

PAUL SCHERRER INSTITUT



WIR SCHAFFEN WISSEN – HEUTE FÜR MORGEN

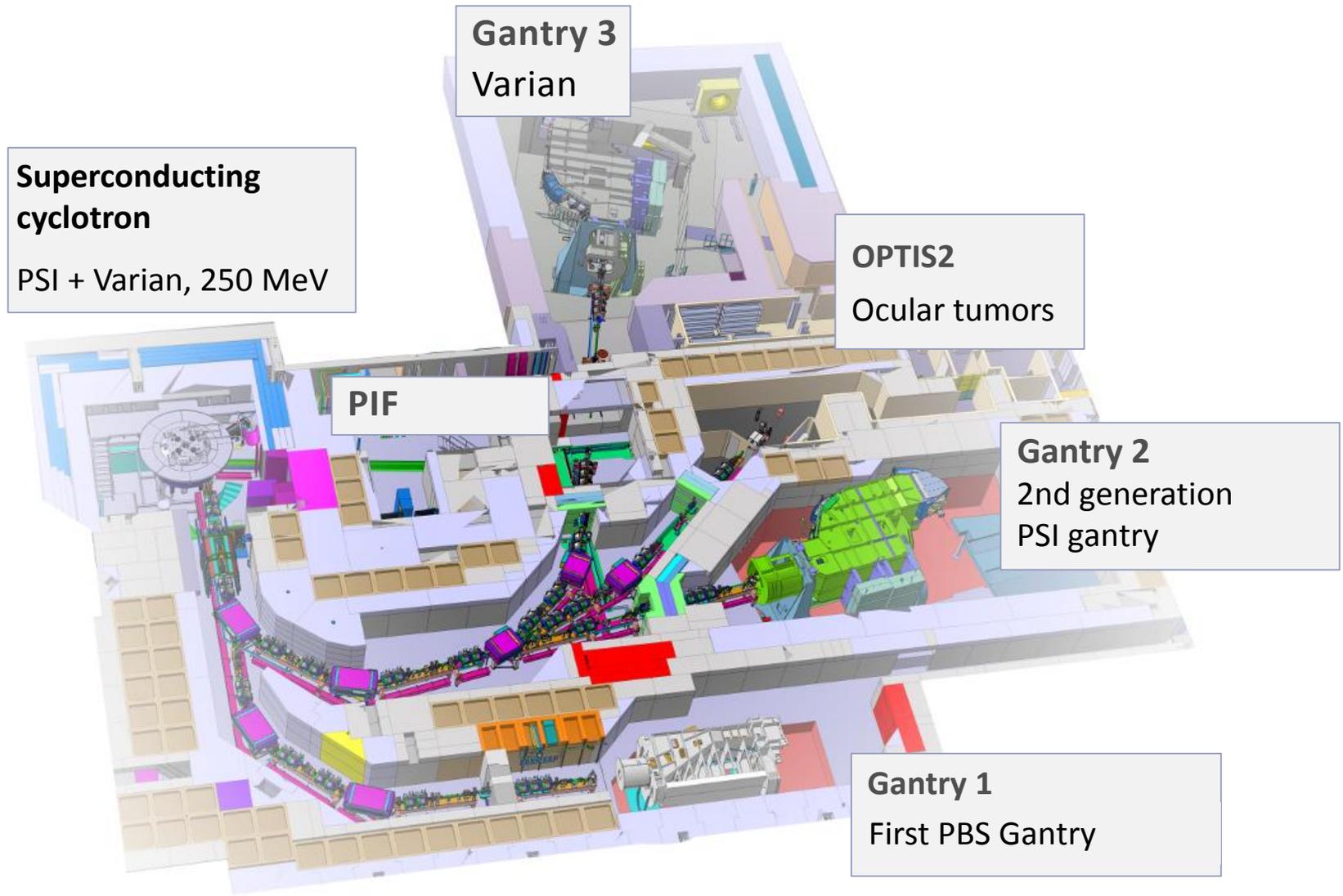
Francis Gagnon-Moisan :: Operations physicist :: Paul Scherrer Institut

PSI monitor systems for proton dose delivery

2nd OMA Workshop 2018 – 4 June 2018



- Introduction
 - The facility
 - The different treatment areas
- The spot scanning concept
- The beamline monitoring
 - Beamline transmission
- Gantry 1 monitor system
- Gantry 2 monitor system
- Monitor calibration and QA



CPT treatment areas

- Gantry 1
 - First spot scanning gantry (started operations 1996)

- Gantry 2
 - In operation since 2013

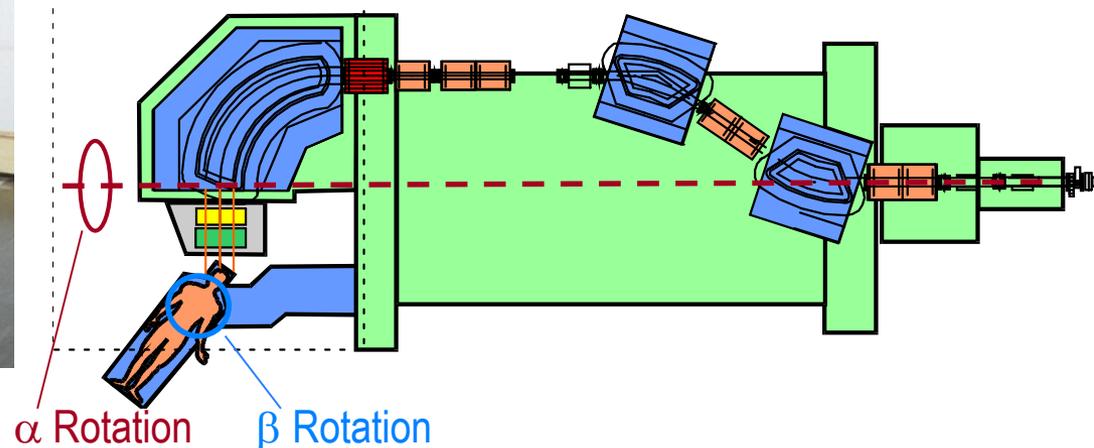
- OPTIS 2
 - Double scattering system
 - In operations since 2010



Gantry 1 - Introduction

The Gantry 1 is the first spot scanning proton beam therapy at PSI

- Implementation of **spot scanning** technique
 - Scanning in one dimension ($\pm 10\text{cm}$)
- During 12 years the only spot scanning gantry **worldwide**
- Due to eccentric design still the **most compact system**, $r = 2\text{m}$



Gantry 2 - Introduction

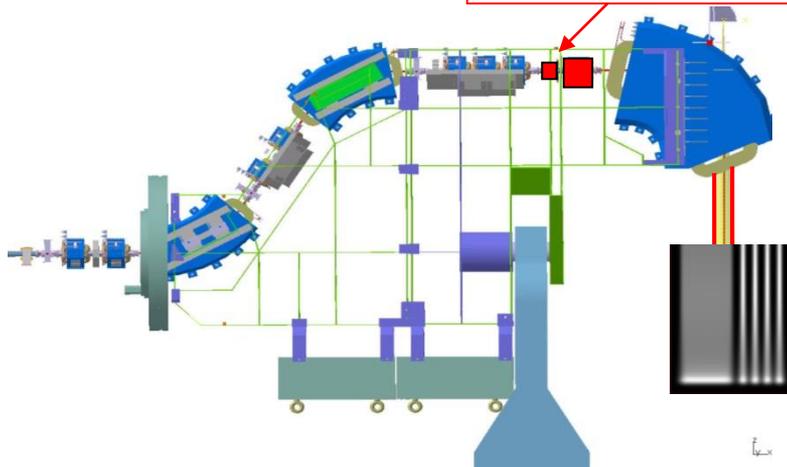
Iso-centric layout with good access to patient

- Mechanical rotation limited to 210°
- Patient table turns 180° for other hemisphere
- No gantry pit (conventional gantry layout)

Fast parallel scanning in 3 dimensions

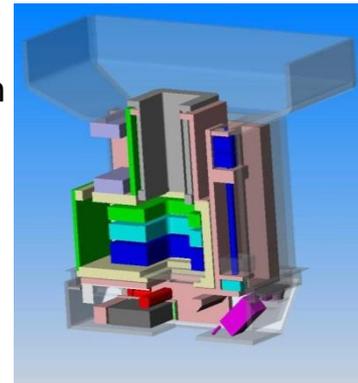
- Scanning in 2d (2 sweeper magnets)
- “Up-stream” scanning (scanning through dipole)
 - Reduction of gantry radius by ~ 1 m
- Parallel beam at iso-center
- Scan area of 12 by 20 cm
- Fast energy changes

Scanner magnets



Compact optimized nozzle

- No range shifter, energy modulation at accelerator
- Telescopic motion of the nozzle to minimize scattering
 - Small pencil beam, $s \sim 3$ mm
- Remote movable pre-absorber for superficial tumors (< 70 MeV)

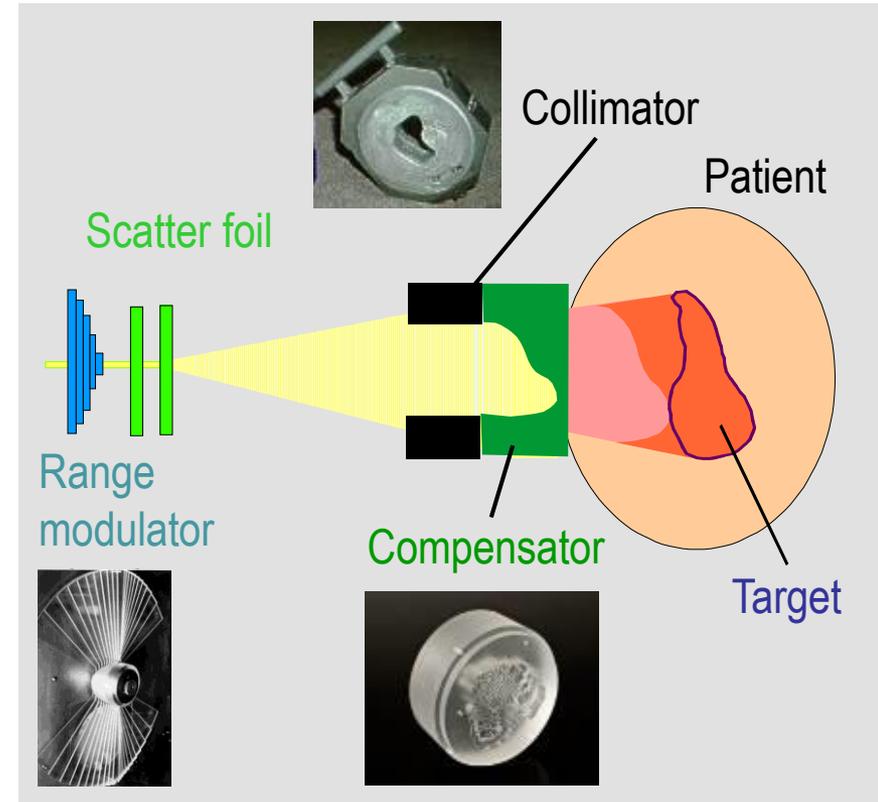
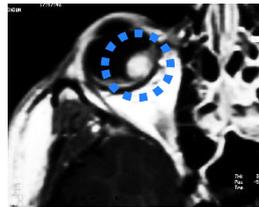


