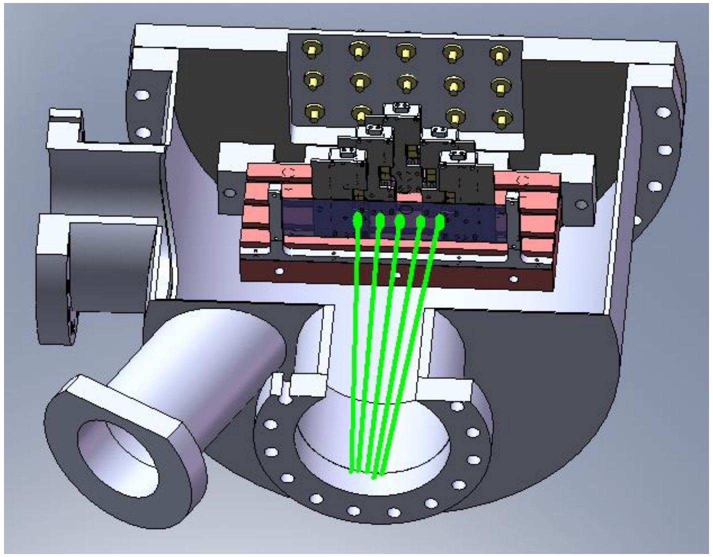
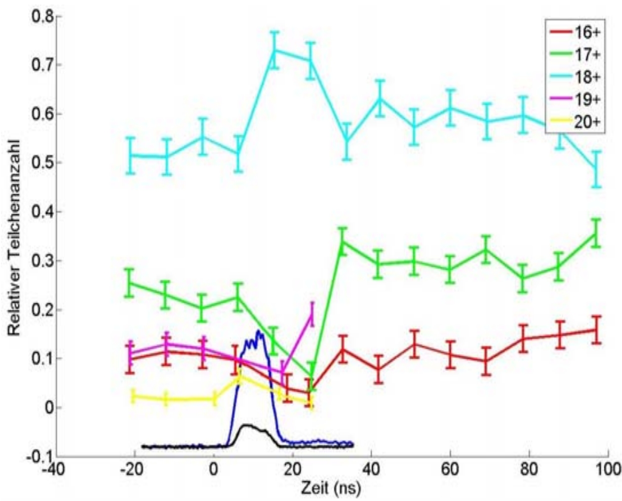
CARAT Workshop

December 15th, 2009

Witold Cayzac

Development of a spectrometer on CVD diamond basis for heavy ion charge state measurements





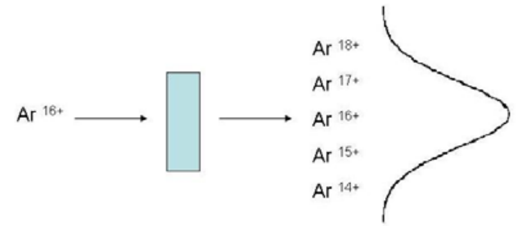
Plan

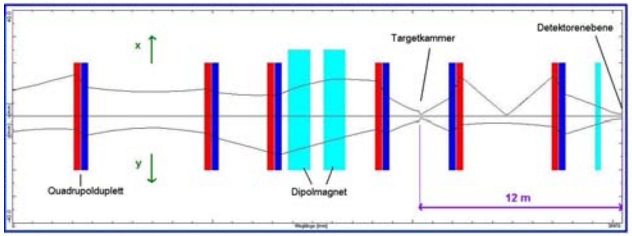
I. <u>Goals of the study</u>
   1. *Charge state distribution*
   2. *Principle of the experiments*

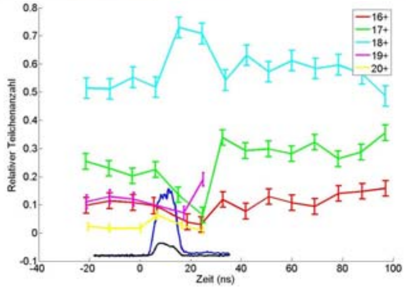
II. Spectrometer requirements
   1. *Detectors on CVD diamond basis*
   2. *Single crystal or polycrystalline diamond ?*

III. Design of the spectrometer
   1. *Diamond samples*
   2. *Signal transmission*

IV. Implementation in experiments
   1. *Analysis of the experimental data*
   2. *Charge state distribution and energy loss*





