



Klinikum rechts der Isar  
Technische Universität München



## EUD-based Biological Optimization for Carbon Ion Therapy

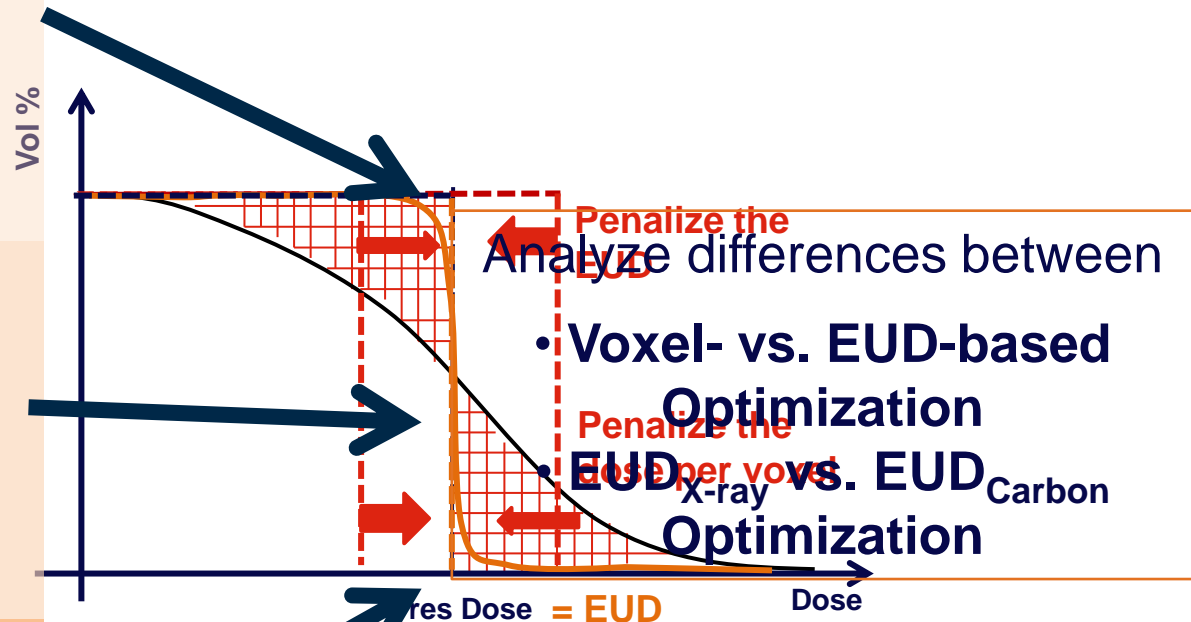
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# Motivation – Enable EUD-based optimization for carbon ion therapy

1 EUD concept for carbon ion therapy

2 Choose objective function

3 Implementation into 3D TPS



# EUD Concept for Carbon Ion Therapy – Equivalent Uniform Effect (EUE)

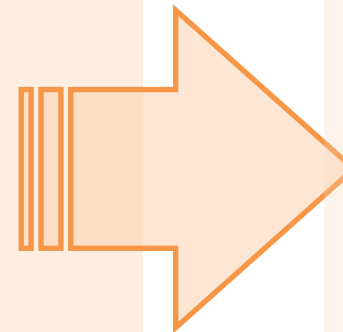
$$EUE = \left( \frac{1}{N} \sum_{i=1}^N E_i^{a'} \right)^{1/a'}$$

$N$  Number of voxel  
 $E_i$  Biological effect in voxel  $i$   
 $E_i = \alpha_{p,i} D_i + \beta_{p,i} D_i^2$   
 $a'$  **Parameter of the Effect-Volume dependence**

- Power mean indicating the effect on the organ as a whole
  - Serial (high  $a'$ ) vs. parallel (small  $a'$ ) organs
- Tumor: Equivalent number of surviving clonogenes

$$S(\{E_i\}) = S(EUE)$$

- OAR: Equivalent NTCP
  - The choice of  $a'$  strongly influences the EUE value



Derive an appropriate description of  $a'$  or use as **fictitious** parameter to **steer** the optimization

