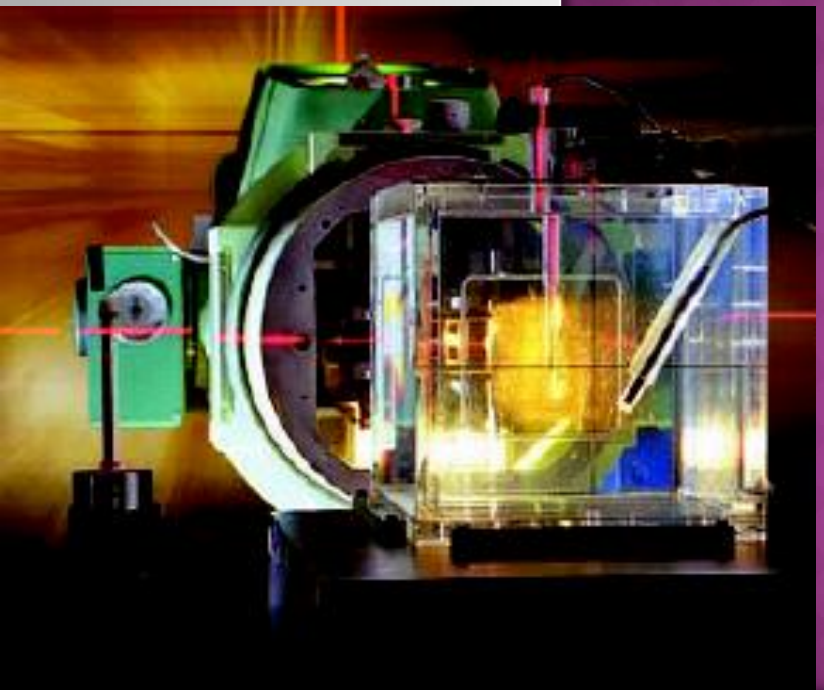
RADIOTERAPIJA



RADIOTERAPIJA

- Primena jonizujućih zračenja u lečenju karcinoma
- Palijativni tretman
- TBI (total body iradiation)-za pripremu tela kod transplantacije kostane srži
- Tretman nemalignih bolesti, ali uz veliki rizik mogućnosti indukcije karcinoma

"DOZIRANJE"

- **Za radikalne kurativne slučajeve**: uobičajena doze za čvrste velik tumore (mete) je 50 Gy do 70 Gy, dok za limfomne tumore (tumore belih zrnaca) doze su od 20 Gy do 40 Gy

- **Kod palijativne radioterapije**: odjednom (6-10) Gy na tumor u metastazi da bi se ublažio bol

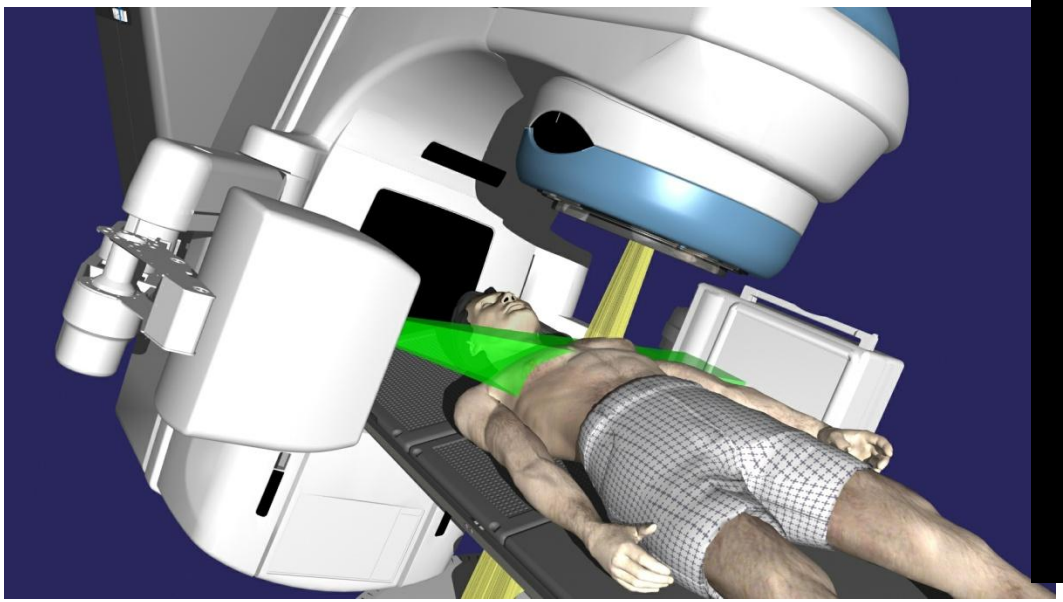
- Ukupna doza se raspoređuje **(frakcioniše)** u dnevne doze obično (1,8 – 2) Gy, 5 dana nedeljno. Ovakav plan uračunava sve moguće retrogradne slučajeve i vikend pauzu

KAKO FUNKCIONIŠE RADIOTERAPIJA

- Zračenje oštećuje DNK ćelije tumorskog tkiva
- **Za razliku od zahteva u zaštiti od zračenja sada biramo ćelijsku SMRT**

- Dve osnovne grupe:

1) **radioterapija spoljašnjim snopom** (teleterapija, perkutana terapija): terapija zatvorenim izvorima zračenja
2) **brahiterapija (intrakavitarna)**: terapija otvorenim izvorima zračenja



VARIAN
TRILOGY

Zahtev za mernu nesigurnost pri isporuci doze volumenu mete

•Da bi se efikasno tretirao tumor i smanjile komplikacije propisana doza mora biti odredjena sa greškom **manjom od 5 %.**

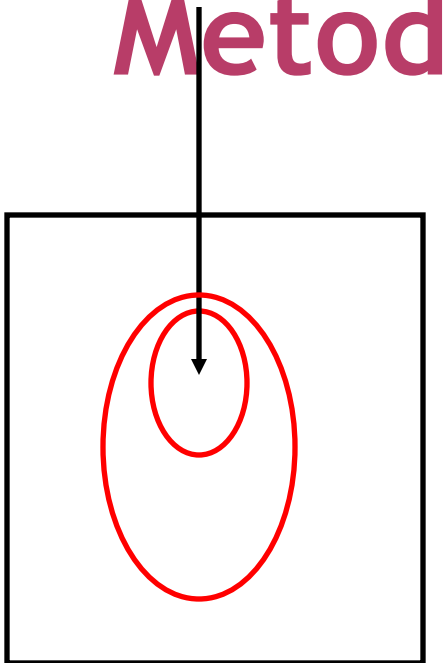
ICRU Rep 24 (1976) i Rep.42 (1988)
IAEA 398
AAPM TG 105 Report (2007)

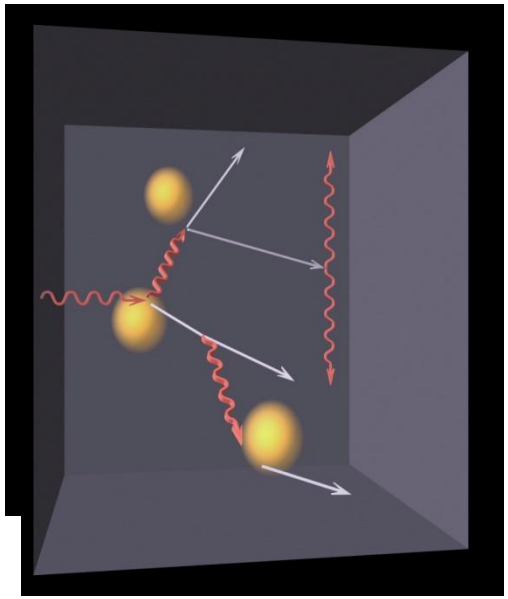
$$\sigma^2 = \sigma_{calib}^2 + \sigma_{doza}^2 + \sigma_{geom}^2 + \sigma_{pokr}^2 + \cdots$$