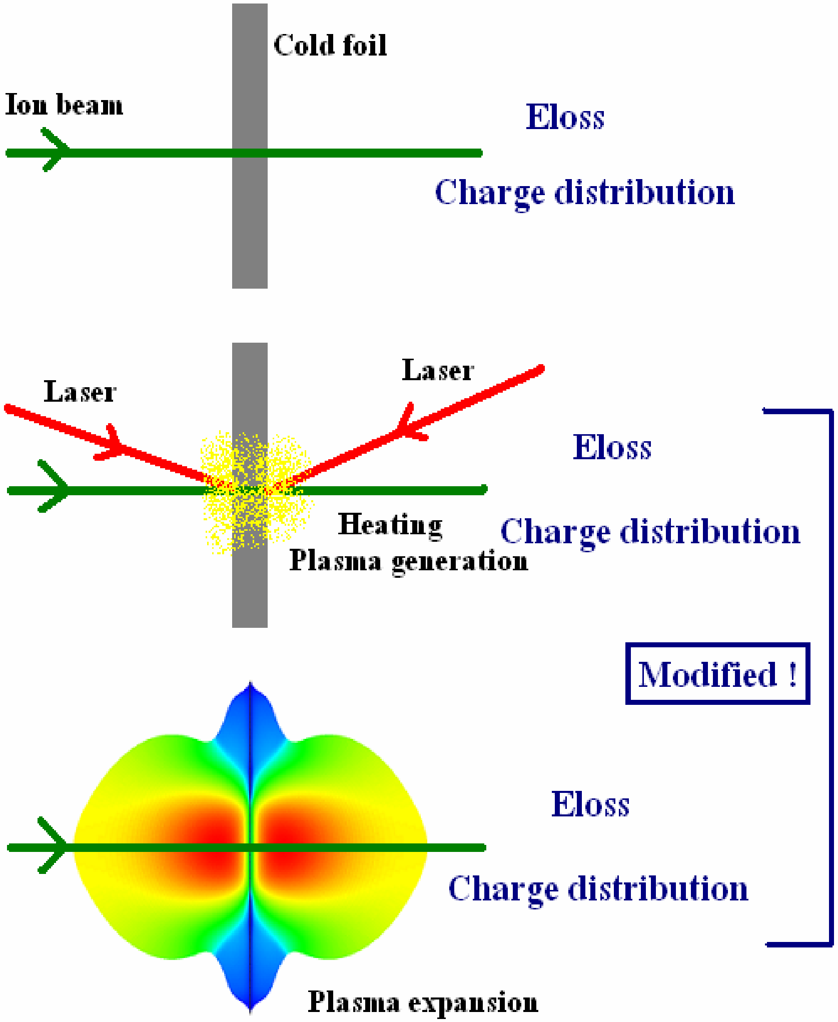


Interaction of ions with matter

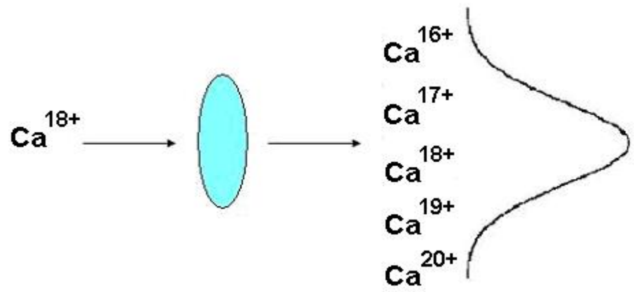
- **Appearance of interaction processes**
  - Energy loss of the projectile
  - Generation of a dynamic charge state distribution in the projectile due to charge transfer processes (competition between ionization and recombination processes)

- **The energy loss depends on two main parameters :**
  - Density of free electrons
  - Charge state of the projectile, charge state distribution

- **These parameters are modified in plasma**



Charge state distribution



- For ions of intermediate mass like calcium at some *MeV/u*, 5 main charge states
  - ➢Heavier than Ca: too complex
  - ➢Lighter than Ca: no significant changes observable

- Equilibrium charge of Ca in a solid is between 17+ and 18+

- <u>Goal of the study:</u> experimental determination of the charge state distribution **in plasma**
  - ➢Accurate, time-resolved measurement
  - ➢Linear and sensitive detector

Principle of the experiments

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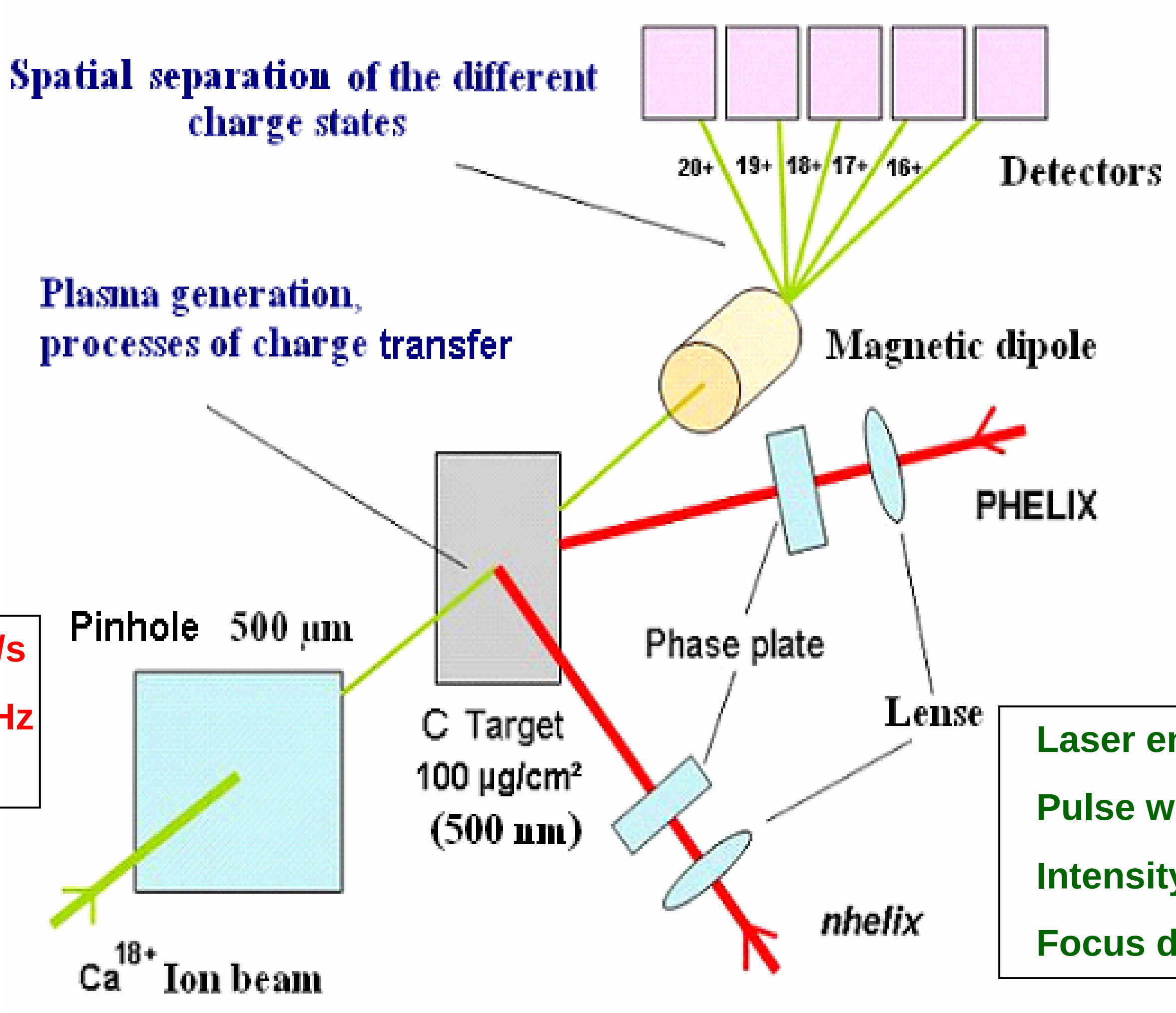
T = 200 eV

