

Treatment plans in particle therapy

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M. Krämer, W.Kraft-Weyrather, C.v.Neubeck, A.Buschbacher,
M.Horcicka, G.Iancu, T.Elsaesser, M.Scholz and M.Durante

M.Kraemer@gsi.de

GSI Darmstadt

Topics

- Ion-Beam Radiotherapy pilot project
1997..2008
(GSI,DKFZ,Uni HD,FZ Rossendorf)
- Physics & Radiobiology
- Dose Optimization (IMPT)
- Verification
- Outlook

Treatment Planning for Raster Scanner

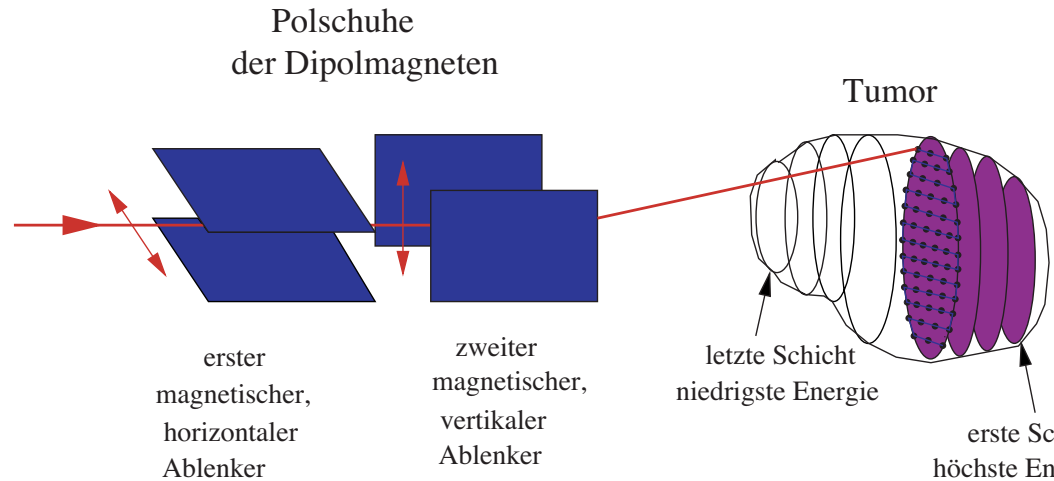
VOXELPLAN (DKFZ)

CT/MR contouring
visualization

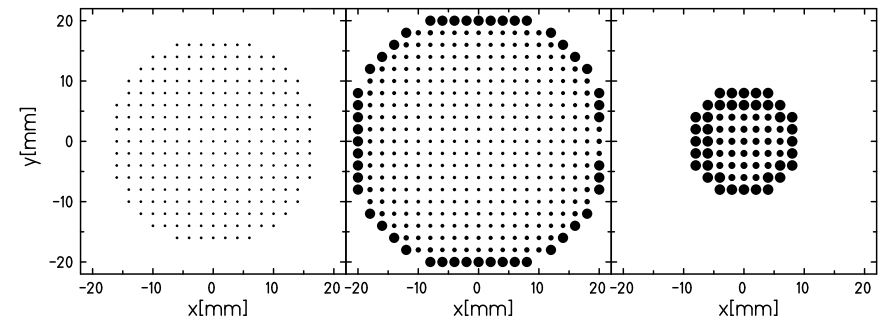
TRiP (GSI)

(Treatment planning for Particles)

- Physical Beam Model
- Radiobiol. Model (LEM)
- Dose Calc./Optim. (IMPT)
- Scanner parameters
Beam energies E_b
Fluence maps $F(E_b, x, y)$



