System design and shock wave phenomena in a liquid Pb target

IMCC Annual Meeting 2025 – DESY

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Outline

- Intro
  - ENEA's previous solutions
- Current studies:
  - Shockwave and cavitation
  - Preliminary simulations
- Conclusions:
  - General considerations
  - Future steps

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About me

- PhD student at University of Bologna: DMSAI program.

- Master thesis in Energy Engineering: **Applications of Liquid Metals for Particle Accelerators.** CFD study on IMCC ENEA's target solution and BDF thermal analysis.

- **CFD Investigations on Heavy Liquid Metal Alternative Target Design for the SPS Beam Dump Facility**; Calviani, M.; Carrelli, C.; Cervone, A.; Cioli Puviani, P.; Di Piazza, I.; Esposito, L.S.; Manservisi, S.; Mazzola, G.; Tricarico, L.; Franqueira Ximenes, R. Energies 2024, 17, 2952. https://doi.org/10.3390/en17122952.

Intro

Beam Intercepting devices (BIDs) characteristic

- Hight volumetric thermal power deposition up to 1e18 W/m^3.
- Beam deposition: 2 ns at 5 Hz.
- Magnetic field: 20 T.
- Geometrical limitations.
- Radiation risk.
- Hight performance for long period.

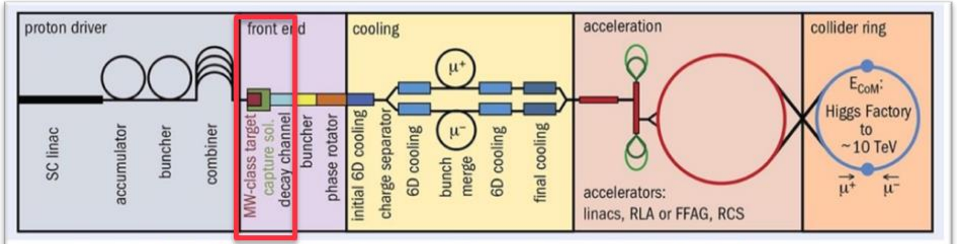
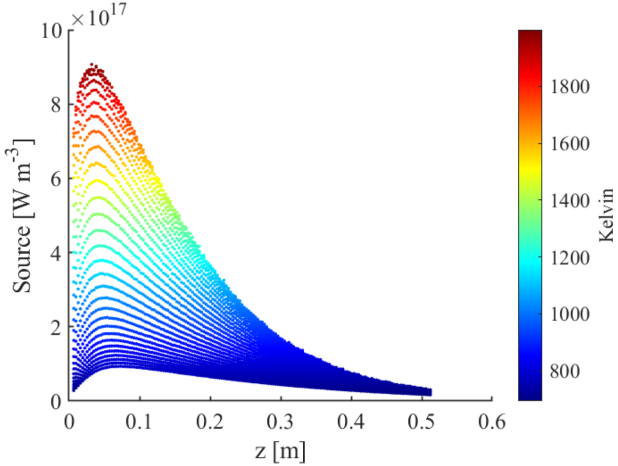


Fig. 2: Layout of the Muon Collider complex as elaborated by the MAP



Power deposition – z axis
Contour of temperature into the liquid lead.
(data source CERN (2023), 2 MWs target)

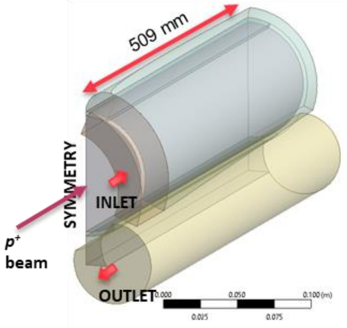
Intro: ENEA's previous solutions

ENEA's previous solutions

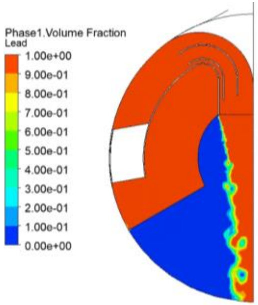
- Studies on the 2MW beam option with 3cm diameter of interaction.
- Hydraulic modelling using Volume of Fluid model Argon-Lead phase.

