532. Wilhelm und Else Heraeus-Seminar

Development of High-resolution Pixel Detectors and their Use in Science and Society
Bad Honef, 25.5.2013

The Timepix detector for ion beam radiotherapy applications

M. Martišíková[1,3], C. Granja[2], J. Jakůbek[2], B. Hartmann[1,3], K. Gwosch[1], P. Soukup[2] and O. Jäkel[1,3,5]

1 UniversitätsKlinikum Heidelberg

2 Institute of Experimental and Applied Physics
Czech Technical University in Prague

3 dkfz. German Cancer Research Center
Heidelberg

4 Medipix Collaboration

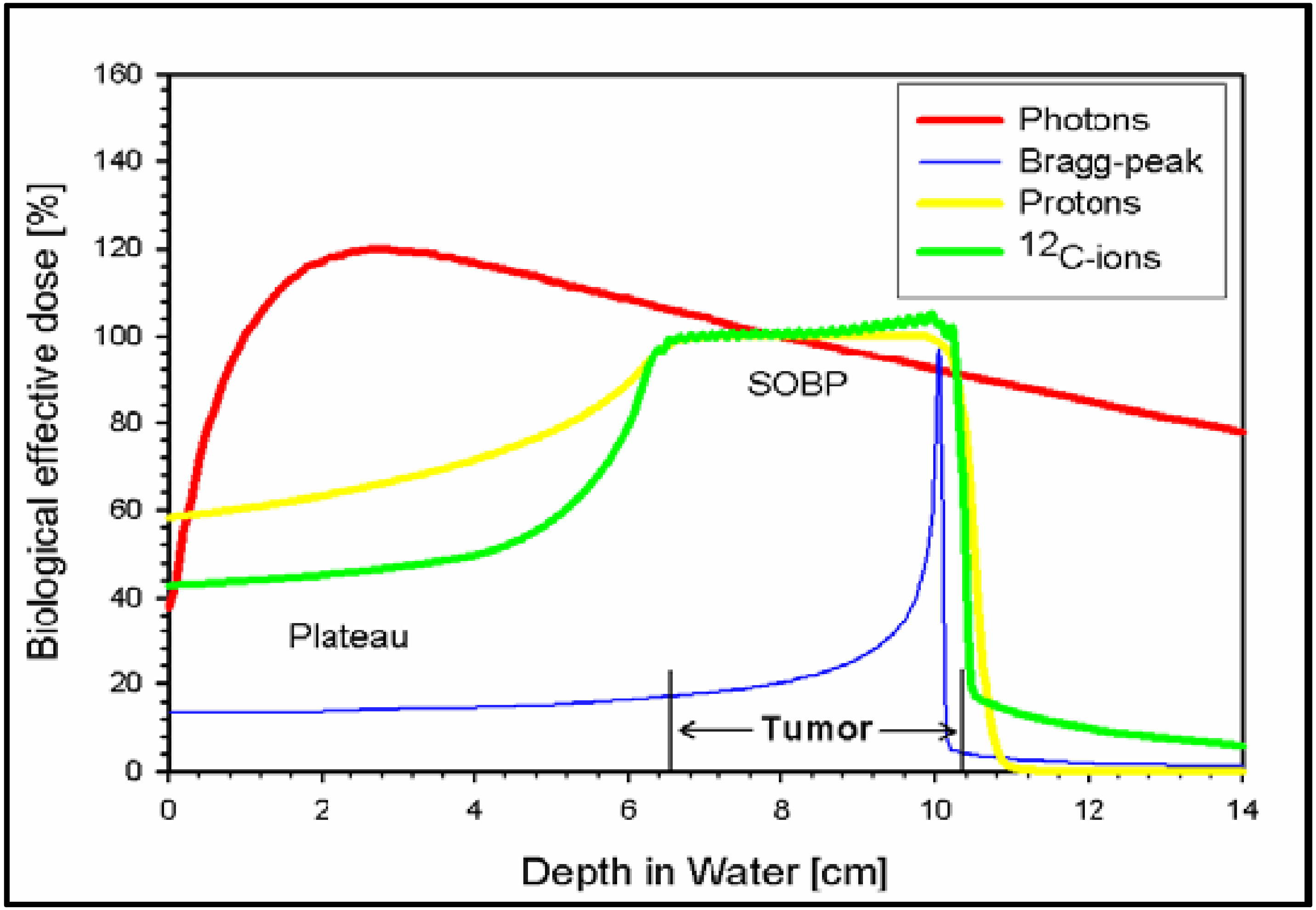
5 HIT Heidelberger Ionenstrahl-Therapiezentrum

