Development of a table top TW laser accelerator for medical imaging isotope production

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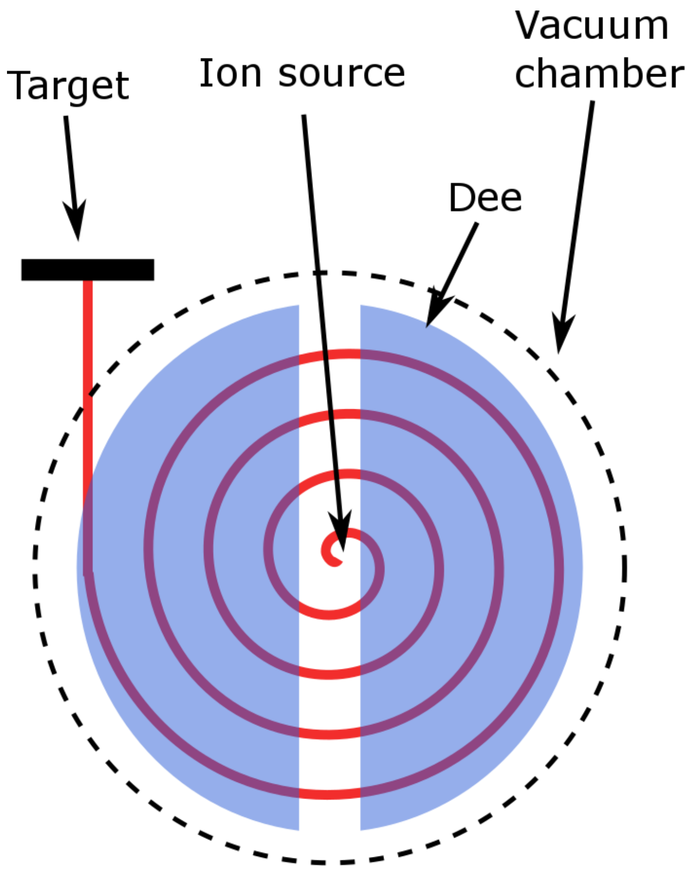
1. PROTON LASER APPLICATIONS S.L,

Motivation

- Radioisotope production for medical applications.
- Positron Emission Tomography (PET).
- Functional imaging.
- Needs a proton source for radioisotope production.

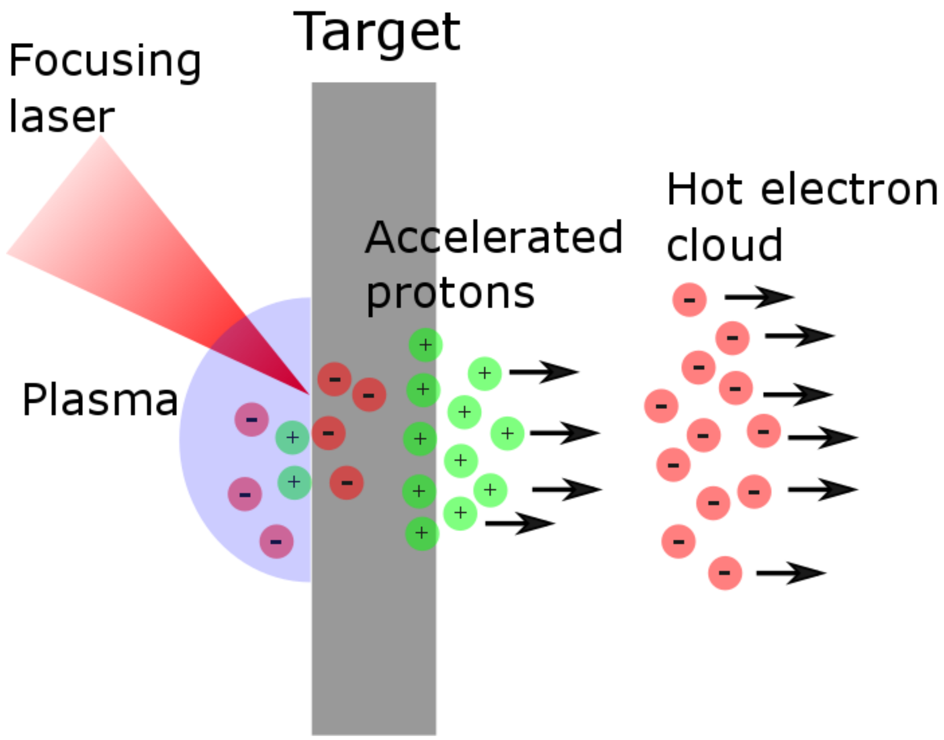
Proton acceleration for radioisotope production

- Proton acceleration with a cyclotron.
- Protons over 10 MeV.
- Radio isotopes: Carbon-11, Nitrogen-13, Oxygen-15, Fluorine-18, etc.
- Medication synthesis.
- Administration to subject for PET imaging.

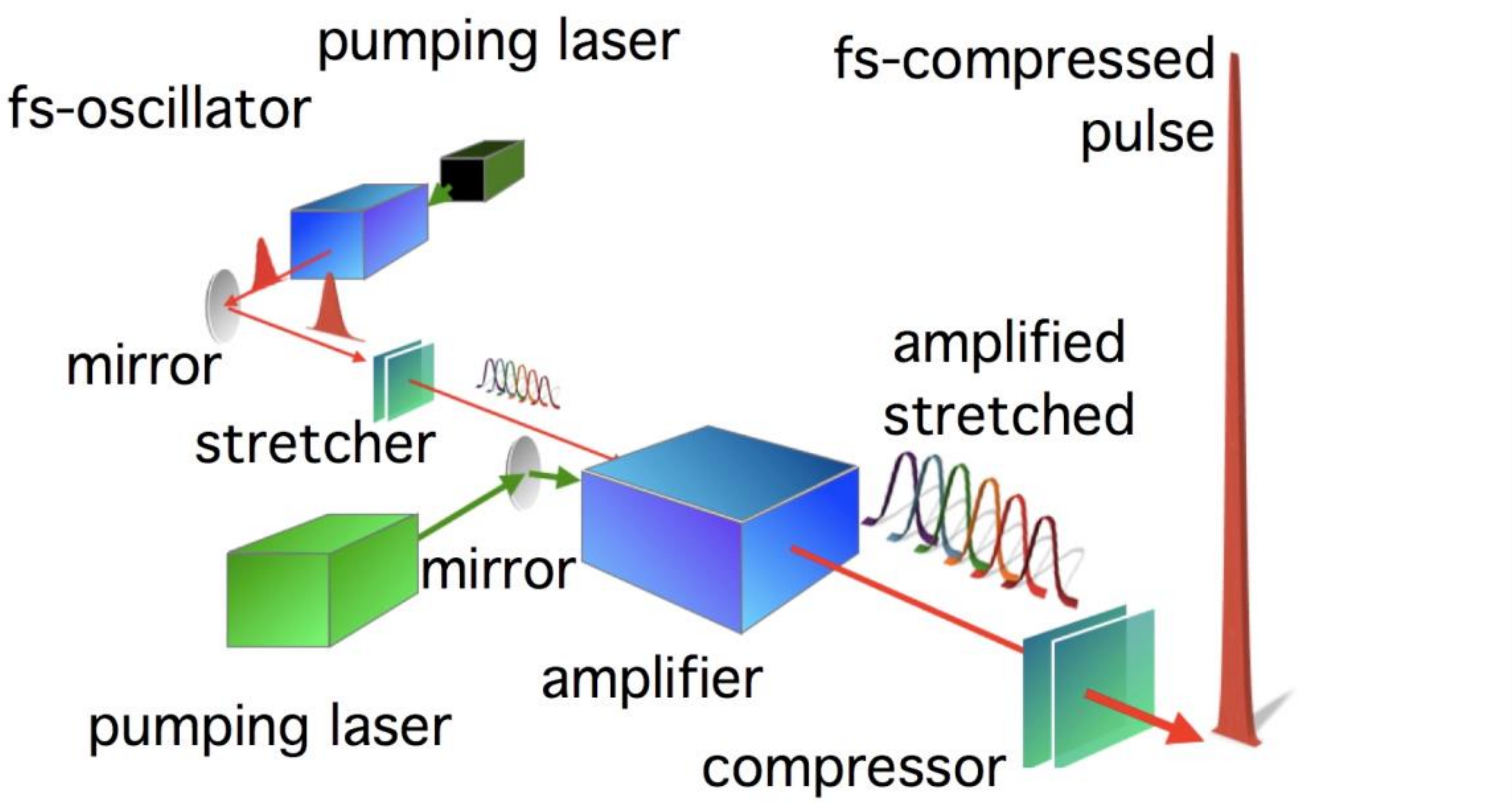


Laser-driven particle acceleration.

