Machine protection and beam loss detection systems

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Fundamentals on machine protection

- logic
  - positive: differential beam toroid signal exceed
  - negative: loss monitor threshold exceed

Recommended: use both ways

- beam modes i.e.
  - diagnostics mode (1..10 bunches, or ERL 100nA)
  - beam start up mode (<30 bunches, or ERL 10uA)
  - medium operation (macro-pulse, or ERL 1mA)
  - full operation (…100mA)

Next mode only permitted if proceeding mode meets requirements
Each mode has own threshold and limitations

Fundamentals on machine protection

- machine modes
  - Injector mode
  - Linac mode
  - ERL mode
  - FEL mode

Defines the beam line where protection is applied

- passive protection
  - collimator and beam cleaning system
  - defined restriction of geometrical aperture
  - good shielding of critical components
  - insertion devices
  - sacrificial device (foils, collimator)
  - damage reduction (isolation vacuum, easy removable)

Increases life time and reaction time, reduce costs in case of failure

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Fundamentals on machine protection

- emergency switch off
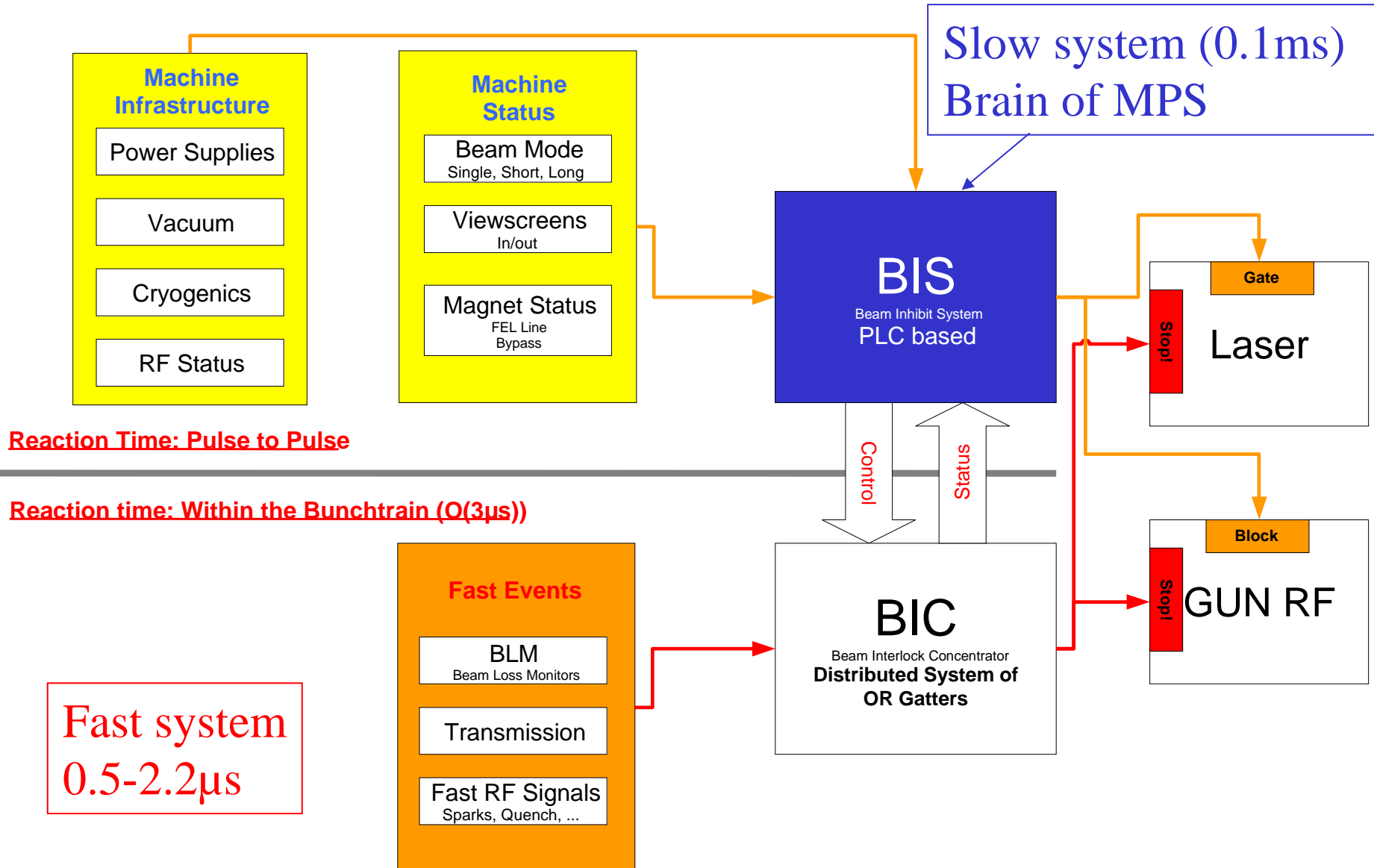 - Laser off   (cable + 200ns ~ 0.5μs-3μs)
  - Emergency dump   (kicker + 200ns ~ 0.5μs)
  - Activation of sweeper   (sweeper + 100ns < 0.2 μs)

