Robust energy enhancement of ultra-short pulse laser accelerated protons from reduced mass targets

K. Zeil, J. Metzkes, T. Kluge, M. Bussmann, T. E. Cowan, S. D. Kraft, R. Sauerbrey, B. Schmidt, M. Zier, U. Schramm

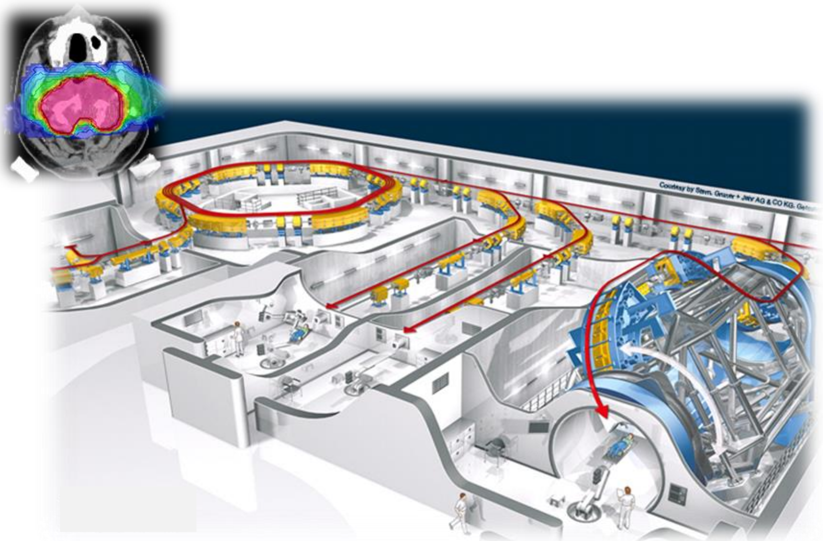
Partner von DRESDEN concept exzellenz-dresden.de

HZDR
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Our motivation – Laser driven ion therapy

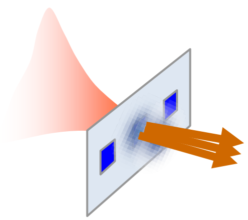
Conventional ion therapy

- Localized dose deposition for precise tumor treatment
- Beneficial for 10-20% of patients

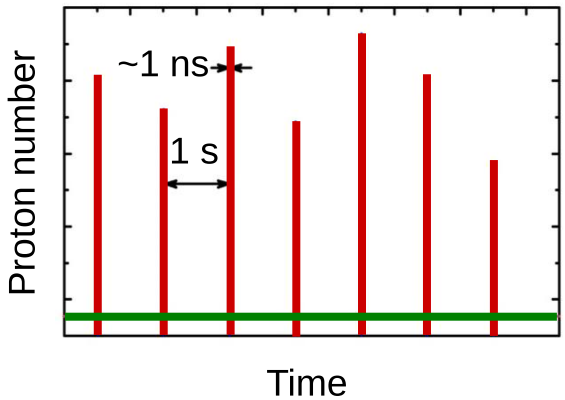


- Large scale setup: accelerator, beam guidance & radiation shielding

Laser driven ion therapy



- high acceleration gradients TV/m
→ compact source and laser beam transport

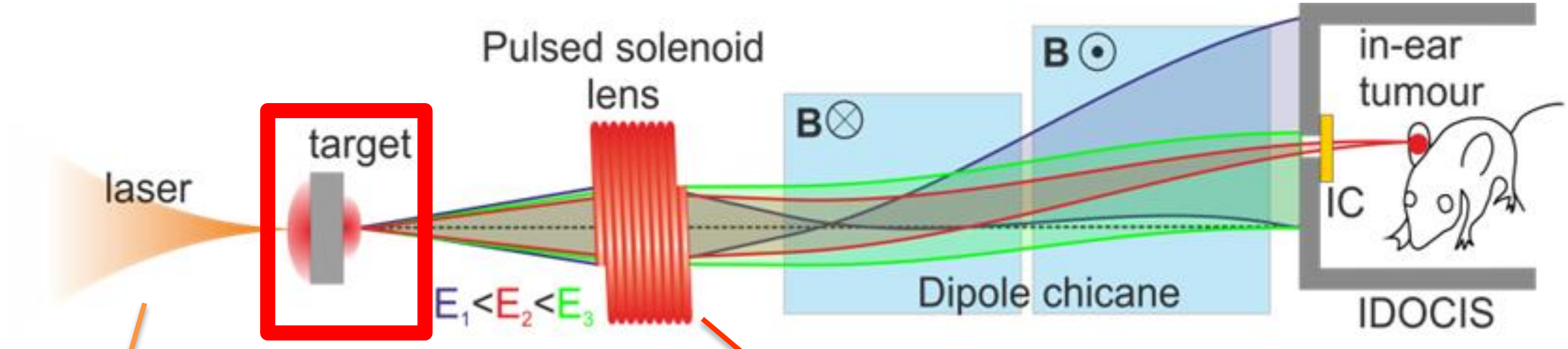


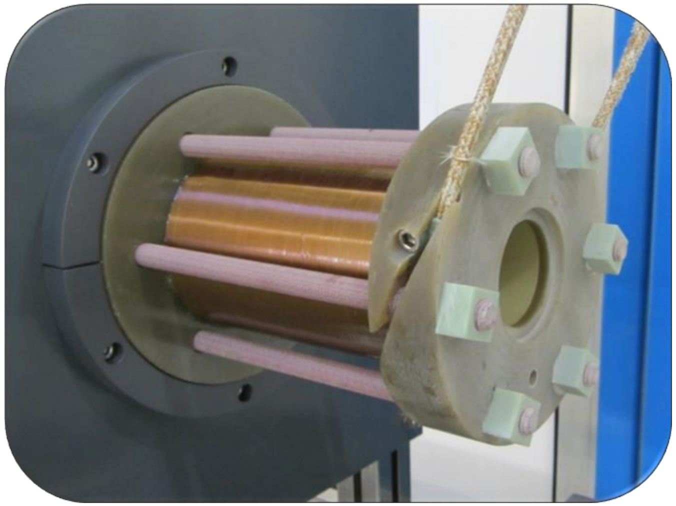
- 10^{10} to 10^{13} ions per pulse
- Short ion pulses: fs to ps at source
- Broad energy spectrum

→ Investigation of radiobiological effects

Facility Image courtesy by Stern, Gruner+Jahr AG & Co KG, Germany
Dose Image courtesy by O. Jäkel, DKFZ Heidelberg, Germany

in vitro irradiations have been performed [Yogo APL 2011, Zeil APB 2012, Bin APL 2012, Doria AIP 2012]



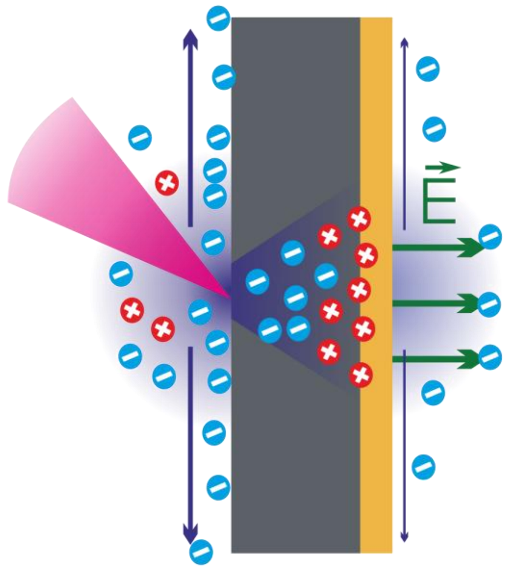


- **Ti:Sapph Draco so far 4 J in 30 fs**
- **upgrade to 30 J in 30 fs @ 1 Hz**

Laser Ion Generation, Handling and Transport

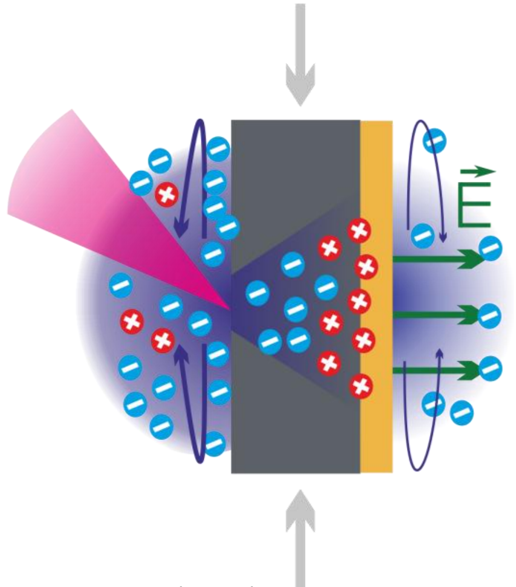
oncooptics

TNSA from Reduced Mass Targets



TNSA at large foil

- electrons laterally spread along the target surface



RMT

- electron reflection at target edges
- T_e and n_e increased
- electron reflux → further heating

