Accelerators and Medicine

Donatella Ungaro

Many projects to talk about …

One hour

Several hours would be needed to enter into details…

General overview of our Projects…

You are welcome to visit us at any time to know more about us!

Outline

1. ADAM Company
2. Applications of Accelerators in Medicine
3. Research activities :
   - LIGHT
   - IORT
   - IN-VIVO DOSIMETER
   - X-EYE
4. Future projects

ADAM Company

- ADAM (**A**pplications of **D**etectors and **A**ccelerators to **M**edicine) is a Company "inspired" by CERN, founded on December 2007 to promote scientific know-how and innovations in medical technology

- Research activity: mainly focused on the construction an testing of linear accelerators and detectors for medical purposes

www.adam-geneva.com

A partnership for hadron therapy

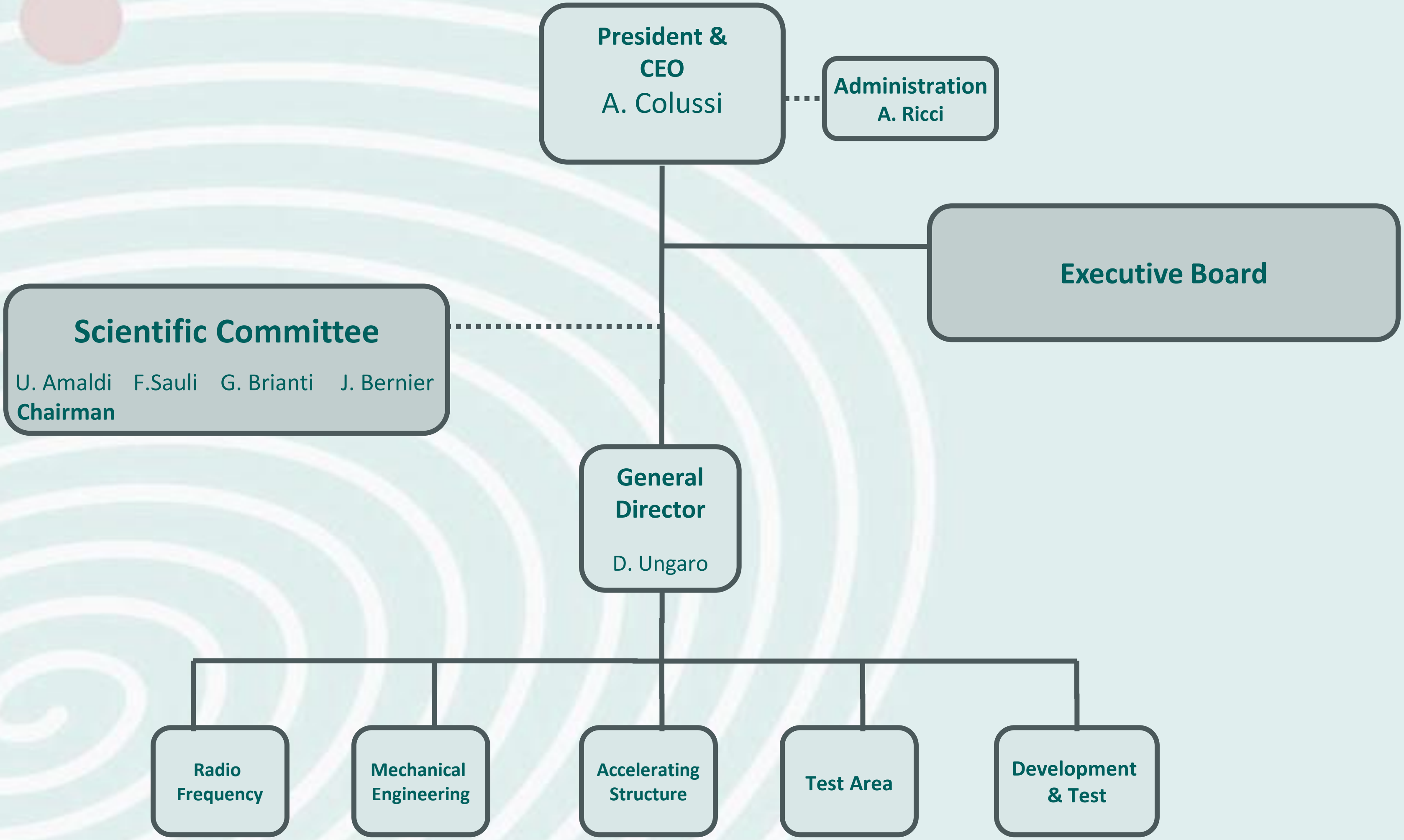
BUL-NA-2008-079

- In May 2008, three new agreements were signed between **CERN**, CNAO, INFN (the Italian particle physics institute) and **ADAM SA** to ensure continued cooperation between the organisations and the exchange of intellectual property

CERN Collaboration Agreement
K1493/TT/AB/007P

Dr. A. Colussi (President and Founder of ADAM) with DG R. Aymar

Organization



F. Borralho, P. Ingenito, G. Levy, C. Mellace, J. Nardulli, A. Patino, G. Pittà, G. Primadei

Medical applications of particle accelerators

Outline

- *How many accelerators ?*
- *Which ones ?*
  - *Radio isotopes productions, for PET, etc.*
  - *Conventional Radiation therapy with photons and electrons*
  - *Oncological therapy with hadrons*

Summary of accelerators running in the world

50% of accelerators running in the world

are devoted to medical applications

CATEGORY OF ACCELERATORS	NUMBER IN USE (*)
High Energy acc. (E >1 GeV)	~120
Synchrotron radiation sources	>100
Medical radioisotope production	~200
Radiotherapy accelerators	> 7500
Research acc. included biomedical research	~1000
Industrial processing and research	~1500
Ion implanters, surface modification	>7000
TOTAL	> 17500

9000

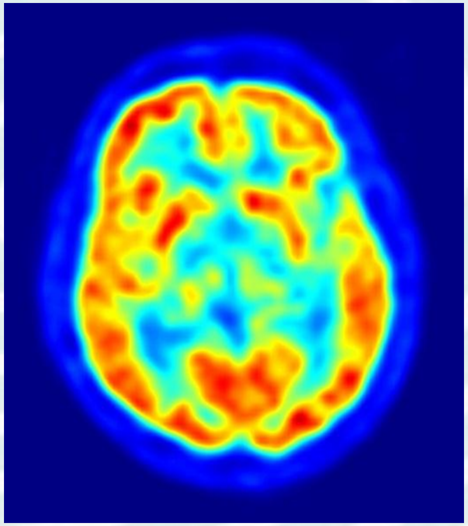
(*) W. Maciszewski and W. Scharf: Int. J. of Radiation Oncology, 2004

Radioisotopes production

Nuclear medicine imaging technique
(PET-Positron Emission Tomography)

→ 3D images of processes in the body

- The system detects gamma rays emitted by a positron emitting radionuclide tracer
- Radio-tracers produced using a cyclotron/Linac close to the PET facility
- Cyclotrons accelerate protons up to 24 MeV



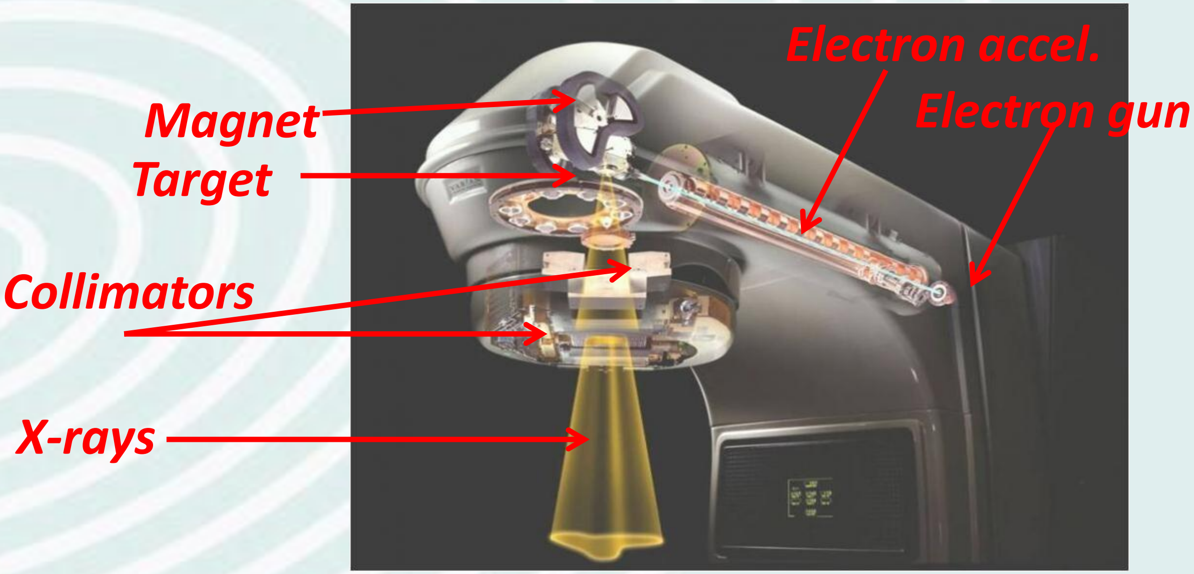
Other applications of Radioisotopes production

- Isotopes production for nuclear medicine
  Cyclotrons with protons with energies up to 70 MeV
- Neutron sources substituting nuclear reactors for isotope production for nuclear medicine
  Proton beam of 150 MeV

Radiotherapy with γ and e-

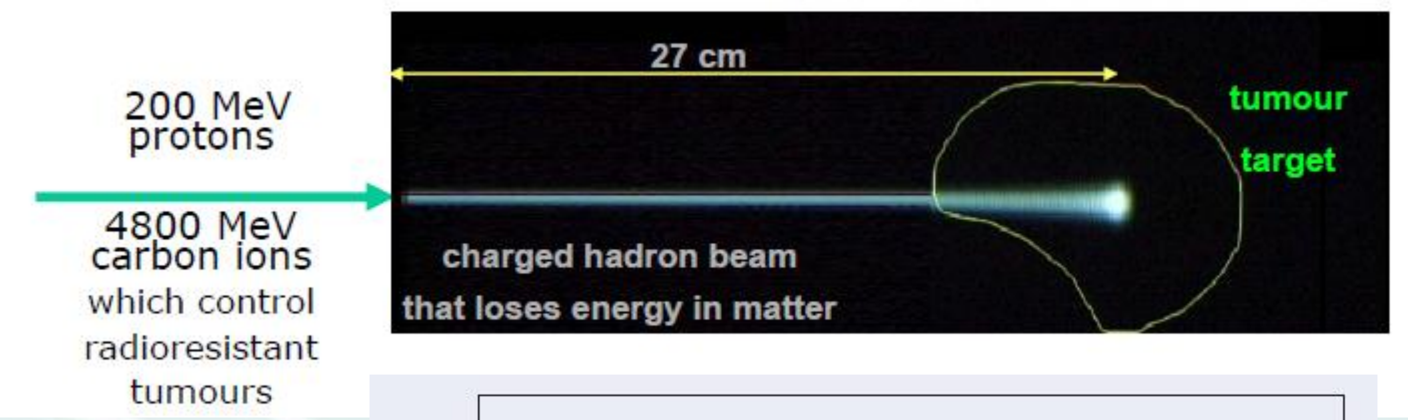
- As source of radiation for modern X-ray therapy, radiotherapists use electron linear accelerators
- They can produce either electrons (5-20 MeV) or photons (obtained by slowing down the electrons in a heavy target)

