Journées FAIR - France

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Studies of high energy density states of matter with intense laser and particle beams

V. T. Tikhonchuk

Centre Lasers Intenses et Applications
University of Bordeaux, CNRS, CEA

Historical perspectives and mutual interests

- **Mutual interests of the Bordeaux University (CELIA and CENBG) and Technical University of Darmstadt (TUD) and GSI in the studies of the matter at extreme conditions: High Energy Density Physics**
- **Complementary experimental tools: PHELIX laser + UNILAC at GSI and LMJ-PETAL project in Bordeaux**
- **Longstanding collaboration between UB, TUD and GSI: participation in common European projects (HiPER, Euratom/EUROfusion), bi-lateral agreements, student exchanges TUD-UB, co-supervised PhD thesis and postdocs**
- **Strategic partnership between Aquitaine Region and Land Hessen since 20 years**

HEDP methodology

High Energy Density Physics is characterized by extremely small and short spatial (microns) and temporal (picoseconds) scales requiring specially designed drivers, diagnostics, modeling and interpretation procedures

- **Drivers have to produce the required thermodynamic conditions: control of the density and temperature, homogeneity on a macroscopic scale, long life time (combination of the laser, X-ray and particle drive)**
- **Diagnostics have to provide access to the main parameters with a sufficient spatial and temporal resolution as direct as possible (sources for a secondary emission: radiography, transmission/absorption, imaging)**
- **Theoretical models have to be compatible with available experimental conditions: micro- and macroscopic models (*ab initio*), hybrid approach (hydro-kinetics), diagnostic models**
- **Sufficient set of data for well-restrained interpretations**

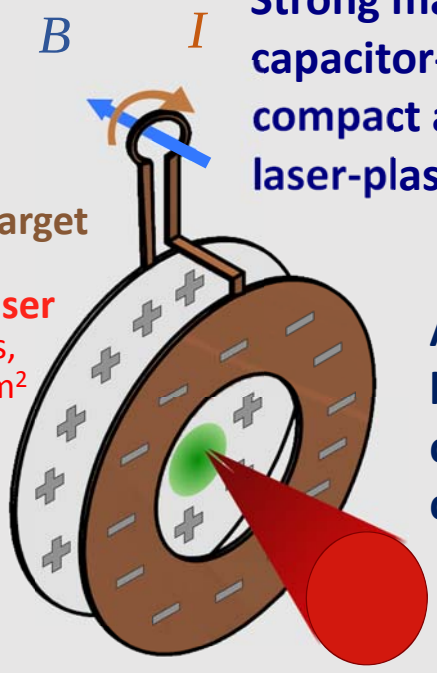
Collaboration axes

CELIA is specialized in high energy density physics, high power lasers and inertial confinement fusion for energy

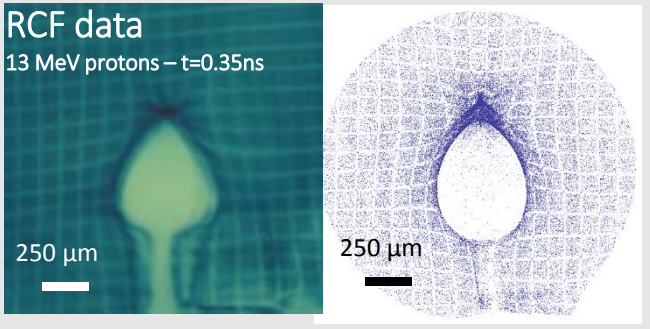
4 axes of collaboration in relation with the FAIR project are identified

- **Matter properties in strong magnetic fields: creation of strong magnetic fields (> 100 T) with intense laser pulses and pulsed power sources, atomic physics in strong magnetic fields**
- **Experimental environment: generation and mitigation of intense electromagnetic pulses in high power laser experiments, protection of diagnostic equipment, activation and debris control**
- **Using of low density targets (foams and gas jets) for efficient particle acceleration and hard X-ray radiation generation: high rep-rate operation**
- **Development of new diagnostic techniques of a matter at extreme conditions: radiography, XANES**