Outline

1. **Ion beam radiotherapy**
2. **Timepix detector**
3. **Studies** for - ion spectroscopy

   - beam monitoring within the patient

Ions vs. photons



Dose conformity to the target better than for photons due to Bragg peak

Charged hadron beam therapy in the world

Facilities

	Protons	C-ions	combined
Europa	9		2
North America	10		
Asia	6	4	1
Afrika	1		

Data: Particle Therapy Cooperative Group, March 2013

Get the most for the patient!

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2. **Timepix detector**
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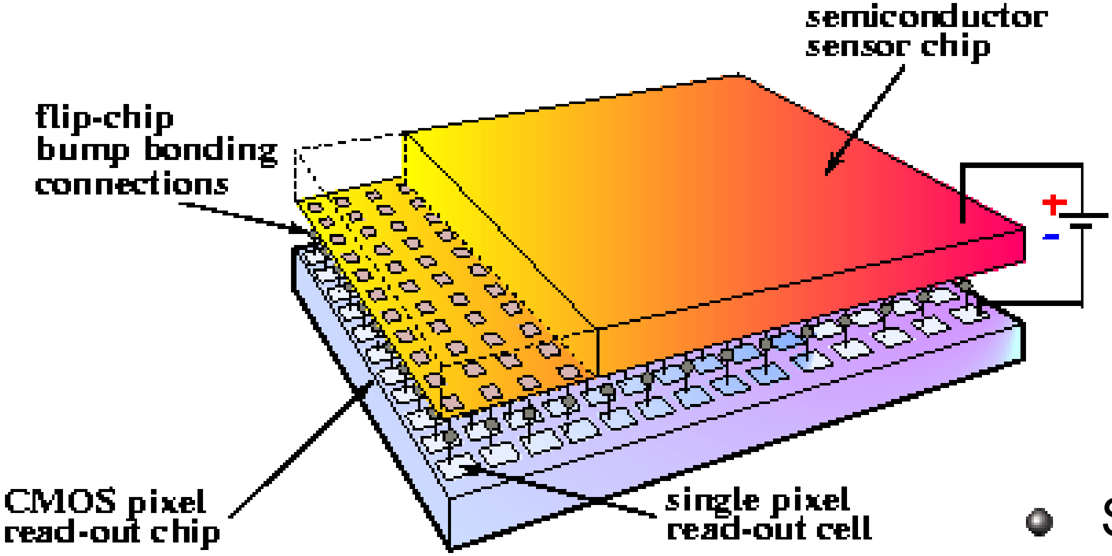
Timepix detector from the Medipix family

Pixel hybrid detector



by the Medipix Collaboration

- Sensor chip: **300 μm thick crystalline silicon**
- Area 1.4 x 1.4 cm^2
- Pixel size **55 x 55 μm^2**
- **USB-based readout FITPix**: Plug & Play with any PC
- Measurement of time of arrival and deposited energy