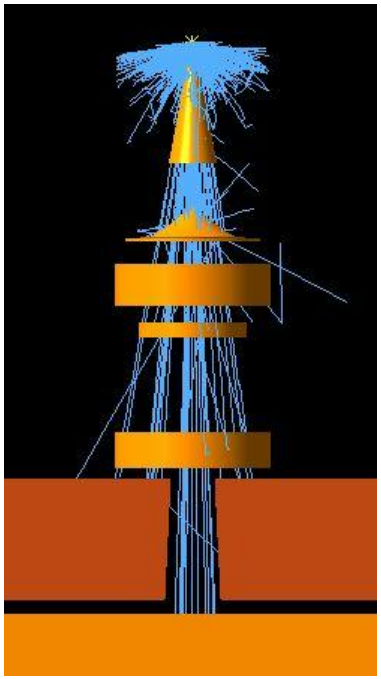
$$\sigma \geq 2\sigma_{doze} = 5\ \%$$

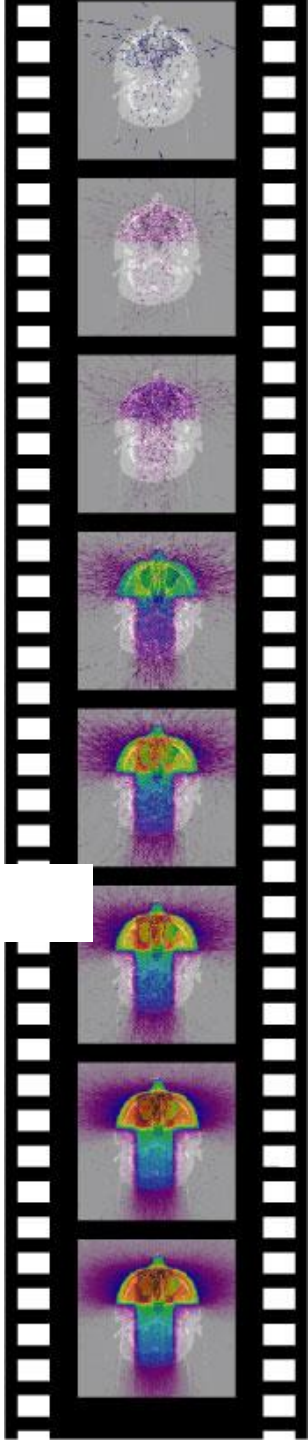
$$\sigma_{doze} = 2.5\ \%$$

Metode proračuna doze









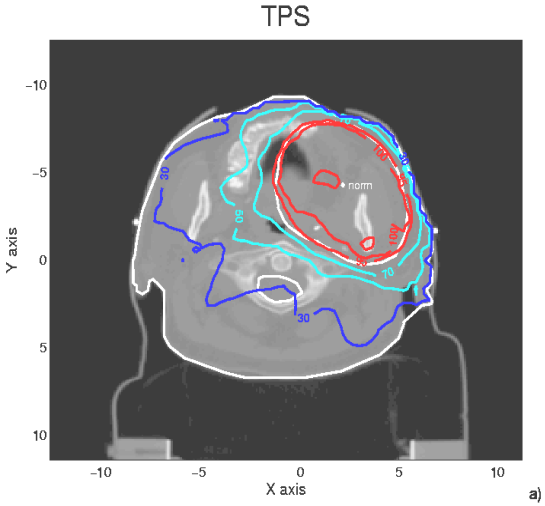
Konvencionalna

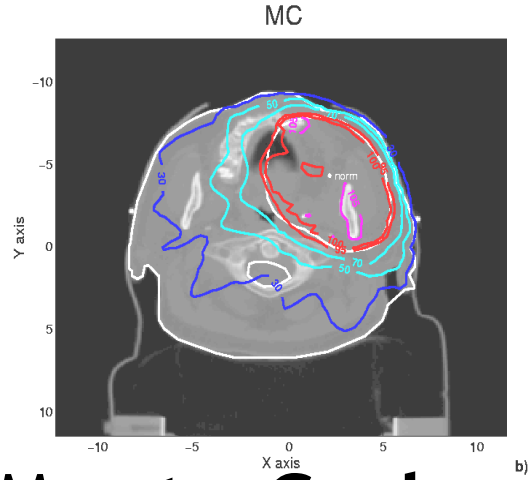
Konvolucija uskog snopa

GLAVA & VRAT

konvolucija

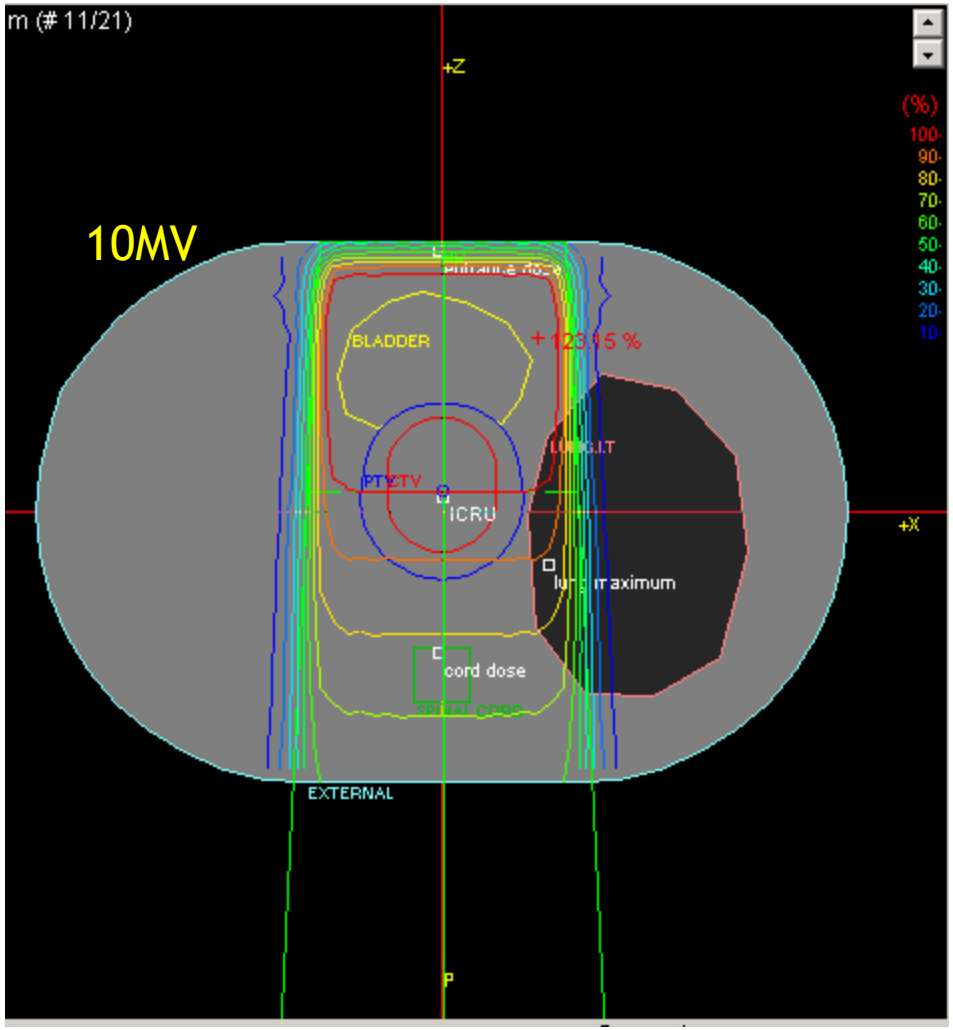
Monte Carlo

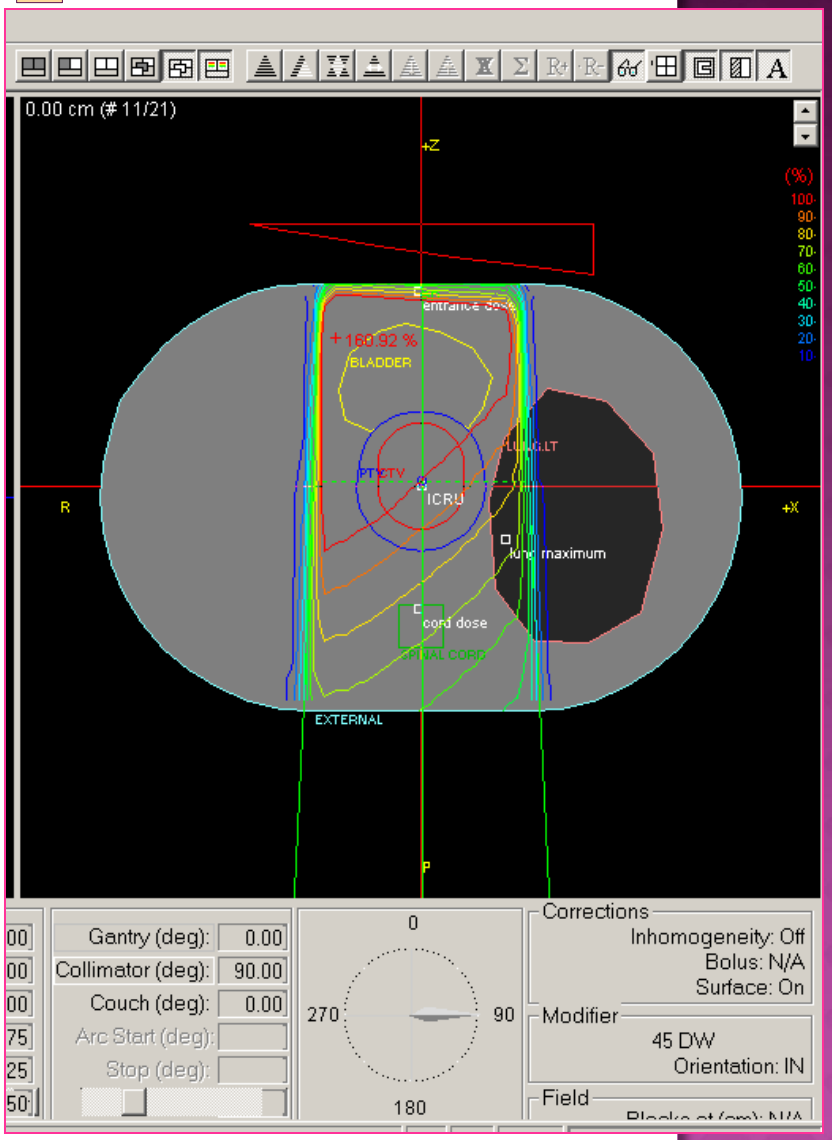




Monte Carlo

PLANIRANJE TERAPJE



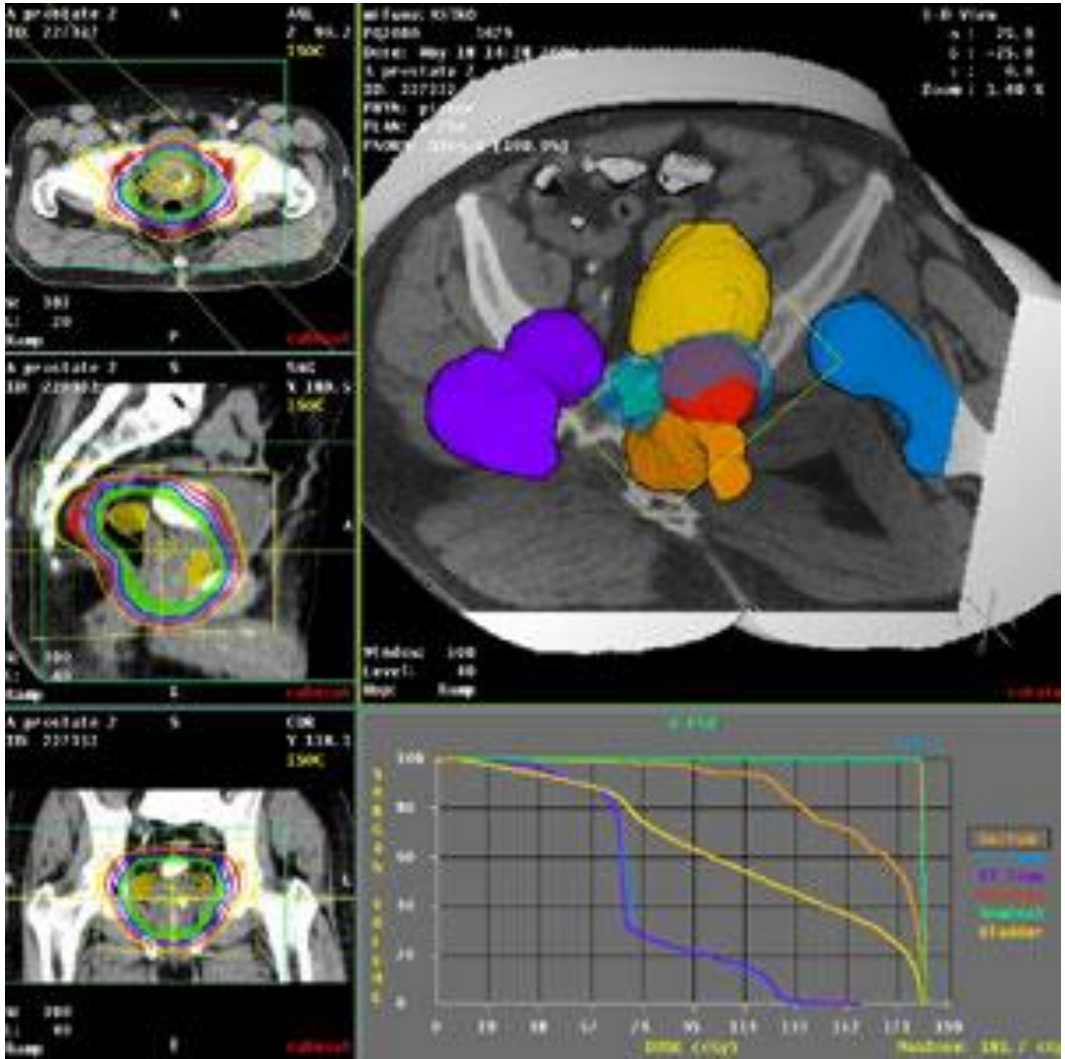


Modifikacija snopa ubacivanje dinamičkog klina

RADIOTERAPIJA SPOLJAŠNJIM SNOPOM-PLANIRANJE

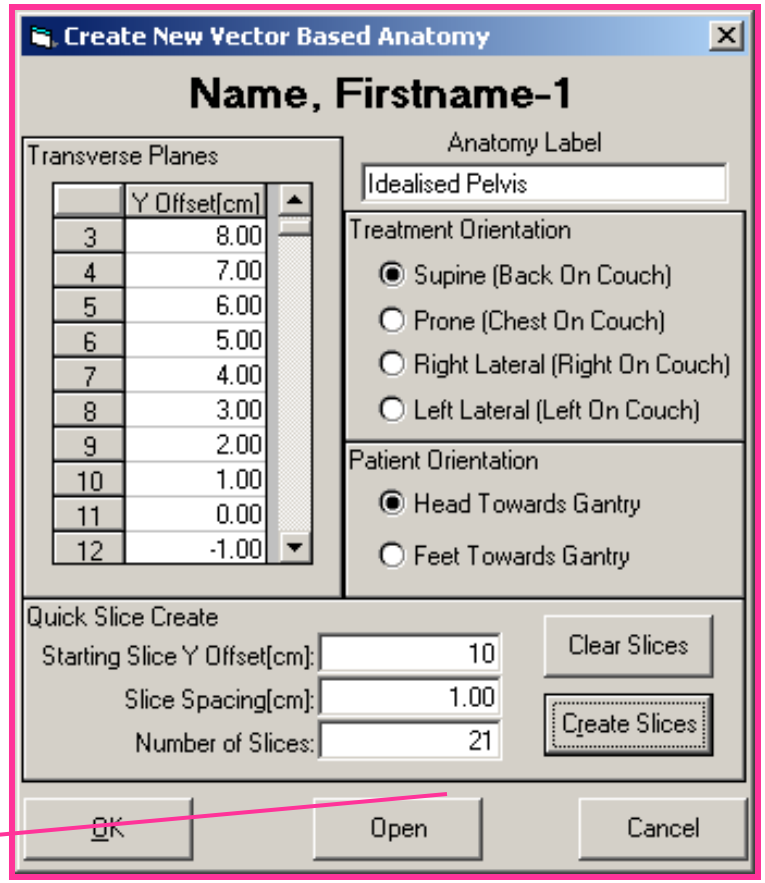
- Konvencionalna – tretman je planiran ili simuliran na posebno kalibrisanim konvencionalnim dijagnostičkim rendgenima uz upotrebu bolusa na tretmanskoj glavi.
- Virtualno simulisana 3 D konformalna radioterapija: upotreba CT slike i posebnog 3D softvera za planiranje
- Intenzitetom modulisana radioterapija: koristi MLC ne samo da oblikuje profil snopa već i da varira intenzitet snopa kroz metu.

3D planiranje korišćenjem podatak dobijenim na CT

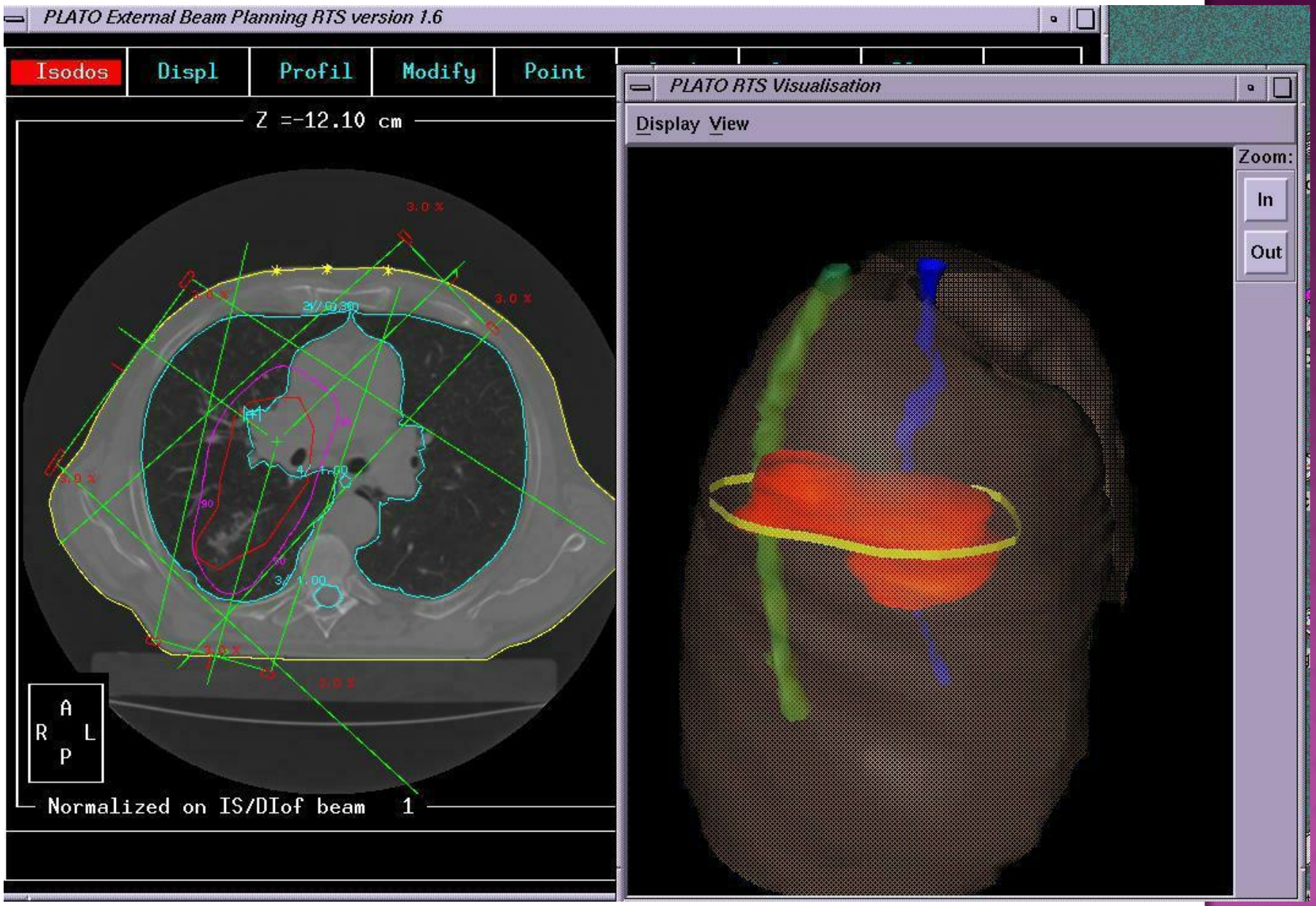


ANATOMIJA PACIJENTA MORA BITI DEFINISANA

- CT slike
- Ostali podaci
- Broj slajsova

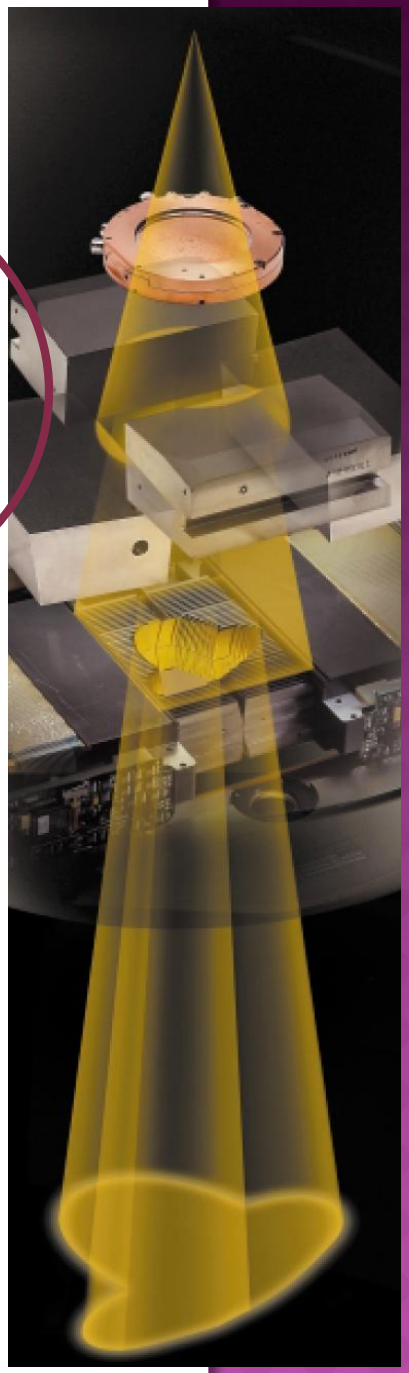


Kreiran 21 slajs na 1 cm dužine


PLATO External Beam Planning RTS version 1.6
Isodos
Displ
Profil
Modify
Point
Z =-12.10 cm
3.0 %
A
R
L
P
Normalized on IS/DIof beam 1
PLATO RTS Visualisation
Display View
Zoom:
In
Out

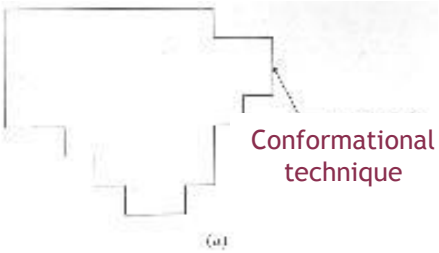
Intenzitetom Modulisana Radioterapija

✓Apertura snopa je oblikovana prema nepravilnom obliku mete (tumora)
✓Modulisan fotonski fluks



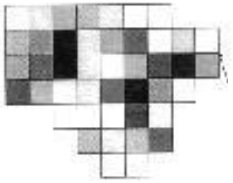
- Distribucija doze homogenija u Planned Target Volume (PTV)

dinamička tehnika

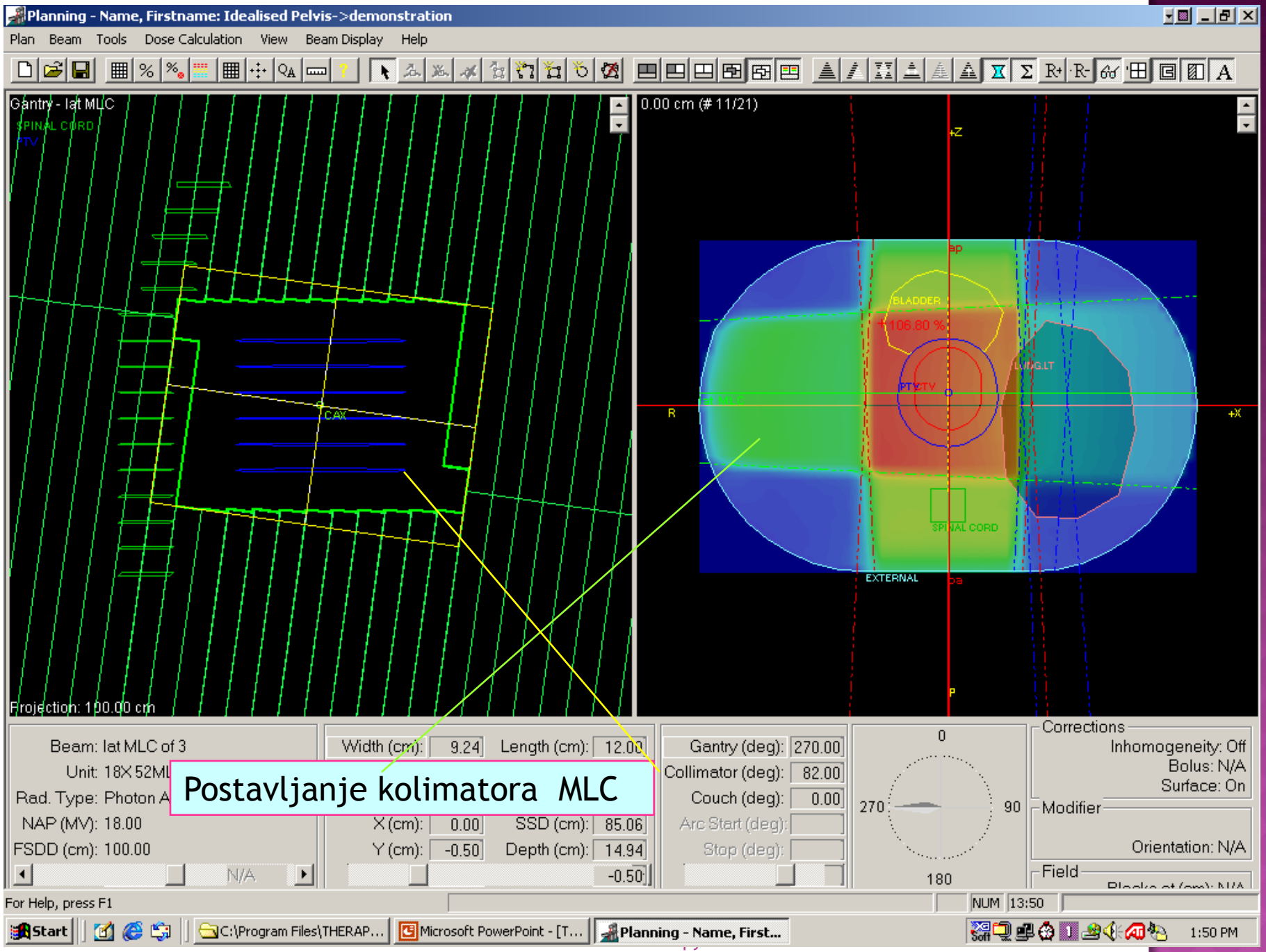


Smanjeno izlaganje zdravog tkiva visokim dozama

Glava i vrat
dojka
prostata



IMRT



Postavljanje kolimatora MLC

KVALITETI SNOPA U RADIOTERAPIJI

1. Niskoenergetsko X (do 100 kV i HVL do 3 mm Al)
2. Srednjeenergetsko X (80 kV - 300 kV

   HVL: 2 mm Al - 4 mm Cu)
3. Gama zračenje ^{60}Co (1,25 MeV)
4. Visokoenergetsk fotoni (1 MeV - 50 MeV;

   $TPR_{20,10}$: 0.5 - 0.84)
5. Visokoenergetski elektroni (3 MeV -50 MeV ;

   R_{50} :1 g/cm^2 - 20 g/cm^2)
6. Protonsko zračenje (50 MeV do 250 MeV;

   R_p 0,25 g/cm^2 - 25 g/cm^2)
7. Teški joni: Z između 2 (He) i 18 (Ar)

   (R_p 2 g/cm^2 - 30 g/cm^2)

CIKLOTRON I SINHROCIKLOTRON

RF napon konstantne frekvencije (10 -30) MHz primenjen je između dve elektrode, a naelektrisana čestica se ubrzava dok prolazi kroz prorez između dve elektrode.

Sinrociklotron je ciklotron kod kog se menja frekvencija RF električnog polja da bi se kompenzovao porast mase čestica koje se ubrzavaju kada njihova brzina počne da se približava brzini svetlosti.

