CARAT Workshop

December 15th, 2011

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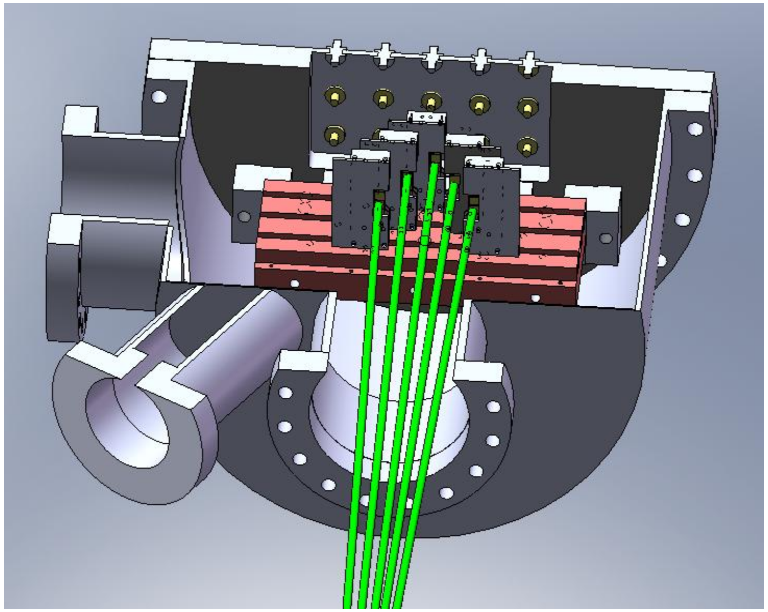
Applications of polycrystalline CVD diamond in plasma physics experiments



Plan

I. Motivation for CVD diamond detectors in plasma physics

1. *Interaction of ion beams with plasma*
2. *Requirements on an ion beam detector*

II. CVD diamond detectors in the plasma physics group

1. *Stop-detectors and charge state spectrometer*
2. *Development and construction*

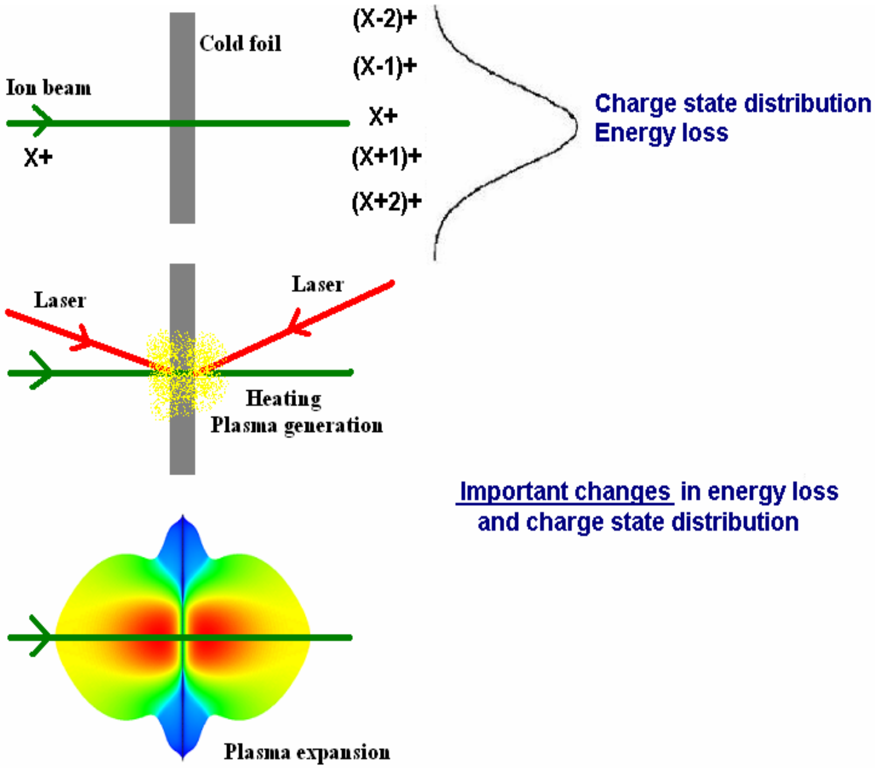
III. Energy loss experiments

1. *Swift ions in a directly heated plasma*
2. *Swift ions in an indirectly heated plasma*

Interaction of ions with matter

- **Heavy ion beam penetrating matter**
  - Energy loss of the projectile
  - Generation of a dynamic charge state distribution in the projectile due to charge transfer processes (competition between ionization and recombination processes)

