Beam Diagnostics at High Power Proton Beam Lines and Targets at PSI

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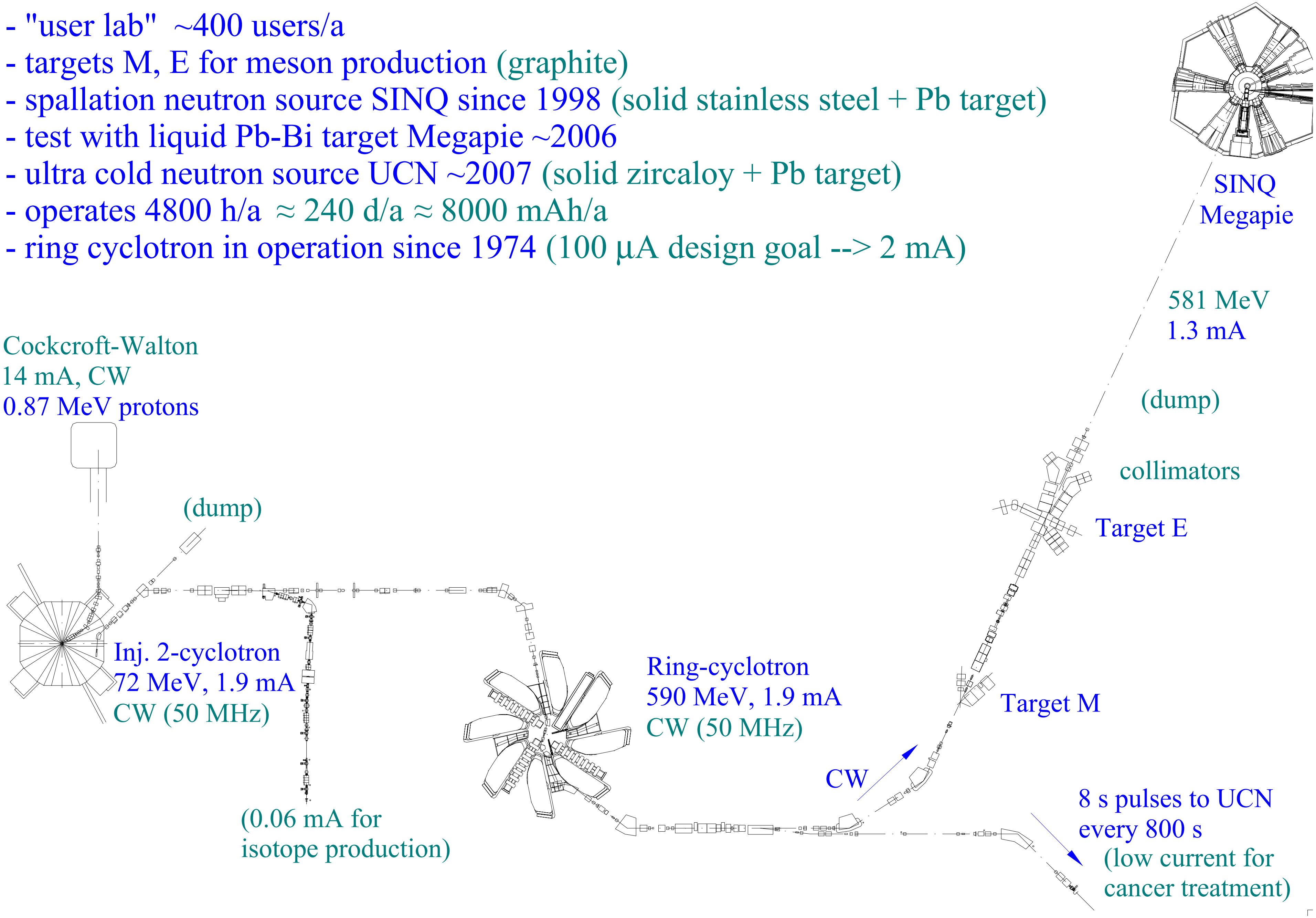
Paul Scherrer Institut, Villigen-PSI, Switzerland

Beam Diagnostics at High Power Proton Beam Lines and Targets at PSI

- introduction facility / overview diagnostics
- thermal damage / beam line and target protection
- profile monitors, BPMs
- electronics
- radiation / handling / infrastructure

PSI high power proton accelerator facility

- "user lab" ~400 users/a
- targets M, E for meson production (graphite)
- spallation neutron source SINQ since 1998 (solid stainless steel + Pb target)
- test with liquid Pb-Bi target Megapie ~2006
- ultra cold neutron source UCN ~2007 (solid zircaloy + Pb target)
- operates 4800 h/a ≈ 240 d/a ≈ 8000 mAh/a
- ring cyclotron in operation since 1974 (100 µA design goal --> 2 mA)



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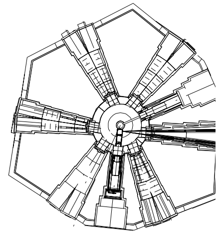

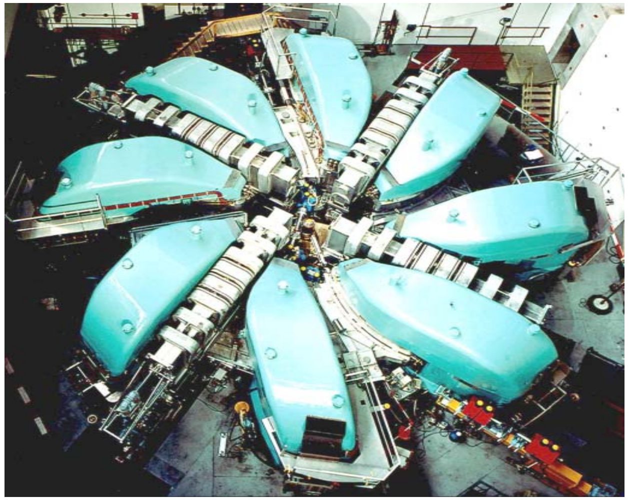

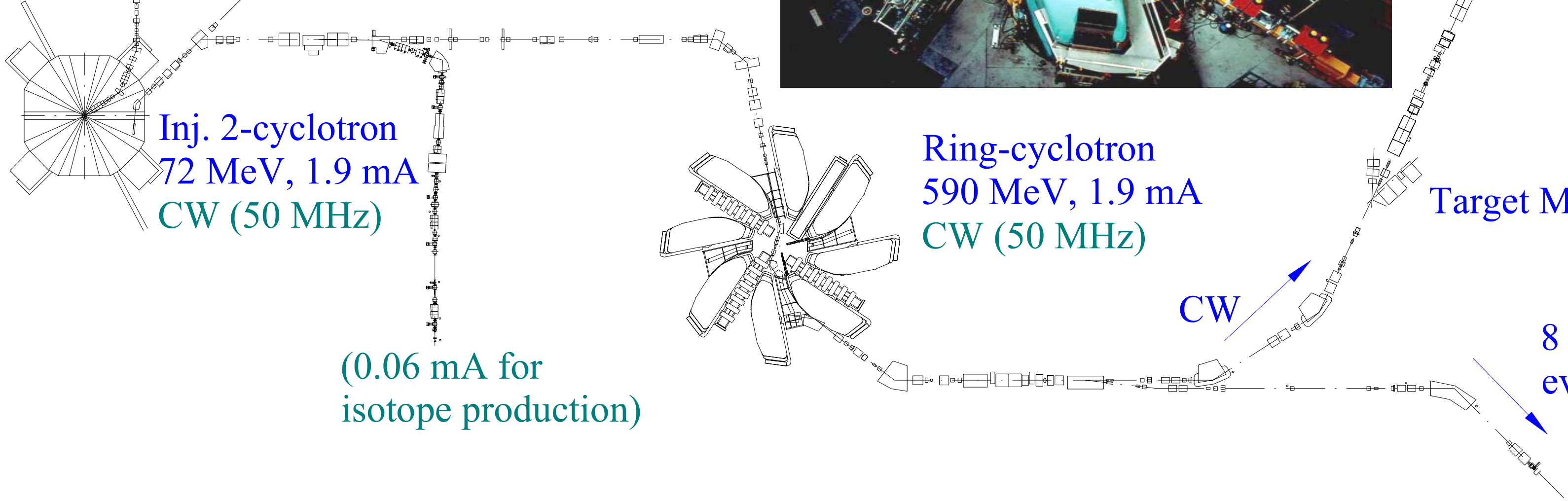

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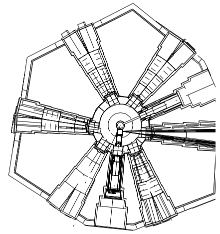

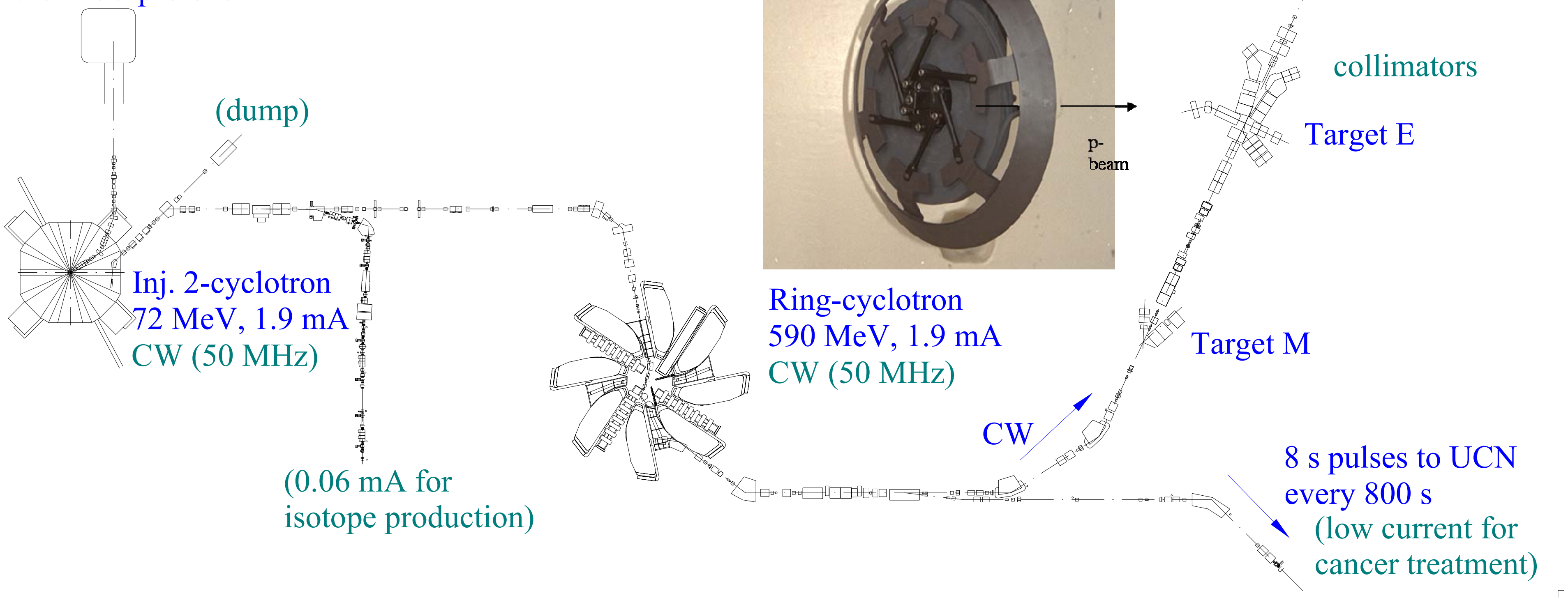

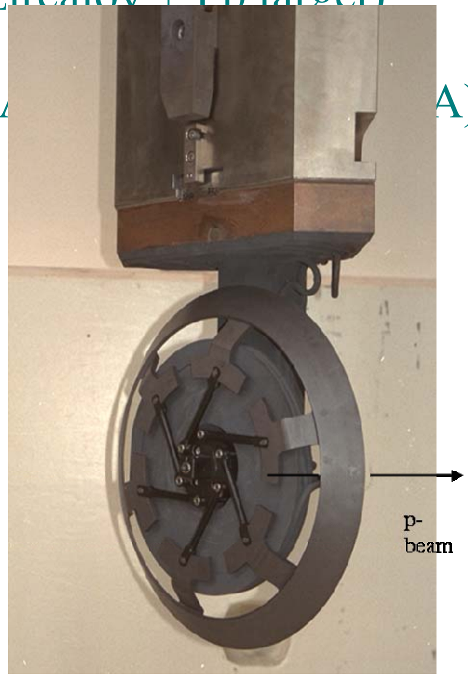

PSI high power proton accelerator facility

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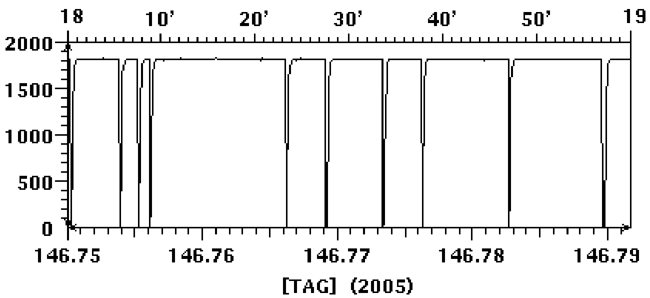
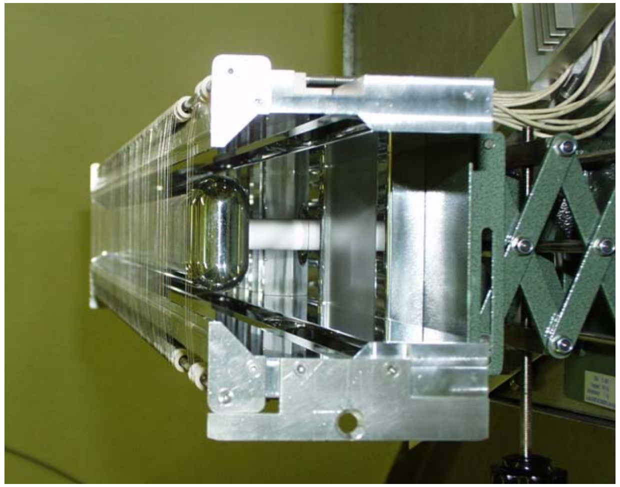
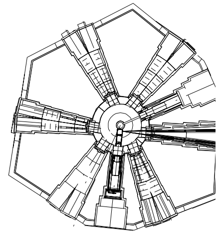
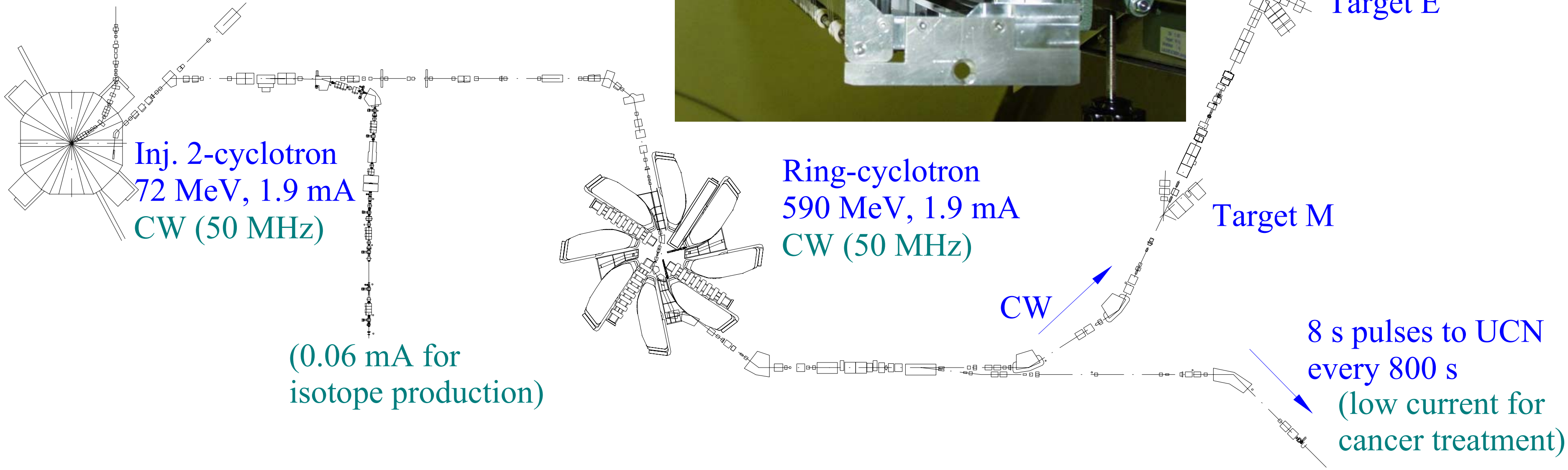


