Radioterapie se svazky elektronů s velmi vysokými energiemi

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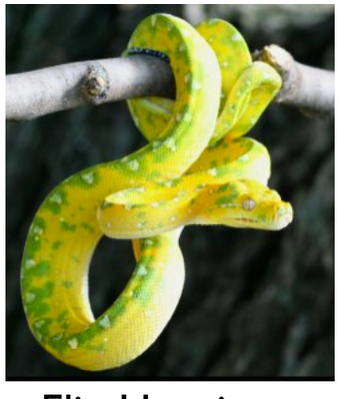
Elin Hynning

Podpořeno

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SLAC NATIONAL ACCELERATOR LABORATORY

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Úvod

- Vyzkum ozarovani prostaty elektrony s velmi vysokymi energiemi (VHEE, 100-250 MeV) byl proveden na zacatku let 2000†. My jsme

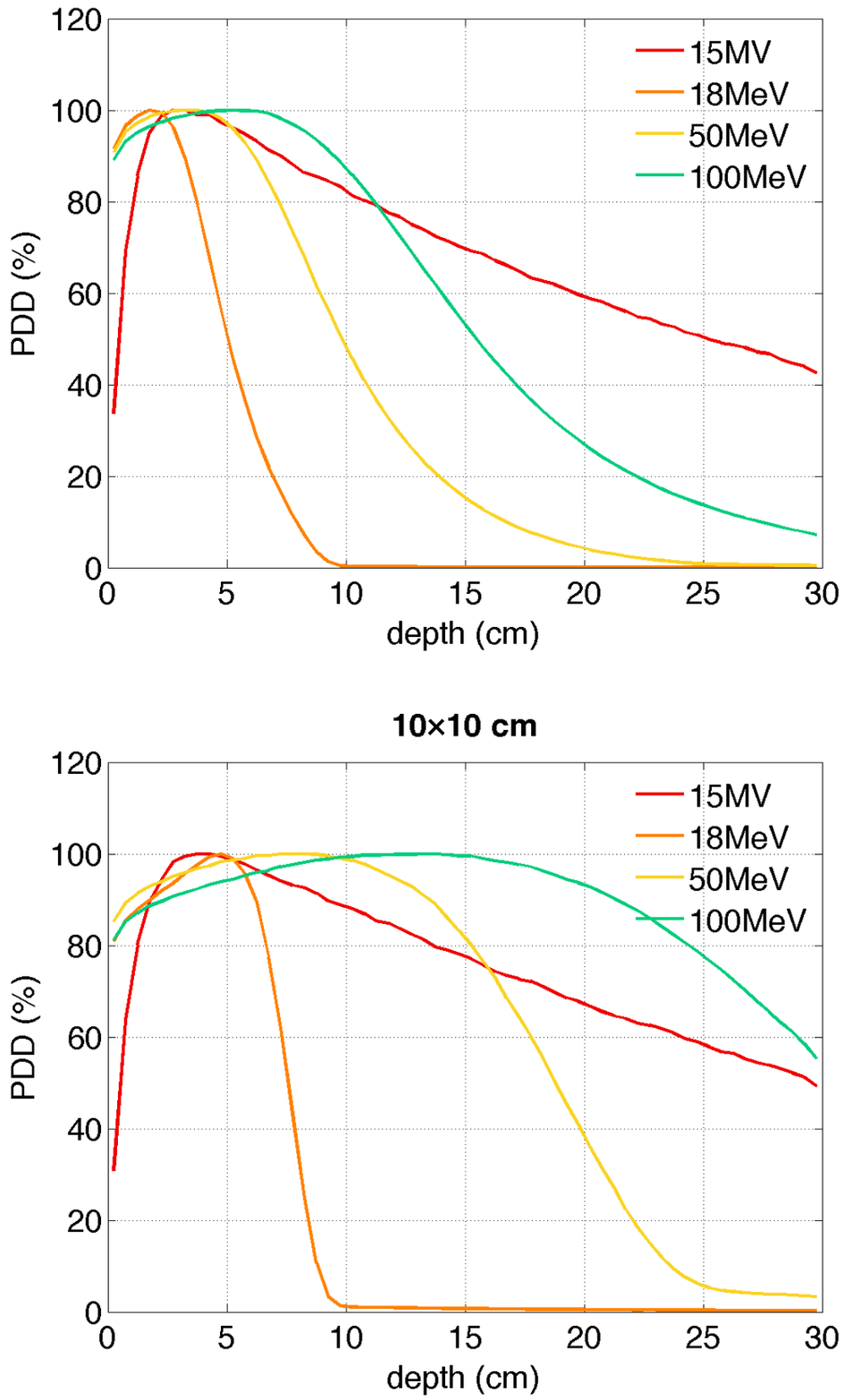
A. zmerili davkove rozlozeni VHEE svazku a porovnali je se simulacemi Monte Carlo.

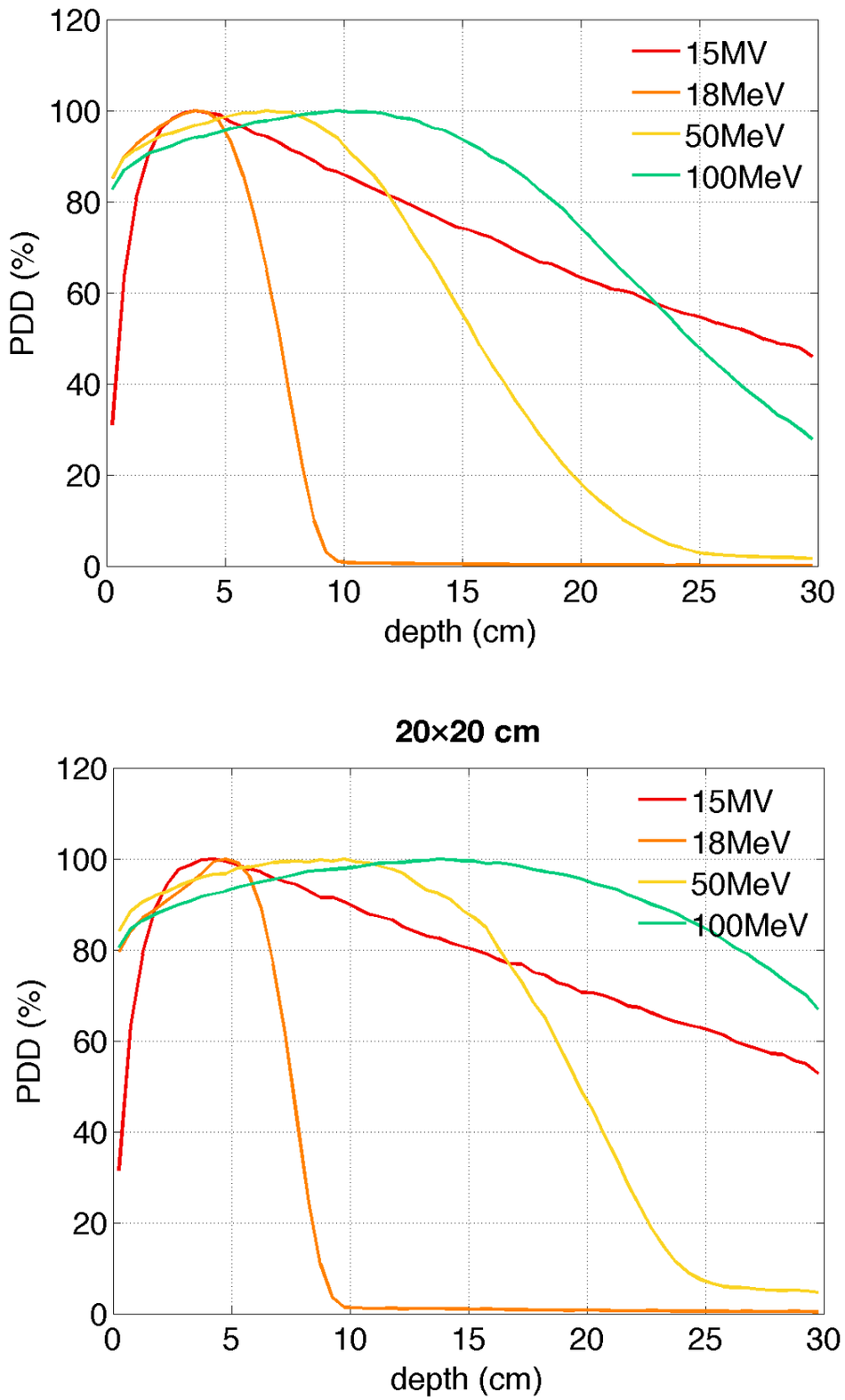
B. vyvinuli planovaci system pro VHEE svazky a pouzili na ctyri pacienty.

C. studovali odezvu rakovinovych bunek na vysoky davkovy prikon.

†DesRosiers et al. **PMB 7**, 2000, Yeboah et al. **PMB 8**, 2002, Yeboah et al. **PMB 13**, 2002

Úvod


2×2 cm
15MV
18MeV
50MeV
100MeV
PDD (%)
depth (cm)
0
20
40
60
80
100
120
0
5
10
15
20
25
30

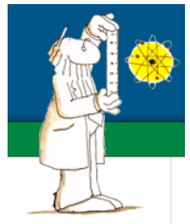

5×5 cm
15MV
18MeV
50MeV
100MeV
PDD (%)
depth (cm)
0
20
40
60
80
100
120
0
5
10
15
20
25
30

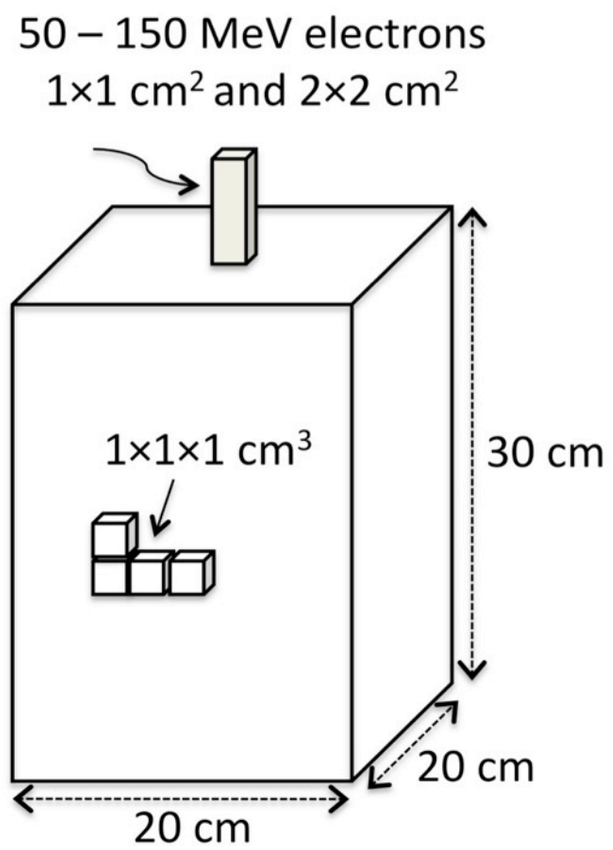
10×10 cm
15MV
18MeV
50MeV
100MeV
PDD (%)
depth (cm)
0
20
40
60
80
100
120
0
5
10
15
20
25
30

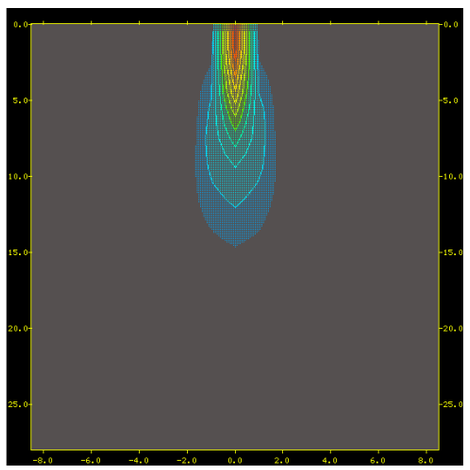
20×20 cm
15MV
18MeV
50MeV
100MeV
PDD (%)
depth (cm)
0
20
40
60
80
100
120
0
5
10
15
20
25
30

Porovnání Monte Carlo

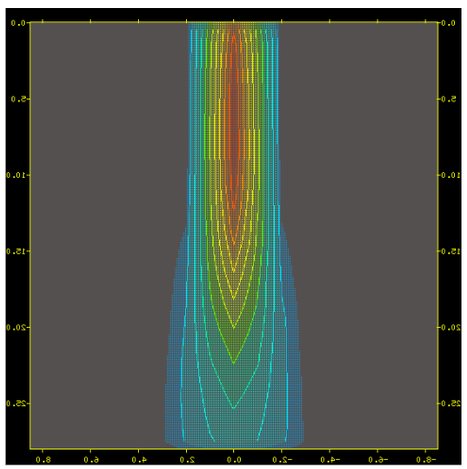
- **Alpha version of TOPAS (Geant4 based)**
- **MCNPX**
- **EGSnrc**







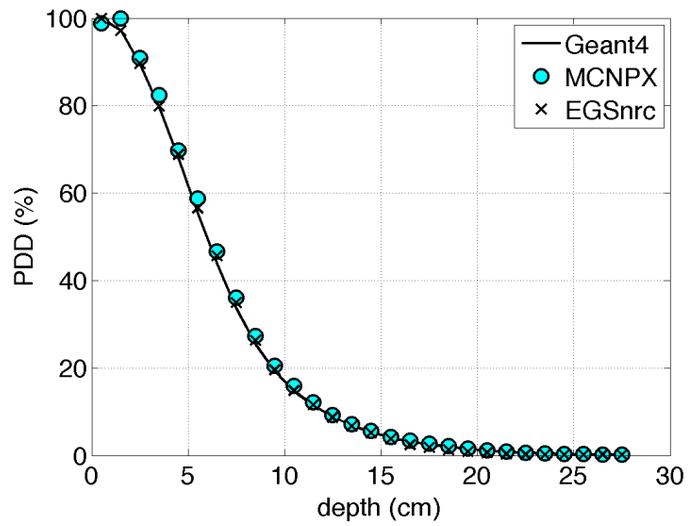
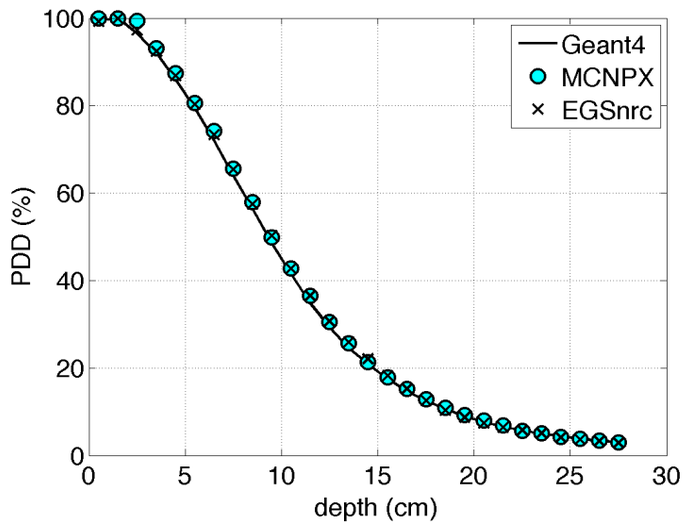
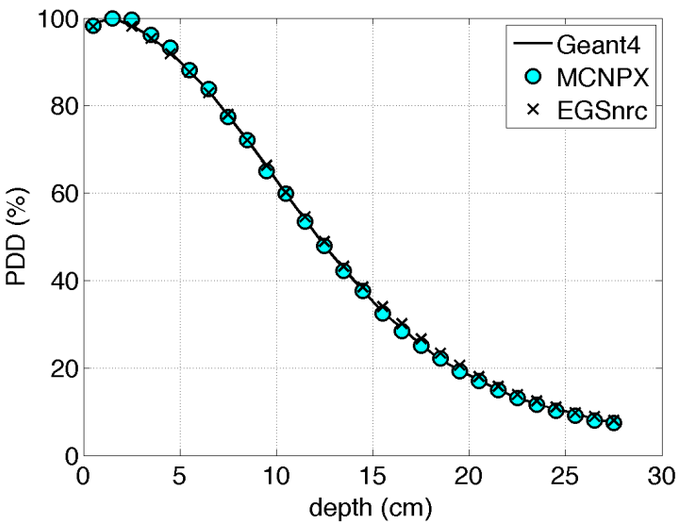
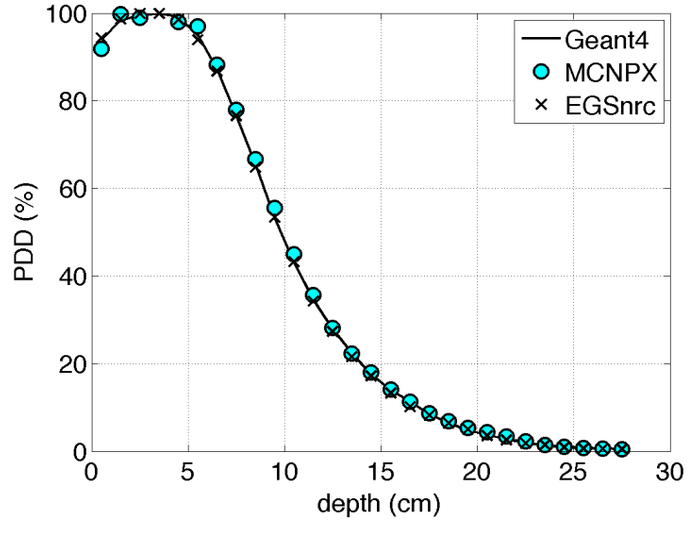
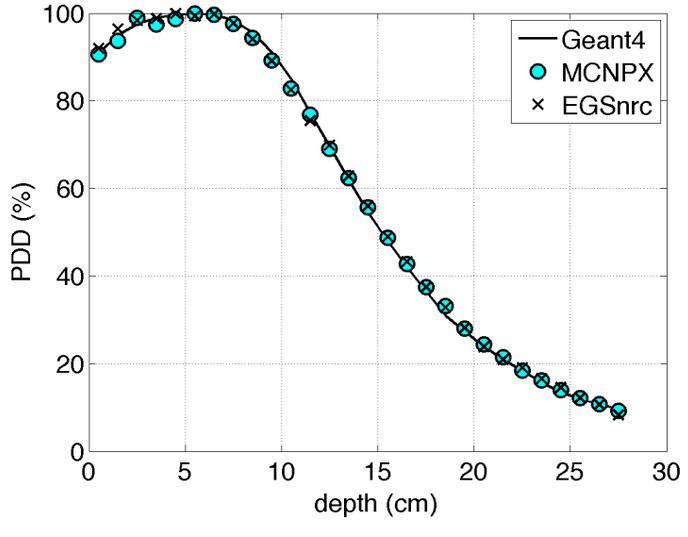
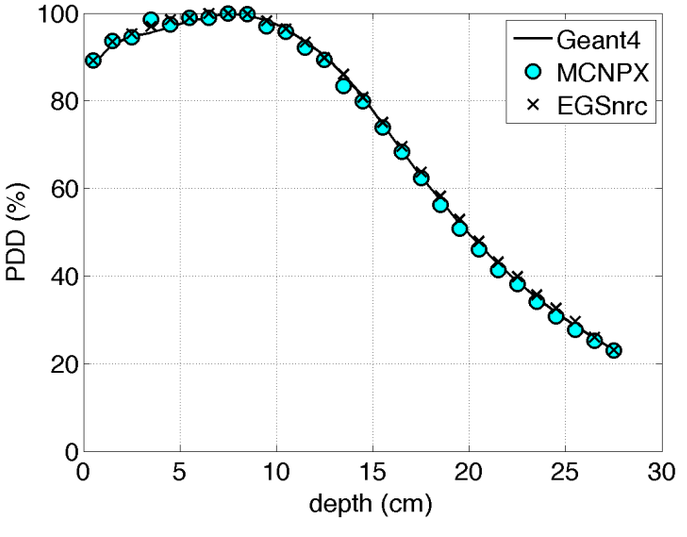
50 MeV 1 × 1cm²



