DOSE DELIVERY SYSTEM OF THE VARIAN PROBEAM SYSTEM WITH CONTINUOUS BEAM

EUCARD^2

WORKSHOP ON INNOVATIVE
DELIVERY SYSTEMS IN PARTICLE THERAPY

TORINO, 23 – 25 FEB 2017

VARIAN
PARTICLE
THERAPY

HOLGER GÖBEL
MANGER BEAM DELIVERY

VARIAN medical systems | proBEAM

TOPICS

Commissioning and performance of Varian ProBeam System

- Central Beam
- Beam Delivery System
- Beam Matching

Continuous Beam versus Pulsed Beam

- Pencil Beam Scanning
- Challenges for Pulsed Beam

Treatment Time

Dose Monitor Stability

Dynamic Peak™ Scanning

2nd Generation IMPT

Dynamic Peak™ Scanning

- Varian IMPT since 2009 clinical
- Focus on dedicated scanning nozzles
- 2 Gy / L / min
- Documented beam precision <0.5 mm radius sphere
- 30 x 40 cm field size
- Total of 17 treatment rooms in Munich, San Diego, Baltimore and Cincinnati

PROPERTIES BEAM DELIVERY I

CENTRAL AXIS BEAM – COMMISSIONING RESULTS

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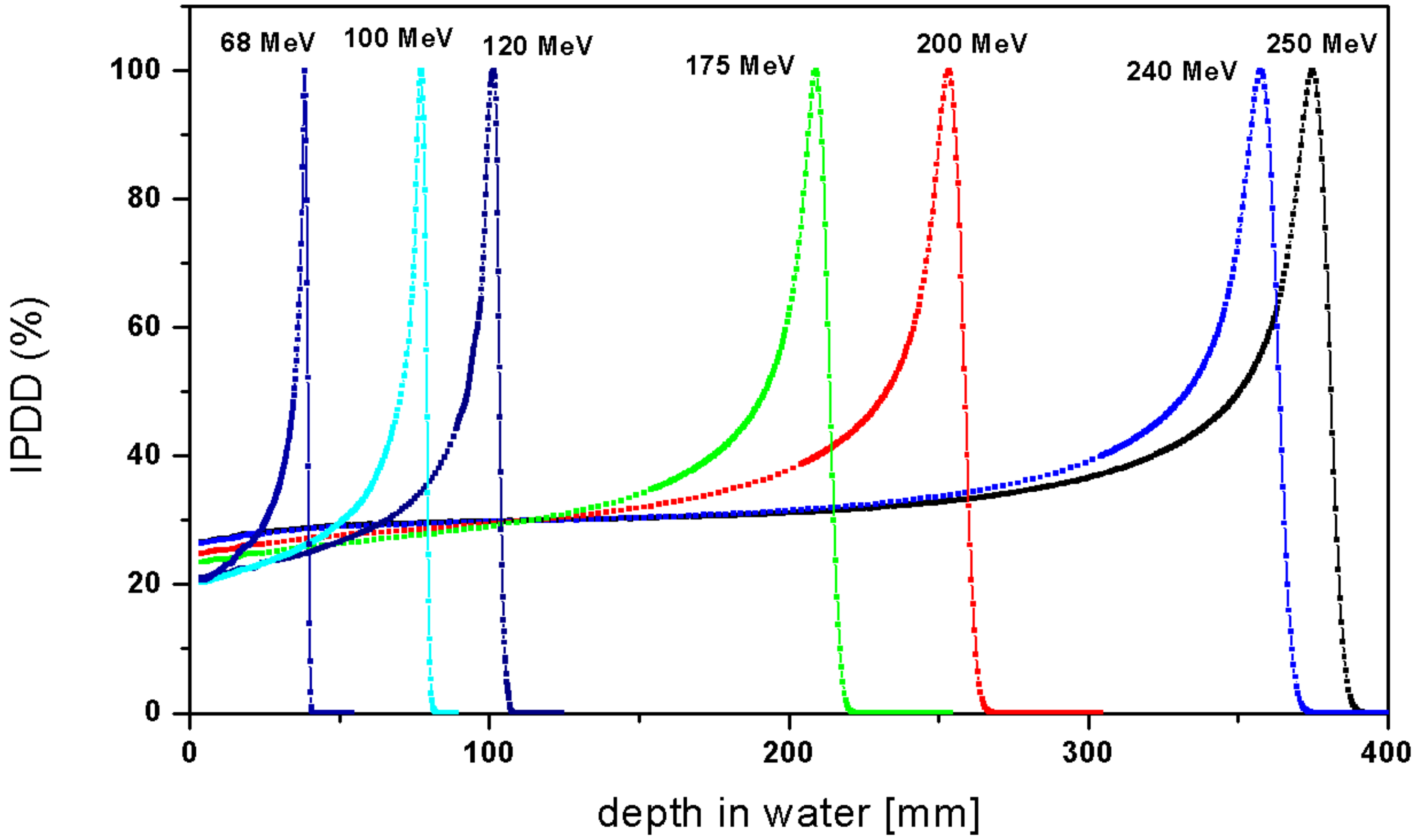
Beamline – Bragg Peaks at isocenter



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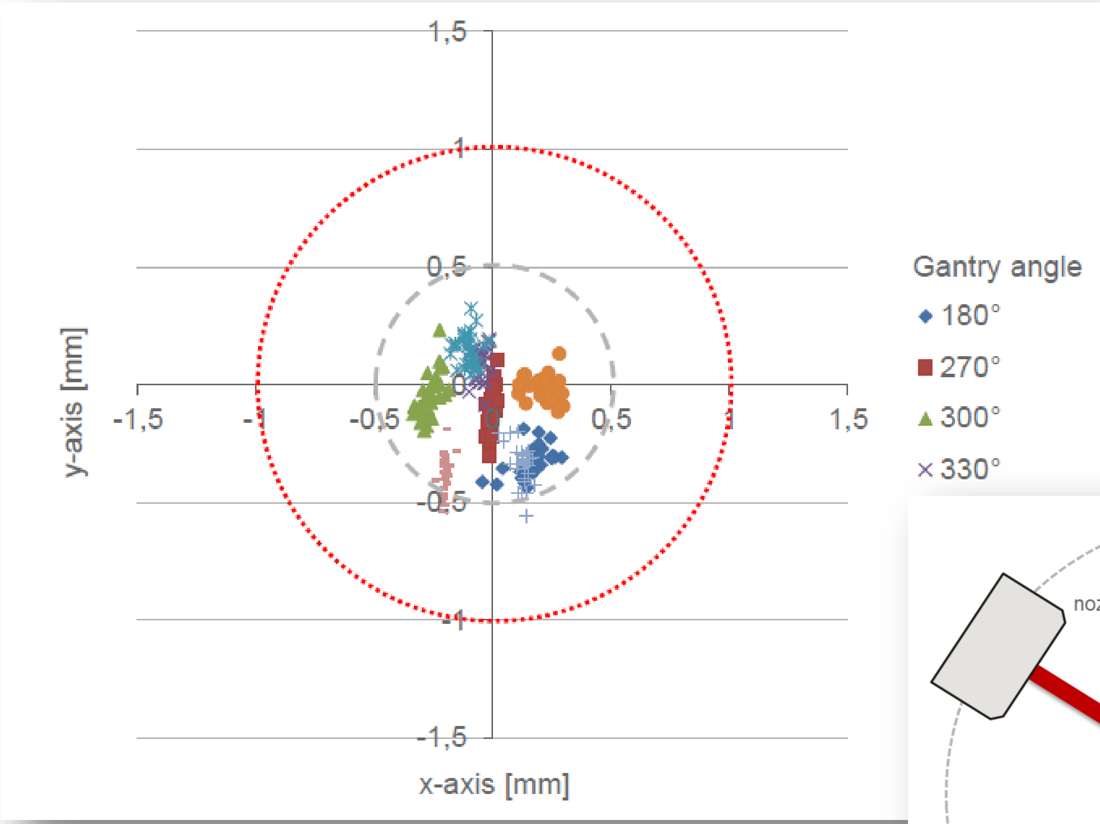
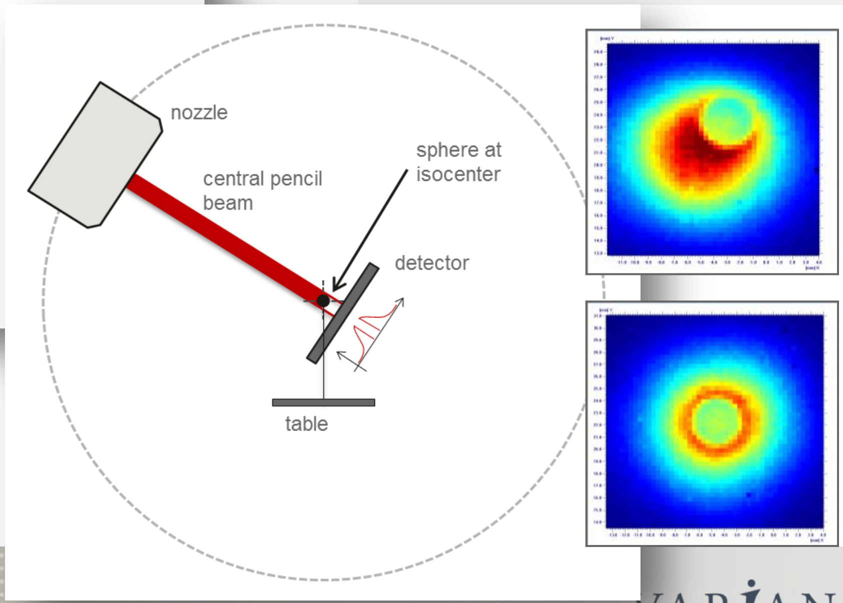
Beamline

