Workshop on picosecond photon sensors

13th March 2014

UniversityHospital Heidelberg

Timing in imaging applications for ion beam therapy

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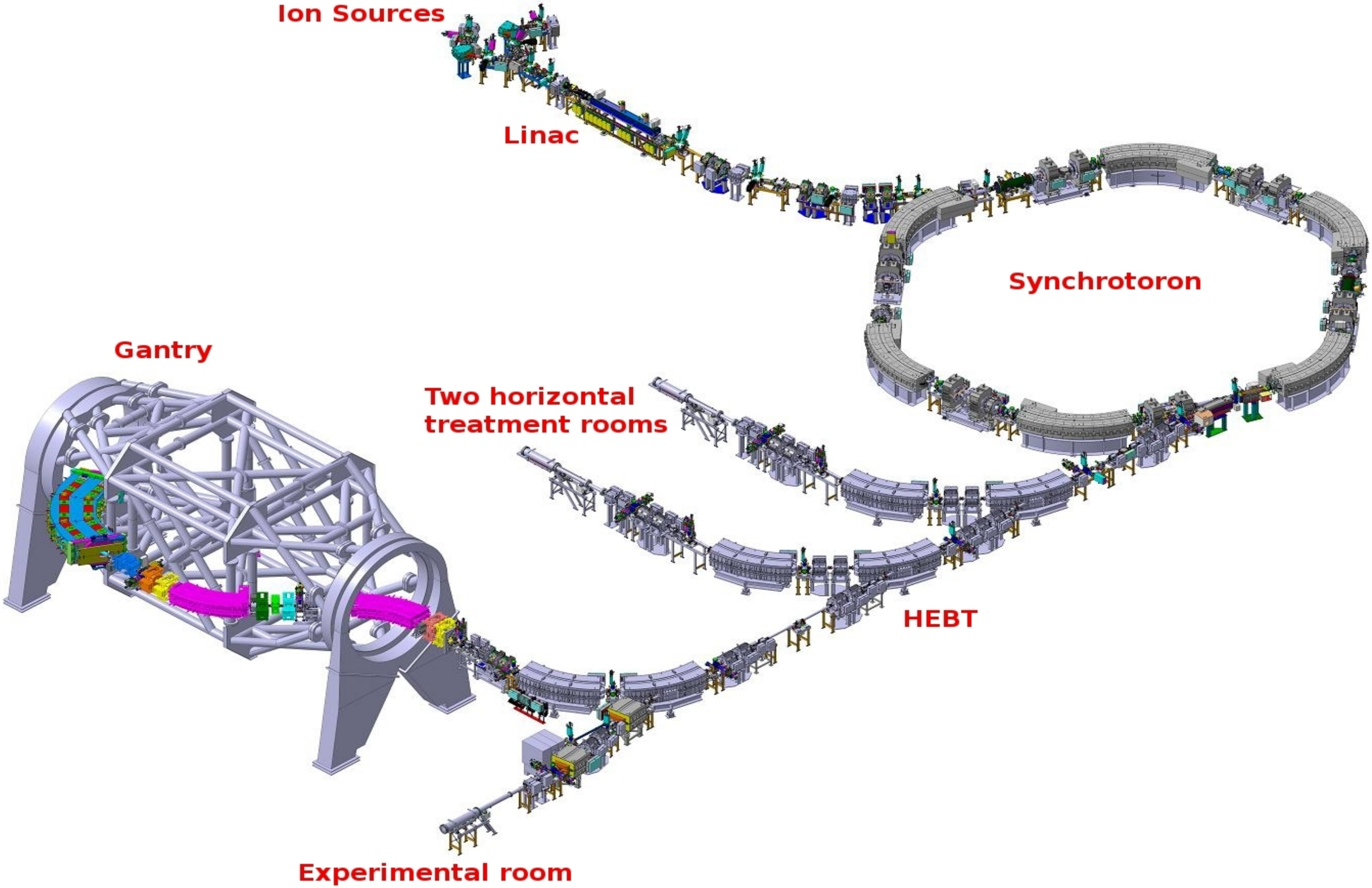
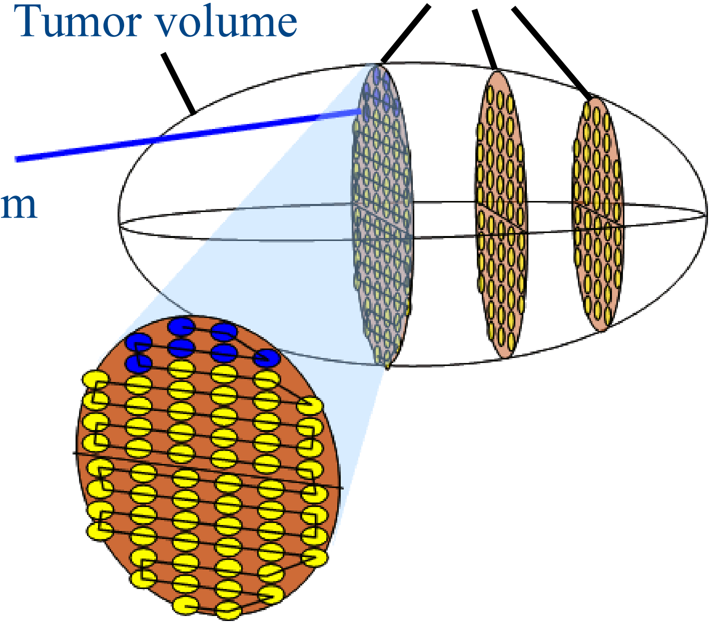
Heidelberg University Hospital
and
Ludwig Maximilians University Munich

The Heidelberg Ion Therapy center



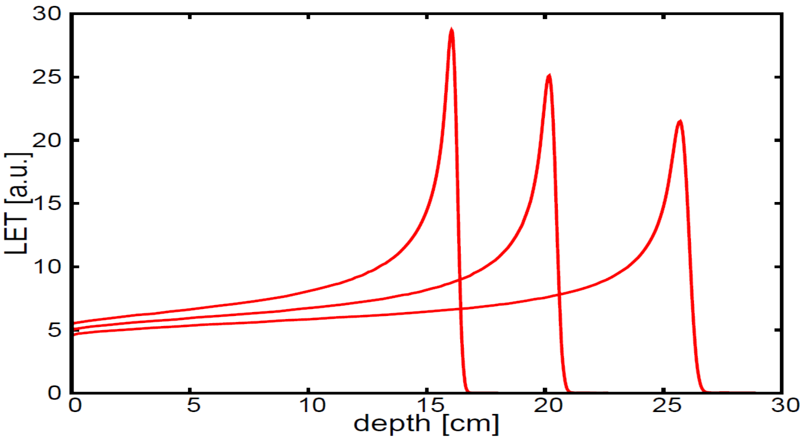
Active Raster scanning technique

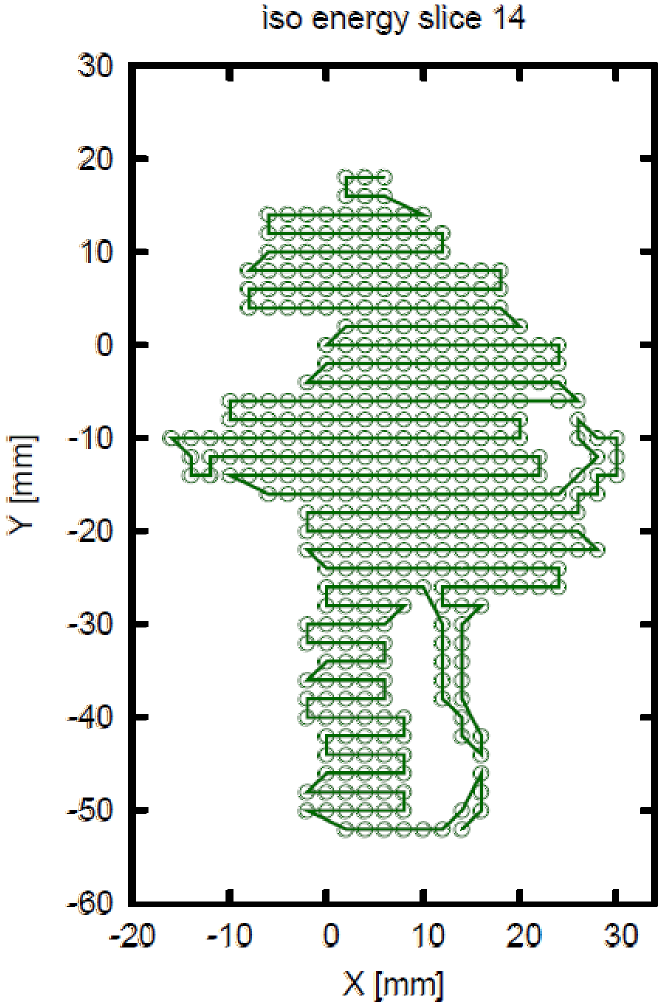


iso energy slices (IES)

