PAUL SCHERRER INSTITUT

PSI

ETH zürich

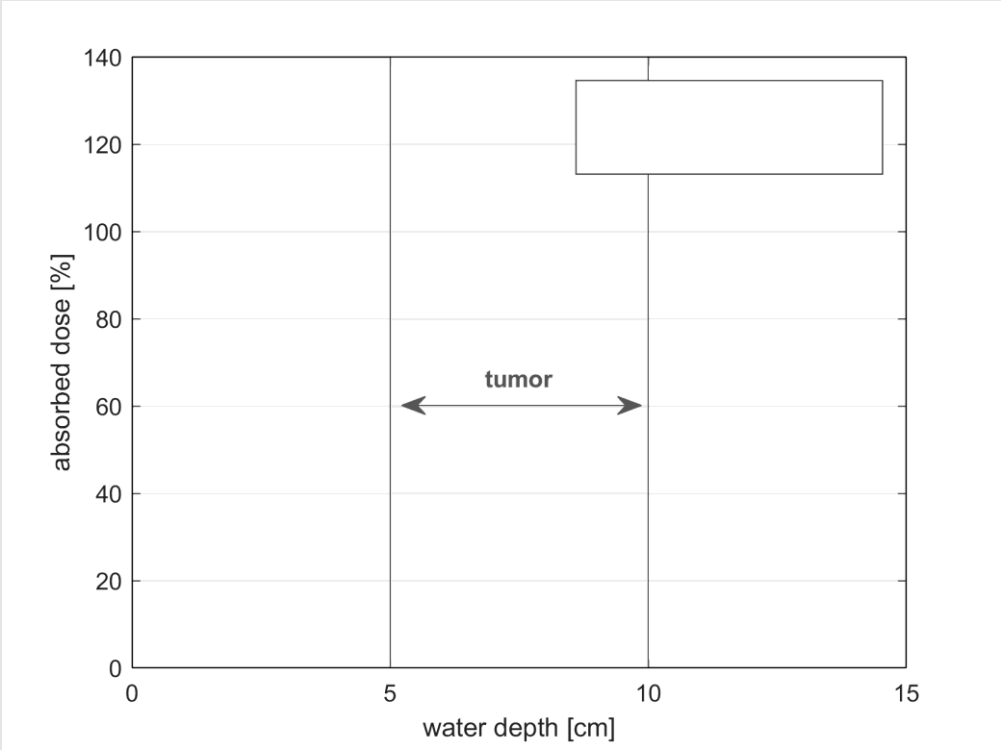
BRIDGE

Vivek Maradia :: Center for Proton Therapy :: Paul Scherrer Institute

Ultra-fast treatment delivery to enhance the potential of proton therapy

08.09.2023 :: SPS and APS annual meeting :: Basel

The advantages of proton therapy



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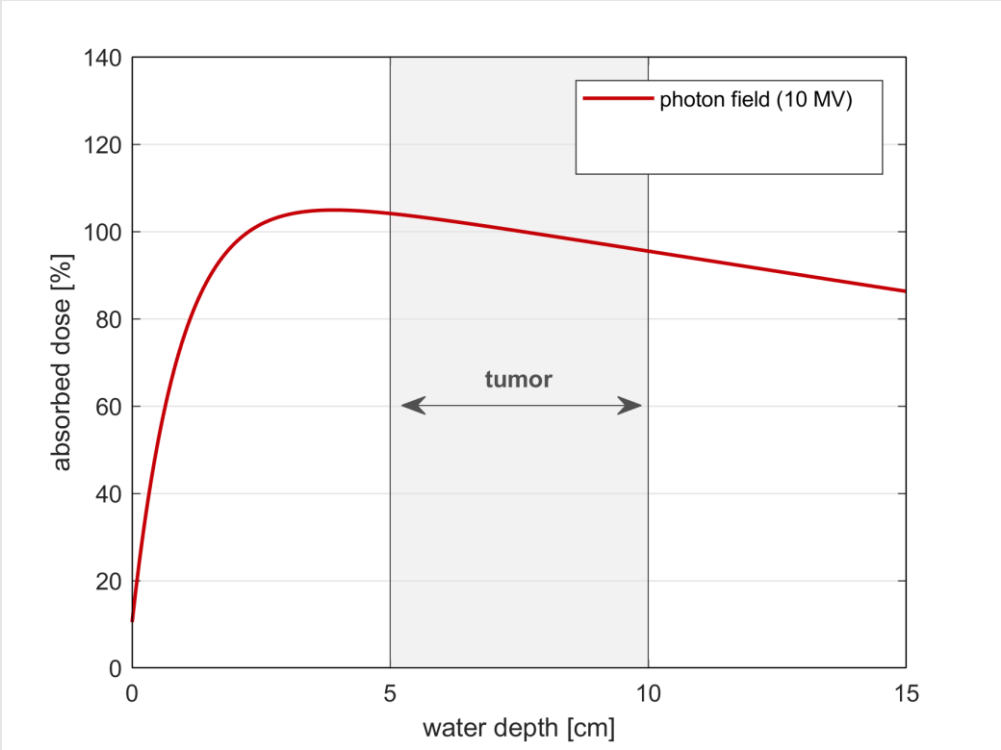

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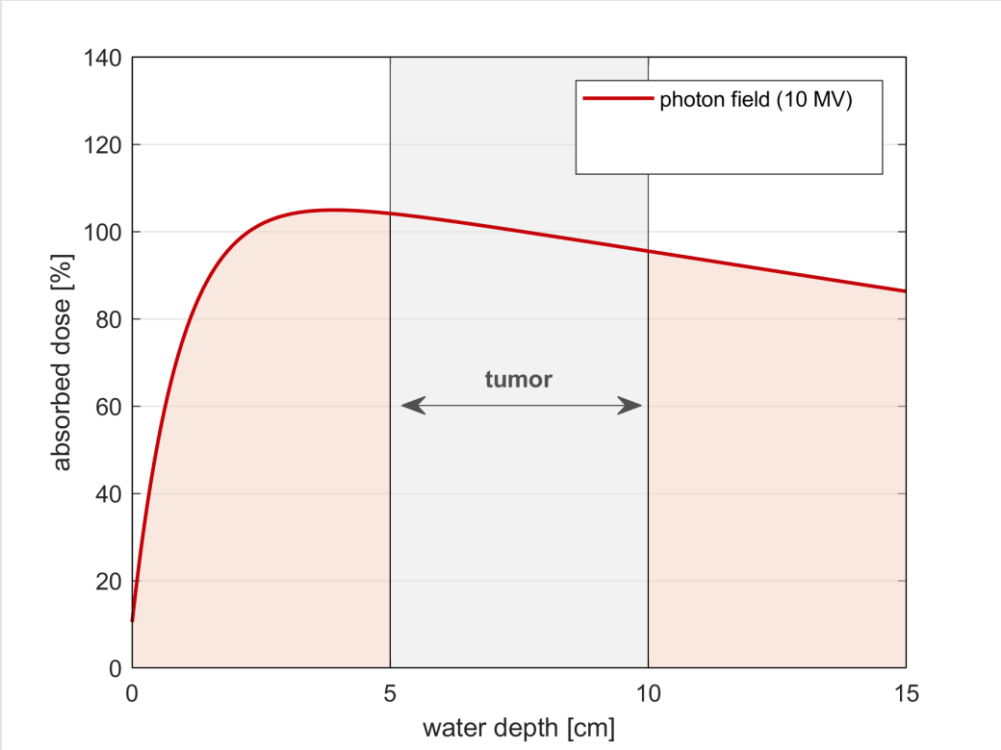

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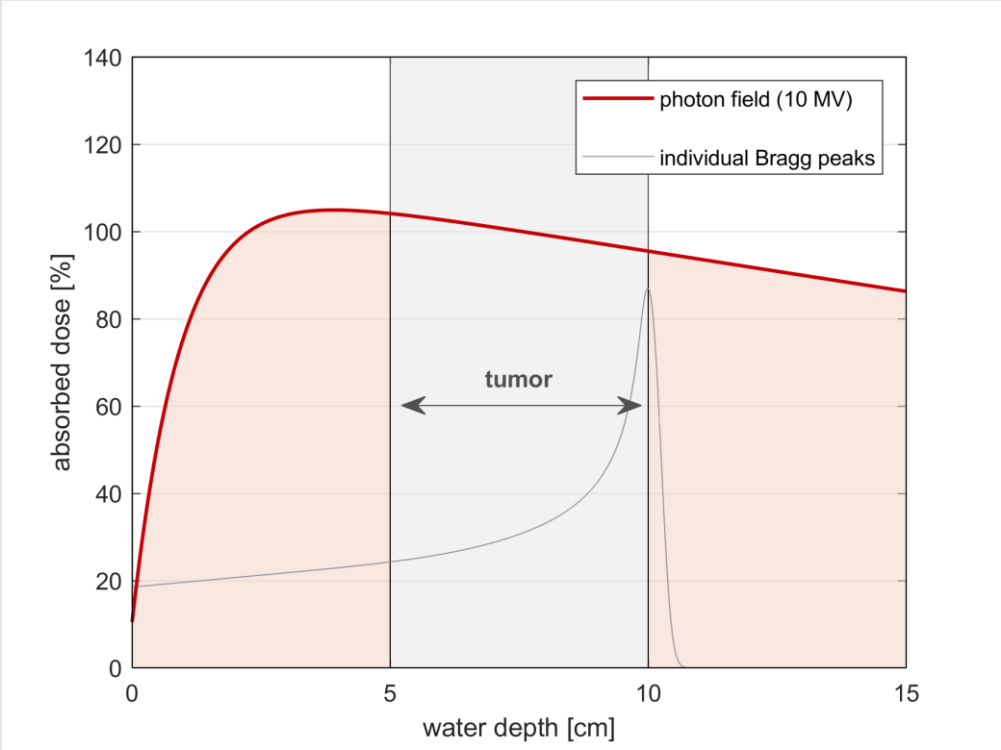

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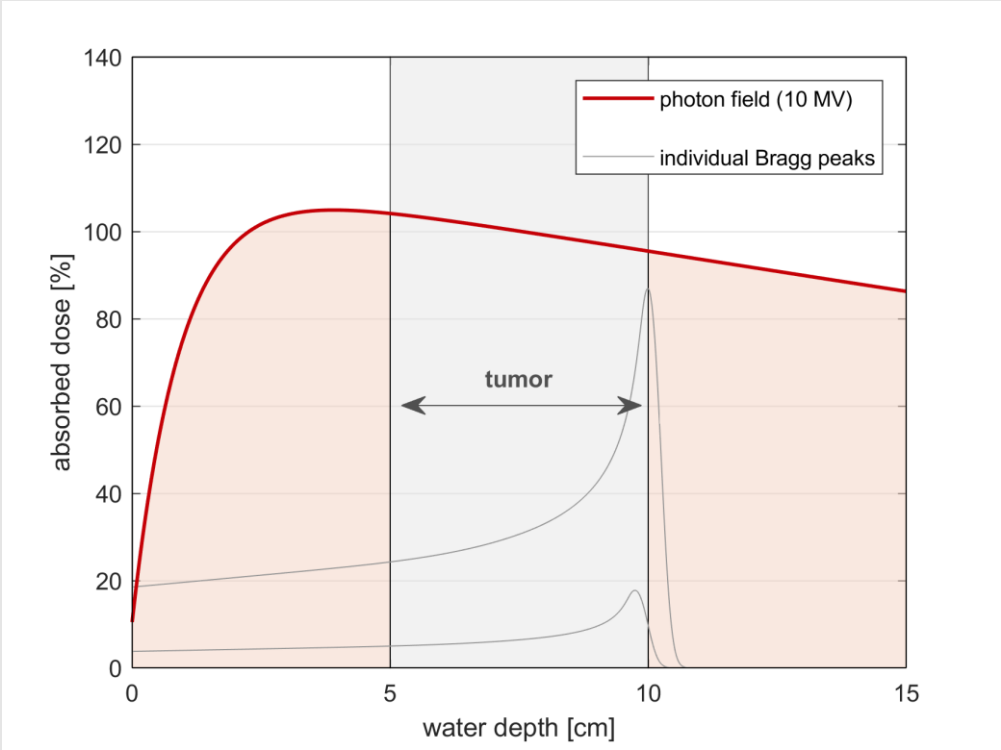

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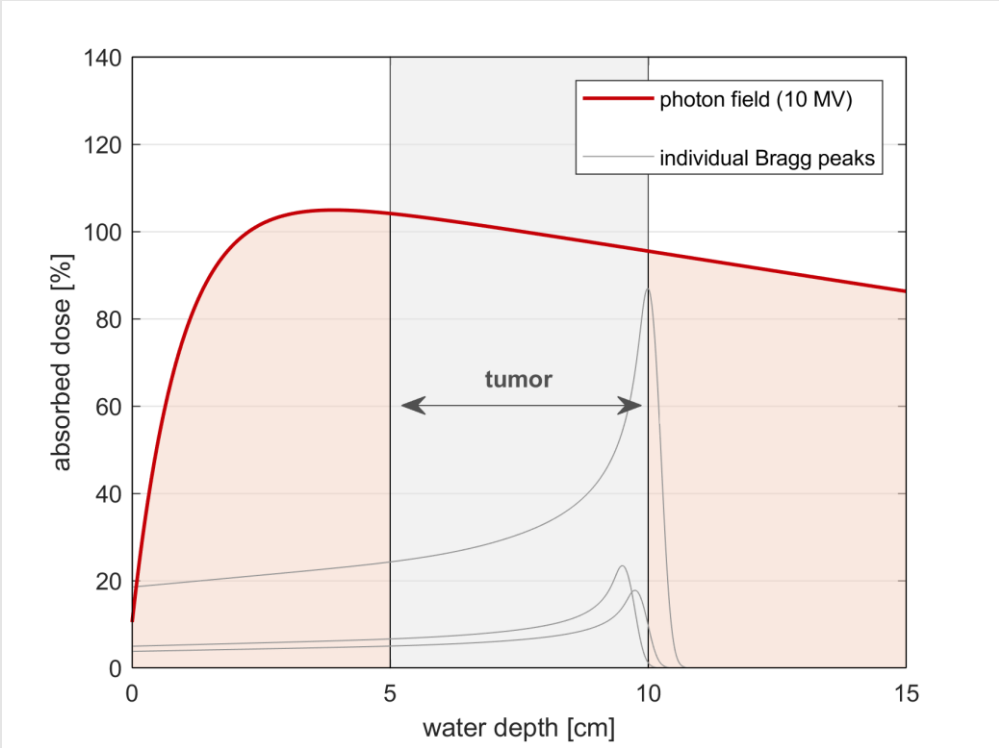

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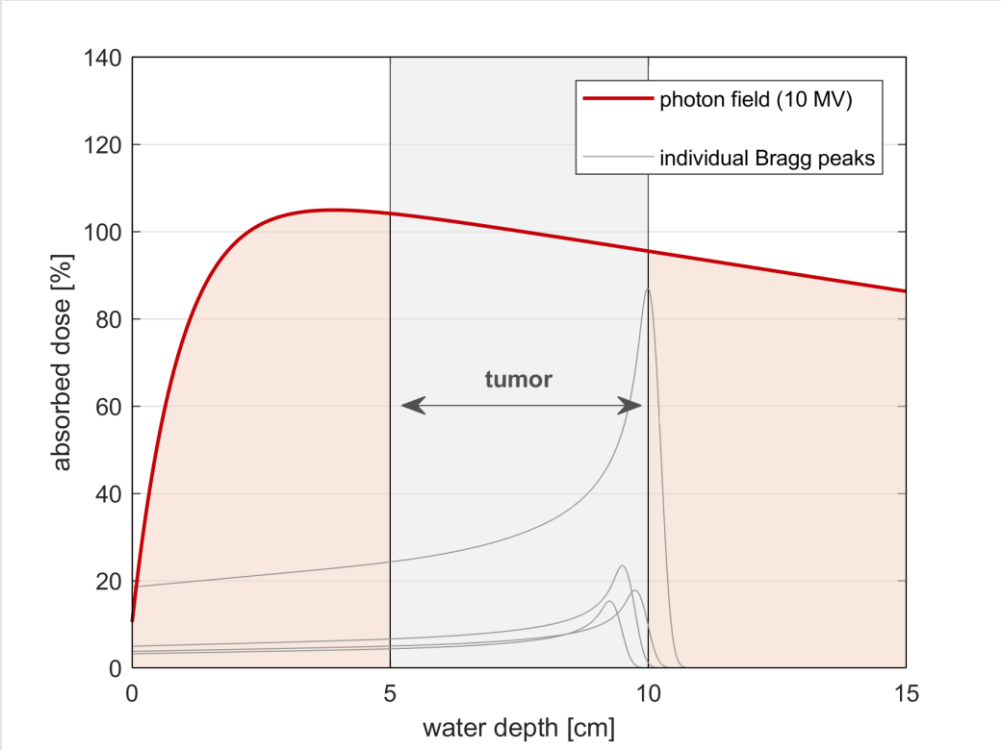

