

# ION BEAMS IN BIOLOGY AND MEDICINE

Heidelberg

26 – 29 IX 2007

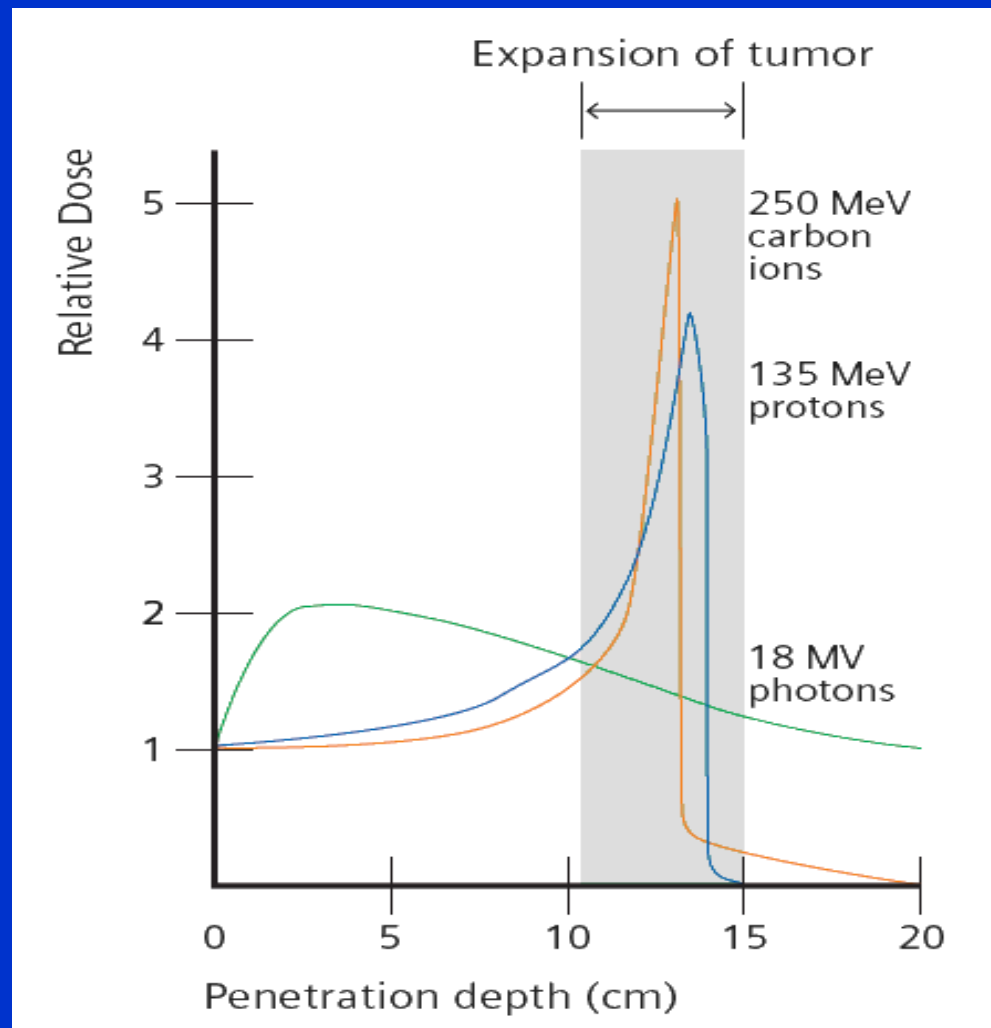
198 uczestników z całego świata

Opracowanie : Dr Krystyna Wosińska

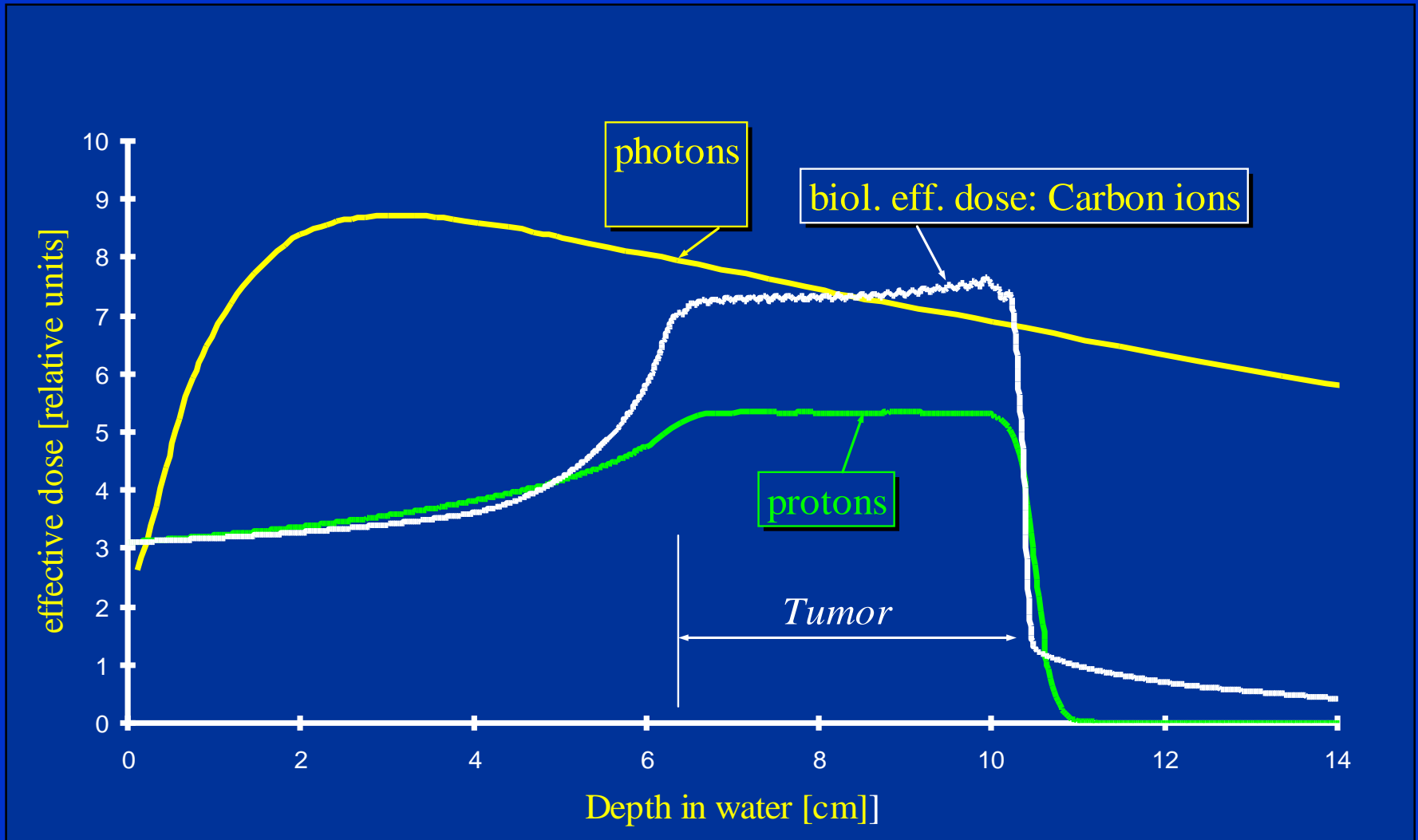
# Plan

- Dlaczego wiązki jonów?
- Kształtowanie wiązki – 2 podejścia.
- Zderzenia jonów z jądrami – straty i korzyści.
- Leczenie ruchomych organów.
- Ośrodki terapii wiązkami jonów na świecie.

# Dlaczego wiązki jonów?



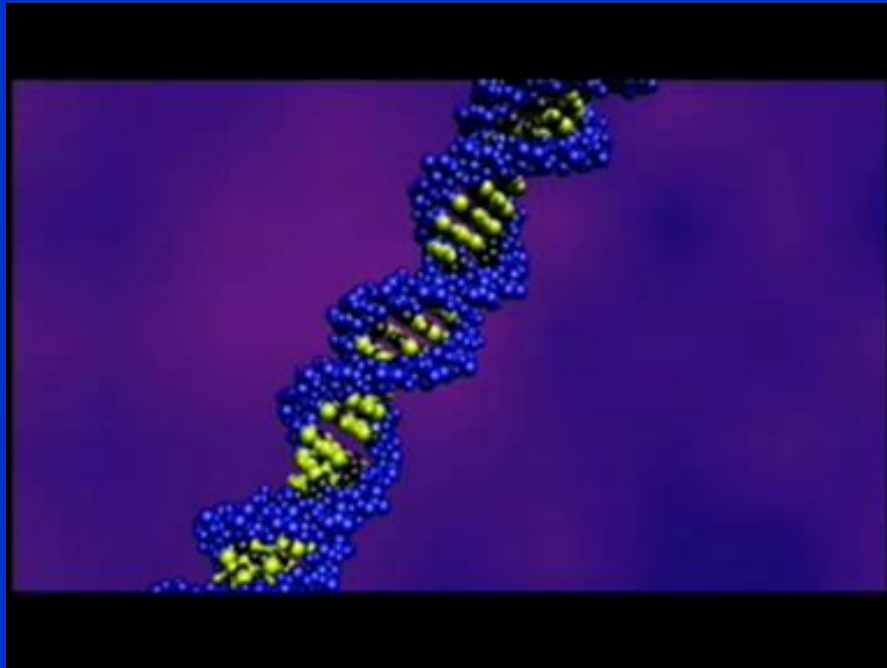
# Dlaczego wiązki jonów?



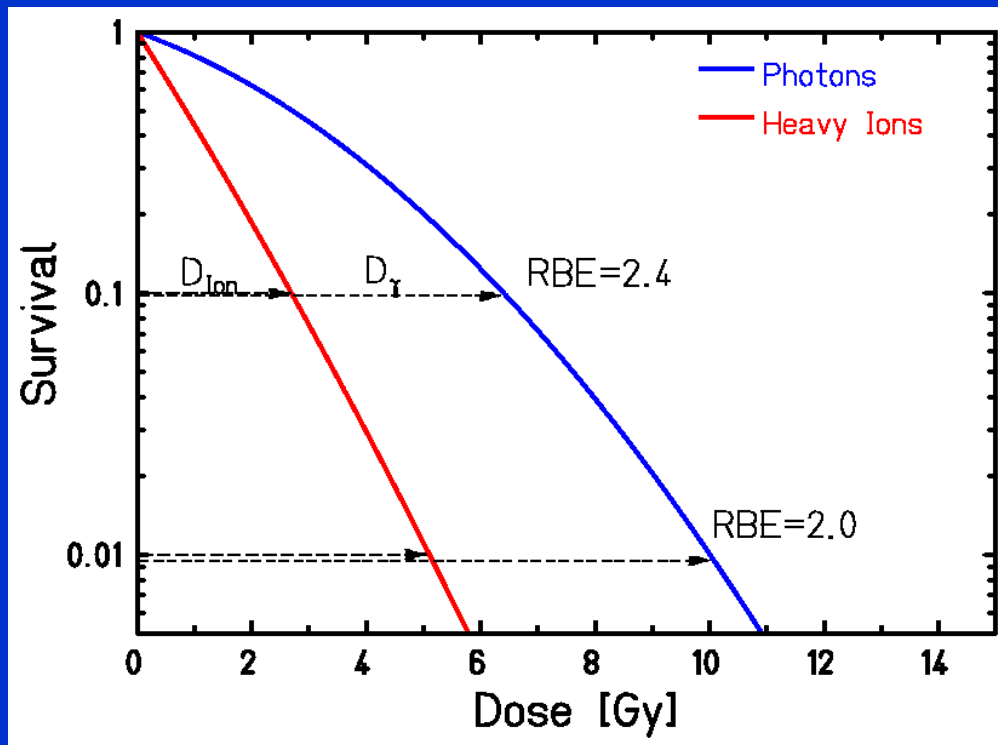
# Dlaczego wiązki jonów?

- Jon węgla deponuje w komórce około 23 razy więcej energii niż proton o tym samym zasięgu.
- Efekty naświetlania jonami komórek są jakościowo różne niż naświetlania fotonami i protonami:

jony powodują więcej nieodwracalnych uszkodzeń DNA w jądrze komórki.