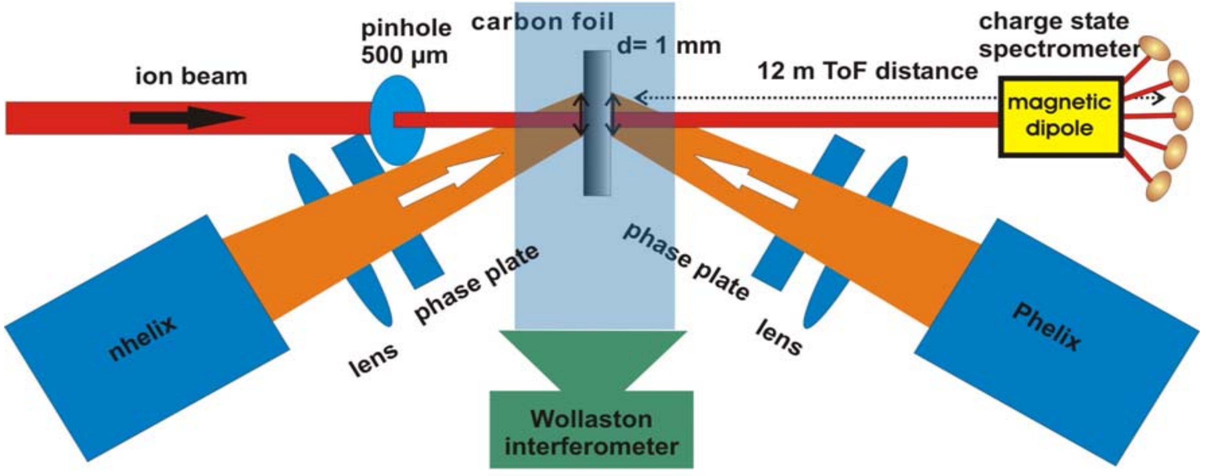
- **In plasma the energy loss and charge transfer cross sections are modified :**
  - Energy transfer to both bound and free electrons
  - Decrease of recombination, increase of ionization processes + cross sections for collisions with free electrons

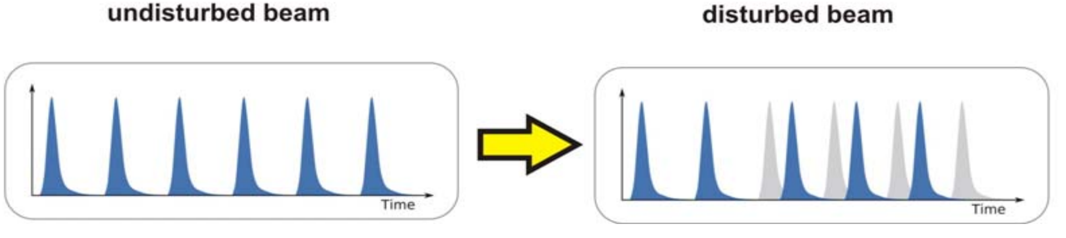


Typical experimental setup

Ar, Ca ions
4-5 MeV/u
T=9.2 / 27.6 ns

~10^3-10^4 particles per micro bunch (3ns)





Time-of-flight measurement
after a 12m distance

Choice of detectors on CVD diamond basis

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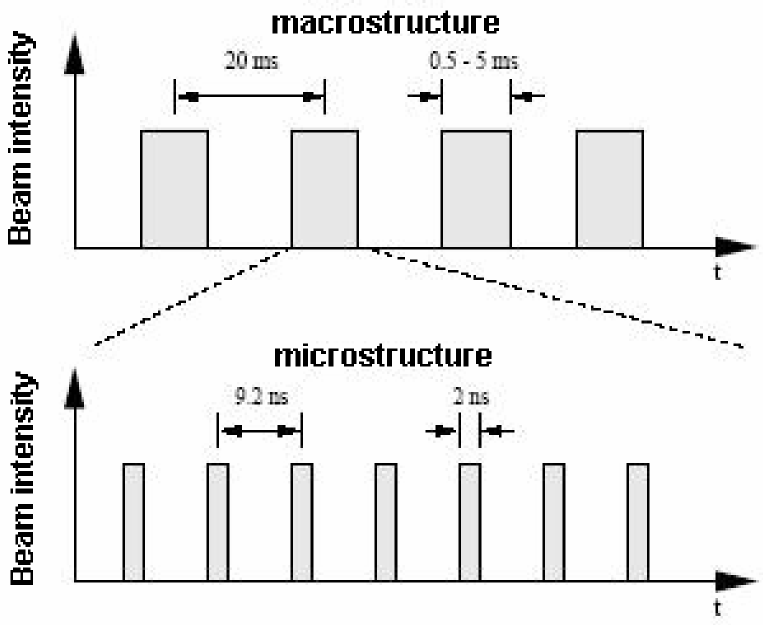
- **We detect particle bunches, no single particles**
  - **At least several hundred ions each 9,2 or 27,6 ns**
  - **Each ion has an energy of more than 200 MeV**

- **High radiation hardness :**
  - Particle currents of *10^{11}-10^{12} ions/s*