Fine Steering to Isocenter

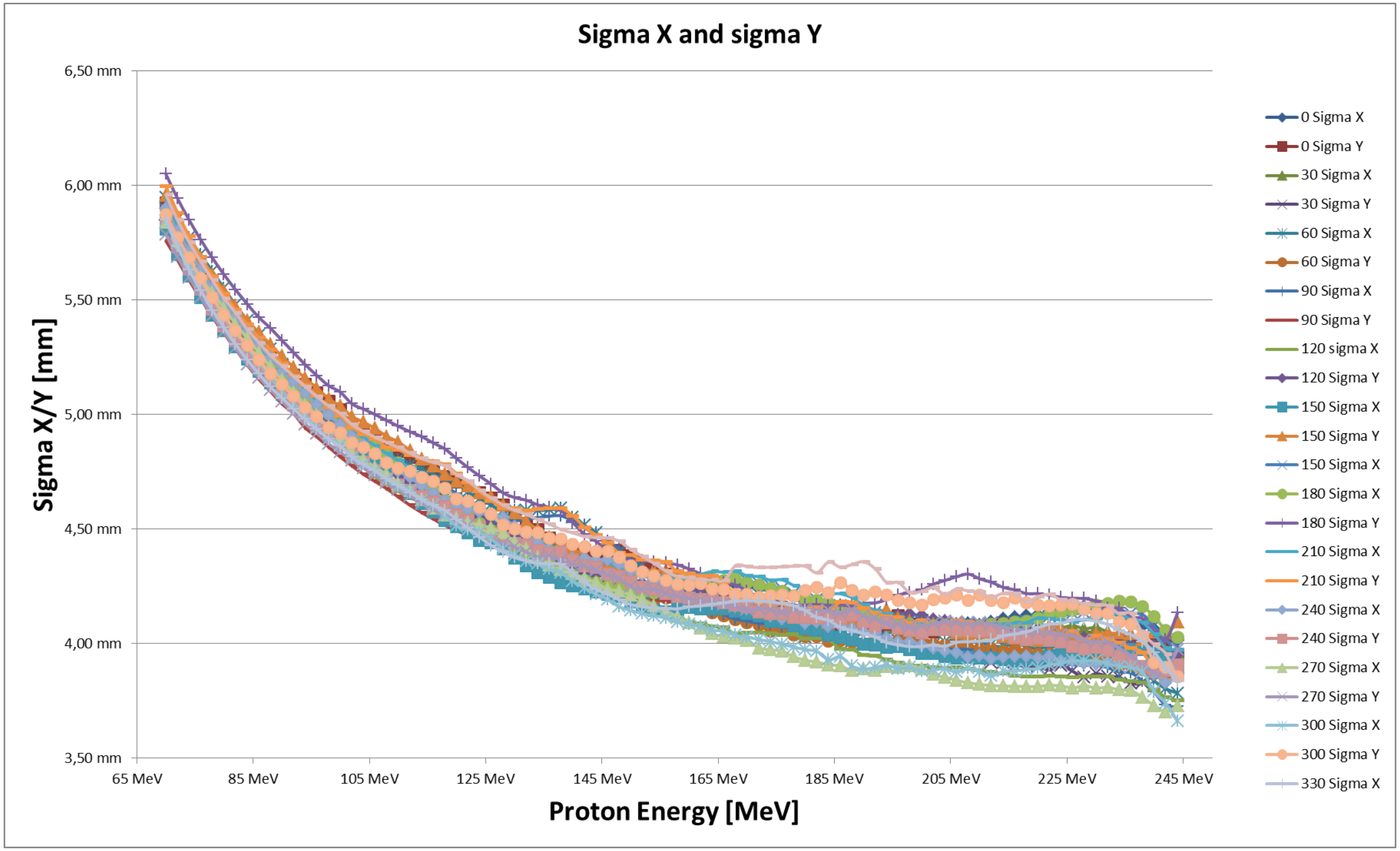


DEDICATED MEASUREMENT TOOLS DEVELOPED BY VARIAN

AUTOMATED AND INTEGRATED INTO COMMISSIONING SOFTWARE TOOL



Beamline – Beam shape at isocenter



PROPERTIES BEAM DELIVERY II

SCANNING BEAM – COMMISSIONING RESULTS

Pro Beam Delivery Nozzle

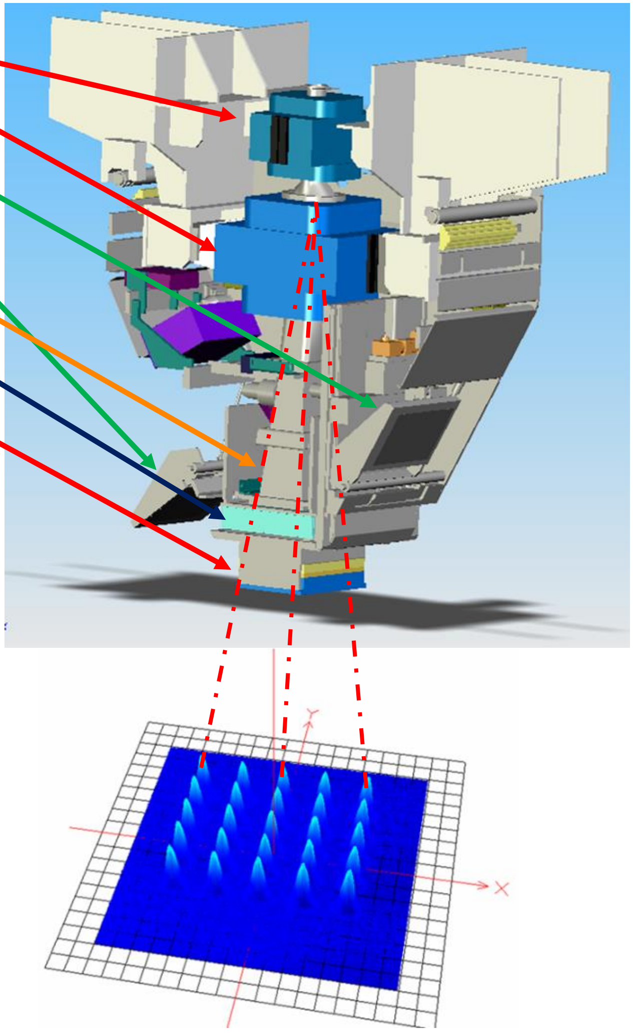
Scanning Magnets

aSi Flat Panels
(kV imaging)

Vacuum Chamber

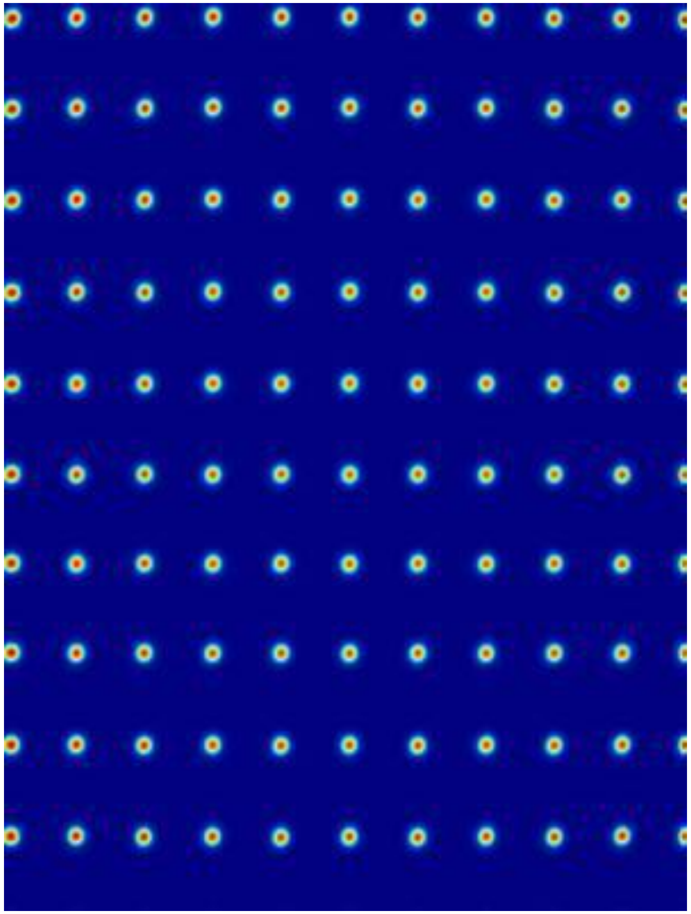
Dose and Position Monitors

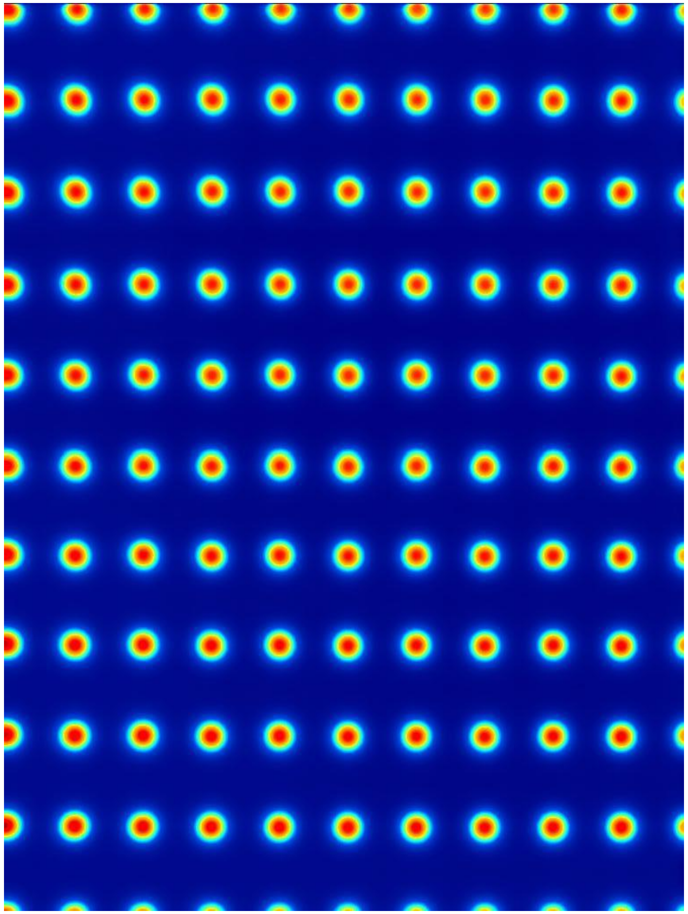
Nozzle extension for Range-Shifter(s)



