Ultra-intense laser interaction with double-layer targets: exploring high-energy photon emission and pair production

Scientific opportunities with APOLLON facilities: from fundamental physics to societal applications
29-30 November 2023 in Paris at Sorbonne University

M. Galbiati, L. F. C. Monaco, K. Ambrogioni, F. Mirani, A. Maffini, & M. Passoni
Department of Energy, Politecnico di Milano, Italy

POLITECNICO MILANO 1863

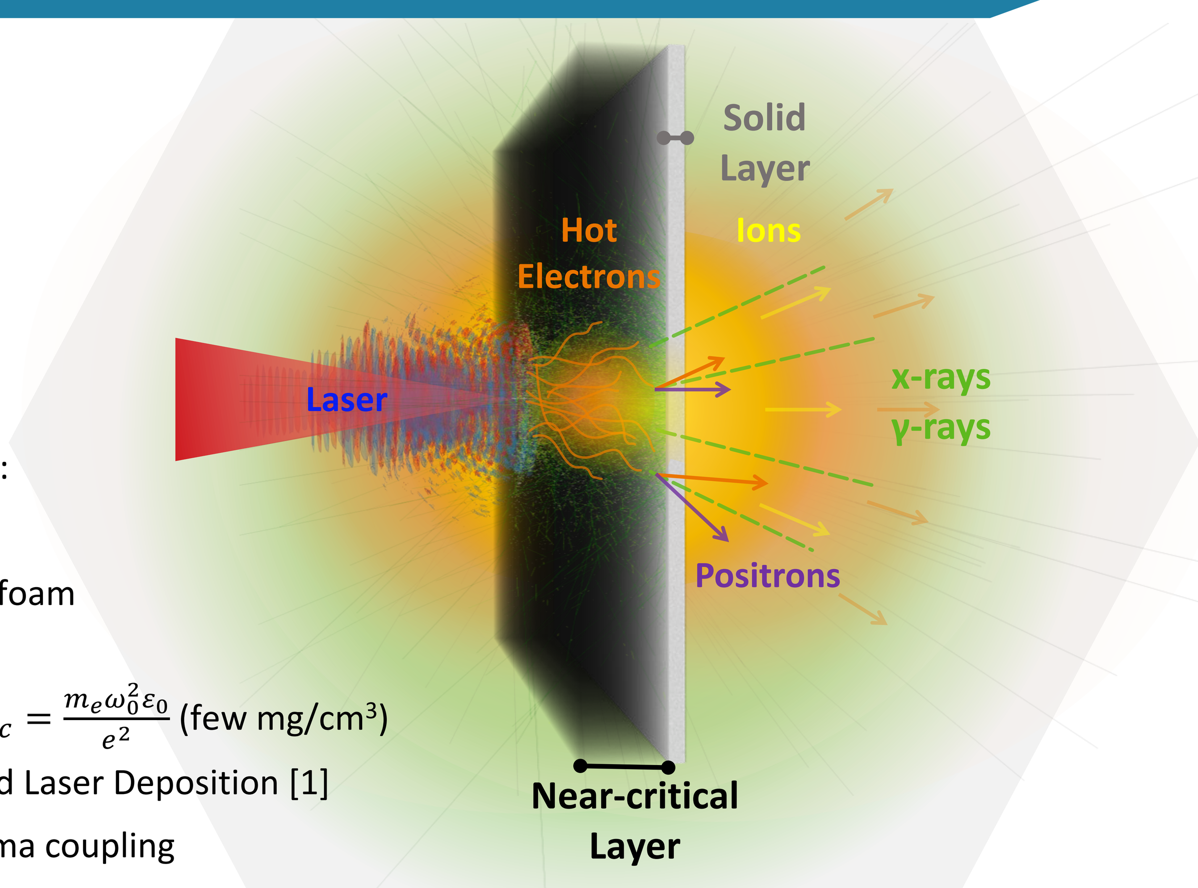
Ultra-intense Laser Interaction with Double-Layer Target

Ultra-Intense Laser pulse:

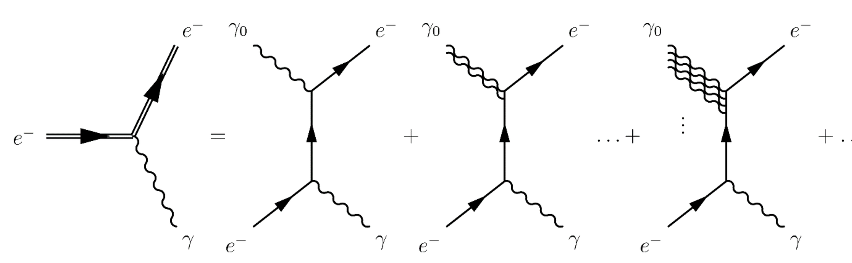
- $\lambda = 0.8$ μm
- fs duration
- μm focal spot
- $a_0 = \frac{eE_0}{m_e \omega_0 c} > 1$
- linearly polarized

Double-Layer Target (DLT):

- solid layer ~ 1 μm
- nanostructured carbon foam
  - thickness ~ 10 μm
  - average density ~ $n_c = \frac{m_e \omega_0^2 \varepsilon_0}{e^2}$ (few mg/cm^3)
  - obtained with Pulsed Laser Deposition [1]
  - increases laser-plasma coupling



High-Energy Photon Emission and Pair Production

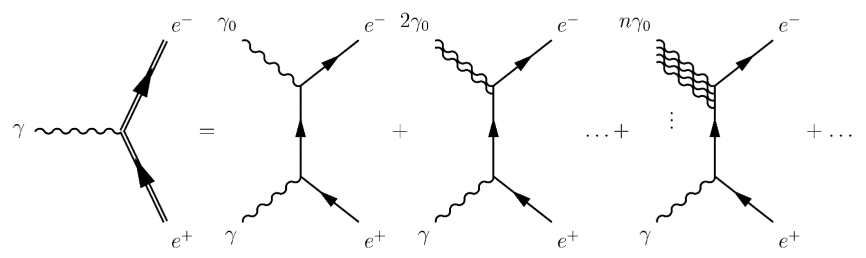


Non-linear Inverse Compton Scattering (NICS):

- a synchrotron-like emission mediated by strong fields [2]
- competing with Bremsstrahlung [3]

Non-linear Breit-Wheeler Pair Production:

- mediated by strong fields [2]
- competing with Bethe-Heitler Pair Production and Trident Processes



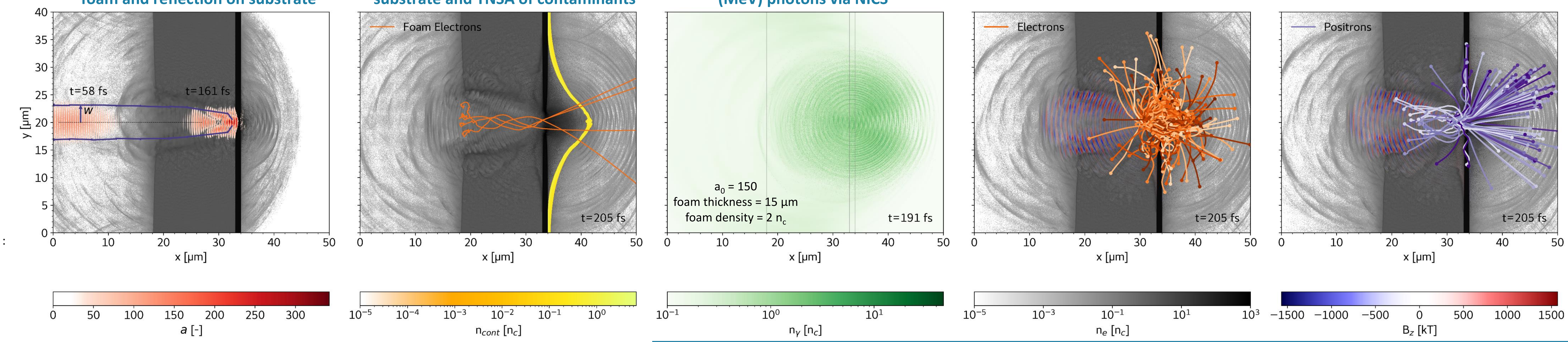
Numerical Investigation:

Particle-In-Cell (PIC) simulations with a run-time evaluation of photon emission and pair production [4,5,6]