OPTIS 2 -Introduction

Ophthalmologic Proton Therapy Installation Switzerland

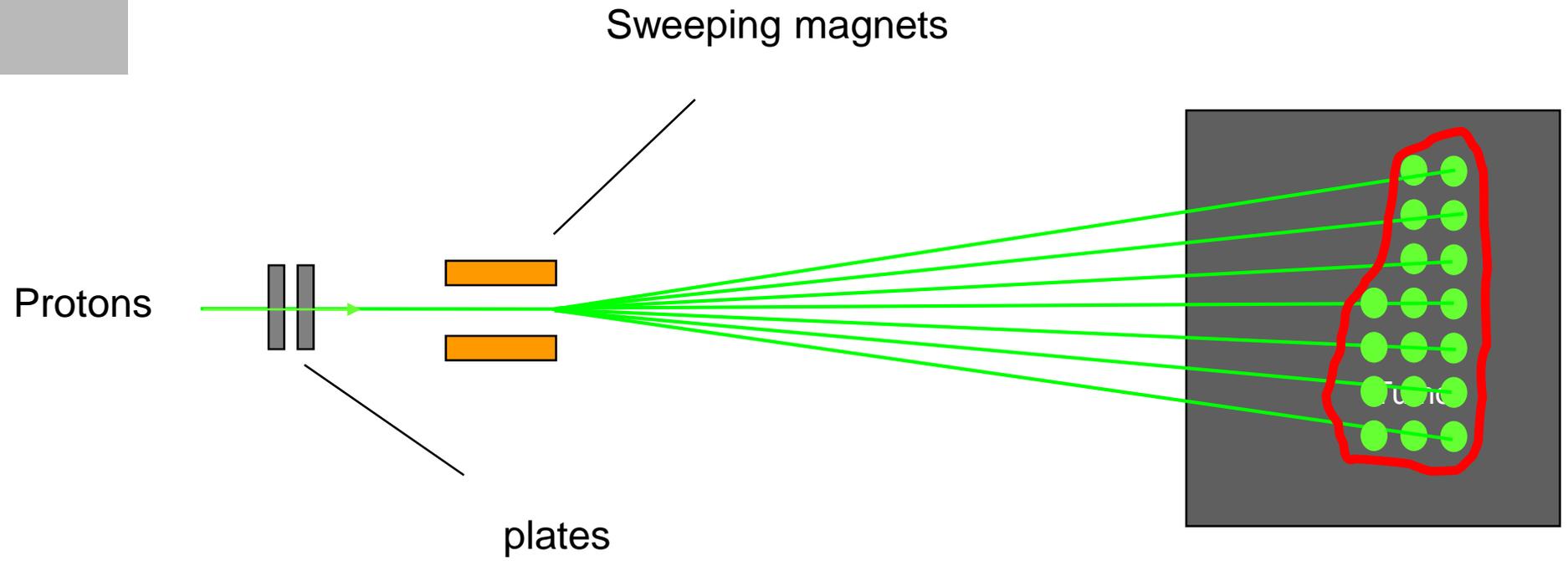


- Treatment of eye tumors
- More than 6000 patients treated since 1984
- Incoming beam 70 MeV
- Only 4 fractions (all in one week)
- Local control tumor control: 99%
- 2010: Upgrade from OPTIS to OPTIS2



- “Imitate” conventional therapy with broad beam
- Patient specific hardware (collimator / compensator)
- Dose not as conformal as one could do it
- Established technique for more than 40 years

The spot scanning concept



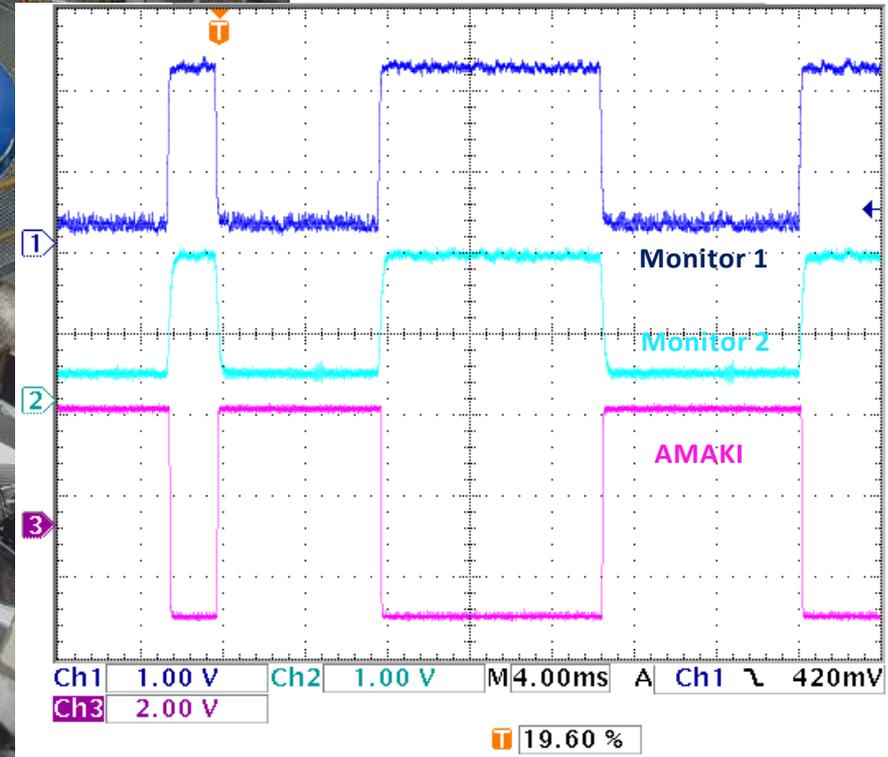
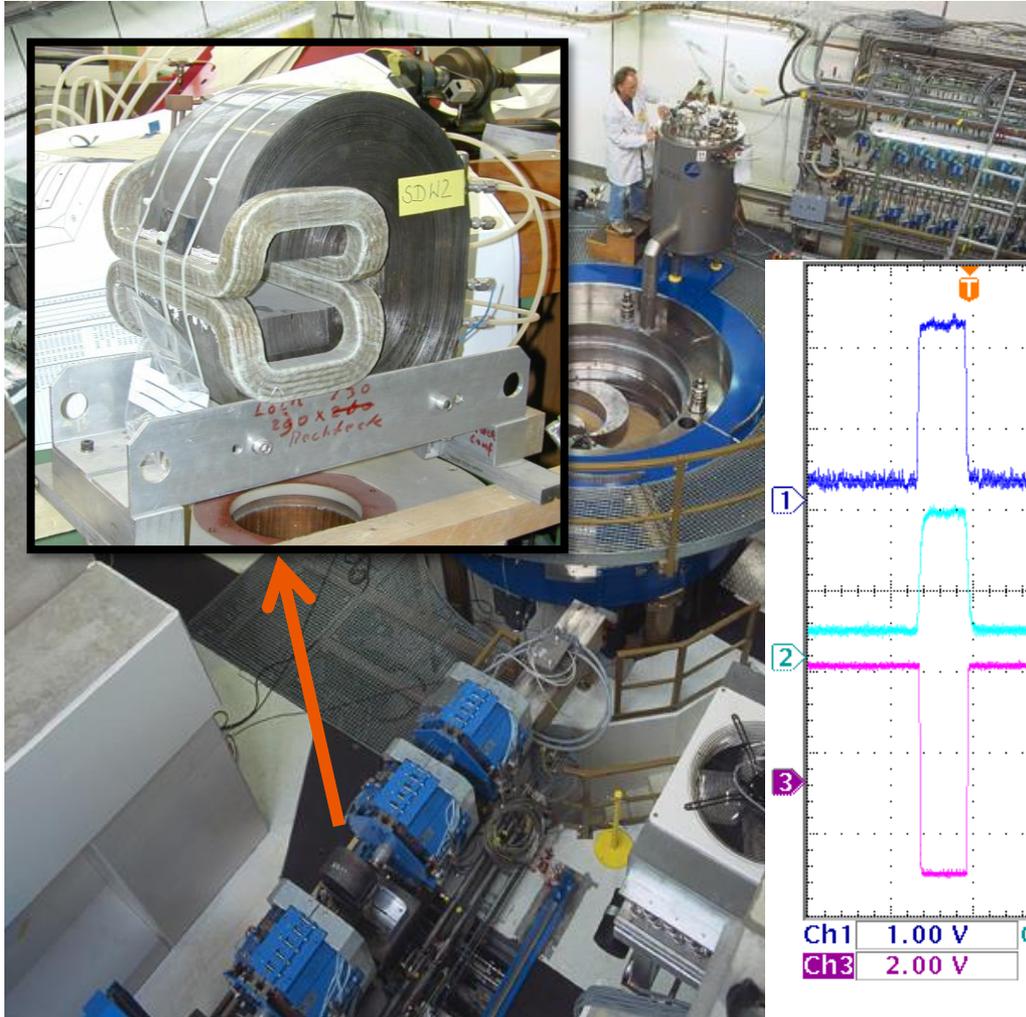
The spot scanning concept

The dose is being delivered by bunches, or *spots*, controlled by a strong magnet