- Electrons are used to treat superficial or semi-deep tumors (**5%** of all conventional treatments);
- Photons are used for deep-seated tumors (**> 90%** of all conventional treatments)

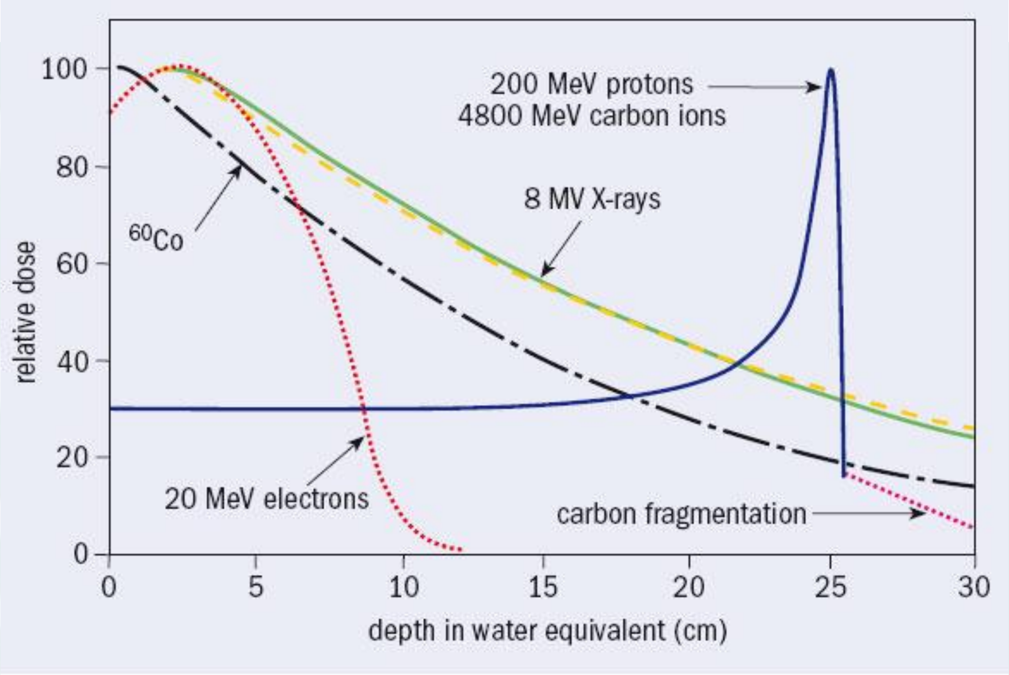


Hadrontherapy

Oncological radiotherapy with non-elementary particles made of quarks: protons, neutrons and light nuclei

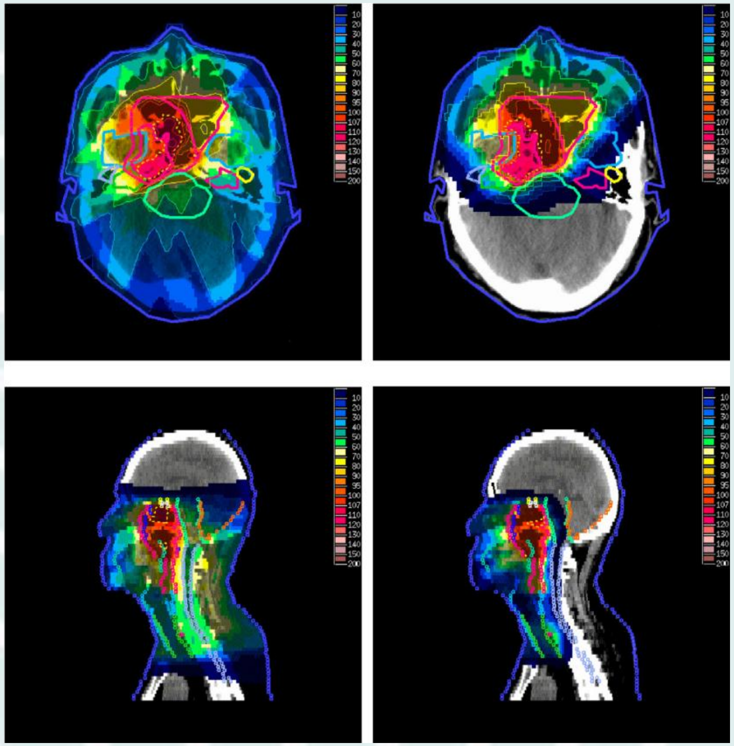


Charged hadrons give the highest dose near the end of their range in the 'Bragg peak' just before coming to rest



Hadrontherapy

- ***Effect:***



(Radio Oncology Journal)

- Currently used cyclotrons and synchrotons with protons up to 250 MeV
- Synchrotons with carbon ions up to 4800 MeV

Linacs: ADAM, protons energies up to 250 MeV

LIGHT
(Linac for Image Guided Hadron Therapy)

2008-2010

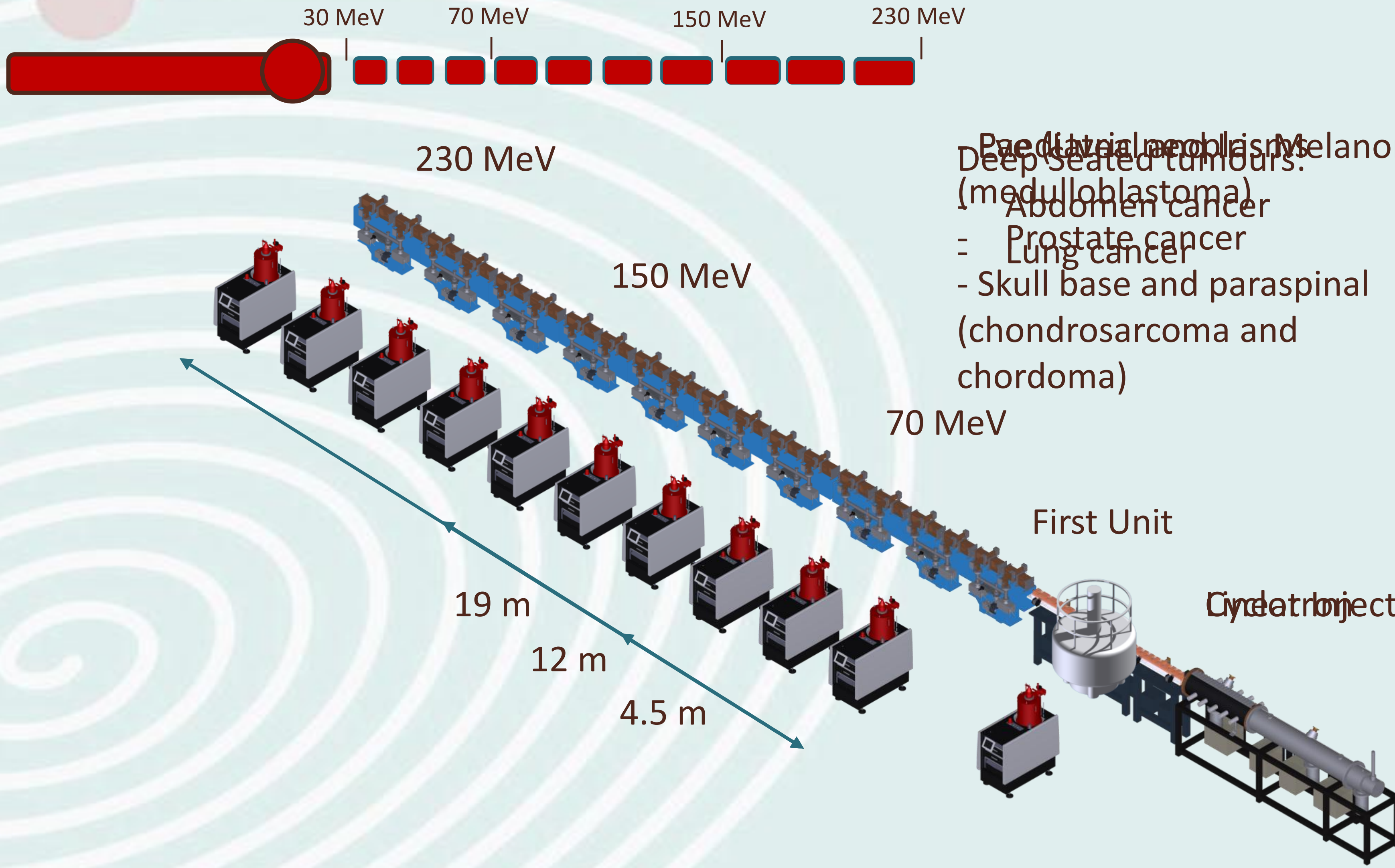
What is LIGHT?

- Linear accelerator designed by A.D.A.M. SA for therapy with protons
  - accelerating structure based on Side Coupled Linac (SLC)
  - working at 2.9985 GHz (S-band), with a 15 MV/m gradient
  - Length: ~20 meters
- Composed of 10 **Units**
  - Each unit composed of 2 **Modules**
  - Each module composed of 2 accelerating **tanks**
- Power provided by a 7.5 MW peak power klystron
  - allowing the Linac to run at 200-Hz repetition rate and 4 μs pulse length

- A.D.A.M. SA took the original ideas of the TERA Foundation

A hadron therapy center based on LIGHT

…



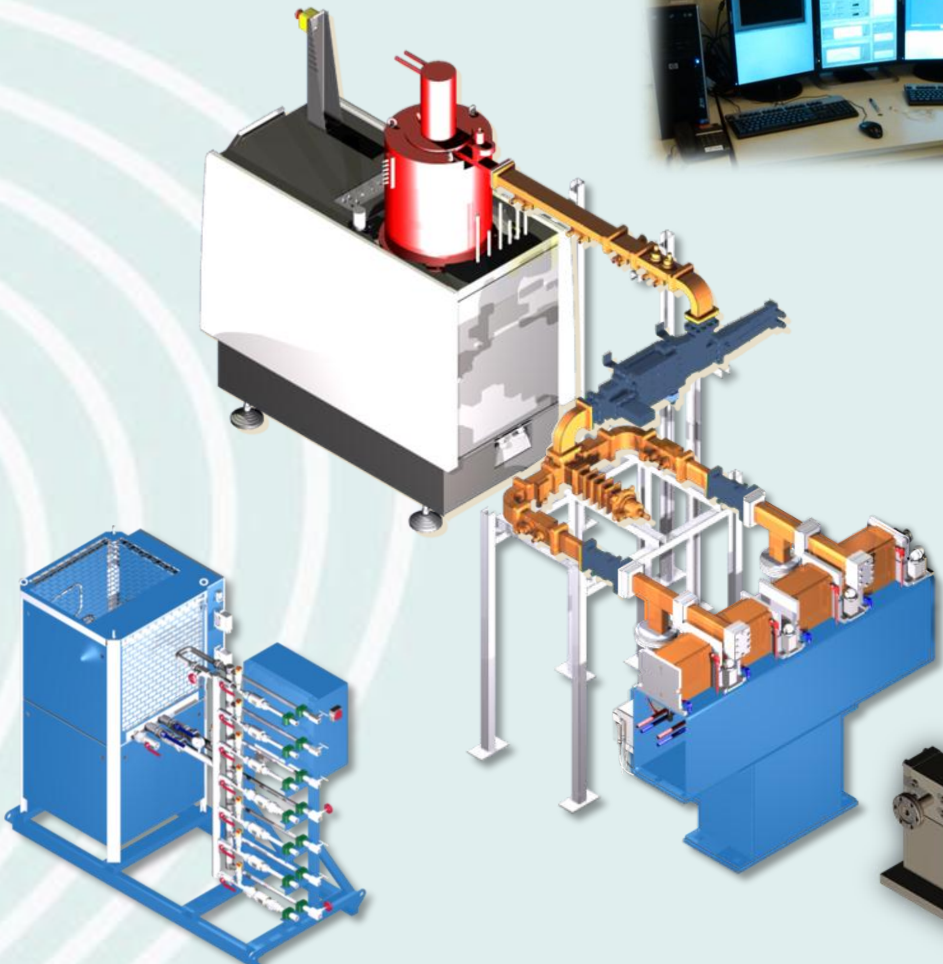
- Paediatric neoplasms (medulloblastoma)
- Eye (uveal Melanoma)