PROTONSKA TERAPIJA (70 GODINA)

1946 Robert R.Wilson, osnivač Fermi National Labs, predložio primenu protona i teških jona u terapiji

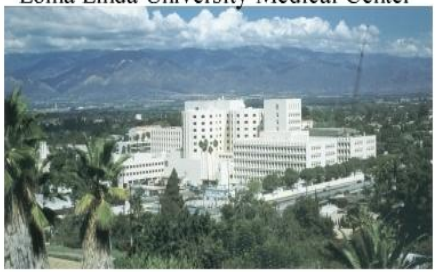
1954 Prvi pacijent u Berkliju

1957-1993 20 centara uvodi protonsku terapiju

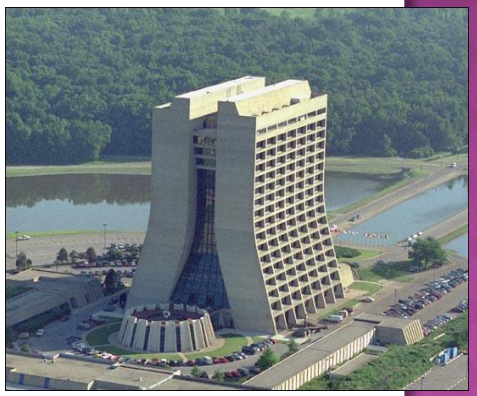
1989 Početak projekta TESLA (INN Vinča)

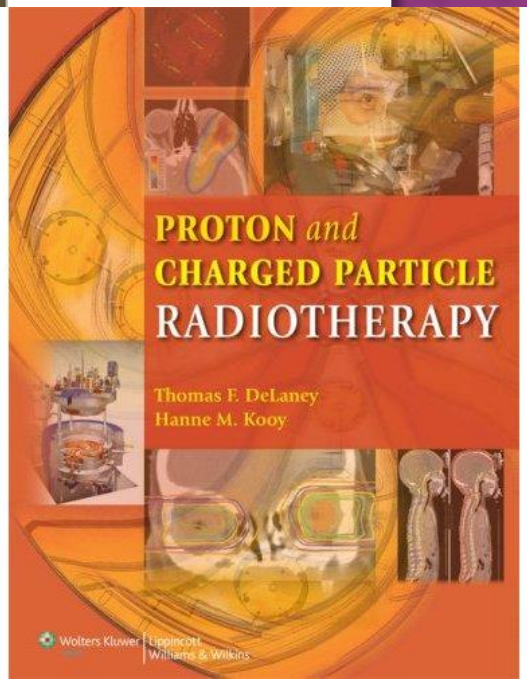
2014 80,000 pacijenata godišnje

Loma Linda University Medical Center



PAUL SCHERRER INSTITUT




PROTON and
CHARGED PARTICLE
RADIOTHERAPY
Thomas F. DeLaney
Hanne M. Kooy
Wolters Kluwer
Lippincott
Williams & Wilkins

PROTONSKA TERAPIJA (E < 90 MEV)

Broj centara: 8

Max. Klinička energija: 60 MeV - 90 MeV

Domet u tkivu (ICRU): 3,1 cm - 6,5 cm

Tip akceleratora: **ciklotron**

Lokacije: Davis, CA, USA; Clatterbridge, UK; Nice, France; Chiba, Japan; Villigen, Switzerland; Vancouver, Canada; Berliin, Germany; Louvain-la-Neuve, Belgium

PROTONSKA TERAPIJA (E > 150 MEV)

Broj centara: 18

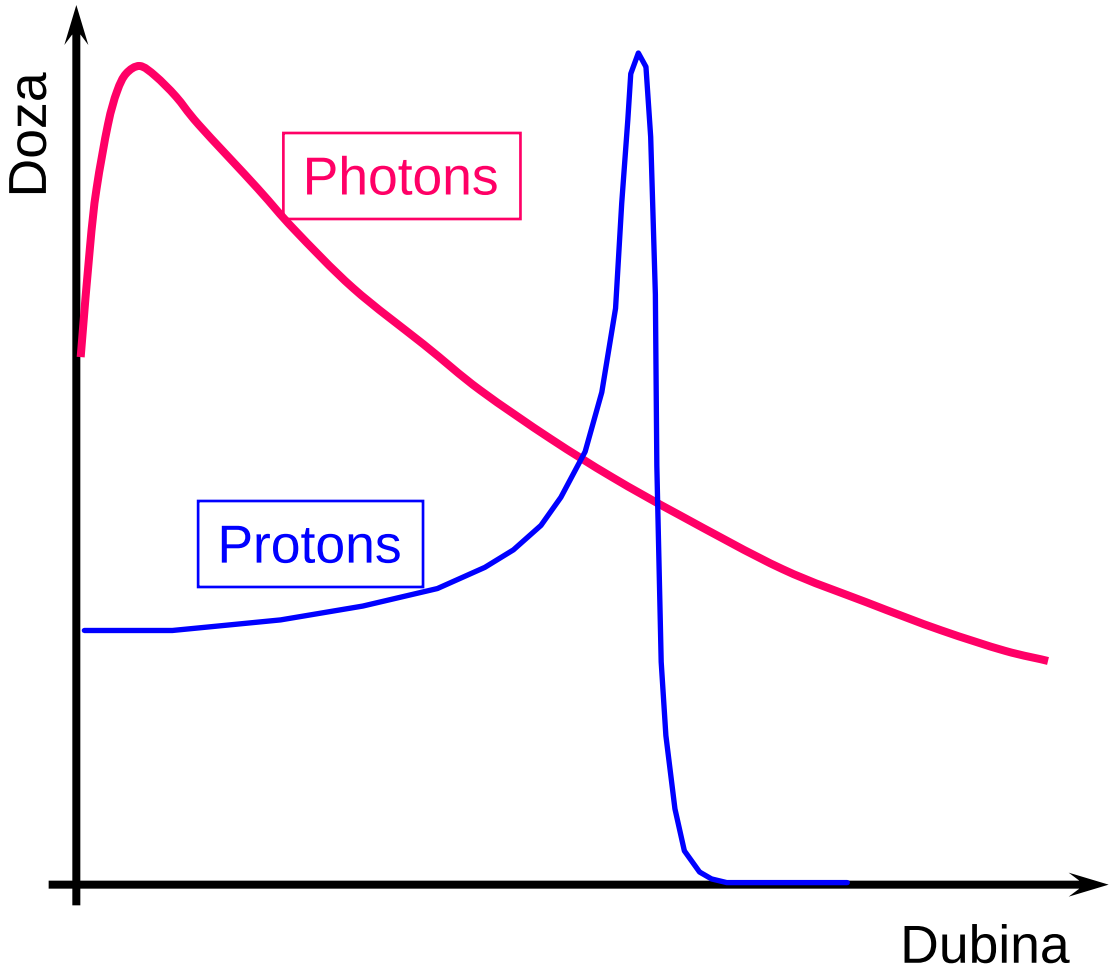
Max. Klinička energija: 160 MeV - 1 GeV

Domet u mišiću: od 17,9 cm

Tip akceleratora:ciklotron, sinhrociklotron, sinhrotron

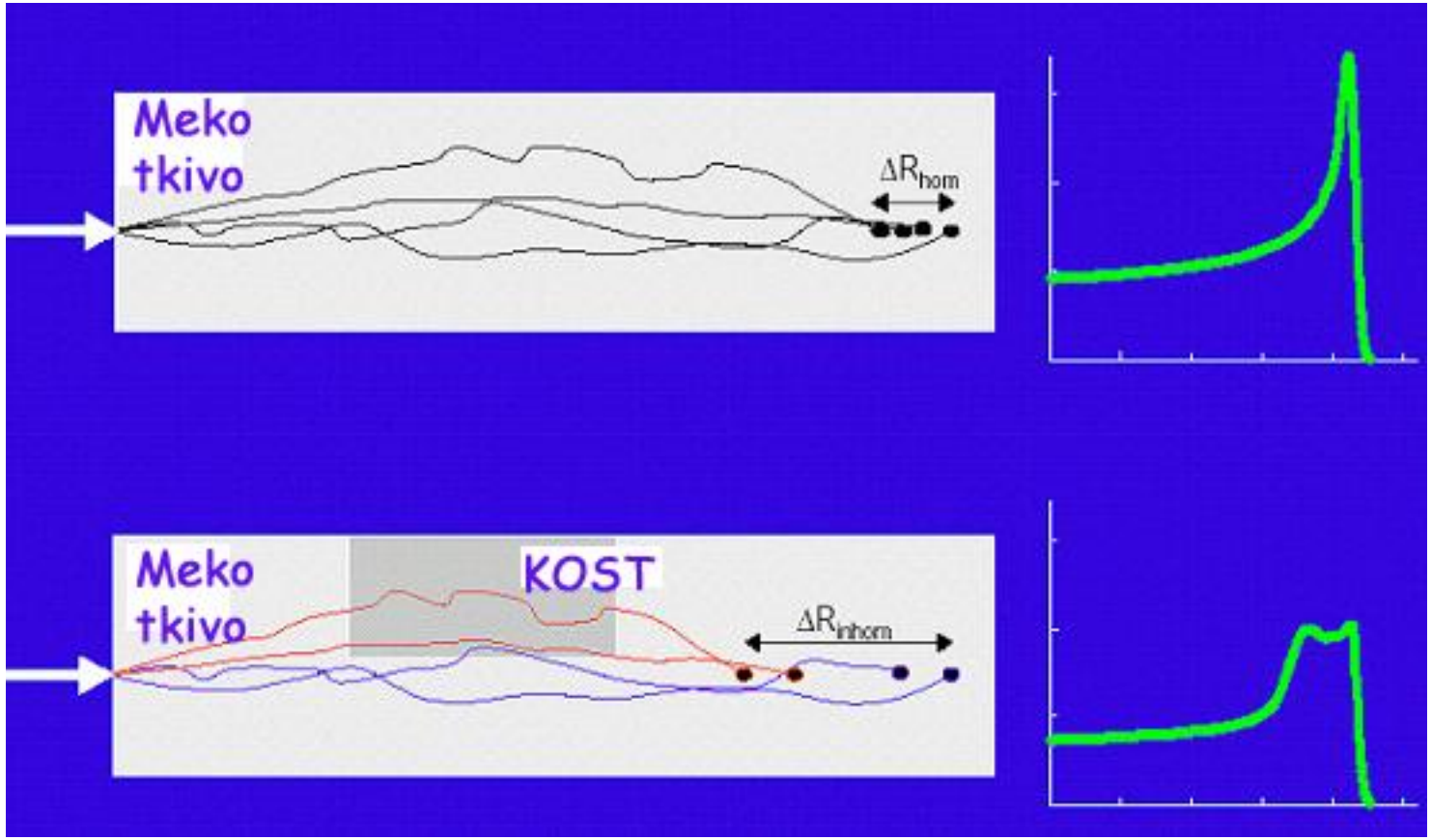
Lokacije: Cambridge, USA; Uppsala, Sweden; Moscow, Russia; Faure, South Africa; Bloomington, USA; Orsay, France; Dubna, Russia; Villigen, Switzerland; Boston, USA; Kashiwa, Wakaza , Hyogo and Shizouka in Japan; Loma Linda, USA; Tsukuba, Japan; Berkley, USA and St Petersburg, Russia

BRAGG PEAK



INTERAKCIJA PROTONA SA MATERIJOM

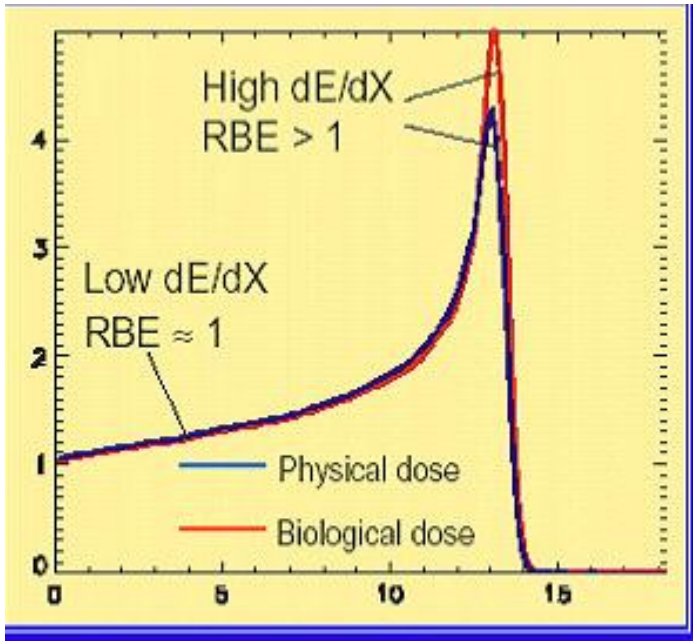
GUSTINA UTIČE NA OBLIK BRAGOVOG PIKA



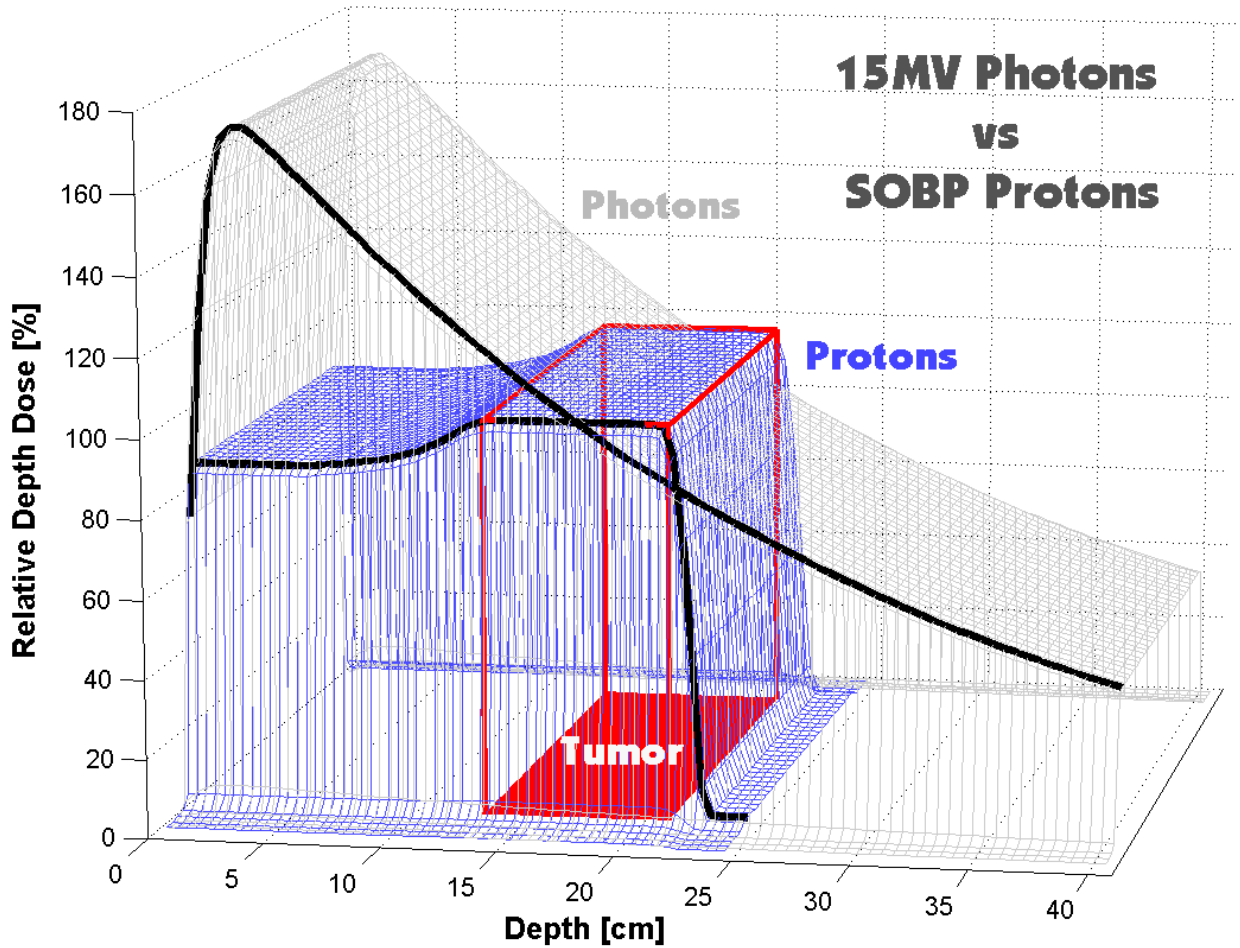
INTERAKCIJA PROTONA SA MATERIJOM

RELATIVNA BIOLOŠKA EFIKASNOST (RBE) JE MERA OŠTEĆENJA TKIVA ZRAČENJEM
RBE JE U ODNOSU SA LINEARNIM TRANSFEROM ENERGIJE LET = DE/DX,

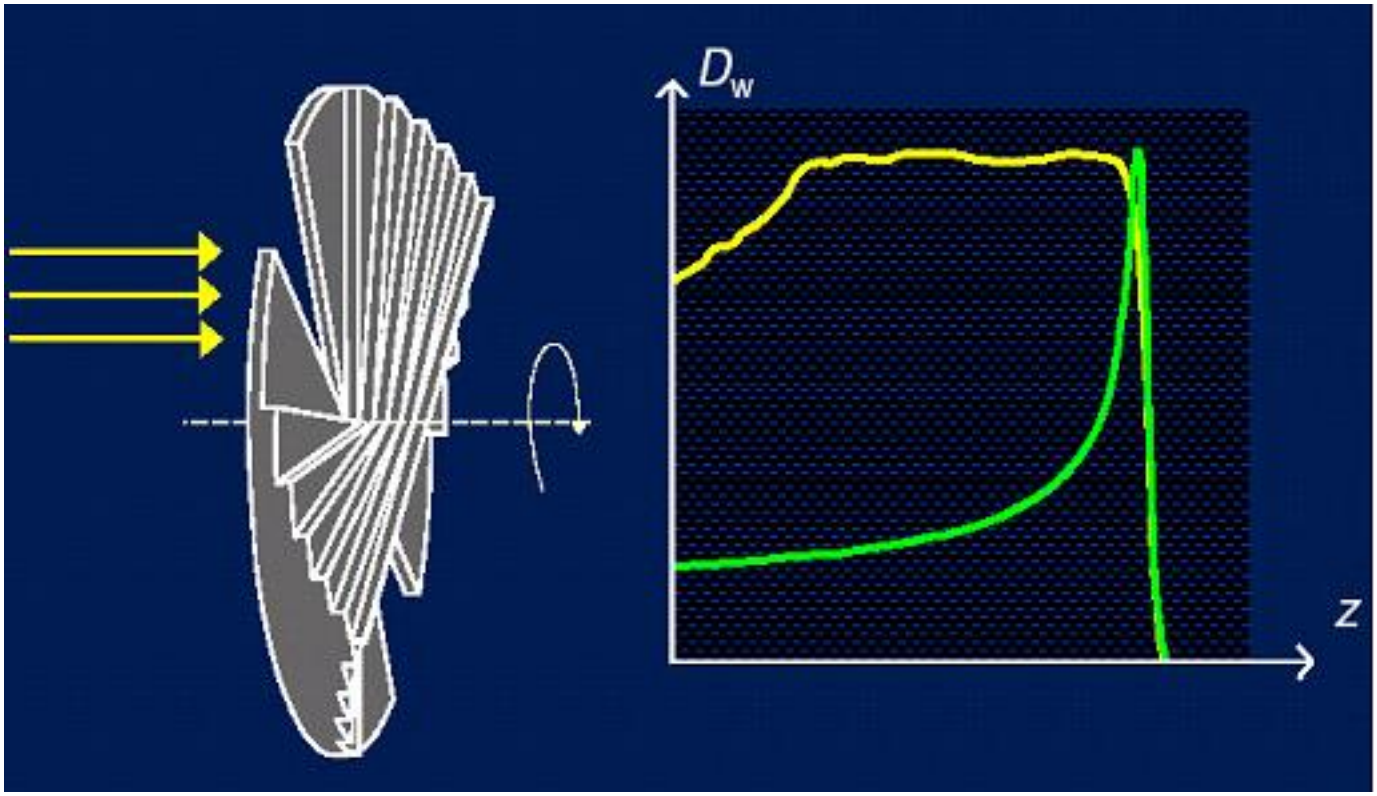
PROTON RBE JE GENERALNO 1.1 ZA SVA TKIVA I DOZE



