PROFILE, CURRENT AND HALO MONITORS OF THE PROSCAN BEAM LINES

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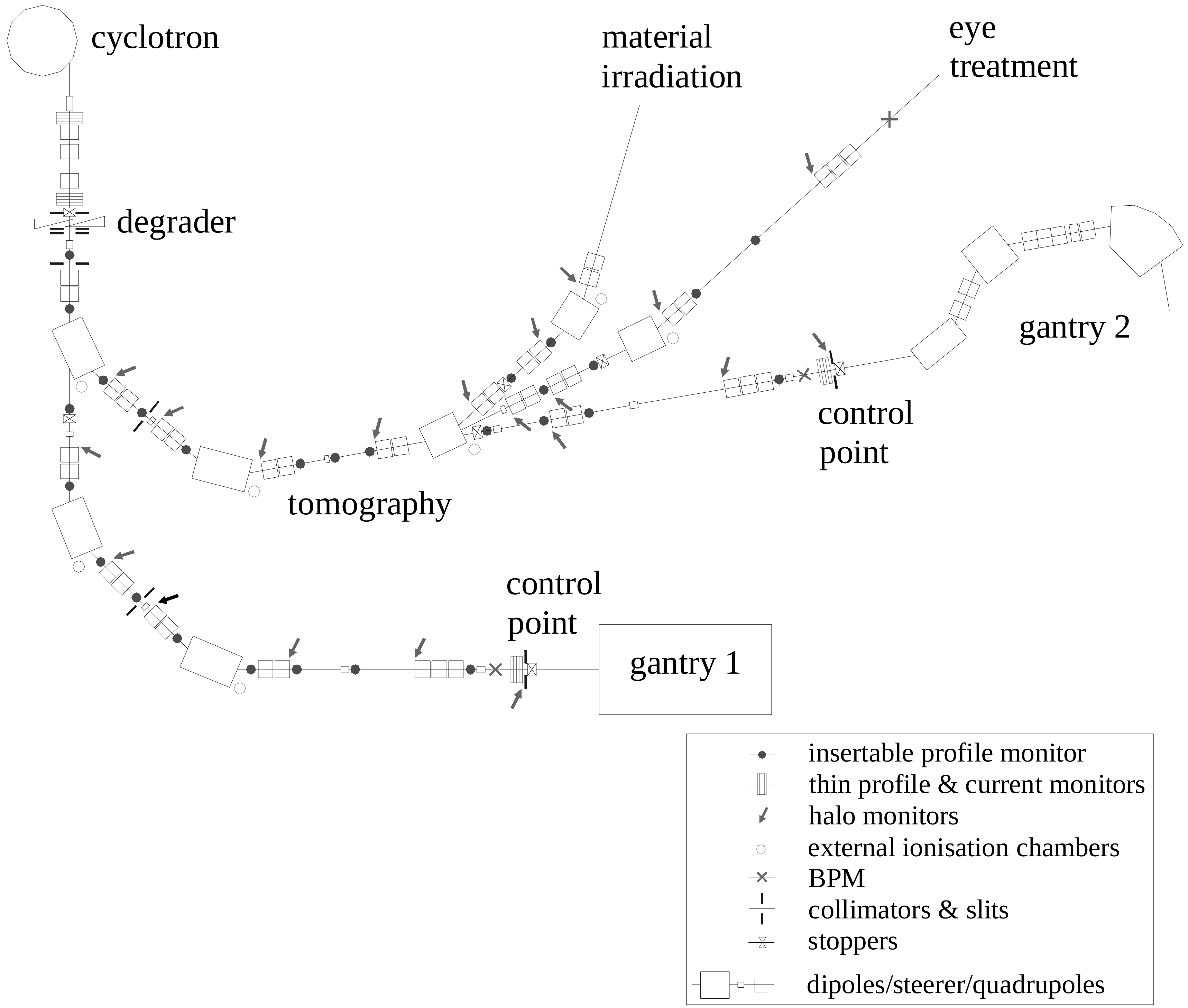
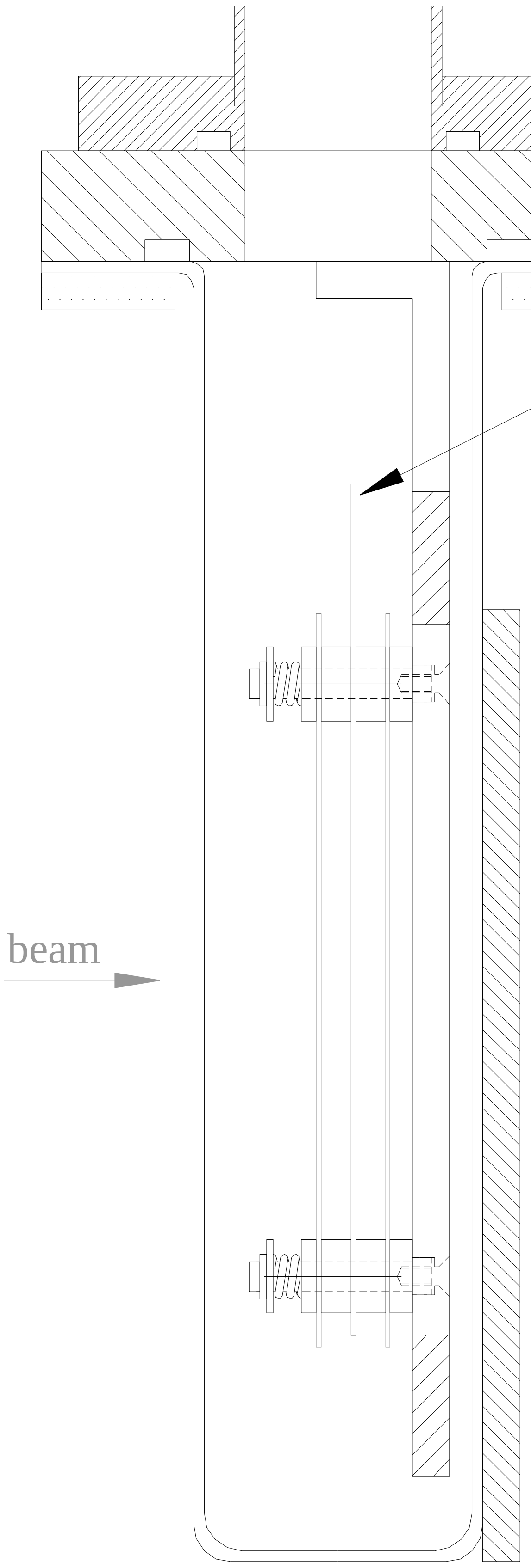
PROSCAN,