Tumor volume

Beam

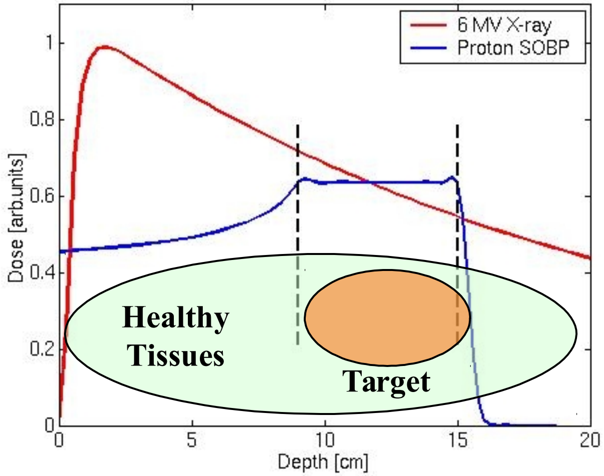




Rationale for ion therapy and range verification

Present

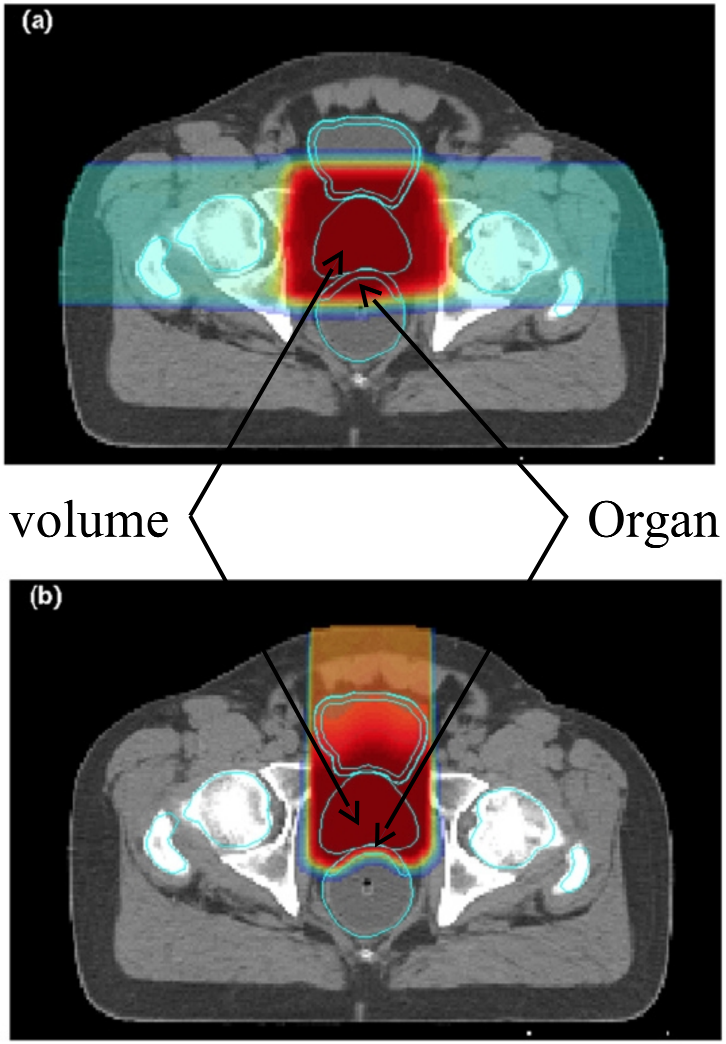
- Reduced integral dose (factor ~3)



Paganetti AAPM 2012

Future

- Reduction of safety margins
  (dose escalations; higher cure rate)
- Use of new irradiation fields
  (use of sharp distal penumbra of Bragg-peaks)



Tumor volume

Organ at risk

Rationale for ion therapy and range verification

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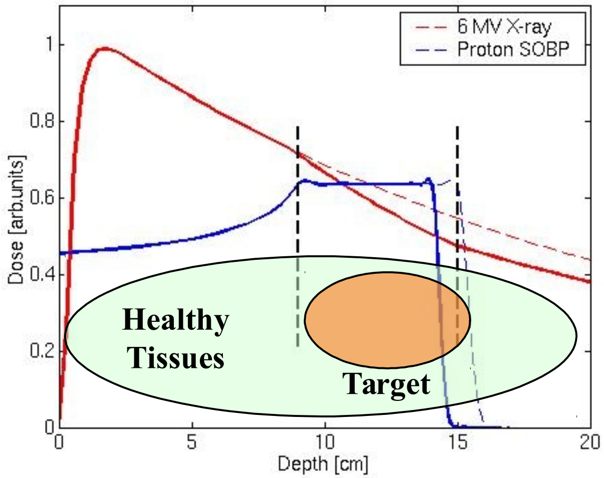

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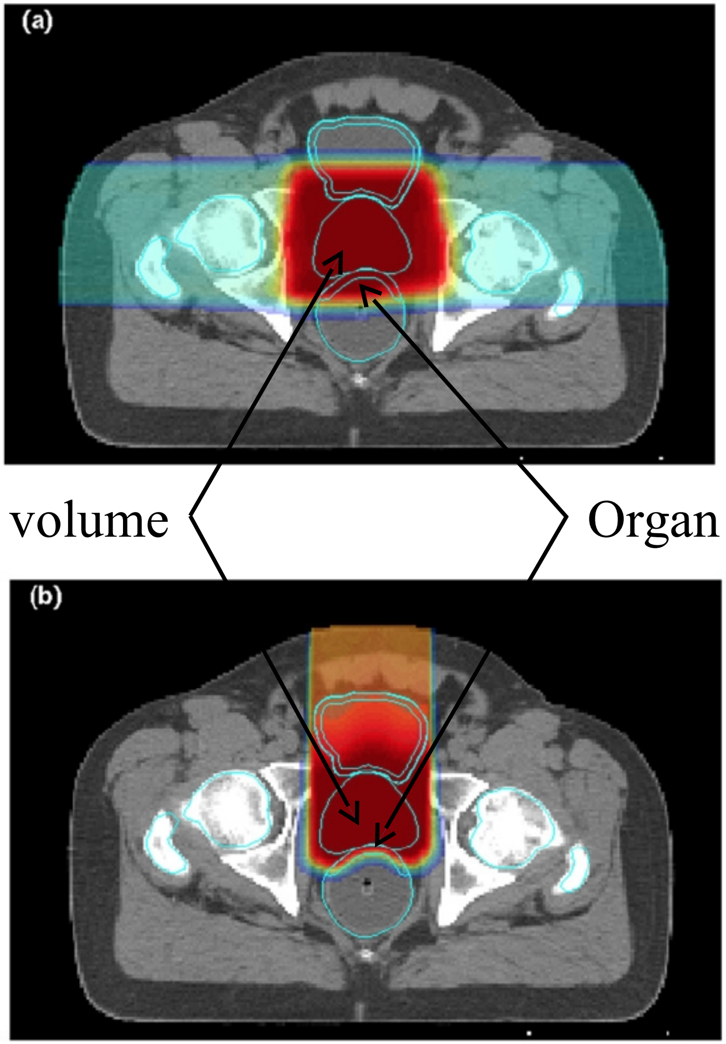

Tumor volume

Organ at risk

Tang et. al. Med.Phys. 2012

Rationale for ion therapy and range verification

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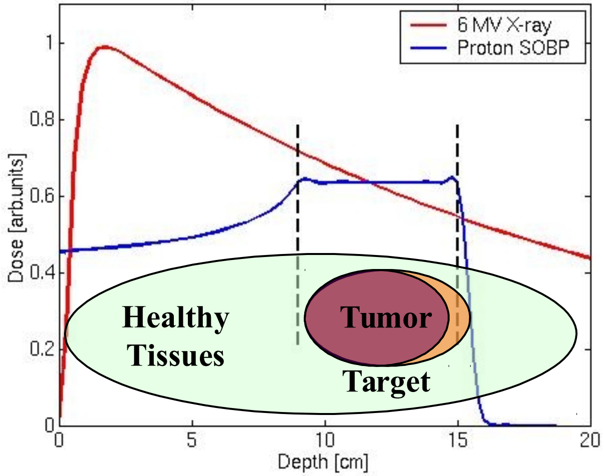

Paganetti AAPM 2012

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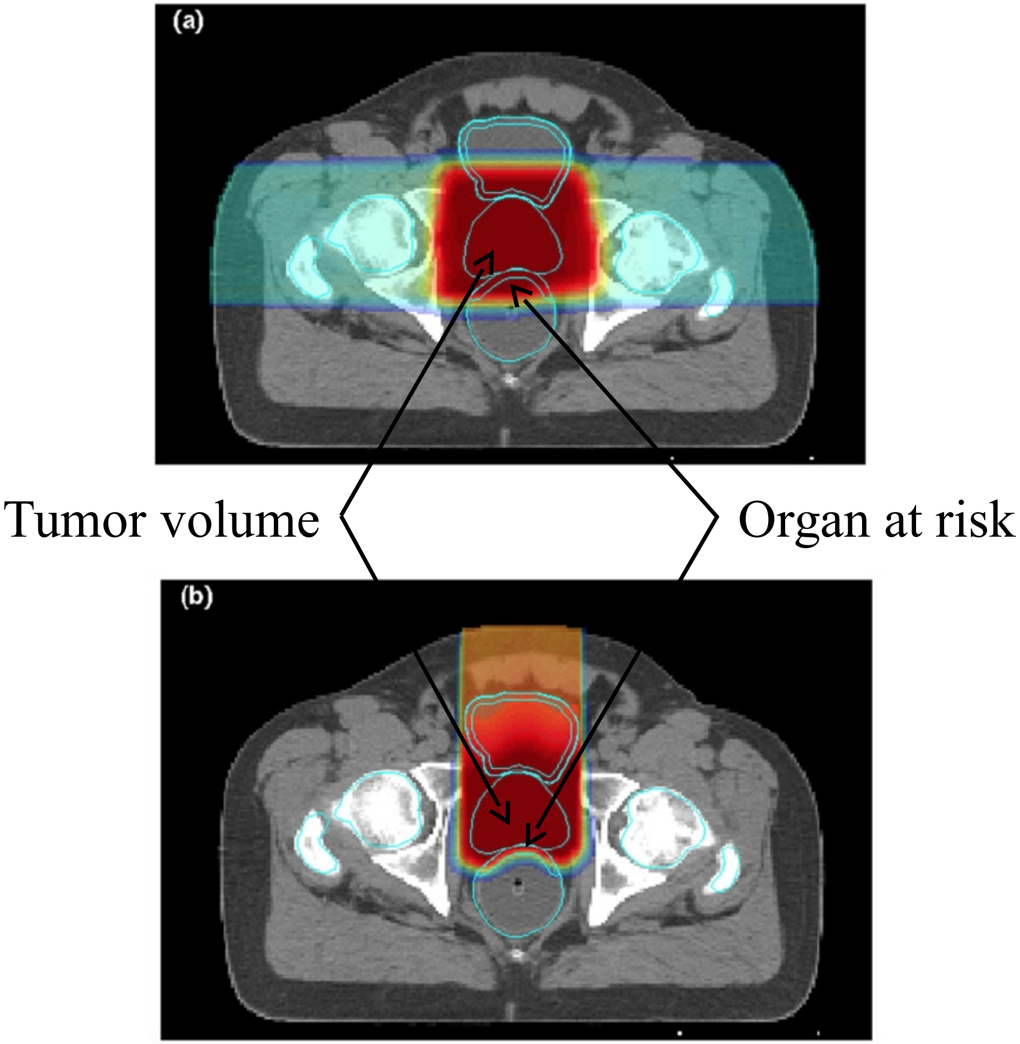


