OncoRay – National Center for
Radiation Research in Oncology, Dresden

Dosimetry of laser-accelerated particle beams used for cell irradiation experiments

Industry meets Academia: Beam Monitoring Instrumentation and Quality Assurance

Darmstadt, November 10-11, 2011

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Technische Universität Dresden, Medical Faculty Carl Gustav Carus
and
Helmholtz-Zentrum Dresden-Rossendorf, Institute of Radiation Physics

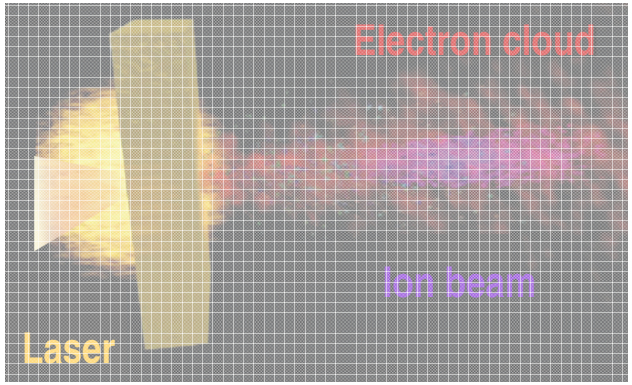
1. Motivation

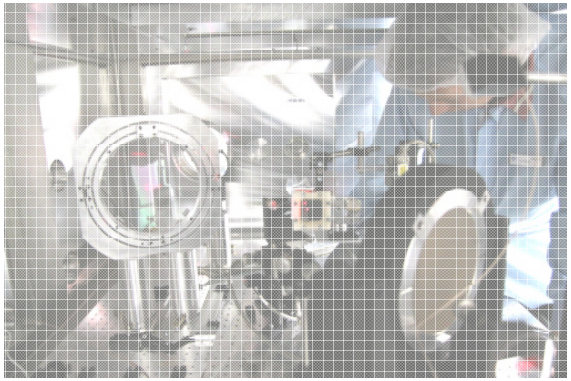
Long-term goal:

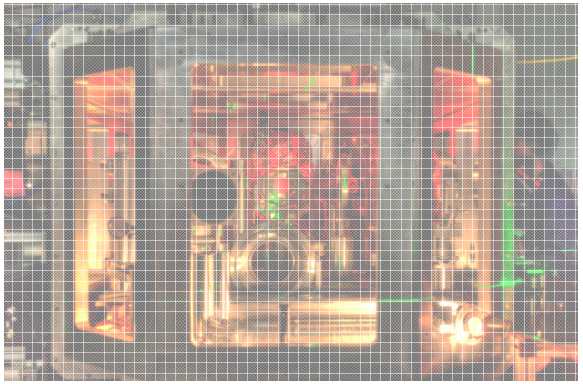
Development of
compact particle therapy facility
based on high intensity laser

by potentially

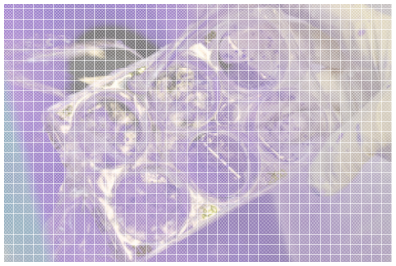
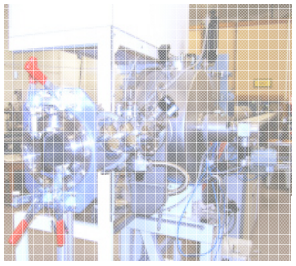
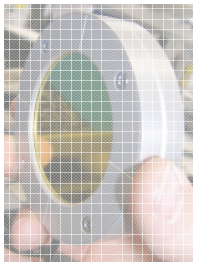
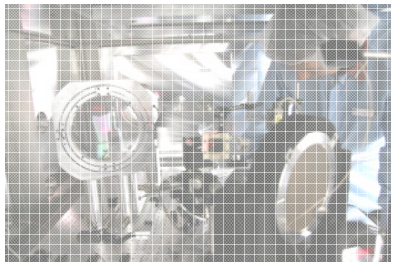
- reducing hadron therapy accelerator to hospital scale
- allowing more compact beam transport (no magnets, only mirrors are needed for laser light transport)







2. The research project onCOOPtics

oncooptics

TECHNISCHE UNIVERSITÄT DRESDEN

University Hospital Carl Gustav Carus Dresden

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

OncoRay National Center for Radiation Research in Oncology Dresden +

ultra optics

IOQ Jena

Friedrich Schiller University of Jena seit 1558

Fraunhofer Institute for Applied Optics and Precision Engineering

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3. Laser driven particle acceleration

Specific properties of laser driven particle beams compared to beam delivery by conventional accelerator:

- Ultra short beam pulses (~ 1 ps)
- Low pulse repetition rate (~ 1 - 10 Hz)
- High single pulse dose (~ 1 Gy) and pulse dose rate (~ 10^{12} Gy/s)
- Instable beams (non-linear acceleration process)
- Large beam divergence (~ 10 degrees)
- Broad energy spectrum
- "Contaminated" beams (p, light ions, n, e^-, γ, X)

3. Laser driven particle acceleration

Laser Radiooncology:

Consequences of laser driven particle beams with respect to their

- Detection and dosimetry
  - high precision (~ 1 %)
  - real time
- Biological effectiveness
- Delivery as therapy beams including
  - particle / energy selection
  - irradiation field shaping
  - background radiation shielding

3. Laser driven particle acceleration

Precondition:

Availability of laser driven particle accelerator

Sufficiently intense laser system for particle acceleration

- Stable and reliable operation with reproducible beam properties
- From laser accelerated electrons …
  … to laser accelerated proton/ion beams

Translational research

- From basic research …
  … to the long-term aim of clinical application
- First step: Radiobiological *in vitro* cell experiments

4. Requirements for cell experiments

Radiobiological:

- Measurement of dose effect curves

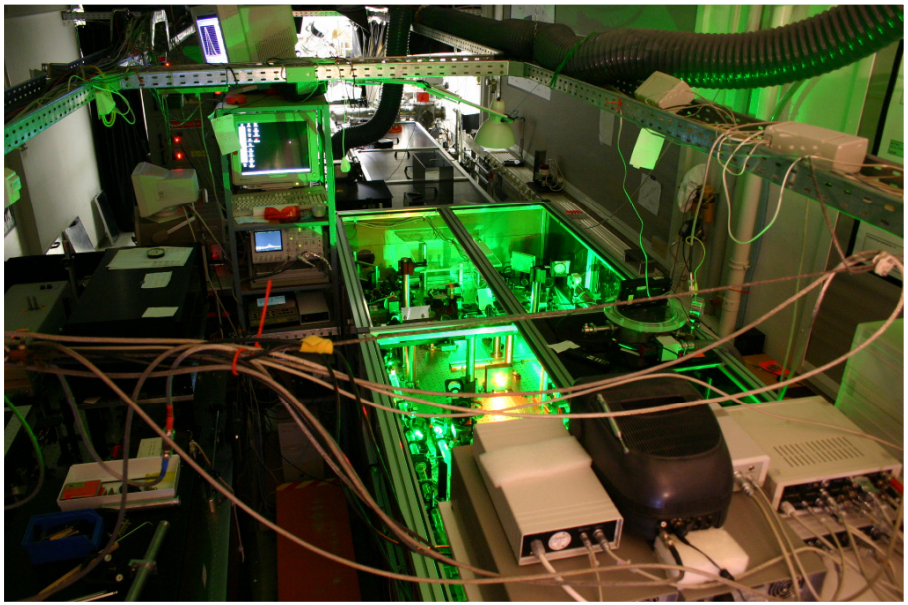
Dosimetric:

