DIAGNOSTIC METHODS IN HADROTHERAPY

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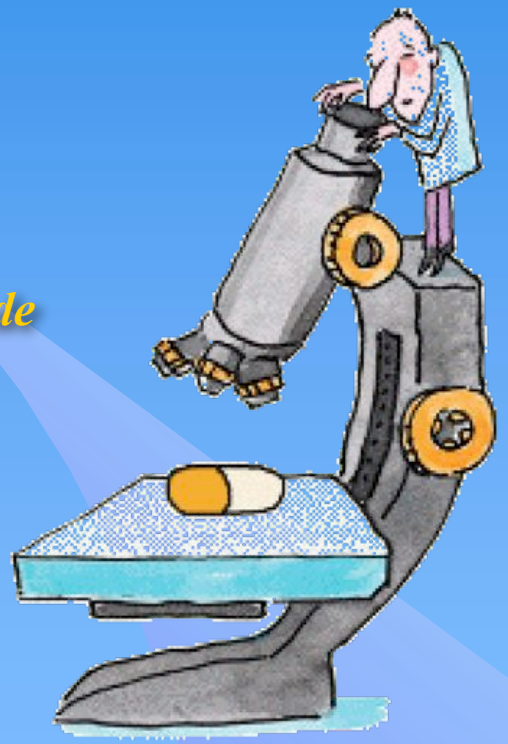
TERA Foundation and CERN

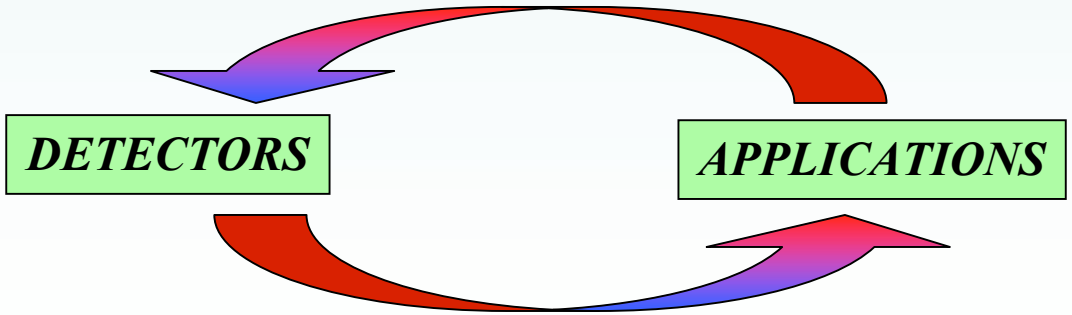
Accelerators and Medical Physics
Troisième Cycle de la Physique en Suisse Romande
EPFL Lausanne, 18 November 2010



TERA

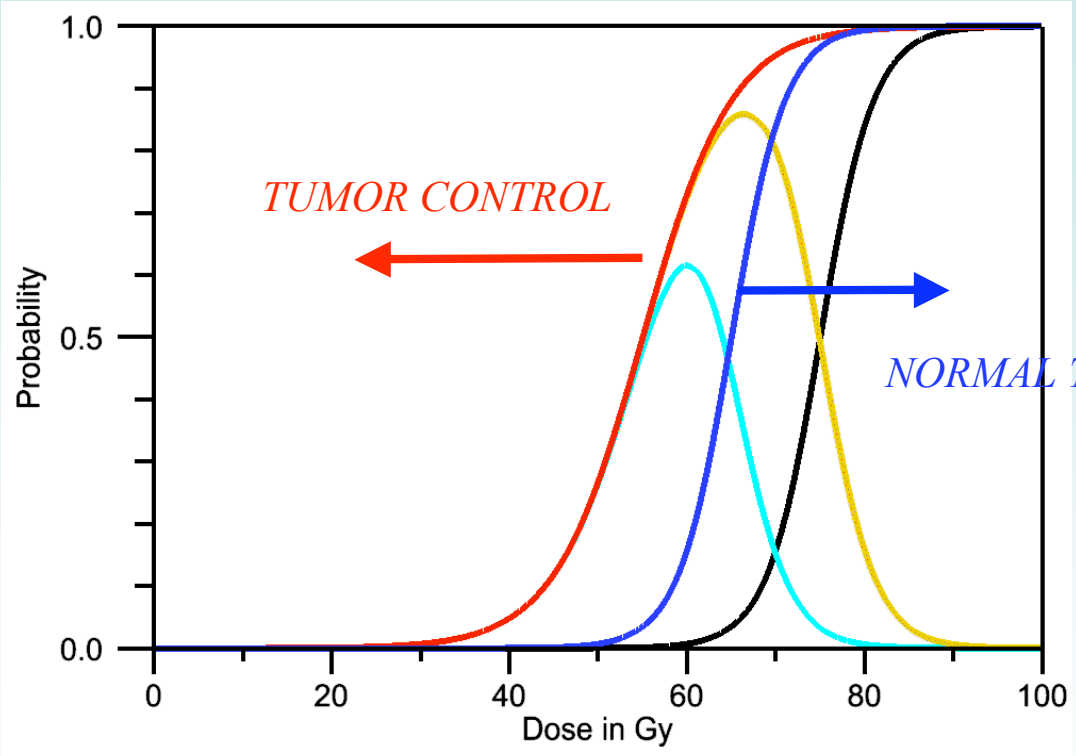
PROGRAMME

1. **Fundaments of hadrontherapy**
   - Radiobiological considerations
   - Treatment plans
   - Methods of in-vivo monitoring and dose determination
2. **Proton Range Radiography**
   - Basic principles
   - Range and position determination
   - PRR System for CNAO
3. **In-beam Positron Emission Tomography**
   - Positron emitter isotope production
   - In-beam and Time-of-Flight PET
4. **Dose monitoring with single particles**
   - Photons: SPECT, Compton imager
   - Charged Particles: Vertex imaging and Nuclear Scattering Tomography