n = g/cm³



Particle current 10^{11}-10^{12}/s

Micro bunch freq. 108 MHz

Energy 4,854 MeV/u

Laser energy 30-40J

Pulse width 8 ns

Intensity 4×10^{11} W/cm²

Focus diameter 1 mm

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Choice of detectors on CVD diamond basis

- **We detect particle bunches, no single particles**
  - **At least several hundred particles each 9,2 ns**
  - **Each particle has an energy of 240 MeV**

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

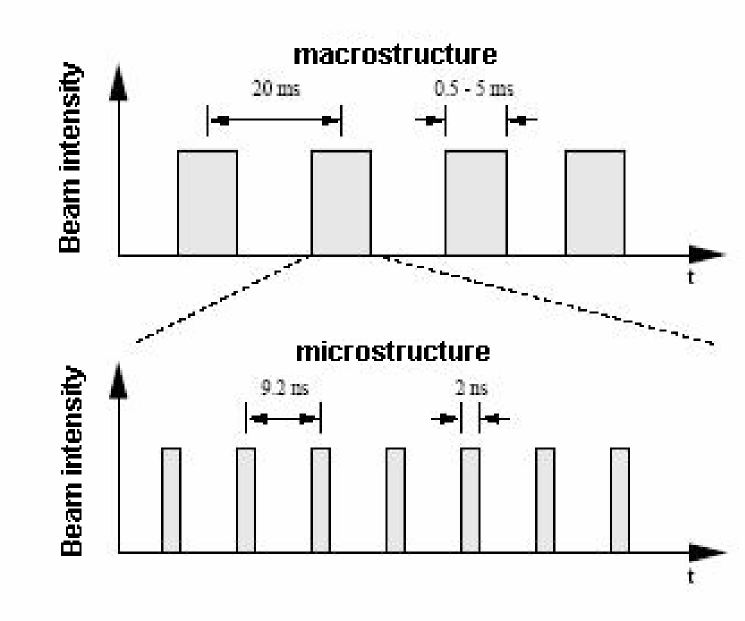
- **High time resolution :**
  - Micro bunch duration *2-3 ns*
  - Time resolution has to be significantly below *1 ns*

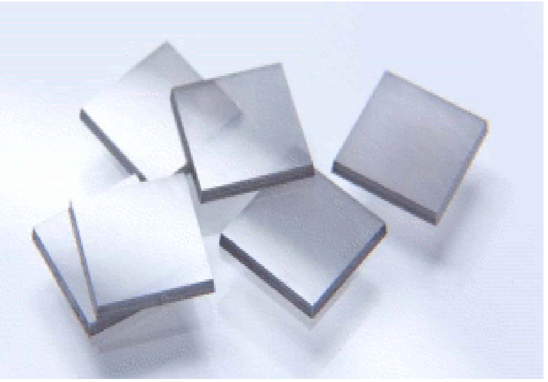
- **Fast detector :**
  - Micro bunch frequency *9,2 ns*
  - Very high repetition rate, time constant of few ns

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

+ Possible use at room temperature (low noise)