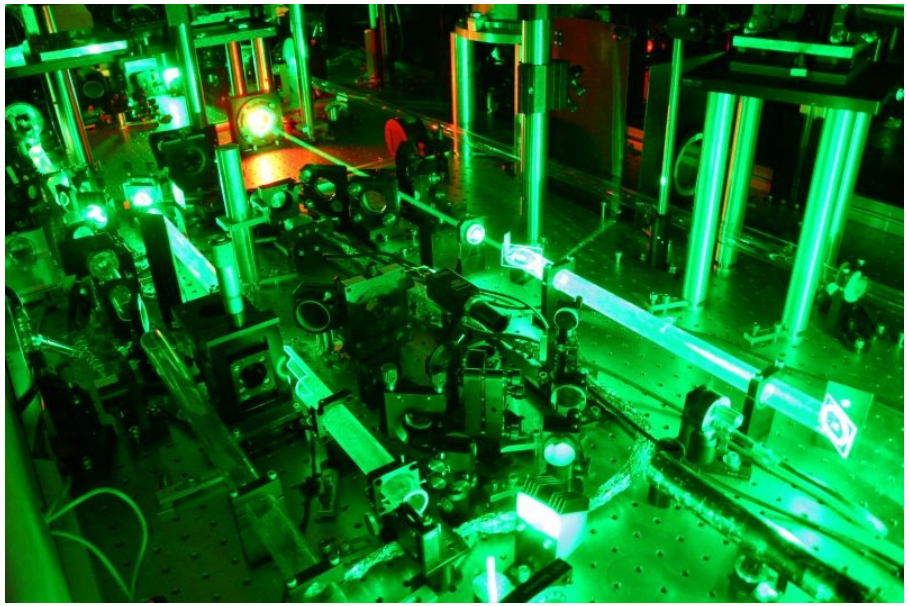
- Homogenous spatial dose distribution and suitable field size
- **Precise absolute dosimetry**
- Delivery of prescribed dose to cells: **online dosimetry**
    - Integration of pulse
    - Time resolution for pulse train

4. Cell experiments with laser electrons

Friedrich-Schiller-University, Jena:

- **JETI (Jena Titan-Sapphire) laser system: 10 TW, 1 J, 80 fs, 10 Hz**
  - ***Electron acceleration up to 50 MeV***
  - Proton acceleration up to 2.5 MeV
  - ***In routine operation, but used for single-shot physical experiments***
  - ***Start of dosimetric and radiobiological experiments in 2007***





4. Experiments with electrons

Detector and dosimeter response:

Electrons	Medical linac	ELBE linac	Laser accelerator
Frequency	3 GHz	13 MHz	10 Hz
Microbunch duration	30 ps	2 ps	30 fs
Microbunch charge	0.1 – 1 fC	77 pC	0.1 – 1 nC
Relative pulse dose rate	1	**10^8**	**10^9**

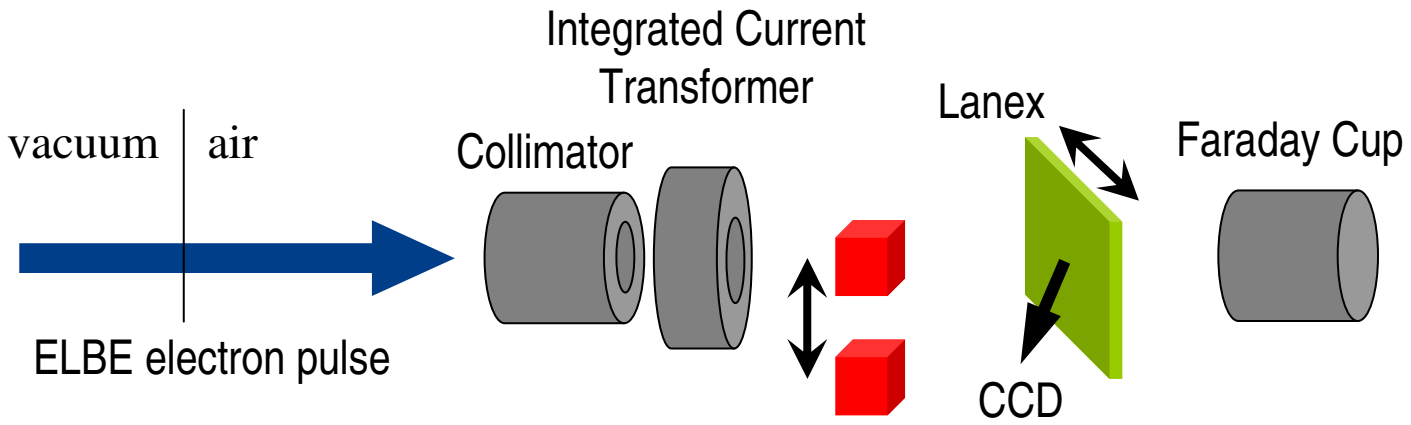
Advantages

- Monoenergetic electrons
- Pulse-to-pulse reproducibility
- Highly flexible time structure of the beam
- Tuneable bunch charge (fC … 0.1 nC)

Measurement of the response of several detectors and dosimeters to high-intensity electron pulses at ELBE

4. Experiments with electrons

Detector and dosimeter response:



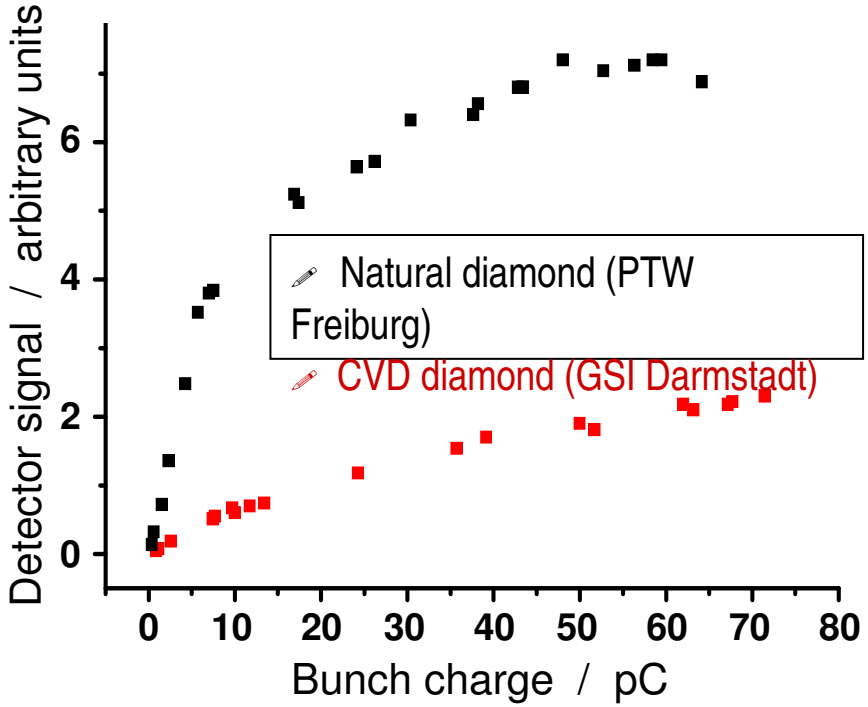
Detectors & Dosimeters

- **Faraday cup (reference)**
- Ionization chamber (IC)
- Thermoluminescence dosimeter (TLD)
- Optically stimulated luminescence (OSL)
- Radiochromic film (EBT, Gafchromic)
- Integrating current transformer, Bergoz Instrumentation
- Imaging plates: Fuji MS, Fuji SR
- Diamond, CVD, GSI Darmstadt
- Diamond, natural, PTW Freiburg
- Scintillating screens: 8 types

