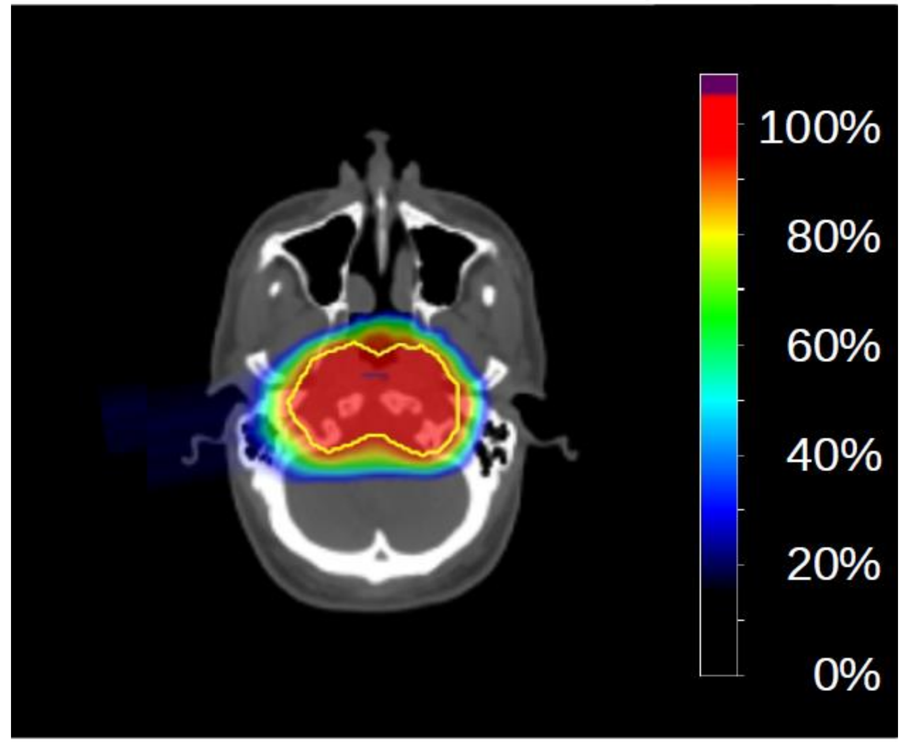
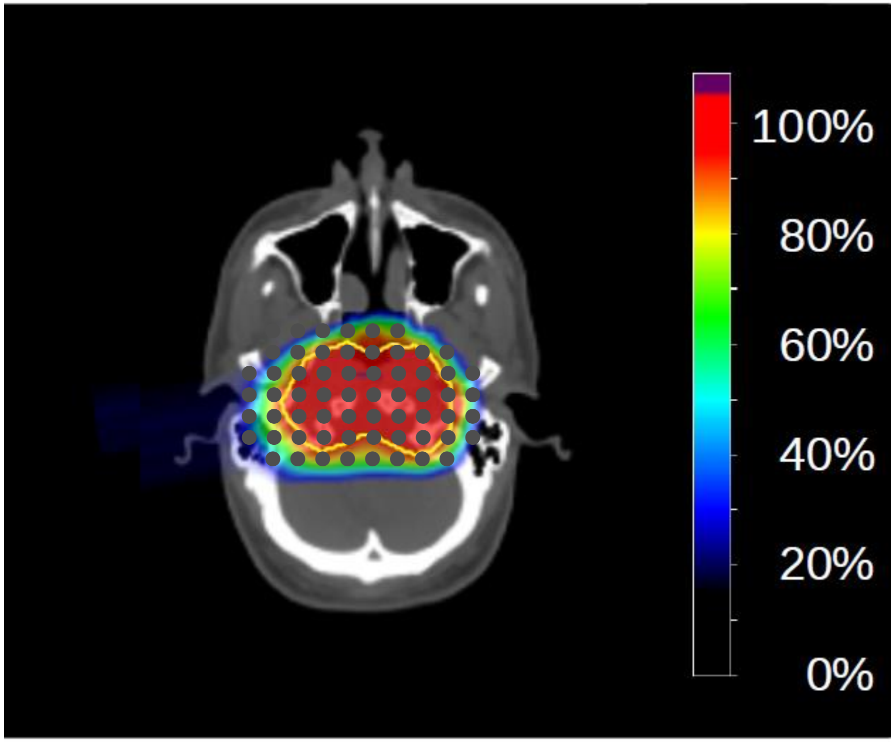

100%
80%
60%
40%
20%
0%

Dose

Range

Position



PAUL SCHERRER INSTITUT

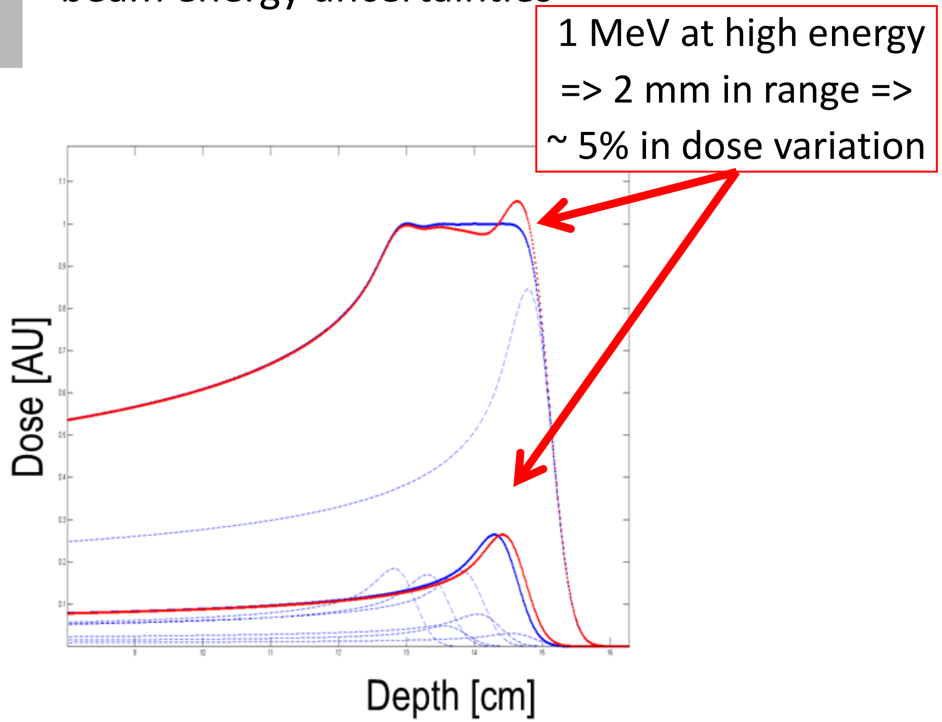
Oxana Actis :: Beam Technology Development :: Center for Proton Therapy :: PSI

Beam position monitoring at PBS therapy system

2nd OMA Topical Workshop: Diagnostics for Beam and Patient Monitoring
4-5 June 2018, CERN

Beam Position Precision Requirements

Longitudinal accuracy
(depth) depends on
beam energy uncertainties



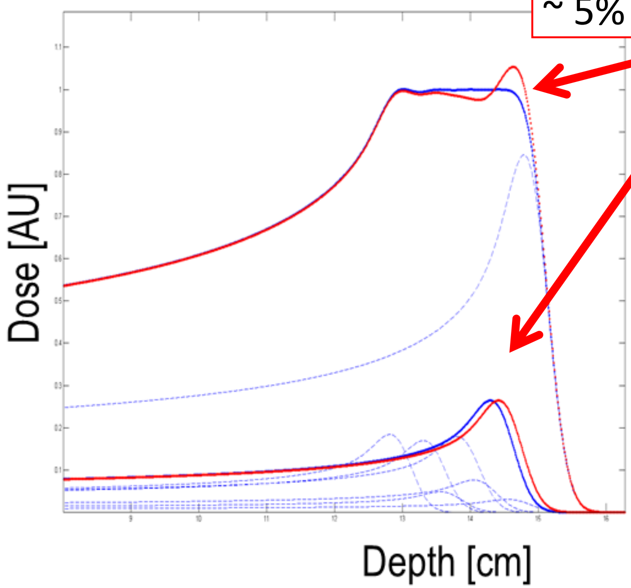
Beam Position Precision Requirements

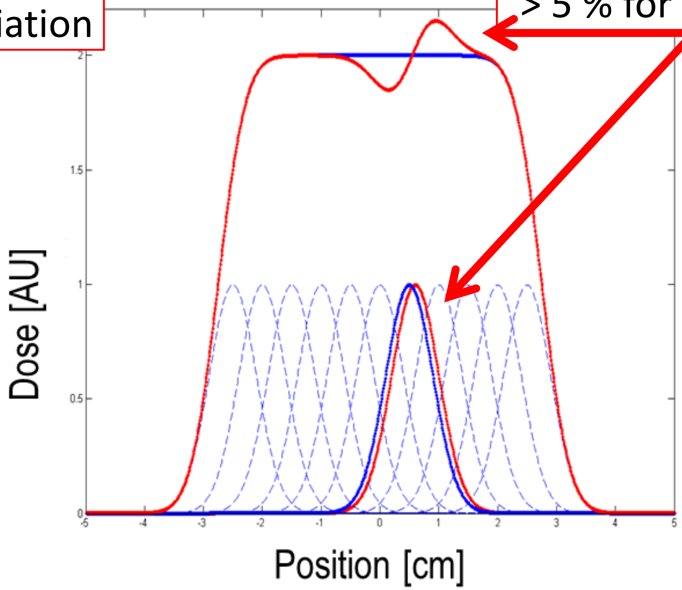
Longitudinal accuracy (depth) depends on beam energy uncertainties

Transverse (lateral) accuracy depends on spot position, grid and size

1 MeV at high energy => 2 mm in range => ~ 5% in dose variation

Spot shift: large dose inhomogeneity > 5 % for 1 mm shift



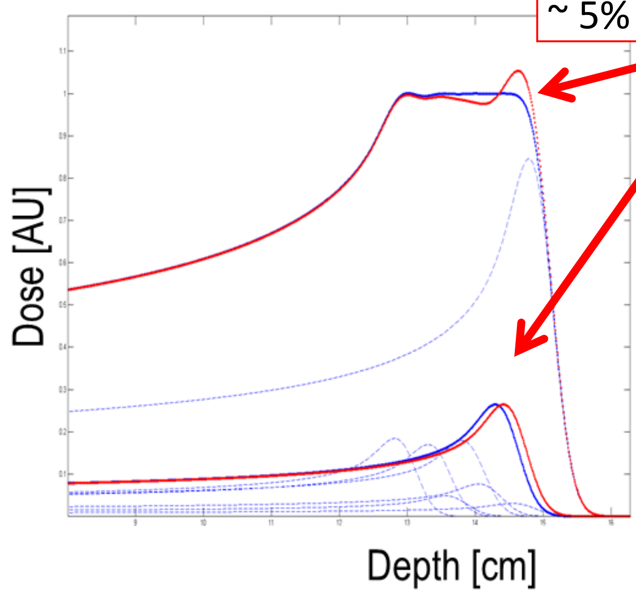


Beam Position Precision Requirements

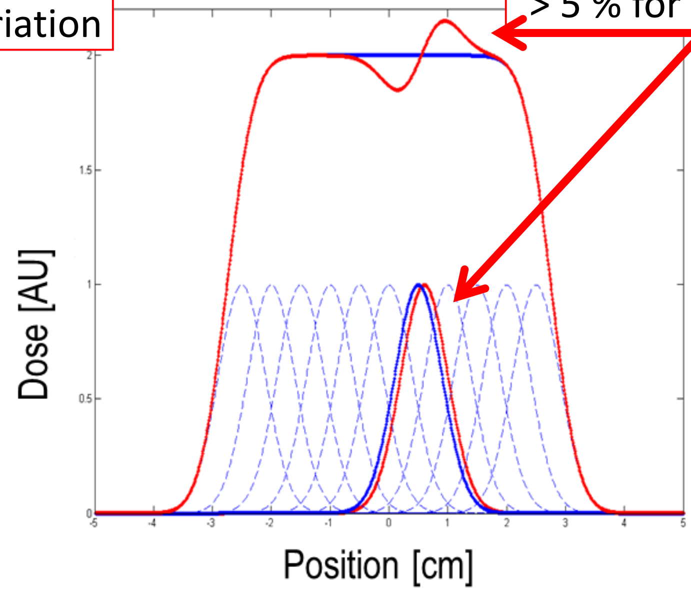
Longitudinal accuracy (depth) depends on beam energy uncertainties

