Novel data relevant for helium ion therapy and their comparison with FLUKA nuclear reaction models

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2 GSI Helmholtz Centre for Heavy Ion Research, Biophysics Department, Darmstadt, Germany
3 CERN - European Organization for Nuclear Research, Geneva, Switzerland
4 INFN - National Institute for Nuclear Physics, Sezione di Milano, Italy
5 JLU Justus Liebig University, II. Physics Institute, Giessen, Germany
6 HIT - Heidelberg Ion-Beam Therapy Center, Heidelberg, Germany
7 CNAO - Centro Nazionale di Adroterapia Oncologica, Pavia, Italy
8 LMU - Ludwig Maximilian University, Munich, Germany
9 UKGM - University Hospital Giessen-Marburg, Department of Radiotherapy and -oncology, Marburg, Germany
10 FIAS - Frankfurt Institute for Advanced Studies, Frankfurt, Germany

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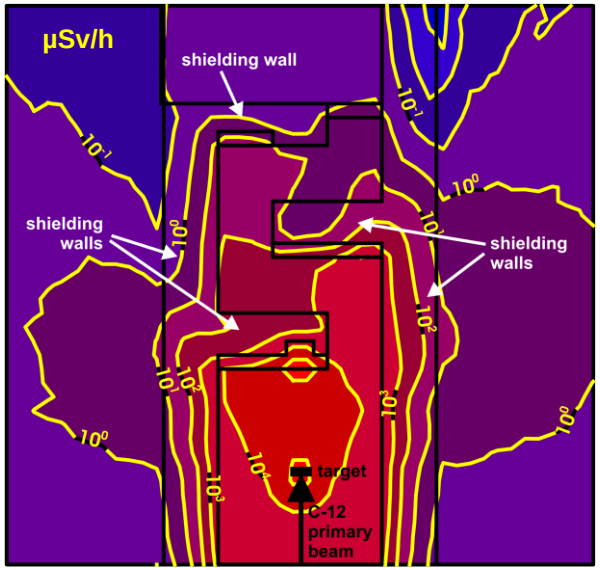
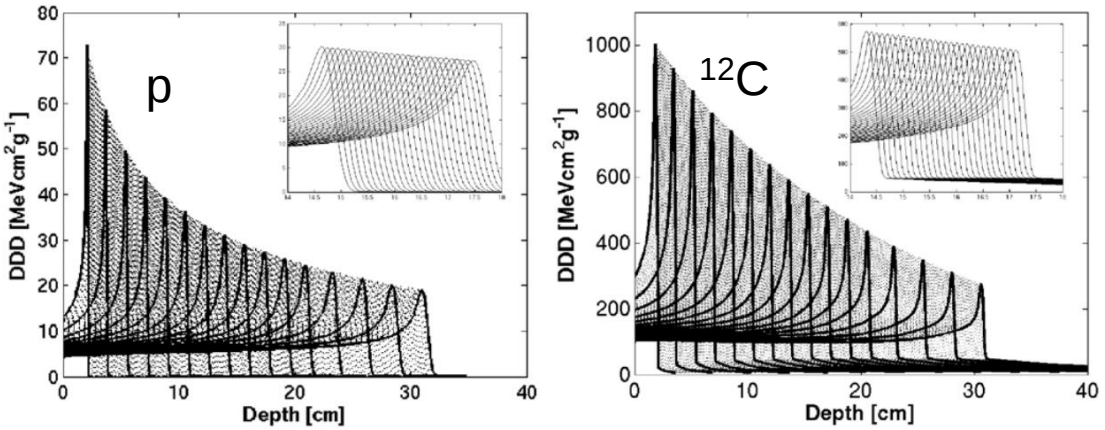
FLUKA – a multi-purpose Monte Carlo code

- Accurate simulation of hadron, heavy ion and electromagnetic particle transport
- Many applications: high energy physics and engineering, radiation protection and shielding, medical physics (**particle therapy**), …