150 MeV 2 × 2cm²

Bazalova et al, AAPM 2012

Porovnání Monte Carlo

	50 MeV	100 MeV	150 MeV
$1\times1cm^2$			
$2\times2cm^2$			

Experimenty s VHEE

- Next Linear Collider Test Accelerator (NLCTA)

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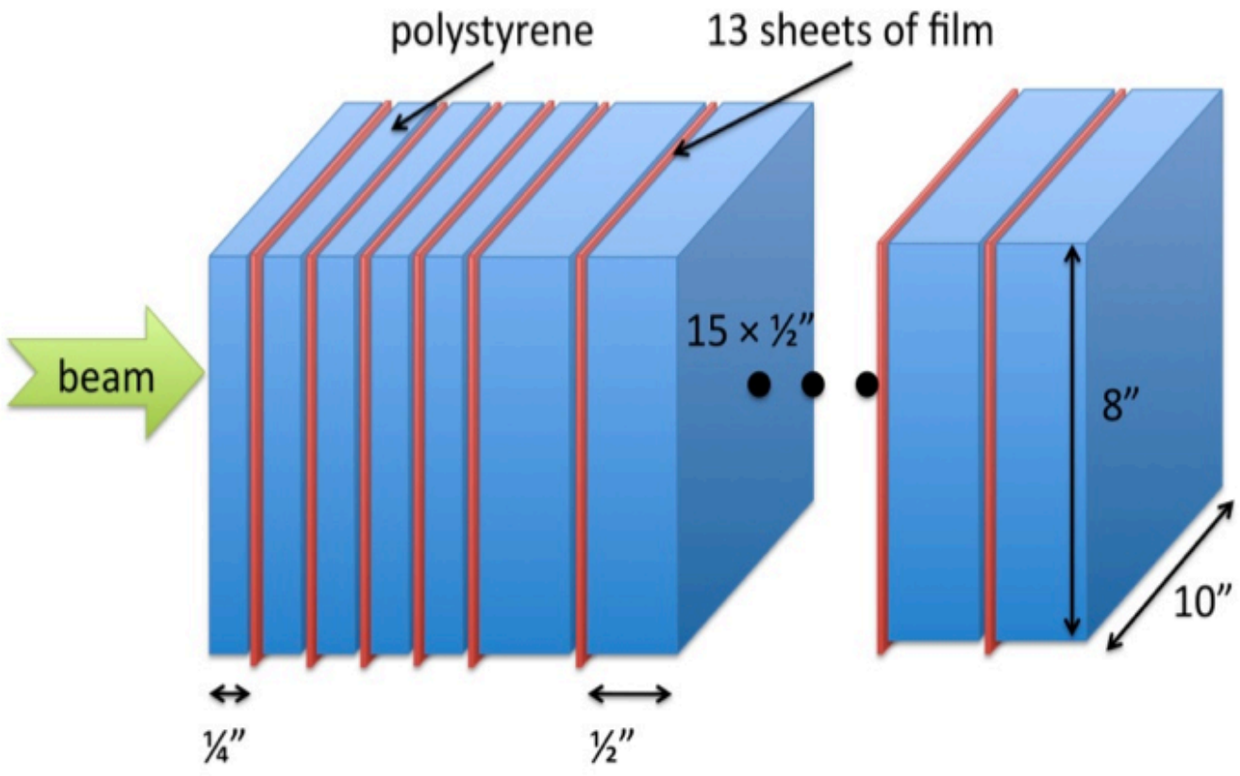
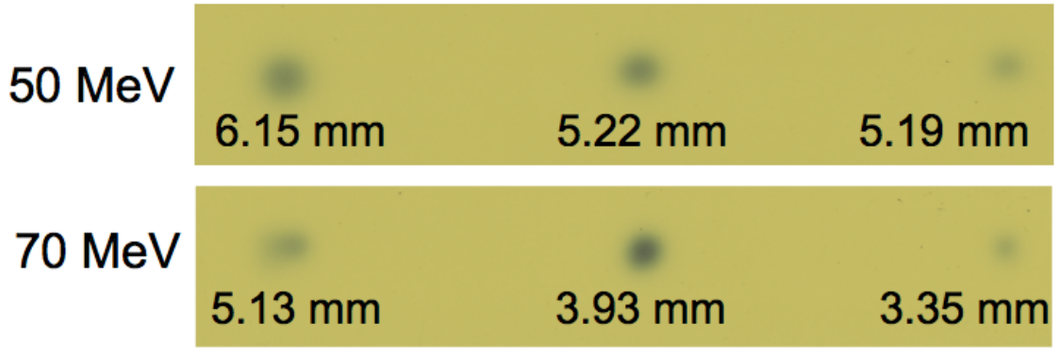
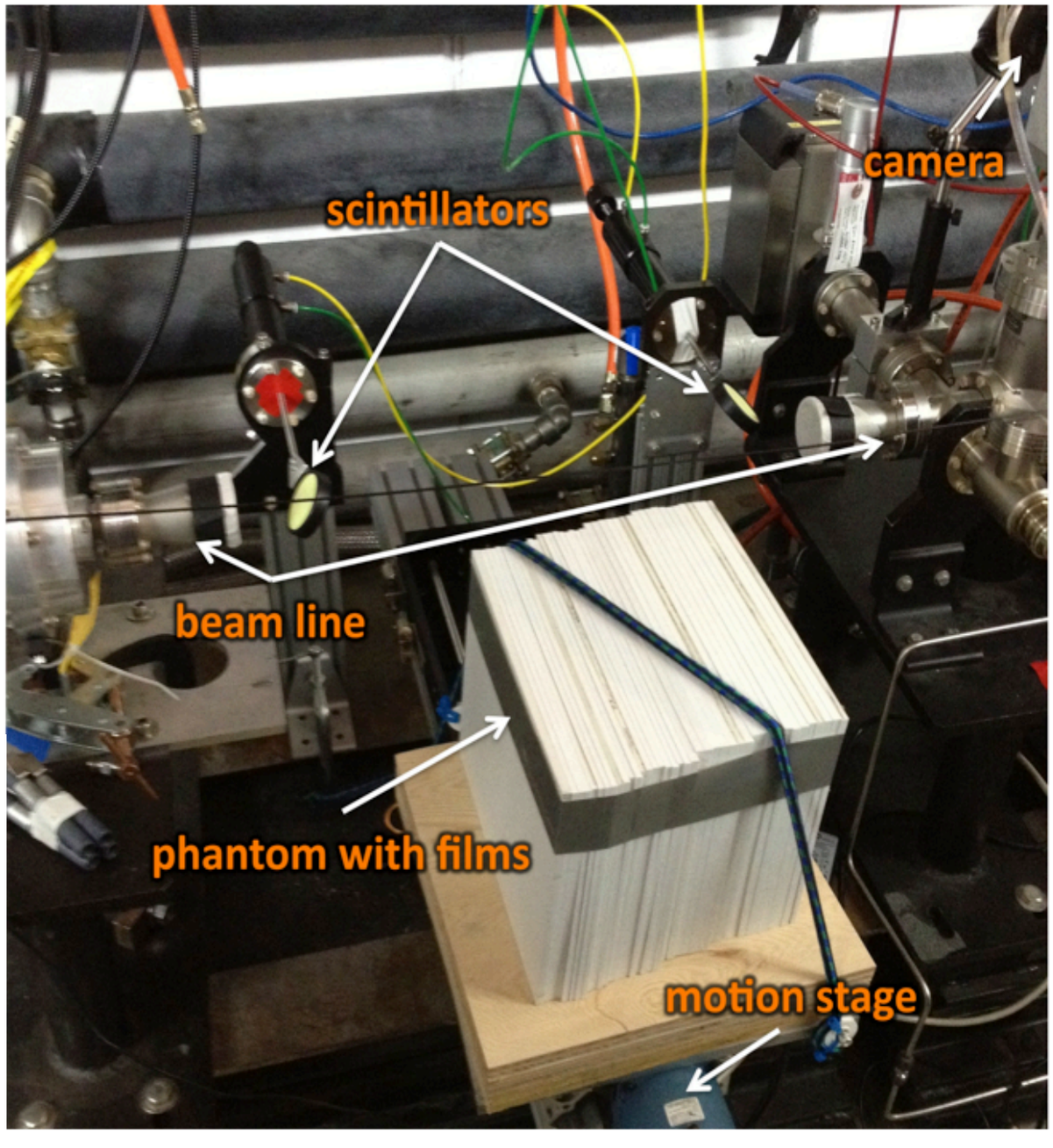




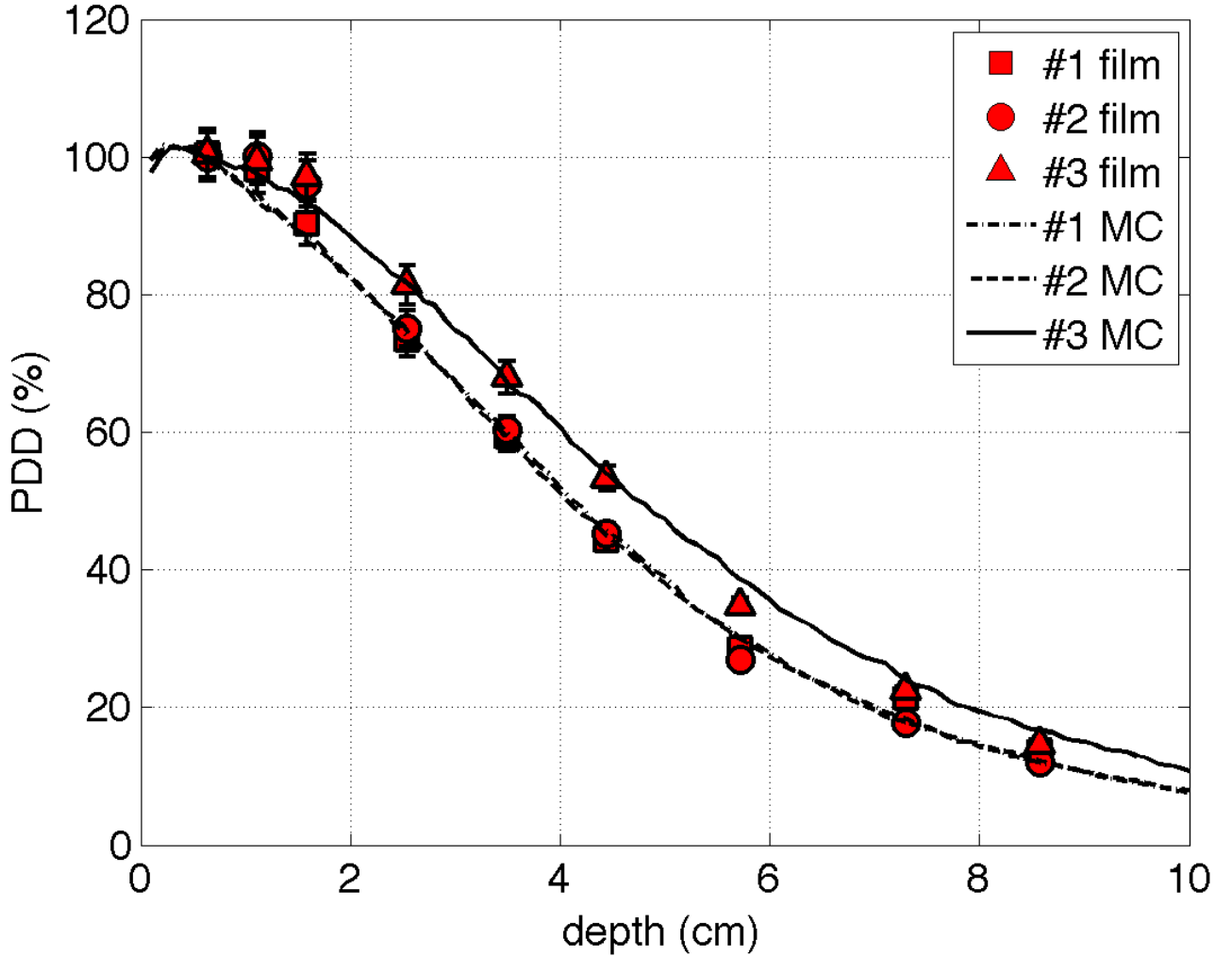


Homogenní fantom

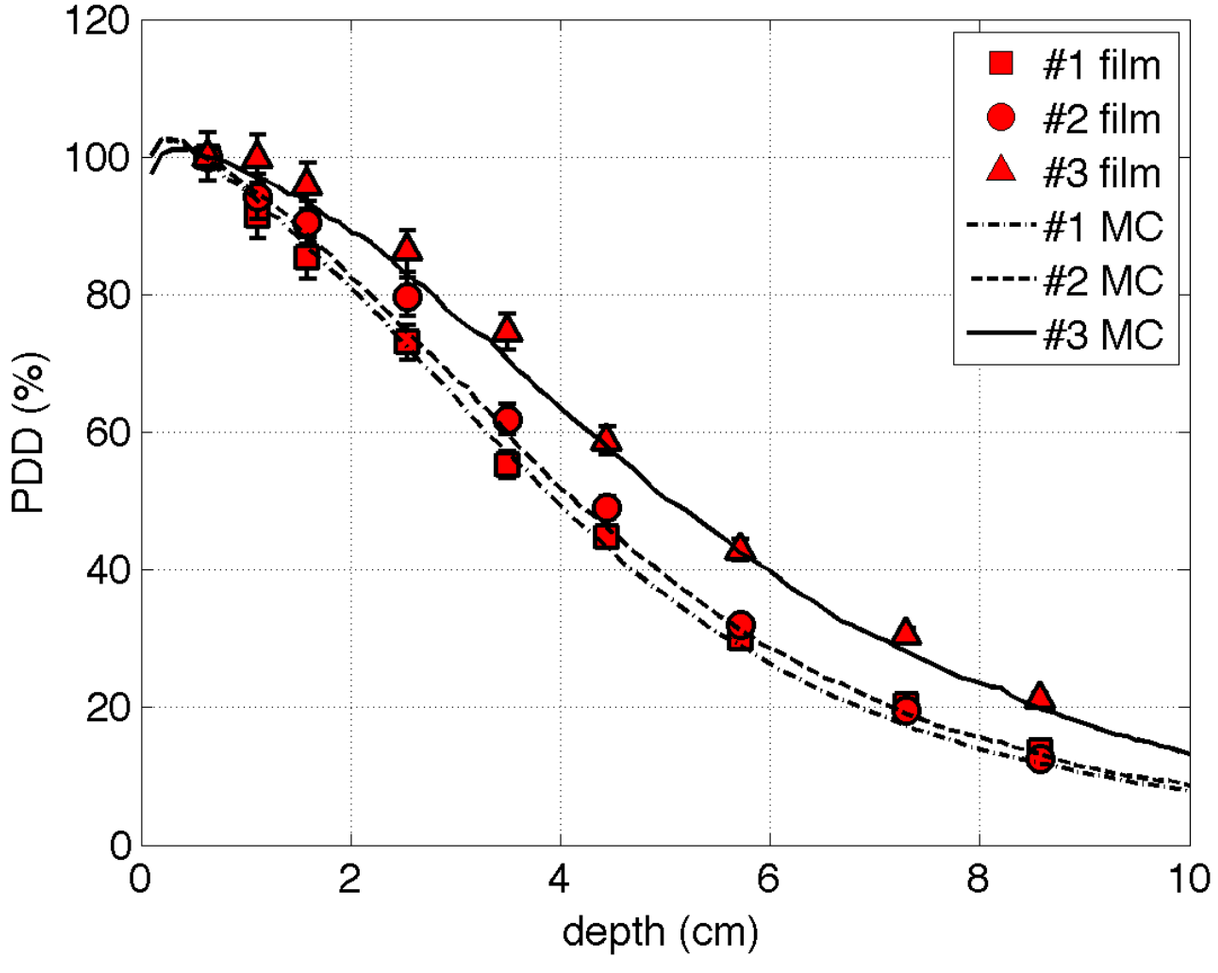
		50 MeV			70 MeV		
		#1	#2	#3	#1	#2	#3
FWHM	*x* (mm)	5.20	5.25	6.47	3.70	3.85	4.13
	y (mm)	5.17	5.18	5.83	3.63	4.00	6.13
Number of pulses		10	20	40	2	10	40

Percentage depth doses (PDDs)

