



UniversitätsKlinikum Heidelberg

Experimental dosimetric comparisons of ^1H , ^4He , ^{12}C and ^{16}O ion beams

T. Tessonier^{a,d}, A. Mairani^{b,c}, S. Brons^b, T. Haberer^b, J. Debus^{a,b}, K. Parodi^{b,d}

^aDepartment of Radiation Oncology, University Hospital Heidelberg, Heidelberg, Germany

^bHeidelberg Ion Beam Therapy Center (HIT), University Hospital Heidelberg, Heidelberg, Germany

^cCentro Nazionale di Adroterapia Oncologica (CNAO), Pavia, Italy

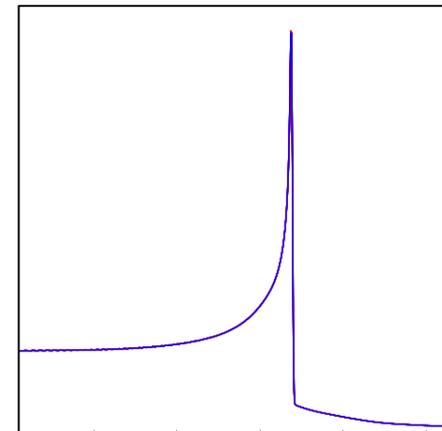
^dDepartment of Medical Physics, Ludwig Maximilian University, Munich, Germany

Introduction

- Worldwide interest in particle therapy
 - **Physical properties** (inverted depth dose profile, finite range,...)
 - **Biological properties** (RBE, OER, ...)
 - ^1H and ^{12}C in clinics
 - Increase of interest for **“new” ions**
 - Publications on comparisons (Monte-Carlo/Analytical)
 - Experimental validations ?
 - Lack of fragmentation data** (therapeutic range)
 - Lack of detailed dosimetric data** (^4He , ^{16}O)

- **Heidelberg Ion Beam Therapy Center (HIT)**

- Active beam scanning delivery
- ^1H , ^4He , ^{12}C , ^{16}O



Bragg-Peak for Carbon ions

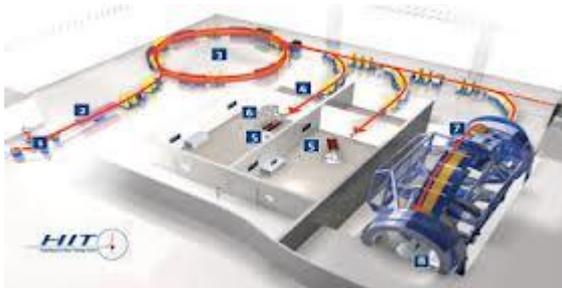
→ **Experimental dosimetric comparisons between ions**

- Pencil-Beam and Spread-Out Bragg Peak

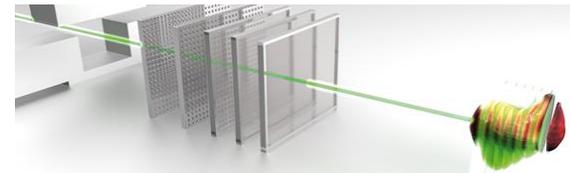
Introduction

Active beam scanning delivery

→ Energy and position selection



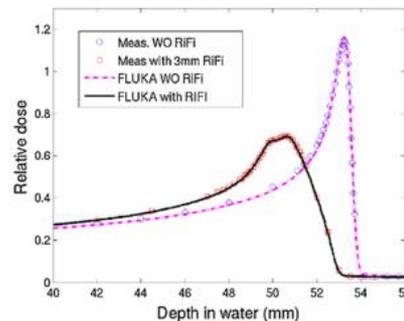
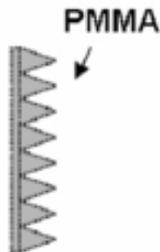
Synchrotron: 50 -430 MeV/u



Raster scanning system

Ripple Filter (RiFi)

→ PMMA material to broaden the beam width (energy spread)

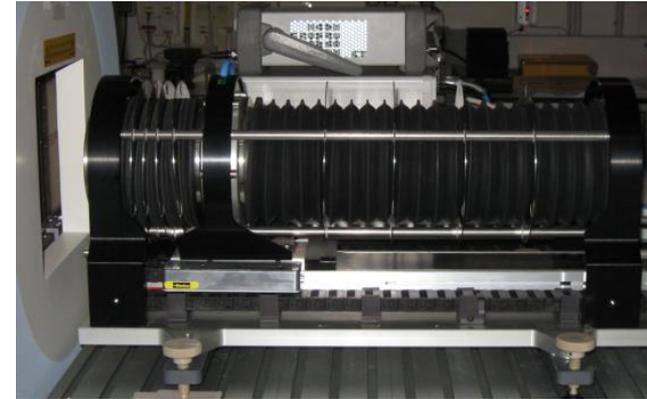


*Figures from UniversitätKlinikum Heidelberg
And Parodi et al, PMB 2012*

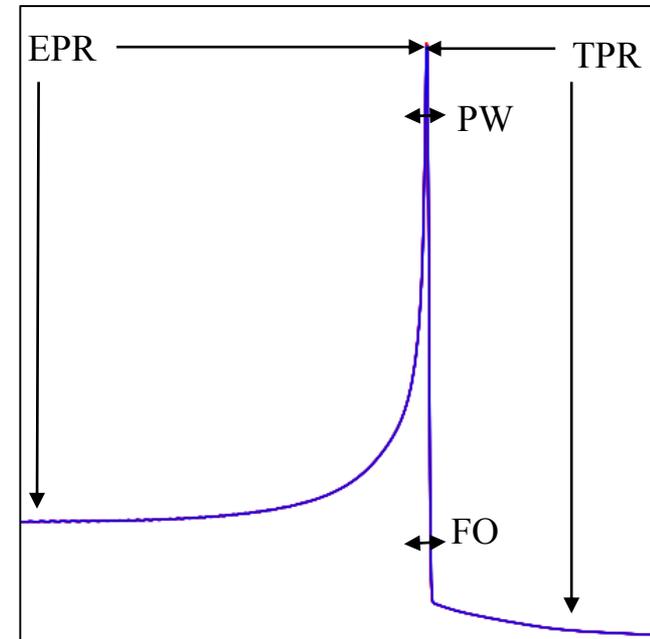
Depth Dose Distribution

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%)