Smilei) WarpX

Physics of Interaction and Secondary Particle Generation

Relativistic laser self-focusing in the foam and reflection on substrate | **Acceleration of electrons toward the substrate and TNSA of contaminants** | **Boosted emission of high-energy (MeV) photons via NICS** | **Non-linear Breit-Wheeler Pair Production**



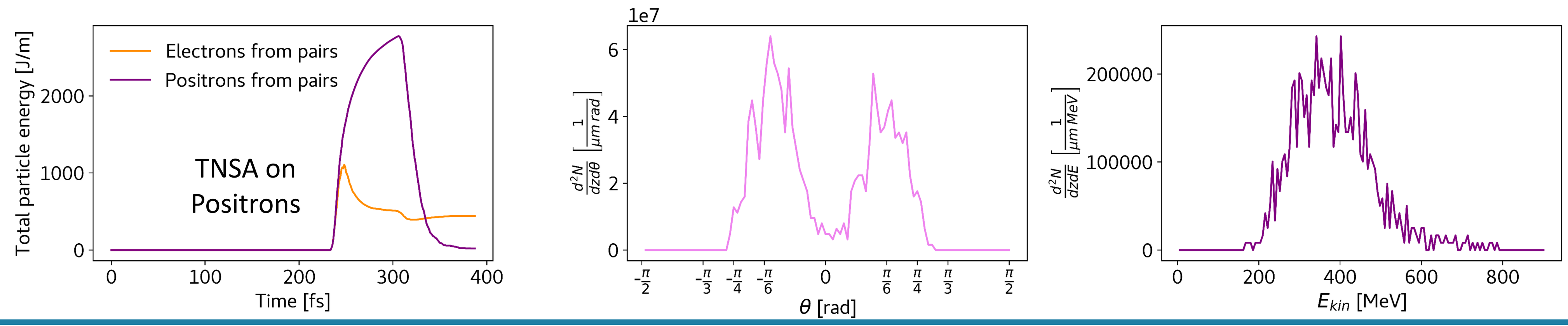
- Relevant parameters for emission and pair generation:
  Electron, Positron and Photon Quantum Parameters,
  maximized in head-on collision of particles with the reflected laser pulse

$$\chi_\pm = \frac{\gamma}{E_s}\sqrt{(\boldsymbol{E}+\boldsymbol{v}\times\boldsymbol{B})^2-\left(\frac{\boldsymbol{v}\cdot\boldsymbol{E}}{c}\right)^2} \qquad \chi_\gamma = \frac{\gamma_\gamma}{E_s}\sqrt{(\boldsymbol{E}+\boldsymbol{c}\times\boldsymbol{B})^2-\left(\frac{\boldsymbol{c}\cdot\boldsymbol{E}}{c}\right)^2}$$

$$E_s = \frac{m_e{}^2 c^3}{\hbar e} = 1.3 \cdot 10^{18} V/m$$

- Self-focusing length [7]: $f \approx \omega_0 \sqrt{\frac{n_c}{n_e}}\left(1+a_0^2/2\right)^{1/2}$
  Length to reach maximum focalization in the foam

Positron beam properties in the optimal case with foam thickness 39 μm and density 1 n_c

