In Silico Comparison of Photons versus Carbon Ions in Single Fraction Therapy of Lung Cancer

Kristjan Anderle

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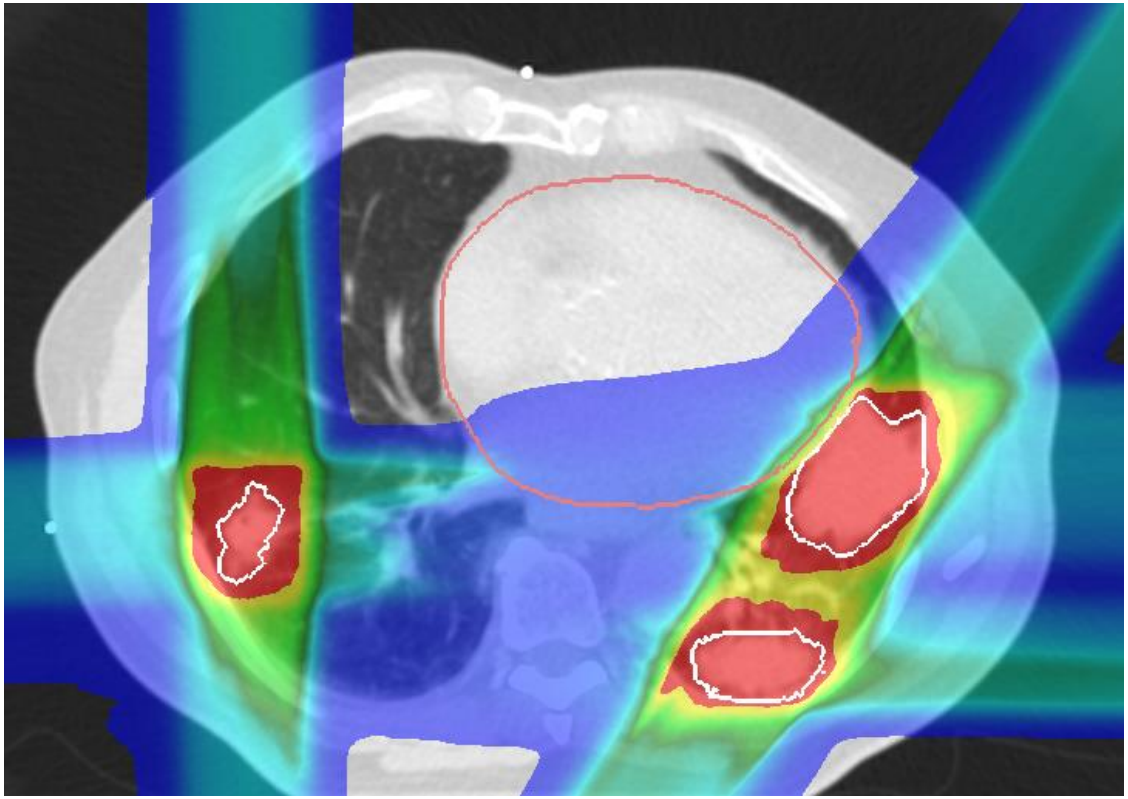
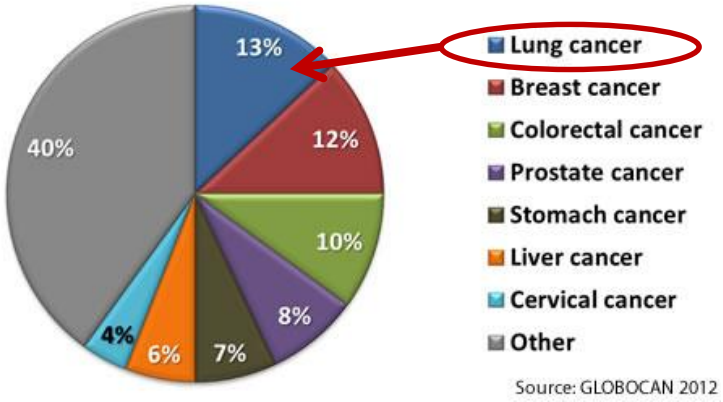
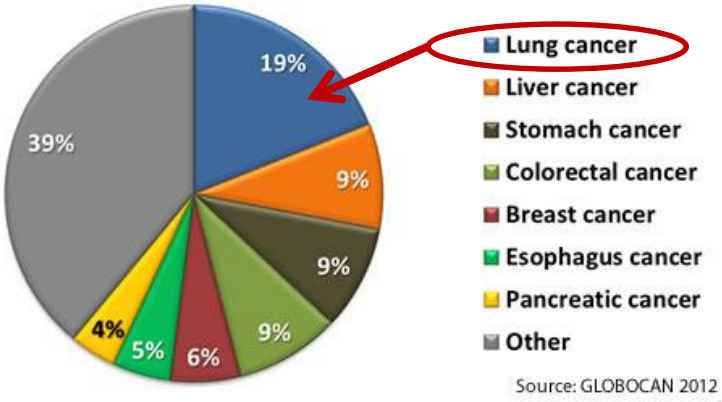


Introduction





Stereotactic Body Radiation Treatment (SBRT)

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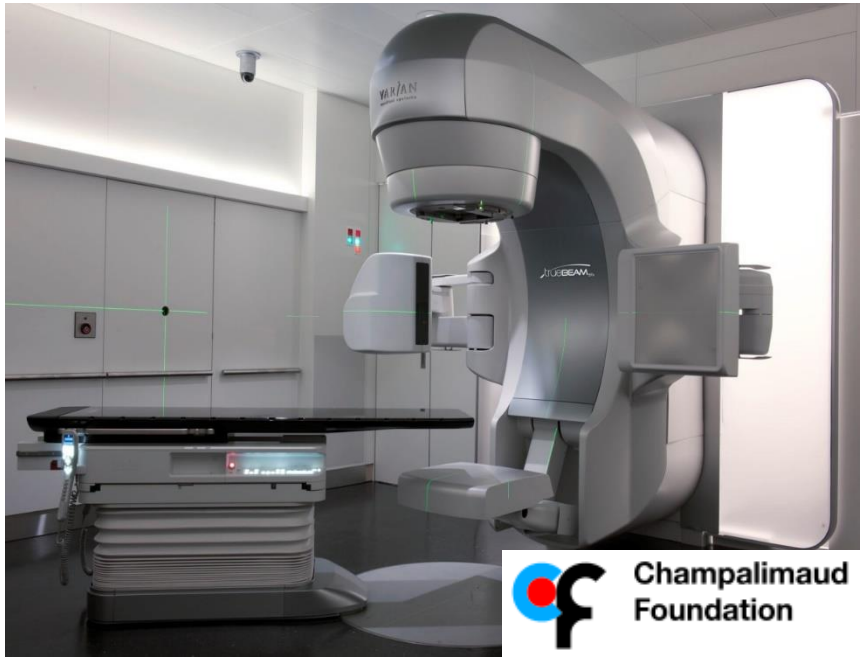
- High precision treatment with photons
- Delivers high dose (up to 30 Gy) in few fractions (1-3)
- Good results for lung cancer in early stages
- Limited for:
  - Multiple tumors
  - Large tumors