PeakFinder Water column

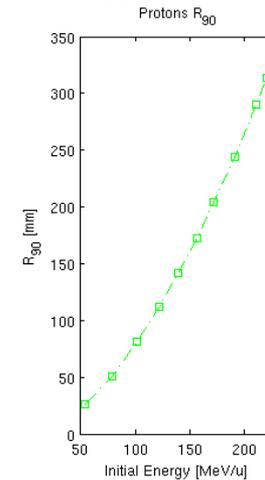
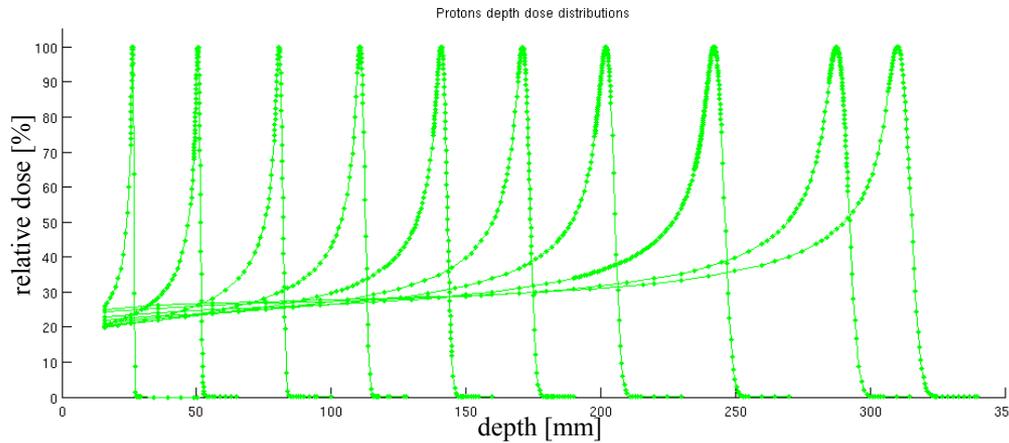


Investigated parameters

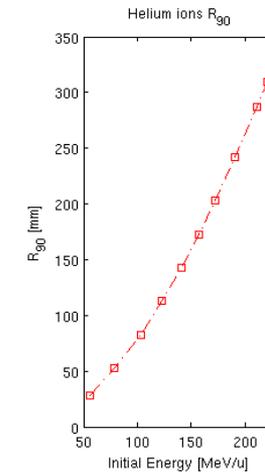
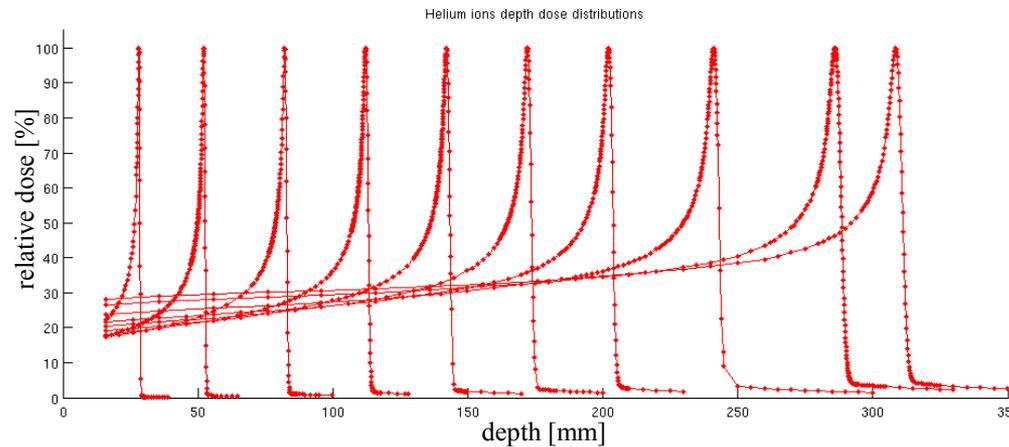
Depth Dose Distribution

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

^1H



^4He

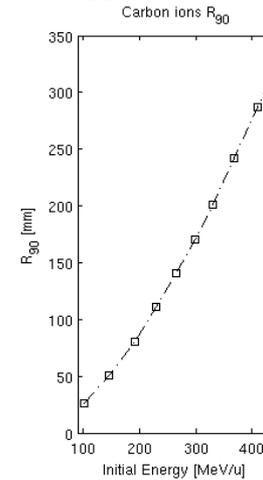
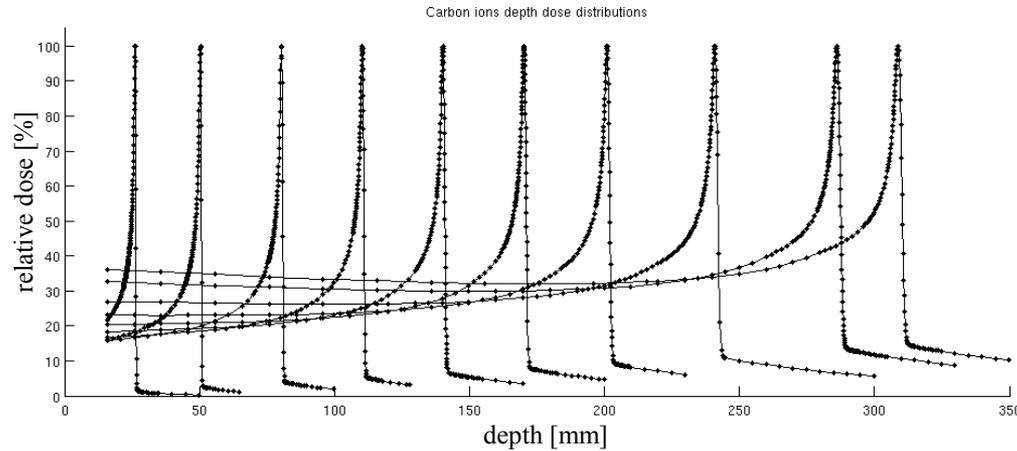