- **High time resolution :**
  - Micro bunch duration *2-3 ns*
  - Time resolution has to be significantly below *1 ns*

- **Fast detector :**
  - Micro bunch frequency *9,2 ns*
  - High repetition rate, time constant of few ns

- **High sensitivity :**
  - Sufficient to detect single particles
  - Linear behaviour in relation to the particle number



+ Possible use at room temperature (low noise)

⇨ **CVD diamond detectors are ideal for our experiments**

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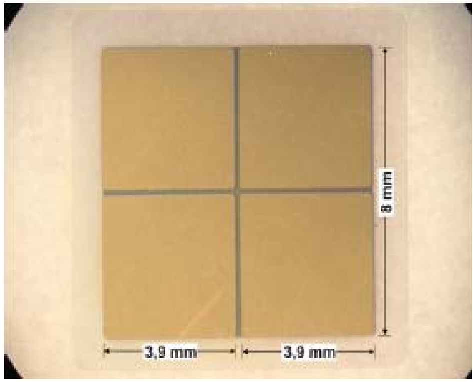
Overview of our CVD diamond detectors

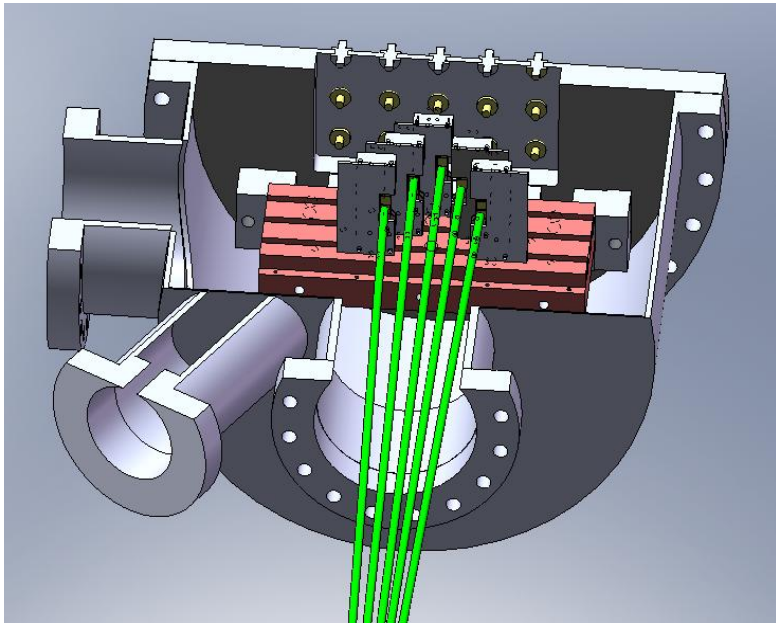


First application (2006)

Stop detectors for energy loss measurement

Surface 8*8 mm²

Thickness 20 µm



Next development (2009)

Charge state spectrometer for energy loss and charge state distribution measurement simultaneously

5 diamonds for 5 charge states

Surface 20*7 mm²

Thickness 20 µm

W.Cayzac et al., RSI, in preparation

Development of the charge spectrometer

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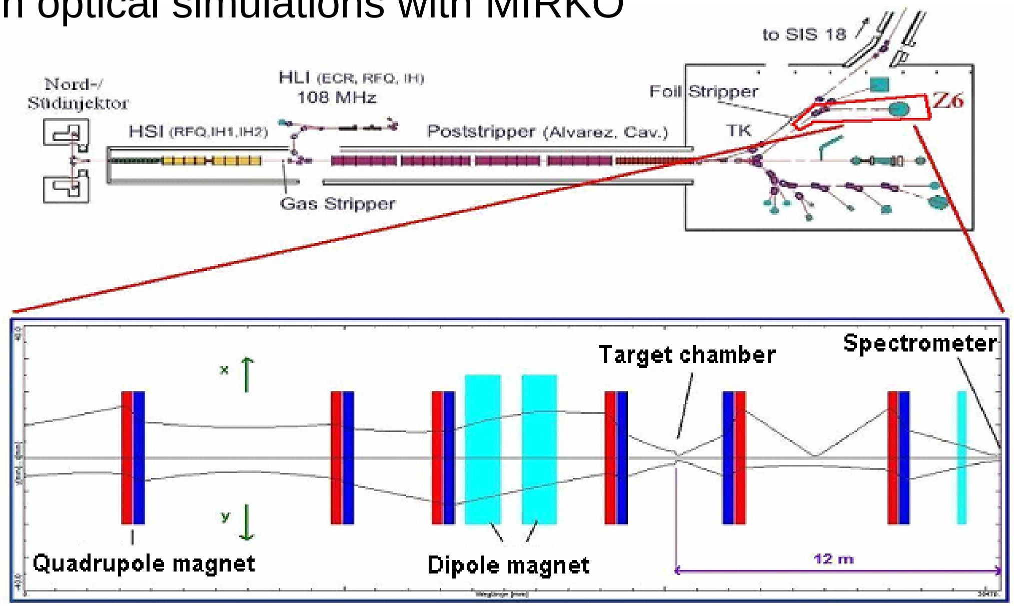
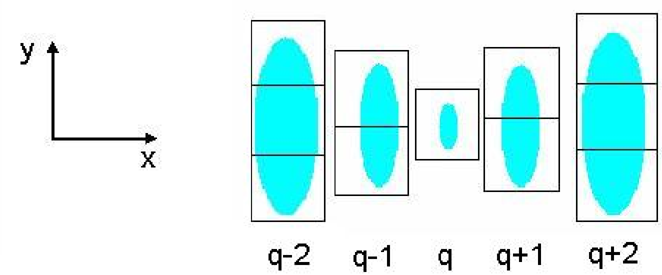
Ion optical simulations with MIRKO