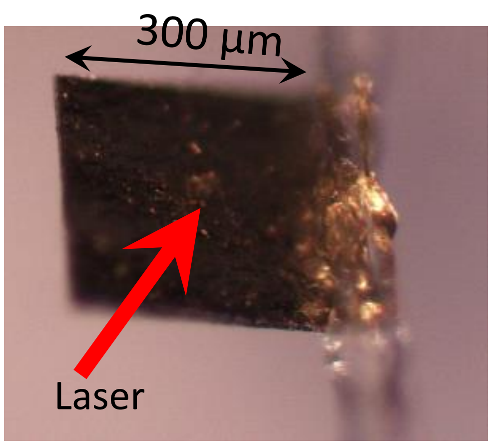
→ increased proton energies

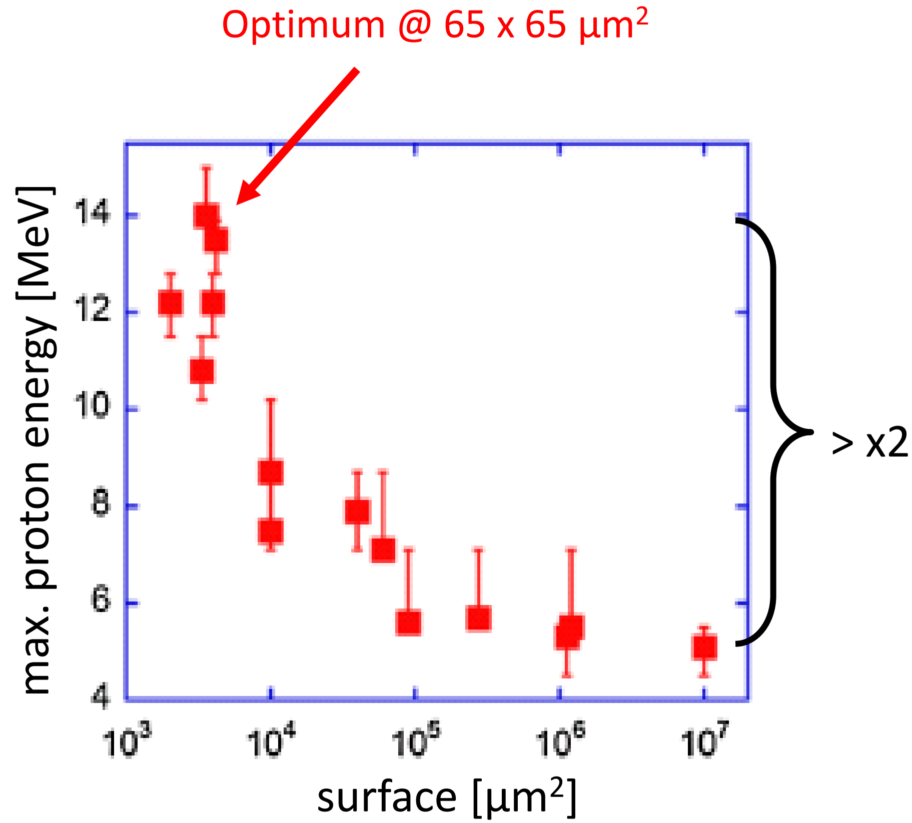
Psikal Phys. Plasm. 15 (2008), Kluge Phys. Plasm. 17 (2010)

LULI experiment

100 TW LULI laser

- τ_L = 400 fs @ 2ω
- I ≈ 10^{19} W/cm^2 on target
- 2 µm thick foil sections of gold

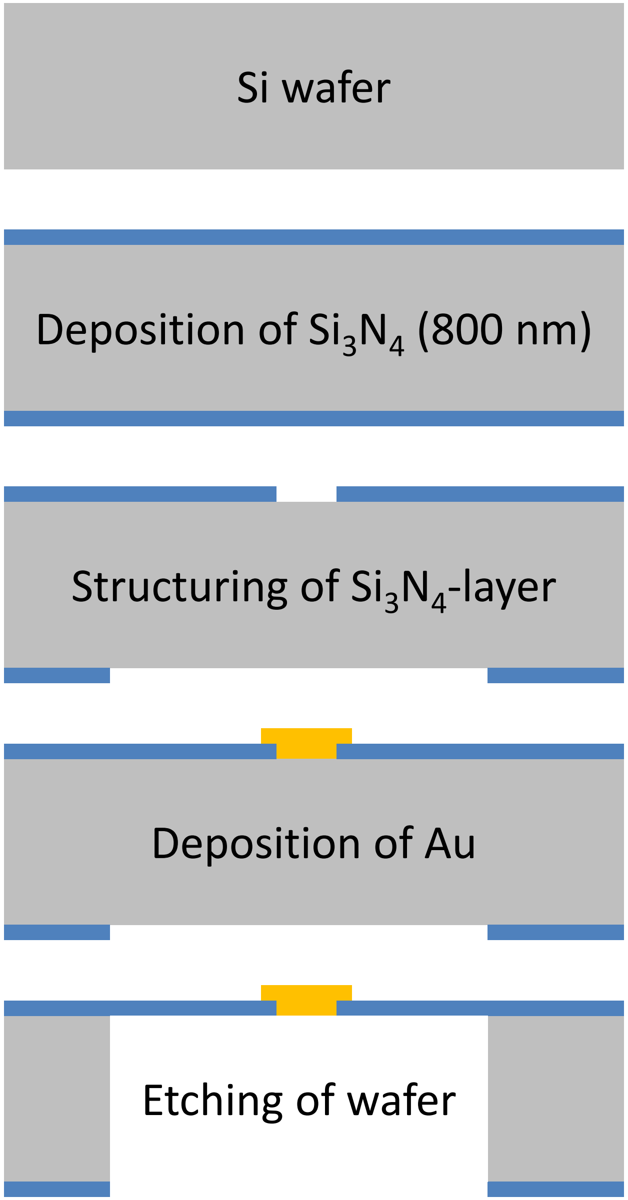


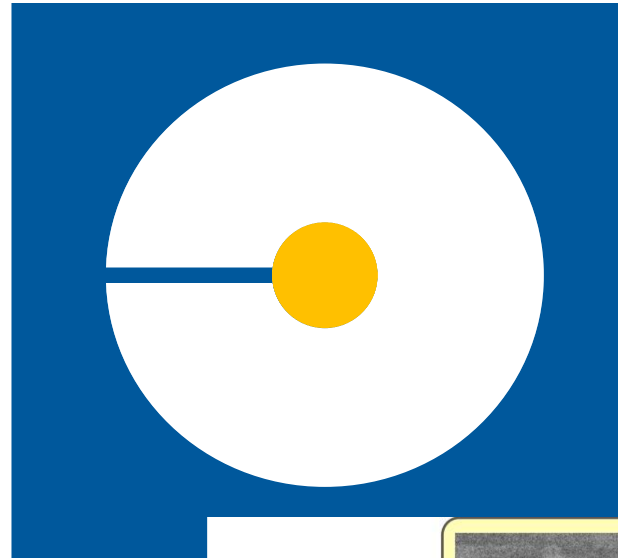


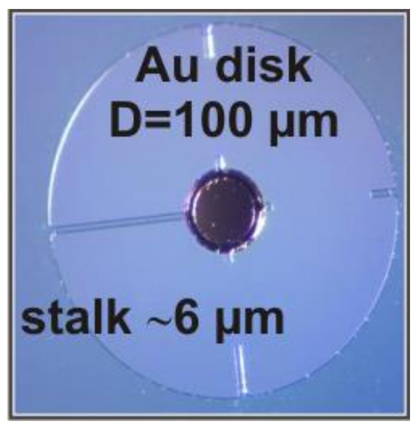
- But small repetition rate : LULI ca. 3 h^{-1} ↔ Draco 10 Hz
- Exploration of maximum energy increase for the given laser parameter and target thickness

