The second generation scanning proton gantry at PSI

Center for Proton Therapy

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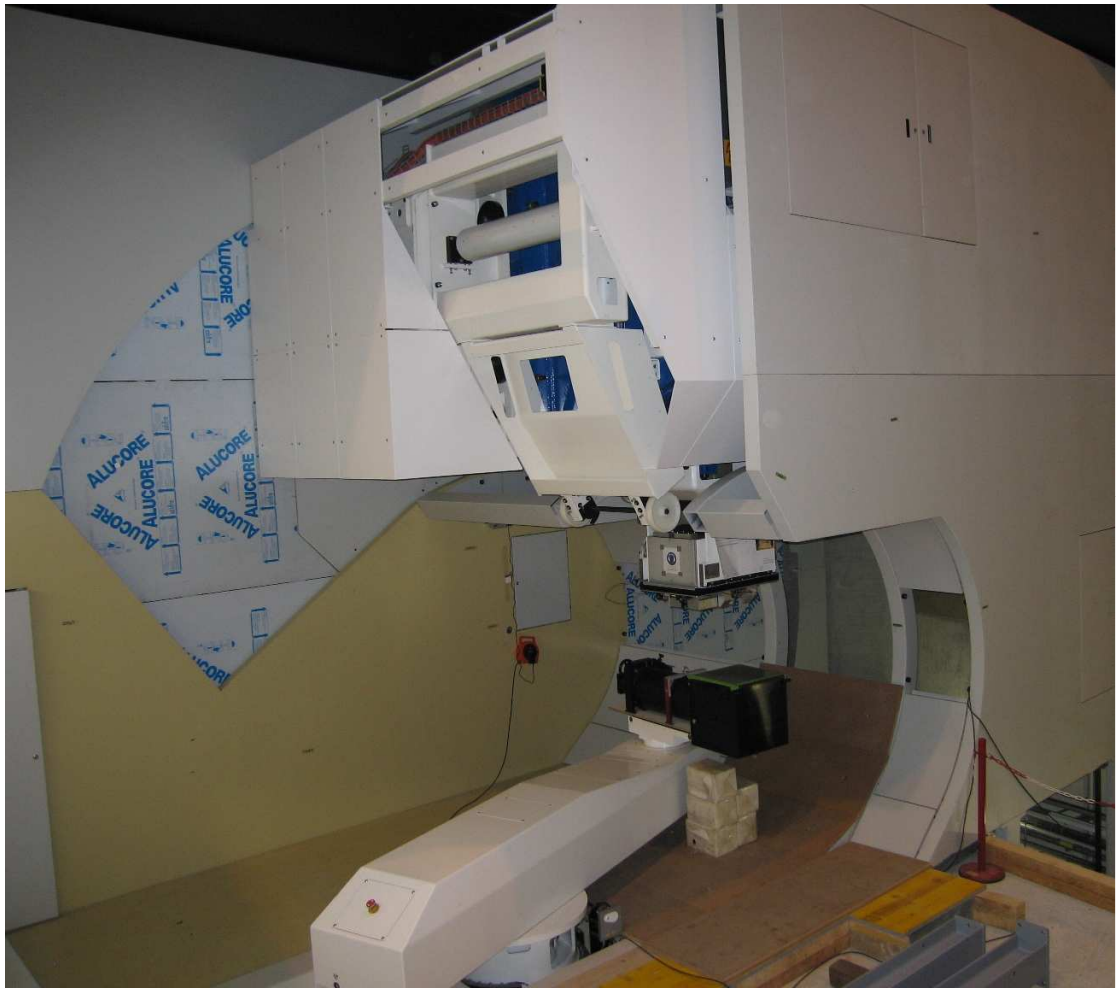
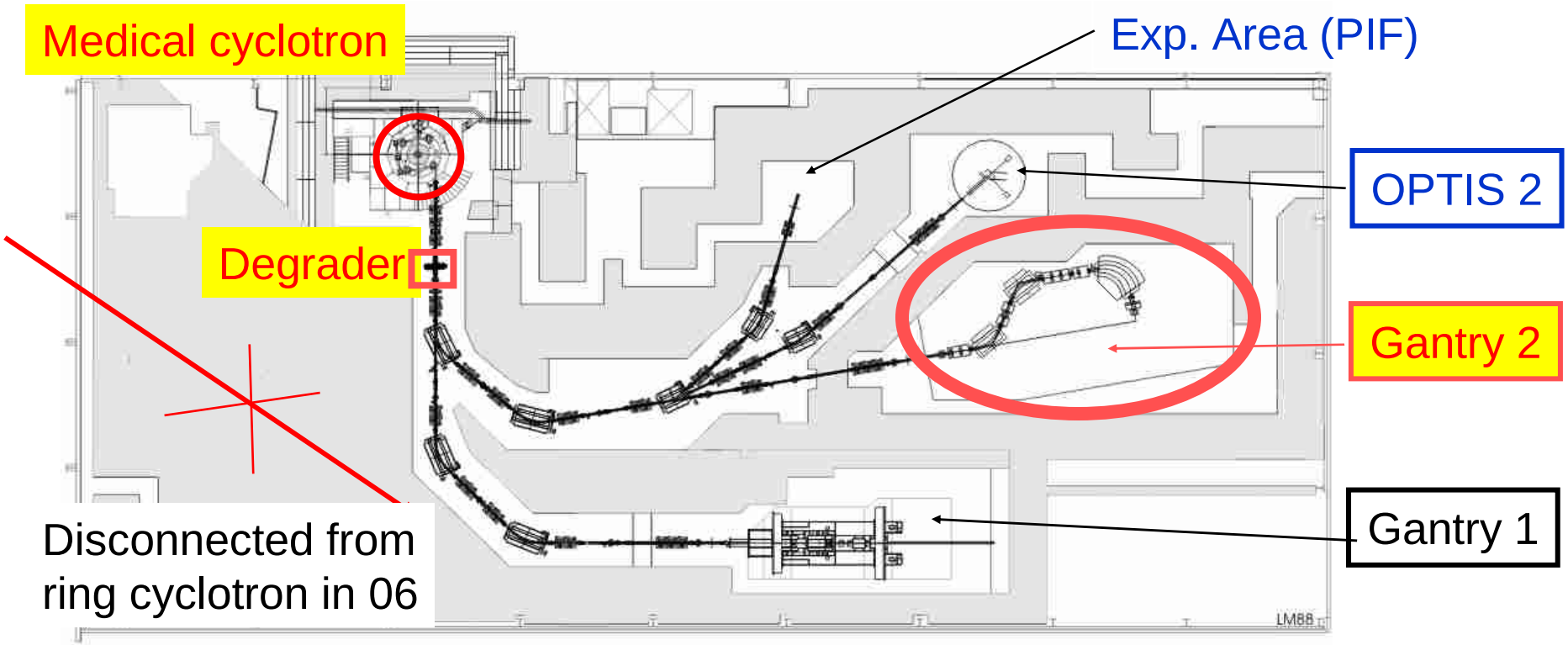
…. any many others



