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Beam Loss Position Monitoring with Optical Fibres at DELTA

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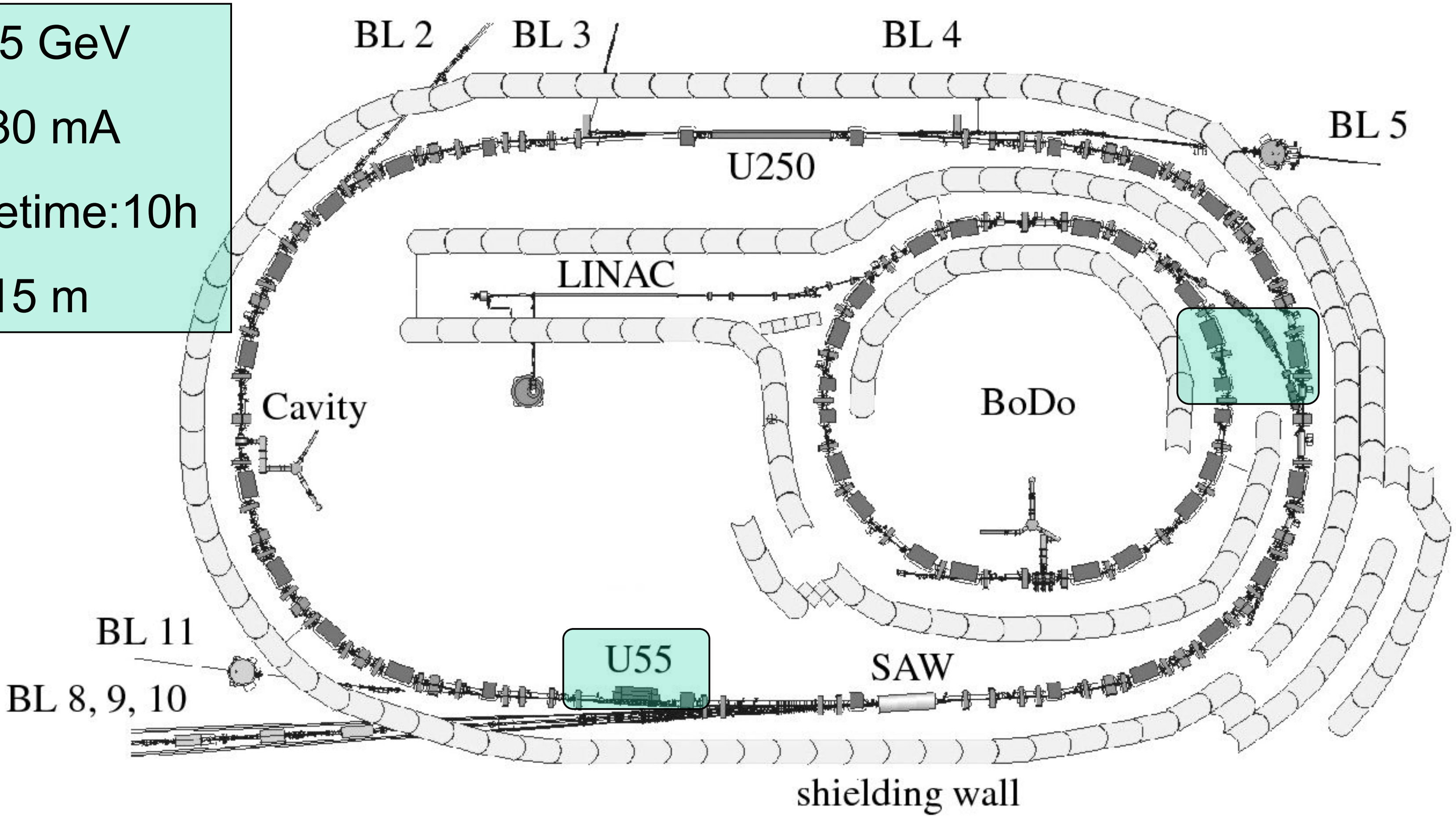
1. Overview of DELTA

- 1.5 GeV
- 130 mA
- lifetime:10h
- 115 m



1. Radiation Sources at DELTA

- The DELTA vacuum chamber is made up of 3 mm V4A steel
- The synchrotron radiation is almost completely absorbed inside the chamber wall
- Beam loss electrons colliding with the chamber generate electro-magnetic cascades. Even at small incident angles a significant amount of the shower particles can leave the vacuum chamber

- **1.5 GeV beam loss electrons are the main source of ionising radiation at DELTA**