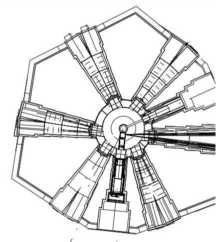


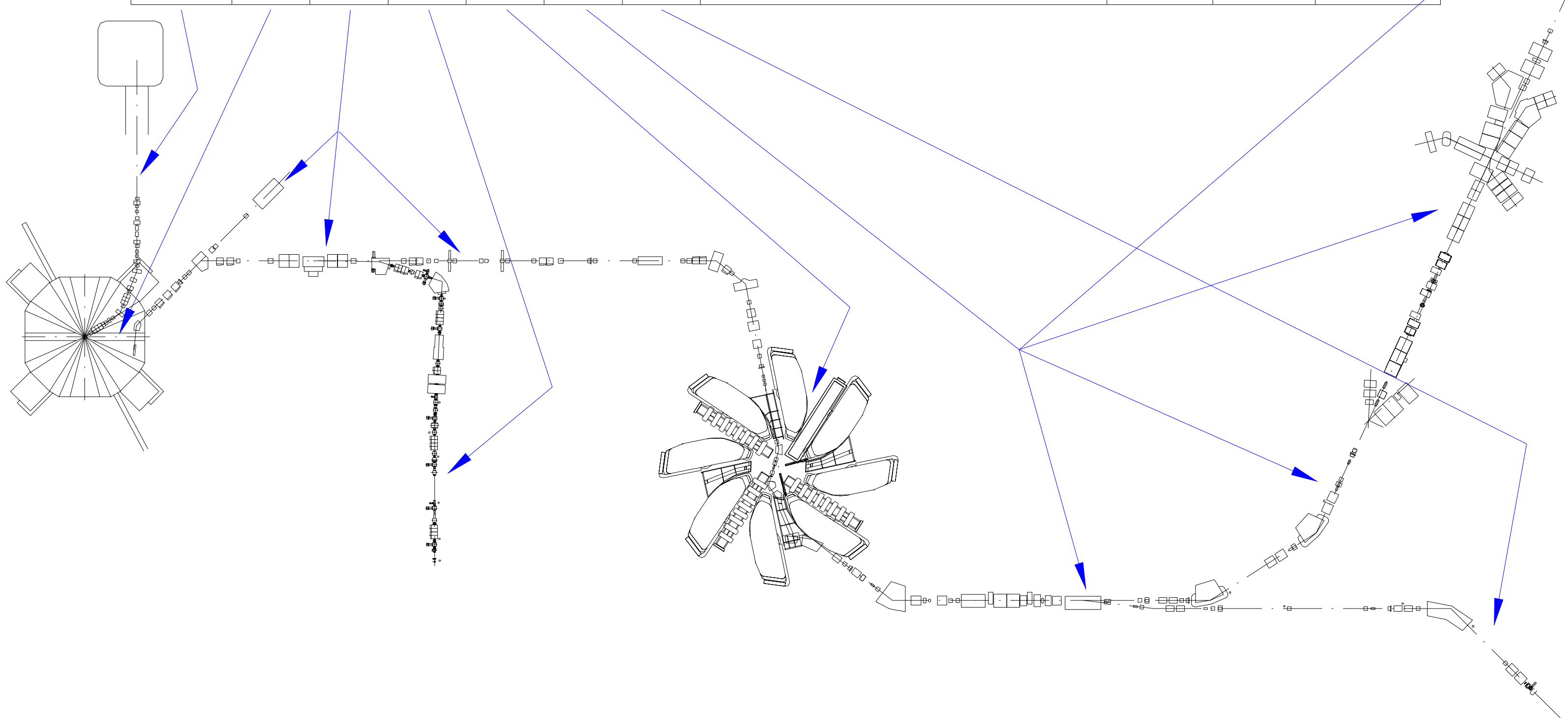




Overview Diagnostics

								setup & tuning	online beam adjust.	machine protection
26		43	15	1	54	30	wire profiles (1 direction)	x		
10							light profiles (1 direction)	x		
						2	harps (both directions)	x		x
		38	14		31	34	bpms (1 direction)	x	x	
1 (DCCT)		3	2		6	1	current monitors	x	x	x
2	1	3	2	2	1		stoppers/dumps	x		
34	23	32	10	18	33	3	collimators (fixed/movable)	x	(1)	x
		2	2	2	17	6	segmented aperture foils (mostly 4 sectors)	x		x
	8	23	9	14	30	15	ionisation chambers	x		x
	5			5			wire probes	x		
	8	1		13			phase probes	x	x	
	1	1		1			time structure			



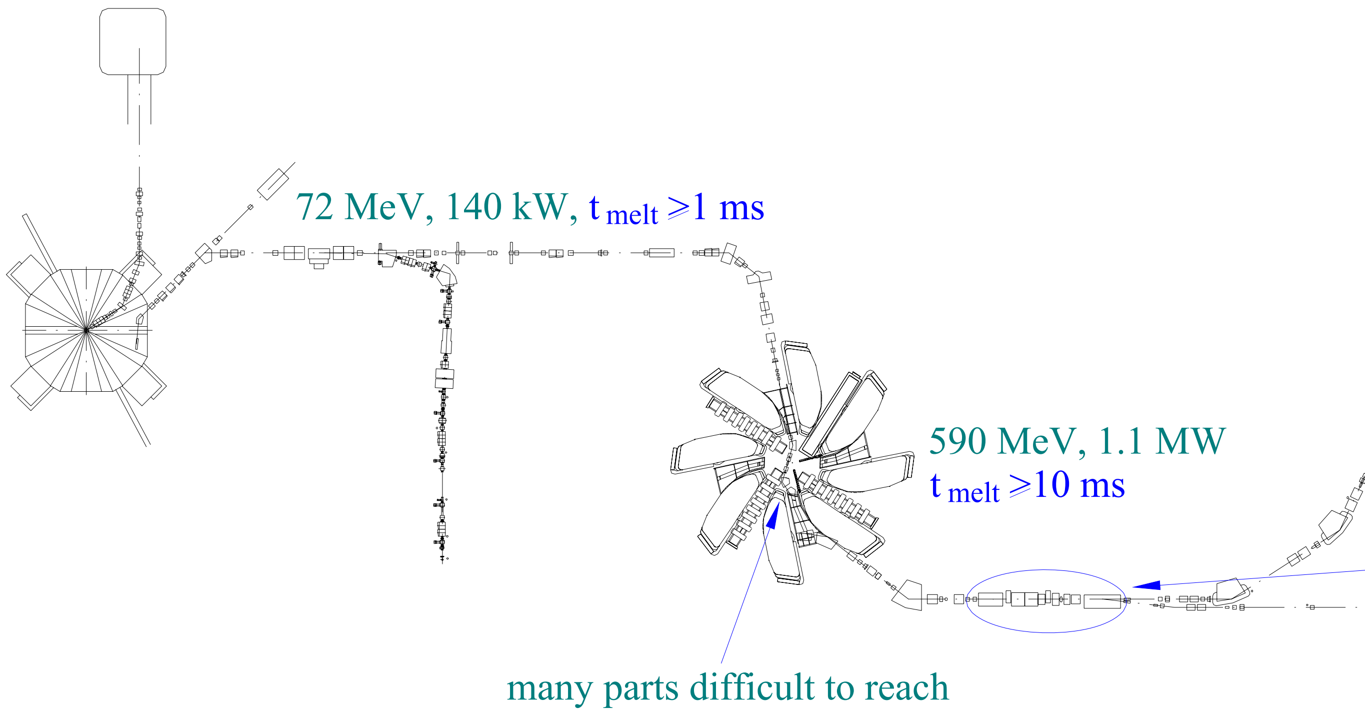


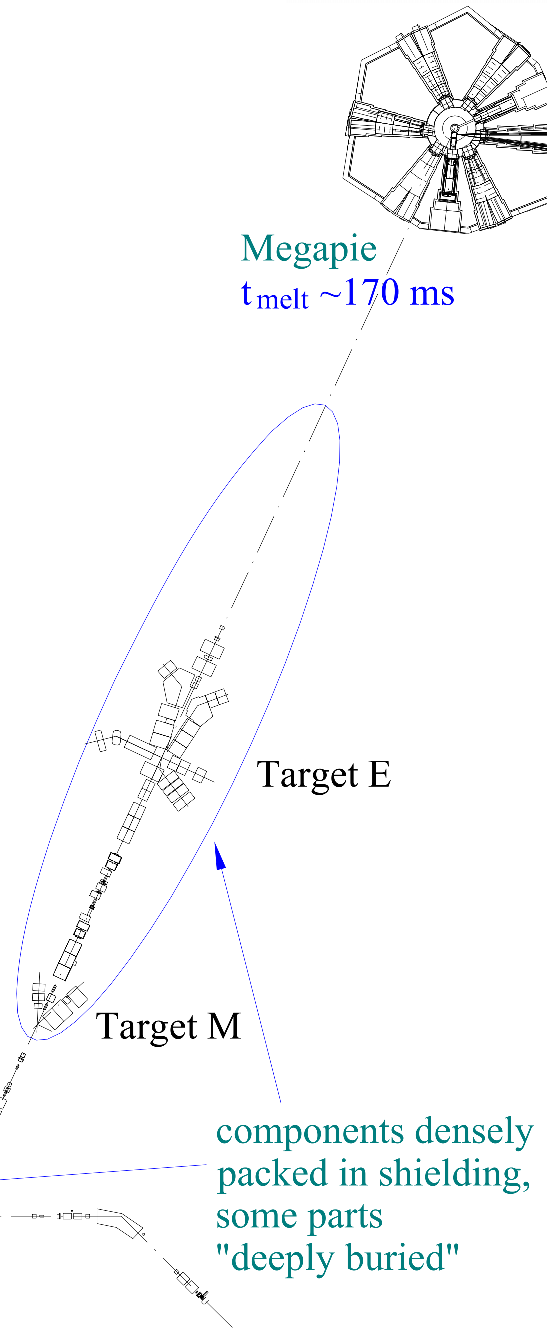
thermal damage

- melting of beam line/cyclotron components by missteered beam
  --> 2...300 days shut down for replacement/repair/remanufacturing
  (no spare parts for many components,
  sometimes lack of documentation/drawings/exact dimensions)
  time t_{melt} depending on beam diameter/energy

- melting of Megapie target and window by too concentrated beam
  (if beam misses Target E: current density increases by a factor 25)
  --> ~300 days shut down

- fast interlock generation needed (<1 ms)

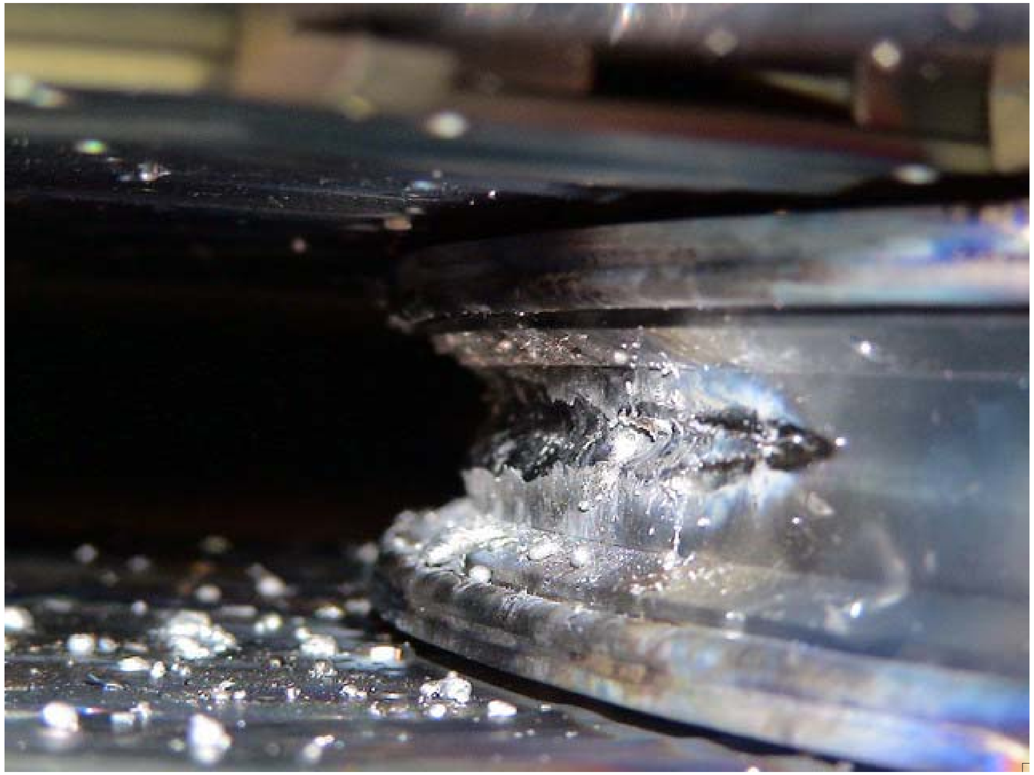




thermal damage

injection into Ring cyclotron:
- collimator (copper/carbon) /
- coil support

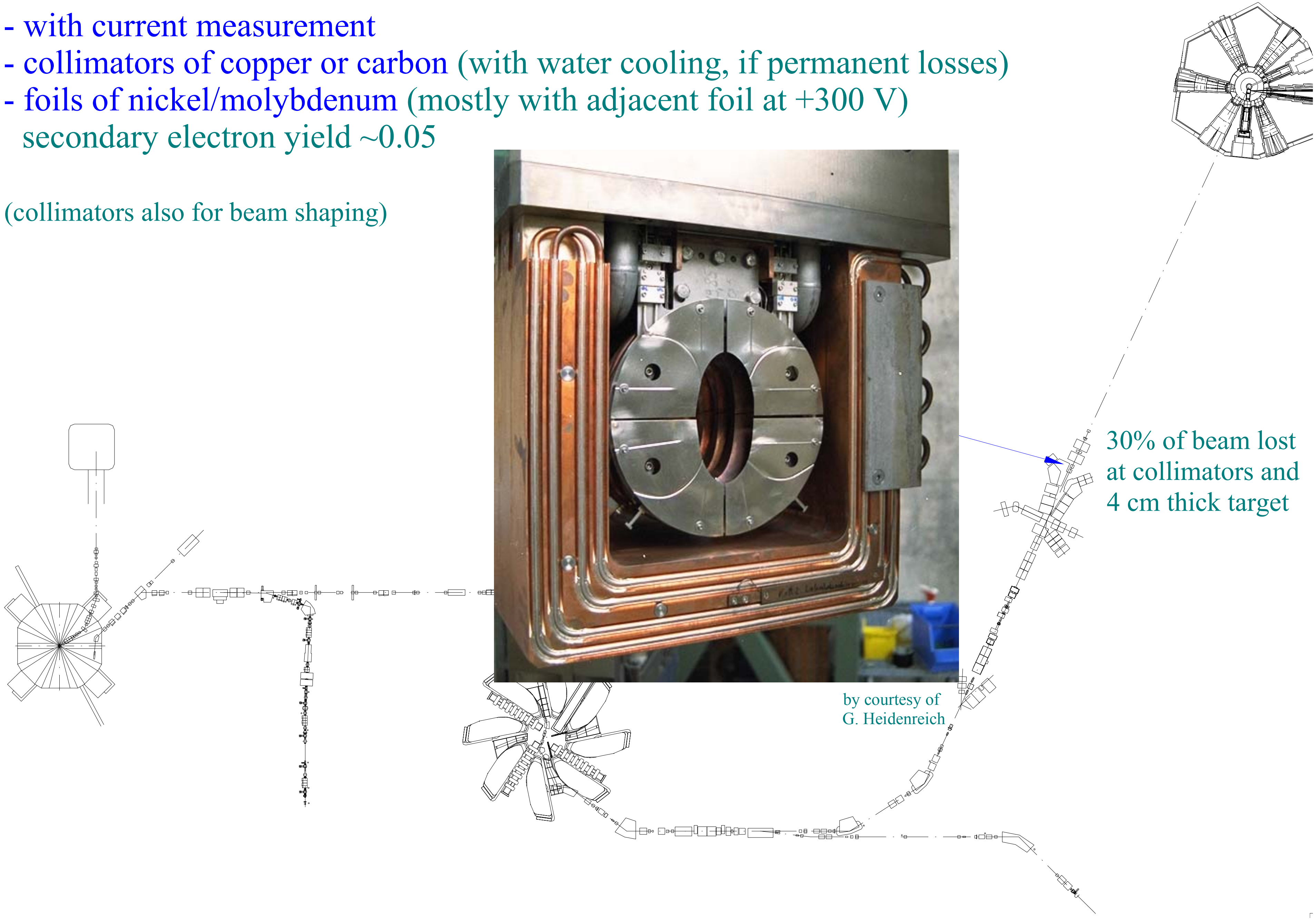
(defect of high-level interlock module, Nov. 2004)



machine protection 1) collimators/segmented aperture foils

- with current measurement
- collimators of copper or carbon (with water cooling, if permanent losses)
- foils of nickel/molybdenum (mostly with adjacent foil at +300 V)
  secondary electron yield ~0.05

