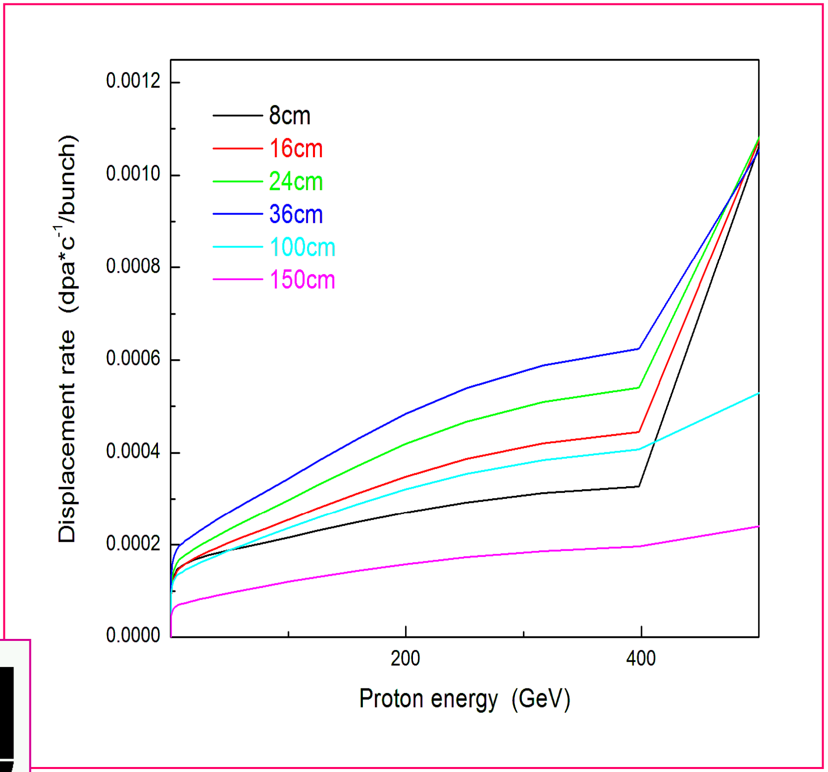
Cryo-Ion-Catcher chamber

Example 5a: Simulation of radiation damage

Radiation damage modelling (point defect formation) in graphite collimator materials of LHC under proton beams irradiation with the energies 450 GeV, taking into elastic and inelastic channels.

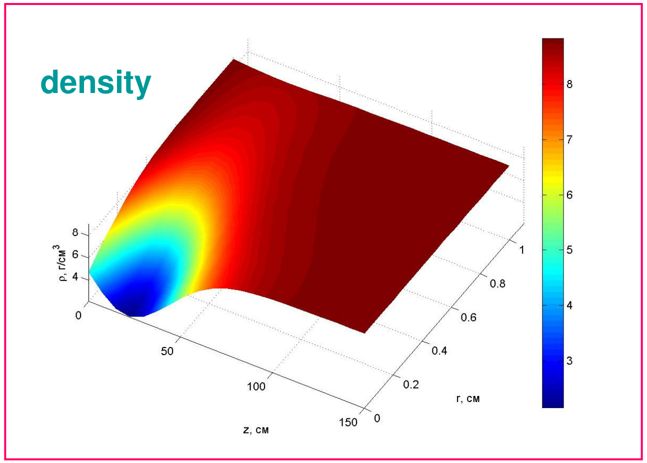
Shown are simulations of generation rates of primary radiation damage (dpa/c) per bunch in graphite by secondary neutrons and protons under 450 GeV proton beam