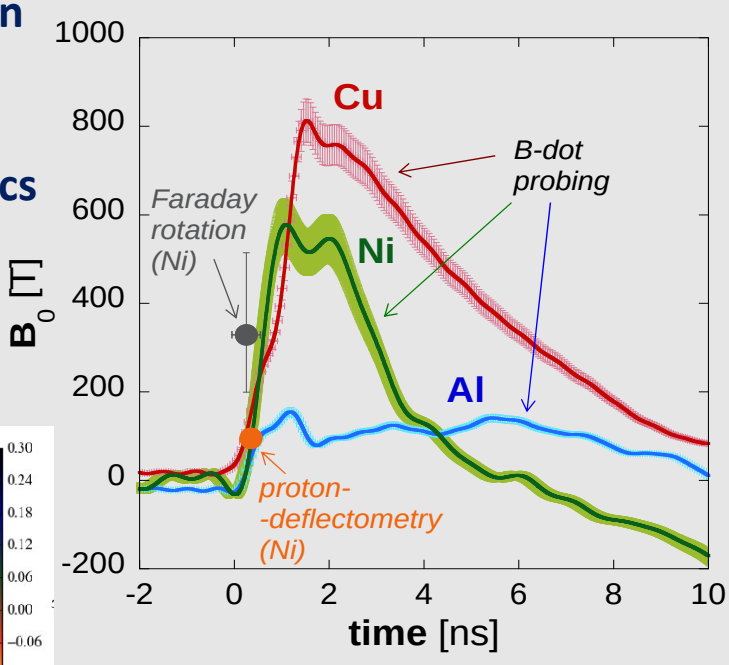
Strong magnetic fields driven with laser pulses



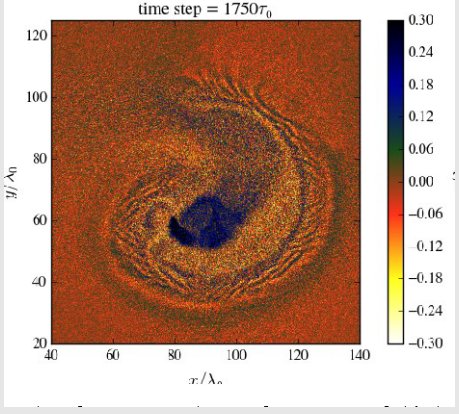
Strong magnetic fields driven with a capacitor-coil assembly presents a compact and portable platform for laser-plasma experiments



Applications to the electron beam guiding proton collimation, magnetic field compression, atomic physics



- **kTesla range, portable platform**
- **ns-scale duration**
- **open-geometry, accessible for diagnostics**
- **magnetization of secondary samples**