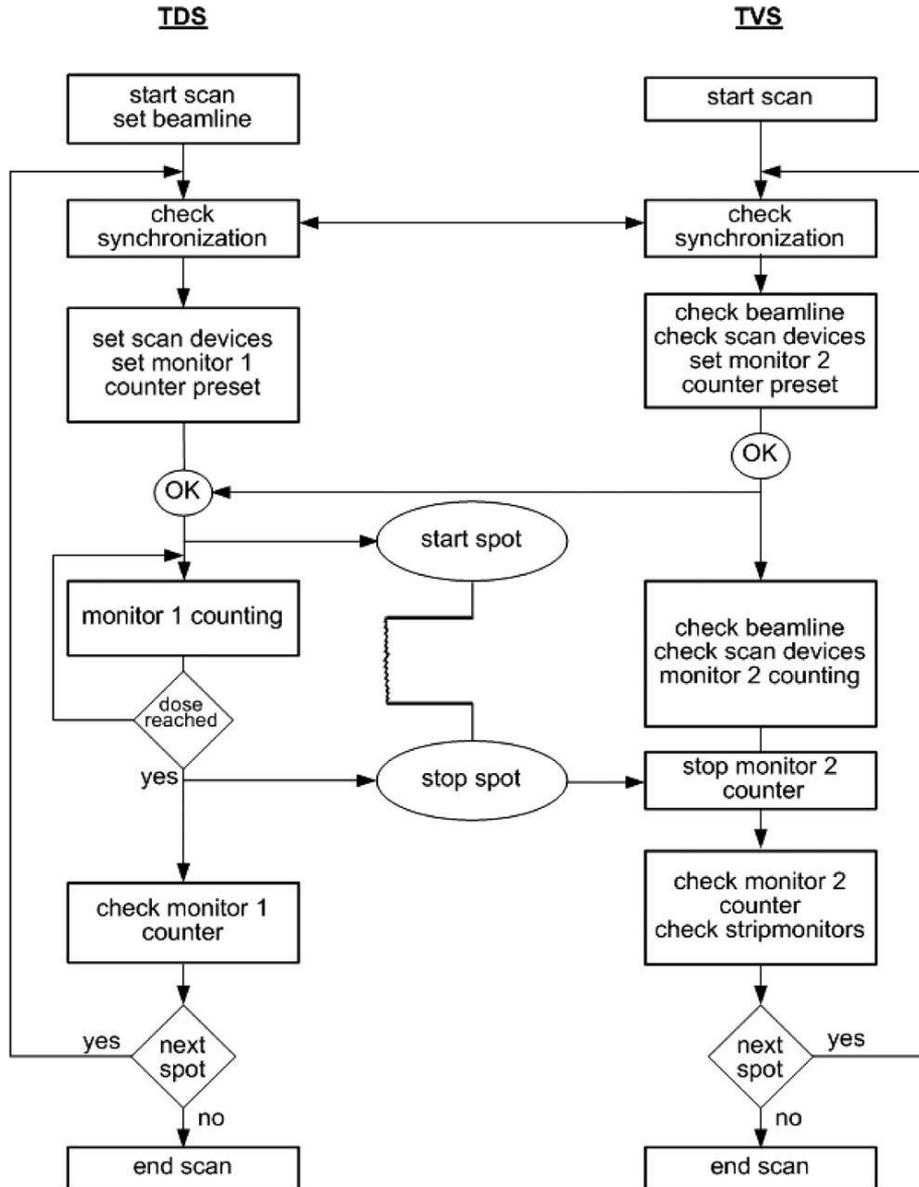
AMAKI

Ablenk Kicker Magnet

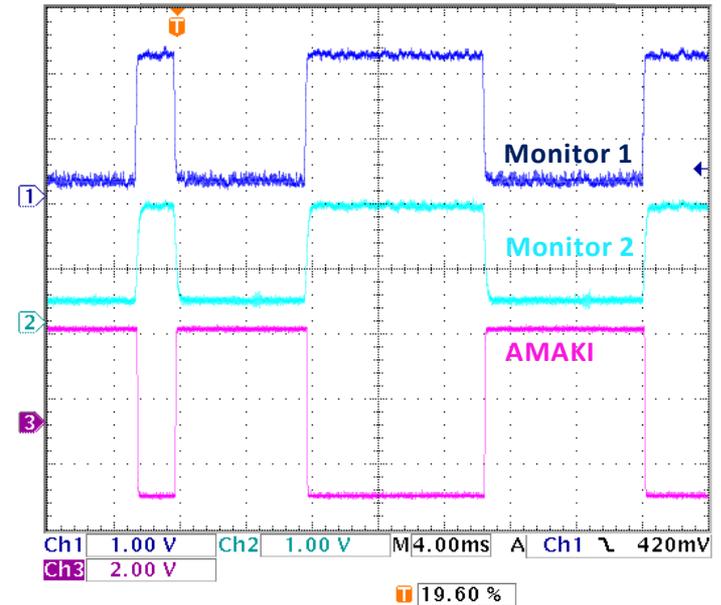
- 72A
- < 300 μ s (typ. 200 μ s)



Spot scanning – delivery and verification

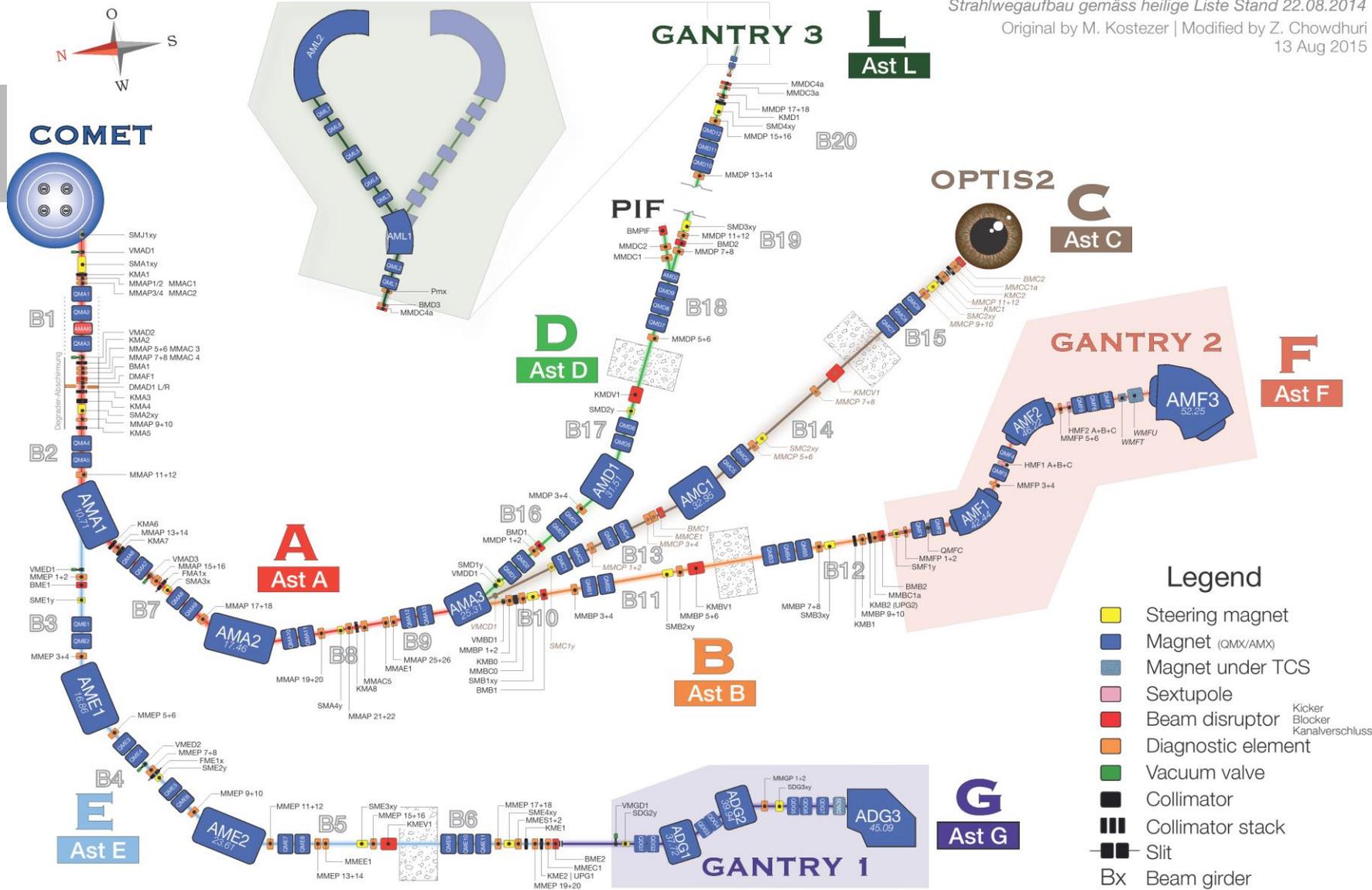


TDS : Therapy Delivery System
 TVS : Therapy Verification System



Introduction – The beamline in more details

Strahlwegaufbau gemäss heilige Liste Stand 22.08.2014
 Original by M. Kostezer | Modified by Z. Chowdhuri
 13 Aug 2015



Legend

- Steering magnet
- Magnet (QMX/AMX)
- Magnet under TCS
- Sextupole
- Beam disruptor
- Diagnostic element
- Vacuum valve
- Collimator
- ▬▬▬ Collimator stack
- ▬▬ Slit
- Bx Beam girder
- Kicker
- Blocker
- Kanalverschluss