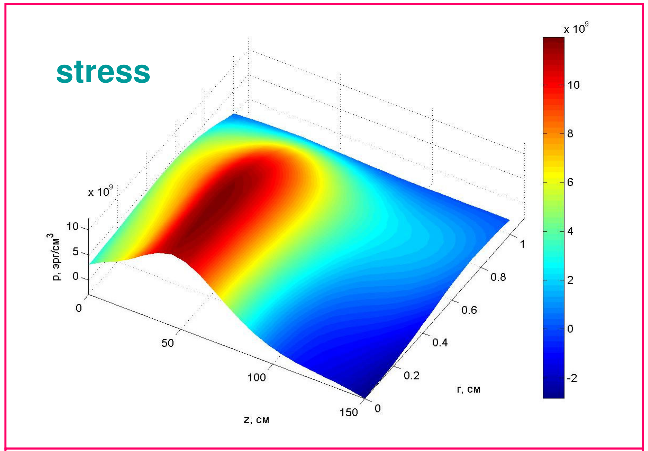


Example 5b: Simulation of shock waves

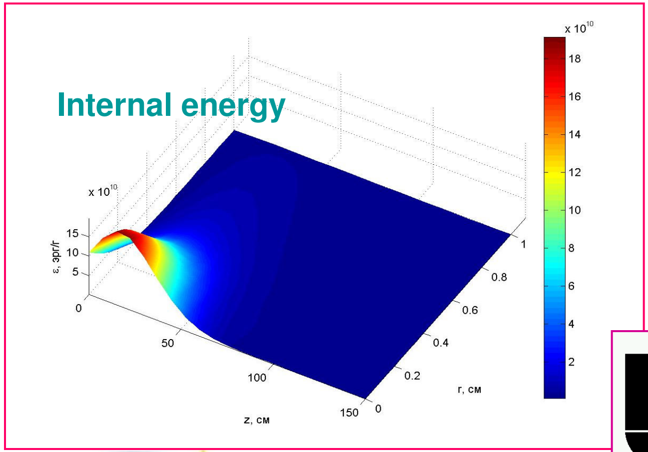
Theoretical modeling of shock waves in copper under 450 GeV proton beam at 600 bunches (15000ns)



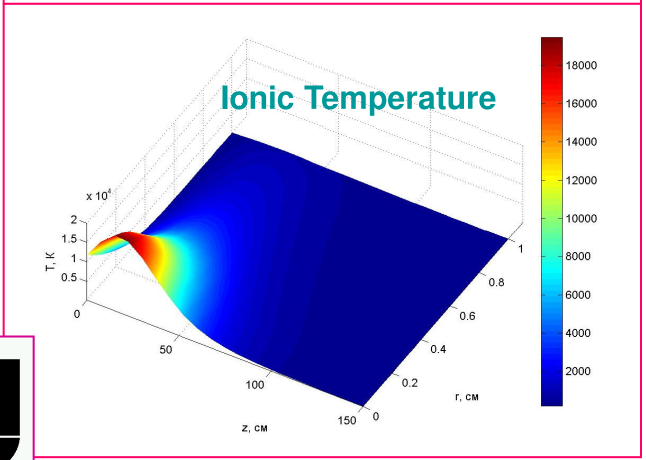
density



stress



Internal energy



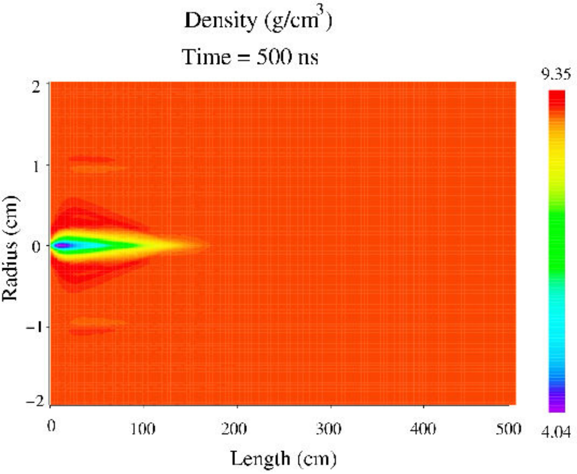
Ionic Temperature

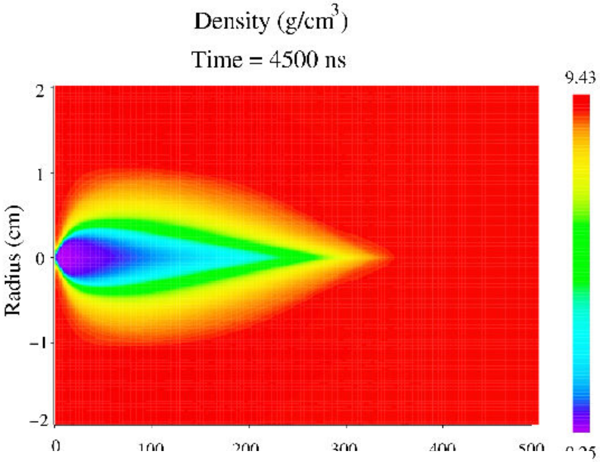
Work in progress:

Development of models for shock wave formation in assembled materials ('sandwich structures') Cu – C.

