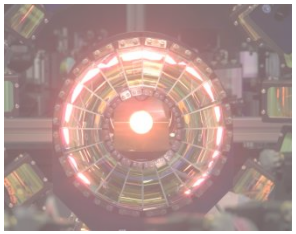
Plasma accelerators as compact proton sources for radiation therapy

Lab status and recent results from Dresden

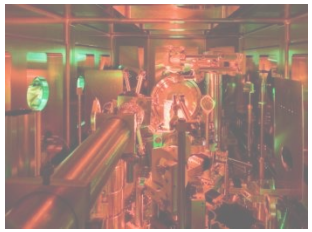
U. Schramm

Laser particle acceleration division
Institut for Radiation Physics

onCOOPtics joint research project





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TECHNISCHE UNIVERSITÄT DRESDEN

Universitätsklinikum Carl Gustav Carus
DIE DRESDNER.

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

OncoRay
National Center for Radiation Research in Oncology Dresden

+

ultra optics

HZDR

Friedrich-Schiller-Universität Jena

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Applied Optics and Precision Engineering

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DRESDEN concept

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Translational Research - Concept

Laser driven dose delivery system

well controlled laser proton accelerator

precise and safe beam delivery
spatial & spectral shaping

absolute real-time
dosimetry

Clinical practice

Clinical trials

In vivo – animals
(3D)

In vitro – cells (2D)