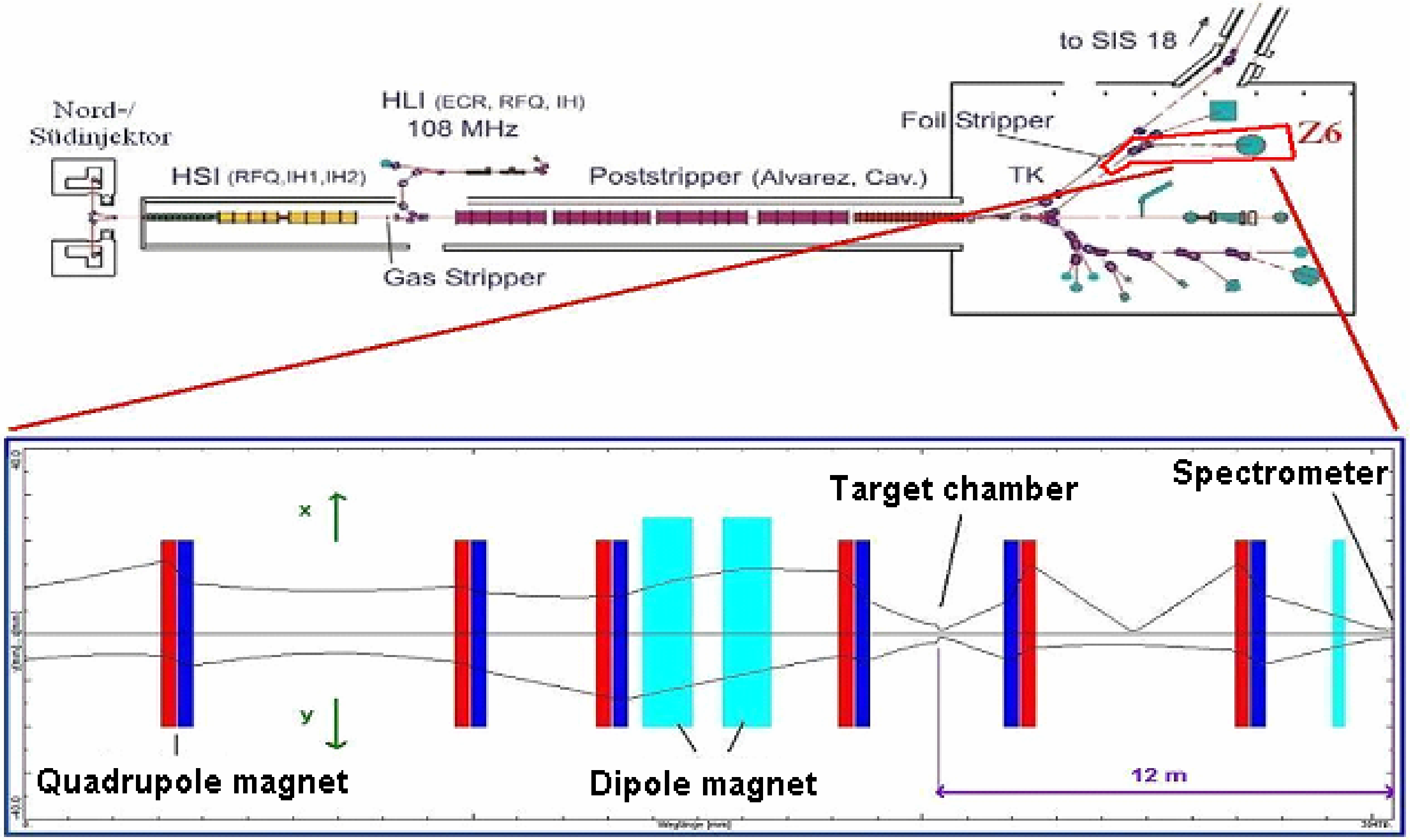
⇒ Use of CVD diamond detectors

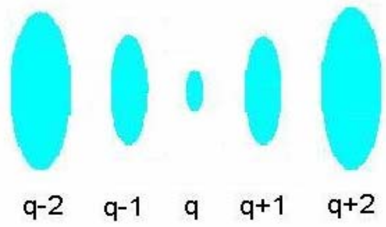




Simulation of ion beams in the Z6 beamline

- Ion optical simulation of the Z6 beamline with MIRKO
- Quantitative investigation of the beam dimensions and properties

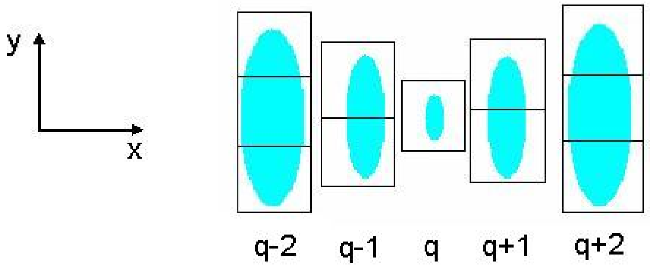




Polycrystalline or single crystal diamond ?