Spot measurements with imaging system

244 MeV

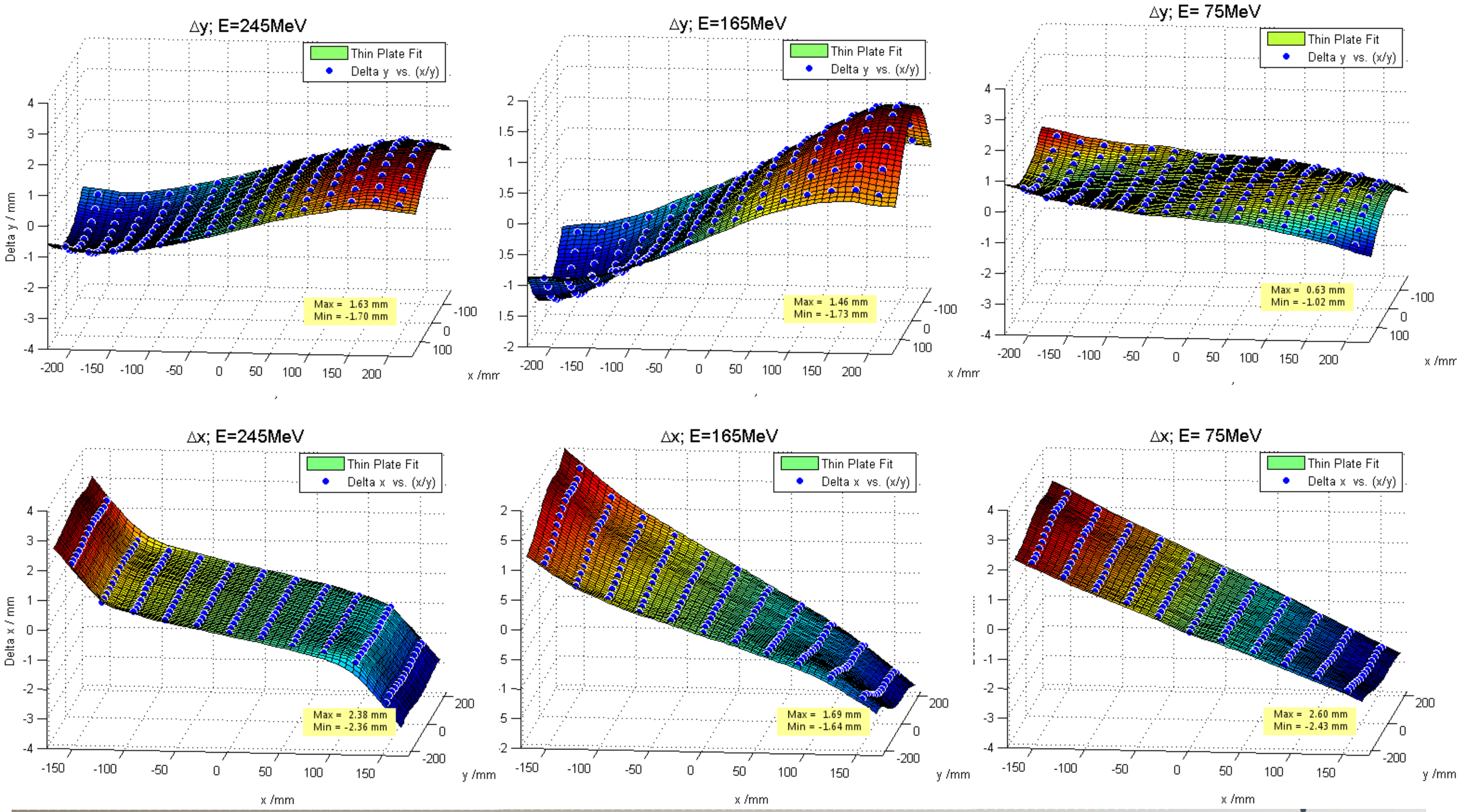




69 MeV

Active detection area 30cm x 40cm

Scanning Magnets – uncalibrated SPTC TR3



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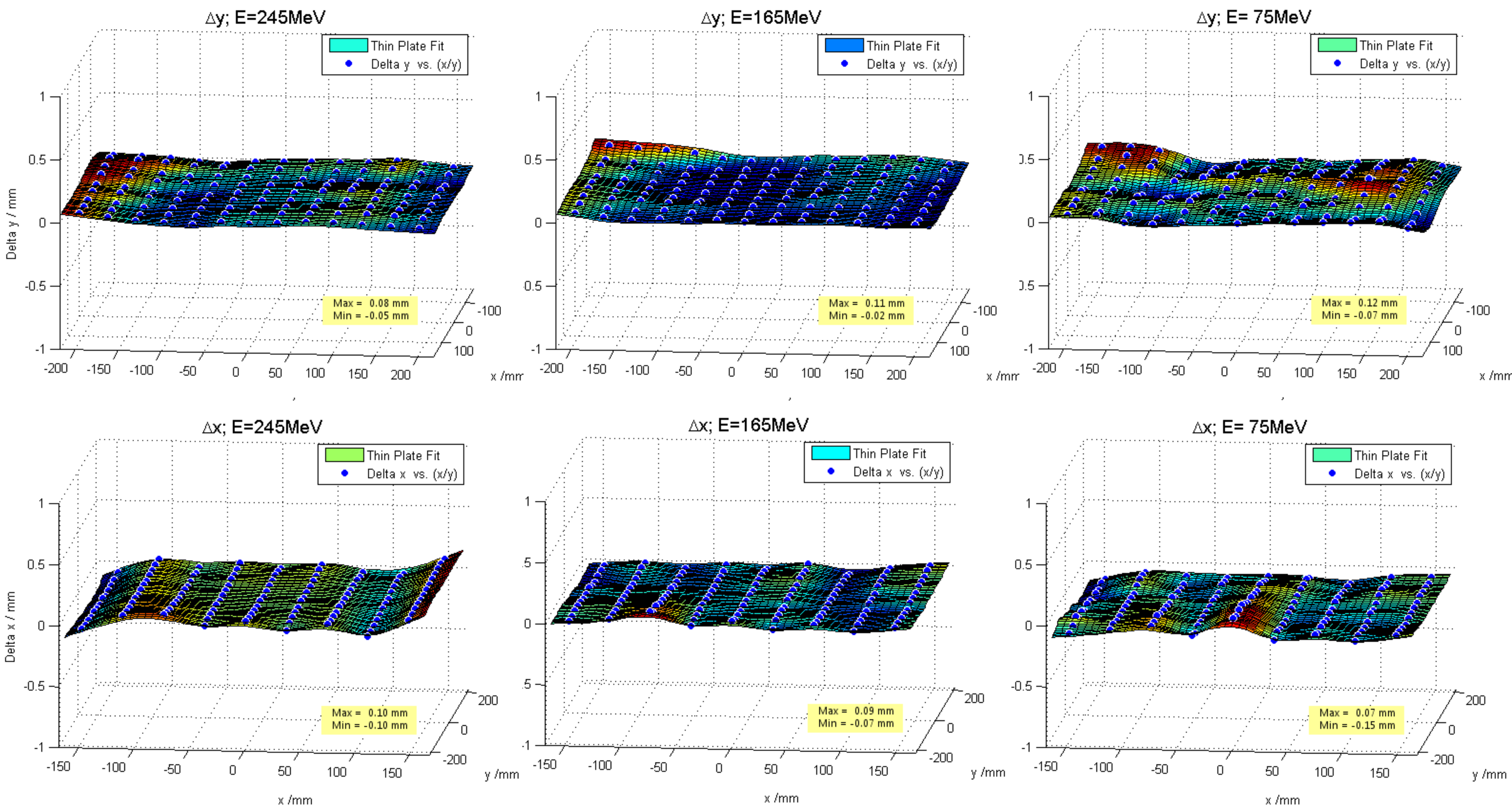
Scanning Magnets – calibrated SPTC TR3



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PROPERTIES BEAM DELIVERY III