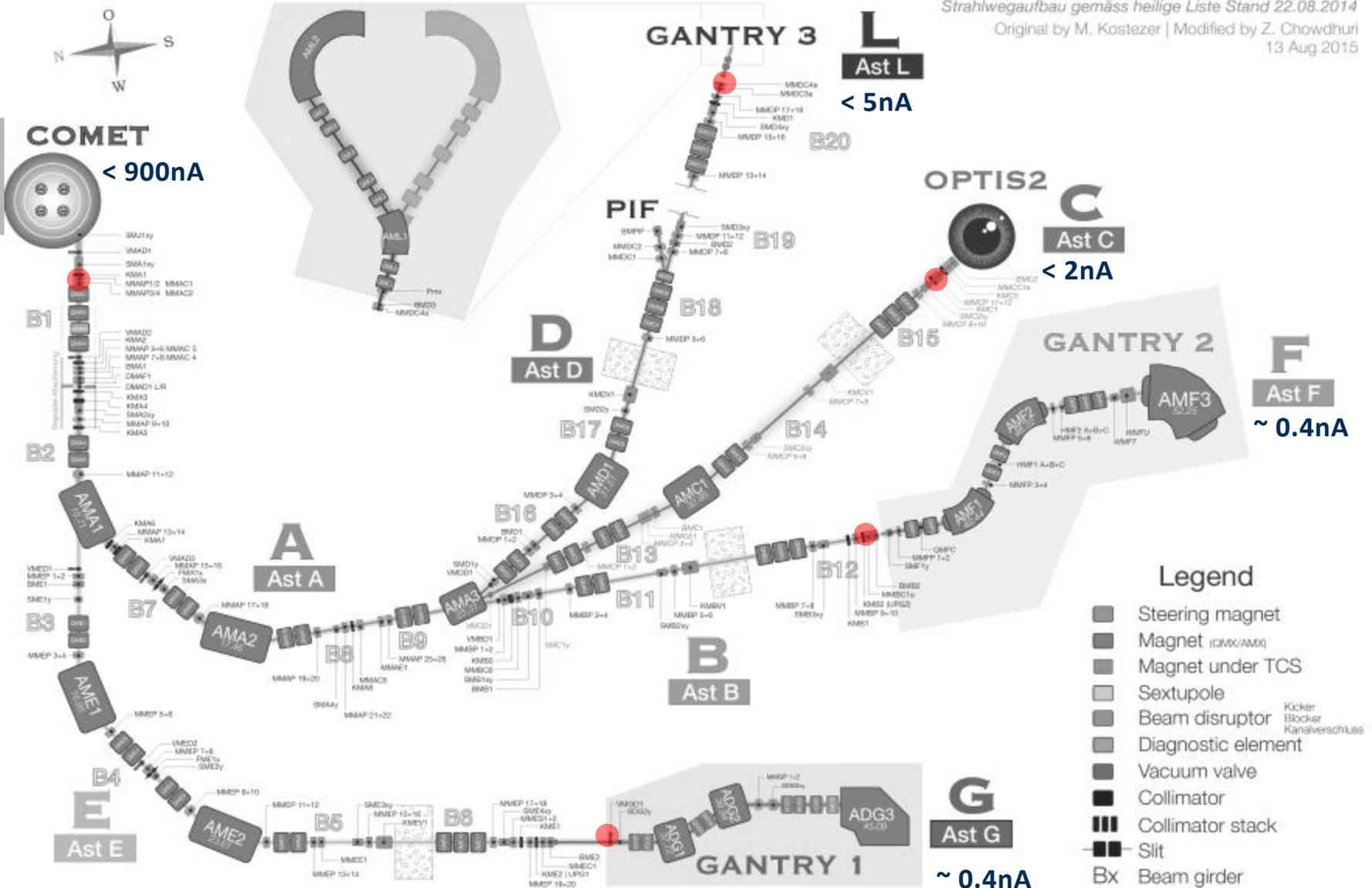


Beam current monitoring

Strahlwegaufbau gemäss heilige Liste Stand 22.08.2014

Original by M. Kostezov | Modified by Z. Chowdhuri

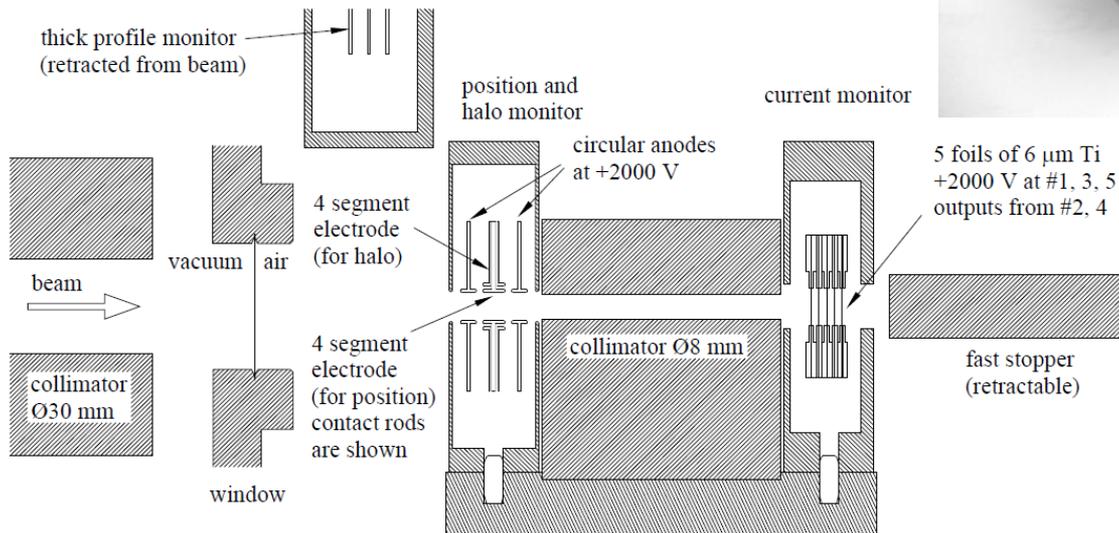
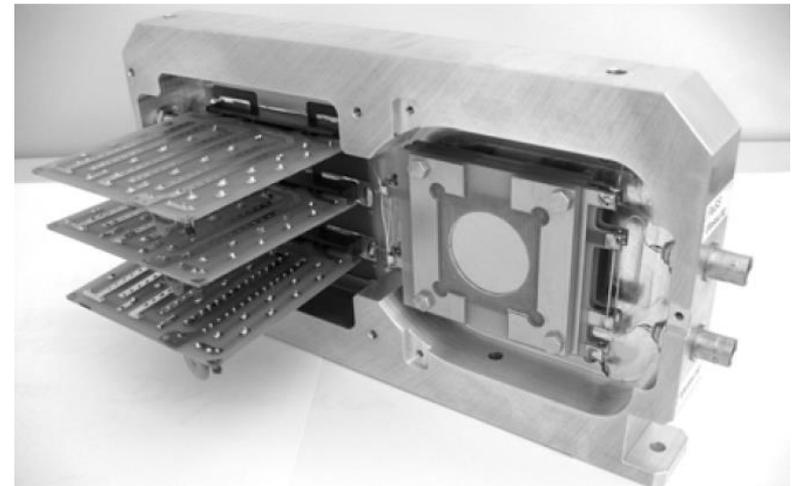
13 Aug 2015



- ### Legend
- Steering magnet
 - Magnet (QMC/AMQ)
 - Magnet under TCS
 - Sextupole
 - Beam disruptor
 - Kicker
 - Blocker
 - Kanalverschluss
 - Diagnostic element
 - Vacuum valve
 - Collimator
 - Collimator stack
 - Slit
 - Beam girder

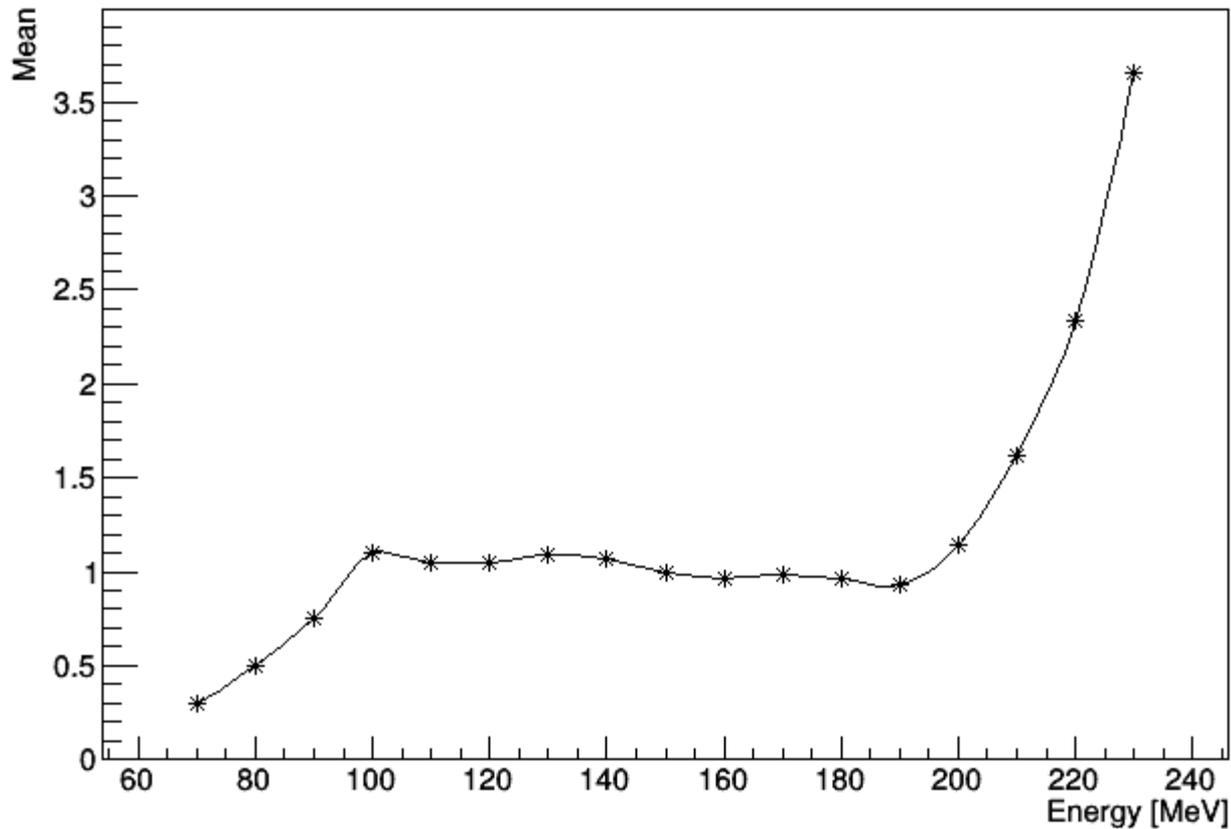
Beamline current monitoring

The current of the proton beam is supervised by many detectors located on the beam path.



Gantry 2 energy modulation

Mean of the transmission at all energies



Mean transmission between upstream and downstream monitors, normalized to transmission at 150 MeV.

