This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 730871.

P219 Experiment at GSI-PHELIX : Introduction, Status, Planning

Experiment Progress Meeting

Online meeting – 23.06.2021

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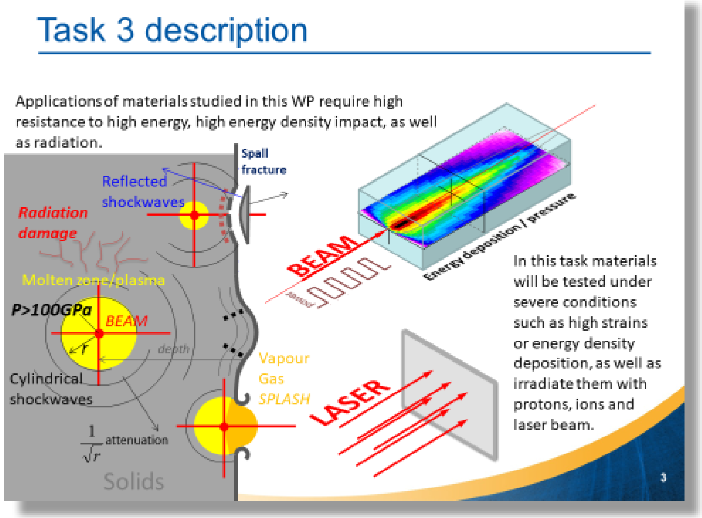
Outline

- Introduction
- Partners
- Proposal
- Simulations
- Instrumentation
- Open Questions
- Proposed Timeline

Introduction to P219 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.
- In October-November '20, the proposal was rated as **A** and **granted 10 shifts/days (including 5 shifs/days preparation)**. The experiment is referenced as **P219**
- P219 was tentatively planned for October '21, but due to PHELIX overly charged schedule, it is now **postponed to January 2022** (starting either on 10^{th} or 31^{st} Jan.). **Date to be frozen** at this meeting.
- Application pending for **Laserlab-Europe TNA support** (travel and subsistence), for 2 persons. Names to be proposed at this meeting.



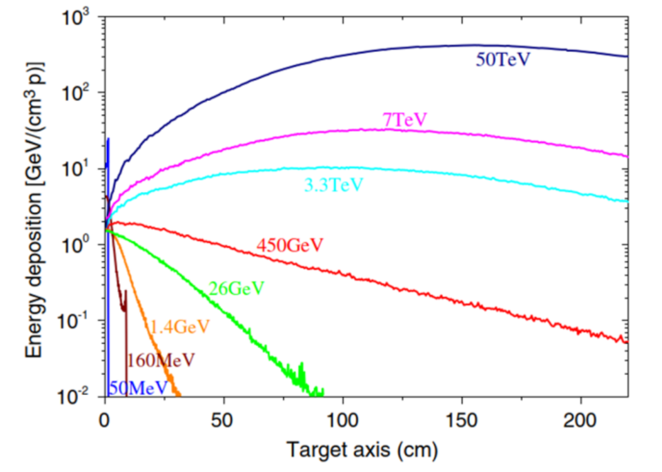


FIG. 14. Energy deposition per incident proton as a function of the depth into the solid graphite target at $r = 0$. The beam size is 0.2 mm for all the presented energies from 50 MeV to 50 TeV.