Outline

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Towards ion spectroscopy

Nuclear fragmentation of carbon ions in tissue has to be taken into account in therapy planning:

$$\boxed{D_{biol} = RBE\left(Z, E, \ldots\right) \cdot D_{physical}}$$

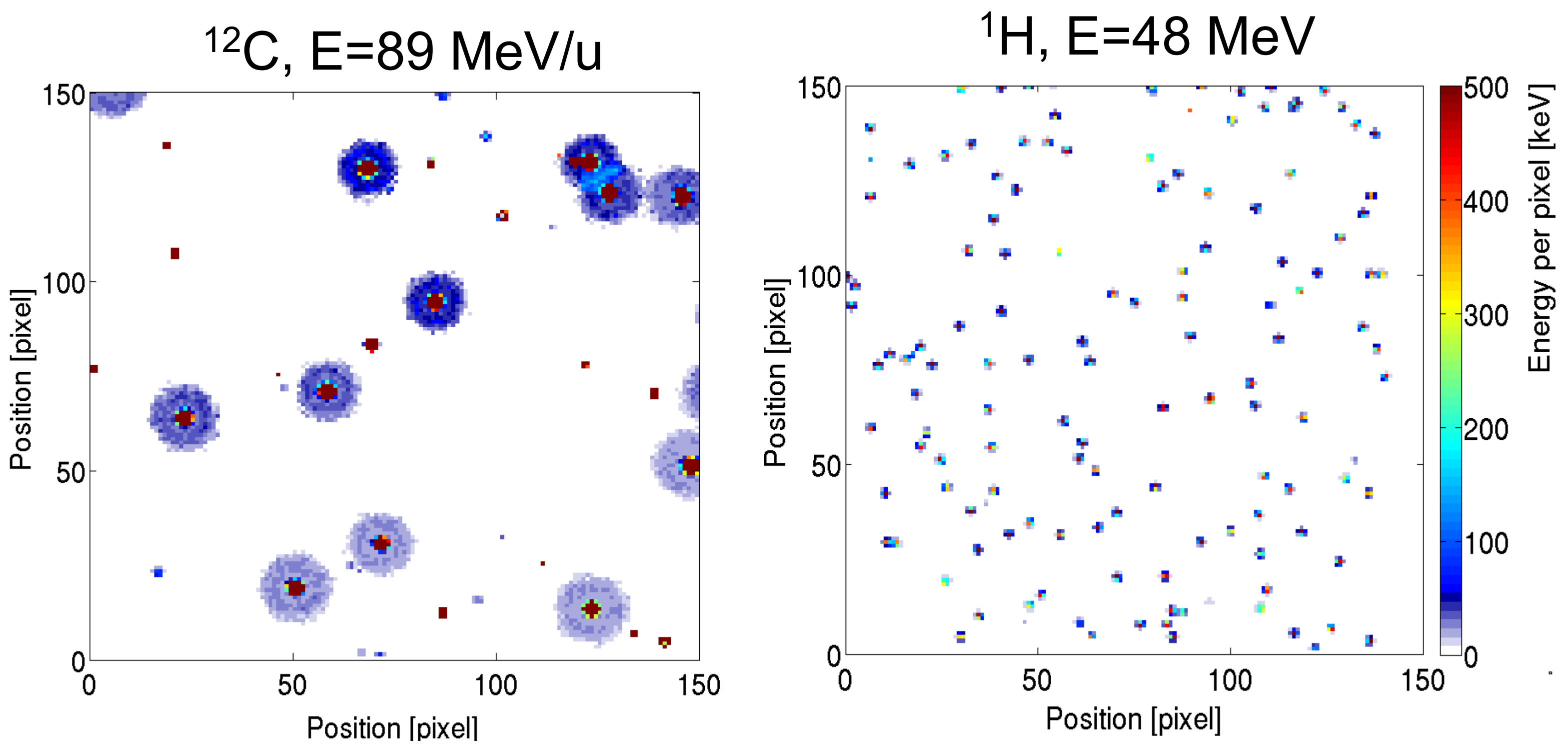
However, only small amount of experimental data available

Problem: the size and complexity of the experiments

Goal: To develop a method capable of collecting large data sets in therapy relevant situations

