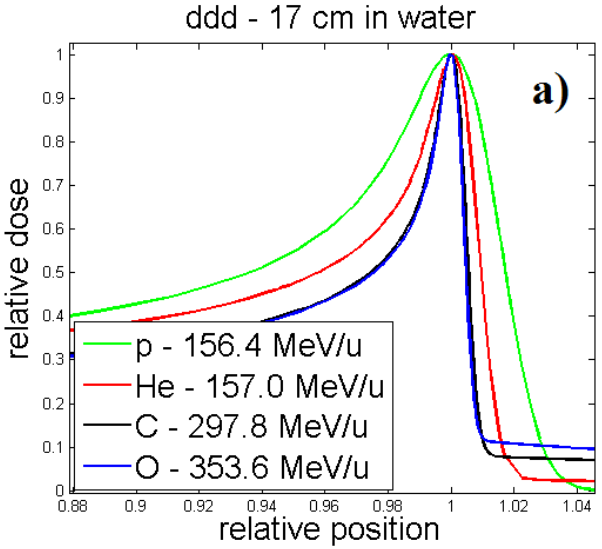
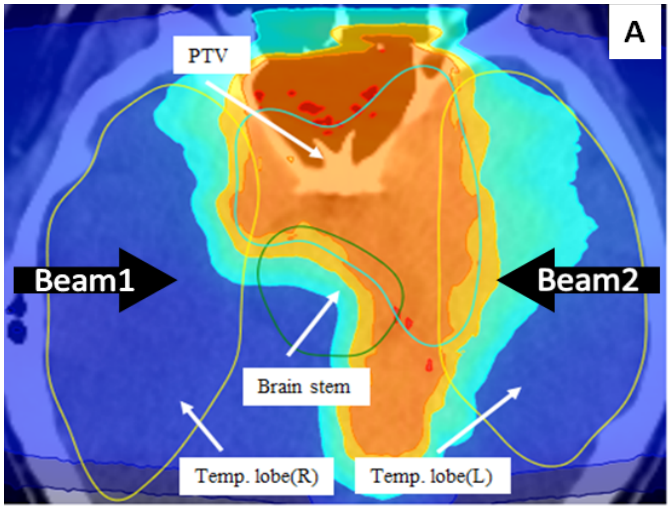
Dosimetric comparison between 1H, 4He, 12C and 16O at the Heidelberg Ion Beam Therapy Center





UNICANCER Centre de Lutte contre le Cancer François Baclesse

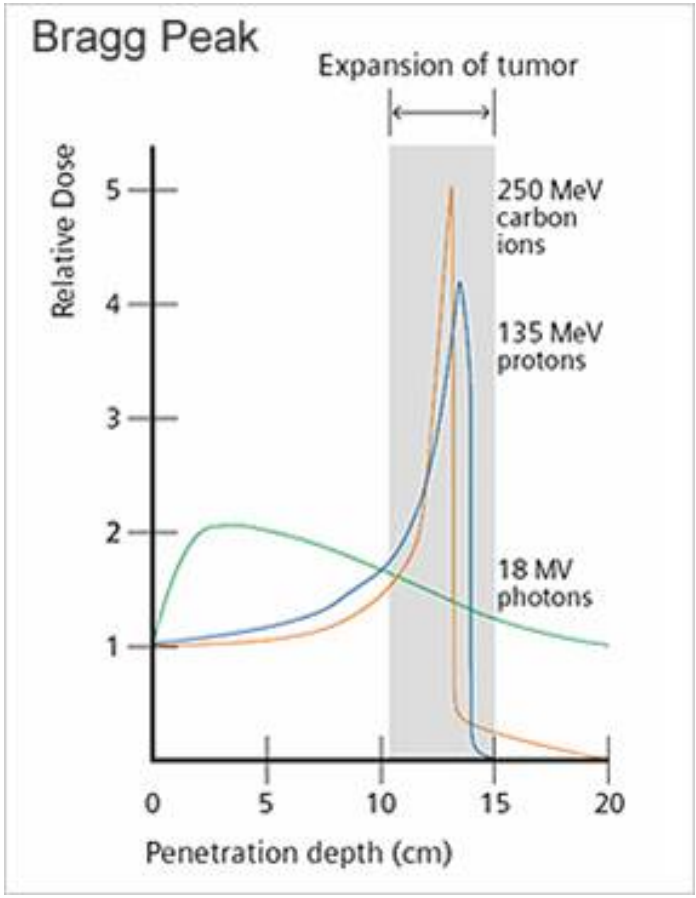
HIT Heidelberger Ionenstrahl-Therapiezentrum

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

UniversitätsKlinikum Heidelberg

Introduction

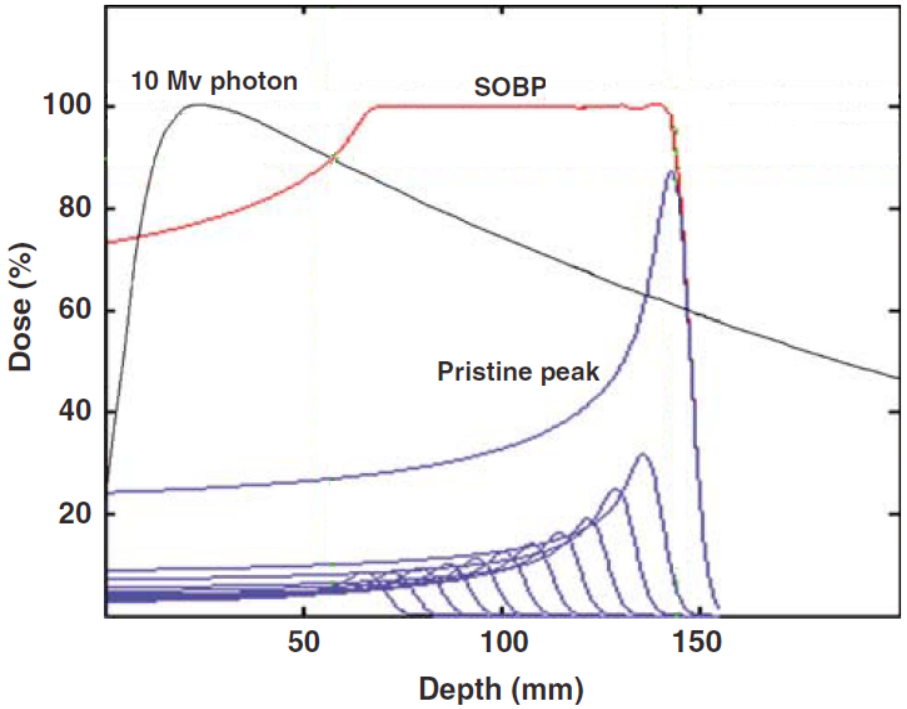
- Worldwide interest in particle therapy
  - Physical properties
    - Inverted depth dose profile
    - Finite range
    - Ion properties



Kraft et al.

Introduction

- Worldwide interest in particle therapy
  - Physical properties
    - Inverted depth dose profile
    - Finite range
    - Ion properties
    - Spread-out Bragg peak (SOBP)

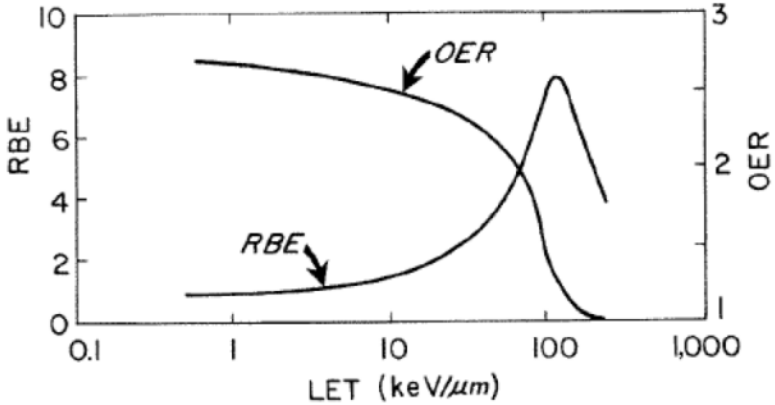


Levin et al 2005

Introduction

- Worldwide interest in particle therapy
  - Physical properties
    - Inverted depth dose profile
    - Finite range
    - Ion properties
    - Spread-out Bragg peak (SOBP)
  - Biological properties (RBE, OER, …)

    RBE = f(LET,D,Tissue)



Hall.

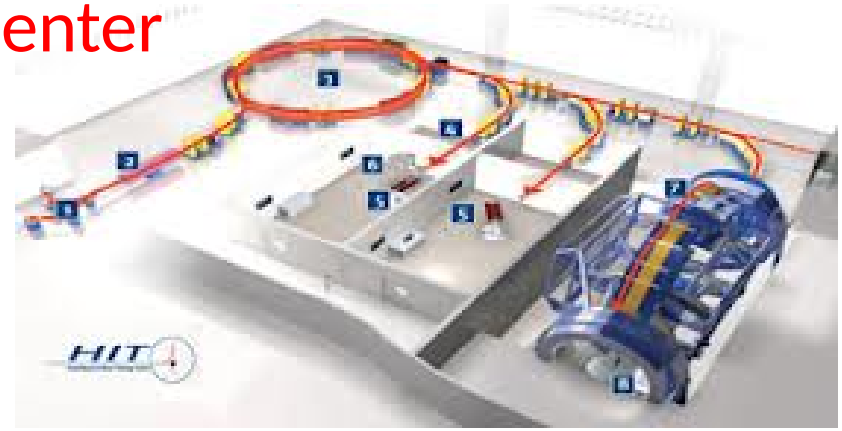
Introduction

- Protontherapy in Caen…
  - Archade … Summer 2018 !

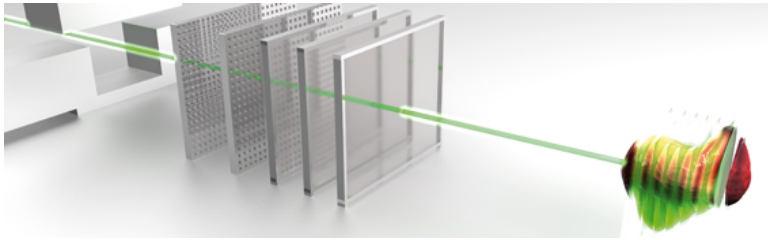
- Particle therapy…
  - Wilson… 1946
  - Berkeley 1954: 1st patient

Introduction

- Heidelberg Ion Beam Therapy Center
  - **Synchrotron**-based facility[1]
  - Active beam **scanning** delivery[2]
  - ^{1}**H** and ^{12}**C** in clinics
  - ^{4}**He** and ^{16}**O** for research



