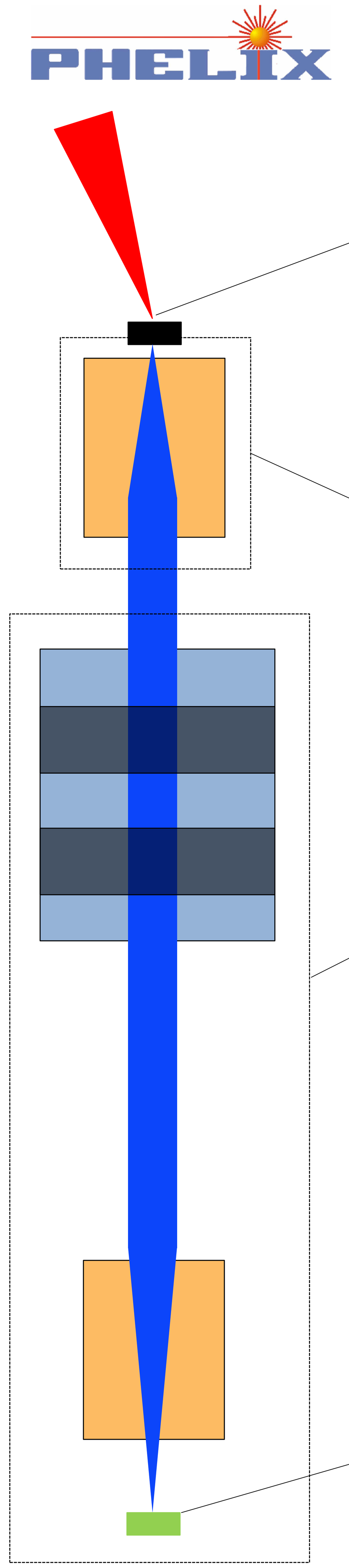
Generation of intense 0.6 MeV/u carbon bunches for stopping power experiments with the LIGHT beamline

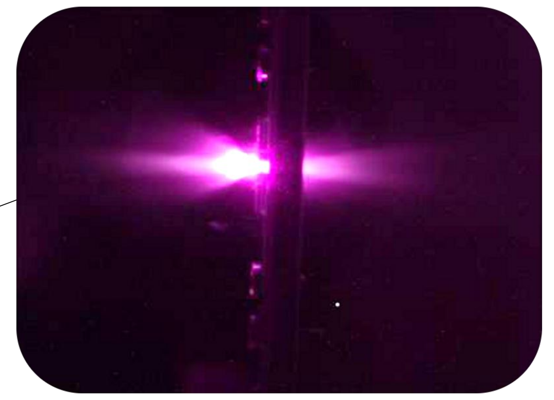
M. Metternich [1,*], H. Nazary[1], D. Schumacher[2], C. Brabetz[2], F. Kroll[3], F.-E. Brack[3,4], T. Cowan[3,4], U. Schramm[3,4], A. Blazevic[2], V. Bagnoud[1,2], and M. Roth[1]

[1]Technische Universität Darmstadt, Darmstadt, Germany; [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany; [3] Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany; [4]Technische Universität Dresden, Dresden, Germany