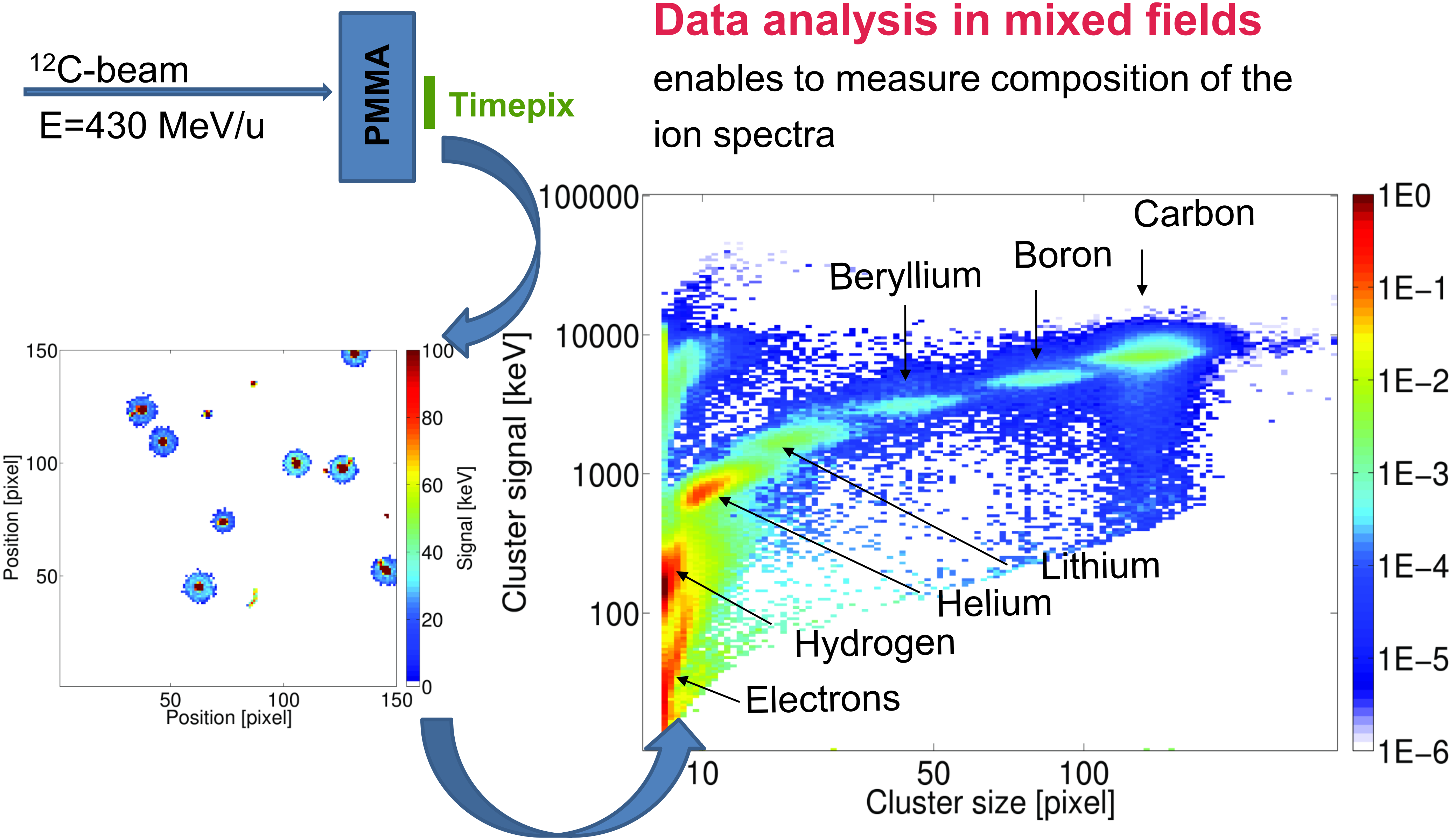
Towards ion spectroscopy

Timepix signal for different ions with the same range in water



PhD-work of Bernadette Hartmann

Towards ion spectroscopy



Data analysis in mixed fields

enables to measure composition of the ion spectra

B. Hartmann, 1. student award at IEEE Nuclear Science Symposium in Anaheim, USA, 2012

Monitoring with secondary ions

Biological changes during the therapy
Organ motion
Incorrect patient positioning

→ **change of the ion range**

→ **the delivered dose distribution can differ from the planned one**

Overdose outside of the target → damage on healthy tissue