(collimators also for beam shaping)



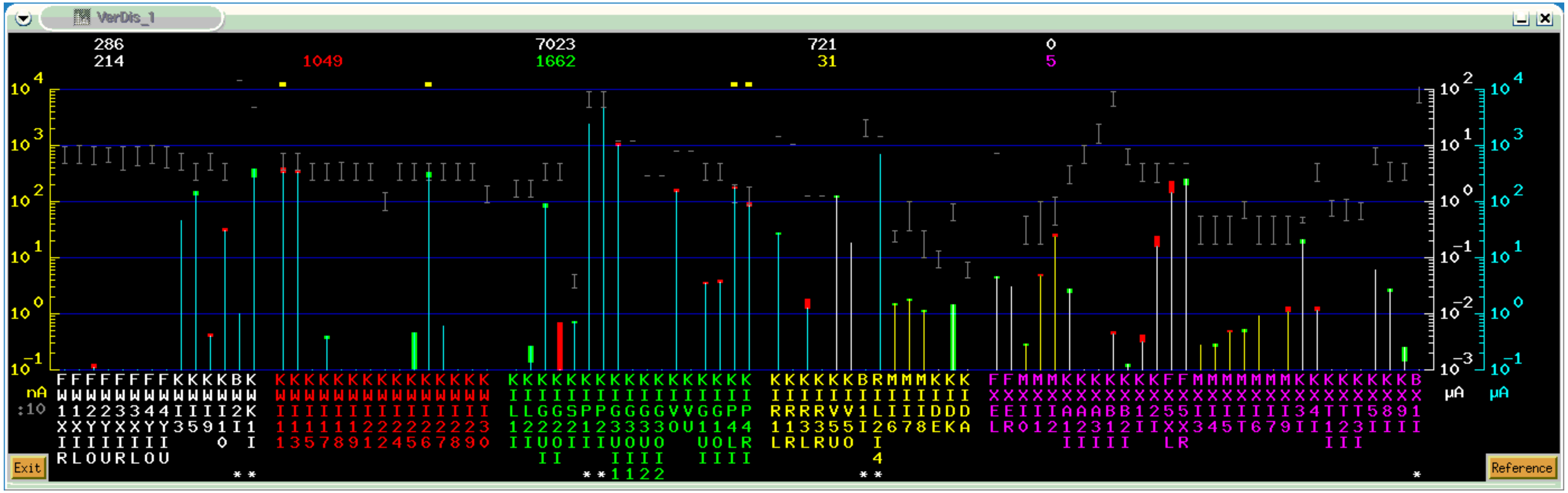
by courtesy of
G. Heidenreich

30% of beam lost
at collimators and
4 cm thick target

also important for tuning:

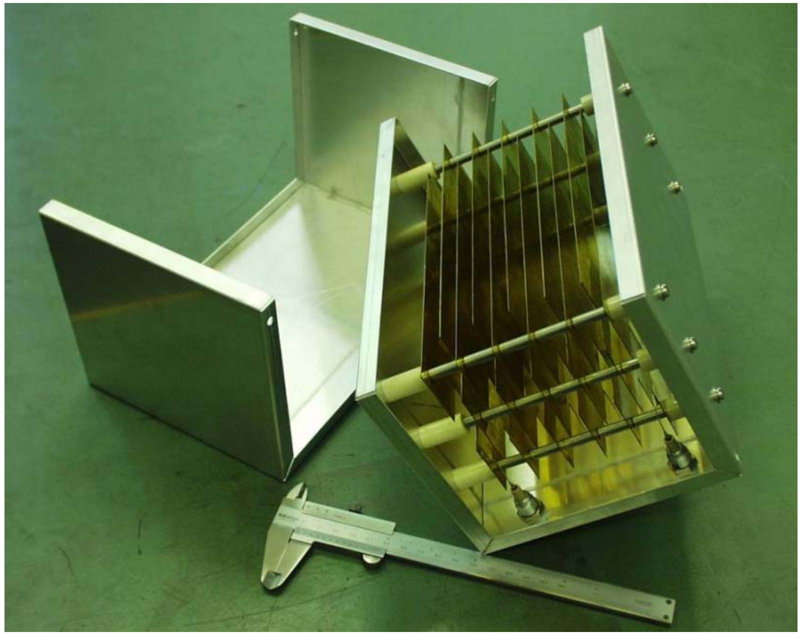
changes of collimator and ionisation chamber currents

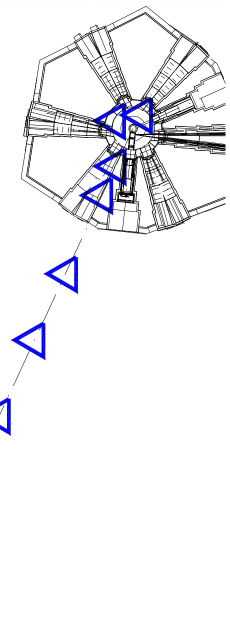
(here between the cyclotrons)

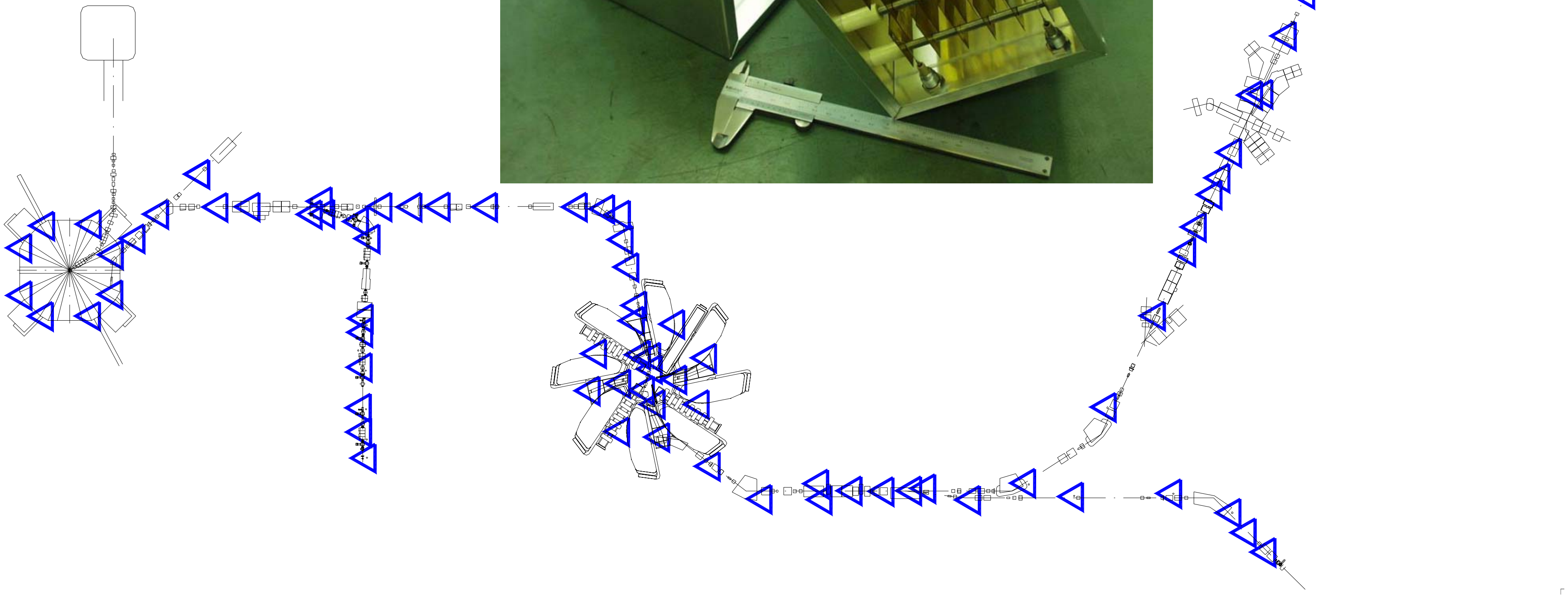


machine protection 2) loss monitoring with ionisation chambers

- placed ~0.1...1 m from beam, fixed position for reproducibility
- useful at beam energies >40 MeV = proton range in steel > 3 mm
- ambient air filled, 300 V, d = 1 cm, 0.002 m
- also circular type around beam tube/cylindrical in shielding
- simple and reliable
- to consider for dose estimates:
  scattering in forward direction,
  shielding by components (!),
  neutrons,
  1 nA signal ≙ 1.3 Gy/d

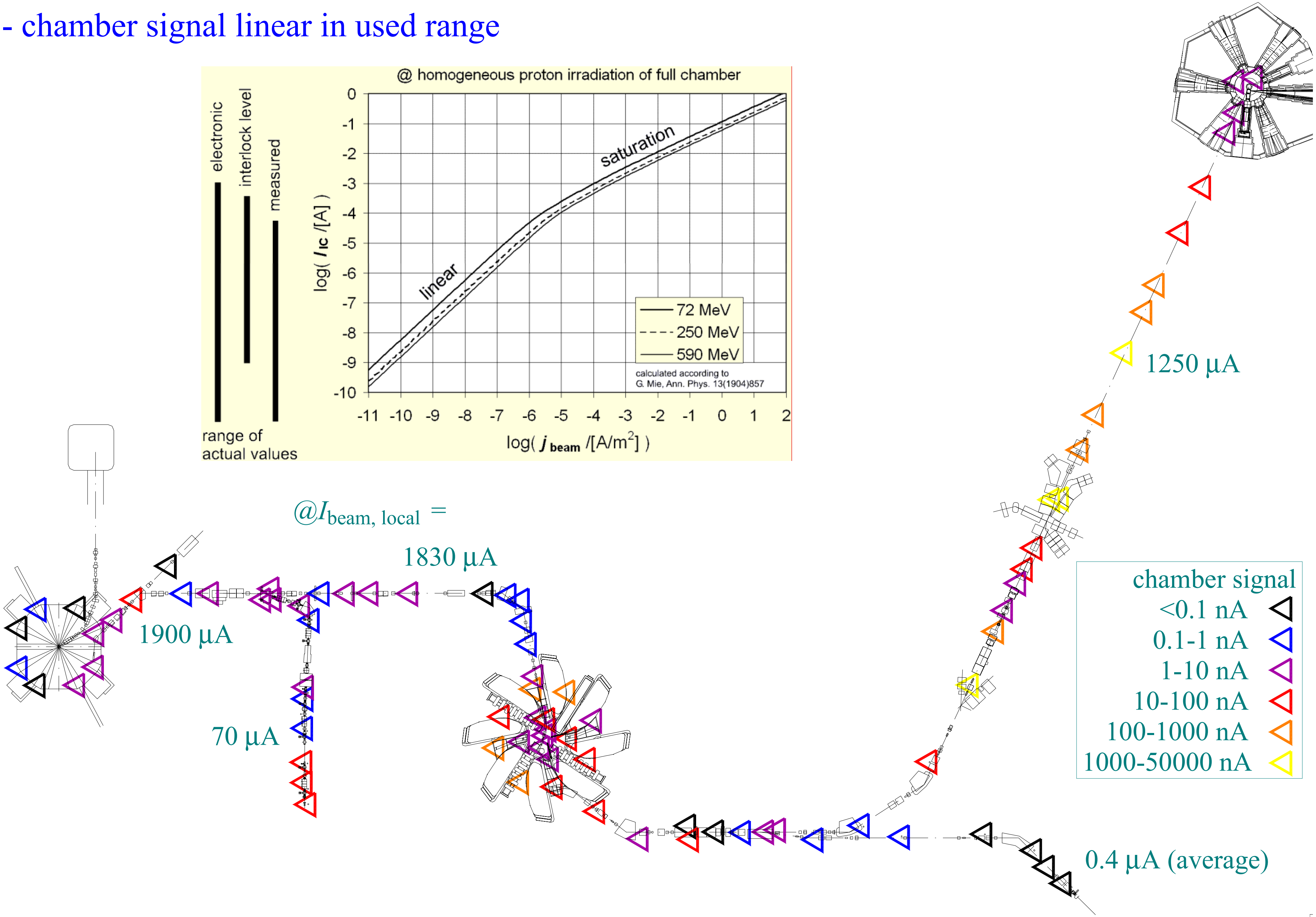






machine protection 2) loss monitoring with ionisation chambers

- chamber signal linear in used range

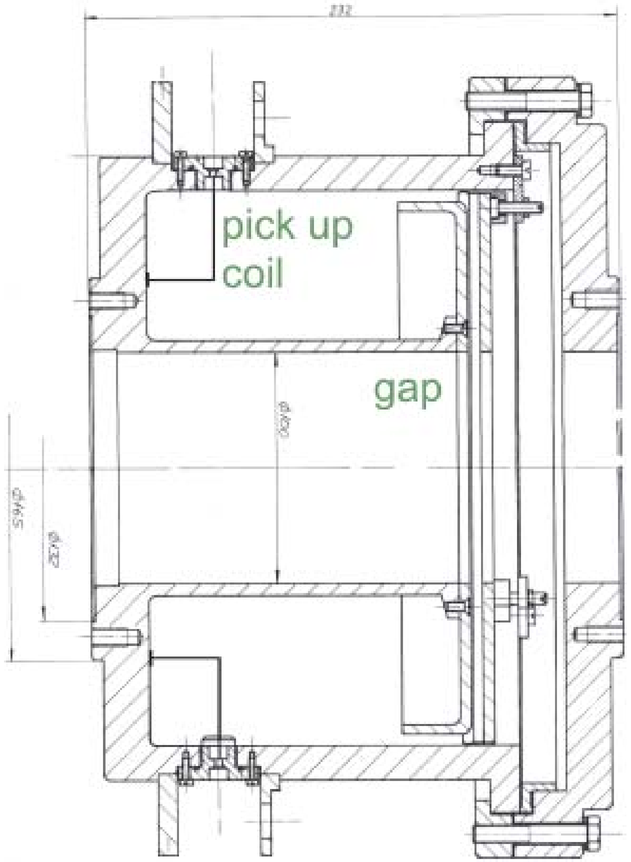


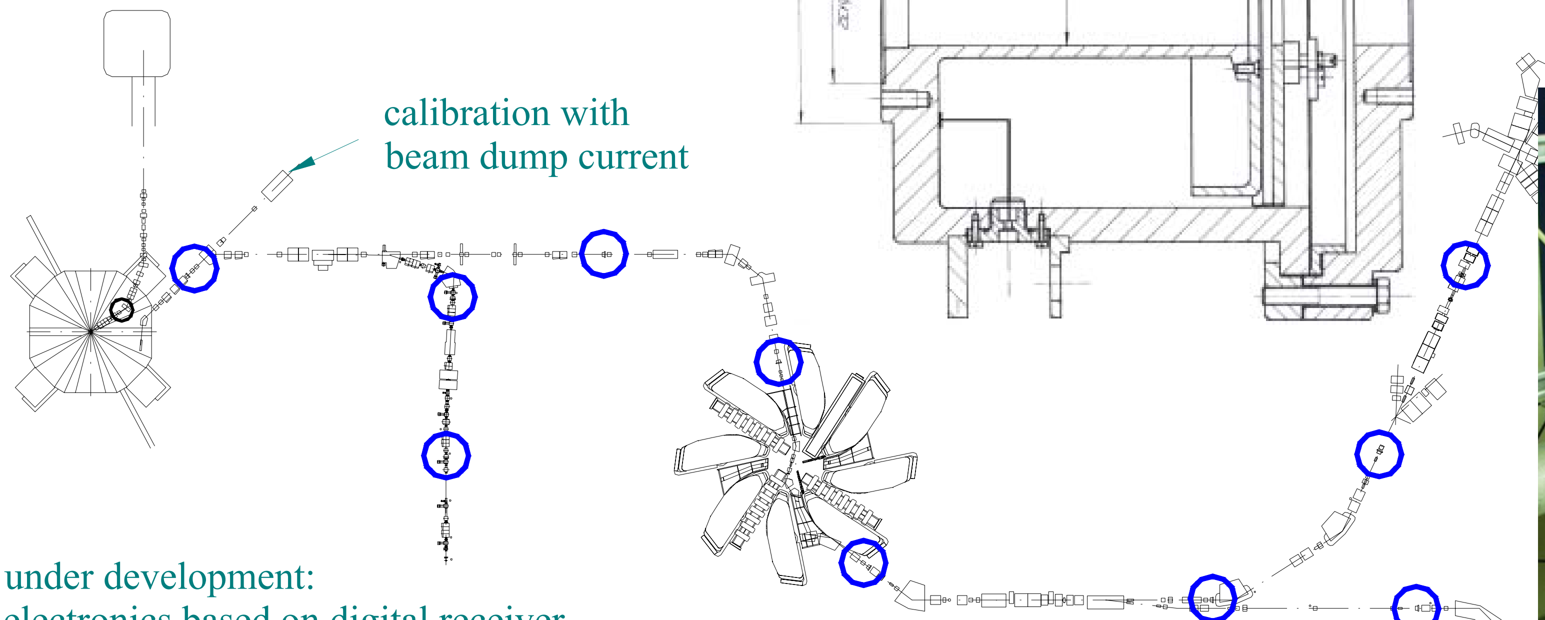
machine protection 3) current monitors/current transmission