BEAM MATCHING BETWEEN ROOMS

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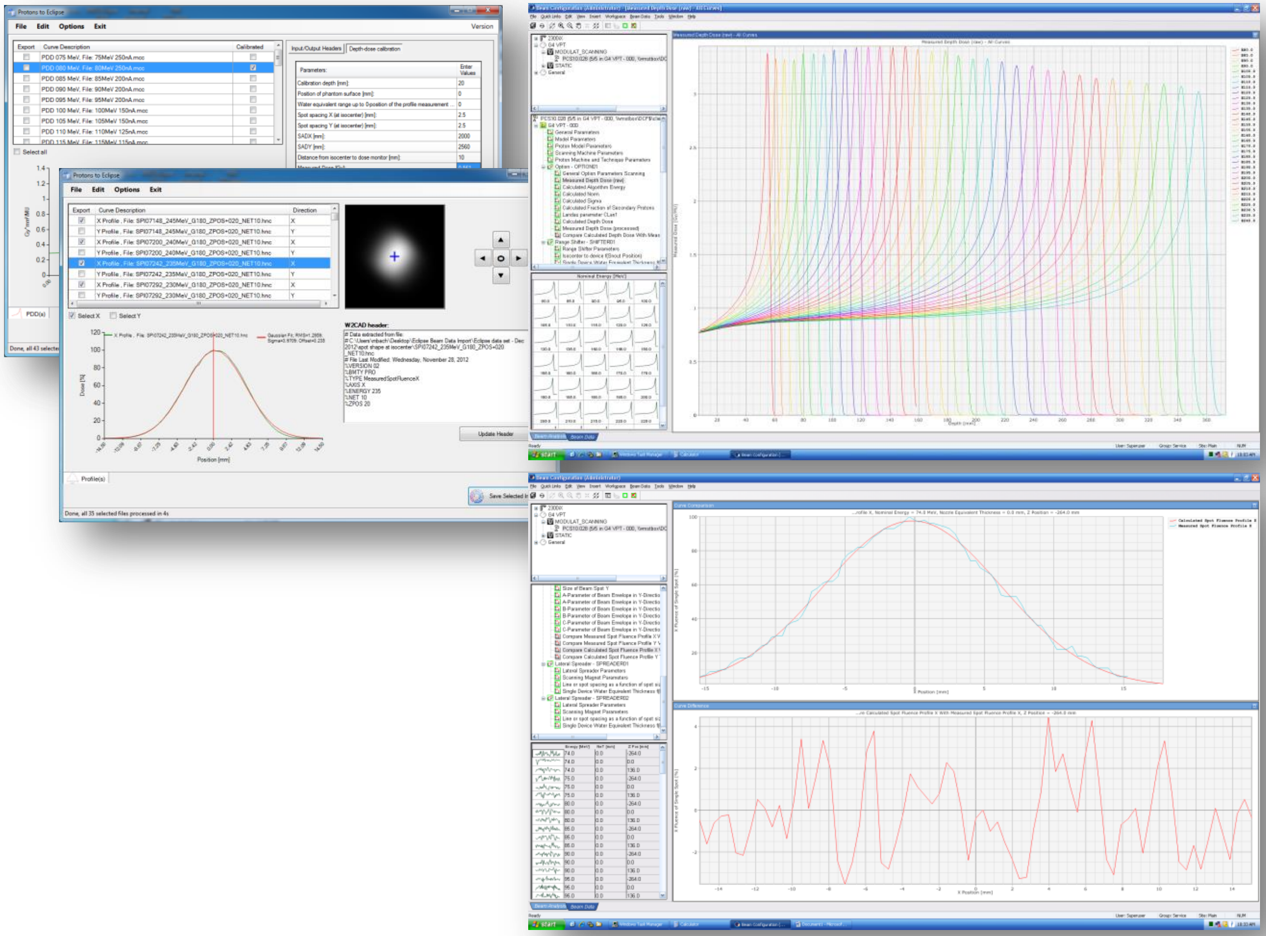
Pencil Beam Scanning

Commissioning of ECLIPSE Treatment Planning System



PENCIL BEAM SCANNING ALGORITHM

- RELATIVE INTEGRATED DEPTH DOSE
- CALIBRATION OF DEPTH DOSE CURVES
- 2D SPOT SHAPES AT DIFFERENT DISTANCES

ALL MEASUREMENTS CAN BE ACQUIRED WITHIN LESS THAN A DAY

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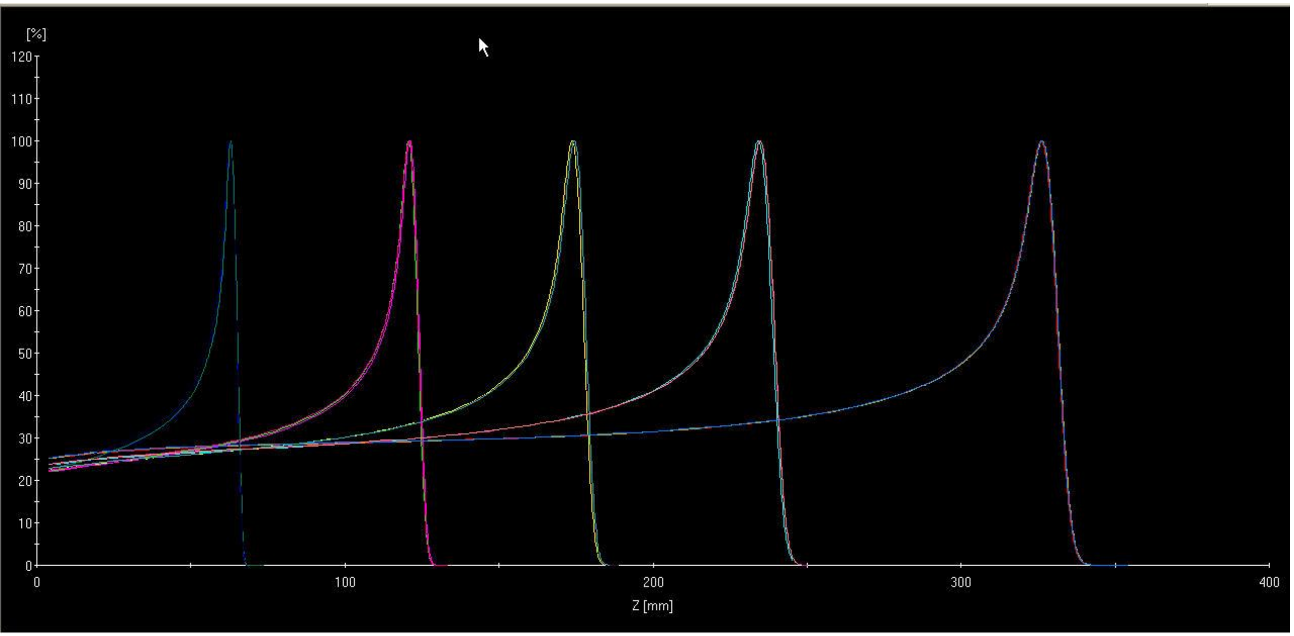
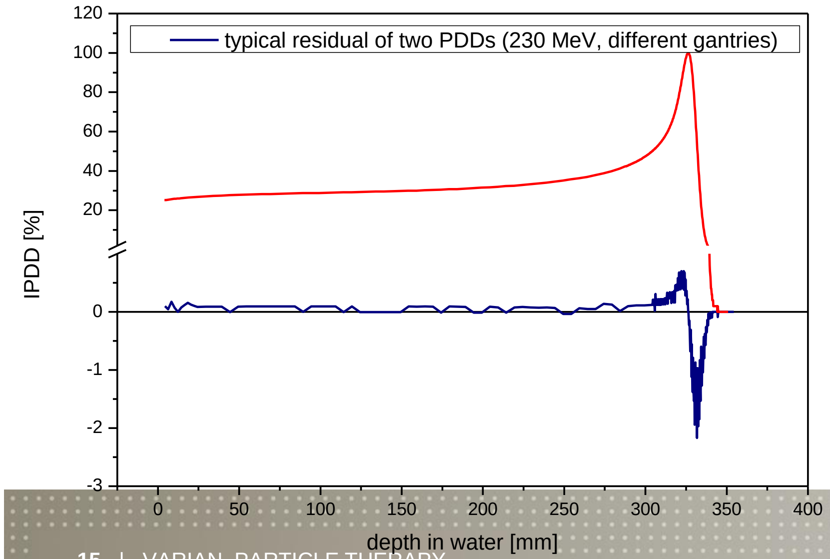
Matching of beam data: PDDs