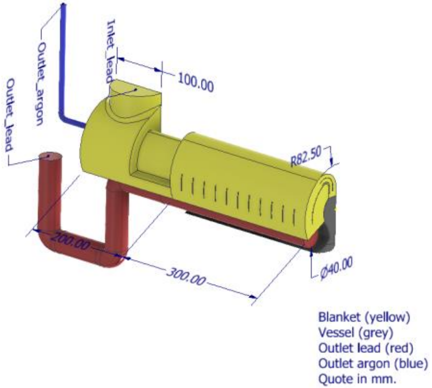
Problems

- Hight mass flow rate.
- Low muon production (CERN).



P. Cioli Puviani, C. Carrelli. Enea 2023.





L. Tricarico, P. Cioli Puviani, C. Carrelli. Enea 2024

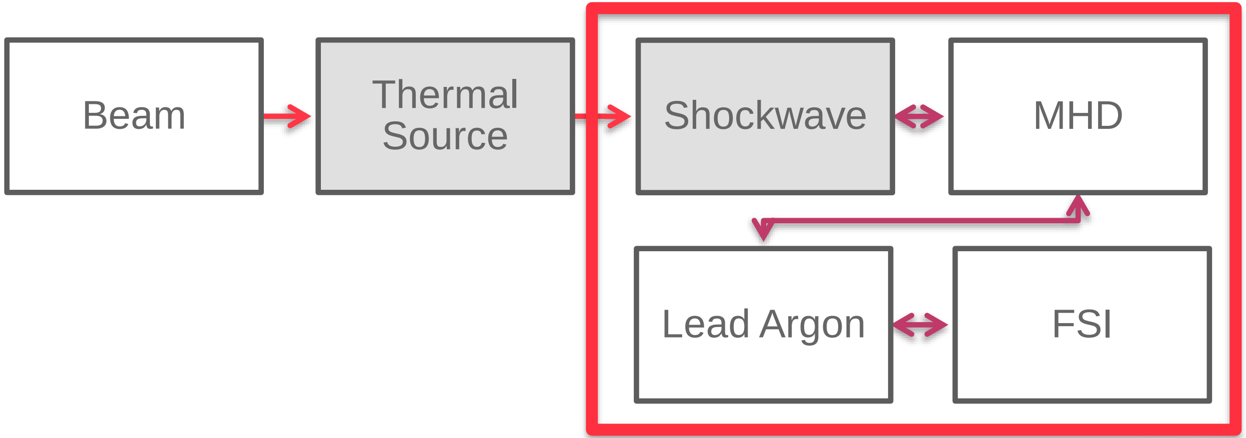
Current studies: Shockwave and cavitation

Physical model: scope

- Identify the pressure and velocity peaks.
- Quantify the characteristic parameters of the ongoing phenomena.

Hypothesis

- The beam doesn't give a momentum to the target.
- The beam deposition happens at constant volume into the interaction region.



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Current studies: Shockwave and cavitation