3D Treatment Plan Example

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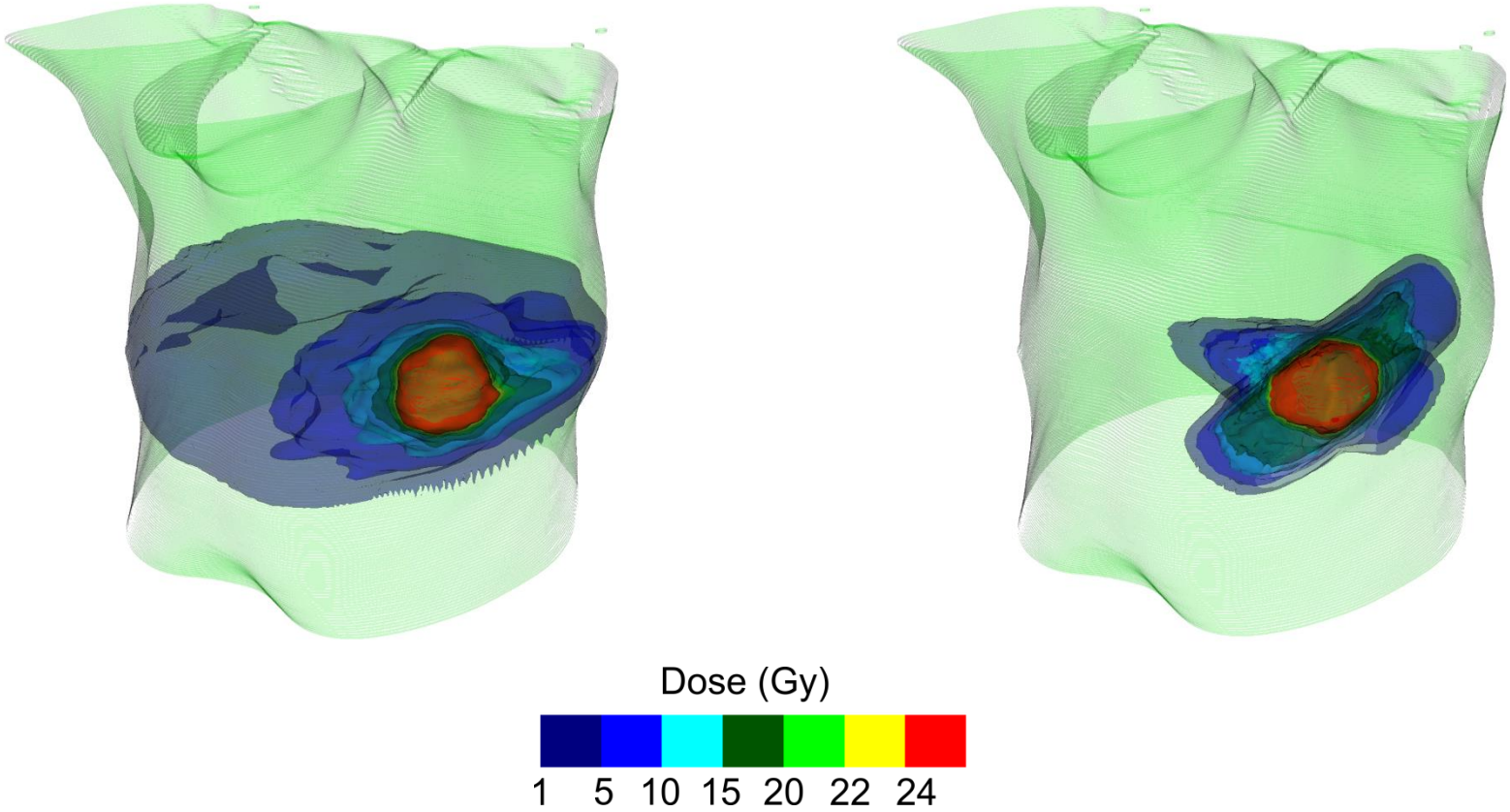
Photons

^{12}C



Particle Therapy

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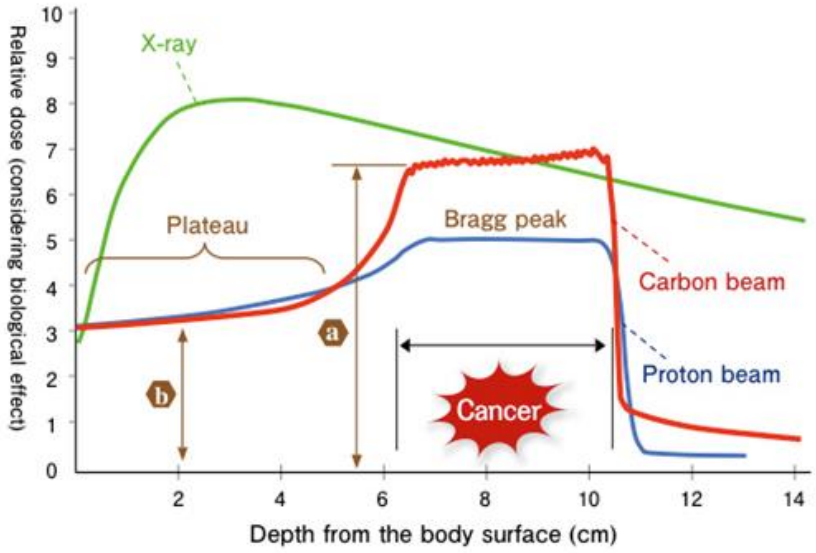
- Advantageous dose profile for radiotherapy
- Bragg peak depends on particle energy
- No or small dose tail after the Bragg peak
- Currently, mostly static targets are treated (head & neck, pelvic)



Source:NIRS,2016

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Motion Effects in Particle Therapy

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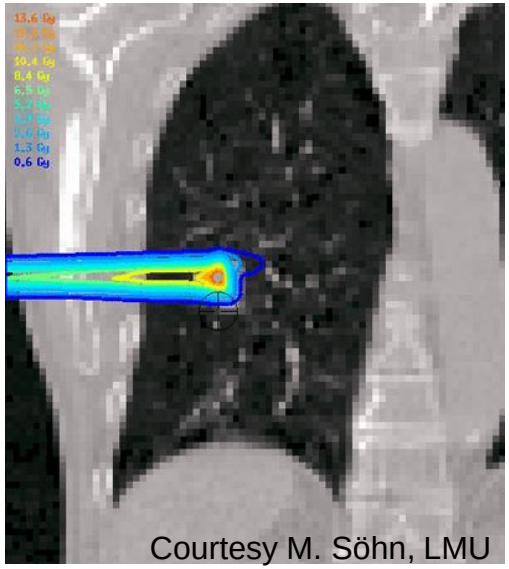
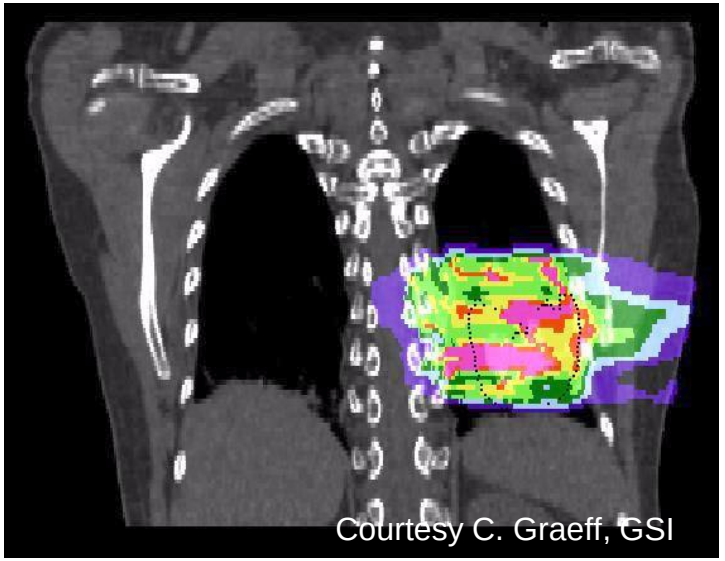
Range Changes



Interplay



Motion Effects in Particle Therapy

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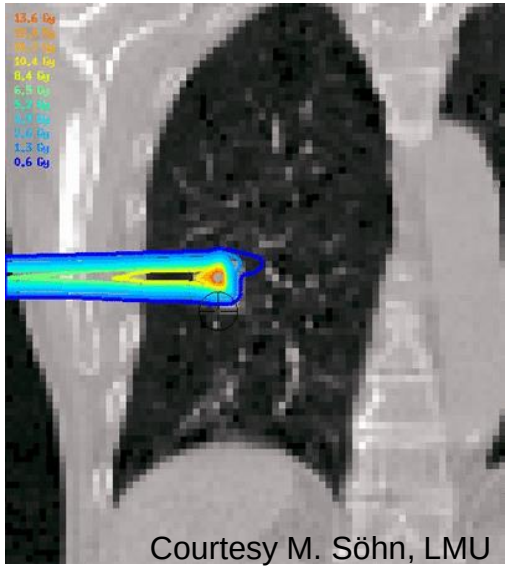