basic research
high pulse dose rate
biological effectiveness RBE

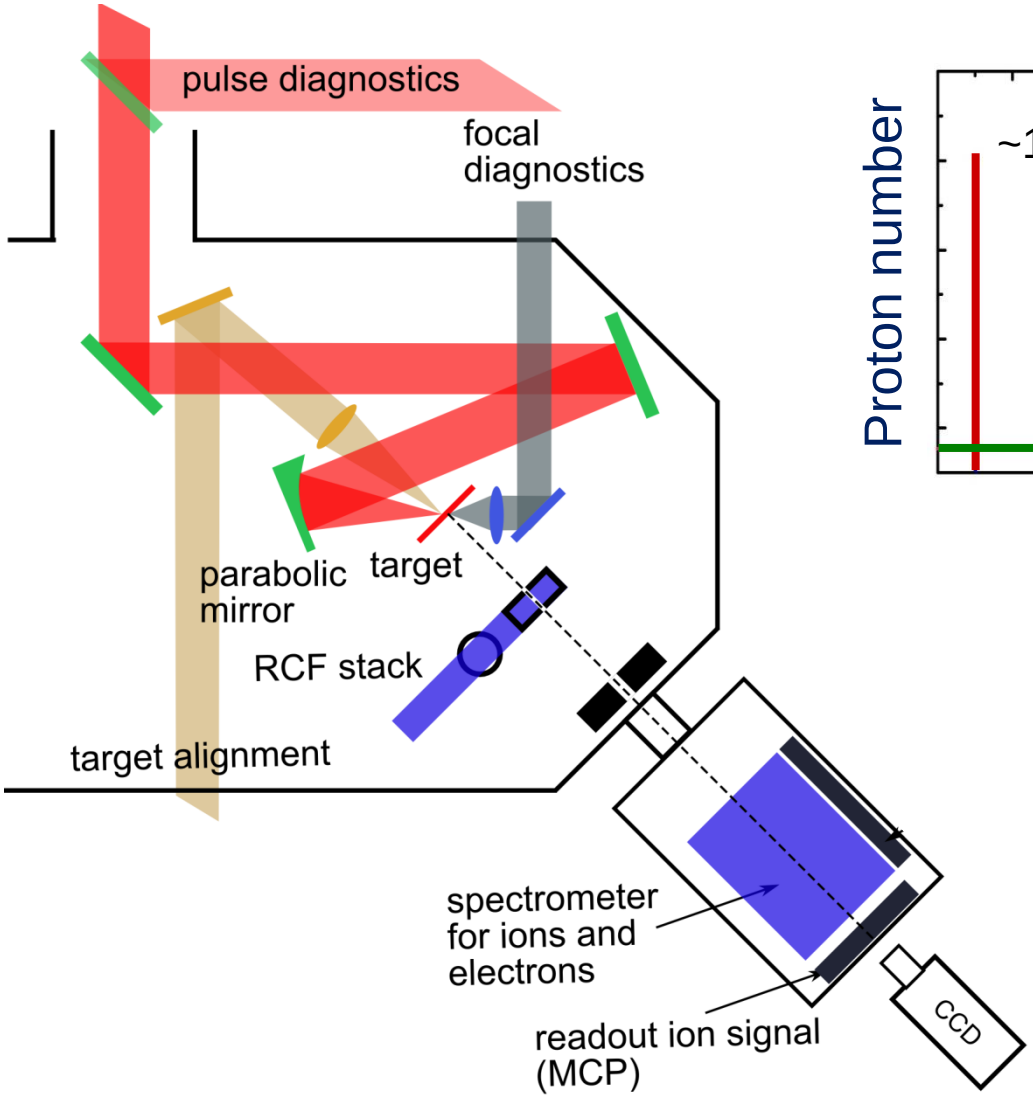
laser development

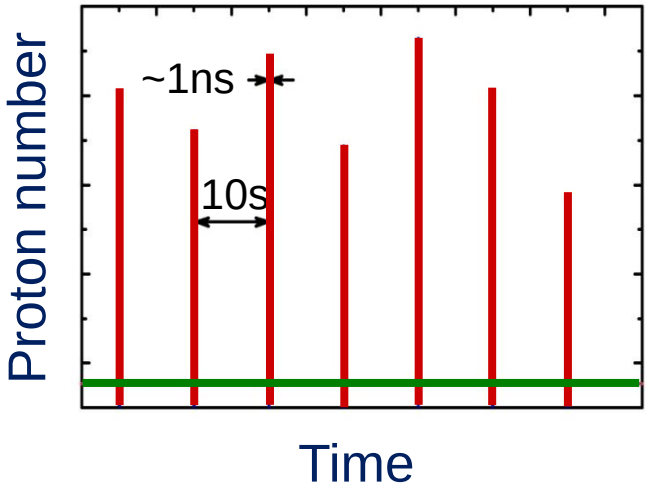
proton energy generation

efficient spectral distribution

Laser-plasma acceleration

Dose controlled radio-biological experiments

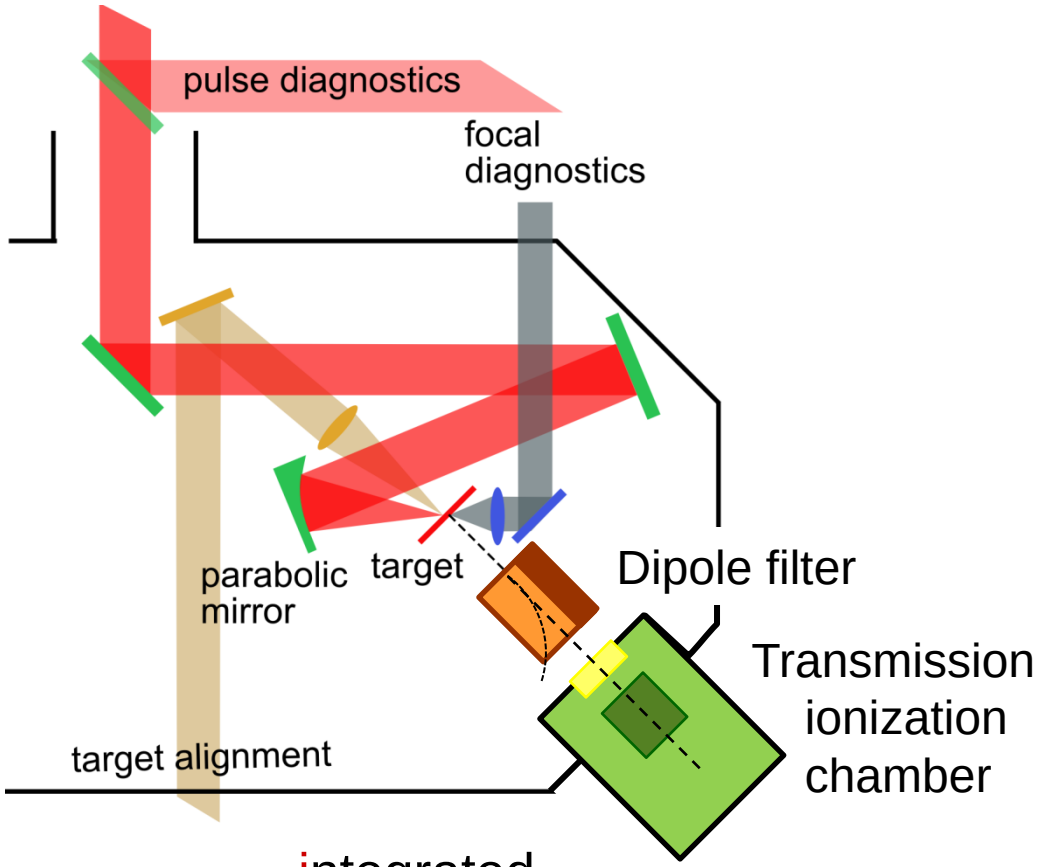




~10^8 Gy / min

~ Gy / min

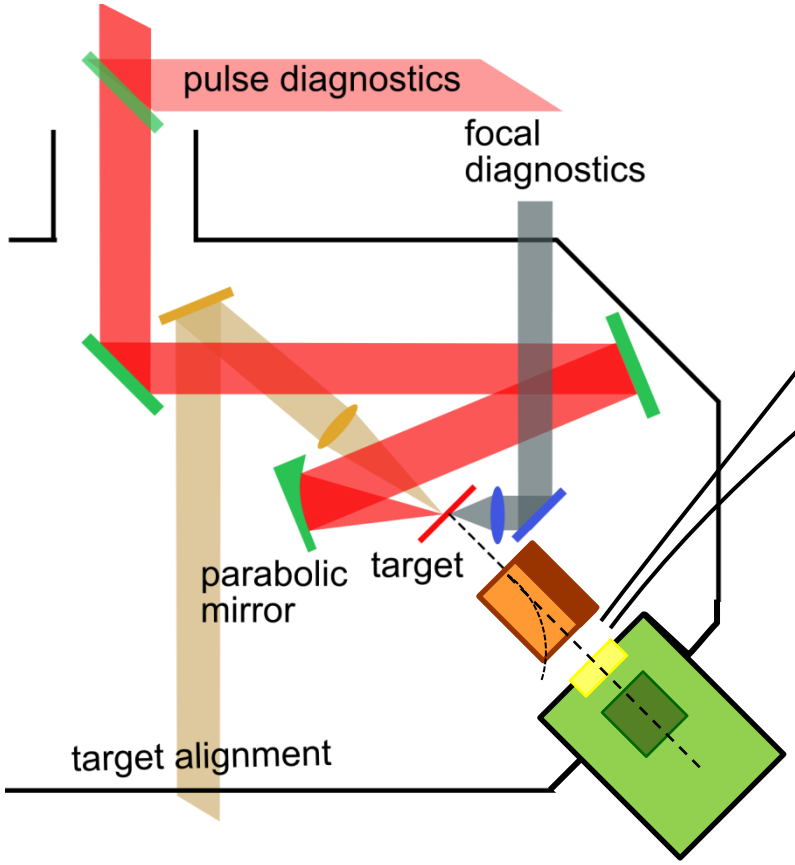
Dose controlled radio-biological experiments

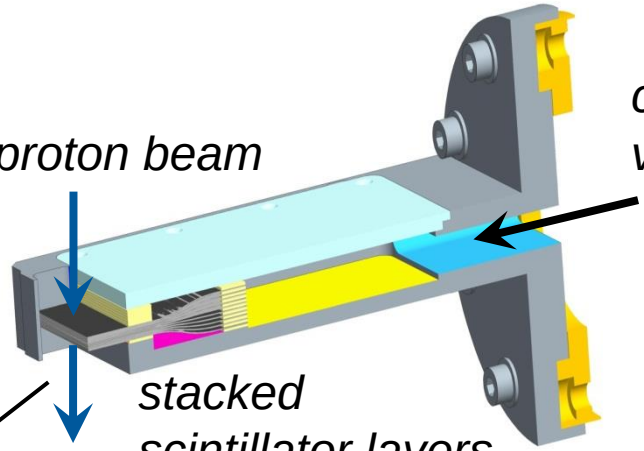


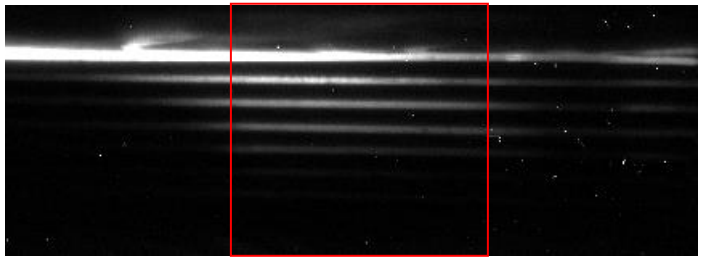
integrated