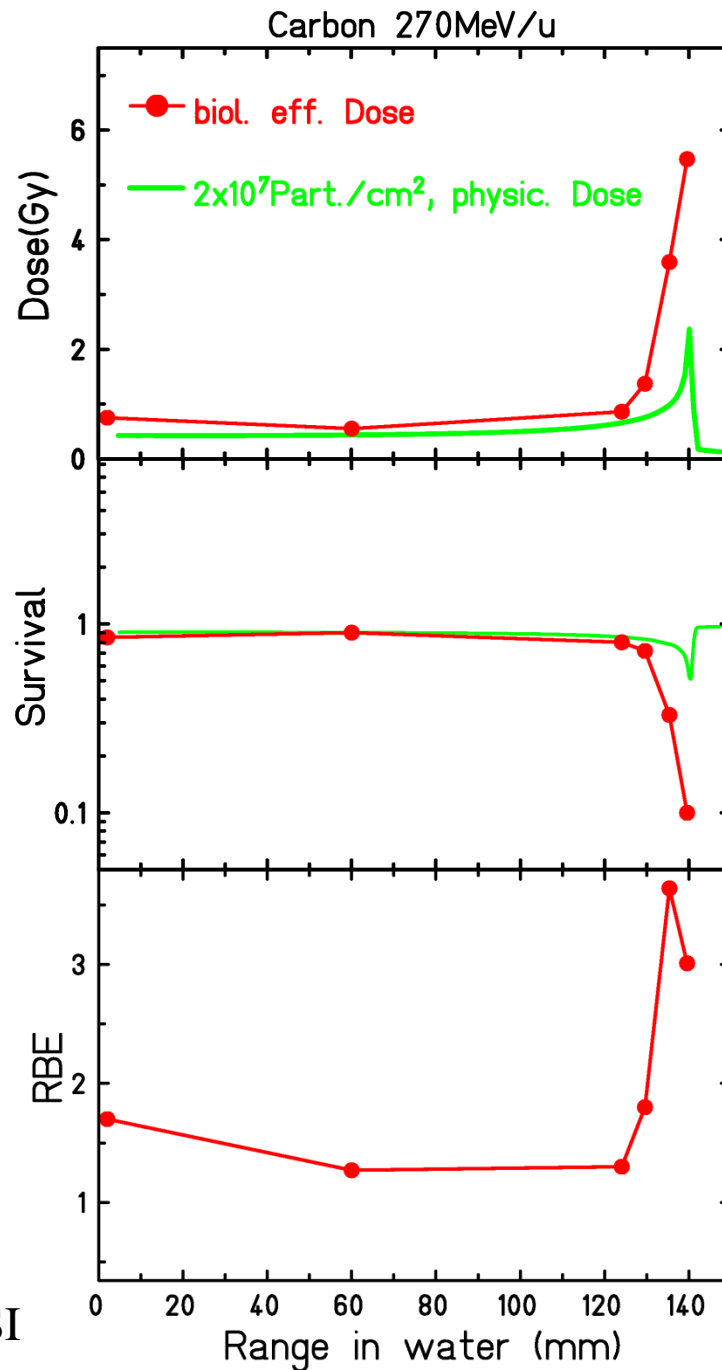
# Definicja RBE (Relative Biological Effectiveness)



$$RBE = \frac{D_{\gamma}}{D_{Ion}} \Big|_{Isoeffect}$$

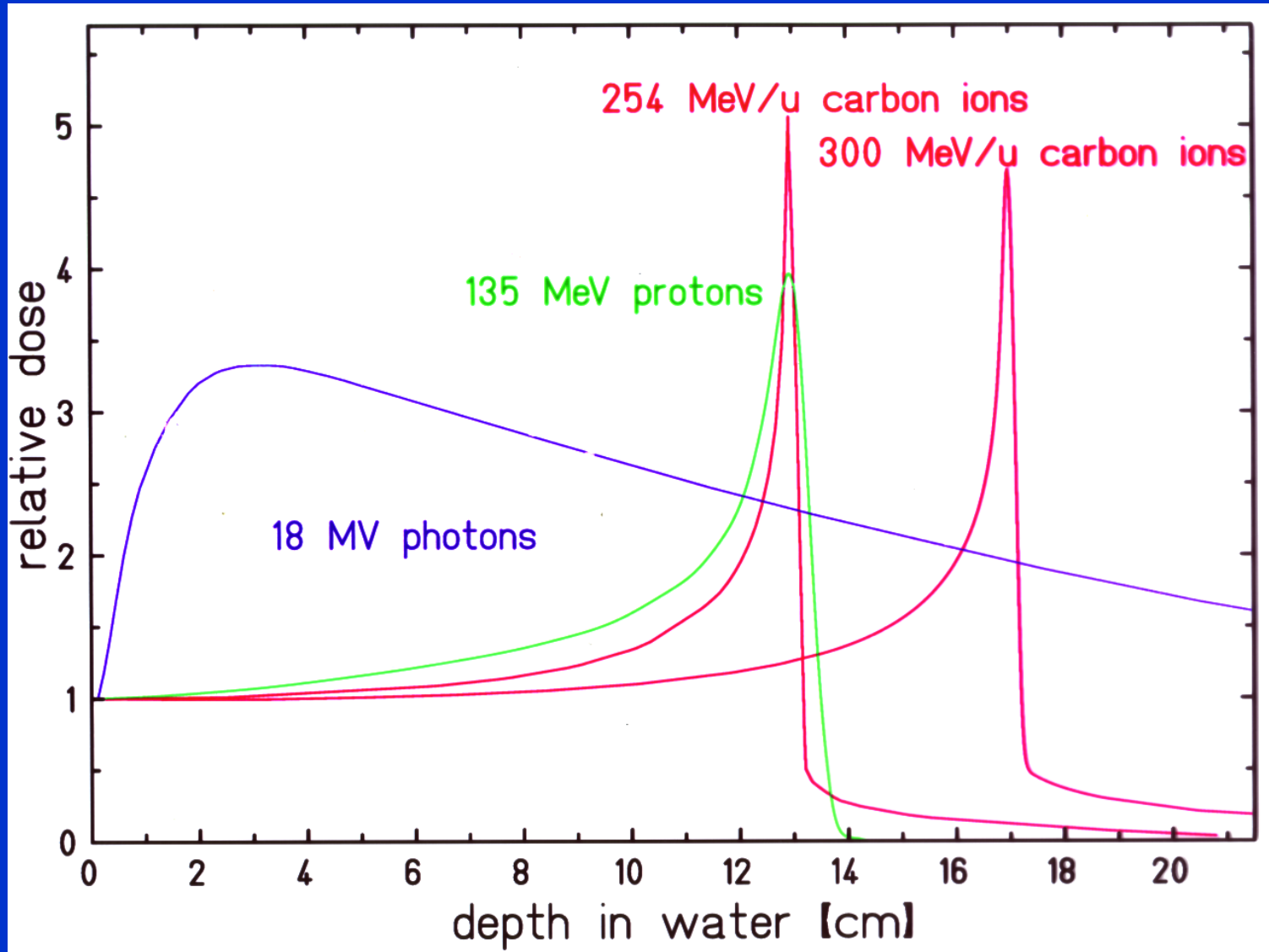
RBE zależy od dawki, LET (Linear Energy Transfer),  
typu komórki...

# Definition of the biological effective dose



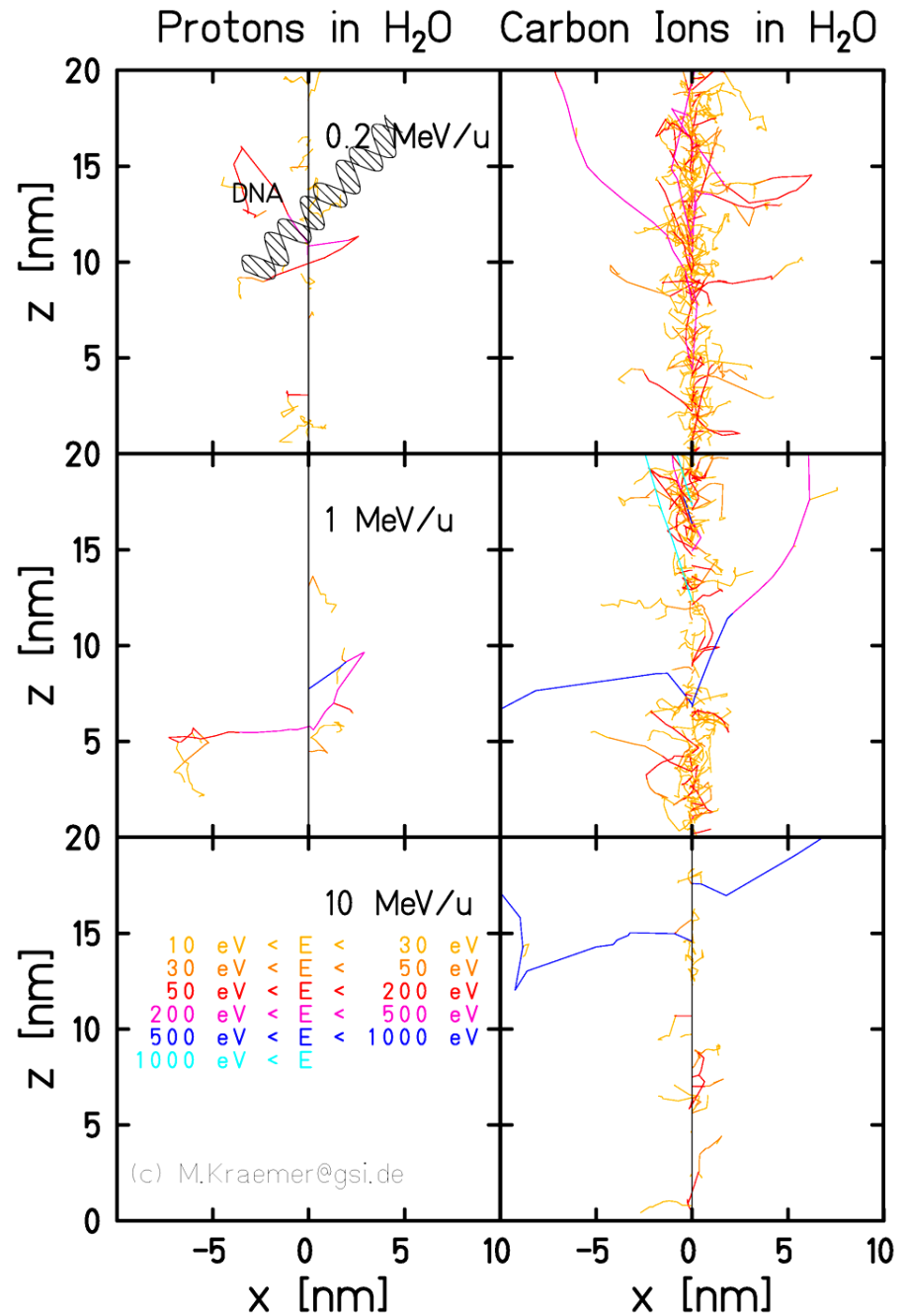
W. K. Weyrather, GSI

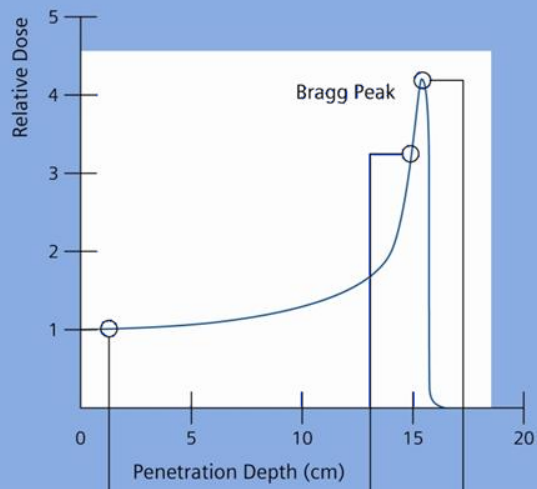
# Dlaczego wiązki jonów?