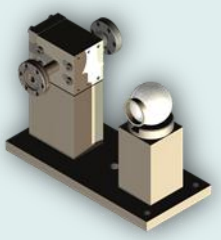
Deep Seated tumours:
- Abdomen cancer
- Prostate cancer
- Lung cancer
- Skull base and paraspinal (chondrosarcoma and chordoma)

LIGHT First Unit @ CERN

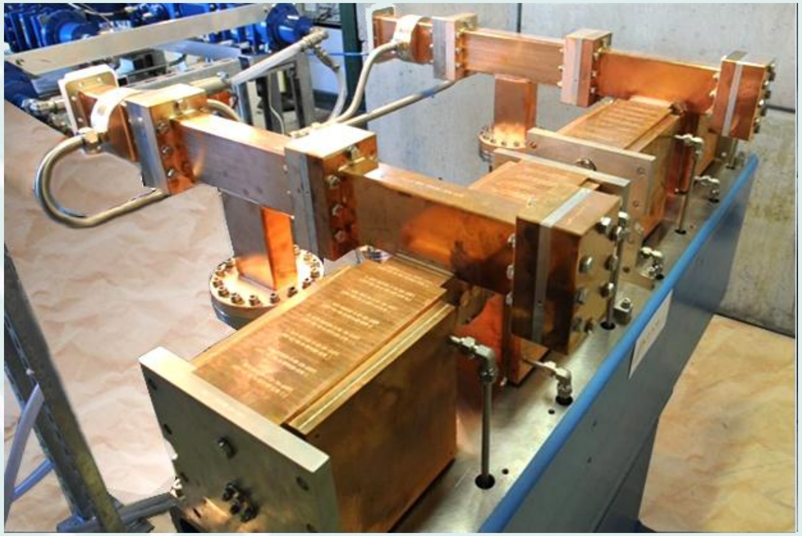
First Unit Systems

1) Accelerating System
2) Control System
3) Cooling System
4) Focusing System
5) RF Network System
6) RF Power System
7) Support System
8) Vacuum System





Inauguration of the First Unit
19.11.2010



…where is the First Unit now?

Shipped to ENEA Laboratories (Frascati, ITALY)
Ready for test beam and for integration in Top Implart Project
… as accelerating unit from 30 to 42 MeV

IORT

2009-2012

What is a IORT ?

- "Intra Operative Radiation Therapy" (IORT)
  - Delivering a single high dose on a tumor bed soon after surgery resection
- **1909**: C. Beck irradiated 7 patients by pulling the tumor into the abdominal wound and irradiating it

'..As the mountain does not come to Mohammed, Mohammed must go to the mountain. In other words, if the tubal light does not reach the deep-seated structures, structures must be brought to the tube…'.

→ Treatments unsuccessful

low beam energy, low dose rates, limited equipment

- **1965**: Abe - First treatment with electrons → successful !

How does it work…

- Video

Existing IORT…

LIAC, Sordina
ITALY
S-band, 3 GHz

MOBETRON, Intraop
USA
X-band, 9 GHz

NOVAC, NRT
ITALY
S-band, 3 GHz

ADAM IORT: a C-band (5,7 GHz) device

- Why C-band?

- Smaller dimensions and weight
- Higher shunt impedance per unit length
- Shorter filling time
- Higher breakdown threshold

S-band vs. C-band cavities

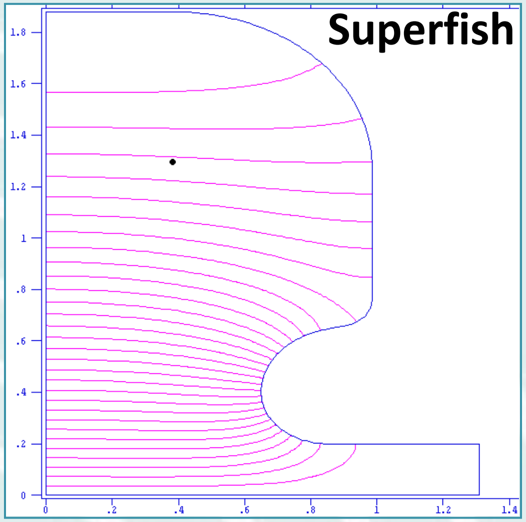
- Why not before?

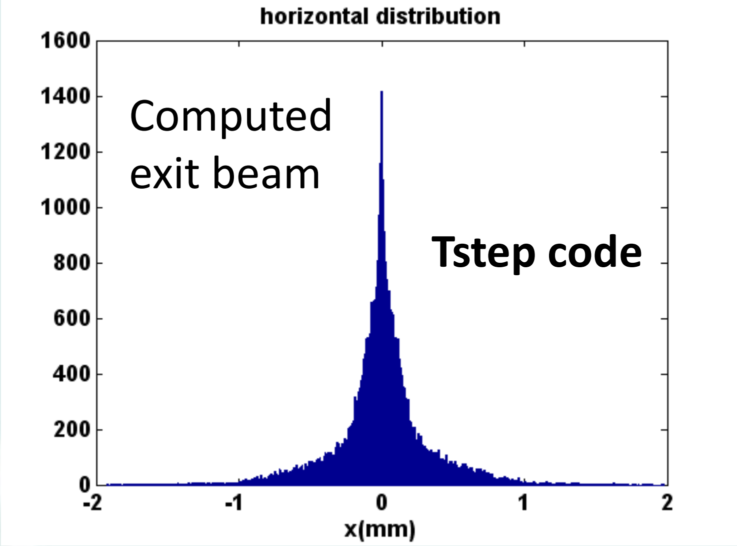
Very difficult to find frequency components (Magnetron, Circulator, Modulator…) in C-Band

Steps of ADAM IORT realization -1-

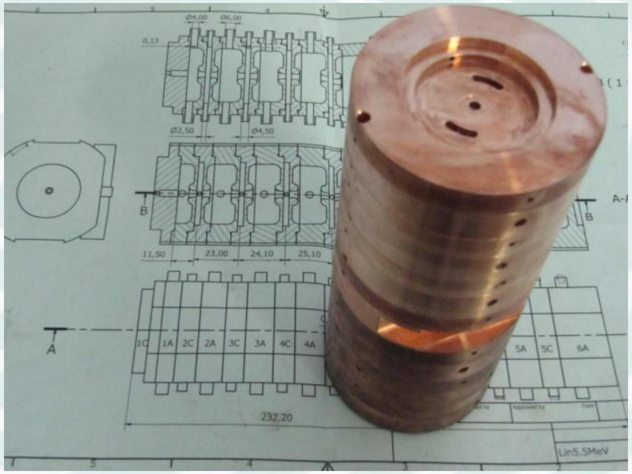
Simulation studies for the optimization of cavities shape and dimension

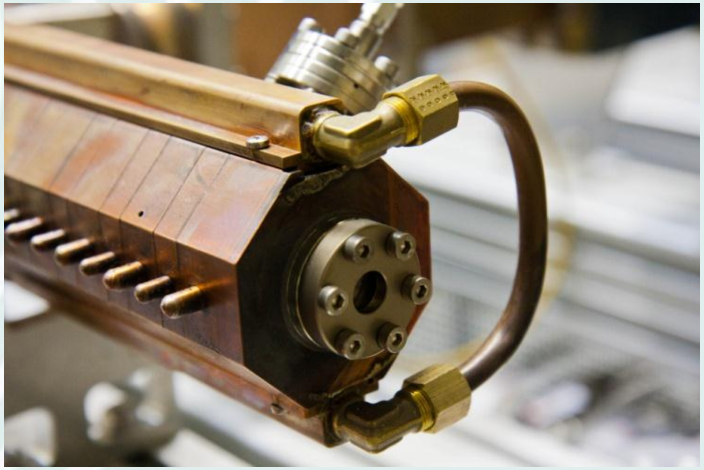
- Superfish, CST Microwave Studio for cavities optimization
- Tstep for beam dynamics computations



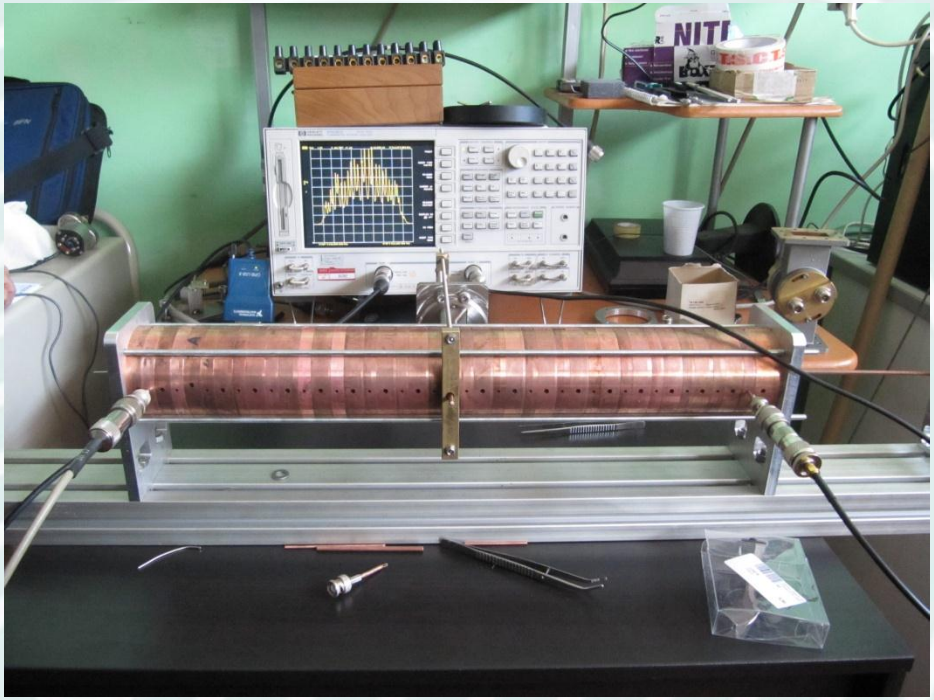


Cavities machined at TSC, Fiumicino





Steps of ADAM IORT realization -2-

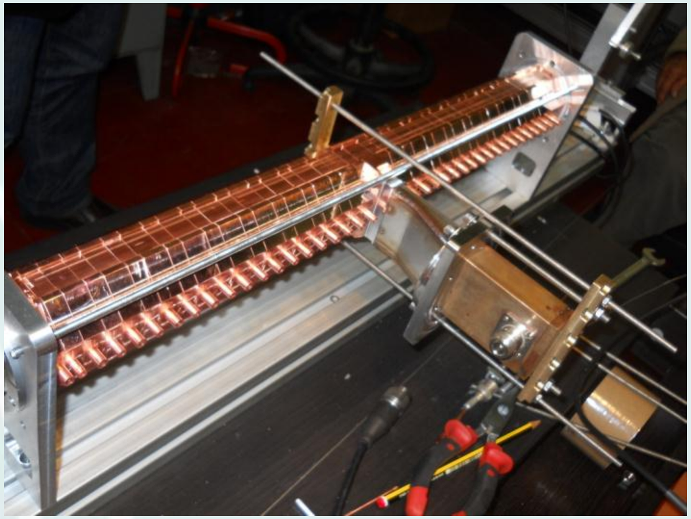


Structure tuning
Frequency tests with Network Analyzer

(TSC)

