Accelerator Research and Development ARD
Topic 4: Novel Techniques for High Gradient Acceleration

Coordination: U. Schramm, HZDR, Dresden
F. Grüner, DESY, Hamburg

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Accelerator Research and Development ARD
Topic 4: Novel Techniques for High Gradient Acceleration

Motivation: Ultrahigh gradients in principle allow for
- unprecedented energy scales
- compact accelerators and light sources
- intrinsic fs-scale synchronization

Technology / Idea: Plasma (wave) based acceleration either
- laser driven or - particle beam driven

Goals are significantly different from Top 1-3 as
- ***full understanding of the underlying physics is an issue***
- ***and simultaneously the demonstration of a reasonable degree of maturity is mandatory***

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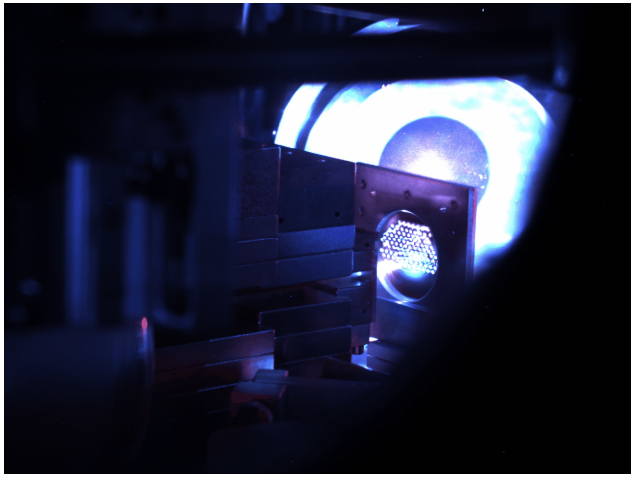
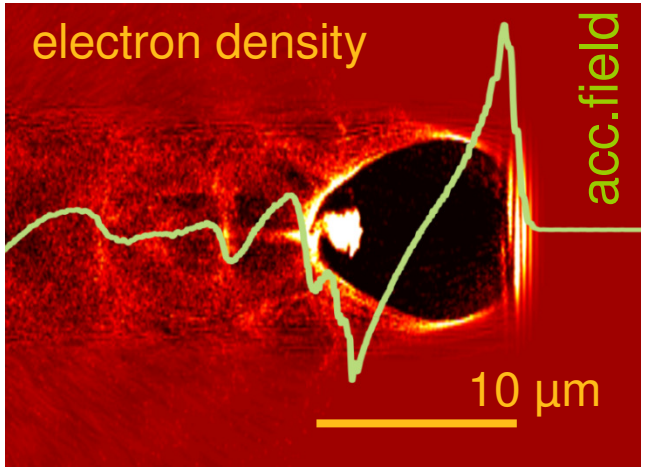


MeV per micron



GeV/cm for 5×10^{18} e/cm^3

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Players and infrastructure

PHELIX Glass laser
0.3 PW, 150 J, 500 fs

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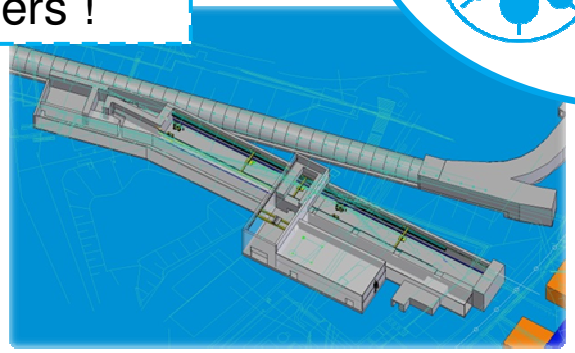
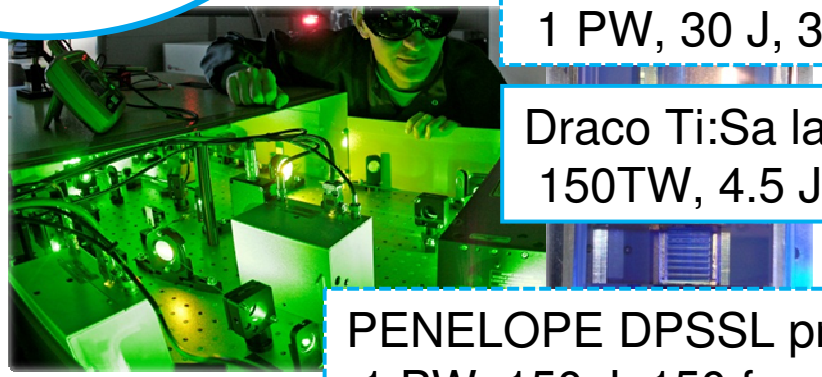
200TW Ti:Sa project
Electron drivers !



Draco PW project
1 PW, 30 J, 30 fs



Draco Ti:Sa laser
150TW, 4.5 J, 30 fs

PENELOPE DPSSL project
1 PW, 150 J, 150 fs

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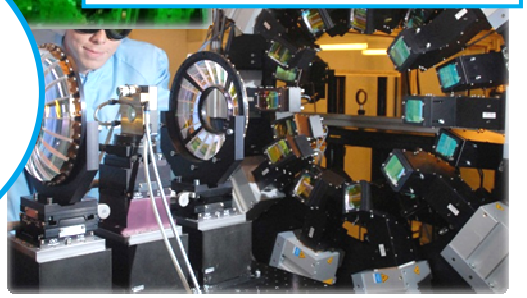
Players and infrastructure

Jeti Ti:Sa laser
30TW, 1 J, 30 fs

POLARIS DPSSL
50 TW, 8 J, 150 fs
200 TW upgrade



PHELIX Glass laser
0.3 PW, 150 J, 500 fs

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Helmholtz-Institut Jena
IOQ Jena

GSI

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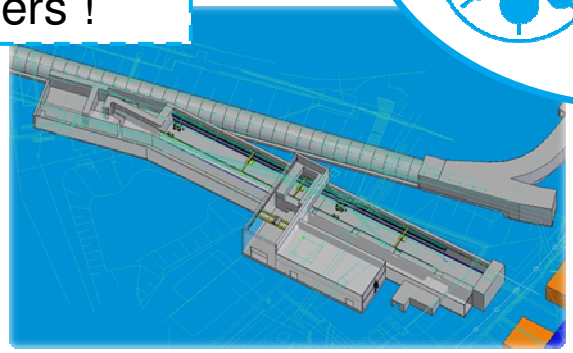
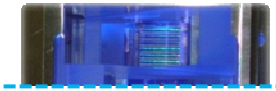
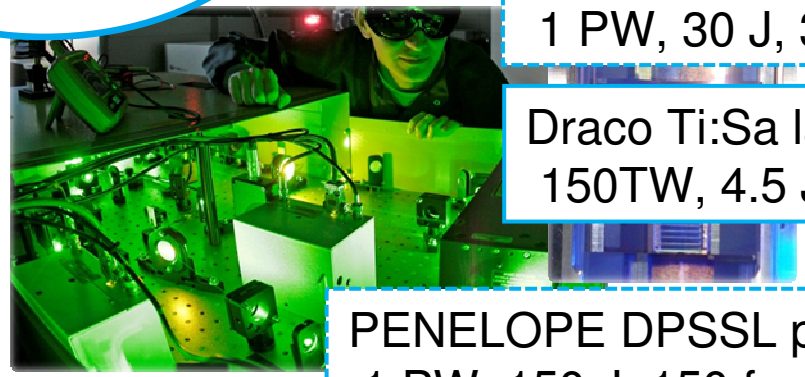
200TW Ti:Sa project
Electron drivers !