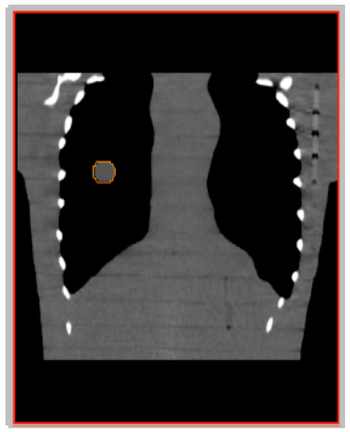
50 MeV

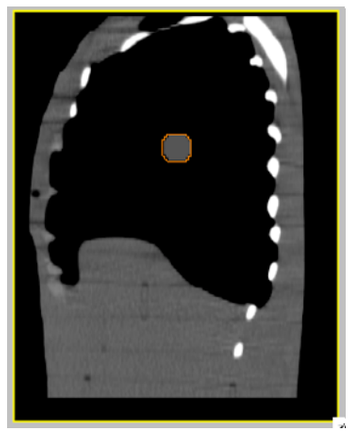


70 MeV



VHEE plány ozařování

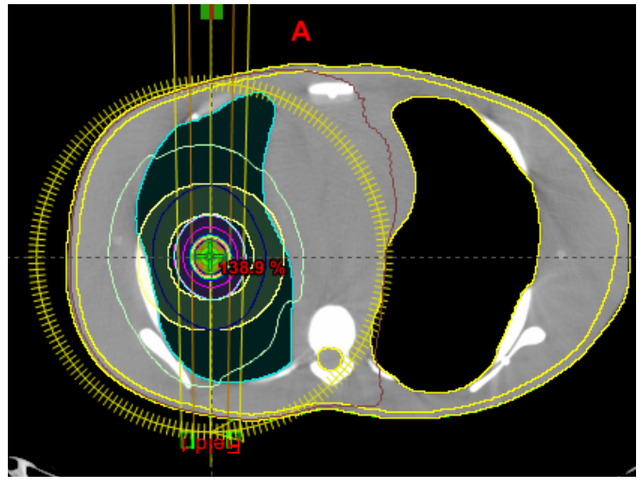




8 cm³ PTV

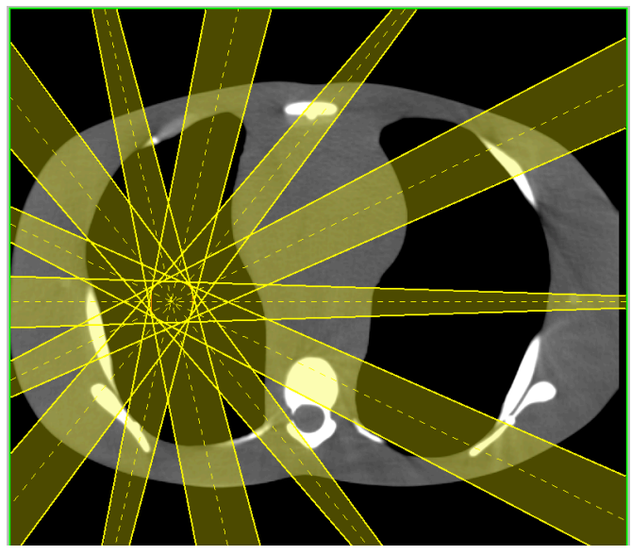
Eclipse

Plan



6 MV RapidArc

EGSnrc



100 MeV VHEE

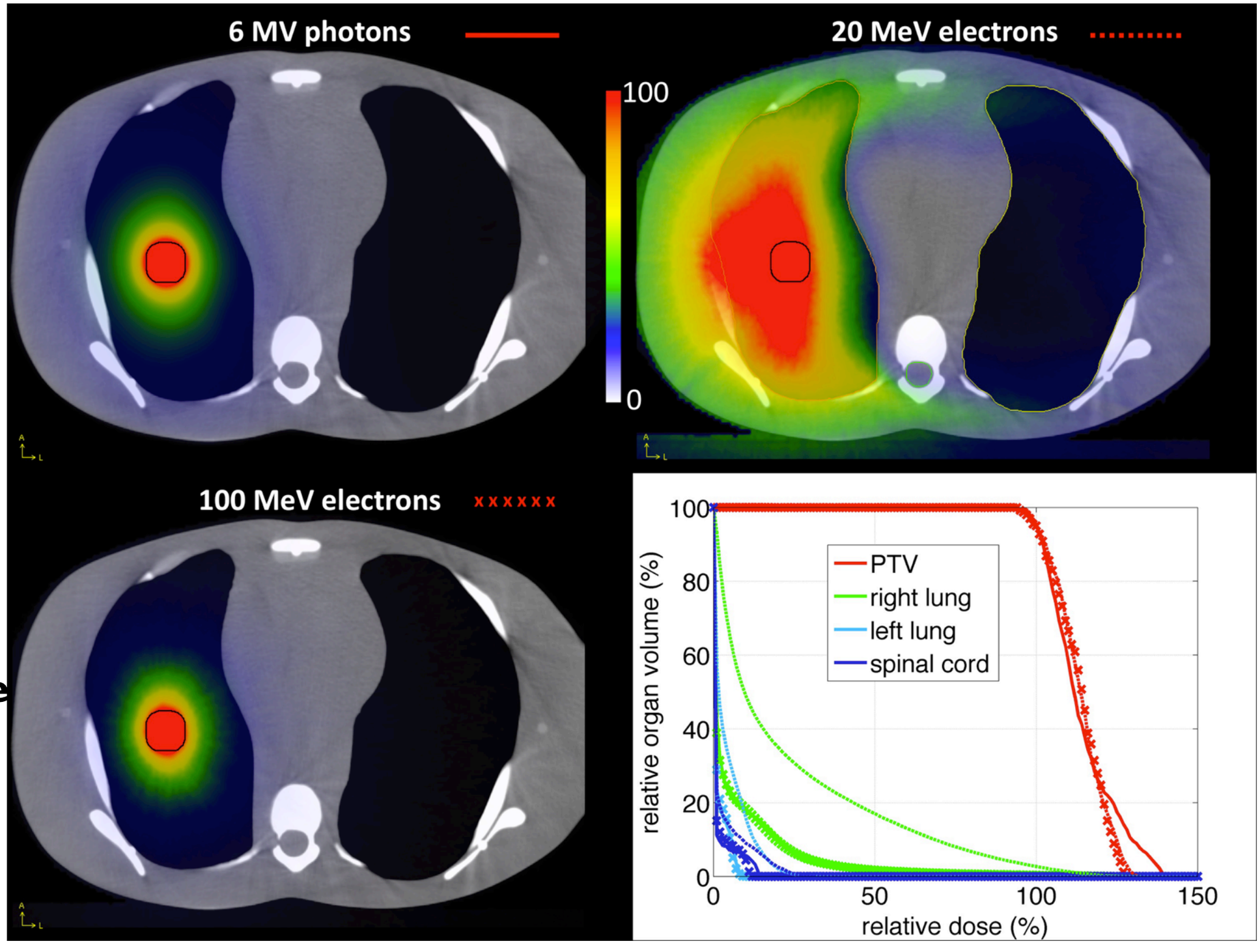
Plicní nádor ve fantomu

Ozarovaci doba pro 10 Gy

TrueBeam > 1 min

Magneticke skenovani svazku ≈ 1.3 s

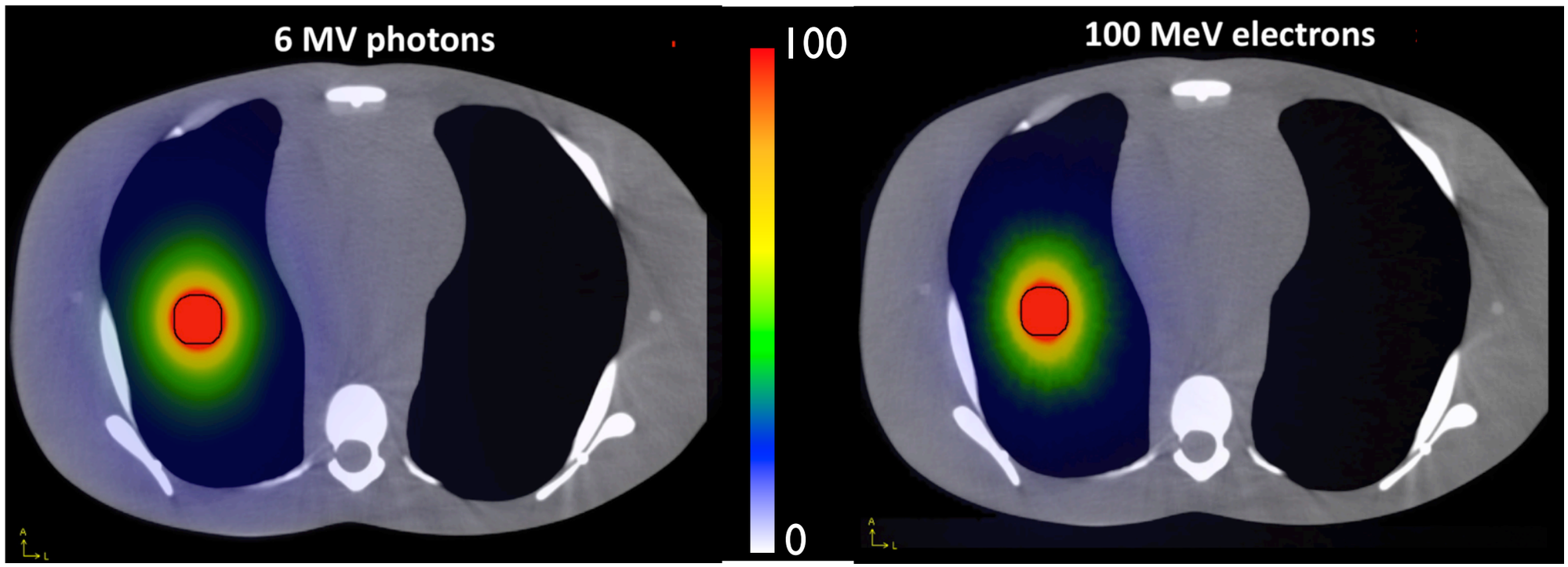
rovnomerne rozlozenych 360 svazku bez optimizace



rovnomerne rozlozenych 360 svazku bez optimizace

Pacienti

rovnomerne rozlozenych 360 svazku bez optimizace



1) Vyvinuti optimizace pro RT s VHEE.

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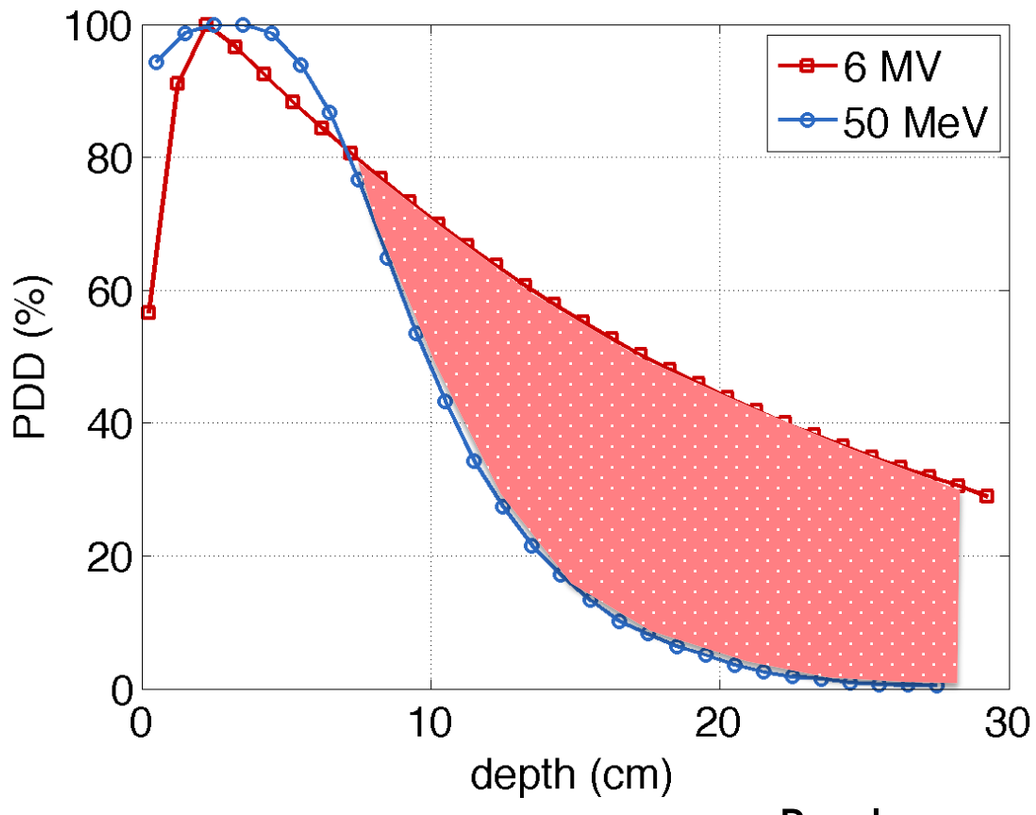
2) Vyhodnotit vyhody rychleho poklesu davky v tkani pro lecbu pediatrickych pacientu.

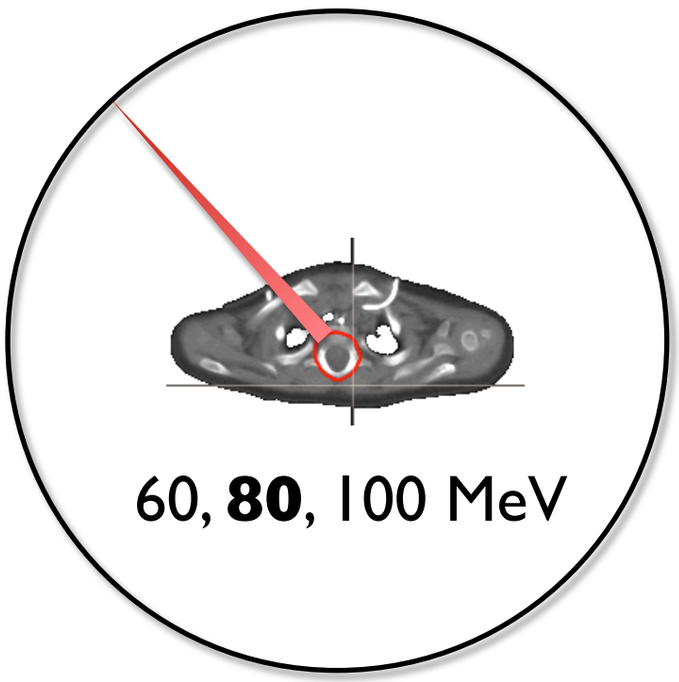
3) Vyhodnotit plany pro pacienty s nadory krku a hlavy, panve a plic.



Bazalova et al, ICCR 2013

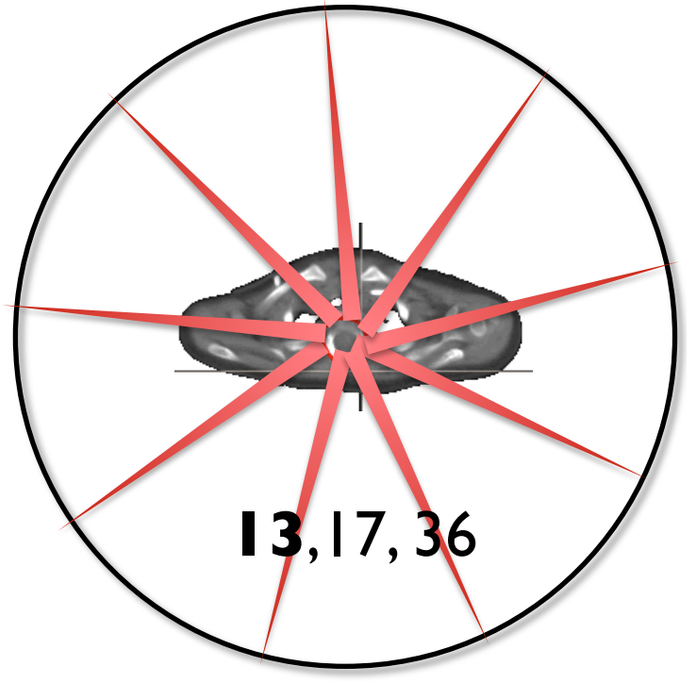
Studované parametry systému

Energie



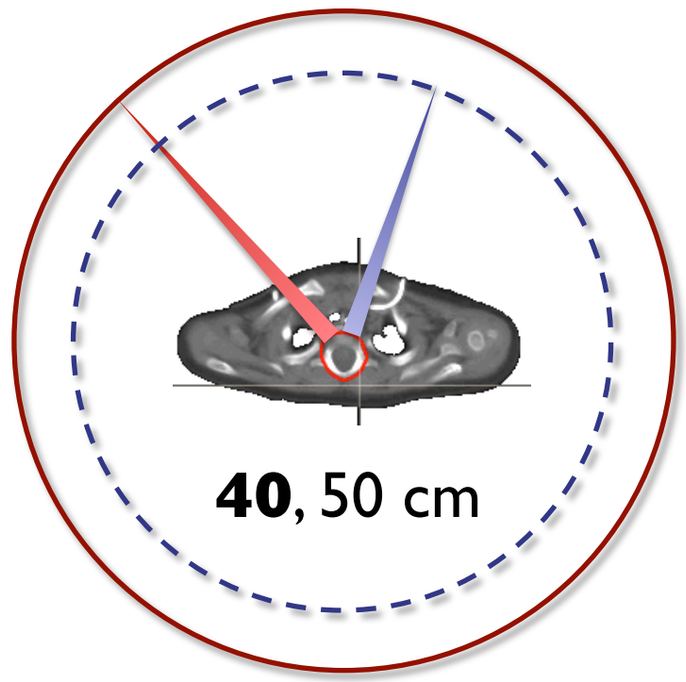
60, **80**, 100 MeV

Pocet svazku (uhlu)



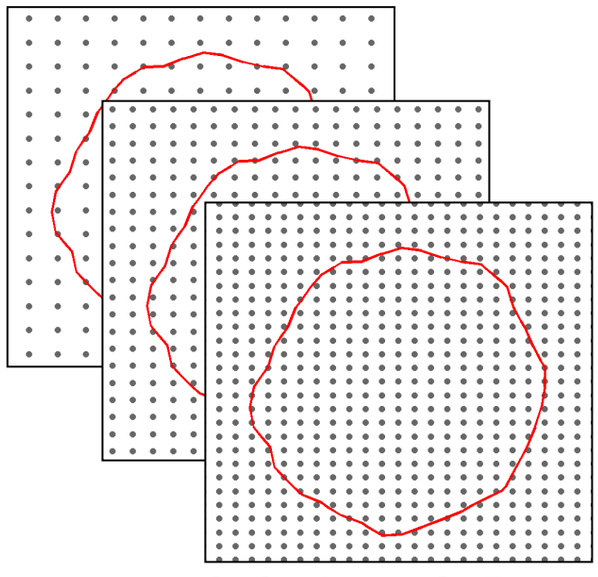
13,17, 36

Polomer ‘tunelu’



