Beam Loss Monitoring and Machine Protection at the ELBE CW Accelerator

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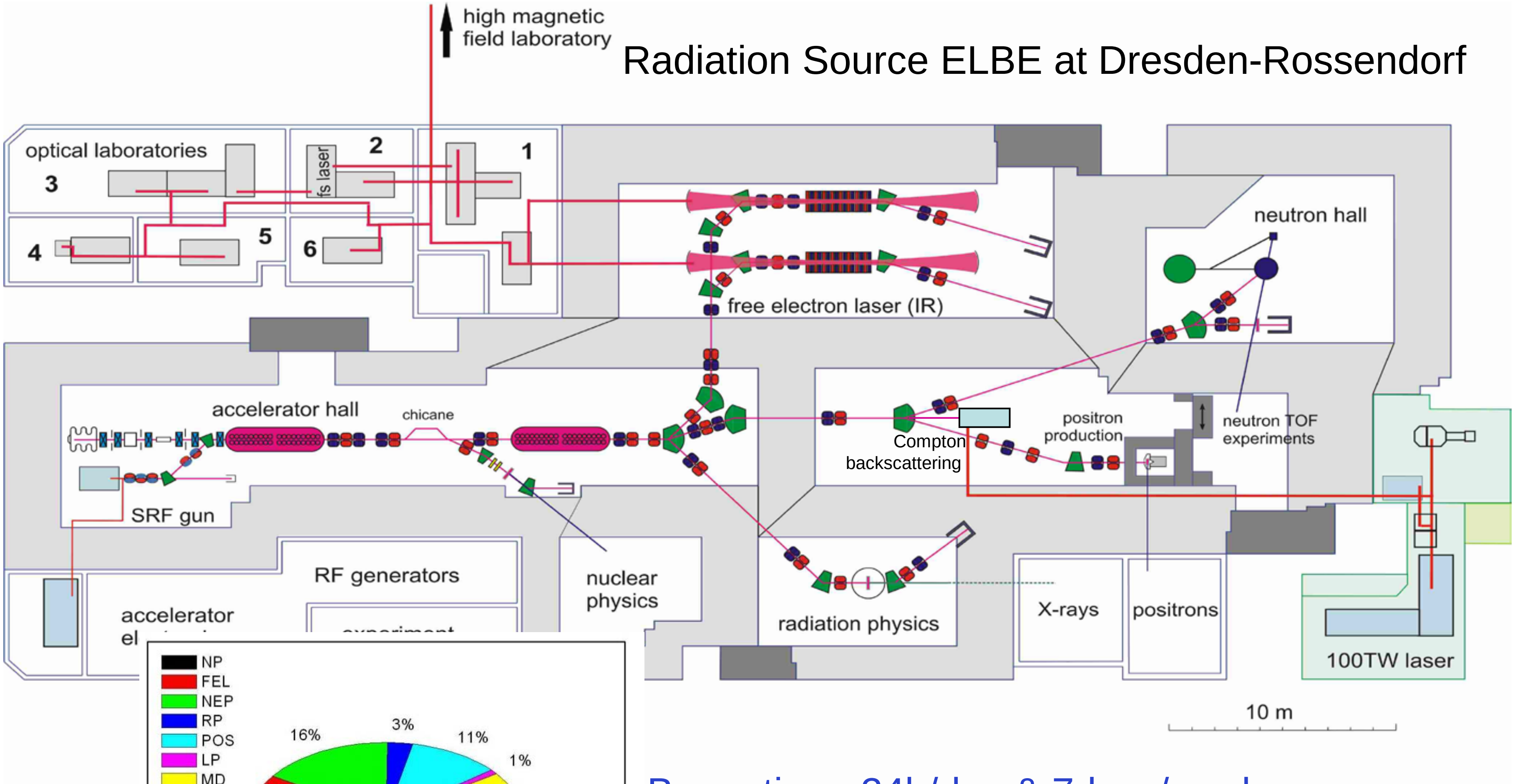
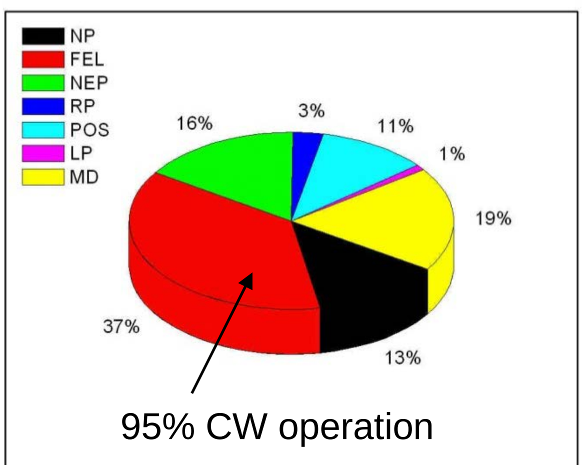
50th ICFA Advanced Beam Dynamics Workshop
on Energy Recovery Linacs
16-21 October, 2011 , Tsukuba, Ibaraki, Japan

- Introduction
    - Overview of ELBE
    - Operation Modes and Application
- Beam Loss Monitors at ELBE
- Machine Protection Systems
- Experiences
- Present & Planned Upgrades

Radiation Source ELBE at Dresden-Rossendorf





Beam time: 24h/day & 7days/week

The Superconducting CW accelerator at ELBE

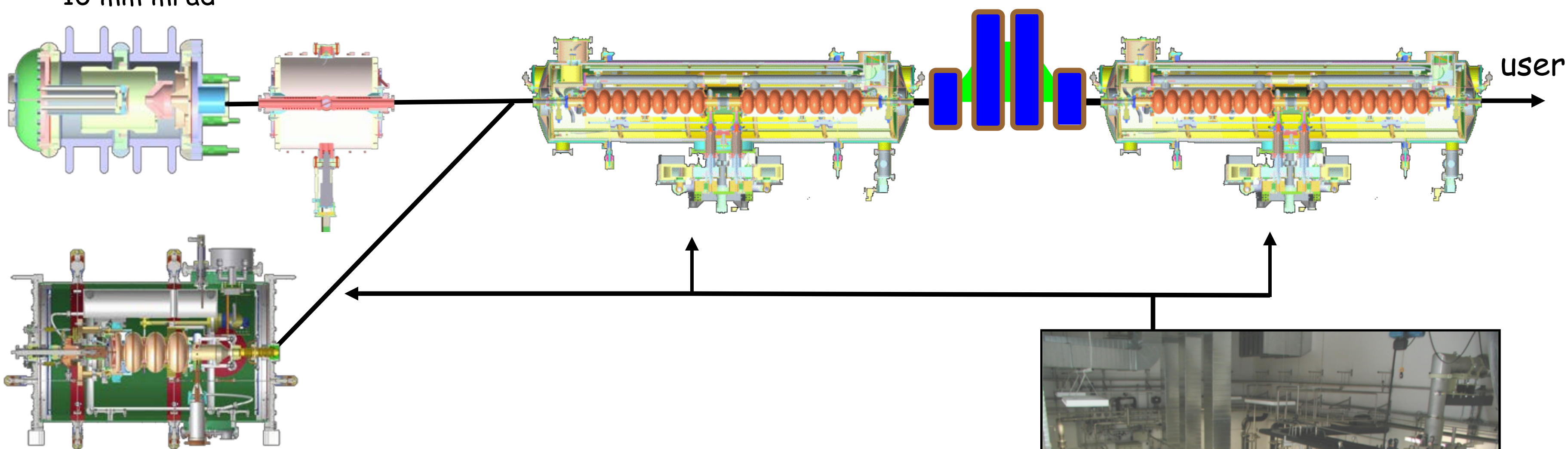
thermionic DC gun
250 kV
<80 pC
≤260 MHz ~ 500ps
~10 mm mrad

