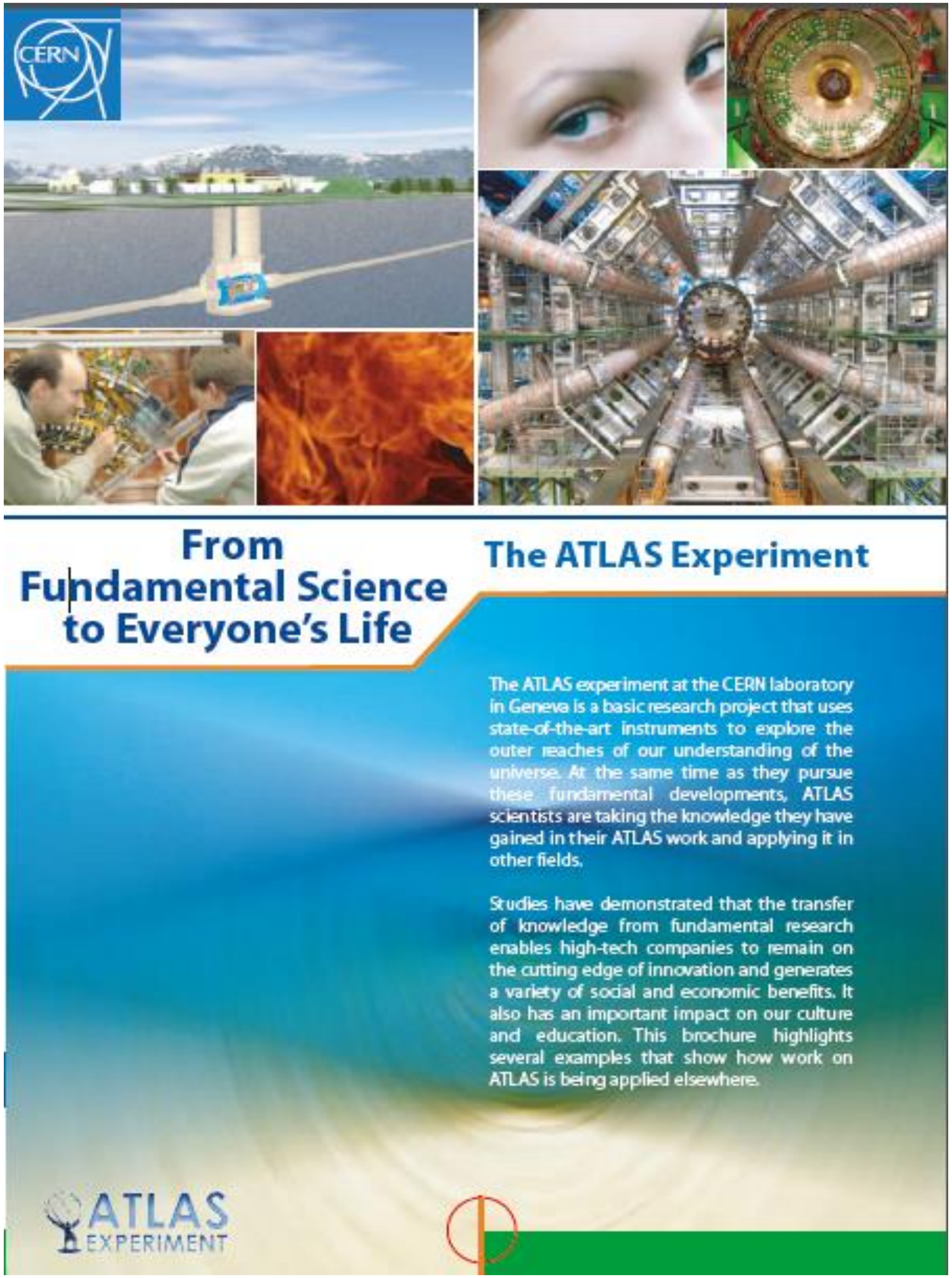
ФИЗИКАТА В МЕДИЦИНАТА

(ДИАГНОСТИКА И ТЕРАПИЯ)

Bulgarian Engineering Teachers Programme
4 October – 10 October 2015
Genève, Switzerland

От фундаменталната наука към живота на всеки един от нас.



From Fundamental Science to Everyone's Life

The ATLAS Experiment

The ATLAS experiment at the CERN laboratory in Geneva is a basic research project that uses state-of-the-art instruments to explore the outer reaches of our understanding of the universe. At the same time as they pursue these fundamental developments, ATLAS scientists are taking the knowledge they have gained in their ATLAS work and applying it in other fields.

Studies have demonstrated that the transfer of knowledge from fundamental research enables high-tech companies to remain on the cutting edge of innovation and generates a variety of social and economic benefits. It also has an important impact on our culture and education. This brochure highlights several examples that show how work on ATLAS is being applied elsewhere.

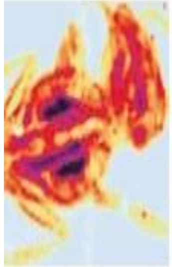
Medical

New, miniature electronic silicon chips have been designed for the ATLAS experiment to track elementary particles close to the collision point of the incoming proton beams. These small pixel semiconductor detectors are characterised by high detection efficiency and low noise, making them ideally suited for X-ray imaging in radiography, protein crystallography and material science. They can detect individual X-ray photons with high spatial precision over a broad energy range with extremely short readout times.

Pixel Matrix with 18 x 160 pixel cells. r comparison a part fa match is shown.

Multi Picture Element Counters

he innermost layers of the ATLAS xperiment are composed of silicon pixel letectors. Close to 100 million individually mplified detector cells are able to letermine and trace the exact position of he charged particles produced in a roton-proton collision. The same type of ixel detector can be used for biomedical naging when a high spatial resolution is eeded, for instance in mammography. he detector simply counts the absorbed -ray quanta individually, via tiny counters nplemented in every pixel. *The method ives a truly digital image of the absorbed -ray dose and has no under- or ver-exposure limitations.* The radiograph s visible in real time eliminating the use of film. Hence, a relatively small nodification of the ATLAS pixel detector as led to digital radiography.

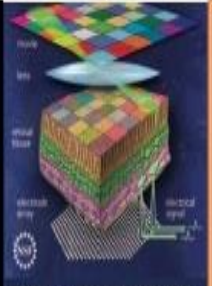


igital radiograph of a hornet.

3D image of gecko skeleton from PIXSCAN.

Computer Tomography

PIXSCAN is a new method for Computer Tomography (CT). It uses the XPAD, a photon counting detector based on the ATLAS pixel chip. *PIXSCAN improves the contrast for soft tissues and produces up to 1000 images per second.* A first prototype has been developed for the examination of small animals. Given the small size of the animal, an extremely high spatial resolution is required. First tomographic images prove the quality of the new techniques. The easy electronic control and the small size is ideal for the combination with Positron Emission Tomography (PET) for simultaneous PET/CT imaging. While PET can only show tumour tissue, the CT image shows the whole organ. Furthermore the X-ray energy selection of the XPAD allows for spectral CT, the only way to have 3D images of different contrast agents in one shot.



An array of electrodes detects the output signals generated by retinal tissue as it responds to a movie focused on the retina's input layer of photoreceptors.

Section of 512-electrode array.

Retina Project

Together with neurobiologists, ATLAS physicists have studied the information that is transmitted from the eye to the brain. The retina is a sophisticated biological pixel detector that converts a visual image into electrical signals, called "spikes". These spikes act as a neural code and communicate the features of an image to the visual centre of the brain. To crack this code, live retinal tissue is examined and a recording system for large-scale neural activity has been developed based on the silicon microstrip detector technology used in the ATLAS experiment. *These experiments help neurobiologists to understand how living neural systems process and encode information and could one day give artificial sight for the blind.*

Technical

All parts of the ATLAS detector are highly sophisticated instruments in which the technology and required performance often exceed the available industrial know-how. Technologies developed for the purpose of research activities produce improvements in many fields and make our daily environment more functional.

Schematic diagram of the ATLAS detector.

8 modules mounted to obtain a pixel detector of 6.8 x 6.5 cm² size.

X-PAD Crystallography

XPAD is an X-ray detector that uses an electronic circuit based on the ATLAS pixel chip. The detector has been developed for X-ray imaging and is adapted to the new generation of high-intensity synchrotron X-ray sources. This radiation is used for the study of the structure of proteins and solid state material. *Results from prototypes using XPAD detectors show that the image quality improves substantially (no noise, high dynamic range) and the timing facilities (bunch selection) allow for new experiments.* A start-up company named imXPAD has been created to build and manufacture these detectors.

Ultrasound Gas Analysis

In ATLAS an ultrasonic analysis technique has been developed to measure the fluorocarbon vapours in the cooling system of the inner detector. This technique has also been used to analyse the gas mixtures in semiconductor production, where often the amounts of heavy elements have to be controlled. The composition of the mixture is determined with a precision better than 1 part in 100 000. *An application in clinical anaesthesia has been tested successfully, indicating that typical clinical anaesthesia mixtures can be resolved with high precision.* The analysis of hydrocarbons in oil refinery operations has also employed this technique.

The ATLAS detector is about the size of a seven-story building.

Emergency Personnel Location

A system for finding and rescuing people in case of an accident in the ATLAS area has been conceived by ATLAS members. A large number (around 800 at the present time) of infrared sensors installed at the experiment site allows an operator in the Control Room to follow the movements of all persons in the ATLAS cavern. The system also generates alarms if a detected person does not move during a defined period of time (unconscious person). The system can be installed at very low costs in virtually all types of environments and is suitable in large areas such as mines where people are often difficult to find. In case of emergency, especially if smoke or fog is present, it helps a rescue team to locate persons in danger.

Culture

Particle physics and cosmology teach us how the interior of matter works and how the universe started and developed into what we can now see all around us. This desire to extend our knowledge and go beyond the present limits is part of our heritage and cultural life. ATLAS makes these modern physics ideas publicly available at various levels via the ATLAS Web site and via informational material including live and animated films.

Mechanical sound recordings can be reconstructed using optical techniques.

Sound Reproduction

Precision optical image processing methods were used by ATLAS members to measure and align each of the 16 000 individual silicon detectors of the ATLAS SemiConductor Tracker. Inspired by this approach the same strategy was applied to measuring precisely the shape of the groove on mechanical sound carriers such as phonograph discs and cylinder records. To analyse the shape of the grooves and extract the audio information, a data reduction and fitting strategy similar to finding and reconstructing particle tracks in the ATLAS detector was used. The sound could be reconstructed with high fidelity and significantly reduced noise level. *As there is no physical contact with the material, the method can be used to restore and preserve delicate or damaged samples and historical sound recordings.* The technology is being applied to historical recordings held by major archives and collections.

DataGrid aims to enable access to geographically distributed computing power and storage facilities belonging to different institutions.

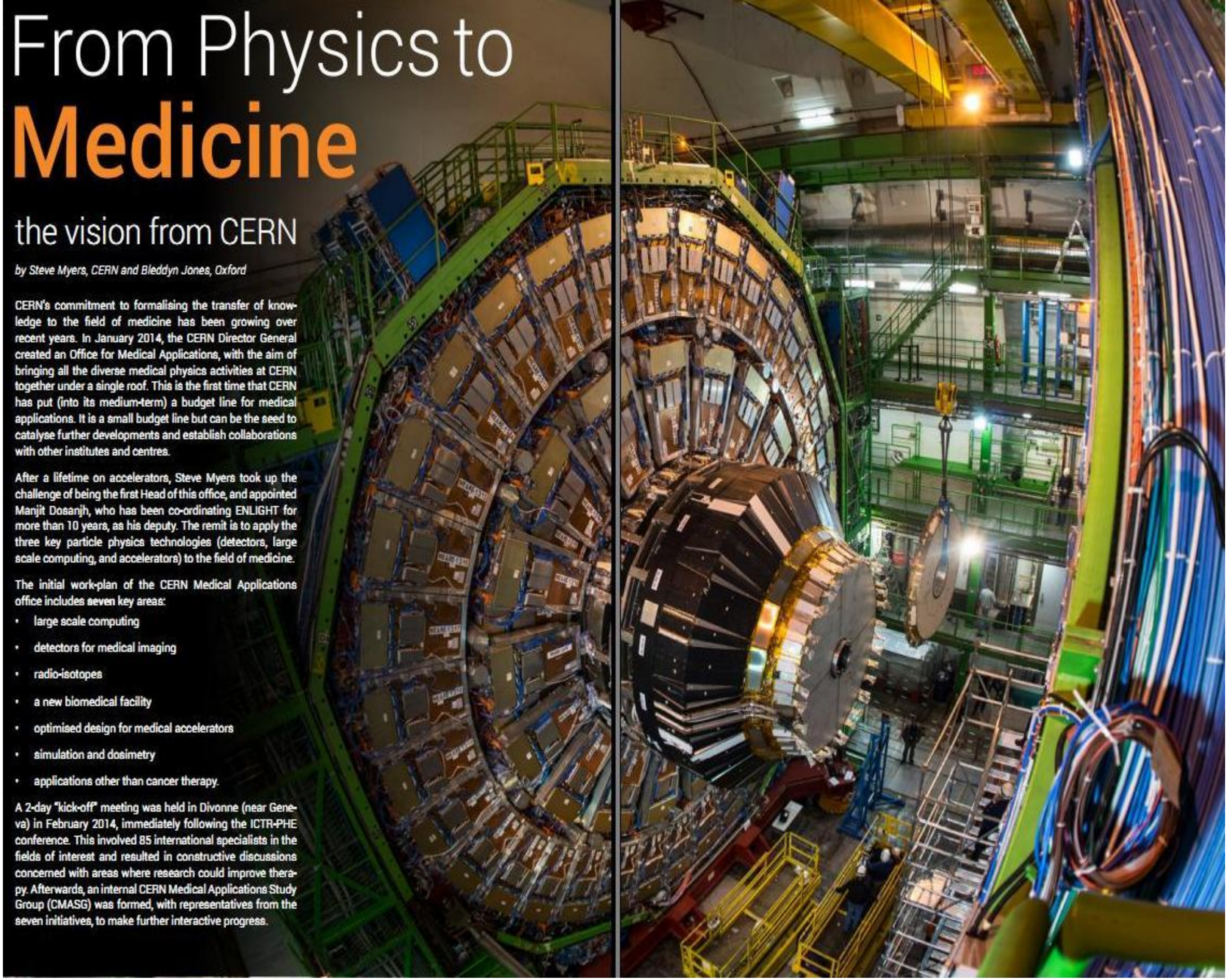
Grid Computing

The ATLAS collaboration is taking part in the operation of a global computing Grid for data storage and analysis. The Large Hadron Collider (LHC) experiments produce several million gigabytes of data annually. Via the computing Grid, data from ATLAS and the other LHC experiments are distributed around the globe and made accessible to all the 10 000 scientists of the LHC experiments located all over the world. *The Worldwide LHC Computing Grid (WLCG) project operates the computing Grid for the LHC experiments, including more than 200 different sites.* It collaborates and interoperates with other major Grid projects. Presently over 20 applications are already running on this infrastructure, including Earth observation, climate prediction, petroleum exploration, proto-biology investigations and drug discovery.

Assembling the ATLAS SemiConductor Tracker (SCT) which consists of approximately 16 000 silicon microstrip detectors with 6.3 million readout channels, built into 4088 modules.

Education

In participating institutes worldwide, graduate and undergraduate students, as well as high school teachers and students, are involved in analysing the data and have been involved in the development, construction and testing of parts of the new detectors. *This work provides experience in modern laboratory work, state-of-the-art research, cooperation in international teams, and complex problem solving. Such an education prepares students for a wide spectrum of professions in science and industry as well as in education and administration.*



From Physics to Medicine

the vision from CERN

by Steve Myers, CERN and Bleddyn Jones, Oxford

CERN's commitment to formalising the transfer of knowledge to the field of medicine has been growing over recent years. In January 2014, the CERN Director General created an Office for Medical Applications, with the aim of bringing all the diverse medical physics activities at CERN together under a single roof. This is the first time that CERN has put (into its medium-term) a budget line for medical applications. It is a small budget line but can be the seed to catalyse further developments and establish collaborations with other institutes and centres.

After a lifetime on accelerators, Steve Myers took up the challenge of being the first Head of this office, and appointed Manjit Dosanjh, who has been co-ordinating ENLIGHT for more than 10 years, as his deputy. The remit is to apply the three key particle physics technologies (detectors, large scale computing, and accelerators) to the field of medicine.

The initial work-plan of the CERN Medical Applications office includes seven key areas:

- large scale computing
- detectors for medical imaging
- radio-isotopes
- a new biomedical facility
- optimised design for medical accelerators
- simulation and dosimetry
- applications other than cancer therapy.

A 2-day "kick-off" meeting was held in Divonne (near Geneva) in February 2014, immediately following the ICTR-PHE conference. This involved 85 international specialists in the fields of interest and resulted in constructive discussions concerned with areas where research could improve therapy. Afterwards, an internal CERN Medical Applications Study Group (CMASG) was formed, with representatives from the seven initiatives, to make further interactive progress.

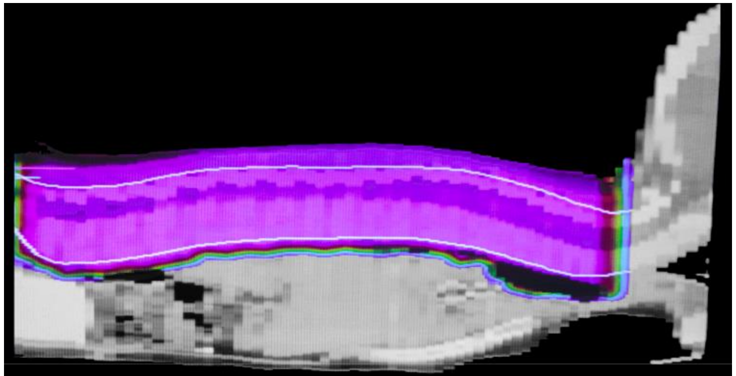
Acknowledgments to Highlights, February 2015

СЪДЪРЖАНИЕ

I. Нуклеарна Диагноситка

PET/CT - Positron Emition Tomography/ Computer Tomography (Хибриден апарат) - физичен принцип на действие.

II. Proton Therapy - *Протонна терапия*



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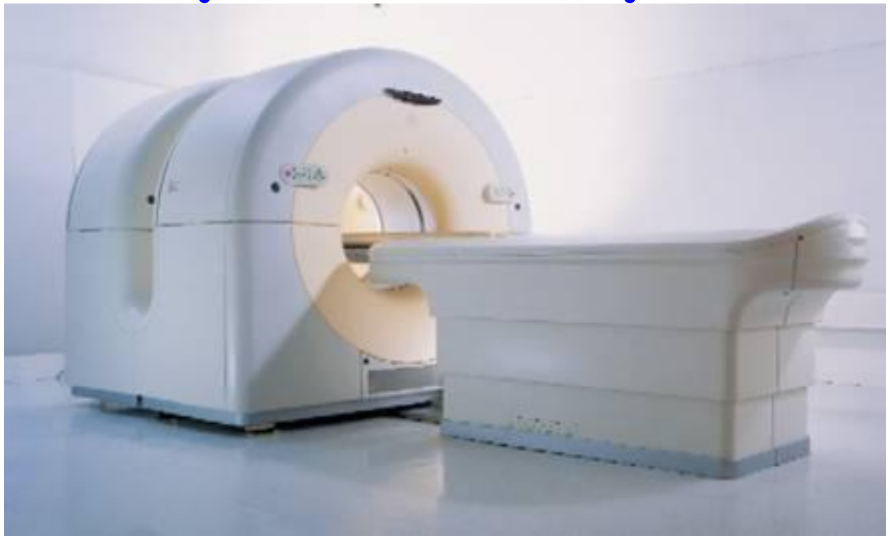
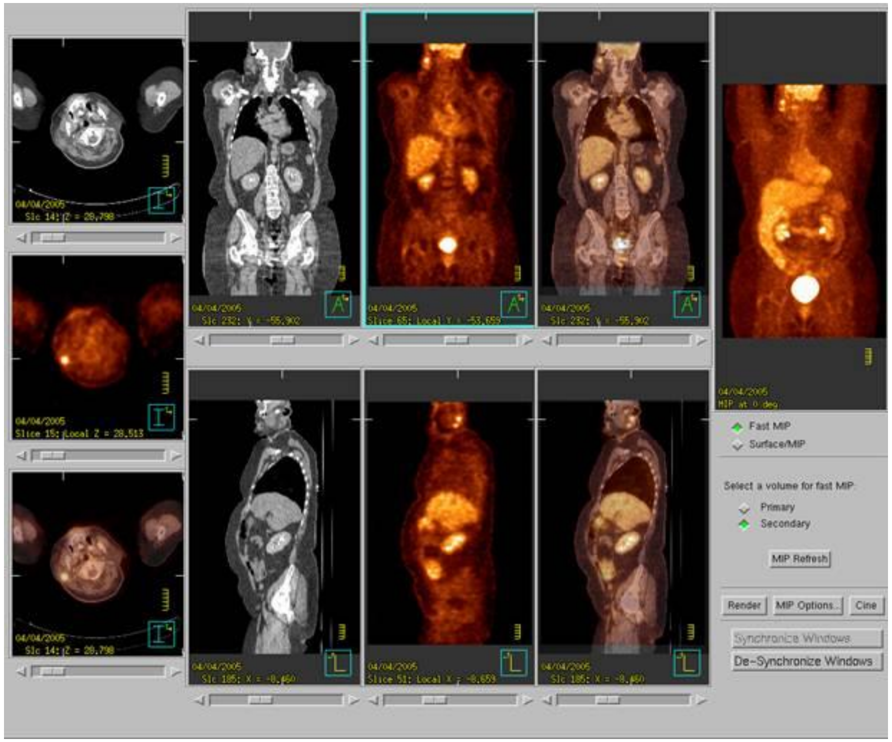




Bene diagnoscitur, bene curatur.

Правилна диагноза – успешно лечение.

Диагностичните методи са високо ефективни, когато могат да повлияят върху терапевтичното поведение при пациента.

Нуклеарната медицина – най - бързо развиващата се образна специалност

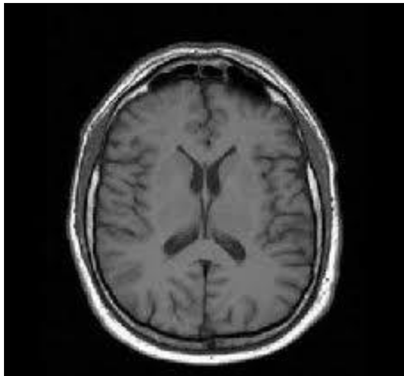
(Позитронно – емисионната томография (ПЕТ) - високо технологична дейност)

- **Нов подход в познанието за биологията и функционалната активност на туморите - подобряване на комплексната диагностика и лечение на онкологичните заболявания.**
- Нуклеарно - медицинските методи имат по - ниска разделителна способност, но висока специфичност и изобразяват **биологичното поведение** - **функцията на изследвания орган и неговия метаболизъм, преди появата на структурни промени.**
- **Анатомо - структурните промени** на изследваните органи са приоритет на останалите образни методи: конвенционална рентгенология, компютърна рентгенова томография (КТ - СТ), ядрено магнитен резонанс (ЯМР – MRI) - висока разделителна способност и ниска специфичност.

Ro графия

CT

ЯМР

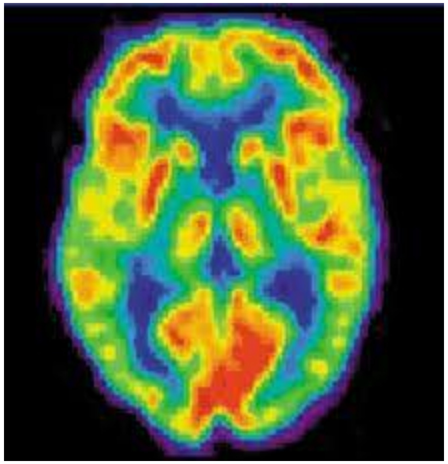


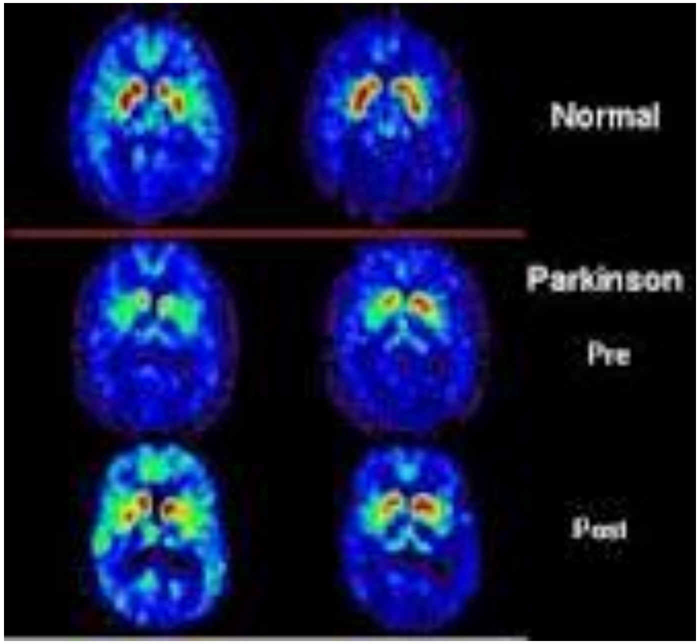
- **Позитронно емисионната томография** (PET) е утвърден метод в нуклеарната медицина с широко приложение в съвременната онкология, позволяващ изследването на **функцията и метаболизма на органите.**

- Това позволява **ранна оценка и диагностика на състоянието на организма, много преди появата на анатомични изменения в даден орган**. Като всяко нуклеарно-медицинско изследване методът е свързан с ***венозно инжектиране*** на **ниски активности радиоактивен материал – радиофармацевтик (185 – 740) MBq - (140μCi/kg).**

- При комбинация на **PET** с компютърна томография ***CT*** (скенер) се получава един изцяло ***нов и съвремен метод за диагностика, наречен позитронно емисионна компютърна томография (PET/CT).***

Конвенционален PET Скенер





Позитронно емисионната томография (ПЕТ)

PET – Positron Emition Tomography

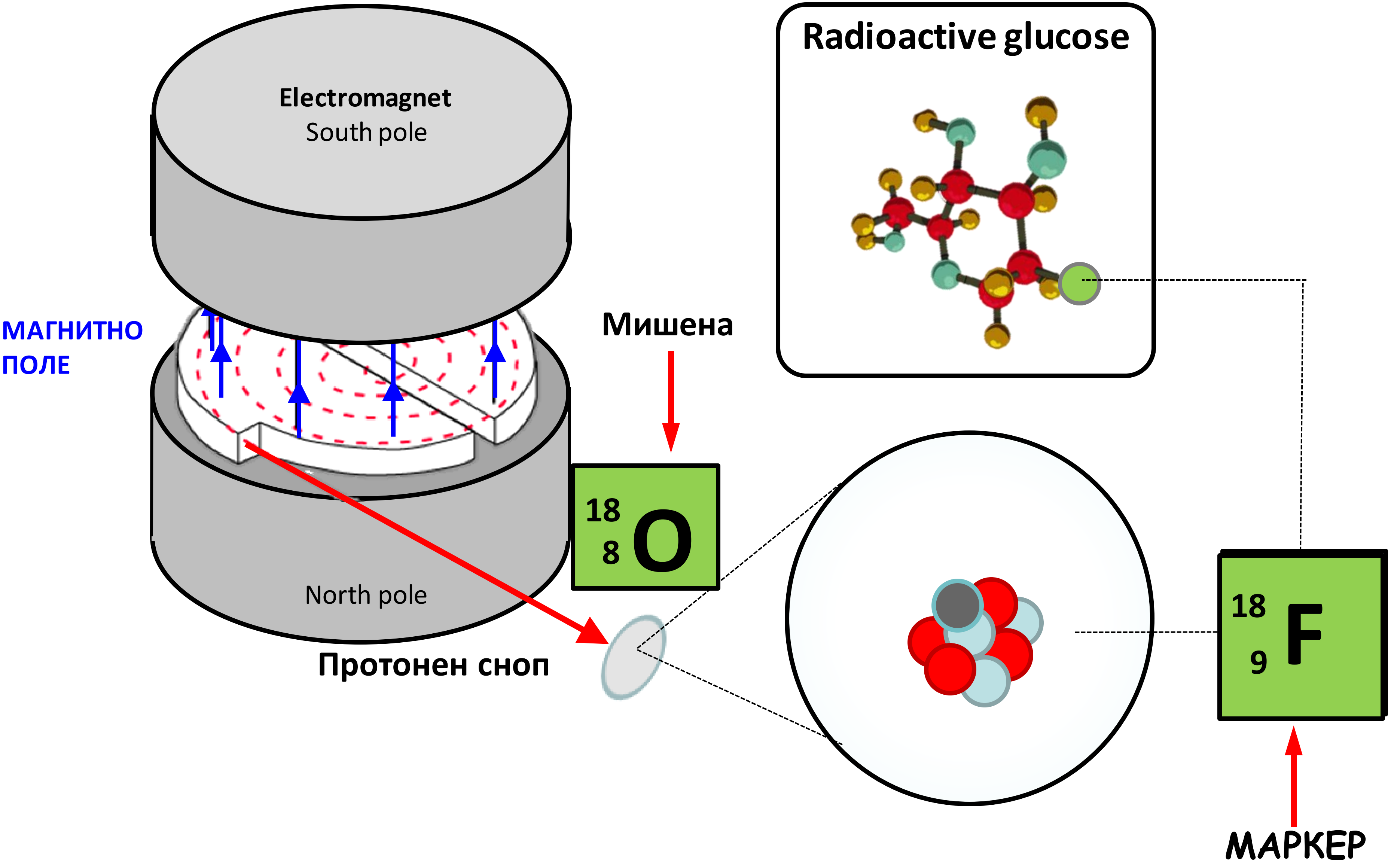
Принцип на действие:

Използва се позитронното лъчение от β^+ превръщането на ^{11}C, ^{13}N, ^{15}O, ^{18}F.

Тези радионуклиди се получават като продукти на ядрени реакции протичащи в ядрени съоръжения - циклотрони.