Draco PW project
1 PW, 30 J, 30 fs



Draco Ti:Sa laser
150TW, 4.5 J, 30 fs

PENELOPE DPSSL project
1 PW, 150 J, 150 fs

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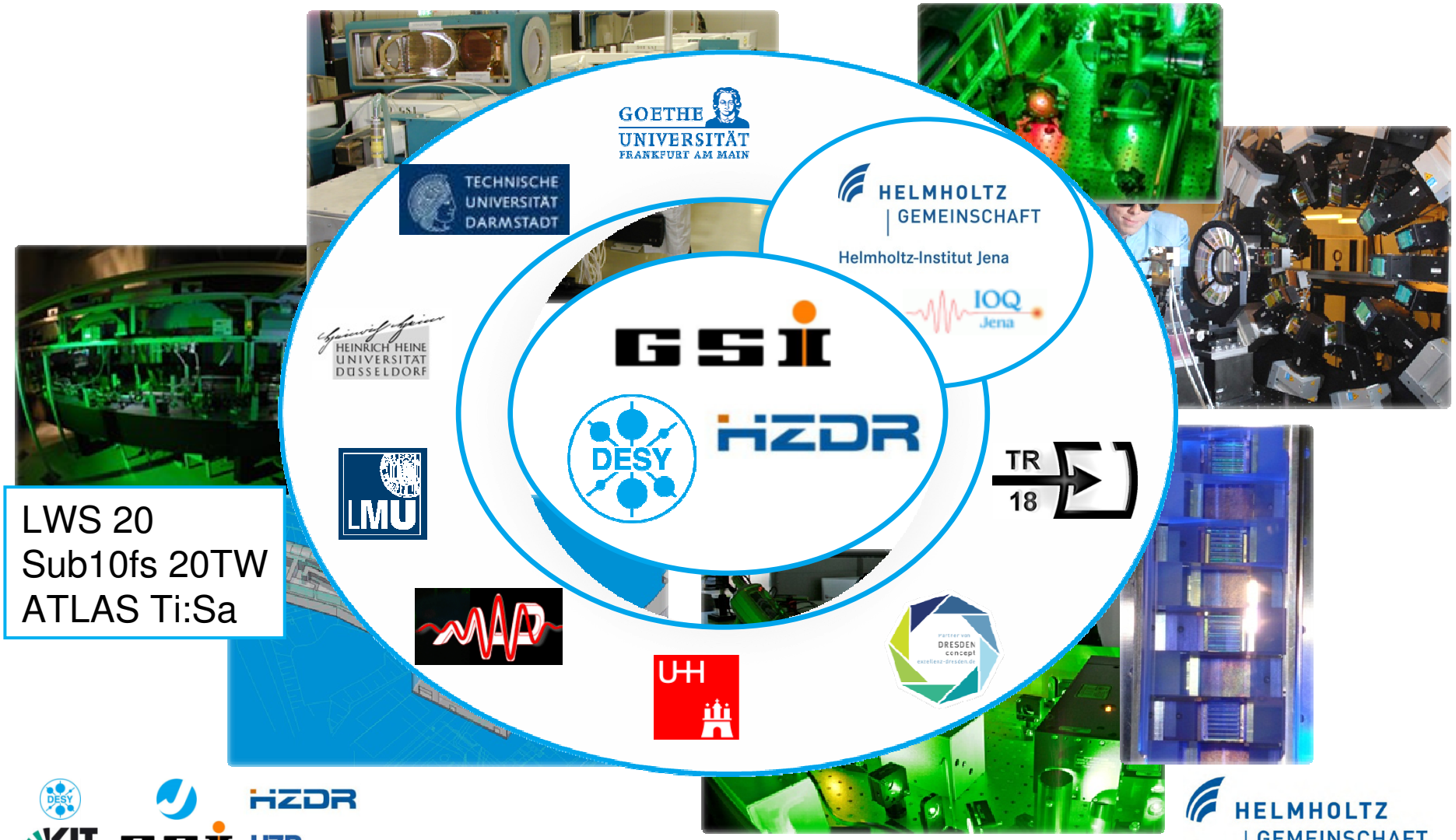
Players and infrastructure



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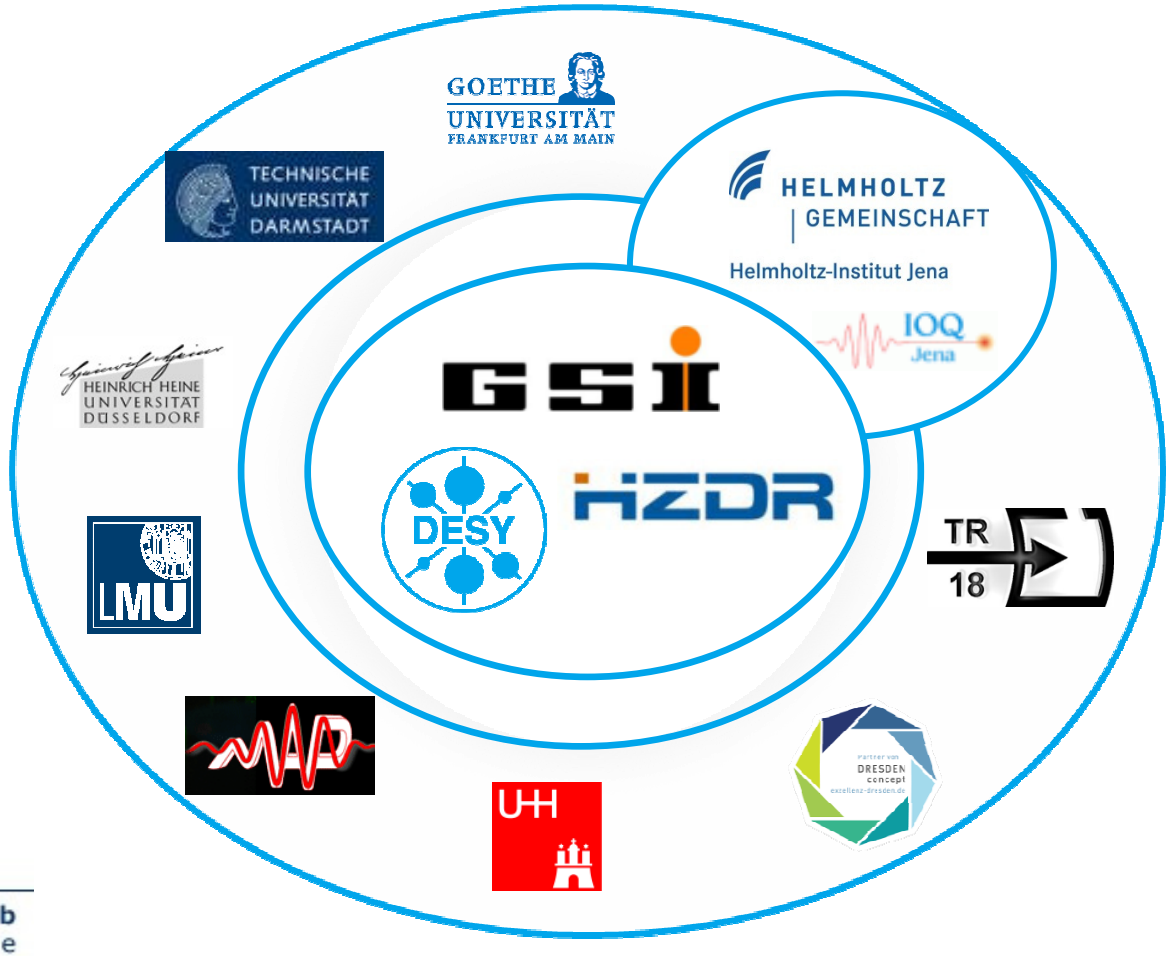
Players and infrastructure / networking



Berkeley Lab

tifr

HiPER

IST

CLF central laser facility

eli extreme light infrastructure

University of Strathclyde

Laserlab Europe

Los Alamos NATIONAL LABORATORY EST. 1943

Laser Ion Acceleration

Status and collaborative tasks

- **Increase of maximum energies above few 10 MeV**
- **Spectral shaping (mono-energetic beams)**
- **Spatial control and transport**
- **Shot-to-shot stability**

novel concepts, targetry
next generation lasers

- **Combination with conventional structures**
- **Applications (e.g. medical)**

two examples for collaborative work within ARD
requiring a high level of maturity