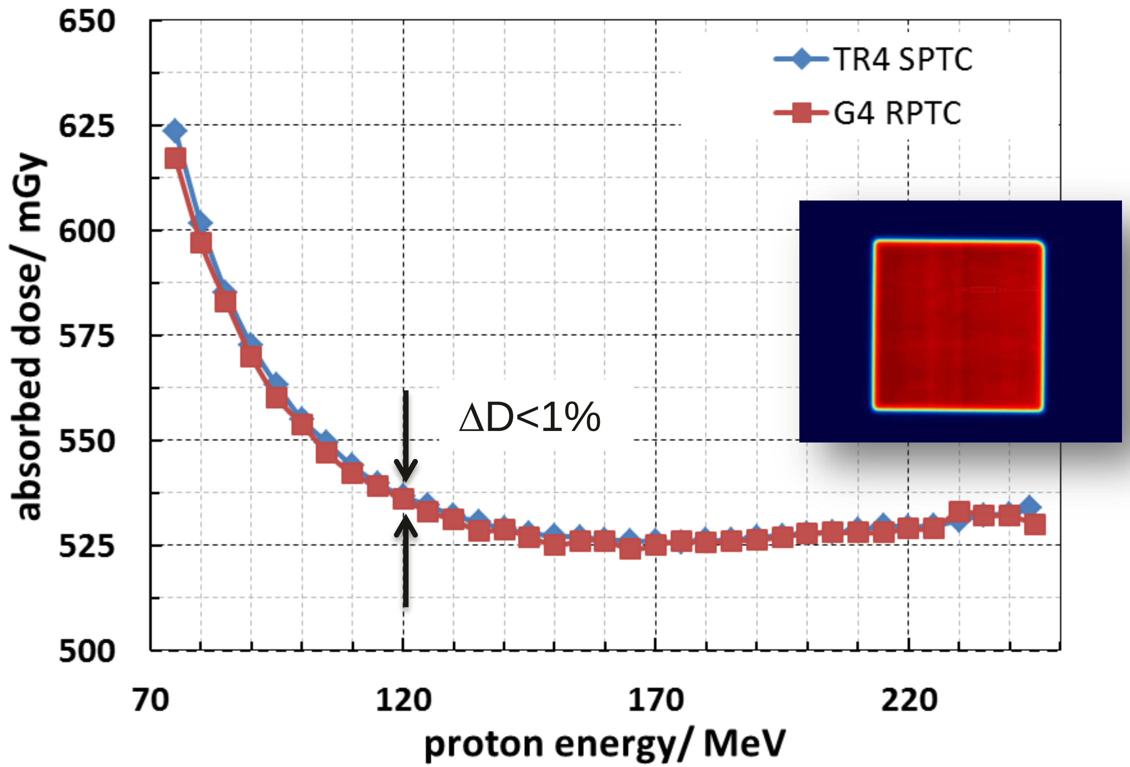


PDDs measured at different gantries



Residual of 2 Bragg Peaks of same beam energy at two different gantries

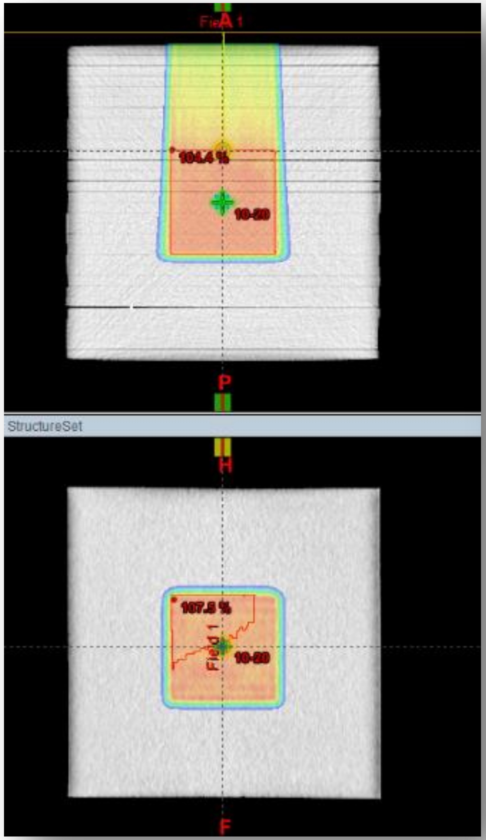
Pencil Beam Scanning
Dose-to-MU Output Calibration

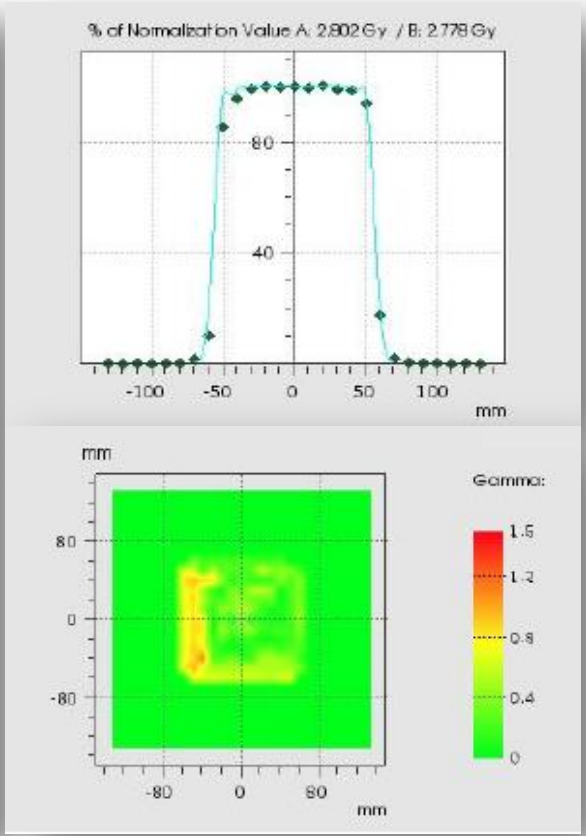


initial system setup in San Diego vs. RPTC Munich

- STABLE PERFORMANCE OF SYSTEM
- NO DAILY OUTPUT ADJUSTMENTS NECESSARY
- NO GANTRY ANGLE DEPENDENCE
- LONG-TIME STABILITY

planned vs. measured dose





(2Gy central – TR3/16Aug2013)

INTITAL SETUP OF TREATMENT PLANNING SYSTEM WITHOUT REFINEMENTS

CUBIC VOLUMES IRRADIATED AND DISTIBUTION MEASURED WITH PTW 2DARRAY

→ PASSRATE 99% FOR GAMMA-TEST (3%/3MM)

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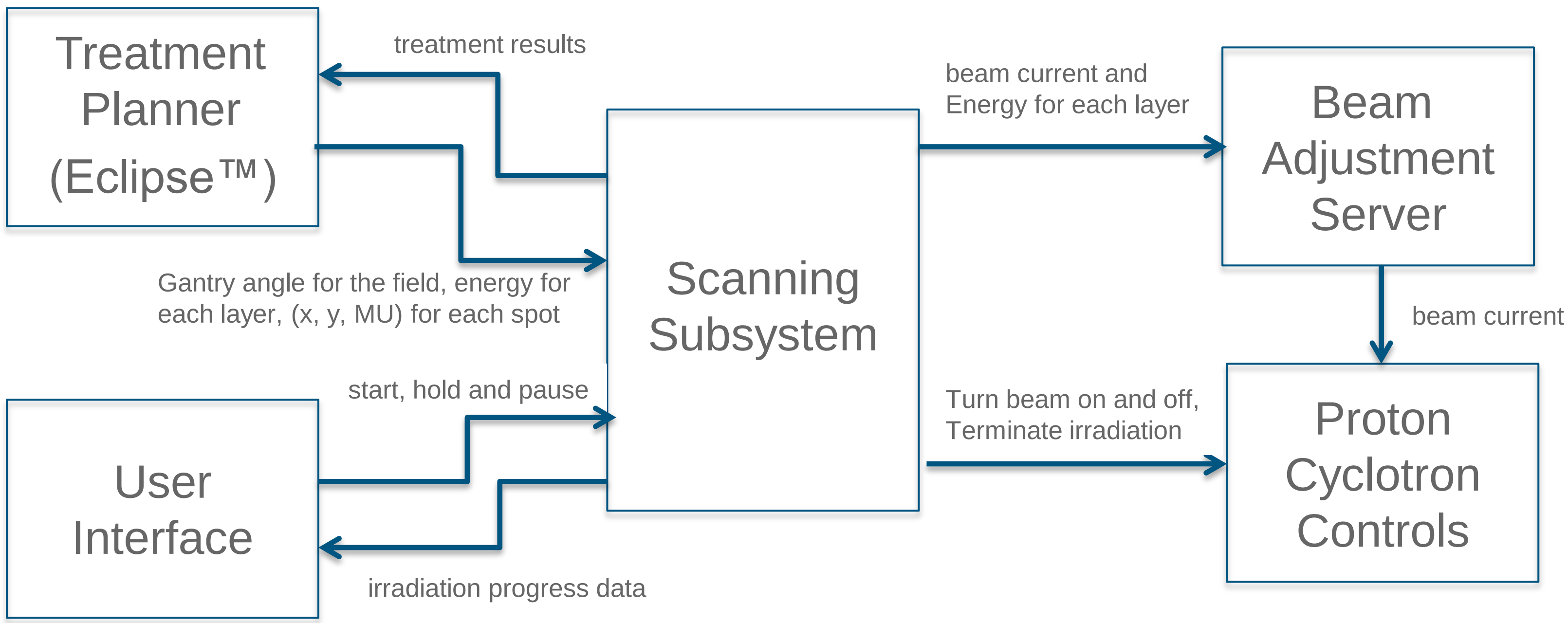
CONTINUOUS BEAM VERSUS PULSED BEAM