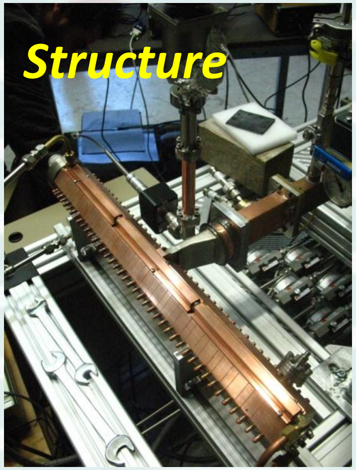
Steps of ADAM IORT realization -3-

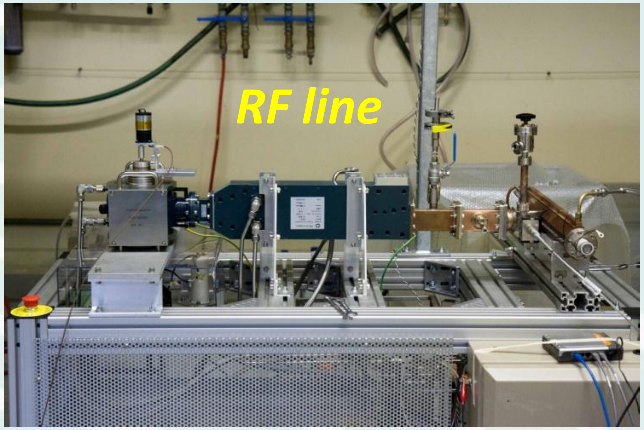
After brazing, the accelerator is ready for final frequency tests

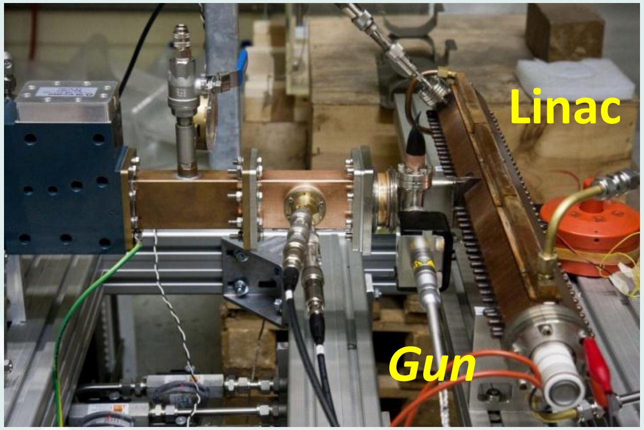


Accelerator shipped to Aprilia (Italy), NRT

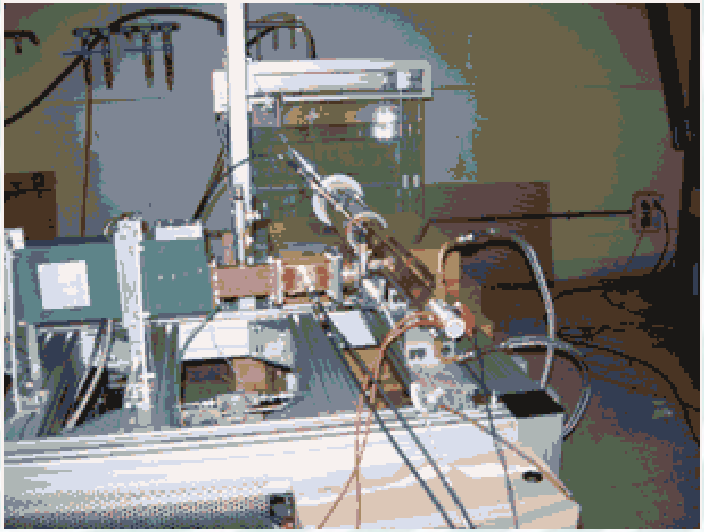
E-beam acceleration tests at NRT



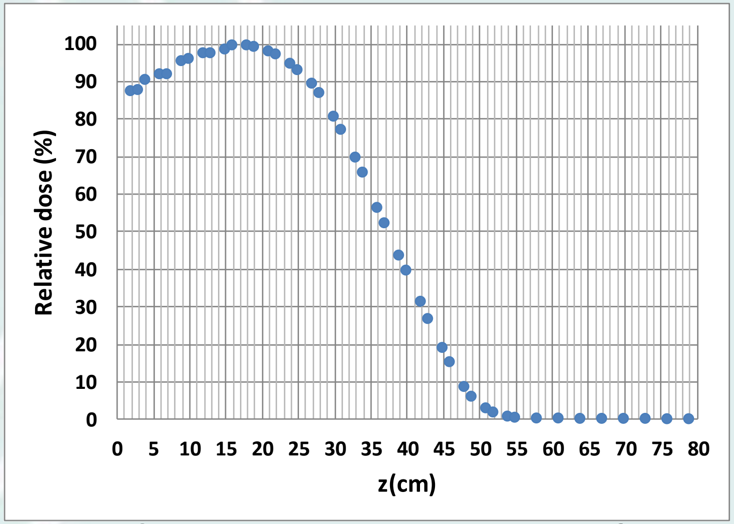




MEASUREMENT OF THE RELATIVE DOSE VERSUS PENETRATION DEPTH IN WATER



C-band IORT Linac under measurement in the water phantom test stand



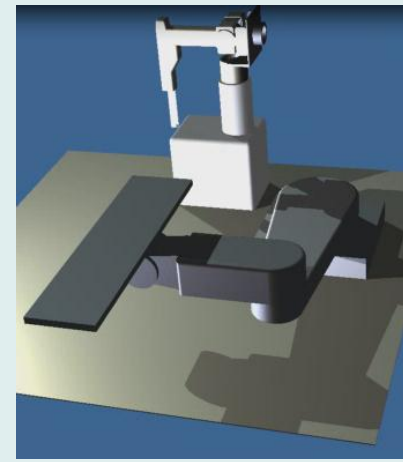
measured PDD curve in a water phantom

One more in the list…

LIAC, Sordina
ITALY
S-band, 3 GHz

MOBETRON, Intraop
USA
X-band, 9 GHz

NOVAC, Nrt
ITALY
S-band, 3 GHz



IORT, ADAM
GENEVA
C-band, 5.7 GHz

In-Vivo Dosimeter

2009-2012

ADAM X-ray dosimeter

- **Motivation:**

  EU Medical Exposure Directive 97/43/

  Medical exposure continues to constitute the major source of EU citizens' exposure to artificial sources of ionising radiation. Medical exposure must show a sufficient net benefit compared with the individual detriment that the exposure might cause, taking into account the benefits and risks of available alternative techniques. All individual medical exposures must be justified in advance, taking into account the specific objectives of the exposure and the characteristics of the individual involved

Requirements for dosimeter in clinical use

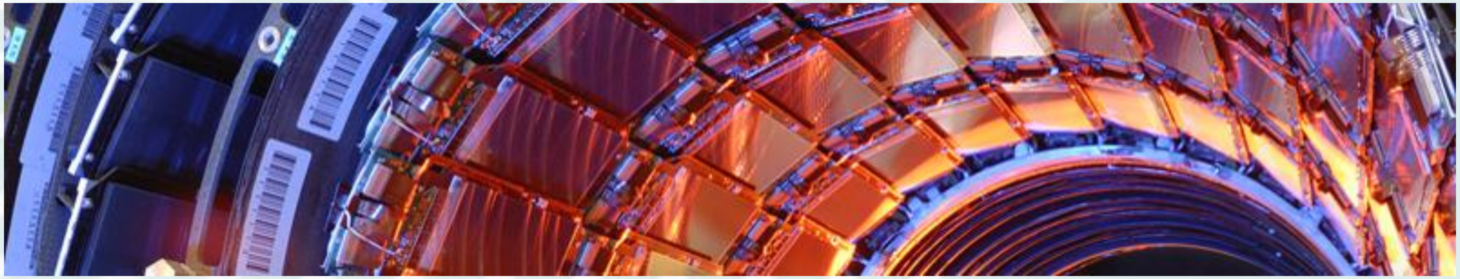
- Must be accurate, i.e. sensitive, linear response etc. within 1% error margin (this can be fulfilled by dosimeters made with many technologies)
- Should not disturb the radiation field
- Should be reproducible
- Reduced dimensions
- Easy and fast online reading
- Radiation hard

Additional advantages of our dosimeter:

- Same sensor for any energy range
- Wireless connection

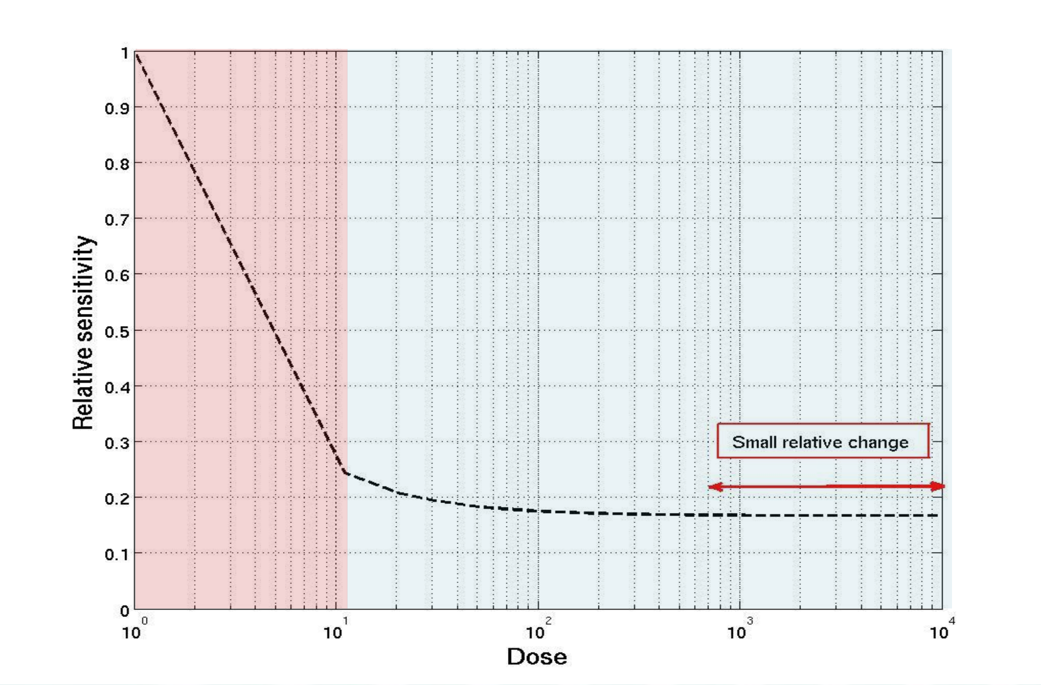
Why semiconductor detectors for dosimetry?