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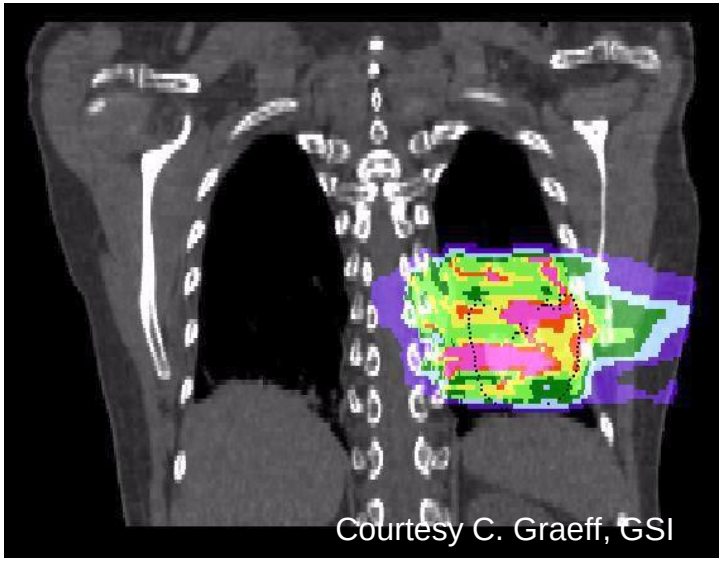

Compensations:

- Include range-changes in target definition (range ITV)
- Optimization in all motion states (4D-optimization)

- Rescanning: instead of delivering the whole dose at once, it is delivered in N steps

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In Silico Study

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- Comparison of lung cancer treatment simulations between **SBRT** and active scanning carbon-ions (**PT**)

- 23 lung cancer patients were actually treated with SBRT

- Comparison:
  - Dose to the tumor
  - Dose to critical organs
  - Dose escalation

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Treatment planning – Cohort I

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- 19 patients, 26 tumors
- Planning objectives:
  - Single fraction of 24 Gy
  - Tumor $D_{99\%}$ > 100%
  - Critical organs limits
- Single field uniform optimization with range ITV
- 10 dose calculations per patient:
  - Without motion, static (end-inhale and end-exhale)
  - With motion, without compensation, 4D-interplay (4x)
  - With motion, with compensation, 4D-rescanning (4x)

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Treatment Plan Examples

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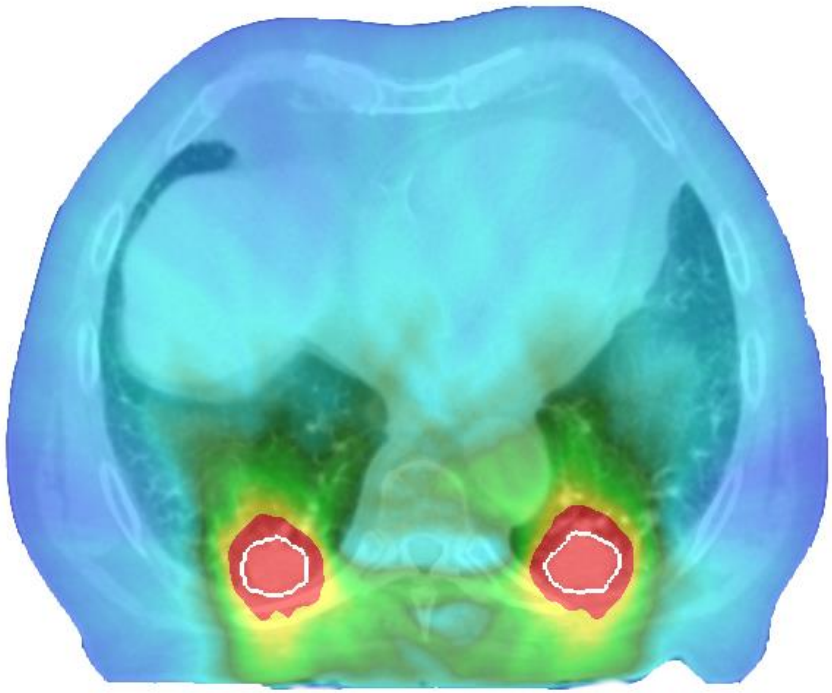

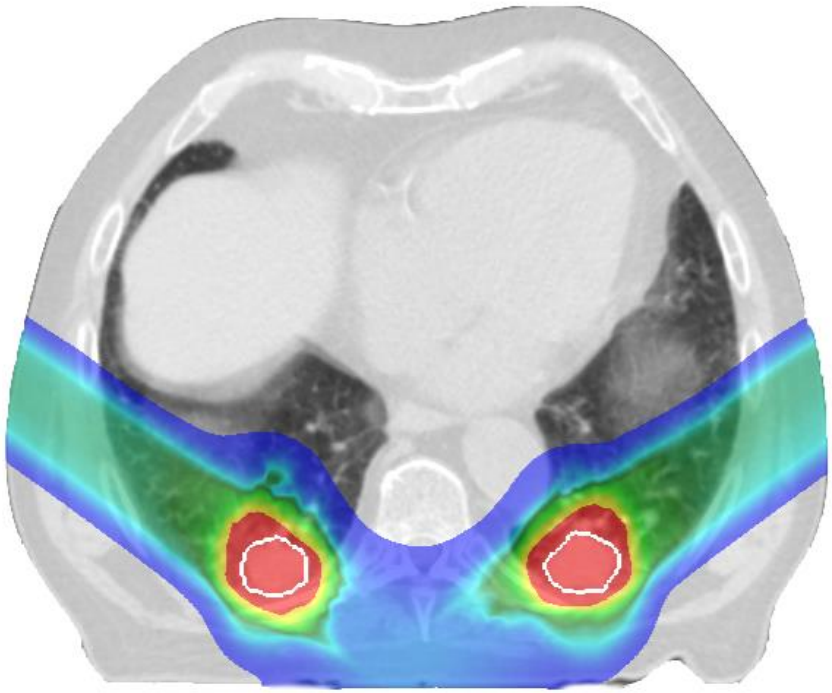

SBRT **PT**

Dose (%)

0 25 50 75 100

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Treatment Plan Examples

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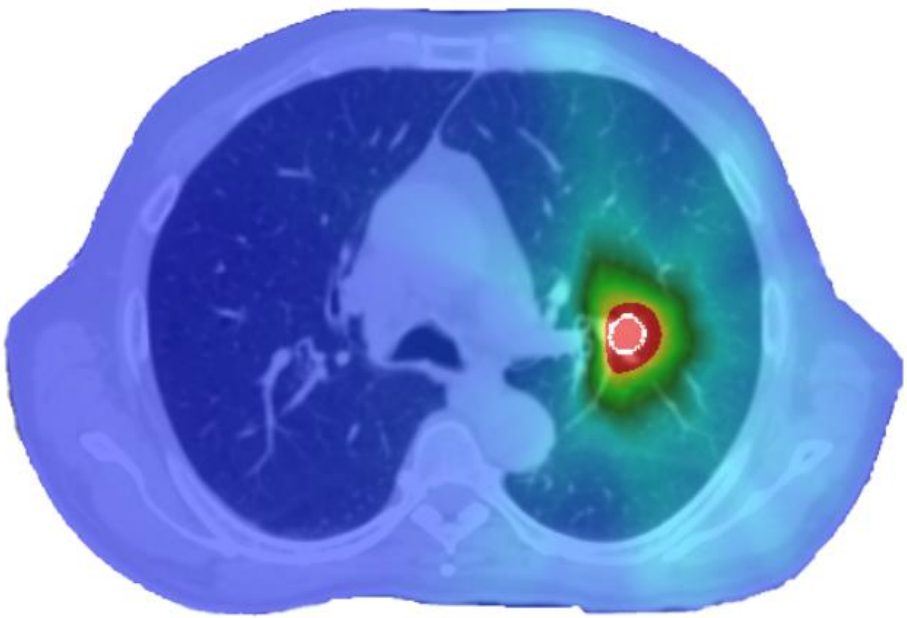

