ELIMED secondary particle diagnostics

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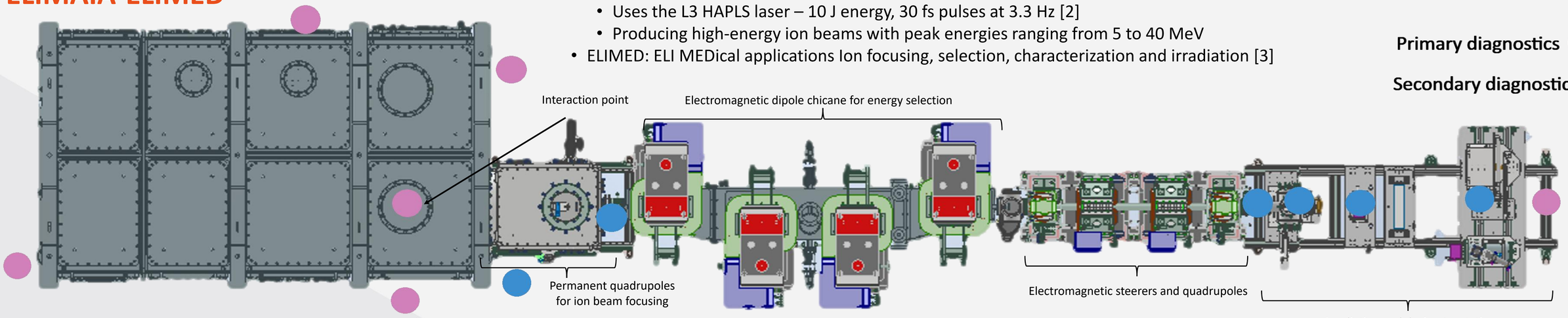
Laser-induced accelerators can produce a broadband spectrum of charged particles to be used for a wide variety of applications including nuclear and particle physics, material science, and nuclear medicine. The produced ion beams are very intense and very short, which makes it very challenging to characterize the beam and secondary radiation. Stray radiation - such as photons, electrons, and neutrons - provides valuable insight into laser–target interaction dynamics. At the same time, it can impact the experimental environment by inducing material activation, increasing detector background rates, and contributing to additional radiation dose, particularly in radiotherapy-related contexts. To address these challenges, the ELIMED beamline is equipped with a comprehensive set of secondary radiation diagnostics deployed at multiple locations along the beam path, enabling detailed characterization of different particle species and their properties.

ELIMAIA-ELIMED

- ELIMAIA: ELI Multidisciplinary Applications of laser-Ion Acceleration [1]
  - Uses the L3 HAPLS laser – 10 J energy, 30 fs pulses at 3.3 Hz [2]
  - Producing high-energy ion beams with peak energies ranging from 5 to 40 MeV
- ELIMED: ELI MEDical applications Ion focusing, selection, characterization and irradiation [3]



Secondary diagnostic by radiation source

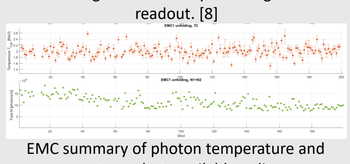
Photons

Photons are created at laser-target interaction point by bremsstrahlung radiation and from primary ion beam interactions with material surrounding the beam path.

Electromagnetic calorimeter (EMC) [7]

- Scintillator stack detector (3 units available)
- Photon temperature range 0-30 MeV
- In air only, movable setup
- Possible to couple with a magnet to suppress electron signal

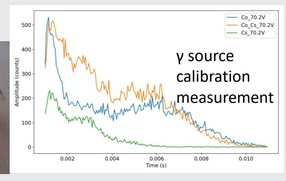
EMC diagram and example of single shot readout. [8]



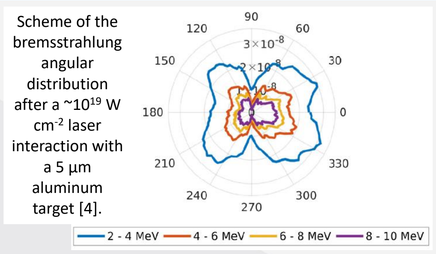
EMC summary of photon temperature and count per shot, available online.

