10 Years of Proton Radiotherapy of Ocular Melanoma at IFJ PAN

10 lat radioterapii protonowej oka w IFJ PAN

Tomasz Kajdrowicz

Cyclotron Center Bronowice, Institute of Nuclear Physics PAN, Kraków, Poland

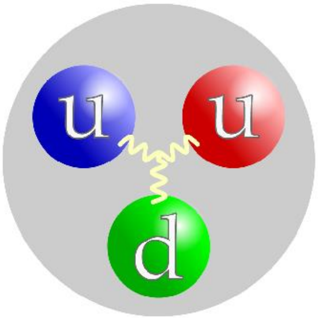
15 April 2021

- Construction of ocular treatment rooms
- Proton eye treatment procedure
- Treatment planning and patient positioning verification
- Solving stroboscopic effect in depth dose distribution
- Research and Development
- Acknowledgements

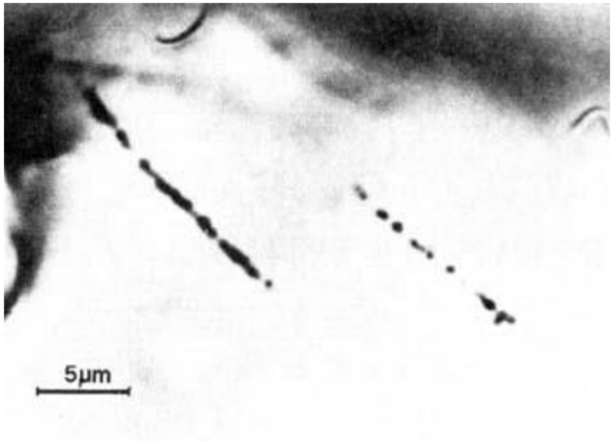
13.7 billion years ago …

10^{-6} to 10^{-5} seconds after The Big Bang …

… quarks started formation of Baryons like protons.

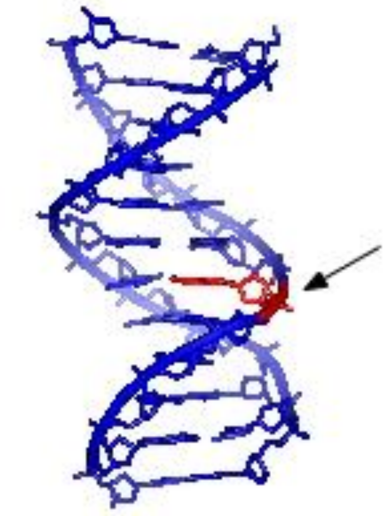


- Proton is forming nucleus of hydrogen
- Hydrogen is the most common chemical element in the universe
- Each proton consists of two up quarks and one down quark
- As a consequence it has a **positive electric charge** …
- … and as such it can be **accelerated by electric field**
- Accelerated protons slow down in matter losing energy mostly due to **multiple electromagnetic collisions** with atomic electrons and nuclei
- Atomic electrons gain energy leading to **ionization of atoms**
- Proton is **1840 times heavier than electron**
- It travels through tissue like matter on average in **straight lines**

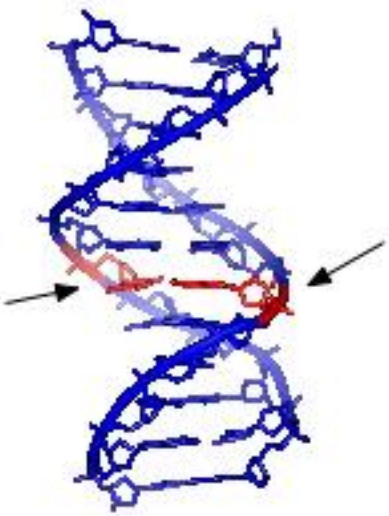


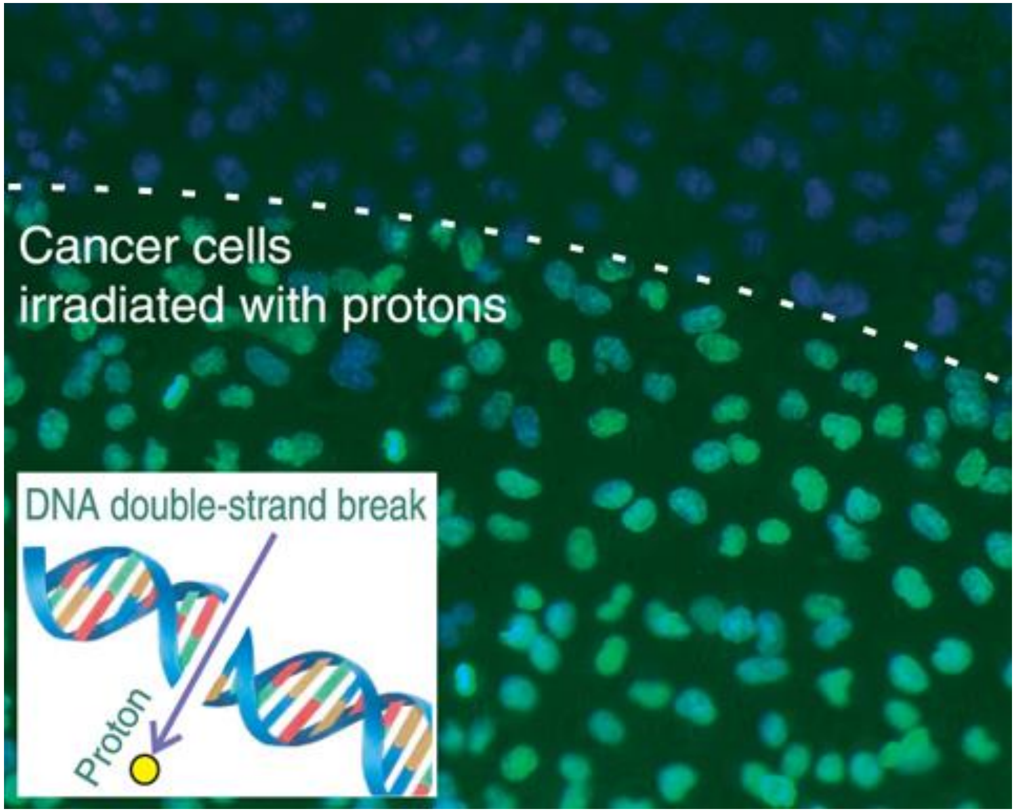
DNA strand breaks

Single



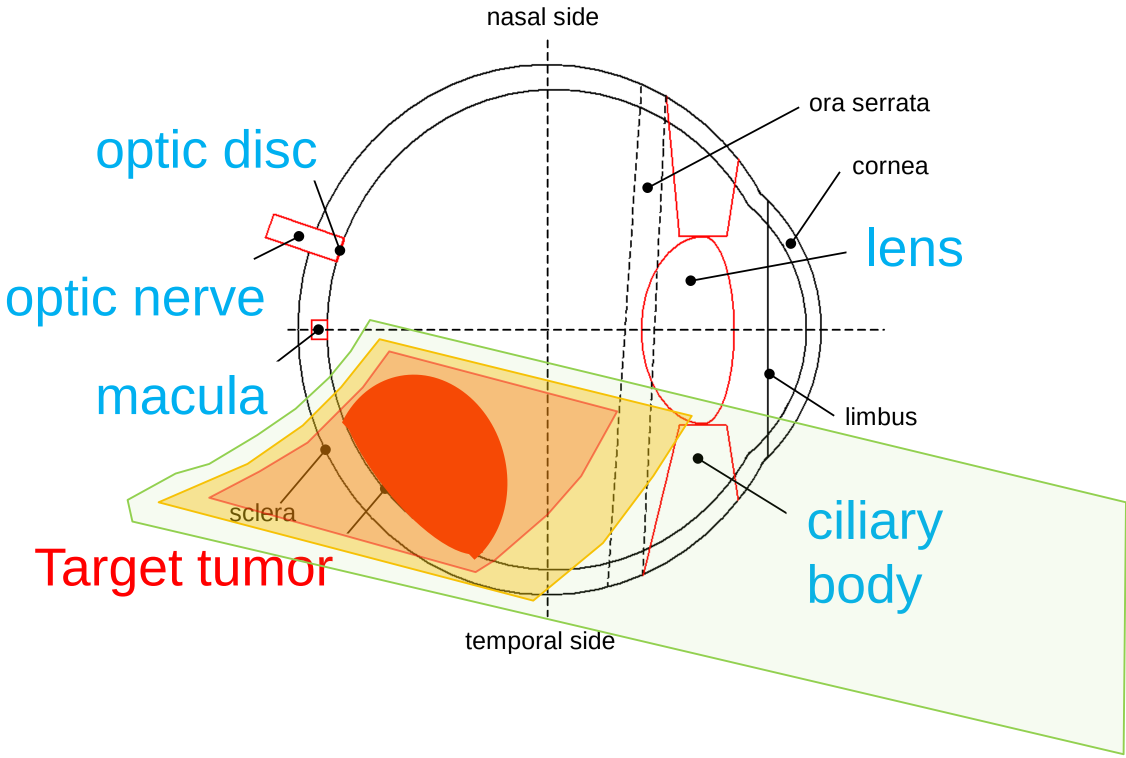
Double





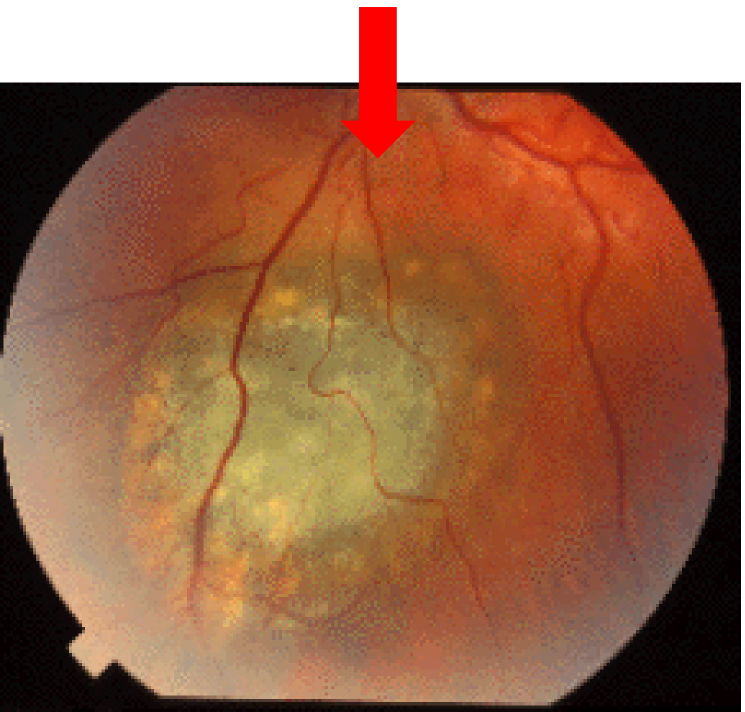
Therapeutic problem

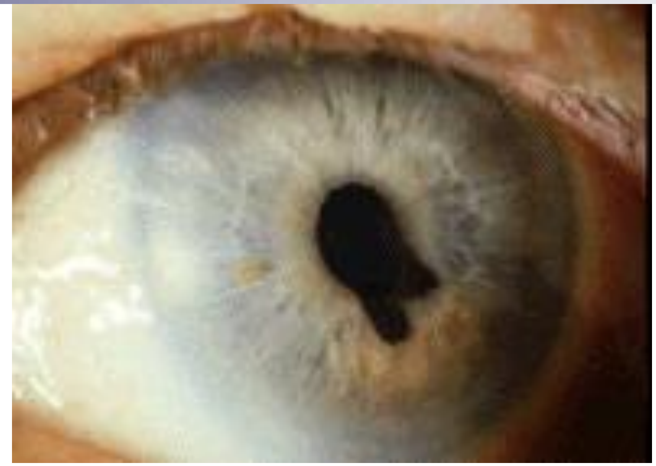
- Minimum dose to kill all tumor cells
- Limit of normal tissue complications
- Main organs at risk (OAR) of an eye
  - Optic disc and nerve
  - Macula
  - Ciliary body and lens

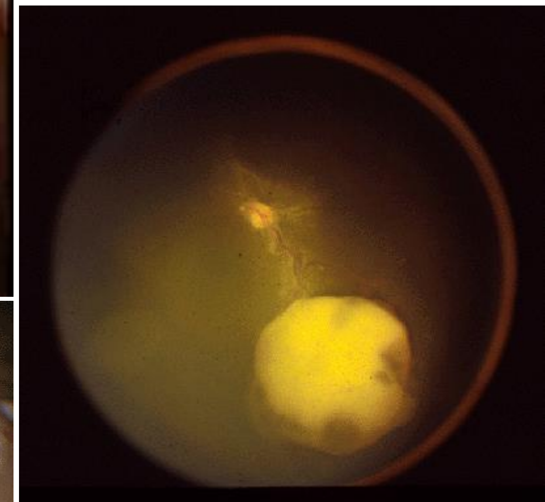


Eye cancer

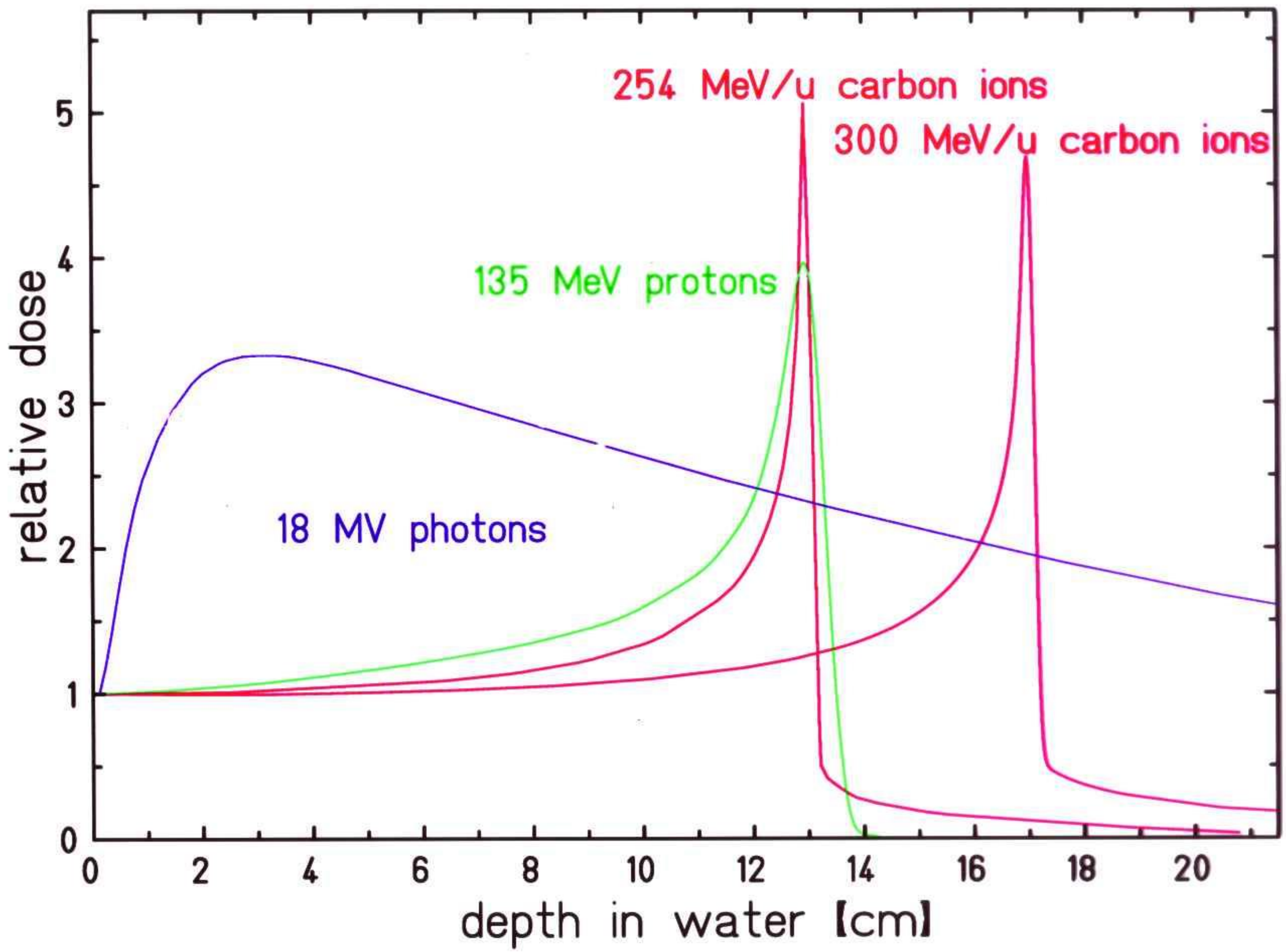
- Iris melanoma
- Conjunctival melanoma
- Malignant melanoma
- Retinoblastoma
- Melanocytoma
- **<u>Choroidal melanoma</u>**

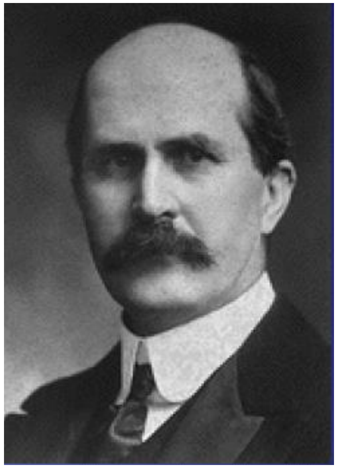






Why protons?





William Henry Bragg
(1862 – 1942)

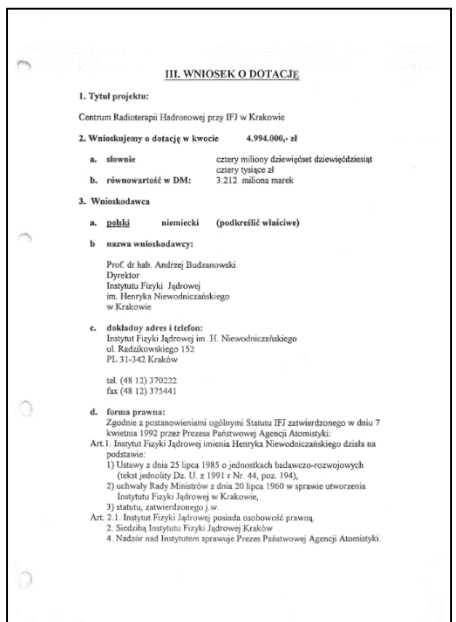
Centrum Radioterapii Protonowej przy IFJ w Krakowie

15th December, 1994

Prof. dr hab. Andrzej Budzanowski submits a project proposal to *„Fundacja Współpracy Polsko-Niemieckiej”* *(Stiftung für deutsch-polnische Zusammenarbeit)*

Partners on German side are:

- Institut fuer Medicin Forschungszentrum Juelich
- Hahn Meitner Institut, Berlin



III. WNIOSEK O DOTACJĘ

1. Tytuł projektu:

Centrum Radioterapii Hadronowej przy IFJ w Krakowie

2. Wnioskujemy o dotację w kwocie **4.994.000,- zł**

a. **słownie** cztery miliony dziewięćset dziewięćdziesiąt cztery tysiące zł

b. **równowartość w DM:** 3.212 miliona marek

3. Wnioskodawca

a. **polski** **niemiecki** **(podkreślić właściwe)**

b **nazwa wnioskodawcy:**

Prof. dr hab. Andrzej Budzanowski
Dyrektor
Instytutu Fizyki Jądrowej
im. Henryka Niewodniczańskiego
w Krakowie

c. **dokładny adres i telefon:**
Instytut Fizyki Jądrowej im. H. Niewodniczańskiego
ul. Radzikowskiego 152
PL 31-342 Kraków

tel. (48 12) 370222
fax (48 12) 375441

d. **forma prawna:**
Zgodnie z postanowieniami ogólnymi Statutu IFJ zatwierdzonego w dniu 7 kwietnia 1992 przez Prezesa Państwowej Agencji Atomistyki:
Art.1. Instytut Fizyki Jądrowej imienia Henryka Niewodniczańskiego działa na podstawie:
1) Ustawy z dnia 25 lipca 1985 o jednostkach badawczo-rozwojowych (tekst jednolity Dz. U. z 1991 r Nr. 44, poz. 194),
2) uchwały Rady Ministrów z dnia 20 lipca 1960 w sprawie utworzenia Instytutu Fizyki Jądrowej w Krakowie,
3) statutu, zatwierdzonego j.w.
Art. 2.1. Instytut Fizyki Jądrowej posiada osobowość prawną.
2. Siedzibą Instytutu Fizyki Jądrowej Kraków
4. Nadzór nad Instytutem sprawuje Prezes Państwowej Agencji Atomistyki.