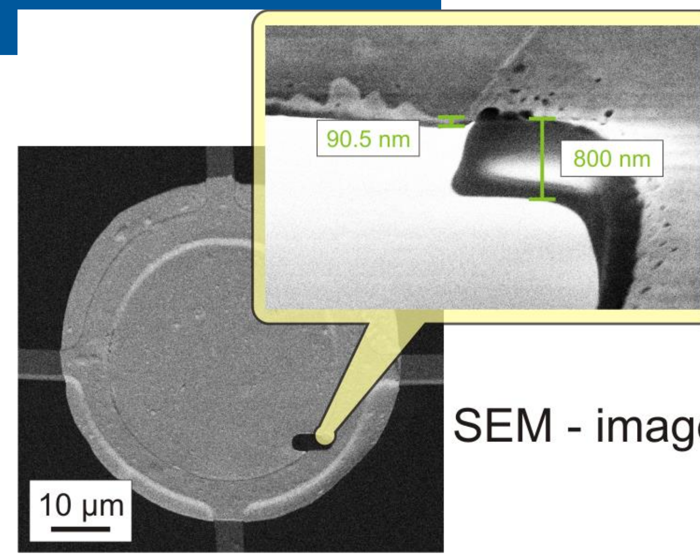
Buffechoux *et al.*, PRL 105 (2010)

Target design – Gold disks





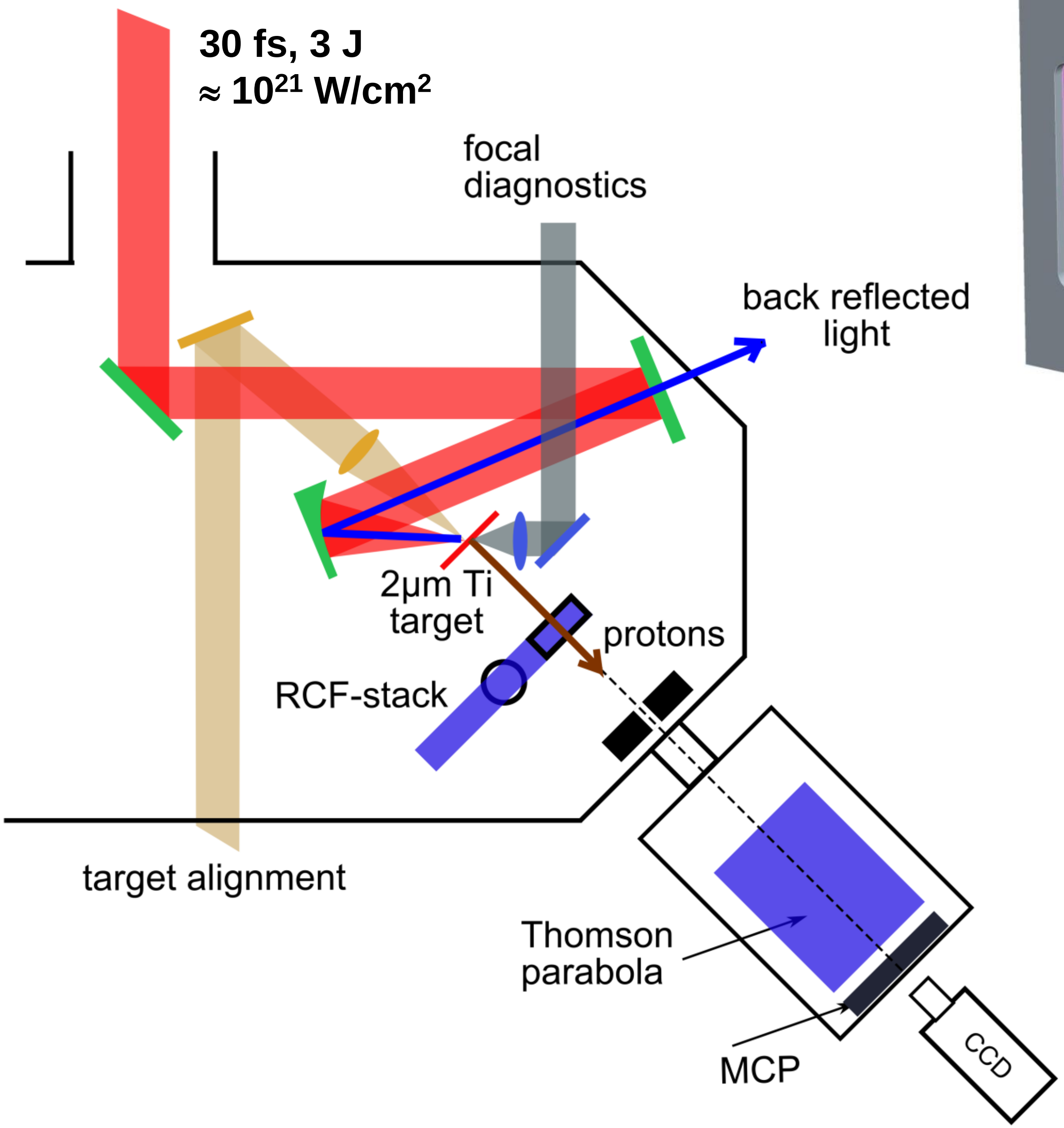


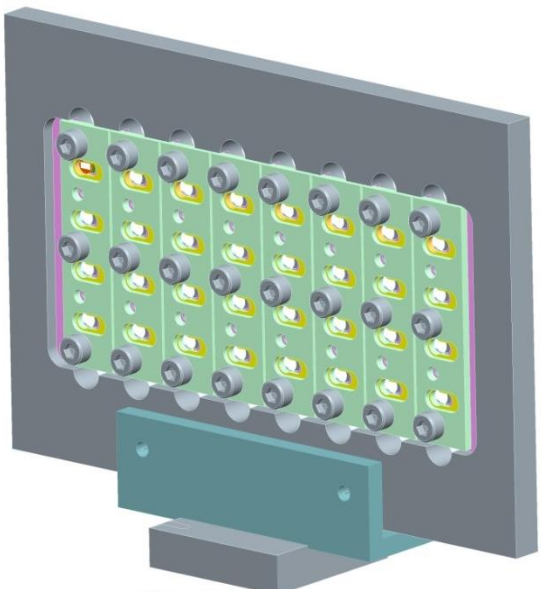


SEM - image

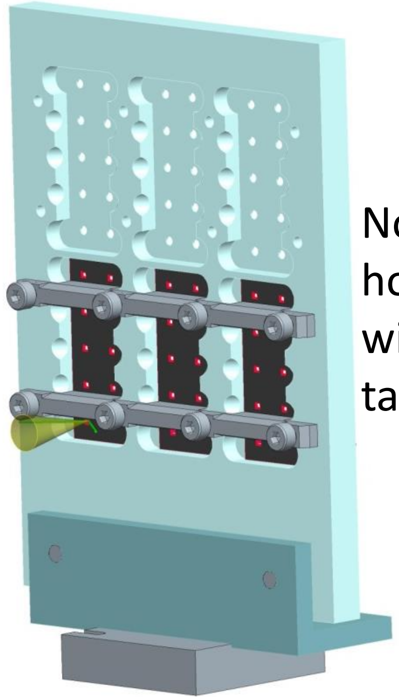
Diameters: 20 – 100 µm
Thicknesses: 100 nm – 1 µm

