The Henryk Niewodniczański
Institute of Nuclear Physics
Polish Academy of Sciences

Proton therapy and other innovative ion-beam applications in IFJ PAN Krakow

Adam Maj

ENSAR

EFINION Workshop
9-11 July 2014; Vrachati, Corinth, Peloponnese Greece

EFINION
nuclear ion beams & tools for society

Large and medium-size scientific centres in Poland

WARSZAWA

- Warsaw University (with Heavy Ion Lab.)
- Warsaw University of Technology
- National Centre for Nuclear Research (in Swierk)
- Institute of Plasma Physics and Laser Microfusion

WROCŁAW

- Wroclaw University
- Wroclaw University of Technology

KRAKÓW

- Jagiellonian University
- University of Science and Technology
- Krakow University of Technology
- Institute of Nuclear Physics (with Cyclotron Centre Bronowice)

Scientific and technological involvement in large nuclear physics laboratories in Europe…

CERN: LHC: CMS,Atlas, Alice,LHCb, CERN2GS, COMPASS; ISOLDE,…

France: GANIL/SPIRAL2, ITER, ILL

Germany: FAIR/GSI, DESY (FLASH, XFEL), W7X

UK: JET

Italy: LNL, LNS, LNF , GranSasso

Sweden: ESS

…and worldwide

Japan: KEK (Belle1, Belle2), T2K, RIKEN

Russia: Dubna JINR

USA: RHIC,MSU/FRIB, Fermilab, CEBAF, SLAC, Oak-Ridge, ANL

AstroparticlePhysics: ESO, Cherenkov Telescope Array, Pierre Auger

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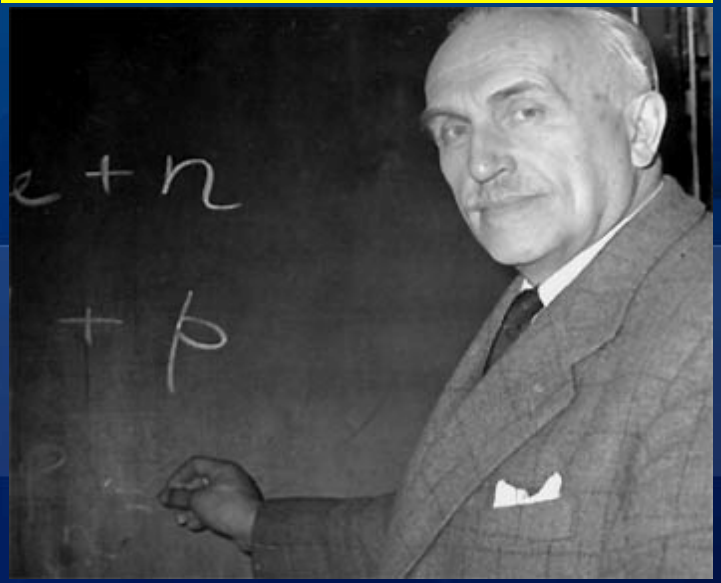
IFJ PAN in Kraków was established in 1955, thanks to Prof. Henryk Niewodniczański, who was the 1st director (until his death in1968). Prof. Niewodniczański was post-doc of Ernest Rutherford.



Since 2003 IFJ PAN belongs to Polish Academy of Sciences (PAN)

- ca. 500 personnel
- Prof. 50, Assoc. Prof. 40, Ph.D. 150
- PhD studies – ca. 90 students
- 6 divisions: 27 departments
- centres of excellence
- centres of advanced technology
- 4 accredited laboratories
- Equipment and Scientific Infrastructure Construction Division

General information

Main Research Fields

- Particle physics and astrophysics
- Nuclear and strong interactions physics
- Condensed matter physics
- Interdisciplinary and applied research
- Theoretical physics

Fundamental rights of nature

Elementary components of matter and their interactions

The universe: the beginning, today, and the future

Complex systems: from quarks and leptons to galaxy groups and financial markets

Basic questions

IFJ PAN projects on MNiSW Roadmap

Coordination:

SPIRAL2 – Polish contribution in international project on ESFRI Roadmap (physics)

SUNLAB – underground laboratory in Sieroszowice – national research centre (physics)

ESS-European Spallation Source – Polish contribution in international project on ESFRI Roadmap (interdisciplinary sciences)

IFJ PAN projects on MNiSW Roadmap

CTA: Observatory for TeV gamma-ray astronomy – Polish contribution in international project on ESFRI Roadmap (astrophysics)

FAIR: Facility for Antiproton and Ion Research – Polish contribution in international project on ESFRI Roadmap (physics)

European XFEL: European X-Ray Free Electron Laser – Polish contribution in international project on ESFRI Roadmap (interdisciplinary sciences)

NLEJ: National Laboratory for Nuclear Energy – national research centre (energy science)

IFJ PAN in FP7 Projects

SPIRAL2PP
ENSAR
TIARA

Hopefully soon: ENSAR2

Divisions

- Division of Particle Physics and Astrophysics (NO1)
- Division of Nuclear Physics and Strong Interactions (NO2)
- Division of Condensed Matter Physics (NO3)
- Division of Theoretical Physics (NO4)
- Division of Applications of Physics and Interdisciplinary Research (NO5)

CCB – Cyclotron Center Bronowice

Accelerators at IFJ PAN Krakow

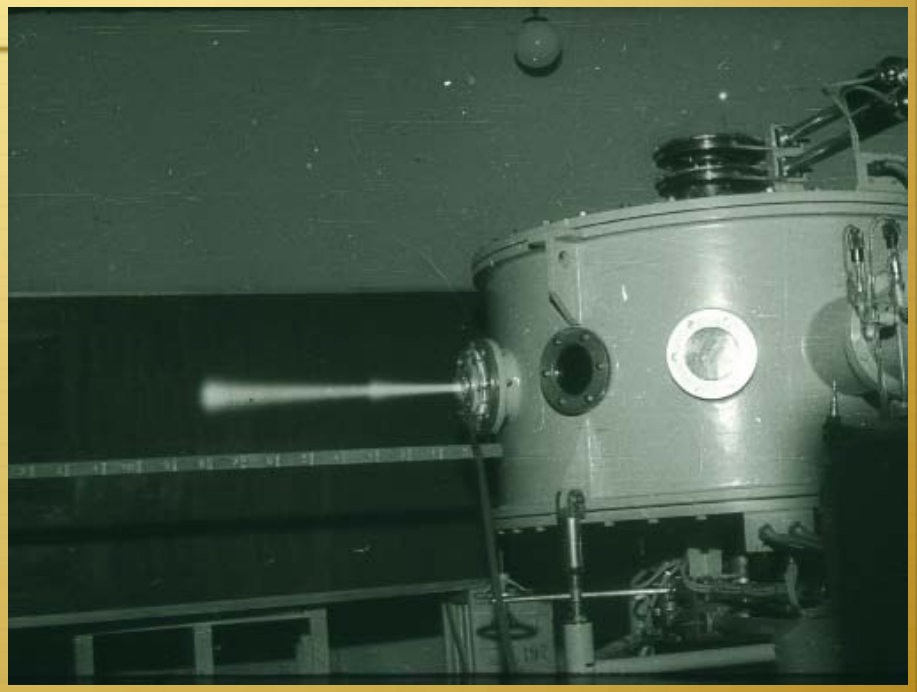
- first cyclotron developed in Poland, 48 cm (1955)

-Soviet built classical U-120 (opened 22.11.1958, stopped 1994), 12 MeV deuterons

-isochronic AIC-144 developed at IFJ PAN (from 1995) 60 MeV protons

2 MeV proton van de Graaff (from Strasbourg) – since ca. 2000

- IBA Proteus C-235 – 230 MeV protons (start of operation Dec 2012)



U-120 classical cyclotron

1. Eye melanoma treatment with the (old) proton AIC-144 cyclotron

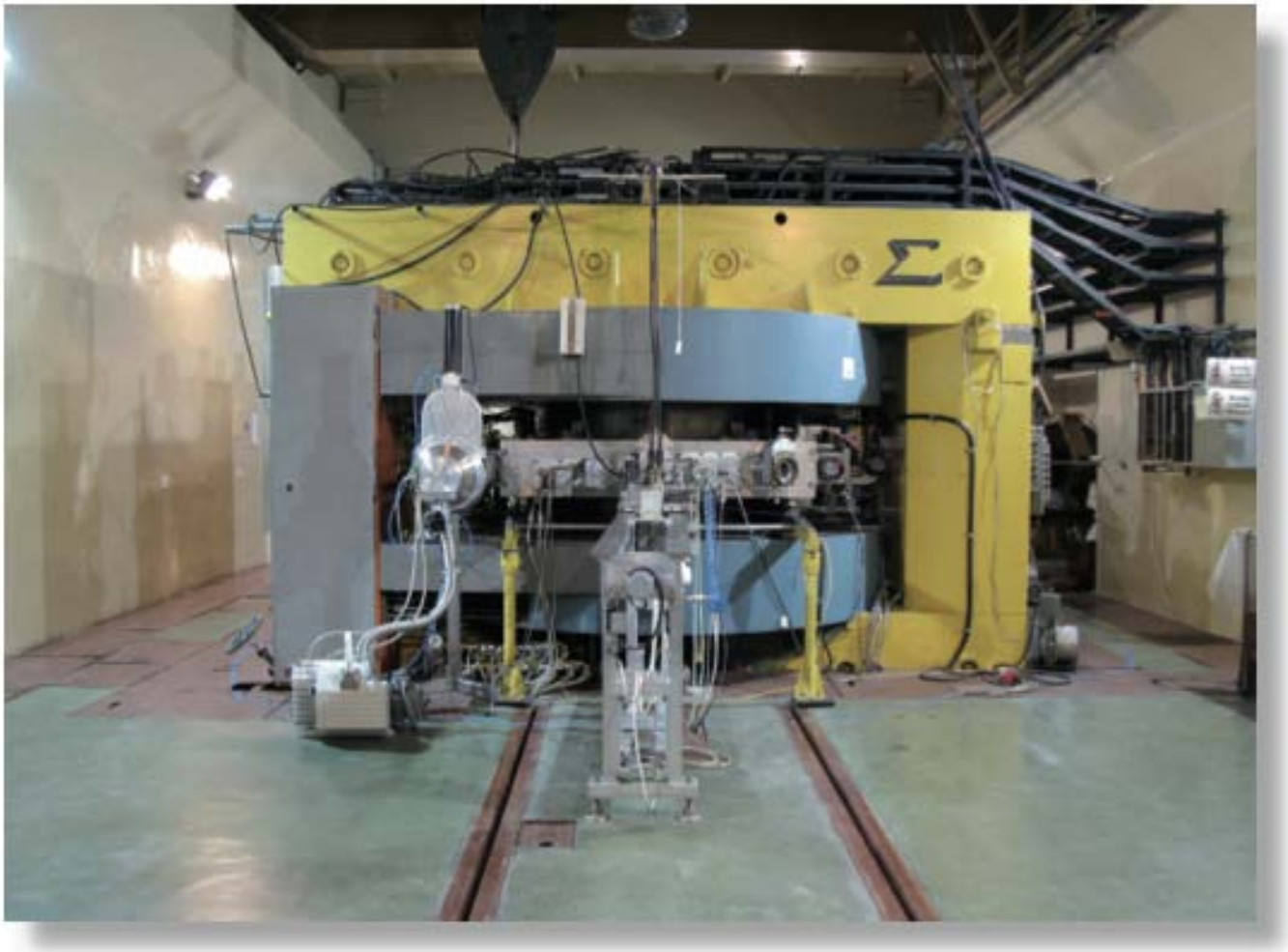


Fig. 1 *The AIC-144 cyclotron. The main magnet, magnet coils, vacuum vessel, RF supply and ion source (centre) are visible.*

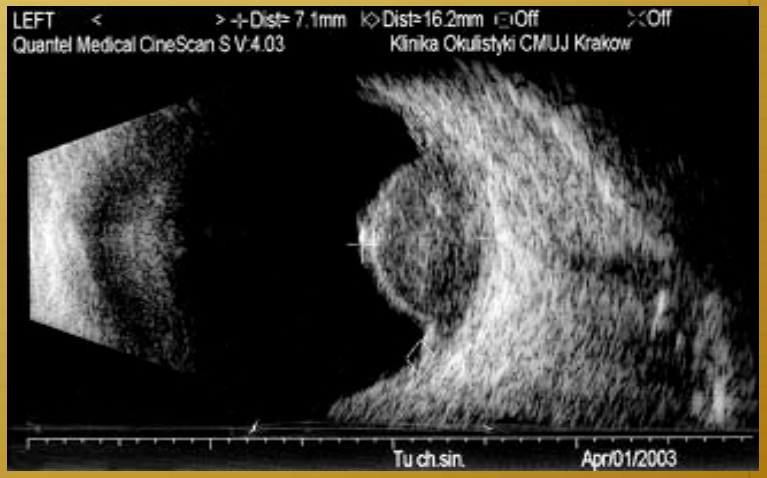
Eye melanoma

Eye malanoma:
-malignous cancer,
-growing inside the eye-ball
-mainly in white population,
-250 cases/year in Poland

Proton radiotherapy of eye - the most successful cancer treatment – survival > 90%

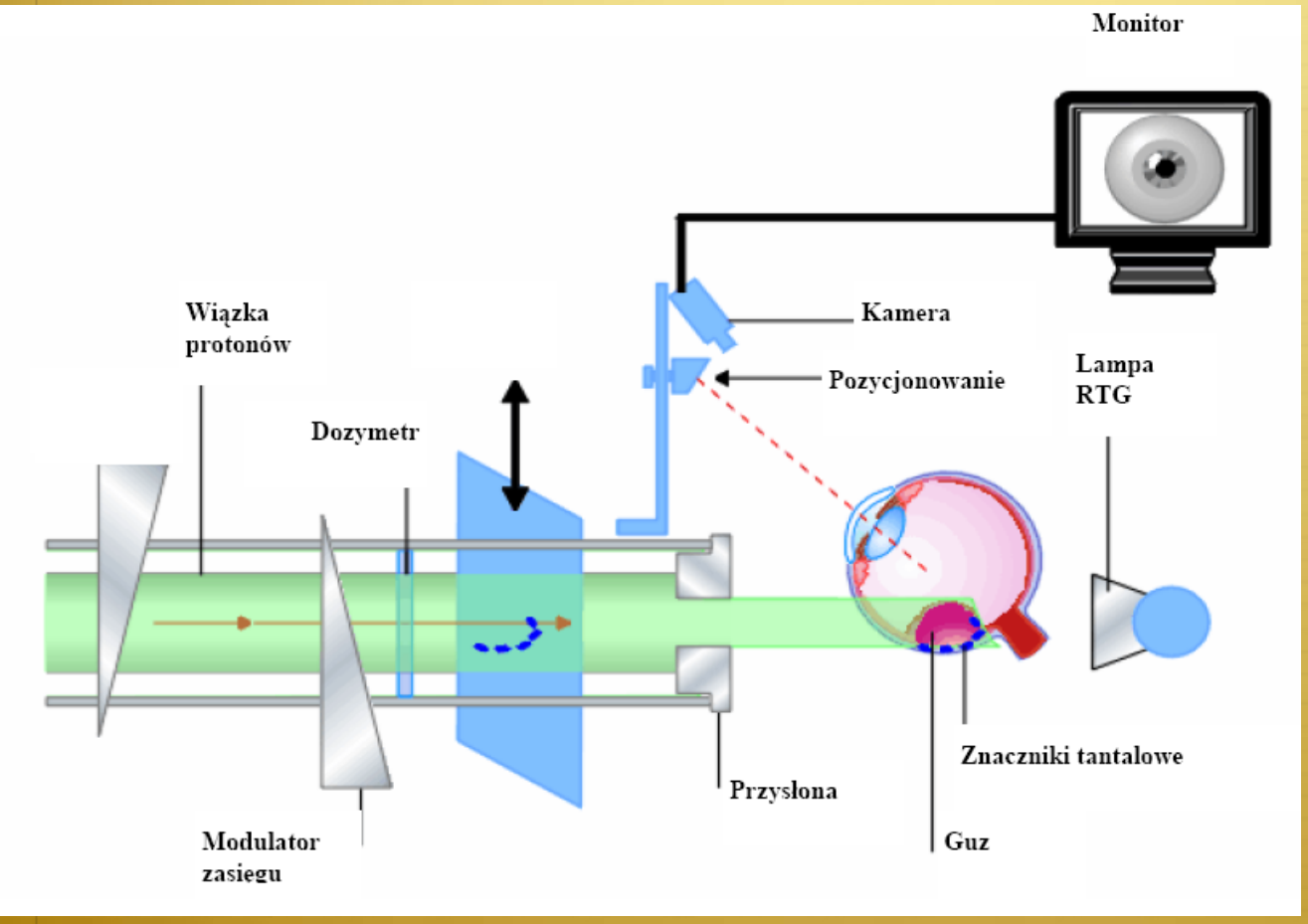
In Europe 7 centers
- Berlin, HMI, D
- Catania, INFN, I
- Orsay, Inst. Curie, F
- Nice, F
- Claterbridge, UK
- PSI Villigen, CH
- IFJ PAN Kraków, PL