Single field: ..50000 spots / ..50 slices



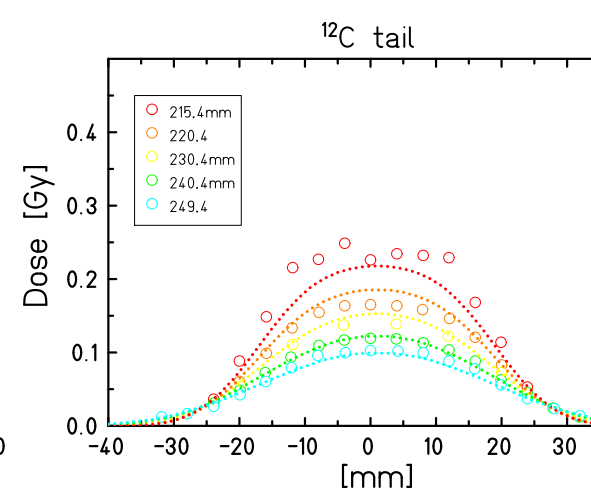
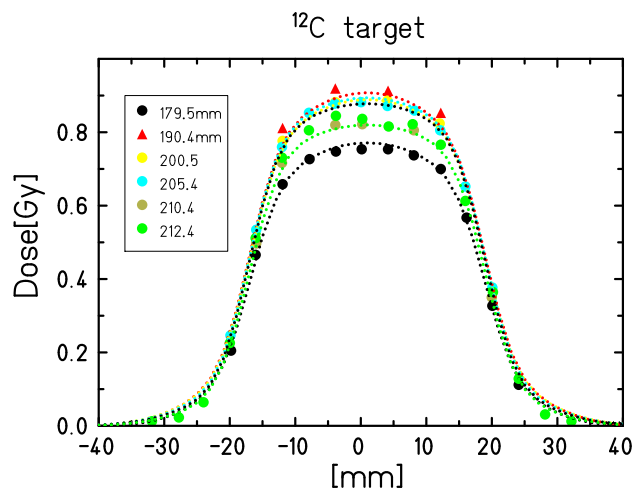
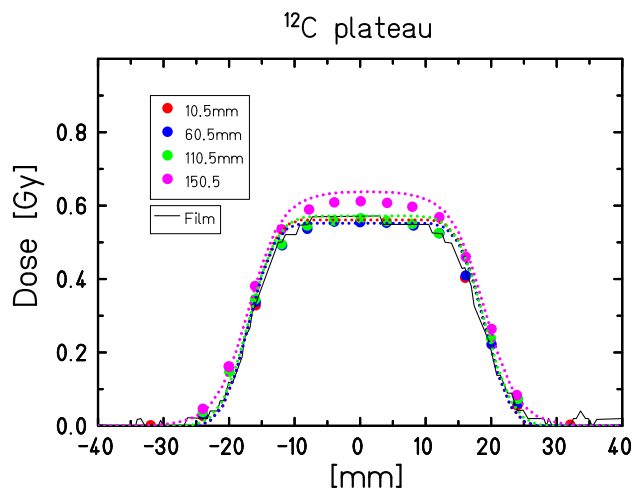
TRiP98/Yield Beam model

Numerical:

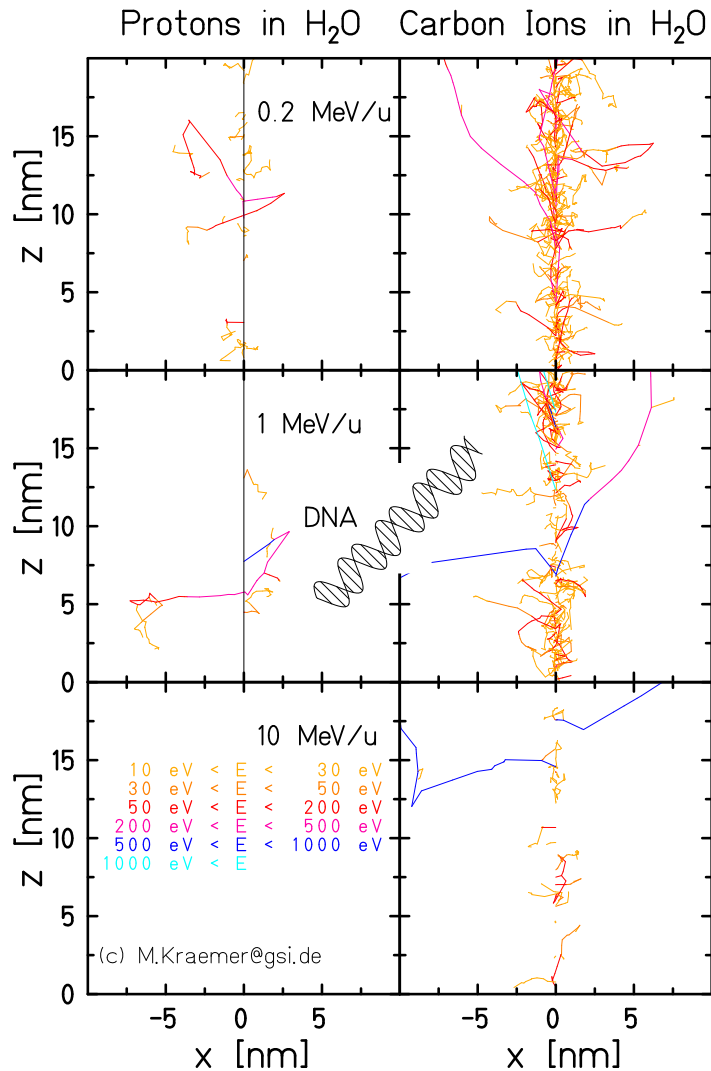
Nuclear fragmentation,
Energy loss/straggling,
+Scattering

