

# Development of accelerator and detector systems for radiation medicine in DLNP JINR

E.M. Syresin\*, N.V. Anphimov, G.A. Chelkov, G.A. Karamysheva,  
M.Yu. Kazarinov, S.A. Kostromin, G.V. Mytzin, N.A. Morozov,  
A.G. Olshevsky, V.M. Romanov, E.V. Samsonov, N.G. Shakun,  
G. D. Shirkov, S.G. Shirkov,

Joint Institute for Nuclear Research,  
Dubna, Russia.

M.Abs, A. Blondin, Y. Jongen, S. Zarembo, D. Vandeplassche,  
IBA, Belgium.

**The project is aimed at developing two directions in radiation medicine :**

- accelerator technique for proton and carbon treatment of tumors**
- and new types of detector systems for spectrometric computed tomography (CT) and combined magnetic resonance tomography (MRT)/positron emission tomography (PET).**

# JINR Medical-Technical Complex on proton beams of synchrocyclotron

1967 – First investigations at cancer treatment;

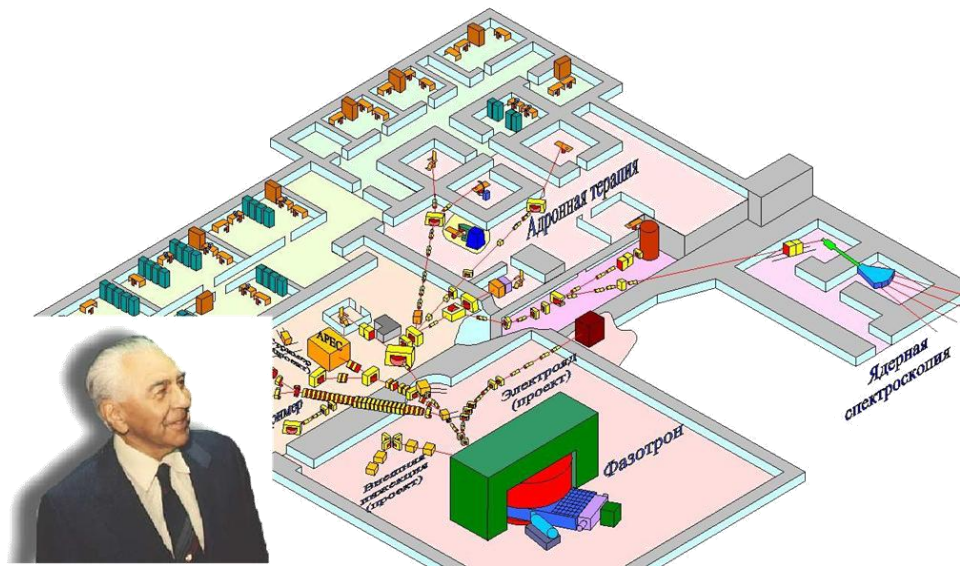
1968 –1974 –84 patients was irradiated by proton beams on synchrocyclotron;

1975 –1986 – Upgrade of synchrocyclotron, creation of Medic-Technical Complex (MTC) of hadron therapy in JINR;

1987– 1996 –40 patients were radiated by proton beams;

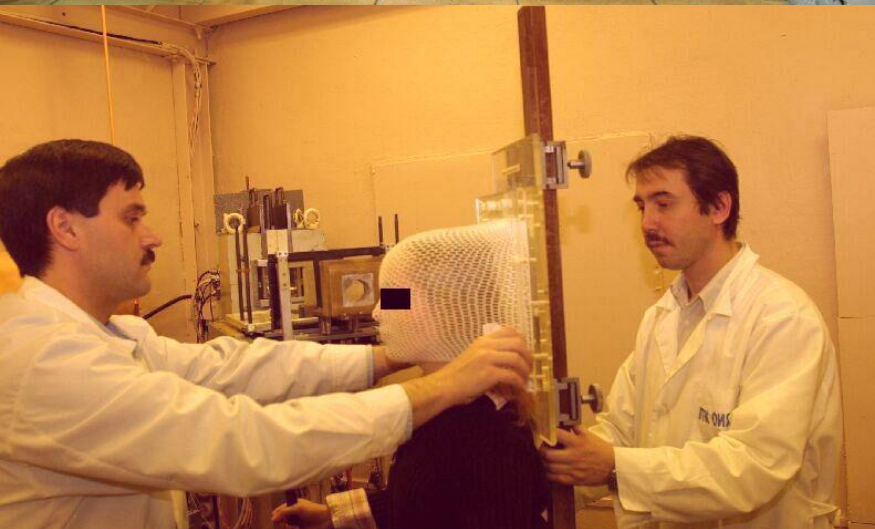
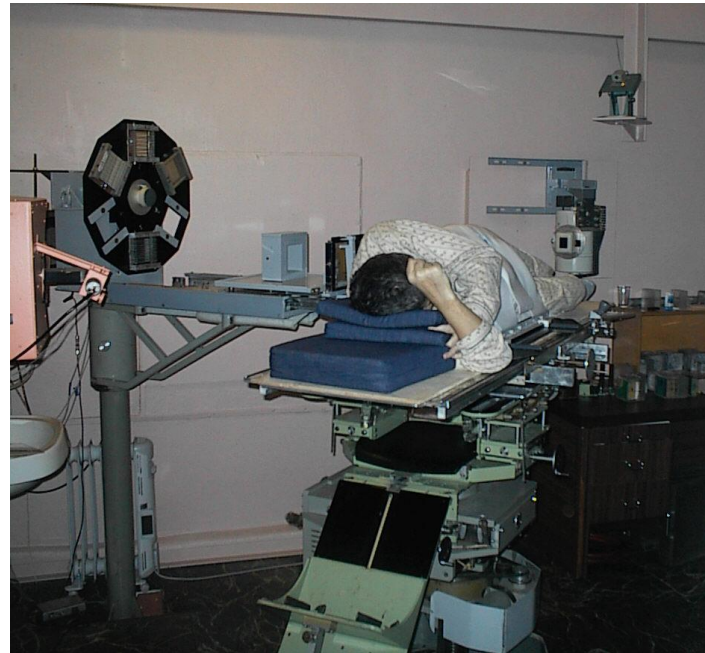
1999, – Creation of radiological department in Dubna hospital;

2000 – 2010, – 660 patients were radiated by proton beam.



During last years around 100 patients per year were radiated by proton beam in JINR Medical-Technical Complex in frame of research program of Medical Radiological Research Center of Russian Medical Academy of Science.

# JINR MTC WITH PROTON BEAMS



**Cancer treatment in cabin №1**

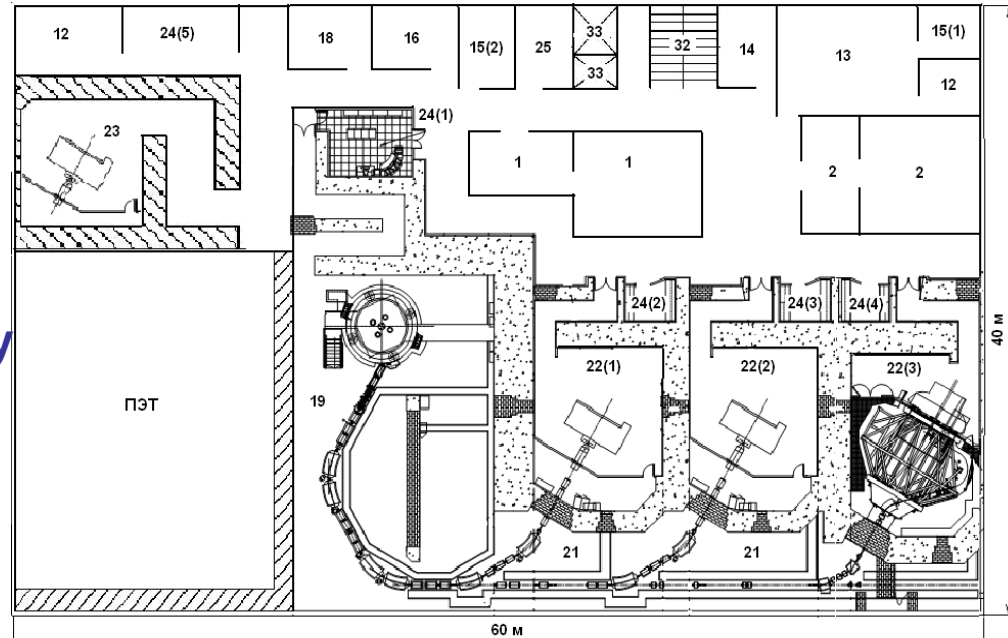
**Prostate treatment equipment**

**3D conformal proton beam treatment were realized in Russia only in JINR.**

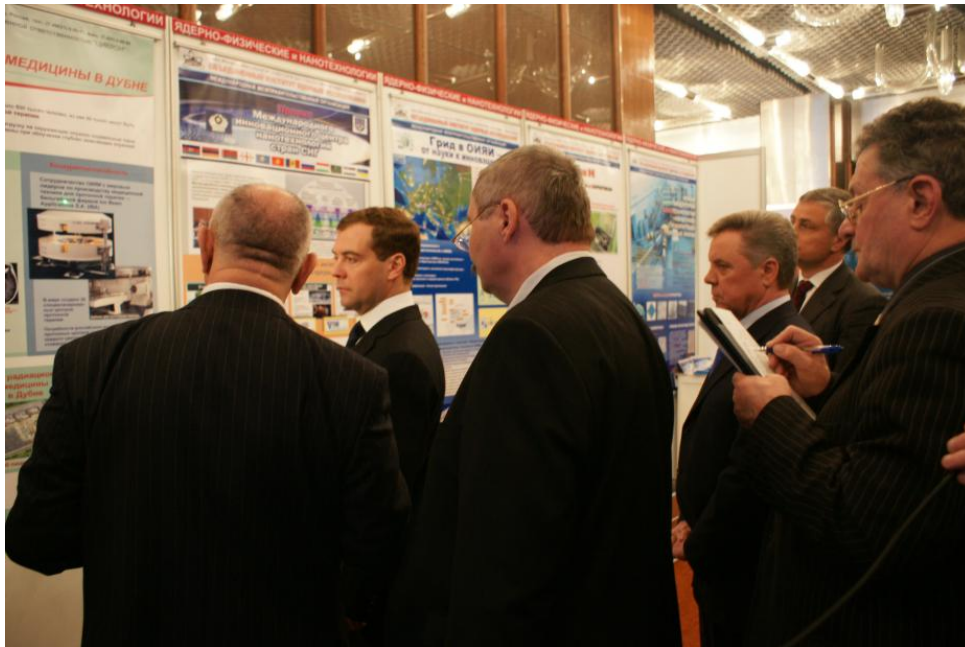
# DUBNA CYCLOTRON CENTER OF PROTON THERAPY

Dubna Center of Radiation Medicine  
(CRM) involves:

Cyclotron Center of Proton Therapy,  
PET center,  
Department of convention radiotherapy  
with electron linac,  
Diagnostic department,  
Proton therapy clinic.