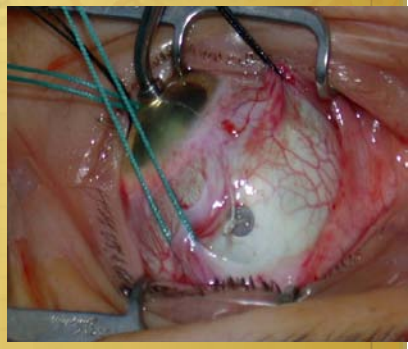
Eye melanoma cancer

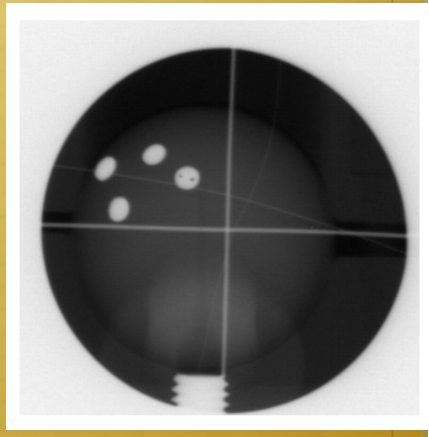


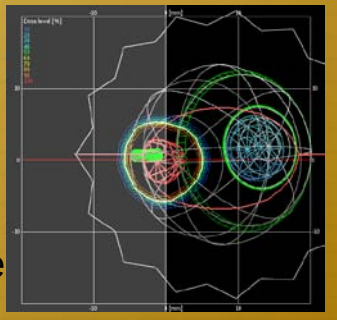
USG of eye cancer

The method of eye treatment







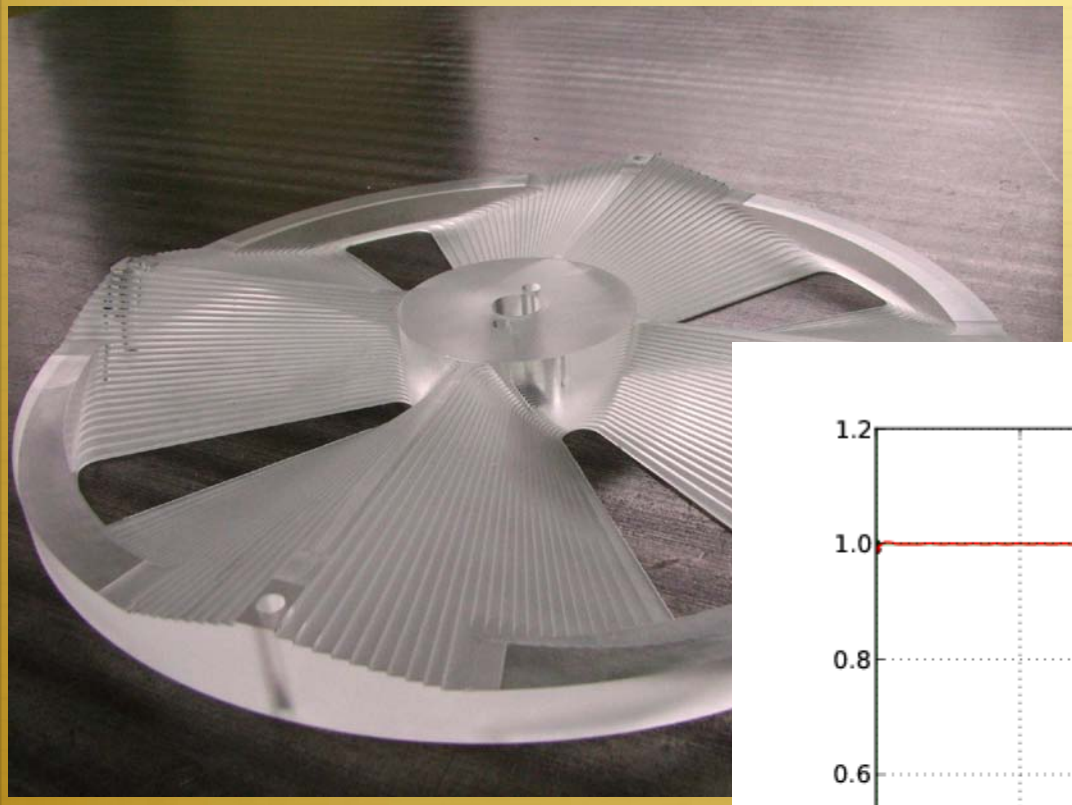


T. Kajdrowicz, M. Bajer
Treatment Planning System Eclipse

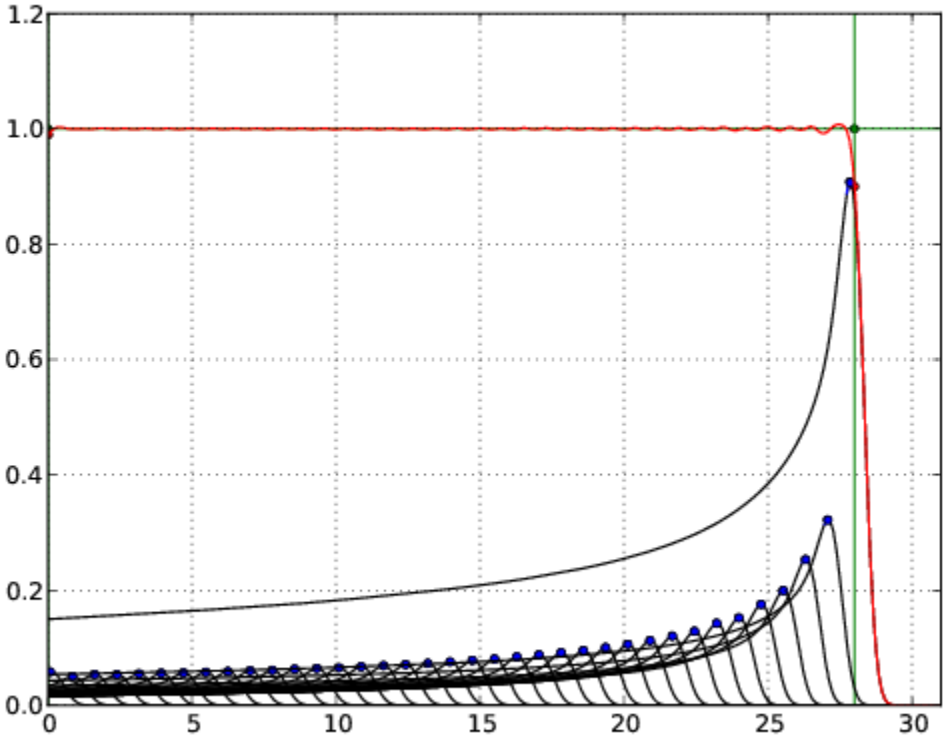
IFJ PAN eye treatment room at AIC-144

Therapy room developed at IFJ 2006-2009 in collaboration with Helmholtz Centre, Berlin

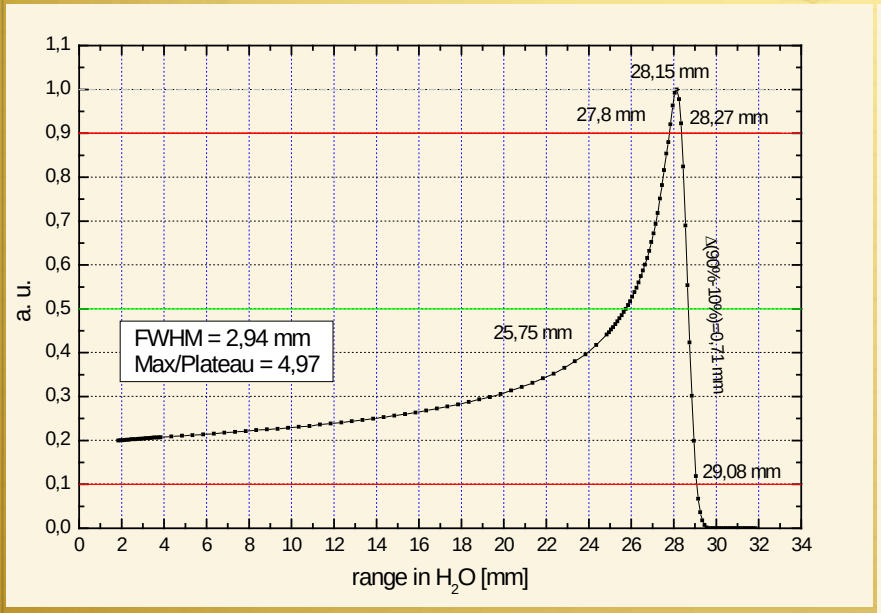
How to broaden of the Bragg peak?

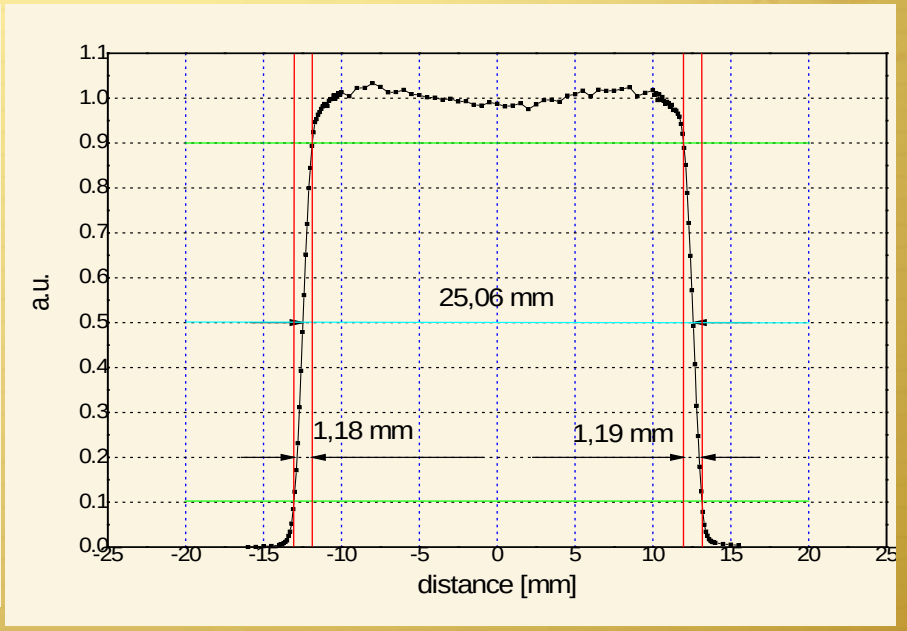


Original range:
28 mm
Modulation of the range:
28 mm



Parameters of eye line beam at AIC-144





PT centre	Range [mm]	Max/plateau	F.W.H.M. [mm]	Distall fall-off $d_{90\%-10\%}$ [mm]
CATANA	30.60	4.68	3.29	0.81
CCO	31.0	4.85	3.65	0.80
PSI	30.0	4.47	-	1.10
IFJ	28.4	4.97	2.94	0.75

Regular patient treatment

- The first patient treated at IFJ PAN in February 2011
- 35 patients treated till the end of 2013
- From April 2013 the eye proton therapy financed by the National Health System
- 50 patients are to be treated in 2014

2. National Consortium of Hadron Radiotherapy NCRH

Grounded: 12.09.2006

IFJ PAN Kraków – coordinator

Akademia Górniczo-Hutnicza

Medical University, Warszawa,

Center of Oncology, Warszawa

Center of Oncology, Krakow

Center of Oncology, Poznań

Holycross Center of Oncology, Kielce

National Center of Nuclear Research, Warszawa

Warsaw Polytechnic

Silesia University

Warsaw University

Phase 1: Cyclotron Center Bronowice at IFJ PAN Krakow

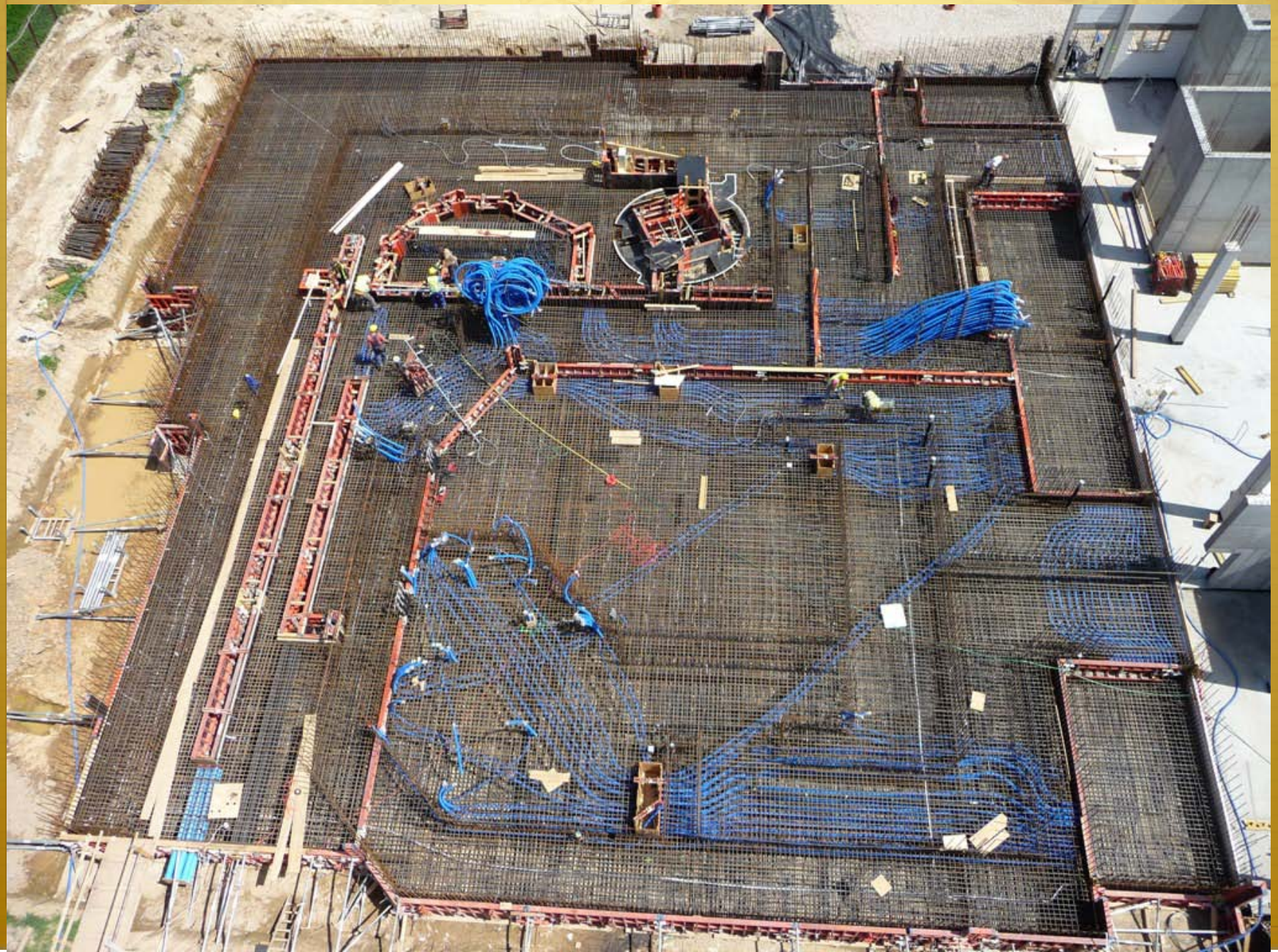
Phase2: Carbon Cyclotron in Warsaw


3.03 2011 Just before the start …..