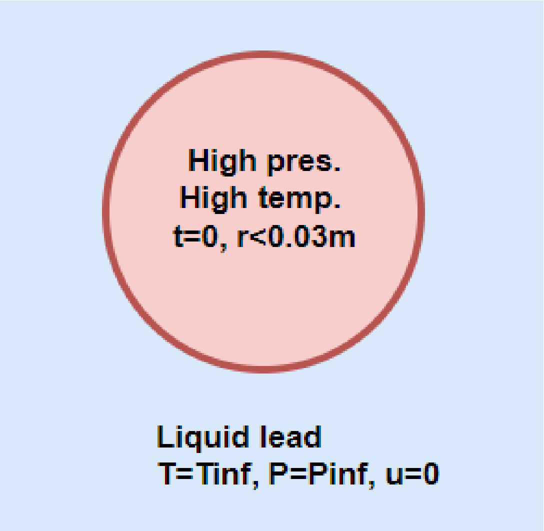
Physical model: initial condition t=0

- Mie Gruneisen EOS: overpressure calculation into the interaction region

$$p = p_{ref} + \frac{\gamma}{V}(E - E_{ref})$$

- Tait EOS: lead compressibility

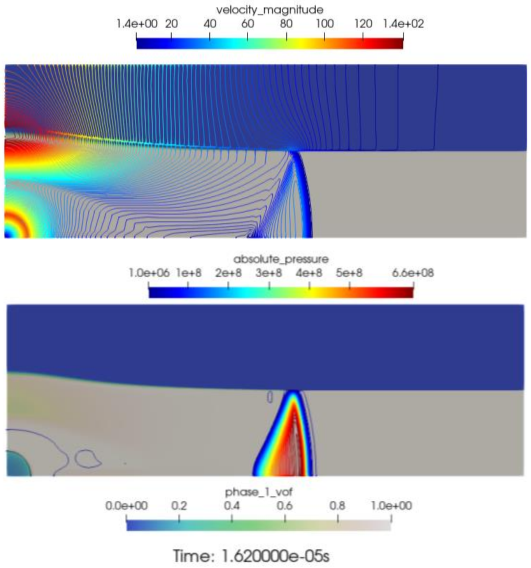
$$\rho = \rho_{ref}\left(\frac{p + B}{p_{ref} + B}\right)^{1/n}$$



Current studies: Shockwave and cavitation

Shockwave and cavitation: stet up

- Over pressure of 5GPa resulting from 1e18 [W m^-3] pick deposition – (data source CERN (2023), 2 MWs target).
- Patch pressure at 5GPa into the interaction zone.
- Compressible liquid lead according to Tait EOS.
- Cavitation model for liquid lead under 10 Pa.
- Incompressible argon and lead vapour.
- Isothermal VOF model.
- Time step 10ns.



Shock and velocity front into liquid lead with cover gas in argon.

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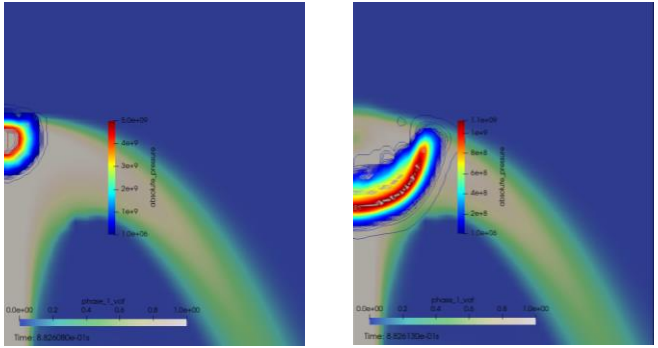
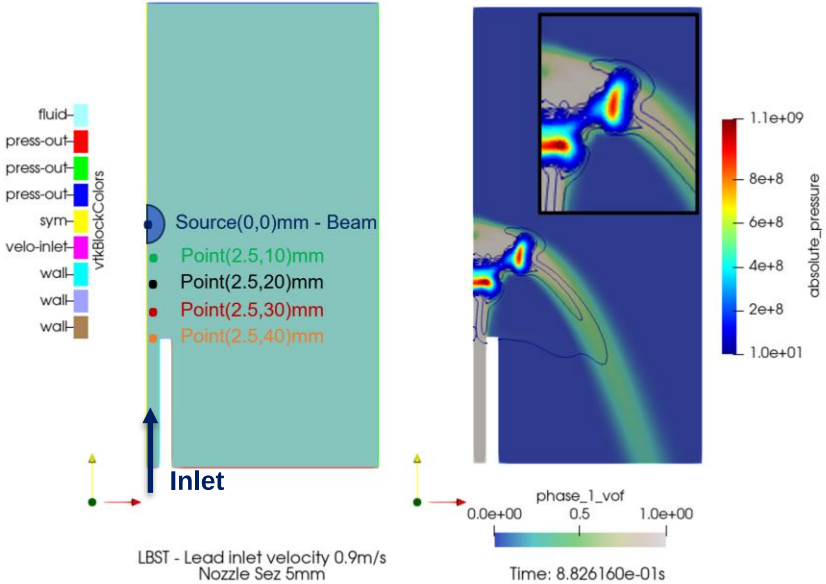
Current studies: Shockwave and cavitation

Preliminary simulations: Lead Bottom Stream Target (LBST)

- Liquid lead jet target with inlet velocity of 0.9 m/s.
- Nozzle section of 5mm.



