Investigation of the ion energy loss in a strongly coupled hydrogen plasma

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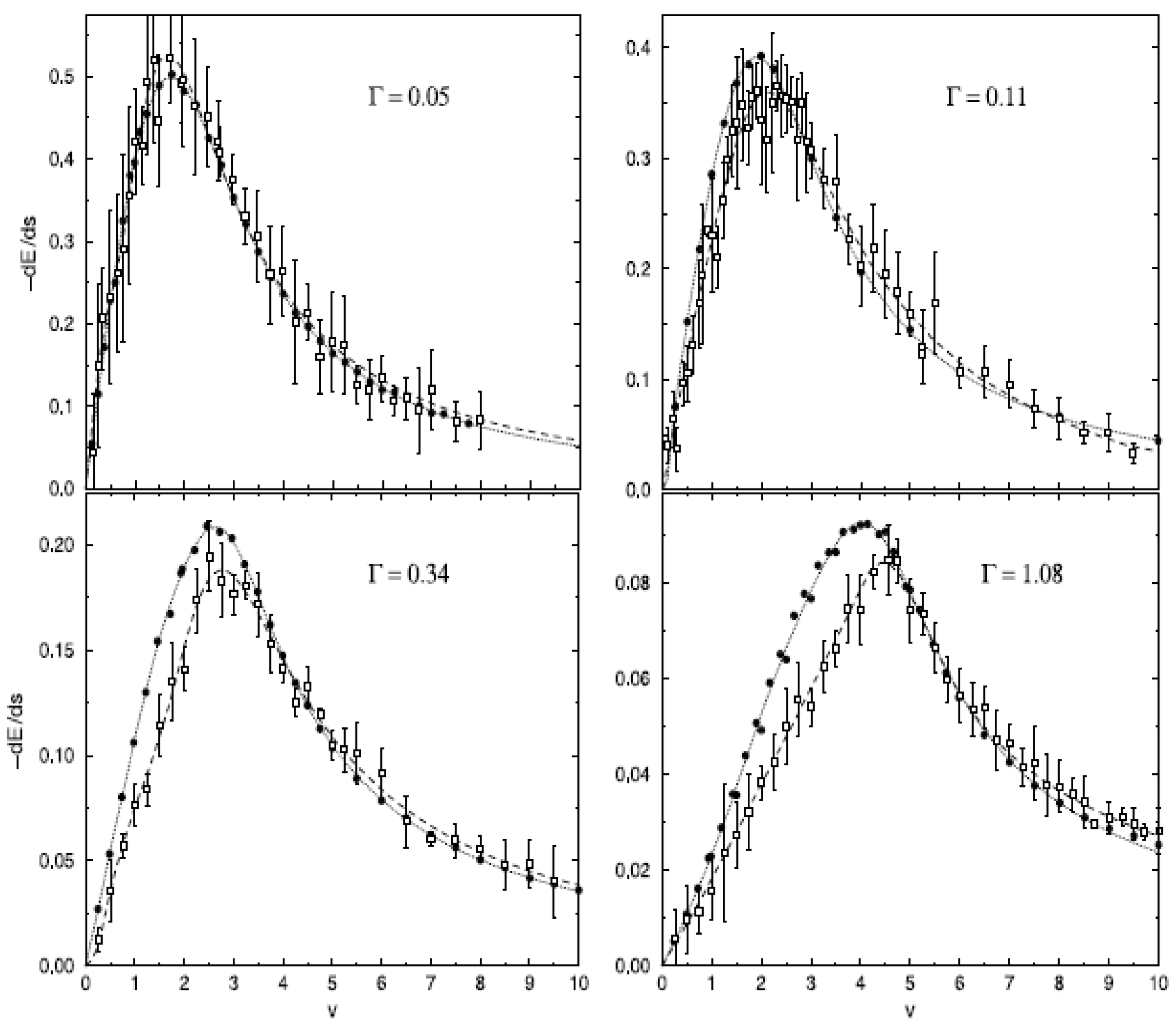
1 - Introduction

- PhD in collaboration between CEA / CELIA and TU Darmstadt / GSI
- Energy loss of ions in **ideal** plasma already adressed, but no experimental data yet for a **strongly coupled** plasma (Γ > 1)
- Energy loss of ions in strongly coupled hydrogen plasma important for ICF (compression phase), EOS of HED matter, electron coolers...