Tumor volume

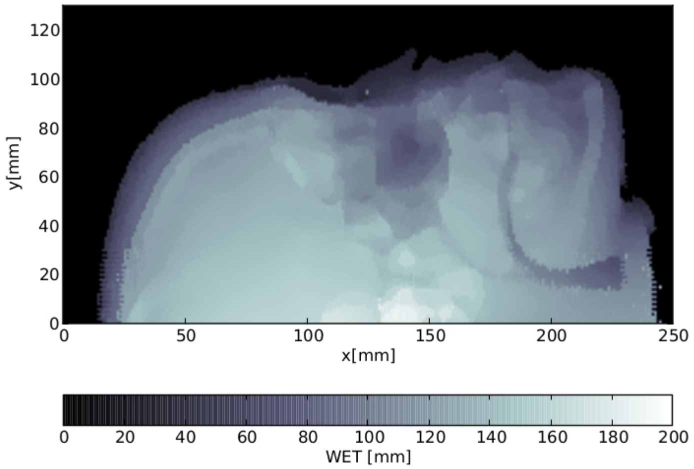
Organ at risk

Tang et. al. Med.Phys. 2012

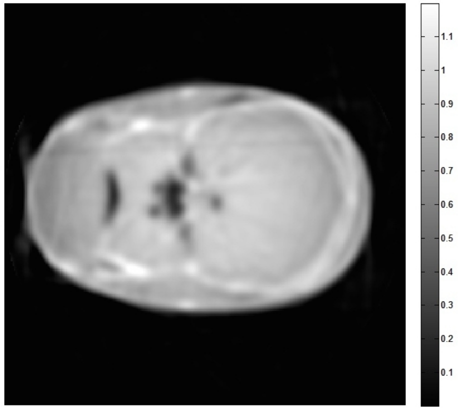
How do we reduce range uncertainties?

