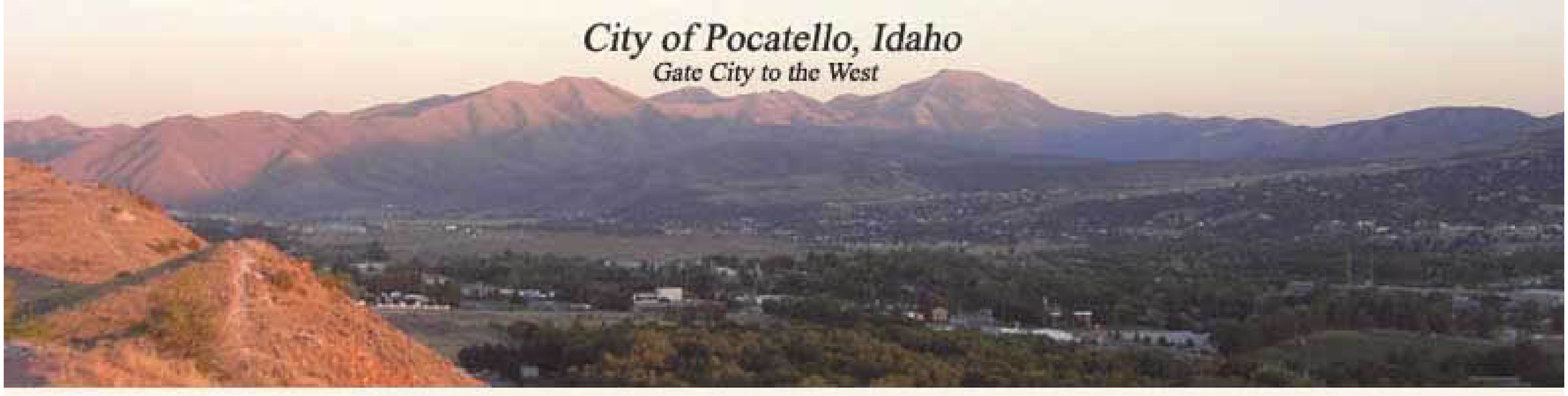
AccApp'07: the Eighth International Topical Meeting on Nuclear Applications and Utilization of Accelerators

July 29 to August 2, 2007, Pocatello, Idaho

talk in session „accelerator technology: instrumentation and control"



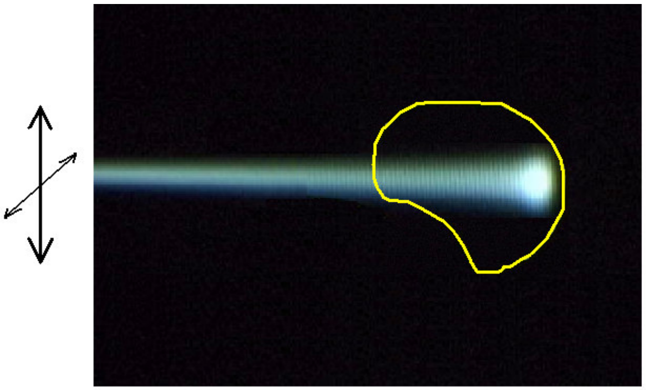
in proceedings: pp. 152-159

Beam Diagnostics for the Proton Therapy Facility PROSCAN

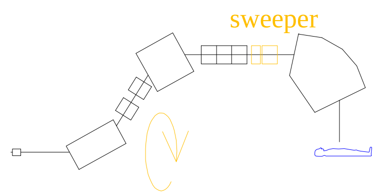
R. Dölling, S. Lin, P.-A. Duperrex, G. Gamma, B. Keil

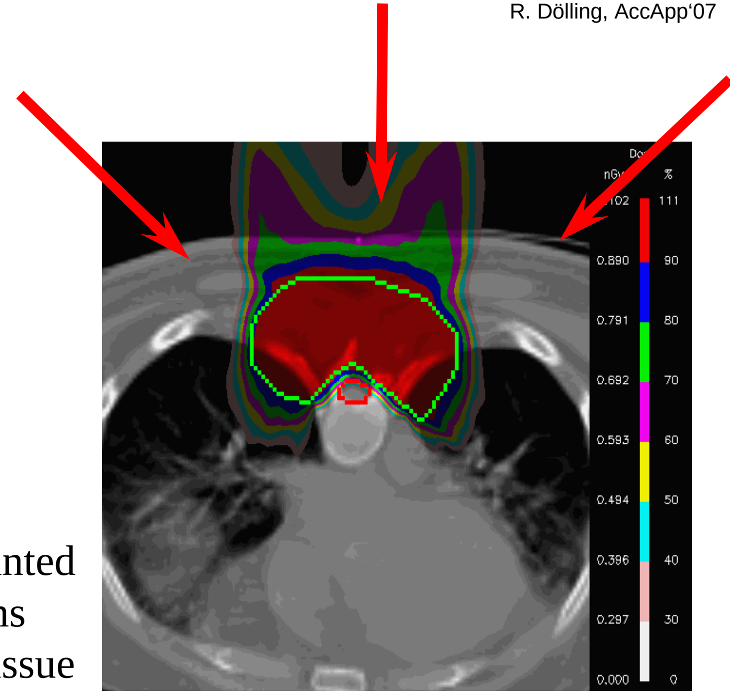
- proton therapy / the PROSCAN facility
- overview diagnostics
- monitors (examples)
- electronics
- measurement/interlock options
- system checks
- nozzle diagnostics

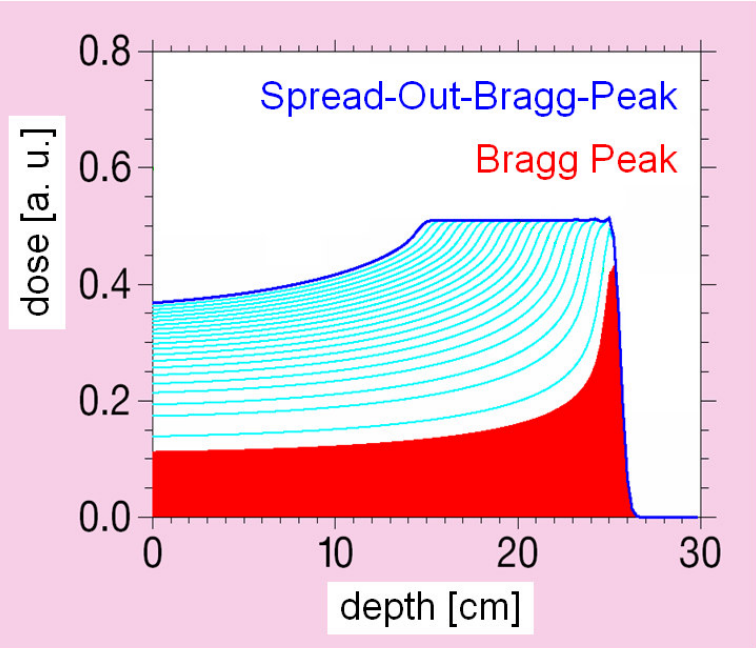
Proton therapy



gantry:







spot scanning:
- tumour uniformly painted
- spares sensitive organs
- low dose to healthy tissue

		patients total	patients /year	fractions
Gantry 1: spot scanning	≥1996	260	150	30
Gantry 2: +fast repainting	≥2008	-	60	30
Optis: broad beam + collimator	≥1984	4800	250	4
Piotron: pion multi-beam	1980-1993	503		