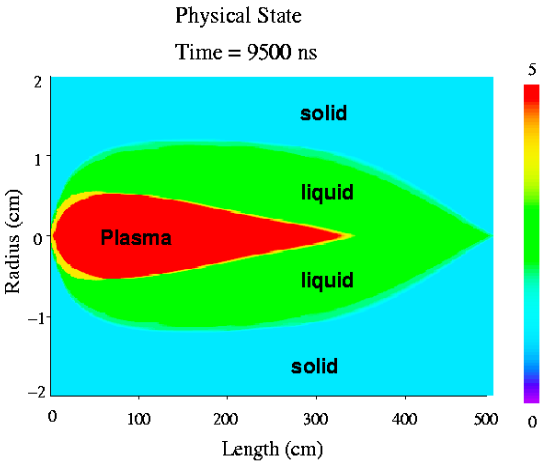
Developments of models of radiation damage formation including cascades and sub-cascade formation in collimator materials of LHC taking into account deposited energy, electronic loss, electronic excitation, elastic and inelastic collisions in materials.

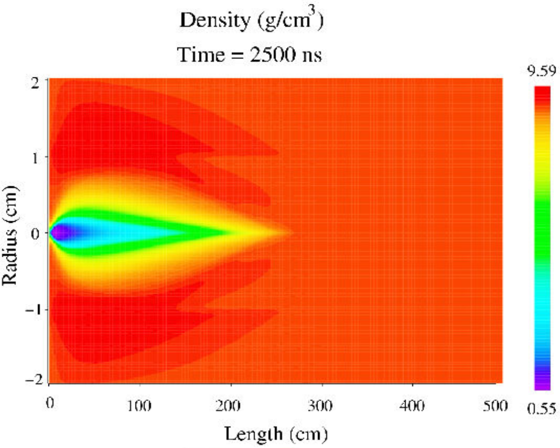
Example 6a: Simulation of SPS and LHC beam on "target"

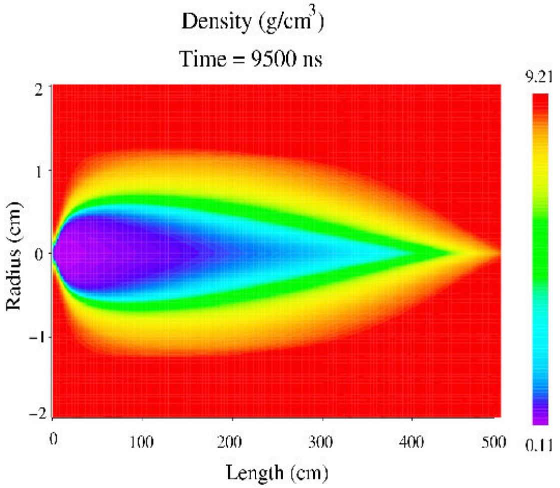

Density (g/cm^3)
Time = 500 ns


Density (g/cm^3)
Time = 4500 ns

HEDP States


Physical State
Time = 9500 ns


Density (g/cm^3)
Time = 2500 ns


Density (g/cm^3)
Time = 9500 ns

N.A. Tahir et al.

- *JAP 97 (2005) 083532.*
- *PRL 94 (2005) 135004.*
- *PRE 79 (2009) 046410.*

Penetration depth = 35 m

Example 6b: Simulation of SPS and LHC beam on "target"

- Simulations are done in two steps:
  1.) Energy loss of protons in matter is calculated by FLUKA
  2.) This data is used as input to a 2D hydrocode, BIG2 to simulate thermodynamic and hydrodynamic response of the target
- This model allows for studying the proton “Tunneling Effect”.
- The penetration depth of the projectile particles is much longer than predicted by a static model.
- LHC protons penetrate up to 35 m in copper and 10 m in graphite.

Example 7: Code development

Merlin – a viable tool for LHC collimator studies!