CHALLENGES

Pencil Beam Scanning
Scanning Control System

One subsystem out of many for Proton Therapy System



Pencil Beam Scanning

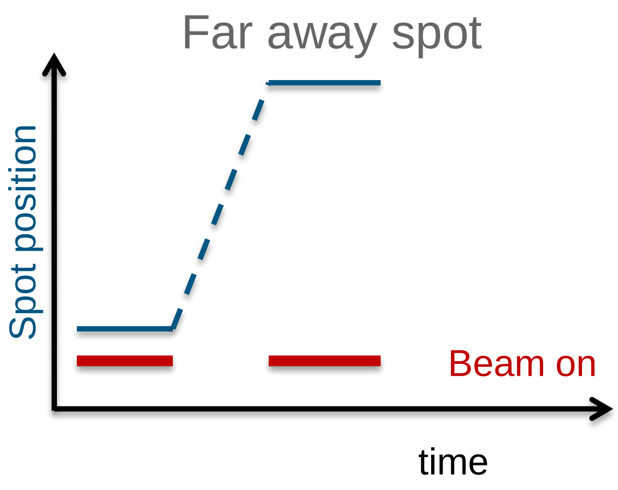
Sequence during irradiation

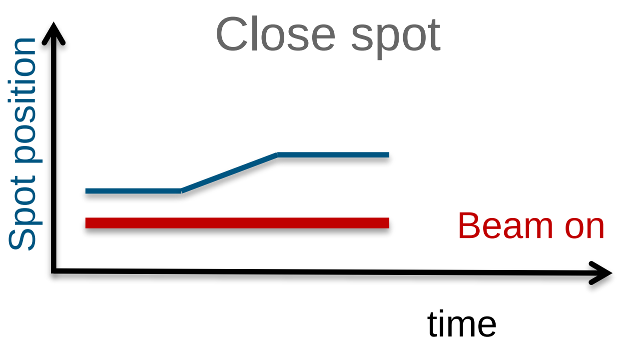
1. Adjust beam energy
2. Set scanning magnet currents for first spot
3. Regulate the required accelerator beam current
4. Start irradiation
5. Measure monitor units until switch limit reached
6. Move beam to next spot (w/ or wo/ beam turned off)
7. Goto 5) until last spot in layer
8. Switch off beam and goto 1) until last layer

Add-ons

- Checking various devices
- Pause, resume, or terminate irradiation at any time
- Acquire irradiation results
- …

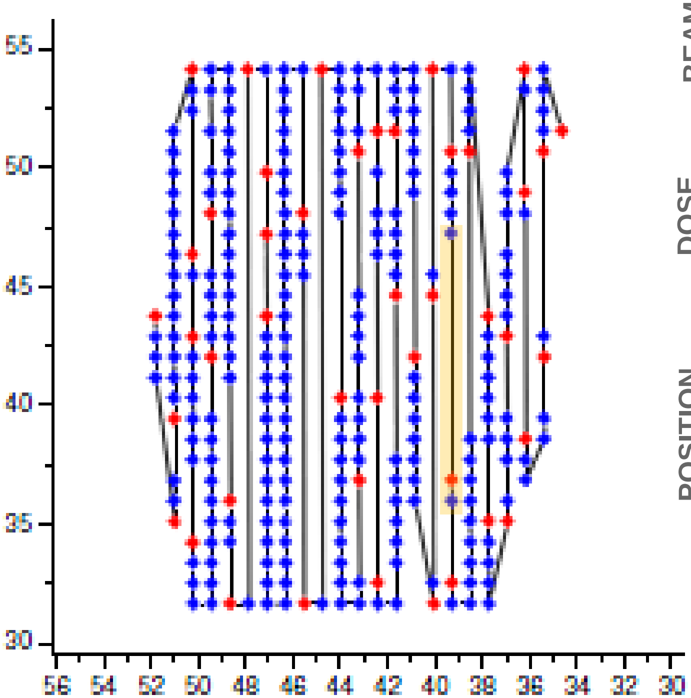
Pencil Beam Scanning
Scanning Method

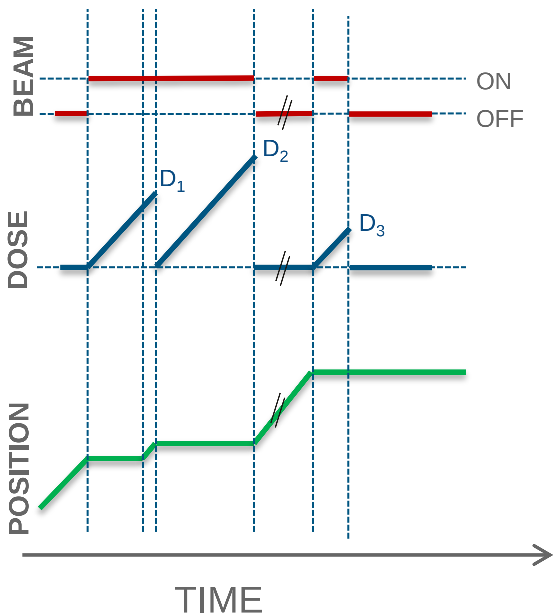




Pencil Beam Scanning

Scanning Method





Irradiation pattern /order of spots is given by treatment plan

„DOSE DRIVEN“ SPOT SCANNING

CONTINUOUS BEAM FROM CYCLOTRON

FAST BEAM ON/OFF BETWEEN CONSECUTIVE SPOTS IN E.G. MEANDER PATTERN

•OPTIMIZED DELIVERY FOR SHORT TREATMENT TIMES

•DEFLECTION IN X- AND Y-DIRECTION: . 0,3 – 0,5 ms (spot to spot)

• VARIATION OF ENERGY LAYER: < 0.9s.

• TYPICAL SPOT DURATION: 3 – 50 ms

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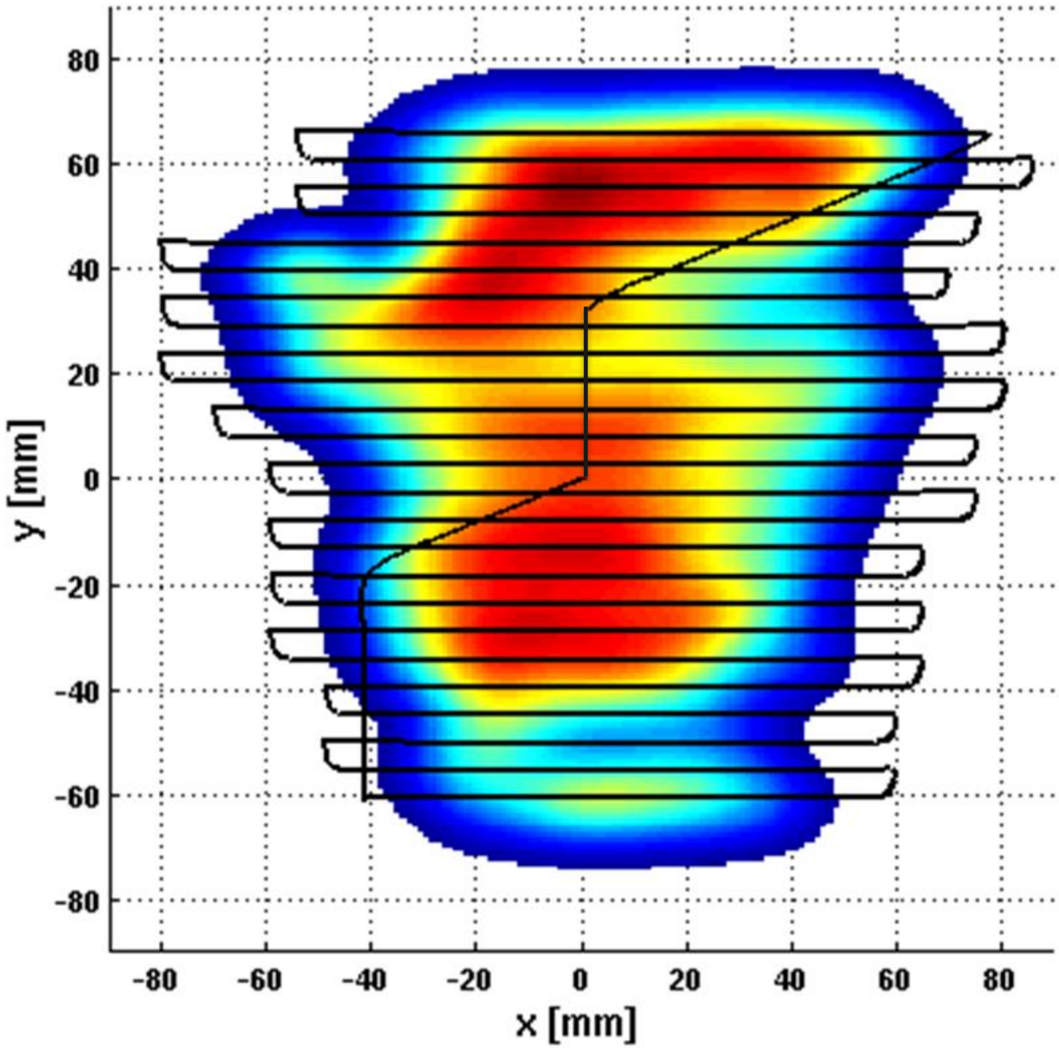
Pencil Beam Scanning



Pencil Beam Scanning
Basic Characteristics for Scanning Technique

FEATURE	SCANNING
energy range at isocenter	Typically 70-245 MeV
average dose rate	2 Gy / l / min
maximum field size at isocenter	30 x 40 cm
beam accuracy at isocenter (radius)	≤ 1 mm
nominal spot size (one sigma value)	5.4 – 4 mm (+/- 15%)
layer switching time	< 0.9 s
IMPT capable	yes