Dosimetry and
cell irradiation
system (Faraday-cup, RCFstacks, cell samples)

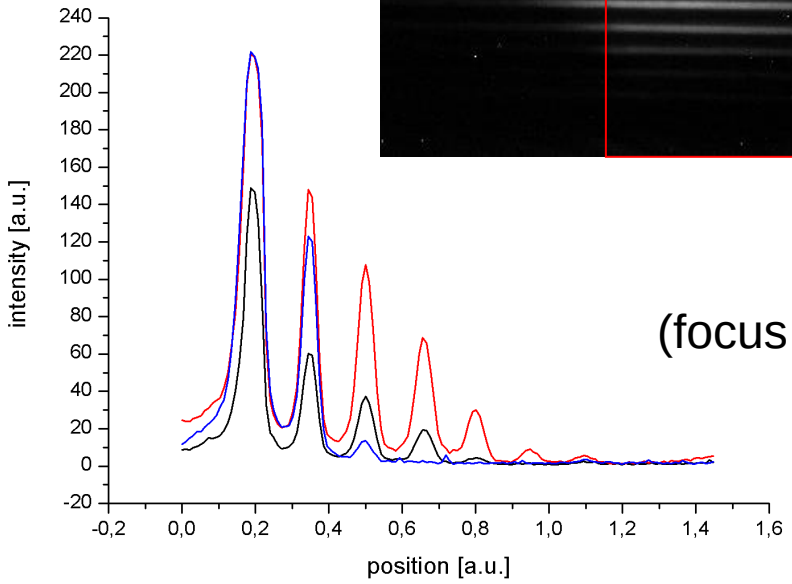
- *Proton energies >5 MeV*
- *Dose rates of Gy/min between 0.1 and 10 Gy (pulse dose / stability)*
- *Energy filtering / transport (radiation protection)*
- *Online and absolute offline dosimetry*
- *Homogeneous irradiation*
- *Sample size ~cm²*
- *Cell irradiation in air*

Online spectral monitoring (spectra and dose)





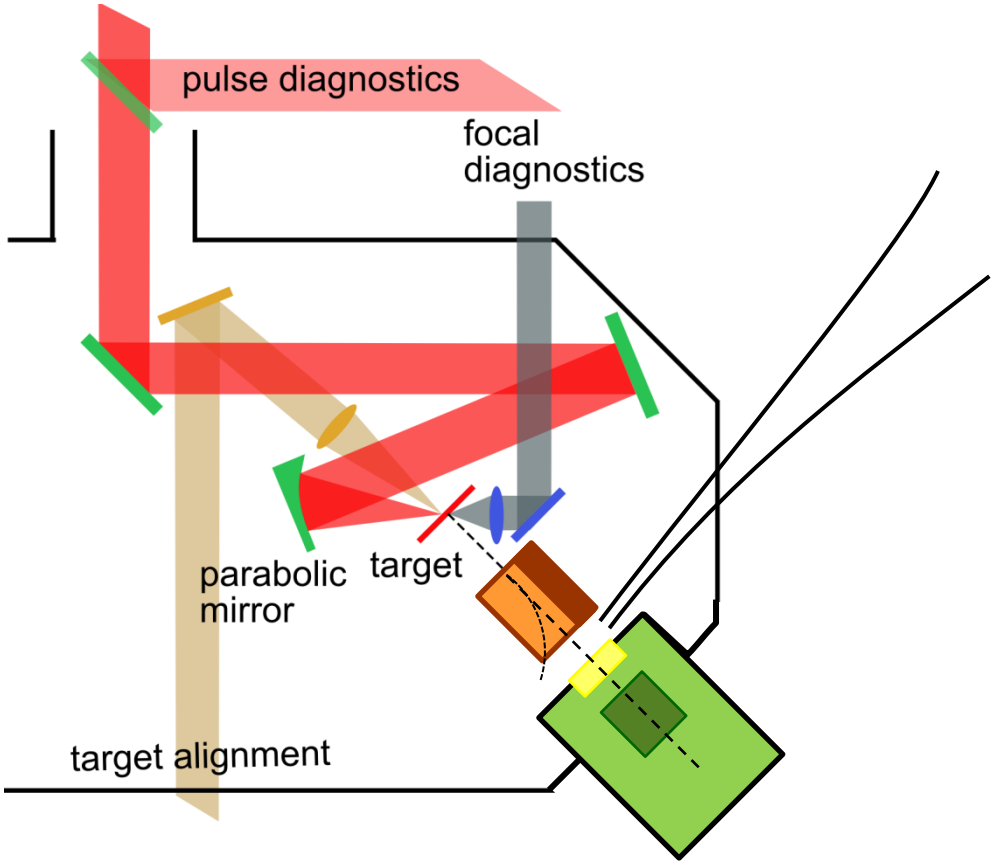




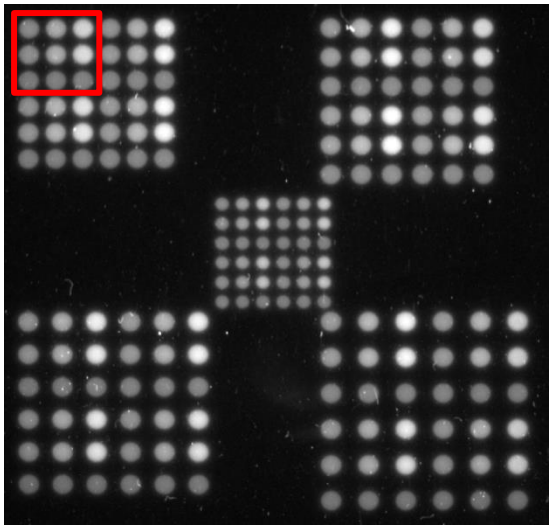
(focus scan)