- Increasing accuracy in range prediction

Ion radiography

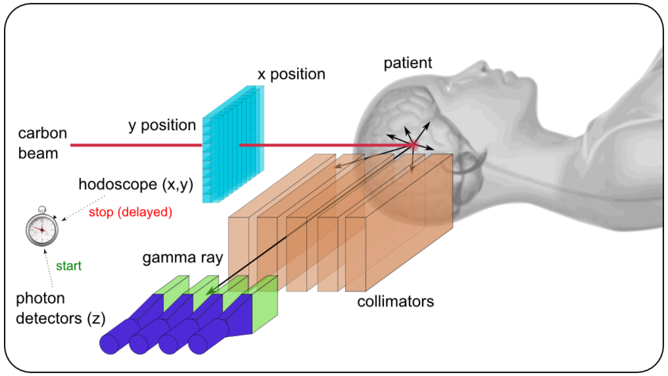


Ion CT



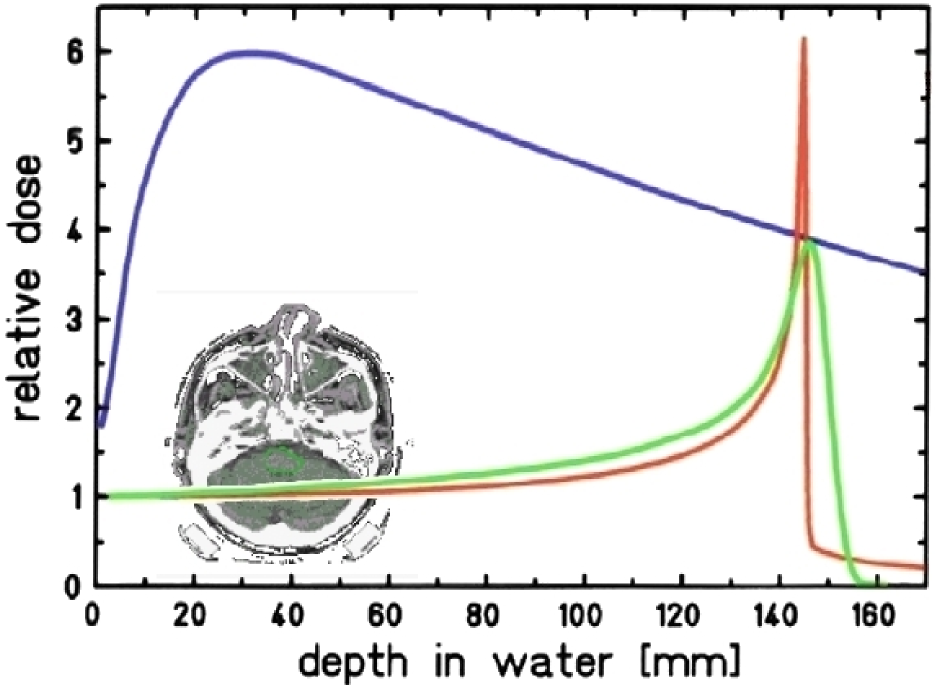
- In-vivo range verification

Prompt gamma cameras



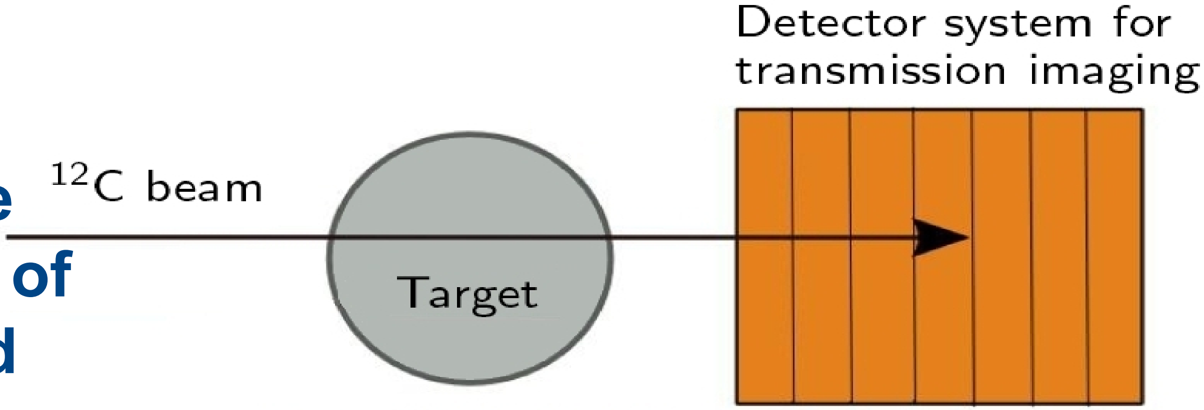
PET

• Ion radiography and tomography:the idea

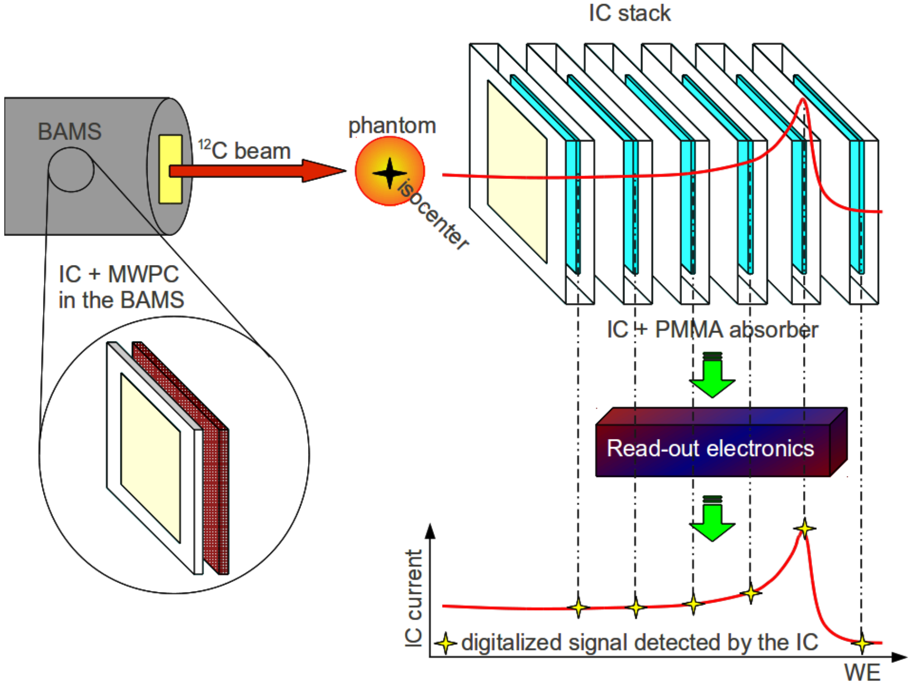


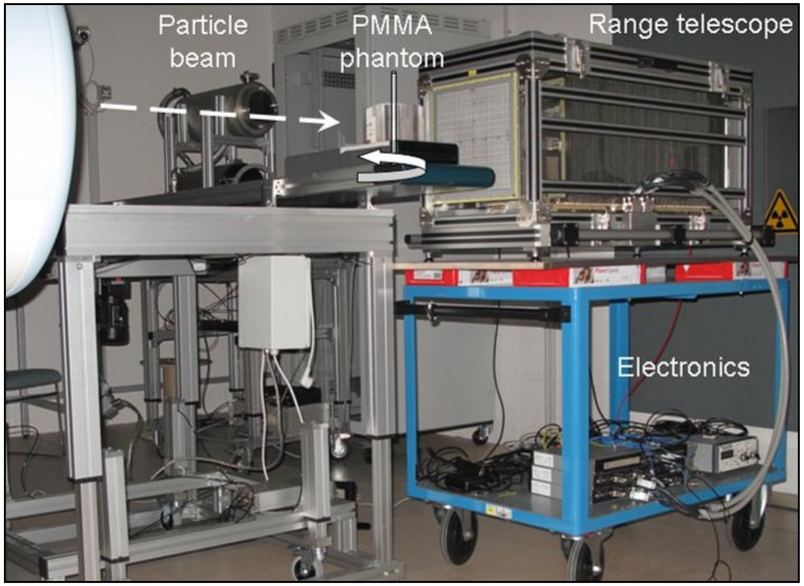
- Use of energetic ion beams prior to or even in-between the treatment low dose to the patient

- position of the
- Bragg peak
- depends on the
- characteristics of
- the transversed
- materials



Detector development: Ion tomography





- 61 PPIC 30x30 cm2
- 3mm PMMA absorber slabs
- 2 Modules of I3200 Thirty two-channel Electrometer+A500 Real Time Controller
- Active scanning beam delivery system

Rinaldi et al., PMB 58 (2013), 413, Highlights of 2013
Rinaldi et al., PMB (2014a,2014b), submitted

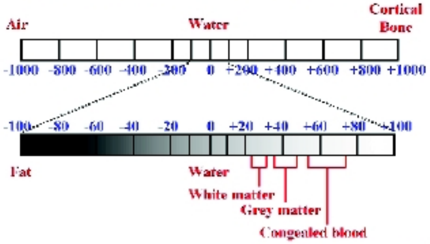
Ion radiography and tomography

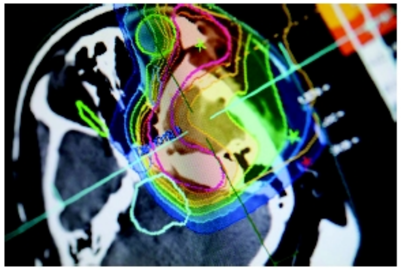
X-ray planning CT

?

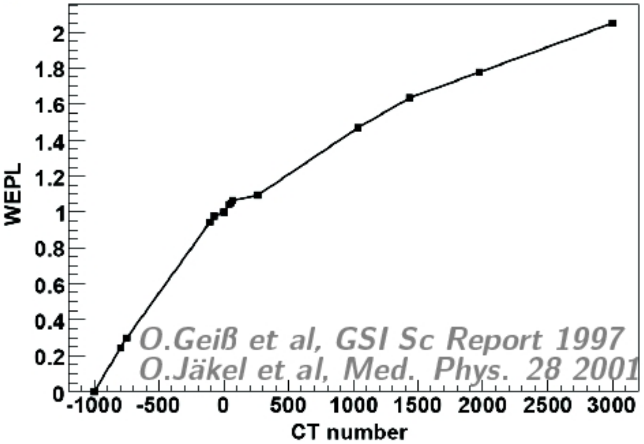
⇒

Ion treatment





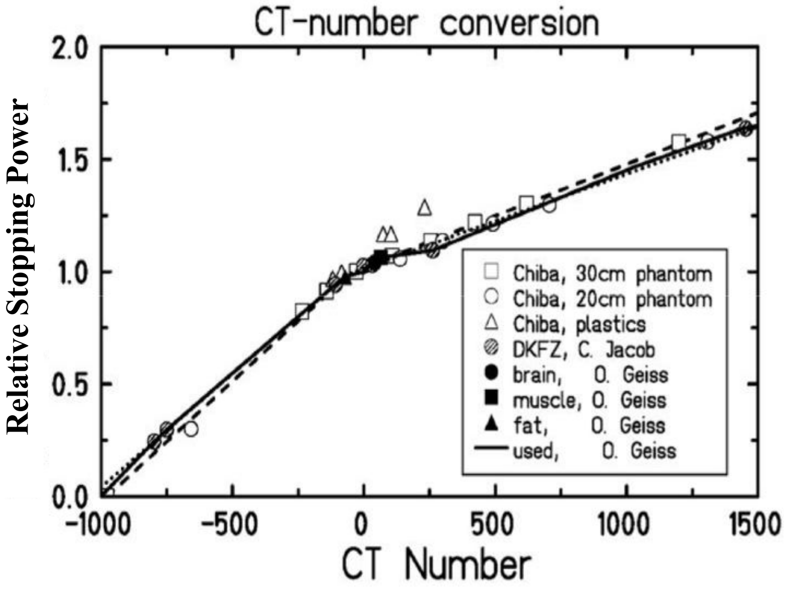
Experimental calibration curves

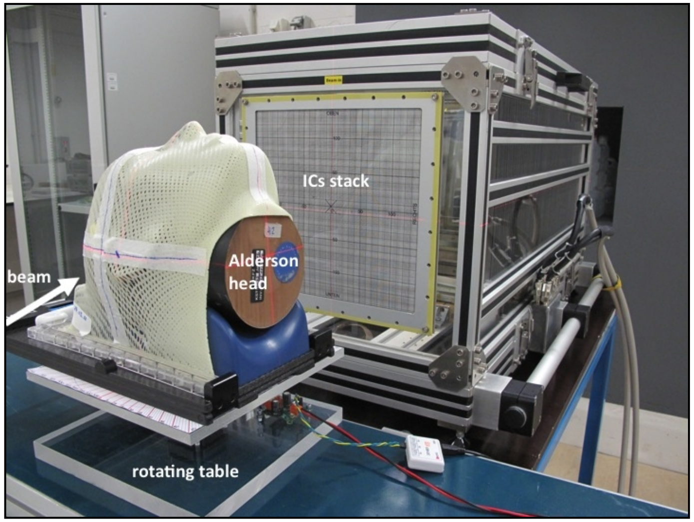


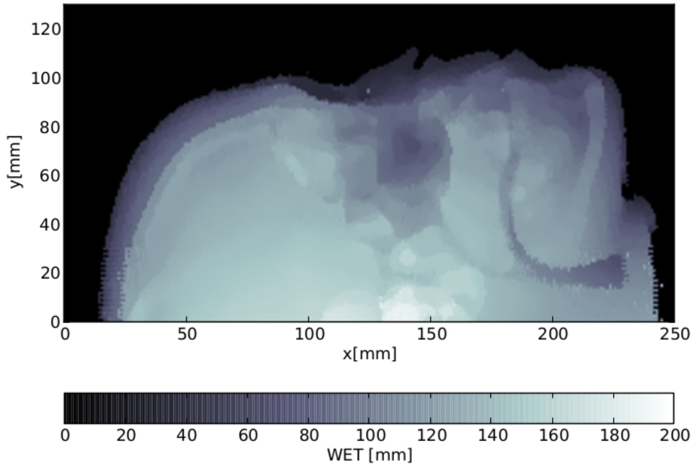
O.Geiß et al, GSI Sc Report 1997
O.Jäkel et al, Med. Phys. 28 2001