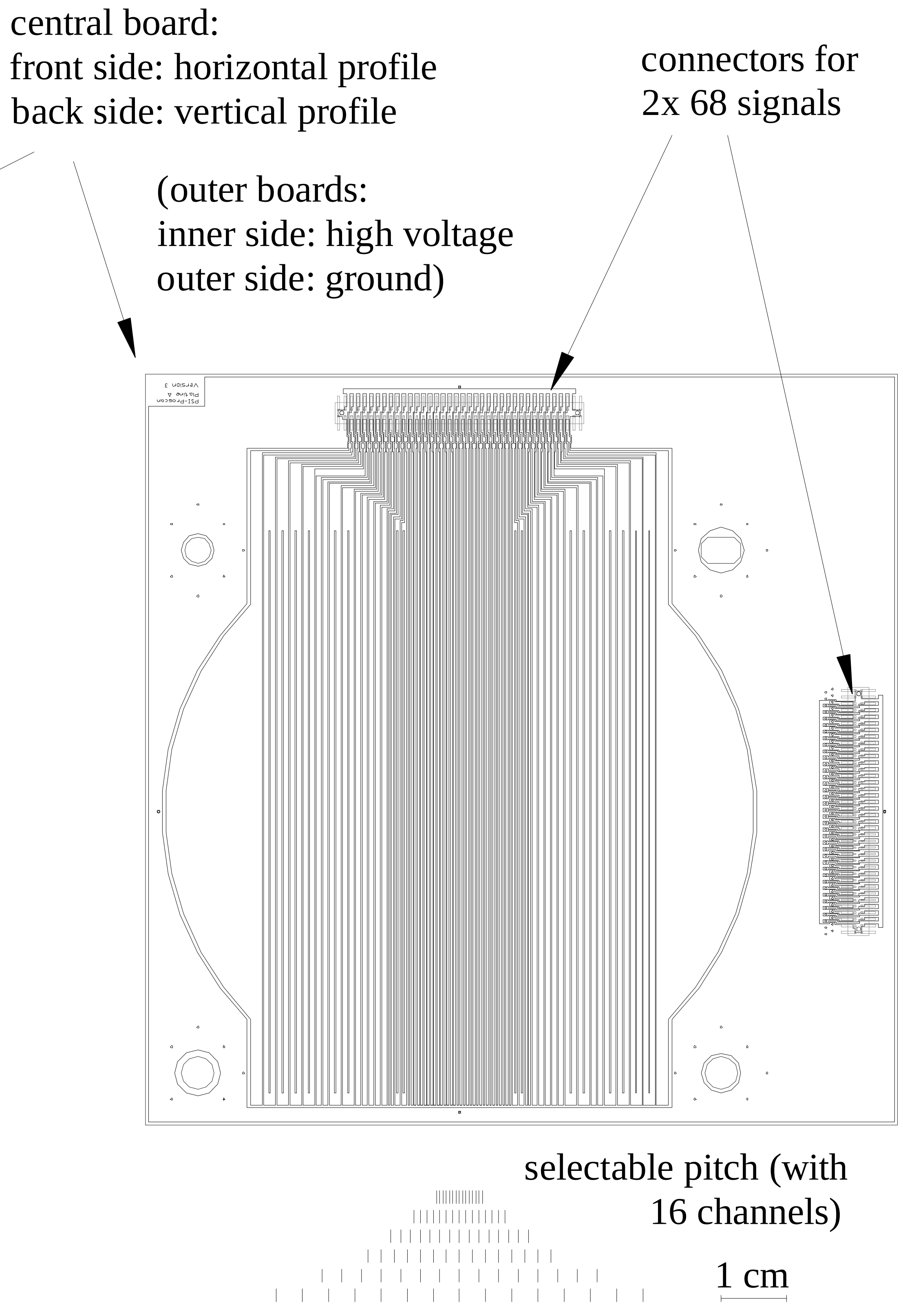
an extended medical facility using proton beams for the treatment of deep seated tumours and eye melanoma, is in preparation at PSI [1]. A 250 MeV proton beam of 1 to 500 nA will be extracted from the COMET cyclotron. After degradation to the range of 230 to 70 MeV it can be delivered (at a maximum current of 10 nA) into one of four areas: Two gantries, an eye treatment room and a material irradiation area. Fast changes of beam energy are foreseen for the spot-scanning treatment of deep-seated tumours in the new gantry 2. Several diagnostics will be used to control the beam parameters in different modes of operation. The first components will be taken into operation this year.



INSERTABLE THICK PROFILE MONITORS

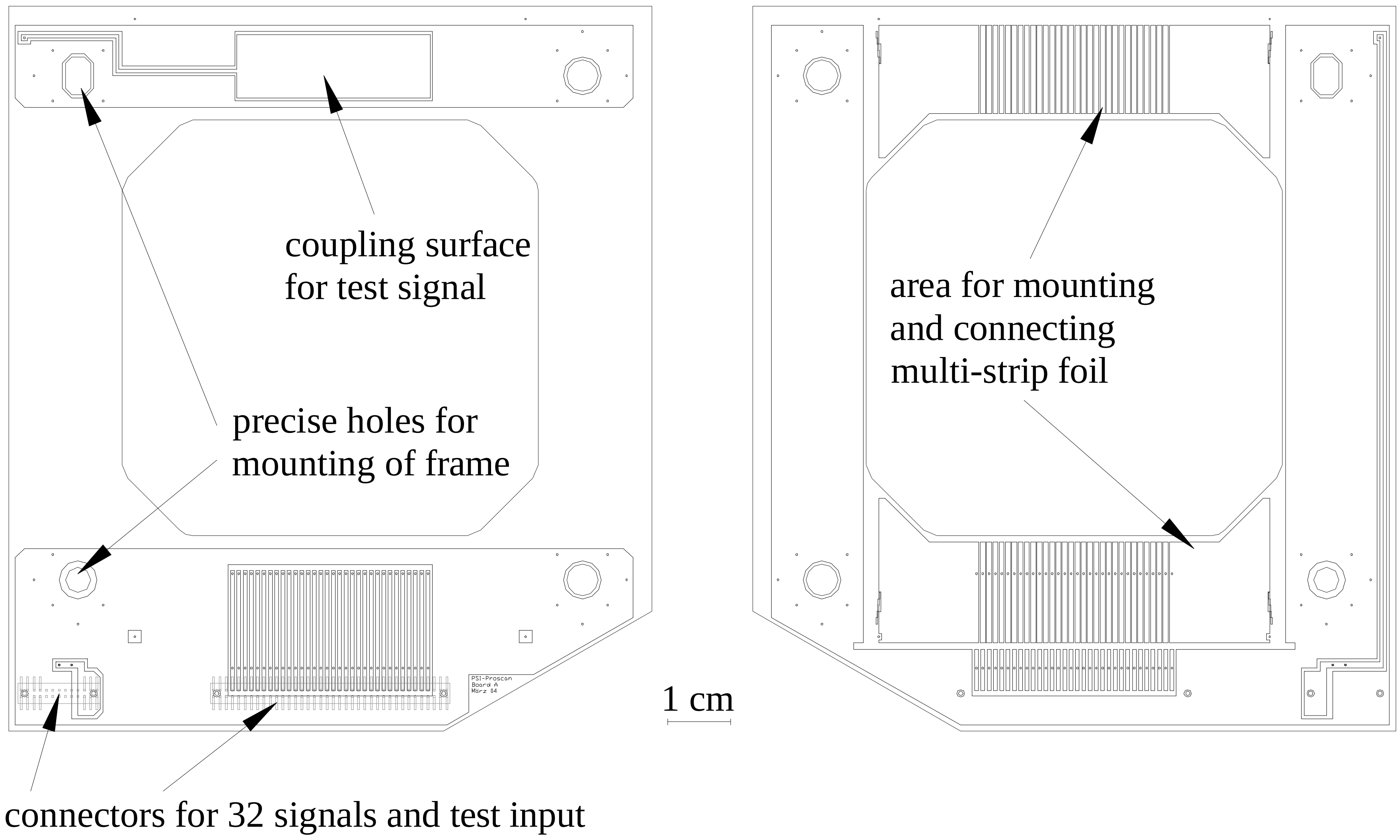
- Multi-Strip Ionisation Chambers at 27 locations
- chamber filled with ambient air and moved by pressured air actuator
- plane separation 4 mm, HV-bias +600 V
- 68 thick-film metallized strips (each plane) on 0.63 mm ceramic board
- read-out of 16 channels per plane (32 at few places for beam tomography)
- external grouping allows adaptation of strip pitch to expected range of beam profile width



