Biological Treatment Planning

- Challenges Resulting from Scanning -

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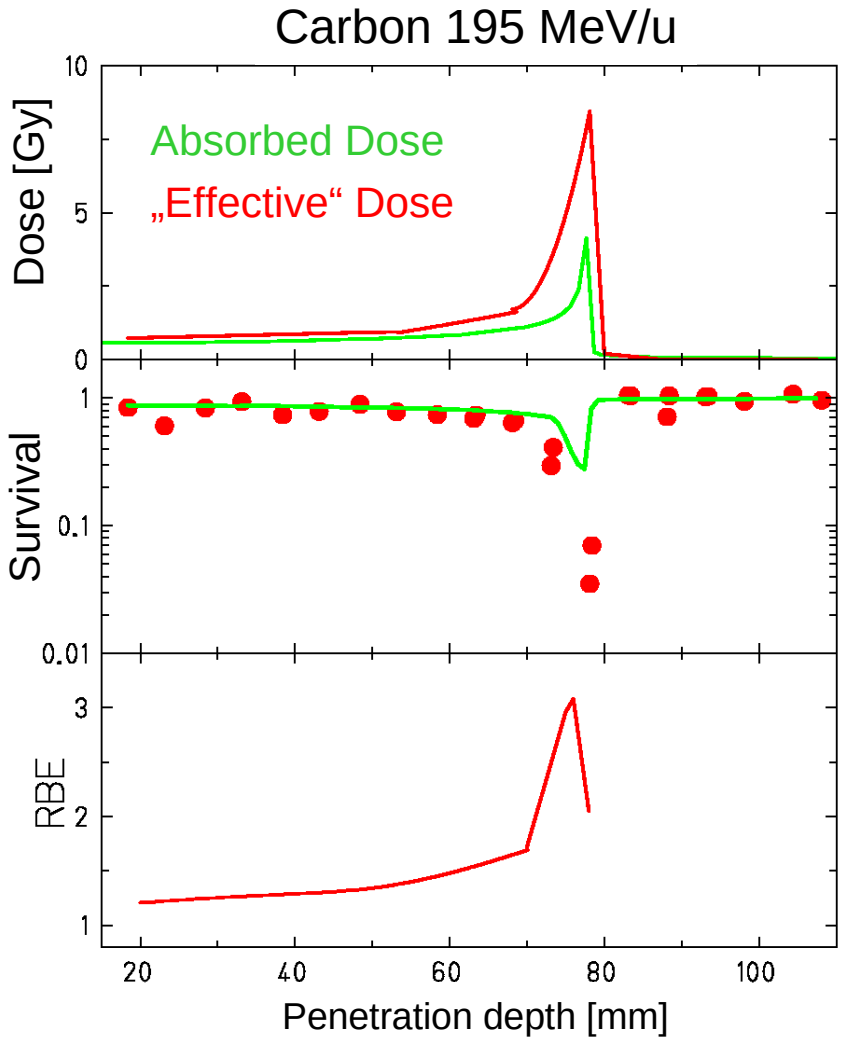
Increased **R**elative **B**iological **E**ffectiveness: **RBE**



Weyrather et al.

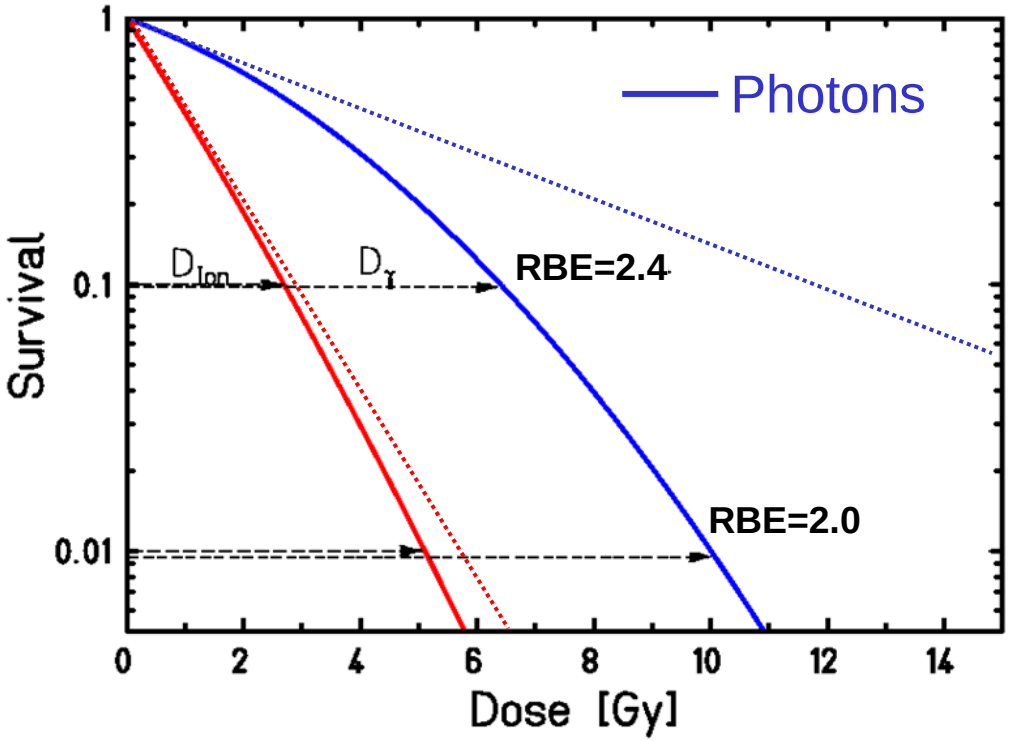
Differential Effect:

Enhancement(Peak)

>>

Enhancement(Plateau)

Definition: **R**elative **B**iological **E**ffectiveness (RBE)



$$S = e^{-(\alpha D + \beta D^2)}$$

$$\alpha_{Ion} \geq \alpha_{Photon}$$

$$\beta_{Ion} \leq \beta_{Photon}$$

$$RBE = \left.\frac{D_{Photon}}{D_{Ion}}\right|_{Isoeffect}$$

$$RBE_{\alpha} = \frac{\alpha_{Ion}}{\alpha_{Photon}}$$

Requirements for Treatment Planning

Challenge:

Homogenous distribution of effective dose in treatment volume

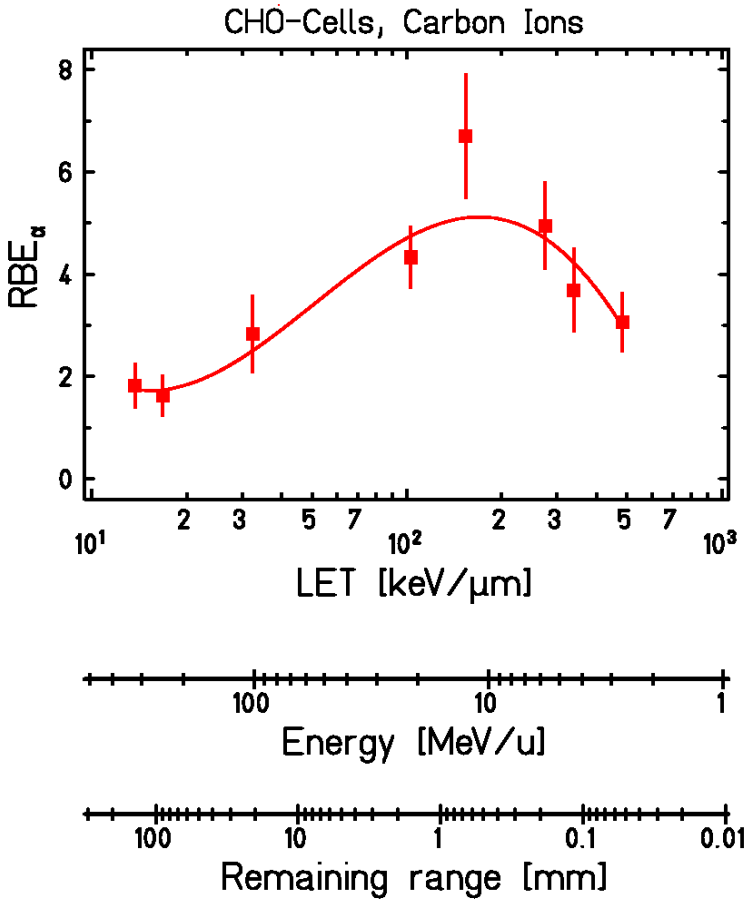
Effective dose distribution in normal tissues

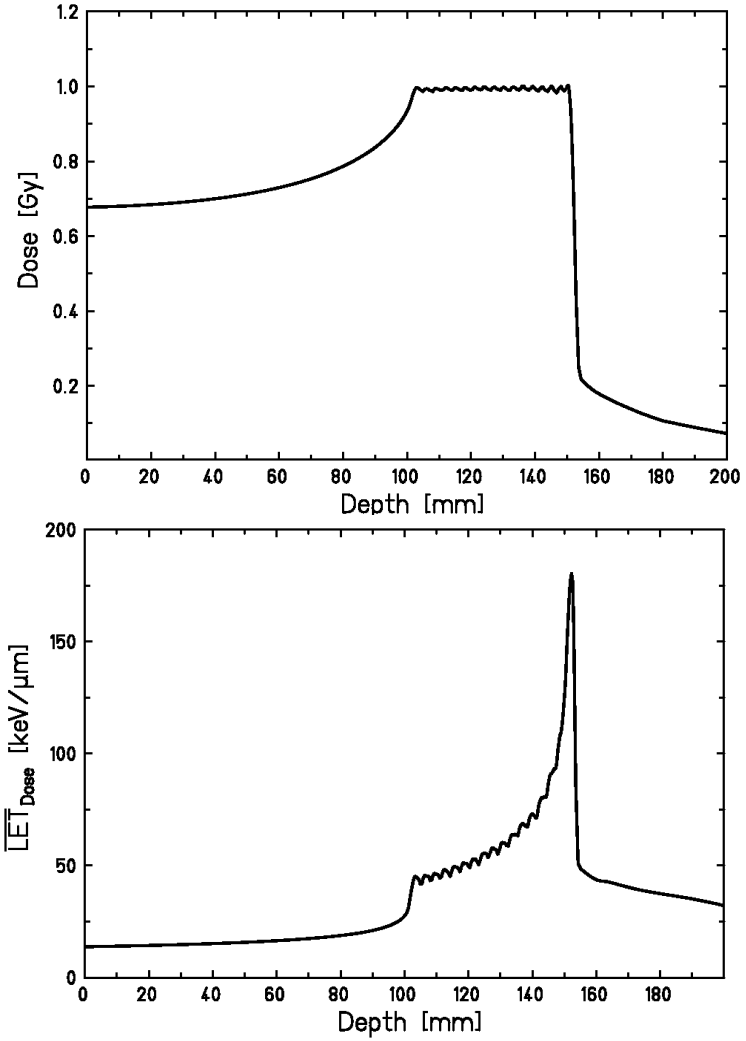
$$D_{RBE} = D_{Phys} \cdot RBE$$

RBE depends on several factors:

- Particle species / LET
- Dose
- Cell / Tissue type
- Oxygen status
- ...