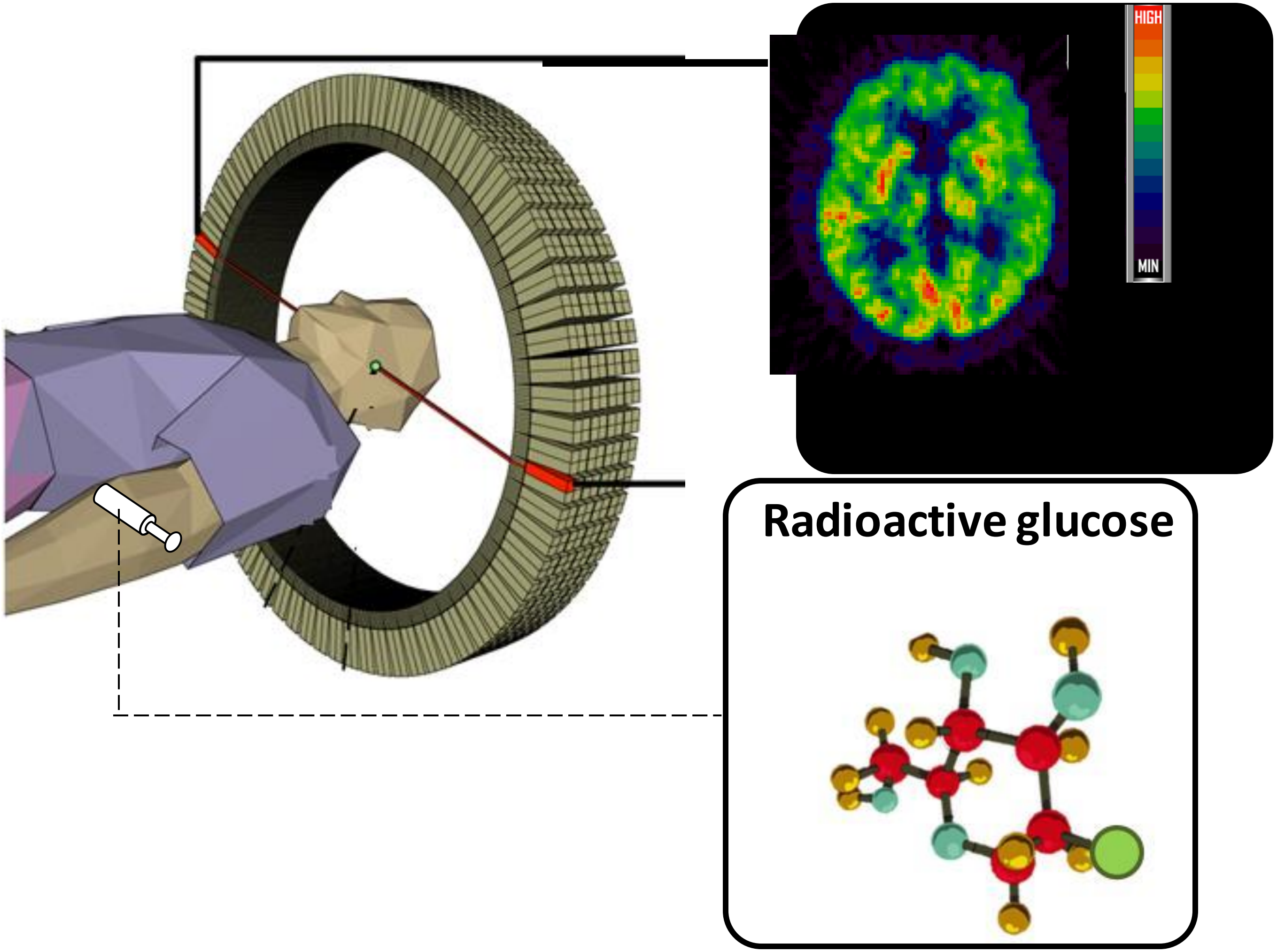
Анихилационното γ лъчение, получено при взаимодействието на позитроните от радиофармацевтика с електрони от изследваните тъкани се регистрира със сцинтилационни детектори, намиращи се около тялото на пациента.

1. Получаване на радиоактивен изотоп (маркер) = радиофармацевтик



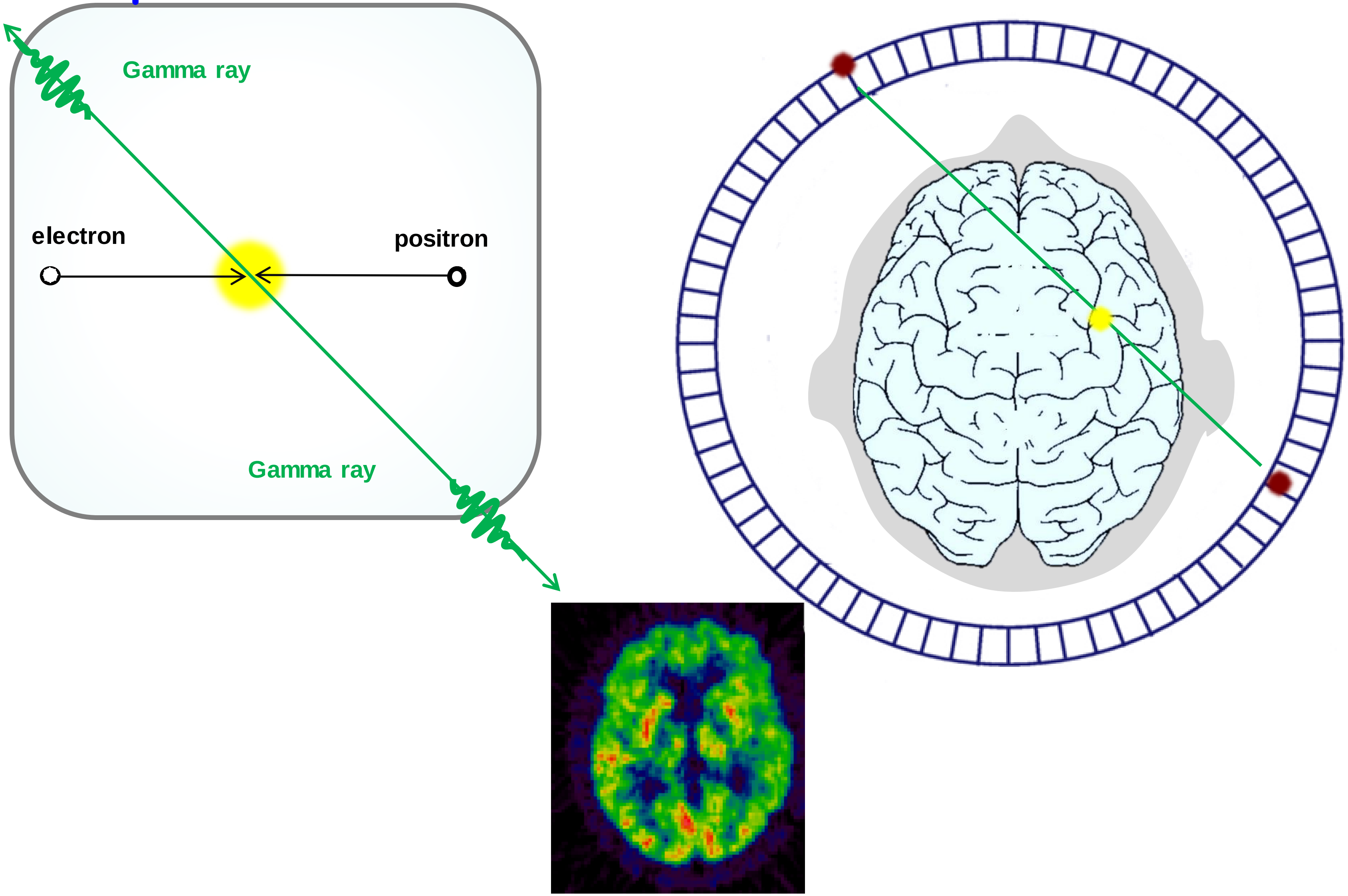
2. Инжектиране на пациента

Радиоактивният изотоп се натрупва в тази област на организма, към която маркера има химичен или метаболитен афинитет.



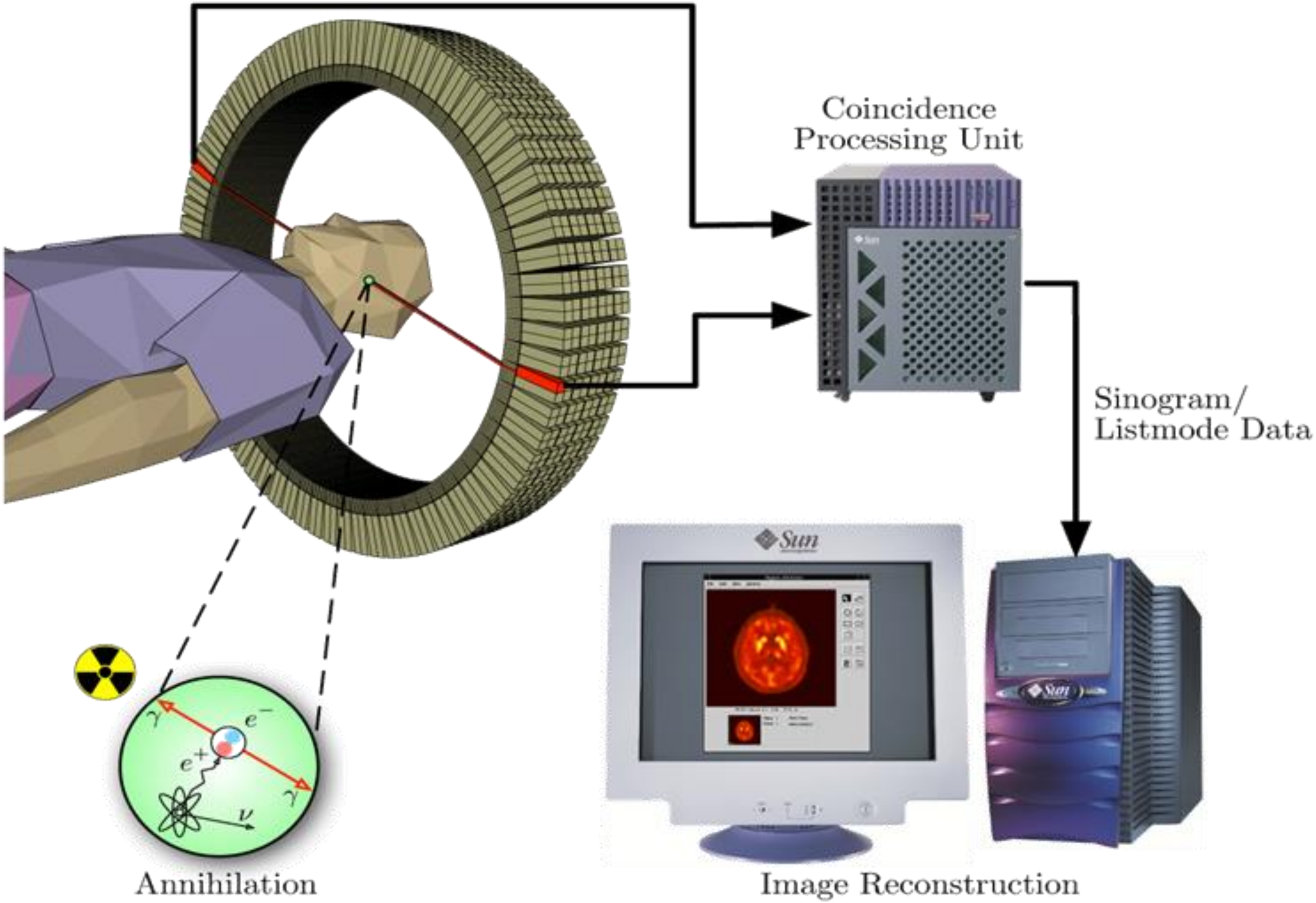
3. Осъществяване на физичното взаимодействие електрон - позитрон

Два фотона анихилационно гама лъчение



4. Детектиране на анихилационно лъчение

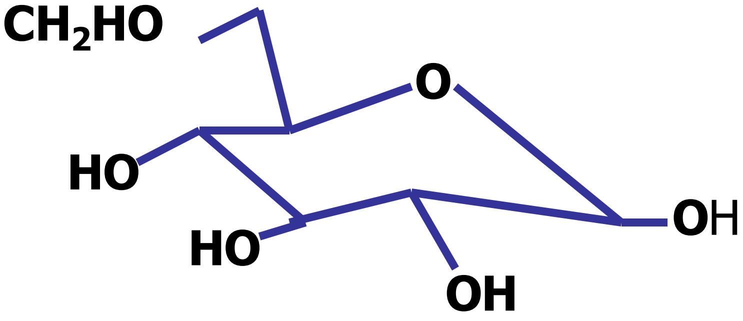
Дететорите работят в схема на съвпадение



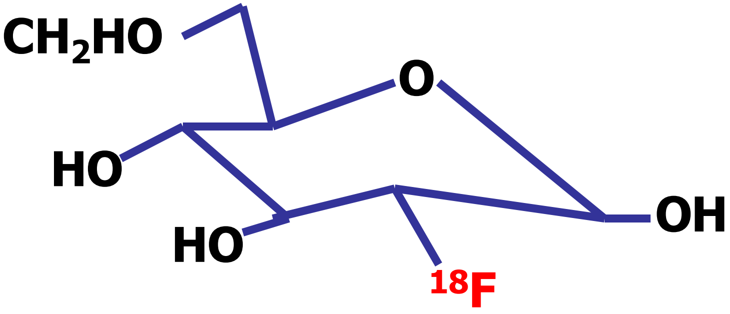
PET Радиофармацевтици

Нуклид	*Период на полуразпад – T1/2*	*Маркер*	*Приложение*
O-15	**2 min**	**Water**	**Cerebral blood flow**
C-11	**20 min**	**Methionine**	**Tumour protein synthesis**
N-13	**10 min**	**Ammonia**	**Myocardial blood flow**
F-18	**110 min**	**FDG**	**Glucose metabolism**
Ga-68	**68 min**	**DOTANOC**	**Neuroendocrine imaging**
Rb-82	**72 sec**	**Rb-82**	**Myocardial perfusion**

FDG (2-deoxy-2-(F-18) fluro-D-glucose)



glucose



2-deoxy-2-(F-18) fluro-D-glucose

- Най – широко използвания радиофармацевтик
- Аналог на глюкозата
- Повечето тумори са със силно повишен глюкозен метаболизъм

Получаване на FDG

- Бобмардиране на подходяща мишена водеща до получаване на ^{18}F.

- Бомбардирането е около 2 часа (1 T1/2).

- ^{18}F – химичен модул (synthesis module), където се осъществяват реакции с повечето реагенти, така че да се получи fluorinated deoxyglucose – FDG.

- Модул (качествен контрол) на синтезиране обхваща няколко стъпки като нагряване, изстудяване, филтриране, химично пречистване и стерилизиране.

Manufacture of ^{18}F

- Proton is accelerated
- Strikes ^{18}O target
- Merges with ^{18}O
- Neutron ejected

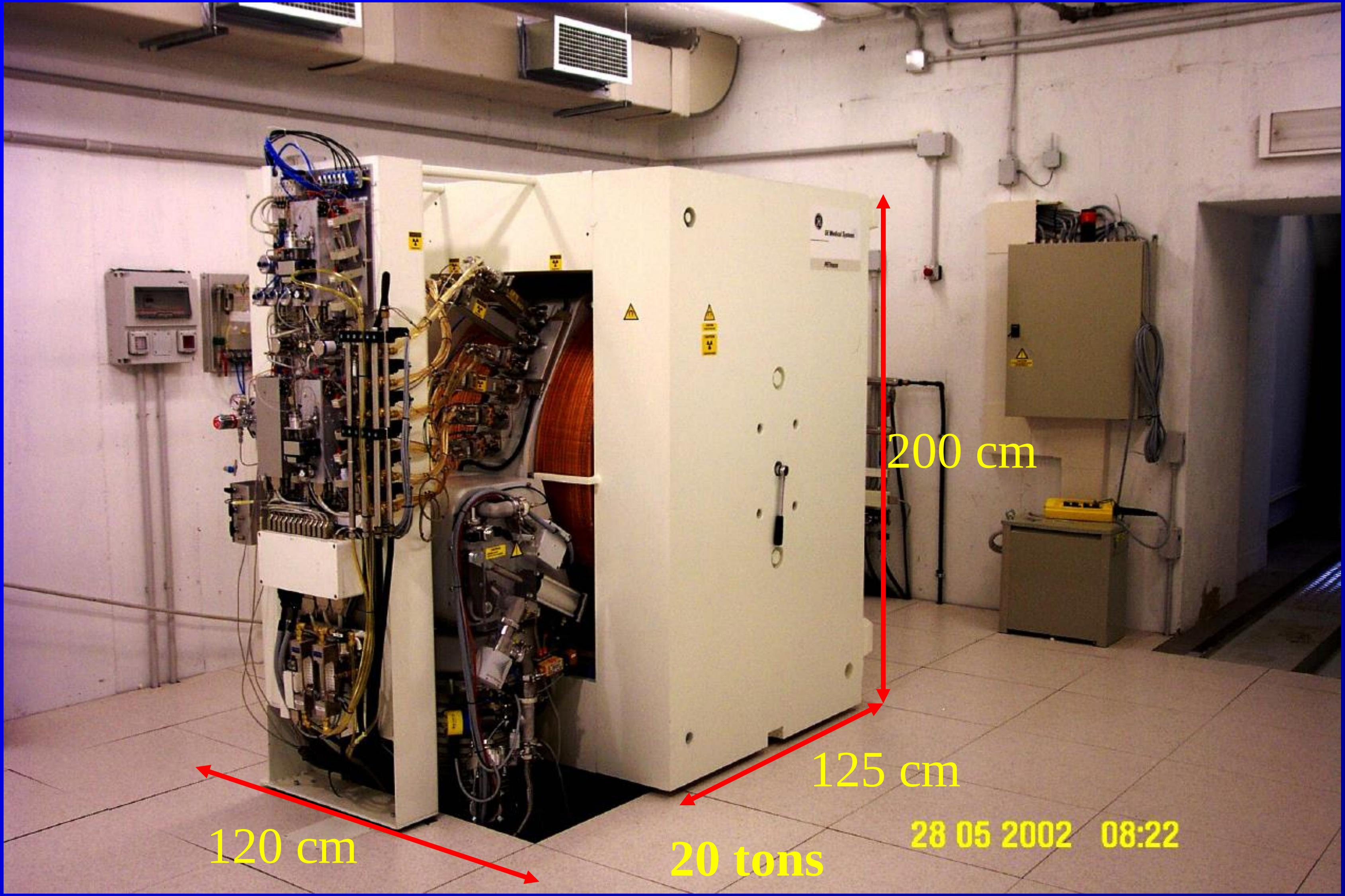
$$^{18}_{8}O + ^{1}_{1}p \rightarrow ^{18}_{9}F + ^{1}_{1}n$$

Principal PET radionuclides

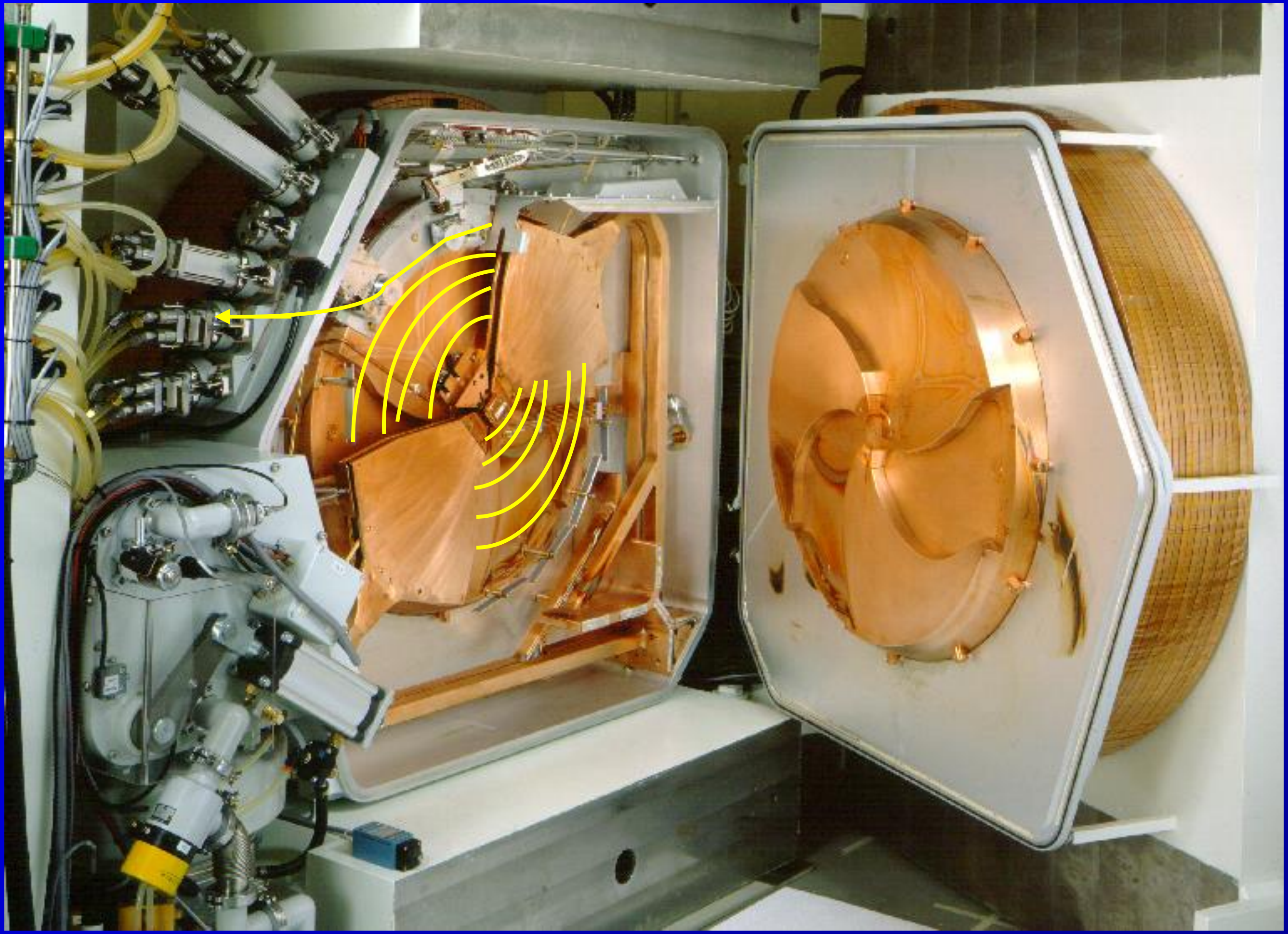
Radionuclide	$T_{1/2}$	Nuclear reaction
Carbon-11	20 min	$^{14}N(p,\alpha)^{11}C$
Nytrogen-13	10 min	$^{16}O(p,\alpha)^{13}N$
Oxygen-15	2 min	$^{14}N(d,n)^{15}O$
Fluorine-18 ($^{18}F^{-}$)	**110 min**	**$^{18}O(p,n)^{18}F$**
Fluorine-18 ($^{18}F_2$)	110 min	$^{20}Ne(d,\alpha)^{18}F$

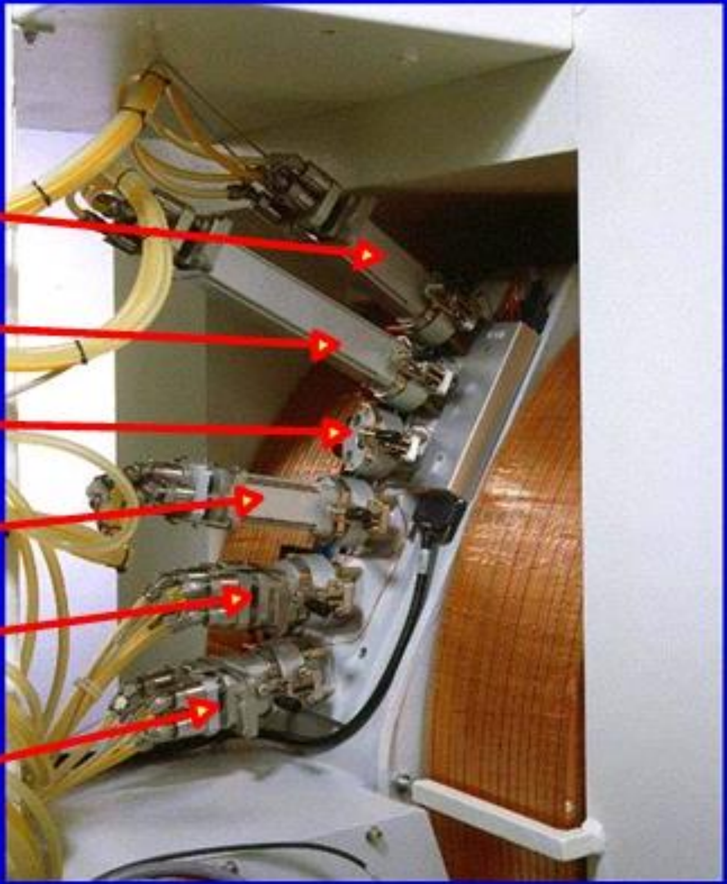
- *Light nuclides*
- *Fundamental elements for organic Chemistry*
- *Potentially, every biochemical process could be traced*

The PETtrace cyclotron



Beam acceleration





6. 18 F target

5. 11 C target

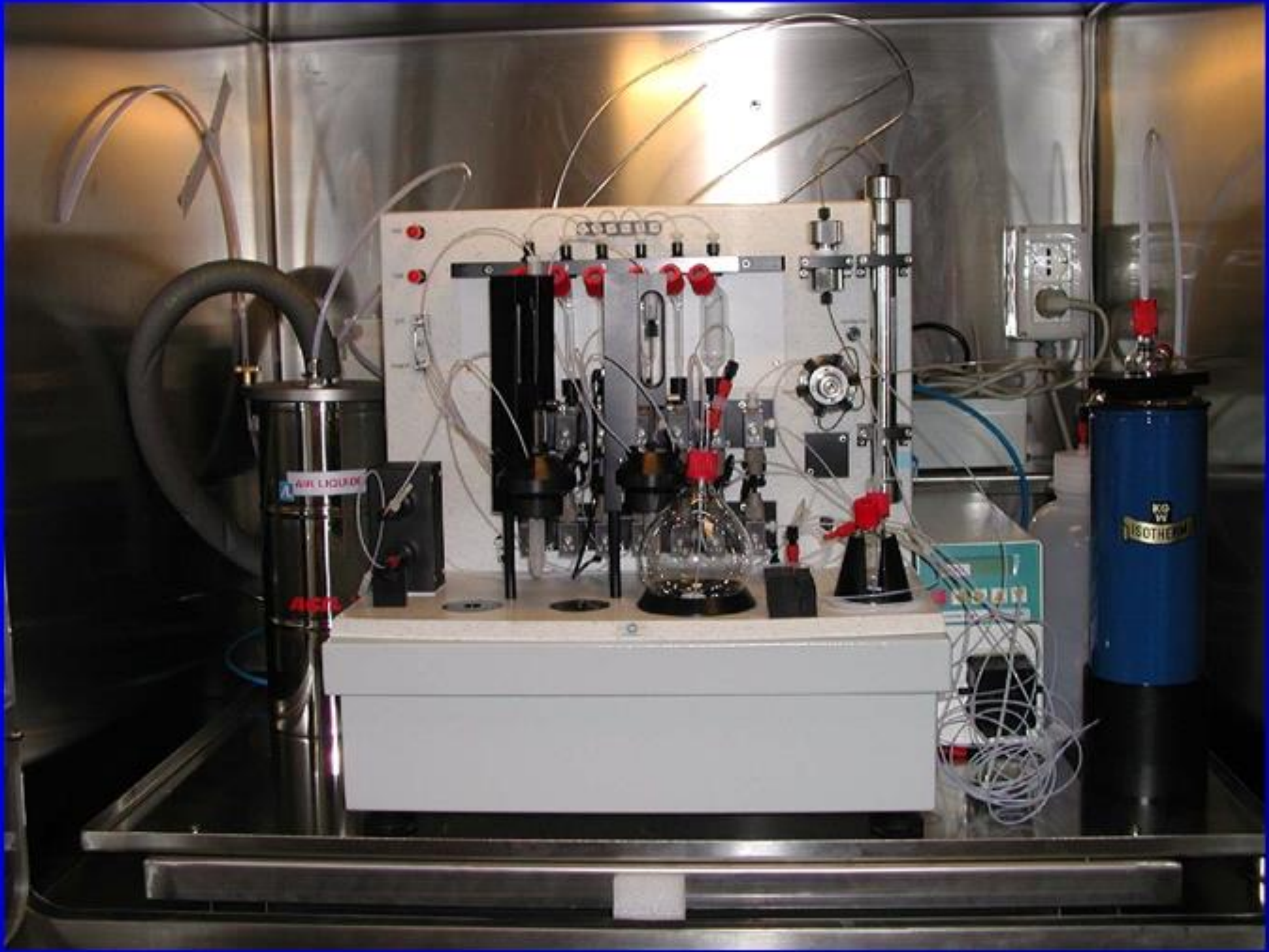
4. 18 F target

3. 15 O target

2. 13 N target

1. 18 F target

МОДУЛ - СИНТЕЗ



РАДИОХИМИЧНА ЛАБОРАТОРИЯ

Routine work cycle at the PET centre in Bologna

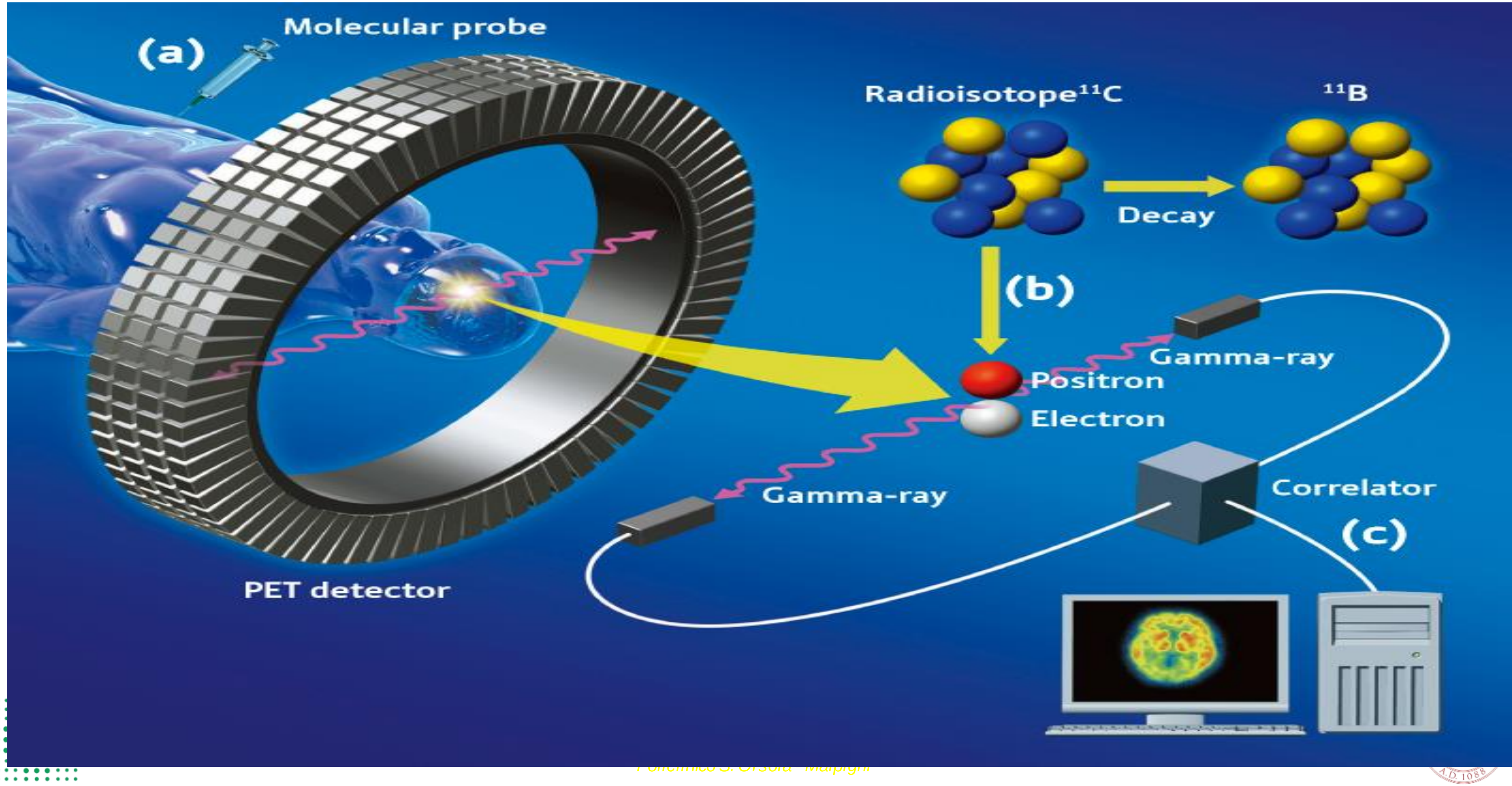
- 5.30: start; environmental and operational tests (temp, gases, voltage …)
- 5.45: pre irradiation of 18F target with H2O16
- 6.00: activity bolus delivered to a research hot cell; test of production; rinse & drying
- 6.00: start testing and loading 18F-FDG module
- 6.10: start of first 18F- production
- 6.15: preparing the vials dispensing unit
- 6.30 – 7.00: checking of cyclotron parameters
- 7.00: preparation of the insulator for unit dose dispensing
- 7.00: start preparation of the QC equipment
- 7.30: first irradiation is almost ready; final check of all systems
- 7.30: start preparation of the 11C module for Choline / Methionine
- 7.45: end of first bombardment and delivery of activity to the 18F-FDG module
- 7.50: rinse the 18F-target; start 18F-FDG synthesis
- 7.50: preparation of the 11C target
- 8.00: start 11C bombardment
- 8.15: end of 18F-FDG synthesis; start of sterilization and vials dispensing
- 8.30: delivery of 11C to synthesis module; start of Choline / Methionine synthesis
- 8.40: first vial of 18F-FDG ready; taken sample for QC
- 8.55: 18F-FDG QC completed; first patient dose dispensed
- 8.55: end of 11C Choline / Methione synthesis; sterilization
- 9.00: 11C Choline / Methione sample for QC
- 9.15: 11C Choline / Methionine QC completed; first patient dose dispensed