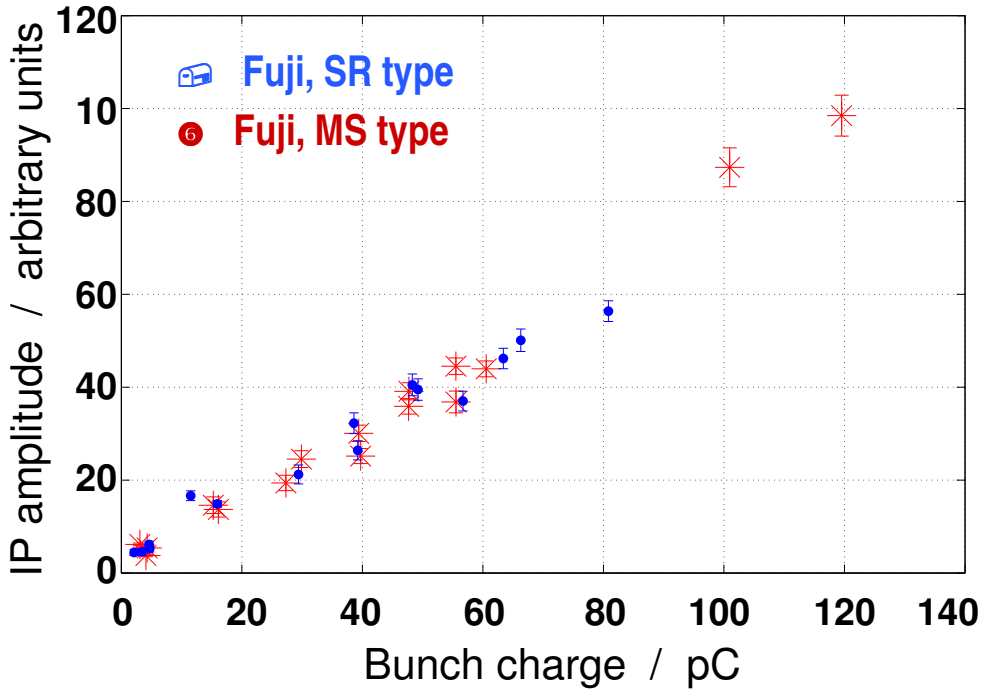
4. Experiments with electrons

Detector and dosimeter response:

Diamond detector



Imaging plate



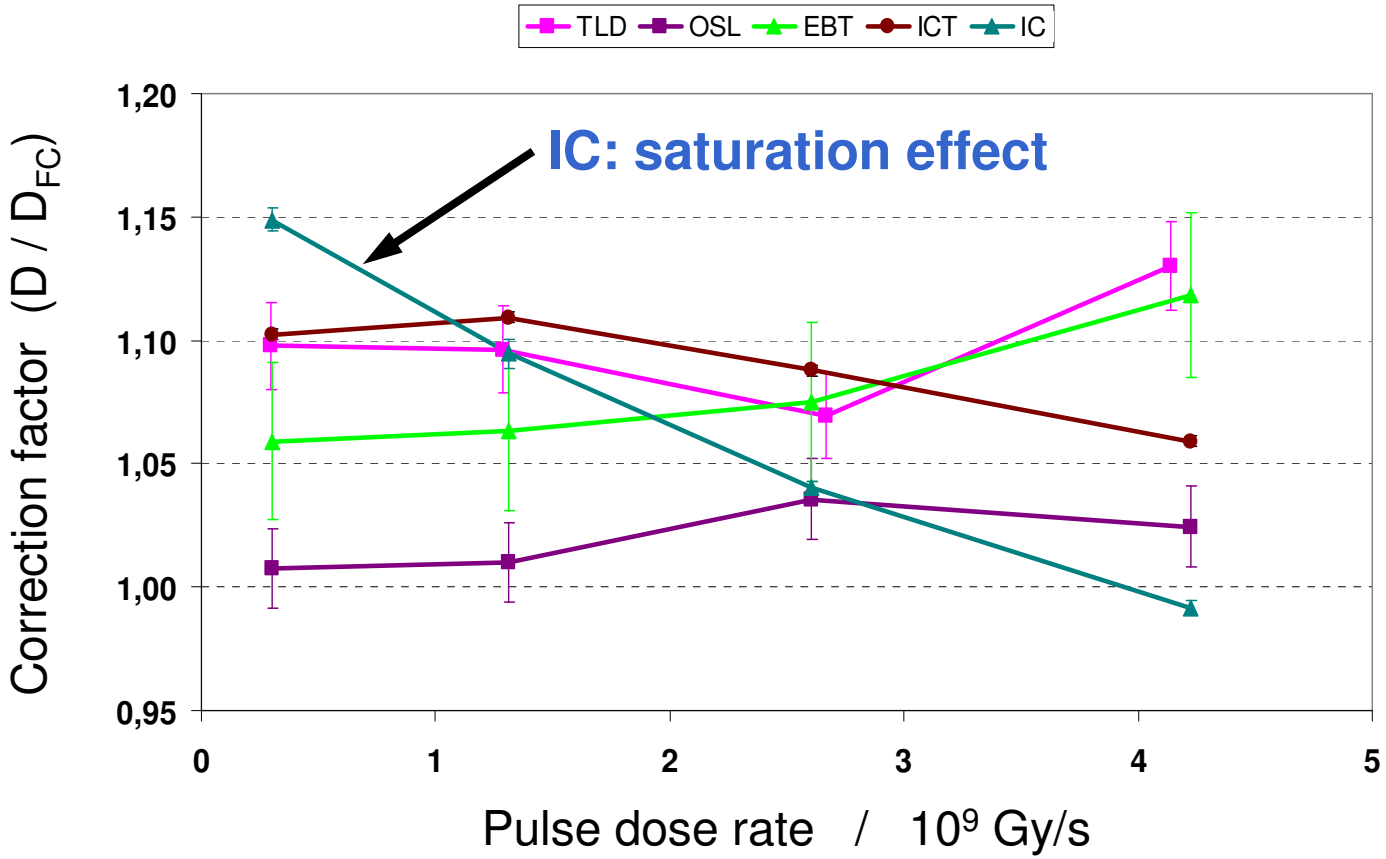
⇨ *Saturation effect*
⇨ *Can be corrected, if it's known*
⇨ *Online*

⇨ *No saturation effect*
⇨ *High dynamic range*
⇨ *Post irradiation readout*

K. Zeil et al.: Rev Sci Instrum 81 (2010) 013307, A. Buck et al.: Rev Sci Instrum 81 (2010) 033301

4. Experiments with electrons

Detector and dosimeter response:

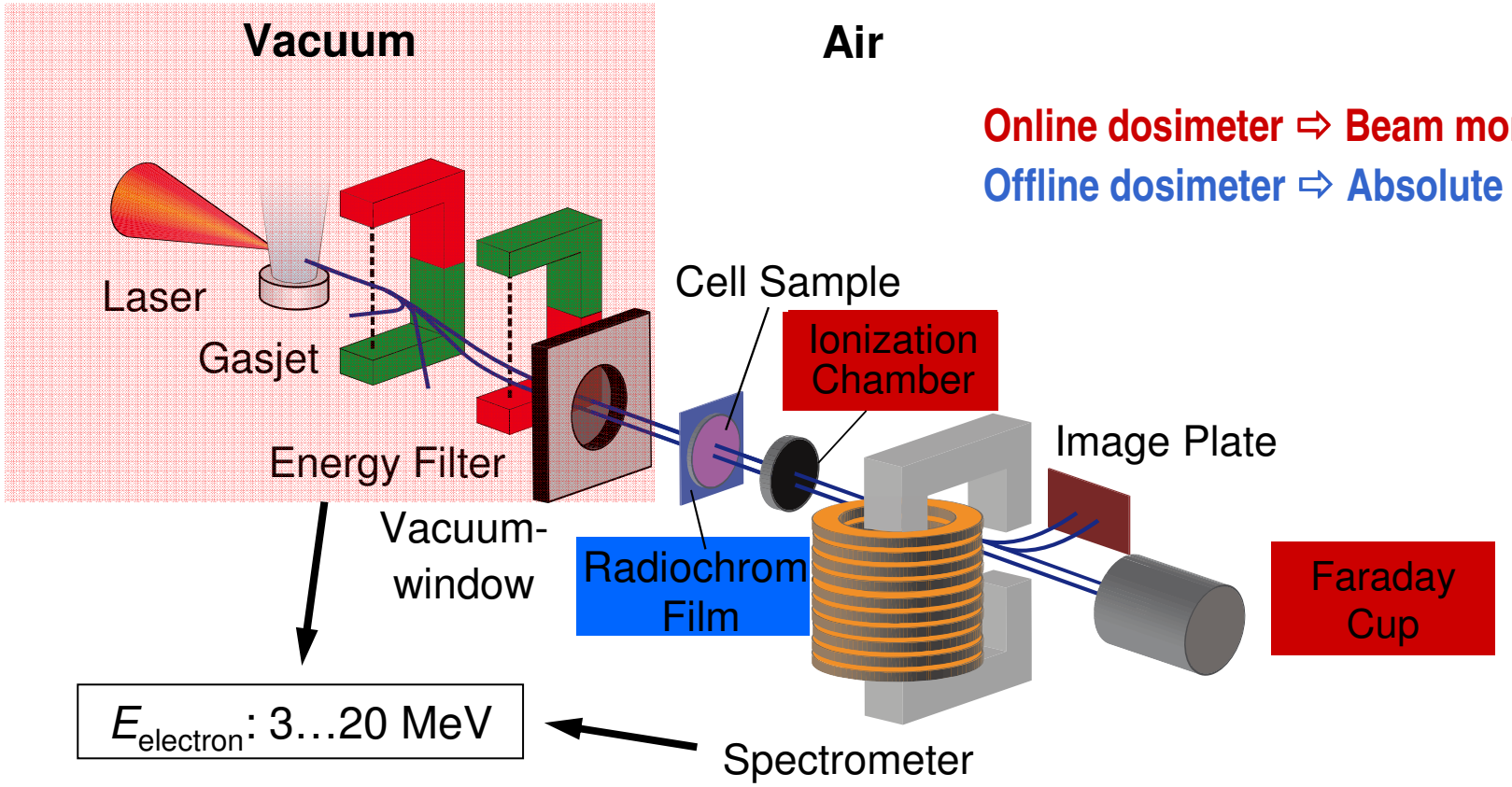


⇨ ***Dosimetry setup for cell irradiation with laser driven electrons***

L. Karsch et al.: submitted to Phys Med Biol

4. Cell experiments with laser electrons

Setup at the laser accelerator JETI:



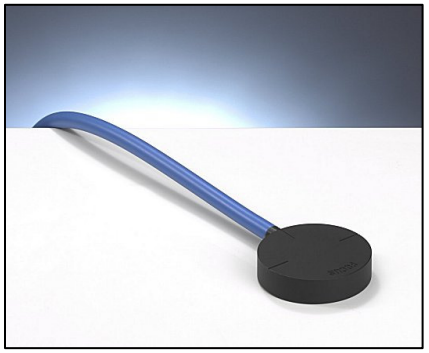
⇨ ***First systematic cell irradiation with laser accelerated particles***

Laschinsky et al.: Radiother Oncol 92(2009)89, Beyreuther et al.: Med Phys 37(2010)1392, Richter et al.: Radiat Meas(2011)in press

4. Cell experiments with laser electrons

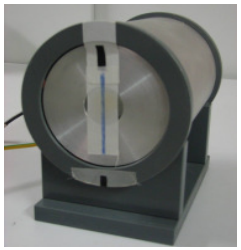
Dosimetry:

Roos ionization chamber (PTW)



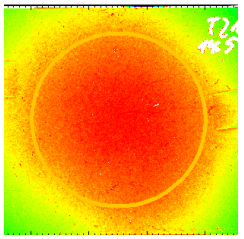
- Relative dose per pulse
- Online

- Dose rate independent absolute dose per pulse
- Online



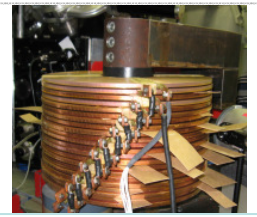
Faraday cup

- Dose rate independent absolute dose
- Spatial dose distribution
- Retrospective



Radiochromic EBT film

- Energy distribution
- Online / Offline



Spectro-meter

Monitoring of all cell and dosimeter irradiation

Measuring before, during and after cell sample irradiation

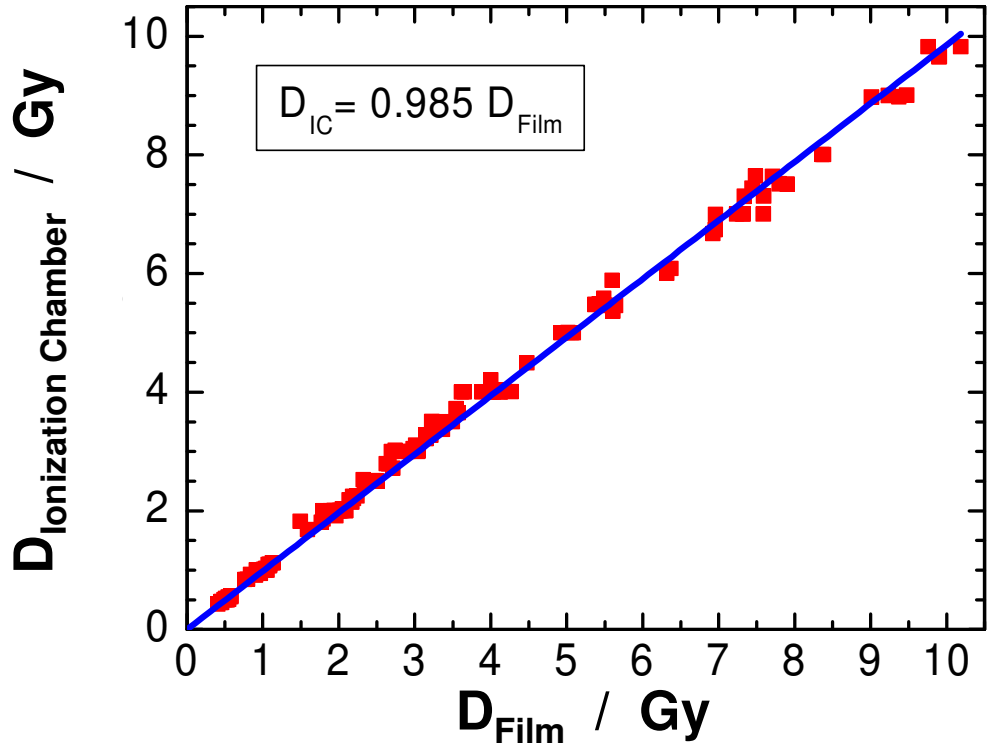
⇨ ***Independent absolute as well as online dosimetry system***