The PROSCAN facility

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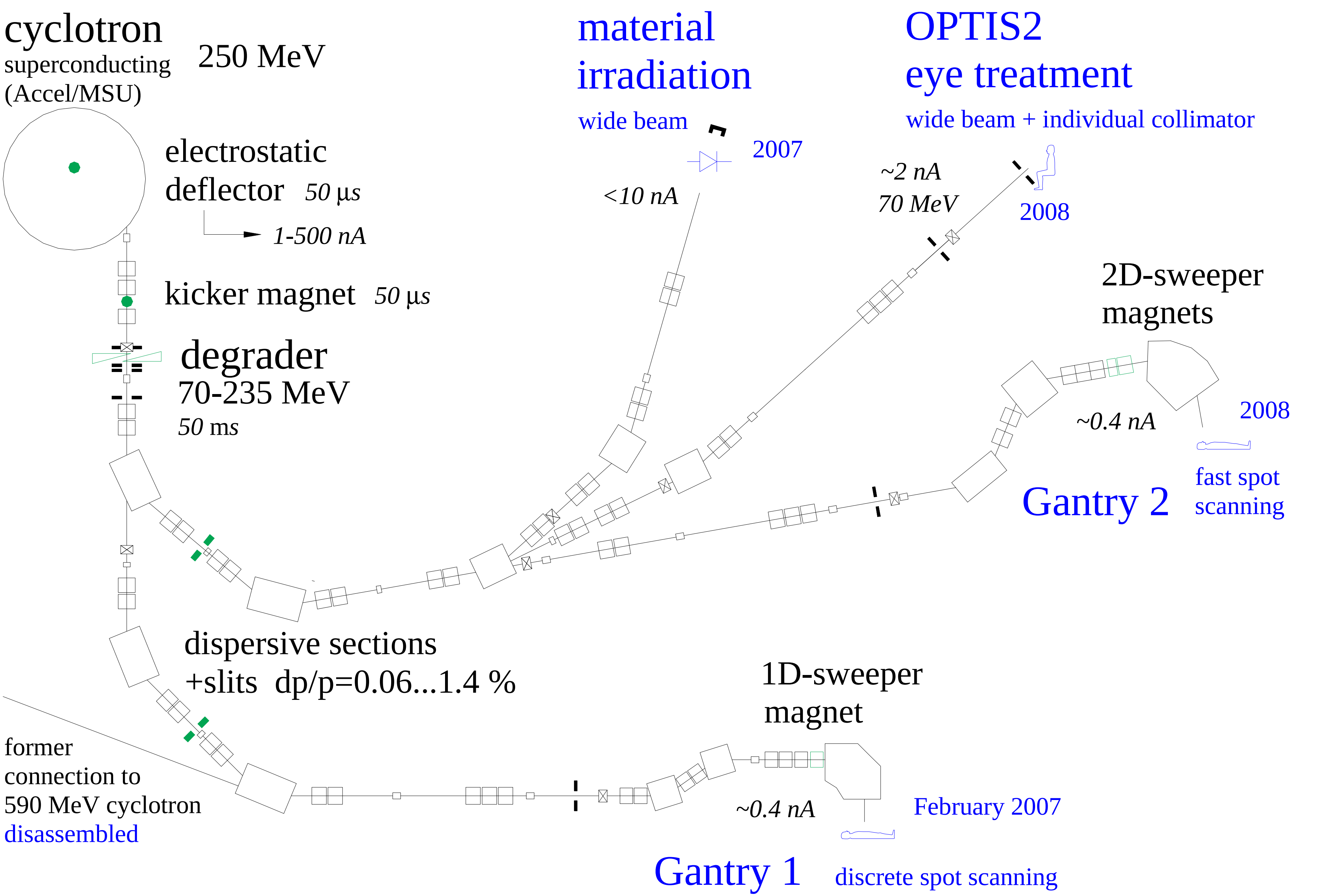
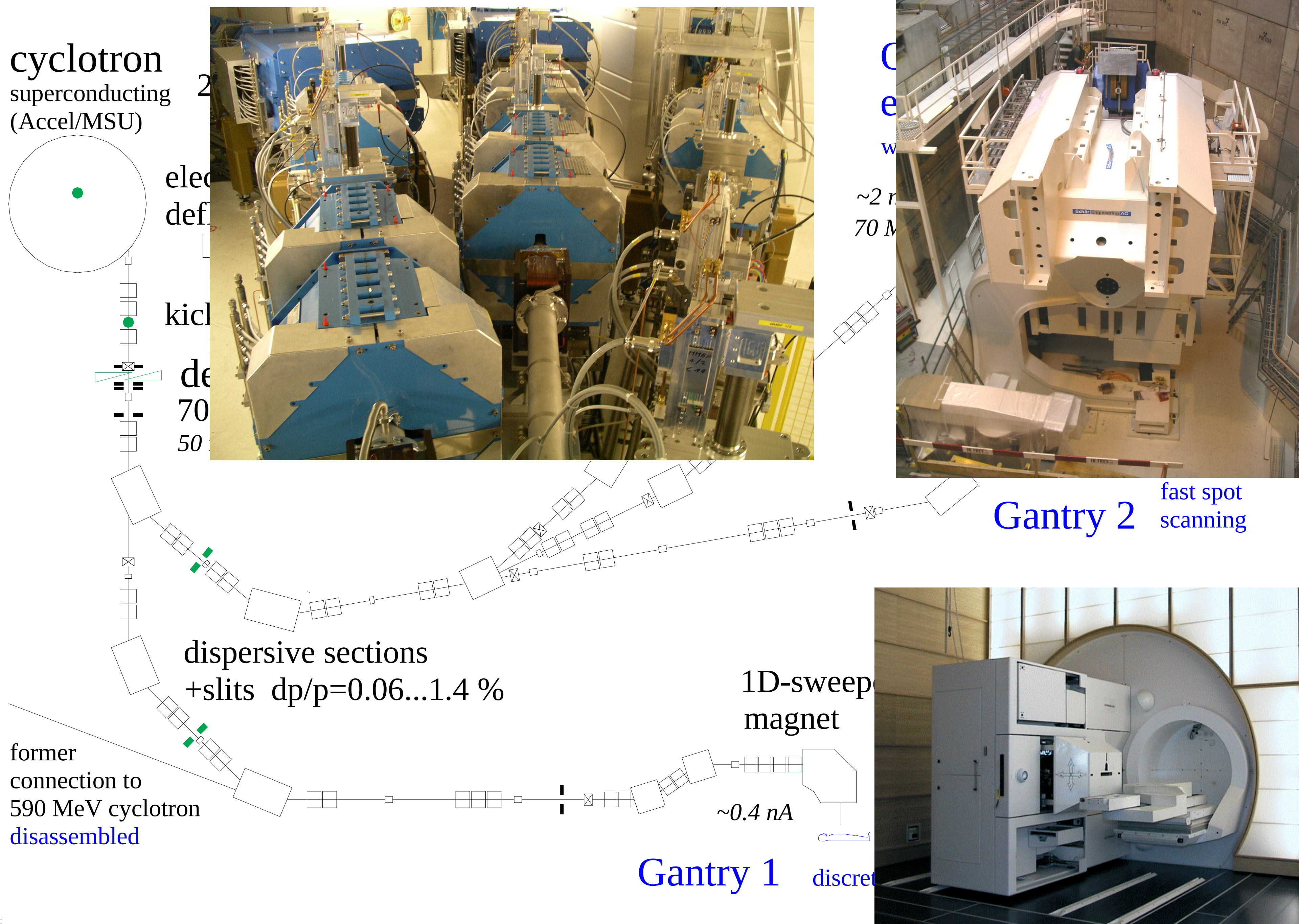
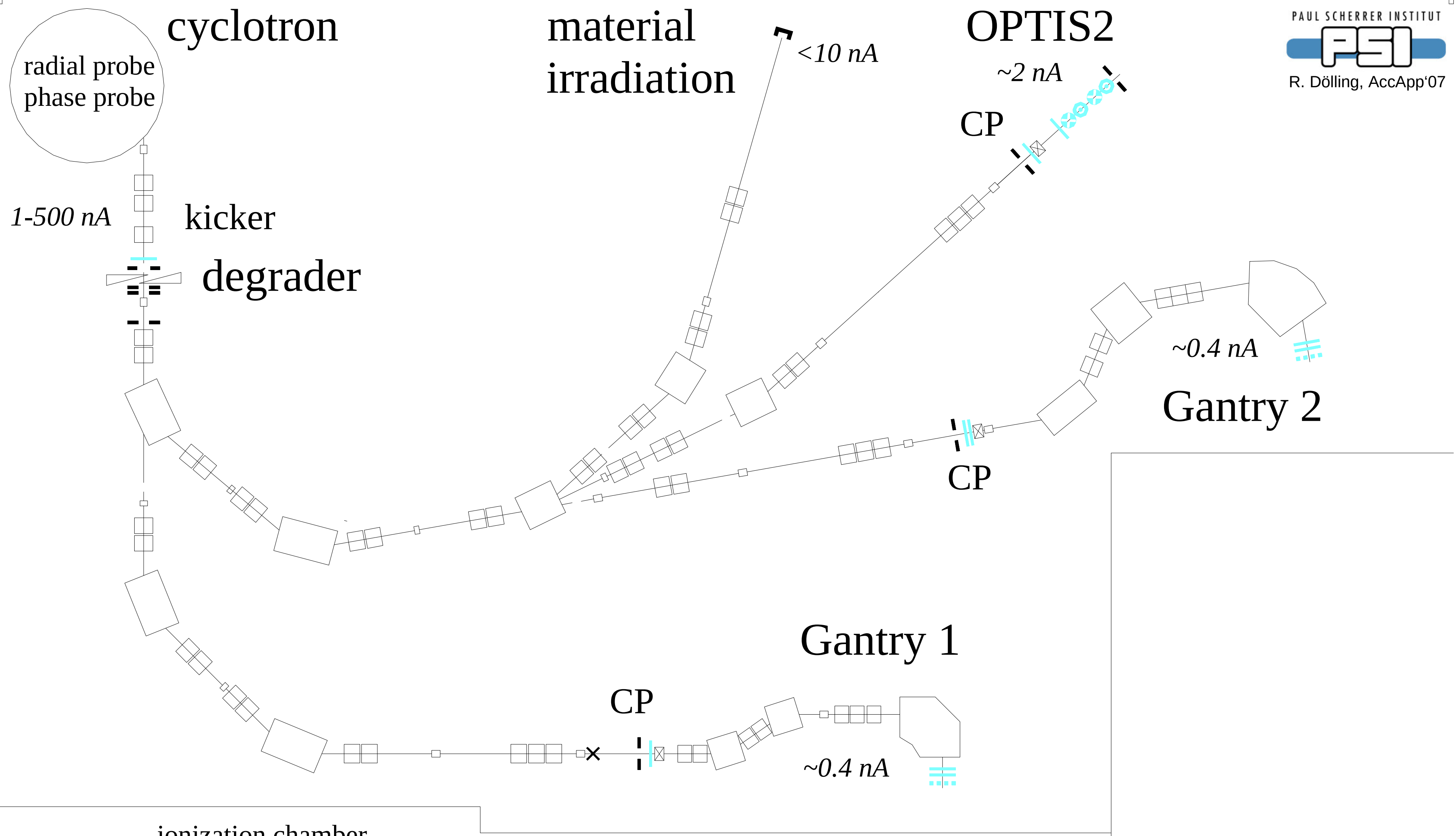