- Requirements on diamond dimensions
  - ➢MIRKO : maximal size of the beams : *5 ⨉ 15 mm²* (in ideal case)
  - ➢Ion range <= 20 µm (below the Bragg-Peak of calcium)

- Single crystal diamond
  - ➢Possibility to place several diamonds of *5 ⨉ 5 mm²* on top of each other
  - ➢Too small, too expensive
  - ➢Too thick



- Polycrystalline diamond
  - ➢Larger surfaces and thicknesses of 20 µm feasible
  - ➢Polarization effects are reduced through the choice of a thin diamond layer
  - ➢Signals are high enough due to the high particle number
  - ➢Signal fluctuations have to stay small…

Simulation of a polycrystalline diamond detector

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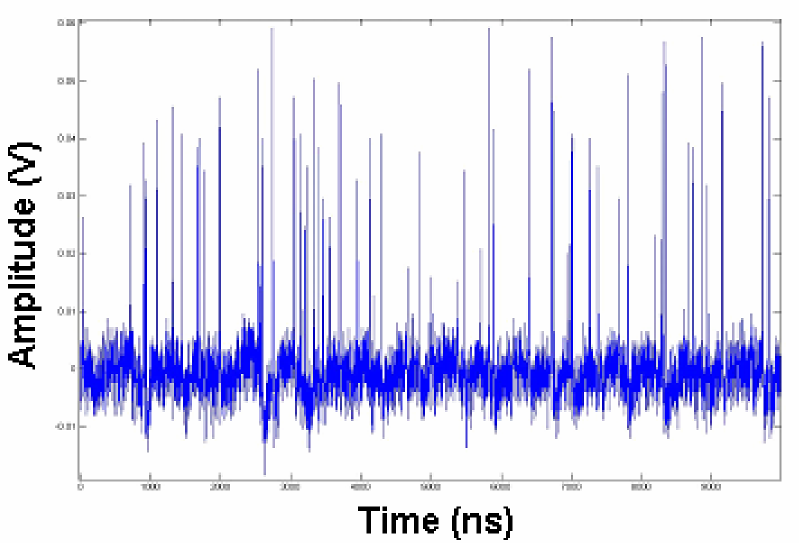
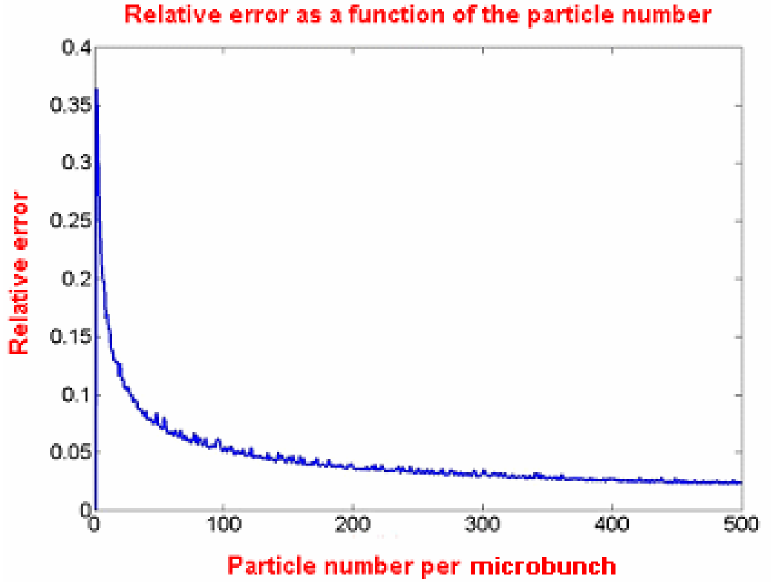
- Goal : estimation of the fluctuations in the surface of signals
- Statistical analysis of experimental data (Ar with 4 MeV/u, *20,5 µm*-thick polycrystalline diamond, single particle signals)
- Monte-Carlo simulation of surfaces of signals in MATLAB
- From 100 particles per detector, small fluctuations





⇨ Choice of polycrystalline diamond

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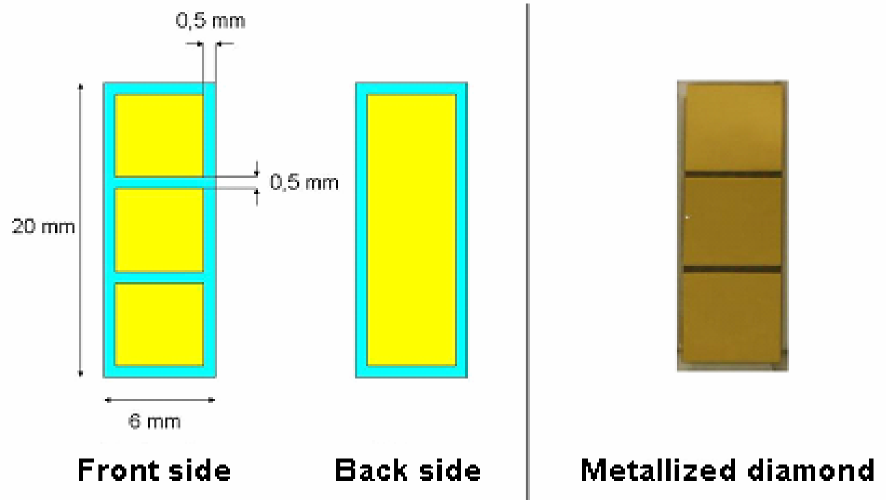
Diamond samples and metallization

- 5 identical polycrystalline highly pure CVD diamond samples from FIAF (***F**raunhofer **I**nstitut für **A**ngewandte **F**estkörperphysik in 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