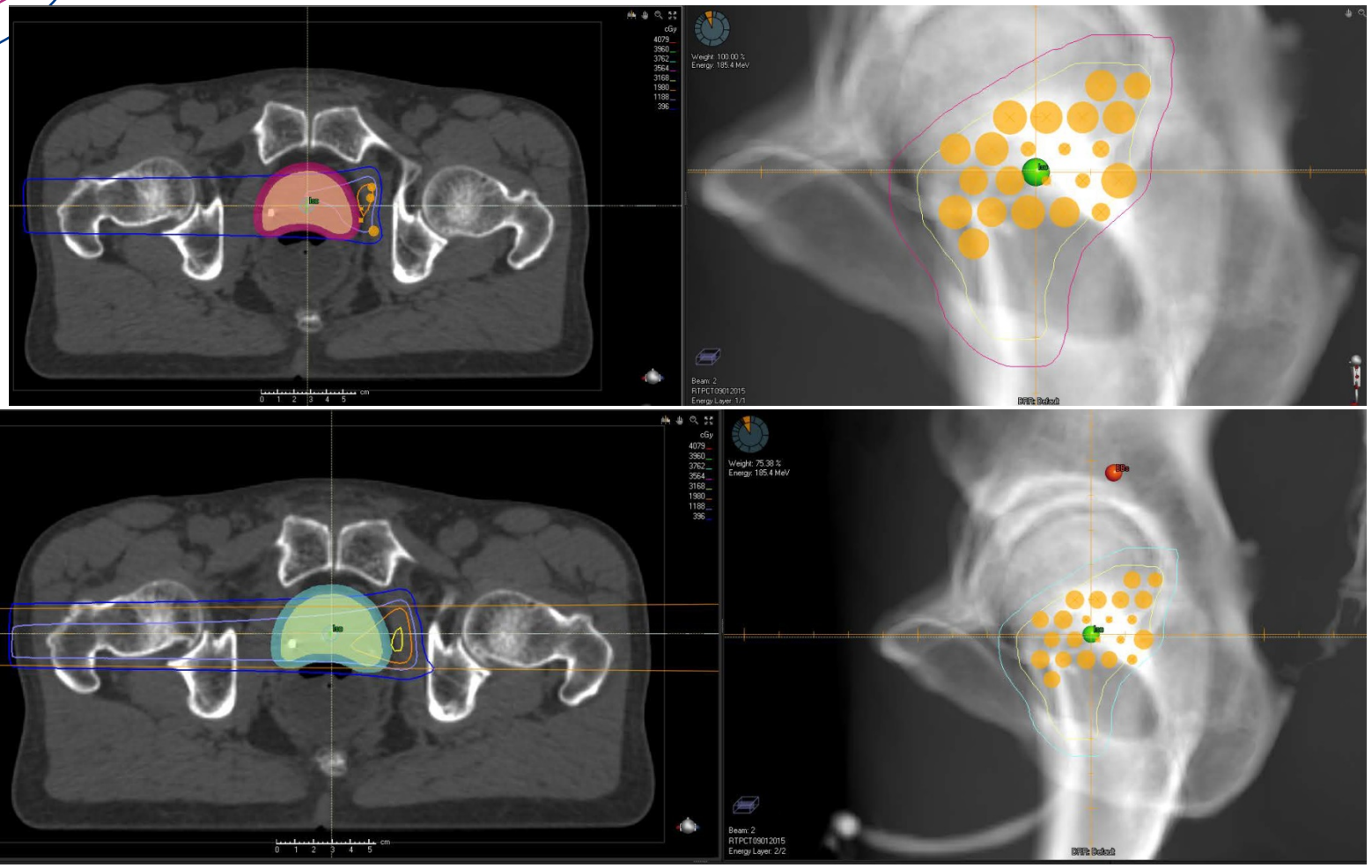
- <u>Active Beam Scanning delivery with Synchrotron</u>
  - →Depth position
  - →Spot size
  - →Lateral position



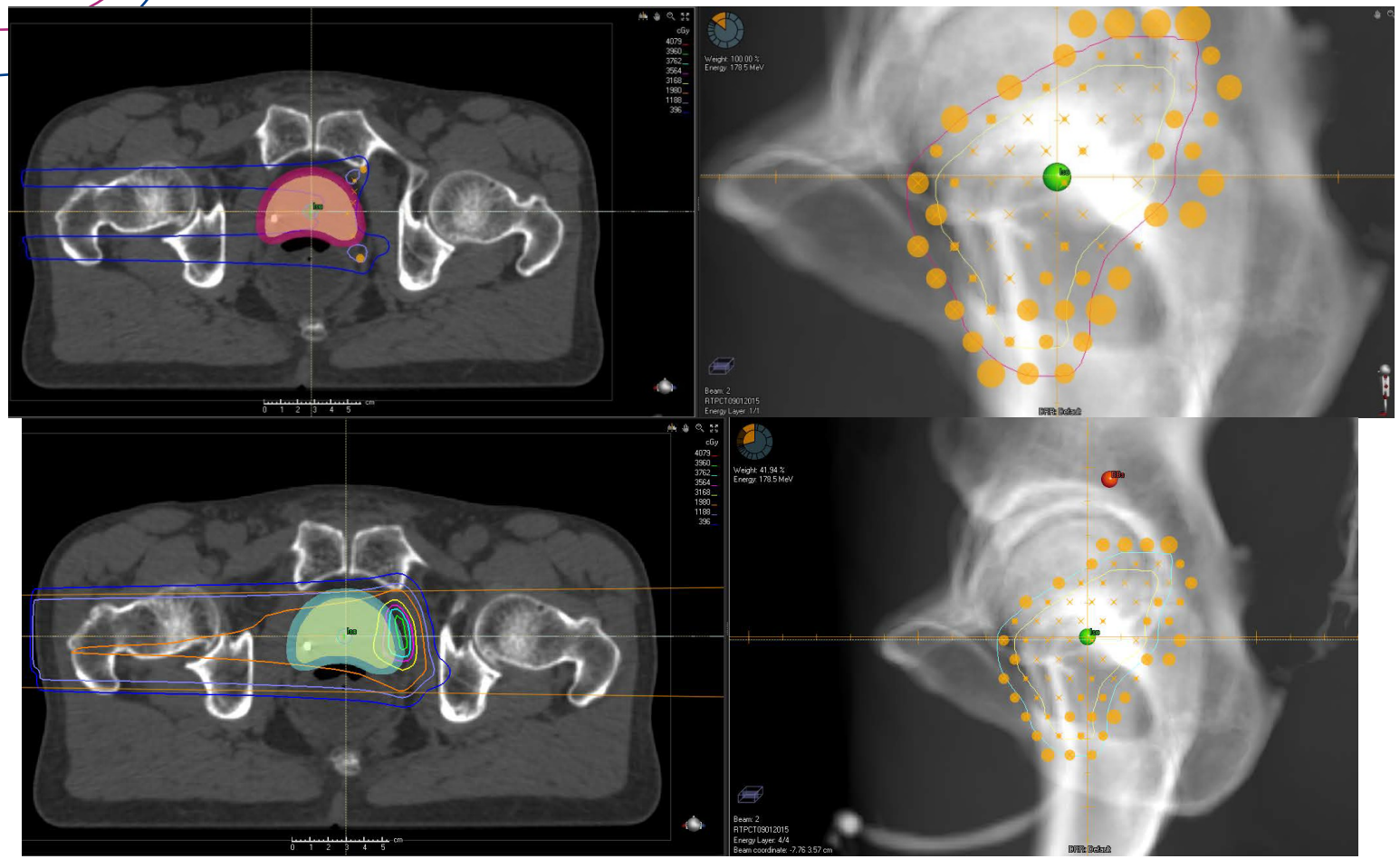
[1,2] Haberer *et al.* (2004 , 1993)