1. Challenges for Dosimetry Systems / Advantages of Fibre Optical Systems

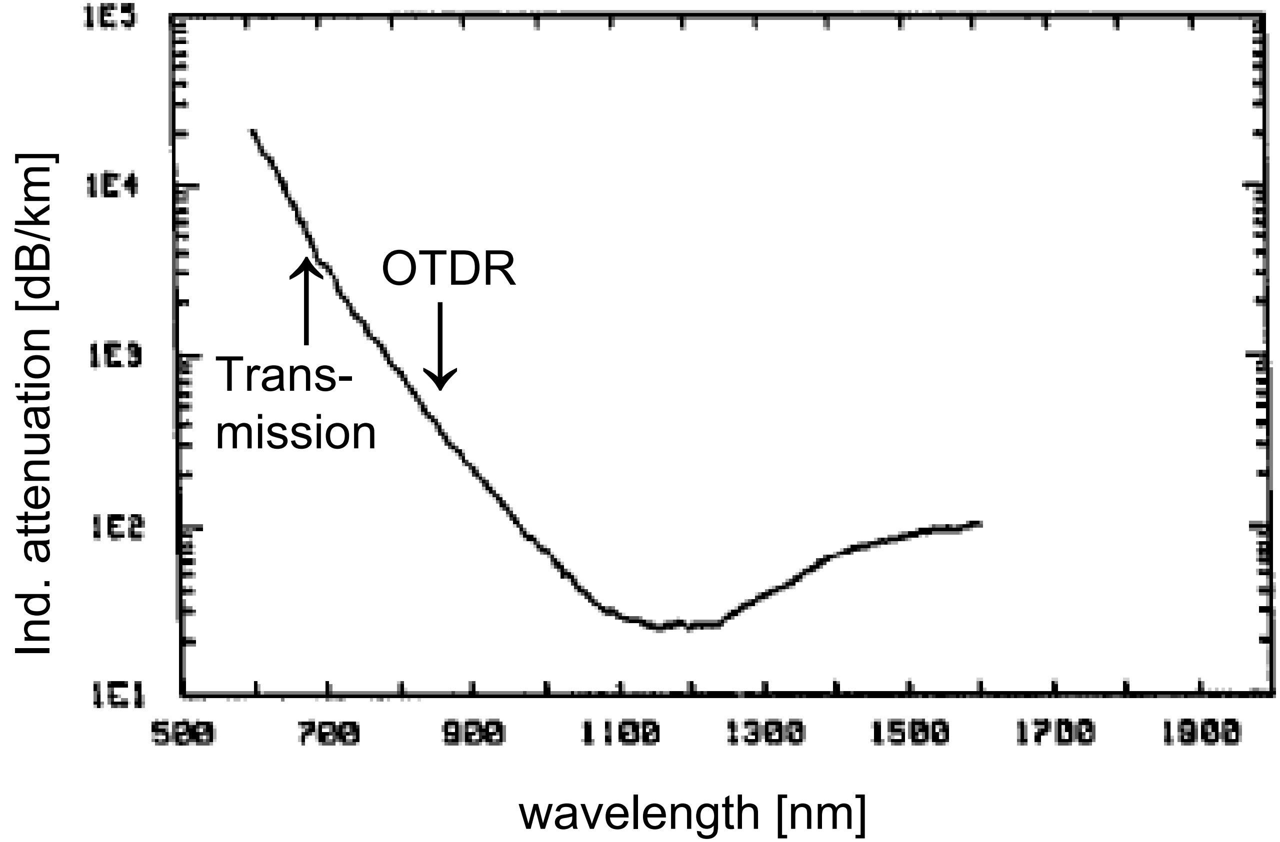
- Measurements in narrow spaces
  → small fibre diameter
- Surveillance of large distances
  → complete surveillance of
  several kilometres
- High-dose measurements
  → up to 1000 Gray
- Evaluation during beam operation
  → possible within a few minutes

→ System with two nanoseconds
time resolution is available

1. Radiation Induced Attenuation of Optical Fibres

- Chemical bonds are split up in the fibre by exposure to radiation (radiolysis)
  Example: $\equiv Si\text{-}OH \rightarrow \equiv Si\text{-}O\cdot + H^0$
- The generated defects are called "colour-centres"
- Transitions between the generated states
  → attenuation of injected light intensity

1. Radiation Induced Attenuation of Optical Fibres



- The sensitivity of a fibre optic radiation sensor system can be chosen by wavelength selection

1. Characteristics of a Fibre Optic Radiation Sensor System

- Linearity between dose α_D and attenuation D

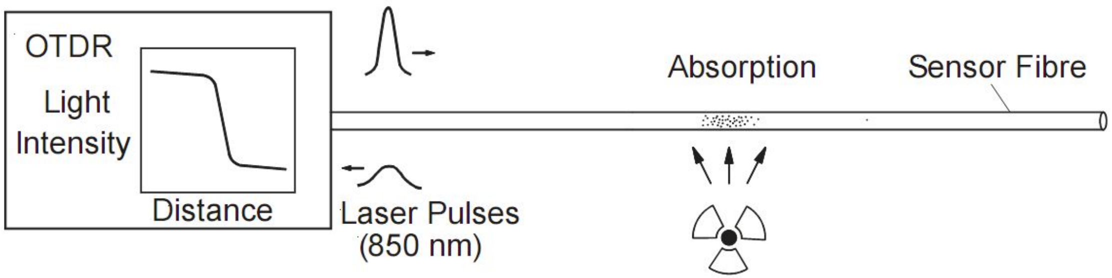
$$\alpha_D = c(\lambda) \cdot D^f \quad [\mathrm{dB/m}] \qquad \mathrm{f} \cong 1$$