Experimental Setup





Mounting of single targets

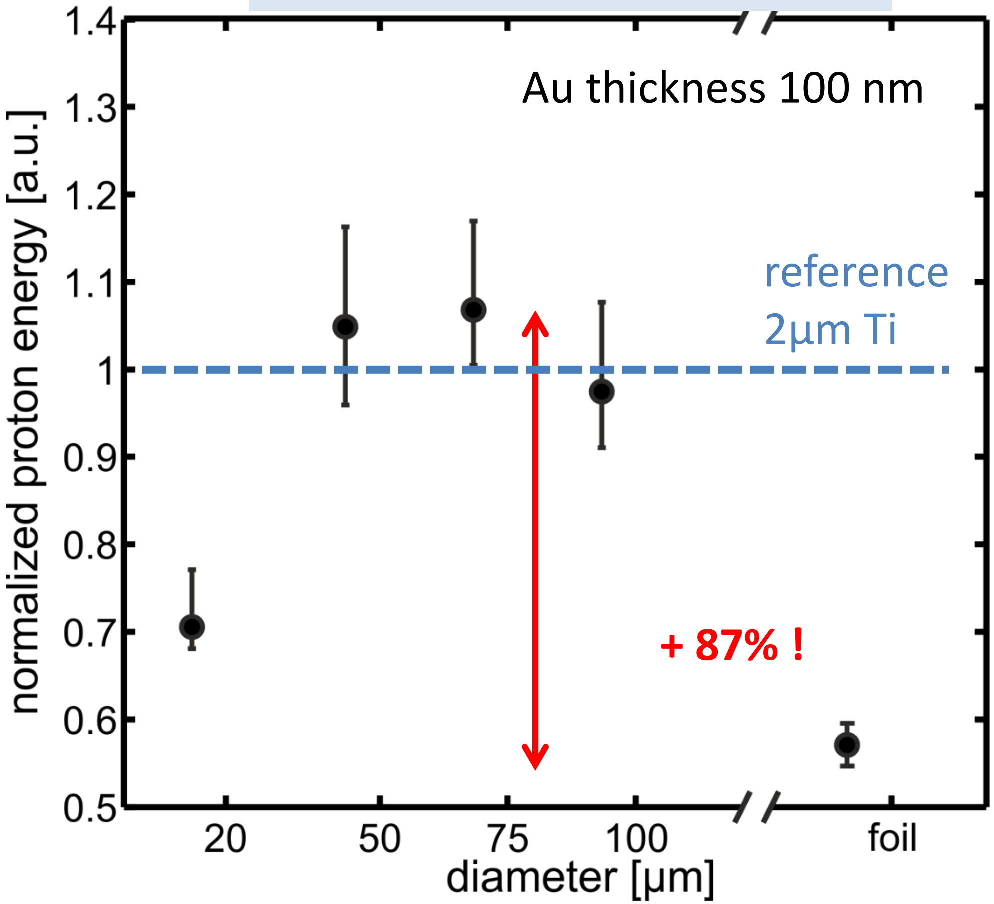


Novel target holder design with separated target support

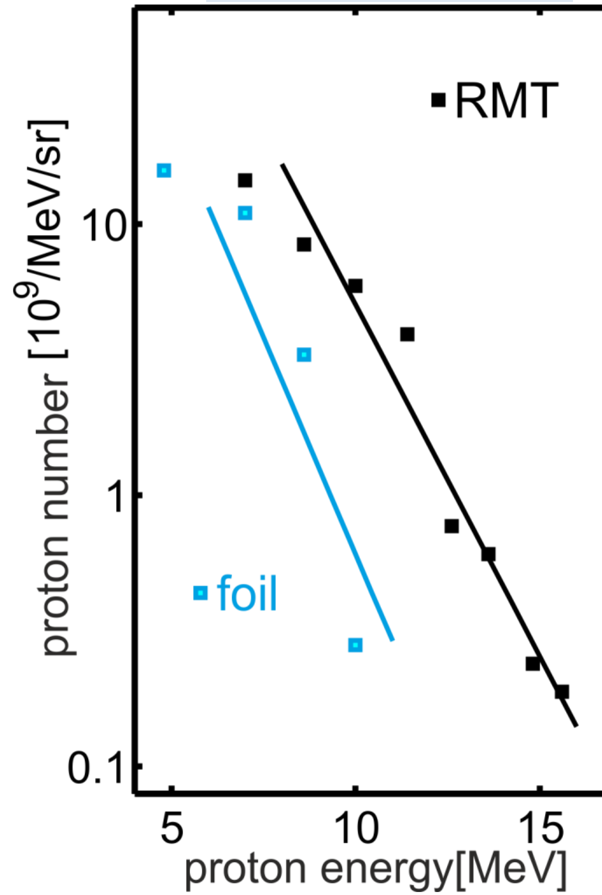
Results gold disks with ultra-short pulses