# Rozkład dawki w komórce (nanometry)

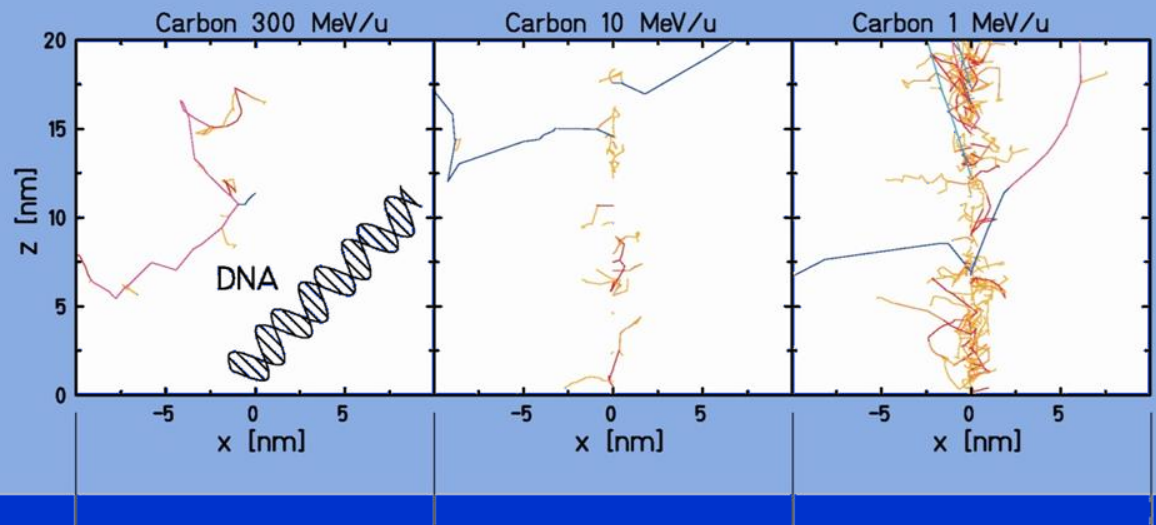




1

2

3

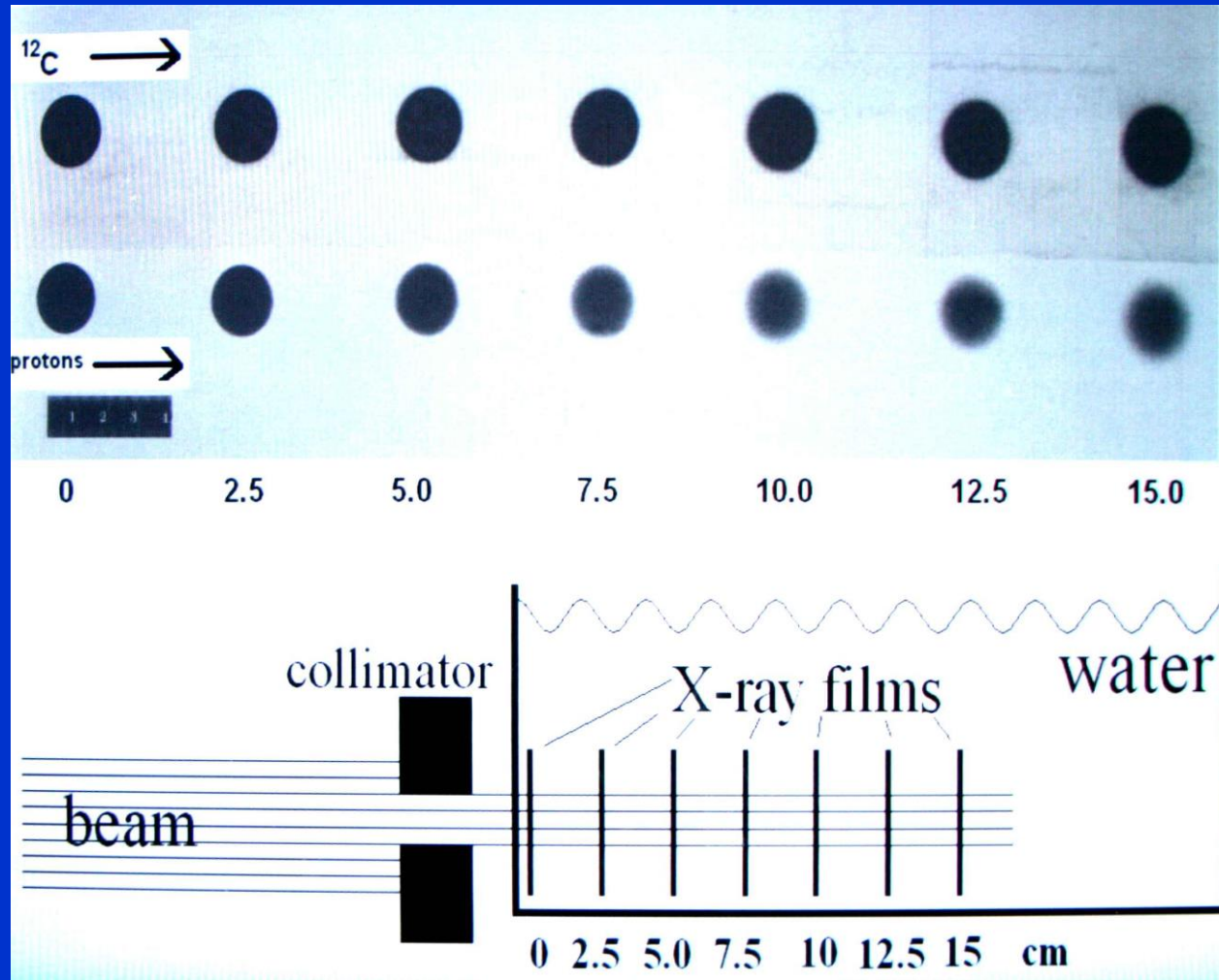


1

2

3

# Rozpraszanie wielokrotne



Zaniedbywalne rozproszenia poprzeczne dla jonów węgla

# Zalety terapii ciężkimi jonami

- Wysoka dawka w tarczy – niska w tkance zdrowej
- Precyzyjne leczenie (milimetrowa dokładność)
- Monitoring on-line z pomocą PET
- Zwiększona skuteczność biologiczna (RBE) w obszarze piku Bragga
- Zróżnicowanie RBE dla różnych komórek

## Dostosowanie wiązki do pacjenta:

- pasywne kształtowanie wiązki -system przesłon i filtrów – Chiba i Hyogo (Japonia)
- aktywne kształtowanie wiązki – raster scanning – GSI, Heidelberg (Niemcy)

Synchrotron  
(Particles up to  
70% of light speed)

Ion Source  
Carbon

Ion Source  
Proton

Linear Accelerator

Online Monitoring

Scanning System

Monitor System

Scanning Magnets

Wire Chambers

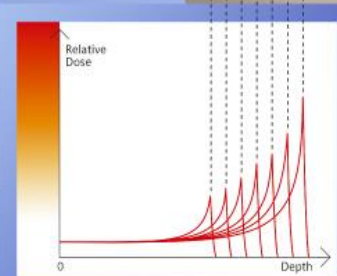
Ionization Chambers

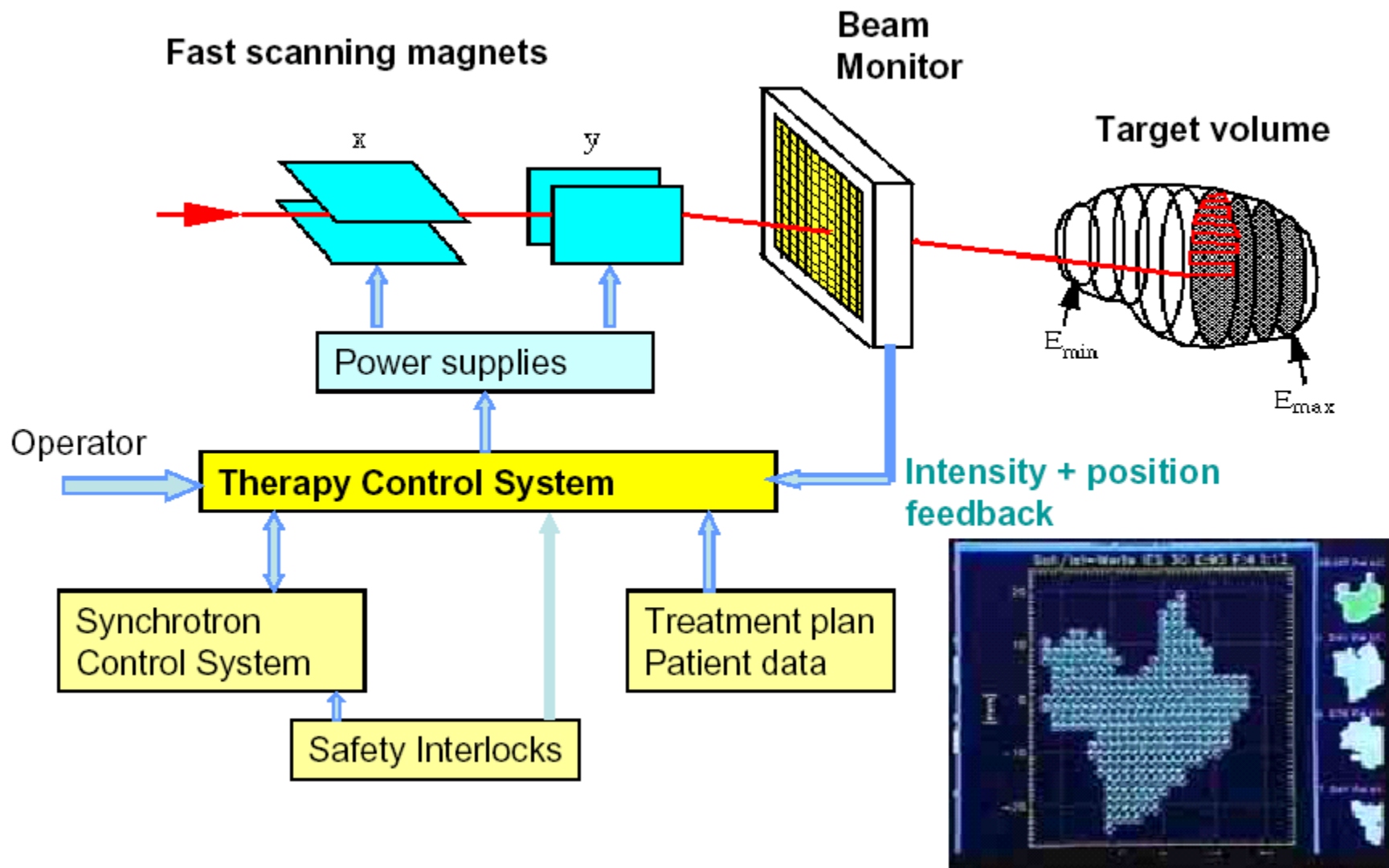
Target Volume

Example

Depth 5 cm:  
Proton 80 MeV  
Carbon 145 MeV/u

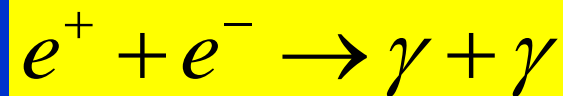
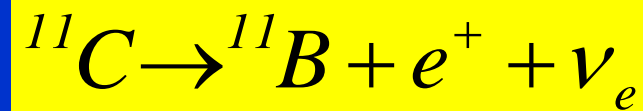
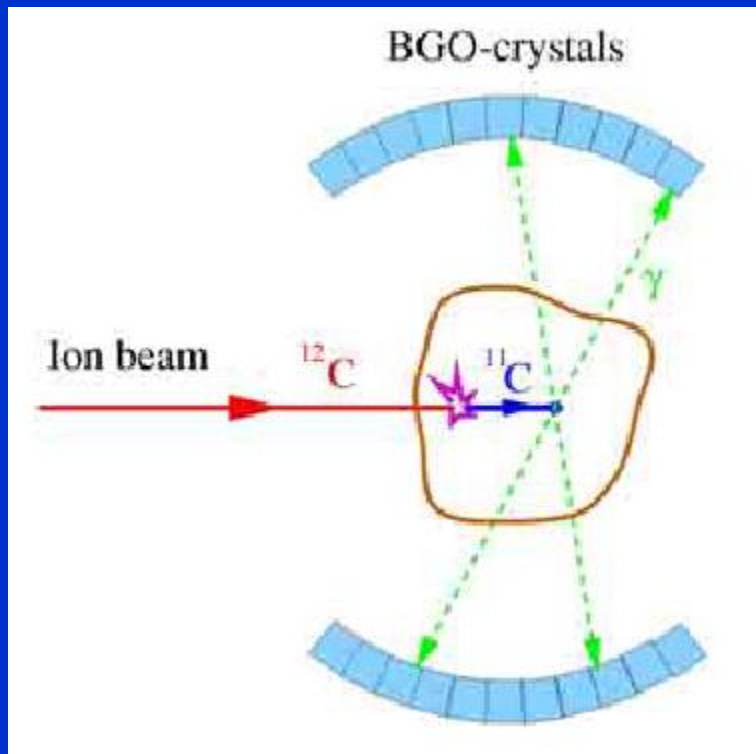
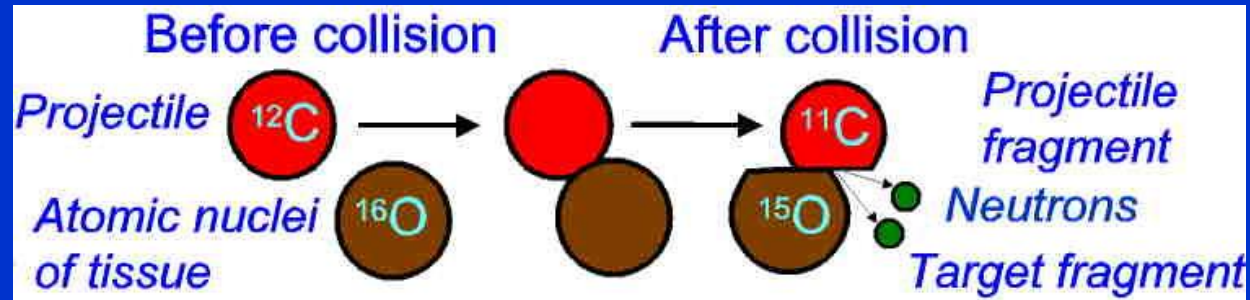
Depth 25 cm:  
Proton 195 MeV  
Carbon 375 MeV/u