- Solid targets, typically Al.
- Thin foils hundredths of nm – few um.
- Laser intensity at target $>10^{18}$ W/cm^2.
- Interaction in vacuum (10^{-5} mbar).
- Wide proton energy distribution.
- “Compact” TW-class laser system.
- 30-50 fs.
- 1-10 J.



Chirped pulse amplification (CPA)



CPA systems

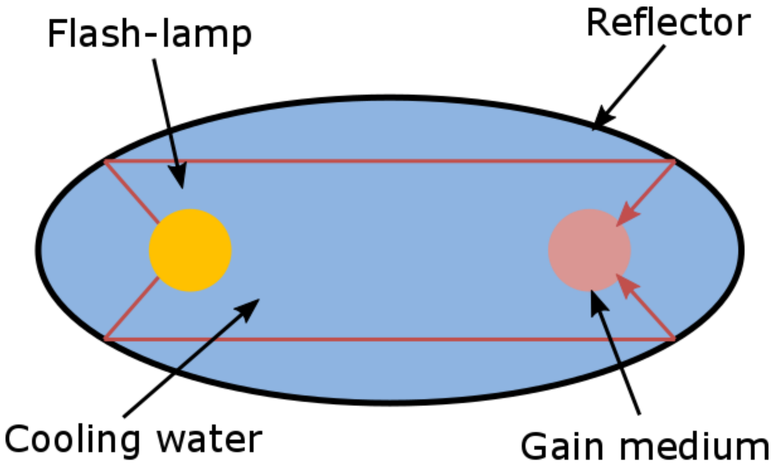
- Commercially available.
- Specifications enough for proton acceleration.
- 10 Hz repetition rate.
- Enough for proof of concept proton acceleration.
- We need higher repetition rate TW systems for practical applications in radioisotope production.

Challenges for higher repetition rate CPA Pump lasers:

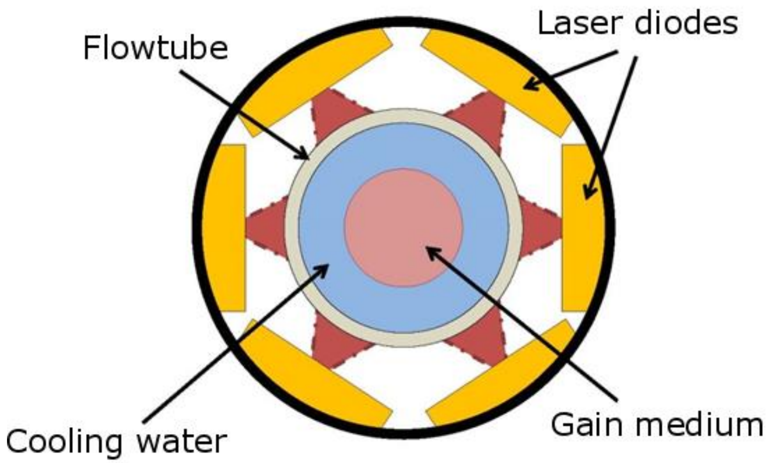
Pump lasers for Ti:Sapphire (Frequency doubled Nd:YAG, Nd:YLF)

- Change from flash lamps to diode pumping.
- Nd:YLF shows less thermal lensing effects.
- Distribute thermal loads into various beamlines.

Flash-lamp

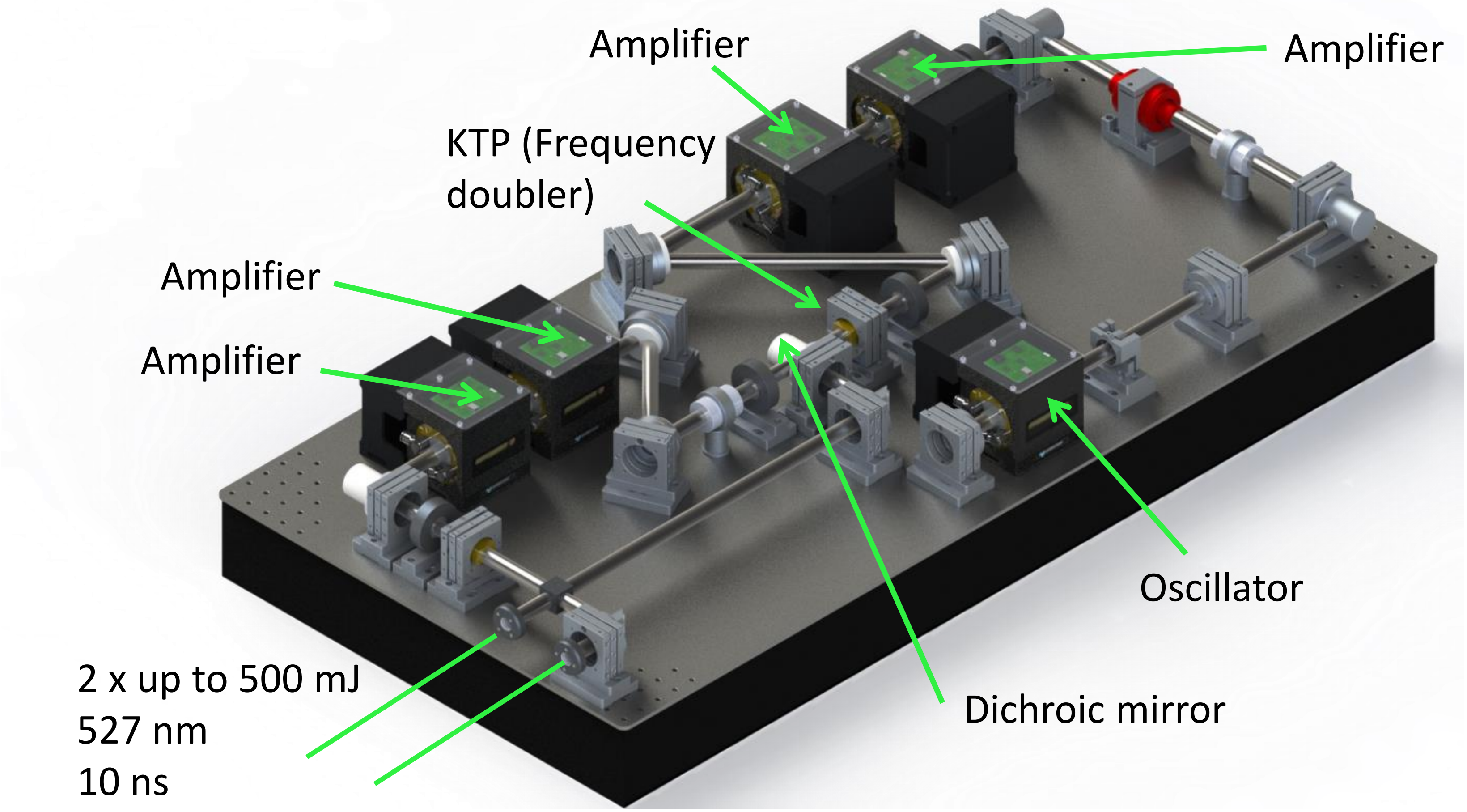


DPSS



“Enxaneta” DPSS laser head

“Olser” pumps

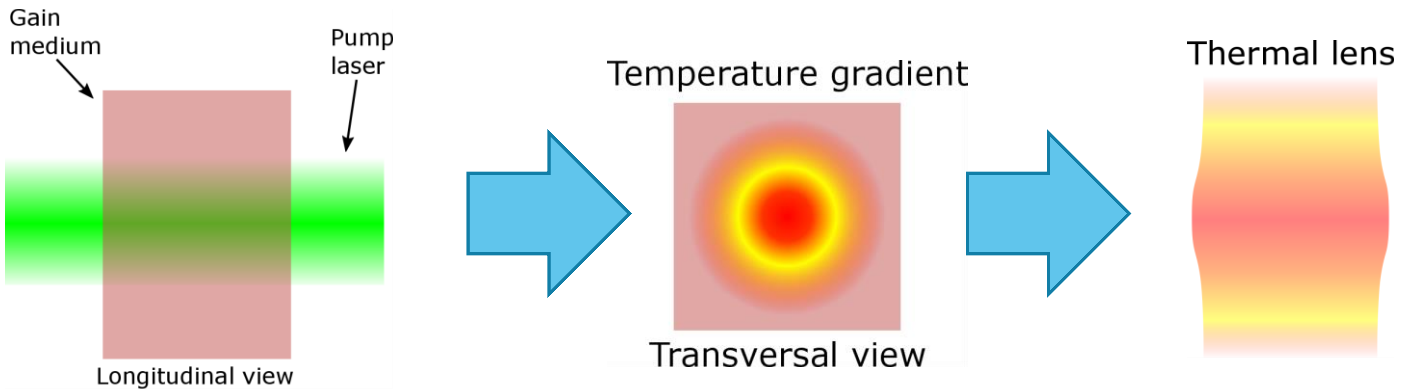


Amplifier
Amplifier
KTP (Frequency doubler)
Amplifier
Amplifier
Oscillator
2 x up to 500 mJ
527 nm
10 ns
Dichroic mirror

