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The CERN Accelerator School

Paul Scherrer Institut

Dr. David Meer

Medical physics commissioning

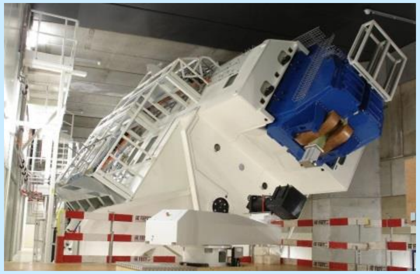
CAS - Accelerators for Medical Applications 2015, June 1st

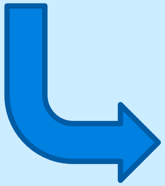
Contents and goal

1. Scope of commissioning
   – Technical commissioning ↔ acceptance tests
   – Overview on different tasks
2. Proton gantry at PSI – Gantry 2
   – My personal background
   – The gantry of MedAustron
3. Commissioning of the beam scanning system
   – Beam tuning
   – Energy calibration
   – Sweeper calibration
   – Dose monitor calibration
4. Mechanical / Geometrical calibration
   – Patient table
   – Imaging systems
5. Devices and tools and devices for quality control
   – Daily check phantom

Goal of this lecture:

- Give exemplary overview on different commissioning task
- Discuss practical technical issues
- Highlight some achievements of PSI Gantry 2





- It’s not the goal and out of the scope of this lecture to provide comprehensive lists of “test and tasks”

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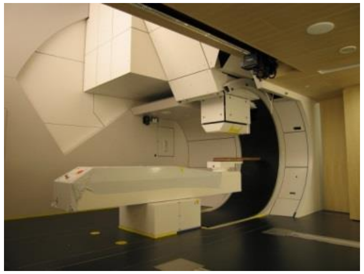
Scope of commissioning

Commissioning and operation of a system



Technical commissioning	Medical physics commissioning	Acceptance tests	Quality assurance (QA)
• Installation of components • Functional component testing	• Integral system tests • Parametrisation of machine characteristics	• Verification of system specifications and performance	• Periodic tests after start of operation • Validate system integrity

Commercial environment:

System producer → End-user

Research environment:

System producer / End-user

Medical commissioning:

Particle treatment room is a complex unit, not only beam line!

- Pencil beam scanning / (scattering) beam line
  - Scanning system / scanning magnets / Beam modifier devices
  - Beam monitoring system (Dose / Position)
- Mechanical systems
  - Rotation of the gantry / movable part of the nozzle
- Patient positioning system
  - Geometrical accuracy for different weights / Transformation of coordinate system
  - Reference systems (cross laser marking iso-center)
- Imaging systems
  - On-board systems (X-ray, cone beam CT, …)
  - In-room systems (CT, PET, …)
- Connection to software
  - Treatment planning system (TPS)
  - Oncology information system (OIS)
- Safety system

Acceptance tests and QA tests

After medical commissioning:

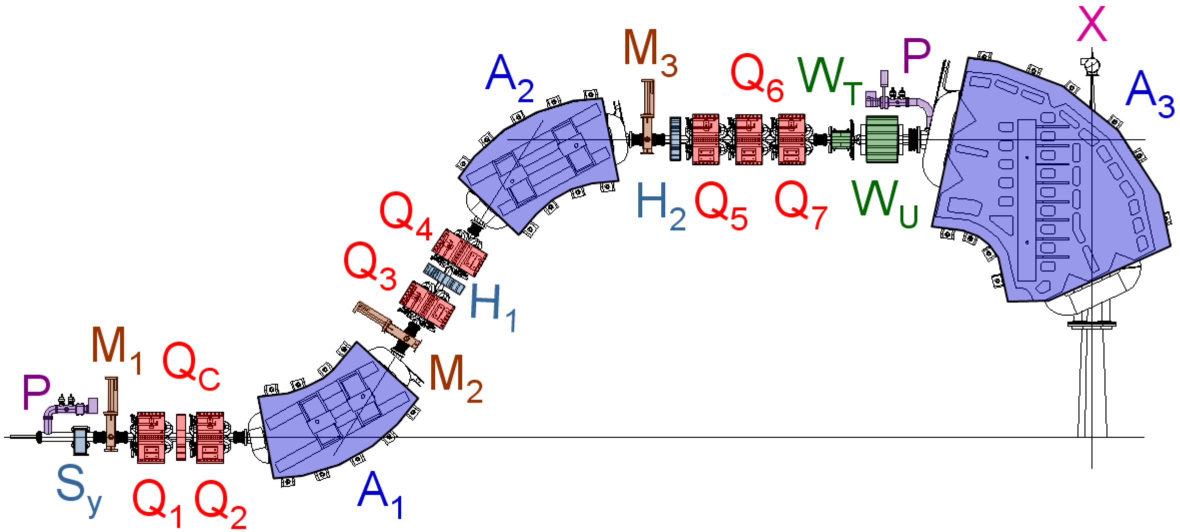
Acceptance test:

- Defined by end-user, defines also extent of test
- Typically done only once
- Verification of system specifications
- "Final tests", End-to-end tests
- Typically ~100 tests
- Successful pass of acceptance tests is precondition to get permit to treat patients (country specific)

Quality assurance test

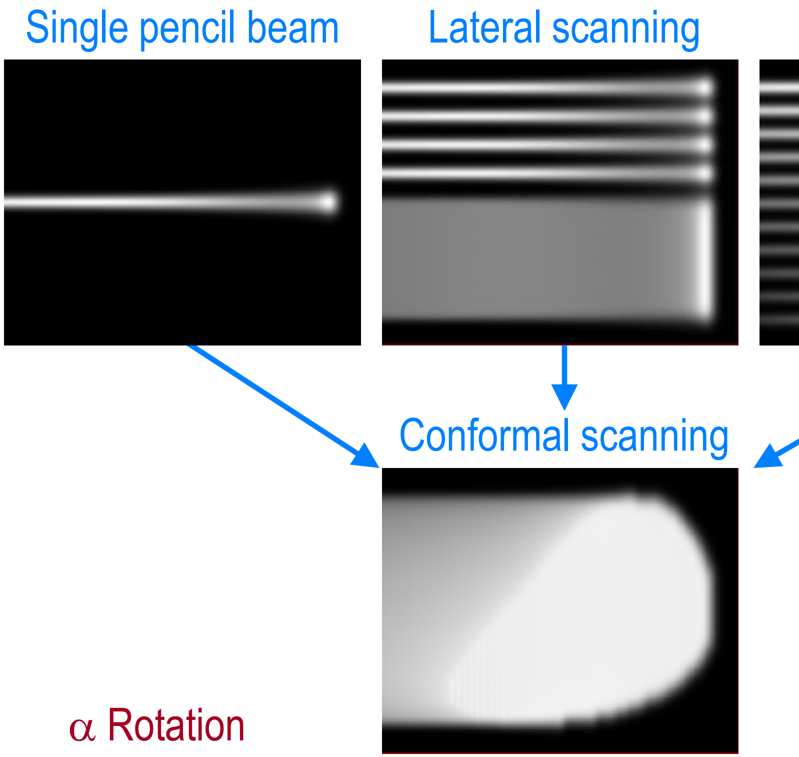
- Repetitive verification of system performance
- System integrity tests (Safety functions)
- Periodicity of tests vary from day to years
  (PSI: Daily / Weekly / Monthly / Yearly / 3-yearly)
- A part of the test is identical with those from acceptance document
- Typically ~100 tests

Proton gantry at PSI – Gantry 2

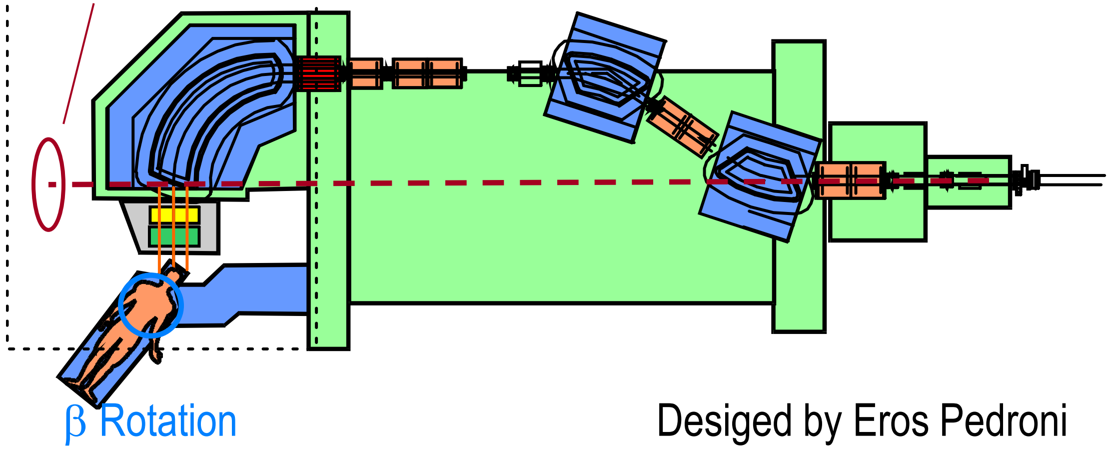


Gantry 1, 1996: First spot scanning gantry

- First gantry with pencil beam scanning
- Start patient operation 1996, for 12 years the only spot scanning gantry worldwide
- Due to eccentric design still the most compact system, r = 2m
- Energy modulation with range shifter
- Lateral scanning only in 1d



Range shifter

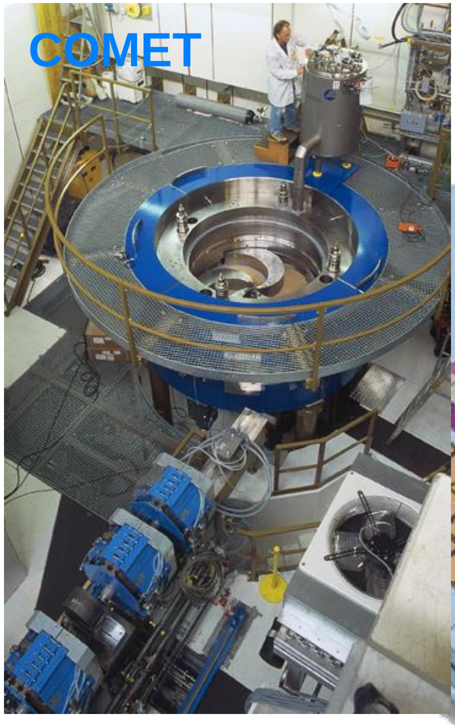


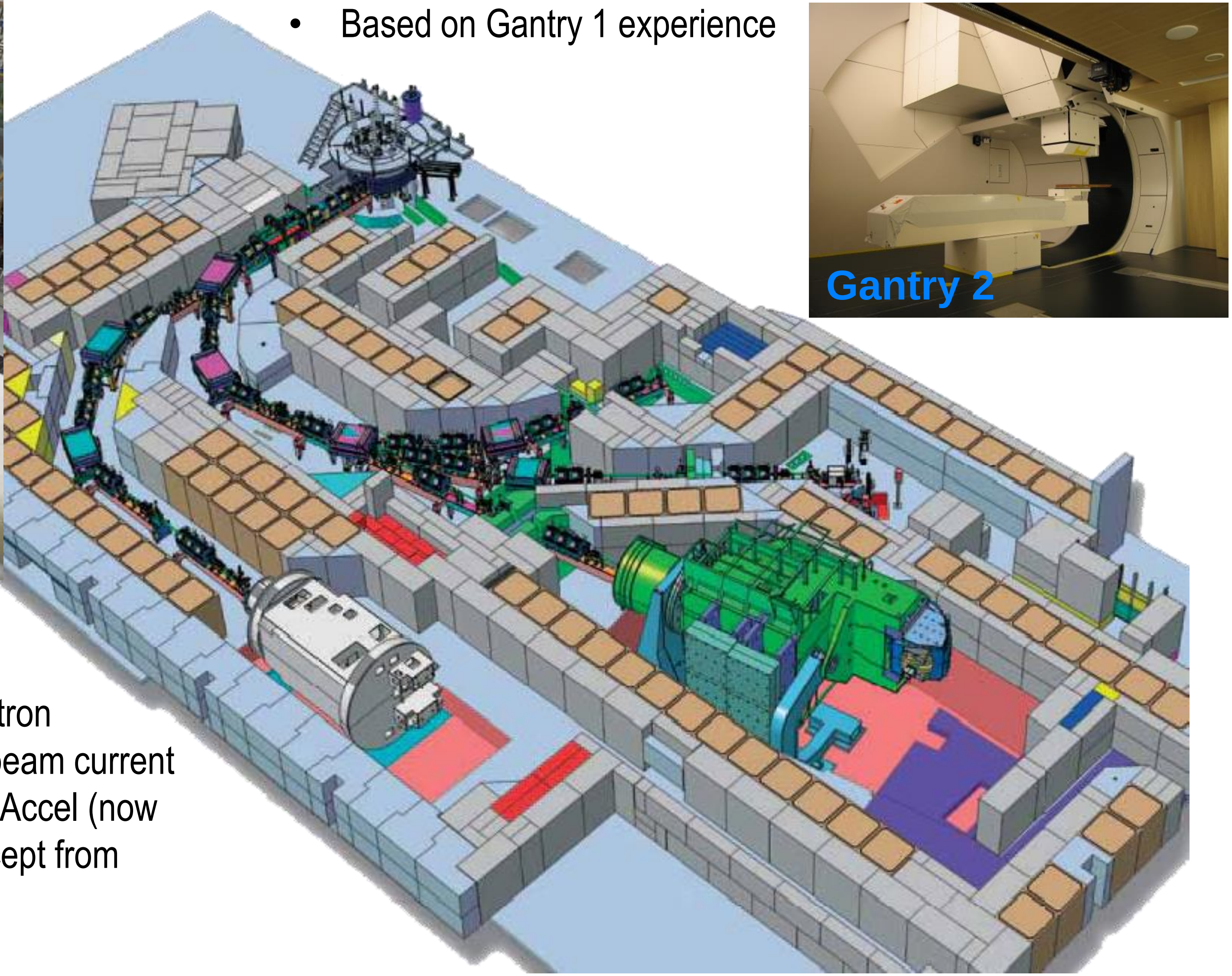
Desiged by Eros Pedroni

PROScan: Expansion of medical program, 2000

Gantry 2:

- Second generation of a pencil beam scanning gantry
- Based on Gantry 1 experience





COMET:

- Superconducting cyclotron
- 250 MeV, up to ~1μA beam current
- Collaboration between Accel (now Varian), based on concept from Michigan University

Layout of the new gantry

Beam line concept builds up on Gantry 1

Coupling point

- Rotational symmetrical phase space
- Fixed collimator (8 mm)

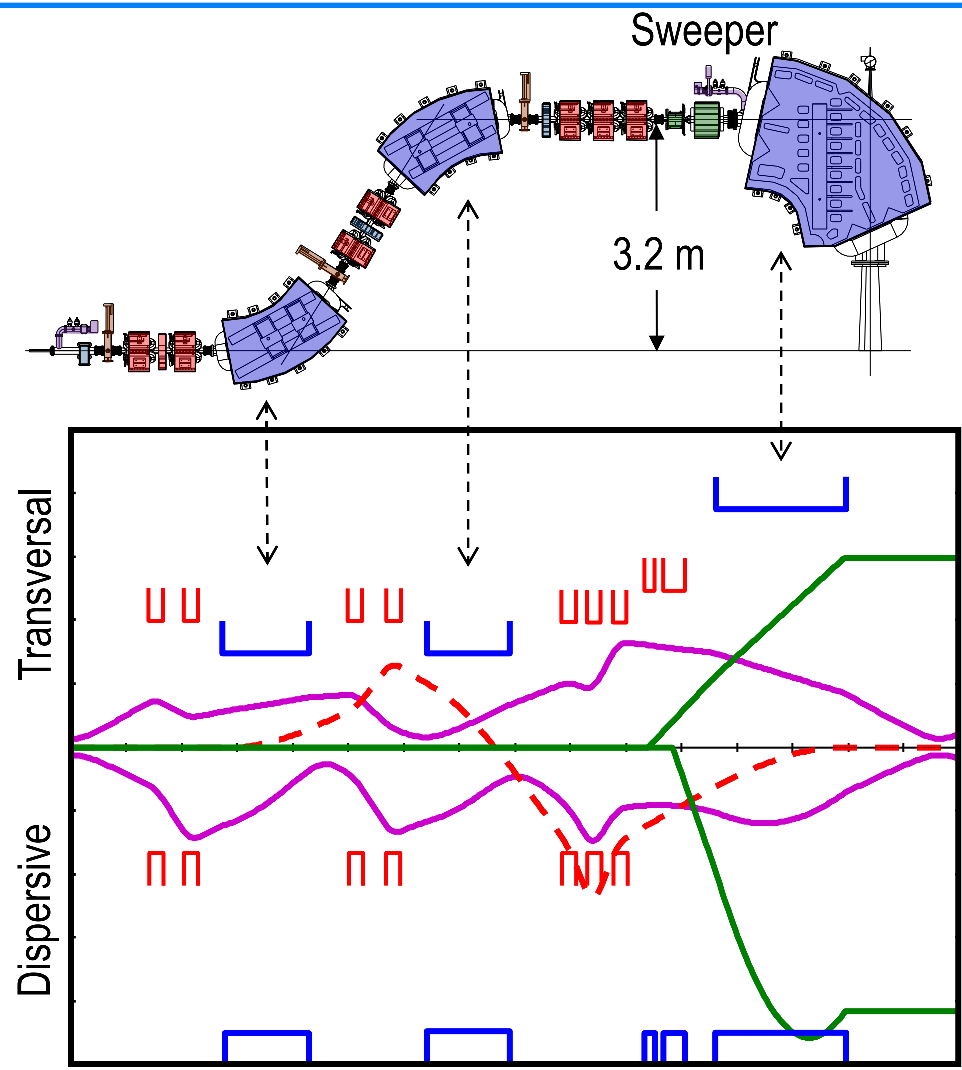
Gantry beamline

- 1:1 imaging from coupling point to iso-center
- Achromatic beam optics
- Upstream scanning
  → Radius reduction > ~1m
- Scanning-invariant beam focus

Energy variation

- Upstream energy modulation with degrader system

Pencil beam characteristics of the next-generation proton scanning gantry of PSI: design issues and initial commissioning results
E. Pedroni *et al.* 2011 *Eur. Phys. J. Plus* 126:66



Purple: Beam envelopes trough Gantry 2
Green: Action of the sweepers
Red: Dispersion trajectory for a 1% momentum band

Double parallel magnetic scanning

Fast parallel lateral scanning

- T sweeper 2 cm/ms
- U sweeper 0.5 cm/ms

Scan area of 12 cm by 20 cm

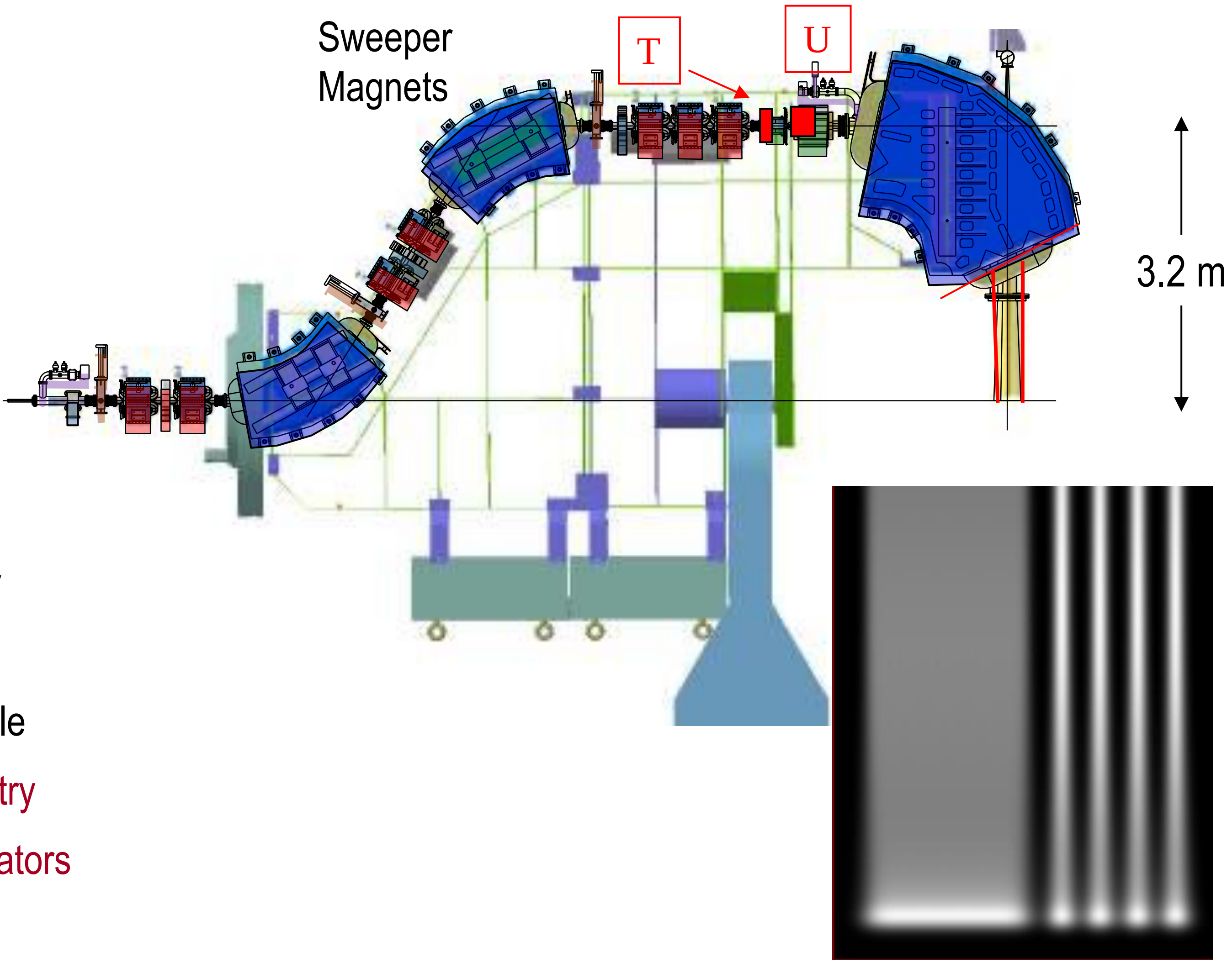
- Motion of patient table for treating larger field sizes (Experience with Gantry 1)

Apparent source at the infinity

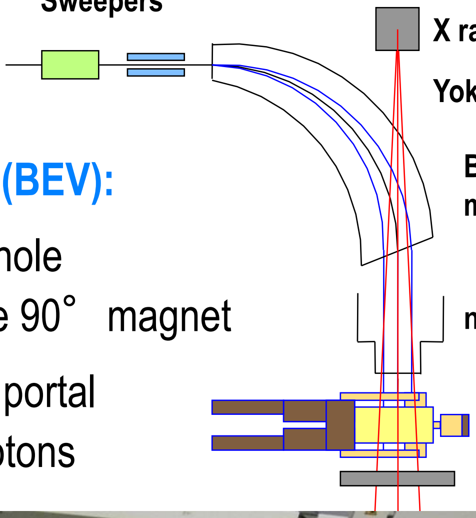
- Simplify treatment planning
- Easy field patching with table
- Simplify verification dosimetry
- Avoid errors from compensators

Parallelism

- Max deviation ~6 mrad (at edge of field)



Imaging: exploring the optimal solution



Requirements:

- Soft tissue imaging
- Portal Imaging
- Real-time imaging
- Treatment position verification
- Intuitive X-ray projections

Beam's Eye View (BEV):

- X-ray through a hole in the yoke of the 90° magnet
- An equivalent of portal imaging with photons

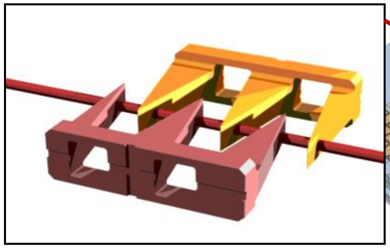
CT on rail (Sliding CT):

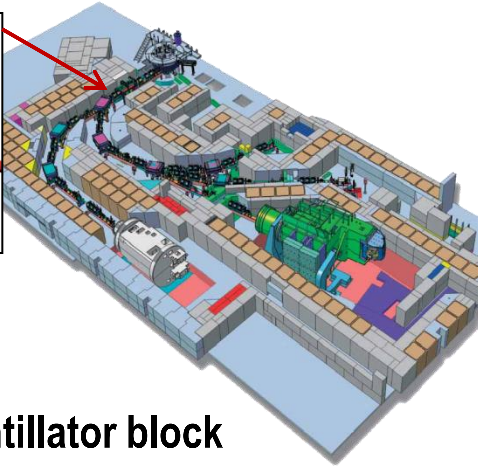
- Within reach of the patient table
- In-room patient positioning

Fast changes of the beam energy

The Gantry 2 and PROSCAN are optimized for fast energy changes:

- Cyclotron provides fixed energy
- Fast degrader right after cyclotron
- Laminated magnets (avoid eddy currents)
- Dedicated power supplies
- Need to consider magnetization and hysteresis effects





