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P219 Experiment at GSI-PHELIX : Proposal, Contributions and Planning

Experiment Kickoff Meeting

Online meeting - 11/12/2020

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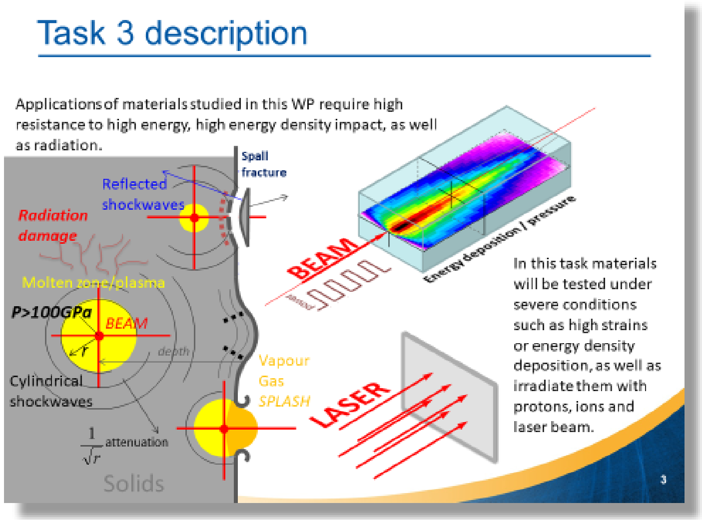
Outline

- Introduction
- Partners
- Proposal
- Some figures …
- Simualations
- Instrumentation
- Open Questions
- Tentative Timeline

Introduction to Laser Irradiation Experiment

- Irradiation with laser pulses has been part of **ARIES - WP17** (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, however its timeline is not compatible with ARIES schedule.
- A proposal for an irradiation experiment at **PHELIX Z6** target station was submitted to GSI PPAC in July '20 for a call between summer 2021 and spring 2022.
- Last October, PHELIX Advisory Committee rated the proposal as **A** and recommended to **grant 10 shifts** (*plus some days for preparation and set up?*) with a question about differences between laser-driven and particle-driven material damage which was successively answered.
- GSU Scientific Managing Director endorsed the proposal on 20.11.2020. The experiment is now referenced as **P219**



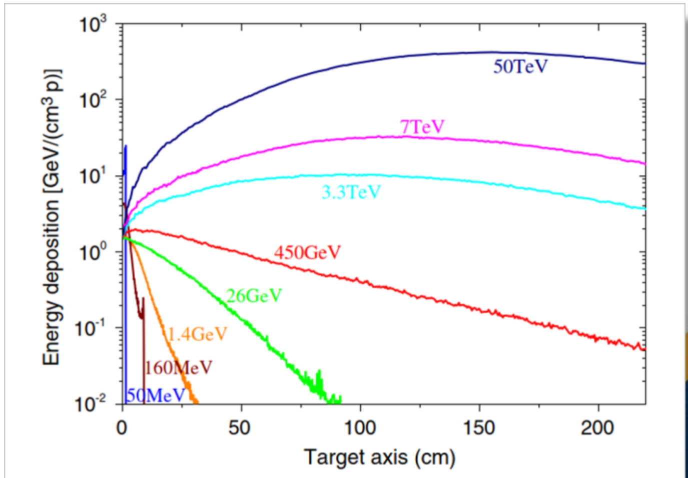


FIG. 14. Energy deposition per incident proton as a function of the depth into the solid graphite target at $r = 0$. The beam size is 0.2 mm for all the presented energies from 50 MeV to 50 TeV.