Richter et al.: Radiat Meas (2011) in press, Karsch et al.: Z Med Phys 21 (2011) 4

4. Cell experiments with laser electrons

Results – Dose measurement:

Correlation between offline (film) and online (IC) dosimetry (irradiation of 163 cell samples)

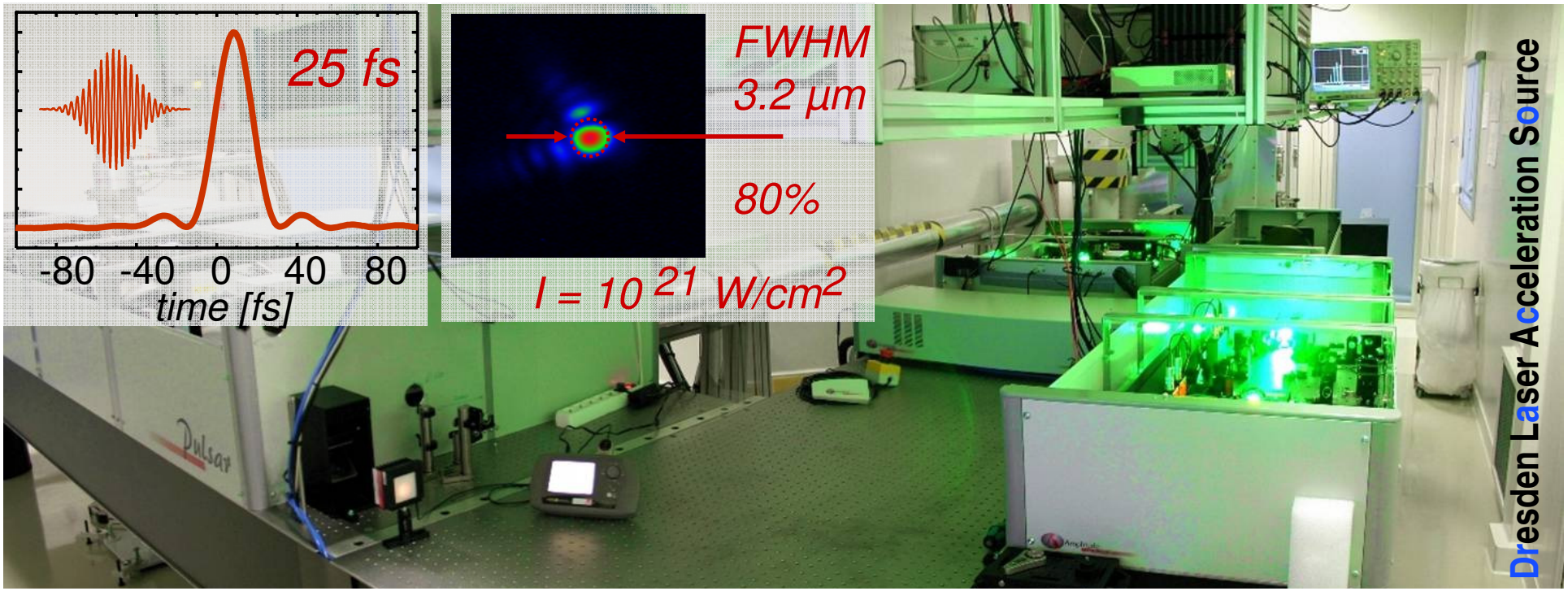


⇨ ***Precise dose monitoring in real time at laser driven beams***

4. Cell experiments with laser protons

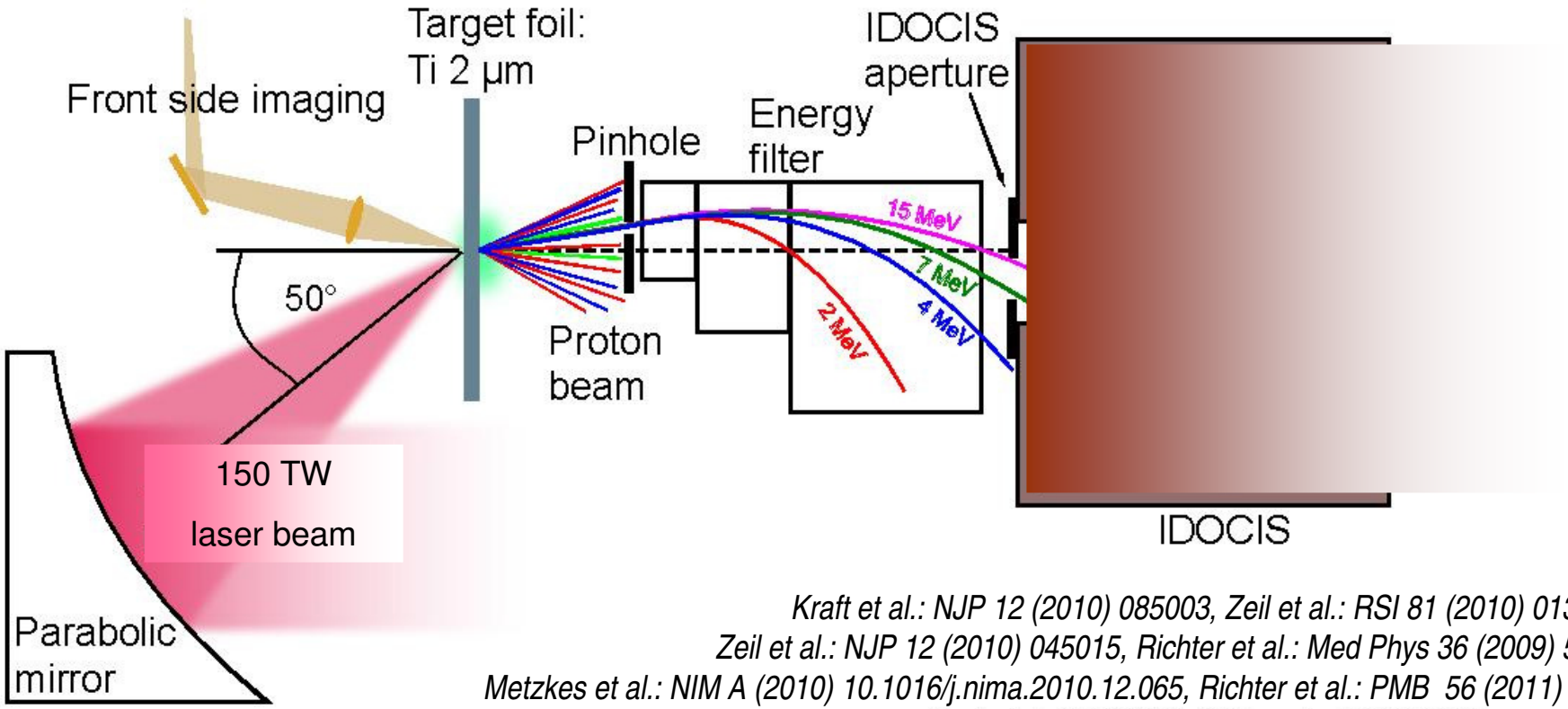
Helmholtz-Zentrum Dresden-Rossendorf:

- **DRACO (Titan-Sapphire) laser system: 150 TW, 4 J, 25 fs, 10 Hz**
  - Commercial system (Amplitude Technologies, France)
  - ***Proton acceleration up to 25 MeV***
  - ***Commissioning and start of experiments in 2009***

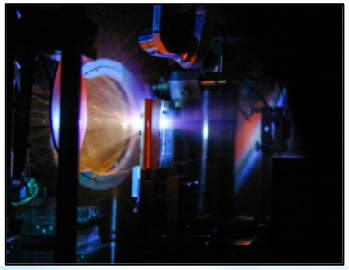


4. Cell experiments with laser protons

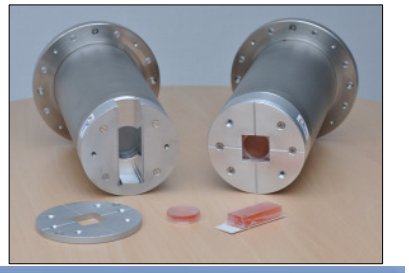
Setup at DRACO:



Kraft et al.: NJP 12 (2010) 085003, Zeil et al.: RSI 81 (2010) 013307,
Zeil et al.: NJP 12 (2010) 045015, Richter et al.: Med Phys 36 (2009) 5506,
Metzkes et al.: NIM A (2010) 10.1016/j.nima.2010.12.065, Richter et al.: PMB 56 (2011) 1529



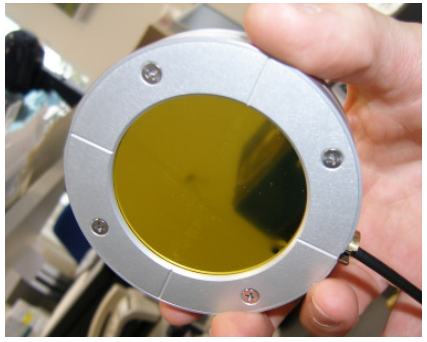




4. Cell experiments with laser protons

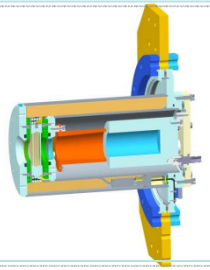
Dosimetry:

Transmission ionization chamber (GSI Darmstadt)



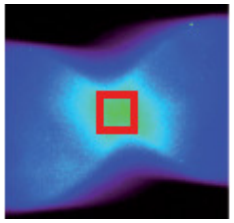
- Relative dose per pulse
- Online

- Dose rate independent absolute dose per pulse
- Online



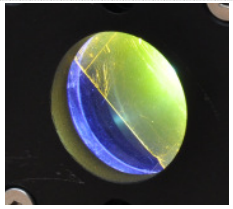
Faraday cup

- Dose rate independent absolute dose
- Spatial dose distribution
- Retrospective



Radiochromic EBT film

- Energy distribution
- Online



Scintillator

Monitoring of all cell and dosimeter irradiation

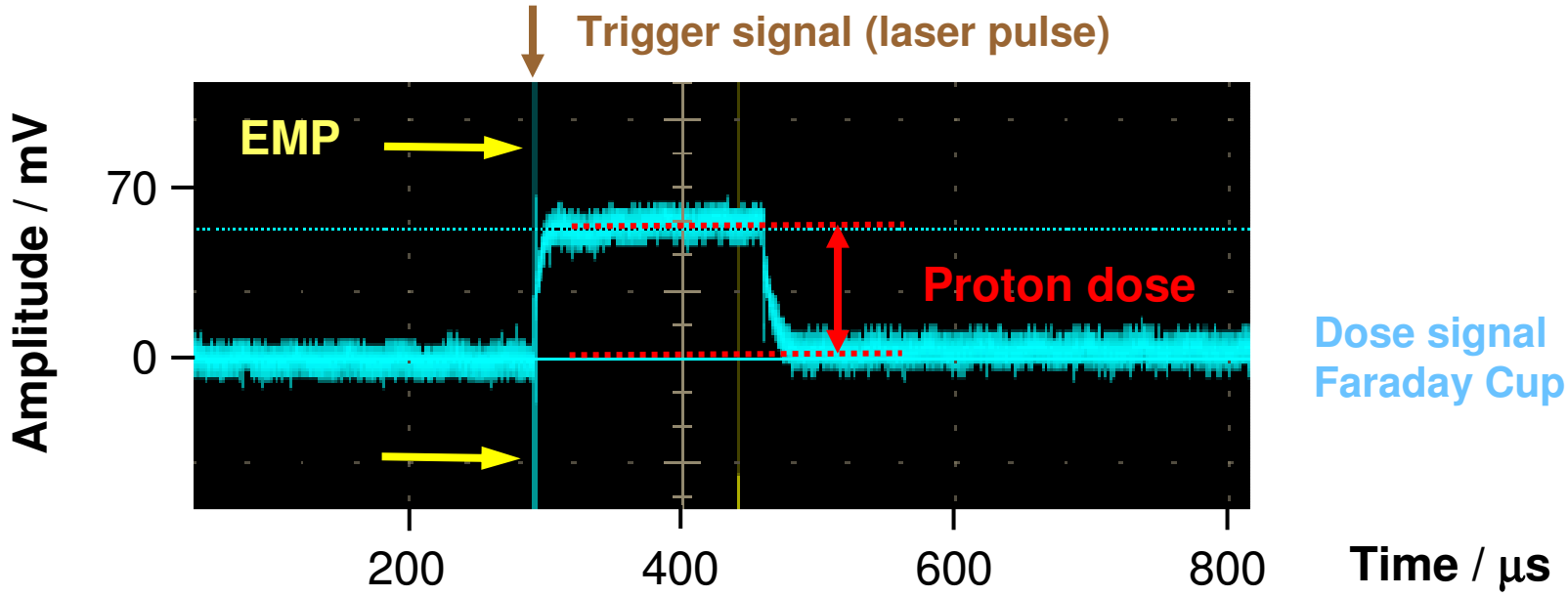
Measuring before and after cell sample irradiation

⇨ ***Two independent absolute as well as online dosimetry systems***

Richter et al.: Med Phys 36(2009)5506, Phys Med Biol 56(2011)1529, Radiat Meas(2011)in press, Karsch et al.: Z Med Phys 21(2011)4

4. Cell experiments with laser protons

Results – Real time measurement with Faraday Cup:

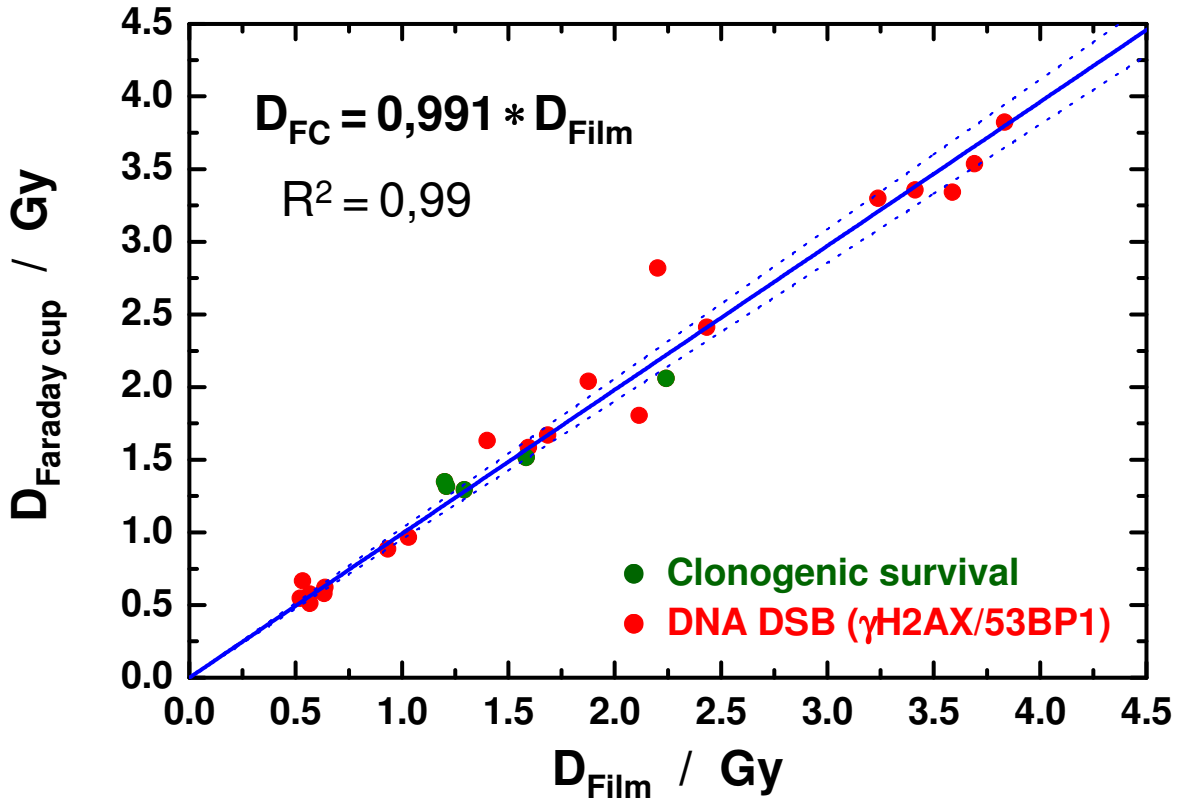


⇨ ***Strong electromagnetic pulse effect, but of short duration***

⇨ ***Precise dose monitoring in real time***

4. Cell experiments with laser protons

Results – Correlation of absolute dose:



⇨ ***Excellent agreement between the two independent absolute dose measurements***

⇨ ***High reliability of dosimetric measurement***

5. Summary and Perspective

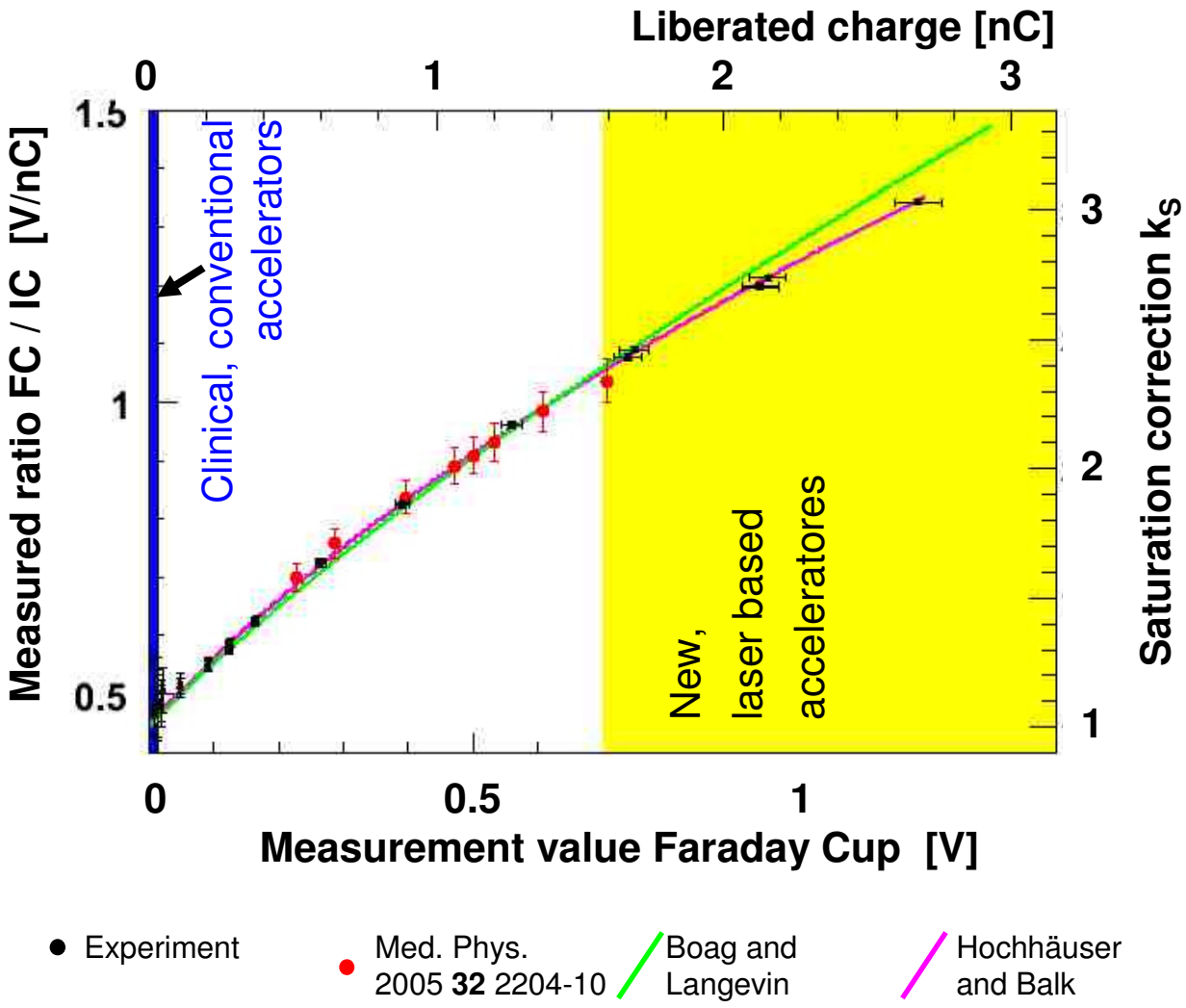
Systematic radiobiological cell experiments have been performed with all key requirements, such as reasonably stable and reliable operation of laser-accelerated particle accelerator, **precise absolute and online dosimetry** and suitable irradiation field formation for both electron and proton beams.