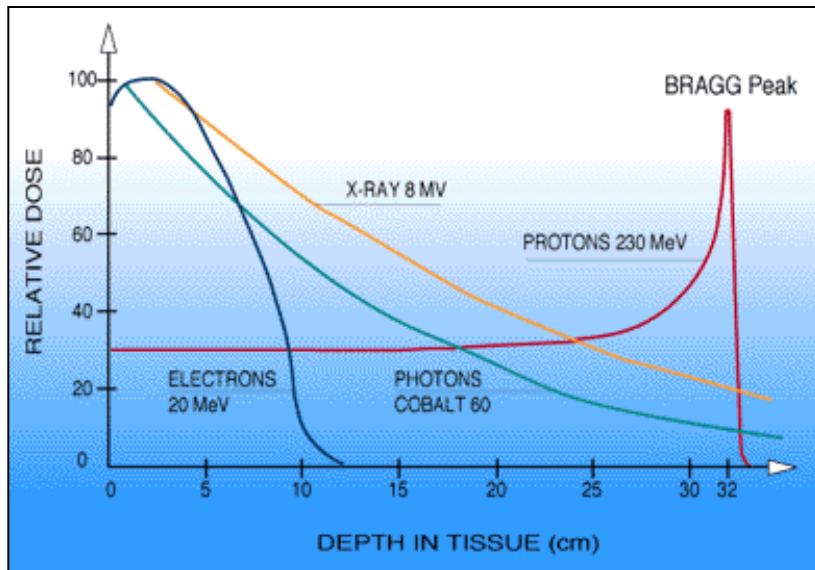
**The scheme of accelerator equipment of Dubna CRM.**



The Center of proton therapy has 3 treatment cabins, 1 with the gantry and 2 rooms with the fixed beams.

About 1000 patients per year will be treated there.

# HADRON THERAPY IN WORLD AND IN RUSSIA



There are 25 centers of the proton therapy and 4 centers of carbon therapy at the world now. More than 60 thousand patients were treated with application of hadron therapy during last 50 years, 60 % of them were treated over last 10 years and 90% of total patients now treated in the hospital based facilities.

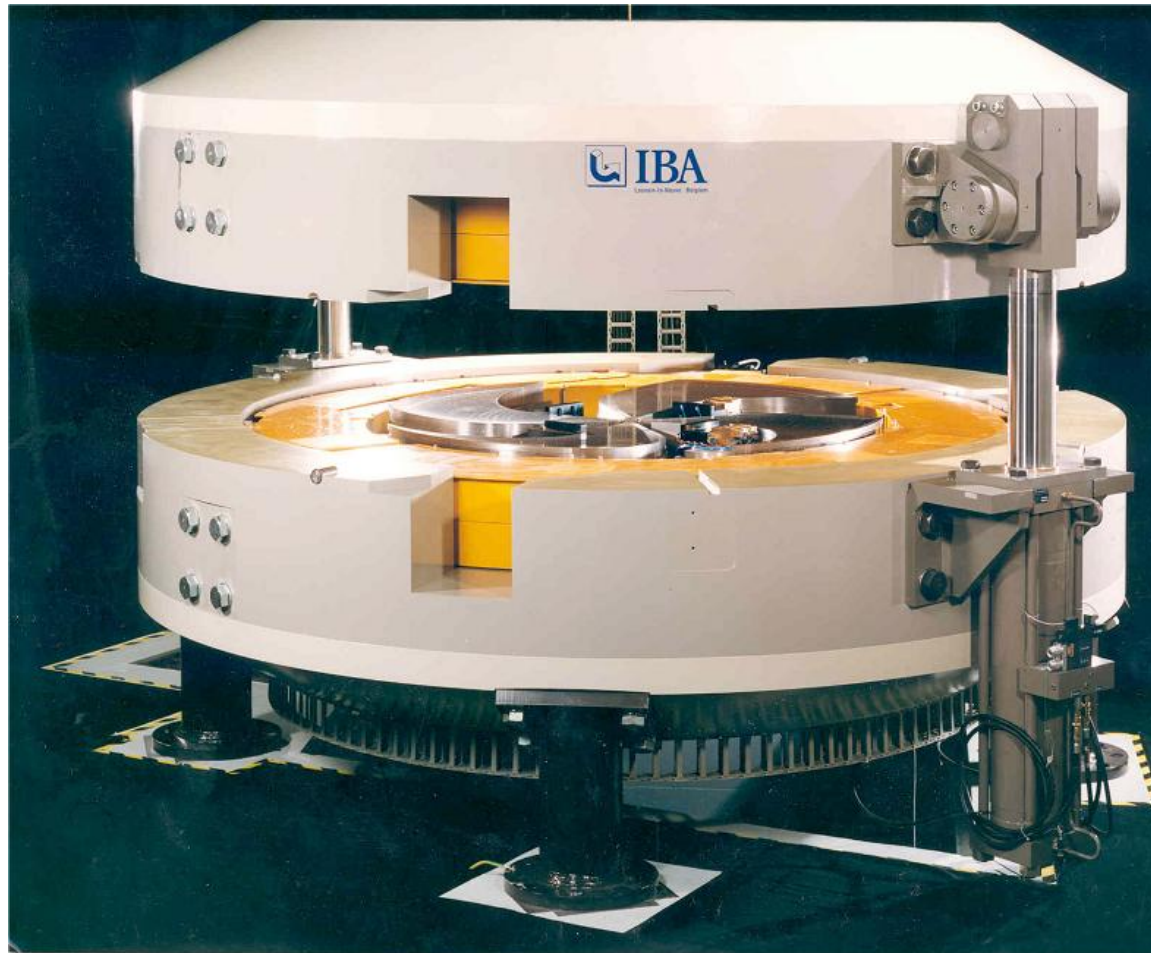
2.3 million of tumor patients there are in Russia 450 thousands of new patients are appeared per year.

The proton therapy is recommended 50 thousands of patients per year in Russia.

# Cyclotrons for hadron therapy in DLNP JINR

- Dubna project of the cyclotron for proton therapy C250 (Alenitsky Yu.G. poster, RUPAC-2010)
- Modification of the proton therapy cyclotron C235 (IBA, Belgium)
- Project of the superconducting cyclotron C400 for carbon ions therapy (IBA, Belgium)

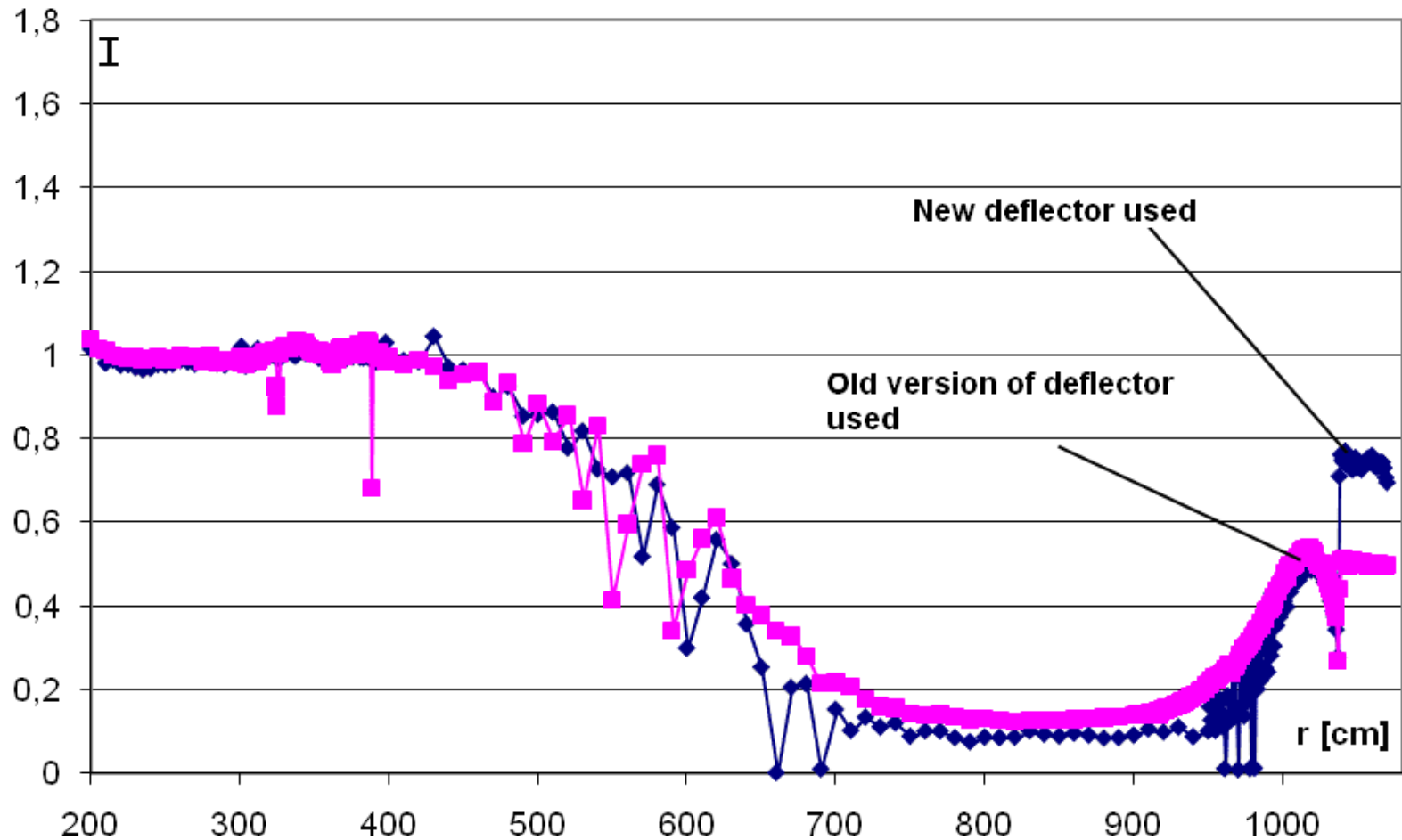
# cyclotron C235



# Proton isochronous cyclotron C235

General parameters	Value
Proton energy, MeV	235
Internal current, nA	300
Beam emittances, $\pi \cdot \text{mm} \cdot \text{mrad}$	12/11
Magnetic field (min/max) T	0.9/2.9
Number of sectors	4
Magnet diameter, m	4.3
Radius of beam extraction, m	1,08
Elliptical hill gap, cm	9,6/0,9
Duant aperture, cm	2
RF frequency, MHz	106.1 (4 harmonic)
Dee voltage, (min/max) kV	60/130
Ion source	PIG, internal
Electrostatic deflector field, kV/cm	170
Extraction efficiency, %	50
Power, kW	446
Weight, t	220