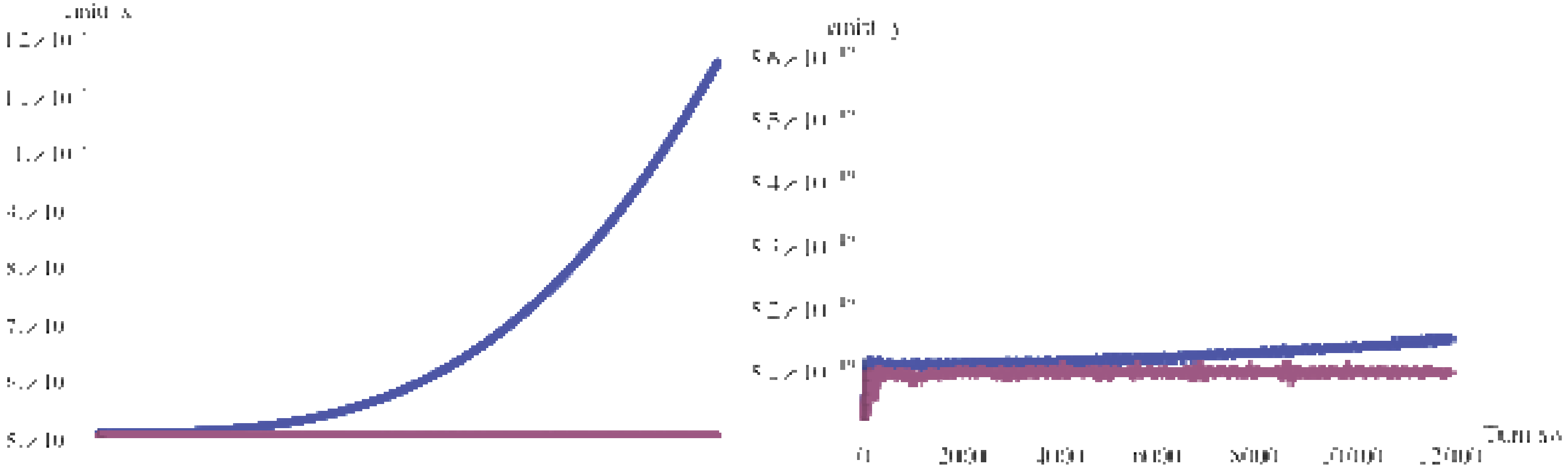
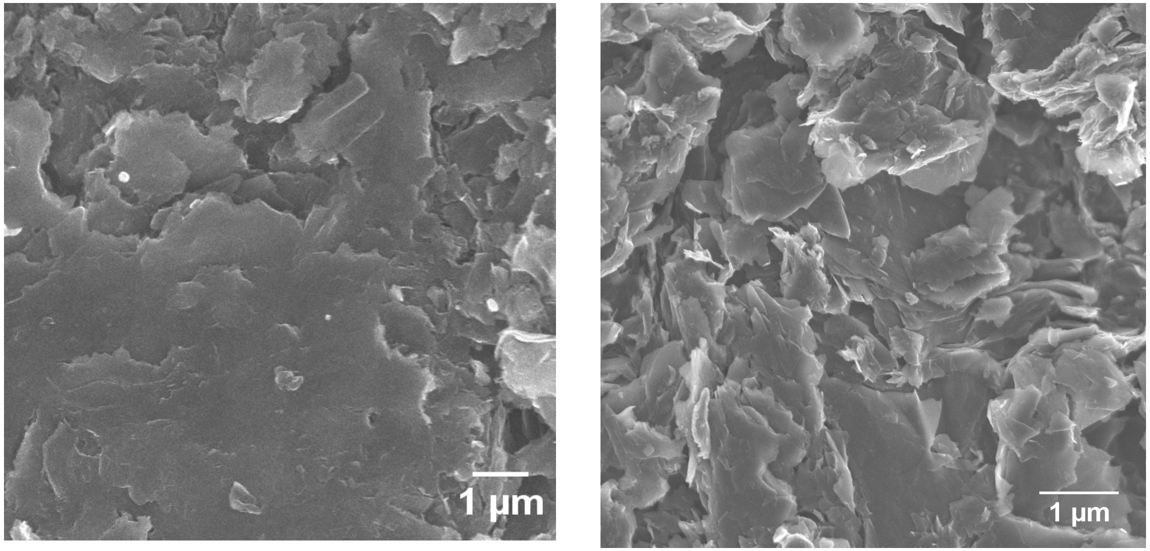


Fig. Transverse and vertical emittance growth with the number of turns of a 1 Sigma Gaussian distribution bunch without (purple) and with (blue) the wakefields .

Why Merlin: its c++ design makes it easy to extend and easy to add or modify behaviour and features of particles and components

Example 8: Material research

- For studies on radiation-induced degradation of thermo-mechanical properties, Graphite and AC 150 carbon-carbon composite samples were irradiated with heavy and light ions of 11 MeV/u and 1 GeV/u specific energy. Structural changes and hardening of high-fluence irradiated graphite are presently under investigation by an experienced scientist and a PhD student.