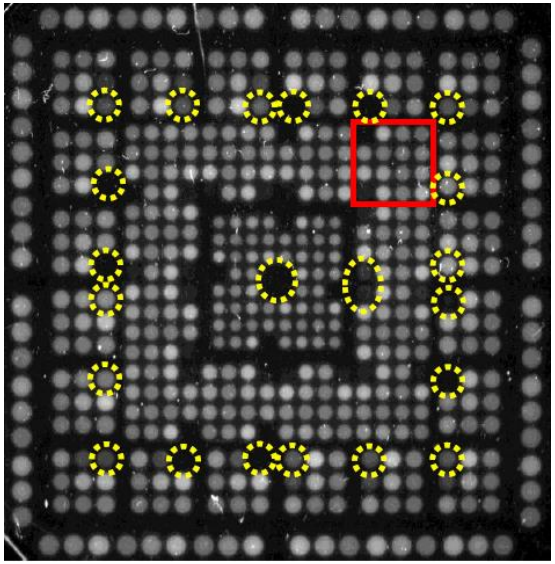
J. Metzkes et al. RSI 83, 123301 (2012)

Online spectral monitoring (2D development)



Test 2D energy (absorber thickness) matrix in front of scintillator

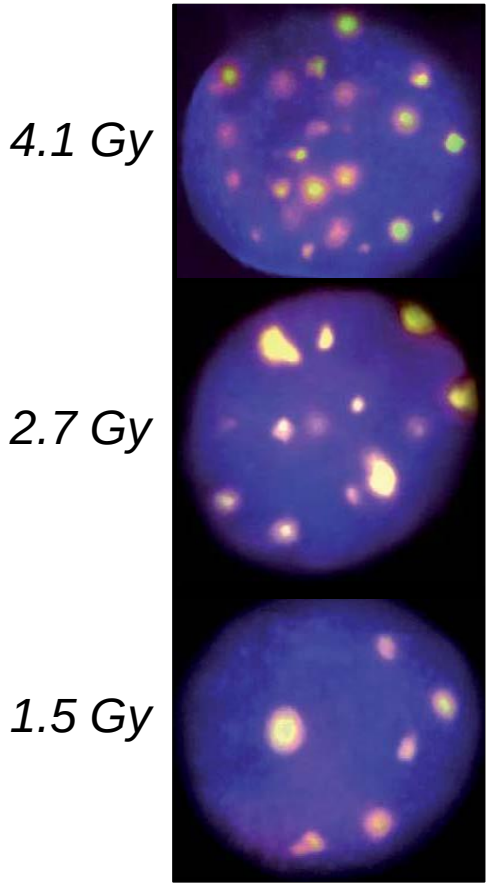


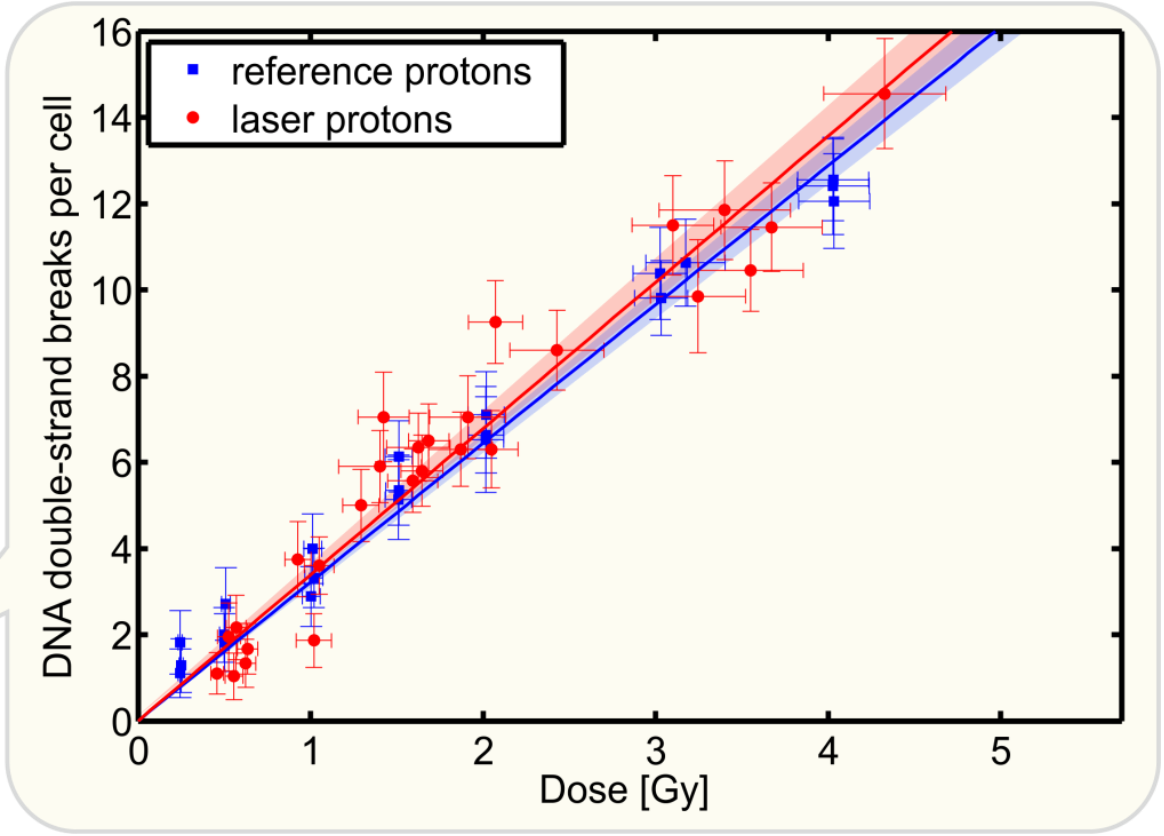


Optimized design

J. Metzkes et al. RSI 83, 123301 (2012)

Dose controlled cell damage …





No significant difference between pulsed and continuous proton radiation (measured for sensitive head/neck SKX cell line repair activity after 24h)

Kraft et al. NJP 12 (2010) 085003, Zeil et al. Appl. Phys. B 110, 437 (2013)