HZDR

maximum proton energy

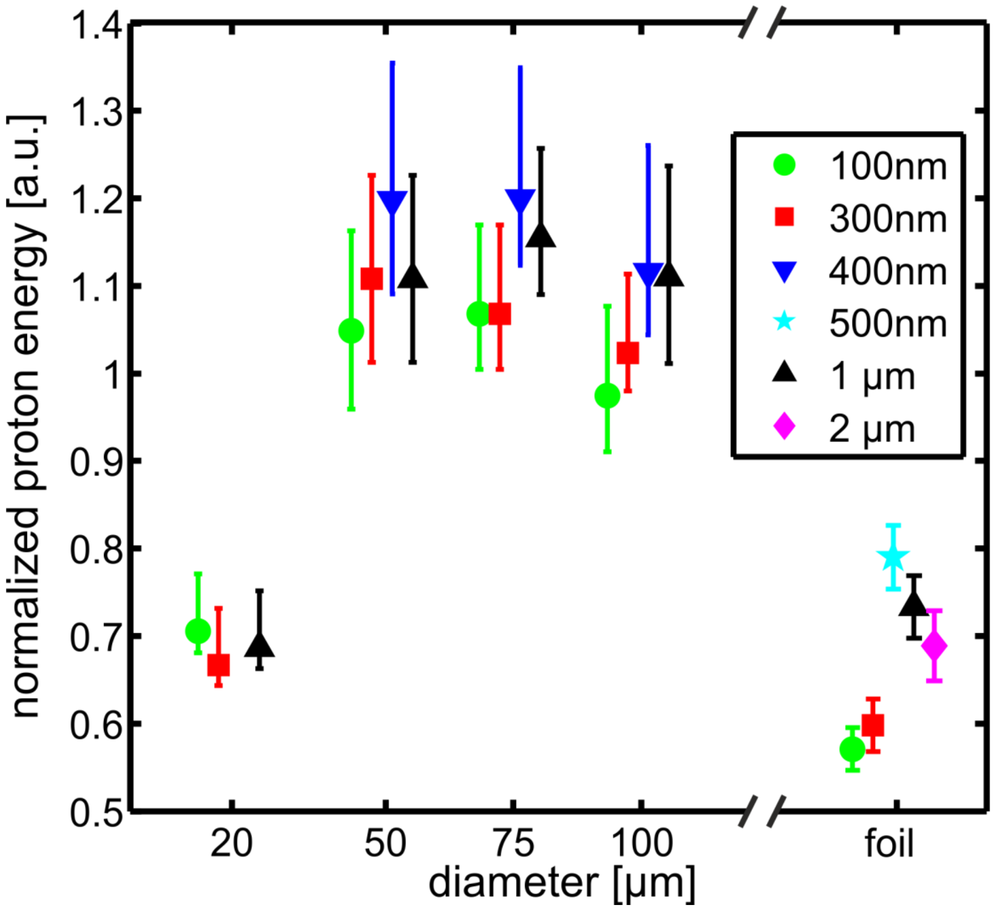


proton yield

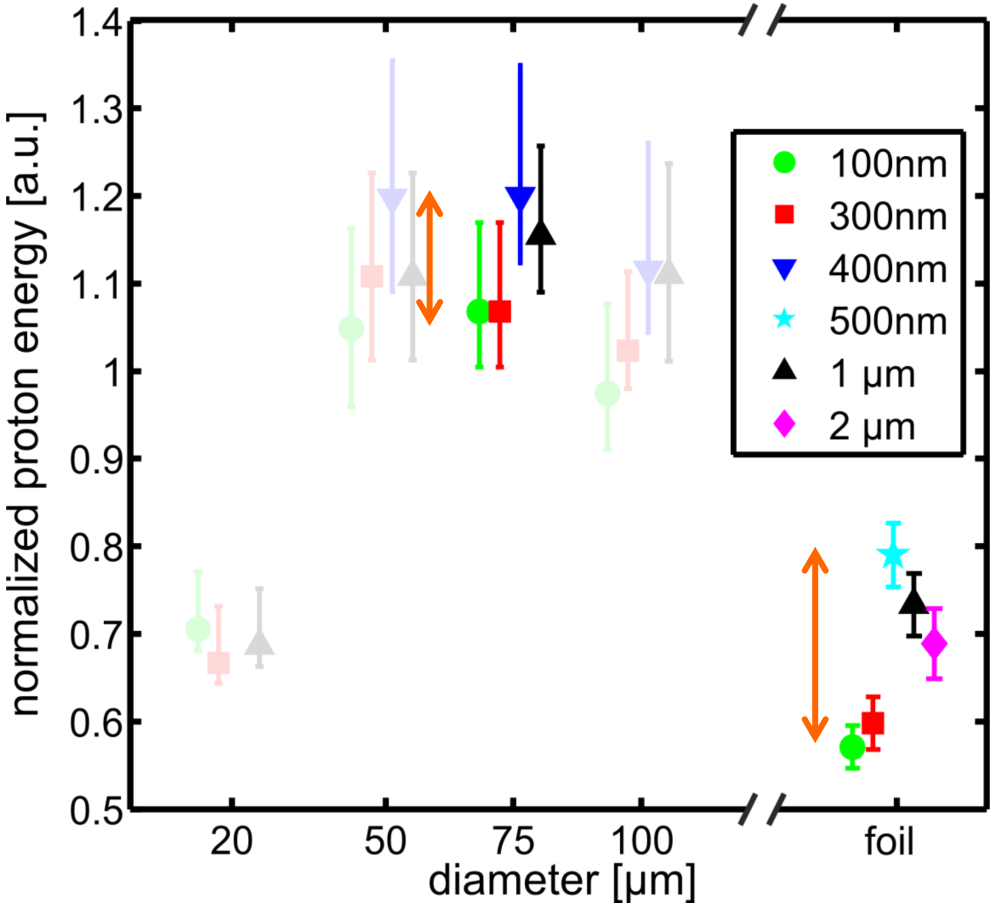


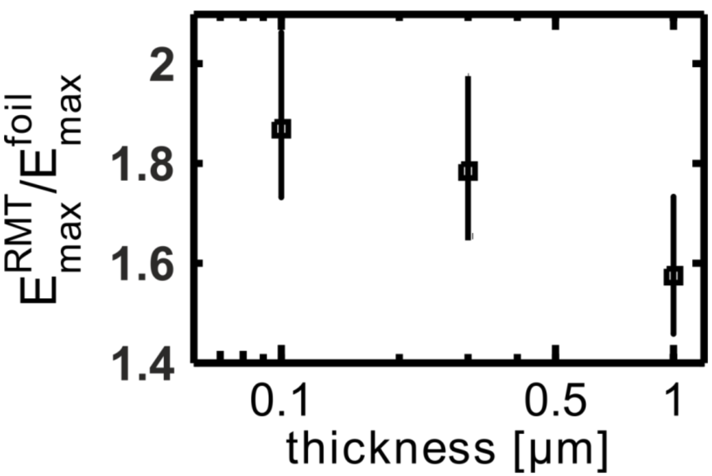
- absolute gain in proton energy and yield for given laser parameters !!
- time averaged hotter, denser and more homogenous sheath

Results of thickness dependency



Results of thickness dependency

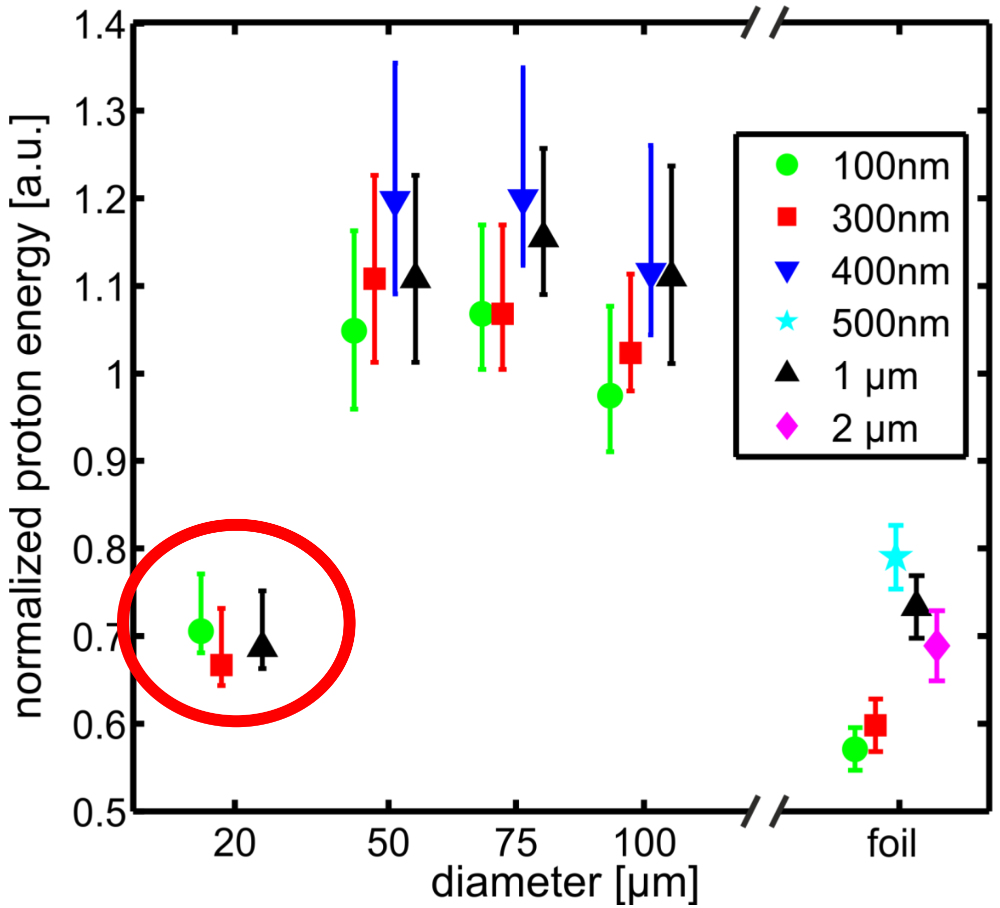




Less pronounced thickness dependence for RMT

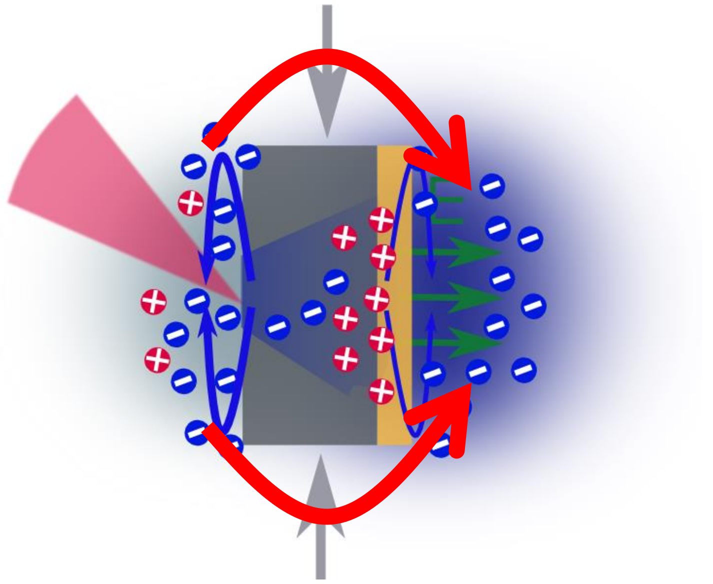
→ Robust against laser contrast fluctuation

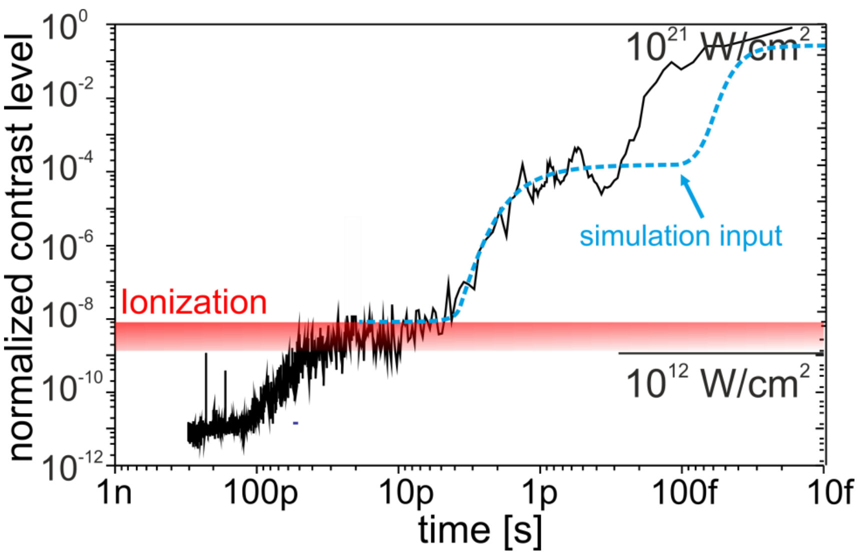
Energy drop for smallest targets?



- smallest target size would allow for reacceleration of electrons during main pulse interaction

Effect of preplasma?