Challenges for higher repetition rate CPA Ti:Sapphire amplifiers:

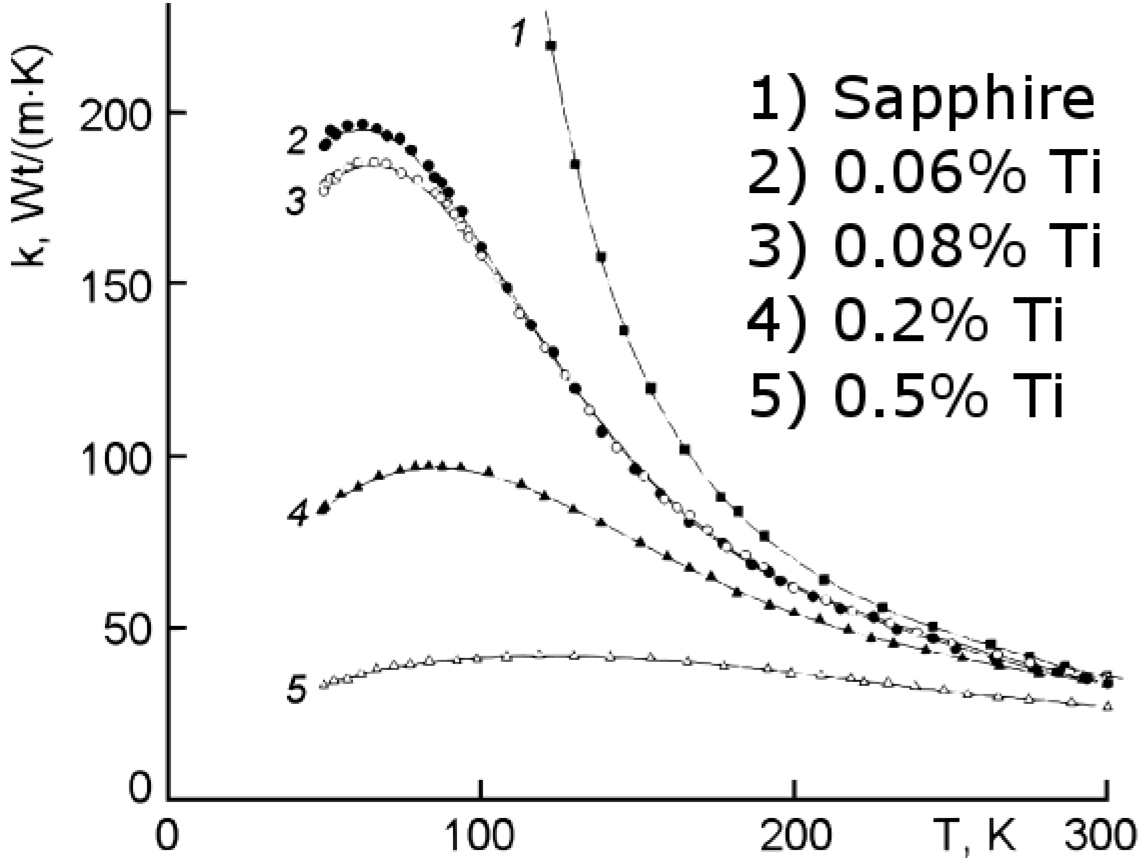
Ti:Sapphire thermal lensing.

$$f_{thermal} = \frac{2\pi\kappa\omega_{pump}^2}{P_{pump}(dn/dT)},$$



- Split thermal load into various amplifiers.
- Pre-compensate thermal lens by diverging seed beam.
- Cryogenic cooling.

Cryogenic cooling of Ti:Sapphire



P. A. Popov, et al. (2011). *Functional Materials*, *18*(4), 476–480.

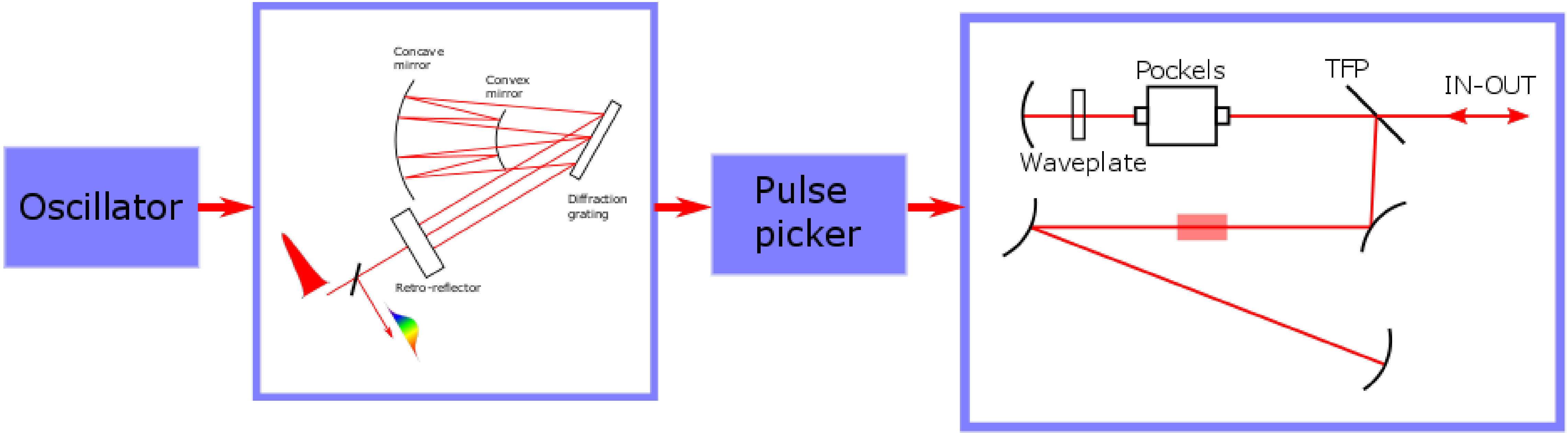
$$f_{thermal} = \frac{2\pi\kappa\omega_{pump}^2}{P_{pump}(dn/dT)}$$

- dn/dT becomes smaller by a factor of two with cryogenic cooling.
- This is the best way to minimize thermal effects for high average power pumping.

Defranzo, A. C., & Pazol, B. G. (1993). Applied Optics, 32(13), 2224–34.

proton laser

Our CPA system front end:

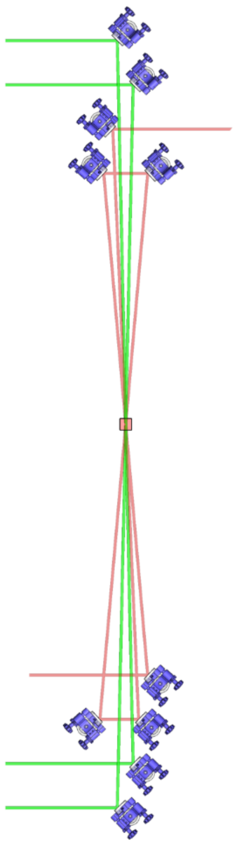


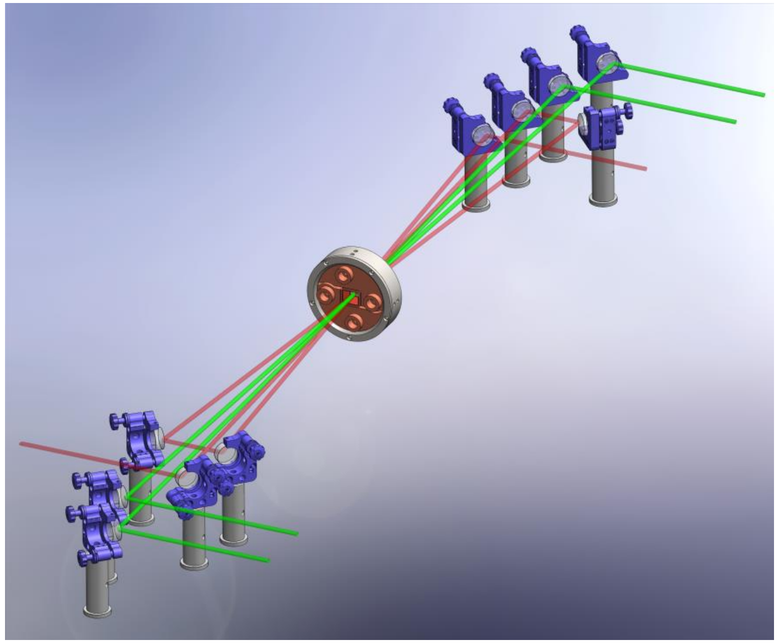
E=1,5 mJ f=100 Hz pulse=100 ps

Input seed into the multi-pass amplification stages

Multi-pass amplification stages

- Two 3-pass amplification stages.
- 8 and 16 mm Ti:Sapphire crystals.
- Water cooled.
- 1st stage 100 mJ pumping.
- 2nd stage 750 mJ pumping.
- Telescopes to pre-compensate thermal lens.
- Convex mirrors in the amplifier for further compensation.