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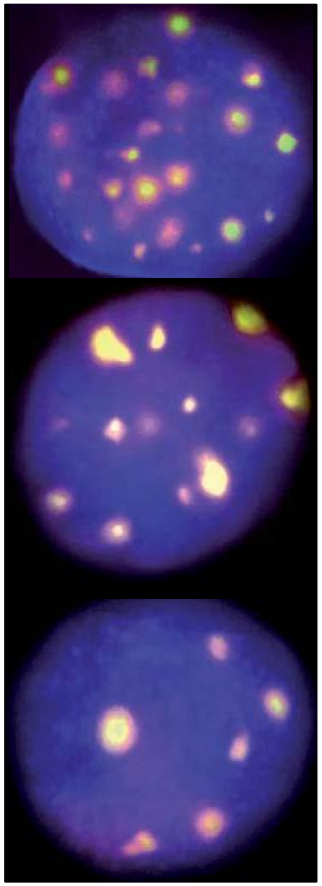
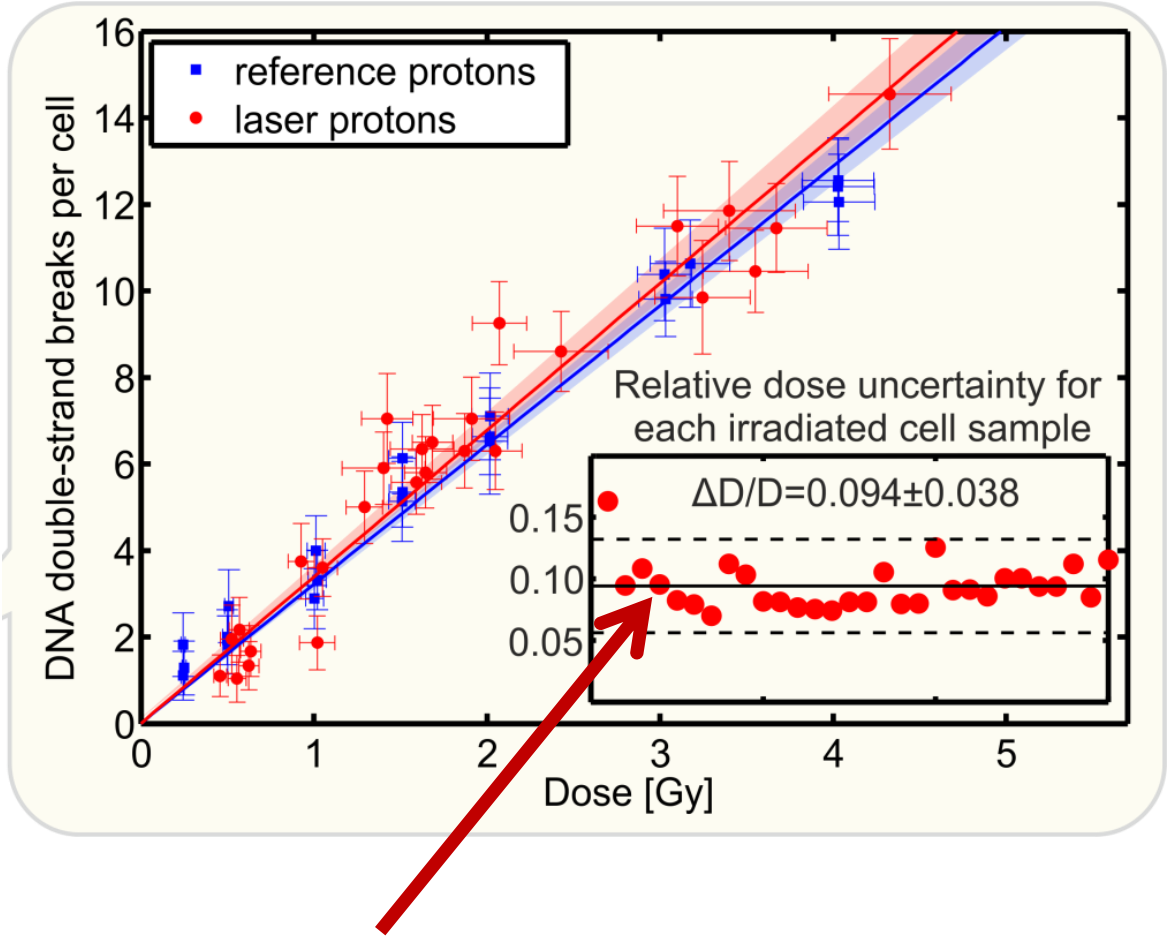
…and beam stability





Dose stability and control for each point below 10%

Kraft et al. NJP 12 (2010) 085003, Zeil et al. Appl. Phys. B 110, 437 (2013)

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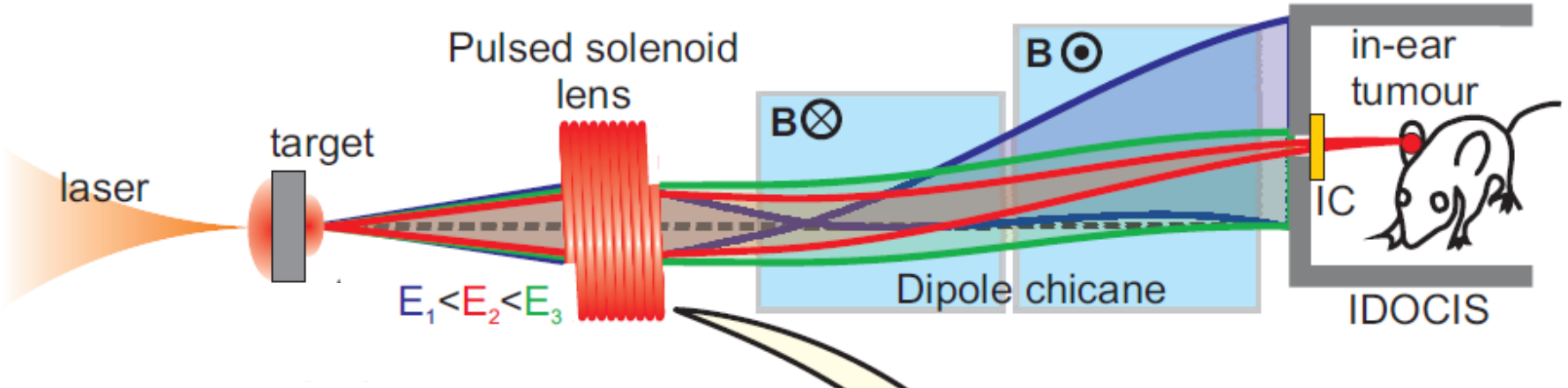
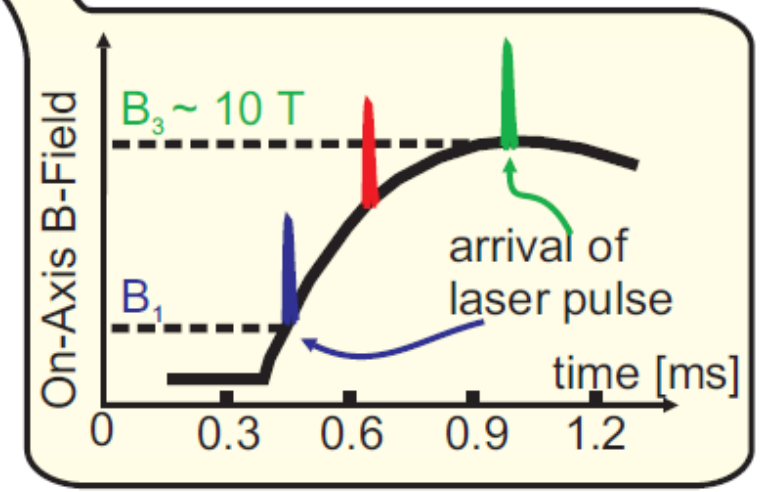
Next steps – animal irradiation



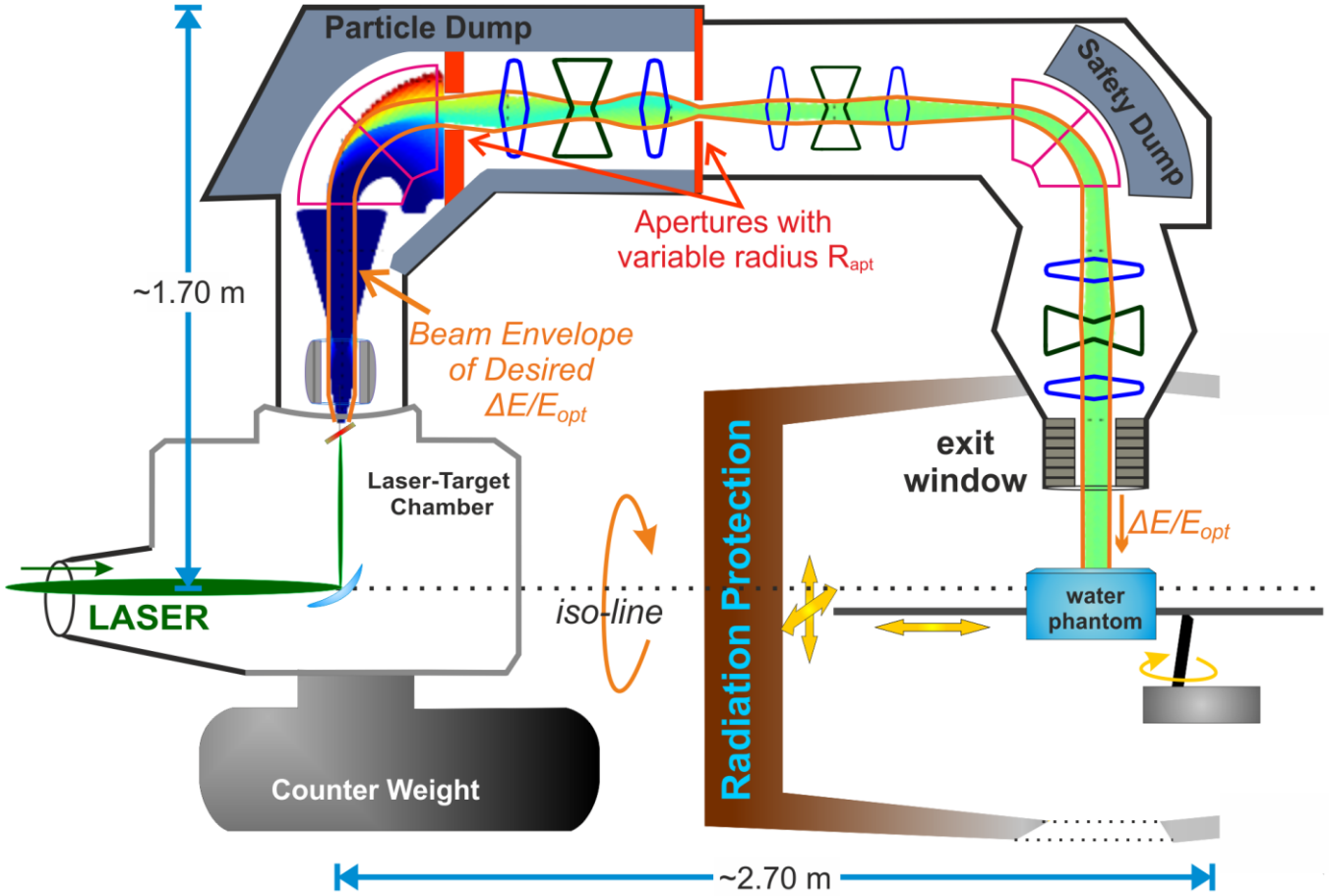
- Pulsed solenoid demonstrated
- Available proton spectra about fine