HIT shielding design



HIT basic data for treatment planning system



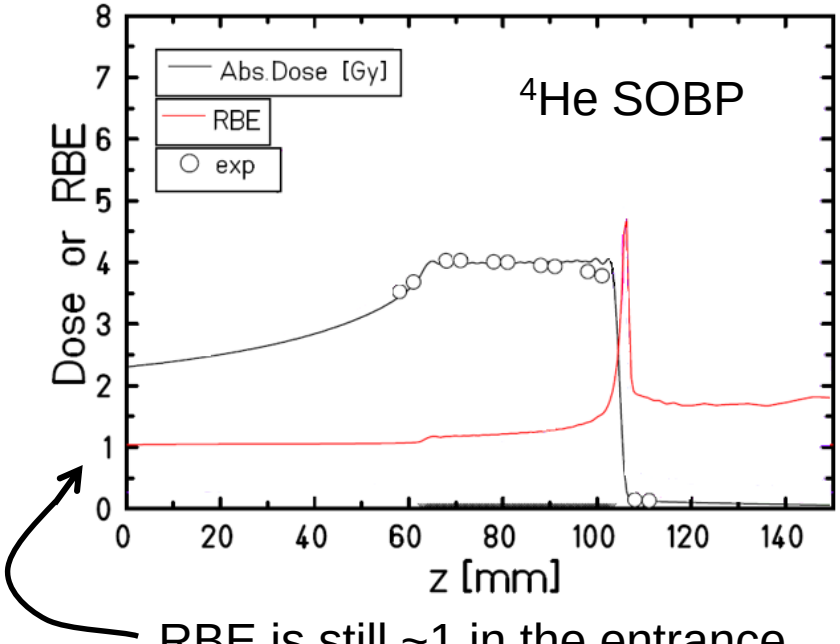
T.T. Böhlen et al. *The FLUKA Code: Developments and Challenges for High Energy and Medical Applications.* **Nuclear Data Sheets 120, 211-214** (2014)

A. Ferrari et al. *FLUKA: a multi-particle transport code.* **CERN-2005-10** (2005)

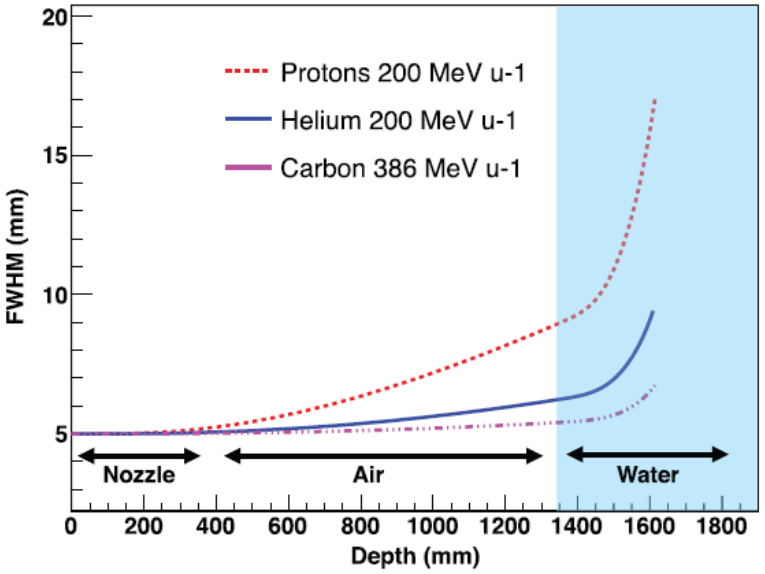
Introduction

Helium ion therapy – an attractive alternative to proton and carbon ion therapy ?

Planned start of patient treatment at the Heidelberg Ion-Beam Therapy Center (HIT): late 2018 !



RBE is still ~1 in the entrance channel.