Principal models of cyclotron for biomedical uses

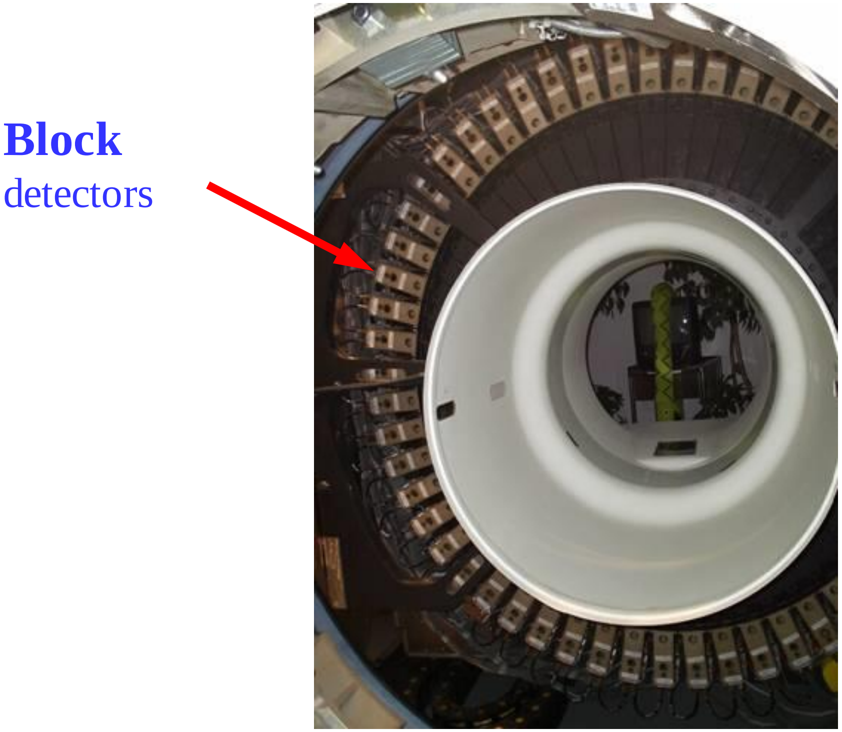
Cyclotron	E_{max} (MeV)	Particles	I_{max} (microA)	N. Max Targets	Dual beam	Ion Source	Self Shield
Advanced TR19	19	H- (D-opt)	150	8	Y	Ext, filament	opt
Siemens Eclipse	11	H-	80	8	Y	Int, filament	Y
GE MiniTrace	10	H-	60	6	Y (2° target fixed)	Int, PIG	Y
GE PetTrace	16.5	H- (D-opt)	80	6	Y	Int. PIG	opt
IBA Cyclone 18/9	18	H- (D-opt)	80	8	Y	Int. PIG	opt

ДЕТЕКТИРАНЕ НА ФОТОНИТЕ ПОЛУЧЕНИ ПРИ АНИХИЛАЦИЯ

Детектира се анихилационно лъчение получавано при взаимодействието на позитроните излъчени от радиофармацефтика, с електрони от изследваните тъкани.

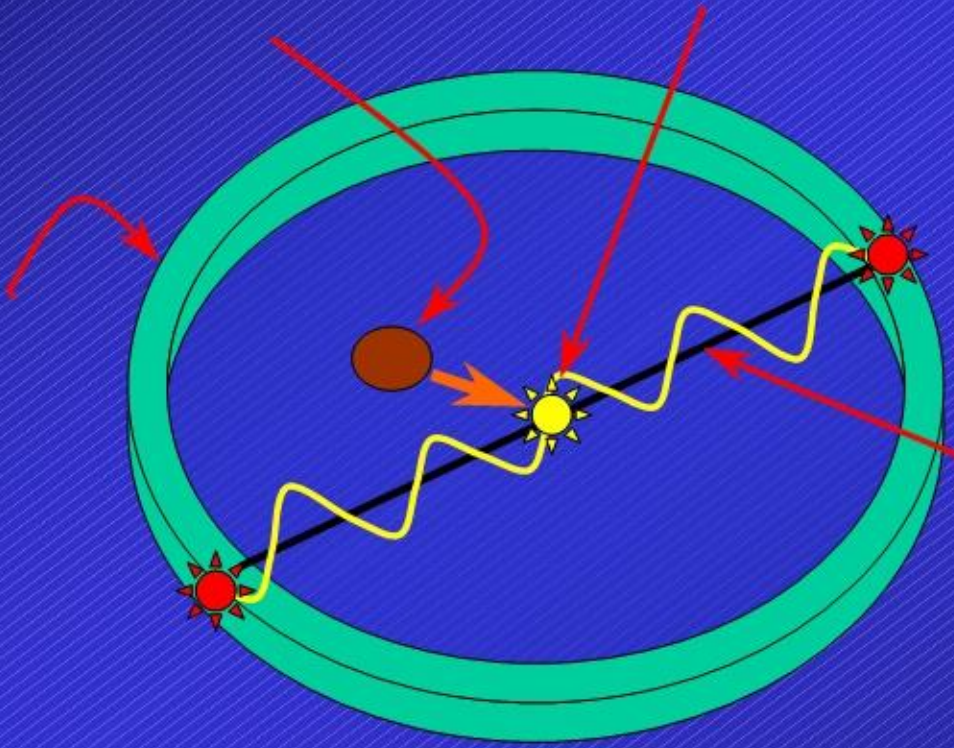


Full Ring Detector System



- Детекторната ситема е съставена от множество сцинтилационни детектори - малки кристали (NaI(Tl)) , (BGO) наредени плътно един до друг по окръжност, всеки от тях свързан с фотоелектронен умножител (ФЕУ).
- Когато гама квант попадне в кристала (NaI(Tl), (BGO) на детектора се появява сцинтилация (изсветване), отделения фотон попада във фотоелектронен умножител където се преобразува в електричен сигнал.
- Дететорите работят в схема на съвпадение по време.
- Отсътвието на фокусиращи колиматори на детекторите, прави метода **много чувствителен**

PET - Принцип на детектиране: *Идеален случай*



Анихилация

Позитрон

Кръгов детектор

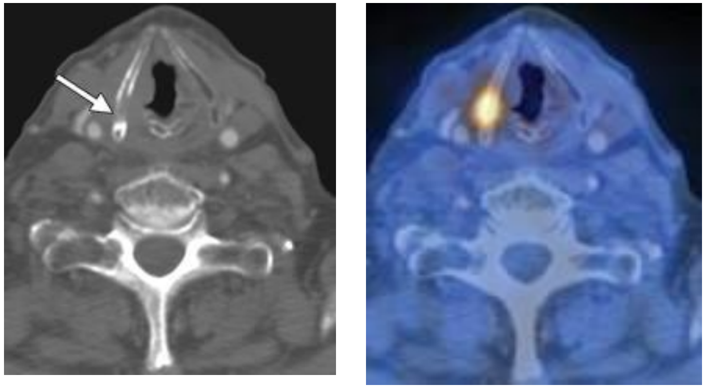
Две събития в детектора в един момент време*

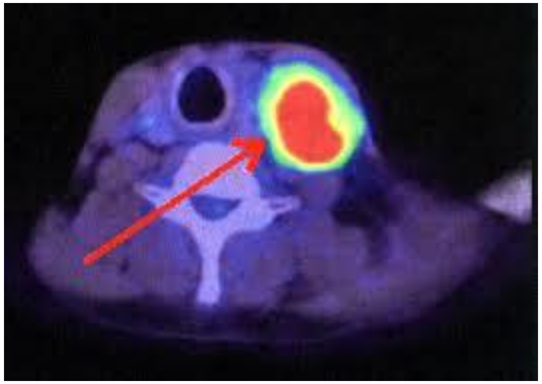
Линия на съвпадение

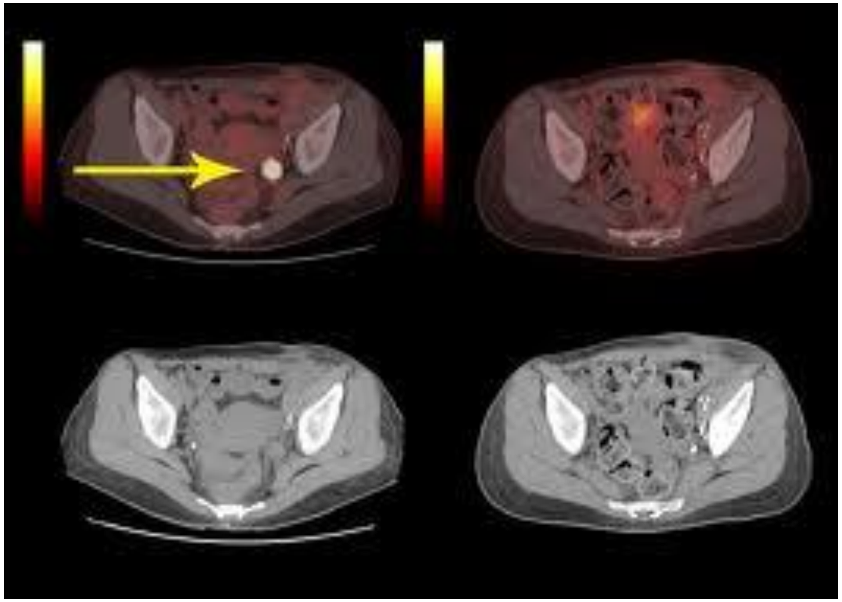
Използва се за реконструкция на образа

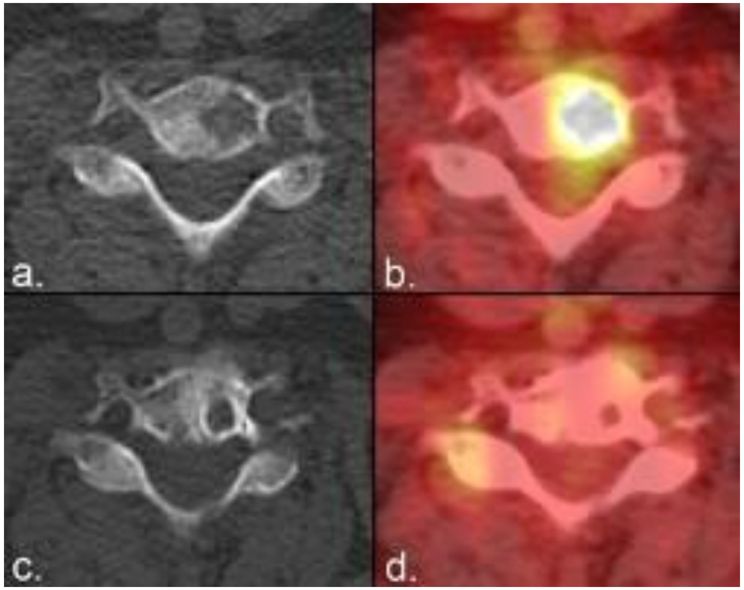
*Времеви прозорец 6 – 12 ns

- Получените сигнали се обработват от софтуер ***(алгоритъм “обратна проекция”)***, в резултат се получава **образ изобразяващ локализацията и концентрацията на съответния радиофармацефтик, източник на позитрони в изследвания орган.**

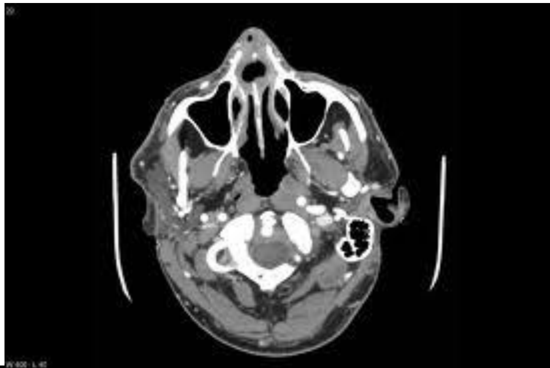


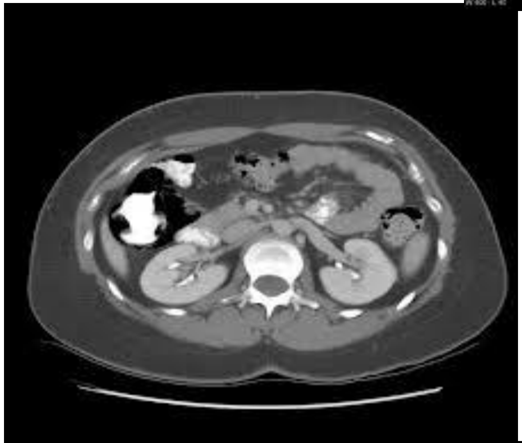




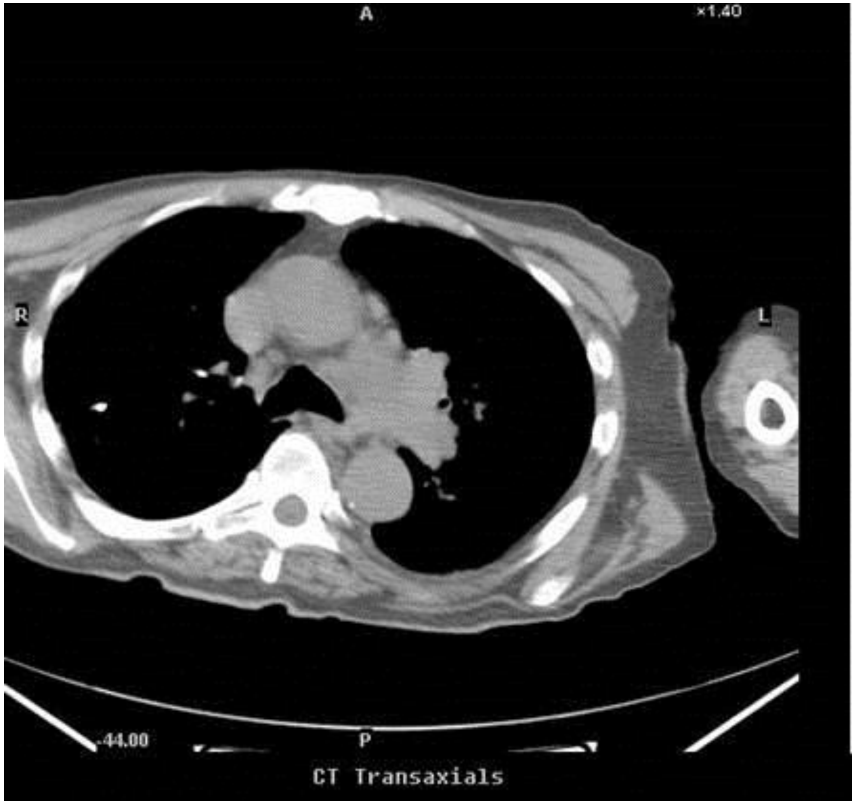


Рентгенова Компютърна Томография
Computer Tomography (CT)



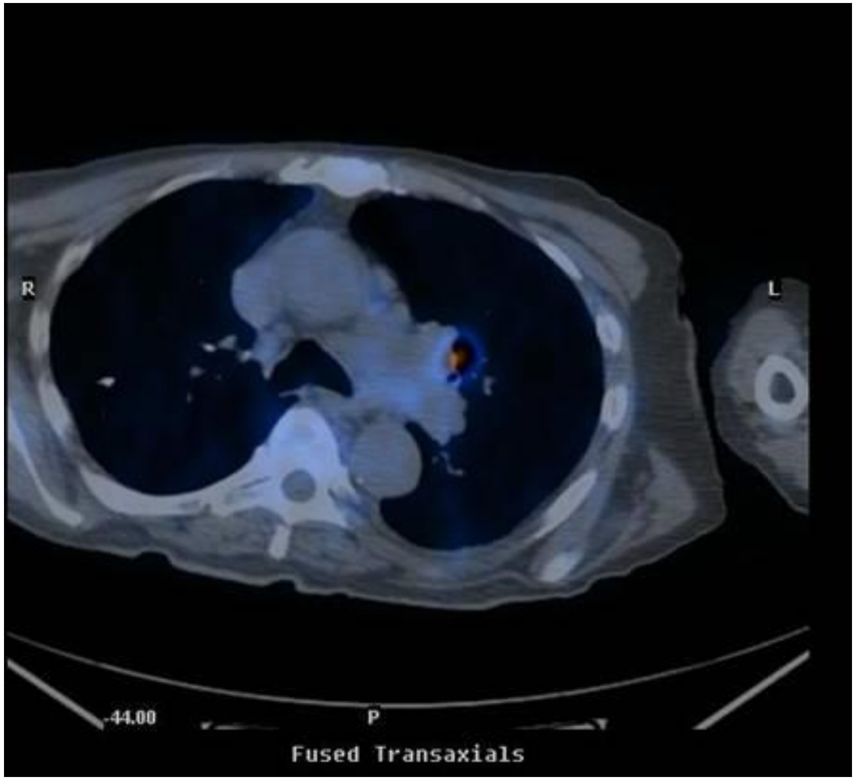


Рентгенова Компютърна Томография - CT



- Анатомична структура
- По - добра резолюция от PET
- Добра разлика между костна и мека тъкан
- **Не може да диференцира активността на заболяванията**

PET/CT Томография



- ☐ Комбиниране на функционалната информация с анатомичните детайли.
- ☐ Точна анатомична регистрация.
- ☐ Висока диагностична точност спрямо PET или CT използвани по отделно.

PET/CT Scanner

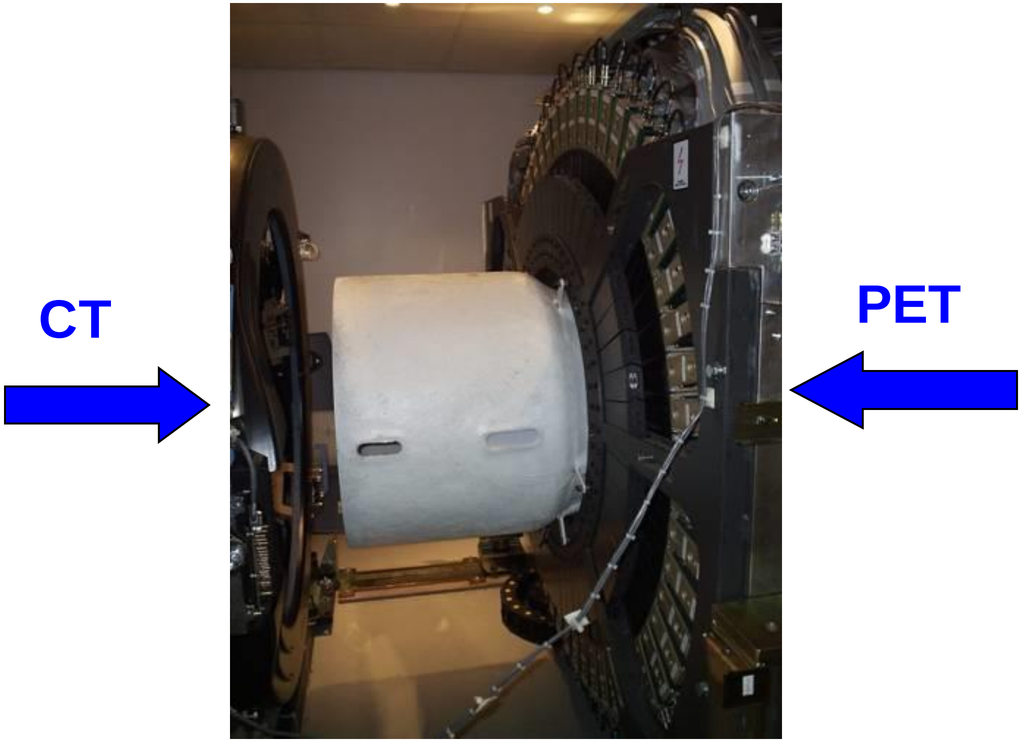
CT unit

PET scanner

PET/CT – Хибриден апарат - физичен принцип на действие

PET & CT в едно гентри

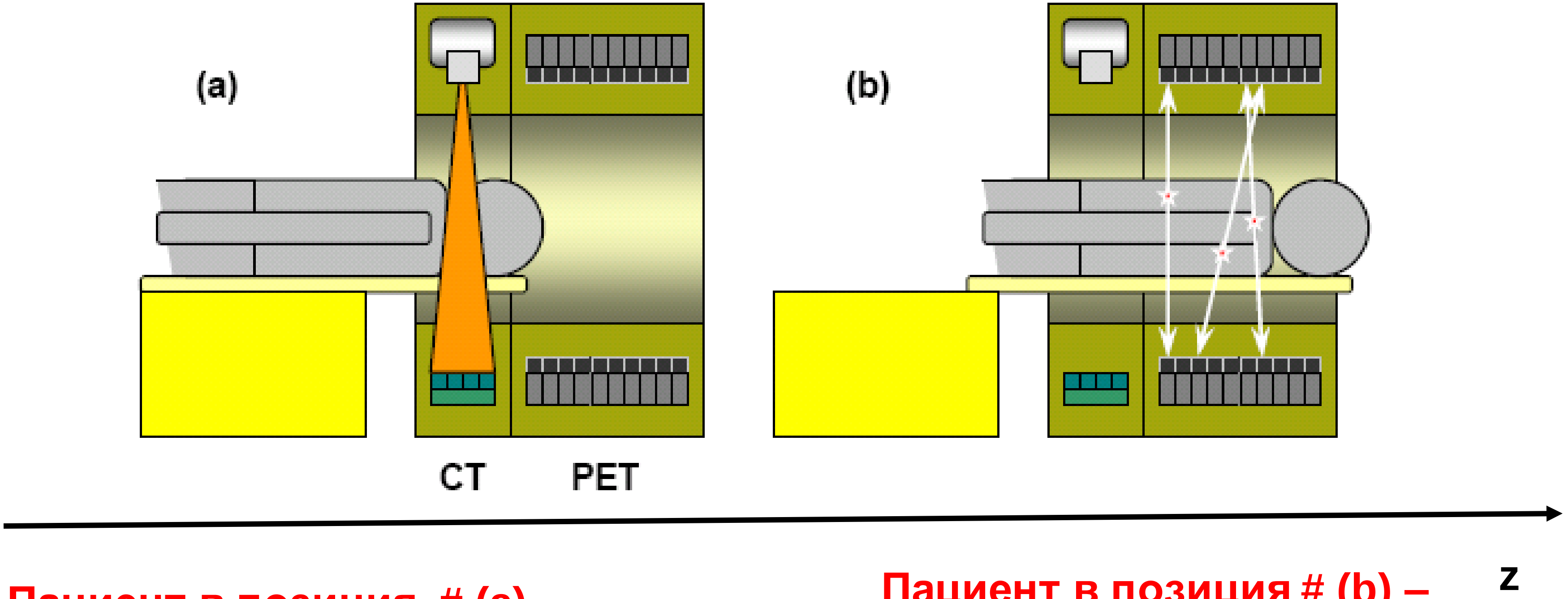
Image Courtesy of Philips



2000г. – д-р David Townsed патентова техническото изобретение

2003г. – BIDMC е първата болница в Massachusetts, USA инсталирала PET/CT

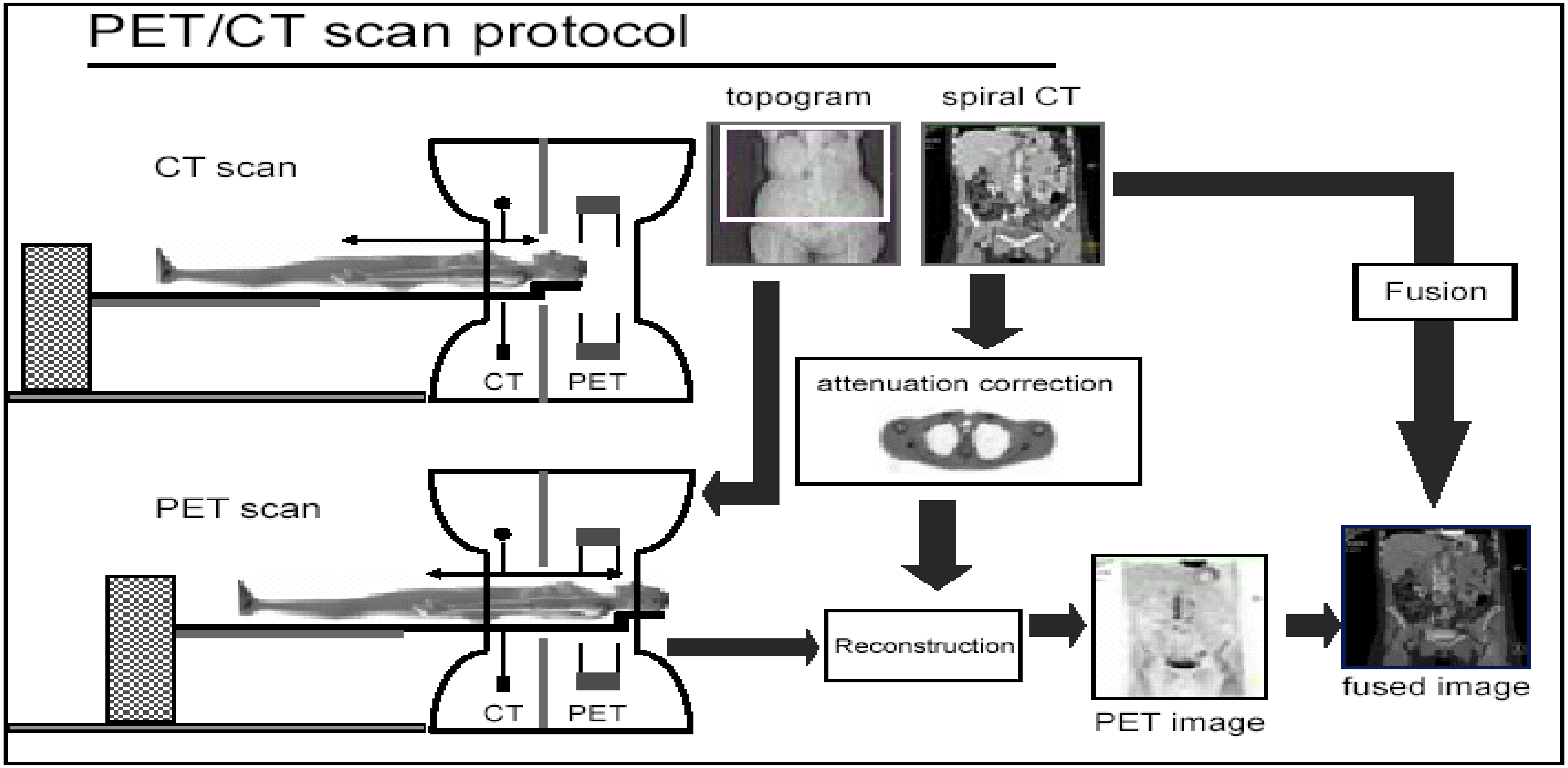
PET/CT Изследване



Пациент в позиция # (a) – CT

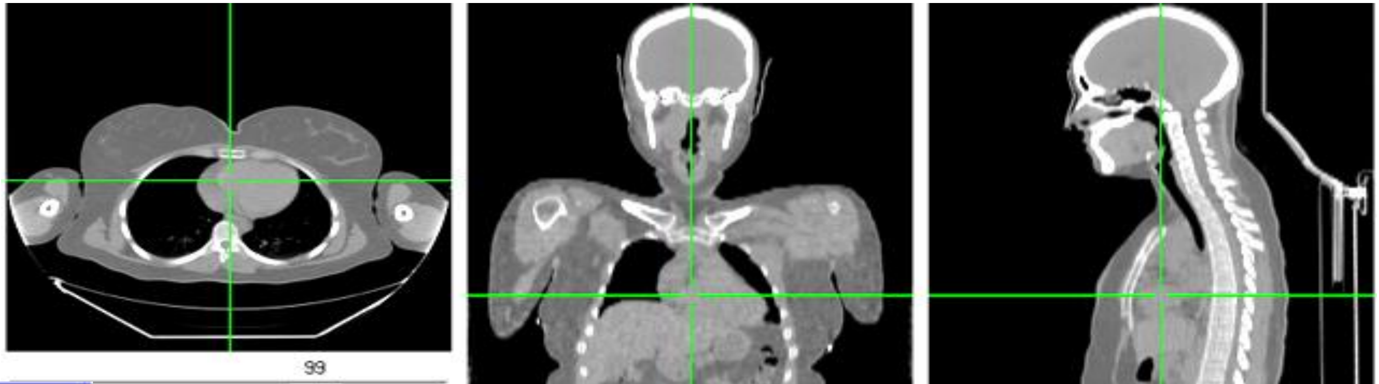
Пациент в позиция # (b) – PET

Двете изследвания се извършват последователно във времето.
Пациентът не се движи по време на двете изследвания.
Пациентната маса се придвижва по оста Z, по дефинирана и контролирана посока.
Като резултат образите от CT и PET се наслагват и се получава обединен образ от проведеното изследване.