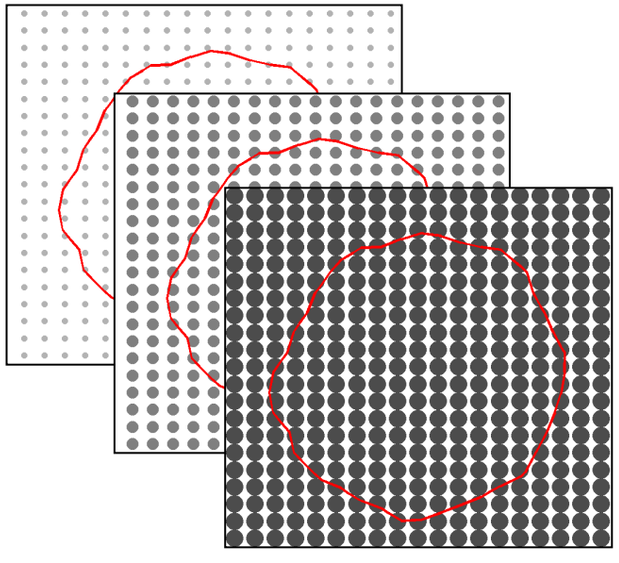
40, 50 cm

Rozestup uzkych svazku



2.0, **2.5**, 3.5 mm

Velikost svazku

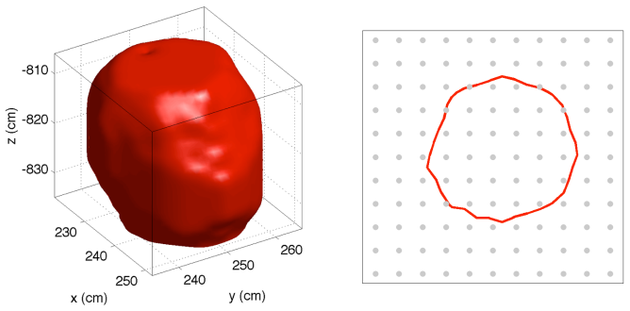


0.1, **1**, 3 mm

Postup optimizace VHEE RT

MATLAB

selecting beamlets to treat PTV

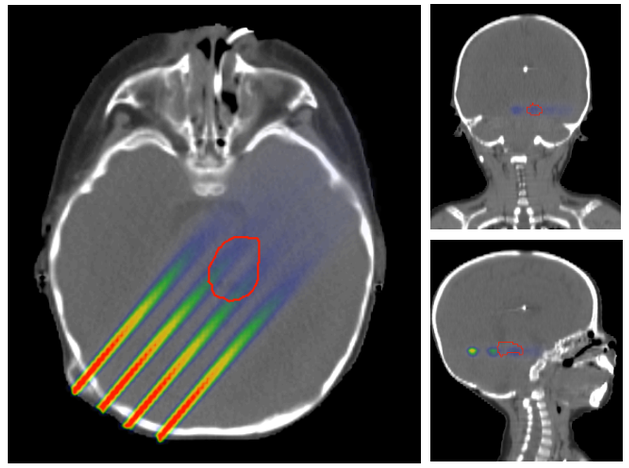


generating EGSnrc input files

```
raysearch1                                                    #!GUI1.0
0
/Users/magdalena/egsnrc10/egsphant/patient_lung.egsphant
0.811, 0.005, 0
1, 0, 1,
-1, 8, -2.215, 3.374, -0.087 , 1,50, 0, 0, , , ,
94.00, 100.46, 1
2, 0, 1, 100, 0, 0, 0, 0
/Users/magdalena/egsnrc10/BEAM_slabs/200MeV3mm.egsphsp1
10000, 0, 500, 33, 97, 0, 0, 0, 0, 0, 0 , 0, 0, 0, 0, 0, 0
##########################
 :Start MC Transport Parameter:

 Global ECUT= 0.811
 Global PCUT= 0.005
 Global SMAX= 5
 ESTEPE= 0.25
 XIMAX= 0.5
 Boundary crossing algorithm= PRESTA-I
 Skin depth for BCA= 0
 Electron-step algorithm= PRESTA-II
 Spin effects= On
 Brems angular sampling= Simple
 Brems cross sections= BH
 Bound Compton scattering= On
 Compton cross sections= default
 Pair angular sampling= Simple
 Pair cross sections= BH
 Photoelectron angular sampling= On
 Rayleigh scattering= On
 Atomic relaxations= On
 Electron impact ionization= On
 Photon cross sections= xcom
 Photon cross-sections output= Off

 :Stop MC Transport Parameter:
 ######################
```

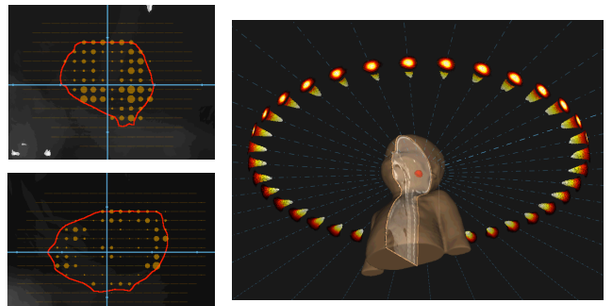
```
raysearch2                                                    #!GUI1.0
0
/Users/magdalena/egsnrc10/egsphant/patient_bigT1.egsphant
0.811, 0.005, 0
1, 0, 1,
-1, 8,-14.672,-5.256, -3.772 , 1,50, 0, 0, , , ,
89.79, 228.46, 1
2, 0, 1, 100, 0, 0, 0, 0
/Users/magdalena/egsnrc10/BEAM_slabs/200MeV3mm.egsphsp1
1000, 0, 500, 33, 97, 0, 0, 0, 0, 0, , 0, 0, 0, 0, 0
##########################
 :Start MC Transport Parameter:

 Global ECUT= 0.811
 Global PCUT= 0.005
 Global SMAX= 5
 ESTEPE= 0.25
 XIMAX= 0.5
 Boundary crossing algorithm= PRESTA-I
 Skin depth for BCA= 0
 Electron-step algorithm= PRESTA-II
 Spin effects= On
 Brems angular sampling= Simple
 Brems cross sections= BH
 Bound Compton scattering= On
 Compton cross sections= default
 Pair angular sampling= Simple
 Pair cross sections= BH
 Photoelectron angular sampling= On
 Rayleigh scattering= On
 Atomic relaxations= On
 Electron impact ionization= On
 Photon cross sections= xcom
 Photon cross-sections output= Off

 :Stop MC Transport Parameter:
 ######################
```

EGSnrc

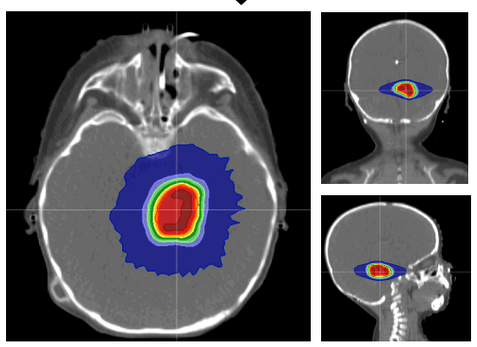


running MC simulations for all beamlets

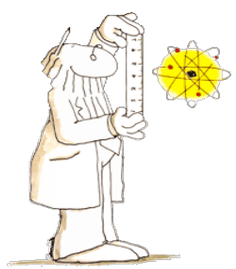
RayStation



spot scanning optimization



final dose distribution



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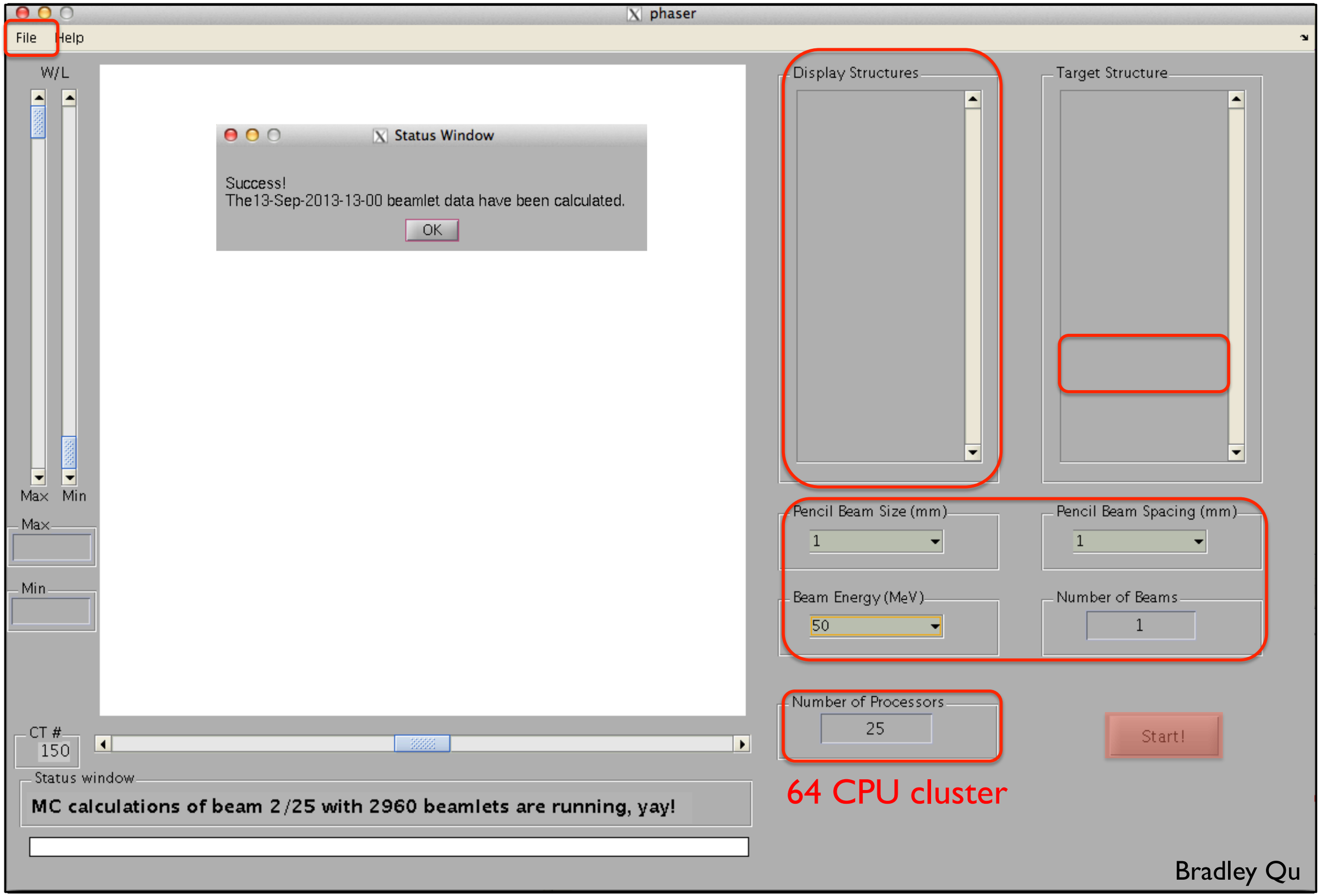
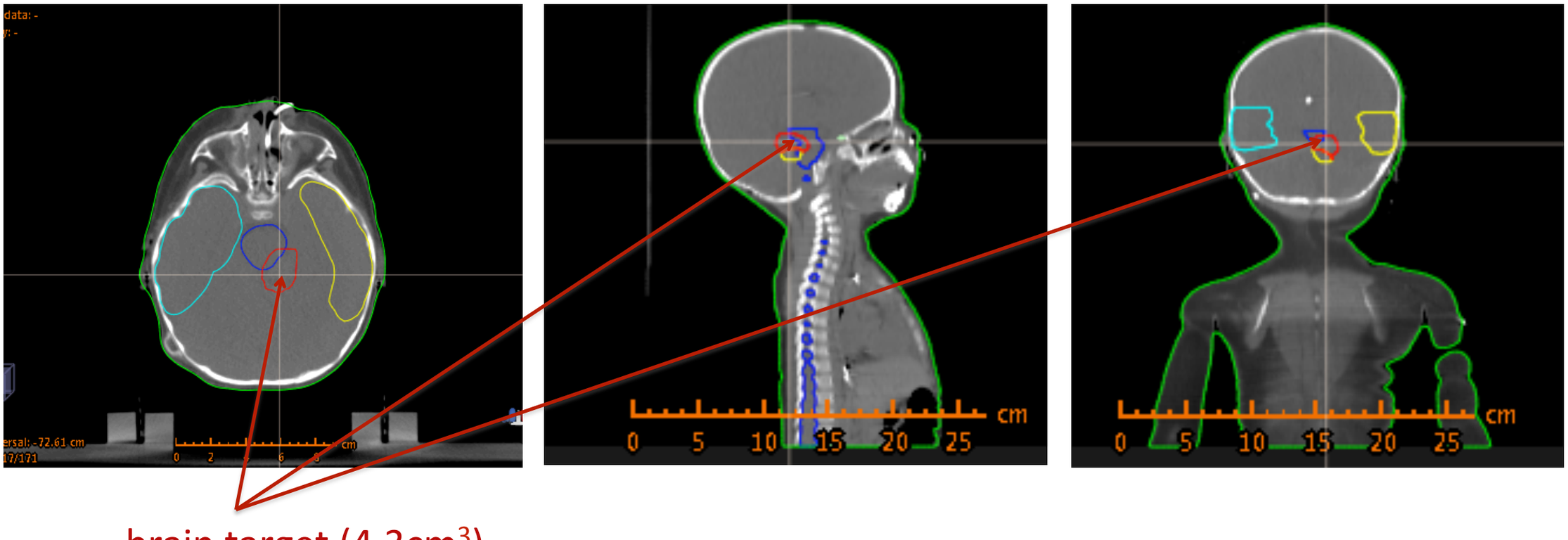
GUI pro MC počítání dávky



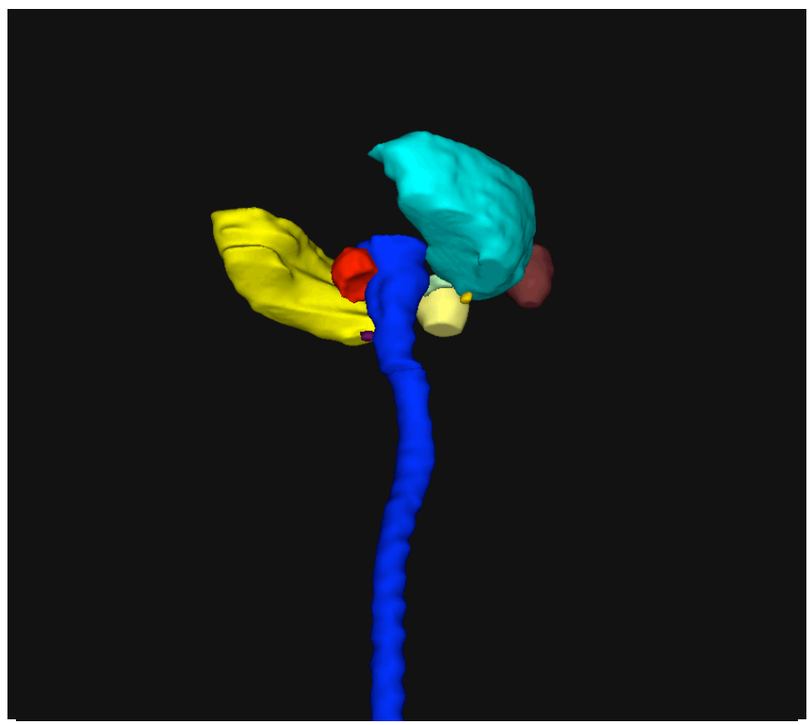
64 CPU cluster

Bradley Qu

Pediatrický pacient



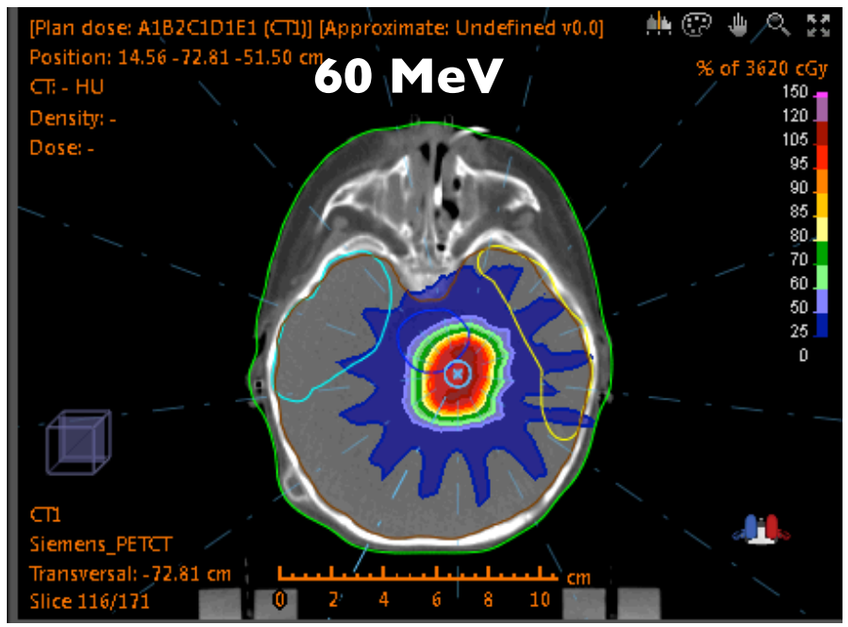
brain target (4.3cm^3)

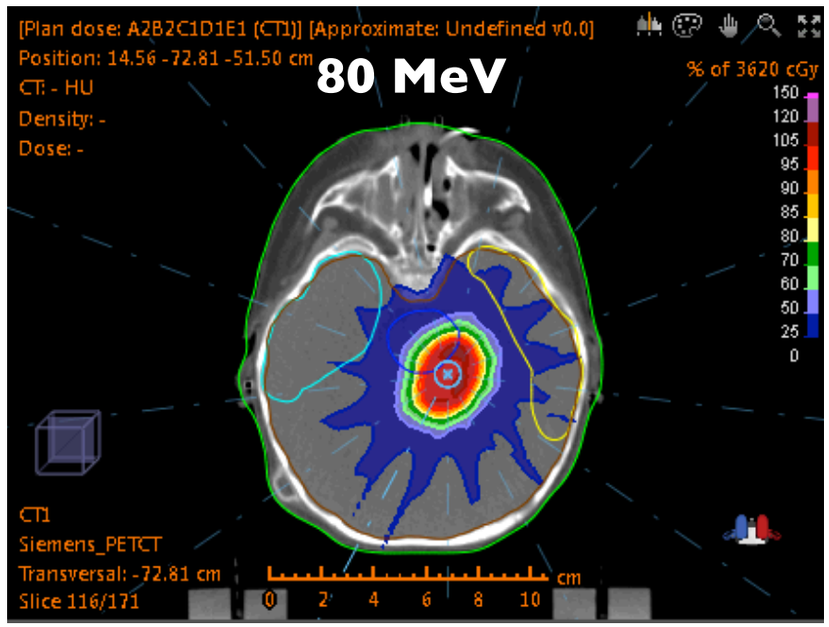


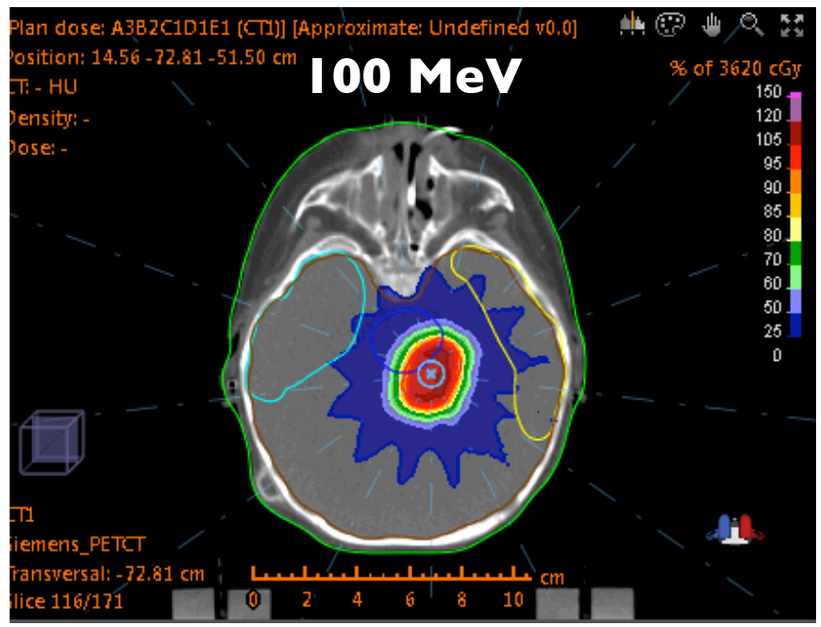
- Pet parametru VHEE systemu bylo studovano
  - **energie svazku**
  - **pocet svazku (uhlu)**
  - **polomer ‘tunelu’**
  - **rozestup uzkych svazku**
  - **velikost uzkych svazku**