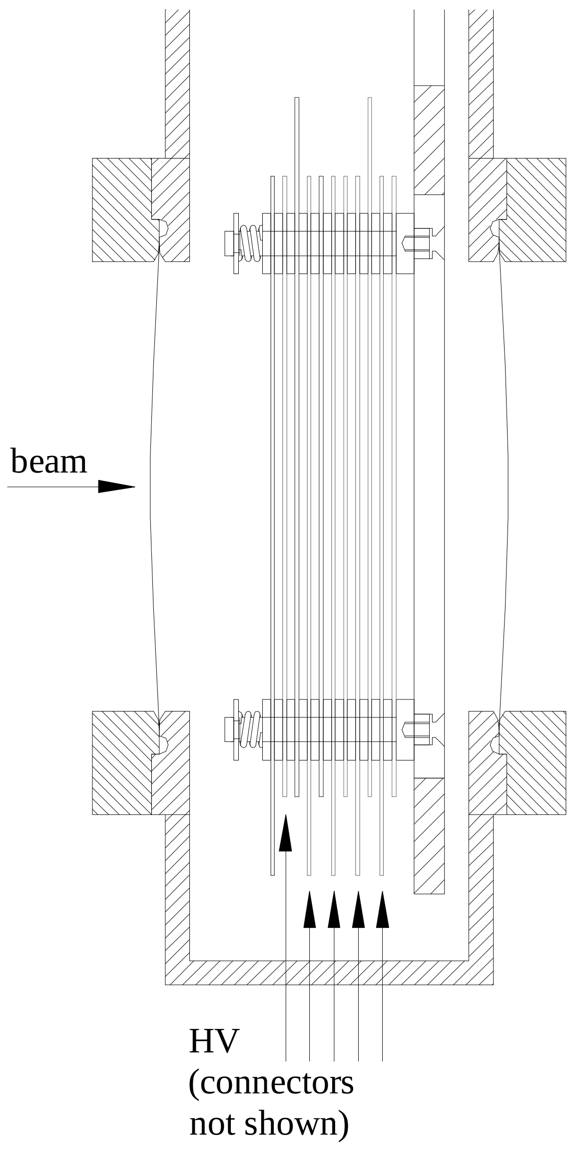


THIN PROFILE- AND CURRENT MONITORS

- 1 broader + 30 regular + 1 broader strip from 6 μm titanium foil
- as Multi-Strip Ionisation Chambers for low beam current density
- as Multi-Strip Secondary-Emission Monitor for higher beam current density
- at few locations, some placed permanently in the beam
- additional full planes for measurement of integral current
- etched strip pattern, pre-tensioned foil mounted/contacted to ceramic PCB:

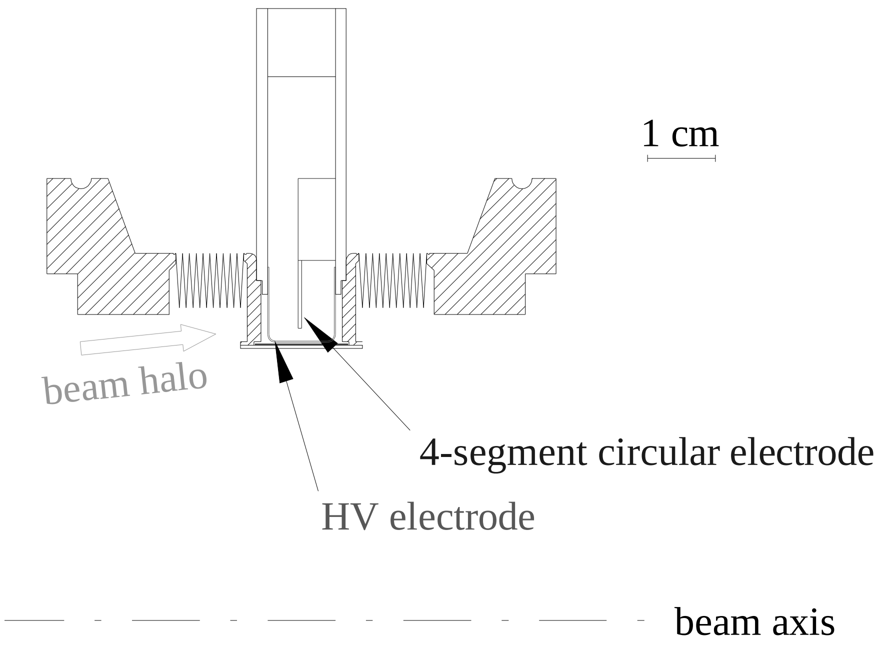


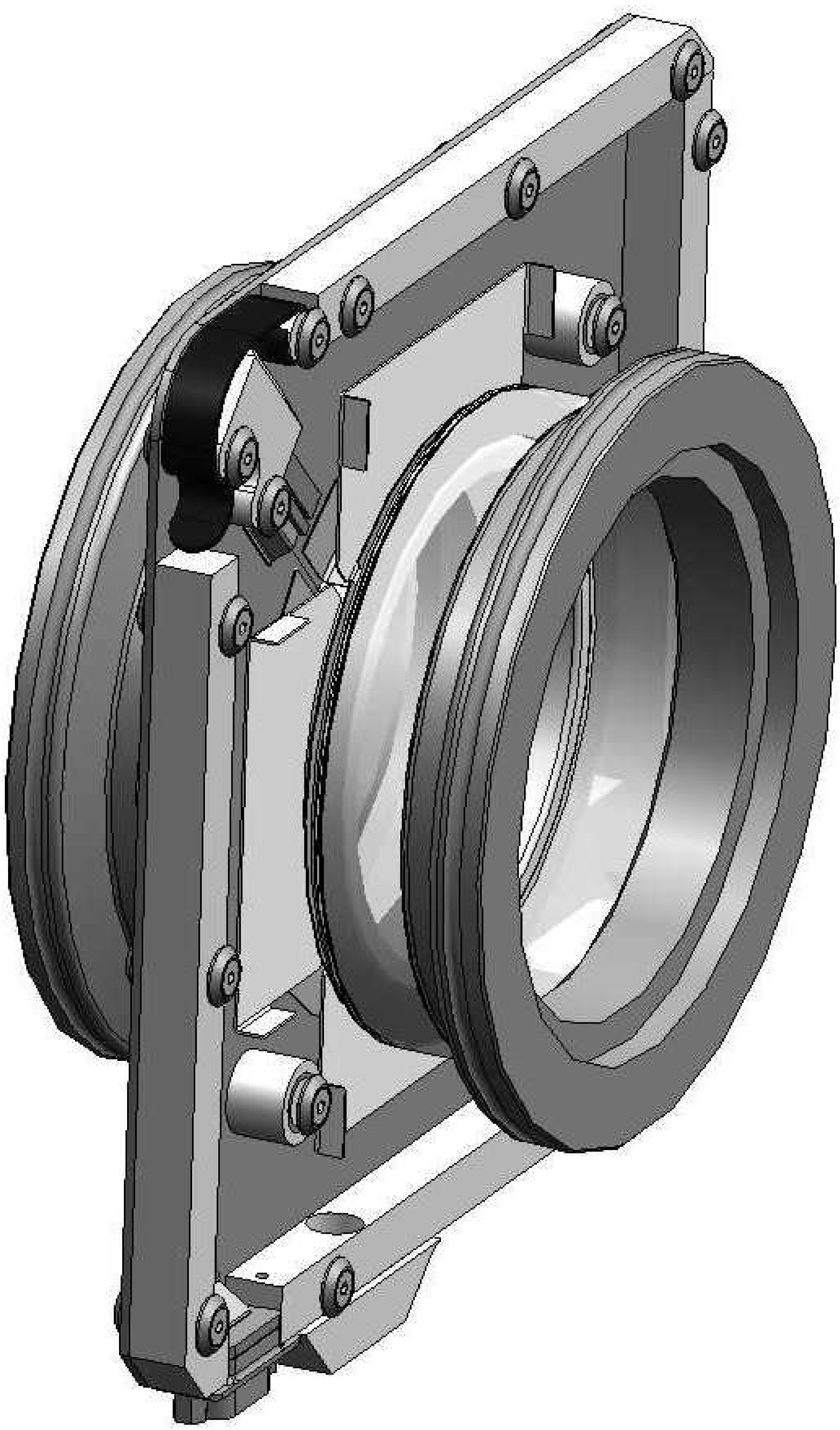
- plane separation 2 mm,
  HV-bias +1500 V for MSIC, IC
  counteracts recombination
  (up to a certain degree)
- windows 25 or 50 μm titanium foil
  clamped
- ratio “signal current/beam current” varies from
  48 to 113 for proton energies of 250 to 70 MeV
- charge collection time ~16 μs