Tabela 1.Ogólny harmonogram realizacji projektu

Nazwa zadania	1995	1996	1997	1998
T-1 Zaistalowanie cyklotronu AIC-144 w hali eksploatacyjnej				
T-2 Adaptacja Cyklotronu AIC-144 dla potrzeb terapii protonowej				
T-3 Sterowanie i automatyzacja pracy AIC-144 w systemie komputerowym				
T-4 Opracowanie i wykonanie traktów transportu i formowania wiązek terapeutycznych				
T-5 Wyposażenie stanowisk radioterapii neutronowej oraz terapii protonowej oka				
K-1. Opracowanie metod i ocena skuteczności radioterapii neutronowej				
K-2 Opracowanie metod leczenia i ocena skuteczności radioterapii neutronowej mięsaków				
K-3 Próby kliniczne terapii protonowej u chorych z czerniakiem oka				
K-4. Monitorowanie aktywności makrofagów metodą ERP od pacjentów leczonych neutronami				
Z-1 Opracowanie nowego modelu zwierzęcych czerników oka u chomików i gerbili				
Z-2 Testowanie zestawu do terapii protonowej na zwierzęcych modelach czerniaka oka				
Z-3 Analiza możliwości wykorzystania spektroskopii ERP dla celów prognostycznych w leczeniu				
Z-4 Porównanie RBE w indukowaniu różnych efektów biologicznych przy użyciu wiązki neutronowej				
Z-5 Opracowanie biologicznej dozymetrii dawki pochłonię-tej w limfocytach krwi ludzkiej				
Z-6 Wczesny i późny odczyn popromienny tkanki zdrowej po napromiennianiu neutronami i protonami.				
Z-7 Obliczenia transportu i depozycji energii promienio-wania w nawiązaniu dla adaptacji cyklotronu AIC-144				
Z-8 Przygotowanie kadry fizyków medycznych dla celów radioterapii hadronowej				
Z-9 Mikrodozymetryczna ocena jakości biologicznej wiązki neutronów i protonów				
R-1 Produkcja radioizotopów medycznych				

Summer 2-week-long Internship at IFJ PAN

Summer, 1997

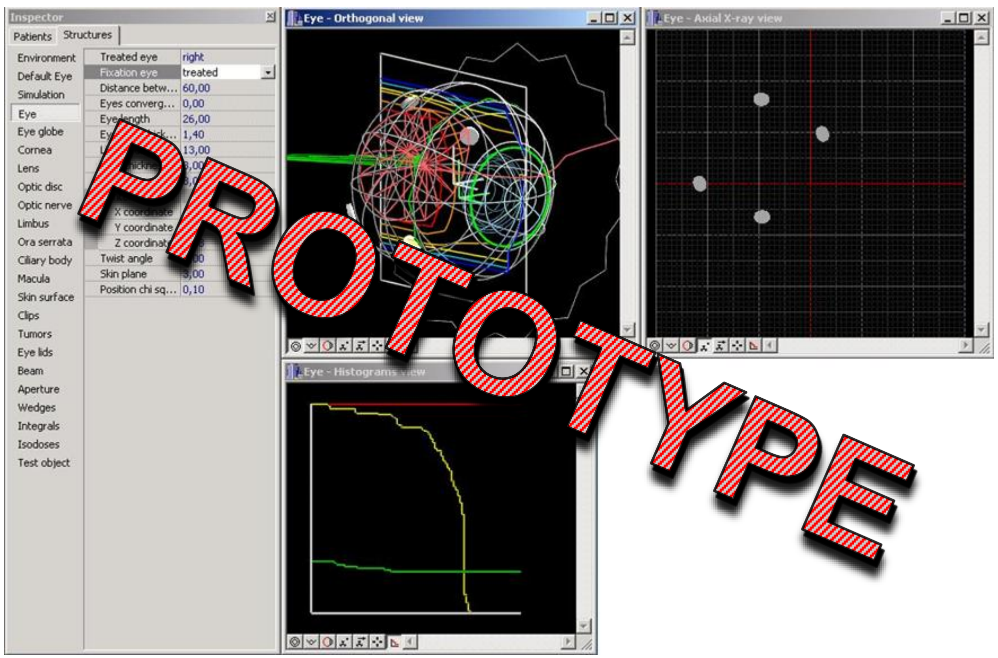
2-week-long internship organized by dr Paweł Olko
to write a prototype of a treatment planning system (TPS)
for proton therapy of ocular melanoma

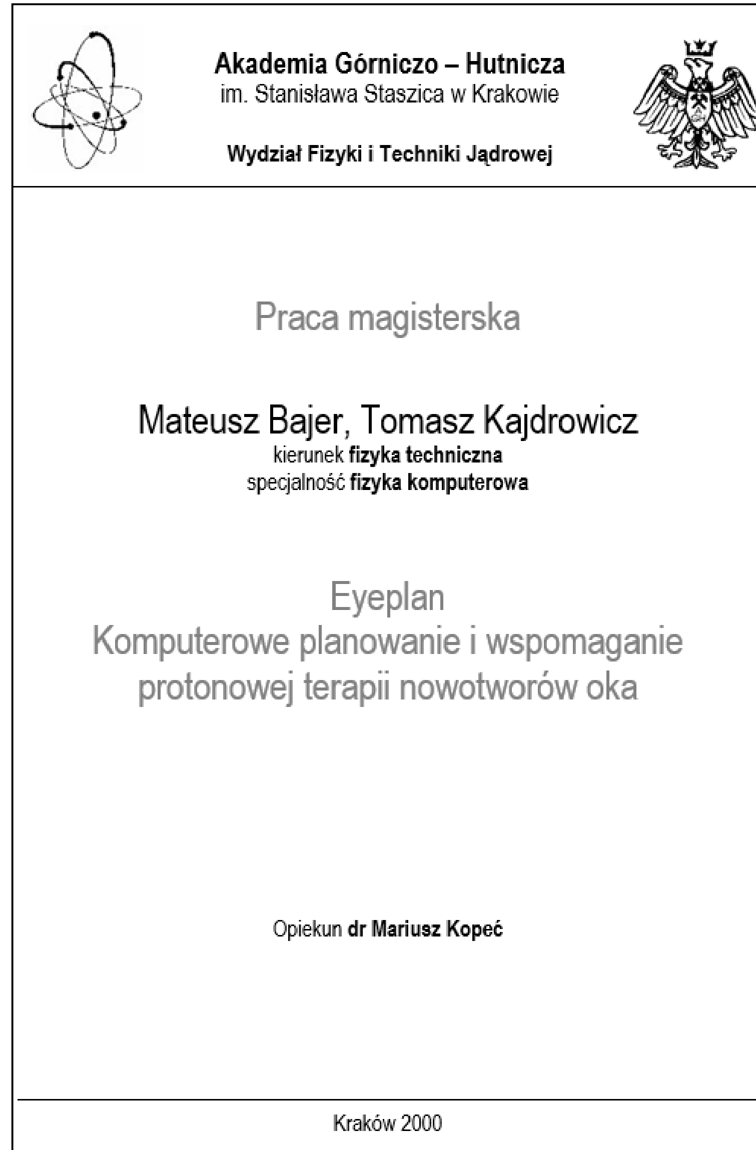
Spring, 2000

TPS functional prototype as a part of Master Thesis

Autumn, 2005

FDA approved and CE marked commercial TPS
(2 free-of-charge licenses for IFJ PAN)





Akademia Górniczo – Hutnicza
im. Stanisława Staszica w Krakowie

Wydział Fizyki i Techniki Jądrowej

Praca magisterska

Mateusz Bajer, Tomasz Kajdrowicz
kierunek **fizyka techniczna**
specjalność **fizyka komputerowa**

Eyeplan
Komputerowe planowanie i wspomaganie
protonowej terapii nowotworów oka

Opiekun **dr Mariusz Kopeć**

Kraków 2000

Starting cooperation with Clinical Partners

First cooperation agreement between Collegium Medicum UJ - Krakow University Hospital and IFJ PAN on development of proton eye therapy signed on 27.06.2005

Funding elements of the treatment room from the National Fund for Fighting Cancer (University Hospital) – 2006

Public tenders and installation of equipment at IFJ PAN – 2007-2008

Szpital Uniwersytecki w Krakowie

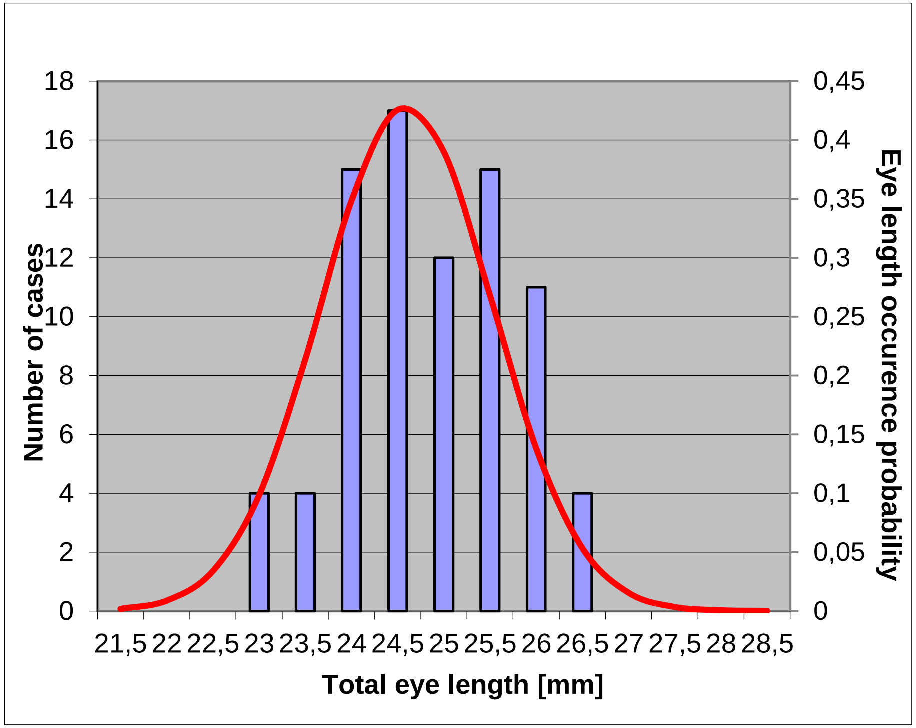
Proton beam range sufficient to treat ocular patients

19th December, 2005

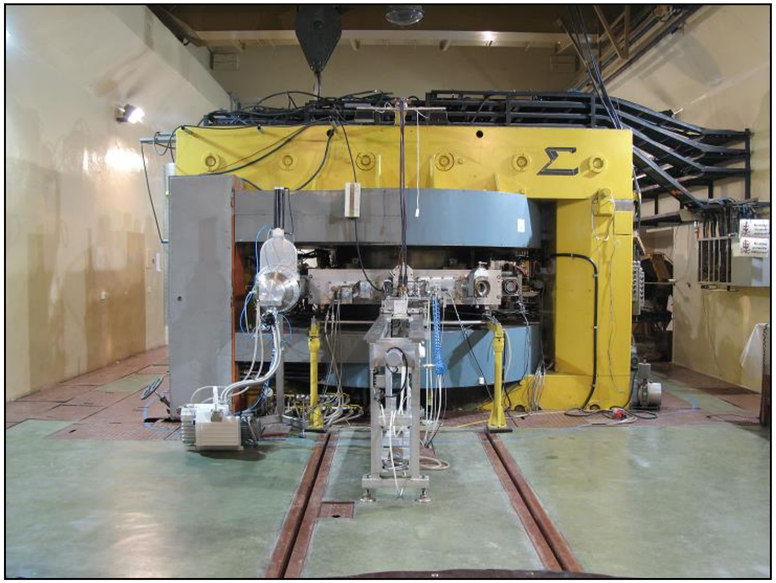
Working Meeting at Kopernika Street in Kraków

- prof. Bożena Romanowska-Dixon
- prof. Paweł Olko
- dr Jan Swakoń
- Tomasz Kajdrowicz

Szpital Uniwersytecki w Krakowie



AIC-144 cyclotron produces 60 MeV protons resulting in range in water of 29 mm.

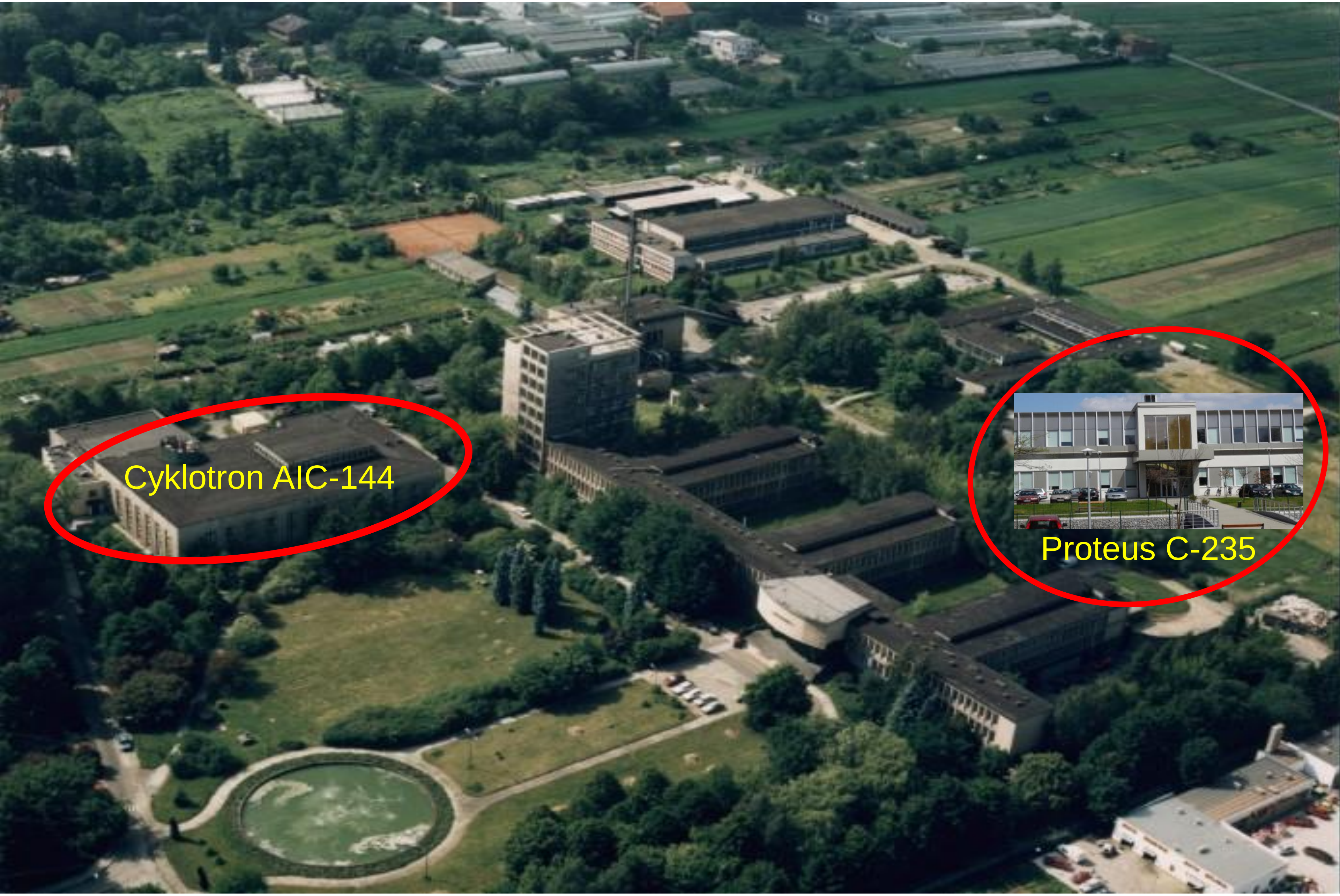


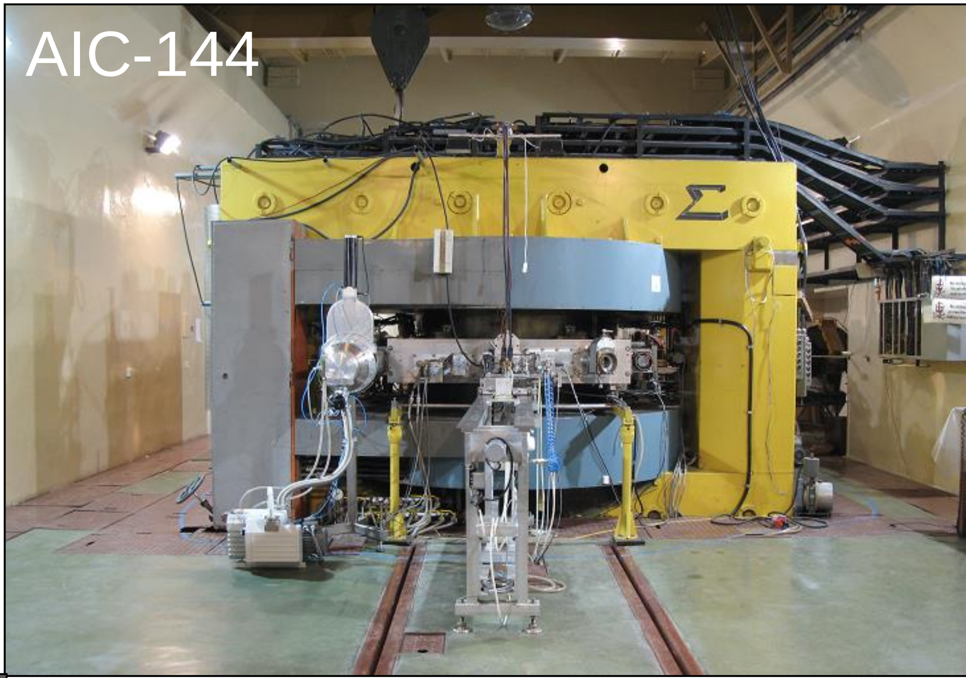
Discussing patient proton beam range requirements for sample Polish population.

Mean eye length with sclera is 24.6 mm.

More than 95% cases could be treated with 60 MeV proton beam from AIC-144 cyclotron.

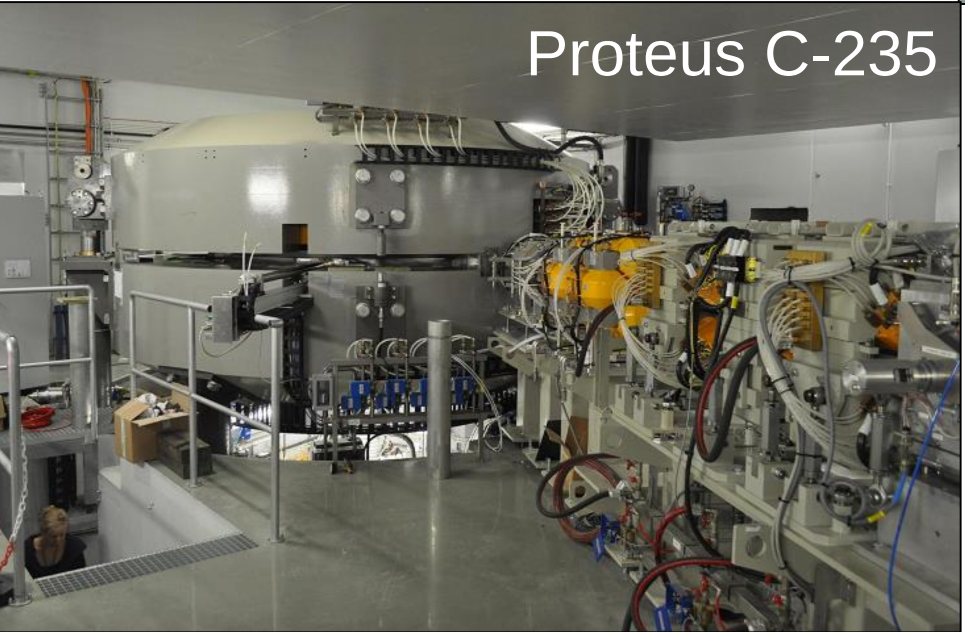
Ocular treatment rooms at CCB IFJ PAN ...