April 2011


Paweł Olko
Magdalena Zydek
Marek Jeżabek
Adam Maj
2011/03/31

Autumn 2011



May 2012

Installation of the Proteus C-235 cyclotron

11 May 2012

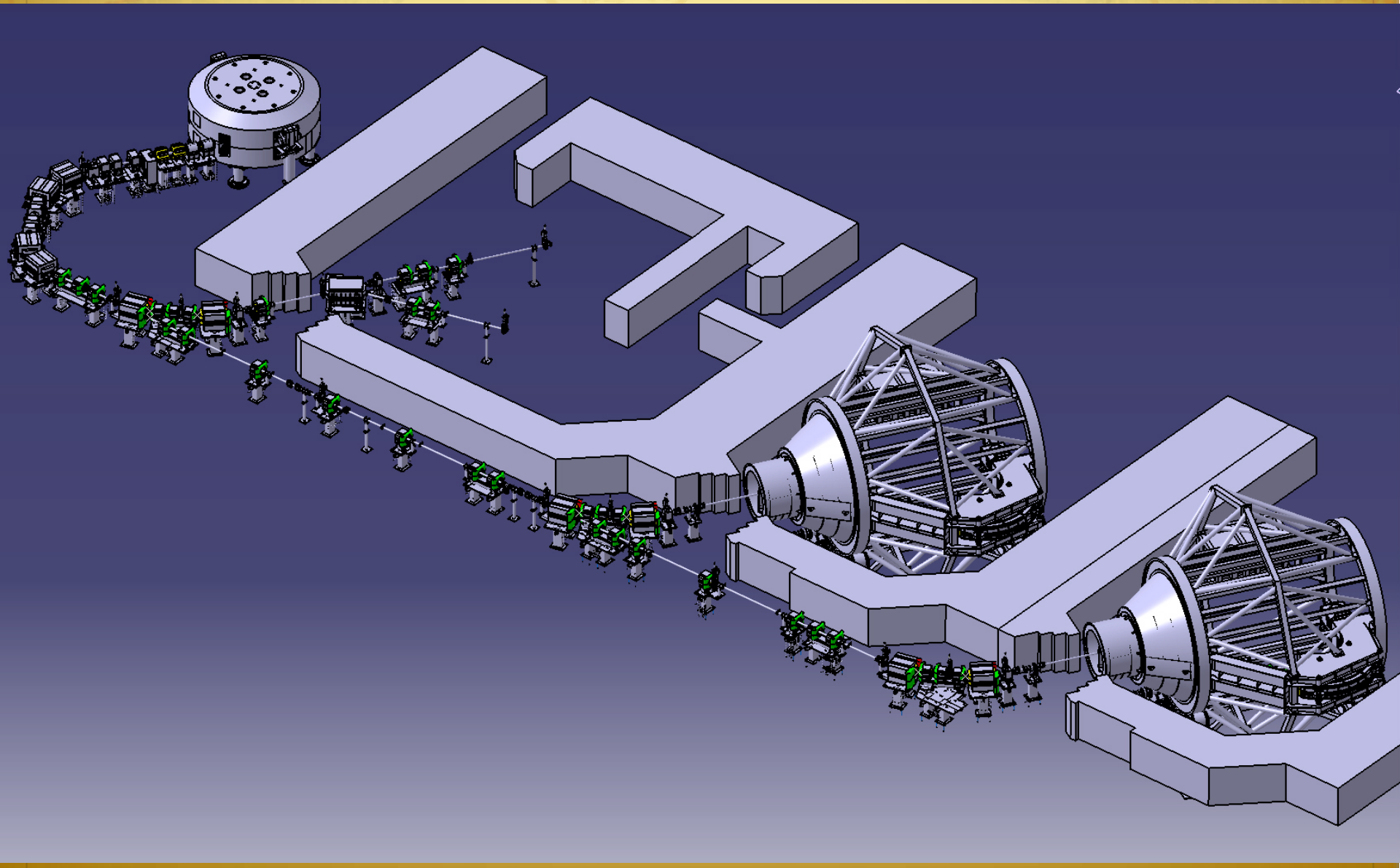
Instalation of IBA Proteus C-235 cyclotron


11 May 2012
iba
Krakow – Proton Therapy Center

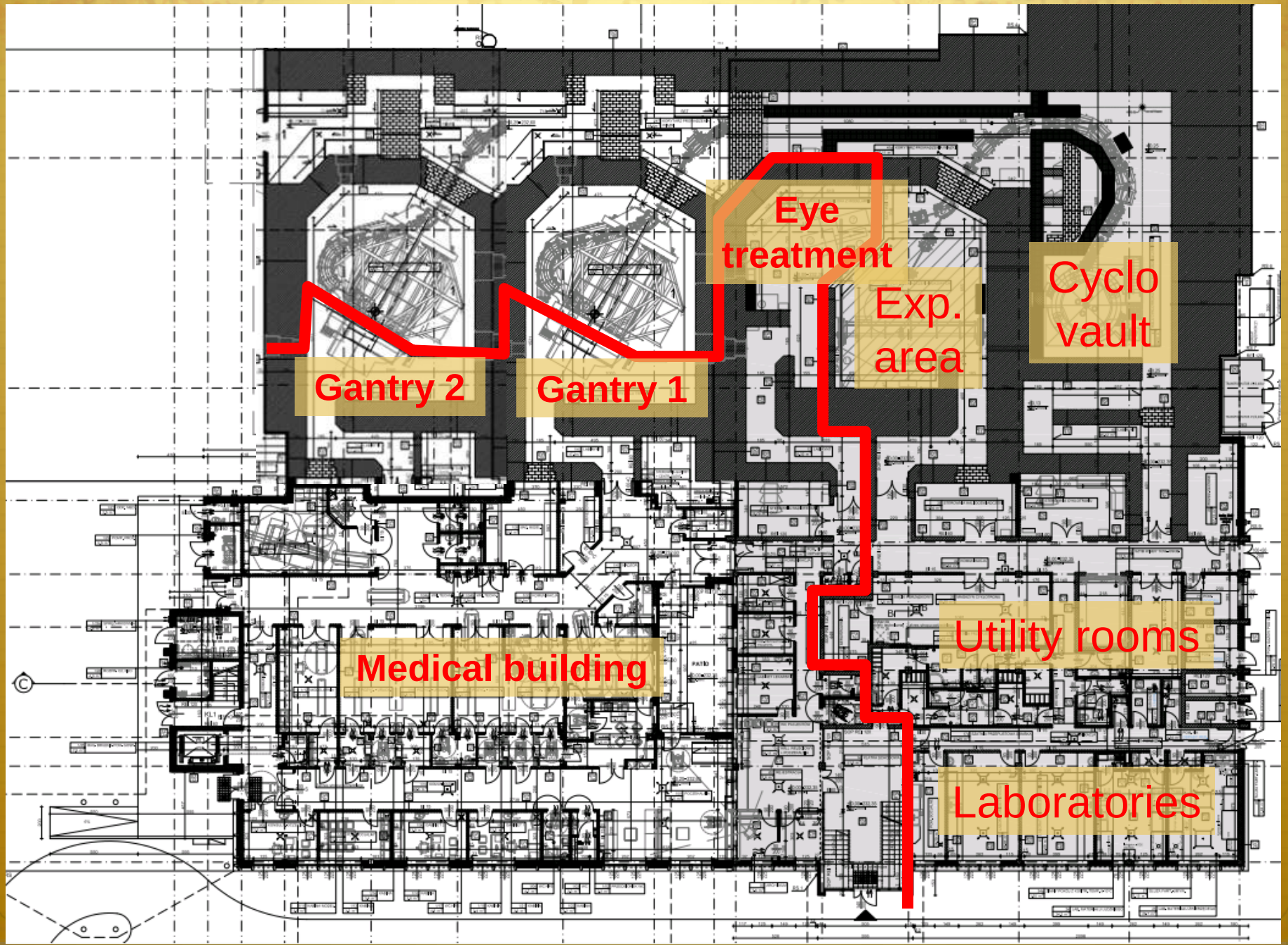
Spring 2013

Autumn 2013

Beam delivery system at IFJ PAN Krakow



General layout NCRH



Proteus C-235 cyclotron

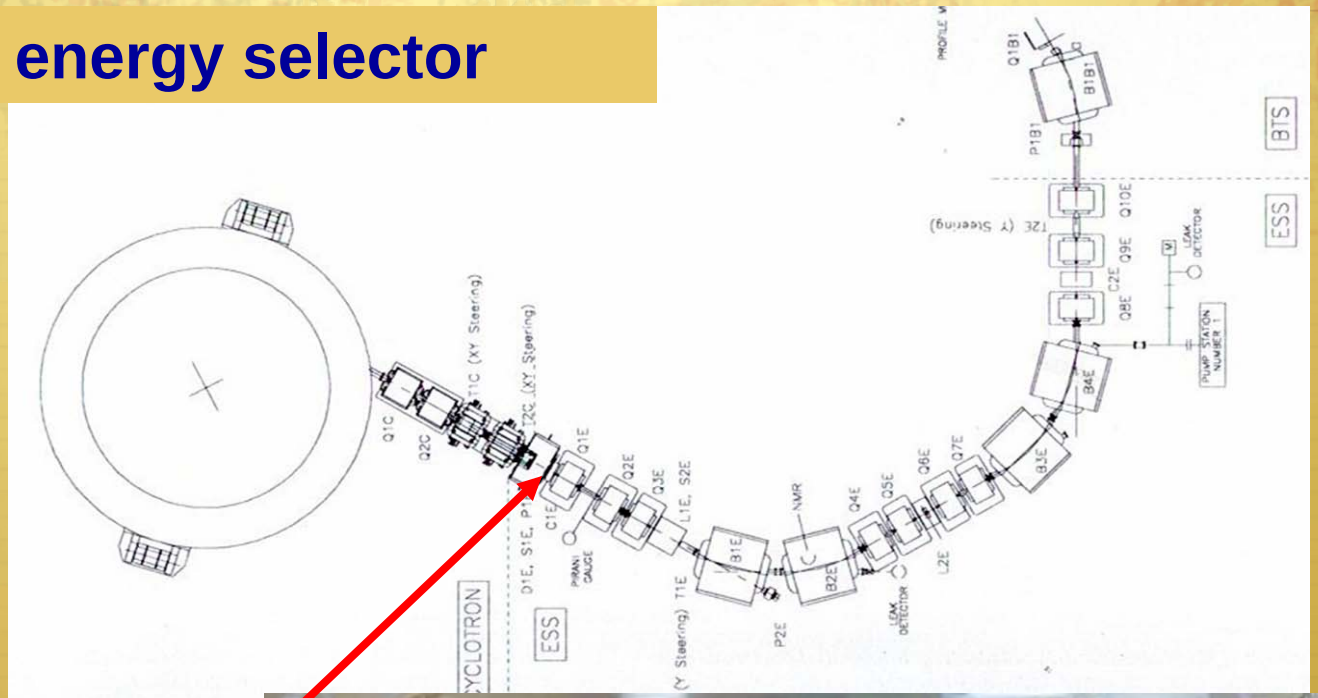
Ion Beam Applications S.A. (IBA), Louvain-la-Neuve, Belgium

cyclotron:	isochronic, 4-sectors, CW
particles	protons
ion source:	P.I.G with hot cathod
proton energy:	230 MeV ($\beta = 0.596$, $\gamma = 1.245$), constant
energy dispersion:	$\Delta E/E < 0.7\%$
beam intensity:	600 nA (4×10^{12} p/s) – 0.1 nA (6×10^{8} p/s)
emmitance	horizonthal - 11 π mm mrad,

diameter 434 cm
height: 210 cm

Proton energy selector

Energy selector
70-230 MeV
$\Delta E/E < 0.7$ %



Beryllium absorber for changing the beam energy

Development of the new eye line and the Medical Device Directive 93/42/EEC

CE marking is a legal requirement for medical devices intended for sale in Europe:

•The Medical Devices Directive (MDD) (Council Directive 93/42/EEC

•

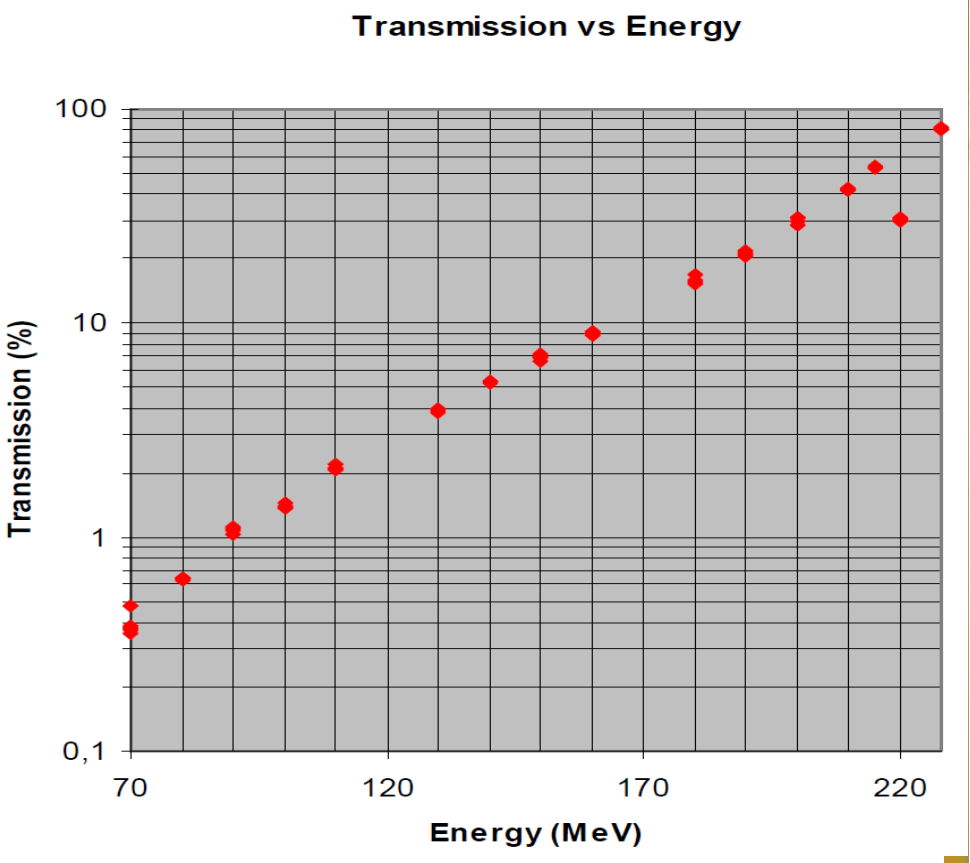
•Revised as 2007/47/EC

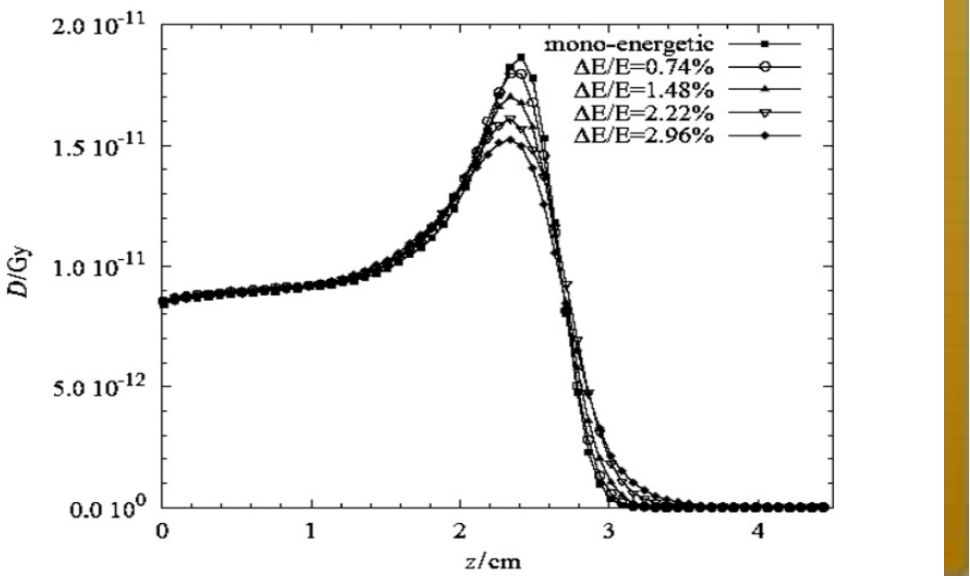
•Compliance with the revised directive became mandatory on March 21, 2010.