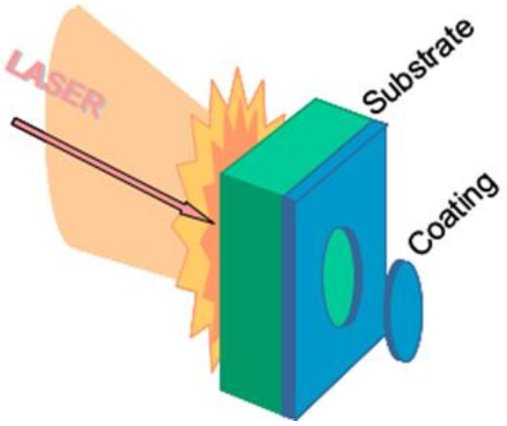
Partners within ARIES and beyond …

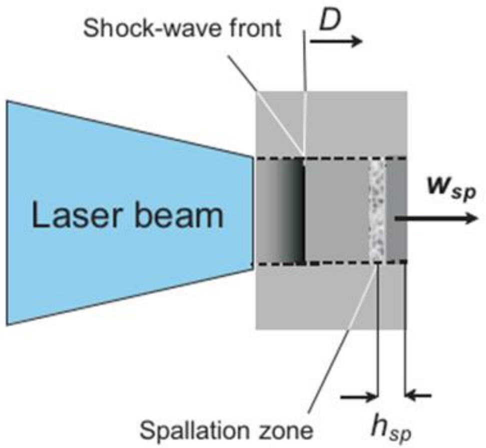
- WWU Münster
  - Marilena Tomut – Principal Investigator
  - PhD doctoral student?
- GSI
  - Dennis Schumacher – Local Contact Person
  - Abel Blazevic
  - Paul Neumayer
  - Marilena Tomut
  - Philipp Bolz
- Politecnico di Torino
  - Lorenzo Peroni
  - Martina Scapin
- ELI-NP
  - Mihail Cernaianu
  - Theodor Asavei
- CERN
  - Alessandro Bertarelli – Principal Investigator, Spokesperson
  - Federico Carra
  - Jorge Guardia Valenzuela
  - Carlotta Accettura
  - Michael Guinchard
  - Oscar Sacristán de Frutos
- *Università di Roma “La Sapienza”*
  - *Michele Pasquali*

- Other partners and participants may possibly join on the way …

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 … other materials also considered (e.g. bulk amorphous alloys, high entropy alloys)
  - 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 …

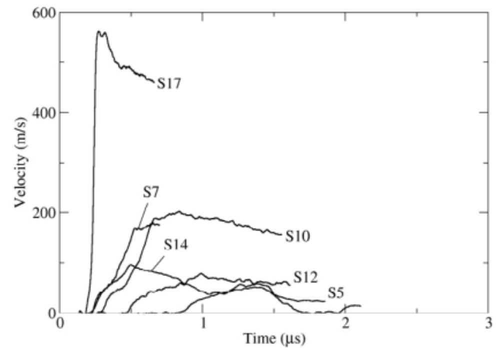
- Laser parameters
  - Pulse energy (E_p): up to 180 J
  - Pulse duration (τ): 1÷ 5 ns
  - Beam spot diameter (d_p): 1 ÷ 1.5 mm (phase plates to be used)
  - Wavelength $\lambda = 530\ nm$
  - Energy absorption ratio $\eta = 50 \div 80\%$
- Some figures assuming an isotropic graphite (ATJ) target with $E_p = 180\ \mathrm{J}$, $\tau = 5\ ns$, $d_p = 1\ mm$, $\eta = 0.8$
  - 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. :

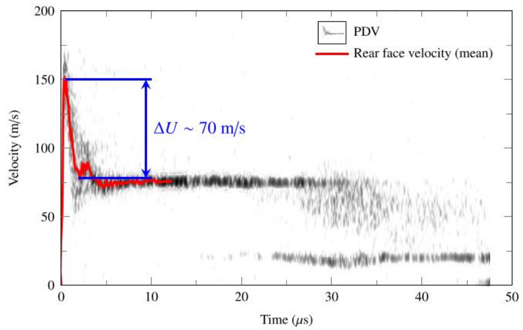
$$p_{1K} := 1.4\left[\left(10^{-2}\frac{I_e}{\frac{TW}{cm^2}}\right)^{\frac{7}{9}}\left(\frac{\lambda}{\mu m}\right)^{-\frac{3}{4}}\right]TPa = 172.293GPa$$