LIGHT beamline overview

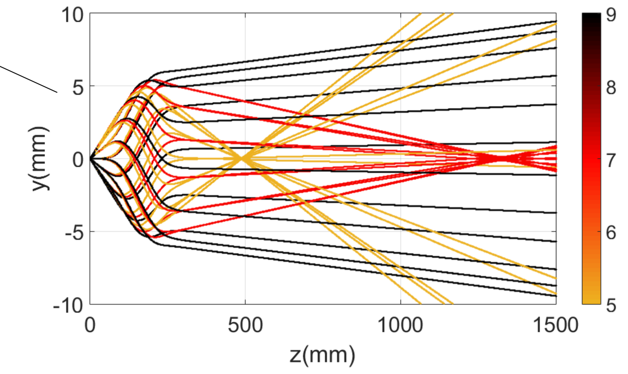


Laser-ion acceleration (TNSA) with PHELIX



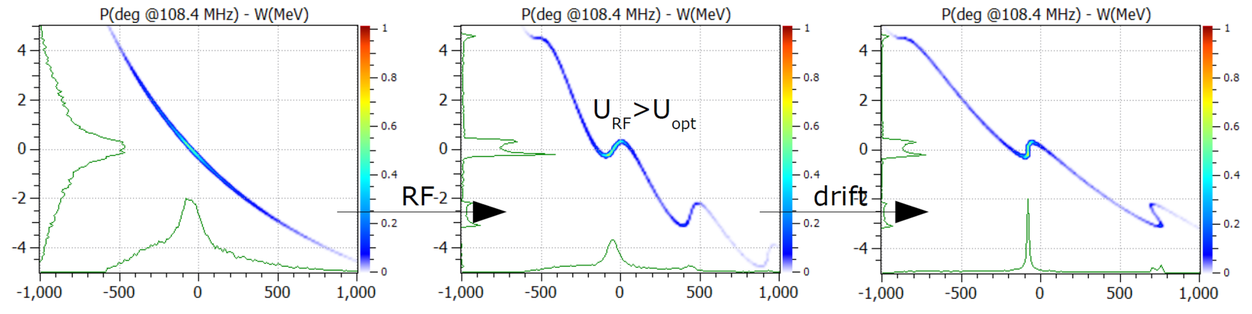
- Exponential decaying energy spectrum
- Cut-off energy > 25 MeV
- Max. divergence > 25° (half opening angle)
- 10^{10} protons at 10 MeV (± 0.5 MeV)

Energy selection and ion transport with pulsed solenoid



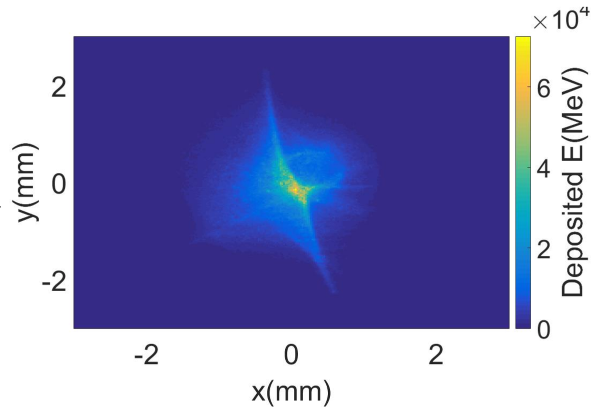
- Chromatic focusing
- Energy selection by aperture
- Aperture: 40.5 mm
- $B_{z,max}$ = 8.7 T
- Capture efficiency up to 34% at 10 MeV (± 0.5 MeV)

Temporal compression (bunching) with rf-cavity



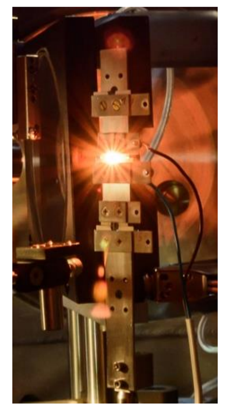
- Cavity parameter: 108.4 MHz, 3 gaps, ~1 MV
- Temporal compression: the deceleration of the fast ions in the front and the acceleration of the slow ions in the back of the bunch can lead to lower bunch length after drift

Focusing with second solenoid (results 2020)



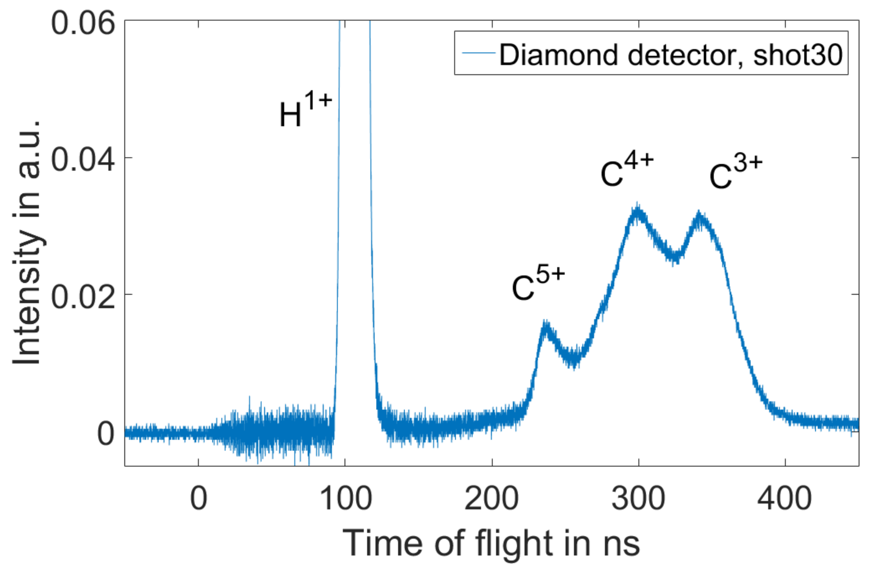
- Focal spot: 0.68 mm (50% of protons are in this spot)
- Protons in focal spot: 6 x 10^8
- Peak-Energy: 7.7 MeV
- Current: 132 mA
- Pulse width: 742 ps
- Focal length: ~300 mm