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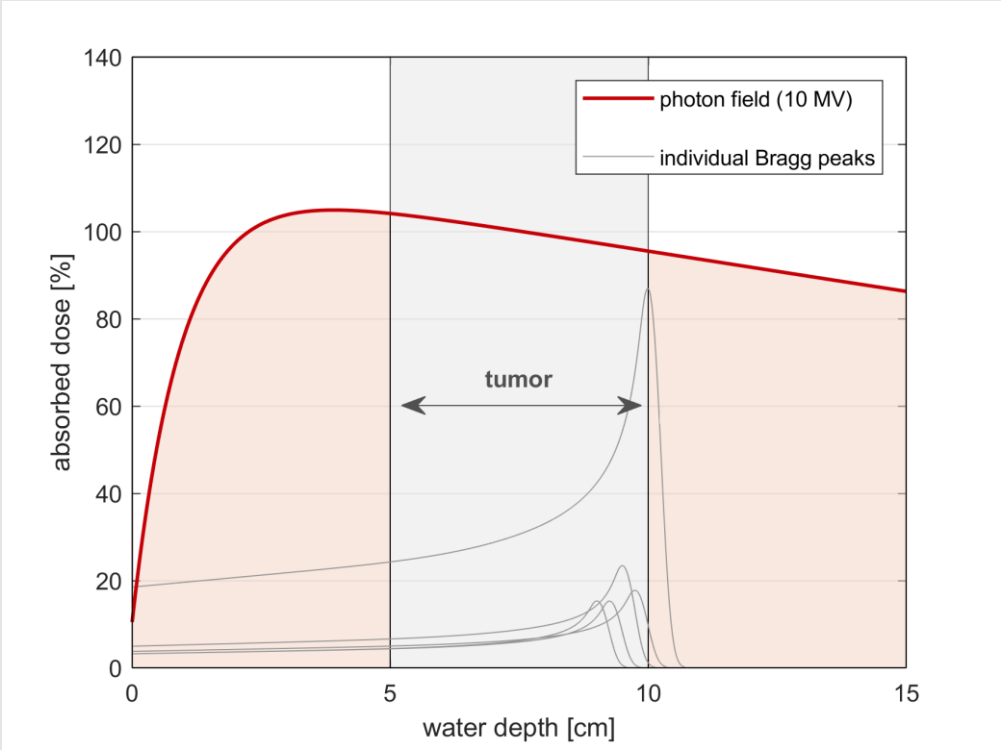

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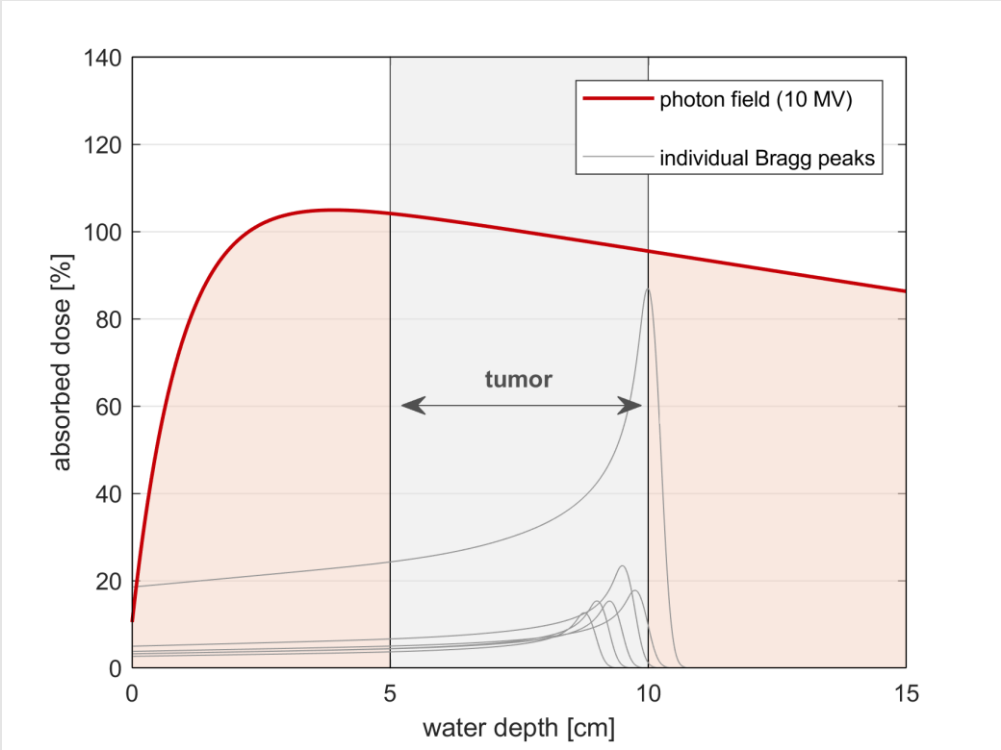

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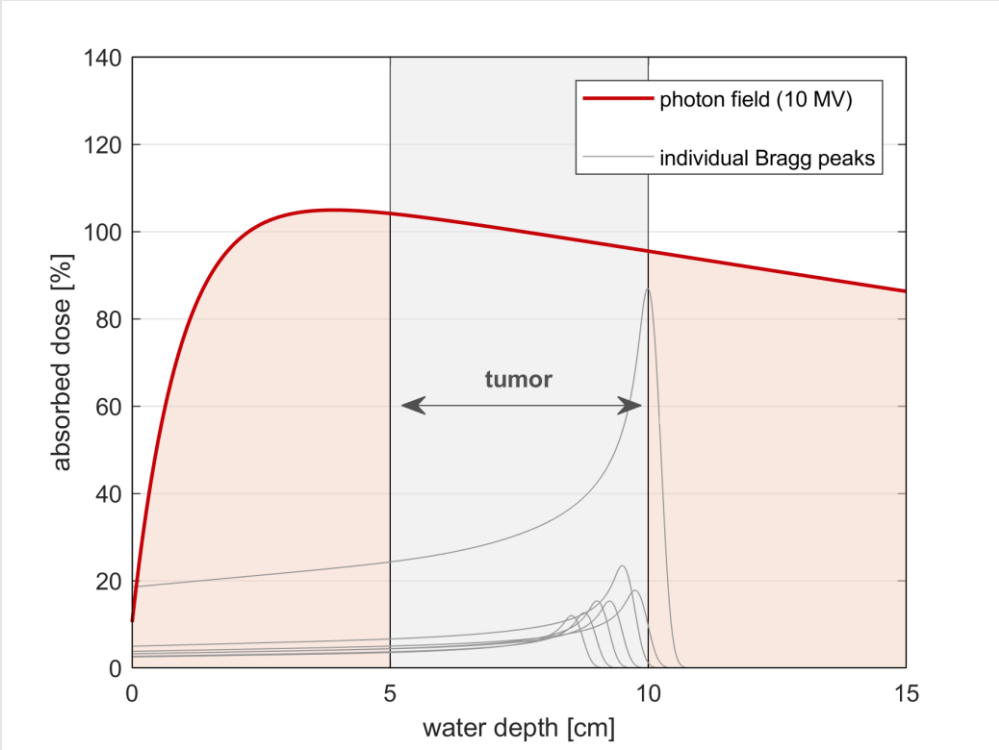

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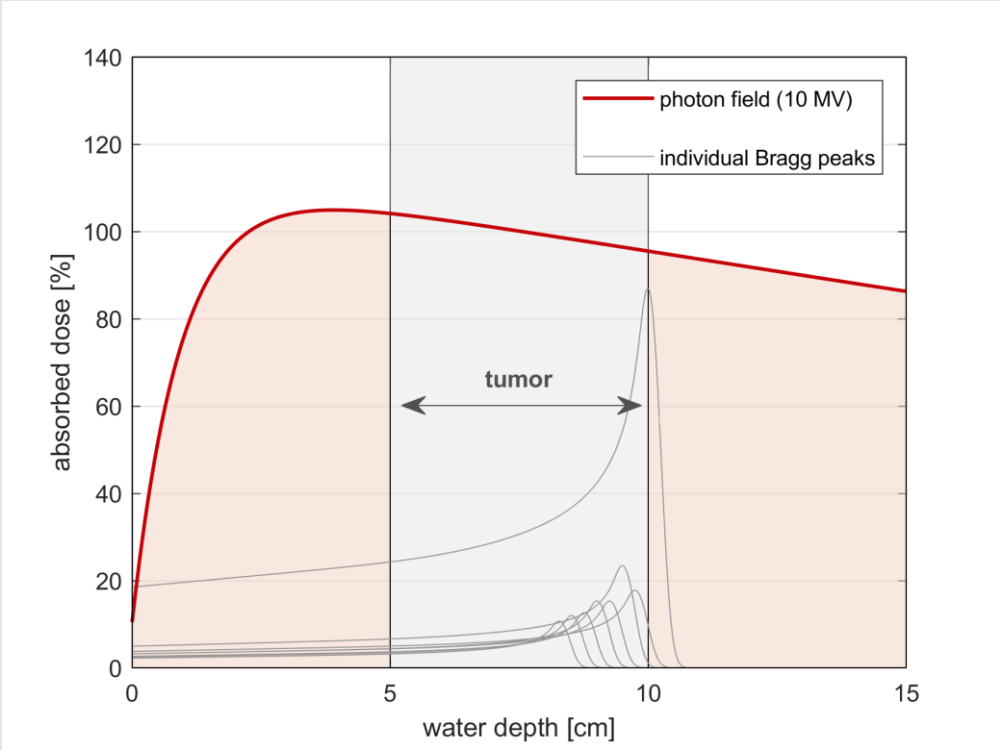

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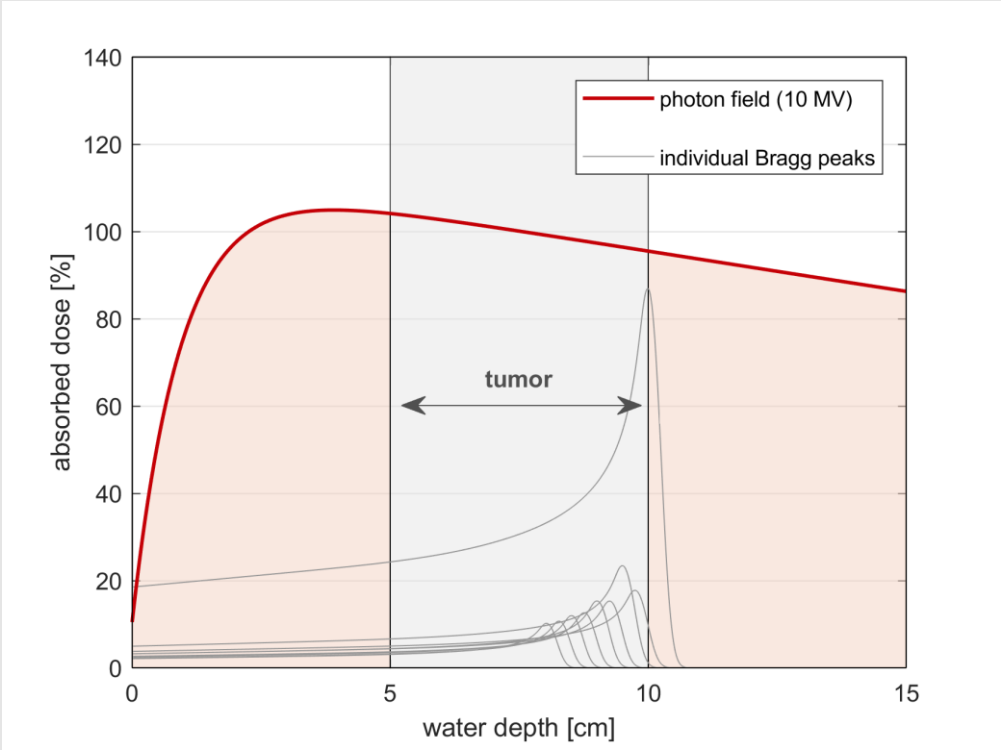

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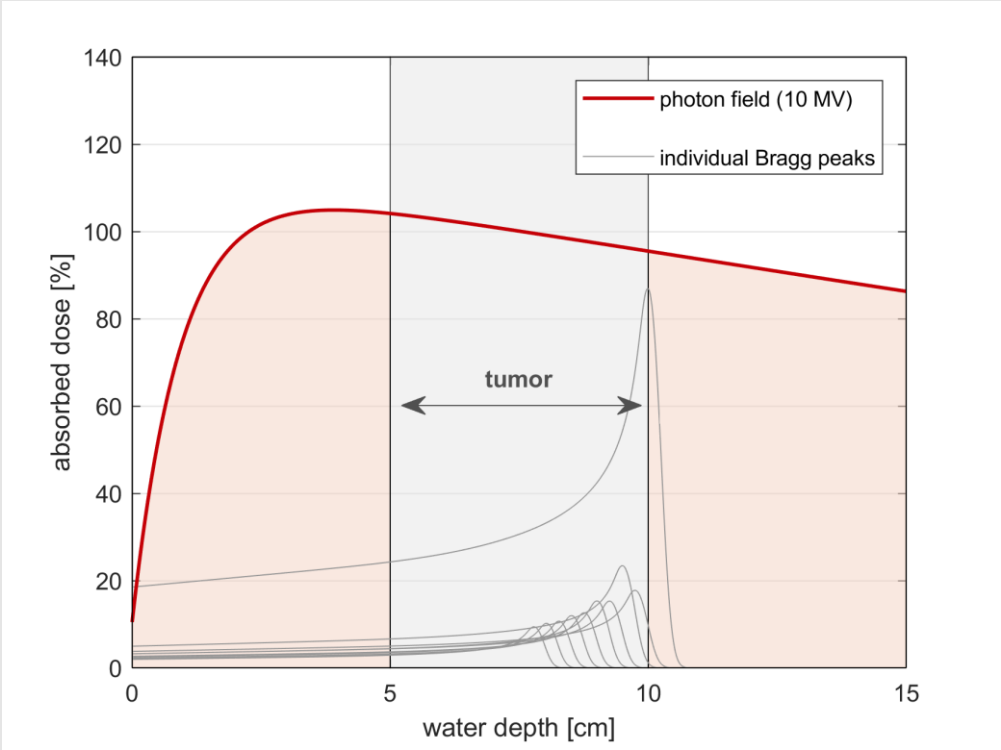

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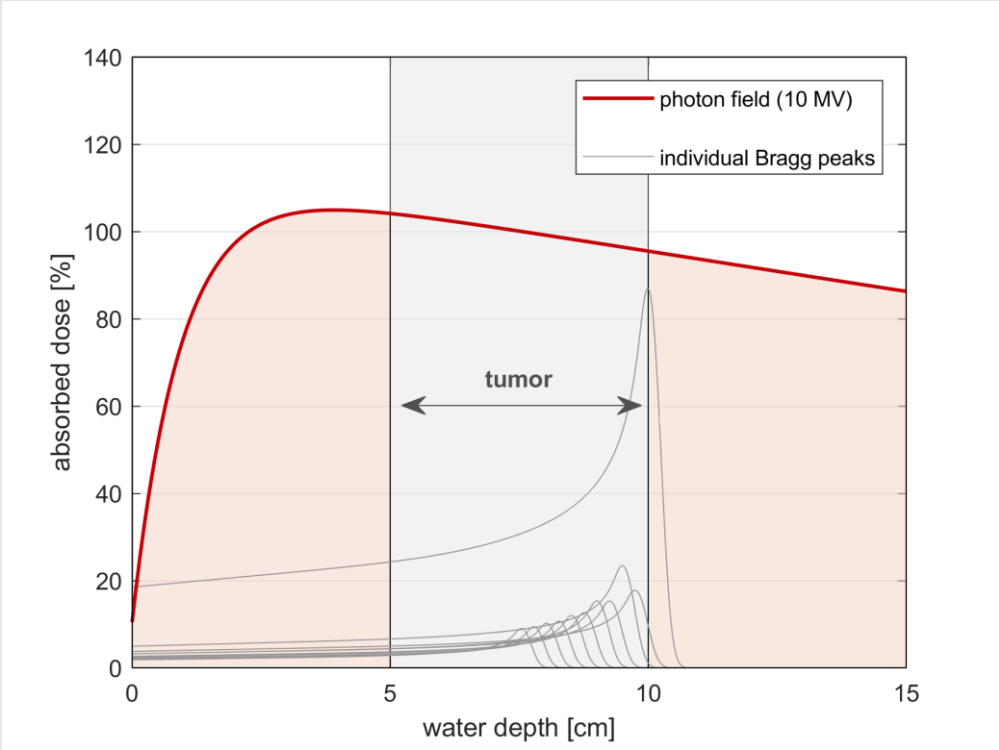