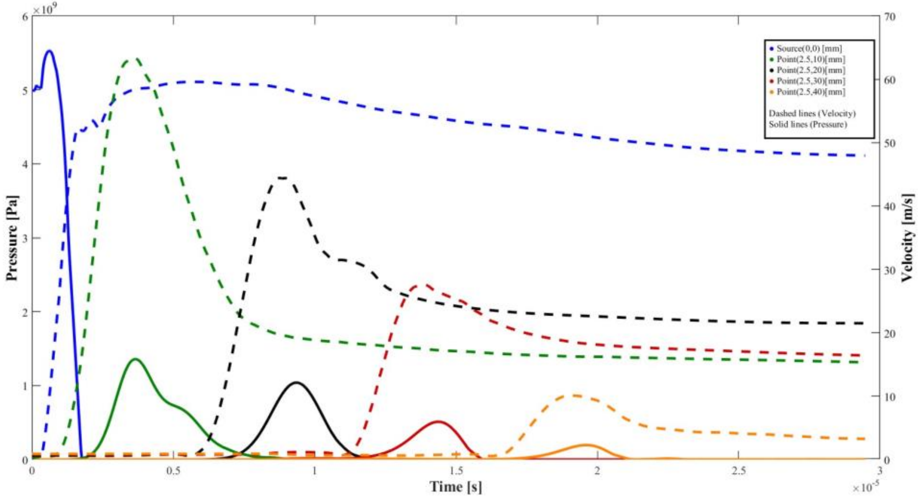
Simulation of shock wave into liquid lead with argon.



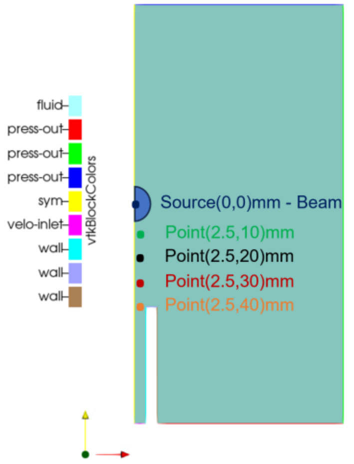
Current studies: Shockwave and cavitation

Preliminary simulations: Lead Bottom Stream Target (LBST)

- Shock wave and velocity profile into the target.



Shock front into liquid lead.