HALO MONITORS/ EXT. IONIS. CHAMBERS

- "**halo-monitors**" = 4-segment ionisation chambers, which protrude circumferentially 5 mm into the beam pipe of 90 mm diameter
- placed adjacent to the quadrupole doublets and triplets
- should give enough signal to detect traversing beam current fractions of below 1 pA
- also gives an online control of the stability of the beam settings





(back plane removed)

- **external ionisation chambers** located behind the dipoles close to the beam pipe (air-filled)
- only losses close to a chamber generate enough signal for the electronics used

CABLES, SHIELDING, NOISE

Low signal currents require (at f << 300 kHz ⇔ $l_{cable} << \lambda/30$)

- omission of ground loops in signal cables!!
  internal shield and "ground" of amplifier is only grounded via the shield of the measurement-cable to ground of detector at beam line ("single point")
- signal cables with low microphonic noise!!
- signal cables with good electrical shield
- low noise input via HV-electrode → filter
- own support for diagnostic cables, separate from water pipes/magnet cables/AC cables/motor cables
- second shield enclosing measurement- and HV-cables from one diagnostic head (copper braid)
- magnetic shield?
- balanced twisted pair cable?
- not individual shielding of each wire
  (cross talk between wires is already negligible due to the very low voltage burden of the electronics used)

Several cables have been tested for their susceptibility to microphonic noise and the effectiveness of the cable shield against external AC electrical fields. Differences of several orders of magnitude were found in both aspects.

We choose two cables of nearly equal performance

- for single signals: "low noise" coaxial cable G03130HT (semiconductor layer between inner isolator and dense copper braid)
- for 32 signals: a 40 wire twisted-pair cable (Huber-&Suhner No. 12 566 226) with a shield from plastic coated aluminium tape and a copper braid enclosing the whole bundle.
  (32 wires carry the signals. The return path is provided by the cable shield and the residual wires, which as well could have been left floating. No advantage is taken from the twisted pair property).

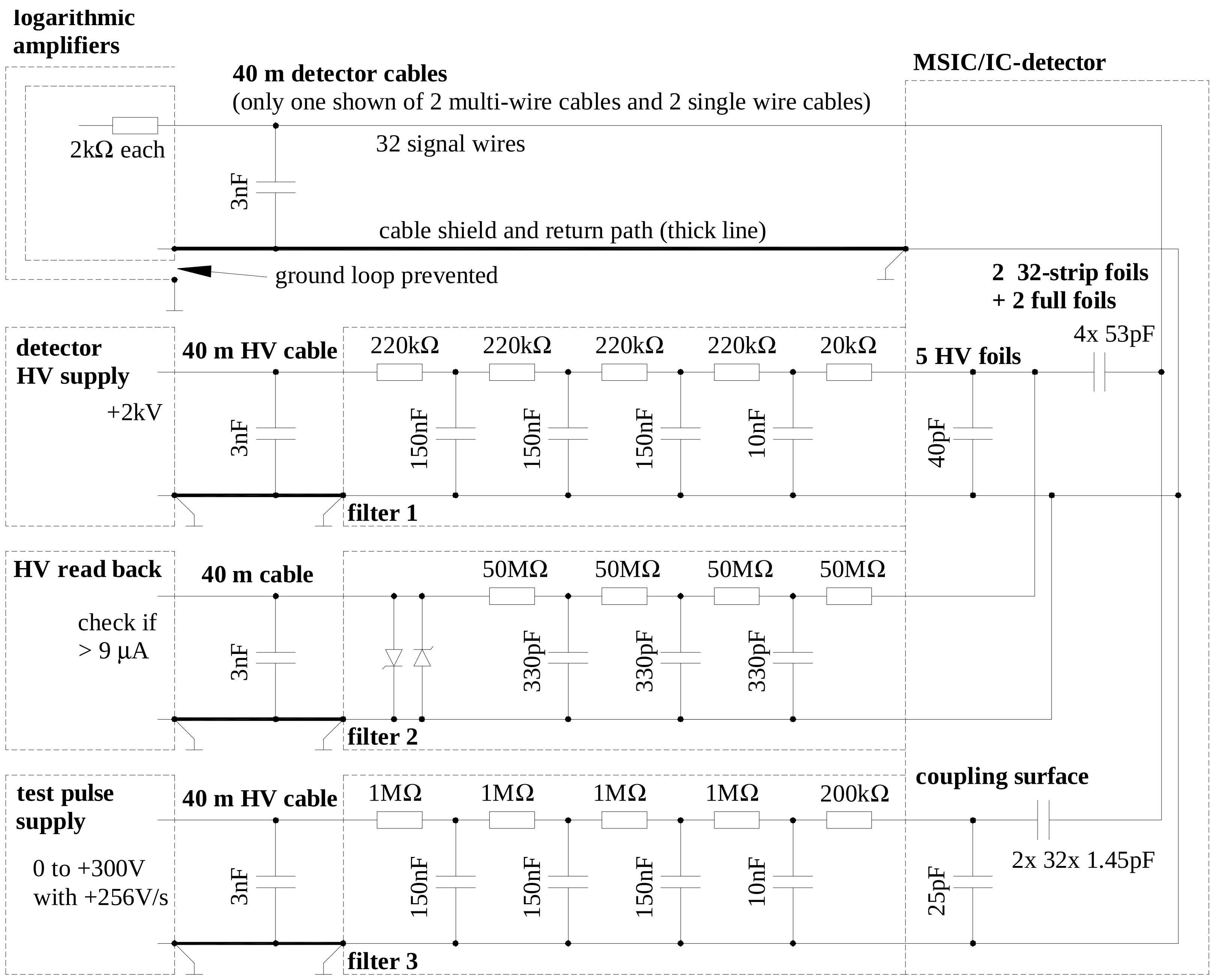
ELECTRONICS

- signal currents of 0.1 pA to 25 μA (per electrode)
- multi-channel logarithmic-amplifier modules
  current range of 20 pA to >200 μA
  up to 4096 beam profiles with minimum time step 1 ms
  trigger input for simultaneous operation of several modules
  algorithms for data evaluation and the generation of interlocks
  outside of shielding for service/prevention of radiation damage

