Diagnostics and Control of Laser accelerated Ion Beams

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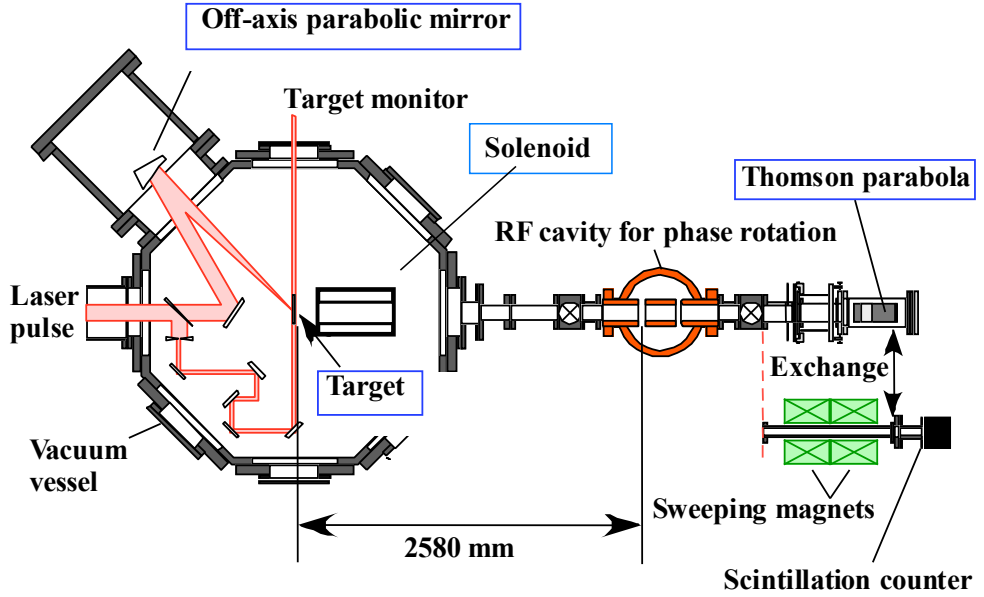
Injector Project



Content

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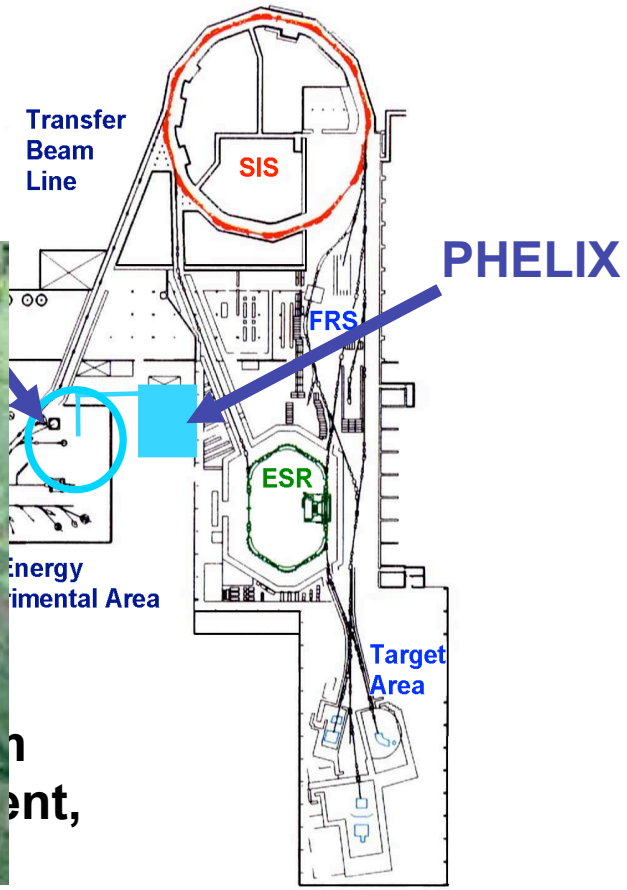
  - ⋆NAIS
  - ⋆Diamond Detectors

LET THERE BE LIGHT

LLP Laser- und Plasmaphysik
Institut für Kernphysik
Technische Universität Darmstadt
Prof. Markus Roth

Motivation

- Leading expertise in both fields (laser acceleration, accelerator technology) available at GSI, surrounding universities, and HIJ
- Optimal use of lase accelerated ions re beam forming, ene selection and debu
- Z6 target area prov and to accelerator diagnostics)



We can provide a versatile testbed to study laser-accelerated particles in conventional accelerator structures

Experimental area Z6

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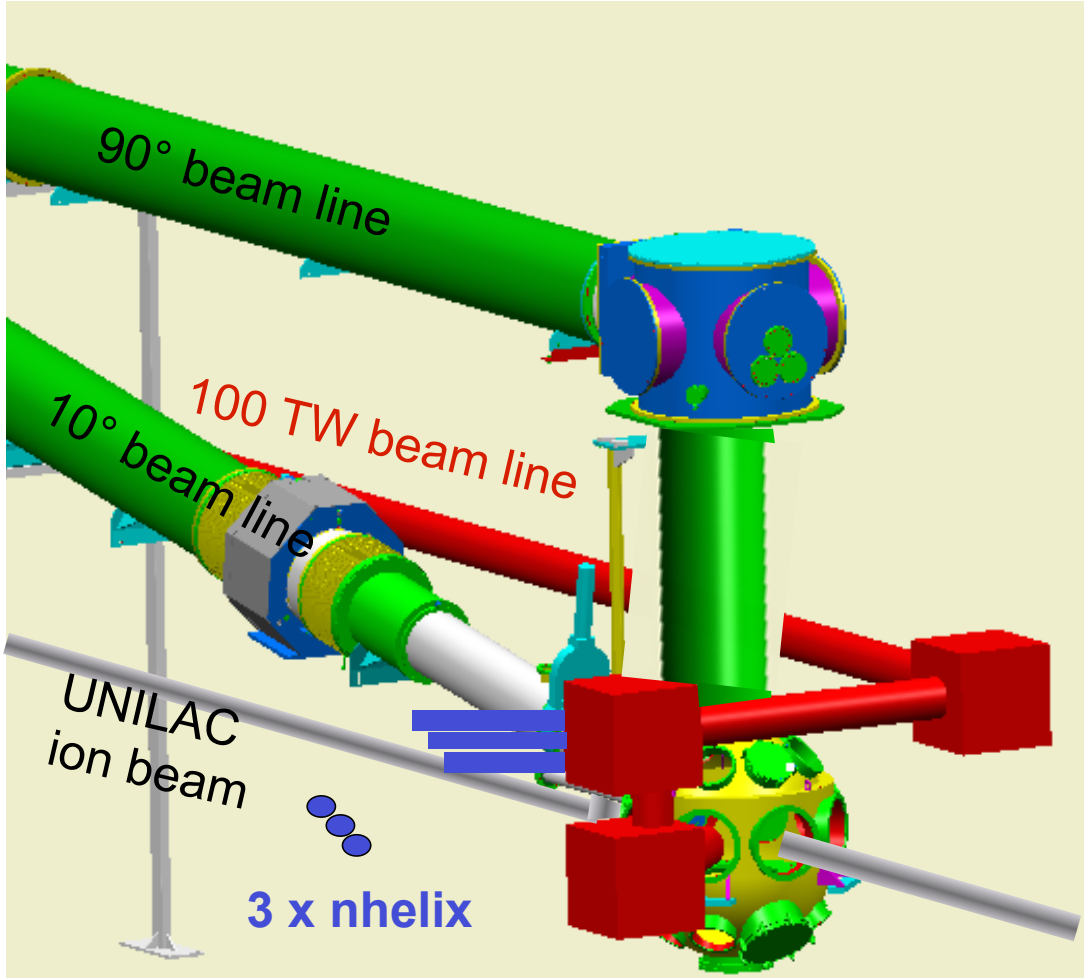


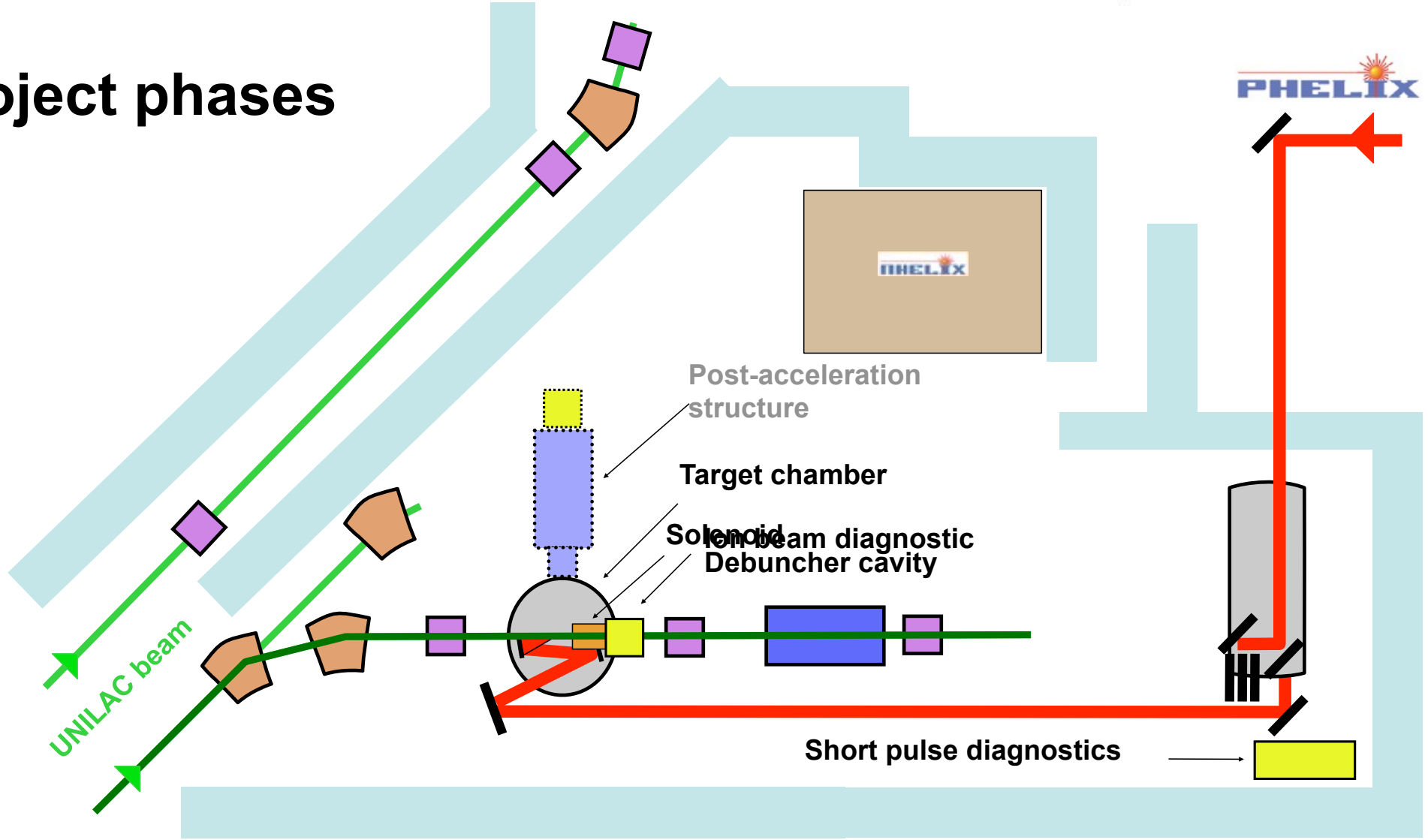
Tools:

- **Unilac ion beam**:
  3<Z<92, E = 3 – 11 MeV/u,
  108/36 MHz, Dt_{ion} = 3 ns
  (FWHM)

- **nhelix laser beam**: diagnostics
  - ✓100 J @ 6–14 ns
  - ✓5 J @ 0.5 ns
    (Thomson scattering)
  - ✓ <1 mJ @ 0.5ns
    (interferometry)