New eye therapy room under development by IFJ PAN will undergo CE marking

Energy selector

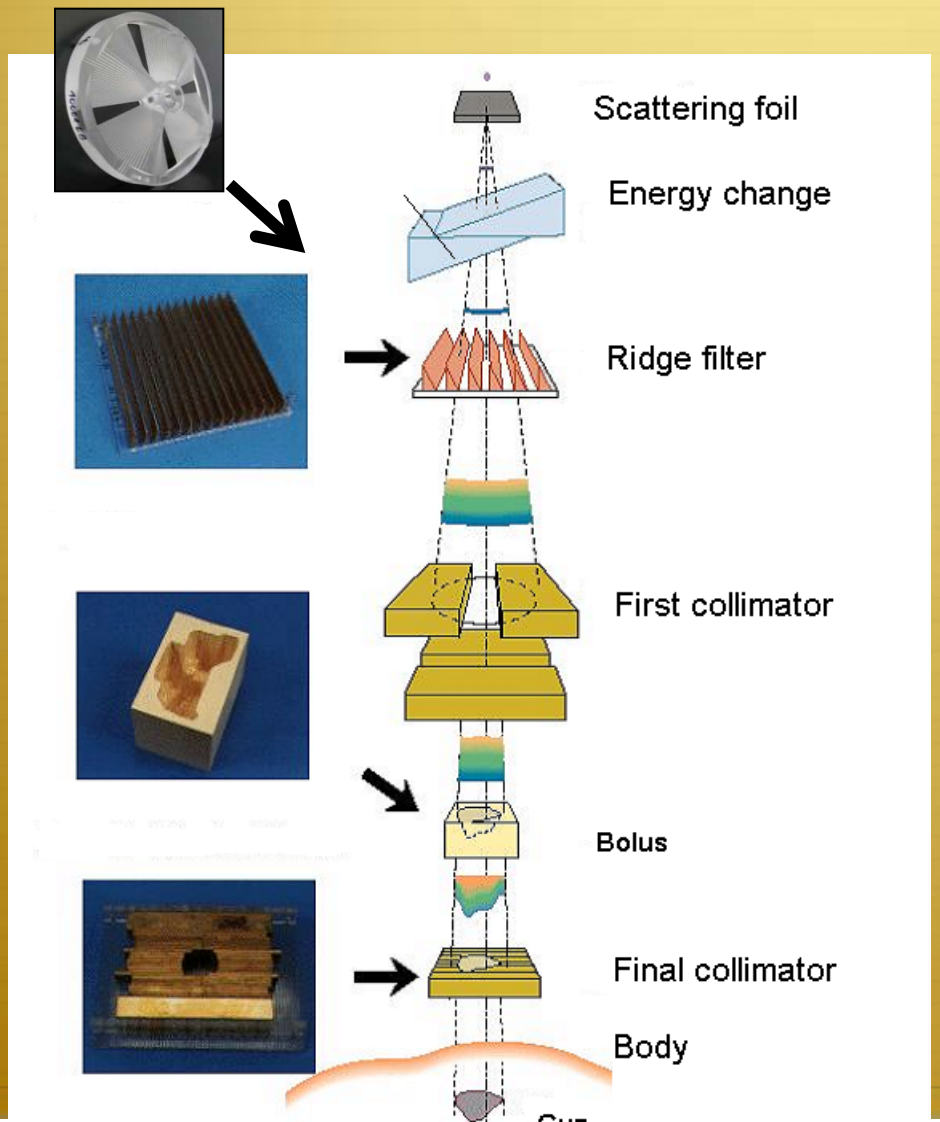
- Proton current 230 MeV minimum 500 nA
- Transmission from 230 MeV do 70 about 0,4% (for Be)
- We need 70 MeV,. 2 nA, distal fall-off < 2 mm



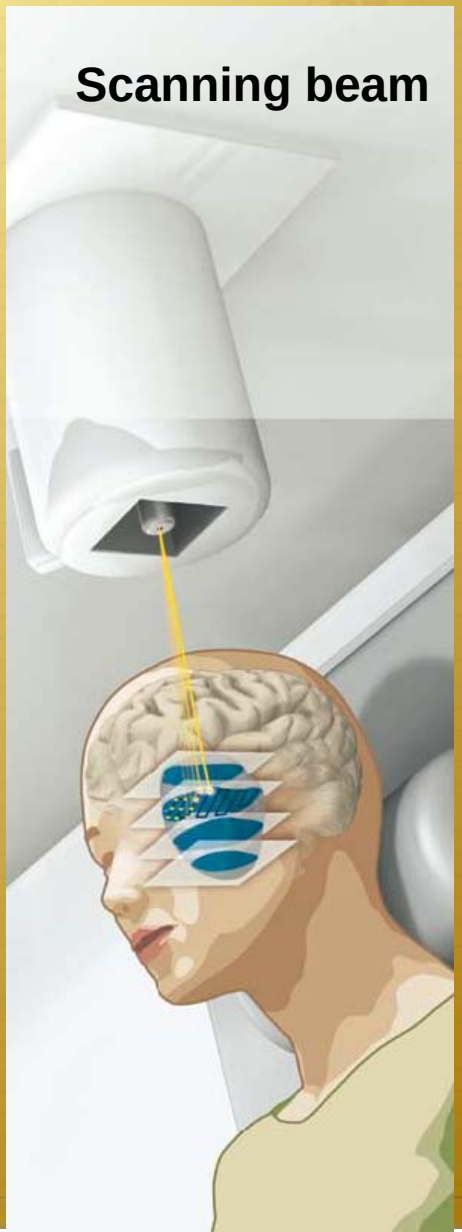


Methods of beam formation

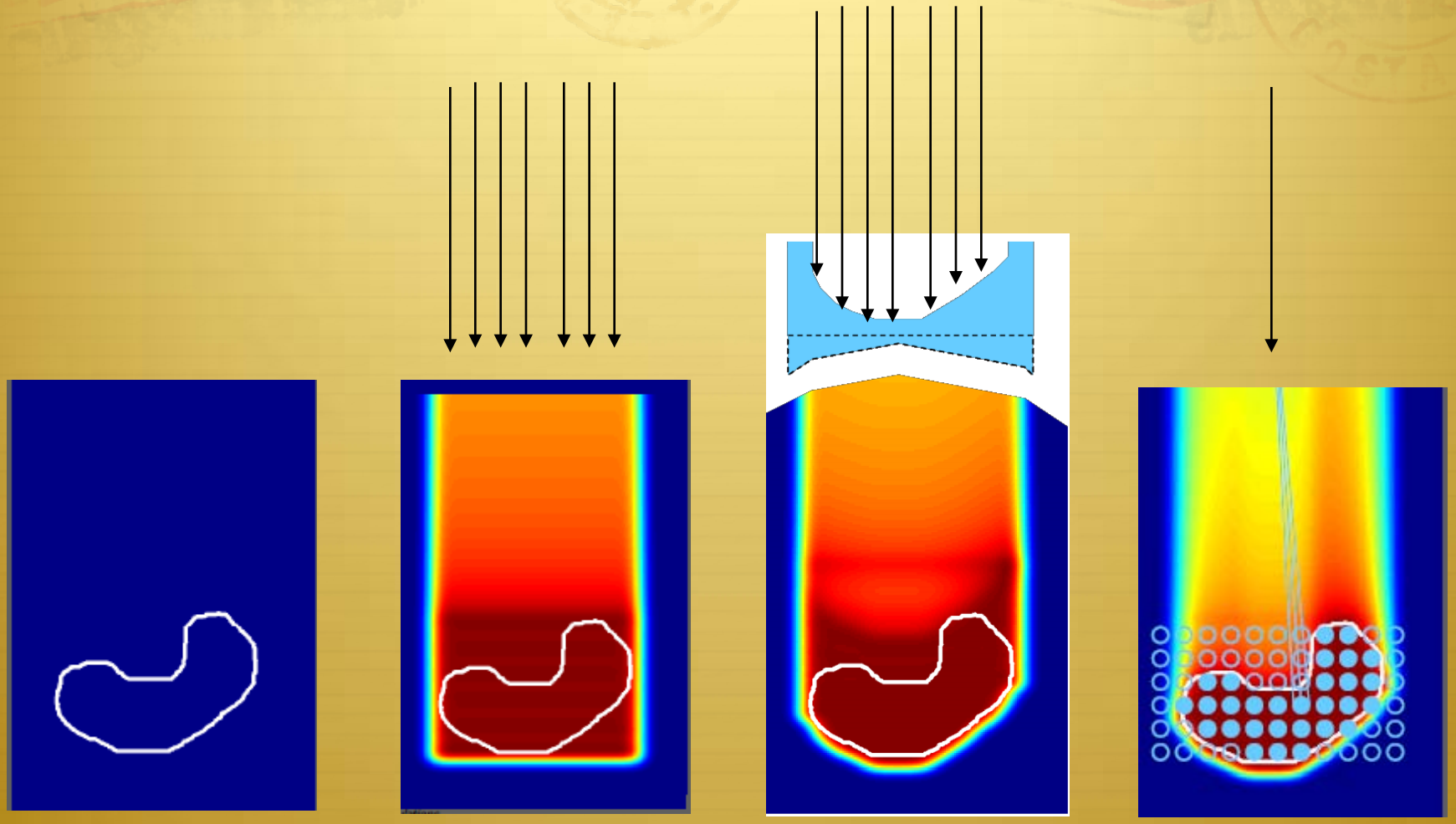
Scattered beam



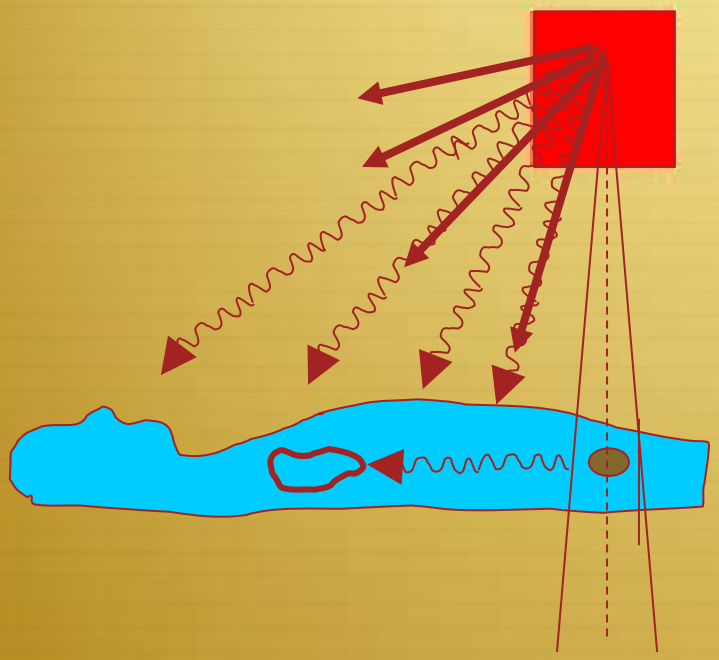
Scanning beam

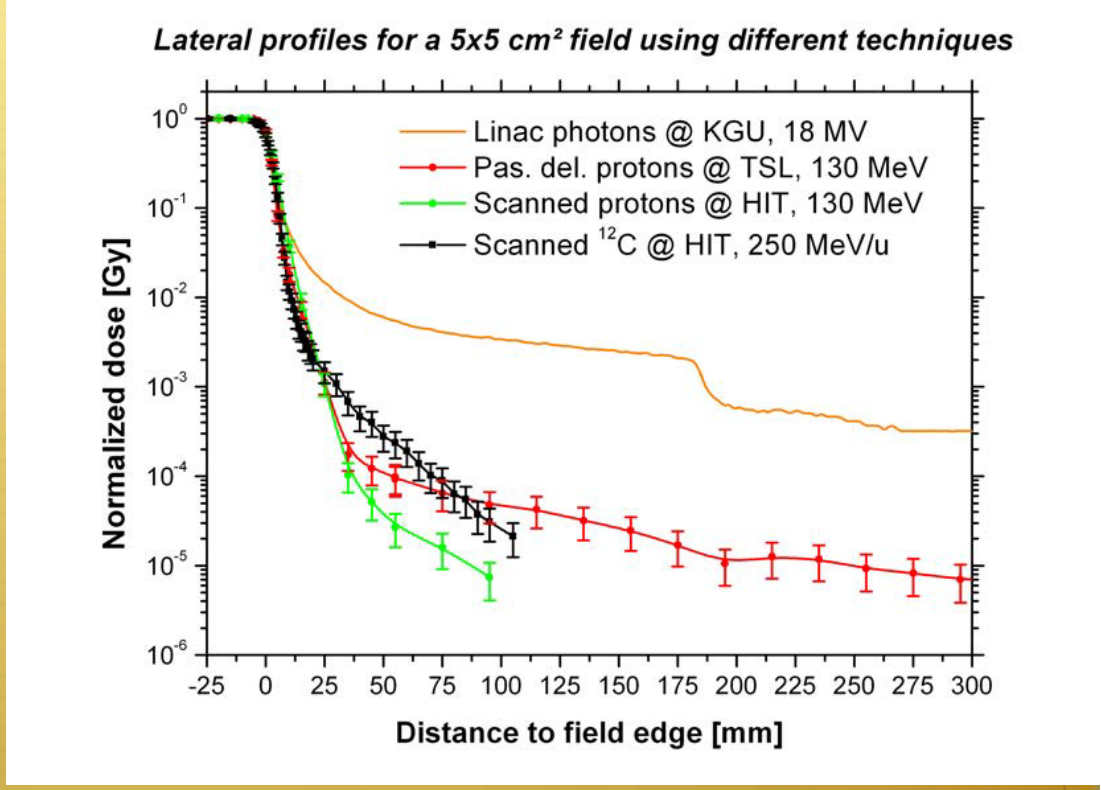


Scanning versus scattered beam



Pencil scanning beam – lower doses from scattered radiation

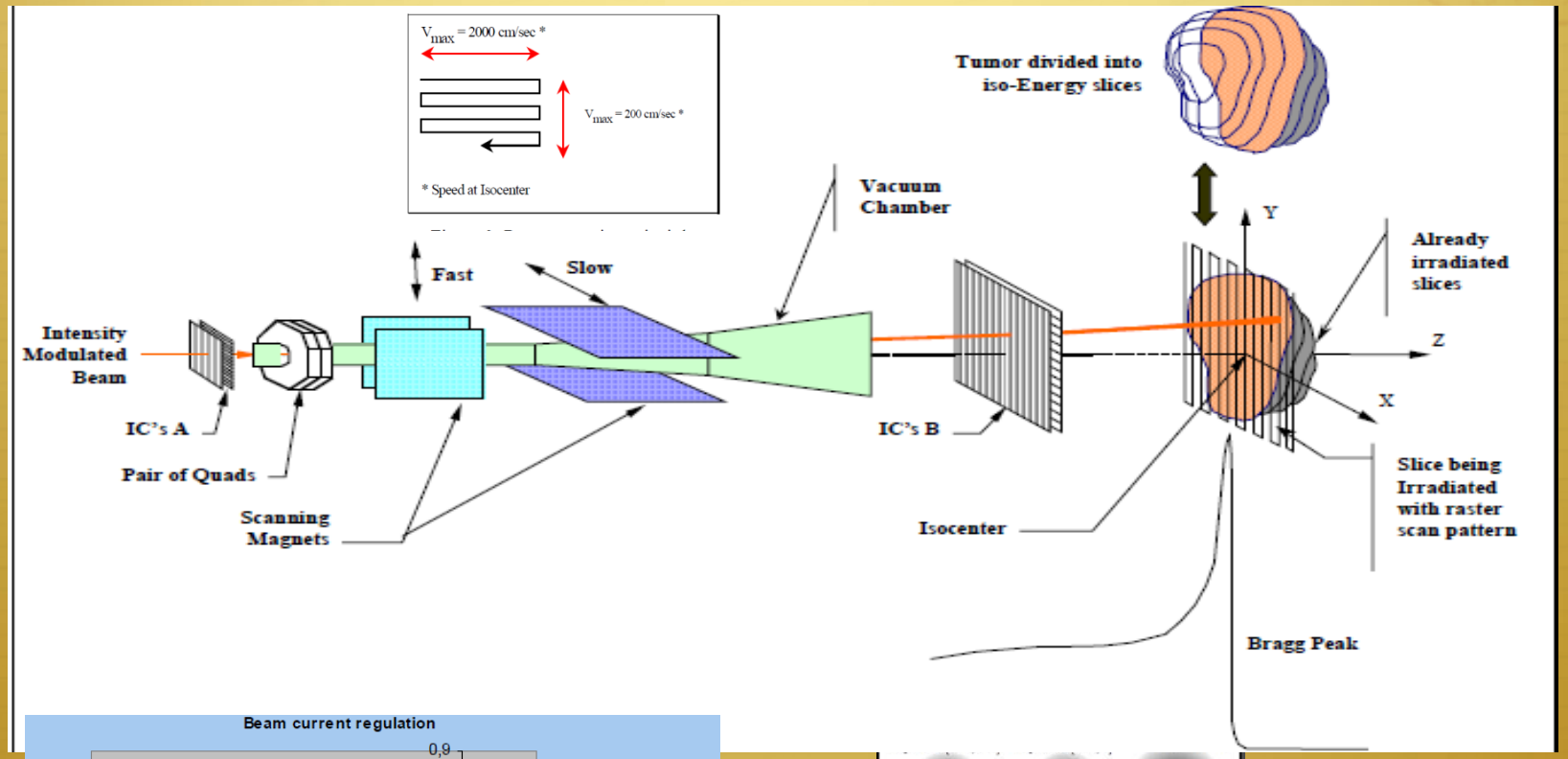


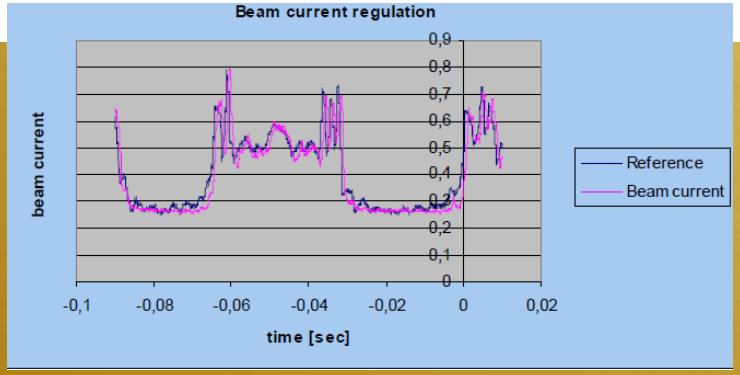


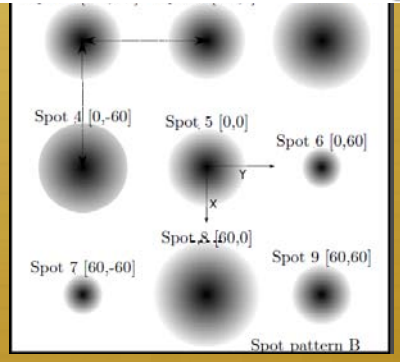
Robert Kaderka, Ph.D Thesis, GSI, 2011

For scanning proton beam the doses for distant organs due to scattered radiation are 2-3 orders of magnitude lower than for MV X-rays