Goal of this PhD thesis

- Generation of a strongly coupled D_2 plasma at Z6 area of GSI with cryogenic target foils heated with the help of the PHELIX laser
- Measurement of the energy loss of UNILAC ion beams in this plasma
- TUD/GSI: wide experience / competence in energy loss experiments
- CELIA: good simulation / calculation tools to design the experiments

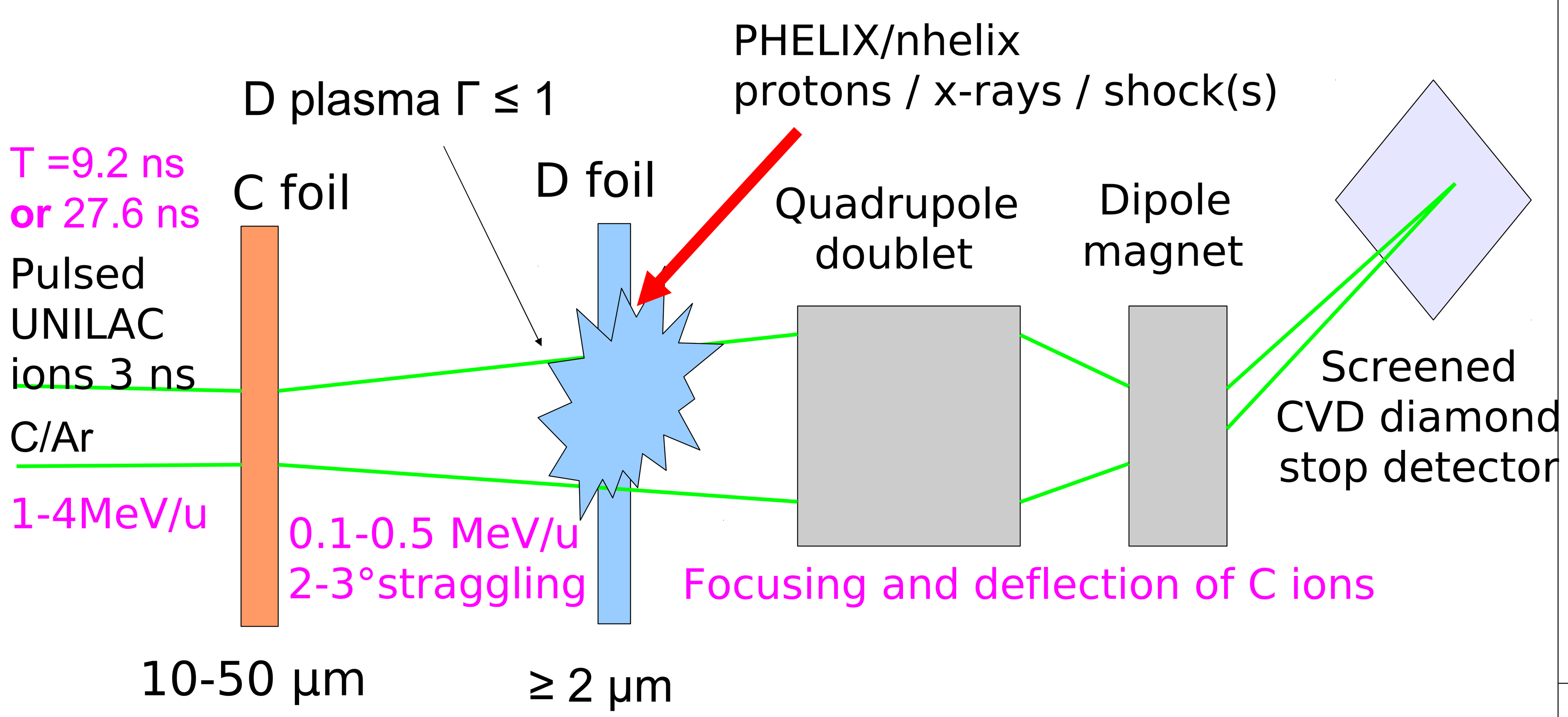
2 - Predicted coupling effects



Normalized stopping power as function of v_{ion} in units of v_{th} with a fixed Z=10 and Γ=0.05, 0.11, 0.34 and 1.08, corresponding to $Z\Gamma^{3/2}$ = 0.11, 0.36, 2 and 11.2. The squares are results of MD-simulations, the circles of Vlasov simulations. [1]

- Only MD simulations take effects of electron collisions into account
- Reduction (10-20%) of stopping power at low ion velocity ($v \le 4.v_{th}$)

3 - Planned experiment with slowed down C ions at GSI

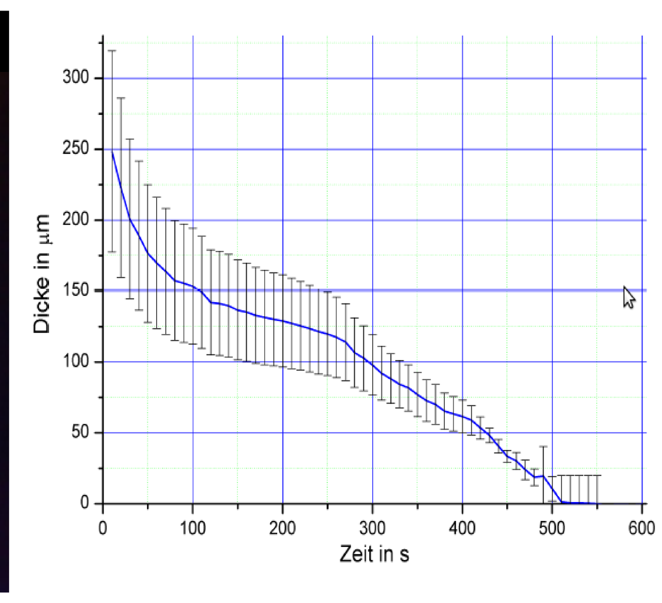


- Necessity to slow ions down to 0.1-0.5 MeV/u with a solid C foil
- Possible detector energy resolution of tenths of keV for 1- 2m TOF
- Necessity of a cold dense plasma in a time ≥ an ion pulse (2-3 ns)

4 – How to generate an homogeneous dense plasma at Γ ~ 1 ?

- Production of thin D_2 cryogenic foil targets at TU Darmstadt (S.Bedacht)

Are homogenous targets of a few µm thickness reachable ?



Left : D_2 cryo-target of 2 mm width ; middle : D_2 plasma out of a solid target created with the nhelix and PHELIX laser systems ; right : evolution of target thickness from electron scattering measurements [2]

- From 250 µm thickness, the target sublimates and becomes thinner
- Time-resolved thickness measurement with chromatic sensors
- Volumetrically heated few-µm-thick D_2-targets to obtain $n_e \approx 10^{22\text{-}23}$ cm^{-3} and T≈ 10 eV, Γ~ 1 – homogenous strongly coupled D_2 plasma (WDM)

Optimal way of heating the D_2 target ?