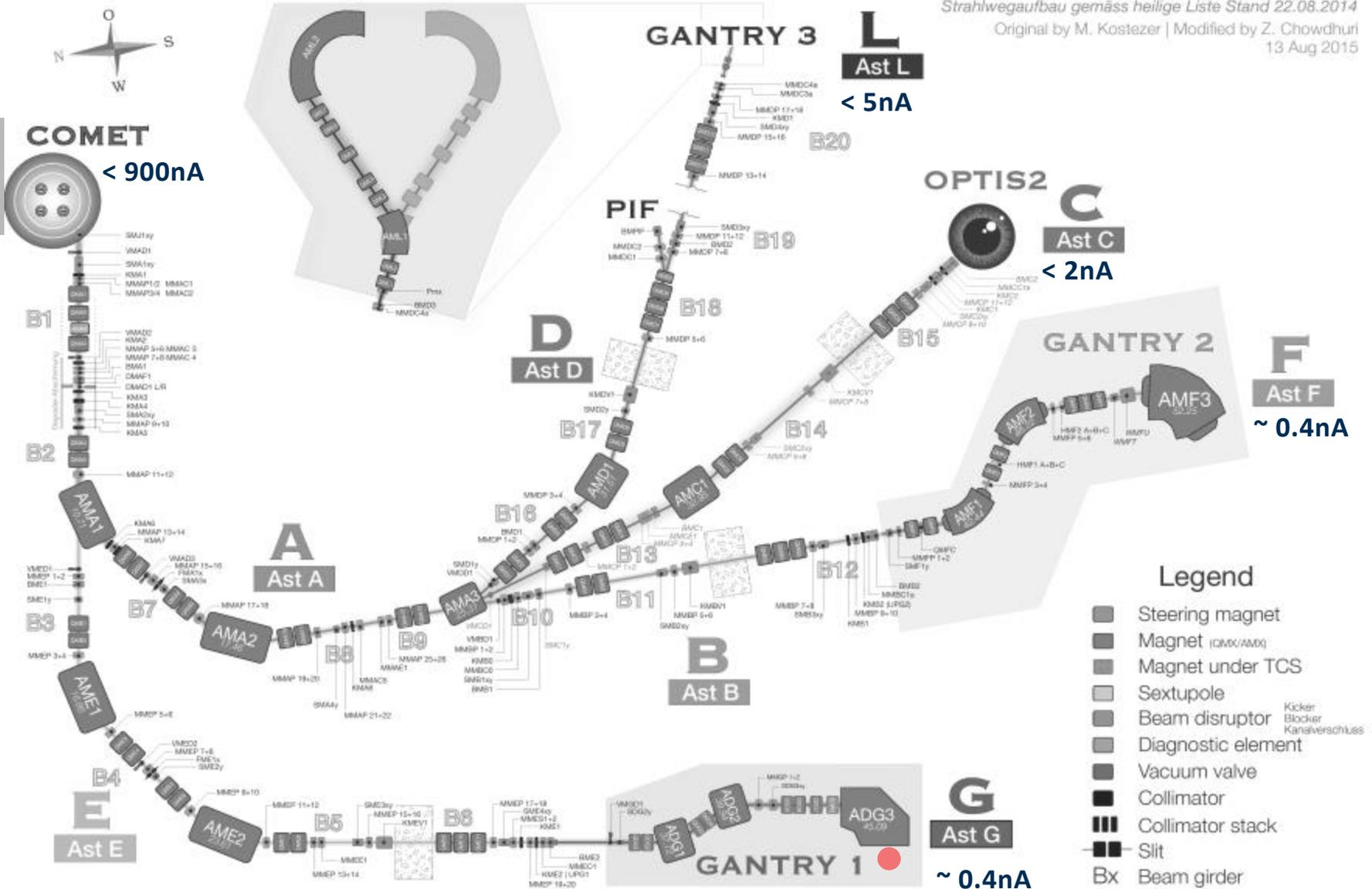


Beam current monitoring

Strahlwegaufbau gemäss heilige Liste Stand 22.08.2014

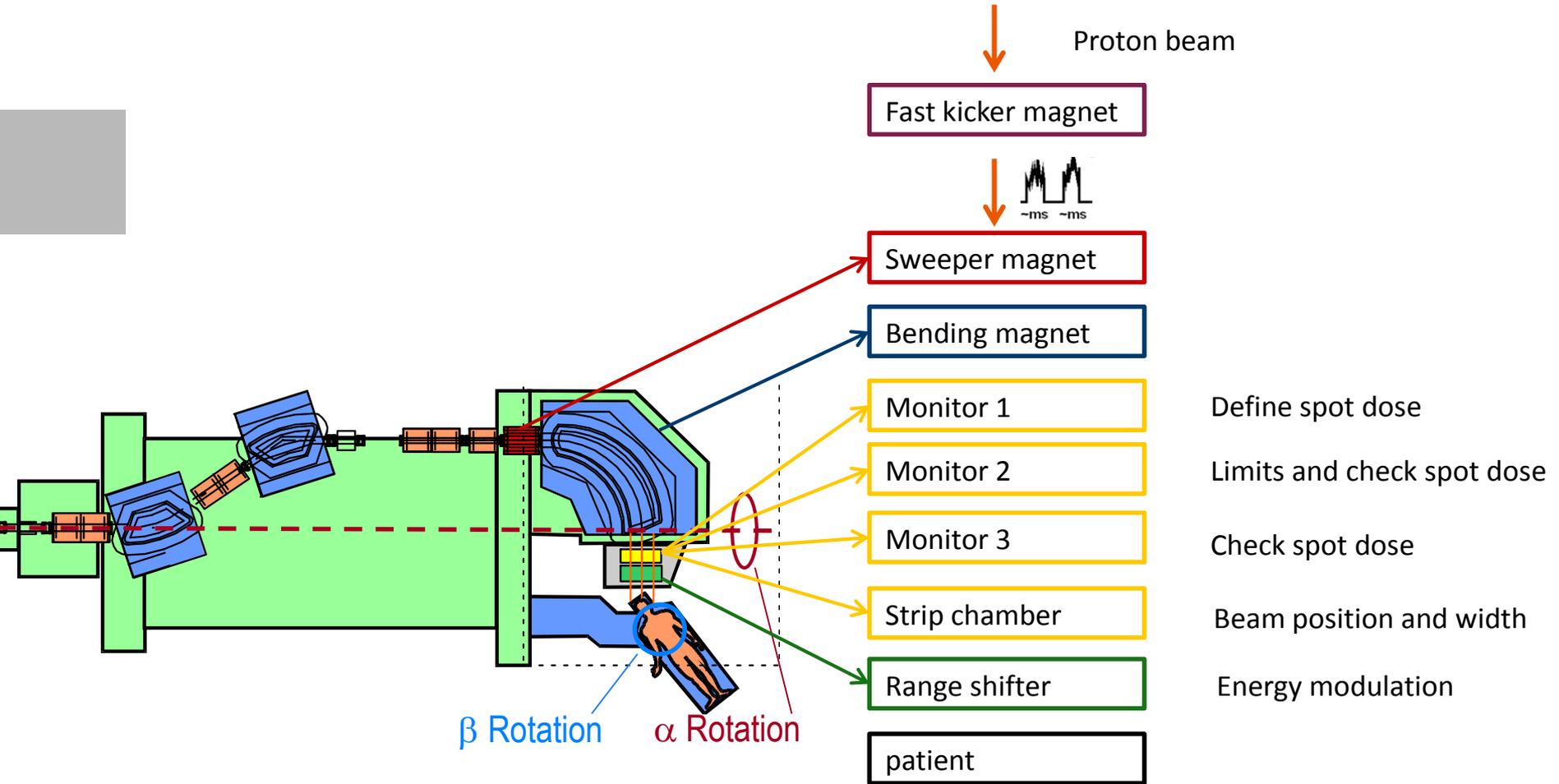
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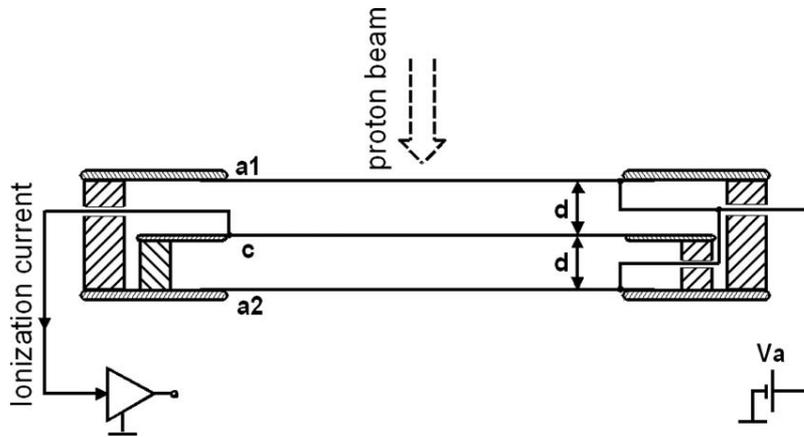
- ### Legend
- Steering magnet
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Gantry 1 monitoring solution