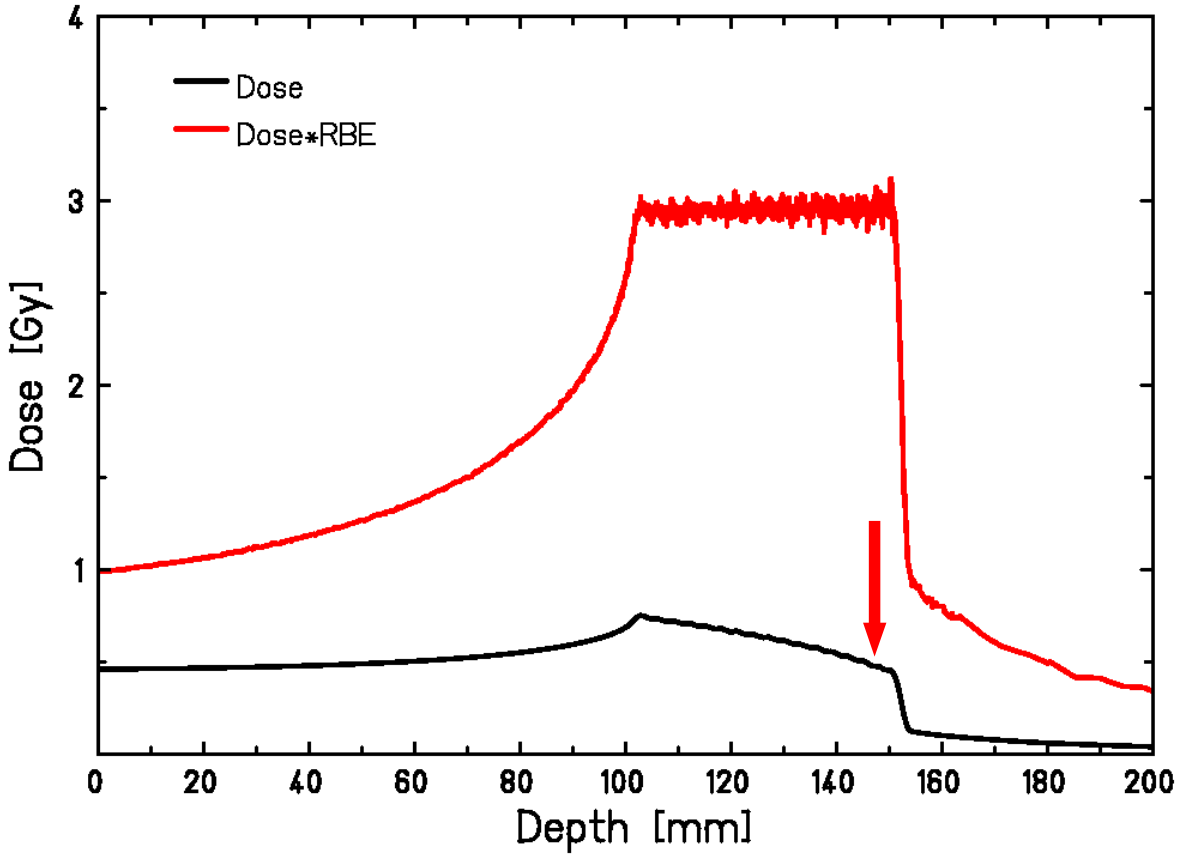
LET ↔ Depth Dependence of RBE





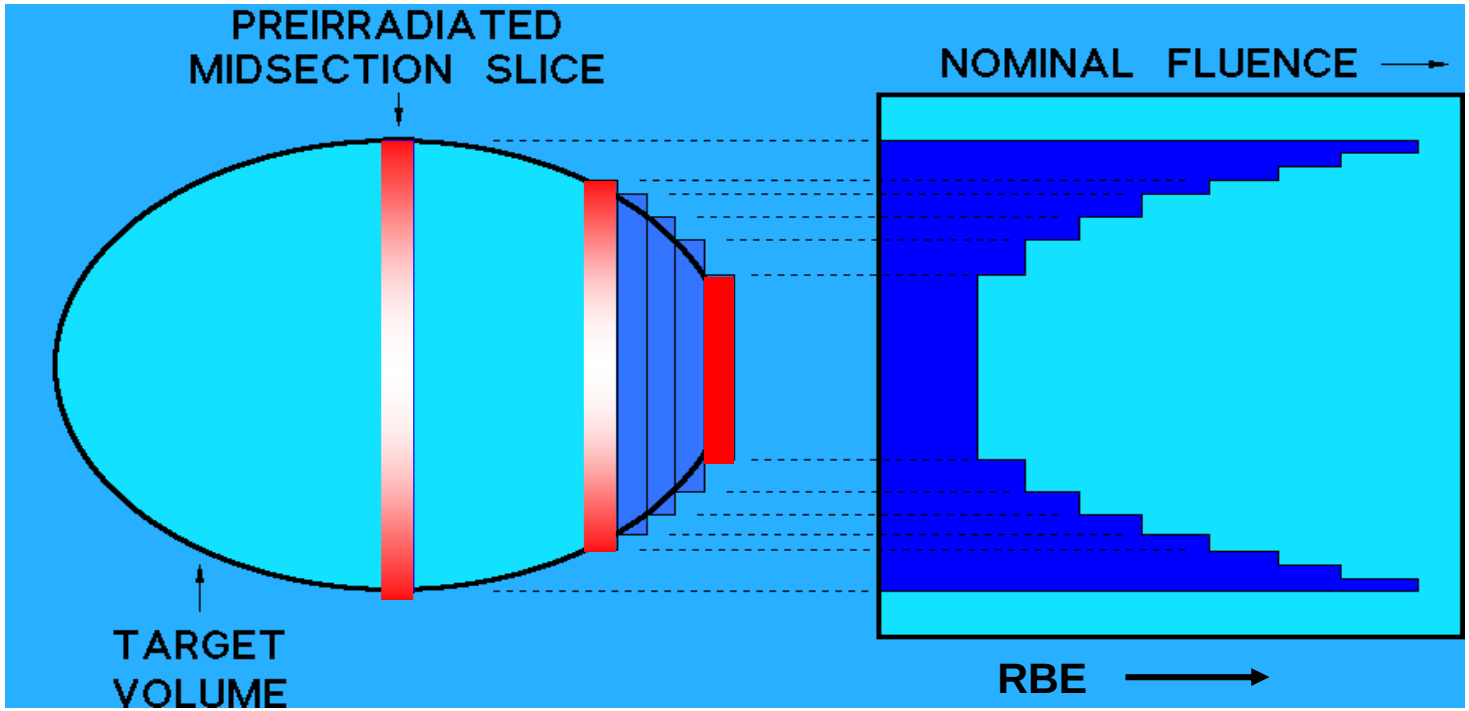
Weyrather et al. IJRB 1999

Depth Dependence of RBE



Reduction of dose at distal end to account for the increase in RBE

Lateral variation of LET

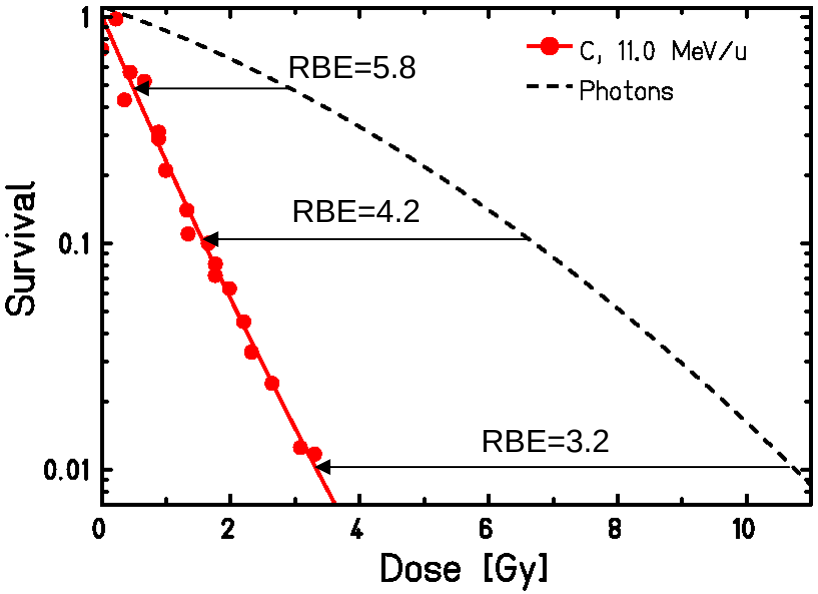


LET

Dose Dependence of RBE

In-vitro:

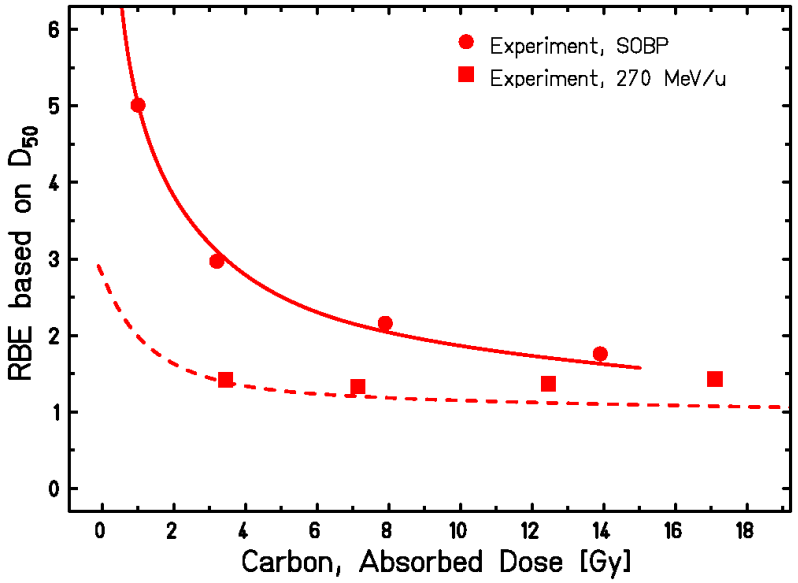
Cell survival / CHO-cells



Weyrather et al., IJRB 1999

In-vivo:

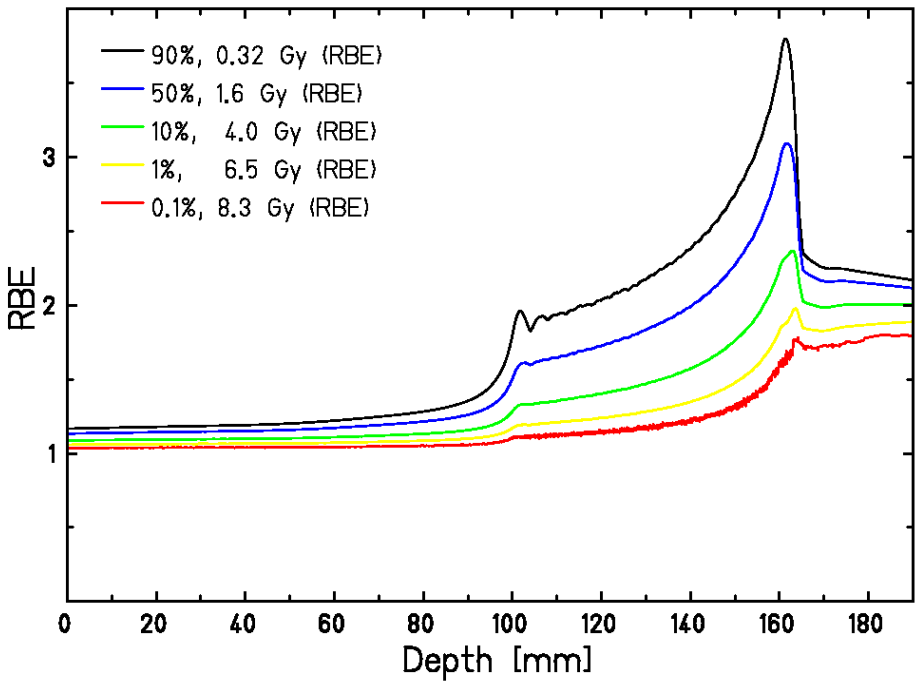
Tolerance of Rat Spinal Cord

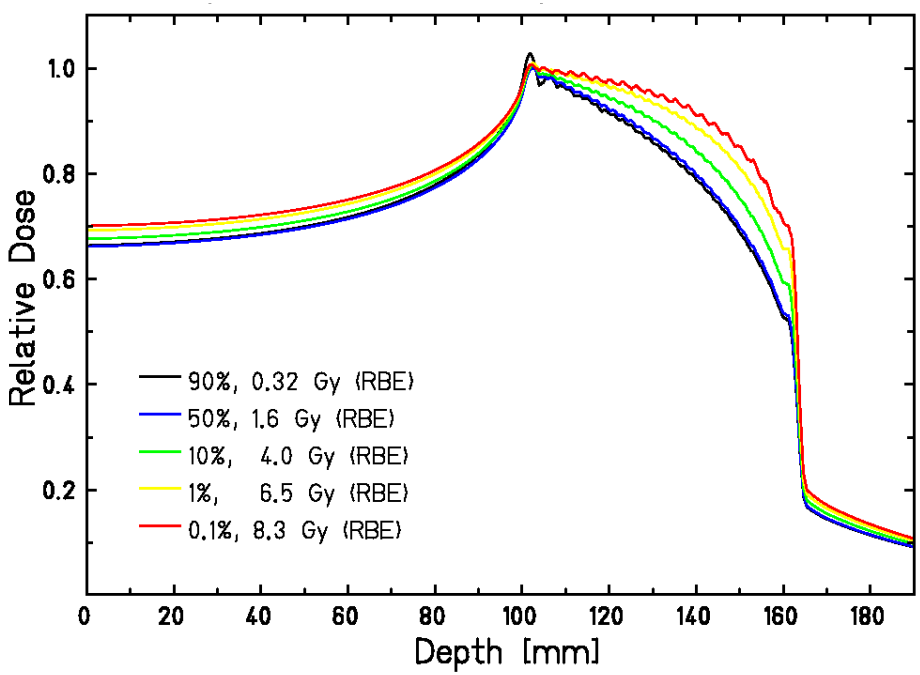


Karger et al. IJROBP 2006

➡ RBE decreases with Dose

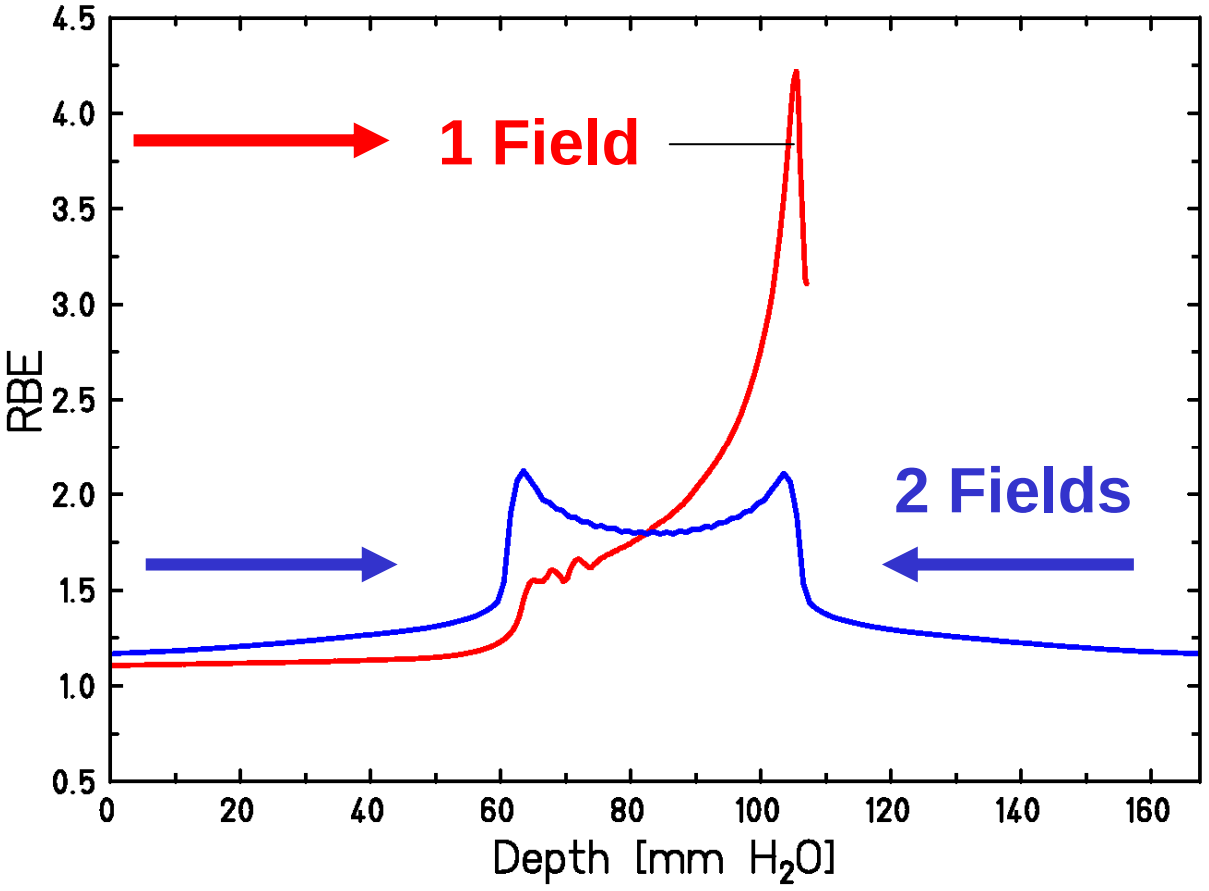
Dependence of RBE on Effect Level





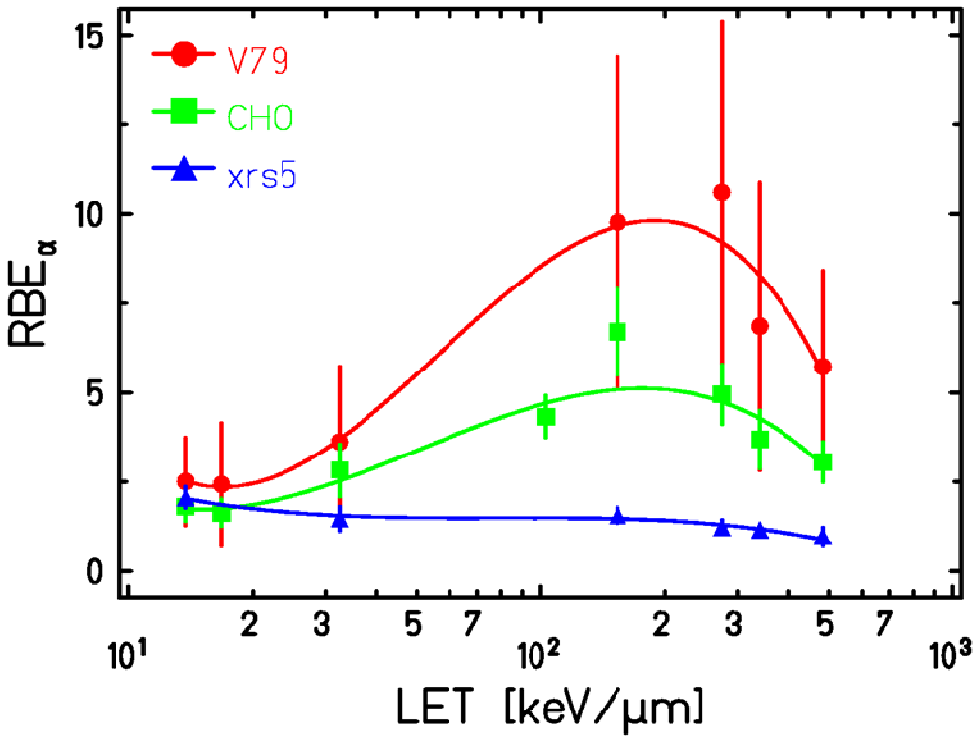
Shape of SOBP depends on effective dose level

Superposition of Fields

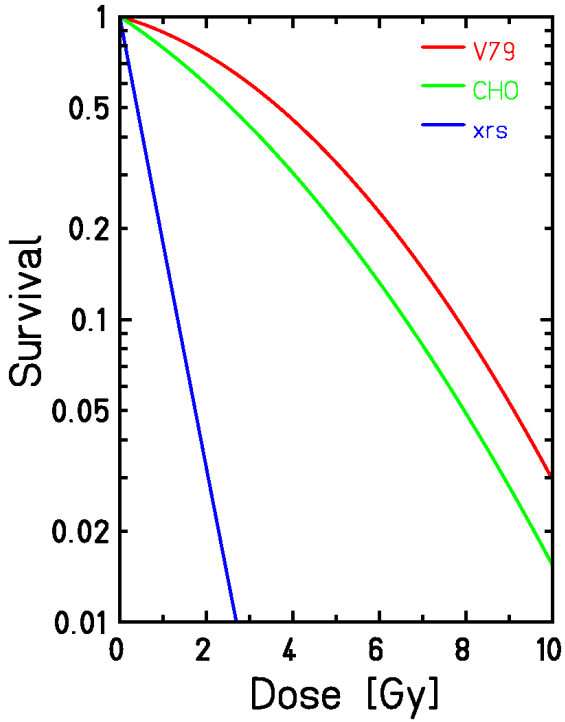


(➡ Distal Edge Tracking not appropriate...?)