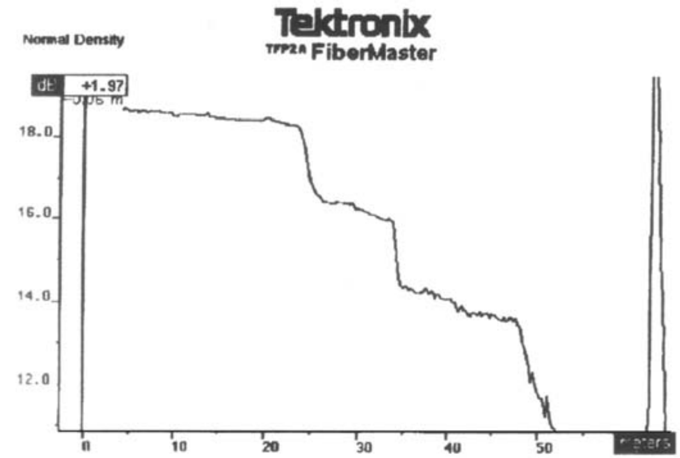
valid for a dose range of 10^{-3} to 10^{3} Gy

- Annealing: loss of accumulated dose information due to regeneration processes of the colour centres.
Enhancement of dose information lifetime by suitable fibre doping

- The attenuation is independent of dose-rate, temperature and light intensity

2. Optical Time Domain Reflectometry (OTDR)





- Used for radiation dose measurement around the complete length of the storage ring. Resolution about 3 Gray
- Measurement of the Rayleigh backscattered part of the injected light intensity
- The time dependent signal is converted to the position of beam loss; spatial resolution ca. 60 cm

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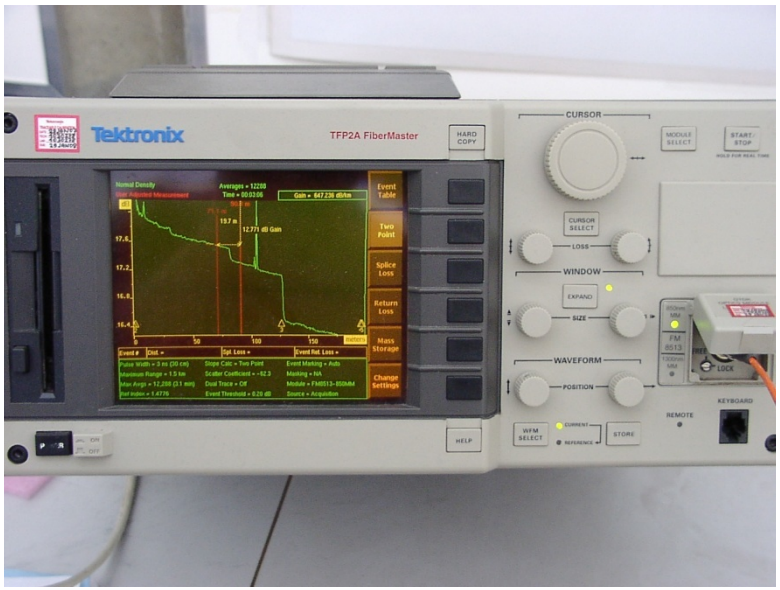
2. OTDR: Hardware