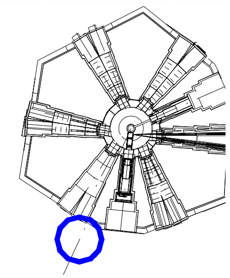
λ/4 resonator excited by axially passing bunches

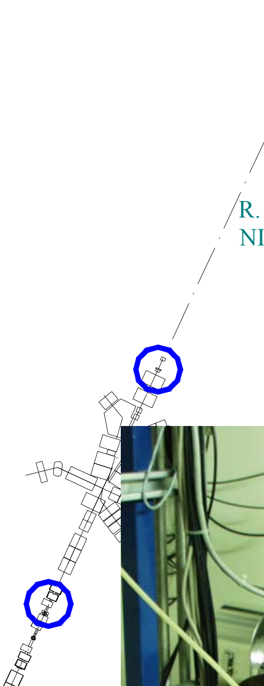
frequency	100 MHZ (2x bunch)
Q cavity	~2000
3dB bandwidth	4 MHz (with filter)
output bandwidth	~10 kHz
dynamic range	0.5 µA ... 2.5 mA
accuracy	~0.5 % calibrated every few days
	~5 % long term

(temperature dependent cable damping
drift of resonator/electronics)



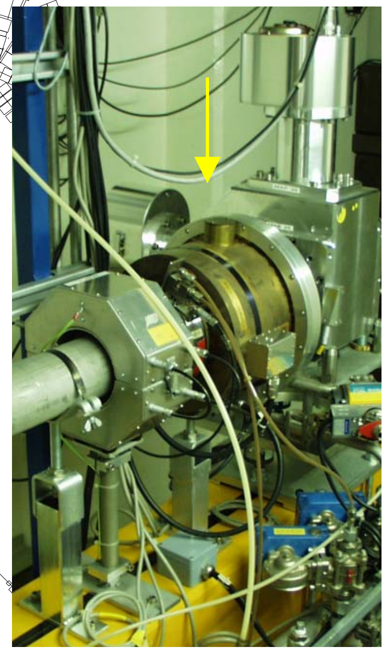






calibration with
beam dump current

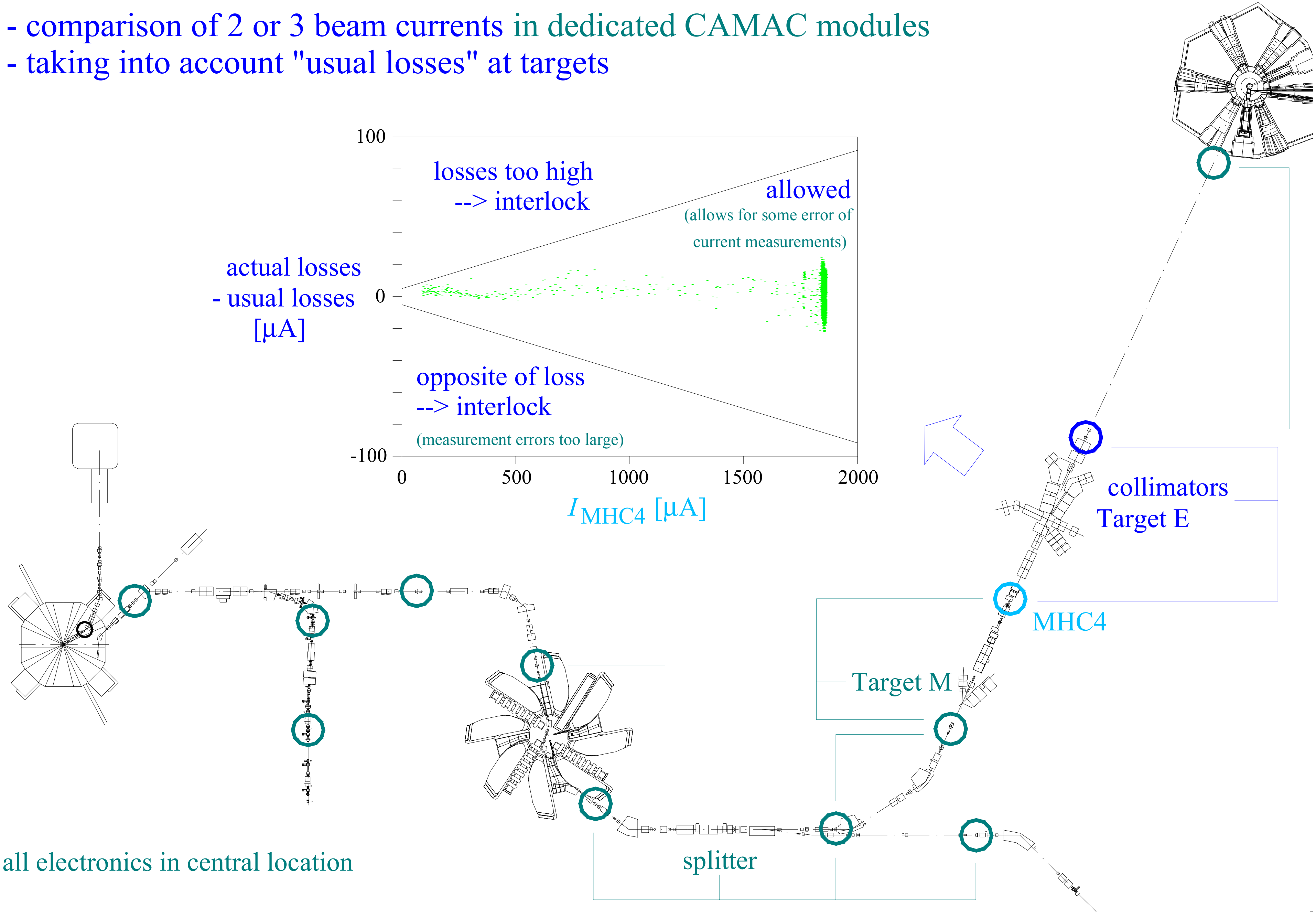
R. Reimann, M. Rüede,
NIM 129 (1975) 53-58



under development:
electronics based on digital receiver
accuracy <1 %, dynamic range 0.05 µA...10 mA

machine protection 3) current monitors/current transmission

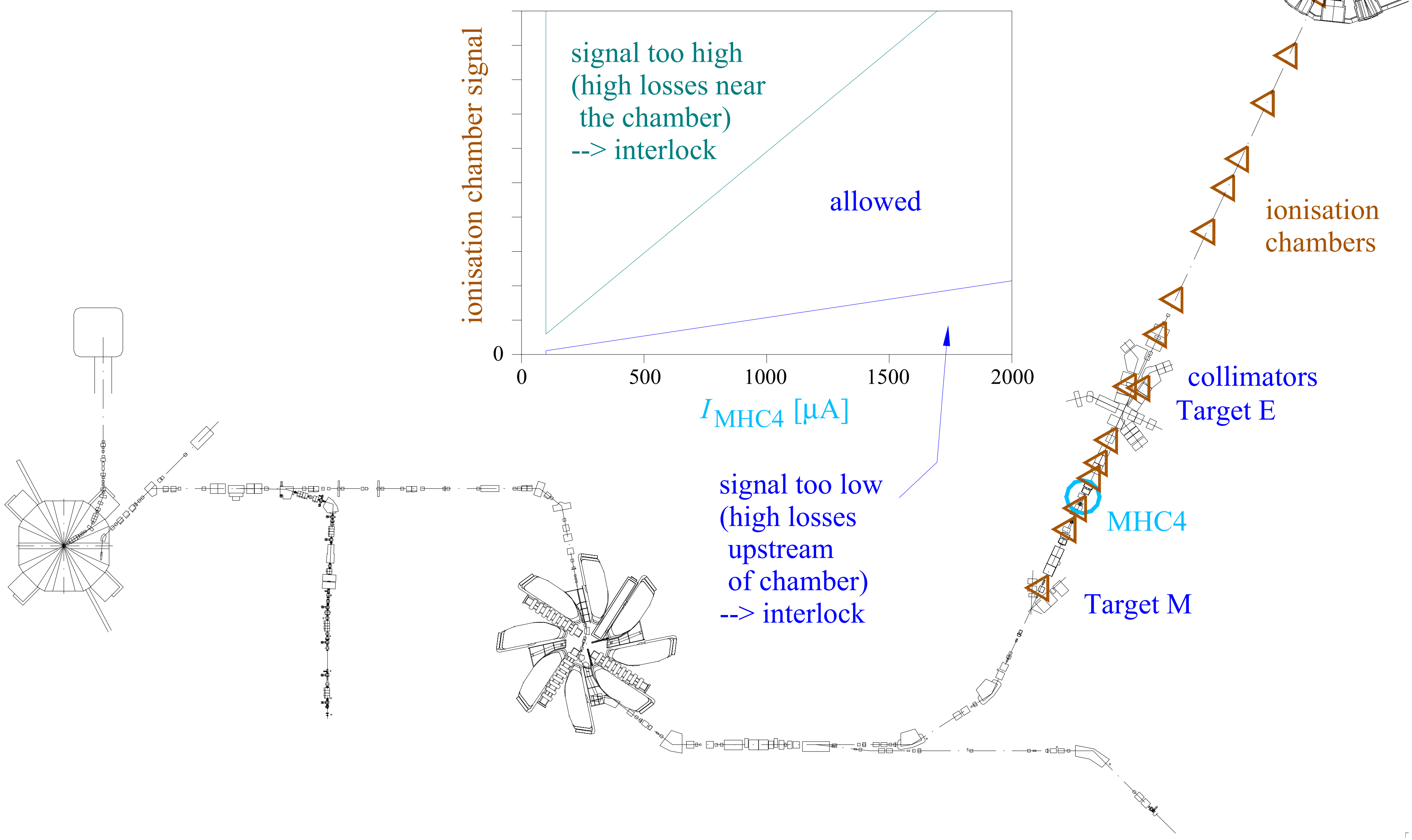
- comparison of 2 or 3 beam currents in dedicated CAMAC modules
- taking into account "usual losses" at targets



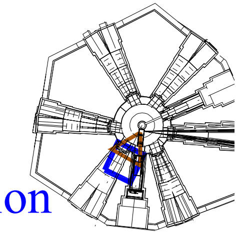
all electronics in central location

machine protection 4) quasi current transmission via loss monitors

- upper and lower interlock limit of ionisation chamber current proportional to beam current I_{MHC4}
- implemented for chambers behind Target M
  (losses proportional to beam current)
- applied at beam current >100 µA



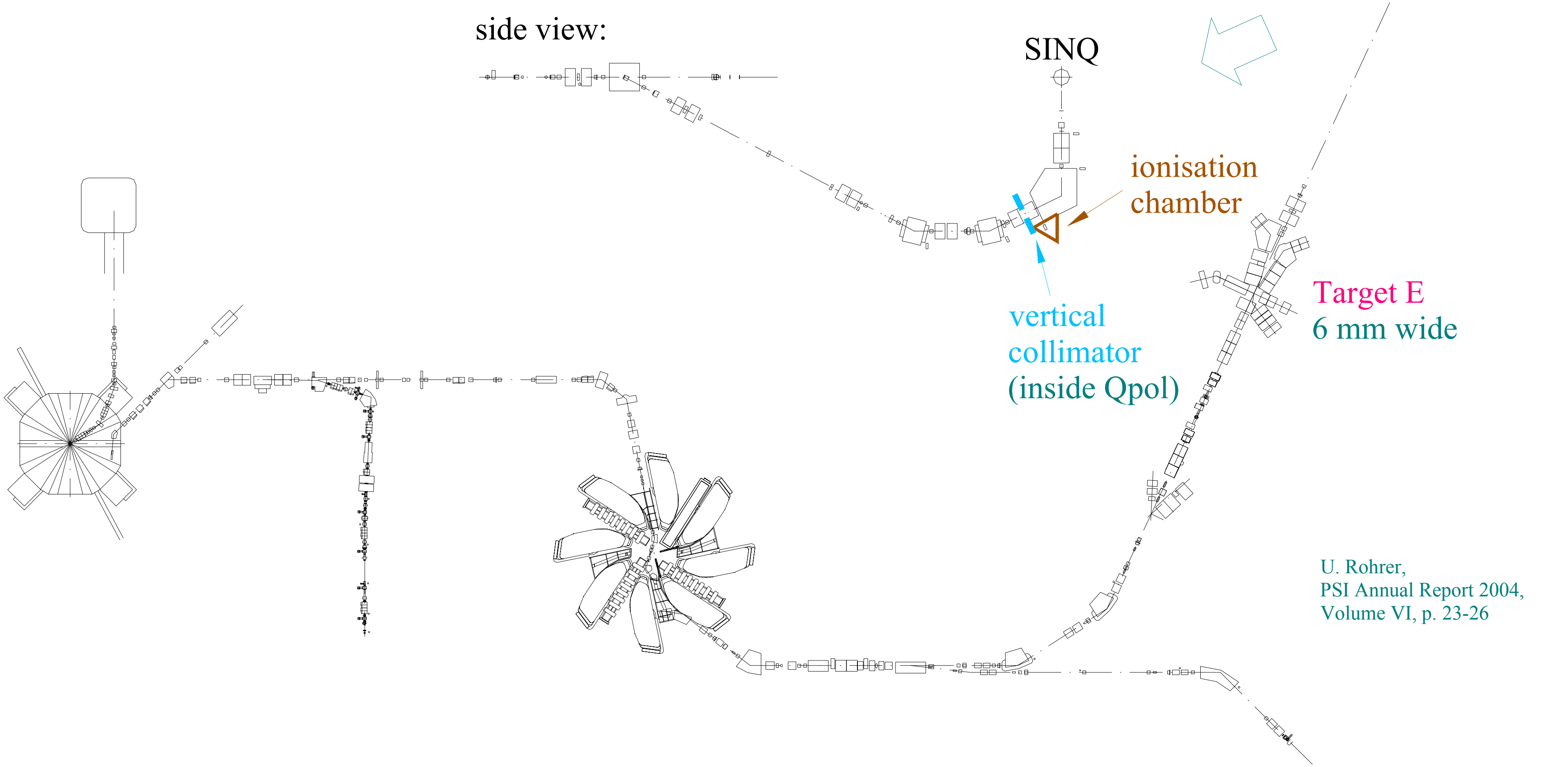
spallation target protection 1)/2) transmission/shift on collimator



if the beam misses Target E --> no scattering --> too concentrated beam

- and 1) no current loss --> interlock from current transmission

- and 2) no energy loss --> beam shifted onto collimator in dispersive transport section
  --> fully passive stopping of bad beam fraction
  --> interlocks from collimator current/chamber current
  generated if ~1‰ of beam misses Target E