Transverse (lateral) accuracy depends on spot position, grid and size

1 MeV at high energy => 2 mm in range => ~ 5% in dose variation



Spot shift: large dose inhomogeneity > 5 % for 1 mm shift



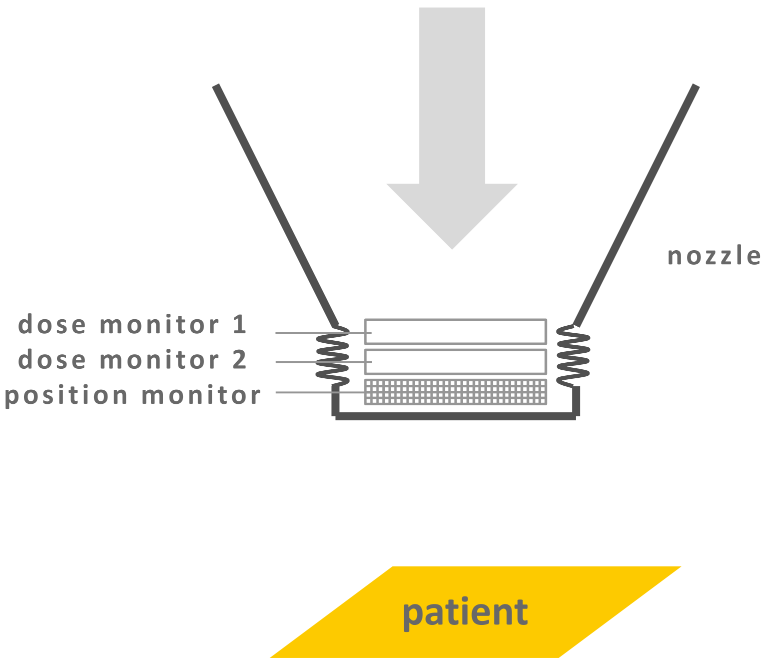
The goal to deliver dose homogeneity of ~ 1% require:

Longitudinal accuracy better than 2mm

Lateral accuracy at sub-millimeter level

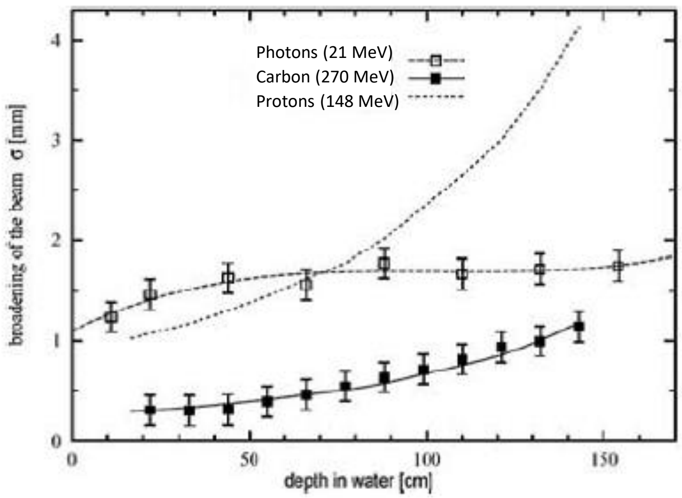
Beam Monitoring System

PBS System



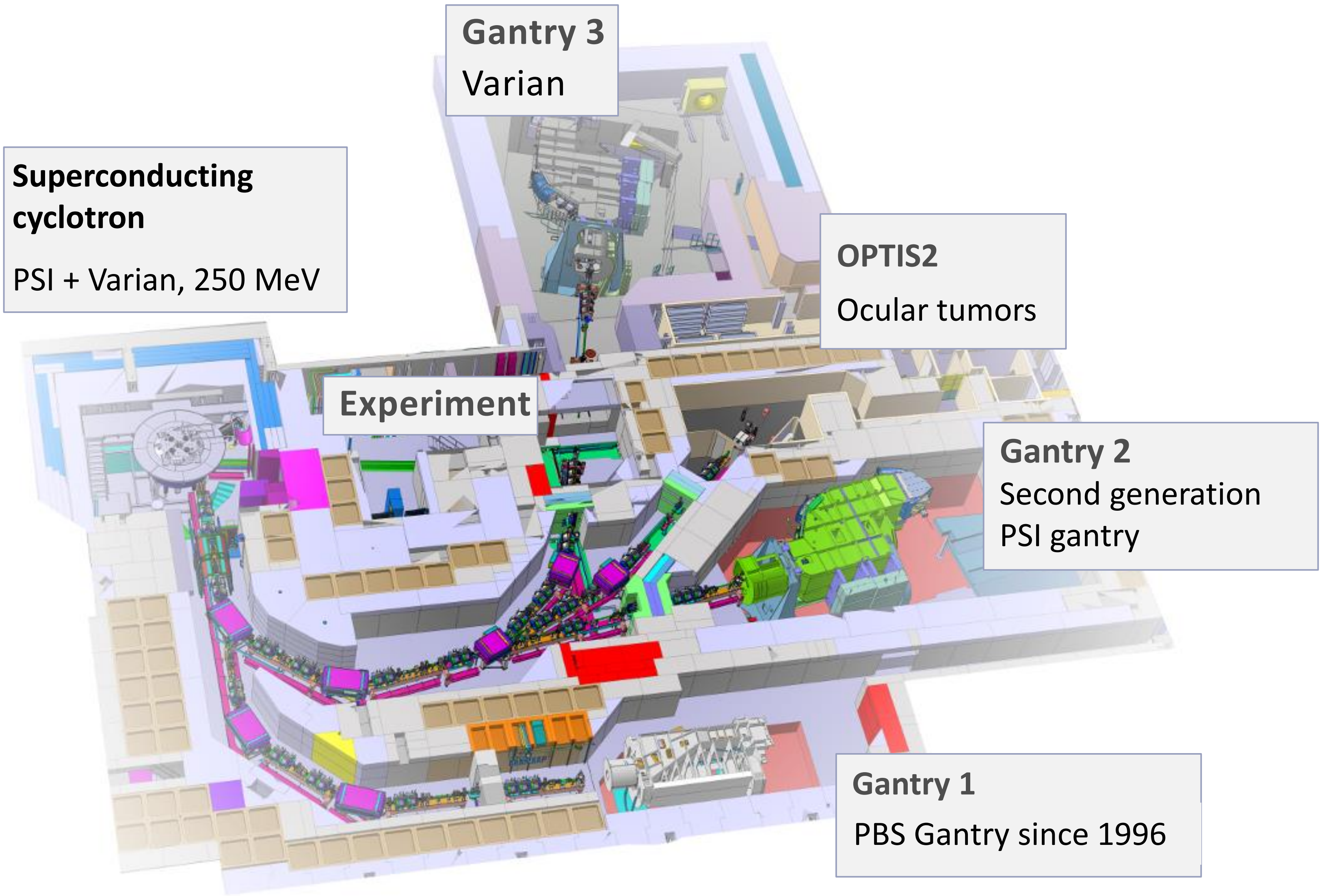
Goal: small spot size

Beam broadening due to multiple scattering



- Detectors with low material budget are required
- Critical for protons

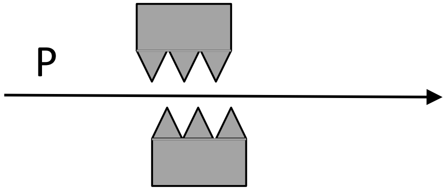
PROSCAN at PSI

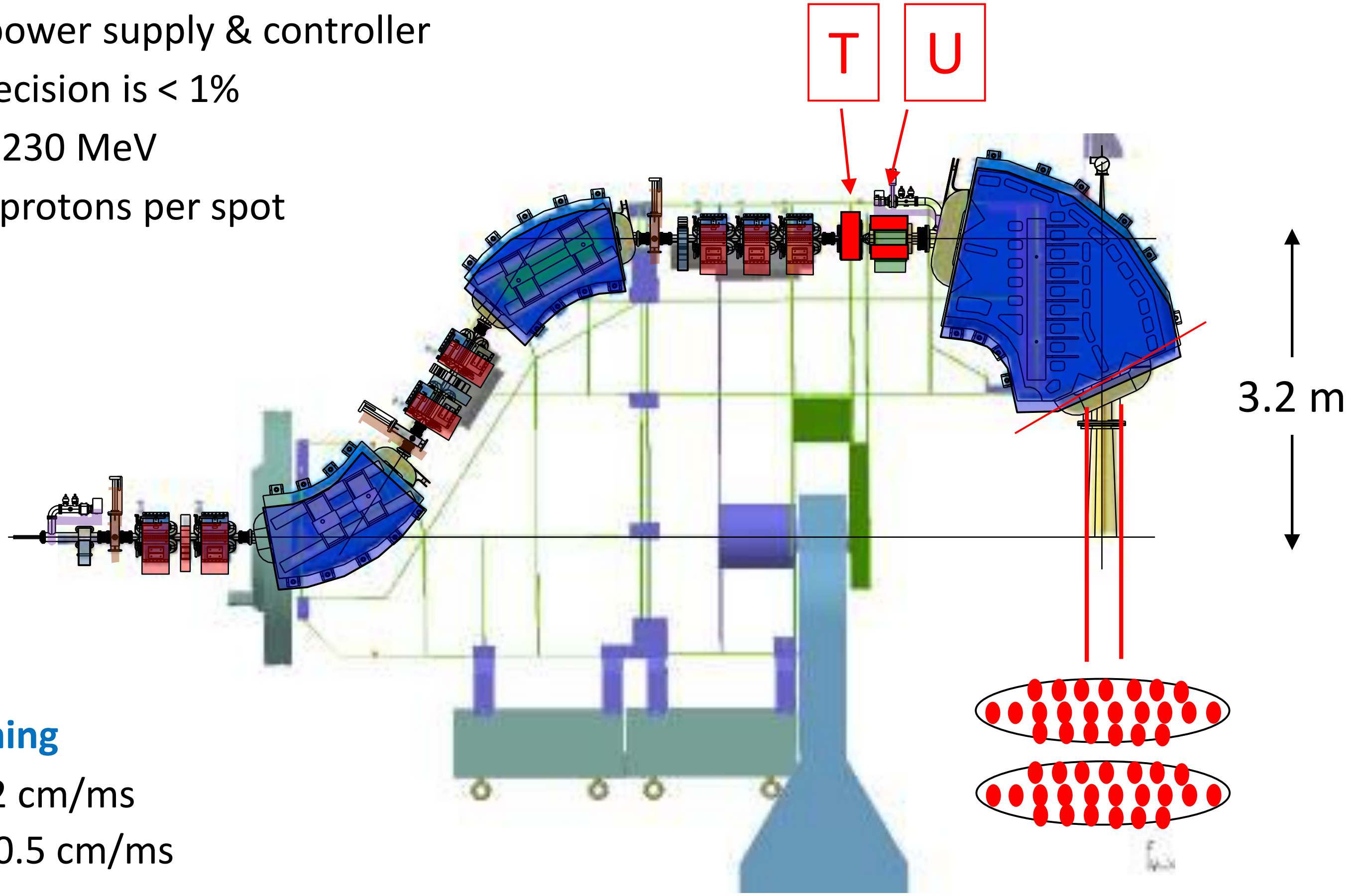


Spot scanning technique @ Gantry 2

Energy

- Degrader based energy change within **< 100 ms**
- Optimized magnet power supply & controller
- Delivered energy precision is < 1%
- Energies from 70 to 230 MeV
- Dose down to 5e05 protons per spot