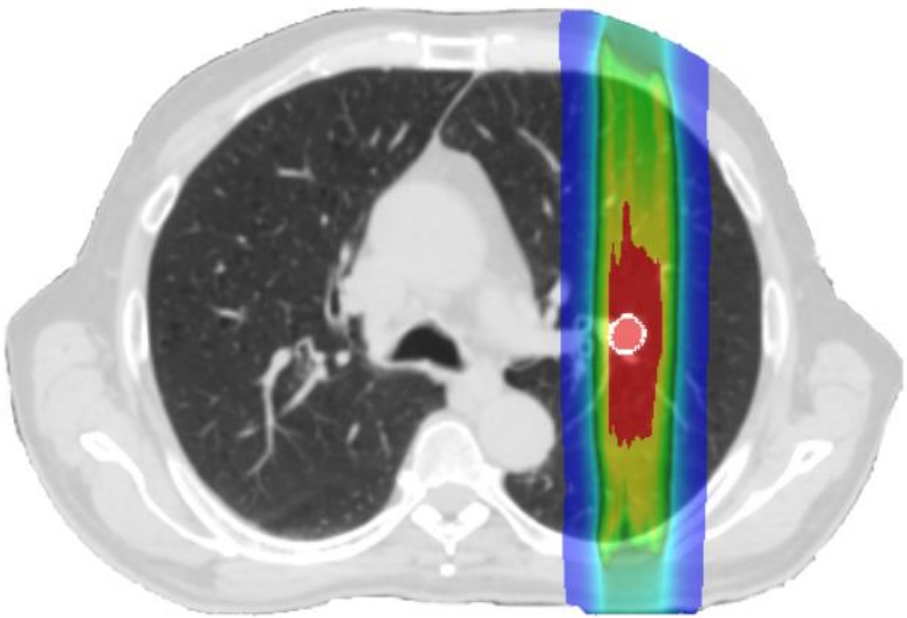

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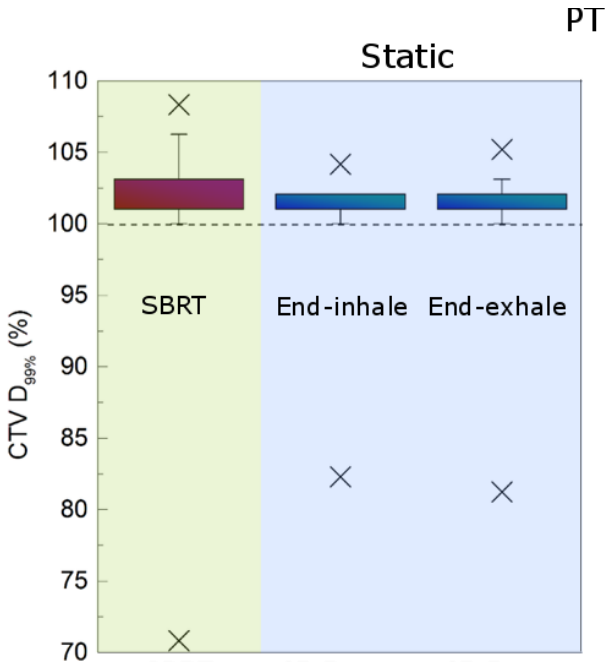
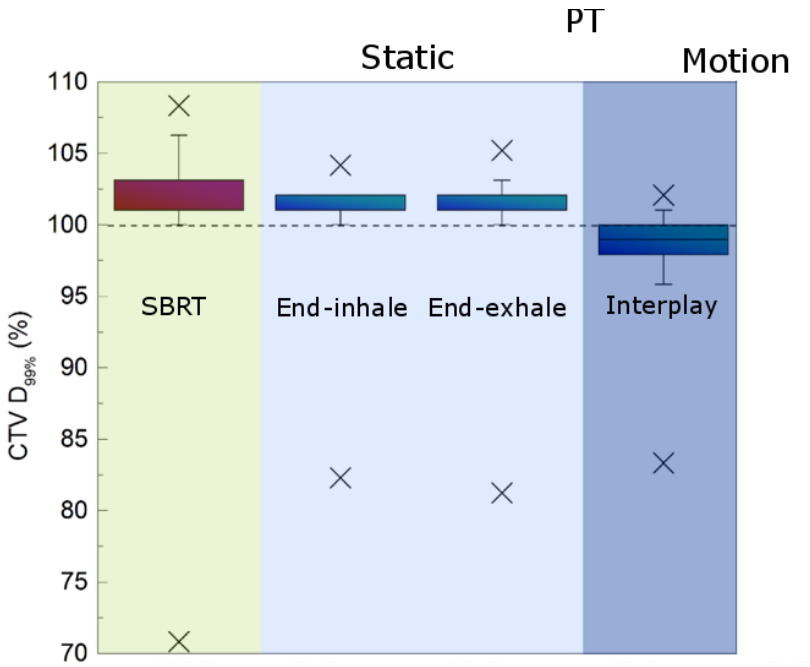
Results – Dose to Tumors

- No difference in tumor dose between SBRT and static PT (3D)



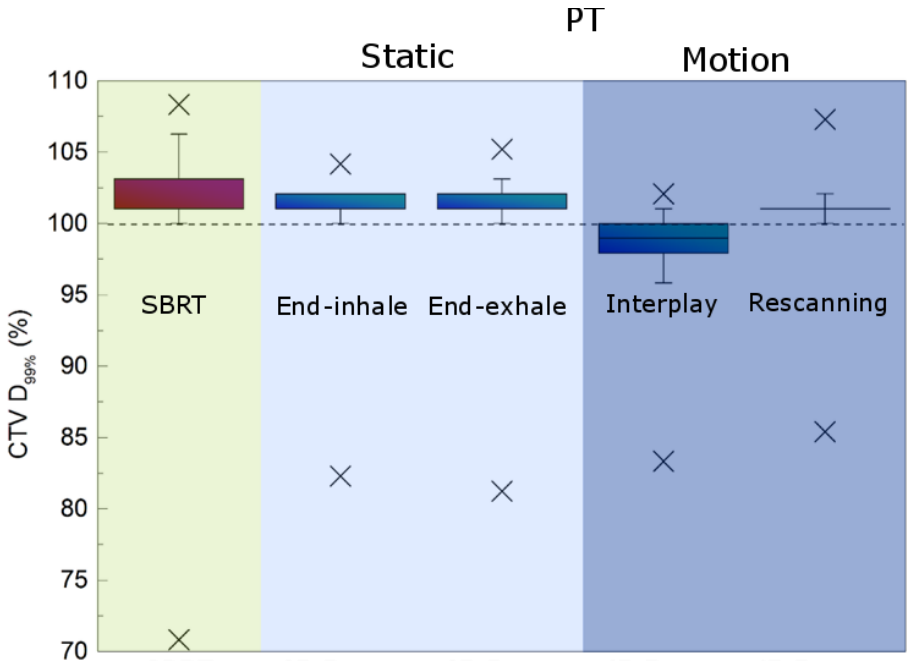
Results – Dose to Tumors

- No difference in tumor dose between SBRT and static PT (3D)
- Without motion compensation the tumor dose is too low (4D interplay)