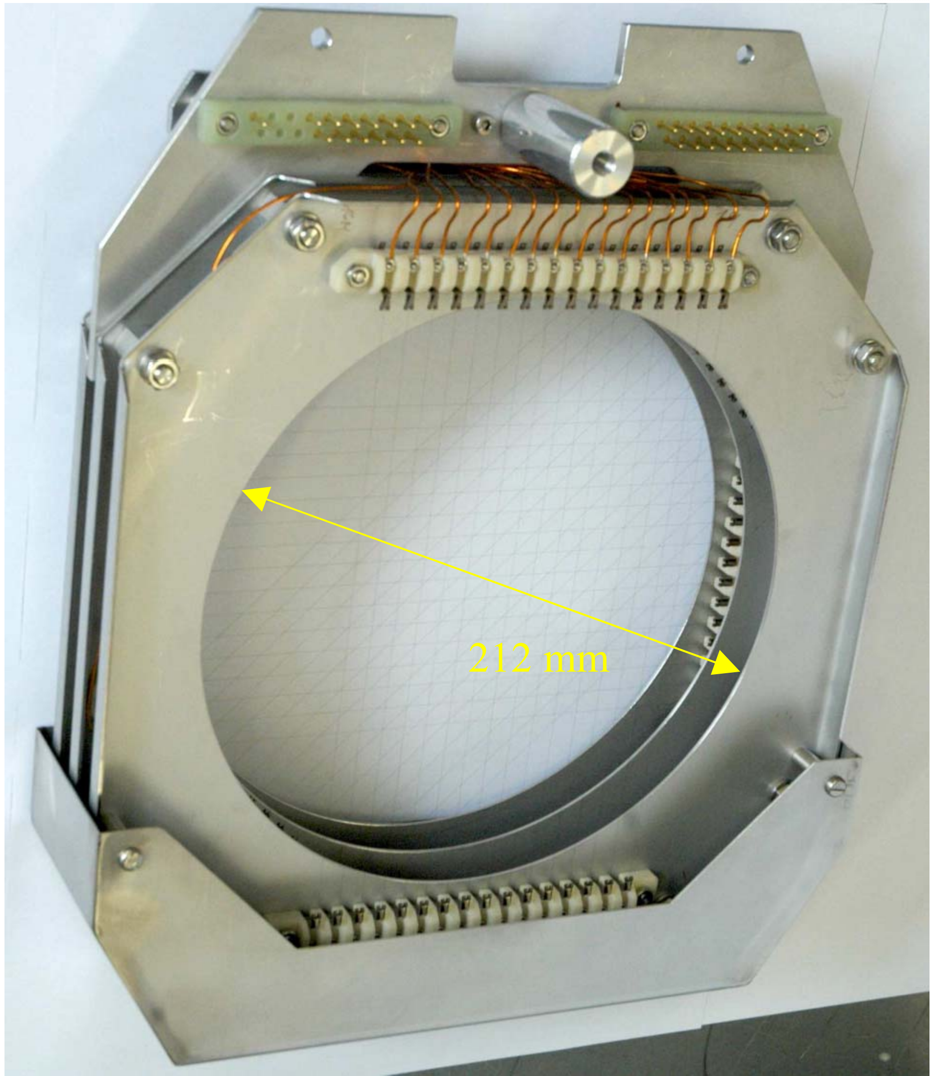


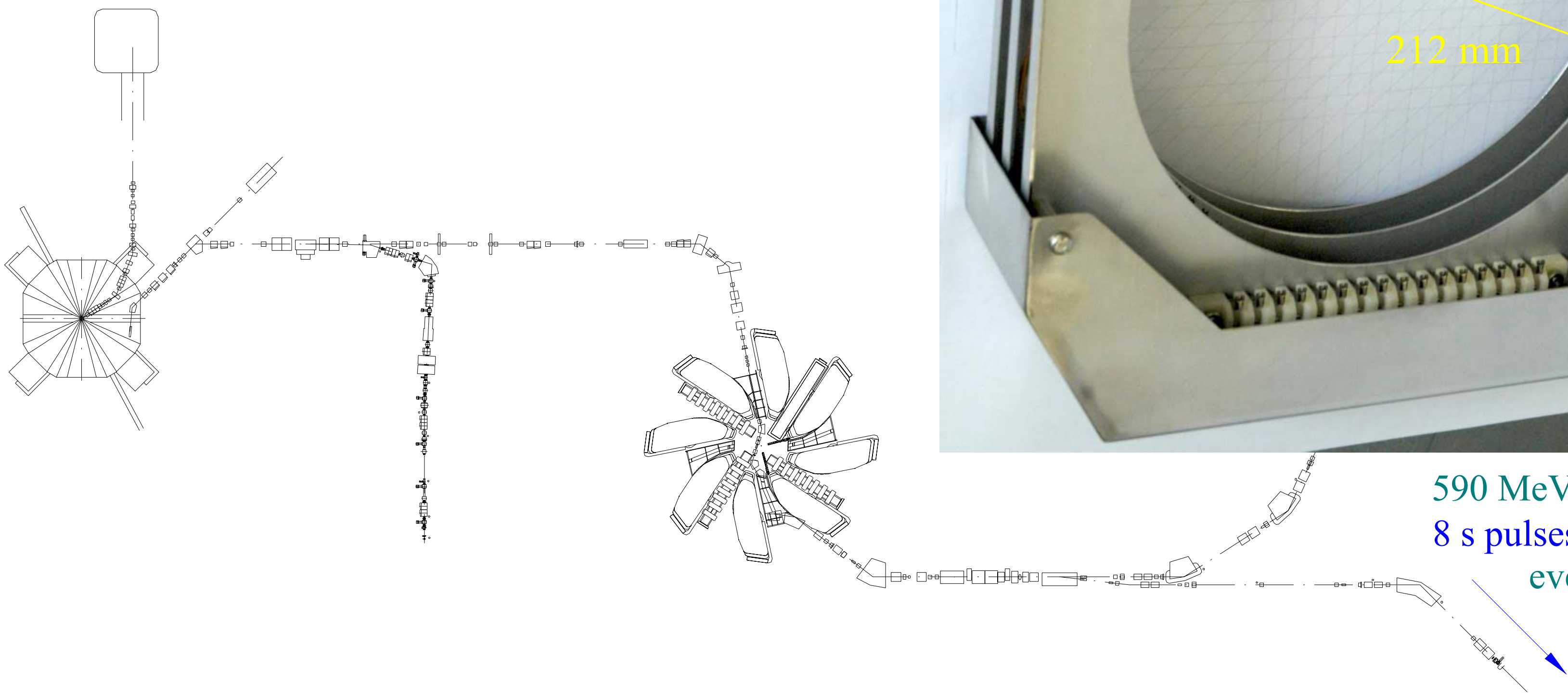
U. Rohrer,
PSI Annual Report 2004,
Volume VI, p. 23-26

spallation target protection 3) harps

harps for UCN: 4 m and 8 m in front of target

- 16 horizontal wires / 16 vertical wires for measurement
- wire pitch 8 mm
- 40 µm molybdenum wires (clamped)
  (molybdenum not far from thermionic emission
  @ nominal beam parameters & long pulses)
- 16 intermediate diagonal wires at +300 V bias
- retractable
- comissioning 2007



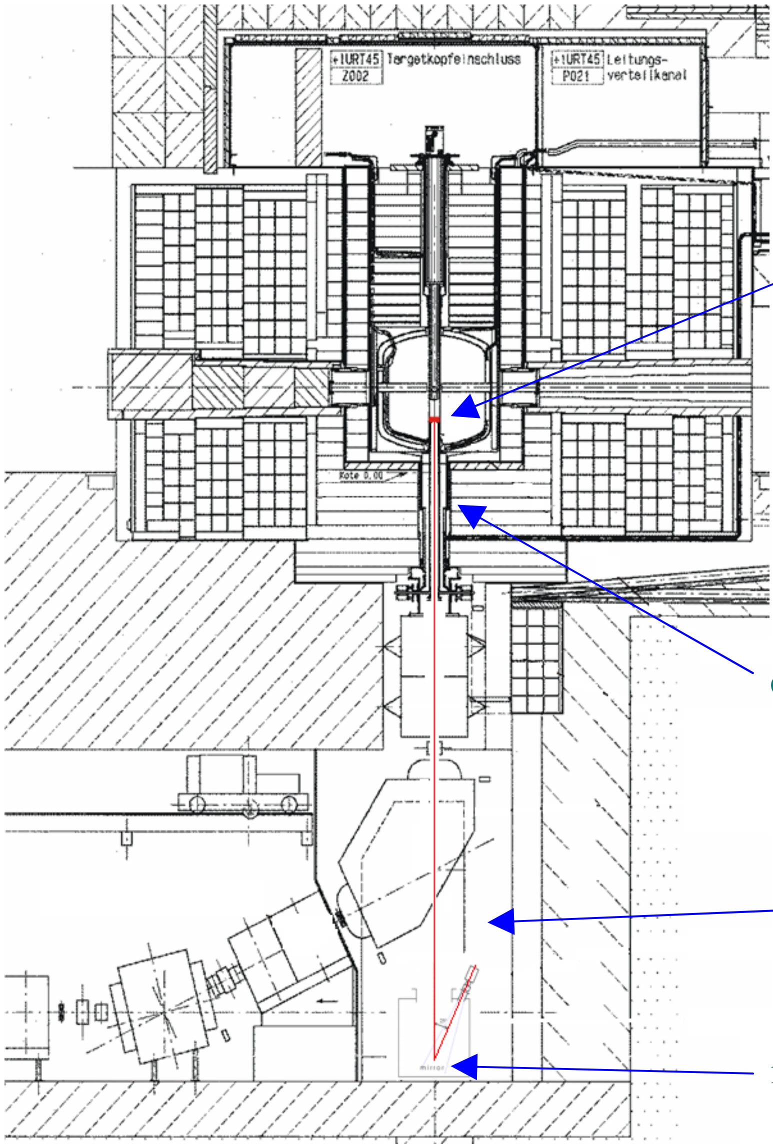


590 MeV, 1.9 mA
8 s pulses to UCN
every 800 s

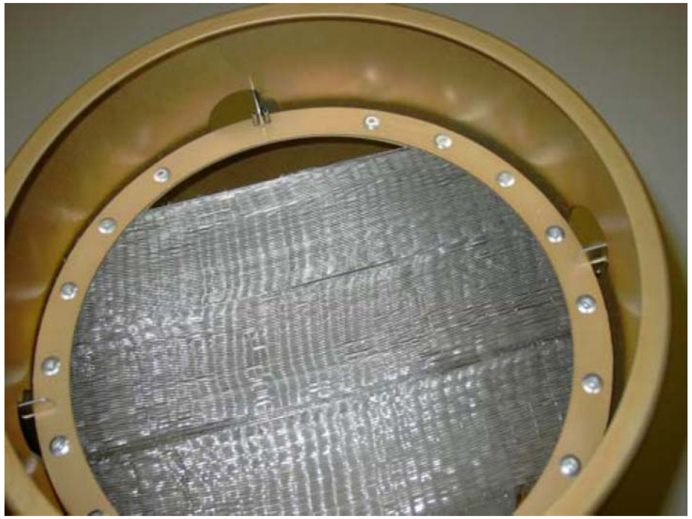
spallation target protection 4) glowing sieve

video observation of thermal radiation from a tungsten sieve heated by the beam

- for Megapie, tested at SINQ ("VIMOS")

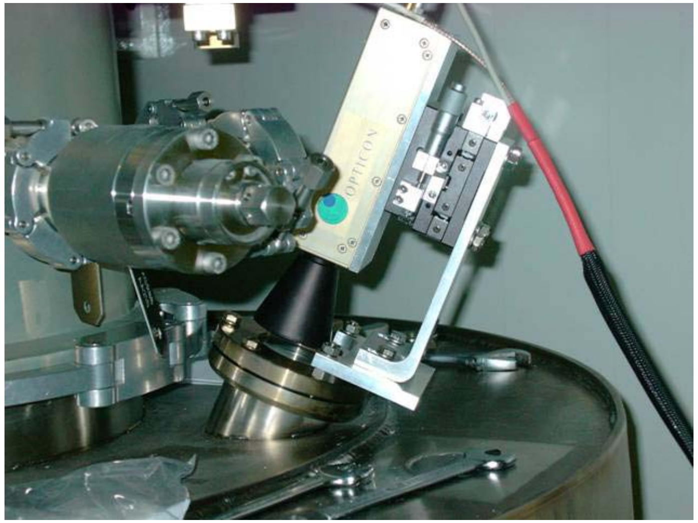


tungsten sieve
0.3 m in front
of target window



collimator

chalnicon radiation hard camera (no lens!)



mirror

spallation target protection 4) glowing sieve

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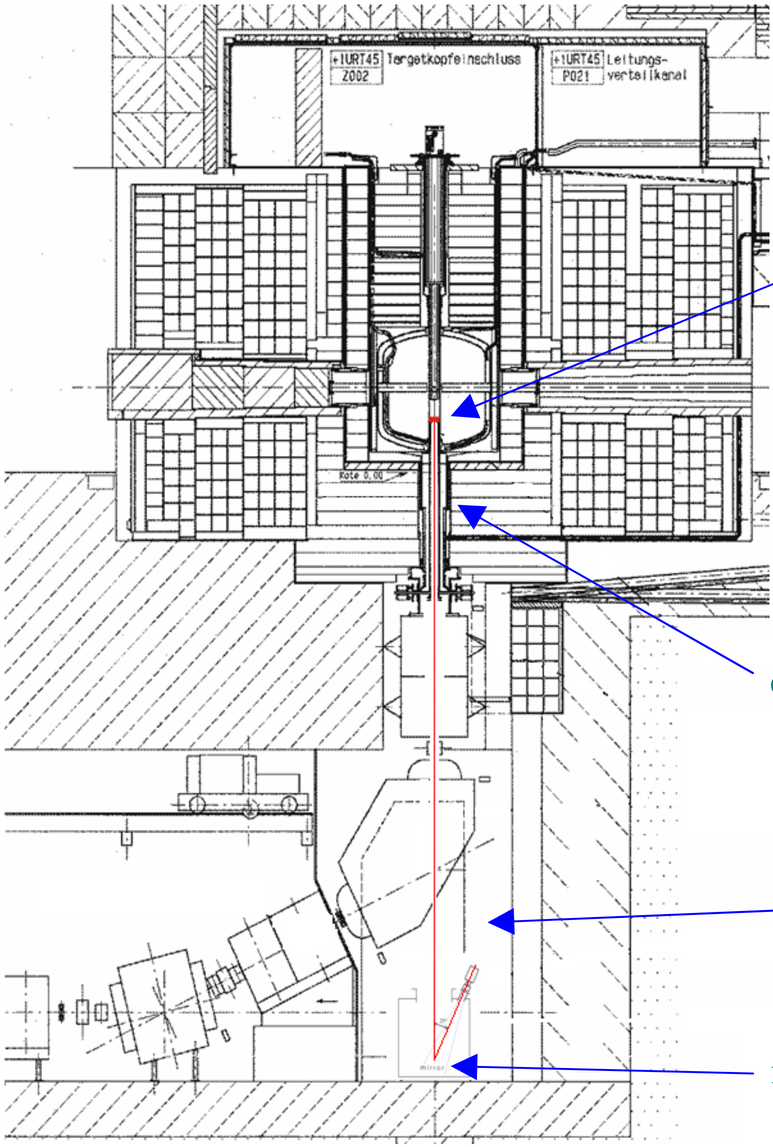

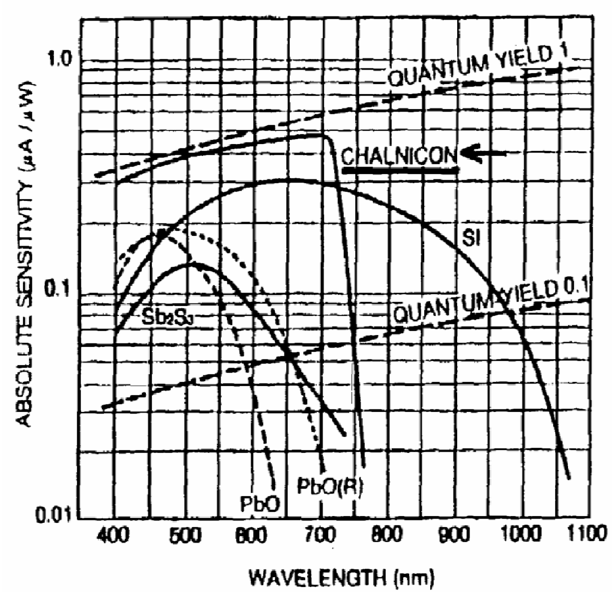

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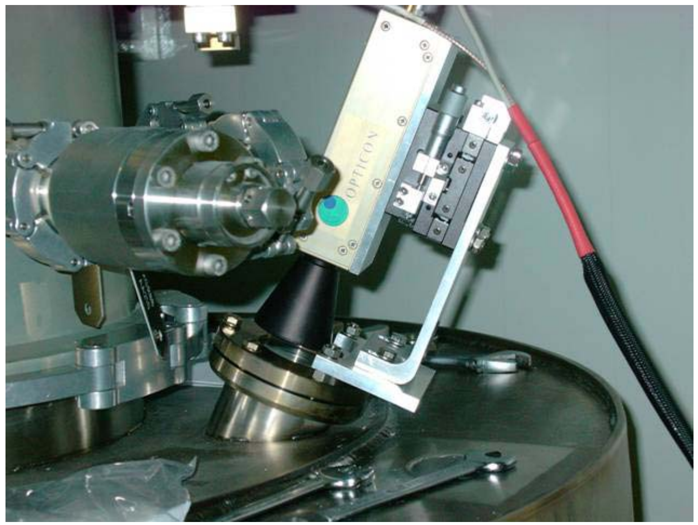