Establishment of in vivo experiments at laser proton beams:
Transition from 2D (cell monolayer) to 3D (tumour volume) irradiation.

Absolute dose measurement with ionization chamber:
Precise saturation correction is required.

5. Perspective: Saturation correction

ELBE electrons:



Measured with usual Roos ionization chamber at typical clinical linac pulse duration:

4 µs

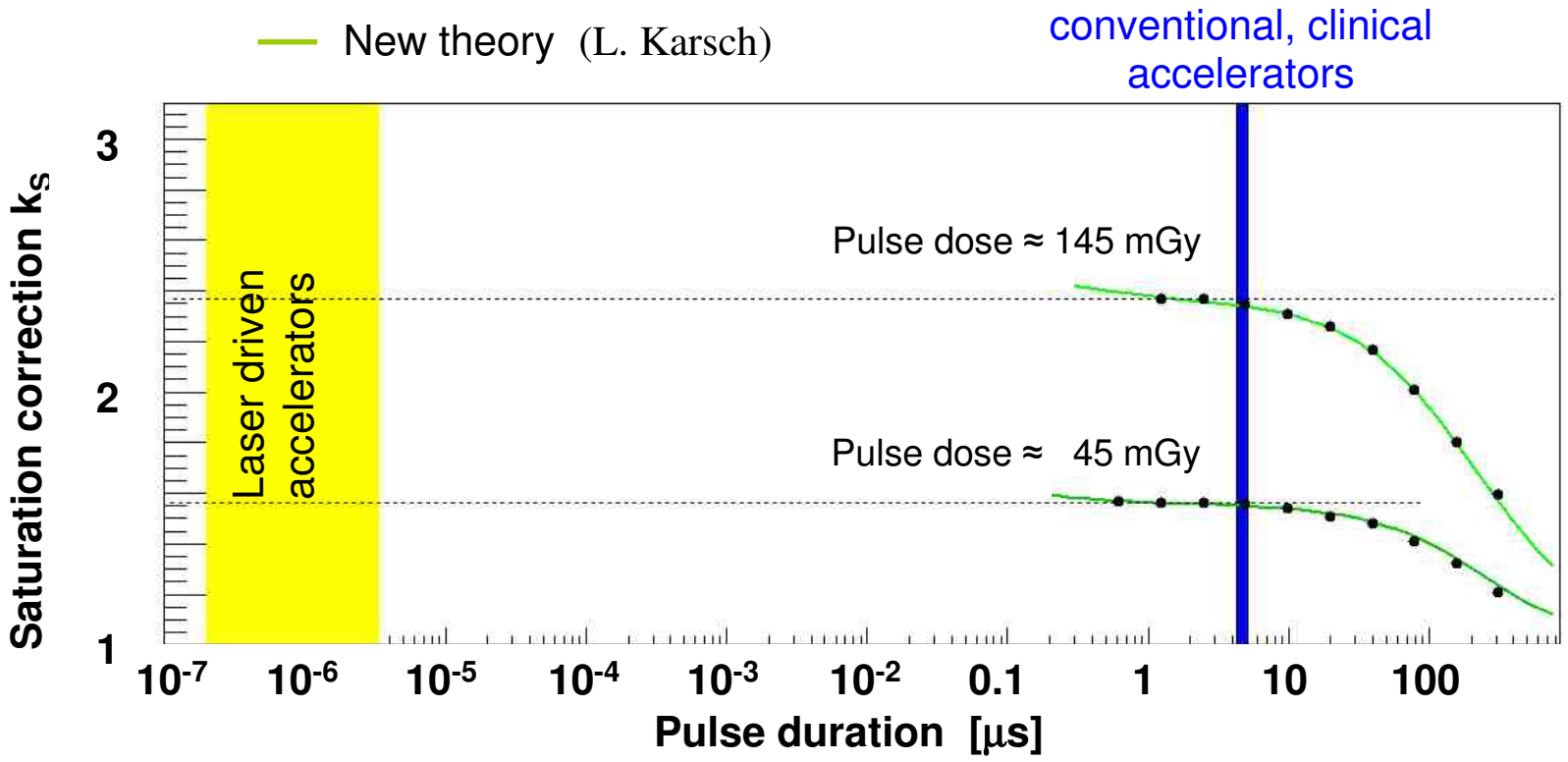
- Results are in good agreement with measurements of other groups
- Formalism of Hochhäuser and Balk is suitable

⇨ ***But not included to standards (1 % accuracy level not yet reached)***

5. Perspective: Saturation correction

ELBE electrons:

- Experiment (L. Karsch et al.: Z Med Phys 21(2011)4)
- New theory (L. Karsch)



⇨ ***The extrapolation of saturation correction to laser-accelerated particle beams needs further verification***

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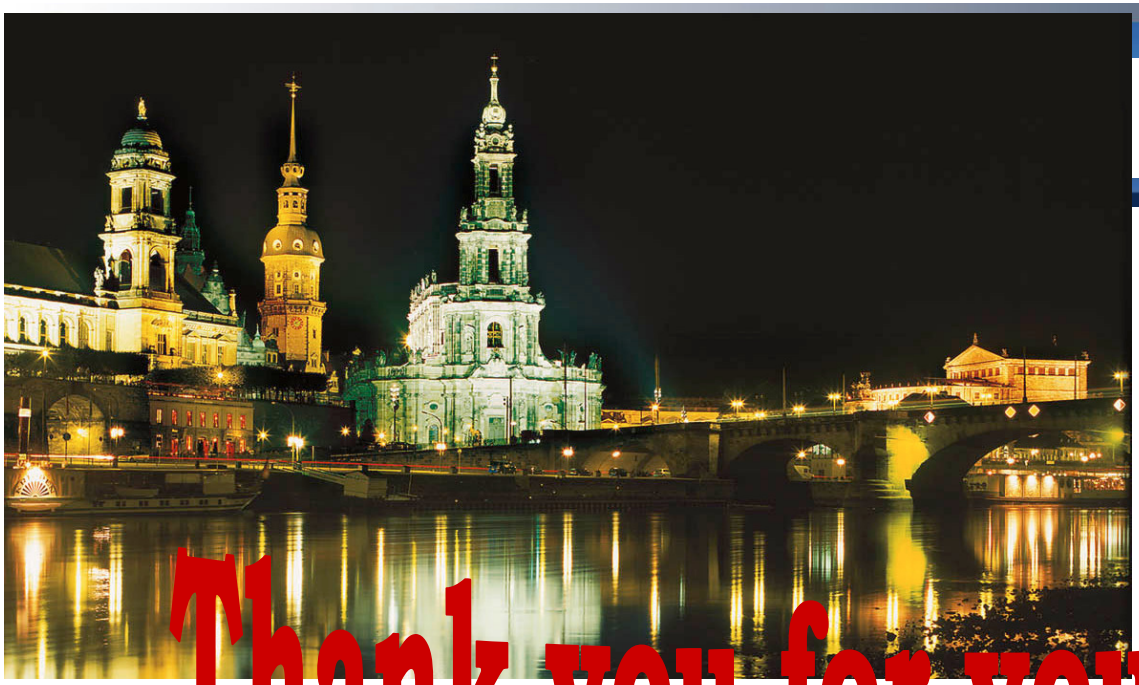

Thank you for your attention!