Maximal size of the beams : *5 × 15 mm²* (in ideal case)

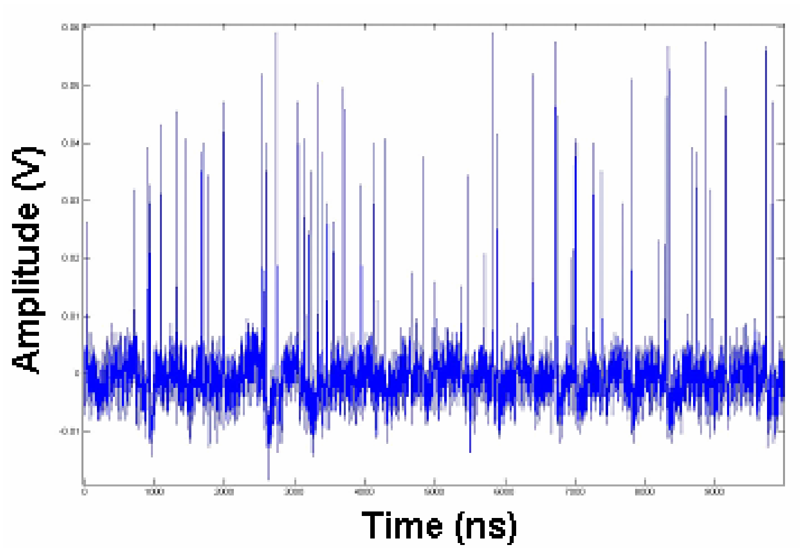
Single crystal diamonds too thick / small / expensive -> not to be used so far...

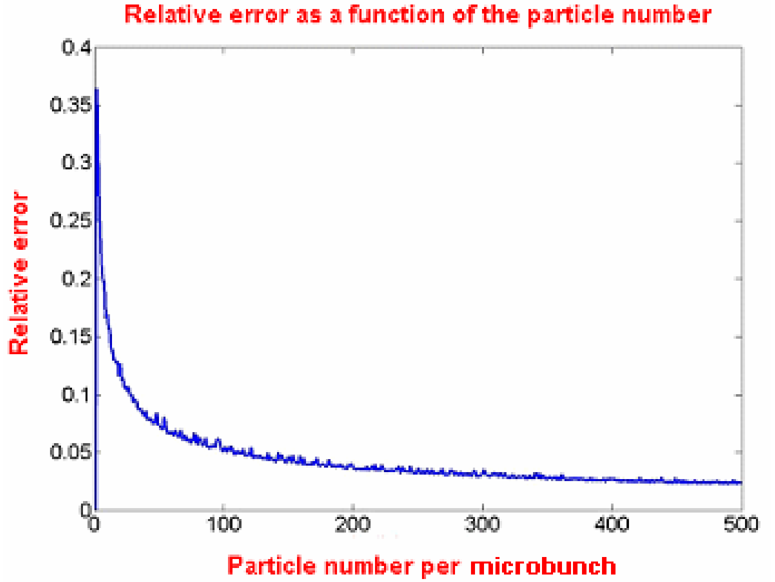
Polycrystalline diamond :

- -Larger surfaces and thicknesses of 20 µm feasible
- -High particle number and thin diamond guarantee a high enough signal
- **-Crucial point: the signal fluctuations have to stay small…**

Simulation of a polycrystalline diamond detector

- Goal : estimation of the fluctuations in the surface of signals
- Statistical analysis of experimental data (Ar with 4 MeV/u, *20,5 µm*-thick polycrystalline diamond, single particle signals)
- Monte-Carlo simulation of surfaces of signals in MATLAB
- From 100 particles per detector, small fluctuations