Underdose inside of the target → risk of tumor recurency

→ **Important to know whether the dose was delivered correctly**

Monitoring with secondary ions

PET-monitoring is applicable for proton and carbon ion beams

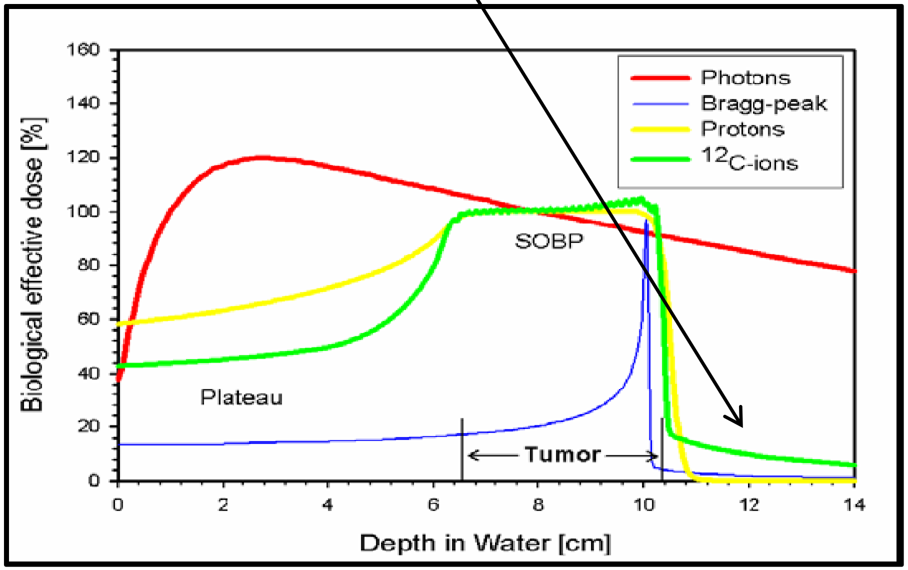
*Parodi et al NIMA **591** p.282 (2008)*

Limitations: - low induced activities in comparison to diagnostics
- movement of beam-activated nuclei (physiological washout processes)

*Knopf et al PMB **54** p.4477 (2009)*

Alternative approaches exploit prompt radiation:

- **Photons**
- **Secondary ions** *[Amaldi et al. NIMA 617 (2010)]*



Predicted advantages:

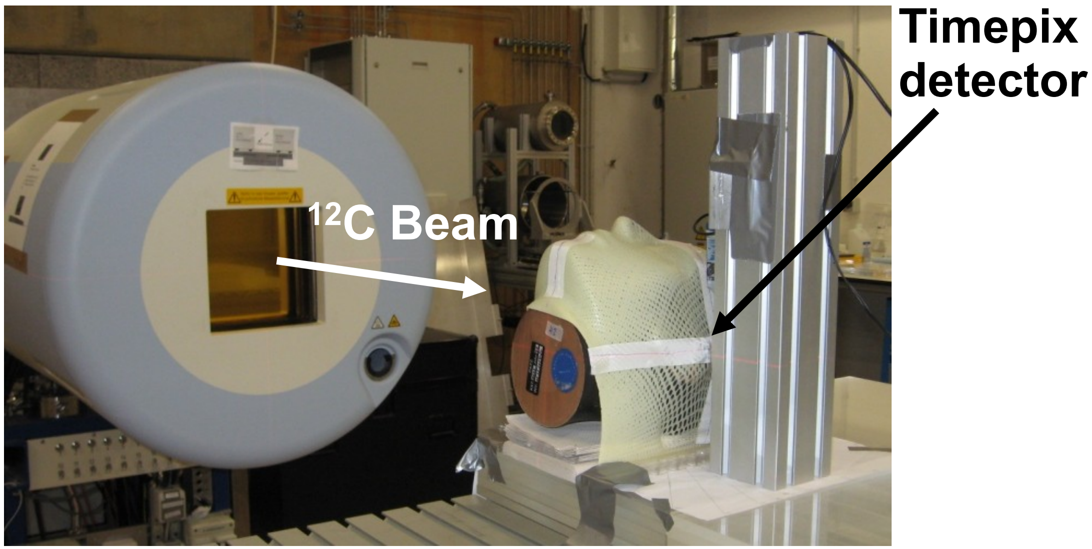
- Originate in prompt processes

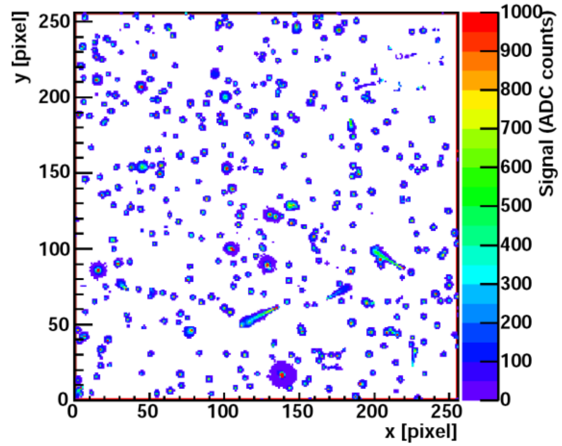
→ less influenced by biological washout
→ no prolongation of time-on-couch due to measurements

- high yield ≈ 0.1/ primary ^{12}C
[Henriquet et al PMB 57 (2012) 4655]

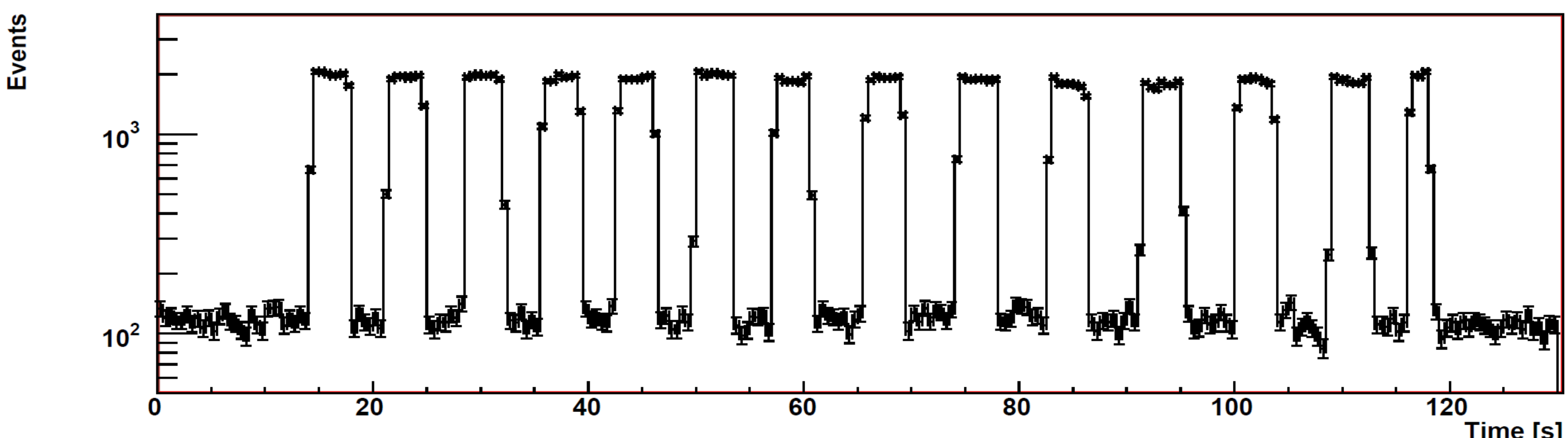
Monitoring with secondary ions

Can we register secondary ions leaving the patient?