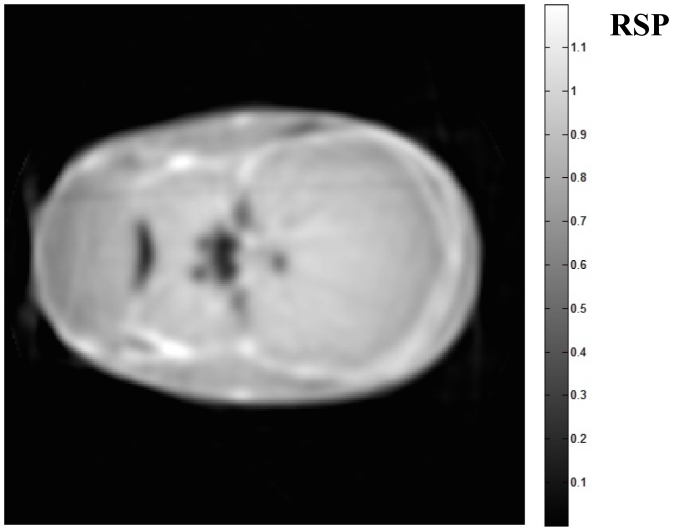
⇒ **1-3% range uncertainties**

Ion radiography and tomography





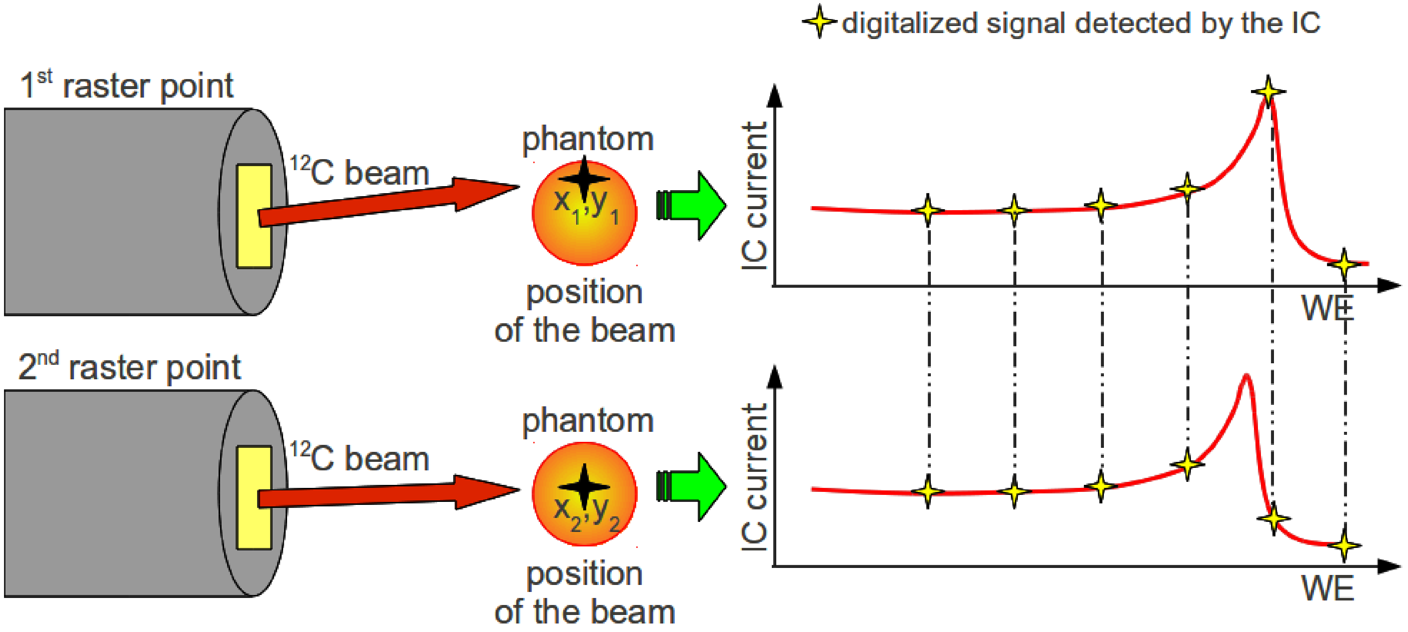


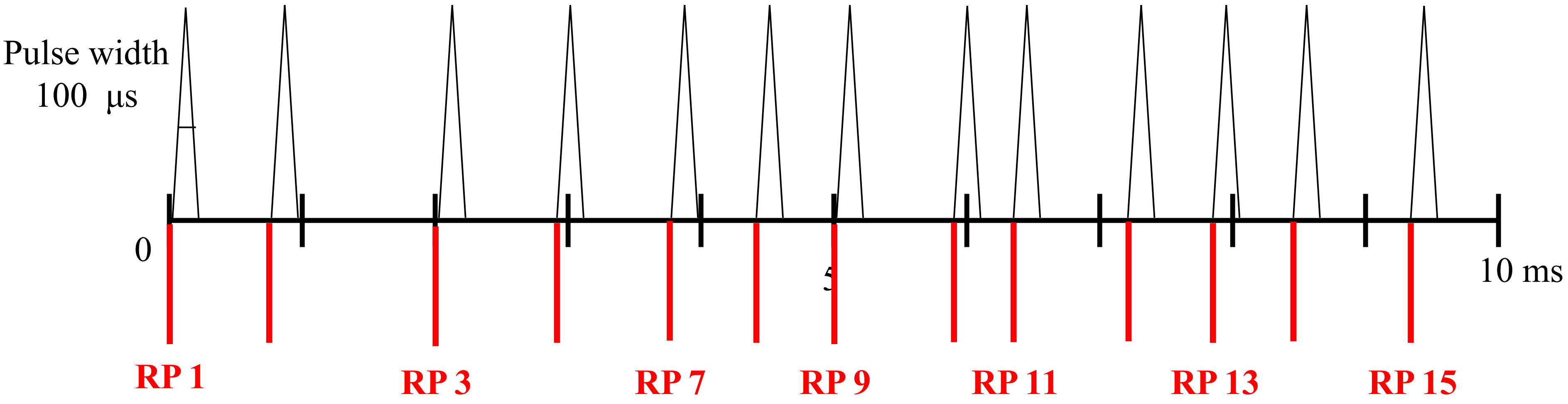


Rinaldi et a

Rinaldi et al., PMB (2014b), submitted

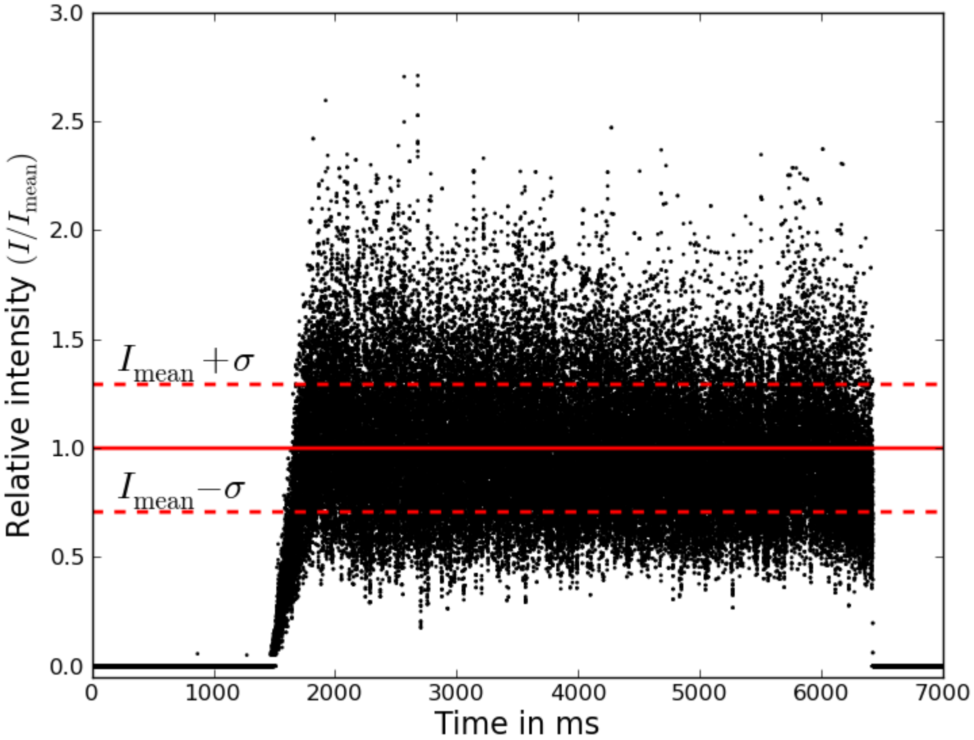
Ion radiography and tomography





Ion radiography and tomography

The beam resides at a given raster point (RP) for a certain time and then slews to the next one. The residence time at a given raster point (tRP) is not known in advance and can vary depending on the number of particles delivered in a raster point (NRP) and the beam intensity (I). In fact, tRP = NRP/I



Typical RP duration is 0.8 to 1.0 ms but they will be as short as 100 µs

Intensity fluctuations of 30%

To reduce the dose delivered to the patient we have to reduce the NRP

Ion radiography and tomography

Old → 2 Modules of I3200 Thirty two-channel Electrometer

+

A500 Real Time Controller

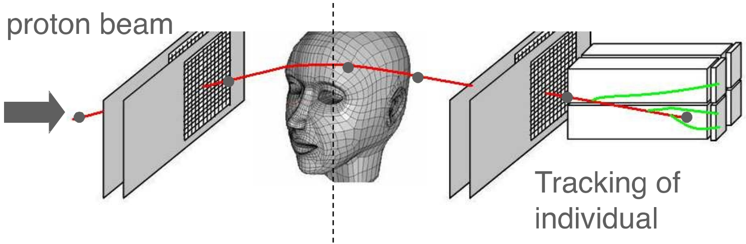
New → I128 Ionization Chamber Controller

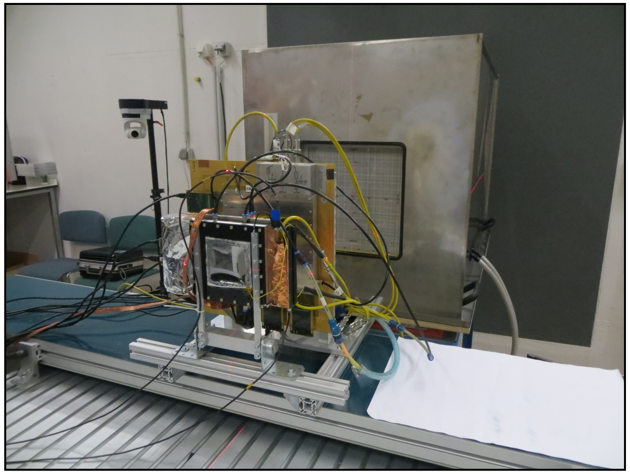
We confirmed that the unit could acquire 50000 contiguous readings at 120 μsec integration without buffer overflow, provided that the host rate was increased from 20 to 200 Hz.