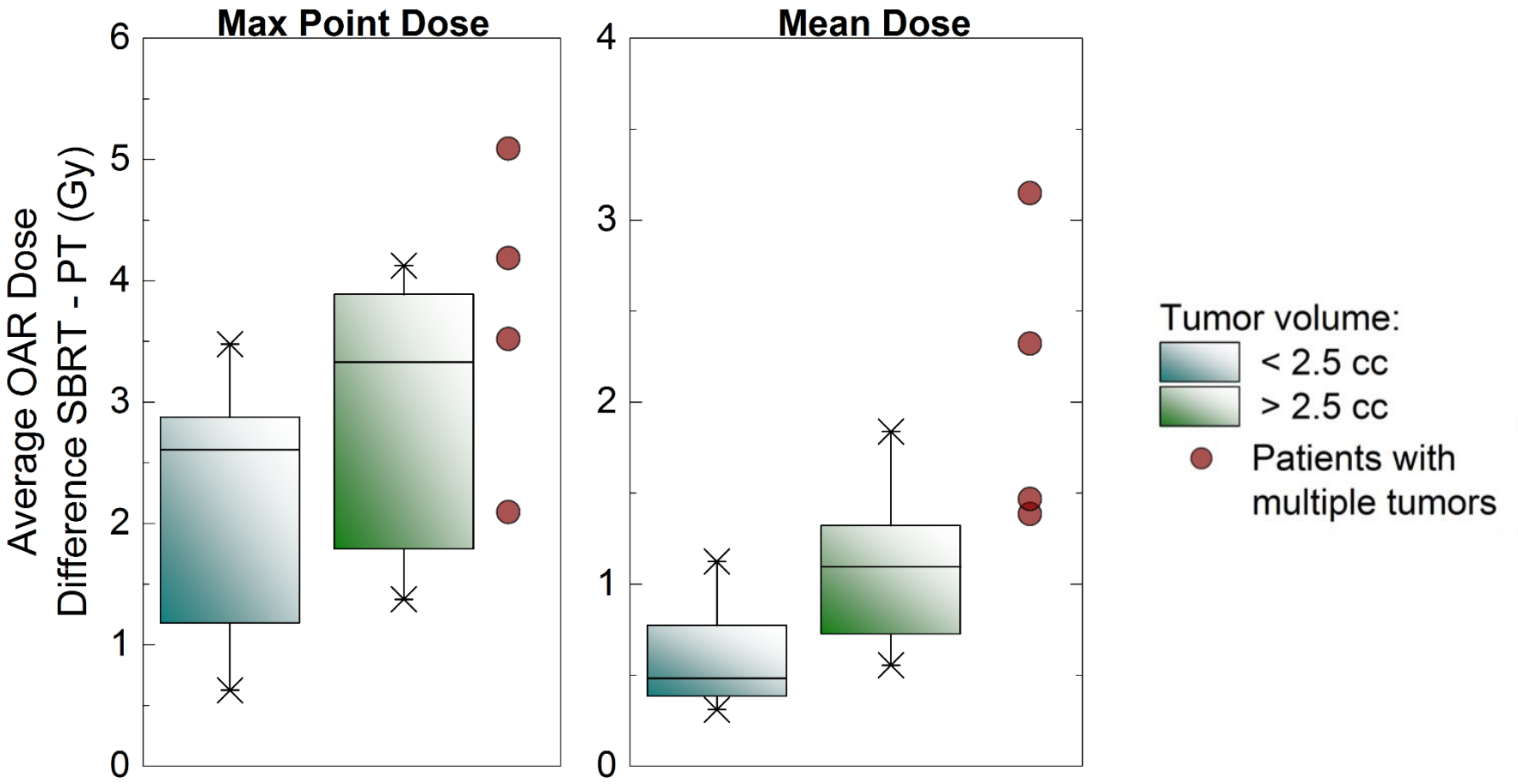


Results – Dose to Tumors

- No difference in tumor dose between SBRT and static PT (3D)
- Without motion compensation the tumor dose is too low (4D interplay)
- Rescanning mitigates tumor motion sufficiently (4D rescan)



Results - Dose to Critical Organs

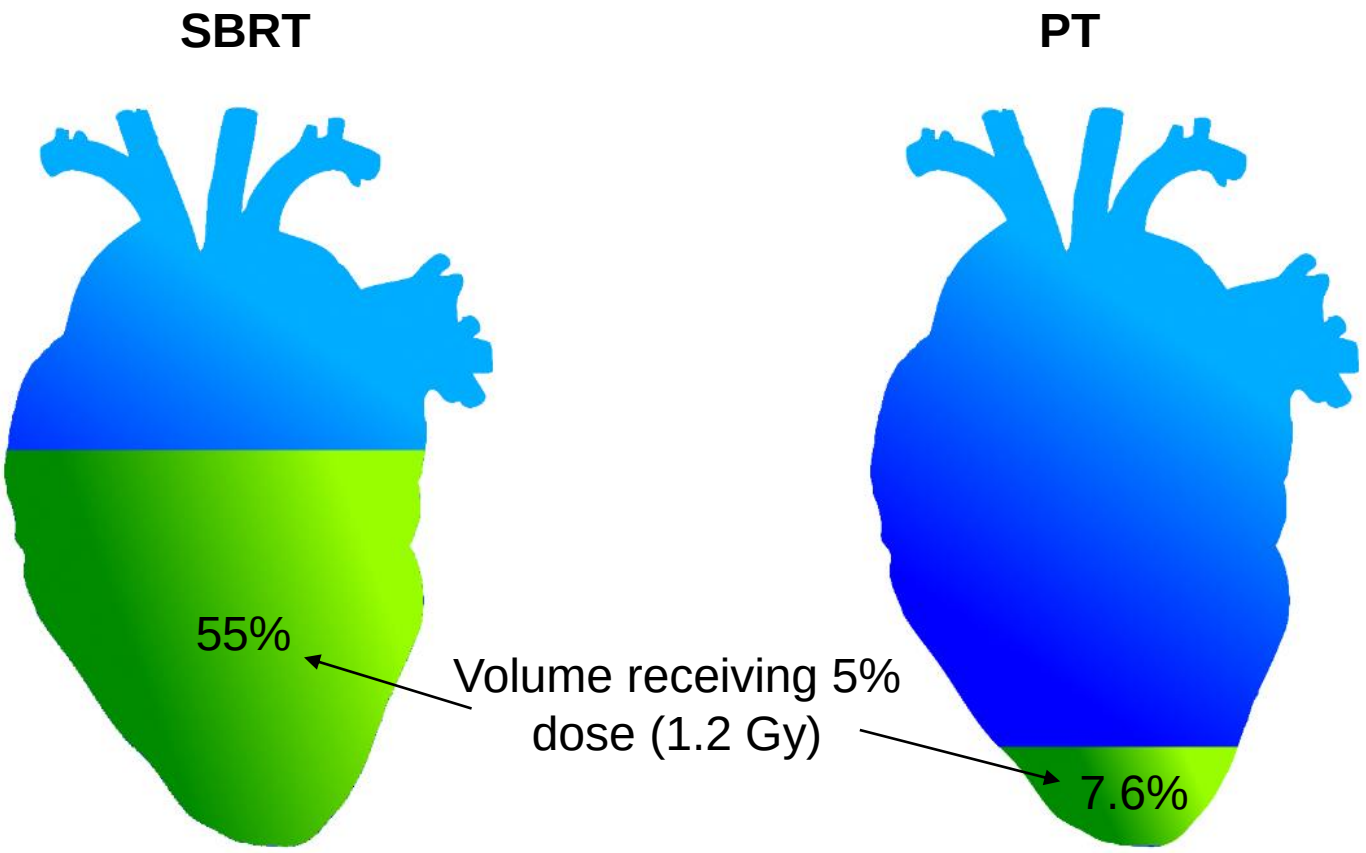


Clinical Trial RTOG 0617

- A RTOG 0617 trial compared 60 Gy and 74 Gy dose to tumors
- In contrast to inital hypothesis, higher dose led to higher mortality
- The only significant difference between two groups was dose to the heart (V5)

(Bradley, JD et al, Lancet Oncology, 2015)

Average Heart V5



Treatment planning – Cohort II

- 8 patients, 24 tumors
- Different fractionation schemes
  - 3 tumors in 2 patients received 3 x 9 Gy
  - 2 tumors received 1 x 20 Gy
  - 1 tumor received 1 x 22 Gy
  - 1 tumor received 5 x 7 Gy
  - All others 1 x 24 Gy
- Intensity modulated particle therapy optimization with rescanning
  - Range ITV
  - 4D-optimization

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Intensity Modulated Particle Therapy Optimization for Multiple Targets

