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The use of ‘planned overshoot’ for reducing dose to healthy tissue and improve treatments robustness for scanned proton beams

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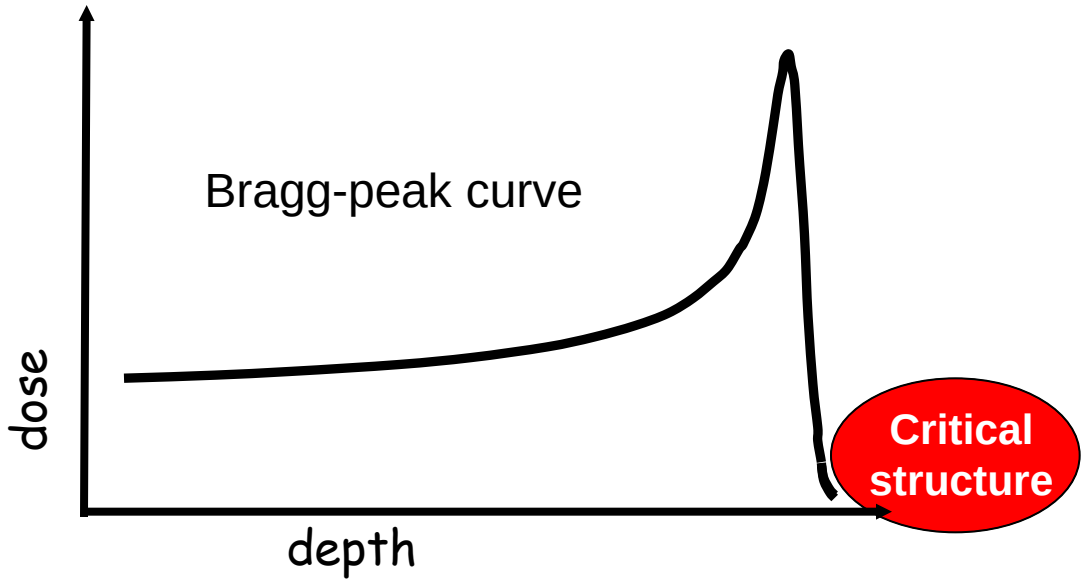
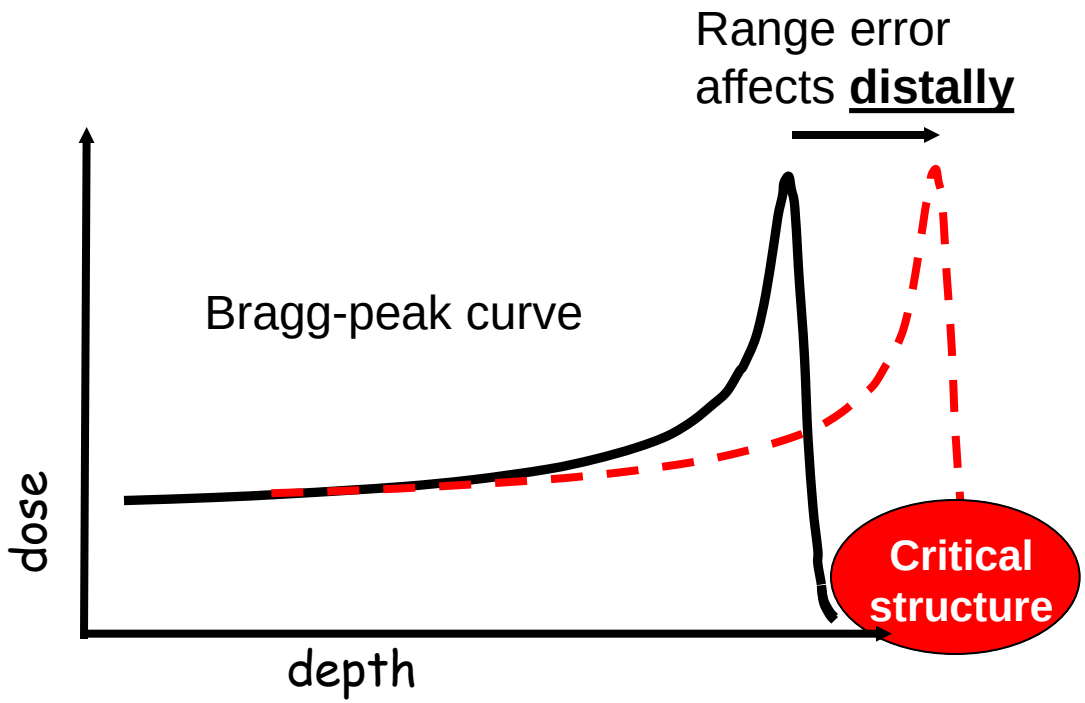
The advantage of using protons for radiotherapy is that they stop…