AIC-144:

- Weight 150 tons
- **60 MeV – 29 mm H_2O**
- Up to 100 nA
- **Pulsed beam at 50 Hz**

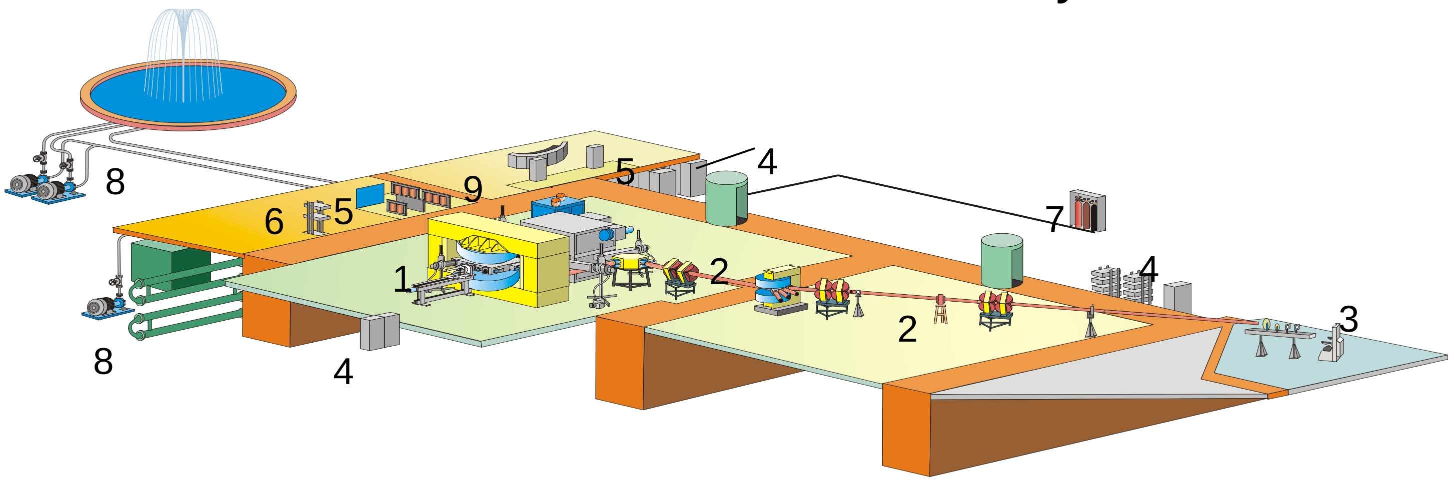


Proteus C-235:

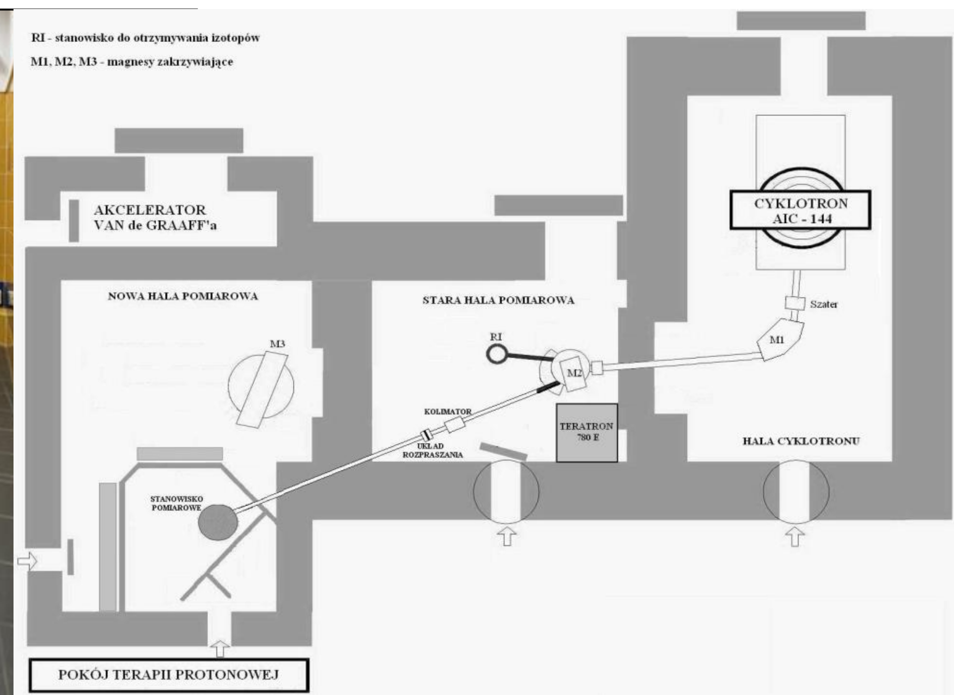
- Weight 220 tons
- **70 – 230 MeV 4 – 32 cm H_2O**
- Up to 600 nA
- **Quasi-continuous beam at 106 MHz**

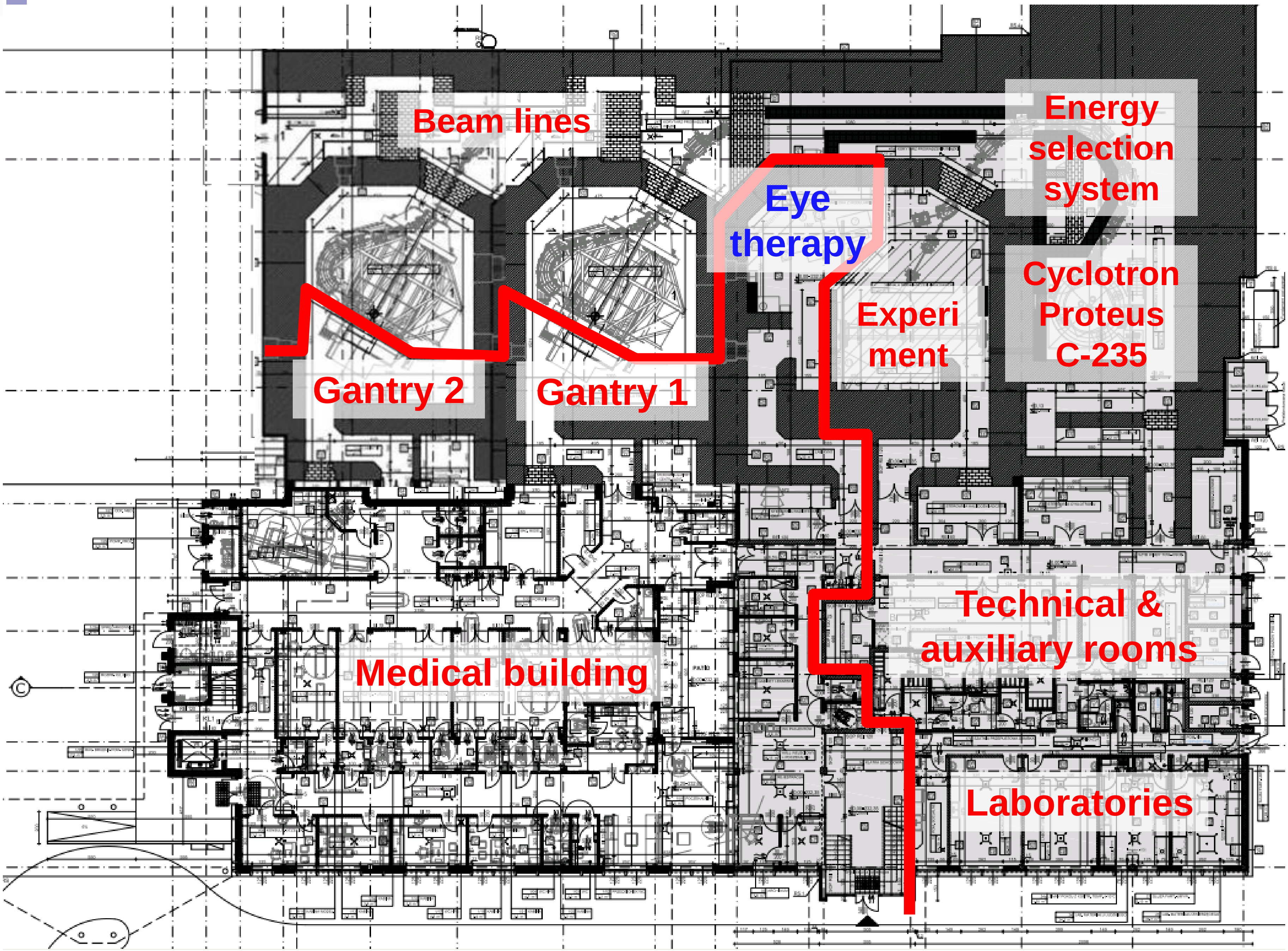
Ocular treatment rooms at CCB IFJ PAN ...

Ocular treatment room at AIC-144 cyclotron



(*Swakoń J., Sulikowski J., Olko P., technical departments and many others*)




Beam lines
Energy selection system
Eye therapy
Cyclotron Proteus C-235
Experi ment
Gantry 2
Gantry 1
Technical & auxiliary rooms
Medical building
Laboratories

Ocular treatment rooms at CCB IFJ PAN ...

Ion Beam Applications s.a.
Chemin du Cyclotron, 3
B-1348 Louvain-la-Neuve, Belgium
Tel: +3210475811
Fax: +3210475810

CE 0088

Declaration of Conformity
Proteus 235

This **SAT.129.2** Proteus 235 installed in:

The Henryk Niewodniczanski - Institute of Nuclear Physics - Polish Academy of Sciences

ul. Radzikowskiego 152,
31-342 Krakow, Poland

is a specific configuration of the Proteus 235 product as described through the Therapy System Delivery note (MID 35596 and ID 2164) and is summarized in Annex A to this declaration.

We hereby declare that the above mentioned device as described through the Therapy System Delivery note (MID 35596 and ID 2164) is a class IIb device and complies with the applicable requirements of the European Council Directive 93/42/EEC as amended by Directive 98/79/EC, Directive 2000/70/EC, Directive 2001/104/EC, Regulation (EC) No 1882/2003, Directive 2007/47/EC.
This declaration of conformity is done according to Annex II, excluding paragraph 4, of the above mentioned directive.

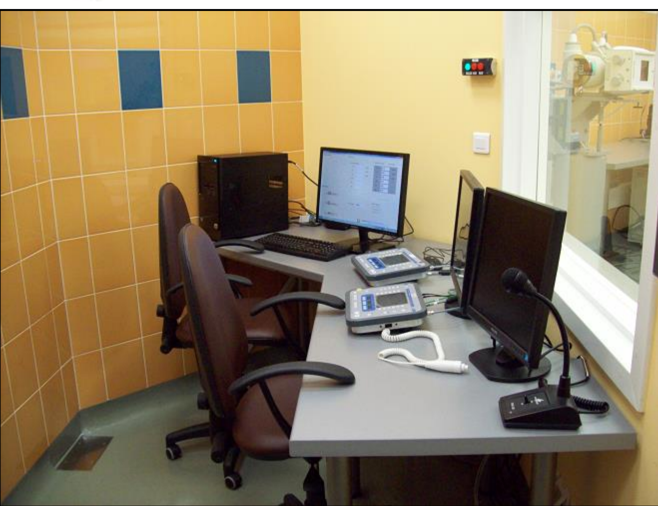
The IBA Proton Therapy System, Proteus 235, is a medical device designed to produce and deliver a proton beam for the treatment of patients with localized tumors and other conditions susceptible to treatment by radiation. The PTS may include a fixed small beam treatment room dedicated to the treatment of patients with localized tumors and other conditions susceptible to treatment by radiation localized to the head and neck.

The product has been manufactured under an ISO 13485:2003 quality management system approved by LRQA, approval number LRQ 0960876.

Louvain la Neuve,
15.03.2016

Anne-Sophie Grell, Ph.D
Group Regulatory Affairs Director
IBA Group

DoC M-ID 43064 0 1/2



- **Developed at IFJ PAN**
- 70 MeV at nozzle entrance
- **CE marking** in collaboration with IBA
- Treating patients since 2016

(*Swakoń J., Horwacik T., Góra Ł. and many others*)

Advantages of the new eye treatment room

- bigger maximum beam range allowing for all treament cases
- excellent beam stability
- robotic chair with isocentric rotation
- authomatic digital imaging
- faster workflow
- patient waiting rooms

International Partners

Andreas Weber

Who helped us?

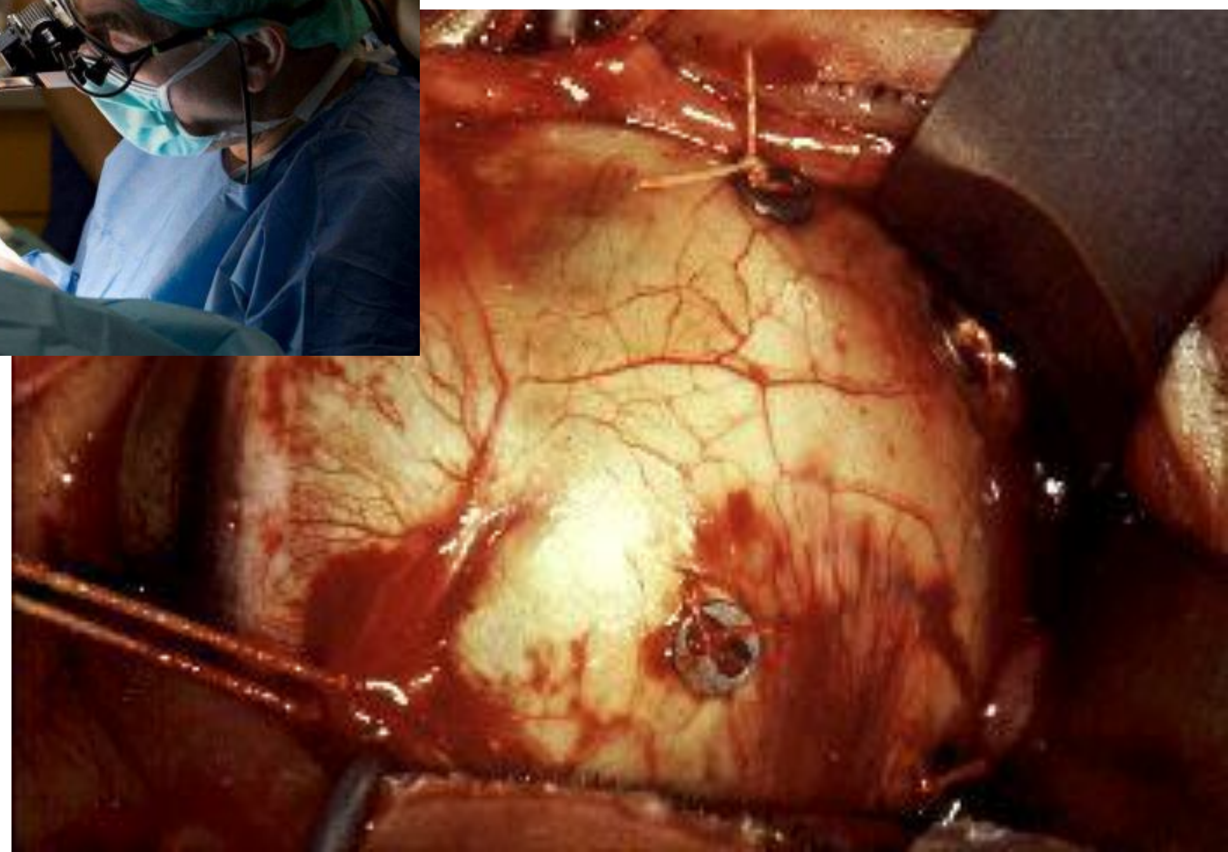
- Hahn Meitner Institut (Helmholtz-Zentrum), Berlin, Germany
- Clatterbridge Cyclotron Centre, Liverpool, UK
- Centre de Protonthérapie (Curie Institut), Orsay, France
- Laboratori Nazionali del Sud, Catania, Italy
- Paul Scherrer Institute, Villingen, Switzerland
- University of Florida Health Proton Therapy Institute, Jacksonville, USA

Whom we helped?

- Fondazione Centro Nazionale Adroterapia Oncologica, Pavia, Italy
- National Cancer Center, Seoul, Korea
- Holland PTC, Delft, Nederlands

Patient preparation – tantalum markers surgery

prof. M. H. Foerster
(Charité, Berlin)

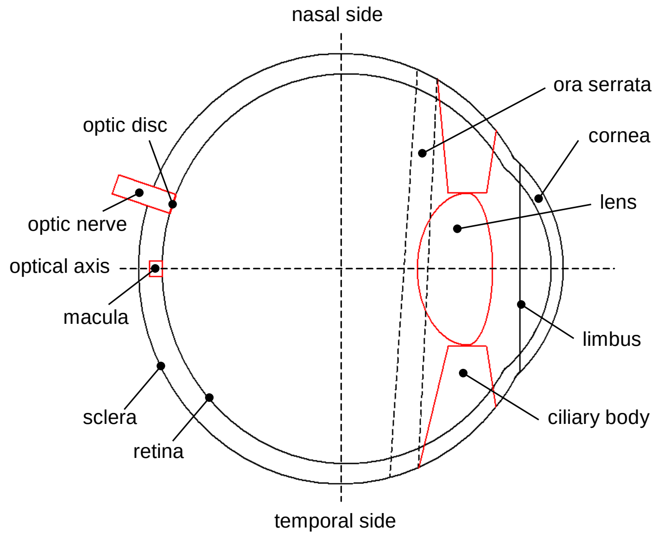


prof. B. Romanowska-Dixon
(CM UJ, Kraków)

Szpital
Uniwersytecki
w Krakowie

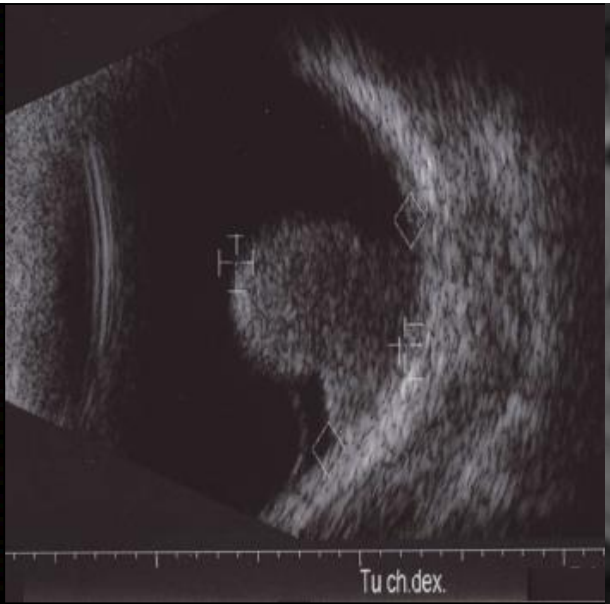
Clinical data needed for treatment planning:

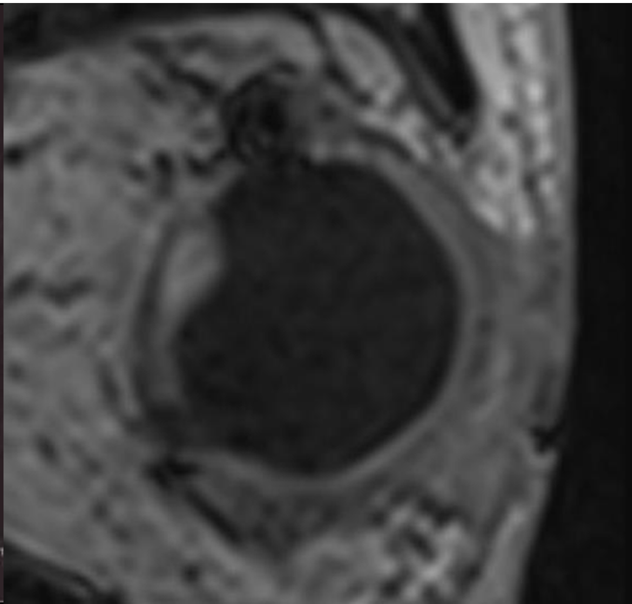
- Intraoperative measurements
- Ultrasound
- IOL Master
- Optical Coherent Tomography
- Fundus images
- MRI / CT



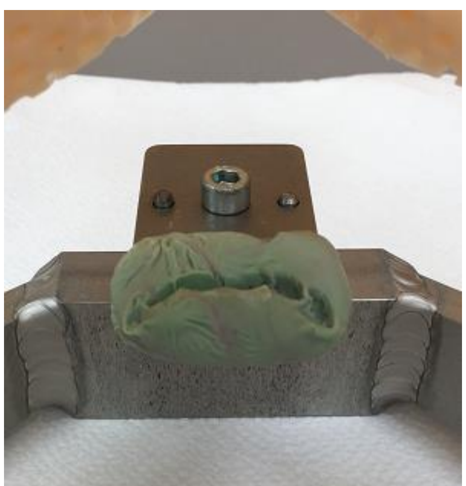
Centrum Onkologii
Instytut im. Marii Skłodowskiej-Curie
Oddział w Krakowie