# PROTON BEAM EXTRACTION EFFICIENCY MEASUREMENTS



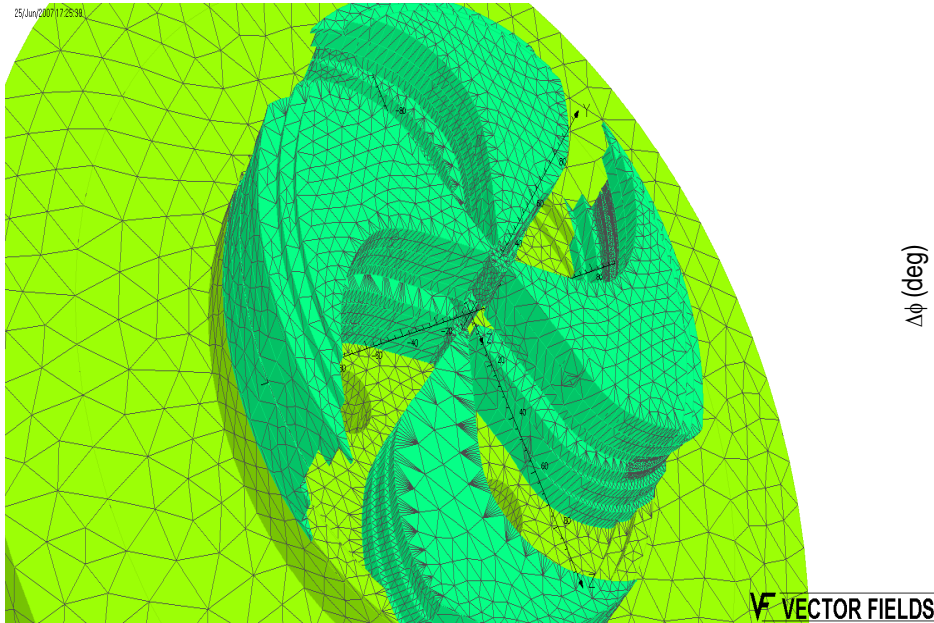
**Improvement of extraction efficiency from 50% to 75% with new extraction system**

# Modified Cyclotron C235

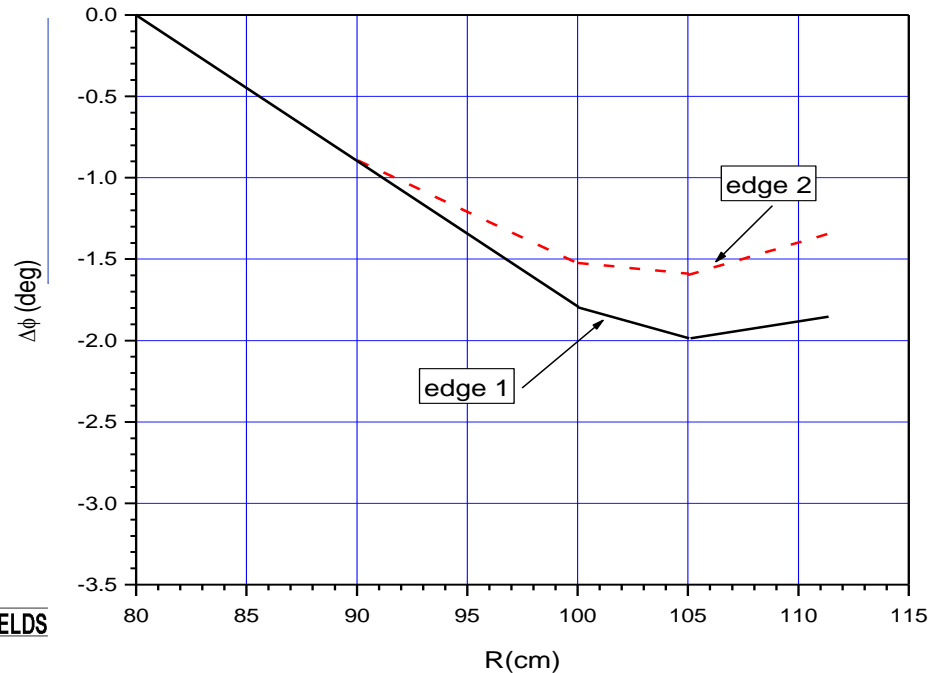
JINR-IBA collaboration develops a medical cyclotron for the proton therapy.

This year it is planned to complete its construction, to start assembling in 2011 and to carry out the beam tests in 2012.

After that the accelerator could be installed in the Dimitrovgrad Centre of proton therapy. The main modernization efforts are directed on optimization of the magnetic system oriented on an increase of the axial betatron frequency.



Simulation of magnetic field.

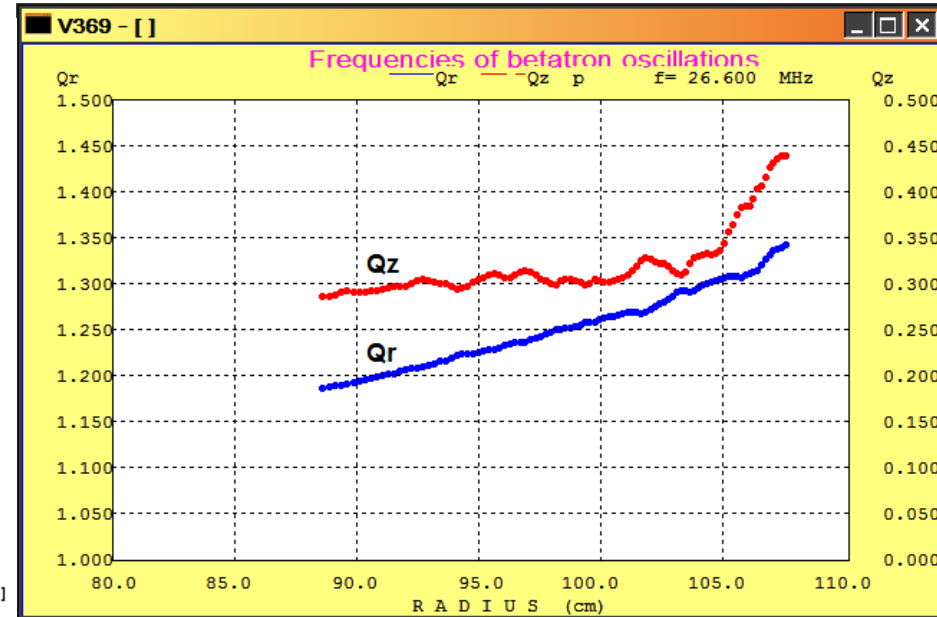
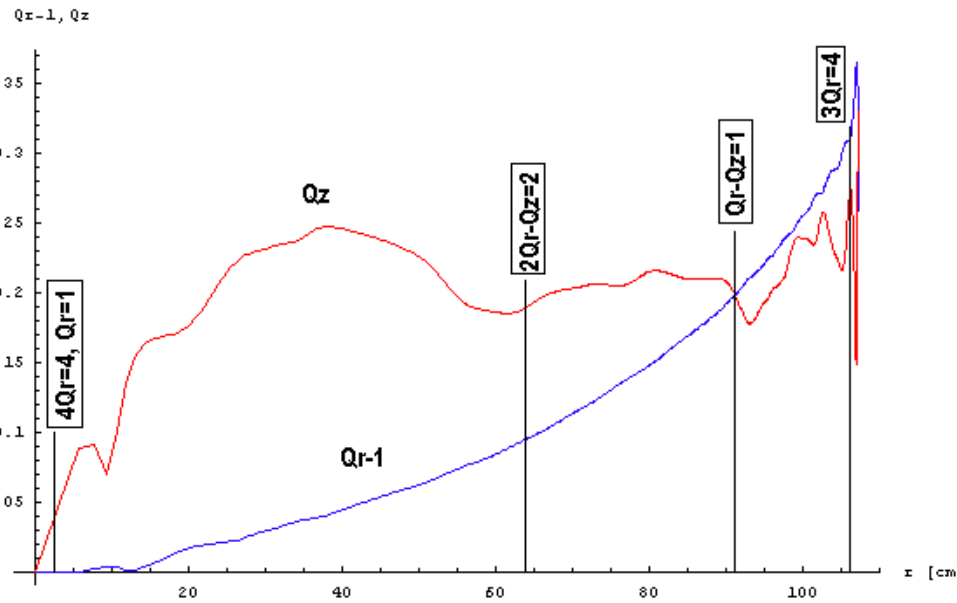


Azimuthal angle variation

# MODIFIED CYCLOTRON C235-V3

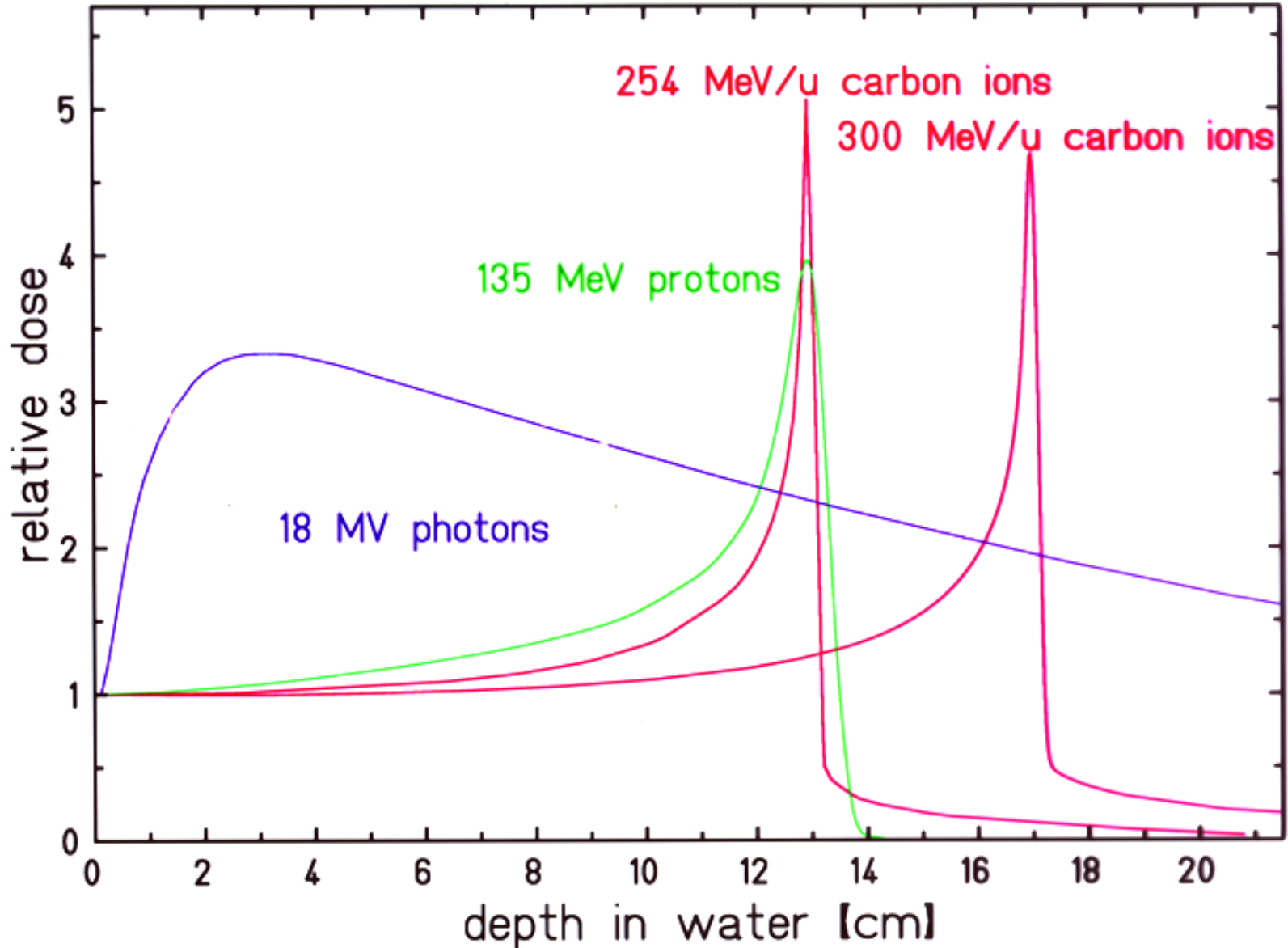
Parameter	C235	C235-V3
Optimization of magnetic field at modification of sector		Modification of azimuthal angle of sectors on $1,5^{\circ}$ - $2^{\circ}$ at $R > 80$
Vertical betatron frequency is increased at $R > 90$	$Q_z = 0,25$	$Q_z = 0,45$
Vertical coherent beam displacement related to effects of median plate should be reduced	6-7mm	1,5-2mm
Beam losses should be reduced at proton acceleration	30-50%	0%
New design of the deflector Beam losses at extraction were reduced	50%	25%