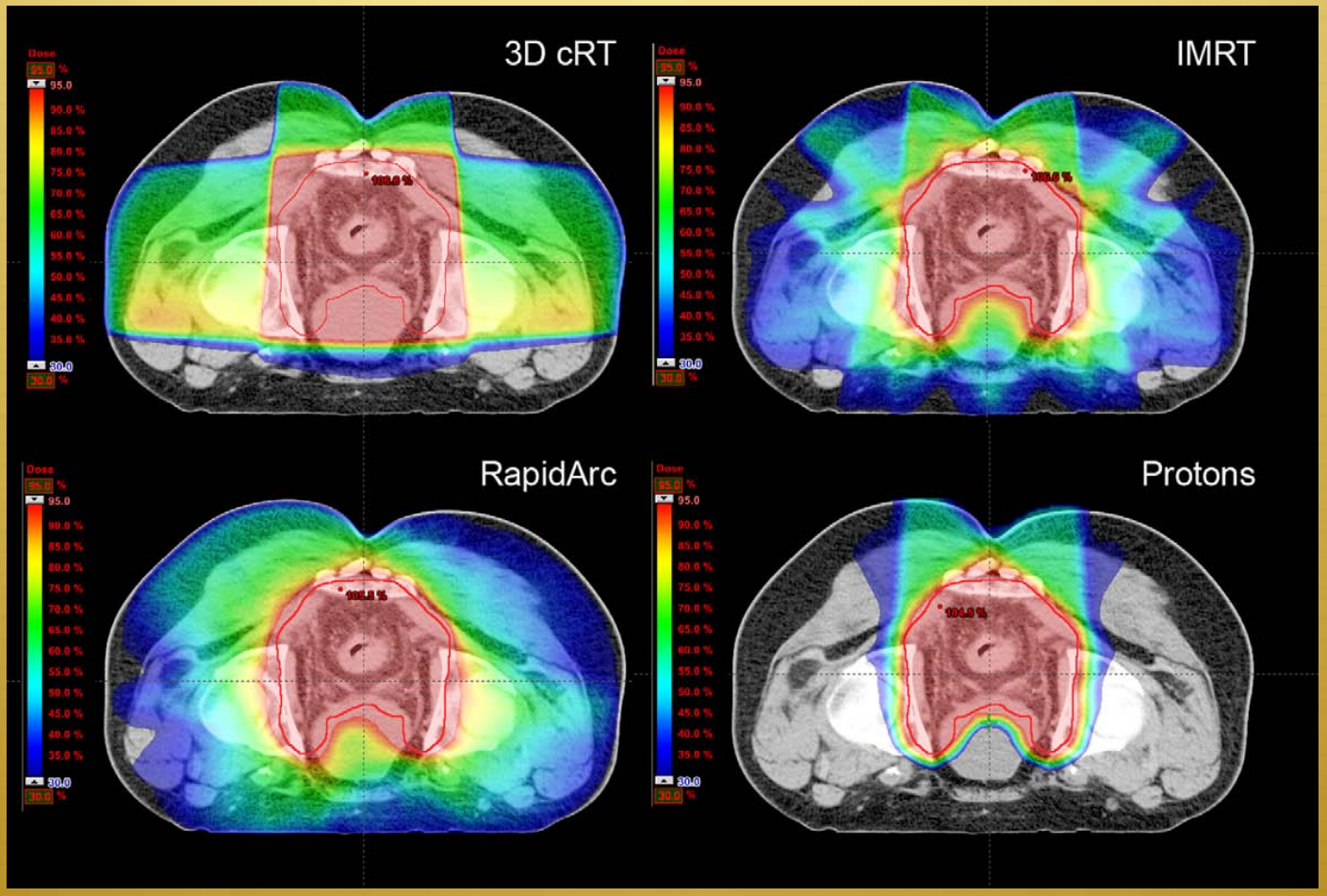
Active beam delivery – pencil beam scanning







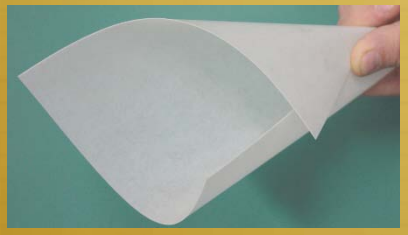
Advantages with proton radiotherapy with gantry scanning beam



Cancer of rectum

Wolff H.A. et al. Radiother Oncol 2012; 102: 30-37

Thermoluminescence foils (2D-TLD) - measurements of scanning beams



TLD foil developed at IFJ PAN

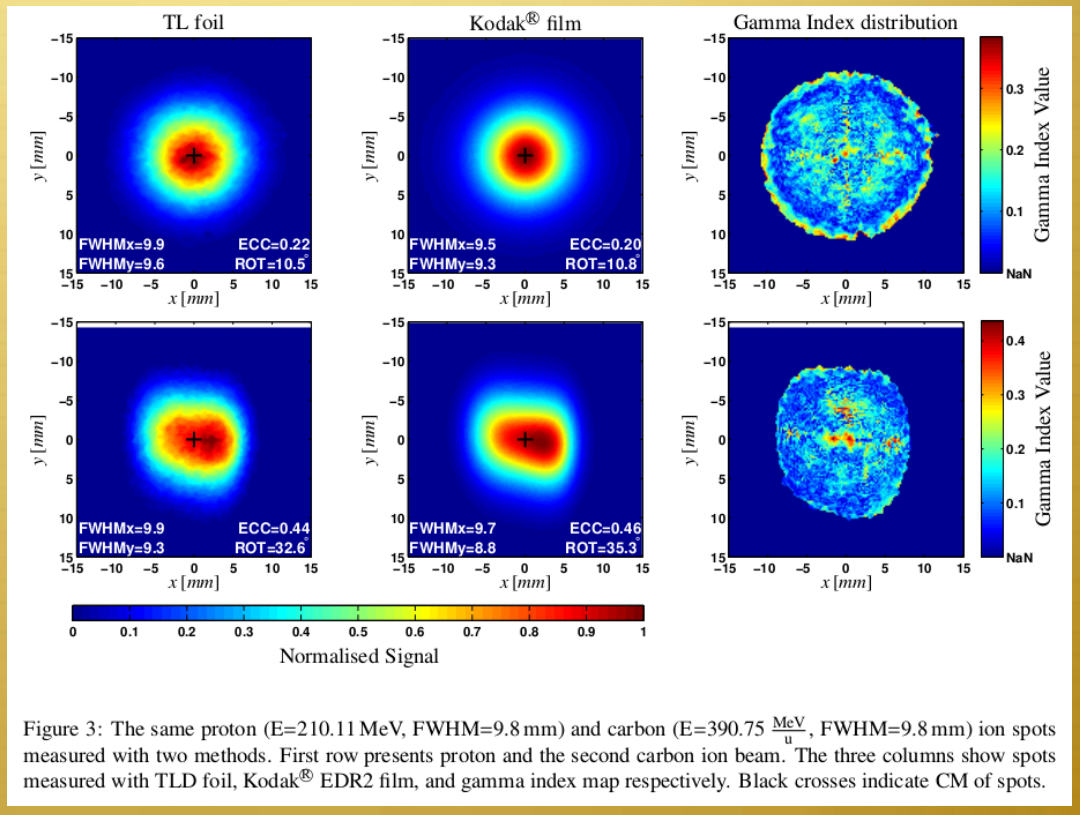
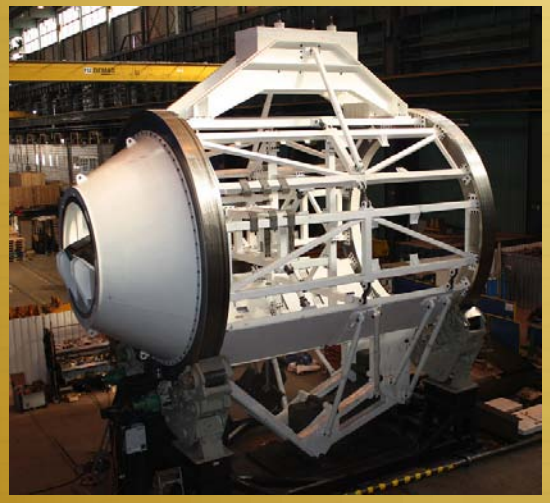
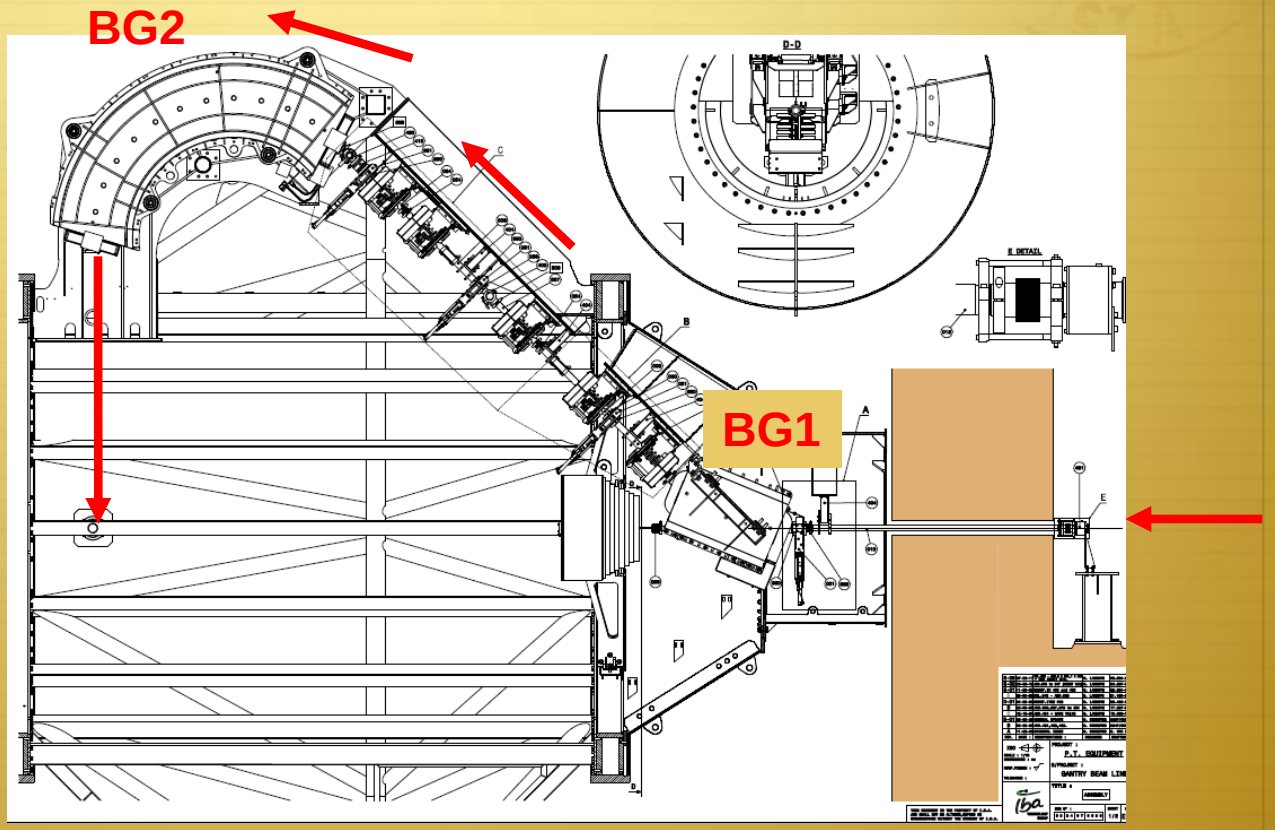


Figure 3: The same proton (E=210.11 MeV, FWHM=9.8 mm) and carbon (E=390.75 $\frac{\text{MeV}}{\text{u}}$, FWHM=9.8 mm) ion spots measured with two methods. First row presents proton and the second carbon ion beam. The three columns show spots measured with TLD foil, Kodak® EDR2 film, and gamma index map respectively. Black crosses indicate CM of spots.

Jan Gajewski, IFJ PAN

IBA dedicated gantry at IFJ PAN

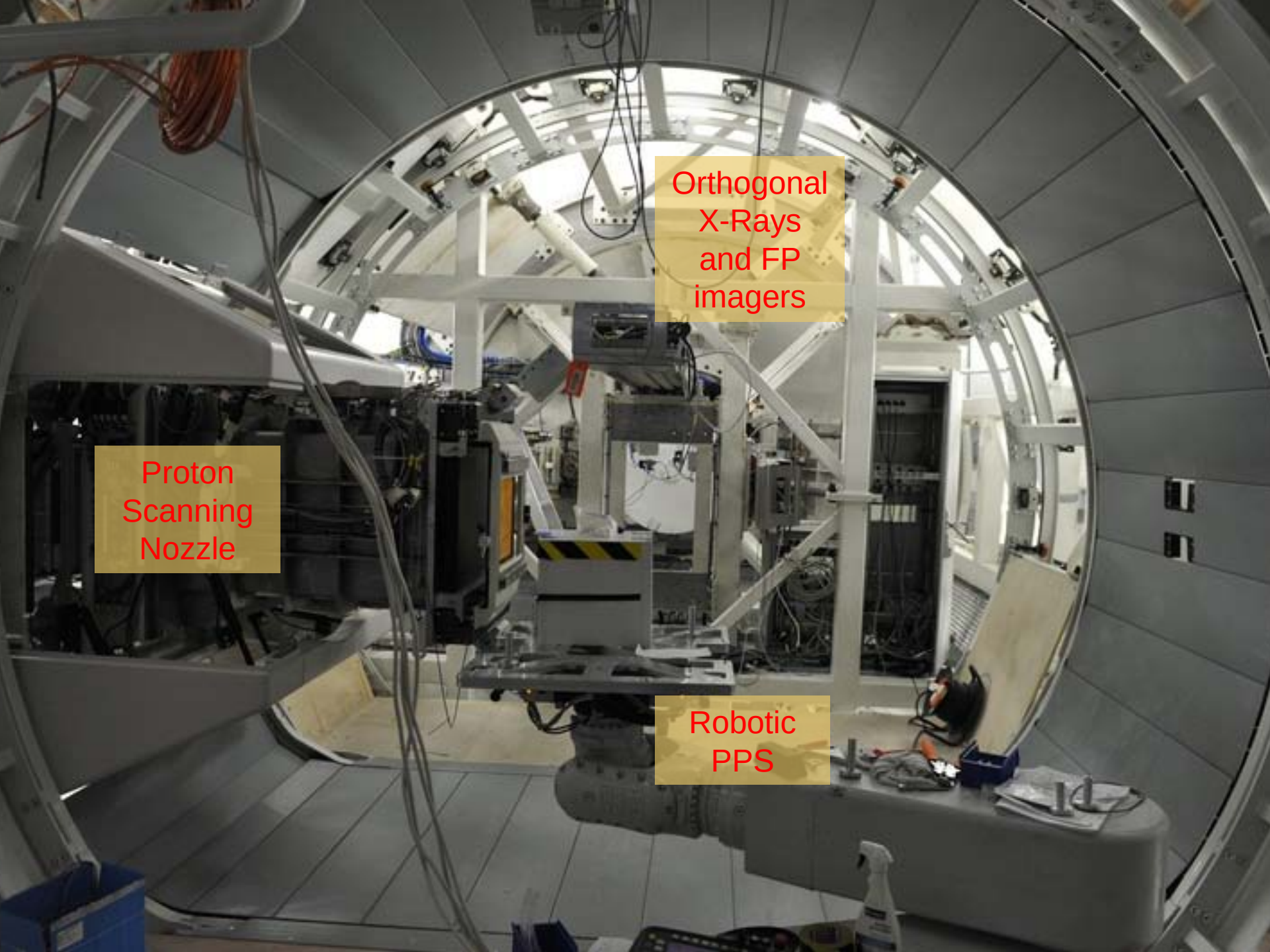




Radius of the bending magnet:

ρ = 1468.5 mm

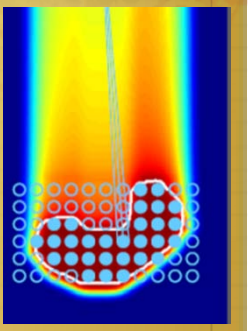
Energy (MeV)	Range (g.cm^{-2})	B1G2		B2G2	
		Current (A)	Field (T)	Current (A)	Field (T)
98.40	4.00	155.39	0.81772	165.39	0.84105
140.10	14.00	226.54	1.17675	239.75	1.20743
191.09	24.00	279.06	1.38966	292.37	1.42410
230.22	33.00	332.45	1.54071	343.86	1.57598