Szpital
Uniwersytecki
w Krakowie

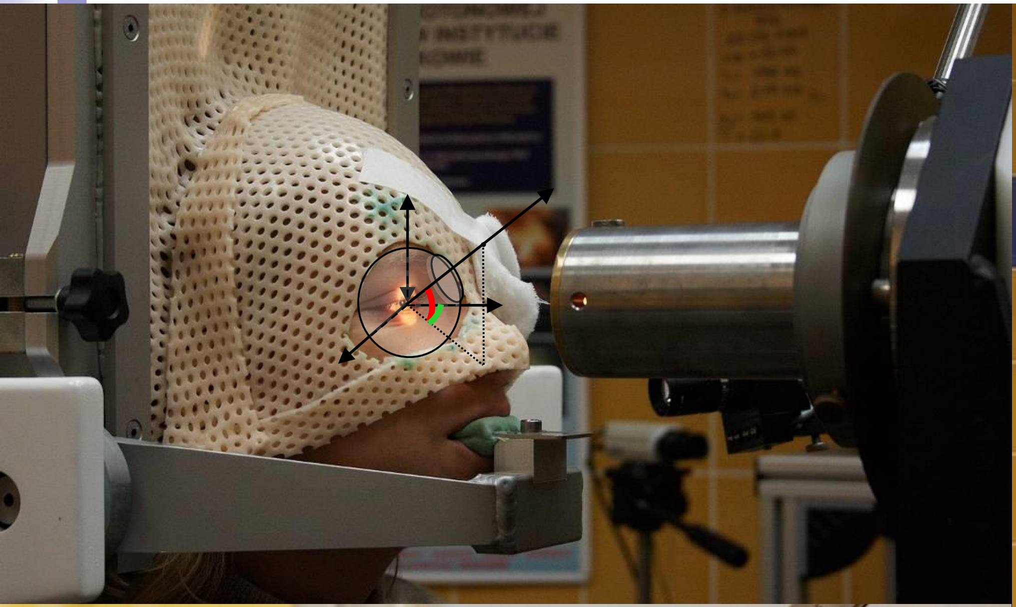


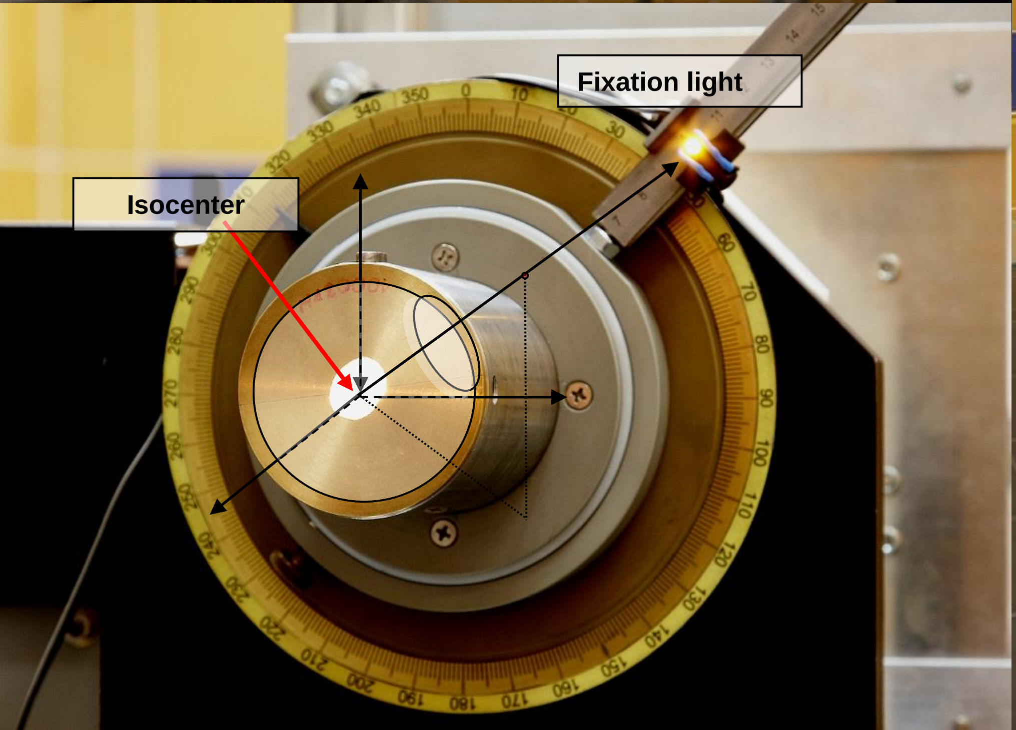


Patient immobilization – thermoplastic mask and bite block



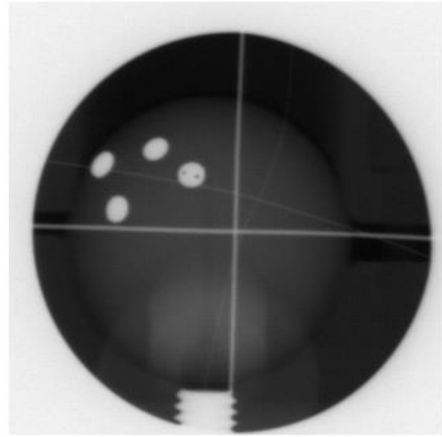
Proton eye treatment procedure – patient positioning

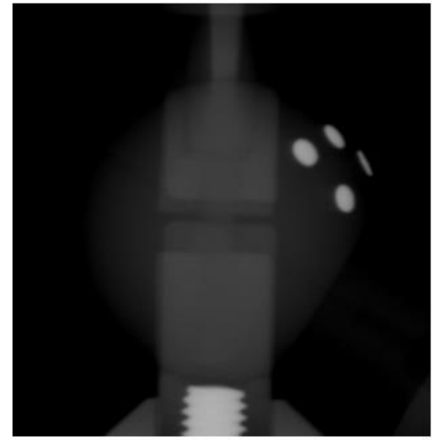


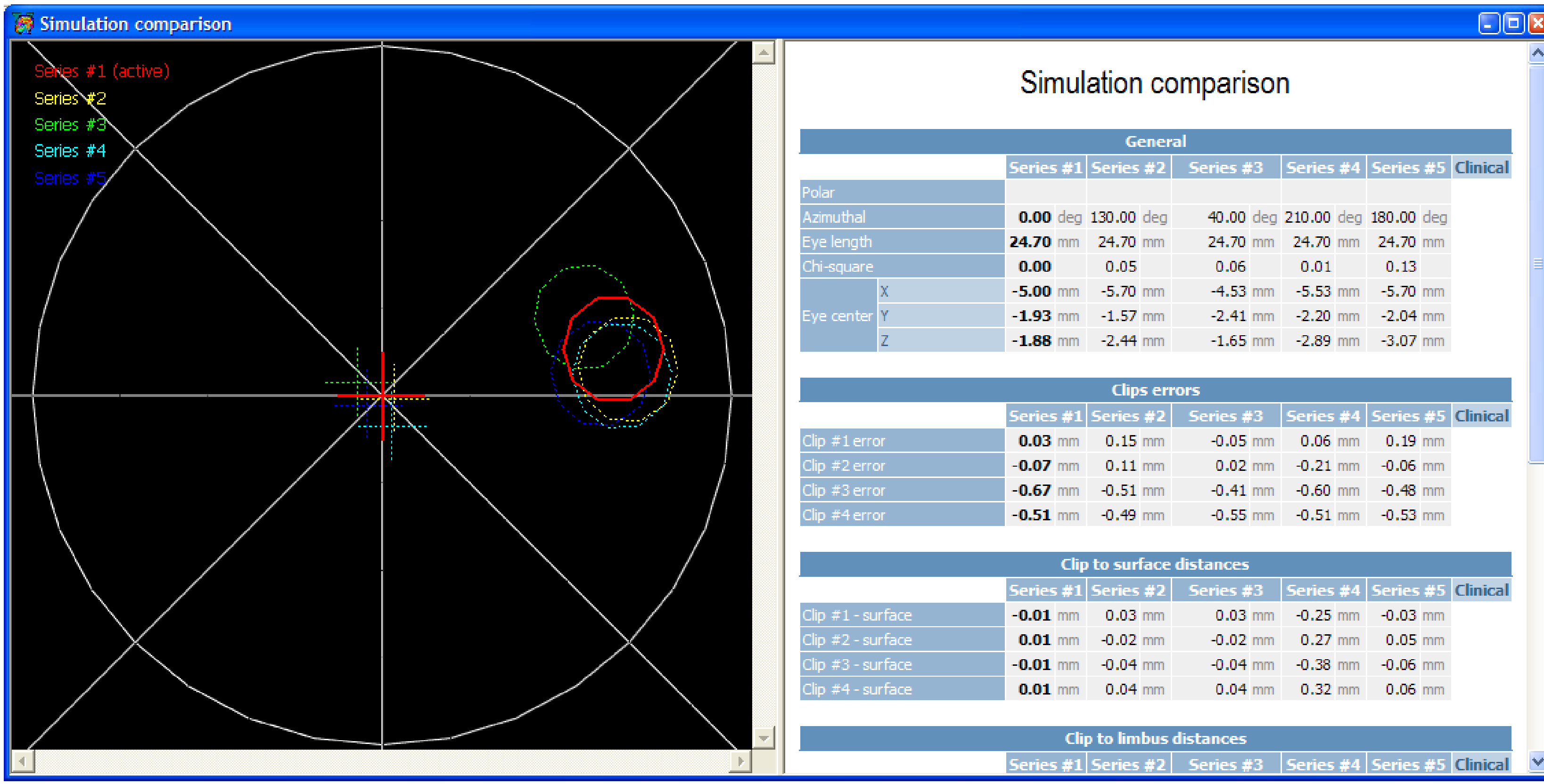


Treatment simulations

- To fit eye ball to markers
- To check patient ability to follow fixation lights







Simulation comparison

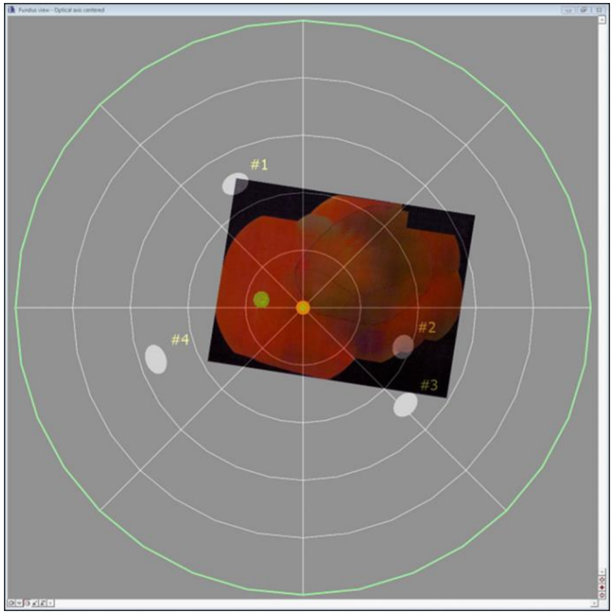
General	Series #1	Series #2	Series #3	Series #4	Series #5	Clinical
Polar						
Azimuthal	**0.00** deg	130.00 deg	40.00 deg	210.00 deg	180.00 deg	
Eye length	**24.70** mm	24.70 mm	24.70 mm	24.70 mm	24.70 mm	
Chi-square	**0.00**	0.05	0.06	0.01	0.13	
Eye center X	**-5.00** mm	-5.70 mm	-4.53 mm	-5.53 mm	-5.70 mm	
Eye center Y	**-1.93** mm	-1.57 mm	-2.41 mm	-2.20 mm	-2.04 mm	
Eye center Z	**-1.88** mm	-2.44 mm	-1.65 mm	-2.89 mm	-3.07 mm	

Clips errors	Series #1	Series #2	Series #3	Series #4	Series #5	Clinical
Clip #1 error	**0.03** mm	0.15 mm	-0.05 mm	0.06 mm	0.19 mm	
Clip #2 error	**-0.07** mm	0.11 mm	0.02 mm	-0.21 mm	-0.06 mm	
Clip #3 error	**-0.67** mm	-0.51 mm	-0.41 mm	-0.60 mm	-0.48 mm	
Clip #4 error	**-0.51** mm	-0.49 mm	-0.55 mm	-0.51 mm	-0.53 mm	

Clip to surface distances	Series #1	Series #2	Series #3	Series #4	Series #5	Clinical
Clip #1 - surface	**-0.01** mm	0.03 mm	0.03 mm	-0.25 mm	-0.03 mm	
Clip #2 - surface	**0.01** mm	-0.02 mm	-0.02 mm	0.27 mm	0.05 mm	
Clip #3 - surface	**-0.01** mm	-0.04 mm	-0.04 mm	-0.38 mm	-0.06 mm	
Clip #4 - surface	**0.01** mm	0.04 mm	0.04 mm	0.32 mm	0.06 mm	

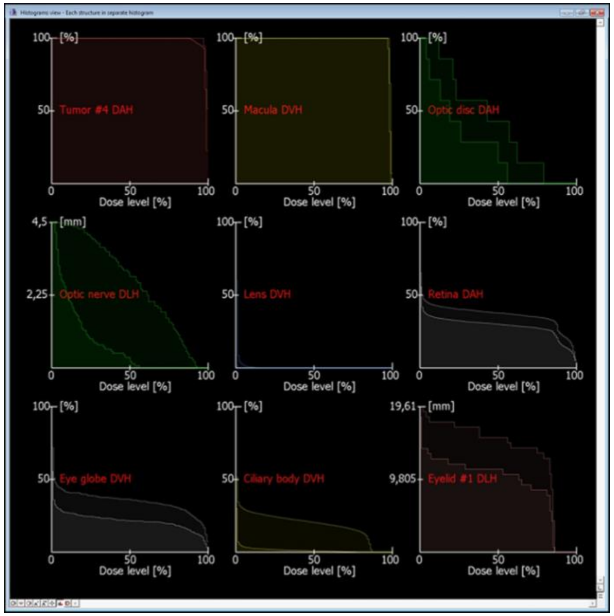
Clip to limbus distances	Series #1	Series #2	Series #3	Series #4	Series #5	Clinical

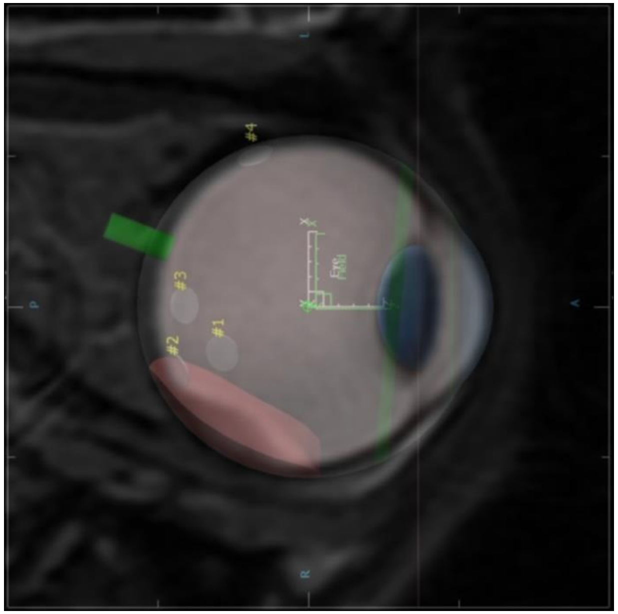
Treatment planning for ocular melanoma

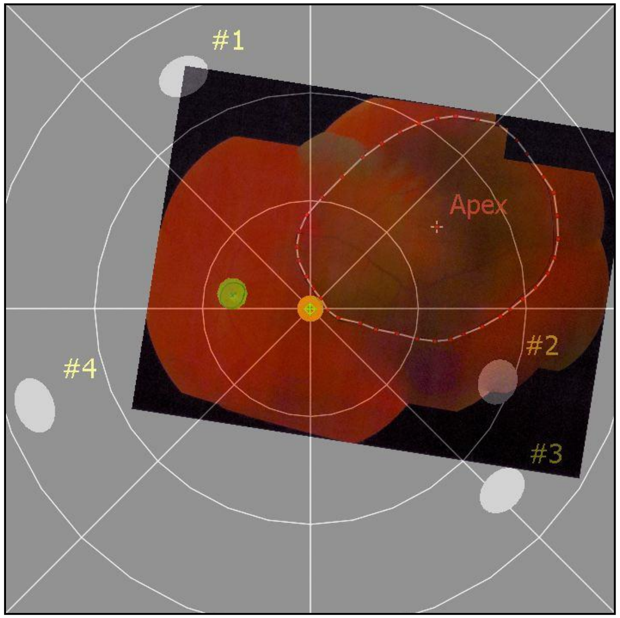


In-house developed software for supporting treatment planning

- Tumor base entrance
- MRI registration
- Plan evaluation



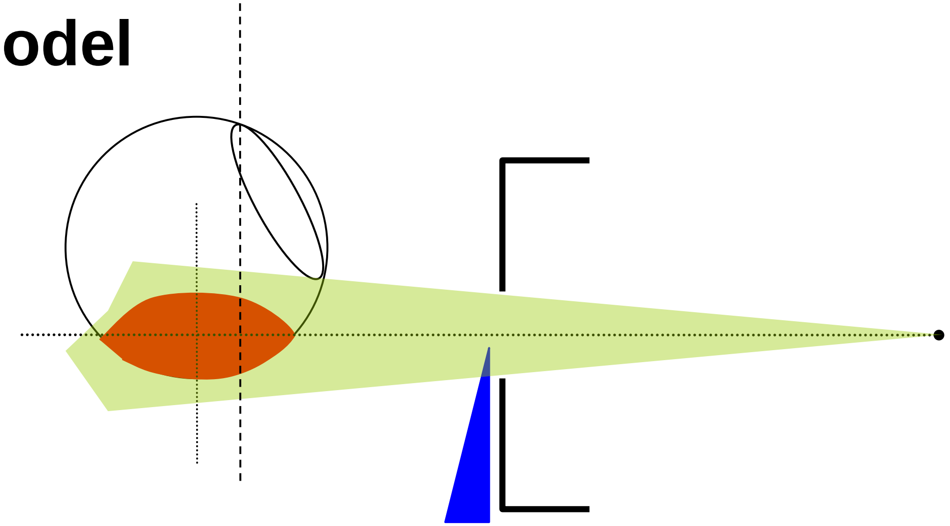


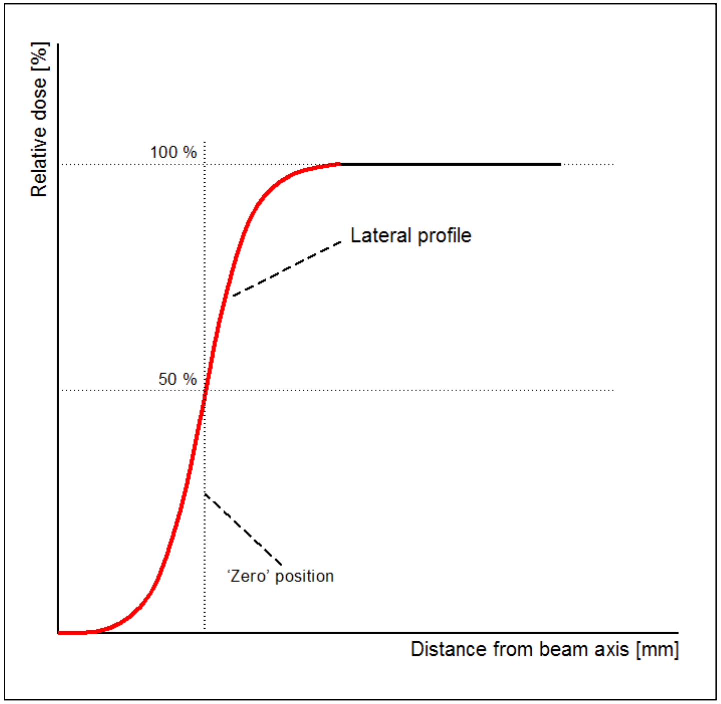


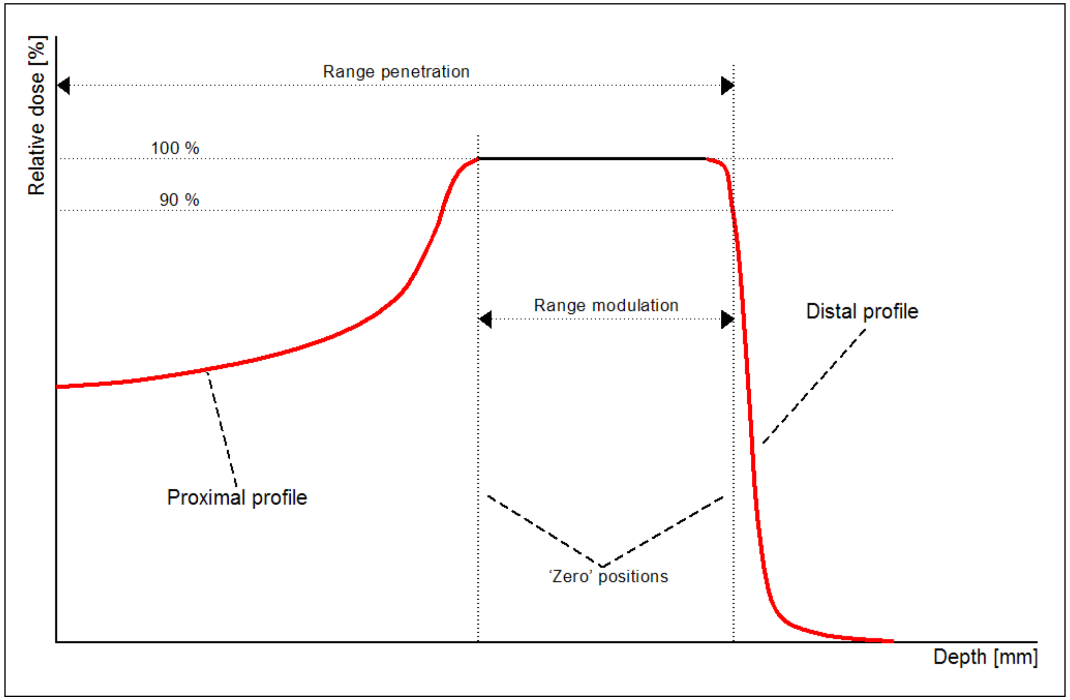
Kajdrowicz T., Kos R.