PTCOG
October 5, 2009

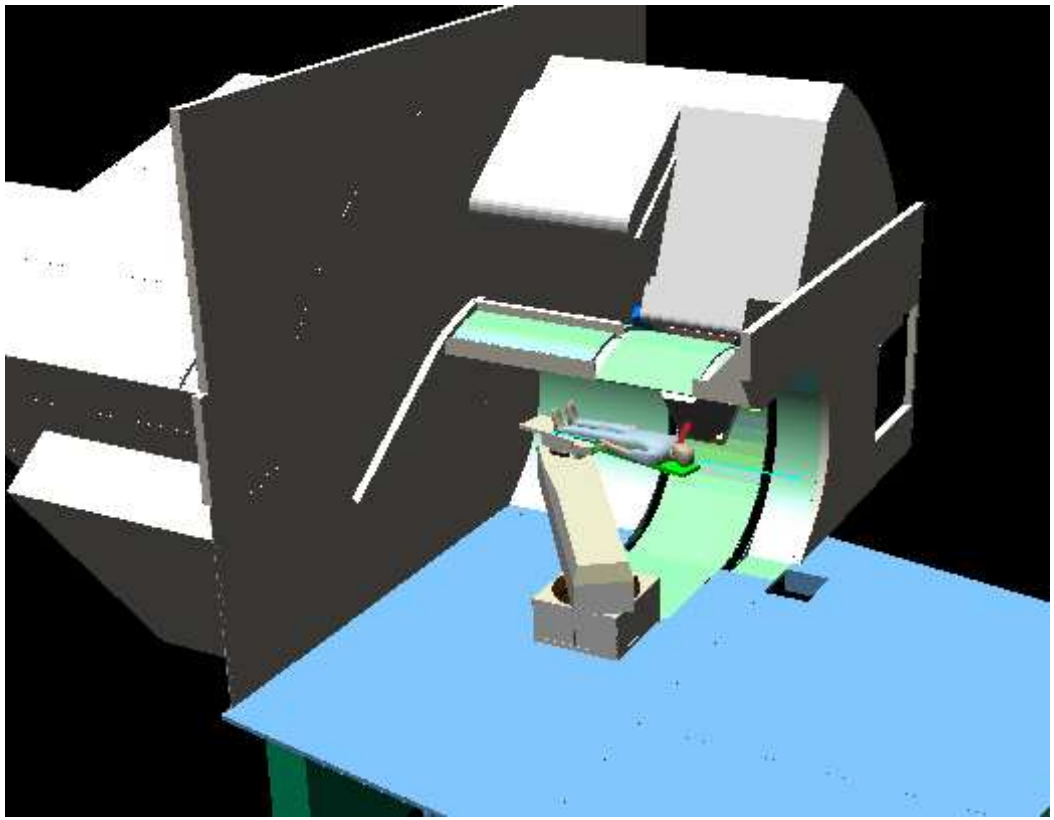
The framework – The PROSCAN project at PSI

- Dedicated superconducting cyclotron COMET
- Gantry 1 scanning patients since 1996 → no shut-downs since August 07
- Horizontal beam line for OPTIS 2 → 1. patients in 2009 – **higher priority**
- Next generation scanning gantry : **Gantry 2** → 1. patient planned for end of 2010



Innovation 1 - Easy access to the iso-center

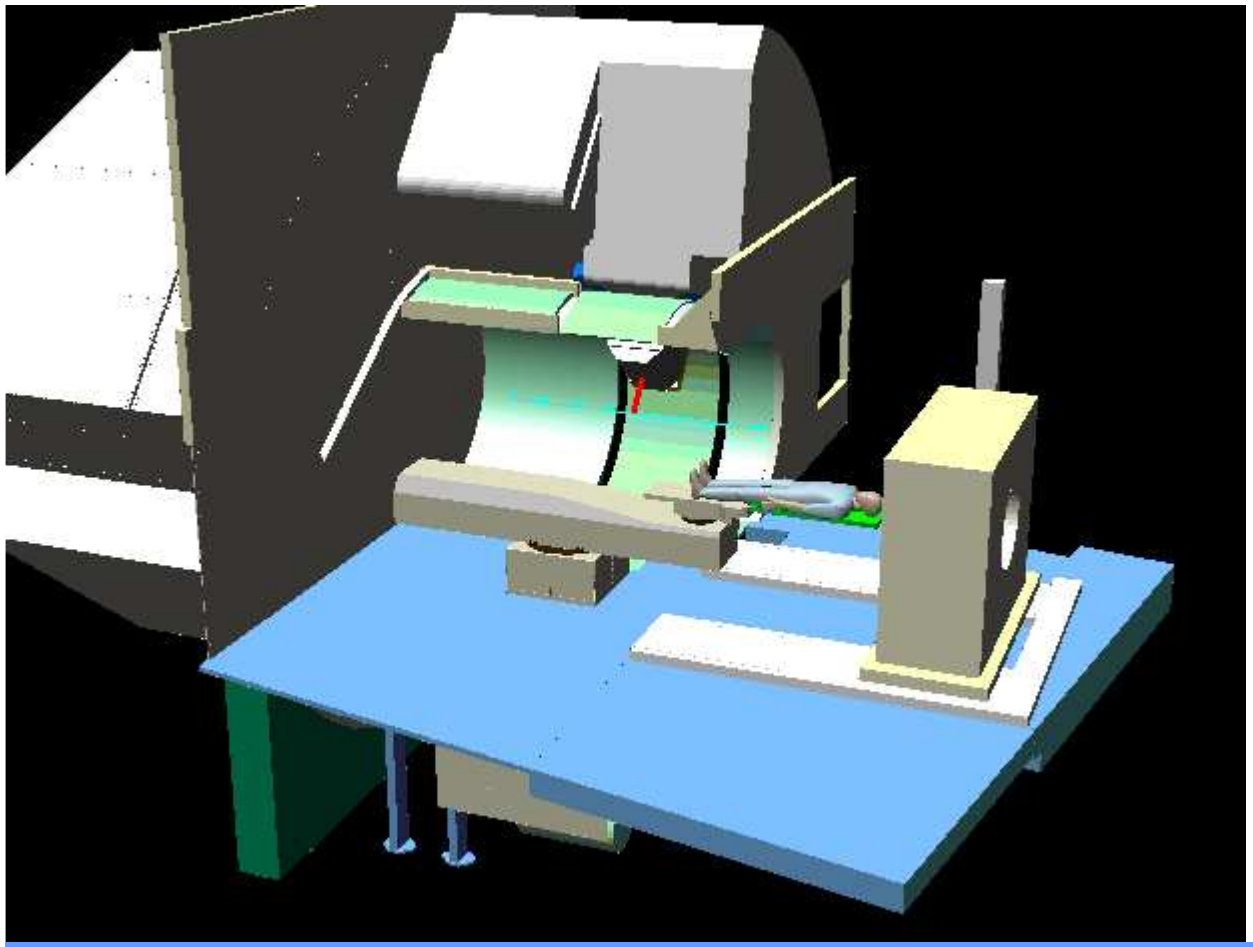
- **Gantry rotation limited to -30°to + 180°** (0° 180° sufficient)
- **Beam delivery flexibility by rotating the table in the horizontal plane**
  - Analogy with longitude and latitude in the world-geography



- Expected advantages:
- Fixed floor for a better access to the patient table
  - Nobody (patient or personnel) falling in the gantry pit
- Fixed walls for mounting supervision equipment like Vision-RT
- Large access space in front of the gantry for mounting commercial equipment
  - Like a sliding CT …

Innovation 2 - In-room positioning with sliding-CT

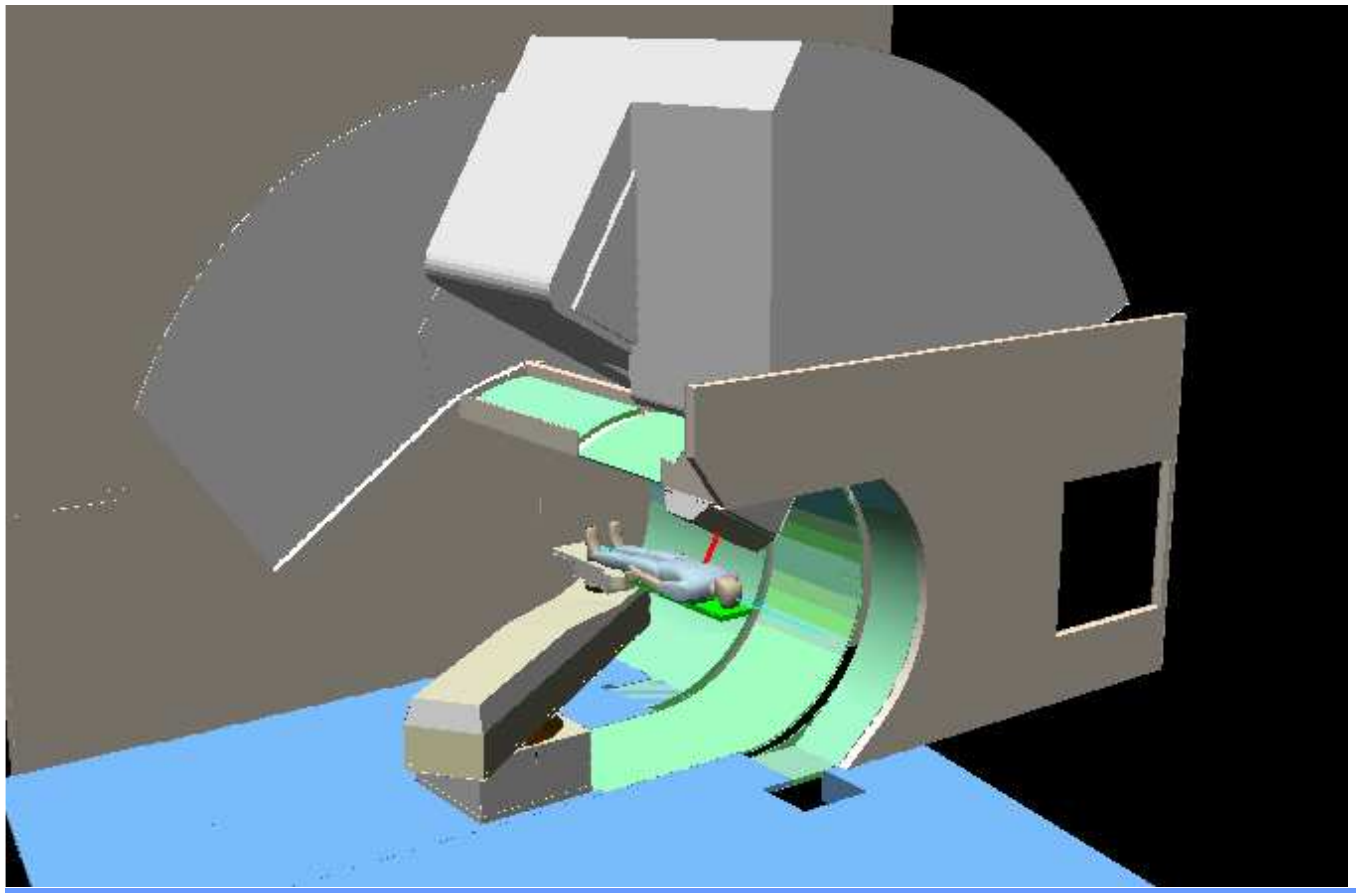
- **Within reach of the patient table**
  - Installing a sliding CT of Siemens