The PROSCAN facility





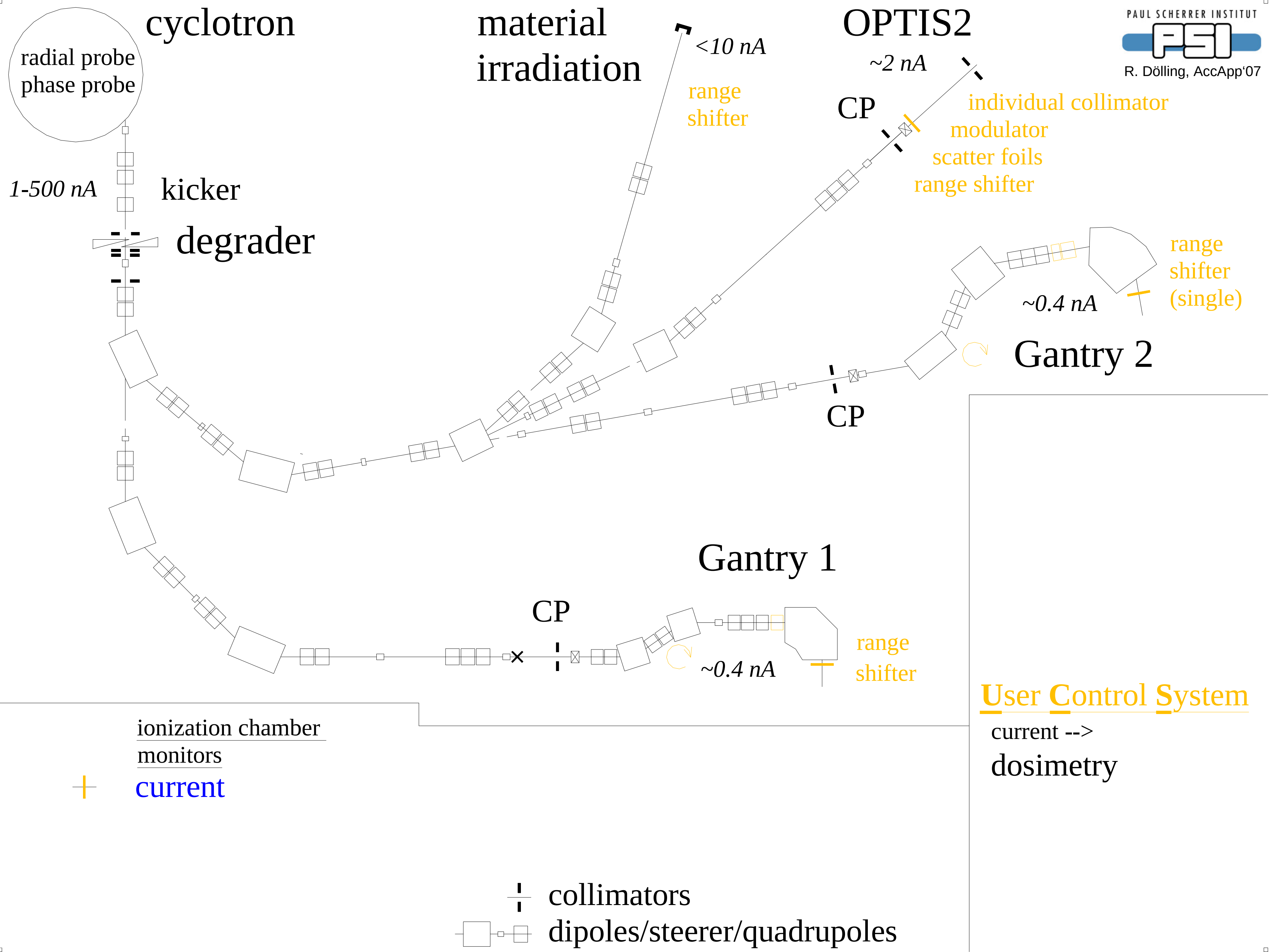
ionization chamber monitors

- current
- profile
- position

- collimators
- dipoles/steerer/quadrupoles

Patient Safety System

current, position,
transmission, dosimetry
(+ non diagnostics) -->
safety



cyclotron
radial probe
phase probe
1-500 nA
kicker
degrader
material
irradiation
<10 nA
range
shifter
OPTIS2
~2 nA
CP
individual collimator
modulator
scatter foils
range shifter
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PSI
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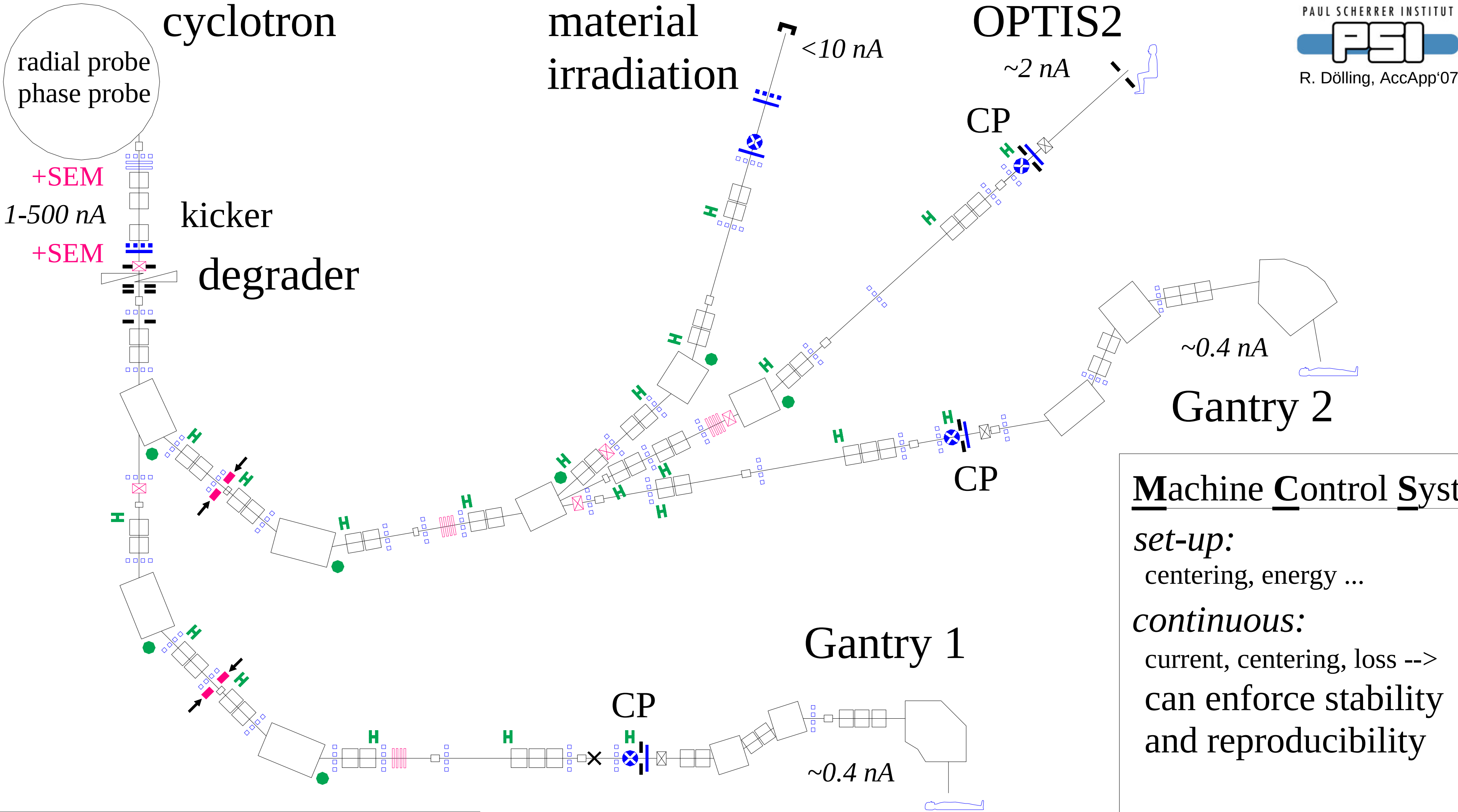
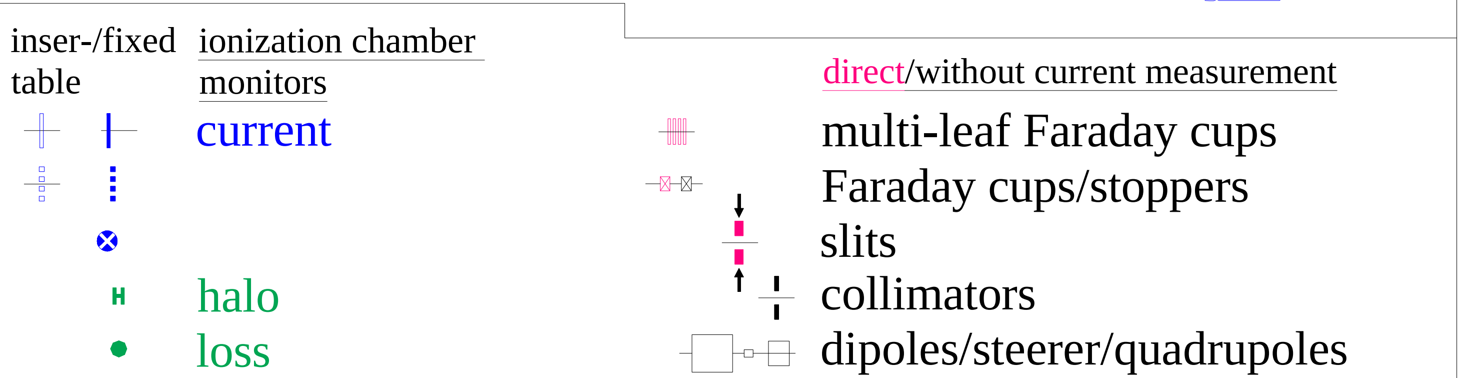
range
shifter
(single)
~0.4 nA
Gantry 2
CP
Gantry 1
CP
~0.4 nA
range
shifter
User Control System
current -->
dosimetry
ionization chamber
monitors
current
collimators
dipoles/steerer/quadrupoles

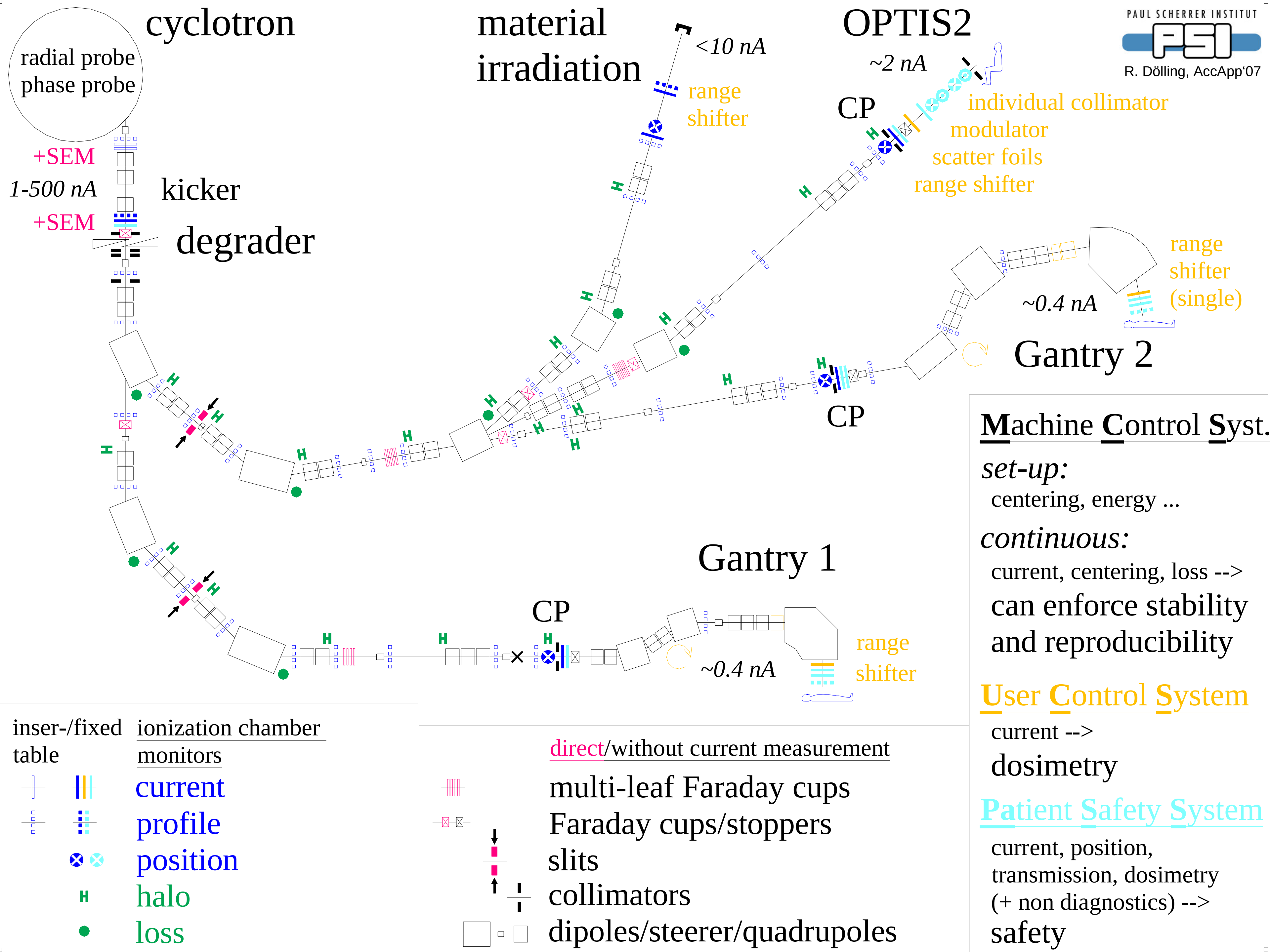


Machine **C**ontrol **S**yst.

set-up:
centering, energy ...

continuous:
current, centering, loss -->
can enforce stability
and reproducibility





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cyclotron
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phase probe
+SEM
1-500 nA
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kicker
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Machine Control Syst.
set-up:
centering, energy ...
continuous:
current, centering, loss -->
can enforce stability
and reproducibility
User Control System
current -->
dosimetry
Patient Safety System
current, position,
transmission, dosimetry
(+ non diagnostics) -->
safety
inser-/fixed
table
ionization chamber
monitors
current
profile
position
halo
loss
direct/without current measurement
multi-leaf Faraday cups
Faraday cups/stoppers
slits
collimators
dipoles/steerer/quadrupoles

Insertable multi-strip ionisation chamber profile monitor

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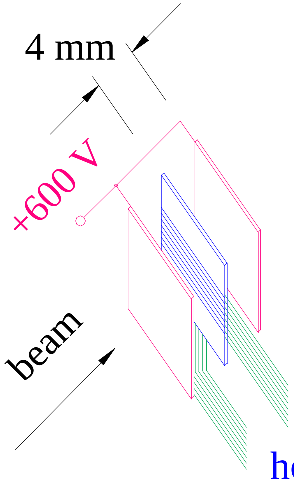
R. Dölling, AccApp'07