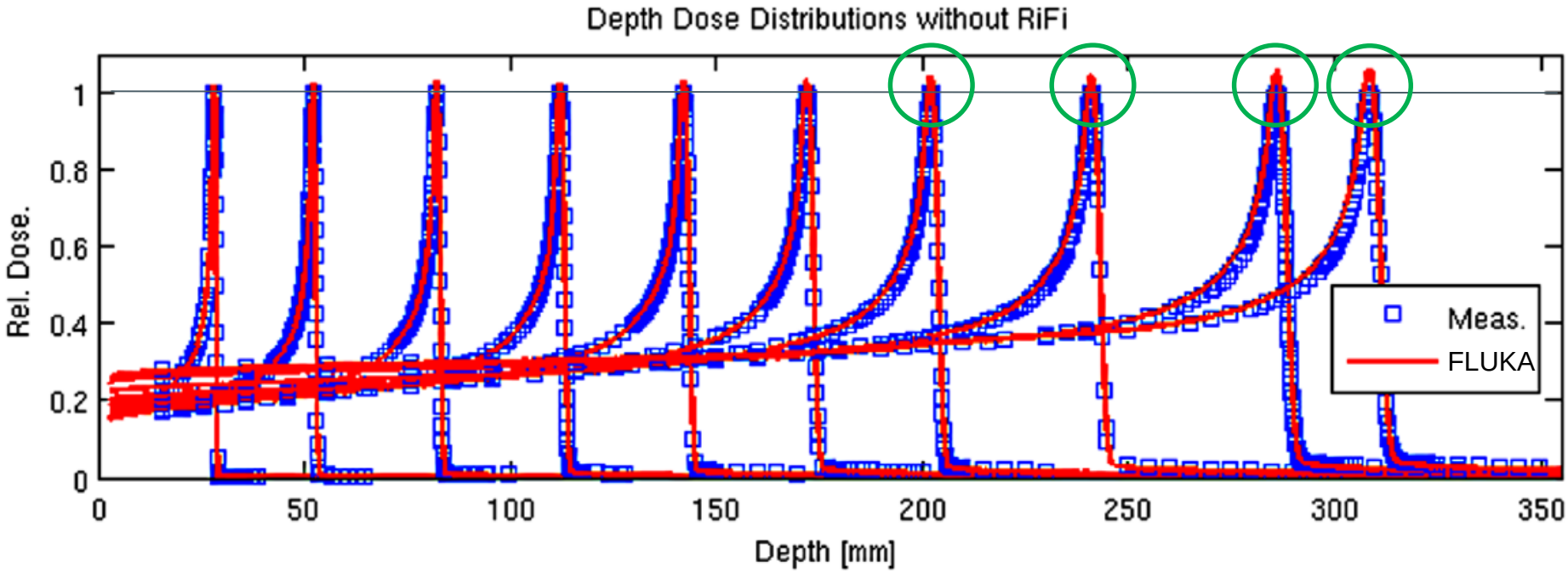


Lateral dose profile almost as sharp as for carbon ions.

left: M. Krämer et al. **Med. Phys. 43** (2016)
right: M. Rovituso et al. **Phys. Med. Biol.** 62 (2017)

Motivation

At HIT, the basic data (Bragg curves and fragment spectra) for the clinical treatment planning system are calculated with FLUKA.