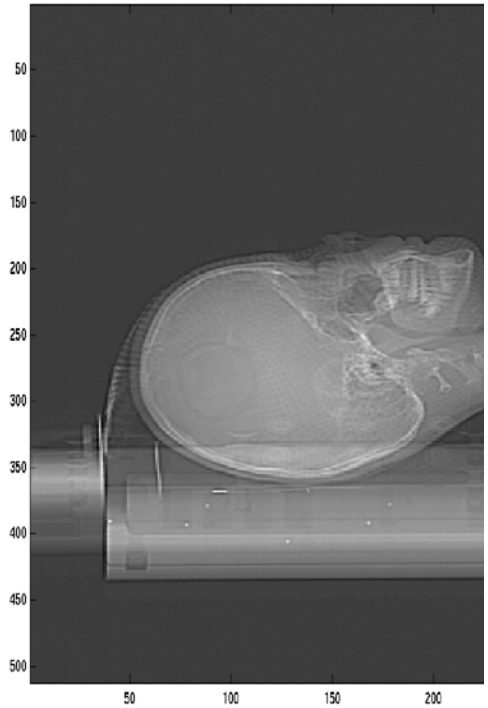
Rationale: protons and uncertainties (range errors)

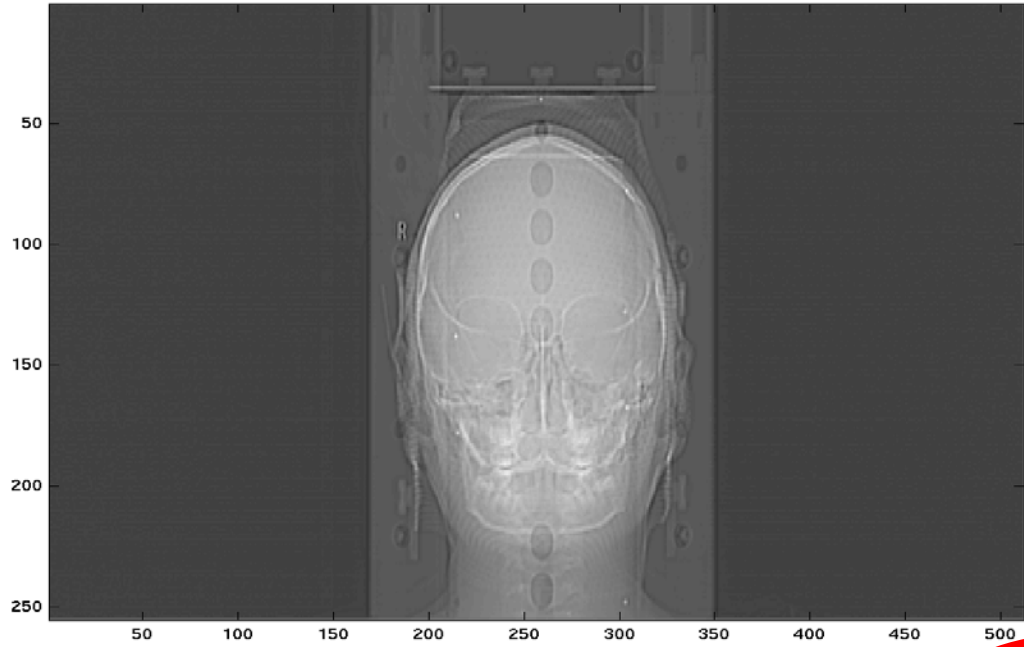
…the disadvantage of using protons for radiotherapy is that you don't always know where!