Small fields ($20 \times 20 \text{mm}$), large depths ($>200 \text{mm}$):

↪ light nuclear fragment angular distributions significant
(Data: O.Geithner, Calc.: G.Iancu)

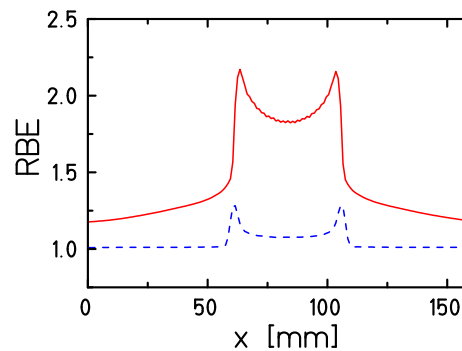
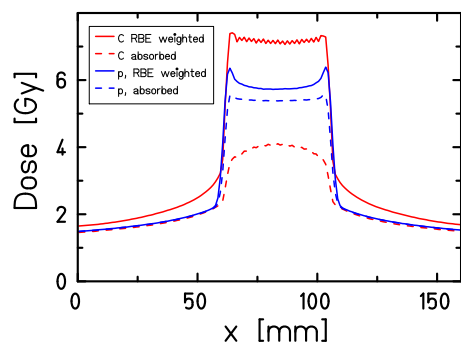
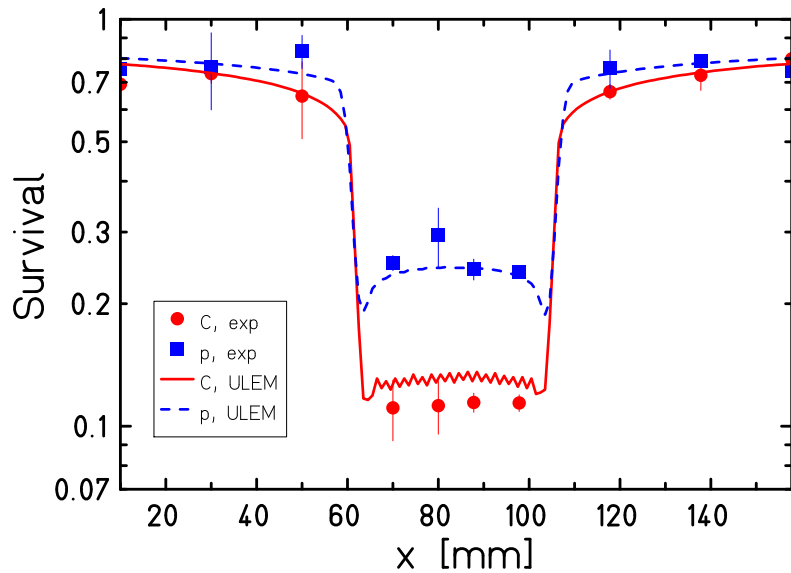


Radiobiology / Microscopic Dose Distribution



- TRAX Monte Carlo (GSI)
- micro/nanometer scale
- ions, electrons
- elementary interactions rather than condensed random walk
- Radiobiology (RBE) ab-initio ?
- No ! Too many unknowns.
- \rightsquigarrow use LEM (M.Scholz,T.Elsaesser)

Universal LEM for Protons+Carbon (preliminary)



Cell survival 1-dim.