Introduction

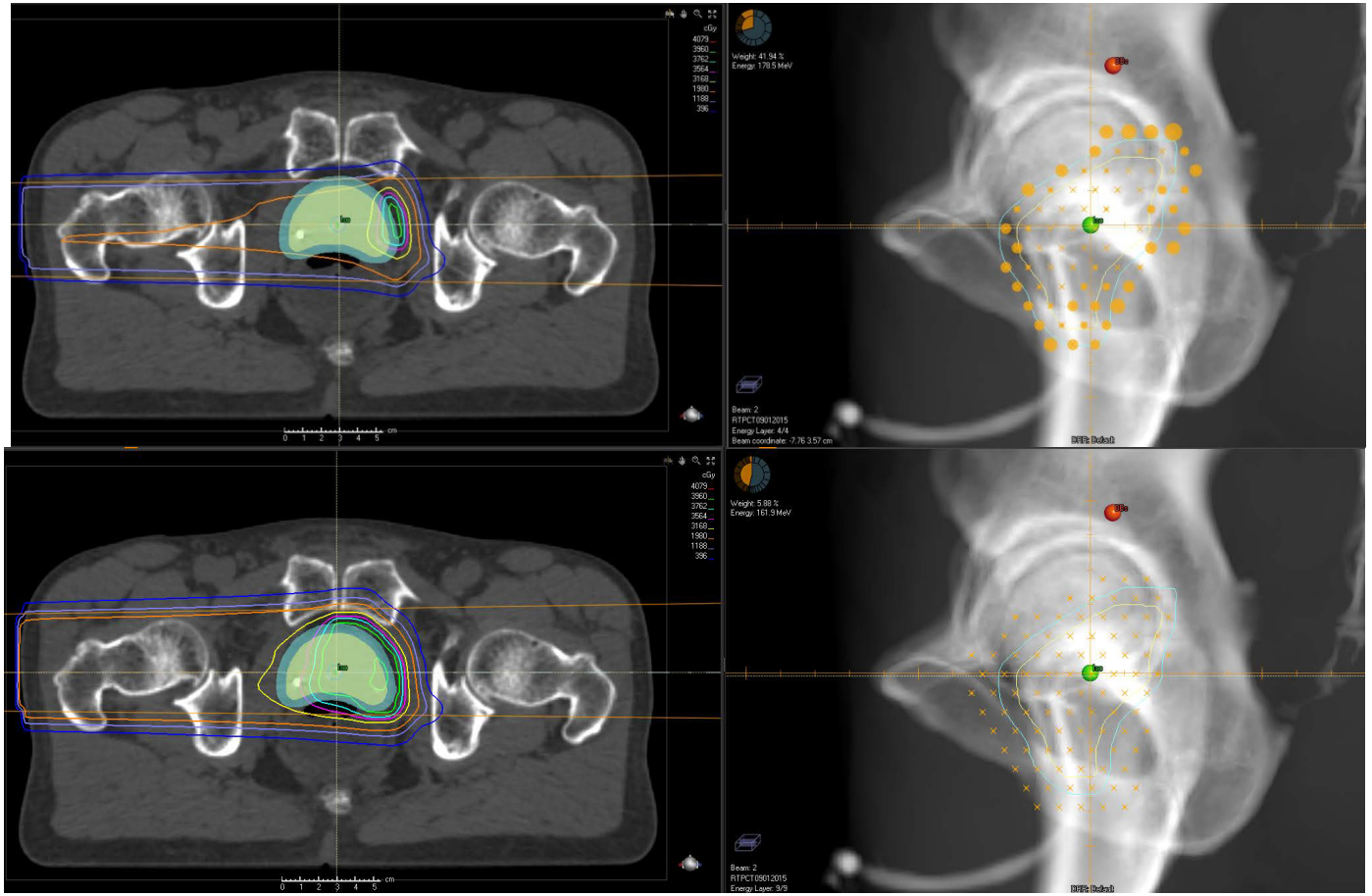
Introduction



Introduction

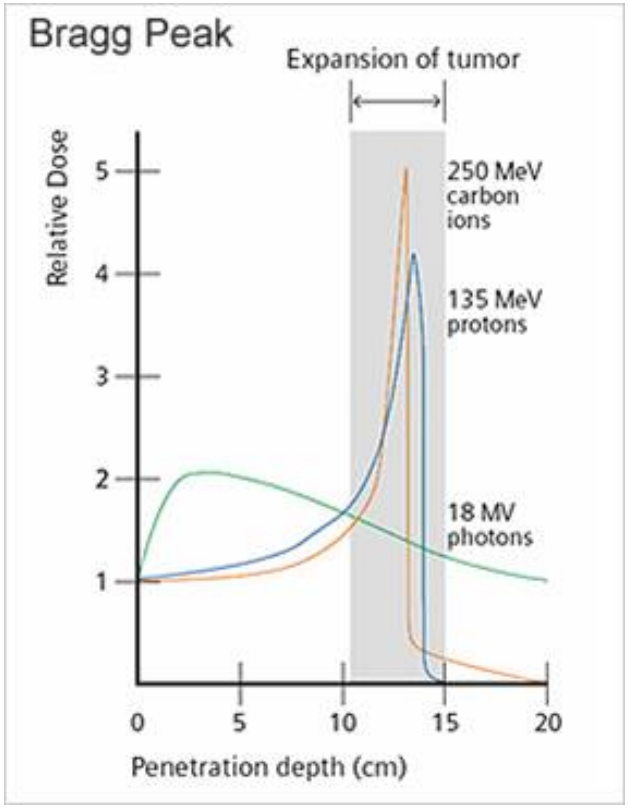


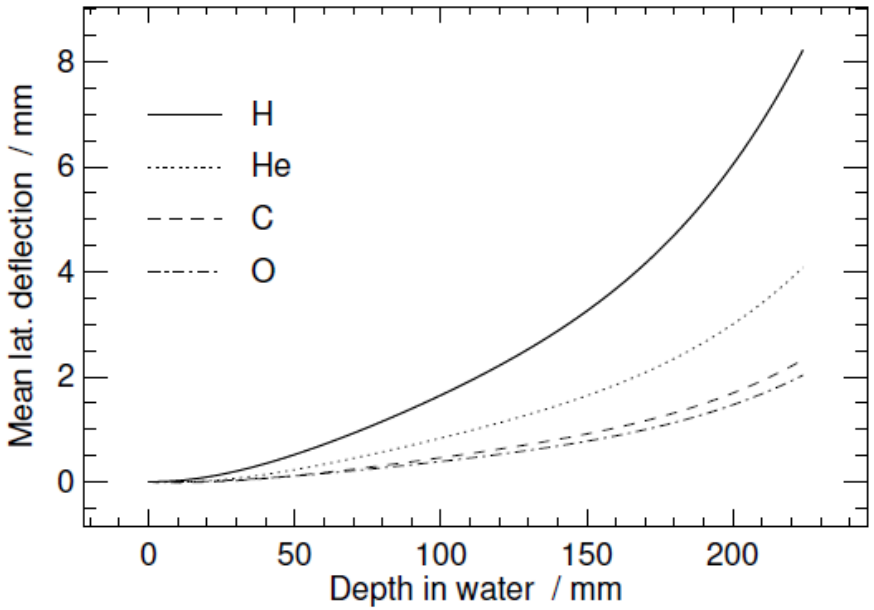
Introduction



Introduction

- Why Helium and Oxygen ions ?





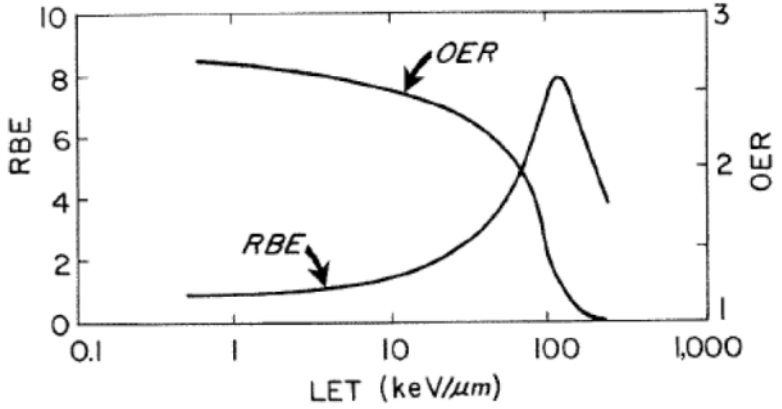
Helium …

→Fall-off (distal, lateral)

→Reduce tail for He

Introduction

- Why Helium and Oxygen ions ?



Oxygen …
→RBE
→OER (Sokol et al 2017)

	RBE, $(\alpha/\beta)_T = (\alpha/\beta)_{NT}$=2Gy				RBE, $(\alpha/\beta)_T$ = 10; $(\alpha/\beta)_{NT}$ =2Gy			
Ion species	Entrance (0 mm)	Proximal (67.5 mm)	Mid (80 mm)	Distal (92.5 mm)	Entrance (0 mm)	Proximal (67.5 mm)	Mid (80 mm)	Distal (92.5 mm)
Proton	1.00	1.13	1.27	2.00	1.00	1.06	1.14	1.51
Helium	1.07	1.52	2.11	4.26	1.06	1.22	1.50	2.57
Carbon	1.44	2.61	3.24	4.82	1.36	1.63	1.92	2.70
Oxygen	1.68	2.83	3.28	4.26	1.55	1.68	1.86	2.31

Dosimetric comparison …

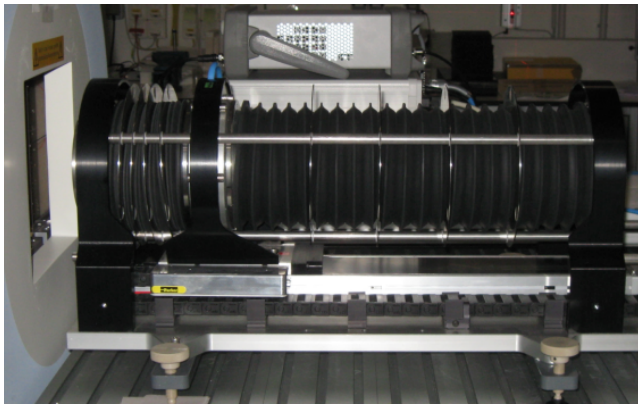
-

Depth Dose Distribution

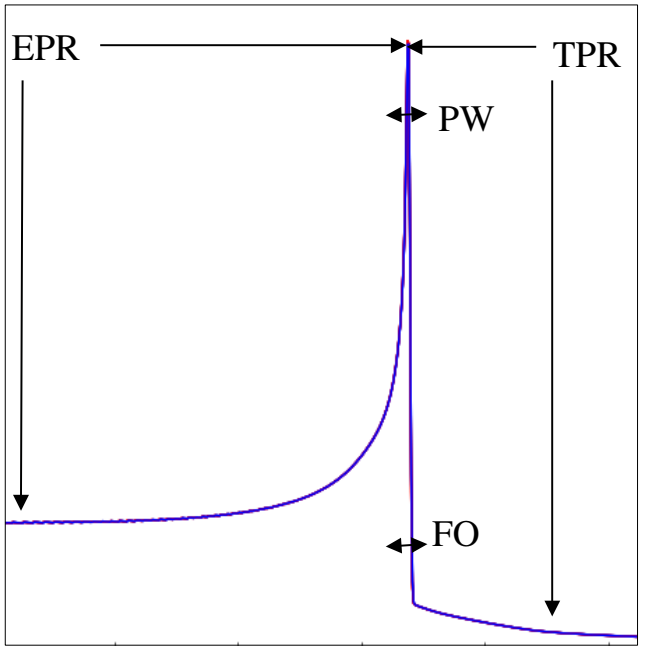
Depth Dose Distribution

Materials and Methods

- Comparisons for 4 ions
- 10 energies in therapeutic range
- Measurements with PeakFinder (PTW)
- Delivery of a quasi-monoenergetic pencil-like beam
- w/wo RiFi
- Investigation of several parameters
  - EPR Entrance-to-Peak ratio (at 16 mm)
  - PW Peak Width (proximal 80% / distal 80%)
  - FO Fall-Off (distal 80%/ distal 20%)
  - TPR Tail-to-Peak ratio (relative dose at 10 mm of distal 90%)
- Charge Collection Efficiency (CCE)



PeakFinder Water column

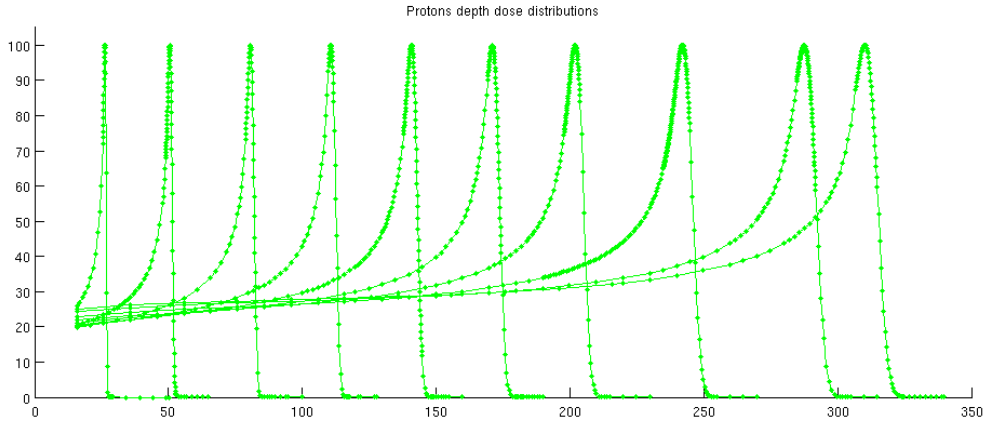


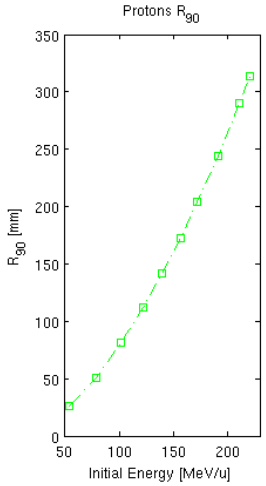
Investigated parameters

Depth Dose Distribution

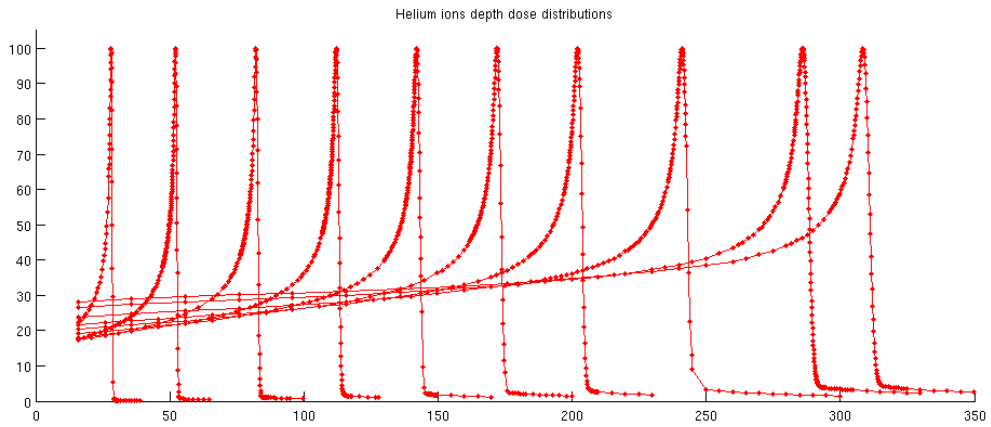
Results : *Depth dose distribution in water / R_{90}=f(E)*

