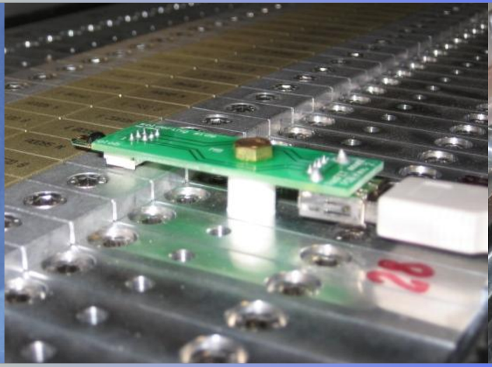
Machine Protection for FERMI@Elettra


L. Fröhlich, A. I. Bogani, K. Casarin, G. Cautero, G. Gaio,
F. Giacuzzo, D. Giuressi, A. Gubertini, R. H. Menk, E. Quai,
G. Scalamera, A. Vascotto (Sincrotrone Trieste, Basovizza, Italy)
L. Catani (INFN, Rome, Italy), D. Di Giovenale

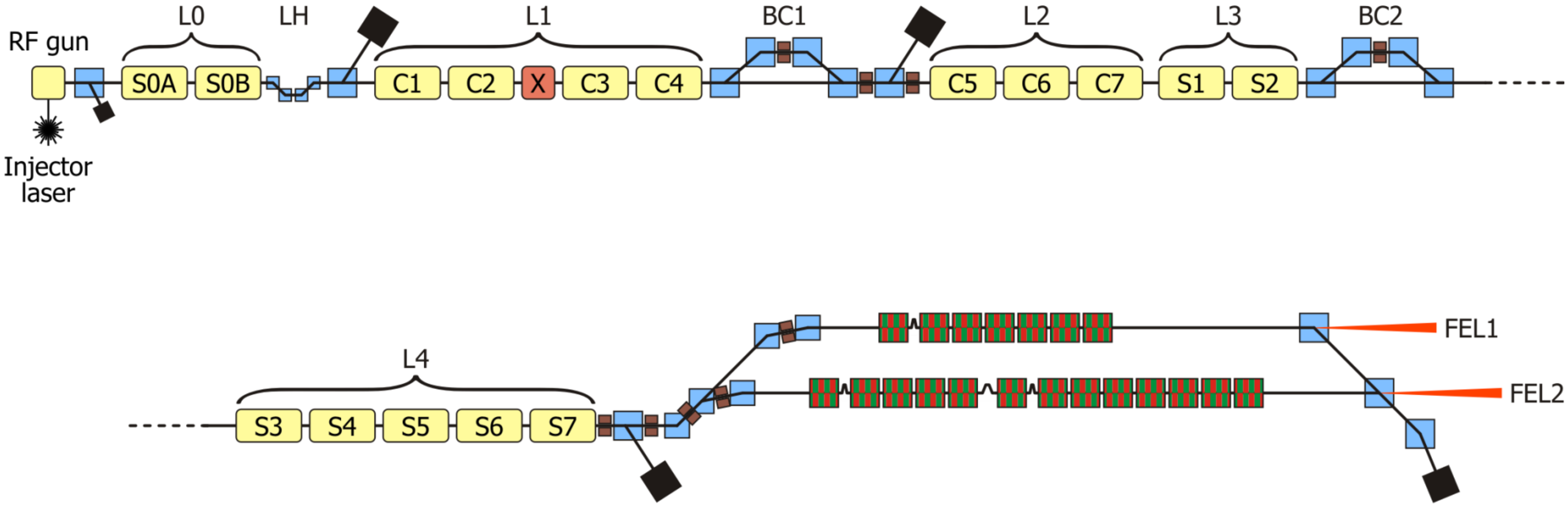
Overview

- FERMI@Elettra
- MPS architecture
- General features

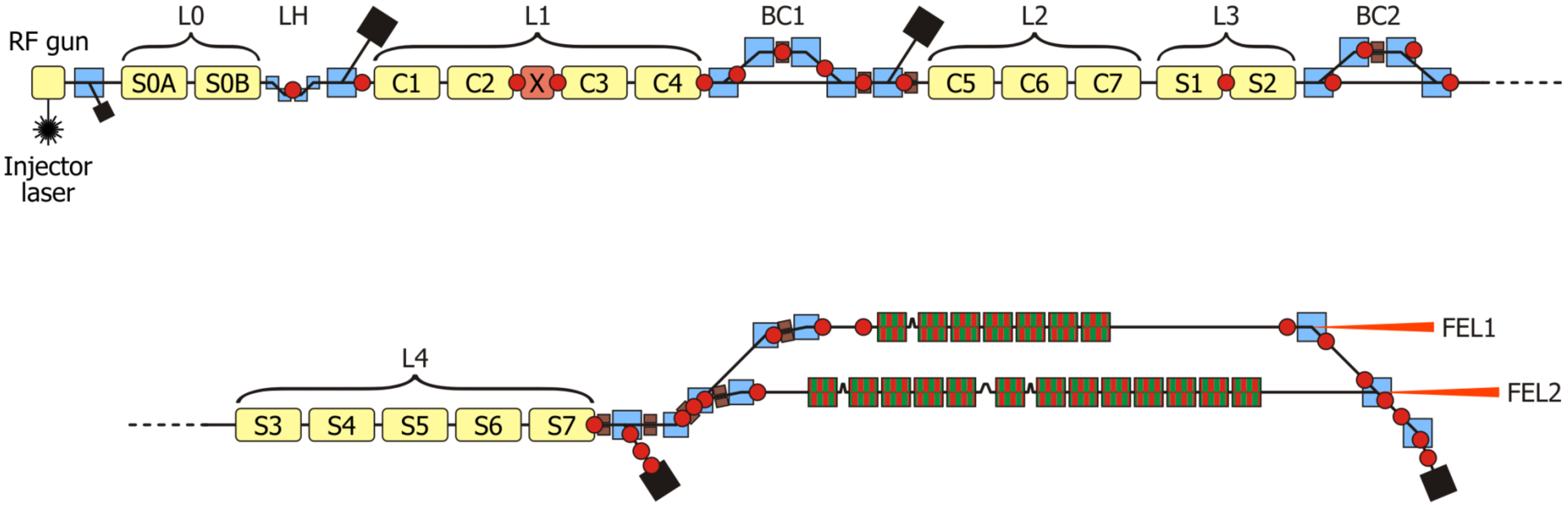
- Subsystems:
  - Fiber beam loss position monitors
  - Ionization chambers
  - RADFET online dosimetry

Elettra & FERMI

FERMI@Elettra

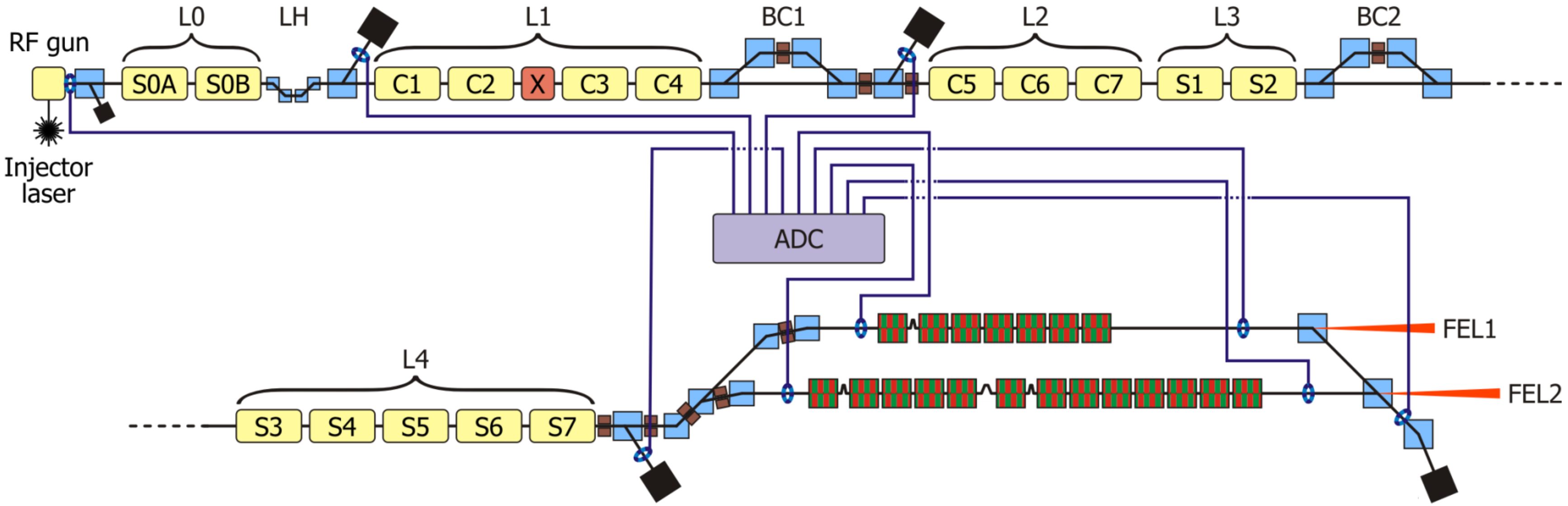


	Energy	Bunch Charge	Repetition Rate	Beam Power
Typical	1.2 GeV	350 pC	10 Hz	4.2 W
Design	1.5 GeV	1 nC	50 Hz	75 W

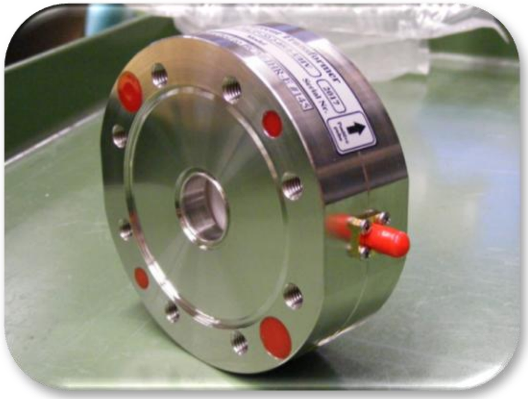


PIN diode BLMs

K. Casarin, E. Quai,
S. Sbarra, A. Vascotto



Charge Monitors



S. Bassanese

Undulator Demagnetization

Relative demagnetization ΔB/B for $Nd_2Fe_{14}B$ magnets:

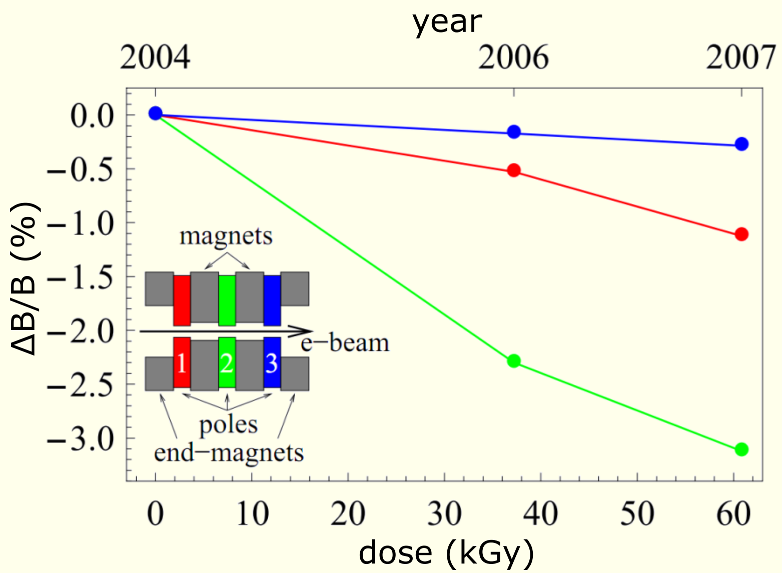
- Fast neutrons: $10^{-5}\,Gy^{-1} – 4\cdot10^{-4}\,Gy^{-1}$ [And07]
- 85 MeV electrons: $4\cdot10^{-5}\,Gy^{-1}$ [Lun89]
- 17 MeV electrons: $4\cdot10^{-8}\,Gy^{-1}$ [Oku94]
- 0 – 85 MeV photons: $2\cdot10^{-9}\,Gy^{-1} – 3\cdot10^{-8}\,Gy^{-1}$ [Lun89]
- 0 – 1.2 MeV photons (^{60}Co): $<2\cdot10^{-9}\,Gy^{-1}$ [Oku94]

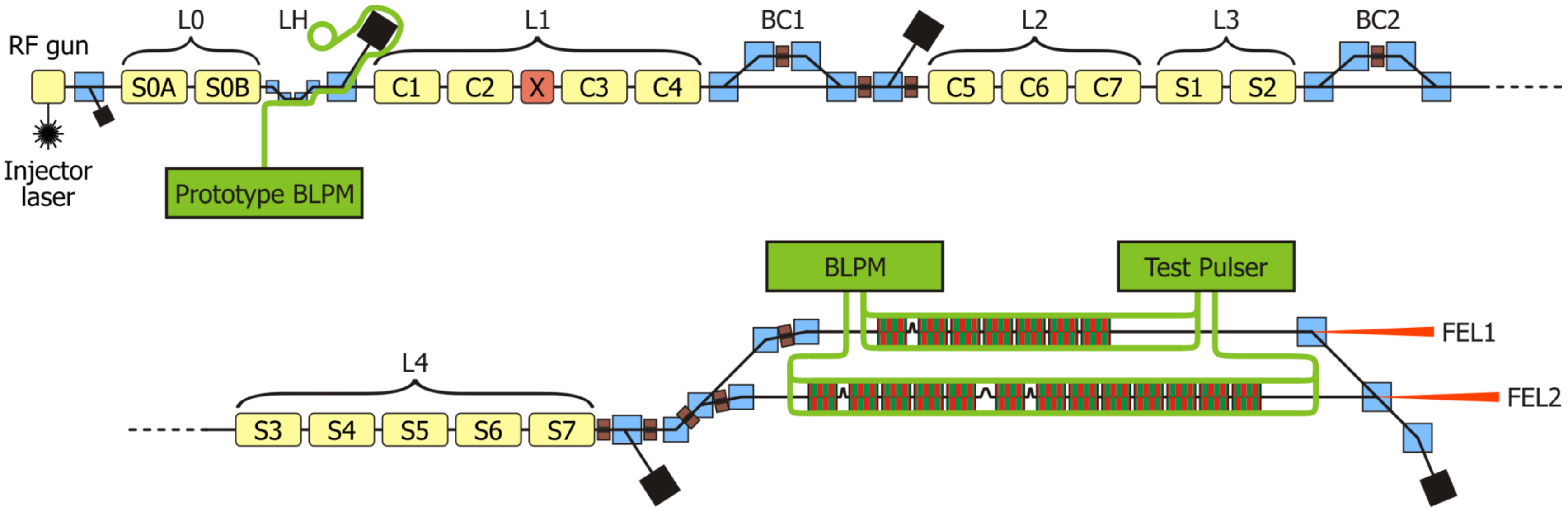
- 450 – 1000 MeV e⁻ beam shower (FLASH undulator):