## Objective functions

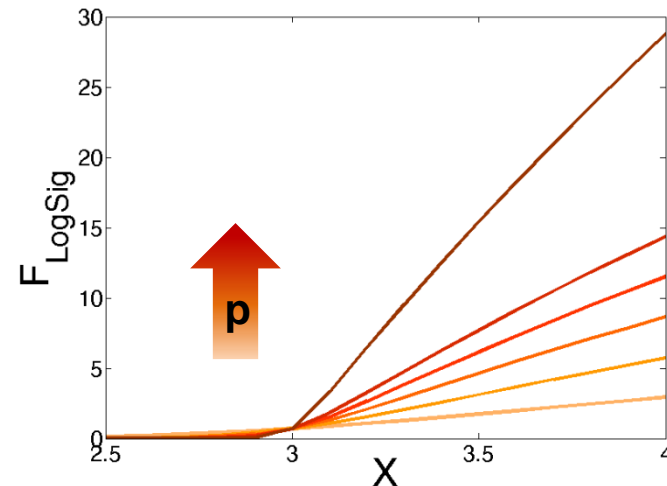
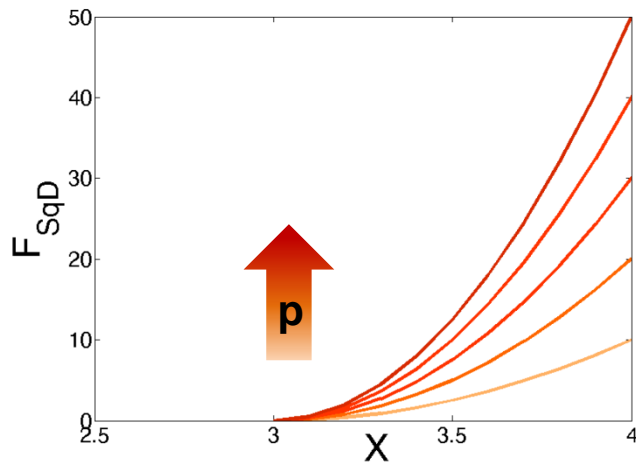
### Sum of Squared Differences (SqD)

$$F_{\text{SqD}} = \sum_s p_s [X - X_{\text{max}}]_+^2$$

### Sum of Log-Sigmoids\* (LogSig)

$$F_{\text{LogSig}} = -\sum_s \log\left(\frac{1}{1 + \left(\frac{X}{X_{\text{tol}}}\right)^{p_s}}\right)$$

**S** Voxel, structures    **X** Dose, biological effect, EUD or EUE    **p** Penalty term



- Need to **prescribe unreachable goal**
- Difficult to set penalties

- Optimizes **beyond the prescribed value** with less priority
- Prescribe max/min tolerable doses

\* Wu Q. et al, 2002, Int. J. Radiat. Oncol. Biol. Phys. 52 224–35

## Voxel- vs. EUD-based objectives

Patient: Head and neck,  
70.4 Gy in PTV, 32 fractions

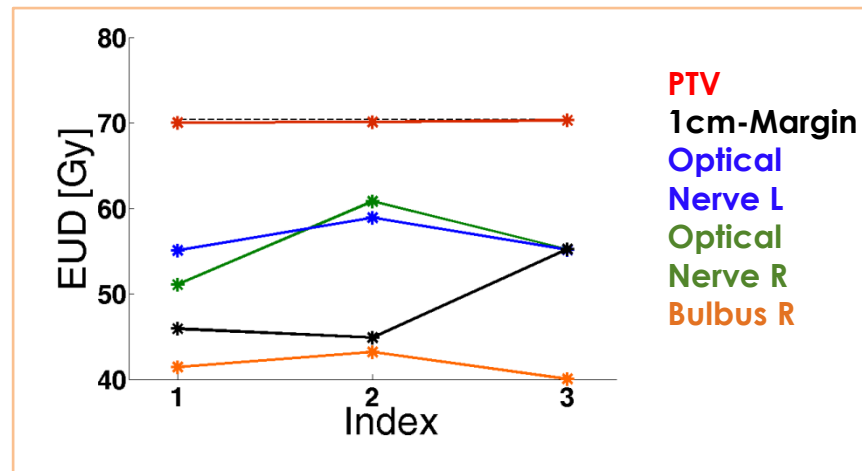
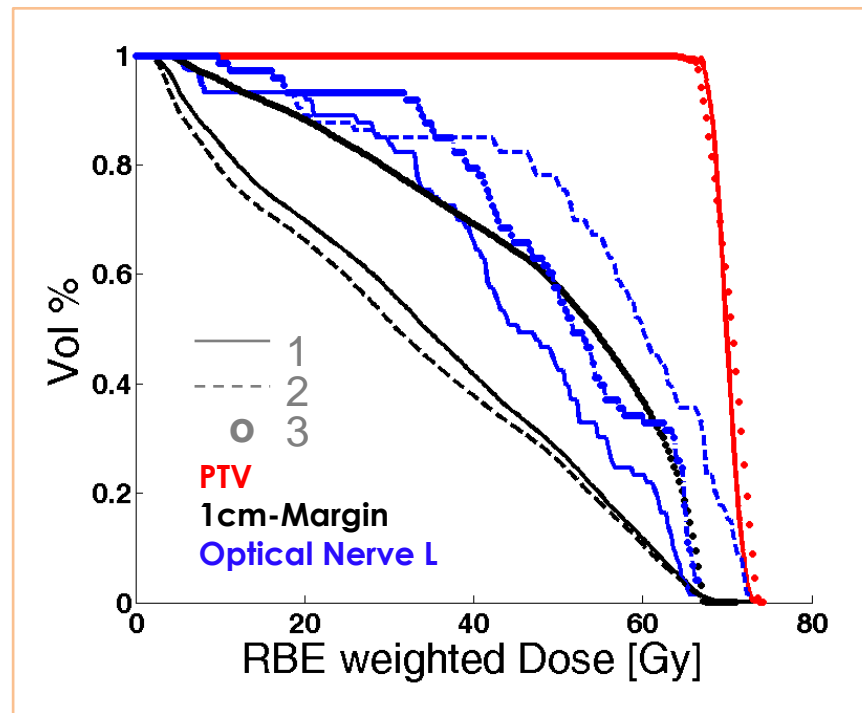
Biological model\*:

LEM I with  $\alpha_x = 0.1 \text{ Gy}^{-1}$ ,  $\beta_x = 0.05 \text{ Gy}^{-2}$

Index	1	2	3
PTV	LogSig-Vox	LogSig-Vox	SqD-Vox
OAR	LogSig-Str LogSig-Vox	LogSig-Vox	SqD-Vox

### Restrictions for all plans:

- OAR are equally important
- Homogeneity Index < 0.12
- Conformation Number > 0.8
- Target Coverage > 0.95



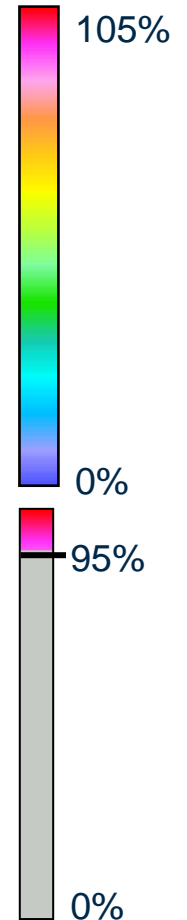
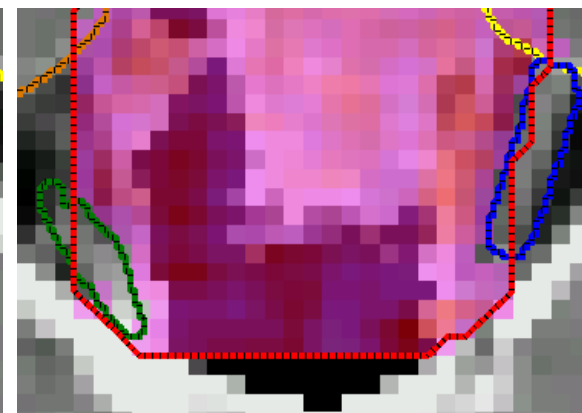
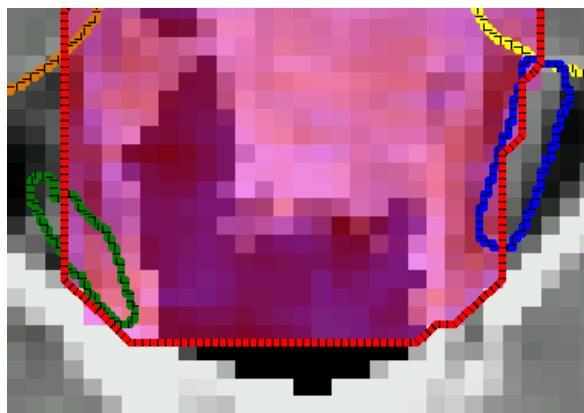
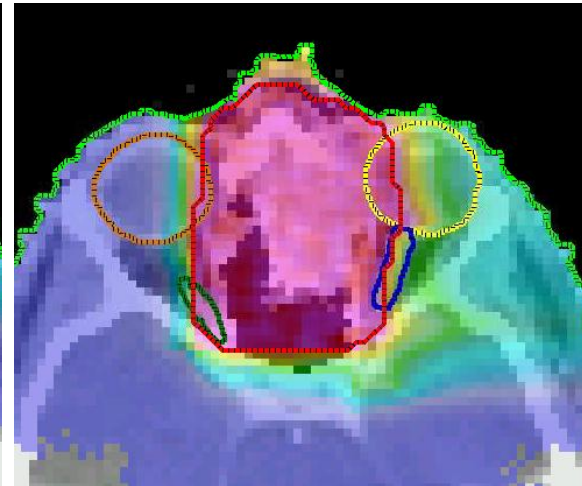
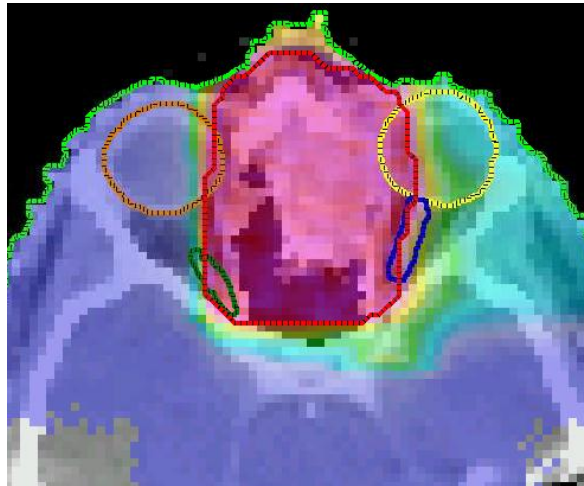
\* <http://toxixt.to.infn.it/lem/>