  - Same data as for treatment planning
    - No DRR
  - Same table
    - No bending corrections
  - Use of time-resolved images (4d) before (and after) treatment
    - Correct for intra-fraction motion
    - Adapt field to the organ situation of the day (soft tissues)
    - Setup and checks for respiration gating

Innovation 3 - BEV X-rays

- **Retractable support with a flat panel**
- **X-ray tube on beam axis**
  - Shining through a hole in the yoke of the 90° bending magnet
- **For simultaneous use to proton beam delivery**

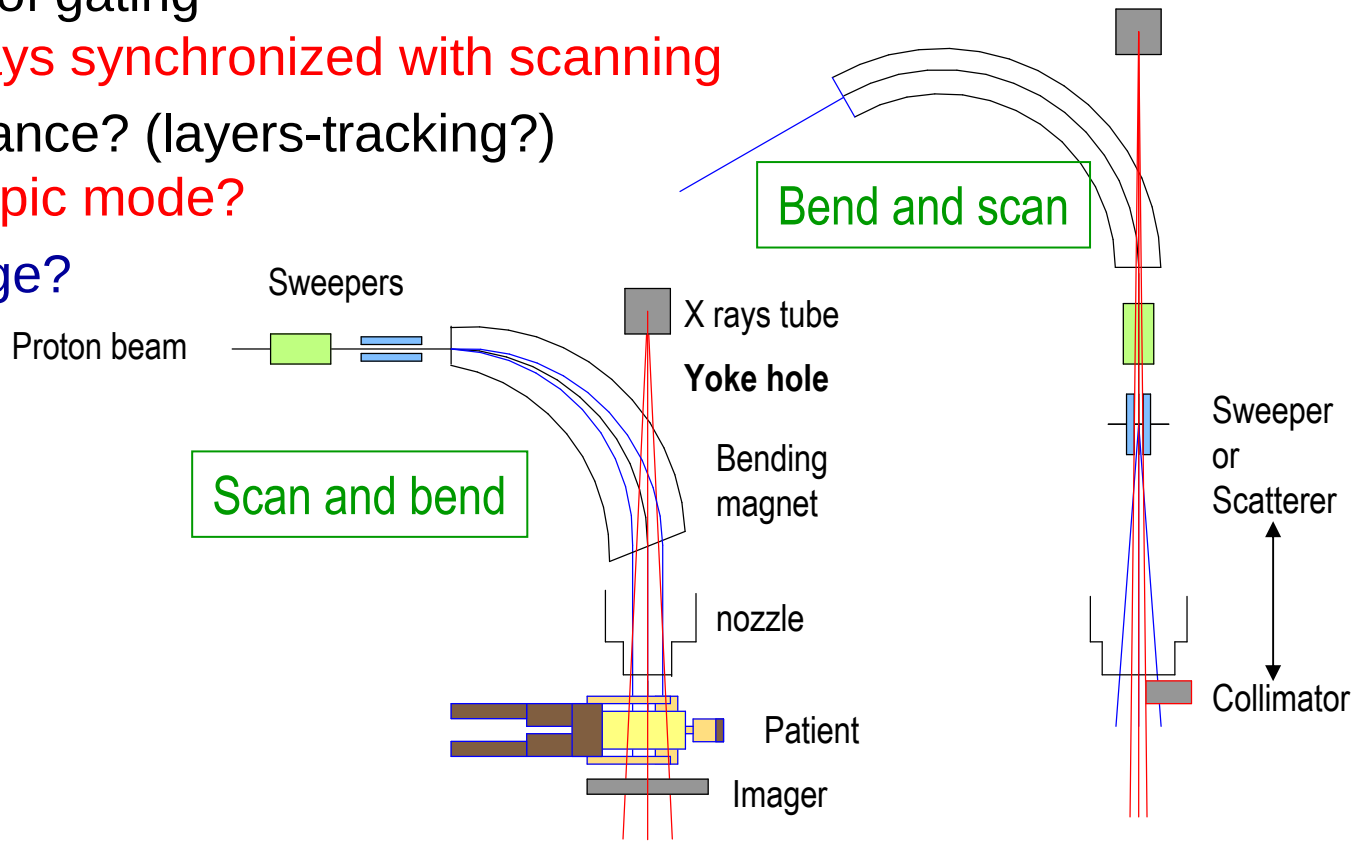


- Allows imaging with small air gap
  - Patient very close to the nozzle exit
- Use of a single image in the beam direction
  - Instead of reconstructing from 2 tilted images

BEV: expected advantages … and problems

- BEV imaging – an equivalent of portal imaging with photons
  - Very large field-of-view (26 cm x 16 cm)
    not masked by equipment or collimators in the beam path
  - QA control of gating
    pulsed X-rays synchronized with scanning
  - Beam guidance? (layers-tracking?)
    …fluoroscopic mode?
- Neutron damage?

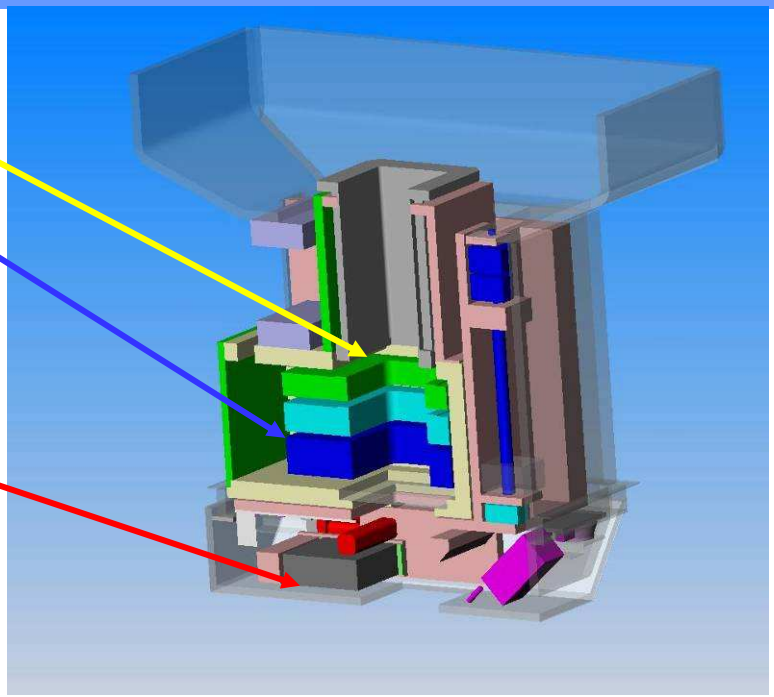
P100
S. Safai



Innovation 4 – A compact optimized nozzle

- **Vacuum "up to the patient"**
  - Sharp pencil beam - 3 mm sigma
- **Two monitors and a strip monitor**
  - 2 mm strips (delivered by TERA collaboration)
- **Removable pre-absorbe**
  - IN and OUT of beam (moto
  - For ranges below 4 – 10 cm
- **Telescopic motion of the nozzle**
  - To reduce air gap (keep patient at isocenter)
- **Option to add collimator and compensators**
  - To shield OAR on top of scanning
  - To simulate passive scattering with a scanning beam
- **Collision protection to treat patients remotely (multiple fields in one go)**
  - Field patching