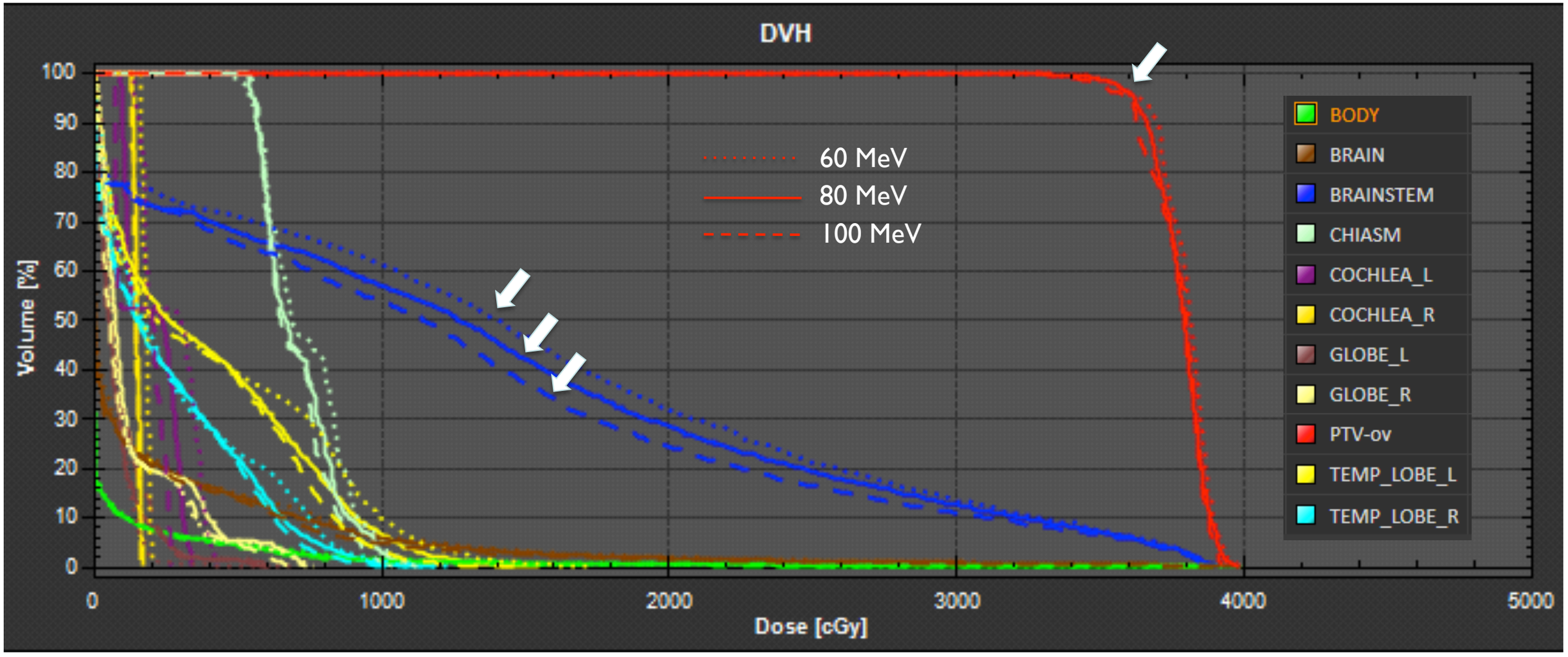
- VHEE plany s ruznymi parametry byly porovnany
- VHEE plan porovnan s klinickym VMAT planem

Energie svazku

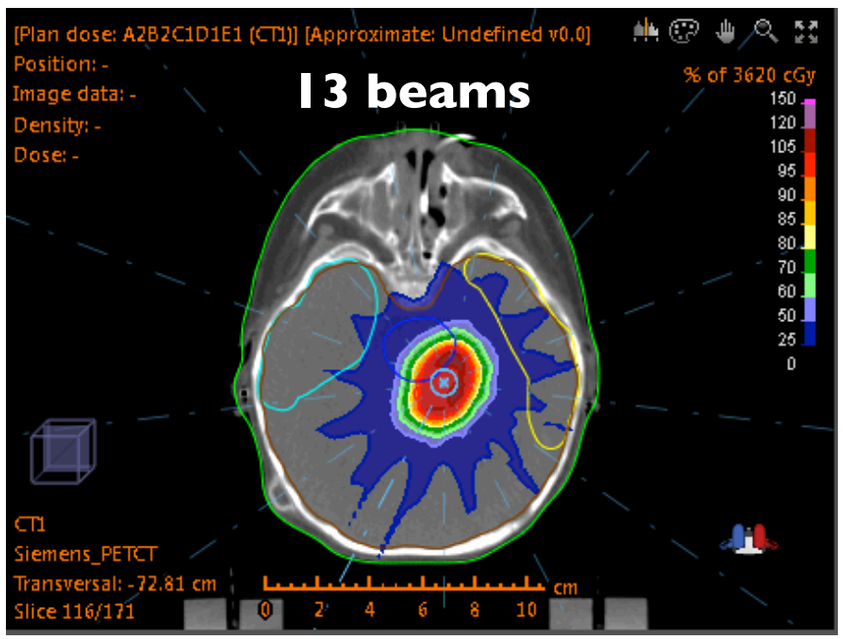


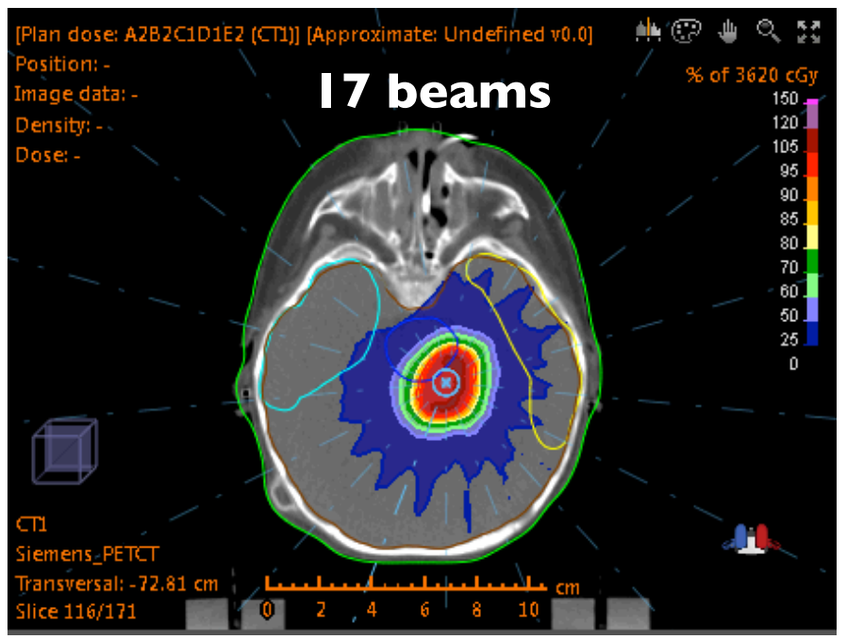


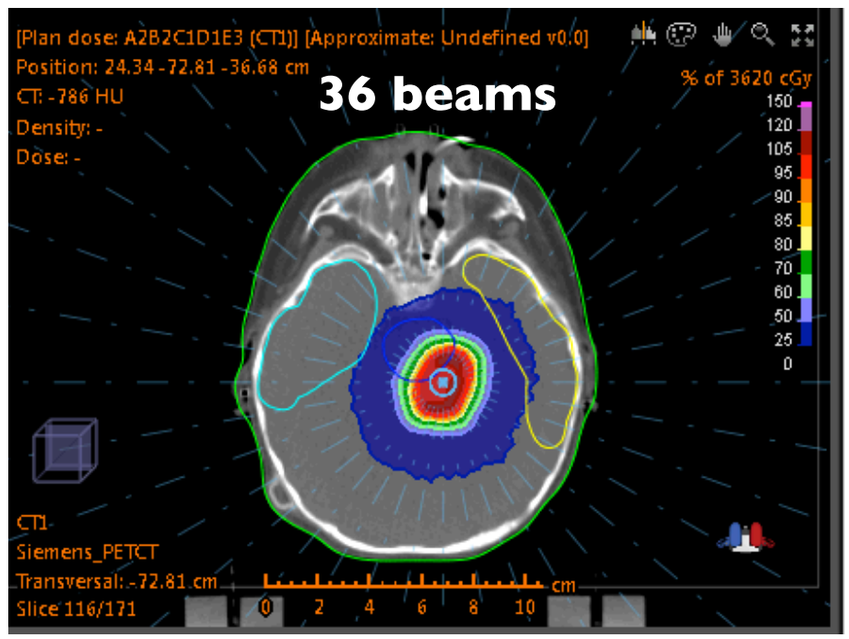


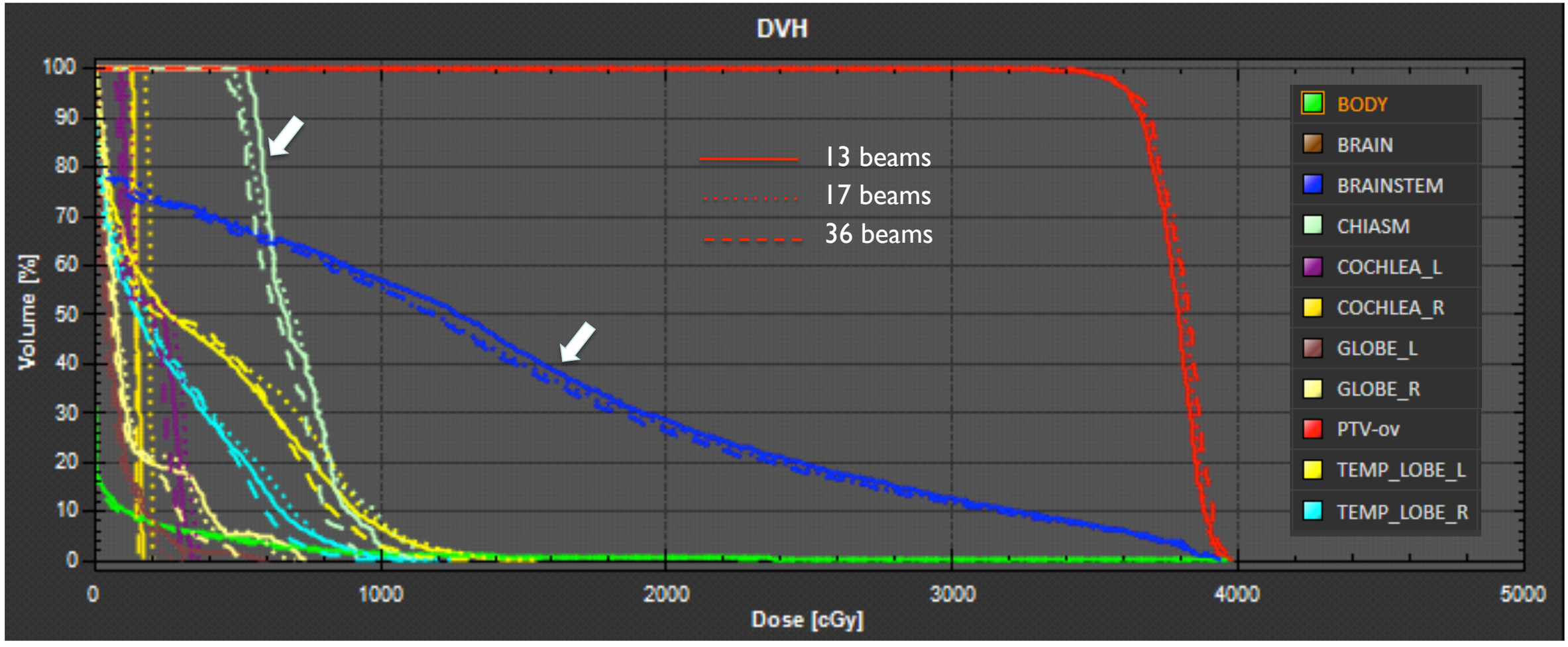


Počet svazků (úhlů)

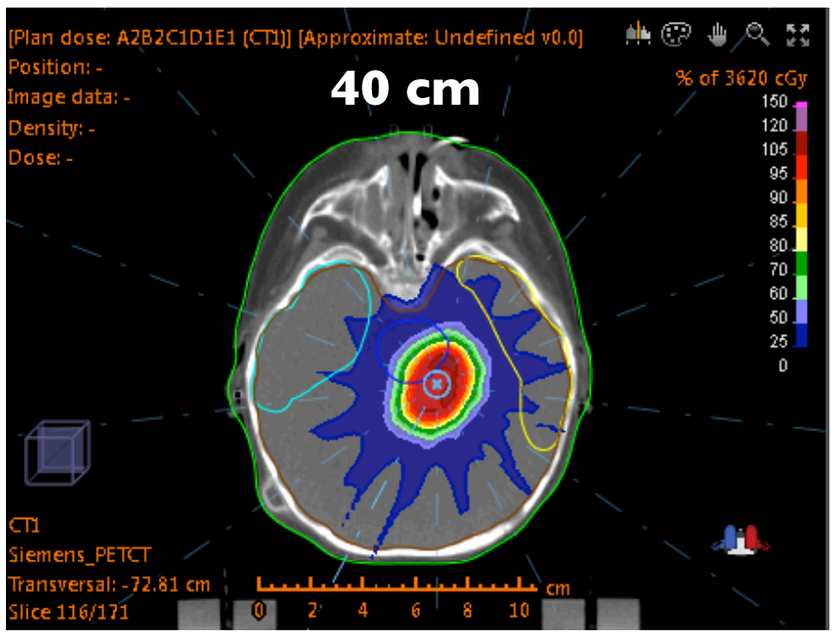


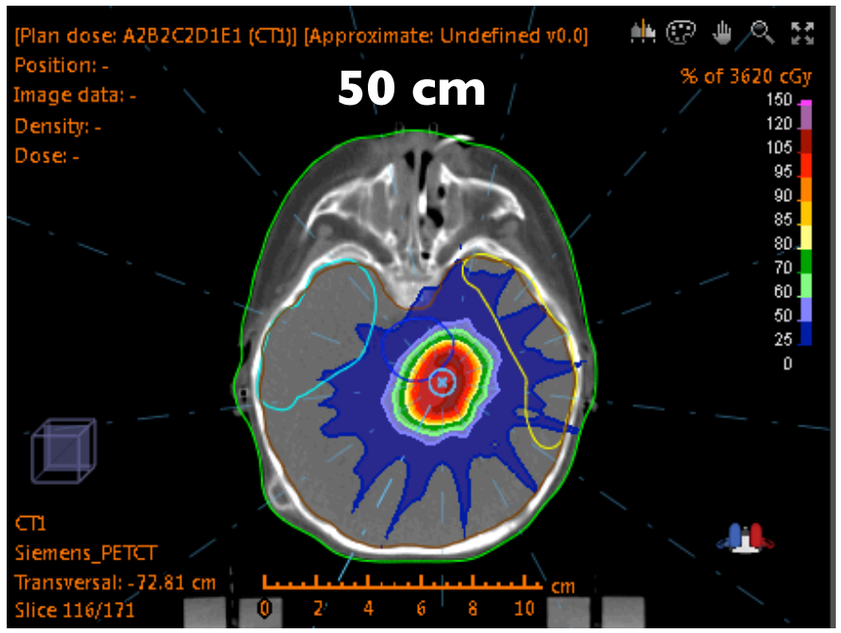


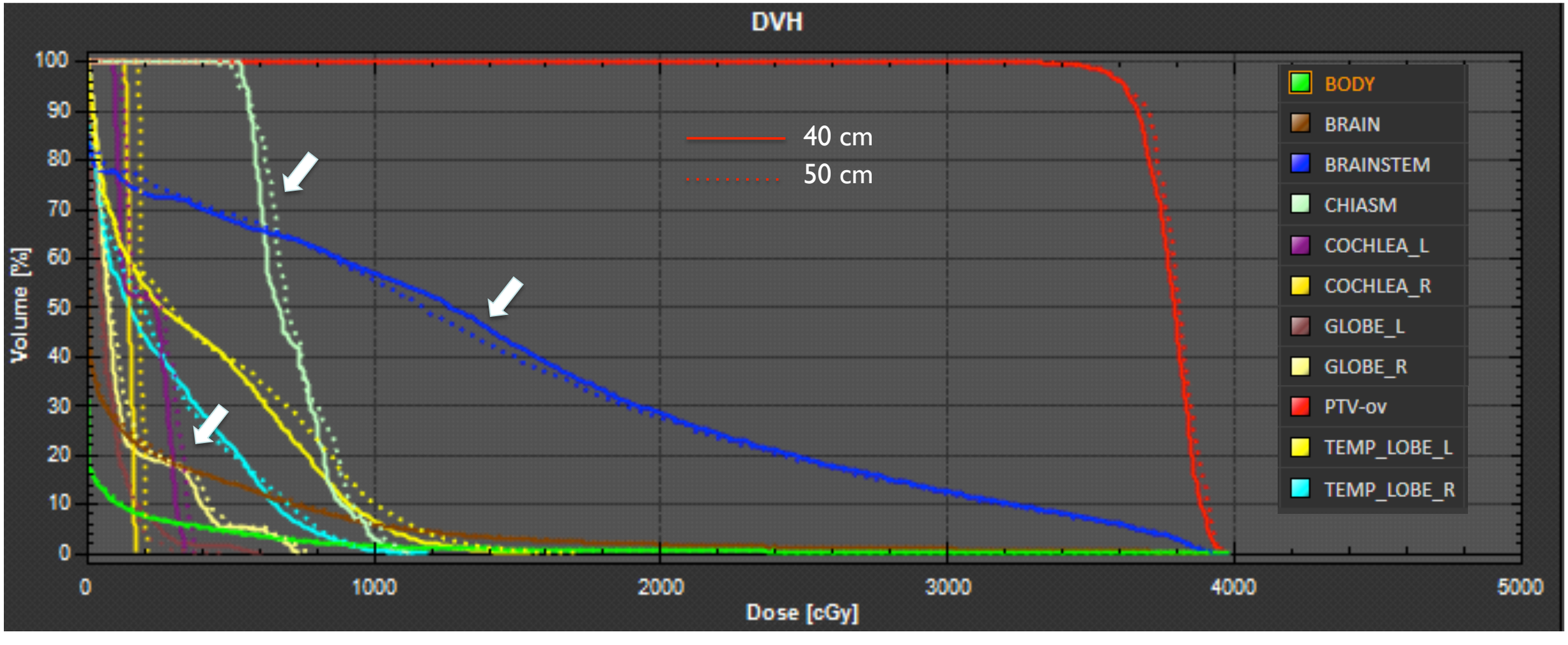




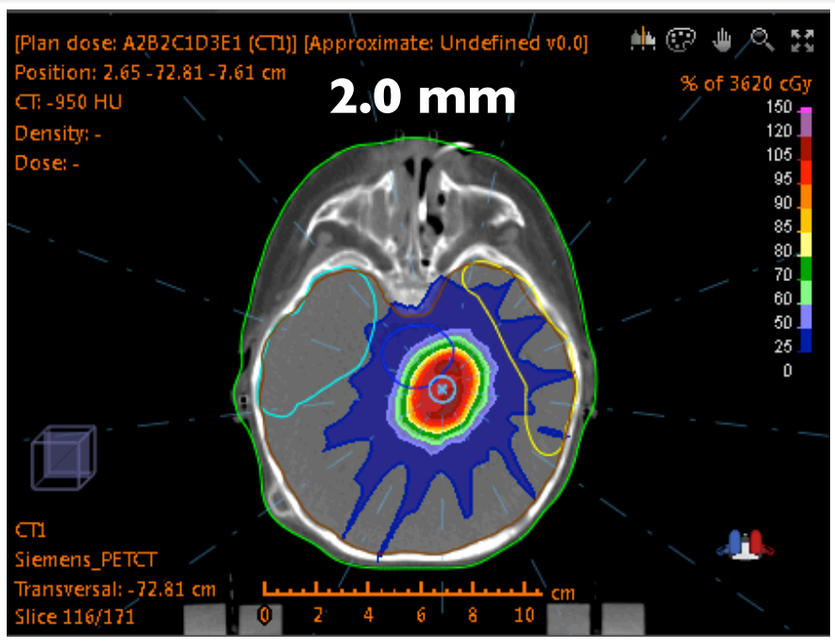
Poloměr ‘tunelu’