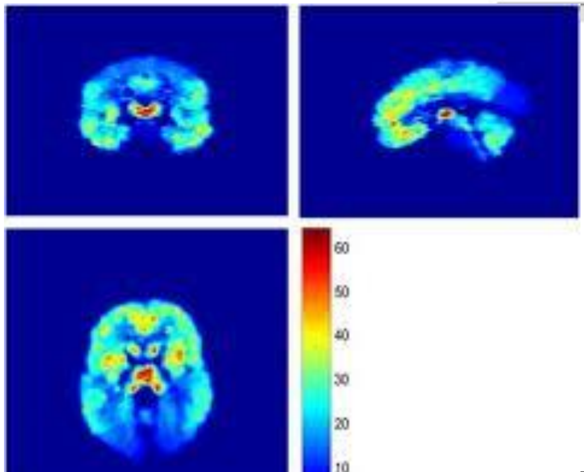


Компютърният Томограф (CT) при PET/CT се прилага за **корекция на отслабването на γ лъчението** и като **анатомична матрица за изобразяване на точната локализация** на ***функционално променените*** *патологични огнища, злокачествени тумори и техните метастази.*

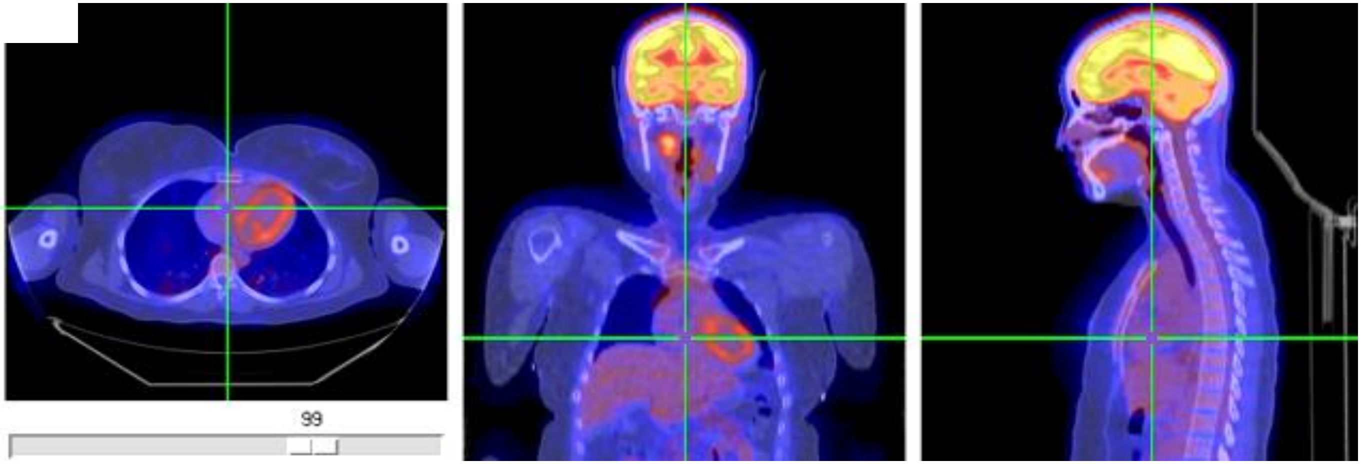
CT образи



PET образи



PET/CT образи

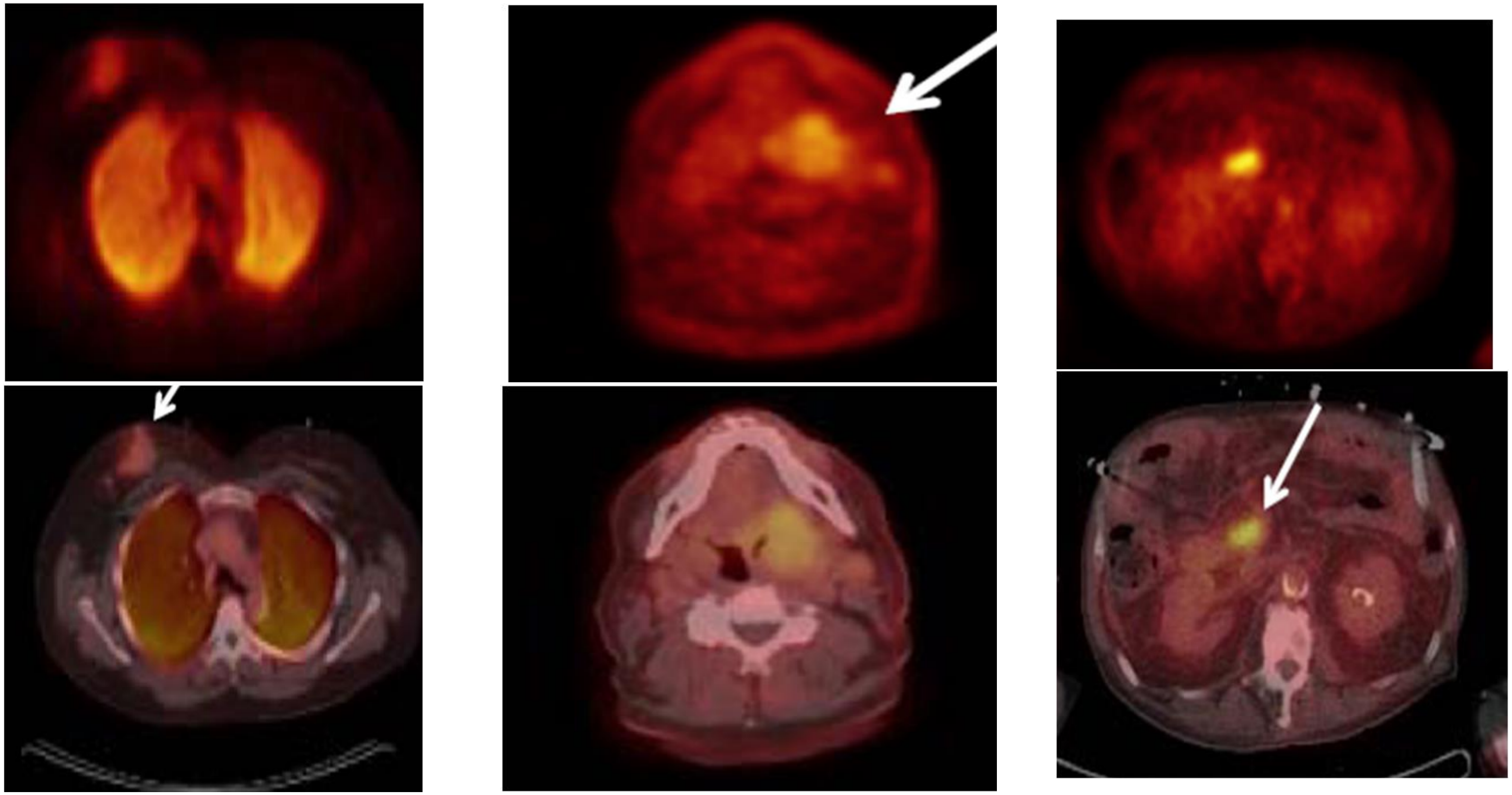


ОБРАЗИ НА РАЗЛИЧНИ ЧАСТИ ОТ ЧОВЕШКОТО ТЯЛО

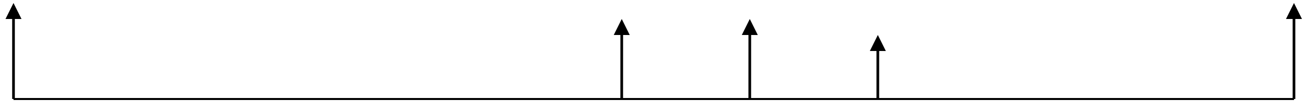
РМЖ **Глава и Шия** **Лимфом**

PET

PET/CT



Необходимо време за изследване на Пациент



Почивка

CT scan

Пациентът може да се облича и рехидратира

0 50 60 65 100

mins

Инжектиране

Пациентът е с изпразнен пикочен мехур

PET scan

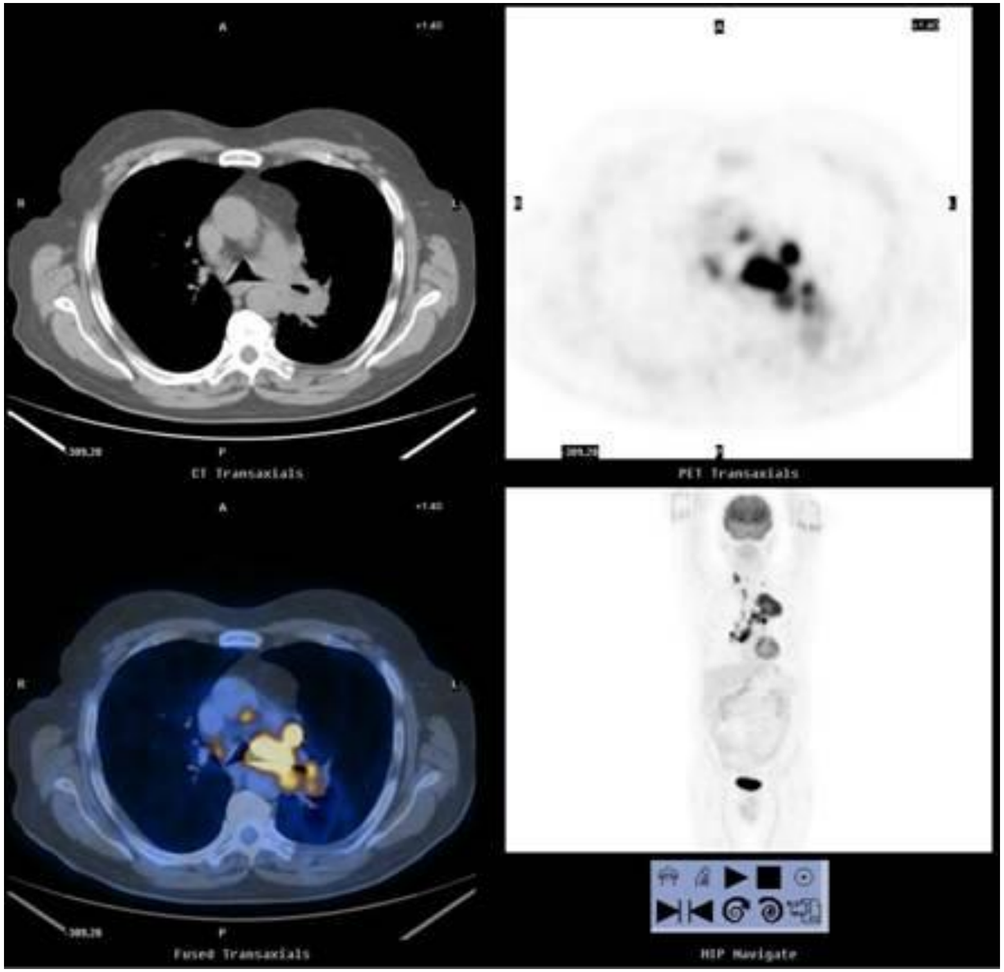
В съвременните PET/CT – времето е по-малко от 20 min.

Клинично Приложение

- Онкология
- Кардиология
- Неврология

Роля в Онкологията

- Диференцира бенигнените от малигнените заболявания
- Стадиране на заболяванията
- Резултатът от лечението
- Повторение на заболяването /рецидив/
- Приложение при Лъчетерапията



Ca Lung

В Онкологията

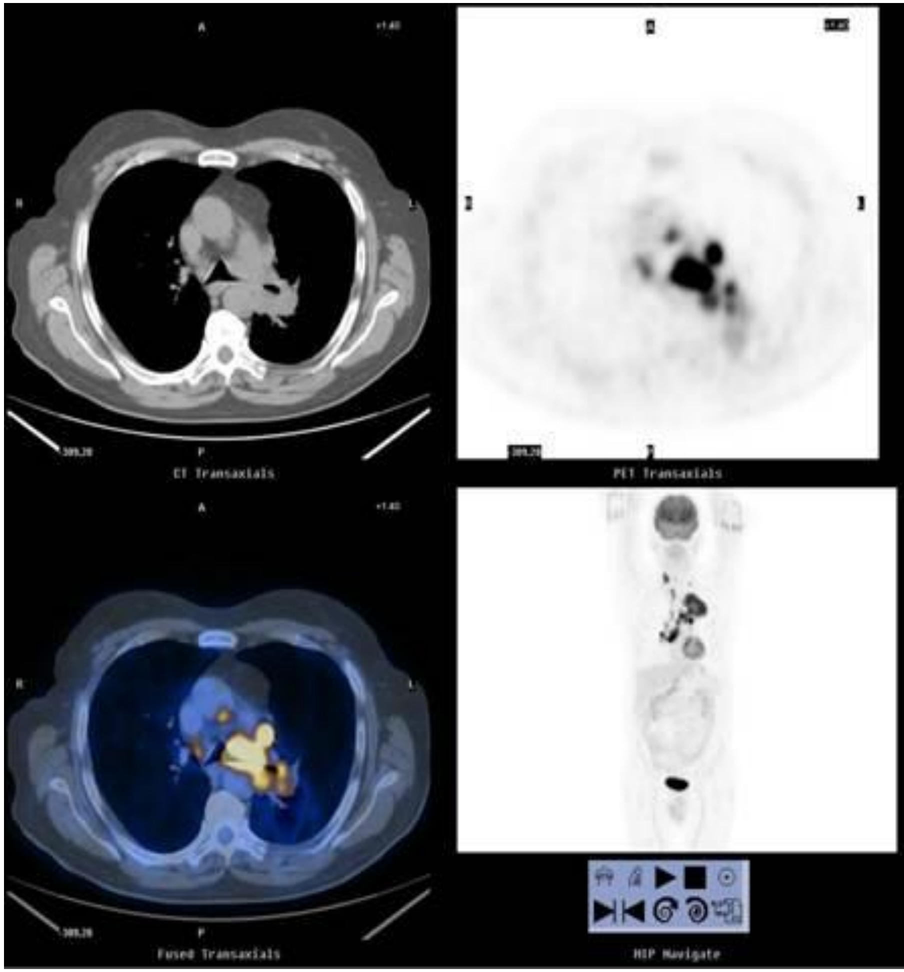
Поставяне на диагноза –
визуализация на жизнеността на тумора, неговите метастази или рецидиви

При тумори ~ 1cm

средна чувствителност 95%*
(91% - 100%)

средна специфичност 90%*

(85% - 100%)



Ca Lung

*Taylor A, et all. A clinical guide to Nuclear Medicine. SNM-USA, 2nd printing, 2003

В КАРДИОЛОГИЯТА

- ☐ Диагноза и оценка тежестта на нарушенията в кръвоorосяването (перфузията) на миокарда.

- ☐ Определяне виталността на миокарда.

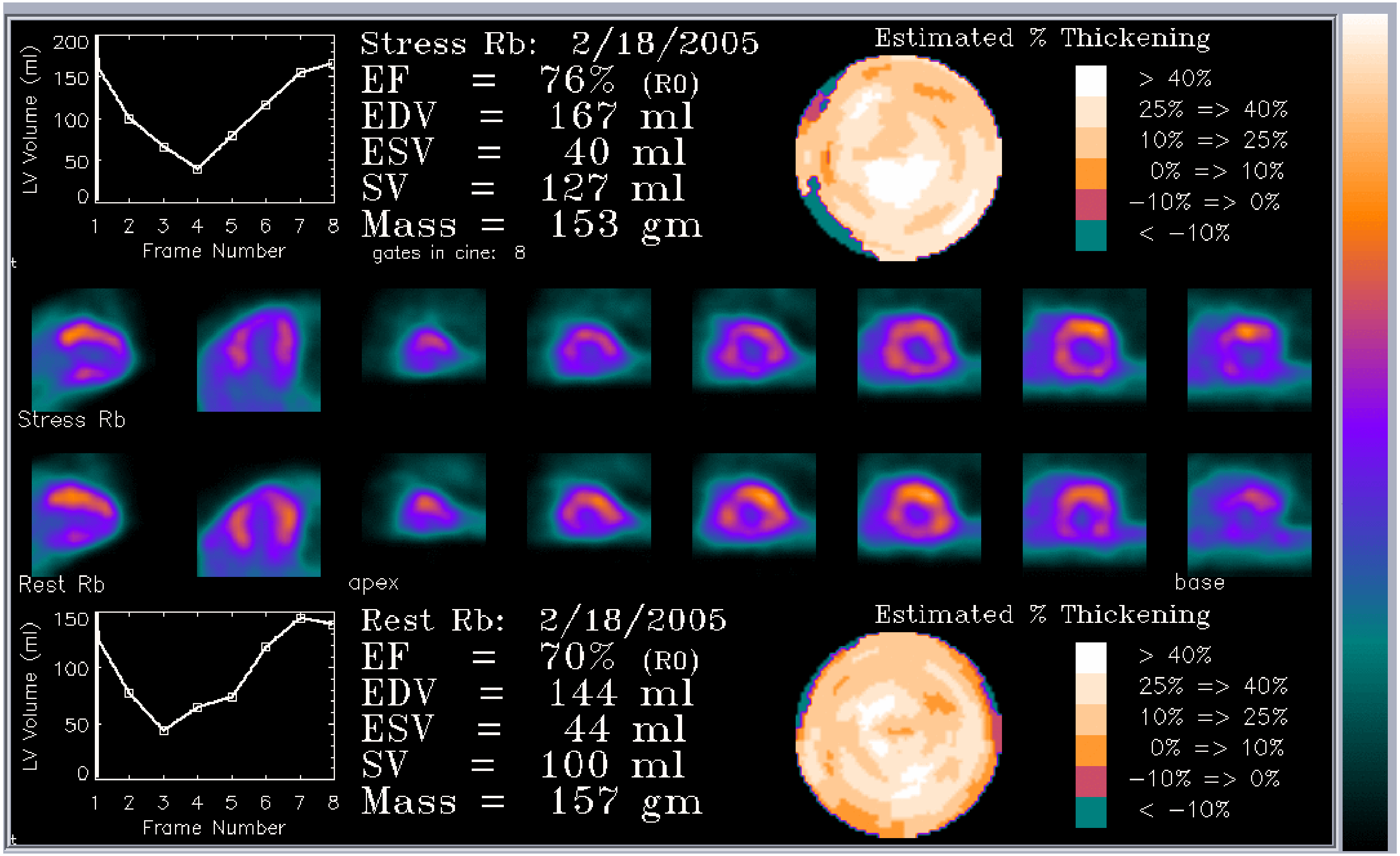
- ☐ Обективна информация за глобалната и регионалната функция на лявата камера.

- ☐ Определяне степента на риска от нови исхемични инциденти.

- ☐ Проследяване ефекта от терапията (медикаментозна, коронарна ангиопластика и байпас).

- ☐ Едновременна информация за кръвоорсяването и за функцията на миокарда.

Едновременна информация
за кръвооросяването(перфузията)
и за функцията на миокарда



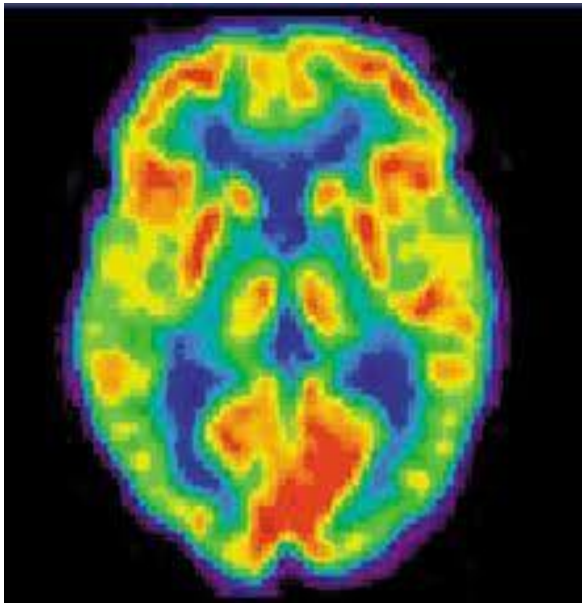
```
Stress Rb:  2/18/2005
EF     =   76%  (R0)
EDV    =   167  ml
ESV    =    40  ml
SV     =   127  ml
Mass   =   153  gm
 gates in cine:  8
```

```
Rest Rb:  2/18/2005
EF     =   70%  (R0)
EDV    =   144  ml
ESV    =    44  ml
SV     =   100  ml
Mass   =   157  gm
```

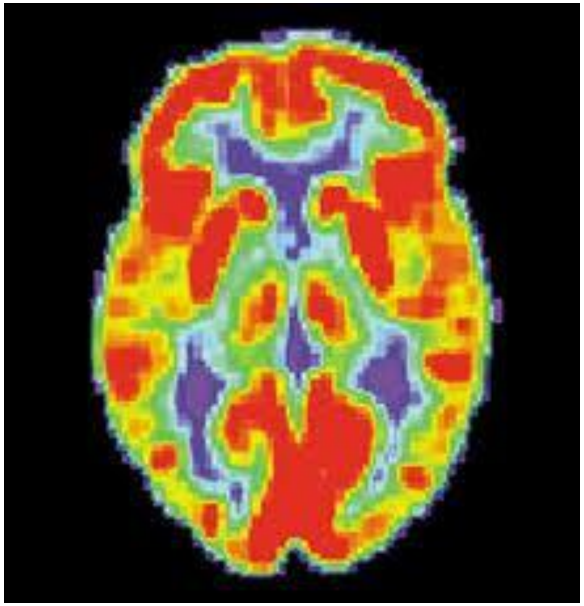
В НЕВРОЛОГИЯТА

- ☐ Доказване на различни съдови заболявания.
- ☐ Локализиране на епилептичното огнище.
- ☐ Диференцирането на дименциите (Болест на Алцхаймер).
- ☐ Визулизиране на туморите в случаите на неясна находка от другите образни методи.

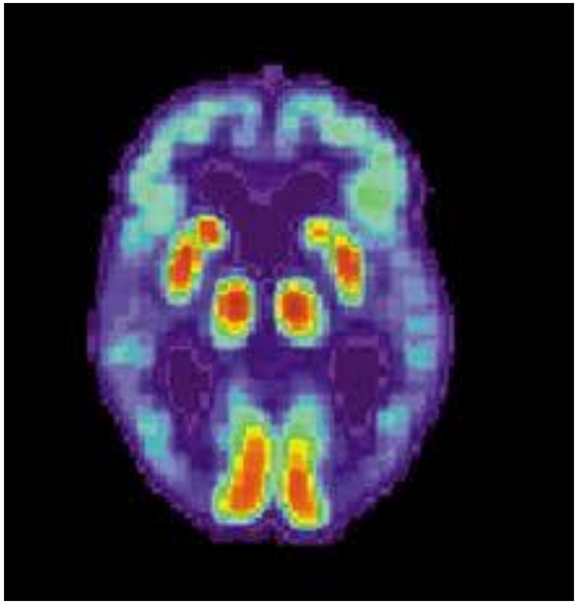
В НЕВРОЛОГИЯТА



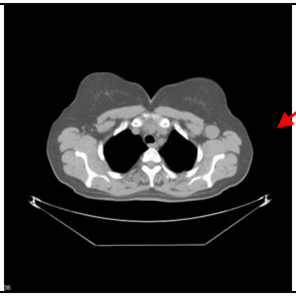
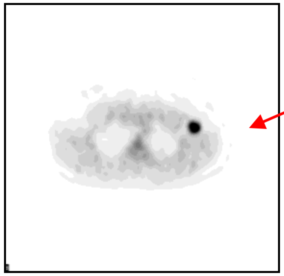
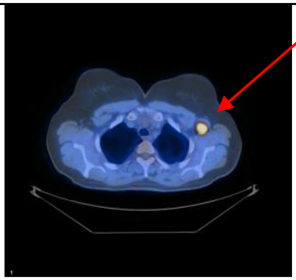
След
травма



Нормален
образ



Болестта
на Алцхаймер

	CT	PET	PET-CT
			
Предимства	**Анатомични образи** **Отлична пространствена резолюция, прецизно позициониране.**	**Функционални образи** **Висока чувствителност и количественост.** **Стадиране и контрол на заболяванията.**	**Обединява предимствата на двете техники: чувствителност, специфичност и количественост.**
Недостатъци	**Ограничена чувствителност при стадиране.**	**Ограничена пространствена резолюция**	**Пациентът поглъща** **доза лъчение ??? ……**
Образи	 **Анатомия**	 **Метаболитна активност**	 **Наслагване на метаболитни и анатомични данни**
Продуктивност	**~ 4-5 Пациента/час**	**~ 1 Пациент/час**	**~ 3 Пациента/час**

Instantaneous Dose Rate from Patient

Radiopharma-ceutical	Dose rate at 0.1 m, µSv/hr	Dose rate at 1m, µSv/hr
Tc-99m MDP (600 MBq)	**114**	**5**
F-18 FDG (350 MBq)	**550**	**70**

Dose rate measured immediately after injection. Note considerably higher dose rate for ^{18}F versus ^{99m}Tc.

ПРИЧИНИ ЗА ОГРАНИЧЕНО РАЗПРОСТРАНЕНИЕ

- ☐ Висока цена на апаратурата

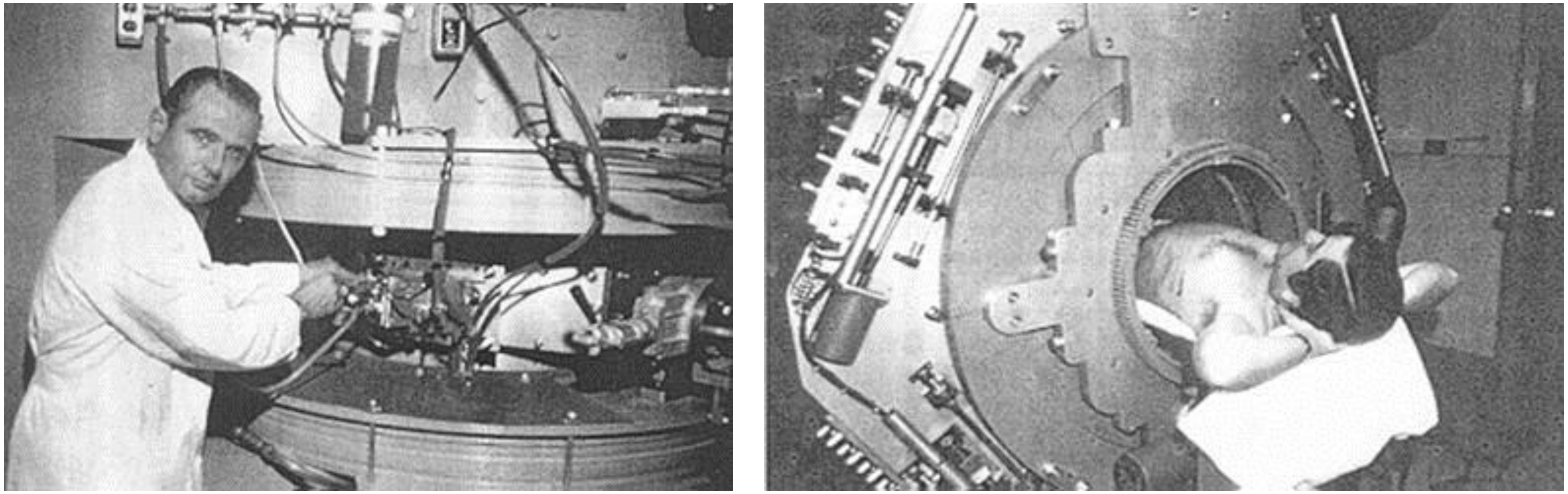
- ☐ Необходимост от циклотрон, който да произвежда краткоживеещи радионуклиди

- ☐ Специално адаптирана апаратура за химичен синтез и контрол на използваните радиофармацевтици

- ☐ Наличие на радиохимична лабораториа

- ☐ Помещения със съответните лъчезащитни изисквания за персонал и население

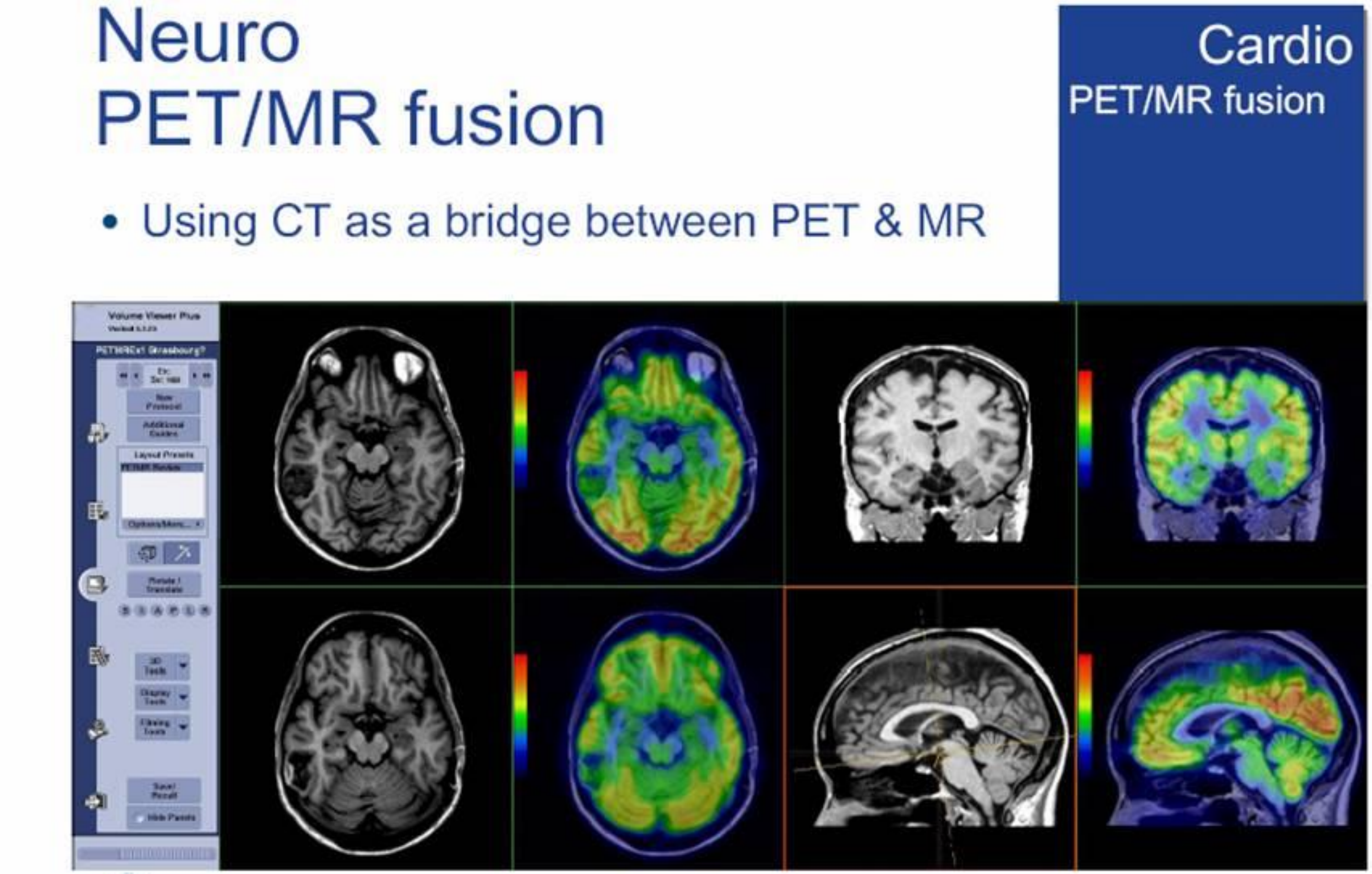
Пионери в PET диагностиката



Michel Ter-Pogossian prepares a radiopharmaceutical for an examination of Henry Wagner Jr
with one of the first PET- scanners (1975).