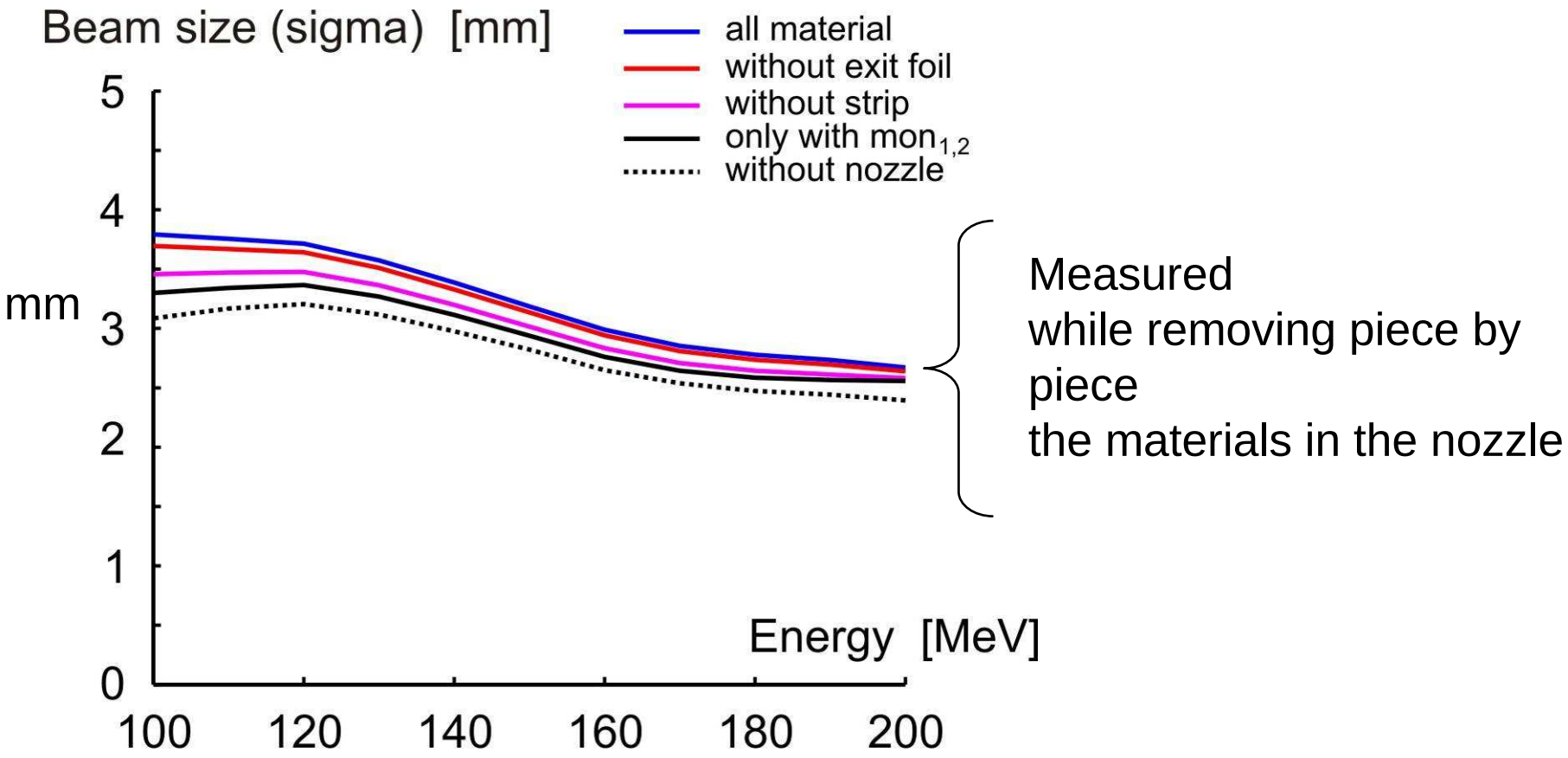
P54
S. Giordanengo



Breaking of vacuum window tested
Sound measured below tolerance - if nozzle closed

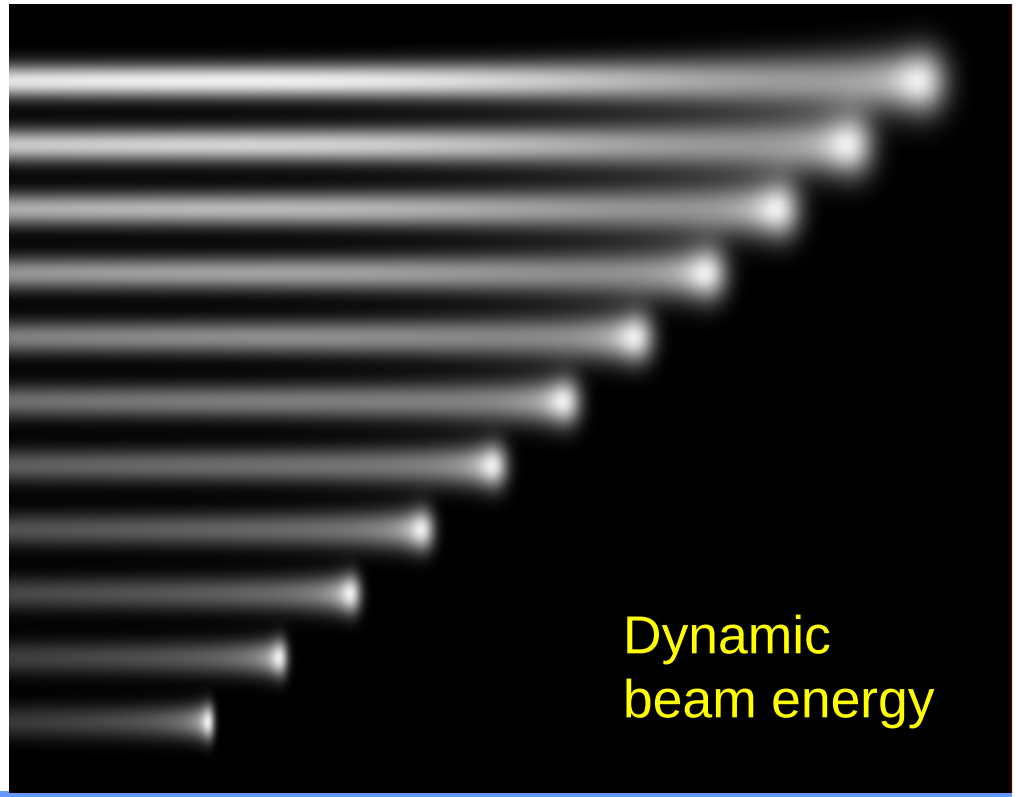
Nozzle: preliminary results - size of pencil beam

- **Use of minimal material in the nozzle for keeping the beam size between 3 and 4 mm sigma at all energies**