→ Parameters expressed as a function of R_{90}

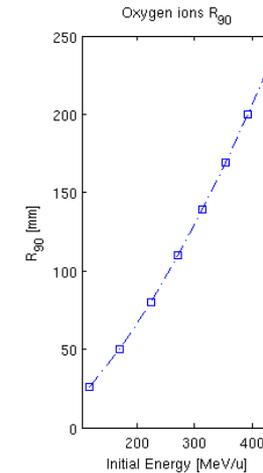
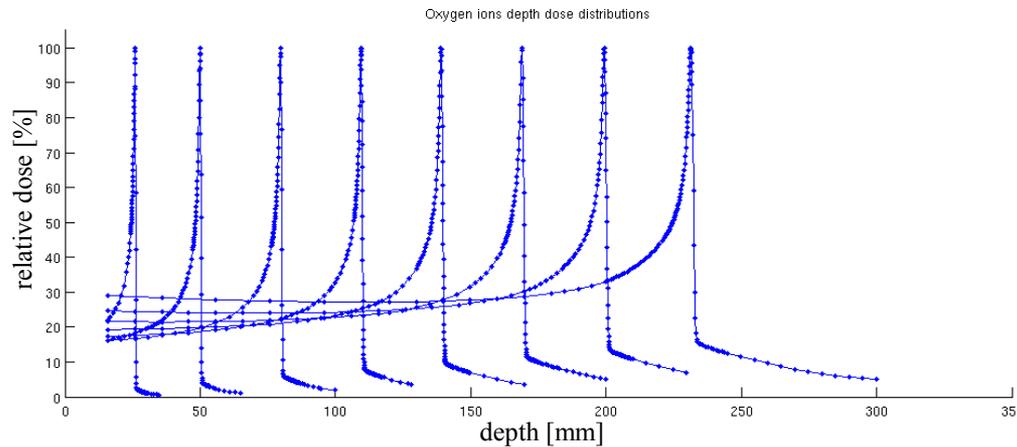
Depth Dose Distribution

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

^{12}C



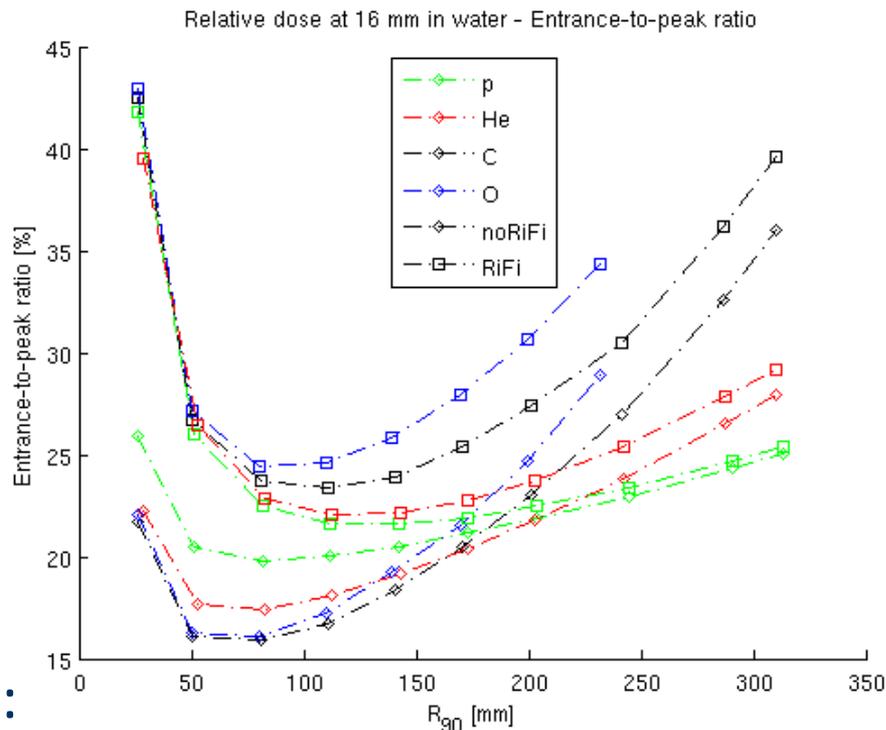
^{16}O



→ Parameters expressed as a function of R_{90}

Depth Dose Distribution

Results : EPR

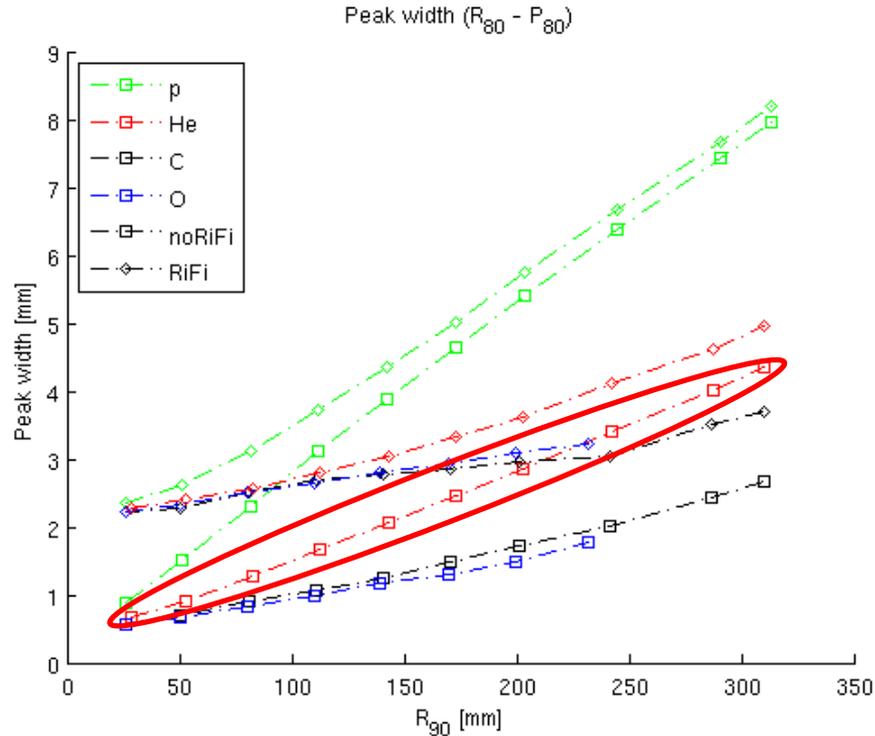


- Without RiFi:
 Advantage of heavy ions (low-middle energies)
 High energies → pronounced fragmentation