spallation target protection 4) glowing sieve

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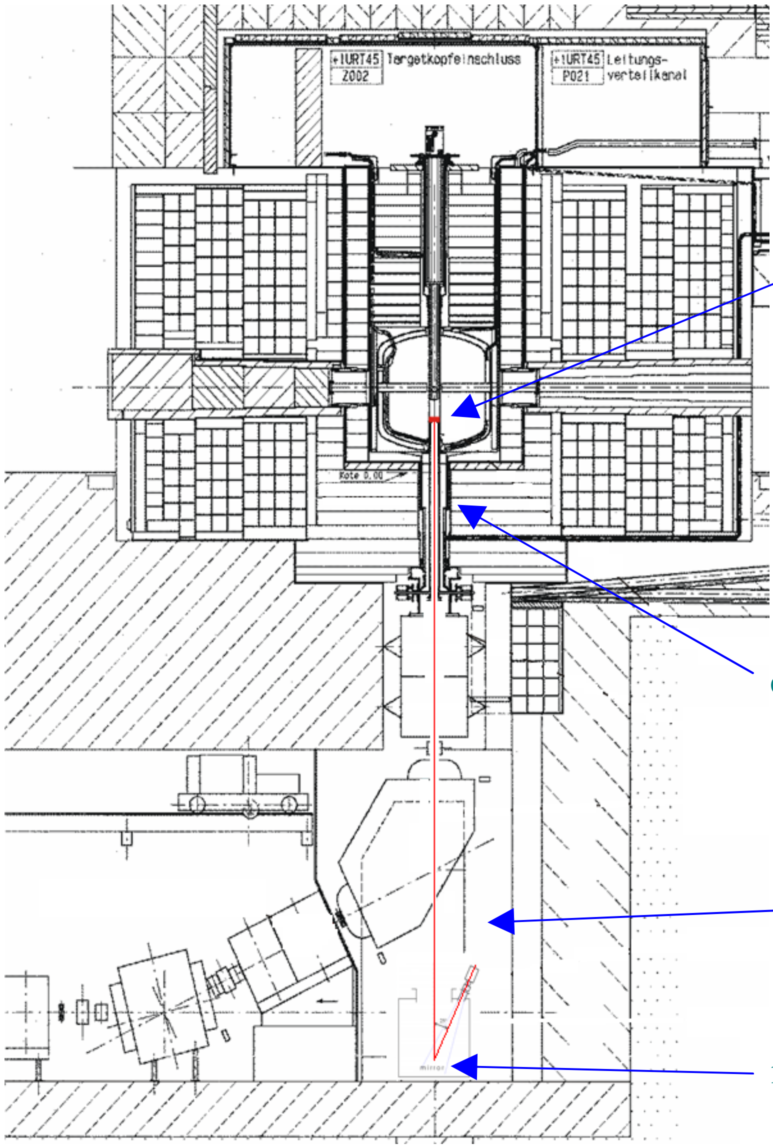
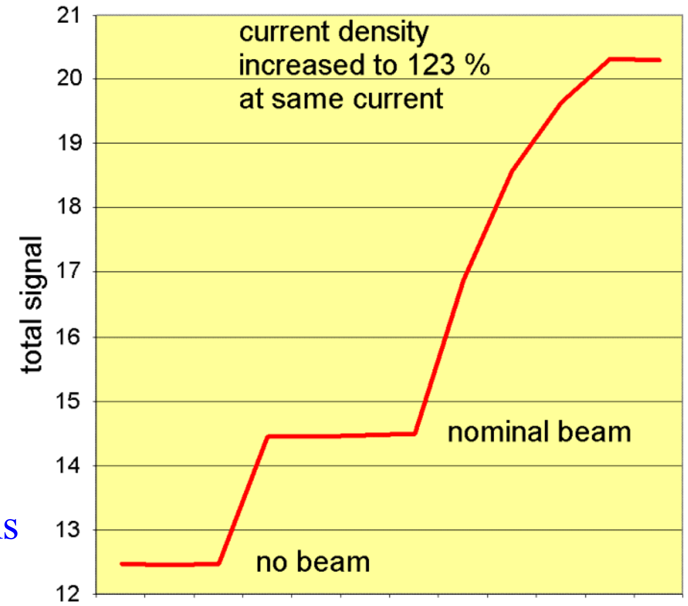


tungsten sieve
0.3 m in front
of target window

- signal from 1000°C
- position ~ ±~1 mm
- time resolution ~40 ms

collimator

mirror



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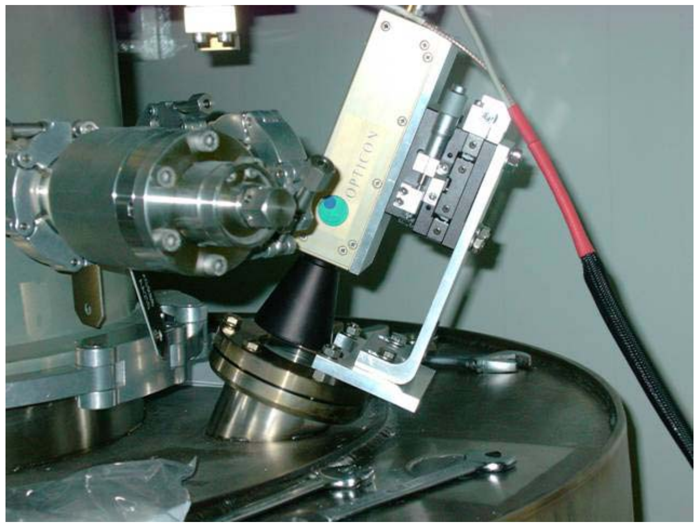
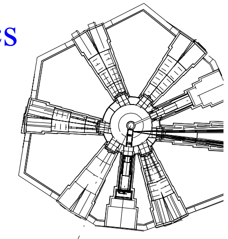
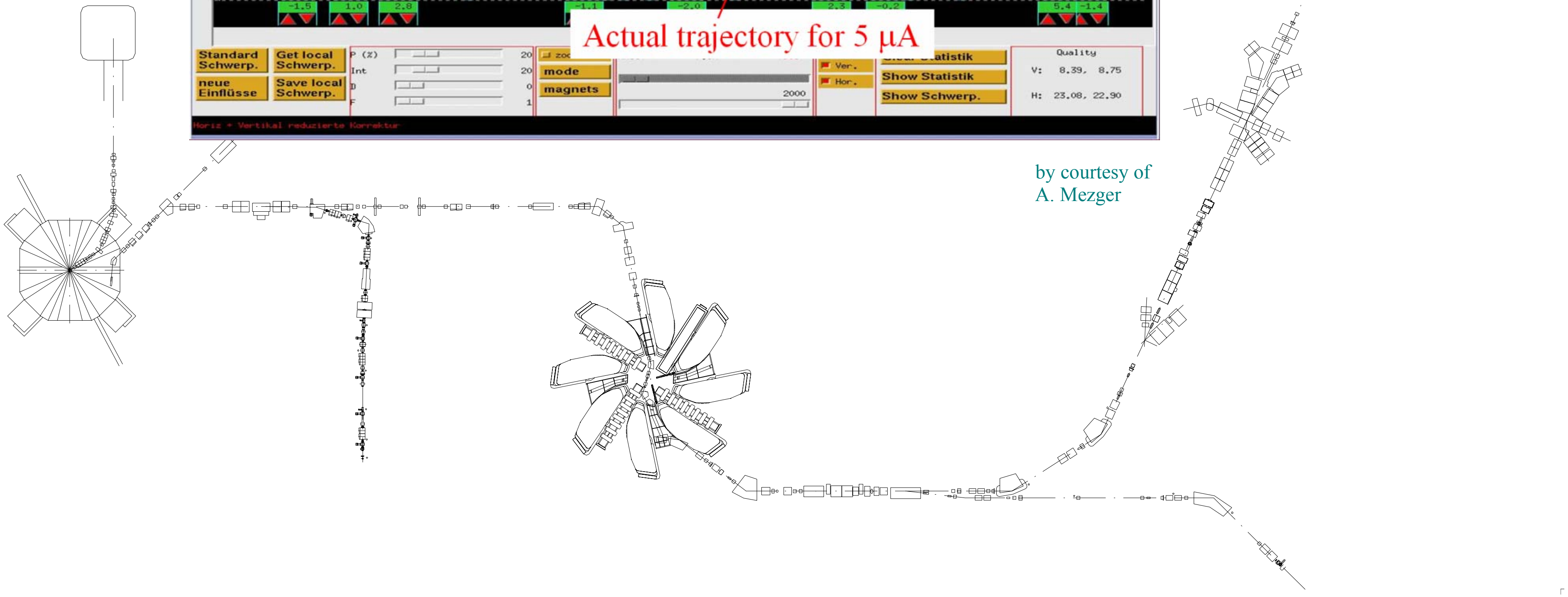


automatic beam centering: bpm and steerer magnets

- frequent beam trips (20...500/day) + fast ramping of beam current (~20 s) + current dependent beam optics
- slow drifts (thermal/ion source/...)

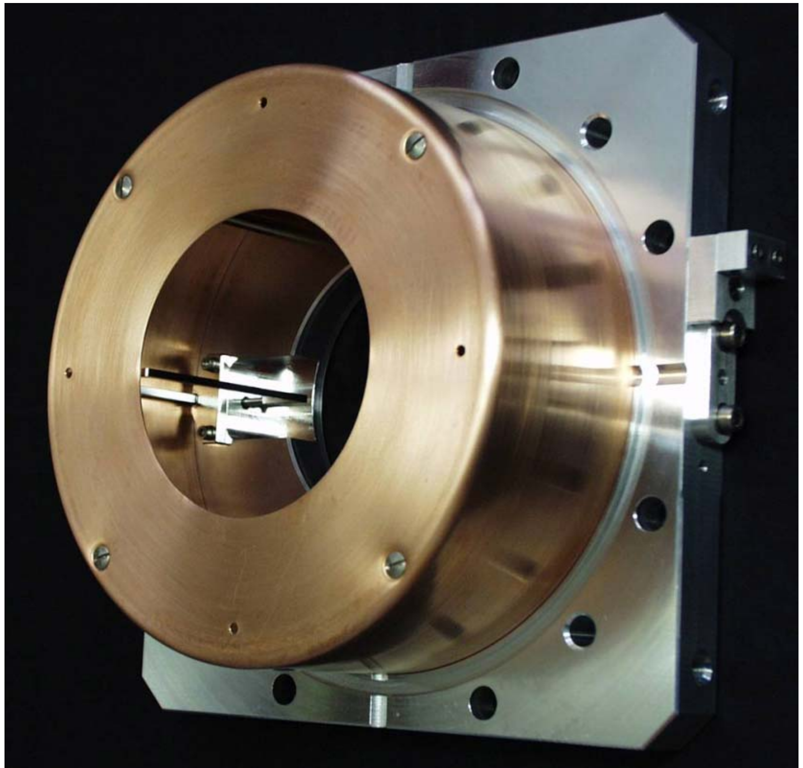
--> automatic centering required (in all beam lines from Injector 2 cyclotron to Target E)

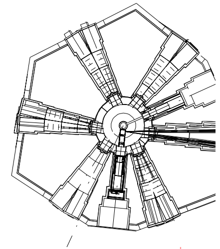


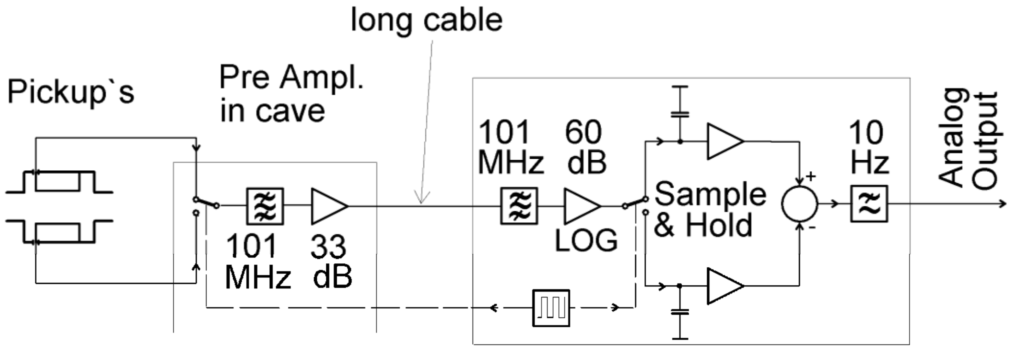


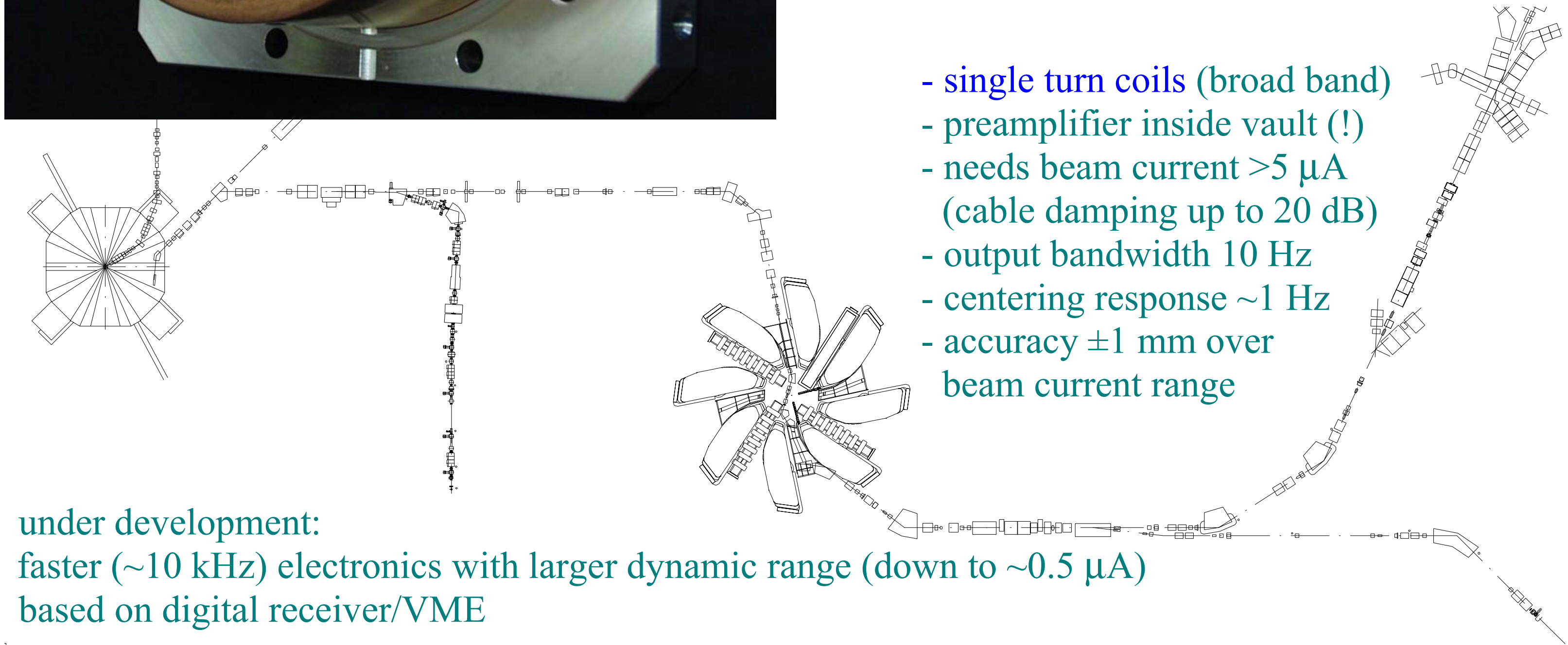
by courtesy of
A. Mezger

automatic beam centering: bpm and steerer magnets









- single turn coils (broad band)
- preamplifier inside vault (!)
- needs beam current >5 µA (cable damping up to 20 dB)
- output bandwidth 10 Hz
- centering response ~1 Hz
- accuracy ±1 mm over beam current range

under development:
faster (~10 kHz) electronics with larger dynamic range (down to ~0.5 µA)
based on digital receiver/VME