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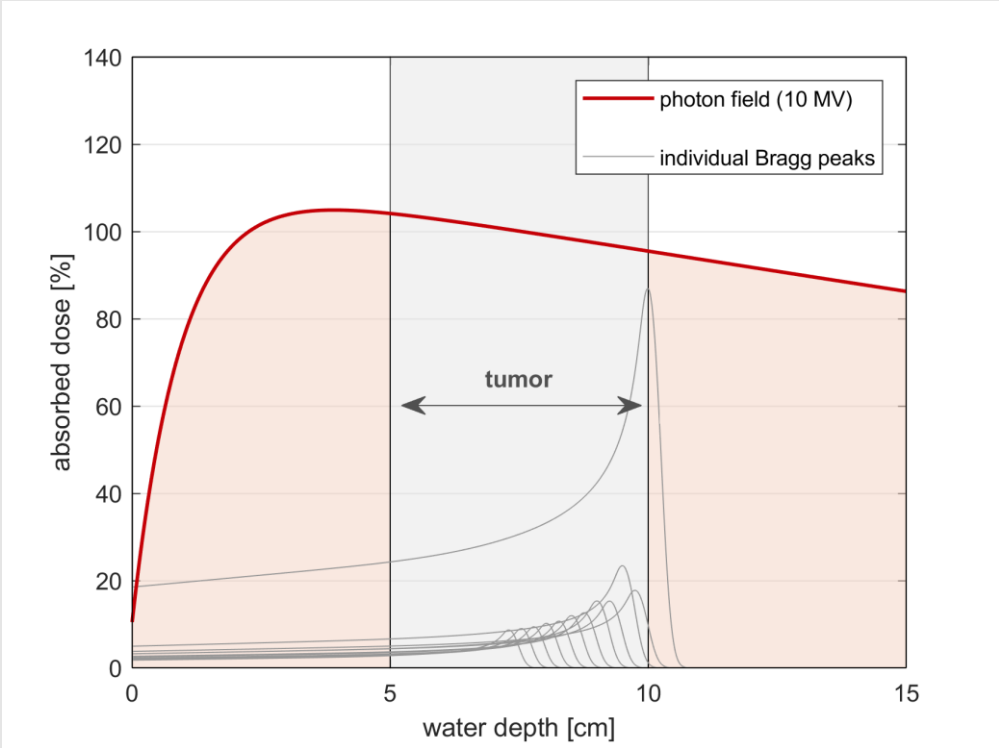

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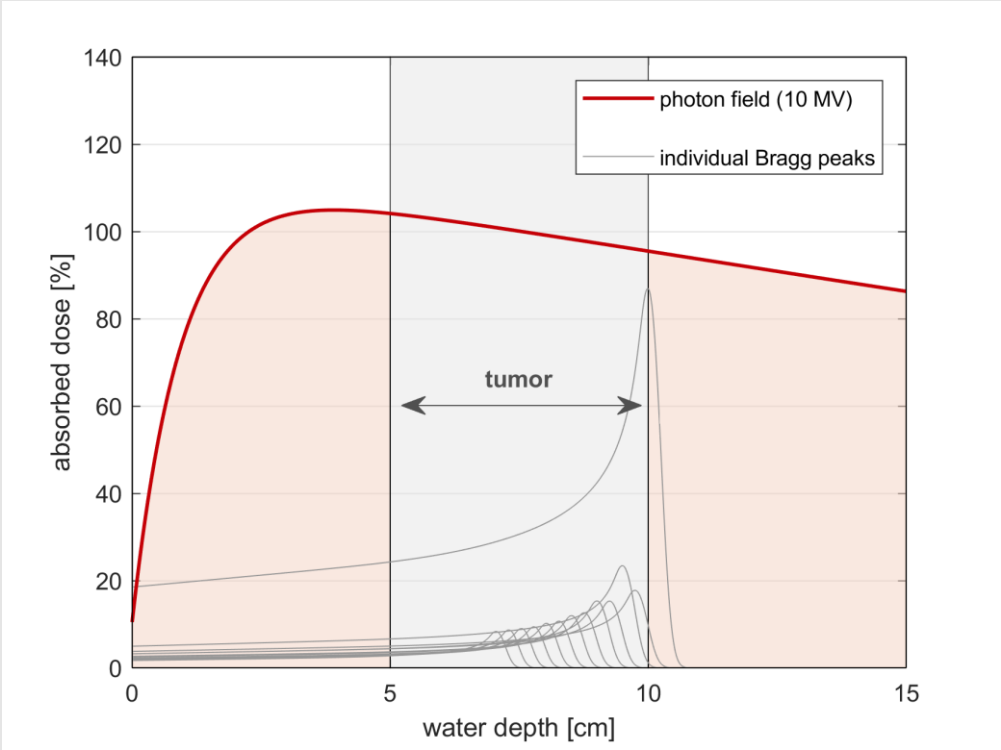

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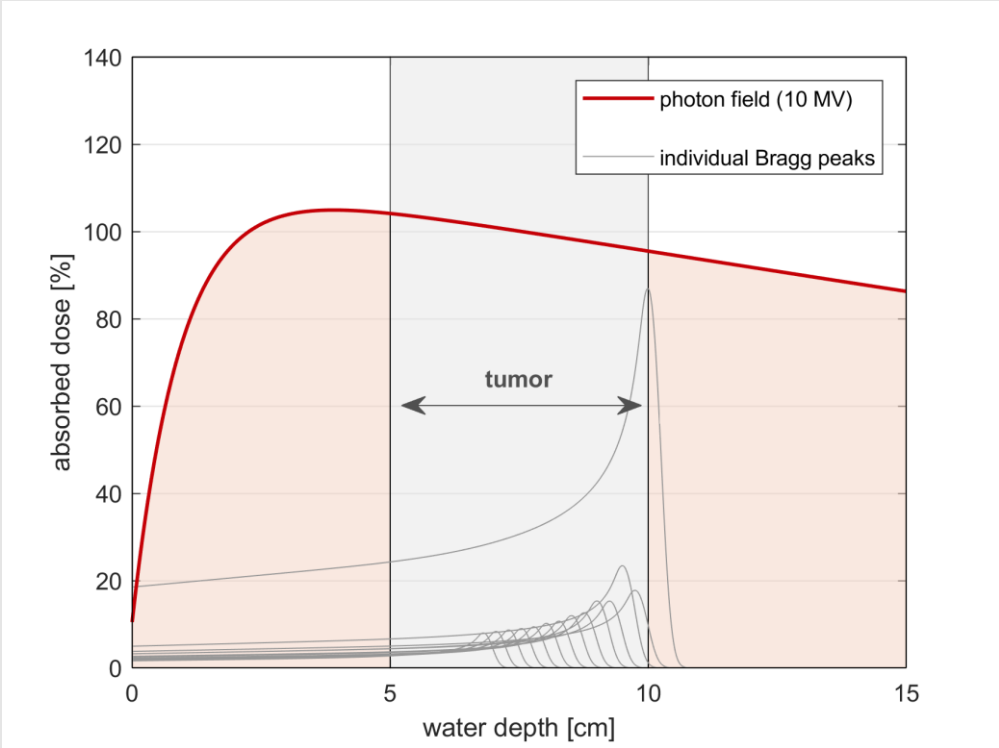

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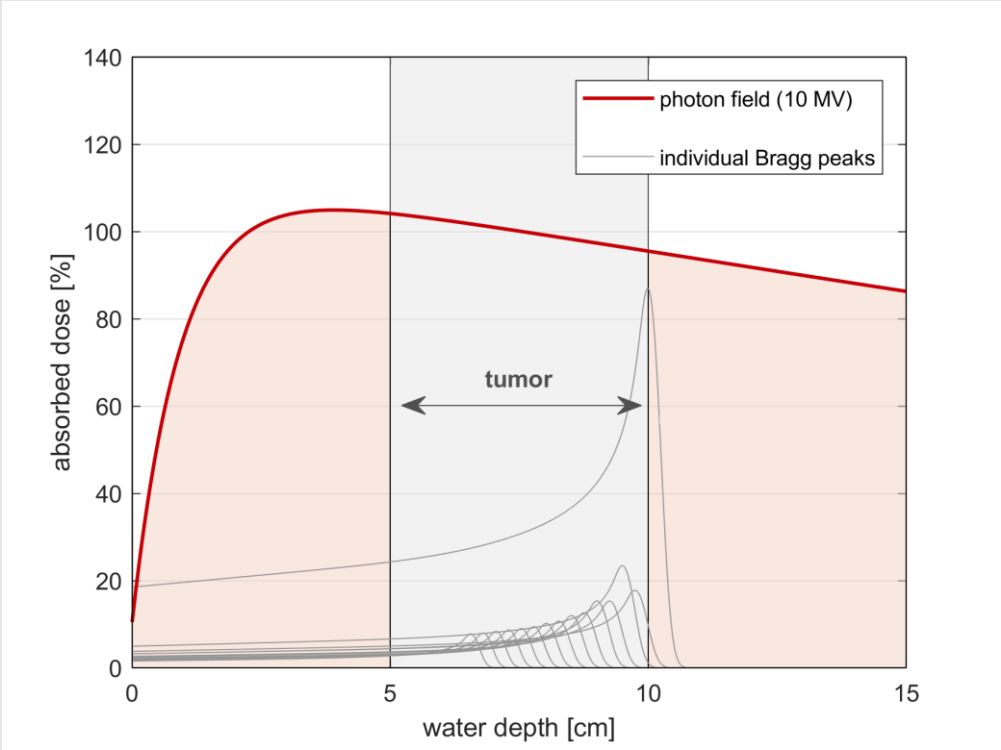

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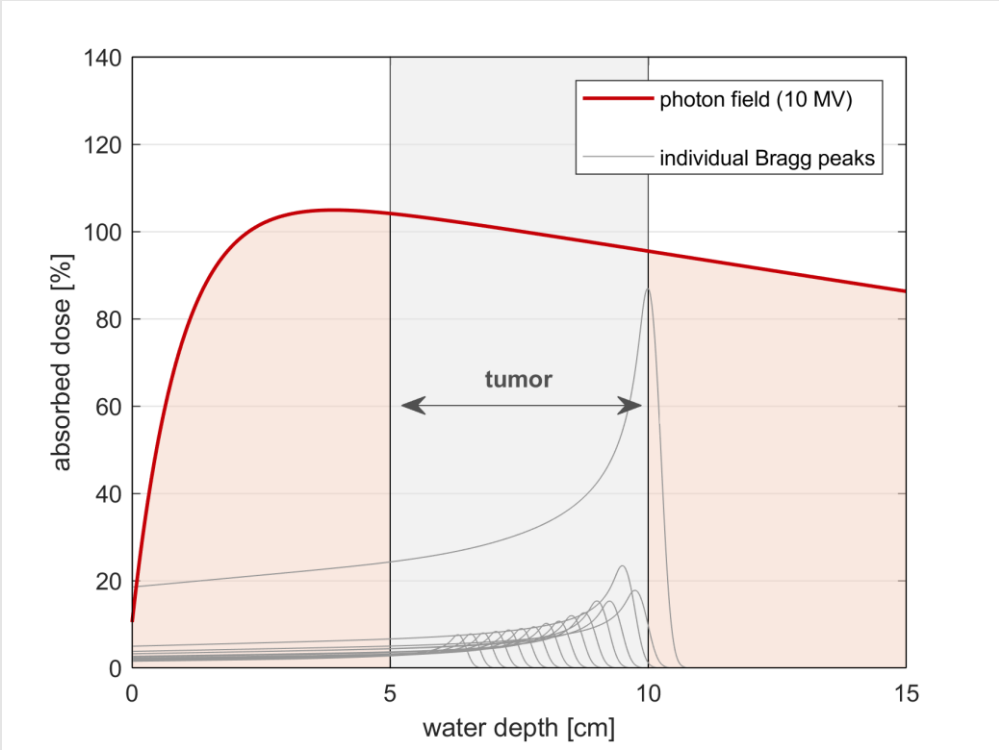

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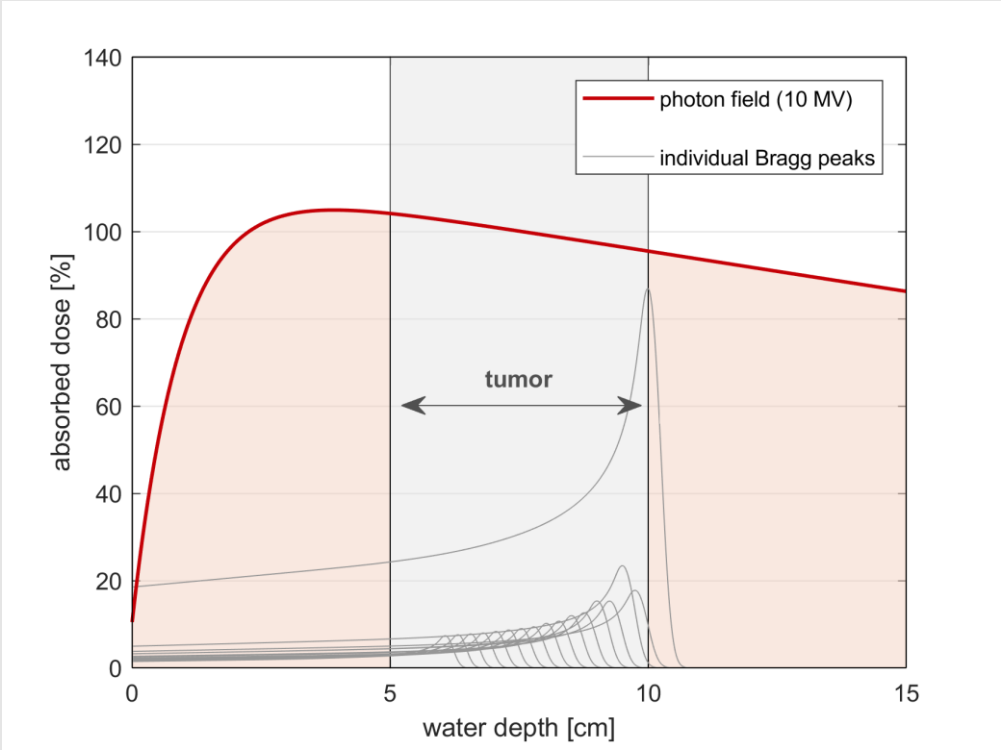

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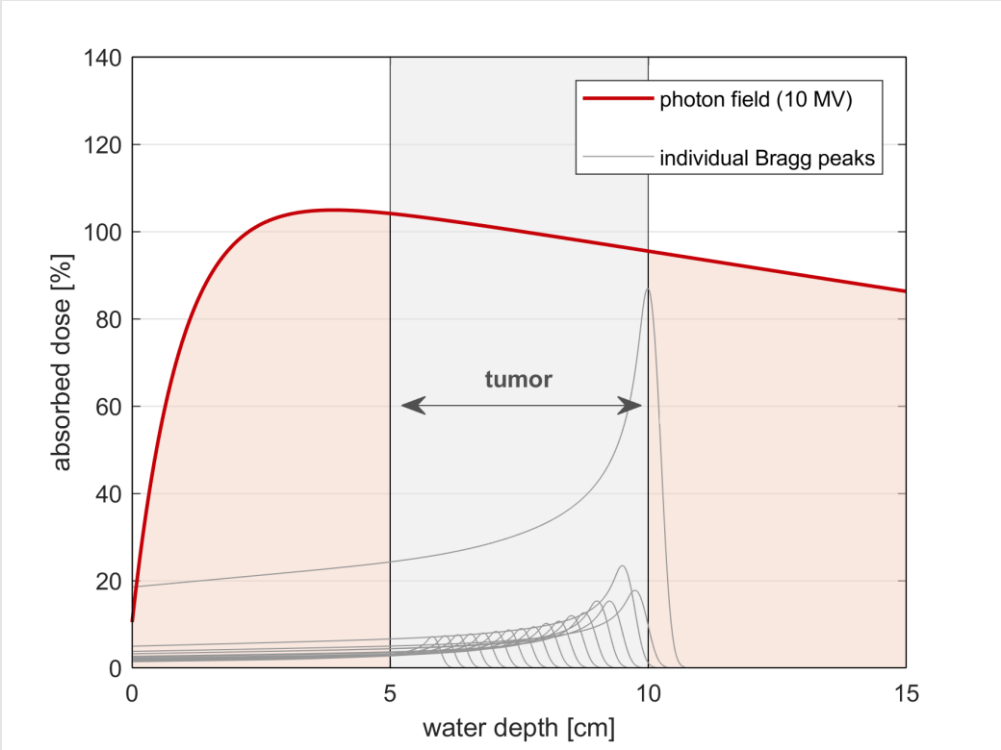