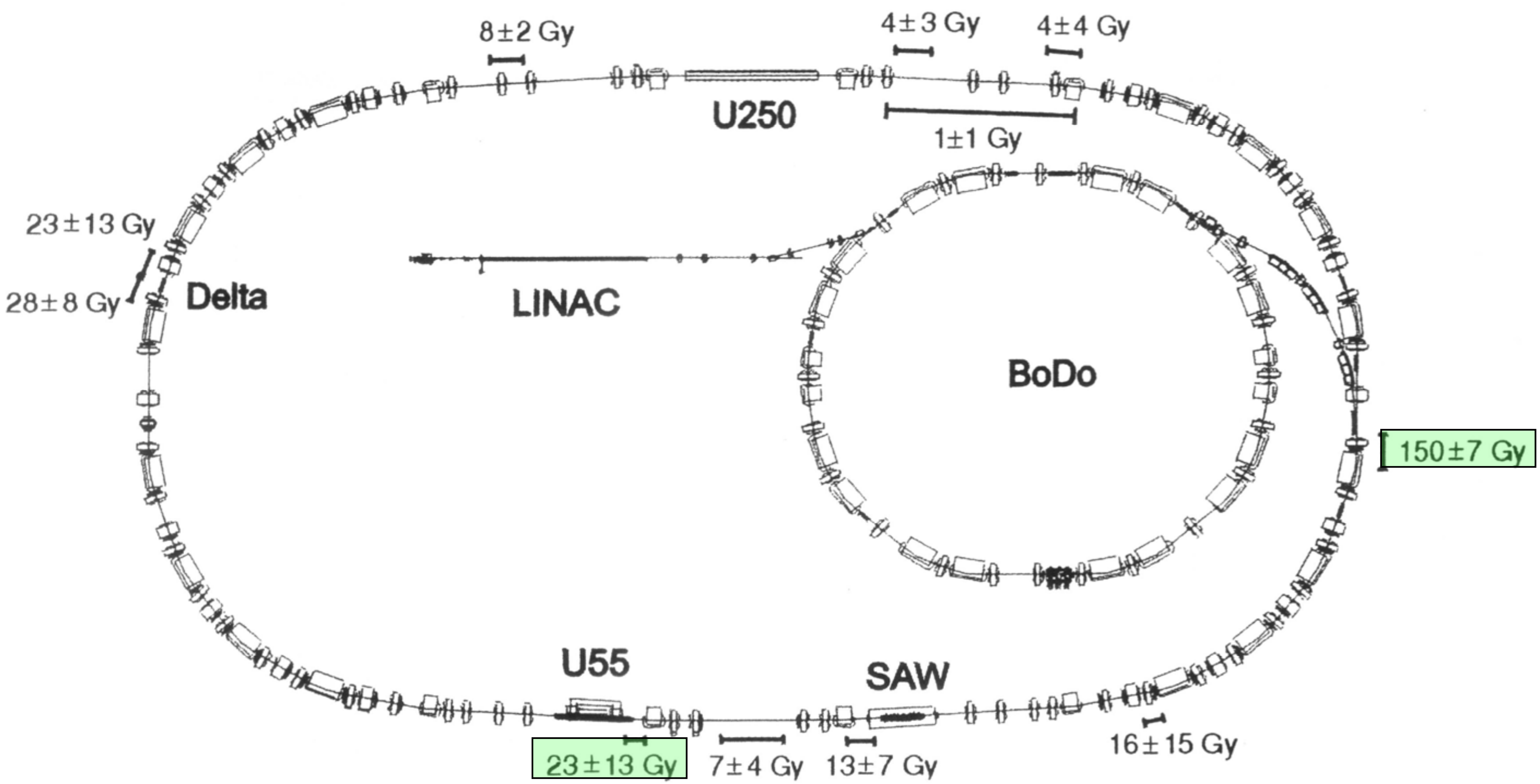


- Tektronix TFP2A
- Selectable wavelength (850 & 1300nm)
- Pulse lengths 1ns, 3 ns, 8 ns, …

Used Fibres:

- Multi-mode fibres with core diameter of 50 µm
- Germanium doped and co-doped with Phosphorus

2. OTDR: Dose Distribution at DELTA (period: 15 weeks)

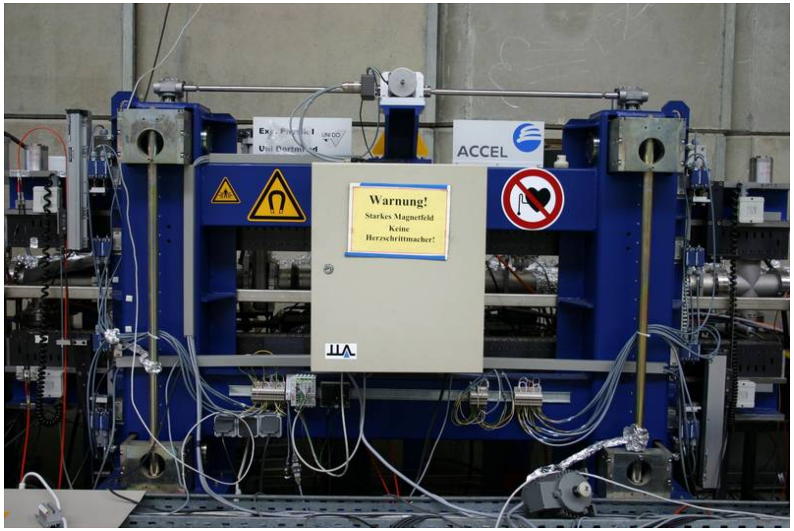


Diploma thesis Manuel Benna (DELTA)

3. Transmission Measurement: Motivation

Radiation effects of the permanent magnet undulator U55

- Magnets are composed of Neodymium-Iron-Boron alloy
- High radiation doses result in an irreversible demagnetization (based on investigations at the ESRF)
- Limiting dose value: 60 kGy