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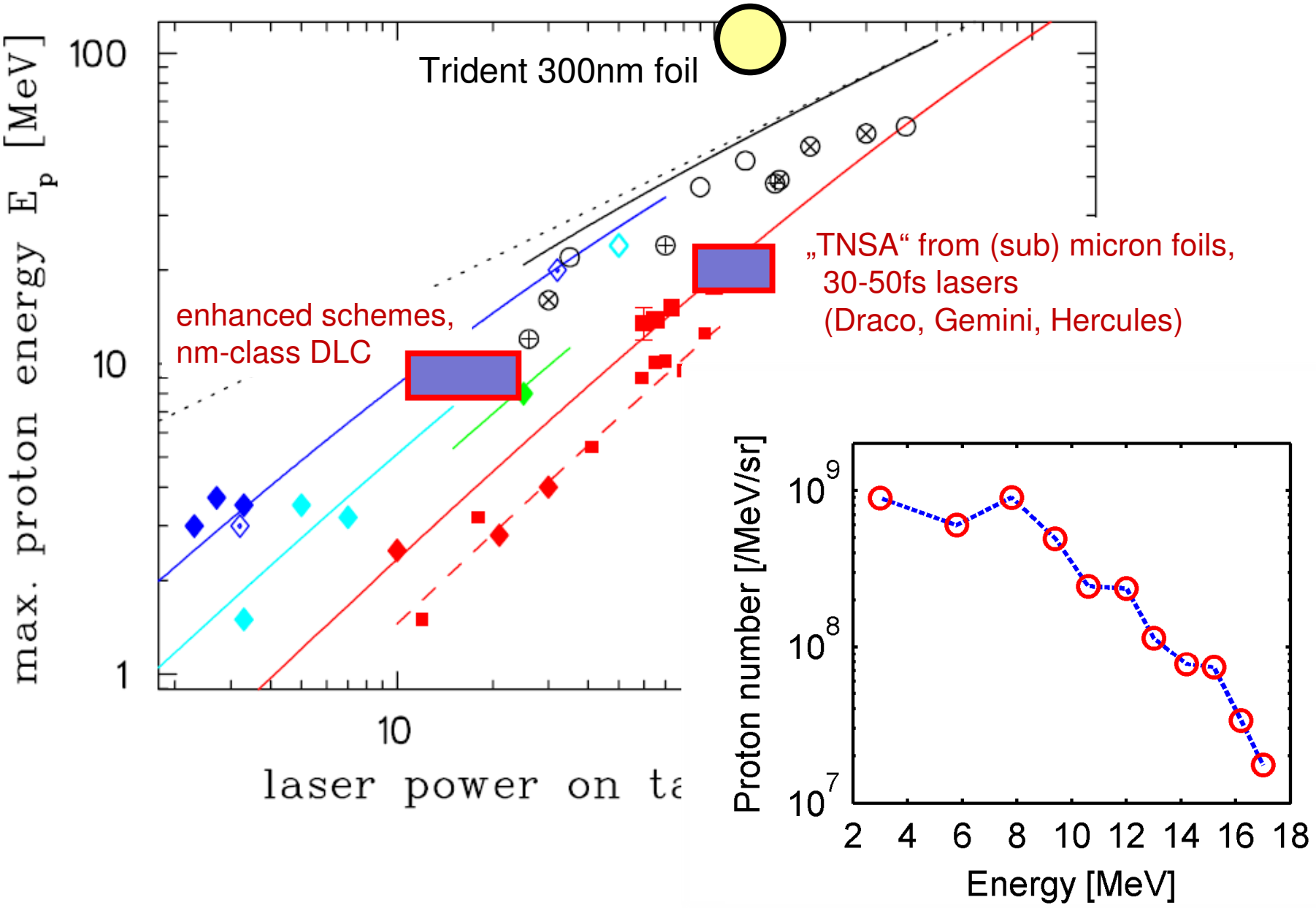
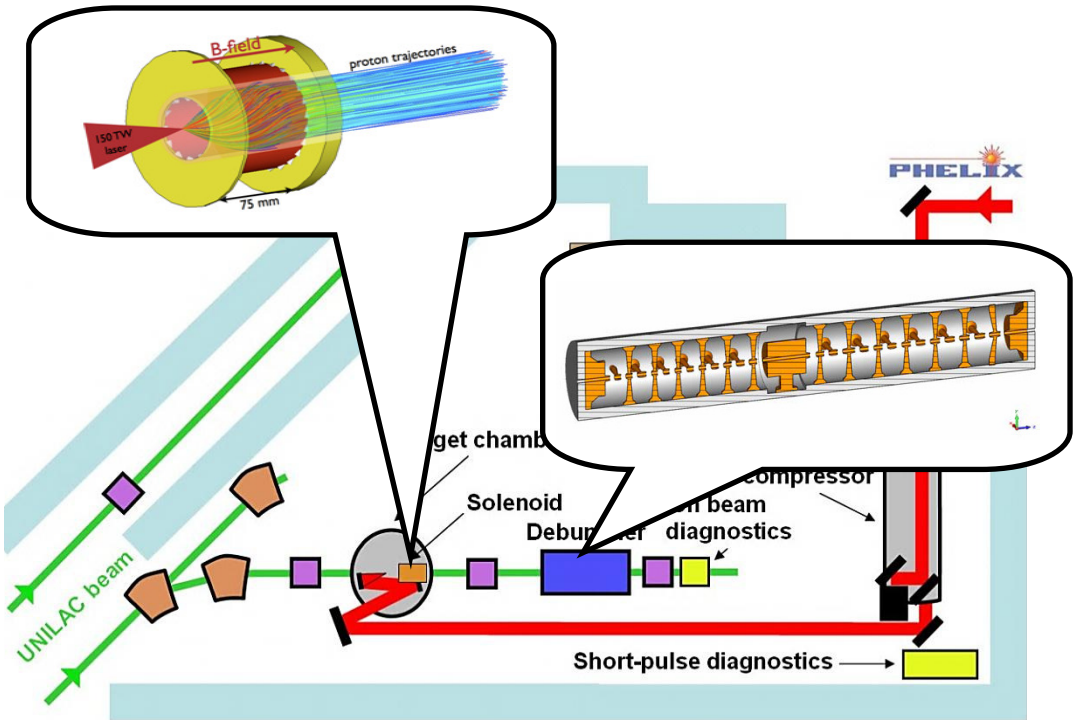
Status and tasks - Particle Energy



Laser-Driven Proton Injector / LIGHT

HI-Jena: interface between laser-based and conv. accelerators: LIGHT-collaboration ("**L**aser-**I**on-**G**eneration, **H**andling and **T**ransport")



HI-Jena:
- project coordination,
- 100-TW compressor,
- laser and ion beam diagnostics,

GSI:
- PHELIX laser, timing, control system,
- beam lines, accel. structures,
- beam diagnostics

TU-Darmstadt:
- acceleration experiments,
- collimation simulations,
- target development

HZDR:
- solenoid for collimation

Univ. Frankfurt:
- accel. structure development

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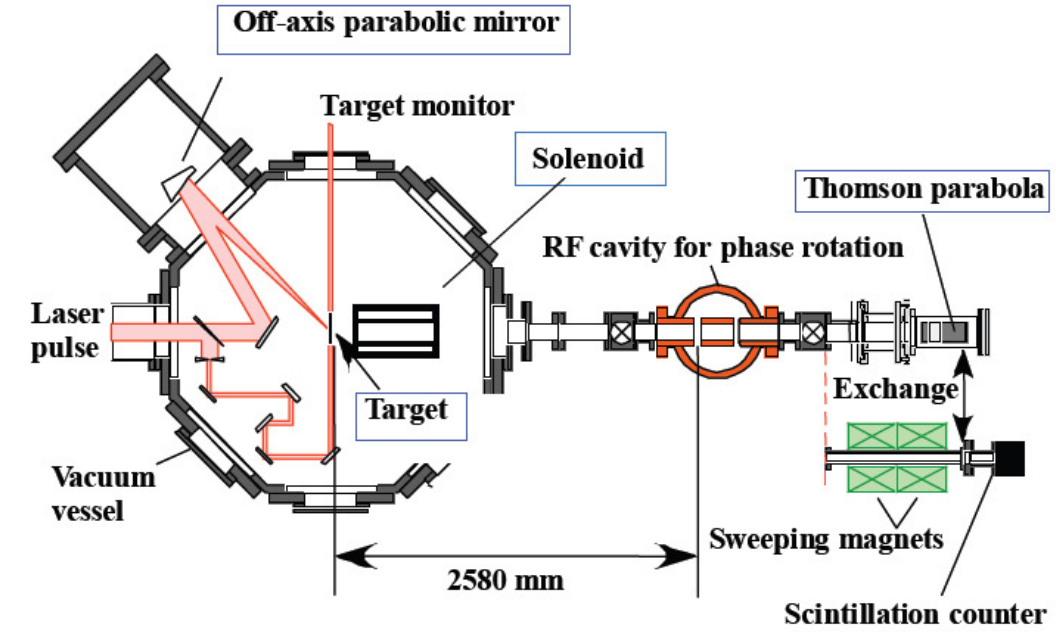
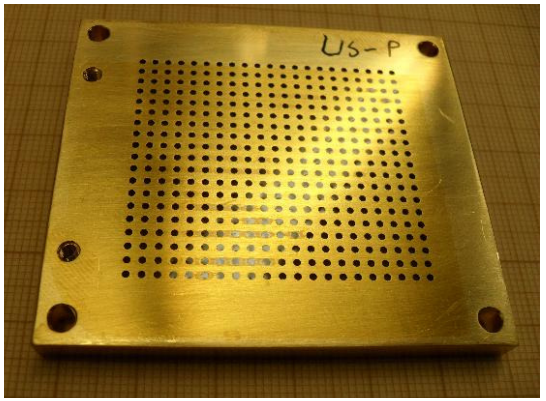