- Silicon detectors can be mass produced; unit price → very low
- They convert electromagnetic radiation directly into electrical signal (unlike currently used passive TLD)
- They produce real-time measurement data which can be immediately stored electronically
- Are extremely accurate: in scientific experiment even single photons can be counted by semiconductor detectors



Largest ever made Si detector: CMS Tracker at CERN, 220m^2 Si sensors, 96M channels

How commercially available diode dosimeters are “radiation hardened” ?



The lifetime/diffusion length is degraded by pre-irradiation or/and intentional impurity doping

Drawbacks:

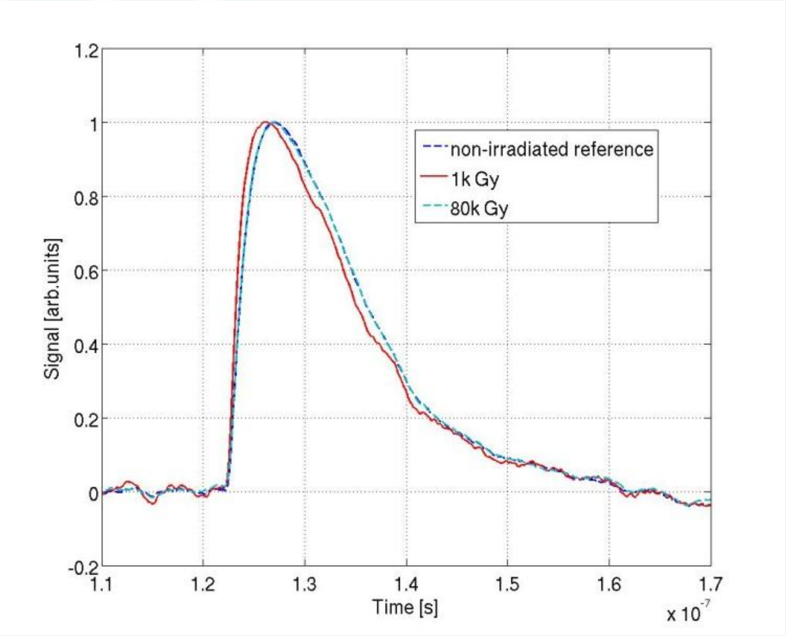
- **Expensive technology**

- Exponential temperature dependence of leakage current

- Poor sensitivity

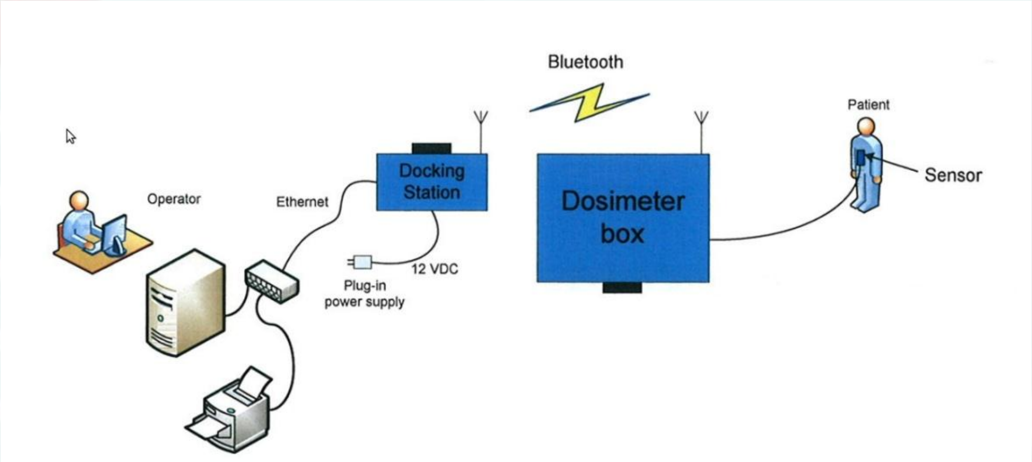
Test at Brookhaven National Lab gamma irradiation facility

- Two 5 sample sets of dosimeter sensors
- BNL has very powerful Cobolt-60 gamma radiation source, mainly used for NASA testing purposes
- Very high doses can be accumulated in short time
- Patient is treated typically with 1-2Gy doses



1k Gy
5k Gy
10k Gy
50k Gy
80k Gy = 40 000 – 80 000 patient treatments

Our Dosimeter & Sensitivity



Estimations based on measurements with Varian Linac at hospital

Measured with Adam dosimeter 1.08nC/pulse
1 Gy dose = 6000 pulses
Sensitivity = **6500** nC/Gy

Difference by factor of 200 !

What others have to offer ?

*SunNuclear IsoRad, sensitivity = **27** nC/Gy
SunNuclear QED, sensitivity = **32** nC/Gy

**source : http://www.sunnuclear.com/documents/invivo.pdf*

ADAM Dosimeter read-out

Follows High Energy Physics commonly adopted read-out scheme:

Charge Amplifier > Shaper > Trigger > Integrator

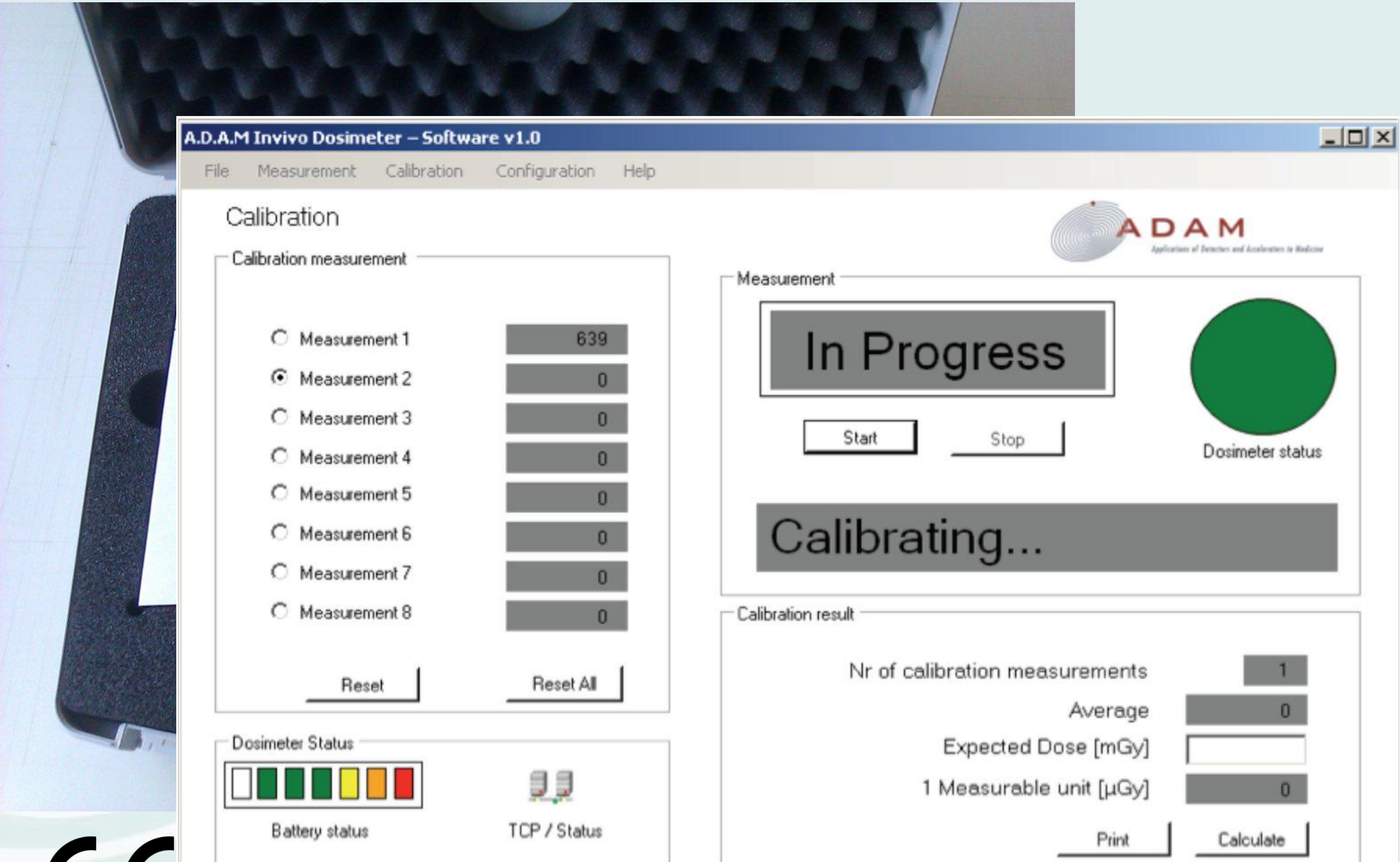
This minimizes influence of stray capacitances, dose rate dependence

ADAM readout truly counts every pulse and integrates the charge delivered from the detector