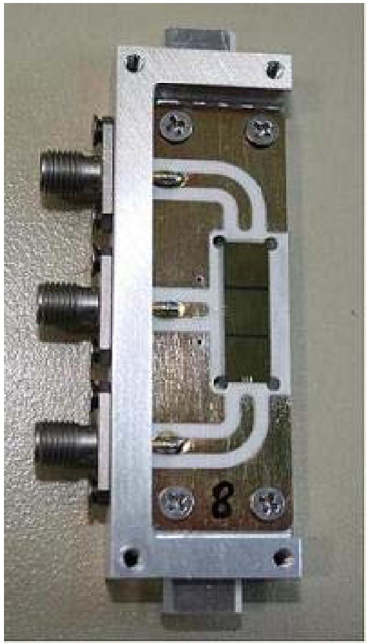
- Electrodes:
  - Front side 3 times *6 × 6 mm²*
  - Back side *6 × 19 mm²*
  - Metallization Ti-Pt-Au



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

Contacting and positioning of the detectors

- 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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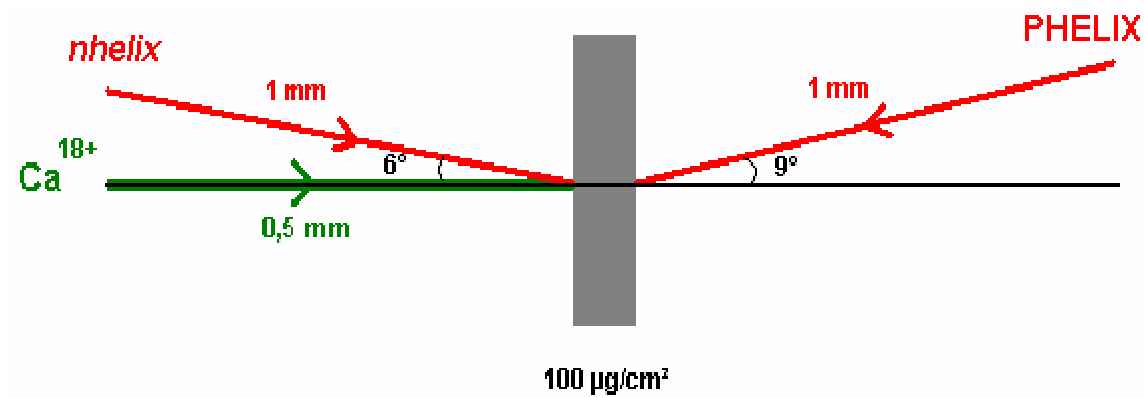
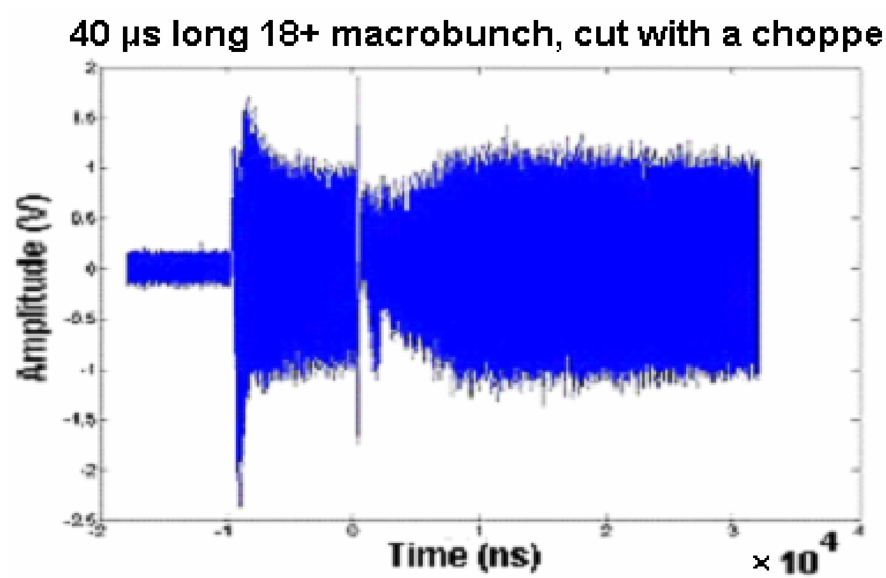
Experiments



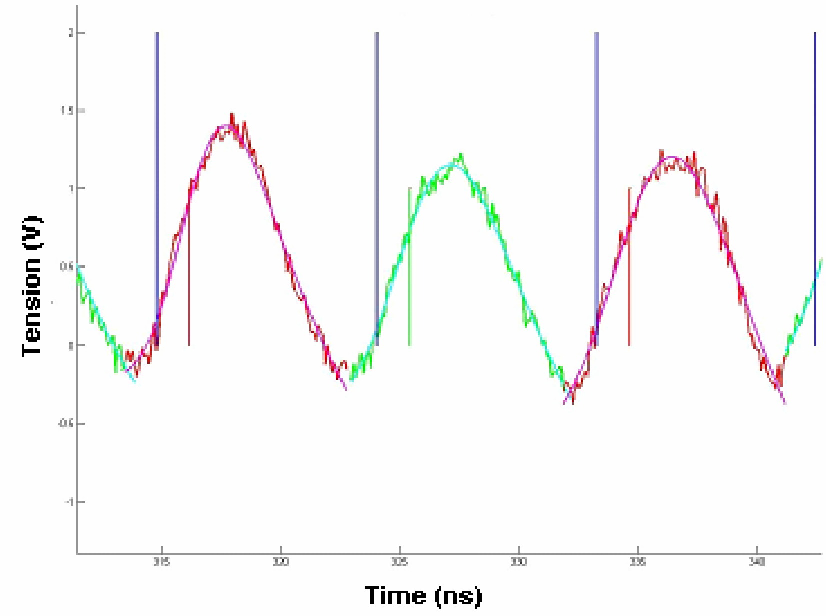
- Two-sided simultaneous irradiation with the lasers *nhelix* and PHELIX
- Ion energy *4,854 MeV/u*
- Micro bunch frequency *108 MHz*
- Ion current *1-2 µA, 10^{11} - 10^{12} particles/s*
- One macro bunch per charge state
- Time range from *0* to *40 ns* important