- **Phelix laser beam**: heating
  - ✓1 kJ @ 1–15 ns
  - ✓50 J @ 0.5–2 ps =>100 TW
    (compressed 12 cm beam)
  - ✓150 J @ 700 ps
    (chirped short pulse)

Project phases



Timeline

2010

- Compressor setup
- Beamlines
- 100 TW pulses in target chamber
- First acceleration experiments

2011

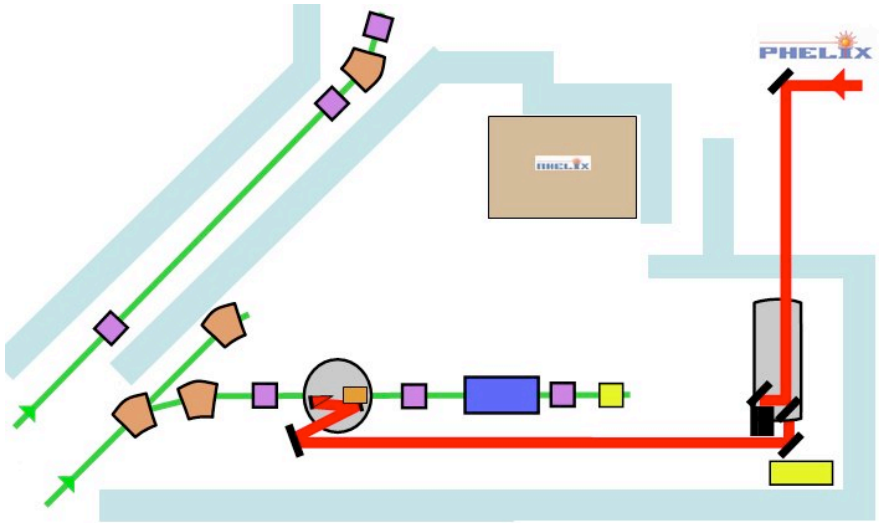
- Collimation and ion beam shaping
- Proton pulse diagnostics
- Test of rebuncher structure with UNILAC proton beam

2012

- Injection into rebuncher structure
- *Injection into post-acceleration structure*

beyond

- Laser acceleration experiments with higher repetition rate at JETI, POLARIS, DRACO and PHELIX
- Possibility to inject into SIS 18
- Higher repetition rate at Z6



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Upcoming project report

Draft of the Project Report

"Laser Ion Acceleration Test Stand at GSI"

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Collaboration partners

Technische Universität Darmstadt [1]
GSI Helmholtzzentrum für Schwerionenforschung Darmstadt [2]
Institut für Angewandte Physik der Universität Frankfurt [3]
Helmholtz-Institut Jena [4]
Forschungszentrum Dresden-Rossendorf [5]

Contributors

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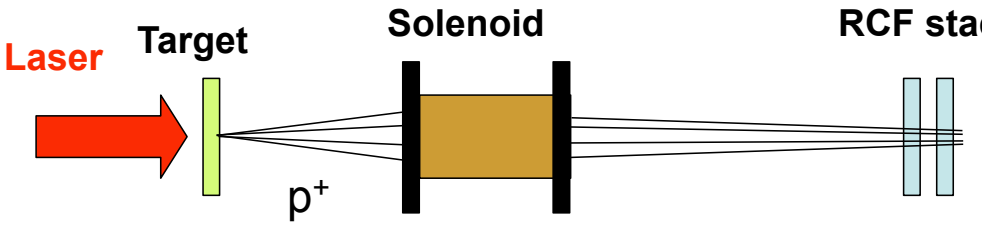
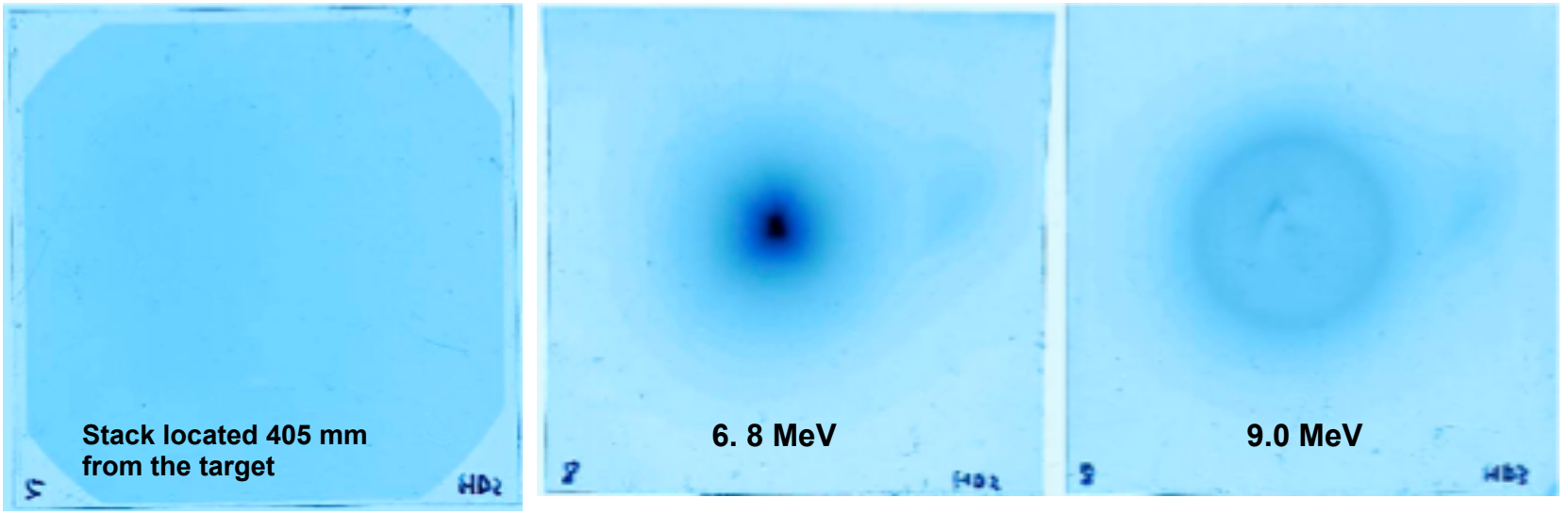
Recent results from preparation experiment

PHELIX beamtime January 2010 (Courtesy of K. Harres, TUD)

- Up to 14 MeV protons were collimated using a coil developed at FZD



reference | (re-)focused | underfocused



Capture of laser-accelerated proton beams with a solenoidal magnetic field

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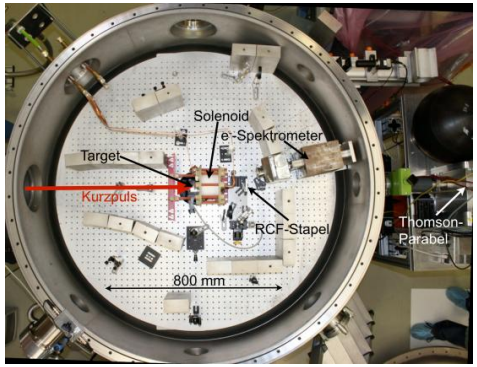
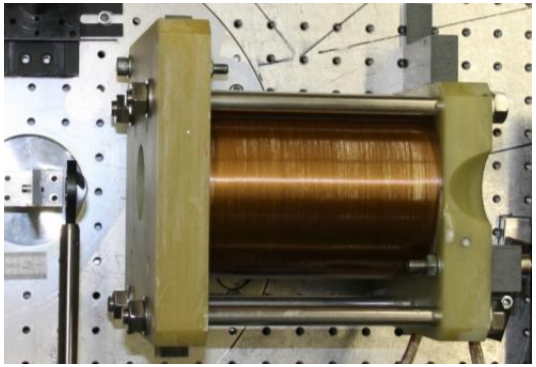
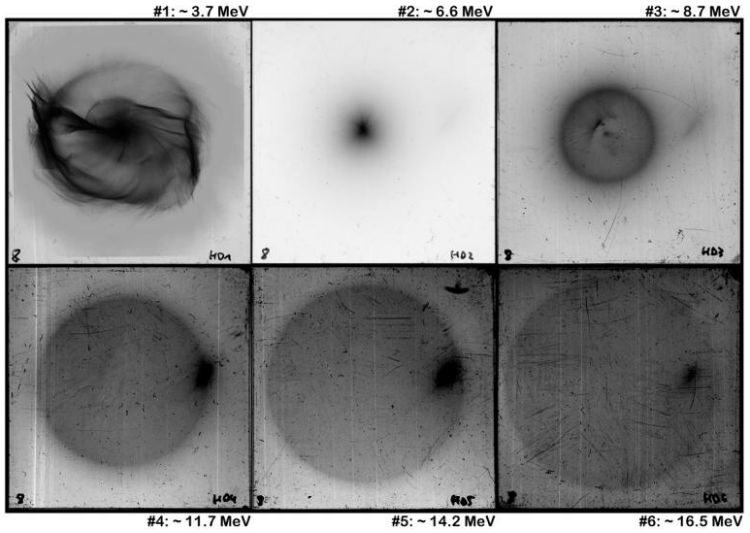
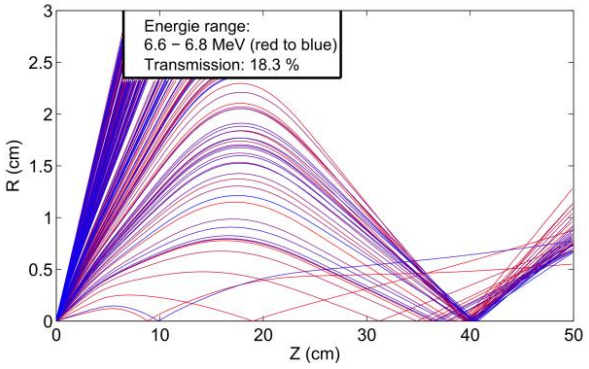


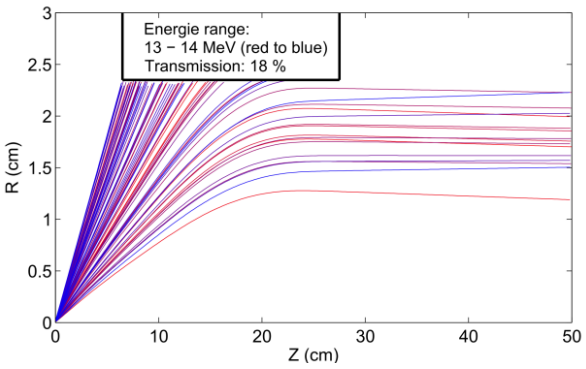


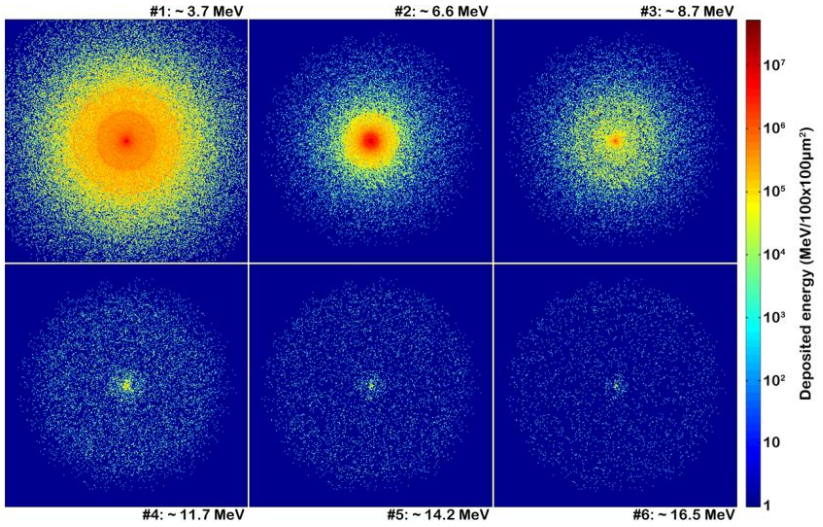


Experiment at Phelix/GSI (top):
- *(left)* setup target chamber
- *(middle)* solenoid version 2
- *(right)* proton signal in RCF detector stack (contrast optimized for the last 3 layers)