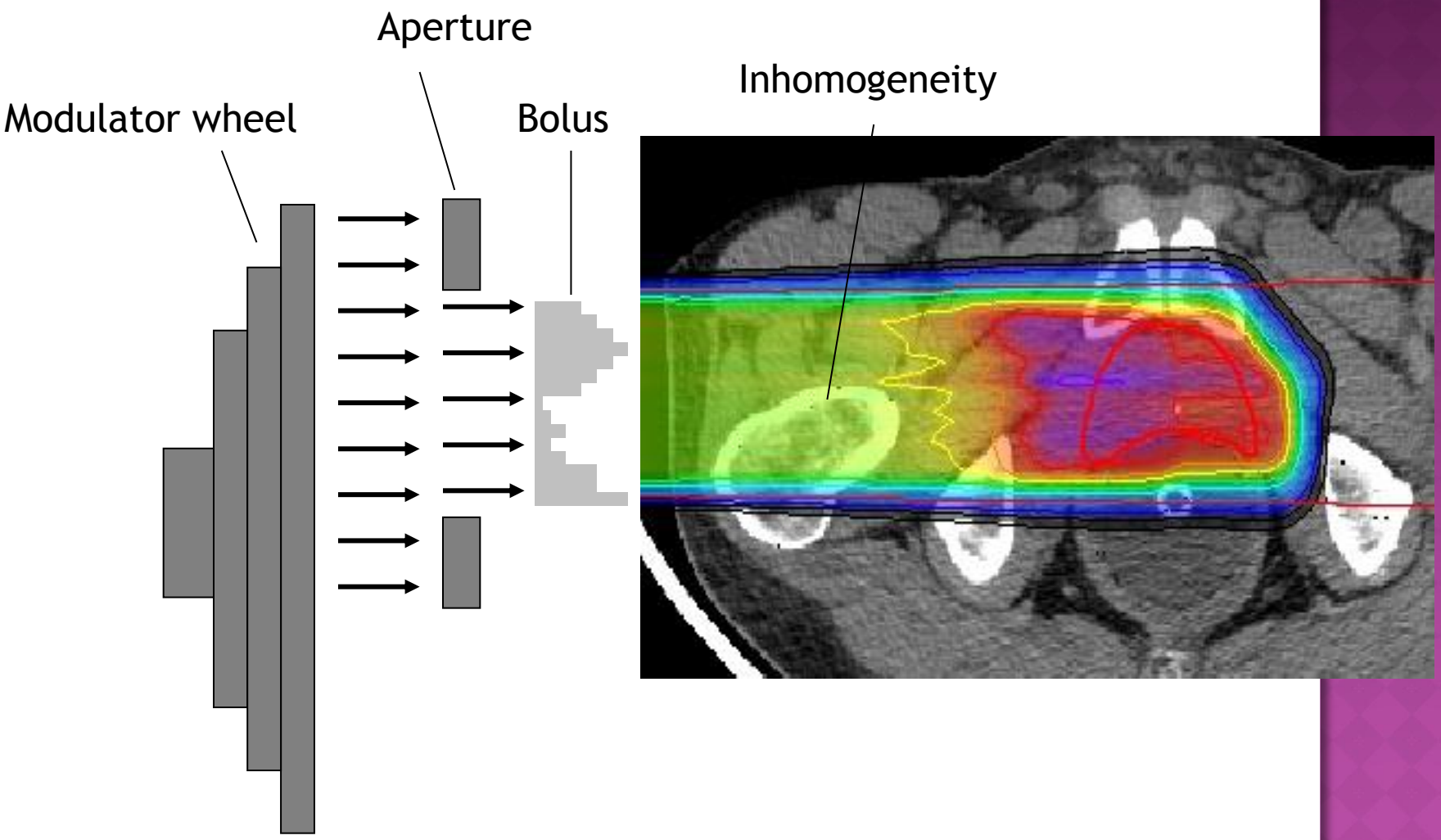
SPREAD-OUT BRAGG PEAK (SOBP)



MODULACIJA DOMETA



DIZAJN PROTONSKOG SNOPA



STRATEŠKI CILJEVI PROTONSKE TERAPIJE

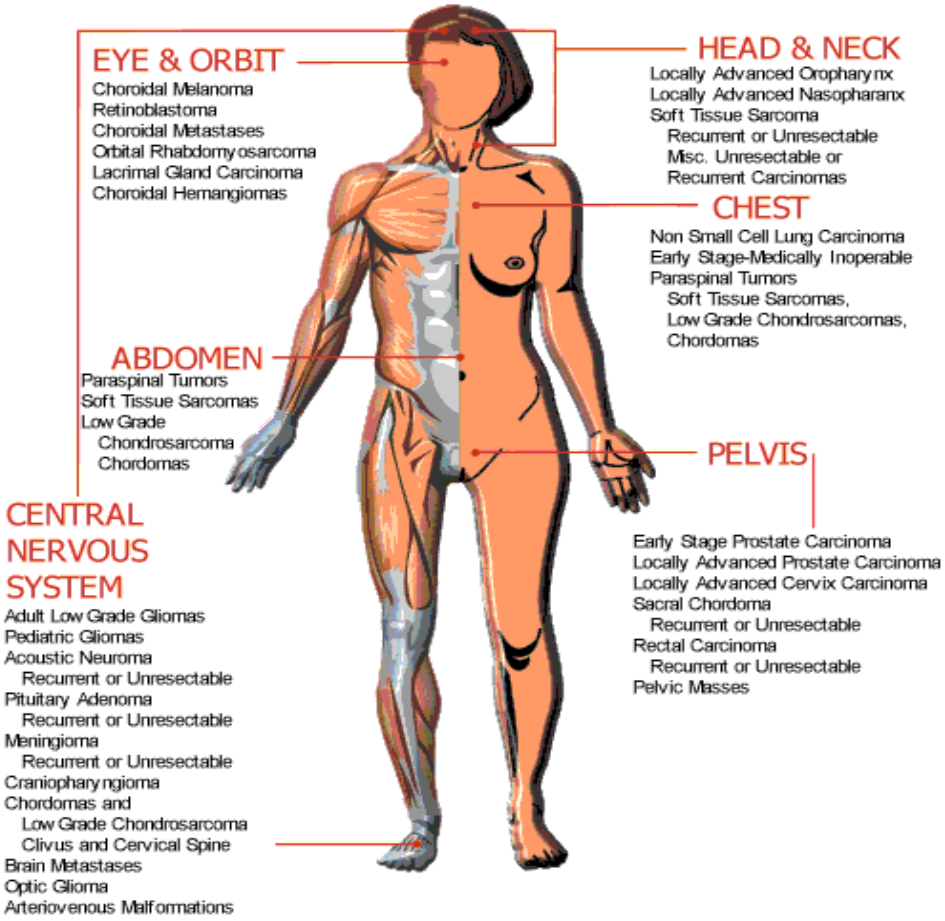
- **Nulta doza iza** Bragovog pika omogućava zaustavljanje snopa ispred zdravog tkiva
- **Niska integralna doza van** mete omogućava tretman velikih tumora
- Protoni su **naelektrisane čestice** koje se lako mogu skretati magnetnim poljem

NEDOSTACI

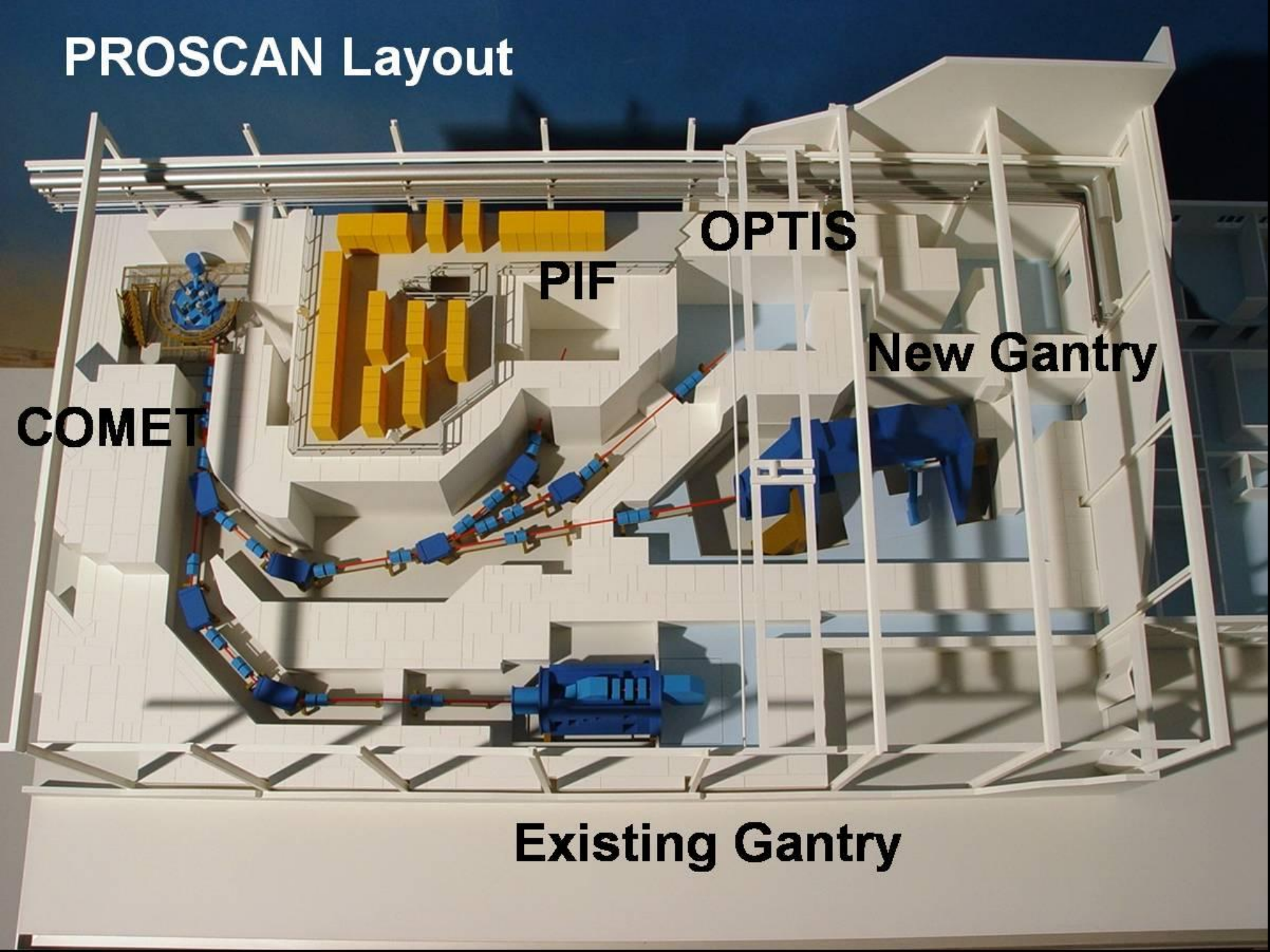
- **Velike dimenzije** akceleratora i transportnih linija
- Duboki tumori zahtevaju **velike energije protona** reda (230-250) MeV;
- Pitanje **visoke cene** same terapije (2 x veća od fotonske terapije)
- **Oprema je mnogo skuplja** reda (25-40) M$ (zavisno od broja tretmanskih sala) u poređenju sa cenom od (3-5) miliona dolara za kompletan konvencionalni radioterapijski departman

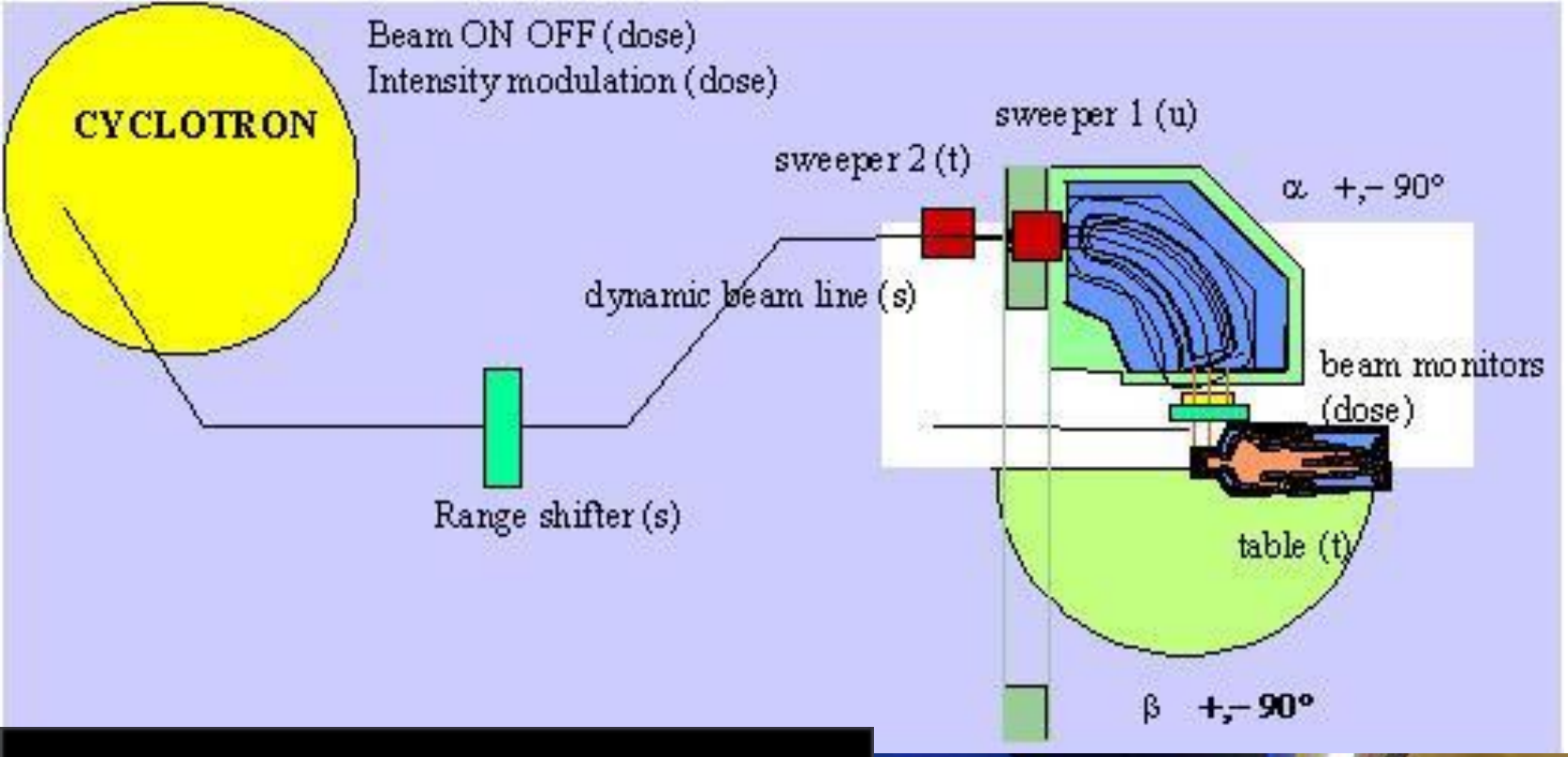
PRIMENA VISOKOENERGETSKIH PROTONA U ONKOLOGIJI