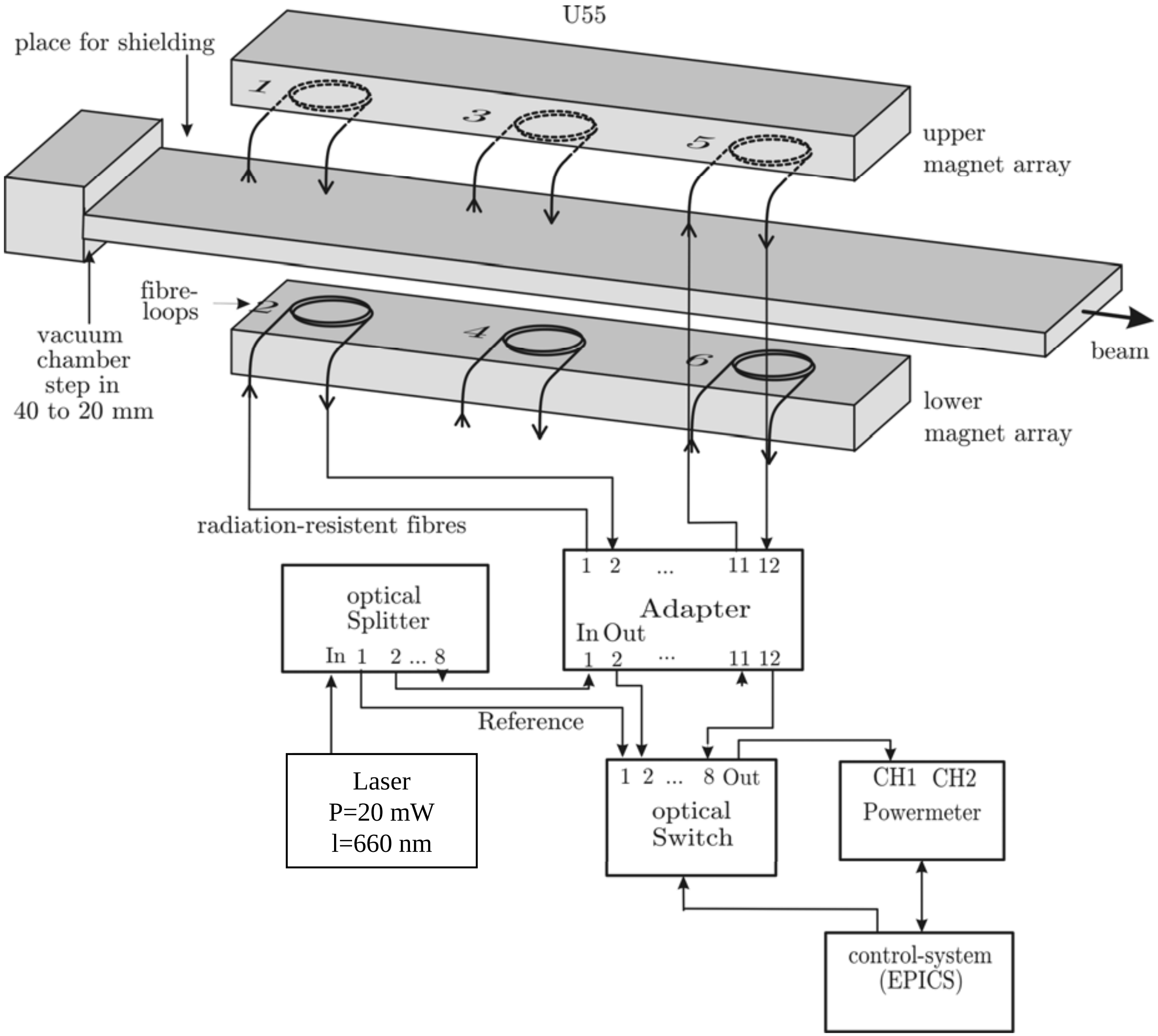
→ limiting dose rate value for the U55:

0.8 Gy/h

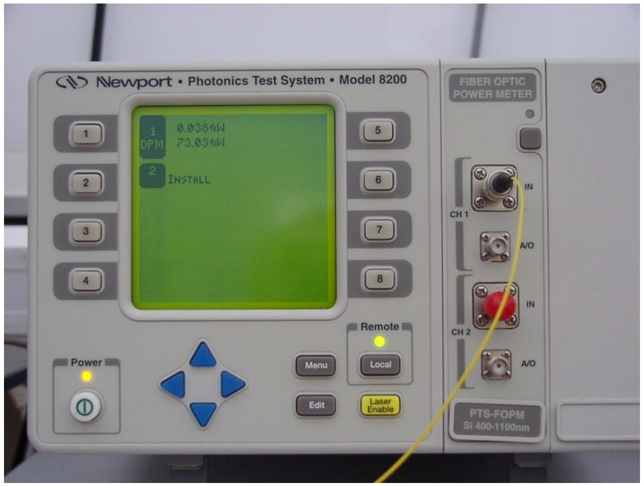
→ planned frequent injection mode will increase the radiation dose