Off-axis parabolic mirror
Target monitor
Solenoid
Thomson parabola
RF cavity for phase rotation
Laser pulse
Target
Exchange
Vacuum vessel
Sweeping magnets
2580 mm
Scintillation counter

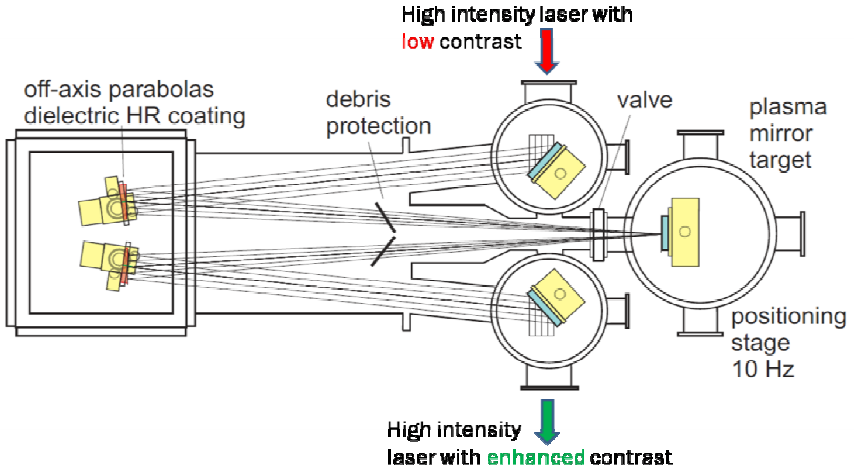
Particle Energy improvement - spectral shaping

Test and validate Radiation Pressure Acceleration @ JETI and POLARIS ⇒ transfer to ARD partners



<u>Requirements for RPA:</u>

- ultra thin multi-species foils: (15±1) nm,
- ultra-high contrast pulses:
  plasma mirror,
- circular polarization:
  novel all-reflective approach



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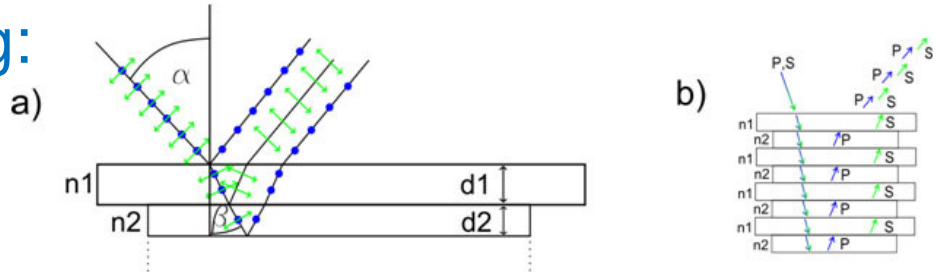
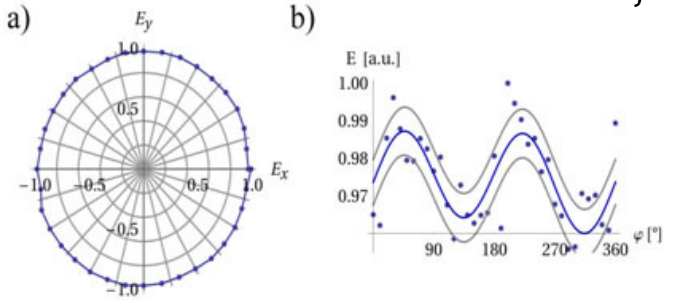
Particle Energy improvement - spectral shaping

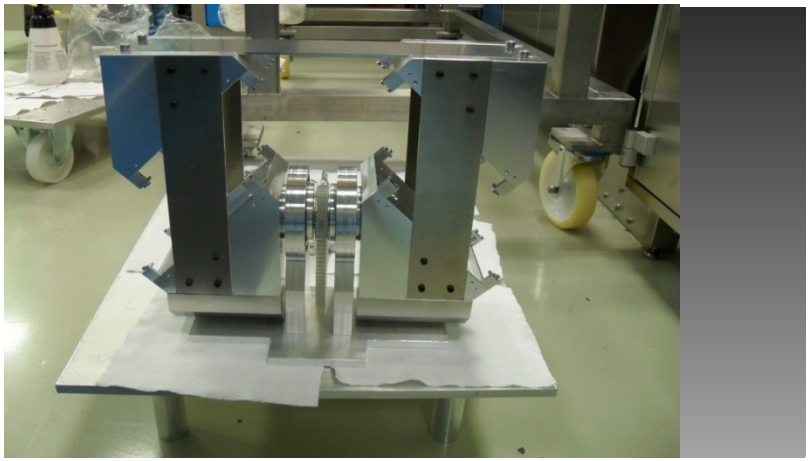
New dielectric multilayer coating:

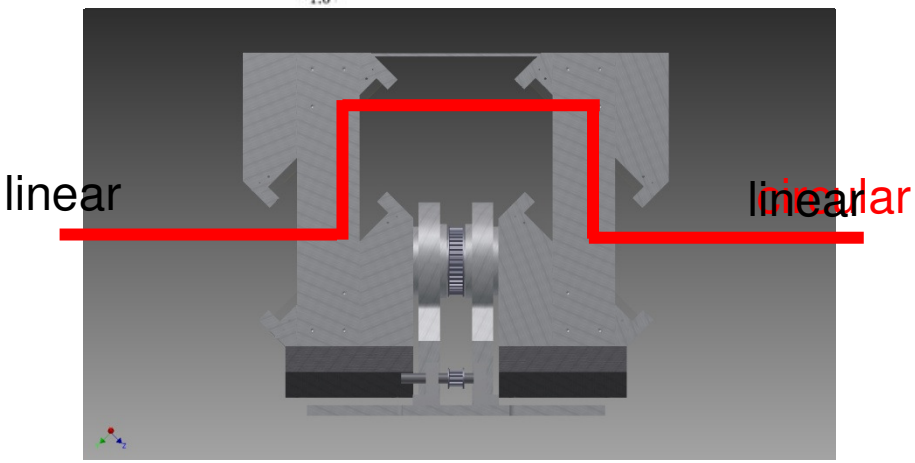
pol.-dependent reflection



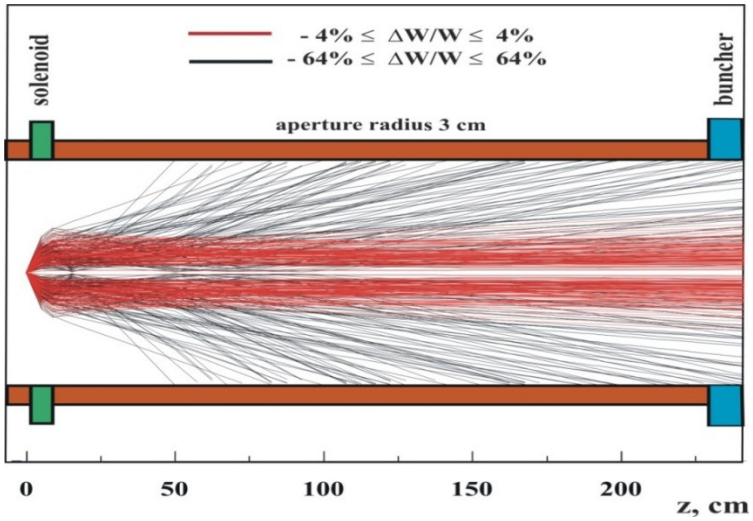
- high reflectivity: $R > 98\%$,
- homogeneous phase-shift over broad bandwidth: $\Delta\lambda = 80$ nm,
- high ellipticity: $\varepsilon_{PSM} = (98.3 \pm 0.6)$ %,
- high damage threshold: 5×10^{12} W/cm^2,
- scalable: up to $\varnothing = 700$ mm





