

A detailed wireframe model of a particle accelerator, likely a synchrotron or cyclotron. The model shows a large, roughly circular ring structure with multiple parallel tracks. In the background, there are several smaller, more complex structures representing different parts of the facility, including what appears to be a target area and various support buildings. The entire model is rendered in a light gray wireframe style against a white background.

Nuclear fragmentation in ion beam therapy

c.schuy@gsi.de

Content

- Motivation

- “New” ions - $^4\text{He}@\text{HIT}$
- Activation measurements

- Online monitoring of the Bragg peak
- Dose Delivery System

- Summary

Motivation

Patients treated

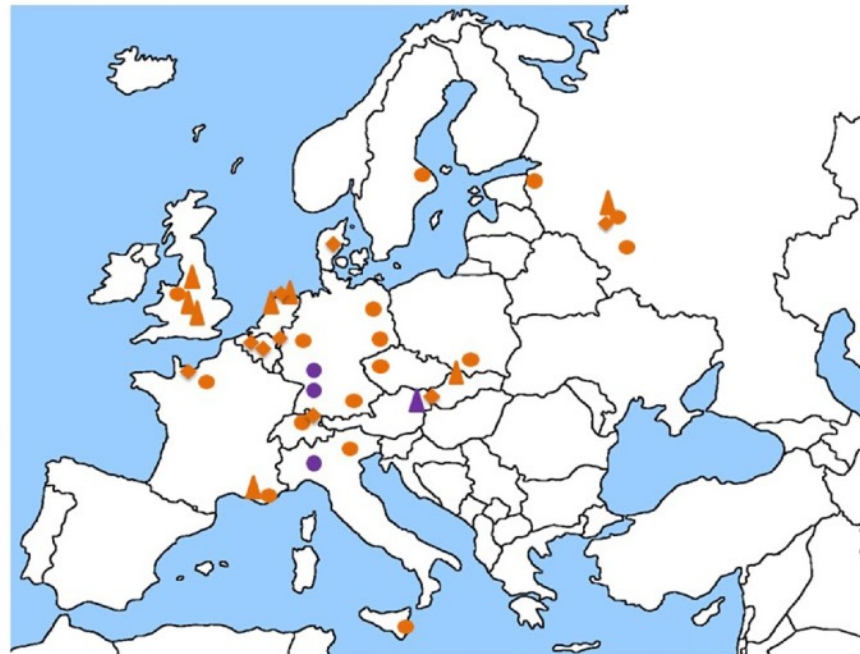
Total of all facilities (in and out of operation):	He	2054	1957-1992
	Pions	1100	1974-1994
	C-ions	21580	1994-2016
	Other ions	433	1975-1992
	Protons	149345	1954-2016
	Grand Total	174512	1954-2016

* estimated, not yet confirmed

Martin Jermann, Secretary of PTCOG, December 2017 (Copyright @ PTCOG)

Motivation

Particle therapy centres in Europe - 2015



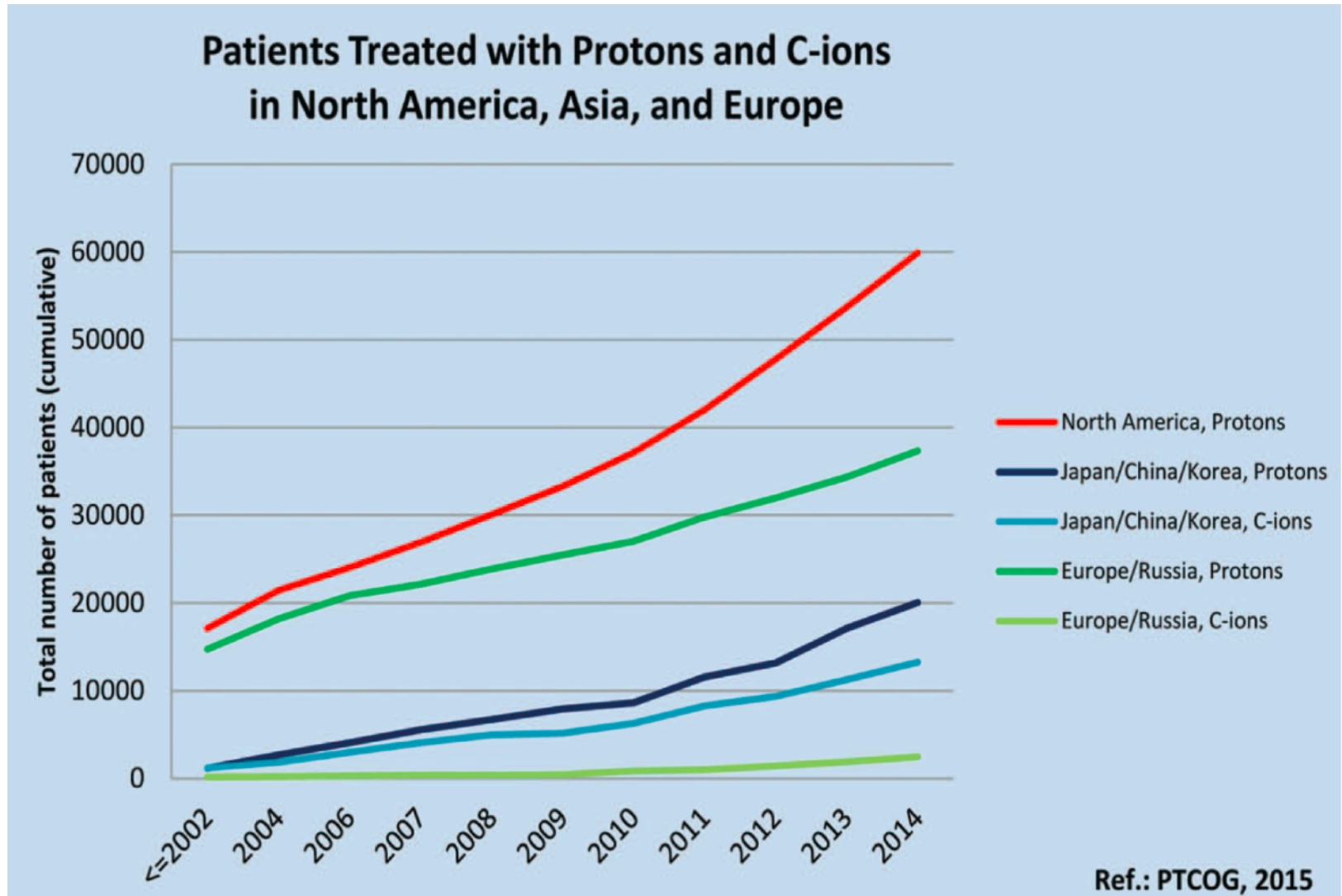
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September 2017 (Copyright @ PTCOG)

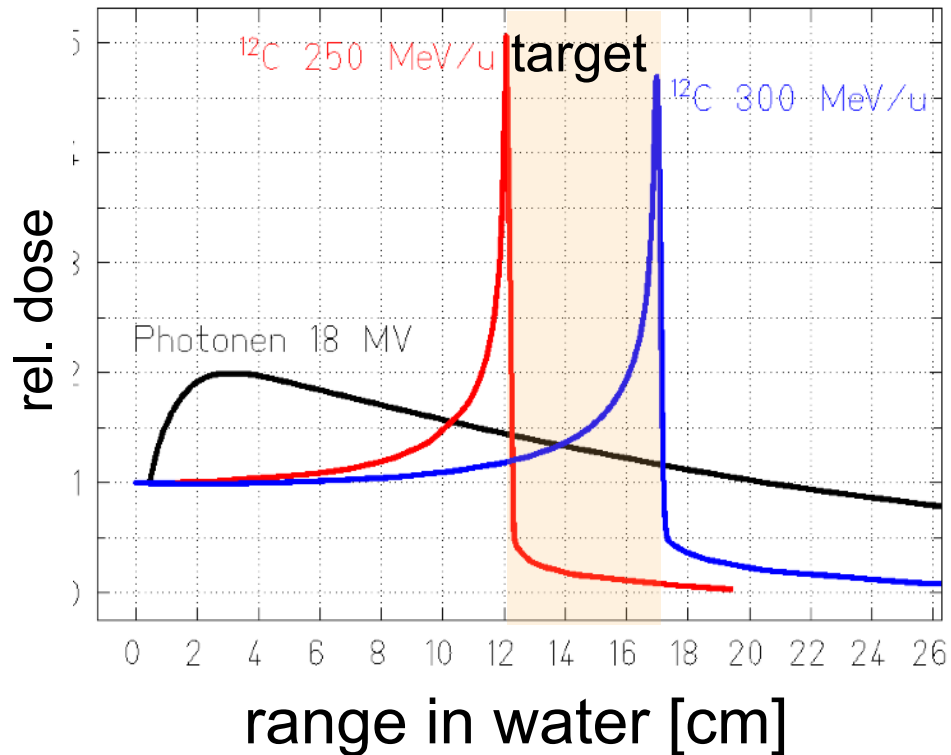
M.Dosanjh 2017 based on PTCOG data

Increase of patient numbers



Motivation

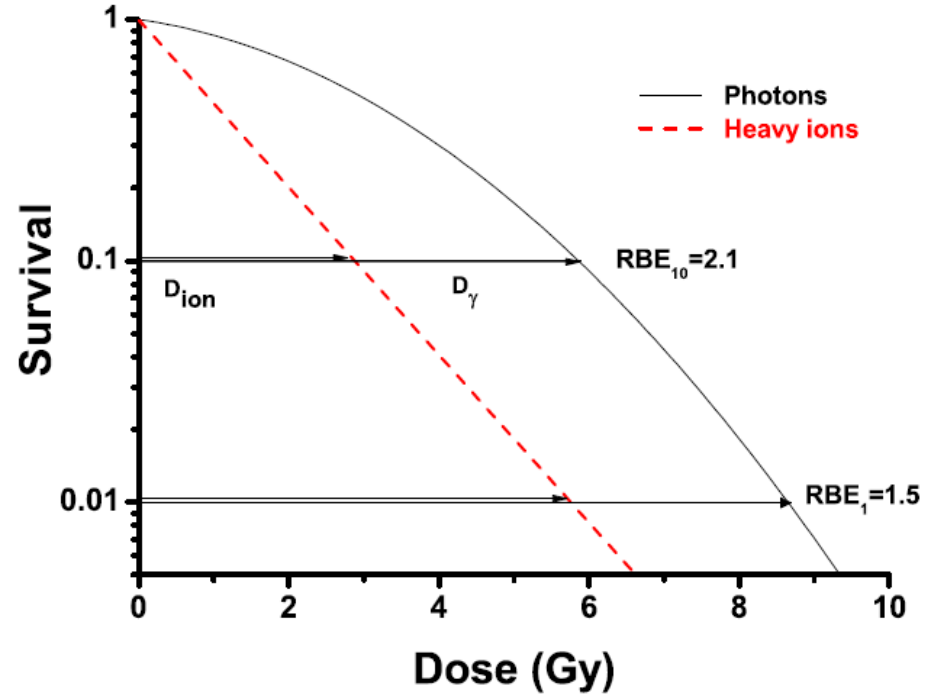
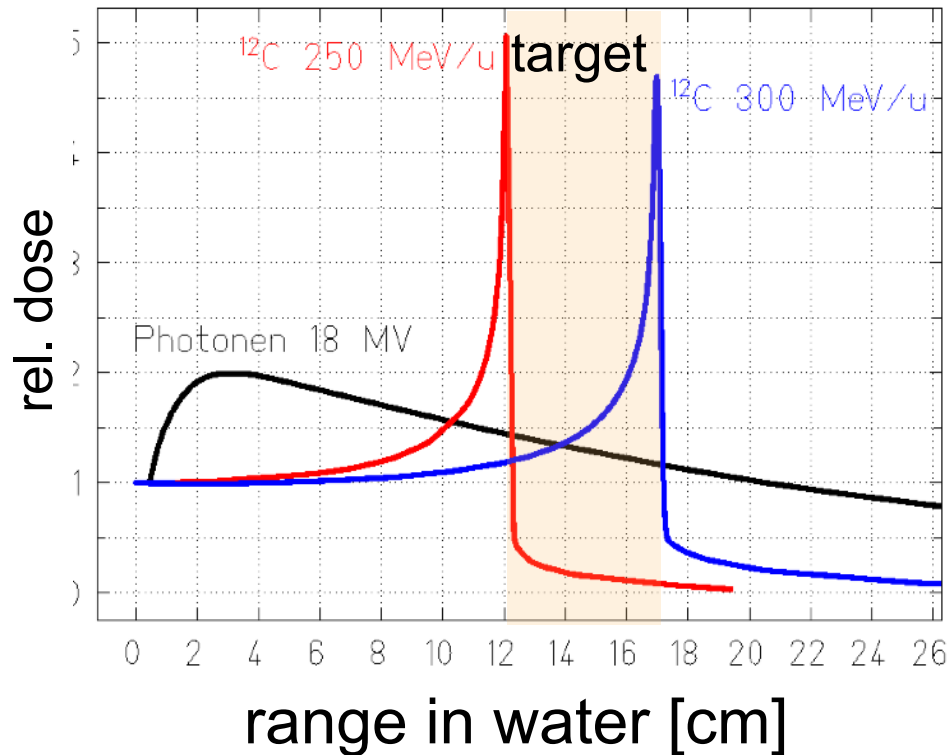
inverse depth dose profile