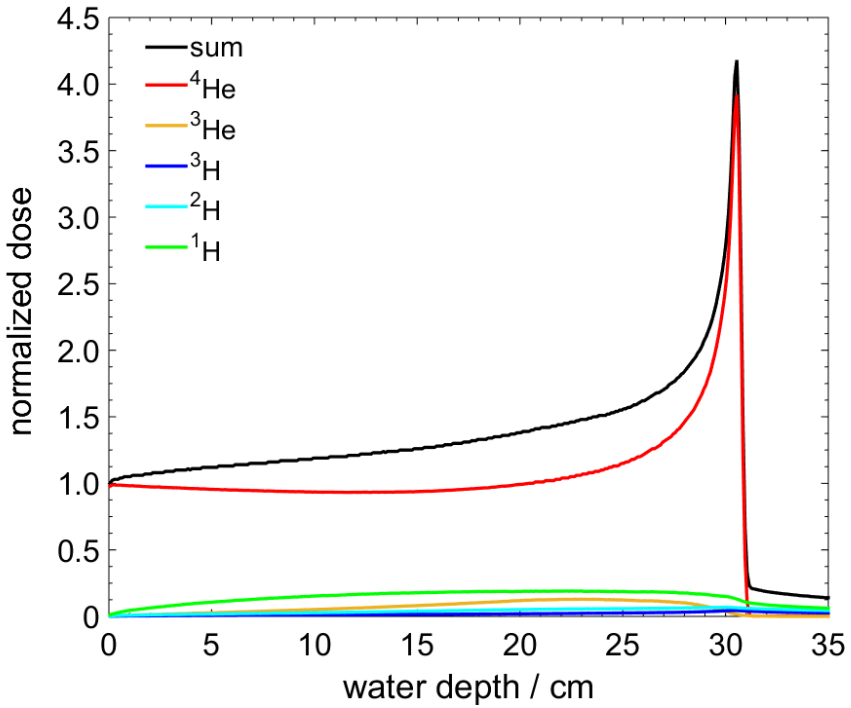


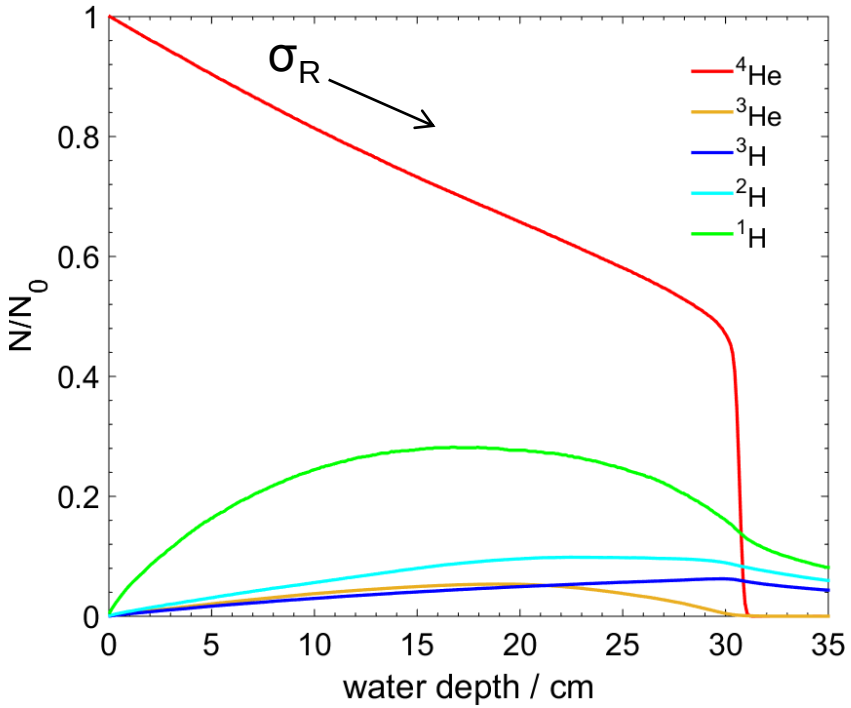
FLUKA slightly overpredicts the ^{4}He Bragg peak heights for high energies (large depths)!

T. Tessonnier et al. **Phys. Med. Biol.** 62 (2017)

Fragmentation of ^{4}He ions: FLUKA calculation

Bragg curve and relative fluences by 220 MeV/u ^{4}He ions stopping in water





Dose tail behind Bragg peak caused by nuclear fragments (^{1}H, ^{2}H and ^{3}H)

Only ~ 50 % of the primary ^{4}He ions actually reach the Bragg peak

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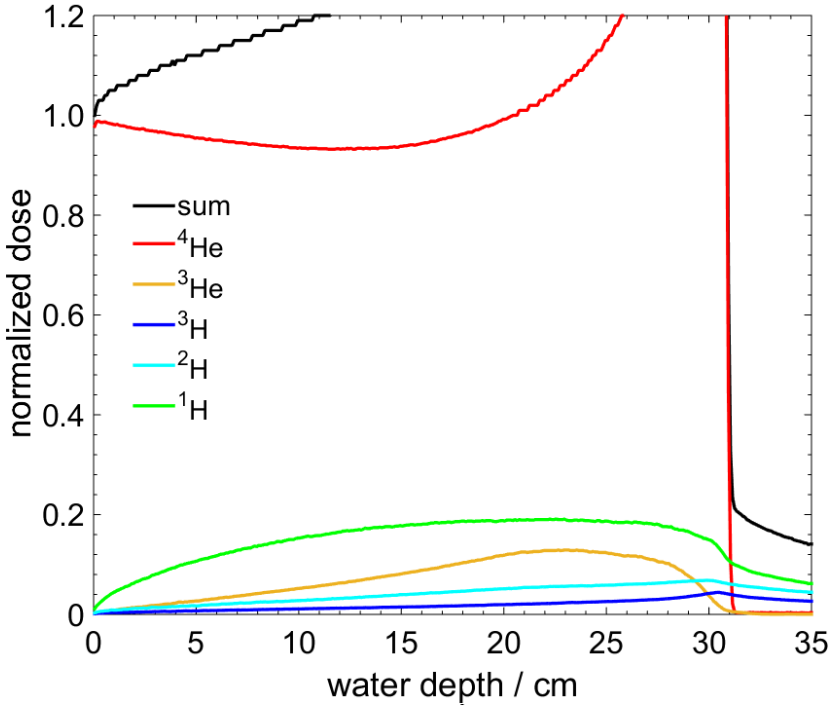