История на Циклотрон, PET & PET/CT

- **1928** Съществуването на позитрона, Paul Dirac
- **1930** Циклотрон, Lawrence et al.
- **1932** Експериментално наблодаване на позитрона, Carl Anderson
- **1953** Детектиране на анихилация, Brownell & Sweet
- **1975** Трансаксиална томография, Ter-Pogossian, Phelps & Hoffman
- **1977** ^{14}C deoxyglucose, Sokoloff et al.
- **1979** ^{18}FDG PET, Relvich et al.
- **1980 - те** Многосрезови CT & PET циклотрони
- **1990 - те** Клинично приложение на PET
- **2000 - те** PET/CT
- **2010** GE инсталира първият PET/CT + MR образна система в **University Hospital Zurich (Nov 2011)**



Neuro PET/MR fusion

- Using CT as a bridge between PET & MR

Cardio PET/MR fusion

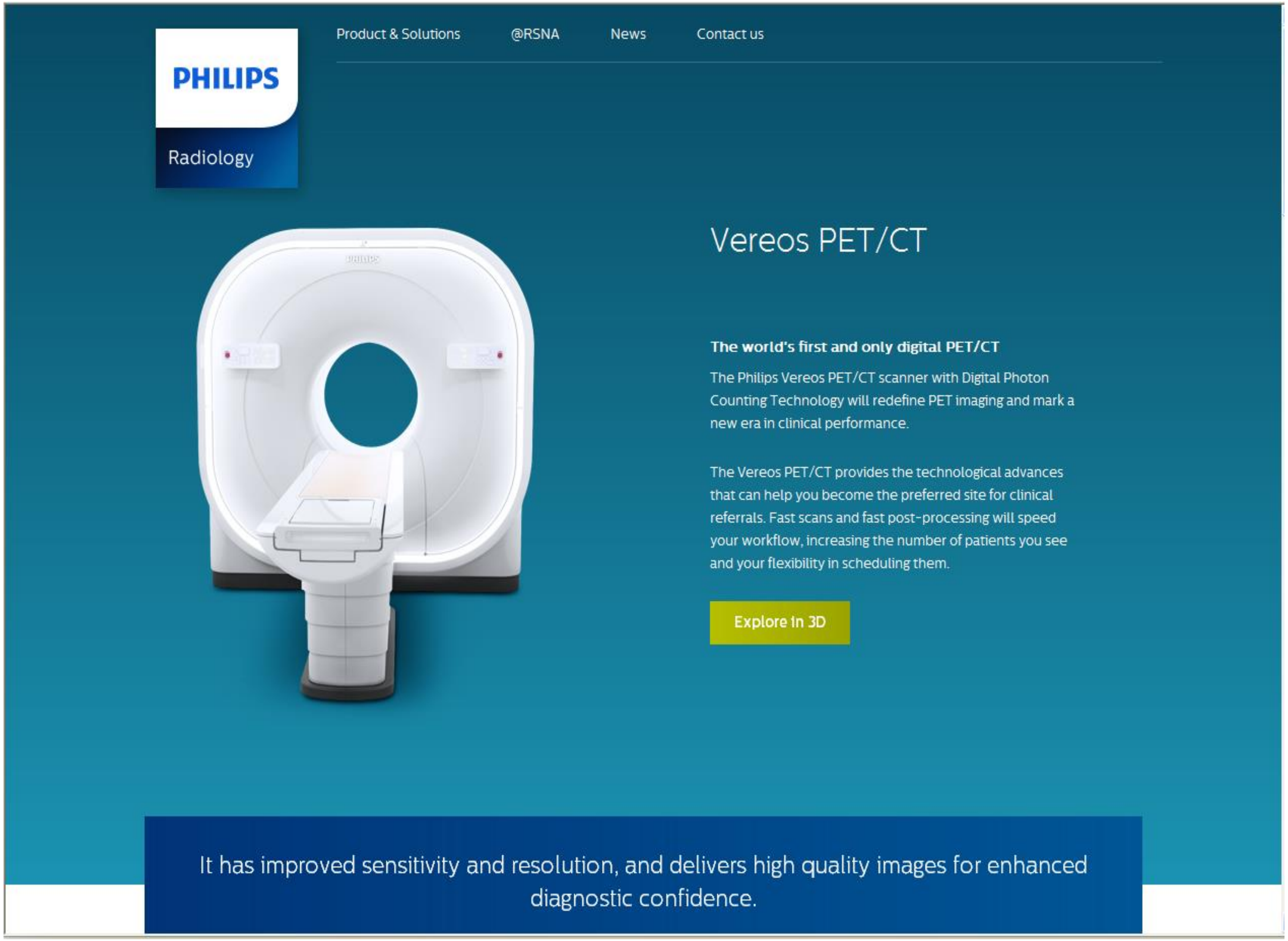
PET machines don't like to work in high magnetic fields. But thanks to more than 30 years of research, since 2010 we have PET/MRI machines installed in clinical settings."

David Townsend

Availabale on: http//:CERN.CH/ENLIGHT/HIGHLIGHTS

June 12, 2014 — Philips Healthcare recently introduced Vereos PET/CT, **the first digital PET/CT (positron emission tomography/computed tomography)** scanner, at the 2014 annual meeting of the Society of Nuclear Medicine and Molecular Imaging (SNMMI) in St. Louis.

Philips Highlights Vereos Digital PET/CT at SNMMI



Vereos PET/CT

The world's first and only digital PET/CT

The Philips Vereos PET/CT scanner with Digital Photon Counting Technology will redefine PET imaging and mark a new era in clinical performance.

The Vereos PET/CT provides the technological advances that can help you become the preferred site for clinical referrals. Fast scans and fast post-processing will speed your workflow, increasing the number of patients you see and your flexibility in scheduling them.

It has improved sensitivity and resolution, and delivers high quality images for enhanced diagnostic confidence.

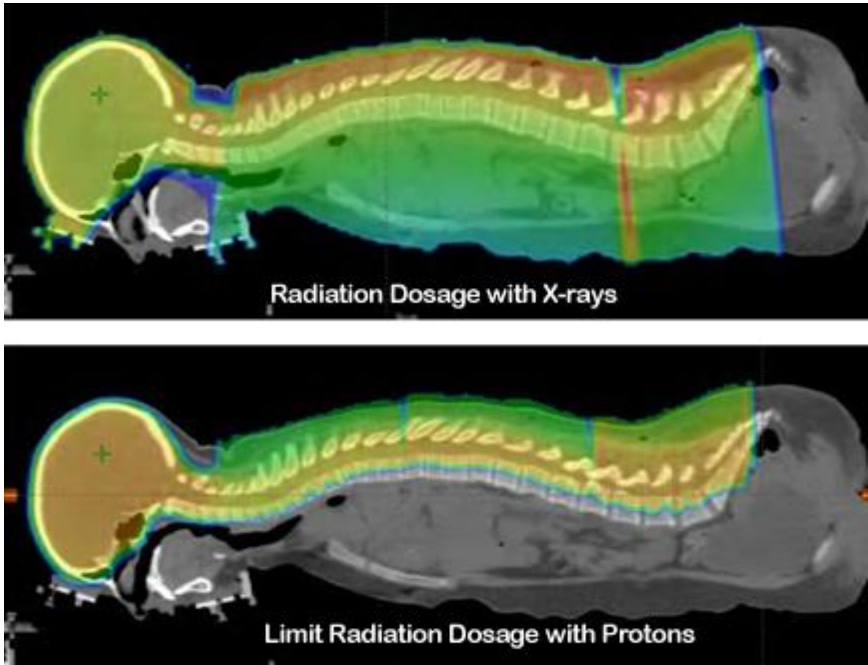
Avaialable on: http://www.healthcare.philips.com/us_en/clinicalspecialities/radiology/solutions/vereos.html?

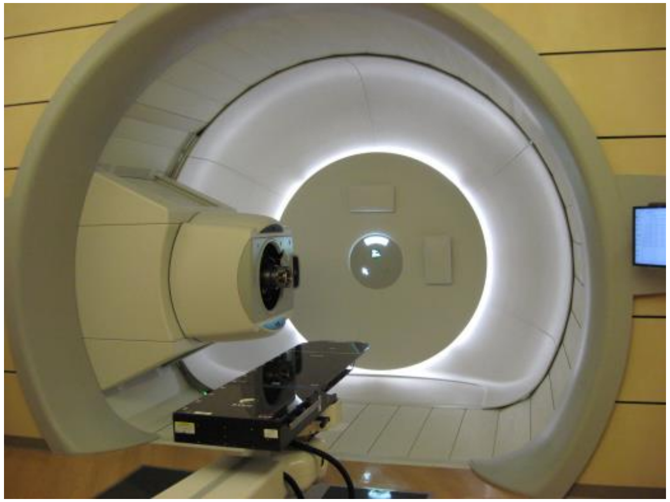
Къде може да бъде открит PET/CT?

УМБАЛ "Света Марина" - Варна

УМБАЛ Александровска - София

II. Proton Therapy - Протонна терапия





РАДИОТЕРАПИЯ
(Терапия с йонизиращи лъчения)

Основна цел:

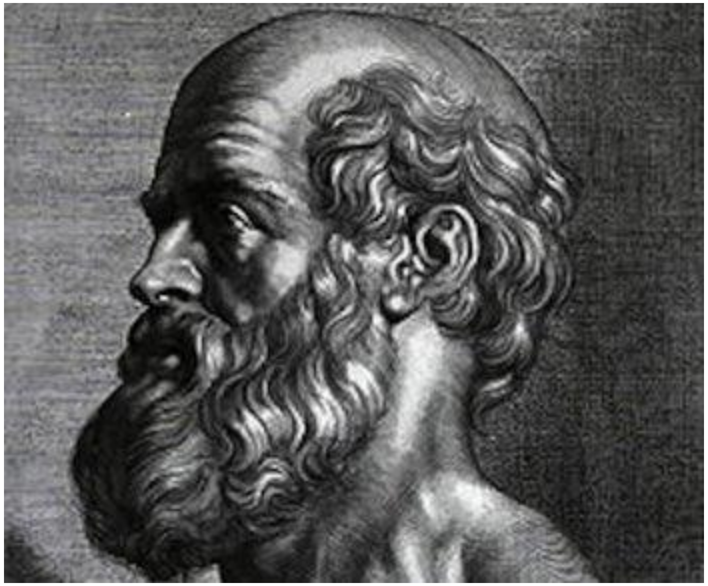
Ликвидиране на жизнеспособността на туморните клетки в даден орган или система на човешкото тяло чрез аплициране на необходимата канцерицидна доза при минимално облъчване на заобикалящите Областта подлежаща на Лъчелечение /ОПЛЛ/ здрави органи и тъкани.

<u>Постигане унищожаването на туморния процес без да се причиняват увреждания на организъм.</u>

Хирургия

РАДИОТЕРАПИЯ

Химиотерапия

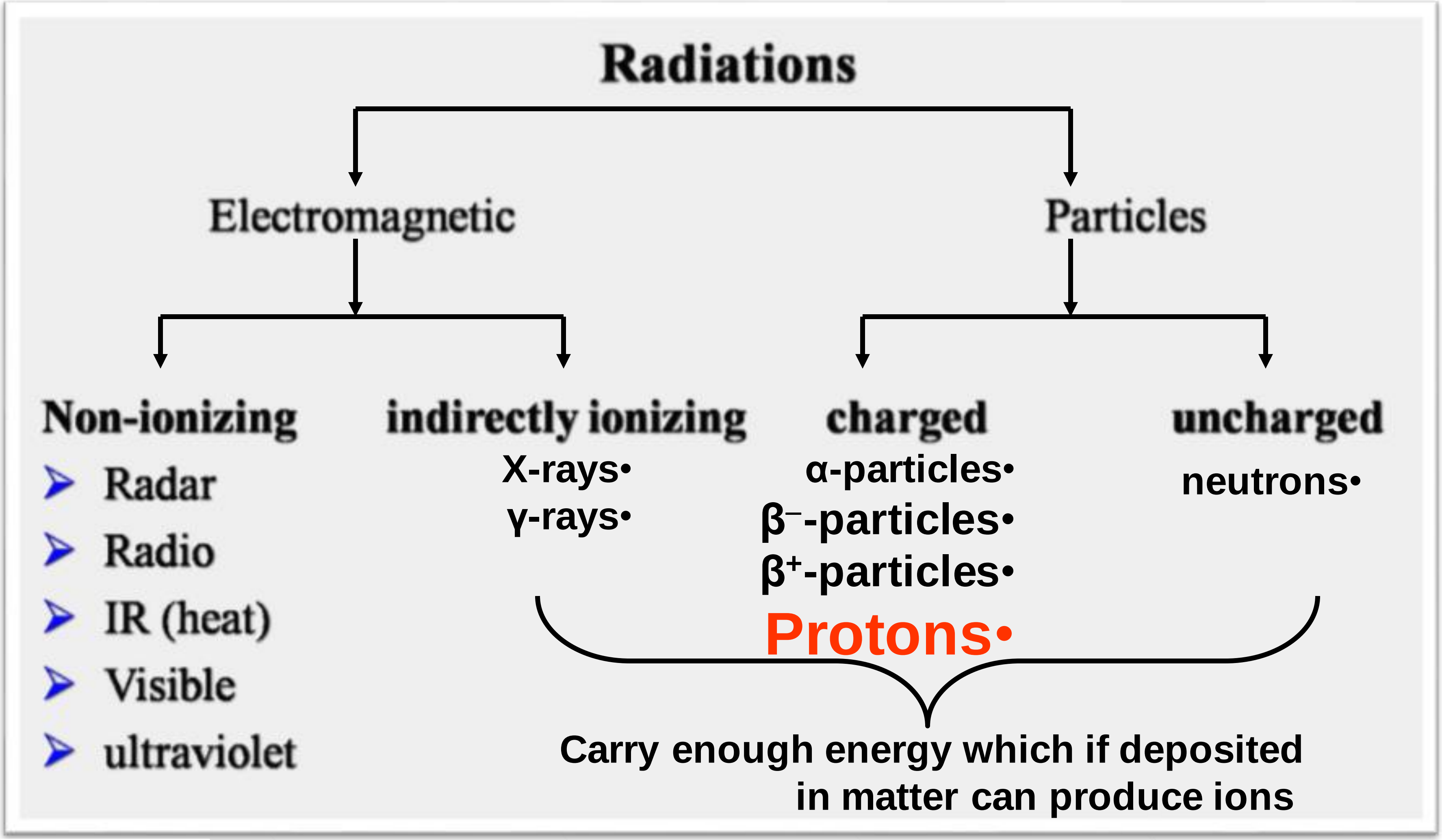


Hippocrates' words

PRIMUM NON NOCERE!

Лекувай, но не увреждай!

Видове Йонизиращи Лъчения



Radiations

Electromagnetic

Particles

Non-ionizing

- Radar
- Radio
- IR (heat)
- Visible
- ultraviolet

indirectly ionizing

X-rays•
γ-rays•

charged

α-particles•
β⁻-particles•
β⁺-particles•
Protons•

uncharged

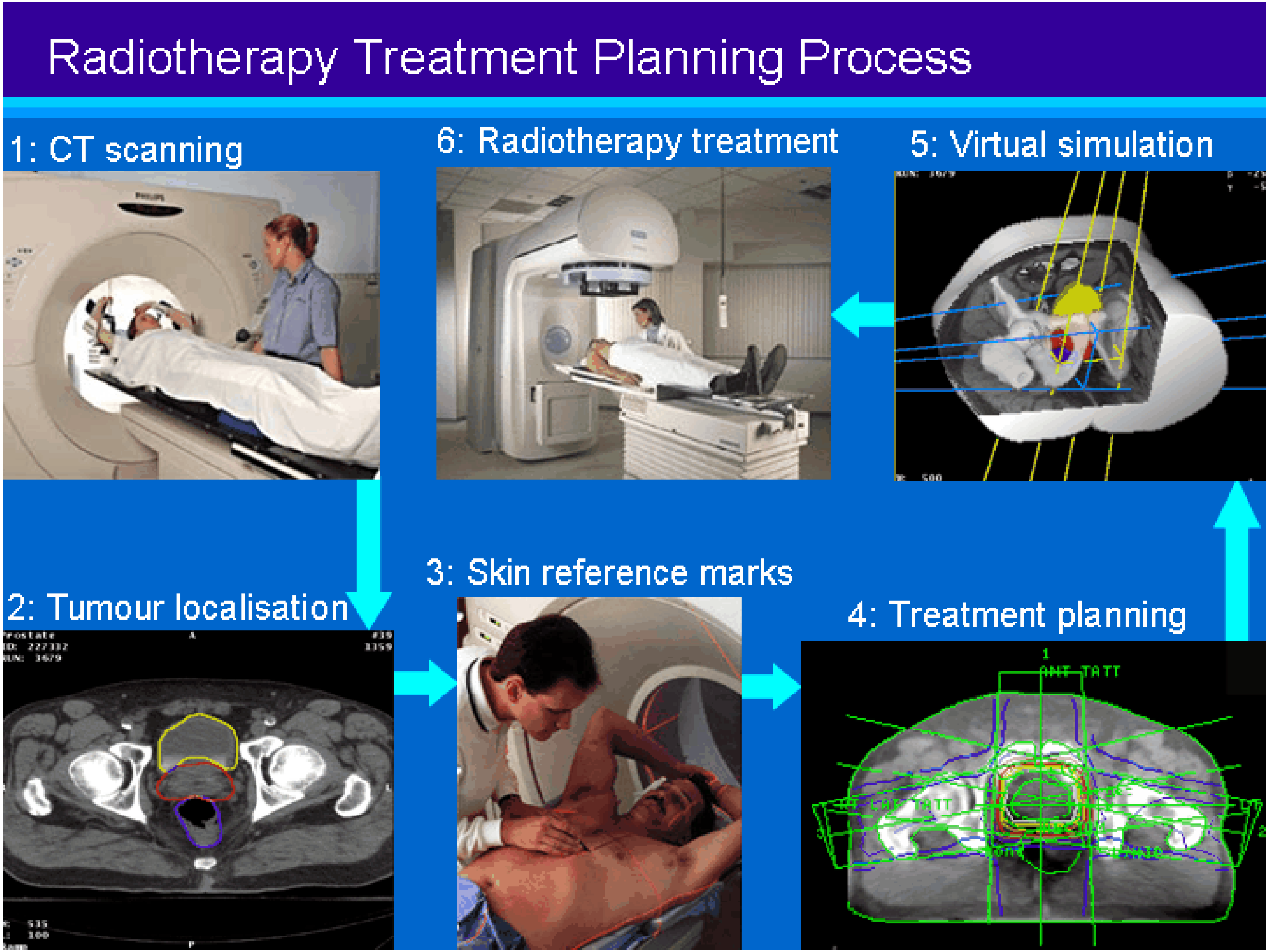
neutrons•

Carry enough energy which if deposited in matter can produce ions

История на Радиотерапията

1895 - Откриване на X лъчи - Vilhem K. Roentgen.
1898 - Откриване на Radium – Maria Curie.
1928 - H&N Cancer клинични резултати.
1950 - Начало на радиотерапията с γ лъчи (Co-60).
1954 - **Начало на протонната терапия** at Berkeley.
1961 - Linear Accelerator (LINAC) at Standford, USA.
1968 - Gamma - knife radio surgery at Uppsala, Sweden.
1971 - Copmuted Tomography.
1980 - Multi Leaves Collimator (MLC).
1988 - Intensity - Modulated Radiotherapy (IMRT).
2000 - Image Guided Radiotherapy (IGRT).

РАДИОТЕРАПИЯ



Radiotherapy Treatment Planning Process

1: CT scanning

2: Tumour localisation

3: Skin reference marks

4: Treatment planning

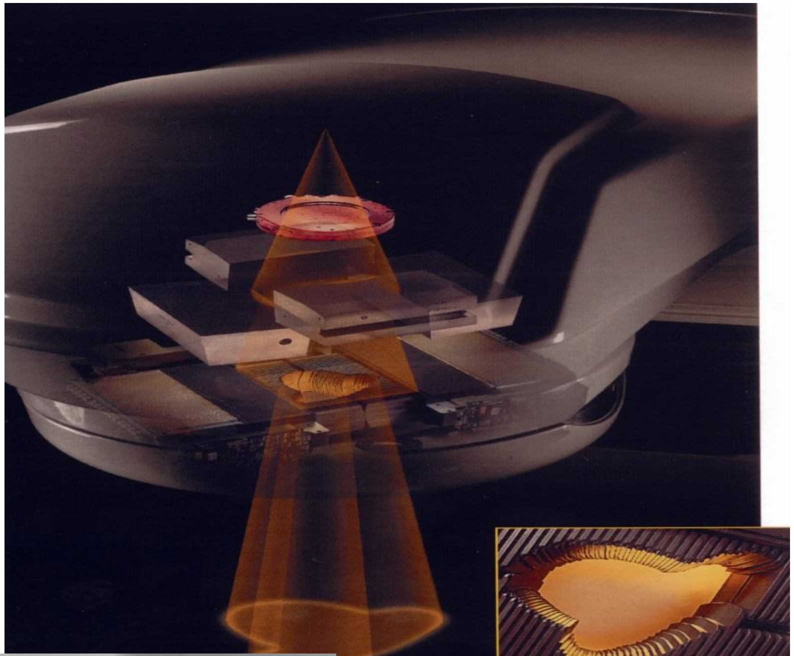
5: Virtual simulation

6: Radiotherapy treatment

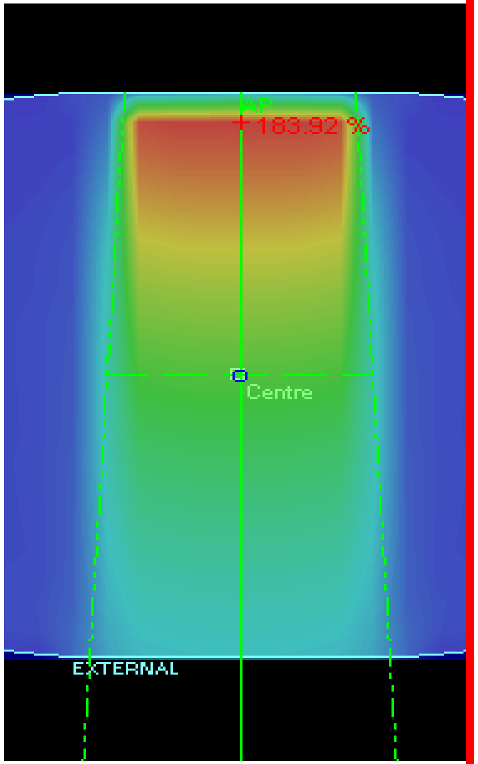
Съвременна радиотерапия с **X rays**

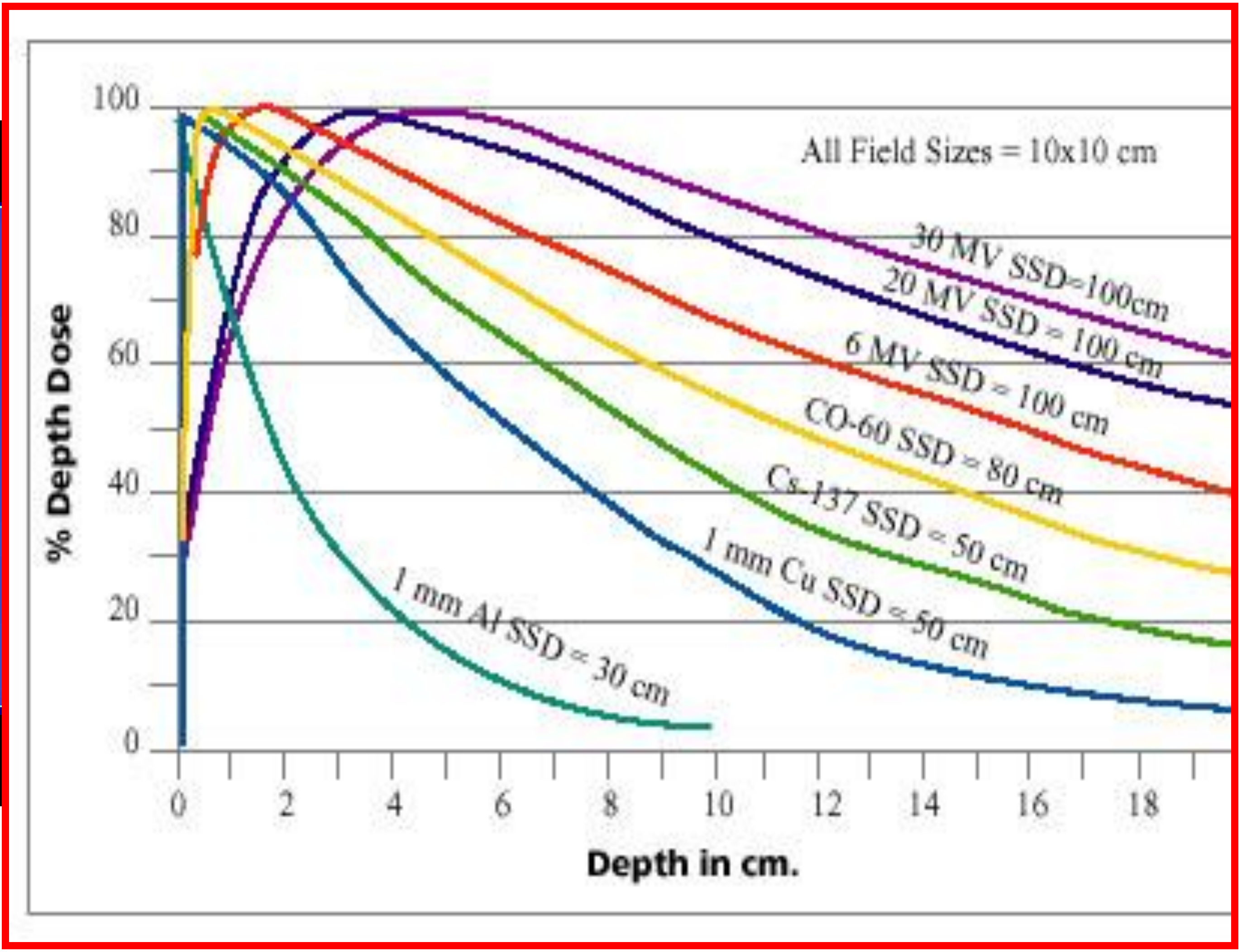
VARIAN Linac
X rays

Линеен Ускорител с MLC

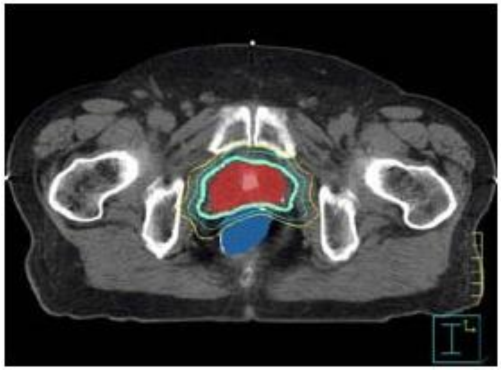


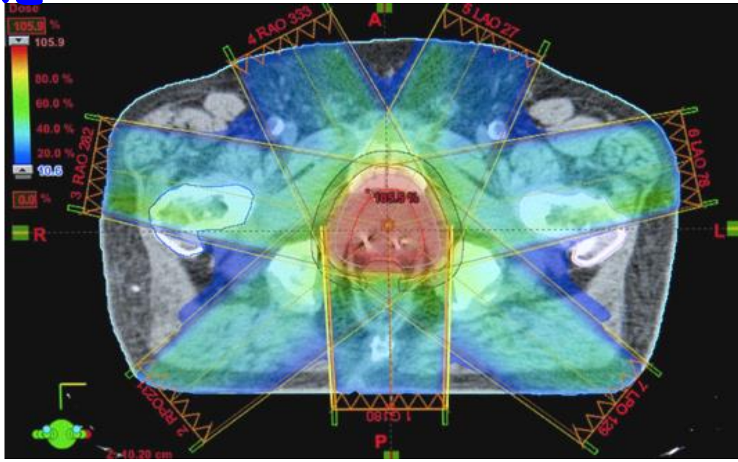
Прониквателна способност на фотонните лъчения в зависимост от Енергията