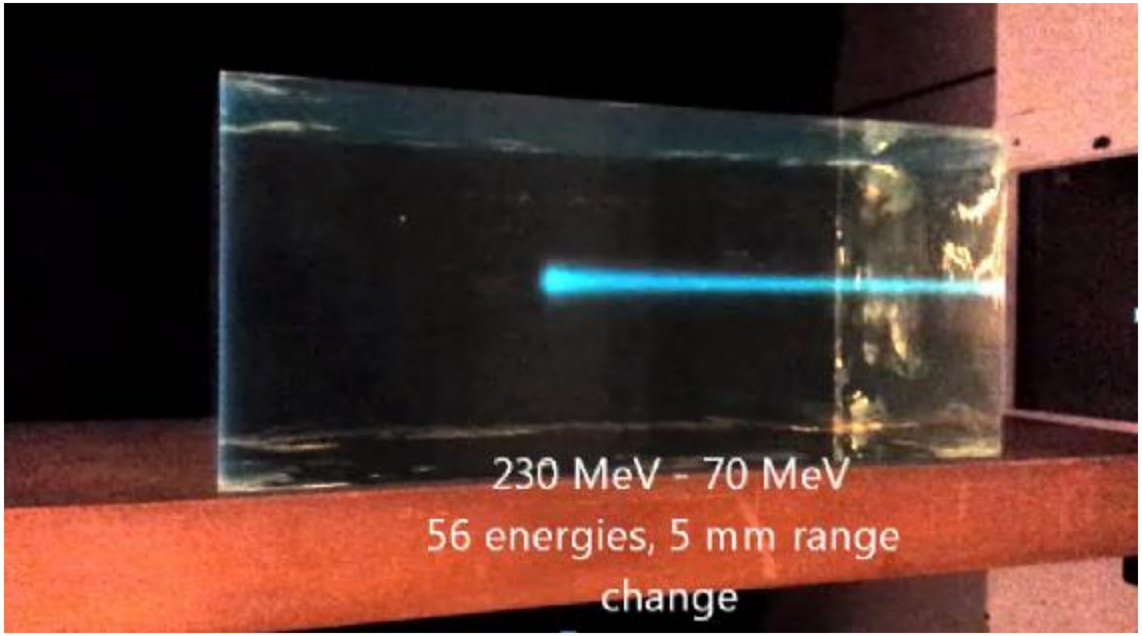
Realized:

- **~100 ms** dead time for range steps of 5 mm

Benefit

- Faster treatments
- Potential for volumetric repainting

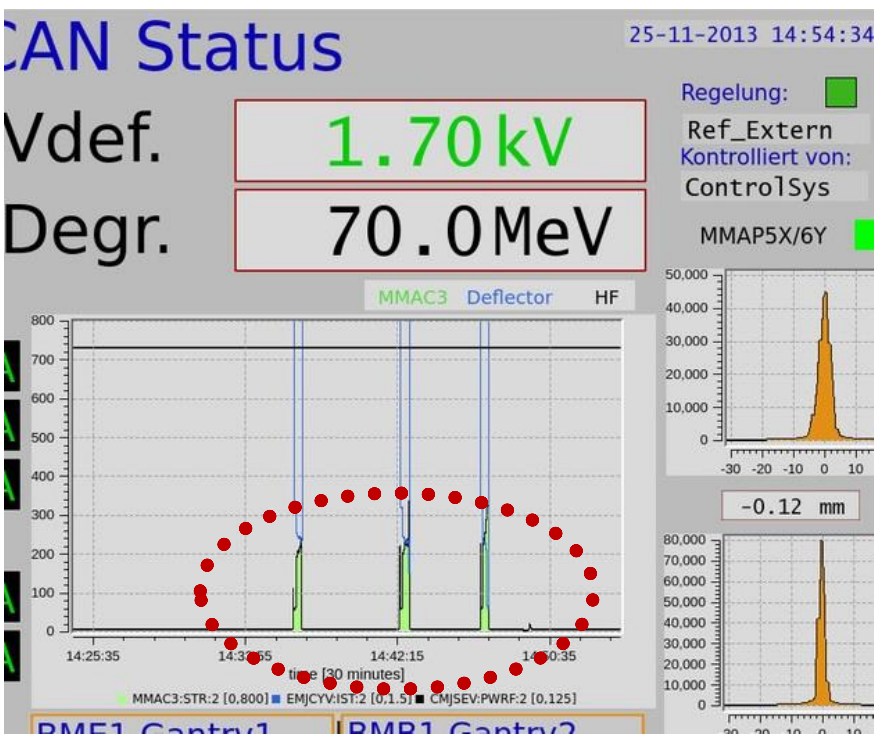
Energy modulation in scintillator block



25. Nov 2013: Gantry 2 starts clinical operation

Start patient treatments after:

- Medical acceptance, development QA procedures and application for operation permit (~<1 year)
- Operated only by radiographer (MTRA) from the first fraction on
- Stable and reliable operation from day 1 on



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LATEST NEWS ARTICLES

- ESTRO: advances in treatment planning
- Installation begins on first MRI-linac
- Emitted particles track treatment dose
- Proton CT improves stopping power accuracy

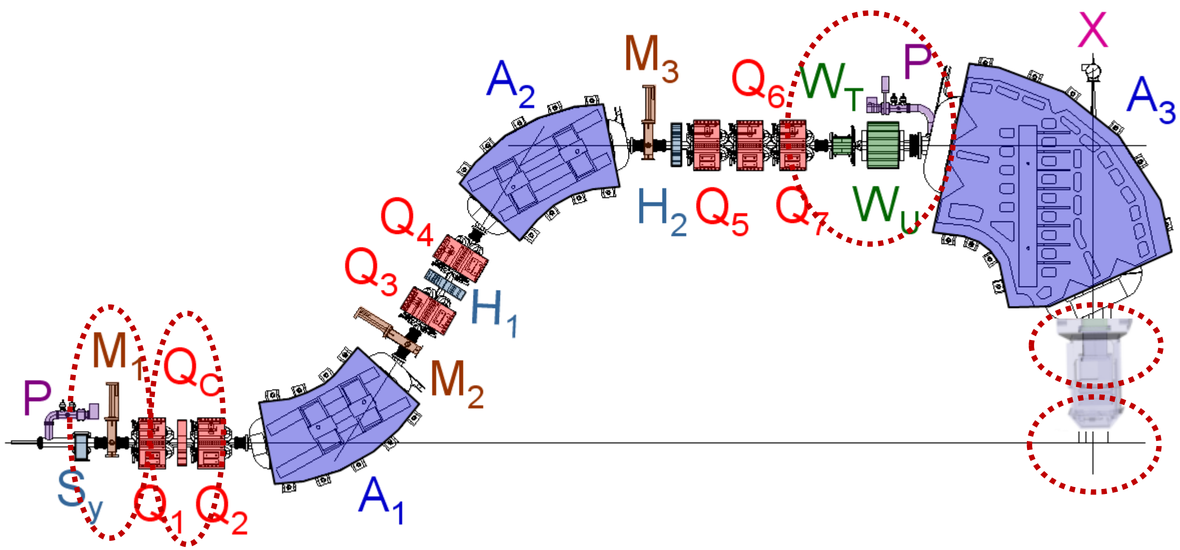
RESEARCH

Dec 20, 2013

PSI's Gantry 2 begins clinical operation

The Paul Scherrer Institute (PSI) in Switzerland has led the way in the development of pencil-beam scanned proton therapy. PSI's Gantry 1 was the world's first spot scanning gantry and has been in clinical operation since 1996. Following this accomplishment, the site developed Gantry 2,

Commissioning of the beam scanning system



Commissioning of the un-scanned beam

Tool to calculate initial setting of beam line

- Transport
- Mad-X, …

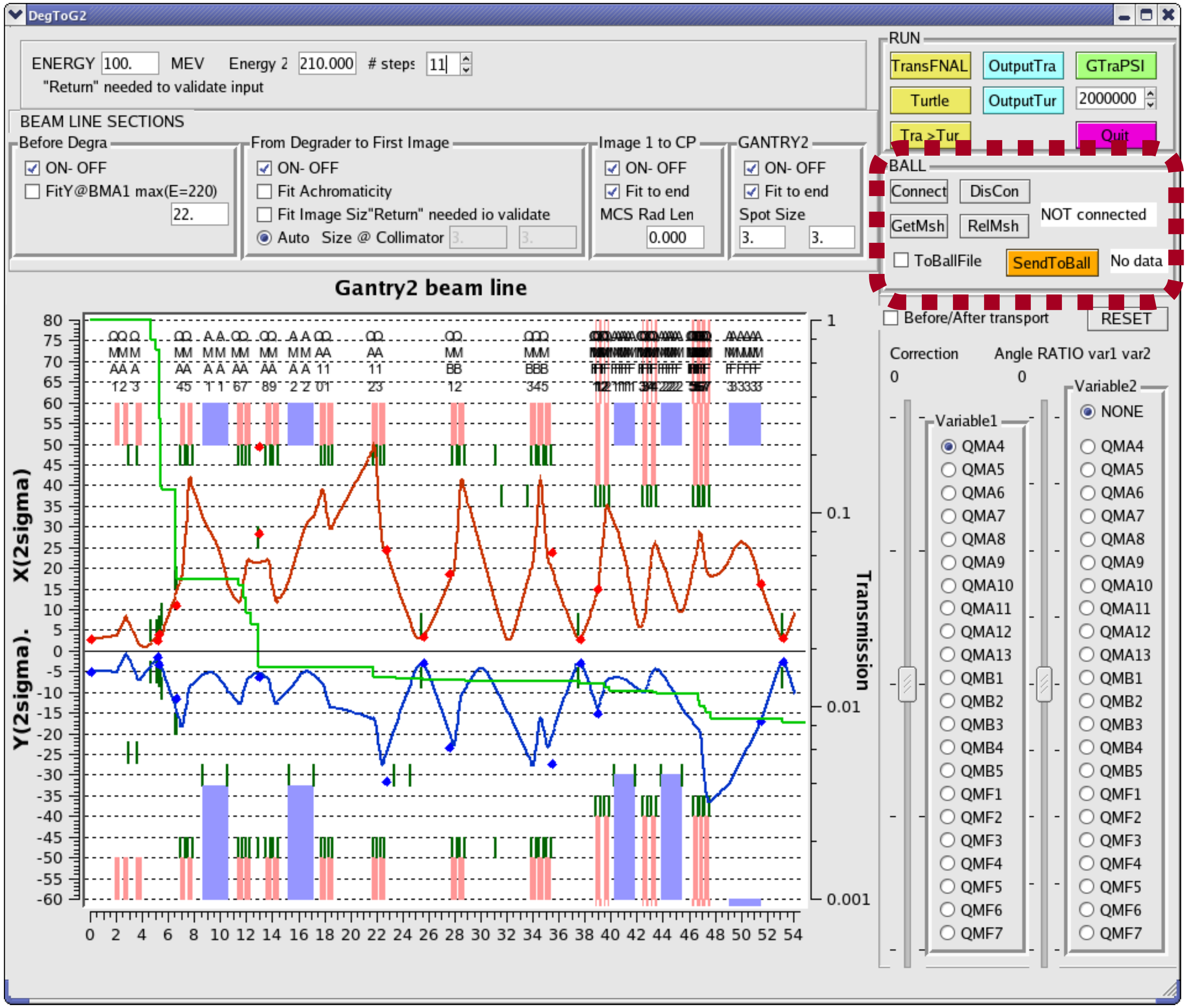
Tracking or other simulations may be required for

- Degrader
- Collimators, slits

Comparison with profile monitors confirm calculations (PSI: >20 monitors from accelerator to iso-center)

Settings for different energies:

- Scaling with momentum
- Fine tuning for discrete set of energies (e.g. 10 MeV) and interpolation in-between

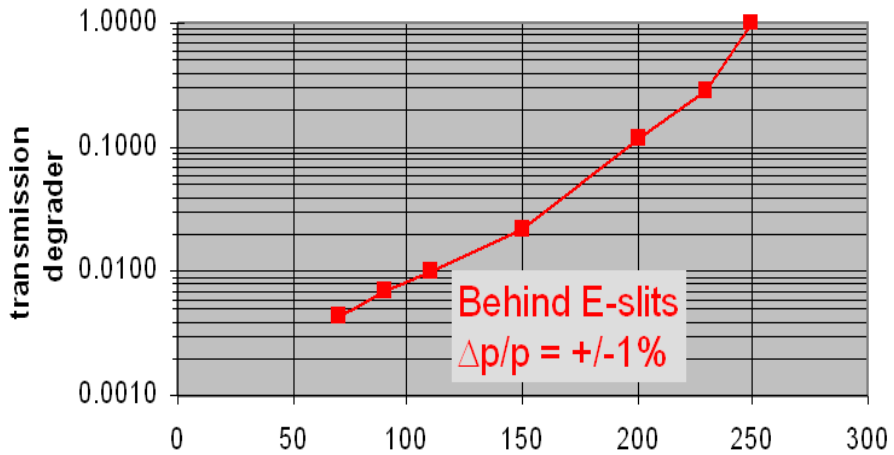


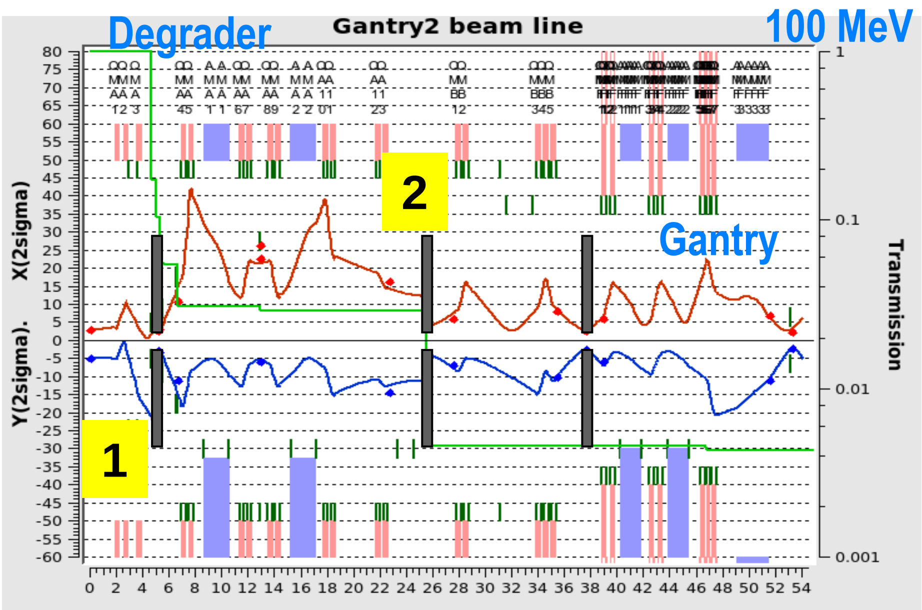
Tool used at PSI for Gantry 2:

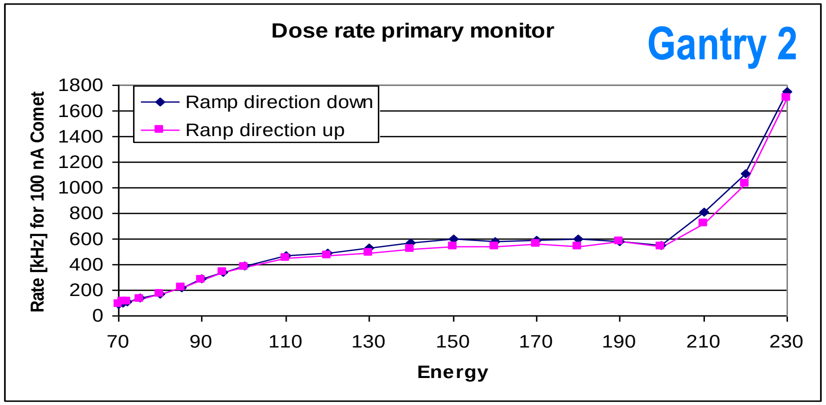
- Based on Transport / turtle
- Direct connection with machine control system

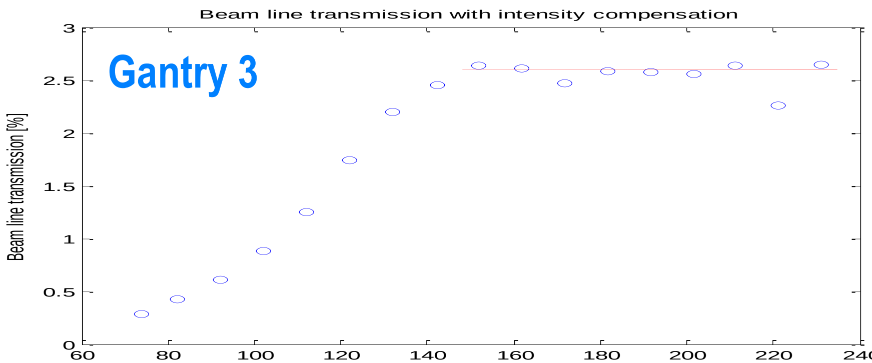
Transmission compensation with the beam line

- Energy losses more than factor 100 in degrader system for 70 MeV!
- "Compensation" of degrader losses for high energies (PSI G2: 100 to 200 MeV, G3 above 140 MeV)
- Defocus beam after degrader with quadrupoles (faster than mechanical blocker)
- Constant beam transmission from accelerator to gantry
- Important aspect for safety





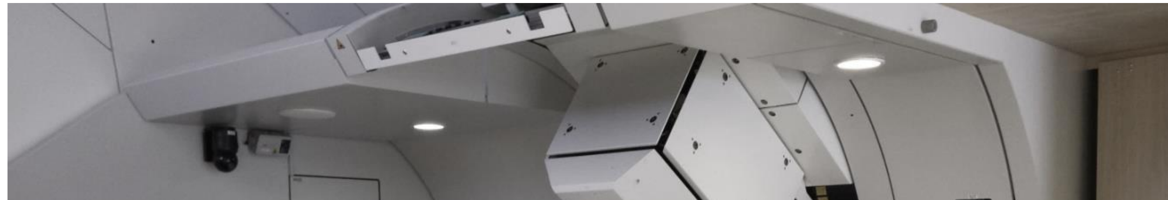


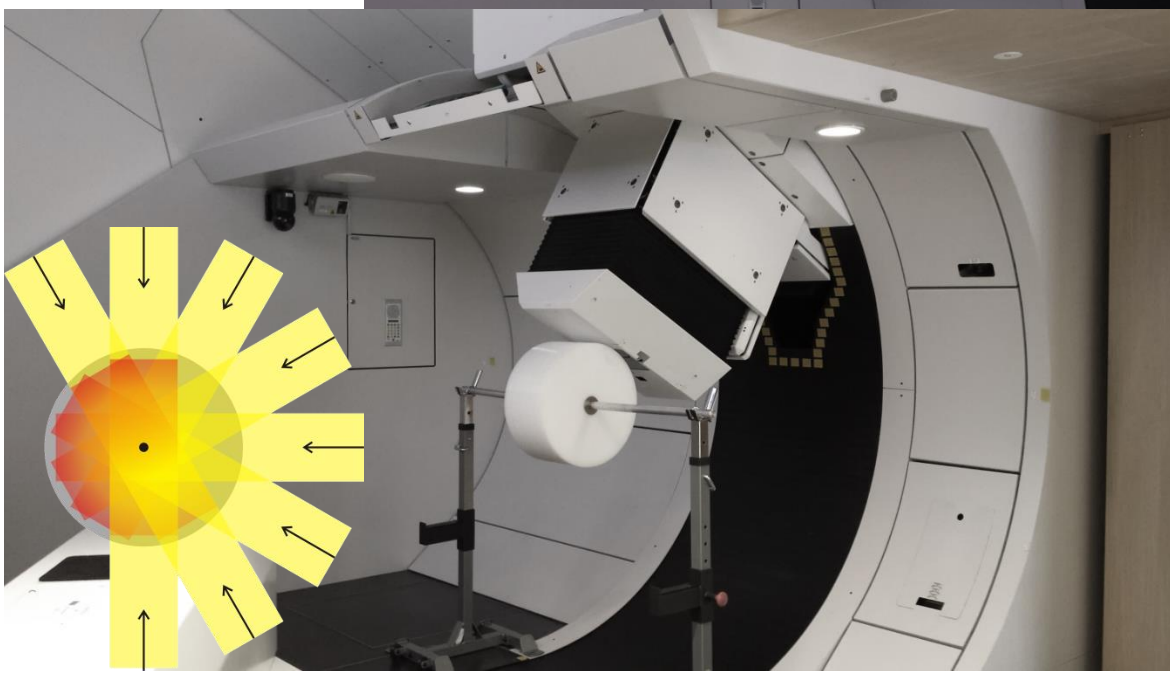


Universal beam dump

Beam needs to be stopped in a controlled way
→ Beam dump

Solution for all gantry angles …



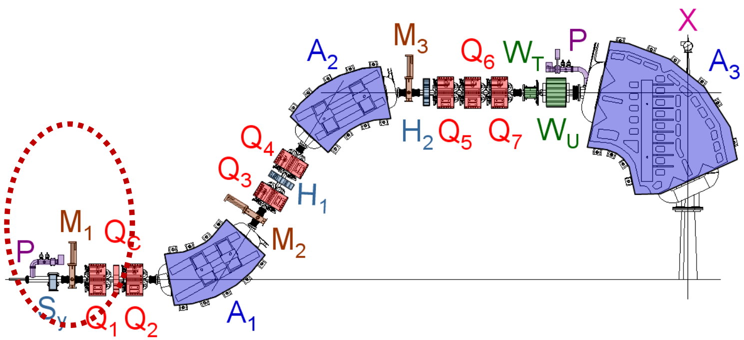


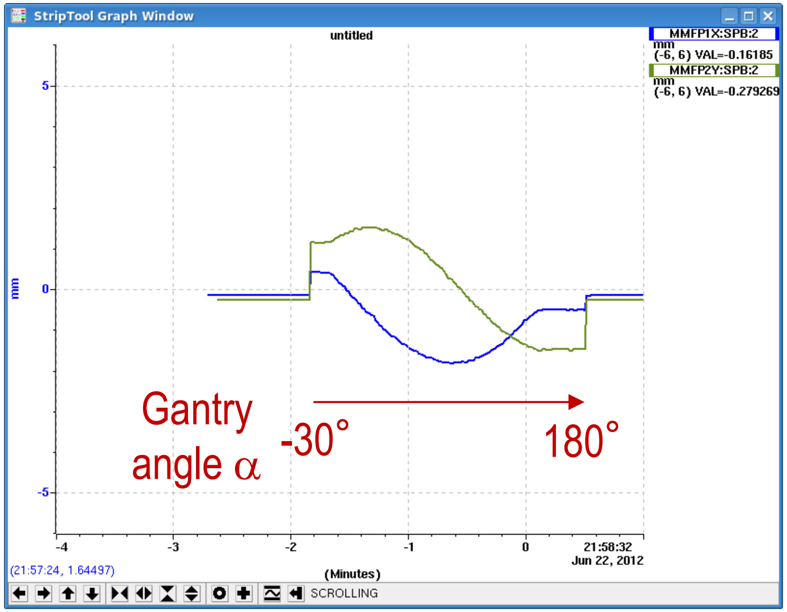
… and even with extracted nozzle!
→ Full remote operation of the gantry and nozzle.