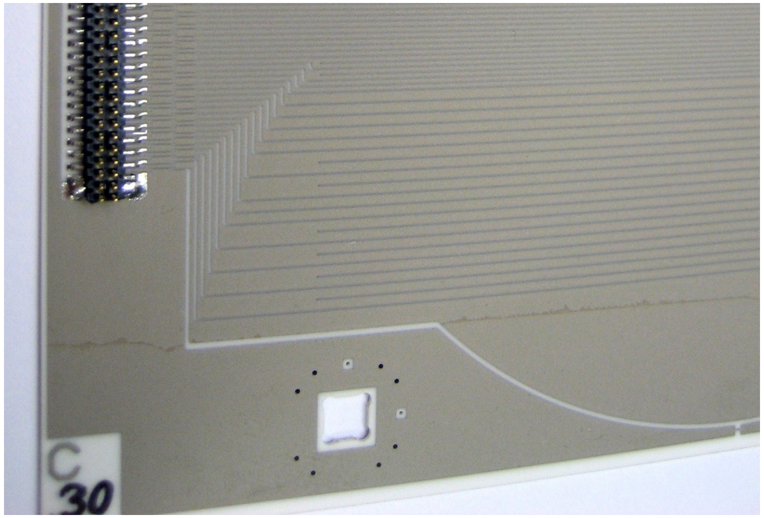


amplification by a
factor 46 ... 117
@70 ... 250 MeV

vertical profile
68 strips (front side)

horizontal profile
68 strips (other side)

center ceramic plate: thick-film pattern

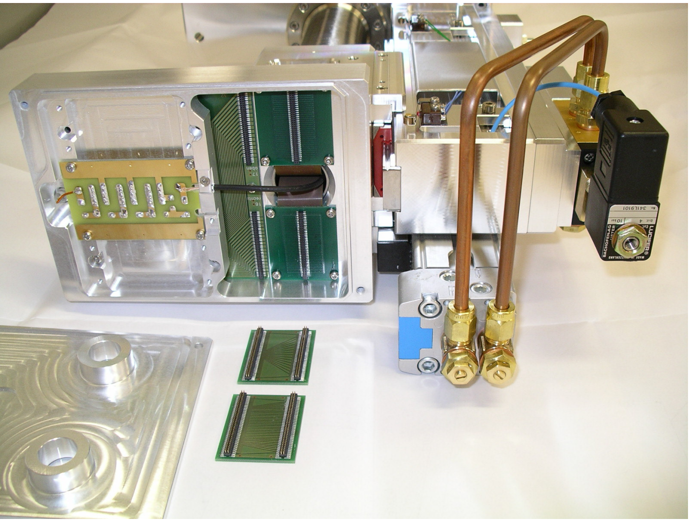


37 installed
(thick --> destructive -->
only 1 used at a time)

information for
- beam alignment
- transport calculations
- beam current

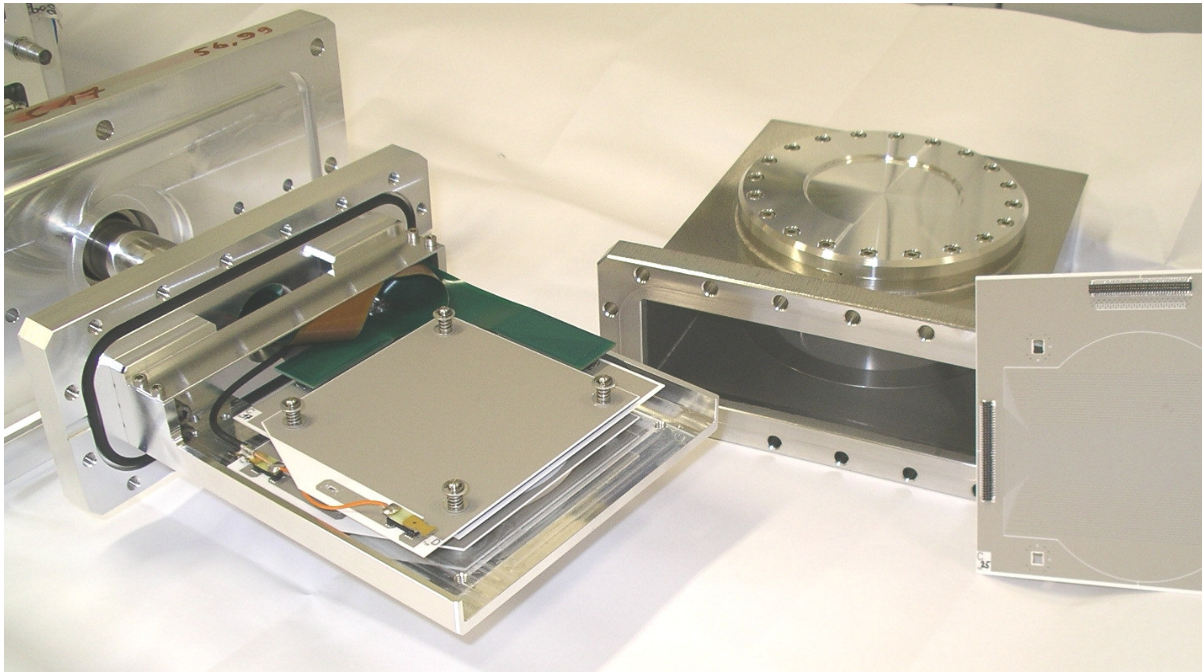
mechanical tolerances to
survey marks on outer
vacuum box <0.2 mm

combined to 16+16 or 32+32 strips
strip pitch selectable 0.5 - 4 mm



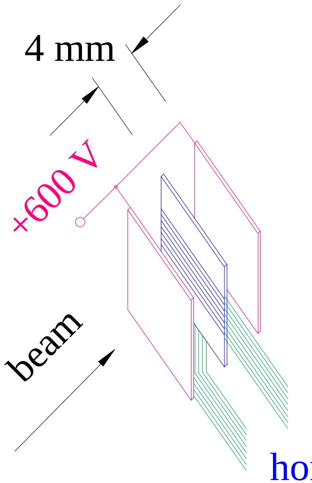
adaptation --> less error of beam width

the detector in an ambient-air-filled box can be moved into the beam



Insertable multi-strip ionisation chamber profile monitor

R. Dölling, AccApp'07



amplification by a
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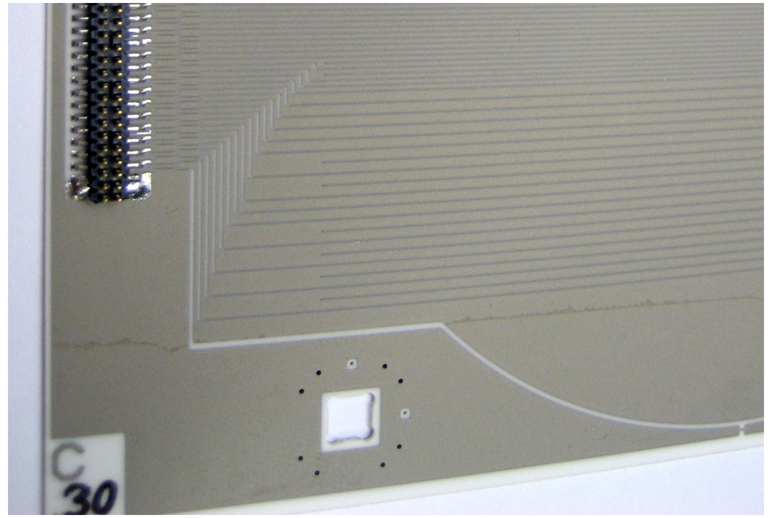

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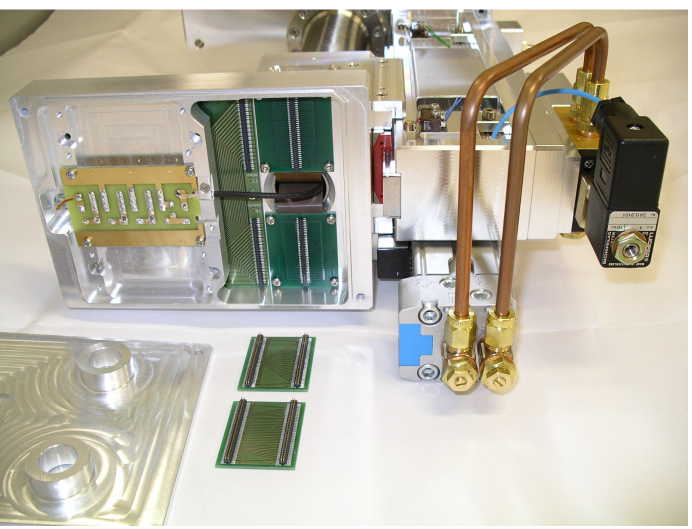