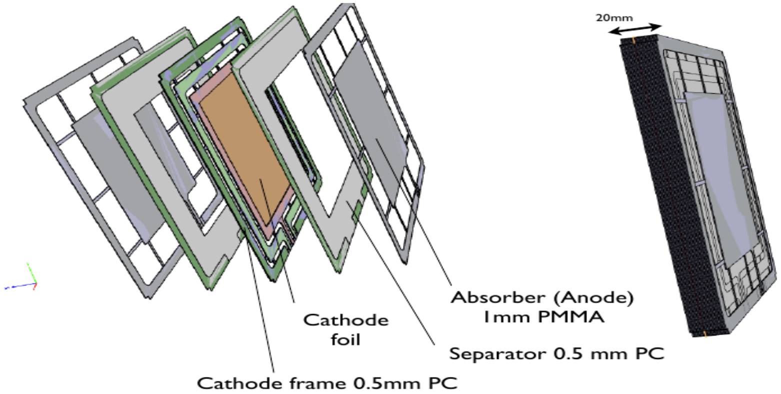
Recommendations for the I128

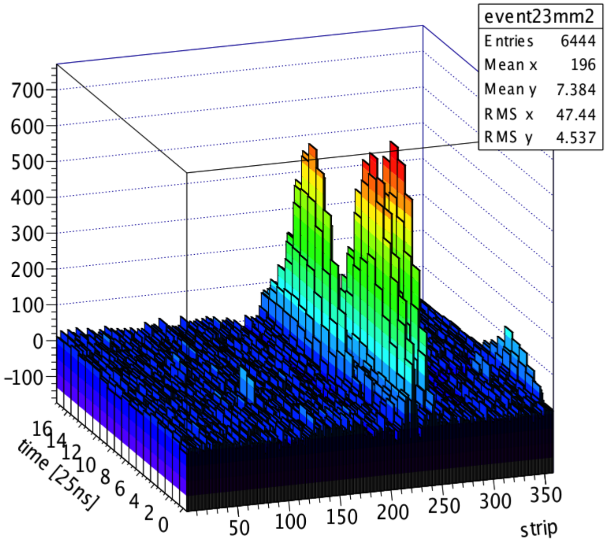
The most valuable single change will be to introduce an adaptive integration mode, where integrations are numerically averaged while the "beam on spot" gate is high, and only the final average is put in the buffer. This should give improved signal to noise without the need for post-processing, and will considerably increase the number of spots that can be acquired without overflowing the buffer.

Ion radiography and tomography





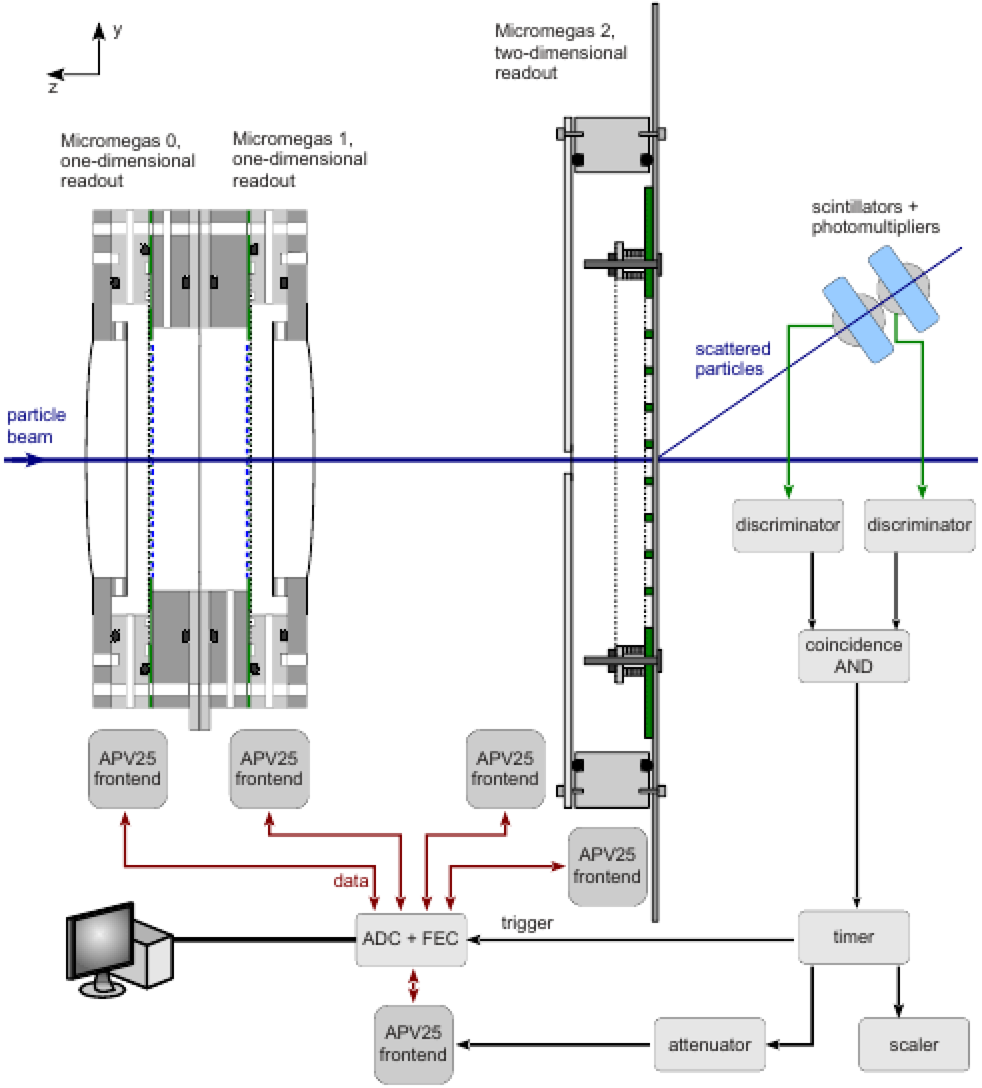


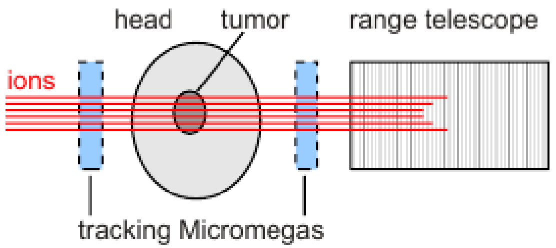


Bortfeldt, Rinaldi et al., PMB (2014), in preparation

- Improvement of the spatial resolution
- Position sensitive detectors
- Integration in clinical workflow and facilities

Ion radiography and tomography



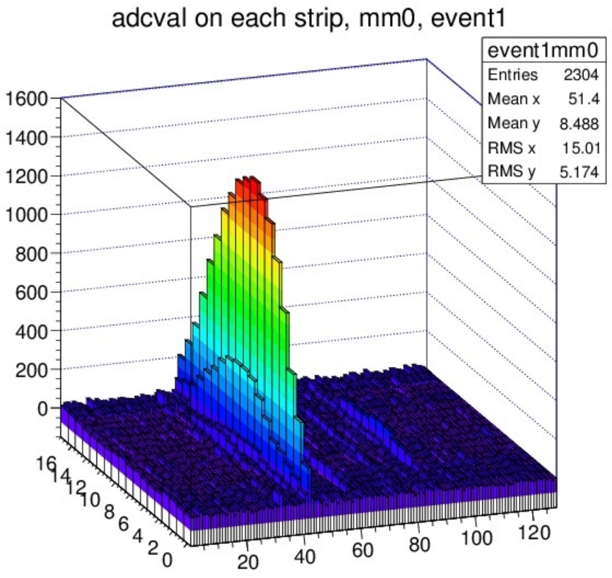


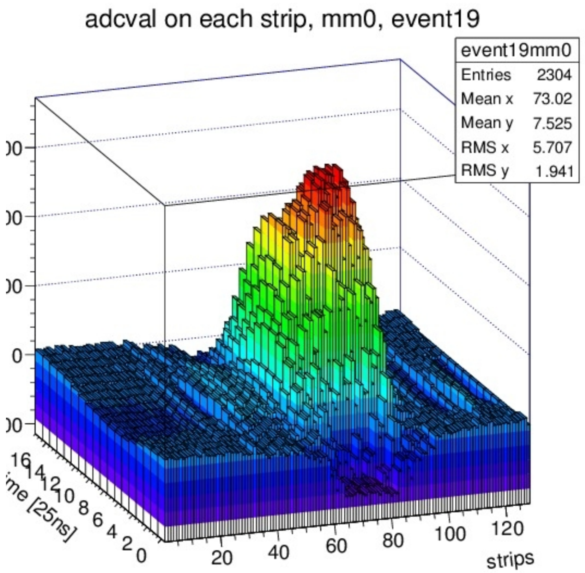
- Micromegas doublet
with 6.4×6.4 cm2 active area and
128 readout strips per layer
- resistive strip Micromegas
with two perpendicular strip planes
are read out using APV25 front-end
boards, interfaced by
the Scalable Readout System
- trigger on scattered particles,
creating coincident hits in
two scintillators.