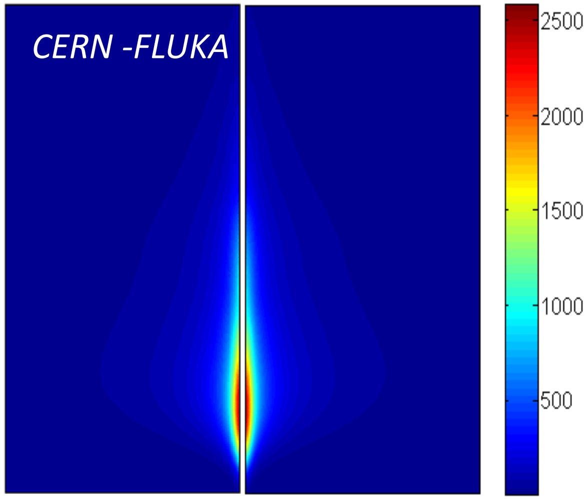
(a) (b)

Low magnification SEM images of polycrystalline graphite sample:
(a) pristine and
(b) irradiated with
5×10^{12} U ions/cm^2.

Example 9a: Material tests and simulation

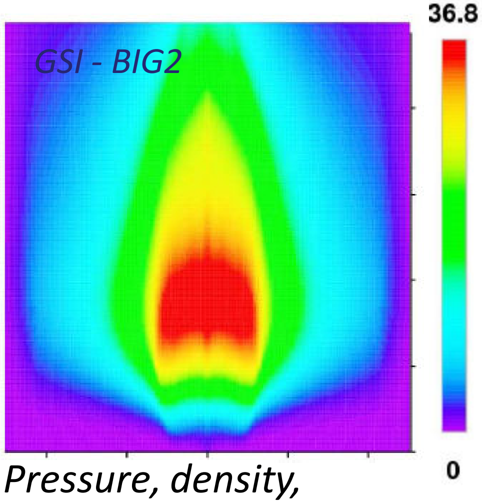
A fundamental aspect of this task is the development of competences and methodologies of analysis based to numerical simulations of the complete problem. To do this, it is essential to look to a **multidisciplinary approach**. As a matter of fact, the problem involves different fields, such as structural and mechanical engineering, thermodynamics, hydrodynamics and physics.