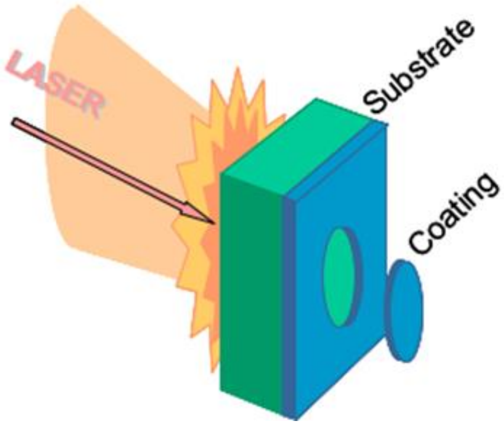
Partners within ARIES and beyond …

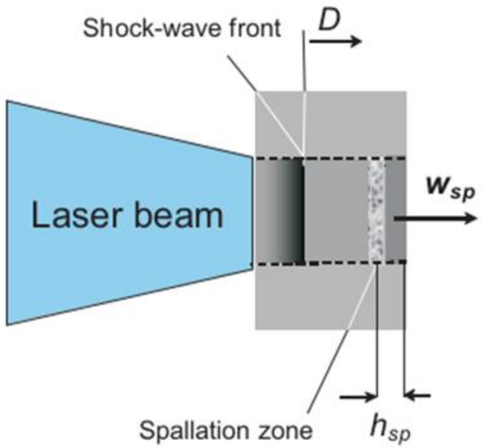
- WWU Münster
  - Marilena Tomut – Principal Investigator
  - PhD doctoral student?
- GSI
  - Dennis Schumacher – Local Contact Person
  - Vincent Bagnoud
  - Christian Brabetz
  - Paul Neumayer
  - Marilena Tomut
  - Philipp Bolz
- Politecnico di Torino
  - Lorenzo Peroni
  - Martina Scapin
  - Alberto Morena
- 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
  - Lucie Baudin
- Università di Roma "La Sapienza"
  - Michele Pasquali
  - Silvio Rasile

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

Experiment Proposal

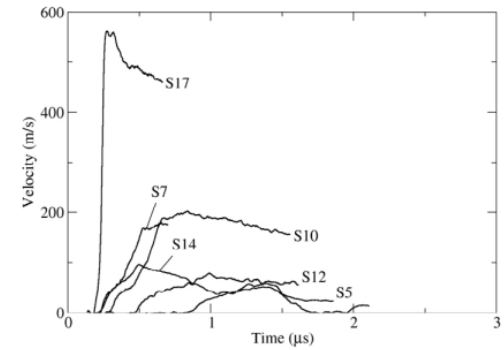
- The experiment aims at testing thin samples (disks or plates) of several materials under intense laser pulses:
  - MoGr (several grades), CrGr (several grades), CFC, Graphite (several grades), CuCD, Carbon Foams … other materials also considered (e.g. bulk amorphous alloys, high entropy alloys from). List to be confirmed
  - Reference targets (e.g. Al) to be foreseen for calibration purposes
  - In-plane and through-plane orientation for orthotropic materials
  - Back face 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). To be confirmed.
  - Thickness varying from 0.25 mm to 2.5 mm
  - Cross-section dimension 10÷20 mm. Cross-check with simulations
  - 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