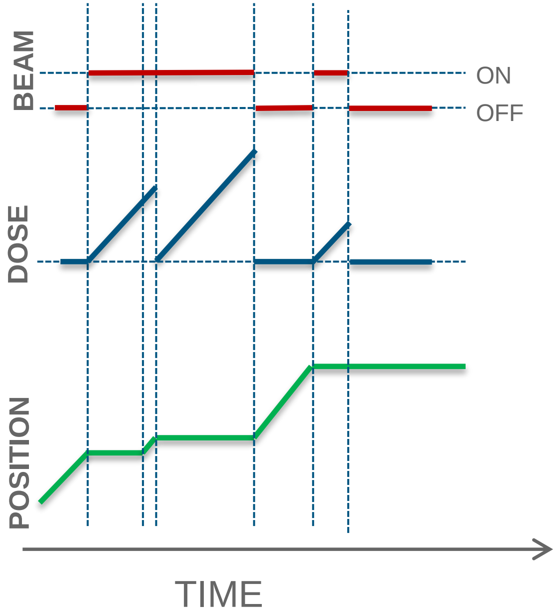
Continuous beam versus pulsed beam
Challenges

- Precision and a minimum spot weight of 1cGy at Bragg Peak and total spot area ($1 cm^2$) translates into

  $8 \cdot 10^6$ protons at 70 MeV and
  $2.5 \cdot 10^7$ protons at 250 MeV

- Spots with high spot weight up to 50cGy:
  $4 \cdot 10^8$ protons at 70 MeV and
  $1 \cdot 10^9$ protons at 250 MeV

(4mm spot spacing, focused beam)



- Time to switch to the next spot / switch off the beam @ high dose rates: ~200µs
- With a continuous beam, one can predict, when to switch

Continuous beam versus pulsed beam

Challenges

- Several pulses will be needed to get to the needed precision:

Case 1: precision 2% per spot,
uncertainty of the number of protons per pulse 20%

=> the planned MU per spot can be irradiated with 3 pulses:
83% + 14% + 3%

Case 2: precision 2%,
uncertainty of the number of protons per pulse 50%

=> the planned MU per spot can be irradiated with 5 pulses
67% + 22% + 7% + 3% + 1%

If the beam is off, this amount of contribution of a pulse to the whole spot is too high, in order to stay within the 0,25 Gy to terminate the irradiation, and second for steering of the beam position, one needs to reduce the contribution of each pulse even more.

Continuous beam versus pulsed beam
Challenges

- A high beam current in the pulse is needed due to low duty factor in order to keep treatment time low

  → Very good control of number of protons extracted per pulse by the accelerator

  → High variability of the number of protons extracted per pulse in order to irradiate spots with high spot weight fast enough and <u>with the needed precision</u>

  → Control loop and interfaces for the next pulse must be very fast in order to take into account the already delivered monitor units (collecting time of ionization chamber is ~100-200µs) and the measured beam position

Continuous beam versus pulsed beam

Challenges

- Saturation effects at high beam currents have to be corrected for the used primary and secondary dose monitor system

- Saturation of commercial available dosimetry equipment may be possible

70MeV: $8 \cdot 10^6$ protons / 10µs = 128nA in the peak (0.13nA averaged)
250MeV: $2.5 \cdot 10^7$ protons / 10µs = 400nA in the peak (0.4nA averaged)

70MeV: $4 \cdot 10^8$ protons / 10µs = 6.4µA in the peak (6.4nA averaged)
250MeV: $1 \cdot 10^9$ protons / 10µs = 20µA in the peak (20nA averaged)

(average curent for 1kHz beam pulse repetiton)

- Beam position and beam width measurement have to be synchronous with the pulse beam time structure

Continuous beam versus pulsed beam

Impact on treatment time

- Increase the minimum spot weight from 1 cGy to several cGy in order to delivery faster with a focused beam, AND to still keep the clinical requirements

- Enlarge the spots by using a range-shifter as a scatterer in order to delivery faster by lowering the precision specifications and by increasing the minimum spot weight, BUT with a much less dose conformity than with focused beam.

PROPERTIES BEAM DELIVERY IV

TREATMENT TIME

DOSE MONITOR STABILITY

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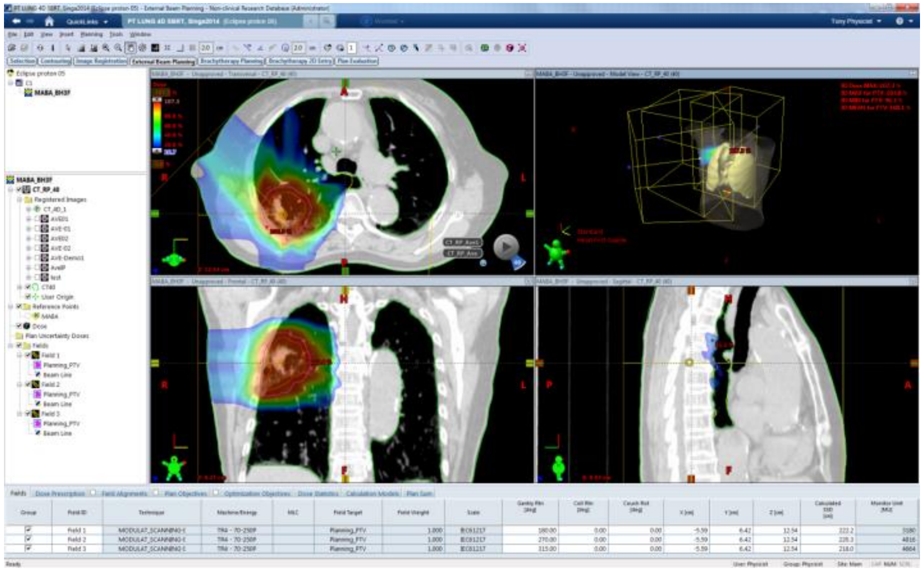
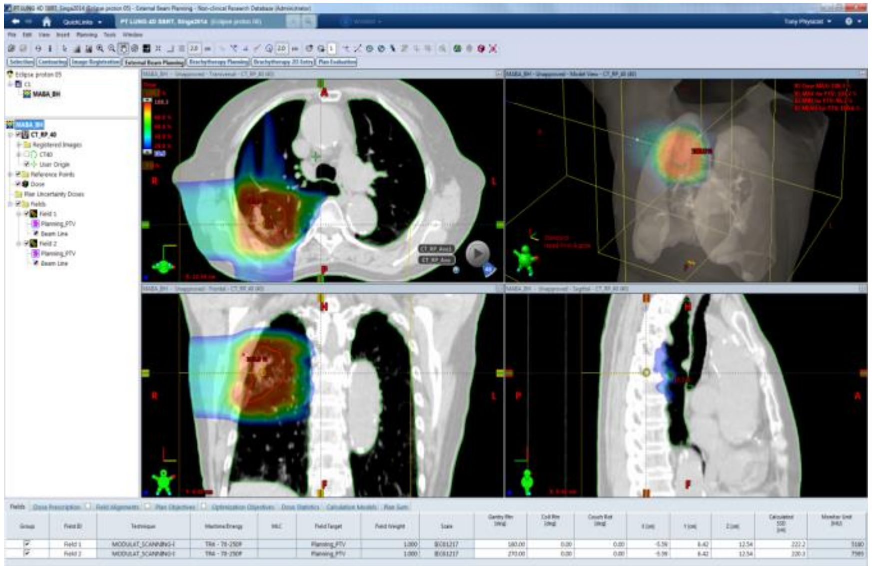
Fast Treatment times

Lung case

Summary of treatment times (calculated)		No layer switch time	200 ms	500 ms	900 ms
2F Plan	Field 1/2	6.6 s	7.8 s	9.6 s	12 s
	Field 2/2	7.6 s	9 s	11.1 s	13.9 s
3F Plan	Field 1/3	4 s	4.8 s	6 s	7.6 s
	Field 2/3	4.1 s	4.9 s	6.1 s	7.7 s
	Field 3/3	3.5 s	4.7 s	6.5 s	8.9 s





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Case 1 – Liver

Motion Managed Using Gating

- Moving shallow liver tumor of close to 1 Liter in size
- 2 field treatment
- 15 fractions of **4.5** Gy
- The Qfix SDX spirometry system was used

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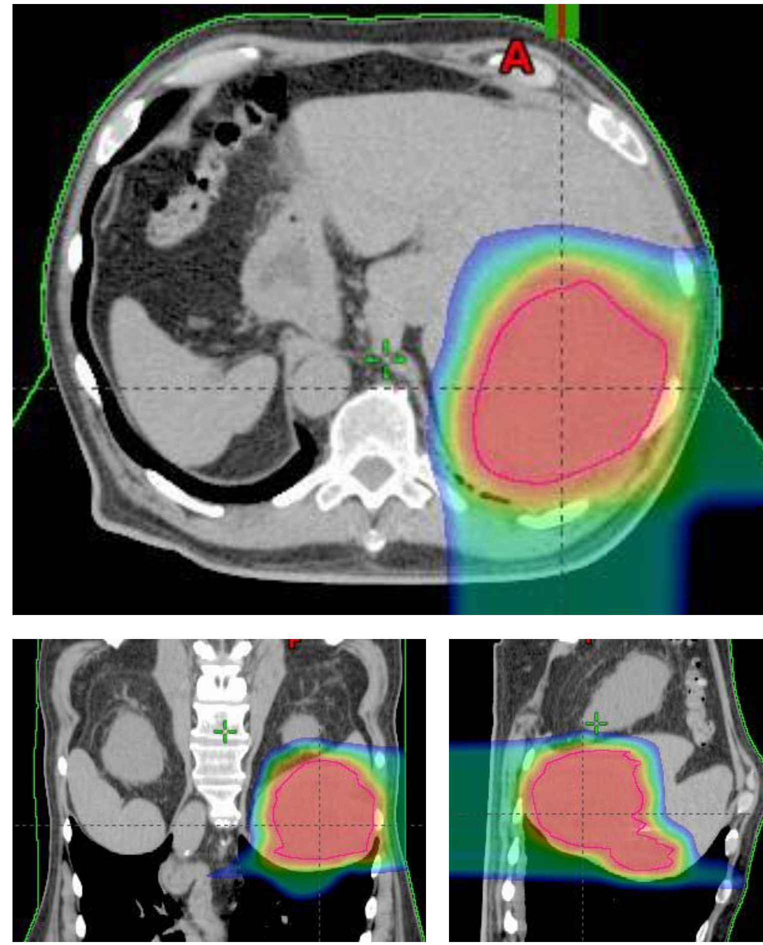
Case 1 – Liver