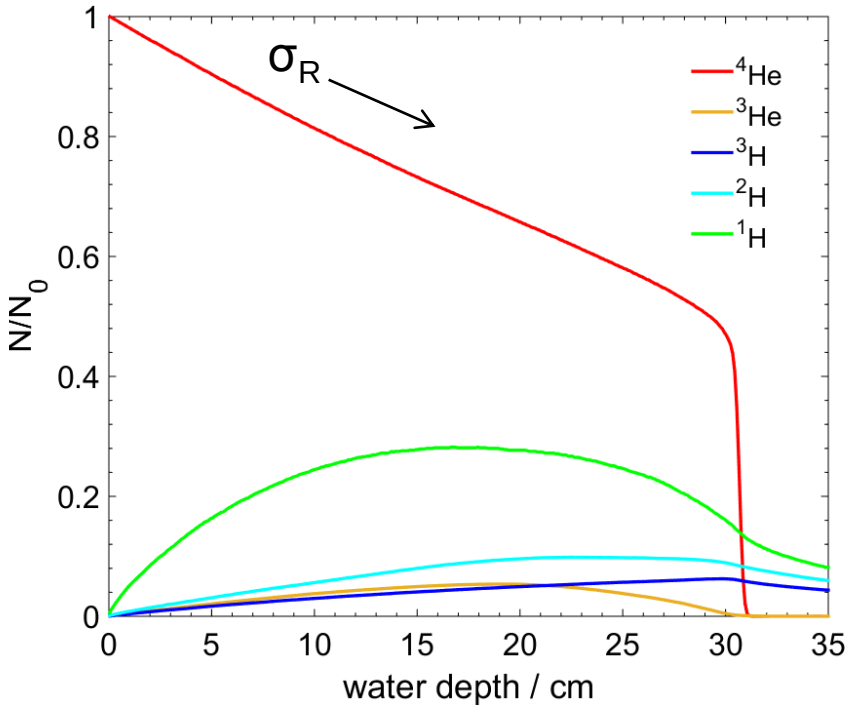

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