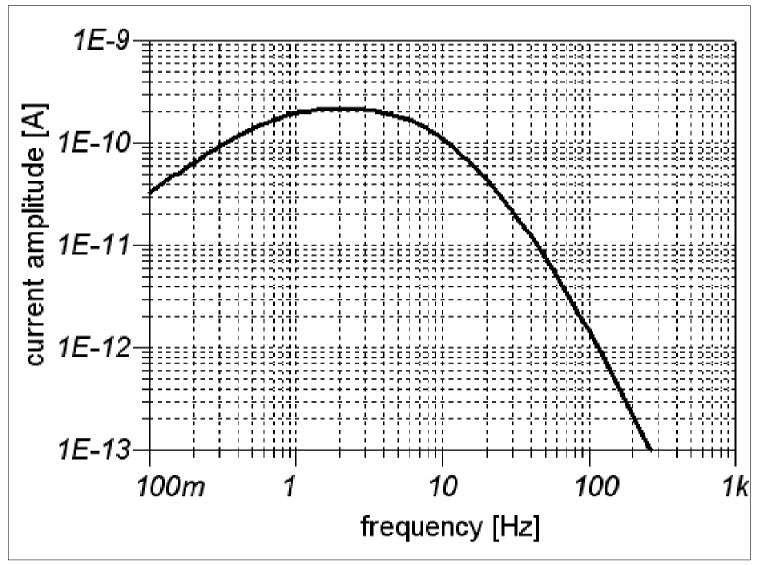
see Poster

FILTERS, NOISE

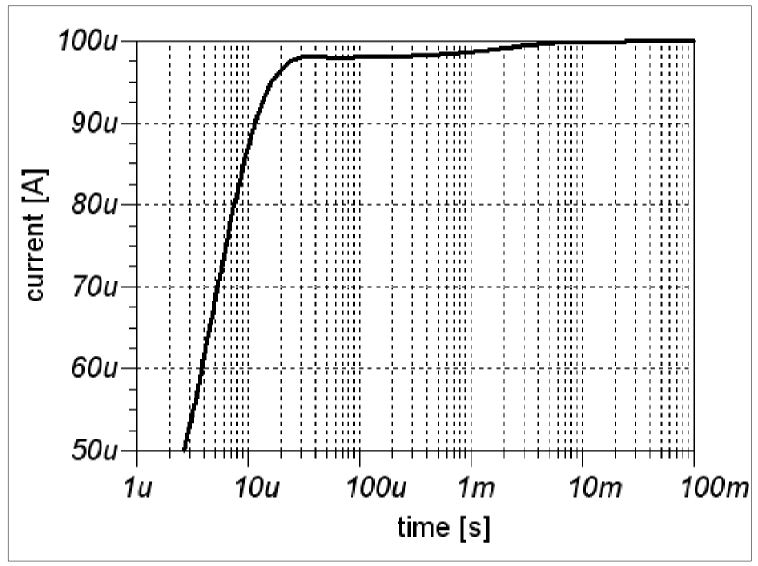
- filters are needed to prevent noise input via high-voltage electrodes (to <1 pA for f ≥ 50 Hz)
- noise is coupled to high-voltage cables by ground loops (100 mV assumed as worst case) and from HV supply
- other requirements to filter: no excessive voltage drop with full signal (~10%)
  only moderate decrease of detector speed (90% of final value in 10μs)
- noise coupling to the HV read-back output and test-pulse input is less critical than to HV input



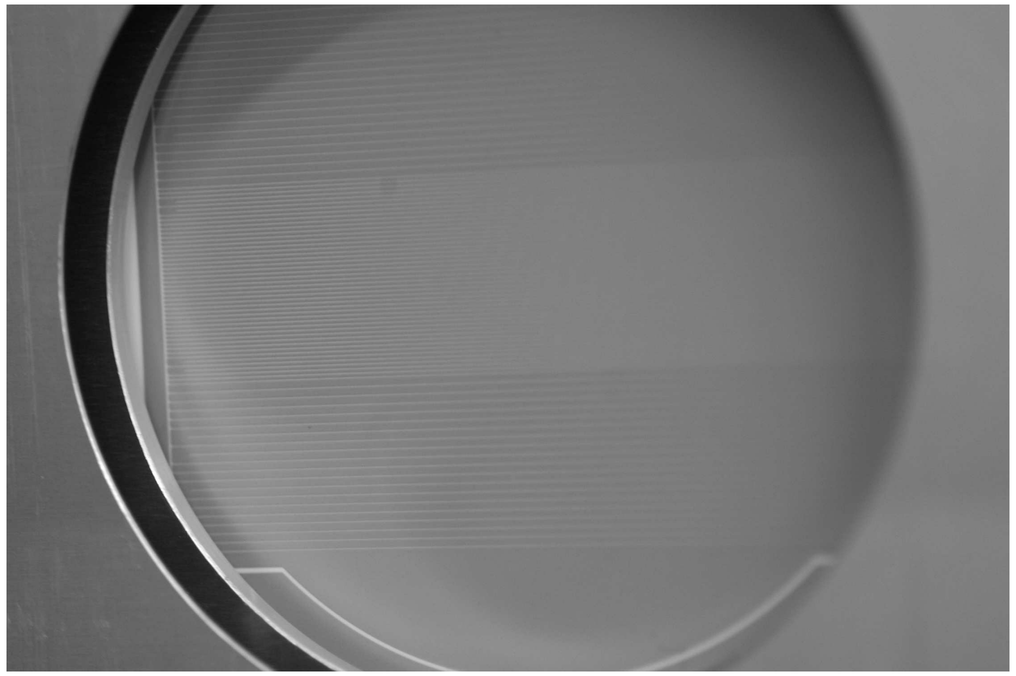
current at read out electronics due to a ripple of 1 V amplitude at entrance of filter 1



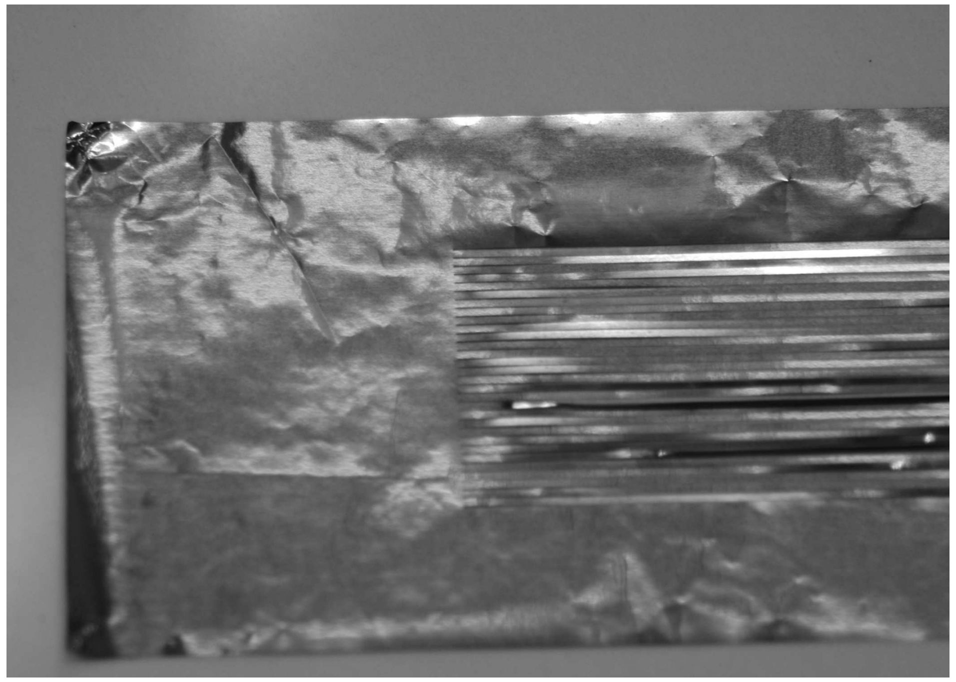
current at read out electronics due to a beam current step