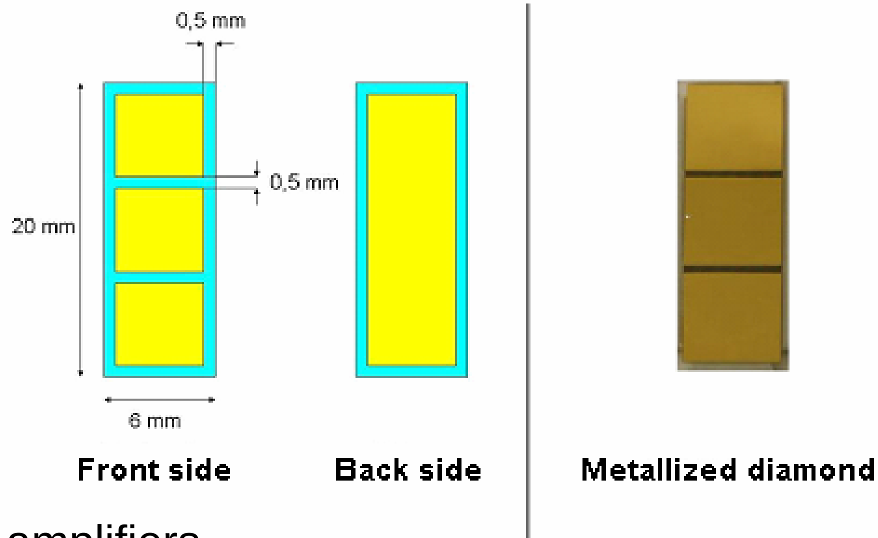
⇨ Choice of polycrystalline diamond

Diamond samples and metallization

- 5 identical polycrystalline highly pure CVD diamond samples (*Diamond Materials GmbH*, *Freiburg*)
- Surface *7 × 20 mm²*: compromise between covering of the beams and increase in capacity
- Thickness *20 µm*: compromise between reduction of polarization and increase in capacity

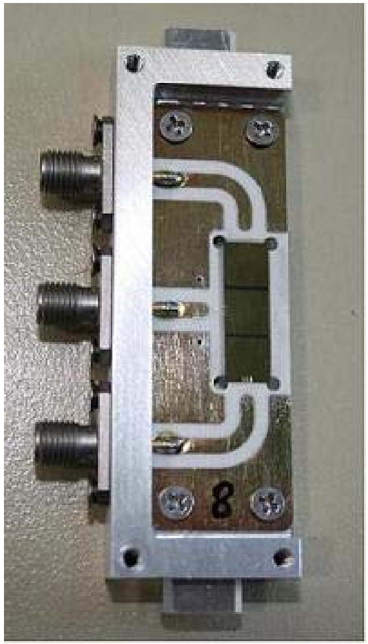
- Electrodes:
  - Front side 3 times *6 × 6 mm²*
  - Back side *6 × 19 mm²*
  - Metallization Ti-Pt-Au

- 3 sectors in each case
  - Time constant *4,5 ns*
  - Compromise between capacity and number of amplifiers



Construction of the spectrometer

- Diamonds bonded on ***50*** Ω ceramics board with copper coating
- Minimal distance of *10 mm* between the middle points of the beams
- System of 3 parallel guide-rails
- Distance in z-direction *4 cm*: maximally *0,1 mm* variation in MIRKO
- For each diamond, signals from sectors are amplified with DBA IV and added



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Experiments with swift ions penetrating a <u>directly heated</u> plasma (A.Frank, PhD thesis)

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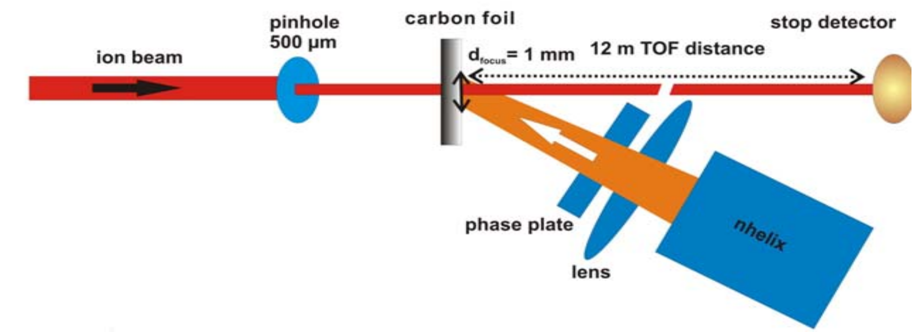
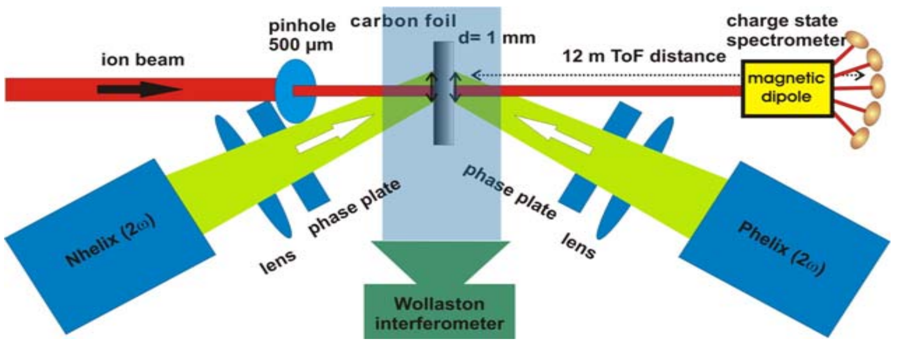