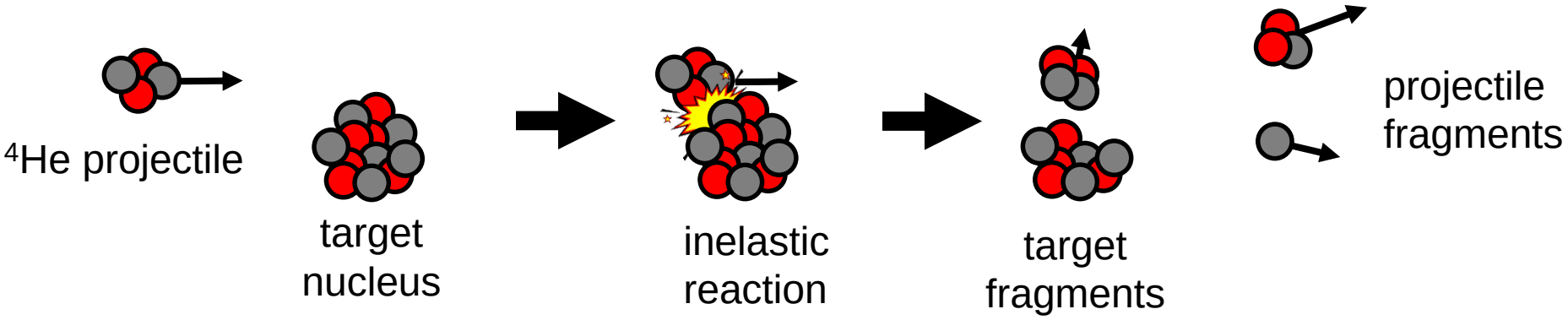
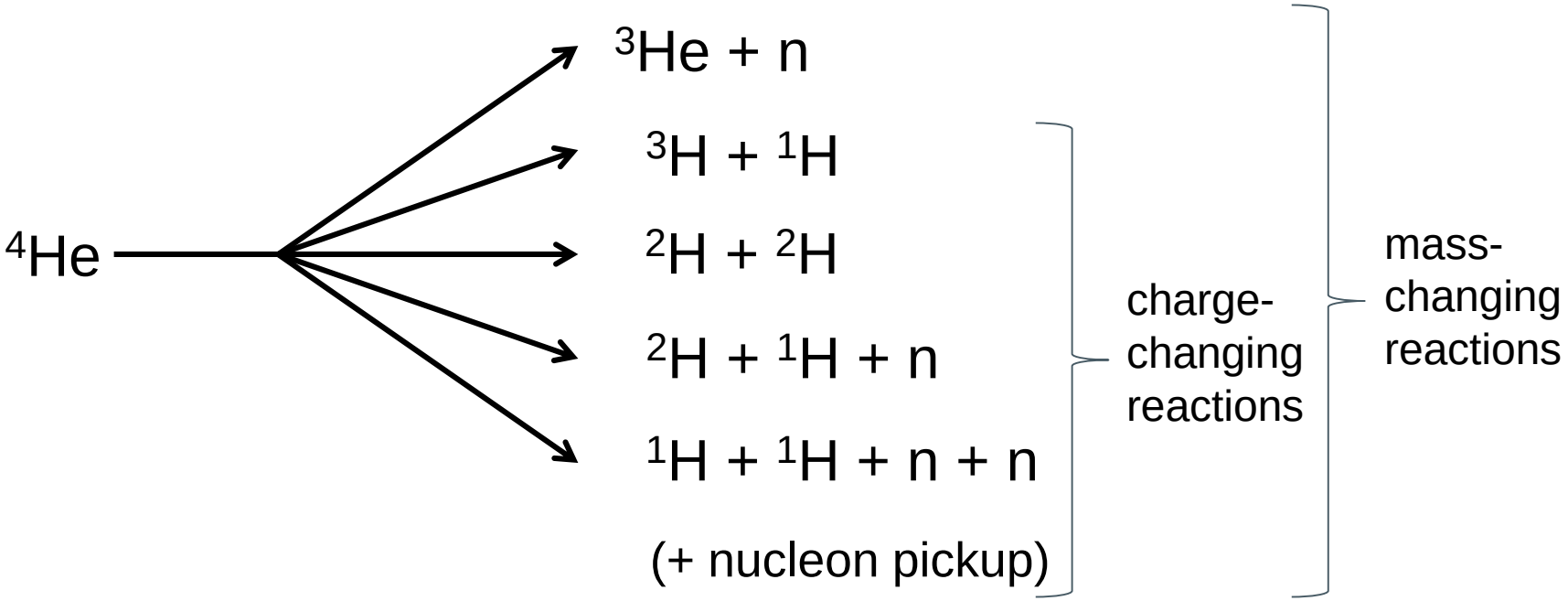
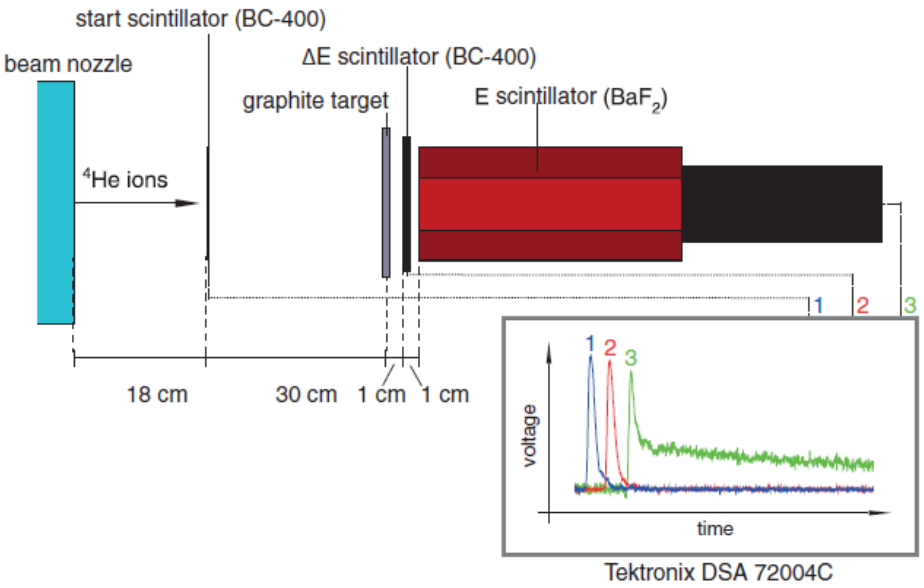