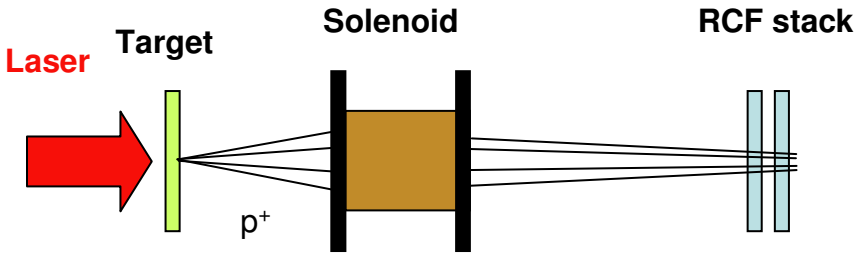


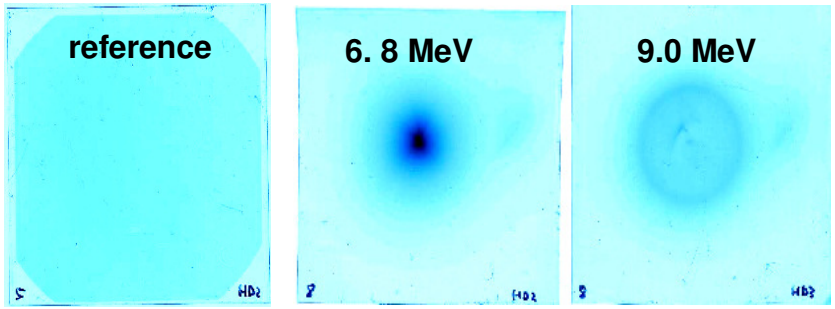
Ion acceleration - spatial shaping and transport



- **Simulations on the coupling of laser-accelerated ions into conventional accelerator structures (Uni Frankfurt)**

- **Experimental test (HZDR, GSI)**





Stack located 405 mm downstream

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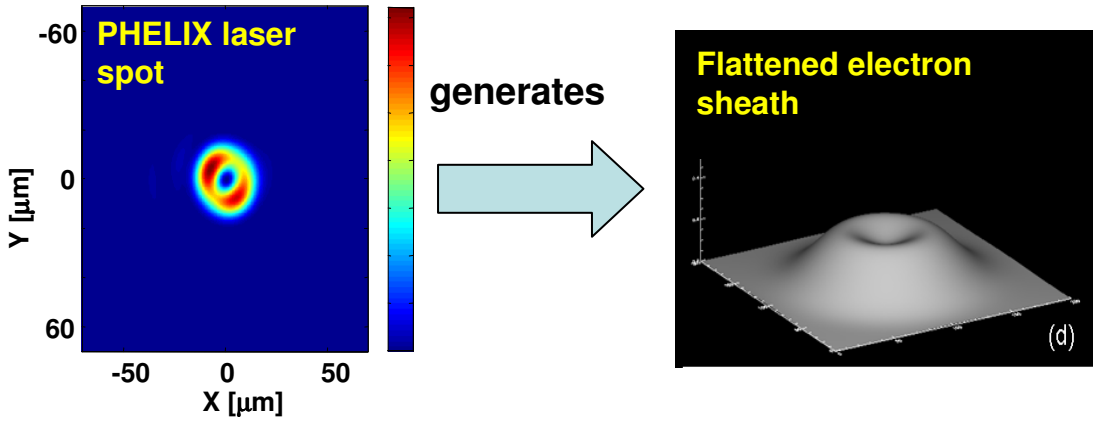
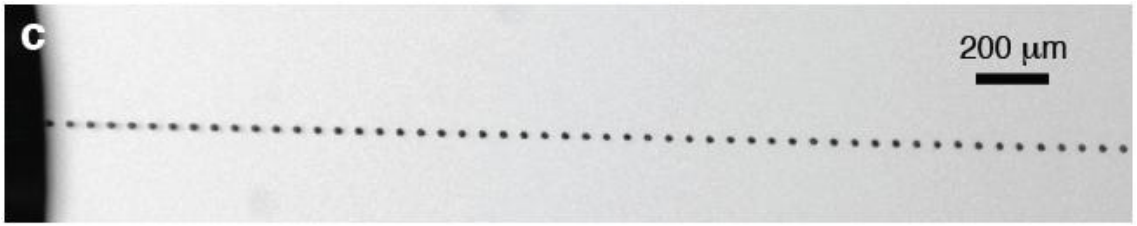
Ion acceleration - spatial shaping and transport

Recent results in engineering laser spots (GSI)



Joint activities in Droplet target implementation (H_2O, H_2, D_2),
(R. Grisenti, GSI, Uni Frankfurt, GSI, HIJ)



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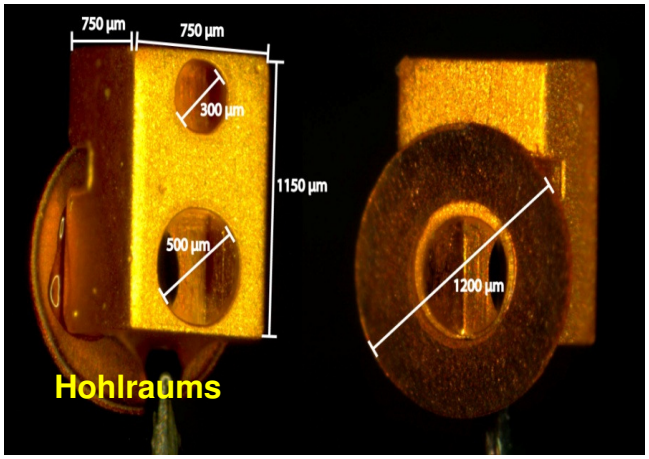
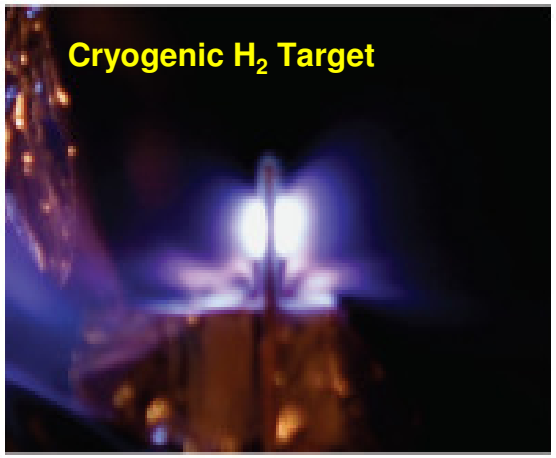
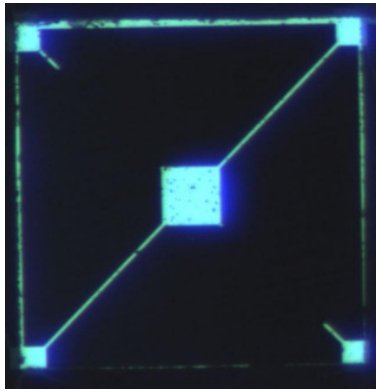
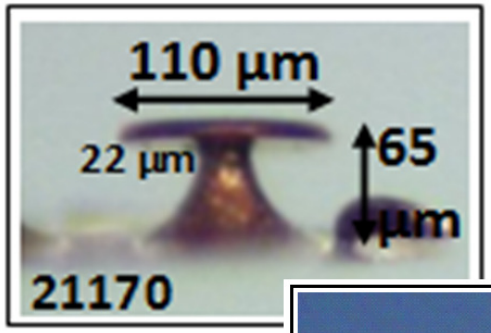
Target expertise