Analysis of the experimental results

- Finding and fitting of signals in each macro pulse with the function :

$$Signal(t) = a_0 + a_1 \cdot t + a_2 \cdot \left(\exp\frac{-(t-\mu)^2}{\sigma^2} * \exp\left(\frac{-t}{\tau}\right) \right)$$



- Charge state distribution : determination of the surfaces of signals of each charge state related to the whole surface of the signals

- Energy loss : TOF method, determination of the centers of gravity ***μ*** of the signals and comparison with the vacuum raster

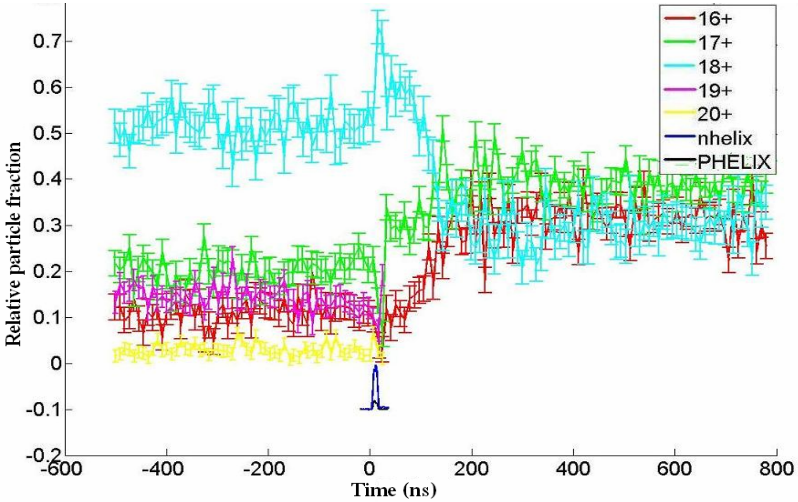
Measurement of the charge state distribution in plasma

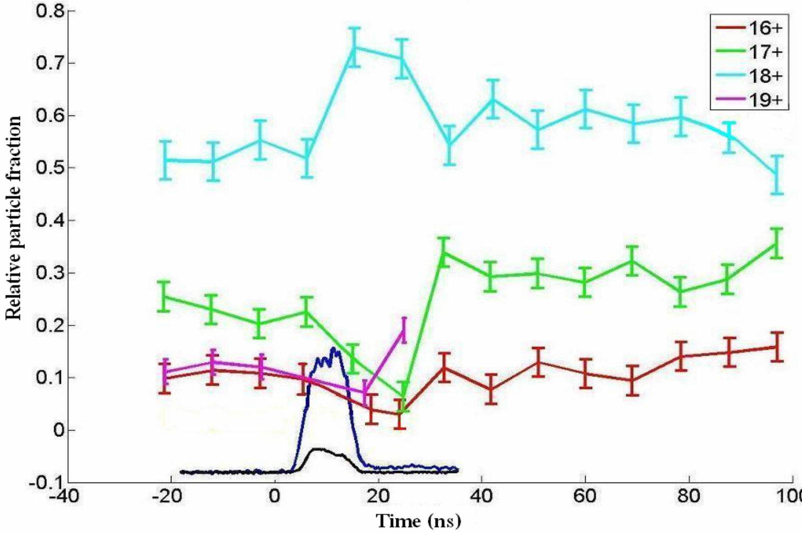
- Plotting of the time variation of the partition of each charge state as well as of the laser pulse
- Error bars *5-8%*
- 20+ statistically too small

- ***Till 0 ns***, charge state distribution in cold foil

- ***0-20 ns:***
  - ➢ 18+ and 19+ increase
  - ➢ 16+ and 17+ decrease
- Plasma generation
- Ionization dominant, recombination weaker