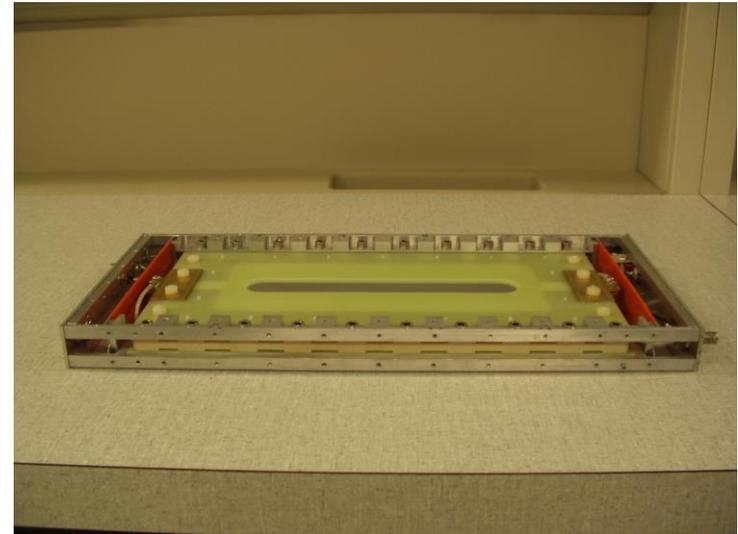
Gantry 1 – beam monitoring system

Monitor 1 & 2 are simple parallel plates ionization chambers



Ionization charges collection time

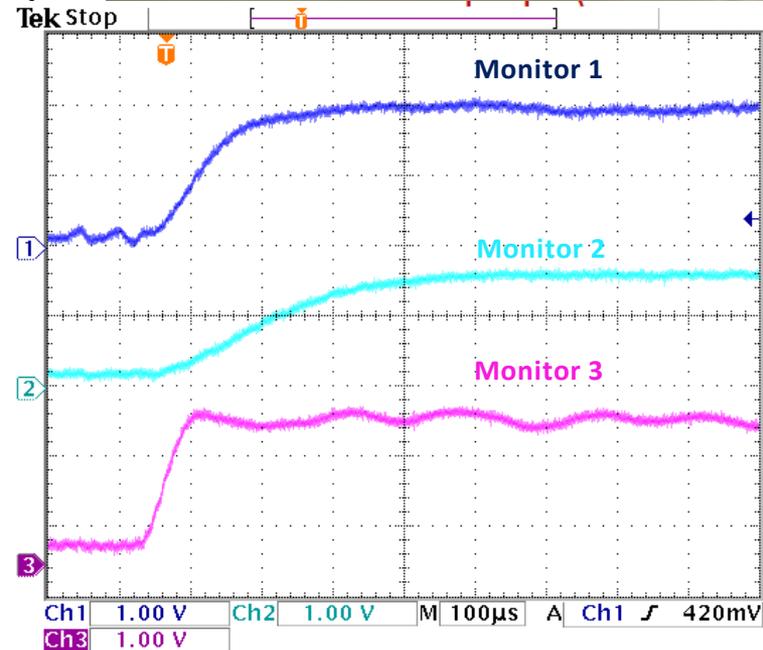
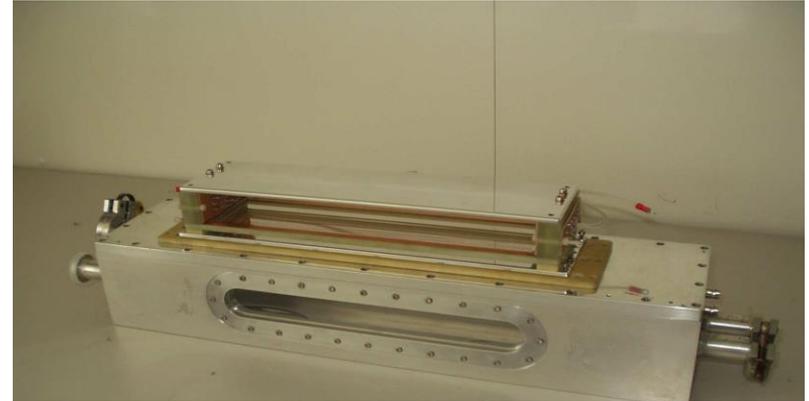
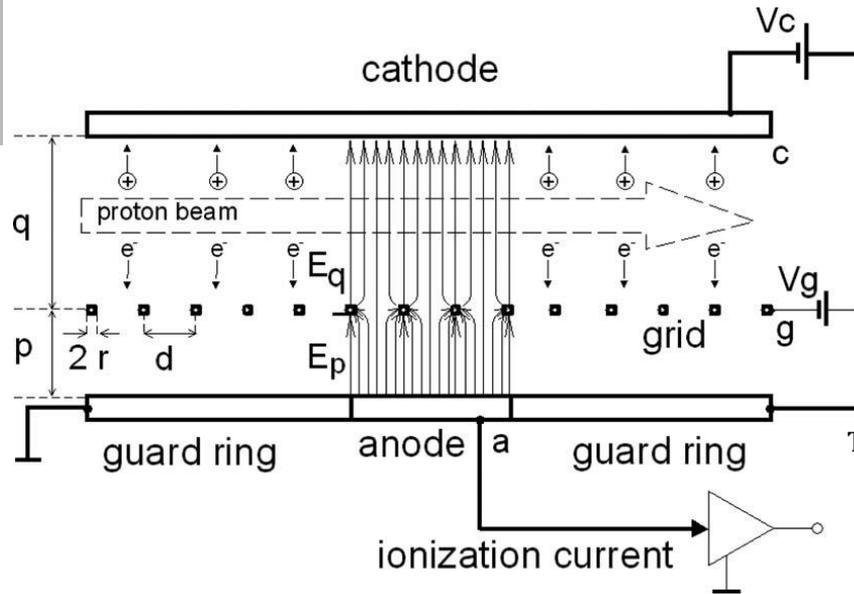
$$t_c = \frac{d}{\mu \times V_a}$$



Advantages	Inconvenients
Simple construction	Slow $t_{ions}(M1) \sim 90 \mu s$ $t_{ions}(M2) \sim 350 \mu s$
	Microphone effect

Gantry 1 – beam monitoring system

Monitor 3 is a Fisch's grid ion chamber



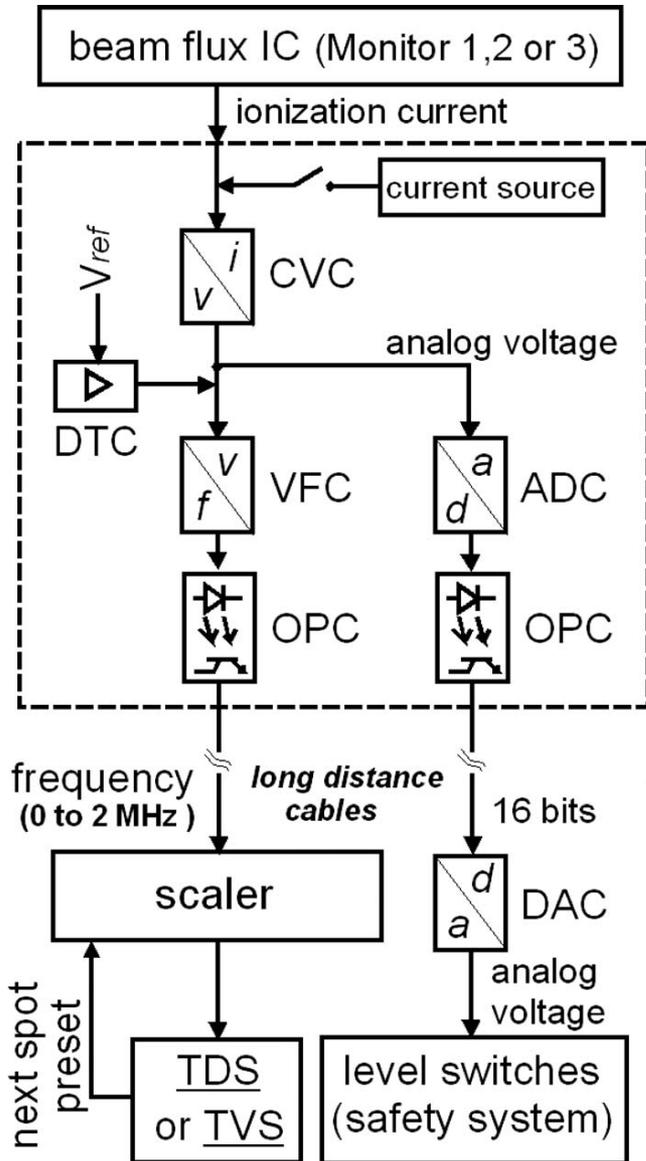
Ch1 Rise
183.7µs

Ch2 Rise
262.9µs

Ch3 Rise
59.43µs

Advantages	Inconvenients
Fast ($t_{ions} \sim 10\mu s$)	Gain is not stable enough
No microphonic effect	Nitrogen gas

Gantry 1 monitors : acquisition



Schematic of the current-to-frequency converter (CFC)

- Ionization currents up to 100nA
- Range : 75fC to 500 fC / count
- Gain variation $\sim 0.1\%$ / year
- Developed at PSI in cooperation with Dipl-Ing. Kramert GmbH