One-sided heating with Nhelix

-Use of the diamond stop-detector

-Problem of laser pulse inhomogeneity

Two-sided heating with Nhelix and Phelix

-Use of the diamond charge spectrometer

-Frequency doubling of both lasers

-Much better heating homogeneity

-Good characterization and understanding of the beam-plasma interaction

Phelix and Nhelix: E = 30 J, 7 ns, I ≈ 5.10^{11} W/cm^2, λ =1064 / 1053 or 532 / 527 nm

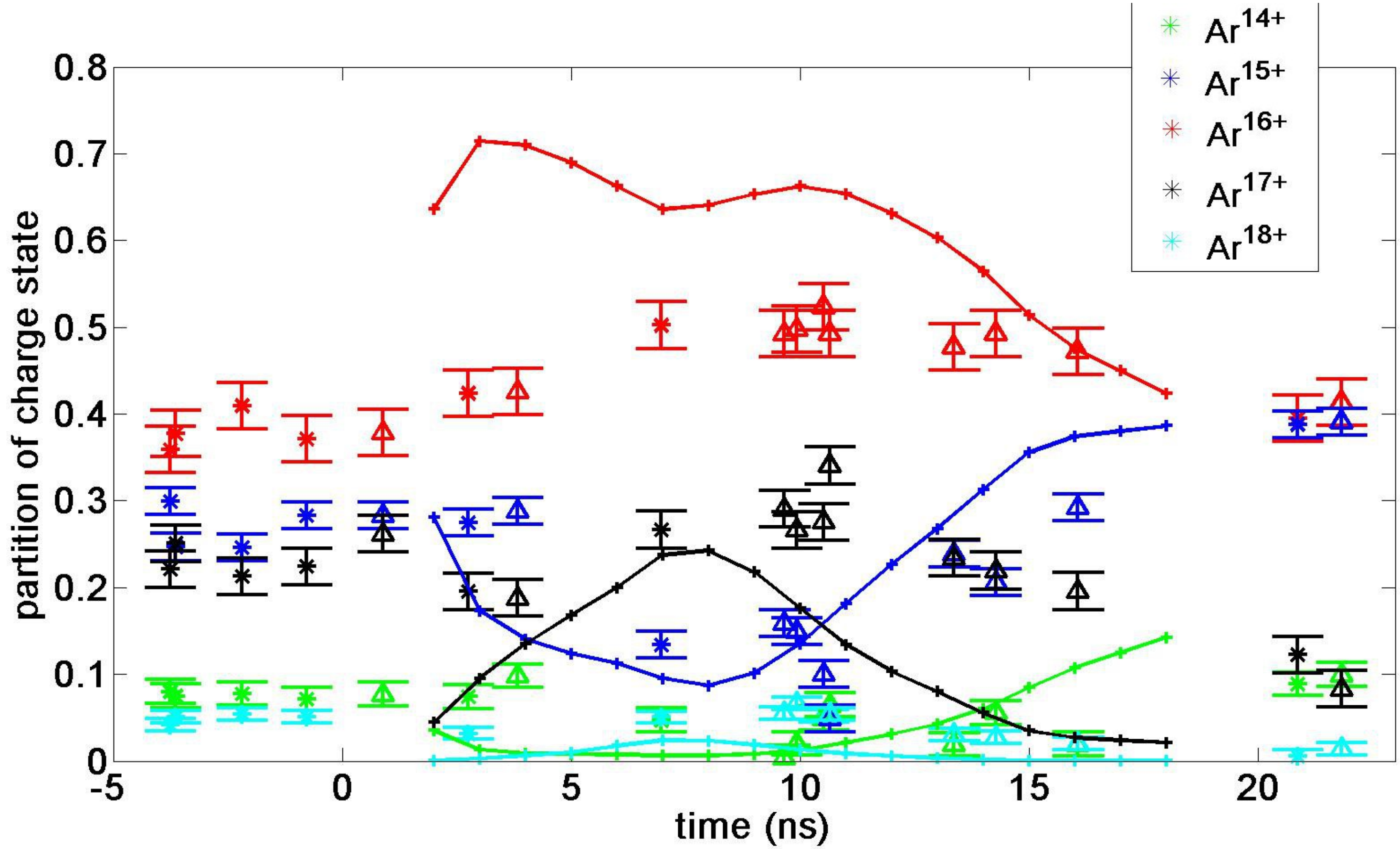
Hot and dense fully ionized carbon plasma, Te = 200 eV, ne = 10^{21} cm^{-3}