$5\cdot10^{-7}\,Gy^{-1}$

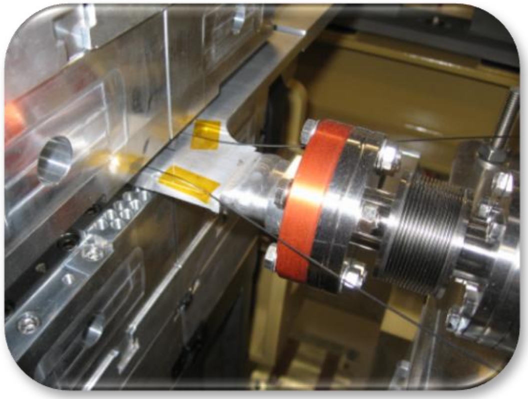
→ 5‰ for 10 kGy

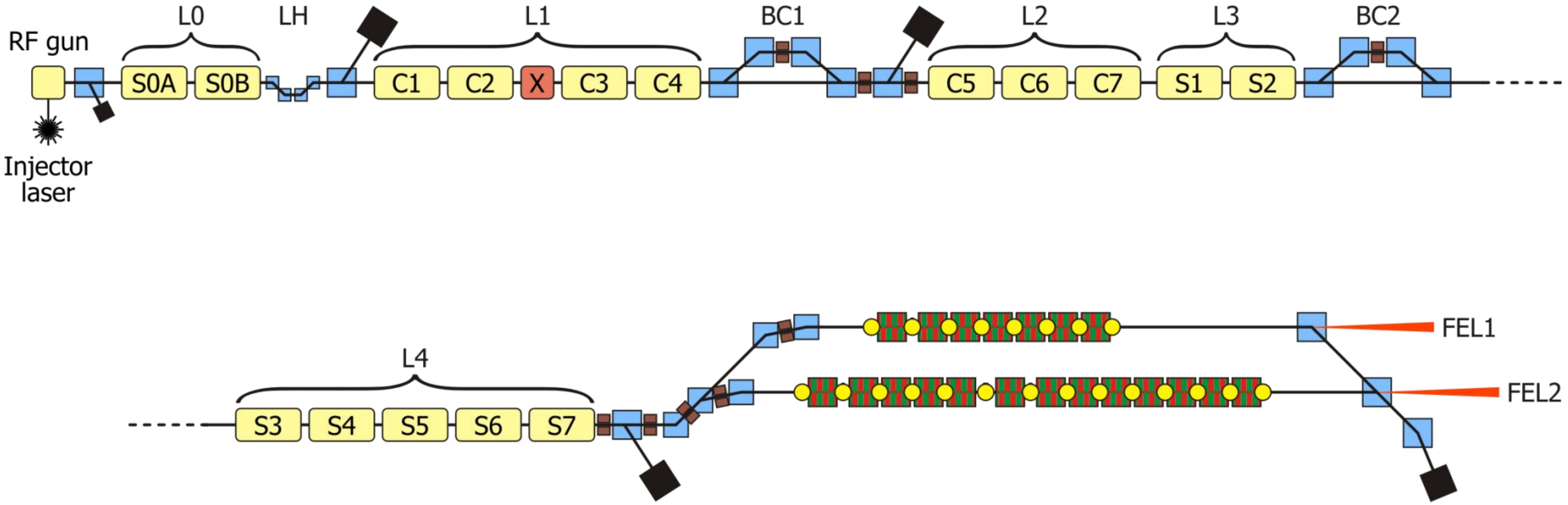
Skupin et al., "Undulator demagnetization due to radiation losses at FLASH", Proc. EPAC'08, pp. 2308–2310





Cherenkov Fiber Beam Loss Position Monitors (BLPMs)

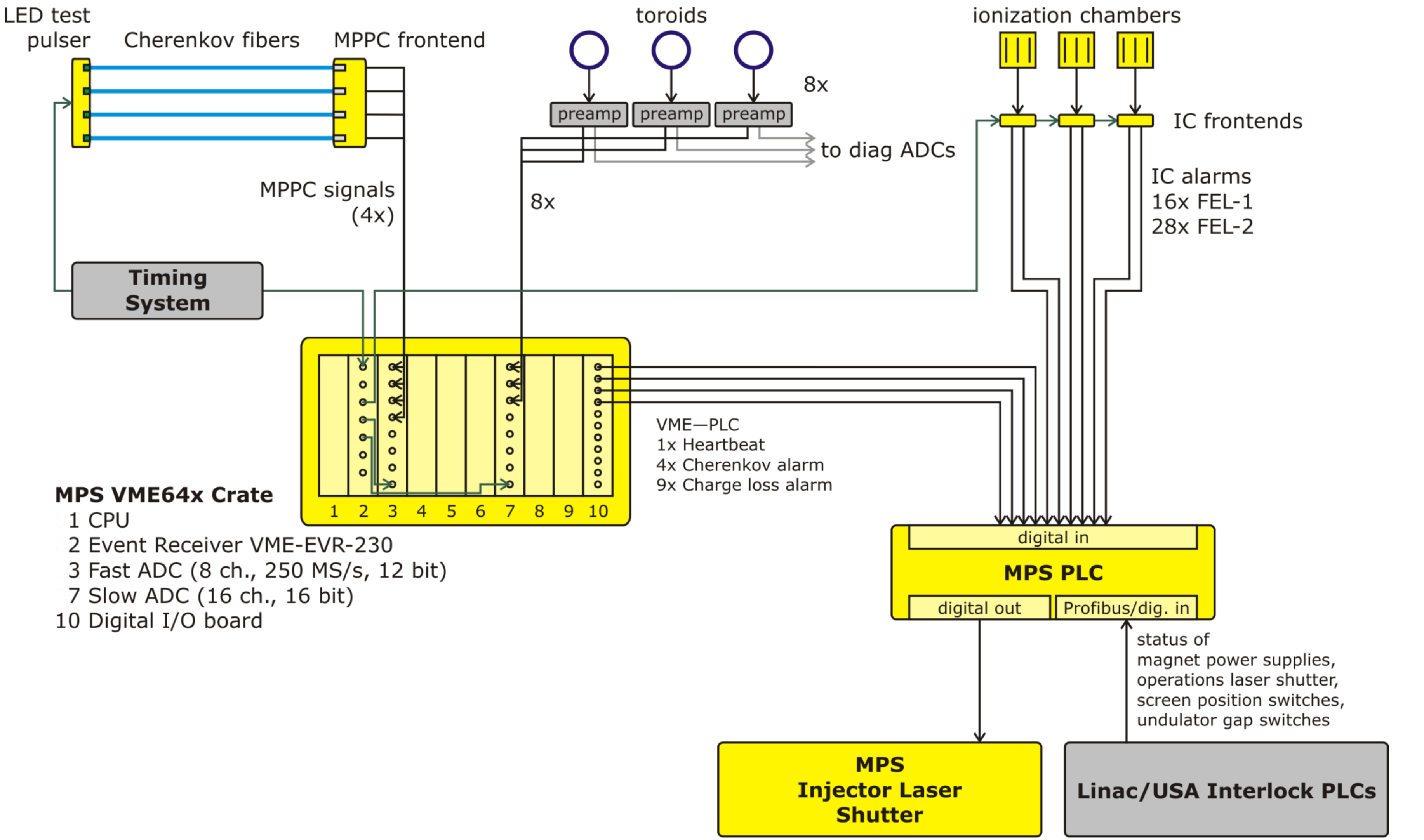




Ionization Chamber Beam Loss Monitors (BLMs)

MPS Architecture & General Features

MPS Overview



MPS VME64x Crate

1 CPU
2 Event Receiver VME-EVR-230
3 Fast ADC (8 ch., 250 MS/s, 12 bit)
7 Slow ADC (16 ch., 16 bit)
10 Digital I/O board

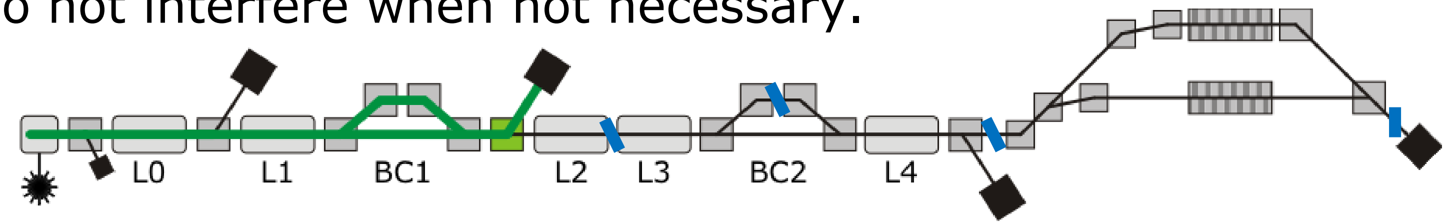
Screens + Dipole Magnets

Screen Interlock

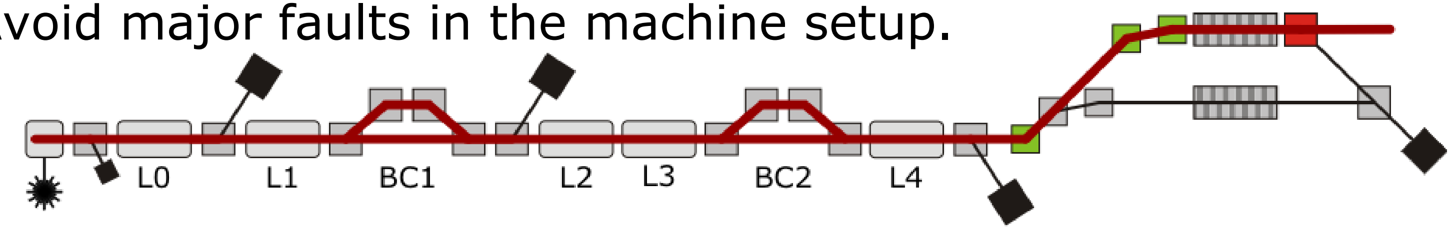
- Inhibits electron beam when:
  - Screens moving or in undefined/forbidden position
  - Linac screen inserted when in FEL-1 or FEL-2 mode
- Only active for screens in current beam path

Operation Mode

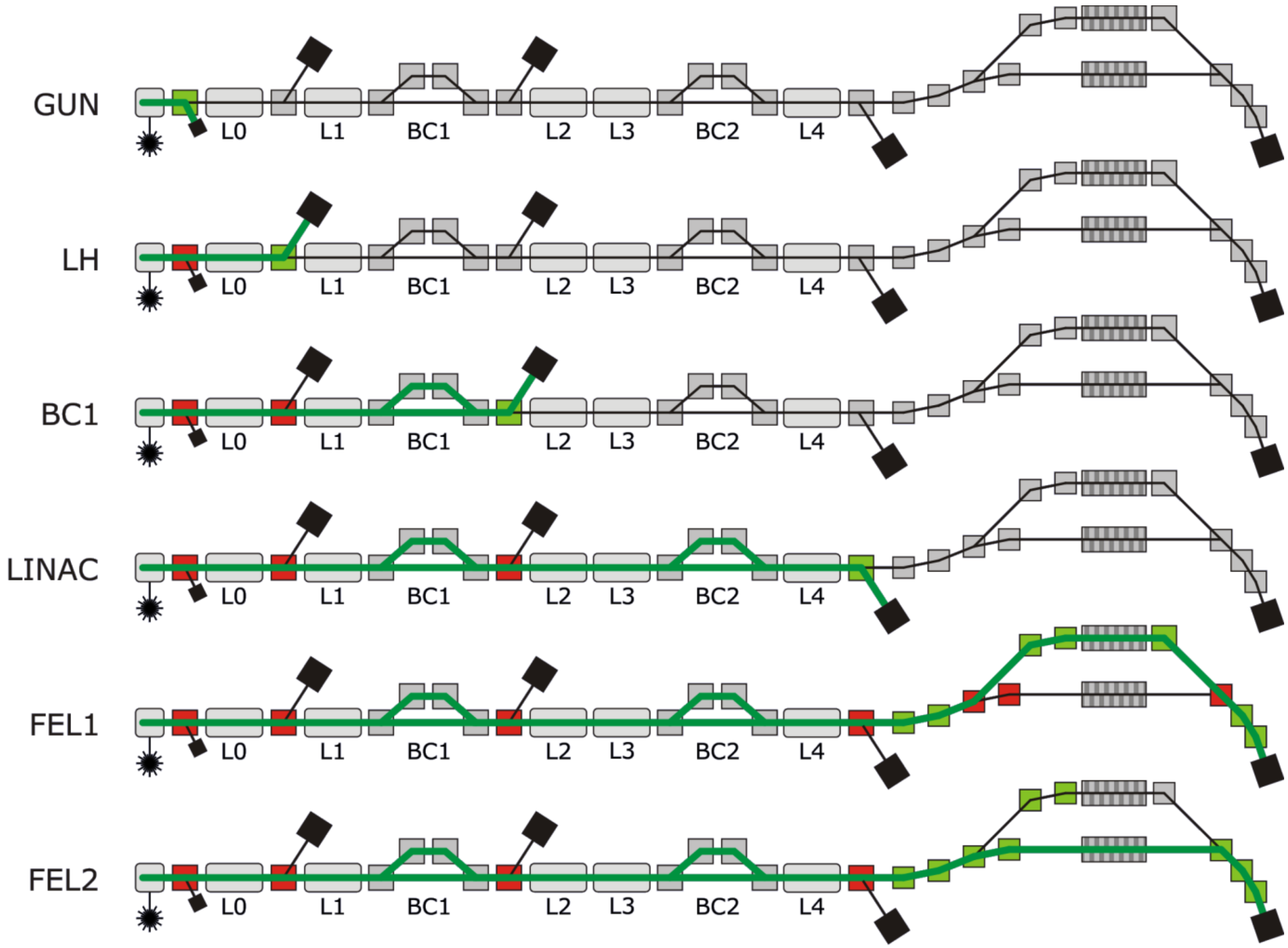
Purpose 1: Do not interfere when not necessary.