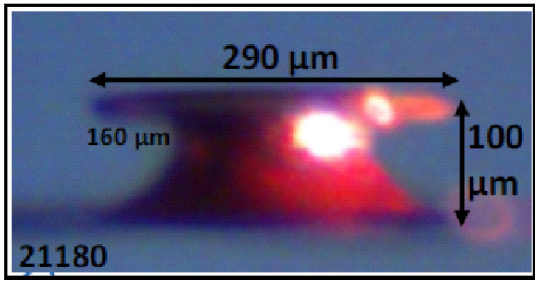


TECHNISCHE UNIVERSITÄT DARMSTADT





HZDR



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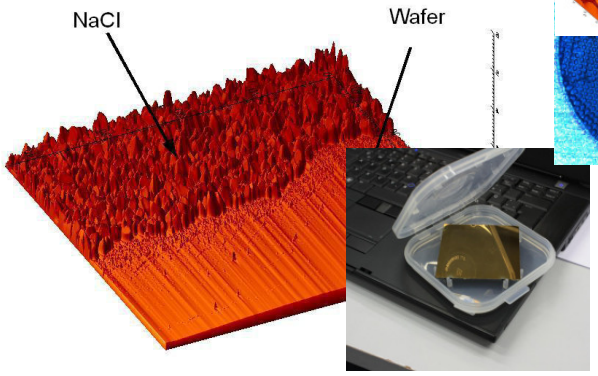
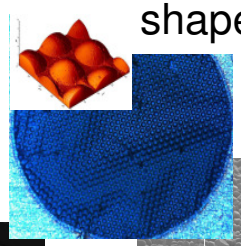
Target expertise

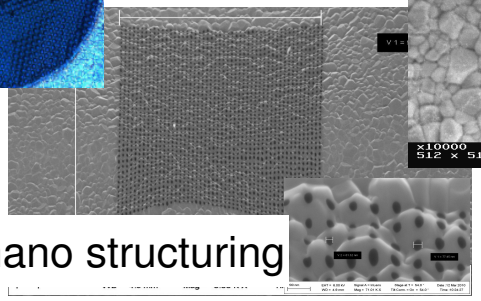
DLC and other thin targets down to 3 nm thickness
shaped targets (in combination with thin foils)
layered (density structured) targets

flatness & control



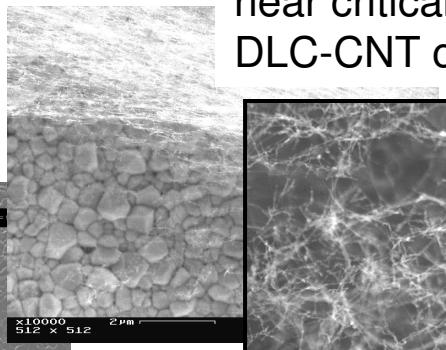
shaped targets

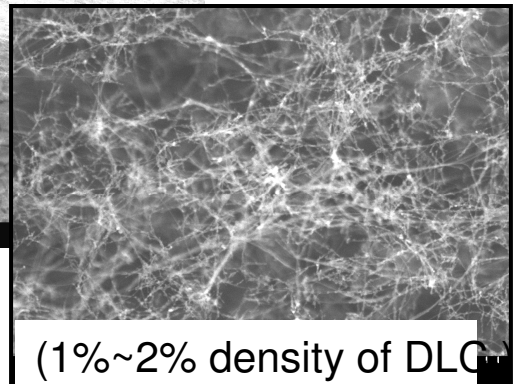




nano structuring

near critical density targets
DLC-CNT composite targets

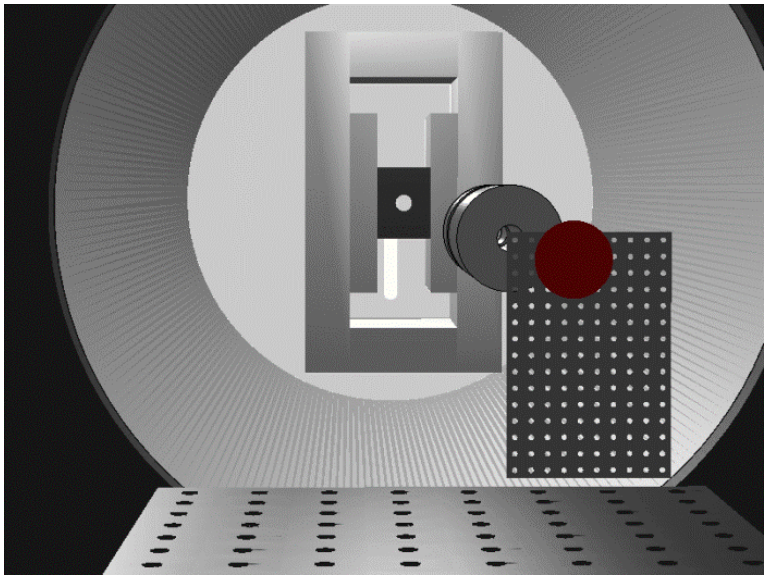


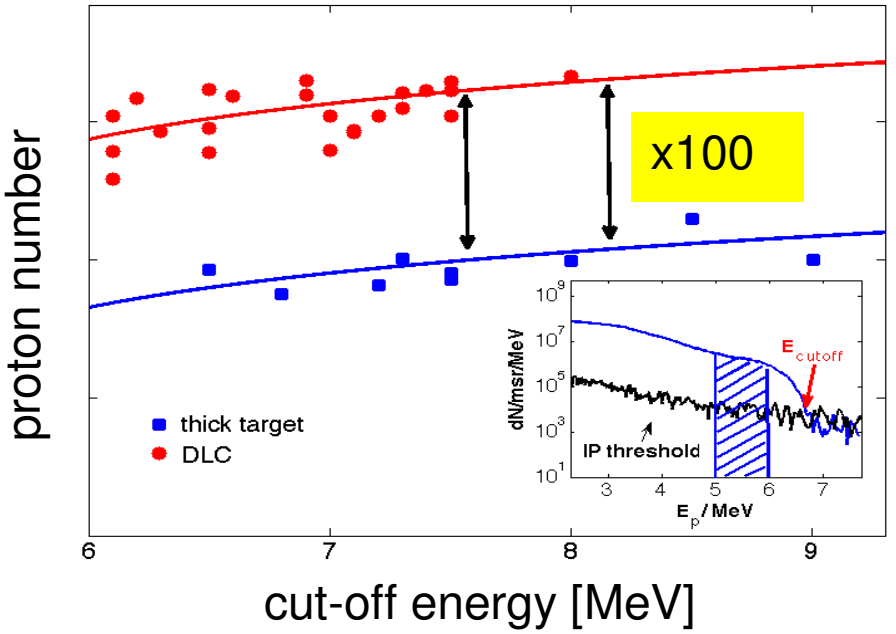


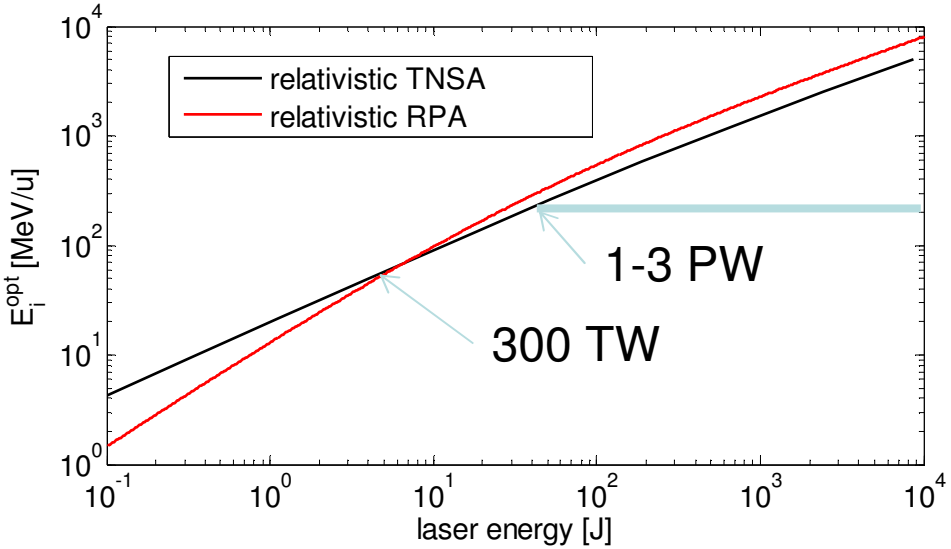
(1%~2% density of DLC)