Innovation 5 - Fast changes of the beam energy

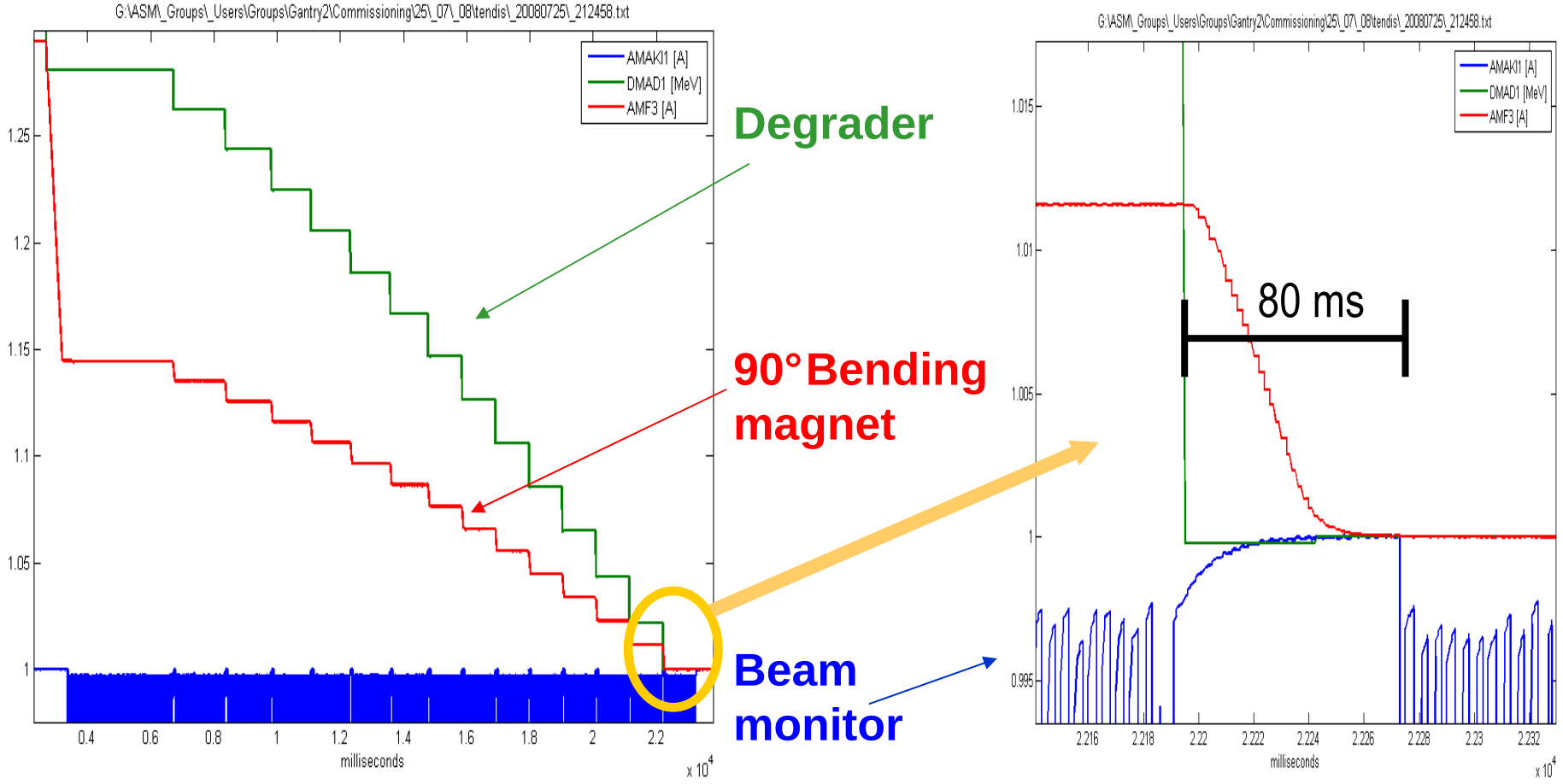
- **Continuous choice of the beam energy**
  - Setting all elements of the whole beam line within a single command (from steering file to MCR)
- **Constant beam transmission from COMET to gantry**
  - "Compensation" of degrader losses from 100 to 200 MeV
- **Fast energy changes**
  - Cyclotron (fixed energy)
  - Fast degrader ahead of the gantry
  - The beam line follows the energy variations in the degrader
- **Shown**
  - 80 ms dead time for small range steps of 5 mm



Example

- **Time pattern of main scanning devices of a scan of a 65 mm dose box (2940 Spots)**

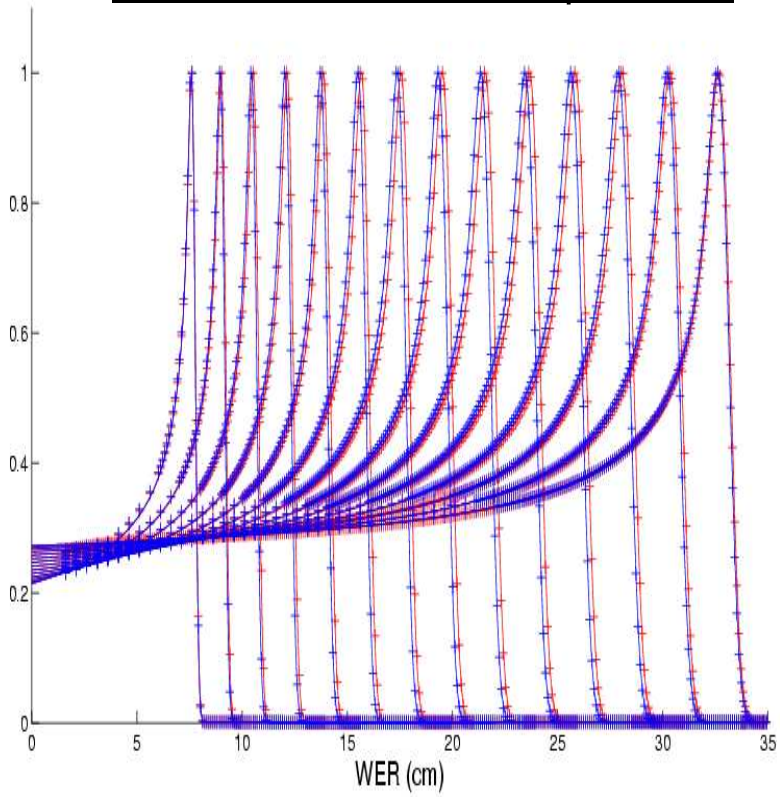
P64
D. Meer



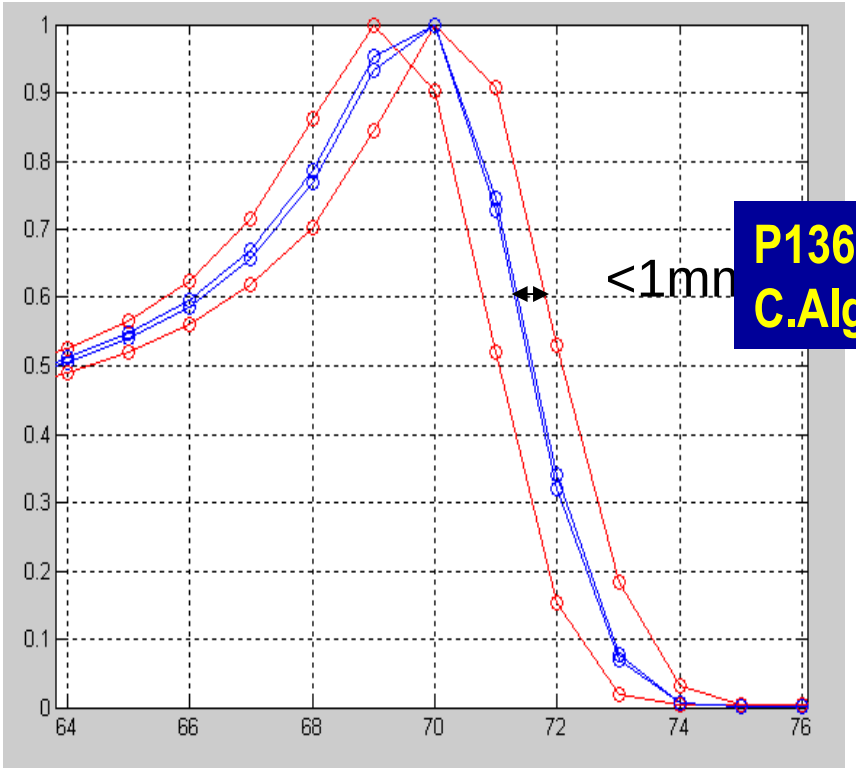
An order of magnitude faster than any other system

Needs to take into account hysteresis effects …

– **Fixed magnetic ramping (100-230 MeV)**
  - **Red: up-down**
  - **Blue: down-up**
– Measured with a water phantom