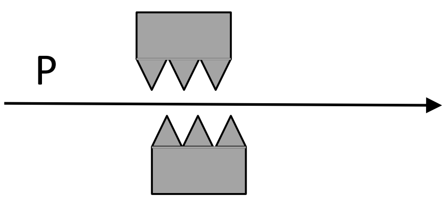
Parallel Lateral Scanning

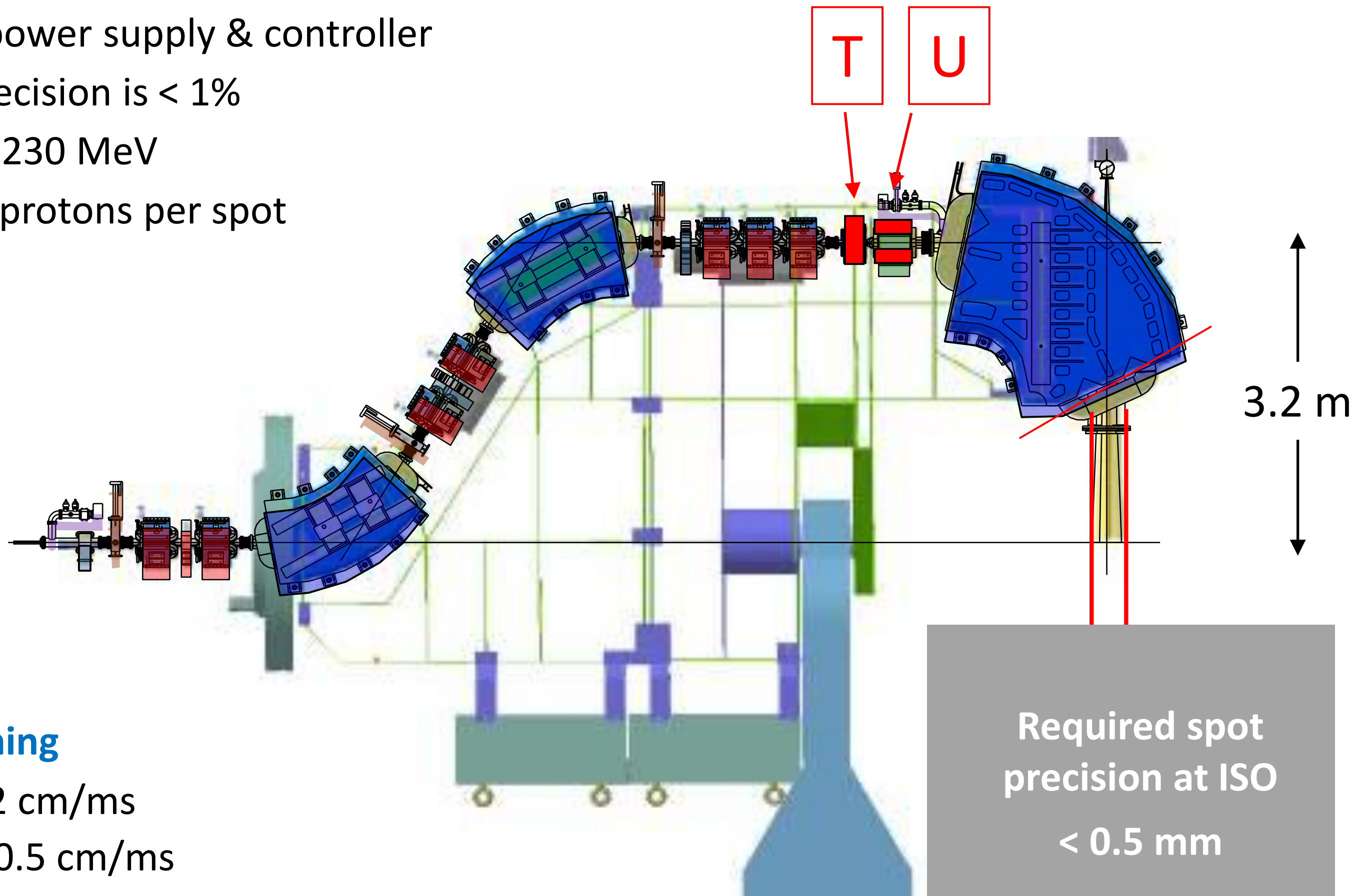
- T sweeper magnet 2 cm/ms
- U sweeper magnet 0.5 cm/ms
- Scan area 20 x 12 cm
- Field patching for larger fields

Spot scanning technique @ Gantry 2

Energy

- Degrader based energy change within **< 100 ms**
- Optimized magnet power supply & controller
- Delivered energy precision is < 1%
- Energies from 70 to 230 MeV
- Dose down to 5e05 protons per spot





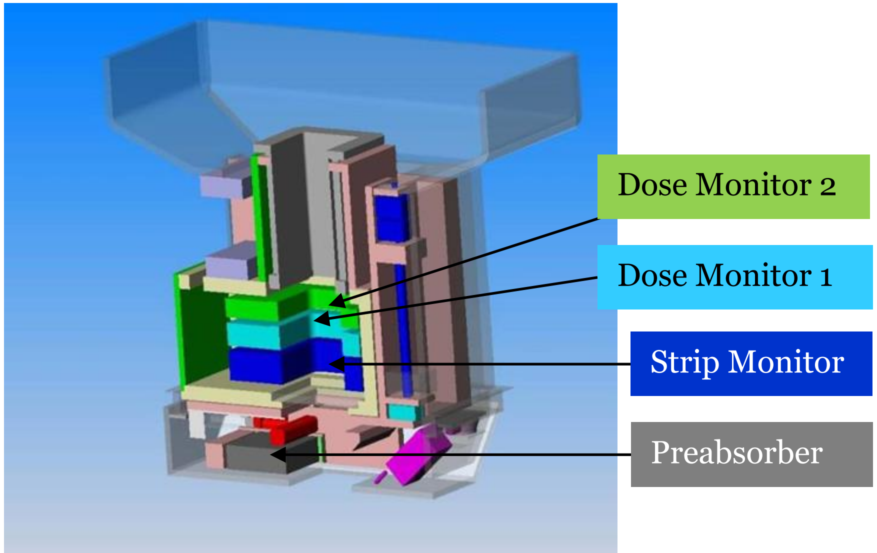
Required spot precision at ISO

< 0.5 mm

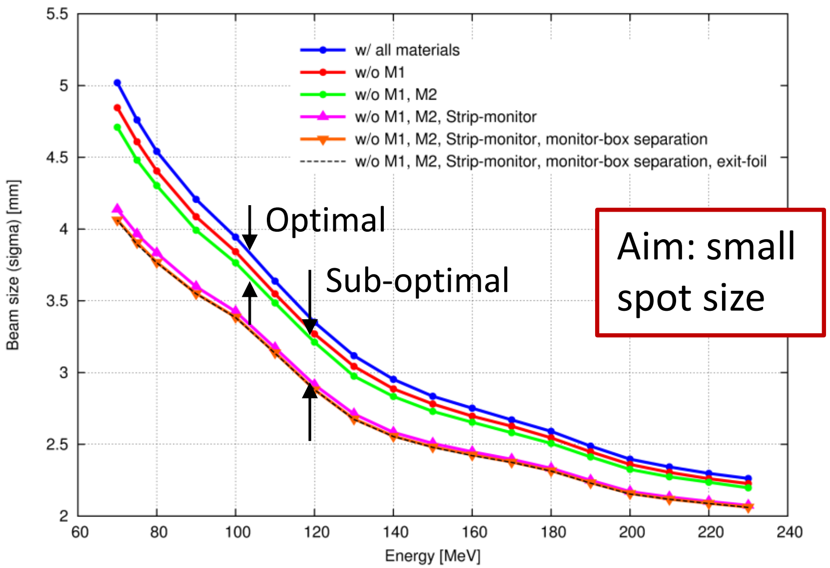
Parallel Lateral Scanning

- T sweeper magnet 2 cm/ms
- U sweeper magnet 0.5 cm/ms
- Scan area 20 x 12 cm
- Field patching for larger fields

Tool for on-line lateral position and dose monitoring



Spot Size at patient location



Radiat Prot Dosimetry. 2009 Nov;137(1-2):156-66

Dose Monitors:

Ionization Chambers (0.5,1 cm, air gap)

Position Monitor

- Choice is based on Gantry 1 experience
- No aging effect (~ 20y experience Gantry 1)
- Stability and flexibility in operation
- (Sub-)optimal material budget (technical limitations)

Tool for on-line position monitoring

2 TERA06 chips

128 channels each

Read-out

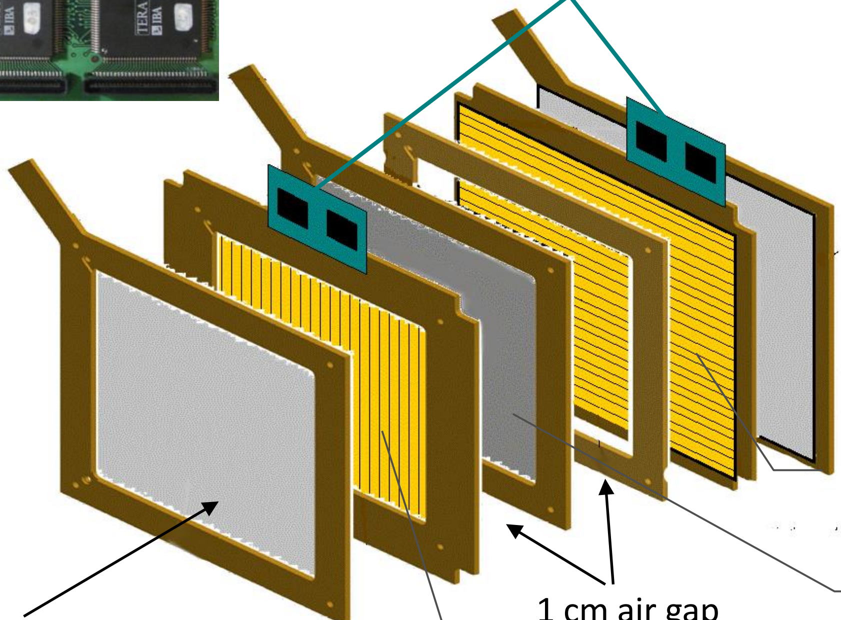
- 16 bit TTL digital output
- 10 MHz digital count frequency
- 200 fC Quantum of charge