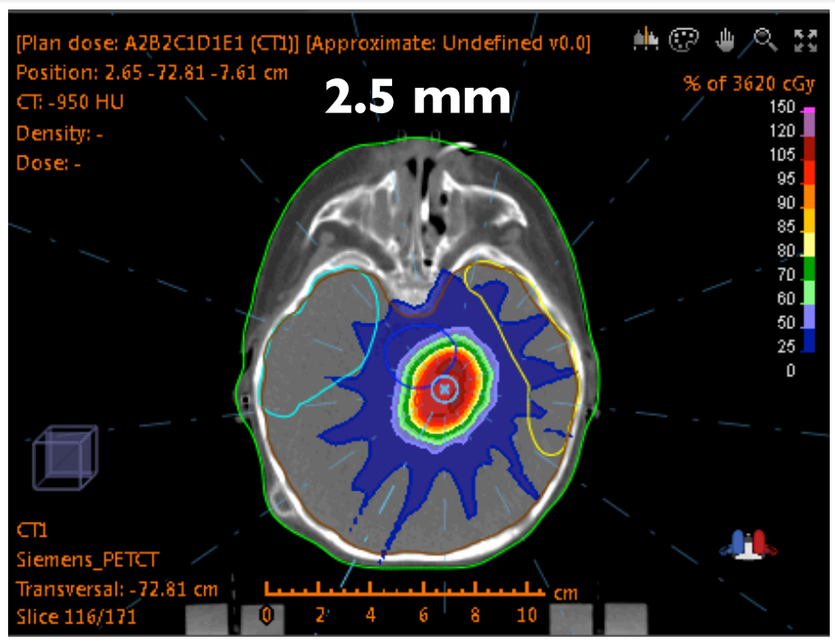


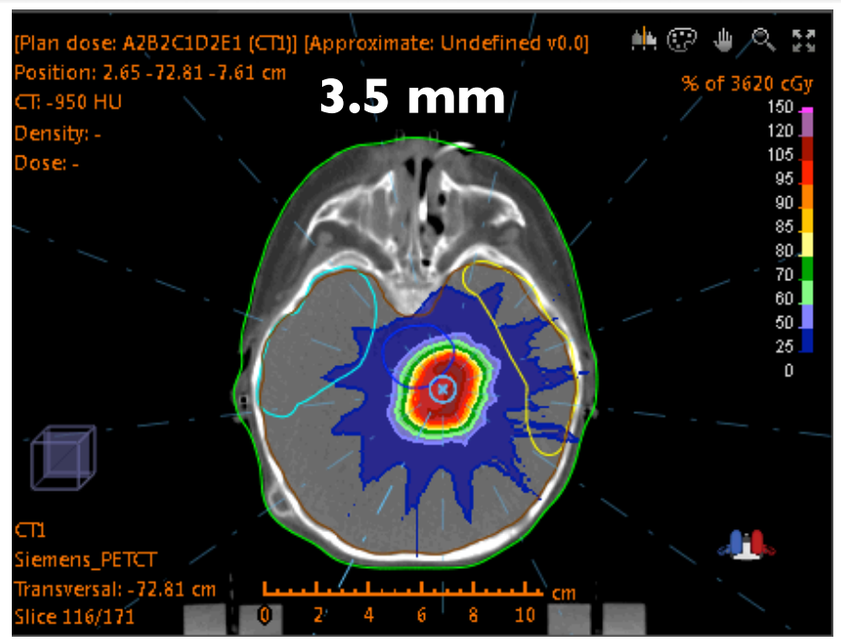


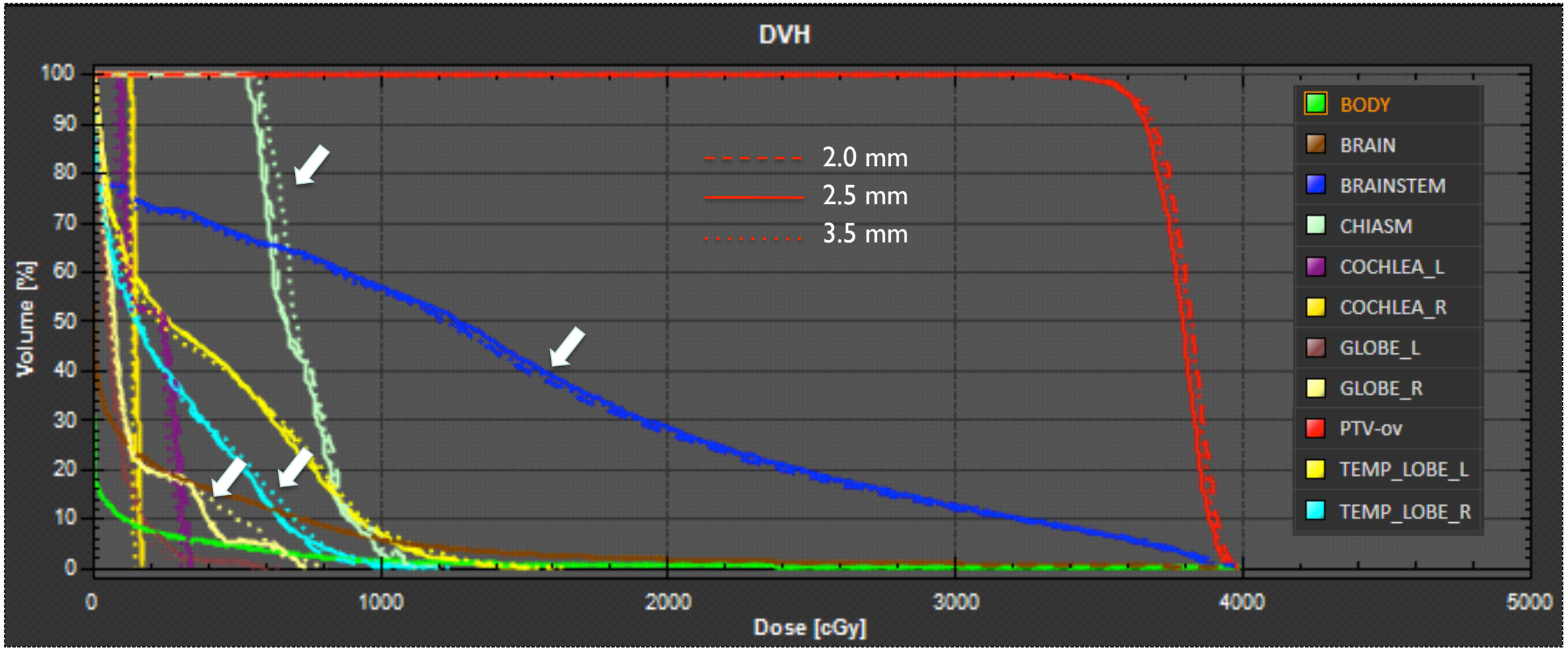


Rozestup úzkých svazků

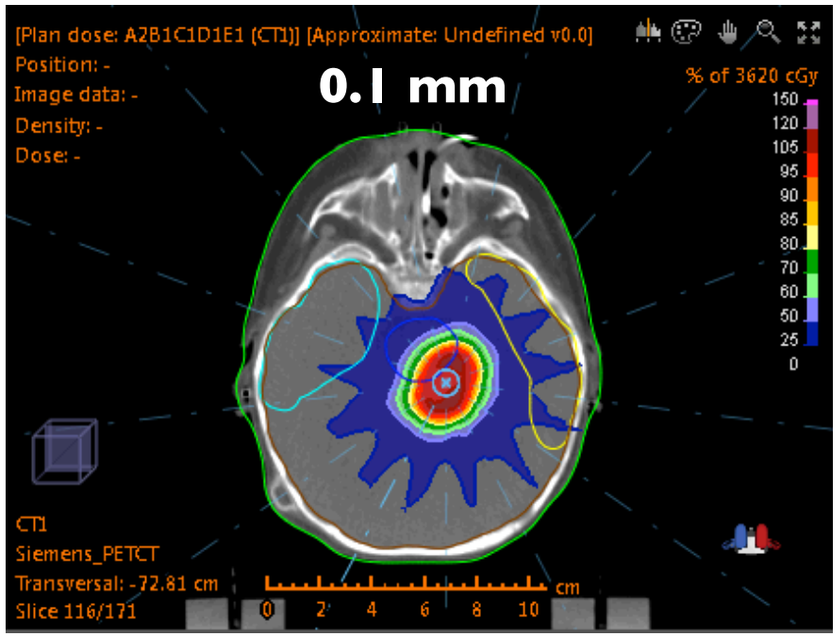


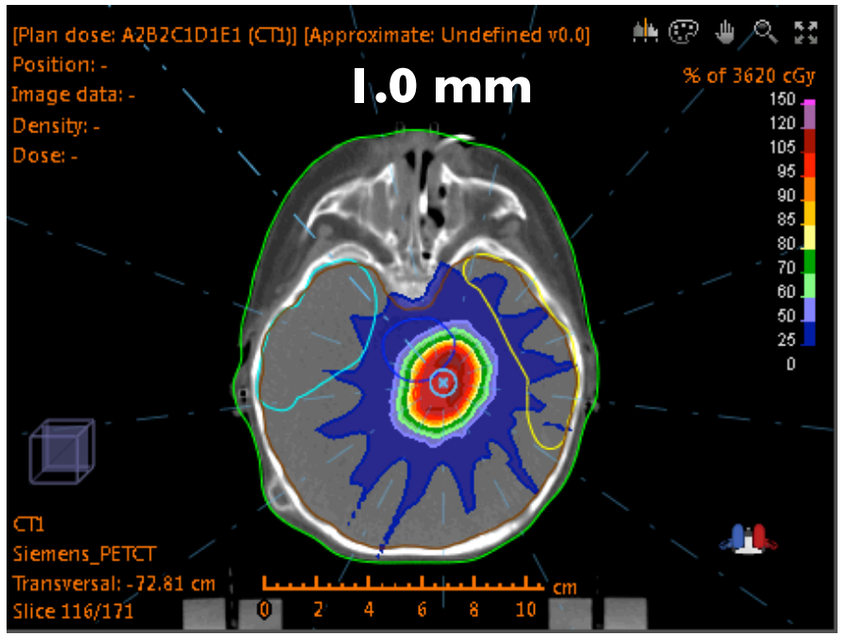


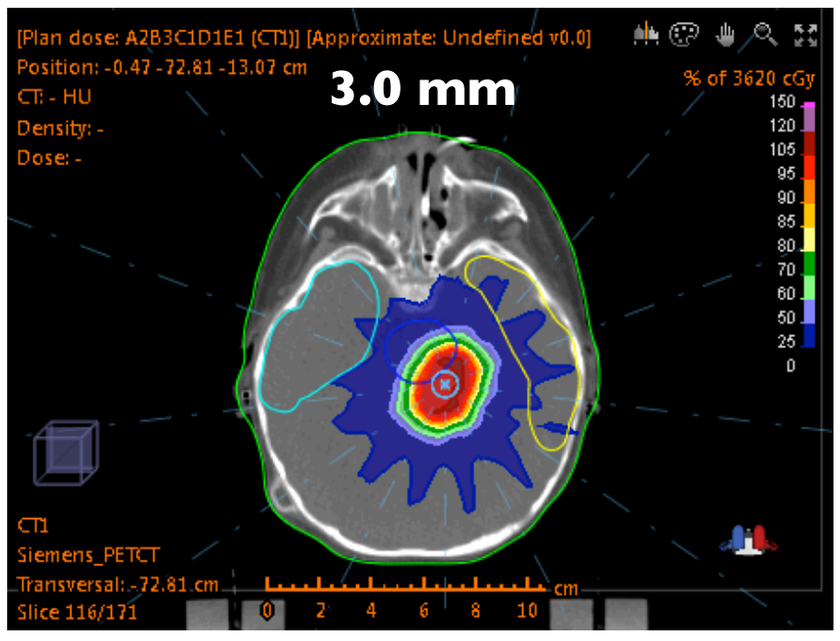


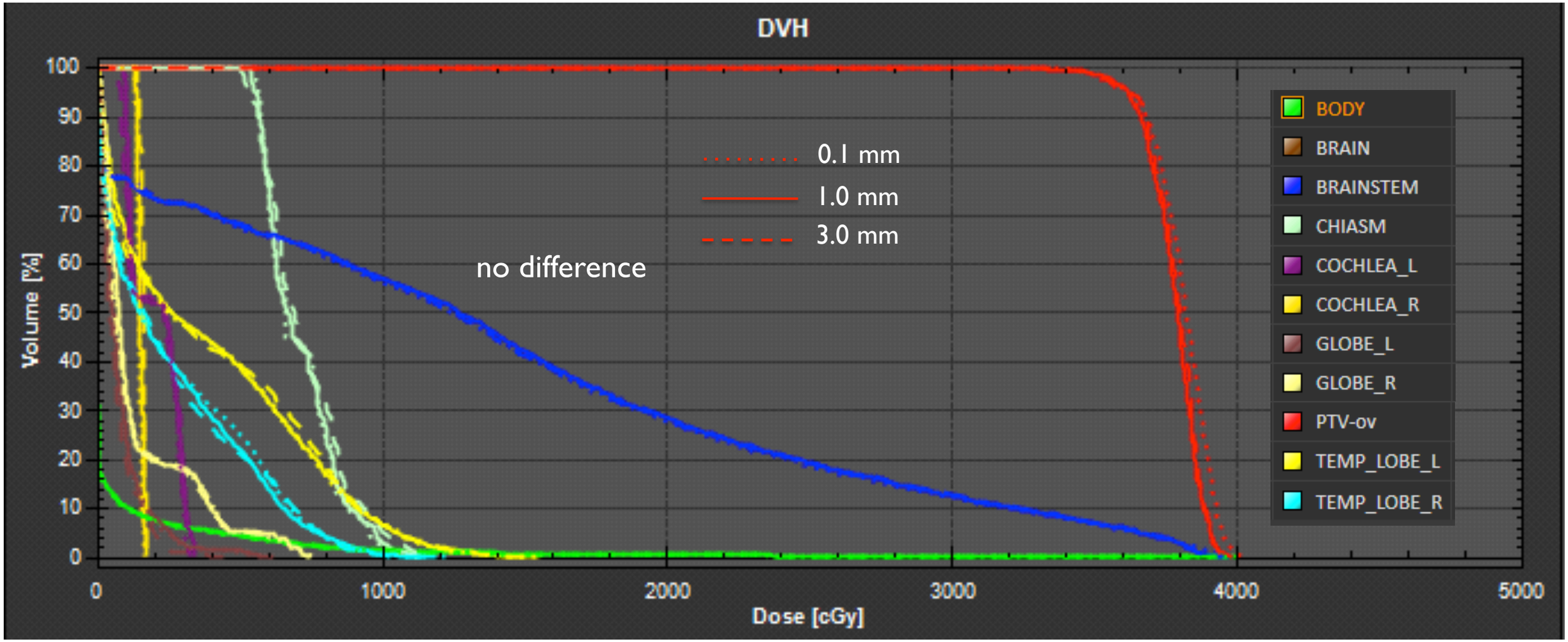


Velikost úzkých svazků

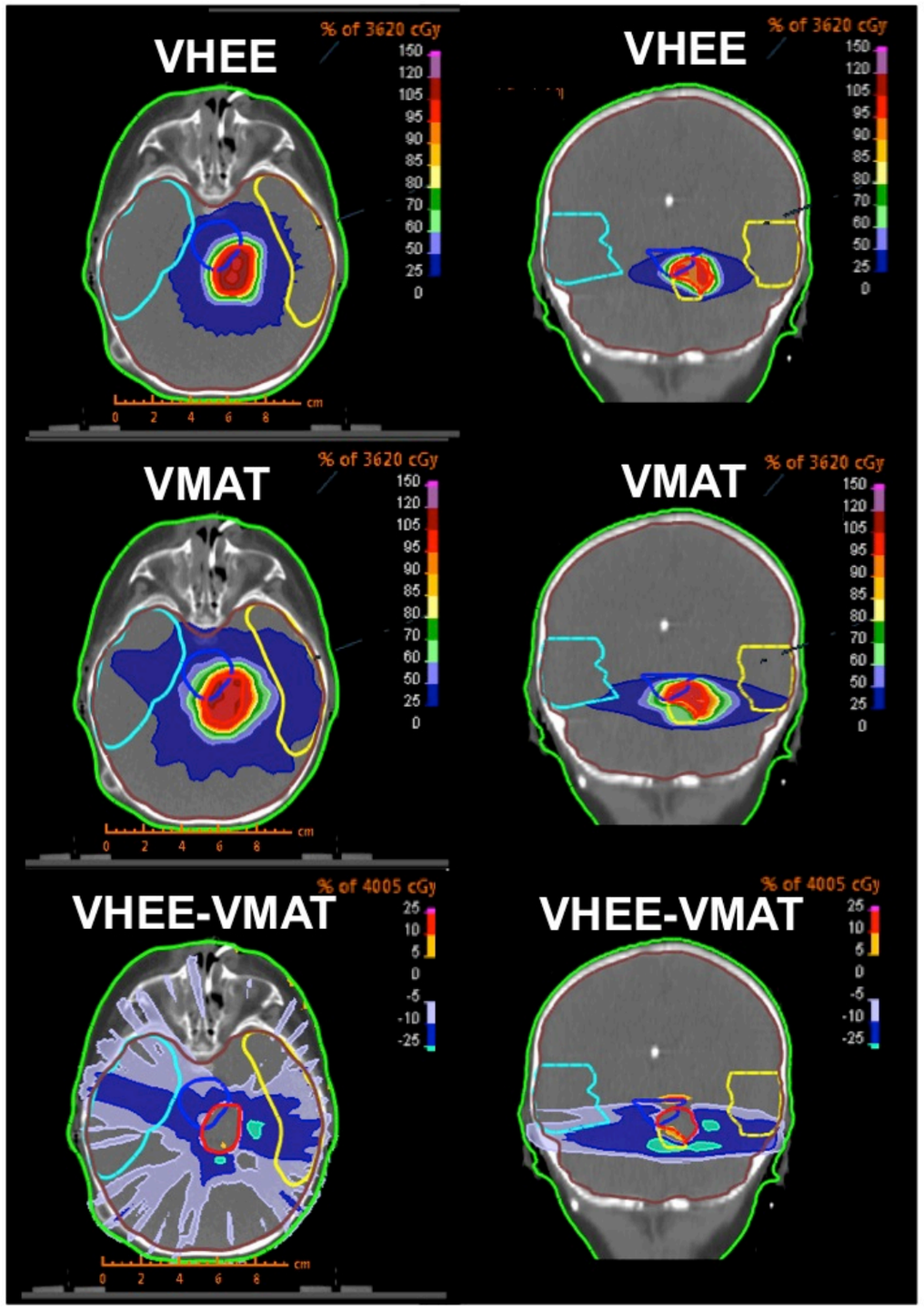


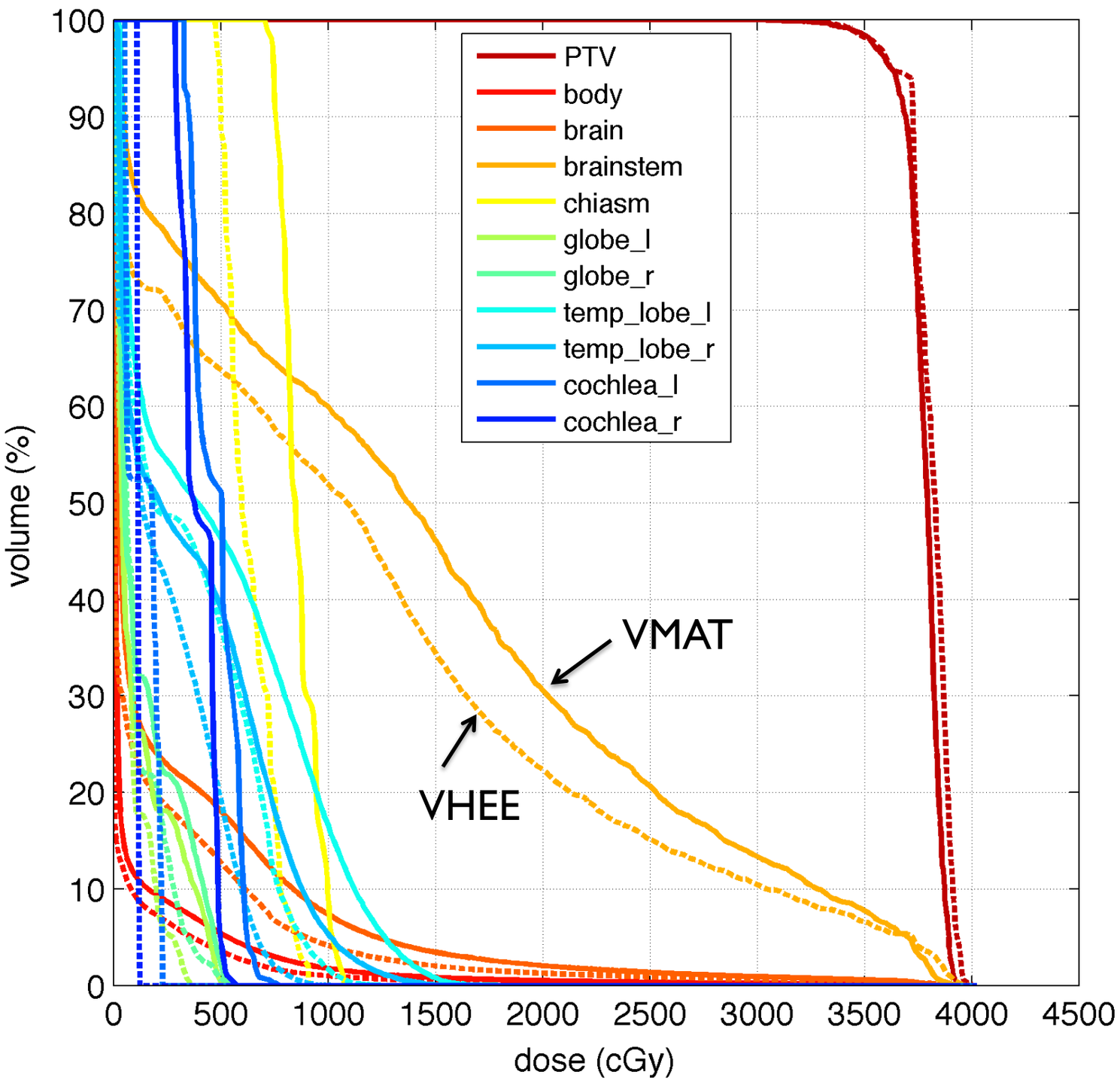






Porovnání s VMAT





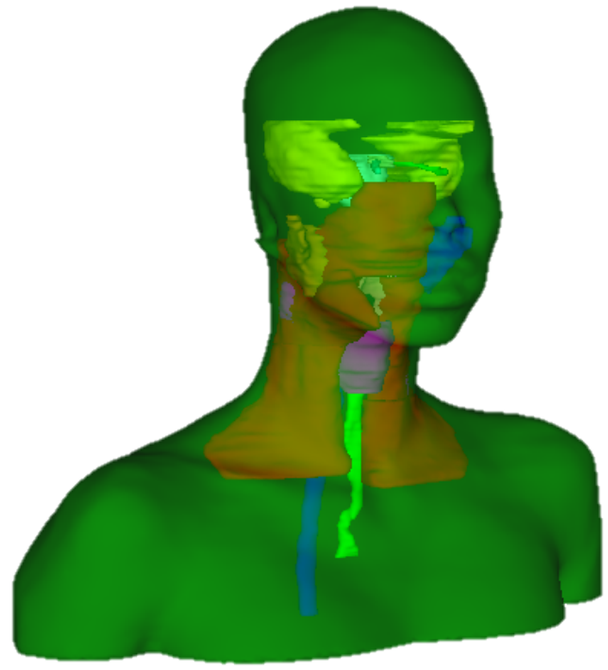