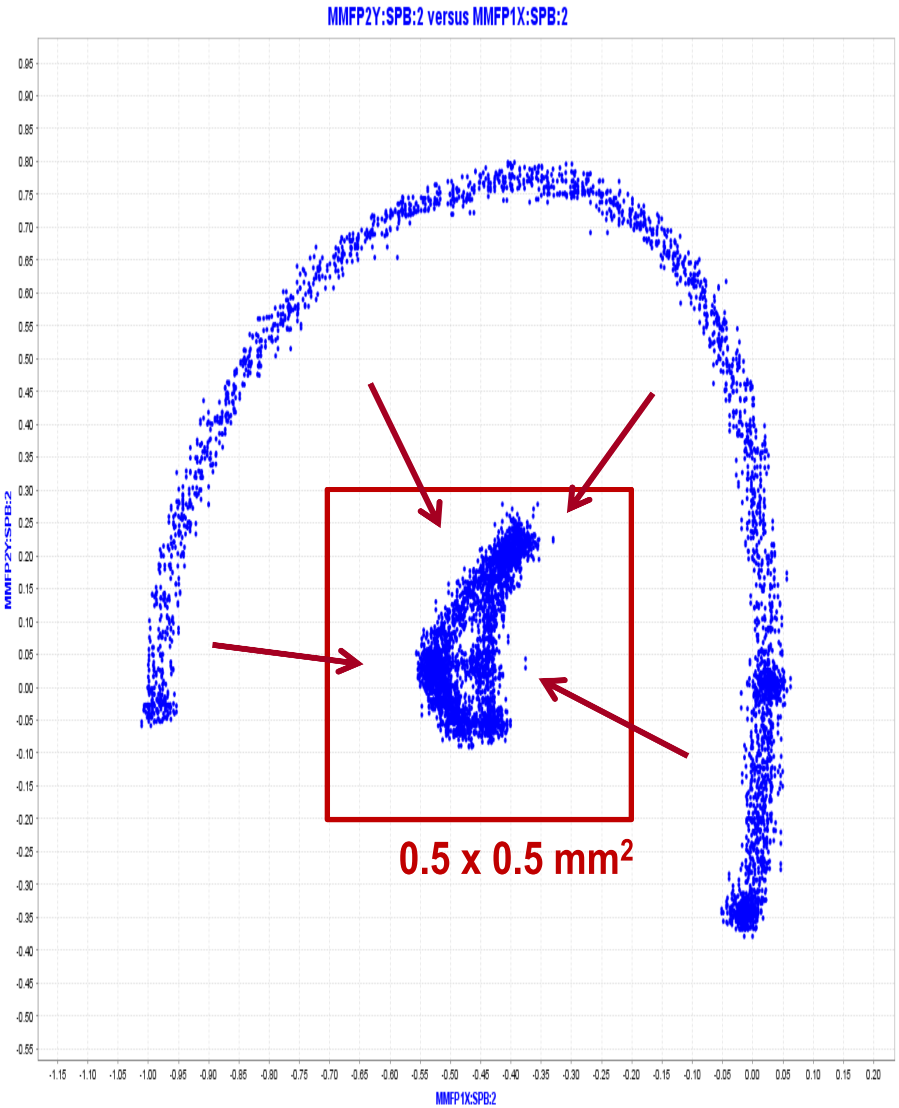
Polyethylene, full scan range (12 cm x 20 cm, 230 MeV), all gantry angles and nozzle extractions

Commissioning of the un-scanned beam

- Centring the beam on mechanical rotational axis of the gantry
- Rotation of the gantry with continuous beam on
- Recording beam position with strip chamber M1



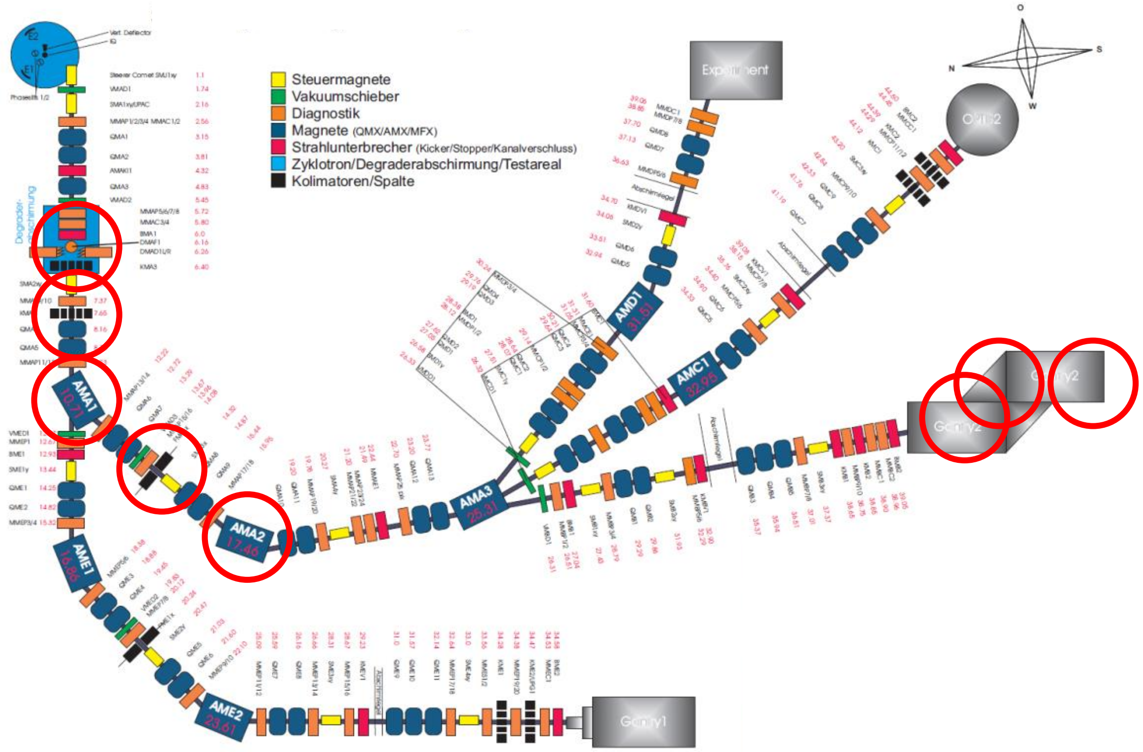




Online verification of beam tunes - BTVS

Beam Tune Verification System – BTVS

- Monitoring & **verification** of the actual **energy setting** of beam line
- Relevant elements for energy selection
  - Degrader
  - Collimators
  - Momentum collimators
  - Dipole magnets (beam switchyard)



Supervision of beam line elements with

- Hall probes (magnets)
- Potentiometers (mechanical axes)

Connection to interlock system to interrupt beam delivery

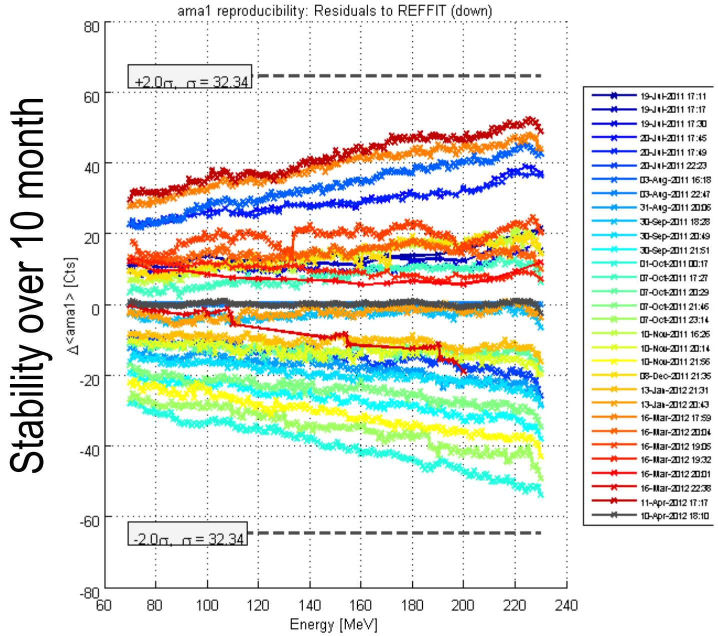
- During beam application the BTVS compares sensor data against pre-defined limits
- Commissioning task:
  - Parametrization of BTVS elements
  - Test connection to safety system (interlock)

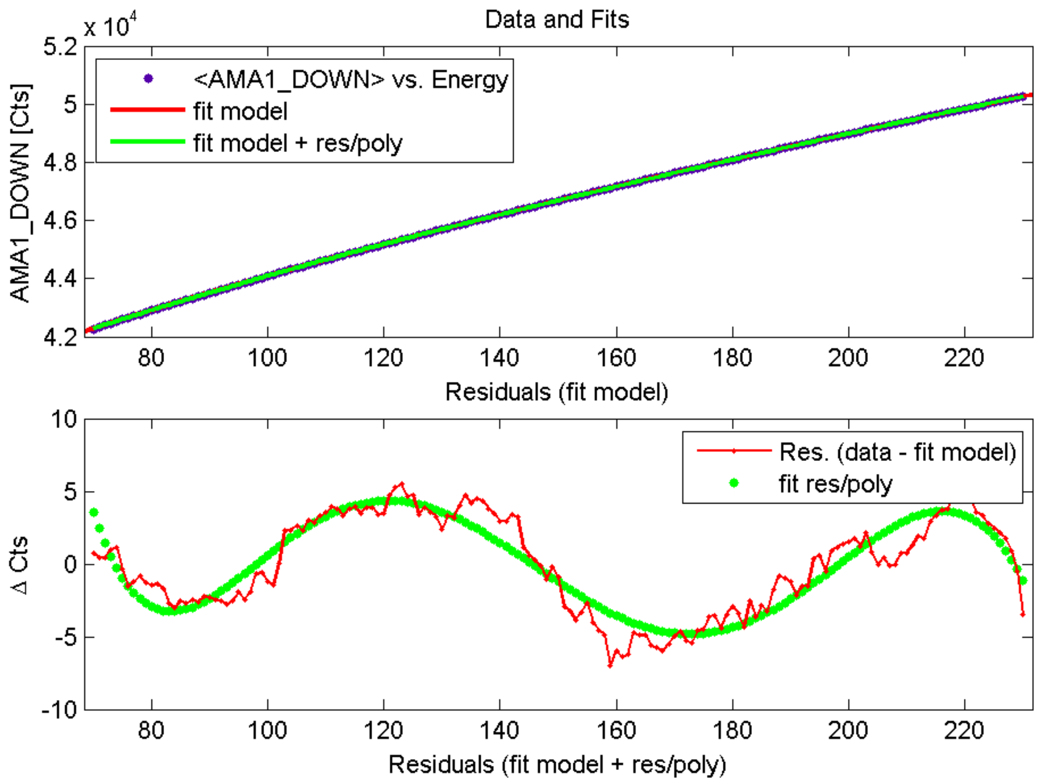
BTVS – Results and resolution

Hall probe signal proportional to beam momentum

$$V_{hallprobe} \propto B \propto p \cdot c = \sqrt{E_{Kin}^2 + 2 \cdot E_{Kin} \cdot E_0}$$

Increasing model precision by empirical polynomial fit, 6th order





Fit model + polynomial fit of residuals

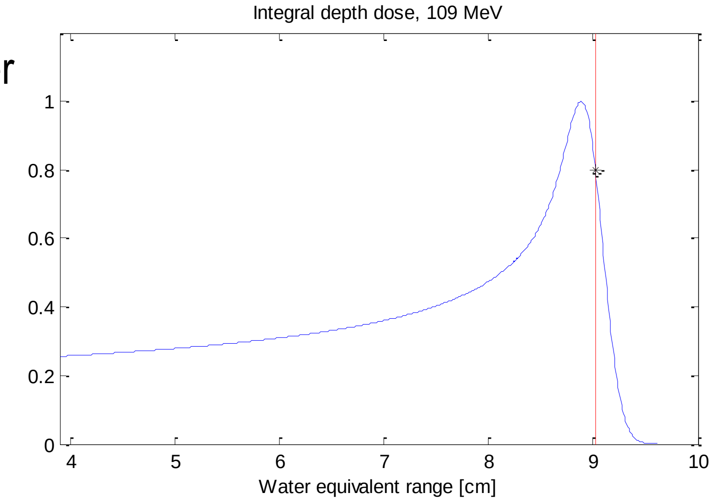
$$y = a \cdot \sqrt{(x-b)^2 + 2 \cdot E_0 \cdot (x-b)} + c$$
$$+ p_7 \cdot x^6 + p_6 \cdot x^5 + p_5 \cdot x^4 + p_4 \cdot x^3 + p_3 \cdot x^2 + p_2 \cdot x^1 + p_1$$

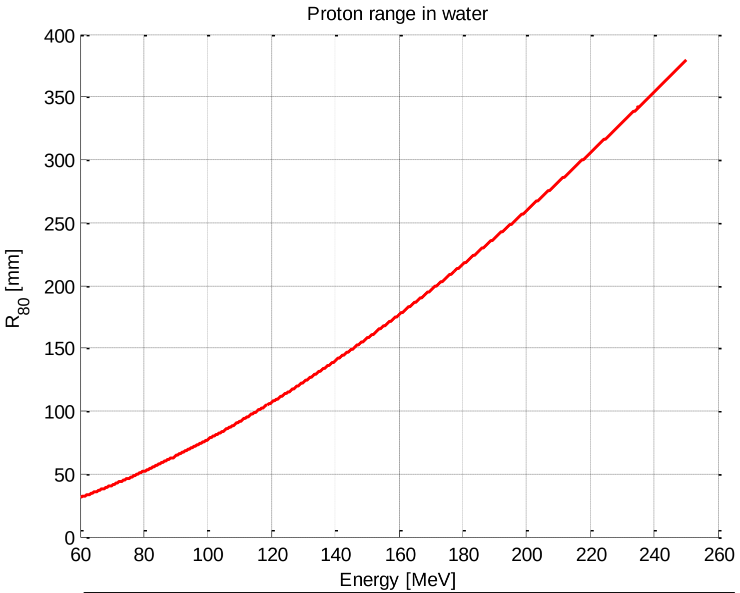
Stability and electromagnetic susceptibility of cabling and electronics limit BTVS resolution to ~ 1 MeV (~ 2 mm WER)

Range – Energy calibration

- Indirect determination of energy by range measurements in water
- (R_{80}) = depth of the distal 80% dose level
  - Little dependence on the energy spread of the proton beam *)
- Energy can be obtained from continuous-slowing-down approximation (CSDA) calculations
  - Based on stopping power integration
  - Collected in ICRU Report 49 (1993)
- Typical calibration procedure:

1. Nominal beam energy from initial beam tuning
2. Measure range R_{80} at iso-center
3. Look-up energy from energy-range table
4. Calibrate / re-label beam tunes
5. Generate new beam tunes and verify new range



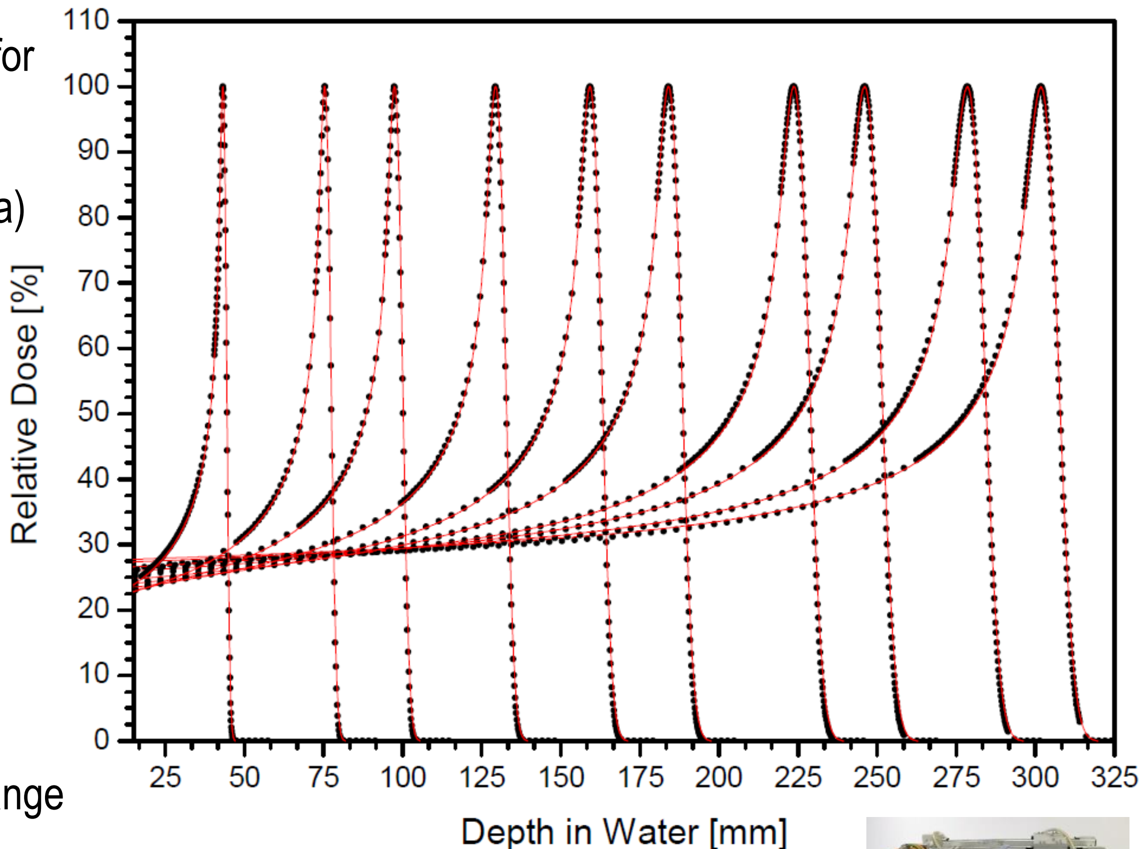


*) Hsi WC, Moyers MF, Nichiporov D, et al. Energy spectrum control for modulated proton beams. *Medical Physics*. 2009;**36**(6)

High resolution integral depth dose measuremer

- Integral depth dose measurement used for
  - Range / energy calibration
  - Depth dose profile (momentum spectra)
    → important input data for treatment planning system (TPS)
    → measurement of the full curve
- Typical pass criteria for range verification: ± 0.5 mm
- Requested precision for range measurements: better than 0.2 mm

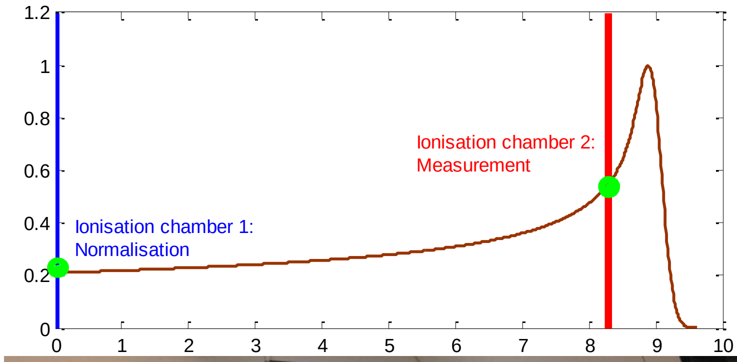
  → 0.1 MeV resolution
  1 mm change in WER ~ 0.5 MeV change
- Adaptive granularity of measurement points in depth:
  - Precise detection of Bragg peak
  - 1 - 4 mm steps in plateau (Energy depended)
  - 0.2 – 0.1 mm steps around Bragg peak

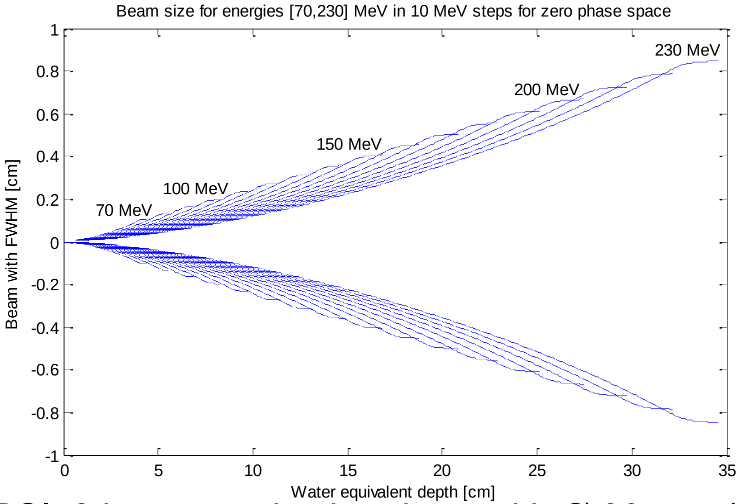


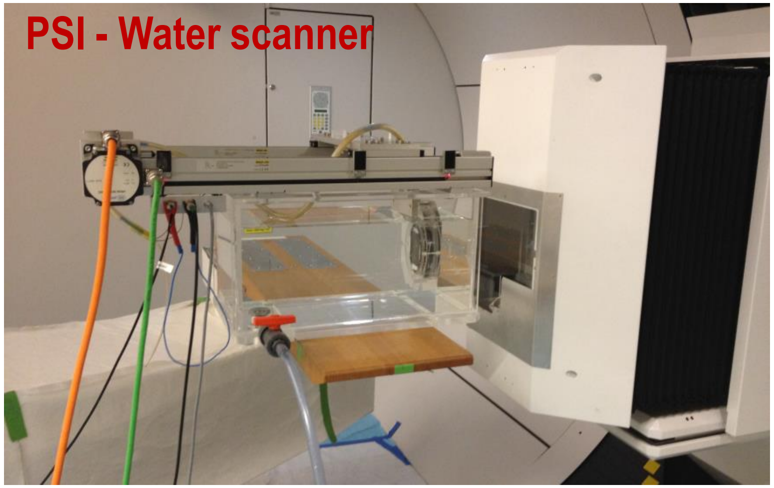
At PSI Gantry 2:
- Tool to ‘calculate’ beam tune for any energy
- Commissioning of ~ 100 beam tunes for clinical use
- 70 MeV – 230 MeV, range steps of ~2.5 mm
- Measurement for one energy fully automated

Range measurement equipment

- Ratio of two IC measurements: plateau / water
  - Place 2nd chamber at entrance
  - Use IC information from dose delivery system
- Integral depth dose measurement:
  → Large plane-parallel chambers needed



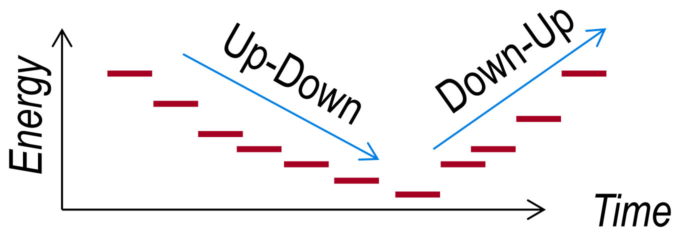




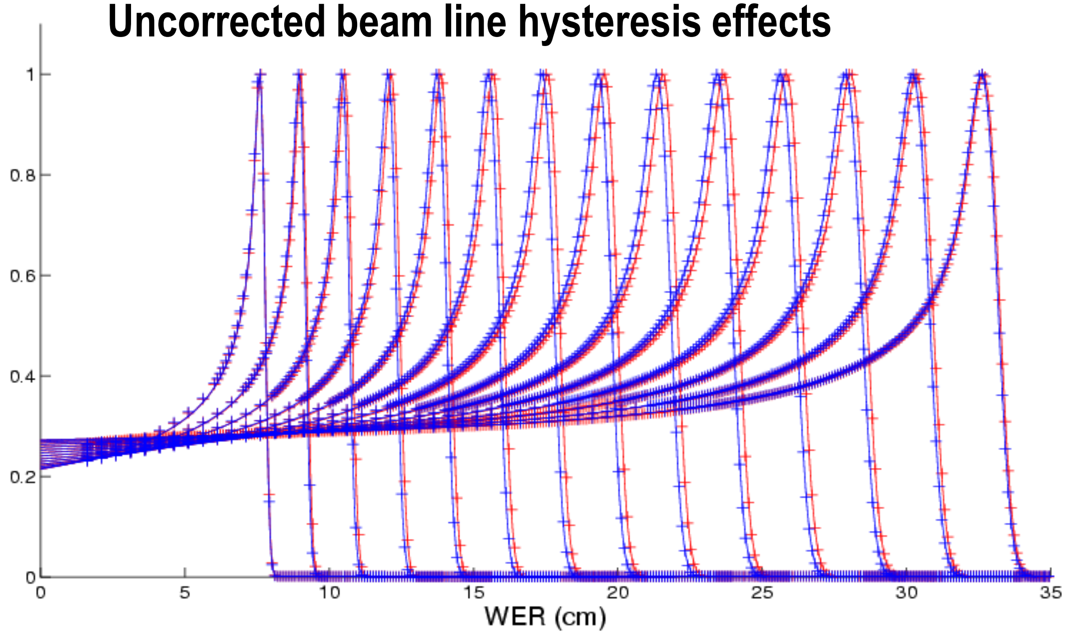
- PSI: 2 home-made chambers with Ø 80 mm / Ø 120 mm
- Alternative from PTW, Ø 80 mm

Beam line hysteresis effects on range

- Hysteresis effects of the beam line need to be considered / corrected
  - Effect on range ~ 1 mm, effects on beam position even larger (at PSI Gantry 2)
- Distinguish between energy sequence directions
- Up – Down (Highest to lowest beam energy)
- Down – Up (Lowest to highest beam energy)
- Usually only one energy sequence, other ramping direction almost doubles commissioning effort

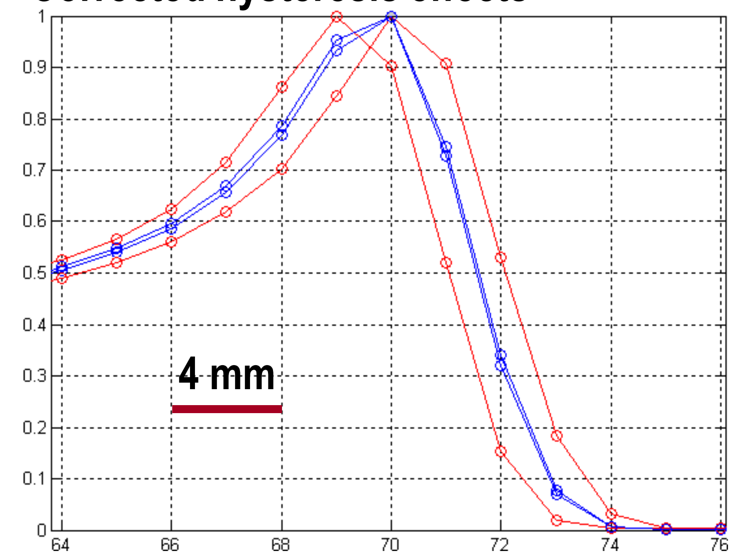


Uncorrected beam line hysteresis effects



Energy sequence: **Red**: Up-Down **Blue**: Down-Up

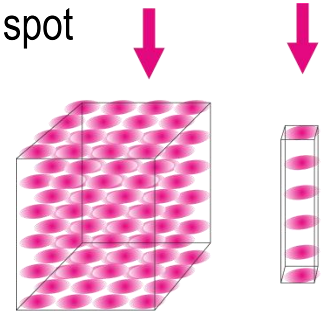
Corrected hysteresis effects



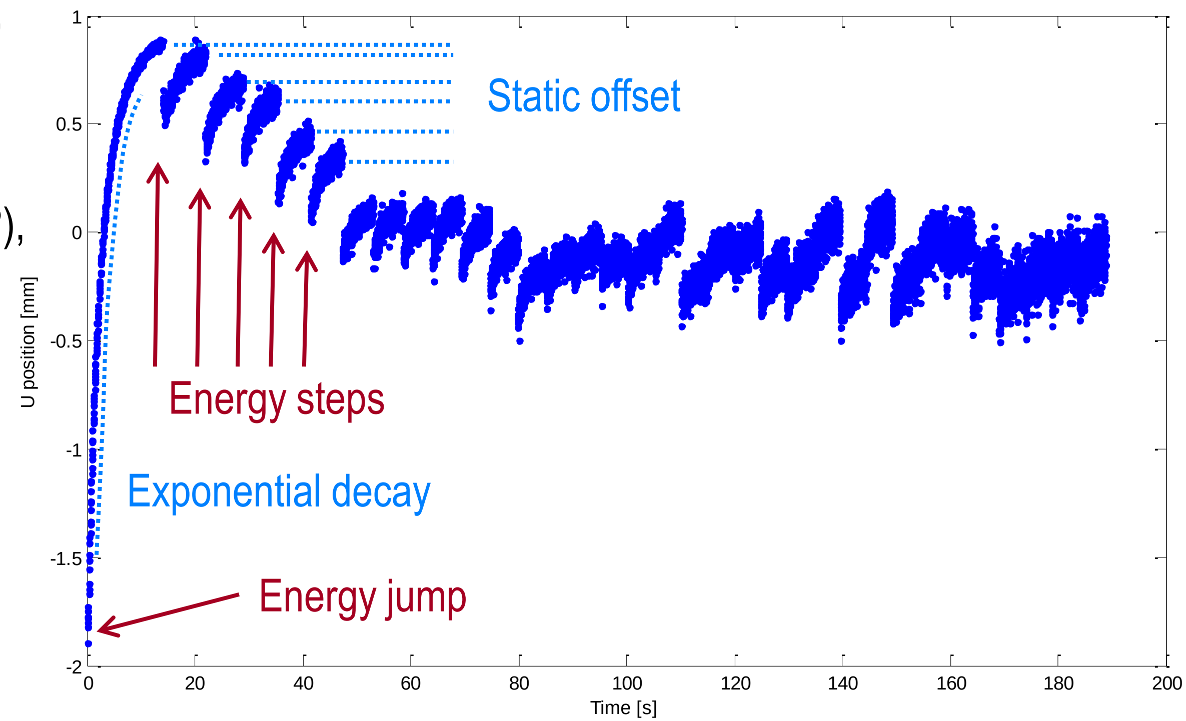
Energy sequence assignment (up ↔ down):
Red: Wrong **Blue**: Correct