E=88.8 MeV/u, r_{water}=2 cm



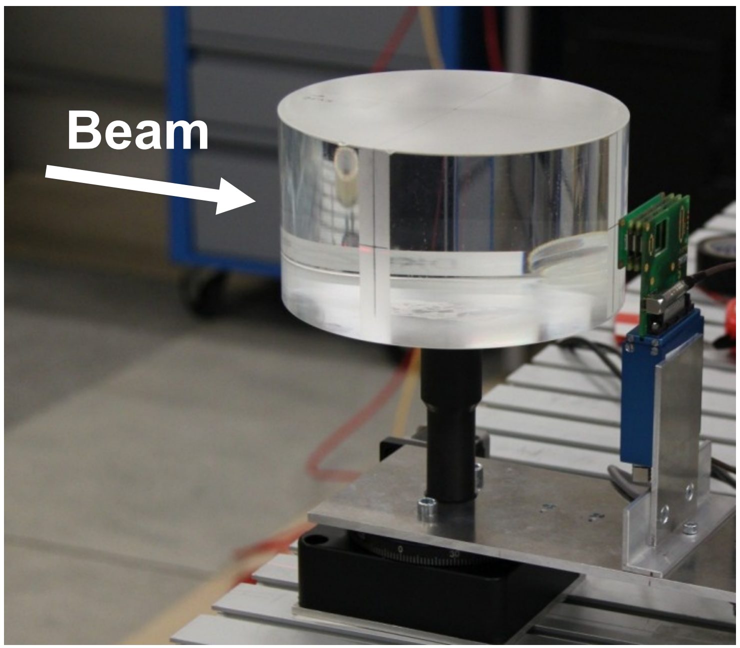
Temporal behaviour of the signal: prompt on the measurement scale

M. Martišíková et al. JINST 6 C11014 (2011)

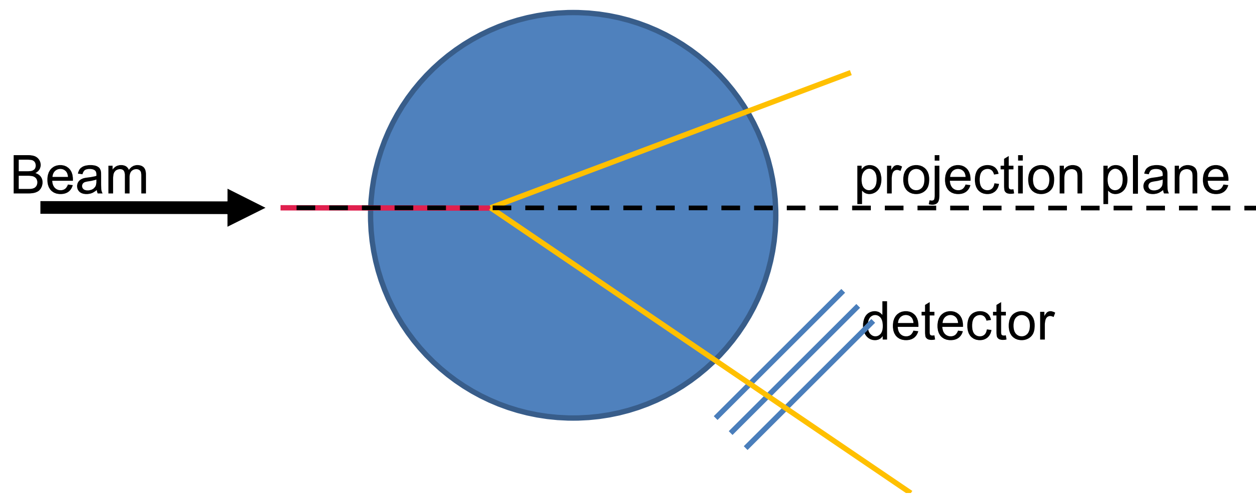
Monitoring with secondary ions

Can we determine the beam properties from tracking of secondary ions?