profile monitors

wire profile monitors

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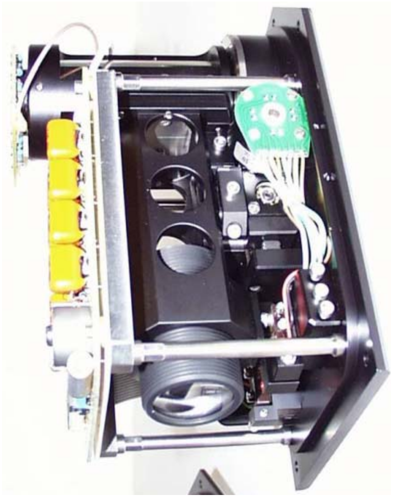
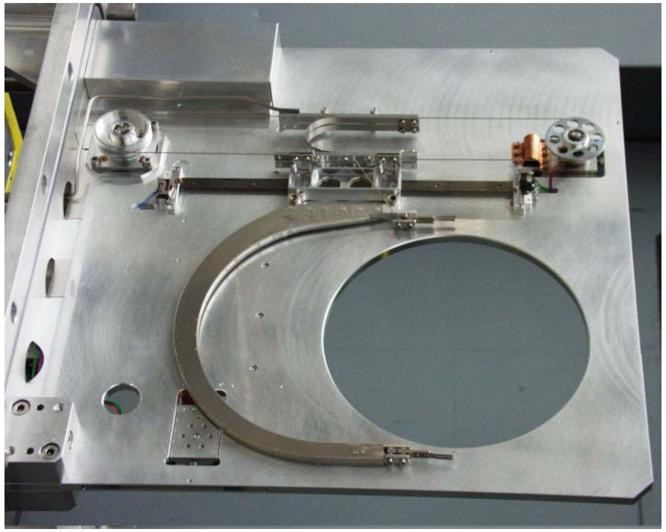
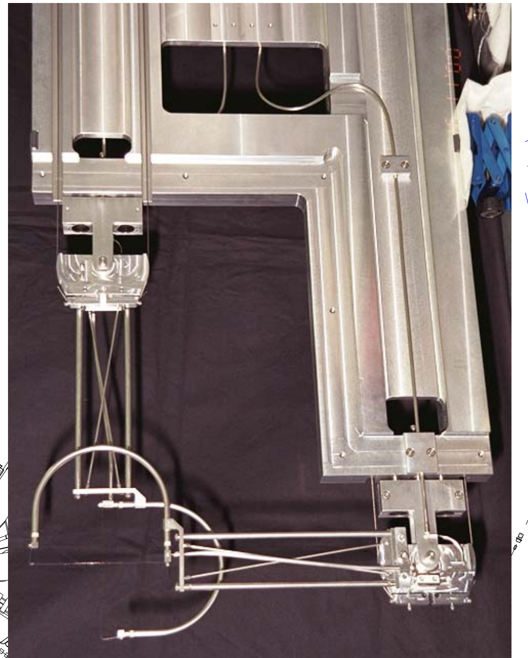
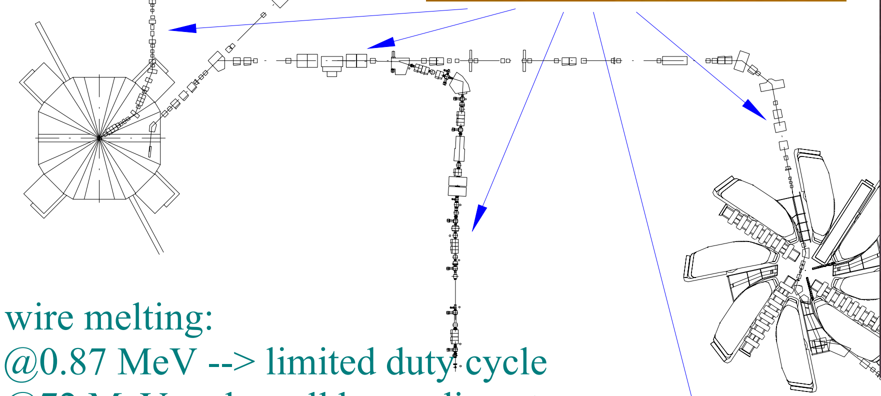
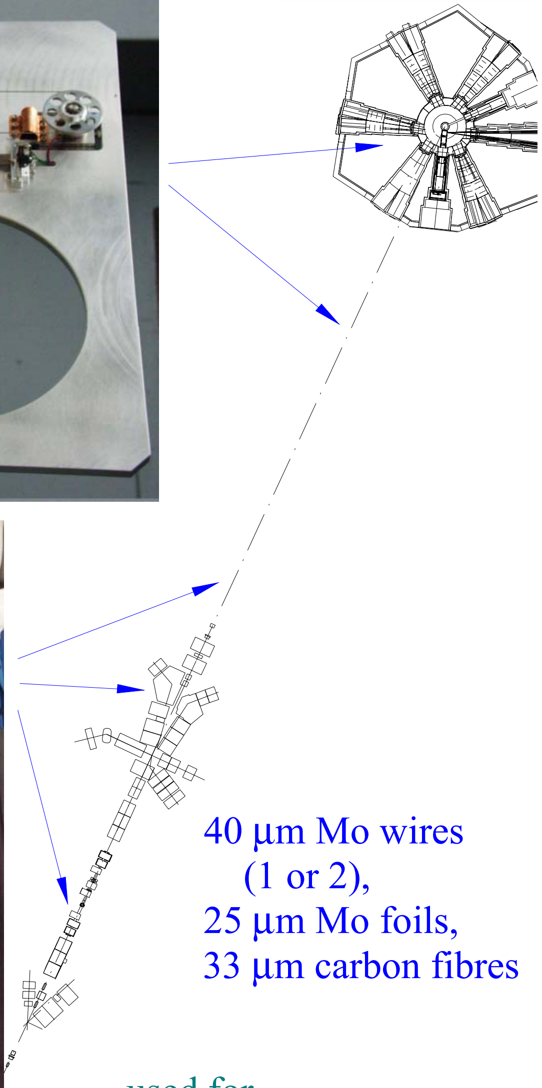
light profile monitors:
fluorescence/lens/PMT

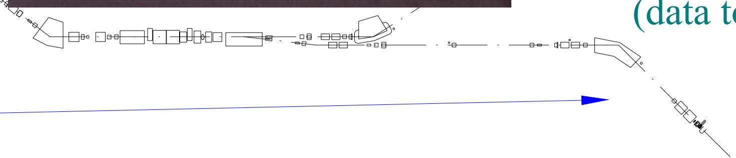












40 µm Mo wires
(1 or 2),
25 µm Mo foils,
33 µm carbon fibres

used for
beam setup/development
(data to "transport" code)

wire melting:
@0.87 MeV --> limited duty cycle
@72 MeV and small beam diameter
--> thermionic emission increases signal
--> interlock from new monitor controller

Electronics

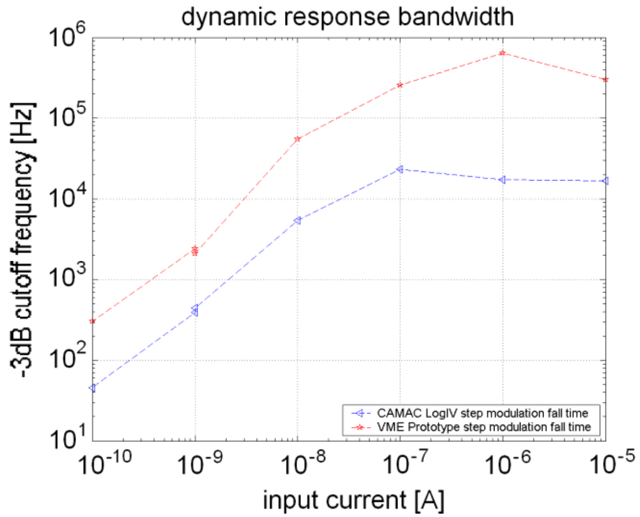
- electronics outside the vaults (2...5 m concrete)
    - no radiation damage/hardness
    - easy access for service
    - 40...150 m long cables

- current measurements with logarithmic amplifiers
    - range 10 pA...10 mA, bandwidth current dependent
    - amplifier ground connected via cable shield to earth at detector (prevents ground loop)
    - cables: good shielding, low microphonics (noise differs by a factor up to 10000!)

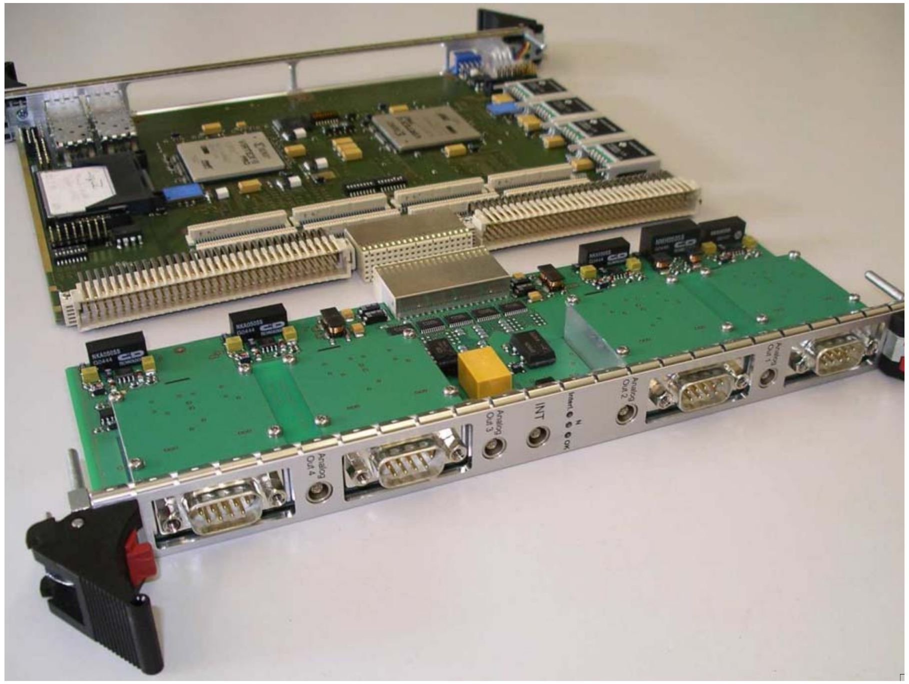
- signal evaluation on board and generation of interlock
    - signal hardwired to control system
    - status and last interlock information readable, interlock levels changeable via bus, rules stored in EEPROM
    - sampling at 1...10 kHz
    - some with external/internal trigger and storage and read-out of up to 8 ksamples/channel

- dedicated front ends combined with universal back ends replace dedicated modules

- change from CAMAC to VME



VME back end (VPC board, talk B. Keil, CTTM02) + 16 channels logarithmic amplifier front end (4 grounds)



systems recapitulation

- machine protection from missteered beam
    1) collimators/segmented aperture foils ("direct" measurement)
    2) ionisation chambers (loss monitoring)
    3) current transmission
    4) quasi current transmission via loss monitors

- spallation target protection from overly focused beam
    1) current transmission
    2) beam shift onto collimator
    3) harps
    4) glowing sieve

- automatic beam centering
    BPMs

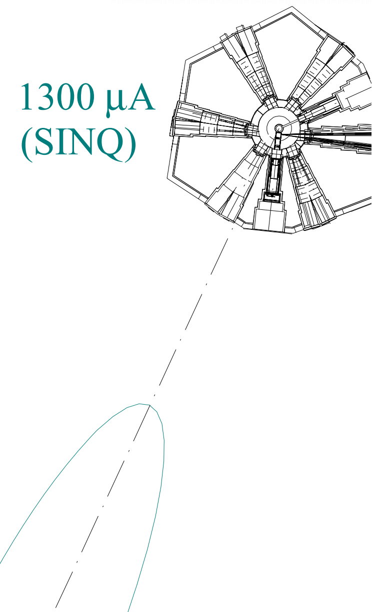
- setup
    wire profiles, light profiles

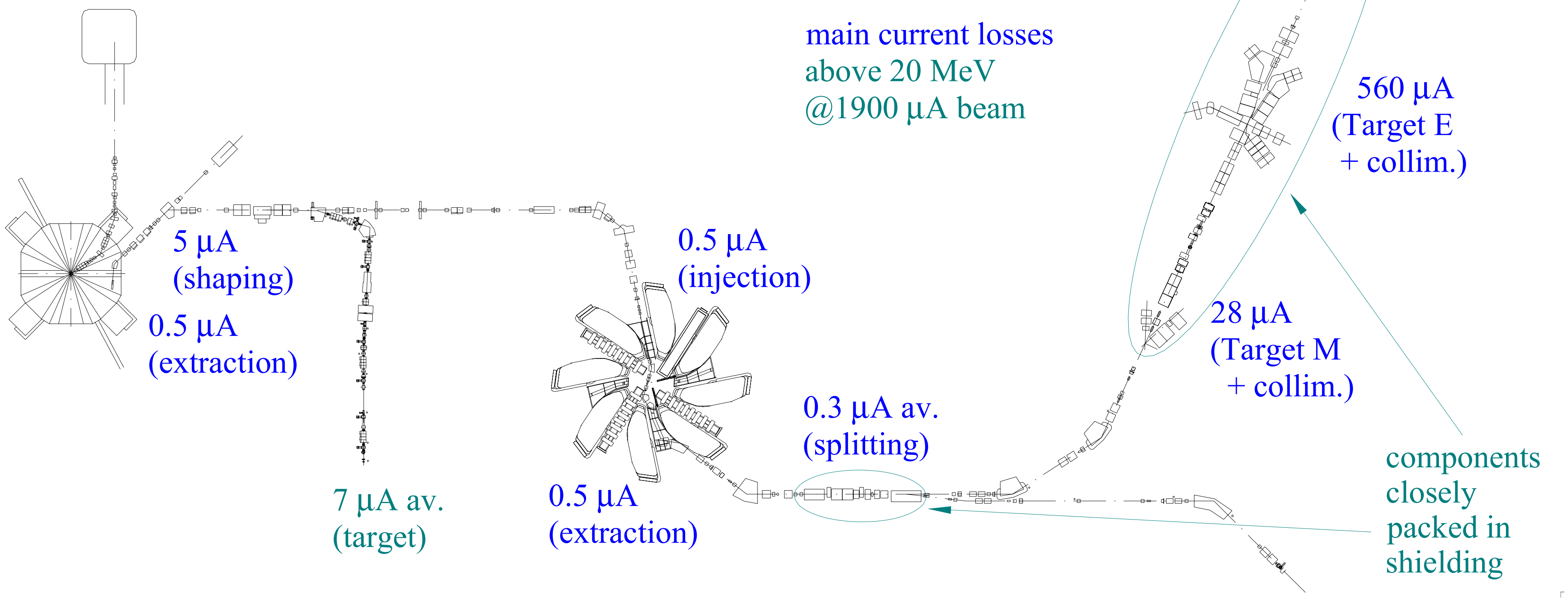
- in the cyclotrons
    wire probes, phase probes, time structure

radiation hardness

- at hot places:
  - only metals/ceramics
  - metal seals (helicoflex/aluminium edge)
  - mineral insulated cables (few m)
  - --> observed damage probably not by radiation
    but of thermal (beam power) or corrosive (cooling water) nature
    (even at wire monitor wires @10^{13} Gy)

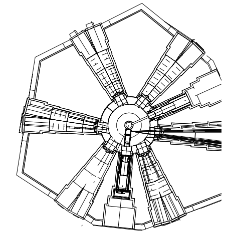
- at not too hot, accessible places possible:
  - epoxy parts/lubricated bearings/motors/potentiometers/scintillators/radhard windows
  - viton seals (get hard but seldom leak if not moved)
  - standard cables (get brittle)

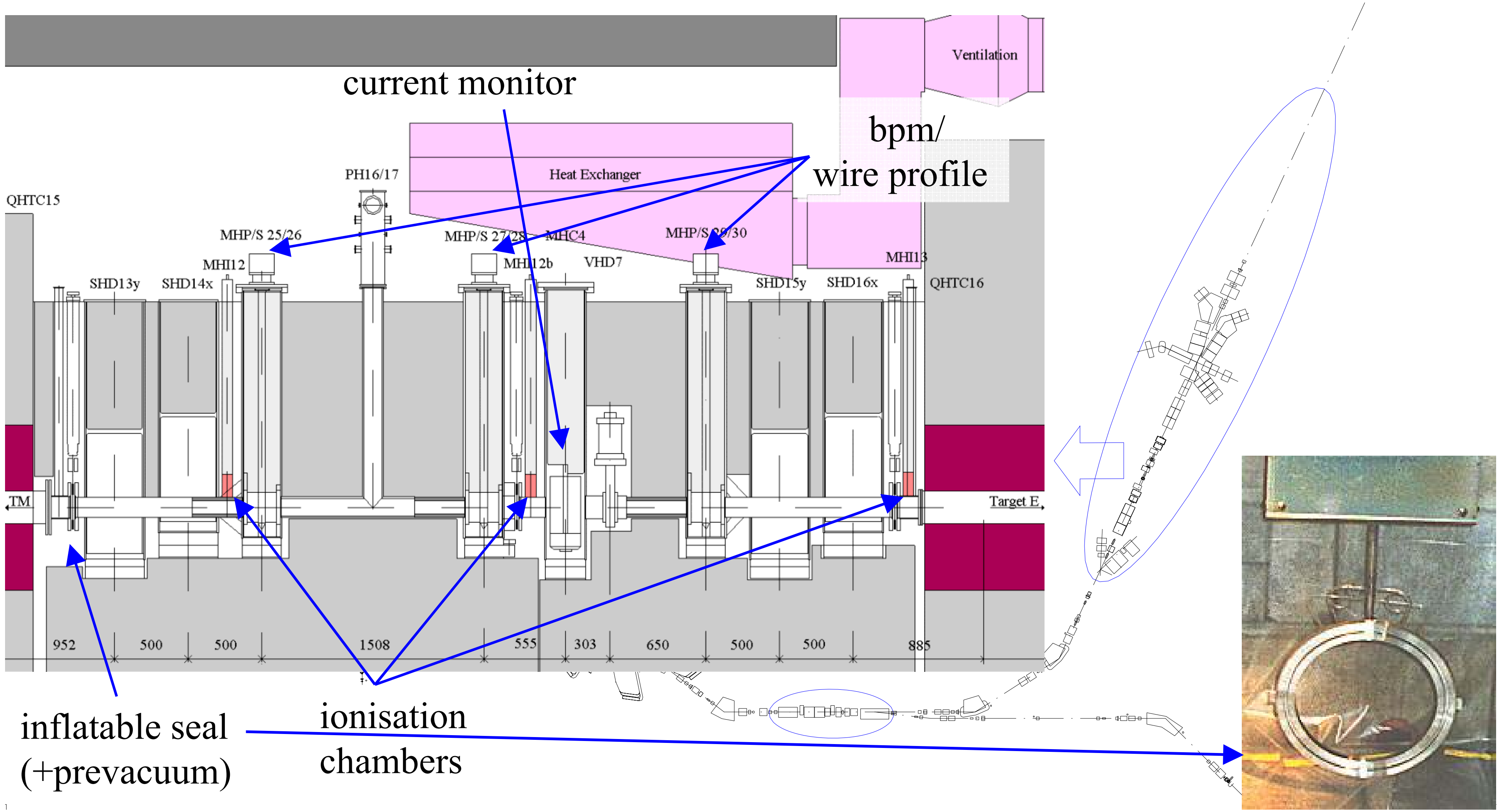




closely shielded components

- access to service level ~2 m above beam
  (after removing 4 m of concrete blocks)
- components under an in-vacuum shielding block (steel)
- in a chimney (vacuum chamber with seal at top)
- (inflatable seals at beam level between vacuum chambers)