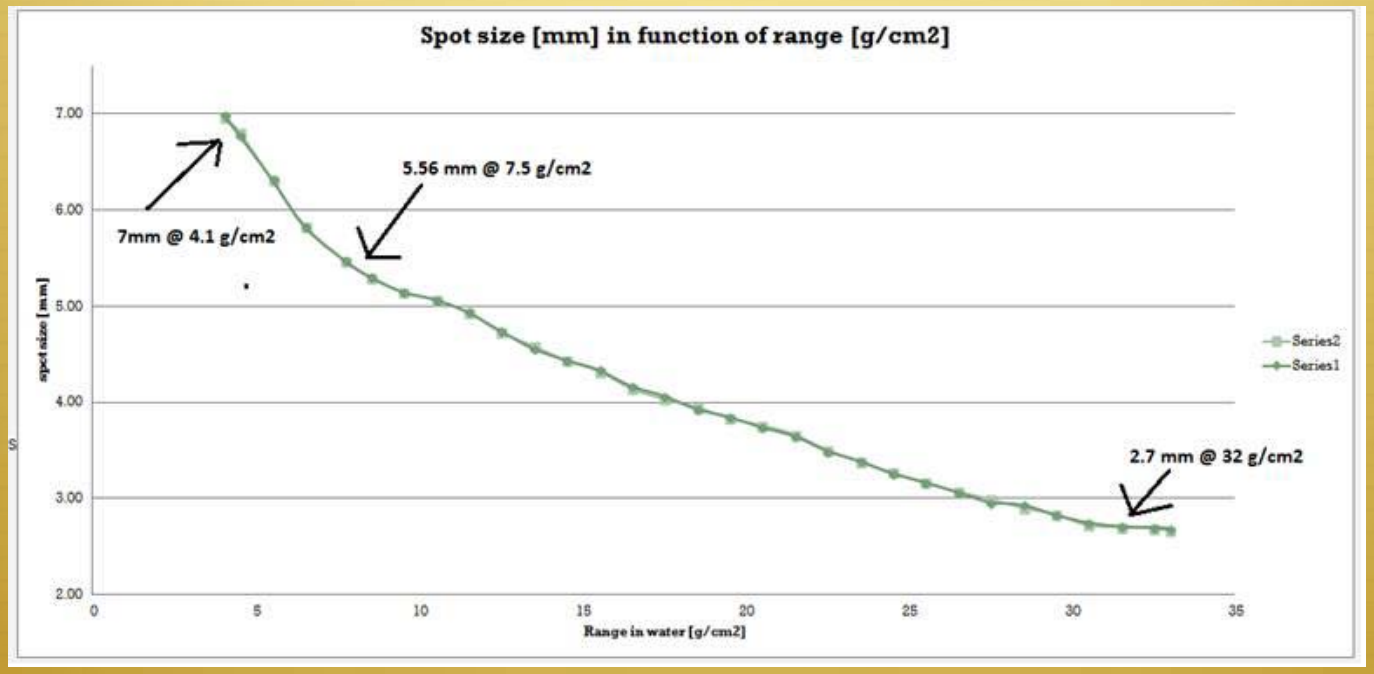

Orthogonal X-Rays and FP imagers
Proton Scanning Nozzle
Robotic PPS

IBA dedicated gantry with the scanning beam

- 3 mm and 6 mm diameters available
- Intensity: dose of 2 Gy delivered to volume of 10 x 10 x10 cm3 in 90 s

IFJ PAN Gantry - Spot diameter





Spot diameter (1 σ) [mm]

Energy [units of range in H_2O /cm]

Planed treatment

starting in October 2015

- 250-350 per gantry after 3-4 years of operation
- 100 eye melanoma patients/year

full operation in 2020

about 600 – 800 patients/year,
about 18 500 fractions/year

The main applications of the scanning gantry

Cancers of:

-Central Nervous System

- head and neck

- prostate

- children

Scientific programme of CCB

1. Radiobiology

2. Nuclear physics

3. Clinical research

4. Dosimetry

Radiobiology for treating cancer

1) Is the RBE for scanning beam equal to RBE for scattered beam?
2) Is for scanning beam the bystander effect observed?
3) Is the RBE higher at the end of Spread Out Bragg peak?
4) Is the clinical RBE for protons = 1.1 suitable for all type of cancers? Scanning beam?
5) Probability of secondary cancer
6) Are the new radiobiological models needed?

Scientific programme of NCRH

1. Radiobiology

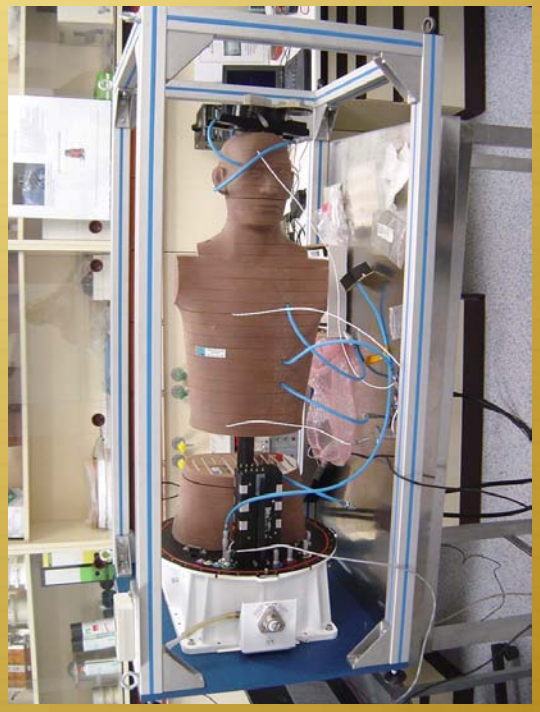
2. Nuclear physics

3. Clinical research

4. Dosimetry

Calibration of cosmic–ray detectors for space dosimetry

99% of ions in cosmic-rays are protons



Phantom with TLDs from IFJ

Laboratories for radiobiology

- Two rooms for preparation of biological materials
- Preparation of the irradiation stand

Timetable of CCB

- signing the contract	08.2010
- start of the construction	03.2011
- installation of the C-235 cyclotron	05.2012
- acceptance tests	11.2012
- medical building and gantry 1	06.2014
- installation of gantry 2	06.2015
- end of the contract	09.2015

Total cost (buildings, cyclotron, eye therapy room, 2 gantries): 62 M€ (85%: EU, 15%: PL)

Proton radiotherapy with gantry in Europe

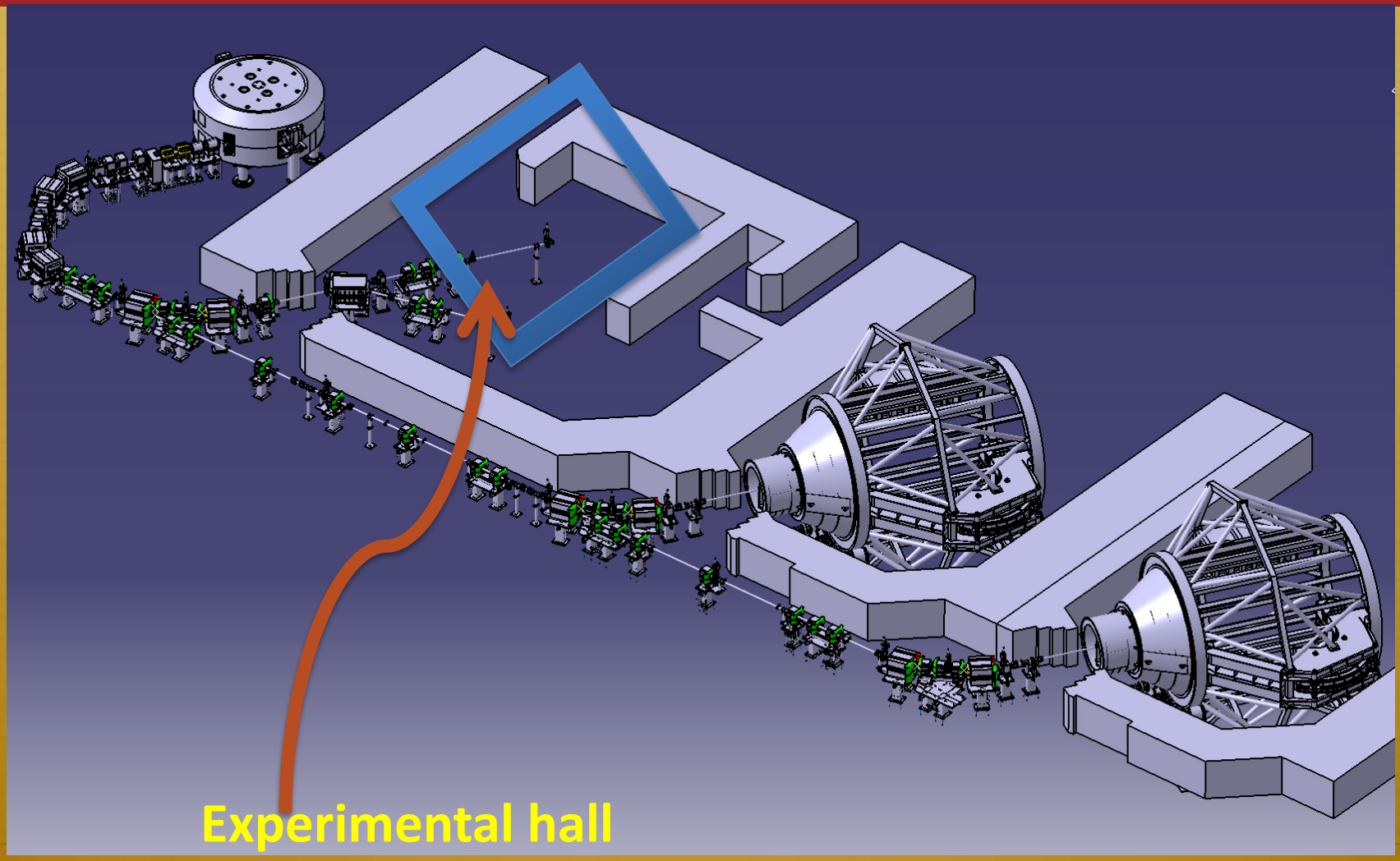
- **Existing centres with gantries**

1. Orsay
2. PSI Villigen
3. Heidelberg
4. Munchen
5. Prague
6. Essen

- **In construction : 6 centers**

1. Dresden
2. Krakow
3. Pavia
4. Trento
5. Uppsala
6. Wiener Neustadt

Although the primary objective of the facility is **proton cancer therapy**, an extensive research program at this cyclotron is planned in the field of **nuclear physics, radiobiology, dosimetry and medical physics**.



Research at CCB Krakow
(Coordinator: A. Maj)

International Advisory Committee (chair: M. Harakeh)

Experimental Program Committee (Coordinator: M. Kmiecik)

Electronics and Data Acquisition Group (Coordinator: M. Zięblíński)

Infrastructure Group (Coordinator: W. Męczyński)

Institutions involved in research

- University of Milano,
- IPN Orsay,
- GANIL
- LNL Legnaro/Padova,
- KVI Groningen,
- Physikzentrum RWTH Aachen,
- ATOMKI Debrecen,
- RIKEN
- IPHC Strasbourg
- IEM CSIC of Madrid
- Univ. of Santiago di Compostela
- Tech. Univ. of Munich
- Nigde Univ., Turkey
- IFIN-HH Bucharest
- ……

- IFJ PAN
- Jagiellonian University (UJ),
- University of Silesia (US),
- University of Warsaw (UW),
- ……

See: http://experimentsccb.ifj.edu.pl

International Advisory Committee

- Faical Azaiez (IPN, Orsay, France)
- Angela Bracco (University of Milano and INFN, Italy)
- Bogdan Fornal (IFJ PAN, Kraków, Poland) - co-chair
- Zsolt Fulop (ATOMKI, Debrecen, Hungary)
- Muhsin Harakeh (KVI, Groningen, Netherlands) - chair
- Robert Janssens (Argonne National Laboratory, USA)
- Stanisław Kistryn (Jagiellonian University, Kraków, Poland)
- Marek Lewitowicz (GANIL, Caen, France)
- Adam Maj (IFJ PAN, Kraków, Poland)
- Krzysztof Rusek (Warsaw University, Poland)
- Hideyuki Sakai (RIKEN, Japan)
- Nicolae Victor Zamfir (IFIN-HH, Bucharest, Romania)
- Wiktor Zipper (University of Silesia, Katowice, Poland)

Beam at the target for the first time: February 21, 2013

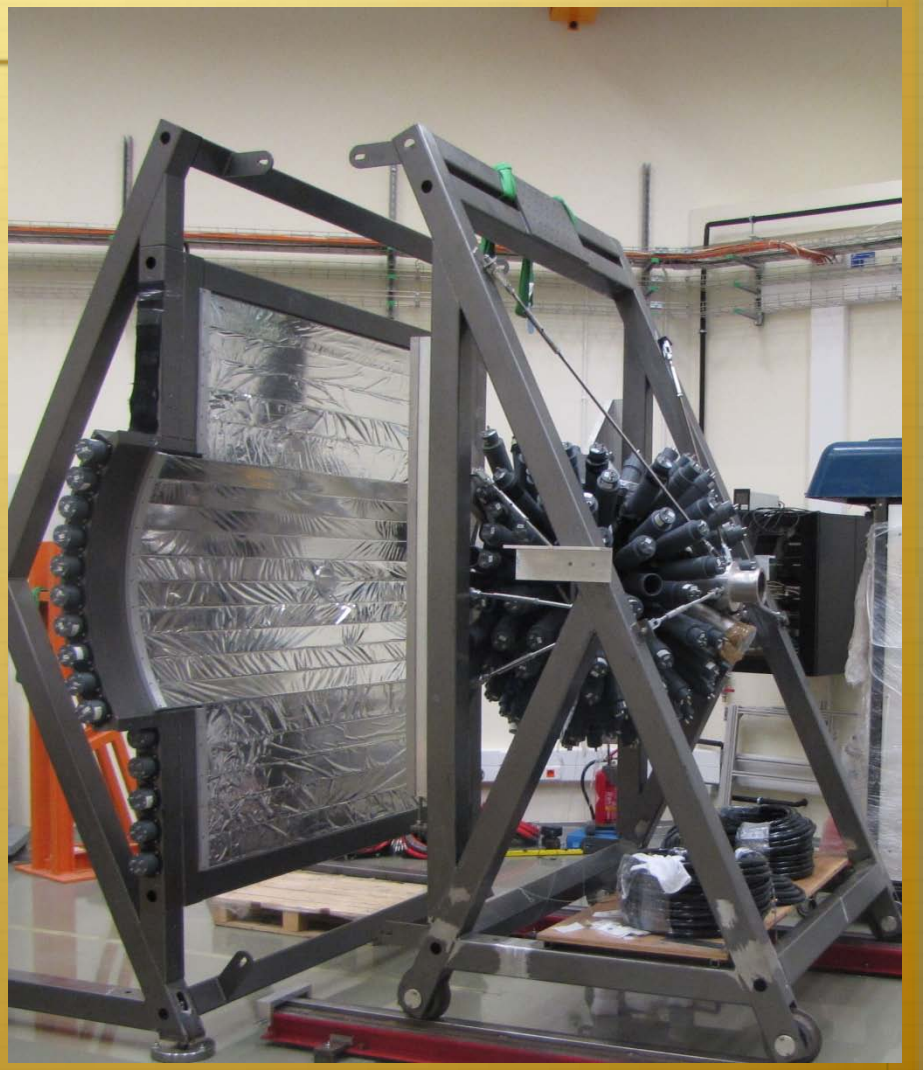
First meeting of the IAB: 30.08.2013

Status of the project was reviewed, LoIs were discussed and recommendations given