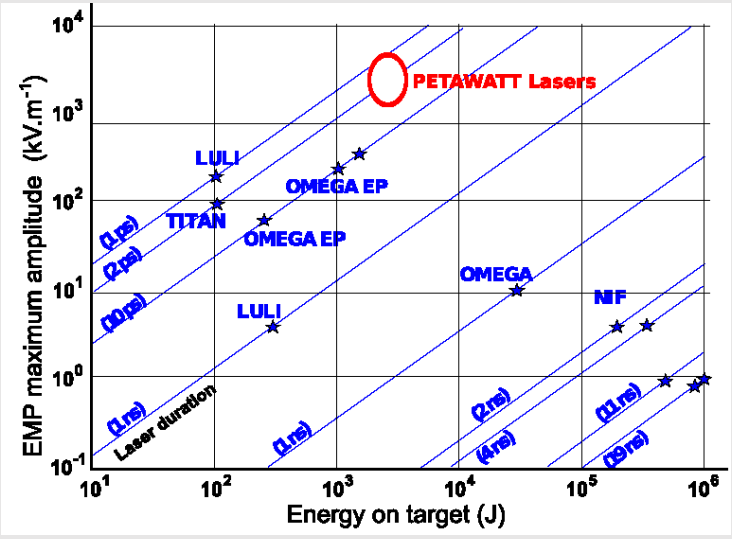


J.J. Santos *et al.*, New J. Phys. 2015

New experiment is planned on PHELIX in October 2017

Electromagnetic fields driven with laser pulses

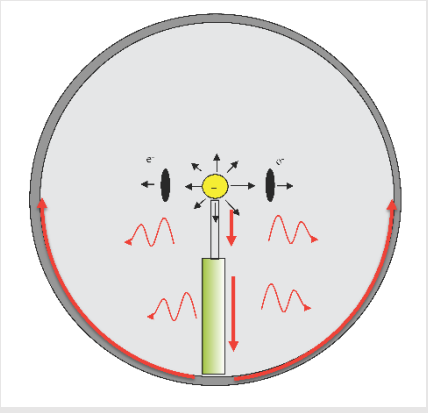
High power laser pulses produce strong electromagnetic pulses presenting threats for equipment and diagnostics



Charge accumulation on a target is recognized as the origin of EMP

Diagnostic techniques are developed and tested

Methods of mitigation are proposed and tested in special experiments

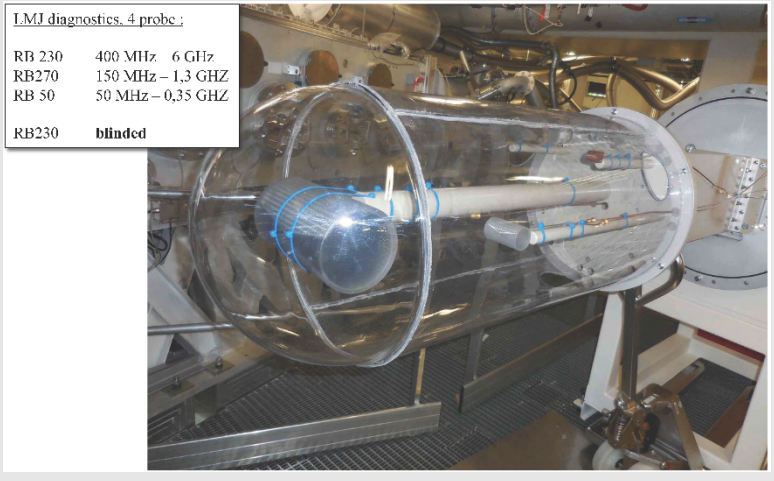


J.L. Dubois *et al.* Phys. Rev E 2014

Methods of electromagnetic protection, activation and debris protection are developed for the PETAL laser system

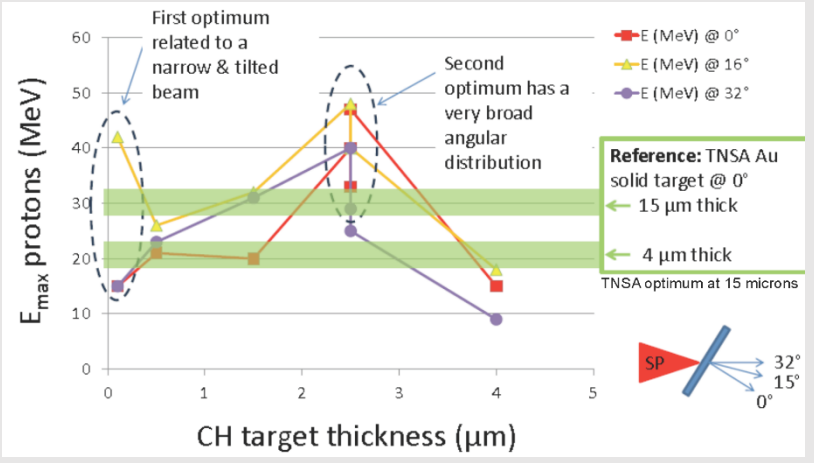
Similar techniques can be applied for the APPA experimental chamber