RF buncher
260 MHz
+1,3GHz
compr. ~ 100:1

linac
1,3 GHz
~20MeV@10 MeV/m
CW

magnetic bunch compressor
R_{56} < 500 mm

linac
1,3 GHz
~20 MeV@10MV/m
CW



Superconducting Radio Frequeny Photo Gun
9.5 MeV
80pC / 1nC
≤13 MHz ~ 5-20 ps
~ 1-3 mm mrad

helium liquifier LINDE
200 W @ 1,8 K

ELBE Parameters

Parameter	Present status	Upgrade 2012 [1)]
electron beam energy / MeV	8 - 40	8 – 40
accelerating energy per cavity / MeV	10	10
average beam current / µA - maximum -typical FEL operation	 1000 800	 1500
bunch charge / pC - thermionic injector - SRF photo injector	 77 100	 77 1000
RF power per cavity / kW	8 - 9	16
electron beam power / kW	32	65

[1)] klystron replacement by 2 x 8 kW solid-state amplifiers
SRF gun with new cavity (35 MV/m peak field)

ELBE operation modes

mode	Diagnostic Mode	high current 1 mA mode	Several low current user modes
application	Machine develop. setting optimiz. beam measurem.	FELs gamma rays	Neutrons for ToF exper. (10 µA) Thomson backscattering (10 Hz) positrons (10 … 100 µA) cell irradiation (pulse train of def. dose)
pulsing	macropulse 0.1 … 20 ms, 25 … 1 Hz	CW	CW or macropulses, reduced micro pulse rate
additional monitoring	Cathode current < 10 µA		Cathode current target & apperture currents
limitation	insertion devices (screens, EOS …)	beam loss near undulators	User equipment (heat load) detector count rate, background

Possible electron beam loss at the ELBE accelerator needs systems for

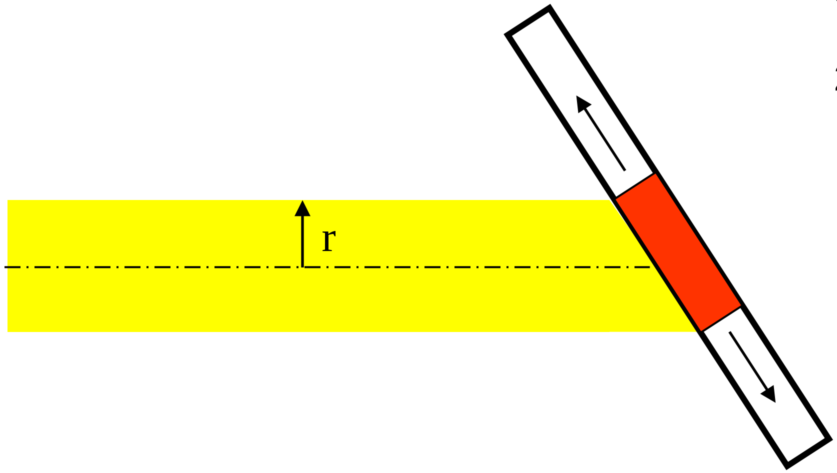
- Personal radiation protection
  permission of 1% beam loss @ 1 mA (10 µA)

- **Machine protection**
  direct damage from the electron beam
  long term radiation damage
  damage in high power RF system

- Background minimization for experiments
  setting optimization by operator

Damage due to energy deposition

1.) long time partial beam loss
(halo, dissp. section)
2.) sudden total beam loss



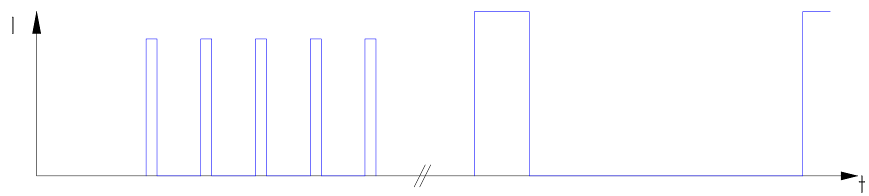
$$T = T_c e^{-\lambda t}$$

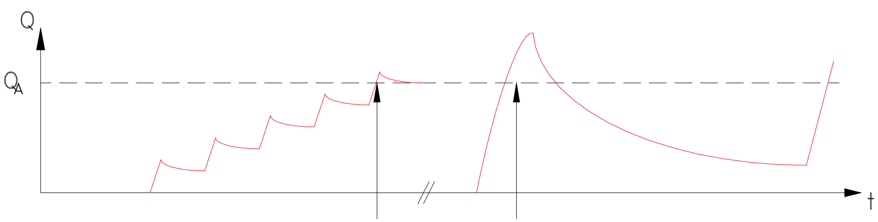
$$\frac{dT}{dt} = \frac{S_c}{C} I_e(t) - \lambda (T - T_{RT})$$