No correction factors needed in our software

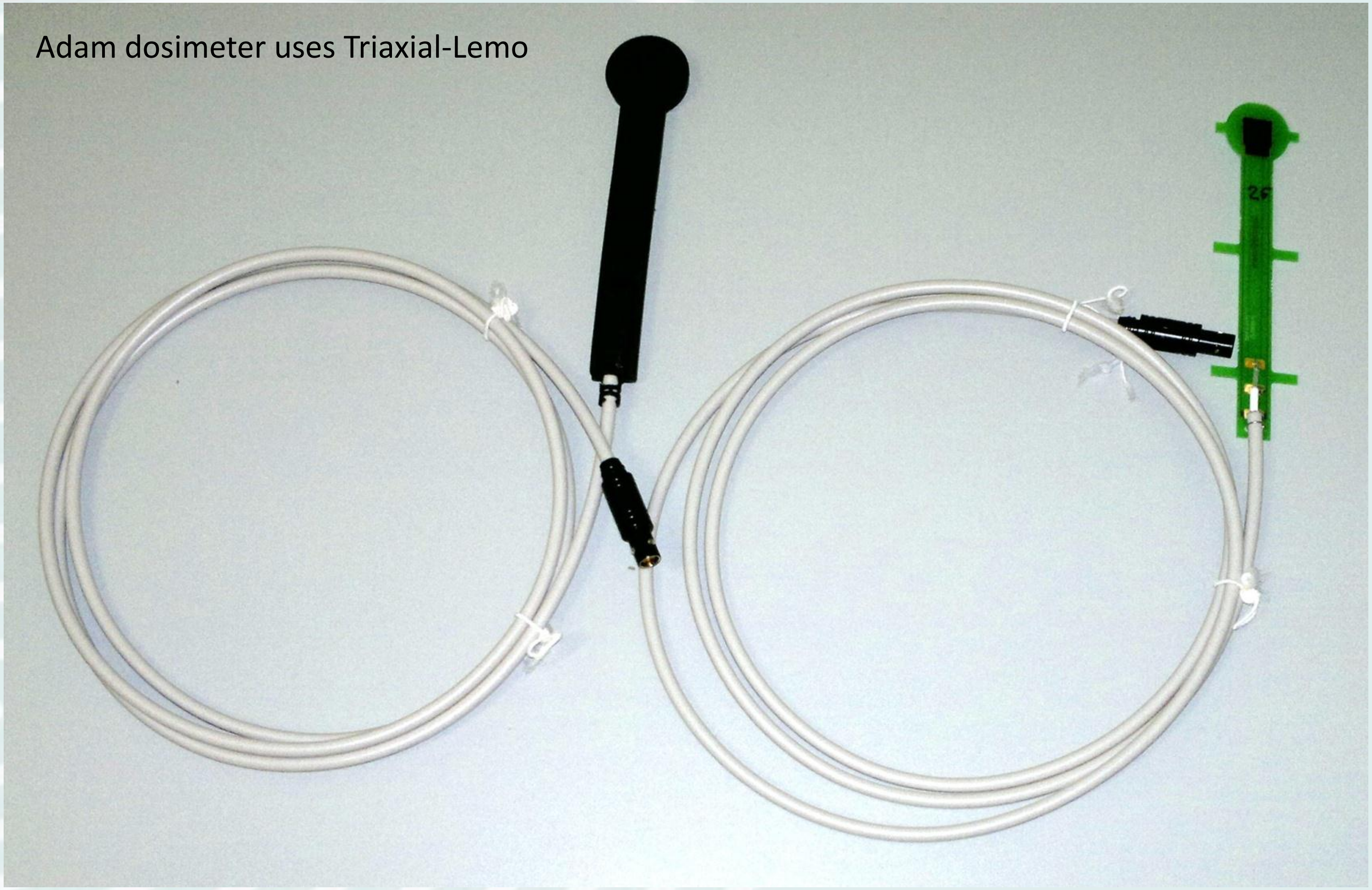
After three years of hard work…

….WE HAVE IT!


A.D.A.M Invivo Dosimeter – Software v1.0
File
Measurement
Calibration
Configuration
Help
Calibration
ADAM
Calibration measurement
Measurement 1
639
Measurement 2
0
Measurement 3
0
Measurement 4
0
Measurement 5
0
Measurement 6
0
Measurement 7
0
Measurement 8
0
Reset
Reset All
Measurement
In Progress
Start
Stop
Dosimeter status
Calibrating...
Calibration result
Nr of calibration measurements
1
Average
0
Expected Dose [mGy]
1 Measurable unit [µGy]
0
Print
Calculate
Dosimeter Status
Battery status
TCP / Status

CE

Final Probehead



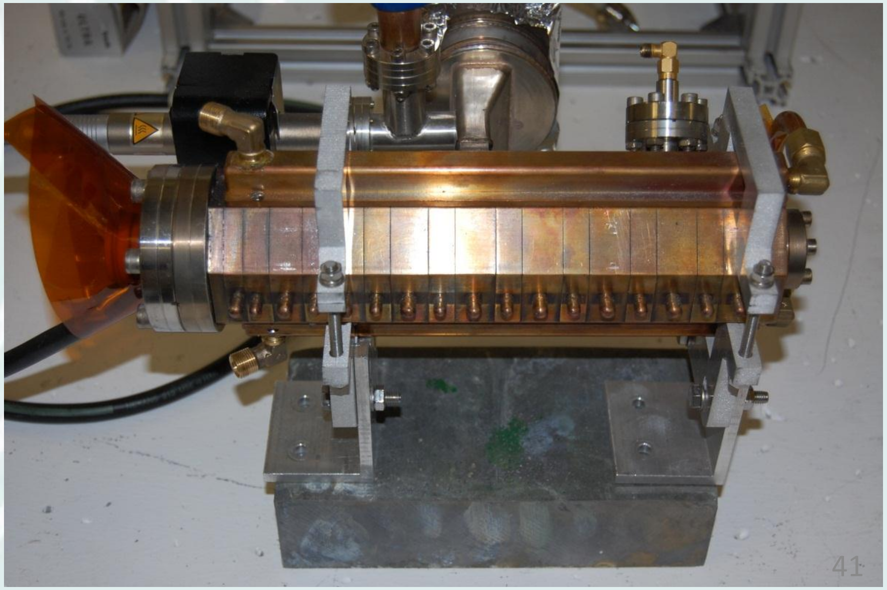
X-EYE

2010-?

What is it ?

- ***C-Band electron accelerator***
  - *Output beam energy* *5.5 MeV*
  - *Output beam current* *100 mA*
  - *Frequency* *5712 MHz*
  - *Pulse duration* *3 us*
  - *Repetition rate* *10-200 Hz*
  - *Dose rate* *2.5 Gy/min @ 1m*

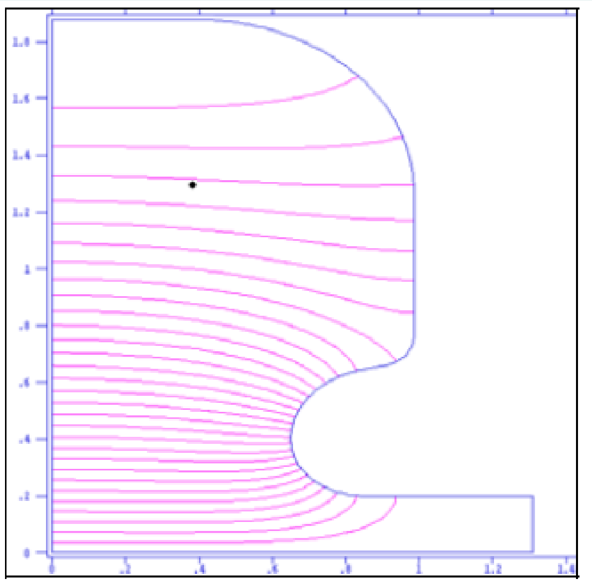
X-Rays linac



Simulation studies

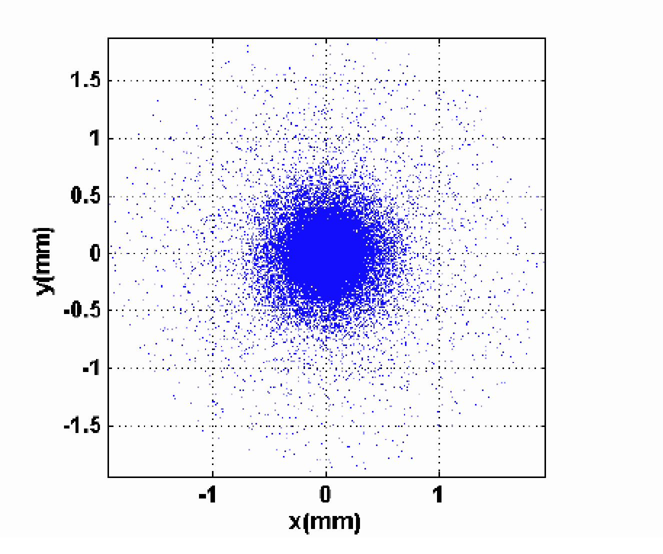
SuperFish Output

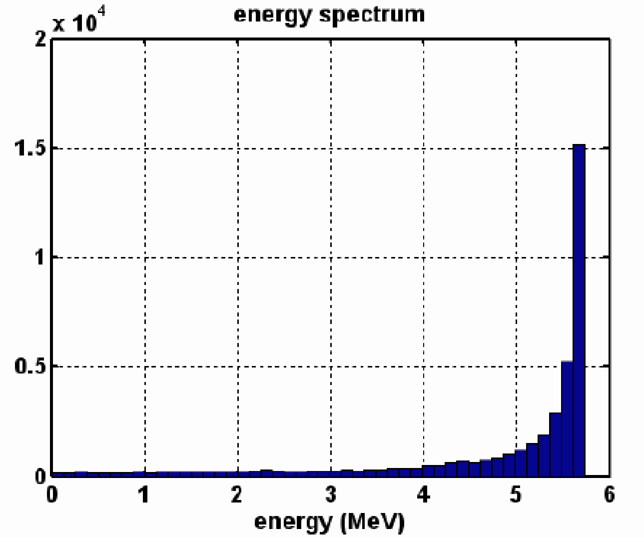
Cavities with $\boldsymbol{\beta} = 1$



- ***Simulation in various steps***
  - ***SuperFish & Tstep for preliminary studies on cavities***
  - ***Further studies in CST Microwave studio***

