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Laser irradiation test at GSI-PHELIX : Proposal and future actions

ARIES WP17 Progress Meeting

Online meeting - 17/11/2020

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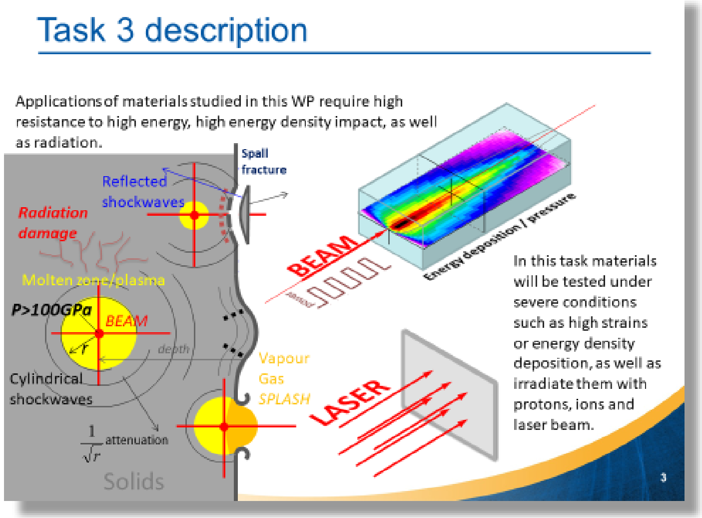
Outline

- Introduction
- Proposal
- Some figures …
- Tentative Timeline

Introduction to Laser Irradiation Experiment

- Irradiation with laser pulses has been part of PowerMat since its beginning (Task 17.3) with the goal to reach energy densities beyond HiRadMat, mimicking extreme future scenarios as in FCC-hh (peak energy density $\sim 50 \frac{kJ}{cm^3}$)
- The initial plan was to have such tests carried out in the new facility being commissioned at ELI-NP
- Present timeline of ELI-NP is not compatible with ARIES schedule. At last July's annual meeting it was agreed to submit to GSI a proposal for an irradiation experiment at **PHELIX Z6** target station
- The proposal was hastily prepared and submitted on 26 July 2020 for the call between summer 2021 and spring 2022.
- Last October, PHELIX Advisory Committee rated the proposal as **A** and recommended to **grant 10 shifts** (less than requested, but still ok if we are efficient ….). The final decision by the Scientific Director should arrive soon …



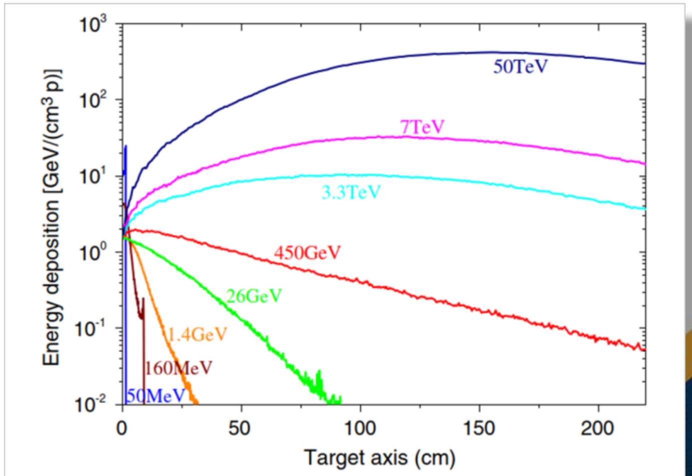


FIG. 14. Energy deposition per incident proton as a function of the depth into the solid graphite target at $r = 0$. The beam size is 0.2 mm for all the presented energies from 50 MeV to 50 TeV.