- With RiFi:
 Advantage of He ions compared to C/O

Depth Dose Distribution

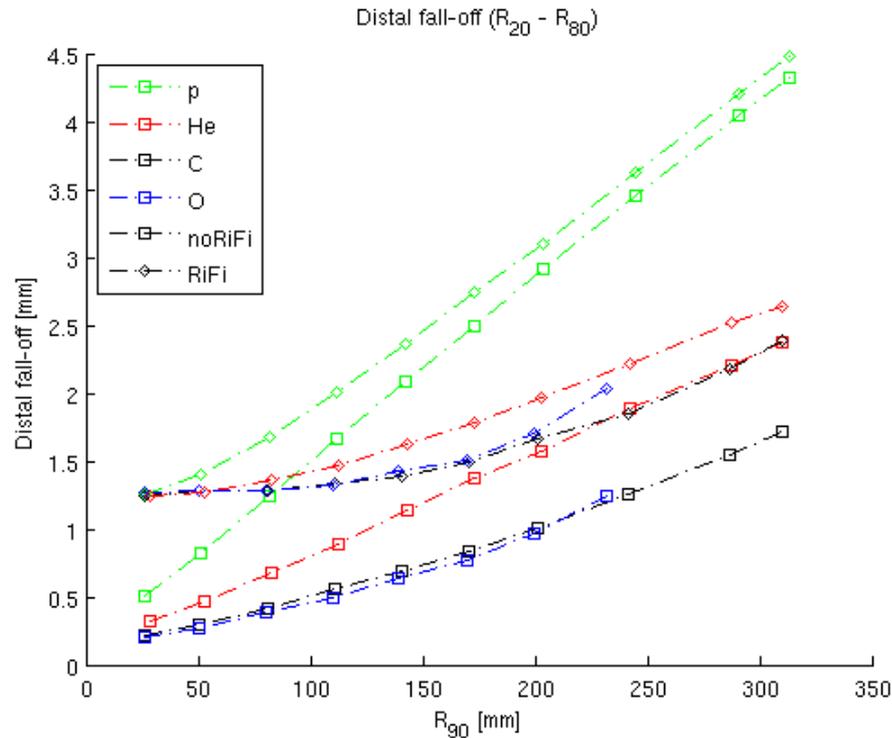
Results : PW



Probably **no need of RiFi** for He ions regarding the PW
(even for low energies ?)