– **Energy setting**
  - **Red: tunes with wrong ramp**
  - **Blue: right order of ramp**
– Measured with a stack of ICs



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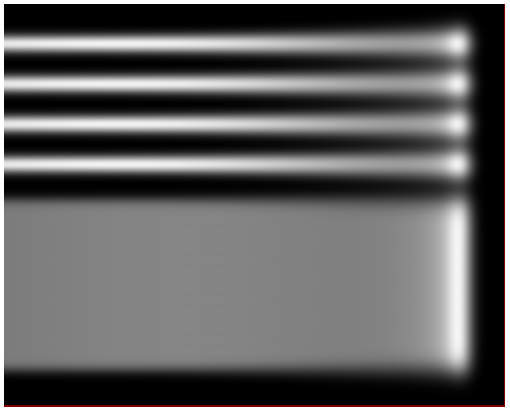
S. Lin

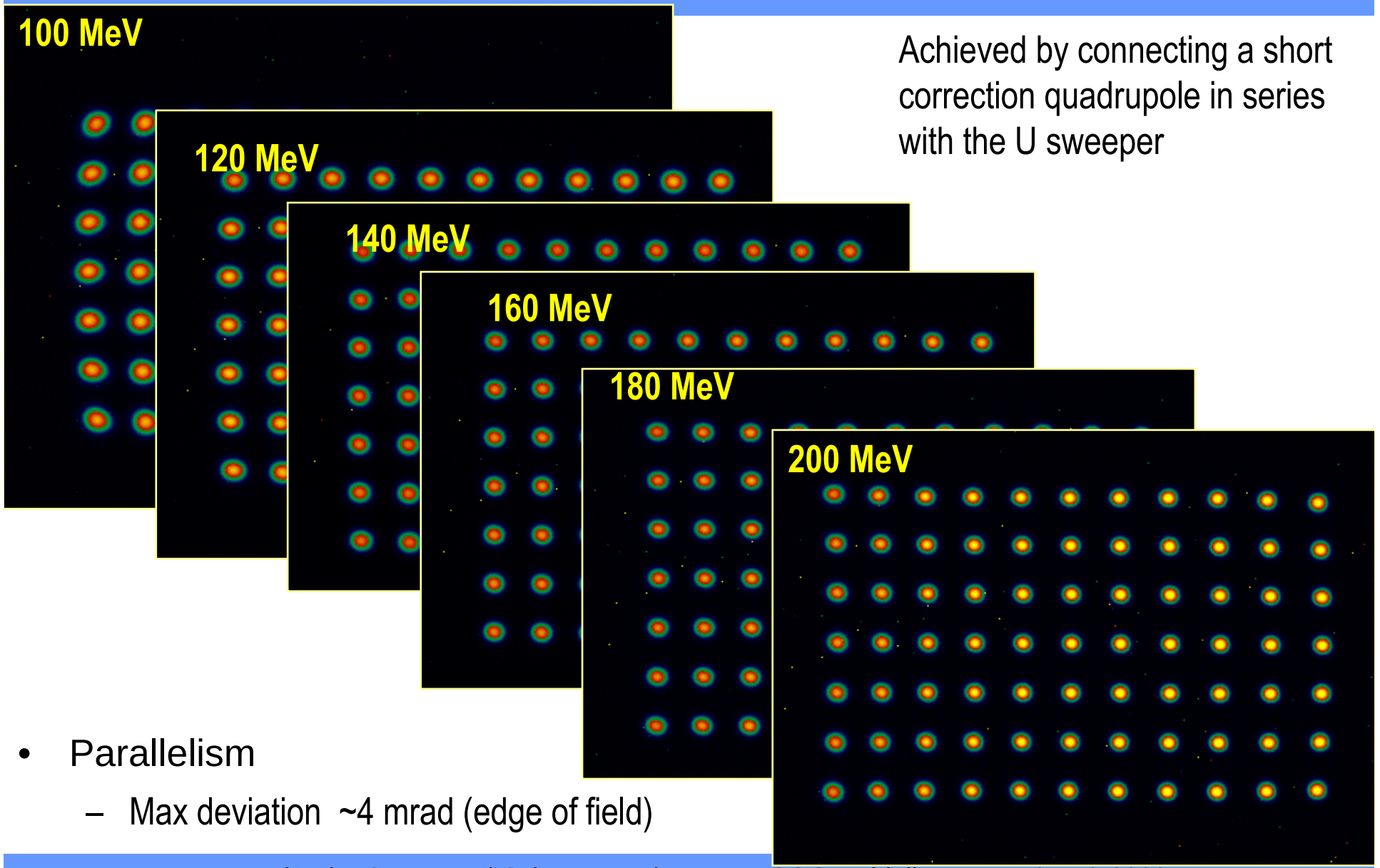
P136
C.Algranati

Innovation 6 - Double parallel scanning

- **Fast parallel lateral scanning**
  - **T sweeper** 2 cm/ms
  - **U sweeper** 0.5 cm/ms
- **Scan area of 12 by 20 cm**
  - **Plus motion of patient table** for treating larger field sizes
    - Experience with Gantry 1
- **Parallelism**
  - Table used as a sweeper-offset
  - Simplify
    - **Treatment planning**
    - **Field patching**
    - **Errors from compensators**
    - **Dosimetry**



Well focused beam for all energies…

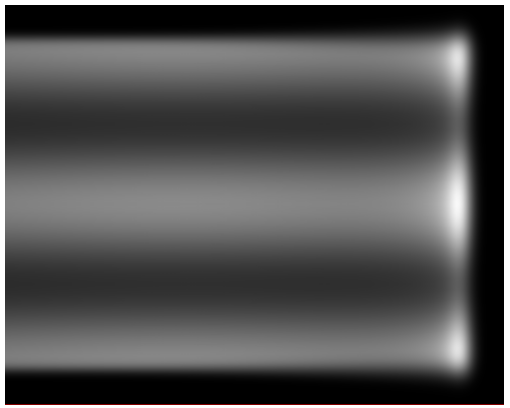


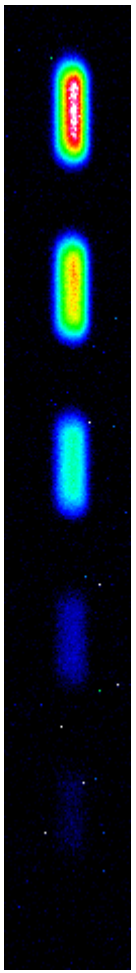
Achieved by connecting a short correction quadrupole in series with the U sweeper

- Parallelism
  - Max deviation ~4 mrad (edge of field)

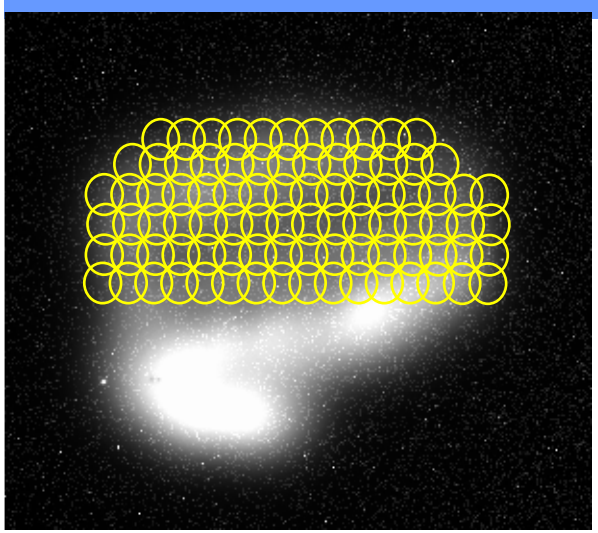
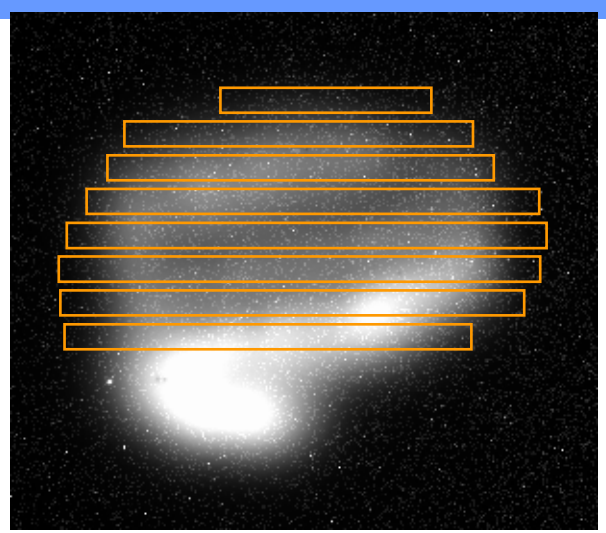
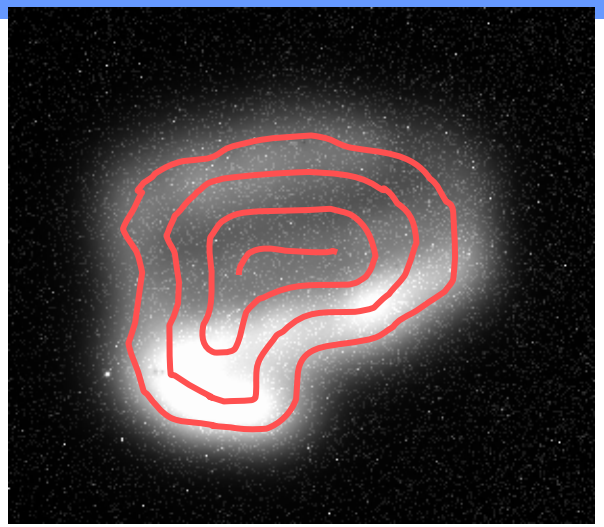
Innovation 7 - Vertical deflector plate (COMET)