Data: W.Weyrather @ HIT

Calc: T.Elsaesser, G.Iancu

(w/ ULEM+TRiP98)

No change of TPS

~> just select another RBE
base data set

Dose Optimization (IMPT)

Objective function:

$$\chi_{abs}^2 = \sum_{\vec{x}} (D_P(\vec{x}) - D(\vec{x}))^2 + \text{constraints(organs-at-risk)} = \min.$$

$$D(\vec{x}) = D_{abs}(\vec{x}, N(\vec{r})) = \sum_{\vec{r}} g(\vec{x}, \vec{r}) N(\vec{r})$$

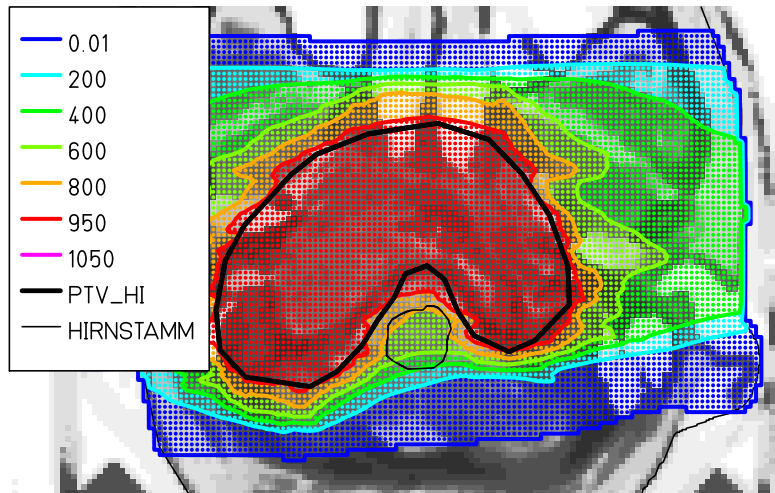
- $g(\vec{x}, \vec{r})$: Contribution of raster spot \vec{r} to *absorbed* dose at voxel \vec{x} ,
- ≈ 1000 $g()$'s / voxel \leadsto multi-GByte problem
- ≈ 70000 free parameters particle numbers $N(\vec{r})$ for 2-field config.

biological dose:

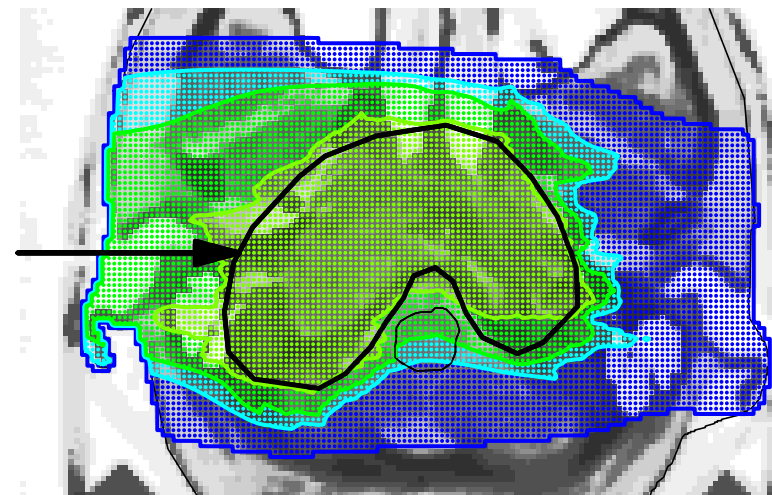
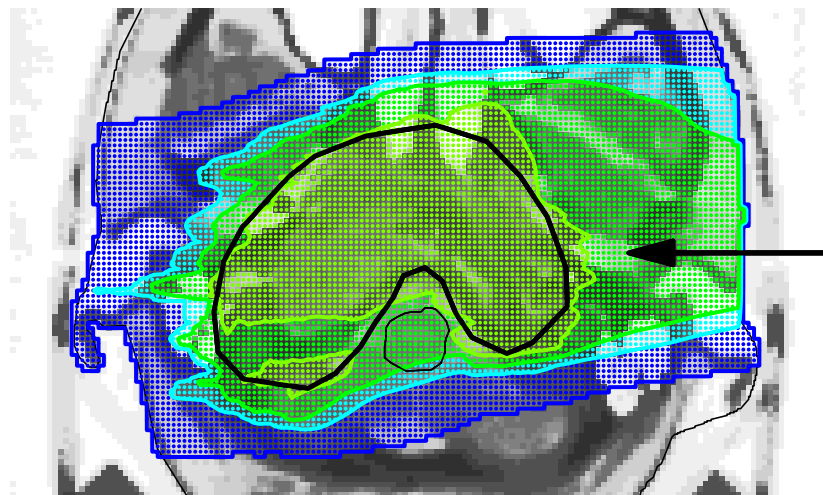
$$D(\vec{x}) = D_{bio}(\vec{x}) = \text{RBE}(\vec{x}, N(\vec{r})) \times D_{abs}(\vec{x}, N(\vec{r}))$$