Generation of intense C-ion bunches



Efficient acceleration of carbon ions

- Field-ionized protons are most efficiently accelerated because of their q/m-ratio
- Hydrogen contaminations on the target surface are removed by ohmic heating -> efficient acceleration of the target surface material (carbon)

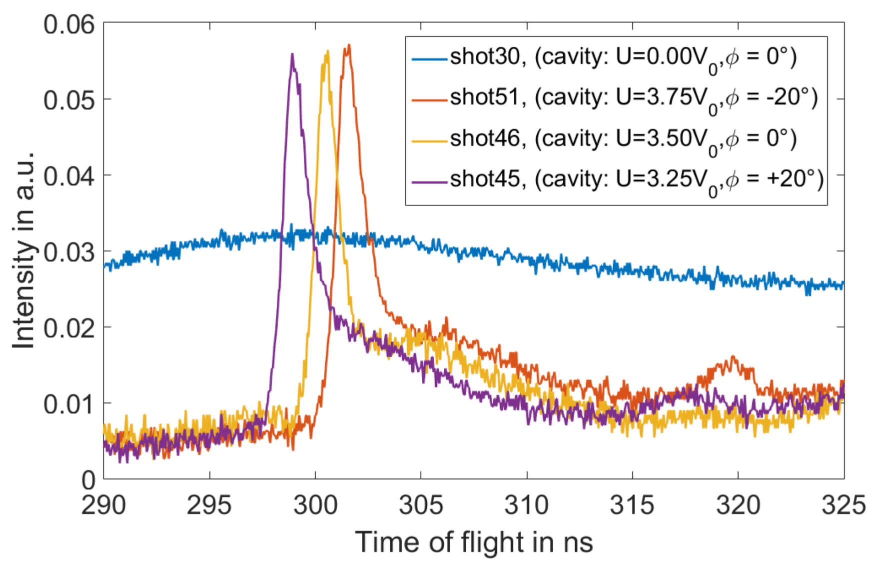


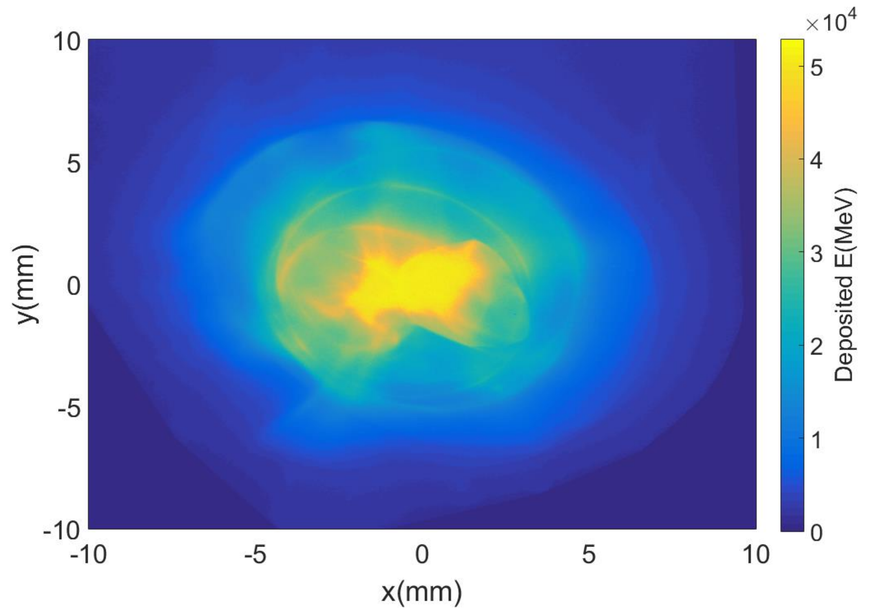
Transport and energy selection of carbon ions