VHEE ozarovaci doba (10 tisic svazku): **1 s** pro 3620 cGy

Studie s dospělými pacienty

Panev

967cm^3 PTV
$D_{90\%}$ = 5000 cGy
2-arc 15 MV VMAT

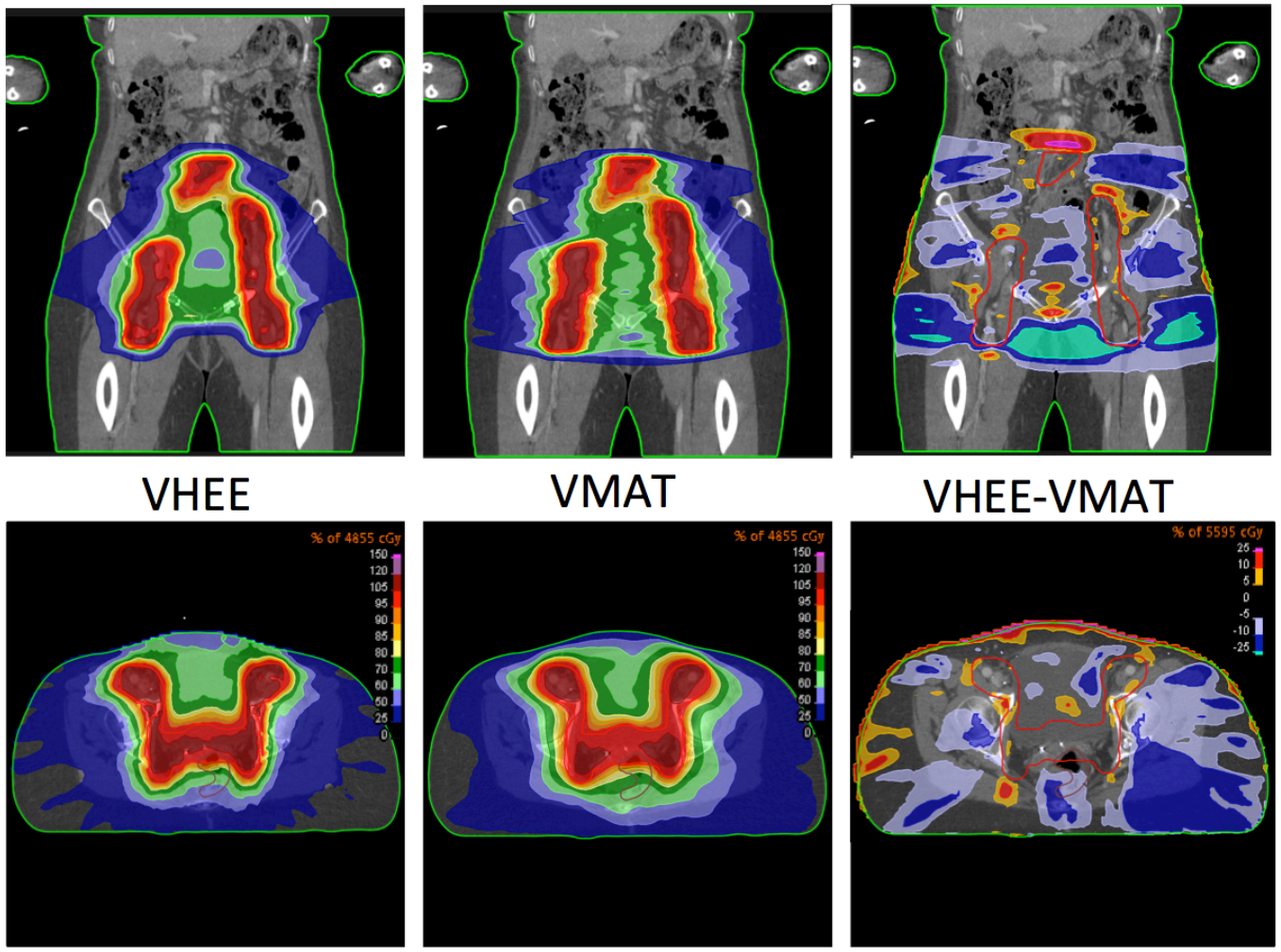
Hlava a krk

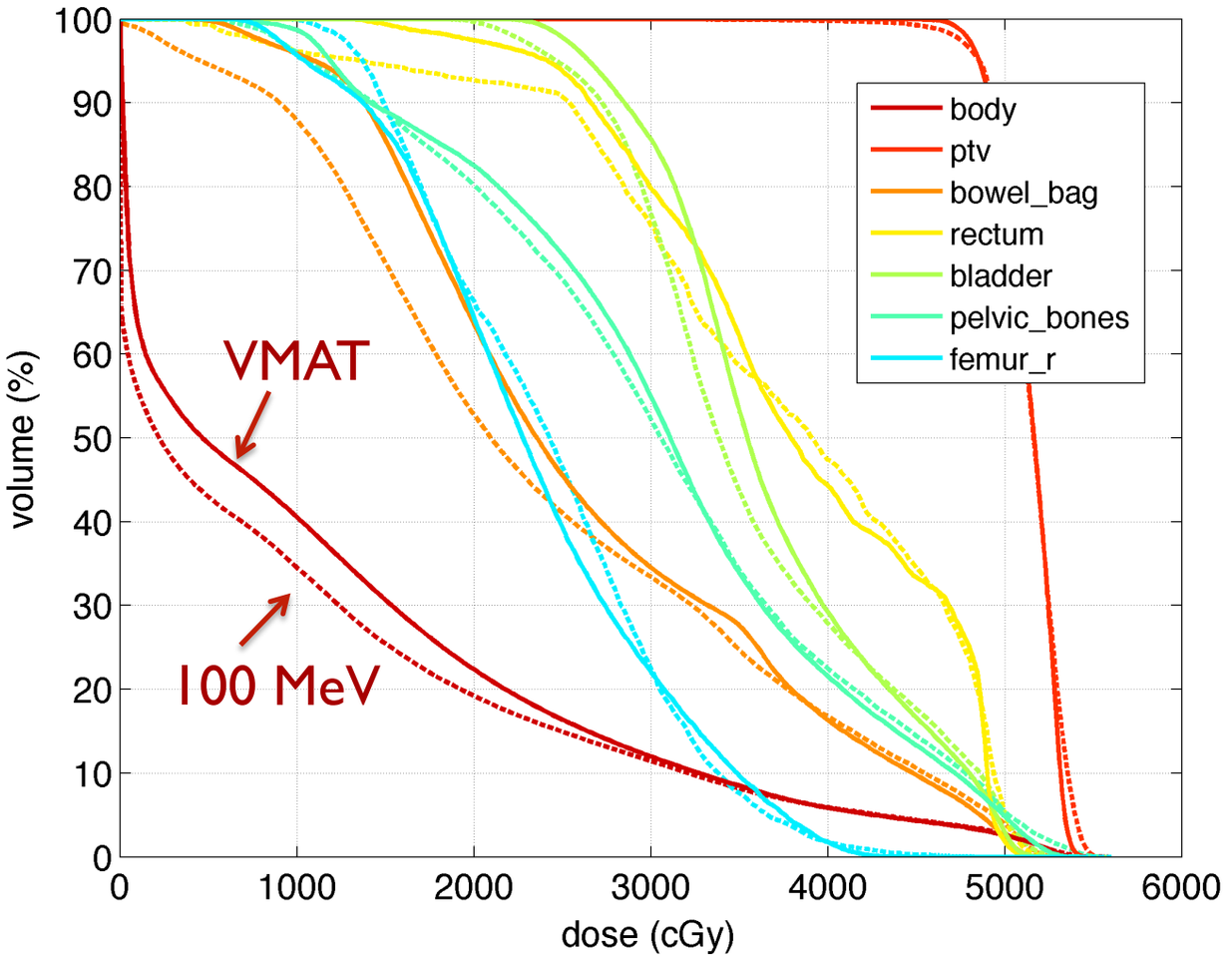


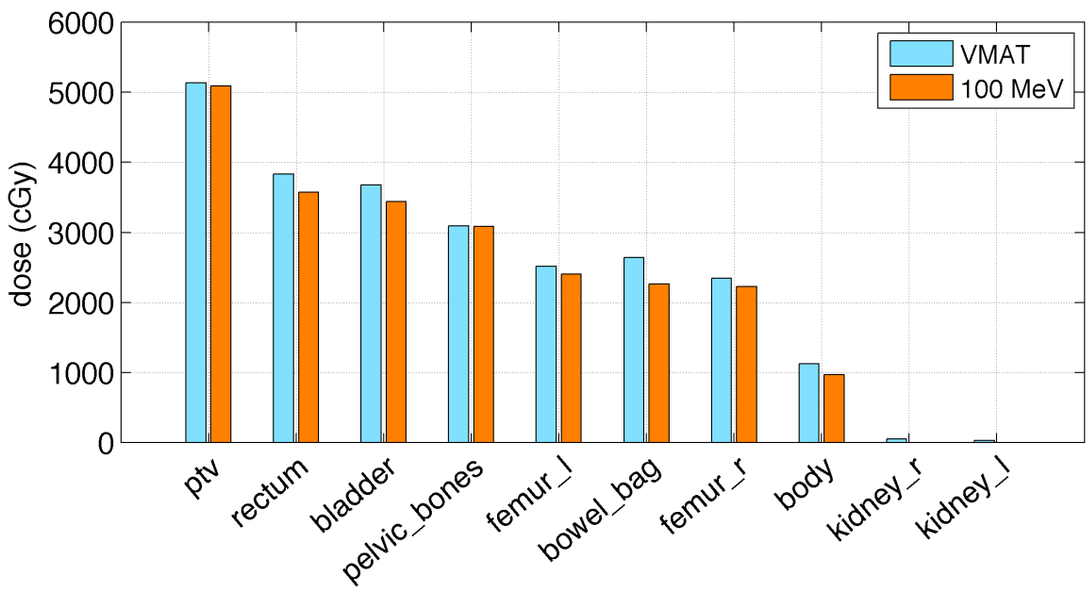
531cm^3 total PTV volume
4 prescription levels $D_{90\%}$ 52-70 Gy
4-arc 6 MV VMAT

Beam energy (MeV)	50	80	100	120	150
Beamlet size/spacing (mm)	3/3	5/5	7/7		
Number of beams	16	25	36		

