Generation, Handling and Transport of Laser-accelerated Heavy Ion Beams

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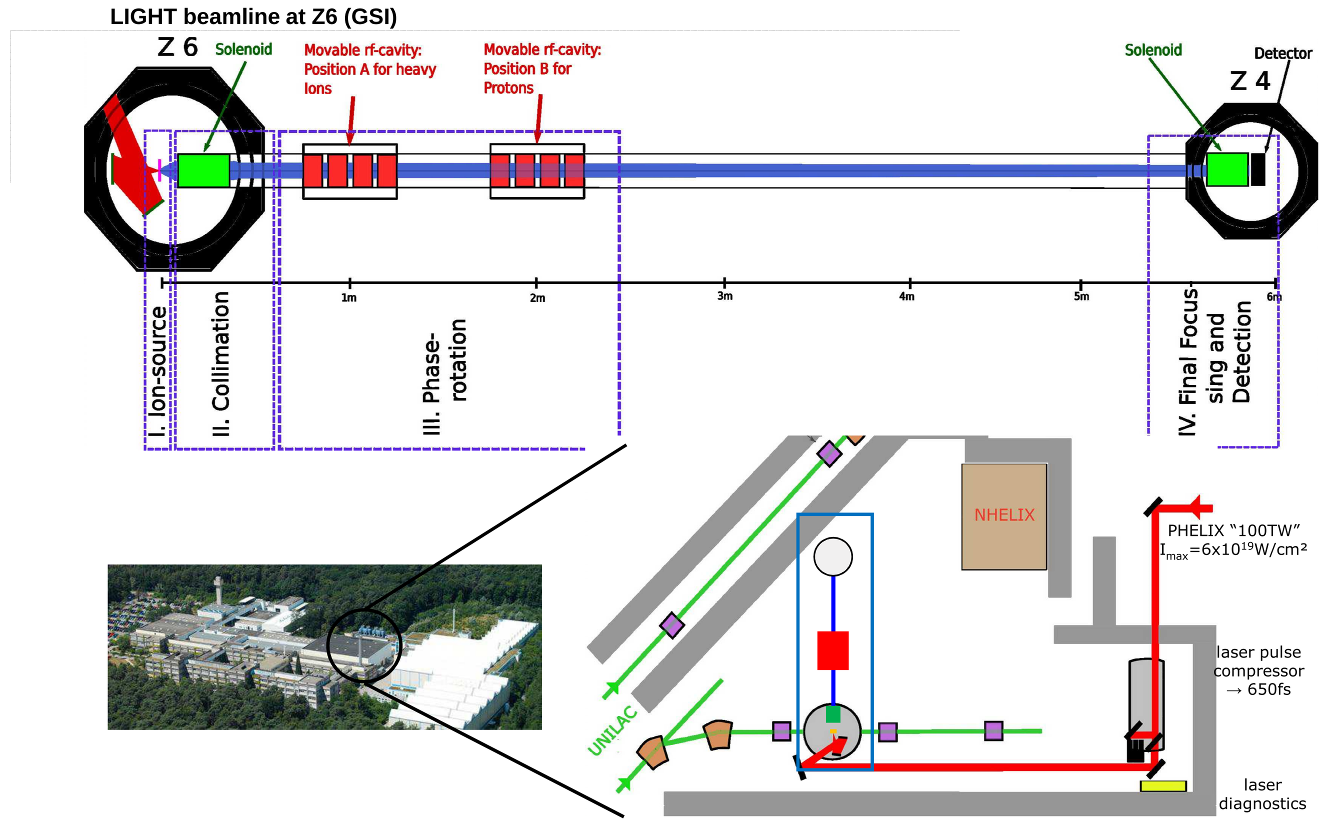
Overview

About the Project [1,2,3]:

- LIGHT for **L**aser **I**on **G**eneration, **H**andling and **T**ransport
- collaboration of TU Darmstadt, GSI, University Frankfurt, HI Jena, HZDR
- ion acceleration driven by the GSI PHELIX laser
- beam shaping via conventional accelerator technology (rf cavity)

LIGHT beamline at Z6 (GSI)