PART 1
FUNDAMENTS OF HADROTHERAPY

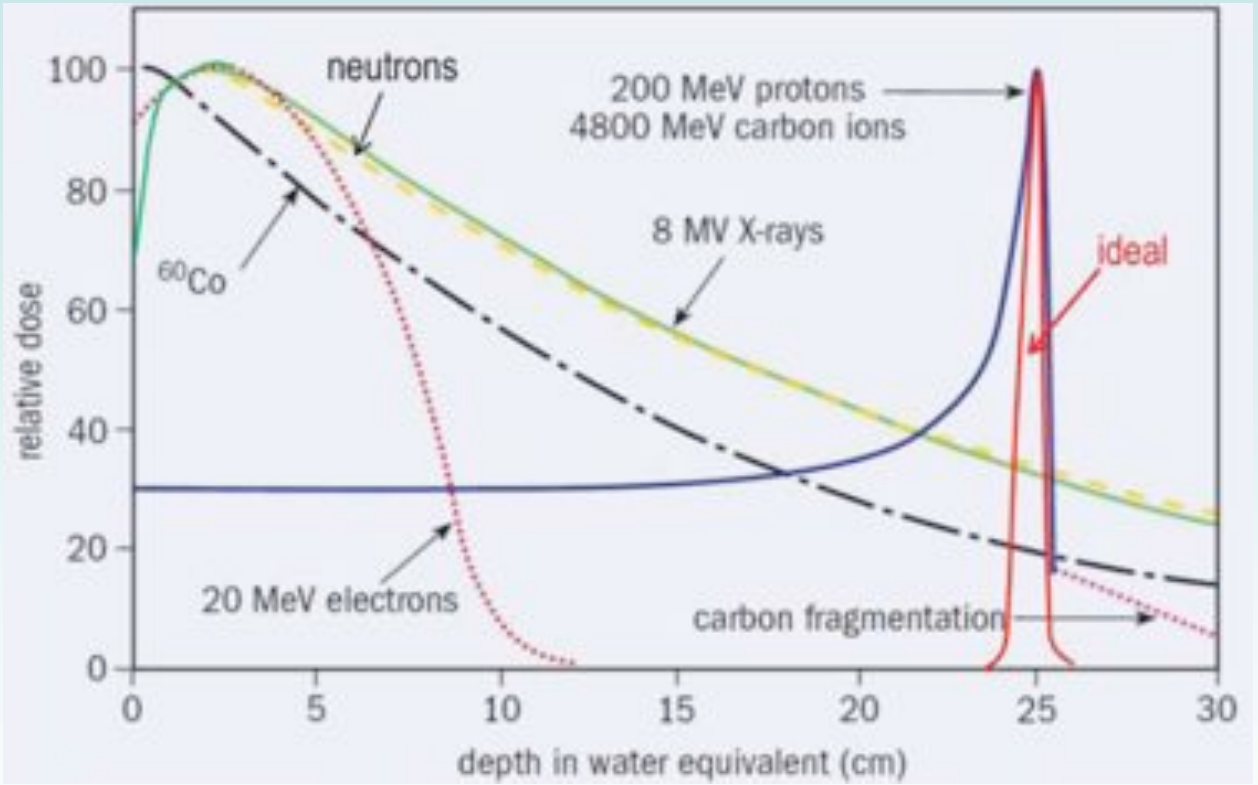
THE CHALLENGE OF RADIOTHERAPY



W. Enghart, Frontiers in Diagnostic Technologies (Frascati Nov. 25-27, 2009)

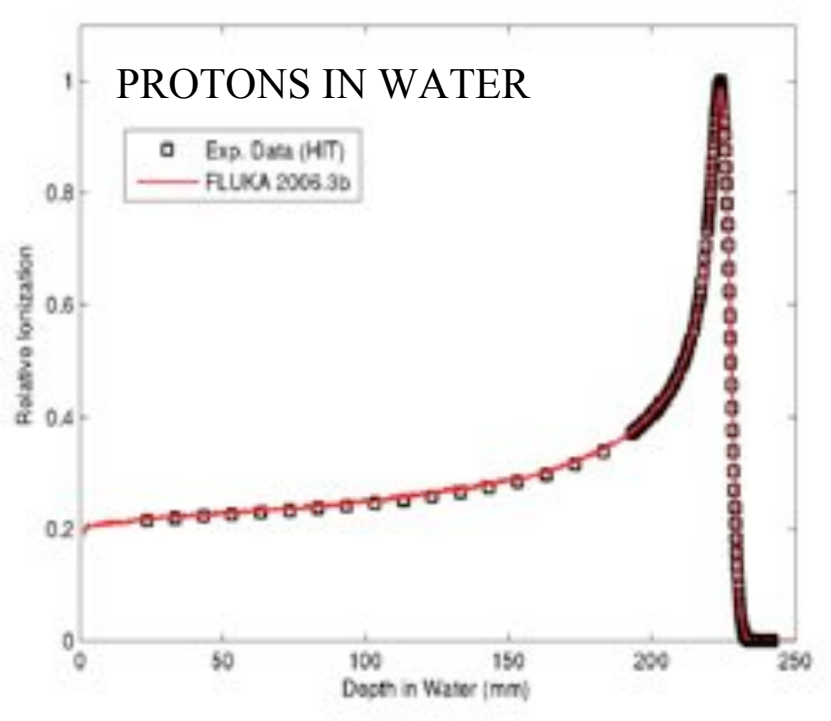
See also Prof. Amaldi lectures

DELIVERED DOSE VS PENETRATION OF RADIATION

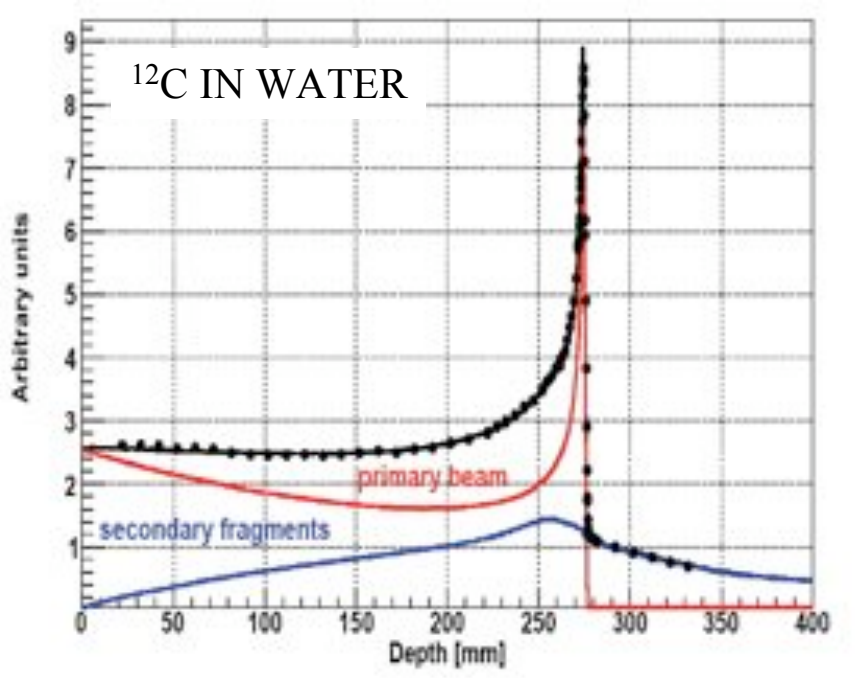


IONS ENERGY LOSS: MEASUREMENTS vs CALCULATIONS

MAJOR MONTECARLO PROGRAMS: GEANT 4 and FLUKA

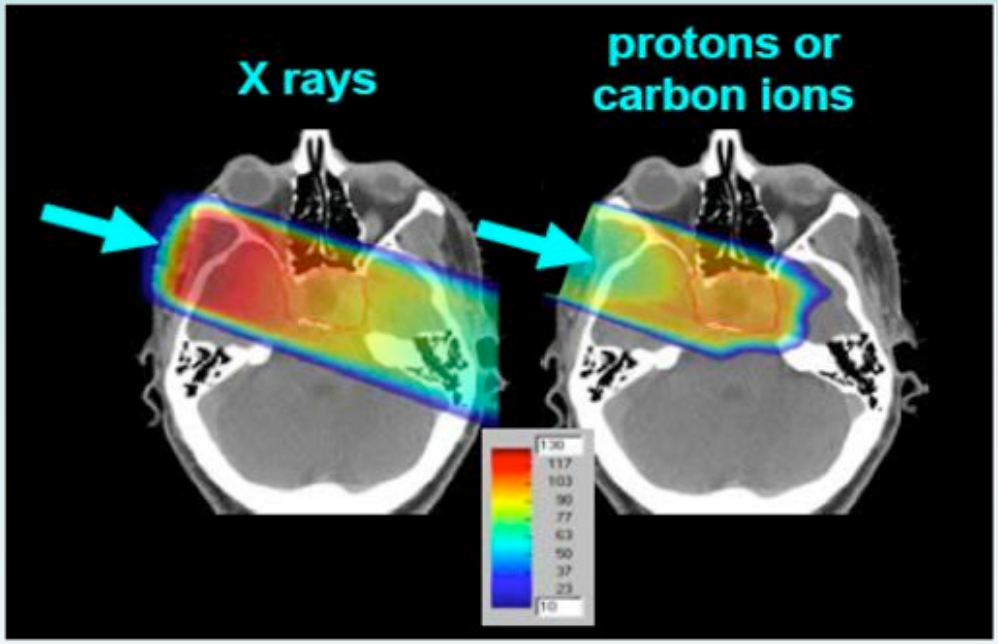


D. Schardt, K. Parodi et al (HIT)



Data: Haettner et al, Rad. Prot. Dos. (2006)
Calculations: A. Mairani, Nuovo Cimento

TREATMENT PLANS: PHOTON VS CHARGED PARTICLES

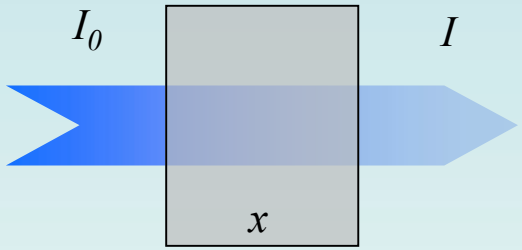


Patient morphology:
X-ray photon absorption (CAT Scans)

Patient treatment with hadrons:
Energy loss of charged particles

ENERGY LOSS OF PHOTONS

Absorption:



$$I = I_0 e^{-\frac{x}{l}} = I_0 e^{-\mu x}$$

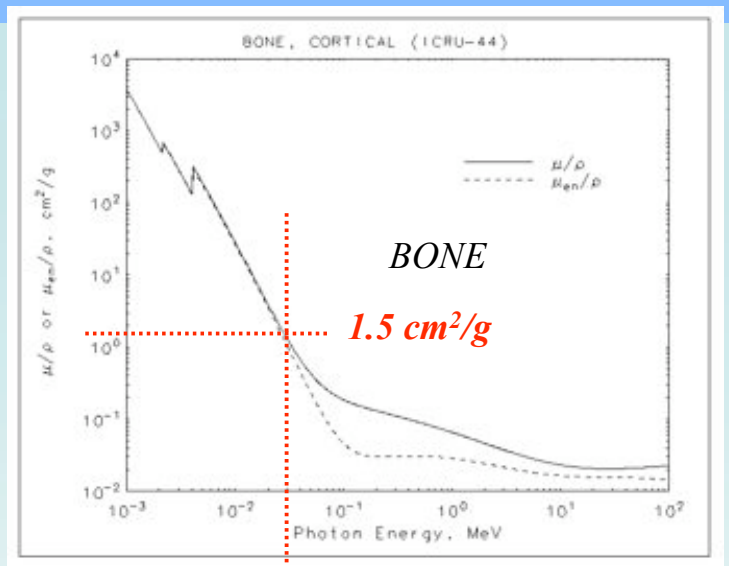
x : material thickness (cm)

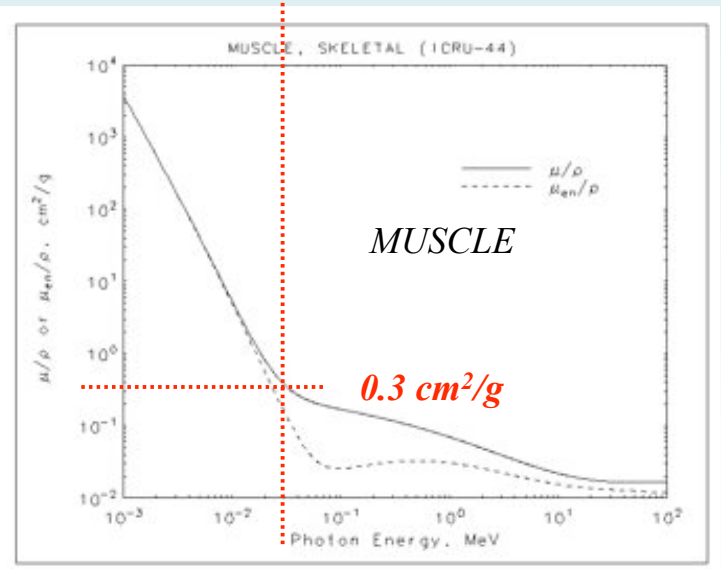
l : linear absorption length (cm)

$\mu = 1/(l\rho)$: mass absorption coefficient ($cm^2\ g^{-1}$)

$$\mu(E) \sim \frac{Z^n}{E^{3.5}}$$

Strong dependence from atomic number (material composition)

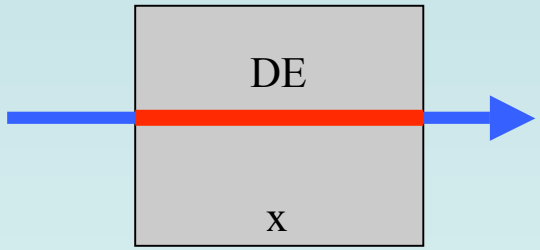




30 keV

http://physics.nist.gov/PhysRefData/Xcom/Text/XCOM.html

ENERGY LOSS OF CHARGED PARTICLES



Differential energy loss:

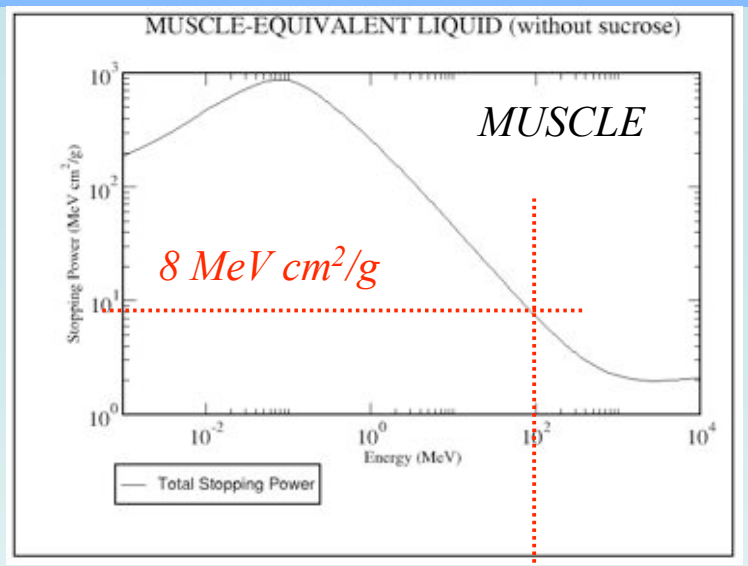
$$\frac{dE}{dx} \sim \frac{Z}{A}\frac{\rho}{\beta^2}$$ ρ: material density

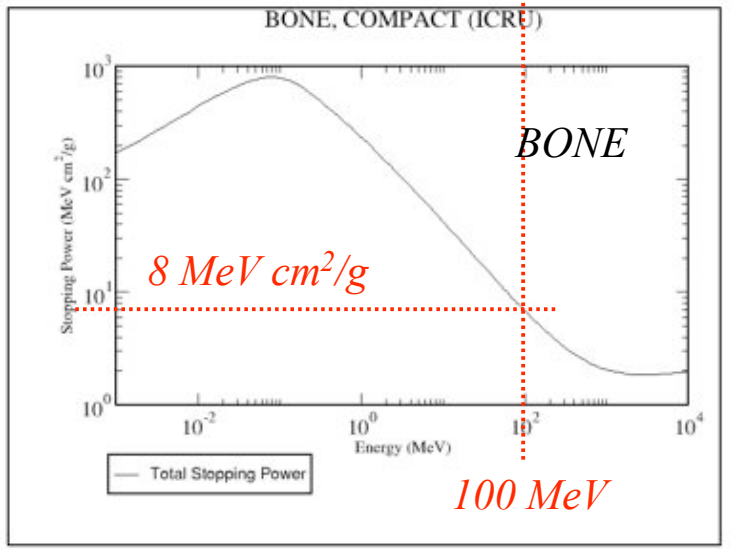
$\frac{Z}{A}$: material atomic number and mass (~2)

β : particle velocity

Mass Stopping Power:

$$\frac{\Delta E}{x}\Big/\rho$$ almost independent from the material composition





http://www.nist.gov/physlab/data/star/index.cfm

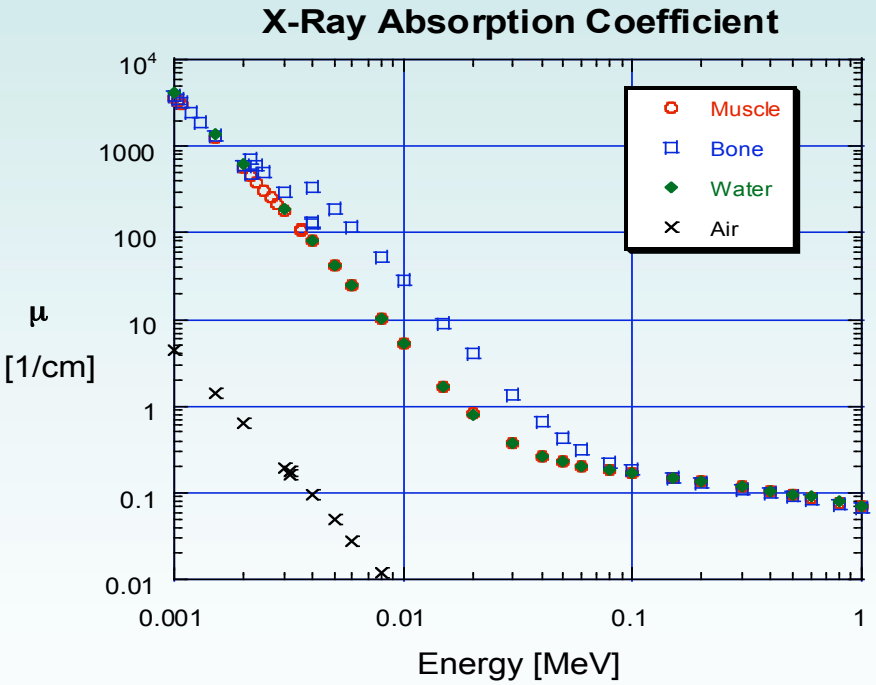
COMPUTED TOMOGRAPHY: X-RAYS VS PROTONS

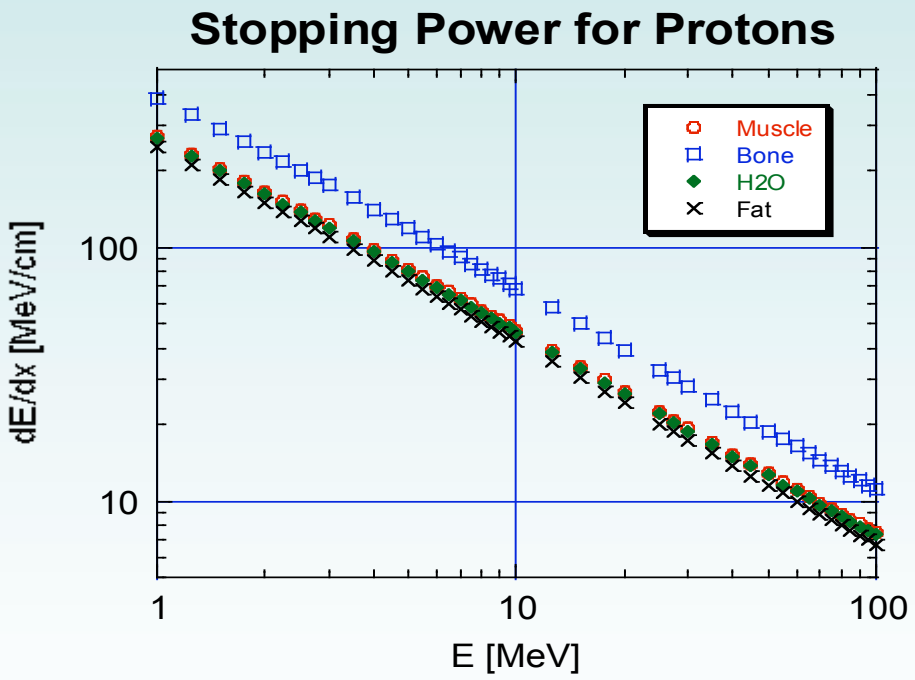
Attenuation of Photons: F(z)

$N(x) = N_o e^{-\mu x}$

Energy Loss of Protons: F(ρ)

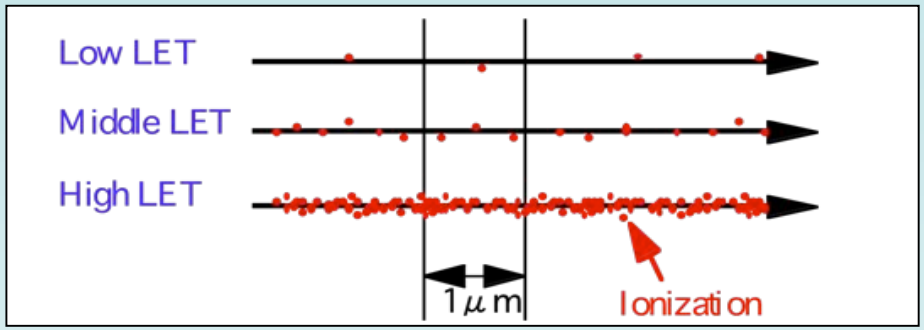
$$\Delta E = \int \frac{dE}{dx} dx$$



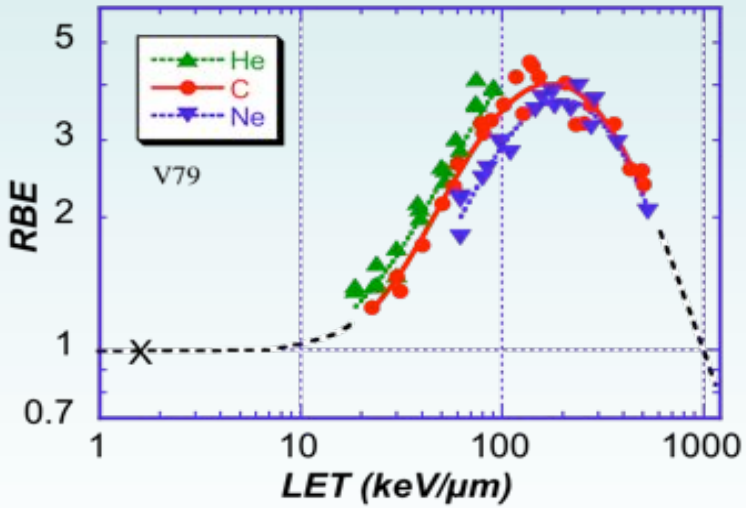


R. Schulte, seminar 2010

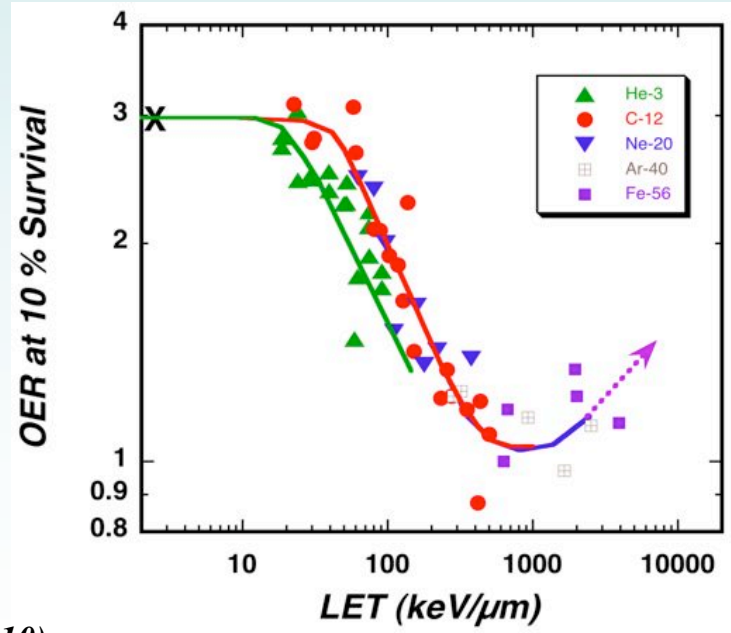
LET: Linear Energy Transfer



RBE: Relative Biological Effectiveness



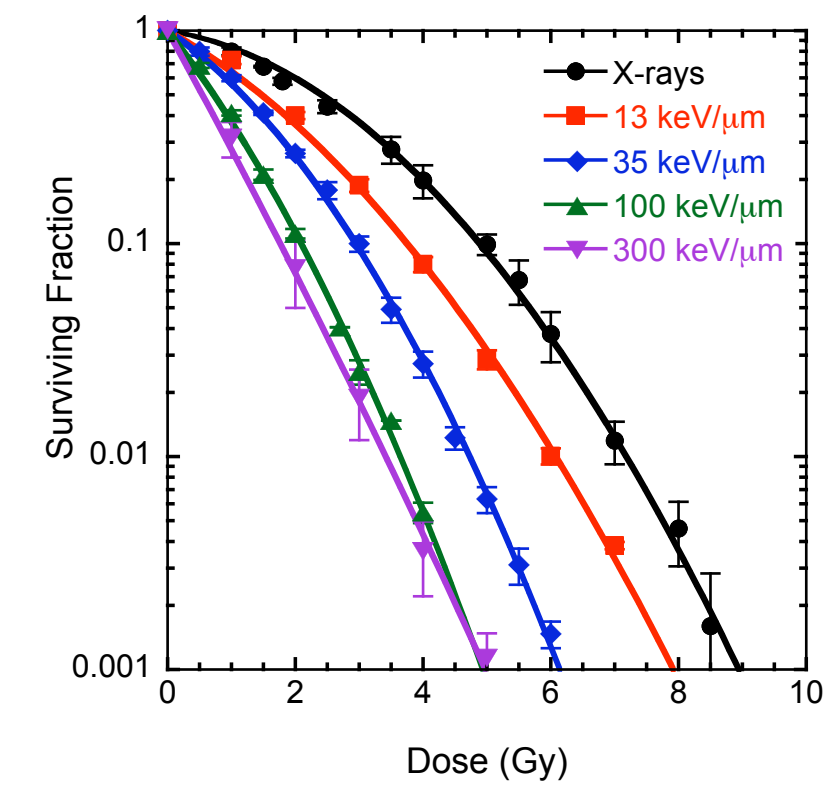
OER: Oxygen Enhancement Ratio



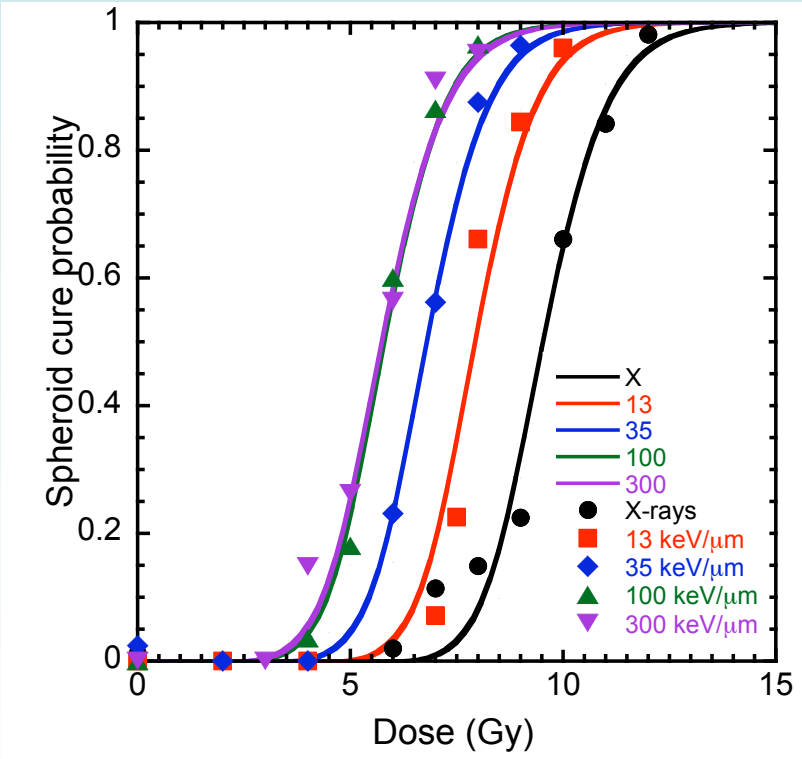
Yoshiya Furusawa,
2d Joint Symposium on Hadrontherapy (Pavia, March 2010)

EFFECT OF RADIATION LET AND TYPE

SURVIVAL PROBABILITY:

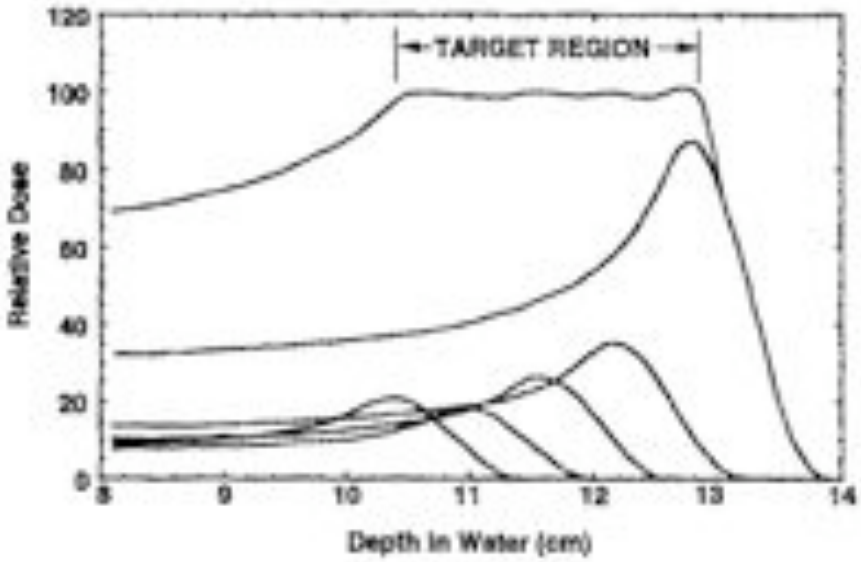


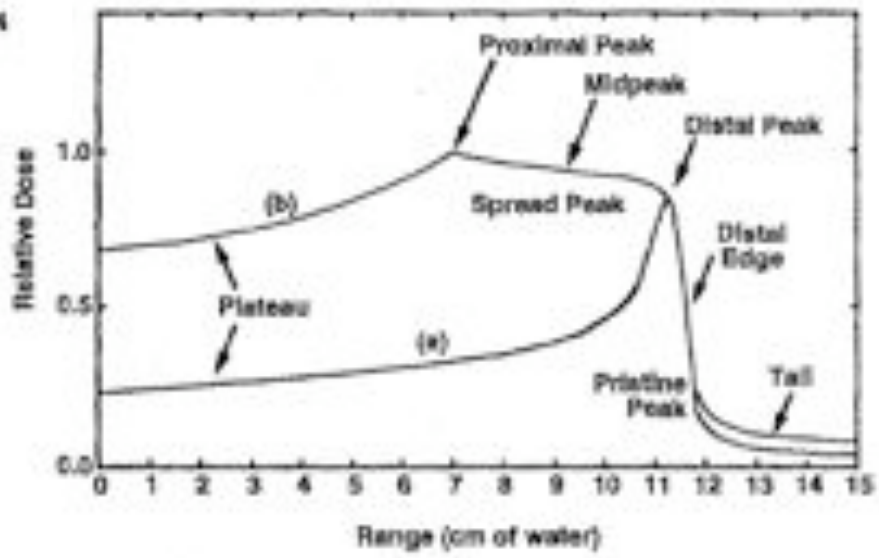
TUMOR CONTROL PROBABILITY:



Yoshiya Furusawa, 2[d] Joint Symposium on Hadrontherapy (Pavia, March 2010)

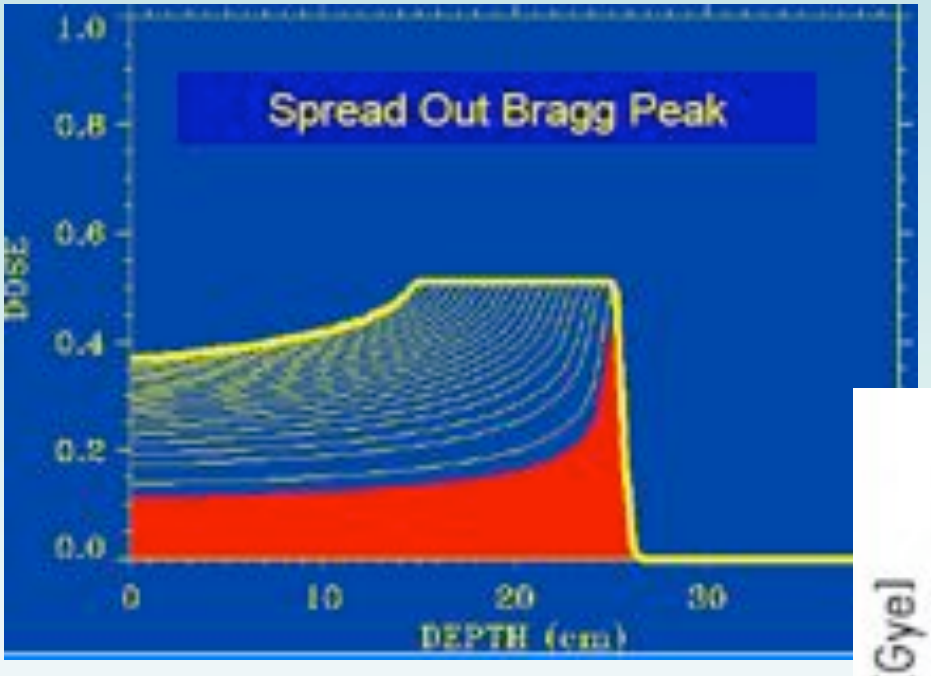
HADRON THERAPY OF EXTENDED TARGETS: ENERGY MODULATION

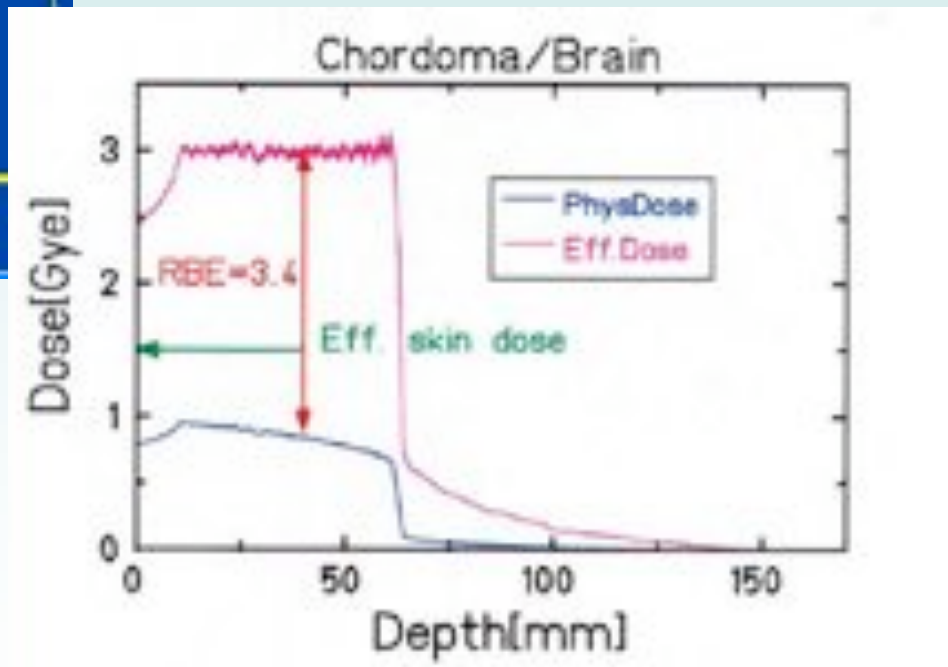




W.T. Chu et al, Rev. Sci. Instr. 64(1993)2055

EXTENDED TARGET: PHYSICAL AND EFFECTIVE DOSE

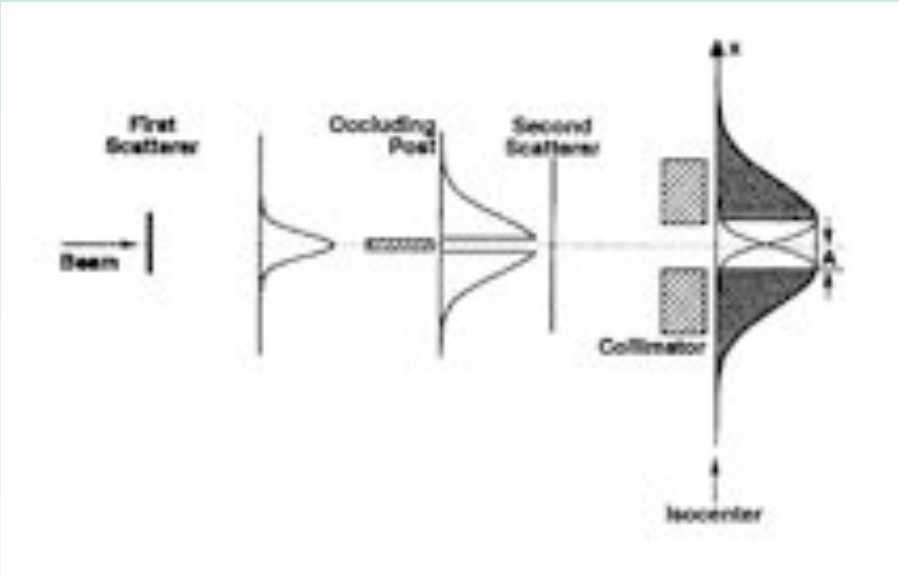




Ugo Amaldi, CERN Colloquium 5.2.09

BEAM WIDENING:

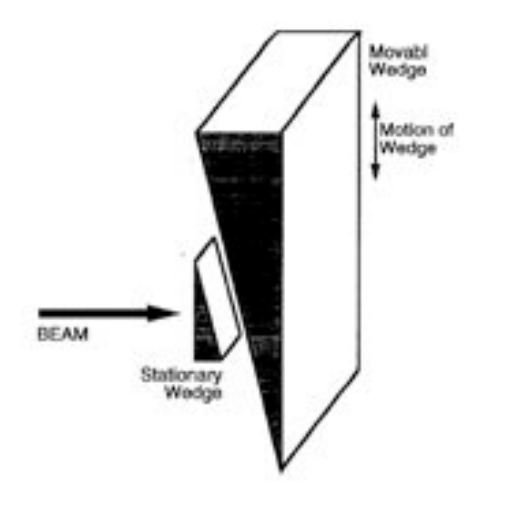
Double beam scatterer with central occluder: quasi-flat field at isocenter



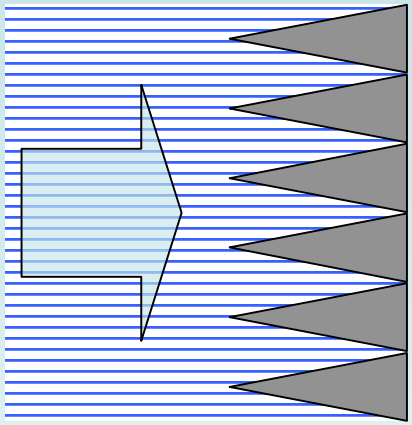
W.T. Chu et al, Rev. Sci. Instr. 64(1993)2055

ENERGY MODULATION WITH RANGE SHIFTERS

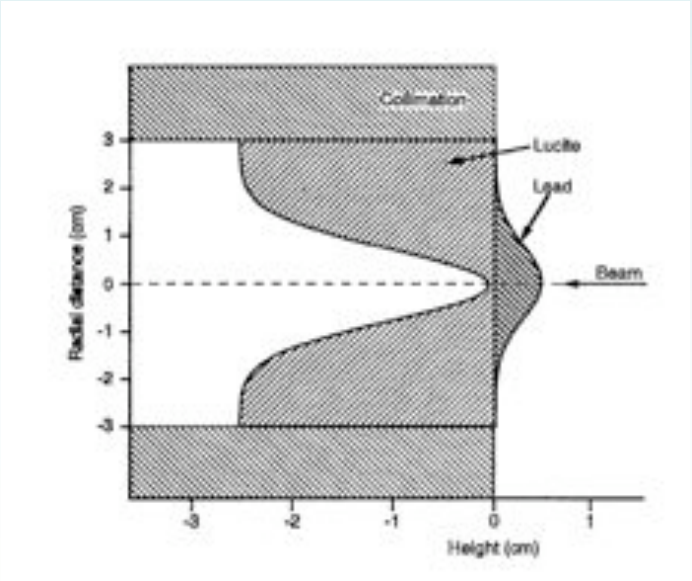
DOUBLE MOVABLE WEDGE:



RIDGE FILTER:

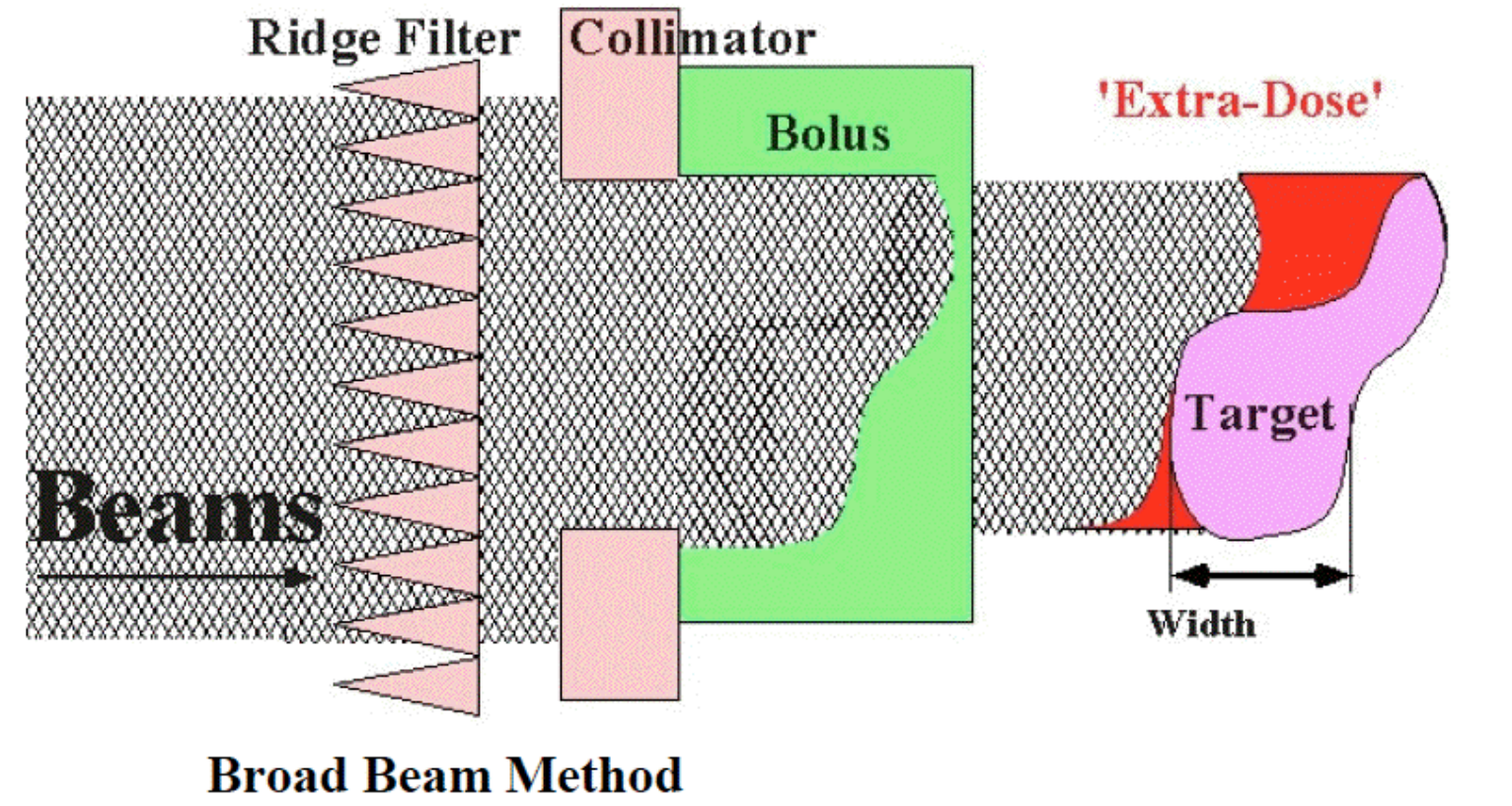


BIMATERIAL FILTER:



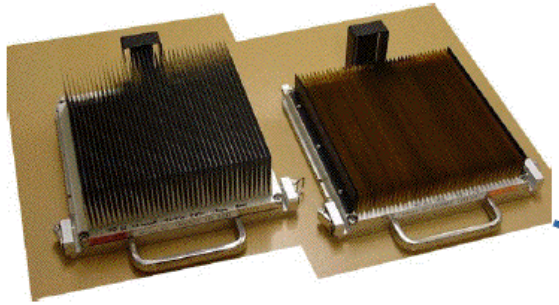
W.T. Chu et al, Rev. Sci. Instr. 64(1993)2055

FILTER, COLLIMATOR AND RANGE COMPENSATION:

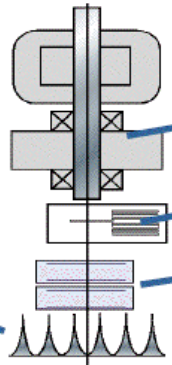


NIRS HIMAC

Equipments of Wobbler method



Ridge Filter

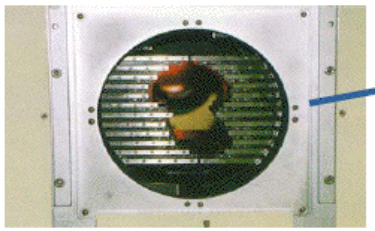


Wobbler Magnets

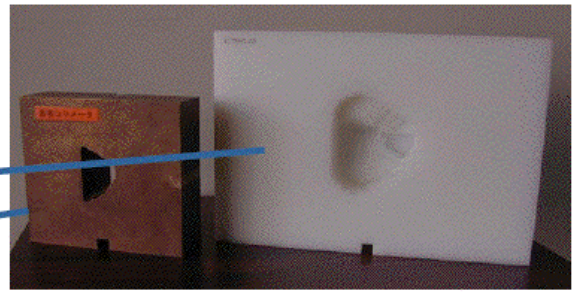
Scatterer

Ionization Chamber

Range Shifter

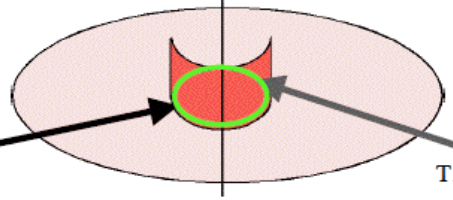


Multi-Leaf Collimator



Patient Collimator

Patient Compensator

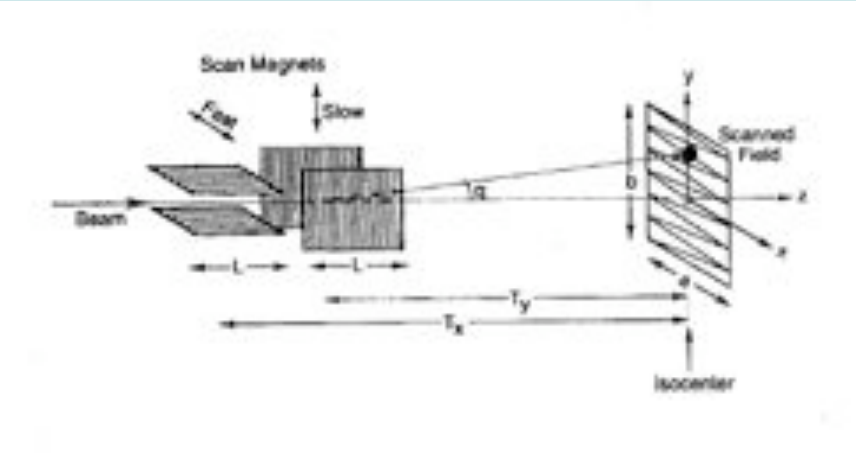


Target

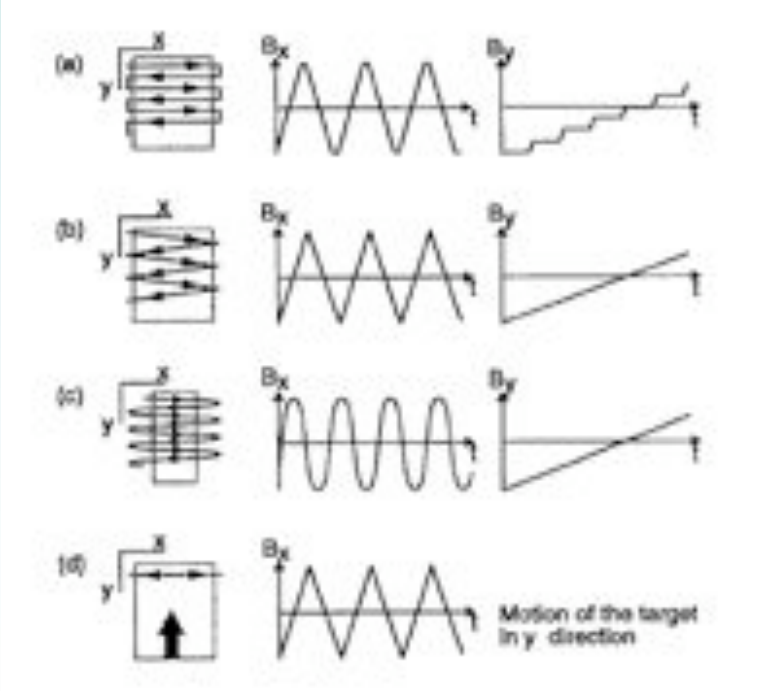
Field

T. Kanai, et al., Int. J. Radiat. Oncol., Biol., Phys. 44, 201 (1999).

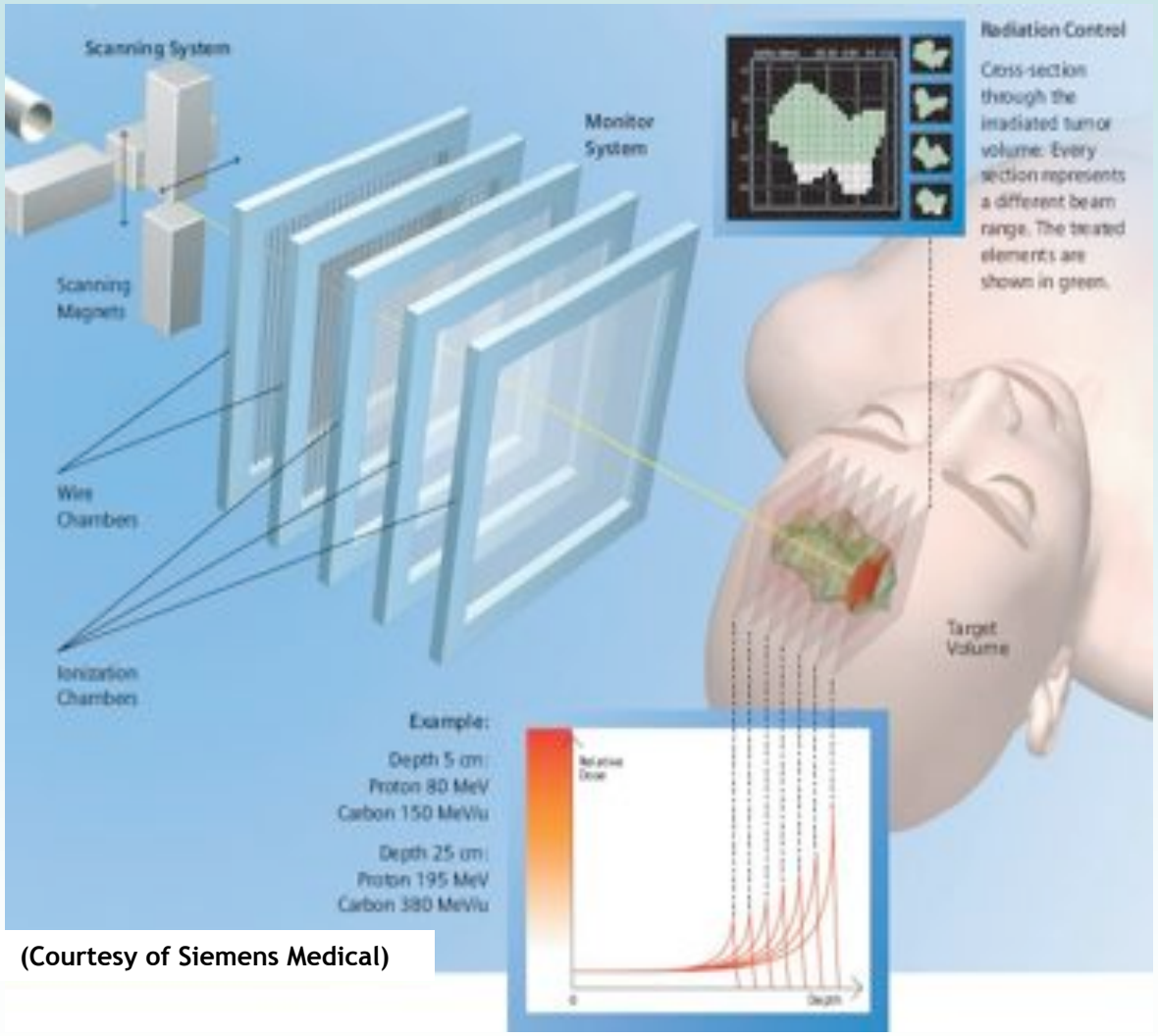
RASTER BEAM SCANNING WITH MAGNETS:



W.T. Chu et al, Rev. Sci. Instr. 64(1993)2055

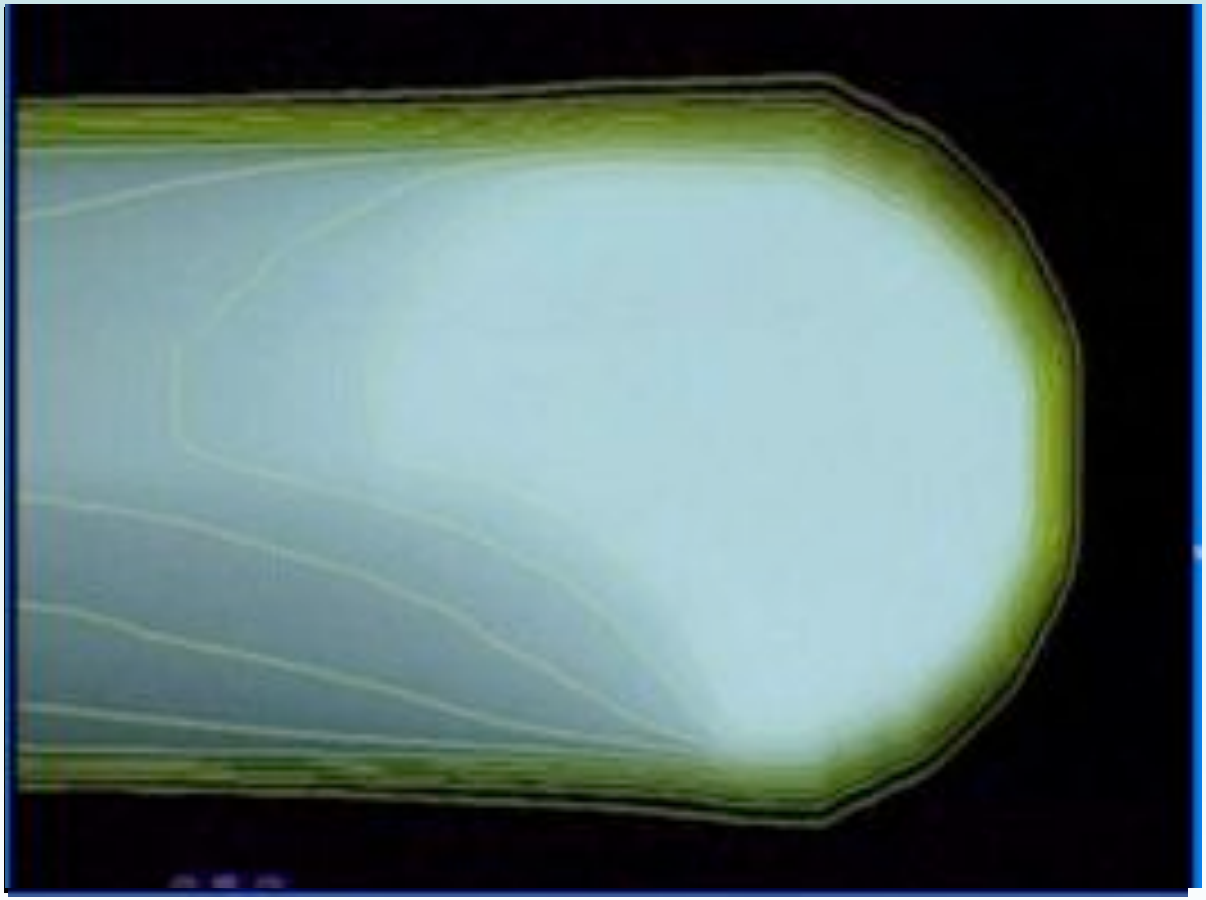


ACTIVE BEAM DELIVERY SYSTEMS AT CNAO:



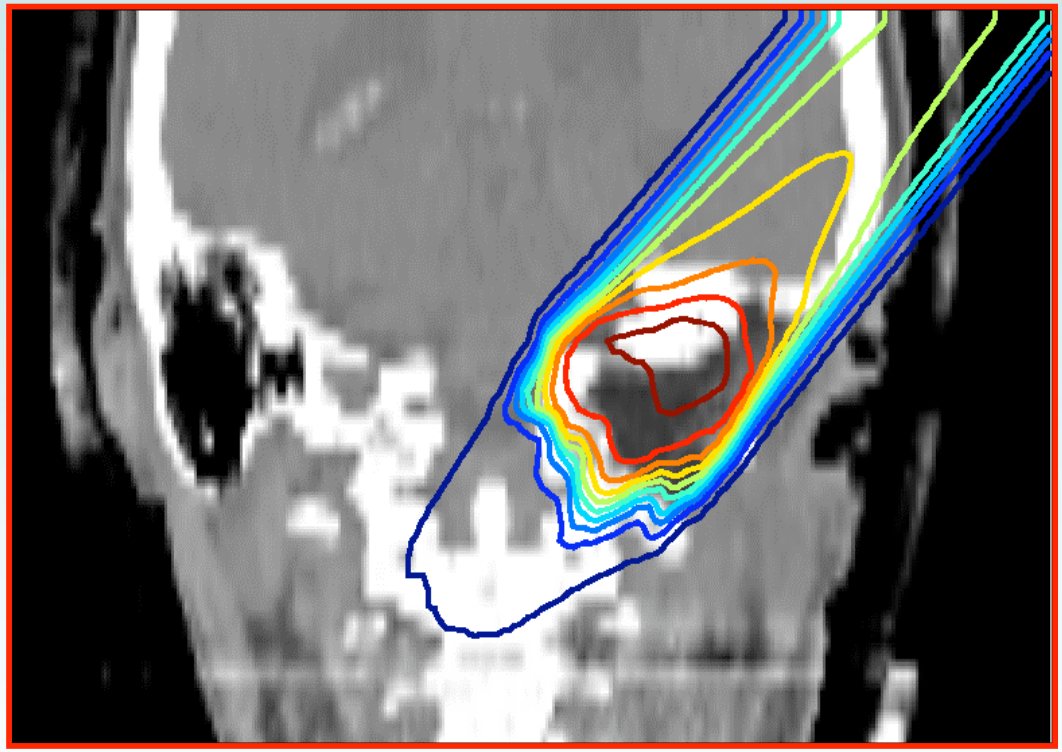
(Courtesy of Siemens Medical)

(SIMULATED) DOSE DISTRIBUTION:



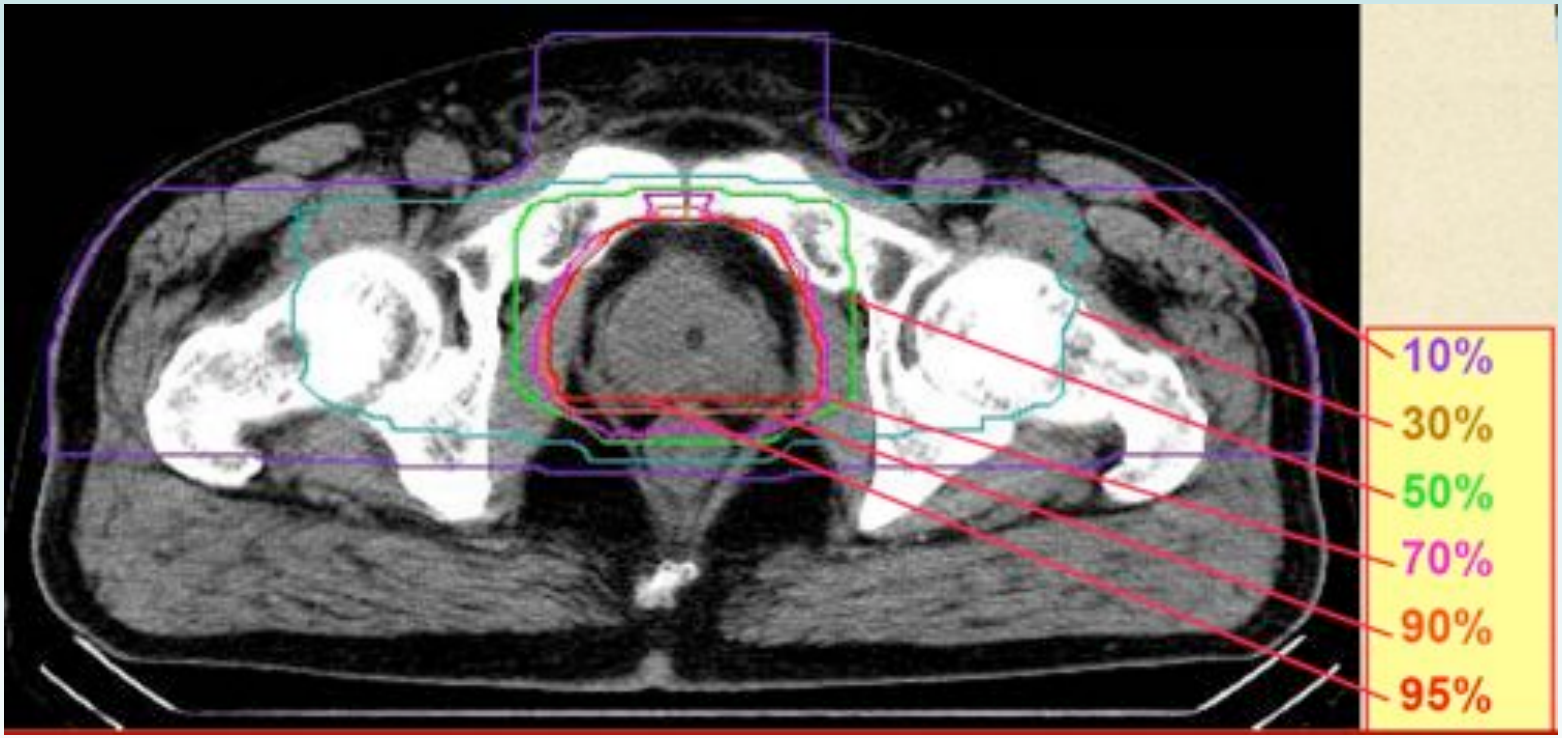
Ugo Amaldi, CERN Colloquium 5.2.09

SINGLE BEAM: COMPUTED ISODOSE DISTRIBUTIONS



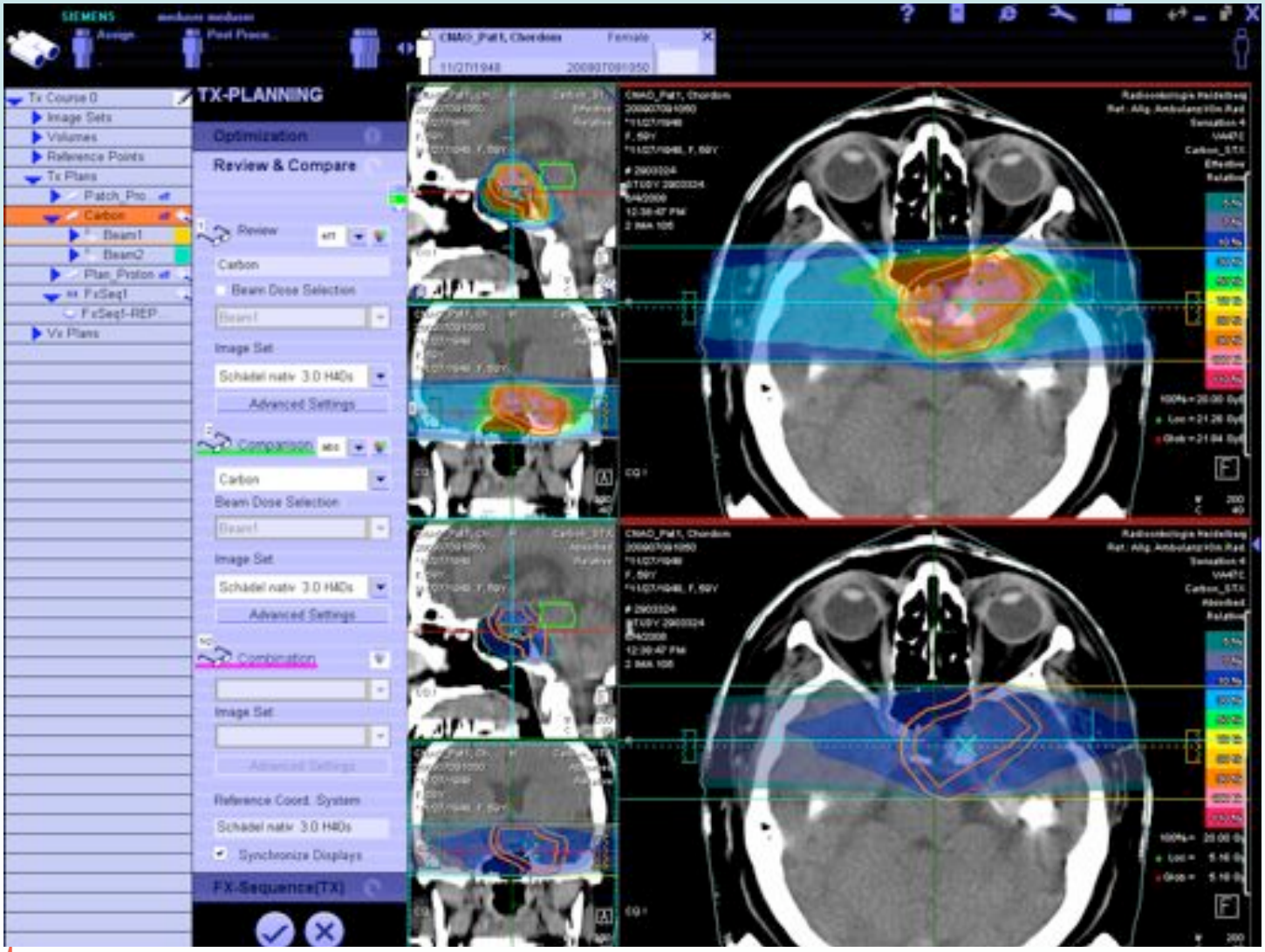
W. Enghart, Frontiers in Diagnostic Technologies (Frascati Nov. 25-27, 2009)