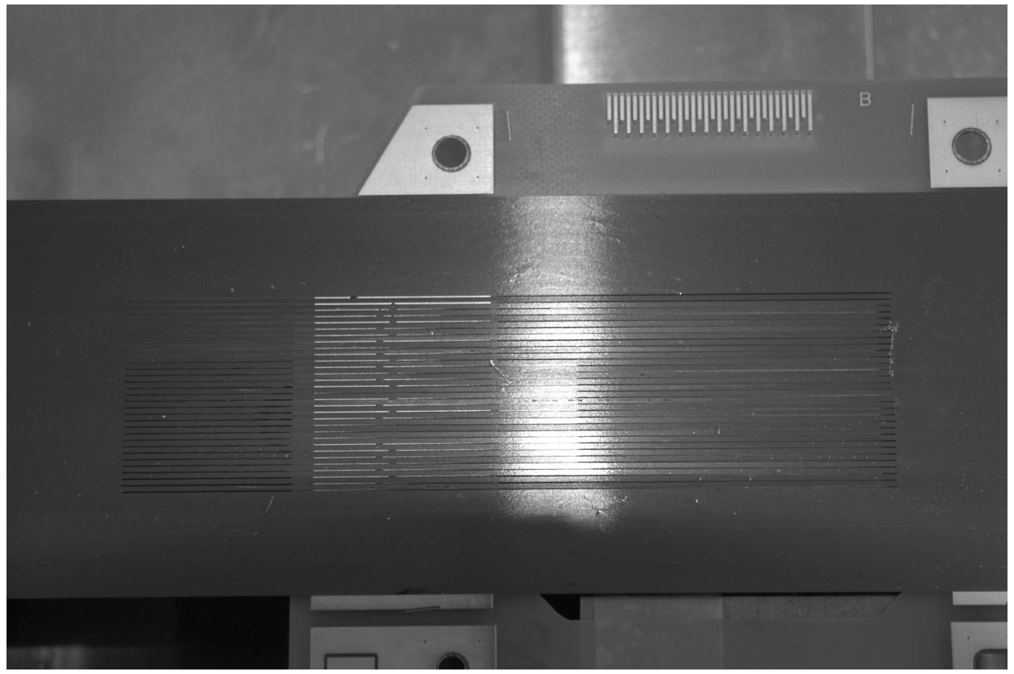
Detector and cable capacitances are roughly estimated.