Cell type dependence of RBE



Photons



Weyrather et al. IJRB 1999

RBE is correlated with repair capacity

(In terms of LQ-model: with α/β-ratio)

Influence of Tissue Composition

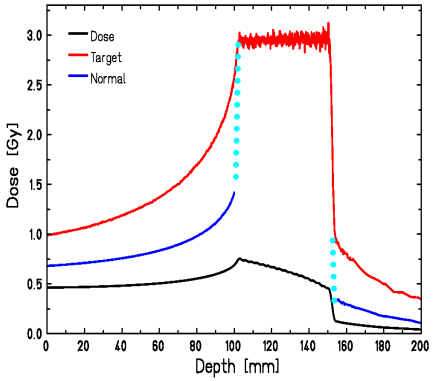
Tumor

Normal 1

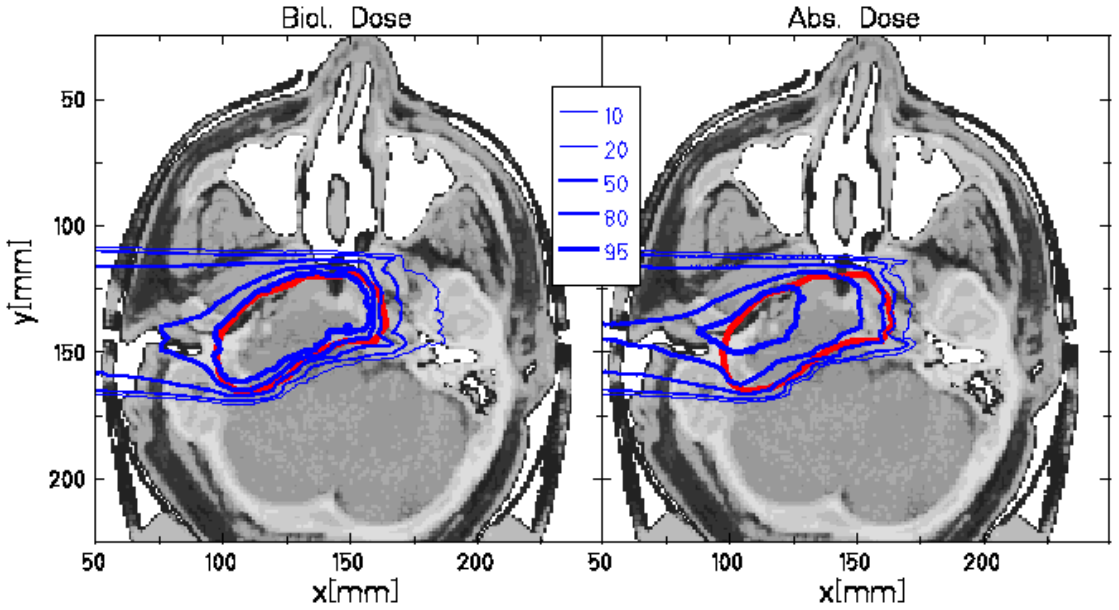
Normal 2

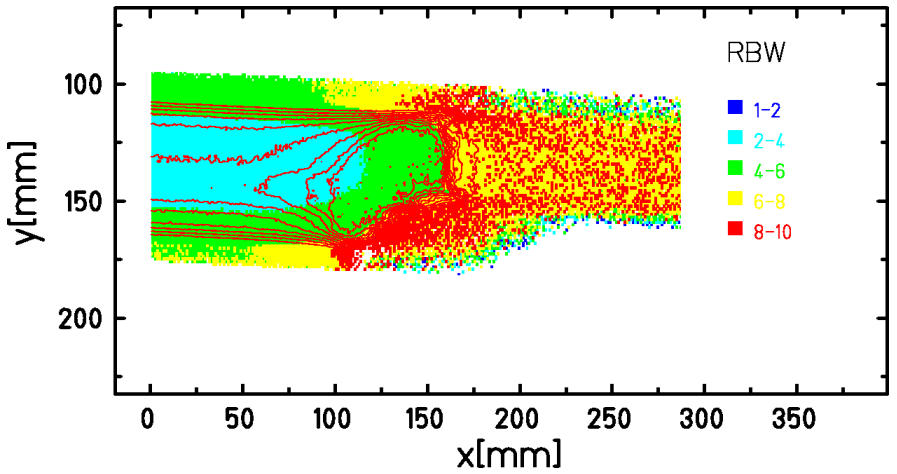
Normal 3

Tissue dependence of RBE might lead to discontinuities of the RBE-weighted dose distribution!



RBE-Map





Krämer et al.

Treatment planning for carbon ions

Complex RBE dependencies: E, LET, D, cell type,…

Interpolation/extrapolation required for
treatment planning in HI therapy

HIMAC	GSI / HIT
Experimental Data	Biophysical Modelling
+ Clinical Neutron Experience	(Local Effect Model LEM)
(‚Fixed' RBE-scheme)	(Variable RBE-scheme)

HIMAC Approach

In-vitro Experiments
(Monoenergetic, high-LET)
$\alpha_{Carbon}(x), \beta_{Carbon}(x)$

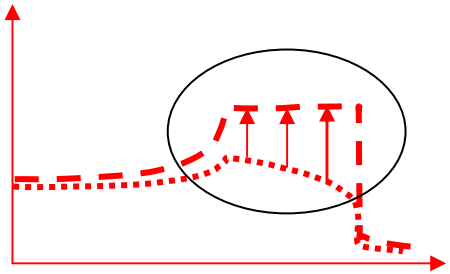
Kanai et al., IJROBP 1999

Algorithm:
Dose Weighted Average

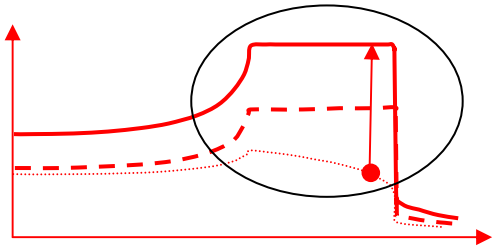
$$\alpha_{Mix} = \sum f_i \alpha_i \qquad \sqrt{\beta_{Mix}} = \sum f_i \sqrt{\beta_i}$$