- Tumor model, animal handling, radiobiological endpoint established and tested with laser-accelerated electrons (Jena)

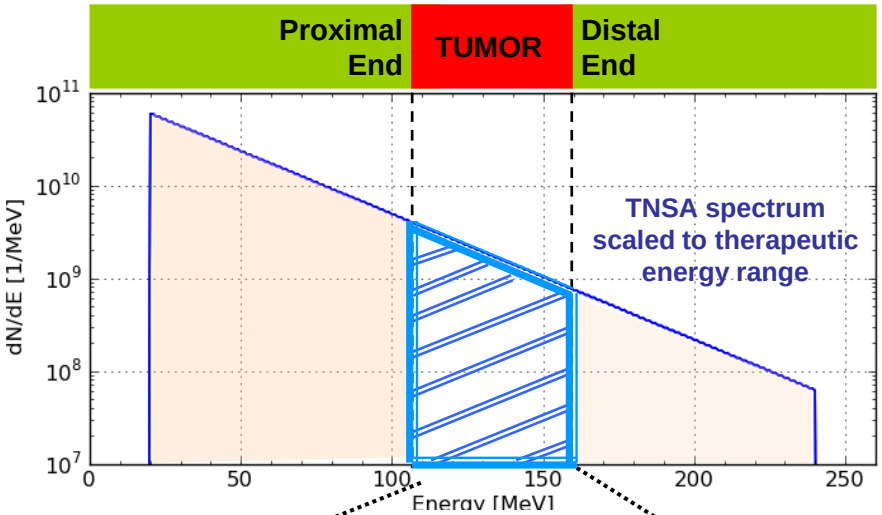
Compact pulsed magnet gantry design

Pulsed high-field (40T solenoid, 8T dipole) air coil magnets for beam guiding

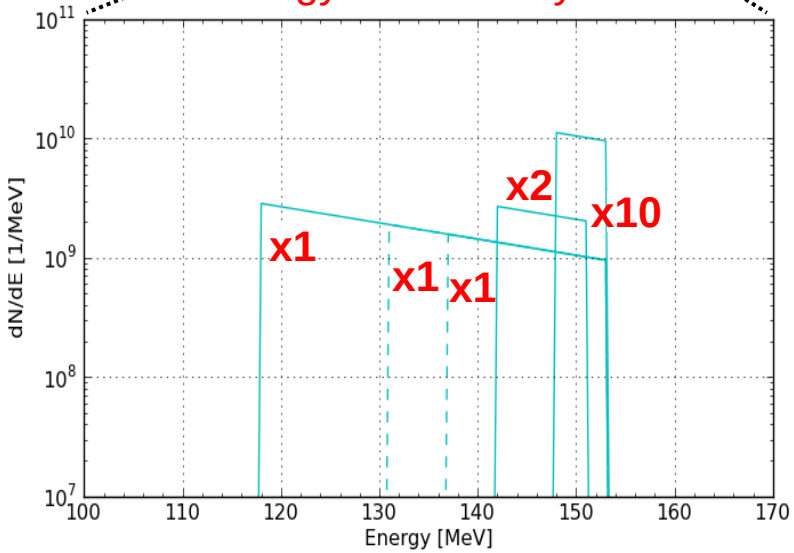


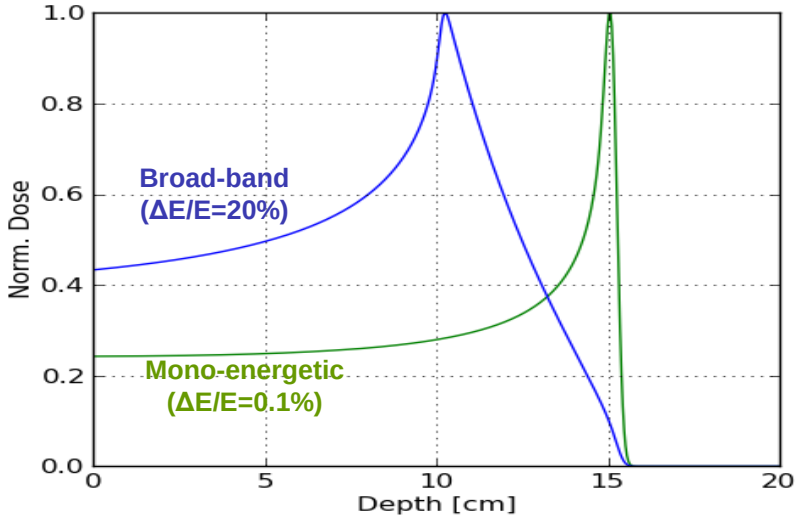
U. Masood et al., submitted 2013

Generation of spread-out Bragg peaks from broad spectra

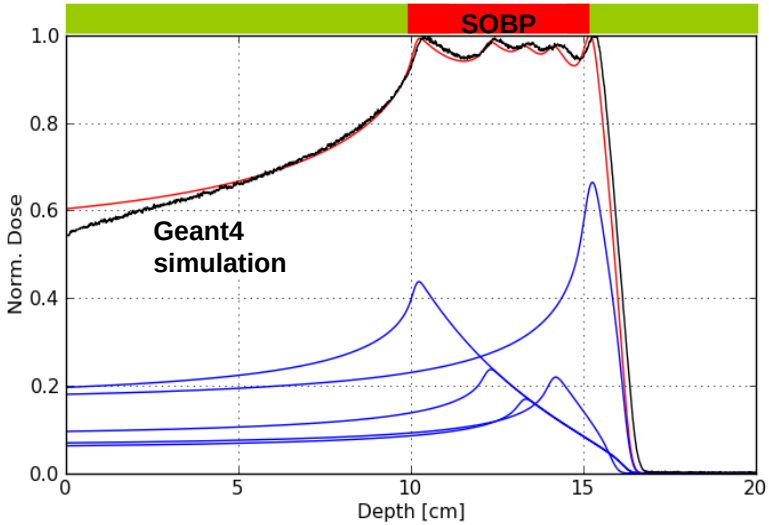


energy selection system



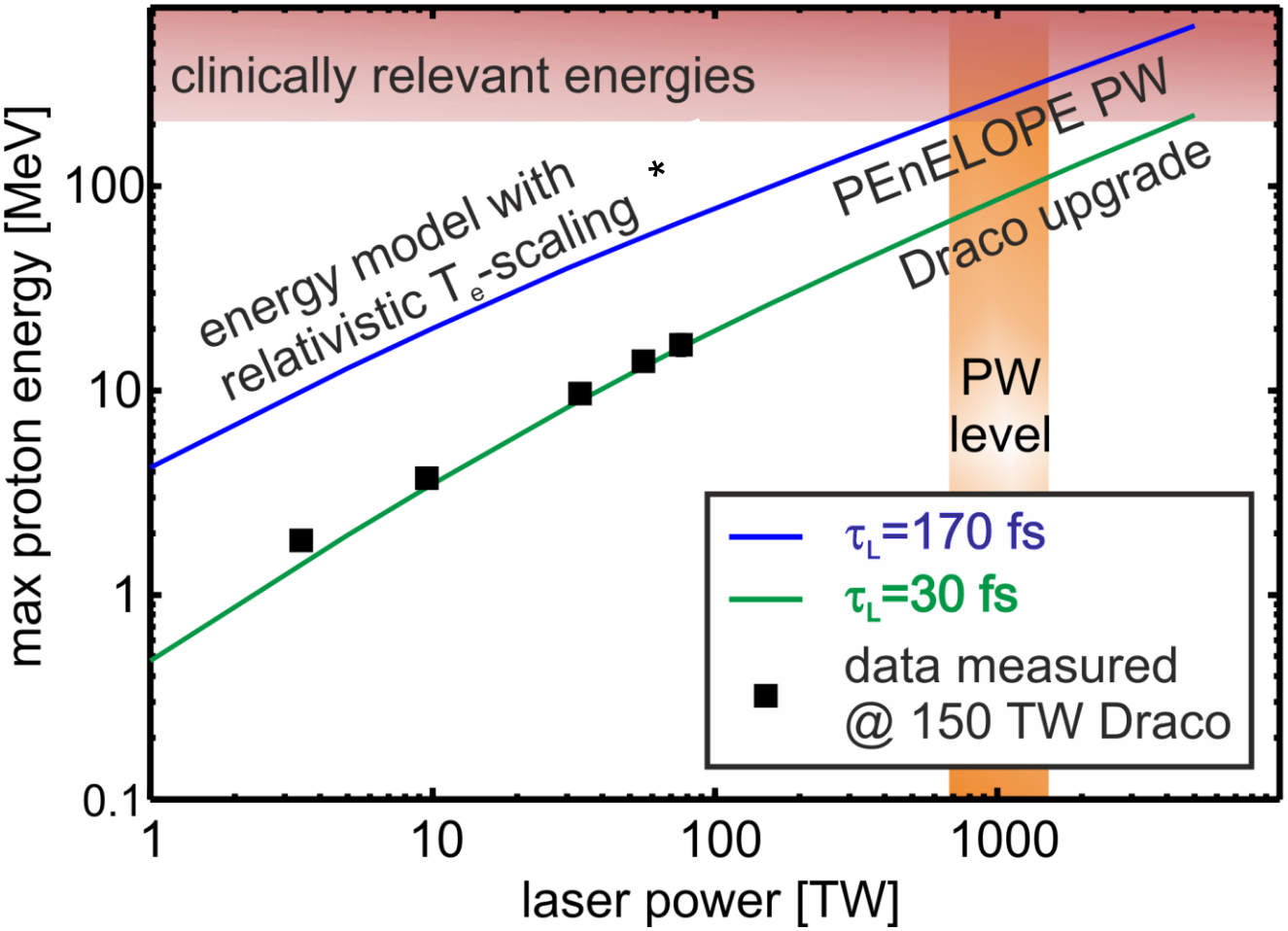


accumulated SOBP in water phantom



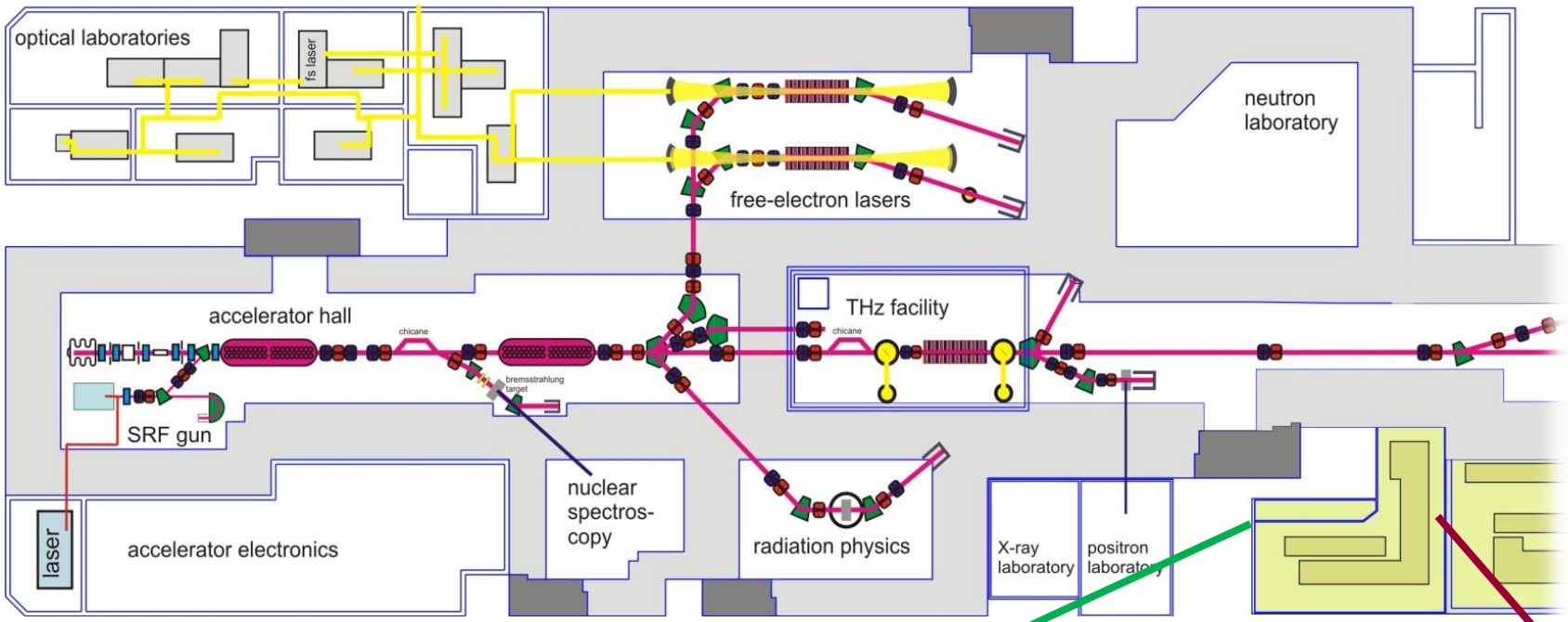
U. Masood et al., submitted 2013

Proton energy scaling (TNSA)



T. Kluge et al., PRL 107 (2011), 205003

ELBE center for high power radiation sources

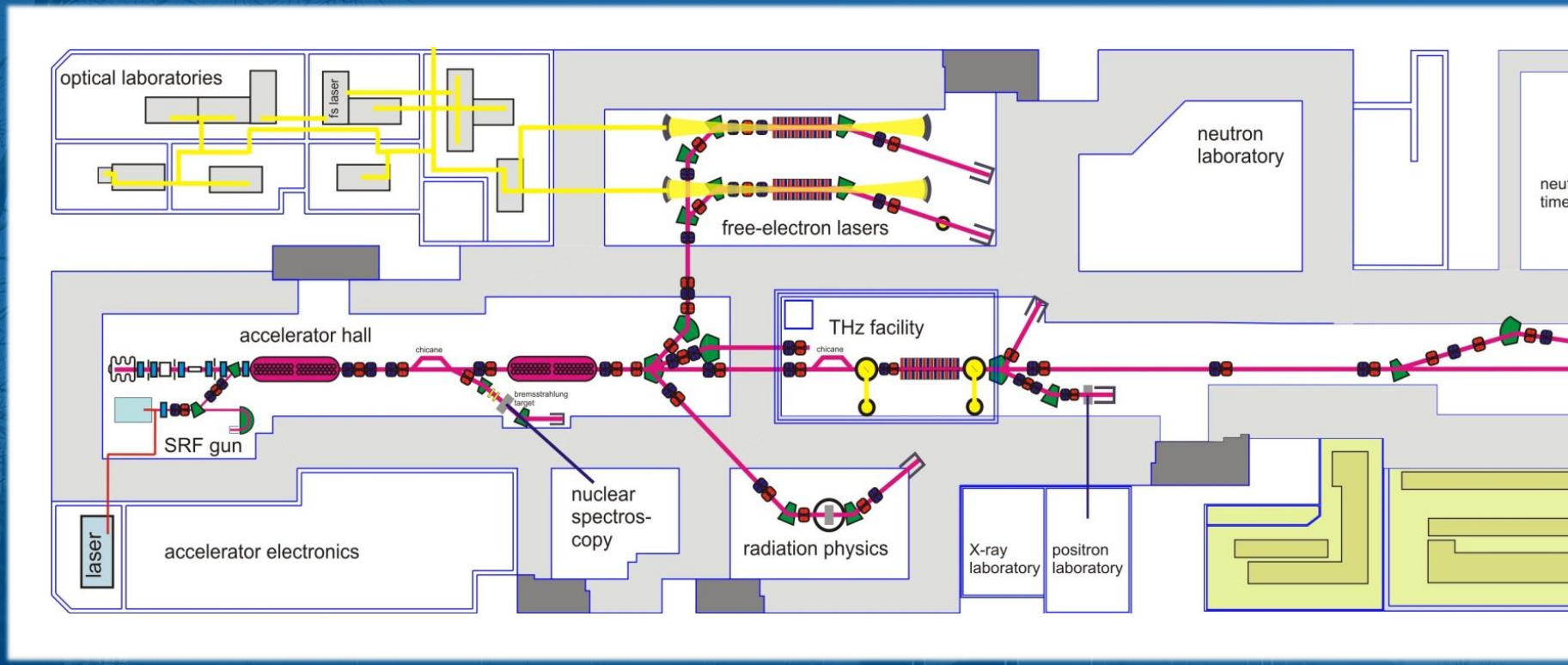


ELBE SRF e-linac

(40 MeV, ps, 100pC up to nC (SRF gun)
pulse compression for super-radiant THz source in preparation