Price for fast energy changes: position drifts

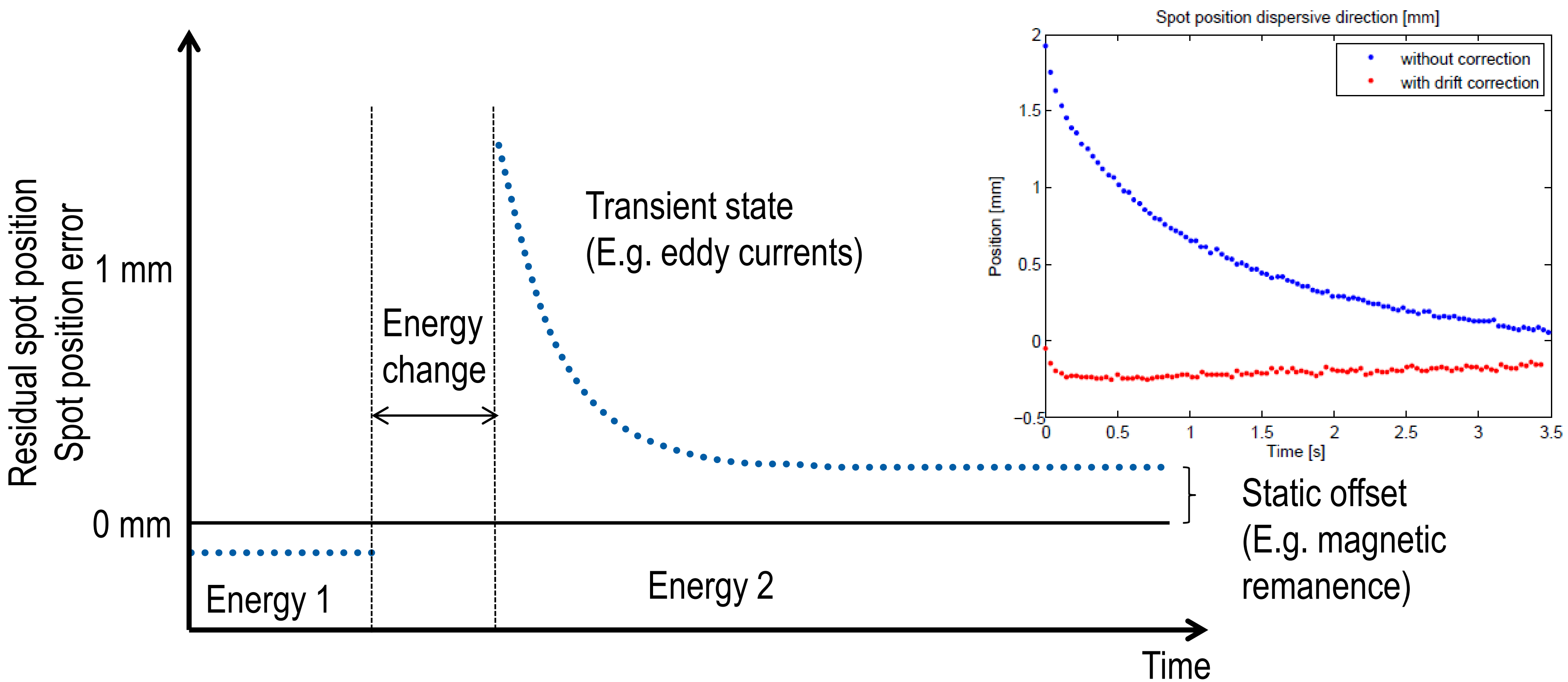
- Two type of energy changes
  - Energy steps: Typical small energy change within a scan sequence (5 mm WER / ~ 3MeV); 100 ms
  - Energy jumps: For ramping and at start of scan sequence (up to 50% of dynamic range); ~ 1s
- Settling time of the beam line in the order of seconds (eddy currents in magnets)
- Observable effect during settling time on
  - Range but very small (<<1 mm)
  - Position drift in dispersive direction, up to 3-4 mm
- Position drift has two components
  - Exponential decay (eddy currents ?),
  - Static offset (magnetisation ?)
- Characterisation with "shrunk target": Same number of spot and MU but no sweeper action



Spot position for "shrunk box", 142 MeV – 72 MeV, 1 Gy



Dynamic corrections on spot position



Transient state:

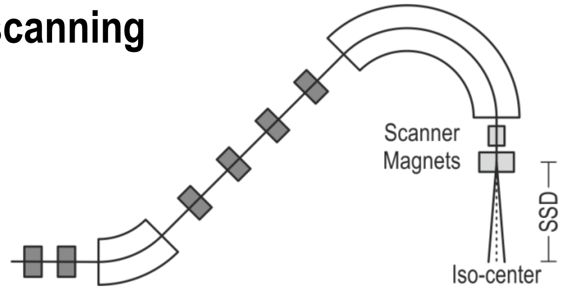
- Experimental characterization possible
- Depends on size of energy step
- Control system corrects spot position based on time information (drift correction) with sweeper magnet

Static offset:

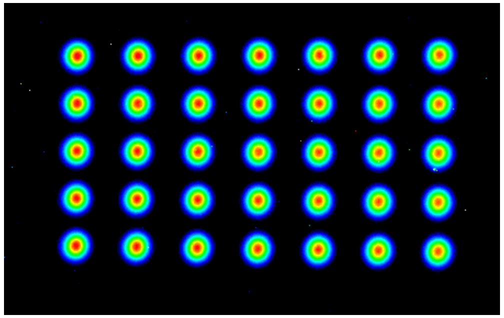
- Depends on previous magnetic history
- Difficult to parameterize but very reproducibale
- Proper ramping of beam line important
- Acceptable if error < 1mm

Calibration of sweeper magnets

Downstream scanning



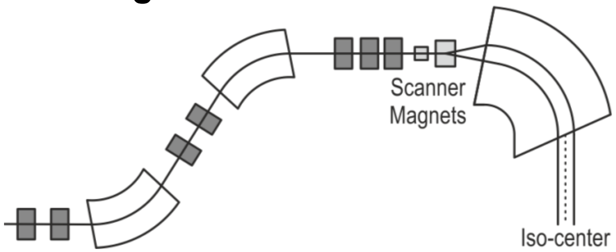
- Sweeper magnets are last active beam elements
- In first order linear correlation between
  - Spot position at iso-center
  - Sweeper current
- Spot shape unaffected for different scan position
- Divergent scanned beam; calibration relies on exact longitudinal alignment at iso-center
- Situation similar to horizontal beam line



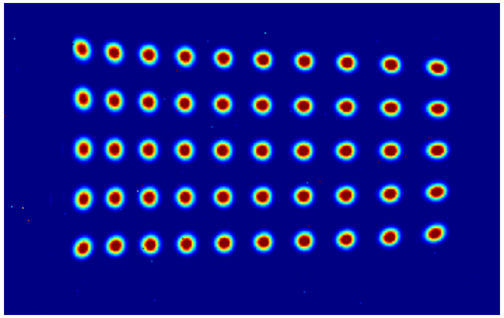
Example:
Horizontal beam line,
PSI test area,
170 MeV

Spot position with
linear current steps,

Upstream scanning



- Sweeper magnets placed in-front of last dipole
- Large gap of last dipole
- Field inhomogeneities can affect spot shape
- Beam focus depends on lateral position
- Beam with little / no divergence (= parallel beam)
- Higher order corrections for position-to-current conversion needed

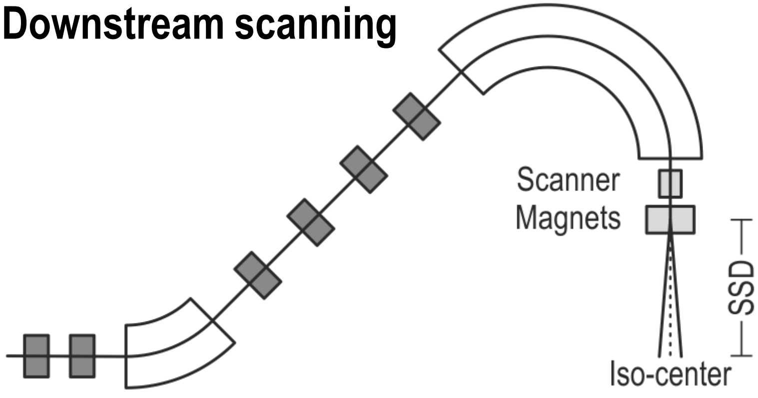


Example:
Gantry 2, 100 MeV

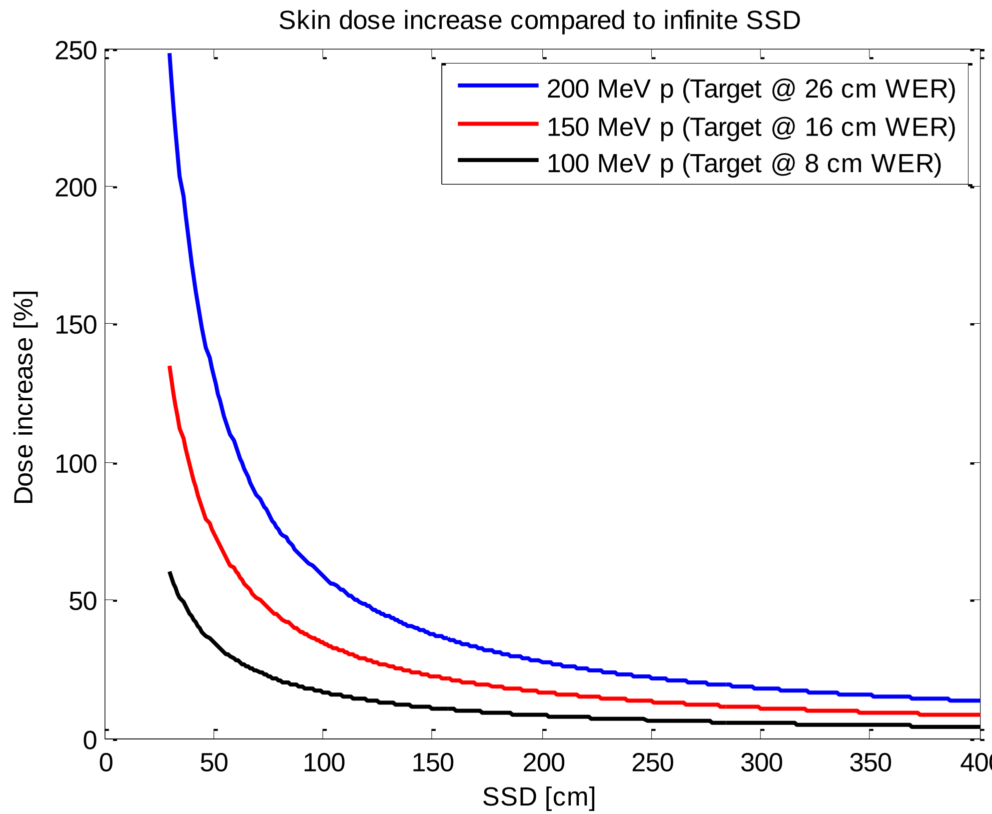
Spot position with
linear current steps

SSD and increased skin dose

Downstream scanning

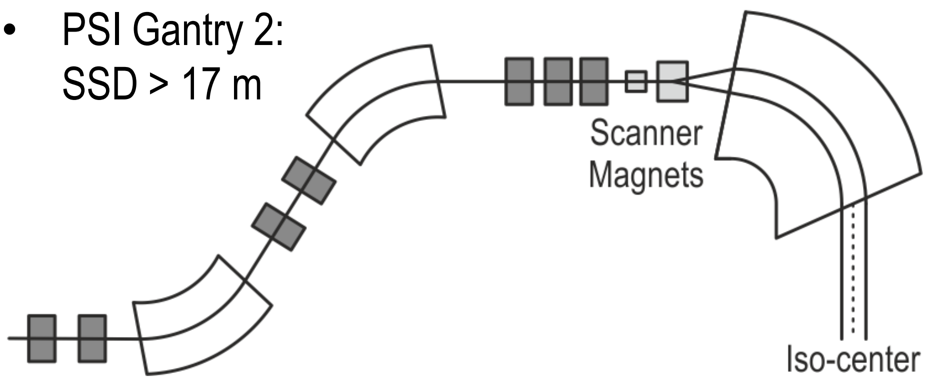


- Typical SSD (source skin distance) ~ 2m



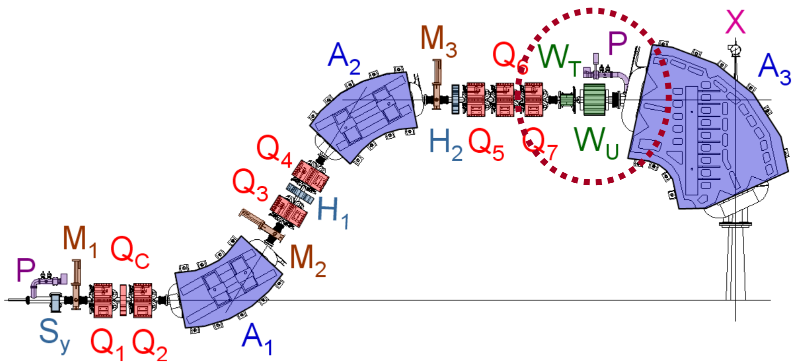
Upstream scanning

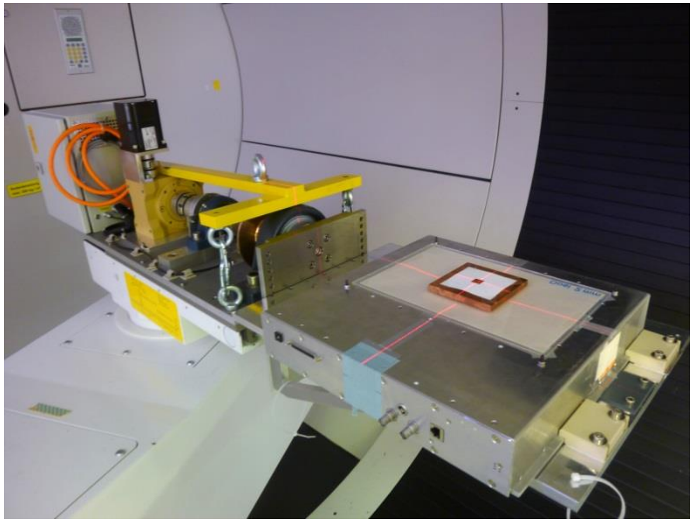
- Almost infinite SSD possible
- PSI Gantry 2:
  SSD > 17 m

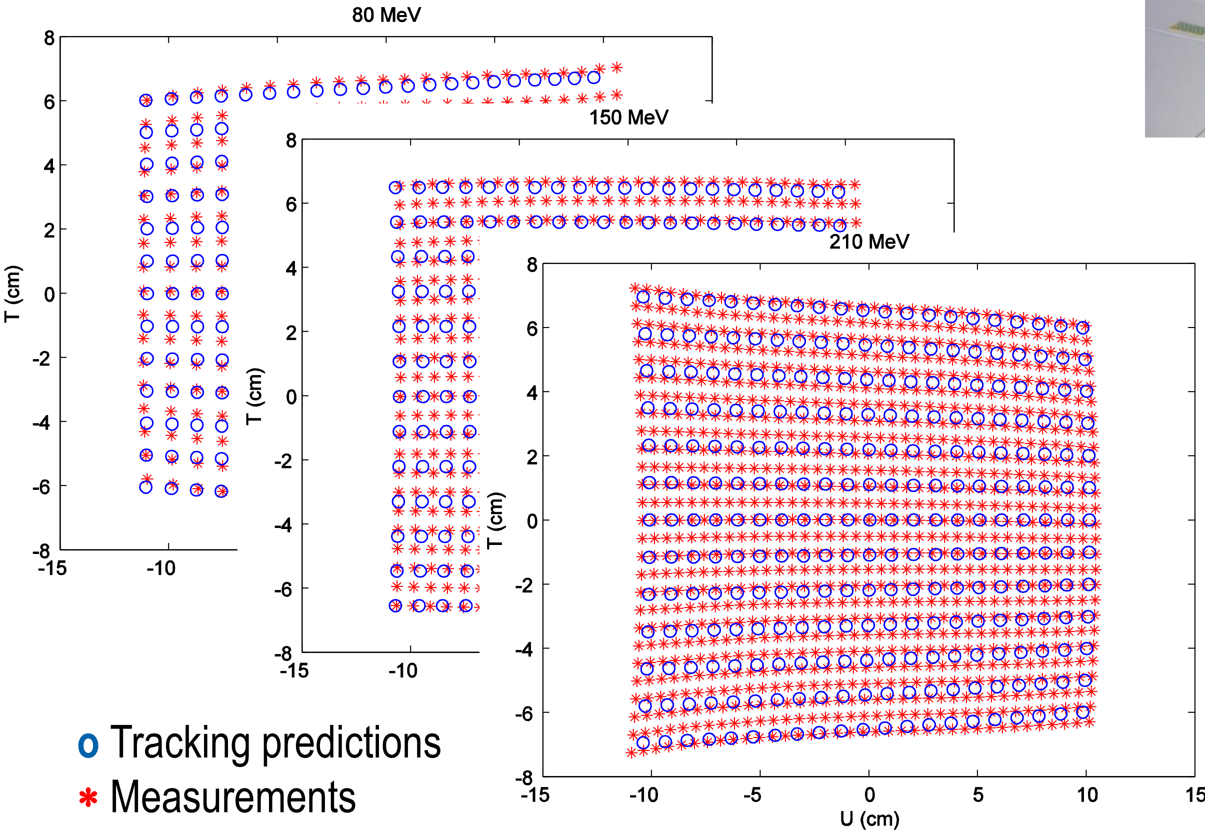


- Skin is a radiation sensible organ
- Reducing skin dose is essential

Measurement setup for sweeper calibration



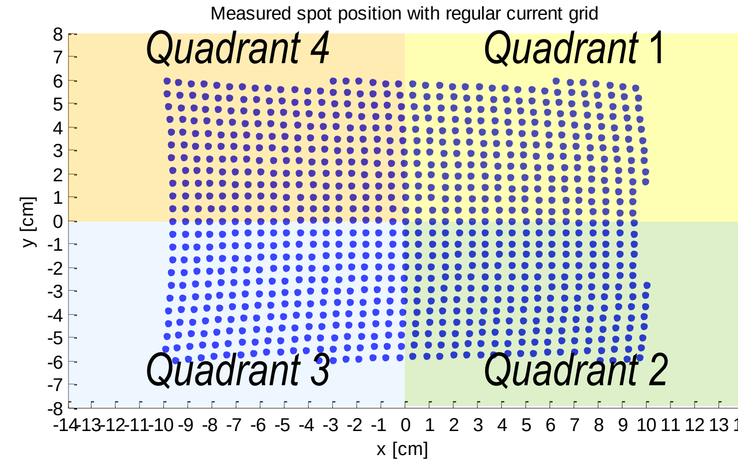


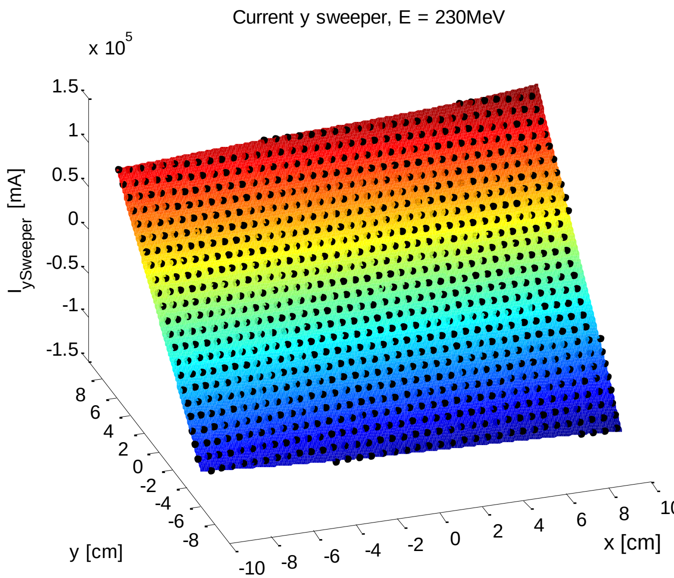


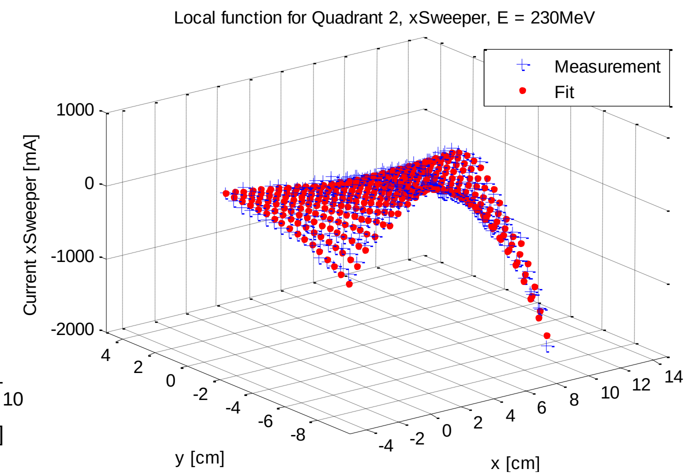
- Device at iso-center for 2d position measurement (strip chamber identical to Nozzle)
- Rotatable support (gantry angles)
- Alignment at iso-center is challenging
  - Room lasers (for α=0°)
  - Lasers on the gantry (different gantry angles)
- Device calibration with collimator

Parametrization of sweeper magnets calibration

- Smooth polynomial function is preferred over look-up table
- Polynomial expression for sweeper current $I_{xSweeper}(x,y)$ and $I_{ySweeper}(x,y)$
- Global fit plus local fit for each quadrant







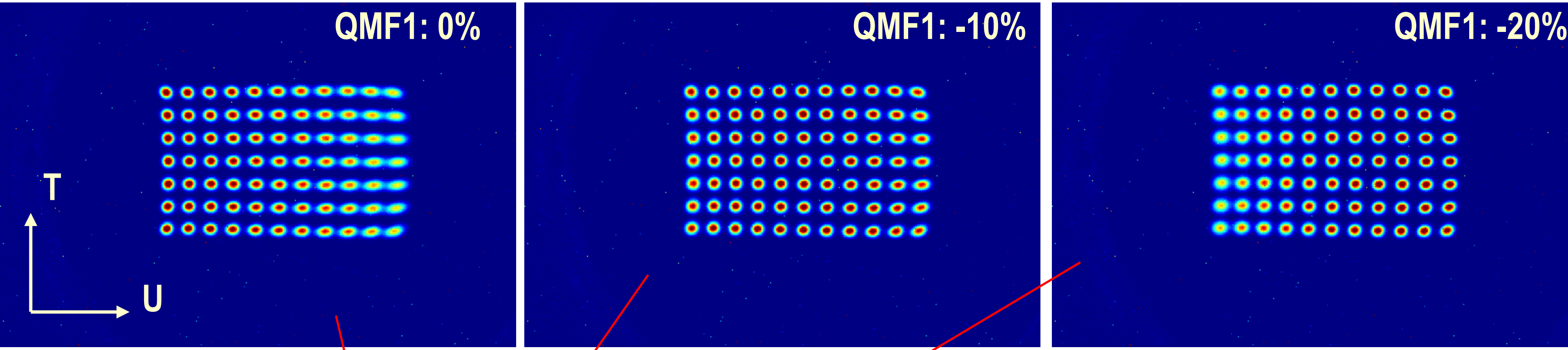
- Sweeper parametrization for every 10 MeV
- Interpolation between energies

$$I_{\text{xSweeper}}(x,y) = \overbrace{g_1 x + g_2 y + g_3 x^2 + g_4 y^2 + g_5 y^3 + g_6 y^4}^{\text{global function}} +$$