Development of Beam model

- Axial & lateral profiles
- Range
- Modulation
- Multiprofile algorithm
- Real time calculations

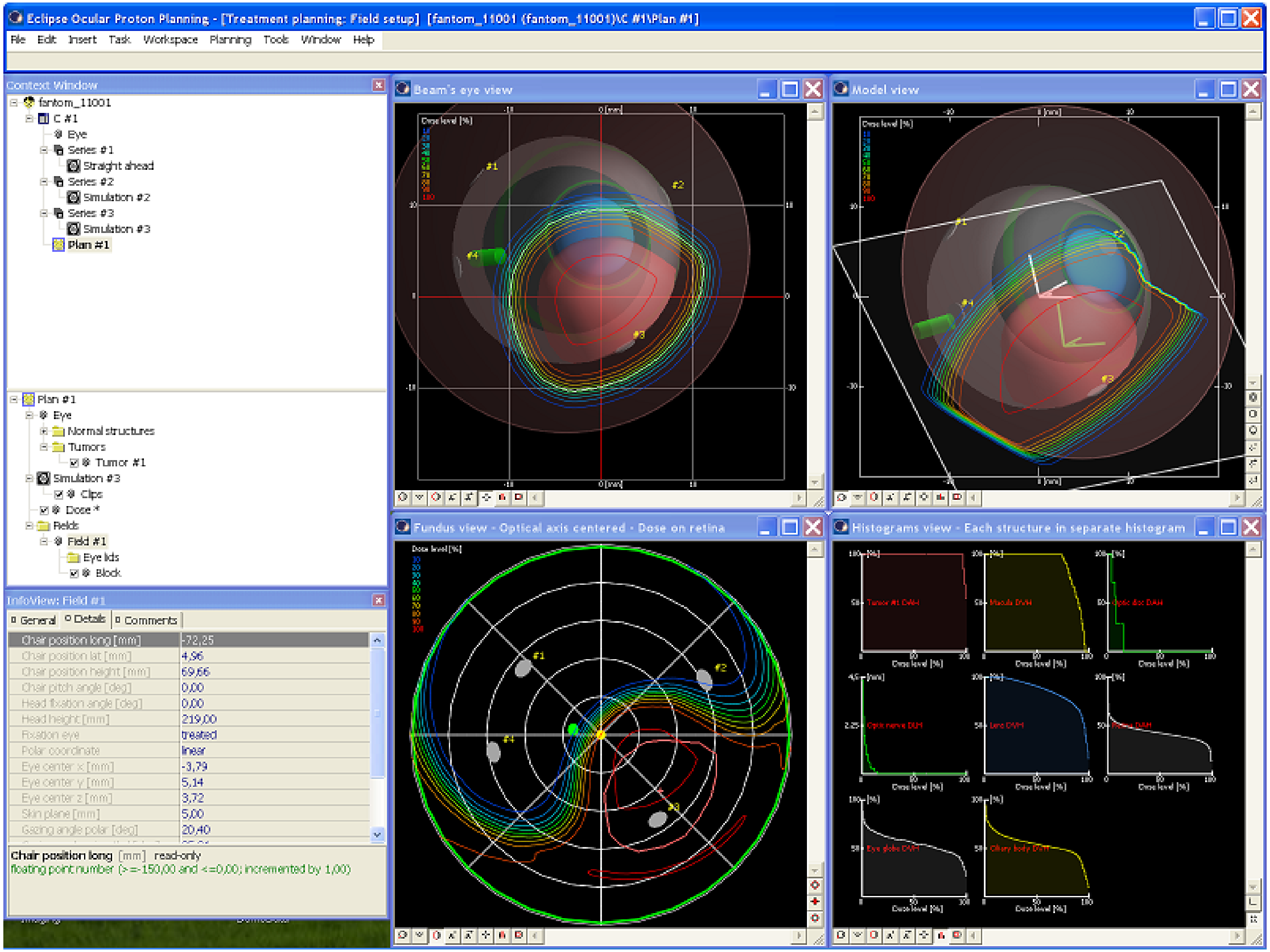






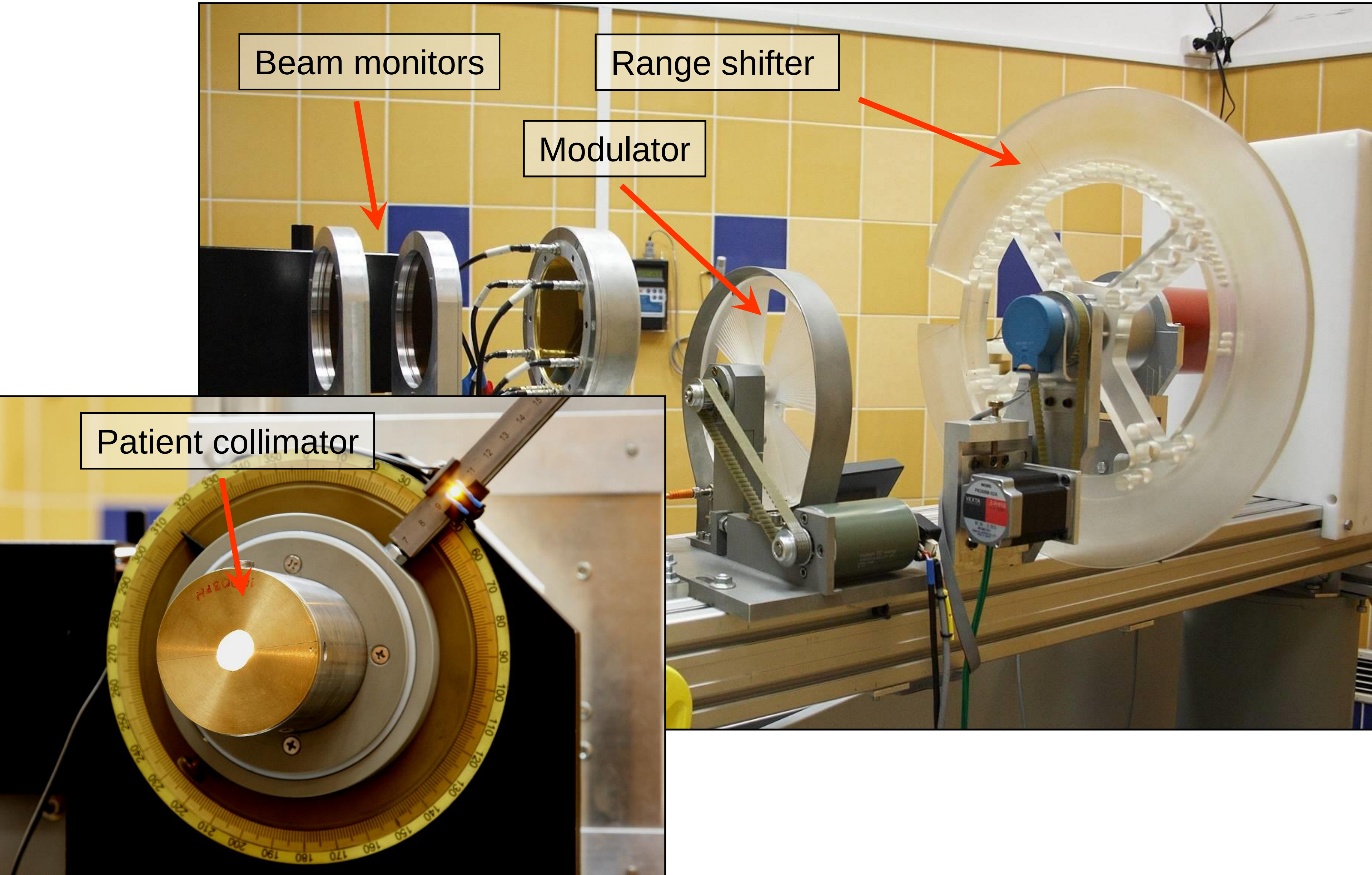
Kajdrowicz T., Kopeć M.

3D dose distribution in Eclipse Ocular Proton Planning

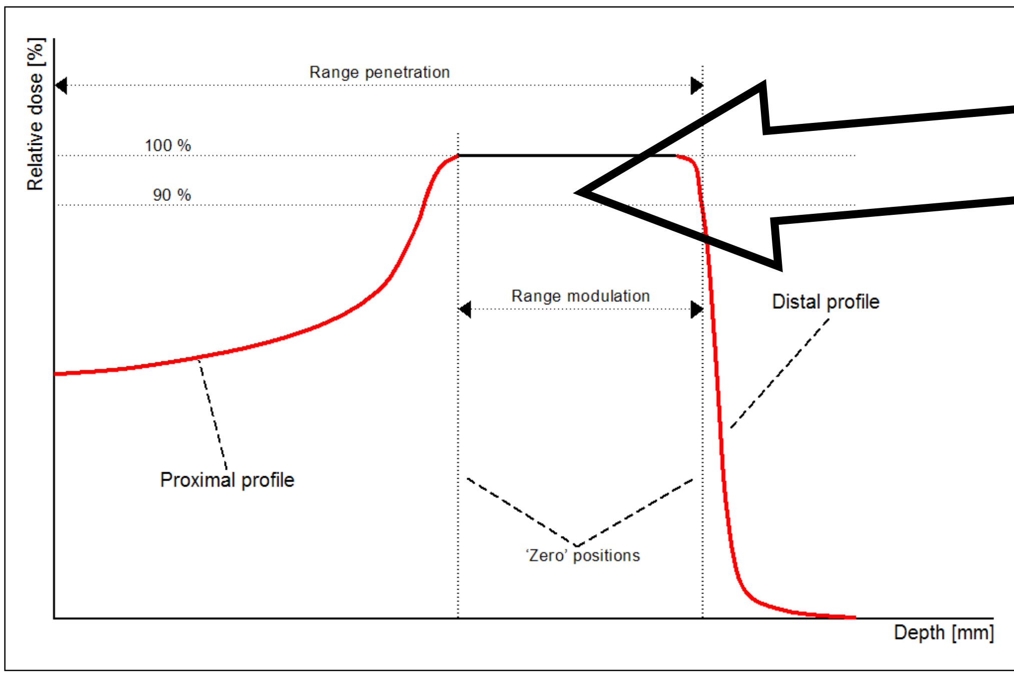


Kajdrowicz T., Bajer M. (Varian Medical Systems Inc.)

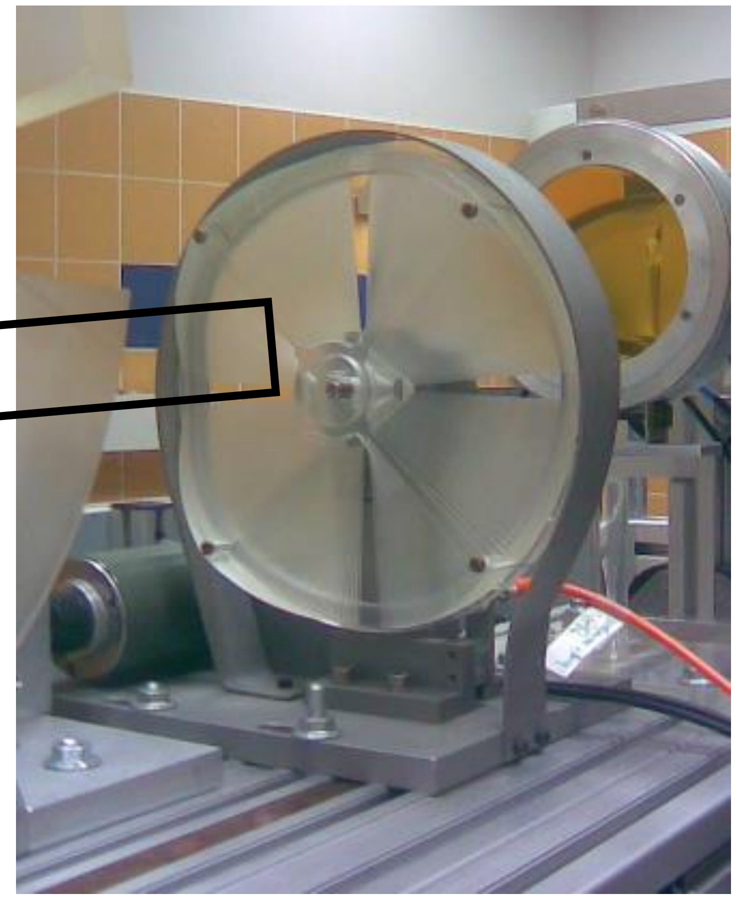
Passive scattering beam formation devices



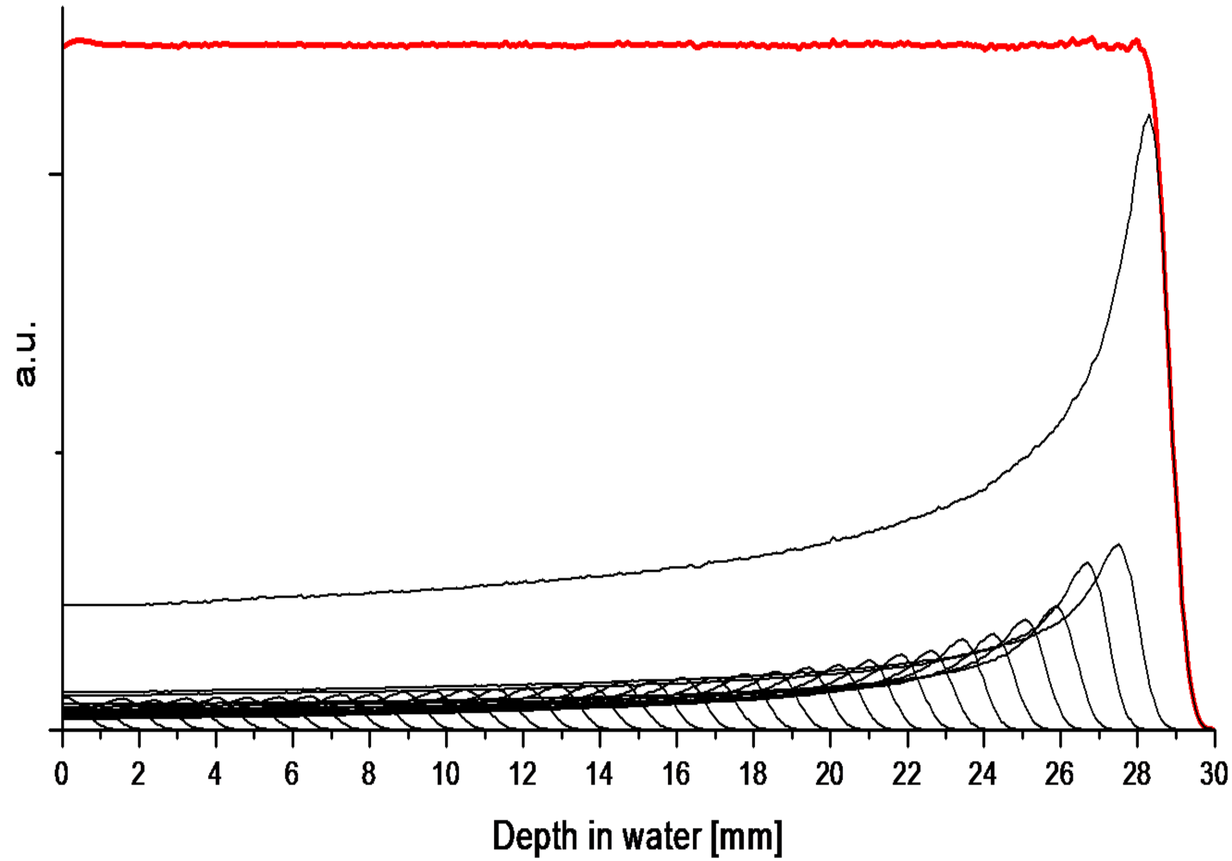
- Range modulation – Spread Out Bragg Peak (SOBP)
  - rotating wheel
  - changing PMMA thickness