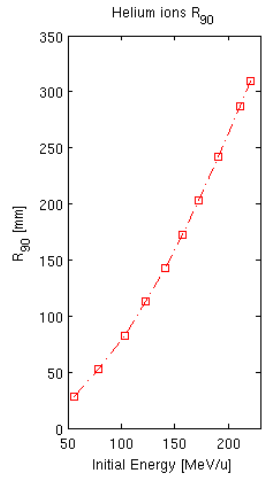
^{1}H





^{4}He

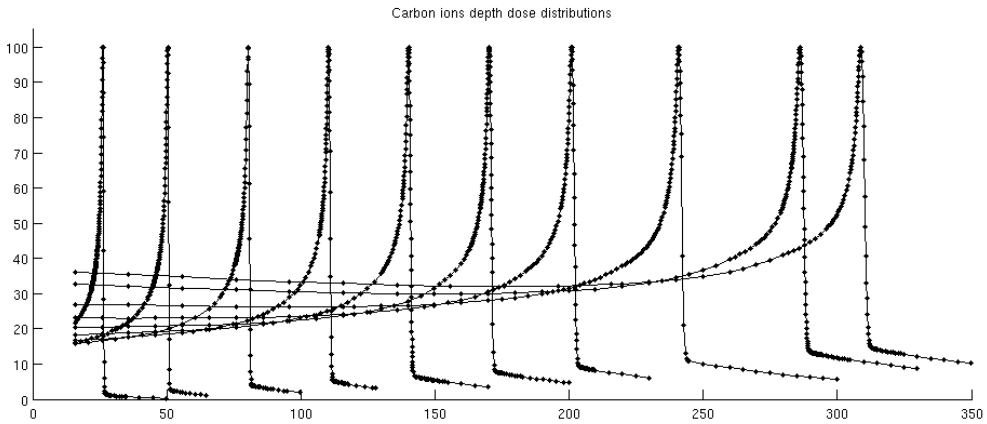


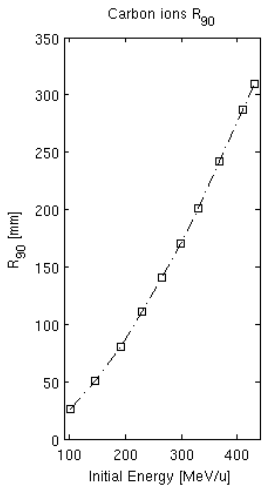


Depth Dose Distribution

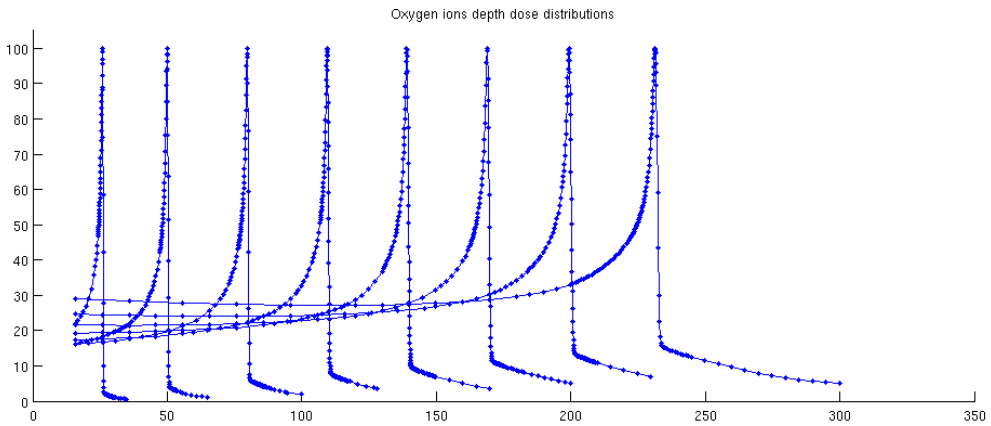
Results : *Depth dose distribution in water / R_{90}=f(E)*

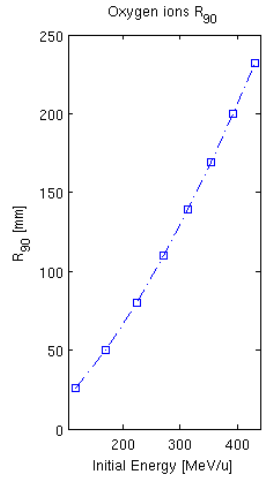
^{12}C





^{16}O

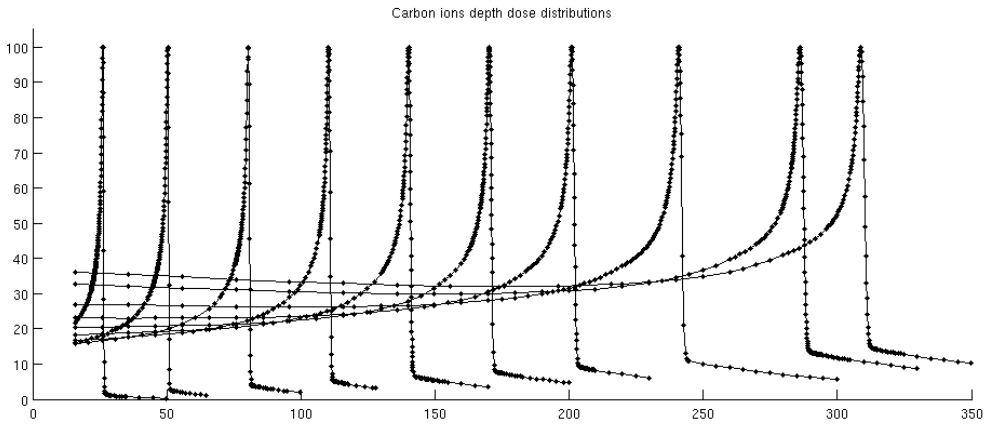


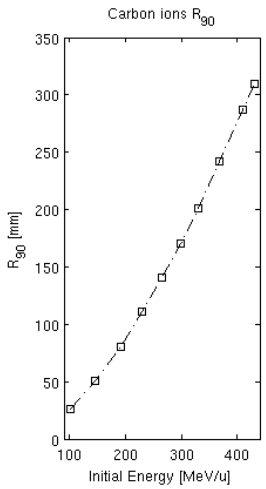


Depth Dose Distribution

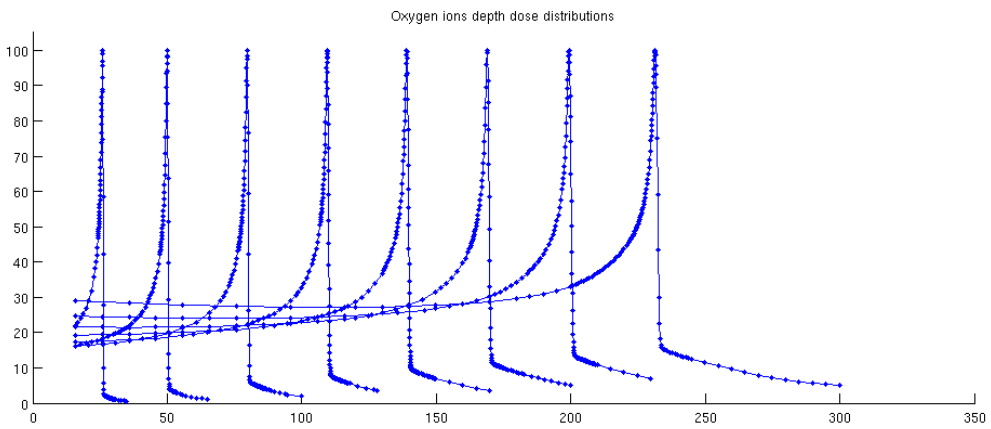
Results : *Depth dose distribution in water / R_{90}=f(E)*

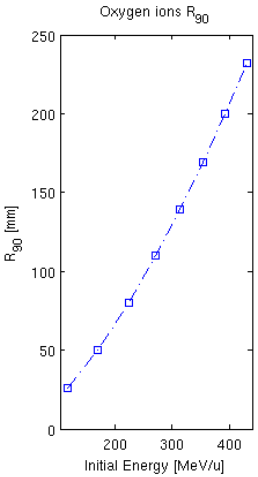
^{12}C

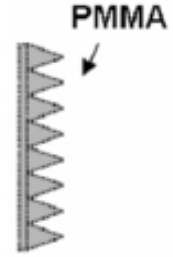




^{16}O



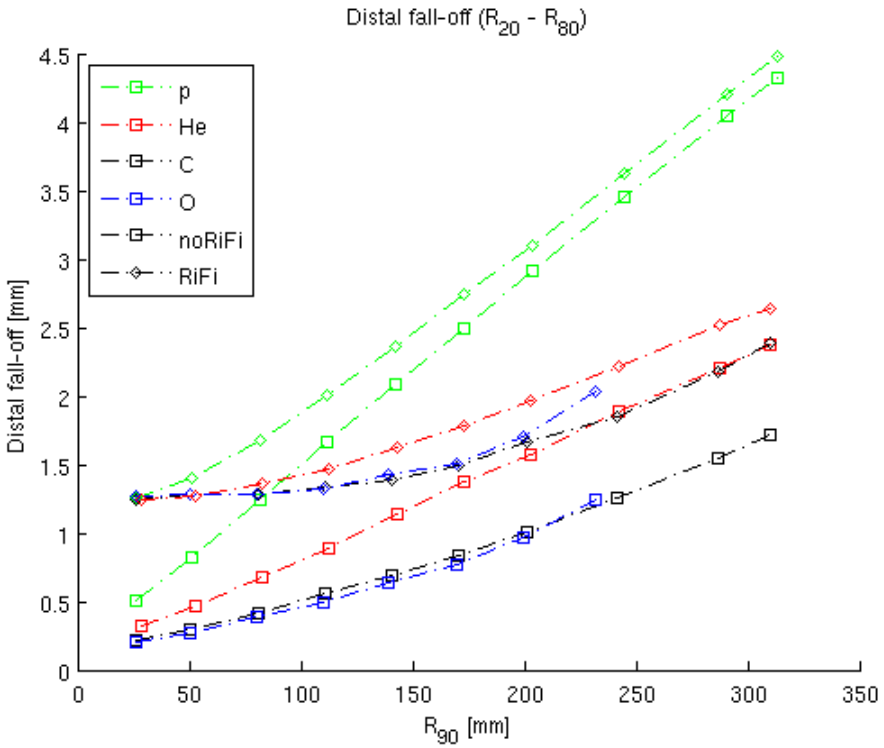




RiFi

Depth Dose Distribution

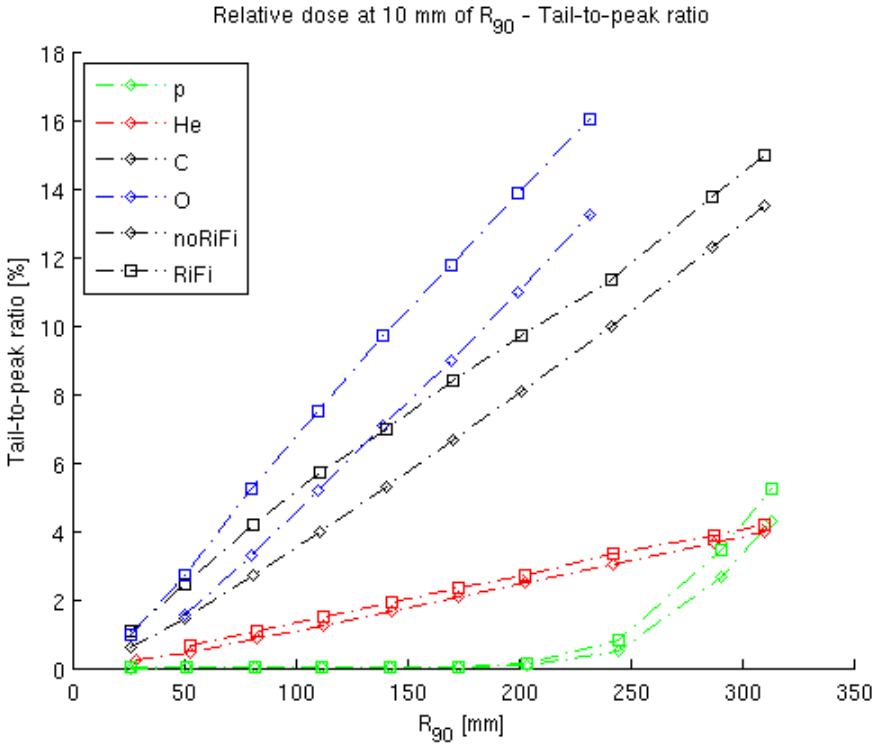
Results : *distal fall-off*



- Improvement of distal FO when using He ions compare to protons
- FO comparable between **heavy ions** and **He ions** with RiFi