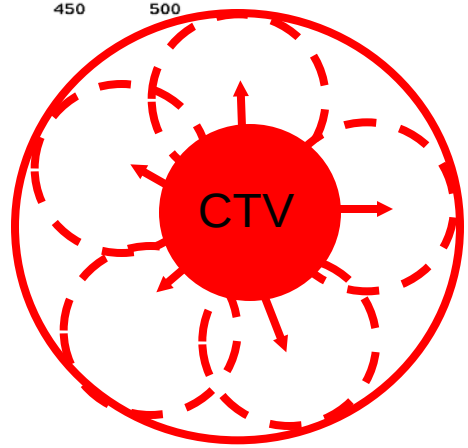
Range errors are generally **systematic** (i.e. these propagates through the course of the therapy)!

Rationale: Protons and uncertainties (set-up errors)





Set-up errors are **randomly** (i.e effect is washed out during the course of therapy) and **isotropically** distributed around the target volume (there is no „favourite misalignment direction“)



Dealing with uncertainties: use of PTV

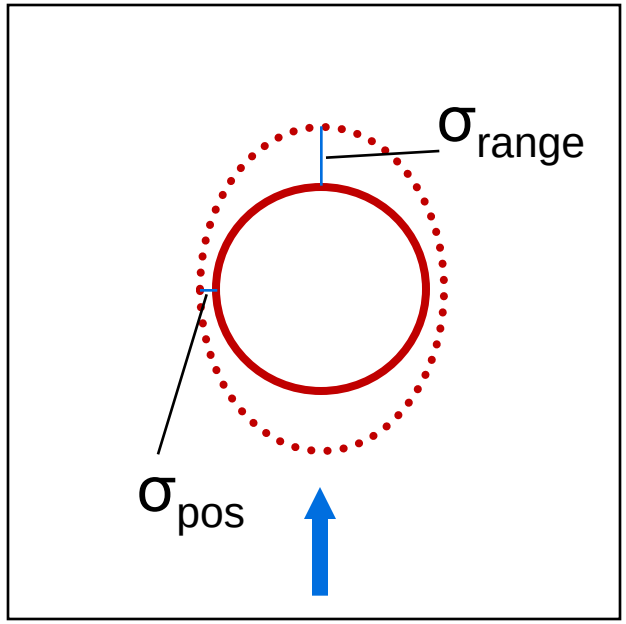
- Definition of a PTV (isotropically expansion of the CTV) is conventional way of dealing with potential delivery errors (set-up and range)

- For **passive scattering** protons, PTV often not used, as uncertainties are dealt with through expansion of apertures and smoothing and smearing of compensator

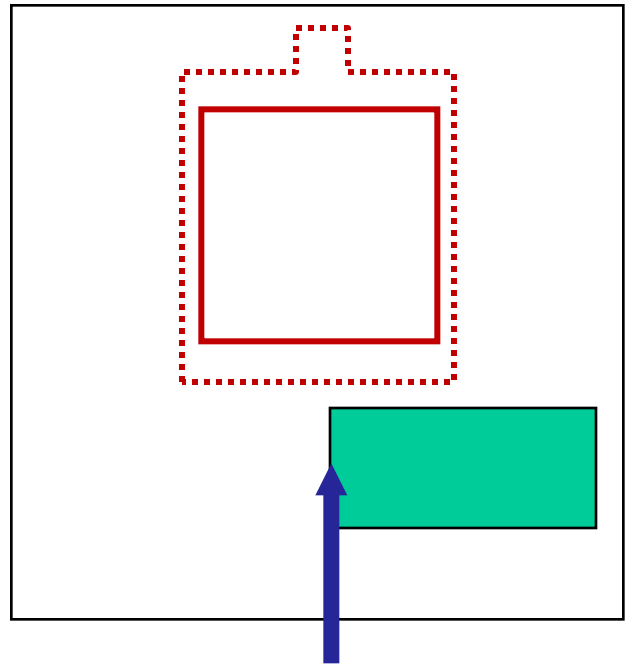
- For **scanned proton** beams: no collimators or compensator. Therefore current method is to define PTV

- Is this necessarily the best approach?