# Dependence of betatron tunes on radius in cyclotron C235 and C235-V3



# CARBON CANCER TREATMENT

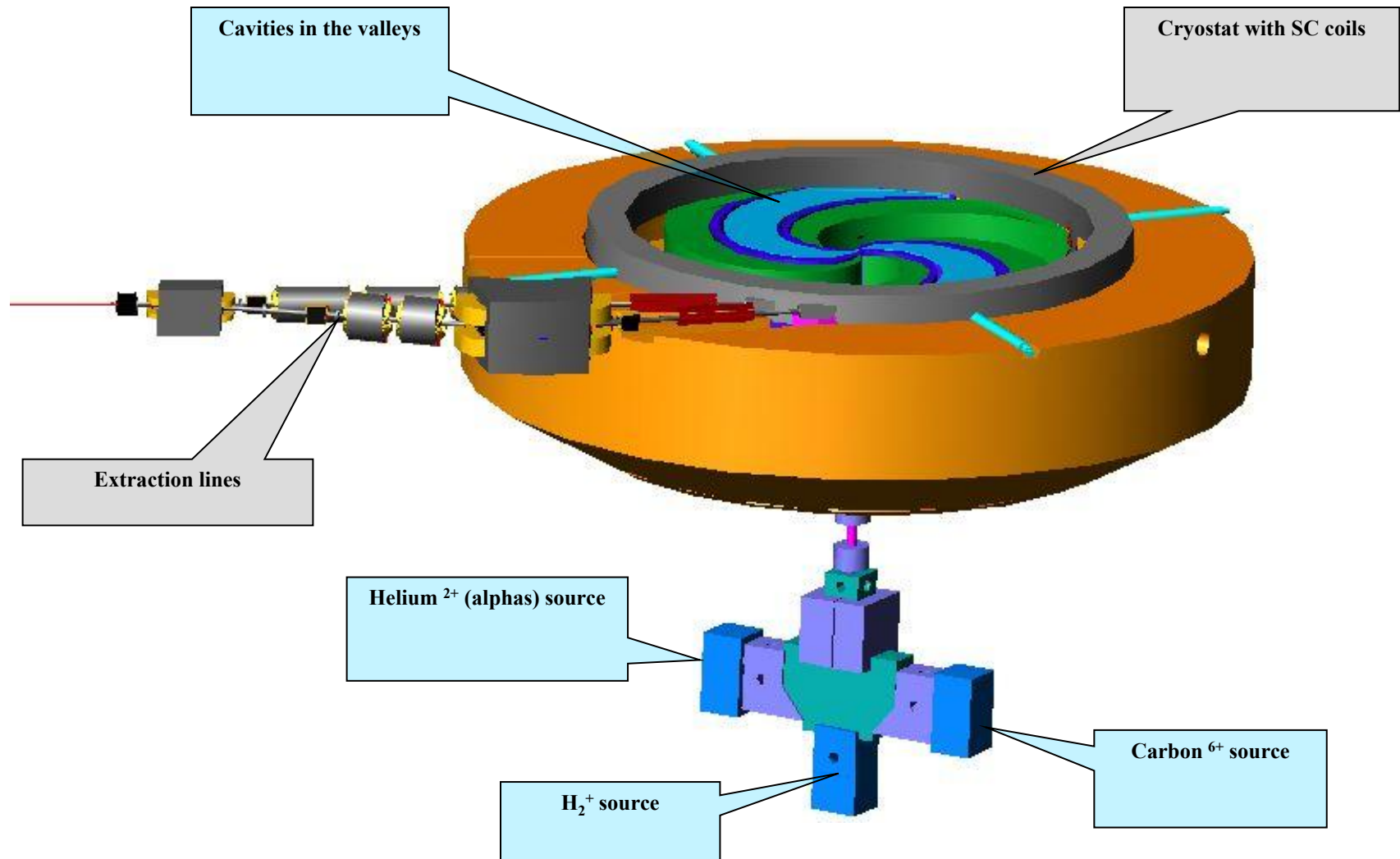
- The carbon  $^{12}\text{C}^{6+}$  ion beams at intensity of  $10^9$  pps are efficiently used for **cancer treatment** especially for patients with radioresistant tumor targets.



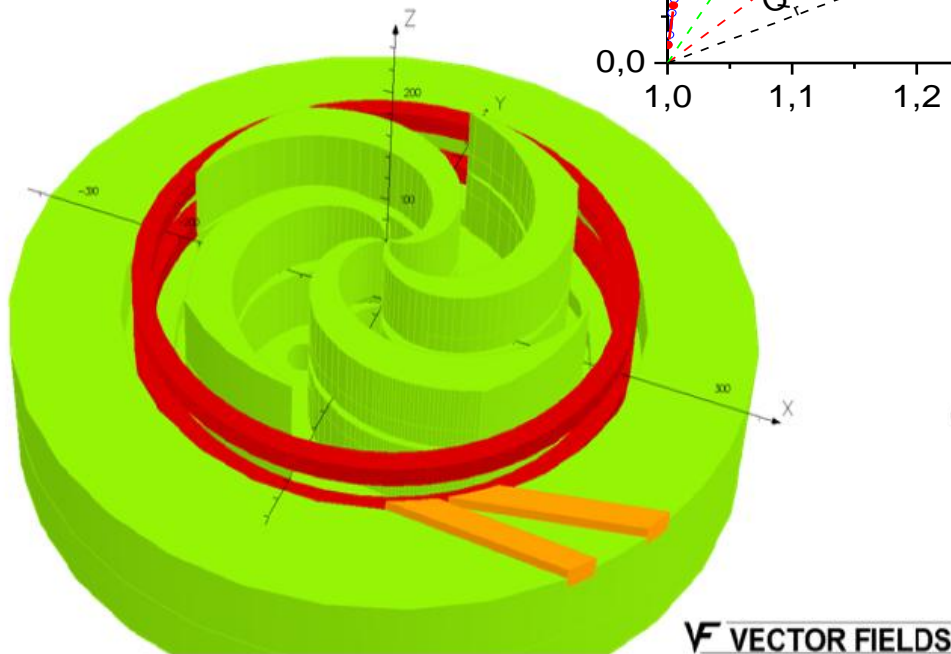
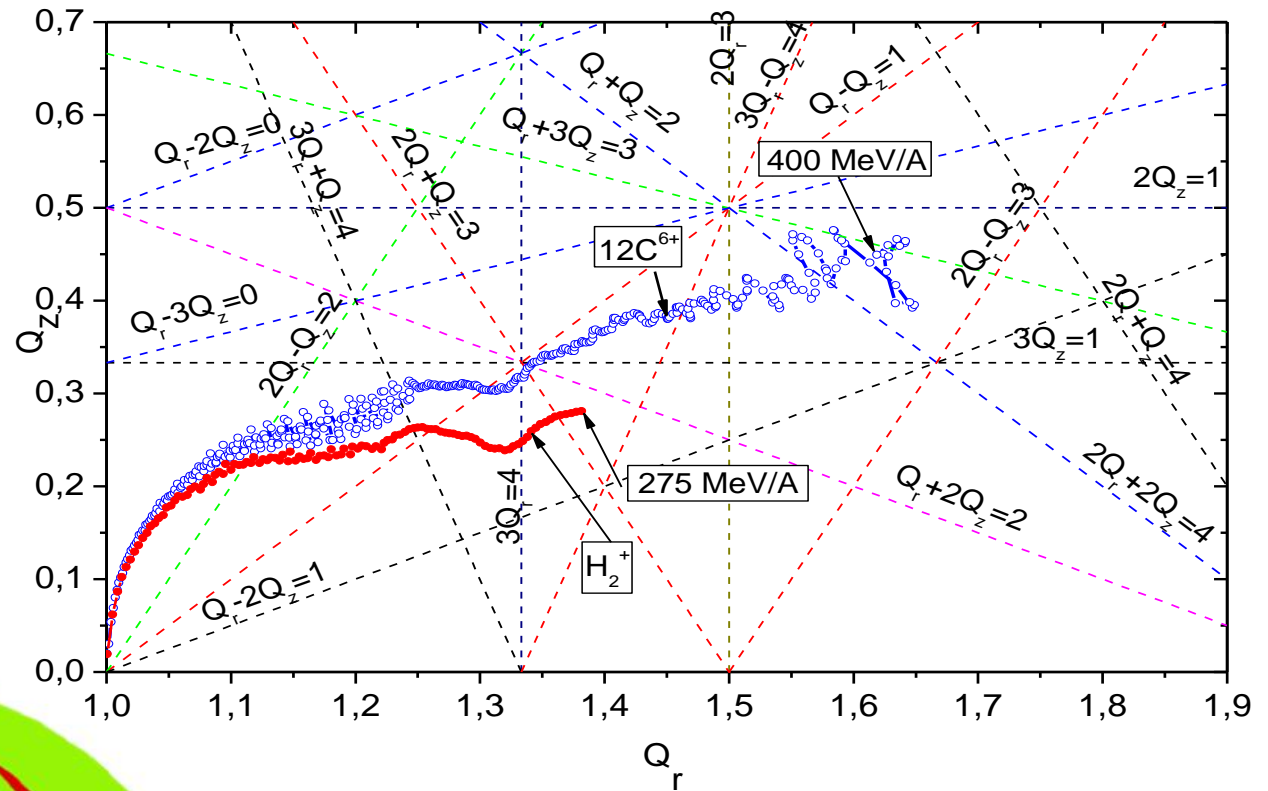
# Superconducting cyclotron C400