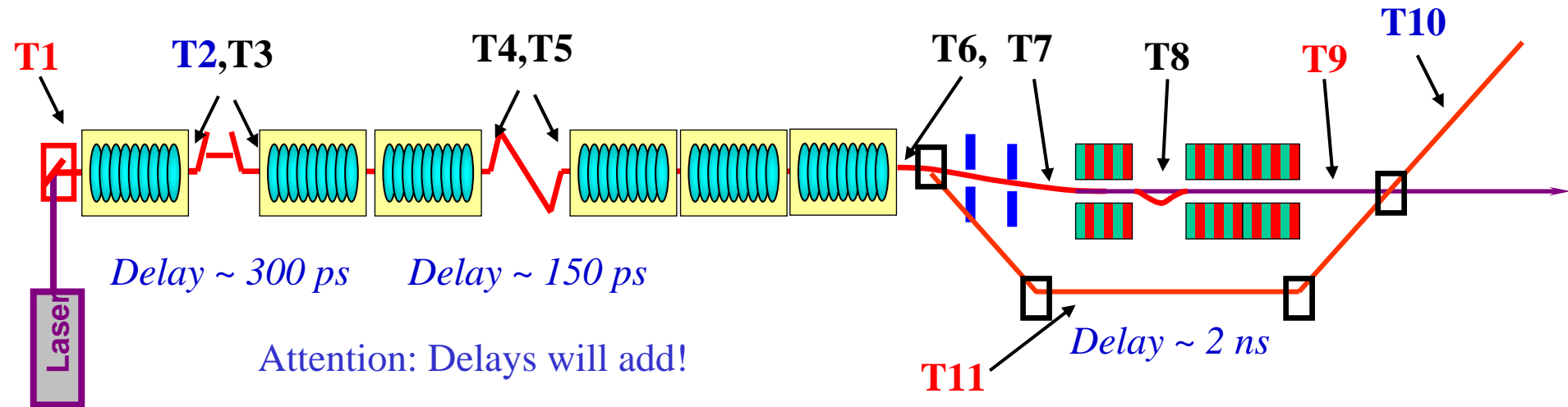Usually fast laser switch sufficient, sweeper is good option