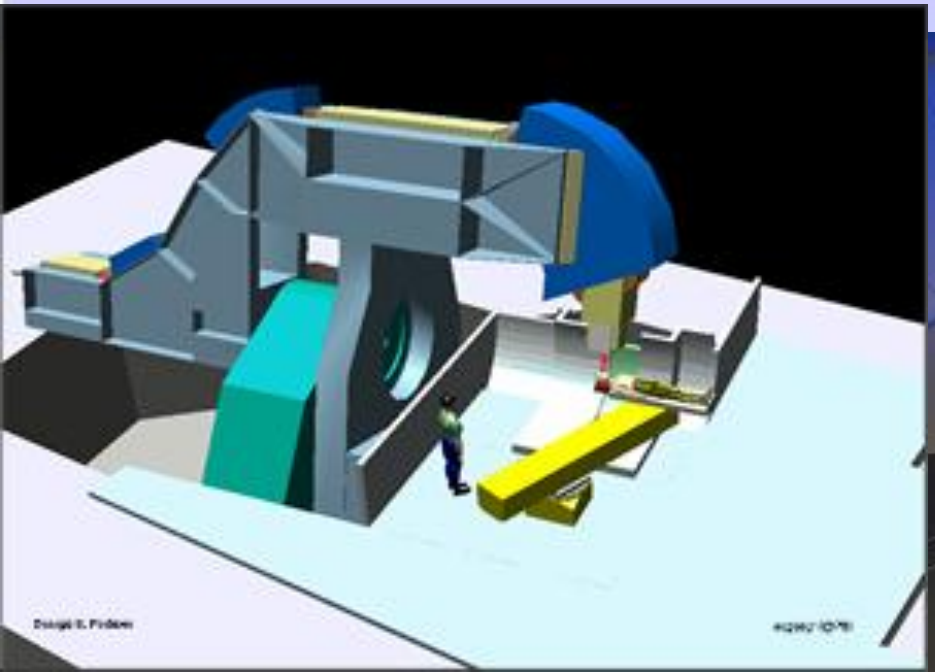
LOKALIZACIJE



PROSCAN Layout



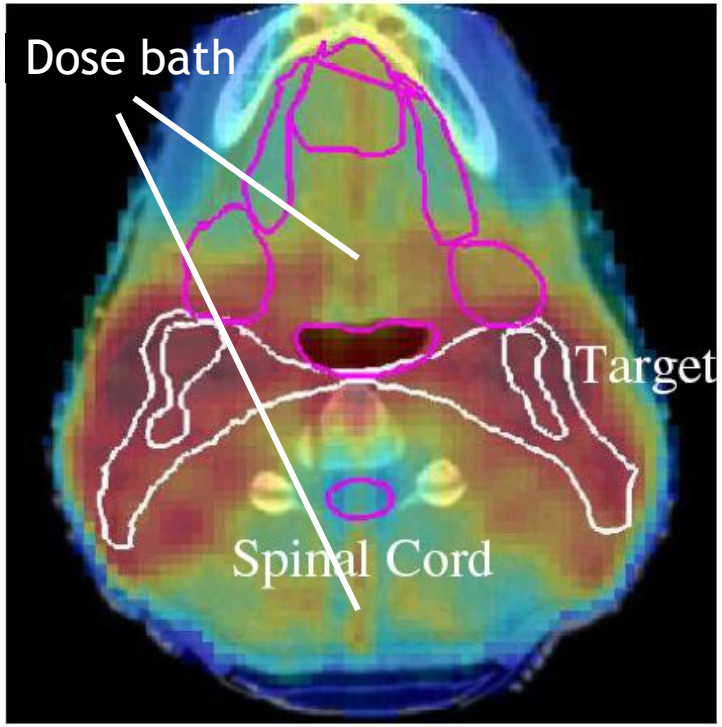

Beam ON OFF (dose)
Intensity modulation (dose)
CYCLOTRON
sweeper 1 (u)
sweeper 2 (t)
α +,– 90°
dynamic beam line (s)
beam monitors
(dose)
Range shifter (s)
table (t)
β +,– 90°



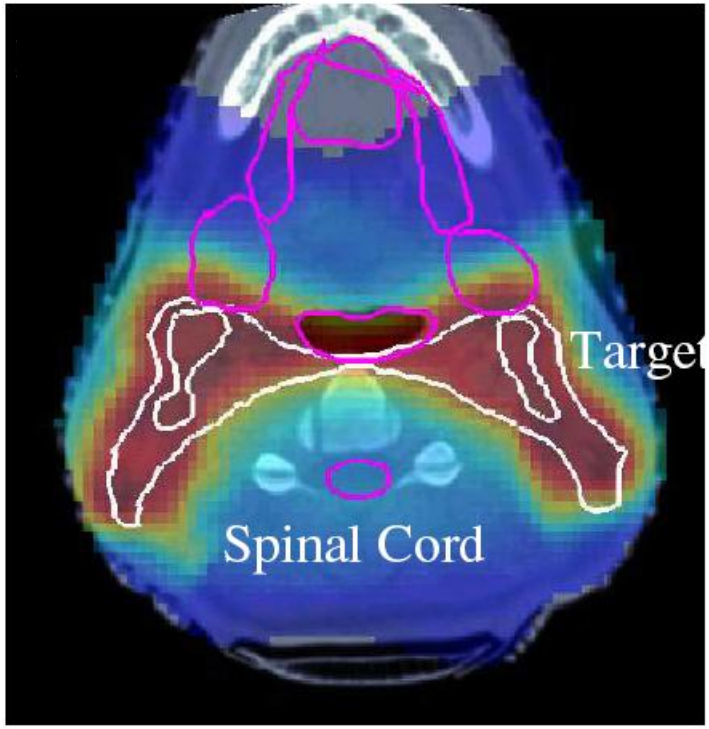
copyright@PSI

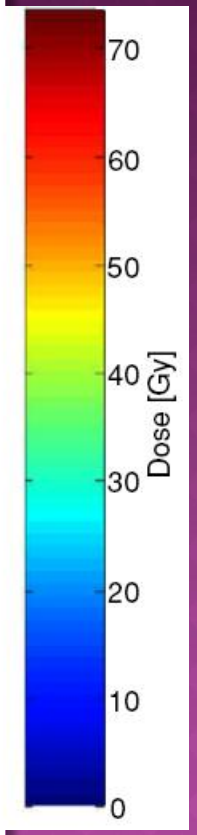
PREDNOST PROTONA: NASOPHARYNX

FOTONI (IMRT)