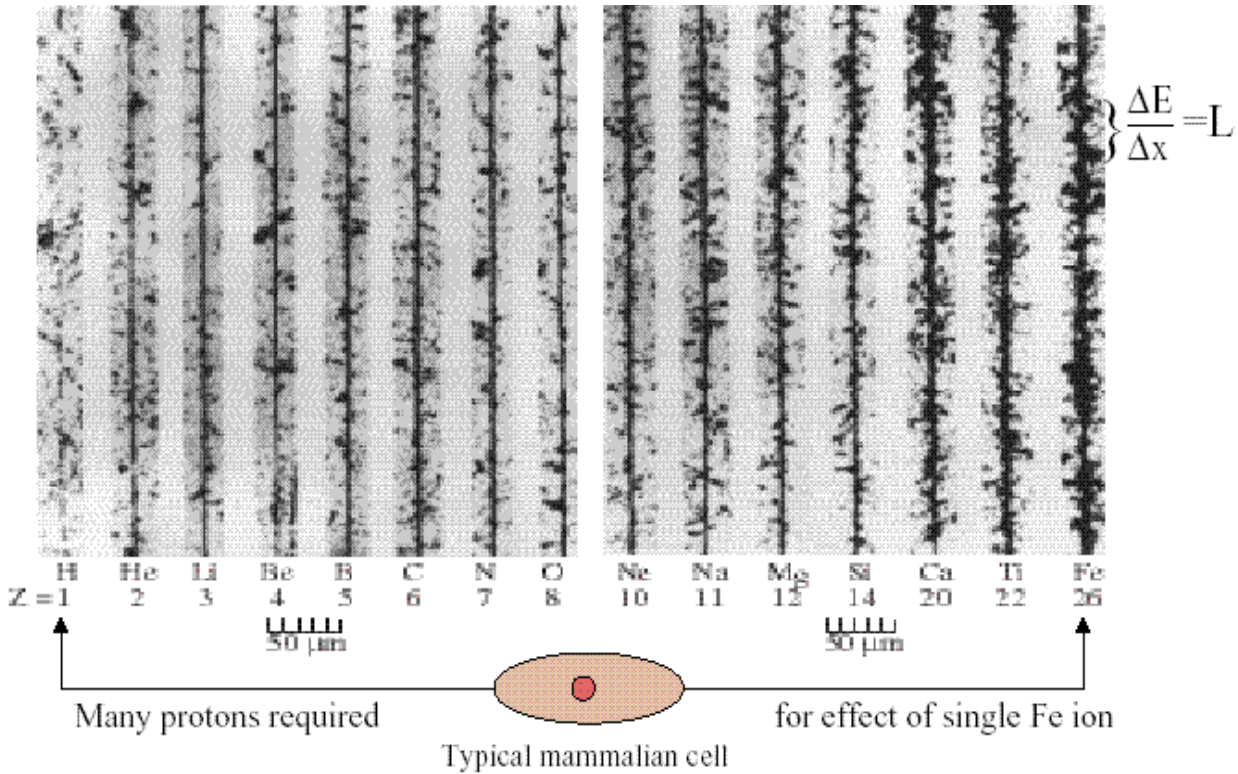
Motivation

inverse depth dose profile

increased biological effect

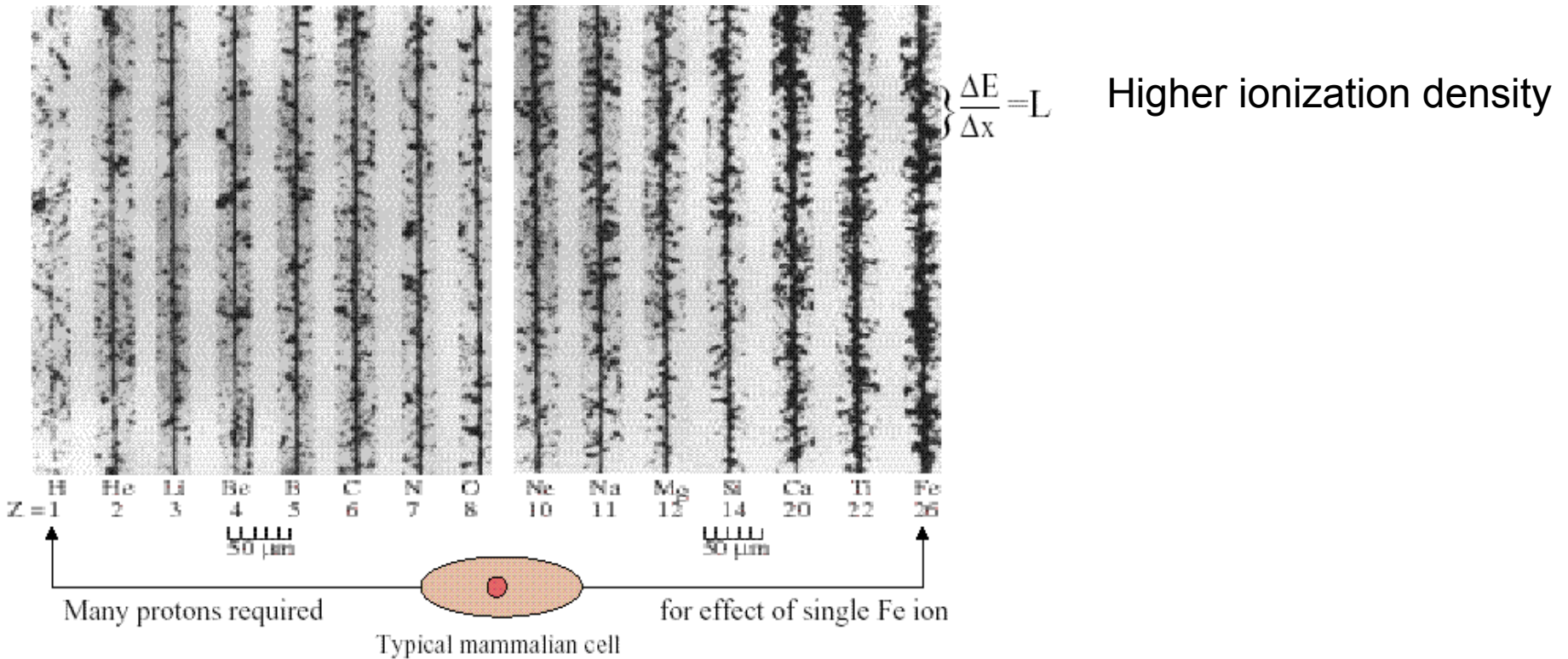


Motiviation



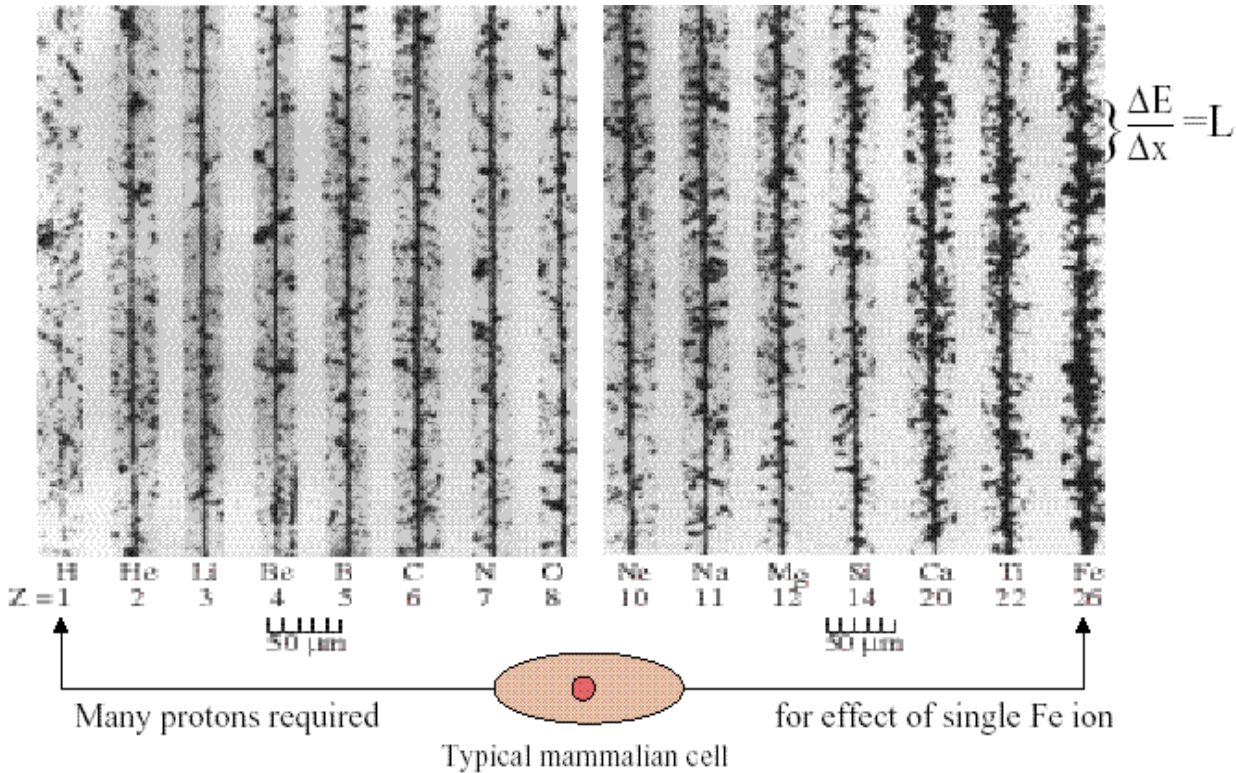
Cucinotta and Durante, *Lancet Oncol.* 2006