CARBON ION DUAL BEAM PROSTATE TREATMENT PLAN :

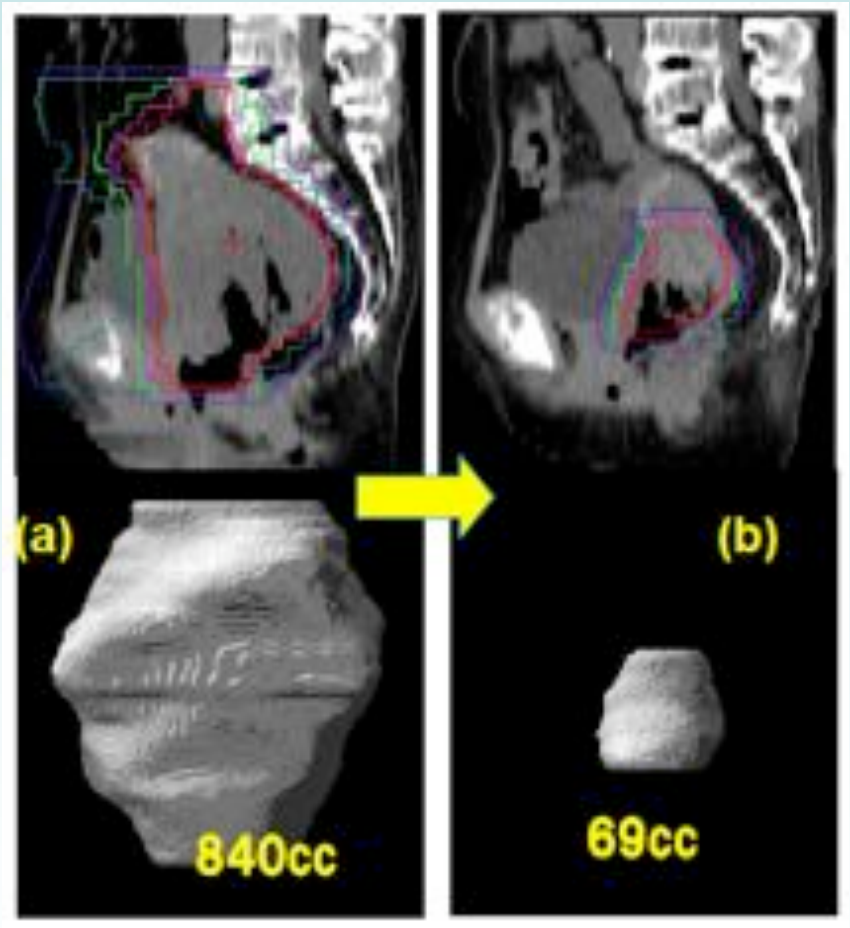


Hirohiko Tsuji, 2d Joint Symposium on Hadrontherapy (Pavia, March 2010)
National Institute of Radiological Sciences (Chiba, Japan)

SIMENS TREATMENT PLAN SOFTWARE AT CNAO:

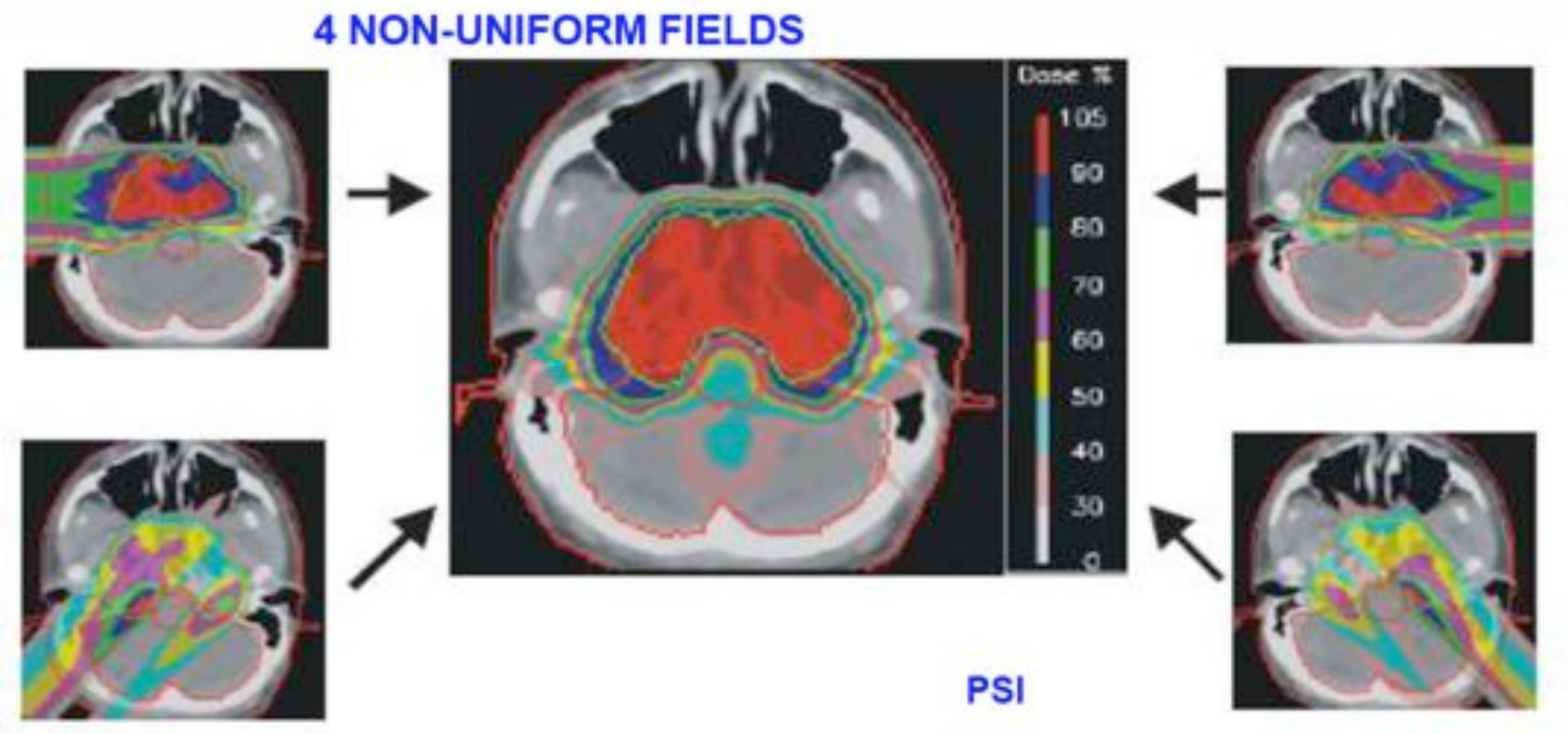


REGION VERIFICATION: TUMOR SHRINKING AFTER FIRST FRACTIONS



Koji Noda, 2d Joint Symposium on Hadrontherapy (Pavia, March 2010)

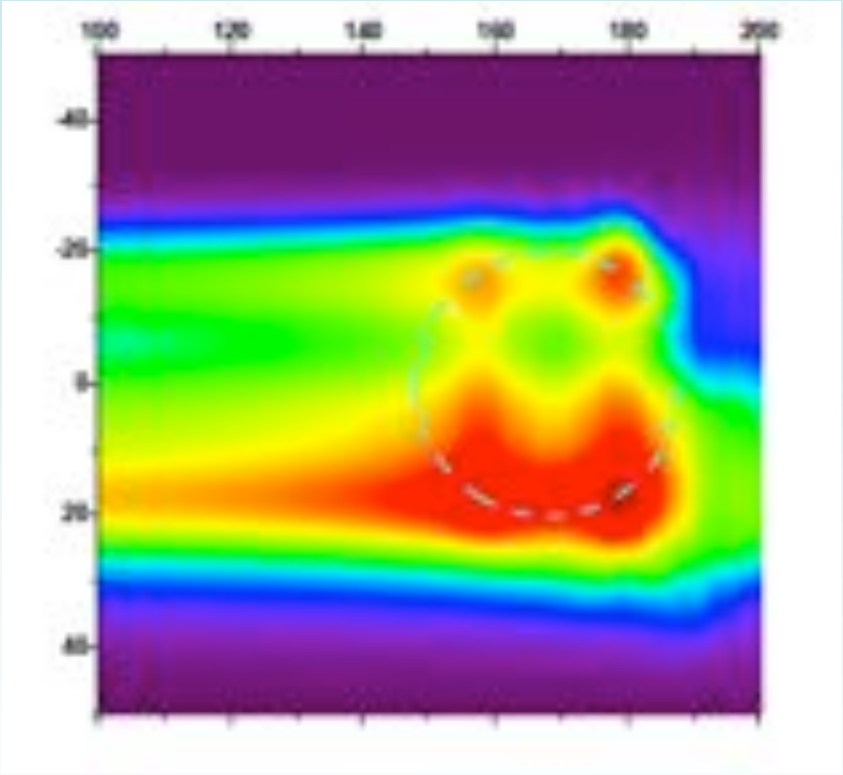
MULTI-FIELD INTENSITY MODULATED THERAPY WITH PROTONS



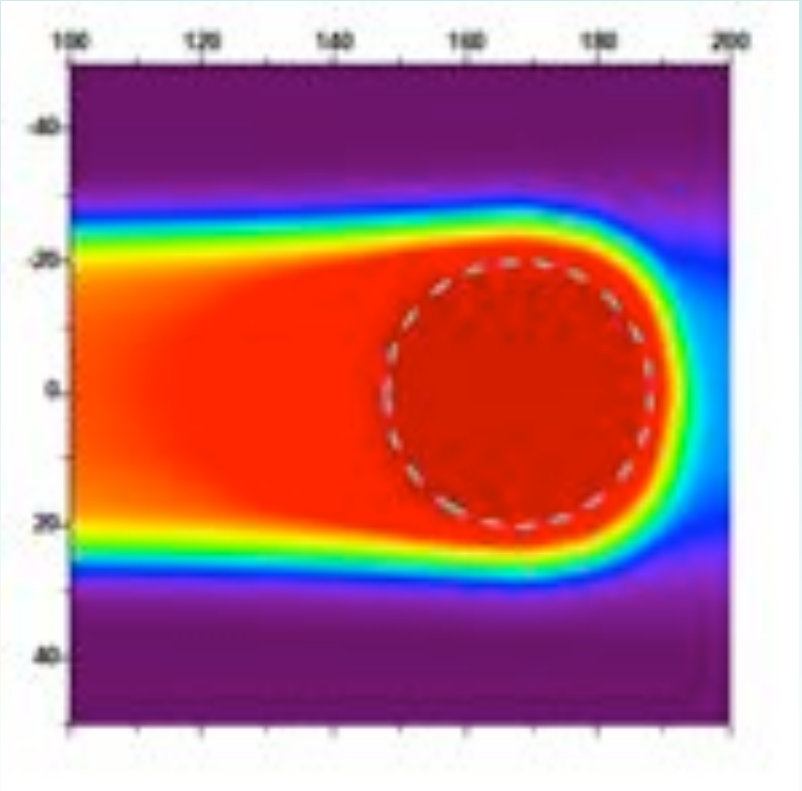
Ugo Amaldi, CERN Colloquium 5.2.09

RASTER SCAN SYNCRONIZED WITH MOTION SENSOR (GATING)

NON-GATING



GATING AND RESCAN



Koji Noda, 2[d] Joint Symposium on Hadrontherapy (Pavia, March 2010)

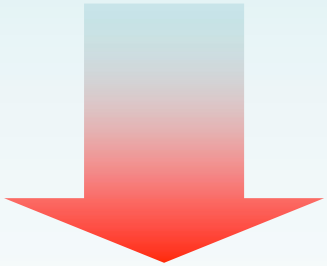
BASIC QUESTIONS IN HADRONTHERAPY:

WHERE IS THE BEAM?