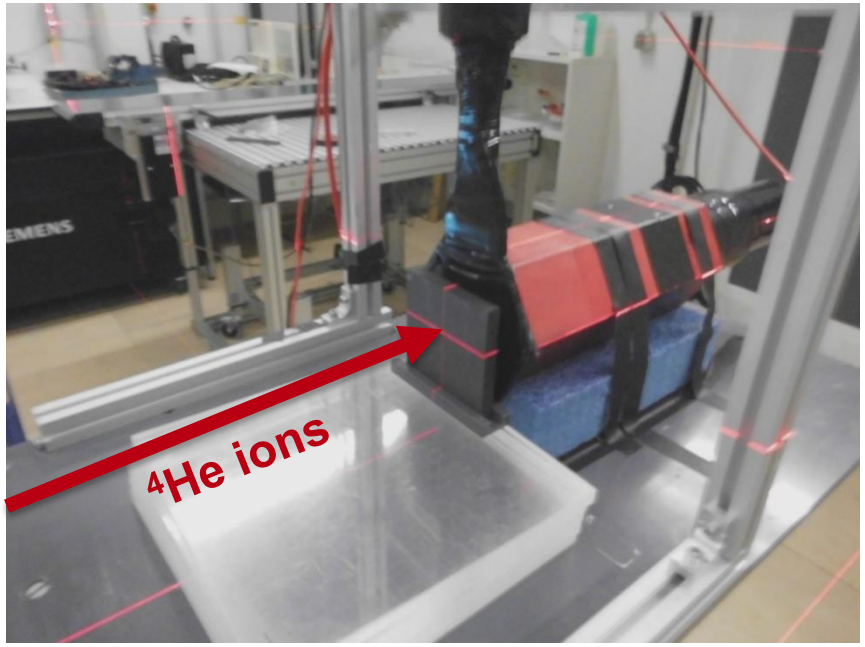


Fragmentation experiment at HIT

- A fragmentation experiment was carried out at HIT in late 2016.

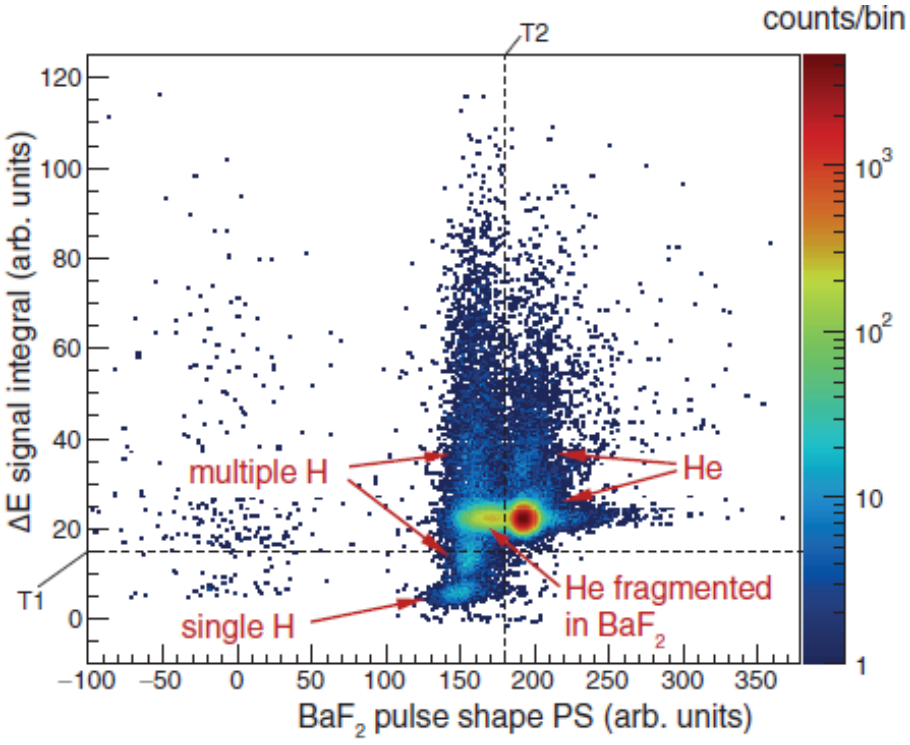
- Charge- and mass-changing cross sections for $^{4}He+^{12}C$ collisions were measured using thin graphite targets and a ΔE-E telescope