A.Frank, A.Blazevic et al., Energy loss of argon in a laser-generated carbon plasma, Phys. Rev. E, 81(2):026401, 2010

A.Frank, A.Blazevic et al., *Energy loss and charge transfer of Ar in laser-generated carbon plasma*, Physical Review Letters, in preparation

Experimental results: charge state distribution

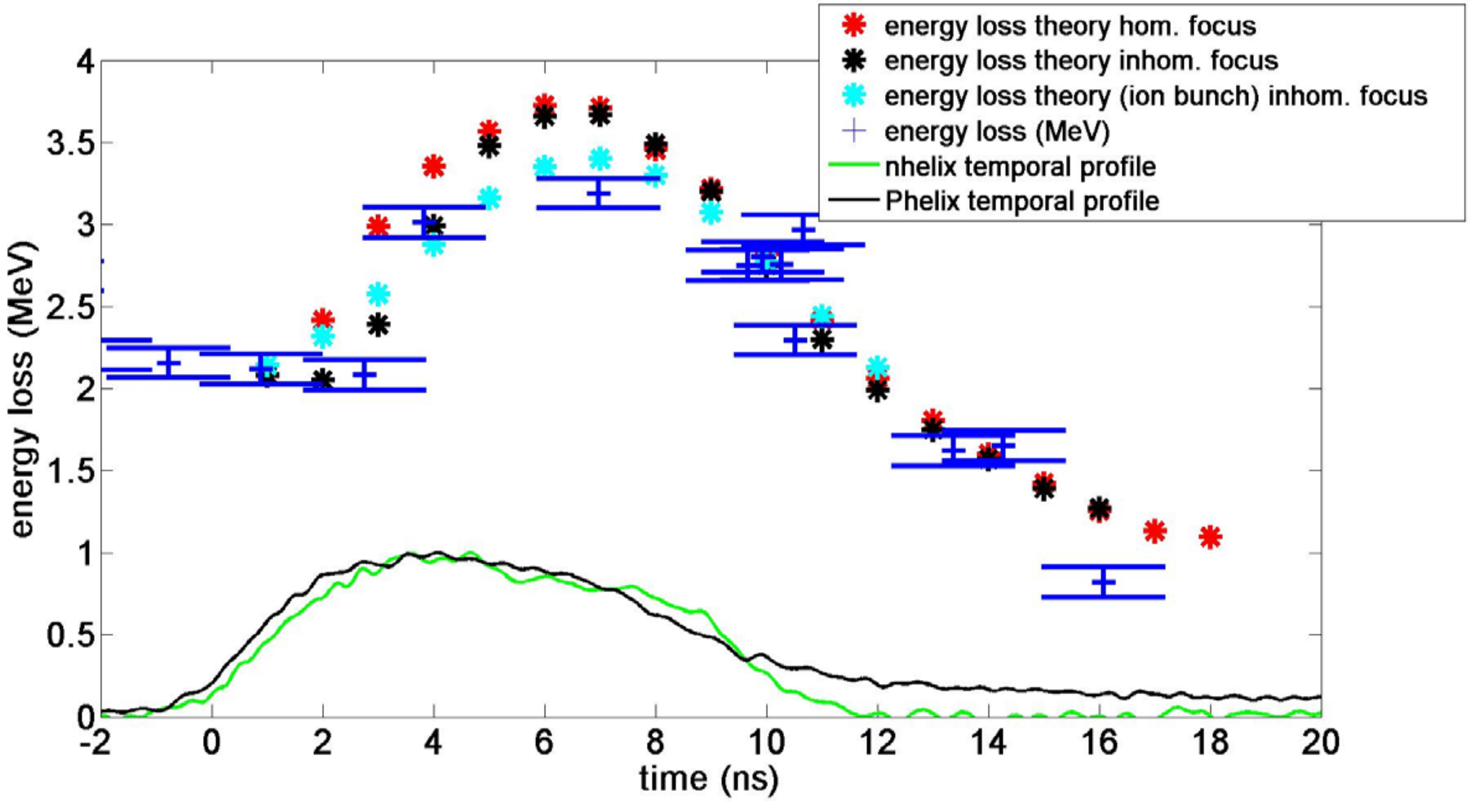
Ar at 4 MeV/u, originally 16+



Theoretical description of charge state distribution with a MC code based on a modified version of the Etacha code + collisions with free electrons

Experimental results: energy loss

Ar at 4 MeV/u



- Increase in energy loss of 60% compared to solid carbon
- Experimental results are in very good agreement with theoretical calculations (modified version of the CaSP code)

Experiments with swift ions penetrating an indirectly heated plasma (D.Schumacher, PhD thesis)