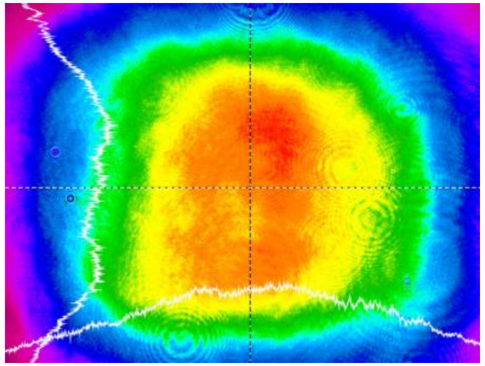




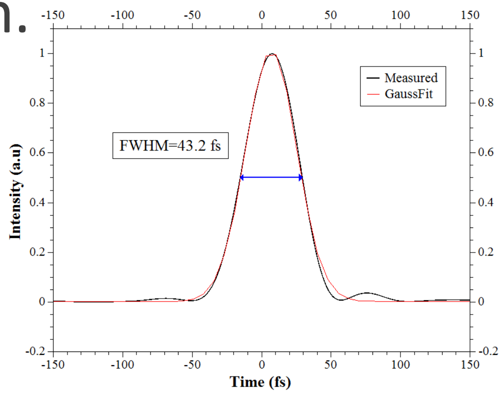
Output characteristics of the system

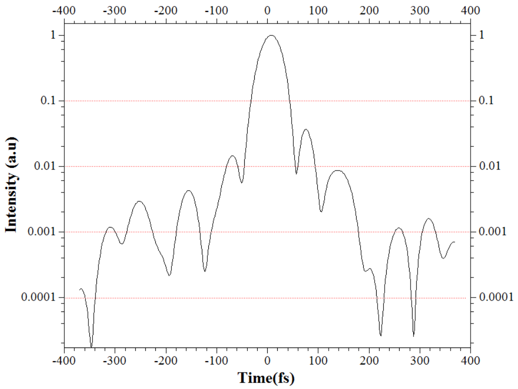
- E=93 mJ after compression.
- t=43.2 fs.
- 2.1 TW
- Dx=8.2 mm.
- Dy=7.7 mm.