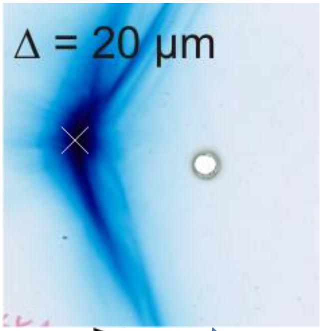


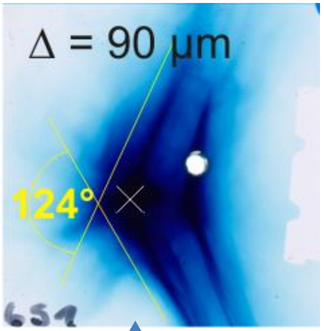
Surrounding preplasma corona worsens rear side field gradient

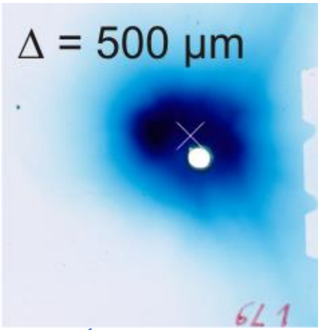
- no surounding preplasma for given contrast

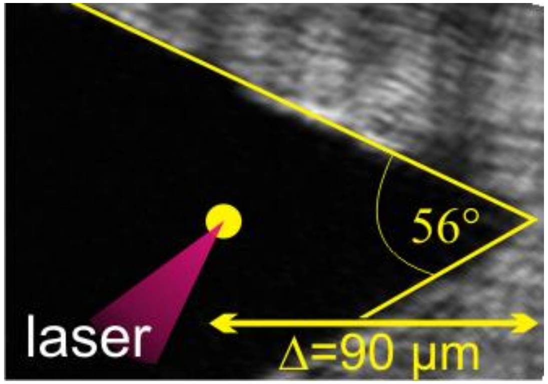
Sokollik NJP 12 (2010), Toncian Phys. Plasm. 18 (2011)