Depth Dose Distribution

Results : *tail to peak ratio*



Low TPR at 10 mm due to **fragmentation** for He ions compared to C/O ions

He < 4% **C/O up to 16 %**

Dosimetric comparison …

-

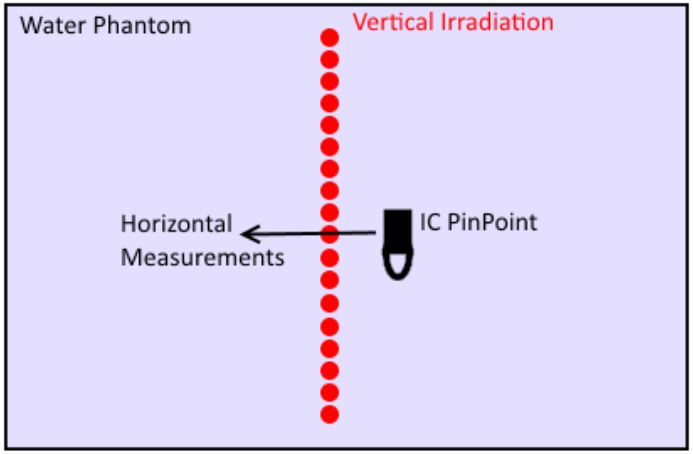
Lateral Dose Distribution

Vertically scanned lines

Materials and Methods

- Comparisons for 4 ions
- 3 energies in therapeutic range
- Measurements in a water tank coupled to 24 motor driven Ionization Chambers
- Delivery of a **vertically scanned beam**
- Measurements of profile at different depth
  - **Simple Gaussian parametrization**
  - Double Gaussian parametrization
  - Parametrization corrected

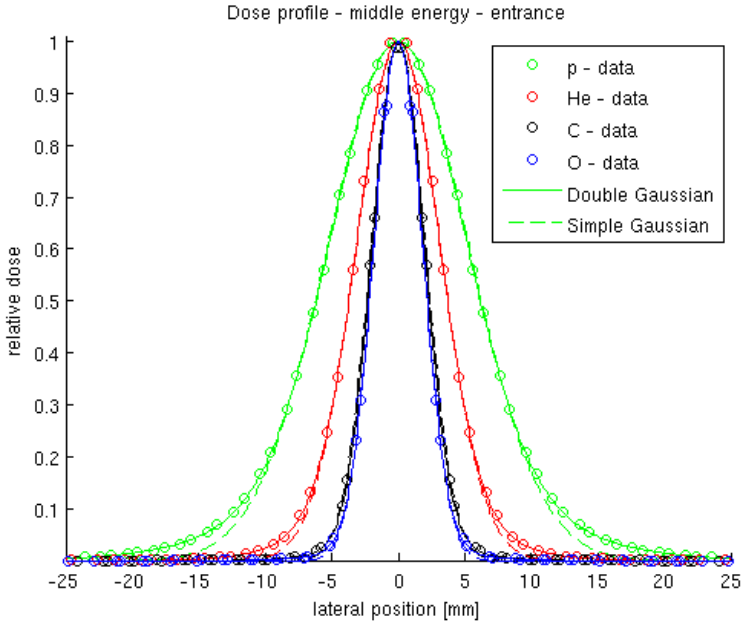
Water Tank + IC

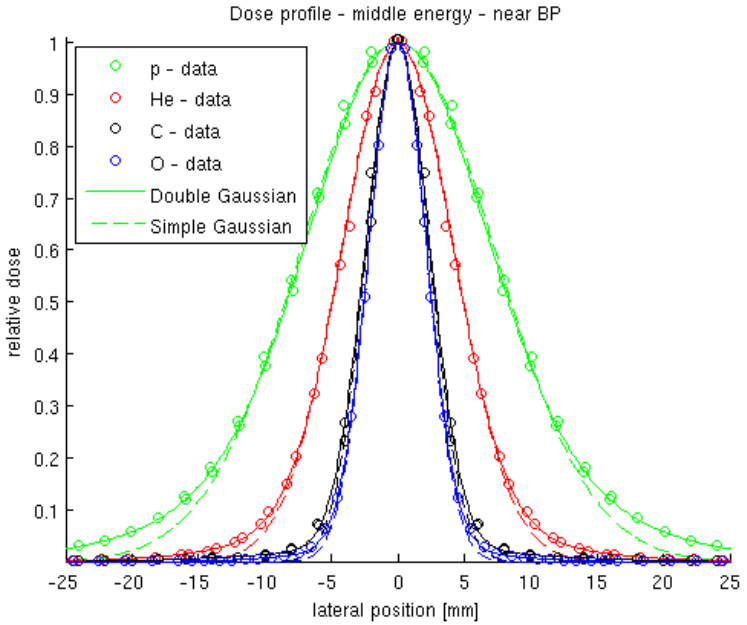


Measurements of verticaly scanned line

Vertically scanned lines

Results





Gaussian parametrizations :

SGP ~ $G_0(\sigma 0)$

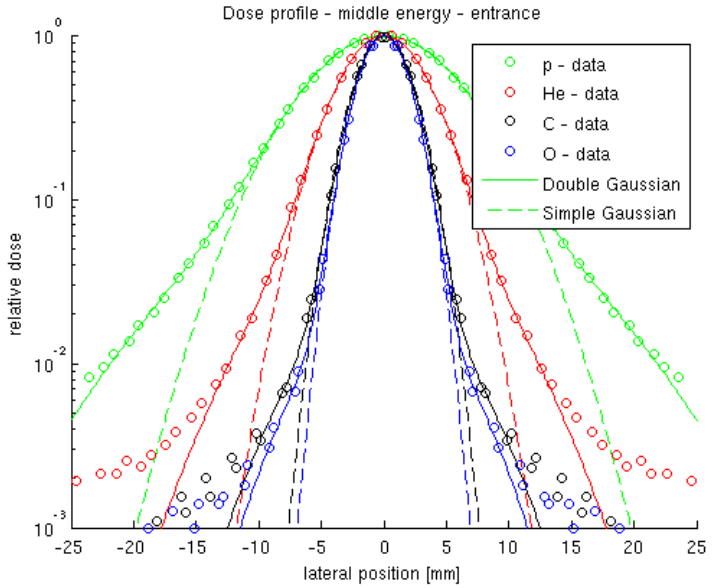
DGP ~ $(1-w)G_1(\sigma 1) + wG_2(\sigma 2)$

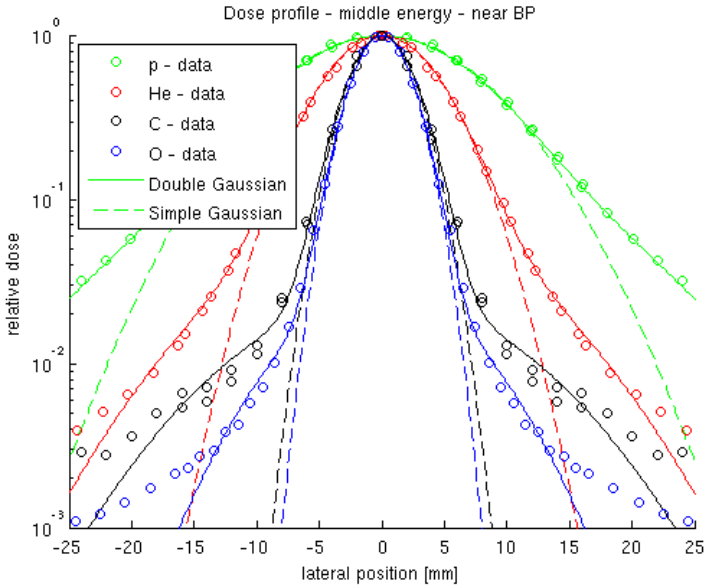
- Different focus size at the entrance of the phantom → not comparable
- Correction to infinite air beam δ:

$$\sigma_{focus}(z_{water})^2 = \sigma_{\delta}(z_{water})^2 + \sigma_{focus,iso}{}^2$$

Vertically scanned lines

Results





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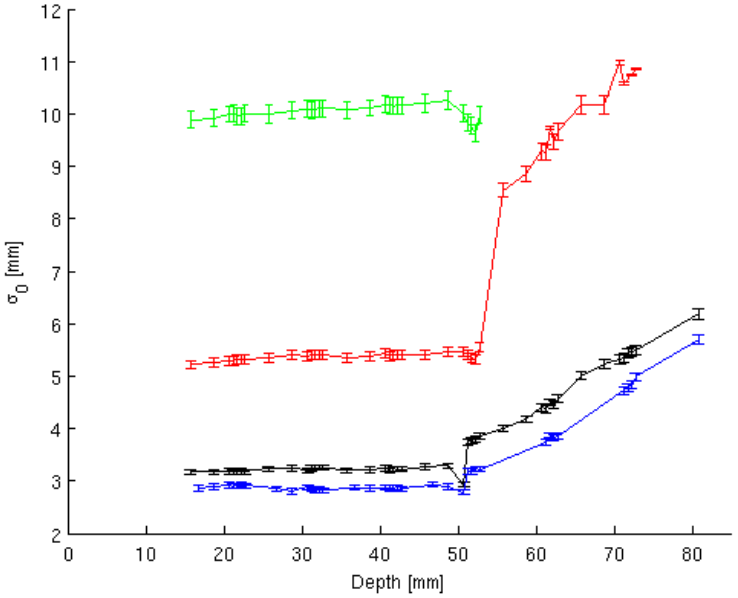
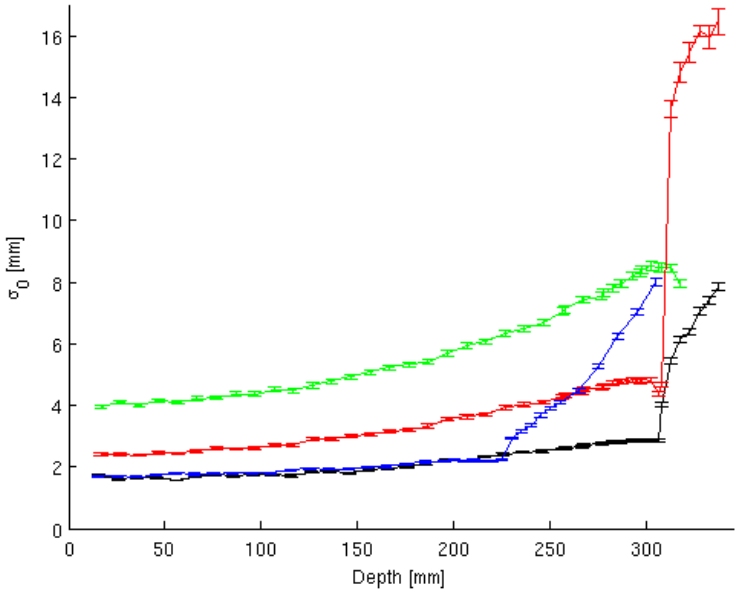
Vertically scanned lines