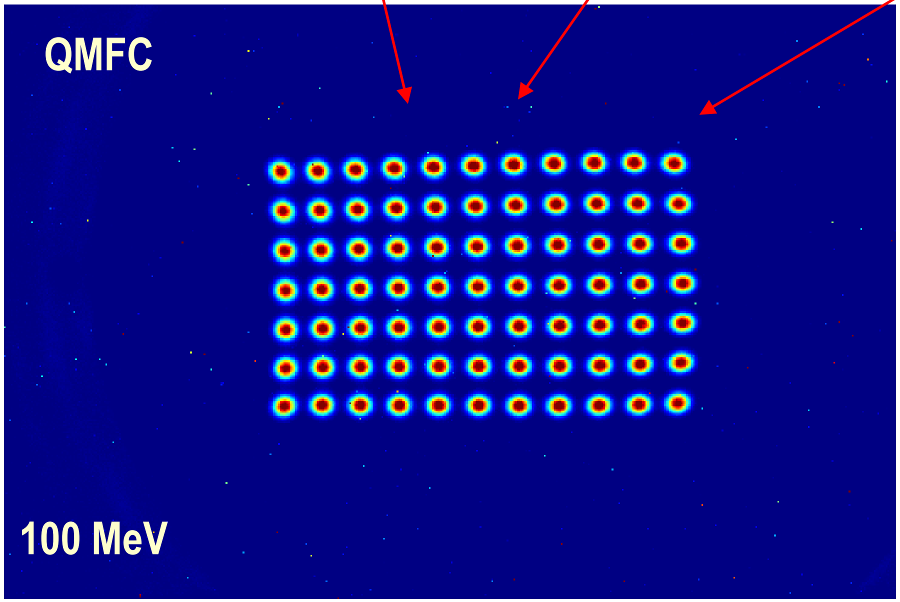
$$\sum_{q=1}^{4} \underbrace{l_1^q xy + l_2^q x^2 y + l_3^q xy^2 + l_4^q x^3 y + l_5^q x^2 y^2 + l_6^q xy^3 + l_7^q x^4 y + l_8^q x^3 y^2 + l_9^q x^2 y^3 + l_{10}^q xy^3}_{\text{local function for each quadrant}}$$

Dynamic beam focusing corrections

Static corrections

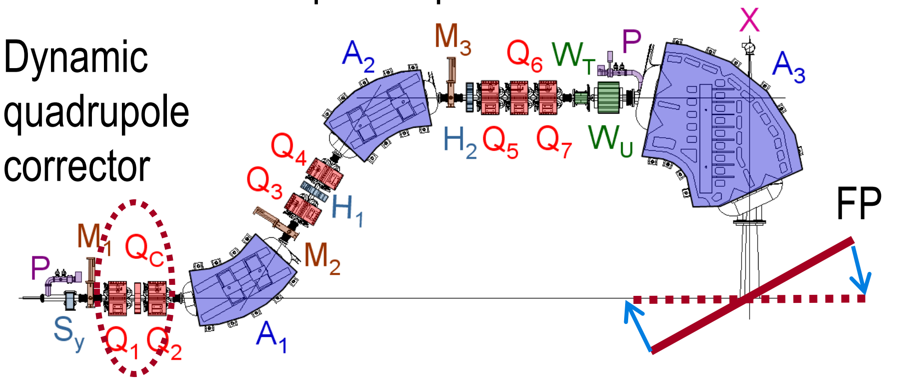


Dynamic corrections



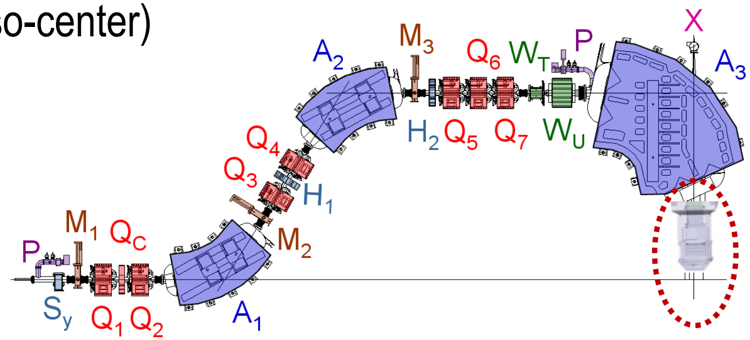
- Focal plane FP not orthogonal to transversal direction at iso-center
  ⇨ Spot shape is changing with position
- Quadrupole corrector in series with U-sweeper
  ⇨ Invariant spot shape

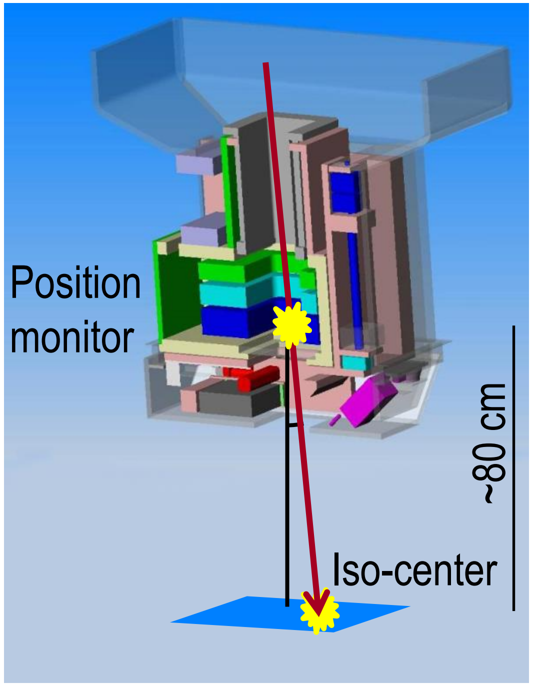
Dynamic quadrupole corrector



Projection of measured position to iso-center

- Position measurement crucial for delivery verification (at iso-center)
- Typical measurement of two orthogonal profiles
  - Strip chamber (segmented ionization chamber)
- Measurement with position monitor in nozzle
- Verification with expected position at iso-center
- Position monitor to iso-center projection
  - Beam angle for full scan range (position and energy)
  - Projection error should be < 0.2 mm
  - Distance monitor - iso-center > 50 cm
    → Measuring beam angel with precision < 0.5 mrad
- Relevant for downstream scanning as well as upstream scanning (deviation from perfect orthogonality)
- Projection calculation on-line or off-line
- At PSI: Telescopic motion of the nozzle (including position monitor)
  - Off-line interpolation of beam angle from look-up table
  - On-line calculation of iso-center position with current nozzle extraction

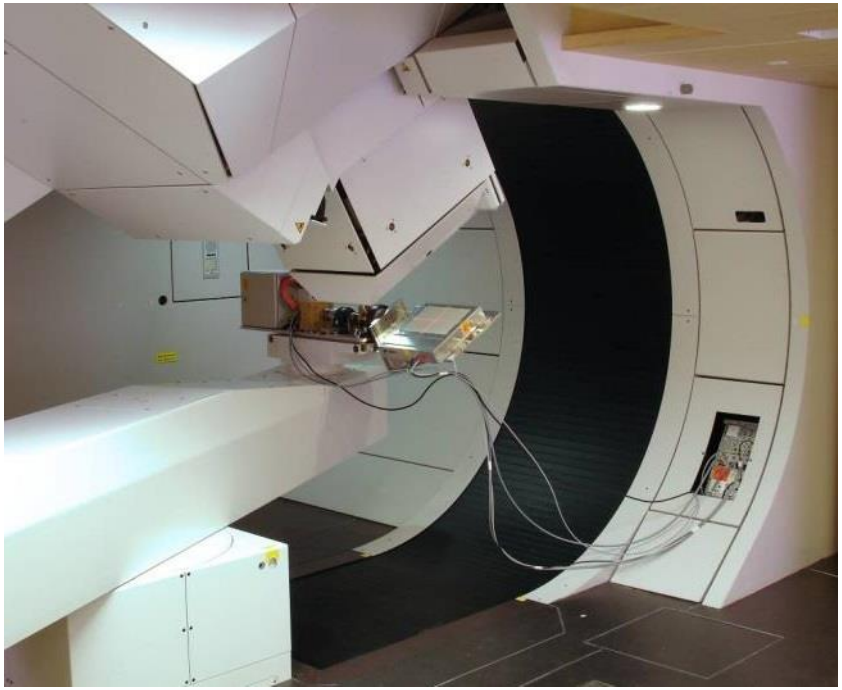




Measuring position to iso-center projection

Measurement tool

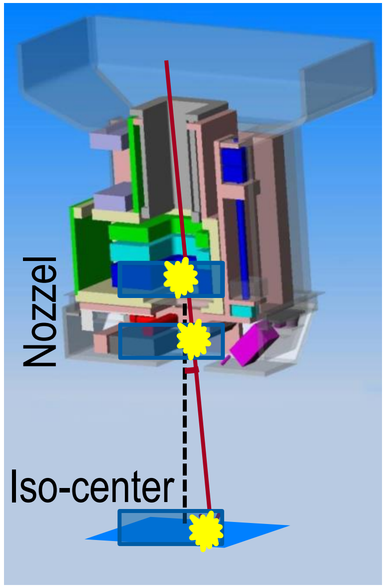
- Strip chambers in nozzle and at iso-center
- Support allows Iso-centric rotation
- Complete remote operation incl. beam dump → Efficient operation
- Read-out by Therapy Control System (TCS)
- Data part of QA log → Simplifies data analysis

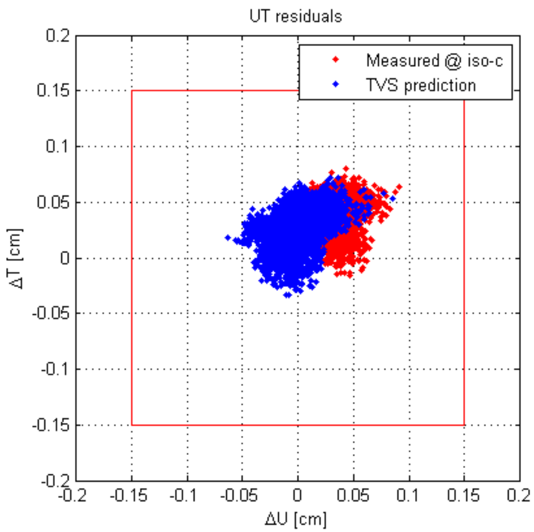


Measuring options

1. Calculate beam angels with data from nozzle and iso-center strip chamber
2. Telescopic nozzle: Calculate beam angels with data from two nozzle positions

- Both options give comparable results





Result

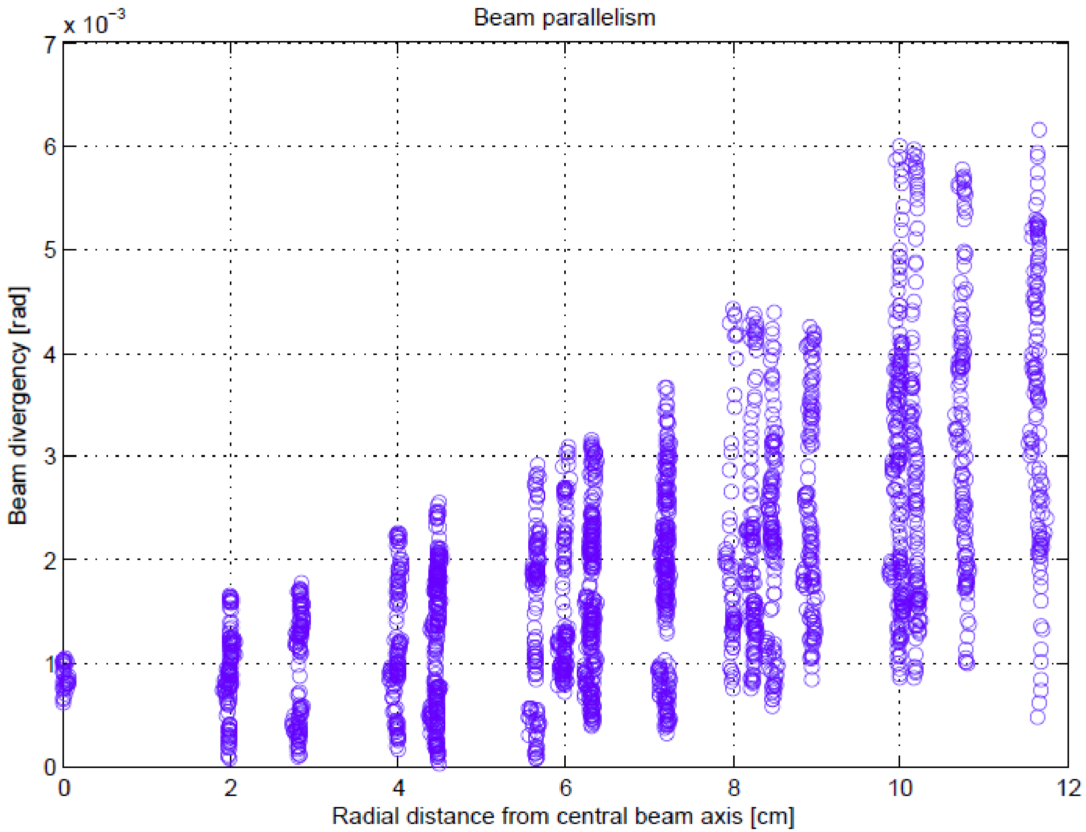
Beam angle for each spot is part of steering file.

TCS uses angel to calculate on-line beam position at iso-center for different nozzle extractions.

Accuracy ~< 0.3 mm

Parallelism of the beam

- Deviations smaller 6 mrad, mainly edge effect of last bending magnet (Corresponds to an SAD of ~17 m)

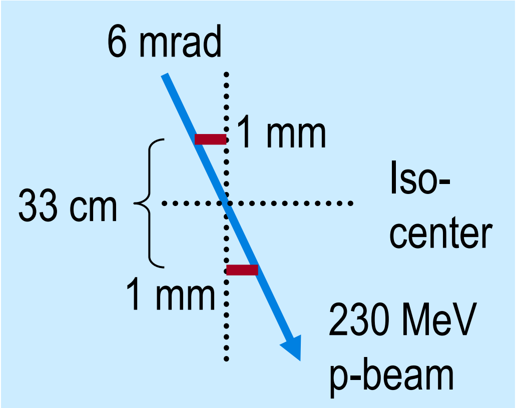


Field center

Field edge

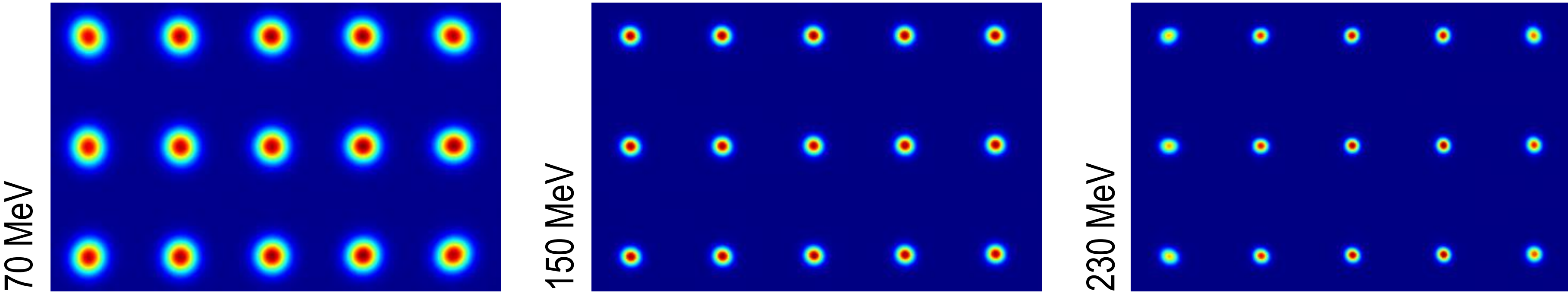
Measurement grid 2x2cm,
All energies,
Full scan range

- Proton range for 230 MeV is ~ 0.33 m. Field center at iso-center
→ Position error due to beam divergence < 1mm



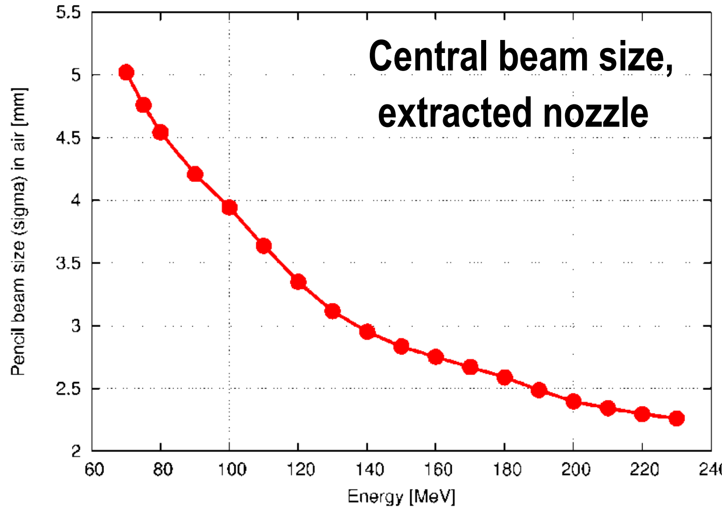
- Acceptable without further considerations in treatment planning

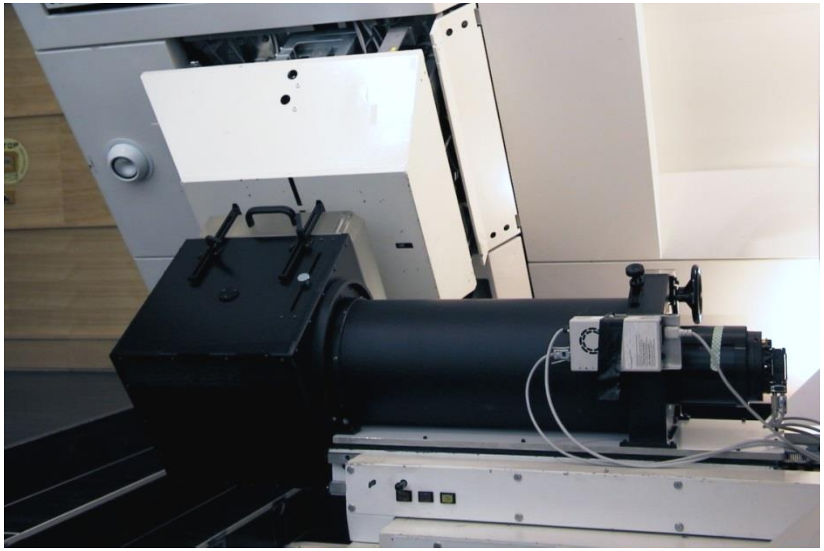
Spot size measurement



At iso-centre, full scan range, in air

- Measurement on scintillating screen with mirror and CCD
- Fit 2-d Gaussian for each recorded spot
- Spot size is important parameter for treatment planning



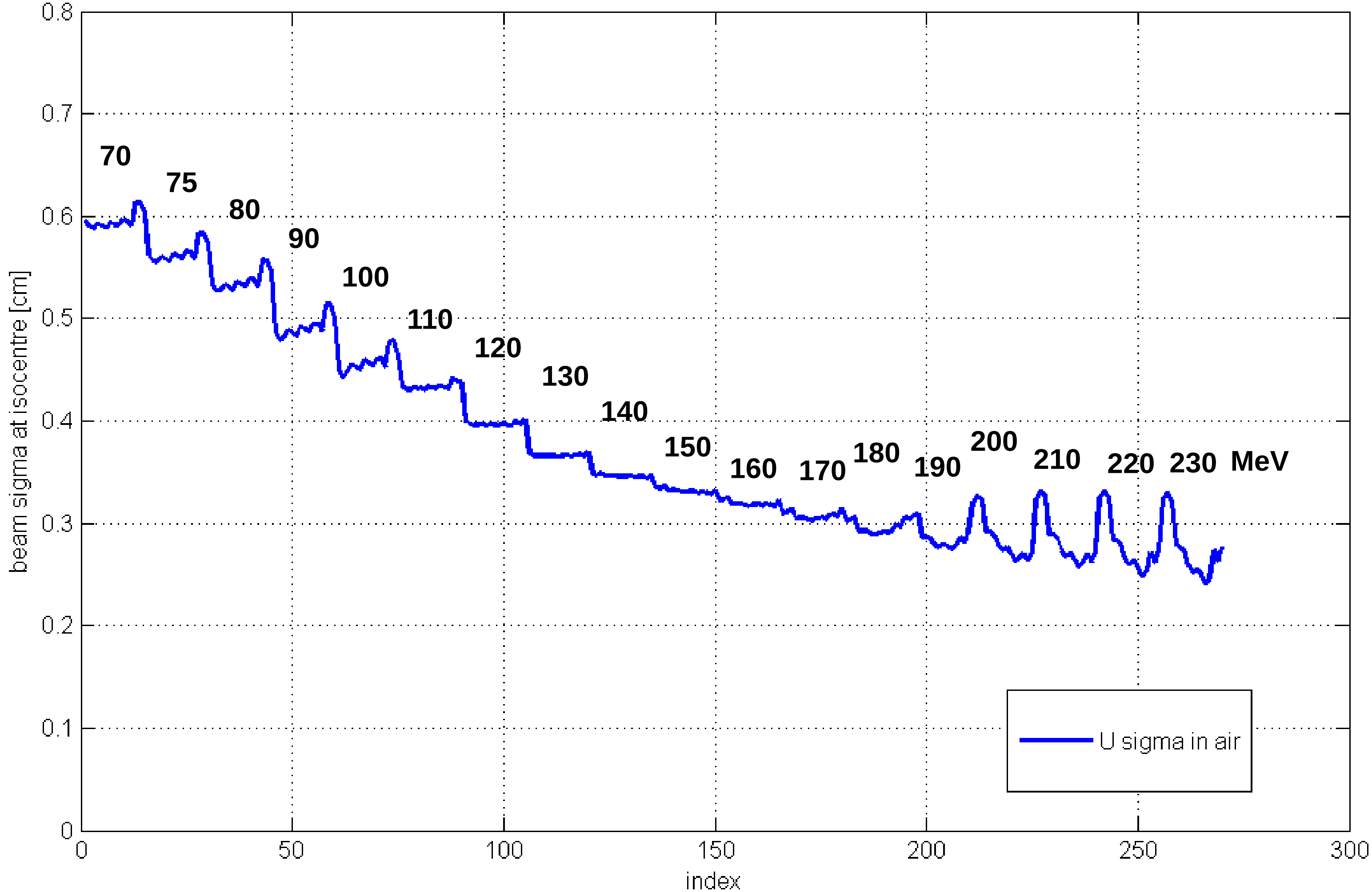


At PSI Gantry 2 (with telescopic nozzle):

- σ (@70 MeV): 5 mm extracted, 6 mm retracted nozzle
- Measure spot size σ at different longitudinal distances s
- Model to calculate $\sigma(s)$ for different nozzle extraction
- Small left ↔ right asymmetry for highest energies