Do we need field specific PTV's?

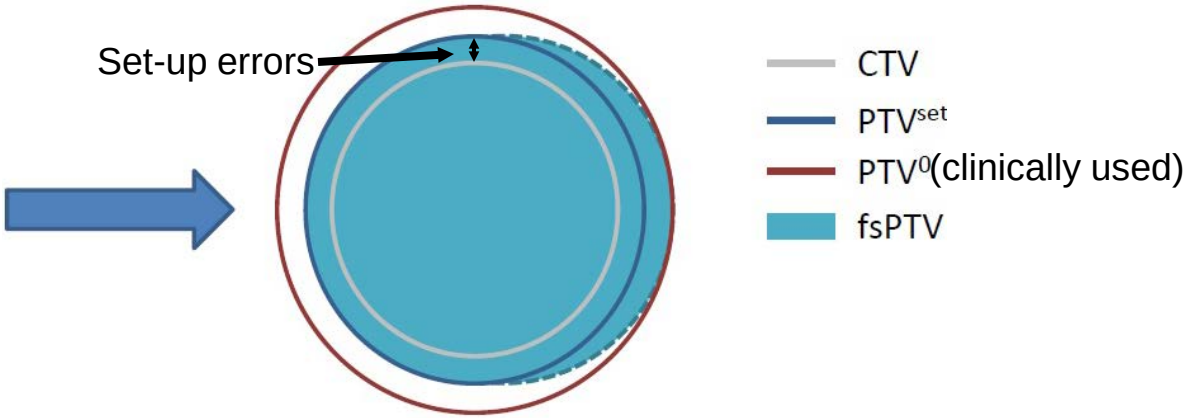


E.g. could be necessary if $\sigma_{pos} <> \sigma_{range}$



..or when passing along strong density interfaces (c.f. smearing of compensators)

Material and Methods

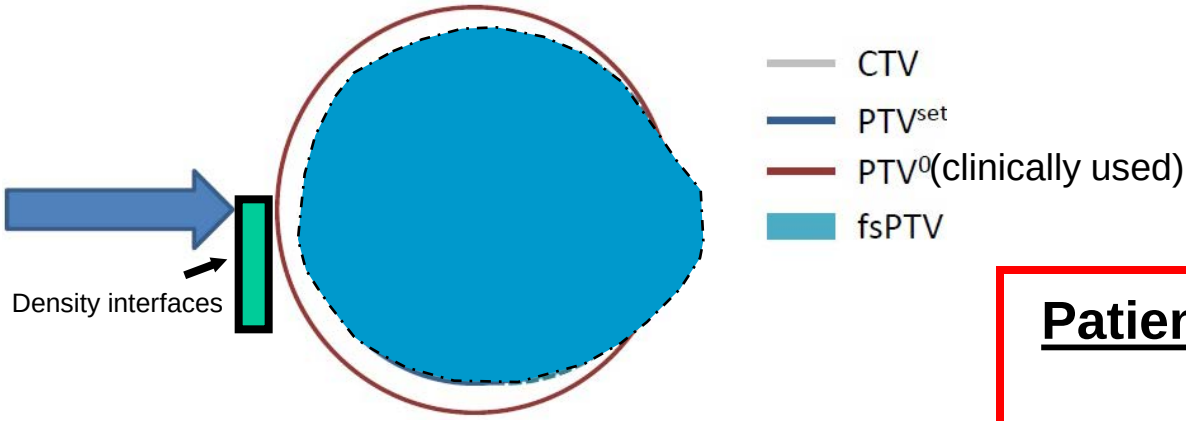


Field Specific PTV:

1) Pencil beams optimized on an artificially modified CT data set (HU +3%)

2) The dose is calculated on the nominal CT data set: this results in a **'planned-overshoot'** for each beam

Material and Methods



Field Specific PTV:

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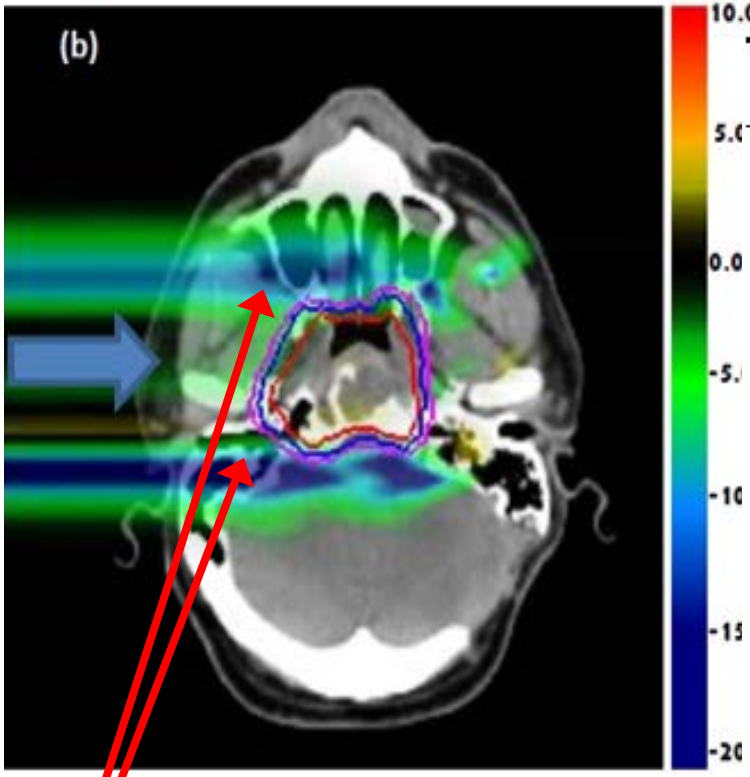
Patient data:

- 10 cases planned with **Single Field Uniform Dose (SFUD)** [and 10 cases with Intensity Modulated Proton Therapy (IMPT)]
- Dose distributions -PTV0 (isotropic) vs fsPTV - compared in terms of dose coverage of the CTV and sparing of healthy tissue.
- Plan robustness to range and set-up uncertainties have been assessed

Results: dose distributions

Difference dose distribution (PTVfs – PTV0)



	CTV				SFUD			Healthy Tissue
Patient	V_{95}	V_{95}^{fsPTV}	Δ		**Int**	**Int^{fsPTV}**	Δ	**Proport.**
1	100,0	100,0	0,0		15,19	13,22	-1,97	-5,9 %
2	100,0	100,0	0,0		9,62	8,26	-1,36	-14,1 %
3	100,0	100,0	0,0		12,70	11,56	-1,14	-9,0 %
4	100,0	99,9	0,0		13,10	10,80	-2,29	-17,5 %
5	100,0	100,0	0,0		12,16	10,55	-1,61	-15,4 %
6	99,8	99,6	-0,2		21,66	20,39	-1,27	-13,0 %
7	100,0	100,0	0,0		7,97	7,15	-0,82	-13,1 %
8	100,0	99,8	-0,2		4,67	3,95	-0,72	-13,2 %
9	99,9	99,7	-0,3		11,99	10,02	-1,97	-16,4 %
10	100,0	99,8	-0,2		15,22	13,23	-1,99	-10,3 %
	±0,4		**-0,1**	**±0,1**			**-1,5**	**±0,5** **-13±3,5**