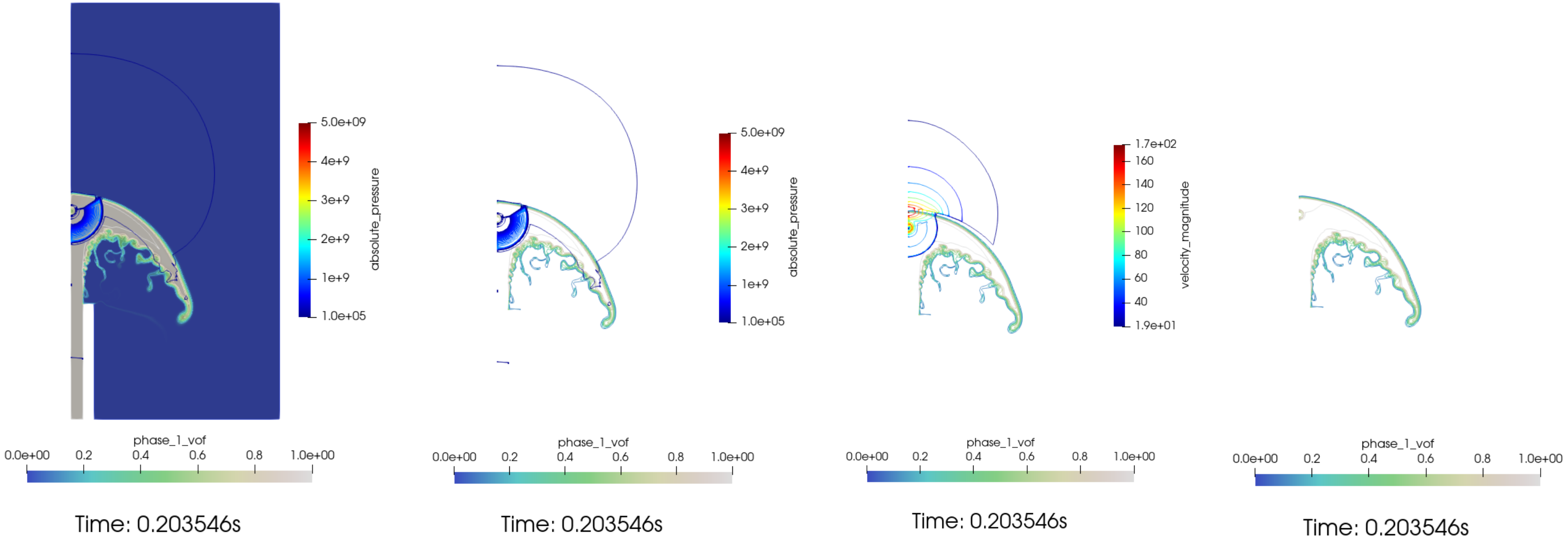


LBST - Lead inlet velocity 0.9m/s
Nozzle Sez 5mm

Current studies: Shockwave and cavitation

Preliminary simulations: Lead Bottom Stream Target (LBST)

- Current calculation: same case fine mesh

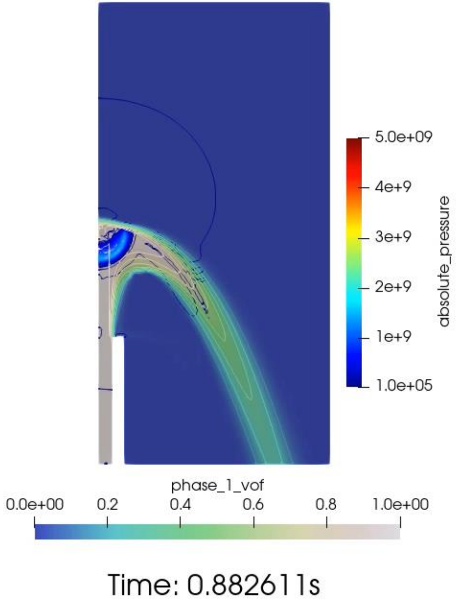


LBST fine mesh.

Conclusion: General considerations

General considerations

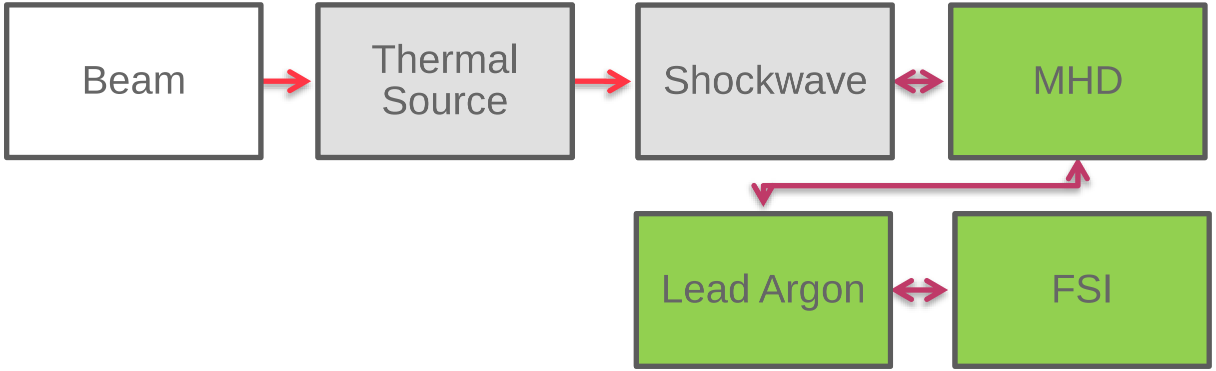
- The hight power energy pulse generates shock waves with a magnitude of several GPa and period of 1e-5s.
- An argon buffer is preferred between the interaction zone and structure: the hight compressibility of argon decries the magnitude of the shock wave.
- It is important to ensure a minimum distance between the beam interaction zone to reduce the magnitude of the shock wave.
- It is important to reduce the mass flow rate for the system loop point of view.
- It is important to reduce the volume of hight density material around the beam interaction zone to ensure higher muon production.



Conclusion: future steps

Future steps

- Implement a fully compressible VOF model.
- Develop a cavity model for vaporization and condensation depending on pressure and temperature.
- Integrate other physical phenomena.



Thanks for the attention

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