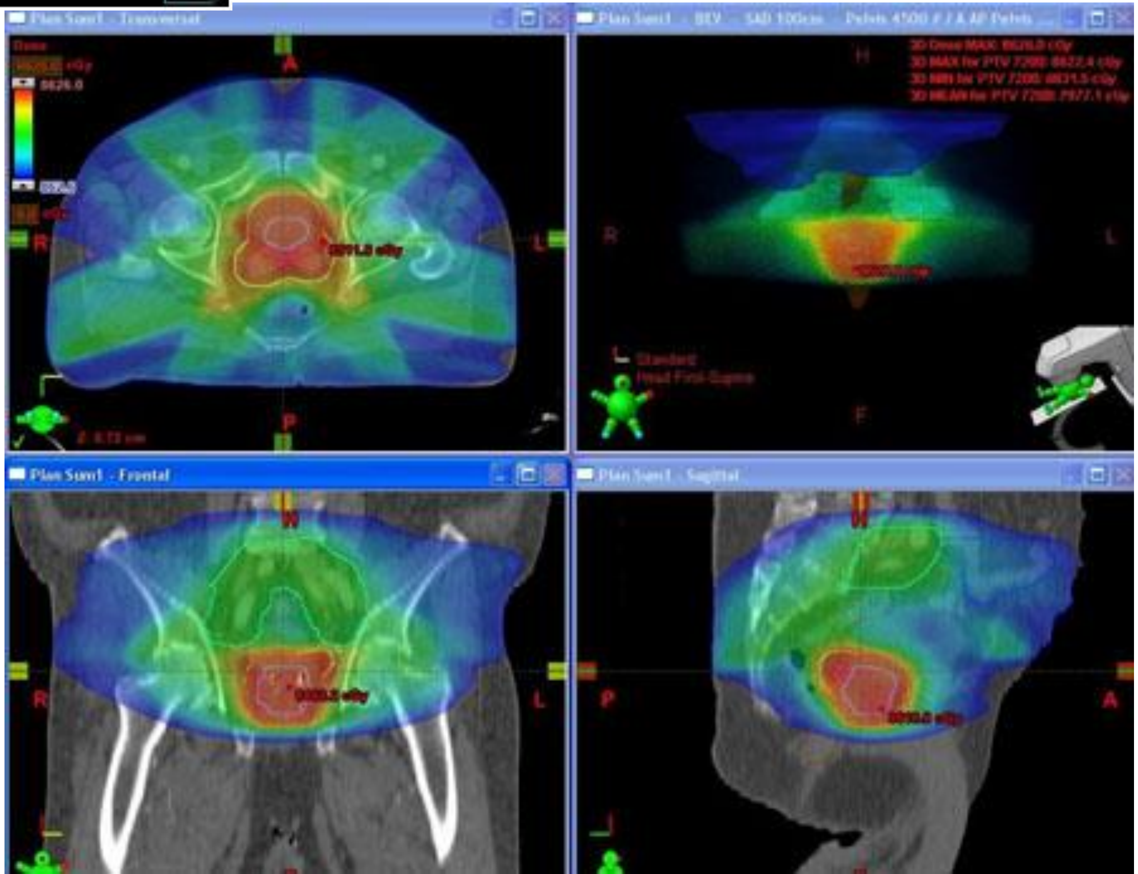




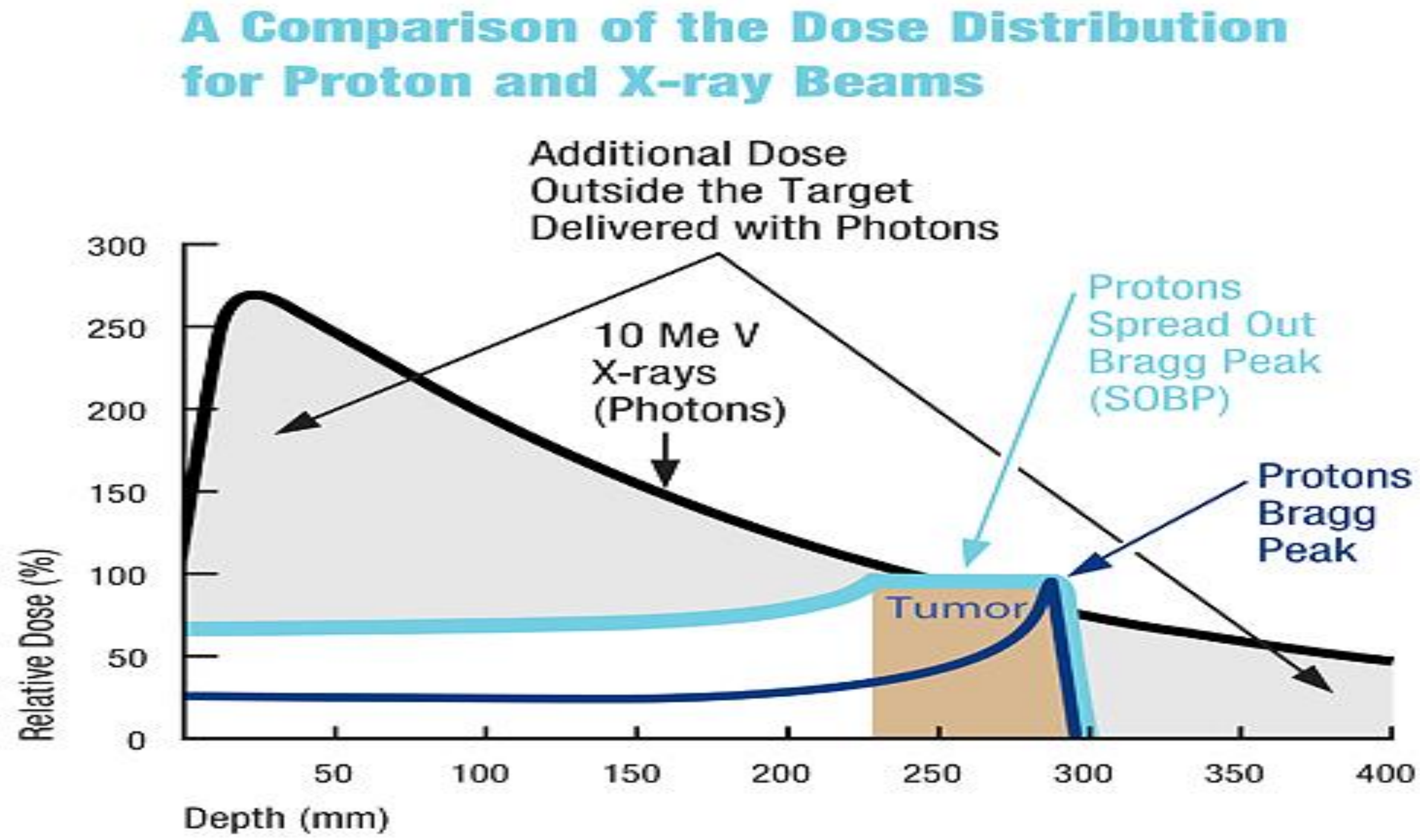
РАДИОТЕРАПИЯ при CA GL. PROSTATAE





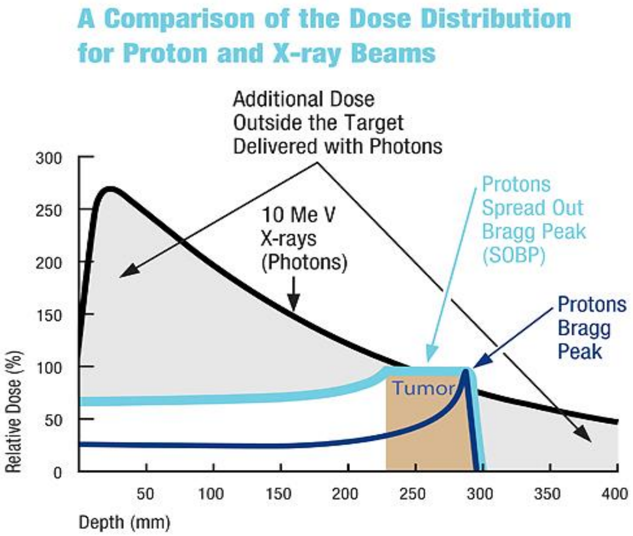


ЗАЩО ПРОТОННА ТЕРАПИЯ ? ? ?

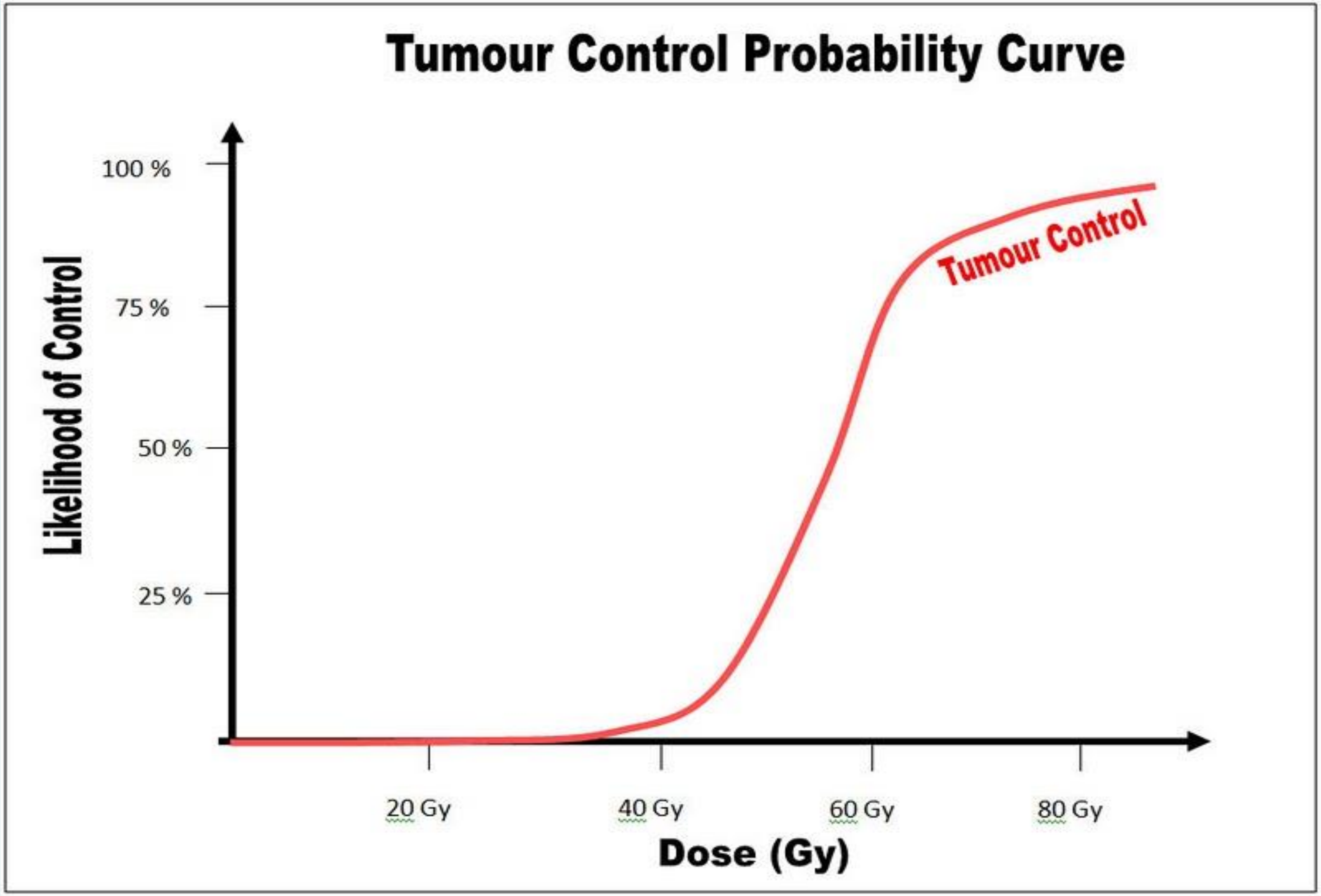


Физични аргументи за използването на протонните снопове в радиотерапията

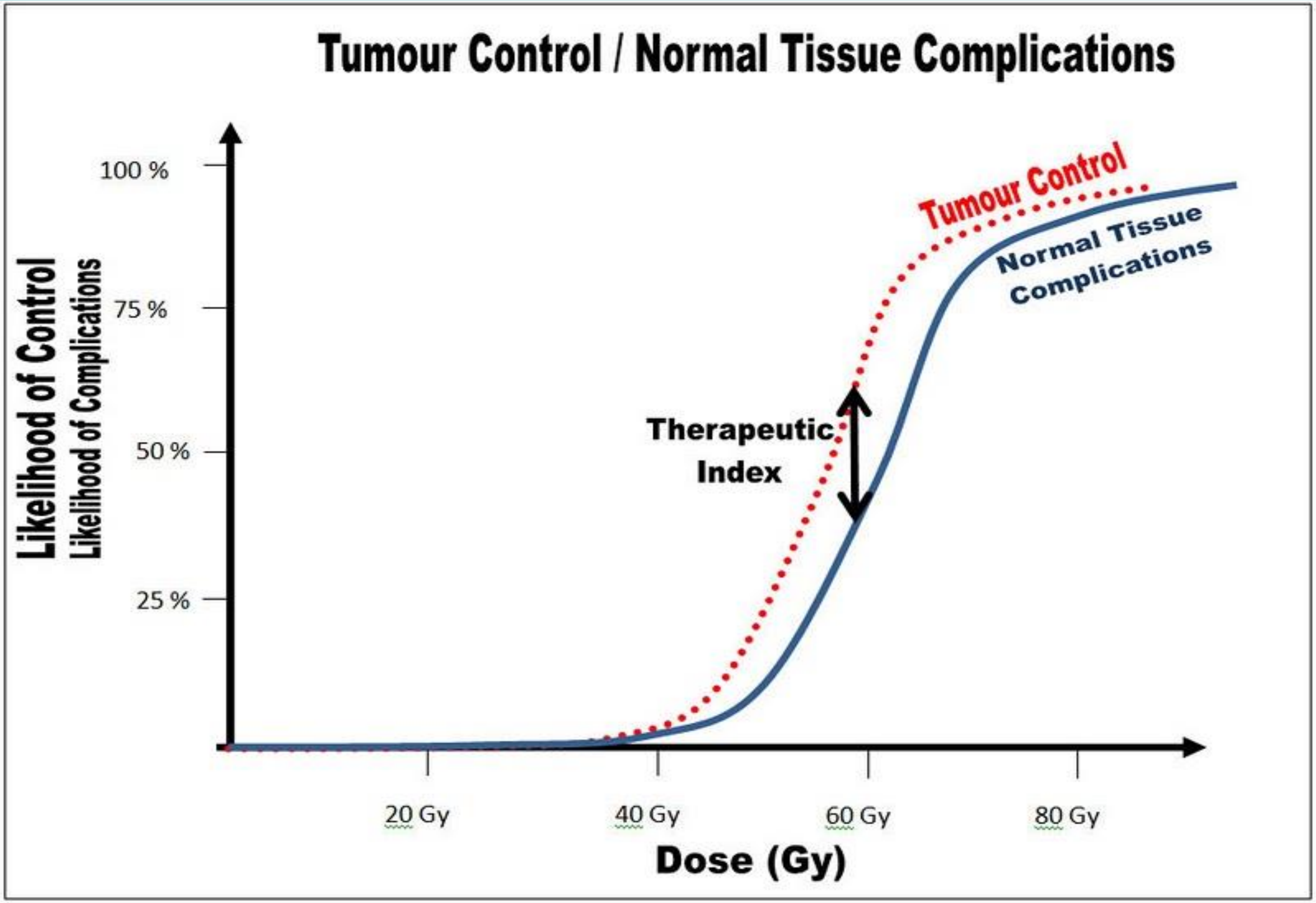
- ❑ обратен профил на дозното разпределение в дълбочина т.е. увеличава се предадената енергия с проникването в дълбочина (явлението Bragg peak)
- ❑ **ниска йонизационна способност**
- ❑ **енергетично модулиране на Bragg peak – получаване на (Spread-out Bragg Peak)**
- ❑ значително запазване на кожния ефект
- ❑ тясна полусянка
- ❑ здравите тъкани получават значително по-ниска доза от облъчвания туморен обем


A Comparison of the Dose Distribution for Proton and X-ray Beams

Вероятност за туморен контрол (TPC)



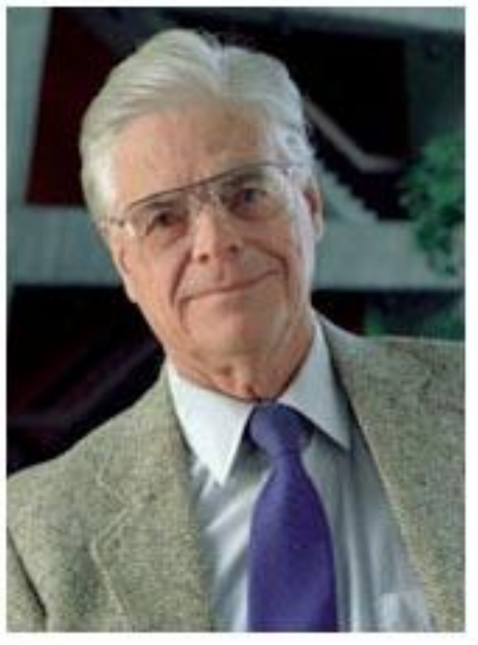
Вероятност за туморен контрол (TPC) и усложнения на здравите тъкани (NTPC)



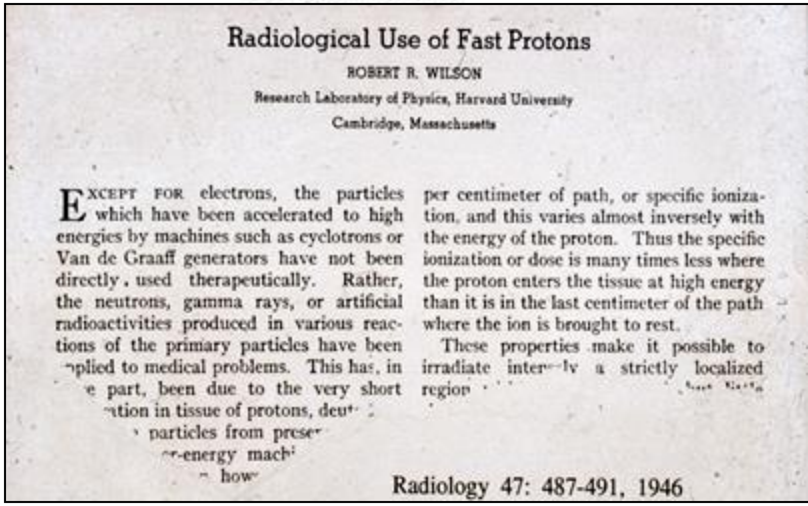
НАЧАЛО на ПРОТОННАТА ТЕРАПИЯ

"A man with a vision "

- 1946 - Prof.Robert Wilson - Harvard physicist.
- Протоните могат да имат клинично приложение.
- Максимална доза лъчение може да се реализира в дълбочина.
- Протонната терапия осигурява максимална защита на здравите тъкани.



Robert Wilson



Radiological Use of Fast Protons

ROBERT R. WILSON

Research Laboratory of Physics, Harvard University

Cambridge, Massachusetts

EXCEPT FOR electrons, the particles which have been accelerated to high energies by machines such as cyclotrons or Van de Graaff generators have not been directly, used therapeutically. Rather, the neutrons, gamma rays, or artificial radioactivities produced in various reactions of the primary particles have been plied to medical problems. This has, in e part, been due to the very short tion in tissue of protons, deu particles from prese r-energy mach how

per centimeter of path, or specific ionization, and this varies almost inversely with the energy of the proton. Thus the specific ionization or dose is many times less where the proton enters the tissue at high energy than it is in the last centimeter of the path where the ion is brought to rest.

These properties make it possible to irradiate inter ly a strictly localized region

Radiology 47: 487-491, 1946

История на Протонната терапия (1)

1938 - *Неутронна терапия* at Berkeley Lab (J. Lawrence and R.S. Stone)

1946 - Предложение за протонна терапия by Robert Wilson in Harvard Cyclotron Laboratory

1954 - Първо клинично приложение in Berkeley.

1957 - Начало на Европейският опит Uppsala, Sweden.

1968 - Протонна установка at JINR, Dubna, Russian Federation.

1969 - Протонна установка at Mosskow, Russian Federation .

1972 - Неутронна терапия at MD Anderson, USA.

1974 - pi meson beam at Los Alamos, USA.

История на Протонната терапия (2)

1975 - Протонен център at St. Petersburg,
Russian Federation.
1975 - Протонен център at Harvard.
(pioneers eye cancer treatment with protons)
1979 - Протонен център Chiba, Japan.

1988 - Proton therapy approved by FDA.

1989- Протонен център at Clatterbridge, UK.

1990 - Particle Therapy Cooperative Group.

1990 - First hospital-based facility at Loma Linda, USA.
1991 - Протонен център at Nice and Orsay, France.

История на Протонната терапия (3)

1993 - Протонна терапия at Cape Town, South Africa.

1996 - PSI proton facility at Villigen, Switzerland.

1998 - Протона терапия at Berlin, Germany.
2001 - Протонен център Massachusetts, USA.
2006 - Протонен център MD Anderson opens, USA.
2007 - Протонен център, Jacksonville, Florida, USA.
2008 - Неутронна терапия re-stated at Fermilab, USA.
2012 - Протонен център, Prague, Czech Republic.

Клинични предимства на протонната терапия

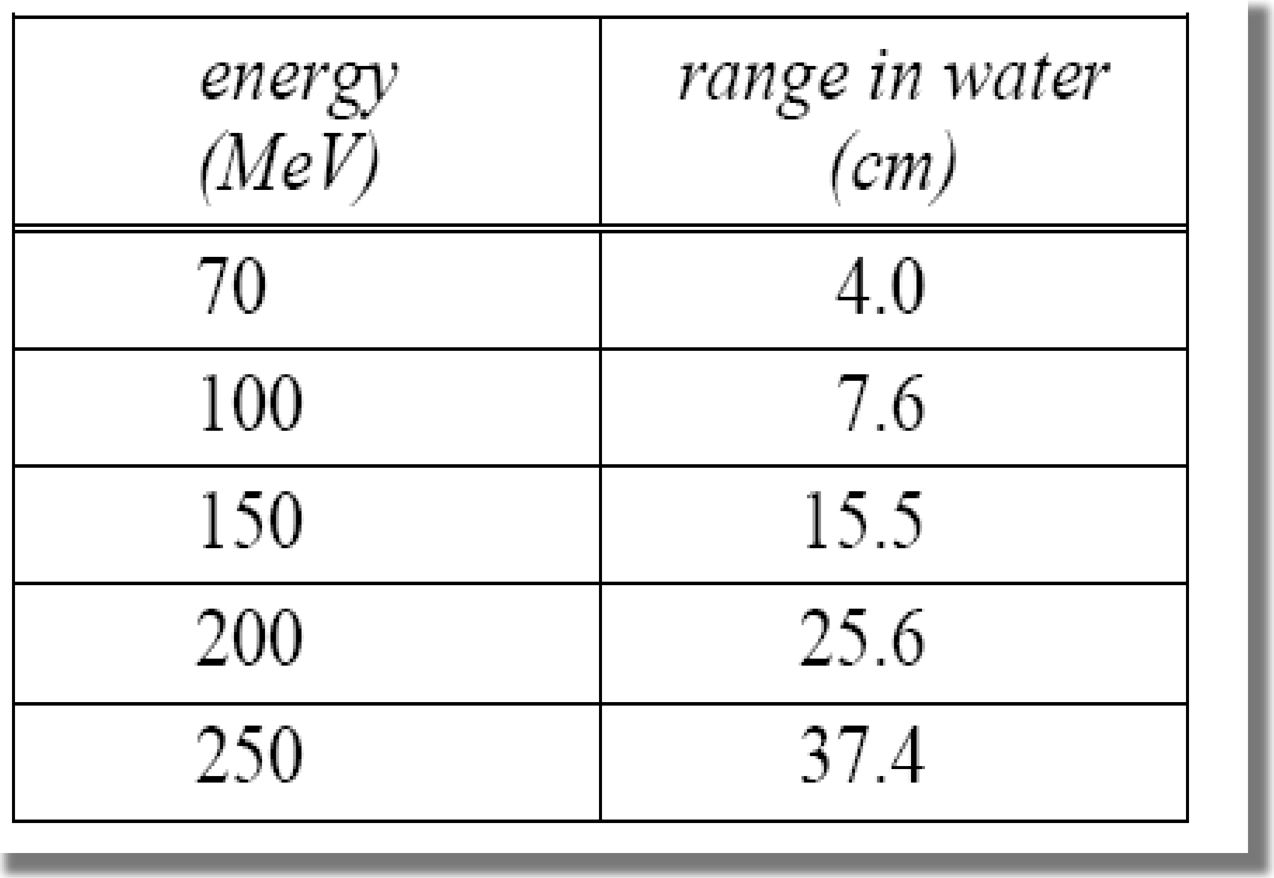
- висока точност на апликираната доза
- висок туморен контрол
- незначителни увреждания на здравите тъкани
- липса на странични ефекти
- ниска вероятност (риск) от вторичен карцином
- неинвазивна терапия

Център за протонна терапия

- Ускорител на протонни снопове
- Транспортна система на протонните снопове
- Процедурно помещение
- Gantry
- Пациентна маса

Ускорител на протонни снопове

ПРОБЕГ НА ПРОТОНИТЕ ВЪВ ВОДА



energy (MeV)	*range in water (cm)*
70	4.0
100	7.6
150	15.5
200	25.6
250	37.4

C230 key specifications

- Compact isochronous cyclotron

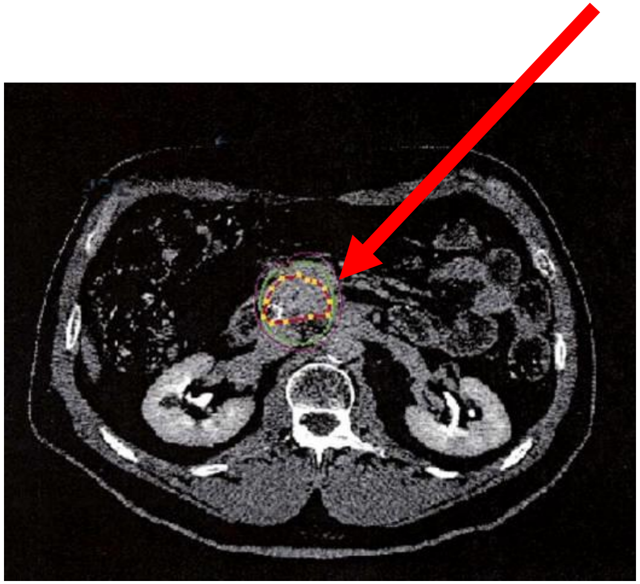
- 235 MeV proton energy
- 300 nA beam current, quasi-continuous
- Typical efficiency : 55 %

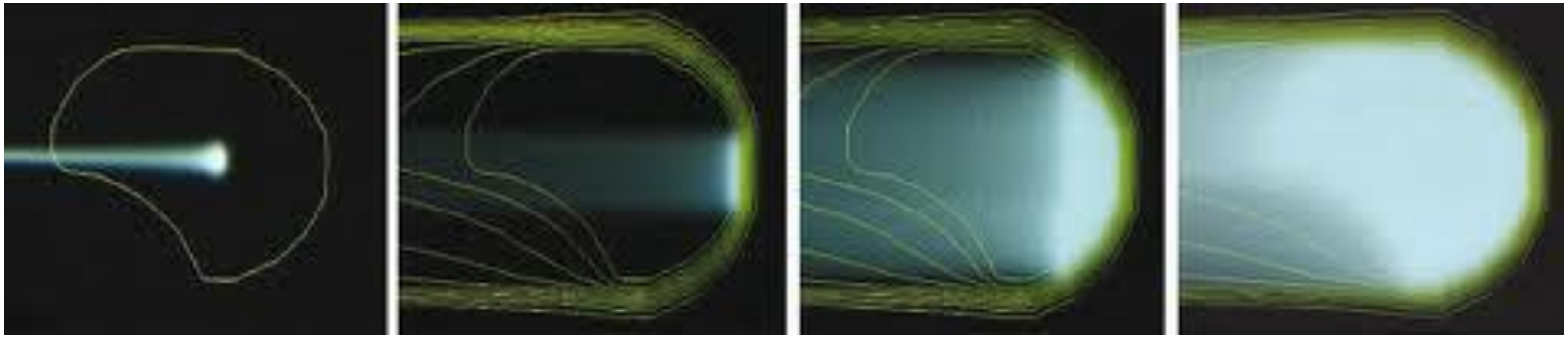
- Approx. weight: 220 T
- Diameter: 4.3 m

- Conventional magnet coil: 1.7 - 2.2 T
- RF Frequency: 106 MHz
- Dee voltage: 55 to 150 kV peak

ПРОТОНЕН СНОП

Клиничен мишенен обем





НАЧИНИ ЗА ФОРМИРАНЕ НА КЛИНИЧНИ ПРОТОННИ СНОПОВЕ

Single Scattering: Delivers a uniform proton dose in small fields with only one scatterer.

Double Scattering: Accepts any energy at nozzle entrance within the 70-235 MeV range.
Reduces the distal falloff. Reduces the lateral penumbra and the radiation level.

Passive Scaterring

Uniform Scanning: The beam spot is moved by magnetic scanning and allows several mini-irradiations.
Full modulation, field uniformity, very safe treatment.

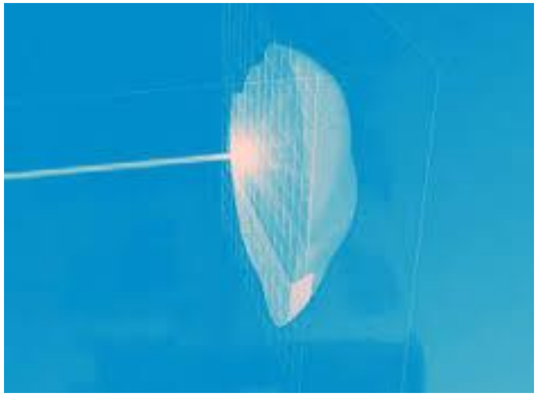
Pencil Beam Scanning: Slice-by-slice irradiation of the target with millimetre precision.
Primary advantages include: multiple fast repainting, no use of aperture, no compensator devices, dose uniformity, intensity modulation (IMPT).