Warp PIC simulations (bottom):
- *(right)* simulated proton signal in virtual RCF detector stack,
- *(middle)* proton trajectories for collimation
- *(left)* proton trajectories for focussing







Heavy ion acceleration using non-thermal laser ablation

(Callisto (LLNL) 05/2010)

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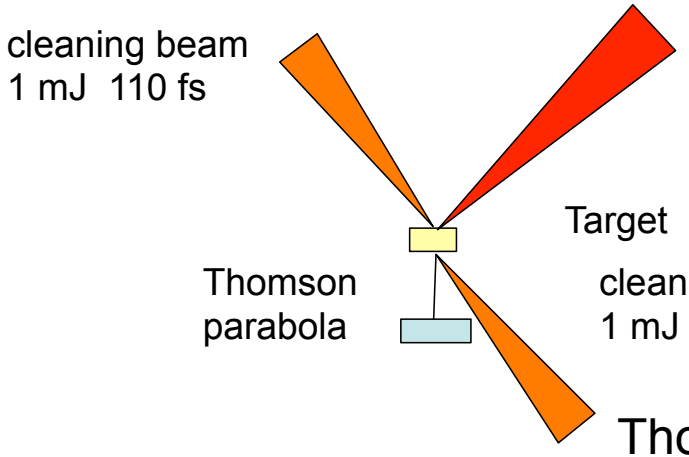
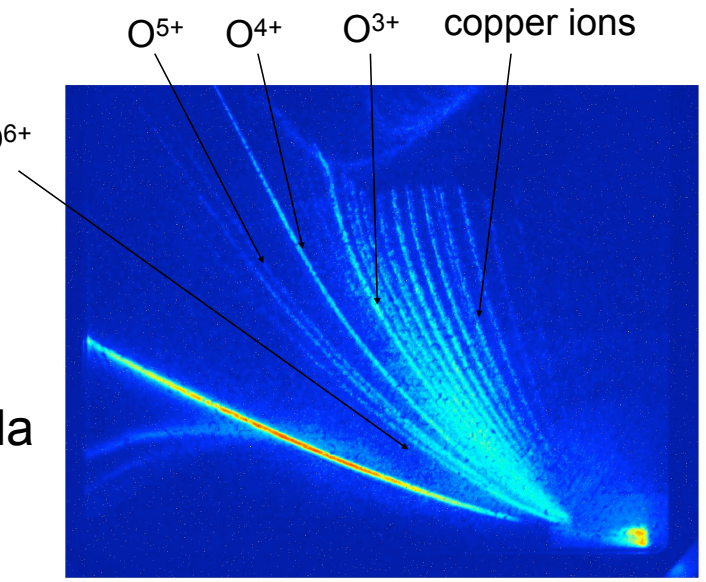
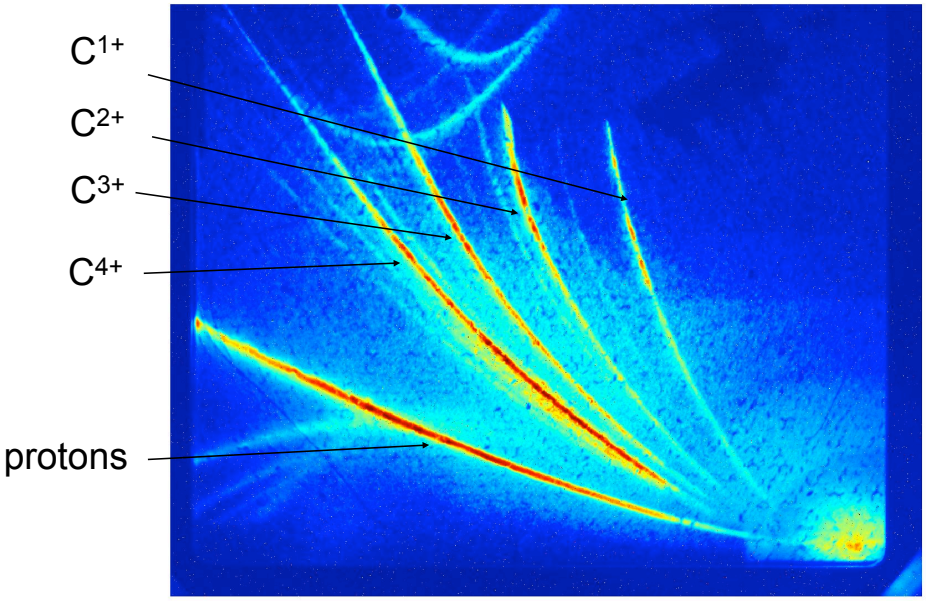
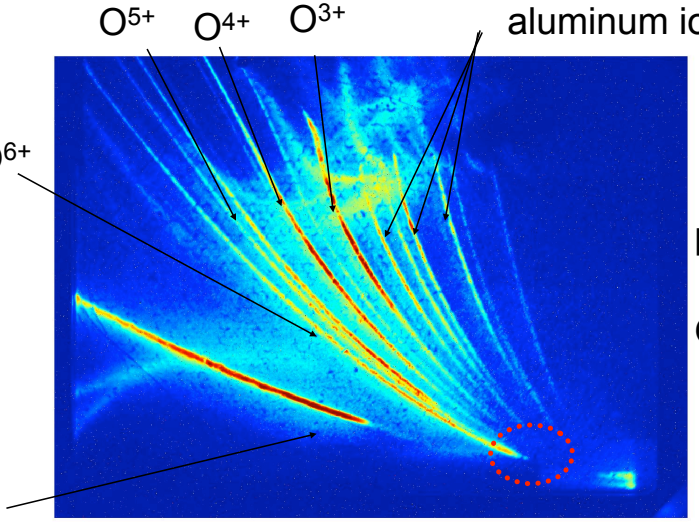


Thomson parabola





Protons: E_{max} ~ 13 MeV C^{4+} - ions: E_{max} ~ 6.5 MeV



p: E_{max} ~ 1.7 MeV

O^{6+} : E_{max} ~ 20 MeV

Proton acceleration experiments with Z-Petawatt

M. Schollmeier, M. Geissel, A.B. Sefkow, M.W. Kimmel, P. Rambo, J. Schwarz and B.W. Atherton[1]

O. Deppert, G. Schaumann, M. Roth[2]

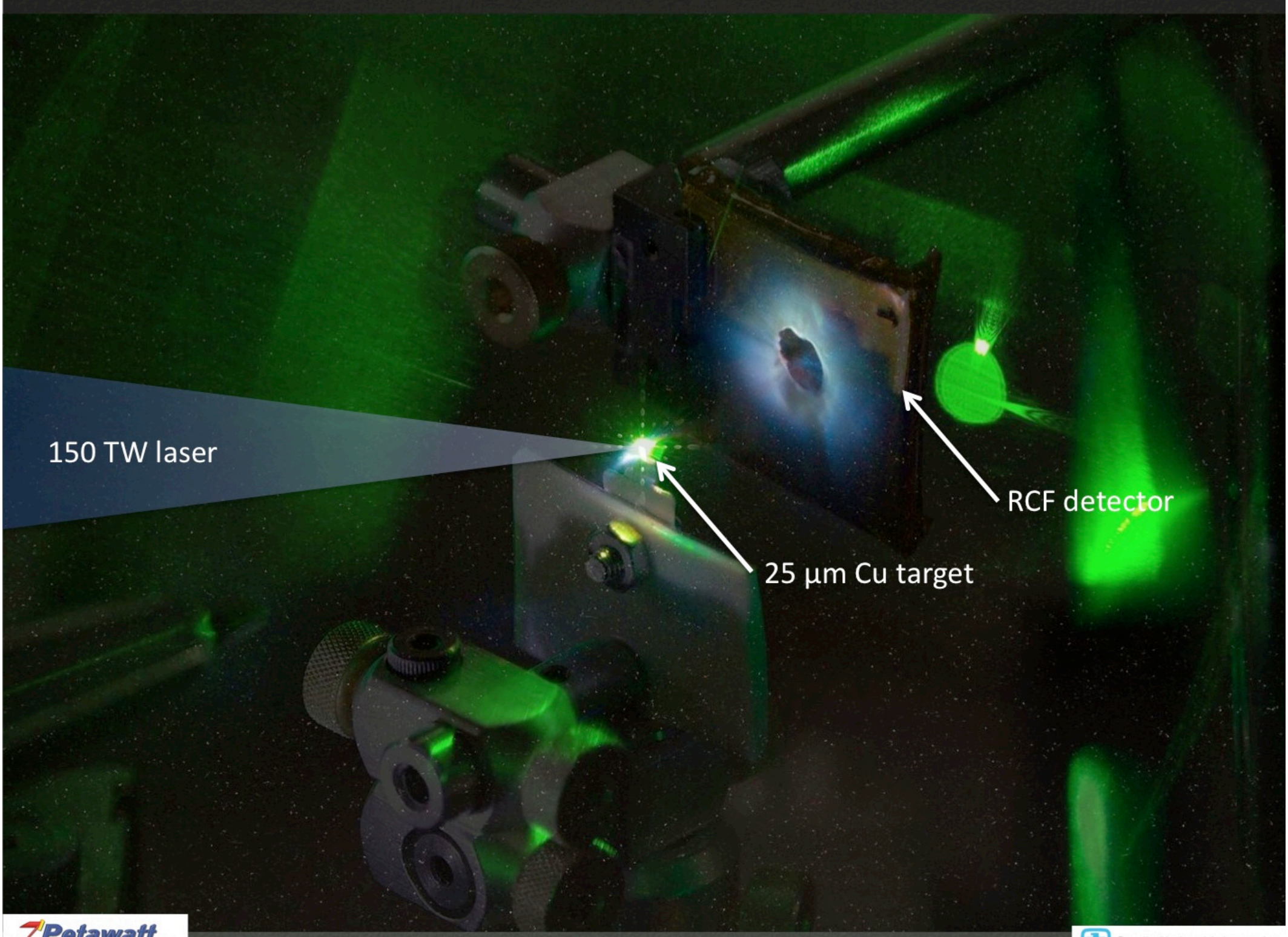
A. Arefiev, B. Breizman[3]

[1]Sandia National Laboratories, Albuquerque, NM

[2]Technische Universität Darmstadt, Germany

[3]University of Texas at Austin

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-4AL85000.