Results

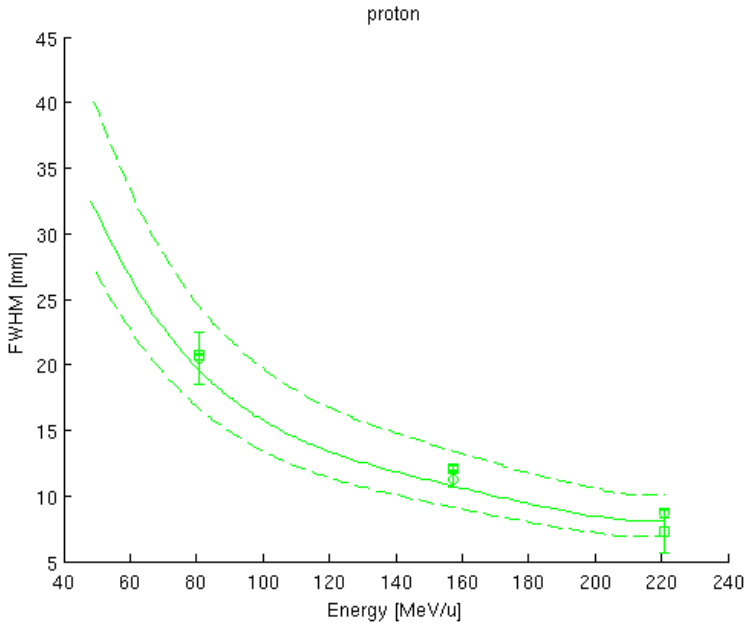


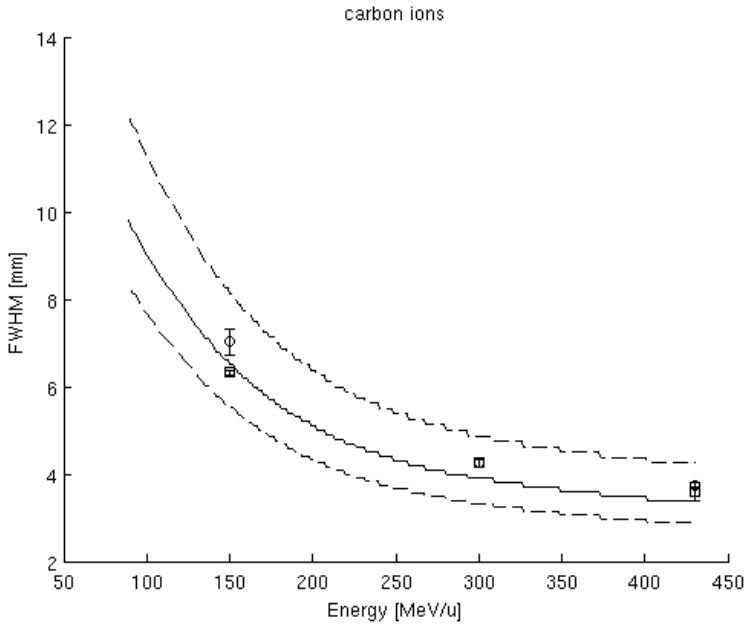


- **SGP** describing the width of the **central core**
- **Correction** for the extrapolated initial focus at the entrance

Vertically scanned lines

Results

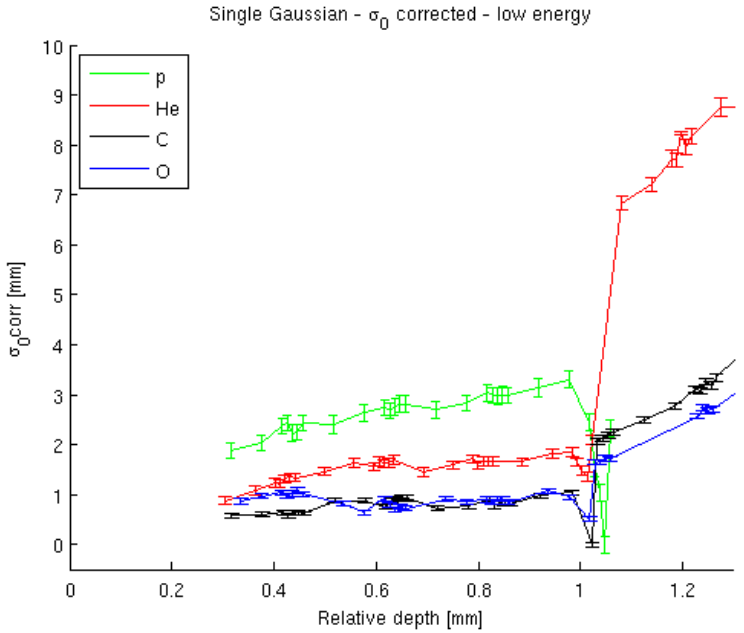


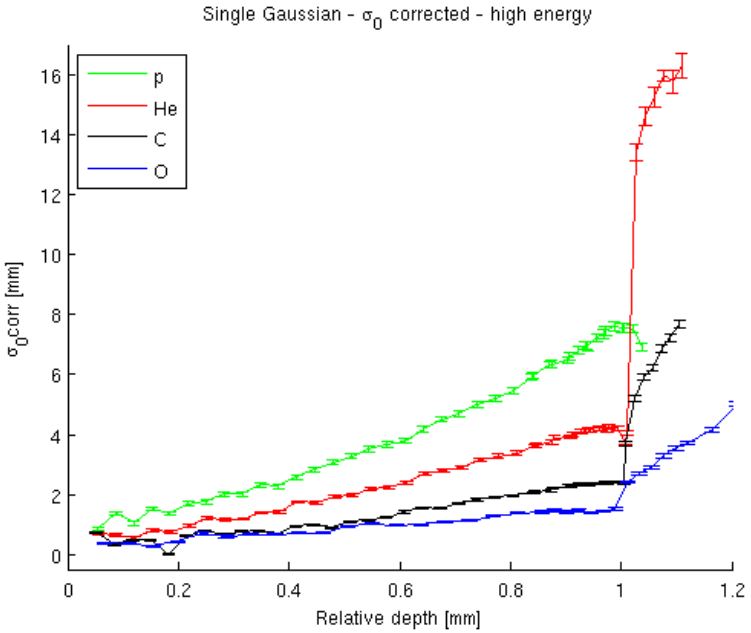


- **Different focus size at isocenter**
  - **Correction for fair comparisons**
- Agreement between expected focus and extrapolated one

Vertically scanned lines

Results





- **SGP** describing the width of the **central core**
- Net **advantages** of heavy ions
- Intermediate results for **He ions**

$$\sigma \sim 1/\sqrt{(M)}$$

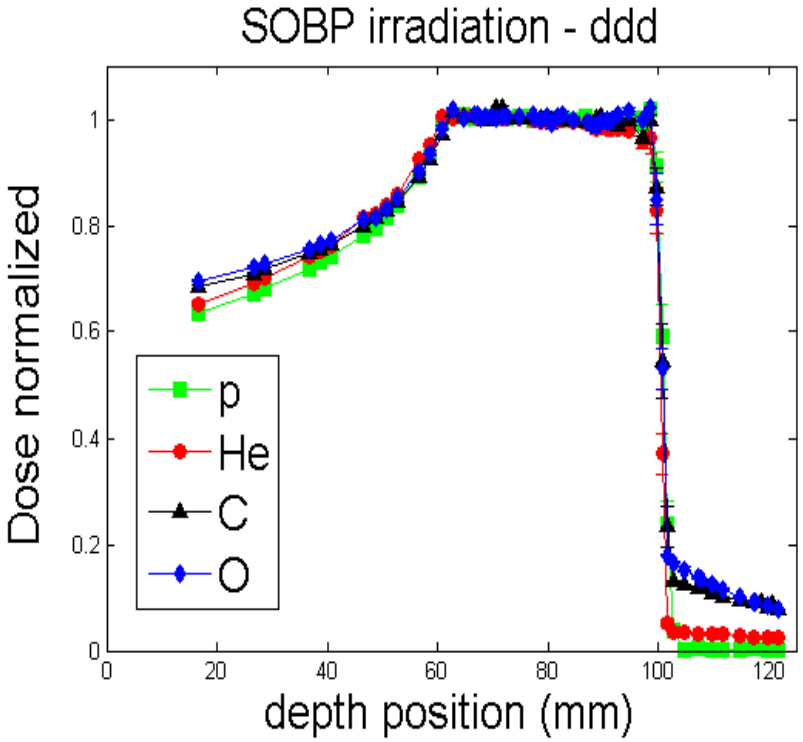
< 2-4 mm compared to H **~ + 1-2 mm** compared to C