Purpose 2: Avoid major faults in the machine setup.

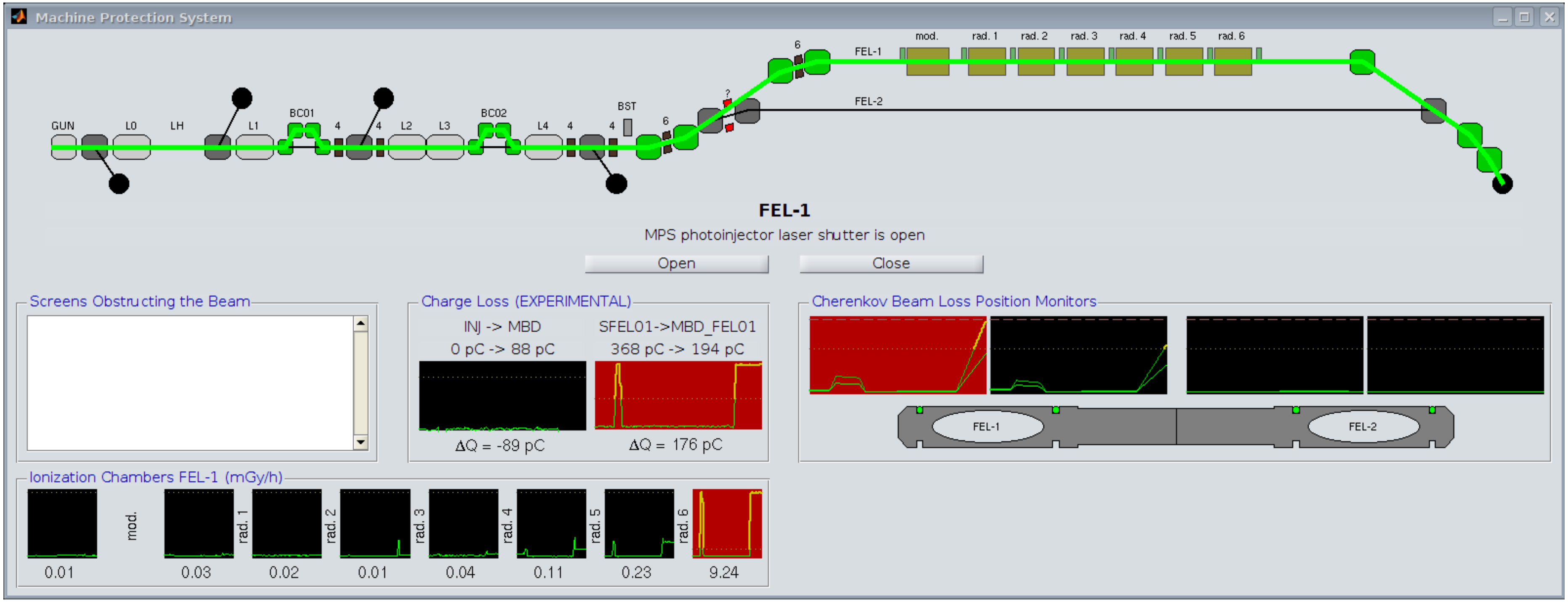


Operation Modes



Dipole currents monitored via DCCT and analog PLC input.

MPS Panel

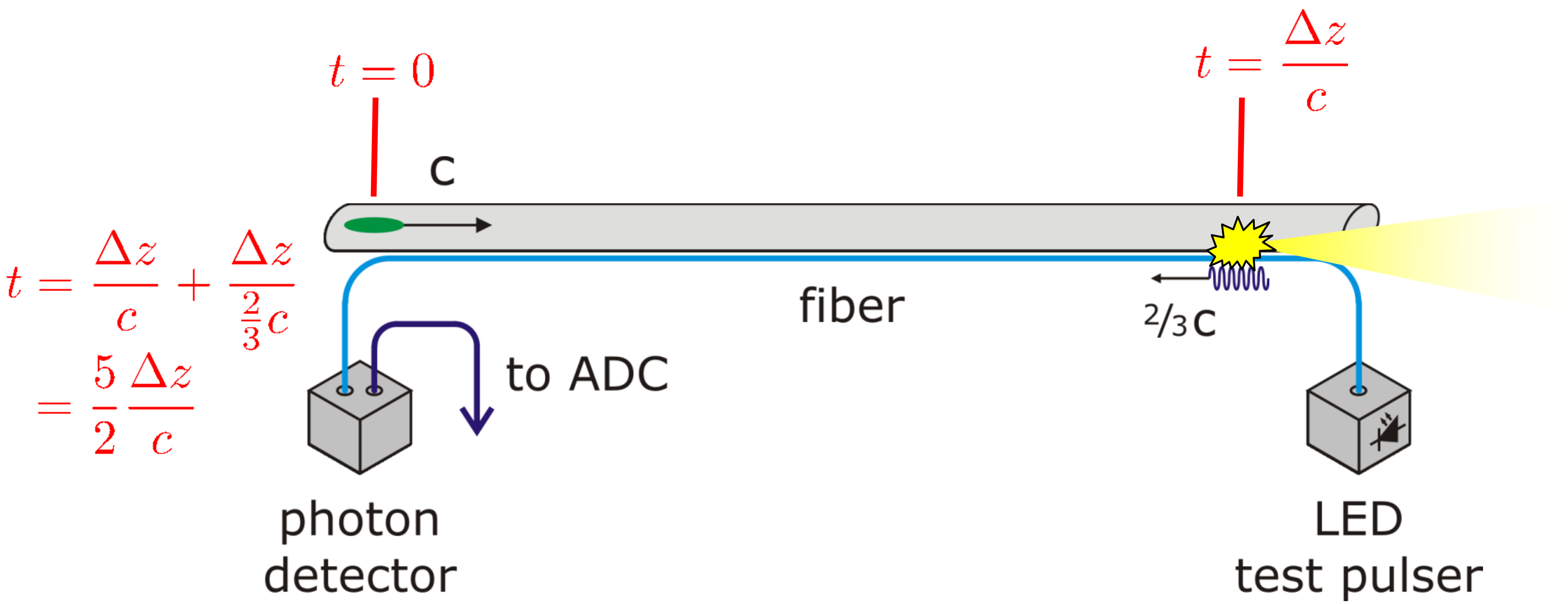


Machine Protection System
GUN
L0
LH
L1
BC01
L2
L3
BC02
L4
BST
FEL-1
FEL-2
mod.
rad. 1
rad. 2
rad. 3
rad. 4
rad. 5
rad. 6
FEL-1
MPS photoinjector laser shutter is open
Open
Close
Screens Obstructing the Beam
Charge Loss (EXPERIMENTAL)
INJ -> MBD
0 pC -> 88 pC
SFEL01->MBD_FEL01
368 pC -> 194 pC
ΔQ = -89 pC
ΔQ = 176 pC
Cherenkov Beam Loss Position Monitors
FEL-1
FEL-2
Ionization Chambers FEL-1 (mGy/h)
0.01
0.03
0.02
0.01
0.04
0.11
0.23
9.24

Cherenkov Fiber Beam Loss Position Monitor

More information:
D. Di Giovenale, L. Catani, L. Fröhlich, “A read-out system for online monitoring of intensity and position of beam losses in electron linacs”, Nucl. Instr. & Meth. A 665, pp. 33–39, 2011.

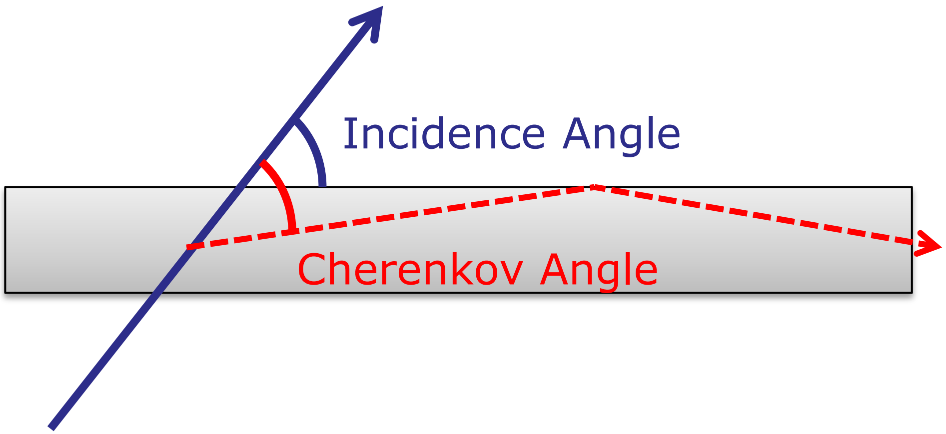
Cherenkov Fiber Beam Loss Position Monitor (BLPM)

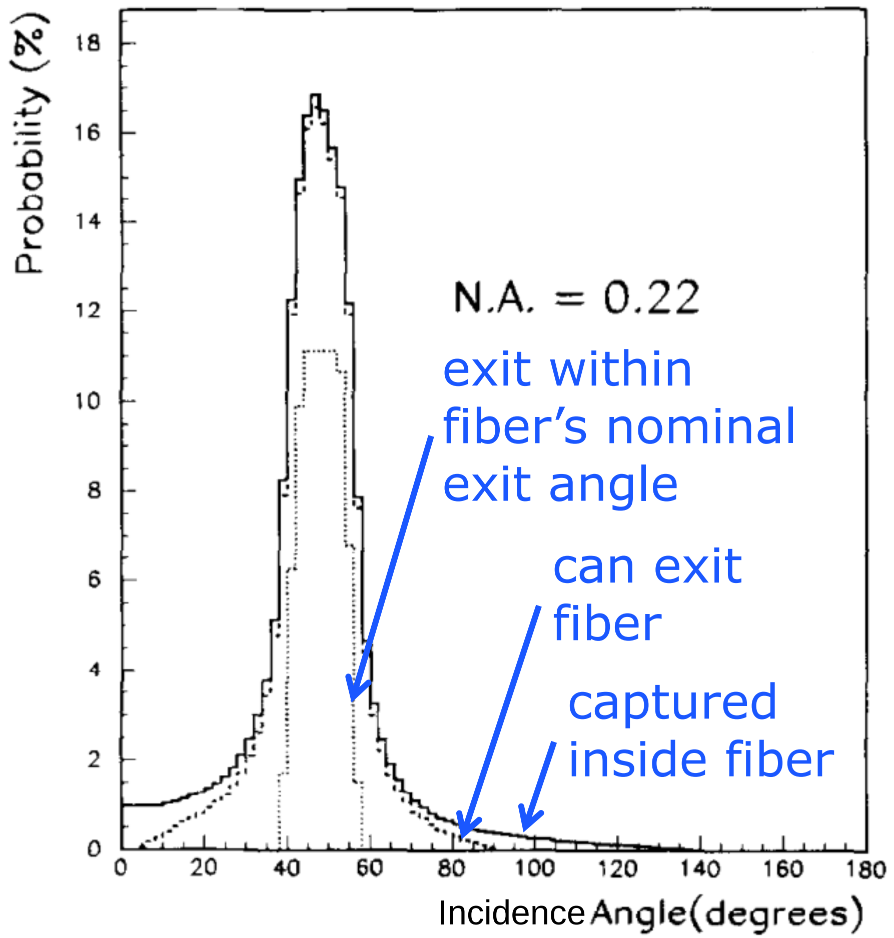


250 MS/s ADC → longitudinal resolution ~50 cm

Capturing Cherenkov Photons

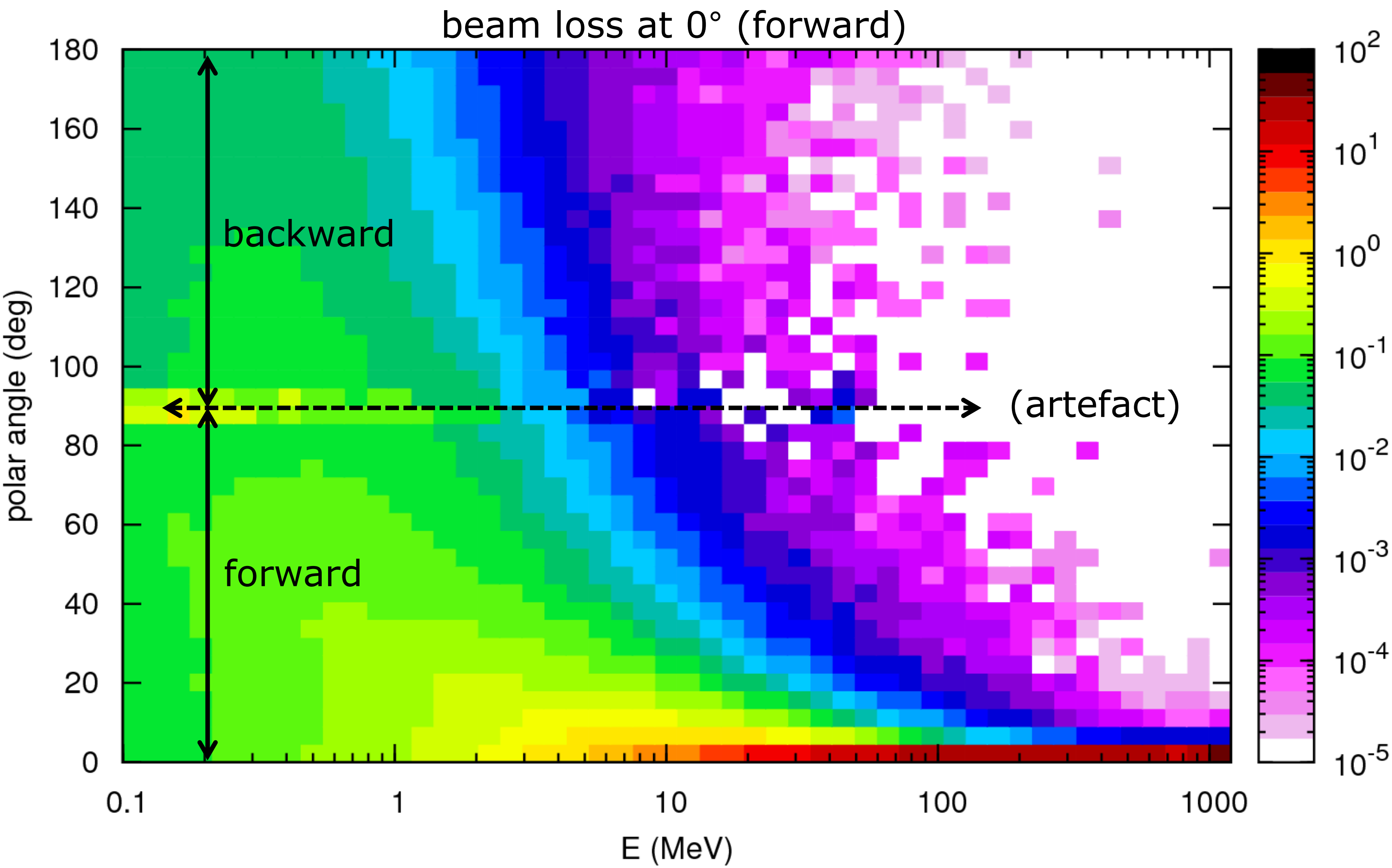
- An electron crosses a fiber at some *incidence angle.*
- It generates one Cherenkov photon.
- What are the photon's chances of making it to the end of the fiber?