<b>accelerated particles</b>	<b><math>\text{H}_2^+</math>, <math>^4\text{He}^{2+}</math>, (<math>^6\text{Li}^{3+}</math>), (<math>^{10}\text{B}^{5+}</math>), <math>^{12}\text{C}^{6+}</math></b>
<b>final energy of ions, protons</b>	<b>400 MeV/amu 265 MeV</b>
<b>extraction efficiency</b>	<b>~70 % ( by deflector)</b>
<b>number of turns</b>	<b>~2000</b>
<b>total weight</b>	<b>700 tons</b>
<b>outer diameter</b>	<b>6.6 m</b>
<b>height</b>	<b>3.4 m</b>
<b>pole radius</b>	<b>1.87 m</b>
<b>hill field</b>	<b>4.5 T</b>
<b>valley field</b>	<b>2.45 T</b>
<b>RF frequency</b>	<b>75 MHz</b>

# View of the median plane in the 400MeV/u Carbon/Proton superconducting cyclotron

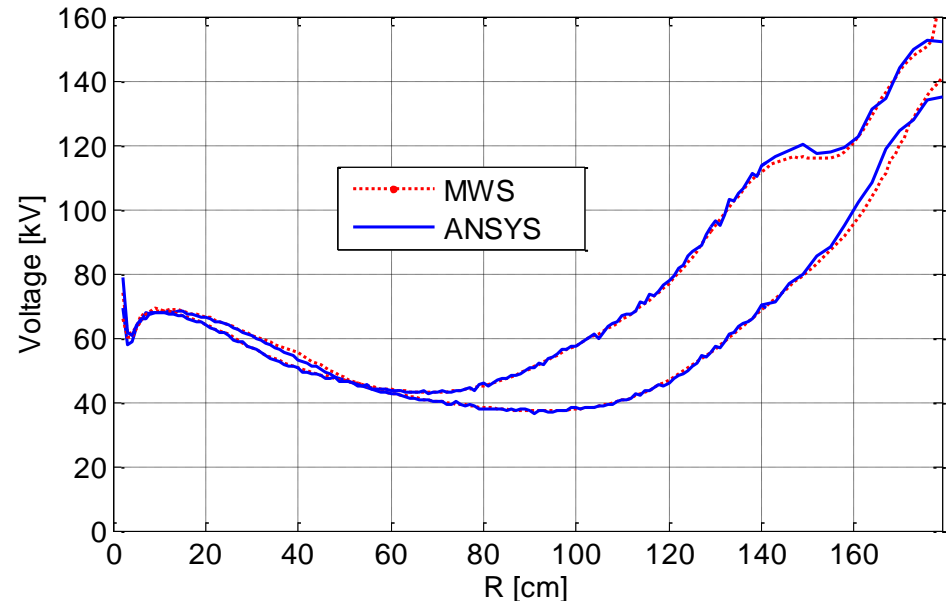
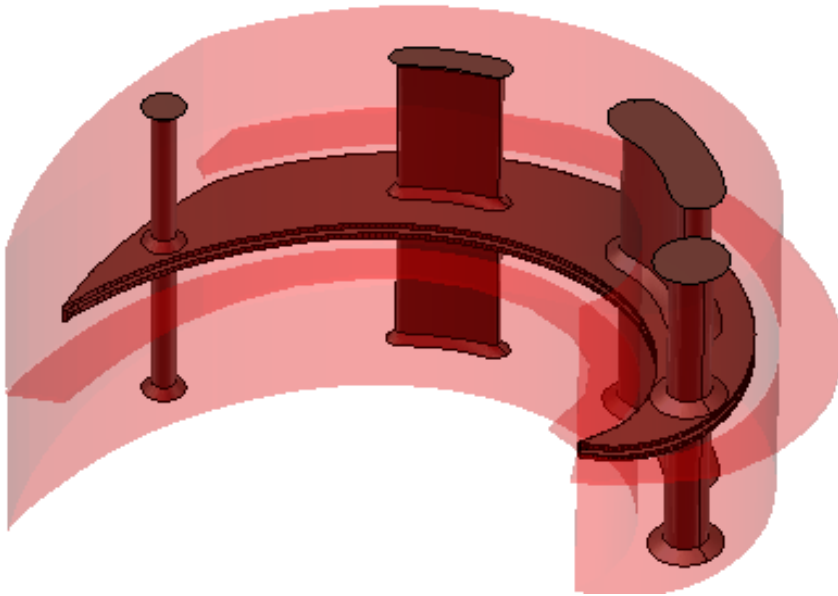


# MAGNETIC SYSTEM



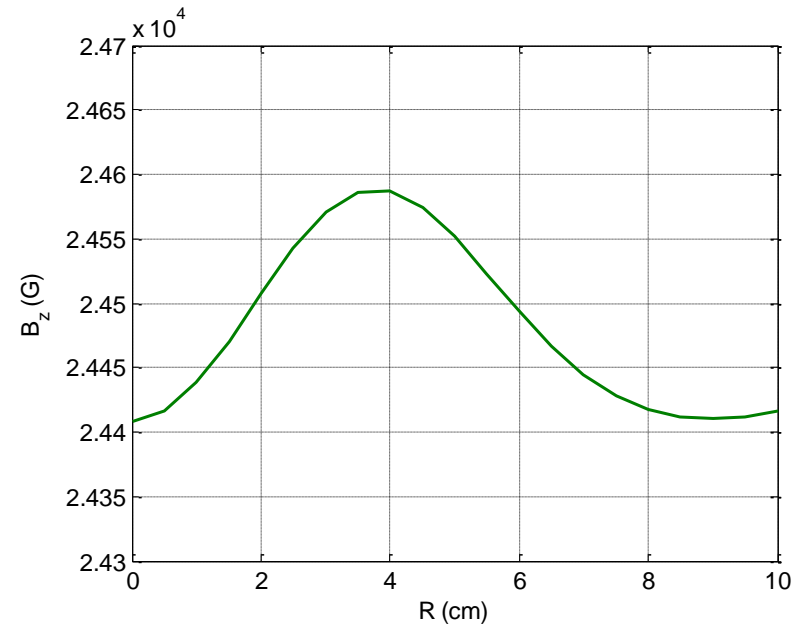
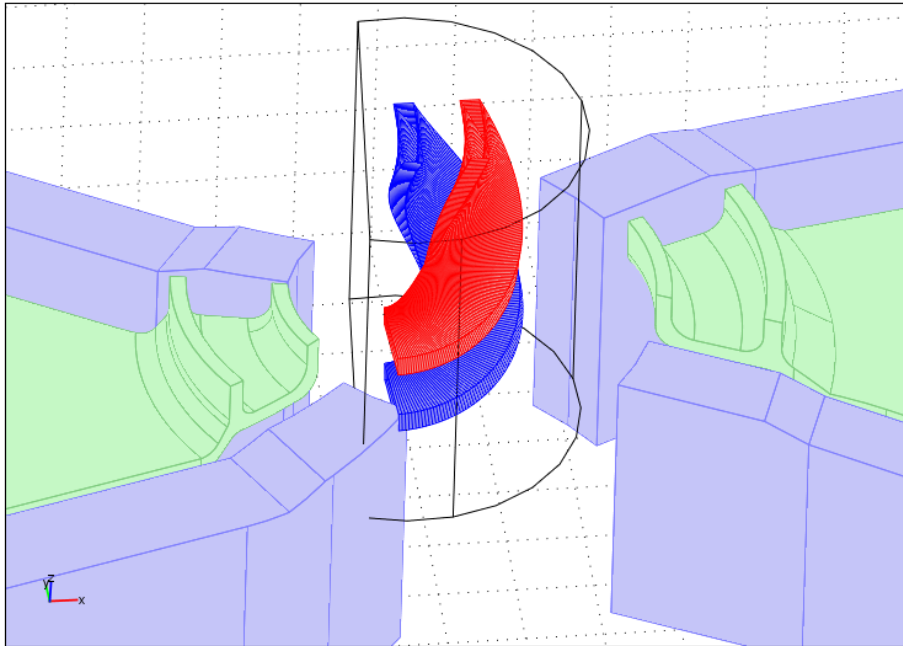
*Working diagram of the cyclotron.*

# *The cavity model*



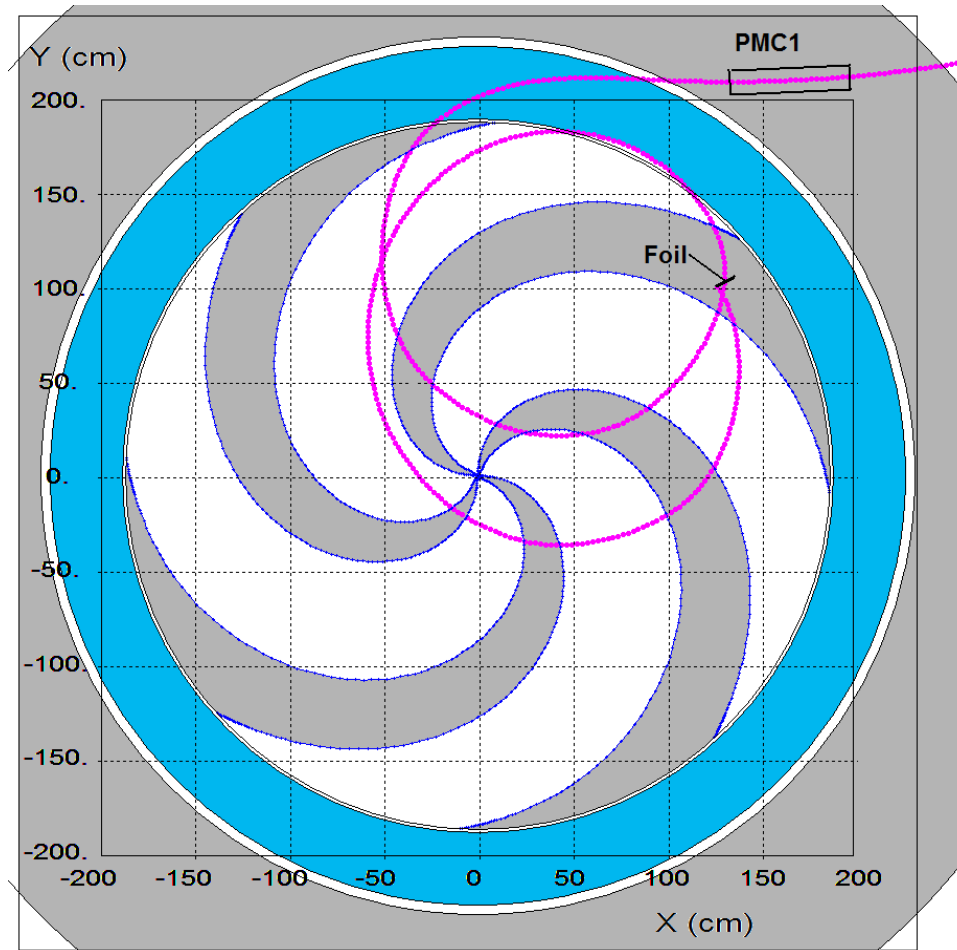
***Voltage distribution along radius.***