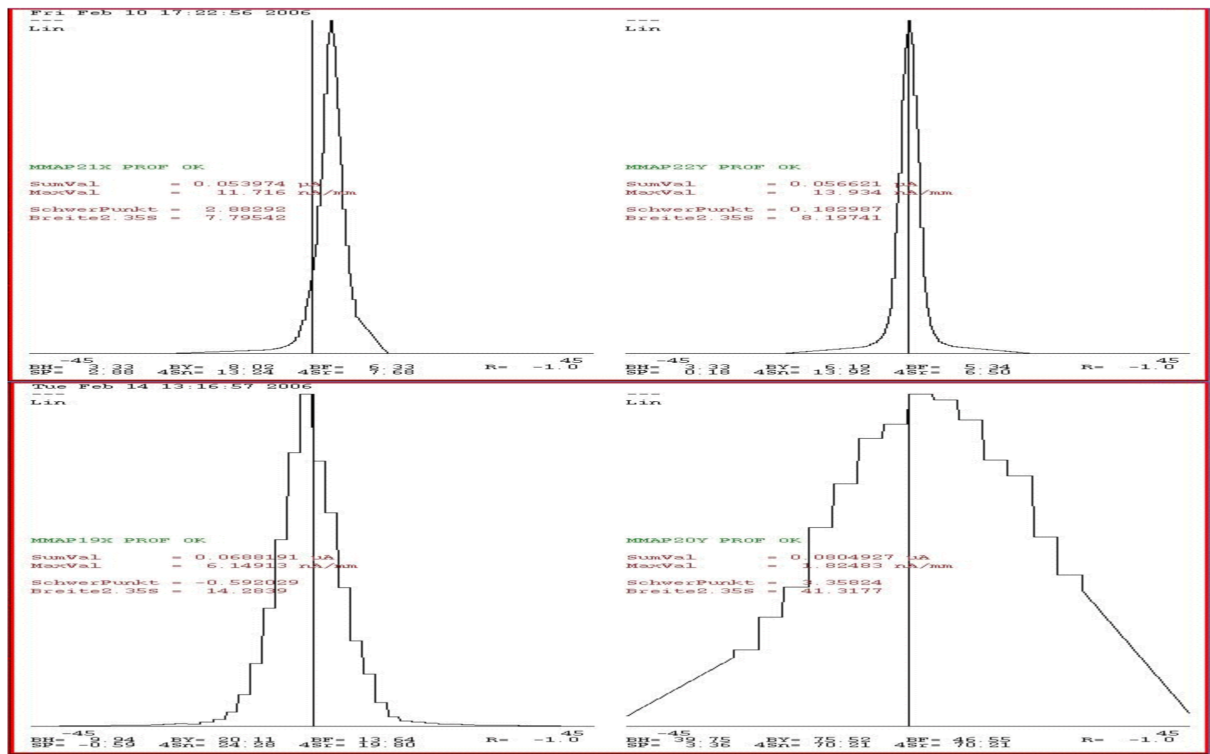

adaptation --> less error of beam width

thin permanent ionisation chamber profile monitor

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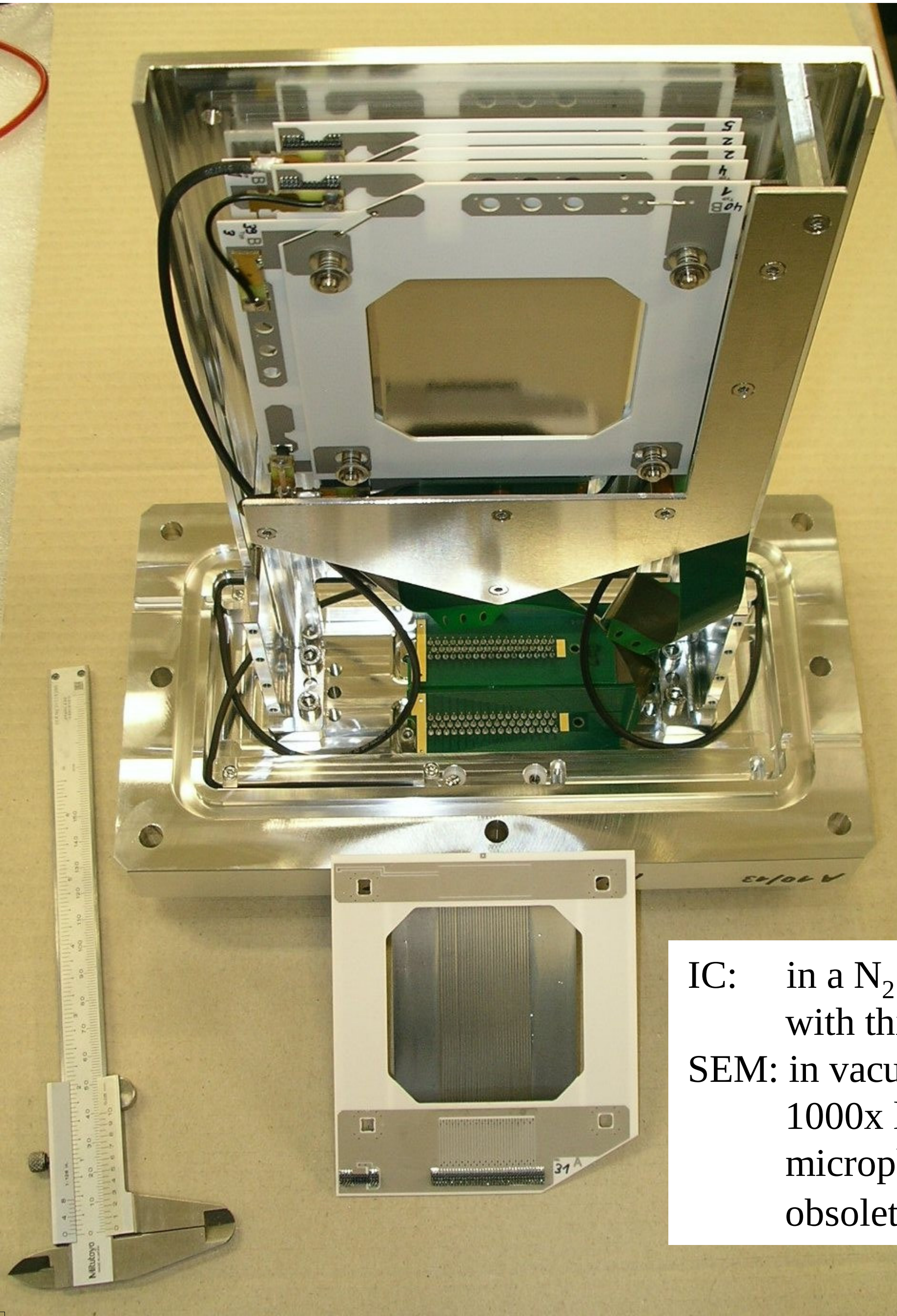
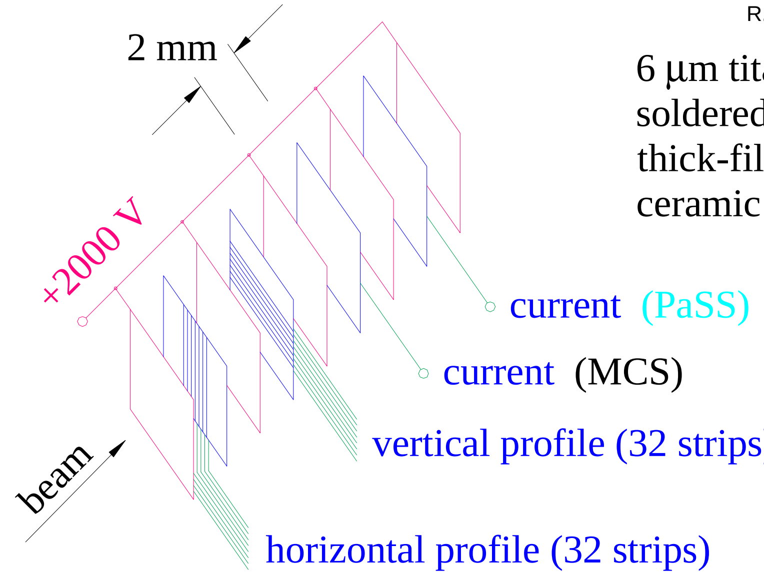


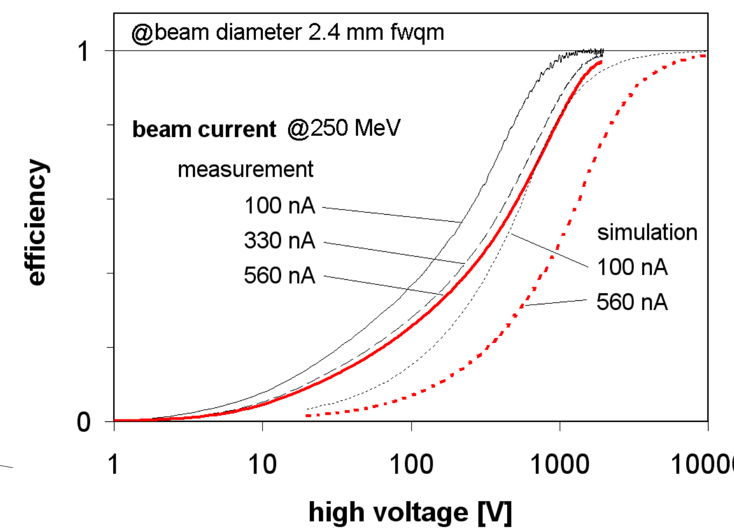
IC: in a N_2 filled box
with thin Ti-windows
SEM: in vacuum
1000x less signal
microphonics
obsolet?



6 µm titanium foils soldered to thick-film coated ceramic frames

collection efficiency due to ion recombination

$$\eta \sim f\left(\frac{\text{gap}^4 * \text{current density}}{\text{voltage}^2}\right)$$ better than expected



Ionisation chamber position and halo monitors

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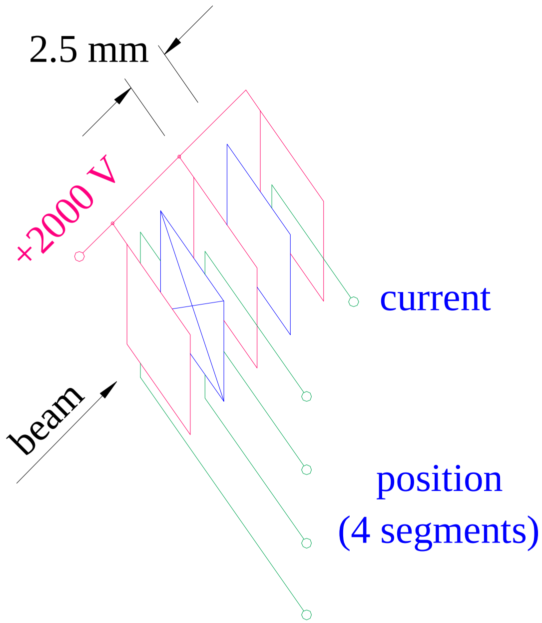
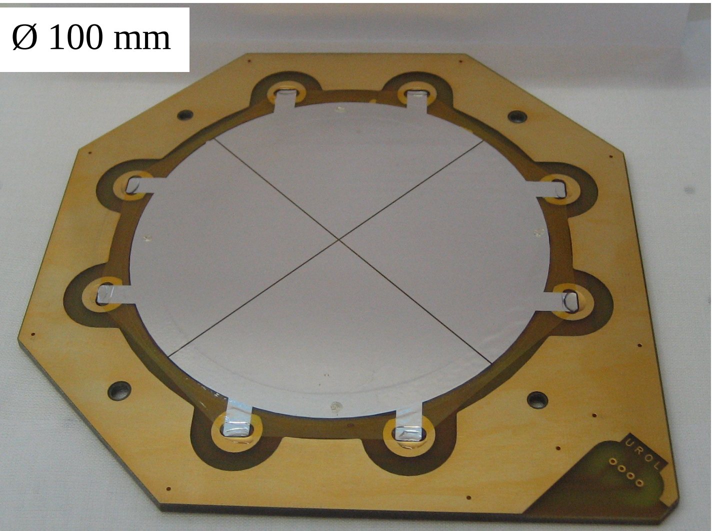
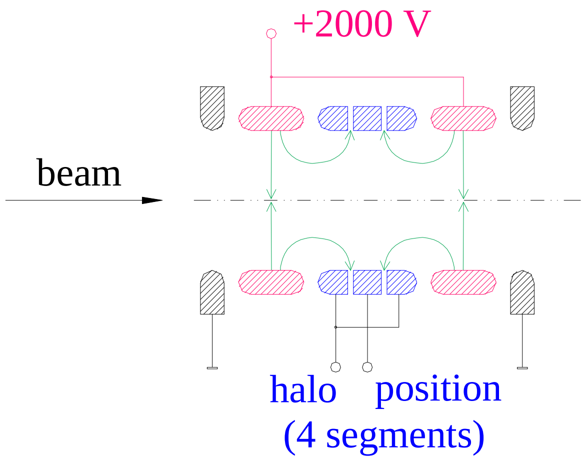
planar (CP experimental area)



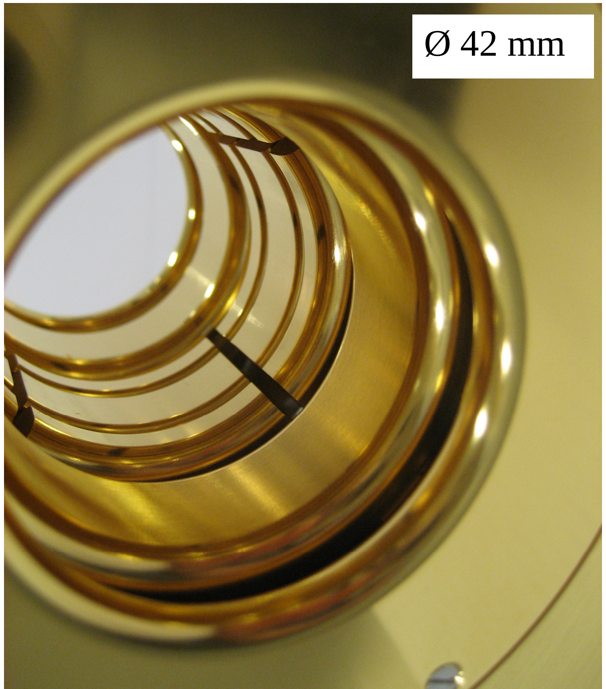
aluminised (double sided) kapton foils



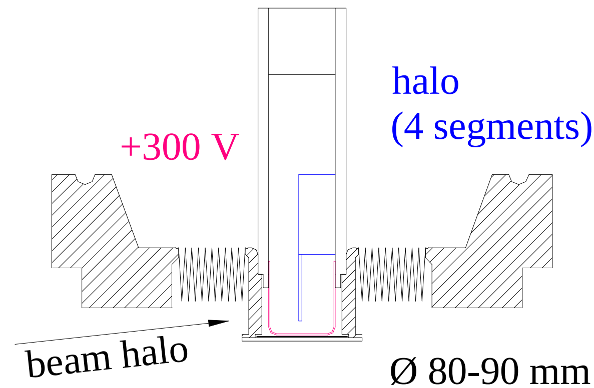
axisymmetric (CP OPTIS2)