150 TW laser
RCF detector
25 µm Cu target

Concept

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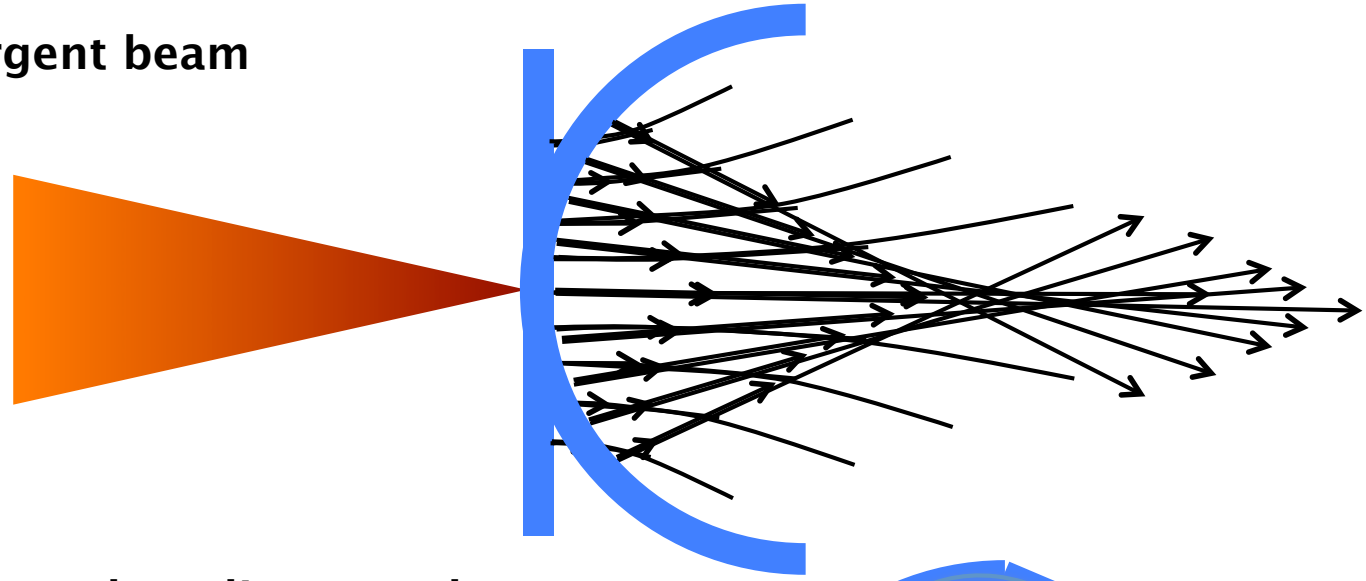
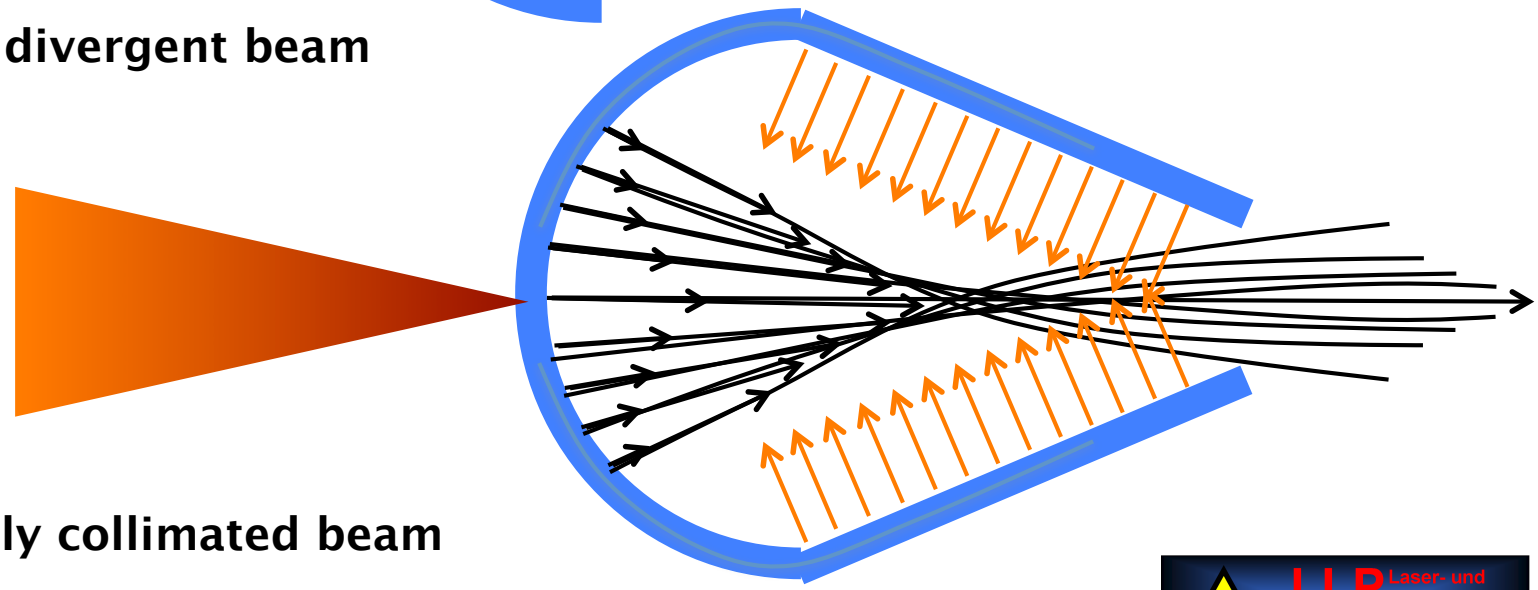
flat foil: divergent beam

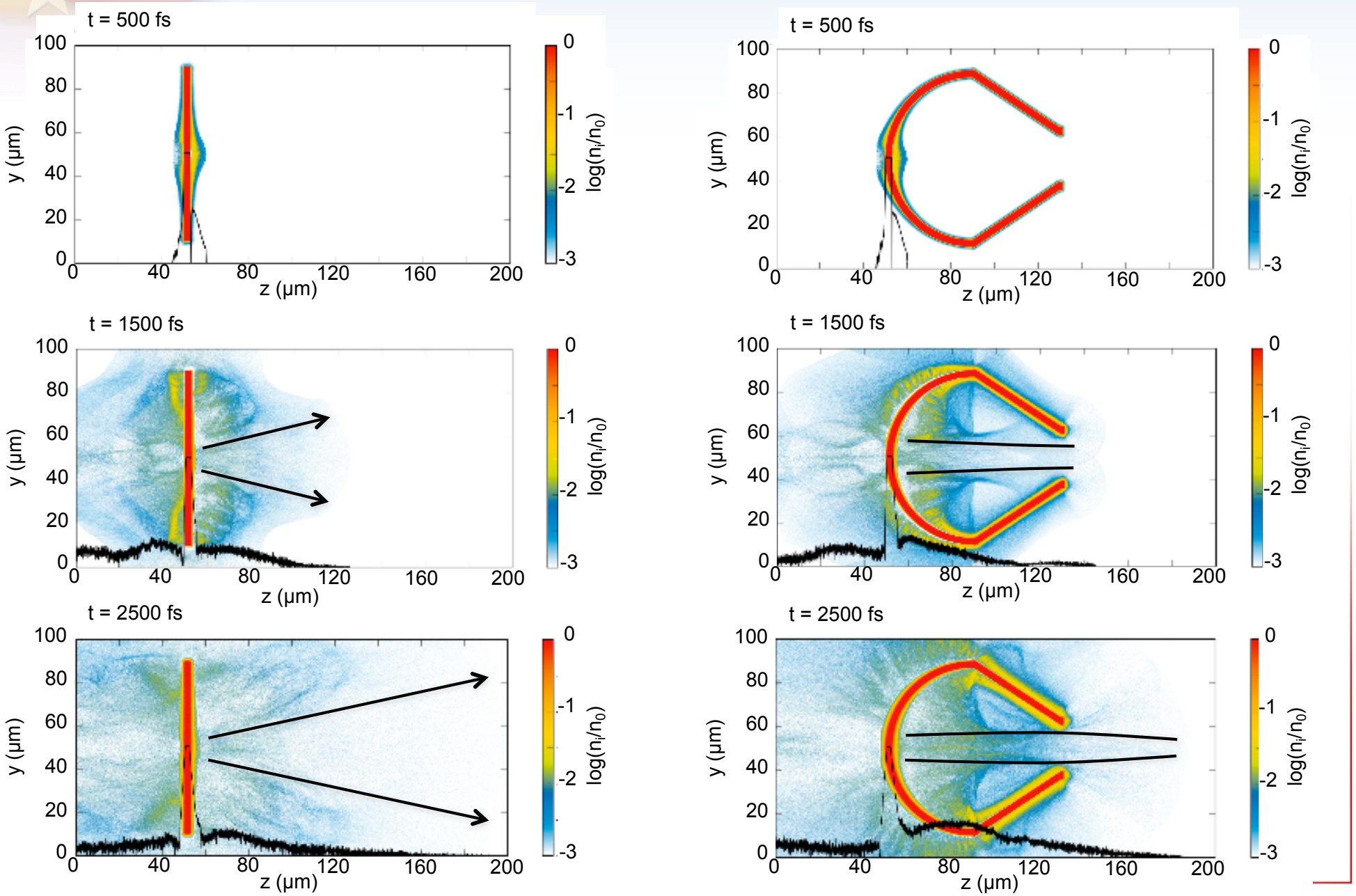


hemi: focusing, then divergent beam



hemi + cone: potentially collimated beam

2D PIC simulations: real space



Petawatt

This work has been performed in collaboration with TU Darmstadt, Germany

Sandia National Laboratories

New target designs can lead to much higher performance and even target compression paving the way to dense matter

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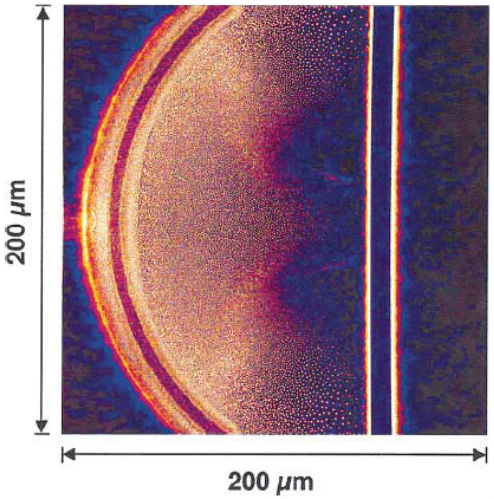

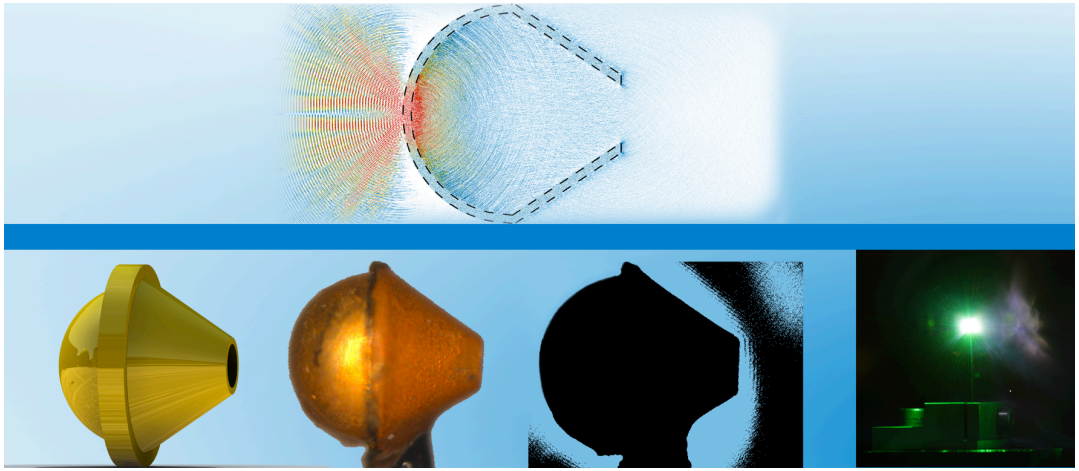

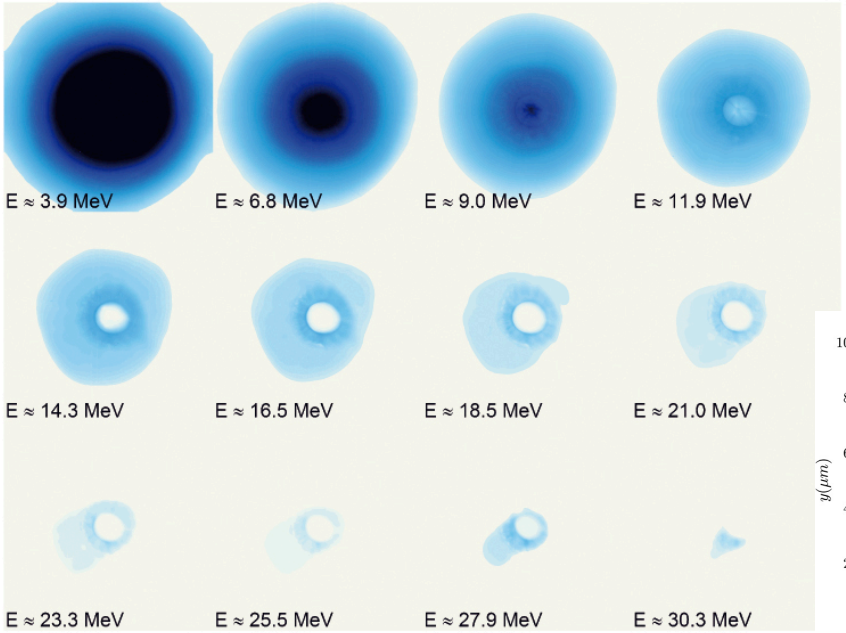

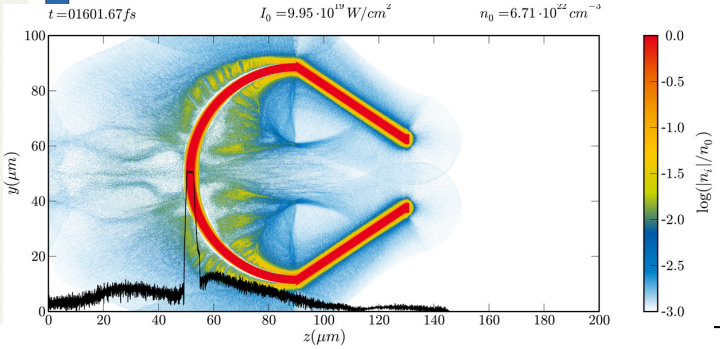

shot#22:

- T03-3 cone: l=316µm, d=163µm
- 115J@750fs@80µm
- Abstand Target-RCF: 51.5mm

Target Production

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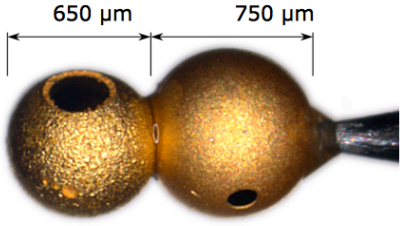

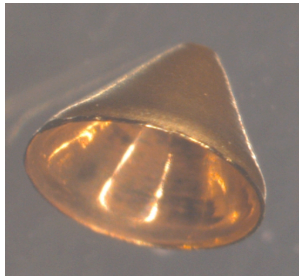

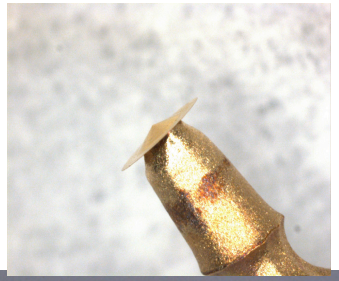

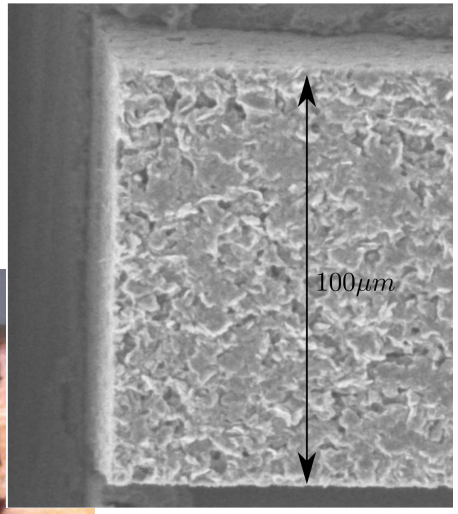

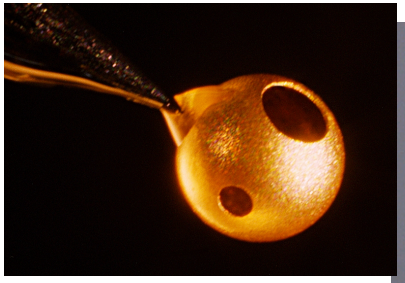

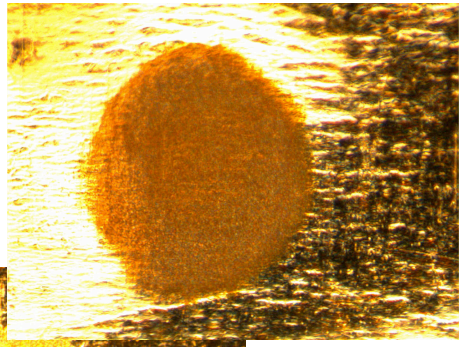

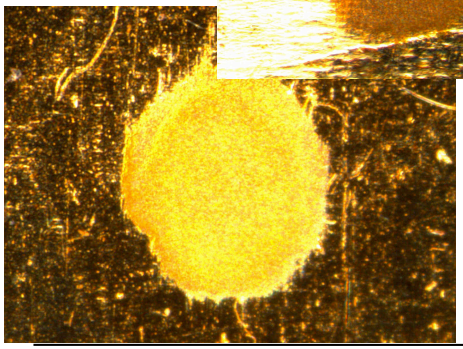

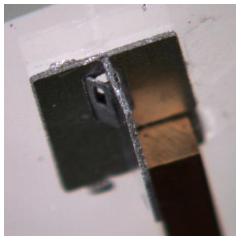

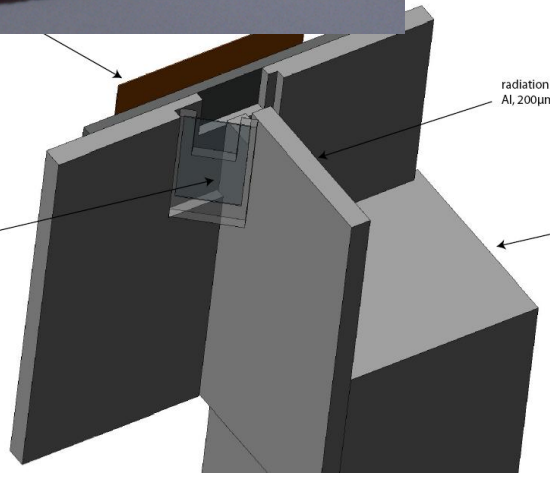

Experiments with cryogenic targets

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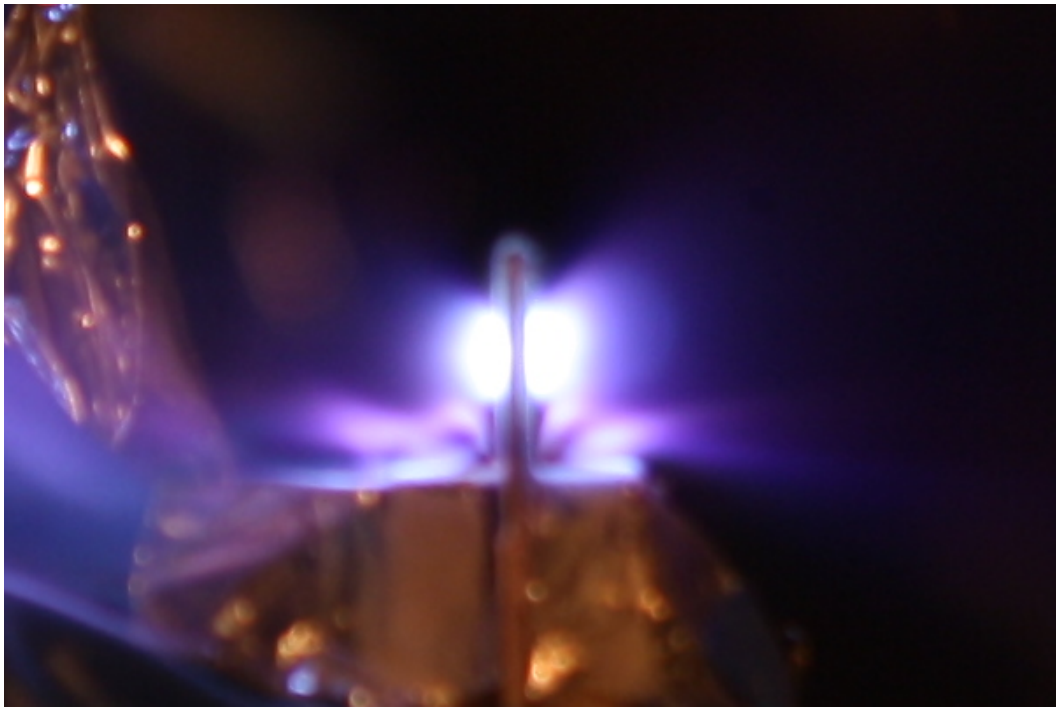
- temperature: 9-14 K
- density: 0,202 g/cm^3
- growth time: 20-40 min
- thickness: 0,5-1 mm (2µm planned)
- diameter: 2 mm



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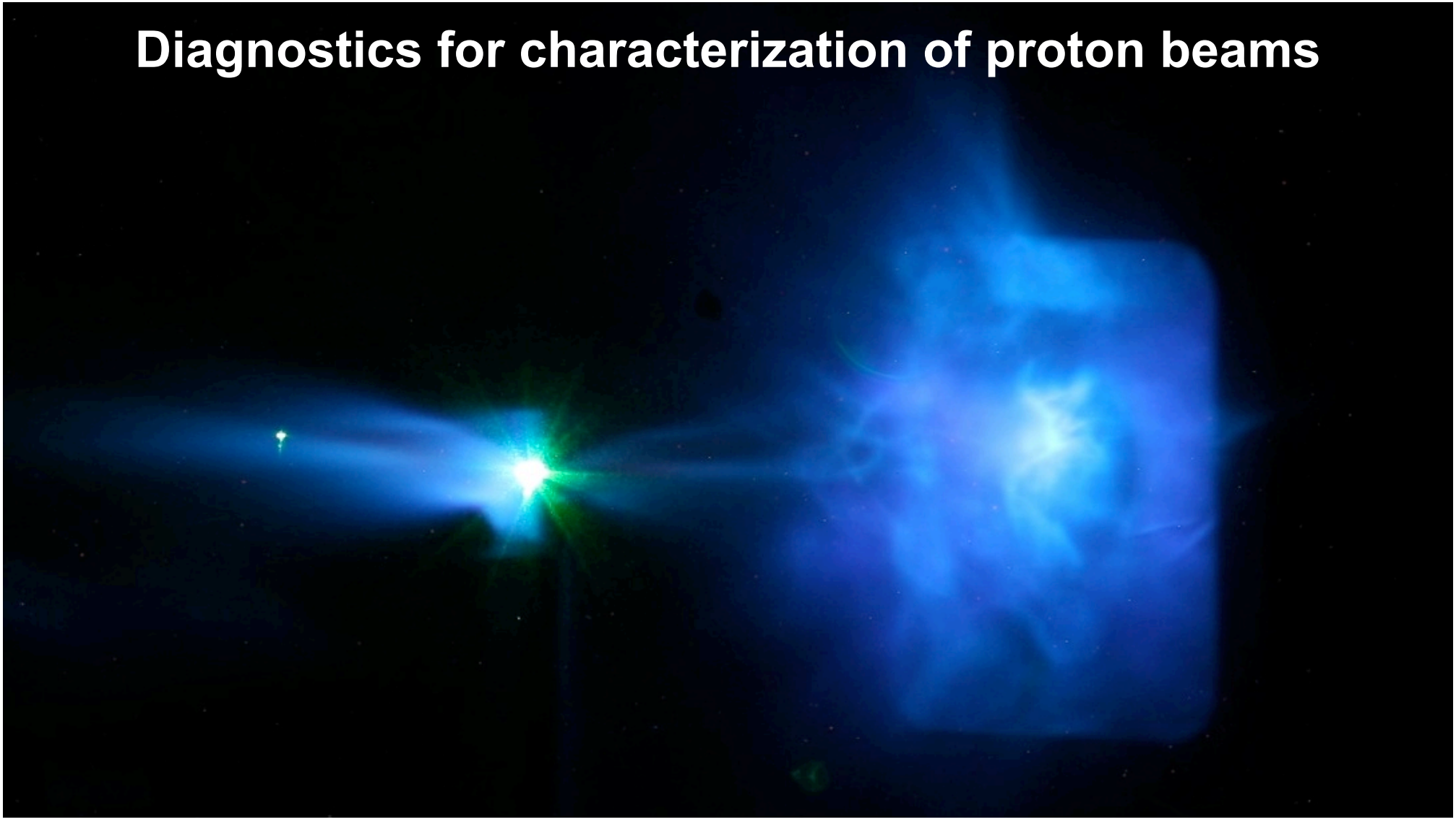
Diagnostics for characterization of proton beams