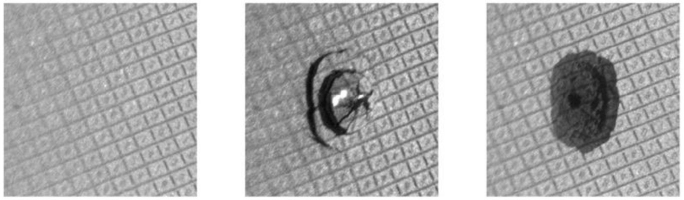
  - With this and assuming a linear Shock EOS $U_s(U_p) := C_0 + S_1 \cdot U_p$ we obtain:
    - Shock velocity $U_{s1} = 9.7 \frac{km}{s}$
    - Particle velocity $U_{p1} = 5.0 \frac{km}{s}$
    - Energy density (kinetic + internal) $E_{T1} = 42.8 \frac{kJ}{cm^3}$
  - These values tend to rapidly decay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

Experiment Diagnostics and PIE

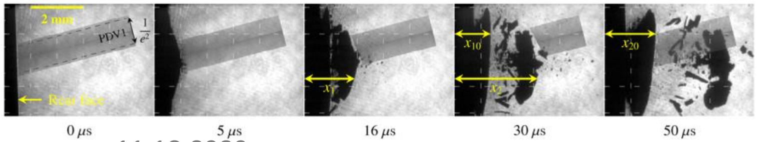
- The most important experimental information is the free surface velocity as a function of time. Through this parameter, a number of additional data and properties can be derived:
  - Maximum pressure in spallation region
  - Strain rate at back surface
  - Material spall strength
  - Coating dynamic 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.



Simulation Activities

- Besides preliminary analytical estimations, **simulations** are necessary to predict the intensity, the profile and the time history of the response
- A strong **decay** is expected in graphitic materials as the shock wave moves away from the impacted surface
- Decay intensity is also function of the material (isotropic, orthotropic) and of the specimen thickness, tentatively 0.25 mm to 2.5 mm
- A 1-D simulation is being performed at **ELI-NP** with **HELIOS** hydrodynamic code, initially using ATJ isotropic graphite
- Numerical results shall allow to determine **specimens thickness**
- When can we expect first results?
- Is it possible to **simulate anisotropic** (i.e. MoGr, CFC, CrGr) **materials**?
- Is it possible to simulate coatings (on one or both faces)?

Instrumentation List

- Non-exhaustive list of possible experiment instrumentation
  - GSI VISAR
  - POLITO VISAR
  - POLITO High Speed Camera
  - CERN Laser Doppler Vibrometer
  - Other instrumentation available at GSI?
- Specifications of these devices to be collected

Open Questions

- Are phase plates available?
- Is the experimental vacuum chamber available at the facility? What are its dimensions? Is it compatible with the foreseen instrumentations (e.g. optical ports)? Can we get the drawings?
- Is this instrumentation sufficient to acquire essential information?
- Will all instrumentation be available at the time of experiment? For how long?
- Does it require time-consuming calibration? How is synchronization working?
- Do we have all skilled operators (e.g. for POLITO VISAR)?
- What is the largest velocity which can be measured by CERN LDV?
- Do we need pulse-laser illumination to support high-speed photography?
- How long is the typical set-up time? One full week? Can we perform useful shots during set-up time?
- Do we have enough time (80 hours) to perform all projected measurements?

Tentative Timeline

- 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
  - October 21. Experiment
  - Nov. 21 – Feb. 22. Post-irradiation examinations and reports
- October ‘21 seems an acceptable compromise between experiment timeline and personnel availability (e.g. avoid conflicts with University exam sessions …)
- To be checked how to obtain Transnational support and what are the conditions and deadlines …
- What are the conditions to “freeze” the experiment time window?

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Thank you for your attention!