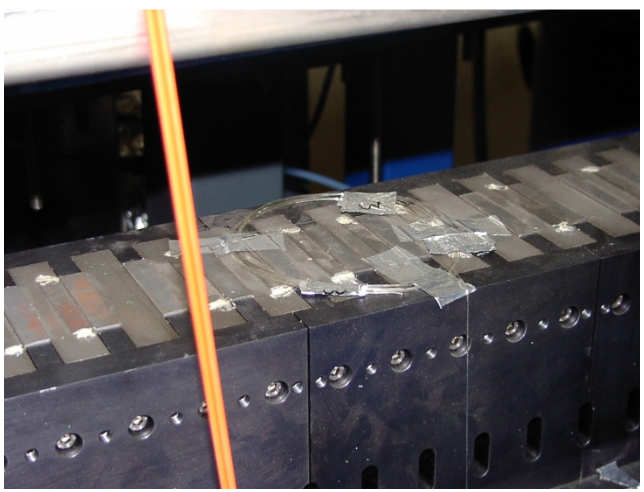
→ **permanent dose surveillance of the U55 needed**

3. Transmission Measurement: Principle and Setup



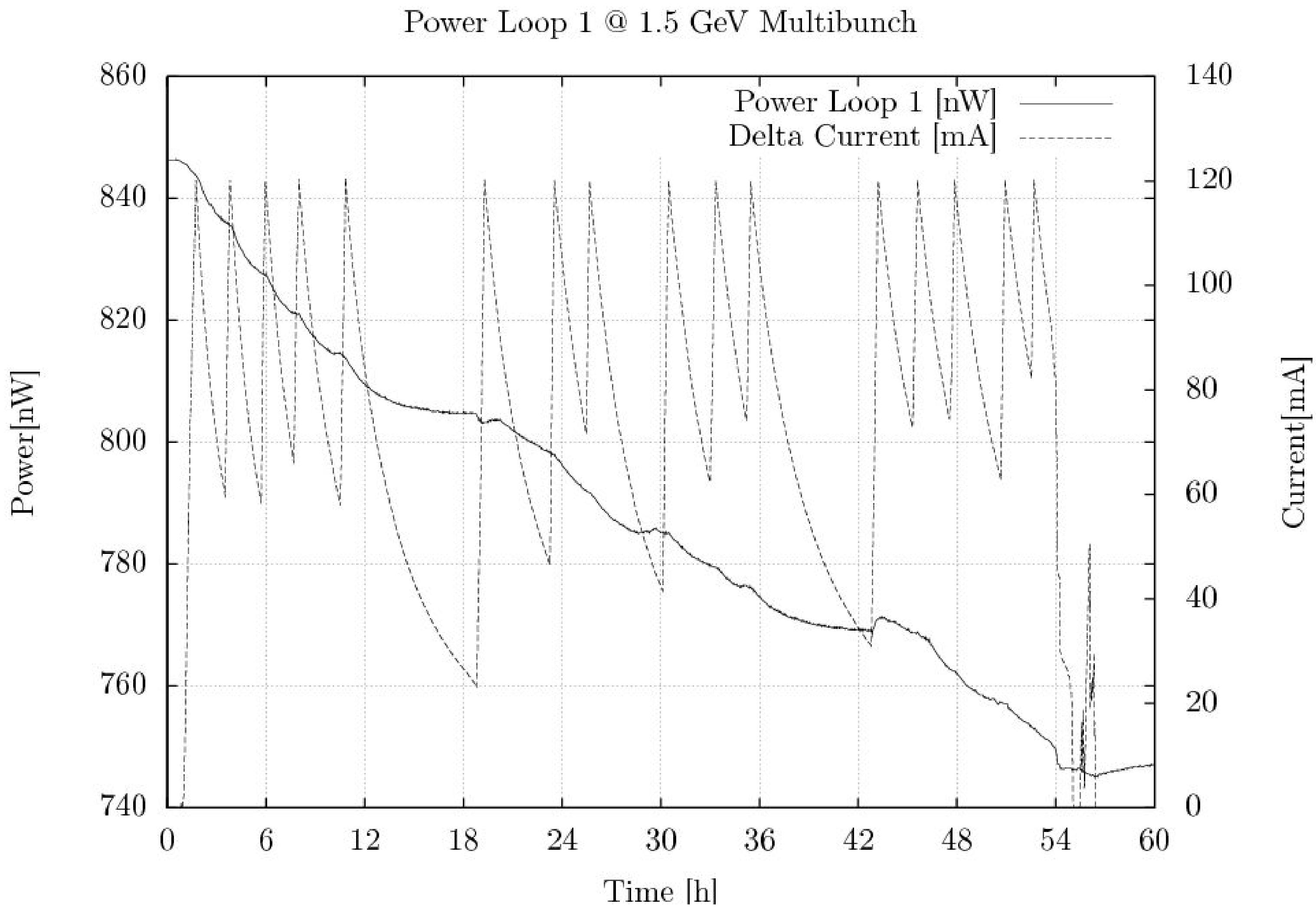
3. Transmission Measurement: Hardware





- Powermeter: Newport Type: PTS-FOPM
- Detectable intensity range: 1pW – 2W
- Used wavelength: 660 nm
- The system has been calibrated using thermoluminescence dosimeter-rods
- accuracy is about 30 %, similar to the TTF-system at DESY