Homogeneous phantom

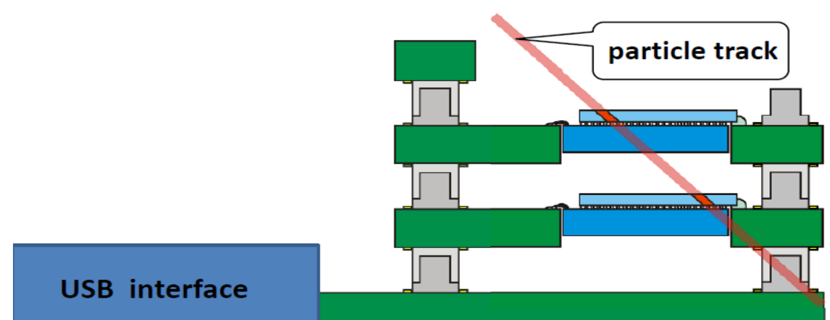


No info on secondary ion origin
→ simple extrapolation technique used



Measurement of impact time:
→ **Coincident particle hits**
→ **Particle direction**

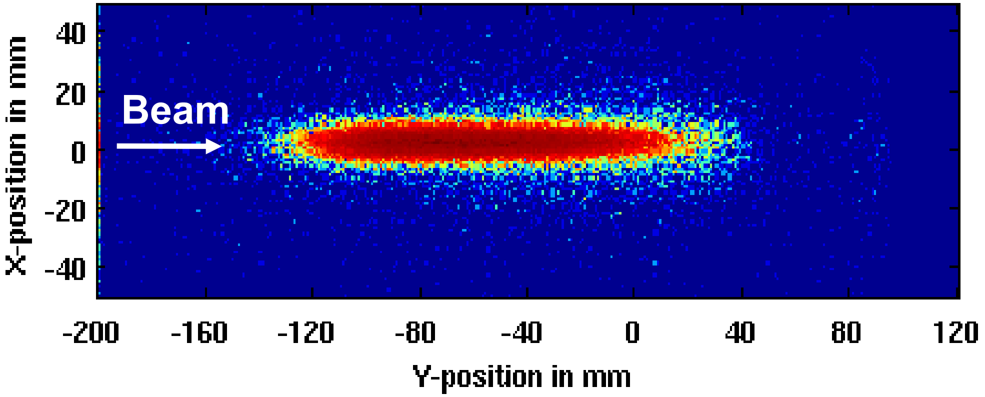
J. Jakubek et al. 2011 JINST 6 C12010



P. Soukup et al. 2011 JINST 6 C01060

Monitoring with secondary ions

Projections of the measured ion tracks to the projection plane:



Analysed for sensitivity to:

- beam energy / range
- beam width
- beam position

K. Gwosch: Diploma Thesis, University of Heidelberg 2012

Summary & Conclusions

Radiotherapy with ion beams:

♦ Physical and biological potential for highly localized dose deposition
♦ Dedicated detection methods necessary to use this advantage for patients

♦ **Pixelized silicon detectors**: - high spatial resolution and online readout
- up to now rarely used for ion beam radiotherapy

Timepix detector: provides imaging of **single ion tracks**
+ measurement of **particle impact time**
+ signal dependent on their **energy deposition** in silicon

Summary & Conclusions

1) Ion spectroscopy for therapy planning:

✓ directly in the phantom
✓ promising for ion discrimination
as needed for fragmentation studies

2) Studies towards ^{12}C beam monitoring exploiting tracking of secondary ions:

- Monitoring in the **homogeneous phantom**:
  - beam position: σ = 0.2 mm
  - beam width: σ = 0.9 mm
  - correlation with range: within 1.3 mm / < 3 mm depending on the method

Acknowledgements

UniversitätsKlinikum
Heidelberg

Deutsches
Krebsforschungszentrum
Heidelberg

Bernadette Hartmann
Klaus Gwosch
Julia Telsemeyer
Lucas Huber
Oliver Jäkel

Heidelberger Ionenstrahl-Therapiezentrum

Stephan Brons
Benjamin Ackermann
Jakob Naumann

Institut of Experimental and Applied Physics of the CzechTechnical University in Prague

Carlos Granja
Jan Jakůbek
Pavel Soukup
Lukáš Opálka
Stanislav Pospíšil

The presented work was conducted in frame of the **Medipix-Collaboration**

Grants: DFG: MA 4437/1-2

Olympia Morata Programm der Universität Heidelberg

Deutsche Krebshilfe