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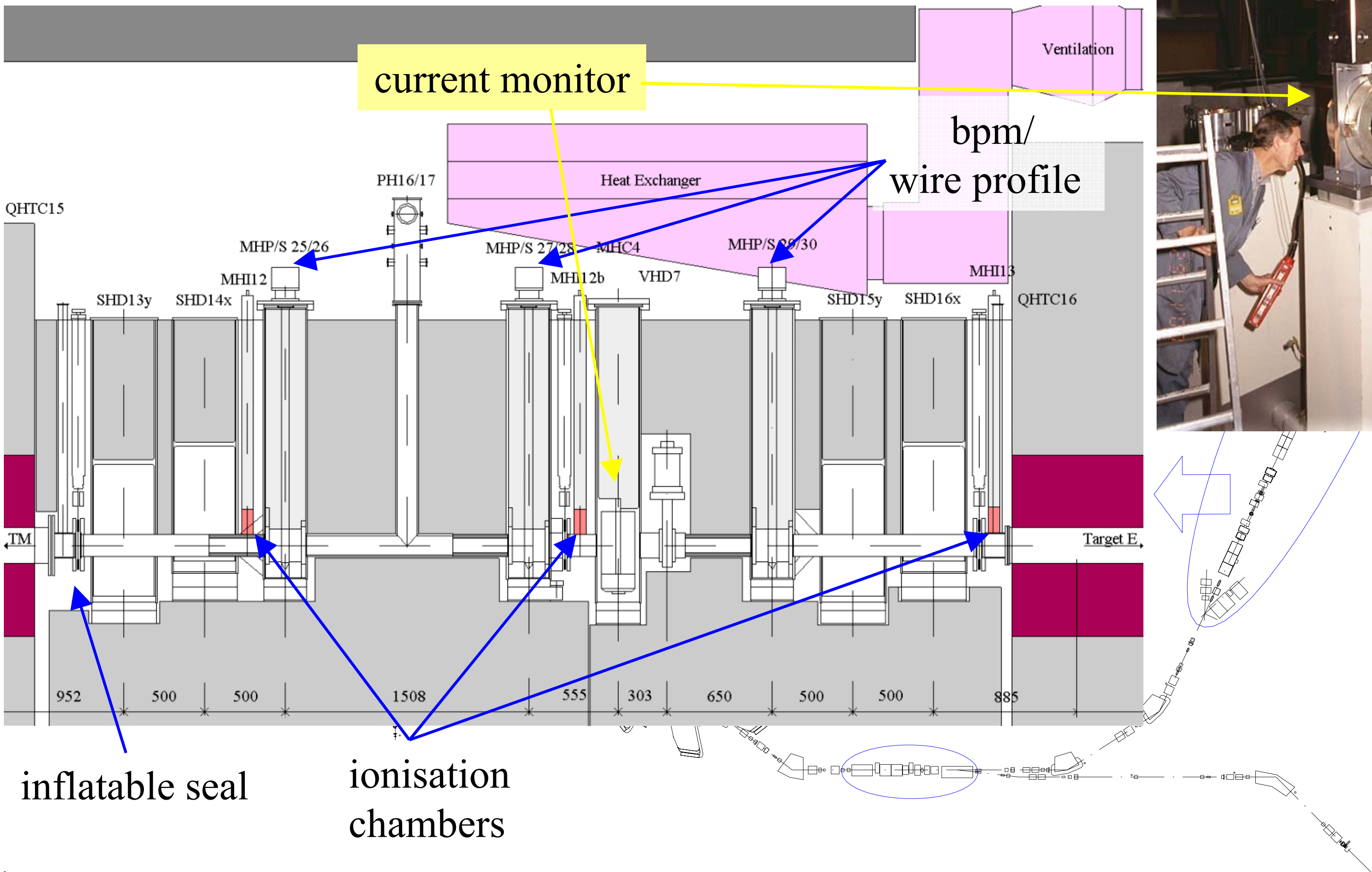

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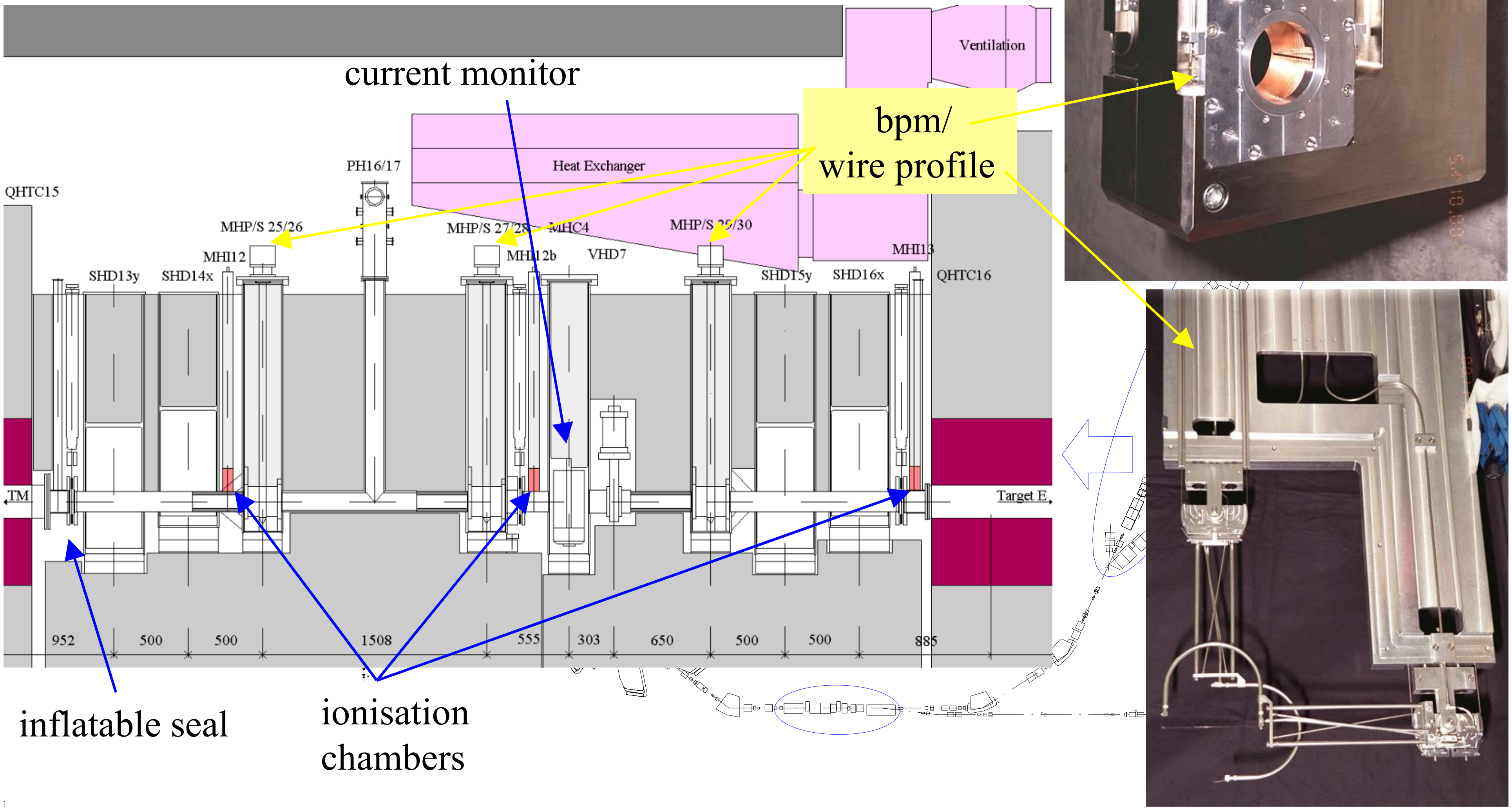
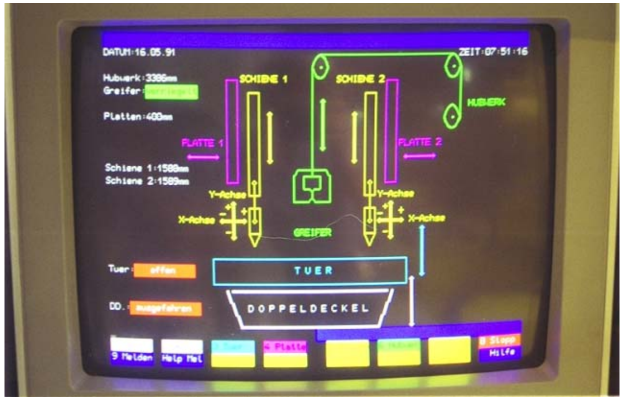


handling of closely shielded components

individual adapters to exchange bottle

exchange bottle display

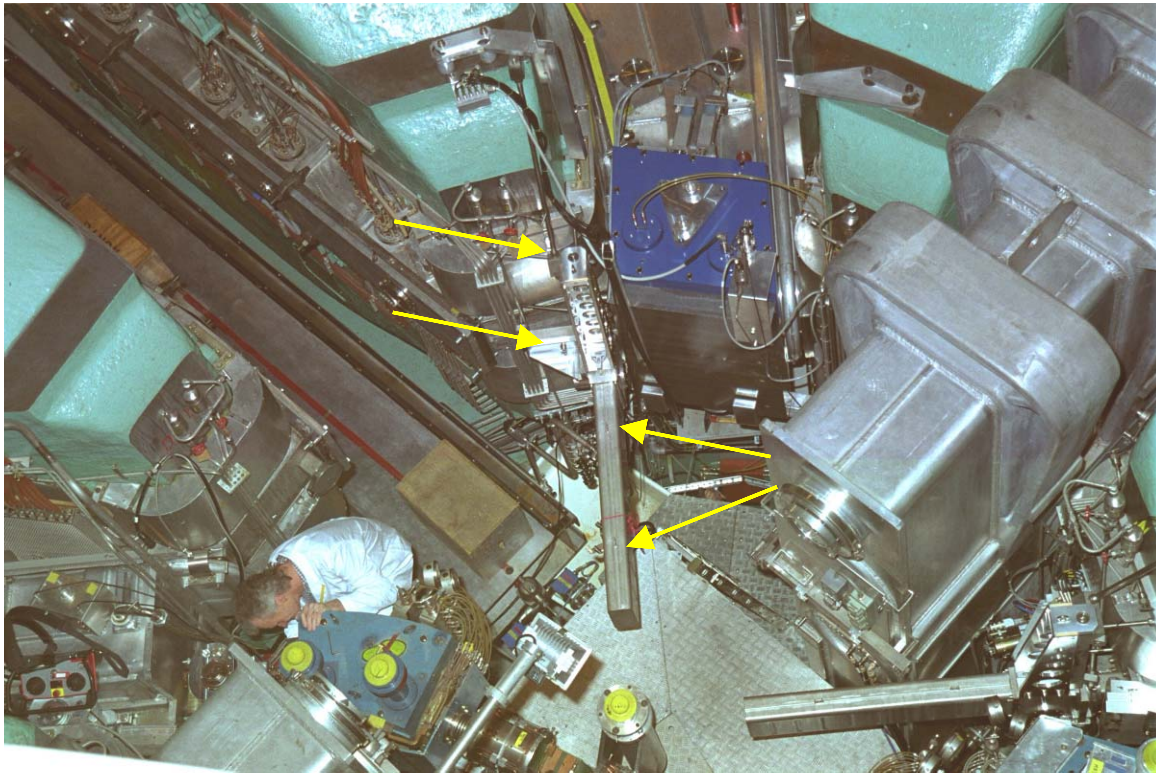


J. Züllig et al.,
PSI Annual Report 2004,
Volume VI, p. 76-77

remote handling facility:
manipulators,
movers
(air filters, ...)
components with grips for manipulator

handling of directly accessible components

e. g.: radial wire probes in cyclotron
- fully removable into housing
- fixed with single srew/guiding rod
- eyes for dedicated crane harness
- dedicated cart
--> removable by a single person



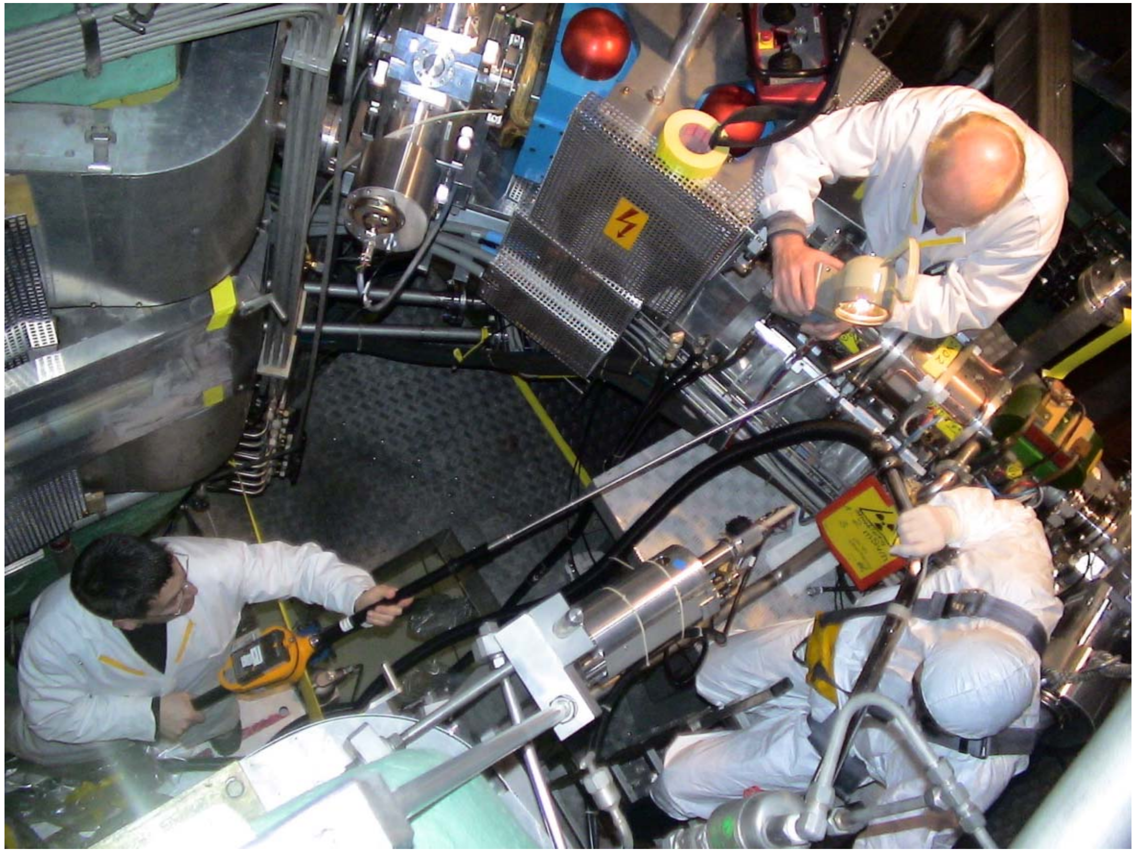
requirements to design:
- fast demountable (few screws, lever mechanisms, guiding rods, ...)
- touchable (no sharp edges, sunk inbus screws, week parts guarded, grips, ...)
- local cranes/lifting gear/fitting carts
- smooth surfaces (for cleaning)

but most important:
- reliable

radiation

dose rate in vaults when beam off:
- ~6 h after beam off --> half rate
- "background" up to ~2 mSv/h
  higher at local hot spots
  can change fast

contamination



personal doses:
- legal limit: 20 mSv/a/person
- in 2004 for all accelerators:
  maximum/person: 6.9 mSv
  sum: 74 mSv/196 persons

measures:
- defined areas/access
- dosimetry/supervision by
  radiation surveillance team (~7 members)
- work planning (>50 mSv notifiable)
- temporary shielding

infrastructure for active components

- remote handling facility
- workshop
- mounting room
- storage hall
- exchange bottles
- radiation surveillance
    - personal dosimetry
    - areal & components dosimetry
    - air & waste water monitoring
  (- dosimeter calibration,
    laundry for zone clothes, ...)