- **Dynamic use of the modulation of the beam intensity**
  - Deflector plate and vertical collimators in the first beam turn after the ion source
  - Time delay to extracted beam in the order of 100 us
- **Example**
  - Delivery of line segments with changing voltages on the deflector plate
  - “Pulsing beam”





Innovation 8 - A very flexible control system

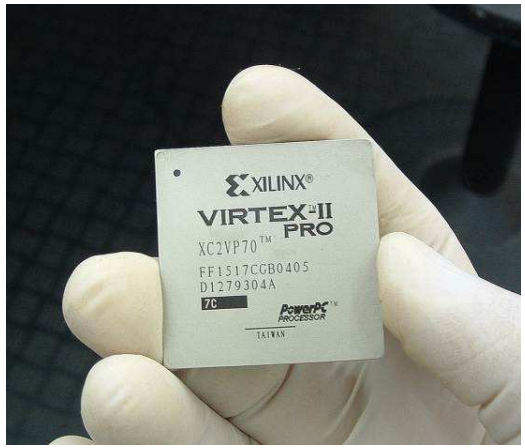
- **Steering file for combined delivery of**
  - **Spots**
    - Spot scanning as the default (starting) mode
  - **Lines**
    - For maximum repainting number and simulated scattering
  - **Contours?**
    - For optimizing repainting and lateral fall-off (difference Gaussian to error-function)
- **Passive scattering**

P52
C. Bula

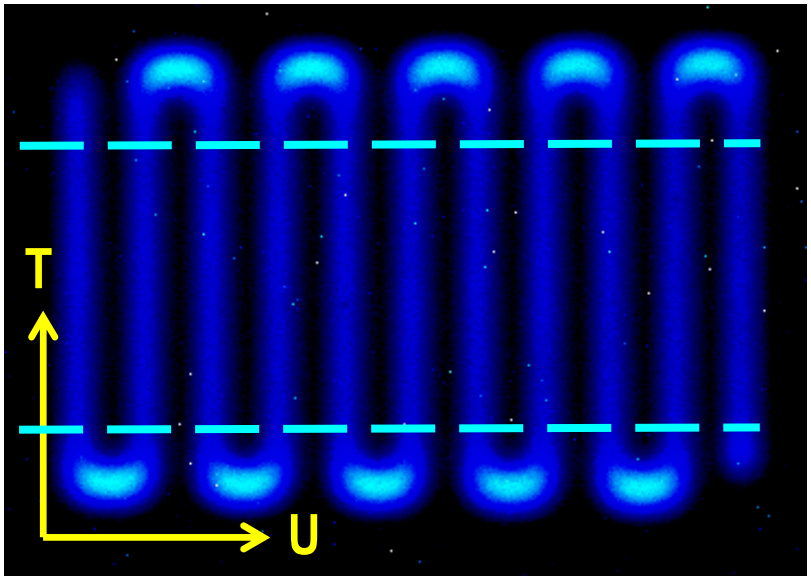
P68
J.Verwey

Innovation 9 - Tabulated dose delivery with FPGA

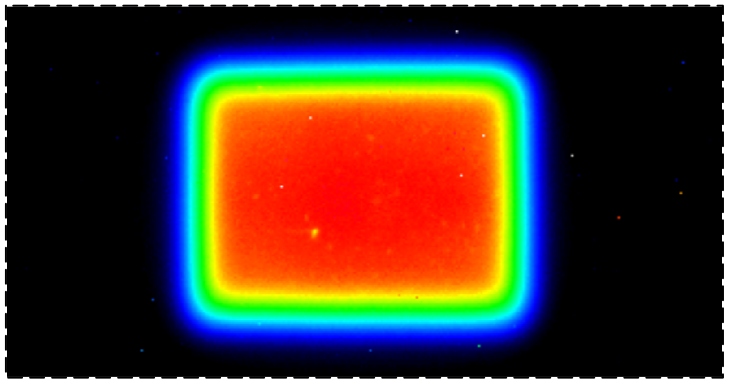
- **Combined tabulated control of**
  - **U-sweeper**
  - **T-sweeper**
  - **Beam intensity**
    - As a function of **time**



Example 1 – U T meander path

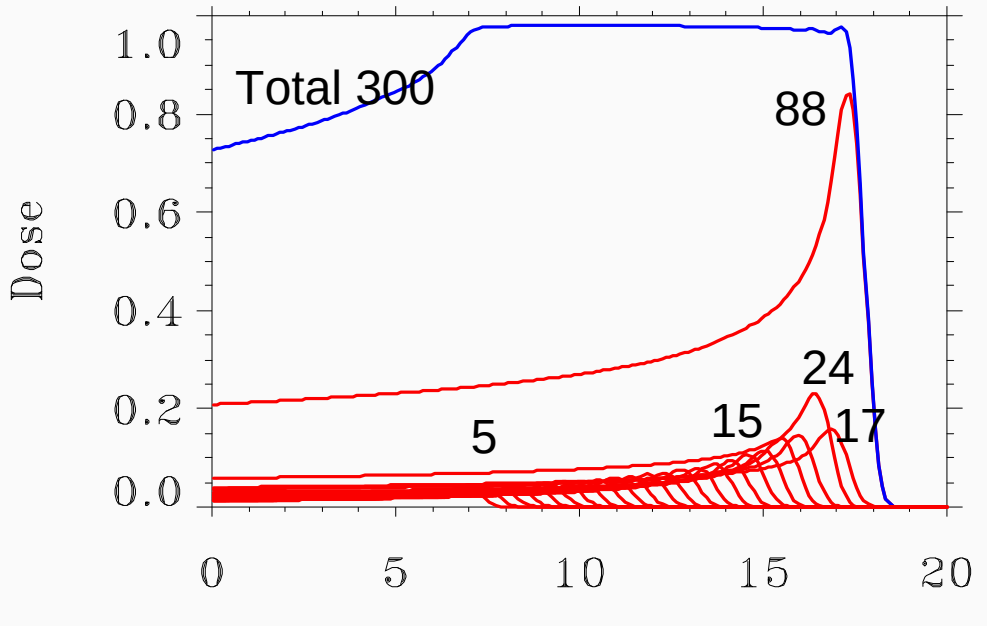


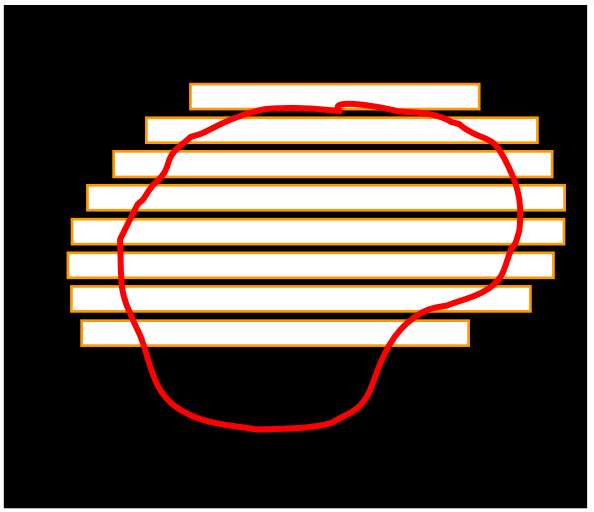
Example 2 - Dose box with continuous scanning
494 energy layers (85 ms per layer)
(6 x 8 cm) in less than 1 minute