Relative Shape of
Depth Dose Distribution

Absolute RBE:
Clinical Neutron Experience



Treatment Planning

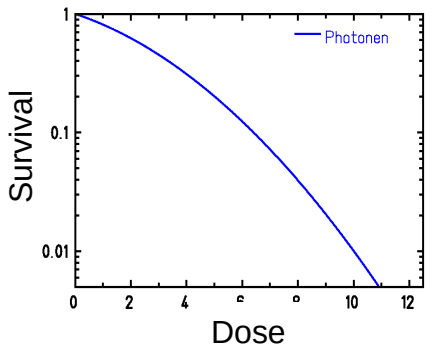


GSI Approach: Local Effect Model LEM

Basic Assumption:

Increased effectiveness of particle radiation
can be described by a combination of the
photon dose response and microscopic dose distribution

Local Effect (Photons) = Local Effect (Ions)



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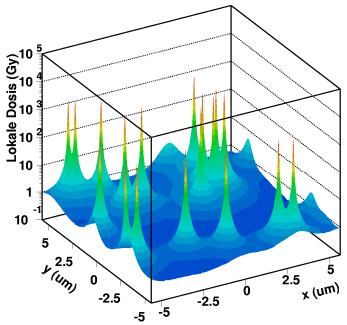
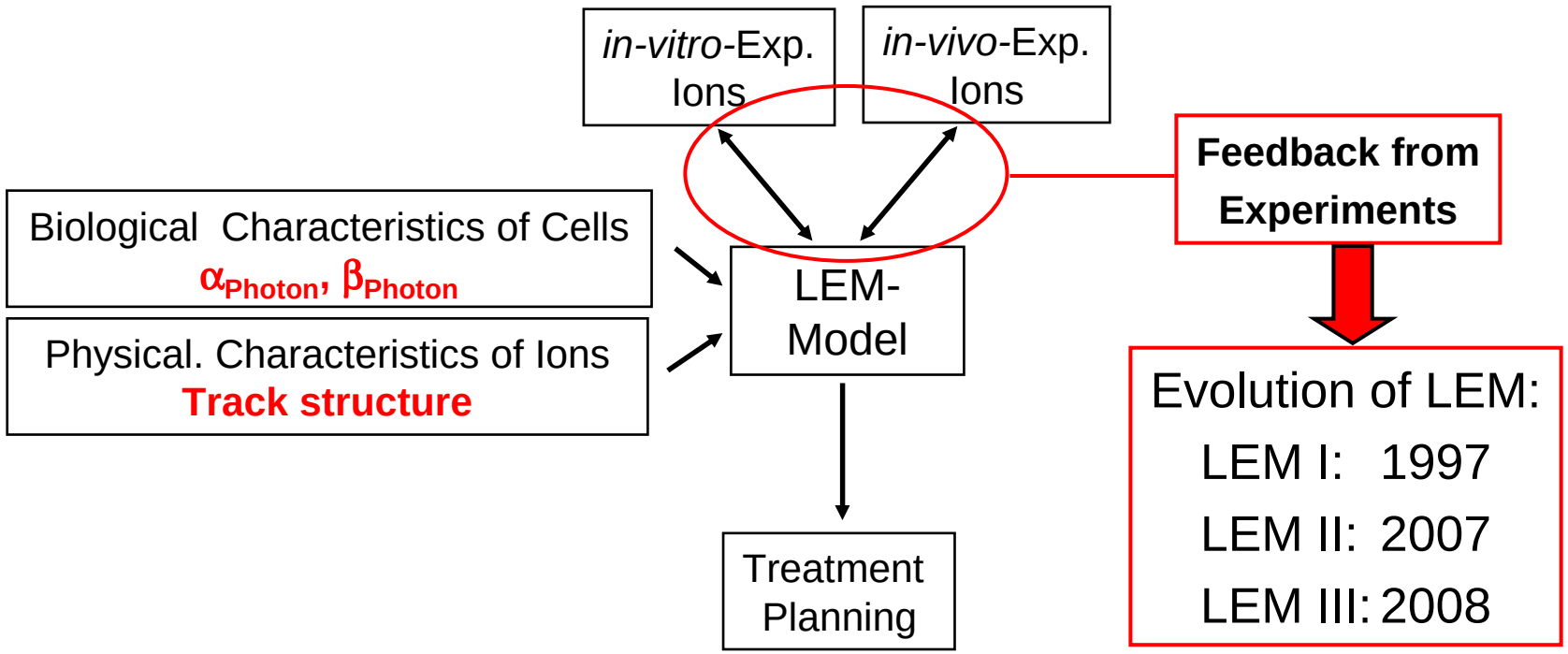


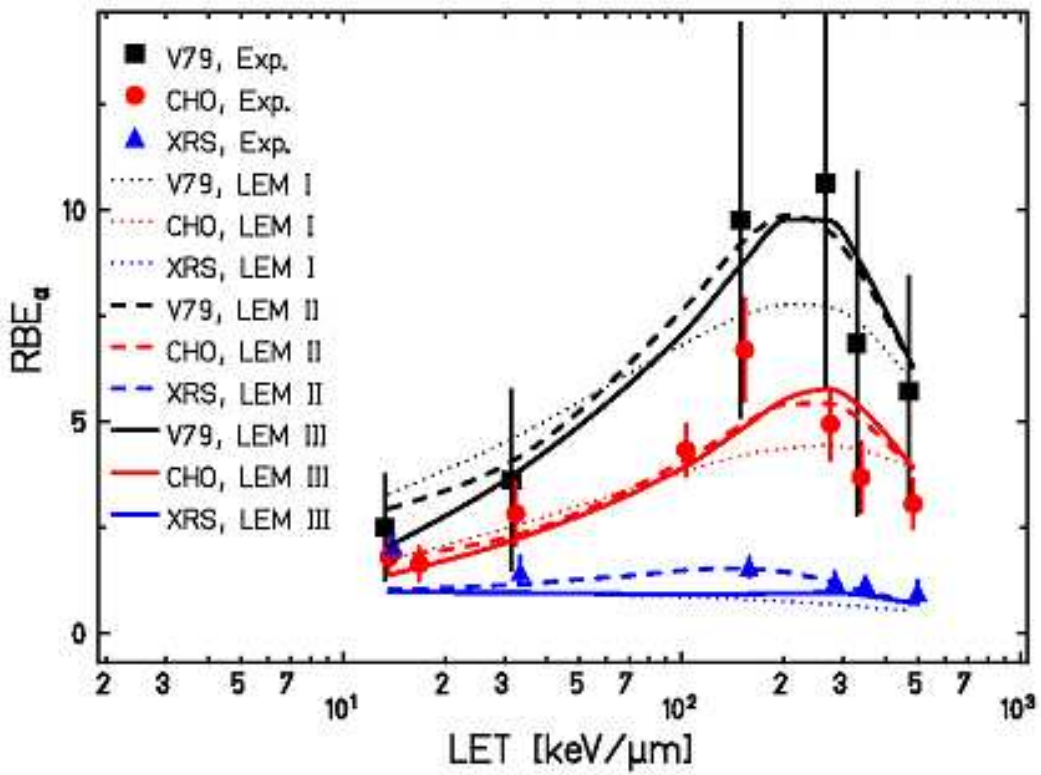
➡ RBE !