Delivered pencil beam in air in Gantry 2

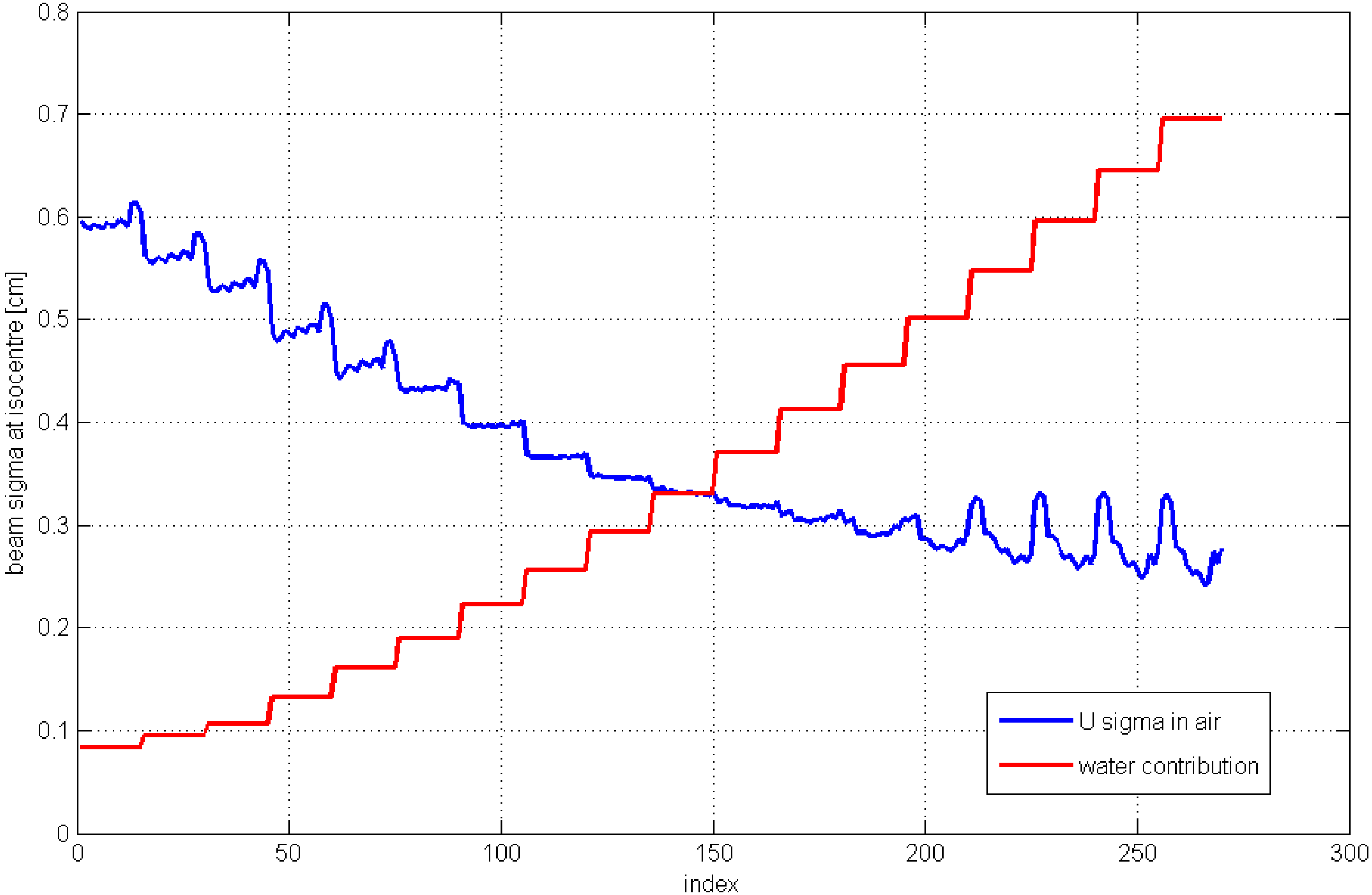
Beam sigma at isocenter in cm



15 spots / 18 Energies

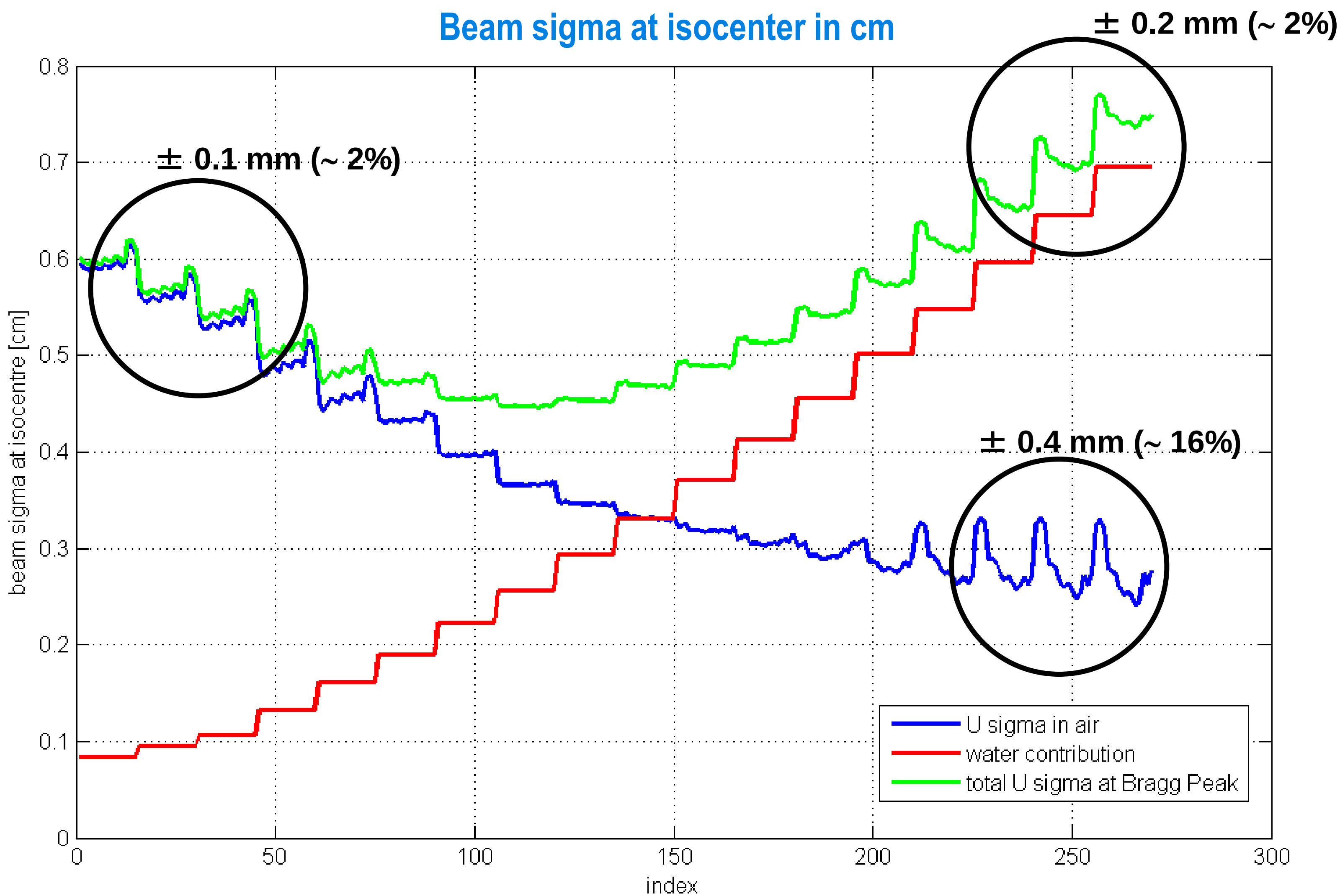
Delivered pencil beam in air in Gantry 2

Beam sigma at isocenter in cm



15 spots / 18 Energies

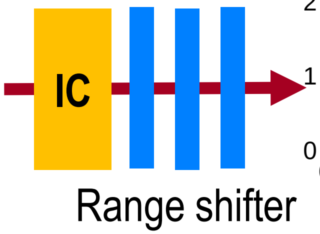
Delivered pencil beam in air in Gantry 2

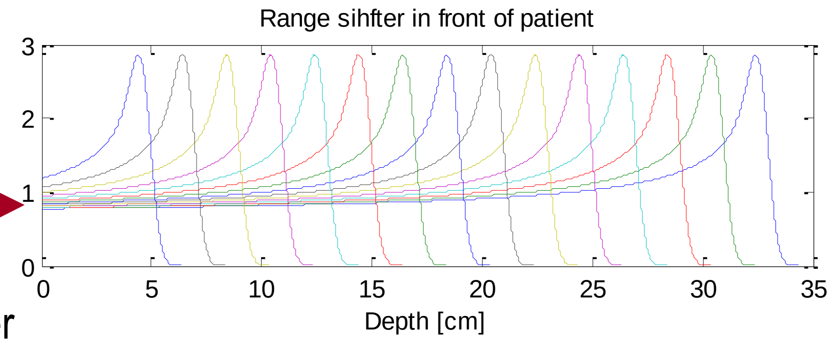


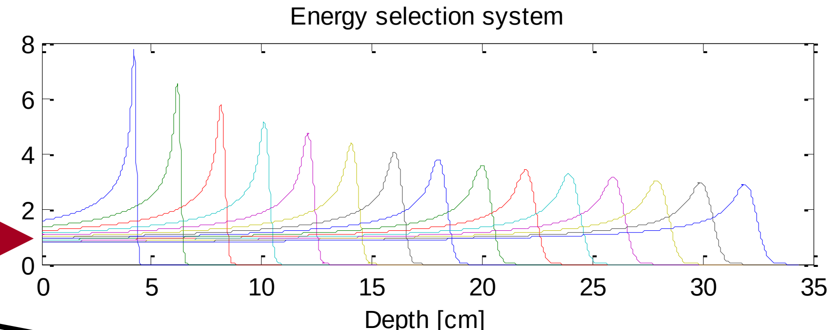
→ Physics helps to reduce the effect, may work for protons
Still an issue for heavy ions due to less scattering (Requires more tuning effort)

Dose monitor (IC) calibration

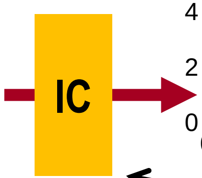
- Energy modulation with range shifter in front of patient
  - Beam has always same energy at dose monitor (IC) location
  - Single conversion factor IC current to # protons







- Upstream energy selection and beam analysis
  - Beam has different energy in dose monitor
  - Energy dependent conversion factor ($\propto$dE/dx)



- Determination of conversion factor with Farrady Cup (FC) measurement

ICRU data (air) polynomial fit | FC measurement @ nominal p_0, T_0, (x,y) | On-line | Off-line

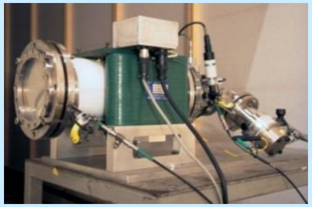
Charge Q_{IC} = dE/dx(E) * $\text{Correction}_{\text{Experimental}}$(E) * Gain_{IC} * 1/ k_{TP} * $\text{IC}_{\text{Homogeneity}}$(x,y) * Q_{elem} * #protons

Typ. values 3.5 - 9.5 | ± 1 % | ~ 37 | ~ 3 % | < 2 %

Dosimetry for scanned proton beams at PSI

Faraday cup measurement

Number of protons / MU



Determines number of incident particles in pencil beam

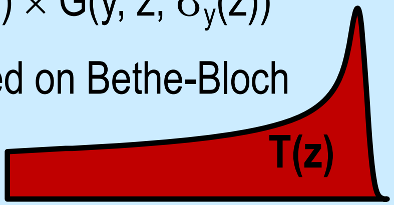
Pencil beam dose model

Predicts number of protons (or MU) needed to fill a 10x10x10 cm^3 box with homogeneous dose of 1.0 Gy

Predicts absolute dose per incident proton

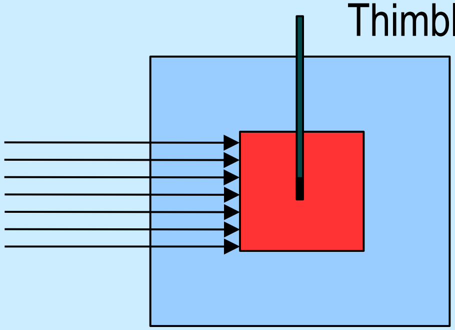
$D(x,y,z) = T(z) \times G(x, z, \sigma_x(z)) \times G(y, z, \sigma_y(z))$

Integral depth dose T(z) based on Bethe-Bloch



Apply scan to phantom

Measure actual dose with certified thimble ionisation chamber following code of practice IAEA TRS 398

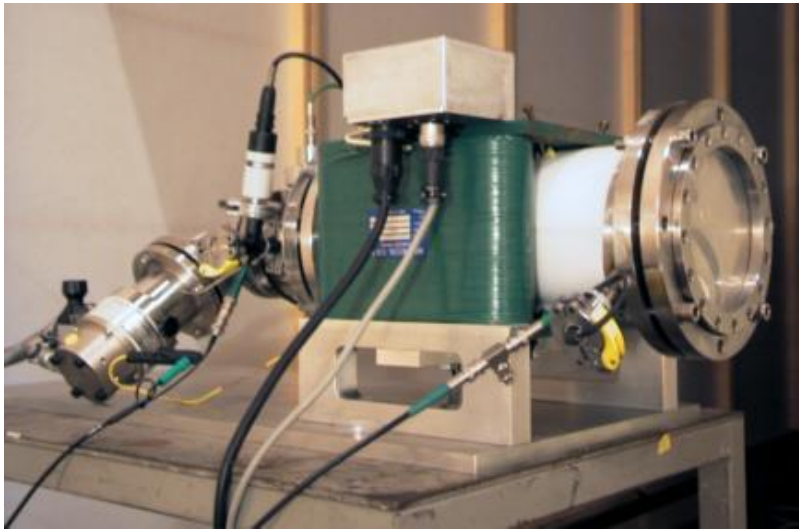


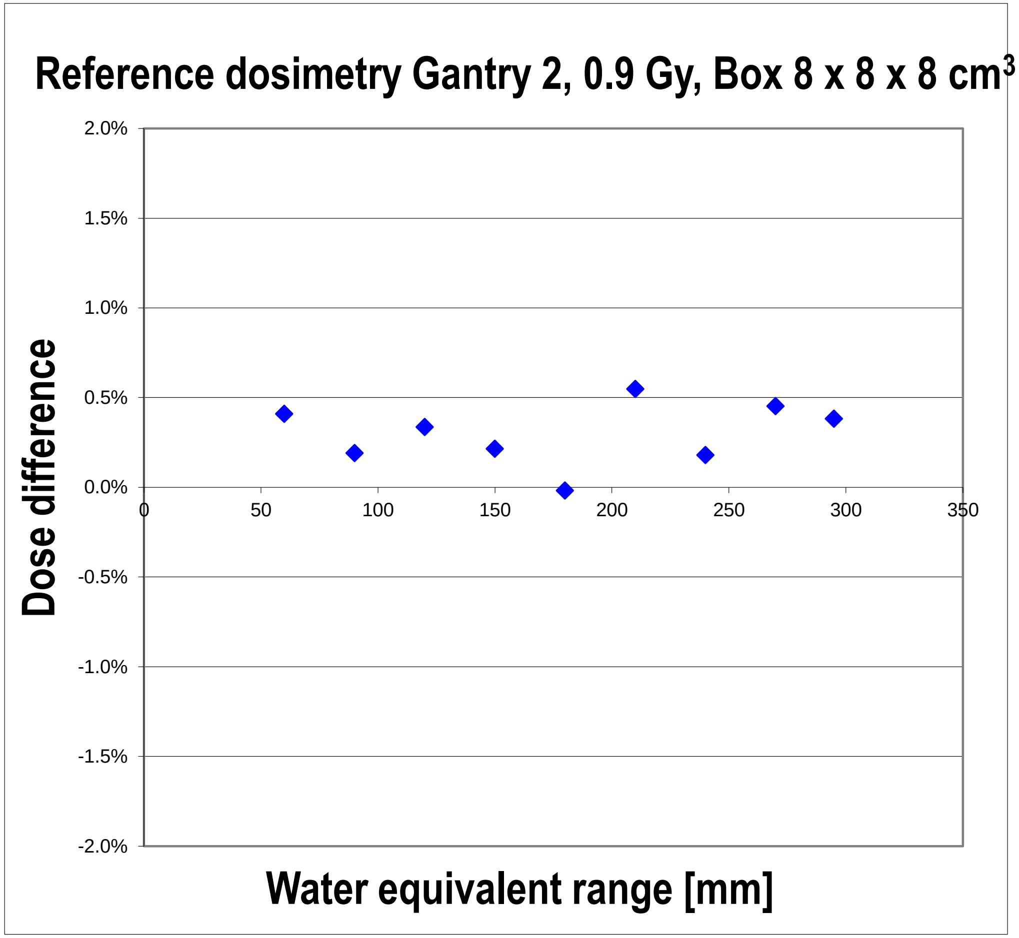
Compare predicted and measured dose

Correction factors for MU calculations

Dose monitor calibration / Dosimetry

- Calibration of primary dose monitor with Faraday-Cup





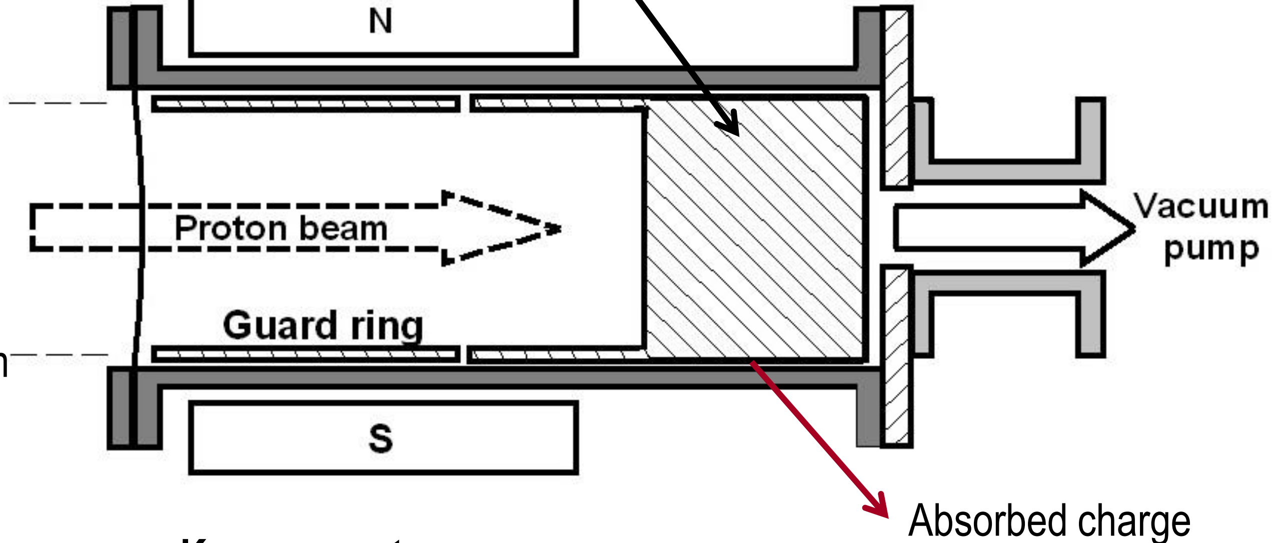
- Agreement with absolute dosimetry on 2-3% level
- Main reason: loosing particles through nuclear interactions (s. next)
- After introducing empirical correction factor: ~ 0.5%

Faraday cup: Technical challenges

Measure collected charge in FC

Avoid secondary electron effect:

- Scattered secondary electrons from:
  - Inner surface
  - Aluminium foil
- Negative guard ring:
  Push back 2nd electrons to entrance window or cup bottom
- Magnet across steel tub:
  Change translational motion of 2nd electrons to rotation, guard ring becomes more efficient

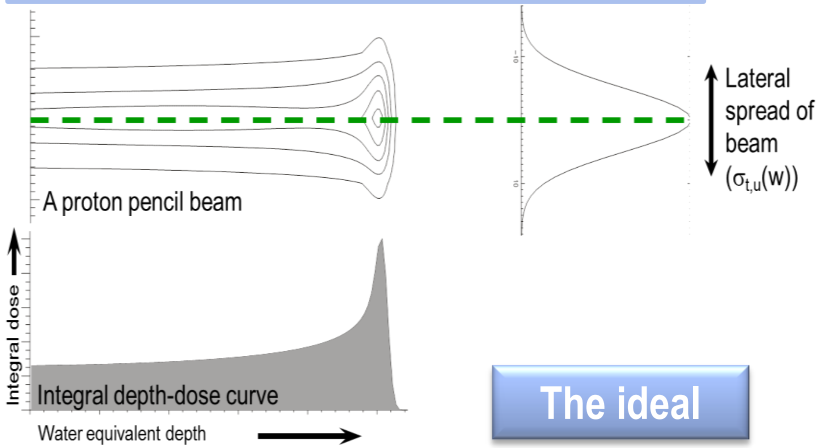


Key parameters:

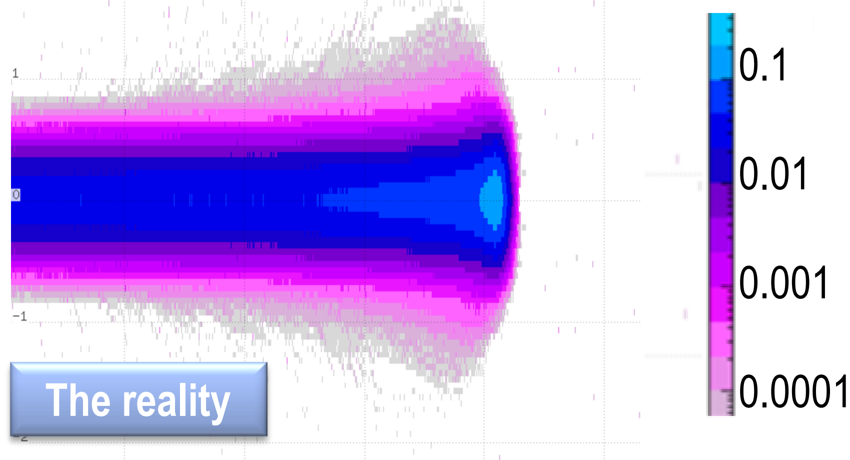
Cup bottom:	Brass, 10 cm (320 MeV protons)
Vacuum:	10e-5 mBar
V_guard ring:	-1000 V
Magnetic field:	25 mT

Beam halo from nuclear interactions

Analytical pencil beam model for TPS



70 MeV protons in water, simulated with FLUKA



Shape of pencil beam is more complex than 2d Gaussian distribution. Effect on dose: Loosing a few %

Modeling option of beam halo:

- Monte Carlo calculations

  Includes all physics processes but high uncertainties and requires benchmarking with data

- Empirical (analytical) model:

  Measurements are part of commissioning, machine dependent characteristic

  Example: Pedroni et al., Phys. Med. Biol. 50 (2005) 541–561

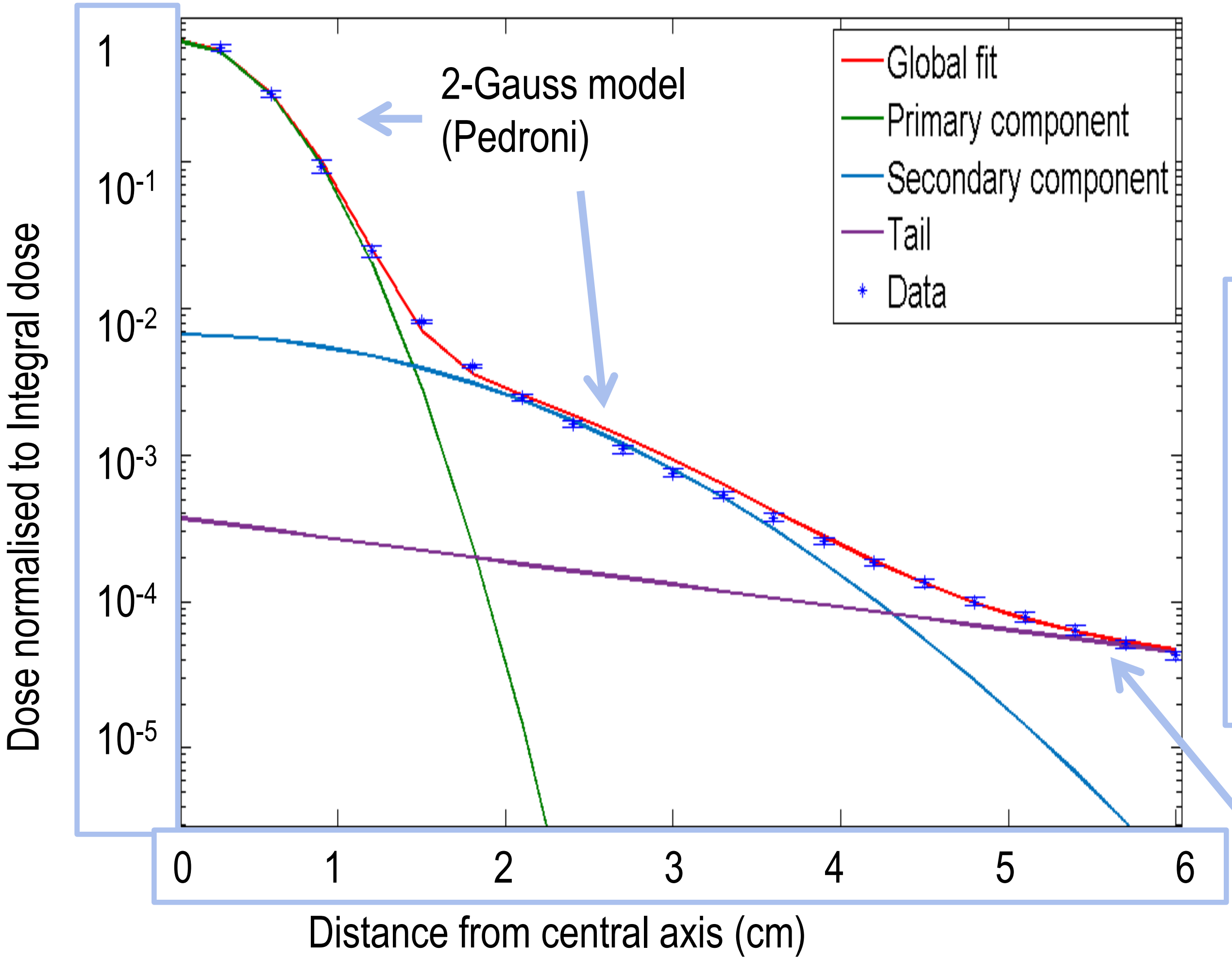
$$D(x,y,w) = T(w)\times\left(\left(1-f_{NI}(w)\right)\times G_2^{P}\left(x,y,\sigma_P(w)\right)+f_{NI}(w)\times G_2^{NI}\left(x,y,\sigma_{NI}(w)\right)\right)$$