# Voxel- vs. EUD-based objectives

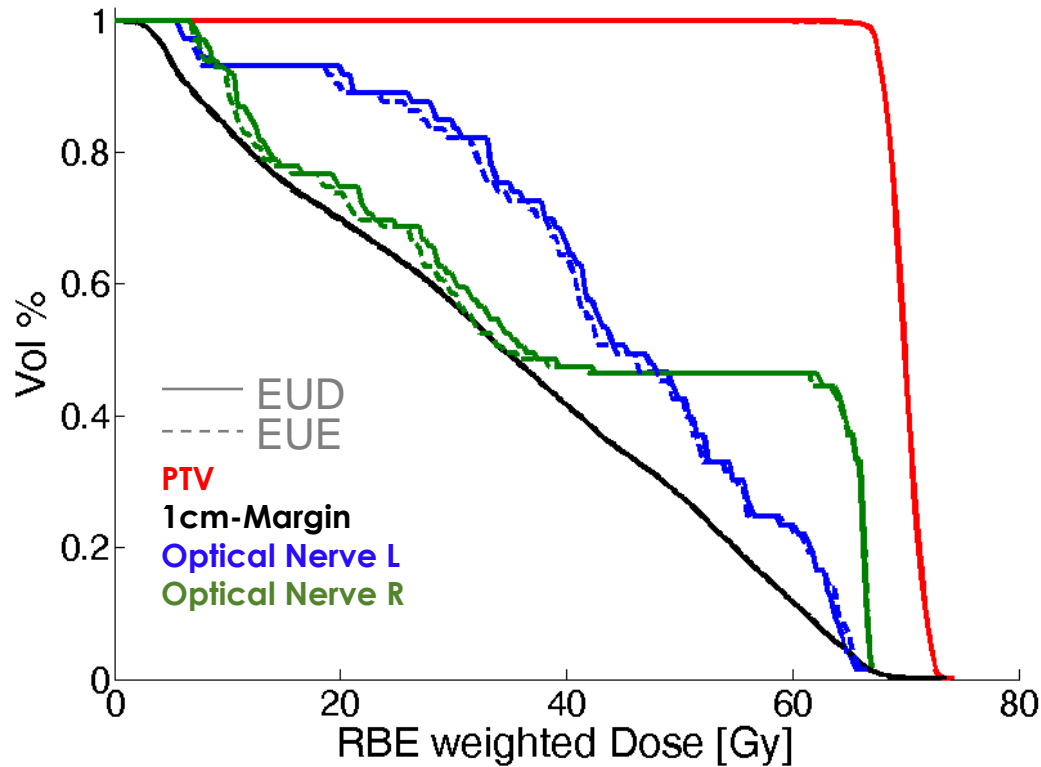
- PTV**
- 1cm-Margin**
- Optical Nerve L**
- Optical Nerve R**
- Bulbus L**
- Bulbus R**

Voxel-based (LogSig)

EUD-based (LogSig)



## EUD- vs. EUE-based objectives



$$EUD = \left( \frac{1}{N} \sum_{i=1}^N (RBE \cdot D)_i^a \right)^{1/a}$$

$$EUE = \left( \frac{1}{N} \sum_{i=1}^N E_i^{a'} \right)^{1/a'}$$

## Conclusions

- Better sparing of NT in general for carbon ion therapy
  - EUD- and voxel-based objective functions reach **plans of similar quality**
- **Easier to steer** optimization with EUD-based objectives
  - Assign a biological meaning to the prescribed objectives
- **EUE**-based optimization works **as well as EUD**-based optimization
  - Need to find an appropriate quantification of the effect-volume parameter

## Acknowledgement

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