$\sim 50m$

CVC : Current-to-Voltage converter

DTC : dead time circuit

VFC : Voltage-to-Frequency converter

DAC : Digital-to-Analog converter

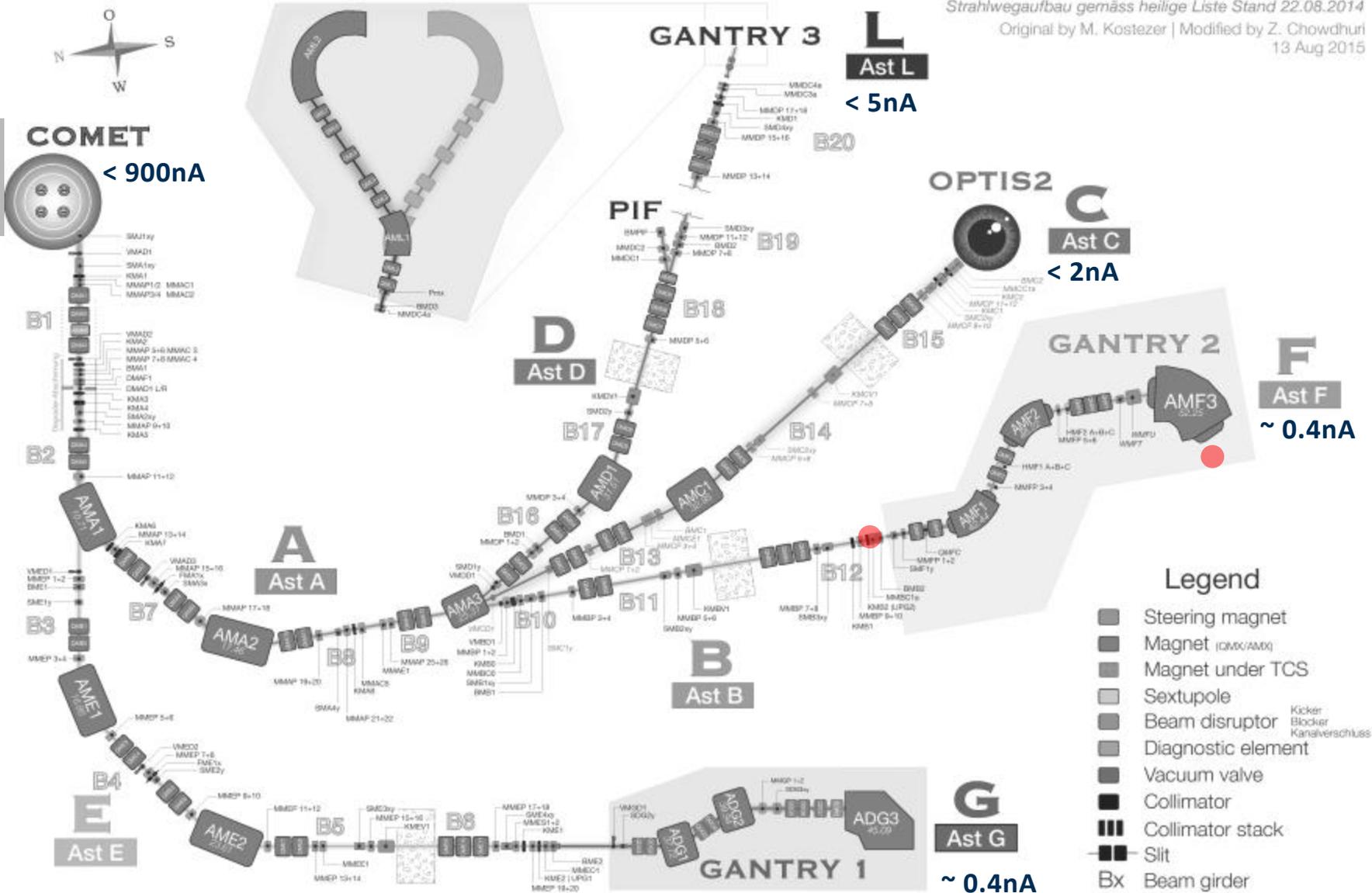


Beam current monitoring

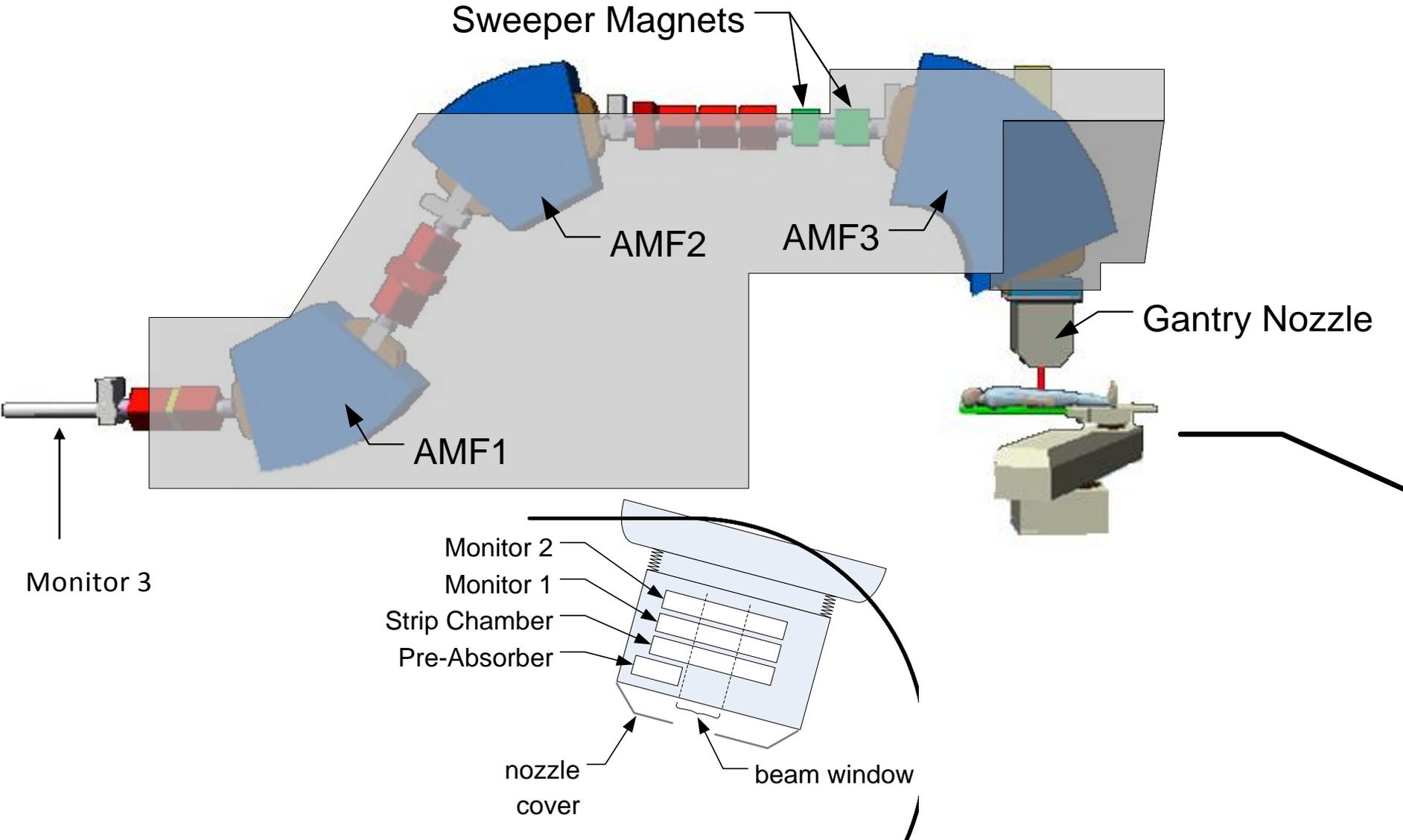
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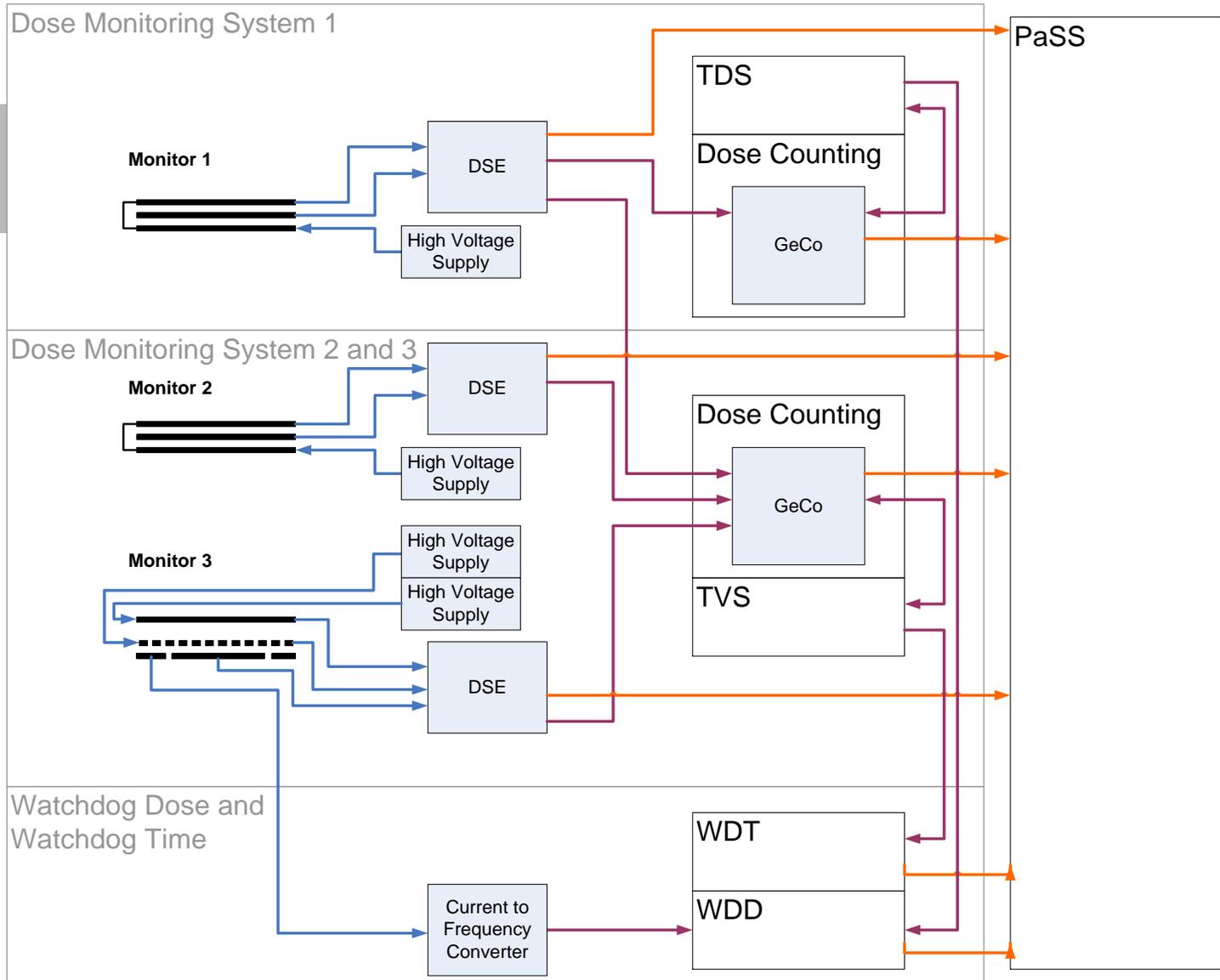
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Gantry 2 - Introduction



Gantry 2 - beam monitoring system



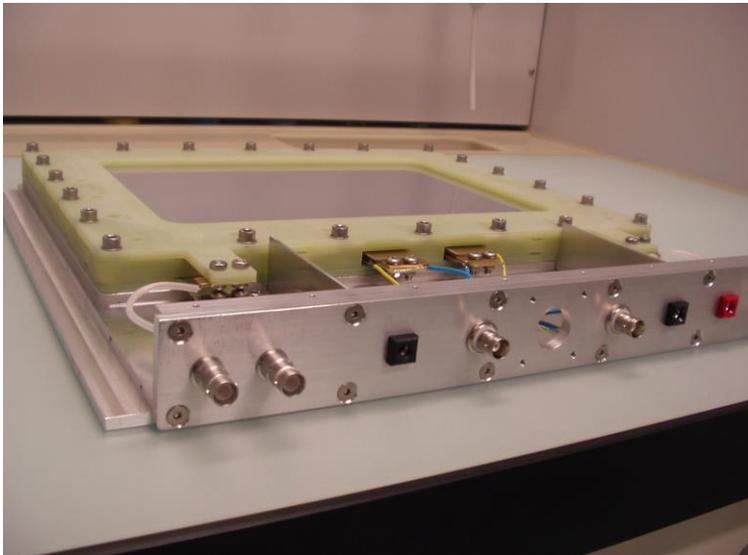
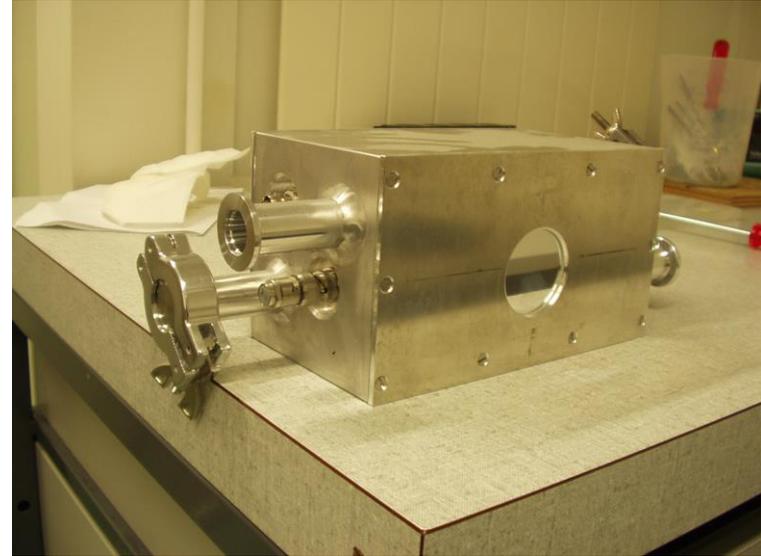
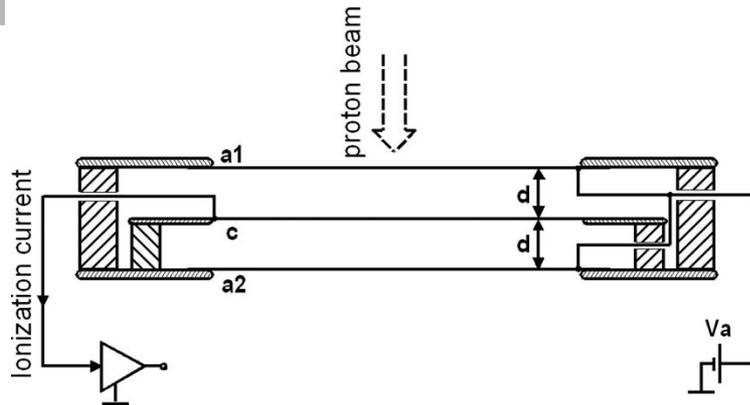
- PaSS signals
- Analog signals
- Digital signals (seriell, parallel)