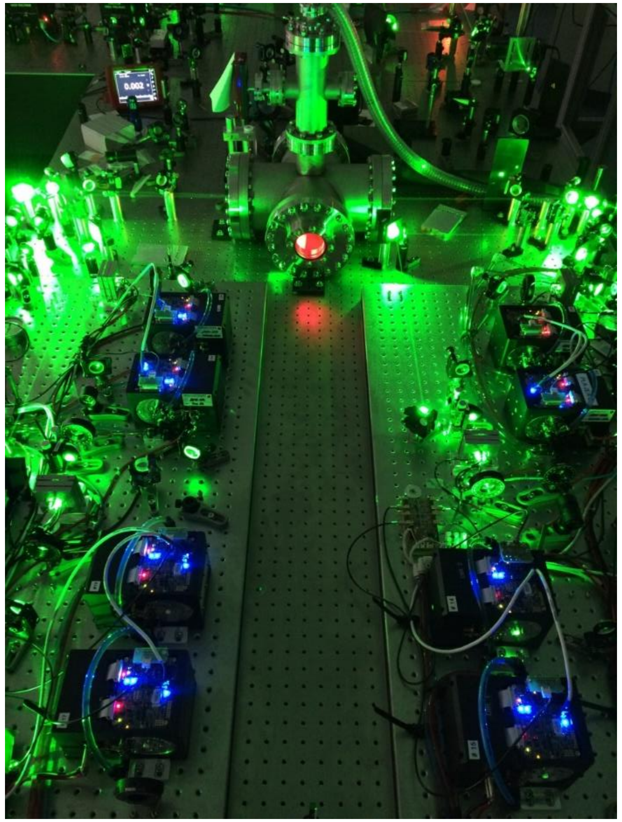
Output beam profile



Pulse duration

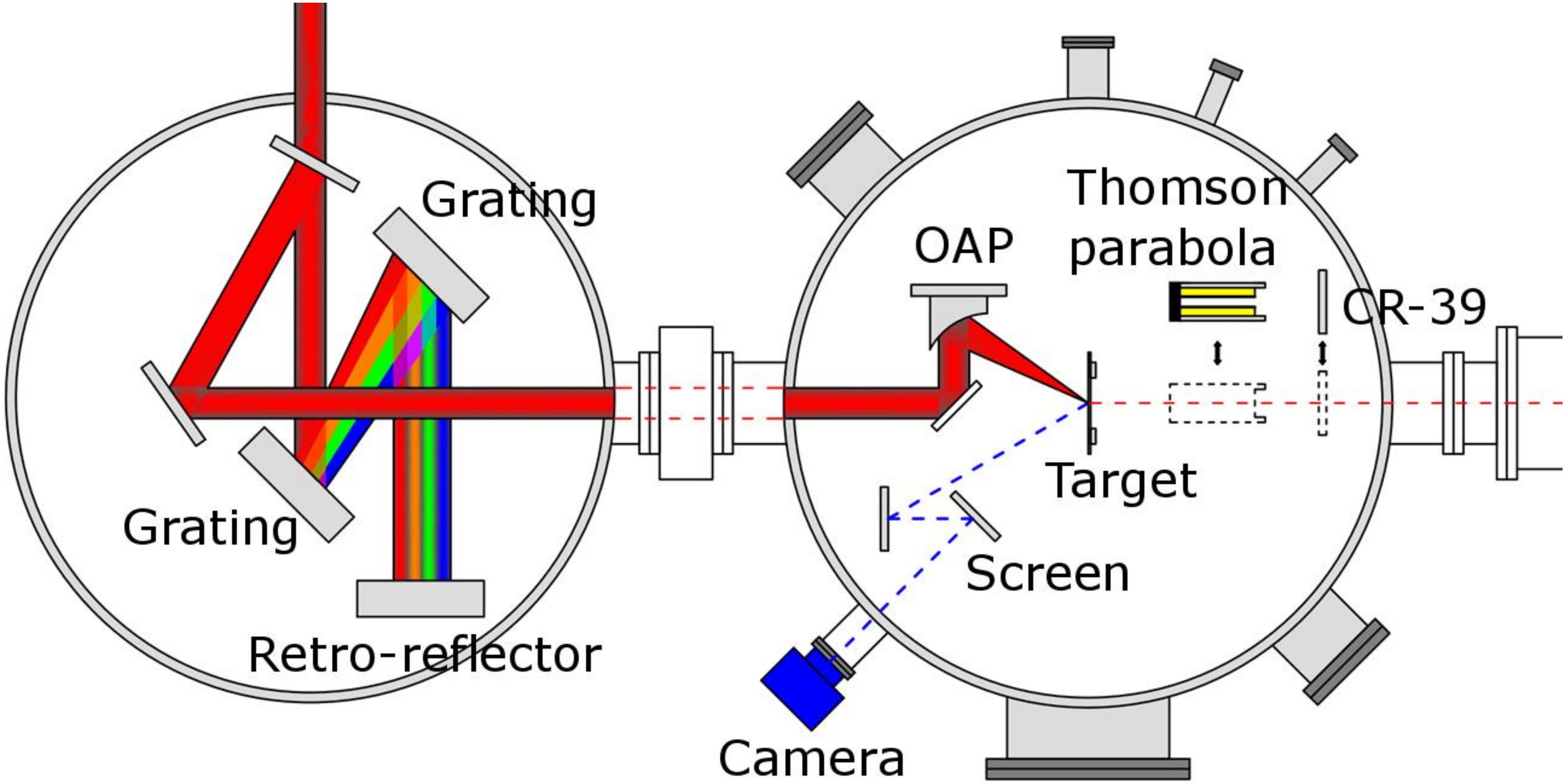




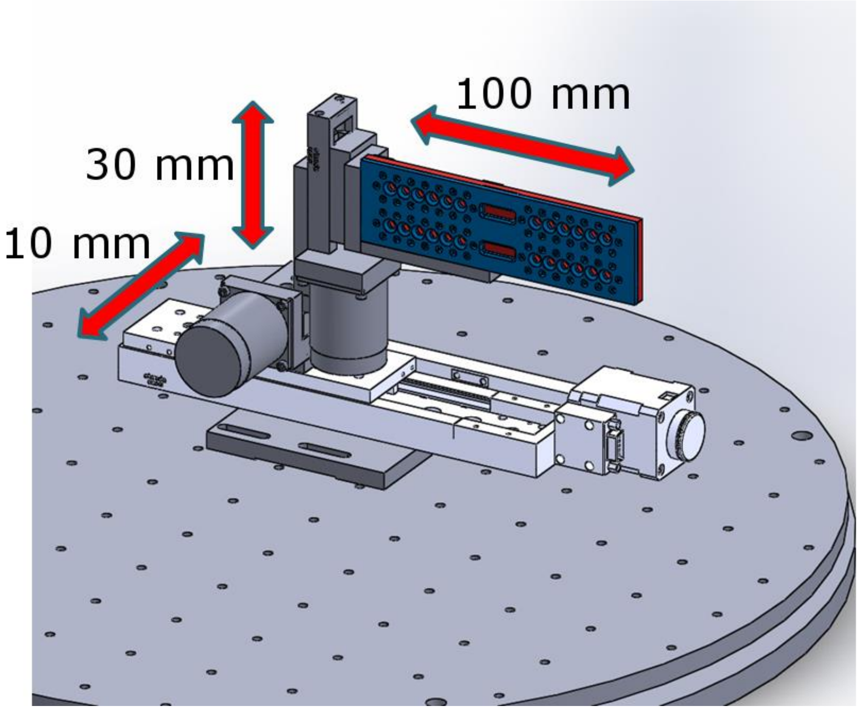


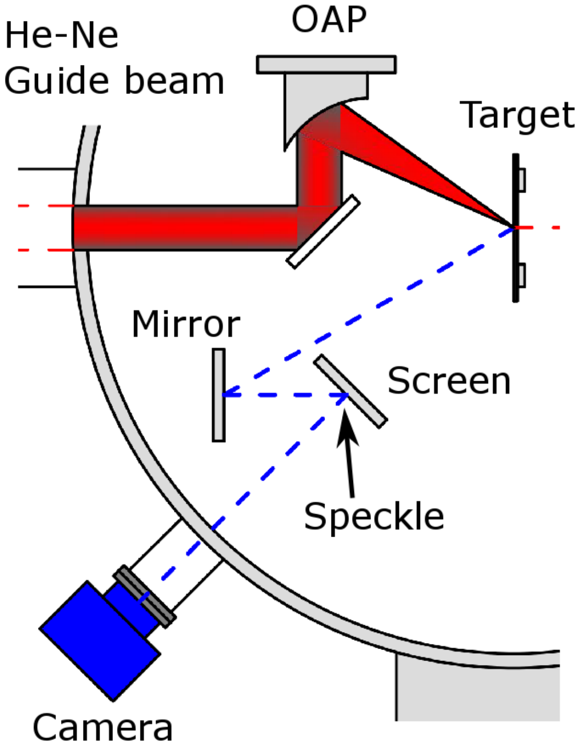
proton laser

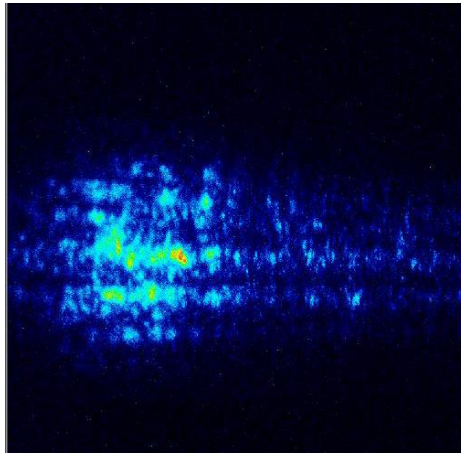
Compression and interaction chambers



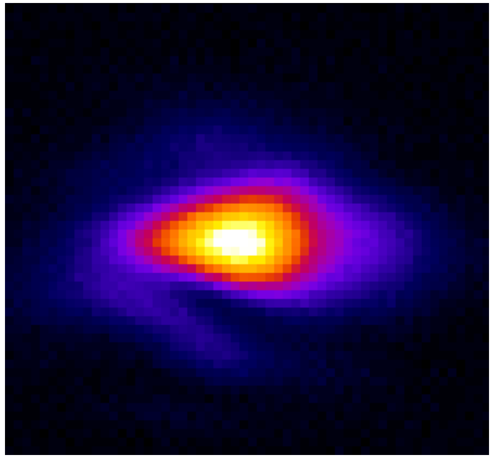
Target positioning

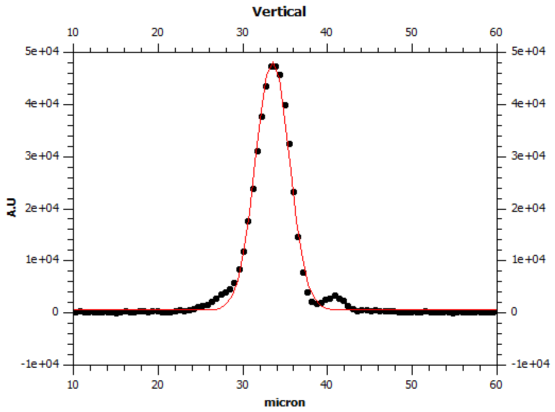