Depth Dose Distribution

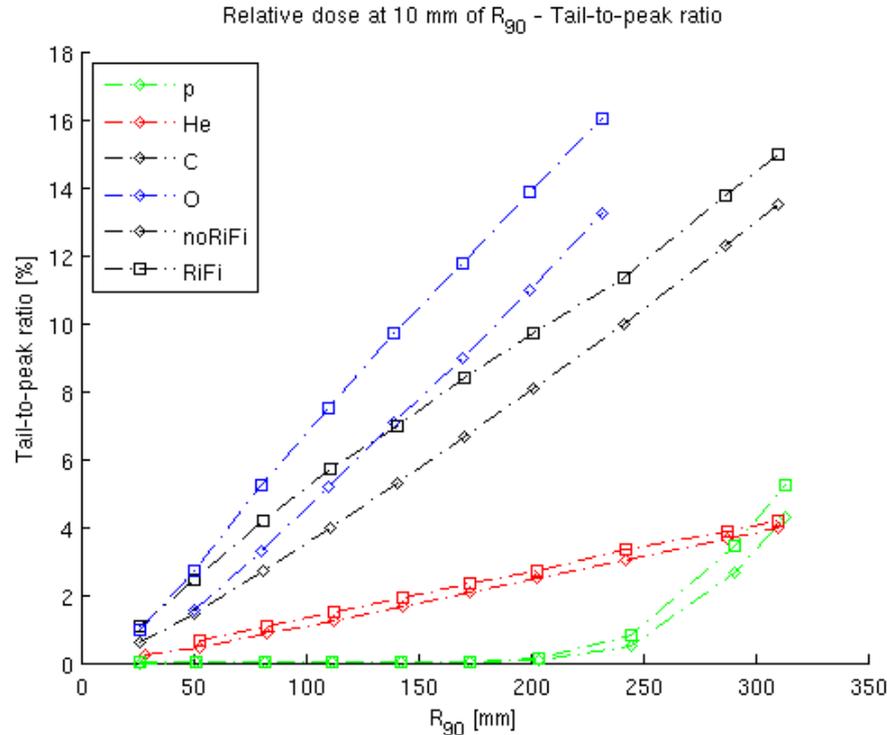
Results : FO



- 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 : TPR



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

He < 4%

C/O up to 16 %

Vertically scanned lines

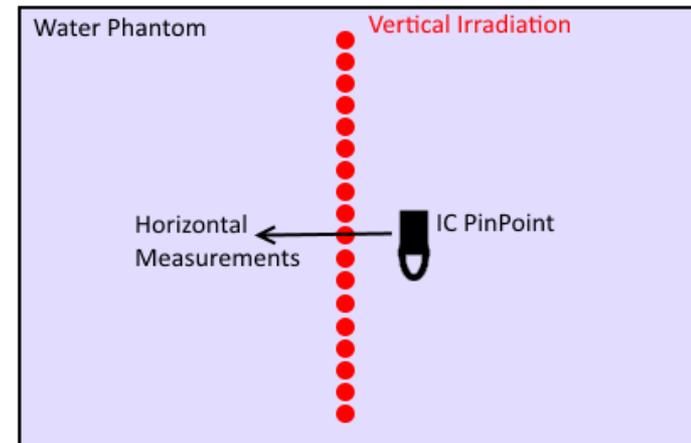
Materials and Methods

- 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



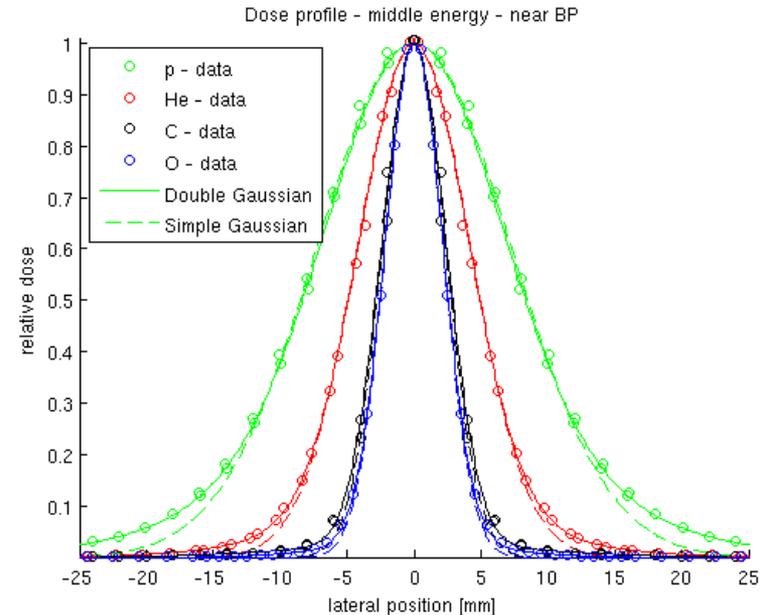
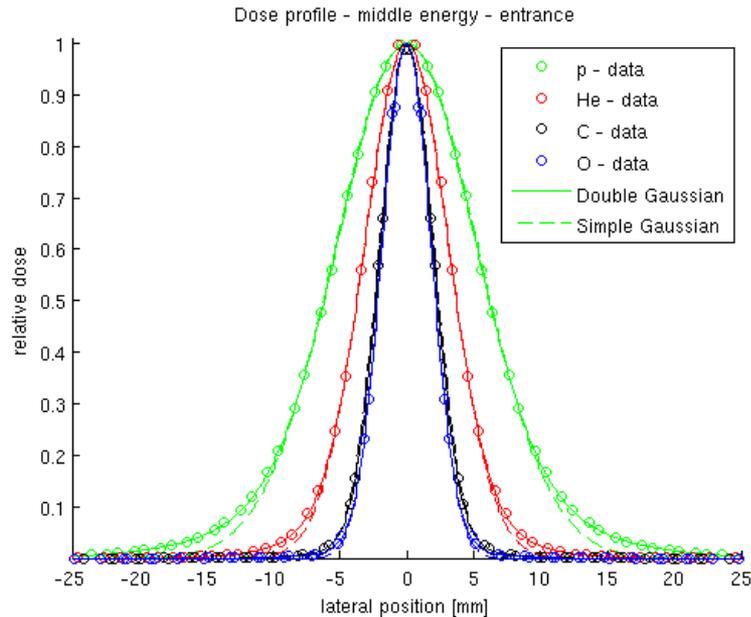
Water Tank + IC



Measurements of vertically scanned line

Vertically scanned lines

Results



Gaussian parametrizations :

$$SGP \sim G_0(\sigma_0)$$

$$DGP \sim (1-w)G_1(\sigma_1) + wG_2(\sigma_2)$$

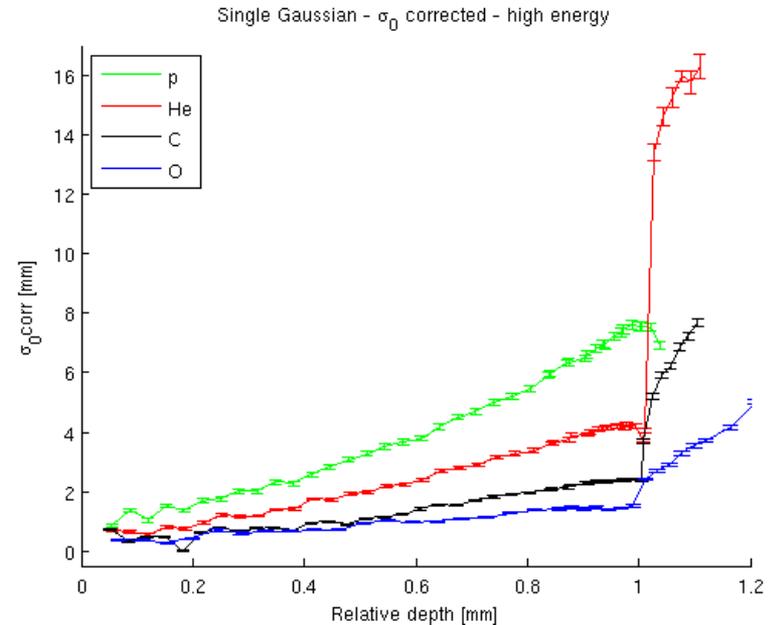
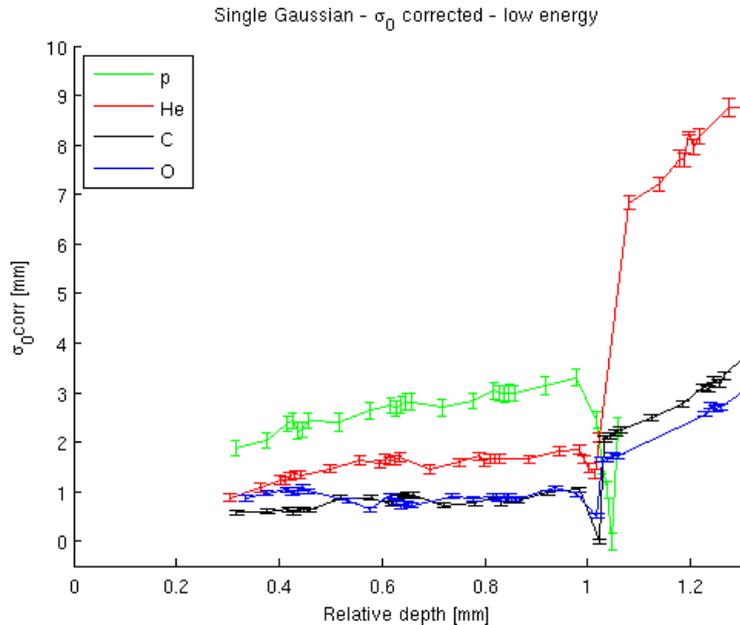
- Different **focus** size at the entrance of the phantom -> **not comparable**