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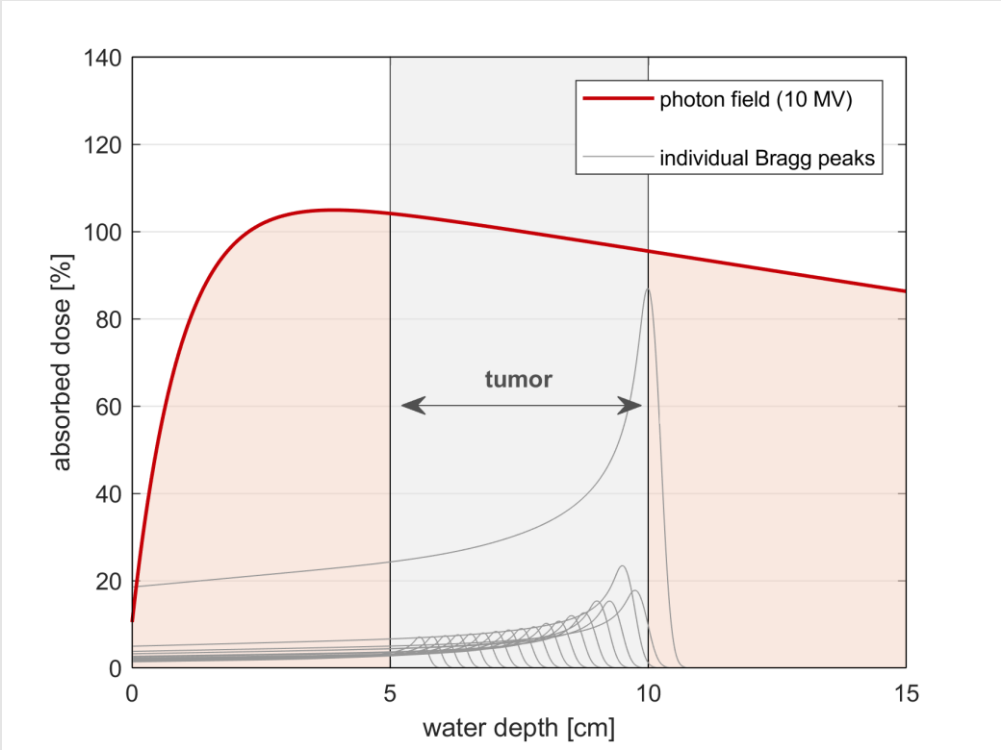

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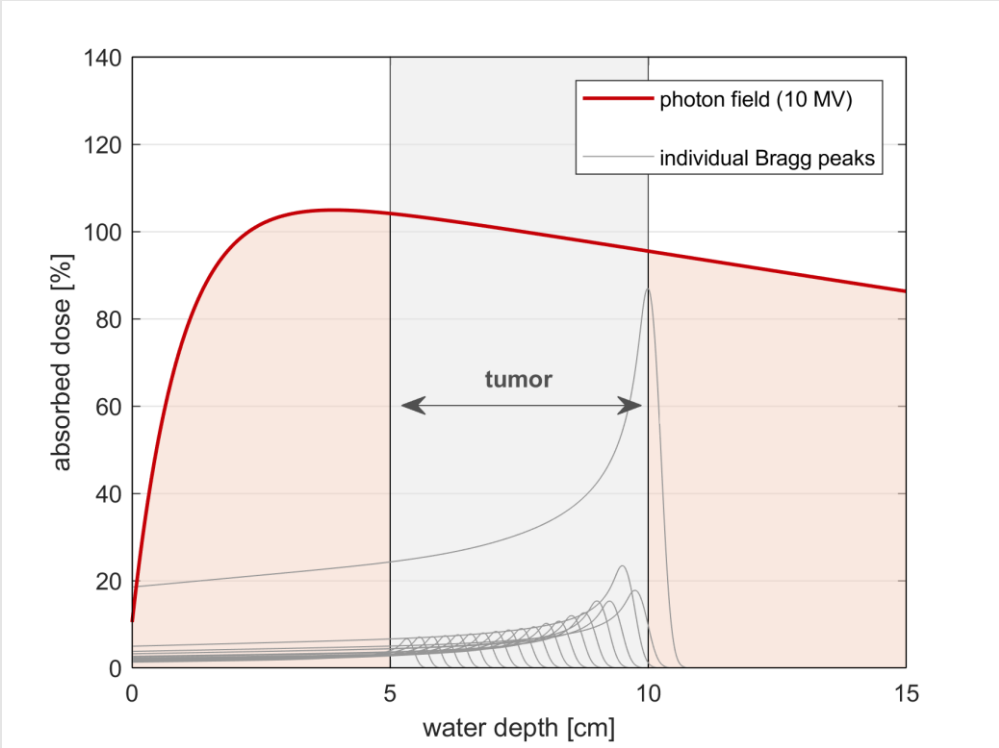

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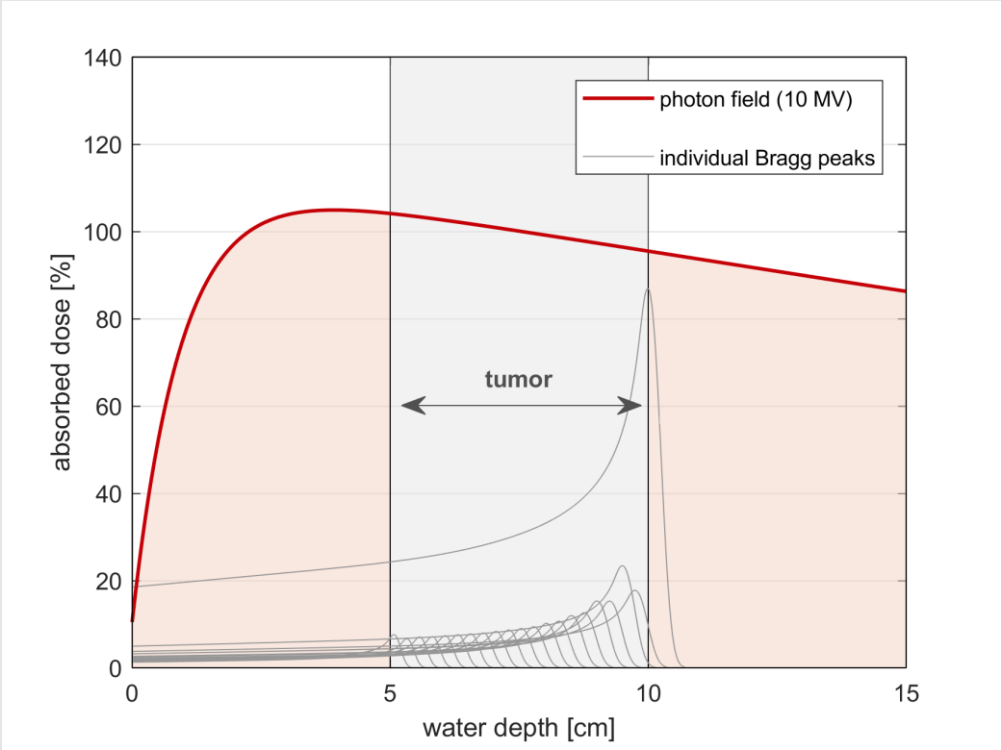

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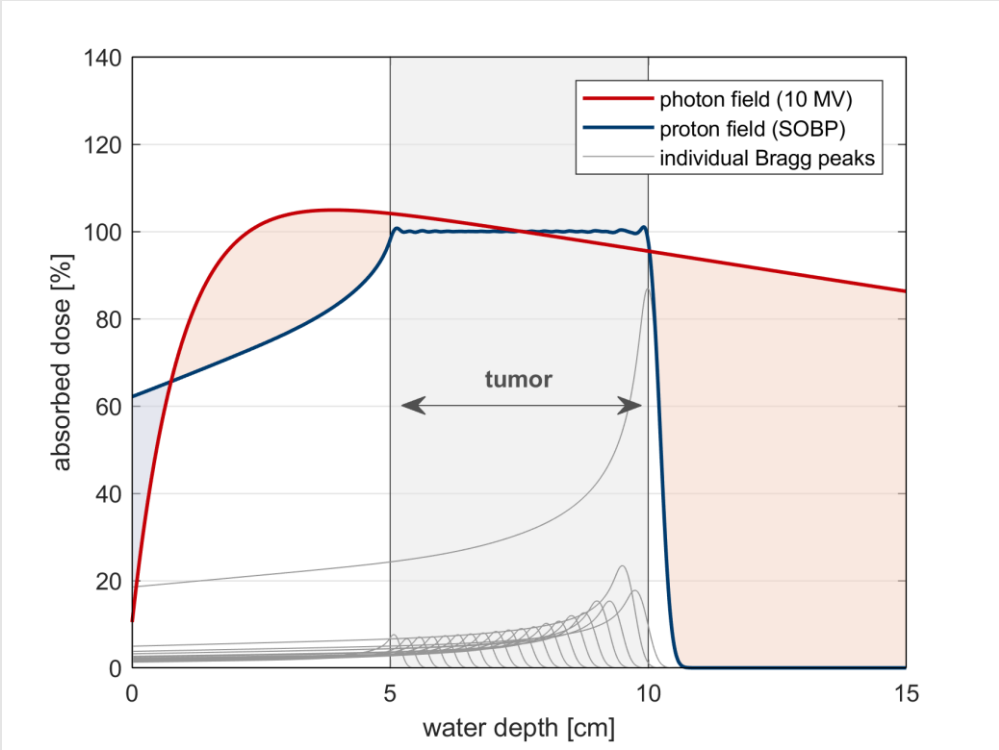
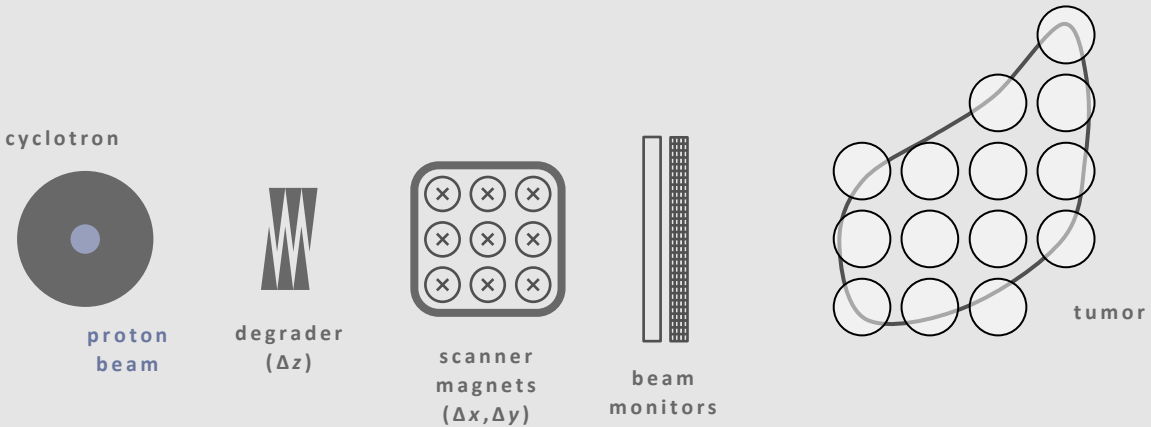


Pencil beam Scanning (PBS) Proton Therapy



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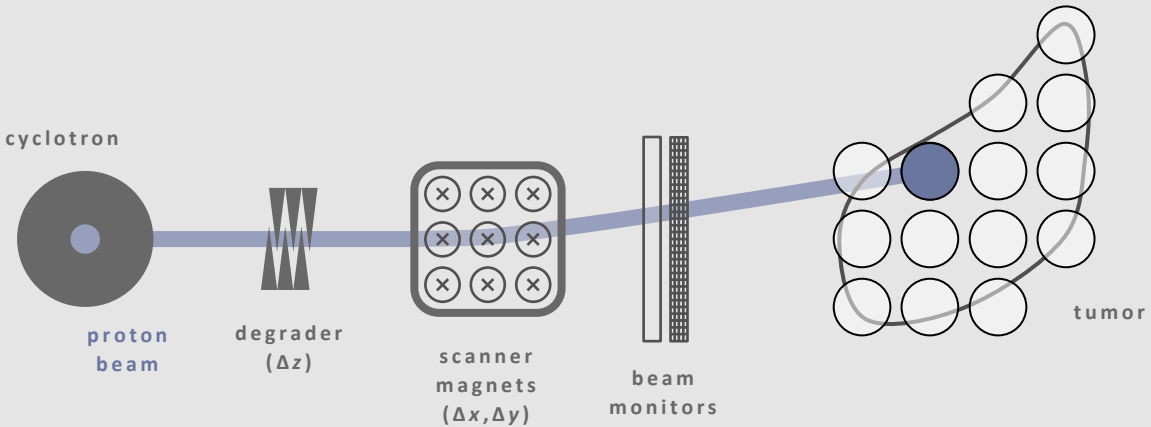

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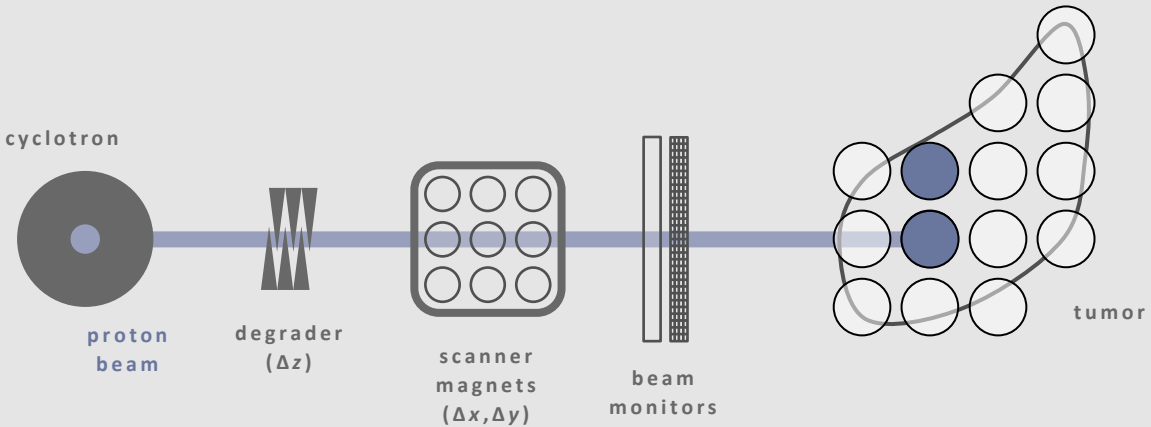

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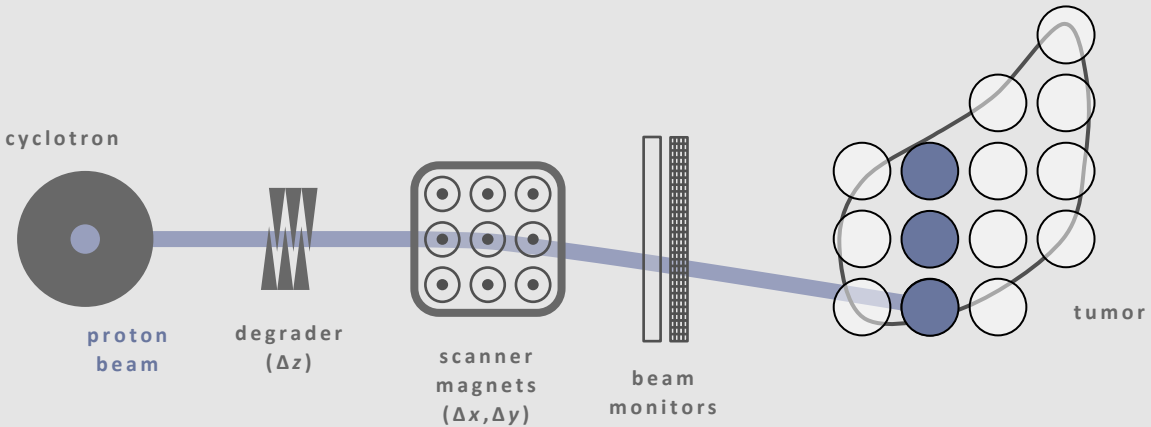

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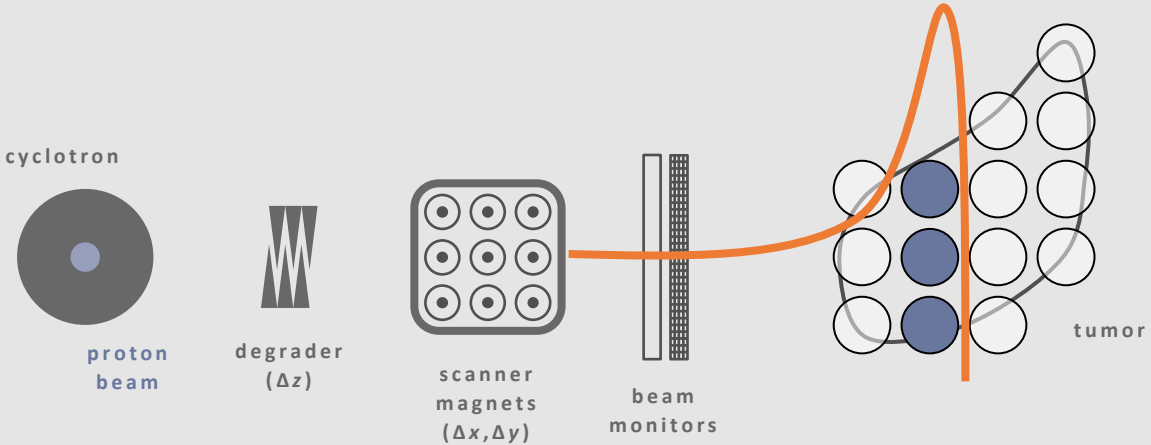