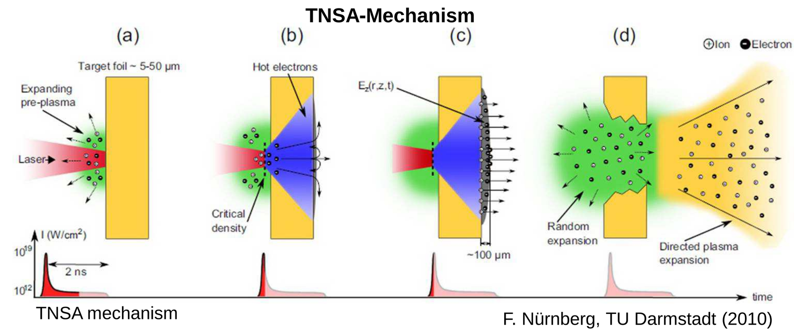


I. Ion Source

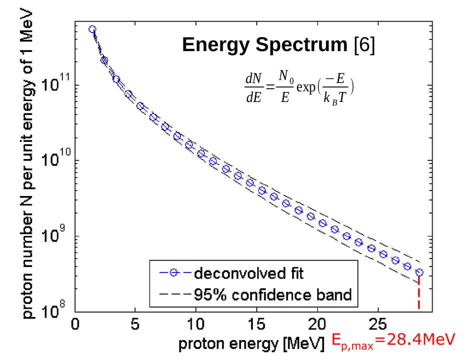
Target **N**ormal **S**heath **A**cceleration (TNSA):

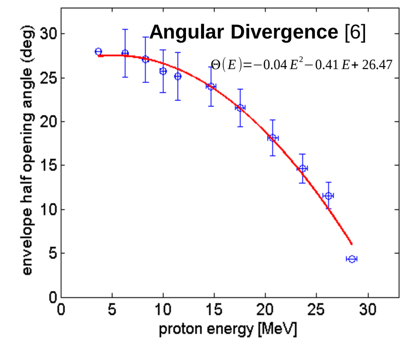
- intense ion source: $10^{11} – 10^{13}$ protons in ~ 1 ps
- low emittance: < 0.01 mm mrad transversal, 10^{-4} eV s longitudinal [4]
- huge accelerating field gradients: MV/µm
- detection of full proton beam with radiochromic film imaging spectroscopy [6] @4 cm behind source
- source size @10 MeV: approx. 50µm

TNSA-Mechanism



F. Nürnberg, TU Darmstadt (2010)

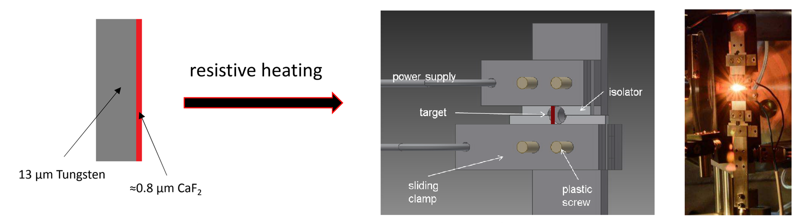




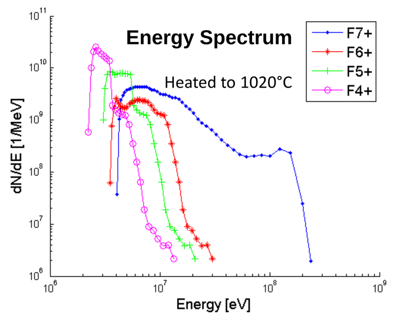
Challenge: Efficient acceleration of heavy ions

Problem: Hydrocarbon pollutions coating surfaces ➡ best q/m accelerated efficient
➡ protons screen electric field
➡ **only protons eff. accelerated**

Solution: Elimination of hydrocarbons on surface



Based on work from: M. Hegelich et al., *MeV Ion Jets from Short-Pulse-Laser Interaction with thin foils*, PRL 89,8 (2002)



II. Collimation

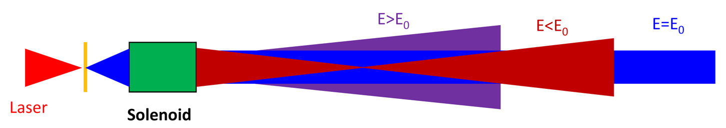
Pulsed solenoid acts as collimator for divergent beam

- magnetic field: 5 – 10 T
- in-air solenoid (no arcing)
- 40.5-mm aperture
- second order focusing effect