PROTONI

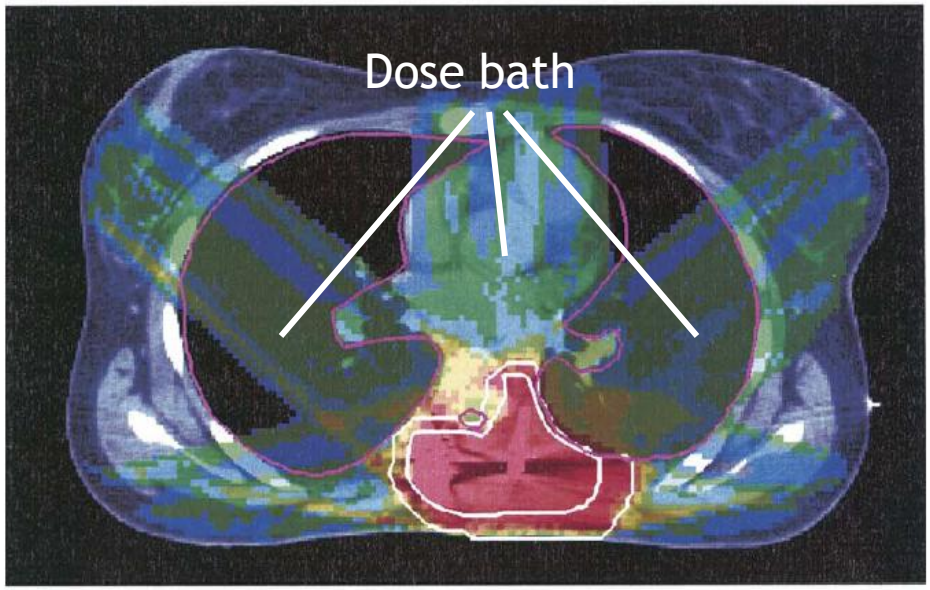


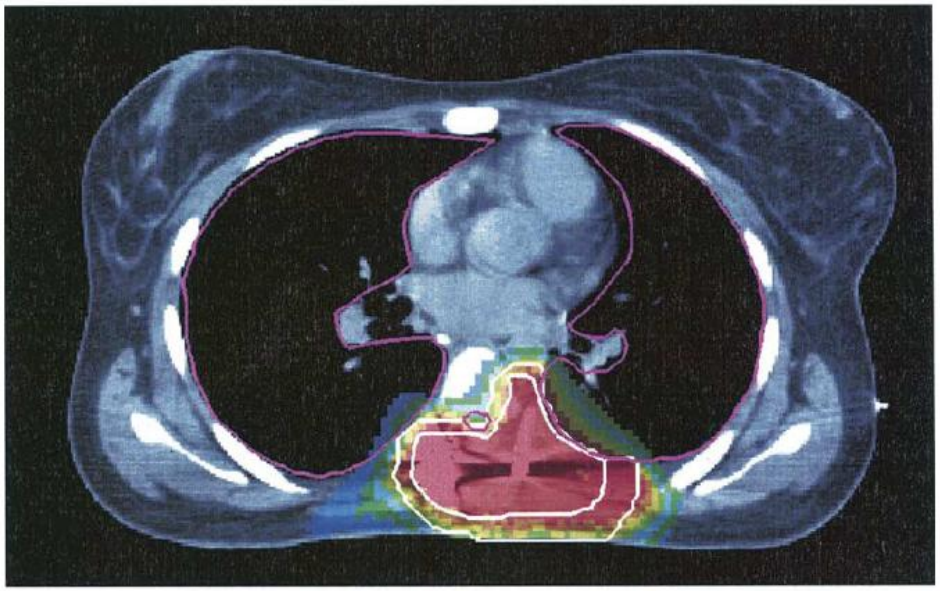


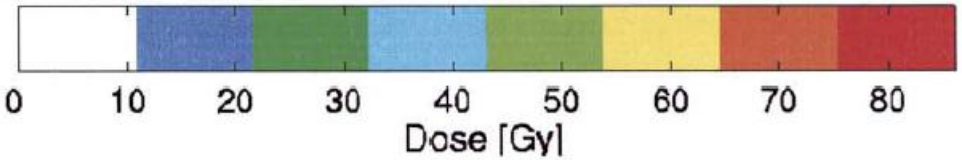
PREDNOST PROTONA: PARASPINAL

FOTONI

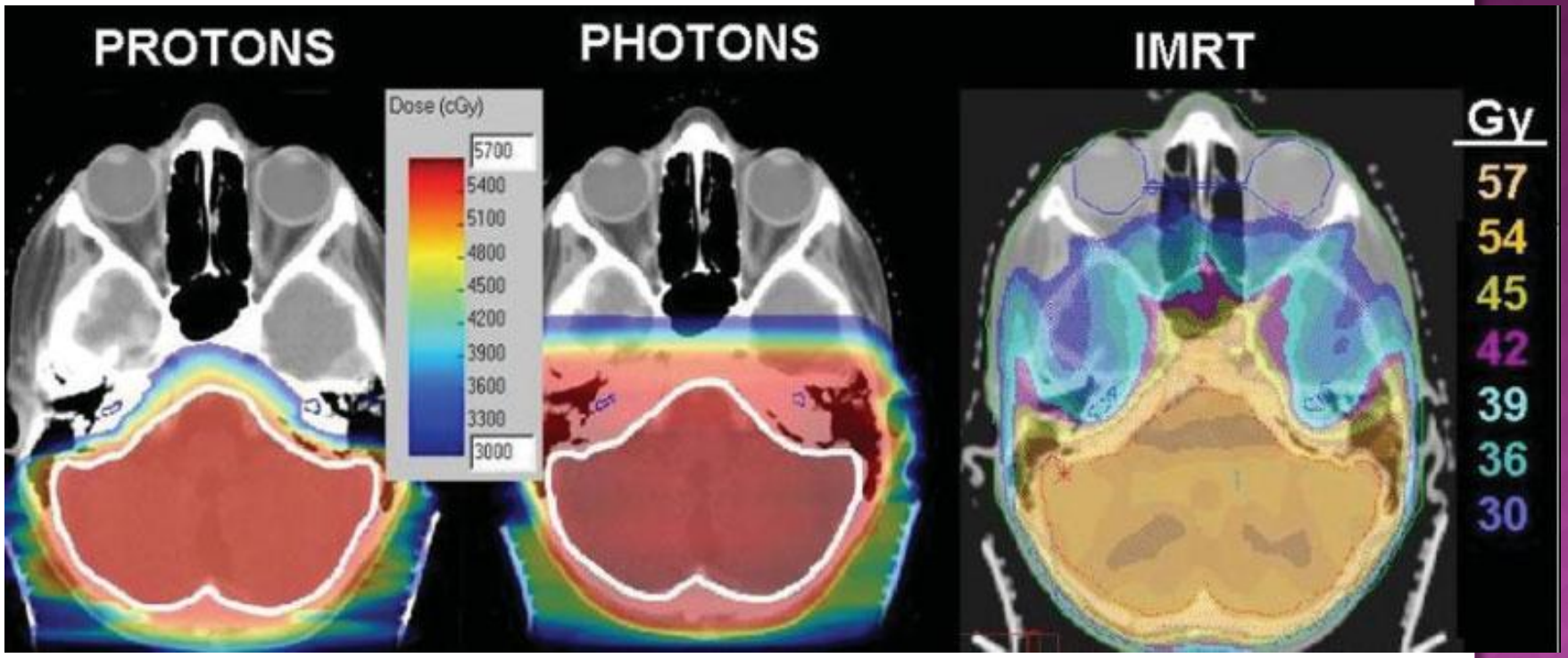
PROTONI





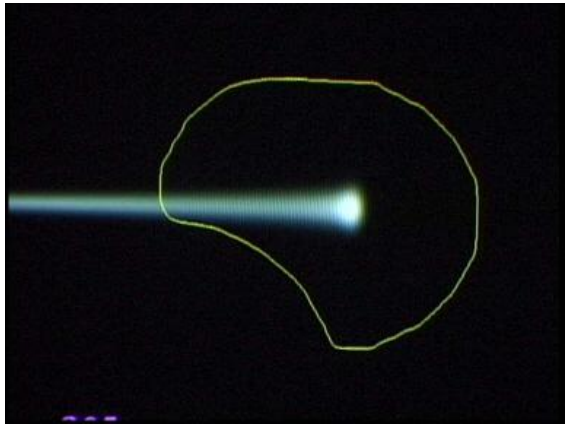


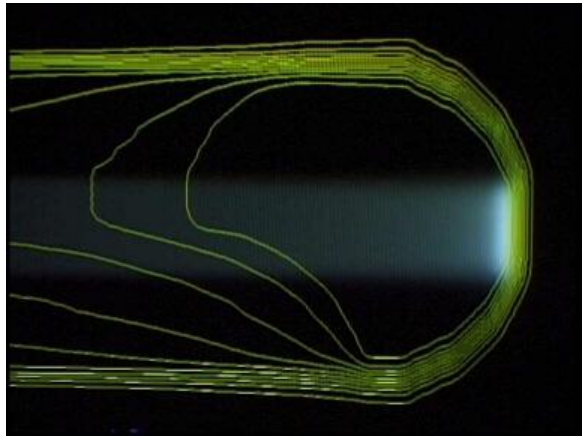
TUMORI CENTRALNOG NERVNOG SISTEMA

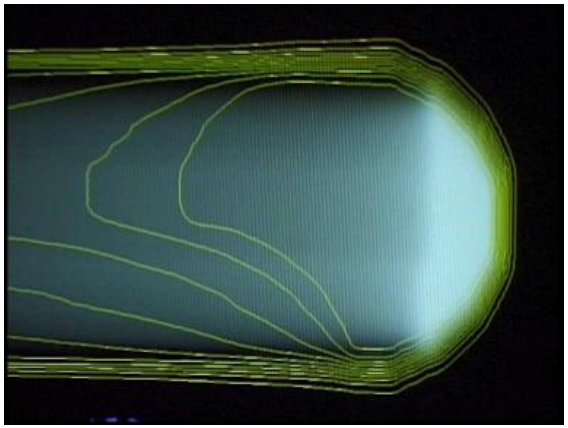


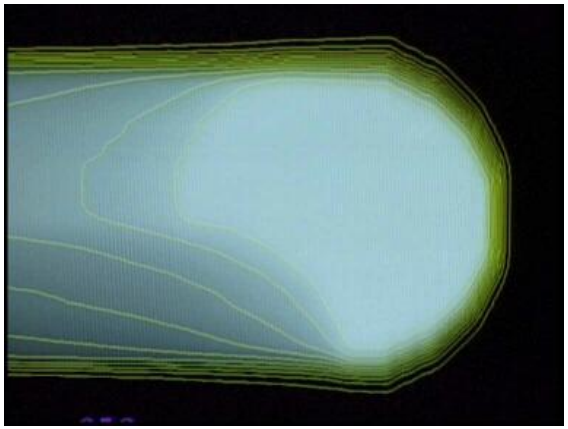
Current Patient

SKENIRANJE SNOPA



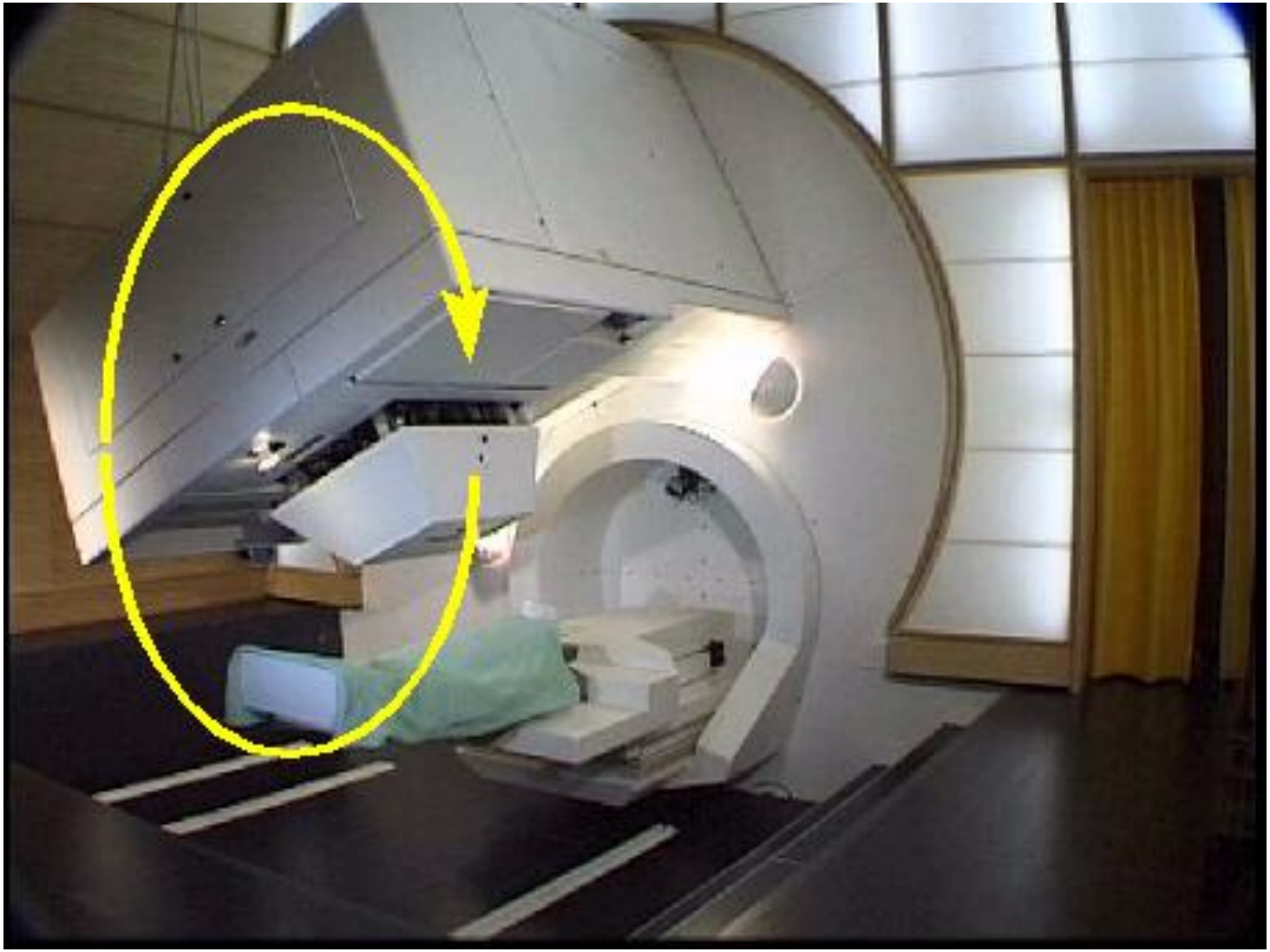


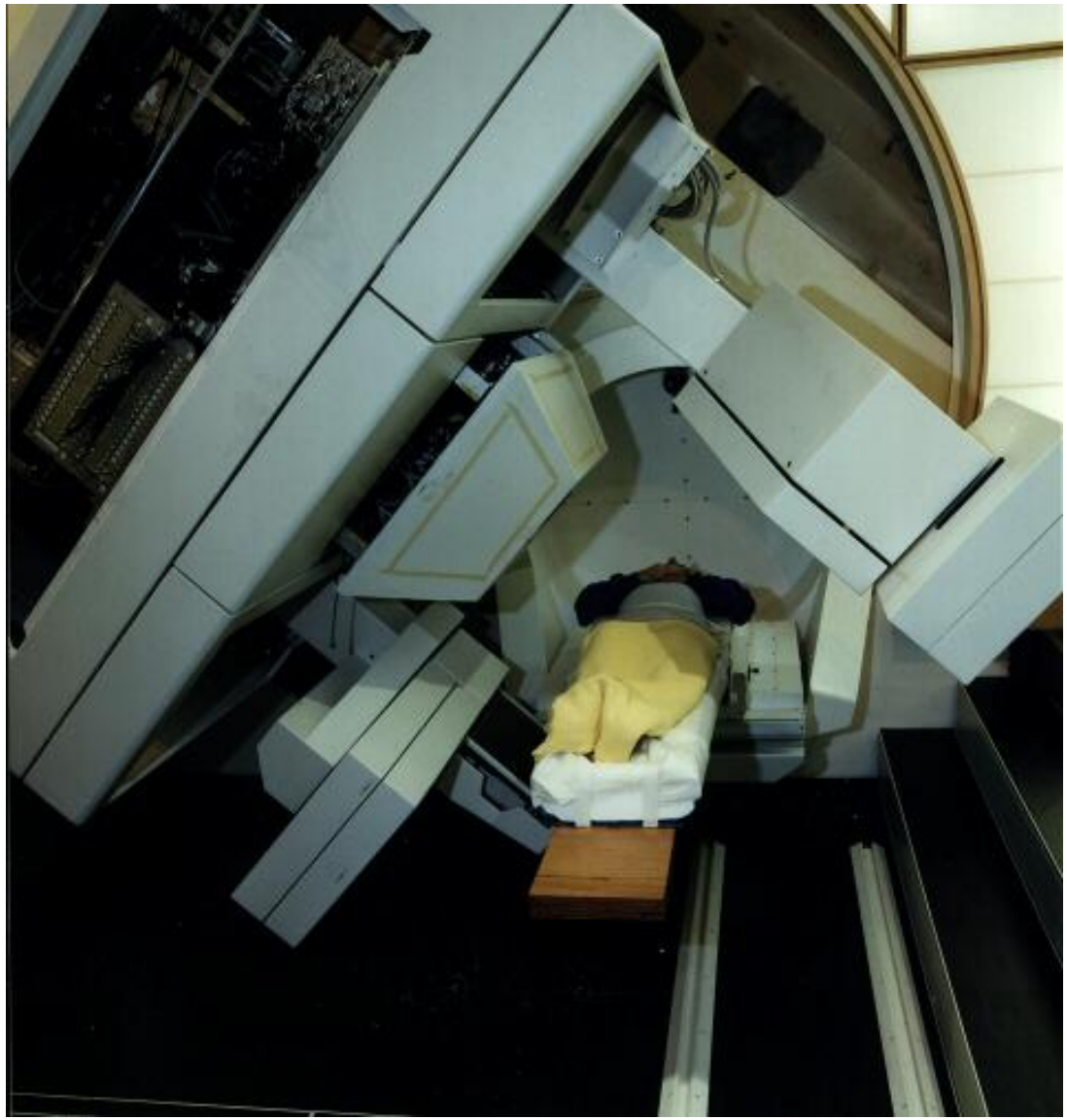




1. Distribucija doze jednog protonskog uskog snopa (doza u tački- "dose spot")
2. Superpozicijom velikog broja pojedinačnih doza dostiže se ukupna doza u meti
3. I još.....Sve tačke

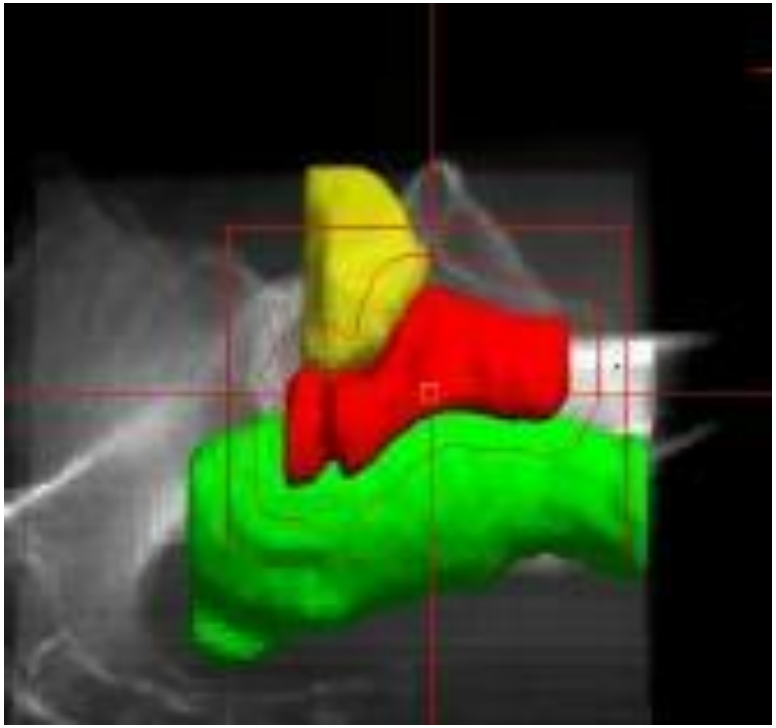
Za metu zapremine 1 l deponuje se 10.000 tačaka za 5 minuta





NISKOENERGETSKA PROTONSKA TERAPIJA

PLANIRANJE TERAPIJE



OKO

Tumor: crveno

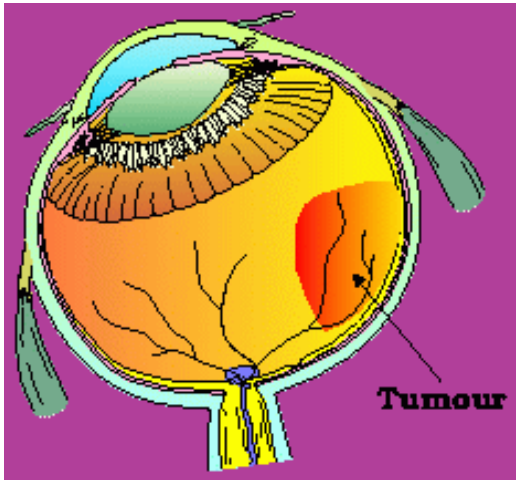
Struktura normalnog tkiva:zeleno i žuto

Apertura: crvena spoljašnja linija

TUMORI OKA

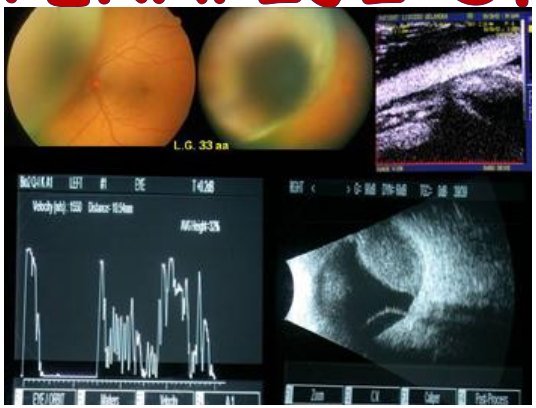
Daje se 50 cGy u 5 frakcija, 5 do 7 dana.
Preživljavanje u prvih 5 godina: 90 %
Preživljavanje posle 5 godina: 80 %
Oko se zadržava u 78 % - 97 % slučajeva u zavisnosti od veličine tumora

Iris melanomas

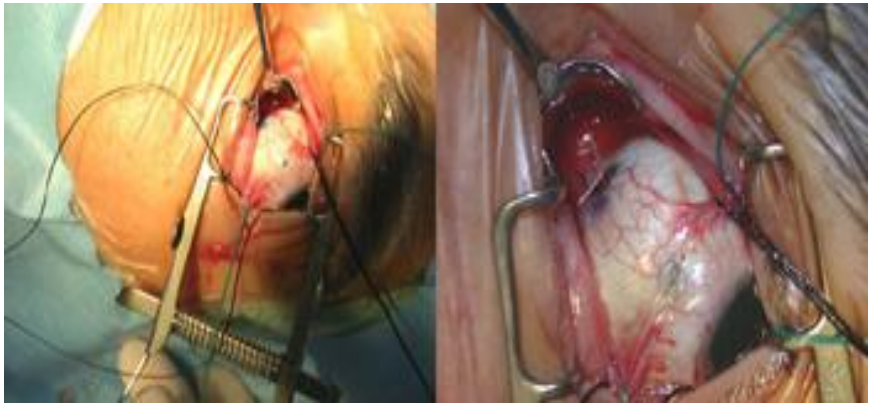


Choroidal melanomas

OSNOVNE FAZE U PROTONSKOJ TERAPIJI OKA

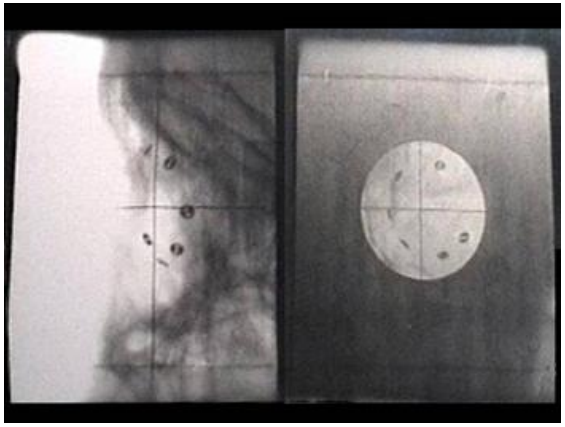


Izbor pacijenta: klinički slučaj



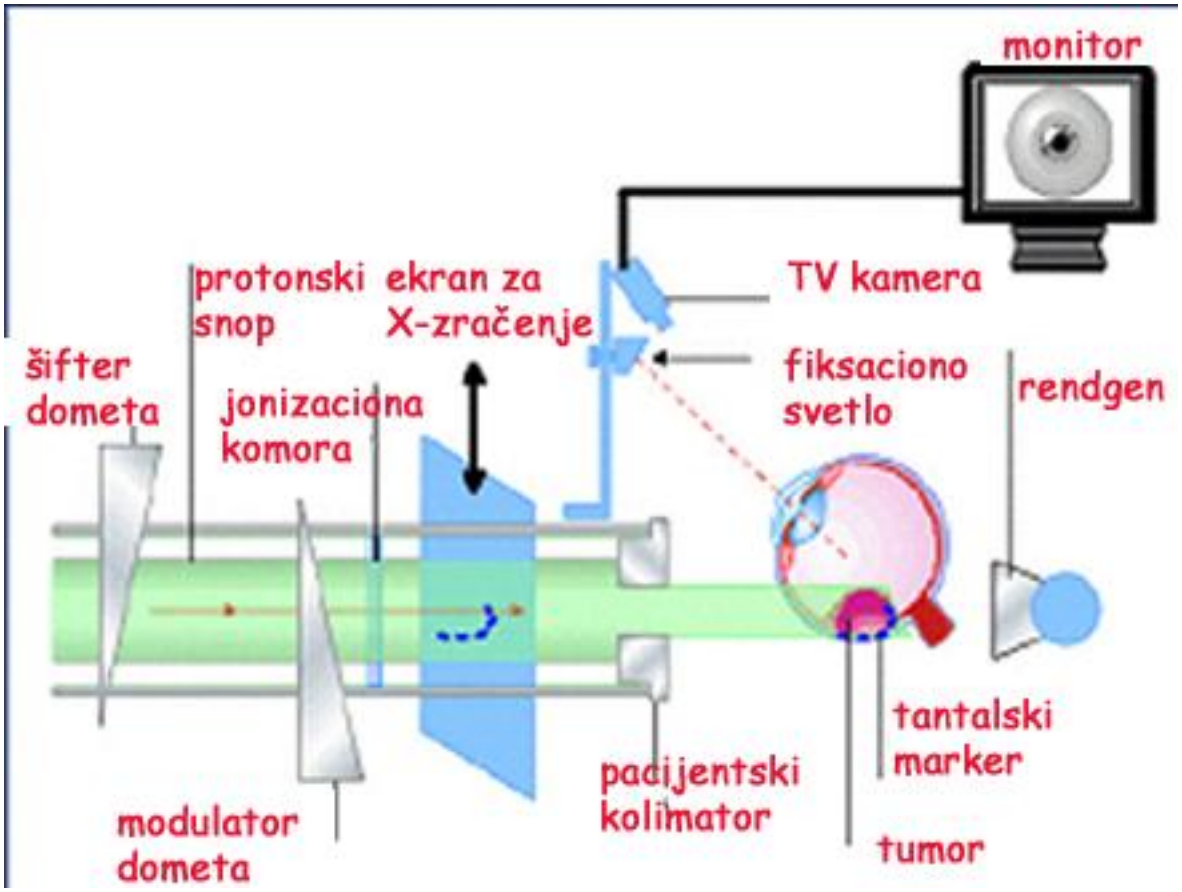
Hirurški tretman: ugradnja tantalskih klipsova kao markera

Simulacija: izrada fiksatora, modulatora, kolimatora



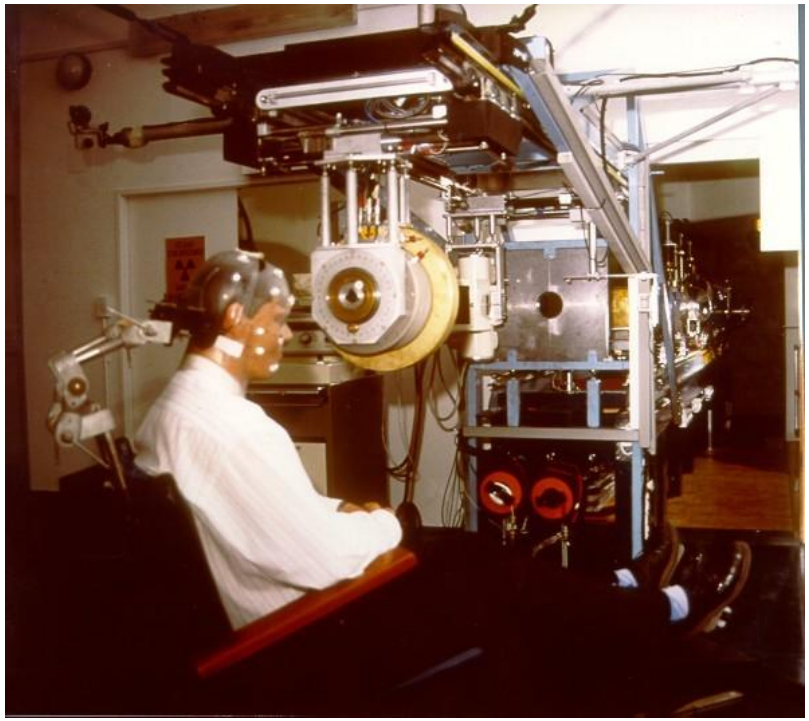
Radiografija: verifikacija položaja markera

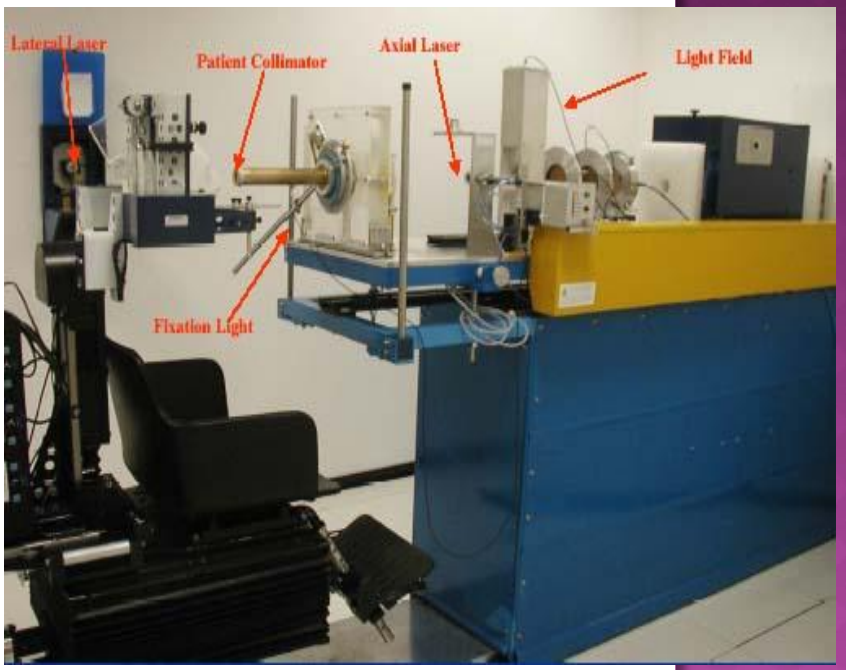
KAKO FUNKCIONIŠE TERAPIJA TUMORA OKA



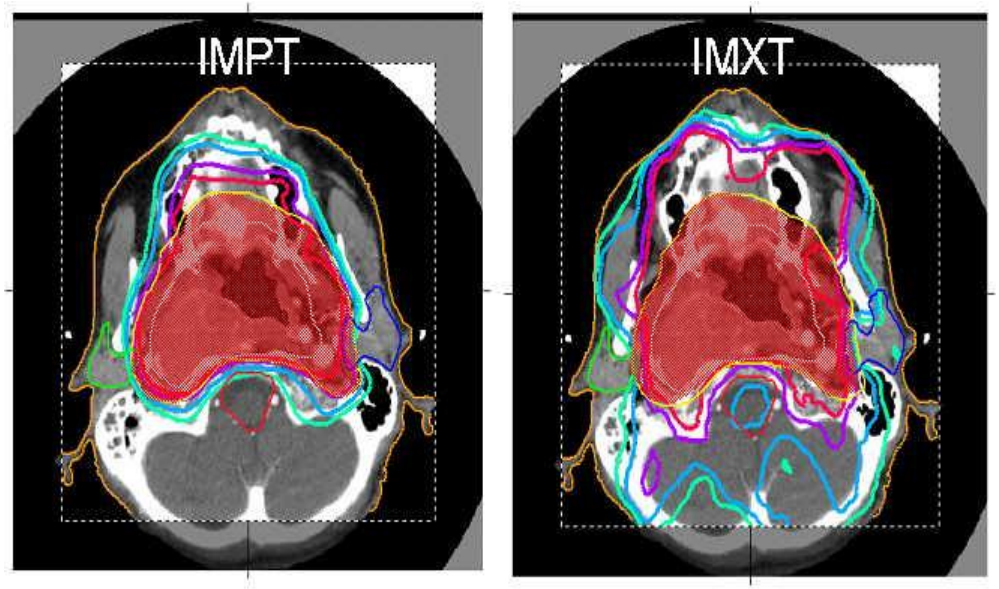
- Volumen mete dobro poznat
- Tantalski klips u oku: marker za pozicioniranje pacijenta
- Klips ne stvara probleme i ne uklanja se posle tretmana
- Individualna maska za imobilizaciju,repoduc. 1/10 mm
- Pokret oka u toku zračenja prekida snop