Varian Medical Systems, *Eclipse Ocular Proton Planning User Guide*, 2007



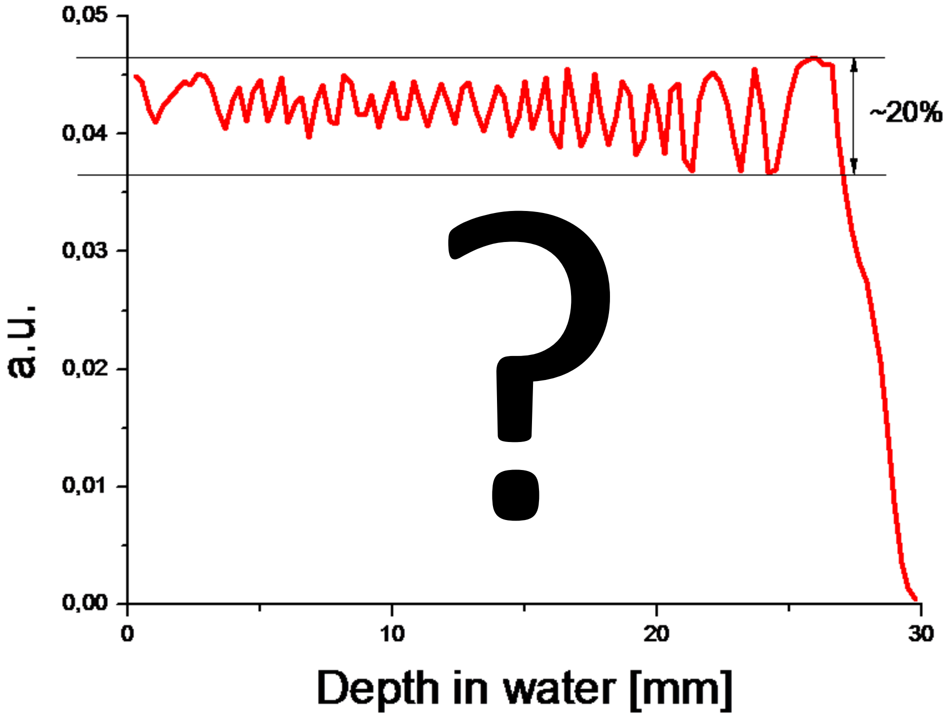
Spread Out Bragg Peak formation



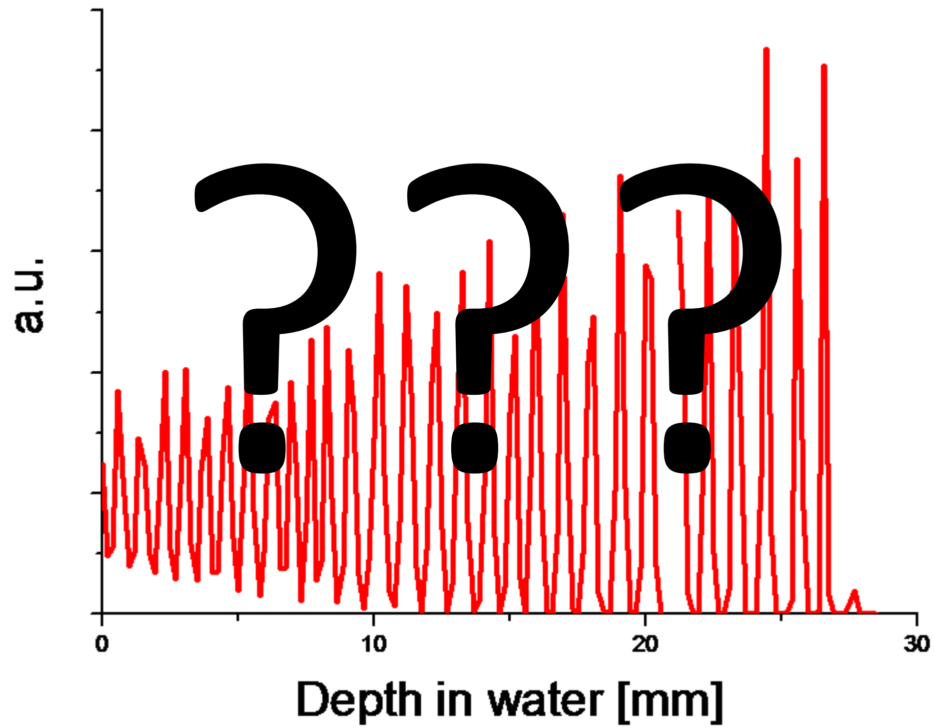
Modulator

Experimental verification of modulators

using 3D water phantom scanner and Markus ioninzation chamber



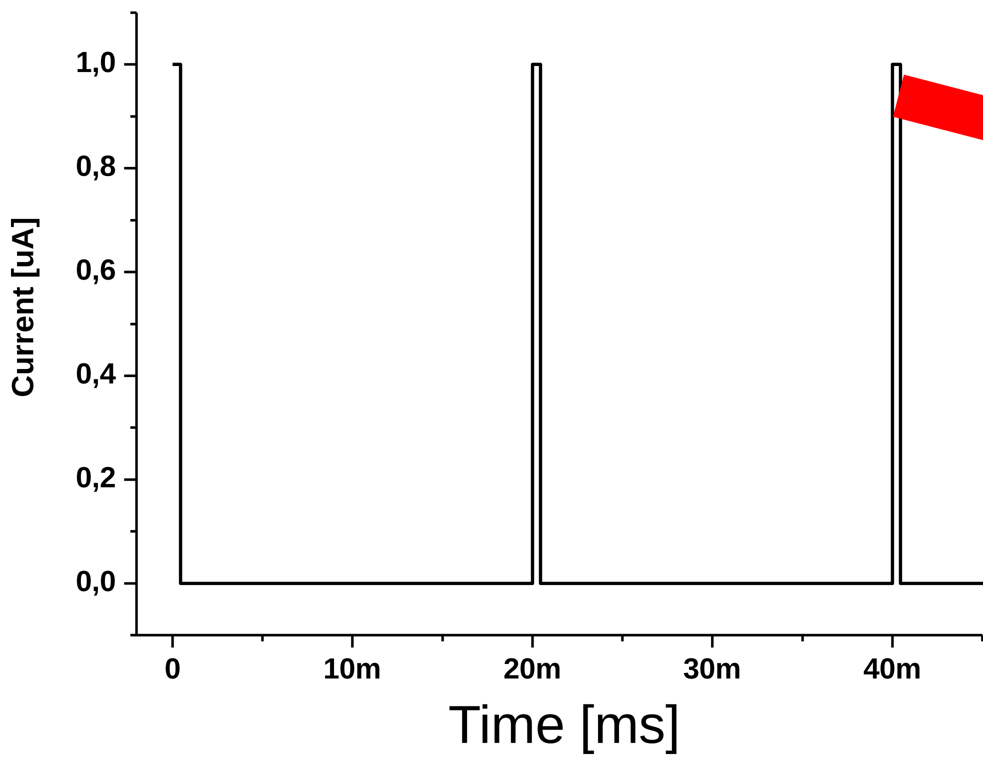
It did not look like SOBP ☹

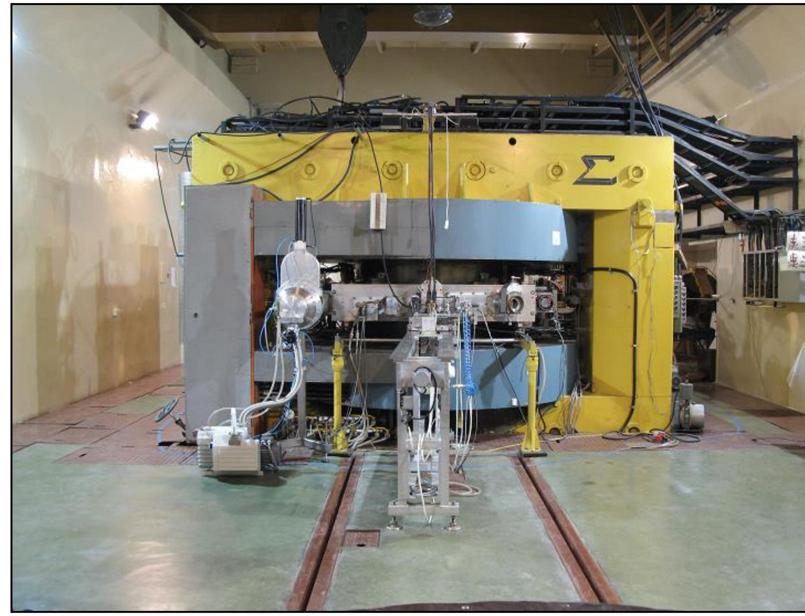


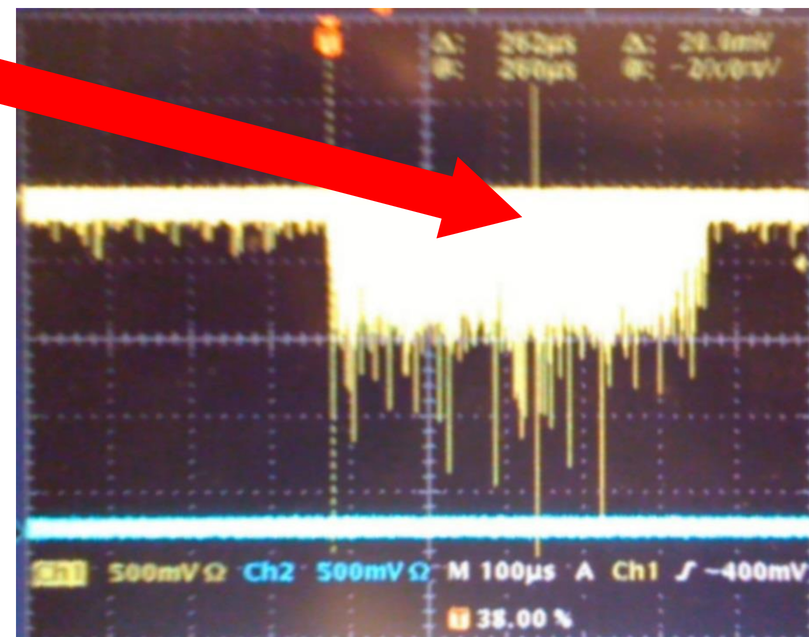
Range modulation

Beam time structure of AIC–144 cyclotron

- Pulse repetition 50 [Hz]
- Pulse lenght 0.46 [ms]

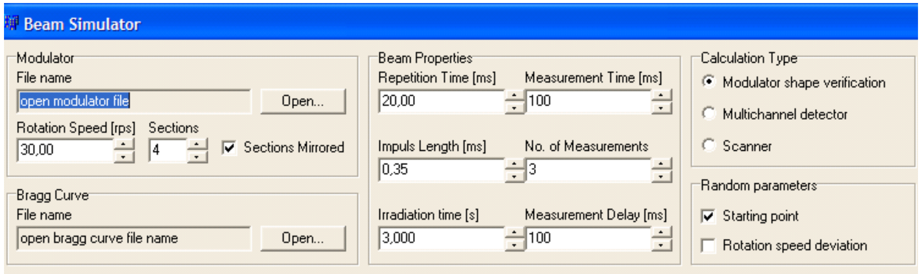


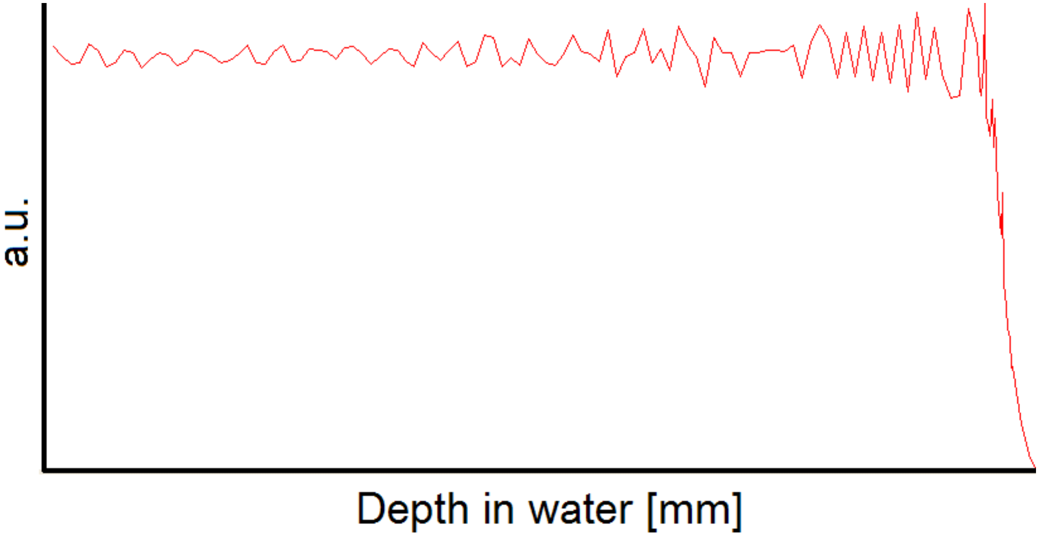


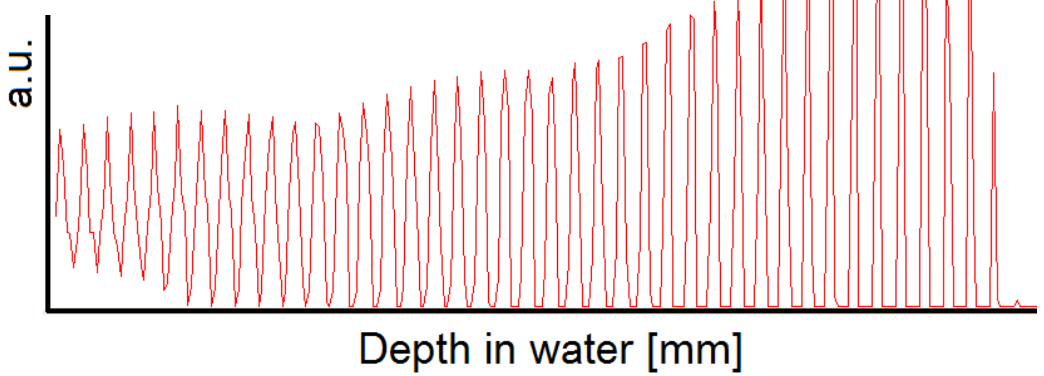


SOBP simulator software

- Beam parameters
- Modulator definition
- Measurement conditions

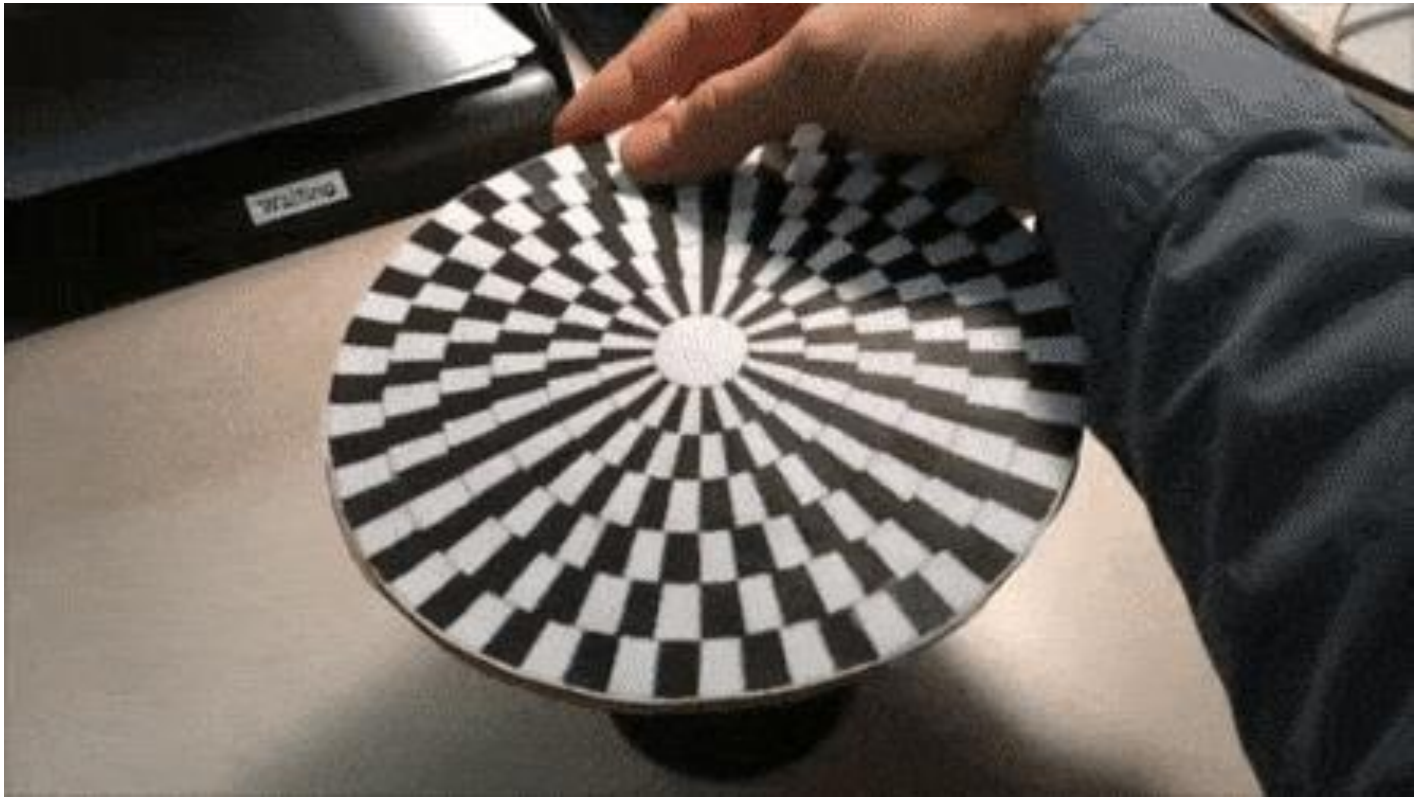






Kajdrowicz T.

- Conclusion from measurements and SOBP simulations
  - problem is not a consequence of wrong measurement conditions
  - it depends on:
    - pulsed beam structure
    - modulator rotational speed
  - … it is a sort of Wagon wheel effect.



Equation for stroboscopic effect

Methods

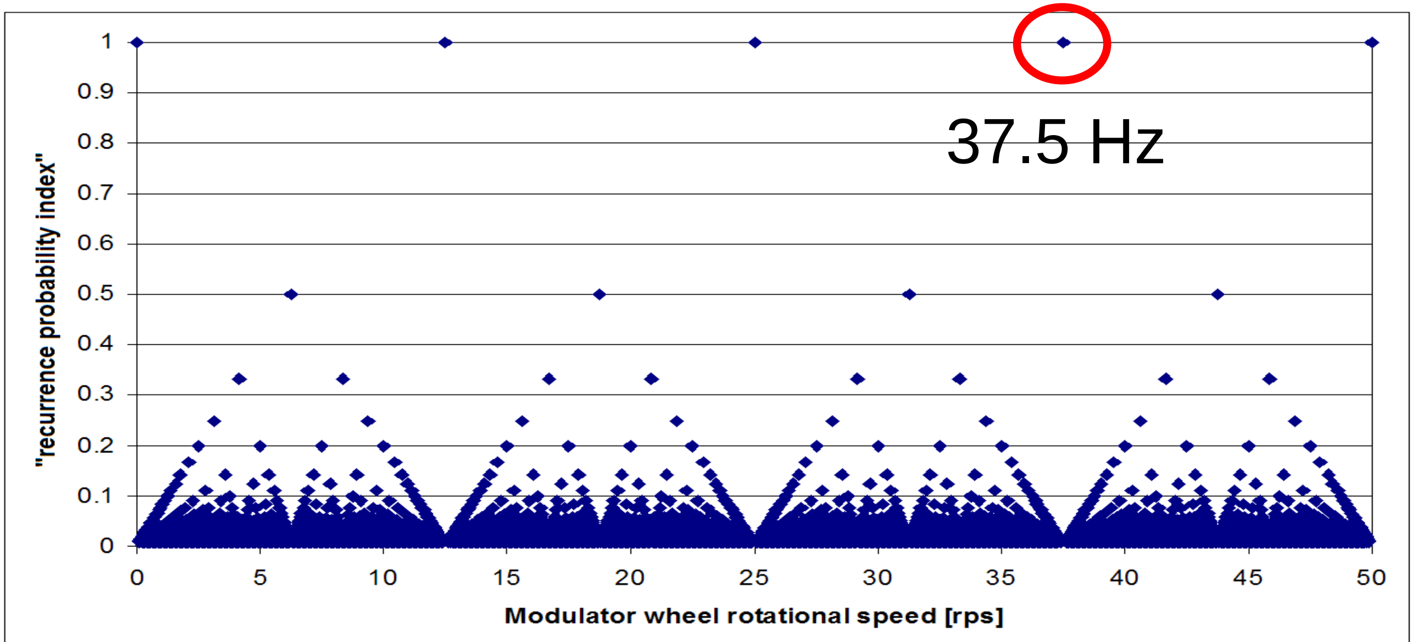
$$T_{modulator} = \frac{M}{n} \cdot T_{beam} \;\rightarrow\; T_{modulator} = \left(k + \frac{m}{n}\right) \cdot T_{beam}$$

where M, k, m, n are all integers and *m* < *n*

T_{beam} – beam pulse repetition time

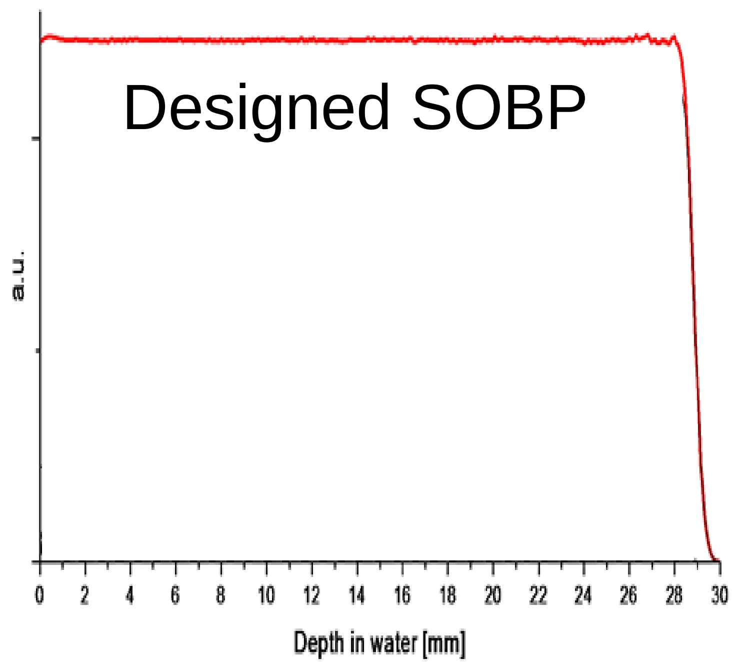
$T_{modulator}$ – modulator wheel section recurrence time

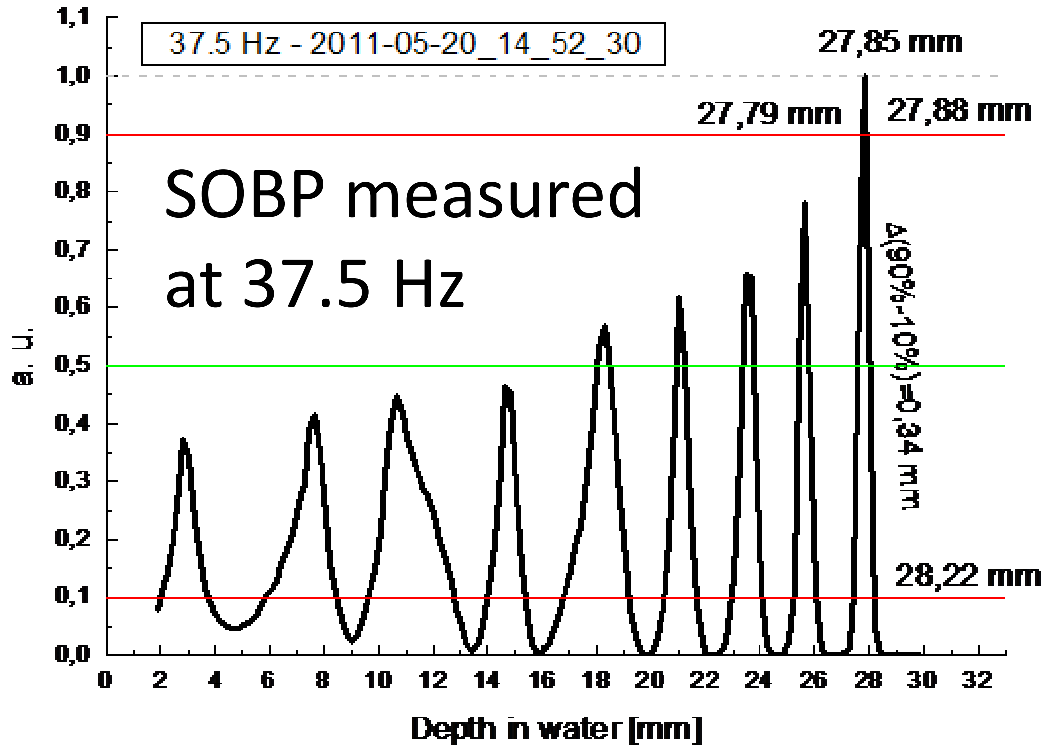
Results



Kajdrowicz T.

Experimental verification of calculations





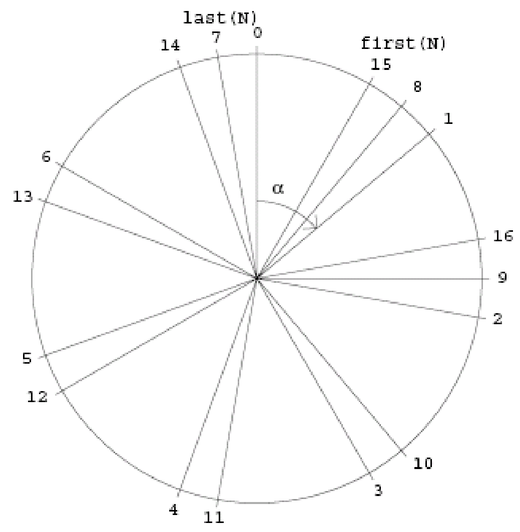
Theoretical model has been confirmed experimentally

Kajdrowicz T.