150 TW laser Draco
(4J in ~30fs)

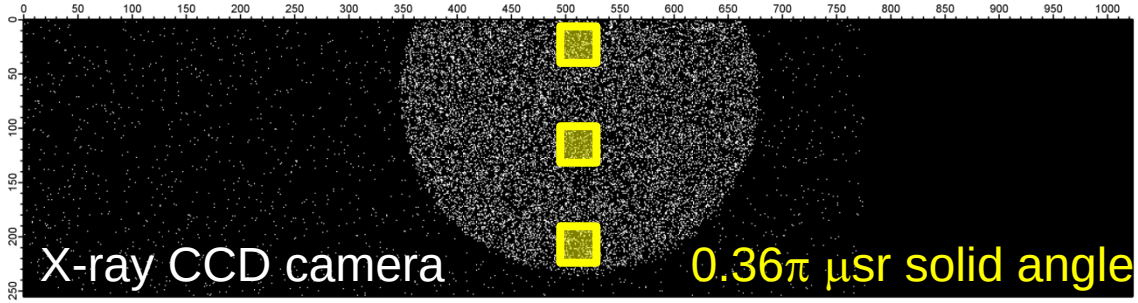
ELBE center for high power radiation sources



Draco-PW: Dual ultra-short pulse beam option
(100TW / 1PW)
installation until end 2013

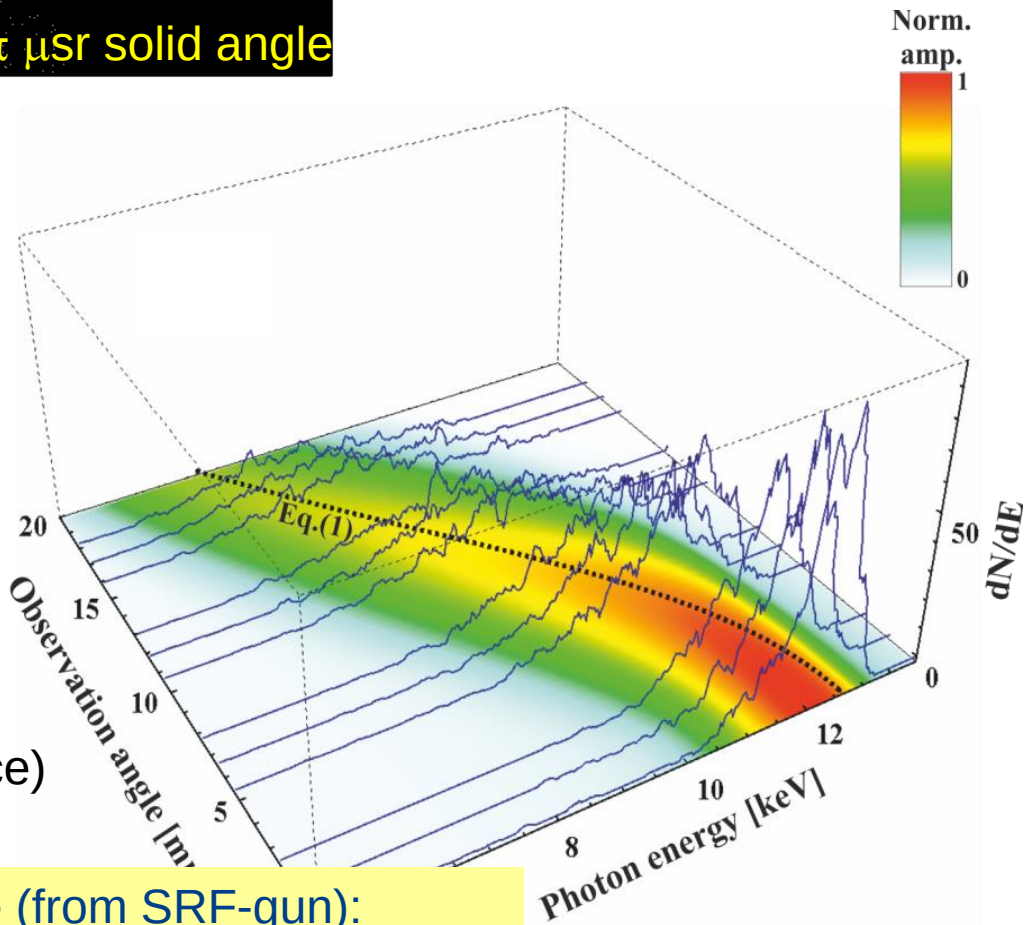
Penelope (~2014): 150J in 150fs, >1Hz rep.rate
fully diode pumped system, active medium (Yb:CaF2)

Thomson X-ray source (@ELBE)



Single pixel absorption events analysis

$$\omega_{sc} = \frac{2\gamma^2 (1 - \cos\varphi)}{1 + \frac{a_0^2}{2} + \gamma^2\theta^2}\,\omega_{laser}$$

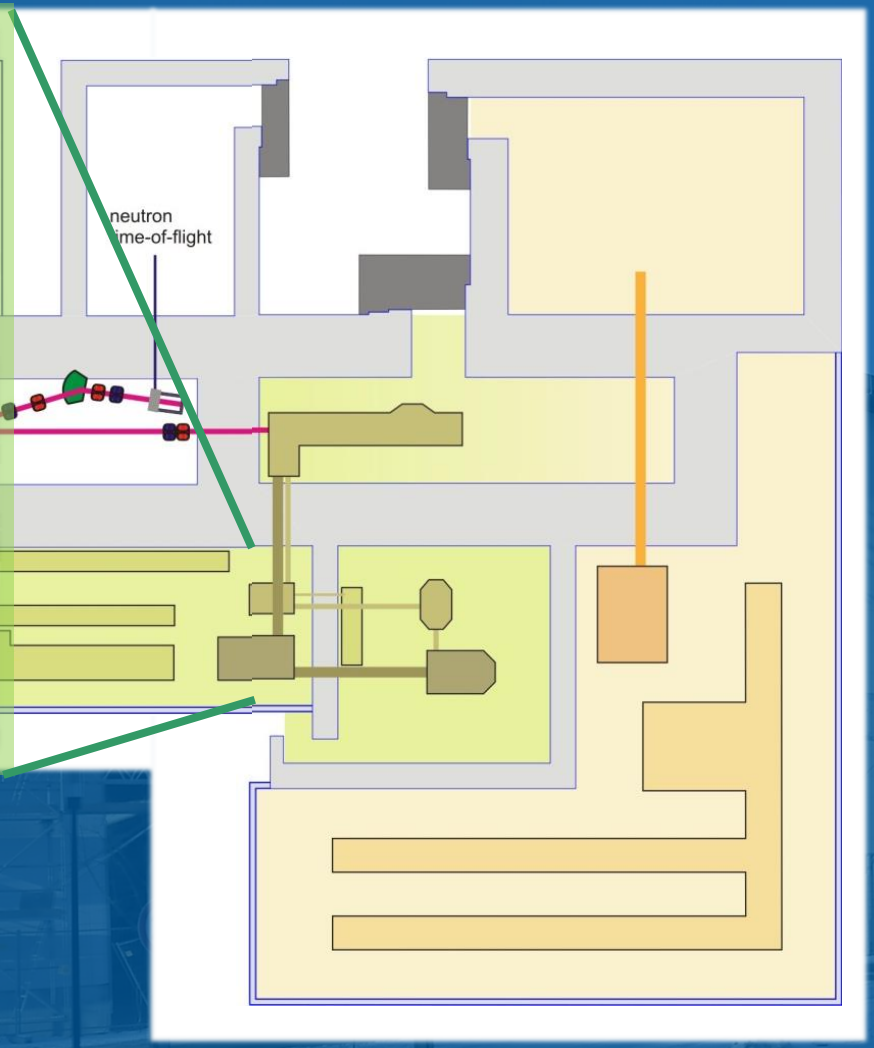


- Emittance means angular spread, smearing the spectrum
- In situ diagnostics (energy, emittance)

using 1 J laser pulse and 1 nC charge (from SRF-gun):
1x10^8 photons per shot in 1.6π μsr (~1/γ)