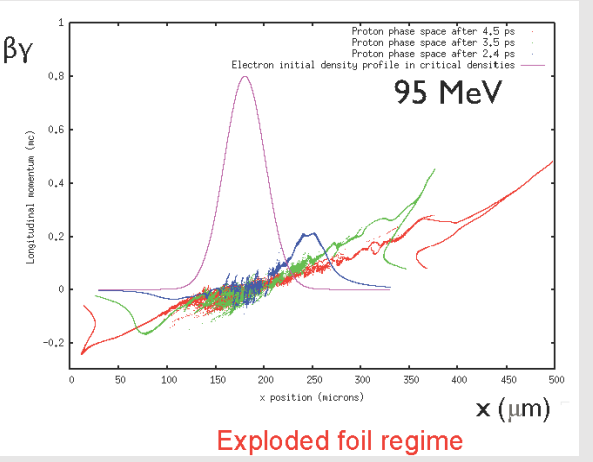
New developments are needed for high repetition rate laser systems



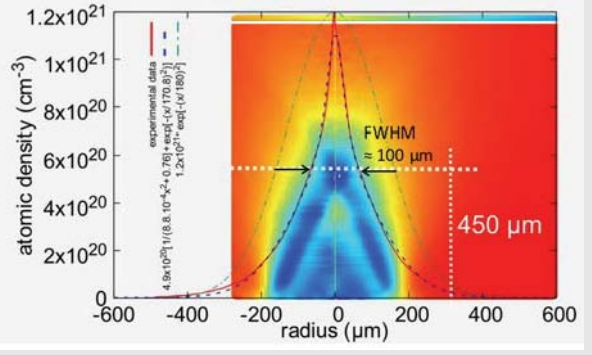
Particle acceleration in low density targets

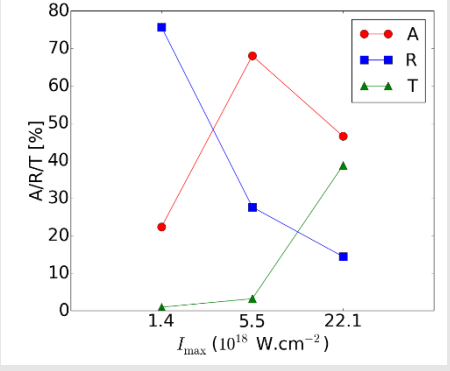
Low density targets offer possibilities for more efficient acceleration of ions to high energy: low debris, high repetition rate





New methods of creation high density pulsed gas jets open possibilities for creation of efficient sources of energetic ions for radiography and imaging