Physics



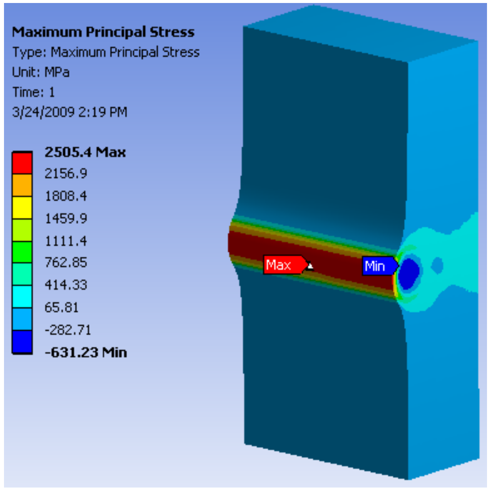
Energy

Thermodynamics/hydrodynam



Pressure, density, temperature

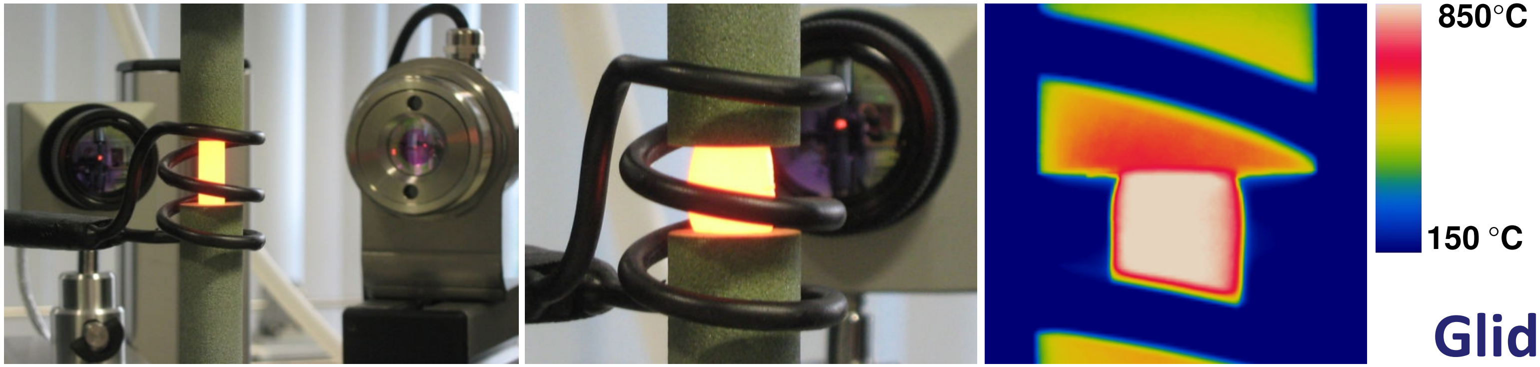
Structural/mechanical engineering



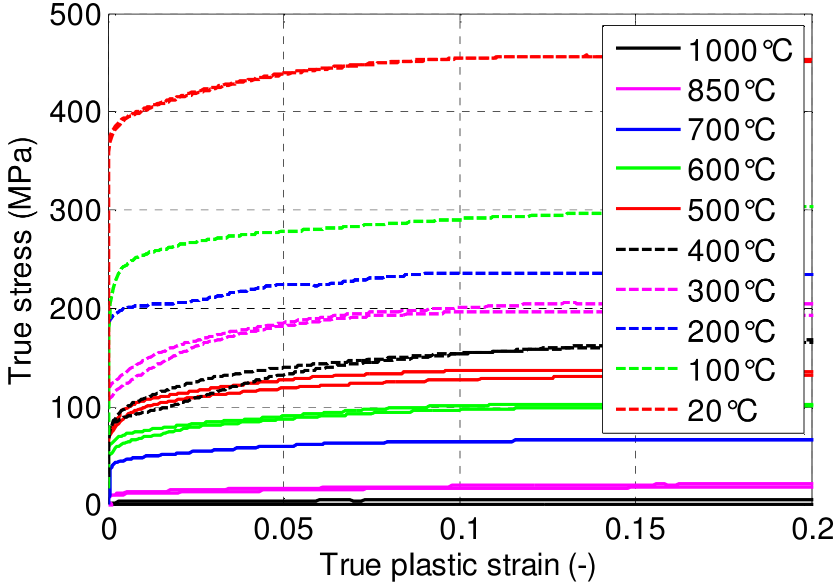
Stress, strain, damage

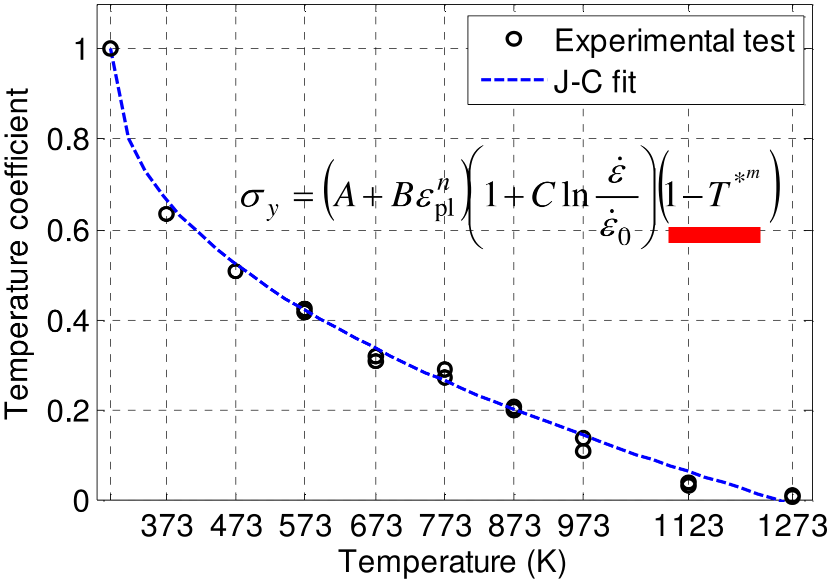
Complex geometry, material behaviour, boundaries...