- \leadsto nonlinear problem, iterative solution
- \leadsto Dose & RBE to be recomputed many times

IMPT partial fields



Two (three) fields suffice
partial fields homogeneous,
except OAR contribution
"robustness" (M.Ellerbrock/DKFZ)



IMPT Computing Resources

Table 1: CPU / Memory "footprint"

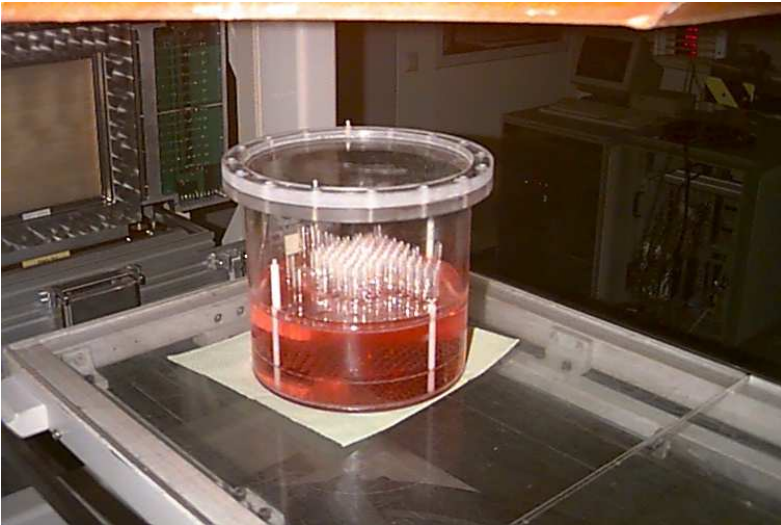
Plan	target voxels	OAR voxels	raster spots	fields	Memory [MB]	#iter	CPU [s]
#135	20000	4000	20000	2	430	57 (12)	1800 (400)
#290	47000	11000	48000	2	1200	43 (10)	4000 (1000)
#305	57000	9000	58000	3	3000	39 (14)	8100 (2900)
#239	86000	7000	70000	2	1800	45 (10)	6000 (1400)

- various minimizer algorithms (M.Horcicka,A.Buschbacher)
- n-field: \approx 1..3 min / iteration, not parallelizable, \rightsquigarrow no "Grid"
- \rightsquigarrow commercial SMP-machines (Ref.: Power4 @ 1.2 GHz)

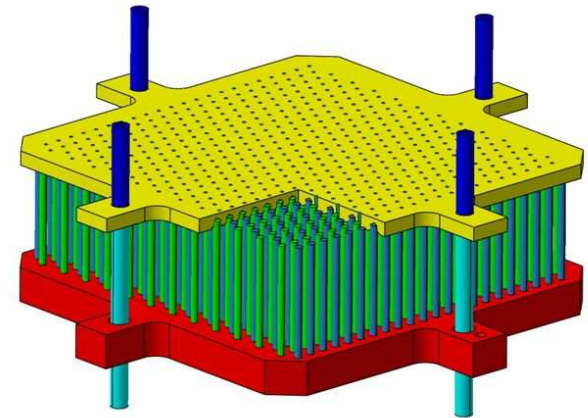
(PMB 53 (23) (2008) 6991-7012)