HORIZONTALNA STANICA



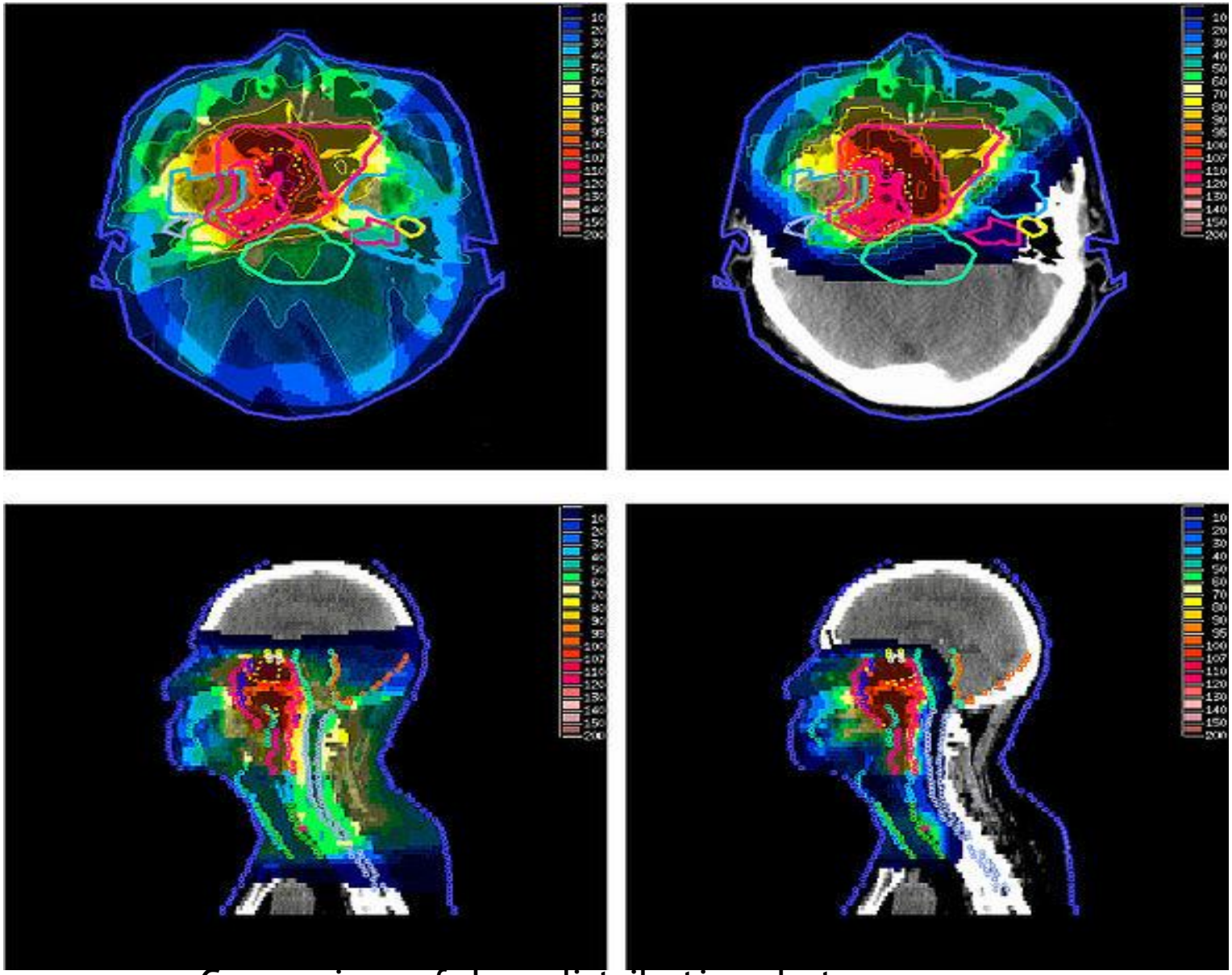


INTENZITETOM MODULISANA PROTONSKA TERAPIJA IMPT



IMPT vs. IMXT plan za glavu i vrat

- Uzak snop protona se magnetski skenira po zapremini mete
- Modulišu se energioja i intenzitet snopa
- Distribucija doze je konformalnija
- Bolja konformacija doze IMPT plana (35, 45, 60, and 70 Gy izodozne linije) na tumoru u meti (crveno)



Comparison of dose distributions between IMPT (right) and IMRT (left).jpg

SRNA 2-KG (OSNOVNI PAKET)

Autori: Dr Radovan D.Ilić, Prof.dr Vesna Spasić Jokić, dr Petar Beličev

Namena: numerički eksperimenti za transport protona, radioterapiju i dozimetriju

Energetski opseg protona: 100 keV to 250 MeV

Baza podataka o materijalima: 279 elemenata

limit: preseci prema ICRU 63

Geometrija: 3 D voxelizovana

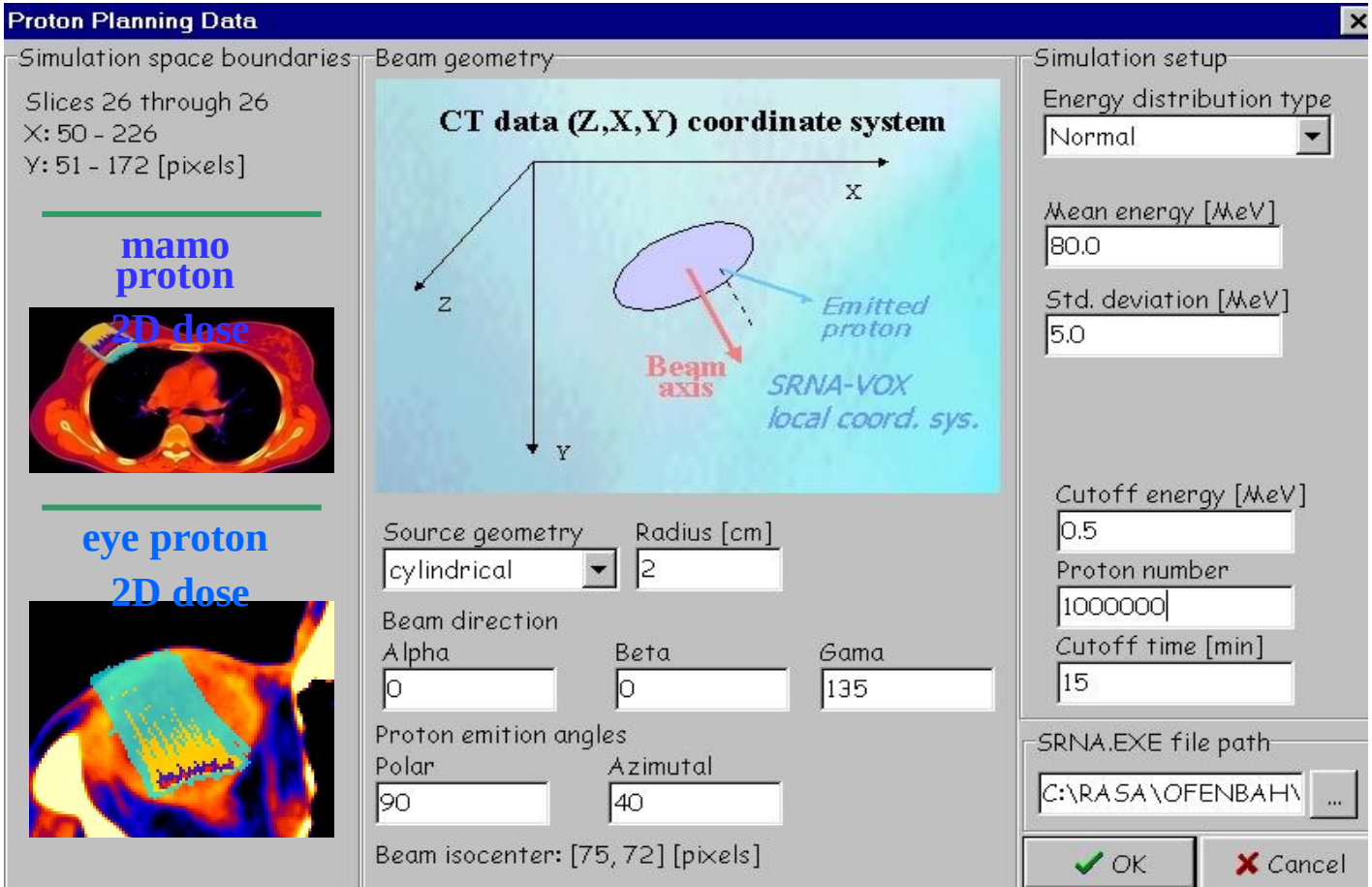
Programski jezici: Fortran 77 za Linux ili Windows

PROZOR ZA PODATKE ZA PLANIRANJE: 3 KORAKA

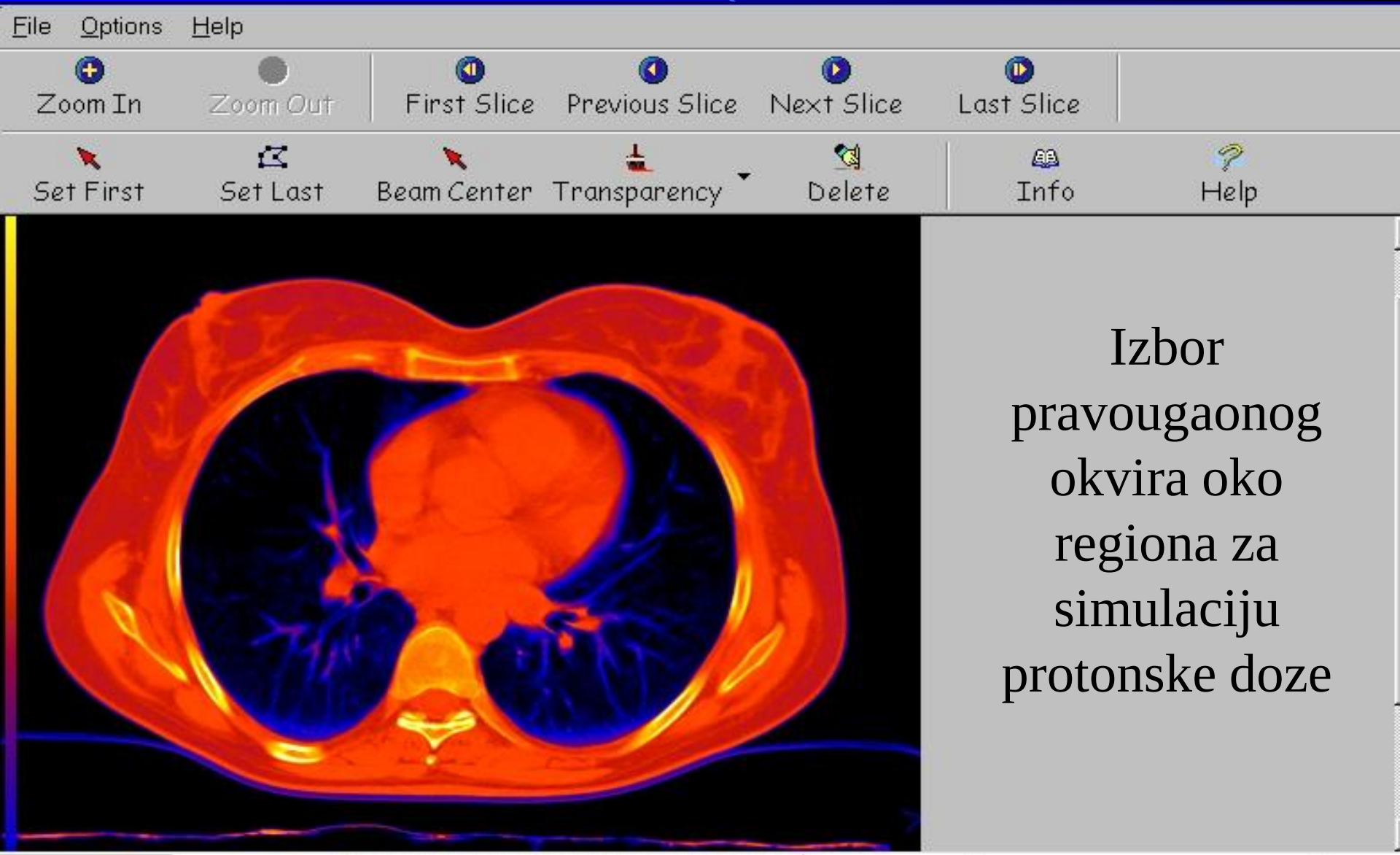
***Lokacija tumora* iz CT snimka**

Plan zračenja izbor tumorske regije u pravougaonom boksu

Odabrana regija se definiše prvim i polsednjim CT slojem u longitudinalnom Z pravcu i izborom transverzalne X-Y ravni



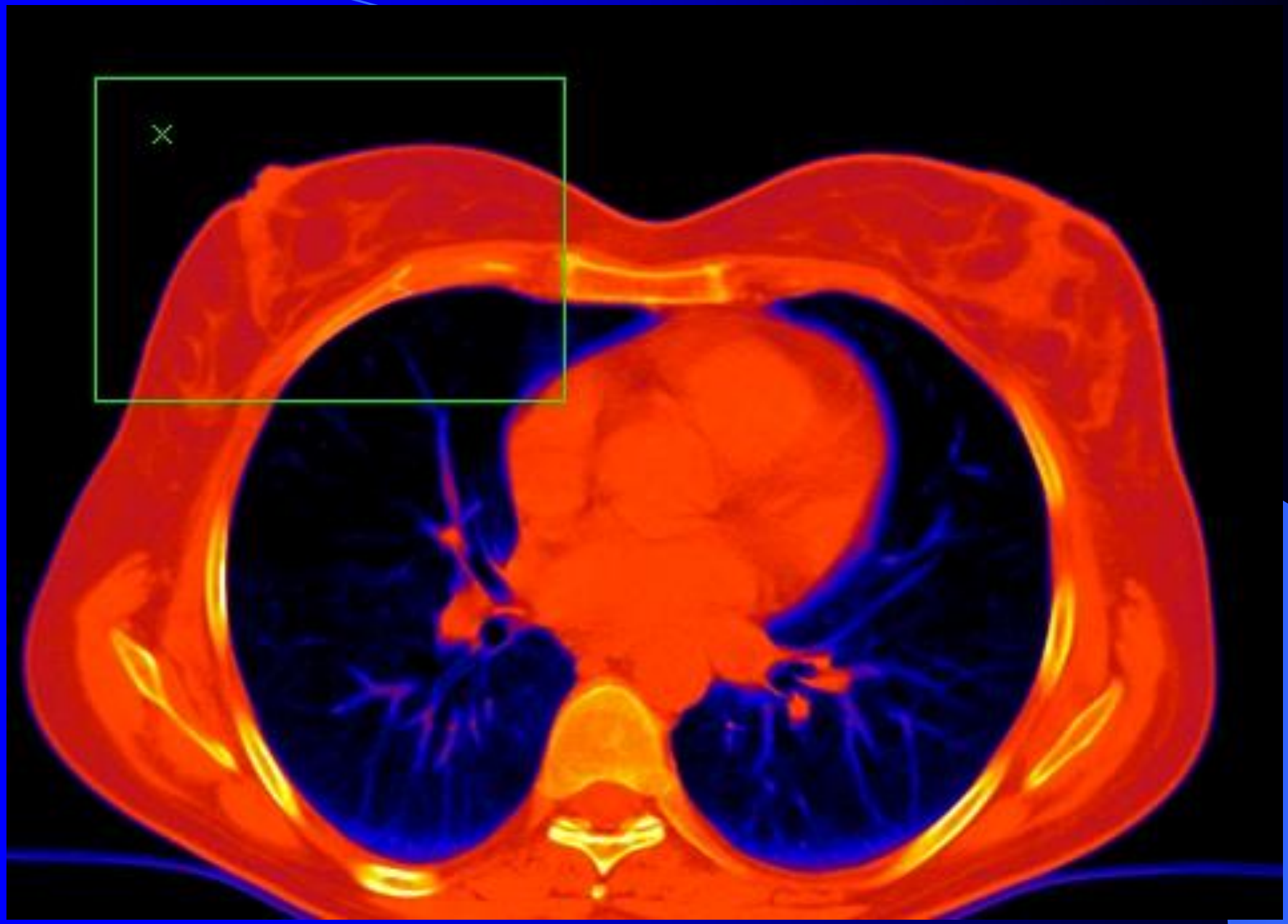
ISTAR – softver za planiranje protonske doze