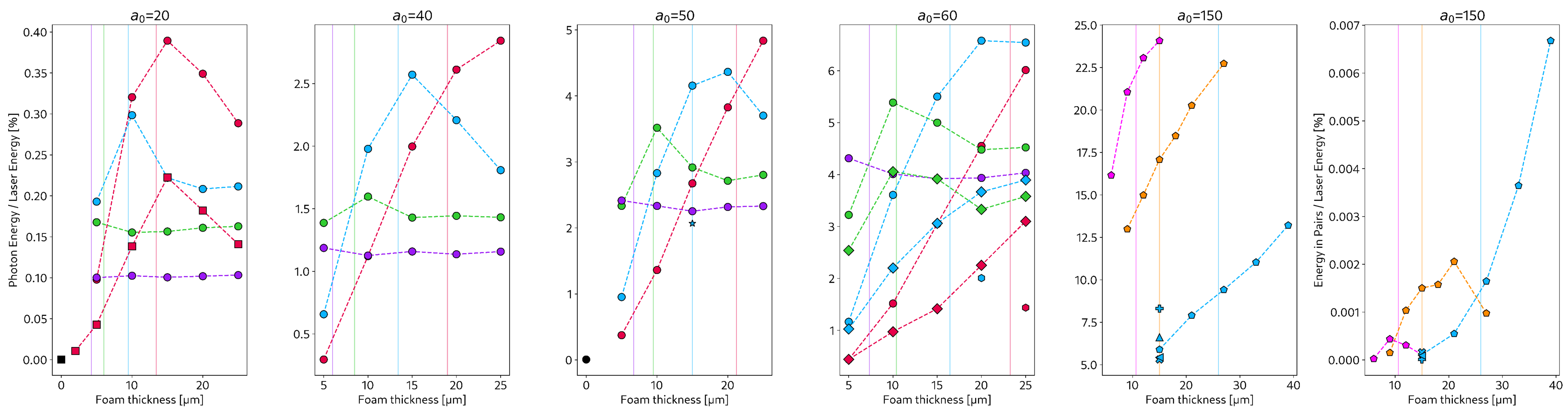


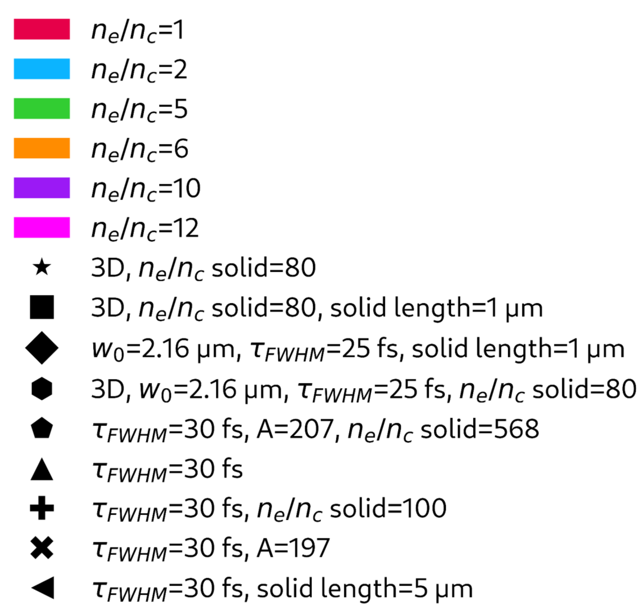
Laser and Target Optimization for Photon Emission and Pair Production

2D [8,9] and 3D [10] simulation scans to evaluate optimal target (density and thickness) and laser (intensity) parameters for conversion efficiency in photons and pairs.

The optimal thickness, when visible, is larger than the self-focusing length. Thick low-density foams enhance pair production. 2D and 3D results show similar trends.

Fixed parameters (unless differently specified): ▪ Laser Waist = 3 μm ▪ τ_{FWHM} = 20 fs ▪ Solid Layer of Aluminum ▪ Solid Density= 450 n_c ▪ Solid Thickness= 2 μm





Conclusion: worth investigating double-layer targets as a multipurpose-source of radiation at facilities like Apollon

Acknowledgments

erc ERC-2022-PoC No. 101069171 PANTANI
CINECA
POLITECNICO MILANO 1863
NanoLab
EUROfusion

References

[1] Maffini *et al.* 2022 *Appl. Surf. Sci.* 599 153859
[2] Di Piazza *et al.* 2012 *Rev. Mod. Phys.* 84 1177
[3] Formenti *et al.* 2022 *Plasma Phys. Control. Fusion* 64 044009
[4] Gonoskov *et al.* 2015 *Phys. Rev. E* 92 023305
[5] Derouillat *et al.* 2018 *Comput. Phys. Commun.* 222 351-373
[6] Fedeli *et al.* 2022 *SC22, IEEE 1-12*
[7] Pazzaglia *et al.* 2020 *Commun. Phys.* 3 133
[8] Galbiati *et al.* 2023 *Front. Phys.* 11
[9] Monaco 2023 *Master's Thesis at Politecnico di Milano*
[10] Formenti *et al.* 2023 *Submitted to Phys. Rev. E*

marta.galbiati@polimi.it
leonardofrancesco.monaco@mail.polimi.it
www.ensure.polimi.it