Verification: Bio-Phantom

Cell survival distributions in 2 dimensions
Ultimate test for models + irradiation
(W.Kraft-Weyrather,C.v.Neubeck)

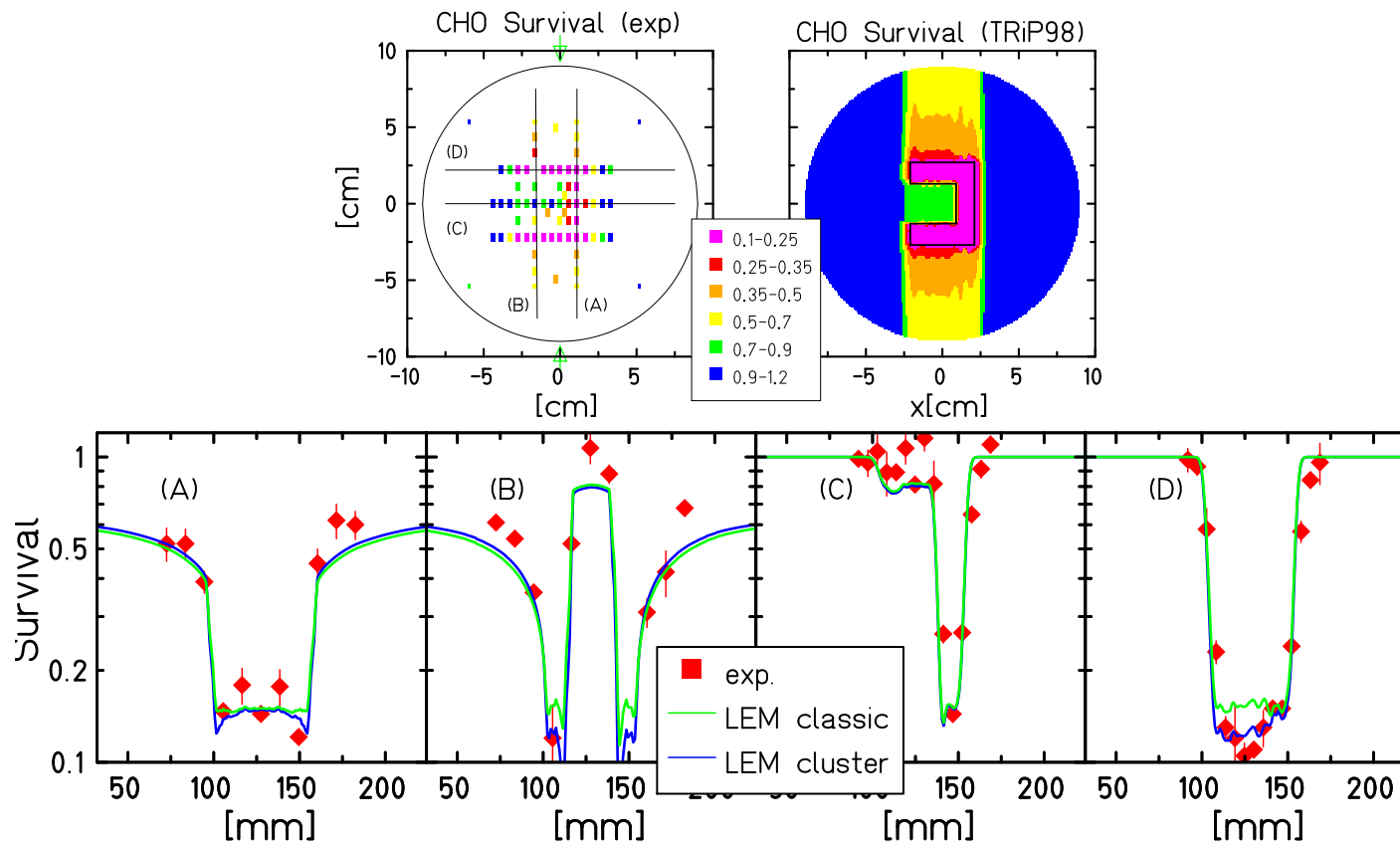


(Patent: PCT/EP 2007/002156)