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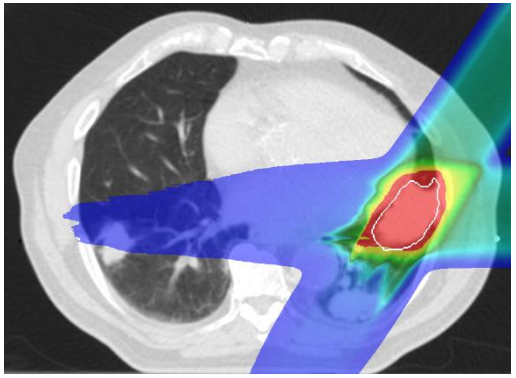
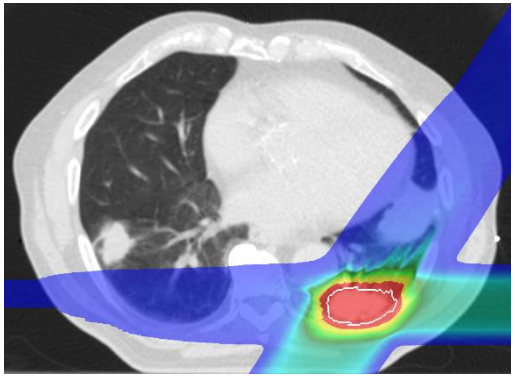
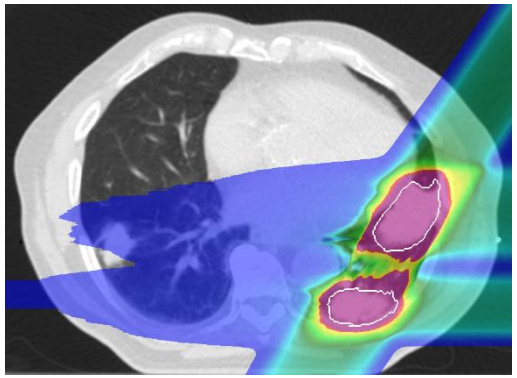
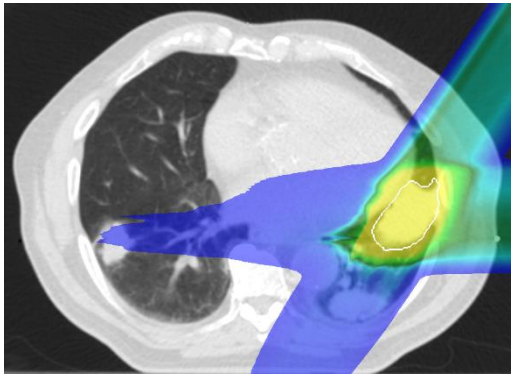
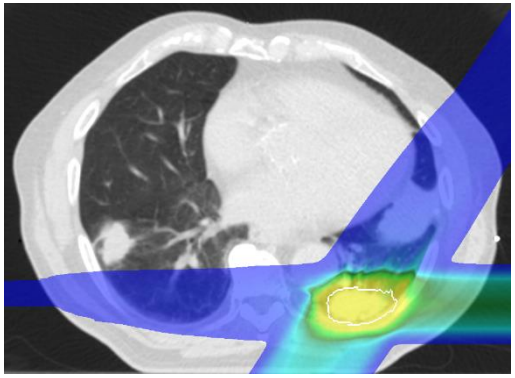
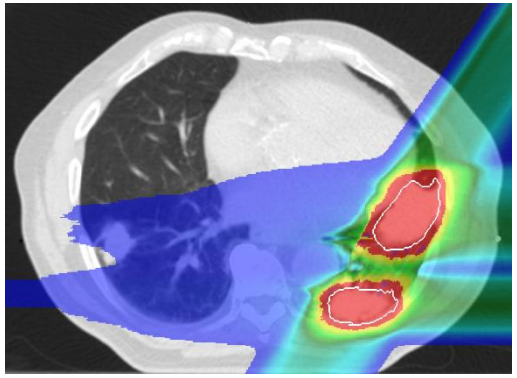
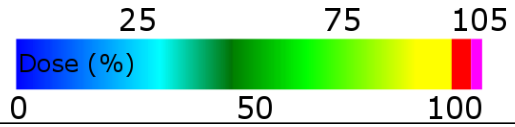
	Target 1	Target 2	Target 1 & 2
Each target optimized individually:			
Targets optimized simultaneously:			



Treatment Plan Examples

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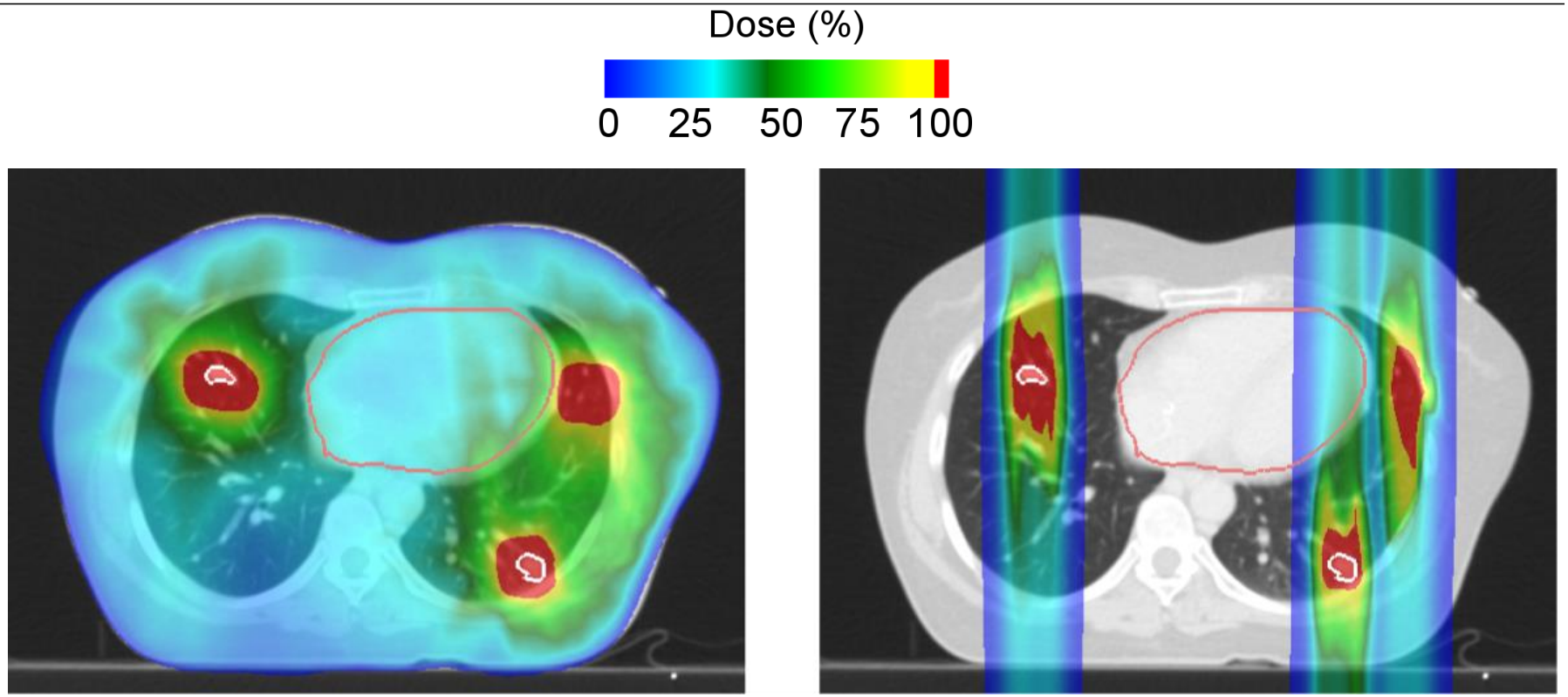

SBRT **PT**

All 5 targets received planned dose with SBRT and PT (CTV $D_{99\%}$ > 100 %)