# Central region with the spiral inflector model

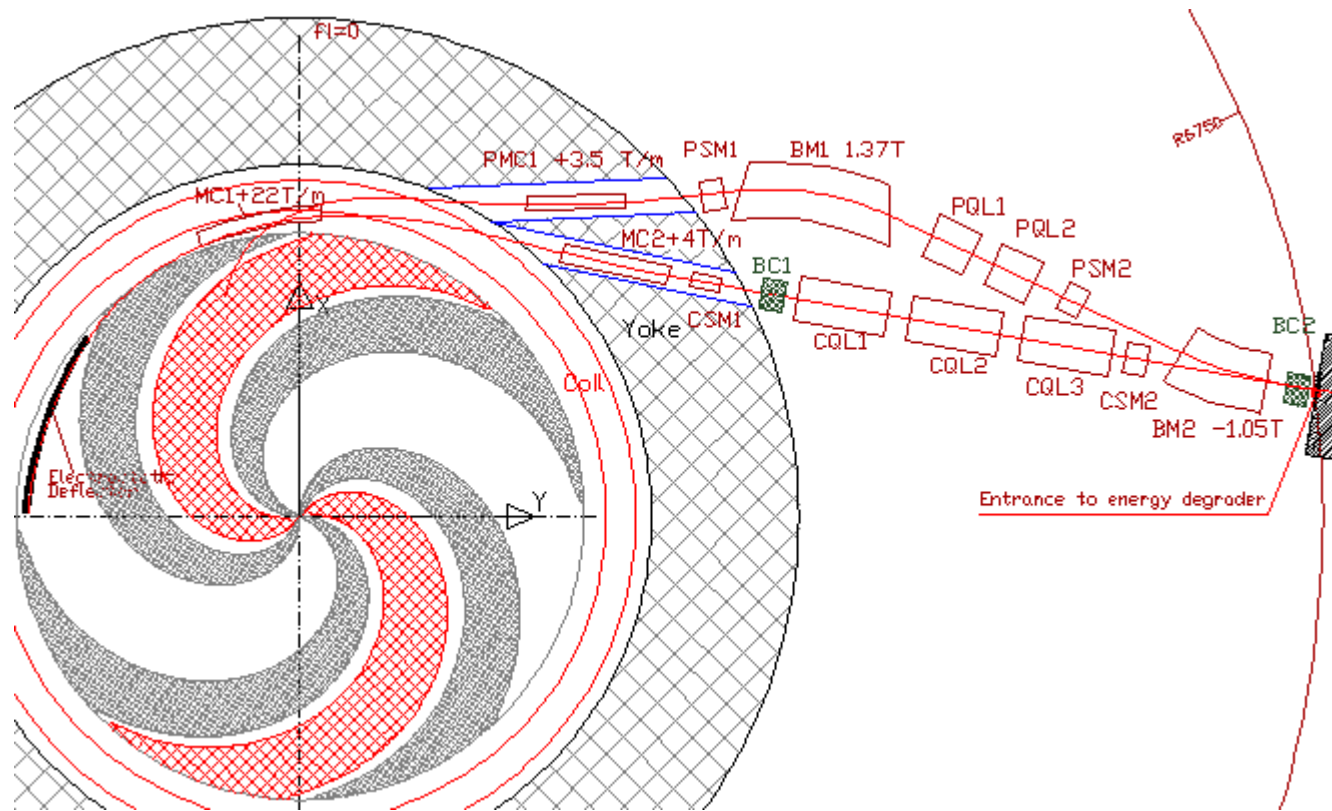


Mean magnetic field in the center region.

# *Two-turn extraction of protons with energy 265 MeV*



# Layout of the C400 cyclotron with two extraction lines.



**The design review of the C400 cyclotron was in 2009. The group of international experts emphasized high quality of the research work done by the JINR.**

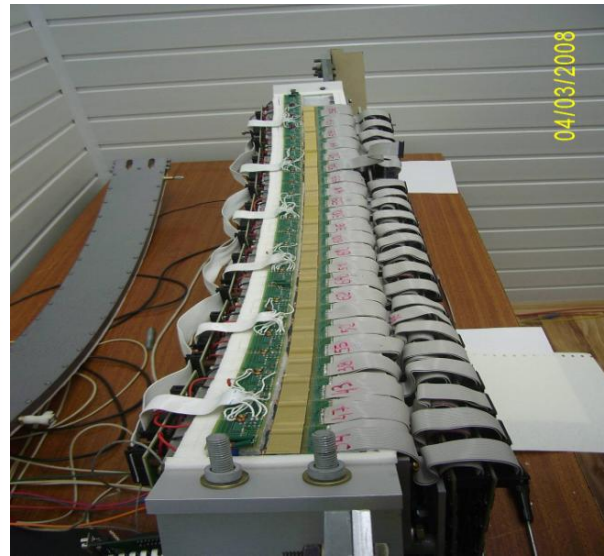
**The construction of C400 is planned to start in end of 2010 in the framework of Archade project (France, Caen)**

*Present status of X-ray  
technique*

GE Innova 2000



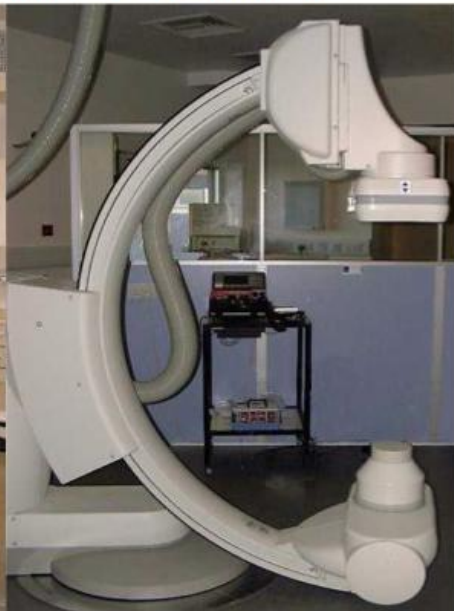
MIS Shimadzu AngioSpeed HF



Philips Allura Xper FD10 F

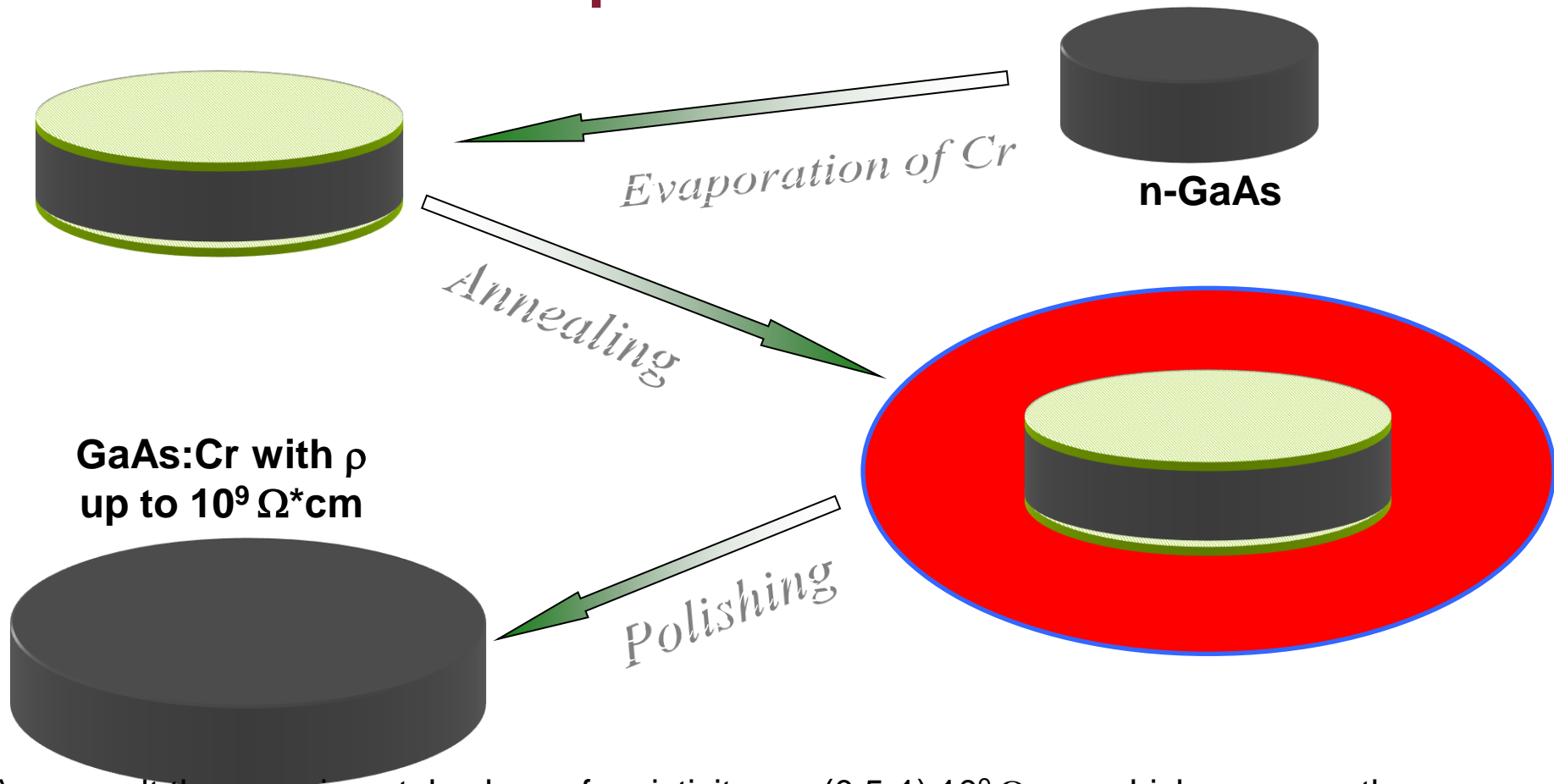


Siemens Axiom Artis dFC



*World market 13 bln. \$/y.,*

# Technological cycle of manufacturing GaAs compensated with Cr



As a result the experimental values of resistivity are  $(0.5-1) \cdot 10^9 \Omega \cdot \text{cm}$ , which are more than an order higher as compared to the resistivity of structures on the basis of traditional LEC SI-GaAs.

Радиационно-стойкие полупроводниковые гамма-детекторы на основе арсенида галлия.

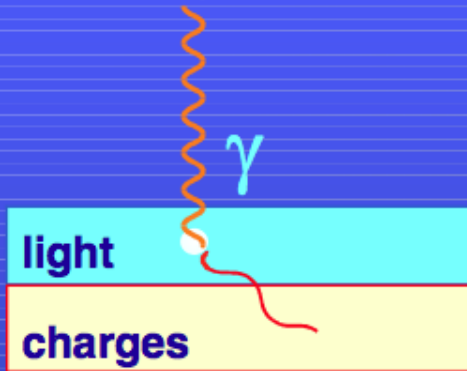
В ходе исследований с GaAs нами было показано, что для энергии гамма-квантов около 30 кэВ сенсор из арсенида галлия в 7-8 раз эффективнее аналогичного сенсора из кремния.