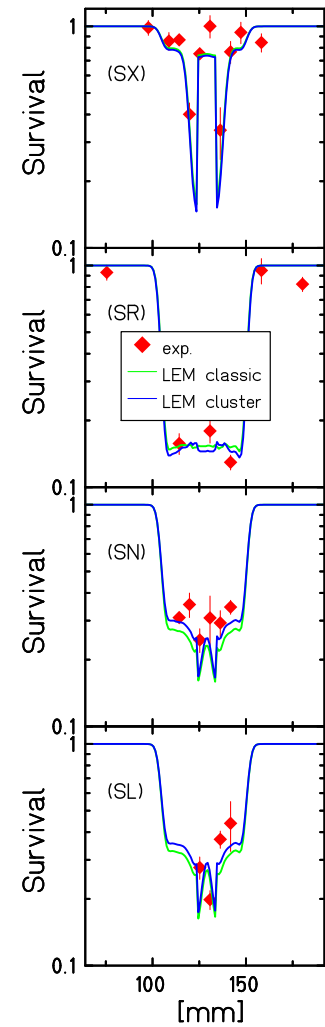
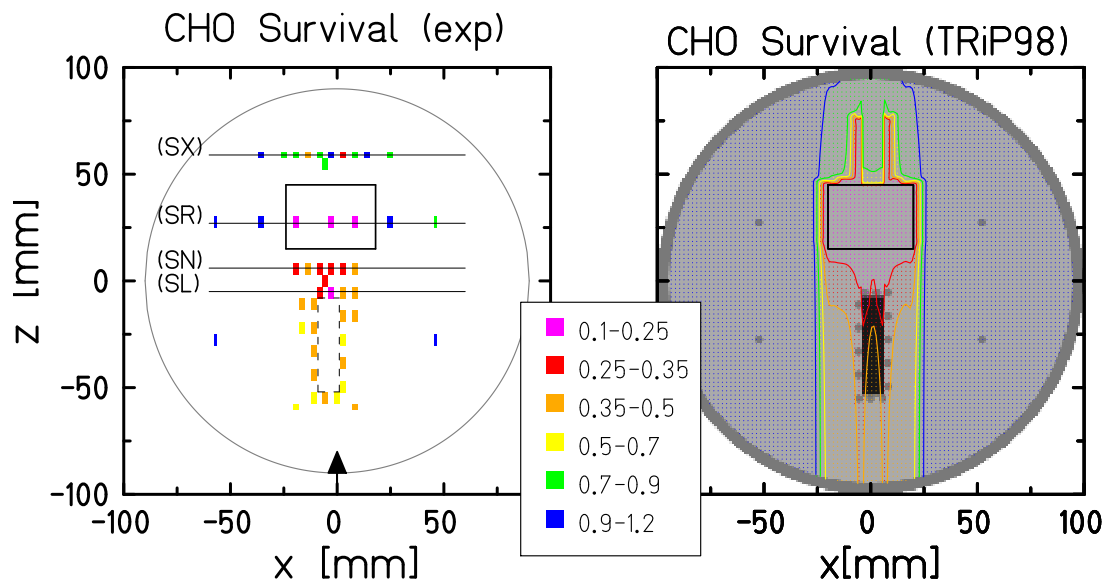
Verification of Multifield Optimization

C-shaped target + OAR; simultaneous 2-field optim.
(C.v.Neubeck, A.Schmidt, W.Kraft-Weyrather)



Cell survival + inhomogeneities

(W.Kraft-Weyrather, G.Kragl)



Summary & Work in Progress

- ✓ 3D(4D) biological treatment planning ^{12}C
- ✓ ^{12}C Multifield optimization (IMPT) verified and in clinical use
- ✓ 430+ patients successfully treated since 1997
- ✓ TRiP98 \rightsquigarrow Siemens "Syngo PT": CE-certified TPS
- TRiP98 as Research Prototype in use @ GSI, HIT, DKFZ, Marburg
- EU-projects: ULICE, Rococo, Allegro, ...

TRiP98 Work in Progress

- Organ Motion tracking & correction
~ (talk C.Bert)
TRiP98-4D as standard version

- Ion beams p, He, Li, O