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Characterization of high-energy bremsstrahlung and electrons

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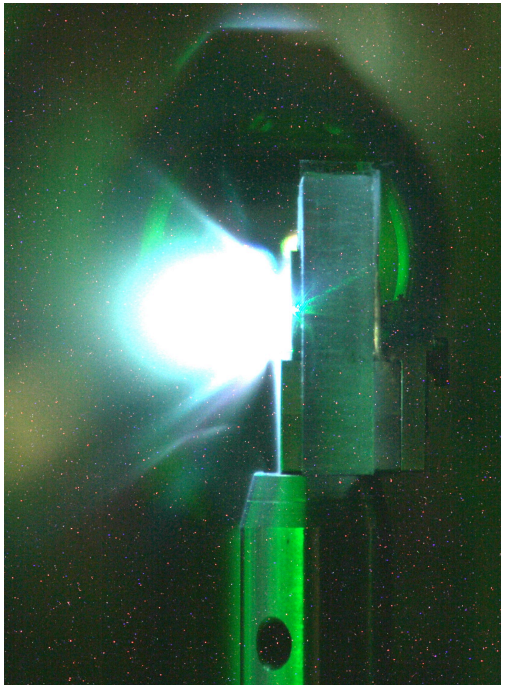
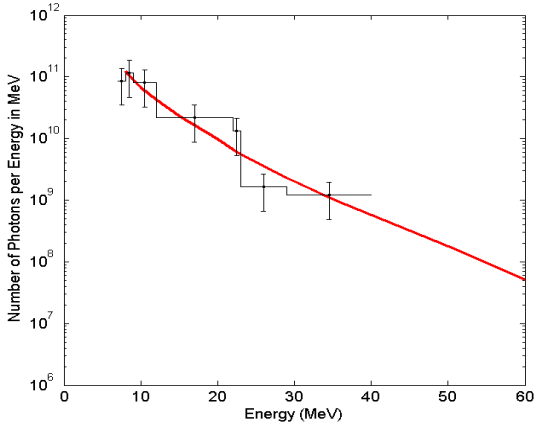
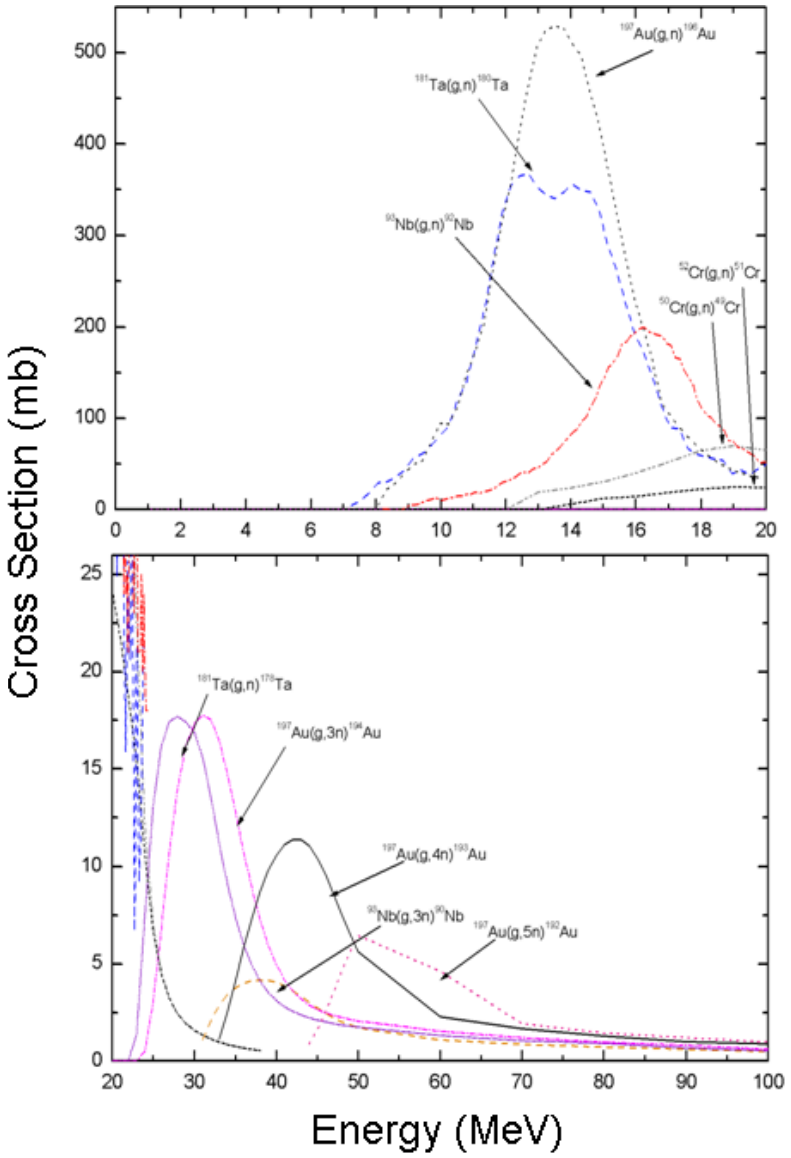


- Compound target as a pseudo alloy:

  composition of several stable elements with different photon-neutron disintegration thresholds

- Large energy range accessible:
  - 7 - 20 MeV via (γ,n)-reaction
  - 7 - 50 MeV via (γ,xn)-reaction
- All components close to laser-plasma interaction zone
- High mass density (13 g/cm^3)
- Suitable half-lives for all isotopes





Radiochromatic film imaging spectroscopy (RIS)

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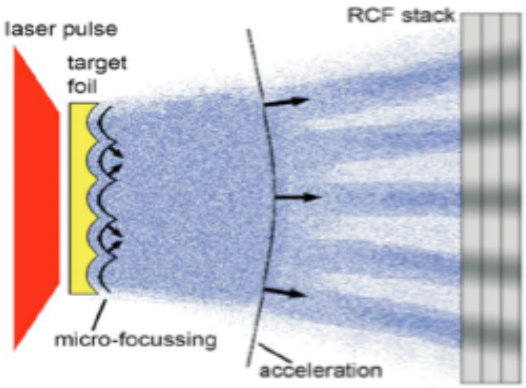
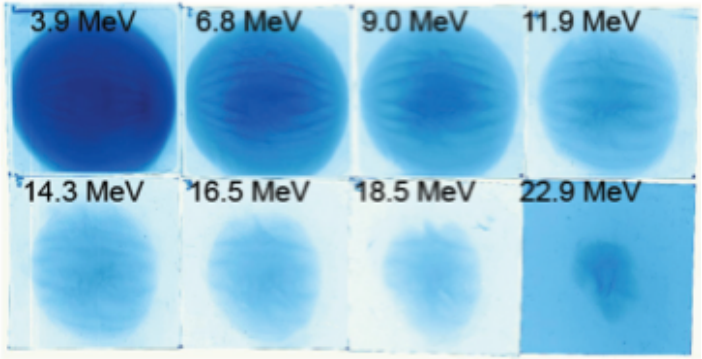
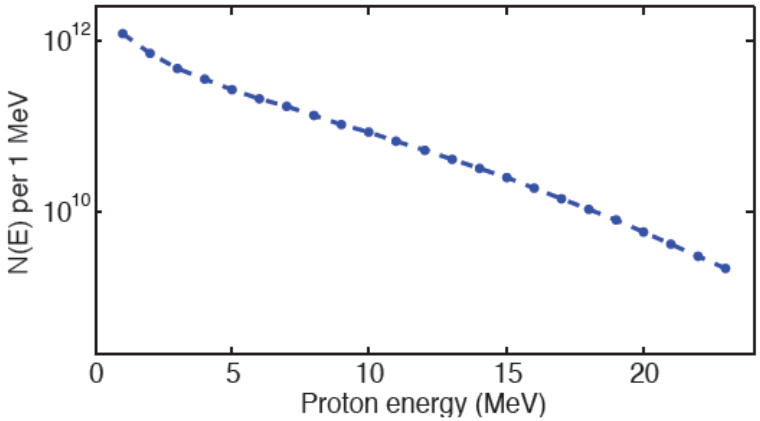


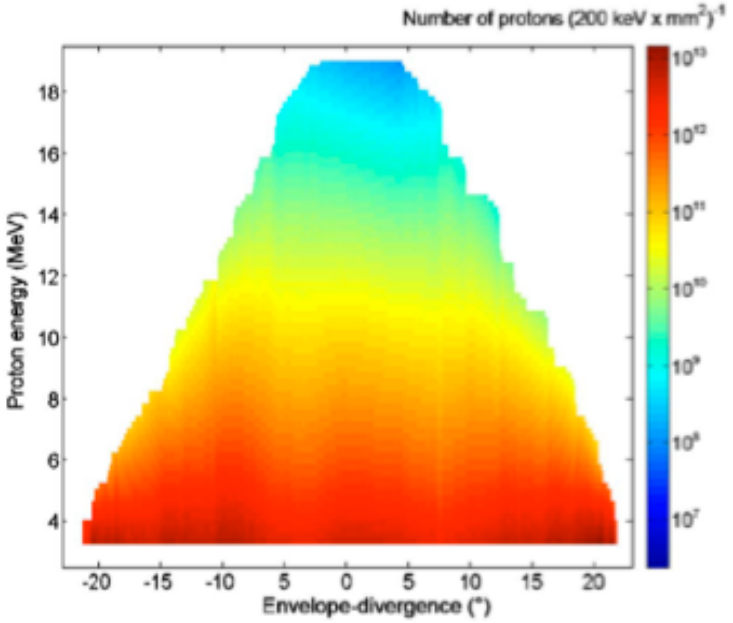




RIS allows for extraction of

- spectrum
- energy conversion efficiency
- energy-resolved opening angle
- energy-resolved source size
- energy-resolved beam profile
- transverse emittance

➔ in a single shot



published by F. Nürnberg et al.,Rev. Sci. Instr. 80, 33301 (2009)