$$t = \frac{d^2}{\mu * V_a}$$

μ = 1.4 (dry air) is the mobility of charged particles in the electric field

V = 1800 V applied HV

d = 1 cm air gap



T-anode 88 channels / 2mm

One 2-sided **Al** cathode

1 cm air gap

0.2 µm Mylar foil

U-anode 128 channels / 2 mm

50µm kapton foil

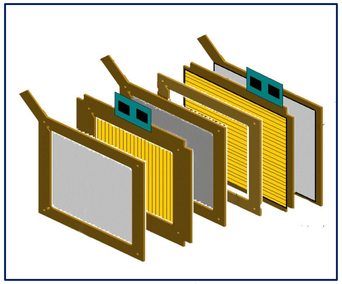
with 17 µm **Cu** electrodes

Since 2009 commercialized by

DETECTOR DEVICES AND TECHNOLOGIES TORINO

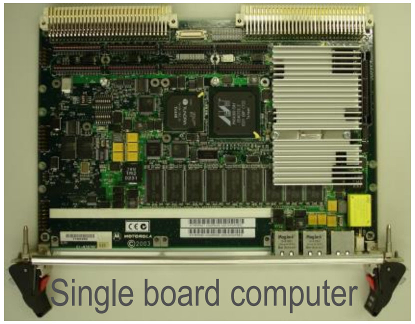
PAUL SCHERRER INSTITUT PSI

On-line signal readout process

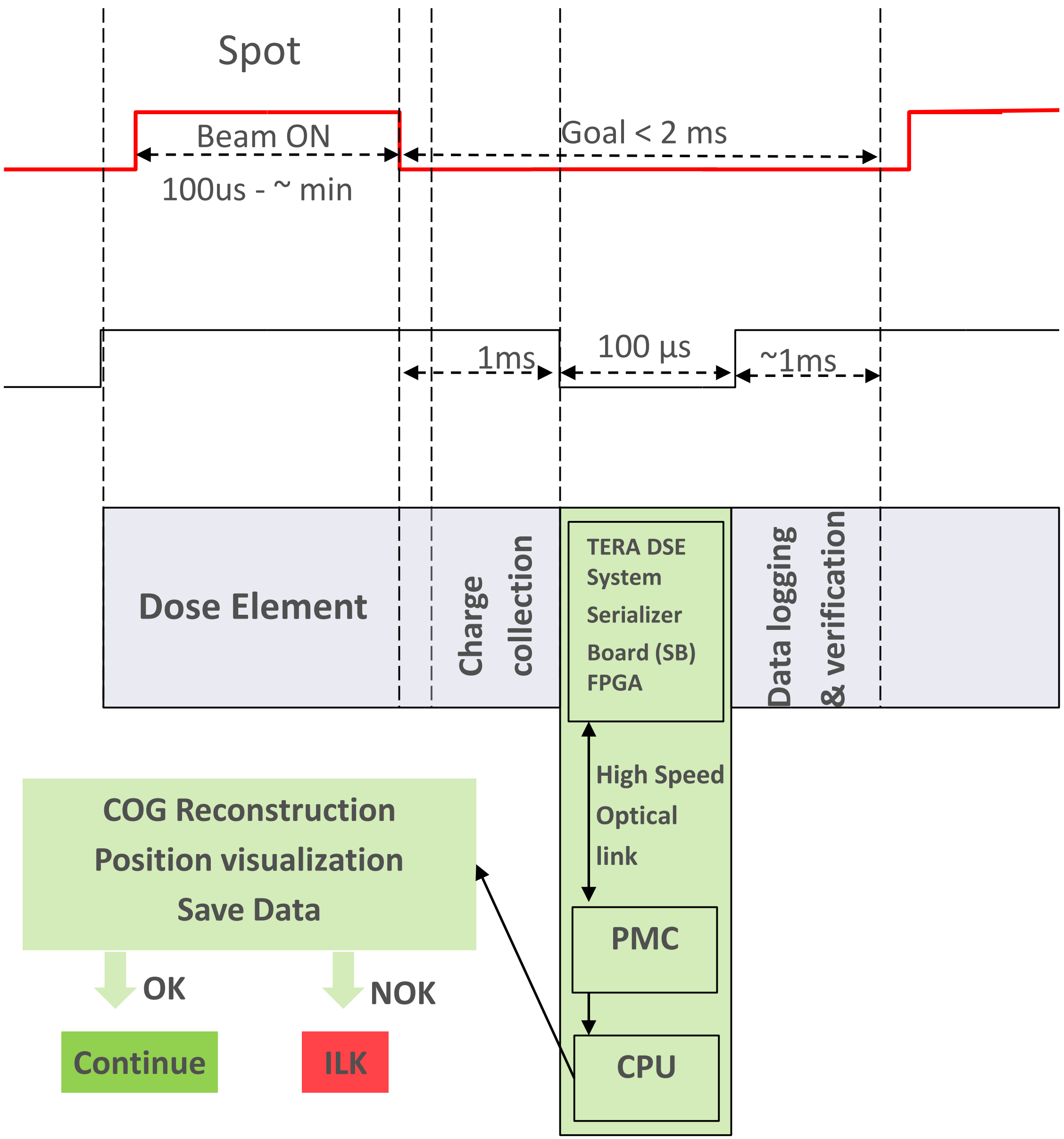


TERA dse

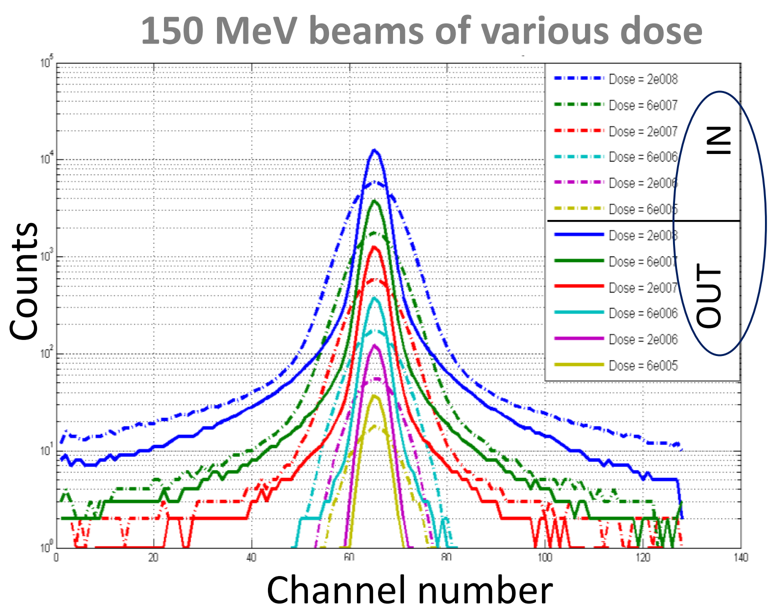
SB



Signal collection → ADC → Front-end electronics → Back-end



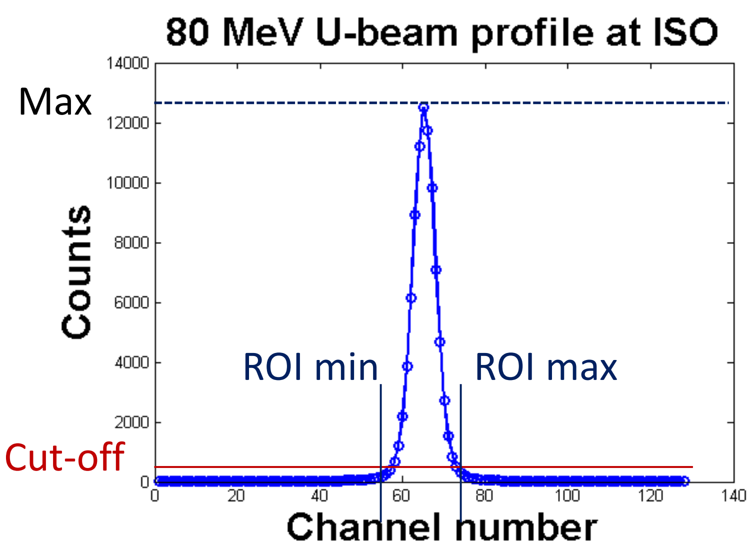
Gantry 2 Beams Reconstruction



Preabsorber position

- Beam size vary with energy
- Dose can be varied over 4 orders of magnitude
- SNR still acceptable for lowest dose signal

⇒ can be reconstructed for all energies and pre-absorber positions



COG algorithm

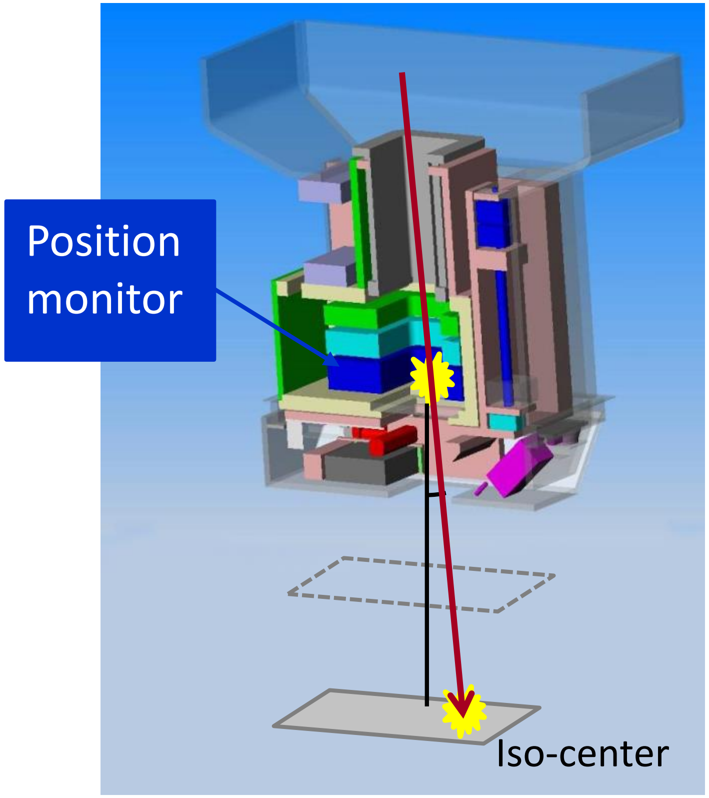
- Fast enough for on-line reconstruction
- Implemented in a FW

- Sensitive to noise/spikes
- Reconstruction uncertainties at the detector edge

Nozzle back projection

On-line position verification

- calculated at ISO using position measured in the nozzle
- same for parallel and divergent beam



Nozzle back projection

On-line position verification

- calculated at ISO using position measured in the nozzle
- same for parallel and divergent beam

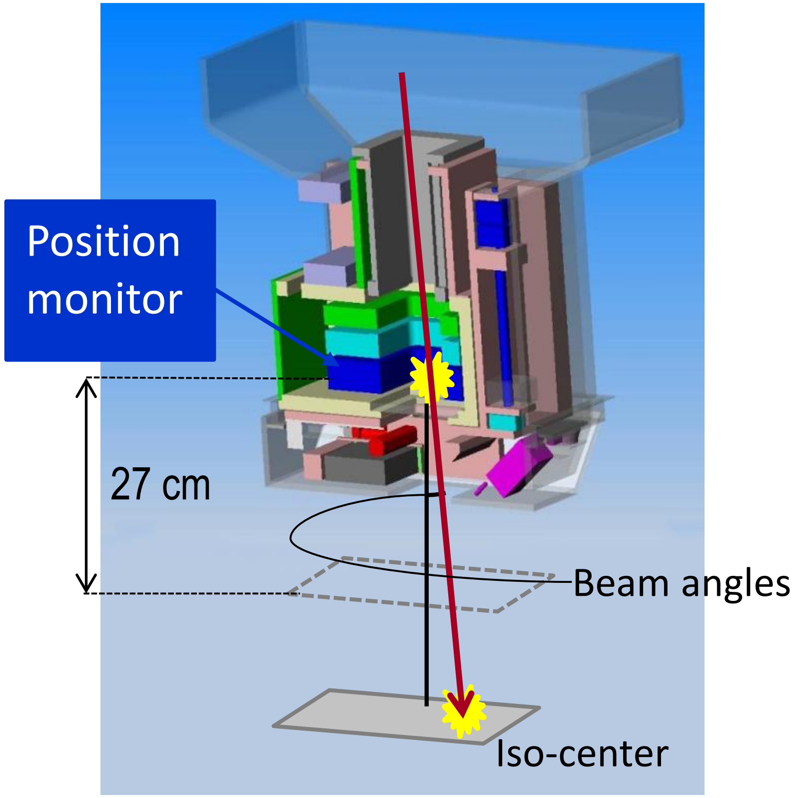
@ Gantry 2

Position measurement of two orthogonal profiles

- Measurement with position monitor in nozzle
- Cross check position at iso-center (monitor position correction)