Motion Managed Using Gating

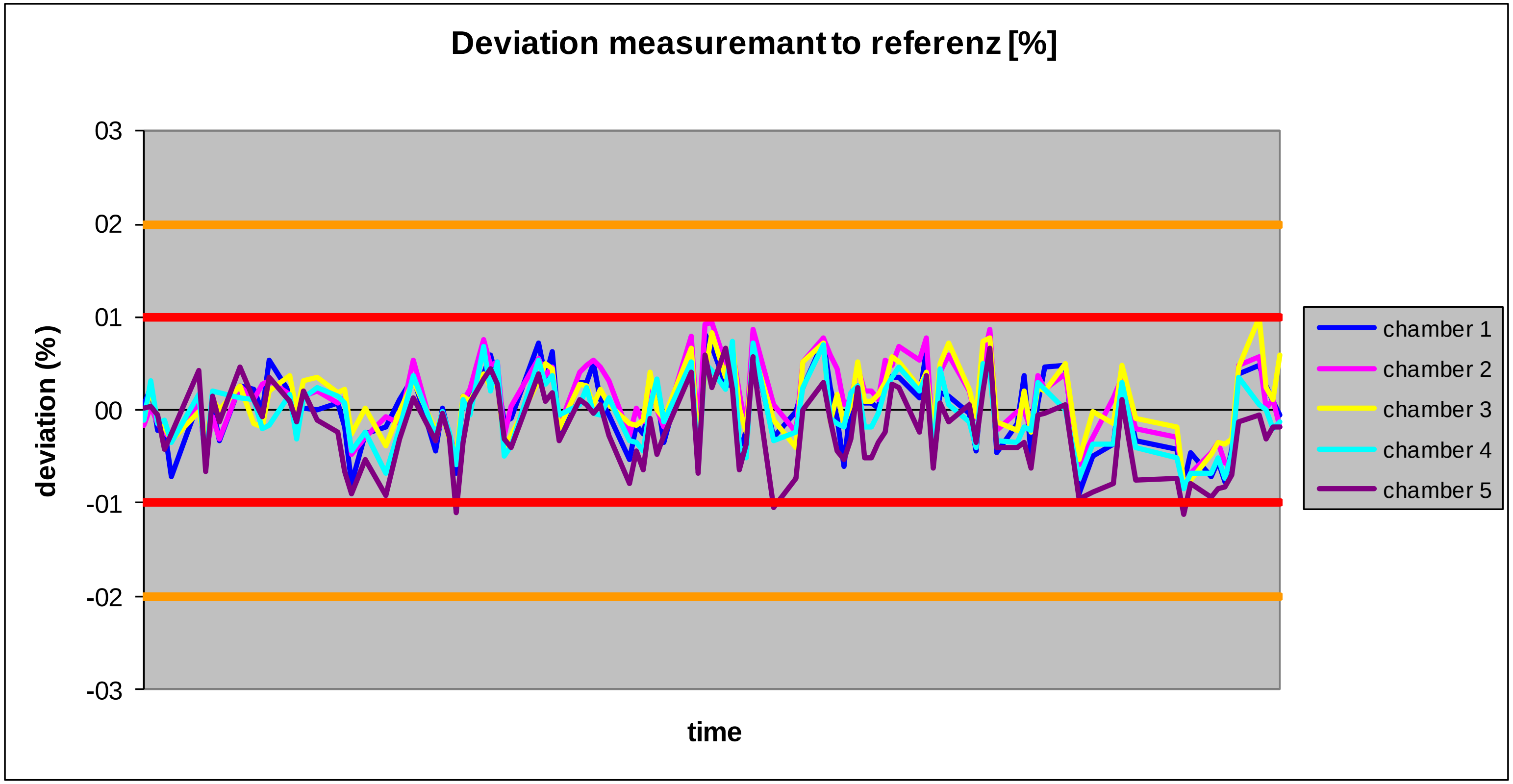
- Fast beam delivery aids in motion management
- Field 1 delivered in 2 breath-holds
- Field 2 delivered in 1 breath-hold



Dose Monitor Stability

Stability

Results of the absolute dose measurements over a 6months period



data courtesy of Mr Skalsky / RPTC Munich

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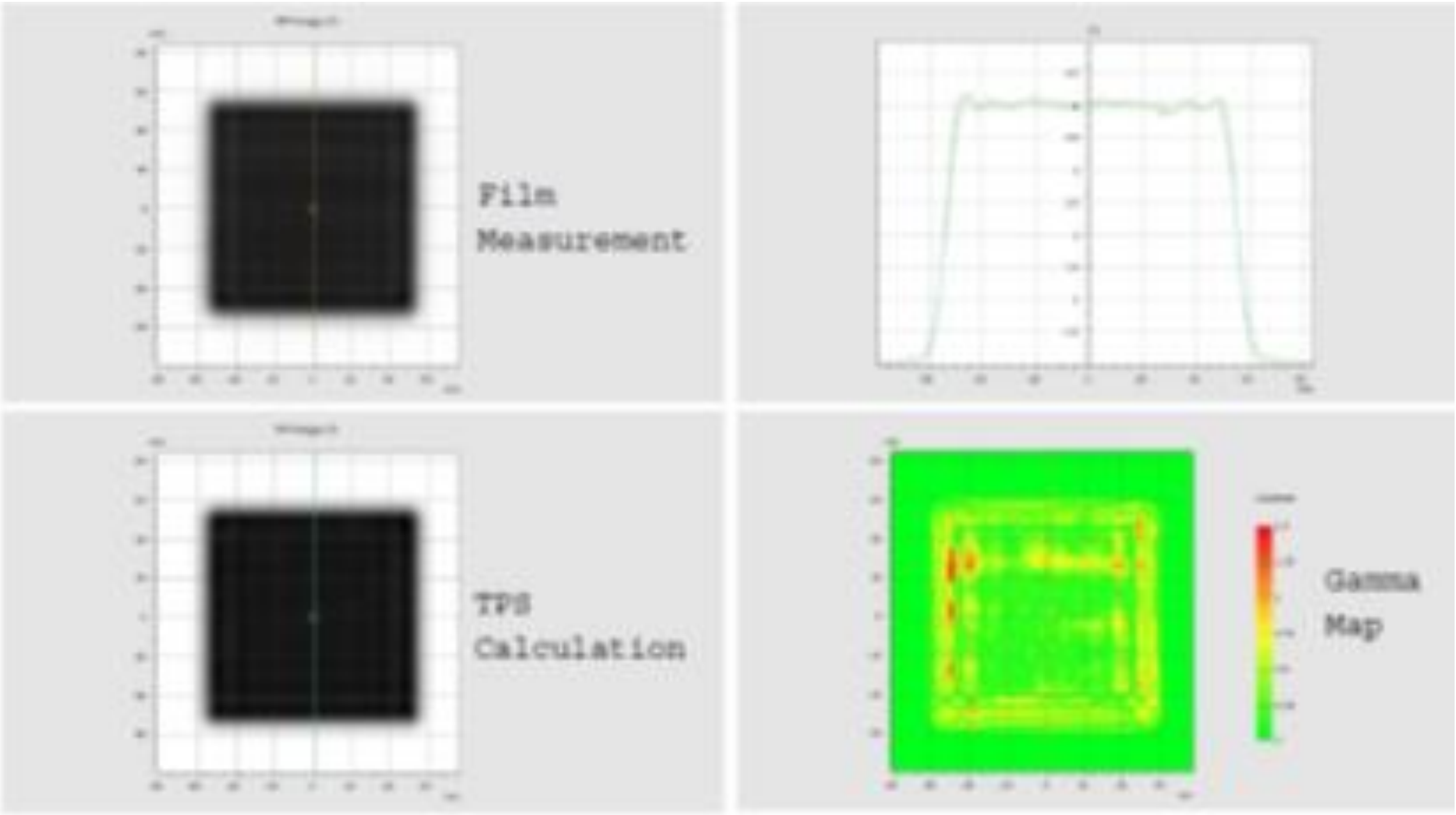
Planned vs measured dose
10cm x 10cm x 10 cm @ 15 cm depth



Gamma Criteria of 3%/3mm: 98.5% (green area)

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Dynamic Peak™ Scanning
2nd Generation IMPT

Dynamic Peak™ Scanning

- Varian IMPT since 2009 clinical
- Focus on dedicated scanning nozzles
- 2 Gy / L / min
- Documented beam precision <0.5 mm radius sphere
- 30 x 40 cm field size
- Total of 17 treatment rooms in Munich, San Diego, Baltimore and Cincinnati

Summary
Pencil Beam Scanning with continuous beam

- High experience in clinical environment
- Short irradiation time per field, even within one breath hold
- Dose delivery is very stable → very good dose conformity
- Well understood technology → installation, commissioning and service can be handled by technicians not experts

THANK YOU FOR YOUR ATTENTION

THANKS TO THE ORGANIZERS

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