3. Results: Measured Fibre Intensity and Beam Current



3. Results: Dose Rates During Standard User Operation

- Measurement during 60 hours at 1.5 GeV during standard user operation; beam lifetime: 4h @ 100 mA
- Gap is opened to maximum during beam injection mode

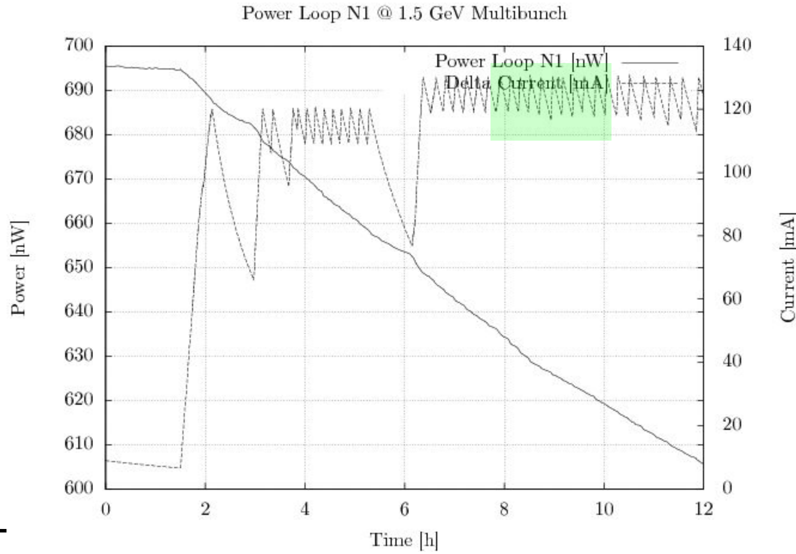
	U55 entrance (upper side)	U55 entrance (lower side)
Dose rate [Gy/h]	0.81 ± 0.23	0.16 ± 0.05

- Limiting value already reached at the upper side
- The dose at the lower side is by a factor 5 smaller

3. Results: Dose Rates during Frequent Injection Mode

- Measurement during 2 hours at 1.5 GeV, **frequent injection**

	U55 entrance (vacuum chamber)
Dose rate [Gy/h]	4.23 ± 1.23

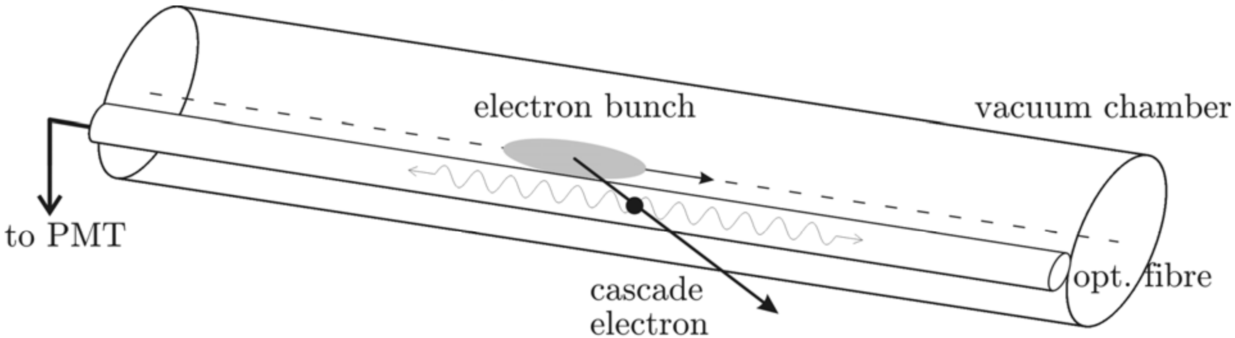


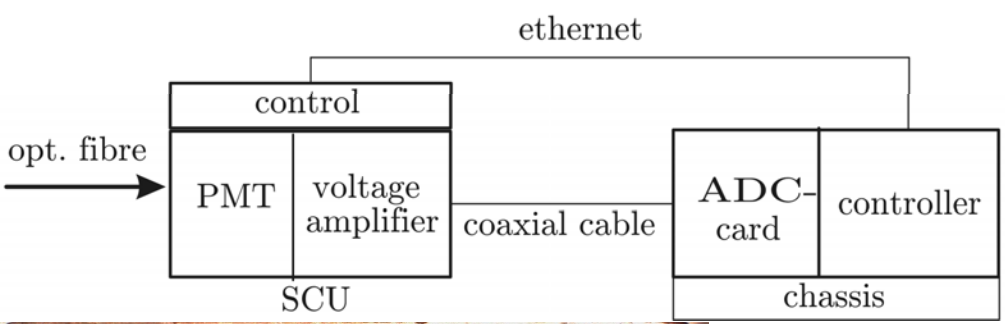
- the limiting value is exceeded by factor 5