Innovation 10: Simulated scattering

- **Magnetic scanning at max. speed**
  - Constant intensity per energy layer
- **Dose shaping with collimators and compensators** (LEIGHT WEIGHT)
  - BEV shaped layers →
- **Very high repainting number**
  - Most distal layer (200ms)
    - 88 scans / liter /minutes
- **Improved uniform scanning**
  - **Simulate scattering** on a scanning-gantry
  - With a **parallel** beam
  - With **variable modulation of the range**
    - Shrinking shape of layers proximally
  - **Part 2 of thesis work of S Zenklusen**



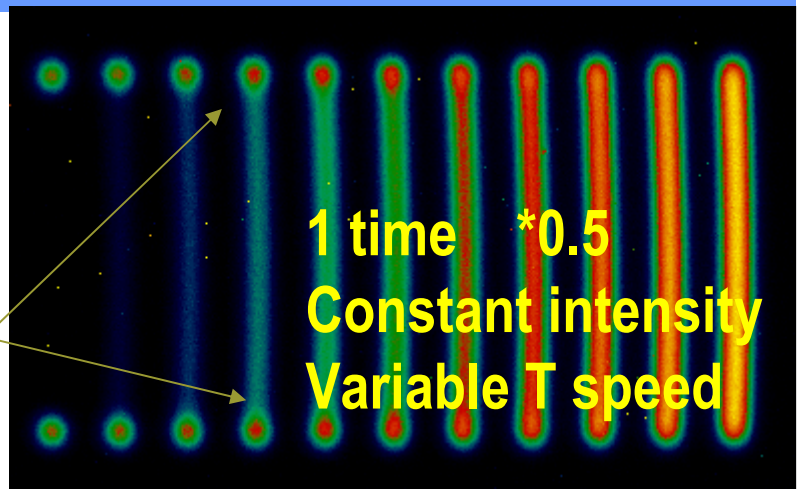


Innovation 11 – Fast volumetric repainting

- **For conformal scanning and IMPT** (without collimators and compensators)
- **Painting of lines**
  - With maximal possible velocity ~ 2 cm / ms, 0.5 cm/ms
    - **…except for those regions where the dose rate are not high enough …**
  - Dose shaping with Beam Intensity Modulation (I.M.)
  - <10 ms per line (10cm + line change)
- **Painting of energy iso-layers**
  - < 200 ms per plane (20 lines x 5 mm)
  - Change of energy (100 ms - 5mm range)
- **Repainting of iso-layers**
  - ~ 6 s per liter (20 energies at 5mm steps)
- **Volumetric repainting capability (aiming at)**
  - 10 repaintings / liter in 1 **or 2** minutes

Innovation 12 – Time driven dose control

- **Time driven devices U - T - I**
  - Dose control with a feed-back loop
    Input: required dose rate
    difference to Monitor 1
    Output vertical deflector plate
- **Paths with variable speed and/or variable intensity**



10 cm in
20-200 ms

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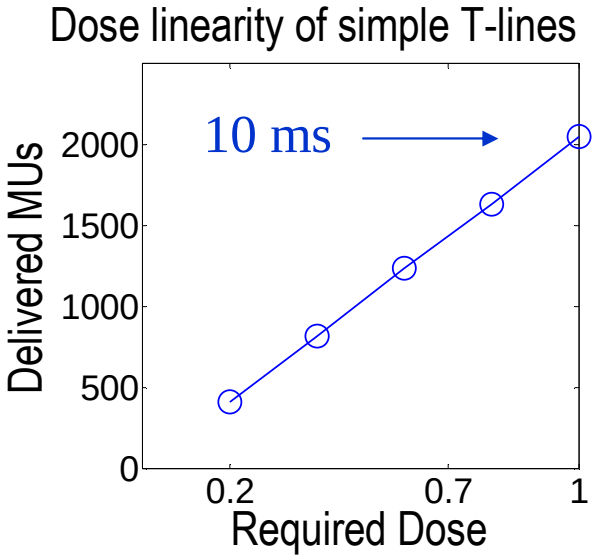
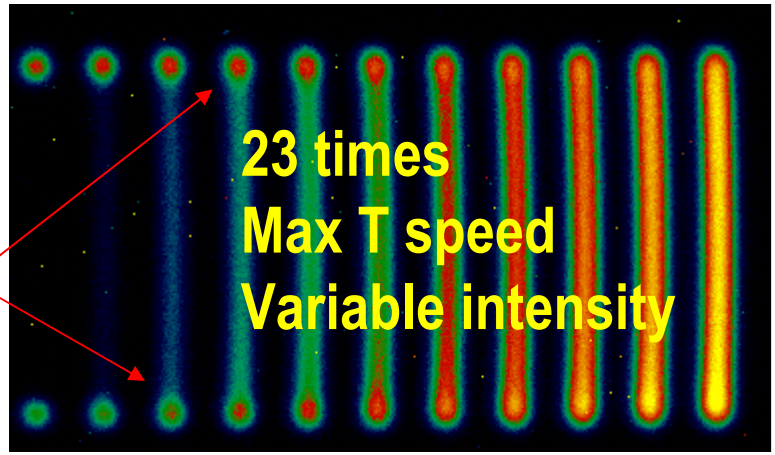
D. Meer

5 ms is the limit … systematic errors !!!



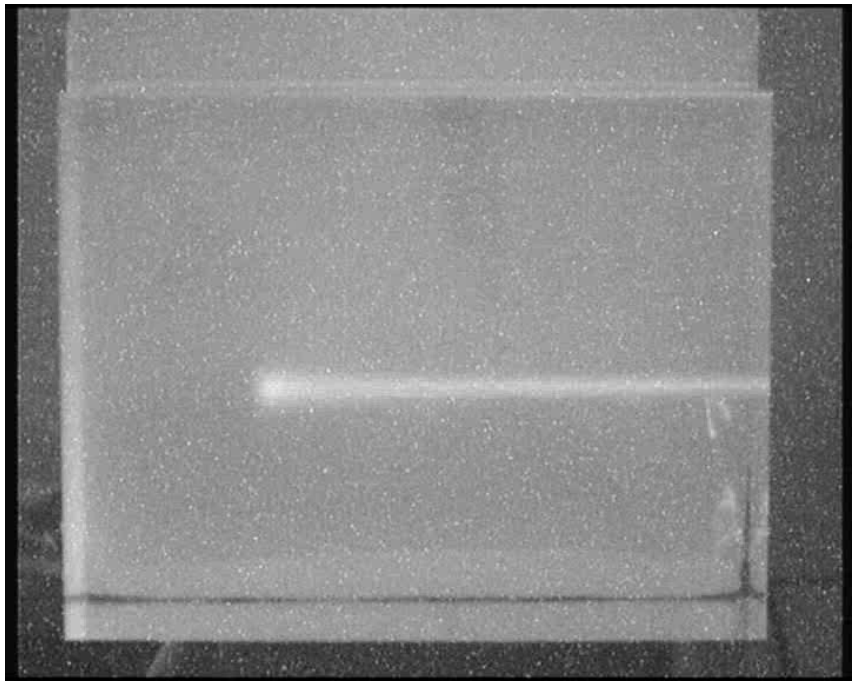
10 cm
in 5 ms



Conclusions

- **Encouraging results with**
  - Beam optics (successfully commissioned)
  - Small beam spot size
  - Double parallel scanning
  - Very fast dynamic beam energy changes
  - Very fast delivery of energy layers
  - Dose control via beam intensity
- **Still waiting for**
  - Control of patient table and gantry rotation
  - Patient handling equipment
  - And architectural finishing of the area

Scintillator block - the beam of Gantry 2 seen with a TV camera



Many thanks to the involved colleagues at PSI for their help

and to YOU
for the attention