Ion species and charge state; Energy of Ions

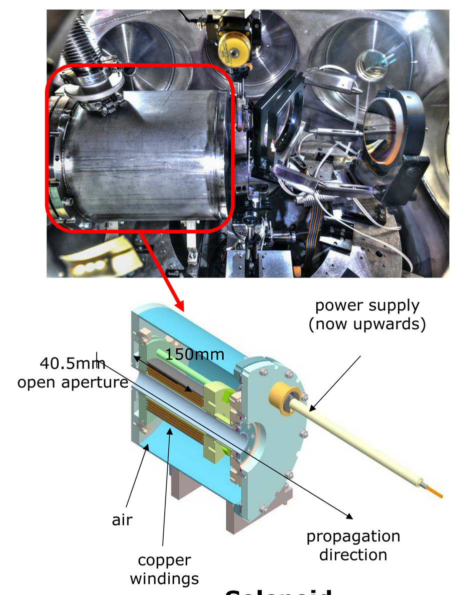
$$\frac{1}{f} = \frac{q^2}{m^2}\frac{1}{4\gamma^2 v_z^2}\int B^2 dz$$

Energy selection by means of chromatic focusing



Efficient transport of protons already demonstrated:

- 34 % of protons in 8 MeV ± 0.5 MeV energy range
- equals $N_P>10^9$ protons

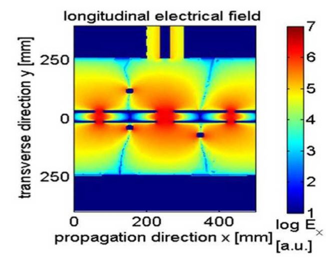


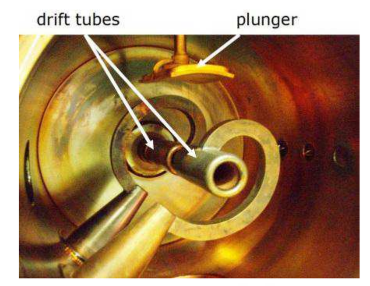
Solenoid

III. Phase Rotation

Implementation of RF-Cavity

- GSI rf cavity
  - ✓ 0.55 m long
  - ✓ 3-gap spiral resonator
- power supplied by the UNILAC rf generator
  - ✓ 108.4 MHz (UNILAC)
  - ✓ rf power >100 kW
  - ✓ applied potential >±1MV

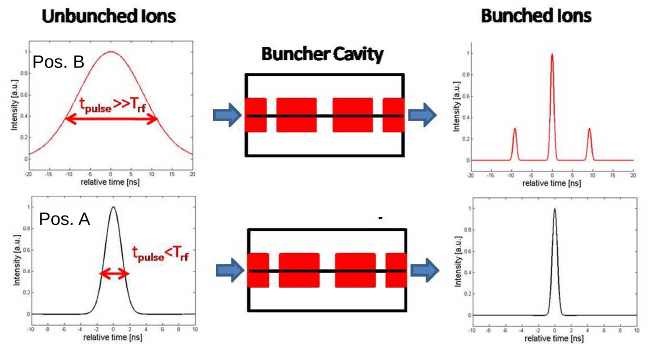




- longitudinal extent of beam at entry of cavity depends on
  - ✓ distance target to cavity
  - ✓ speed of ions

In case of slow ions (heavy ions) and cavity at 2 m
➡ T_{pulse} >> T_{rf} (= 9.2 ns) ➡ multi-bunching

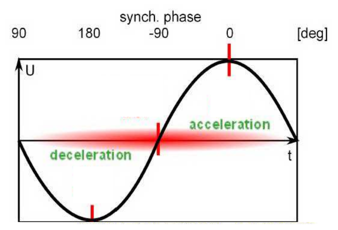
Solution: **Move cavity closer to target** (Pos. A)

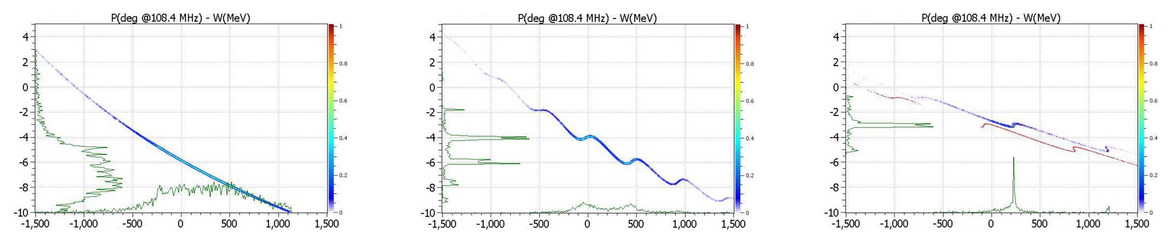


III. Phase Rotation (cont.)

Phase Rotation with RF-Cavity

- timing of rf-phase to achieve injection of ions at -90° synchronous phase
- longitudinal divergence depends on rf-power:
  - ✓ "freezing" of longitudinal extent = energy compression
  - ✓ over-compensation of longitudinal divergence => short and intense beams (T_{FWHM}<1ns)