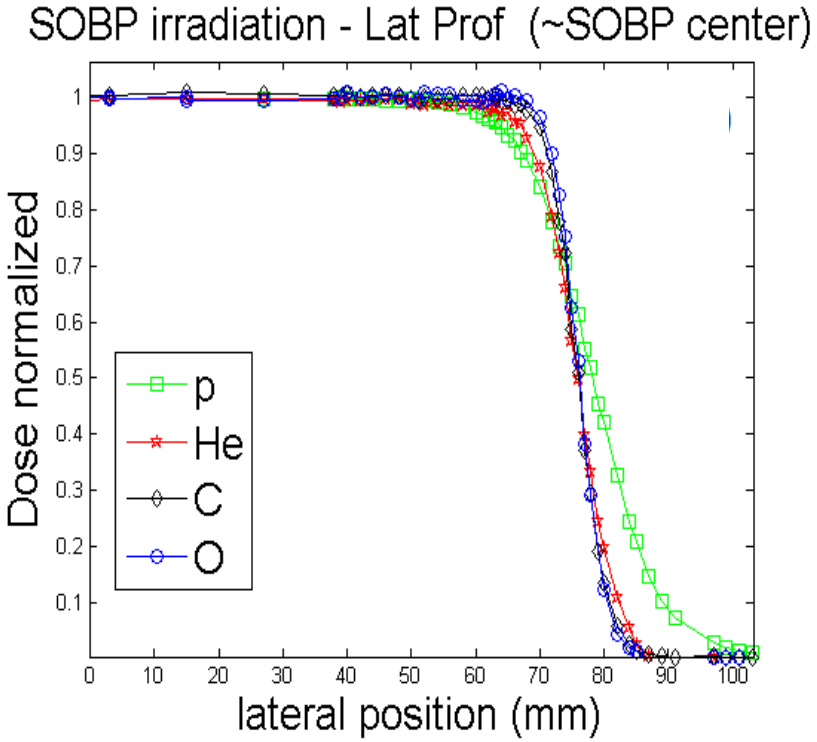
Dosimetric comparison …

-

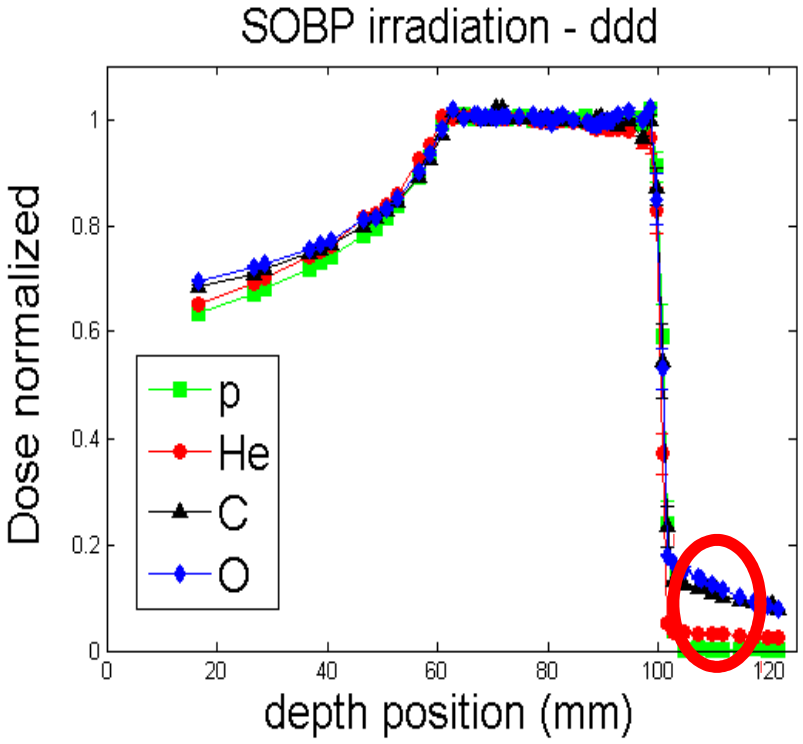
Spread Out Bragg Peak

SOBP

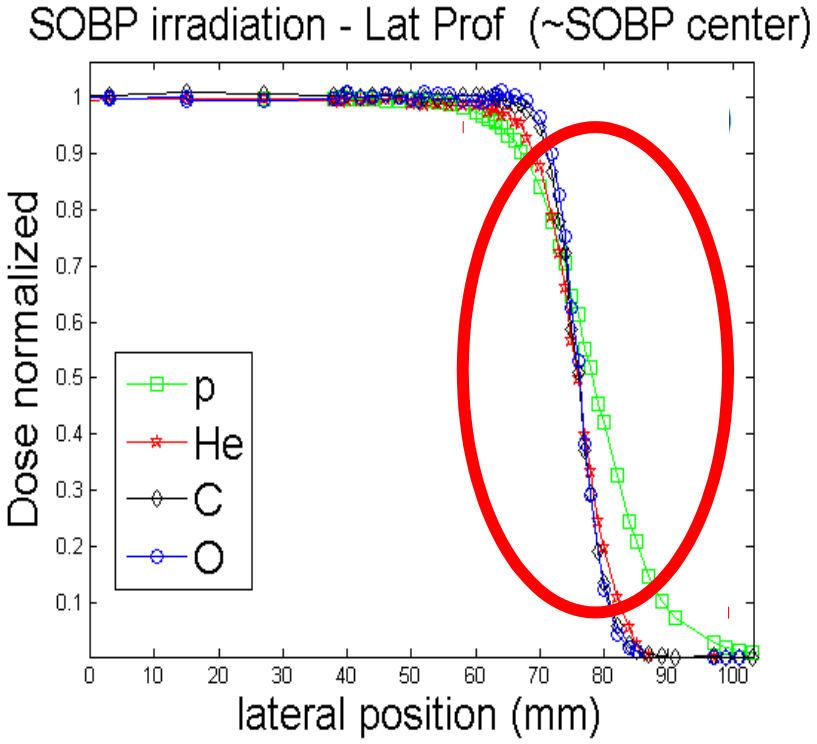

SOBP irradiation - ddd
Dose normalized
depth position (mm)
p
He
C
O


SOBP irradiation - Lat Prof (~SOBP center)
Dose normalized
lateral position (mm)
p
He
C
O

SOBP



→HI tail > 10%



→p LFO > 7mm

SOBP

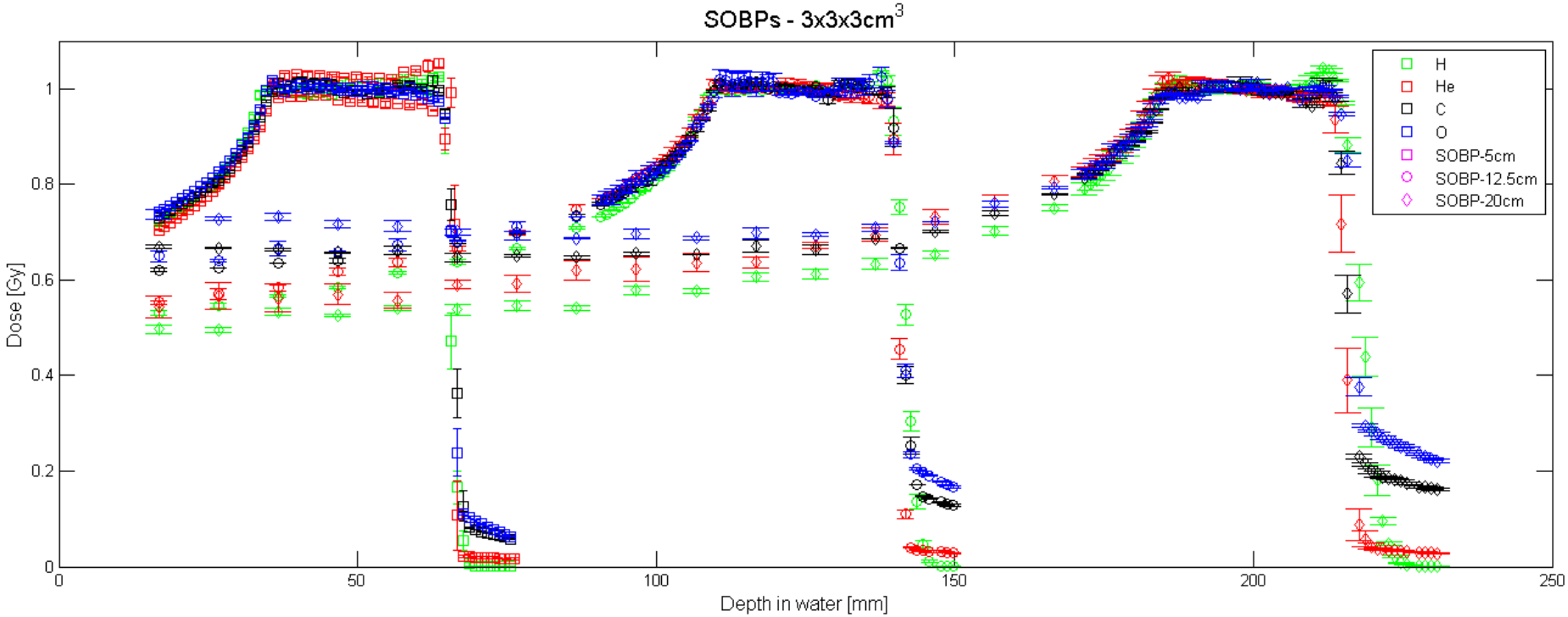
After modelisation in FLUKA…

Physical Optimisation of SOBP

SOBP

After modelisation in FLUKA…

Physical Optimisation of SOBP

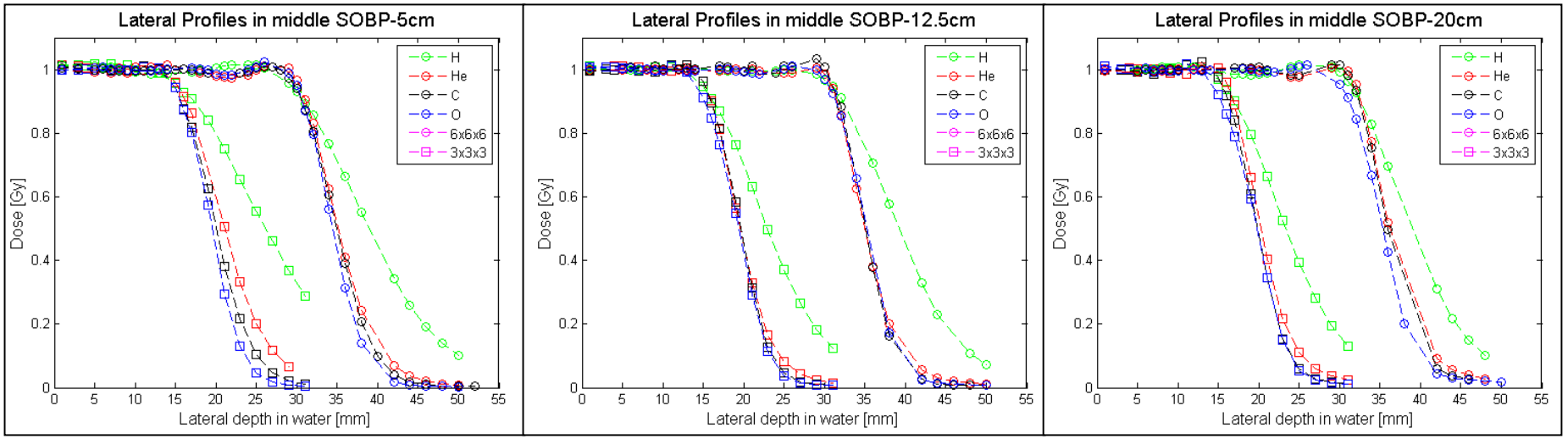


→HI tail > 20% at large depth !

SOBP

After modelisation in FLUKA…

Physical Optimisation of SOBP

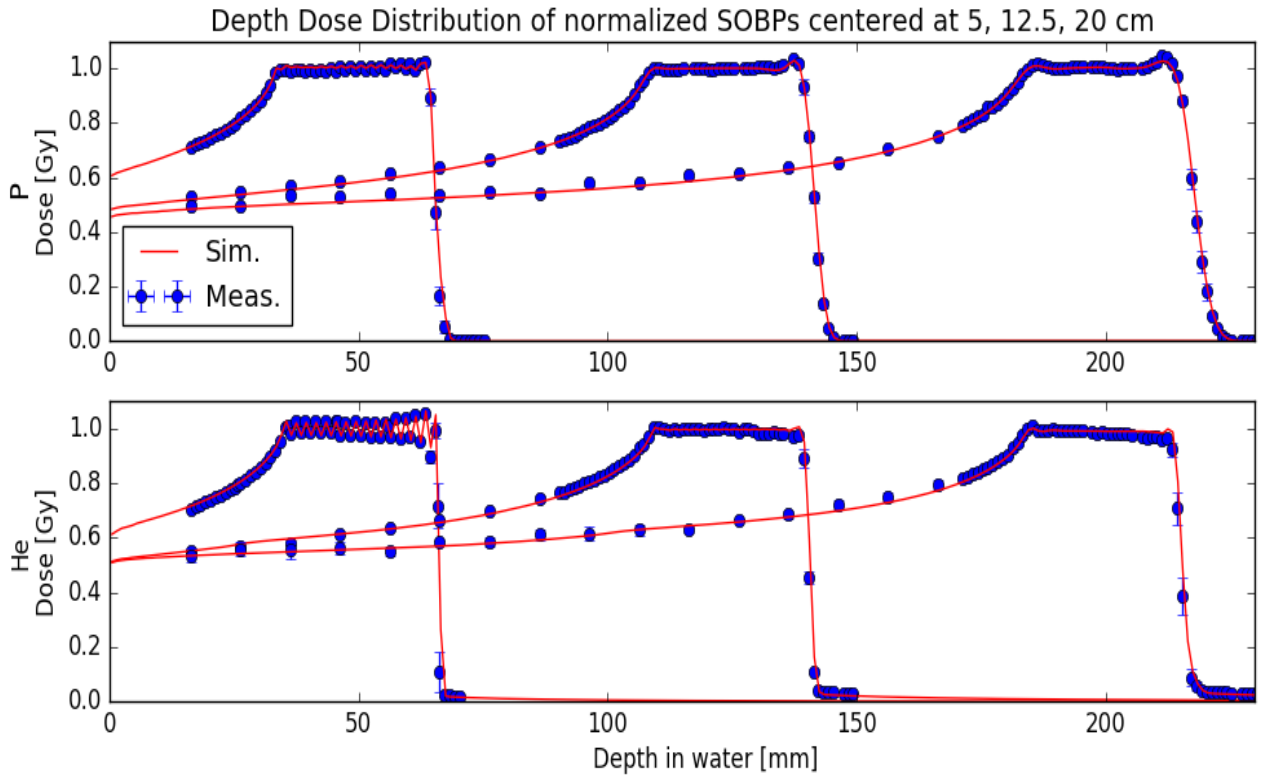


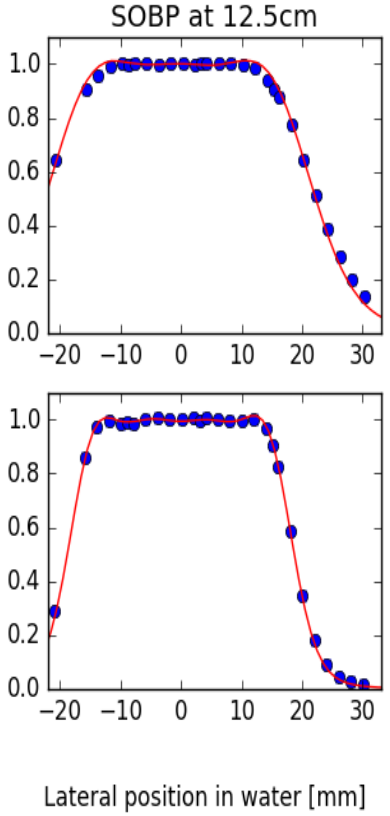
- **Irradiated lateral size similar** in the SOBP region for **He, C and O** ions. Larger size for H of about ~10-15mm