$$1 \cdot 10^9 \, KA^{-1} s^{-1}$$ **1 ms**

$$\tau = \frac{1}{\lambda} = \frac{I_{max}}{I_c} 1ms = 1s$$

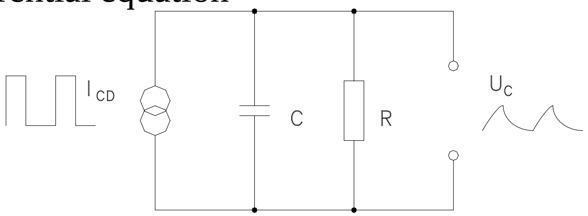
1 µA





beam switch-off

Integration circuit has a similar differential equation

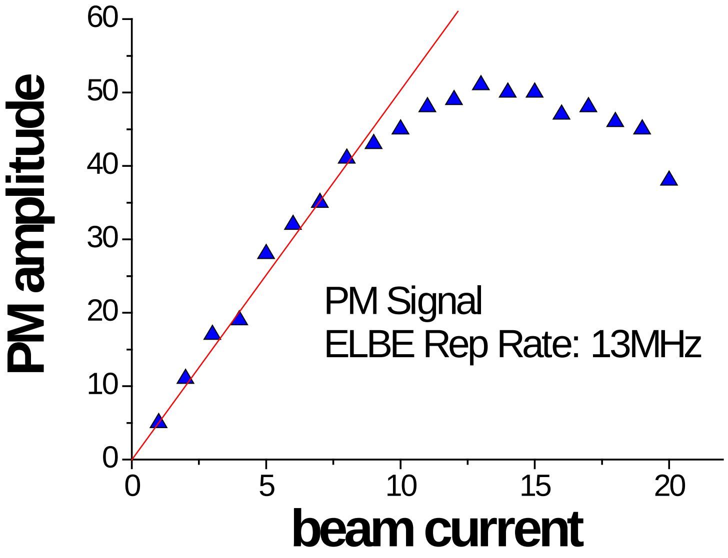


one device with one threshold for both cases

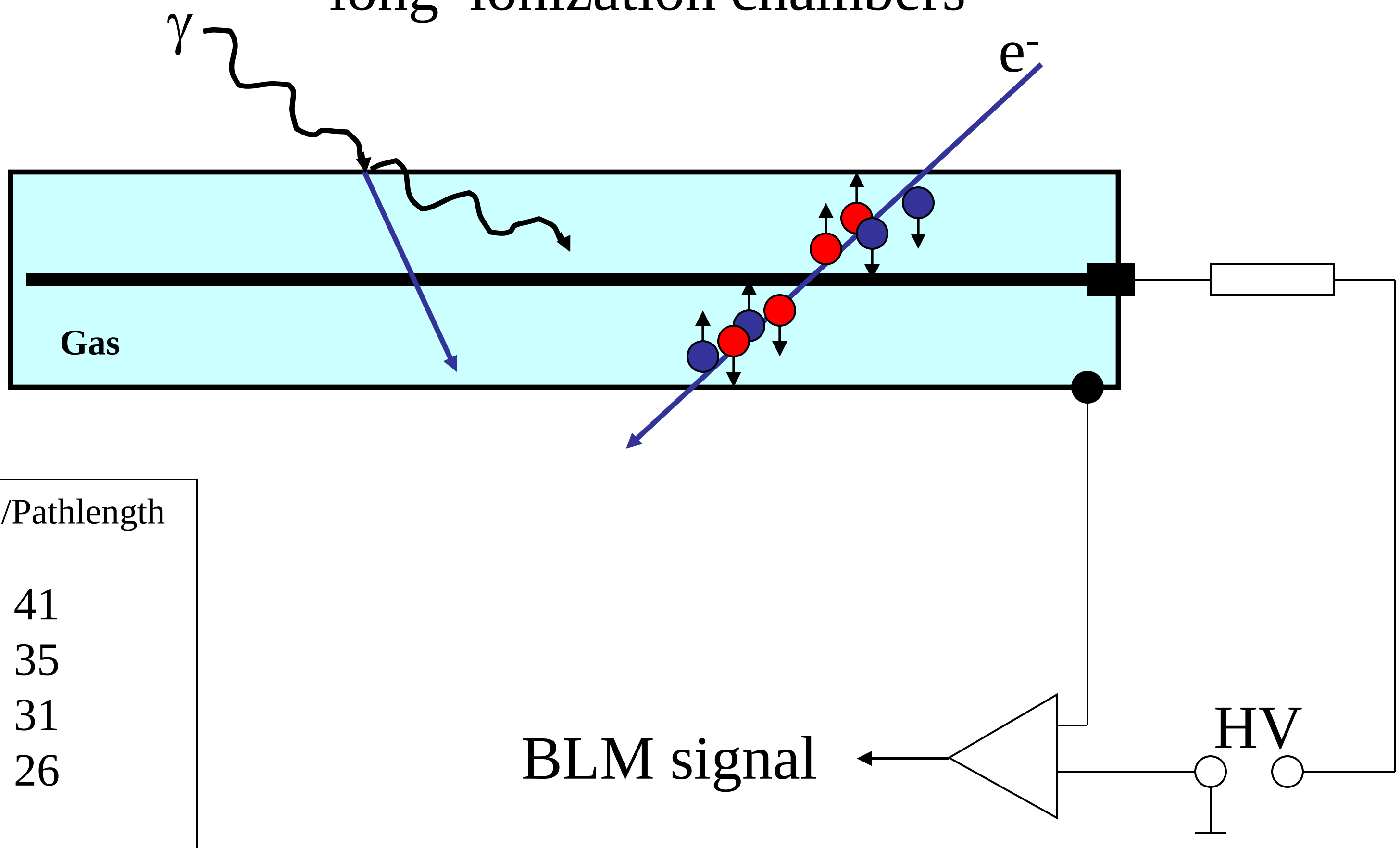
comparison of tested monitors (2002)

	Compton detector	Photomultiplier	Coaxial cable ionization chamber
sensitivity **dynamic range**	~ 1 μA > 100 dB	<< 1 μA ~ 40 dB (13 MHz) 260 MHz ?	~ 0,3 μA >100 dB
timing	T_{rise} ~ 2 ms	T_{rise} ~ 1 ns	T_{rise} ~ 0,6 ms
complete beamline monitoring	NO ! yes, if 3 devices/10 m wall openings?	NO ! yes, if 3 devices/10 m wall openings?	YES!
local resolution	according to detector distribution	according to detector distribution	segmentation until physical resolution ~ 0,5m
expenses	cheap (25 €/piece + cable)	expensive !! (600 €/piece + cable)	cheap, 23 €/m + cable
references	S-Dalinac	Cebaf	SLAC

Main disadvantage of photomultipliers:
saturation effect at high current beam losses



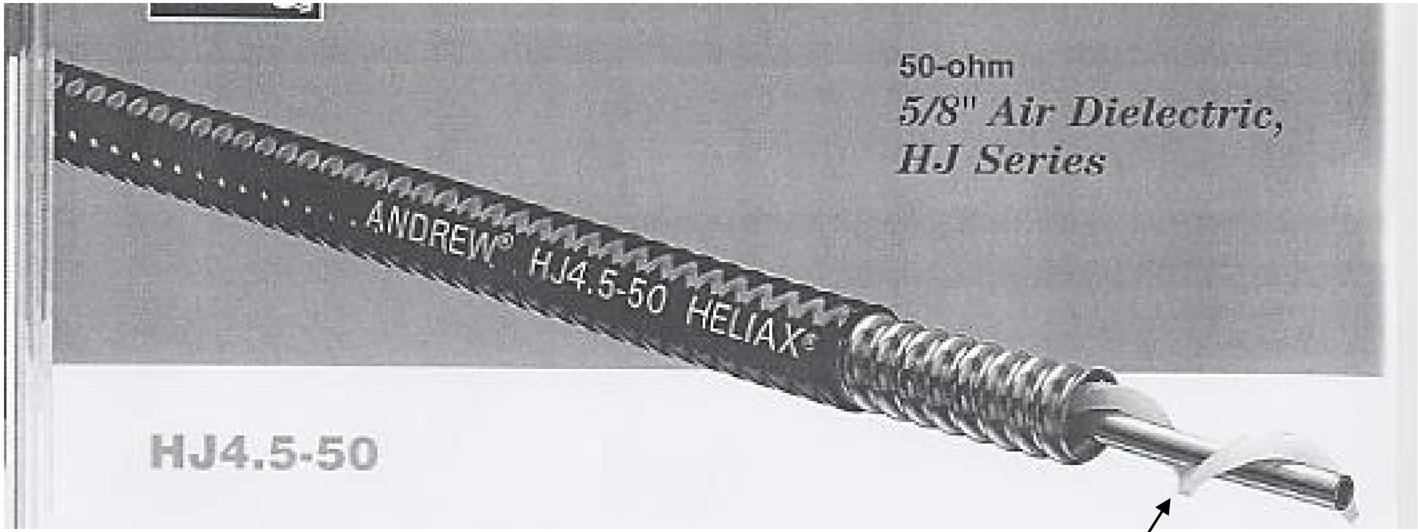
long ionization chambers



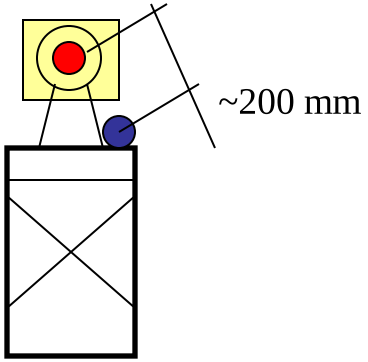
Gas	Ions/Pathlength
He	41
N_2	35
O_2	31
Ar	26