Motivation



Cucinotta and Durante, *Lancet Oncol.* 2006

Motiviation



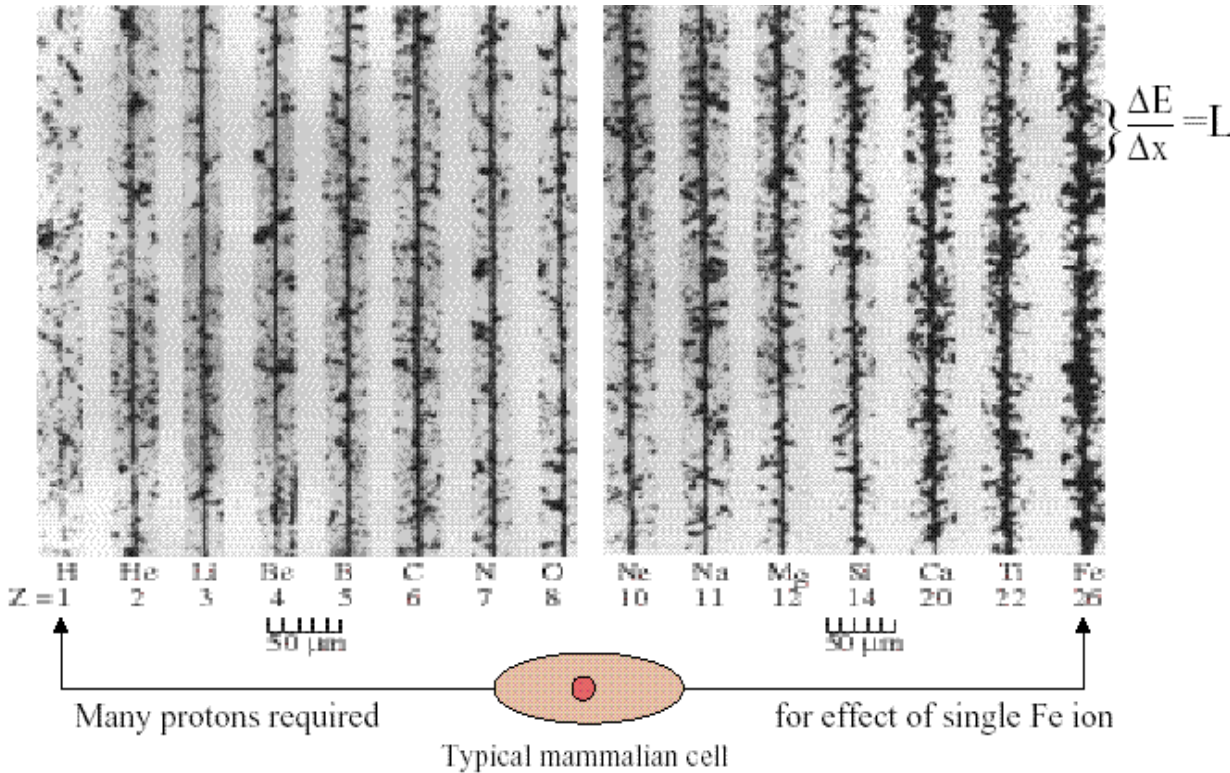
Higher ionization density



More complex damage

Cucinotta and Durante, *Lancet Oncol.* 2006

Motivation



Higher ionization density



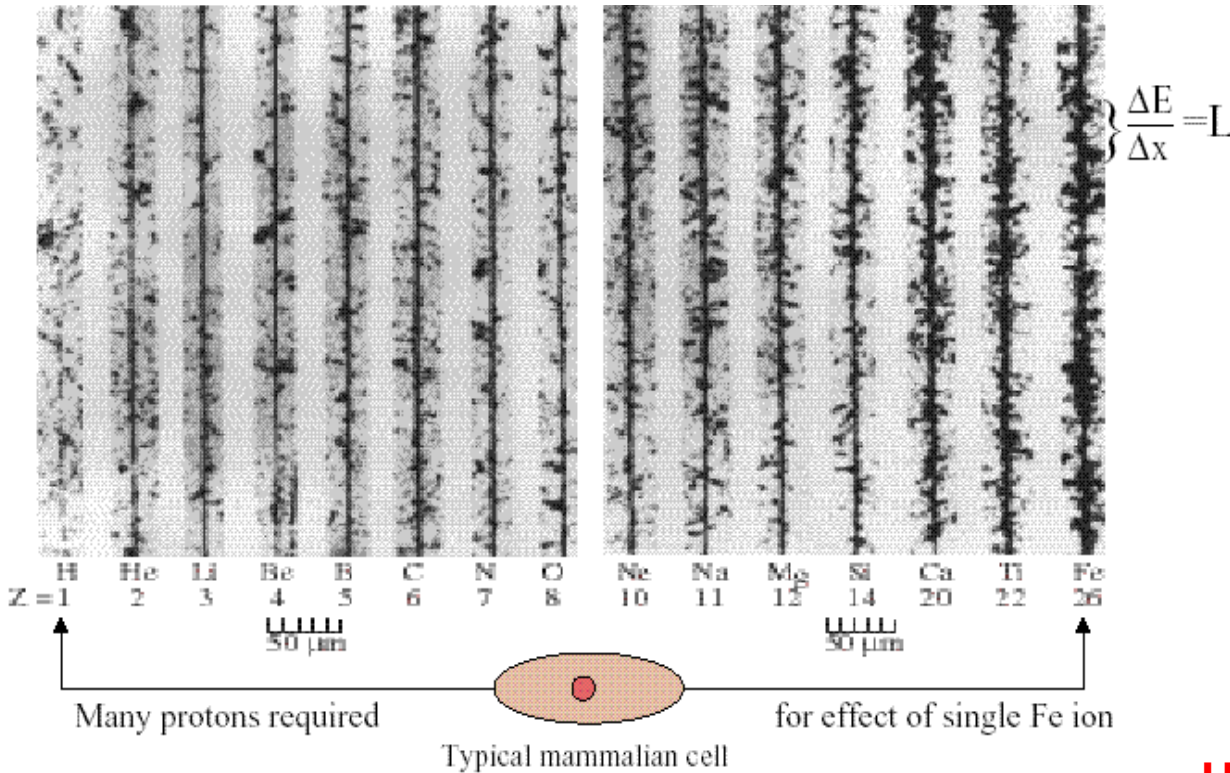
More complex damage



More difficult to repair

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Motivation



Higher ionization density



More complex damage



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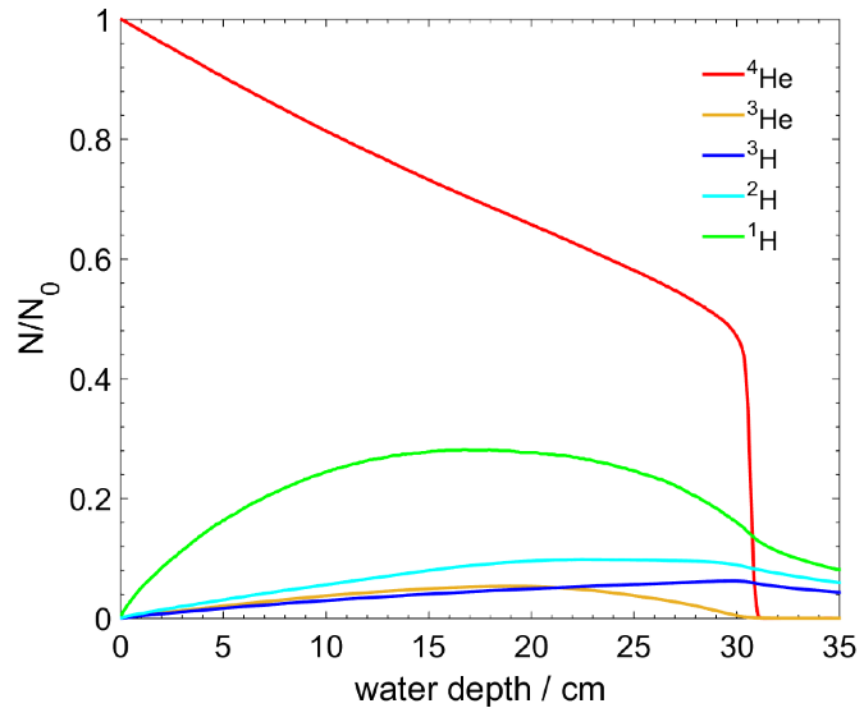


Higher biological efficiency

Cucinotta and Durante, *Lancet Oncol.* 2006

Motivation

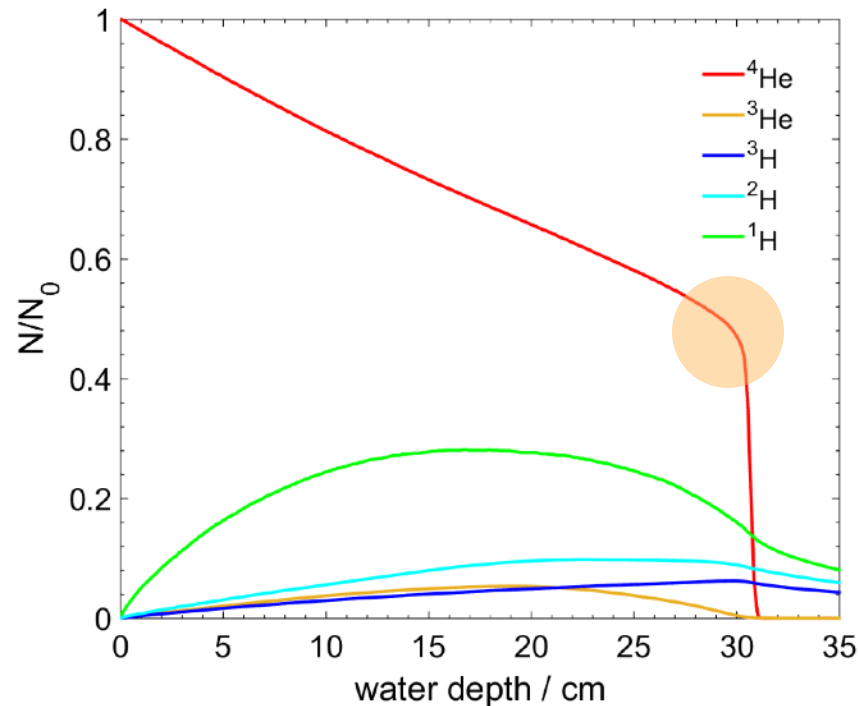
Relative fluence
 220 MeV/u ^4He ions stopping in water



calculation courtesy of F. Horst

Motivation

Relative fluence
220 MeV/u ^4He ions stopping in water



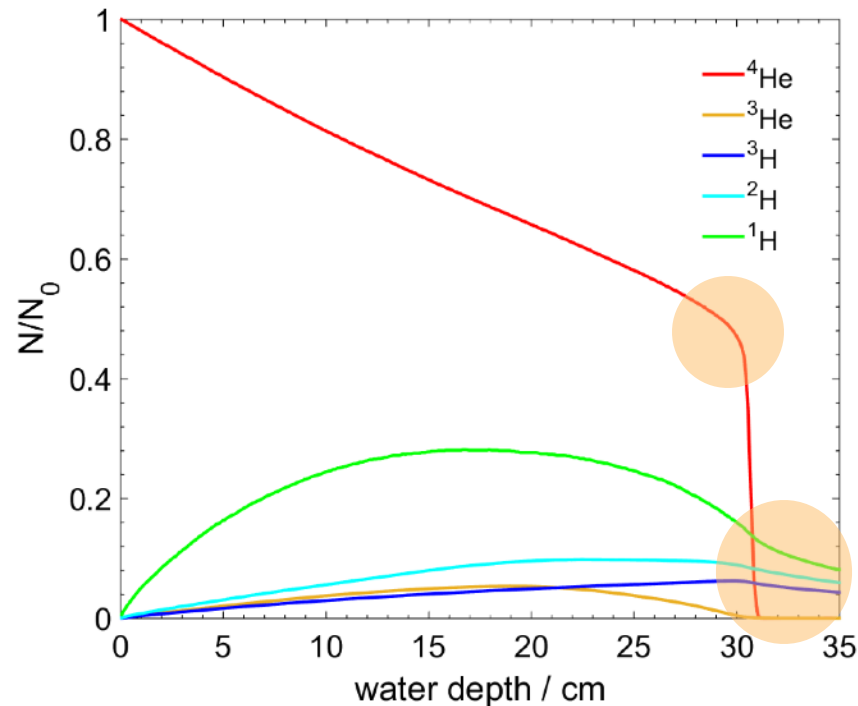
- ~ 50 % of the primary ^4He ions reach the Bragg peak

calculation courtesy of F. Horst

Motivation

Relative fluence

220 MeV/u ^4He ions stopping in water



calculation courtesy of F. Horst

- ~ 50 % of the primary ^4He ions reach the Bragg peak
- lighter fragments have increased penetration depth

Motivation

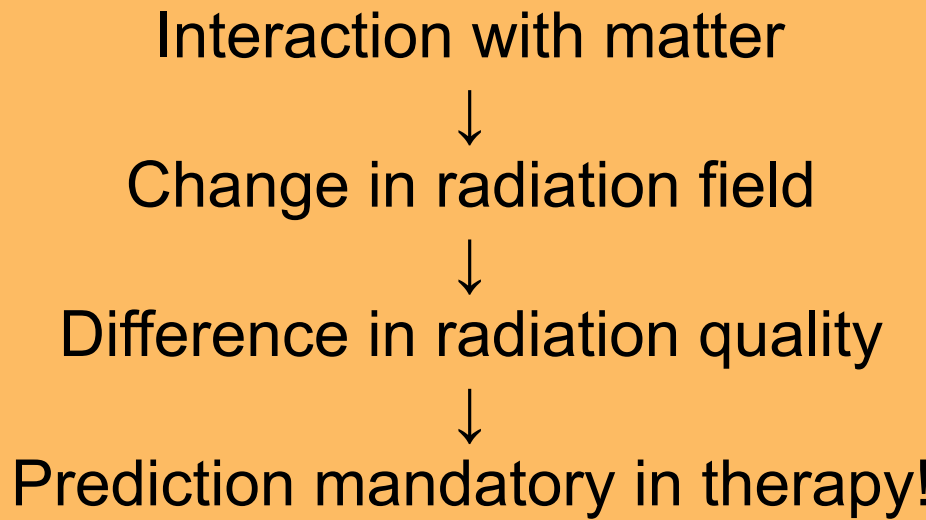
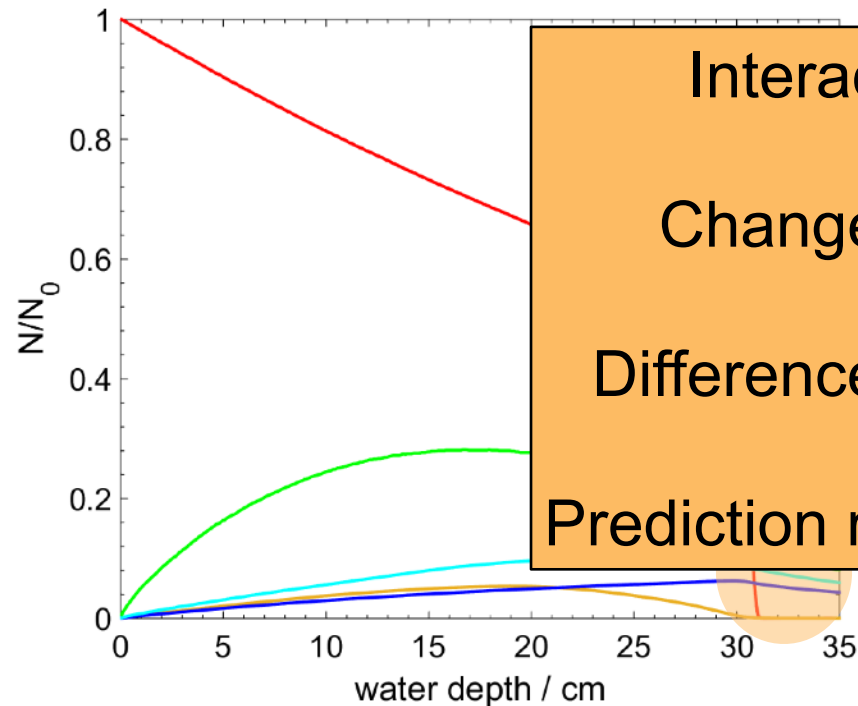
Relative fluence
220 MeV/u ^4He ions stopping in water