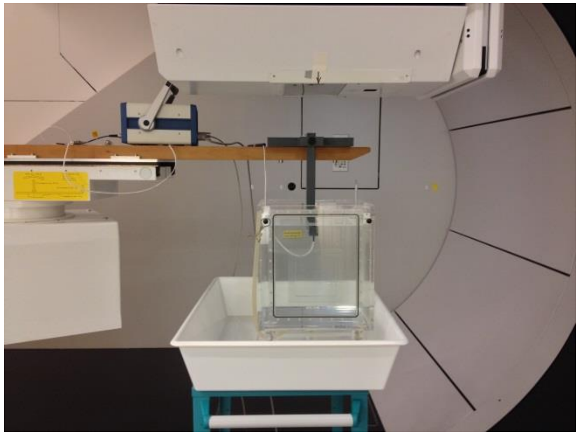
Integral depth-dose — Primary beam (2-d Gaussian) — Nuclear interaction (2-d Gaussian)

Empirical characterization of beam halo

- Measuring dose profile with small ionisation chamber at different radii
- Time consuming measurements, automatization needed

Example: Dose profile for 150 MeV at 12 cm water equivalent range





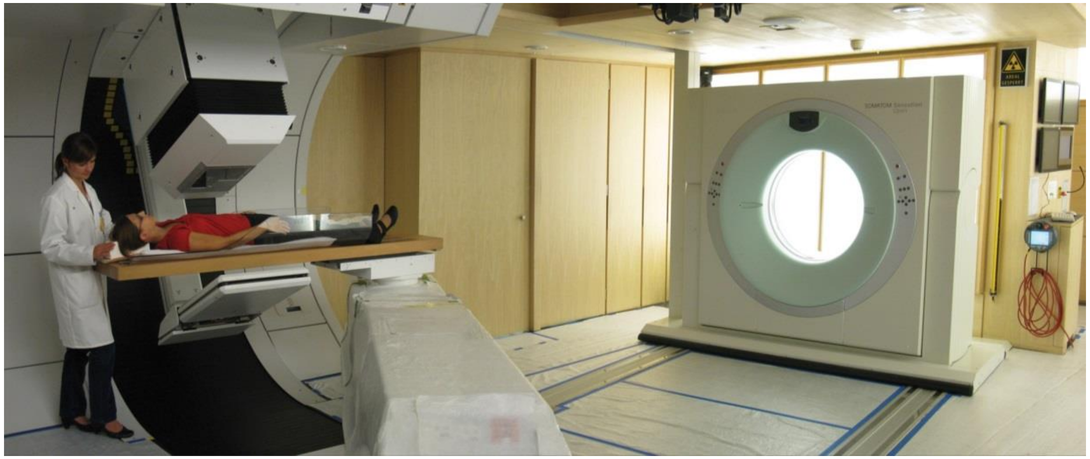
1^{st} Gauss: dominates 0-1.5 cm, sigma energy-dependent

2^{nd} Gauss: dominates 1.2-2.4 cm, sigma energy dependent

Tail: 4-10 cm from central axis, flat in energy and depth

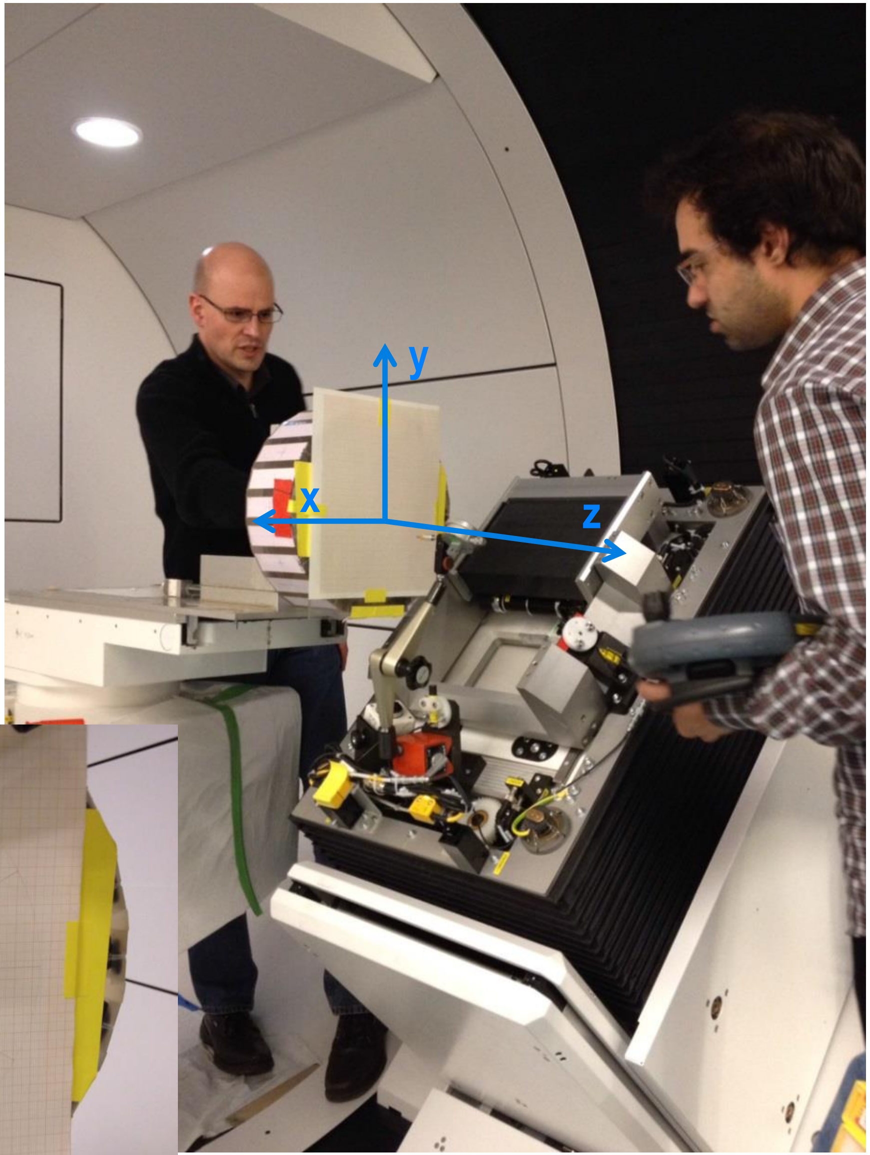
Tail described by exponential function

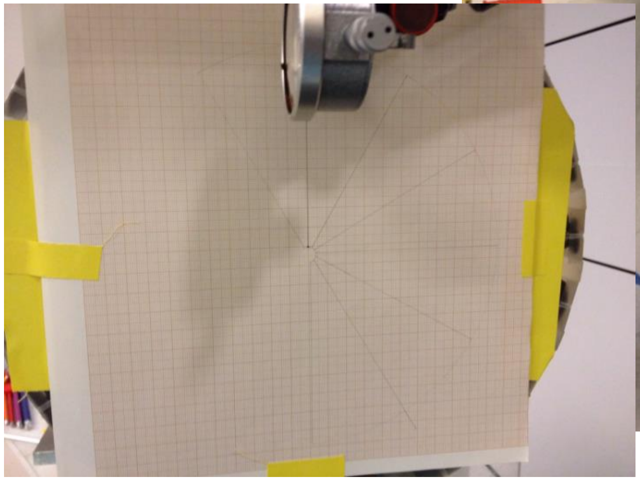
Patient table and imaging systems



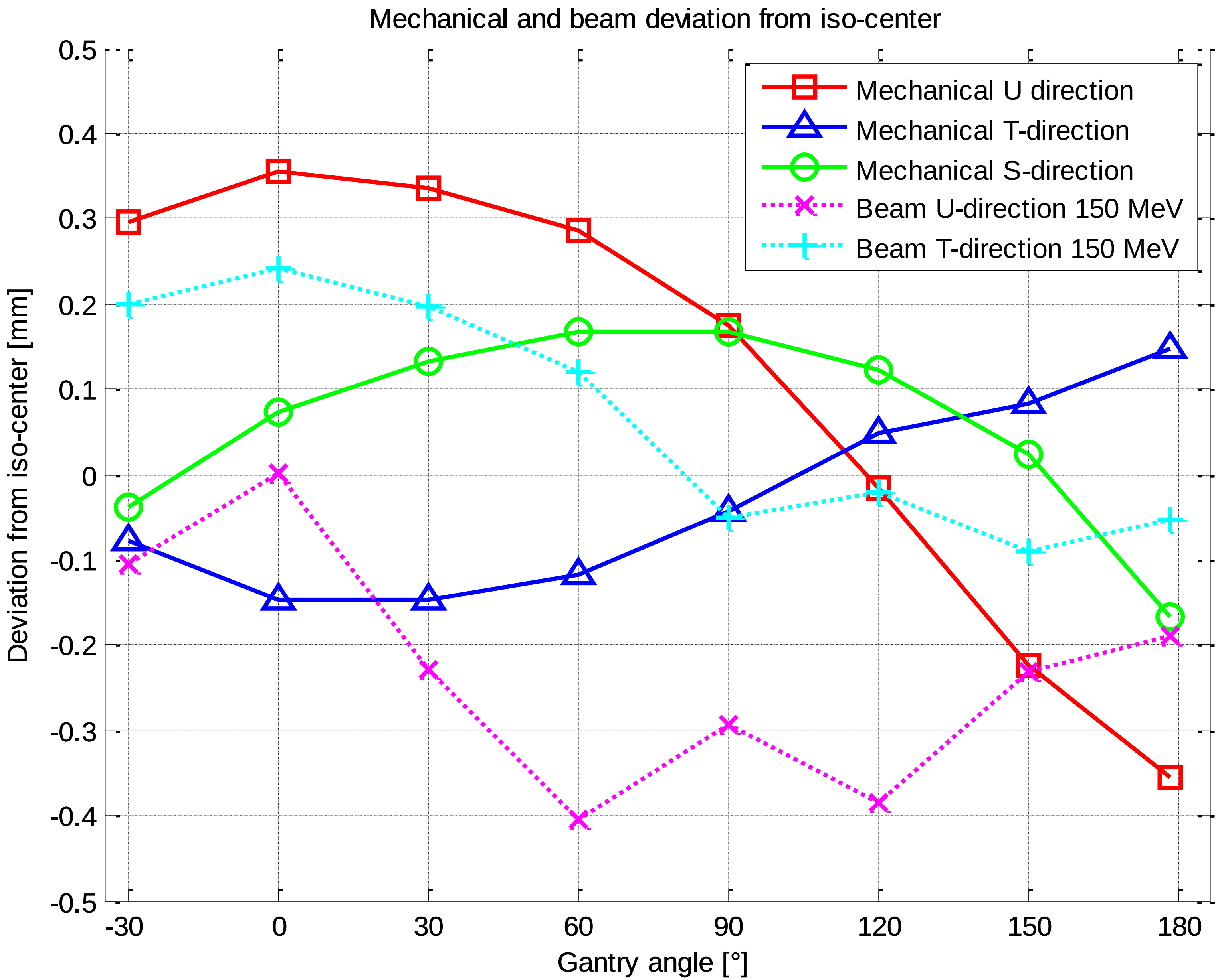
Theoretical vs. mechanical iso-center

- The theoretical iso-center is a point defined in the original drawings
- The mechanical iso-center is a point defined by the axis of rotation of the gantry
- At PSI we are using:
  - Mechanical iso-center for xy coordinates (the gantry rotates in the xy-plane)
  - the z coordinate of the theoretical iso-center
- Measurement with mechanical probe indicator
- Alternative with optical methods (laser tracker)





Mechanical and beam stability at iso-center



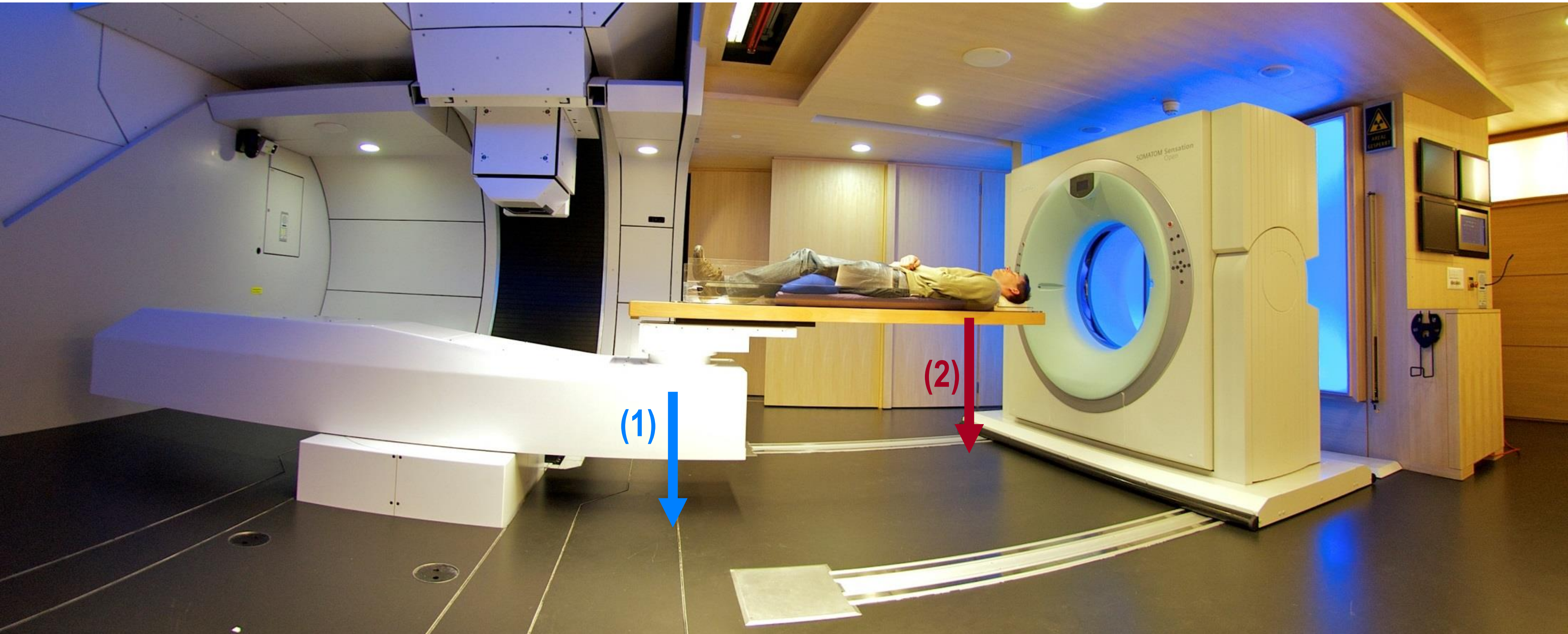
Calibration of the patient table

Bending of patient table (1)

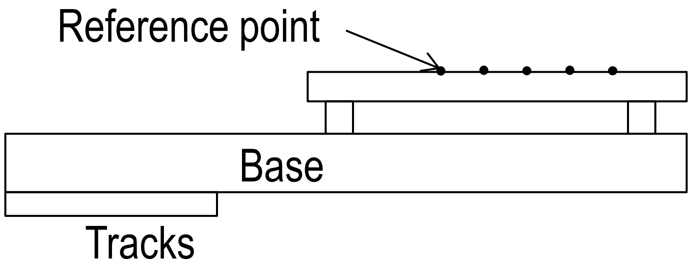
- Depending on table position (CT / irradiation site) and load
- Bending up to several mm
- Requires a calibration with a precision < 0.5 mm for all potential irradiation point on the table and and at CT-position

Bending of patient couch (2)

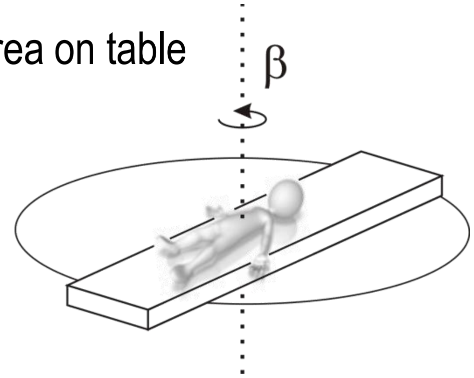
- Depending on load but independent of table position
- Bending is already considered in treatment planning if same patient couch is used for imaging

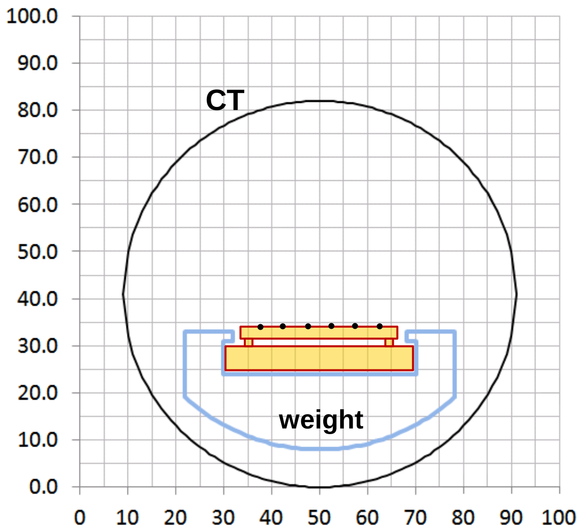


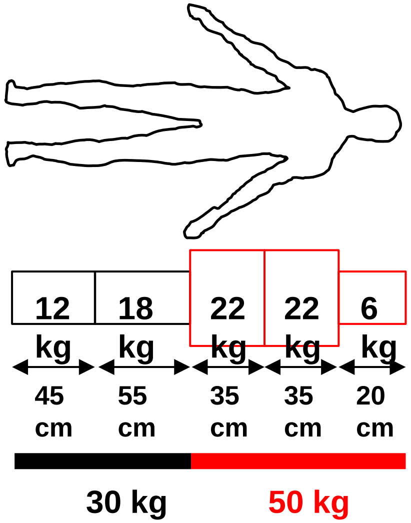
Patient table calibration procedure



- Platform with reference points
- Separation between platform with reference points and platform (base) with weights
- Weight load from 20 to 180 kg, compatible with CT
- Each reference points is brought to iso-center
- Difference ΔX, ΔY, ΔZ between nominal und actual position is recorded for calculation of correction-values
- Automated measurement procedure with laser tracker
- Calibration only for irradiation area on table but different table angel



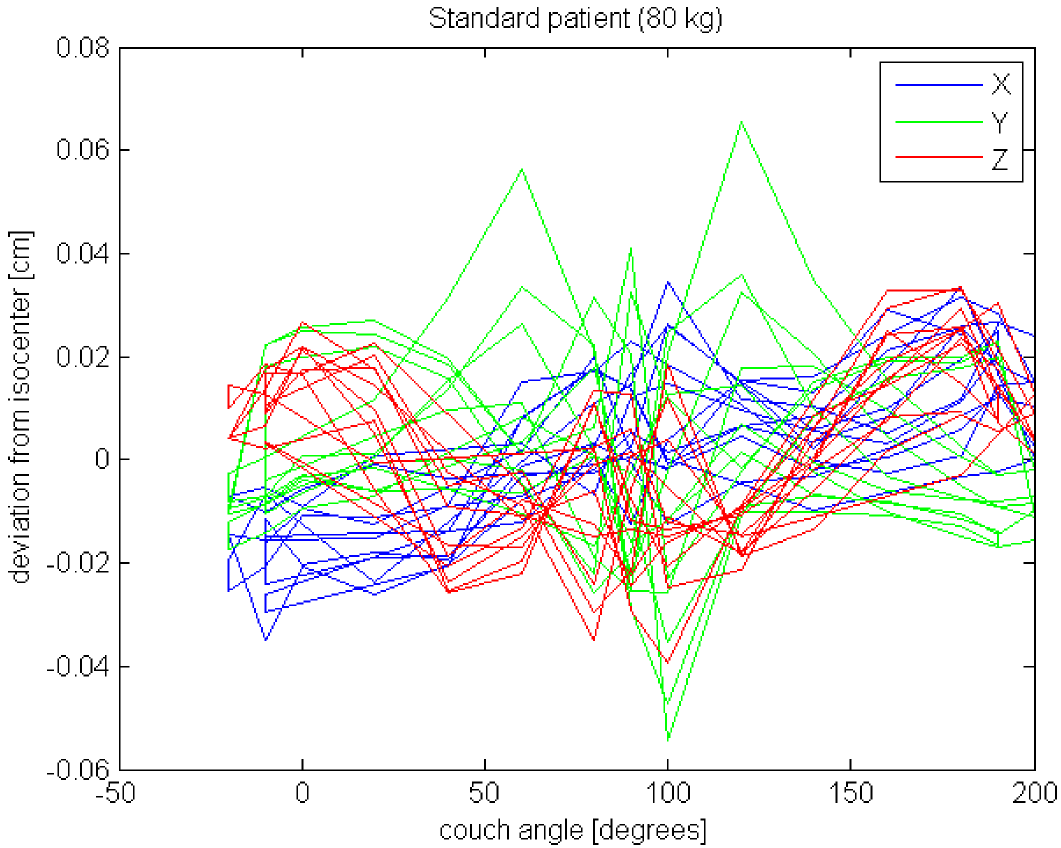


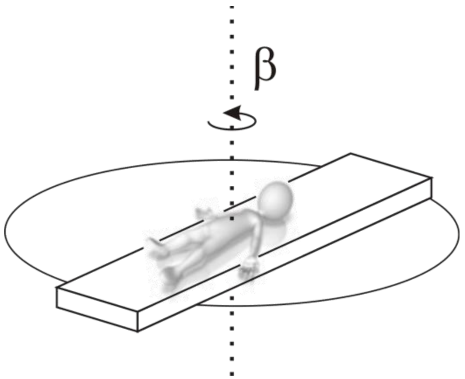


Standard
(IEC60601-1)
80 Kg
190 cm

Patient table calibration results

- High mechanical reproducibility ~ 0.3 mm (Pre-condition for accurate calibration)
- Automated overall calibration procedure based on laser tracker
  (First measurements with: touch probe and optical position recognition)
- Precision at imaging / irradiation position: ± 0.6 mm for patient load from 20 kg to 180 kg
- Long-term stability: QA shows that calibration still valid after more than 1 year

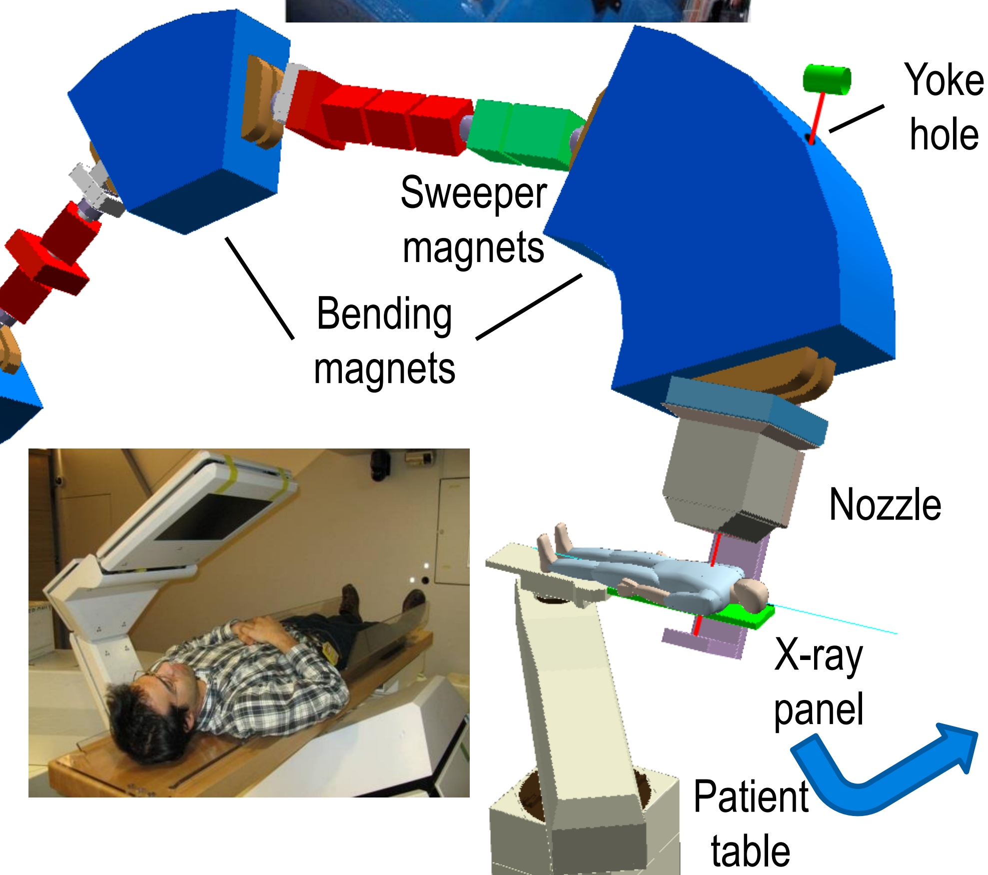




On-board X-ray imaging system

- System used for patient position verification
  → Absolute position calibration required
- Geometry calibration for all gantry angles
- Typical calibration error < 0.5 mm
- Reproducibility of measurements < 0.4 mm

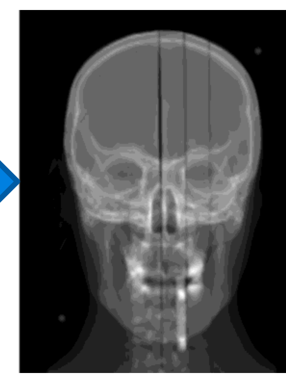
X-ray tube



Patient position verification

Planning CT

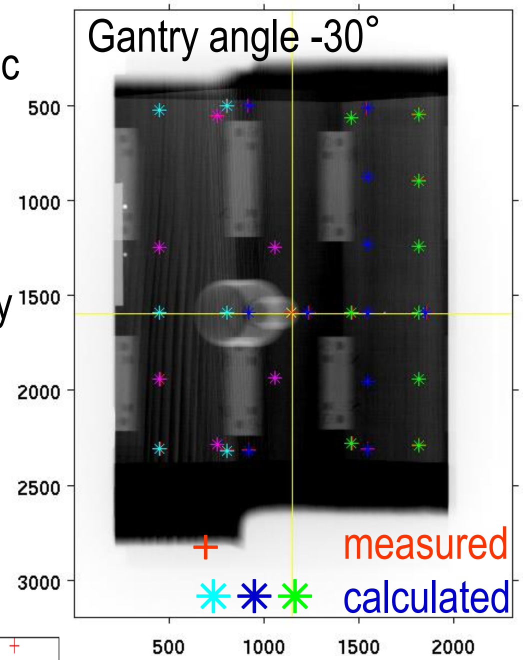
Beam's eye view image



Digitally Reconstructed Radiograph (DRR)