**Thank you for your attention**

# *X-ray detectors*

## Indirect Conversion

(scintillator - photodetector)

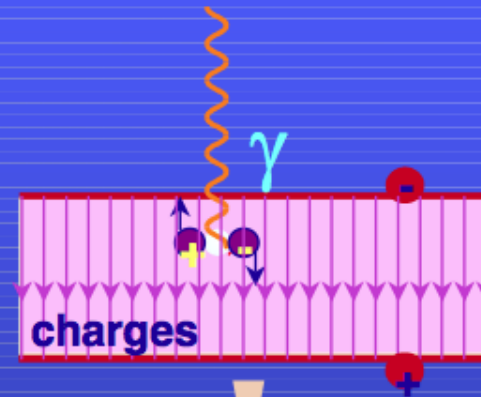


1000 charges  
at 60 keV

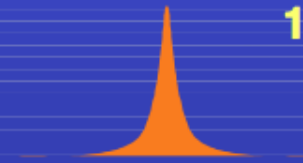


## Direct Conversion

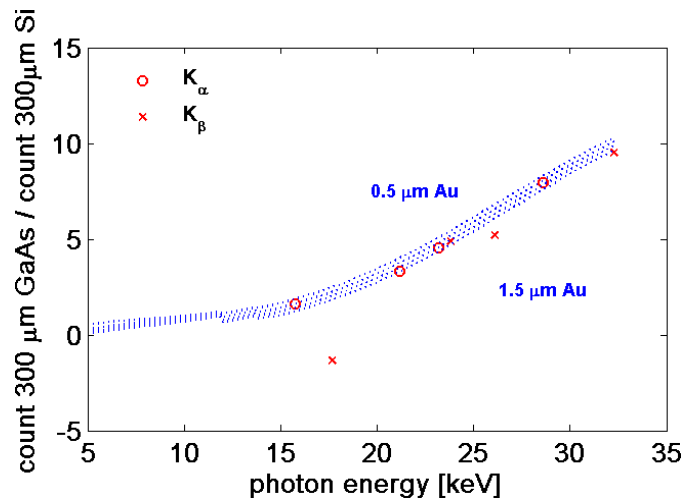
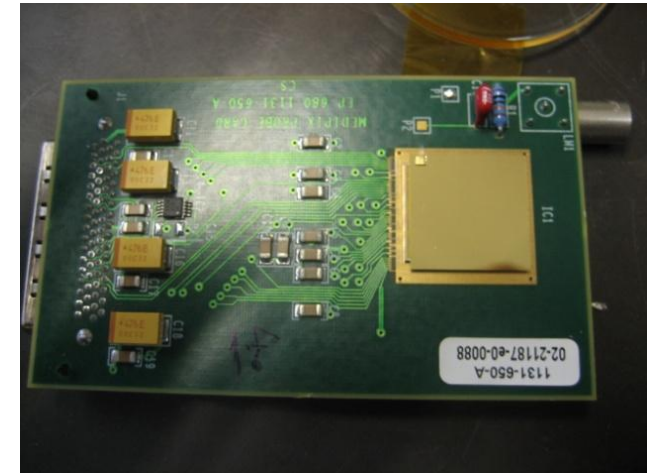
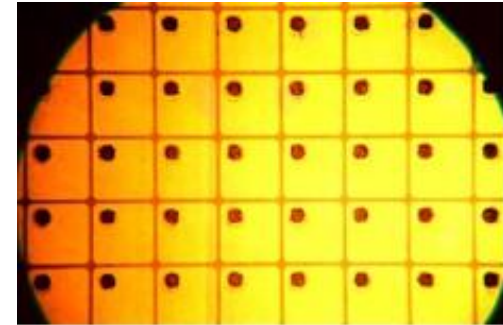
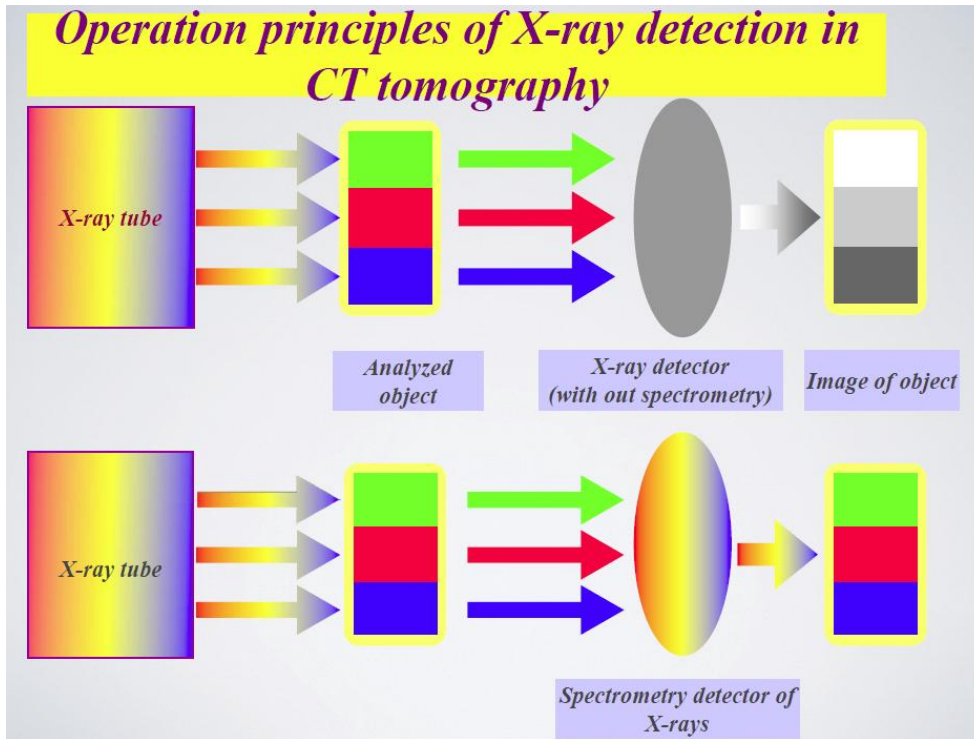
(semi-conductor)



10 000 charges  
at 60 keV



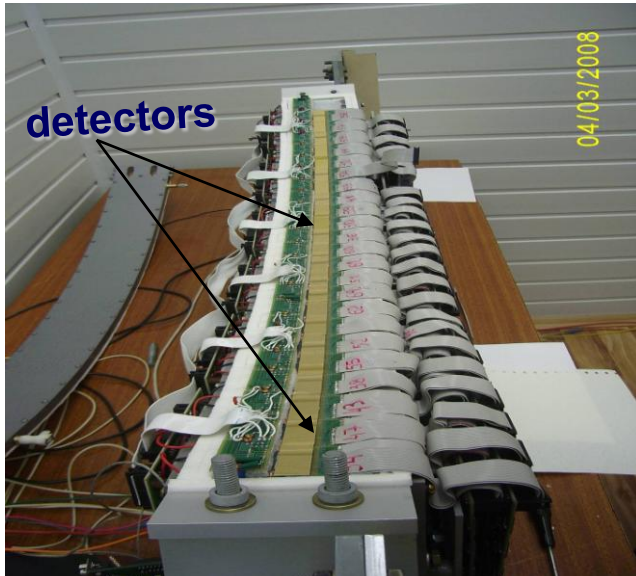
# Development and production of pixel semiconductor detectors



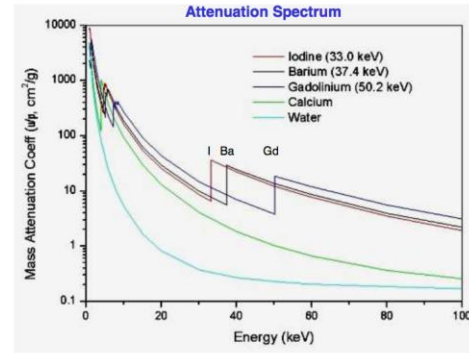
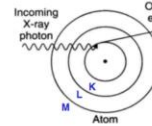
**GaAs pixel detector with pixel size of 50  $\mu\text{m}$  and 65536 channels of electronics**