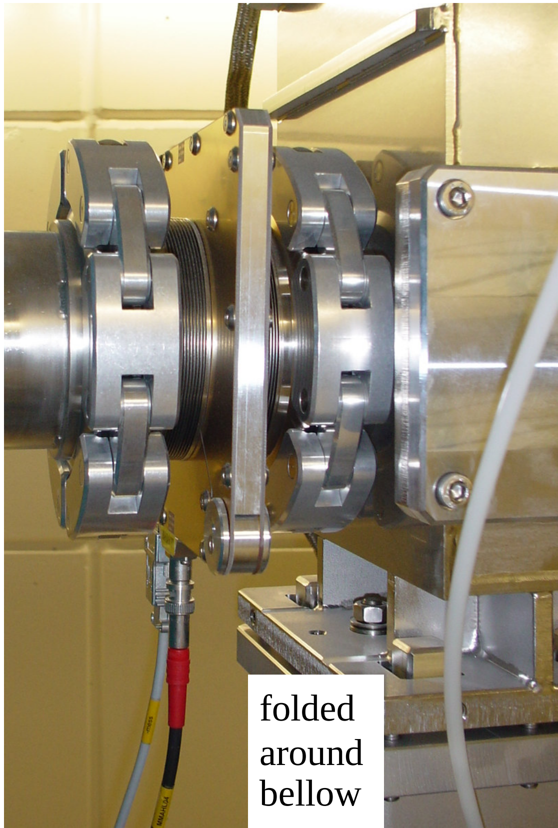


separatrices (electric field lines)
define drainage areas



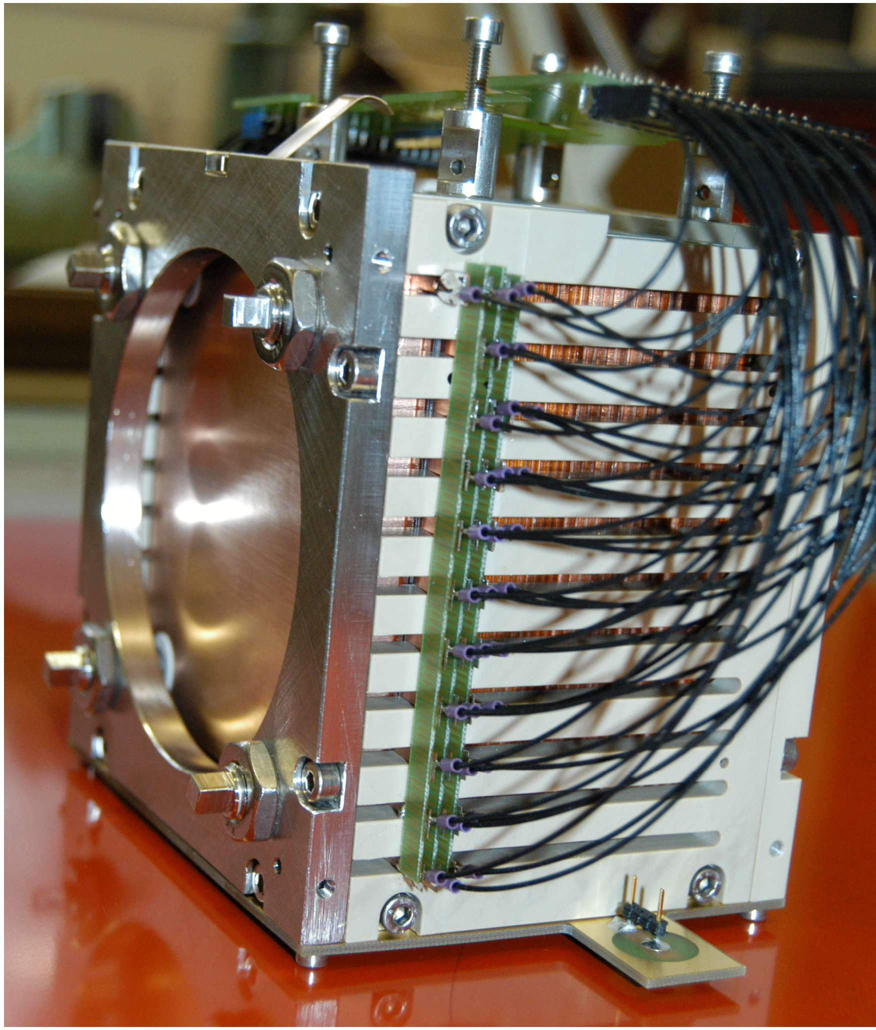
axisymmetric (beam lines)

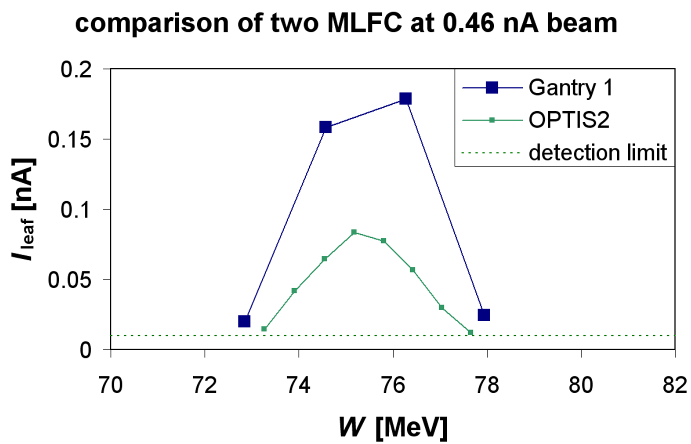


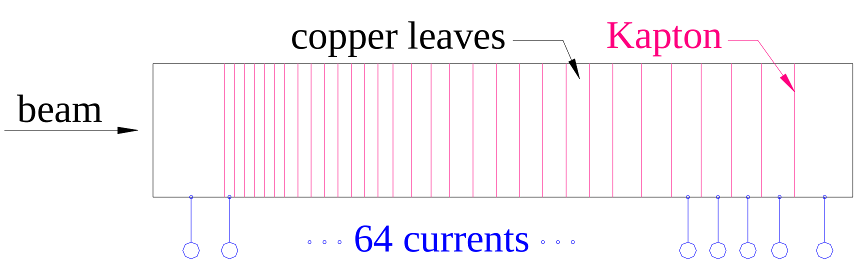


Multi-Leaf-Faraday-Cups measure beam energy

- the beam energy distribution is determined from the measured range distribution
- the beam is stopped in a stack of 64 copper sheets of varying thickness
- the copper sheets are separated by Kapton foils
- the 64 currents (>10 pA) are measured
- MLFC is mounted on a compressed-air actuator
- in vacuum, no active cooling --> max. 200 kJ/day
- two variants: for OPTIS2: 65 - 86 (- 252) MeV,
  for gantries: 68 - 252 MeV
- a refined evaluation is needed for an accurate range determination





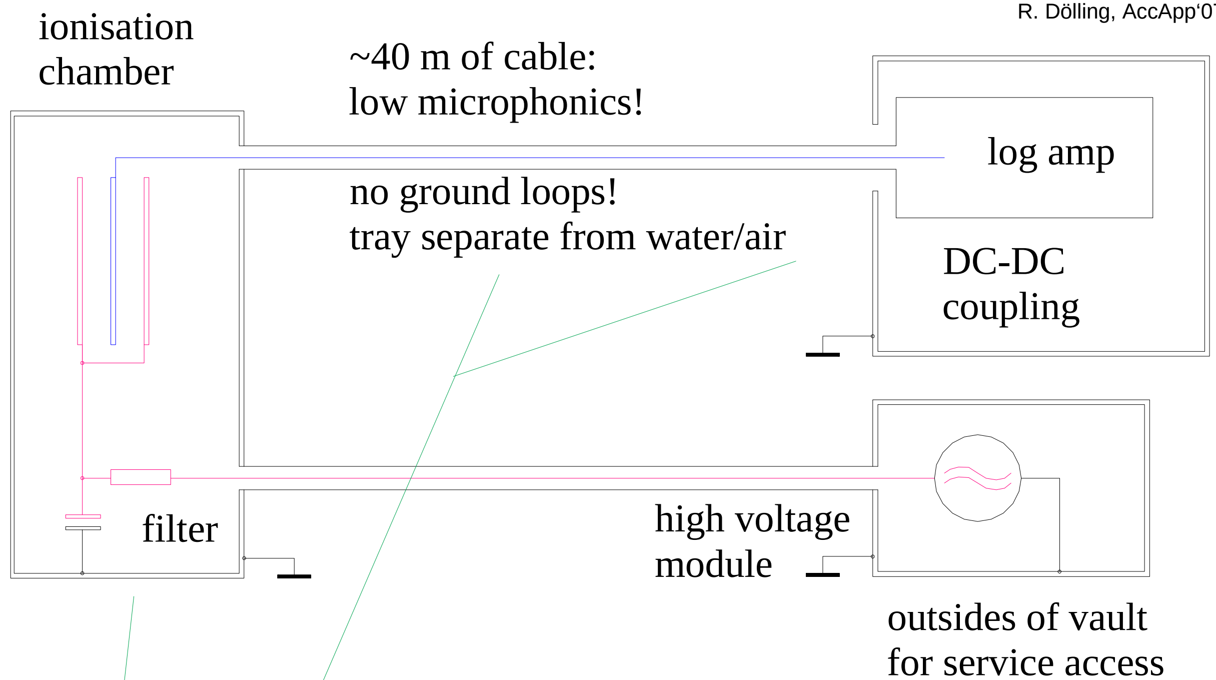


Cables and Electronics (MCS)

beam fraction to be detected:
~1 pA ... 1 μA

ionisation chamber amplifies
by a factor 43 ... 1600
depending on beam energy
and geometry

signal 50 pA ... 50 μA



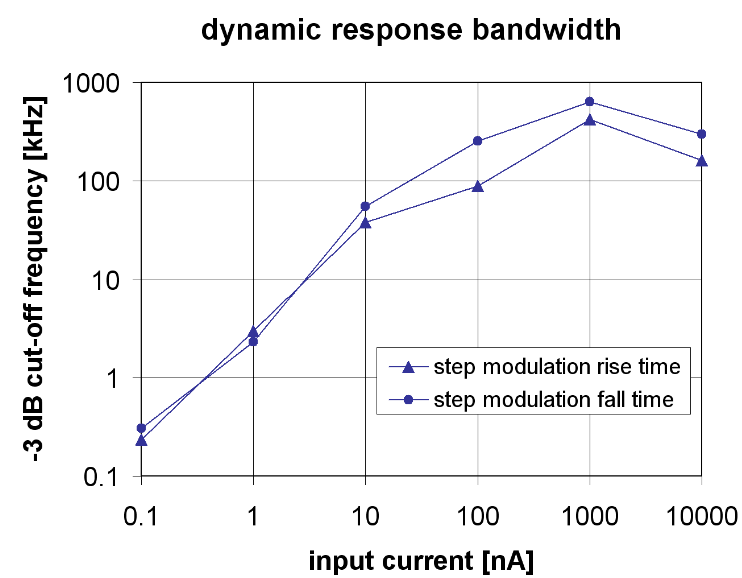
logarithmic amplifier range:
~10 pA ... 10 mA