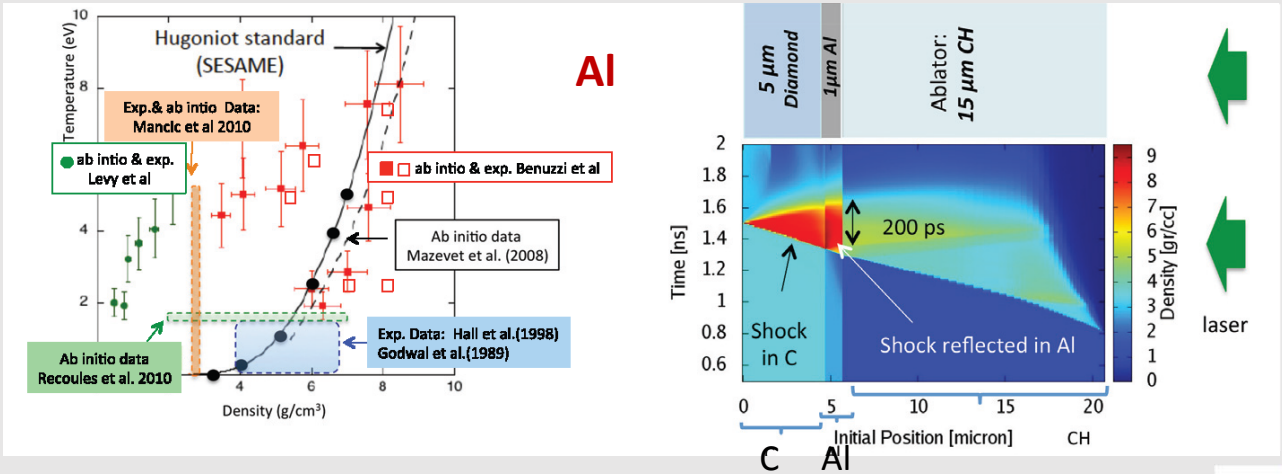


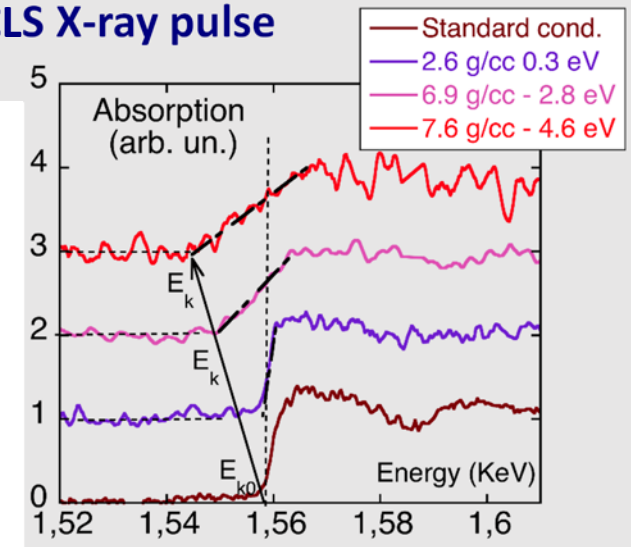
- **Optimization of ion acceleration techniques**
- **Experimental validation**
- **Applications to diagnostics**

E. d'Humières *et al.* Plasma Phys. Contr. Fus 2013
SL-GT-10 gas jet system: SOURCE LAB

Probing of phase and metal-isolator transitions

XANES technique provides access to extreme states at high pressures and temperatures: a sample is heated with a fs laser pulse and probed with a LCLS X-ray pulse



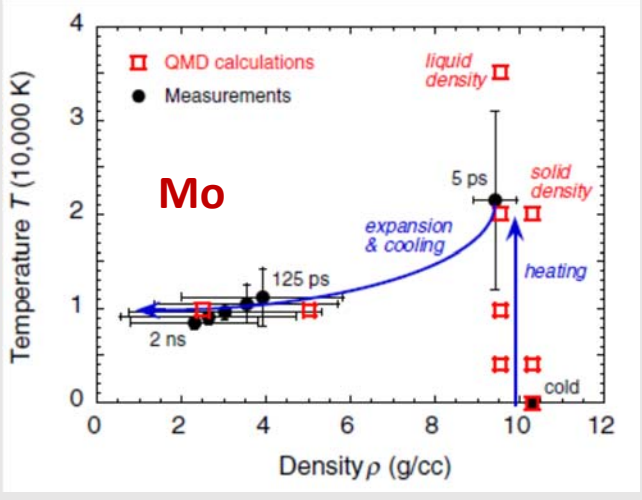


Spectral features of the phase transition:

- **vanishing of XANES modulations**
- **K-edge broadening and shift**

Two complementary models reproduce well the data:

- ***ab initio* Quantum Molecular Dynamics (QMD) simulations**
- **Plasma model – DFT + pseudo atom + MD + XANES simulations**