→ Air ! (N_2)

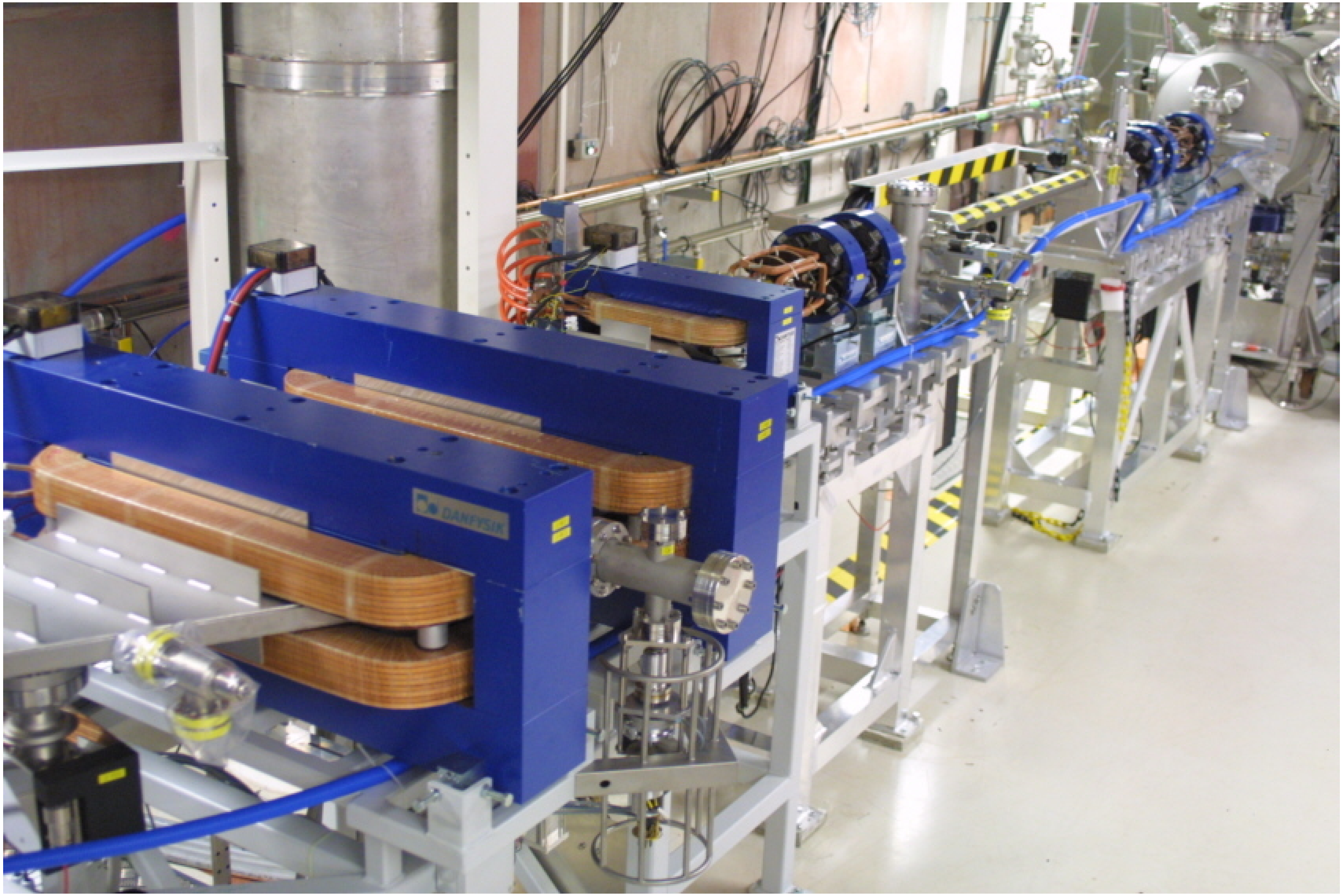
Heliax radio frequency cable



Spacer



Beam Loss Monitors at ELBE