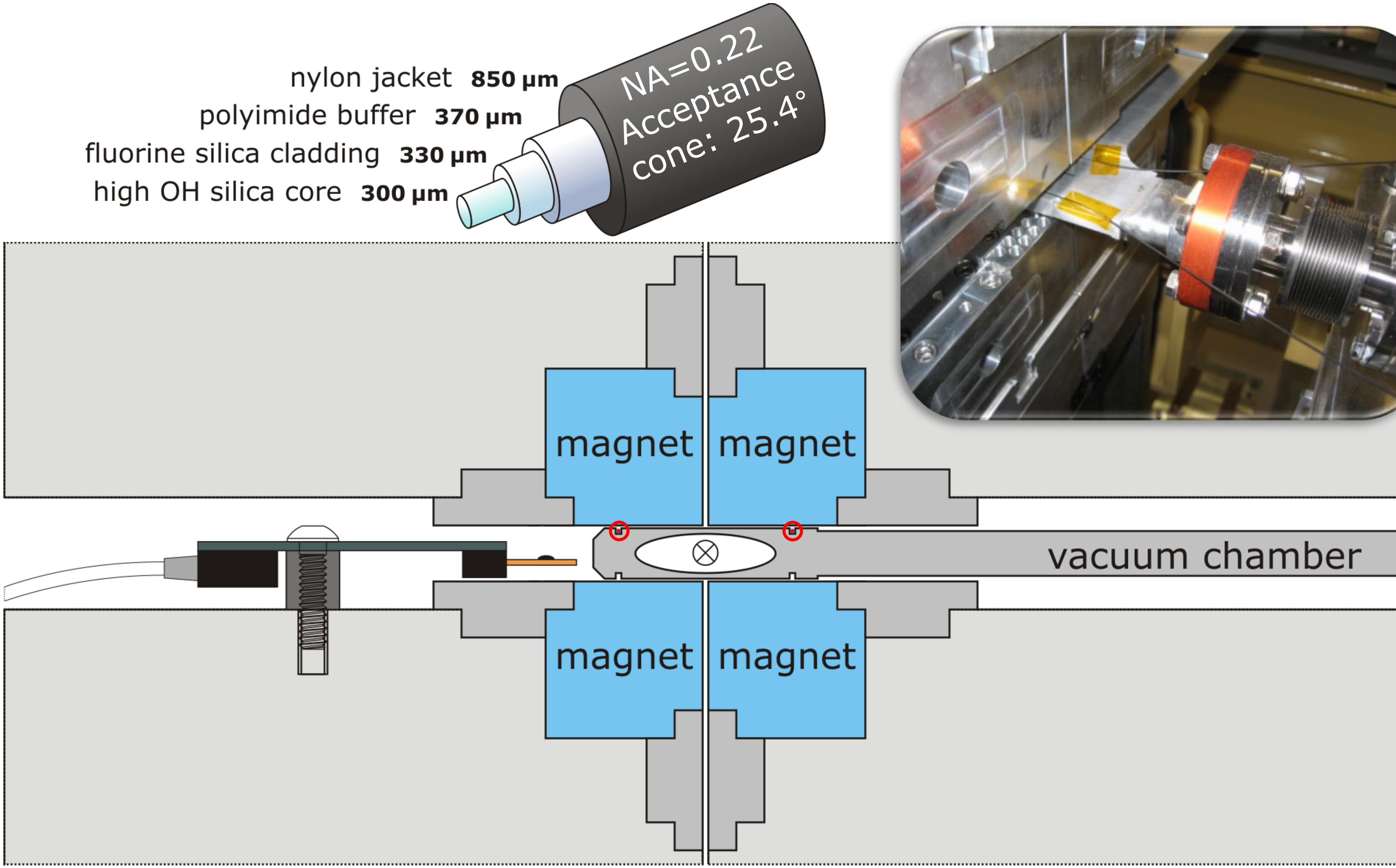


P. Gorodetzky et al., "Quartz fiber calorimetry", Nucl. Instr. and Meth. A 361, pp. 161–179, 1995.

e^+/e^- Fluence within Fiber

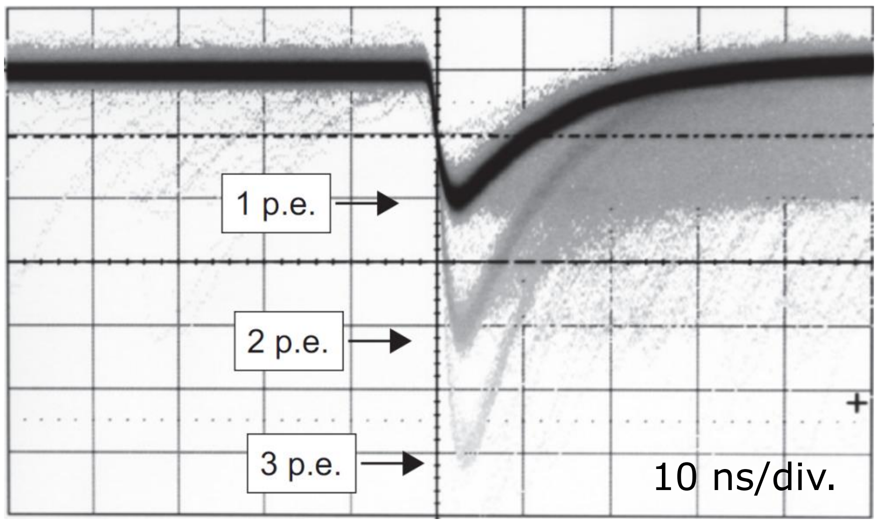


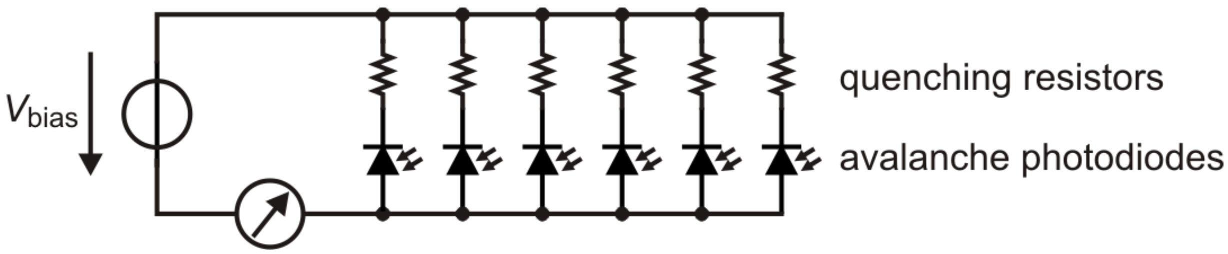
Undulator Cross Section



Multi-pixel Photon Counters (MPPCs)

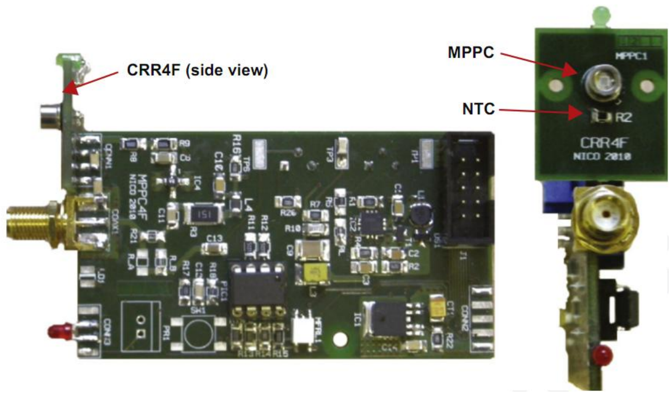
- Array of avalanche photodiodes (APDs) connected in parallel
- Reverse bias → photon causes APD breakdown
- Photomultiplier-like gain
- Dynamic range limited by number of APDs
- Rise time: some 100 ps
- Hamamatsu S10362-11-050U: 400 APDs at ~70 V reverse bias

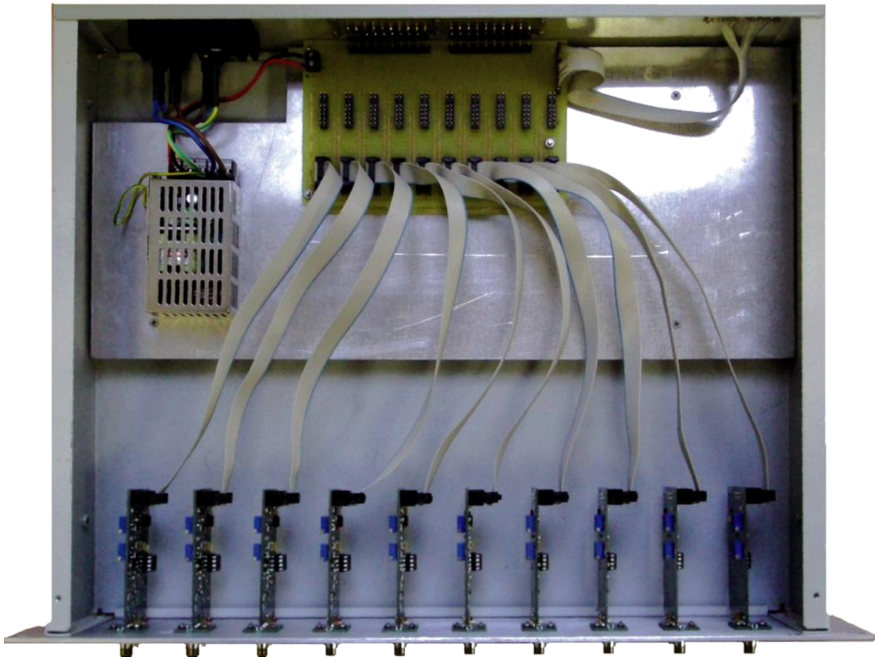




MPPC Frontend

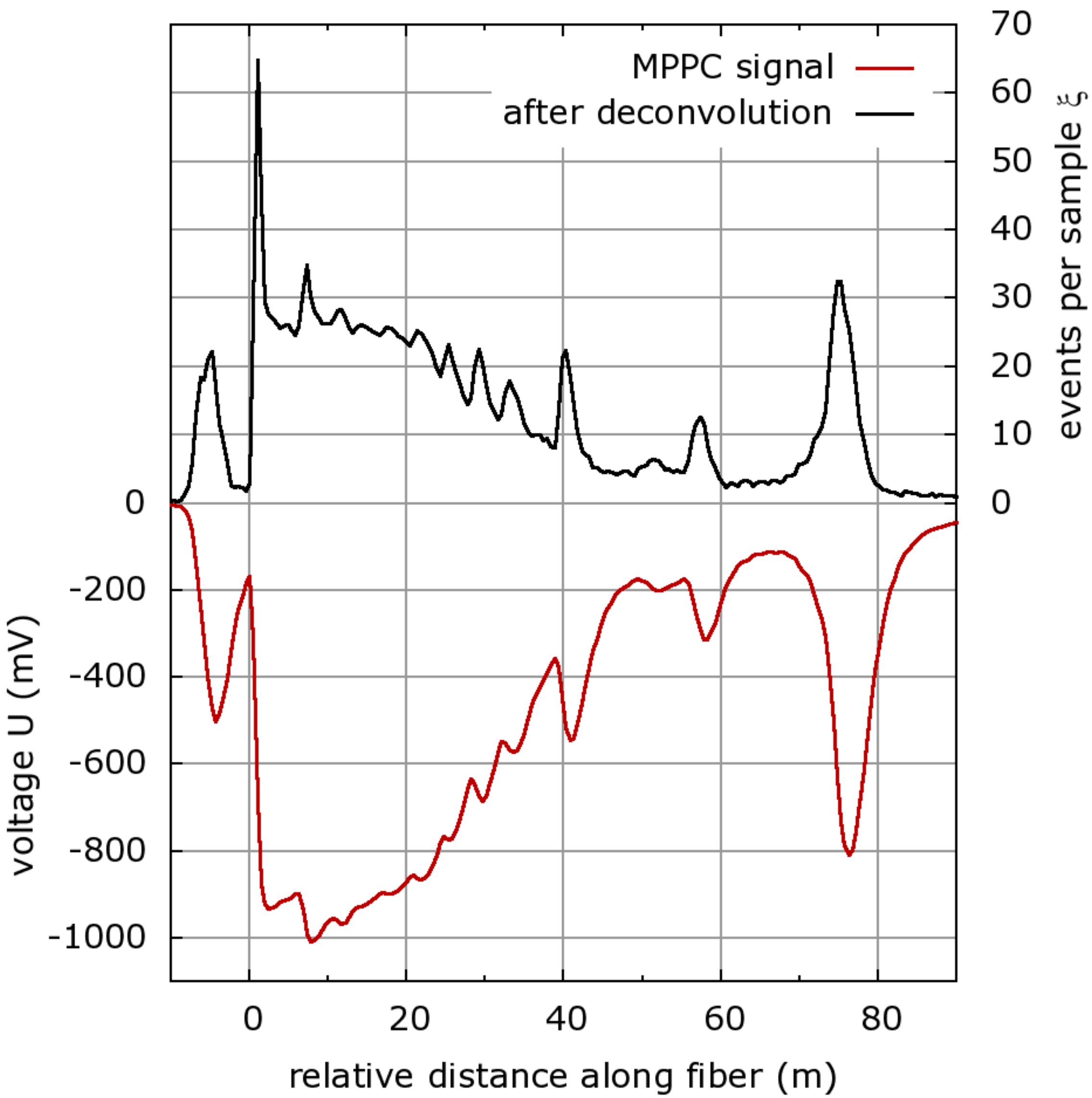
- Modular electronics
- Temperature-compensated gain
- Voltage output (50 Ω)
- Configurable alarm thresholds