Gantry 2 - beam monitoring system

Based on Gantry 1, but with some modifications

For monitors 1 & 2

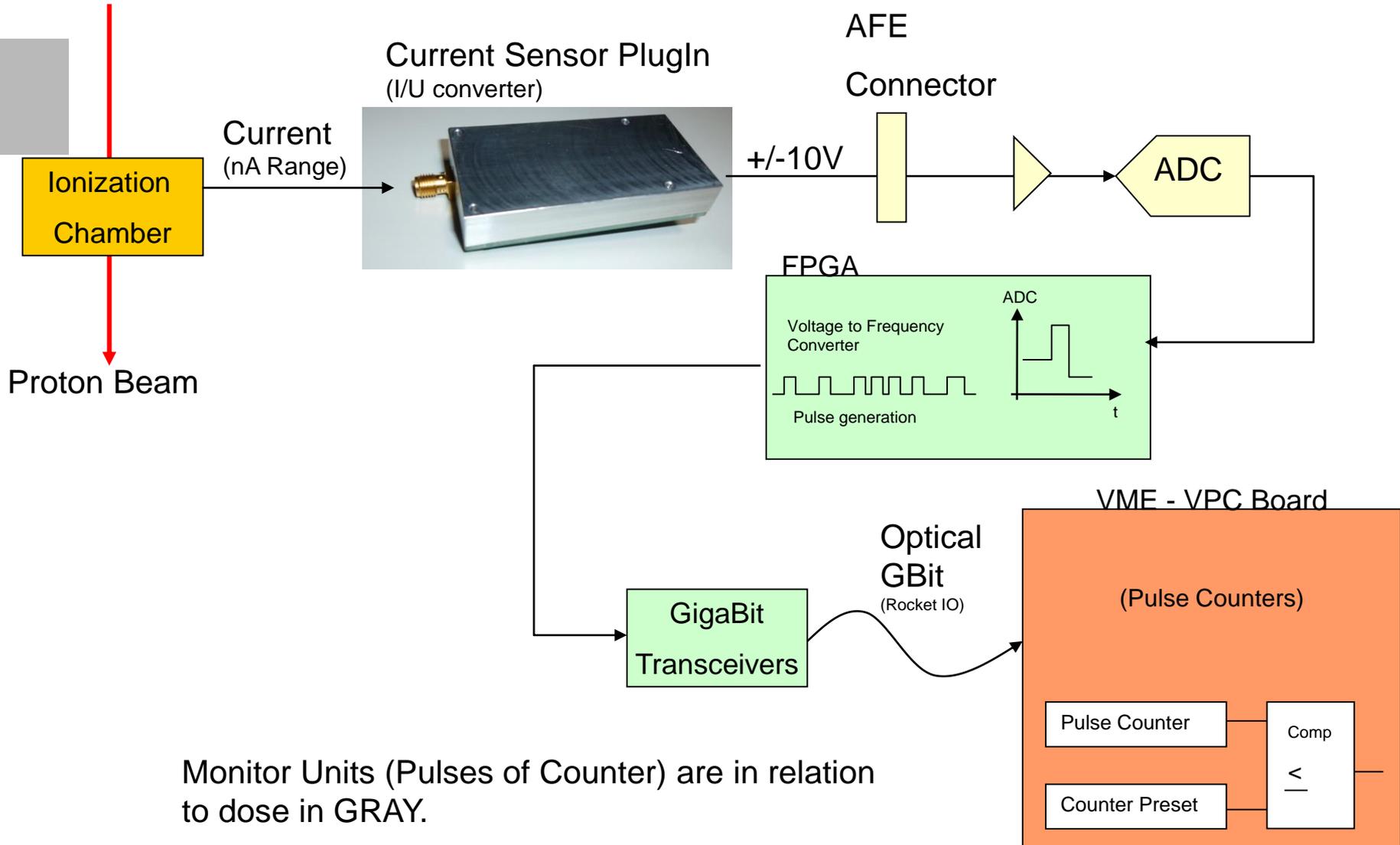
- 2D scanning area (12x20)cm



For monitor 3, the 2D scanning concept cannot be implemented

- Detector located at the coupling point
- Fixed beam passing through

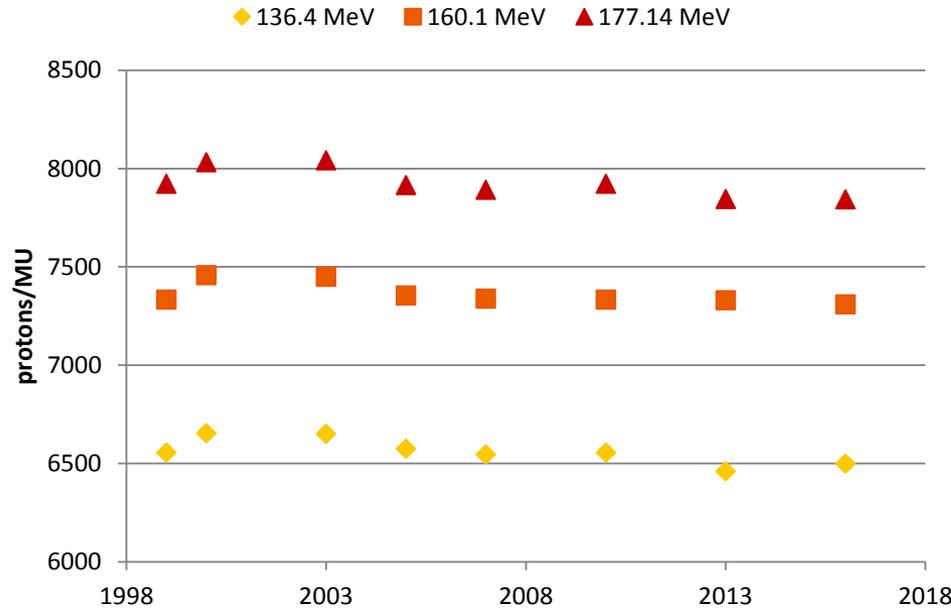
Gantry 2 – monitors acquisition



Monitor Units (Pulses of Counter) are in relation to dose in GRAY.

Monitor calibration : golden standard

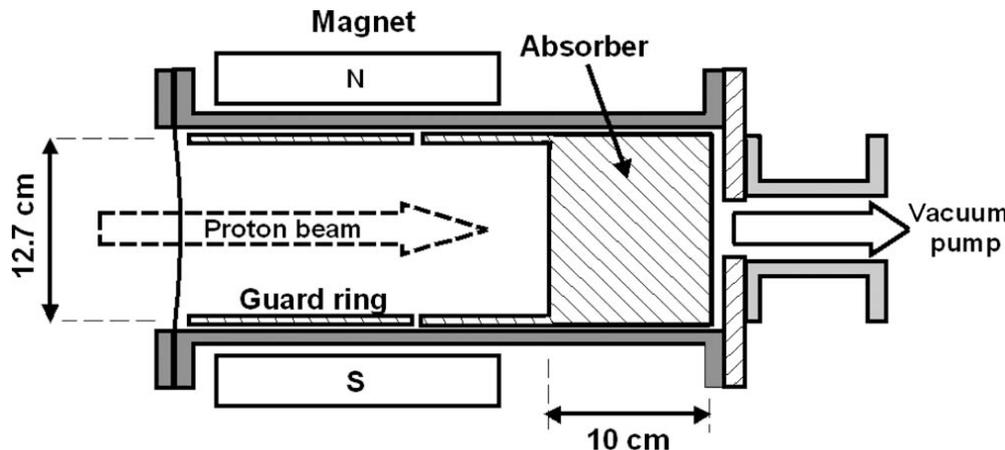
Gantry 1 monitor 1 calibration



Faraday's cup

- Used for all gantries at PSI
- Allows to precisely calculate the number of protons (N_p) for the arbitrary monitor units (MU)

$$N_p = \frac{Q_F / e}{MU}$$



The dose in water is directly related to this calibration value

$$D_w = (1.602 \times 10^{-10}) \frac{N}{a} \left[\frac{S(E)}{\rho} \right]_w$$

a = effective area of the beam cm^2
 $[(S(E)/\rho)]$ = mass electronic stopping power of proton of energy E in water

Advanced proton beam delivery techniques (e.g. line scanning) requires new development of dose monitoring

- Faster detector
- Detector less sensitive to environment condition
 - Acoustic noise
 - Temperature (and humidity & pressure)



My thanks go to Alex Koschik, David Meer, Martin Grossmann, Michael Eichin, Rudolf Döling



Dose delivery verification

SOBP box of (6x6x6)cm, 21 energy layers : 1Gy

Two types of ionization chambers

Exradin T1 (collecting volume : 0.05cm³)

At 50% of the distal fall-off

IBA FC65-G (collecting volume : 0.65cm³)

Center of the SOBP



Calculated Dose center of SOBP - Gantry 2 [Gy]