Laser-Ion Acceleration for biomedical studies

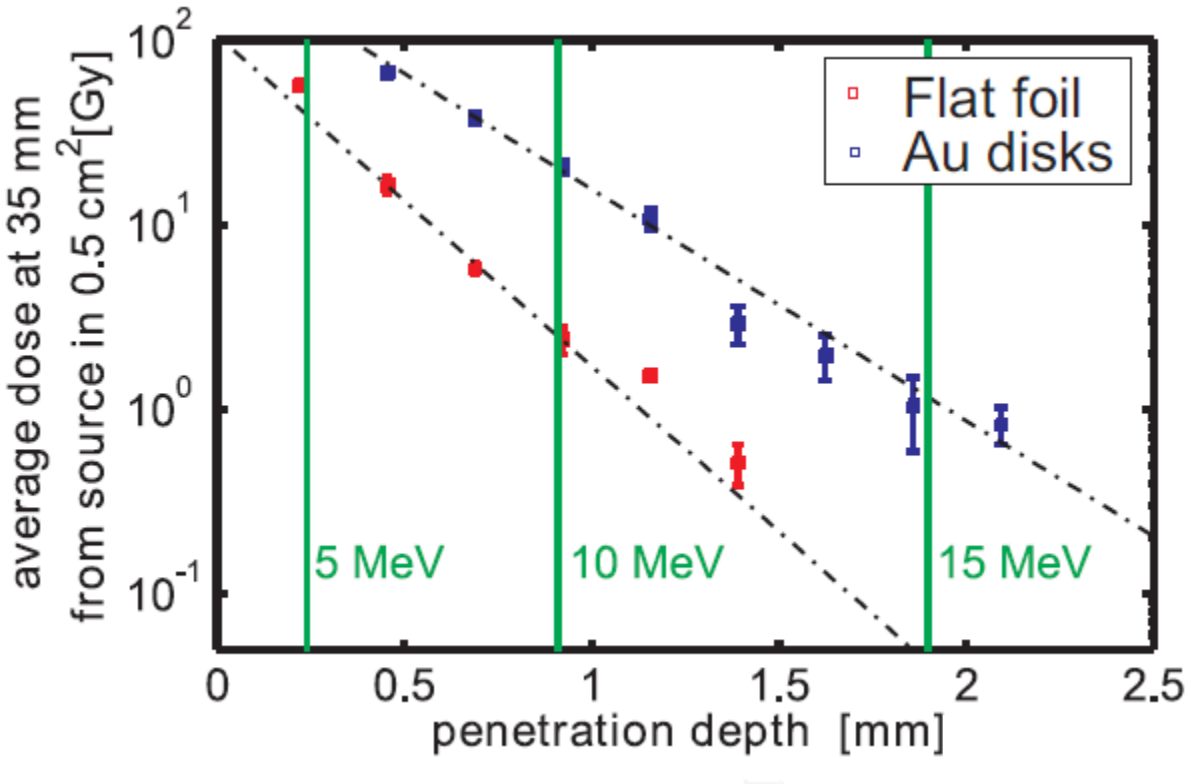
- Efficient acceleration with nanometer thin diamond-like carbon foils (100x more ions compared to µm targets)
- 1 ns proton pulses for high dose cell experiments (9 Gy in 1 ns) at 5.2 MeV

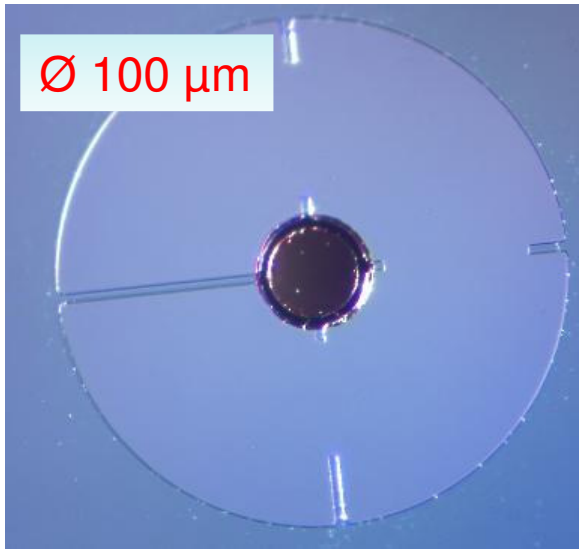






Laser-Ion Acceleration for biomedical studies





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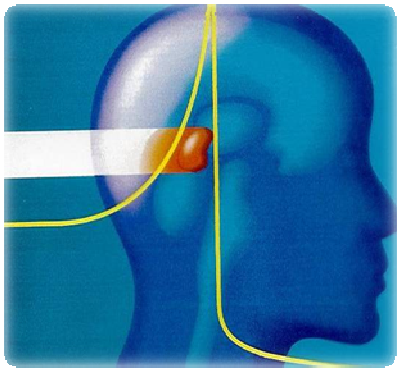
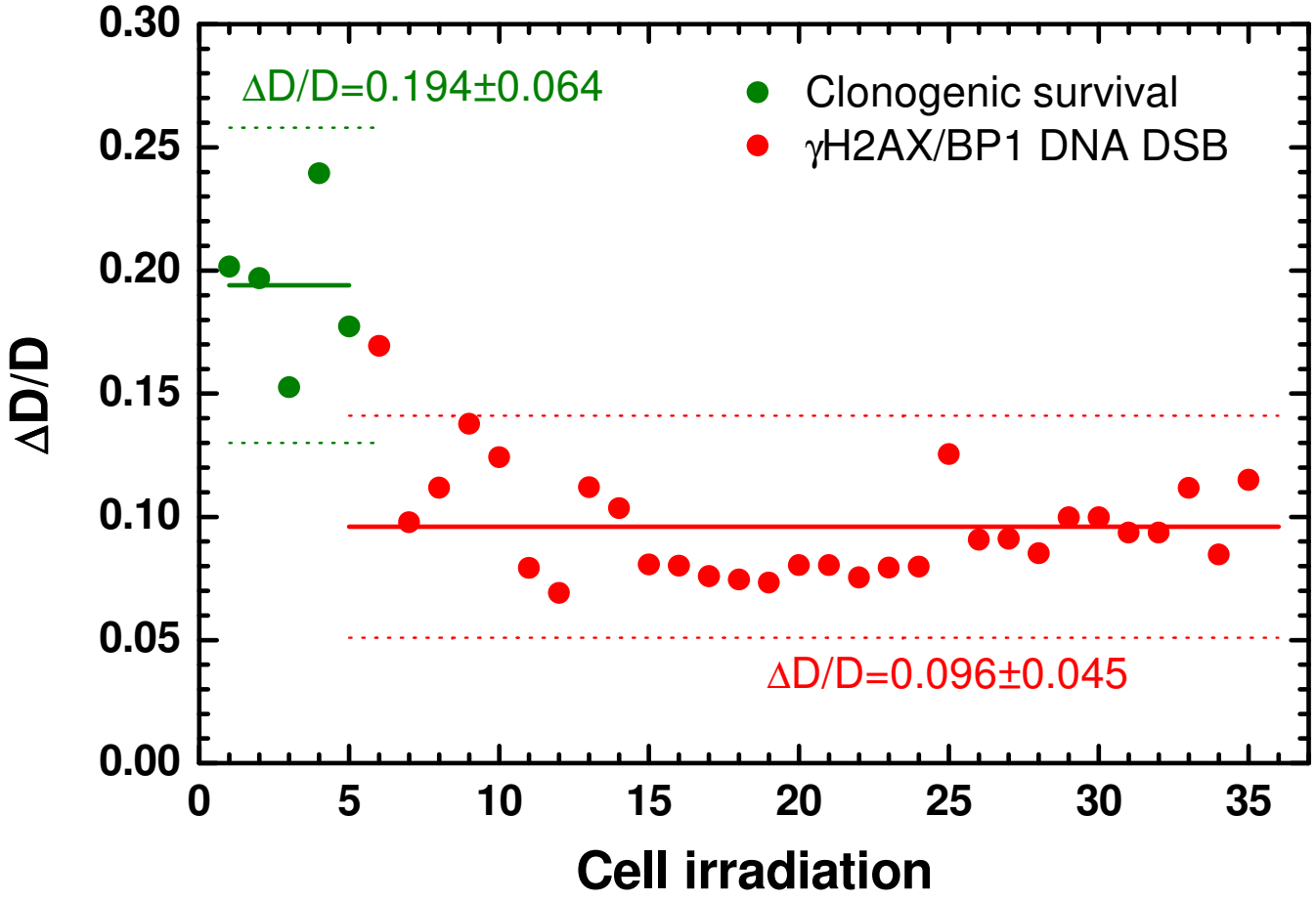
Requirements for cell irradiation experiments