→ **Correction** to an infinite narrow beam δ :

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

Vertically scanned lines

Results



- **SGP** describing the width of the **central core**
- **Net advantages** of heavy ions
- Intermediate results for **He ions**
 - < **2-4 mm** compared to H
 - ~ **+ 1-2 mm** compared to C

SOBP Irradiations

Materials and Methods

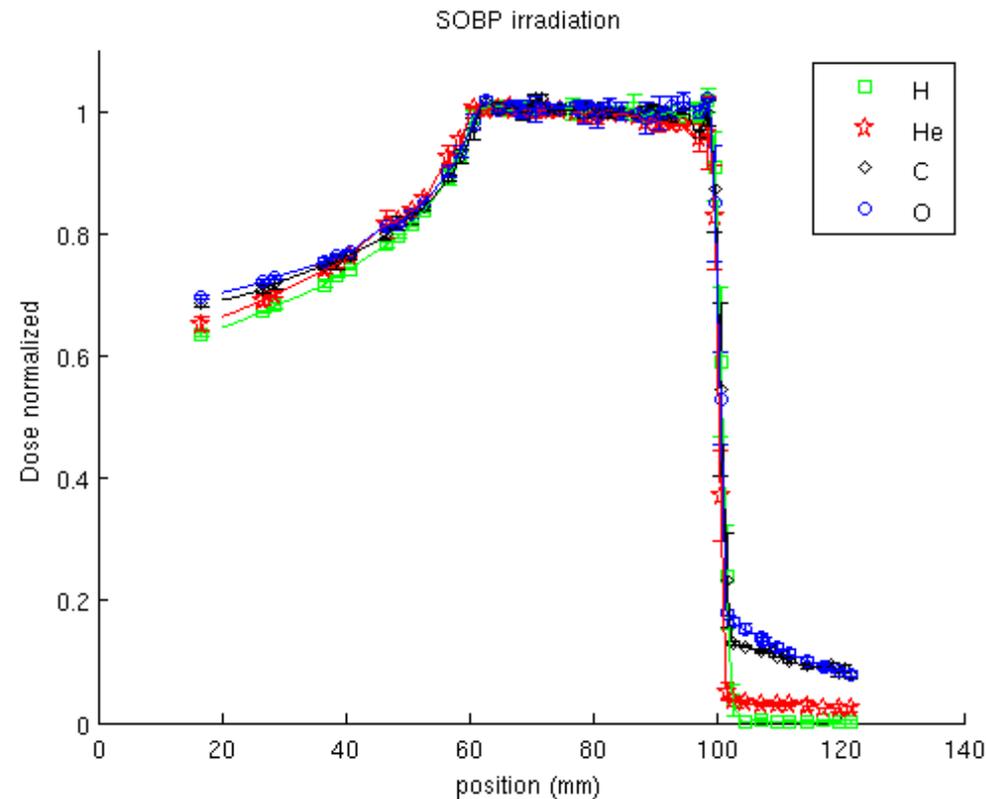
- Comparisons for 4 ions
- **Spread Out Bragg peak (SOBP)**
 - 14x14x4 cm³ centered at 8cm
- SOBP optimized for **1 Gy**
- C and O ions **with RiFi**

- Active scanning beam delivery
- Measurements in the water tank :
 - Depth dose profiles
 - Lateral profiles
- **Normalization** of the results to the SOBP mean dose
 - Monitor calibration not finalized for He (+5%) and O ions (+8%)

SOBP Irradiations

Results – Depth Analysis

- Parameters :
 - Entrance-to-Plateau ratio (**EPR**)
 - Distal Fall-Off (**FO**)
 - Tail-to-Plateau Ratio (**TPR**)
 - SOBP characteristics
(Homogeneity, Mean dose, Size, ...)

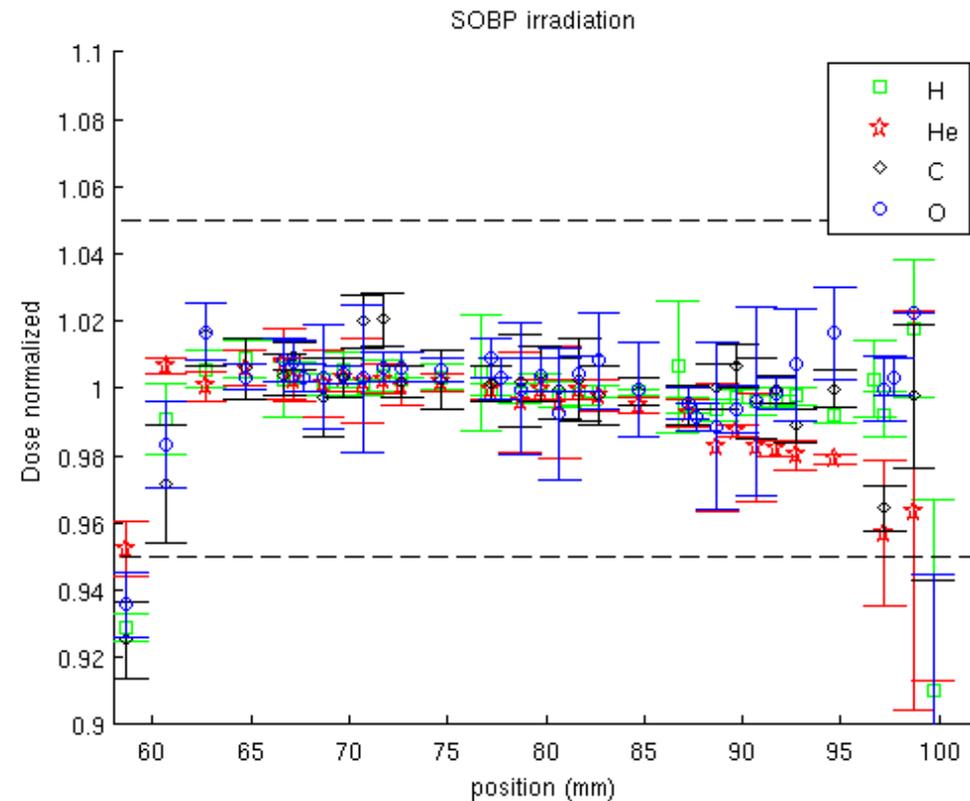


SOBP Irradiations

Results – Depth Analysis

- Parameters :
 - Entrance-to-Plateau ratio (**EPR**)
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(Homogeneity, Mean dose, Size, ...)