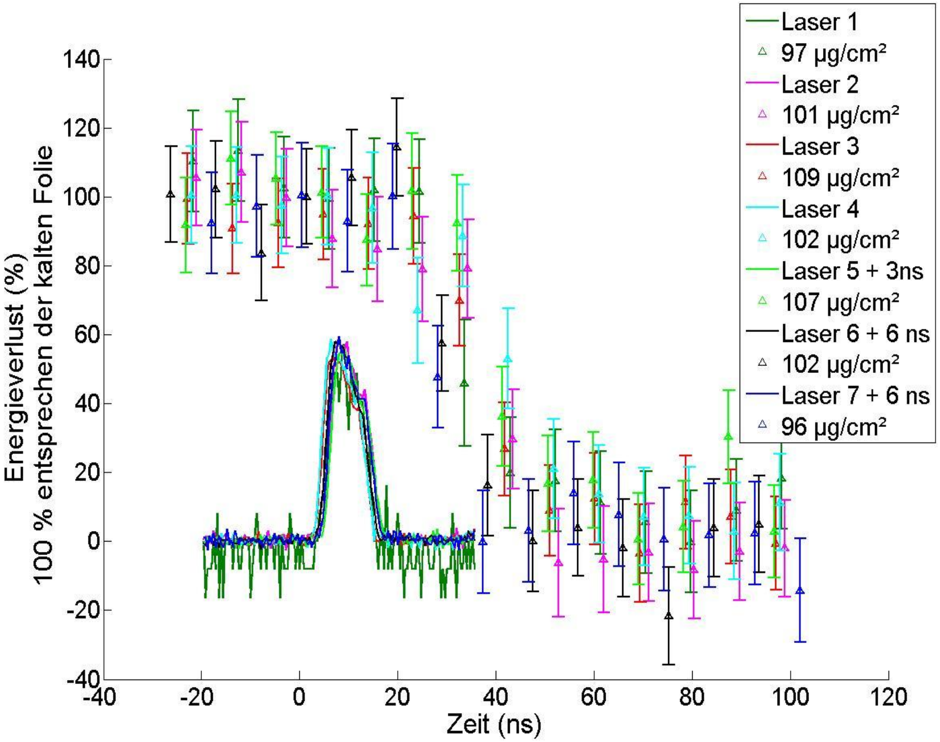
- ***20-40 ns:***
  - ➢ 18+ and 19+ decrease
  - ➢ 16+ and 17+ increase
- Expansion of the plasma and decrease in mass density
- Ionization weaker, recombination dominant





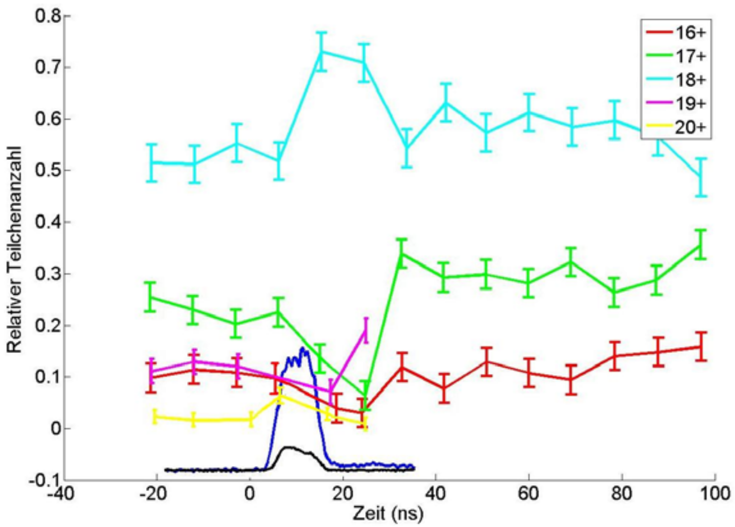
Measurement of the energy loss in plasma

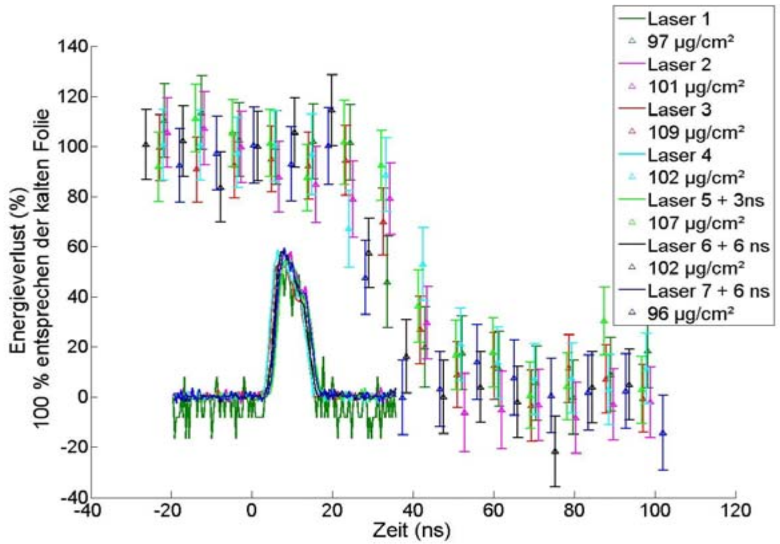
- Combination of 7 measurements for 18+
- ***Till 0 ns:*** energy loss in cold matter
- ***0-20 ns:*** energy loss constant
  - ➢decrease of the mass density
  - ➢increase of the stopping power
- ***20-40 ns:*** energy loss decreases because of decrease of the mass density
- ***After 40 ns:*** nearly 0 in vacuum or rare cold gas
- Error bars till *20%* (small Δt)



Summary

- Spectrometer planned, built and successfully tested
- Precise time-resolved measurement of a charge state distribution of ions interacting with laser-generated plasma with particle currents of 10^{11}-10^{12} *ions/s*
- Linear and radiation hard spectrometer
- The measured data is in qualitative agreement with the expectations
- Opens new possibilities in charge detection, prototype





Thank you for your attention

- Acknowledgements to:
  - **Plasma physics and PHELIX department**: Mr Roth, Stölker, Blazevic and colleagues
  - **Detector and diamond laboratory** : Mrs Berdermann, Mr Träger, Voss, Ciobanu and colleagues
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