Izbor pravougaonog okvira oko regiona za simulaciju protonske doze

ISTAR – softver za planiranje doze protona

Izbor prvog i poslednjeg sloja i centra snopa



ISTAR - Proton dose planning software

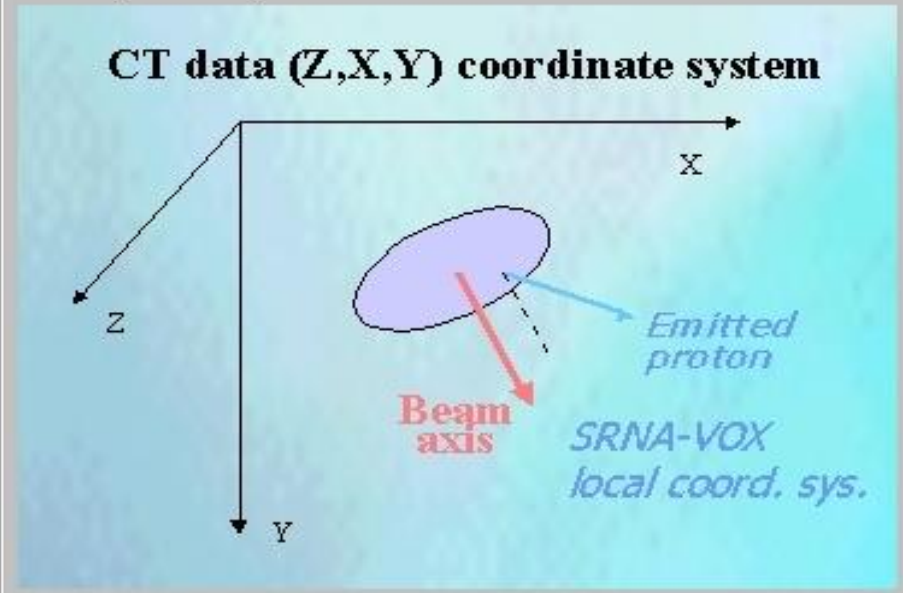
Izbor finalnih CT i geometrijskih podataka i pravljenje fajlova za simulaciju

Proton Planning Data

Simulation space boundaries

Slices 26 through 26
X: 50 - 226
Y: 51 - 172 [pixels]

Beam geometry



Source geometry: cylindrical
Radius [cm]: 2

Beam direction
Alpha: 0
Beta: 0
Gama: 135

Proton emition angles
Polar: 90
Azimutal: 40

Beam isocenter: [75, 72] [pixels]

Simulation setup

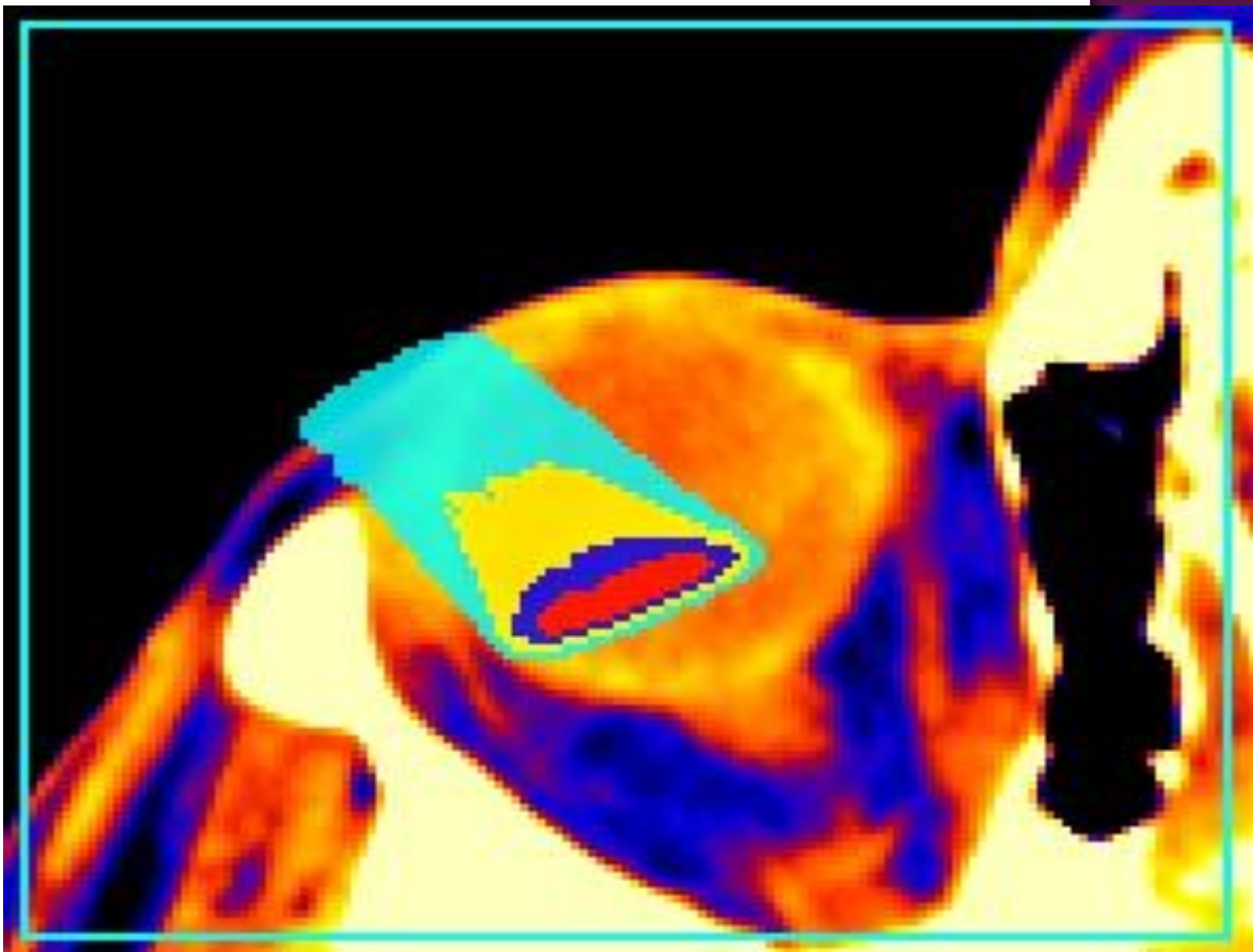
Energy distribution type: Normal
Mean energy [MeV]: 80.0
Std. deviation [MeV]: 5.0
Cutoff energy [MeV]: 0.5
Proton number: 1000000
Cutoff time [min]: 15

SRNA.EXE file path

C:\RASA\OFENBAH\ ...

OK Cancel

Raspodela doze u ekvatorijalnoj ravni oka, simulacija SRNA-VOX kodom, 50 MeV energija protona, korak 1.2 MeV. 20, 60, 80 i 100 % izodoze



20 %

60 %

80 %

100 %

RASPODELA DOZE U DOJCI U CENTRALNOJ RAVNI SNOPA ZA 65 MEV PROTONE SA REZOLUCIJOM 1,5 MEV

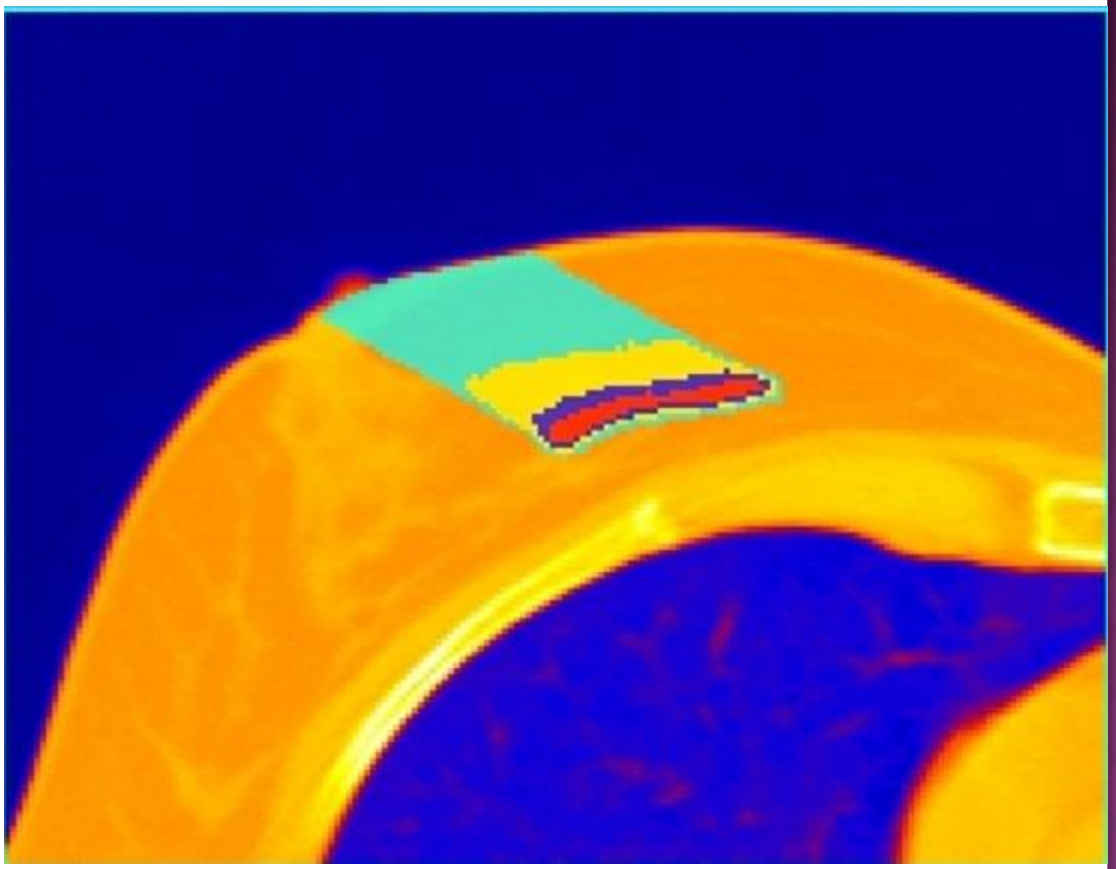
Izodoze

20 %

60 %

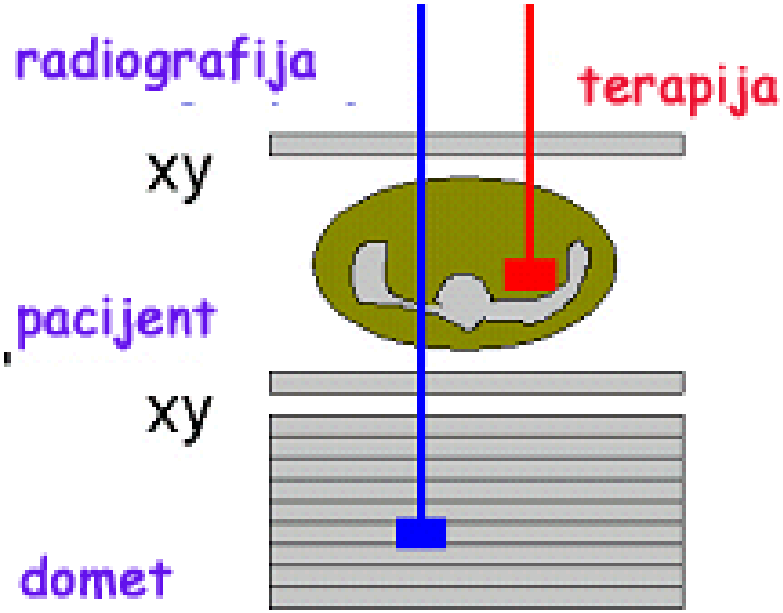
80 %

100 %



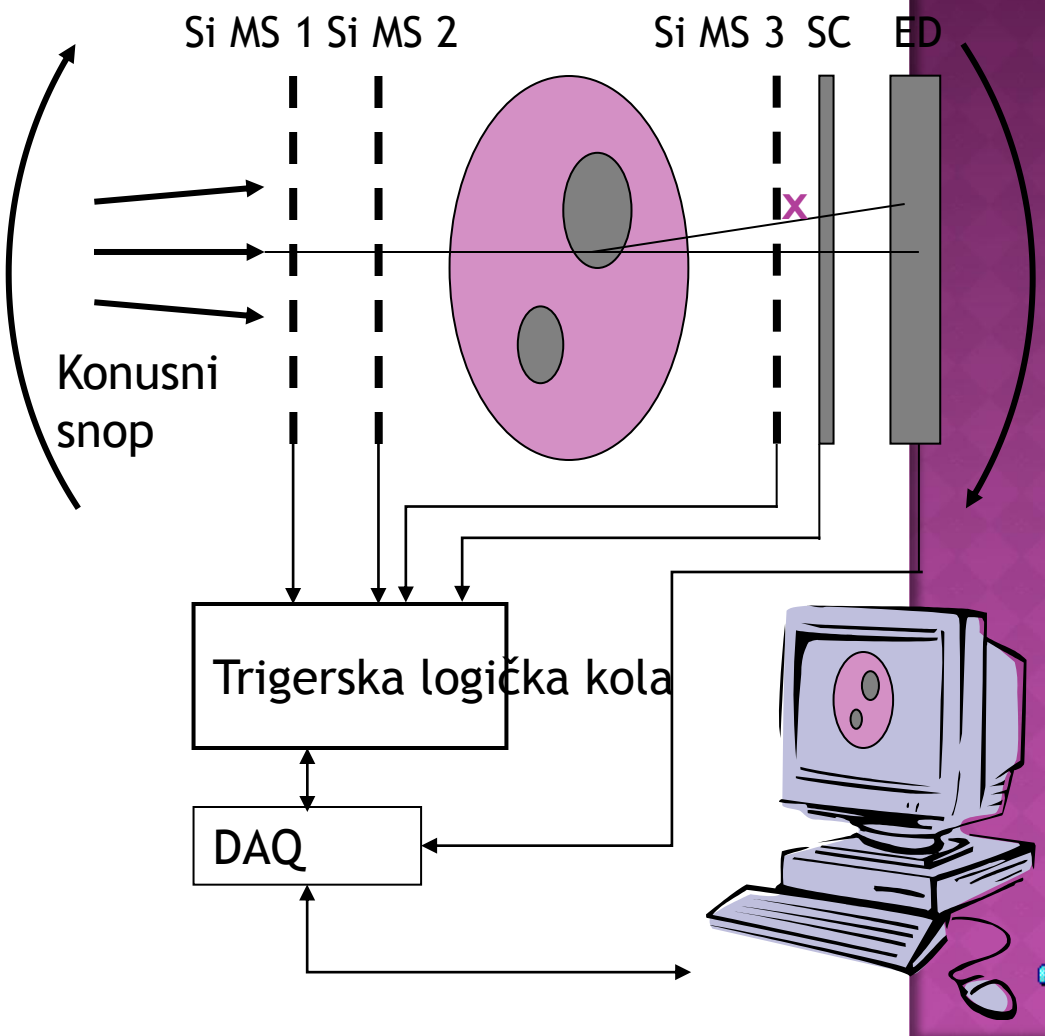
PROTONSKA TRANSMISIONA RADIOGRAFIJA

Slika je 2 D mapa srednjeg rezidualnog dometa protona koji izlaze iz pacijenta



KOMPJUTERIZOVANA TOMOGRAFIJA PROTONSKIM SNOPOM

- Rekonstrukcija 3 D
- Silicijumska tehnologija
- Konusna geometrija snopa
- Zanemarivanje rasejanih protona i neutrona



PROTON CT

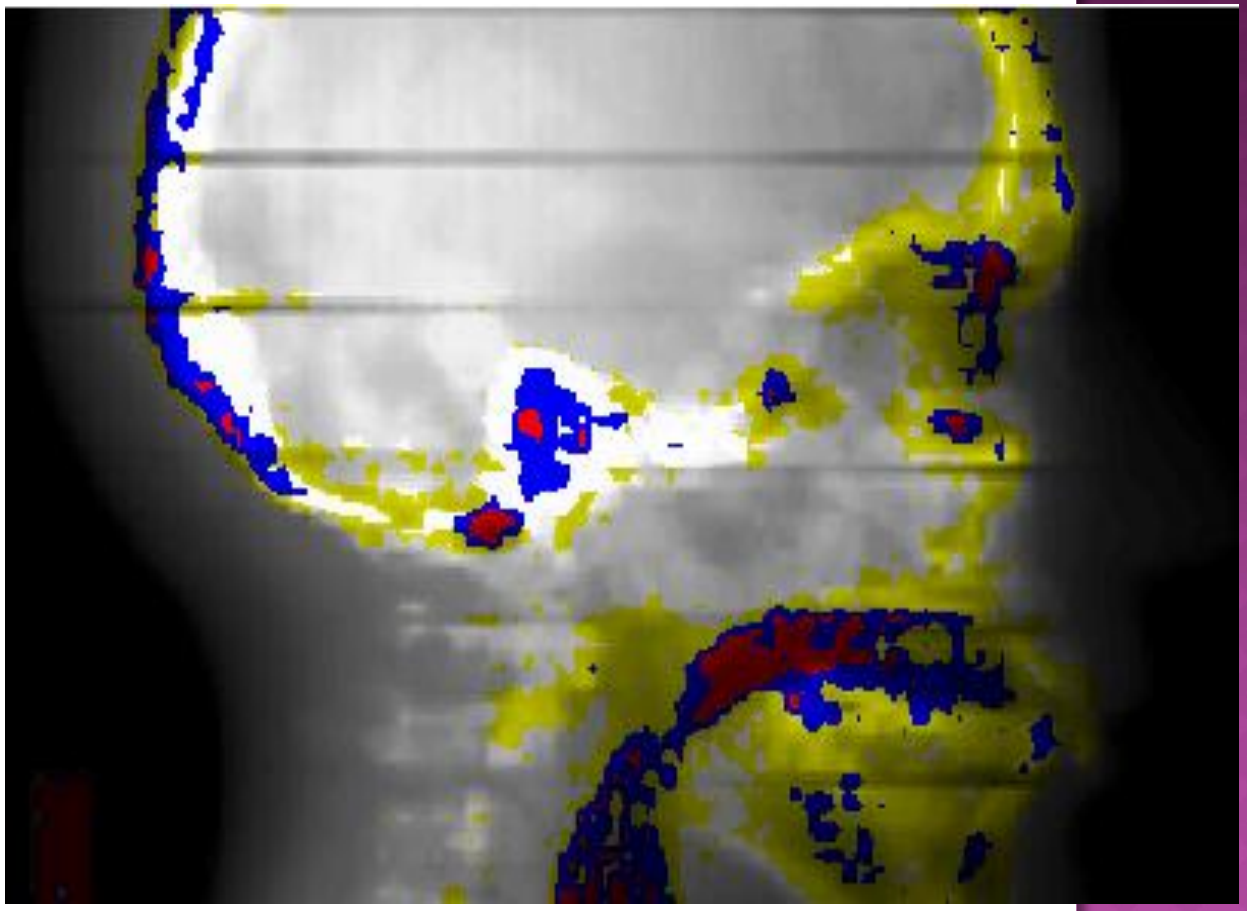
Opsezi nesigurnosti

(mereno sa PTR)

> 5 mm

> 10 mm

> 15 mm



Aldersonov fantom glave