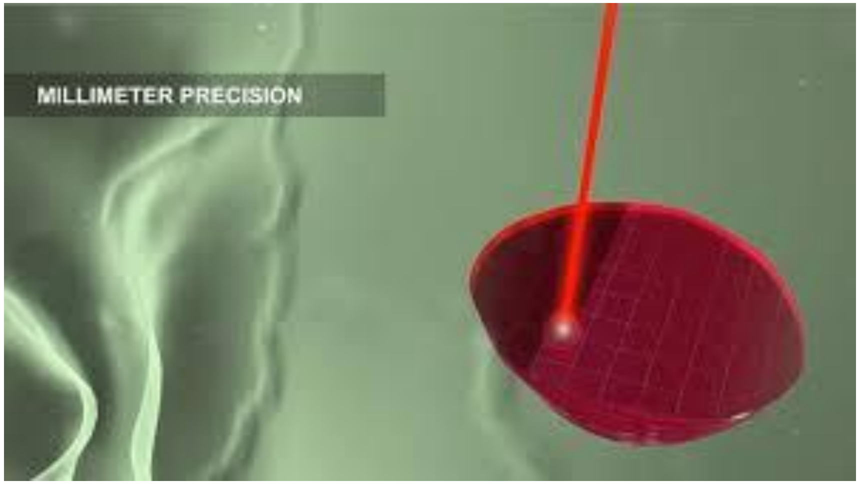
Active Scanning

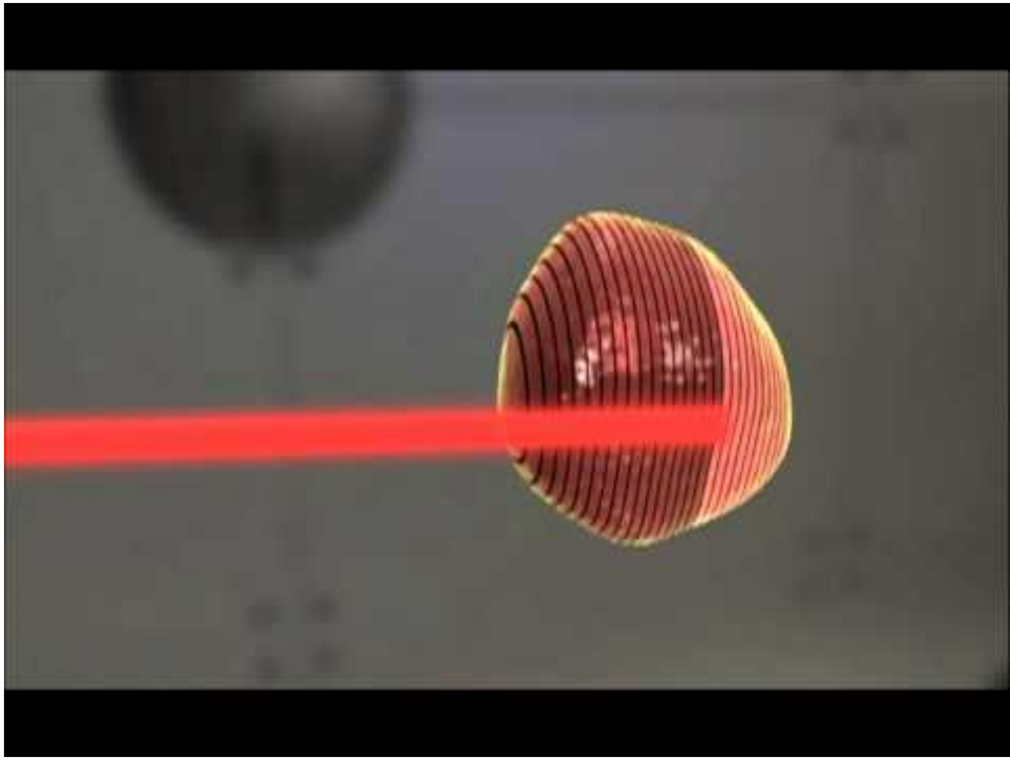
ФОРМИРАНЕ НА ПРОТОННИЯ СНОП ЗА КЛИНИЧИНО ПРИЛОЖЕНИЕ

II. Активно сканиране

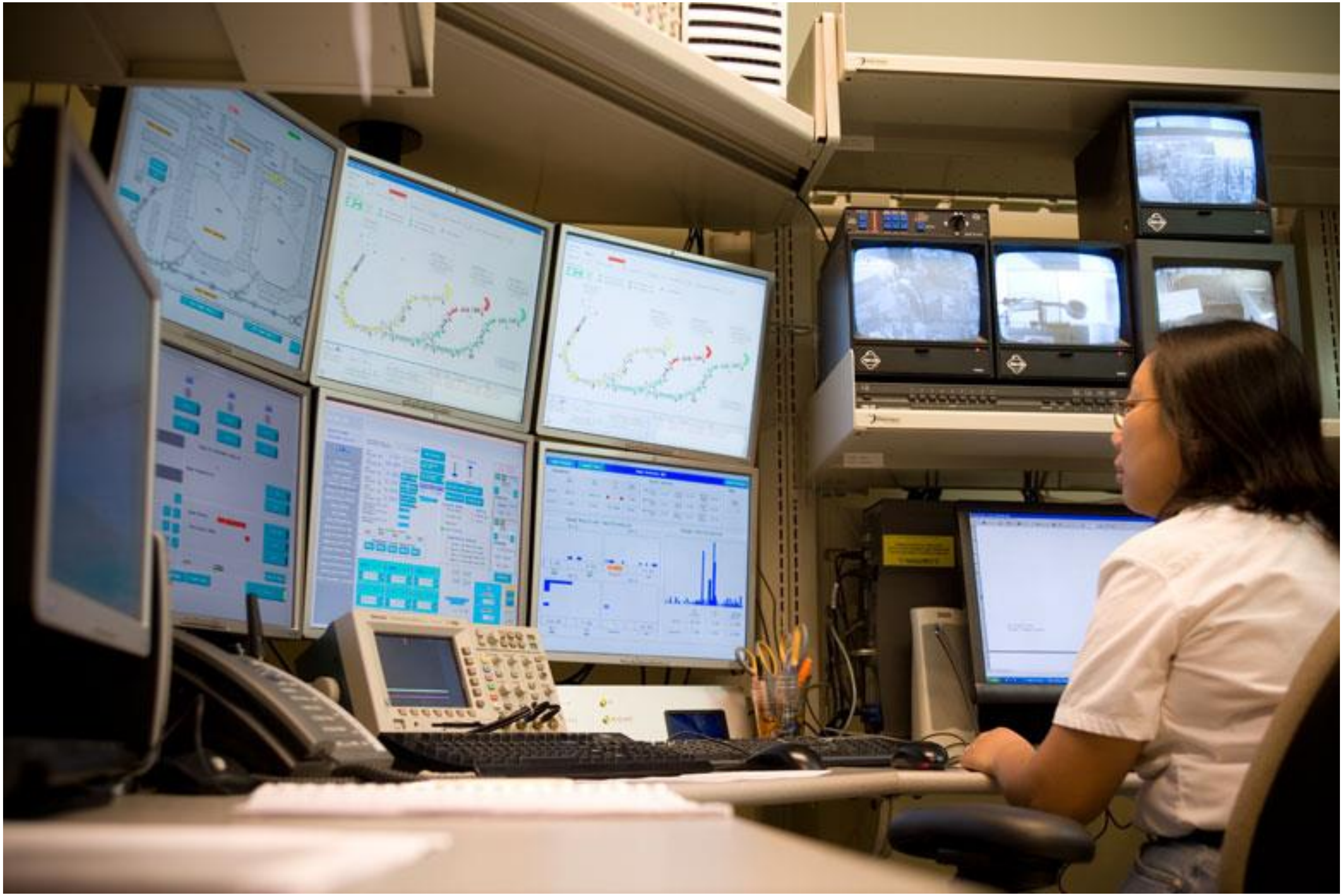
(Pensil Beam Scannig)







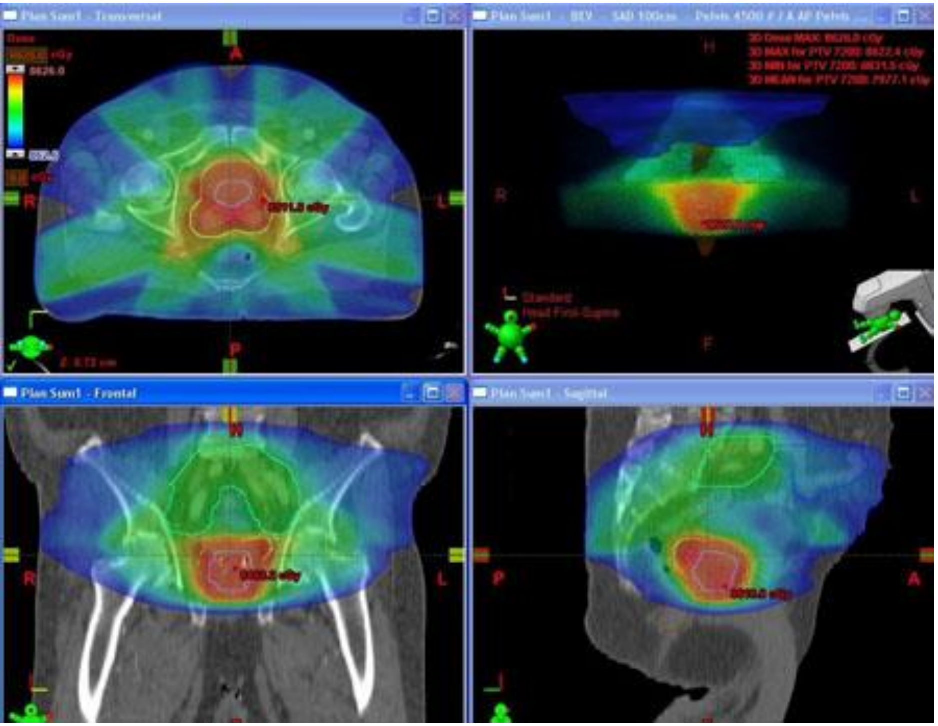
Control room of Proton Therapy Center

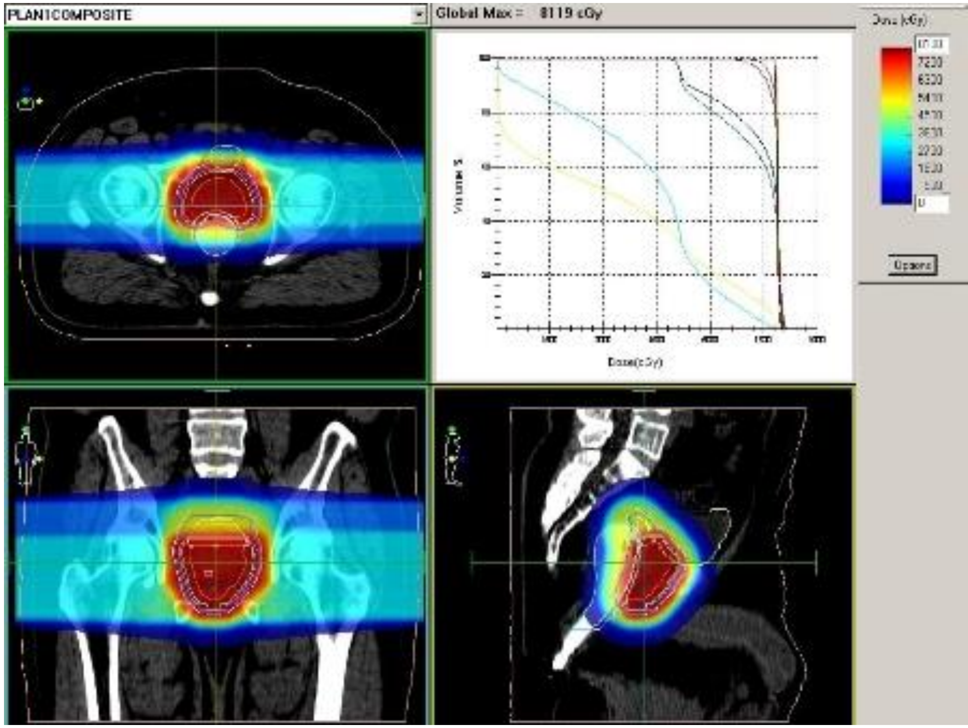


РАДИОТЕРАПИЯ при CA GL. PROSTATAE

IMRT с X лъчи

Proton Therapy

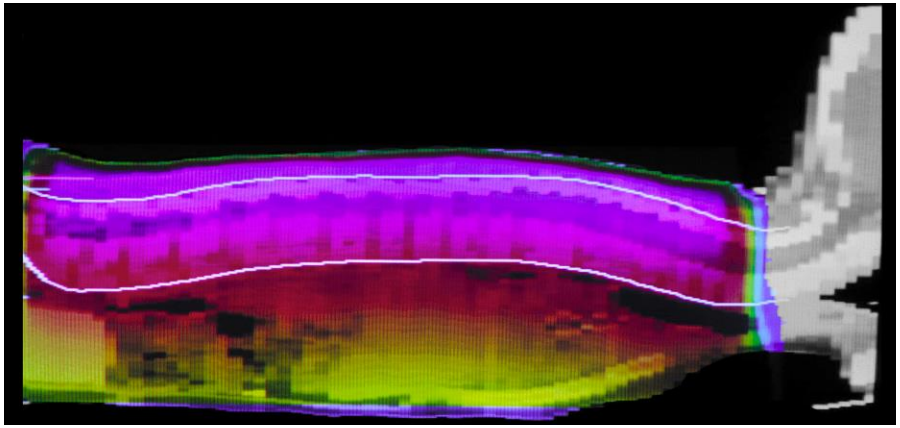




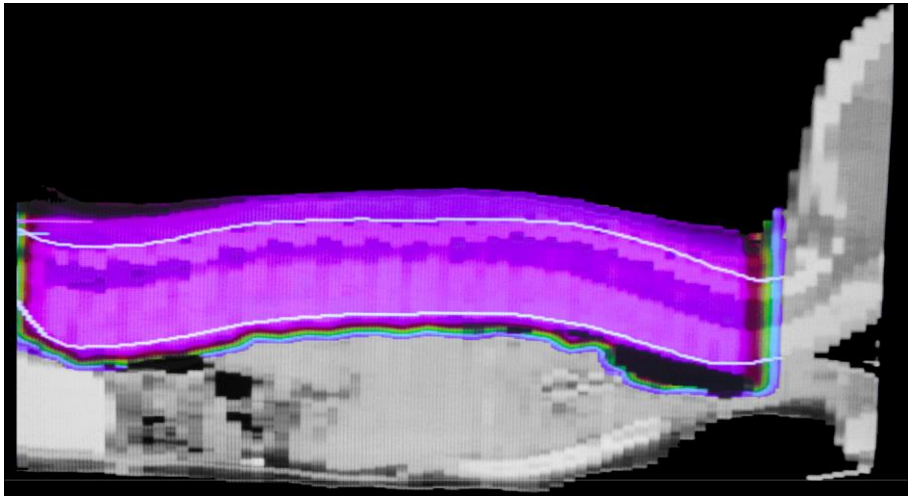
Протонна терапия

Радиотерапия при Cancer Pediatric Decease (Medulloblastoma)

IMRT с X лъчи



Протонна терапия



PROTON THERAPY for Lung CA

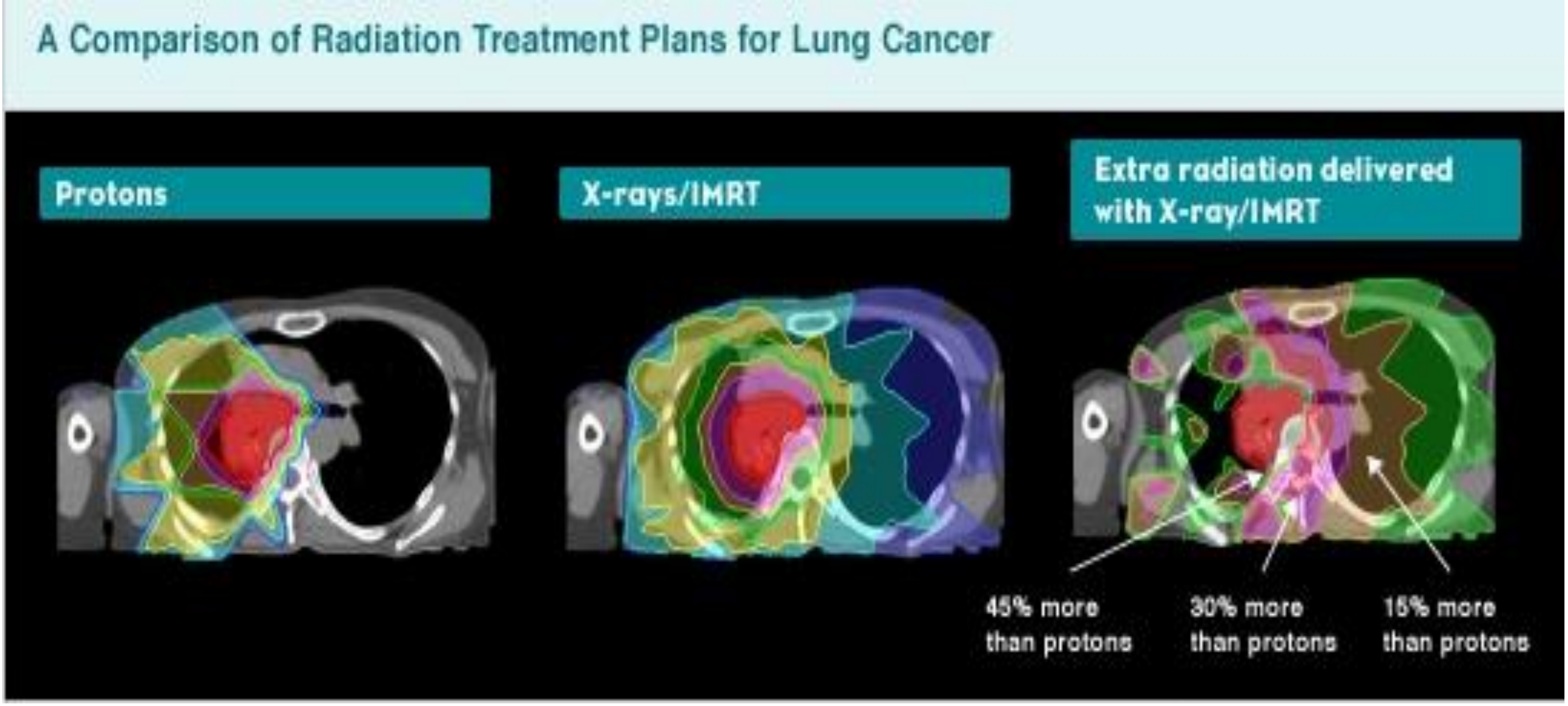
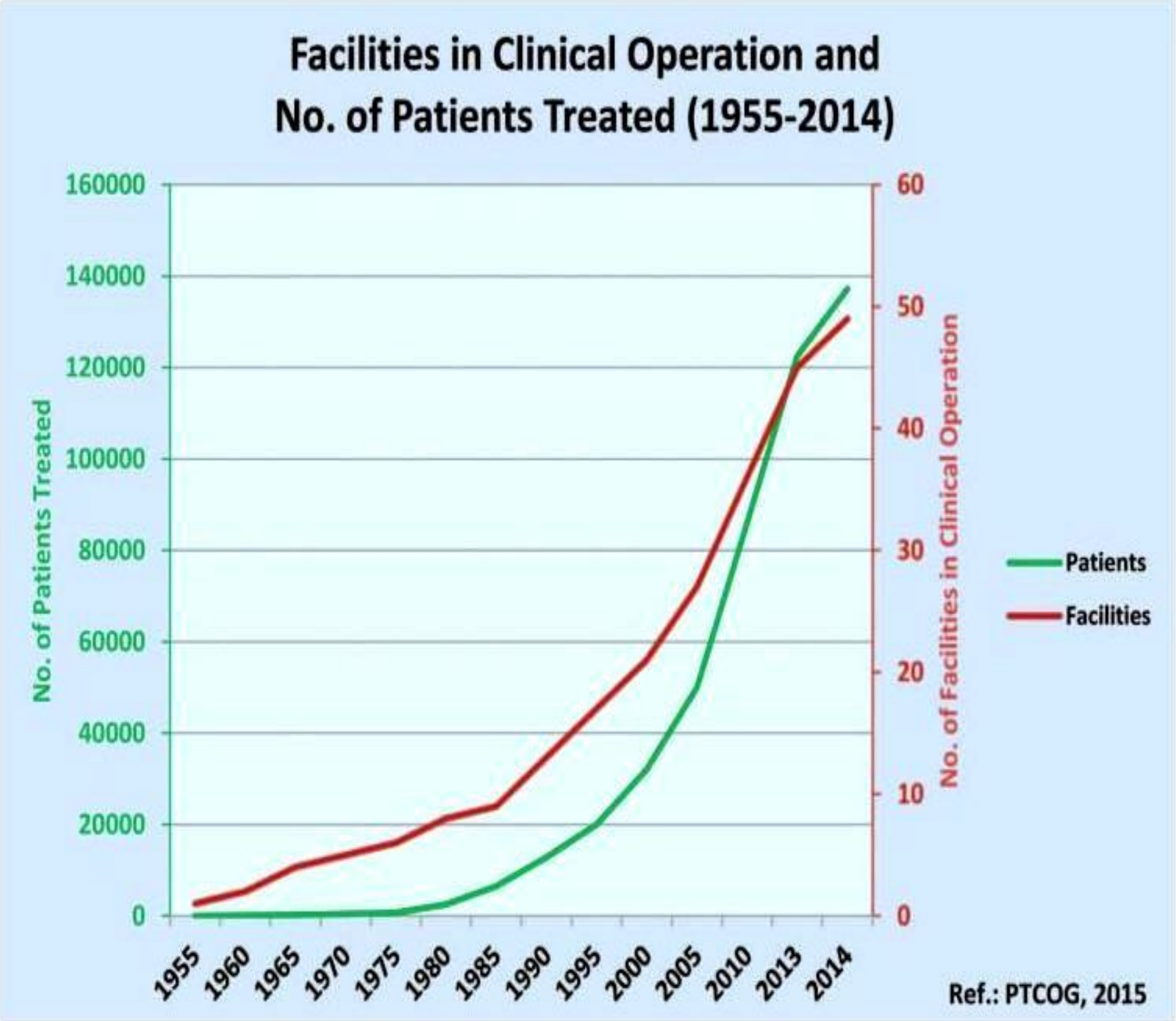


Figure 1. Facilities in clinical operation and the number of patients treated from 1955 to 2014.

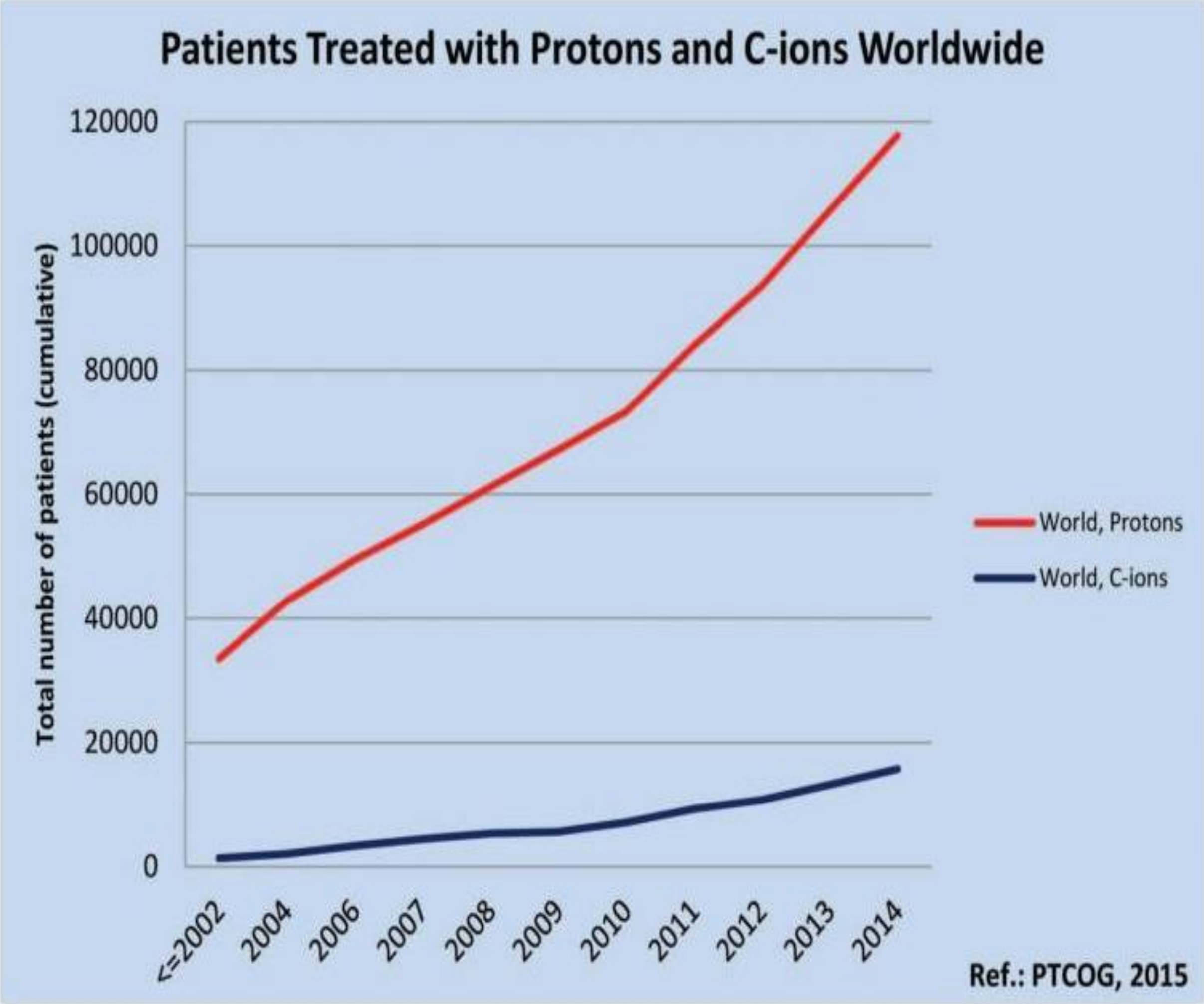


Ref.: PTCOG, 2015

INTERNATIONAL
JOURNAL
of PARTICLE
THERAPY

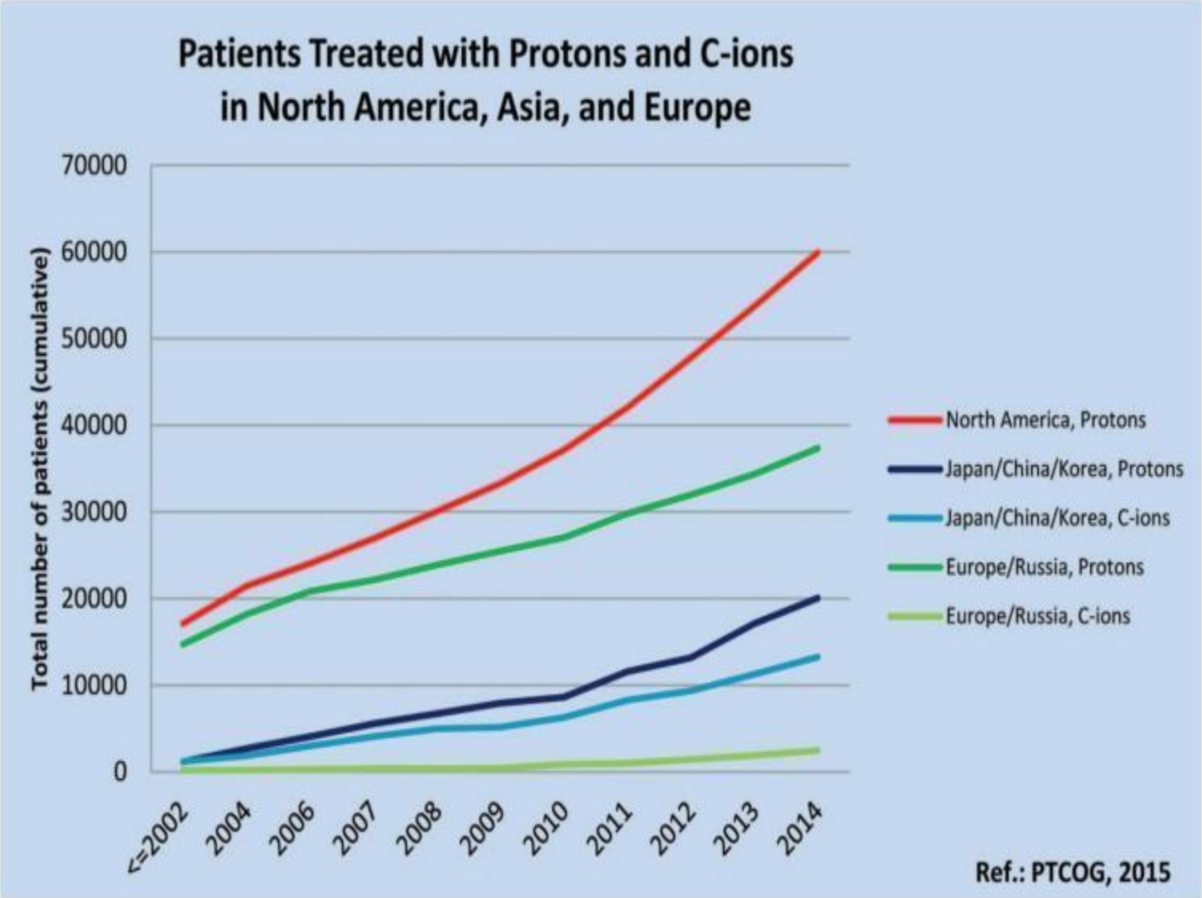
Particle therapy statistics in 2014

Figure 3. Patients treated with proton and carbon ions worldwide.


Patients Treated with Protons and C-ions Worldwide

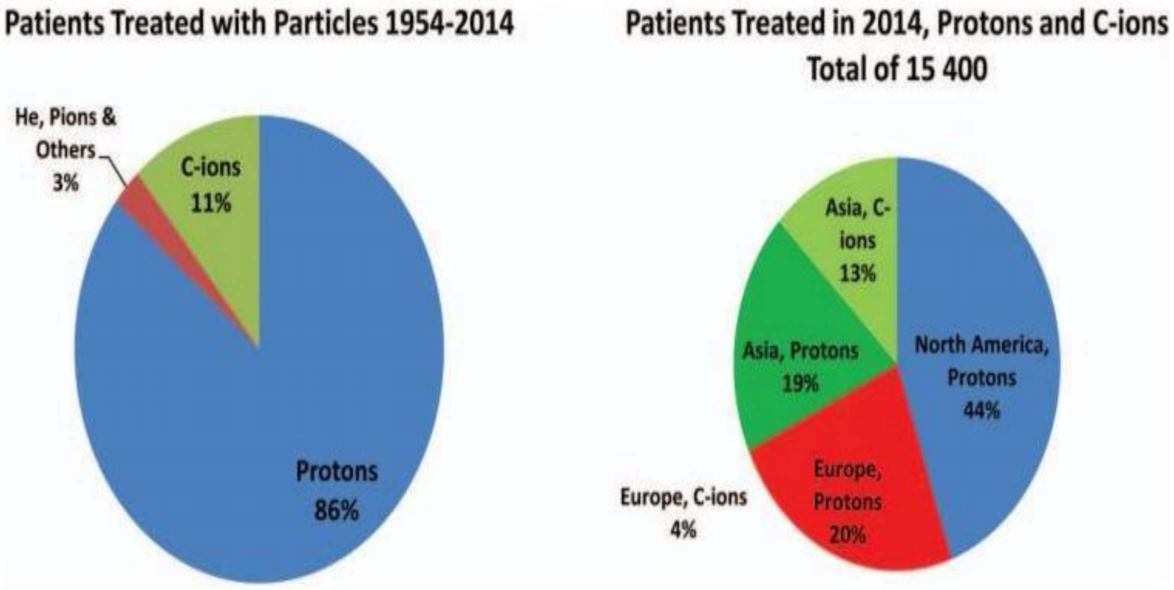
Ref.: PTCOG, 2015

Figure 2. Patients treated with protons and carbon ions in North America, Asia, and Europe.

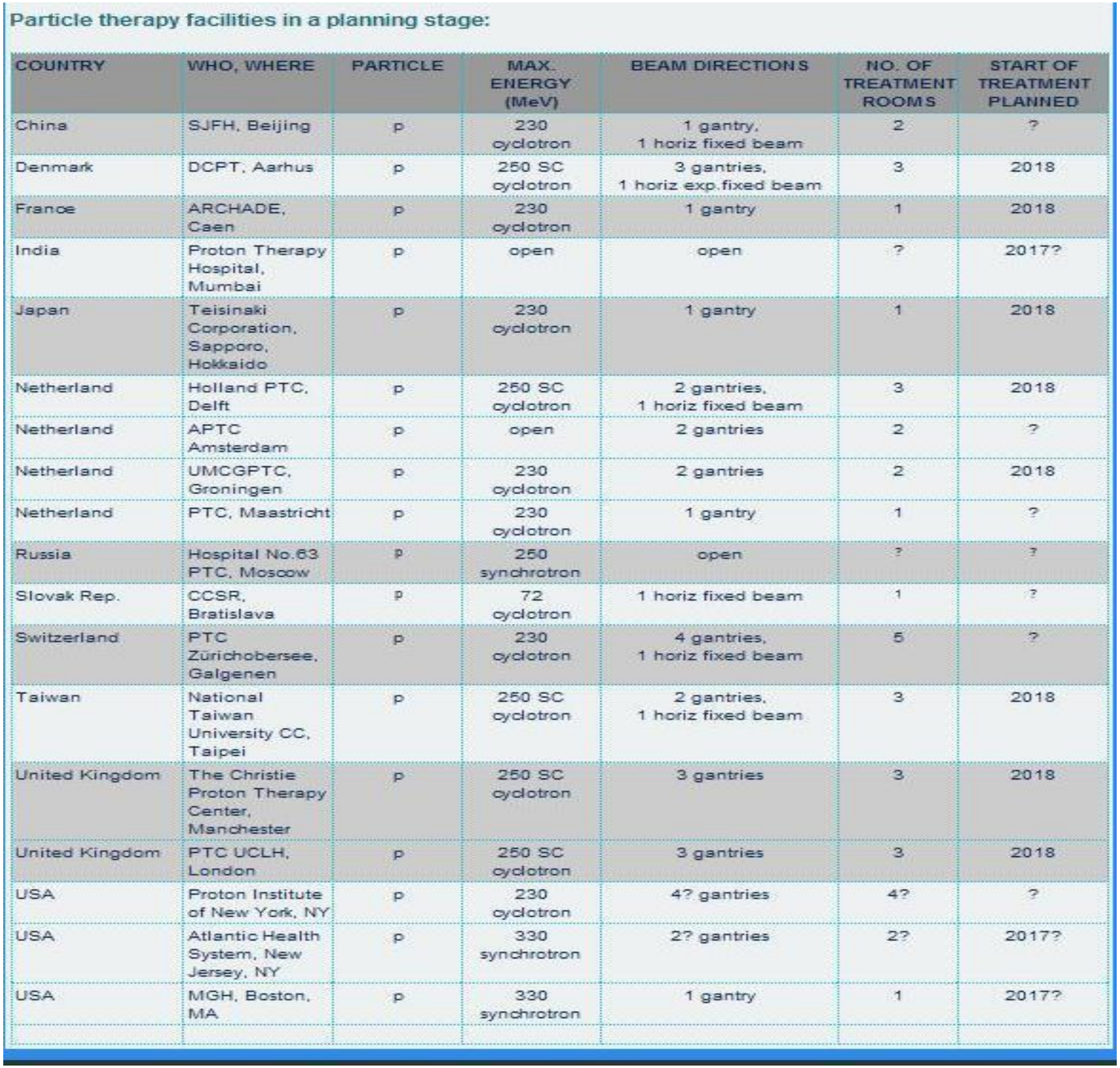


Ref.: PTCOG, 2015

Figure 4. Pie charts depicting (A) patients treated with particle from 1954 to 2014 and (B) patients treated in 2014 with protons and carbon ions (total = 15 000).