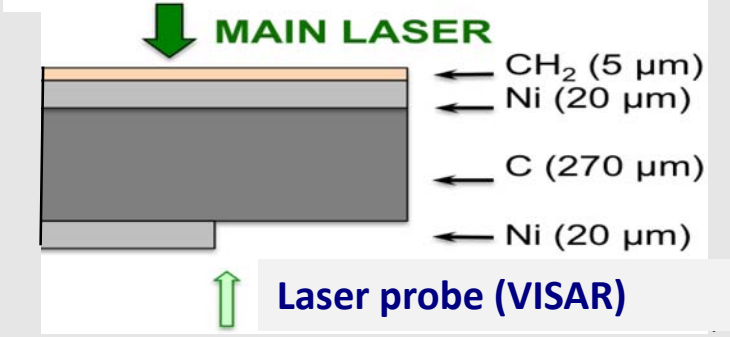
F. Dorchies et al. Phys Rev B 2015

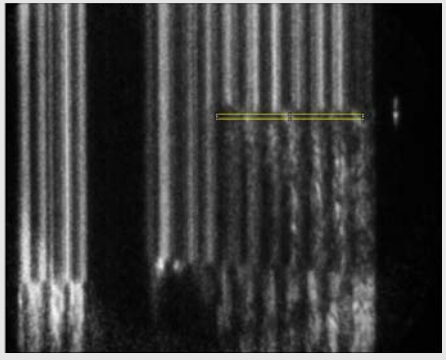
Study of Warm Dense Matter

Measurements of the characteristics of matter in extreme conditions

Created by shocks driven by ns-lasers

Equation of state and phase transition in diamond

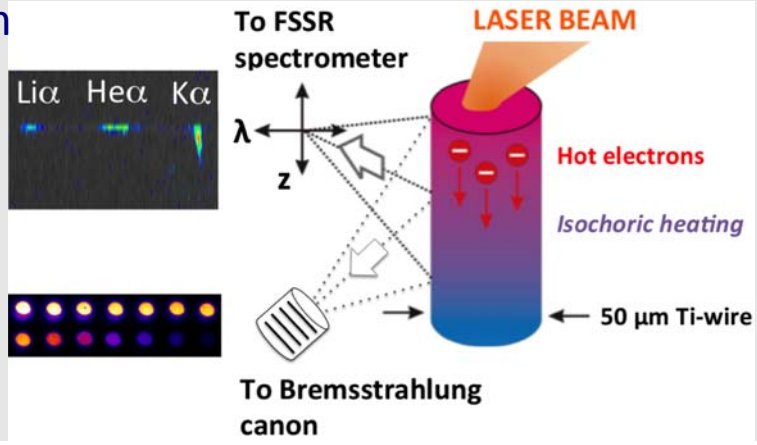


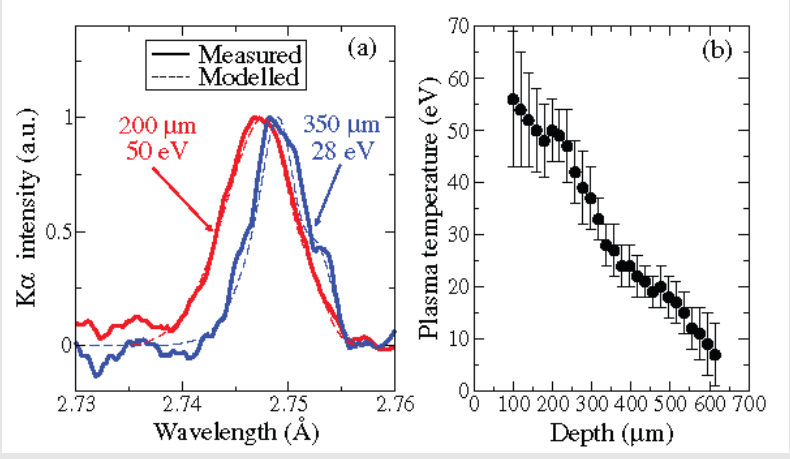


D. Batani EPL 2016

Created by fs-laser isochoric heating

Ti wire heating with high current electron beam

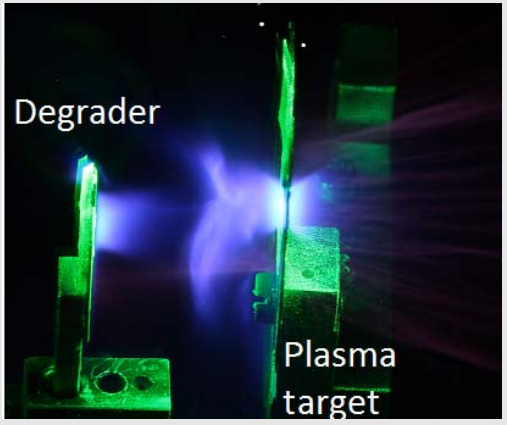


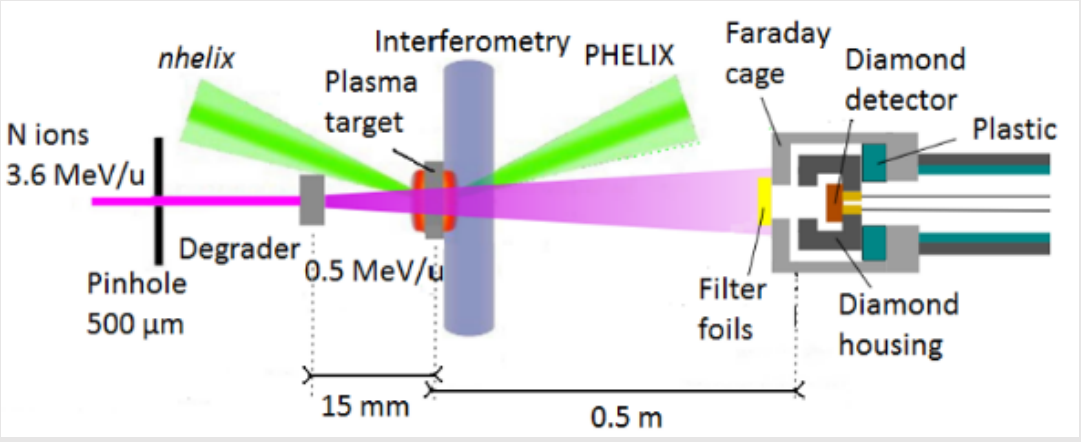


A. Schönlein et al. EPL 2016

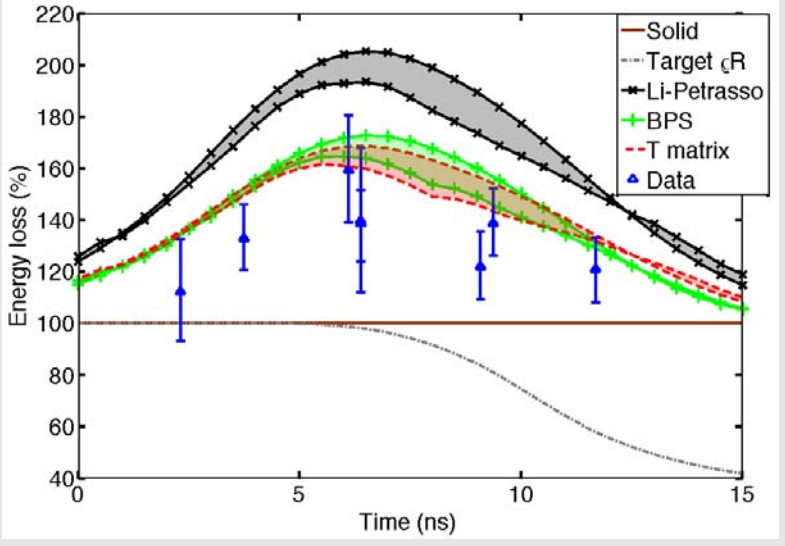
Ion stopping power near the Bragg peak

Measurements of the ion stopping power in WDM is a challenging and unexplored domain





- **First conclusive energy-loss data of multi-charged ions at the Bragg peak in an ideal, nondegenerate laser plasma**
- **T matrix and BPS stopping-power models agree with the data**
- **Perturbative stopping models are ruled out**
- **Importance of close collisions at the Bragg peak**
- **Future experiments with other ions (alphas) and in a degenerate plasma**



W. Gayzac et al. Phys Rev E 2015, Nat. Comm. 2017

Conclusions – perspectives

Combination of lasers with ion accelerators opens a new chapter in the HED physics

- **Equation of state – isochoric heating and pressure release – phase transitions and strong magnetic fields**
- **Ion acceleration and transport processes in warm dense matter**
- **New diagnostic techniques: XANES, X-ray TS, ion radiography**
- **Control of the electromagnetic and radiation environment in the experiment, high repetition rate operation**

Coordination of collaboration activities in France – synergy with ILP and GDR HDE

CELIA contribution: 10 permanents, students, doctorates and postdocs

- **Joint experiments on PHELIX + UNILAC**
- **Preparation for DAY 1 experiments on FAIR**