Energy phase diagrams: a) 3m behind target; b) 3m behind target with rf-cavity; c) 6m behind target with rf-cavity = shortest bunch

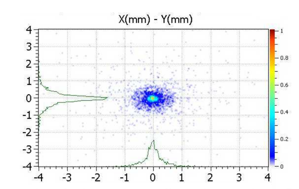
IV. Final Focussing and Detection

Final focussing with second solenoid

- focus radius of below 1 mm from simulations
- for protons already demonstrated

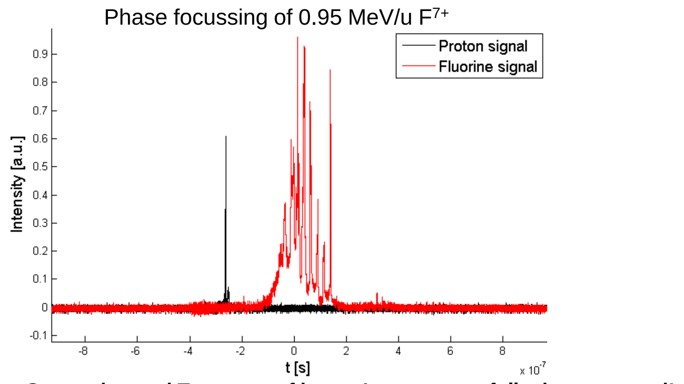
Detection resulting beam with diamond detecor

- 13 µm thick diamond membrane
- 1 mm² of sensitive area
- impedance matching for fast readout



Simulation of smallest focus for F^{7+}

Phase focussing of 0.95 MeV/u F^{7+}



Generation and Transport of heavy Ions successfully demonstrated!

- formation of multitude of peaks due to bunching in cavity and different charge states
- energy/u and particle numbers lower as for protons because of overall lower generation efficiency

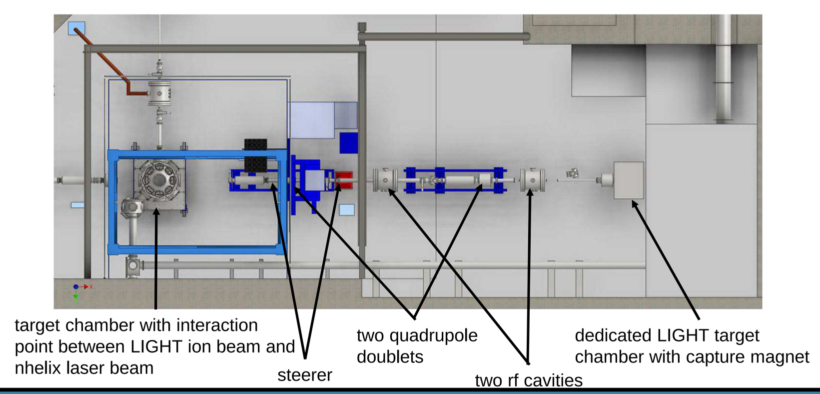
Outlook

2017

- ➢ analysing transported heavy ion beam of latest beamtime

2018-2020

- ➢ further improvement of heavy ion transport and phase focusing
- ➢ reconstruction of LIGHT to create capabilities for energy loss measurements in plasma with pulse lengths T<1 ns
  - ➢ dedicated target chamber for LIGHT ion source and collimation
  - ➢ implementation of rf cavities and beam transport elements



References:

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[4] S. C. Wilks et al., *Energetic proton generation in ultra-intense lasersolid interactions*, Phys. Plasmas 8, 542 (2001).

[5] T. Cowan, *Ultralow Emittance, Multi-MeV Proton Beams from a Laser-Virtual Cathode Plasma Accelerator,* PRL 92,20 (2004)

[6] F. Nürnberg *et al.*, *Radiochromic film imaging spectroscopy of laser-accelerated proton Beams,* RSI **80**, 033301 (2009)

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