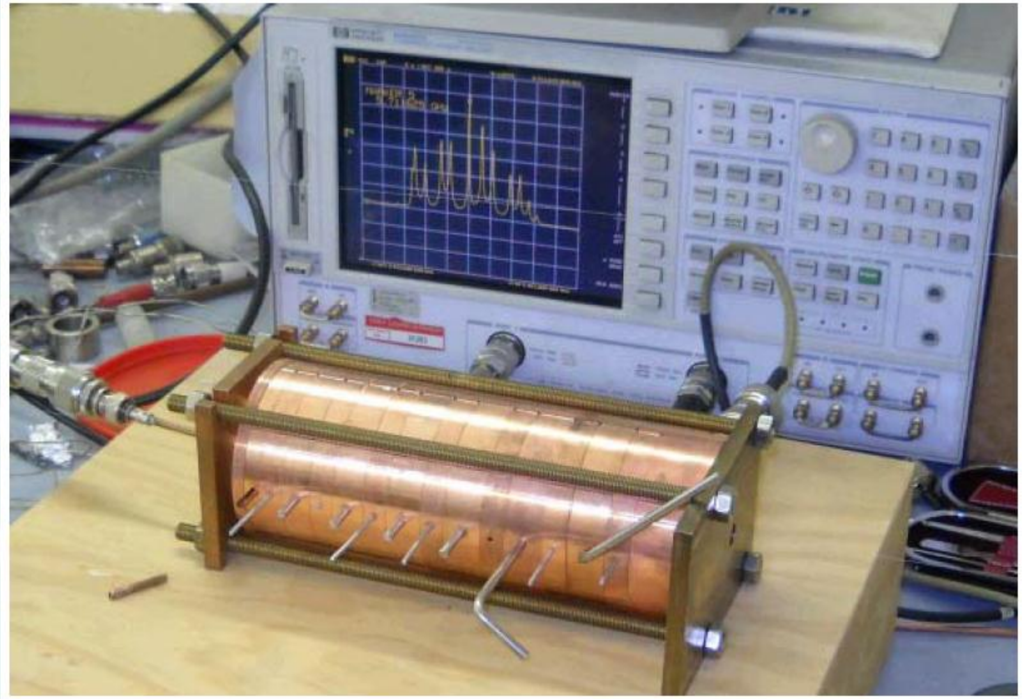
Tstep: Beam Spot and Energy spectrum

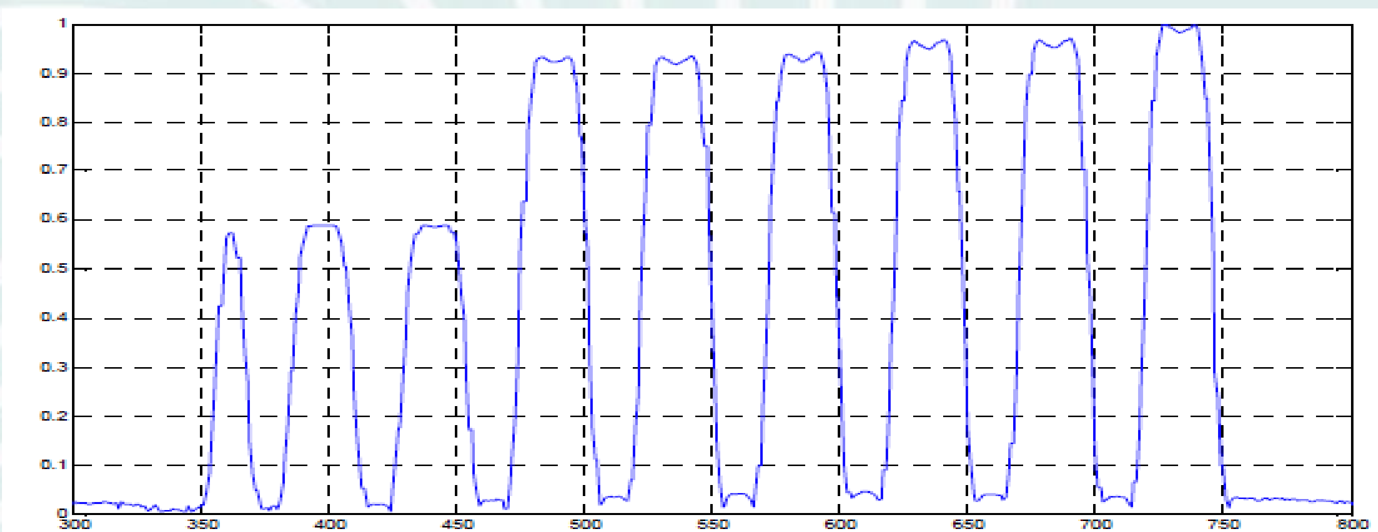




Tests on the cavities

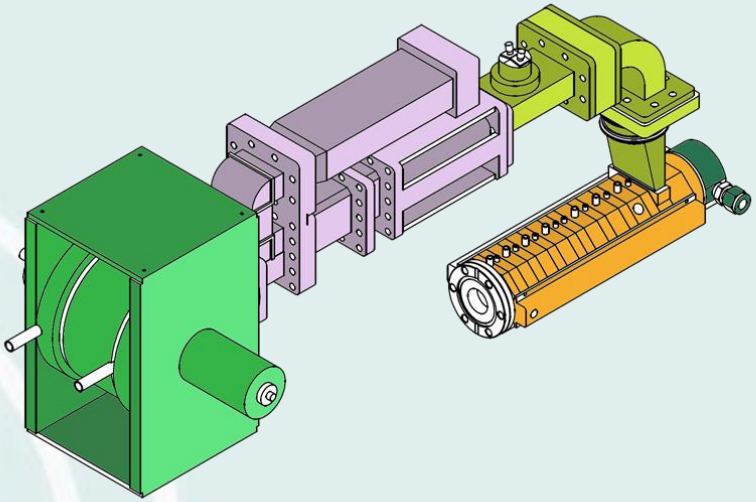
- Cavities built by TSC, Fiumicino
- Tests with network analyzer
- Axial electric field
- Tests are successful: Linac ready for beam

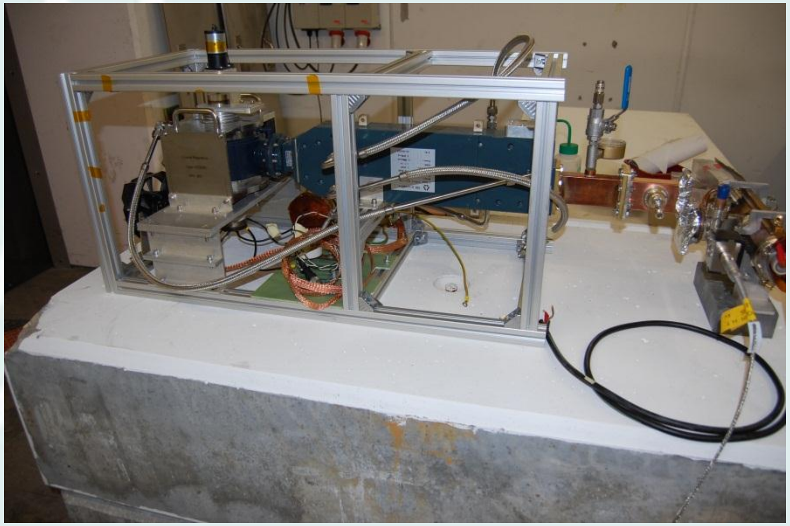




The RF-Line

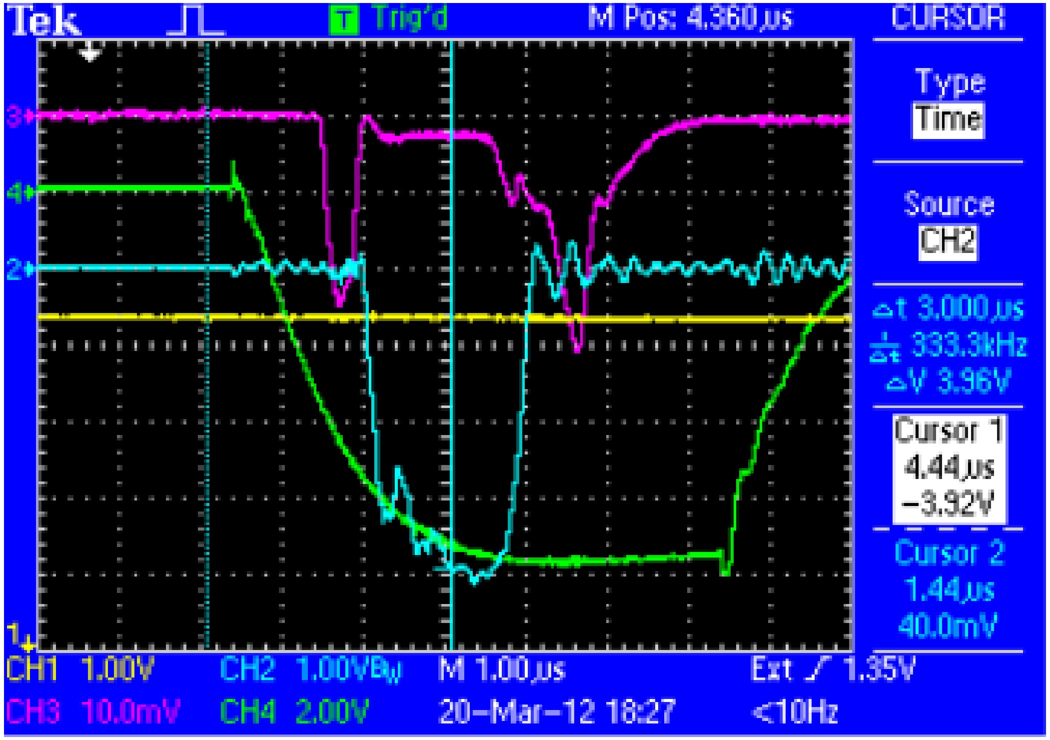
- ***System composed of***
  - *C-Band 2.5 MW Magnetron*
  - *4-port C-Band Circulator with 2.5MW peak and 2.5kW aver. power load*
  - *Gas port and Bi-directional coupler*
  - *EGUN*
  - *Linac*
  - *Modulator*





Finally Beam …

- After tuning the accelerator:
  - Measurement of E-Gun current with a Rogowski coil
  - Of the Linac-Energy inserting various 1mm Al layers
  - Of the beam spot

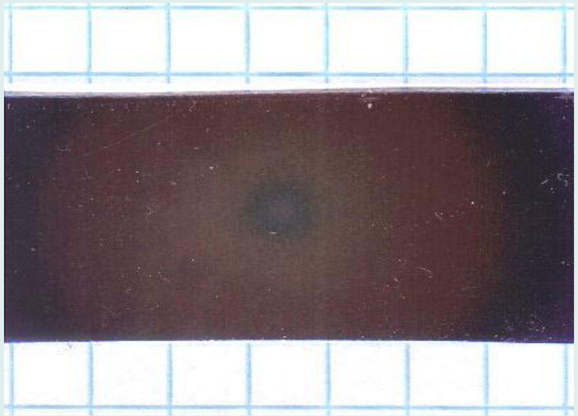


TDS 2024B - 17:12:28 20/03/2012

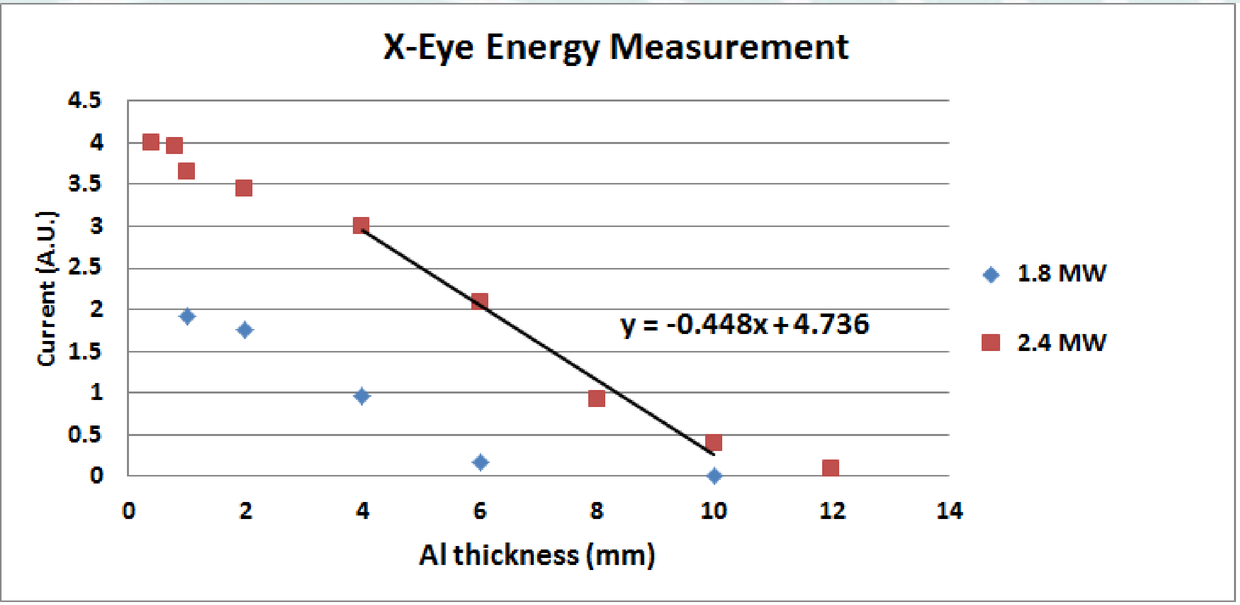
What do you see here:

- *The E-Gun tension*
  - *2kV/Div → ~10 kV*
- *The Current emitted with 0.8 mm of Al*
  - *20mA/div → 80 mA*
- *The reflected current (A.U.)*
- *The vacuum level*

- **Beam spot measurements**
  - Beam spot measurement with radiachromic film
  - Radius measured to be 2 mm

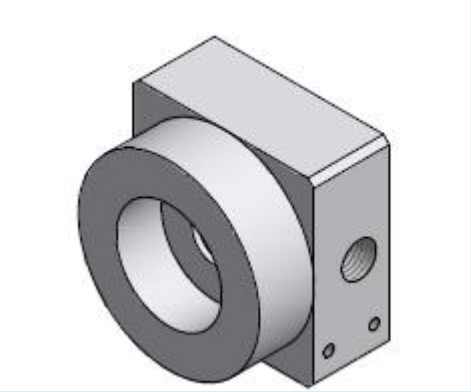


- **Measuring the energy**
  - Measurements at 1.8 and 2.4 MW
  - At 2.4 MW, Energy close to 6 MeV



Next step…

- The Tungsten target
  - Diameter of 19 mm
  - Thickness of 1mm
  - 99.95% pure tungsten
  - Encapsulated in a Aluminum structure for the cooling
  - It will be attached to a lead collimator
  - Simulations with Geant4 and MCNP5



Why?