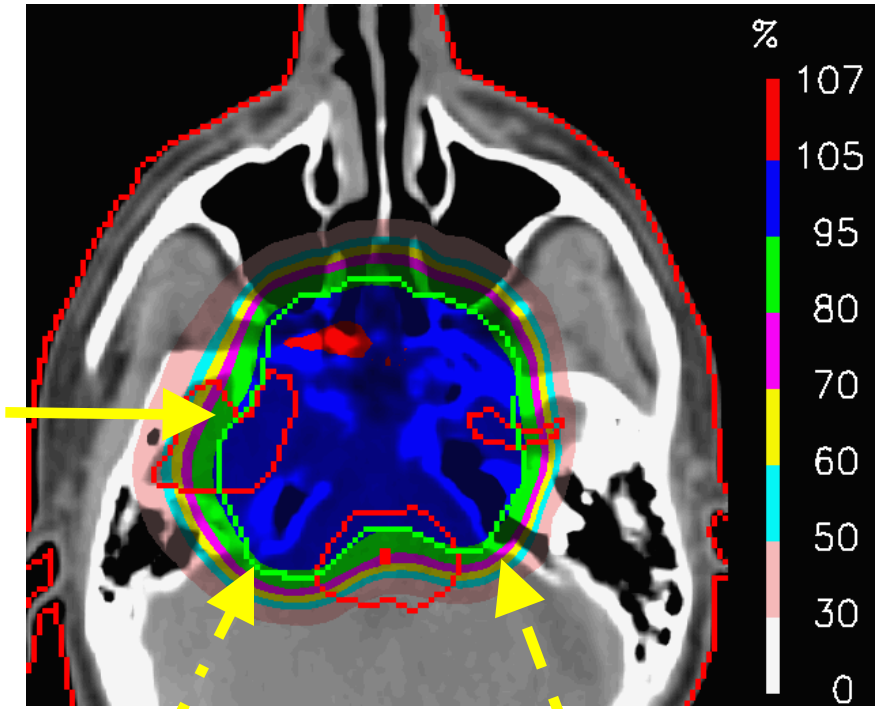
Lateral dose reduction

Reduction in the integral dose

Results: Robustness

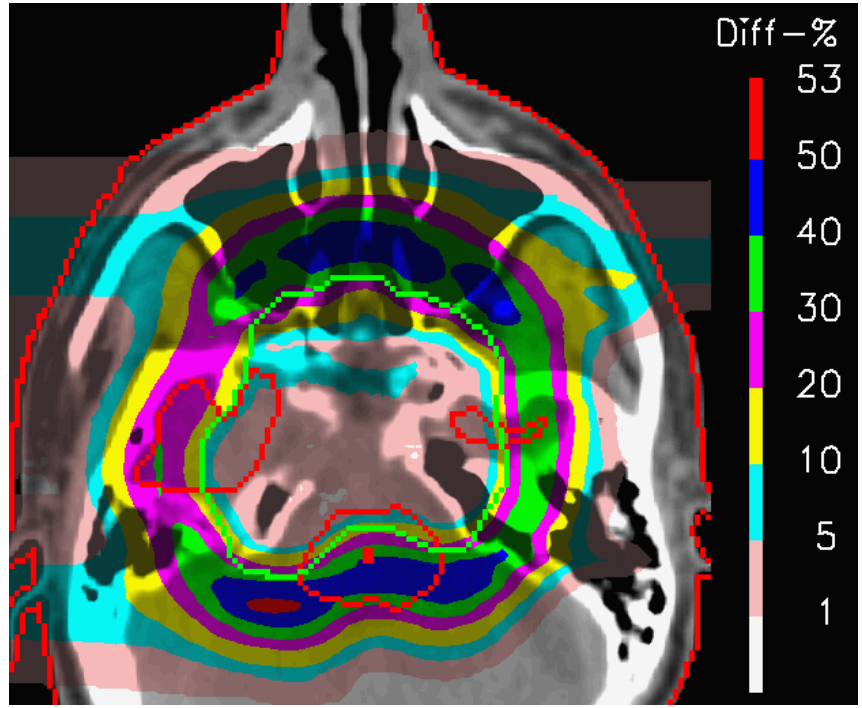
Nominal dose distributions

SFUD



Error-bar distribution

SFUD



Assess plan robustness:

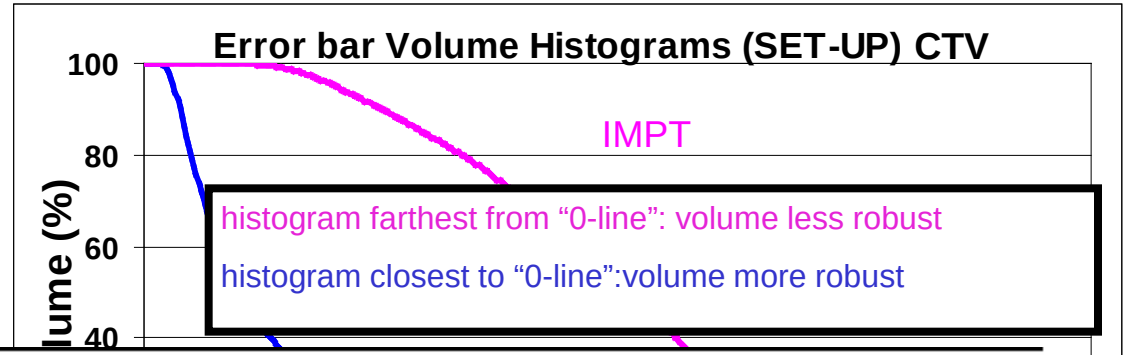
1. calculate n- ‘error’ dose distributions
2. reduce the data into an error-bar distribution

Albertini F et al, 2011 PMB

Results: Robustness

From ‘error-bar distribution’ it is possible to extract

‚Error –Bar Volume Histograms‘ and Metrics (e.g. E5%)



SFUD CTV

	RANGE underdosage uncertainties (%)						SETUP underdosage uncertainties (%)					
patient	E_2	E_2^{fsPTV}	Δ	E_5	E_5^{fsPTV}	Δ	E_2	E_2^{fsPTV}	Δ	E_5	E_5^{fsPTV}	Δ
1	4,2	3,7	-0,5	2,5	2,3	-0,2	11,1	12,2	1,1	8,0	8,9	0,9
2	1,8	2,1	0,3	1,4	1,8	0,4	11,2	15,9	4,7	8,0	12,9	4,9
3	2,6	2,1	-0,5	1,4	1,6	0,2	13,4	14,6	1,2	9,2	10,2	1,0
4	18,0	16,7	-1,3	12,6	12,5	-0,1	30,1	36,8	6,7	24,7	30,7	6,0
5	2,6	3,1	0,5	1,8	2,4	0,6	12,9	23,0	10,1	9,6	15,5	5,9
6	10,3	8,8	-1,5	6,3	6,2	-0,1	20,7	24,2	3,5	14,3	17,1	2,8
7	9,9	8,0	-1,9	6,2	6,2	0,0	21,0	24,8	3,8	14,6	17,6	3,0
8	9,5	8,4	-1,1	6,1	7,2	1,1	17,4	21,2	3,8	11,6	14,6	3,0
9	2,4	3,0	0,6	1,6	2,2	0,6	6,4	9,6	3,2	4,9	7,8	2,9
10	3,6	3,0	-0,6	2,6	2,2	-0,4	25,0	25,0	0,0	22,2	22,2	0,0
			-0,6	**±0,9**		**0,2**	**±0,5**			**4**	**±3**	**3**	**±2**

Summary

- **The use of a PTV achieved by isotropically expanding the CTV is not the optimal solution as range errors affect the dose distribution mainly in the distal part of the target.**

- **The fsPTV here proposed is easy to implement clinically AND it shows a great potential for reducing dose to healthy tissue and improving the morbidity of patients.**

- **The use of fsPTV improves the plan robustness to range uncertainties (for SFUD plans).**

Limitations:

- **Hypo-fractionation with big set-up uncertainties (impact of set-up and range errors are comparable)**
- **Critical for fields crossing high density and abutting against OAR**
- **IMPT plans**

Thank you