accuracy of ±2% from 100 pA ... 1 mA
yet not fully reached

charge-collection time of ionisation chamber: ≥12 μs

low-pass by cable capacity and input resistor: 7 μs

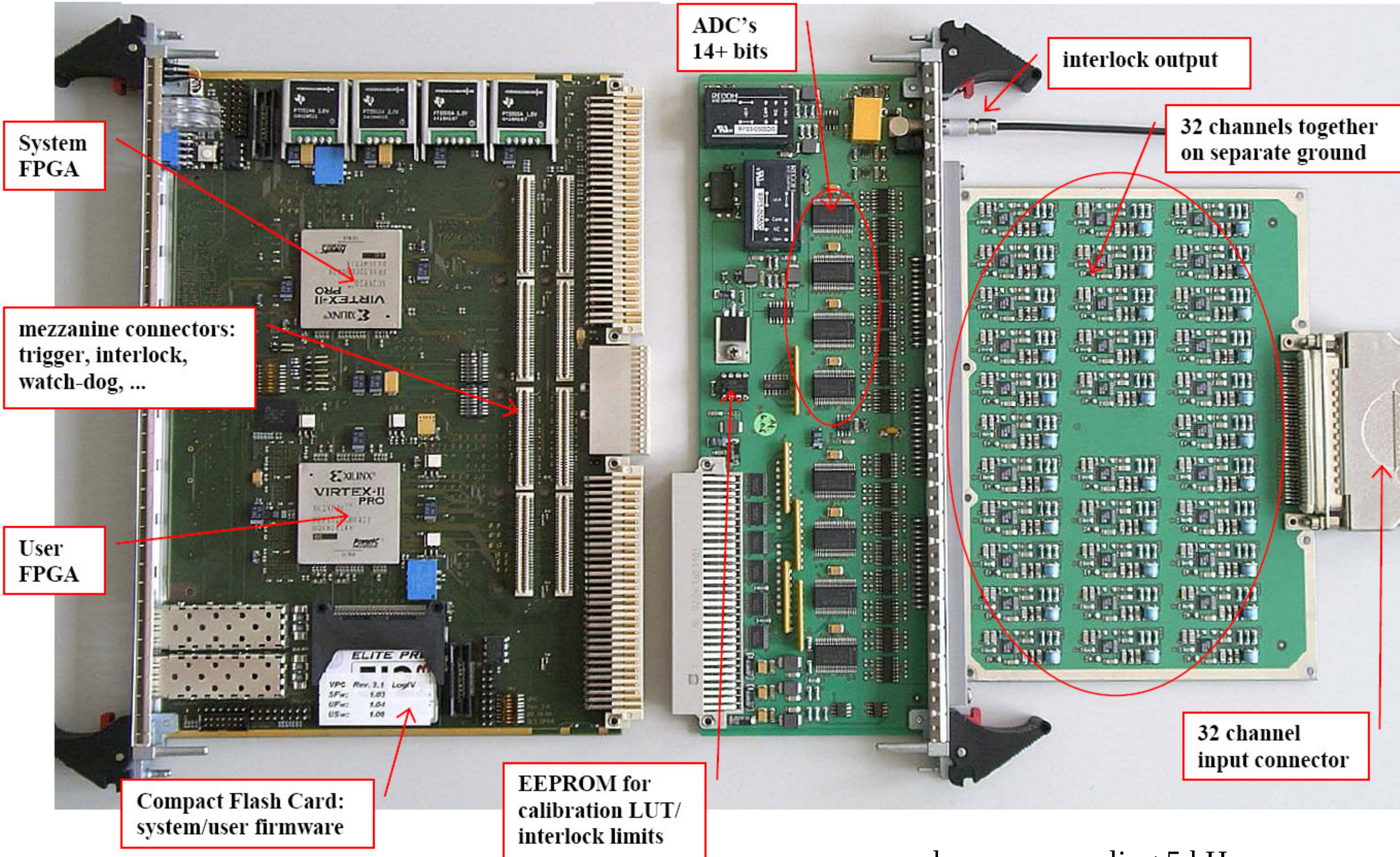
current-dependent bandwidth of log amp:



sampling speed: 200 μs (improvable)

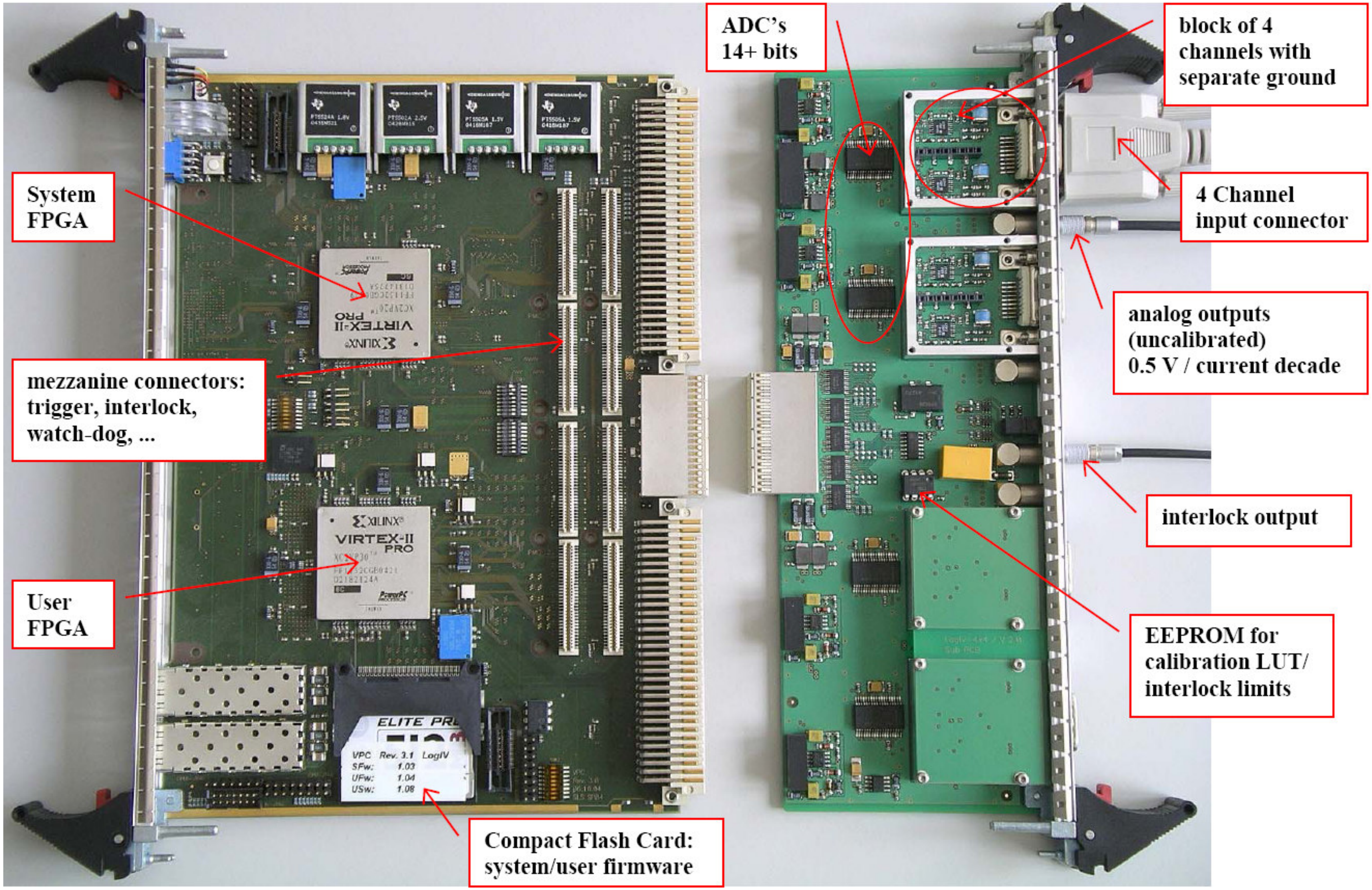
VME PMC carrier board

32 channel logarithmic amplifier LogIV32



synchronous sampling 5 kHz

VME PMC carrier board 4x4 channel logarithmic amplifier LogIV4x4



synchronous sampling 5 kHz

Measurement capabilities of LogIV

- ***in module available (5 kHz update)*** →
  (requestable by MCS)
  - **individual** signal currents*
  - **series** of profiles (=all currents)**

- ***in MCS derived (on user request)***
  energy-dependent conversion factors
  - beam currents

- ***in module derived*** *from simultaneously sampled currents*
  - sum
  - maximum
  - center position/width (profile)
  - hor./vert. position (halo-mon.)
  - current ratios
  - current integral

  (only LogIV32, only LogIV4x4)

  each signal is doubly available: filtered with configurable low-pass filters A, B

- beam current
  → every profile monitor is a current and transmission monitor too
- beam current ratios (transmission)
- beam current integral

* *user request to MCS, MCS individually asks module via VME → readings not simultaneous*

** *up to 4095 profiles (each simultaneously sampled) with n * 0.2 ms separation (n=1 ...~∞)*
(trigger + en-bloc readout requestable by MCS)

Interlocks in the MCS check the beam and the detectors

- ***from LogIV*** (latency few ms, filter configurable)
  - beam current or transmission too high/low
  - beam current integral too high/low
  - beam position/width wrong
  - losses too high/low
  - detector high-voltage readback too low
  - output of twin-detectors too different
  - module error

- ***from high-voltage modules*** (1 ms)
  - detector voltage too low
  - supply current too high (short)
  - module error

- IL limits and IL activation configurable in the modules
- IL activation configurable in the MCS
- IL not depending on machine-tune or user mode (possible)
- no fast evaluation of signals arriving distributed to several modules (possible)

Interlocks in the MCS check the beam and the detectors

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a separate system
with different electronics

and capabilities

- IL limits and IL activation configurable in the modules
- IL activation configurable in the MCS
- IL not depending on machine-tune or user mode (possible)
- no fast evaluation of signals arriving distributed to several modules (possible)

MCS

this resembles the MCS-IL-system at PSI's MW-beam lines
there: prevents the beam from melting beam pipe/components

here: enforces stability and reproducibility of the beam

PaSS

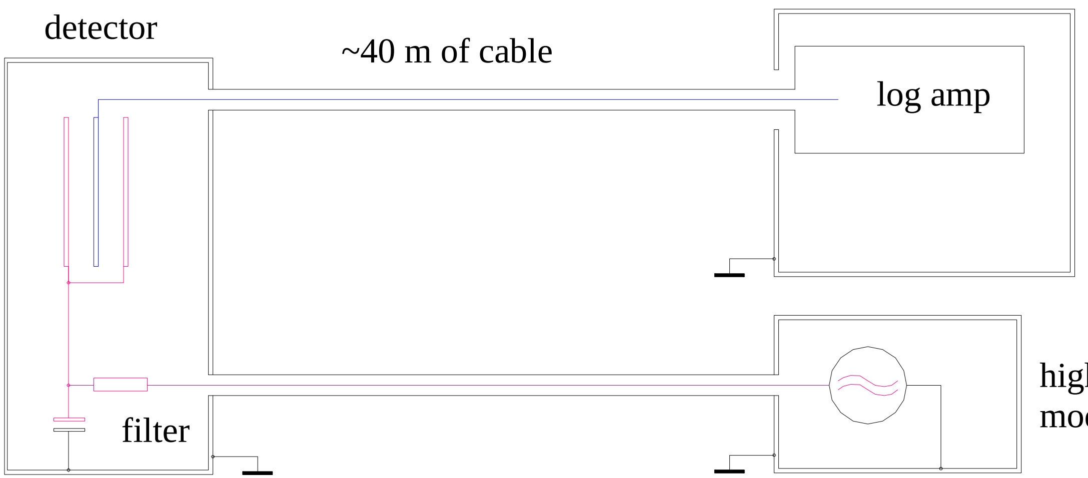
the Patient Safety System
alone has to guarantee
the patients safety

Diagnostics system checks in the MCS

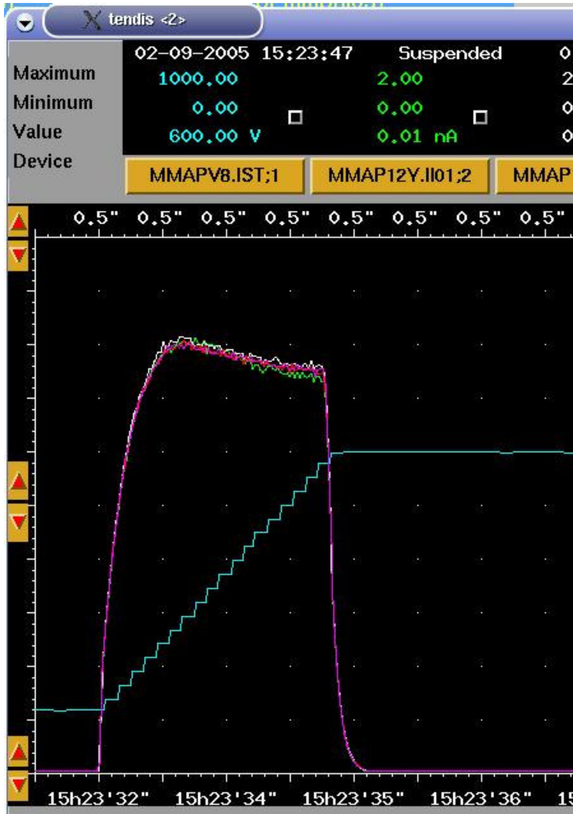
- ***permanent (by Interlocks)***
  - self check electronic modules (watch dog)
  - consistency of twin-detectors
  - high voltage read-back of some IC & SEM
  - high-voltage supply currents of all IC & SEM (short-circuit)