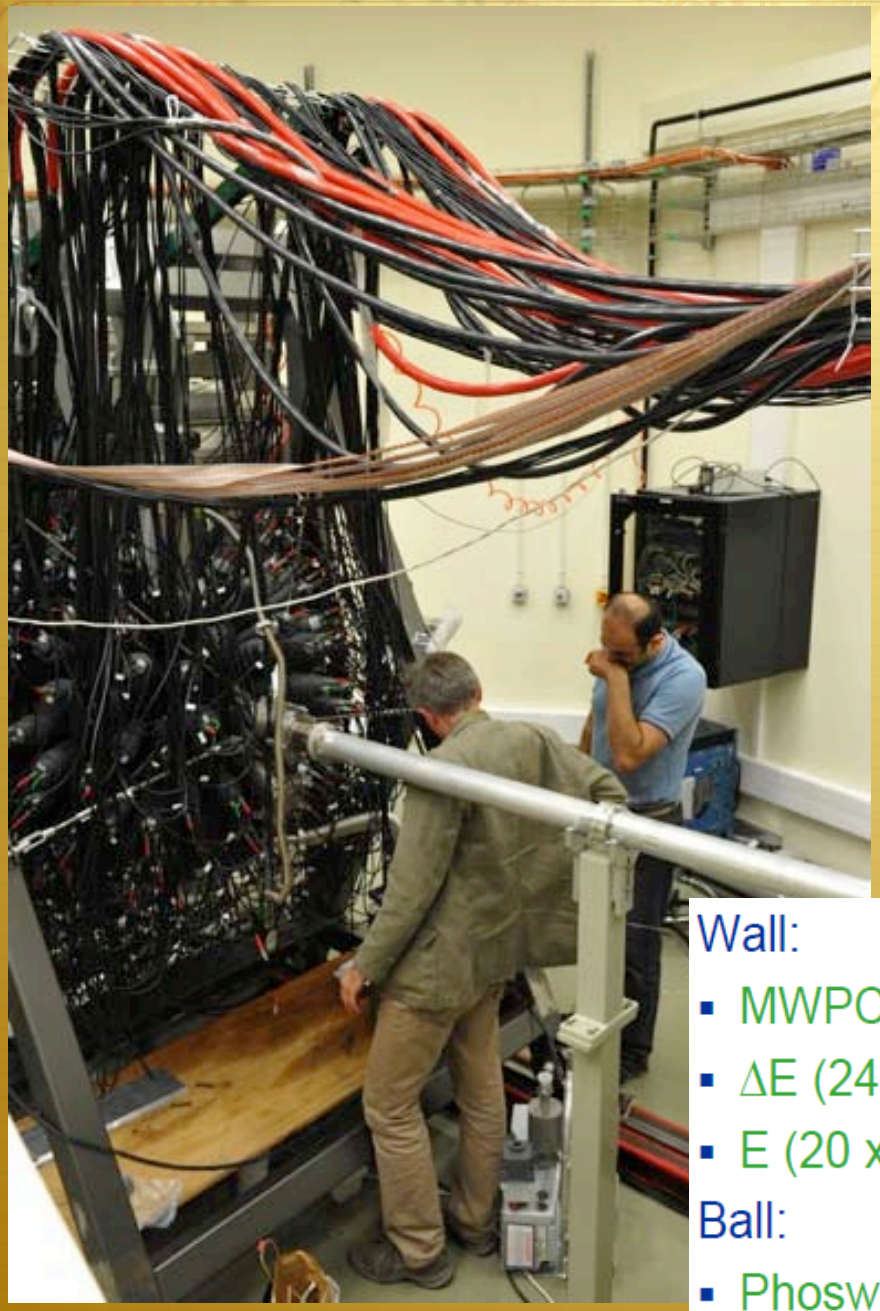
New call for proposalas and LoIs:
http://experimentsccb.ifj.edu.pl/pdfs/Call_for_Proposals_CCB.pdf

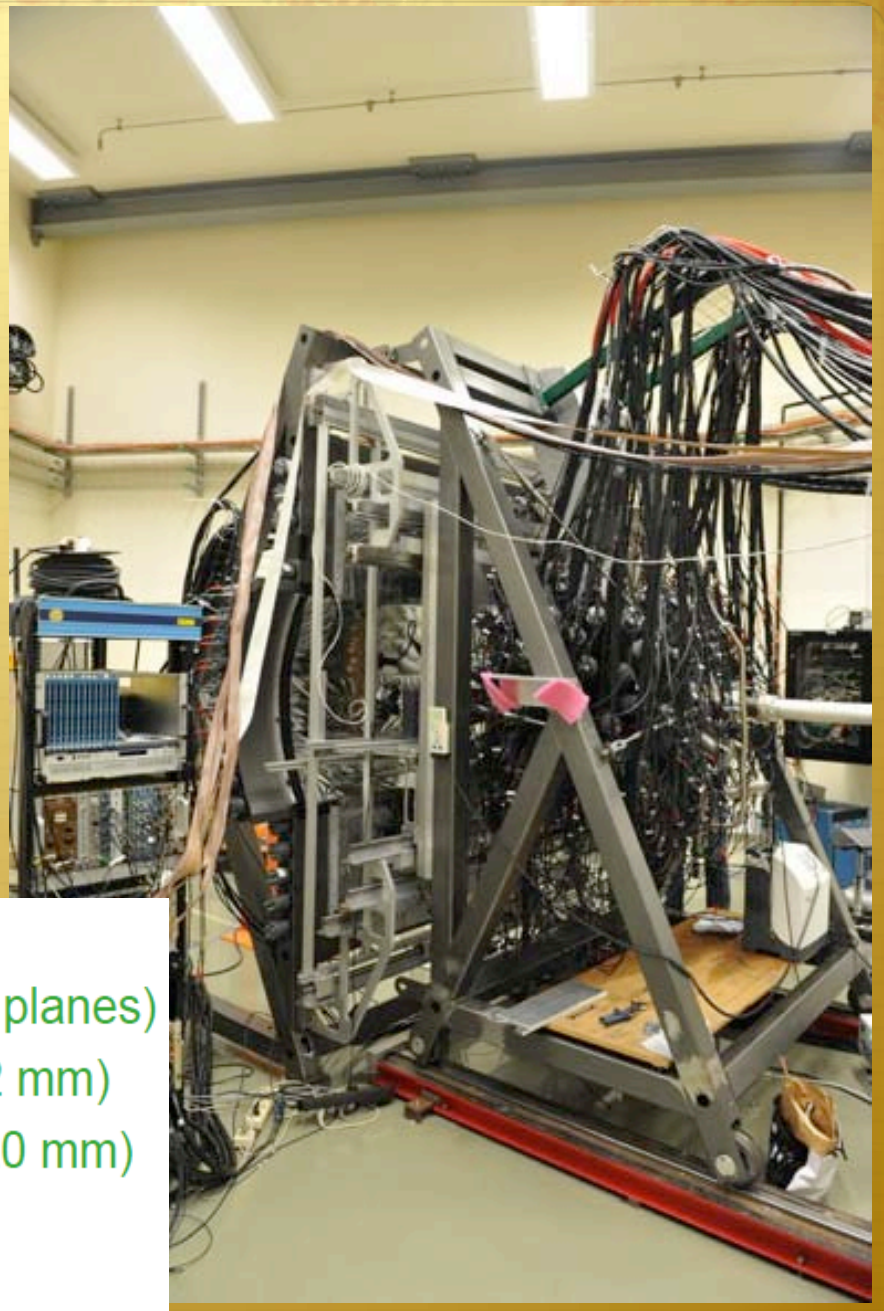
Following the recommnedationf of the IAB presently 2 major detector systems are foreseen:

1. Detector BINA (moved from KVI Groningen) for light nuclei reactions studies



The program to study the dynamics of few-body systems





Wall:

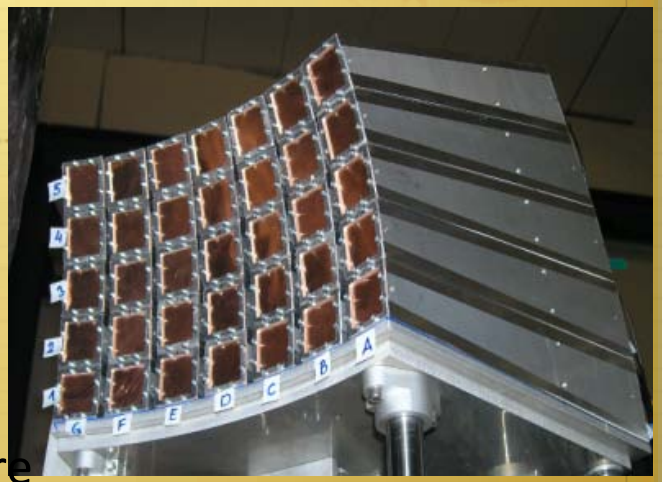
- MWPC (3 planes)
- ΔE (24 x 2 mm)
- E (20 x 120 mm)

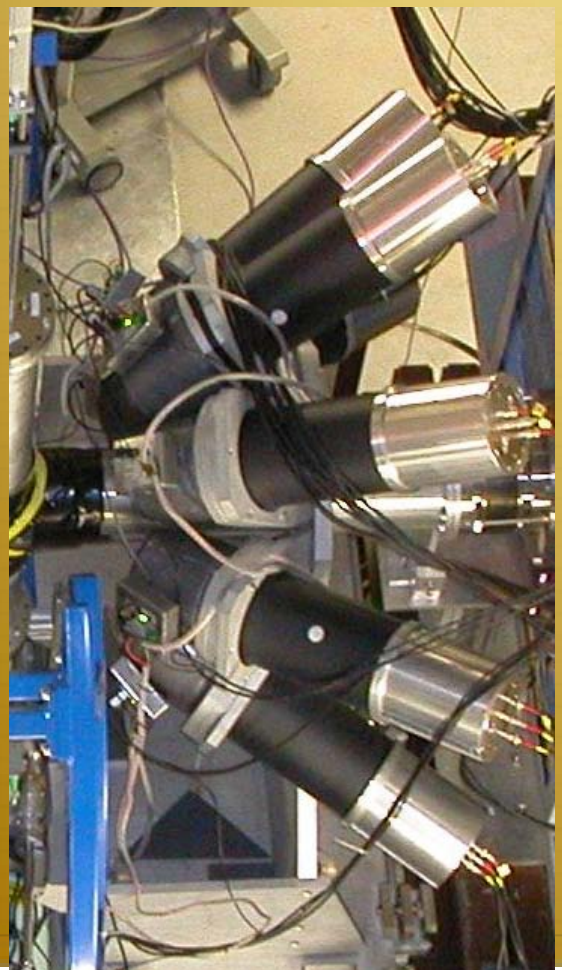
Ball:

- Phoswich (149 x 90/30 mm)

Gamma-decay of Giant and Pygmy Resonances

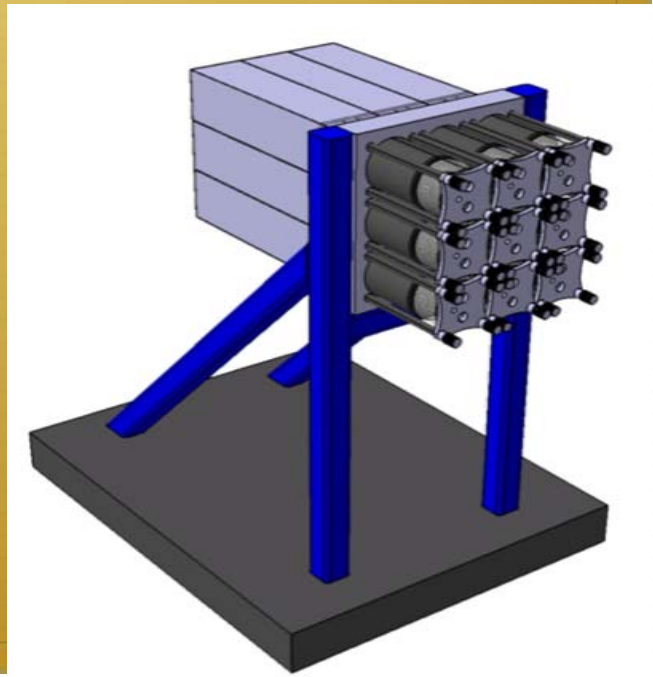
1. **KRATTA** array (CsI telescopes) at forward direction to measure the energy of inelastically scatter protons in order to reconstruct the excitation energy (resolution ca. 1%) and select excitation energy bins





2. **HECTOR** array to measure high energy gamma-rays

3*. **PARIS** Demonstrator for PDR measurements with high-resolution, in coincidence with KRATTA



4*. **Germanium array**

* - *in dedicated campaigns*

Comissioning od HECTOR array in Krakow – July 2014

Test bench for detectors and electronic tests (in preparation)

Tests of various $LaBr_3$ detectors (CALIFA and PARIS) have been performed at CCB inn March 2013 and June 2014
(within GANAS@NUPNET project)

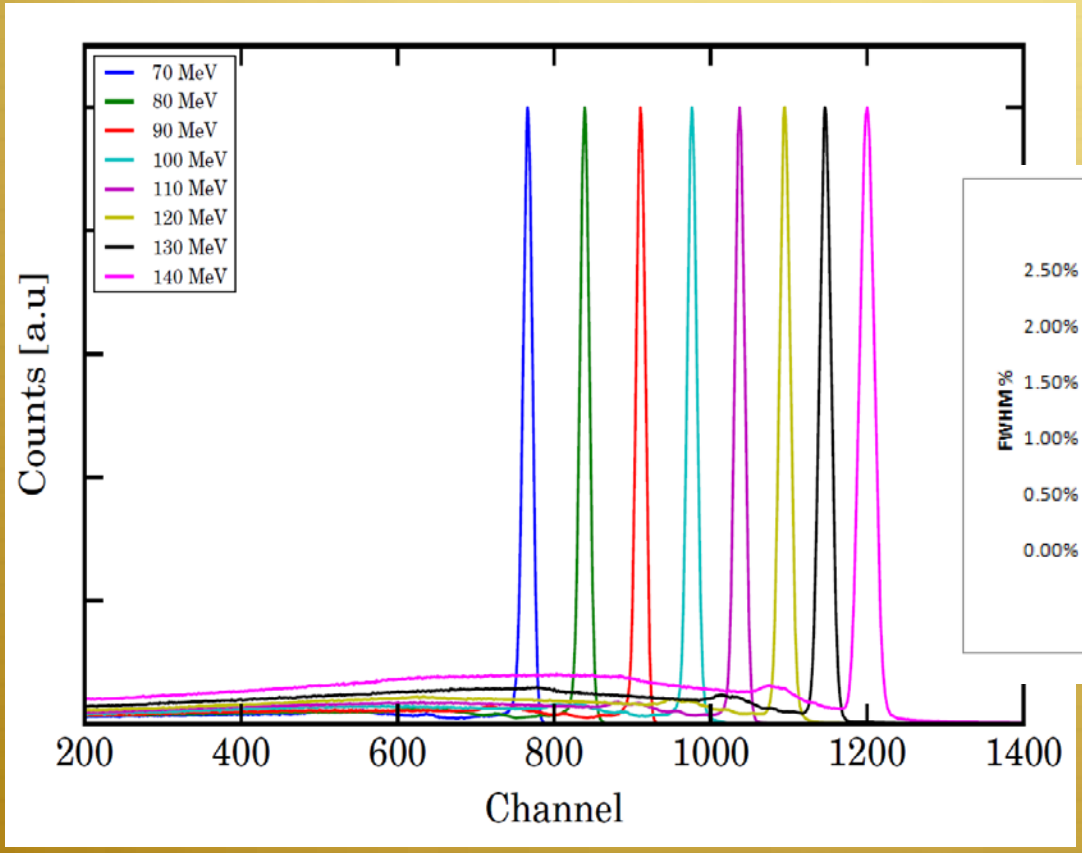
45 physicists from abroad participated

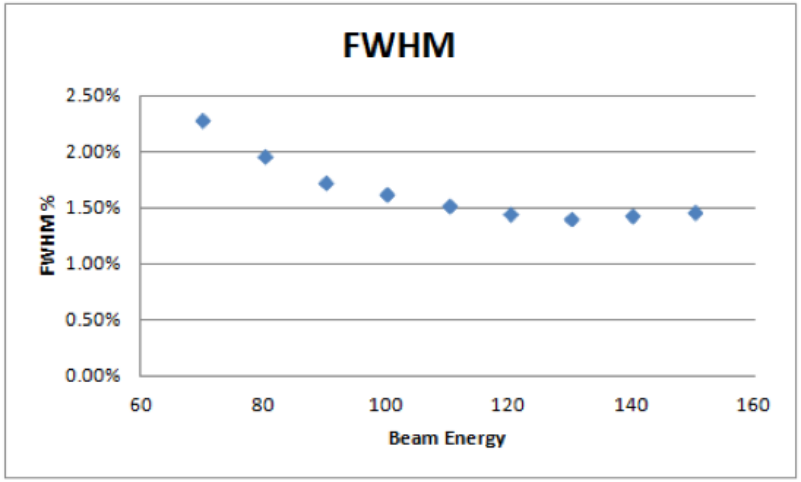
IPN Orsay
IEM CSIC of Madrid
Universfity of Milano
Tech. Univ. of Munich
IPHC Strasbourg
Univ. of Santiago di Compostela
IFIN-HH Bucharest
ATOMKI Debrecen,
Nigde Univ., Turkey
RIKEN, Japan
University of Aachen

Heavy Ion Laboratory, Warsaw
Jagiellonian University, Krakow
Silesian University, Katowice


Scattered protons
70 – 230 MeV protons

First proton spectra from the Ti(p,p') reaction measured at CCB with a $LaBr_3$ detector



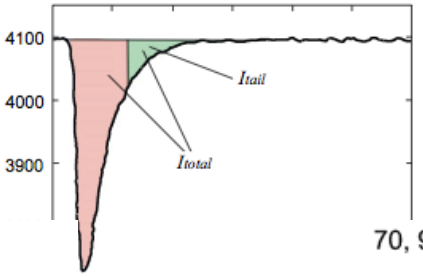


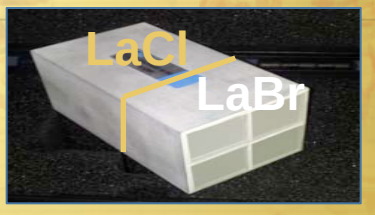
Spectra of protons at different beam energies measured with a 2" x 2" x 2" $LaBr_3$:Ce crystal at 5 deg. relatively to the beam axis. The spectra are normalized to have the same height of a proton peak.