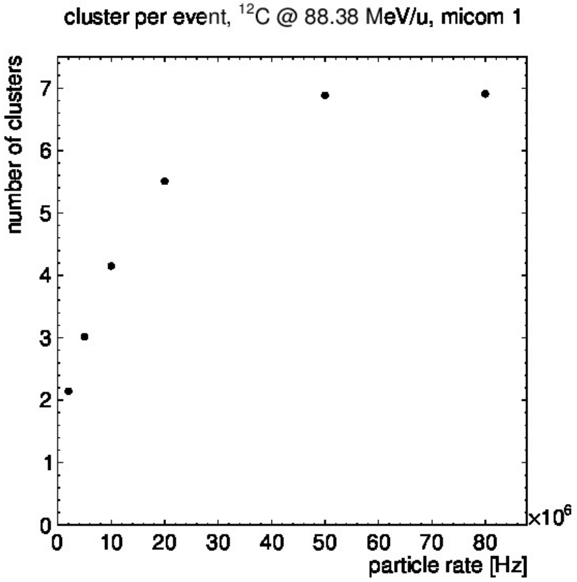
Ion radiography and tomography

Measurements with:

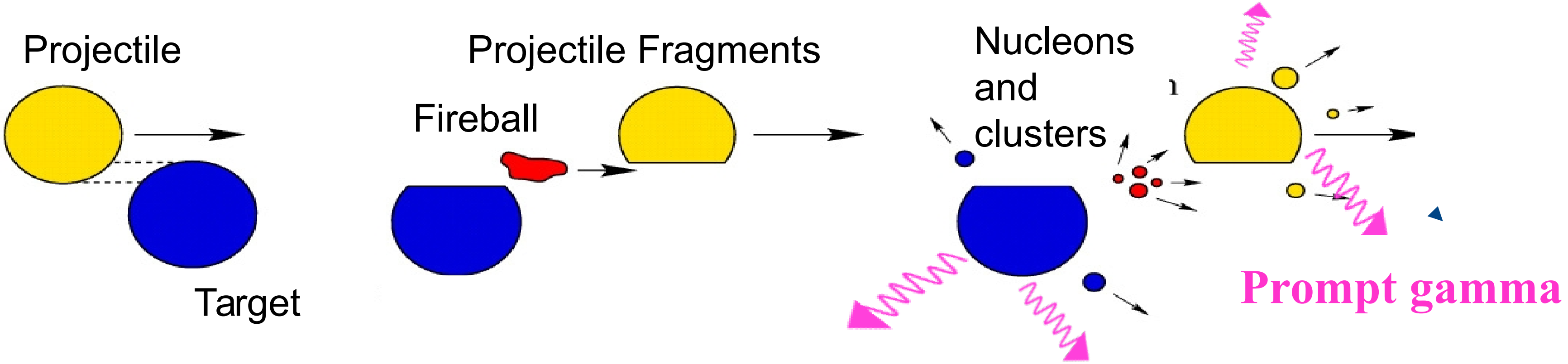
- protons with energies between 48 MeV/u and 221 MeV/u and particle rates of 80 MHz to 9 GHz
- carbon ions with energies between 88 MeV/u and 430 MeV/u particle rates of 2 MHz to 80 MHz



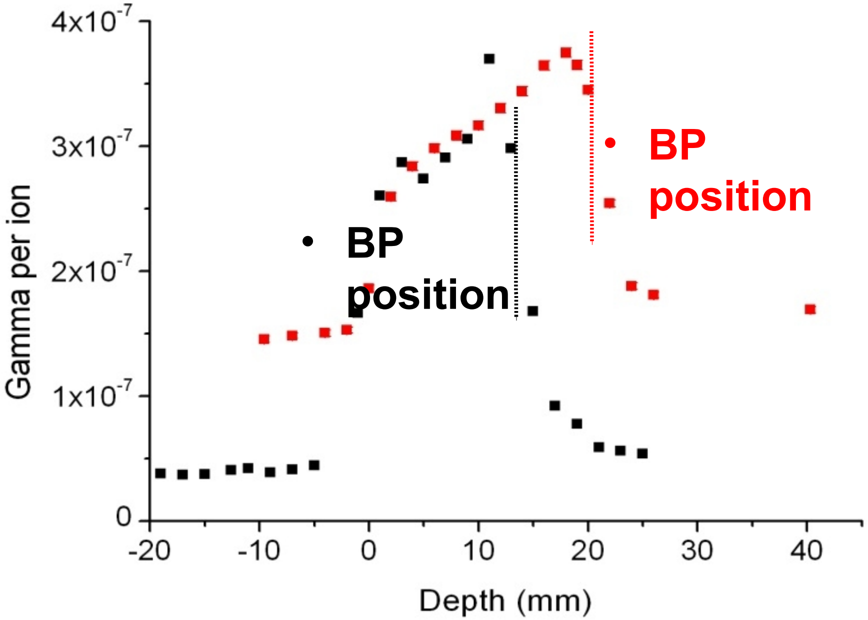




Prompt gamma based range verification



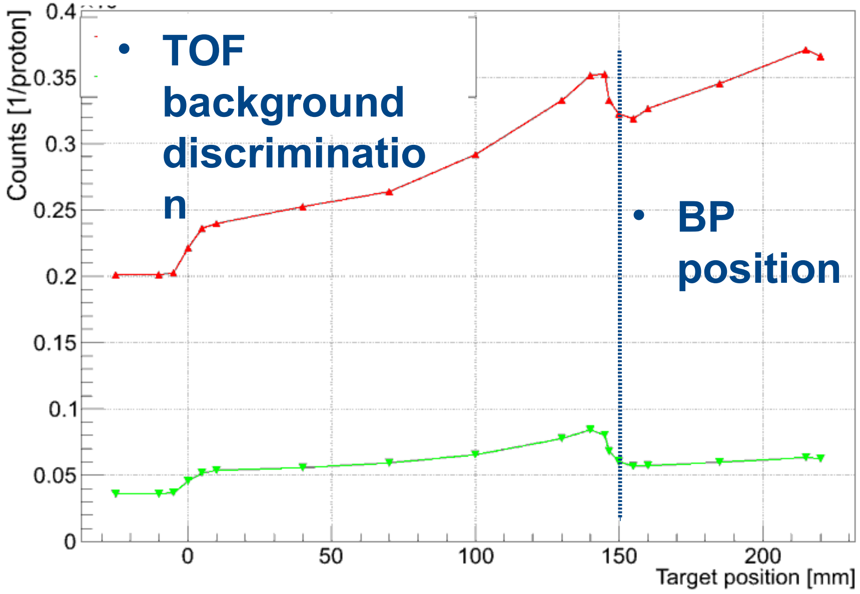
75, **95** MeV/u 12C ions on PMMA



- **BP position**

- **BP position**

160 MeV protons on PMMA



- **TOF background discrimination**

- **BP position**

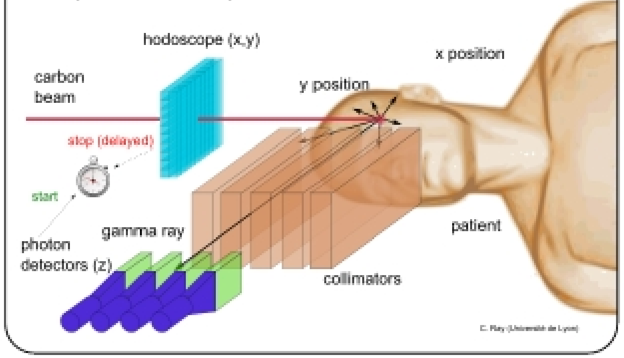
ENVISION collaboration: Dauvergne et al (IPNL Lyon), Prieels et al (IBA)

How to measure prompt gamma

Collimated camera

→ **single and multislit**

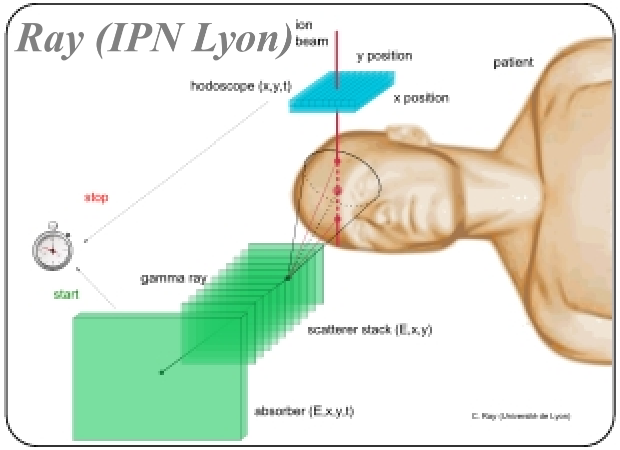
Ray (IPN Lyon)



Compton camera

→ **electronic collimation**

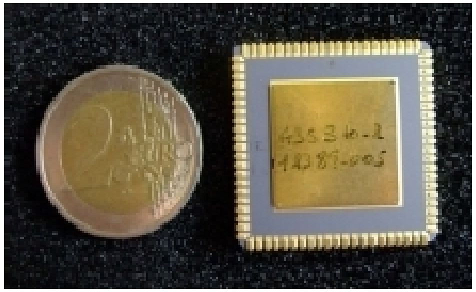
Ray (IPN Lyon)



Common device: Hodoscope

Hardware

- array of scintillating fibres (1x1 mm2)
- 2 prototypes: 2x32 and 2x128 fibres
- time resolution ≤ 1 ns
- goal: count rates up to 10^8 1/s