- critical item for machine protection
  - activation of components (permanent losses, >10W)
  - personal protection (permanent losses) -> shielding of tunnel
    - $E<20MeV$ mainly against γ, medium shielding required
    - $E>20MeV$ mainly against giant neutron
    - $E>300MeV$ dominated by fast neutrons
  - hardware: cables (>10MGy), optical components (0.1-1MGy) electronics/cameras (1-10kGy), permanent magnets NdFeB?
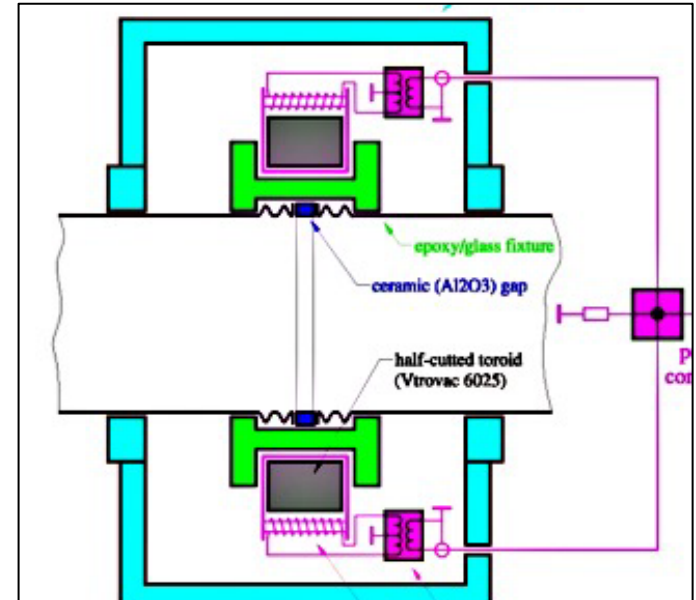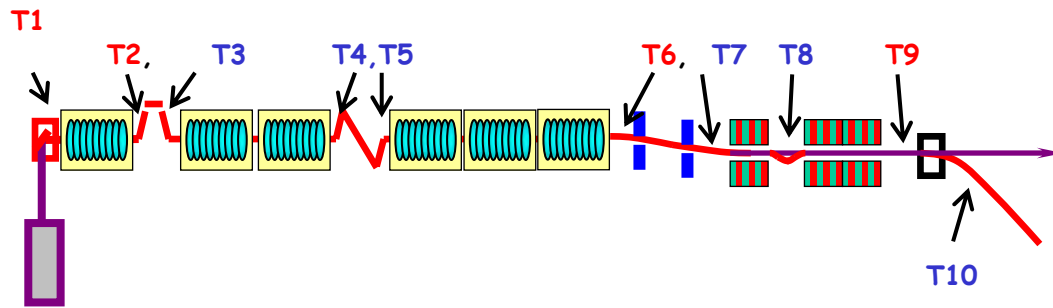 - vacuum chamber: heating slowly, sudden losses

Beam Inhibit System

Machine Infrastructure
- Power Supplies
- Vacuum
- Cryogenics
- RF Status

Machine Status
- Beam Mode
  Single, Short, Long
- Viewscreens
  In/out
- Magnet Status
  FEL Line
  Bypass

Slow system (0.1ms)
Brain of MPS

BIS
Beam Inhibit System
PLC based

Gate

Stop!

Laser

Control | Status

Reaction Time: Pulse to Pulse

Reaction time: Within the Bunchtrain (O(3μs))

Fast Events
- BLM
  Beam Loss Monitors
- Transmission
- Fast RF Signals
  Sparks, Quench, ...

BIC
Beam Interlock Concentrator
Distributed System of OR Gatters

Block

Stop!

GUN RF

Fast system
0.5-2.2μs

Transmission Based Protection System for TTF

Delay ~ 300 ps   Delay ~ 150 ps

Attention: Delays will add!

Delay ~ 2 ns

Dev.	Name	Z-Position	Dev.	Name	Z-Position	Comment
T1	Toroid/3Gun	1,25 m	T9	Toroid/12Exp	244,97m	FEL Beamline, total length
T1	Toroid/3Gun	1,25	T11	Toroid/16Byp	161,254m	Bypass Beampath, total length
T2	Toroid/2UBC2	20,548 m	T10	Toroid/?Dump	Ca. 248,9 m	Make sure beam reaches the dump (FEL Beamline)
T2	Toroid/2UBC2	20.548 m	T10	Toroid/?Dump	Ca. 248,9 m	Make sure beam reaches the dump (Bypass)