■ ~ 50 % of the primary ^4He

Bragg peak

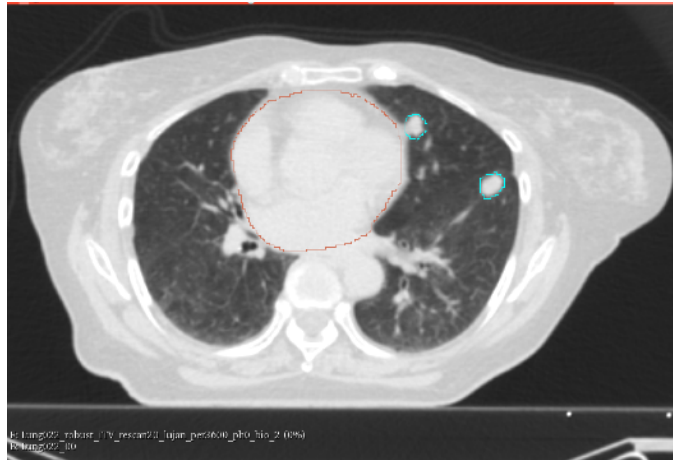
its have

etration

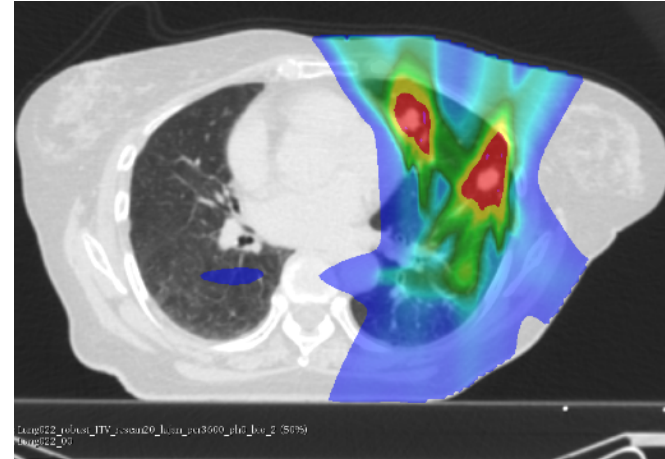
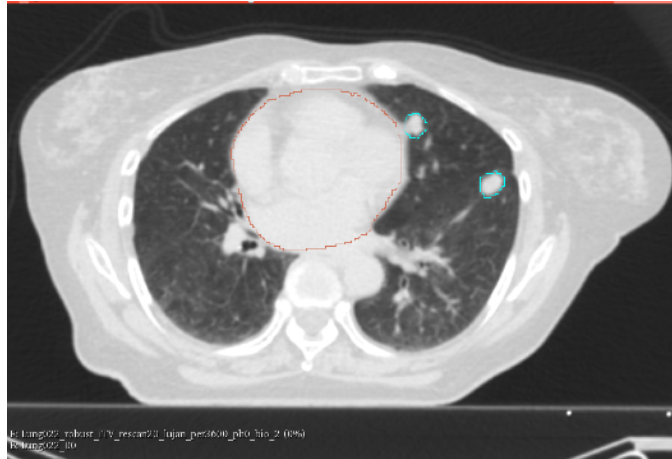


calculation courtesy of F. Horst

Insertion - Treatment planning

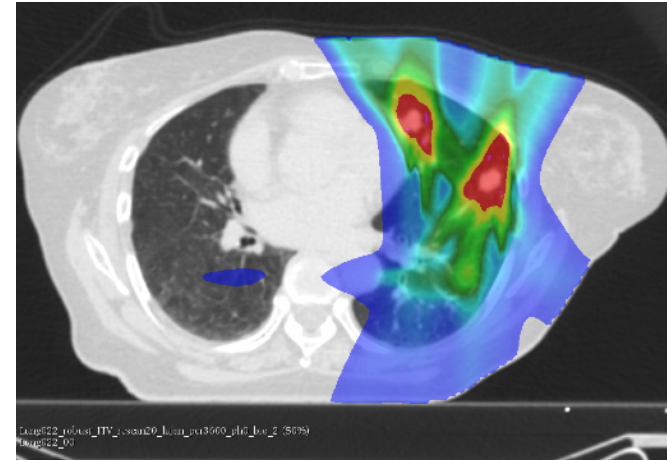
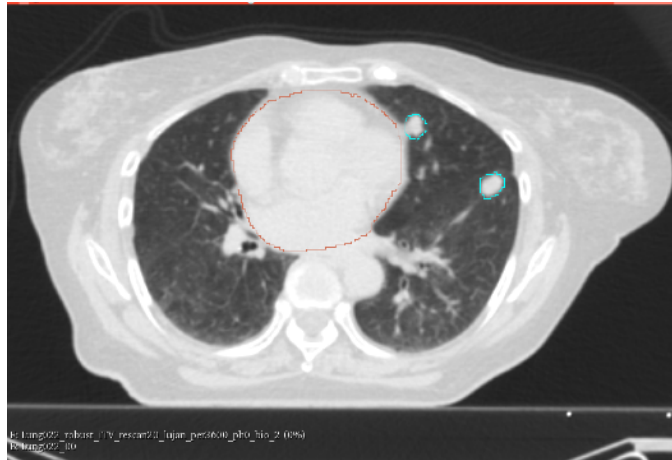


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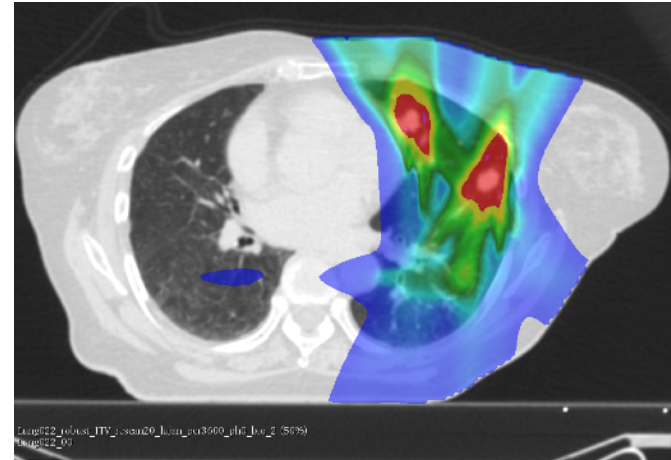
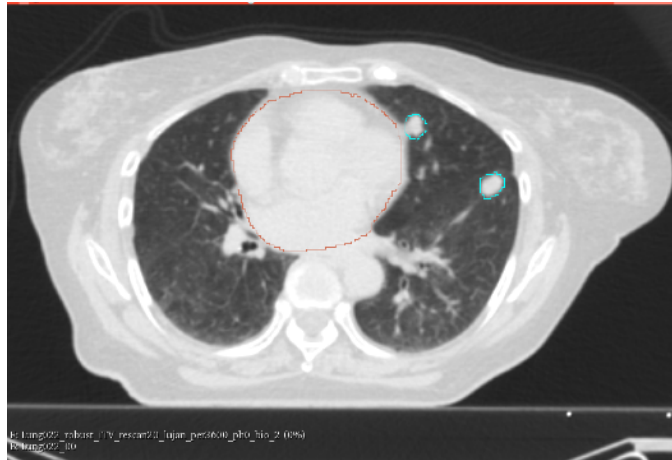
- TPS is trying to find optimal treatment within constraints
 - Biological effectiveness included!

Insertion - Treatment planning



- TPS is trying to find optimal treatment within constraints
 - Biological effectiveness included!
- Hybrid approach

Insertion - Treatment planning

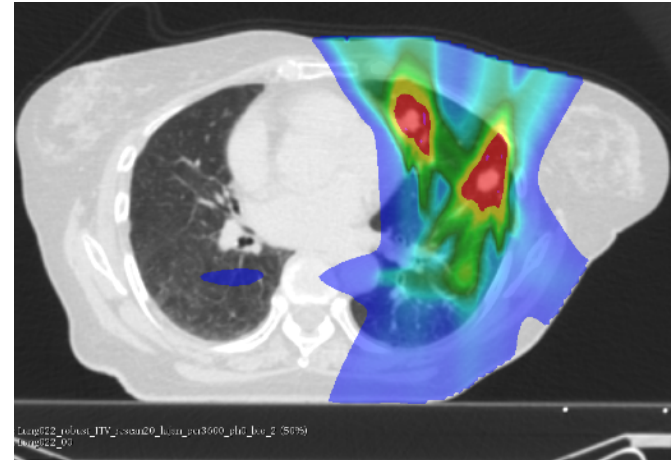
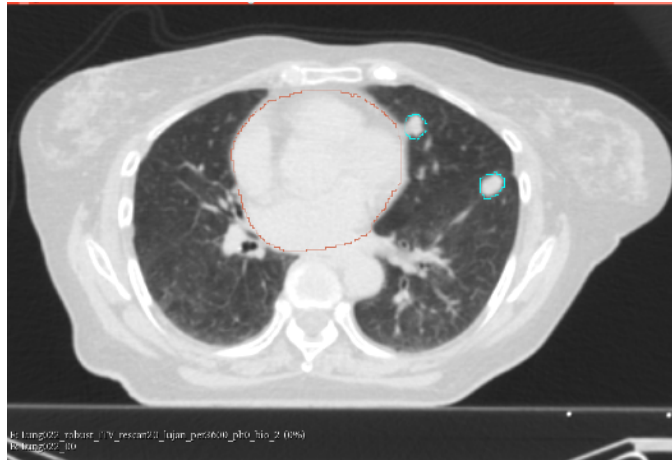


- TPS is trying to find optimal treatment within constraints
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- Hybrid approach
 - Benchmark experiments (QA) using water -> Base data



PTW website

Insertion - Treatment planning

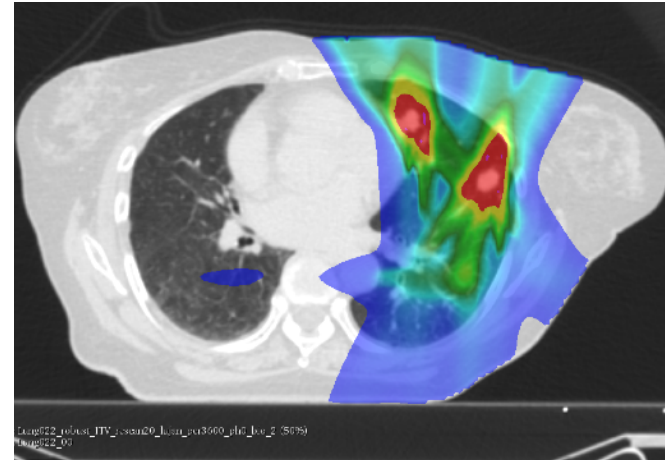
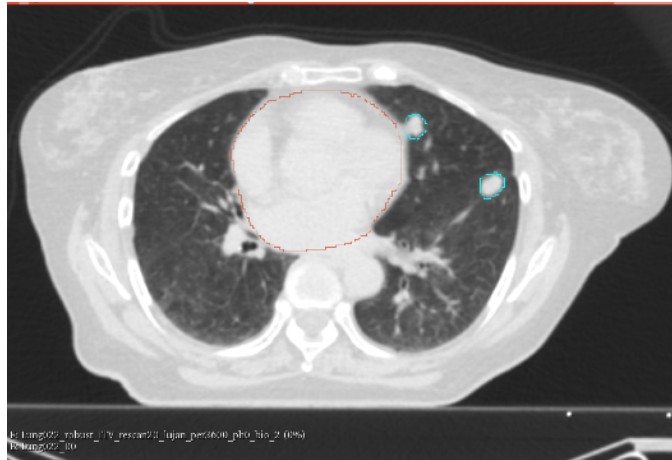


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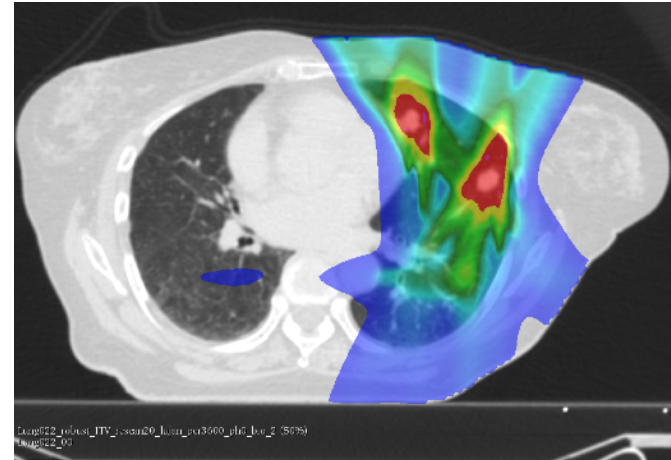
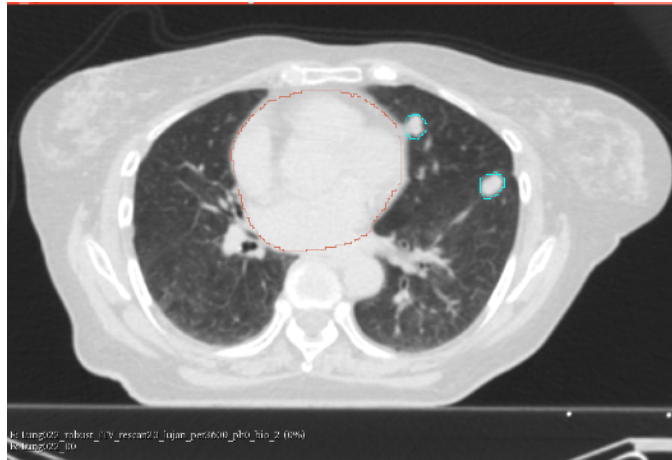


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 - Deterministic Code (e.g. TRiP98) for planning



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 - Deterministic Code (e.g. TRiP98) for planning
- Plan QA



PTW website

“New” ions - ^4He @HIT

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Bevalac USA

Total of all facilities (in and out of operation):	He	2054	1957-1992
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“New” ions - ^4He @HIT

Bevalac USA

Total of all facilities (in and out of operation):	He	2054	1957-1992
<ul style="list-style-type: none"> physical and biological “compromise” between protons and ^{12}C 			994
			016
			992
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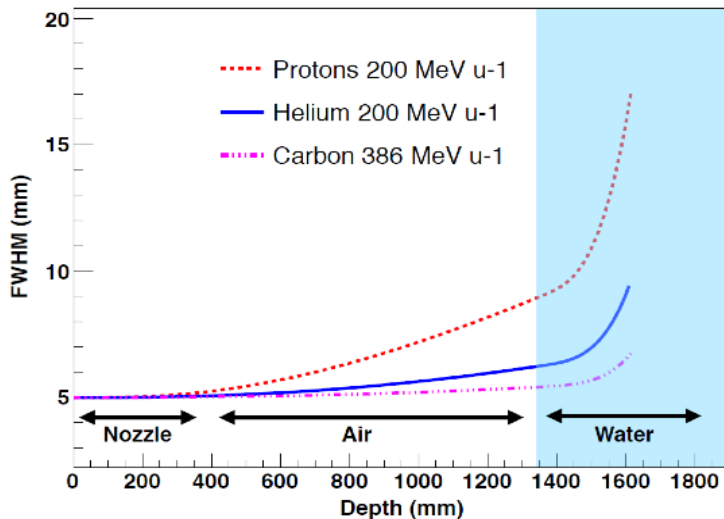
Total of all facilities (in and out of operation):