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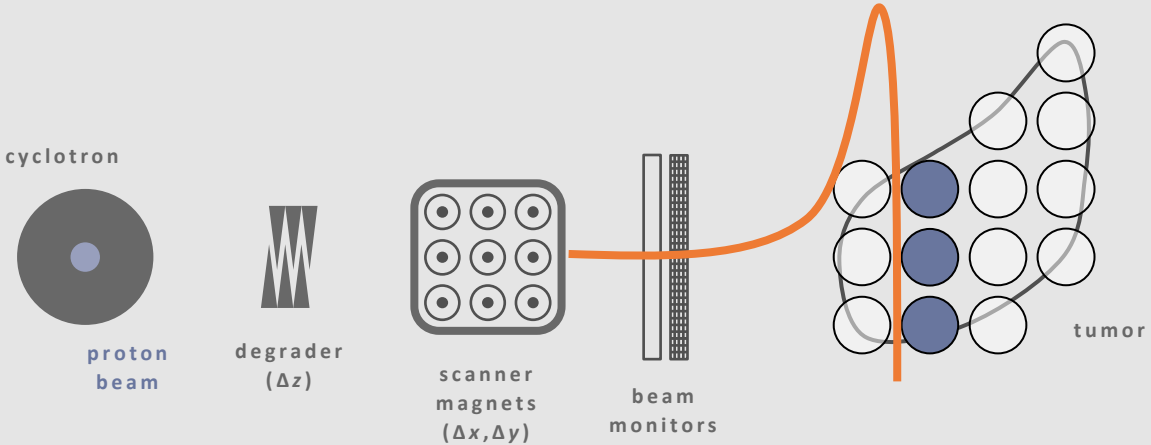

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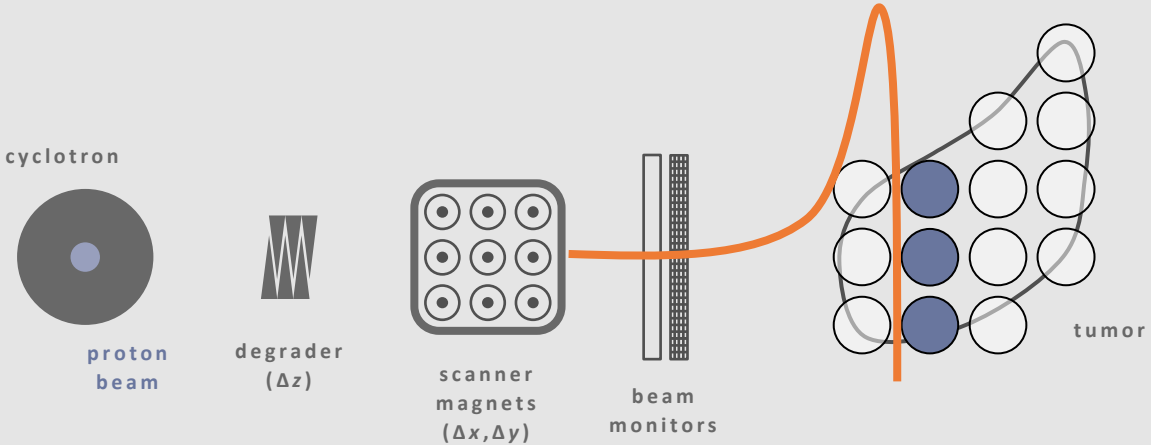

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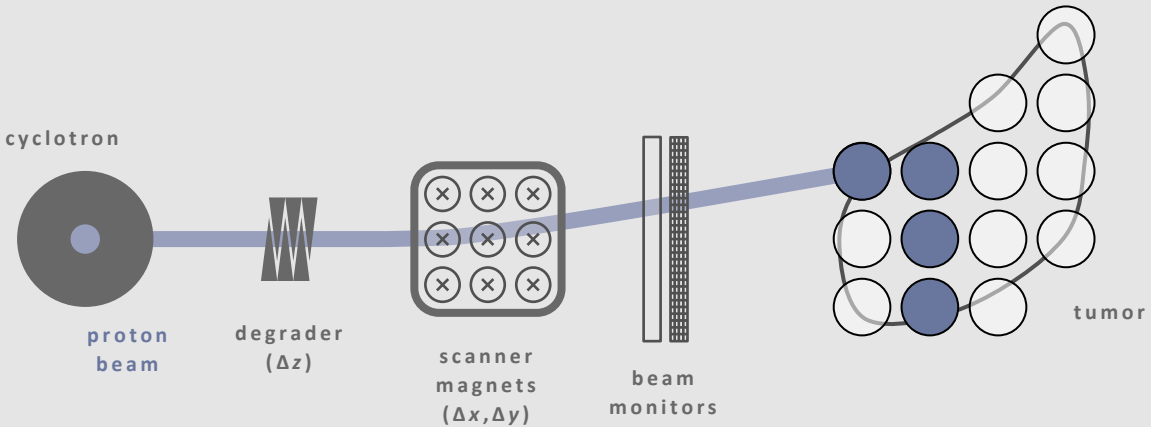

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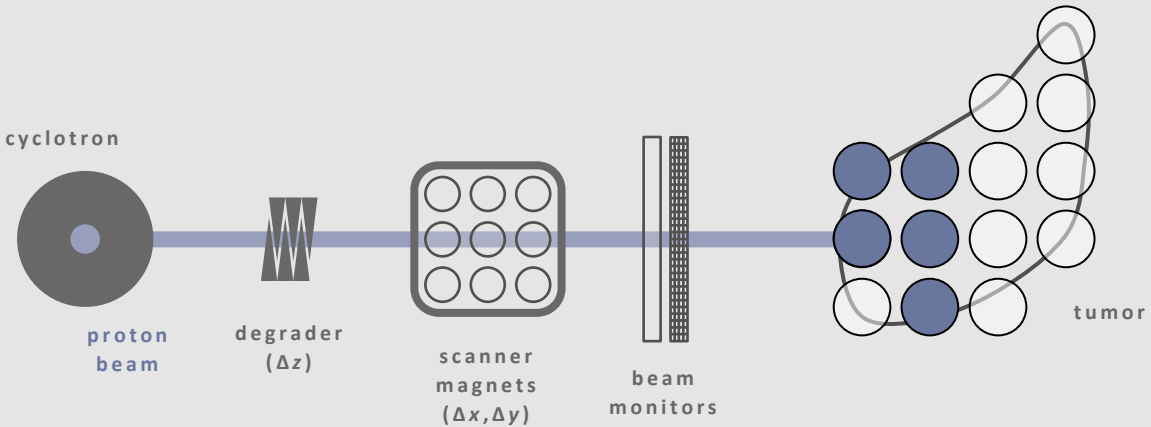

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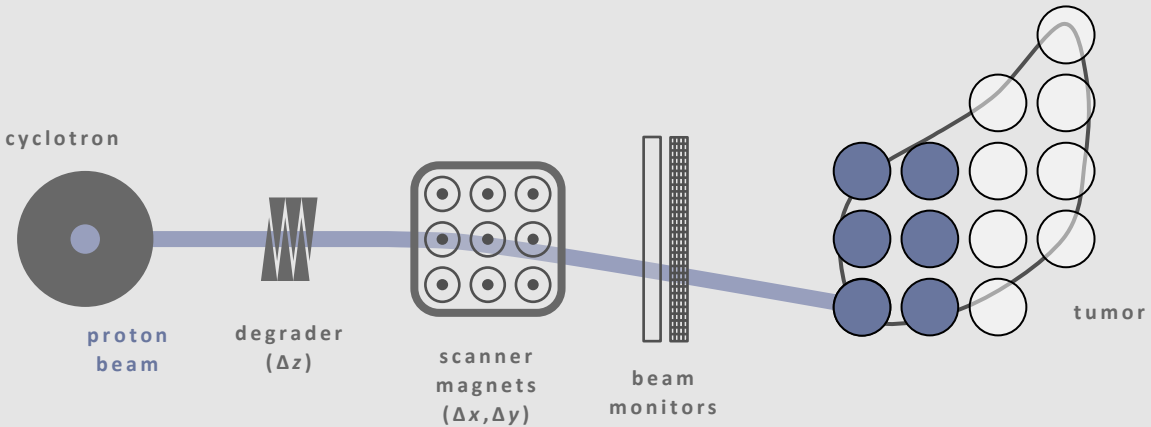
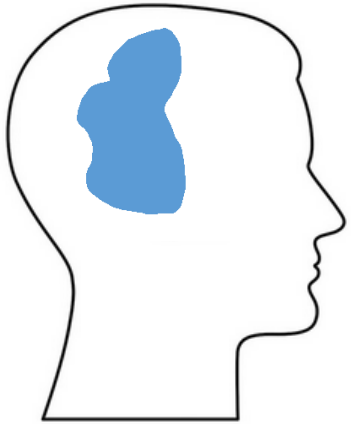


Pencil Beam Scanning (PBS) proton therapy

November 25th, 1996

A PBS technique was used to treat a cancer patient for the first time



Static tumour

Pencil Beam Scanning (PBS) proton therapy

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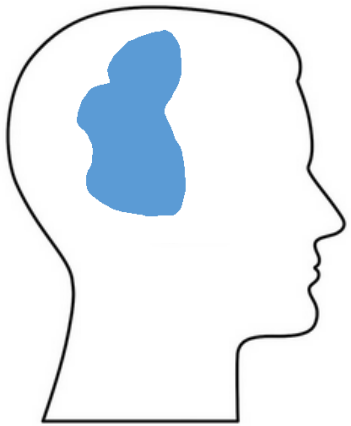
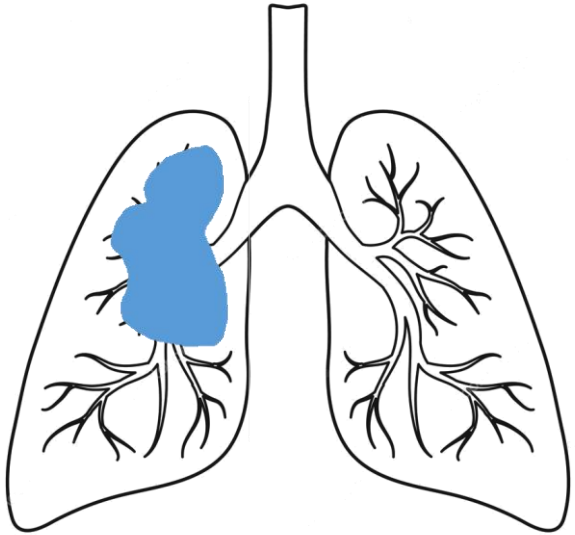
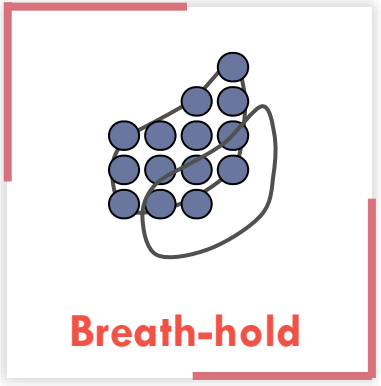


Static tumour



Moving tumour

Conventional motion mitigation techniques



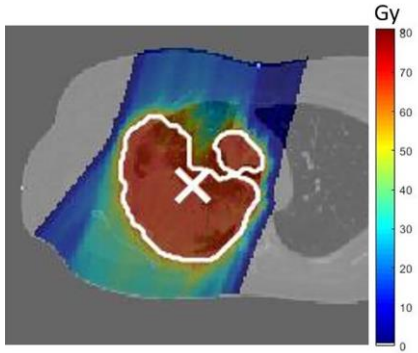
What if we flip the problem around?

What if the treatment is delivered so fast that all the motion is frozen?

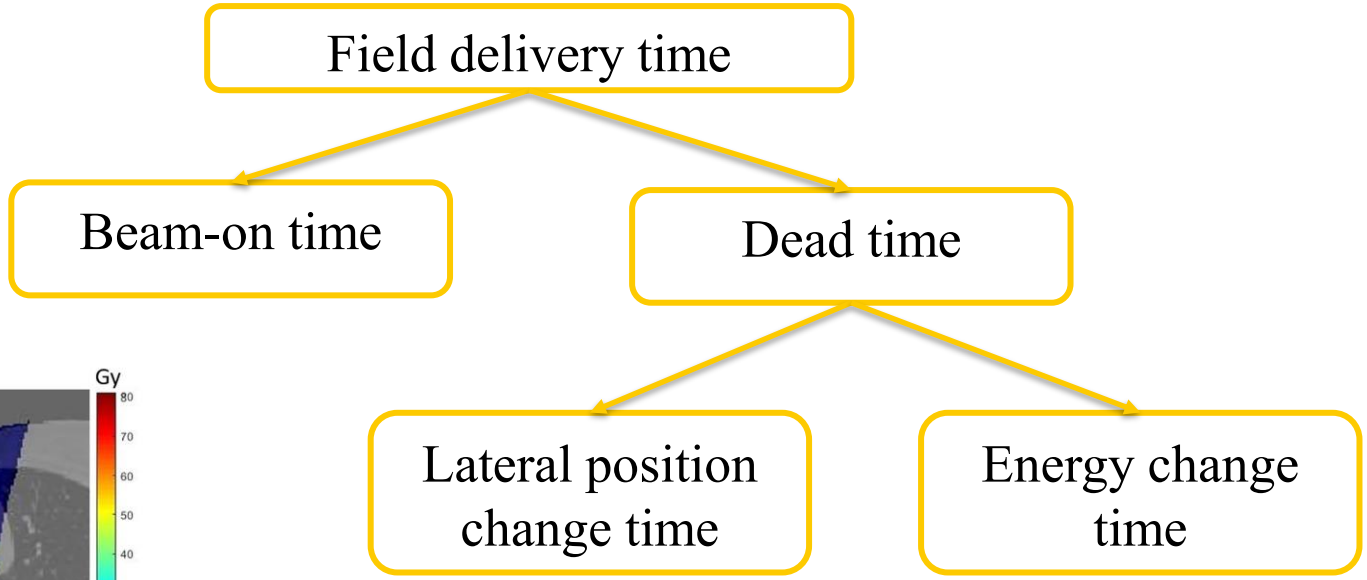
Ultra-fast treatment delivery

Field delivery within a single breath-hold (5-10 sec)

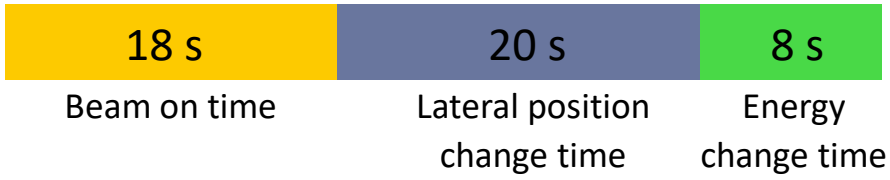
PBS field delivery time



Lung case PTV: ~400 cm^3



Field delivery time : 46 sec



Beam on time reduction

= 46s

Beam on time

Lateral position change time

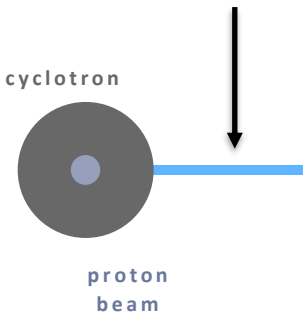
Energy change time

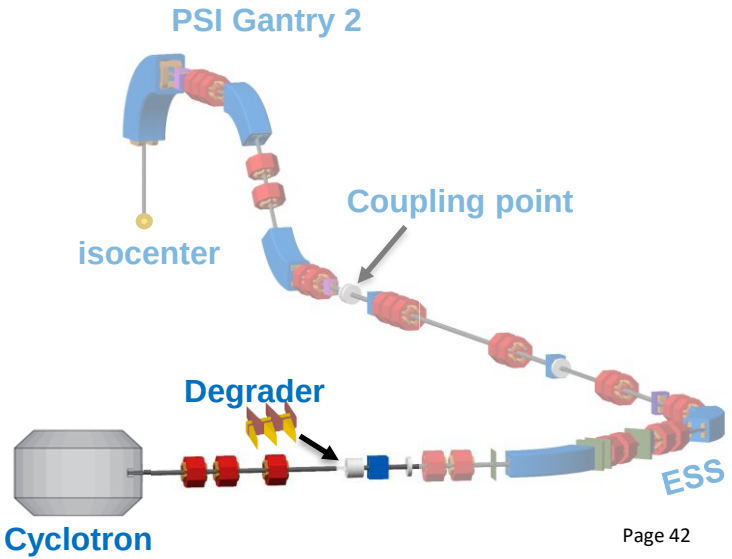
Cyclotron based proton therapy facility

250 MeV

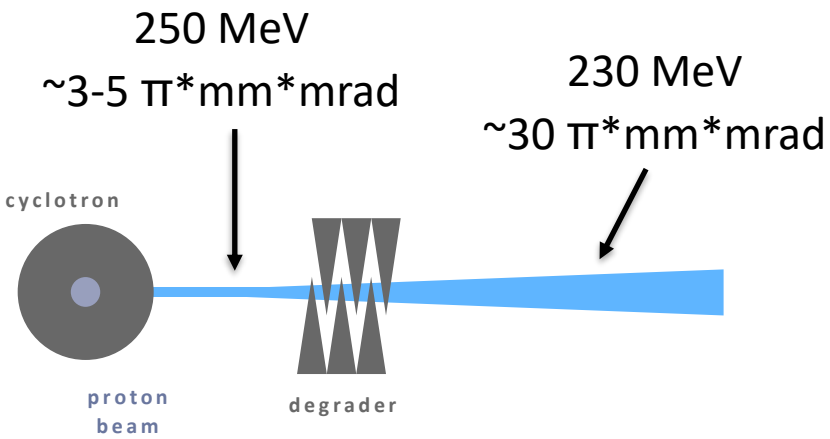
Emittance:

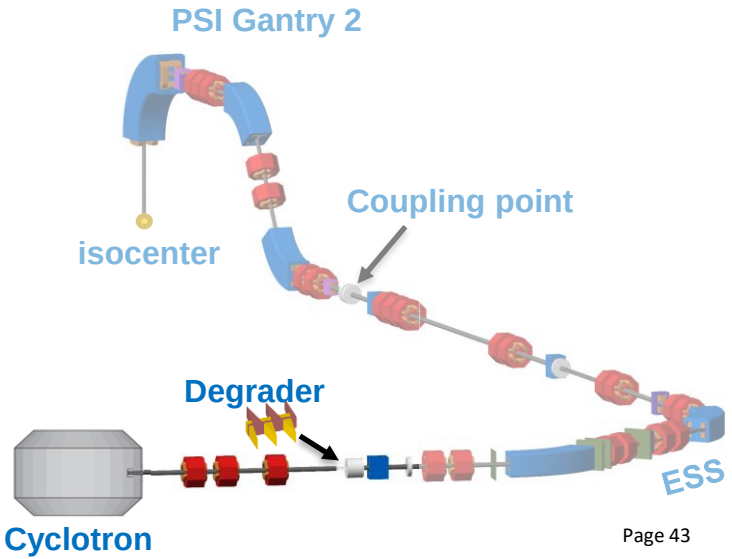
~3-5 π*mm*mrad





Cyclotron based proton therapy facility





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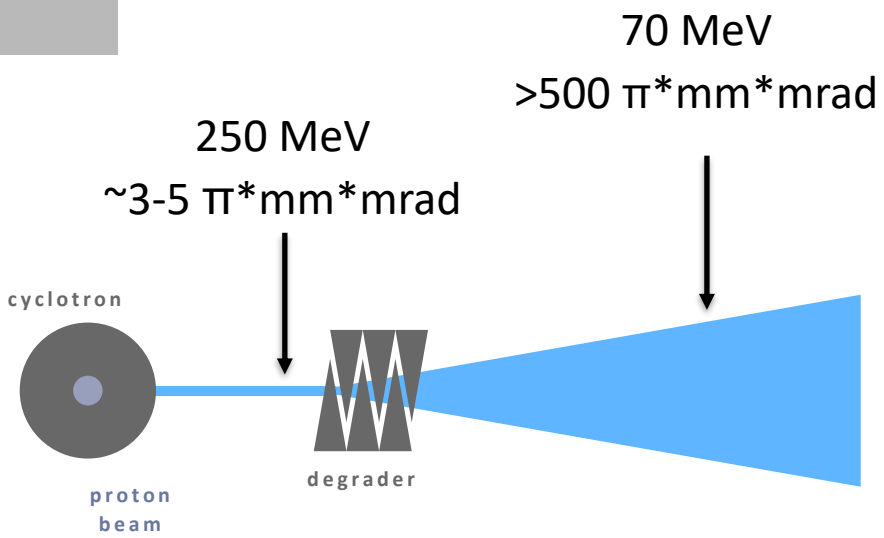

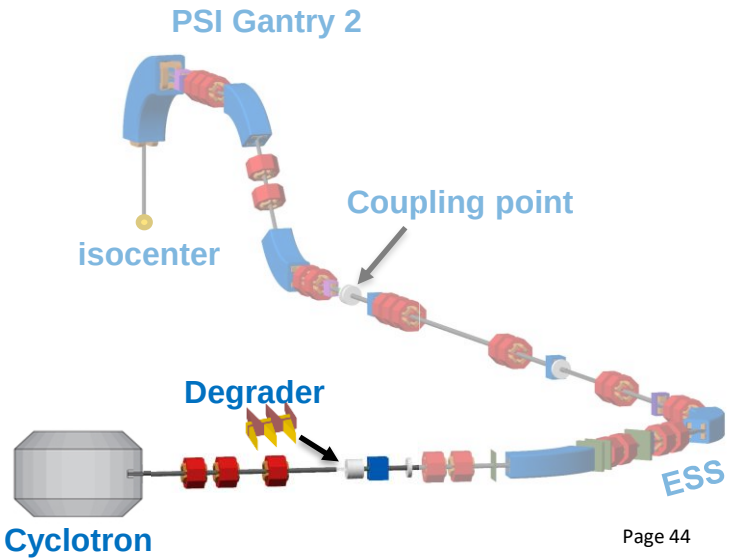

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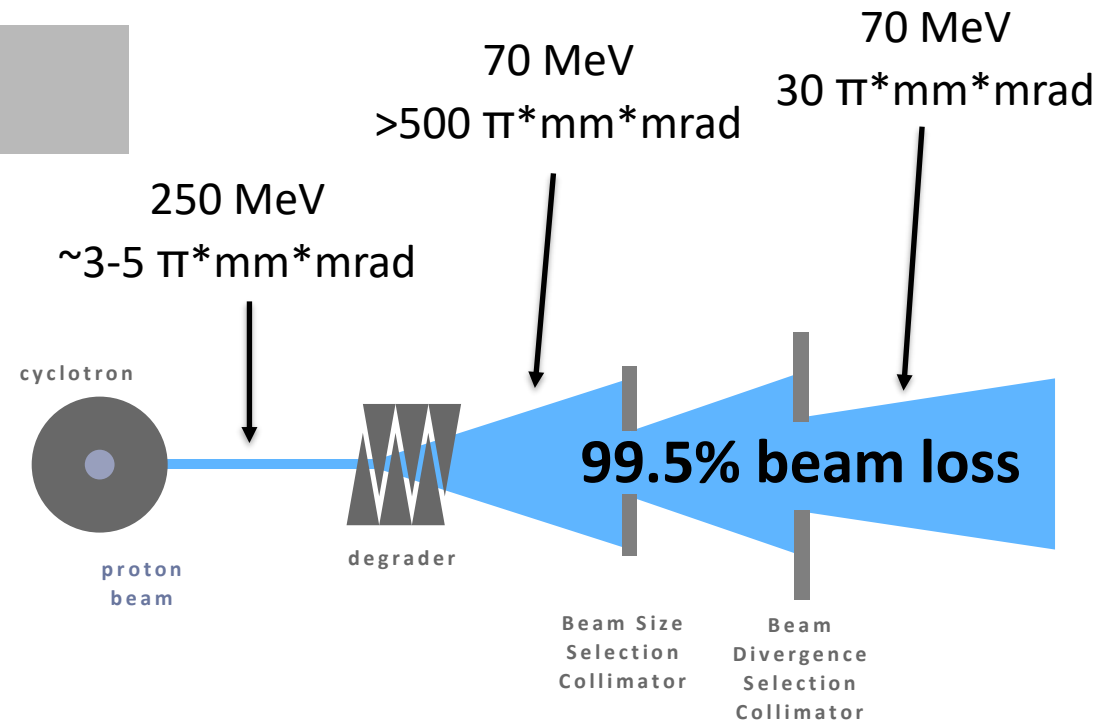
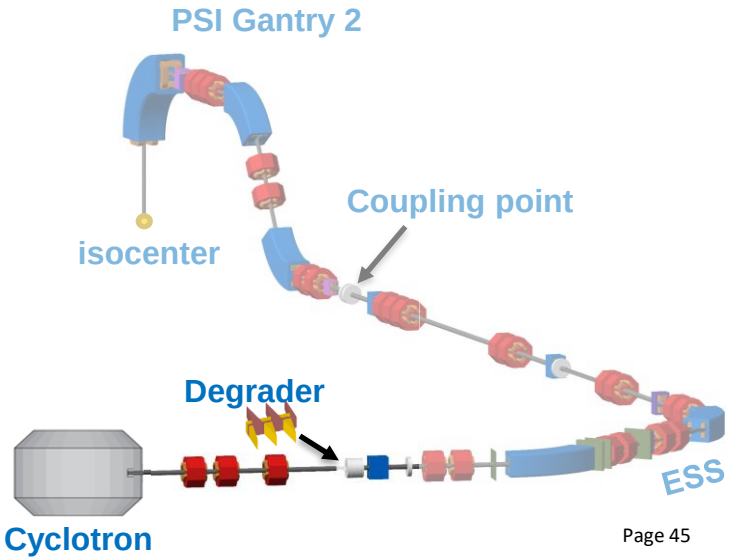
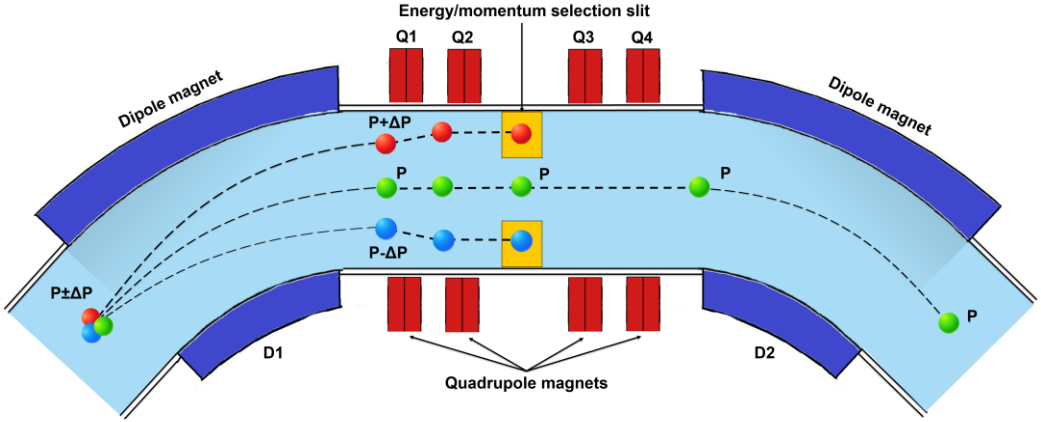


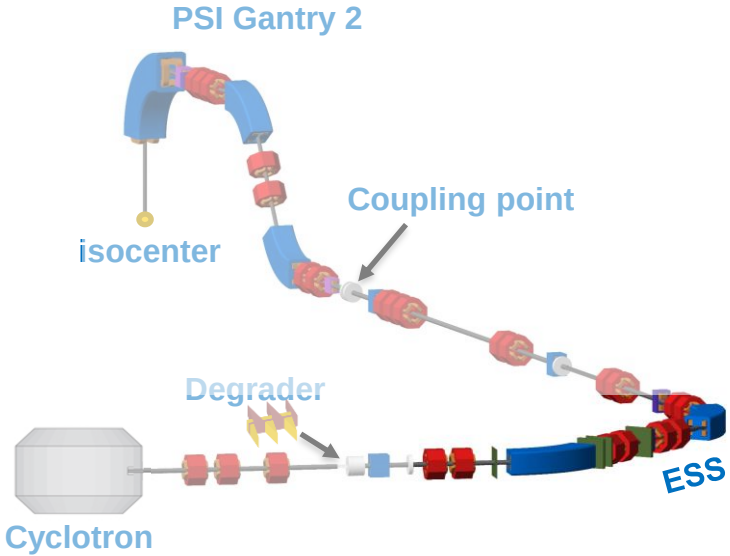


Most of the facilities transports

30 pi*mm*mrad or less emittance

Cyclotron based proton therapy facility





Factor 6-10 beam loss

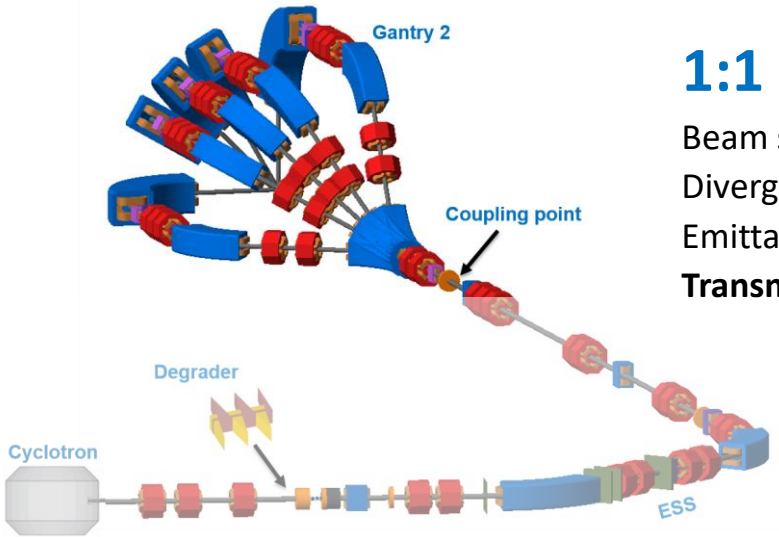
(Depending on the energy of the beam)

Range Straggling
in the degrader increases the
momentum spread of the beam.
For 70 MeV beam, it is about ± 4.5%

Cyclotron based proton therapy facility

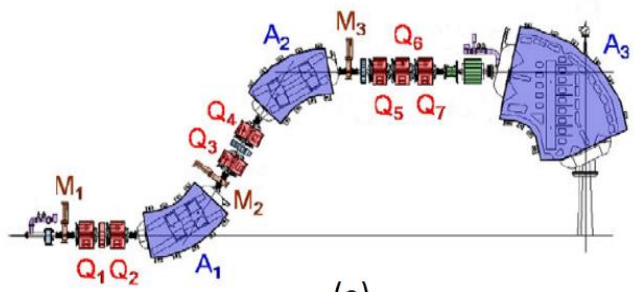
At gantry entrance:
Emittance = Beam Size * Divergence

To achieve gantry angle independent beam at isocenter, we need to have same emittance in both planes at gantry entrance.