SOBP Irradiations

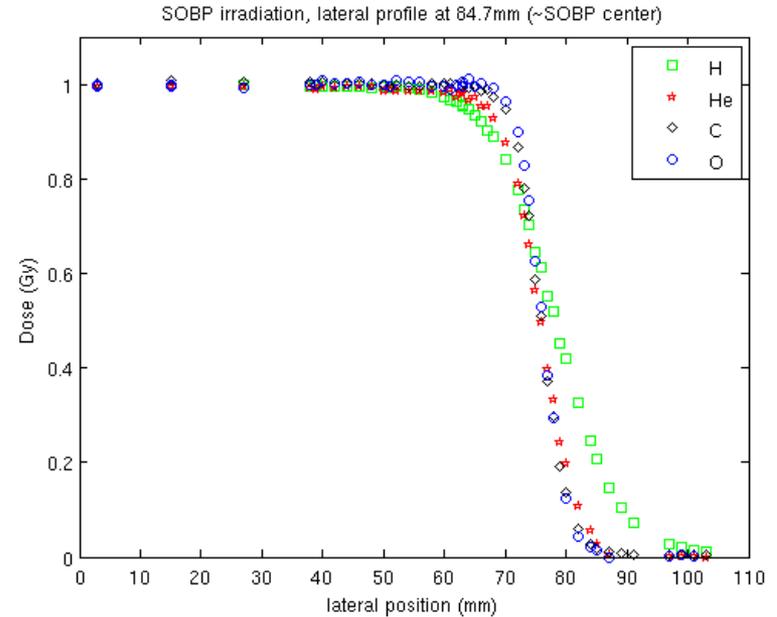
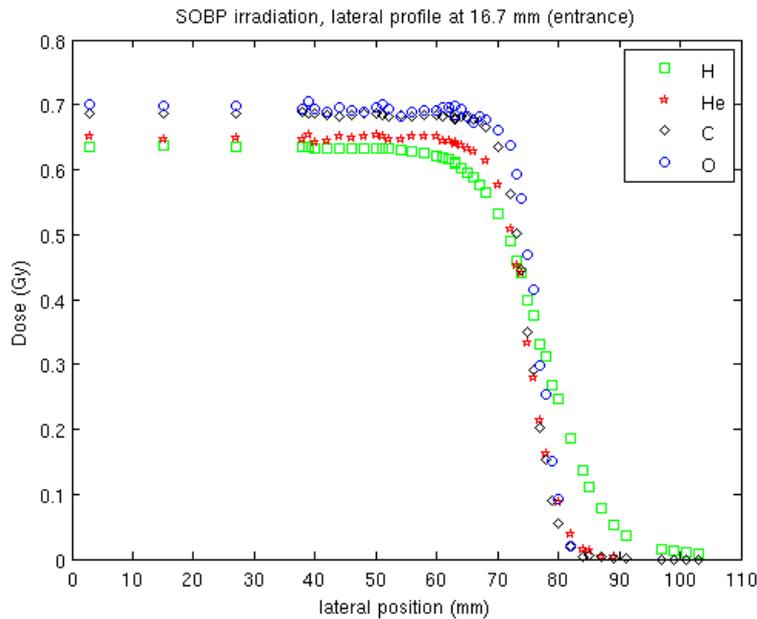
Results – Depth Analysis

	EPR	Size	Range	FO	TPR	Hom	Mean	σ
H	63%	42.5mm	99.7mm	1.7mm	0%	3.3%	0.1%	0.6%
He	65%	42.7mm	99.3mm	1.3mm	3%	4.7%	0.3%	0.9%
C	69%	42.0mm	99.5mm	1.5mm	12%	3.9%	0.3%	0.8%
O	70%	42.7mm	99.5mm	2.0mm	15%	4.9%	0.2%	0.9%

- **EPR : Similar**
~ better for H and He
- **TPR : advantage for He or protons**
→ no/small fragmentation
- **FO : Slight advantage of He**
→ No RiFi compared to C / O
→ Sensitive volume of the chambers !
- **Homogeneity < 5%**
→ He / O ions inside the tolerance

SOBP Irradiations

Results – Lateral Profile Analysis

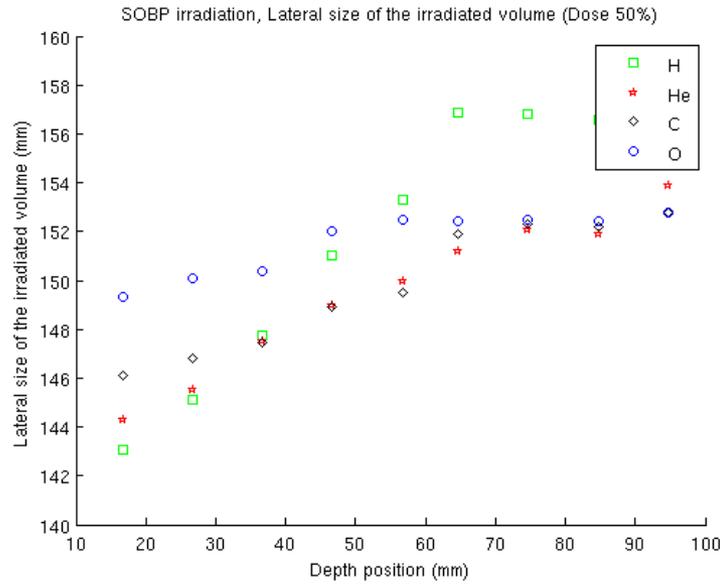
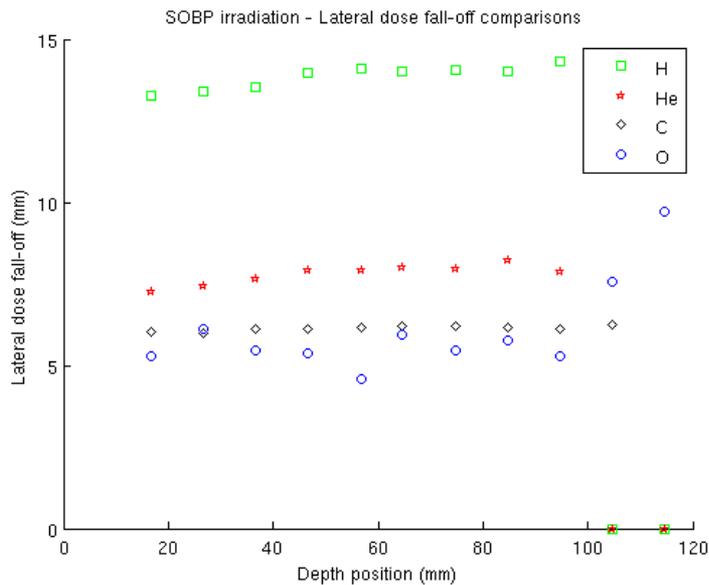