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- Less energy straggling -> protons
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016
992
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courtesy of M.Rovituso (Thesis)

PTCOG, December 2017 (Copyright @ PTCOG)

“New” ions - ^4He @HIT

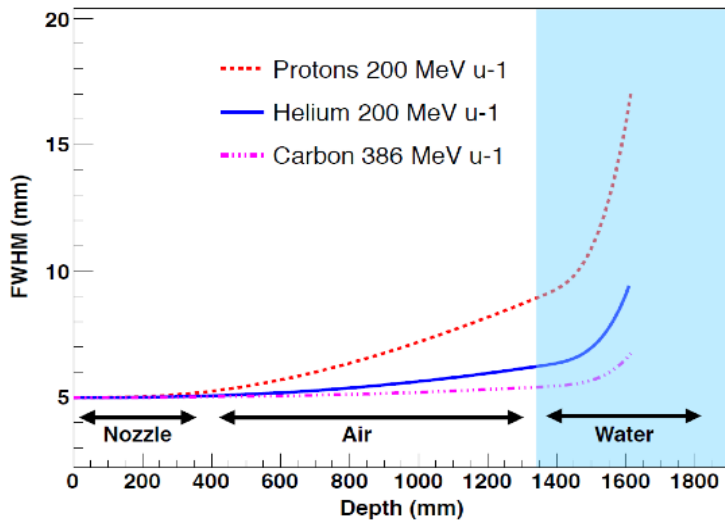
Bevalac USA

Total of all facilities (in and out of operation):

Ion	2054	1957-1992
He	016	016
H	016	016
C	016	016
N	016	016
O	016	016
Ne	016	016
Ar	016	016
Kr	016	016
Xe	016	016
Bi	016	016
Pb	016	016
U	016	016

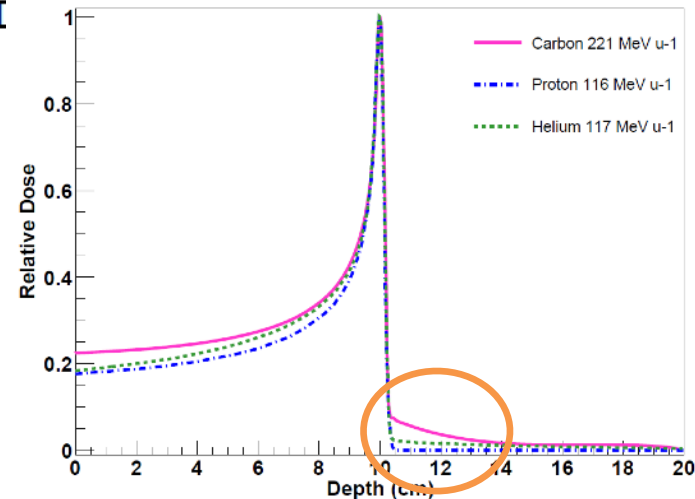
- physical and biological “compromise” between protons and ^{12}C
- RBE in Bragg peak region > protons
- Less energy straggling -> protons
- Less lateral scattering -> protons
- Less projectile fragmentation -> ^{12}C

* es



courtesy of M.Rovituso (Thesis)

TCOG, I



courtesy of M.Rovituso (Thesis)

“New” ions - ^4He @HIT

- Planned start for ^4He @HIT 2019

“New” ions - ^4He @HIT

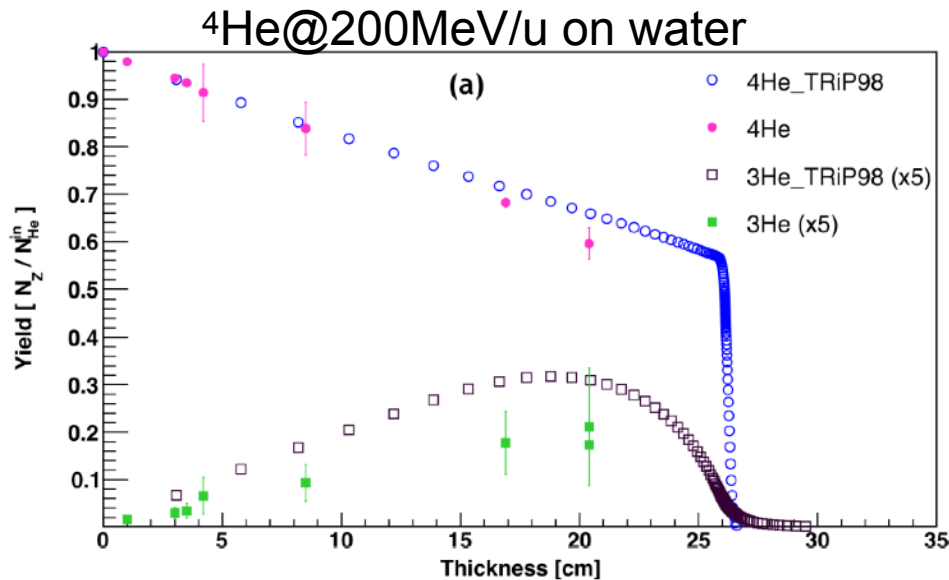
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- **Inaccurate/missing** cross section data

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- Measurement campaign to benchmark TRiP98

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 - Attenuation of the primary beam

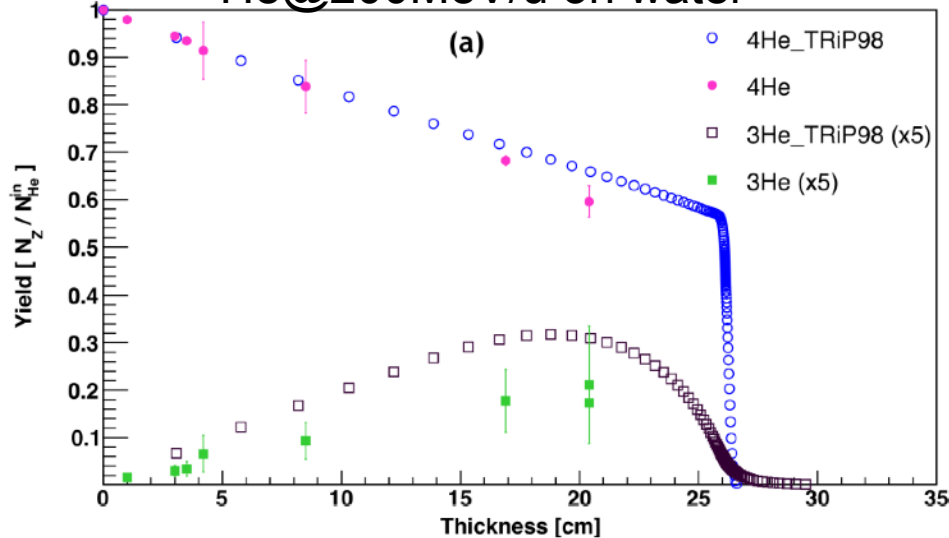


M.Kraemer et al, Med. Phys. 2016

“New” ions - ^4He @HIT

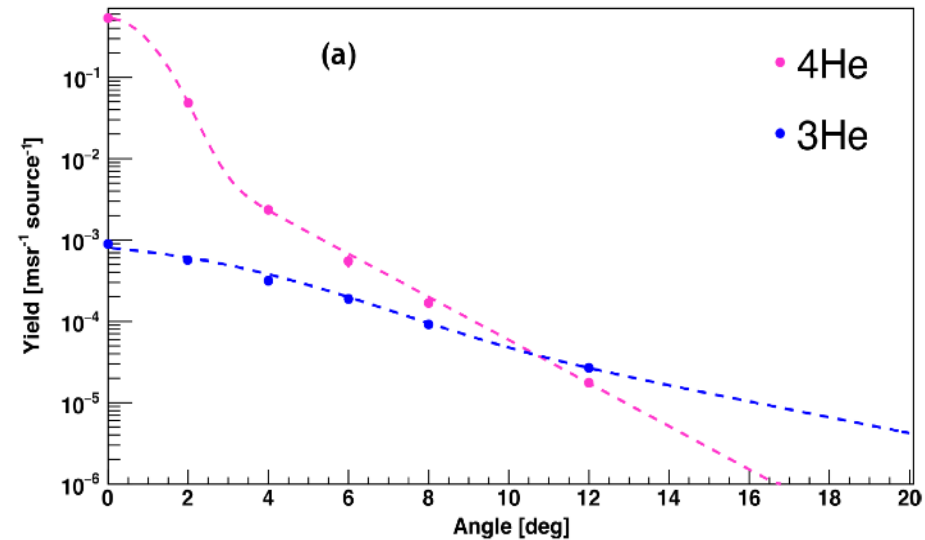
- Planned start for ^4He @HIT 2019
- Inaccurate/missing** cross section data
- Measurement campaign to benchmark TRiP98
 - Attenuation of the primary beam
 - Double differential yields