Example 9b: Plasticity - Temperature



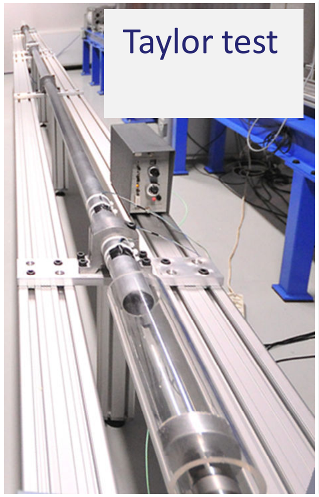
Glidcop

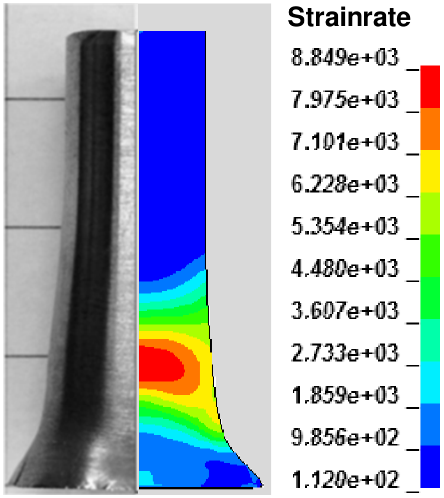




$$\sigma_y = \left(A + B\varepsilon_{\mathrm{pl}}^n\right)\left(1 + C\ln\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)\left(1 - T^{*m}\right)$$

Example 9c: Plasticity - Strainrate





216 m/s

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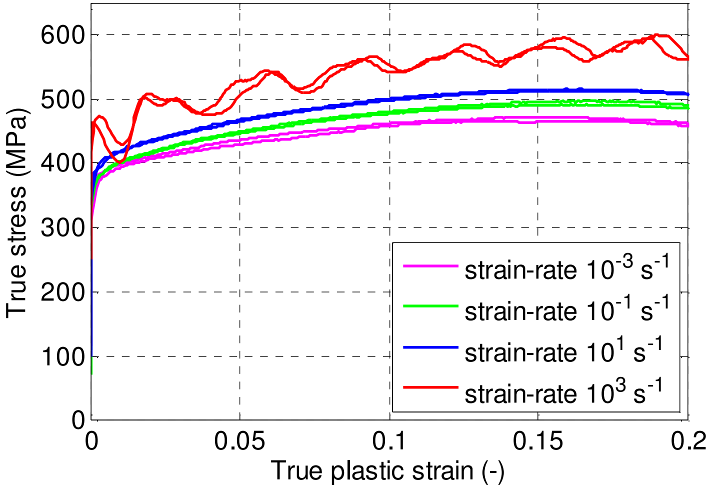
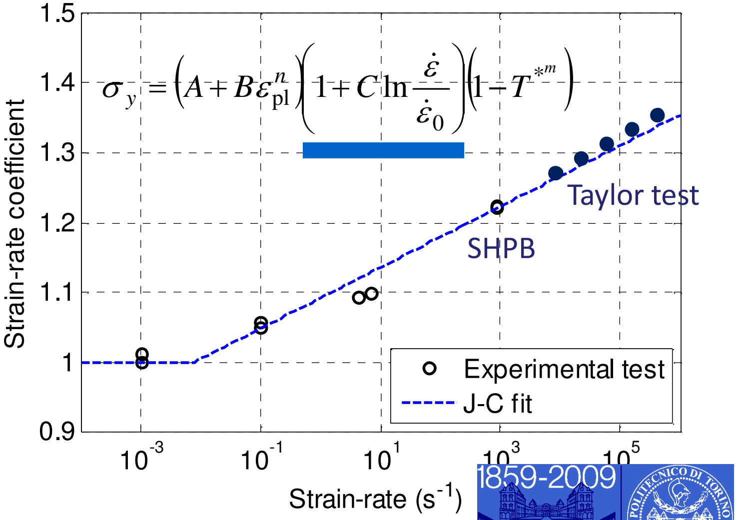