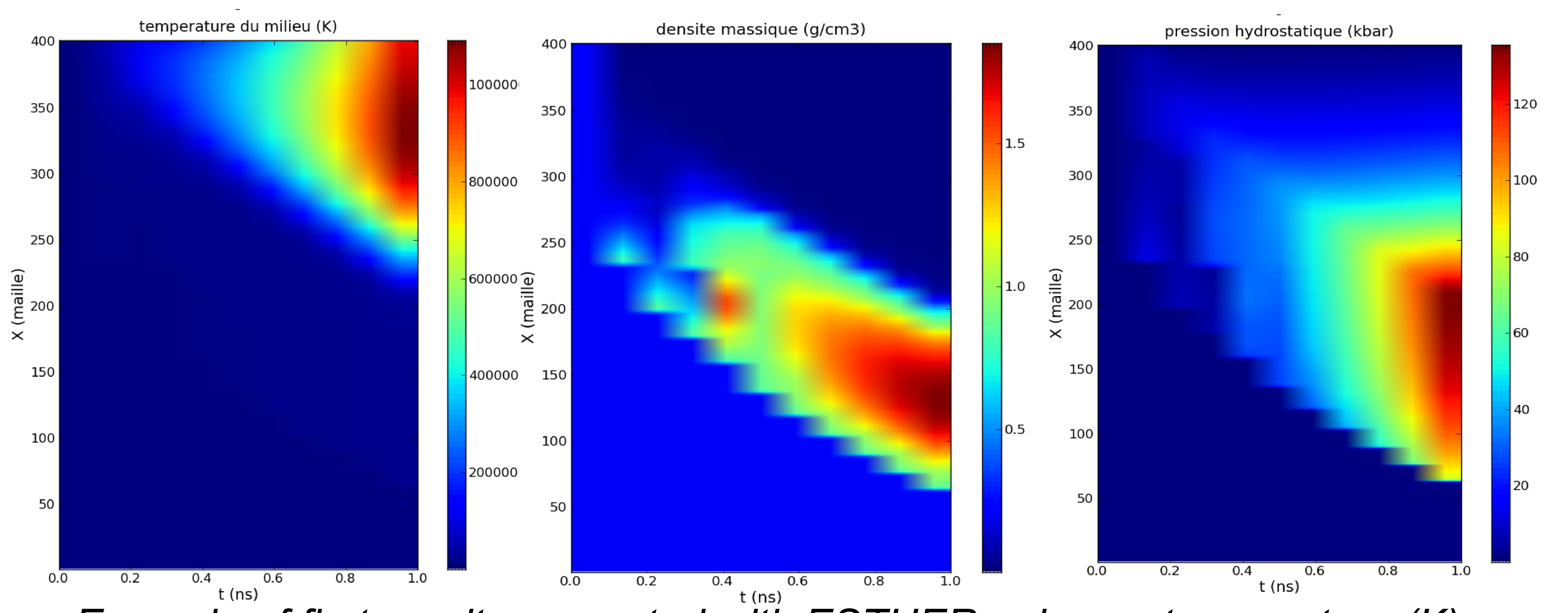
→TNSA proton heating with the new 100 TW beamline of PHELIX at GSI. Sufficient deposited energy / homogeneity ? Beamline to be upgraded...

→Laser-driven shock compression with nhelix and / or PHELIX. Inhomogeneity of density profile, influence of corona ?

→X-ray laser heating with hohlraums from Targetlabor of TU Darmstadt. Necessity of coupling hohlraum with the cryogenic system...

5 – Simulation work - Optimization of laser / target parameters

- ESTHER (1D lagrangian hydrocode) for laser-target interaction [3]
  - Good modelling of interaction / energy deposition at low fluence.
  - Precise calculation of laser, x-ray and proton heating of cold targets.
  - Till now, Quotidian EOS [4] and SCAALP transport coefficients [5].



Example of first results computed with ESTHER : plasma temperature (K), mass density (g/cm³) and hydrostatic pressure (kbar) as obtained from a laser shock in a 10 µm D_2 target after 1 ns at 5.10^{11} W/cm²

- Transport codes for ion-plasma interaction [6]
  - Trumpet : stationnary, collisional, very fast
  - M1: unstationnary, collisional, electromagn. fields, more precise, fast
  - Good description of ion transport in (in)homogenous medium

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[4] More et al., Phys. Fluids 31 (10), October 1988
[5] Faussurier G., Blancard C. et al., POP 17, 052707, 2010
[6] Regan C., PhD thesis, CELIA 2010