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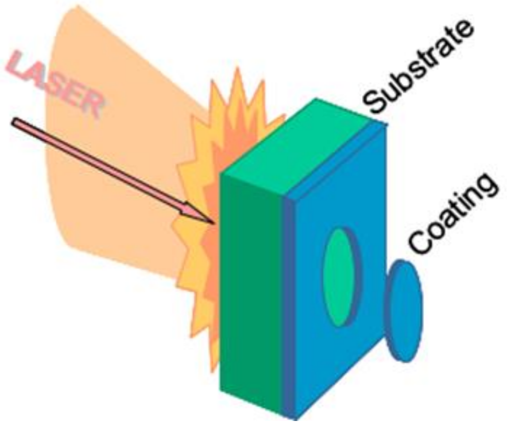
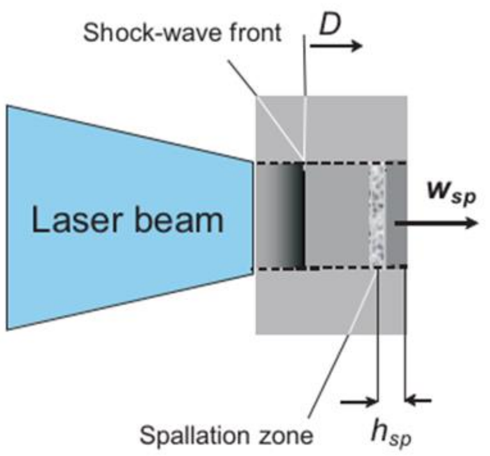
Experiment Proposal

- The experiment aims at testing thin samples (disks or plates) of several materials under intense laser pulses:
  - MoGr (several grades), CrGr (several grades), CFC, Graphite (several grades), CuCD, Carbon Foams …
  - Reference targets (e.g. Al) to be foreseen for calibration purposes
  - In-plane and through-plane orientation
  - Back face may be coated (Mo, Cu) to probe thin film adhesion (LASAT – Laser Adhesion Test)
  - In some cases, impact face may be Al coated to get rid of “messy” laser-plasma interaction and obtain a “clean” planar wave in substrate (need to be confirmed by simulations)
  - Thickness varying from 0.25 mm to 2.5 mm
  - Cross-section dimension 10÷20 mm
  - In total **~40 specimens**, including **~10 for set-up** and calibration purposes (typically well-known metals as Al and/or Ta)
- A strong shock wave will be generated in the impacted face, quickly decaying while moving towards the back face, possibly down to the acoustic regime (depending on sample thickness), but still strong enough to generate spallation near the back face





Some figures …

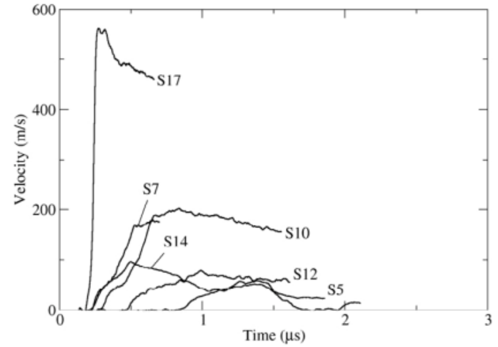
- Laser parameters
  - Pulse energy (E_p): up to 180 J
  - Pulse duration (τ): 1÷ 5 ns
  - Beam spot diameter (d_p): 1 ÷ 1.5 mm (phase plates to be used)
  - Wavelength $\lambda = 530\ nm$
  - Energy absorption ratio $\eta = 50 \div 80\%$
- Some figures assuming a graphite target with $E_p = 180\ \mathrm{J}$, $\tau = 5\ ns$, $d_p = 1\ mm$, $\eta = 0.8$
  - Irradiance $I_e = \frac{\eta E_p}{A_p \tau} = 3.67 \frac{TW}{cm^2}$
  - The ablation (max) pressure can be related to the irradiance by semi-empirical formulae, e.g. from Krasyuk et al. :

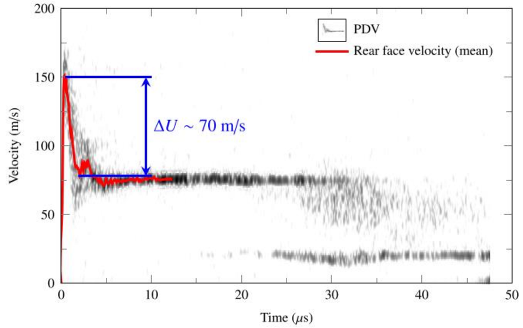
$$p_{1K} := 1.4 \left[\left(10^{-2} \frac{I_e}{\frac{TW}{cm^2}} \right)^{\frac{7}{9}} \left(\frac{\lambda}{\mu m} \right)^{-\frac{3}{4}} \right] TPa = 172.293 GPa$$