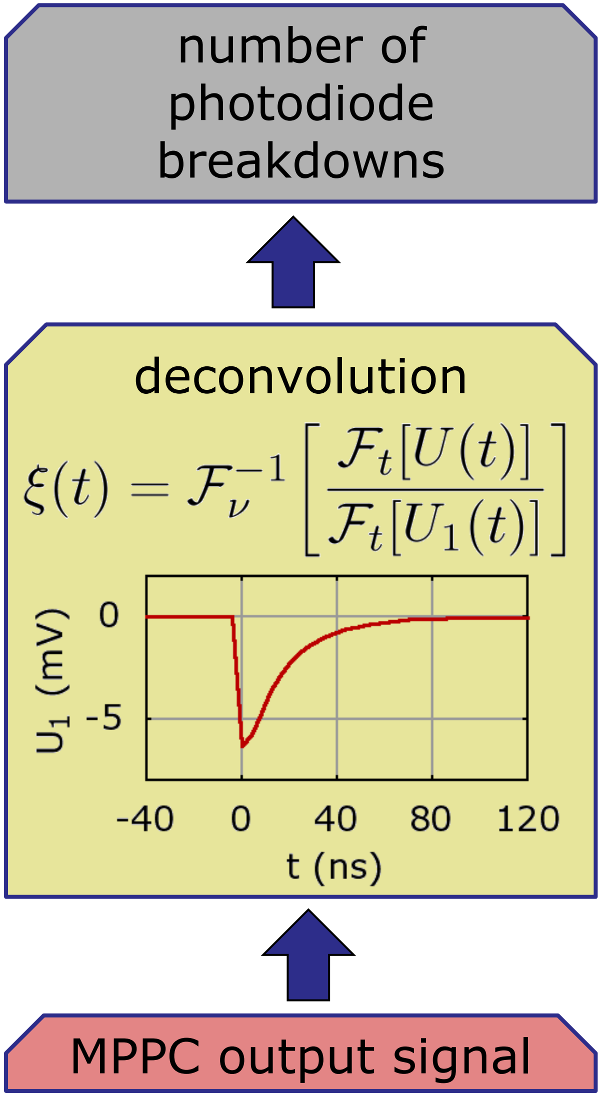




Electronics: D. Di Giovenale

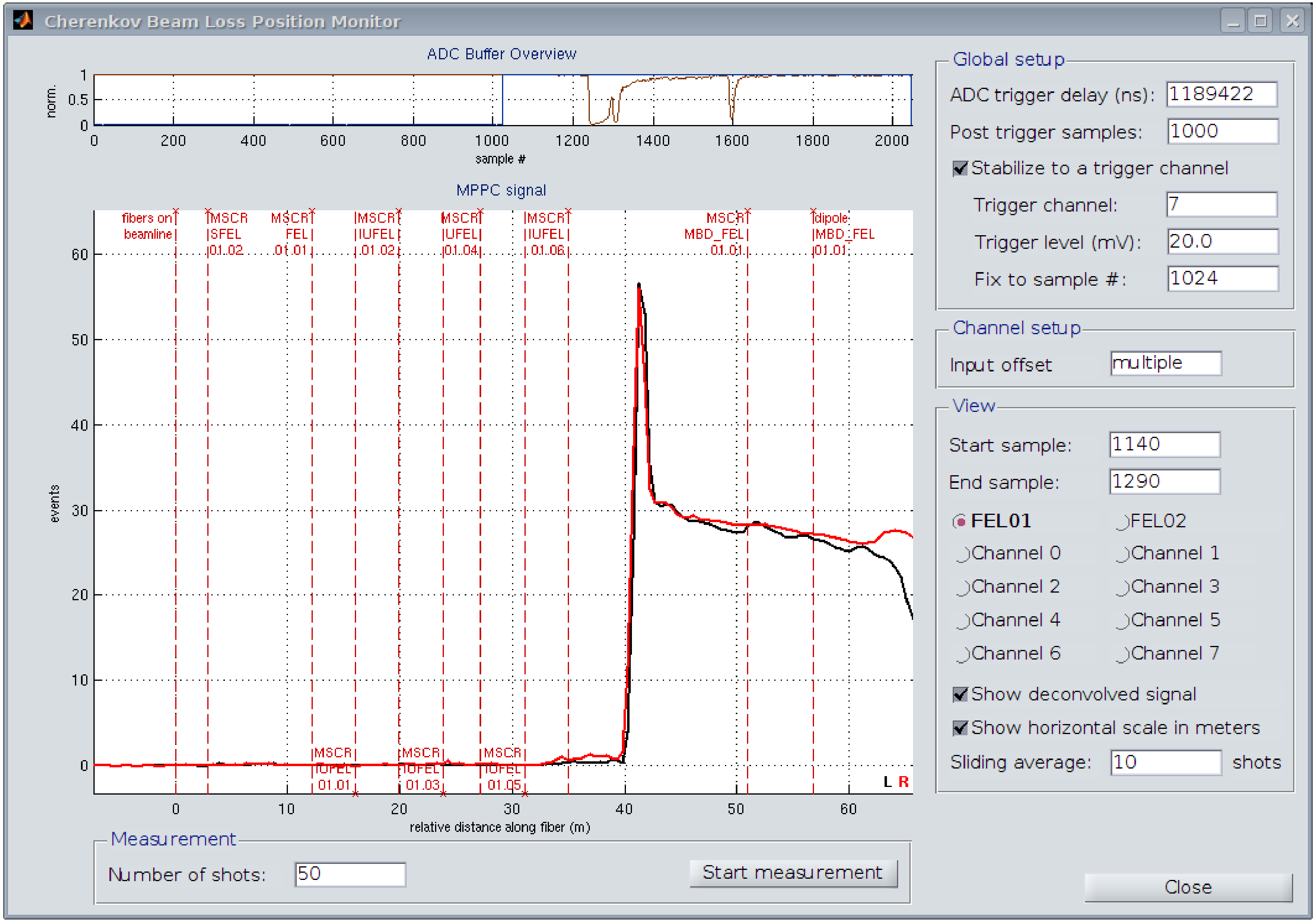
Signal Processing





$$\xi(t) = \mathcal{F}_{\nu}^{-1}\left[\frac{\mathcal{F}_t[U(t)]}{\mathcal{F}_t[U_1(t)]}\right]$$

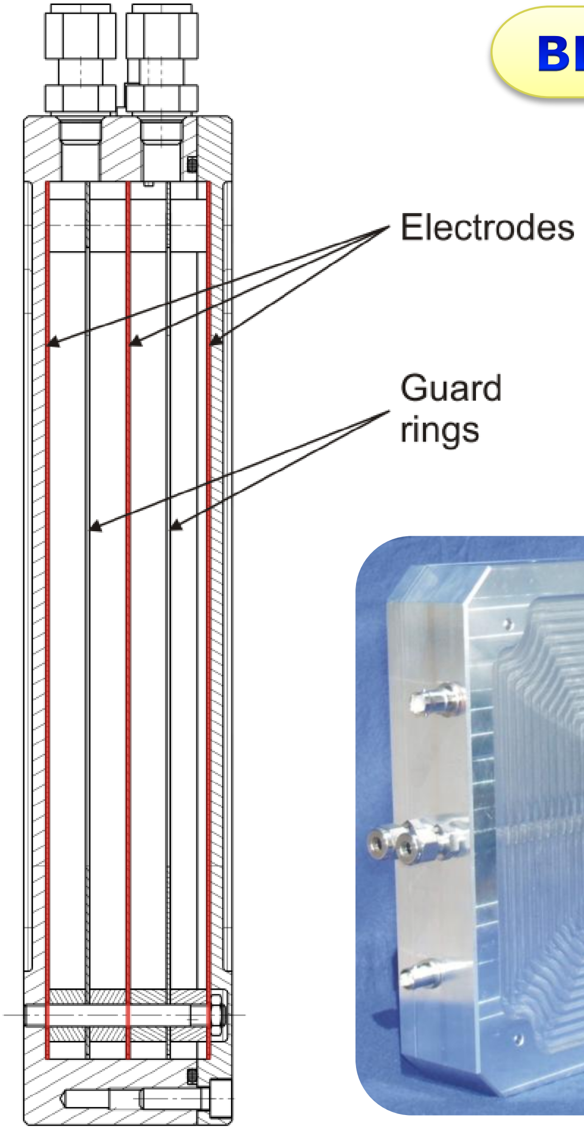
Viewer Application



Ionization Chambers

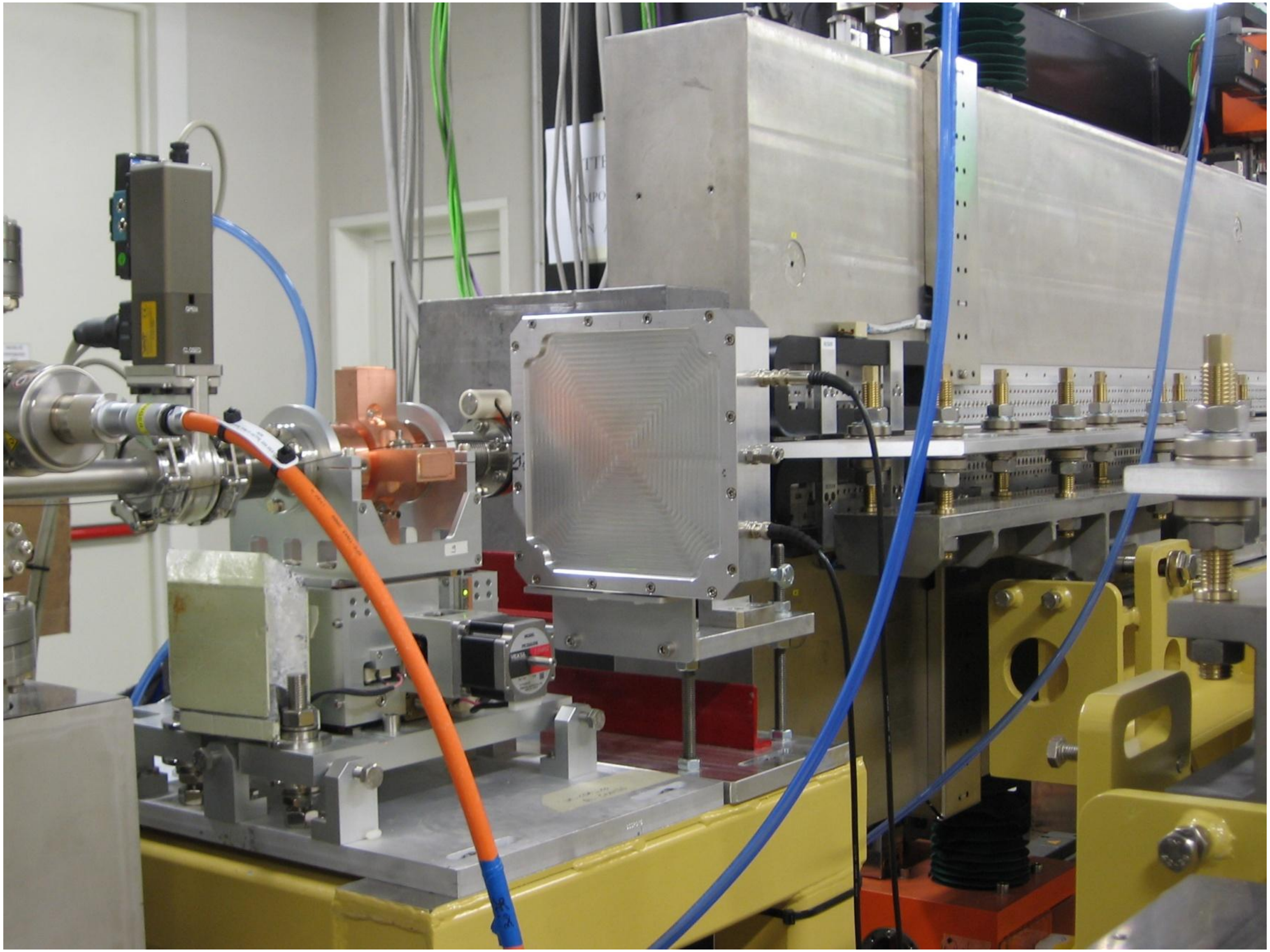
Ionization Chambers

- Milled aluminum enclosure
- Electrodes: printed circuit boards
- Use in air or with gas flux
- Volume:
  1.3 l
- Voltage:
  up to 1000 V
- Sensitivity (air):
  ~46 μC/Gy
- Leakage current:
  ≪ 200 fA (at 1000 V)
- Fermi:
  1 ionization chamber in air
  per undulator segment (19 total)