- Particles with the same magnetic ridigity ρ are getting tranported through the beamline simultaneously
- $\rho = \frac{\gamma m v}{Bq} \rightarrow E_1 = \left(\frac{q_1}{q_2}\right)^2 \frac{m_2}{m_1} E_2$
- ToF-distance: 3.2 m

➢ H^{1+}(5.4 MeV/u), C^{4+}(0.6 MeV/u)

Temporal compression and focusing of C-ions (results 2021)

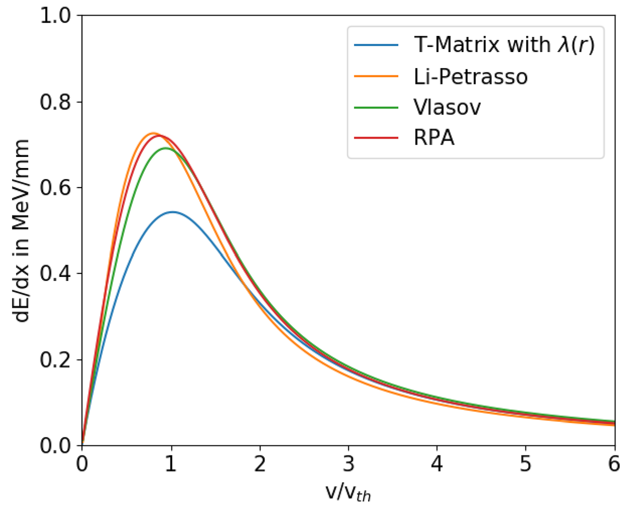




- Peak-Energy: 0.6 MeV/u
- Pulse width (yellow peak): 1.2 ns (FWHM)
- Cavity energy transfer depends on the ion energy

- Focal spot: 8.4 mm (50% of ions are in this spot)
- C-ions in focal spot: 1.3 x 10^9
- Focal length: ~1 m
- RCF type: HD