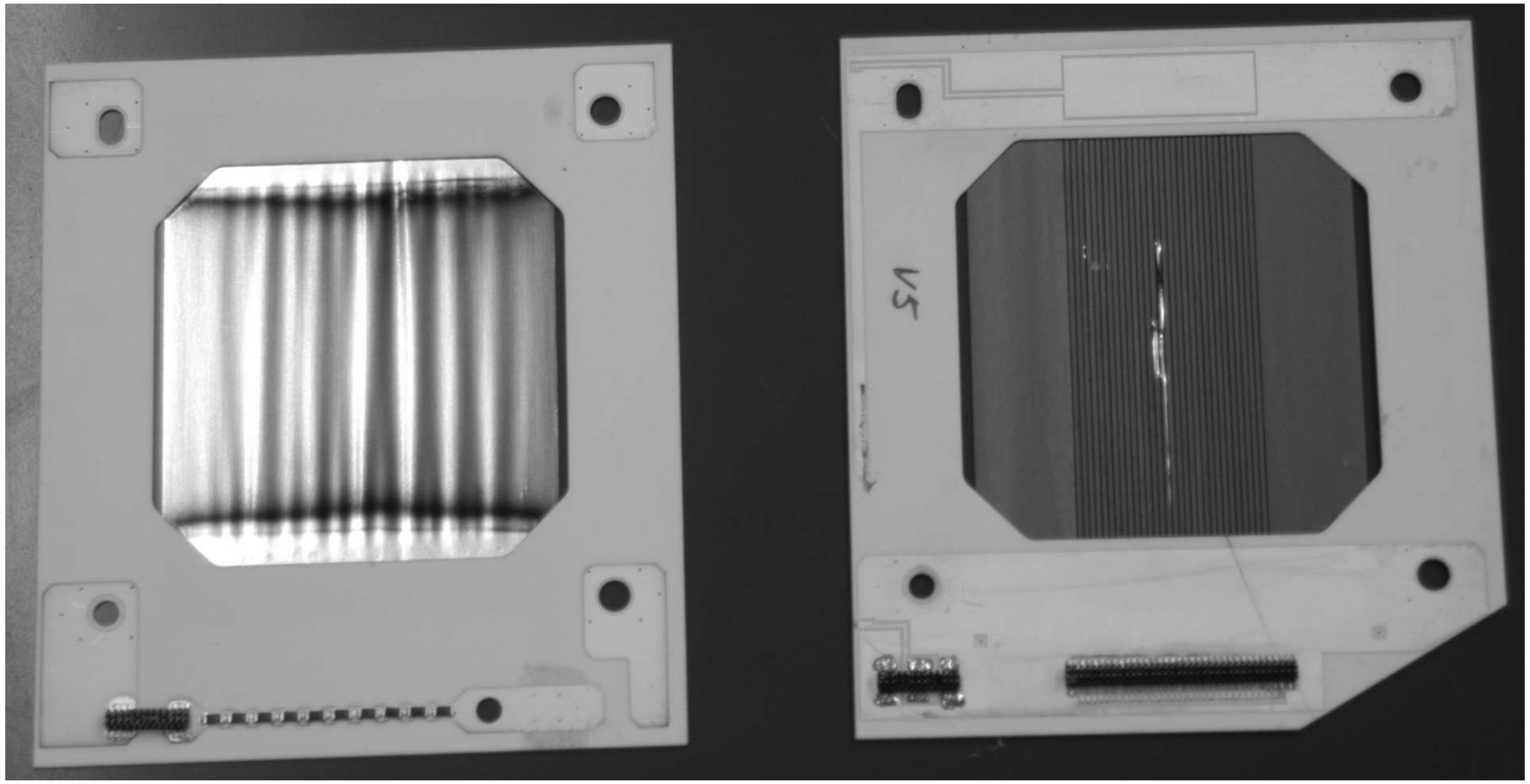
thick MSIC, prototype



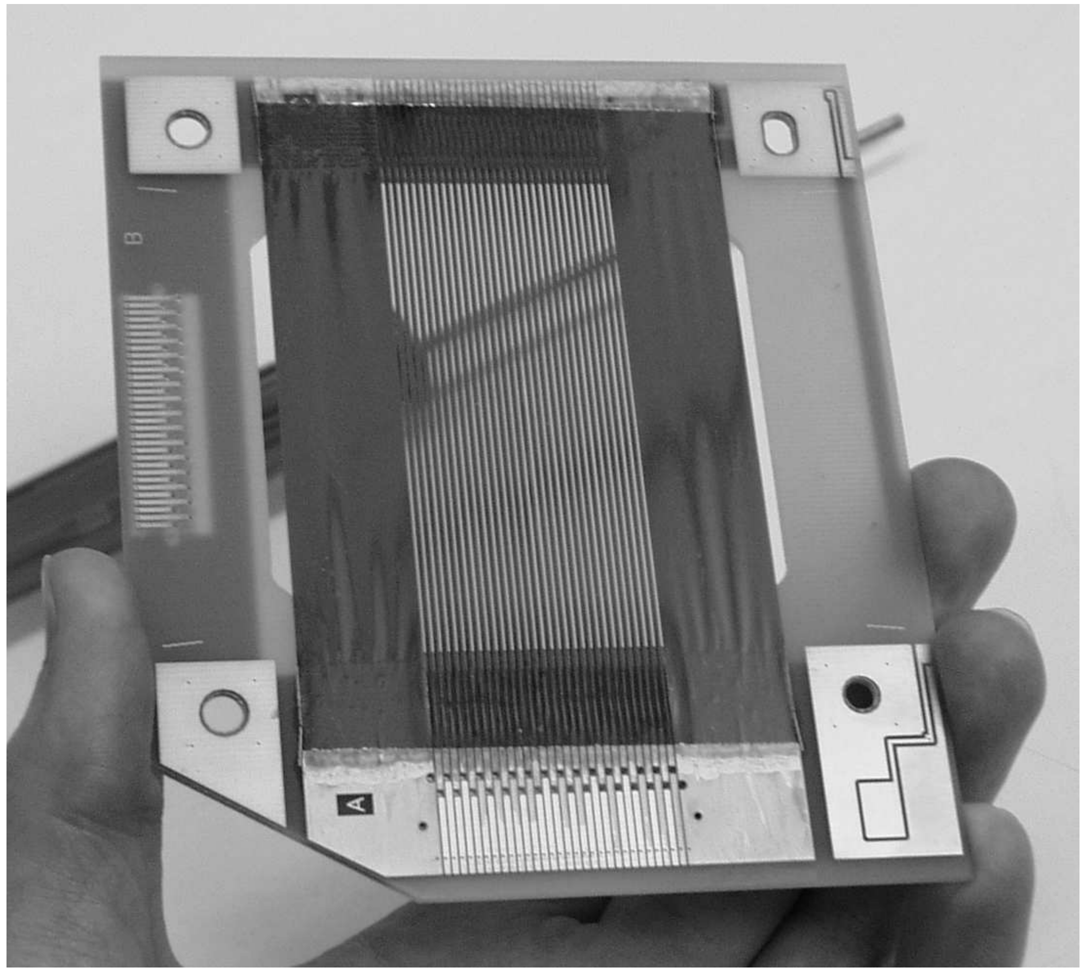
6 μm titanium foil with 1 mm strip pitch



pre-tensioned



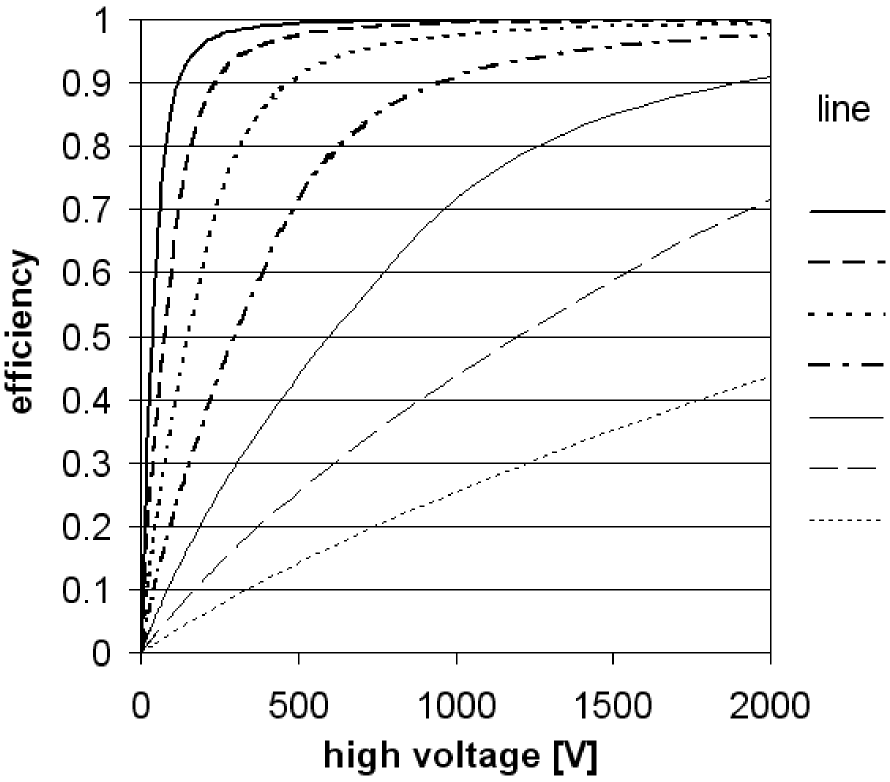
soldered to ceramic board
(creases due to shrinking of metal coating of foil → to improve)



solder test on PCB

SATURATION DUE TO RECOMBINATION

- air filled ionization chamber:



$\frac{(\text{beam current}[nA])(\text{gap}[mm])^4}{(\text{beam diameter}[mm])^2}$ @beam 250 MeV	beam diameter [mm] @beam 250 MeV, 512 nA and gap 2 mm or @beam 250 MeV, 32 nA and gap 4 mm or @beam 70 MeV, 13.6 nA and gap 4 mm
2	64
8	32
32	16
128	8
512	4
2048	2
8192	1

(round proton beam with homogeneous current density assumed)

(calculated according to Mie)

Mie, G., „Der elektrische Strom in ionisierter Luft in einem ebenen Kondensator“, *Ann. Phys. (Leipzig)* **13,** 857-889 (1904).
See also: H. Attix, “Boag’s treatment of Mie’s theory” in *Introduction to radiological physics and radiation dosimetry*, Wiley, 1986, pp. 334-336.

The efficiency is a function of

$$\frac{(\text{plane separation})^4 * (\text{beam current density})}{(\text{high voltage})^2}$$

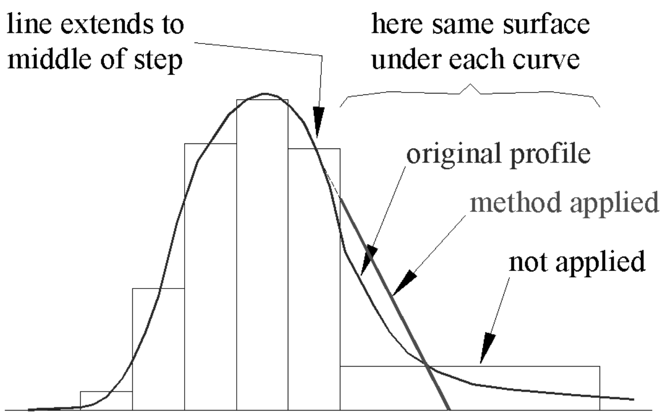
(Hence the efficiency for other values of beam current, beam diameter, plane separation or high voltage can be taken from the graphs.)