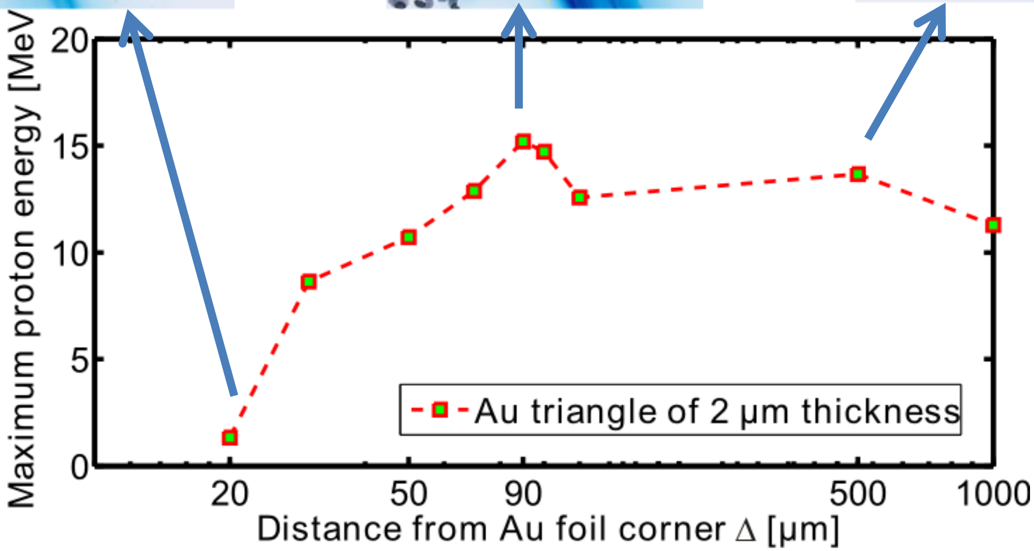
Influence of edge fields





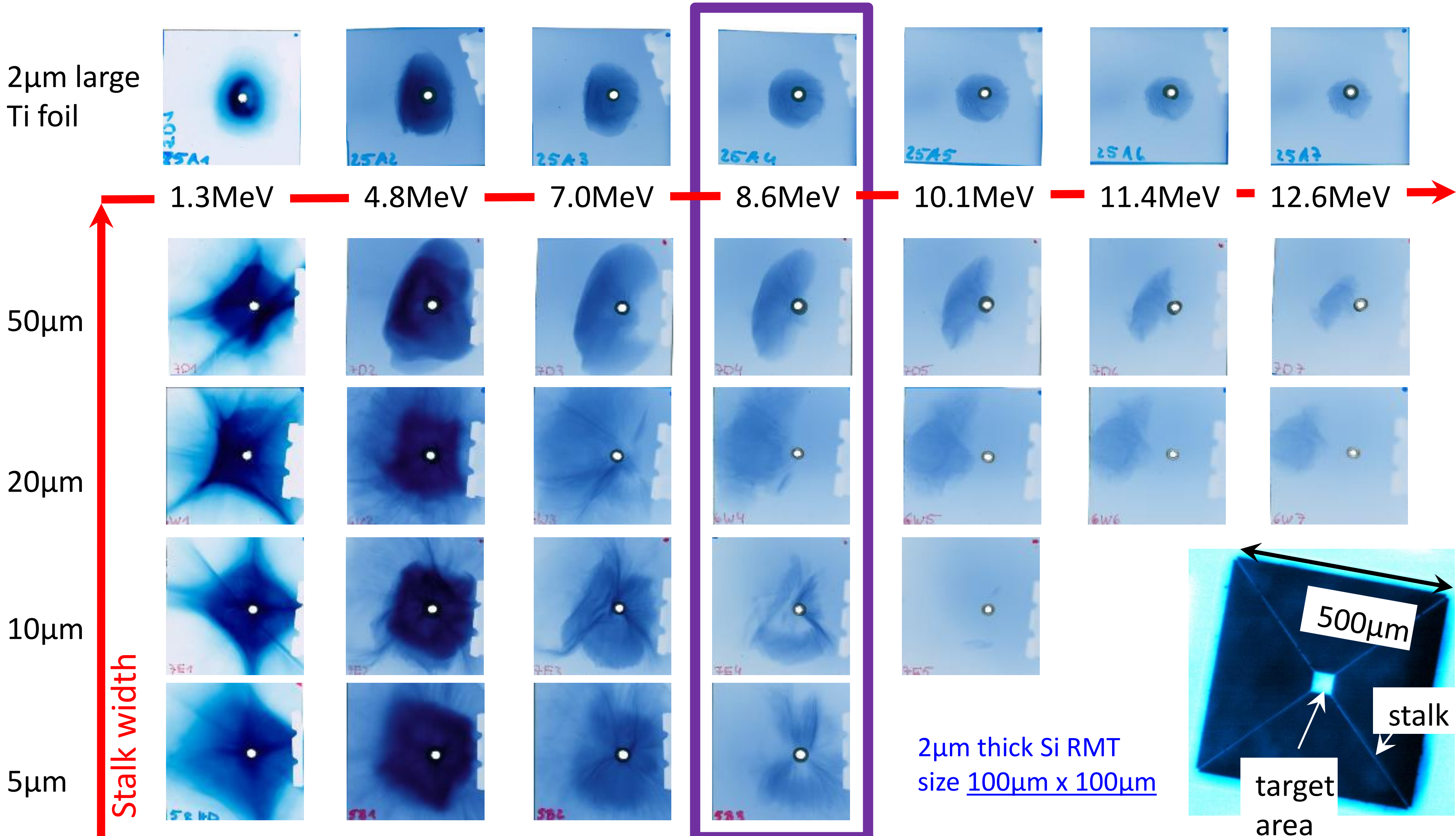






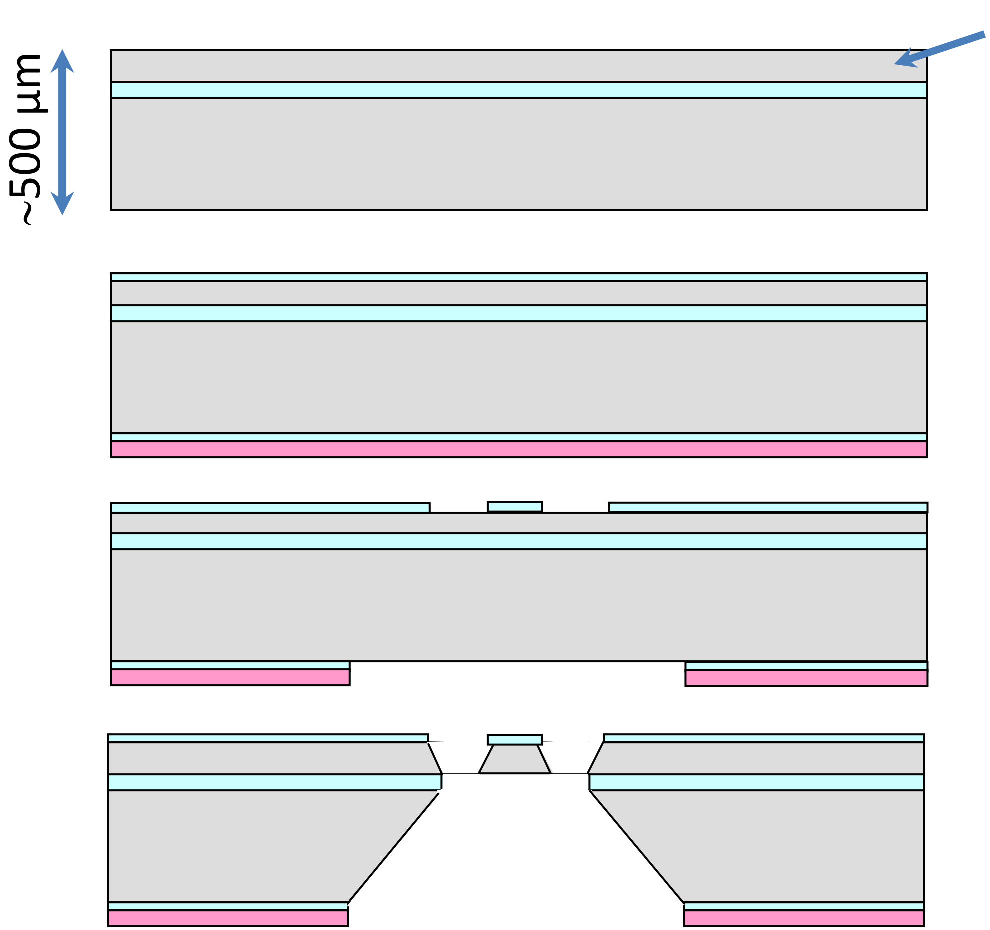
- reduced proton acceleration performance and destruction of smooth proton beam profile

Influence of target mounting



- similar field strength at edges as in focal region
- edge fields prevent efficient plasma expansion

Target design – Silicon RMTs



2 µm thickness

SOI-Wafer

SiO_2 layer from thermal oxydation and deposition of a 500 nm Si_3N_4 layer as etching mask

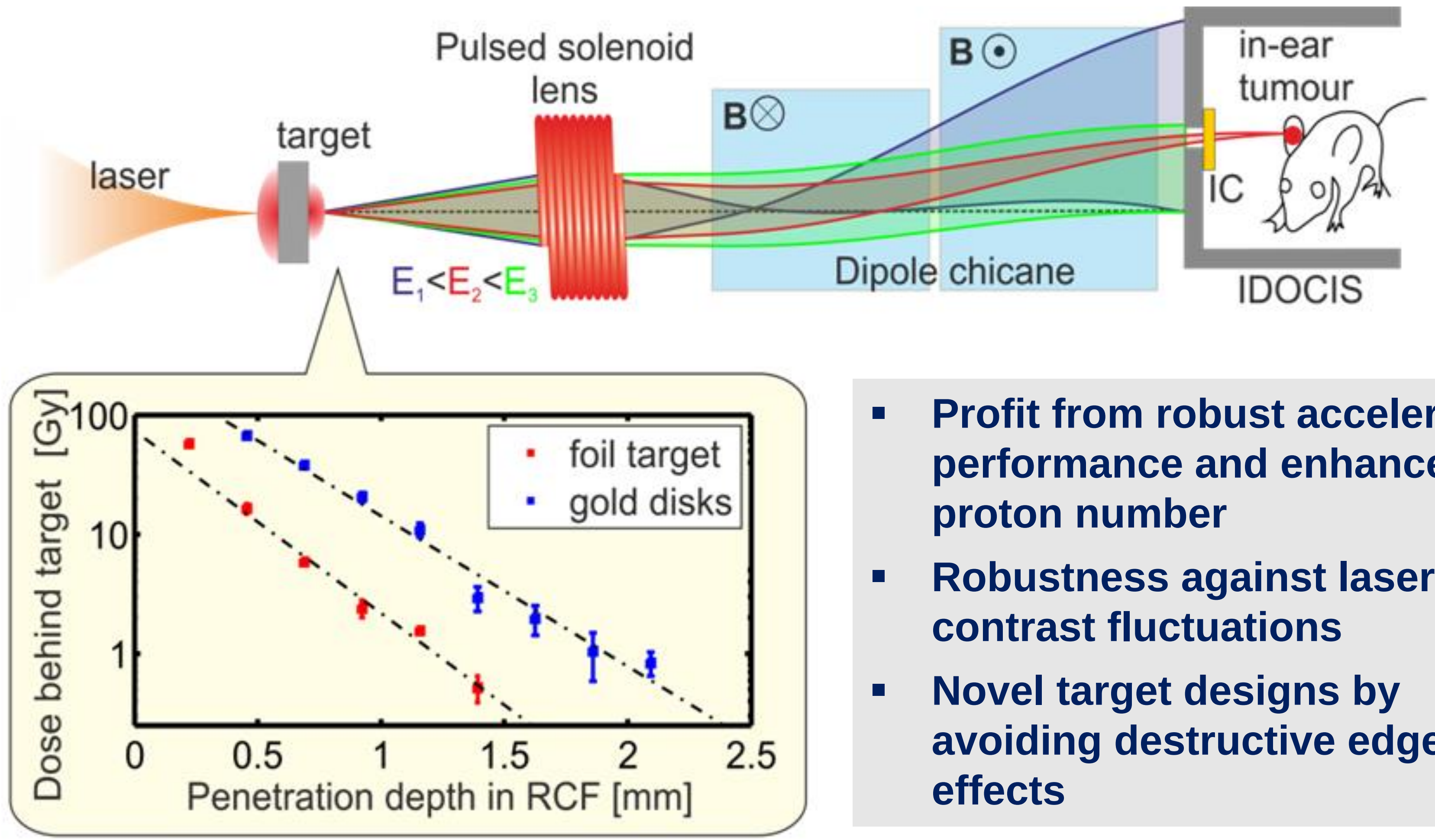
photo lithography to structure front and rear side

front and rear side etching, burried layer as boundary

Silicon membrane:

- free-standing, robust
- structuring and deposition of layers possible
- optical surface quality

Summary



- **Profit from robust acceleration performance and enhanced proton number**
- **Robustness against laser contrast fluctuations**
- **Novel target designs by avoiding destructive edge effects**

multiple filamentation of freely propagating 100 TW beam in air

Center for high power radiation sources

New lab space (800 m²):