Treatment Planning: GSI approach

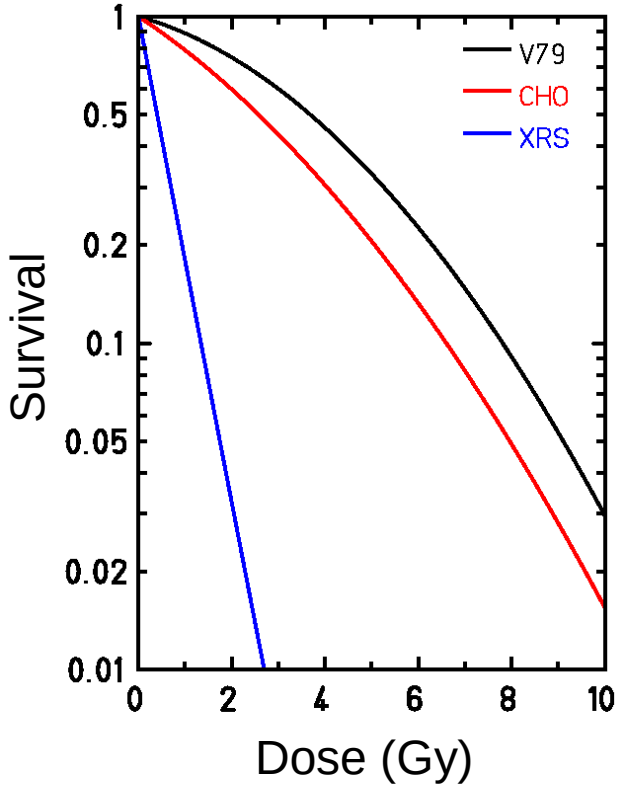


Comparison with Experiments: Influence of Cell Type

Carbon-Ions



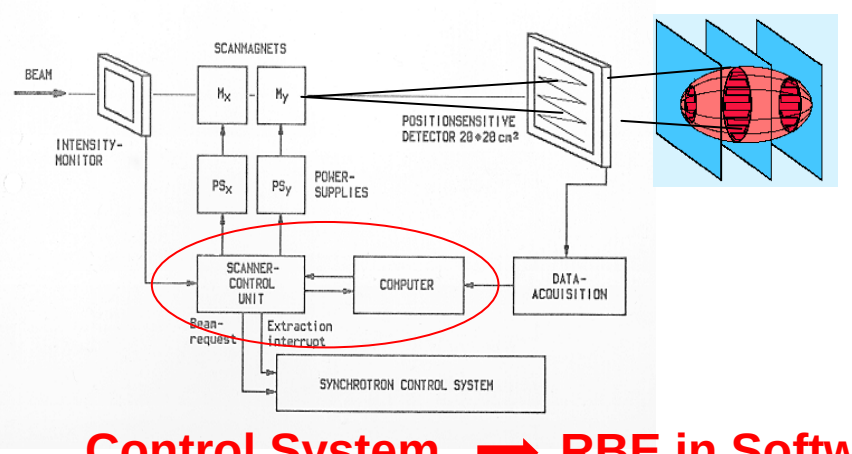
Photons



Exp. Data: Weyrather et al. IJRB 1999
LEM I: Scholz et al., Rad. Env. Biophys 1997
LEM II: Elsässer et al., Rad. Res. 2007
LEM III: Elsässer et al., IJROBP 2008

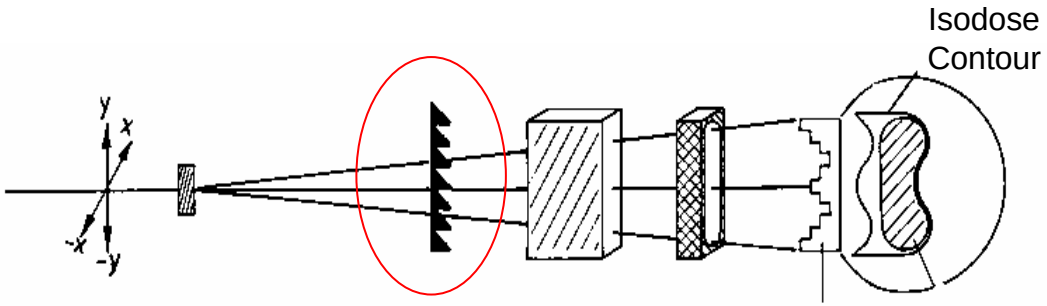
Comparison of Beam Delivery Systems

Active Delivery



Control System ➡ RBE in Software

Passive Delivery



Ridge Filter ➡ RBE in Hardware

Summary I

- RBE values vary with LET, depth, dose, biological system, ...
- Increase of RBE within SOBP requires shaping of depth dose profile
- Complex dependencies of RBE require interpolation/modelling for treatment planning
- LEM is capable to reproduce the essential features of RBE dependencies with sufficient quantitiative precision over the whole therapeutically relevant range from protons to neon ions
- LEM represents a useful tool for treatment planning studies aiming at optimization of ion beam therapy with respect to ion species, tumor / normal tissue characteristics, fractionation etc.

Summary II

- To be implemented: Oxygen effect
- Treatment planning for passive delivery systems in principle is as complex as for active beam delivery (reduction to 2-dimensional distribution in the case of passive delivery?)
- Active beam delivery is extemely flexible allowing to deliver any arbitrarily shaped field; any desired dose distribution can be applied