Treatment Plan Examples

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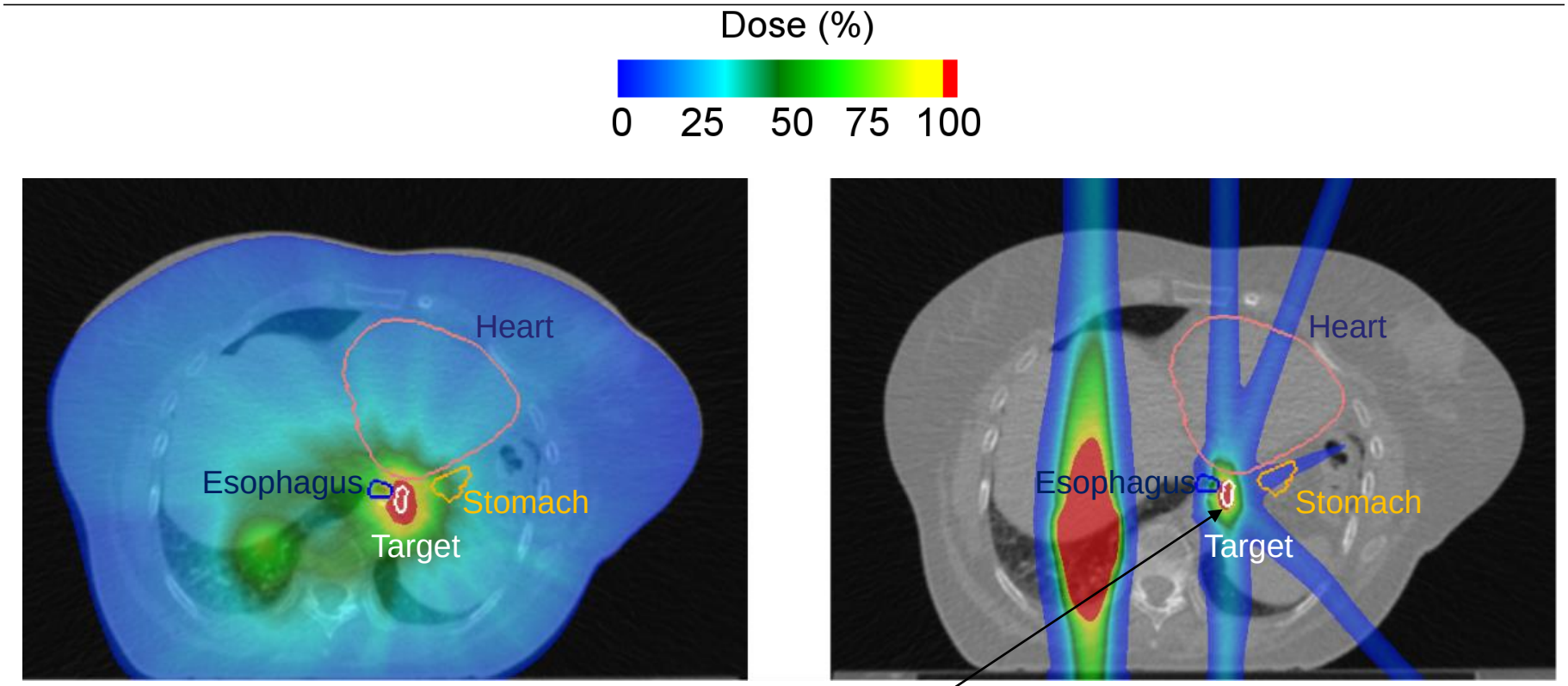
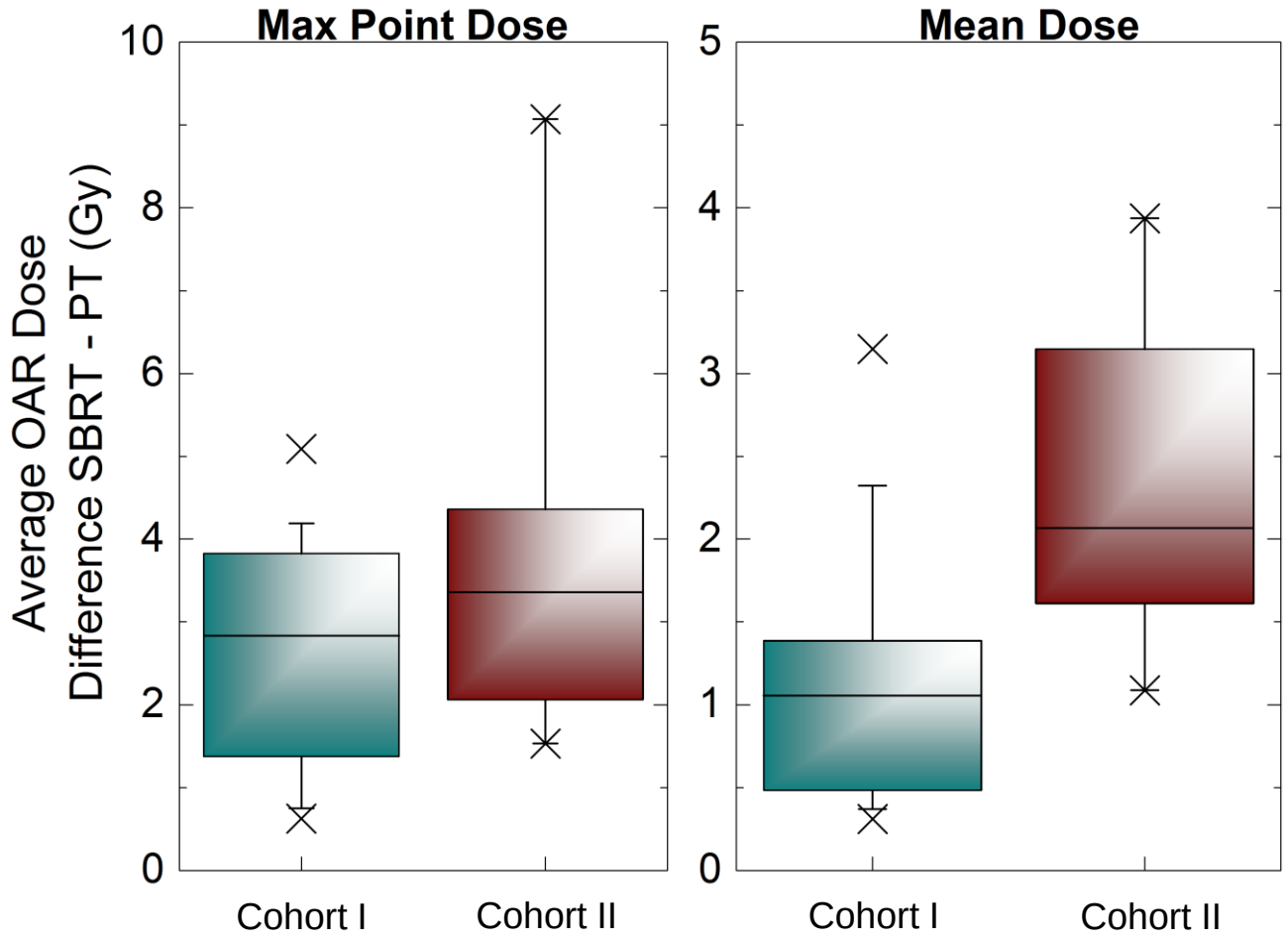


SBRT **PT**

Planning dose not met with PT
(SBRT $D_{99\%}$ = 100%, PT $D_{99\%}$ = 75%)

Results – Dose to Critical Organs



Average Heart V5

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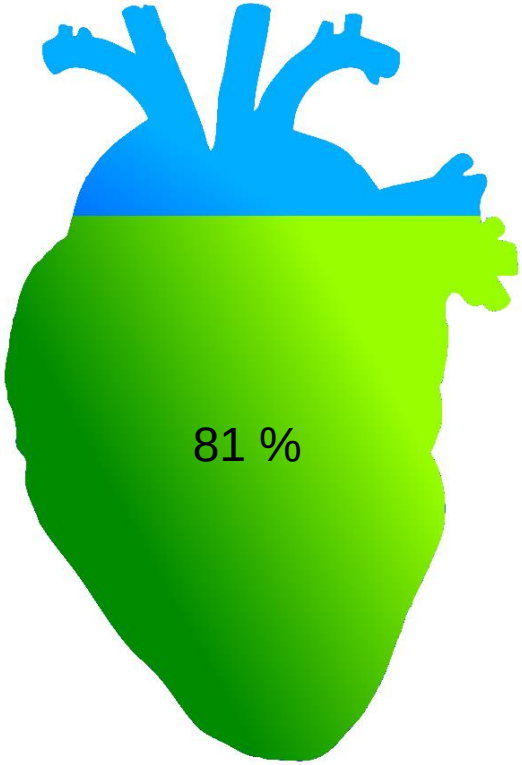
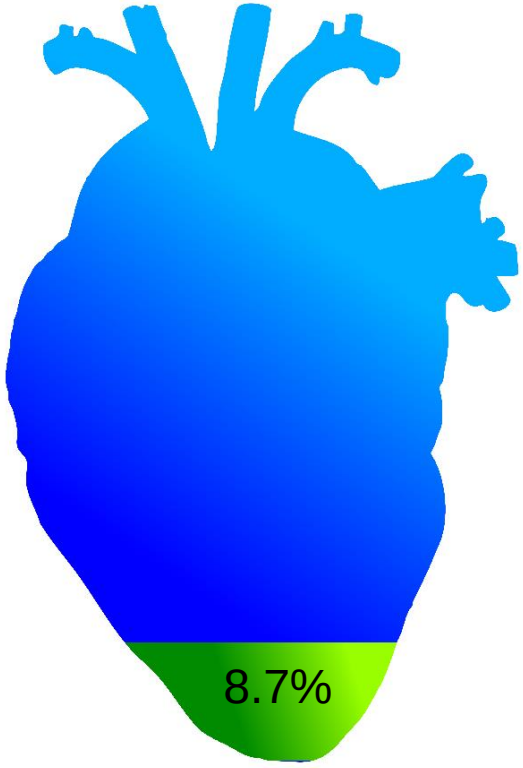
SBRT