- clean rooms – workshop –

- Yb:CaF_2 active medium
- 150 J in 150 fs on target @ 1 Hz

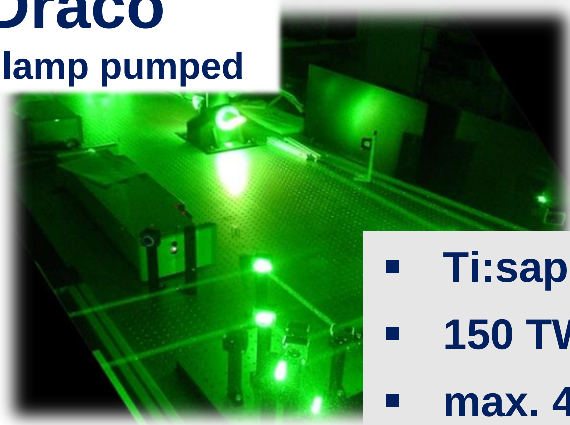
PENELOPE

PW diode pumped system

M. Siebold, F. Röser, D. Albach, M. Löser

Draco

flash lamp pumped

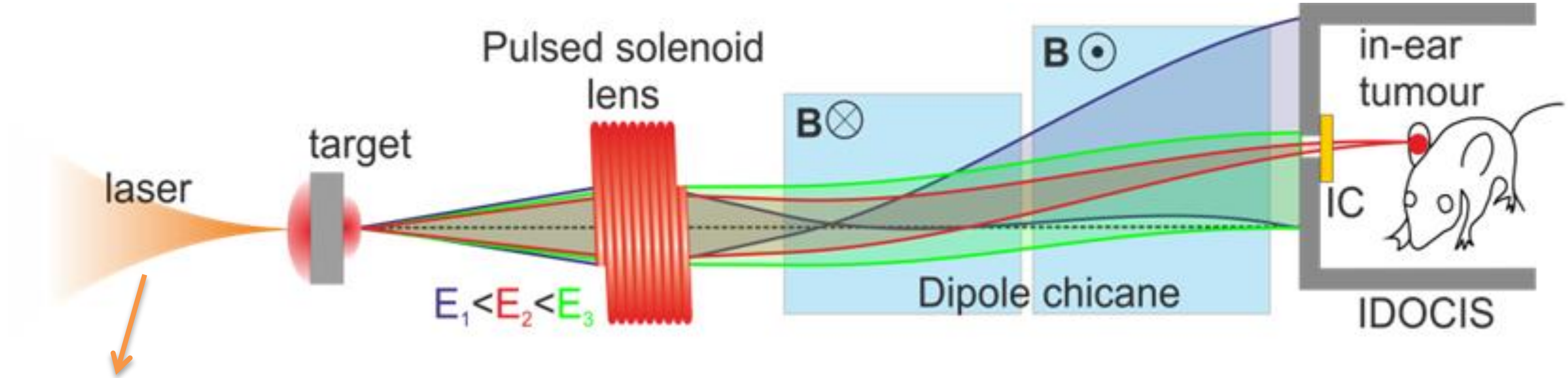


- Ti:sapphire active medium
- 150 TW ultra-short beam
- max. 4.5 J in 30 fs on target @ 10 Hz

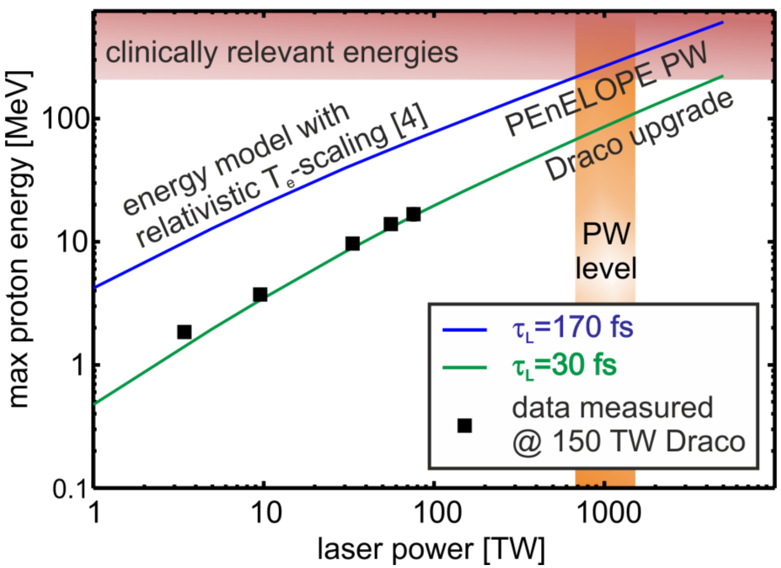
DRACO experiments

Our motivation – Laser driven ion therapy

in vitro irradiations have been performed [Yogo APL 2011, Zeil APB 2012, Bin APL 2012, Doria AIP 2012]



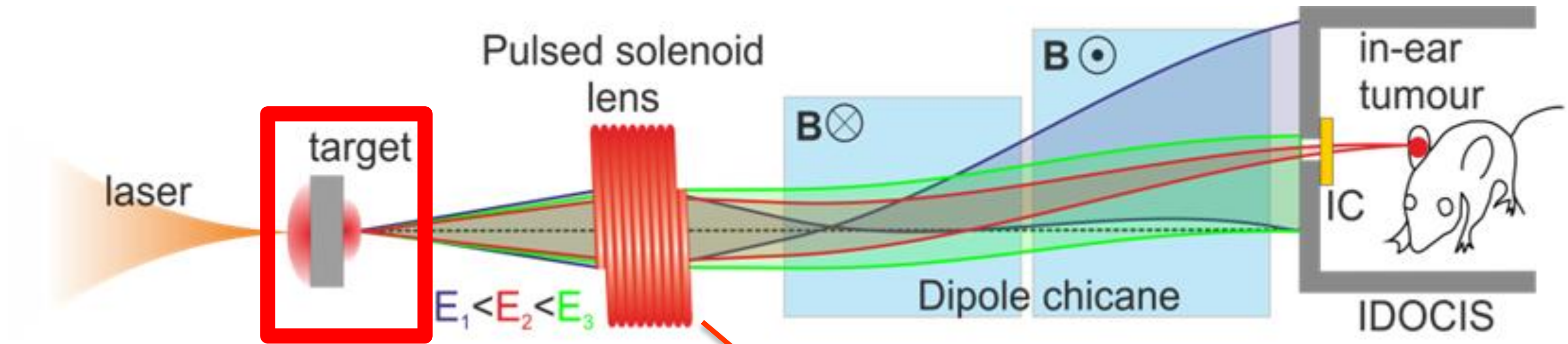
Proton energy scaling

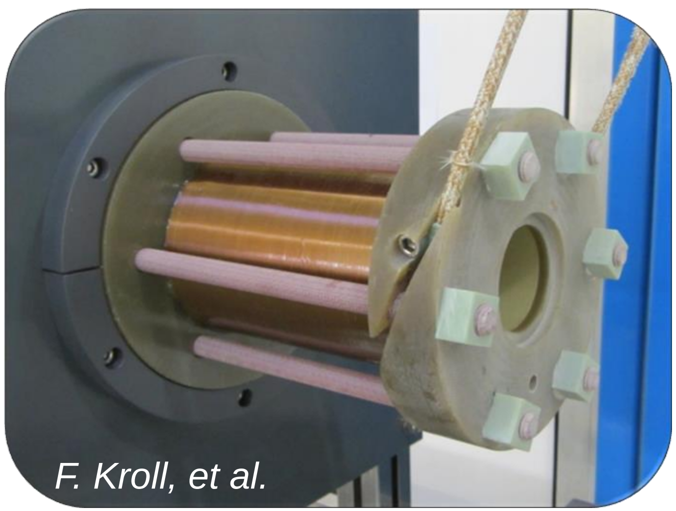


[4] T. Kluge et al., PRL ***107****, 205003 (2011)*

- **Ti:Sapph Draco so far 4 J in 30 fs**
- **upgrade to 30 J in 30 fs @ 1 Hz**

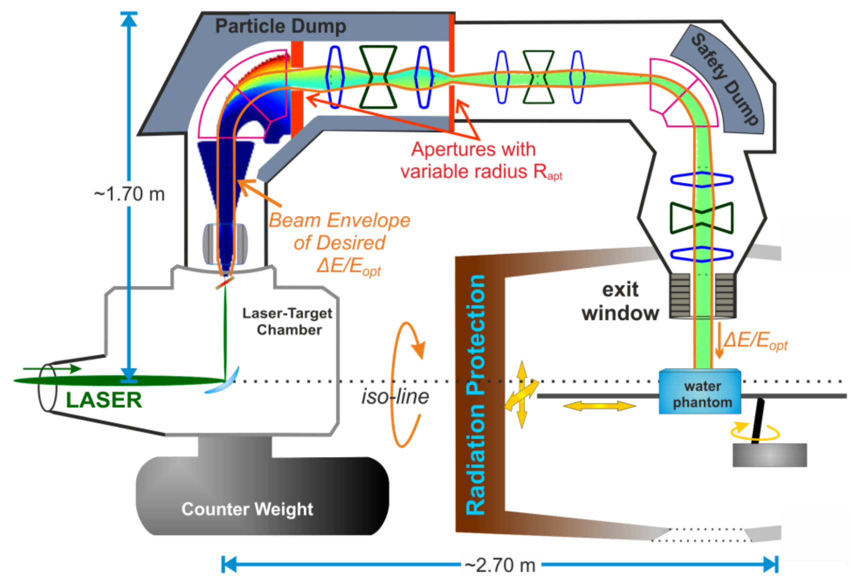
In vivo irradiations with laser protons





F. Kroll, et al.

Gantry for laser-driven proton therapy



U. Masood, et al.

Laser Ion Generation, Handling and Transport

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