WHERE IS THE PATIENT?

WHERE IS THE TUMOR?

WHAT IS THE DELIVERED DOSE?



ACTIVE MONITORING FOR TREATMENT QUALITY ASSURANCE

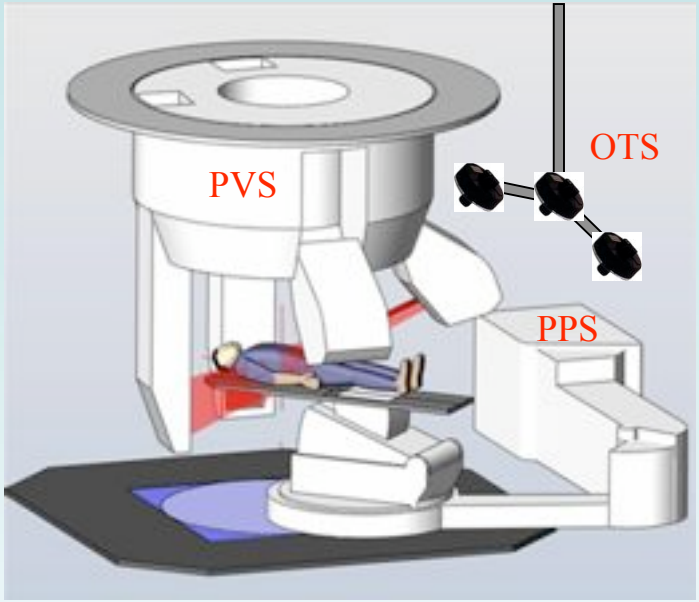
PATIENT MONITORING: STANDARD OFF-BEAM IMAGING

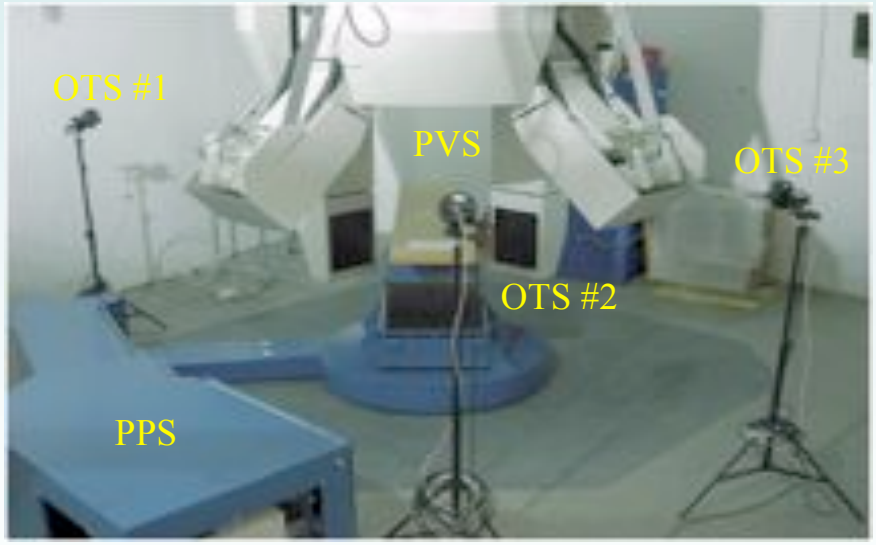
X-RAY COMPUTER TOMOGRAPHY
CT-SCAN

POSITRON EMISSION TOMOGRAPHY
PET

PATIENT POSITIONING VERIFICATION AT CNAO

6 Degrees of Freedom Patient Positioning System (PPS)
X-ray patient Verification System (PVS)
3D Real-time IR Optical Tracking (OTS)



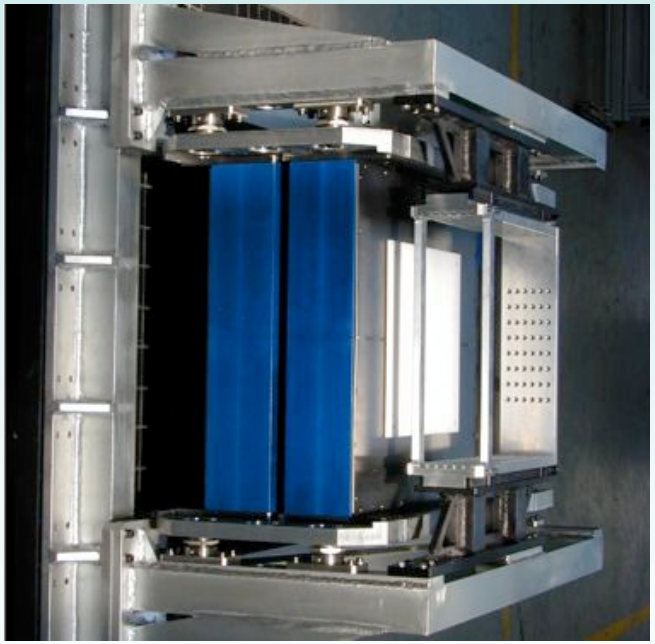


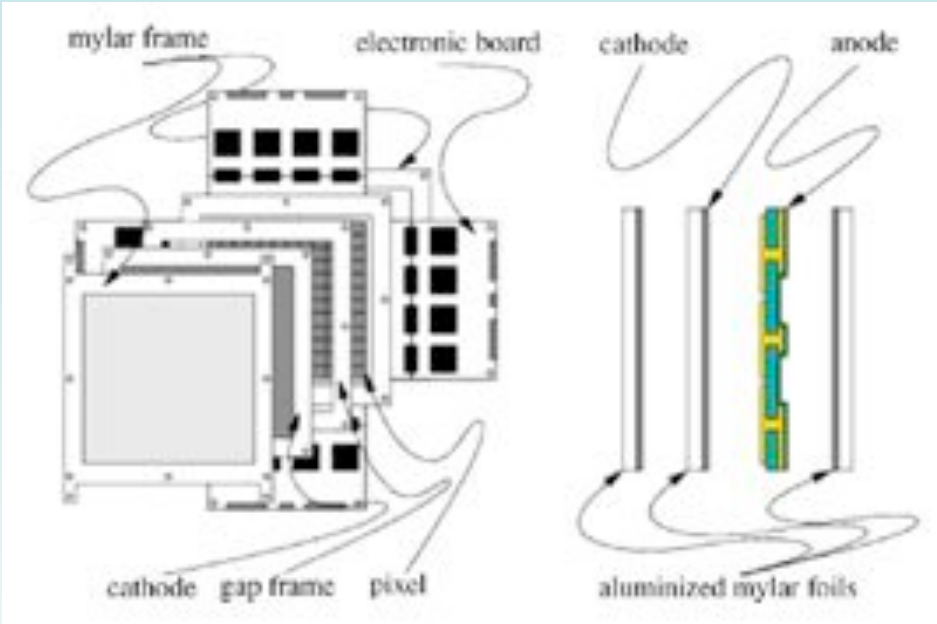
CNAO

CENTRO NAZIONALE DI ADROTERAPIA ONCOLOGICA

Guido Baroni,
2d Joint Symposium on Hadrontherapy
(Pavia, March 2010)

PIXEL IONIZATION CHAMBERS

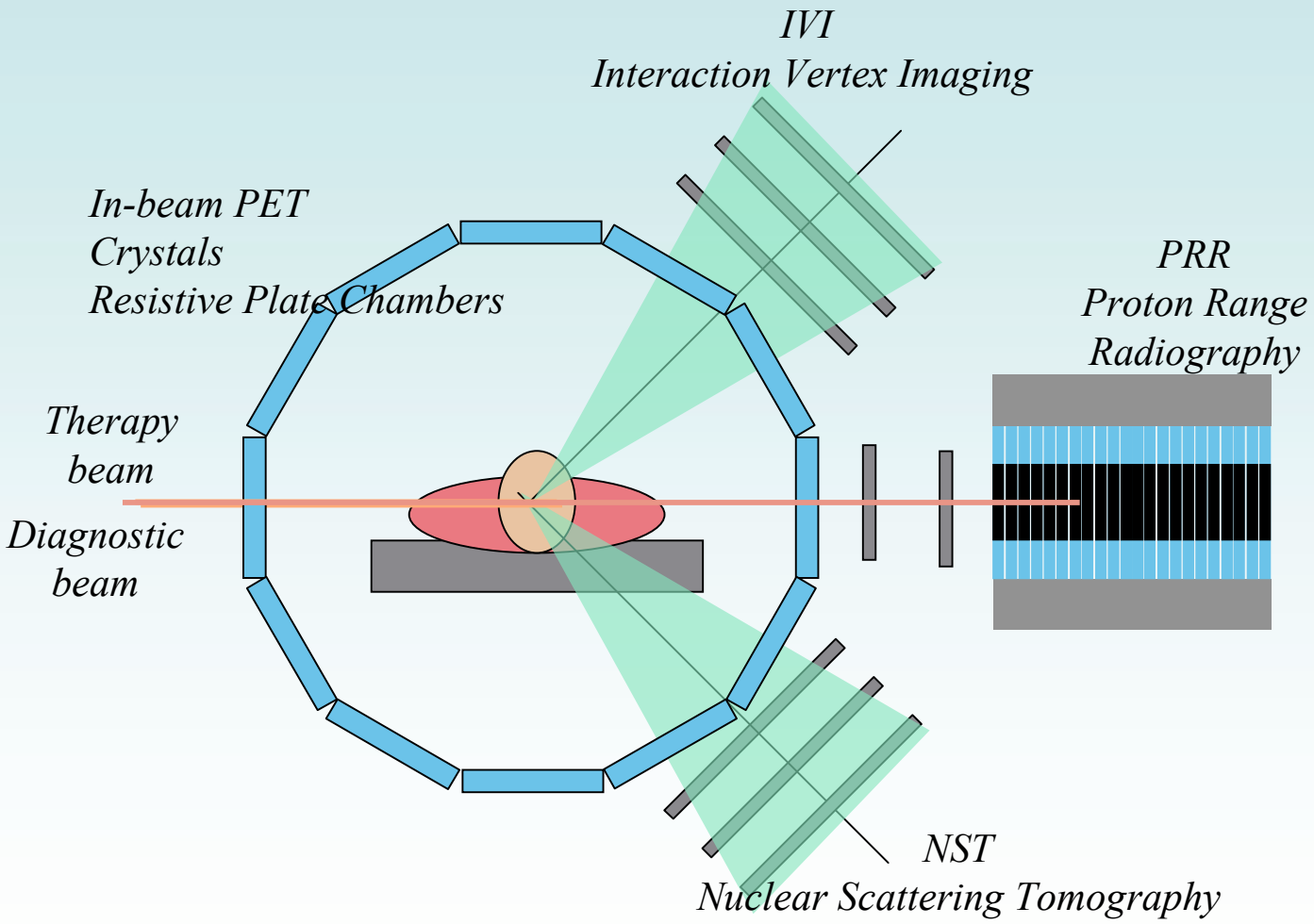




A. La Rosa et al,
Nucl. Instr. and Meth. A572(207)257

M. Ciocca, 2^{d} Joint Symposium on Hadrontherapy (Pavia, March 2010)

AQUA: ADVANCED QUALITY ASSURANCE



EUROPEAN NOVEL IMAGING SYSTEMS FOR ION THERAPY

FRAMEWORK FP7 PROGRAM

- IN-BEAM POSITRON EMISSION TOMOGRAPHY MONITORING
- MONITORING WITH SINGLE PARTICLES
- IN-VIVO DOSIMETRY AND MOVING ORGANS
- IN-VIVO DOSIMETRY, TREATMENT PLANNING AND CLINICAL RELEVANCE
- MONTE CARLO SIMULATIONS OF IN-VIVO DOSIMETRY

16 BENEFICIARIES
~ 6 M€ OVER 4 YEARS
APPROVED 1.2.2010