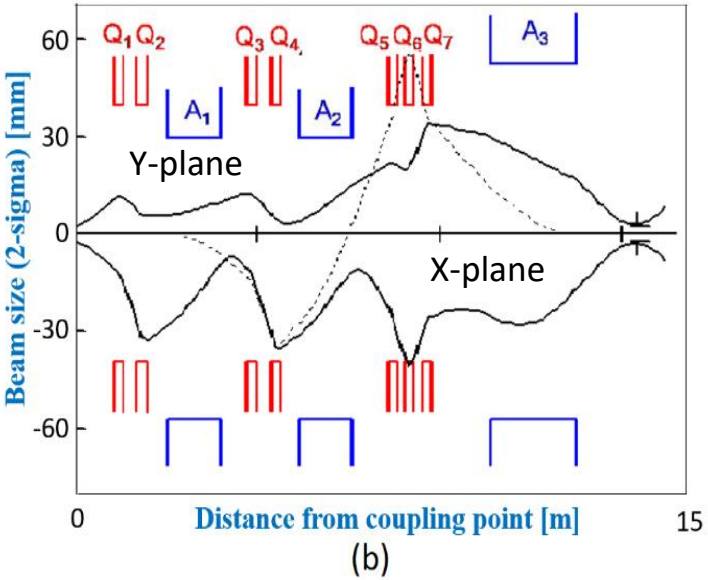


1:1 imaging

Beam size : 3 mm
Divergence : 10 mrad
Emittance : 30 π*mm*mrad
Transmission : 57%

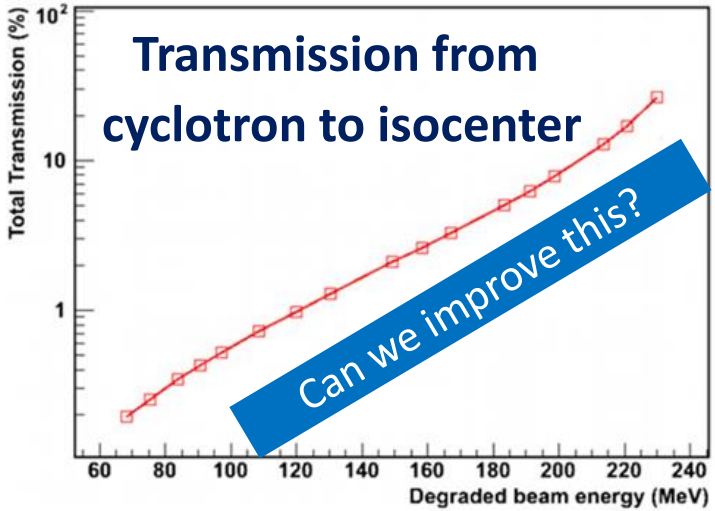


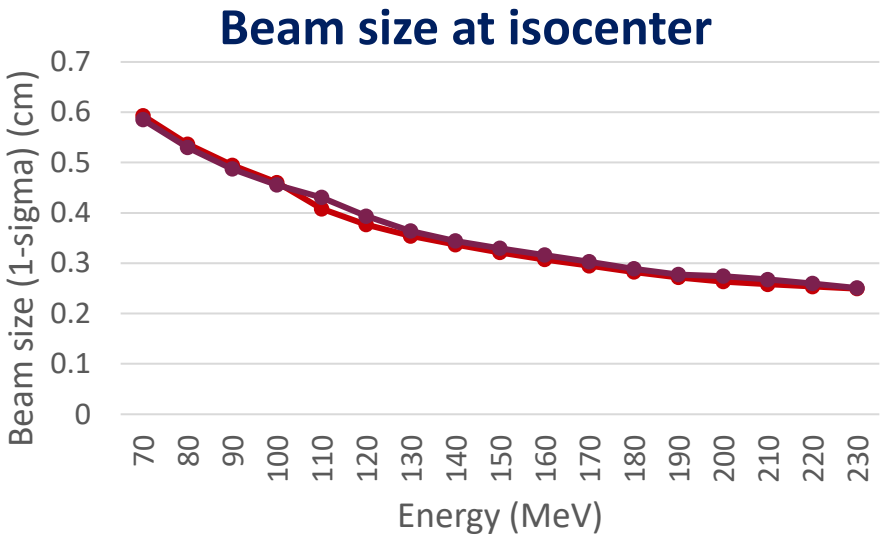
(a)



(b)

Cyclotron based proton therapy facility





Transmission in commercial systems

Varian medical system : ~factor 10 less compared to PSI G2

IBA systems : similar to PSI

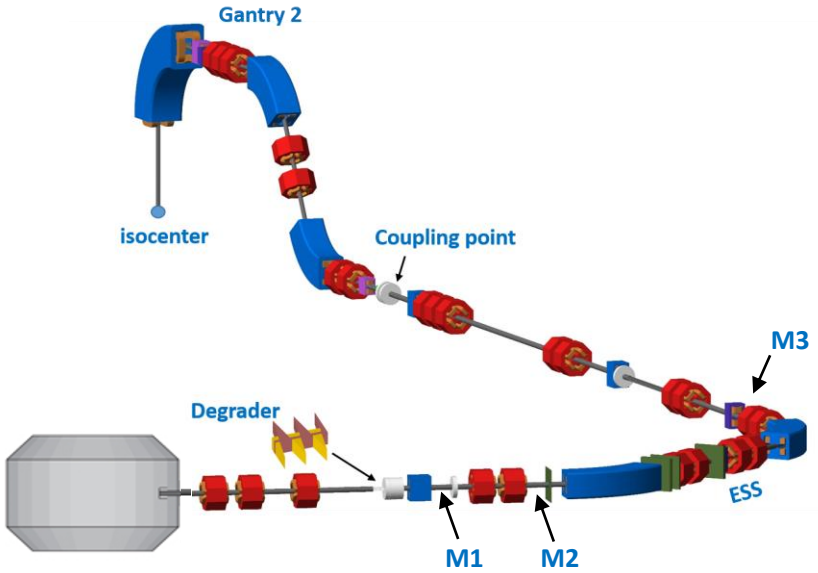
Beam size in commercial companies

Varian medical system : similar to PSI G2

IBA systems : ~1.7 times larger

Monte Carlo simulation model

We have developed a simulation model in **BDSIM** and validated with our clinical tune.



Transmission comparison for 70 MeV beam

	M1	M2	M3	Coupling point	isocenter
BDSIM Simulation	10 ± 0.3%	1.47 ± 0.04%	0.23 ± 0.007%	0.22 ± 0.007%	0.13 ± 0.004%
Measurements	10.1 ± 0.7%	1.46 ± 0.1%	0.21 ± 0.015%	0.21 ± 0.015%	0.13 ± 0.002%

Maradia et al. 2021, *Medical physics*

How to achieve higher transmission?

Higher transmission

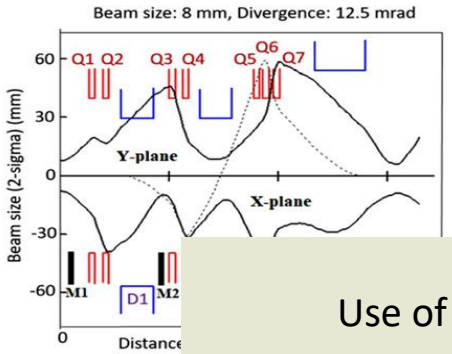
Higher emittance transport

Higher emittance transport through gantry

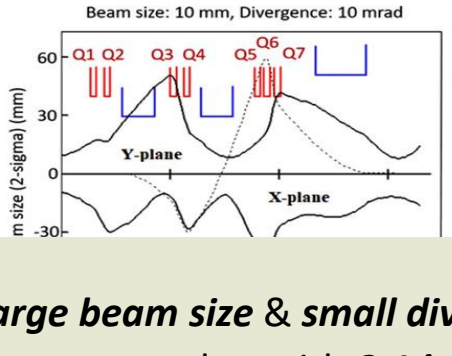
Maradia et al. 2022, *Medical physics*

Gantry beam optics (Emittance: 100 π*mm*mrad)

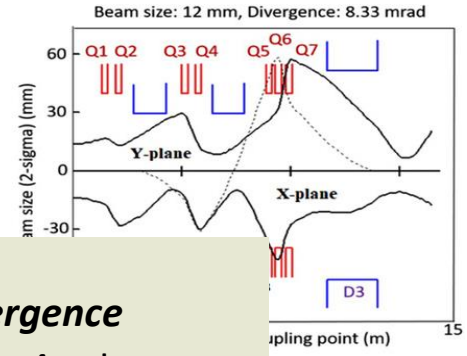
1:1 imaging



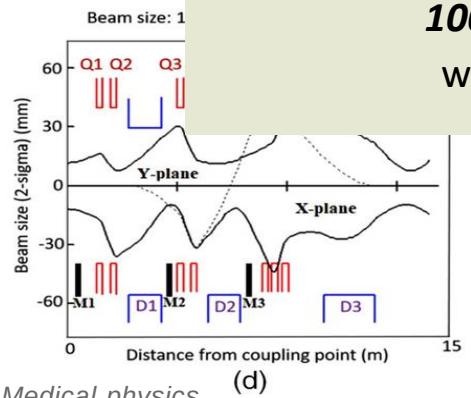
1.25:1 imaging



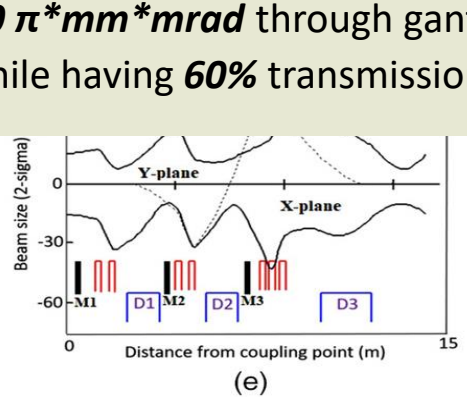
1.5:1 imaging



1.7

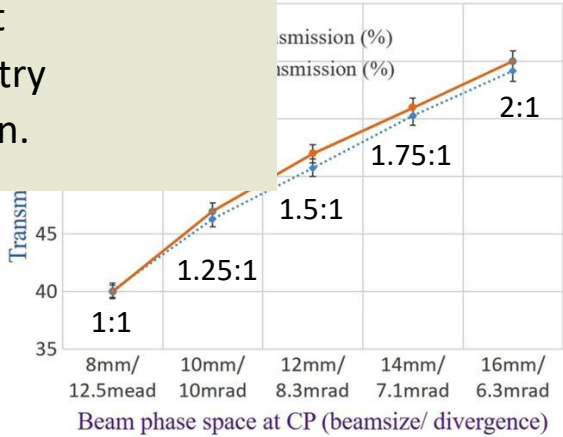


(d)



(e)

Use of ***large beam size*** & ***small divergence*** at gantry entrance together with ***2:1 imaging*** beam optics will allow to transport ***100 π*mm*mrad*** through gantry while having ***60%*** transmission.



Maradia et al. 2022, *Medical physics*

How to achieve higher transmission?

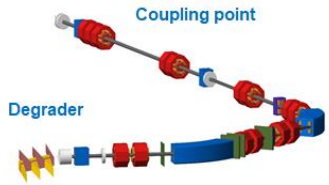
Higher transmission

Higher emittance transport

Higher emittance transport through gantry

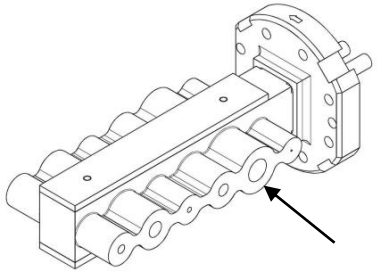
Maradia et al. 2022, *Medical physics*

Higher emittance through fixed beamline (degrader to gantry)

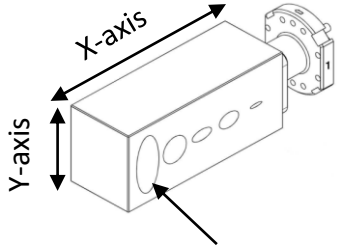


Maradia et al. 2021, *Medical physics*

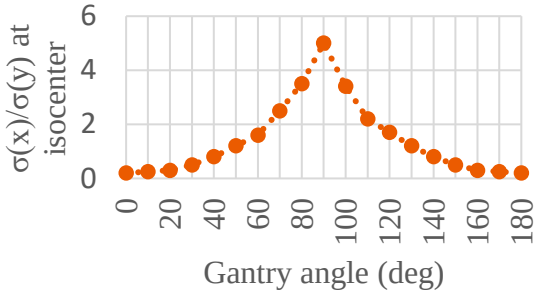
Fixed beamline

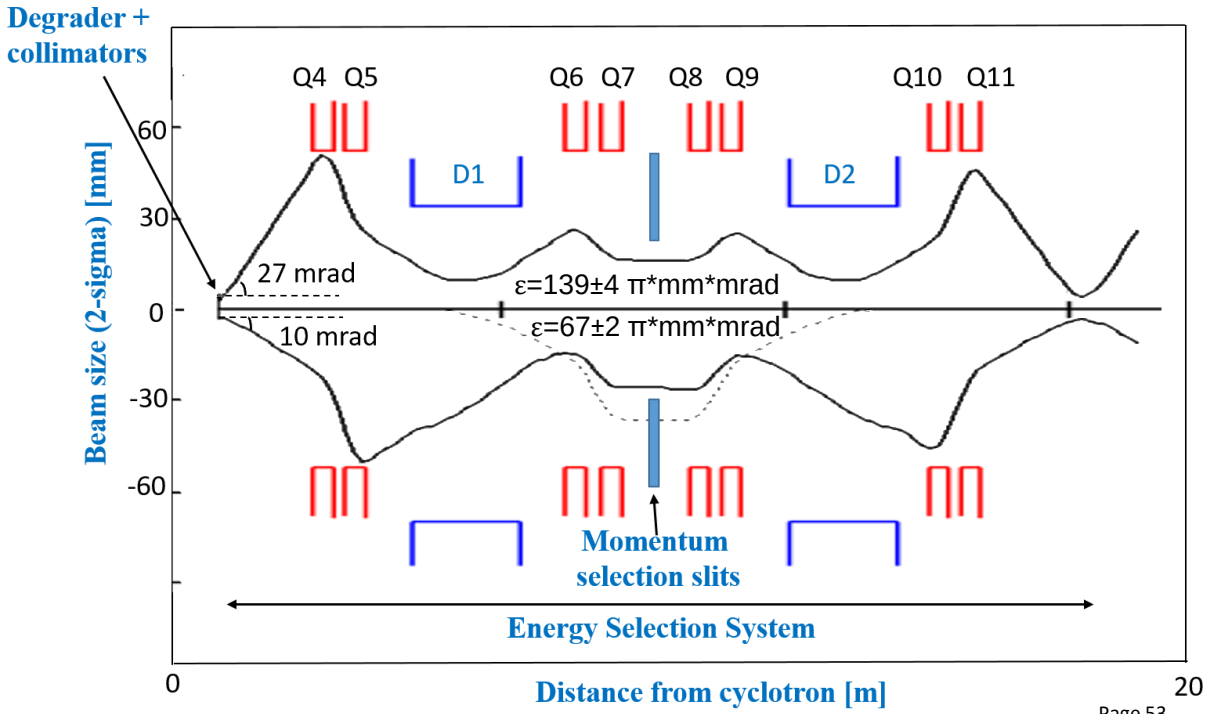


Beam size selection
Collimator (only round shaped)



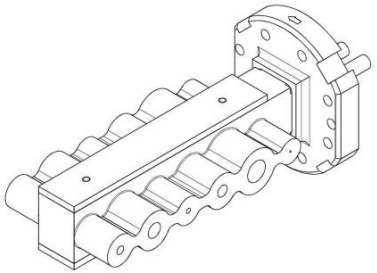
Beam divergence selection
Collimator (1 round, 4 elliptical shaped)



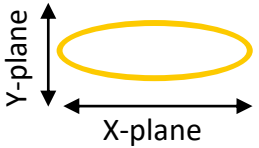


Maradia et al. 2022, *Frontiers in physics*

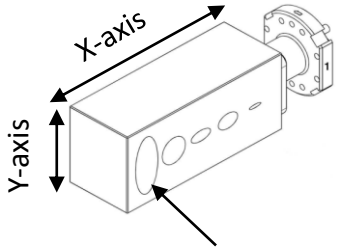
Emittance selection collimators



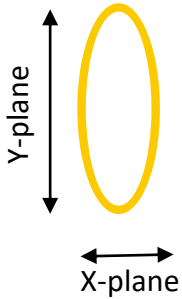
Beam size selection
Collimator (only round shaped)



Beam size
Selection
collimator



Beam divergence selection
Collimator (1 round, 4 elliptical shaped)



Beam divergence
Selection
collimator

Emittance:

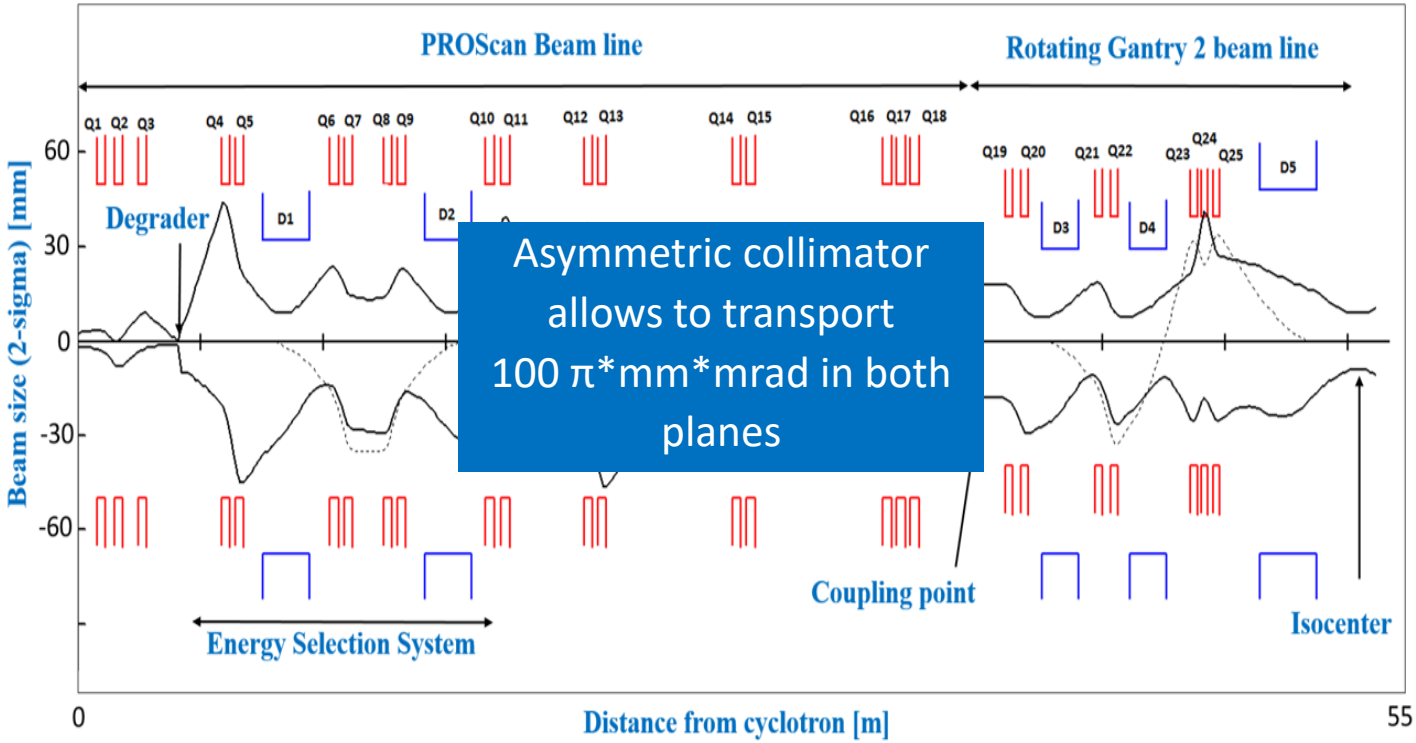
100 π*mm*mrad

Maradia et al. 2021, *Medical physics*

Asymmetric collimator

Y-axis:
Beam size: 4 mm
Divergence: 25 mrad

X-axis:
Beam size: 10 mm
Divergence: 10 mrad



Maradia et al. 2021, *Medical physics*

Transmission gain with asymmetric collimator

For 70 MeV beam

Clinical beam optics : **0.13%**

Asymmetric collimator + 2:1 imaging : **0.72%**

(1.5 times larger beam size compared to clinically used beam size at PSI)

Gain : ~ factor 6

Maradia et al. 2021, *Medical physics*

How to achieve higher transmission?