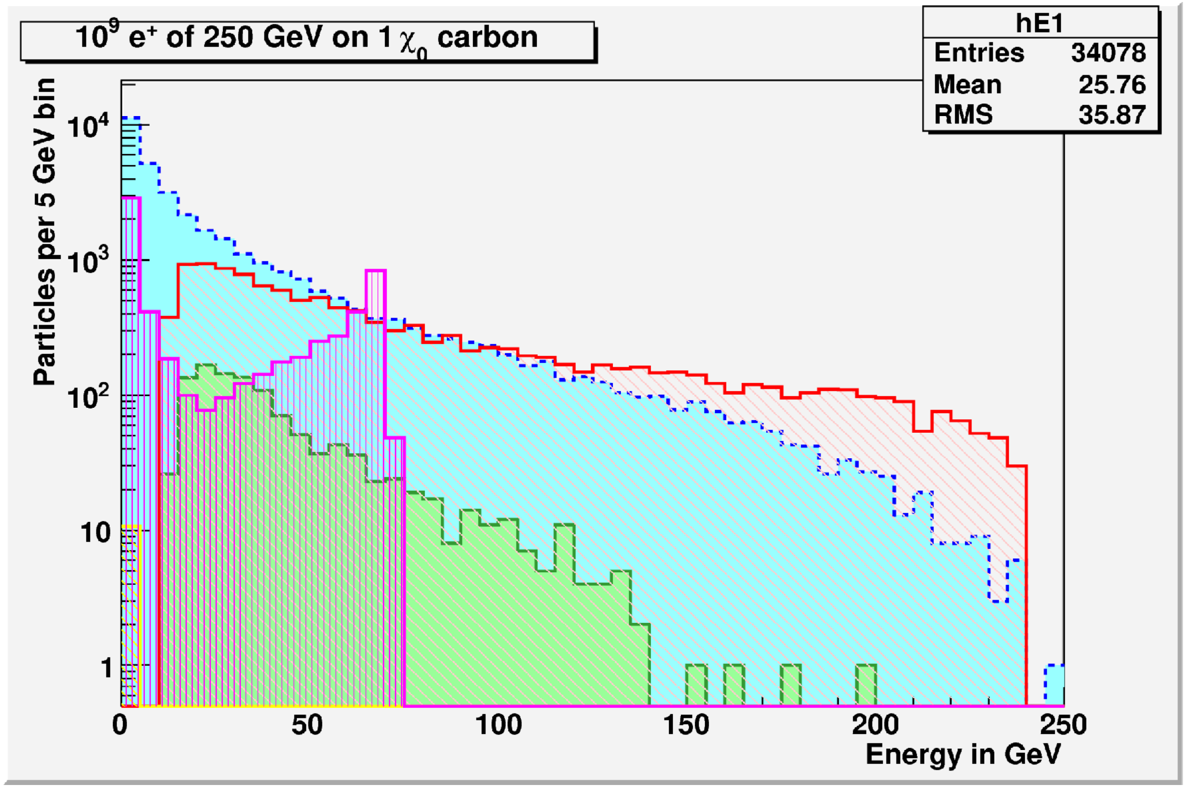


$$\sigma_y = \left(A + B\varepsilon_{pl}^{n}\right)\left(1 + C\ln\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)\left(1 - T^{*m}\right)$$

Example 10: Myon production at LHC and CLIC

Studies of underground produced by collimators in CLIC and LHC. Results will benchmarked and compared to beam loss monitor data.

(More details were presented in the highlight talk by A. Rossi)



Key results at present:

- 7.6 e-5 muons per halo particle
- Assuming 2e7 halo particles per bunch,
- predict 1500 muons per bunch
- Muons distributions being studied by CLIC MDI and detector groups

Status and Problems

- The WP tasks have all started.
- The progress reports during the WP meeting in March were very positive.

- Problems:
  - No feedback from Univ. of Malta.
  - Some minor delays in sub-tasks which no foreseen impact on the total project success.

Summary & Outlook

- WP 8 has a huge bandwidth from simulation to experiment, from material science to accelerator development.
- The EuCard activities help to form new collaborations and help to establish interdisciplinary links to push accelerator R&D.
- Many activities already produce results. Prototypes are built and experiments are performed to benchmark the theoretical studies.
- Personal note:
  GSI expects first beam on cryocollimator in 2011

GSI / FAIR in 2016

Thank you

for your attention!

Extra Slide 1

Some Useful References

N. A. Tahir, R. Schmidt et al.,

1) J. Appl. Phys., **97** (2005) 083532. **[LHC]**

2) Phys. Rev. Lett. **94** (2005) 135004. **[LHC]**

3) Laser Part. Beams **25** (2007) 639 – 647. **[SPS]**

4) New J. Phys. **10** (2008) 073028. **[SPS]**

5) Nucl. Instr. Meth. A 606 (2009) 186 - 192 **[SPS]**

6) Phys Rev. E **79** (2009) 046410. **[LHC]**