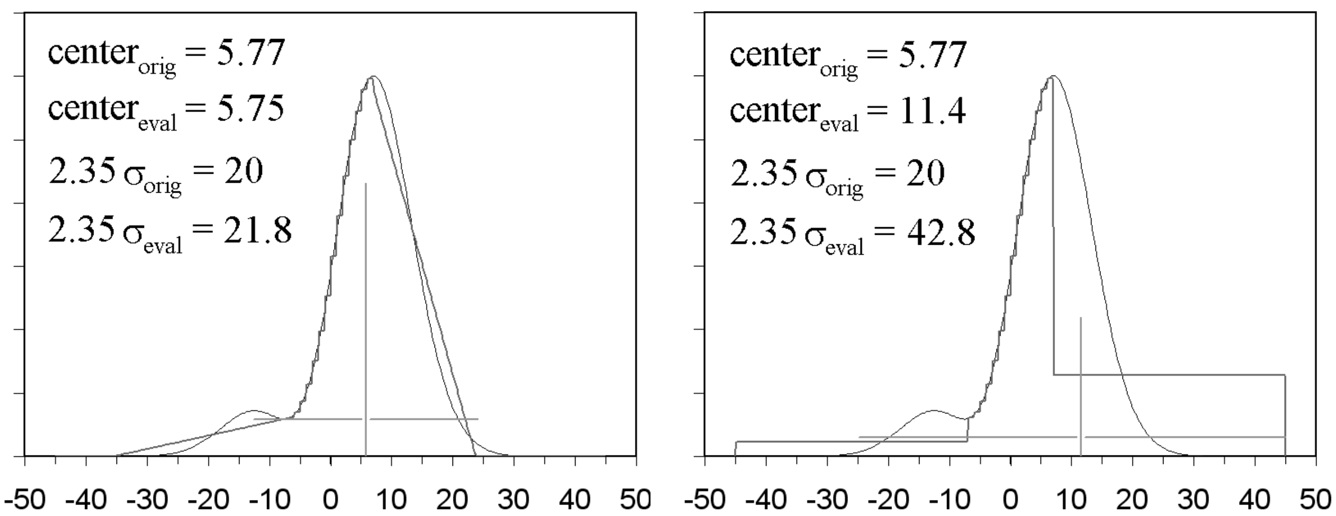
- smaller beam diameters, higher beam currents
  → recombination effects can be dominant

- same devices are placed in vacuum: secondary emission monitors
  → no saturation (but signal a factor of 1000 smaller)

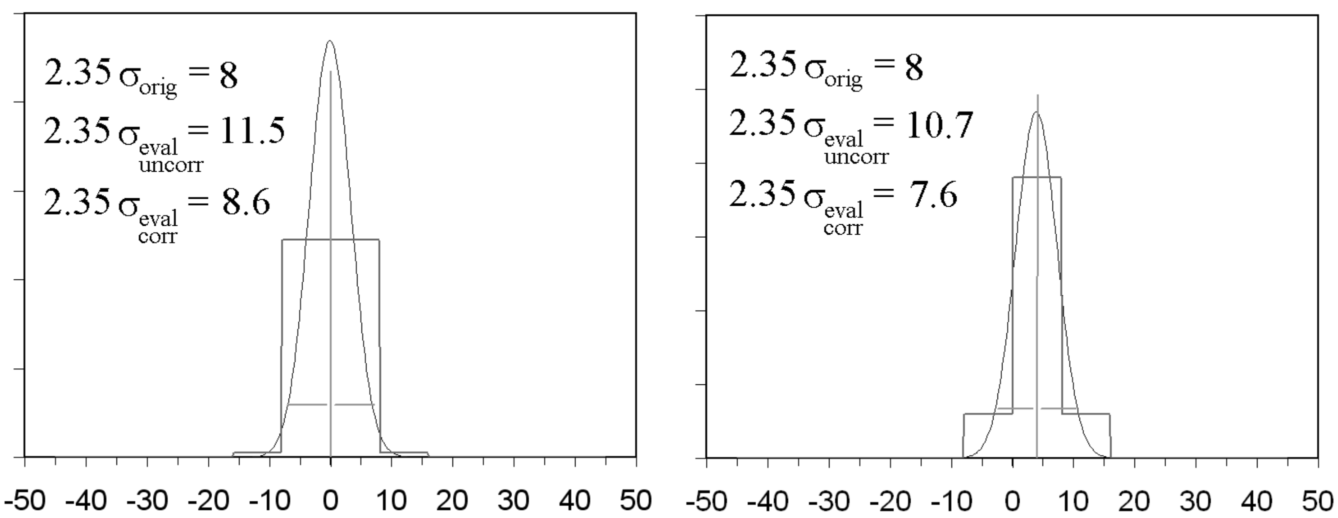
PROFILE EVALUATION

- limited number of amplifier channels available (16 or 32)
- profile centre and width must be determined over a large range of width (from 1. and 2. moments)
- →correct treatment of data from outer broader strips needed:





- →correction for narrow profiles: $\sigma_{corr} = \sqrt{\sigma^2_{uncorr} - 0.16\, s^2_{pitch}}$
  (useful with beam FWHM-width ≥ strip pitch s_{pitch})



(position dependent)

- from simulations: with 16 strips: beam width and center are accurately determined in a range FWHM-width = (1x … 10x) s_{pitch}
  (no noise included)
- varying strip pitch → option to further enlarge the range of beam profile width accessible with a fixed detector configuration

DETECTOR FAILURE SURVEILLANCE

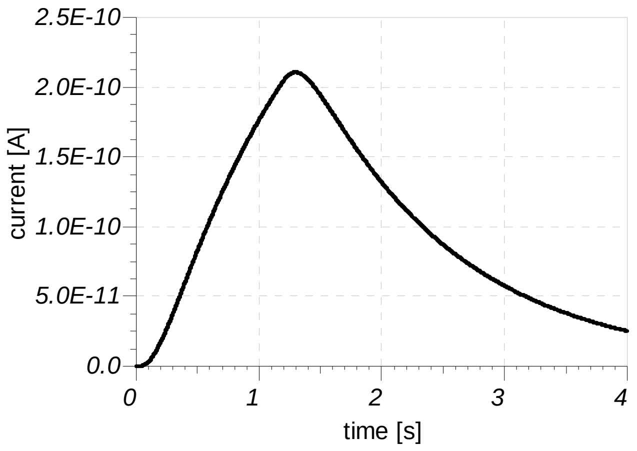
- the thin detectors are elements of the patient safety system

- needed for a correct measurement:
  - intact foils in correct position
  - high voltage at HV-foils
  - signal path uninterrupted
  - signal path and signal foil isolated (i.e. not short circuited to ground/HV/other signal path)
  - air present in ionization chamber resp. vacuum in secondary emission monitor
  - intact current measurement electronics

- possible failures:
  - break of foil or solder joint → displacement of foil/loss of isolation/loss of signal
  - bad connectors/break of PCB or cable wires → loss of signal
  - humidity/radiation damage/sparking/sputter effects at detector/connectors/cables → loss of isolation
  - holes in foil from radiation damage/sparking/spark induced burning of foil (in air) → loss of signal ("blind spot")
  - local change of emission coefficient of secondary emission monitors ("blind spot")

- surveillance options:
  - switching off/on of high voltage induces a test pulse which is compared to previously collected data → all failures but "blind spots" detected
  - capacitive coupling of a test pulse to the end of the strips opposite to the readout-side → dito

    simulated for thin detector:



  - read back of potential of last high voltage electrode (HV-electrodes are connected in series from supply)
  - check of current sum from several measurement planes of a detector against each other → "blind spots" from holes in foil detected
  - same between detectors → "blind spots" from changed emission coefficient detected

ANORDNUNG DER SEGMENTE DES POSTERS

Insertable Thick Profile Monitors

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Profile-, Current- And Halo-Monitors Of The PROSCAN Beam Lines

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Saturation due to recombination

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Cables, shielding, Noise

Electronics

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Thin Profile- and Current Monitors

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Profile Evaluation

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Filters, Noise

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Halo Monitors/ Ext. Ionis. Chambers

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Detector Failure Surveillance

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