Searching for optimal asynchronous modulator rotational frequency

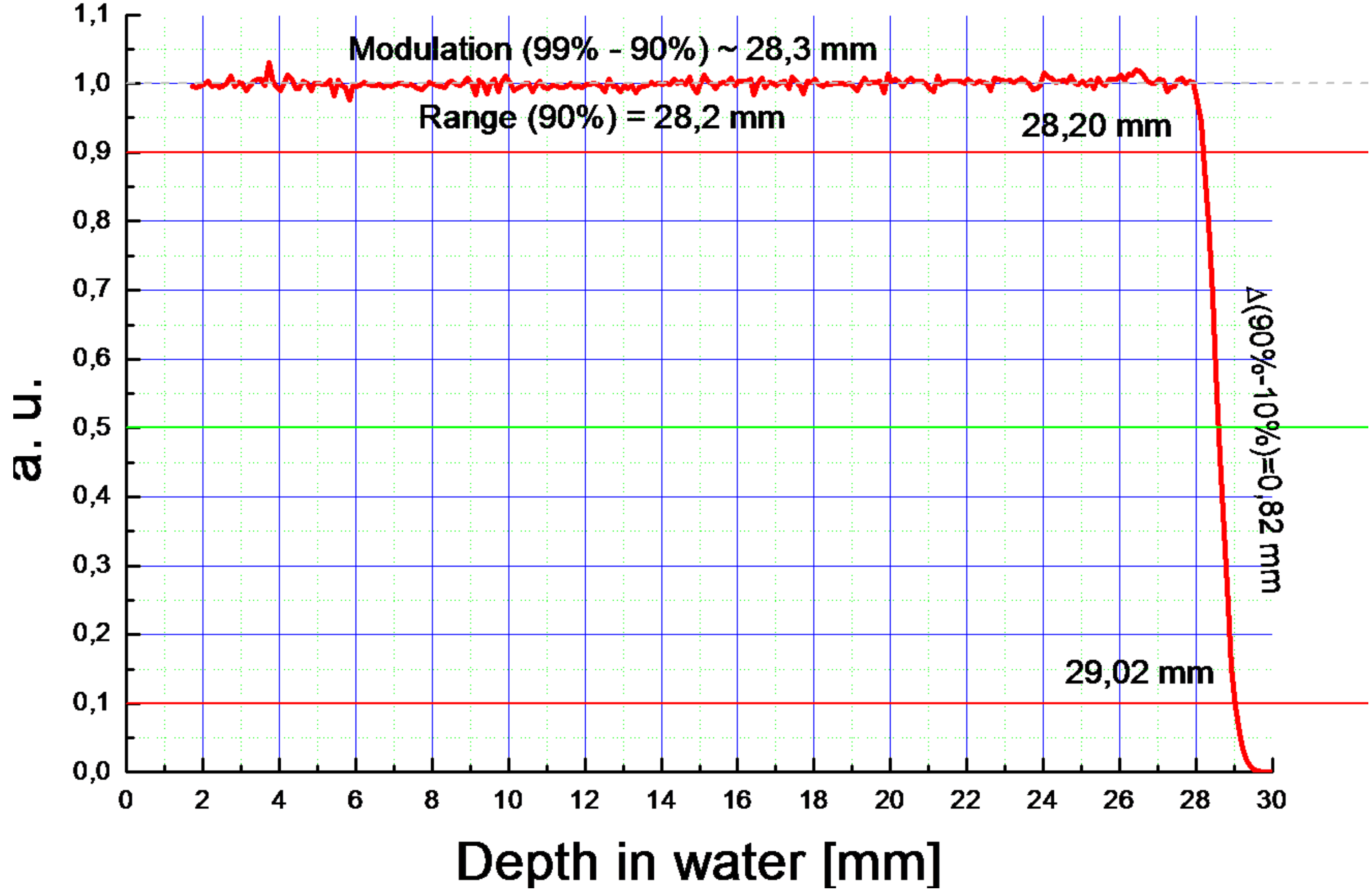
$$W_n(\alpha) = \{x_1, \ldots, x_n\} \quad \text{for} \quad x_n = n\alpha \,(\mathrm{mod}\, 1)$$

$$\text{where} \quad n = 1, 2, \ldots \quad \text{and} \quad \alpha \in [0, 1)$$



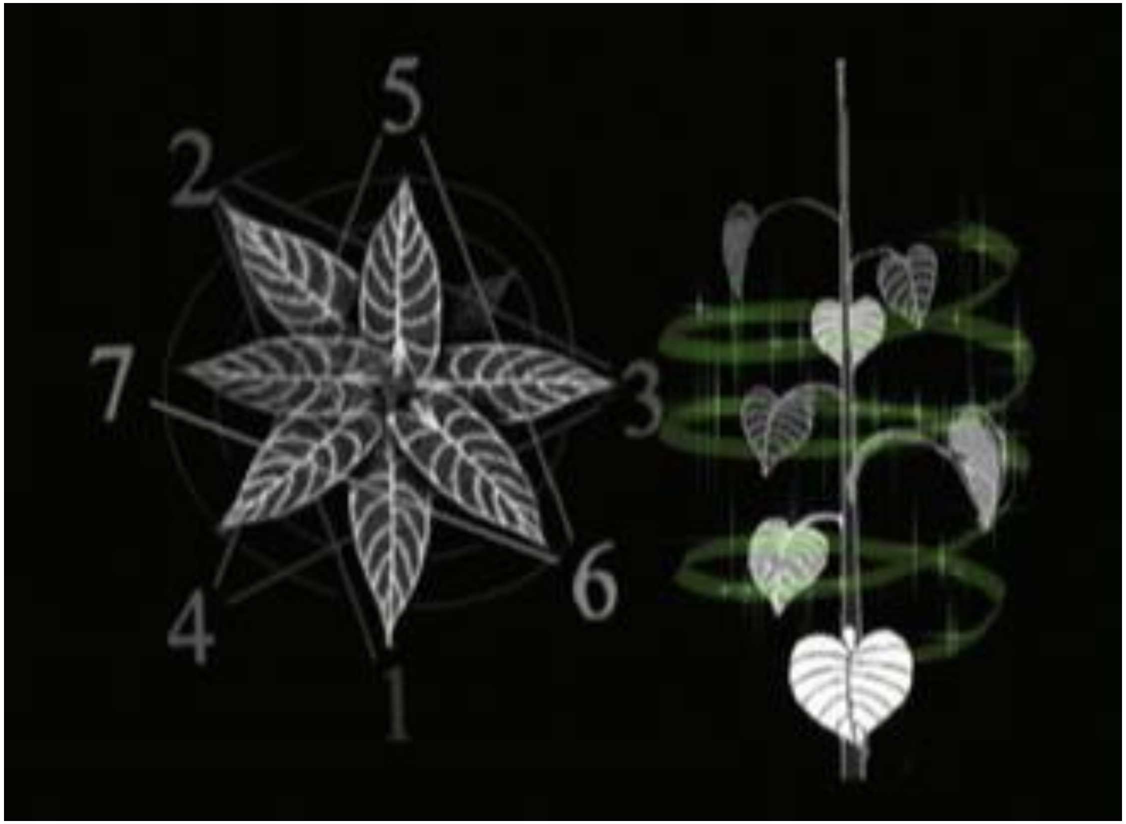
Kajdrowicz T.

FINAL RESULT – Perfect SOBP at 33.1 Hz



Kajdrowicz T.

Nature solves the equidistribution equation



Phylotaxis of a plant

equidistribution of sun light over leaves

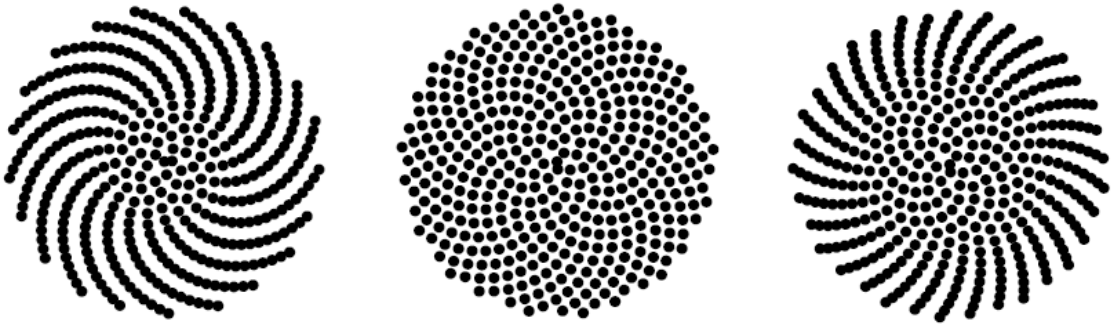
Golden angle

$$\alpha = \tau = \frac{\sqrt{5}-1}{2}$$

Rotational speed of modulator:

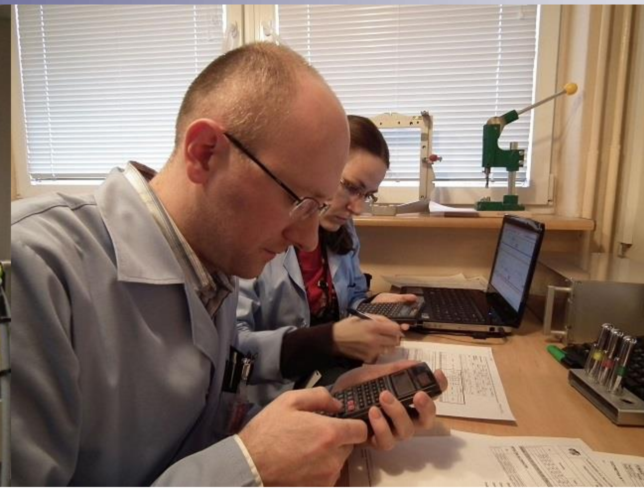
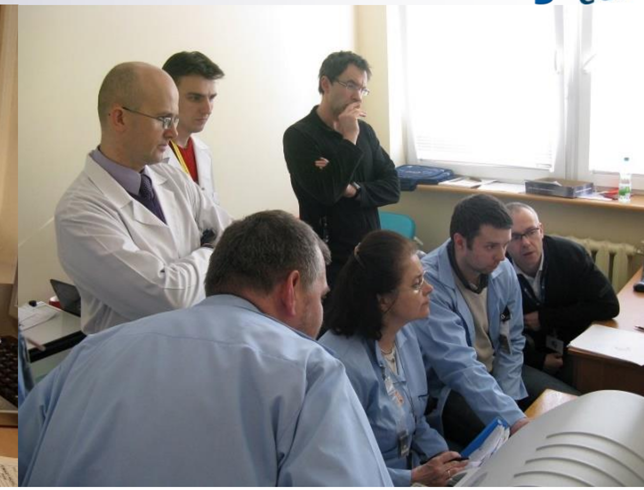
~ 32.725 Hz

- **Golden angle**:
  - Most uniform distribution of beam pulses (no recurrence)
  - Very low dose discrepancy, but …
  - Mechanically unavailable frequency
  - ~32.725 Hz is unfortunately very close to a high resonant frequency (32.8125 Hz) by less then 0.1 Hz



Golden Angle – 0.1° Golden Angle Golden Angle + 0.1°

2011.02.15 – Preparation to the first treatment

My name is A, QA – quality assurance

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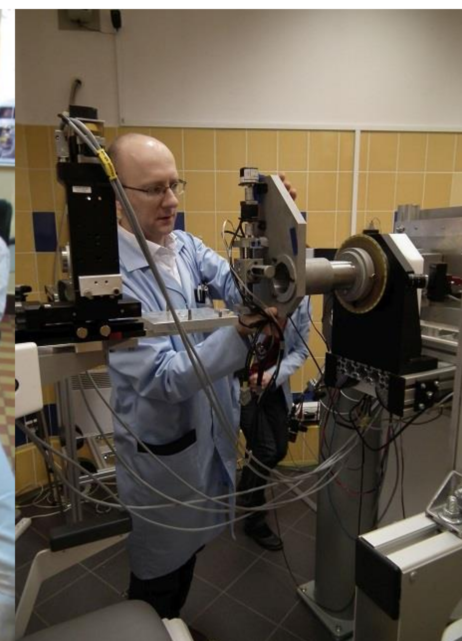
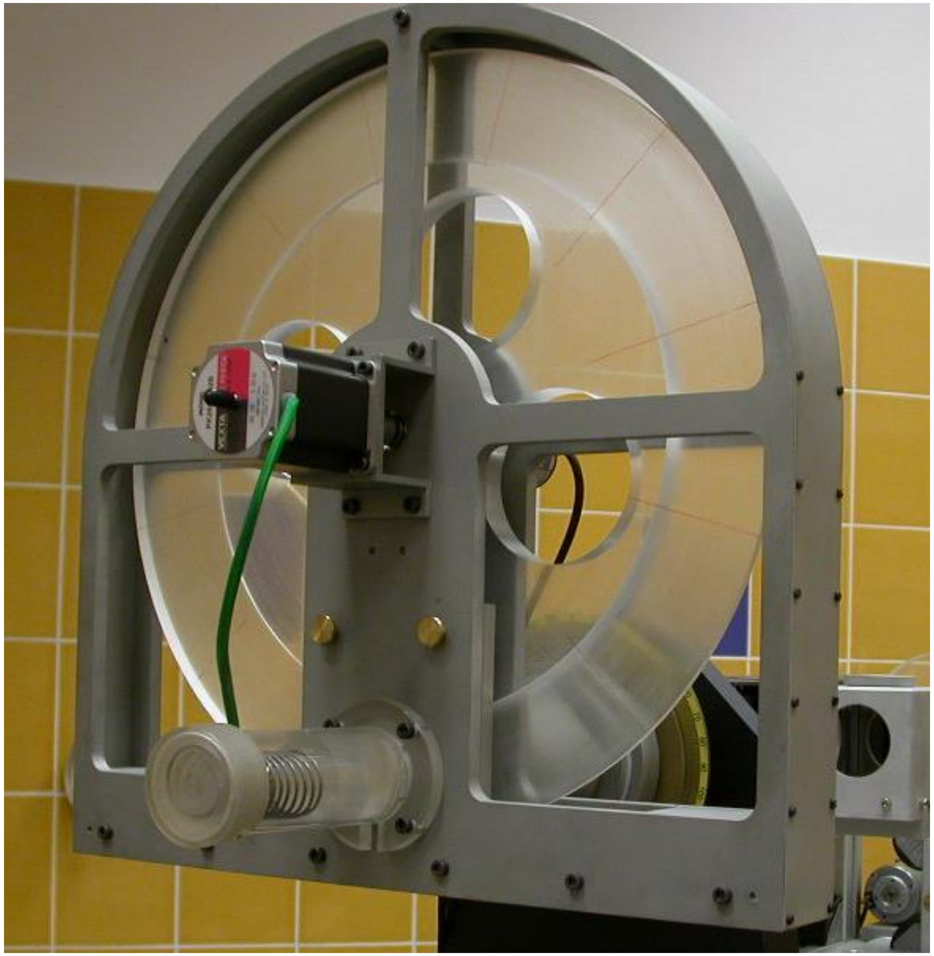



Quality Assurance

In-house developed phantoms and scanners



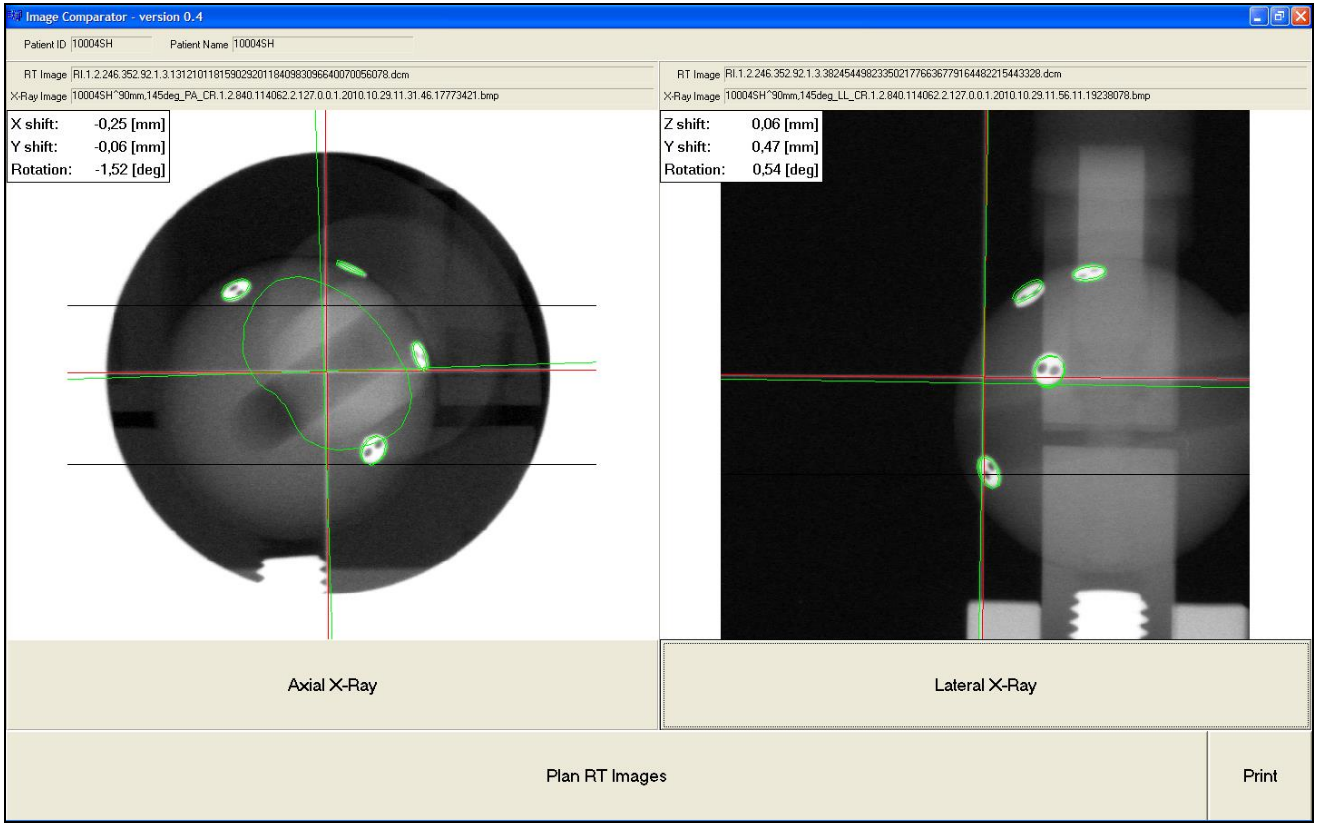
PMMA range phantom

Lateral profile scanner

3D scanner and water phantom

2011.02.15 – Treatment of the first two patients

In-house developed Patient Positioning Verification System

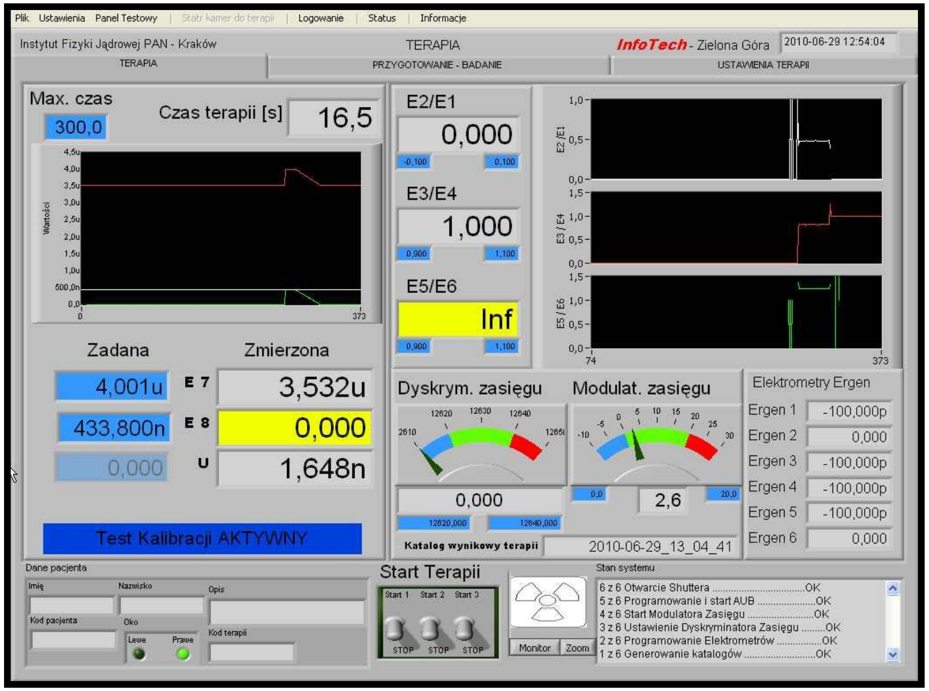


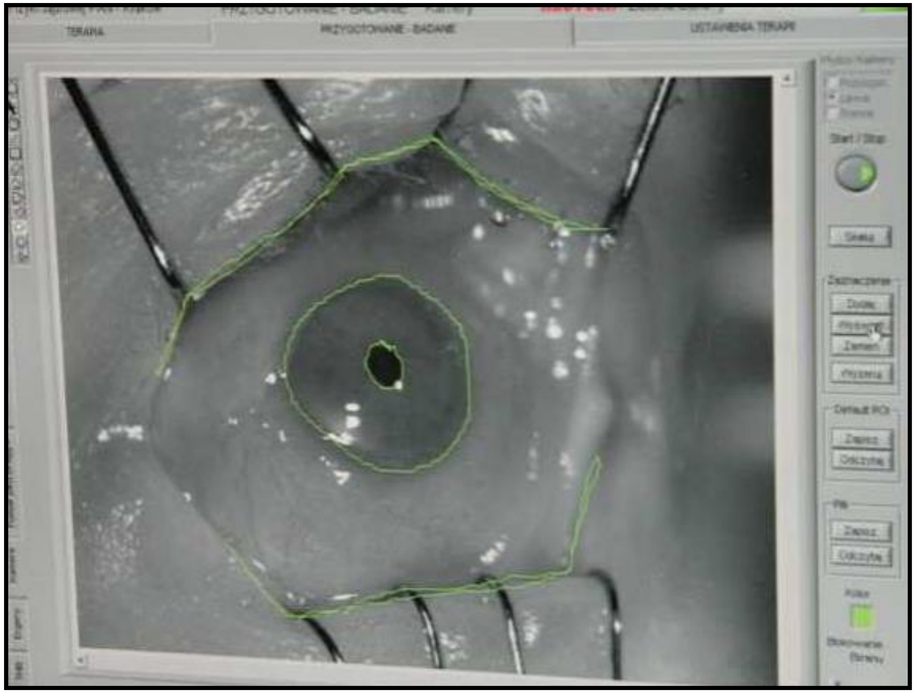
It allows for quick patient positioning with submilimeter precision

Kajdrowicz T., Kos R., Knapp P., Olko K.