ПРОТОННИ ЦЕНТРОВЕ В ЕТАП НА ПЛАНИРАНЕ



Particle therapy facilities in a planning stage:

COUNTRY	WHO, WHERE	PARTICLE	MAX. ENERGY (MeV)	BEAM DIRECTIONS	NO. OF TREATMENT ROOMS	START OF TREATMENT PLANNED
China	SJFH, Beijing	p	230 cyclotron	1 gantry, 1 horiz fixed beam	2	?
Denmark	DCPT, Aarhus	p	250 SC cyclotron	3 gantries, 1 horiz exp.fixed beam	3	2018
France	ARCHADE, Caen	p	230 cyclotron	1 gantry	1	2018
India	Proton Therapy Hospital, Mumbai	p	open	open	?	2017?
Japan	Teisinaki Corporation, Sapporo, Hokkaido	p	230 cyclotron	1 gantry	1	2018
Netherland	Holland PTC, Delft	p	250 SC cyclotron	2 gantries, 1 horiz fixed beam	3	2018
Netherland	APTC Amsterdam	p	open	2 gantries	2	?
Netherland	UMCGPTC, Groningen	p	230 cyclotron	2 gantries	2	2018
Netherland	PTC, Maastricht	p	230 cyclotron	1 gantry	1	?
Russia	Hospital No.63 PTC, Moscow	p	250 synchrotron	open	?	?
Slovak Rep.	CCSR, Bratislava	p	72 cyclotron	1 horiz fixed beam	1	?
Switzerland	PTC Zürichobersee, Galgenen	p	230 cyclotron	4 gantries, 1 horiz fixed beam	5	?
Taiwan	National Taiwan University CC, Taipei	p	250 SC cyclotron	2 gantries, 1 horiz fixed beam	3	2018
United Kingdom	The Christie Proton Therapy Center, Manchester	p	250 SC cyclotron	3 gantries	3	2018
United Kingdom	PTC UCLH, London	p	250 SC cyclotron	3 gantries	3	2018
USA	Proton Institute of New York, NY	p	230 cyclotron	4? gantries	4?	?
USA	Atlantic Health System, New Jersey, NY	p	330 synchrotron	2? gantries	2?	2017?
USA	MGH, Boston, MA	p	330 synchrotron	1 gantry	1	2017?

Официалното издание на Particle Therapy Cooperative Group
том I, брой 1, 2014

VOLUME ONE / ISSUE ONE / Summer 2014

International Journal of Particle Therapy

The official journal of the Particle Therapy Cooperative Group

- *Preliminary Outcomes for Reirradiation of Recurrent Rectal Cancer*
- *Patient-reported Hip Symptoms after Proton Therapy for Prostate Cancer*
- *Comparing Proton Therapy and VMAT for Prostate Cancer*
- *A Case of Proton Therapy for Spinal Cord Compression from Extramedullary Hematopoiesis*
- *Proceedings from PTCOG-52*

INTERNATIONAL JOURNAL of PARTICLE THERAPY

http://theijpt.org/

- Протонната терапия е следващата логична стъпка в развитието на радиотерапията, подобрявайки дозното разпределение.

- Протонната терапия е сериозно предизвикателство за професионалистите, работещи съвременни форми на радиотерапията.

- Днес протонната терапия е атрактивна, прецизна и модерна форма на радиотерапията.

Scripps Proton Therapy Center, San Diego, USA

- XV- ия - Протонен център – 20 Февруари 2014
- 250 MeV
- 5 Gantries, 5 процедурни помещения, 2400 пациенти/годишно
- Инвестиция – $220 млн.

Dr. Carl Rossi – "Using pencil beam to treat tumors is like using a very fine paint brush to apply the radiation, whereas earlier proton technology is more like using a can of spray paint".

Available on: http://itnonline.com/article/scripps

Paul Scherrer Institute, Villigen, Switzewrland

ACCEL for PROSCAN at PSI
One of the very first best place for protontherapy in Europe

- ☐ March 22, 2007 - the second generation (ACCEL), Paul Scherrer Institute, VILLIGEN, Switzewrland.

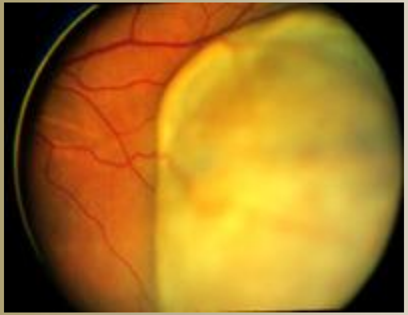
- ☐ The world's first commercial superconducting cyclotron for routine medical use.

Proton-Radiotherapy:

Eye tumors

Fundus of the eye

PRIOR to therapy



Fundus of the eye

AFTER therapy

Local Tumor Control (at actuarial 10 years and depending in size and site)

- **98 % (PSI, > 4700 patients)**
- **95.7% (MGH/MEEI)**

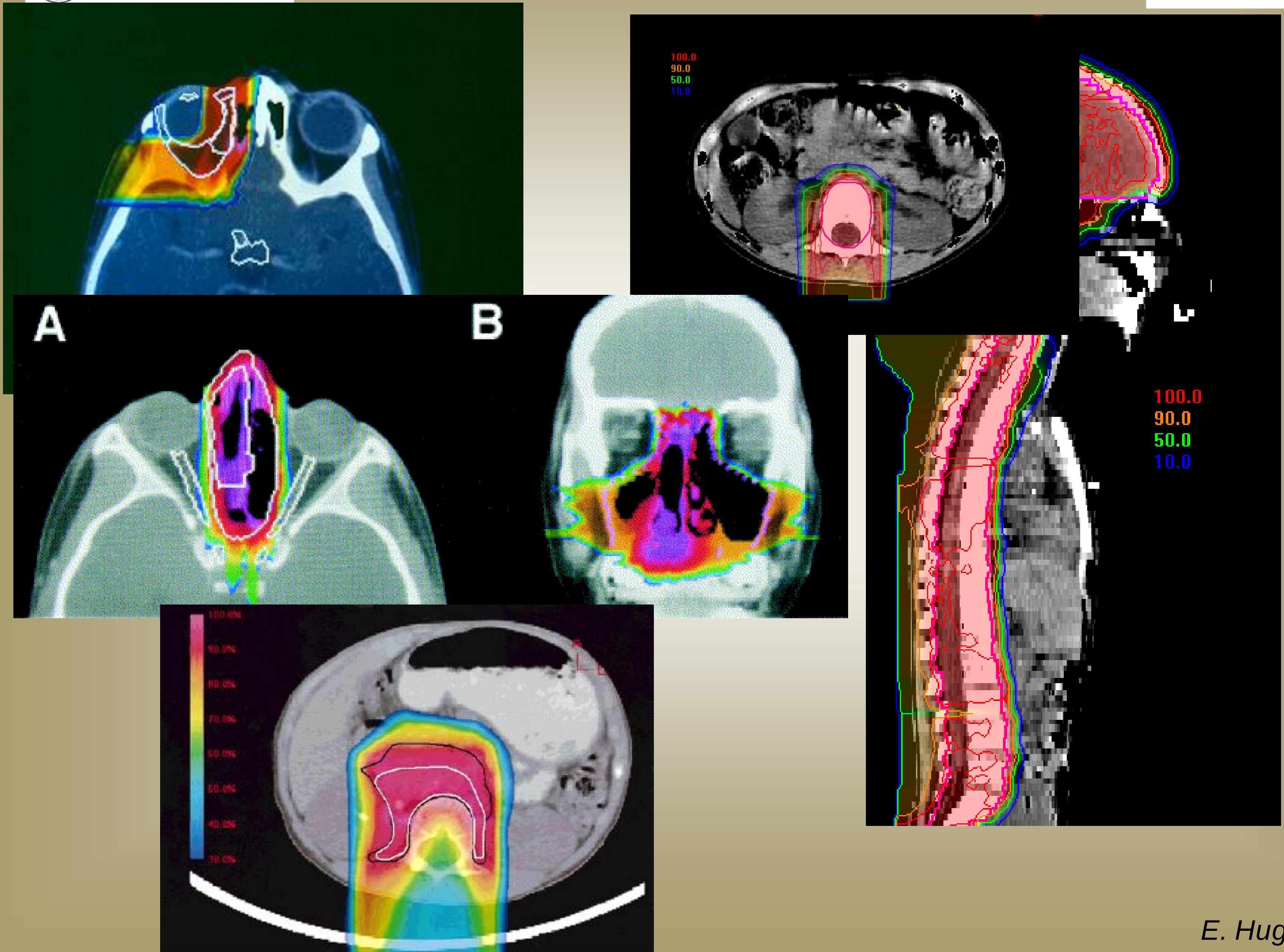
Retention of the eye: depending on tumor size and location, about 70-97% (PSI)

E. Hug

Universität Zürich

Pädiatrische Protonen- Radiatiotherapie

PAUL SCHERRER INSTITUT PSI



E. Hug

ПЕРСПЕКТИВИ ЗА РАЗВИТИЕ

- ☐ Последни постижения в ядрените и информационните технологии.
- ☐ Последни постижения в CERN.

The recent technical innovations in proton therapy - modulation of pencil proton beams, intensity modulated proton therapy (IMPT) and grid proton therapy **(reducing a radiation beam diameter from 1 mm to 25 µm)** – will allow us to really accurately "paint" the dose to the tumor and spare critical structures, much as we do with intensity-modulated photon therapy (IMRT), but also to further reduce the dose compared to IMRT [1,2].

[1] COMBS, S.E., JAKEL, O., HABERER, T., DEBUS, J., Particle therapy at the Heidelberg Ion Therapy Center (HIT) / Integrated research/driven university-hospital-based radiation oncology service in Heidelberg, Germany, Radiother. Oncol. 95 1 (2010 Apr.) 41-44.
[2] LOMAX, T., Grid therapy: the IMPT approach, 2012
Available from: http://medicalphysicsweb.org/cws/article/research/49072

Future prospects for proton therapy
Mar 5, 2012

"Don't treat tomorrow's patients with yesterday's proton therapy technology." This was the opening observation from Marco Schippers, speaking at last week's **ICTR-PHE meeting in Geneva**, Switzerland. Schippers, from the Paul Scherrer Institute (PSI) in Switzerland, emphasized the necessity of developing novel proton therapy techniques, citing a **wish list** of **"five highs":**

higher quality, **h**igher accuracy, **h**igher flexibility, **h**igher intensity and **h**igher energy.

He also listed one **low**: lower equipment costs – generally achieved via a reduction in the size of the accelerator system.

Available on: http://medicalphysicsweb.org/cws/article/opinion/48842

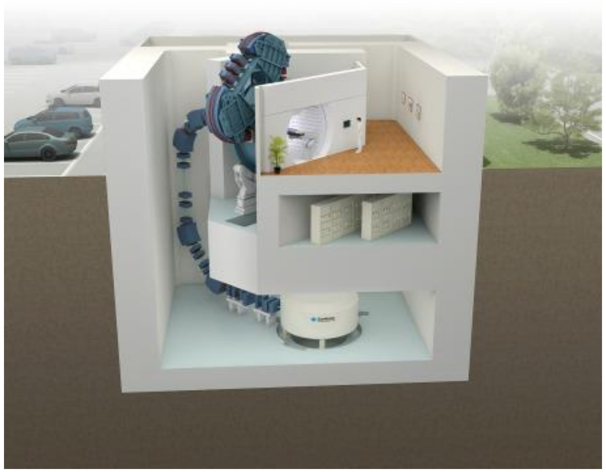
Towards a novel, low-cost PT accelerator

- Lower cost & standardized Proton Therapy System
- Compact treatment room and small footprint
- Shorter installation time on site
- Operator less
- Reduced maintenance

Proteus One : low cost, smaller footprint

Compact Proton Therapy in record time at Aizawa Hospital

The next generation Proton Therapy System is already installed.

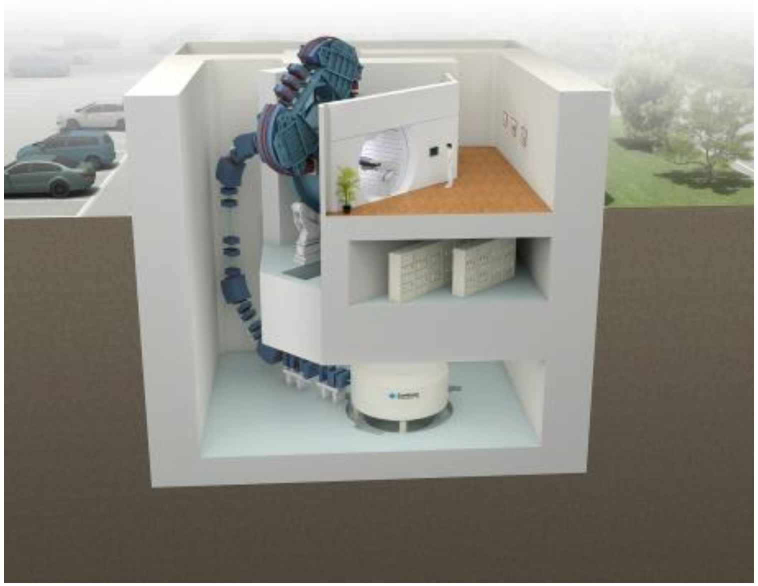


Available: http://www.lightions.com/news/compact-proton-therapy-in-record-time-at-aizawa-hospital/9

Sumitomo Heavy Industries, Ltd. (President and CEO: Shunsuke Betsukawa; hereinafter referred to as "SHI") today announces that clinical treatment started at Aizawa Hospital (Chairman and Director: Takao Aizawa; hereinafter referred to as "Aizawa") in Matsumoto, Nagano Pref. on September 30, 2014 as the first proton therapy facility in Koshinetsu region. (10 patients were treated per a day on October 6.)

This proton therapy system has a single gantry treatment room in the world's first vertical arrangement with a short length compact gantry and a 230Mev cyclotron which enables significant space saving. This system incorporates Multi-purpose nozzle which enables either conventional broad beam or pencil beam scanning, depending on treatment planning for a targeted disease.

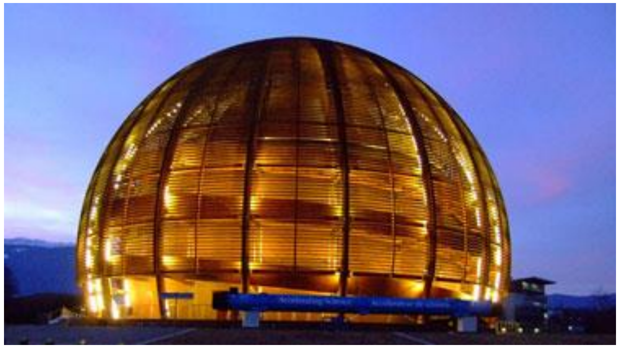
Furthermore, accurate patient positioning by 2D & 3D image guidance is possible.



Available on: http://www.shi.co.jp/english/info/2014/6kgpsq0000001ln0.html

CERN и Медицинската физика

CERN: catalysing collaboartion for medical advances – March, 2012



CERN established the **Physics for Health (PHE) workshop.**
"I think that the first thing we have to do is to understand each other, to know what is needed, what is available and what is possible," explained **Rolf-Dieter Heuer, Director General of CERN.**

INITIATIVES:

- ☐**Biomedical research**
- ☐**Accelerator design**
- ☐**Radioisotope development**

Available on: http://medicalphysicsweb.org/cws/article/opinion/49110

CERN и Медицинската физика

CERN INTENSIFIES MEDICAL PHYSICS RESEARCH – Feb, 2014

The ultimate aim is for CERN to establish itself as an important facilitator of medical physics in Europe. **"Since the start of this year, we are trying to combine all of our research on medical applications at CERN into one coordinating office,"** explained **CERN's Director-General Rolf Heuer**, speaking at the recent ICTR-PHE (**International Conference on Translational Research in Radio-Oncology and Physics for Health in Europe**) meeting in Geneva, Switzerland.

Available on: http://ictr-phe14.web.cern.ch

WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the April 2014 issue of *CERN Courier*.

It is 60 years since a proton beam was first used to treat cancer at the Berkeley cyclotron. Since then, research has spread to other countries and other beams, notably carbon ions. In February, experts at the ICTR-PHE 2014 conference in Geneva discussed current progress in using these and other techniques derived from nuclear and particle physics in the service of medicine.

It is 80 years since two theoretical physicists first calculated the neutrino cross-section and concluded that "there is no practically possible way of observing neutrinos". Forty years later, measurements of neutrinos by the Gargamelle team at CERN helped to reveal the quark structure of matter. Now, another 40 years later, the MINERvA experiment at Fermilab continues a long tradition at the two labs in studying neutrinos.

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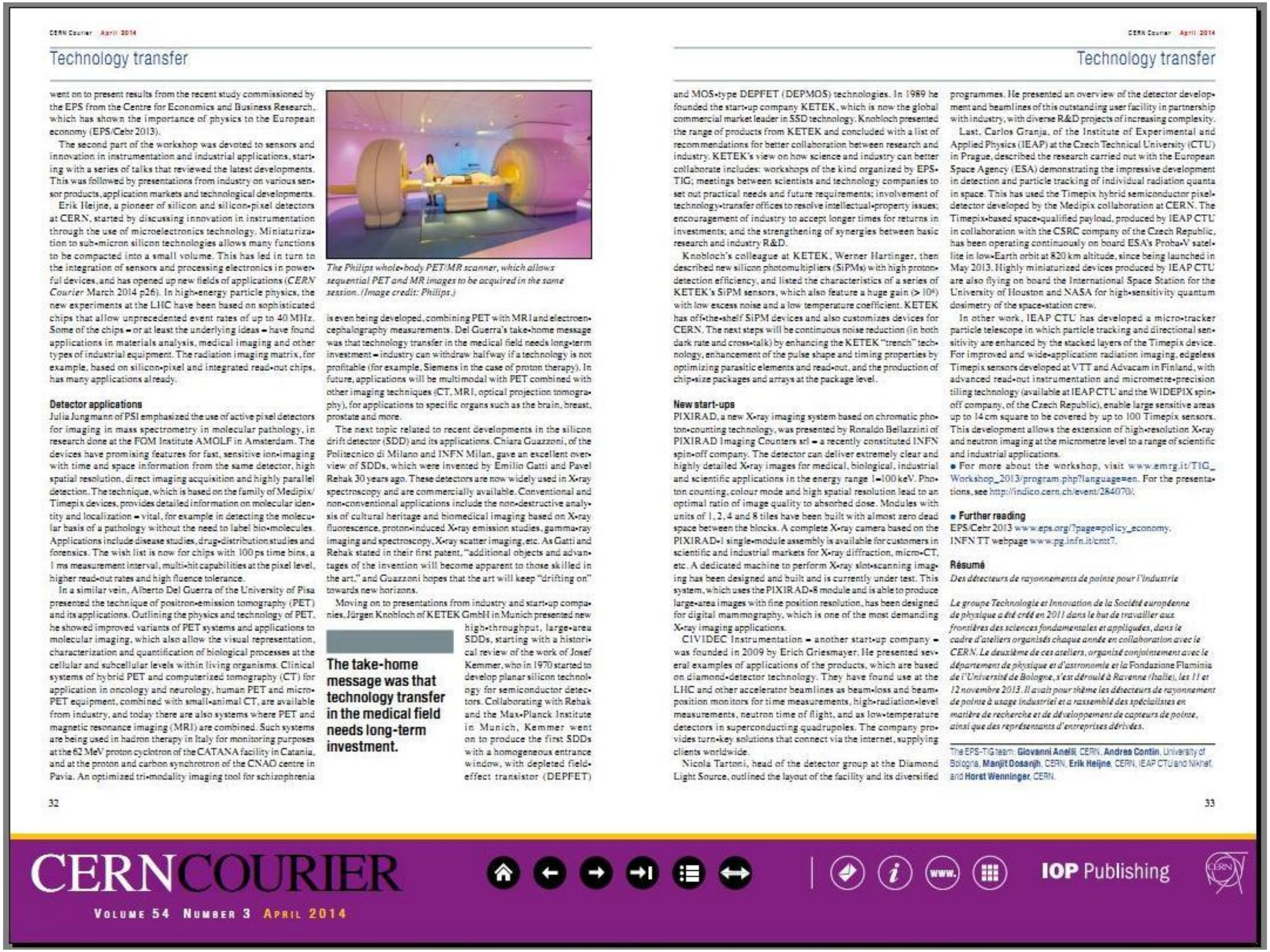

went on to present results from the recent study commissioned by the EPS from the Centre for Economics and Business Research, which has shown the importance of physics to the European economy (EPS/Cebr 2013).

The second part of the workshop was devoted to sensors and innovation in instrumentation and industrial applications, starting with a series of talks that reviewed the latest developments. This was followed by presentations from industry on various sensor products, application markets and technological developments.

Erik Heijne, a pioneer of silicon and silicon-pixel detectors at CERN, started by discussing innovation in instrumentation through the use of microelectronics technology. Miniaturization to sub-micron silicon technologies allows many functions to be compacted into a small volume. This has led in turn to the integration of sensors and processing electronics in powerful devices, and has opened up new fields of applications (*CERN Courier* March 2014 p26). In high-energy particle physics, the new experiments at the LHC have been based on sophisticated chips that allow unprecedented event rates of up to 40 MHz. Some of the chips – or at least the underlying ideas – have found applications in materials analysis, medical imaging and other types of industrial equipment. The radiation imaging matrix, for example, based on silicon-pixel and integrated read-out chips, has many applications already.

Detector applications

Julia Jungmann of PSI emphasized the use of active pixel detectors for imaging in mass spectrometry in molecular pathology, in research done at the FOM Institute AMOLF in Amsterdam. The devices have promising features for fast, sensitive ion-imaging with time and space information from the same detector, high spatial resolution, direct imaging acquisition and highly parallel detection. The technique, which is based on the family of Medipix/Timepix devices, provides detailed information on molecular identity and localization – vital, for example in detecting the molecular basis of a pathology without the need to label bio-molecules. Applications include disease studies, drug-distribution studies and forensics. The wish list is now for chips with 100 ps time bins, a 1 ms measurement interval, multi-hit capabilities at the pixel level, higher read-out rates and high fluence tolerance.

In a similar vein, Alberto Del Guerra of the University of Pisa presented the technique of positron-emission tomography (PET) and its applications. Outlining the physics and technology of PET, he showed improved variants of PET systems and applications to molecular imaging, which also allow the visual representation, characterization and quantification of biological processes at the cellular and subcellular levels within living organisms. Clinical systems of hybrid PET and computerized tomography (CT) for application in oncology and neurology, human PET and micro-PET equipment, combined with small-animal CT, are available from industry, and today there are also systems where PET and magnetic resonance imaging (MRI) are combined. Such systems are being used in hadron therapy in Italy for monitoring purposes at the 62 MeV proton cyclotron of the CATANA facility in Catania, and at the proton and carbon synchrotron of the CNAO centre in Pavia. An optimized tri-modality imaging tool for schizophrenia is even being developed, combining PET with MRI and electroencephalography measurements. Del Guerra's take-home message was that technology transfer in the medical field needs long-term investment – industry can withdraw halfway if a technology is not profitable (for example, Siemens in the case of proton therapy). In future, applications will be multimodal with PET combined with other imaging techniques (CT, MRI, optical projection tomography), for applications to specific organs such as the brain, breast, prostate and more.

The Philips whole-body PET/MR scanner, which allows sequential PET and MR images to be acquired in the same session. (Image credit: Philips.)

The next topic related to recent developments in the silicon drift detector (SDD) and its applications. Chiara Guazzoni, of the Politecnico di Milano and INFN Milan, gave an excellent overview of SDDs, which were invented by Emilio Gatti and Pavel Rehak 30 years ago. These detectors are now widely used in X-ray spectroscopy and are commercially available. Conventional and non-conventional applications include the non-destructive analysis of cultural heritage and biomedical imaging based on X-ray fluorescence, proton-induced X-ray emission studies, gamma-ray imaging and spectroscopy, X-ray scatter imaging, etc. As Gatti and Rehak stated in their first patent, "additional objects and advantages of the invention will become apparent to those skilled in the art," and Guazzoni hopes that the art will keep "drifting on" towards new horizons.

The take-home message was that technology transfer in the medical field needs long-term investment.

Moving on to presentations from industry and start-up companies, Jürgen Knobloch of KETEK GmbH in Munich presented new high-throughput, large-area SDDs, starting with a historical review of the work of Josef Kemmer, who in 1970 started to develop planar silicon technology for semiconductor detectors. Collaborating with Rehak and the Max-Planck Institute in Munich, Kemmer went on to produce the first SDDs with a homogeneous entrance window, with depleted field-effect transistor (DEPFET) and MOS-type DEPFET (DEPMOS) technologies. In 1989 he founded the start-up company KETEK, which is now the global commercial market leader in SSD technology. Knobloch presented the range of products from KETEK and concluded with a list of recommendations for better collaboration between research and industry. KETEK's view on how science and industry can better collaborate includes: workshops of the kind organized by EPS-TIG; meetings between scientists and technology companies to set out practical needs and future requirements; involvement of technology-transfer offices to resolve intellectual-property issues; encouragement of industry to accept longer times for returns in investments; and the strengthening of synergies between basic research and industry R&D.

Knobloch's colleague at KETEK, Werner Hartinger, then described new silicon photomultipliers (SiPMs) with high proton-detection efficiency, and listed the characteristics of a series of KETEK's SiPM sensors, which also feature a huge gain $(> 10^6)$ with low excess noise and a low temperature coefficient. KETEK has off-the-shelf SiPM devices and also customizes devices for CERN. The next steps will be continuous noise reduction (in both dark rate and cross-talk) by enhancing the KETEK "trench" technology, enhancement of the pulse shape and timing properties by optimizing parasitic elements and read-out, and the production of chip-size packages and arrays at the package level.

New start-ups

PIXIRAD, a new X-ray imaging system based on chromatic photon-counting technology, was presented by Ronaldo Bellazzini of PIXIRAD Imaging Counters srl – a recently constituted INFN spin-off company. The detector can deliver extremely clear and highly detailed X-ray images for medical, biological, industrial and scientific applications in the energy range 1–100 keV. Photon counting, colour mode and high spatial resolution lead to an optimal ratio of image quality to absorbed dose. Modules with units of 1, 2, 4 and 8 tiles have been built with almost zero dead space between the blocks. A complete X-ray camera based on the PIXIRAD-1 single-module assembly is available for customers in scientific and industrial markets for X-ray diffraction, micro-CT, etc. A dedicated machine to perform X-ray slot-scanning imaging has been designed and built and is currently under test. This system, which uses the PIXIRAD-8 module and is able to produce large-area images with fine position resolution, has been designed for digital mammography, which is one of the most demanding X-ray imaging applications.

CIVIDEC Instrumentation – another start-up company – was founded in 2009 by Erich Griesmayer. He presented several examples of applications of the products, which are based on diamond-detector technology. They have found use at the LHC and other accelerator beamlines as beam-loss and beam-position monitors for time measurements, high-radiation-level measurements, neutron time of flight, and as low-temperature detectors in superconducting quadrupoles. The company provides turn-key solutions that connect via the internet, supplying clients worldwide.

Nicola Tartoni, head of the detector group at the Diamond Light Source, outlined the layout of the facility and its diversified programmes. He presented an overview of the detector development and beamlines of this outstanding user facility in partnership with industry, with diverse R&D projects of increasing complexity.

Last, Carlos Granja, of the Institute of Experimental and Applied Physics (IEAP) at the Czech Technical University (CTU) in Prague, described the research carried out with the European Space Agency (ESA) demonstrating the impressive development in detection and particle tracking of individual radiation quanta in space. This has used the Timepix hybrid semiconductor pixel-detector developed by the Medipix collaboration at CERN. The Timepix-based space-qualified payload, produced by IEAP CTU in collaboration with the CSRC company of the Czech Republic, has been operating continuously on board ESA's Proba-V satellite in low-Earth orbit at 820 km altitude, since being launched in May 2013. Highly miniaturized devices produced by IEAP CTU are also flying on board the International Space Station for the University of Houston and NASA for high-sensitivity quantum dosimetry of the space-station crew.

In other work, IEAP CTU has developed a micro-tracker particle telescope in which particle tracking and directional sensitivity are enhanced by the stacked layers of the Timepix device. For improved and wide-application radiation imaging, edgeless Timepix sensors developed at VTT and Advacam in Finland, with advanced read-out instrumentation and micrometre-precision tiling technology (available at IEAP CTU and the WIDEPIX spin-off company, of the Czech Republic), enable large sensitive areas up to 14 cm square to be covered by up to 100 Timepix sensors. This development allows the extension of high-resolution X-ray and neutron imaging at the micrometre level to a range of scientific and industrial applications.

- For more about the workshop, visit www.emrg.it/TIG_Workshop_2013/program.php?language=en. For the presentations, see http://indico.cern.ch/event/284070/.

- **Further reading**

EPS/Cebr 2013 www.eps.org/?page=policy_economy.
INFN TT webpage www.pg.infn.it/cntt7.

Résumé

Des détecteurs de rayonnements de pointe pour l'industrie

Le groupe Technologie et Innovation de la Société européenne de physique a été créé en 2011 dans le but de travailler aux frontières des sciences fondamentales et appliquées, dans le cadre d'ateliers organisés chaque année en collaboration avec le CERN. Le deuxième de ces ateliers, organisé conjointement avec le département de physique et d'astronomie et la Fondazione Flaminia *de l'Université de Bologne, s'est déroulé à Ravenne (Italie), les 11 et 12 novembre 2013. Il avait pour thème les détecteurs de rayonnement de pointe à usage industriel et a rassemblé des spécialistes en matière de recherche et de développement de capteurs de pointe, ainsi que des représentants d'entreprises dérivées.*

The EPS-TIG team: **Giovanni Anelli**, CERN, **Andrea Contin**, University of Bologna, **Manjit Dosanjh**, CERN, **Erik Heijne**, CERN, IEAP CTU and Nikhef, and **Horst Wenninger**, CERN.

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