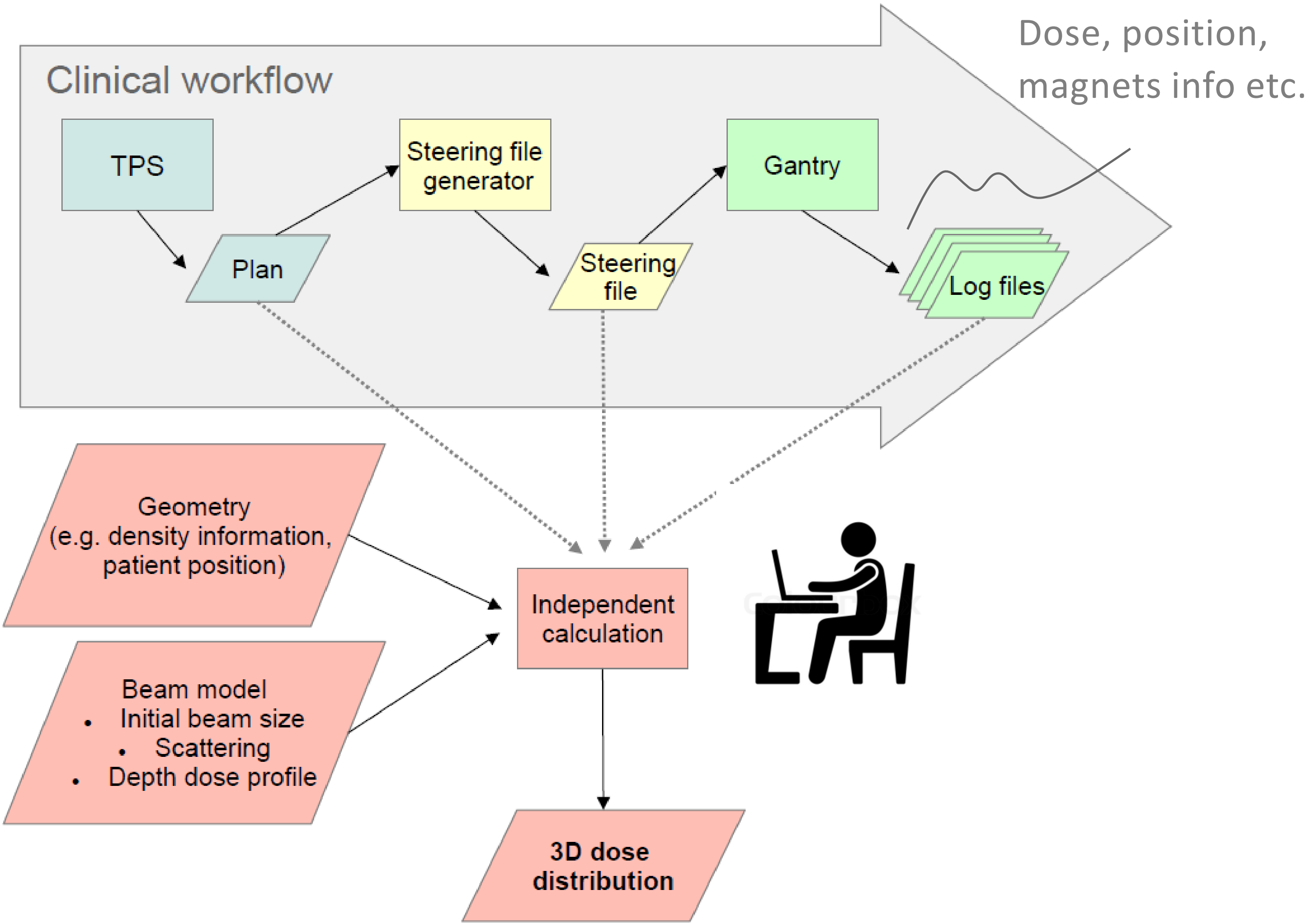
Position monitor → iso-center projection

- **Beam angles** for full scan range (per position and energy)
  - Projection error should be < 0.2 mm
  - Distance monitor - iso-center ~ 70 cm
  - **Precision < 0.5 mrad**



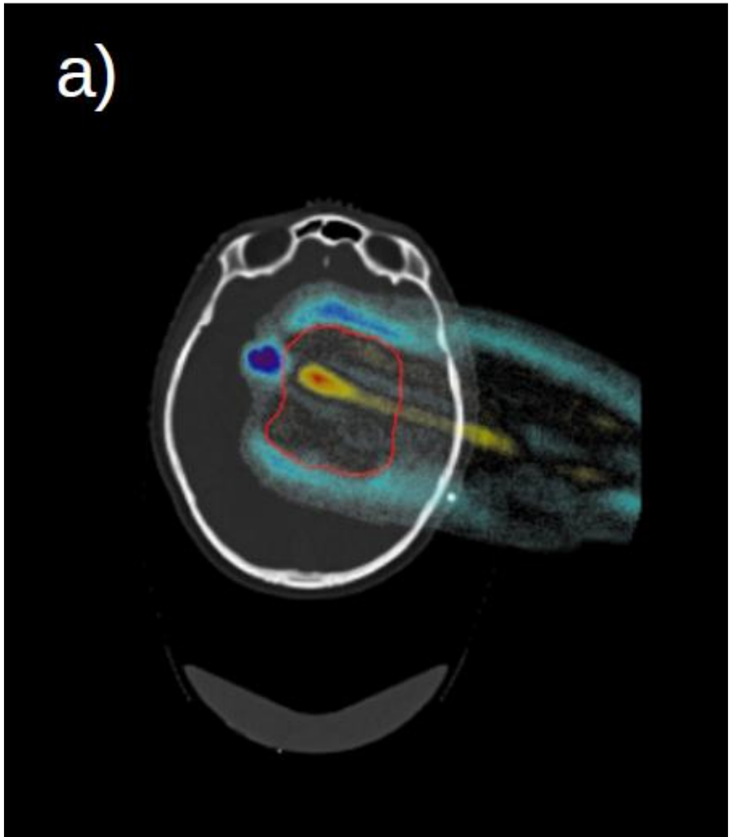
Projection calculation off-line: interpolation from LUT