VHEE a VMAT - pánev

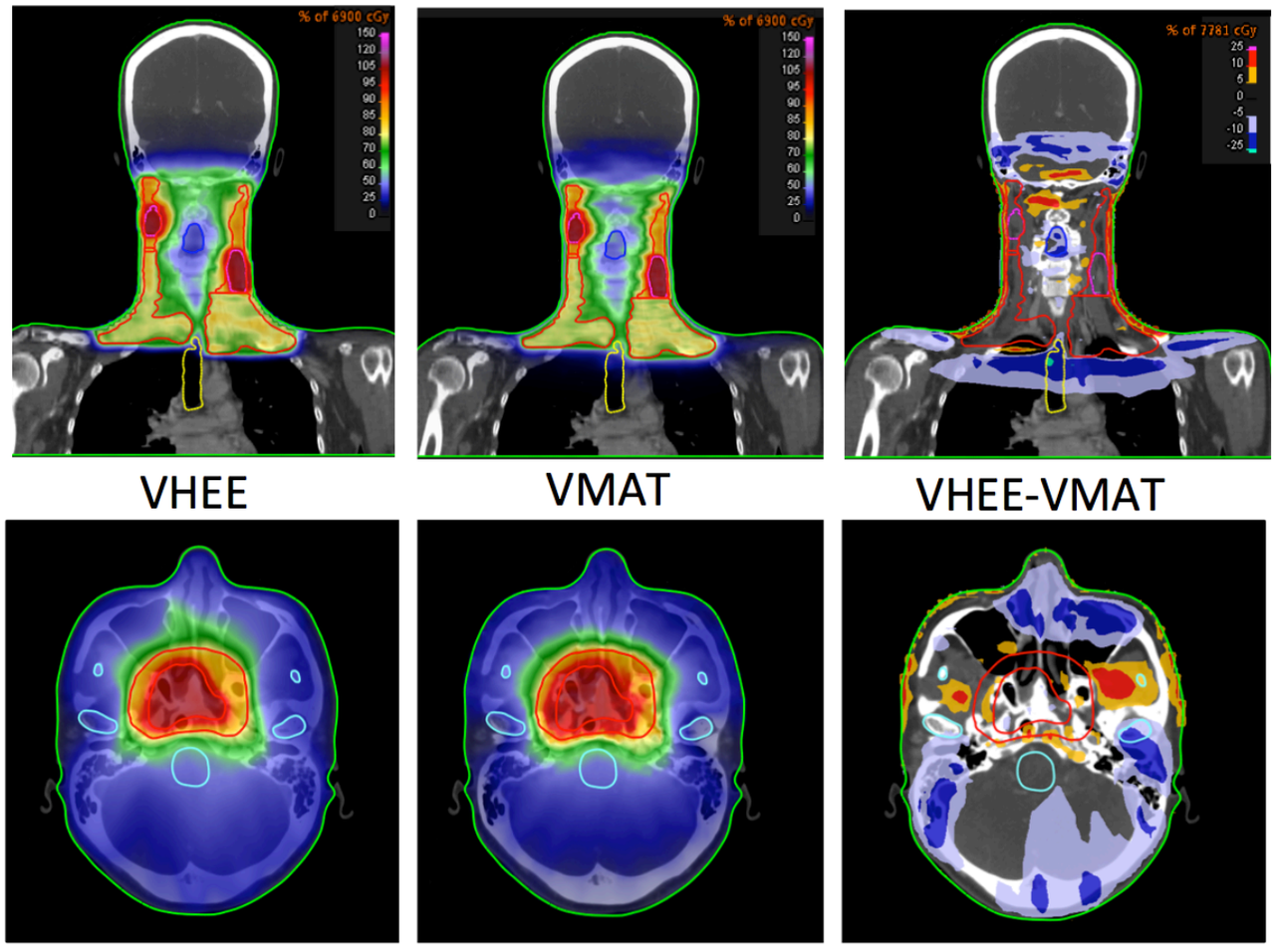


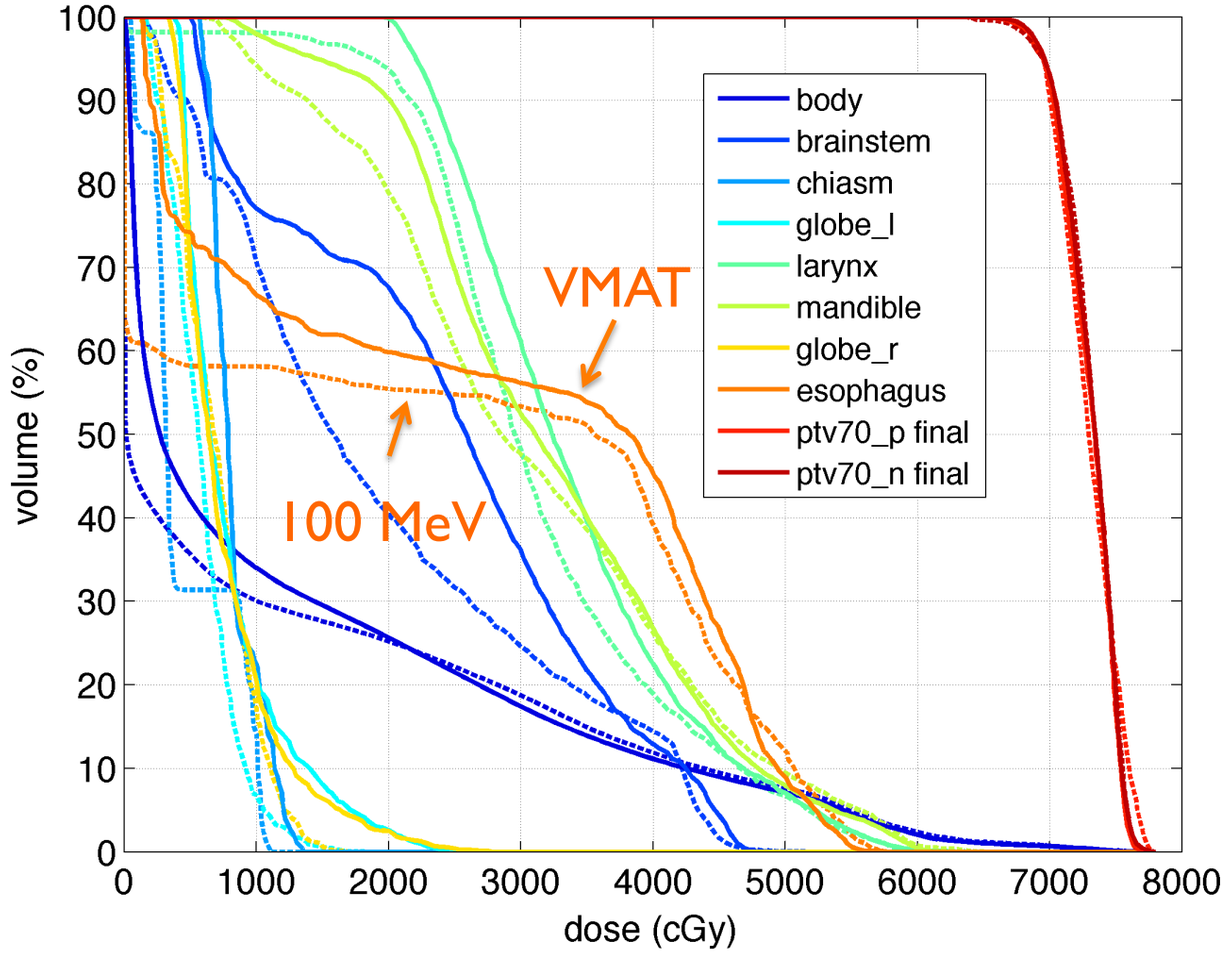


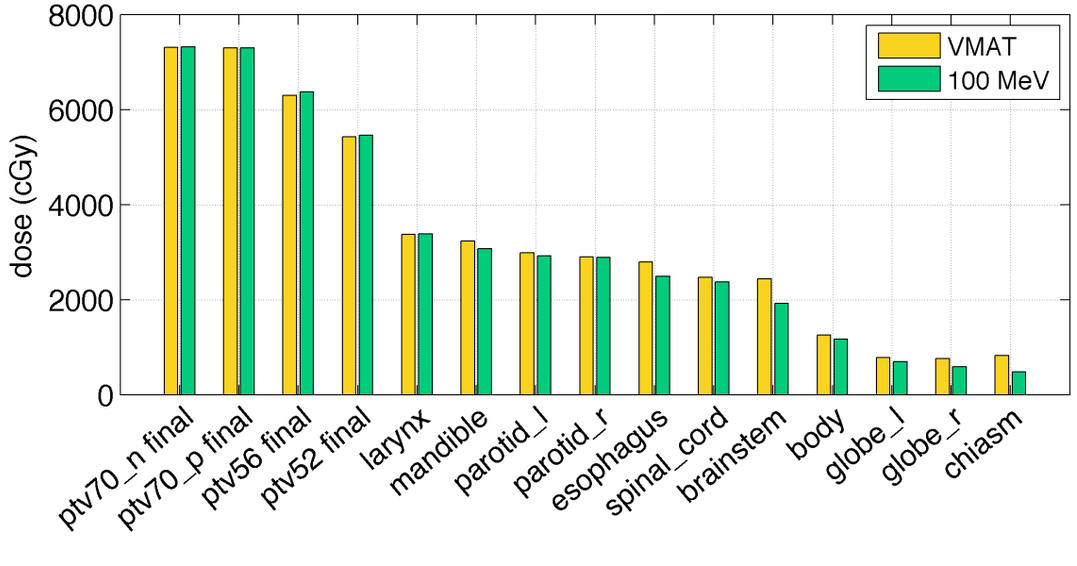


- 25 100 MeV svazku s 5 mm rozestupy
- **~1.6e12** elektronu pro davku 5,000 cGy
- Celkem uzkych svazku: **31,300**
- Doba ozarovani: ~3.1 s

VHEE a VMAT – hlava a krk

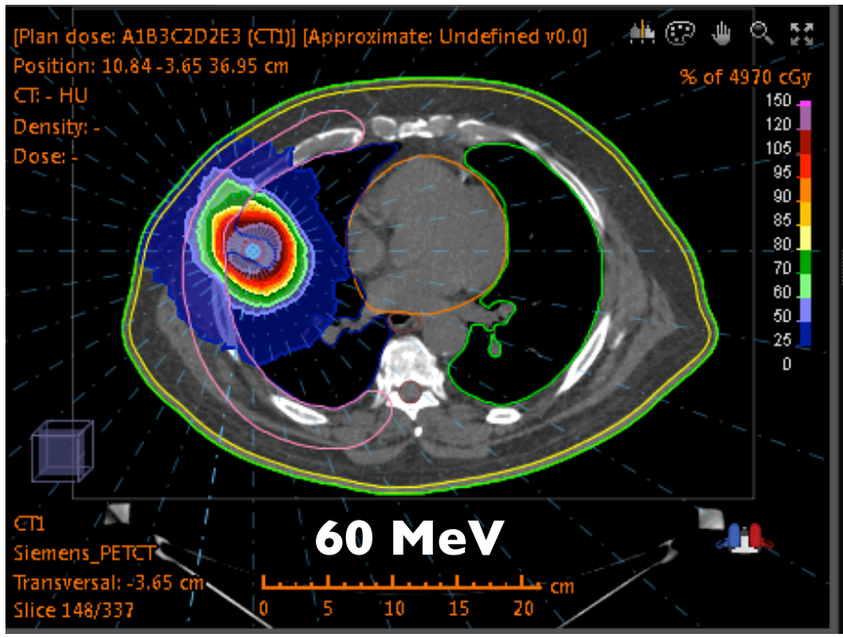


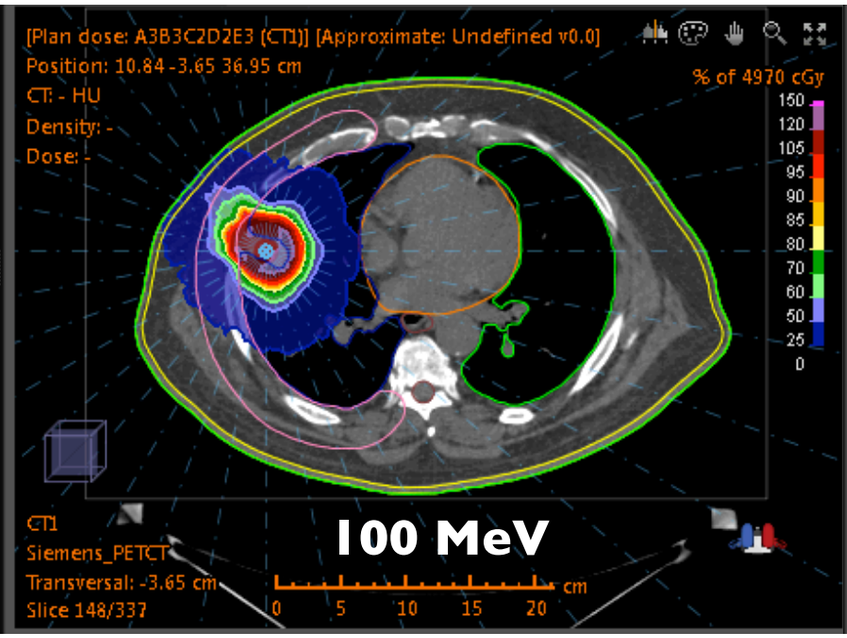


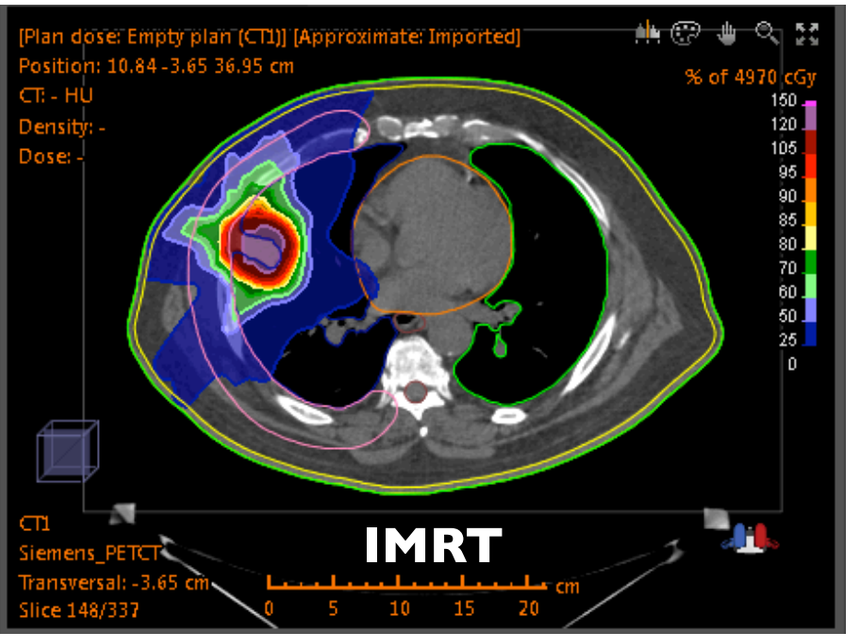


- 25 100 MeV svazku s 5 mm rozestupy
- **~1.3e12** elektronu pro davku 7,000 cGy
- Celkem uzkych svazku: **25,400**
- Ozarovaci doba: ~2.5 s

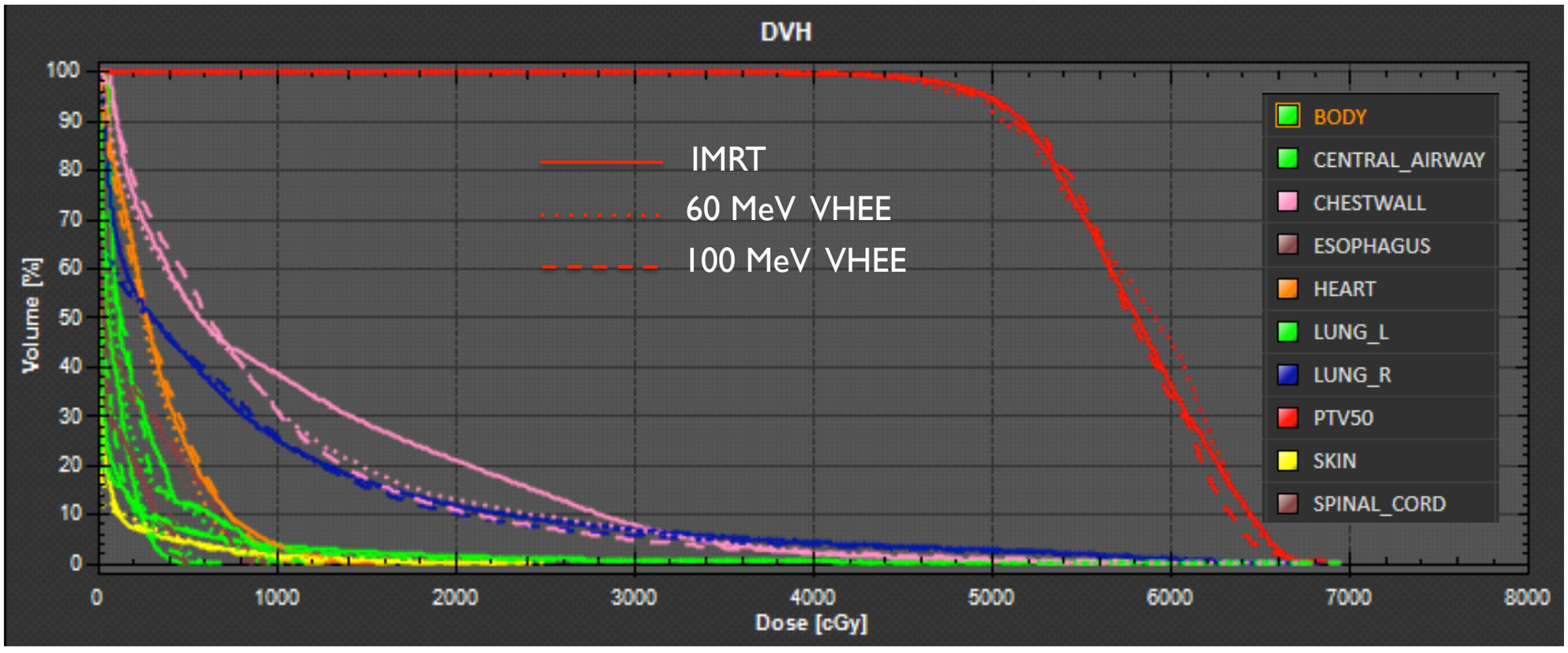
VHEE a IMRT - plíce

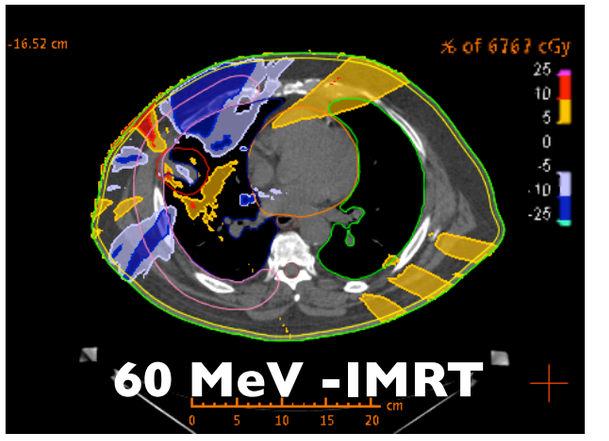


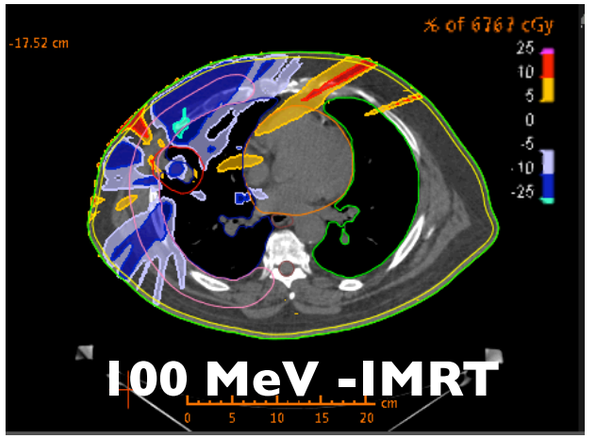




PTV objem: 88 cm³ Pacient vazi 100 kg







Závěr

- Monte Carlo simulace pro pocitani davky dorucene svazky elektronu s vysokymi energiemi byly overeny na SLAC NLCTA.
- 8 cm^3 nador na plicich by mohl byt ozaren 100 MeV elektrony davkou 10 Gy za 1.3 s.
- Optimizace VHEE planu v RayStation dosahla lepsich davkovych rozlozeni nez VMAT.
- Predbezne *in vitro* naznacuji, ze rakovinove bunky umiraji rychleji, jsou-li ozareny vysokymi davkovymi prikony.

Dekuji za pozornost