Plan Comparisons Between 1H and 4He

Plan Comparisons Between 1H and 4He

MCTP Platform – Physical Optimisation

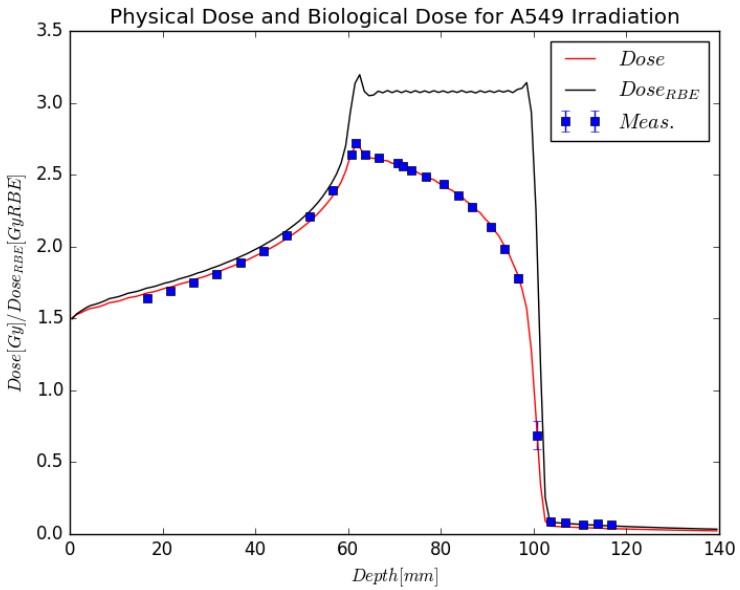


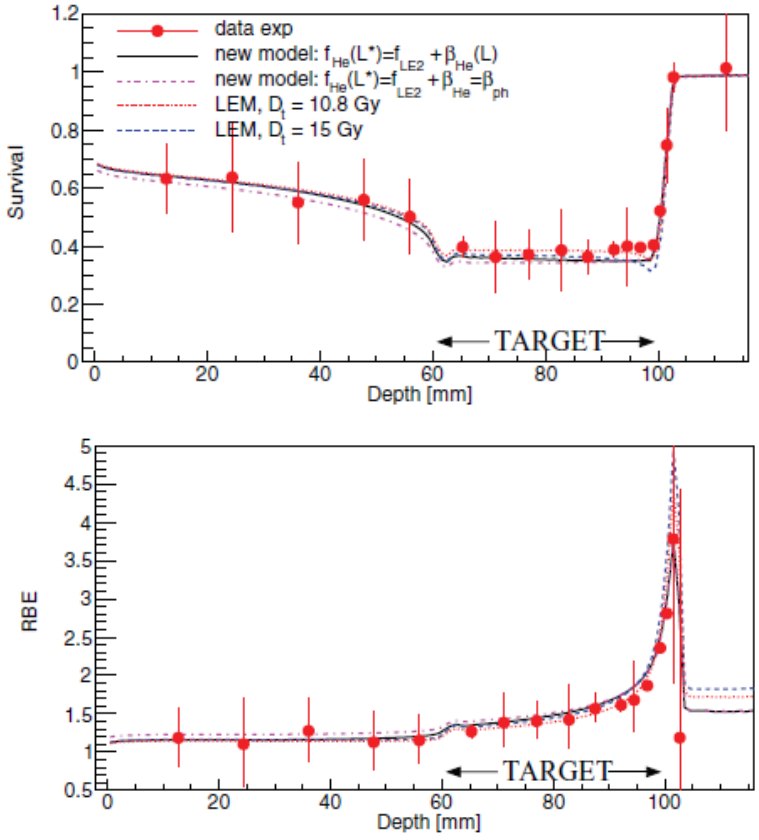


Böhlen *et al.* (2013)

Plan Comparisons Between 1H and 4He

MCTP Platform – Biological Optimisation





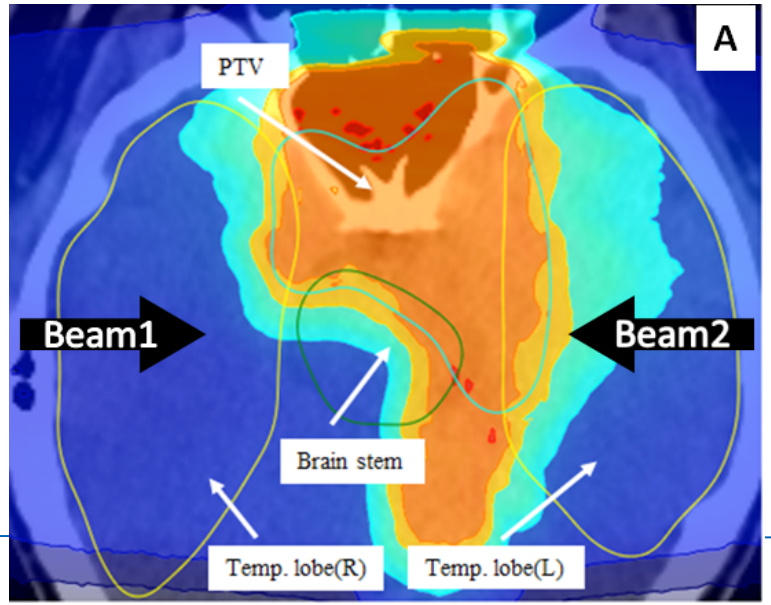
→ **Validated in-house model for He (5%) and p (2%)**

Mairani *et al*. (2016)

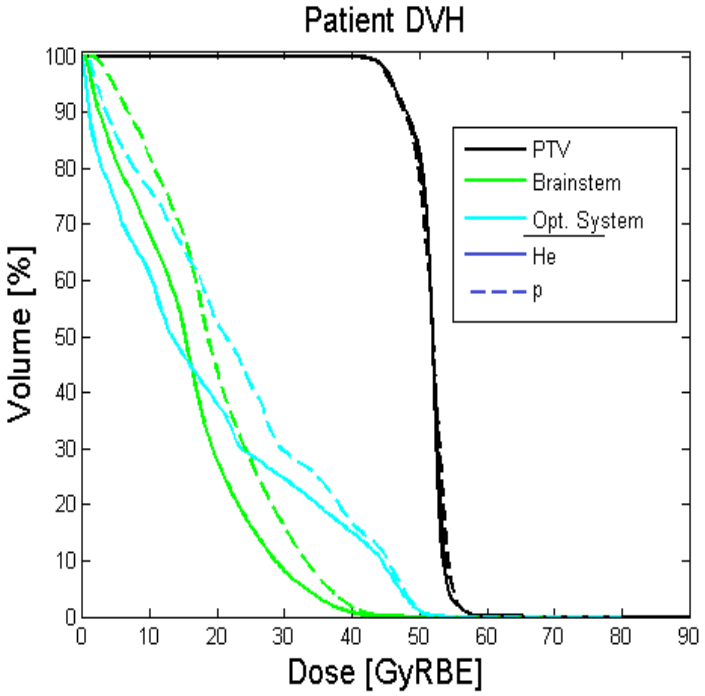
Plan Comparisons Between 1H and 4He

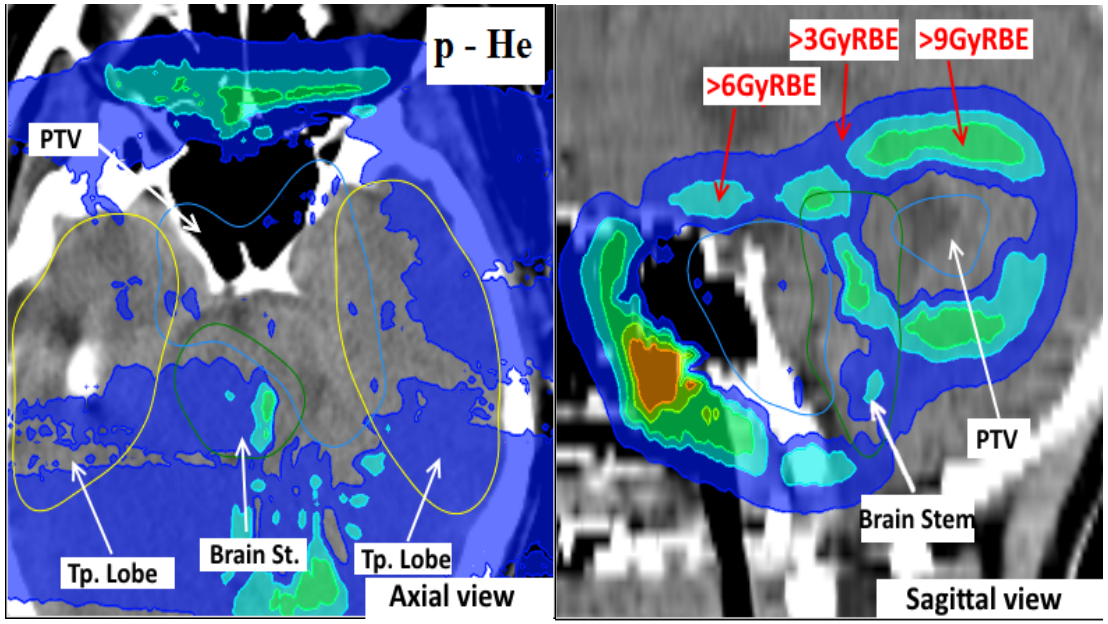
- Meningiomas treated with proton (4 patients)
- **Re-optimization** with **FLUKA–MCTP** for **helium** ions **AND protons**
- **Dose** in PTV 1.8 GyRBE

- Tissue types CNS α/β=2 , PTV α/β=3.7
- **Protons** without RiFi, **variable RBE** (calculated “online”)
- **Helium** ions with RiFi, **variable RBE** (calculated “online”)
- Comparisons : DVH for **PTV** and **OAR**



Plan Comparisons Between 1H and 4He





Comparable **PTV coverage**

Better sparing of OAR with He

Less dose to normal tissues

Perspective …

- **Still a lot to do …**
  - LET / RBE / OER optimization (+ biological characterization)
  - **Dual ions optimization !**
  - In-Vivo monitoring/Range verification … (prompt, PET, fragments)
  - Nuclear models …
  - Ion imaging …
- **Clinical practice !**
  - Uncertainty reductions
  - Robust Optimization
  - DECT
  - Biological dose fast recalculation
  - Detectors !!!

Prof. Thomas Haberer
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Stephan Brons
Julia Bauer
… HIT team !

Prof. Katia Parodi
Tiago Marcelos (BrainLab)
…

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Till Böhlen (MedAustron)

Thank you !