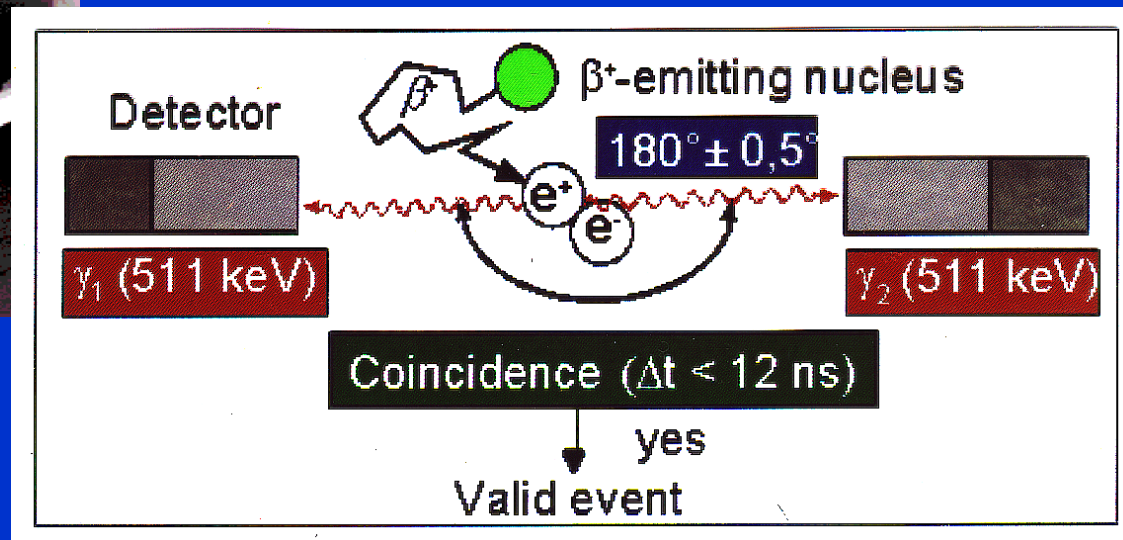
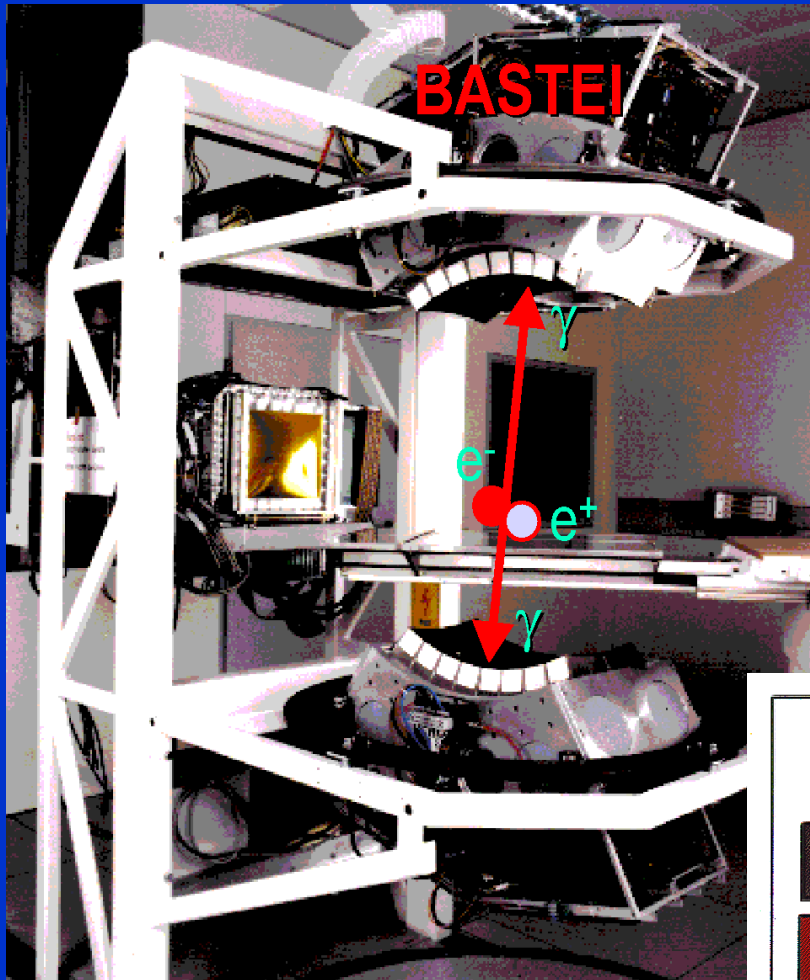
# Monitoring on-line z pomocą PET