BLM–IC02

Ionization Chambers



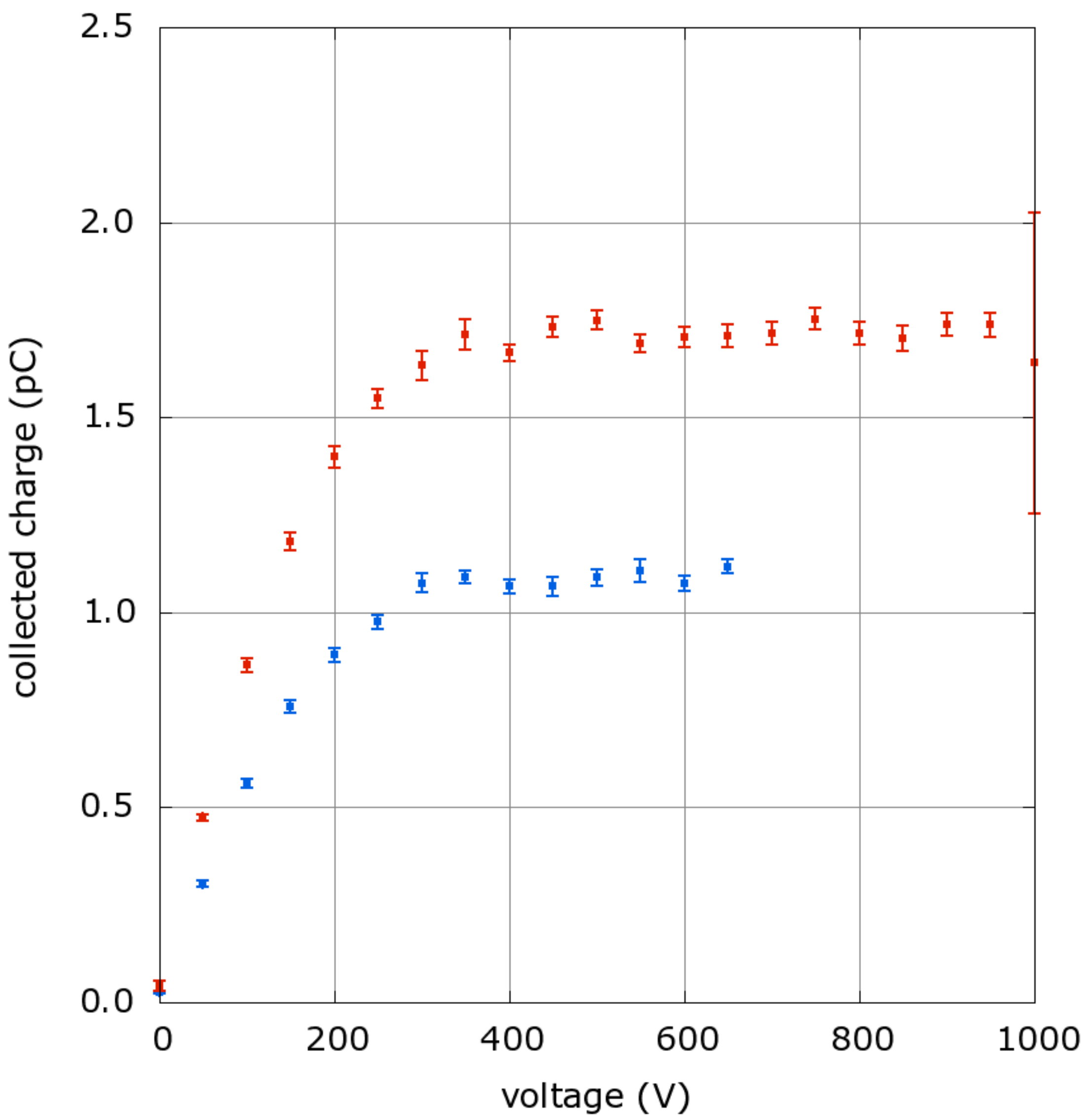
Ionization Chamber Frontend

XPi DAS

- Modular data acquisition system
- Ethernet interface
- 1× HV up to 2000 V, ≤ 1 W
- 4× Charge-integrating amplifier
  Ranges: 0…50 pC – 0…1.8 nC
  Integration time: 1 ms – 1 s
- 20-bit ADC
- Noise w/ Fermi chamber: <0.4 μGy/h

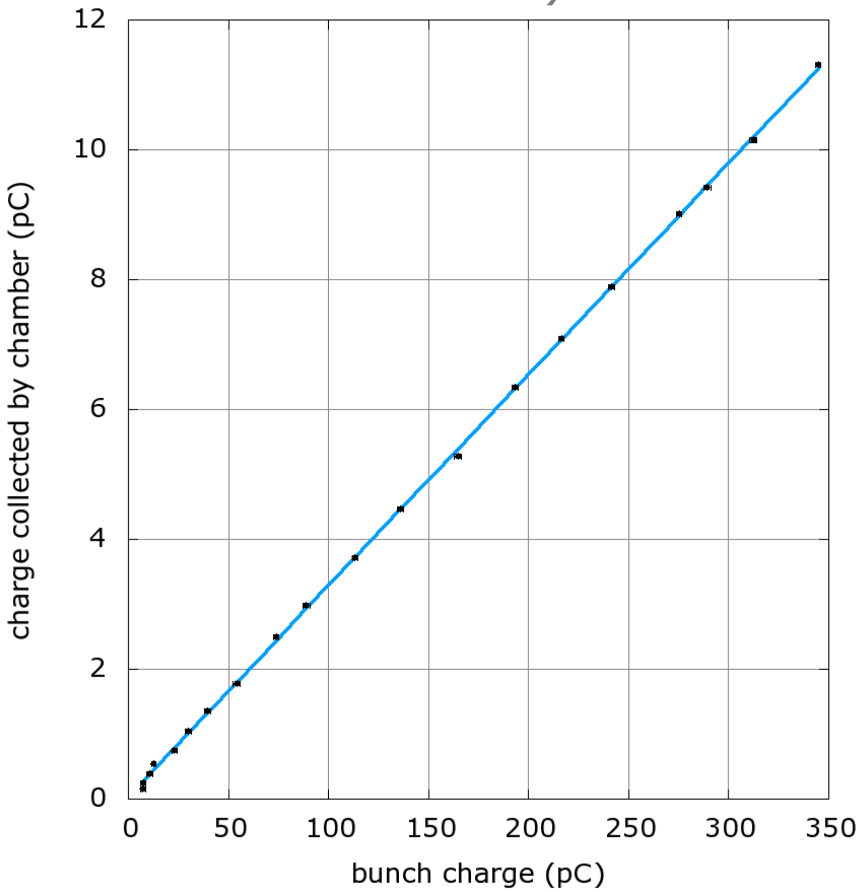
Collection Efficiency

- Air filled chamber
- Charges collected:
  - Electrons
  - Oxygen ions (O_2^-)
  - Positive ions (N_2^+ etc.)
- Integration time: 3 ms (2 ms sufficient to collect all charges)

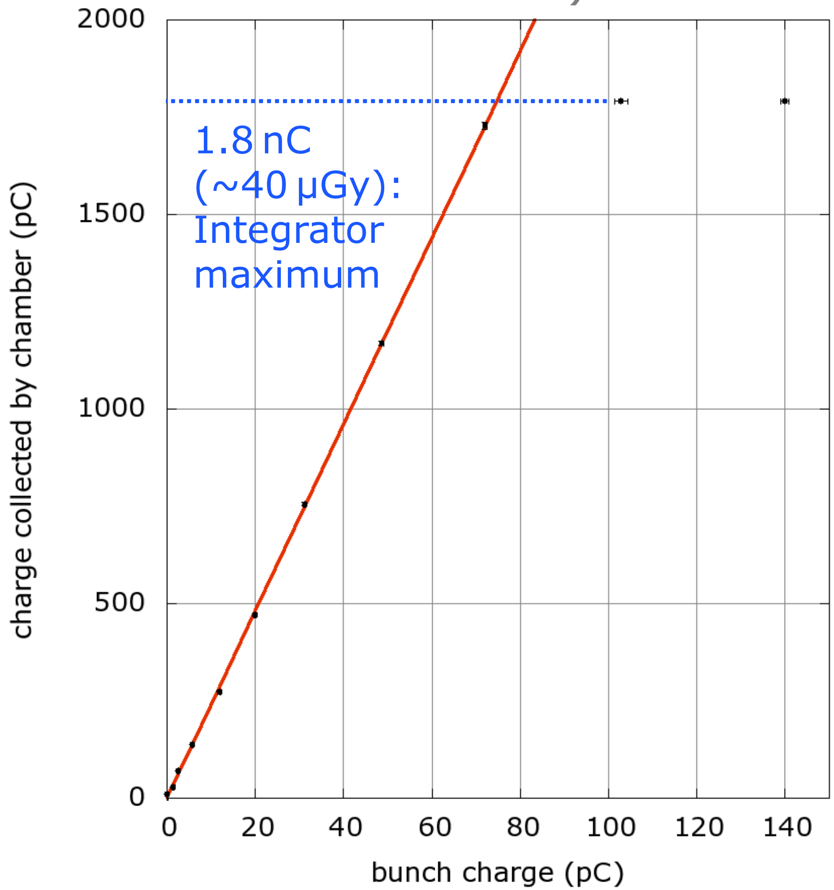


Linearity at 1000 V

Low dose rates
(~20 cm downstream of screen)

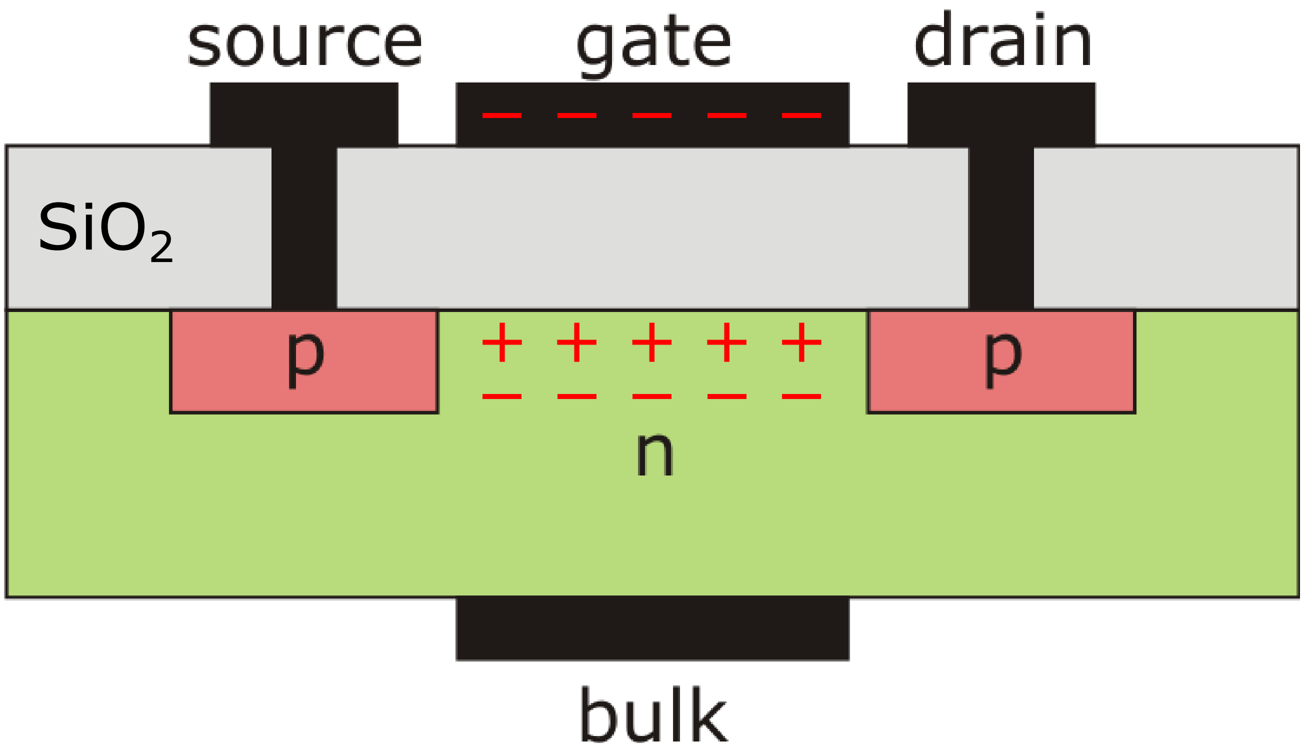


High dose rates
(~4 m downstream of screen)



