HiRatMat Experiment 12

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Motivation & Objectives

- Design of protection systems based on computer simulations, especially for the new regime of LHC energy and intensity.
- Calculations based on static simulations; beam structure and hydrodynamic effects not taken into account.
- Damage limit of equipment used for:
  - Design of protection systems
  - Protection procedures
  - Settings of protections systems
- How confident are we on the simulations?
- What are the consequences of a full LHC beam impact?
- Experiment objectives:
  - Reproduce the “tunneling effect”
  - Validate simulations
Motivation & Objectives

Simulations show that LHC beam can penetrate up to $\sim 25\text{m}$ in solid carbon (2.28g/cc) and up to $\sim 35\text{m}$ in copper.

SPSTT40 accident: $3.4\times 10^{13}\text{p}^+ @ 450\text{GeV}$ into the vacuum chamber
Simulations

- Using SPS & LHC beams
- Different beam sizes: 0.1mm, 0.2mm & 0.5mm
- Target materials: Copper and Carbon
- Running iteratively FLUKA & BIG 2
  - FLUKA: particle interaction and Monte Carlo package capable of simulating multi-TeV energies
  - BIG 2: a sophisticated two-dimensional hydrodynamic code
Simulations: Methodology

- FLUKA: calculates initial energy deposition profile
- Input to BIG 2 that calculates a modified density map
- Input to FLUKA to recalculate an energy deposition profile
- Iteration interval is determined by the time during which the target density reduces by 15-20%
Experiment simulation

- HiRadMat beam
- 440GeV p+, 288 bunches, 1.15E11 p+/bunch
- Sigma beam = 0.2mm
- Copper target: 5cm radius and 150cm length
- Density 8.95g/cc
Simulations 0.2mm

Temperature evolution

- 0.5 us
- 1.5 us
- 2.5 us
- 3.5 us
- 4.5 us
- 5.5 us
- 6.5 us
- 7.2 us

Melting
Simulations 0.2mm

Density evolution

![Graph showing density evolution over time with different curves for varying times (0.5 us to 7.2 us). The x-axis represents distance (z [cm]) and the y-axis represents density (g/cc). Each curve represents a different time interval, with distinct colors for each time point.]
tunneling

0.5mm sigma beam

![Diagram showing tunneling and density vs. target length for different times.](image)
Simulations 0.2mm

Pressure evolution

- 0.5 us
- 1.5 us
- 2.5 us
- 3.5 us
- 4.5 us
- 5.5 us
- 6.5 us
- 7.2 us

pressure [GPa] vs. z [cm]
Setup

- Three copper targets.
- Each target composed of 15 cylinders of 4 cm radius and 10 cm length
Setup

- Aluminum enclosure with two pieces: top and bottom
- 2 cm thickness with a 1 cm indentation for the cylinders
- Protection caps at the front and the rear (1cm diameter hole)
Setup
Setup
Protection caps

- Simulations show that after 4000 ns, 156 bunches, the peak temperature on the front face of the first copper cylinders is around 3200 K and that the material is mostly in the liquid state with very little gas bubbles.
- The cohesion forces of the liquid will make it remain together.
- The target will quickly solidify after the beam is switched off.

(N. A. Tahir)
Pressure evolution (0.5mm)

Target remains in the elastic regime -> target stable during the course of the experiment
Pressure evolution (0.5mm)
Procedure

- The experiment will be done in two phases
- Phase I (week 24)
  - Commissioning & calibration of detectors
- Phase II (week 27)
  - Verification of detectors
  - Irradiation of targets
- Post-Mortem (~4 months later) (C. Theis)
  - Visual inspection of targets
  - X-ray inspection (to be confirmed)
  - Storage for future investigation
## Procedure

### Phase I

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<th>$I_{beam}$</th>
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<th>$N_{bunches}$</th>
<th>$T_{ospace}$ [ns]</th>
<th>repetition</th>
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<th>particle</th>
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**total intensity** $3.57 \cdot 10^{13}$

### Phase II

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**total intensity** $6.91 \cdot 10^{13}$
Post-Mortem

- Estimated cool-down time ~4 months
- A special area will be prepared with plastic sheets (avoid contamination)
- Remotely opening of the target using the auxiliary mushrooms.
- Remote visual inspection
- After inspection the target will be closed again
Detectors

- 3x pCVD diamond
  - fast data acquisition (~ns)
  - rad-hard
  - high linearity
  - high sensitivity
- 3x SEM
  - fast data acquisition (~ns)
  - high linearity
  - Low sensitivity
- 3x PT100: temperature measurements
  - Steady state temperature at 2\textsuperscript{nd} cylinder (fiberglass insulation)
Detectors
Diamond signal

Diamond signal (0.1mm beam sigma)

fluence (part/cm²/p+)

z (cm)

3rd block

6th block

13th block

300ns

1500ns

4300ns

6800ns
Temperature measurements

steady state temperature of each block

Graph showing the steady state temperature of each block with and without 'tunneling'.
Summary

- **Unique opportunity** to understand the consequences of a high-intense high-dense beam impact.
- **Validate** simulation tools and methodology
- **Extrapolate** results and simulations to LHC regimes
- Impact on **protection systems** and **procedures** (Ex: TCDQ)
- **Create** and **study** Warm Dense Matter
FIN
Warm dense matter

- $T \sim 0.2\text{eV} - 10\text{eV}$
- $\rho \sim \text{solid density}$
- $P \sim \text{kbar - Mbar}$