J. Pawelke, Institute  
of Radiation Physics,  
Forschungszentrum  
Dresden-Rossendorf



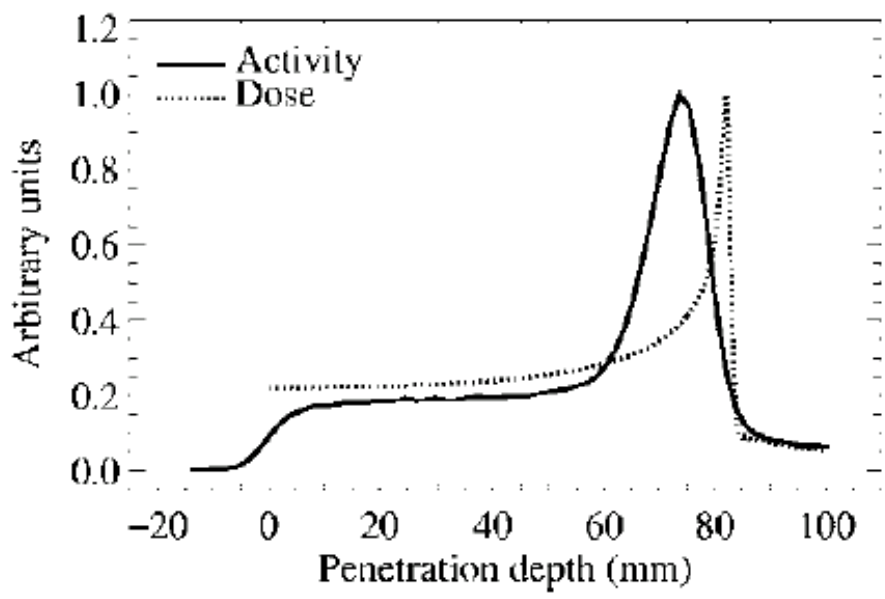


# Monitoring on-line z pomocą PET

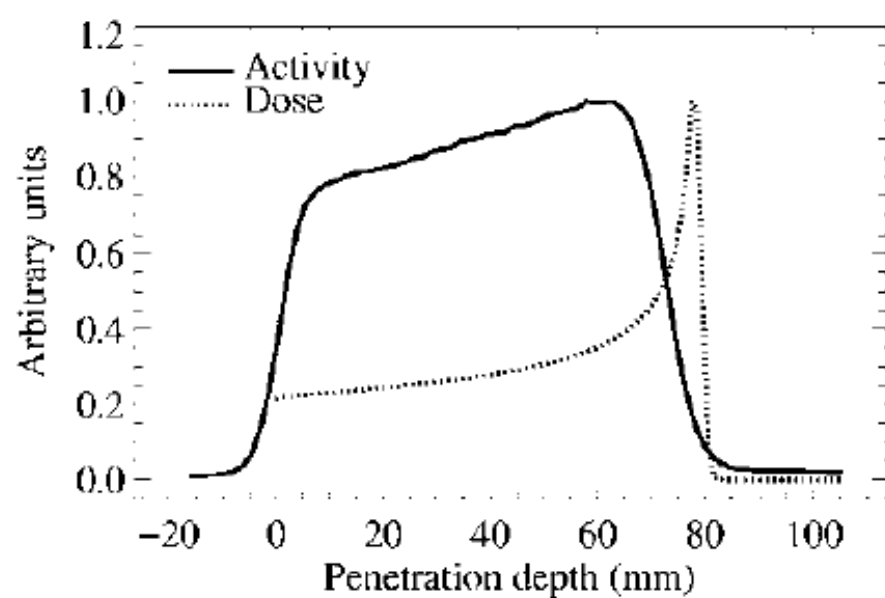


# Monitoring on-line z pomocą PET

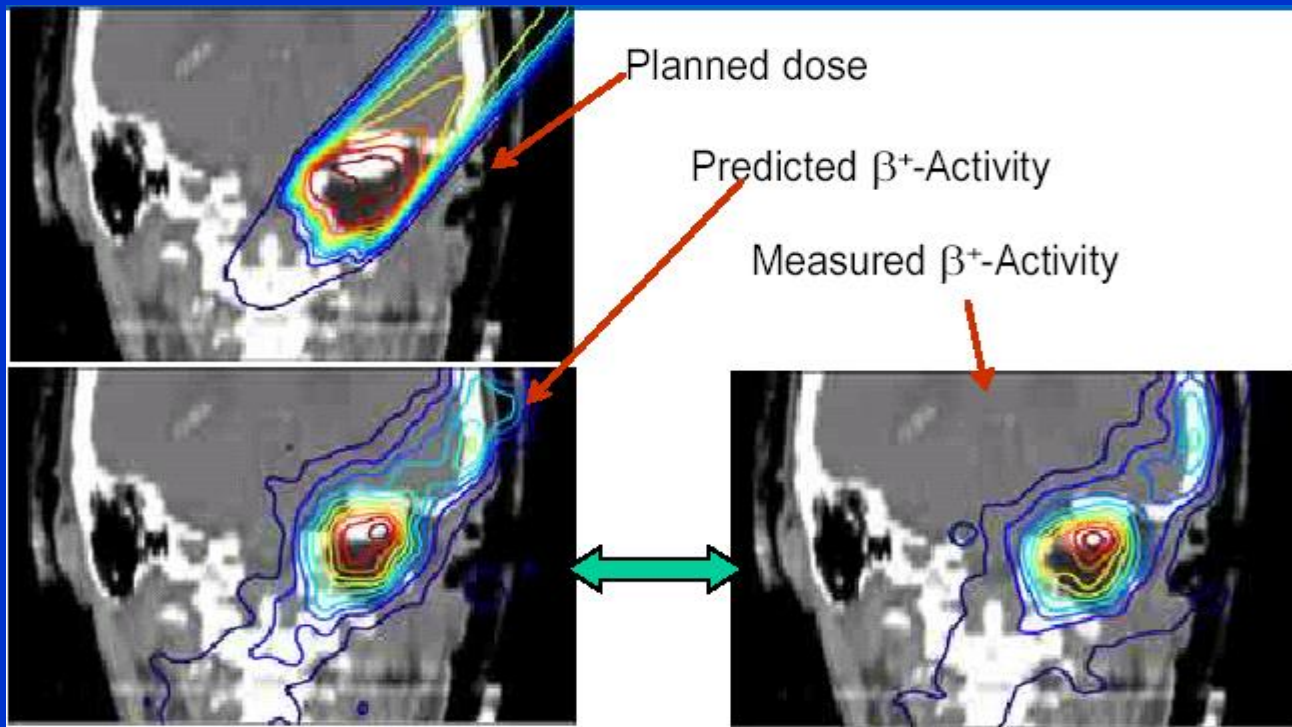
carbon ions



protons



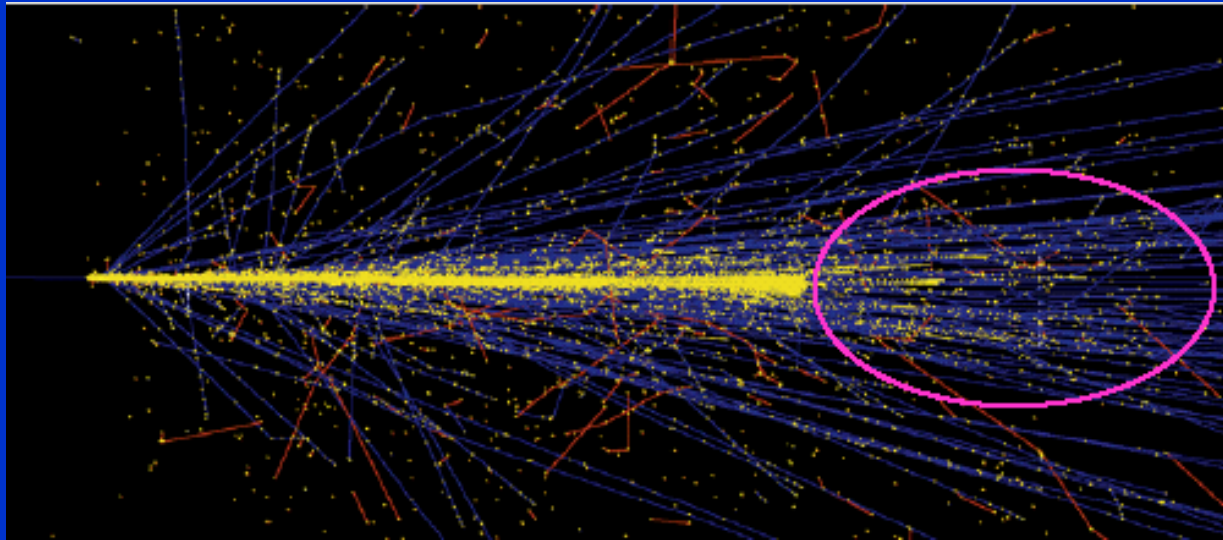
# Monitoring on-line w terapii jonami węgla w GSI Darmstadt



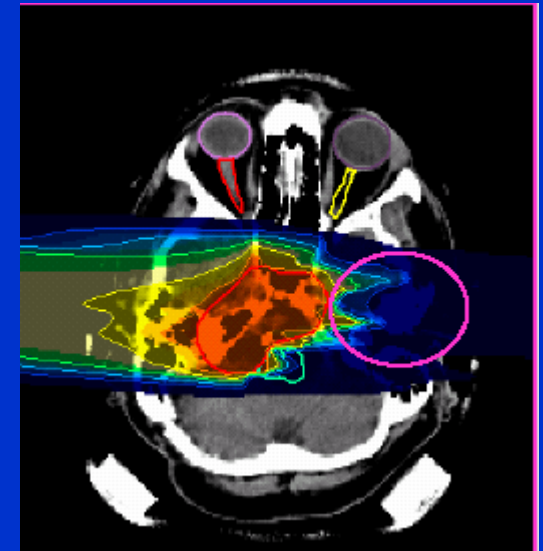
- kontrola zasięgu wiązki
- weryfikacja położenia pola naświetlania
- detekcja rozbieżności między planowanym a rzeczywistym leczeniem
- kontrola przebiegu kolejnych sesji

# Fragmenty jądrowe w terapii wiązkami jonów węgla

D. Schardt, Department of Biophysics, Gesellschaft für Schwerionenforschung, GSI, Darmstadt



Wiązka wysokoenergetycznych jonów węgla w wodzie.

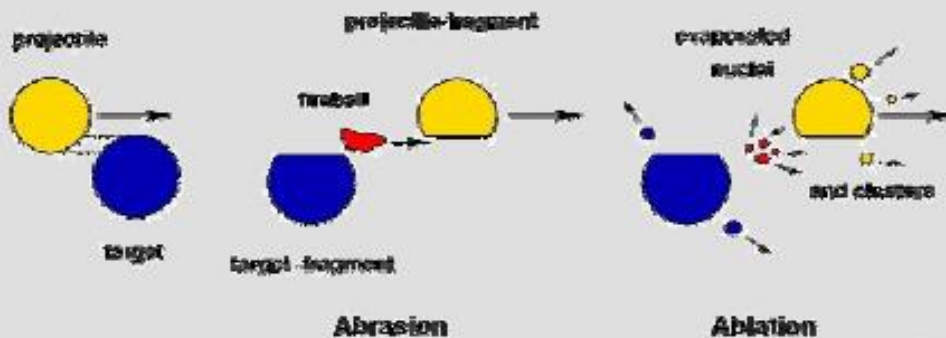


Terapia jonami węgla 100-400 MeV/u.

# High-energy fragmentation reactions

Peripheral collisions at high energies

R. Serber 1947



„Geometrical“ reaction cross section

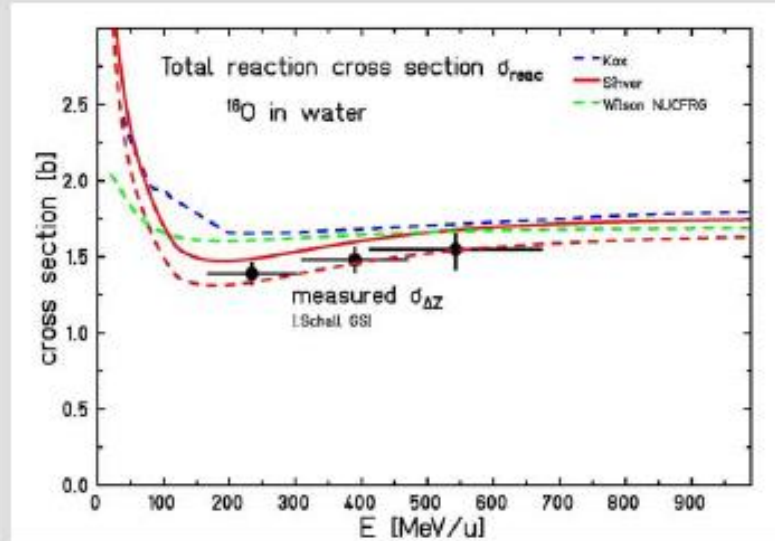
$$\sigma_{\text{tot}} = \pi r_0^2 \cdot (A_p^{1/3} + A_t^{1/3} - b)^2$$

Brad-Peters (1950)

$$\frac{d\Phi}{dx} = n\sigma\Phi; \quad \Phi(x) = \Phi(0) \cdot e^{-n\sigma d}$$

Ion flux decreases exponentially with absorber depth d

D. Schardt

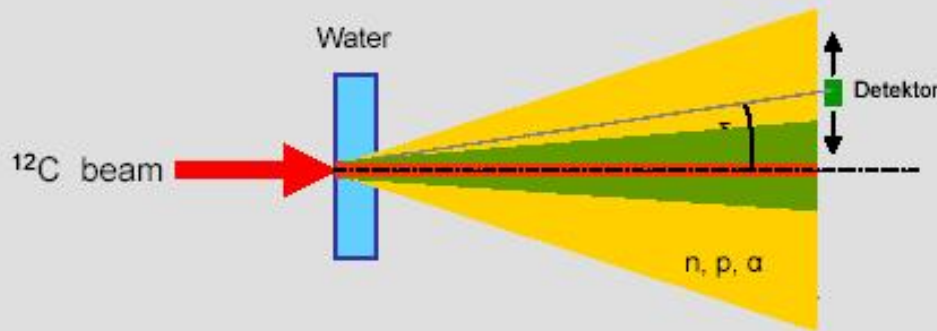
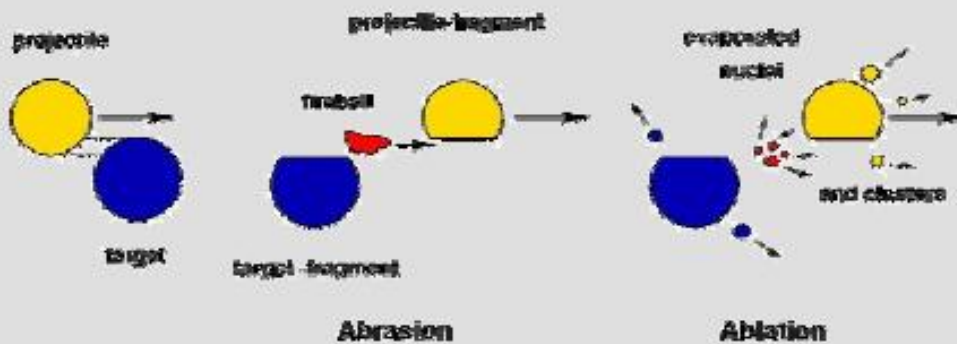


Total reaction cross section and mean-free-path in water

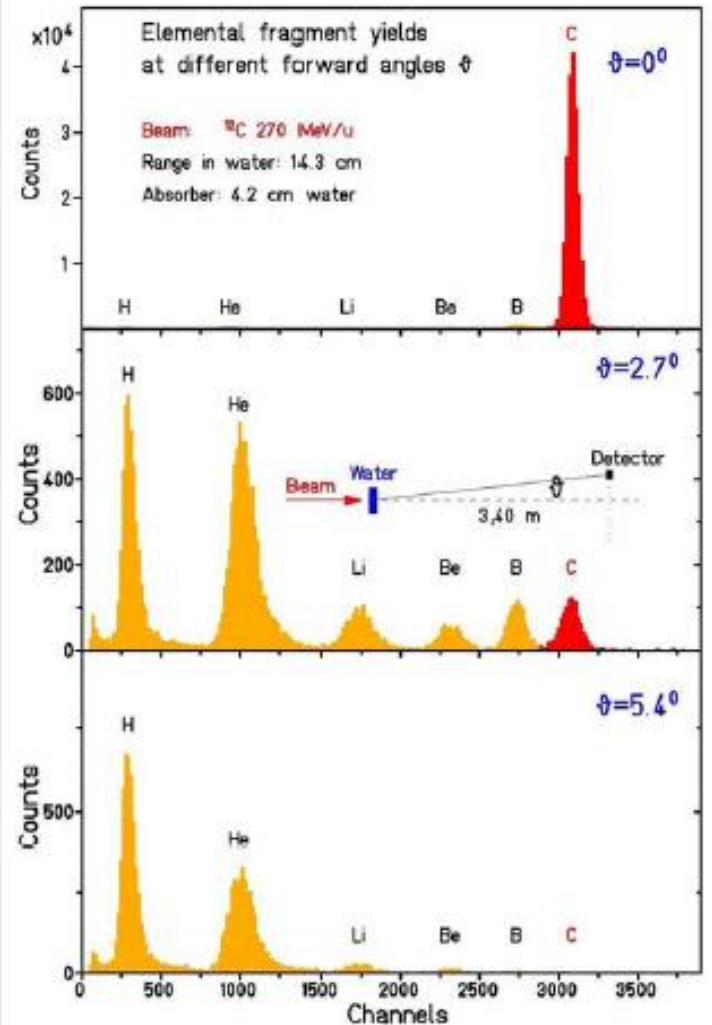
Ion	E [MeV/u]	$\sigma$ [mb]	$\lambda$ [cm]
p	200	350	85
<sup>4</sup> He	200	770	39
<sup>12</sup> C	300	1420	21
<sup>20</sup> Ne	500	1580	16