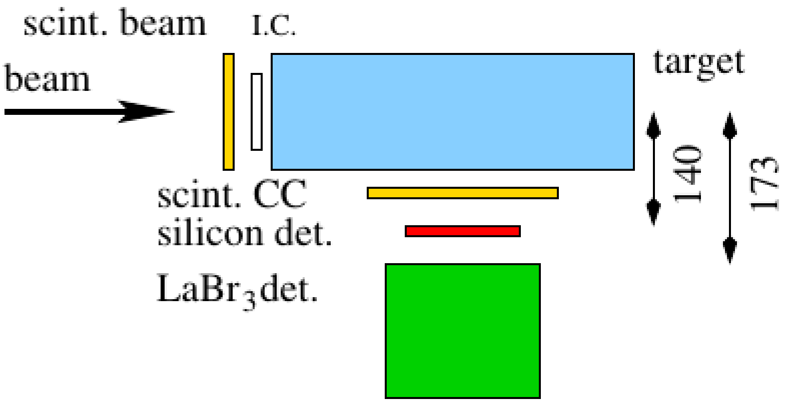


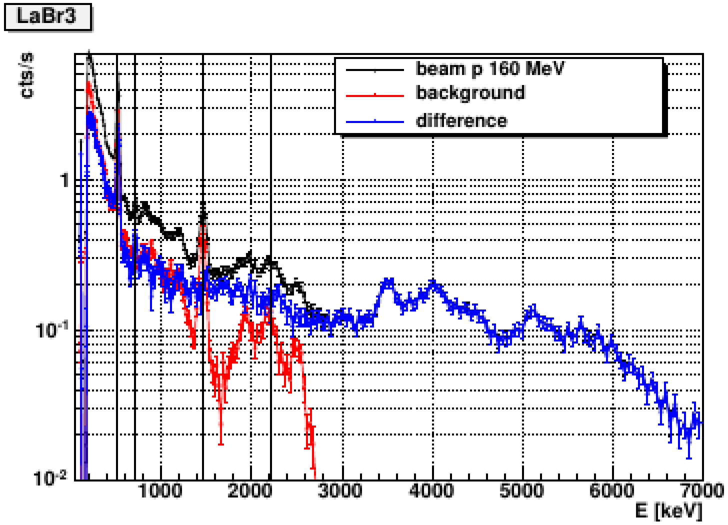
Electronics

- development of ASIC
- new version with DLL ⇒ timing

IPN Lyon

Test measurements: HIT with carbon ions





Single rates

- silicon detector: $2.5 \cdot 10^{-4}$ cts/ion (scaler, thres. 350 keV)
- absorber: $4.5 \cdot 10^{-3}$ cts/ion (scaler, thresh 180 keV)

Coincidence rates

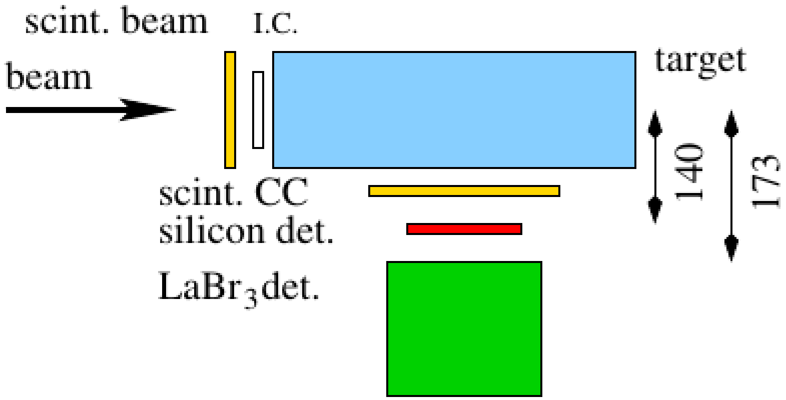
- all events: $2.6 \cdot 10^{-5}$ cts/ion (scaler)
- uncharged: $2.9 \cdot 10^{-6}$ cts/ion (software cuts)

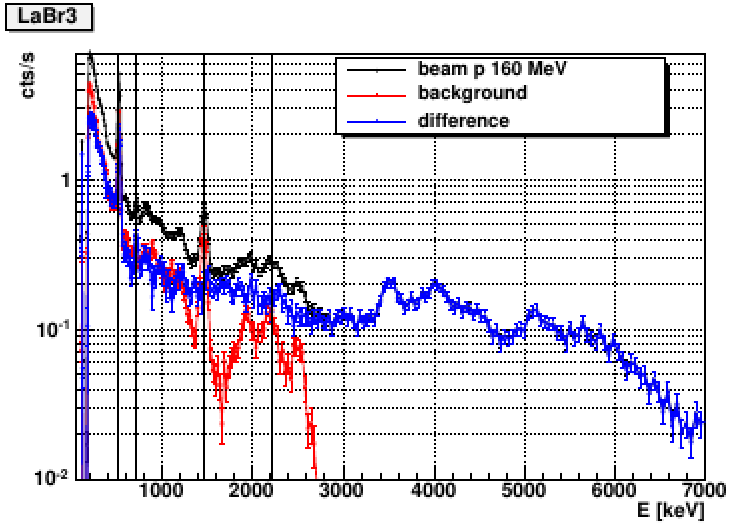
Extrapolation to prototype dimensions

- silicon det.: $1.4 \cdot 10^{-2}$ cts/ion single
- absorber: $6.6 \cdot 10^{-2}$ cts/ion single

IPN Lyon

Test measurements: HIT with protons





Single rates

- silicon detector: 8.9 · 10^{-6} cts/ion (scaler, thres. 350 keV)
- absorber: 4.3 · 10^{-4} cts/ion (scaler, thresh 180 keV)

Coincidence rates

- all events: 1.7 · 10^{-7} cts/ion (scaler)
- uncharged: 9.2 · 10^{-8} cts/ion (software cuts)

Extrapolation to prototype dimensions

- silicon det.: 5 · 10^{-4} cts/ion single
- absorber: 6.3 · 10^{-3} cts/ion single

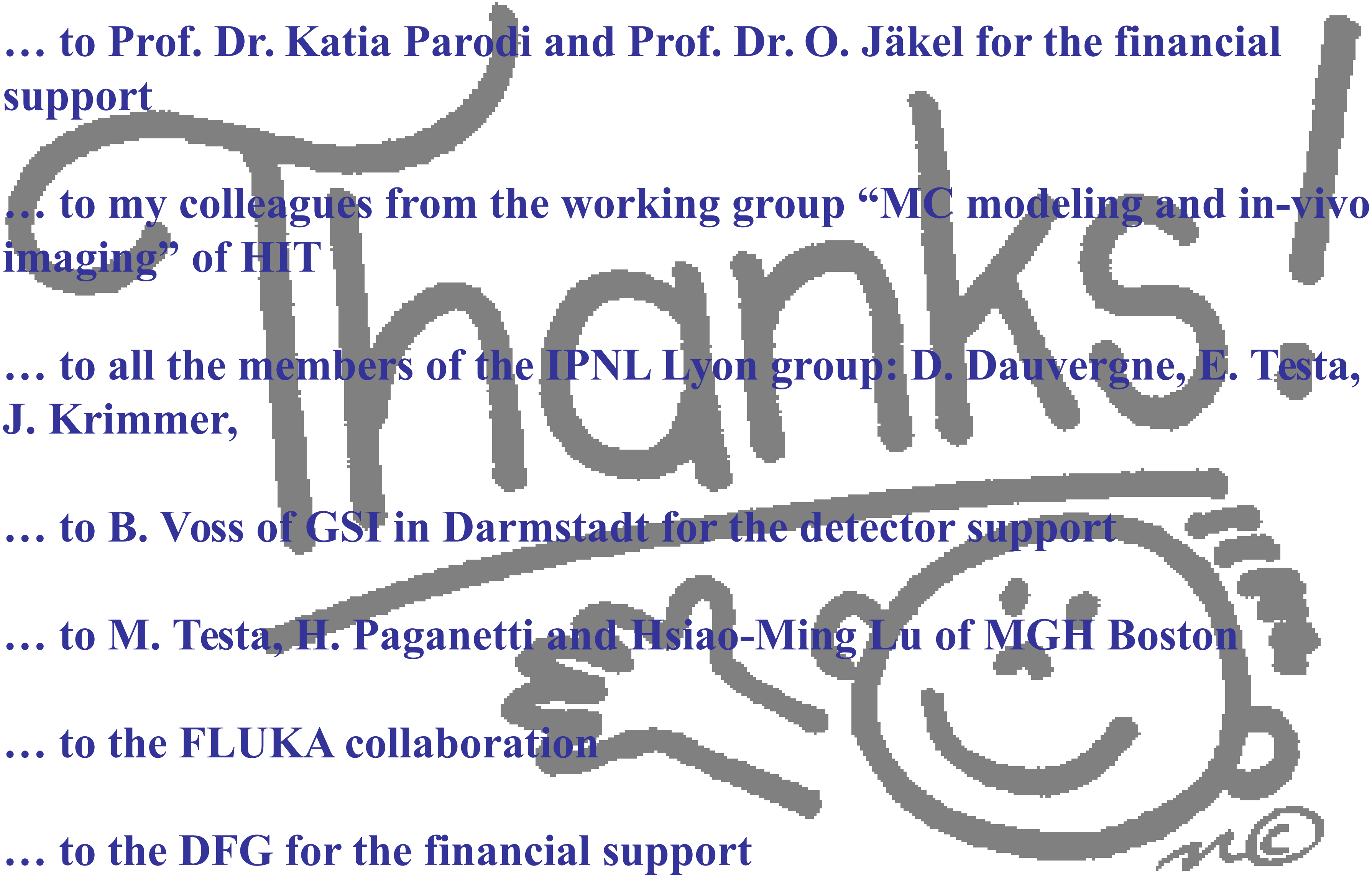
For proton therapy conditions (1010 p/s)

absorber needs to be segmented

IPN Lyon

Thank you

Acknowledgements



… to Prof. Dr. Katia Parodi and Prof. Dr. O. Jäkel for the financial support

… to my colleagues from the working group “MC modeling and in-vivo imaging” of HIT

… to all the members of the IPNL Lyon group: D. Dauvergne, E. Testa, J. Krimmer,

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… to M. Testa, H. Paganetti and Hsiao-Ming Lu of MGH Boston

… to the FLUKA collaboration

… to the DFG for the financial support