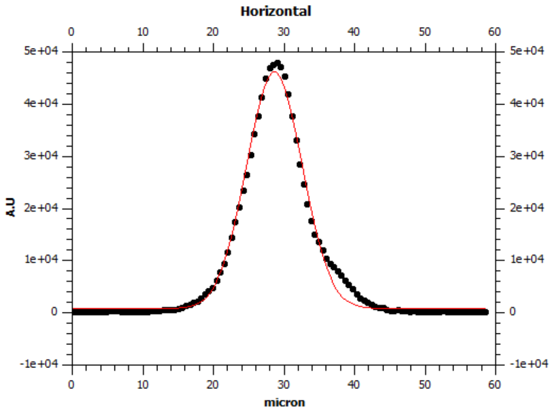




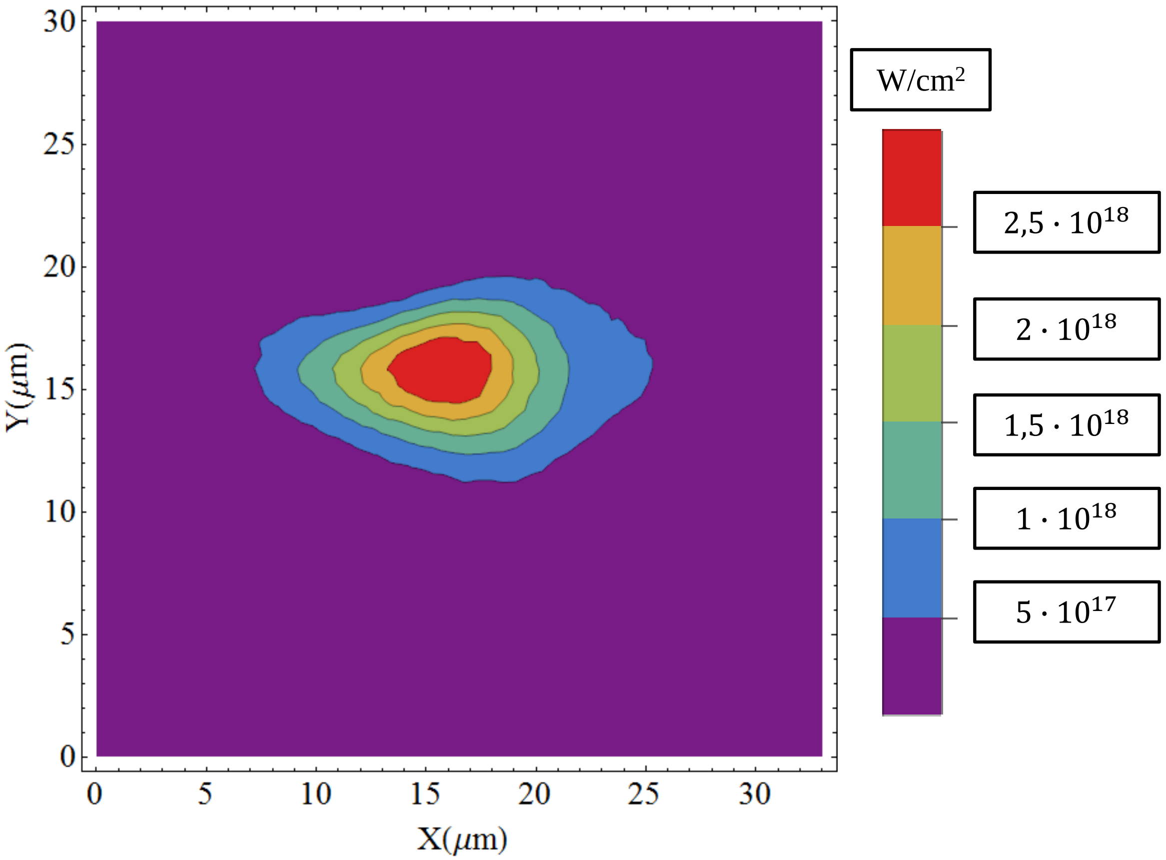
Focal spot





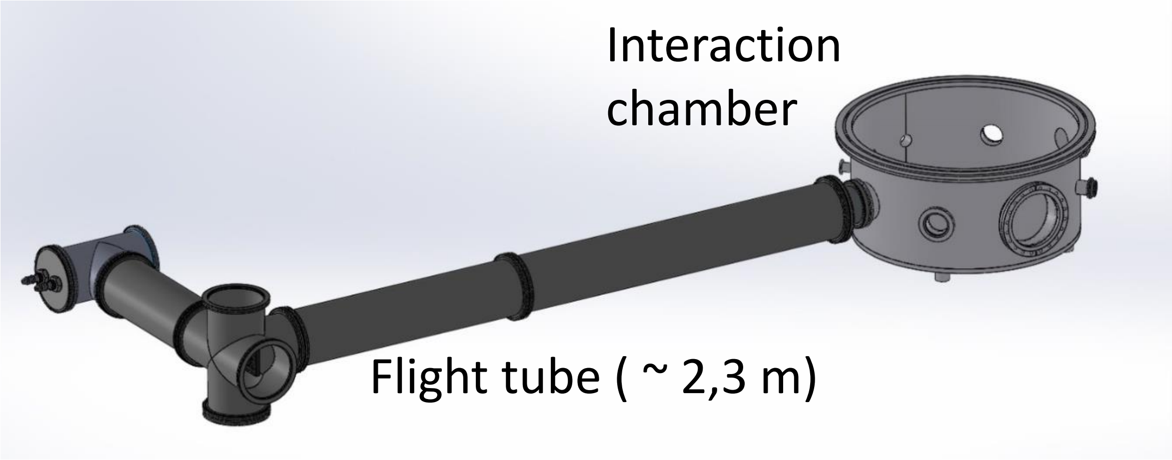


FWHM (x)=9 um
FWHM(y)=5 um

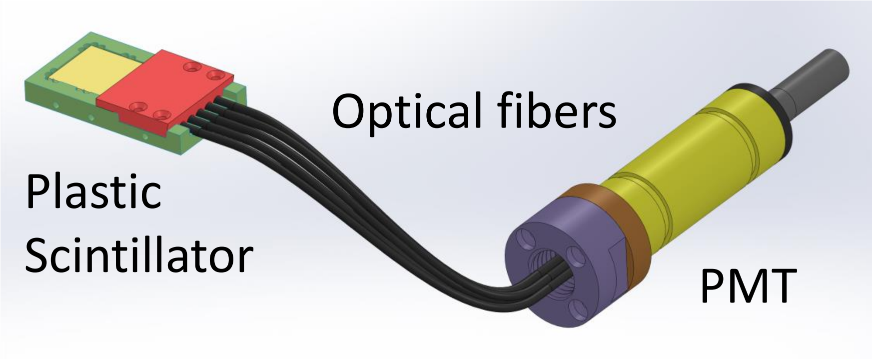


proton laser

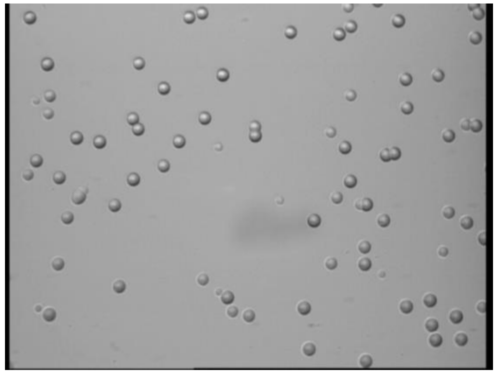
Diagnostics
Time of Flight detector:

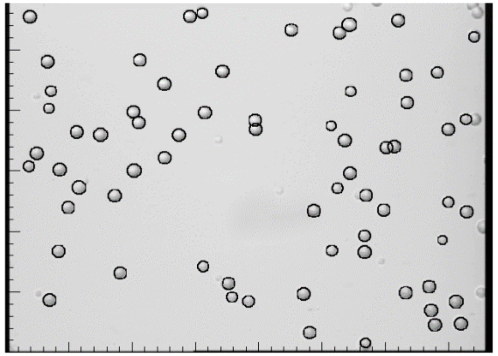


Scintillation detector

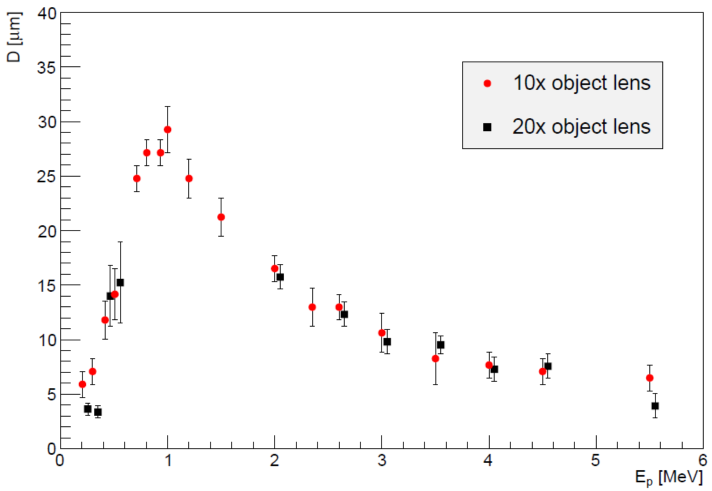


Diagnostics
CR39 chips:

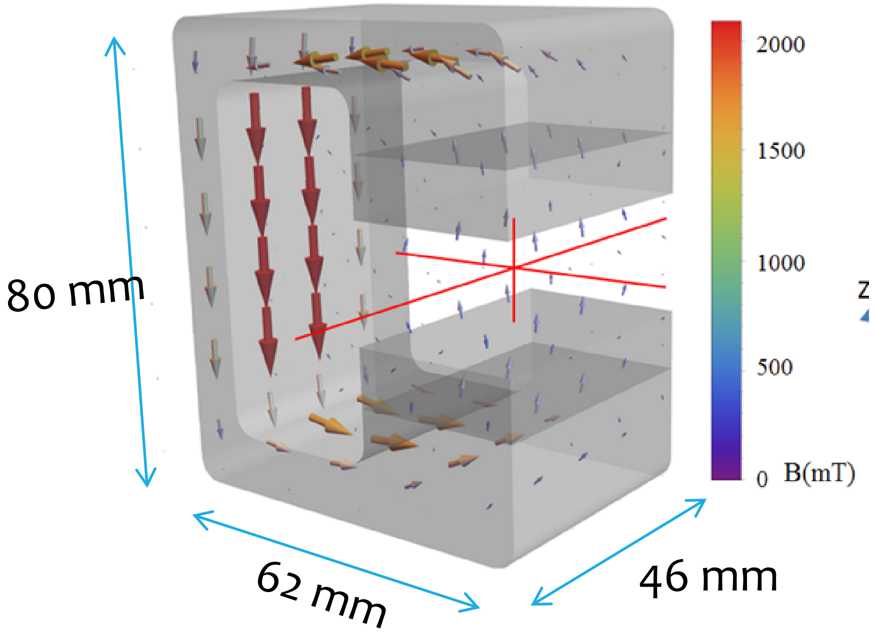


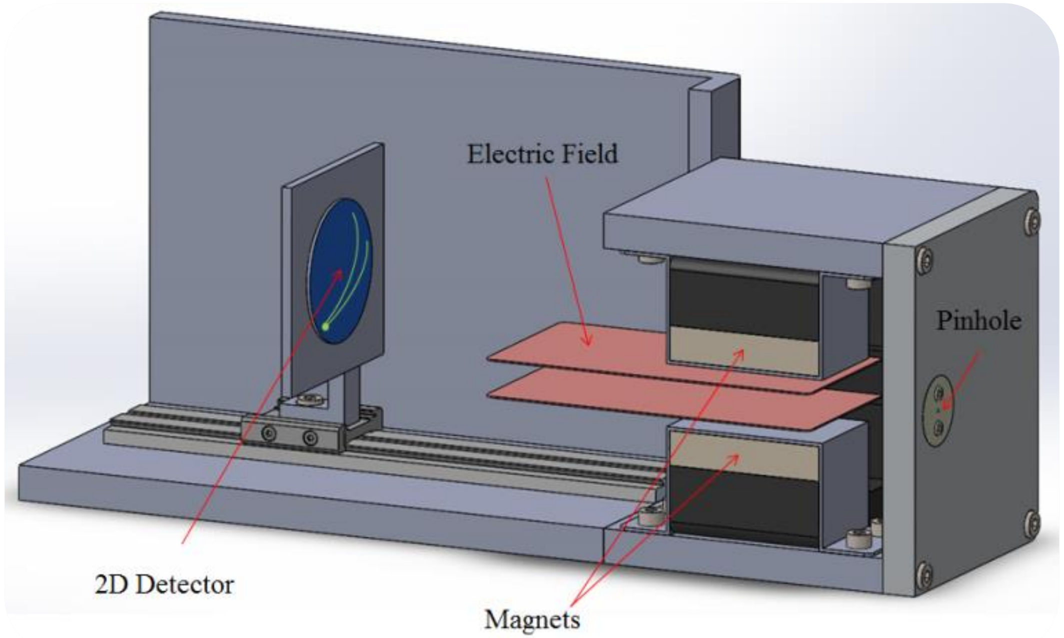


- Response calibrated in a conventional accelerator.
- Calibration curve relates proton energy with track diameter.

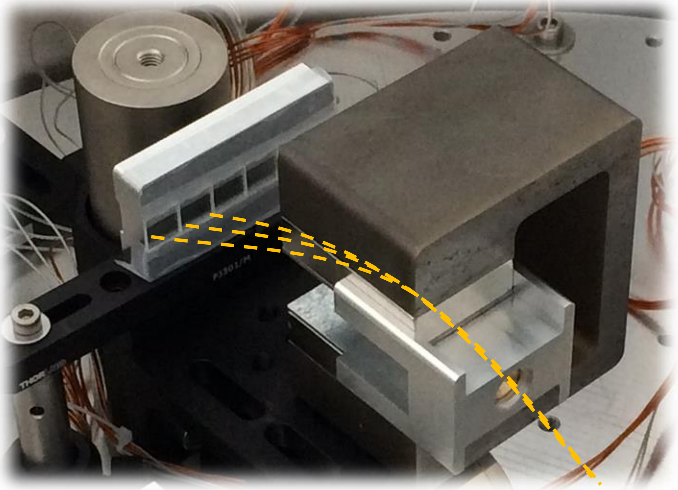


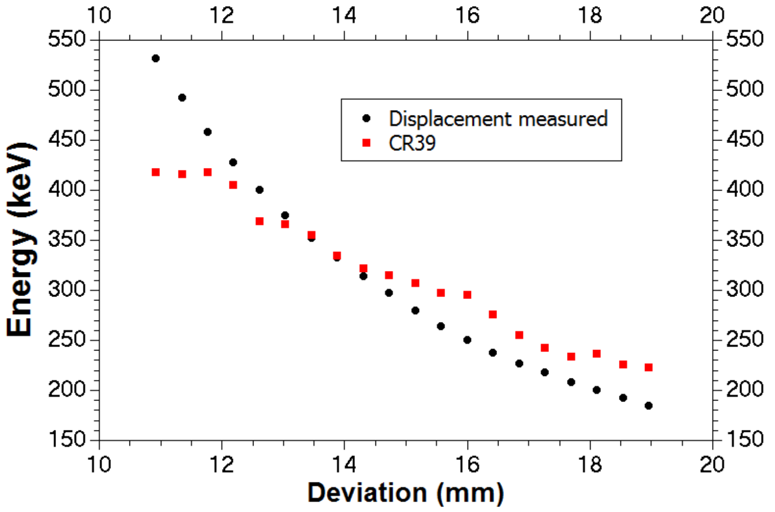
Diagnostics
Thomson parabola

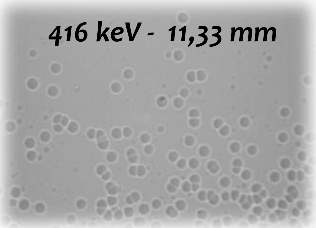


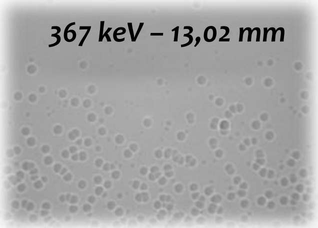


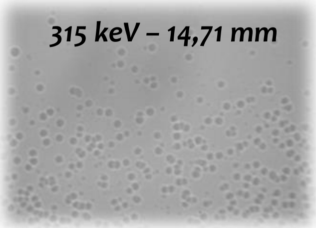
Results
Proton acceleration:

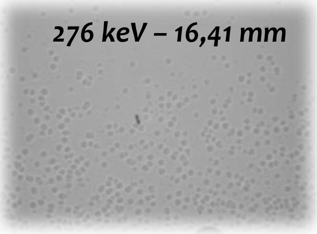




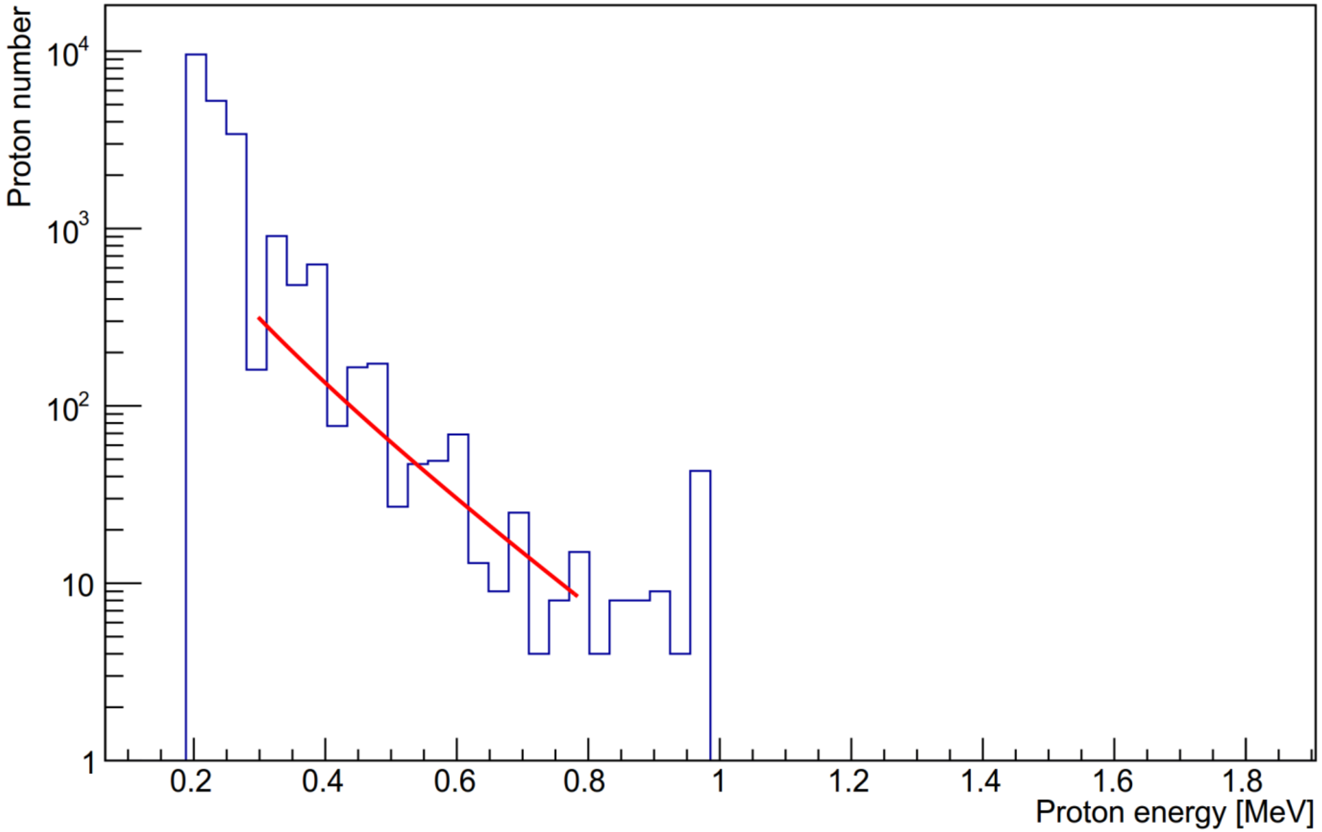








Results
Proton spectra:



System upgrade

- Drive pump lasers for the second multi-pass amplifier up to 500 mJ per beam (total pump energy 2 J).
- Adjust beam sizes of pump and seed to maintain fluences.
- Implementation of cryogenic cooling.

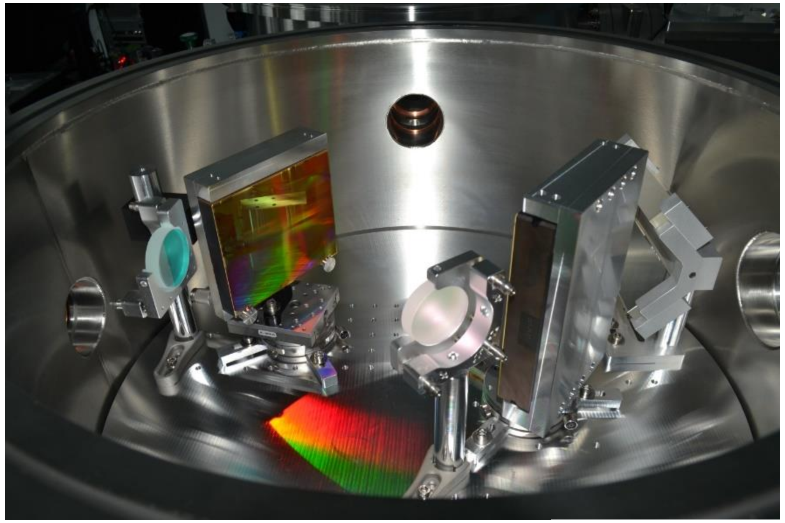
Summary

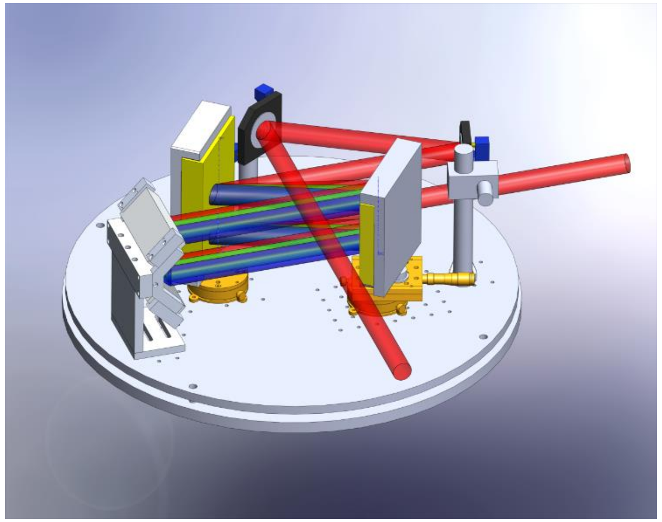
We have implemented a working TW laser system at a repetition rate of 100 Hz.

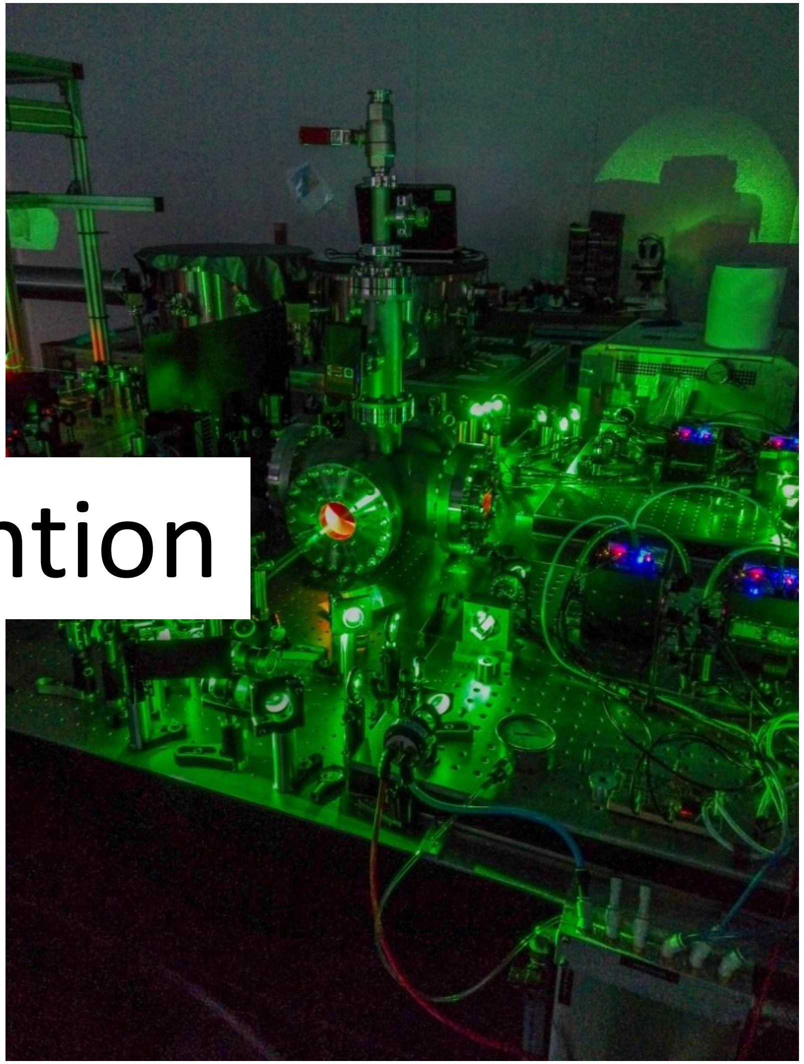
Telescopes and convex mirrors in the multi-pass amplification stages pre-compensate the termal lens effects.

Our laser is capable of accelerating protons up to 1 MeV in the current state.

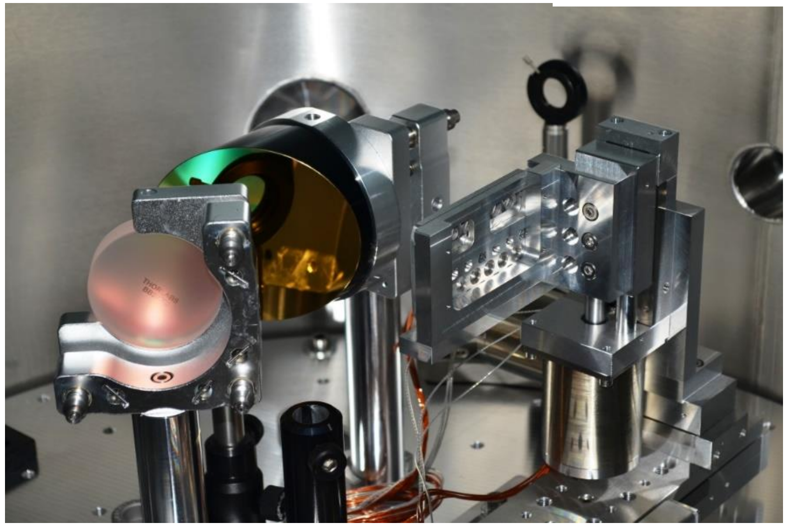
Work in an energy upgrade is in progress to reach 10 TW at 100 Hz using cryogenic cooling in the last amplification stage.







Thanks for your attention



proton laser