- ***periodically (~1/day) without beam (by MCS-routines)*** *(not ready at present)*
  - high-voltage supply currents of all IC & SEM (leakage current)
  - influence test of all IC & SEM & MLFC (complete systems):

response must be reproducible

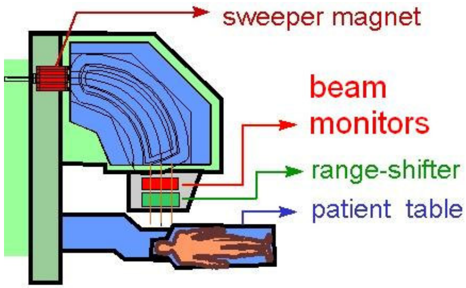


defined voltage ramp (or step)



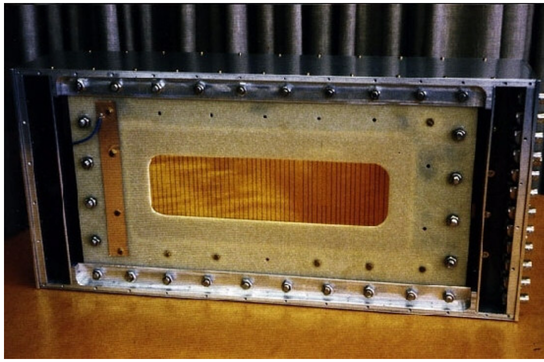
Nozzle diagnostics for dosimetry (Gantry 1)

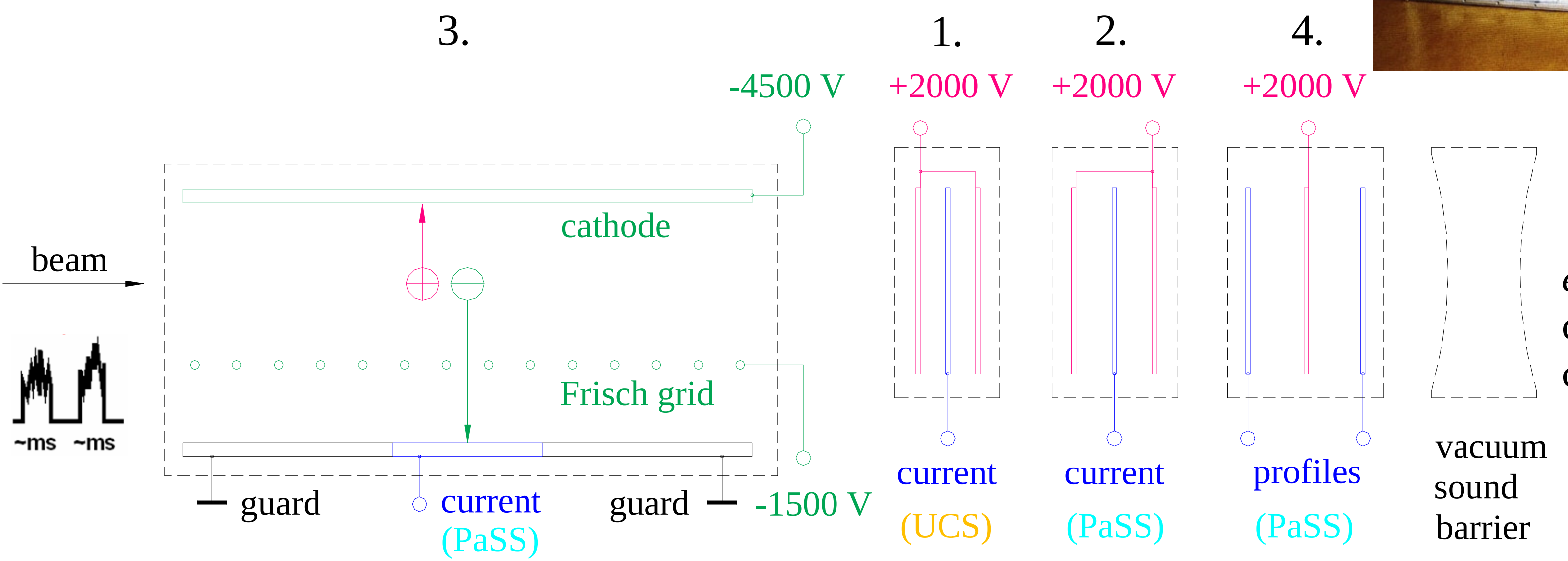
R. Dölling, AccApp'07



1. planar IC, defines the spot dose (UCS),
   collection time 90 µs, 23 cm * 3 cm, 20 µm aluminised Mylar foils, ambient air
2. planar IC, verifies the spot dose after each spot (PaSS),
   microphonics! collection time 350 µs
3. Frisch-grid monitor, verifies the spot dose after each spot (PaSS),
   no microphonics, position/current dependency, collection time ~10 µs, nitrogen
4. two planar multistrip-IC, check hor.+vert. beam position for each spot (PaSS, σ ~0.1 mm),
   strip pitch 4.4 mm, 25 µm aluminised Kapton/Mylar foils

(additional beam-position check by Hall probes in sweeper magnet and last bending magnet, PaSS, σ ~1 mm)





electronics:
current to frequency converters + counters

Nozzle diagnostics for dosimetry (Gantry 1)

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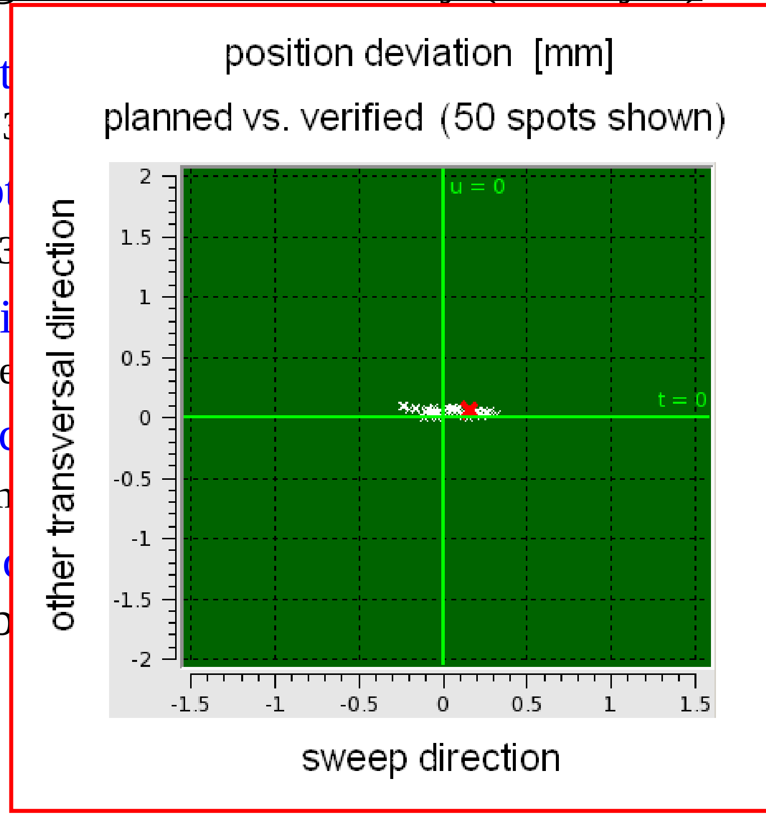
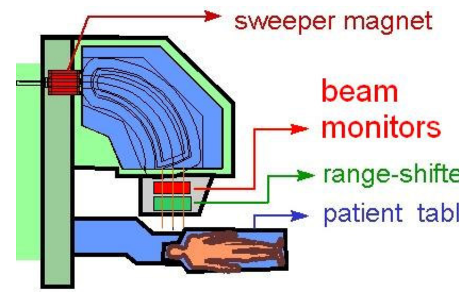
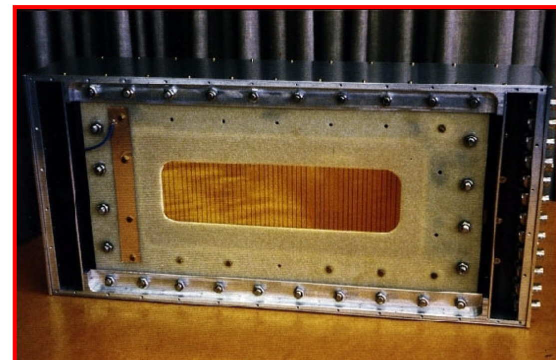
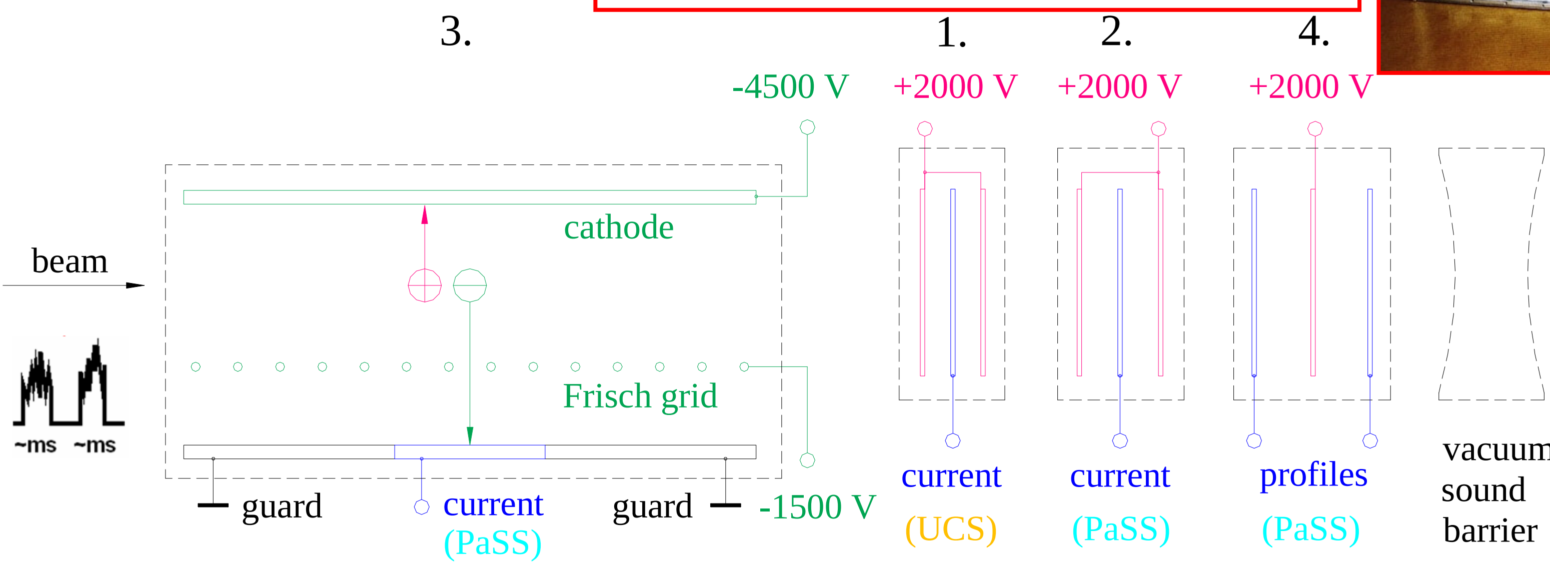
1. planar IC, defines the spot
   collection time 90 µs, 23 cm * 3
2. planar IC, verifies the spot
   microphonics! collection time 3
3. Frisch-grid monitor, verifi
   no microphonics, position/curre
4. two planar multistrip-IC, c spot (PaSS, σ ~0.1 mm),
   strip pitch 4.4 mm, 25 µm alum

(additional beam-position c
sweeper magnet and last b









electronics:
current to frequency
converters + counters

- an ensemble of diagnostics has been tailored to the needs of the proton therapy at PSI
- it is used extensively for commissioning and set-up
- it worked successfully for patient treatment