^4He @200MeV/u on water



M.Kraemer et al, Med. Phys. 2016

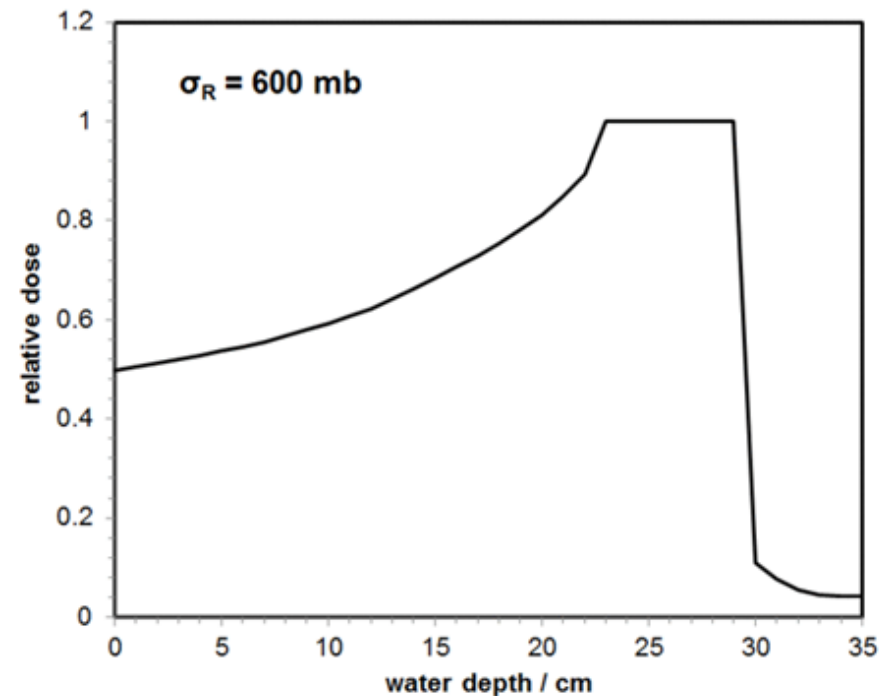
^4He @120MeV/u on 4.28cm water



M.Rovituso et al, PMB 2017

“New” ions - ^4He @HIT

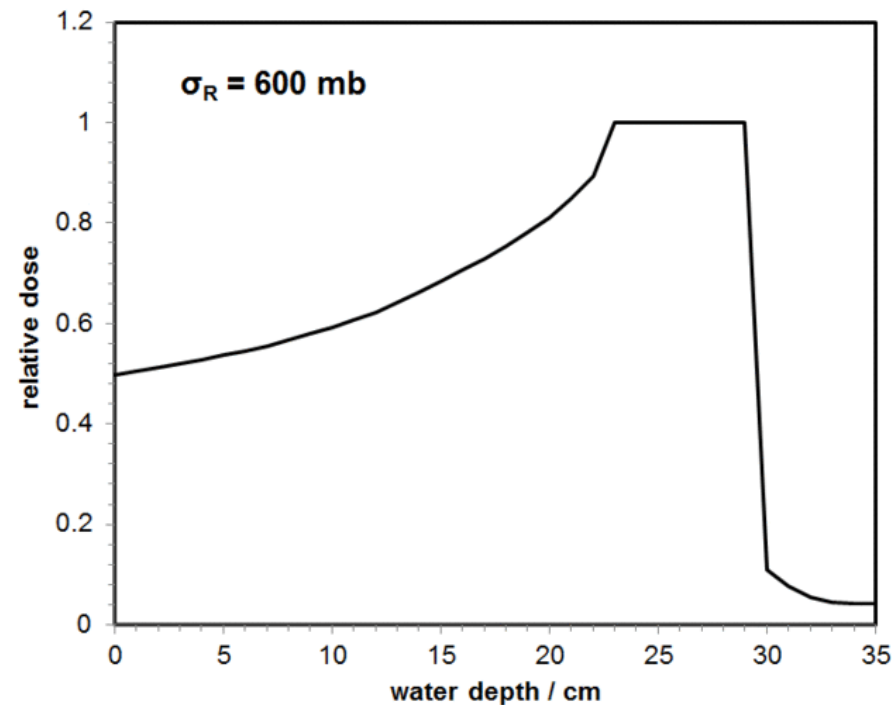
SOPB calculated in H₂O



calculation courtesy of F. Horst

“New” ions - ^4He @HIT

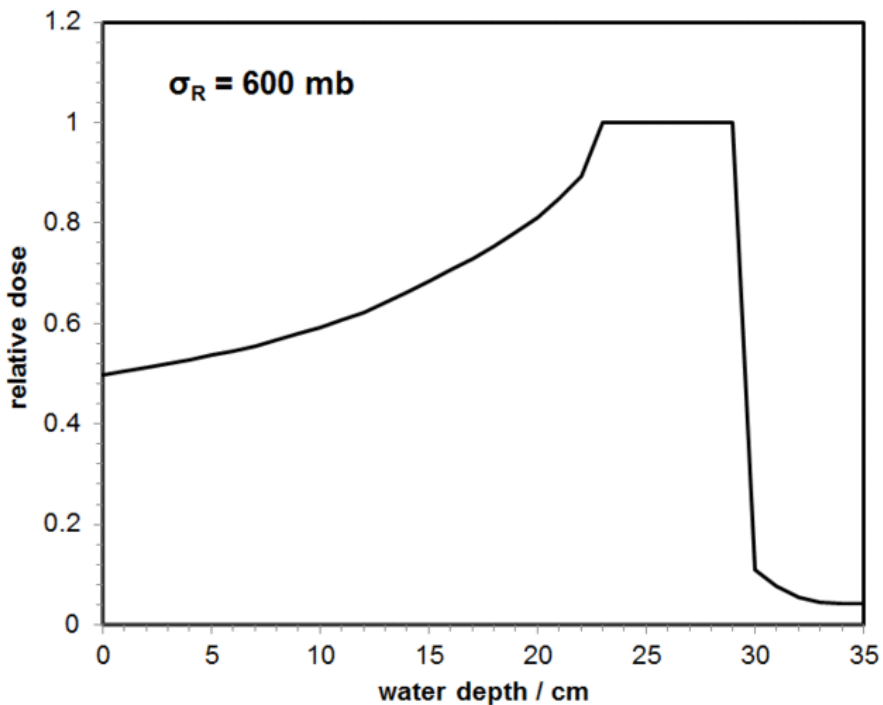
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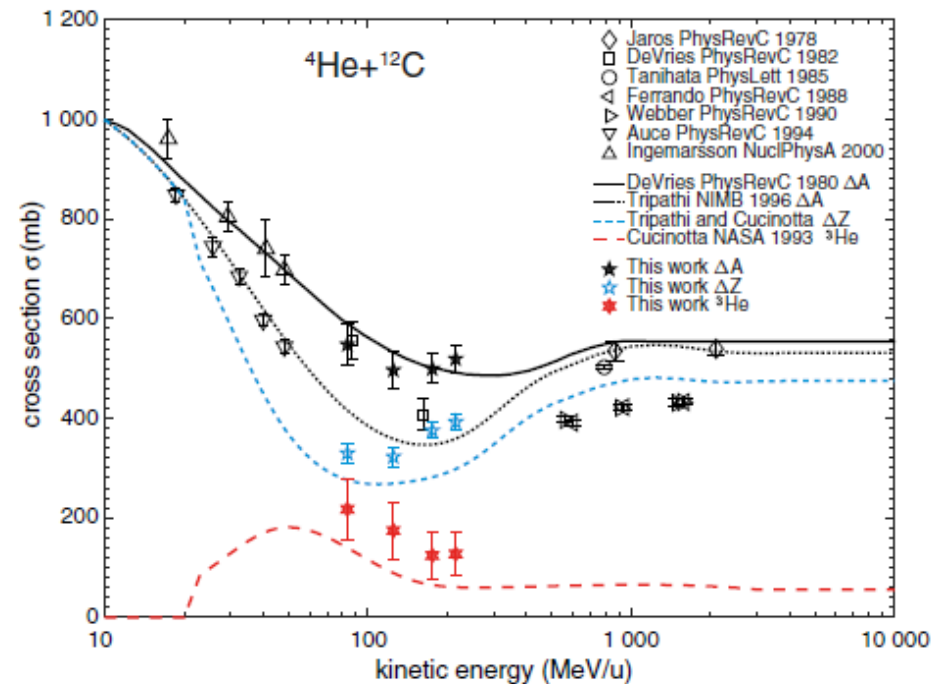
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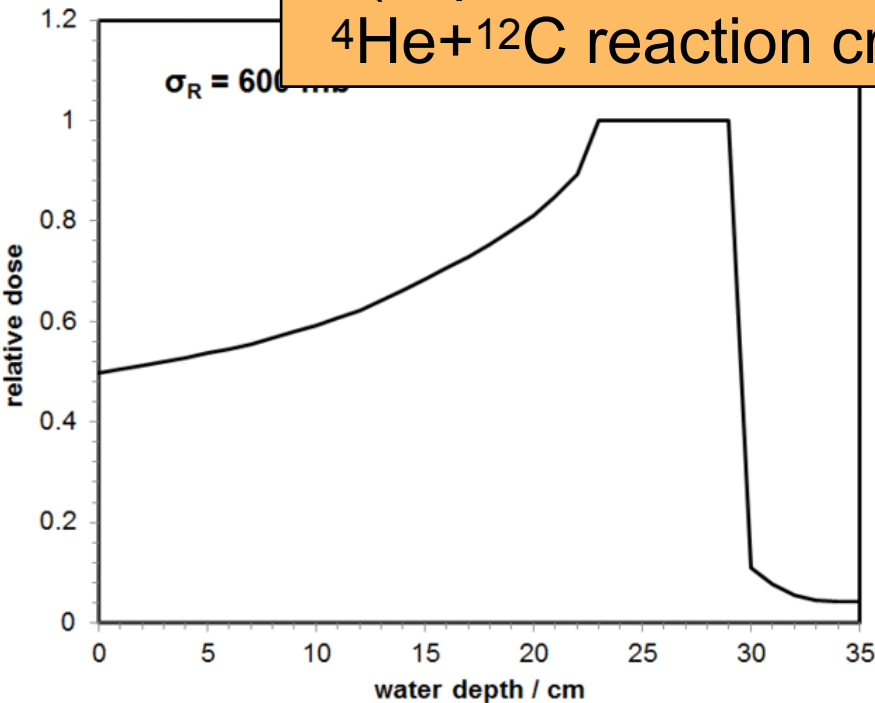
calculation courtesy of F. Horst



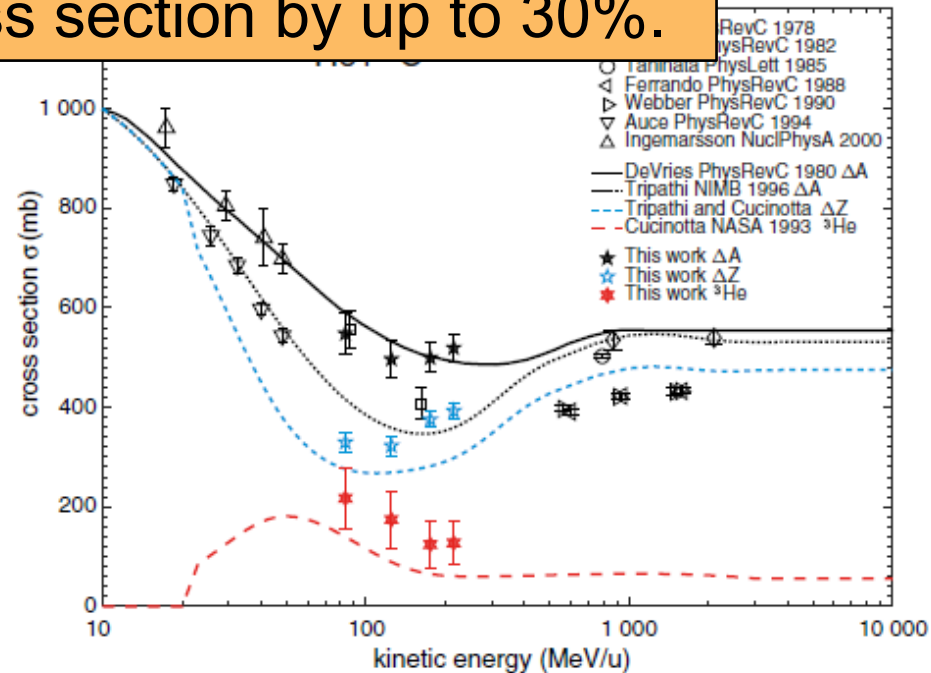
F. Horst et al. Phys. Rev. C 2017

“New” ions - ^4He @HIT

SO **Tripathi cross section parametrization (implemented in TRiP) under-estimates the $^4\text{He}+^{12}\text{C}$ reaction cross section by up to 30%.**