Higher transmission

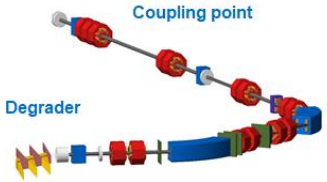
Higher emittance transport

Momentum/energy spread reduction

Higher emittance transport through gantry

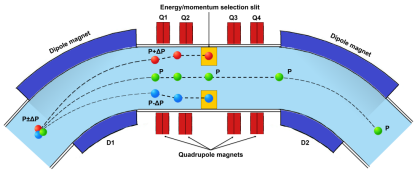
Maradia et al. 2022, Medical physics

Higher emittance through fixed beamline (degrader to gantry)



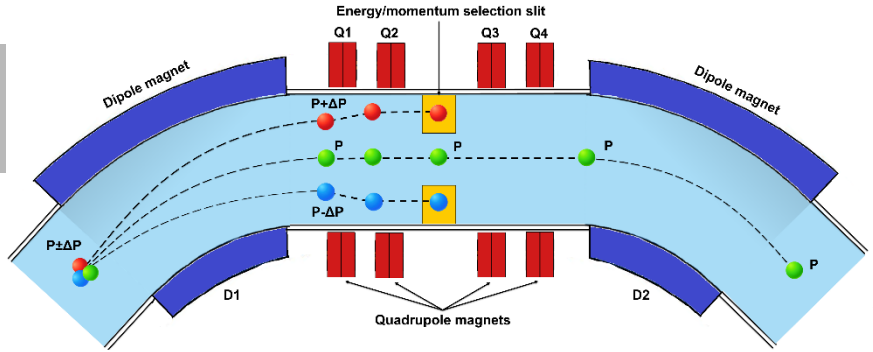
Maradia et al. 2021, Medical physics

Momentum/energy spread reduction with new ESS



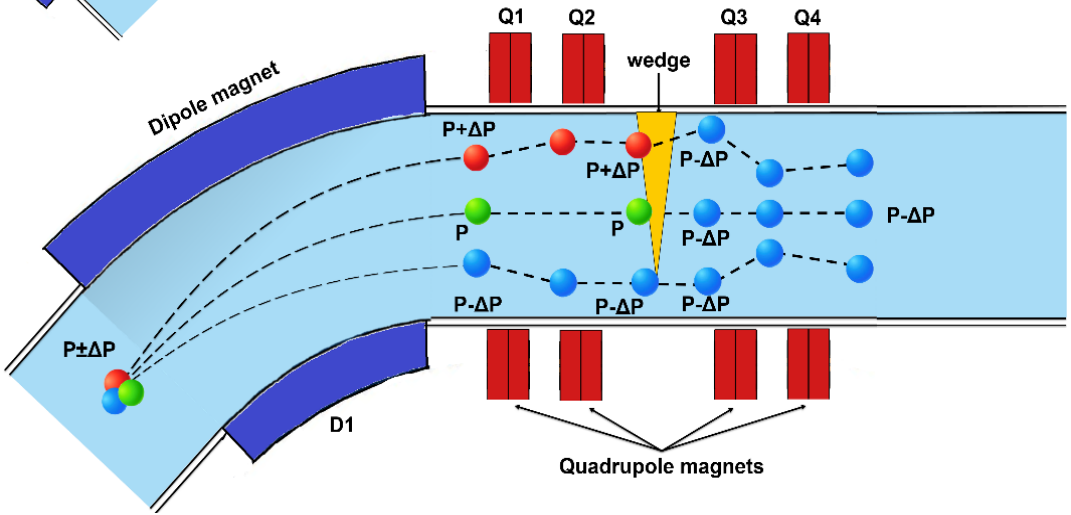
Maradia et al. 2023, Nature Physics

Energy/momentum spread selection



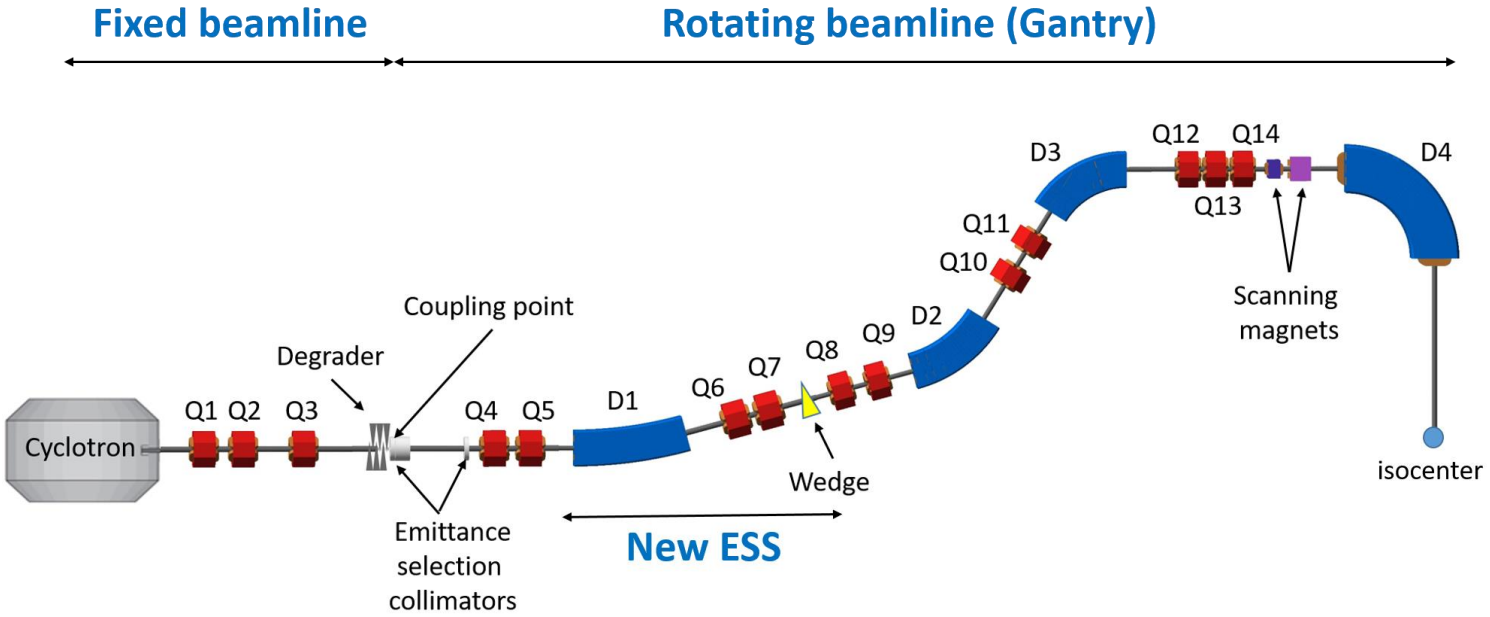
Conventional ESS

New ESS



Maradia et al. 2023, *Nature Physics*

Gantry with momentum cooling capabilities

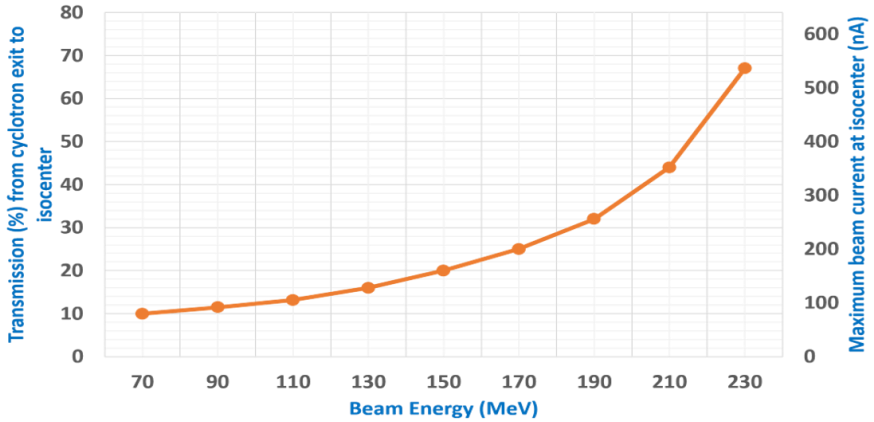


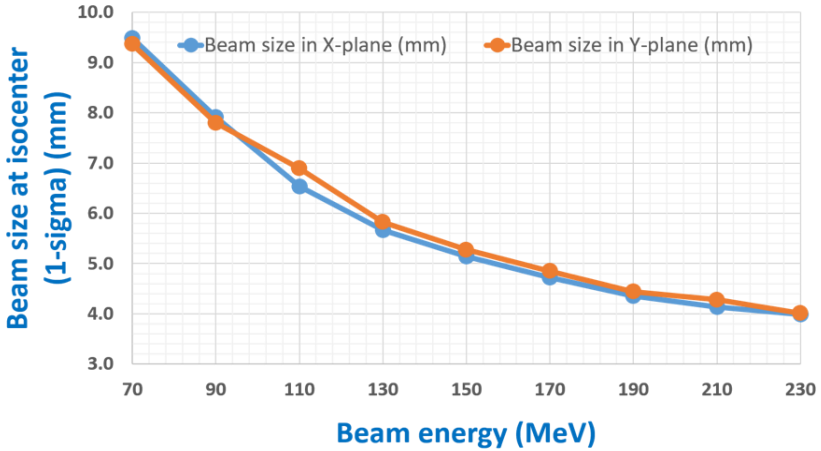
250 MeV → 70 MeV

Momentum spread: ± 4.5% → Momentum spread: ± 0.4%

Maradia et al. 2023, *Nature Physics*

Transmission and beam size





For 70 MeV beam

Clinical beam optics : **0.13%**

Momentum cooling + 2:1 imaging : **10%**

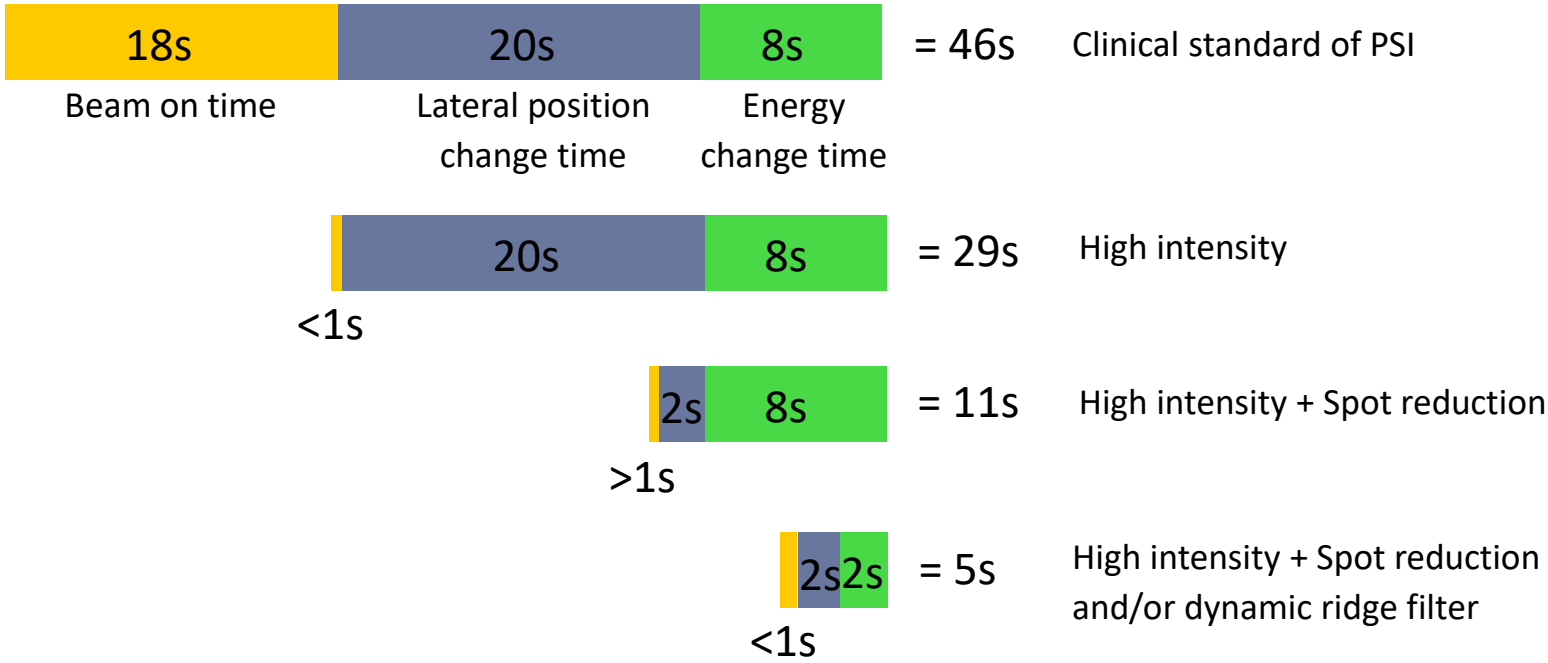
(1.7 times larger beam size compared to clinically used beam size at PSI)

Gain : ~ factor 80

(proof of principle measurement performed in PSI's OPTIS2 beamline)

Maradia et al. 2023, *Nature Physics*

Ultra-fast treatment delivery



Conclusion: Ultra-fast treatment delivery

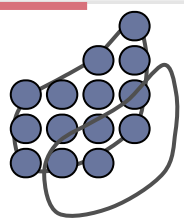
Possible to deliver a single field within a single breath-hold (5-10 sec).

Towards cost effective personalized cancer care

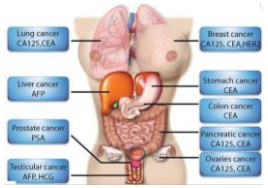
Based on the clinical requirement one could choose different combination of techniques to shorten delivery time.

Impact of ultra-fast treatment delivery

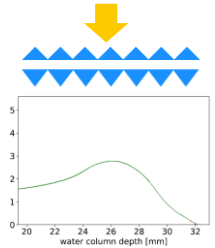
Efficient treatment delivery (increased patient comfort)



Field delivery within a single breath-hold (5-10 sec)

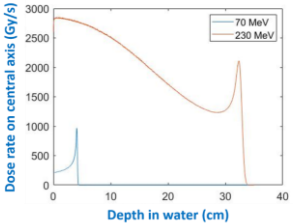


Treatment of new indications with protons



Treatment planning with ridge filter

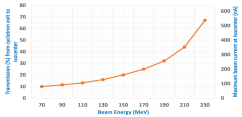
>40 Gy/s
Spares healthy tissues



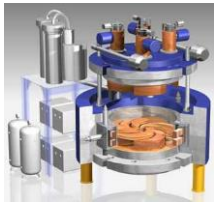
Conformal FLASH Delivery with patient specific ridge filter

Possibility to achieve Ultra-high dose rates

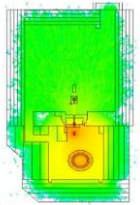
10% transmission
For 70 MeV beam



Cyclotron current limited to 50 nA



Reduced shielding requirement



Reduced shielding requirement (investment cost reduction)

Wir schaffen Wissen – heute für morgen

"If I have seen further it is by standing on the shoulders of Giants" - Isaac Newton (1676)

My thank go to

- Serena Psoroulas
- Tony Lomax
- Marco Schippers
- David Meer
- Isabella Colizzi
- Rudolf Doelling
- Christian Baumgarten
- Oxana Actis
- Zema Chowdhuri
- Robert Schafer
- Jan Hrbacek
- Cyclotron operation group
- Technical support group
- Radiation protection group