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Limitation of RIS

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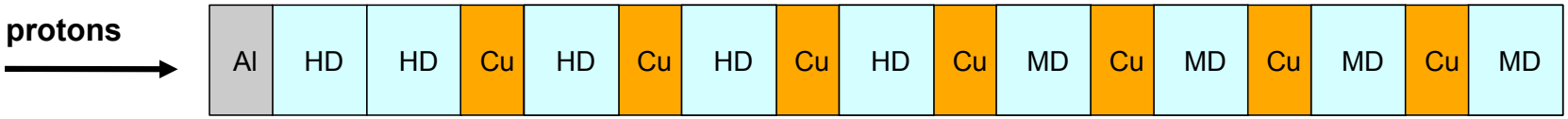
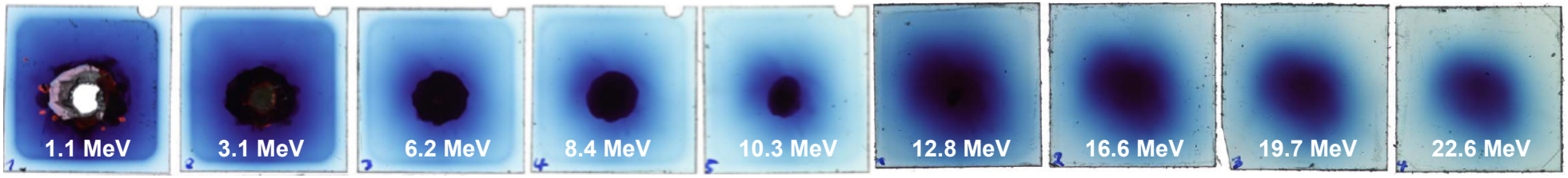
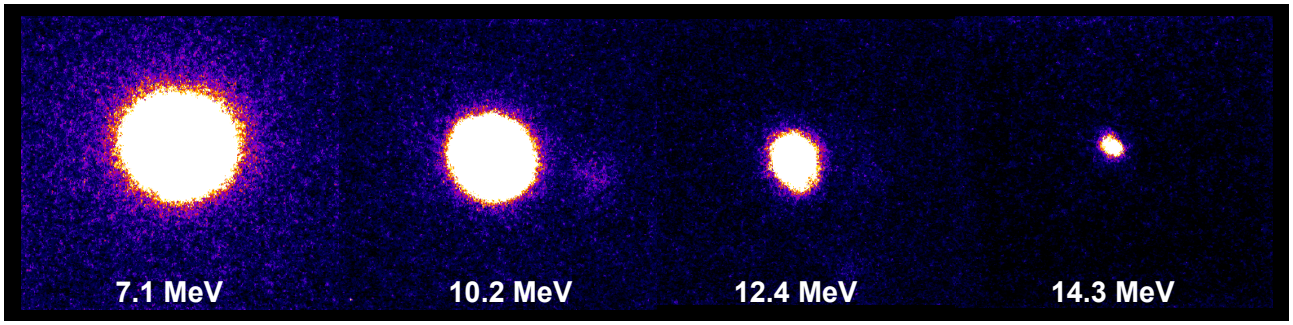
Problem appeared at Vulcan laser facility of the Rutherford Appleton Laboratory (UK):

- Target: Titanium foil of 10 µm thickness
- Laser: 194.4 J@18 ps on target, focus diameter 10 µm
- RCF to target distance: 26 mm





Copper activation:
dose rate >1 mS/h
20 min after shot



➔ High proton flux in high-power laser-proton-acceleration leads to saturation or disintegration of the RCF

Nuclear activation imaging spectroscopy (NAIS)

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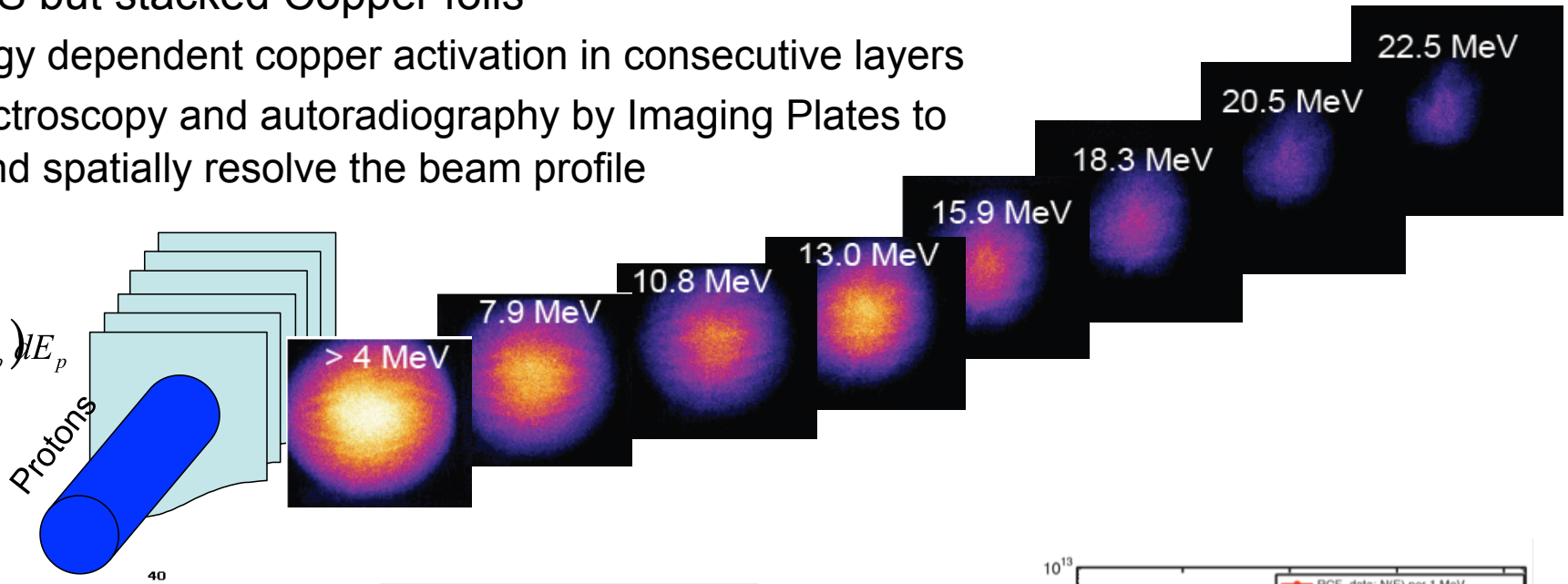
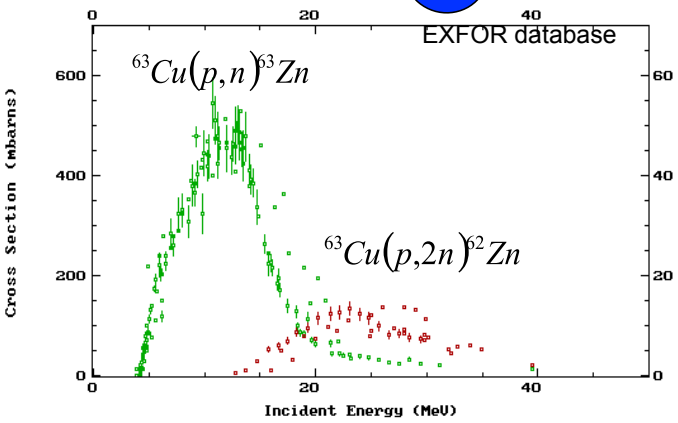
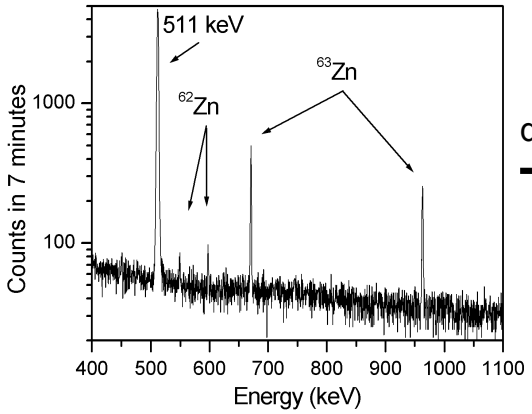
- Similar to RIS but stacked Copper foils
  - Proton energy dependent copper activation in consecutive layers
  - Using γ-spectroscopy and autoradiography by Imaging Plates to spectrally and spatially resolve the beam profile

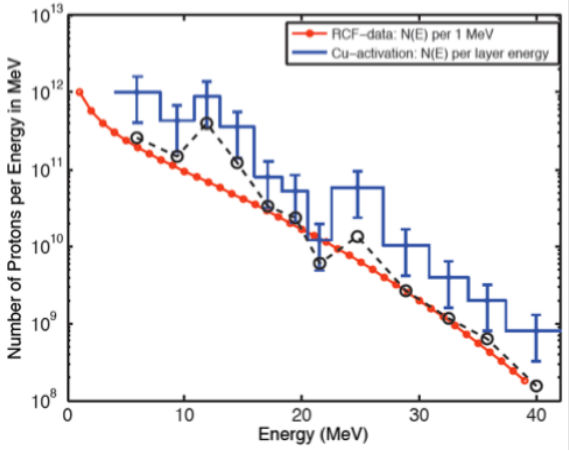
$$Y = N_T \int_{S_n}^{\infty} \sigma(E_p) N_p(E_p) dE_p$$







deconvolution



A detector system for ion beams at GSI

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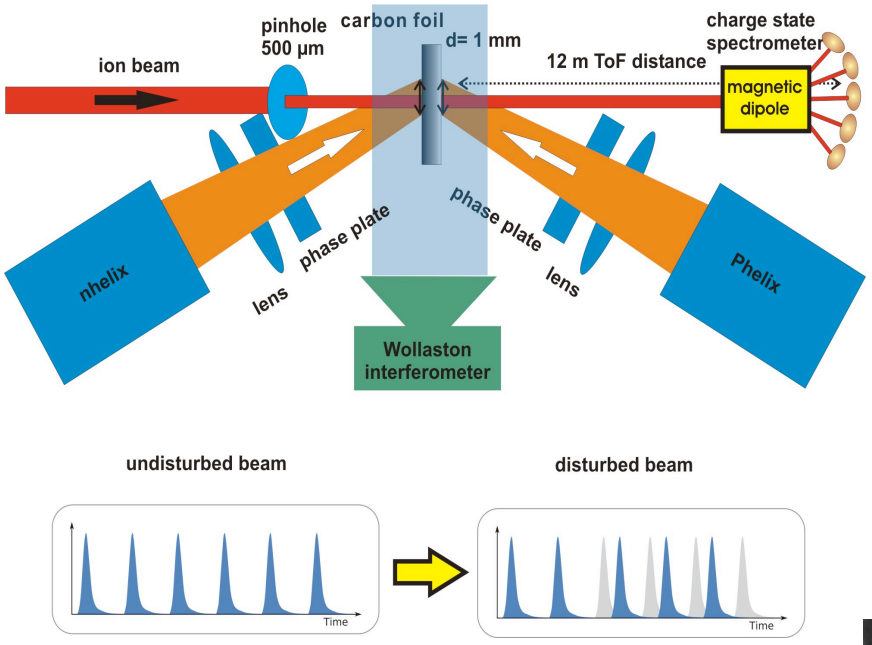
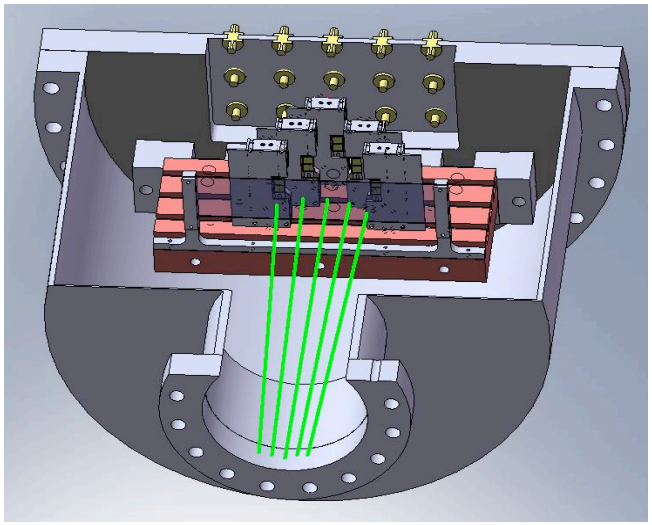
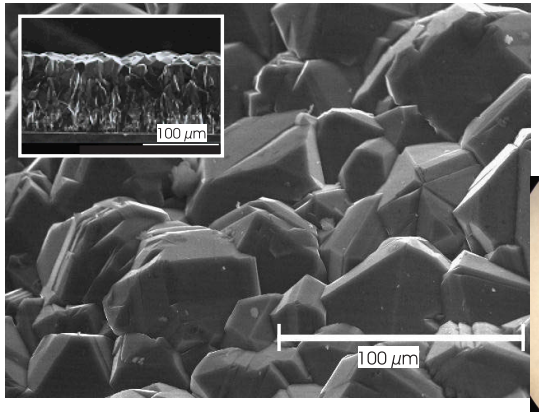


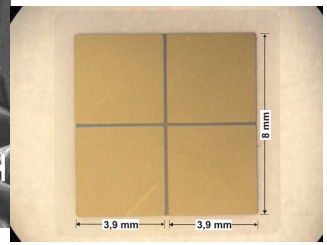


Ion beam:

^{48}Ca at 4.9 MeV/u at 108 Mhz



Temporal resolution 28-65 ps
Sensitivity: 1Ar atom (5 Mev/u)
1.5 10^{10} Electron/Hole pairs
Radiation resistant



Spectrometer:

5 stripes of polycrystalline diamond with A=7x20mm^2 of 20 µm thickness

Experimental results

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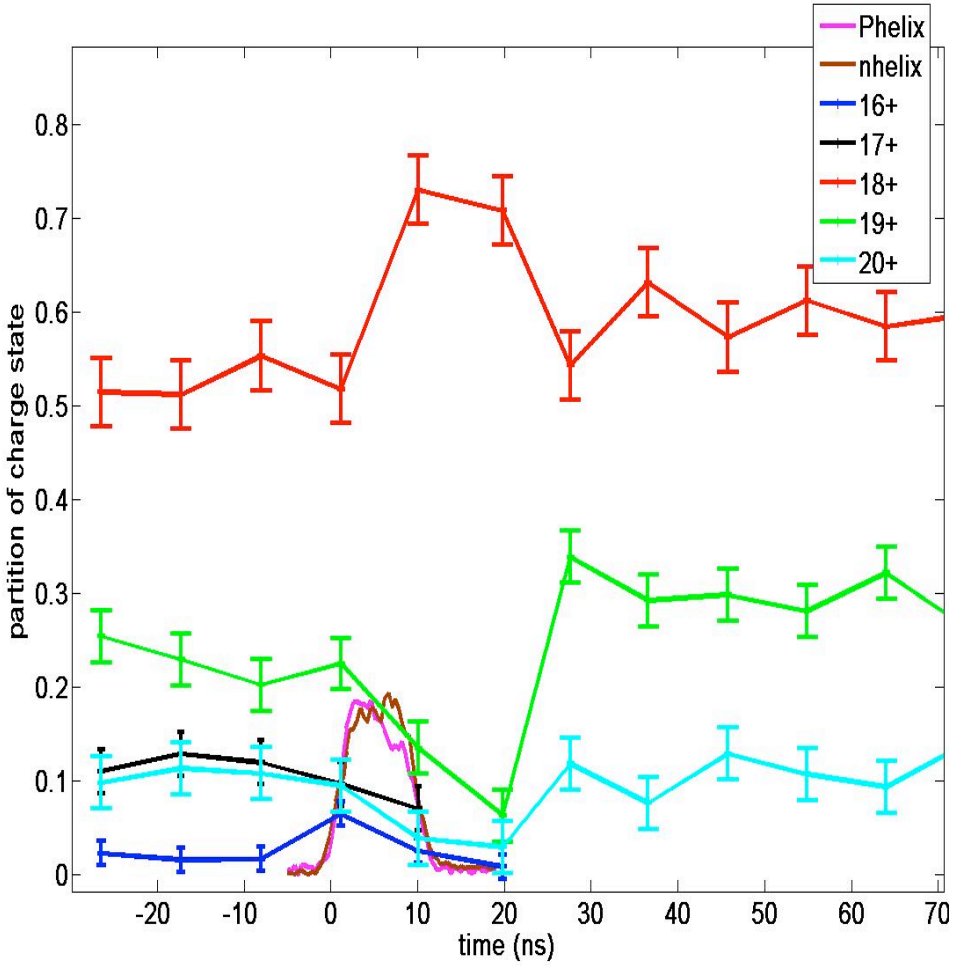

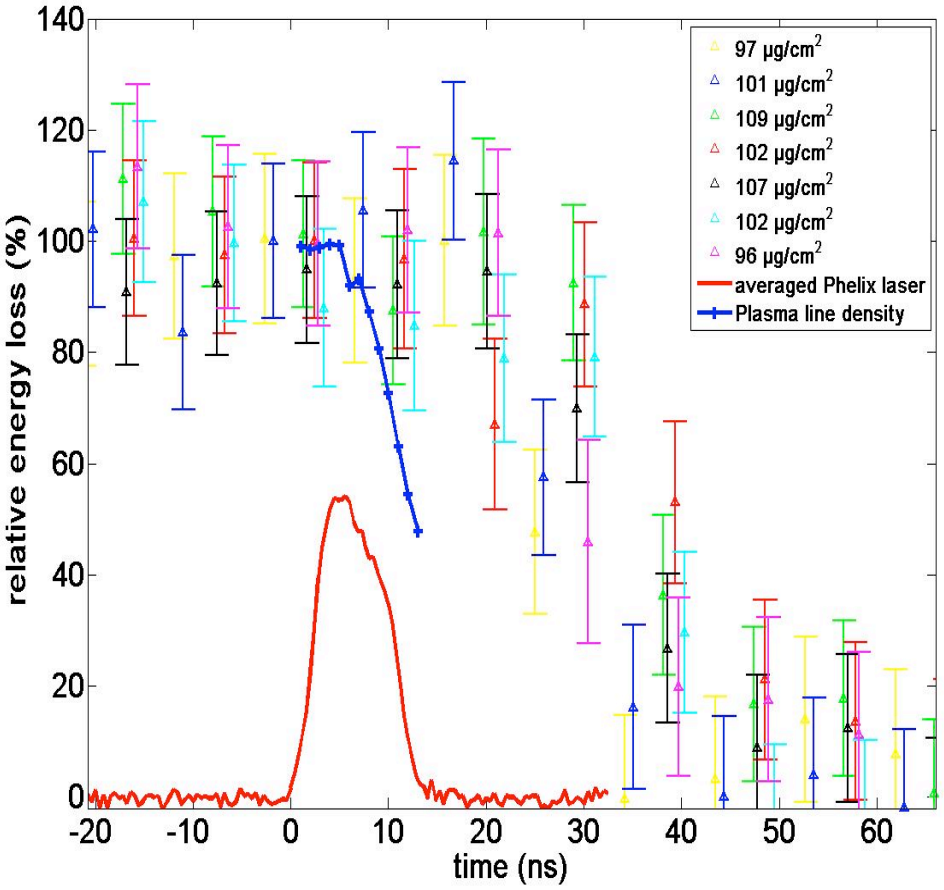

Next Steps

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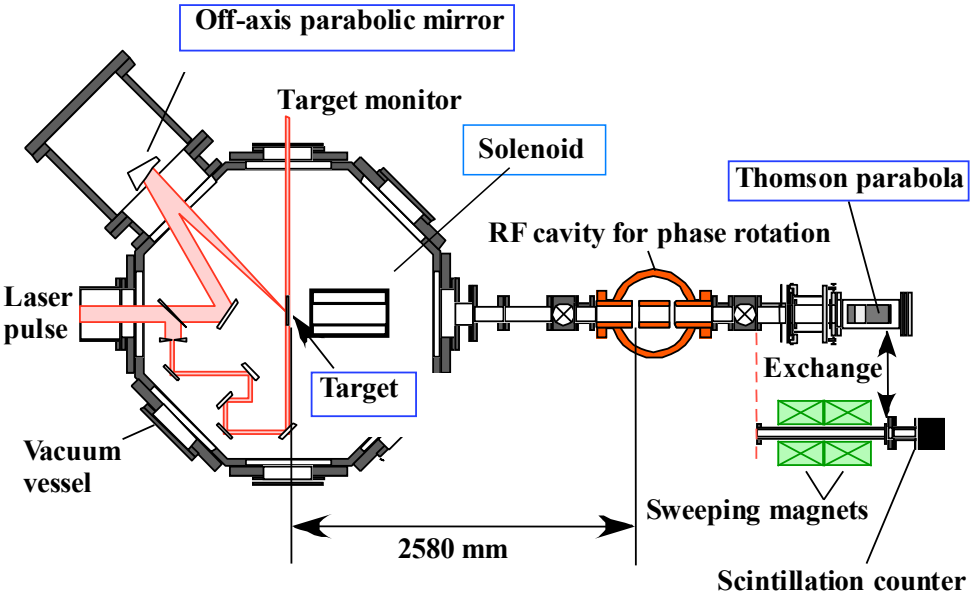
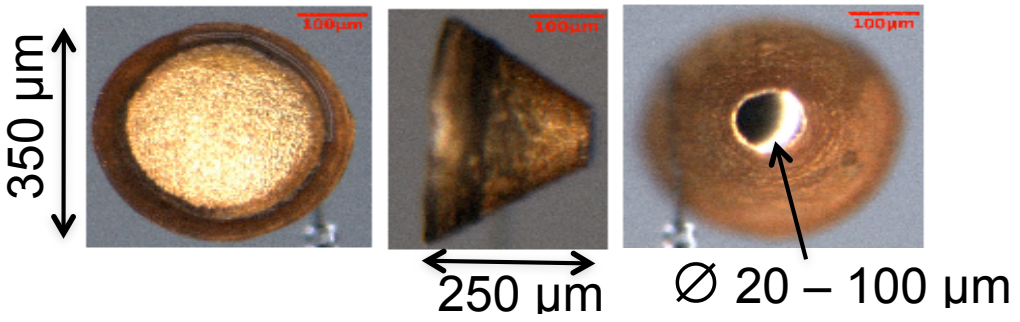
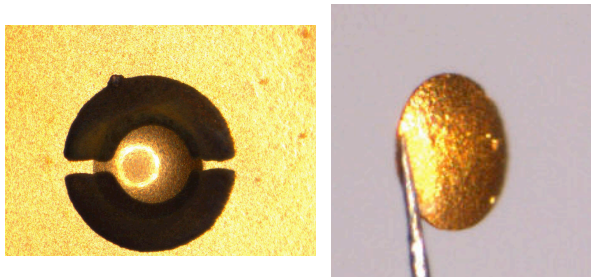
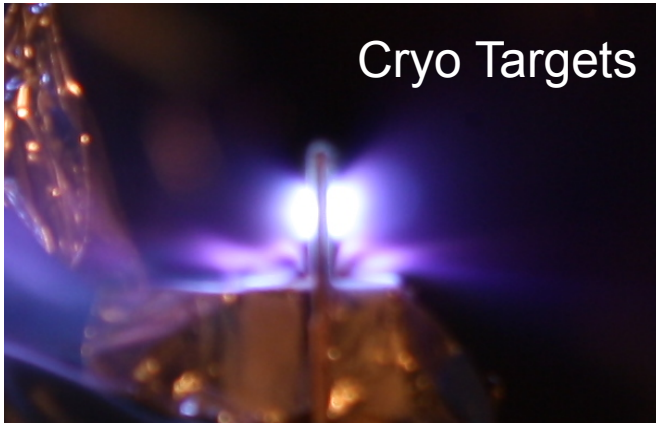


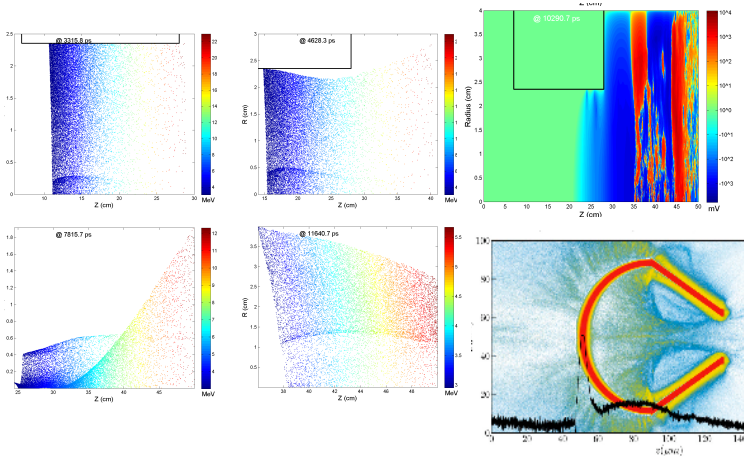
Apollo Targets





Mass limited Targets





Combine WARP/PSC VORPAL

and the Simulation Expertise of GSI/TUD/Frankfurt