calculation courtesy of F. Horst

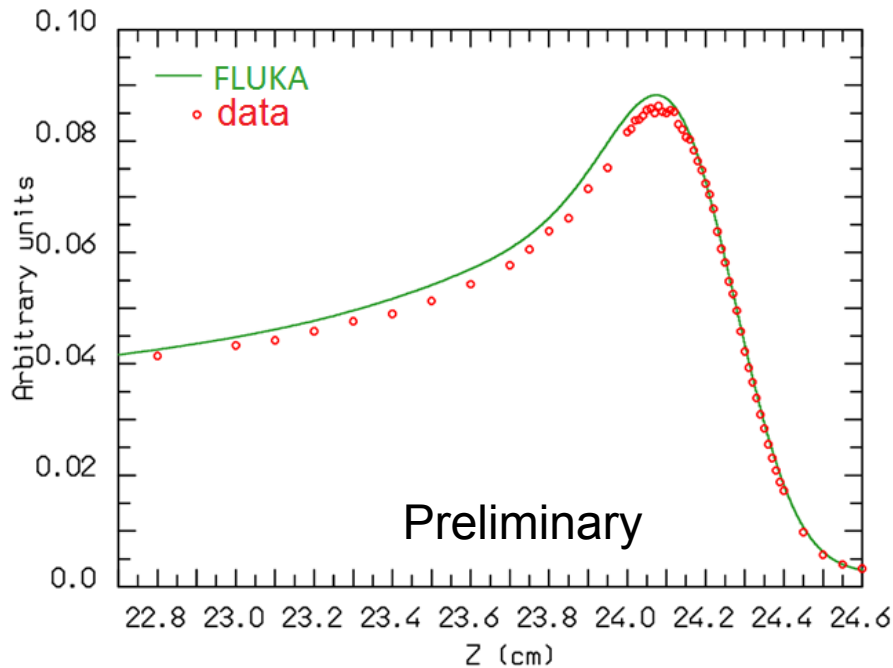


F. Horst et al. Phys. Rev. C 2017

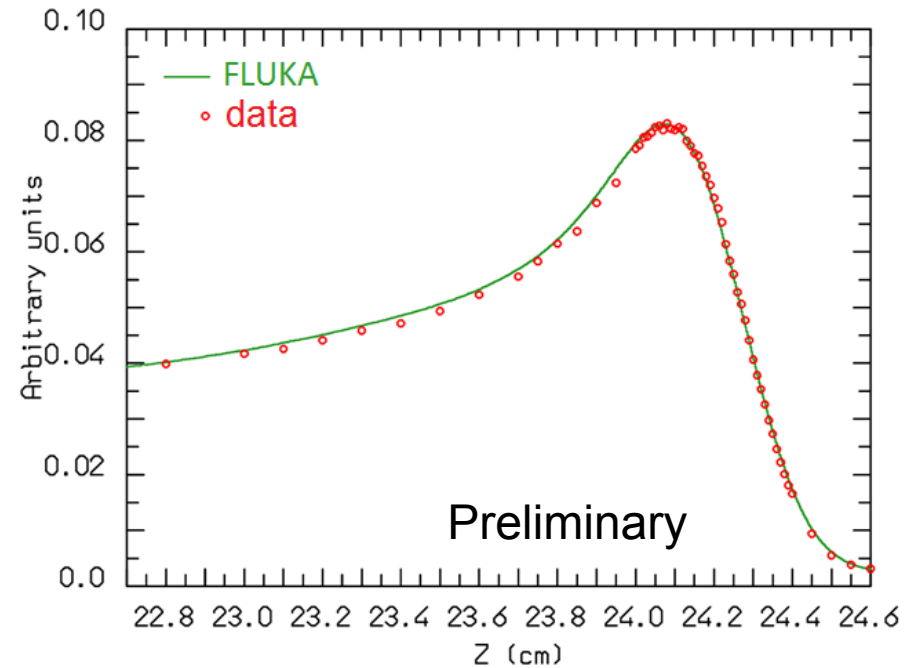
“New” ions - ^4He @HIT

Collaboration with Fluka core developers

Old Model



New Model



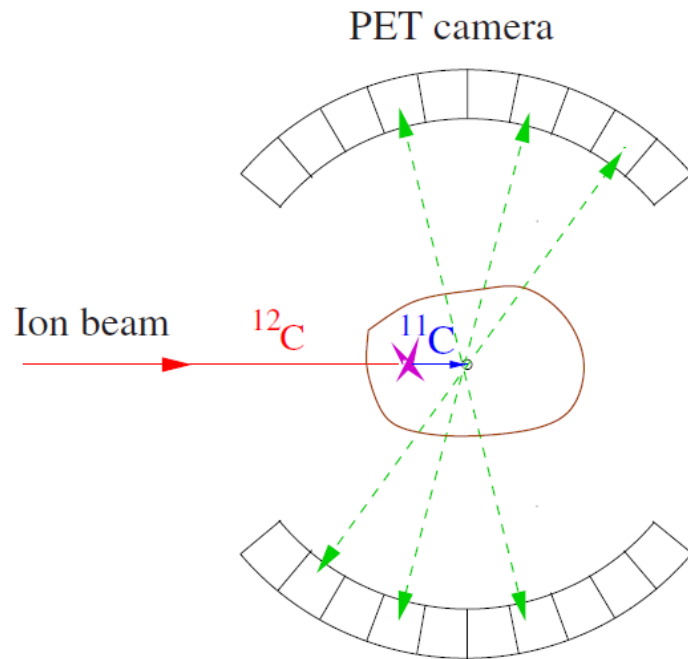
Courtesy of F. Horst and G. Arico*

* as shown at MCMA 2017

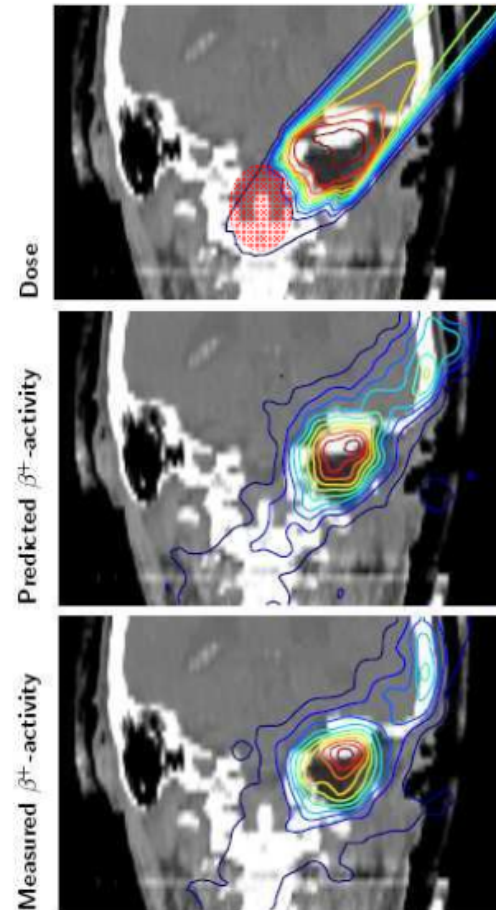
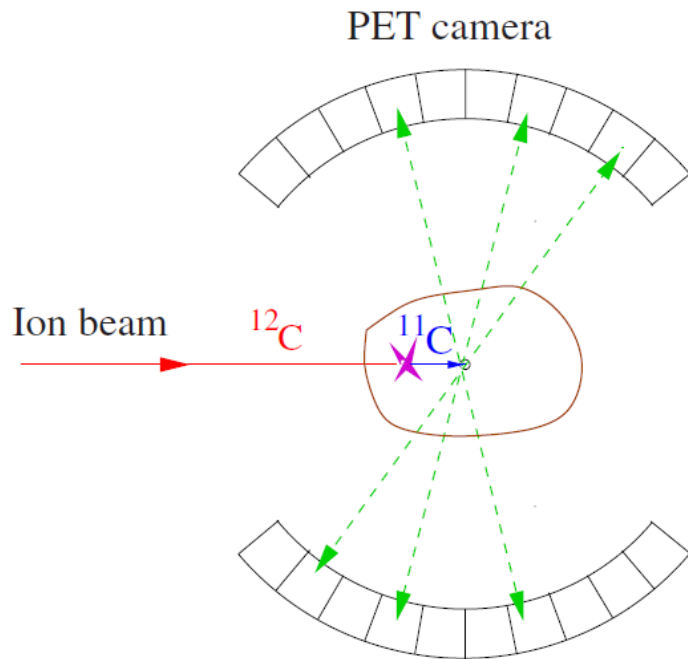
- So far ...

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 - Fragmentation -> Dose degradation

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 - Fragmentation -> **Dose degradation**
 - **But** can be **also** useful -> PET



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*W. Enhardt et al,
Nucl. Instr. Meth. Phys. Res. A 2004*

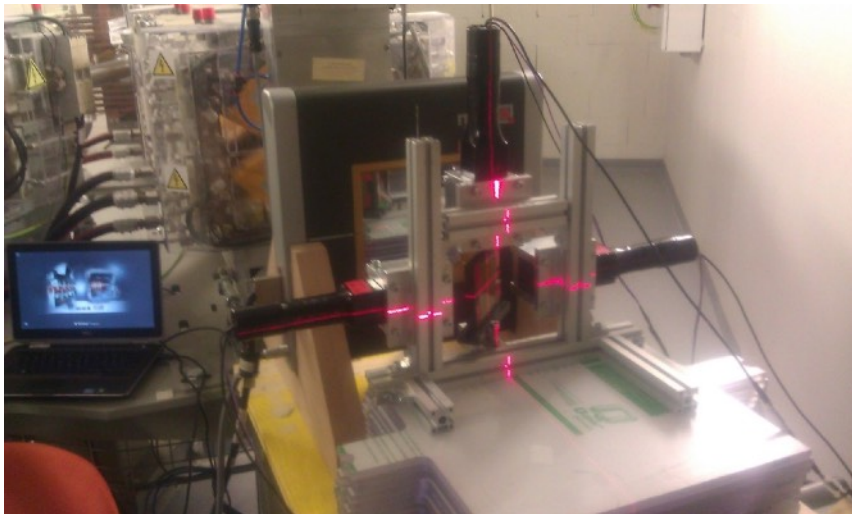
Activation measurements

- PET measurement approach -> Target fragmentation

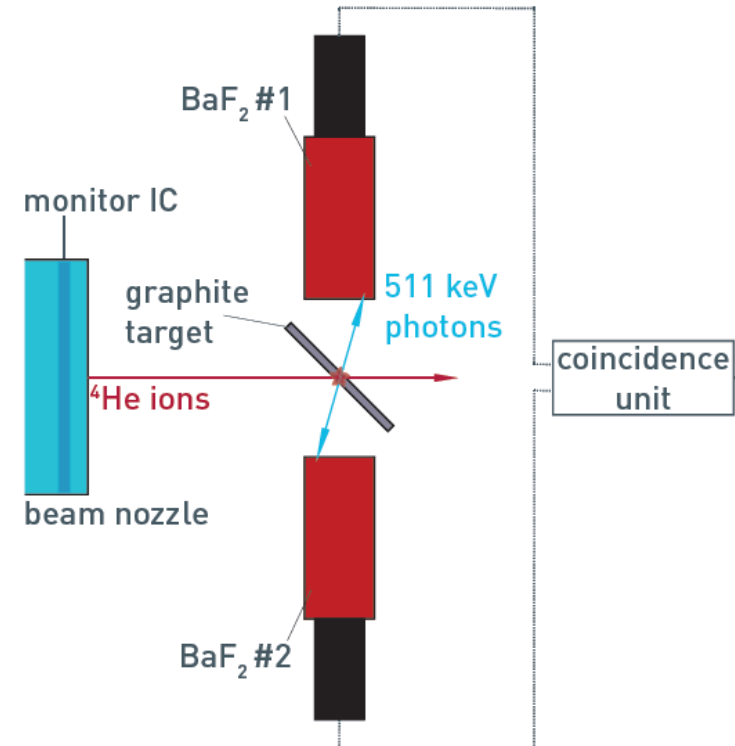
Activation measurements

- PET measurement approach -> Target fragmentation

Protons on carbon



Test experiment at Trento proton therapy center, Italy in June 2017



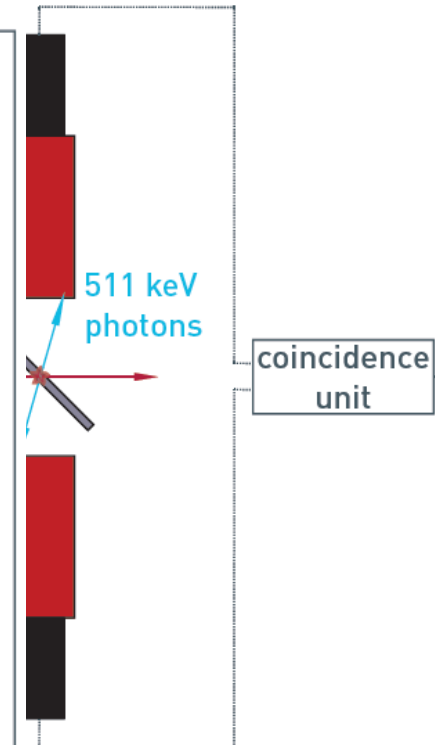
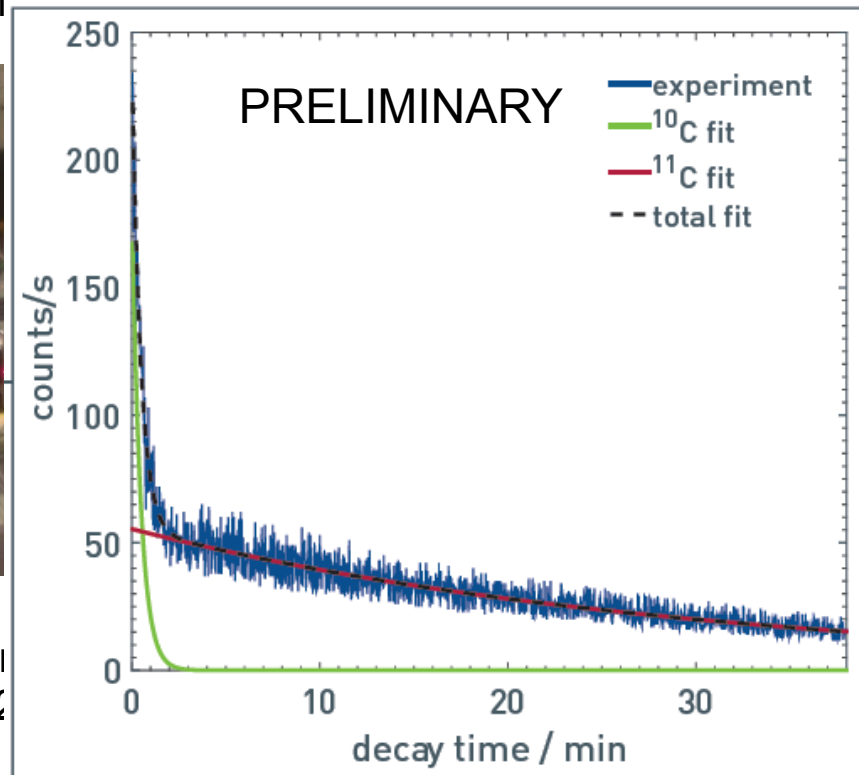
Activation measurements

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Proton



Test experiment at TRIUMF center, Italy in June 2018



Activation measurements

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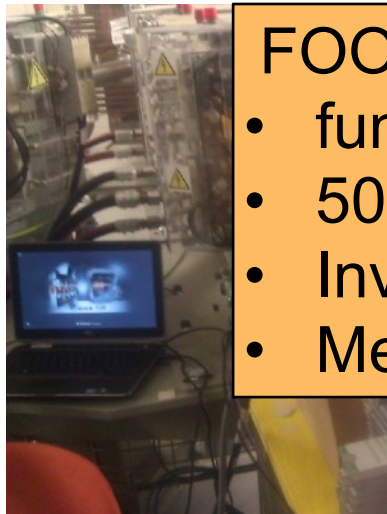
Proton

250

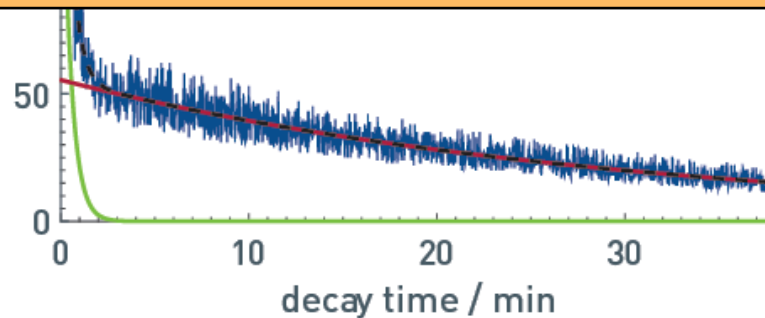
FOOT collaboration (FragmentatiOn Of Target)