Patient QA: a posteriori dose delivery control



Position failure example

Log file dose reconstructions for the first fraction of the first patient

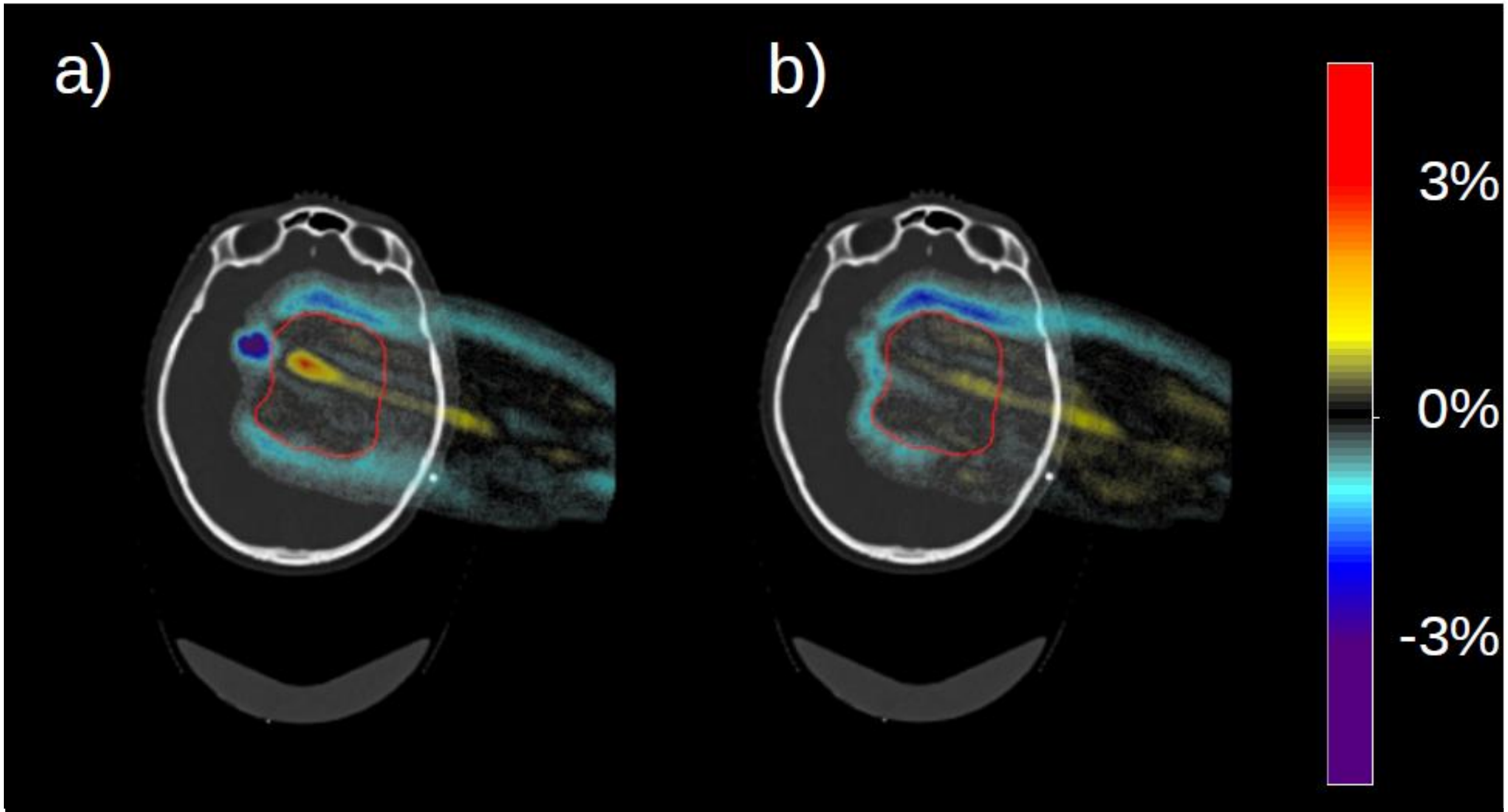


A systematic hot- and cold track

G. Meier, 2015: https://doi.org/10.3929/ethz-a-010531621

Position failure example

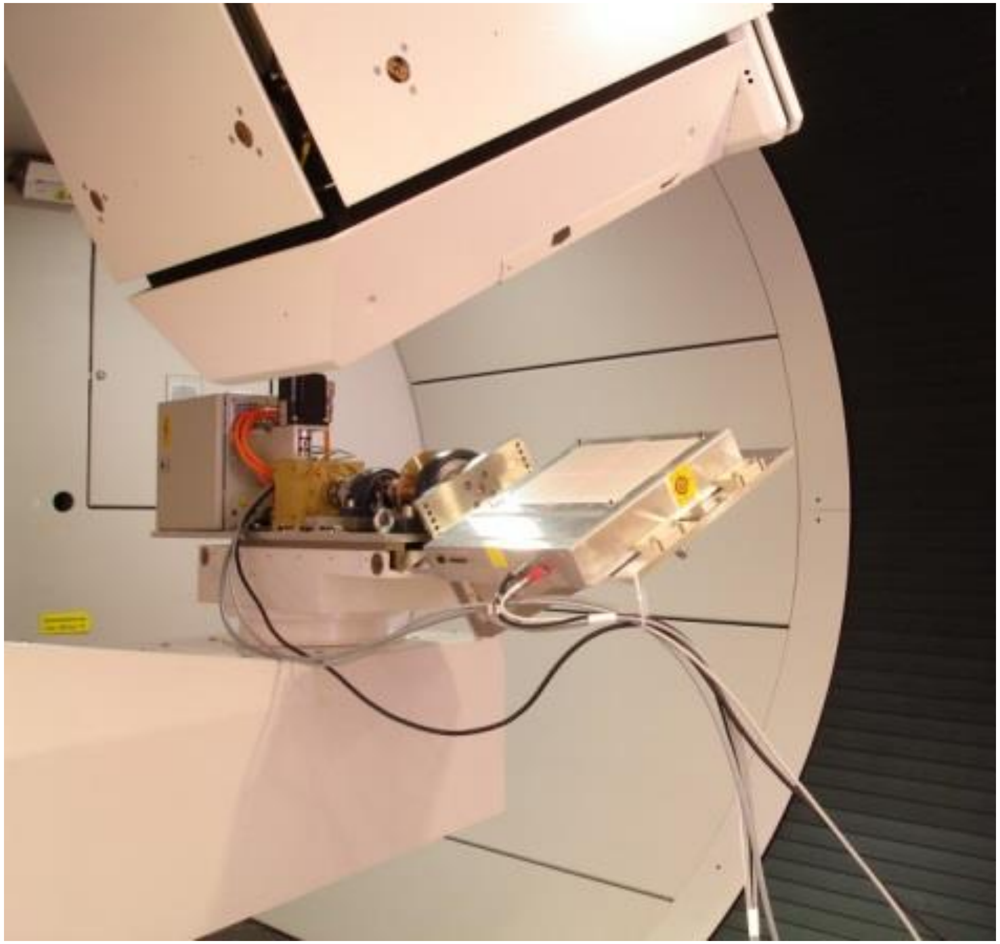
Log file dose reconstructions for the first fraction of the first patient



A systematic hot- and cold track　　Reconstructed dose after bug fix

G. Meier, 2015: https://doi.org/10.3929/ethz-a-010531621

Machine QA: Integrated quality assurance



Therapy Verification System

Single LogFile with on-line reconstructed mean, sigma and integral for each dose spot

Optional for QA

Full profiles logging for Nozzle and additional Strip or MiniStrip chamber mounted at ISO for

- Periodic QA
- Sweeper magnets calibration etc.