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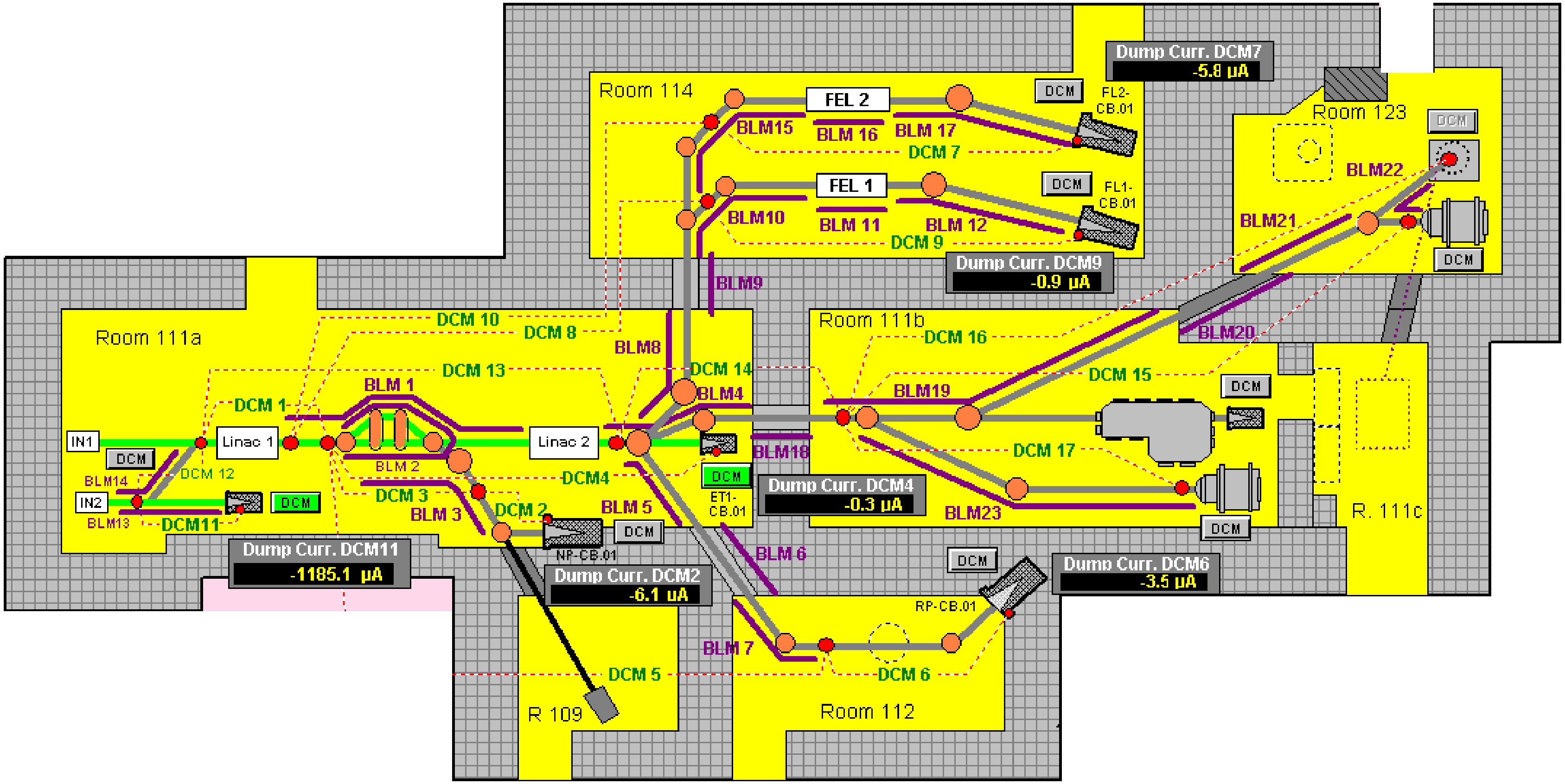
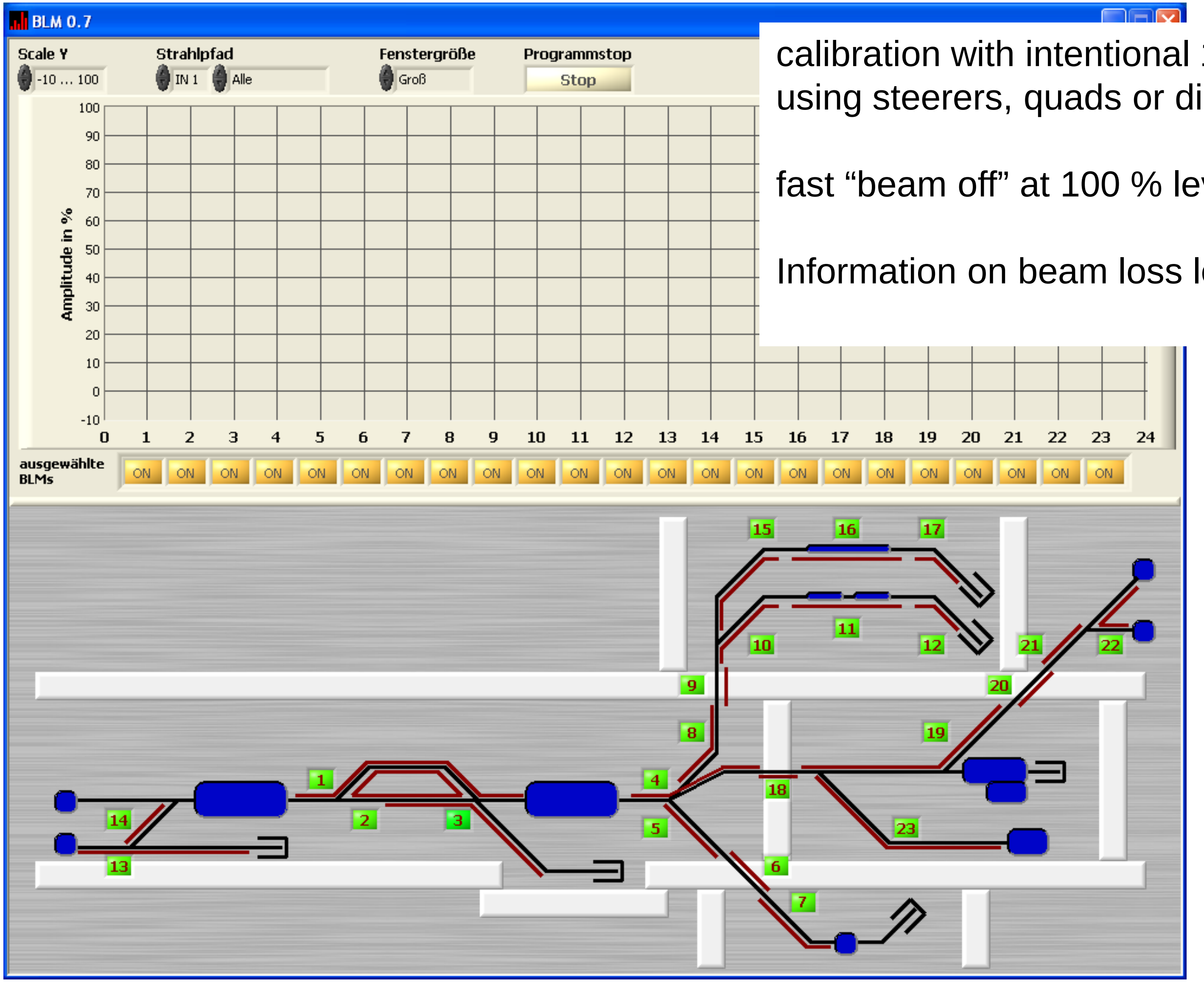