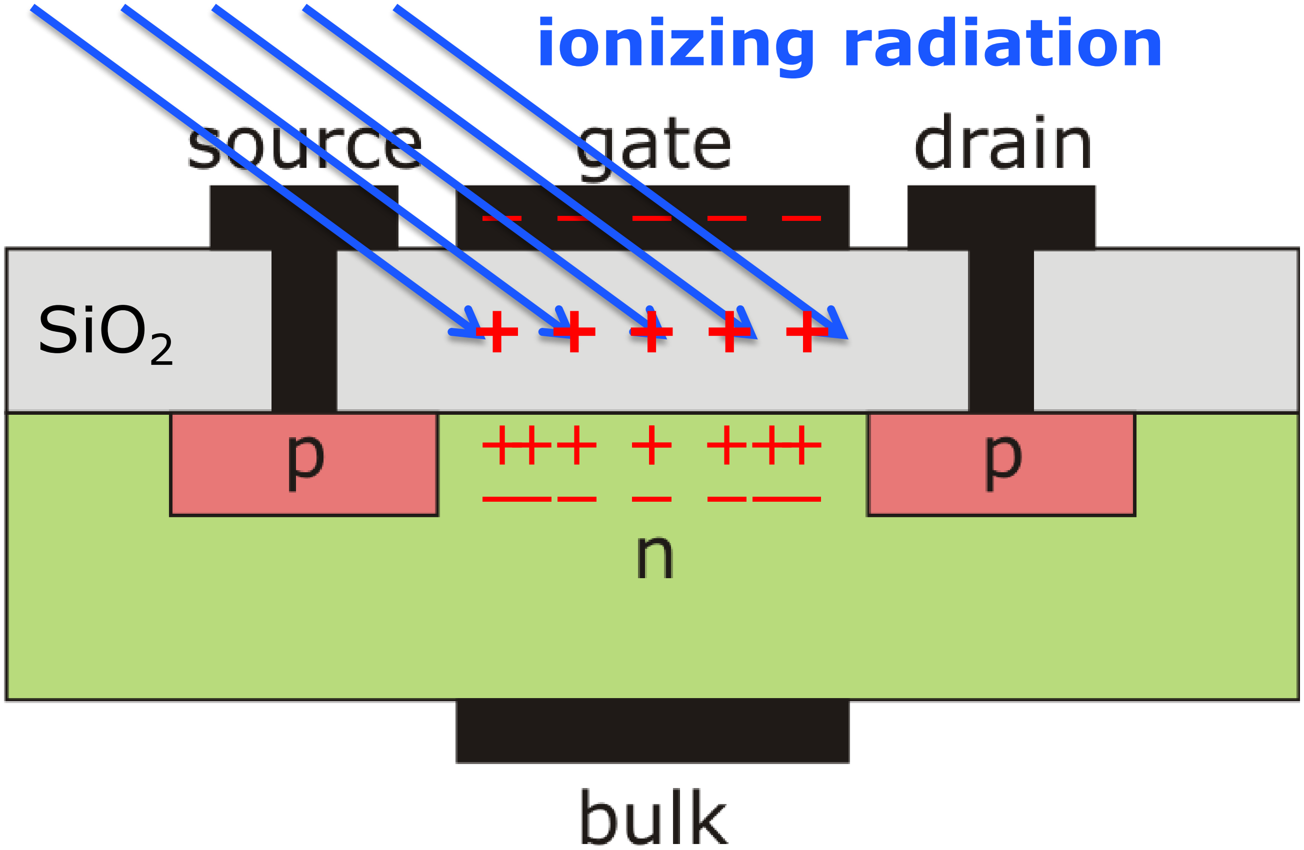
Online Solid-State Dosimetry

P-channel MOSFET



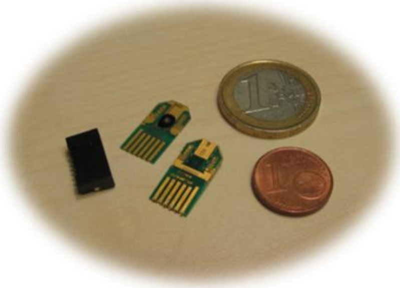
negative gate potential → conductive inversion layer

P-channel MOSFET



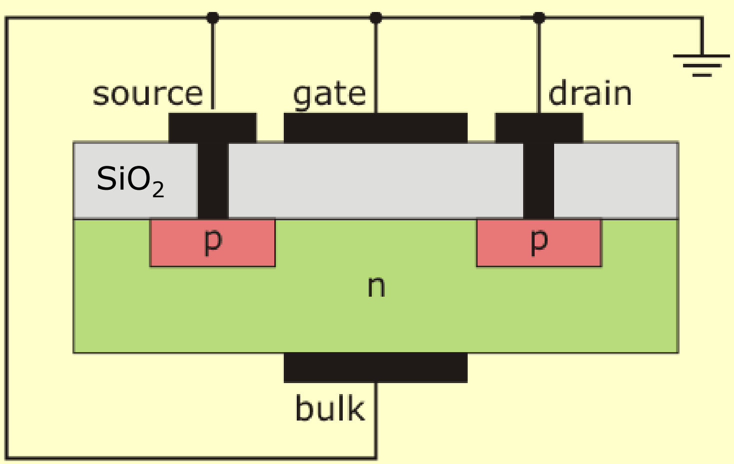
ionizing radiation → stationary charges in insulation layer

RADFET Dosimeters

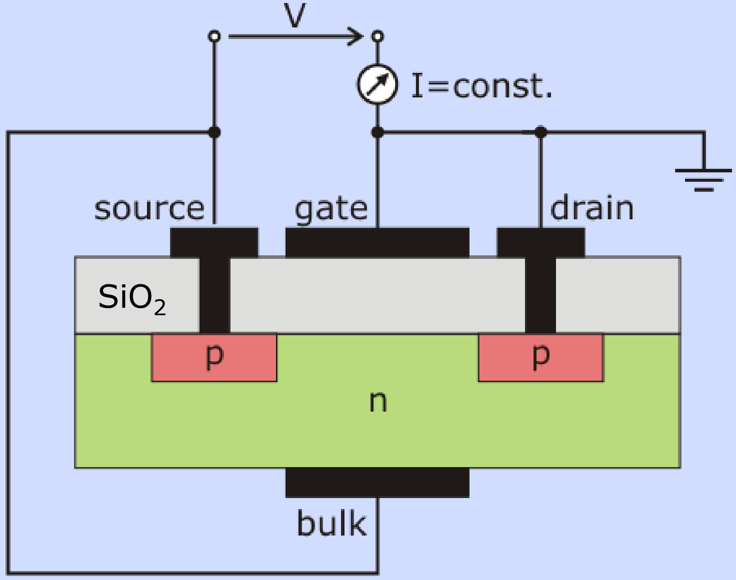


- REM Oxford Ltd. RADFET RFT-300-CC10G1
- Chip contains 2 p-channel MOSFETs with 300 nm insulator layer

exposure
"zero bias"



read-out



Track voltage for constant current (490 μA) between source and drain

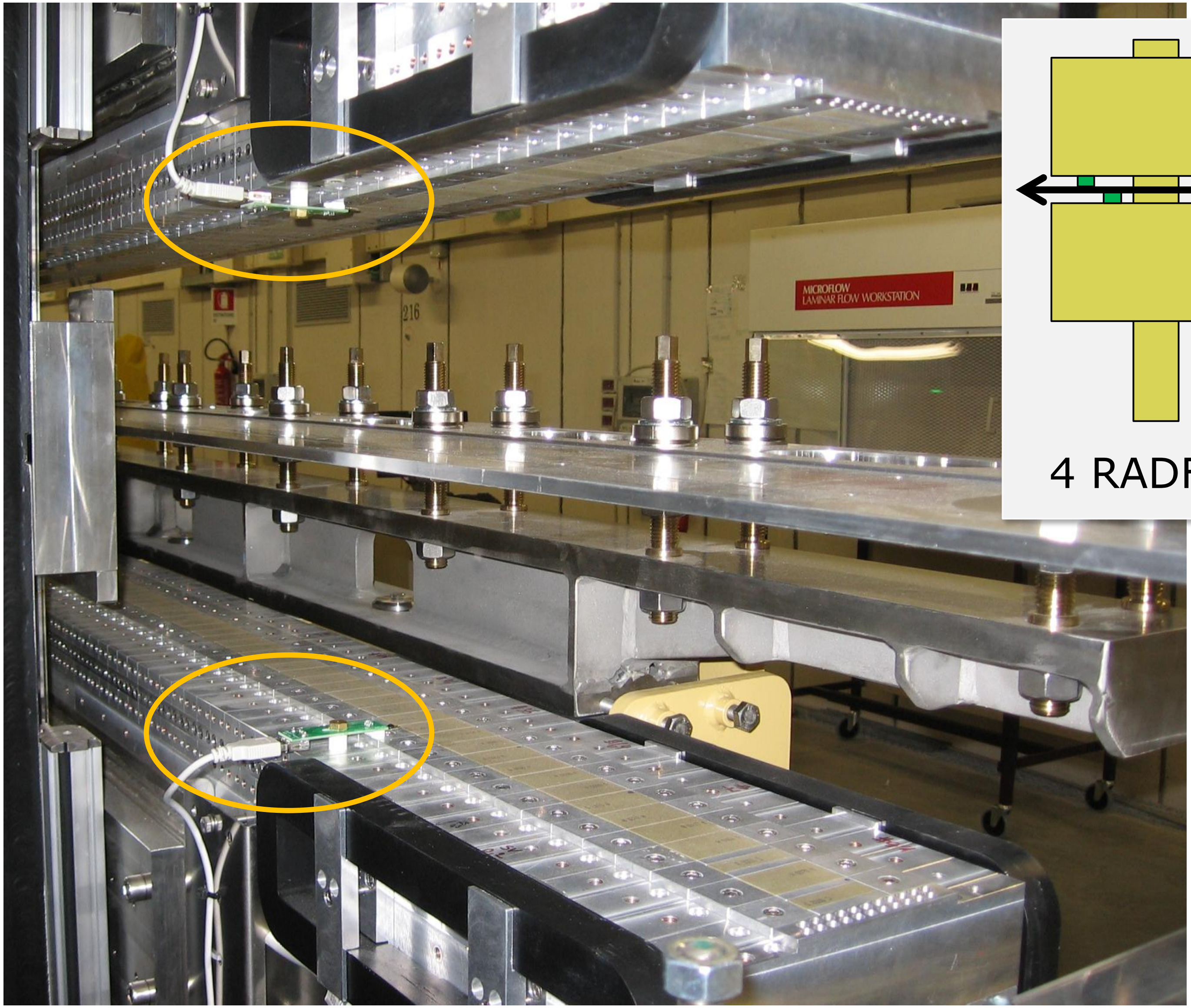
Dosimeter Reader

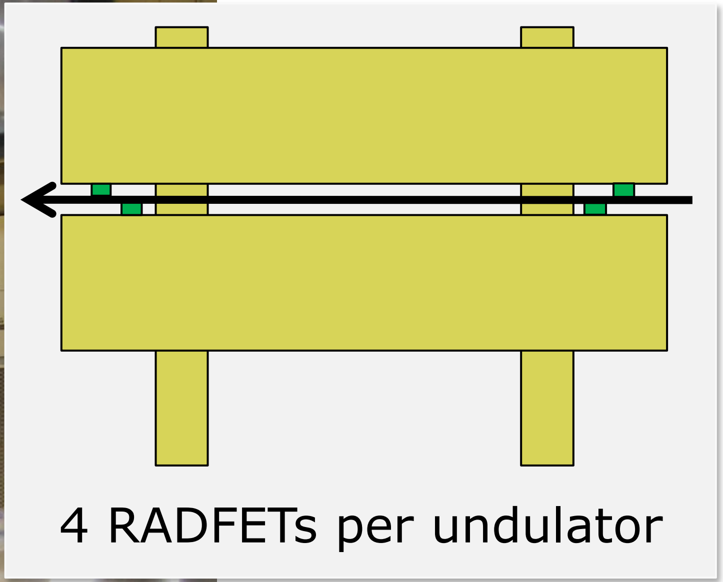
L01-DOSFET

- Ethernet interface
- 4 RADFET channels
- Fixed read-out current: 490 µA
- Voltage read-out: 24 bit ADC, up to 25 V
- Programmable interlock output
- Uses standard USB cables