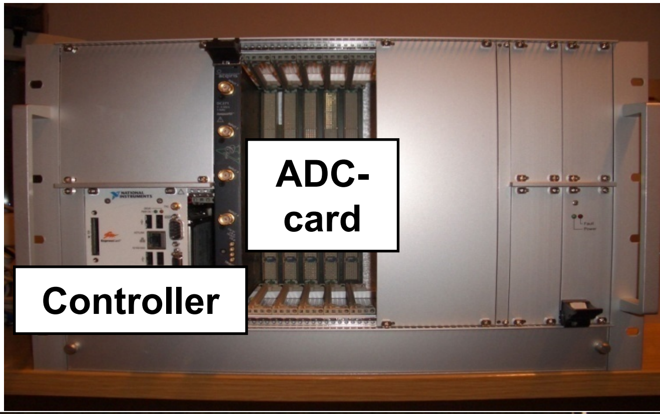
- First measure: Optimisation of the lead shielding in front of the U55
  → dose rate lowered by factor 2 → sufficient for standard beam operation

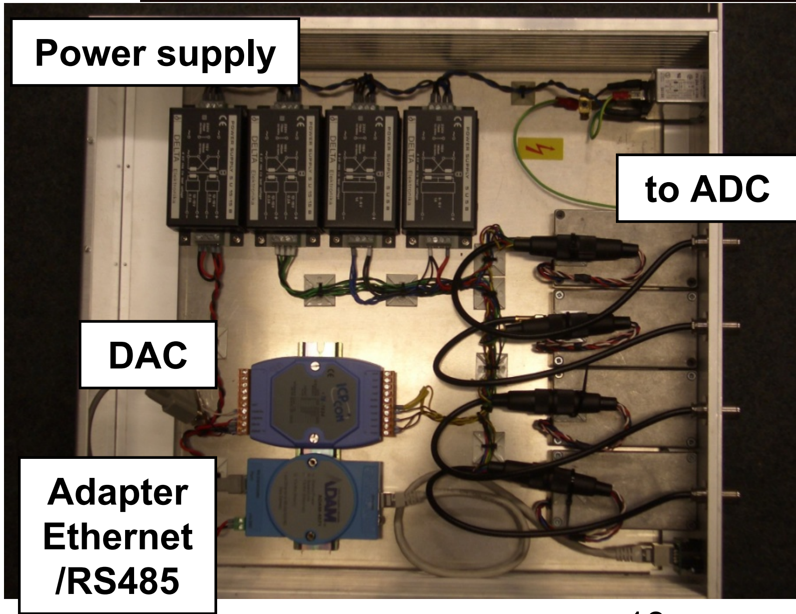
  → **redesign of the lead shielding until start of frequent injection mode**

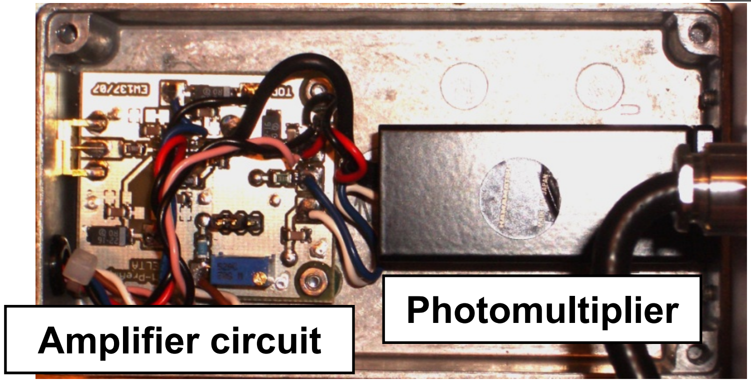
4. Cerenkov-Light Detector: runtime measurement to localise beam losses











4. Cerenkov-Light Detector: Principle of Measurement

- Runtime-measurement to localise beam losses
  → detector is connected to the upstream-side
- Time resolution: 2 ns given by sampling rate of the ADC (1 GS/s)
- Spatial resolution: 0.24 m in longitudinal direction
- Used wavelength range: 500 nm – 650 nm (maximum at 550 nm)
- Multi-mode-step-index fibres (core diameter: 300 µm) consisting of undoped silicon dioxide with high content of OH^- ions

5. Summary:

- Fibre optic radiation sensor systems are well suited for accelerators:
  - usable in narrow spaces
  - dose range is up to 1000 Gy
  - evaluation during beam operation
- OTDR:
  - used for dose surveillance of the complete Delta vacuum chamber
  - dose resolution: 3 Gy
- Transmission measurement:
  - used for dose surveillance of the U55 permanent magnet undulator
  - dose resolution: 60 mGy
- Cerenkov-light detector:
  - system has been installed and functionality has been proven
  - will be used for increase of injection efficiency
  - real-time beam loss position monitoring with single bunch resolution of 2 ns

Acknowledgement

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