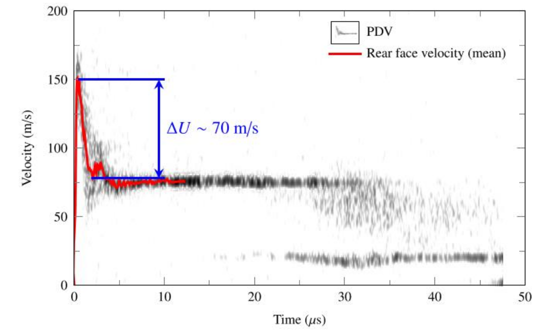


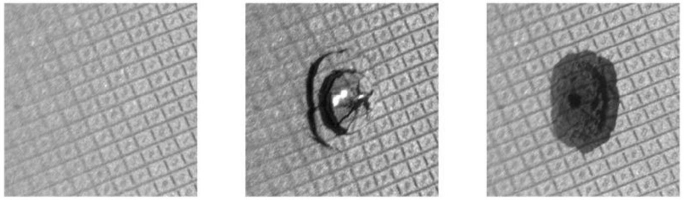


Experiment Diagnostics and PIE

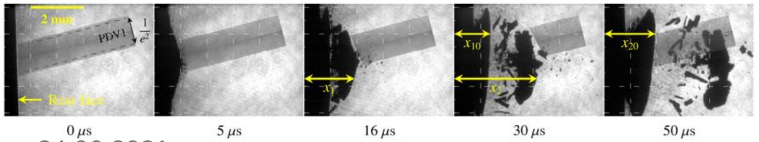
- The **most important** experimental information is the **free surface velocity** as a function of time. Through this parameter, a number of additional data and properties can be derived:
  - Maximum pressure in spallation region
  - Strain rate at back surface
  - Material spall strength
  - Coating dynamic adhesion strength
- Online monitoring should focus on the behavior of back (free) surface.
  - Free surface velocity acquired by **VISAR**; LDV (limited to 24 m/s) could be used away from centre or at end of phenomenon, when surface velocities drop below threshold. **To be cross-checked with simulations**
  - Possibility of High speed photography of free surface ?
- 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

- 1-D simulation first performed at **ELI-NP** with **HELIOS** hydrodynamic code, using ATJ isotropic graphite
- Results used as initial input for explicit simulations (LS-Dyna) at POLITO to study shock wave propagation (presentation by L. Peroni)
- Numerical results should allow determining **specimens thickness** and velocity profile (temporal and spatial) on back surface to calibrate VISAR and LDV (aim at radially-offset location or study tail of the signal?)
- Is it possible to **simulate anisotropic** (i.e. MoGr, CFC, CrGr) **materials**?
- Is it possible to include coatings in simulations (on one or both faces)?

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Instrumentation List

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

Technical Questions

- Z6 Test Station
  - How long for the preparatory phase (e.g. chamber mounting, table preparation …)
  - Any specific safety requirement?
- Experimental Chamber:
  - Is it compatible with several instruments simultaneously (i.e. VISAR, LDV, High Speed Camera …)?
  - Are specimens supports already available? Compatible with which dimensions?
- GSI VISAR (see Christian's presentation):
  - What are its specifications (Max acquisition time, max/min measurable velocity …) ?
  - Who will operate it?
  - How many shots for calibration/synchronisation?
  - Any available reference measurements on well know-materials? Available publications?
- POLITO High Speed Camera:
  - Is it available at the time of the experiment?
  - What are its specifications?
  - Who will operate it?
  - Is pulse-laser illumination needed? Available?
- Specimens
  - Can we freeze their dimensions (thickness and diameter)?
  - Any requirement of (back) surface roughness? Any reflectivity issue?
  - Can we freeze the list of materials, including BAA and HEA?

Logistics Questions

- Personnel
  - How many people can/should be simultaneously present at test station?
  - Is it recommended/possible to visit the facility before the test?
  - Any access restriction?
  - Who should we include in TNA support request?
- Material
  - Procurement timeline for specimens (including coatings) to be defined
  - Any specific support component or tool to be procured/supplied (e.g. holders …)?
- Costs
  - Experiment takes place beyond WP17 closure date (31.12.2021). All material costs should be engaged and paid before end of the year …
  - Informal agreement with ARIES Project Leader to pay travels on ARIES WP1 which will remain operational until 30.04.22

Proposed Timeline

- September ‘21. Complete numerical simulations on maximum spectrum of materials (likely not possible for all). Who? ELI-NP (Helios), POLITO (Helios, LS-Dyna), CERN (Autodyn), UniRoma (?)
- Summer ‘21. Start specimens procurementJun. 21 – Jul. 21. Pre-irradiation measurements and controls
- November ‘21. Specimens available and pre-irradiation examined
- January-February ‘22. Experiment (**proposed start date 31 January,** if all agree)
- Feb. ‘22 - Mar.’22. First post-irradiation examinations and preliminary reports
- April ’22. Presentation at ARIES close-out meeting

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Thank you for your attention!

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. :

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

  - 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
  - Confinement (e.g. water) does not seem to be necessary to reach FCC-like conditions…