23 BLM cables used at ELBE (2011)

typical length is 3 – 5 m

fast interlock, ~2 ms

Beam Loss Monitors at ELBE

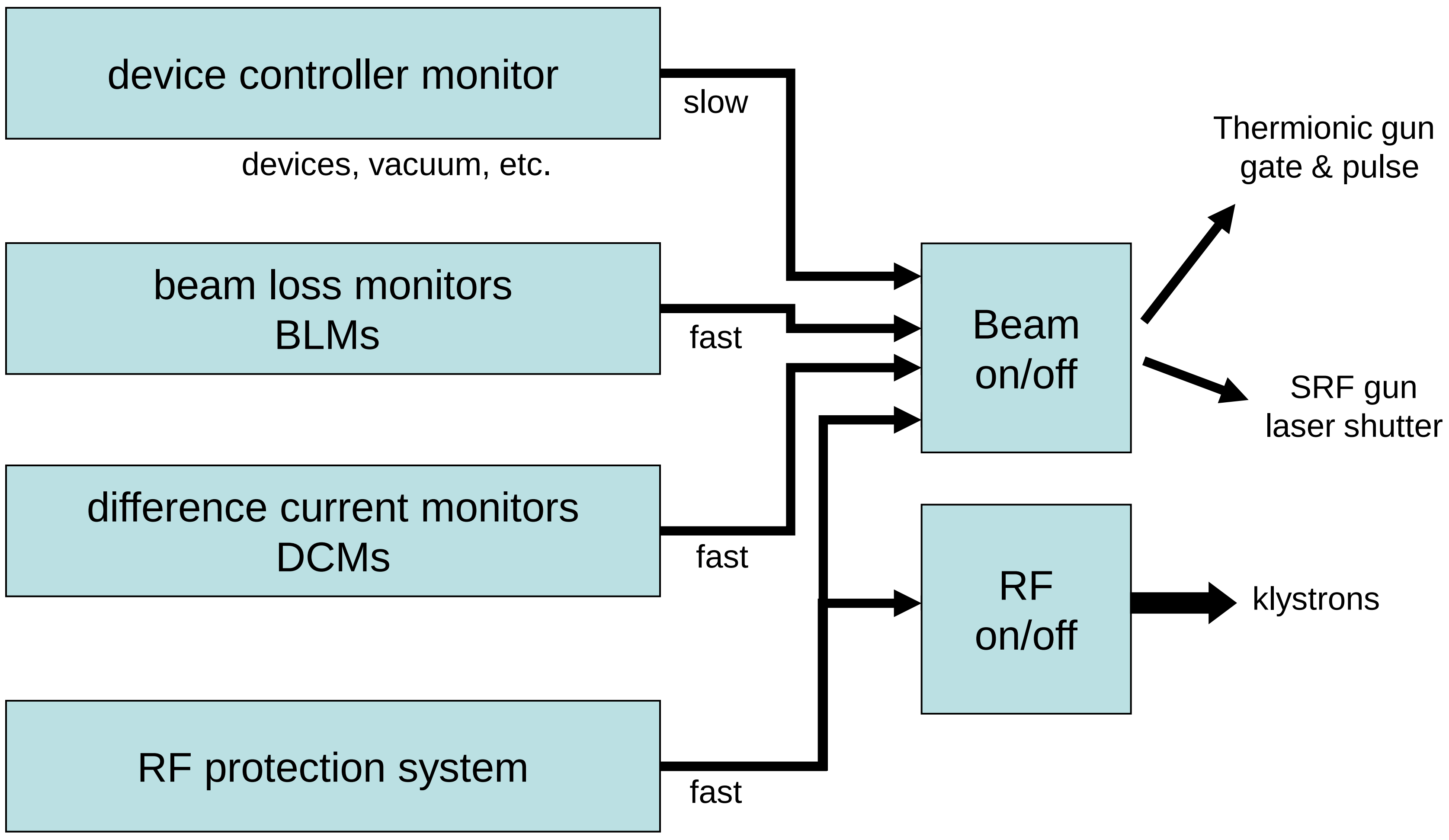


calibration with intentional 10 µA beam loss using steerers, quads or dipoles

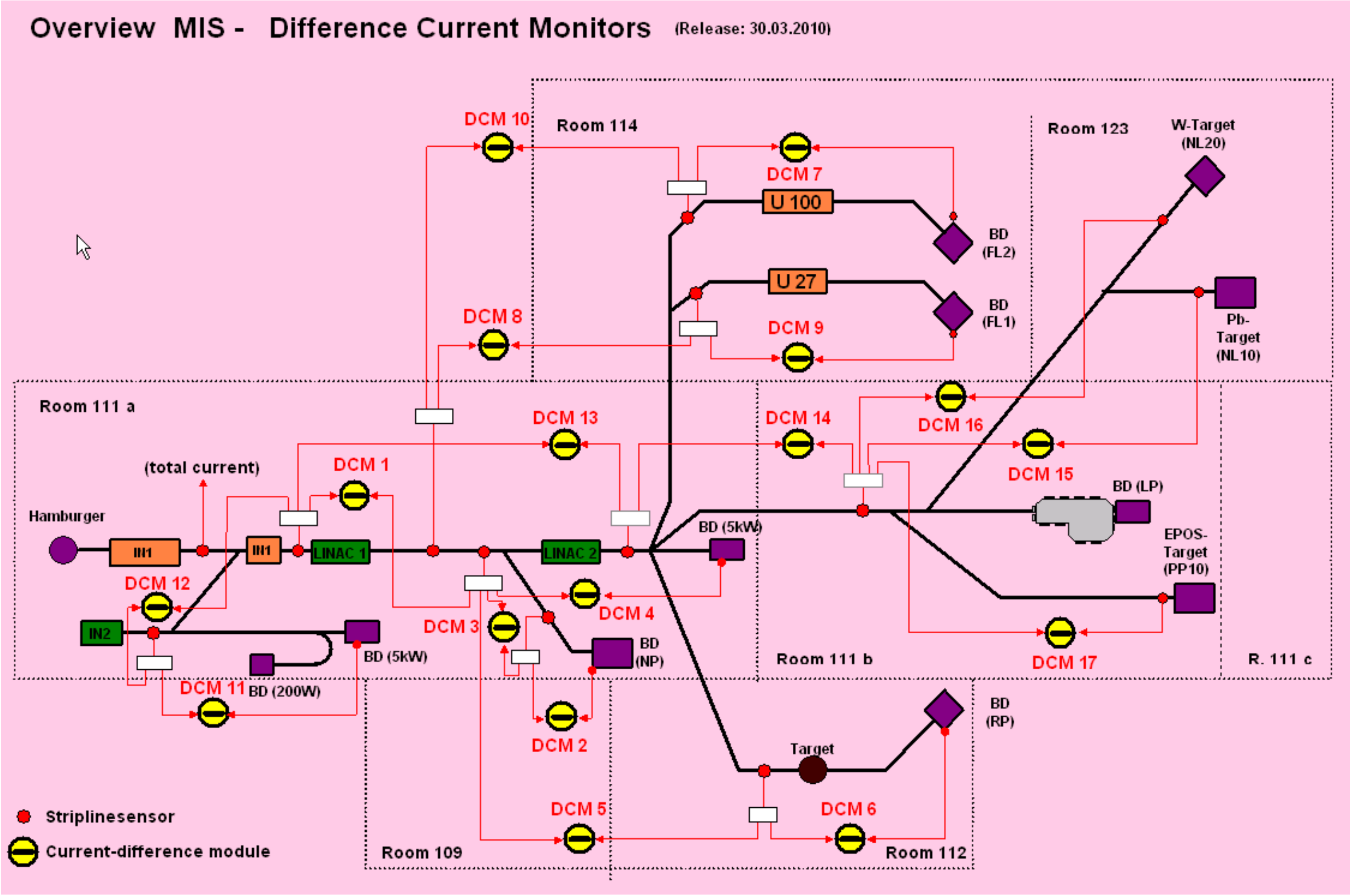
fast “beam off” at 100 % level