A. Jochmann, et al., PRL 111, 114803 (2013)

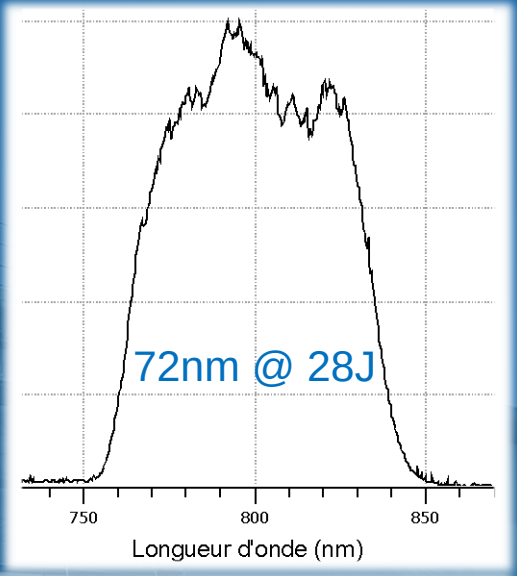
ELBE center for high power radiation sources



Draco dual-beam schedule:

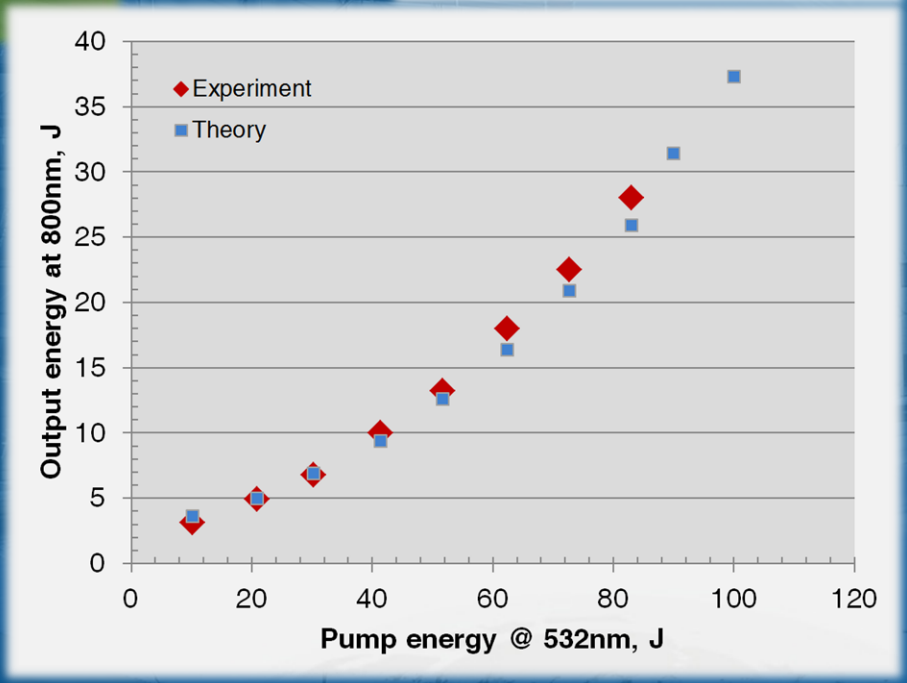
150TW (4J in 30fs on target) with
improved contrast in new target areas - 10 / 2013
PW (30J / 30fs) amplifier installation until 11/2013, on target 3/2014

Draco PW installation

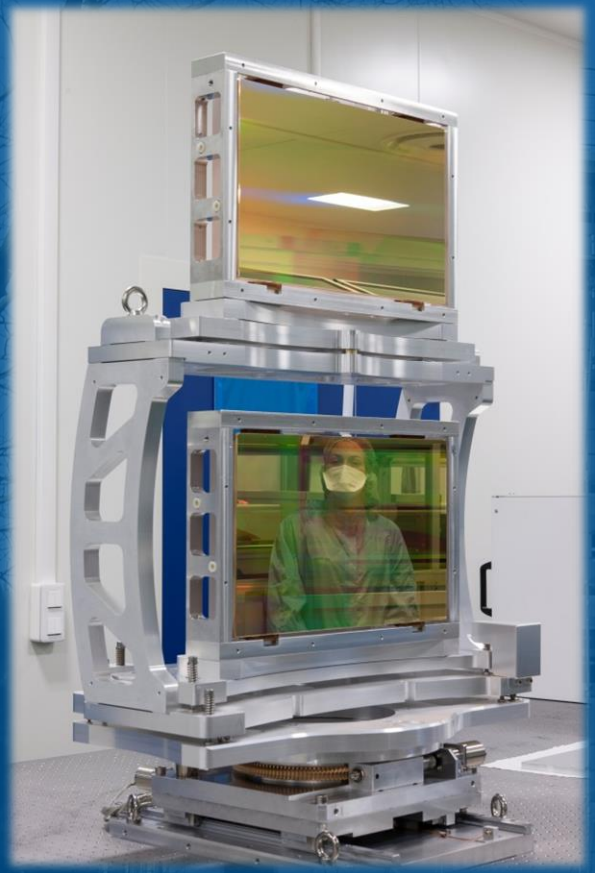


Amplifier commissioning in Evry until 6/2013
with 80J pump energy (out of 120J)

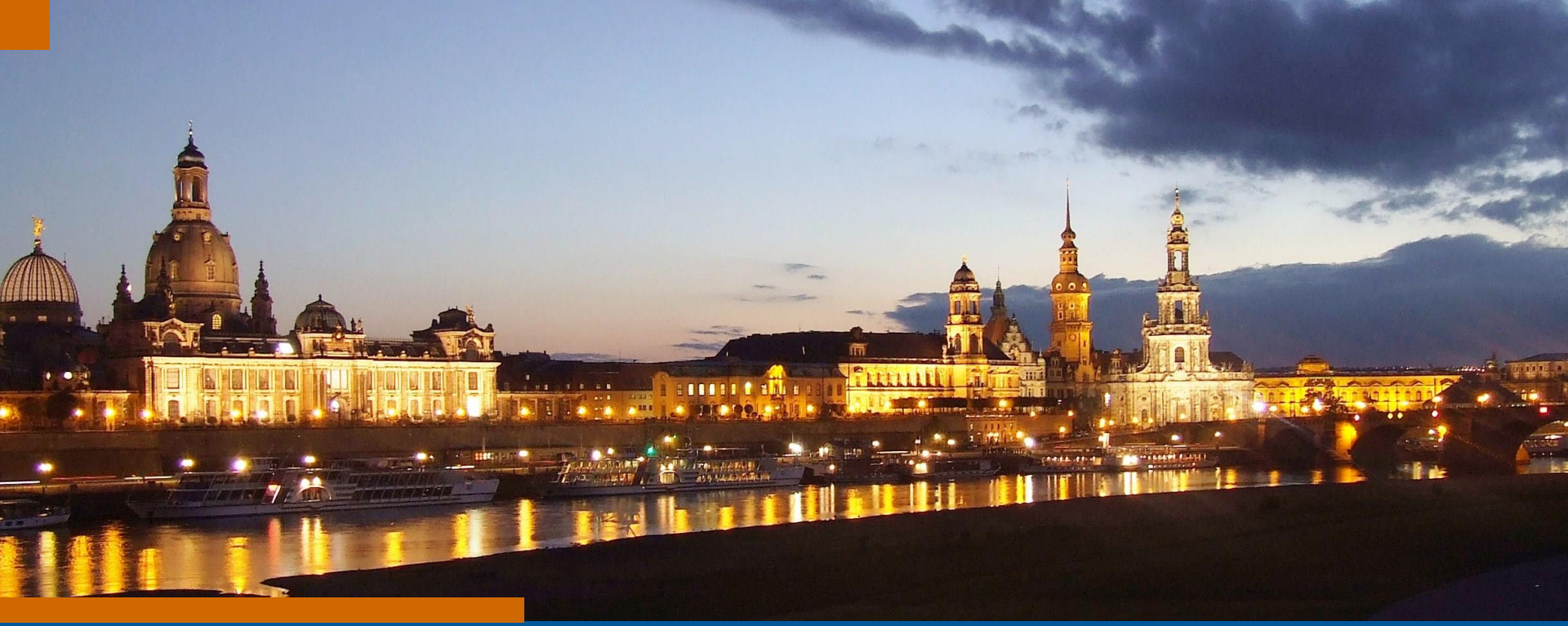
2.5J to be amplified to ~40J with
pulse-to-pulse stability 0.4% RMS
>70nm FWHM bandwidth
wavefront quality Strehl > 0.7 (w/o DM)



Draco PW installation / pulse compression



Full compressor alignment (in air) demonstrated with 0.27 lambda PV wavefront distortion at ~30cm clear aperture (~20cm beam dia.)
(JY gold gratings 565x300)



- K. Zeil, J. Metzkes, S. Kraft, F. Kroll, C. Richter, et al.
- A. Irman, J. Couperus, A. Jochmann, H.P. Schlenvoigt, et al.
- M. Bussmann, A. Debus, T. Kluge, et al.
- M. Siebold, S. Bock, U. Helbig, F. Röser, M. Löser, et al.
- U. Schramm, T. Cowan, R. Sauerbrey

- J. Pawelke, L. Karsch, W. Enghardt, E. Beyreuther, et al.

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