# Fragment spectrum

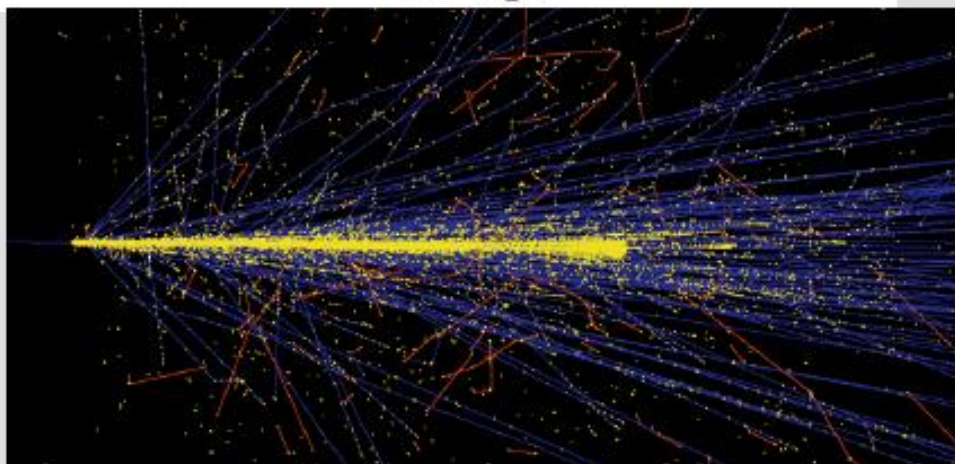
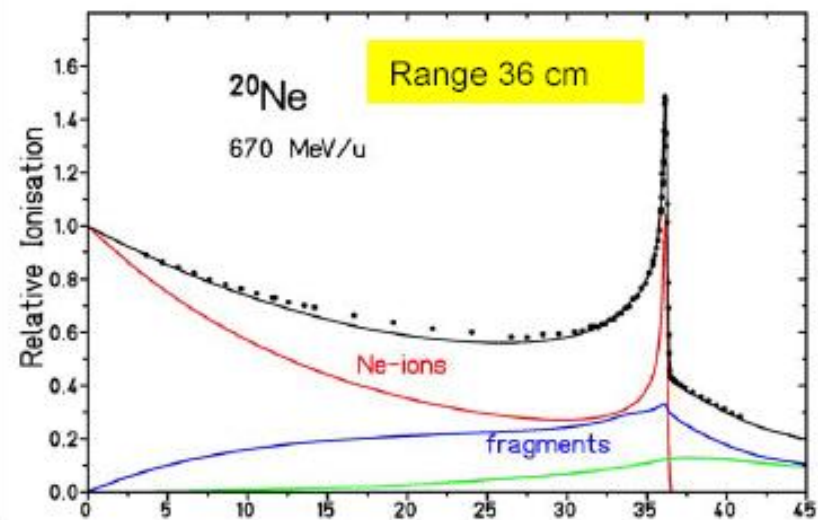
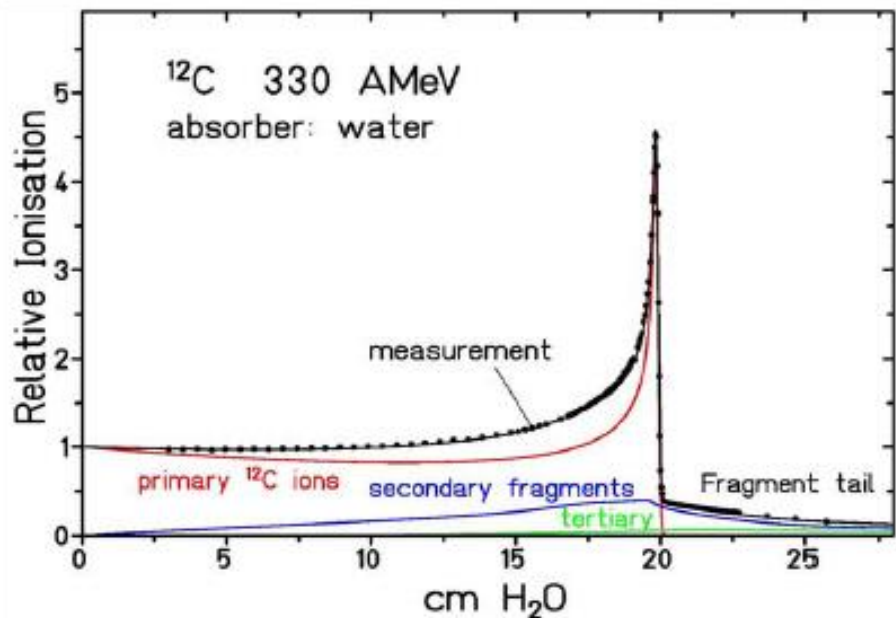
Peripheral collisions at high energies  
R. Serber 1947



D. Schardt



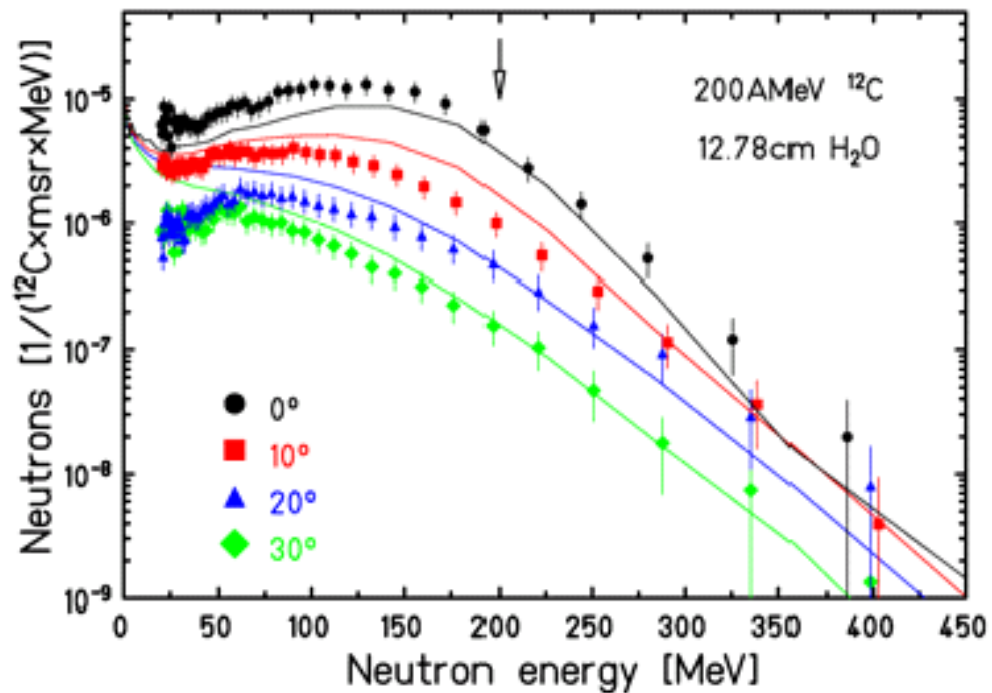
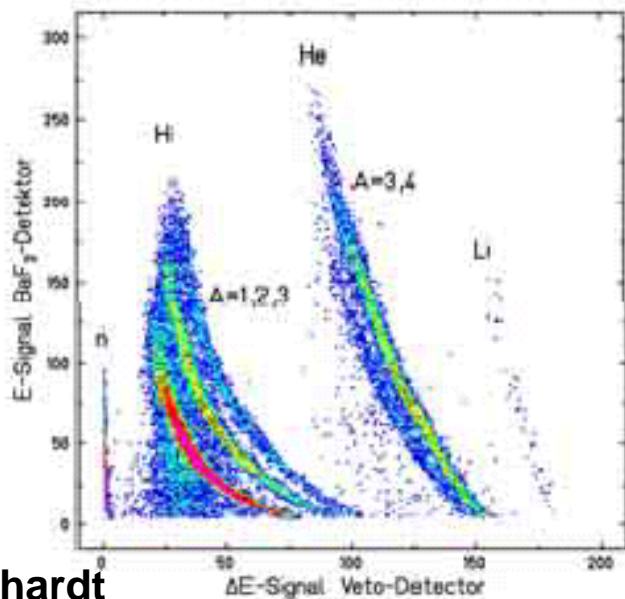
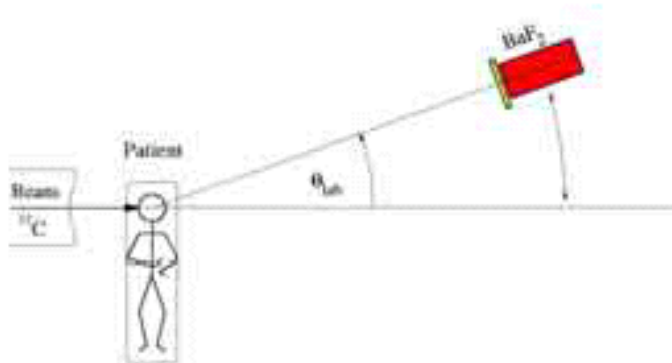
# Significance of fragmentation effects - Bragg curves



→ RBE(Z,E)  
Spectral data required

D. Schardt

# Fast neutron component



Monte Carlo code PHITS (H.Iwase GSI)

Fast neutron yield:  $0.54 \text{ n per C-ion} \pm 20\%$

Dose contribution:  $< 1\%$  of treatment dose



## Summary

- **Nuclear fragmentation is a significant effect and has to be included to best knowledge into physical models for ion treatment planning**
- **Spectral data are essential for RBE-calculations in complex particle field**
- **Long dose tail is mainly caused by charged light fragments (p, $\alpha$ )**
- **Neutron dose is about 1% of treatment dose, similar as in proton therapy**

# Leczenie ruchomych organów

## 3D online motion compensation (3D-OMC)

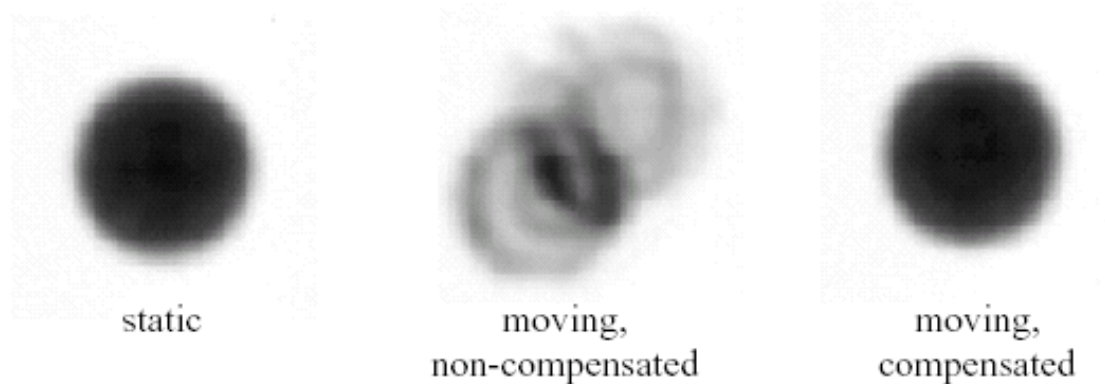
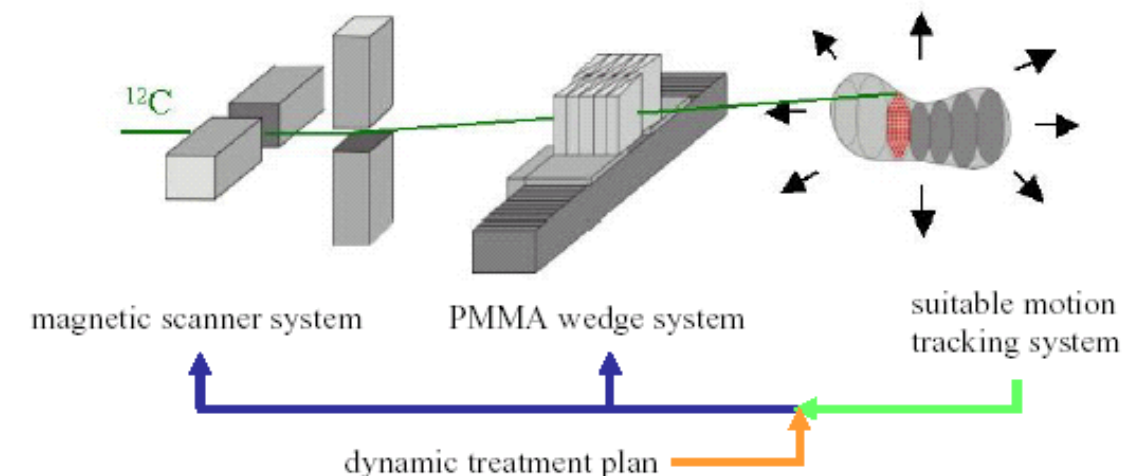
Okragły stół:

C. Bert,

K. Herfarth,

S. Minohara,

S. Webb



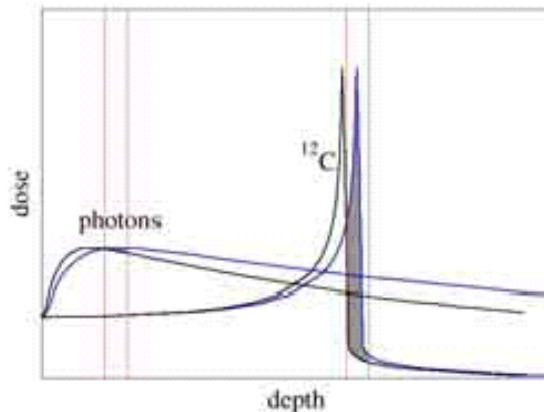
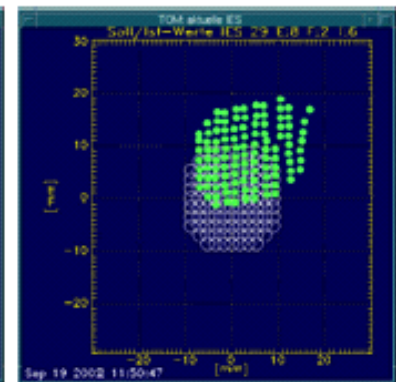
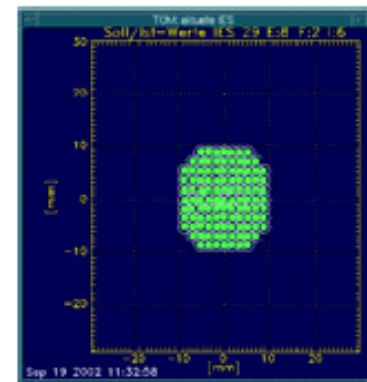
➤ real-time, highest precision

# Target Motion and Volume Conformity



- volume conformal irradiation requires **precise knowledge of target location**

- active beam delivery: **strong interferences between scanning and target motion**



- charged particles: sensitivity in all **three dimensions**

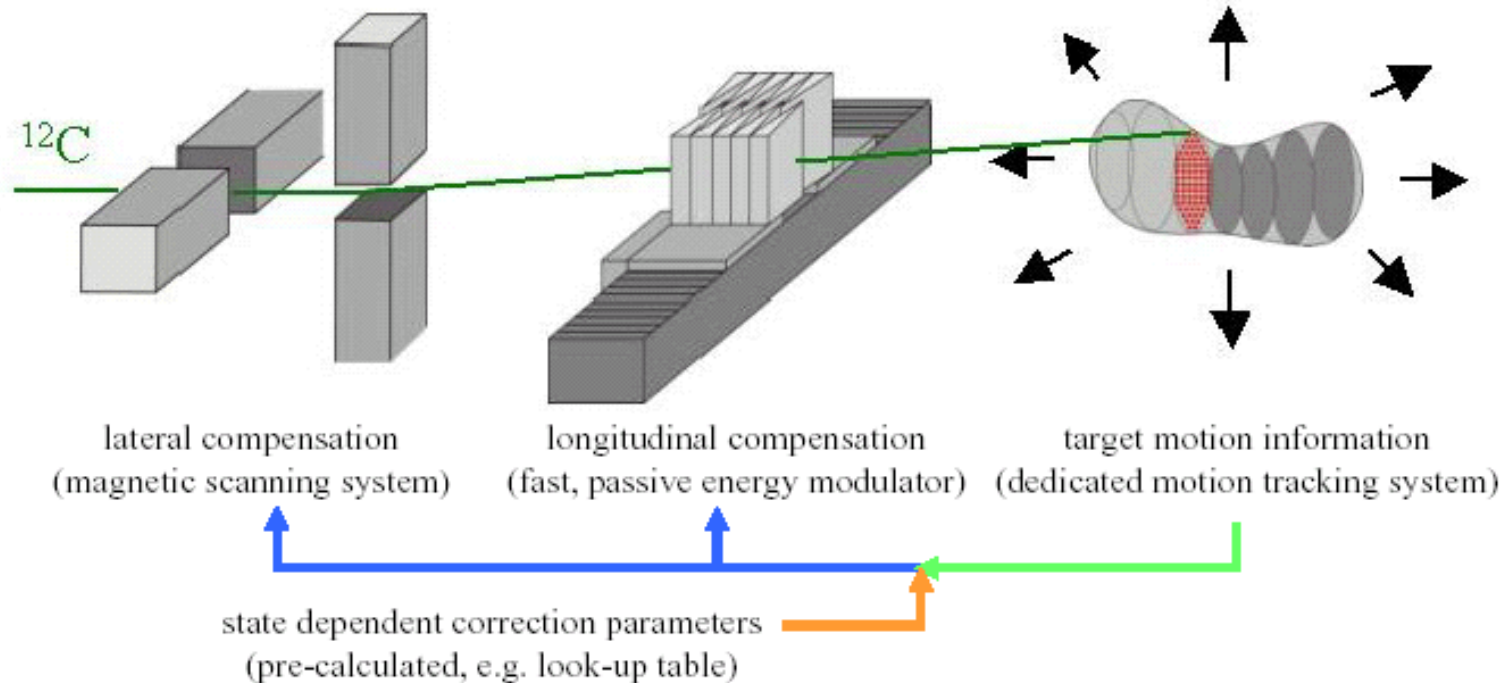
# 3D Online Target Motion Compensation



~~irradiation technique~~

treatment planning

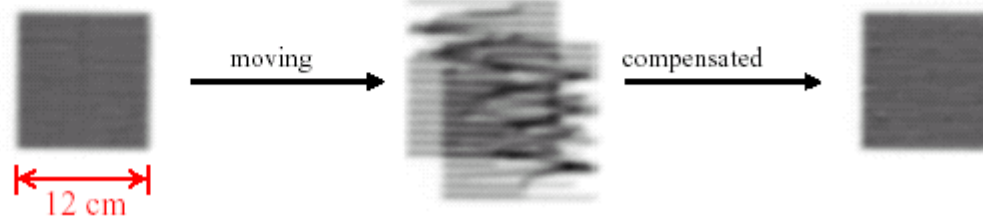
motion tracking



## Commissioning of Prototype Setup @ GSI



- lateral motion compensation successfully tested



- realistic 3D dose distributions successfully delivered to moving phantoms



Sven O. Grözinger, GSI Darmstadt

# Ośrodki terapii wiązkami jonów

- HIMAC – Chiba (Japonia) - 3100 pacjentów od 1994 r.

Heavy Ion Medical Centre

- Hyogo Ion Beam Medical Center – Hyogo (Japonia) – 150 pacjentów od 2002 r.

- Heavy Ion Research Facility – Lanzhou (Chiny) – 27 pacjentów od 2006 r.

- GSI –Darmstadt (Niemcy) ponad 300 pacjentów od 1997 r.

# The Austrian National Ion-Irradiation Facility

## The Location in Wiener Neustadt

University of Applied Sciences

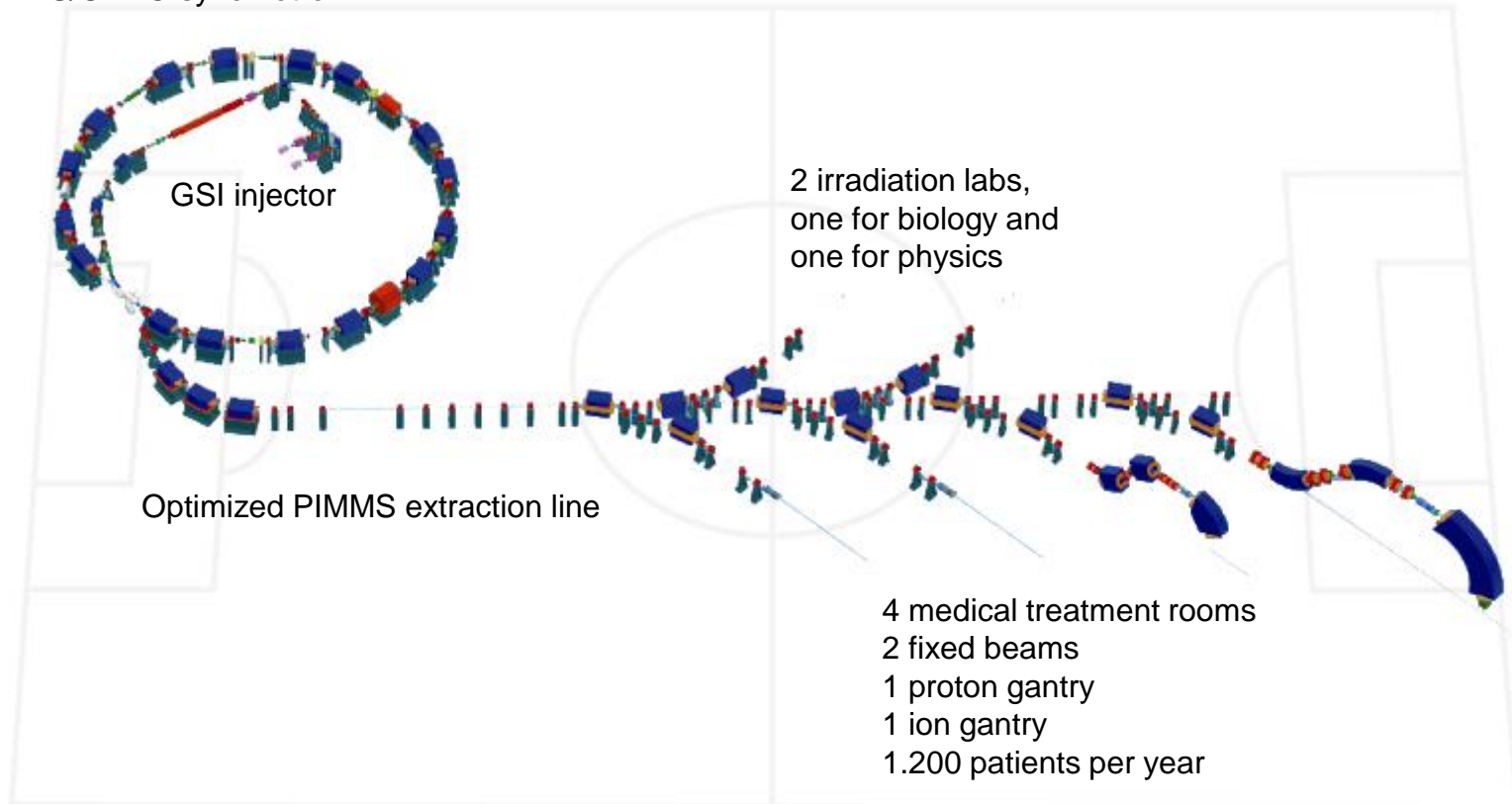


The real estate

First beam is expected in 2012

# Design Study

PIMMS/CNAO synchrotron





# Marburg, U. Weber

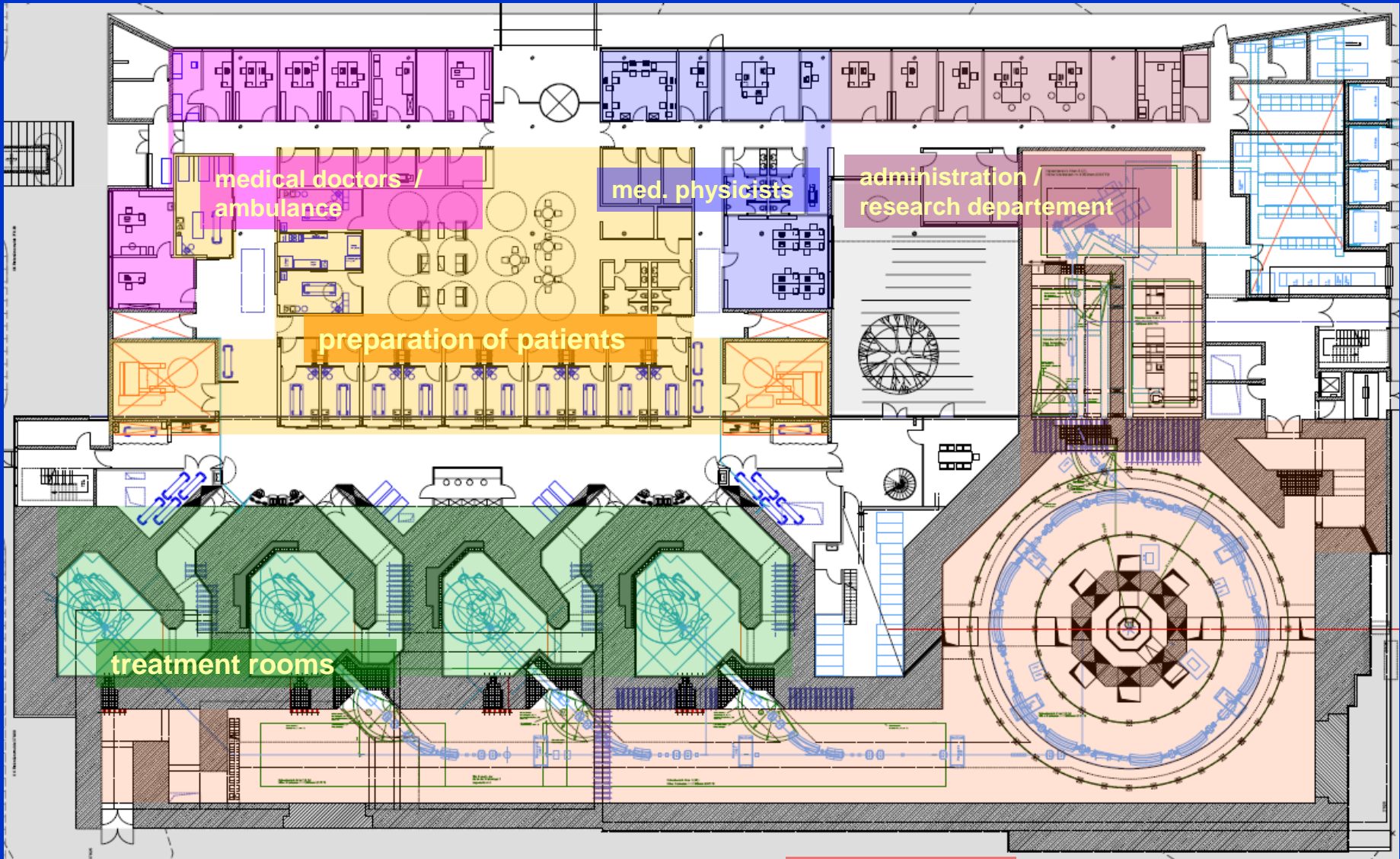


## Partikeltherapieanlage Marburg Universitätsklinikum Gießen Marburg GmbH

Vorstellung Projekt PT-Anlage  
4. Projektgruppensitzung 20. März 2007

Generalplaner  
**hammeskrause** architekten  
Stuttgart

**mit**  
Welsch + Partner, TWP  
Jaeger Mornhinweg + Partner, HUSK  
Müller + Bloher, ELT, Förderanlagen  
Stephen Eulich, LA  
Halken + Richter, Brandschutz