Information on beam loss level for operators

Machine Protection System

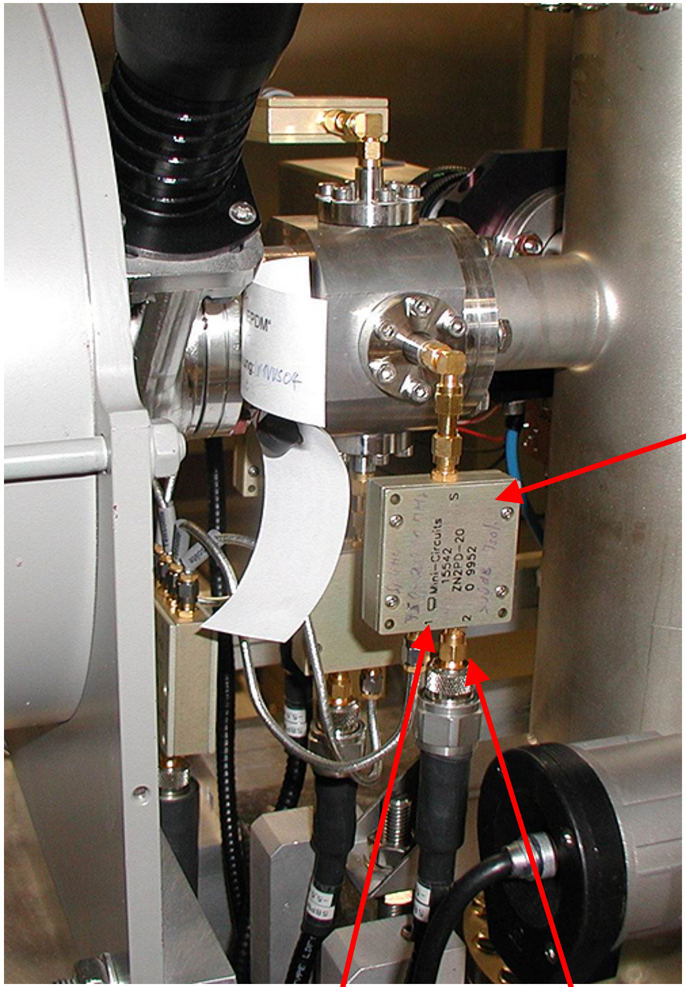


Machine Protection System



Machine Protection System

$\lambda/4$ stripline detector



signal splitter ZN2PD-20 mini-circuits

co-use: DCM and BPM

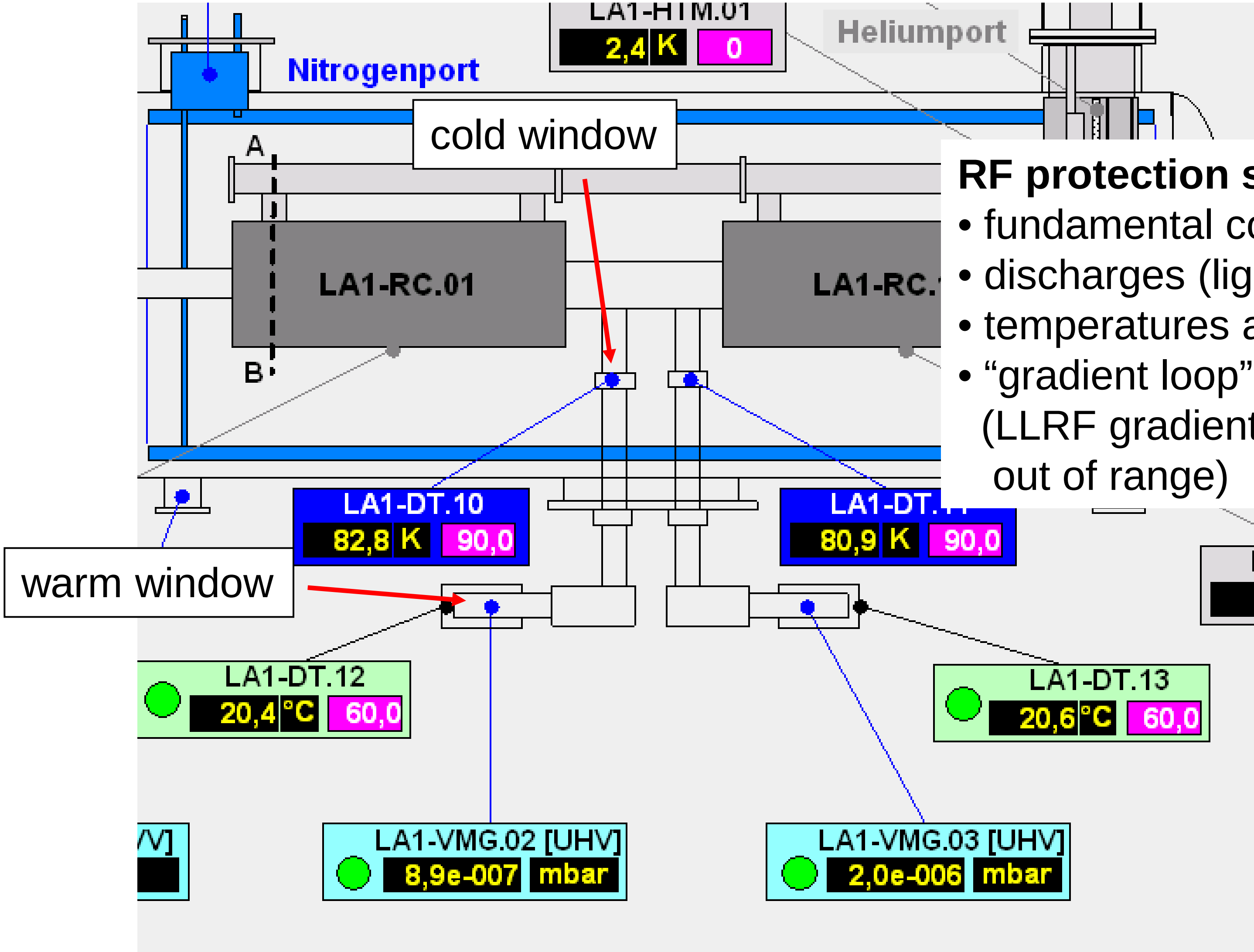
Differential Current Measurement (DCM)