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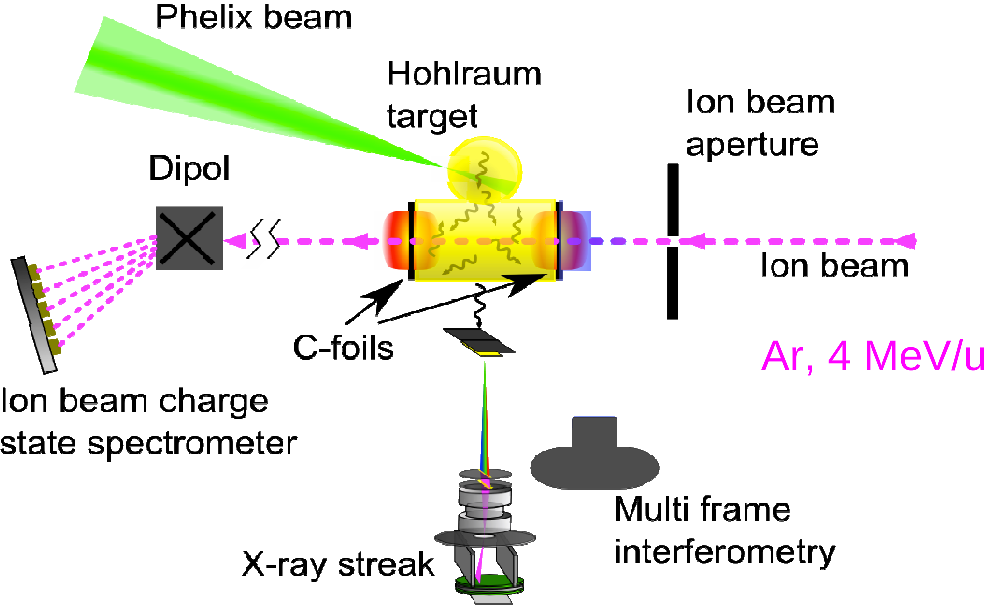
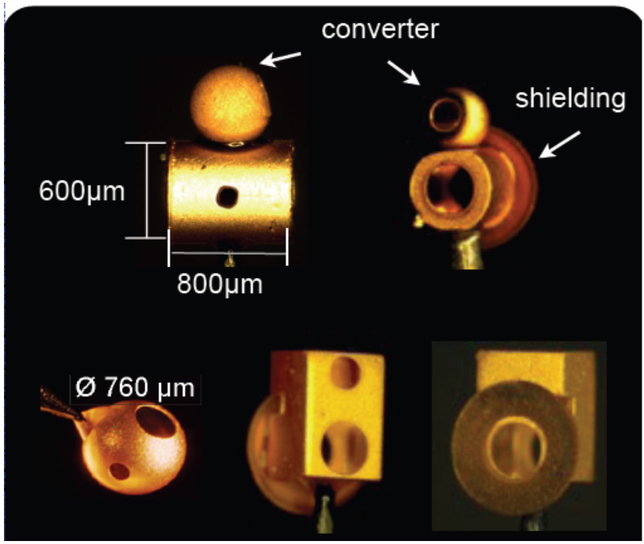


High shielding hohlraums



High conversion hohlraums

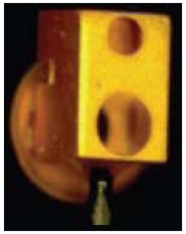
- Gold hohlraum cavities produced at TU Darmstadt
- Indirect plasma generation out of 500 nm C-foils with the Phelix laser via a converter
- **Laser parameters:** PHELIX: 150 J, 1.5 ns, 527 nm
- Very dense and homogeneous, partially ionized plasma (~ 10^{22} cm^{-3}, 30 eV)

D.Schumacher et al., in preparation

Indirect scheme – experimental results

Energy loss (Ar 4 MeV/u)

high conversion hohlraums (Trad = 43 eV)



high shielding hohlraums (Trad = 33 eV)

- Energy loss till 128-119% (direct heating: 160%): reduced energy loss
- Partially ionized, nonideal plasma
- After ~ 7 ns, expanding gold plasma mixes with the carbon plasma

- Proof-of-principle experiment, to be optimized (shielding, simulations...)
- Charge state distribution to be analyzed...

Summary

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- CVD diamond stop-detector and charge state spectrometer developed and used in ion beam-plasma experiments at Z6 area
- The use of CVD diamond
  - enables simultaneous measurements of energy loss and charge state distribution
  - substantially improved the quality and precision of the experimental data
- Single crystal diamond of 1*2 cm² as possible next improvement

- Successful energy loss and charge state distribution measurements in the directly and indirectly heated scheme

- Direct heating: complete understanding of the plasma and beam-plasma interaction, development of a theoretical model confirmed by the experimental results
- Indirect heating: more challenging, proof-of-principle experiments, to be continued with improved hohlraum design and diagnostics

- Extension to slow ions, deuterium plasma, new regimes of ion stopping in plasma

Thank you for your attention