;Y

Charge Measurement: Toroids

T1 T2, T3 T4,T5 T6, T7 T8 T9

T10

epoxy/glass fixture

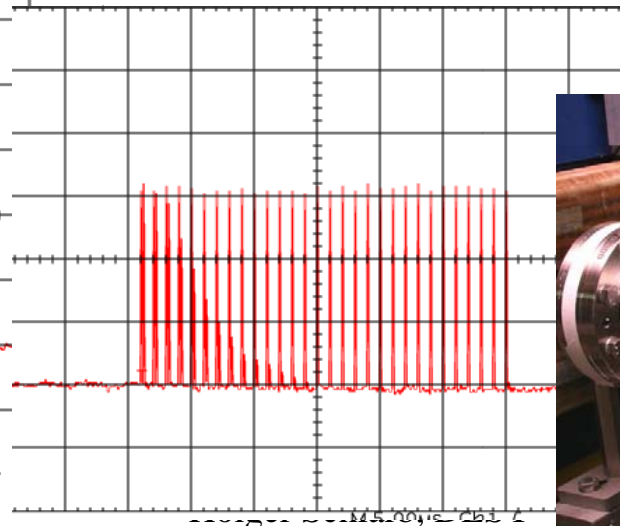ceramic (Al2O3) gap

half-cutted toroid
(Vtrovac 6025)

In House Development:

- **Single Bunch Resolution ~ 5 10^{-3}**
- **Measurement Range up to 5nC (0.5V/nC)**
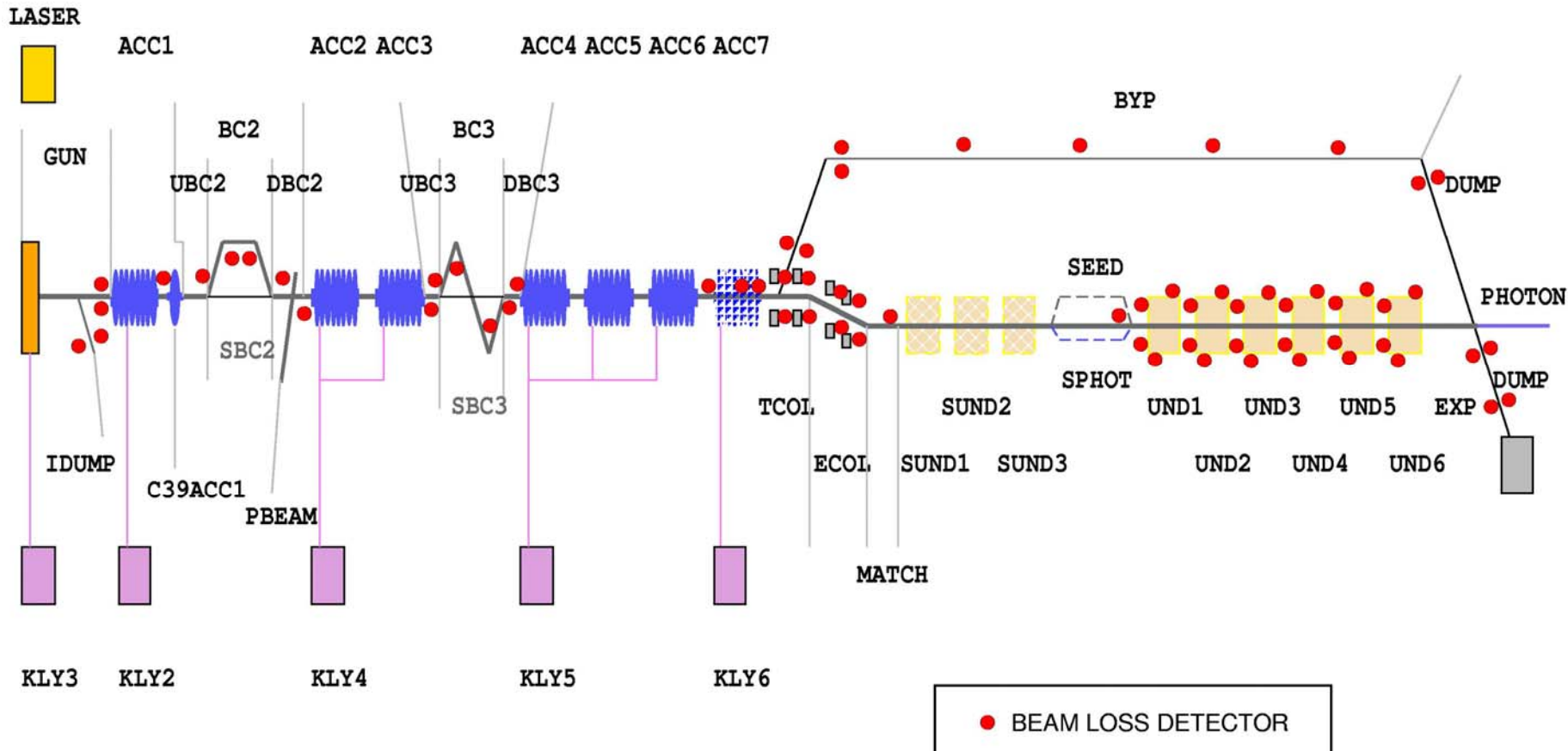- **Suitable for 9 MHz Bunch Rep. Rate**
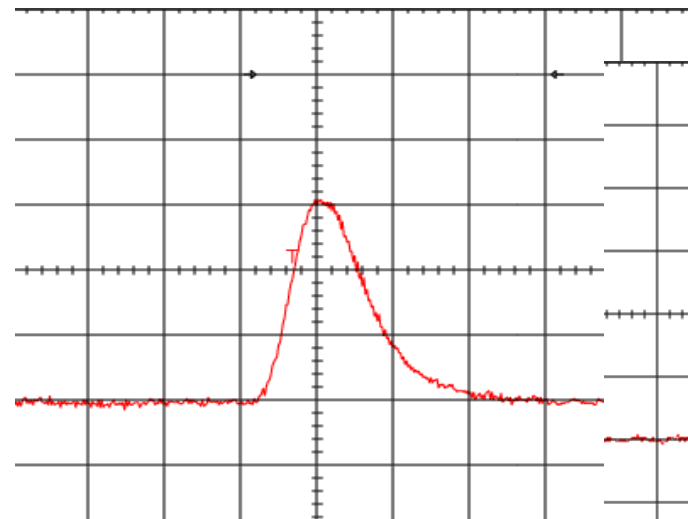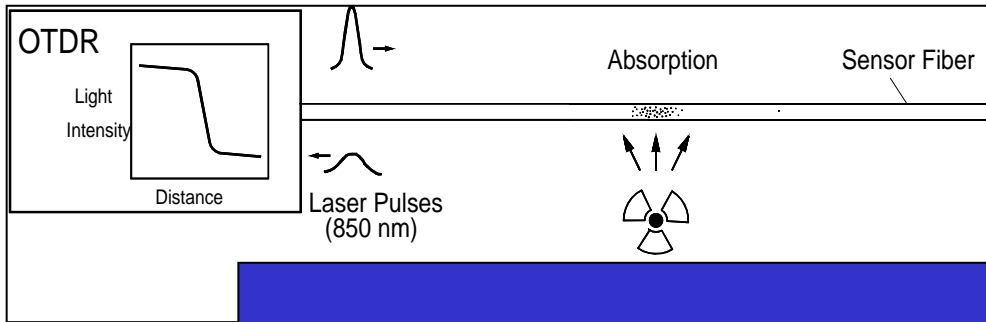
Single bunch 1.2 nC

Train of 30 bunches

Loss Monitor System

≈ 60 Fast Loss Monitors (Photomultipliers) at critical Positions

Radiation Monitoring

Light Guide Systems

System	Dosimeter	Beam Loss
measures	Light Attenuation	Cerenkov Radiation
Properties of fibers	MM GI Fiber Phosphor-Doping Small annealing	MM SI Fiber No Doping Large diameter
Detectors	OTDR	Photomultiplier
	Powermeter	

Radiation losses in undulator

• limits beam operation current to about 20nA (+20nA darkcurrent)

• already several kGy accumulated (20-30% of expected lifetime)

• reduced rep. rate to 2 Hz, and rf pulse duration to 60µs (dark current)

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Courtesies Körfer, Pflüger