- funded by INFN
- 50+ researchers
- Inverse kinematic strategy
- Measurement ready 2019/20

ence



Test experiment at T1 center, Italy in June 2018

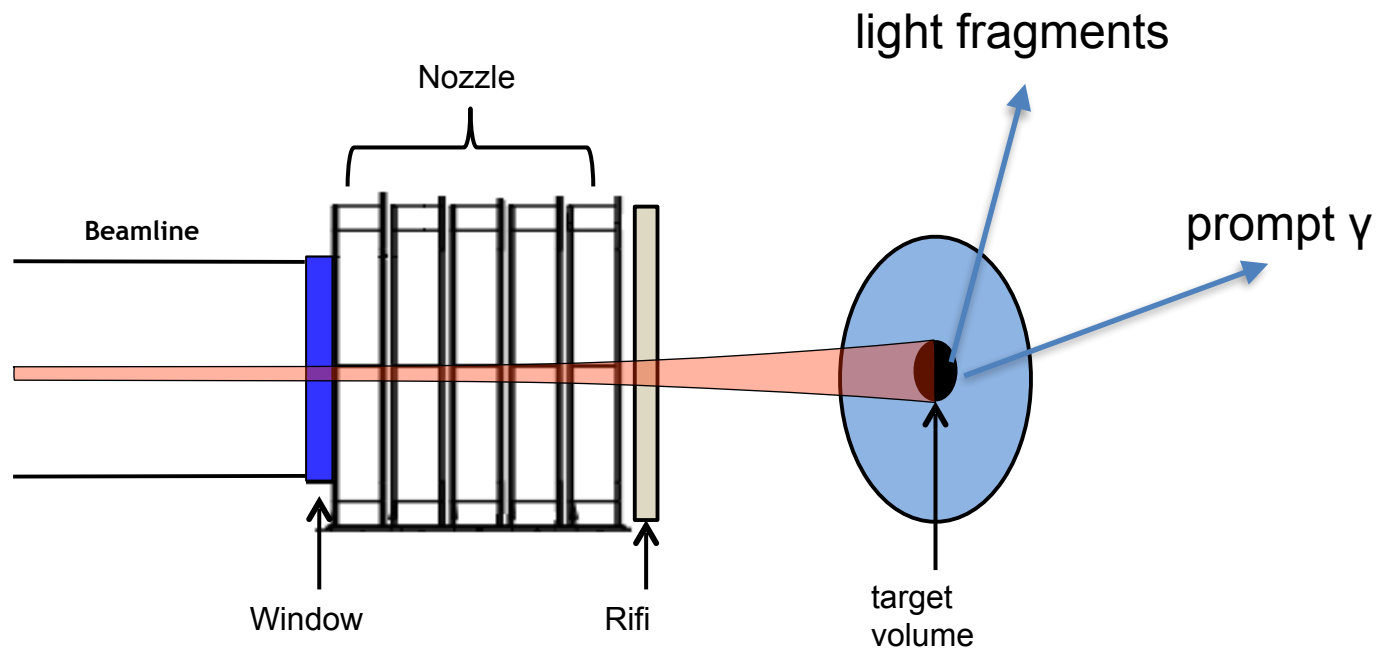


Online monitoring of the Bragg peak

- PET is typically used **after** the treatment

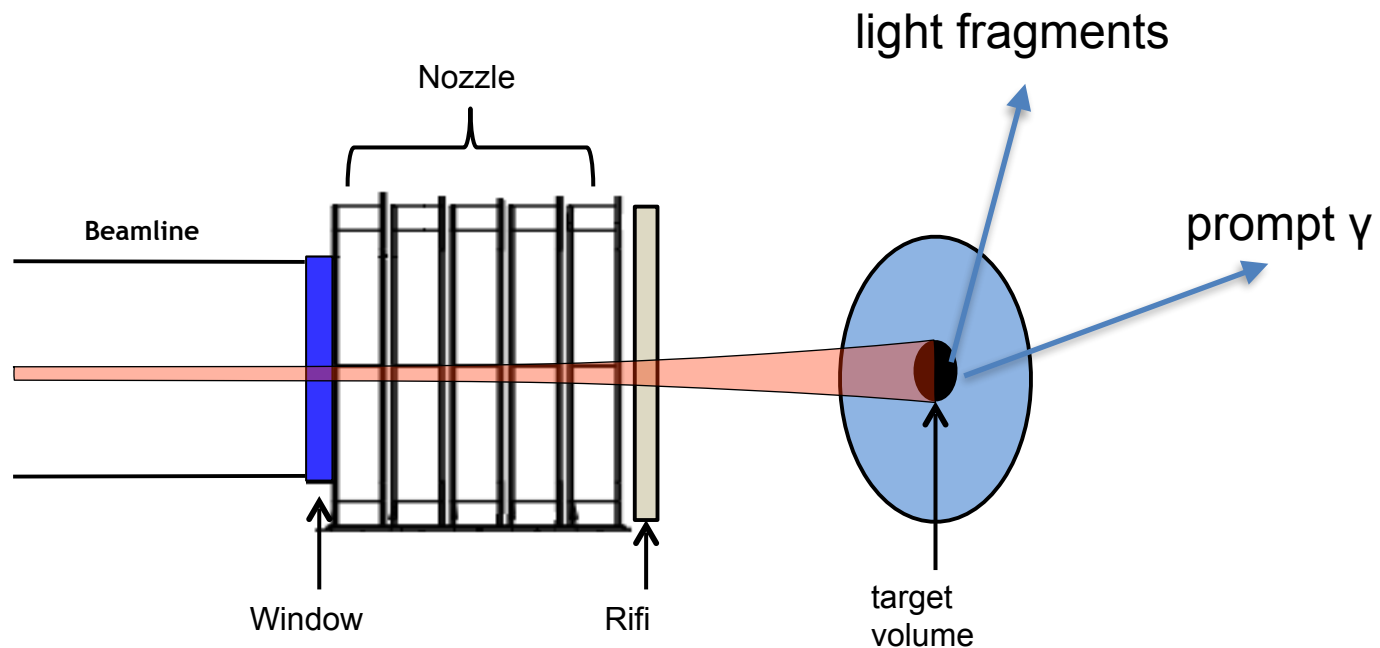
Online monitoring of the Bragg peak

- PET is typically used **after** the treatment
- Use prompt radiation to monitor treatment in real time



Online monitoring of the Bragg peak

- PET is typically used **after** the treatment
- Use prompt radiation to monitor treatment in real time
- Problem -> Perform measurement within constraints of treatment

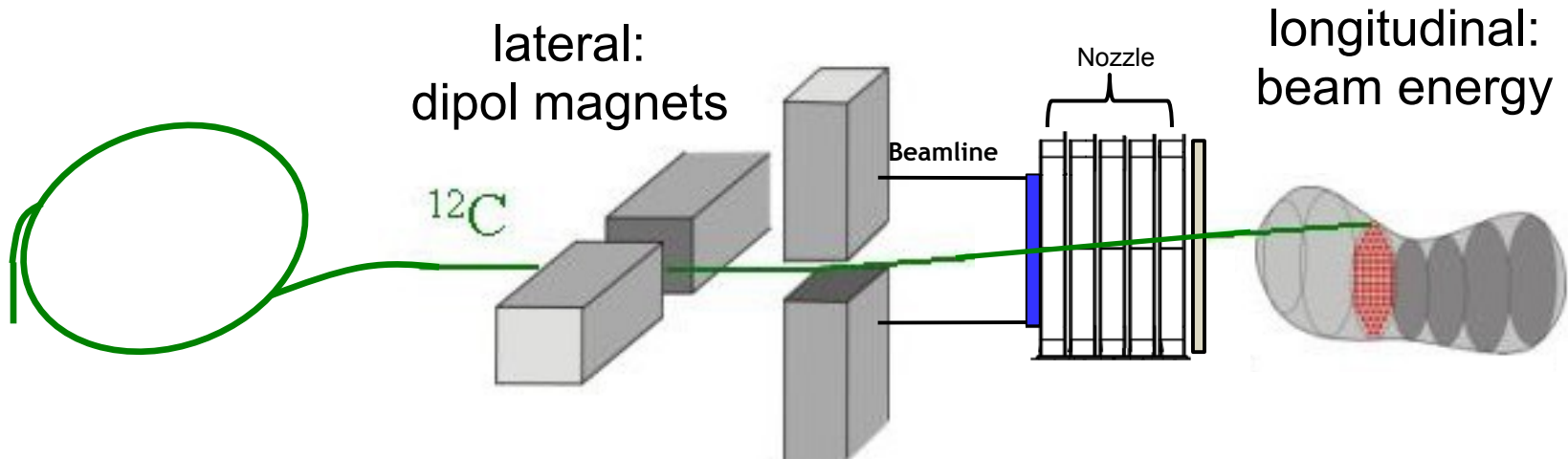


Dose Delivery System

- collaboration of CNAO and GSI for a next generation scanning system

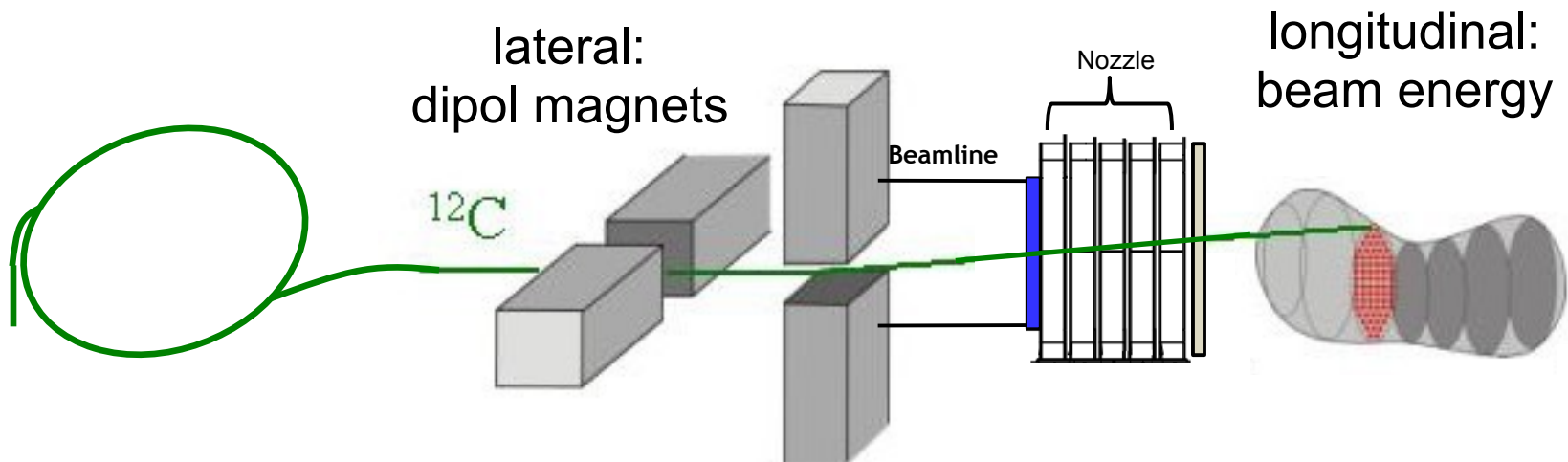
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- => **core** of the irradiation **controls**



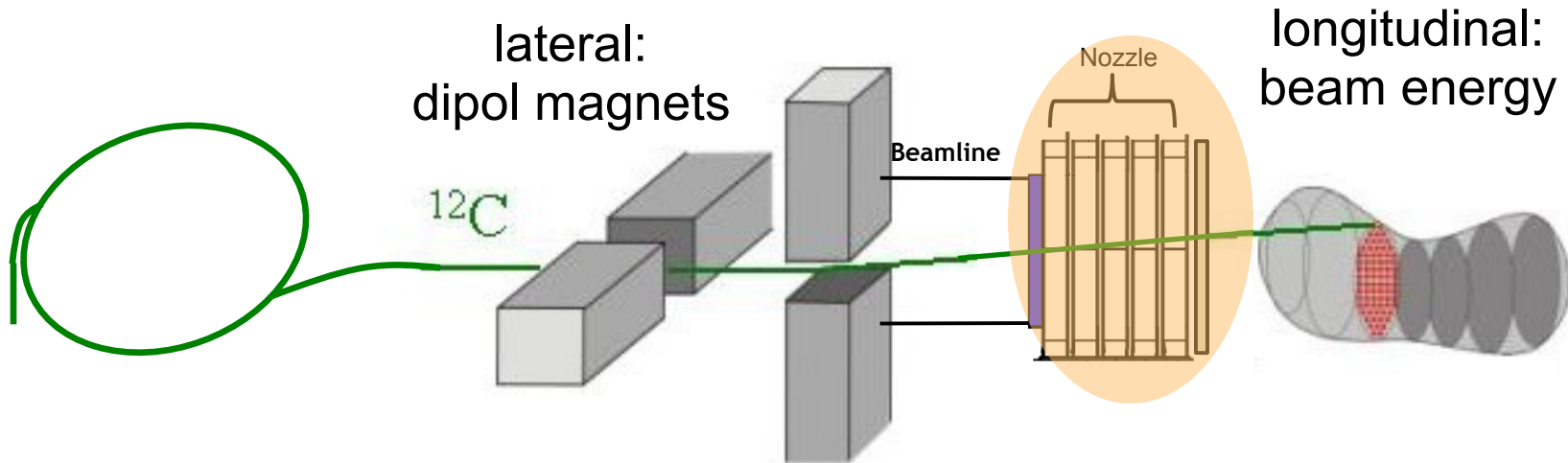
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 - 4D (**tumor motion**) capabilities



Dose Delivery System

- collaboration of CNAO and GSI for a next generation scanning system
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- Main problem -> **Fast** Beam monitoring detectors!

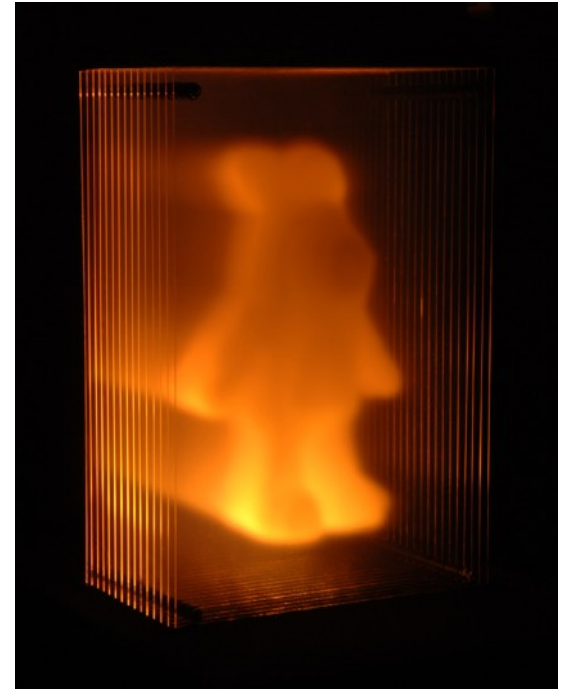


Summary

- High quality cross section measurements are always needed!

Summary

- High quality cross section measurements are always needed!
- But there is more for the nuclear physics community to do:
 - Online monitoring of the Bragg peak -> Experimental expertise
 - Dose Delivery System -> Detector R&D



Thanks for your attention