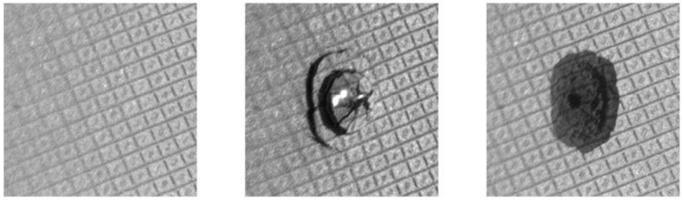
  - With this and assuming a linear Shock EOS $U_s(U_p) := C_0 + S_1 \cdot U_p$ we obtain:
    - Shock velocity $U_{s1} = 9.7 \frac{km}{s}$
    - Particle velocity $U_{p1} = 5.0 \frac{km}{s}$
    - Energy density (kinetic + internal) $E_{T1} = 42.8 \frac{kJ}{cm^3}$
  - These values tend to rapidly decay as the wave moves away from the impacted surface (decay to be determined by simulation)
  - Confinement (e.g. water) does not seem to be necessary to reach FCC-like conditions…

Experiment Diagnostics and PIE

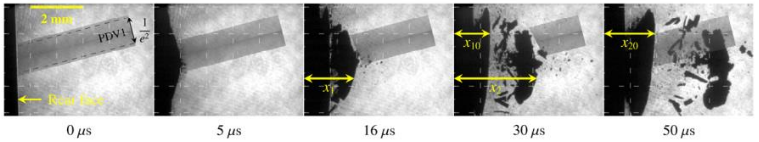
- The most important experimental information is the free surface velocity as a function of time. Through this parameter, a number of additional data and properties can be derived:
  - Maximum pressure in spallation region
  - Strain rate at back surface
  - Material spall strength
  - Coating dynamic adhesion strength
- Online monitoring should focus on the behavior of back (free) surface.
  - Free surface velocity acquired by VISAR and possibly LDV for thicker samples, where surface velocities are expected to decay below 100 m/s
  - High speed photography of free surface (coated or uncoated) by High Speed Camera
- Post Irradiation Examination shall complement online measurements
  - SEM imaging of front and back surfaces
  - Raman spectroscopy of affected regions
  - Micro-tomography
  - ….







(a) Laser imaging at t=0. (b) t=10.44 μs. (c) Post-mortem.



Instrumentation and Open Questions

- Non-exhaustive list of possible experiment instrumentation
  - GSI VISAR
  - POLITO VISAR
  - POLITO High Speed Camera
  - CERN Laser Doppler Vibrometer
- Is this instrumentation sufficient to acquire essential information?
- Does it require time-consuming calibration?
- Do we need pulse-laser illumination to support high-speed photography?
- Is an experimental chamber under vacuum necessary? Is it available at the facility? If no, do we have the budget to build it?
- Do we have enough time (80 hours) to perform all projected measurements? If not, what can we drop?

Tentative Timeline and Contributions

- The experiment should be carried out before the end of WP17 (Dec. 21), i.e. late summer/early fall 2021.
- My guess for experiment design and preparation:
  - Nov. 20 – Feb. 21. Numerical simulations of the experiment for selected materials to select irradiation conditions and determining specimen dimensions. Who? ELI-NP (which tool?), with support from GSI, CERN (FLUKA?, Autodyn?), POLITO (LS-dyna?)
  - Mar. 21 - May 21. Preparation of samples and experiment set-up
  - Jun. 21 – Jul. 21. Pre-irradiation measurements and controls
  - Aug. 21 – Sept. 21. Experiment
  - Oct. 21 – Feb. 22. Post-irradiation examinations and reports
- Participant list (simulations and/or experimental)
  - GSI/WWU. Marilena, Philipp and Z6 support (local contact person Dennis Schumacher). Planned PhD thesis with WWU Münster (possible joint supervision with CERN?)
  - POLITO. Martina, Lorenzo
  - ELI-NP. Mihail, Theodor
  - CERN. Alessandro, Federico, Jorge, Carlotta, Oscar, Michael, Anton
  - Any other beneficiary?
- To be checked how to obtain Transnational support and what are the conditions and deadlines …
- Possible time conflicts as well as synergies with HRMT experiments (Multimat 2) to be checked …