Integrated equipment for daily QA

RANGE

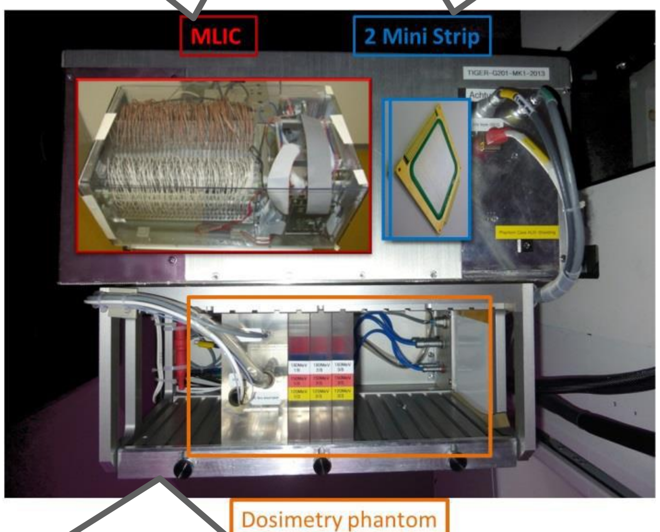
Multi-Layer Ionization Chamber

- 128 channels
- Parallel readout

POSITION

Mini-Strip Chamber

- 7x7 cm active area
- 32 chanels/side
- 0.22 cm spacing



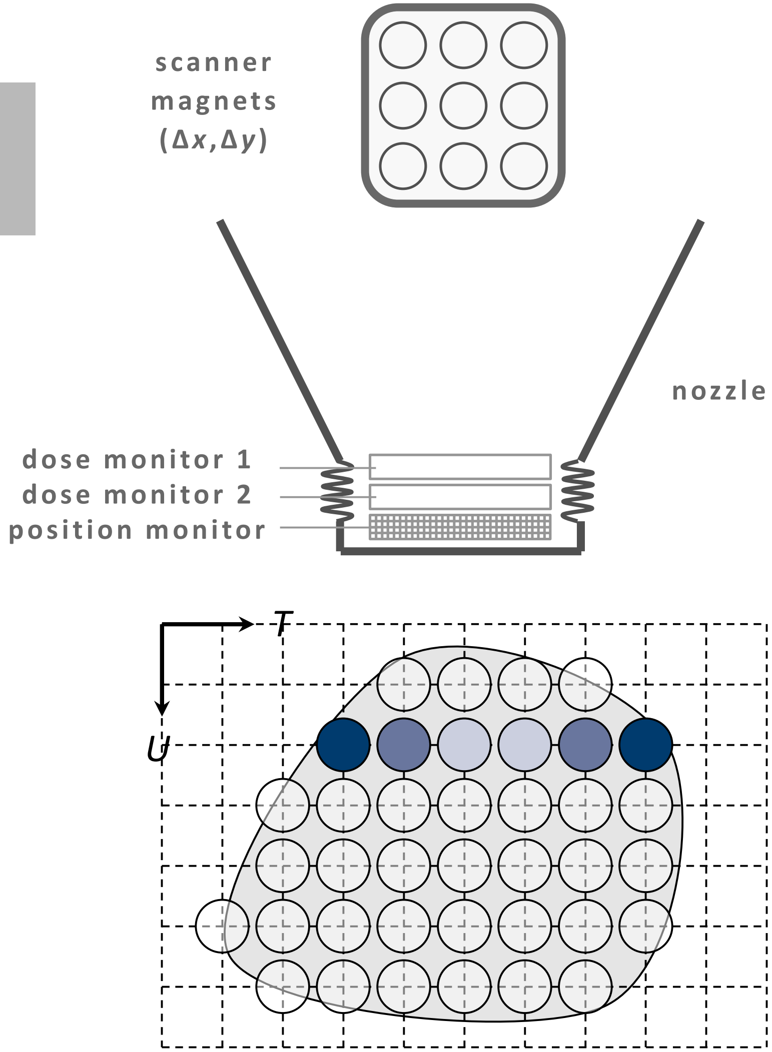
DOSE

2 ICs for dose verification in SOBP region & fall-off

- Stack of plexiglass blocks for various depth
- Temperature sensor

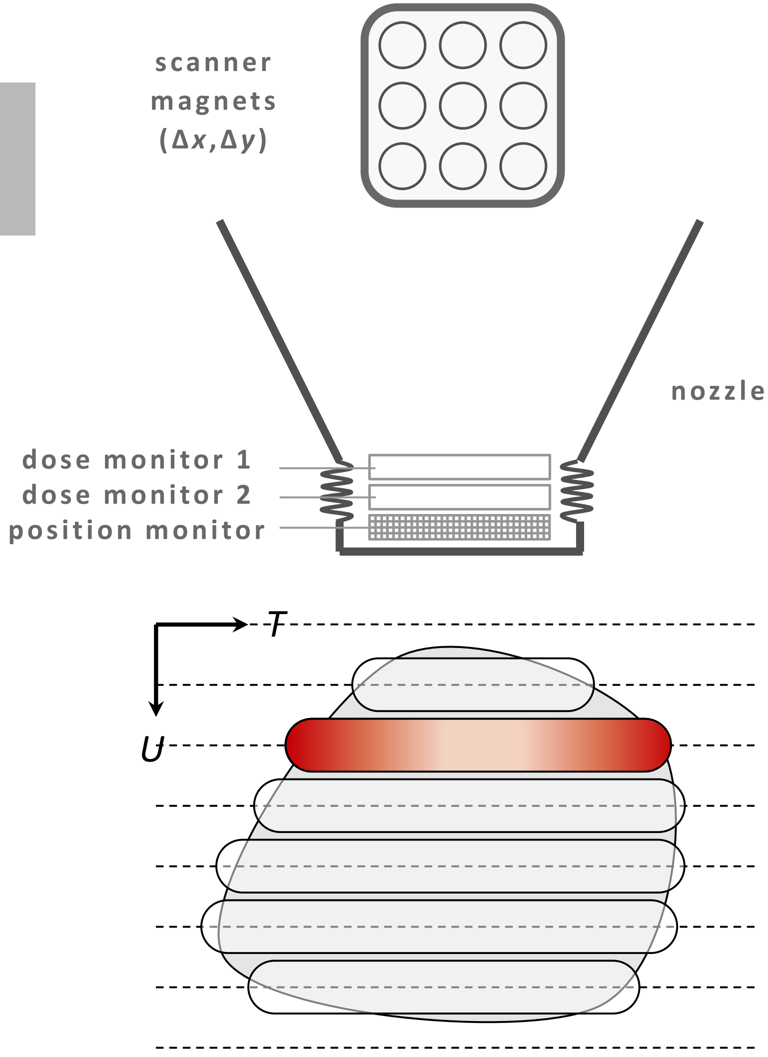
O.Actis, PMB 01/2017

Line scanning at Gantry 2



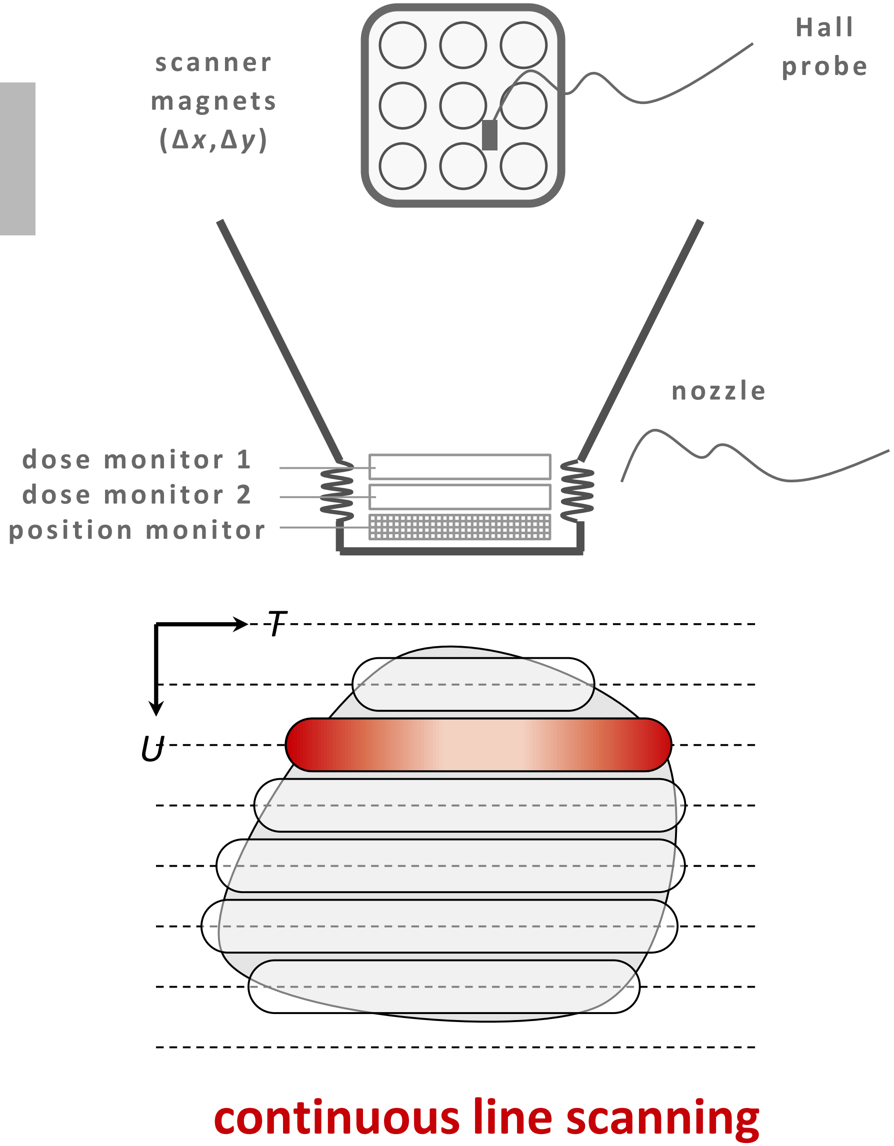
discrete spot scanning

Line scanning at Gantry 2



continuous line scanning

On-line Monitoring for Line Scanning



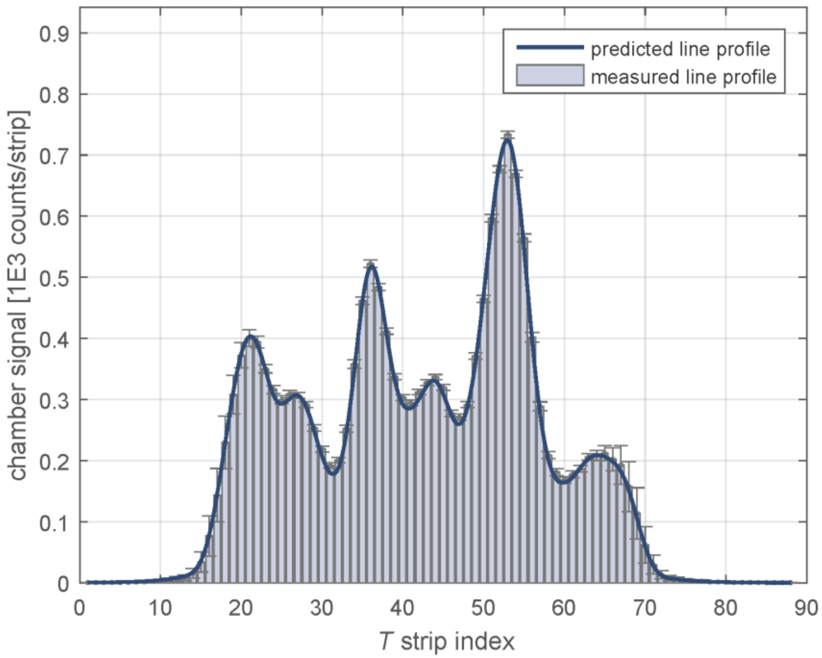
G. Klimpki, NIM-A 02/2018

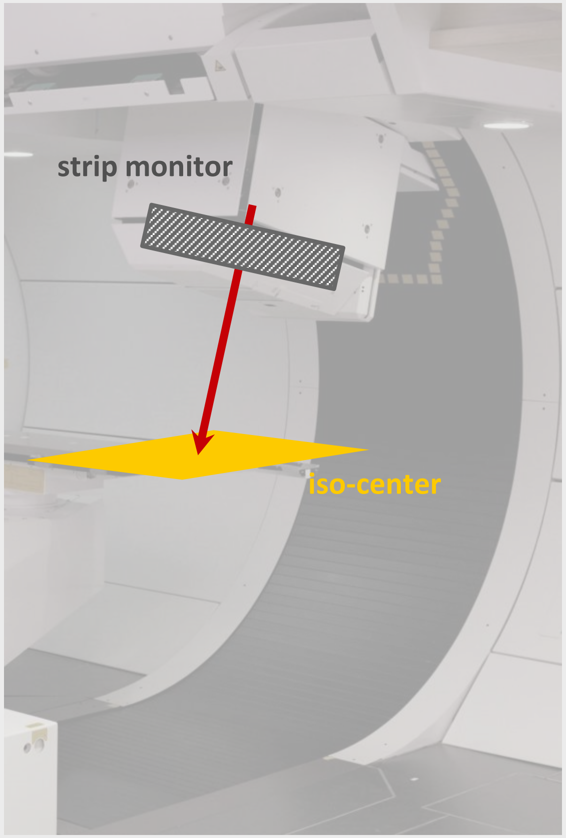
Real-time monitoring during the dose element application (every 10 µs)

- position within tolerance (± 1.5 mm)
- current within tolerance (± 5%)

Real-time monitoring after the dose element application

On-line monitoring: profile comparison

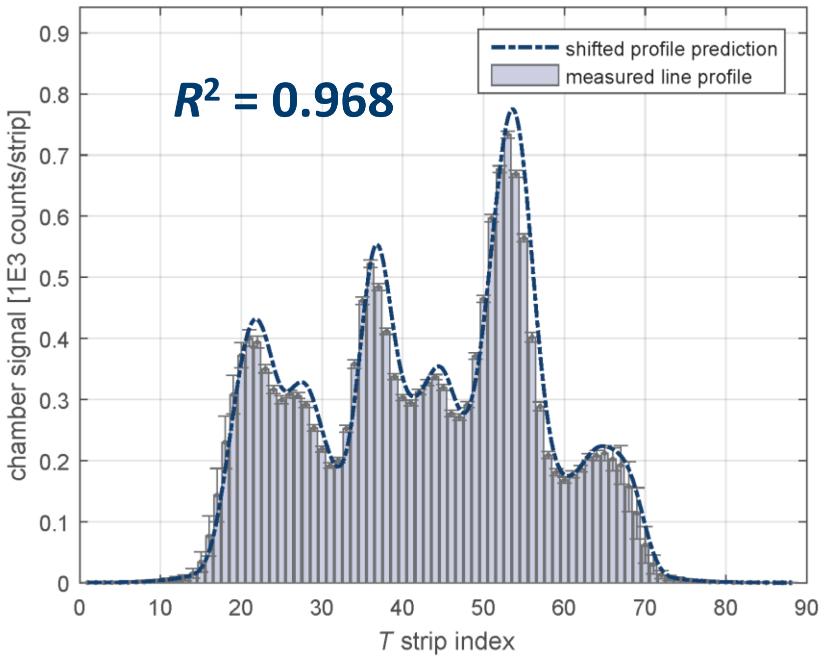


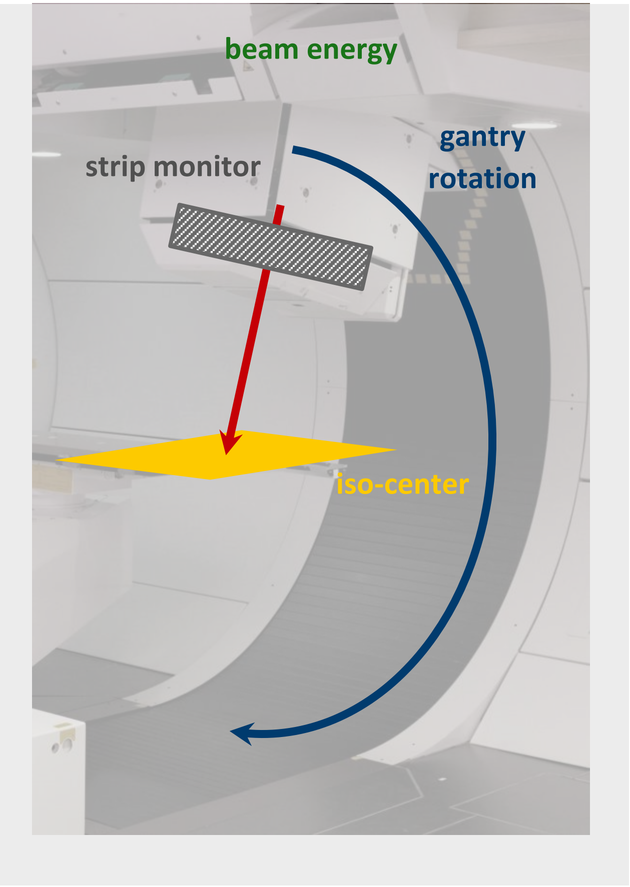


On-line monitoring: profile comparison

5D interpolation method models response for all combinations

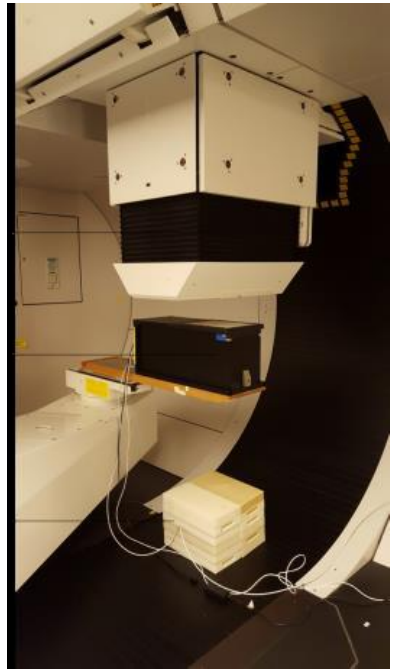
(α,E,Δs,U) = (15°, 115 MeV, 25 cm, 5 cm)

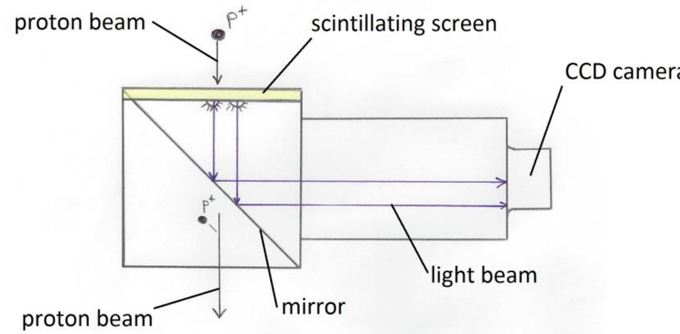




G. Klimpki, PMB 2017

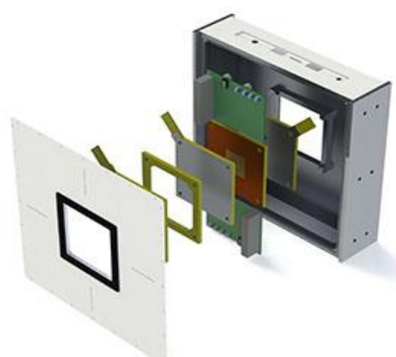
2D Detectors for beam monitoring



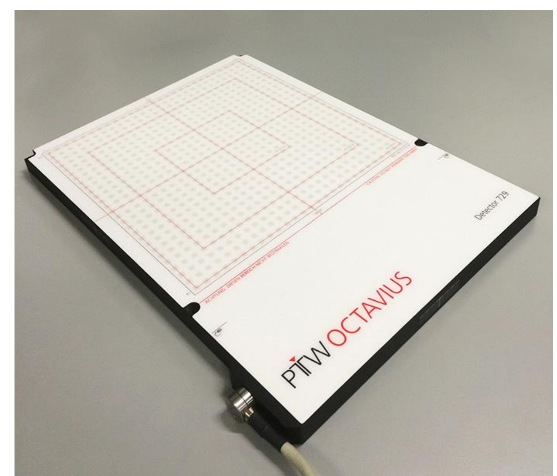


Black box contains:

- Sclintilating foil
- Mirrow
- Camera

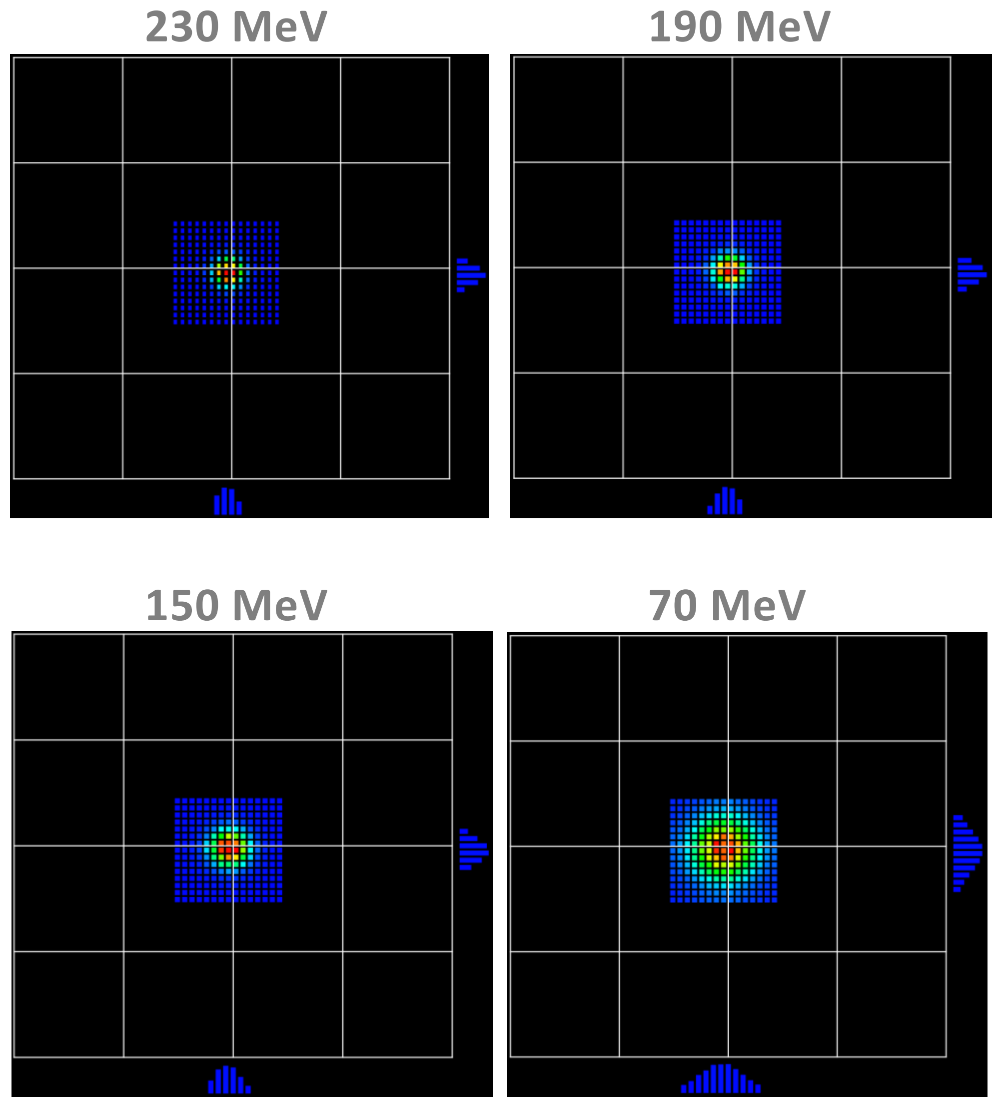


DETECTOR
DEVICES AND TECHNOLOGIES TORINO

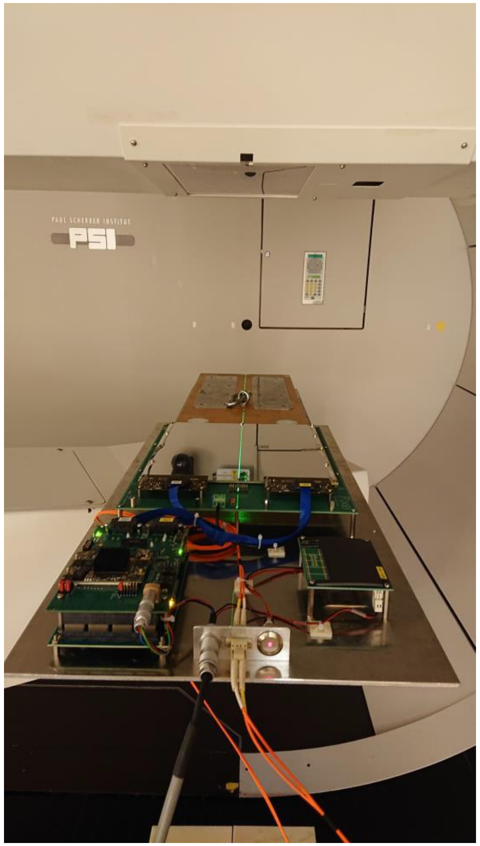


Pixel detector prototype

- Readout integraed in TCS
- Detection principle – IC
- Material: PCB based
- Detector size: 12x12 cm
- Pixel size 2 mm



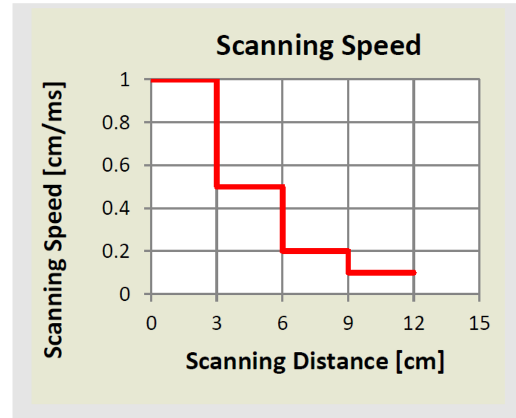
Pixel detector for Gantry2

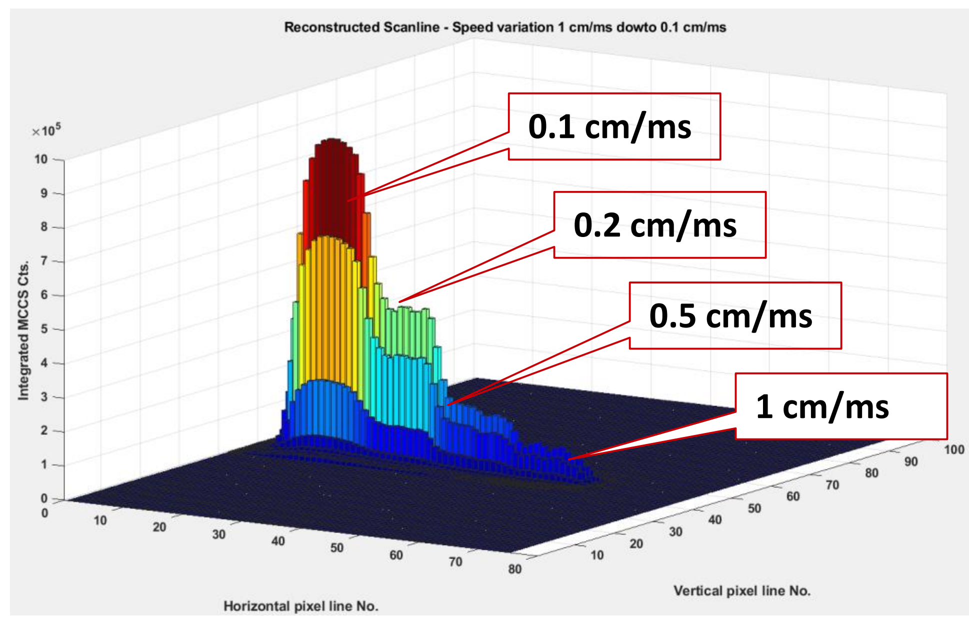


Active area:

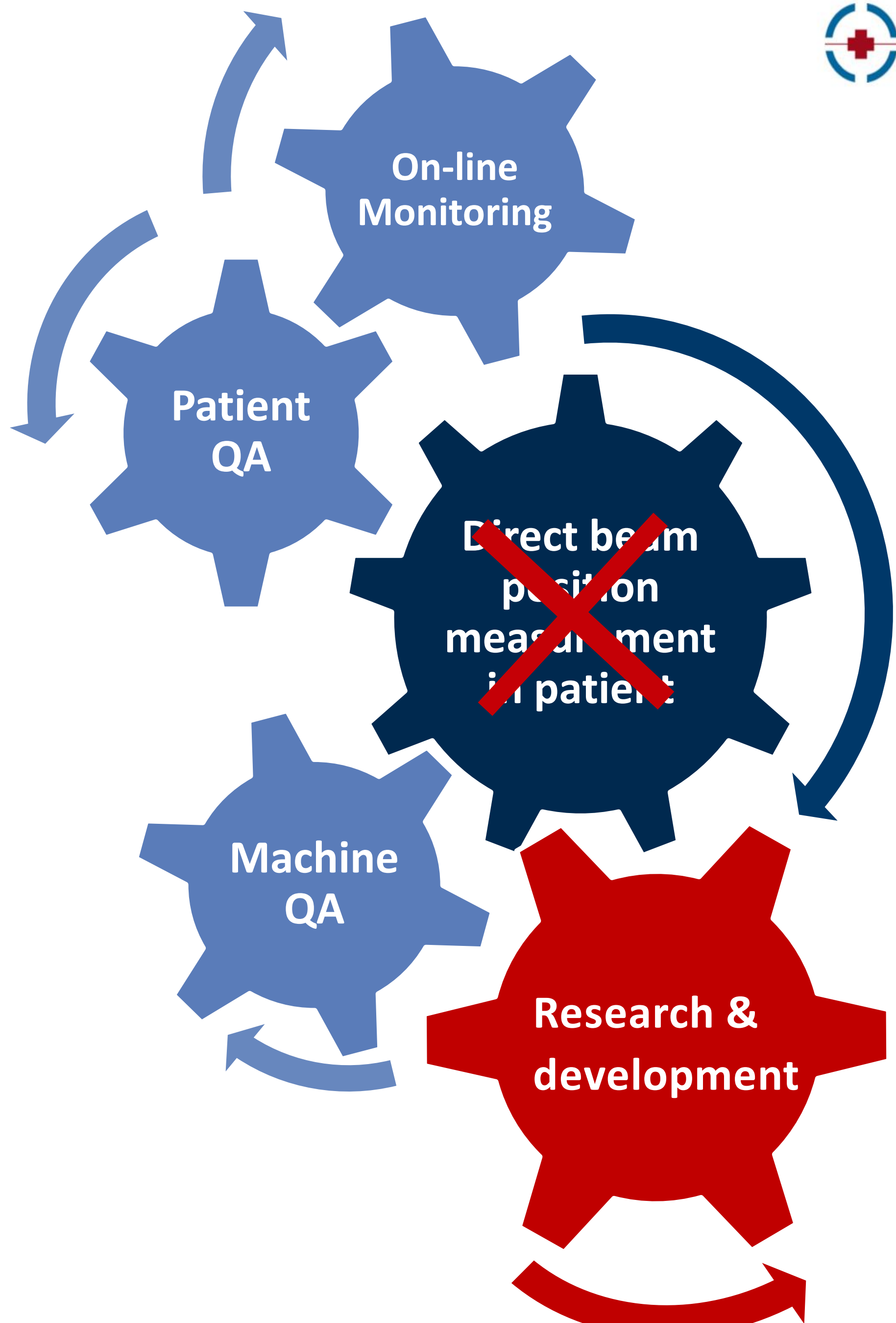
26.25 cm x 18.75 cm

Pixel size: 2.5 x 2.5 cm





Take home message



Take home message