- Parameters:

- Lateral Dose FO (D80%/D20%)
- Irradiated volume size (D50%) evolution

SOBP Irradiations

Results – Lateral Profile Analysis



Lateral FO :

FO H >>> FO He > FO C ~ FO O

→ non negligible scattering for H

Evolution of the **irradiated volume** size (from relative 50% dose):

Similar in the SOBP region for He, C, O ions

Larger for H in SOBP region (related to FO)

→ He ions results close to heavier ones

Conclusion

- Therapeutic use of Helium ions had been discontinued after the end of the clinical experience at the Berkeley National Laboratory in 1992
- Experimental results indicate **^4He as a good candidate** for further particle therapy **improvements** :
 - Favorable physical characteristics
 - Smaller lateral scattering than ^1H
 - Very low tail-to-peak ratio compared to ^{12}C or ^{16}O

- **Detailed dosimetric data** for model validation

Experimental dosimetric comparisons at Heidelberg Ion Beam Therapy Center of ^1H , ^4He , ^{12}C and ^{16}O ion beams, Tessonnier *et al.* Physica Medica 2015 (JS SFPM 2015) + To be submitted...

- **^4He MC-generated database** based on experimental data (DDD+profiles)

→ Used for radio-biological experiment + model validation

Biologically optimized helium ion plans: calculation approach and its *in vitro* validation, Mairani *et al.*, submitted...

Comparisons between Monte-Carlo FLUKA predictions and experimental measurements for Helium ions at the Heidelberg Ion Therapy Center, Tessonnier *et al.*, To be submitted ...

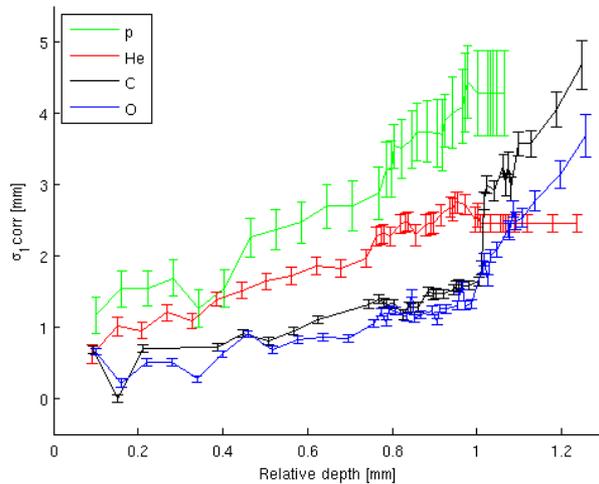
- **MC-TPS** for plan comparisons

- **Pre-optimization** tables ? (linked with biological model)

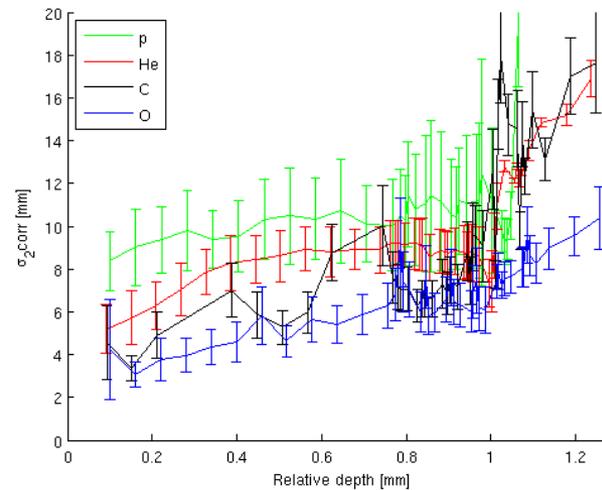
**THANK YOU
FOR
YOUR ATTENTION**

Backup DGP

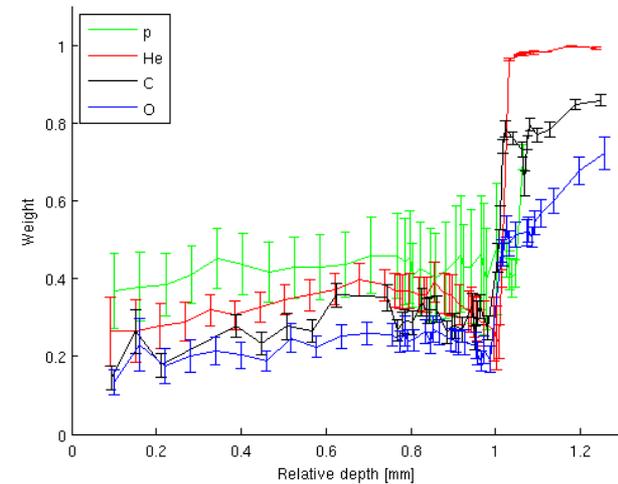
Double Gaussian - σ_1 corrected - middle energy



Double Gaussian - σ_2 corrected - middle energy



Double Gaussian - weight - middle energy



Profiles - Log