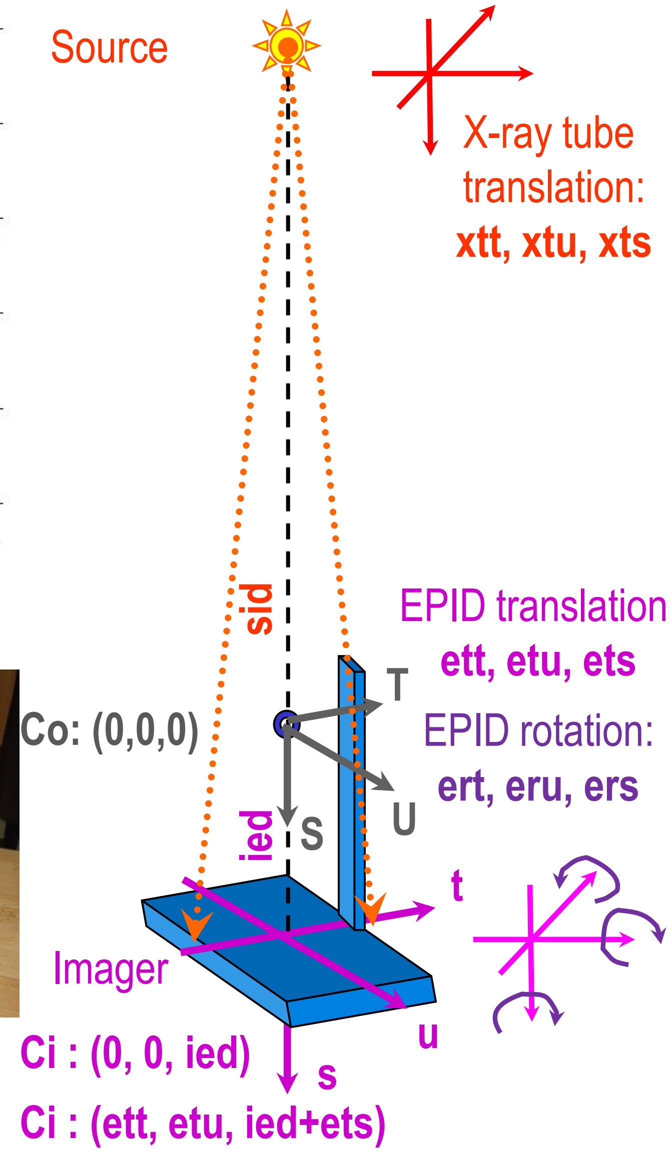
Calibration of Beam's Eye View Imaging system

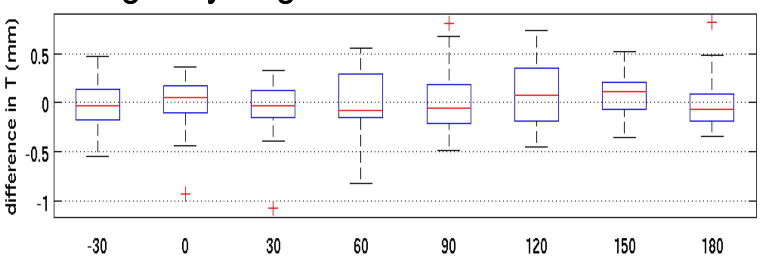
- Geometrical calibration of Electronic Portal Imaging Device (EPID) with calibration phantom
- Align the phantom at iso-center
- Optimizing geometry parameters by minimizing distance between project marker on imager and measurement
- Acquire BEV images at different gantry angles



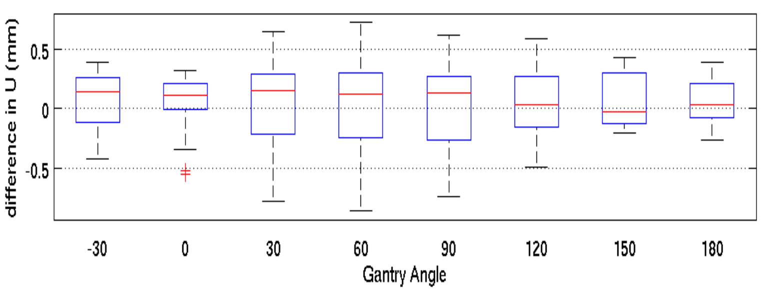
After EPID calibration

Calibration phantom





After EPID calibration

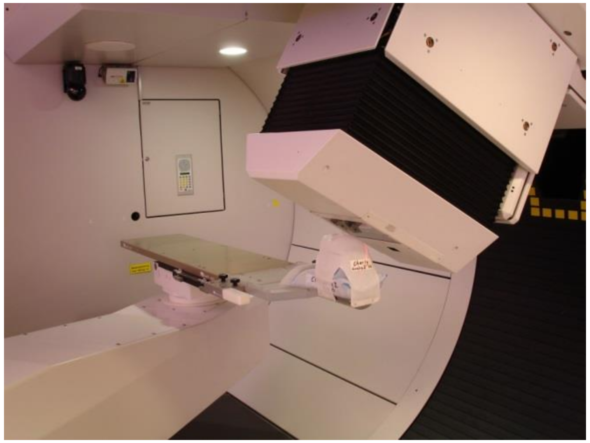


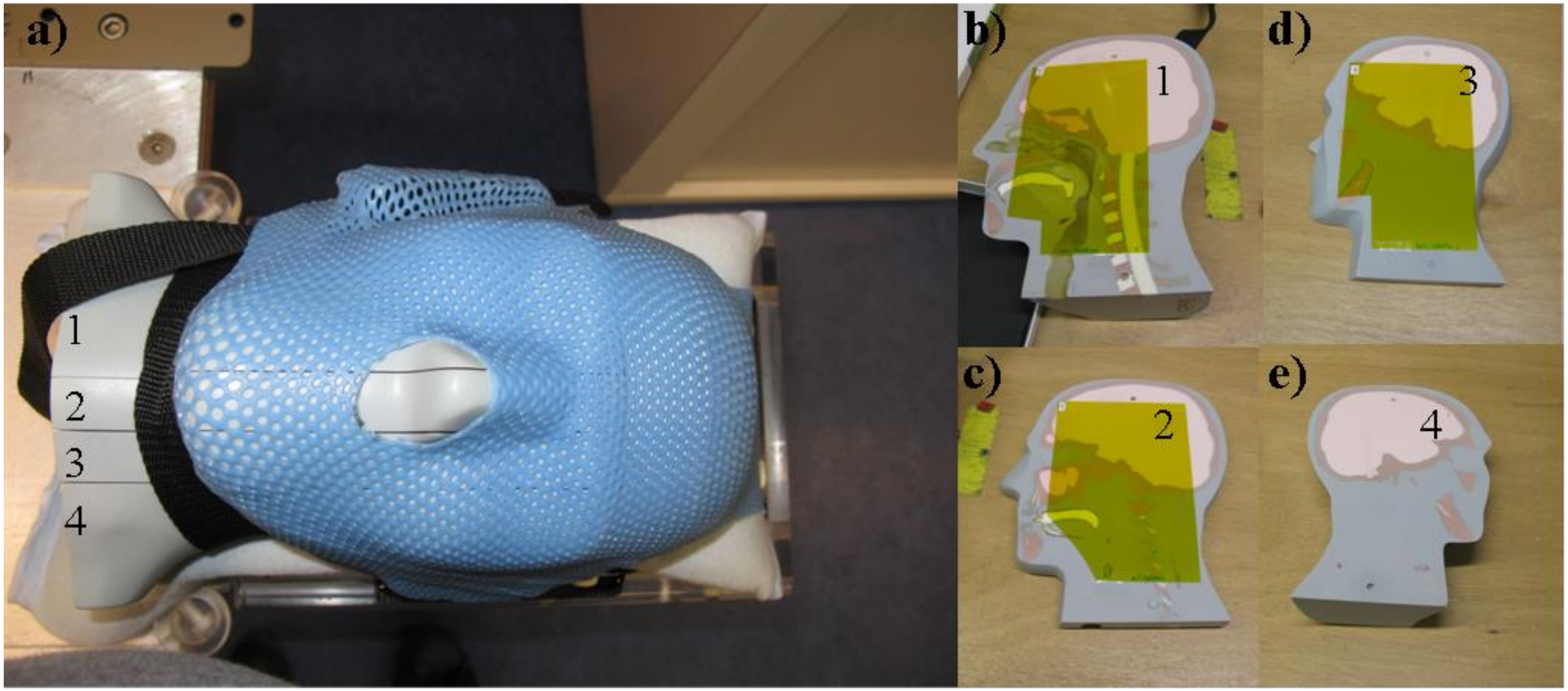
Devices and tools and devices for quality assurance (QA)

End-to-end treatment test

Full chain is tested:

- Data acquisition with planning CT – TPS – steerfile conversion – Dose application
- Anthropomorphic head phantom ('Charlie')
- Dose validation with film (Gaphchromic EBT2)
- Test repeated after major system upgrades
- Training of staff

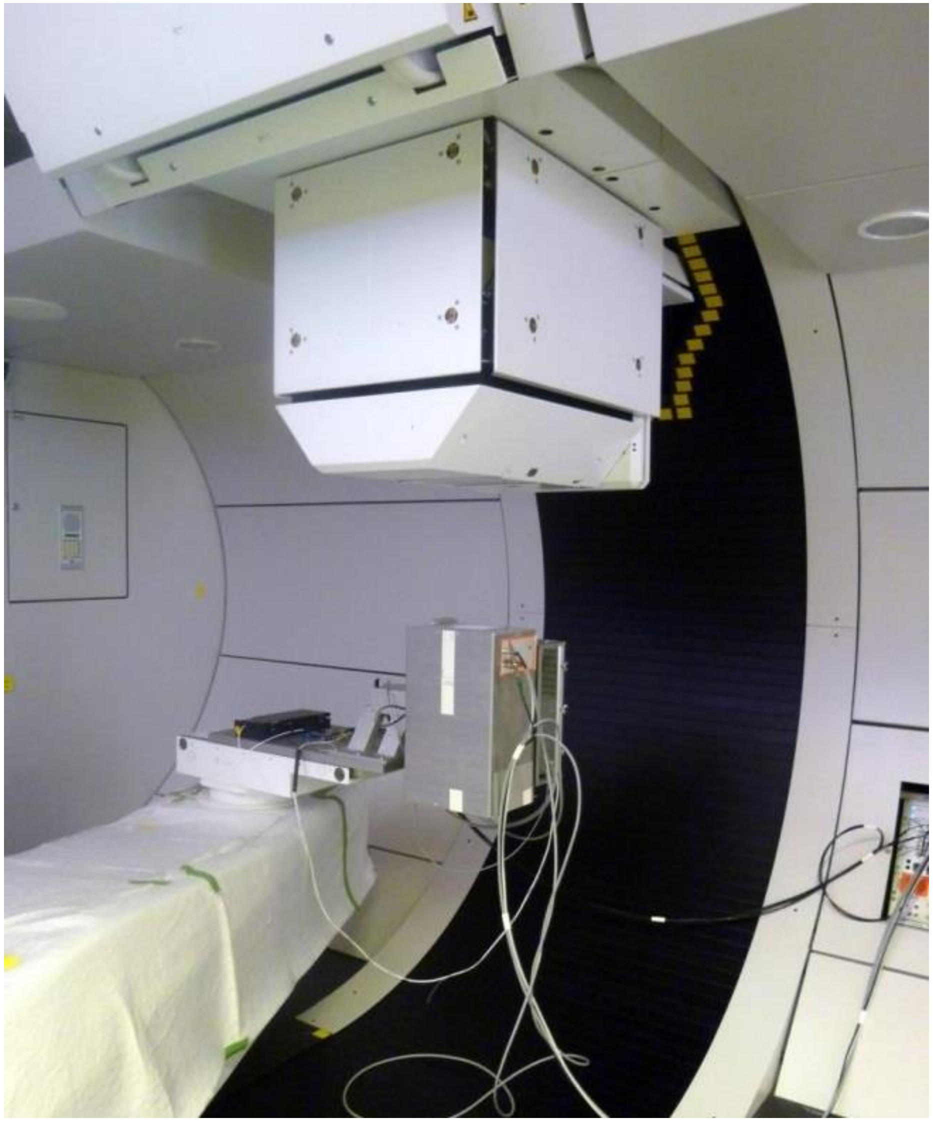




Daily machine QA: Daily check

During a daily check essential parameters of the machine are checked with a dedicated phantom

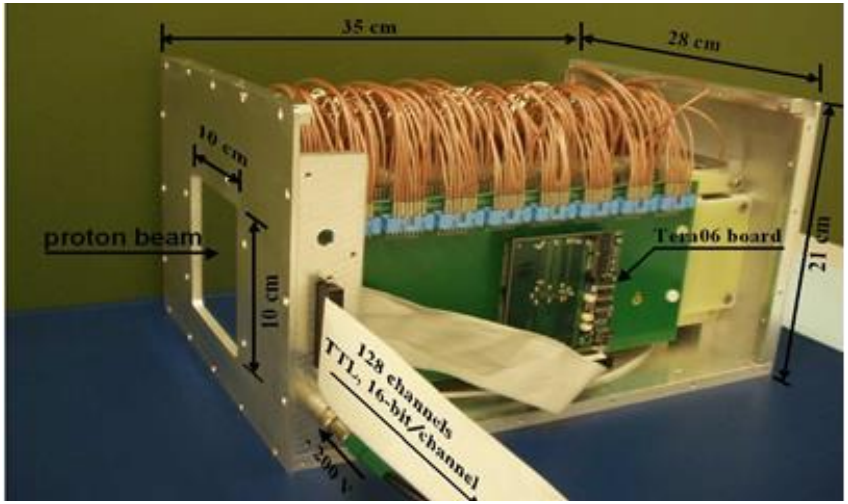
- Visual iso-center check
- **Monitors gain** and offset check
- p/T measurement
- Kicker magnet test
- Common measurement for
  - **Beam centering**
  - T,U and S-axis scan
  - Table rotation test
  - **Energy** range scan
- Change to Therapy mode
- Mastership and Supervision Check
- Essential **interlocks** test
- **Dose check** using two IC
  - bigger chamber for an SOBP
  - Smaller chamber for a distal fall-off

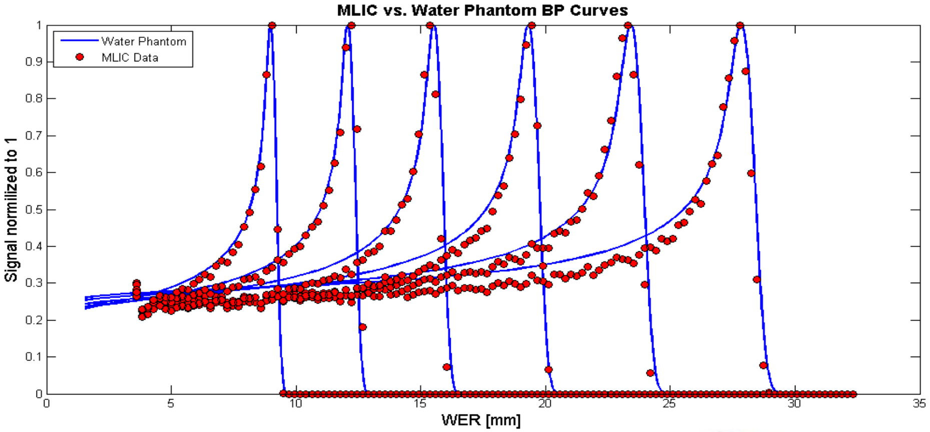


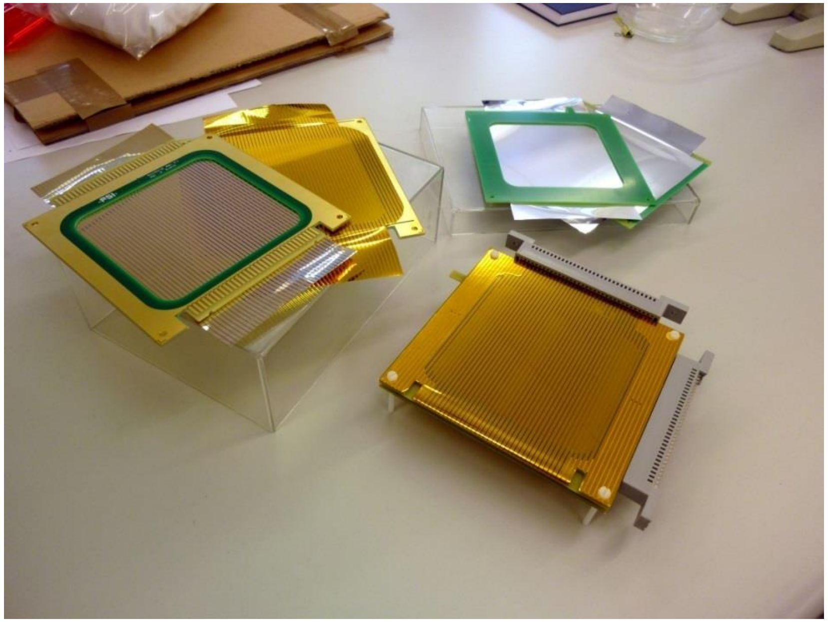
Daily check: Hardware

Daily check phantom includes following detectors:

- 2 ministrip chambers, 32 channels
- Multilayer Ionization Chamber, 128 channels
- 2 ionization chambers in a Plexiglas phantom
  - IBA FS65-G (Center of the filed)
  - Exradin T1 (50% of falloff)
- PT-100 temperature sensor







Commercial MLIC:
IBA - Zebra

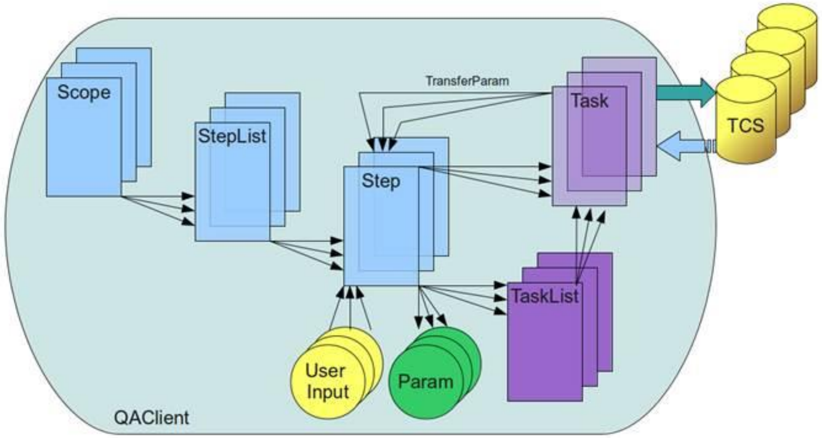
Daily check: Optimized for efficiency

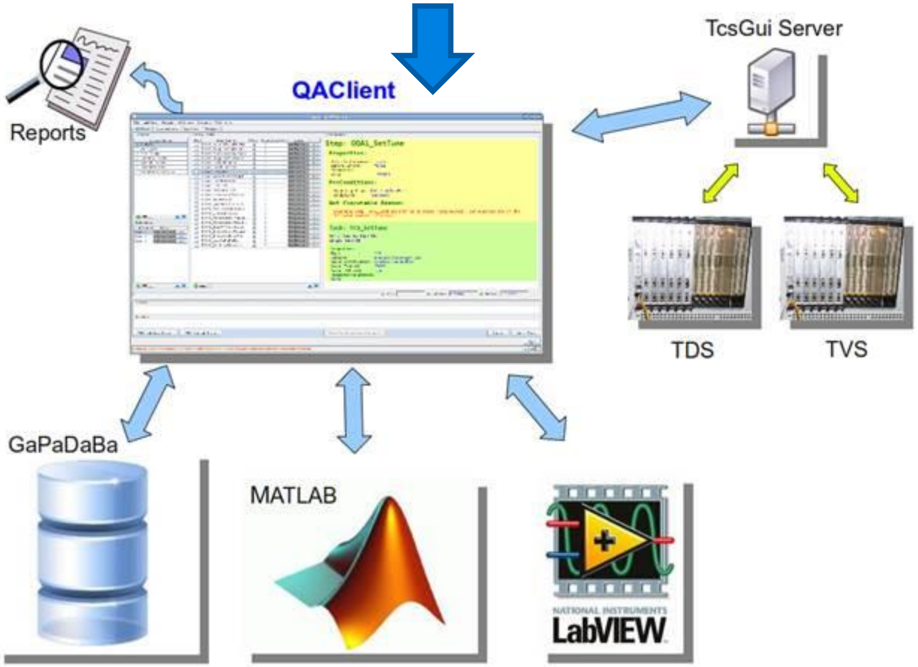
Pre-treatment QA, takes place in the mornings

- Successful completion is required for patient irradiation
- Tests should take about 30 minutes

Optimized for efficient operation

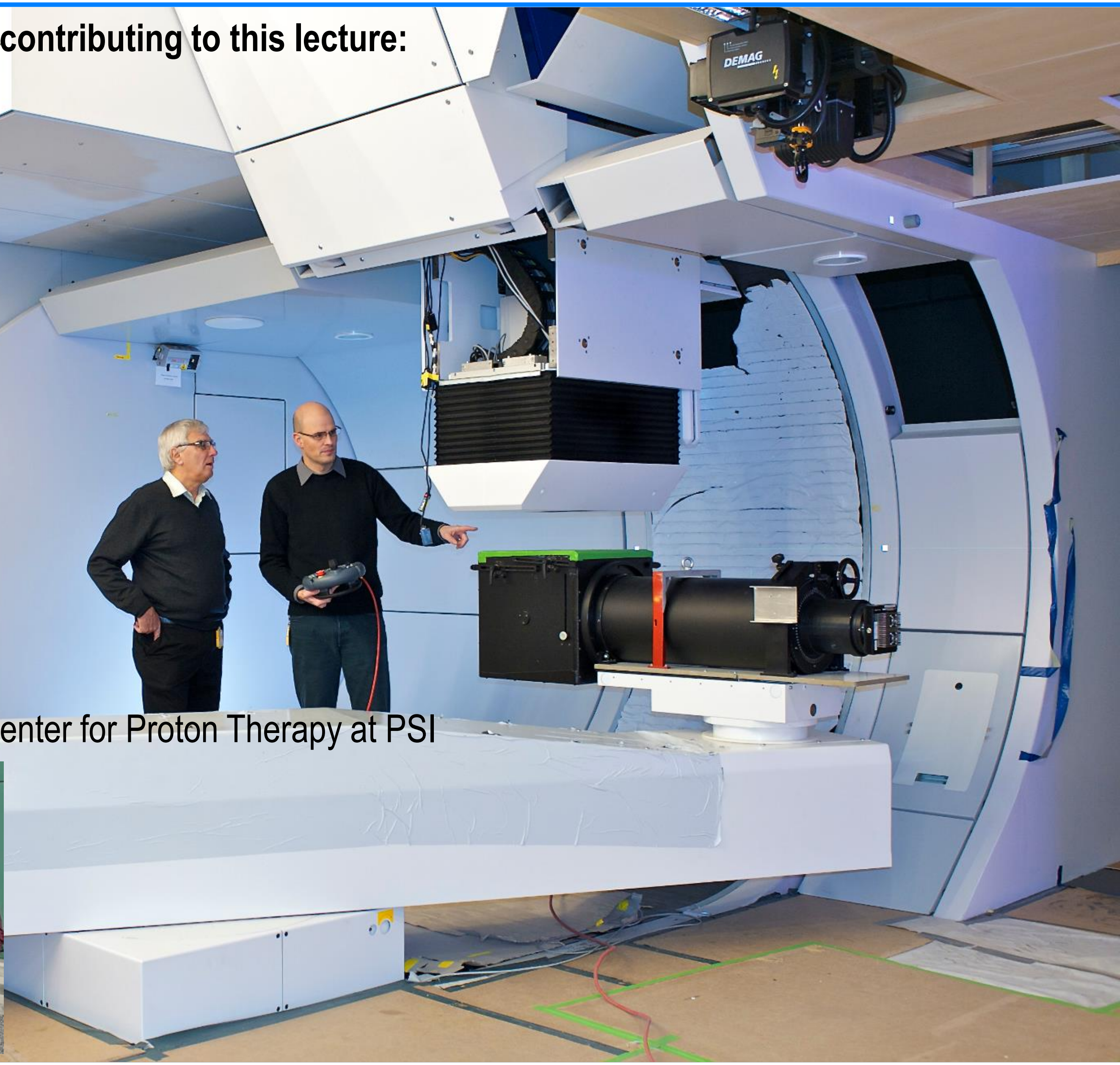
- Automated data exchange between systems
- Hardware interface, number of plugs, patch panel
- Script-like application of steering files, also used during commissioning (table calibration)





Conclusion

Acknowledgments



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