Proton eye treatment procedure

Treatment delivery – 4 fractions, 15 Gy_{RBE} each





Nomber of fraction	Dose delivered (planned) [CGE]	Dose delivered [CGE]	Independent dose controle [CGE]	Total dose [CGE]	Time [s]
Fraction 1	15.00	15.001	15.068	15.001	51
Fraction 2	15.00	15.044	15.057	30.045	53.5
Fraction 3	15.00	15.020	15.043	45.065	60.5
Fraction 4	15.00	15.026	15.026	60.091	63.5

The team almoast complete

prof. M. Jeżabek

Movie by dr hab. Jerzy Grębosz
Terapia protonowa nowotworów oka
sekretariat.ccb@ifj.edu.pl

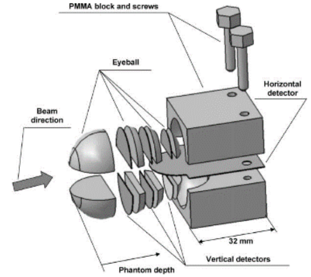
Patient summary

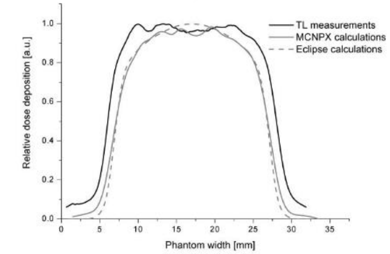
- 292 patients of University Hospital in Krakow treated:
  - 128 patients at AIC-144
  - 164 patients at CCB ELTR
- *Age between 17 to 75 years
  - 52 years on average
  - 3% patients below < 22
- *Female 46%, Male 54%
- *Right eye 49%, left eye 51%
- *Tumor height
  - < 5mm 72 %
  - 5-10mm 24 %
  - > 10mm 4%
- *Follow up of 93% patients → 97% local control

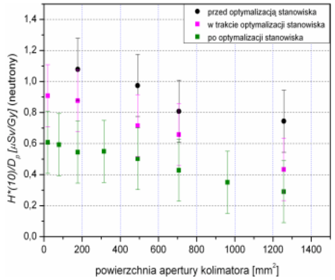
*Romanowska-Dixon B, Markiewicz A, Sas-Korczyńska B, Medoń D, Walasek T. Evaluation of intraocular proton beam irradiation complications after choroidal melanoma treatment. Klinika Oczna / Acta Ophthalmologica Polonica. 2016;118(4):289-292. doi:10.5114/ko.2016.71741.
*Romanowska-Dixon B Terapia protonowa czerniaka naczyniówki, Seminarium, 2016

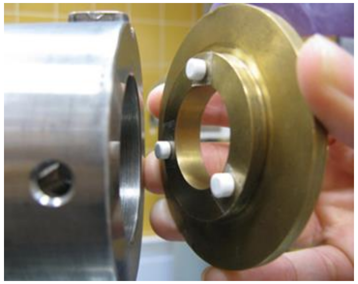
Detectors and dosimetry

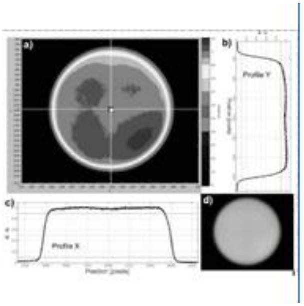
- Two-dimensional dosimetry of radiotherapeutical proton beams using thermoluminescence foils, *Czopyk L, Kajdrowicz T, Kłosowski M, et al. (2007)*, Radiation Protection Dosimetry (2007), pp. 1–5
- Individual patient shielding for a proton eye therapy facility, *Cywicka-Jakiel T, Stolarczyk L, Swakoń J, et al.*, Radiat. Meas., **45** (2010) 1127
- Evaluation of risk of secondary cancer occurrence after proton radiotherapy of ocular tumours, *Stolarczyk L, Horwacik T, el al., 2011,* Radiat. Meas. 46*,* 1944-1947
- Alanine dosimetry of 60 MeV proton beam - preliminary results, *Michalec B, Mierzwińska G, Sowa U, et al. (2012)*, Nukleonika, 57, 503-506
- A monitoring system for the 60 MeV radiotherapy proton beam at IFJ PAN using a scintillating screen and a CCD camera*, Boberek et al. (2014)*, Romanian Rep. Phys. 66, 5–15
- Dosimetric characterization of collimators for spatially fractionated proton therapy of the eye, *Tobola-Galus A, Swakoń J, Olko P*, Radiation Protection Dosimetry, Volume 180, Issue 1-4, August 2018, Pages 351–354

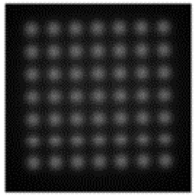


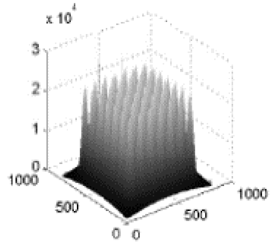












Radiobiology

- Metastasis inhibition after proton beam, β- and γ-irradiation of melanoma growing in the hamster eye, *Romanowska-Dixon B, Elas M, Swakoń J, et al.*, Acta Biochimica Polonica, 2013, Vol. 60, No 3/2013 307–311
- Relative biological effectiveness of the 60-MeV therapeutic proton beam at the Institute of Nuclear Physics (IFJ PAN) in Kraków, Poland, *Słonina D, Biesaga B, Swakoń J, et al.*, Radiat Environ Biophys. 2014 Nov;53(4):745-54
- Response of human lymphocytes to proton radiation of 60 MeV compared to 250 kV X-rays by the cytokinesis-block micronucleus assay, *J. Miszczyk J, Rawojć K, Panek A, et al.*, Radiother. Oncol., 115 (2015) 128-134
- Biological effects and inter-individual variability in peripheral blood lymphocytes of healthy donors exposed to 60 MeV proton radiotherapeutic beam, *Panek A, Miszczyk J, Swakoń J,* Int. J. Radiat. Biol., 94 (2018) 1085-1094

- and more …

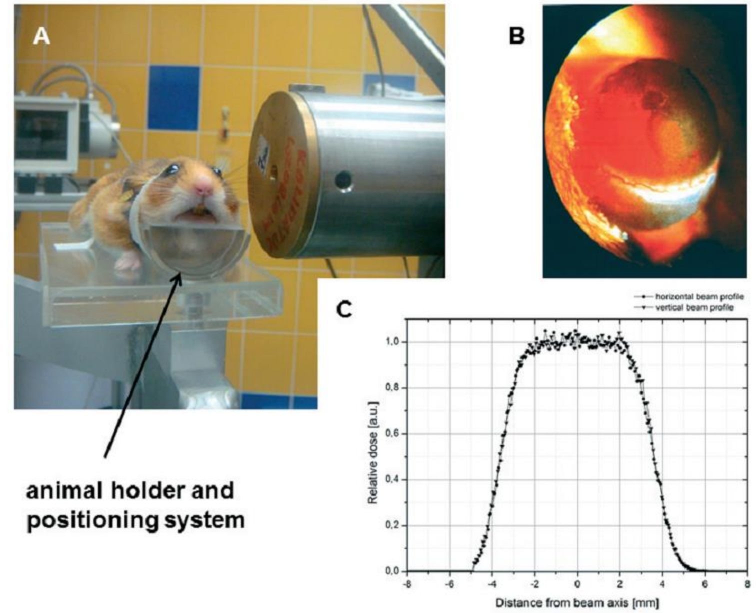


Figure 1. Hamster eye irradiation with proton beam.
(**A**) Hamster in the animal positioning system, (**B**) hamster eye with the tumor, magnification 10x and (**C**) proton beam dose depth distribution and lateral profiles of the beam used for hamster eye irradiation.

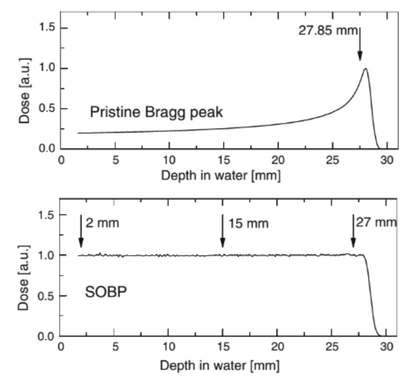


Fig. 1 Depth–dose distributions of the proton beam produced at the IFJ PAN Kraków (nominal energy 60 MeV) measured in a water phantom using a Marcus ion chamber. *Upper panel*: pristine beam; *lower panel*: SOBP. *Arrows* indicate positions at which cells (human fibroblasts) were irradiated: near (at 27.85 mm) the maximum of the Bragg peak in a pristine beam, and at three depths (2, 15, and 27 mm) of the SOBP of full width 28.4 mm

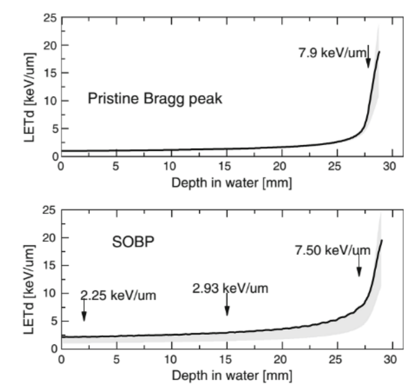
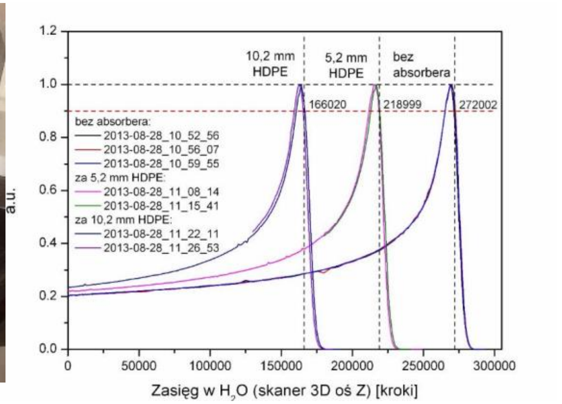


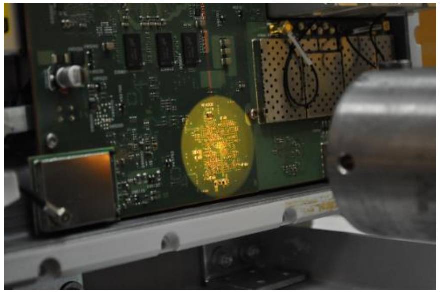
Fig. 2 Depth distributions of dose-averaged LET (LET_d) and of IQR of LET_d (*shaded*) of the proton beam produced at the IFJ PAN, simulated by Monte Carlo calculations. *Upper panel*: pristine beam; *lower panel*: SOBP. Calculated values of LET_d at irradiation positions are also shown

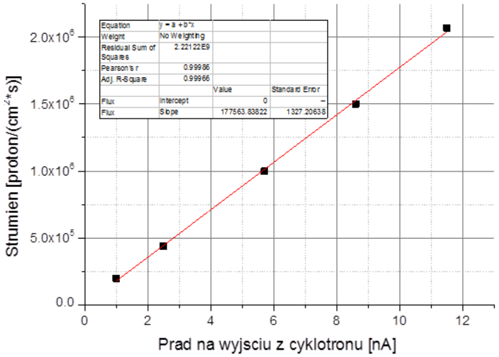
Testing electronics and intercomparisons

- Testing of electronics
  for first Polish satelite LEM

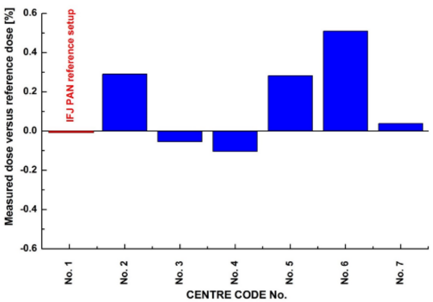


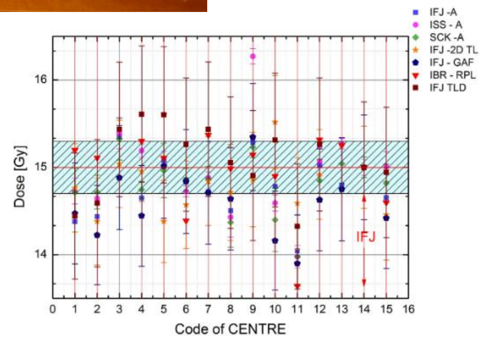
- Testing of electronics
  for GSM basestation
  of the manned flight to Moon





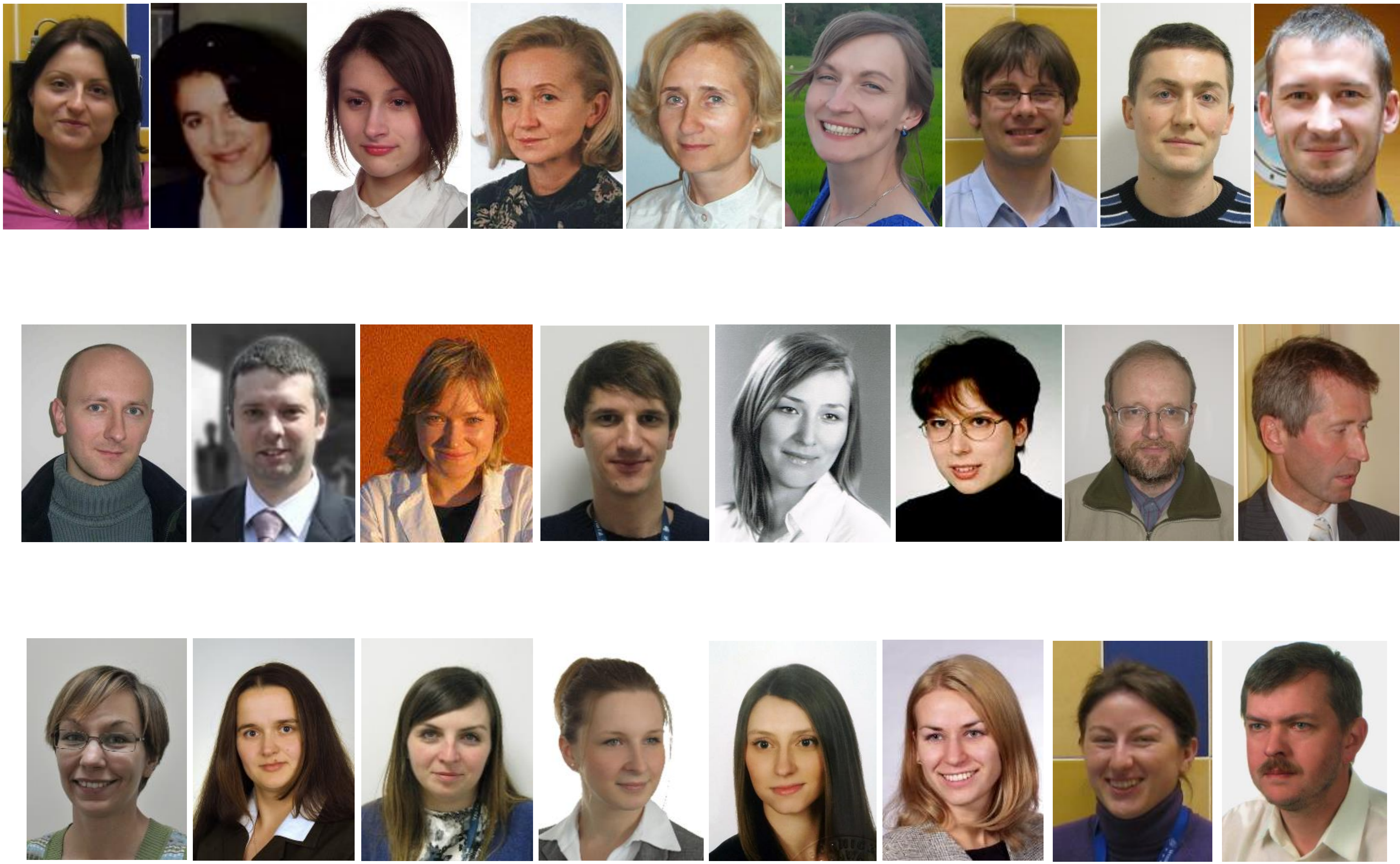
- PTCOG OPTIC group intercomparison
  using mailed dosimetry





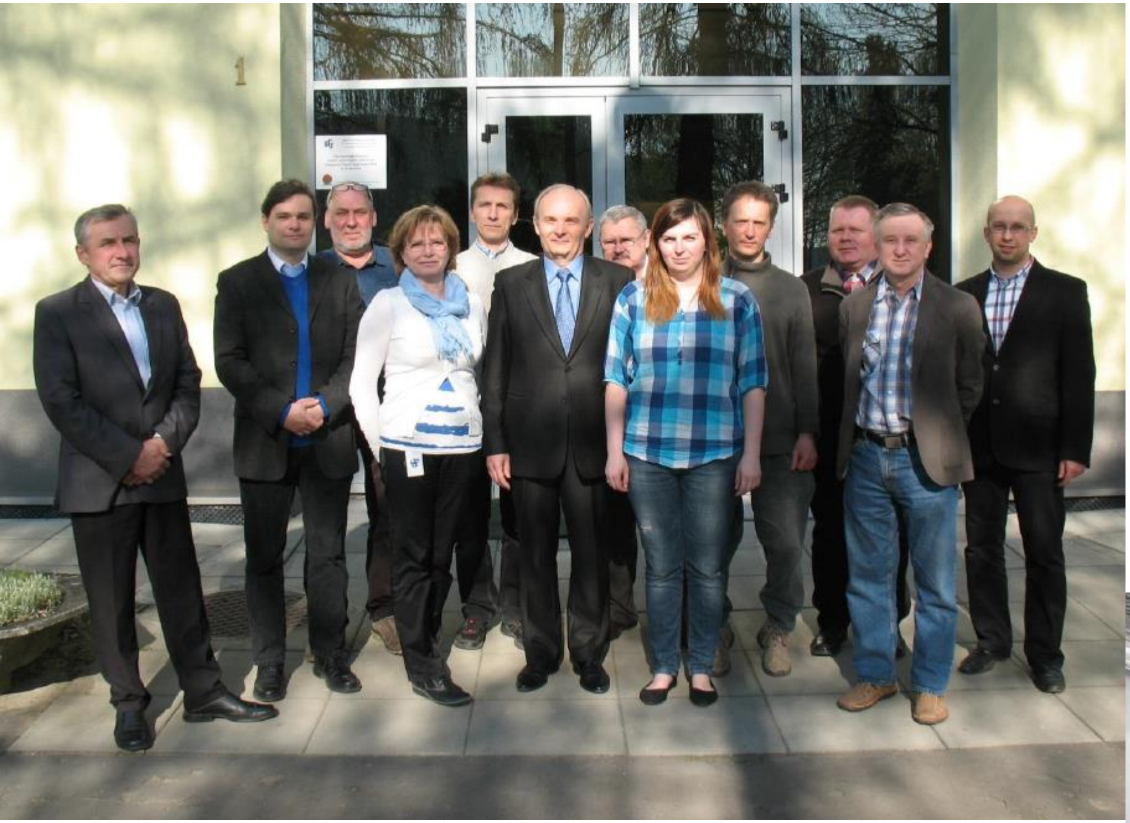
- and more …

The proton eye physics team (10 years compilation)



Cyclotron teams & IT team

IT Team



DCA Team after last patient irradiation on AIC-144

DCP Team during commissioning of Proteus C-235

Special thanks to our Clinical Partners

In developing and executing the clinical part of this project, the team of IFJ PAN **physicists** and **engineers** closely collaborated with

ophthalmologists, **radiation oncologists**, **radiologists**, **medical physicists**, **radiation therapist** and **nurses** from the Department of Ophthalmology and Ophthalmic Oncology (Collegium Medicum of the Jagiellonian University) and with

radiation oncologists from the Centre of Oncology – Institute in Krakow (currently National Institute of Oncology in Krakow).

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Oddział w Krakowie

Podziękowania dla

Obecnej i poprzednim Dyrekcji IFJ PAN

Kierownika Centrum Cyklotronowego Bronowice

Kolegów i Koleżanek z *Samodzielnej Pracowni Radioterapii Protonowej*

Kolegów i Koleżanek z *Działu Cyklotronu AIC-144*

Kolegów i Koleżanek z *Centrum Cyklotronowego Bronowice*

Kolegów i Koleżanek z *Działu Cyklotronu Proteus*

Kolegów i Koleżanek z *Zakładu Badań Radiacyjnych i Radioterapii Protonowej*

Kolegów i Koleżanek z *Zakładu Fizyki Radiacyjnej i Dozymetrii*

Kolegów i Koleżanek z *Działu Budowy Aparatury i Infrastruktury Naukowej*

Kolegów i Koleżanek z *Zakładów Naukowych*

Kolegów i Koleżanek ze *wszystkich laboratoriów badawczych i pomiarowych*

Kolegów i Koleżanek ze *wszystkich działów administracyjnych i ekonomicznych*

Kolegów i Koleżanek ze *wszystkich działów technicznych i pomocniczych*

Pracowników *Szpitala Uniwersyteckiego w Krakowie*

Pracowników *Narodowego Instytutu Onkologii Oddział w Krakowie*

Członków *Narodowego Konsorcjum Radioterapii Hadronowej*

Przyjaciół i Sympatyków projektu