- *Proton energies >5 MeV*
- *Dose rates of Gy/min between 0.1 and 10 Gy (pulse dose / stability)*
- *Energy filtering / transport (radiation protection)*
- *Online and absolute offline dosimetry*
- *Homogeneous irradiation*
- *Sample size ~cm²*
- *Cell irradiation in air*

integrated Dosimetry and cell irradiation system (Faraday-cup, RCFstacks, cell samples)

Stability requirements with respect to dose



- first experiment with reliable dose & dose uncertainties
- about **4500** fully controlled and monitored shots

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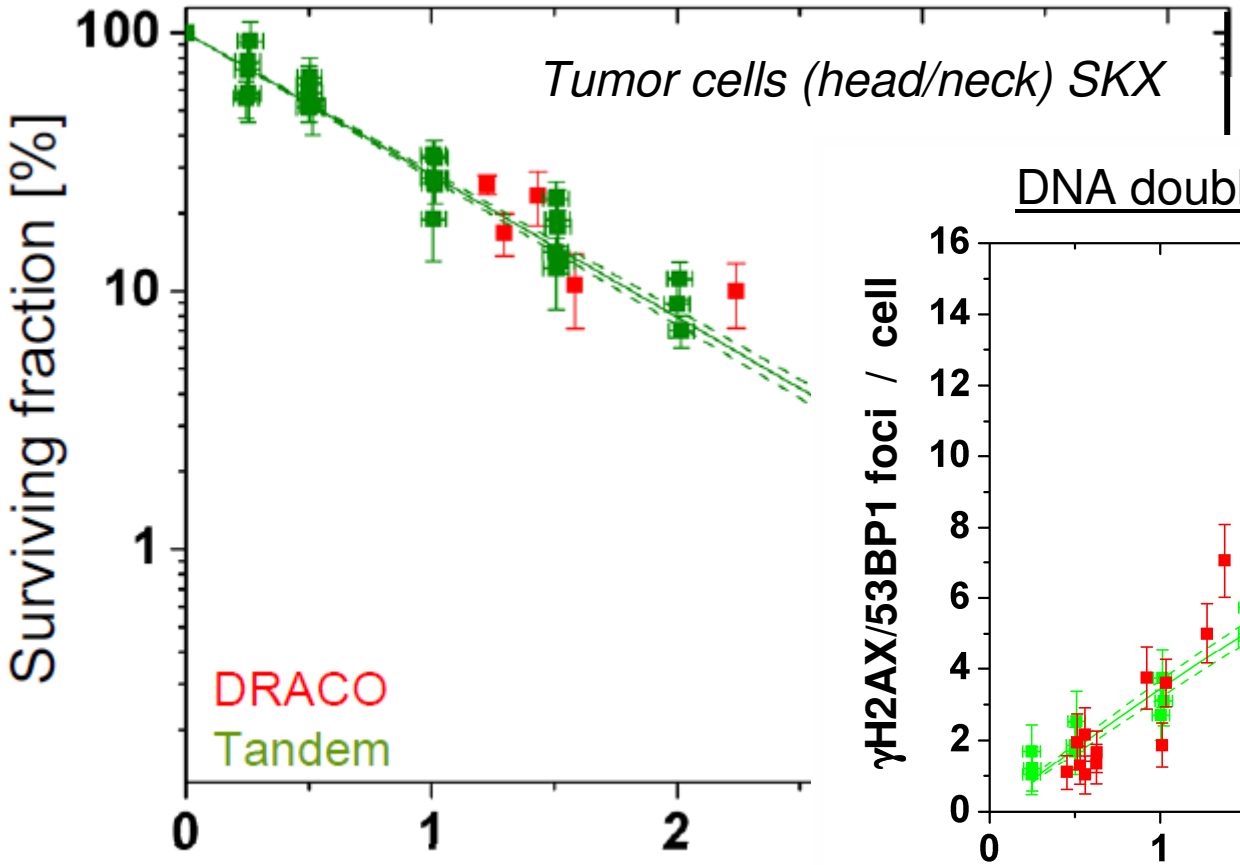
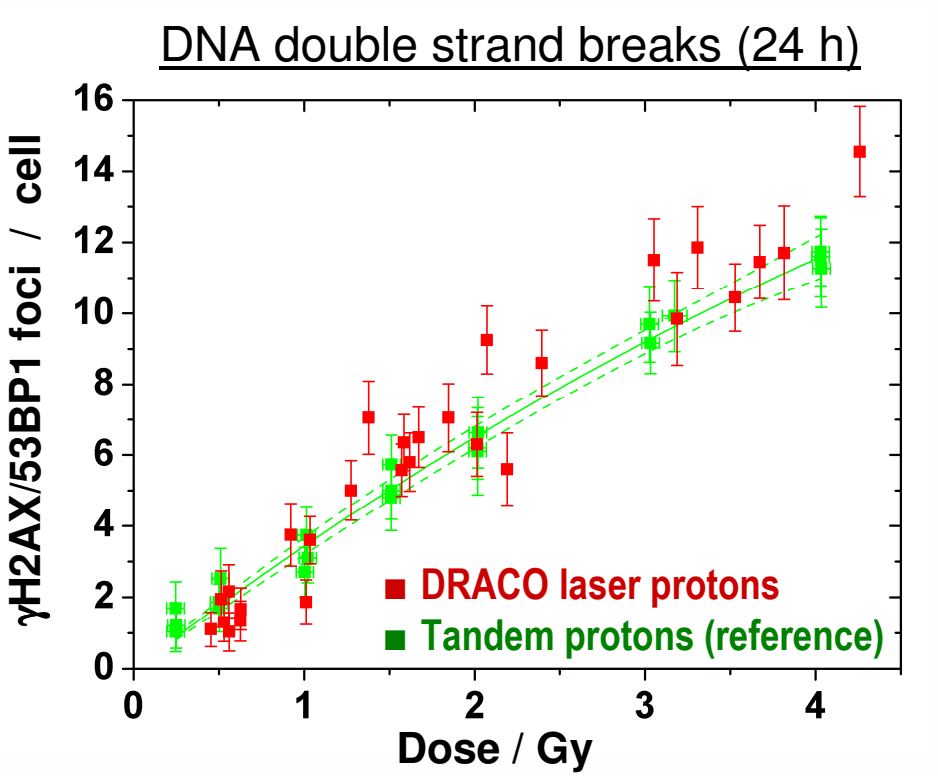
Preliminary results …





Similar experiments in Munich, HIJ and at GSI

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Within HGF: 3(4) centers involved,
operating and building 4(6) lasers with >100TW power,
all with broad accelerator expertise

Universities: 2(4) operating >100TW systems, long term experience

Added ARD value: - combining the expertise of individual research teams (usually competing) for joint larger scale approaches
- triggering novel (joint) projects

Thanks to V. Bagnoud, M. Kaluza, M. Roth, J. Schreiber

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