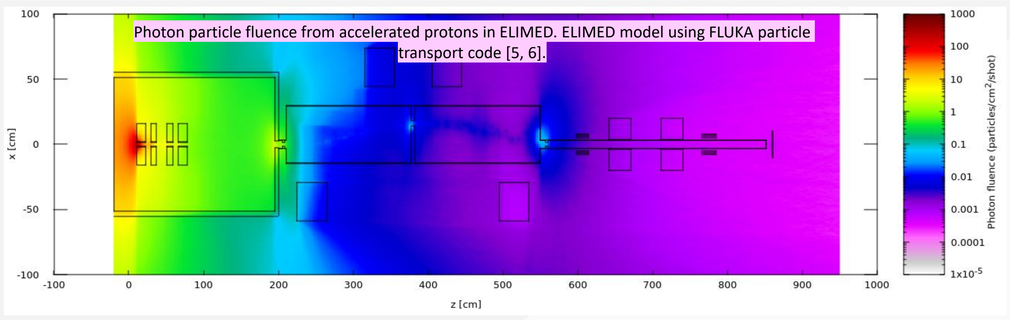
Solid state gamma detector

- Scintillator + solid-state photodetector
- Single photon sensitivity
- In air and in vacuum



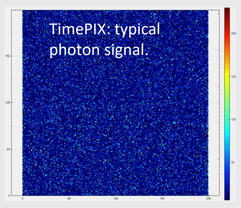
Scheme of the bremsstrahlung angular distribution after a ~10^{19} W cm^{-2} laser interaction with a 5 µm aluminum target [4].





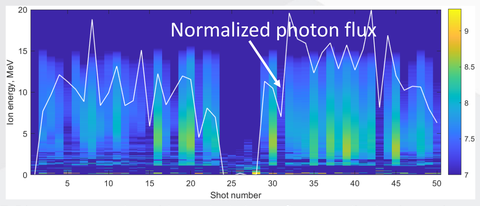
TimePIX

- 1-200 keV photon energy for good efficiency range
- In vacuum and in air



Diamond Time-of-Flight (ToF)

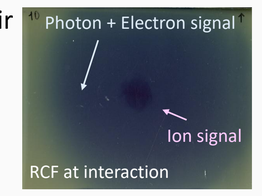
- Solid-state ionization detector, mainly ion diagnostics
- Provides photon flux calculation
- In vacuum



ToF ion energy per shot with attached photon flux normalized to its maximum.

Radiochromic film (RCF)

- Passive detector
- Photon and electron signal not distinguishable
- Possible to determine angular distribution near interaction
- In vacuum and in air

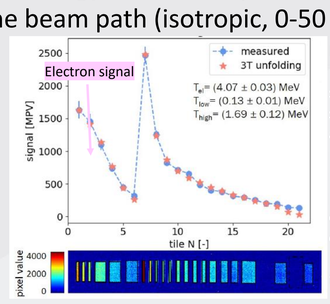


Electrons

Created in laser-target interaction primarily by front-surface laser absorption (mostly 20-40° angular distribution on laser axis, 0-5 MeV energy distribution), also, from primary ion beam interactions with material surrounding the beam path (isotropic, 0-50 keV kinetic energy).

EMC

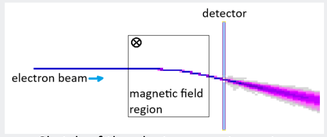
- Primarily X-ray diagnostics capable to measure electron signal using 3T unfolding analysis
- 0-5 MeV energy range



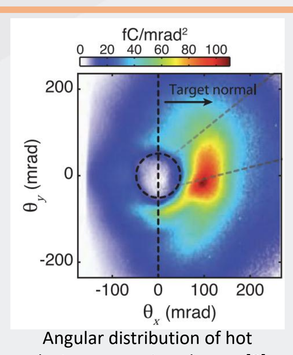
Post-processed scintillation signal image and unfolding result showing mixed field of photons and electrons. T_{el} denotes the hot electron temperature.

Electron spectrometer

- In preparation
- Electromagnet with scintillator screen detector
- Electron energy range 1-100 MeV
- In vacuum



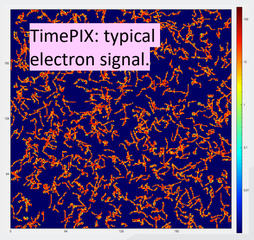
Sketch of the electron spectrometer operating principle.