PT



Results – Dose Escalation

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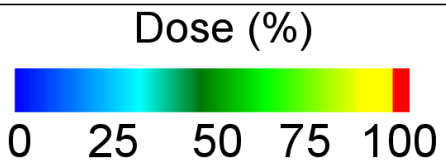
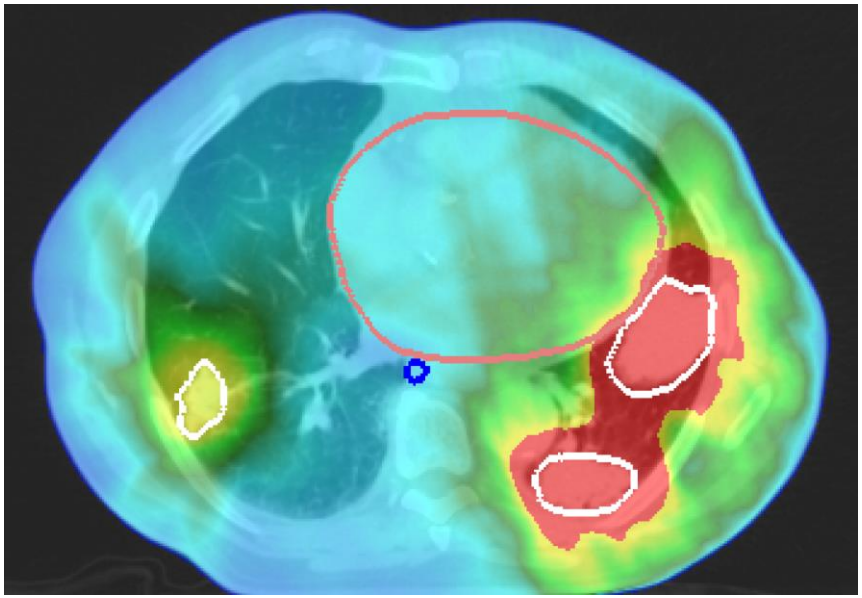
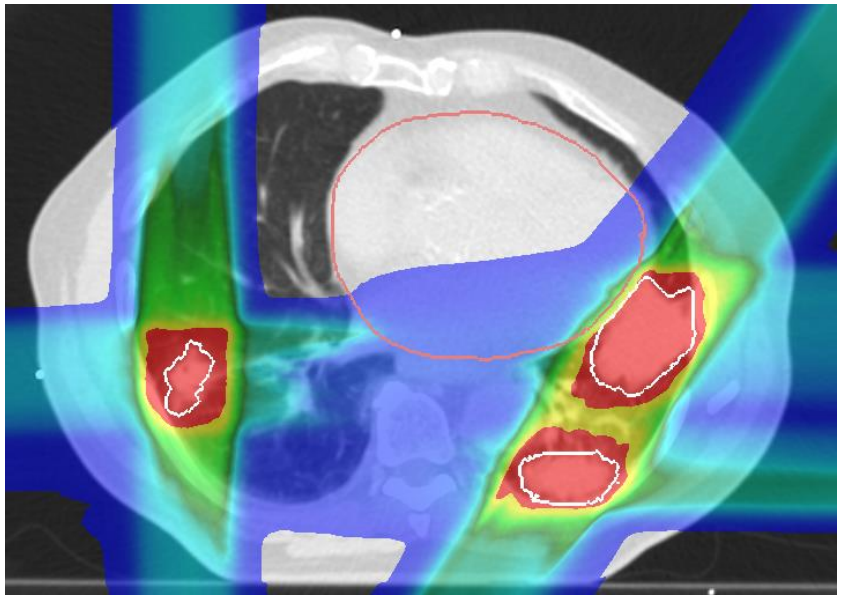


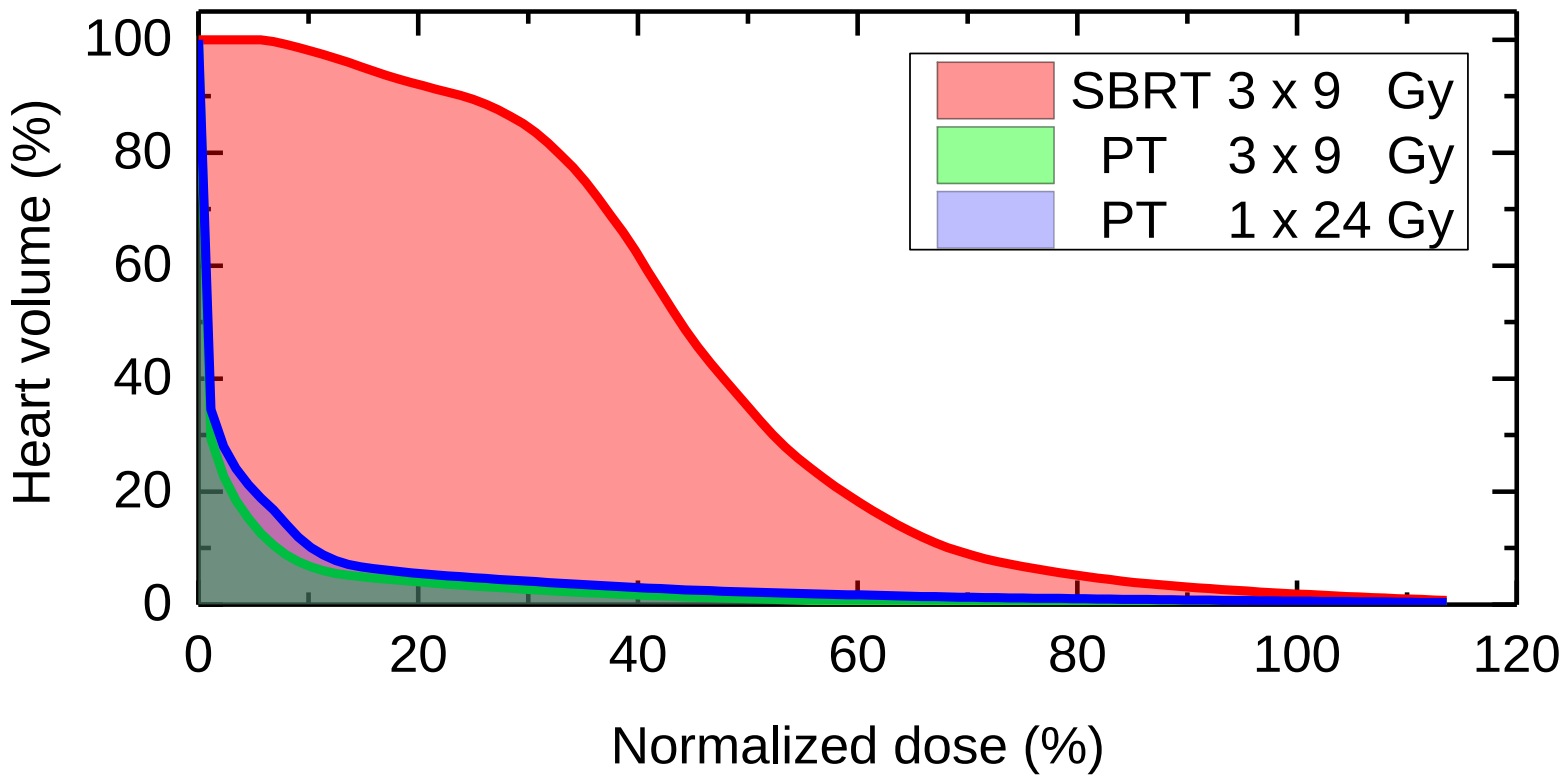




1 tumor: 1 x 22 Gy
2 tumors: 1 x 21 Gy
2 tumors: 3 x 9 Gy

5 tumors: 1 x 24 Gy

Heart Dose Volume Histogram



Conclusions

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- PT delivers the same dose to tumors as SBRT,
  while depositing significantly less dose to normal tissue

- PT could deliver full ablative dose in single fraction,
  where SBRT could not

- Patient selection for PT:
  - ✓ Multiple targets
  - ✓ Large tumors
  - x Small tumors with large motions

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Outlook

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- First lung cancer patients treated with active scanning carbon-ions at NIRS, Chiba (Japan)

- As part of a LOEWE grant, results from this study will be used for actual lung cancer treatment at MIT – especially the multiple target case.

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