# X-ray computer tomograph

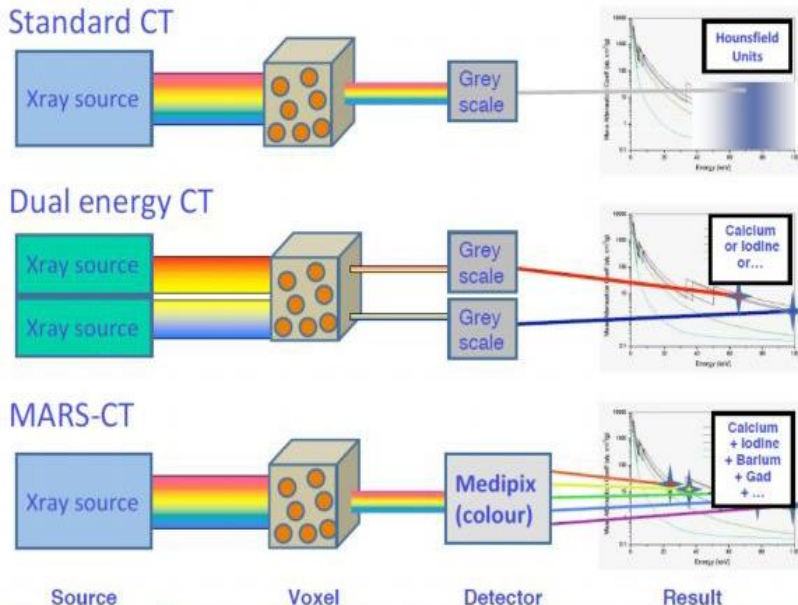
K-edge and attenuation



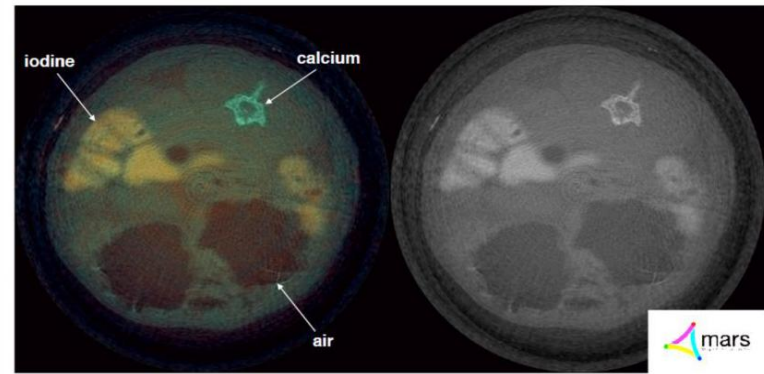
Photoelectric Effect



## Energy information in CT



## PCA/Multiple materials

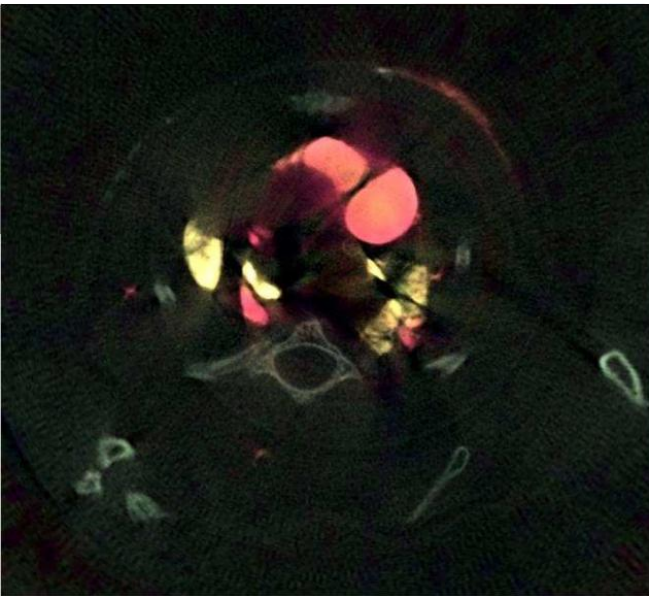
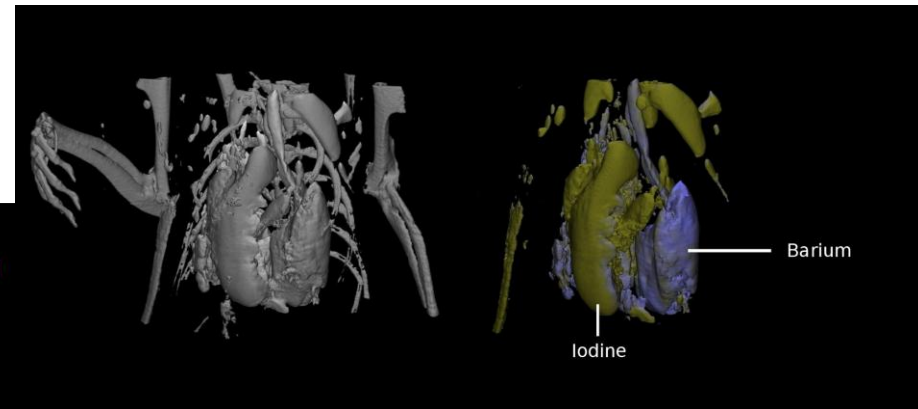


X ray images obtained at different wavelengths for iodine, calcium and air

Scheme at transition from standard gray X-ray picture to color picture of separate structures

# SPECTROMETRY X-RAY DETECTION IN COLOR RADIOGRAHY

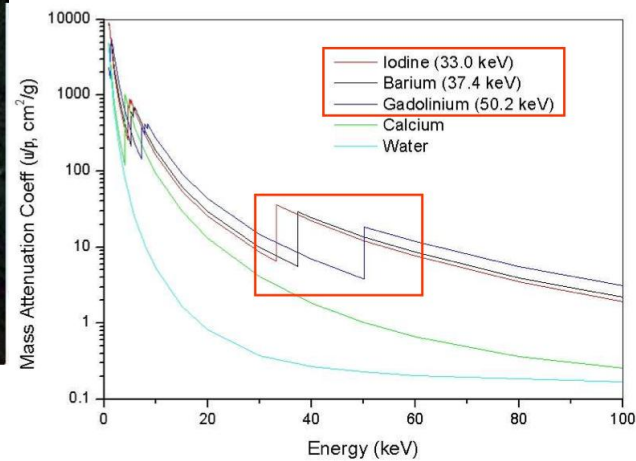
## Dual Energy Radiographs



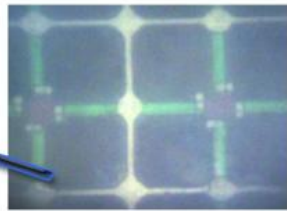
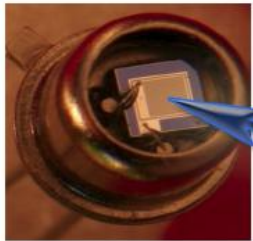
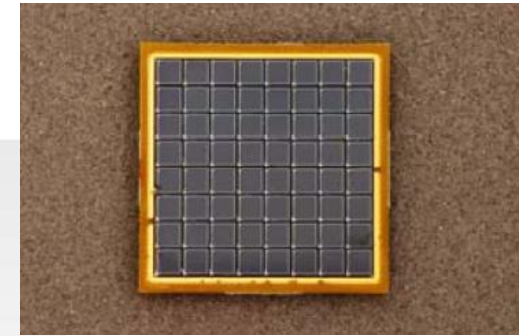
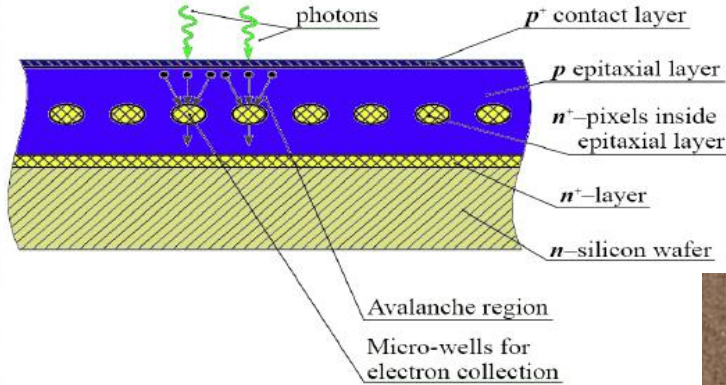
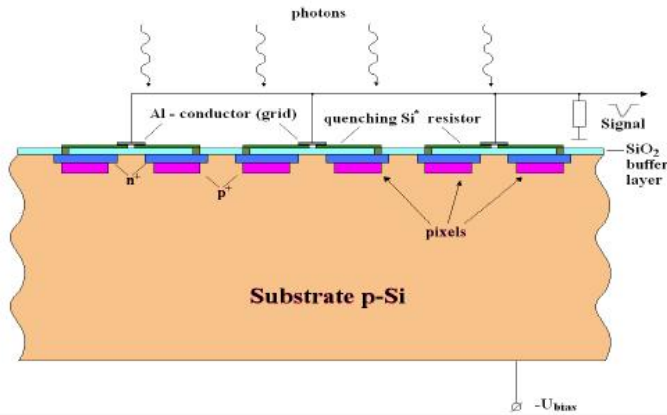
Iodine: Pulmonary circulation

Barium: Lung

Bone: normal structure



# Novel Micropixel Avalanche Photodiodes (MAPD) with super high pixel density



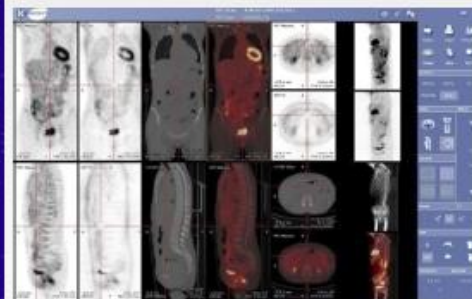
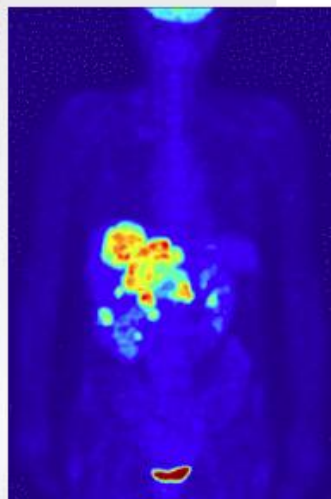
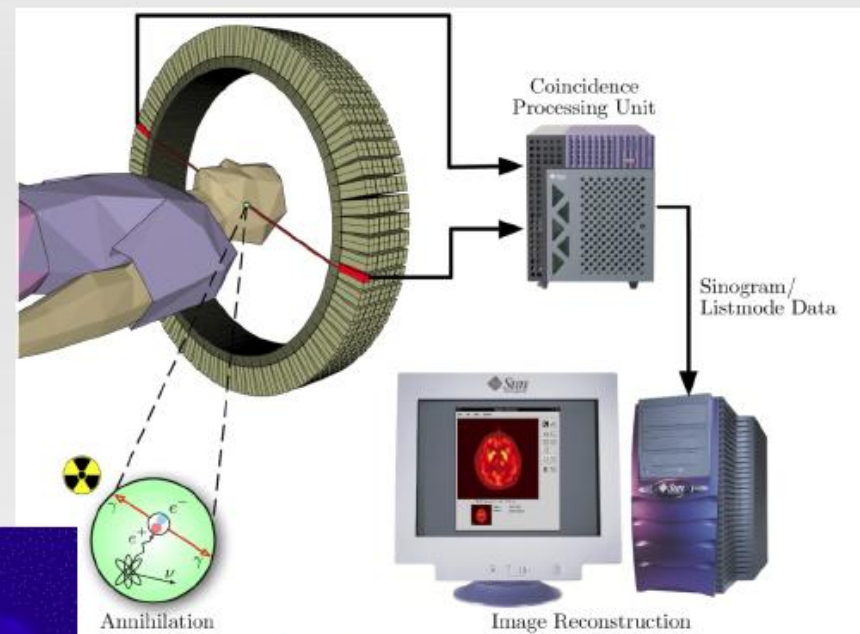
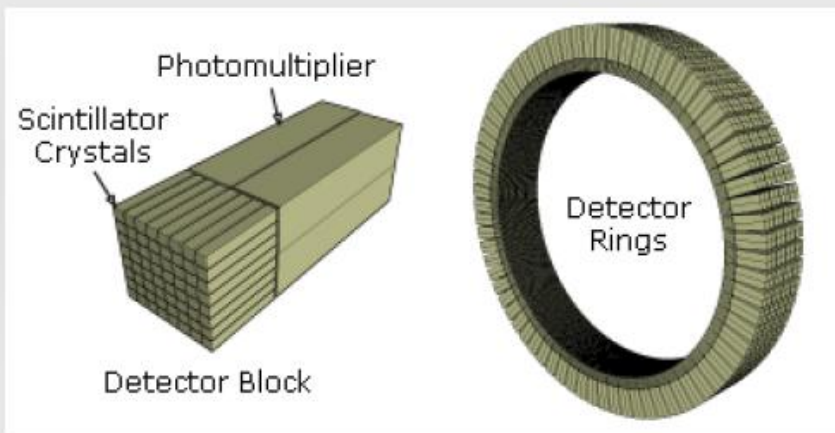
## MAIN FUTURE OF MAPD

- High Dynamic Range (pixel densities of up to 40000 mm<sup>-2</sup>)
- Photon Detection Efficiency up to 30 %
- Gain up to 10<sup>5</sup>
- Better radiation hardness
- Insensitivity to magnetic field.
- Compact and rigid
- Low voltage supply (<100 V)

### Drawbacks:

- Temperature dependence (a few %%/°C)
- High dark rate (> 0.5 MHz/mm<sup>2</sup>)
- Large Recovery time.

# MAPD APPLICATION FOR POSITRON EMISSION TOMOGRAPHY



# MAPD APPLICATION FOR COMBINED PET/MRT