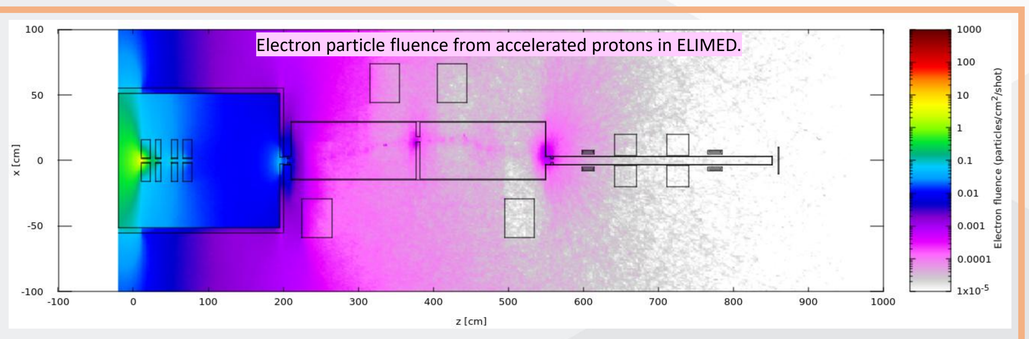


Angular distribution of hot electrons escaping plasma. [9]

TimePIX

- Also sensitive to electron signal
- Range few keV – several MeV





Others

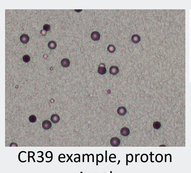
- RCF: passive detector sensitive to electrons
- Diamond ToF detectors: electron signal less distinguishable from photon signal
- Solid state gamma detector: also sensitive to electron signal

Neutrons

Neutrons are created during primary ion beam interactions with material surrounding the beam path. Neutron production is isotropic from point of origin.

CR39

- Passive track detector
- In air and in vacuum
- Able to detect trace quantities of radiation
- Indirect neutron detection (proton recoil)



CR39 example, proton signal.

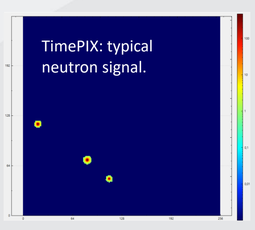
Example of CR39 films on a movable stage inside vacuum chamber.

Berthold LB 6419 detector [10]

- Active neutron dose rate detector
- Thermal neutron detector coupled with hydrogen-rich moderator
- Measures H*(10) – ambient dose equivalent
- Energy range thermal to several MeV
- In air

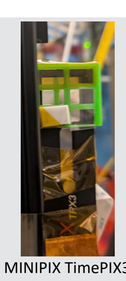
Neutron dose recorded with Berthold LB6419 during experimental campaign compared with simulated dose.

Berthold LB 6419 at irradiation location.

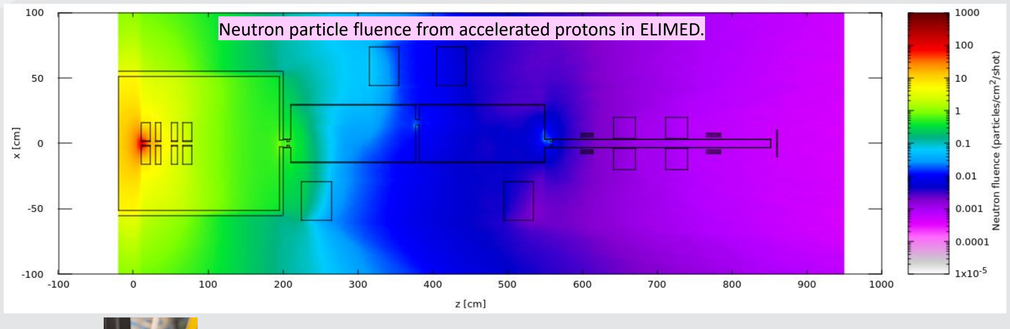


TimePIX

- Indirect neutron detection through neutron converters
- Range: thermal – fast neutrons depending on converter

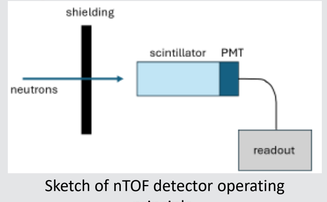


MINIPIX TimePIX3 with attached neutron converters.



Neutron Time-of-Flight detector (nTOF)

- In preparation
- Scintillator based detector
- Fast neutron range (1-20 MeV)
- In air



Sketch of nTOF detector operating principle.

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REFERENCES
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