Outlook: stopping power experiments

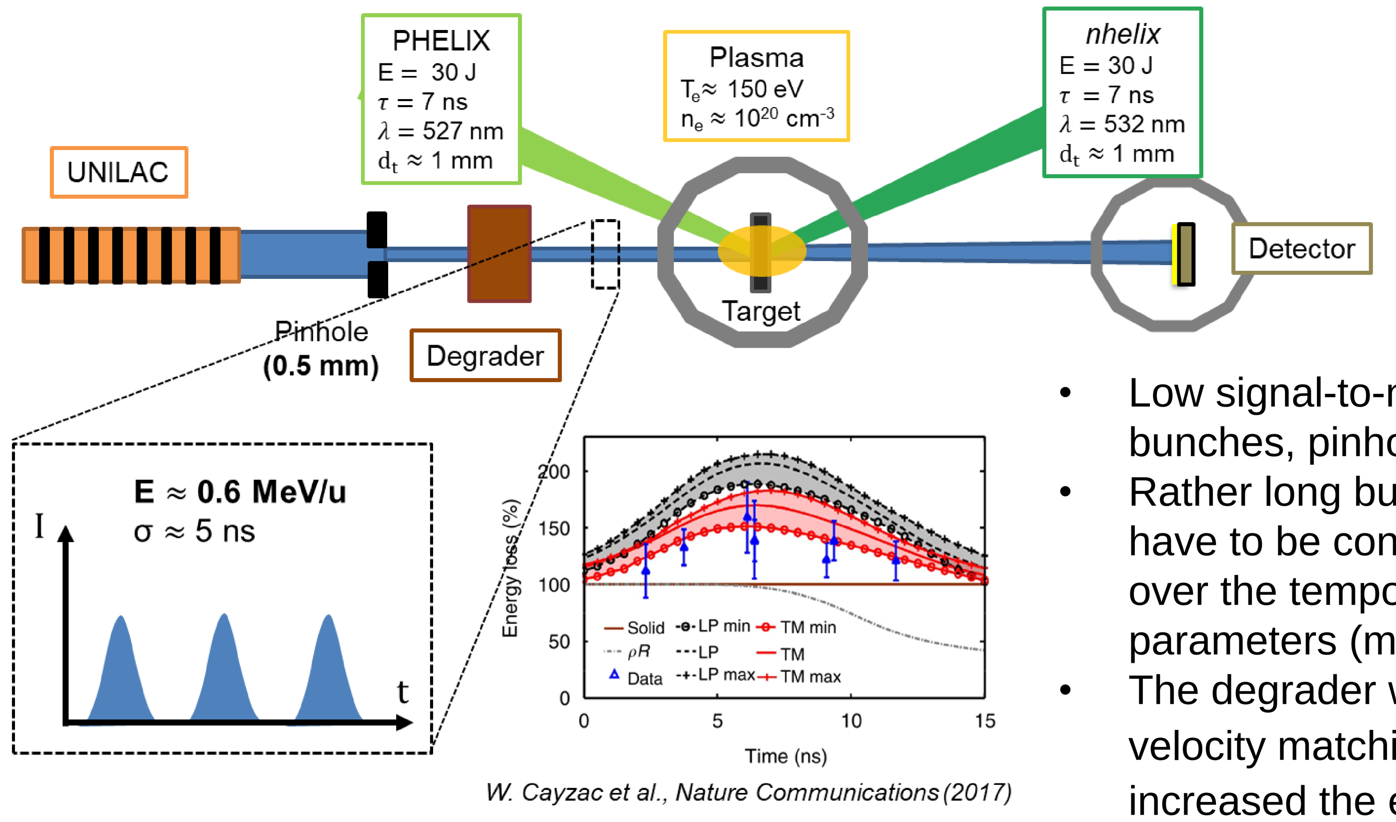


Stopping power theory

- Typical parameters of laser-generated plasmas (ns-pulse):
  - Temperature: 150 eV (~7 ns)
  - Density: 10^{20} cm^{-3} (~7 ns)
  - Relevant time frame: 5 – 10 ns
- Maximal coupling effects when $(v_{proj} \approx v_{th}^{e,i} \propto \sqrt{T_{e,i}})$

  ➢ $v_{proj} \approx$ **0.6 MeV/u**
- For stopping power experiments with ToF the ion bunch should be as monoenergetic, slow and short as possible

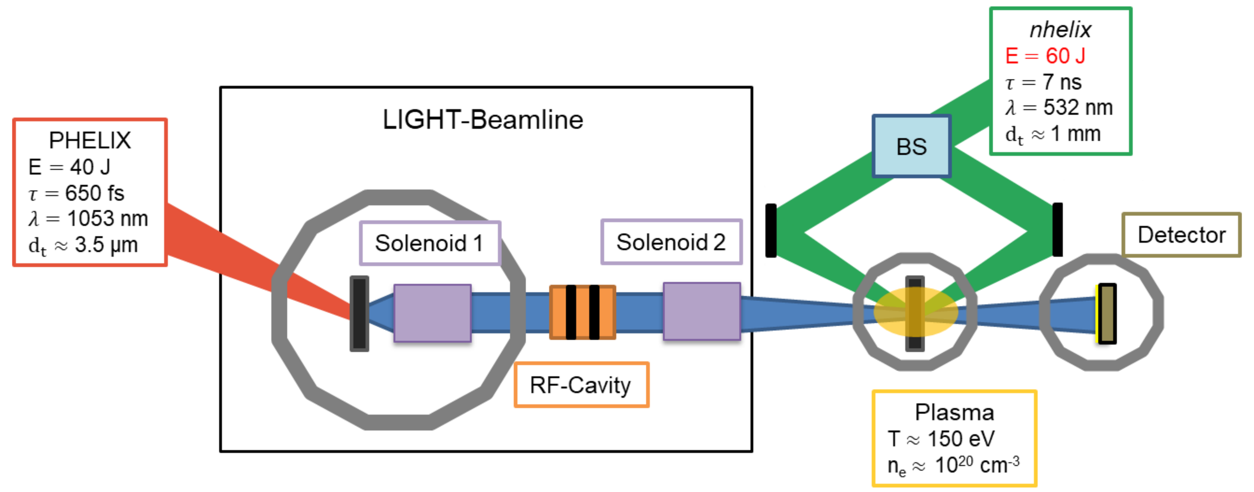
Stopping power experiment with LINAC ions at GSI (results 2017)



W. Cayzac et al., Nature Communications (2017)

- Low signal-to-noice ratio (micro bunches, pinhole and degrader)
- Rather long bunches (σ ≈ 5 ns) have to be considered by averaging over the temporal changing plasma parameters (main uncertainty)
- The degrader which was used for velocity matching $(v_{proj} \approx v_{th}^{e,i})$ increased the energy spread of the ions

Stopping power experiments with LIGHT



- Better signal-to-noice ratio because of the high intensities
- Shorter ion bunches (less uncertainties due to averaging effects)
- Infrastructure almost ready at GSI