- I told you what, you might wanna know why
  - We like physics, physics is fun …

Medical applications

– Proposal from Istituto Regina Elena, Rome, IT

Title:

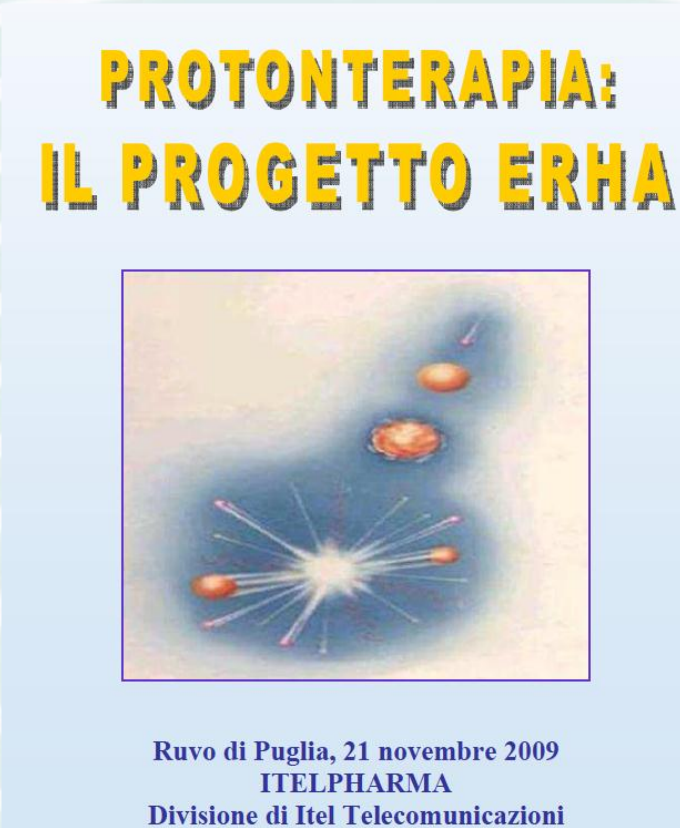
"Development and optimization of a dedicated self-shielded system to perform accelerated partial breast irradiation in prone position after breast conserving surgery"

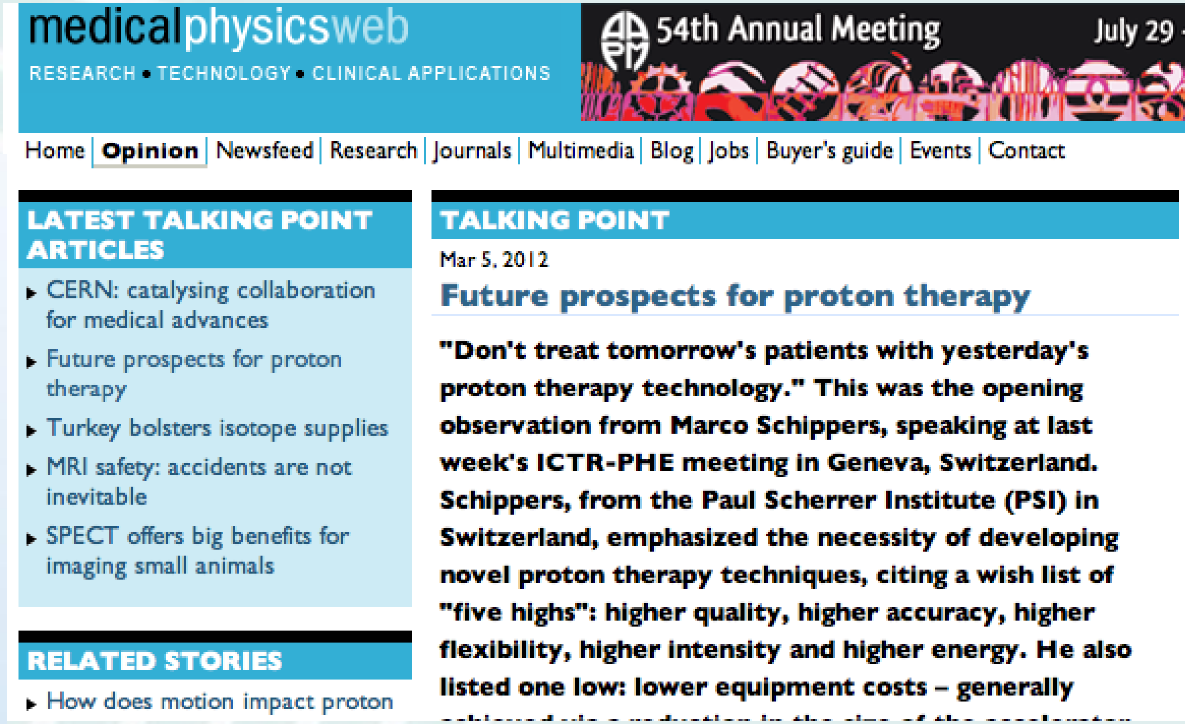
– Idea:

- Breast RT standard for patients with breast cancer
- 50 Gy in 25 fractions of 2 Gy
- Main advantage is to increase dose per fraction, therefore decreasing total time and limiting normal tissue affected
- Prone position is best as it minimizes the movement of target area
- Goal: to have a self-shielded system

Future projects

AMIDHERA
Ruvo di Puglia, Italy





LATEST TALKING POINT ARTICLES

- CERN: catalysing collaboration for medical advances
- Future prospects for proton therapy
- Turkey bolsters isotope supplies
- MRI safety: accidents are not inevitable
- SPECT offers big benefits for imaging small animals

RELATED STORIES

- How does motion impact proton

TALKING POINT

Mar 5, 2012

Future prospects for proton therapy

"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, higher accuracy, higher flexibility, higher intensity and higher energy. He also listed one low: lower equipment costs – generally

IMPULSE
PSI, Switzerland

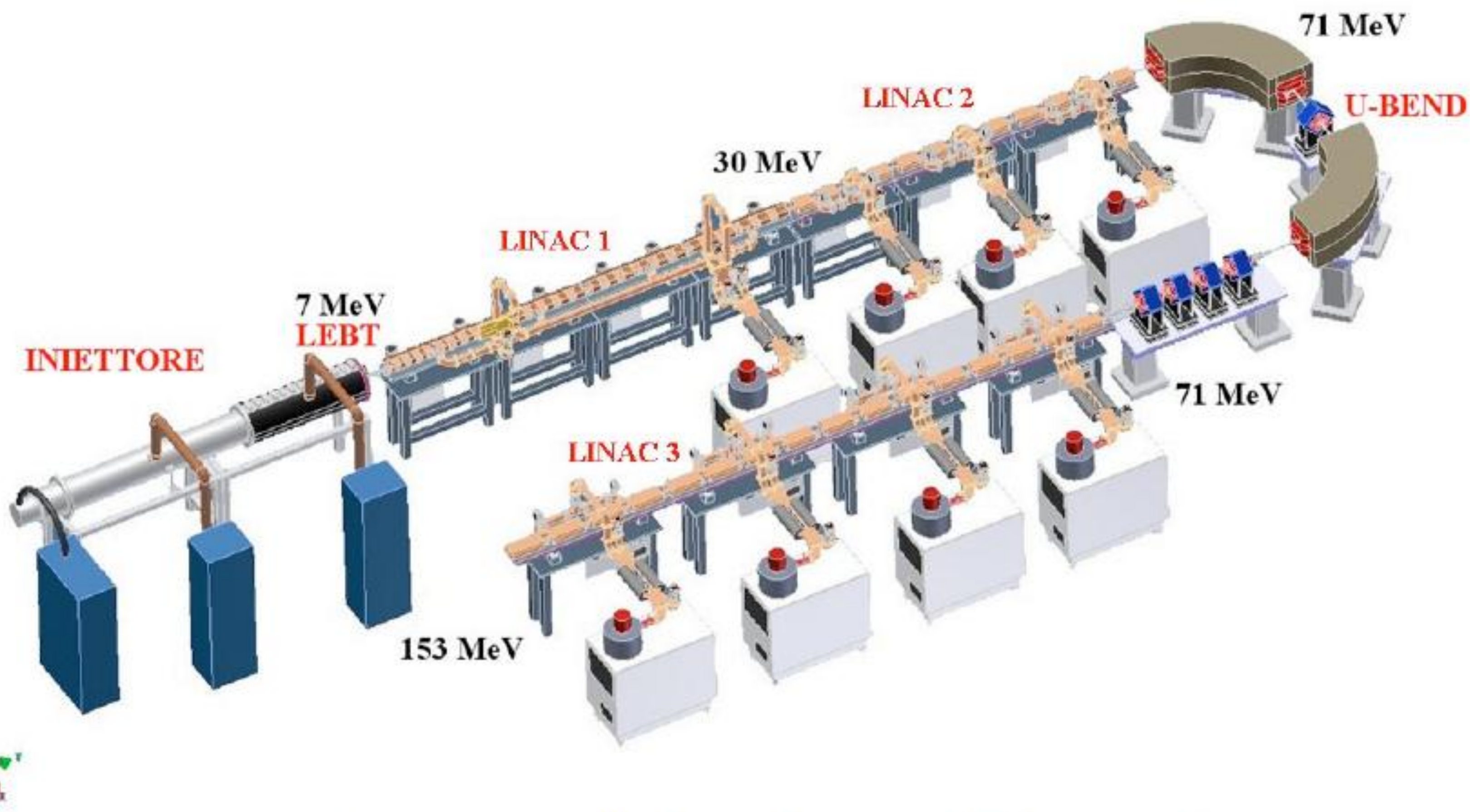
Impulse @ PSI

Development and test of a linear accelerator to boost protons for cancer therapy and proton radiography at 350 MeV

- *Where: PSI, Zurich*
- *Idea: Increase the proton energy from 250 to 350 MeV*
- *Advantages:*
  - *Increase therapeutic possibilities*
  - *Radiography with protons*
- *Why: Treat tumors close to vital organs*
- *How: coupling a dedicated linac to the existing cyclotron*
- *How: Four units of 1.6m each accelerating p of 25 MeV each*
- *Who:* MIGHT *be a close collaboration of PSI, ADAM and TERA*

Amidhera @ ruvo (ba) - italy

Proton-therapy center in Puglia (IT) to accelerate protons up to ~150 MeV



Acceleratore con indicazione dei vari moduli acceleranti

Conclusion

“ La Fisica è bella e utile”

Prof. Ugo Amaldi

Thank you for your attention!

...and thanks to Adriana, Angela, Claudio, Jacopo, Patrick, Titti…. for their help!