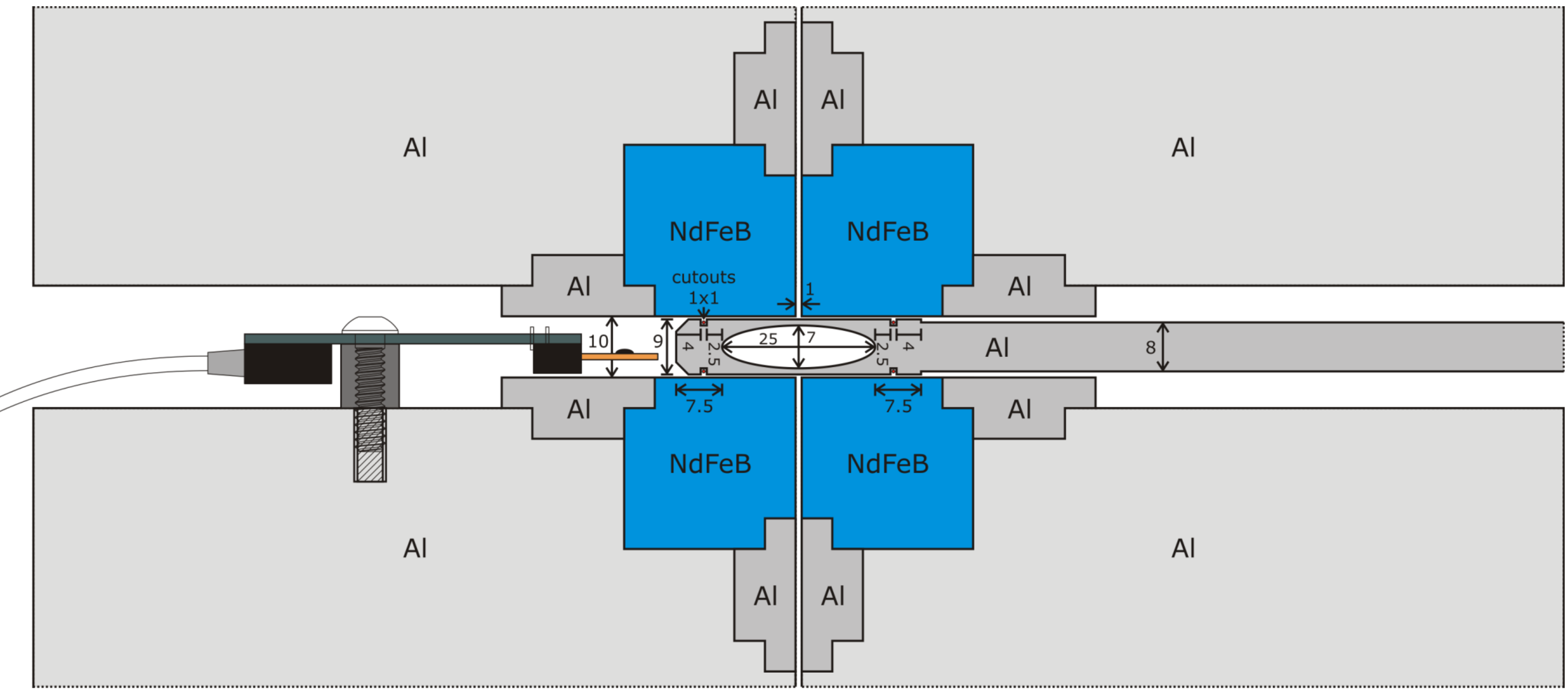
Photo: M. Peloi

Undulator with Open Gap



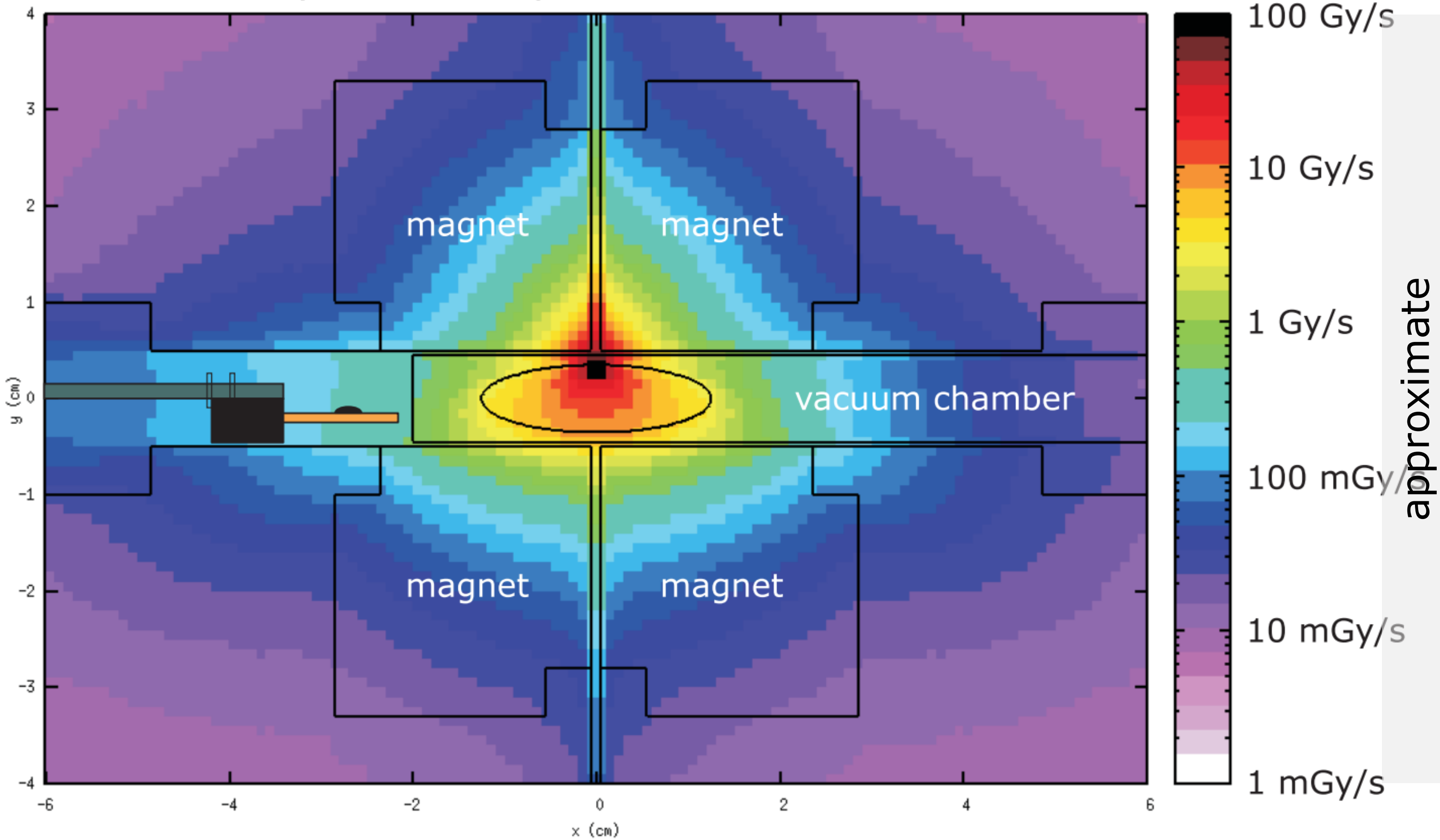


Undulator Cross-Section



Dose Rates

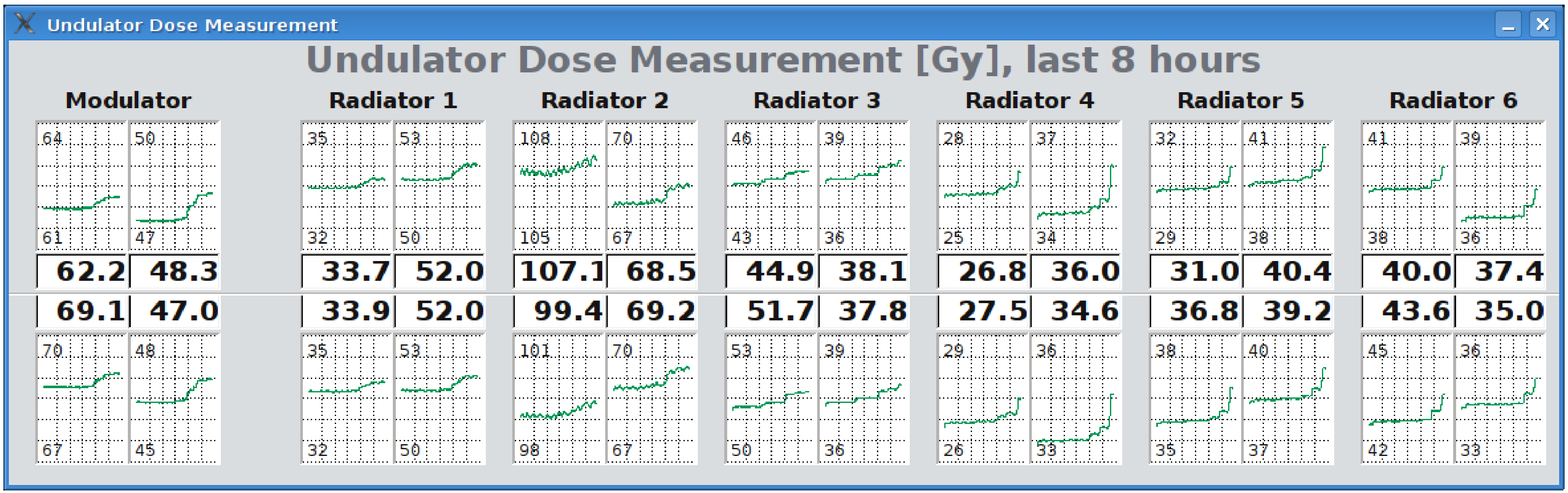
impact of 500 pC bunches at 10 Hz



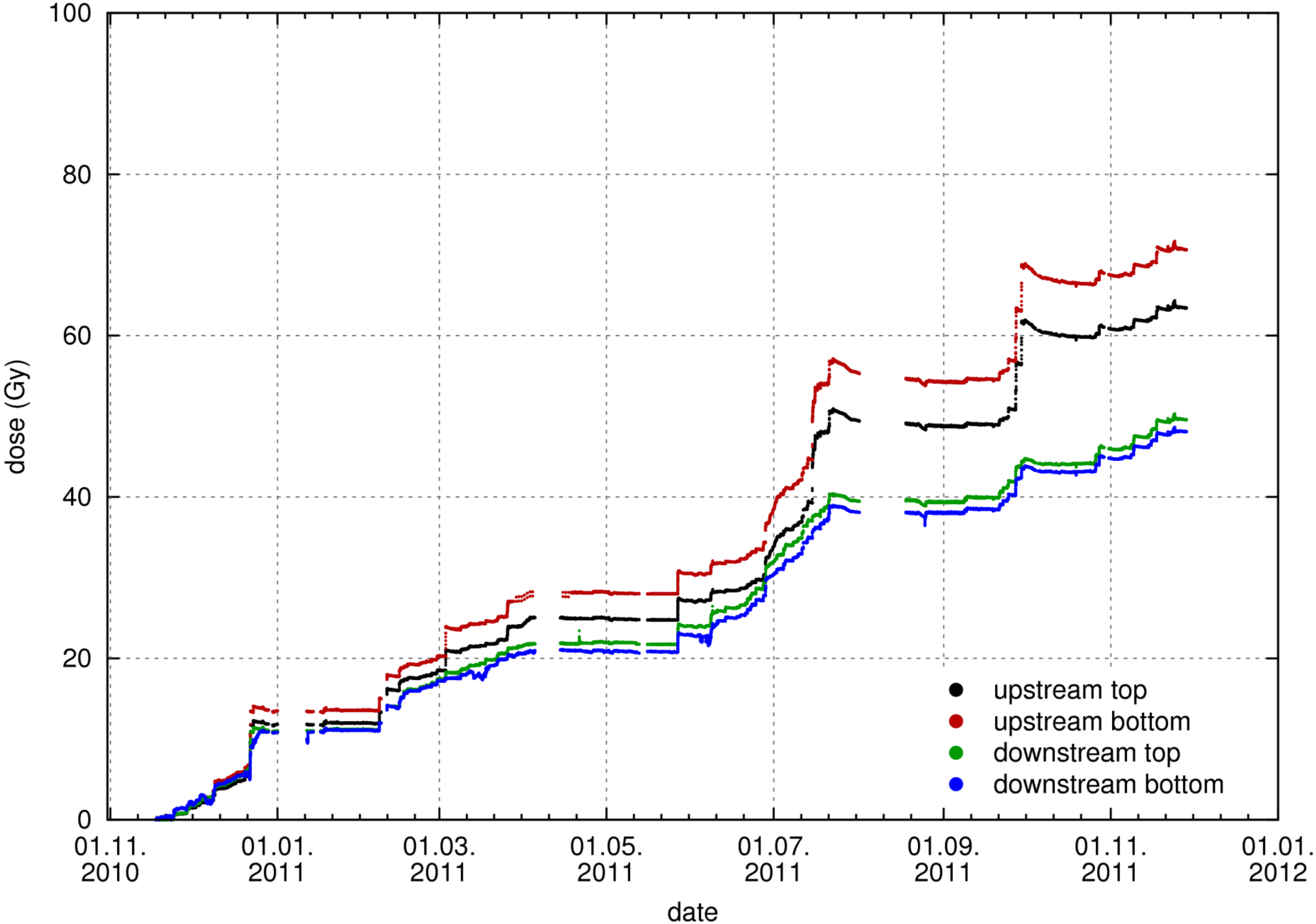
Calibration

unpublished data

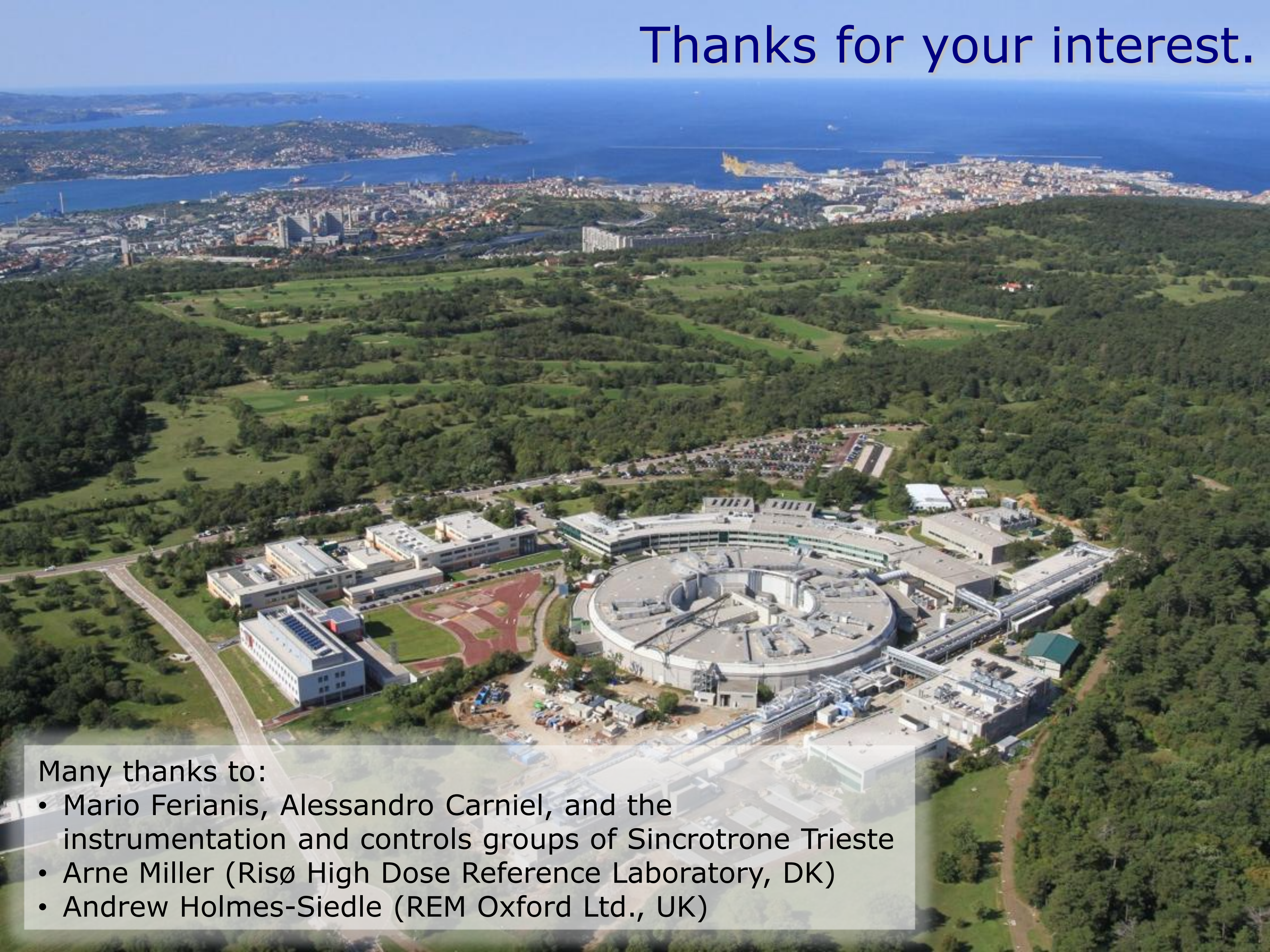
Control Panel



Dose History Modulator FEL-1



Thanks for your interest.



Many thanks to:

- Mario Ferianis, Alessandro Carniel, and the instrumentation and controls groups of Sincrotrone Trieste
- Arne Miller (Risø High Dose Reference Laboratory, DK)
- Andrew Holmes-Siedle (REM Oxford Ltd., UK)