medical doctors / ambulance

med. physicists

administration / research department

preparation of patients

treatment rooms

accelerator

## Schedule for Particle Therapy in Marburg

preparation of building site	01.03.07
start of construction	<b>01.08.07</b>
start installation of accelerator	<b>01.08.08</b>
start installation of med. equipment	03.11.08
first beam in treatment room	01.07.09
first 3D scanning	01.04.10
begin of clinical operation	<b>31.08.10</b>

# PROTON THERAPY OF EYE MELANOMA at IFJ Kraków, Poland, *M. Waligórski*

## Partners:

Institute of Nuclear Physics, IFJ  
(60 MeV AIC-144 cyclotron)  
Clinic of Ophthalmology CMUJ  
Centre of Oncology Kraków

## Project:

Approved: 2006  
Installation: 2007  
Commissioning: 2008  
First patients: Dec. 2008

## Funds:

-National  
-IAEA TC



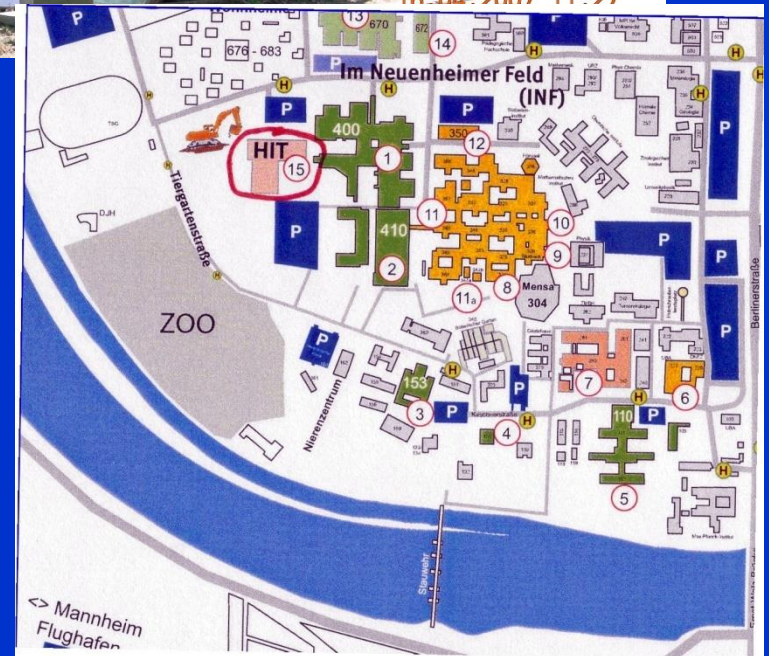
Optical line at 60 MeV pAIC-144 cyclotron IFJ Krakow

Project will fulfill the national requirements for eye melanoma  
proton radiotherapy (100 cases/year)

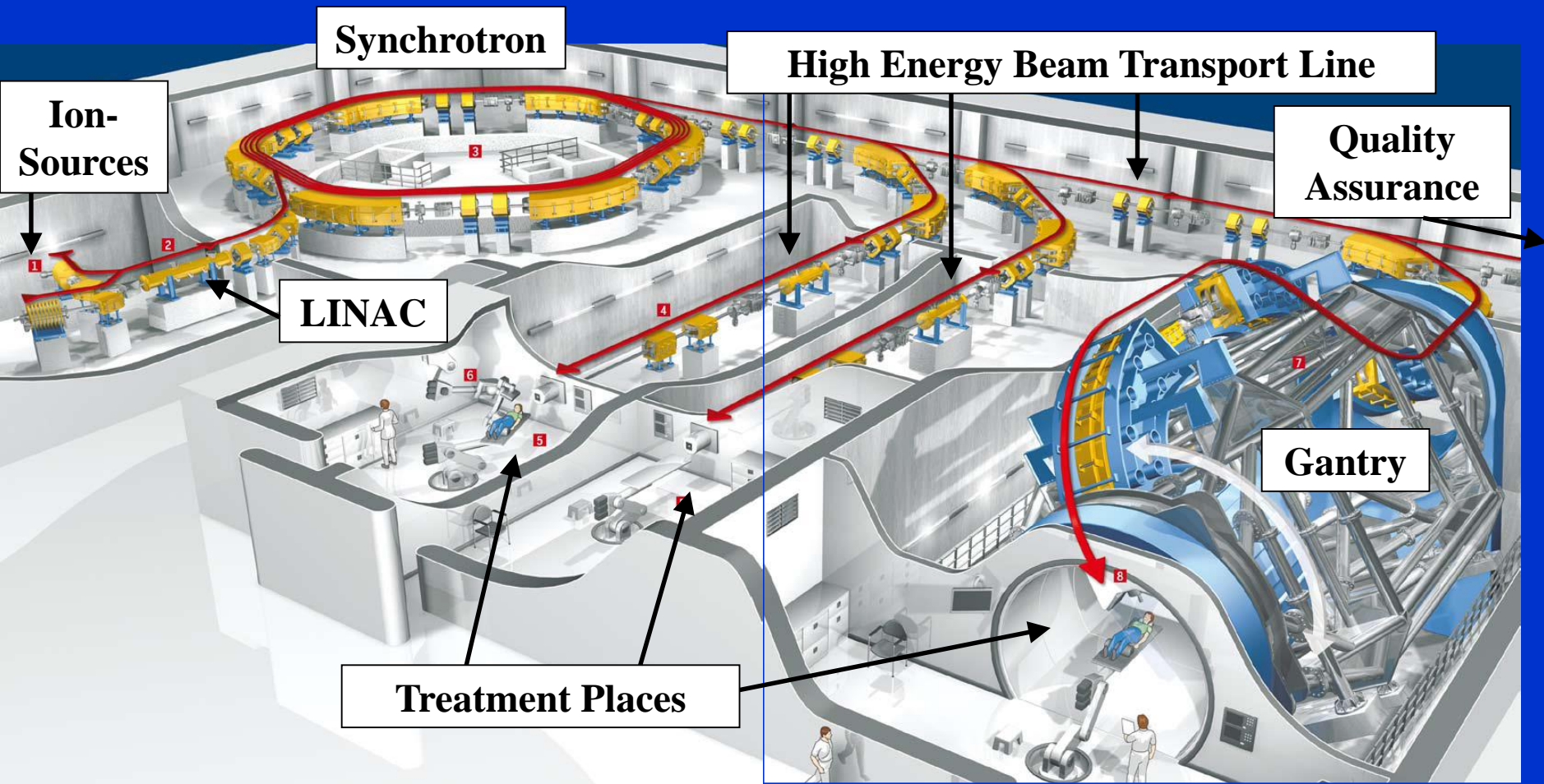
# HIT Heidelberg Ion Therapy



Location in Heidelberg



# Accelerator Overview



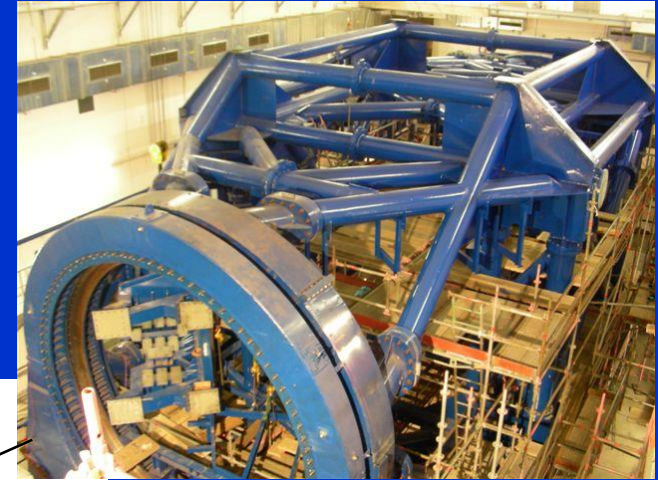
# Synchrotron



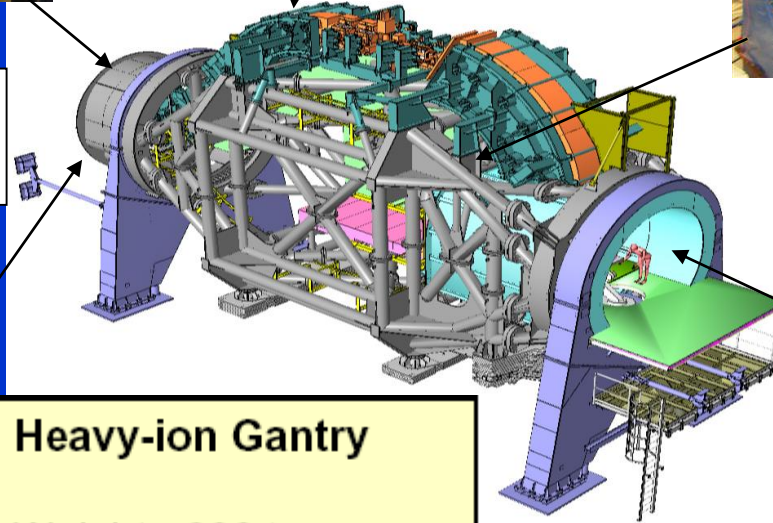
11.04.2006 11:20



# Gantry



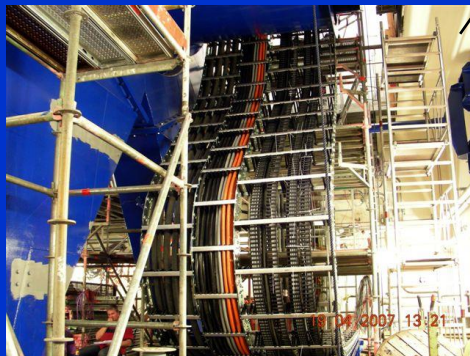
1. Rotation at  
21.04.2007



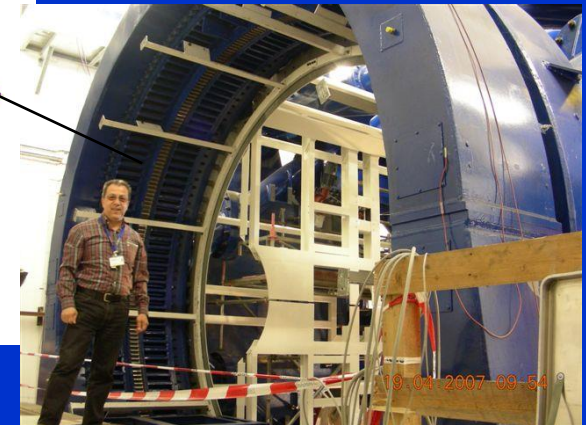
## Heavy-ion Gantry

Weight: 600 t  
25 m long  
13 m diameter  
Deformation < 0.5 mm

Manufacturer: MAN



OSPACE





# FIRST PATIENT

The first Rx hopefully takes place in late winter 2007/8!