if difference is larger then set here → beam is shut off

signal proportional to beam current from position Z

signal from position Z + somewhere downstream

Problems: -linearity over dynamic range
-performance below 13 MHz micropulses

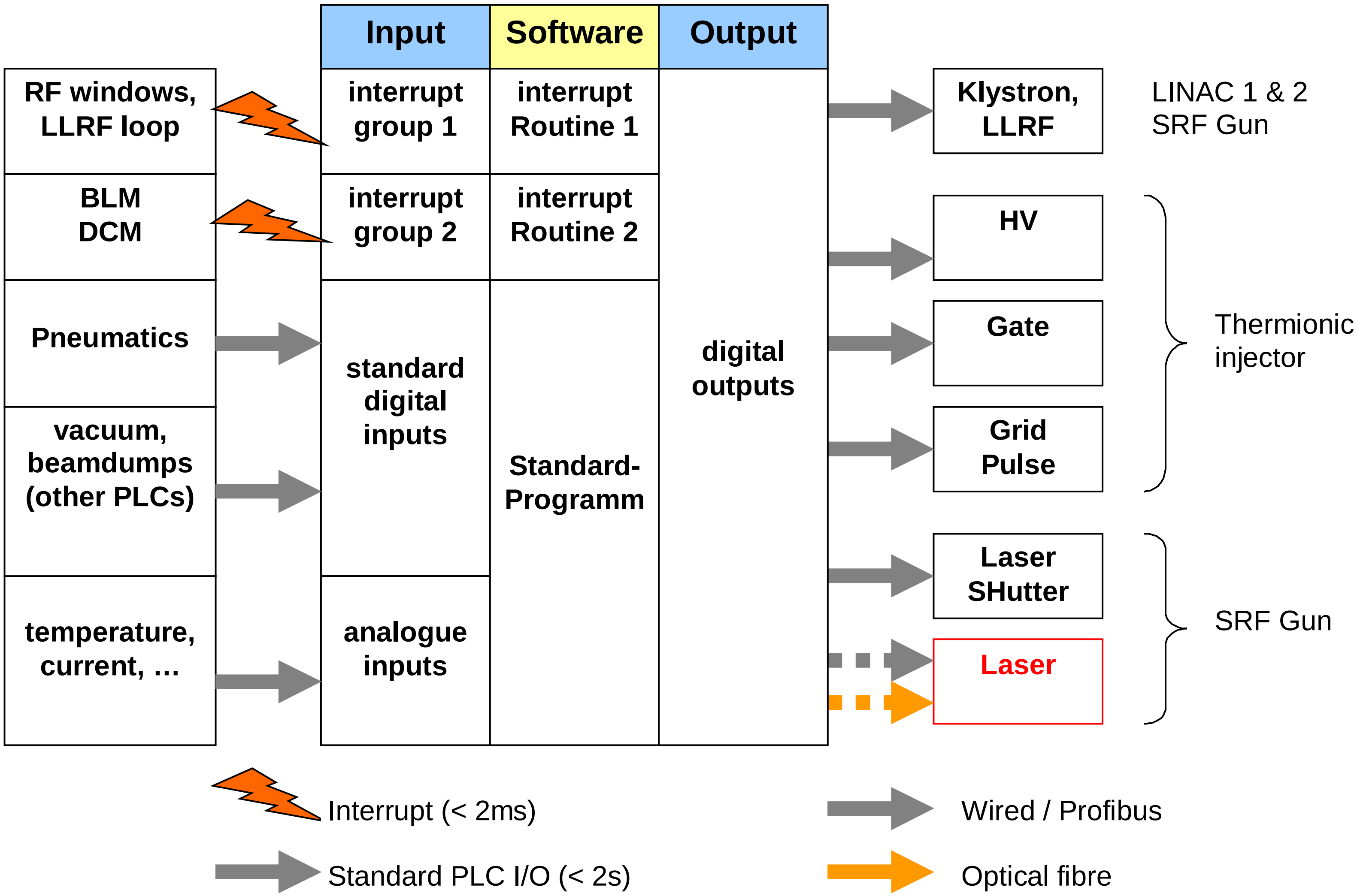


RF protection system

- fundamental coupler vacuum
- discharges (light sensors) and
- temperatures at coupler windows
- "gradient loop" error (LLRF gradient loop control signal out of range)

Machine Protection System

SIMATIC Industrial Automation System



Since installation of the redundant beam loss monitor (BLM) & different current monitor (DCM) system ELBE has been without serious damage due device or operator failures.

But high radiation level due to CW operation:

- radiation from field emission in the SC cavities
- beam losses (halo, energy jitter & drift) in the dipole magnets
- settings are not perfect and unstable (RF phase drifts)
- beam alignment and setting optimization with high current (beam loss in OTR screens, need more sensitive cameras)
- high dark current from the SC RF photo gun

Consequences:

- more frequent high-voltage breakdown at thermionic injector
- more frequent damage in gun electronics
- damage of vacuum valves, cables, cameras and plastic parts

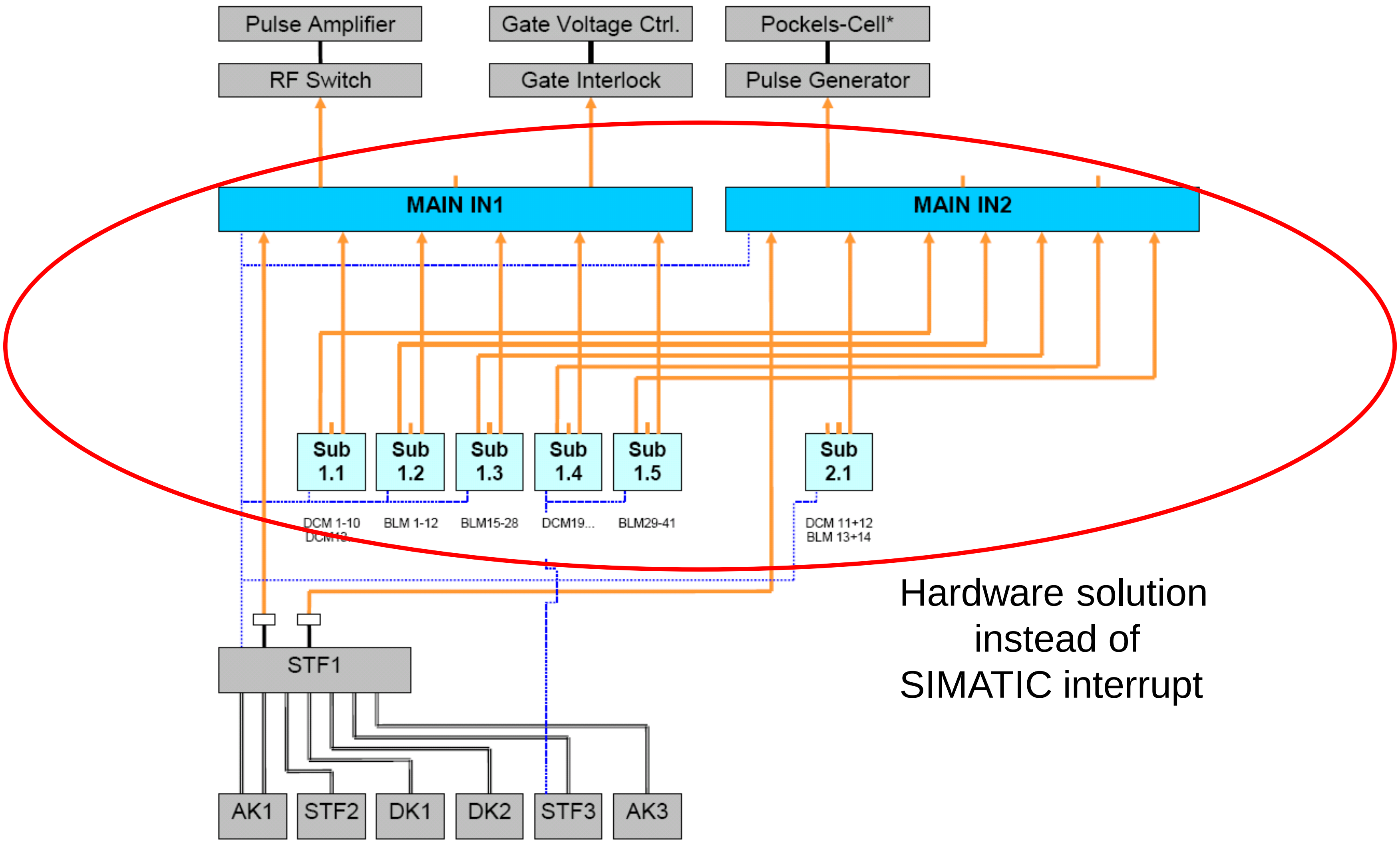
Present & Planned Upgrate

- Faster Response needed due to higher beam current: < 1 ms

- Improvement of the DCM electronics
  bunch charge 10 – 77 pC -> 10 – 1000 pC
  pulse frequency 13 MHz -> 125 kHz – 26 MHz

- More sensitive and improved local resolution of beam loss system for a better identification of sources and reduction of beam loss level.

Present & Planned Upgrate



Hardware solution
instead of
SIMATIC interrupt

Thank you for your attention

Thanks to my colleagues at ELBE and all collaborators.

The ELBE Crew visiting
the German Watch Museum Glashütte/Saxony
December 2010

The people who did the work:
M. Justus, U. Lehnert, P. Michel, R. Schurig, M. Hempel (HZDR/ELBE)
P. Evtushenko, K. Jordan (JLab)
A. Büchner, F. Herbrand, F. Gabriel, H. Langenhagen (HZDR/FWF)