Pulse Shape Analysis

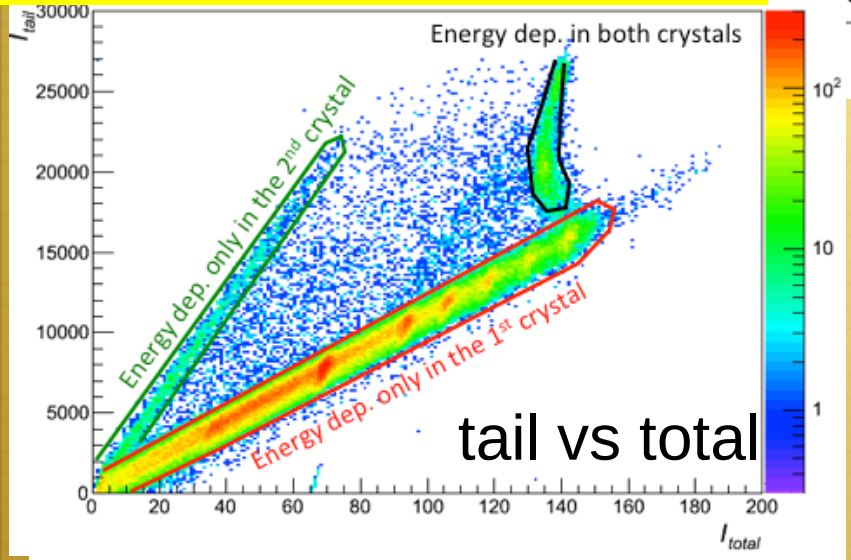
LaBr/LaCl Phoswich

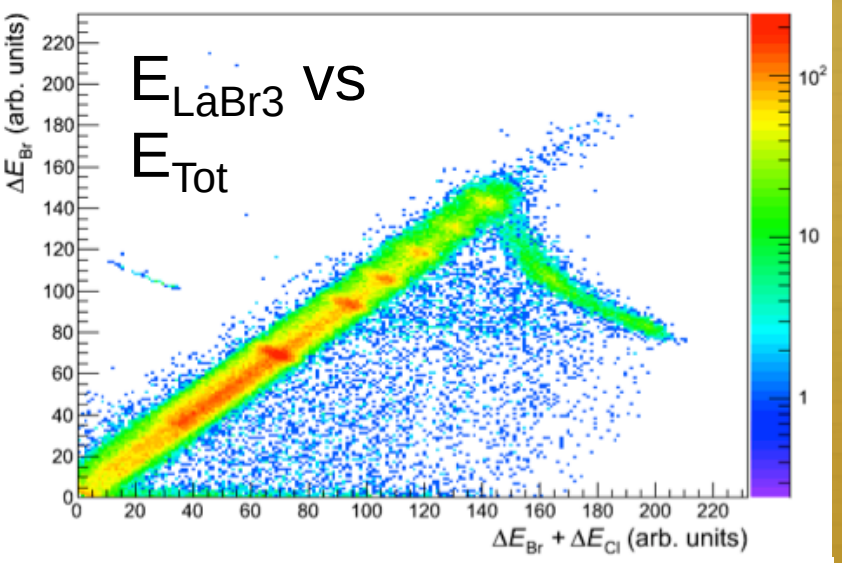
(court. of O. Tengblad)

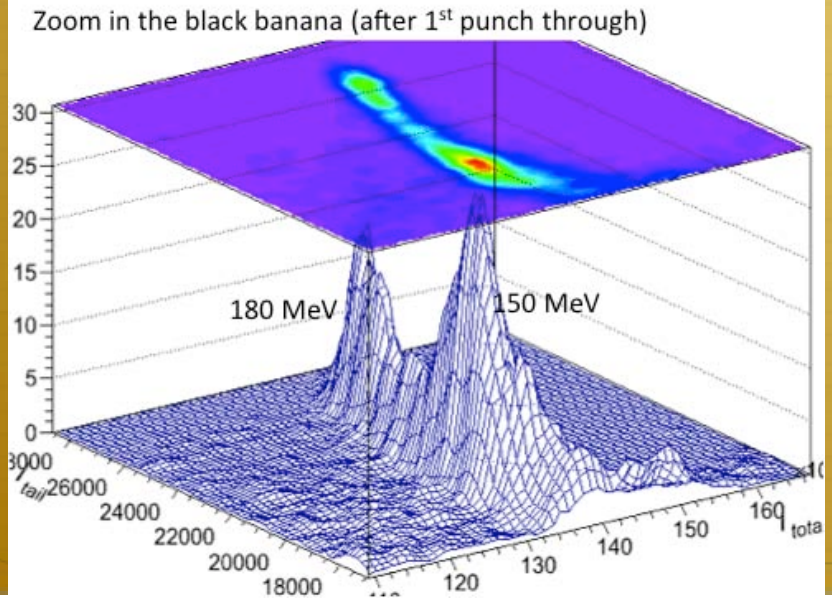


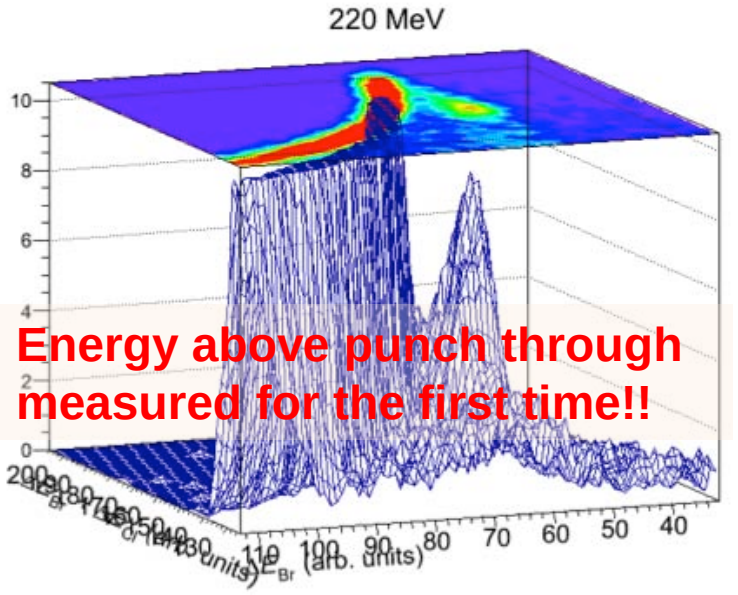


70, 90, 100, 110, 120, 130, 150, and 180 MeV









Energy above punch through measured for the first time!!

National Laboratory of Cyclotrons

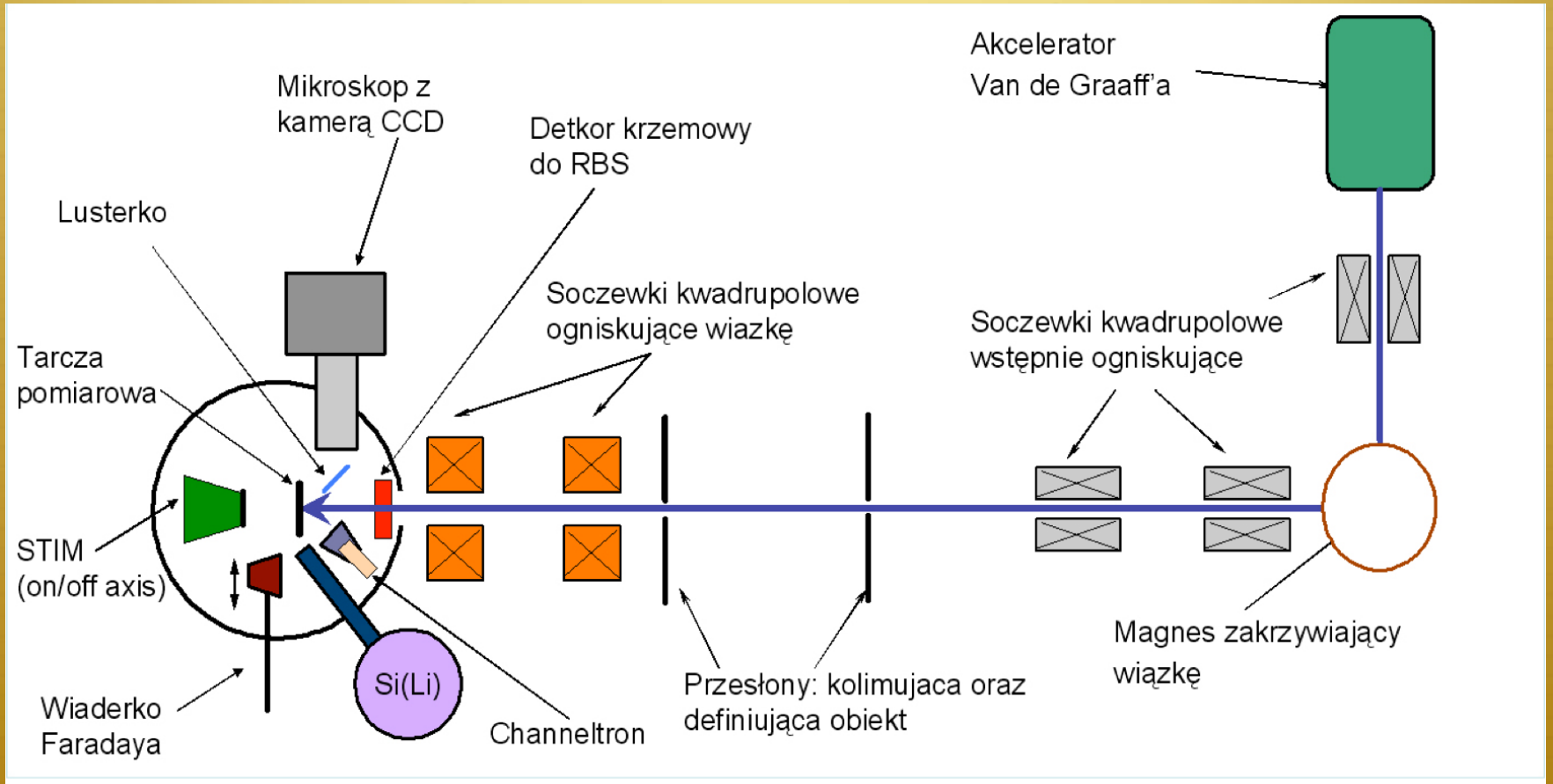
Warsaw / Kraków

Ongoing efforts to include NLC (CCB at IFJ PAN and HIL at Warsaw University) in the HORIZON2020 ENSAR project as Transnational Access Facility

The nuclear physics research programme of NLC aims at obtaining high quality data on nuclear properties at and around the valley of stability. Therefore, it is complementary to the programmes of large-scale European RIs, which are concentrated on the physics of nuclei very far from the stability line, often at the limits of detection.

The investigations carried out in Warsaw and Kraków are also in many aspects complementary - at CCB high-energy proton beam is available while at SLCJ beams of heavier nuclei from boron to argon can be accelerated.

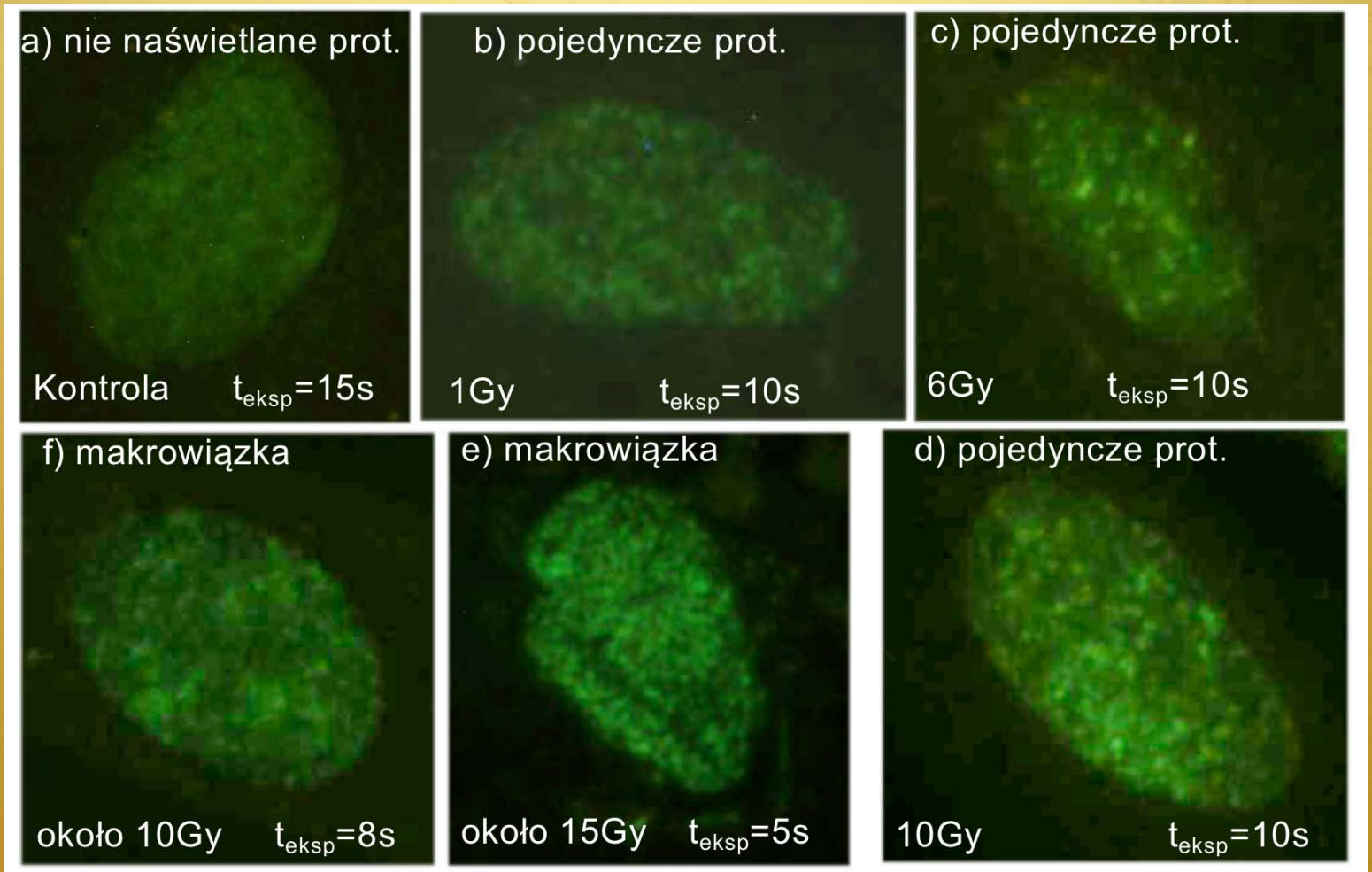
3. Response of biological cells after single proton hit irradiation (2 MV van de Graaff)



Rys. 21 Schemat całości układu prowadzenia wiązki od akceleratora do komory pomiarowej

Study of double strand DNA break after one proton hit

Wojciech Polak, Ph.D. Thesis
Krakow, 2006



Rys. 62 Podwójne przerwania helisy DNA widoczne w jądrach fibroblastów naświetlonych różnymi dawkami promieniowania protonów.
a, b, c, d – komórki naświetlane konkretną liczbą protonów.
e, f – komórki naświetlane szeroką wiazką.

Outreach activity at IFJ PAN

Performance "Physics – The Largest Spectacle of the Universe" - Małopolska Reasercher's Night, 2013.
Ca. 1200 visitors in one day

Recent *bottom-up* initative in Poland - to construct the IFMIF facility in Rzeszow (called ELA-MAT)

ELA MAT

Joint European Laboratory for Advanced Materials Testing

Summary

1. Proton radiotherapy of eye melanoma started at IFJ PAN Krakow in February 2011 on AIC-144 60 MeV cyclotron

2. The 230 MeV IBA cyclotron is used for basic research and detector tests from Jan. 2013

3. Two IBA scanning proton gantries will be operational in 2014 (gantry1) and in 2015 (gantry2)

4. Radiobiological and other application studies are conducted with the proton 2 MV van de Graaf

5. IFMIF-ELAMAT facility in Poland? - New polish initiative with strong IFJ PAN participation

The Henryk Niewodniczański
Institute of Nuclear Physics
Polish Academy of Sciences

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and many others