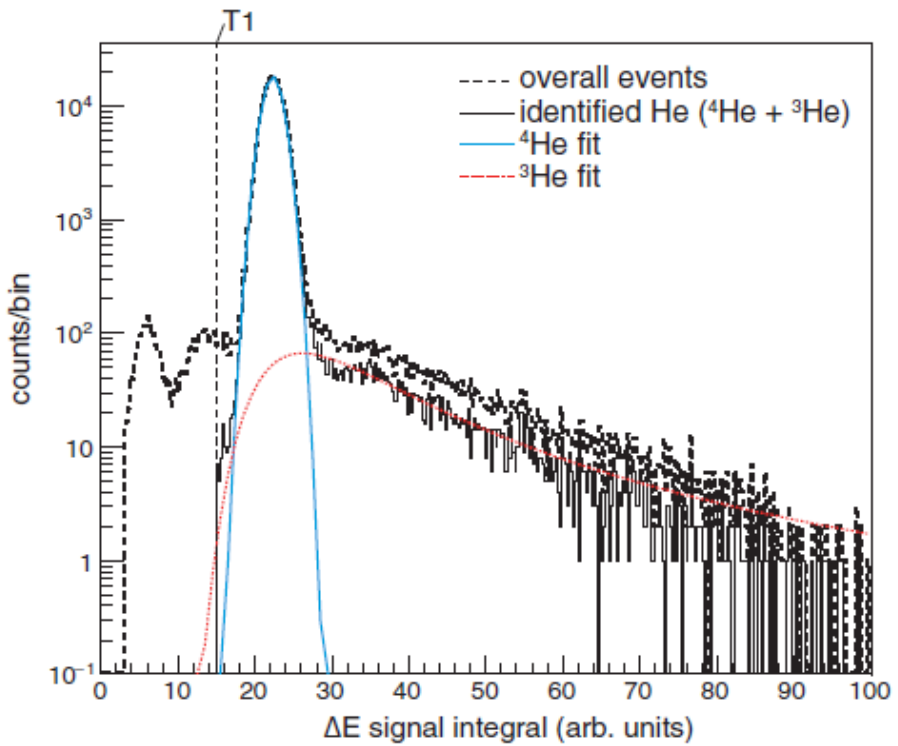




Fragmentation experiment at HIT

130 MeV/u ^{4}He ions behind 1 cm graphite

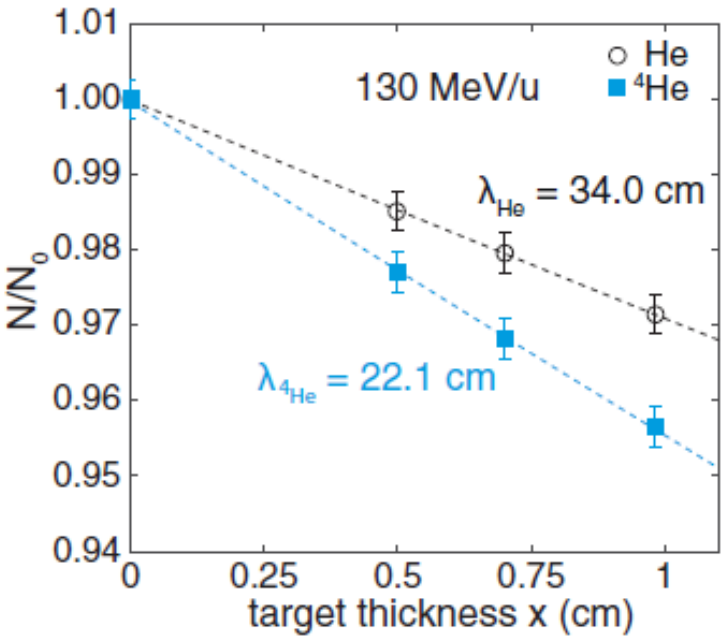




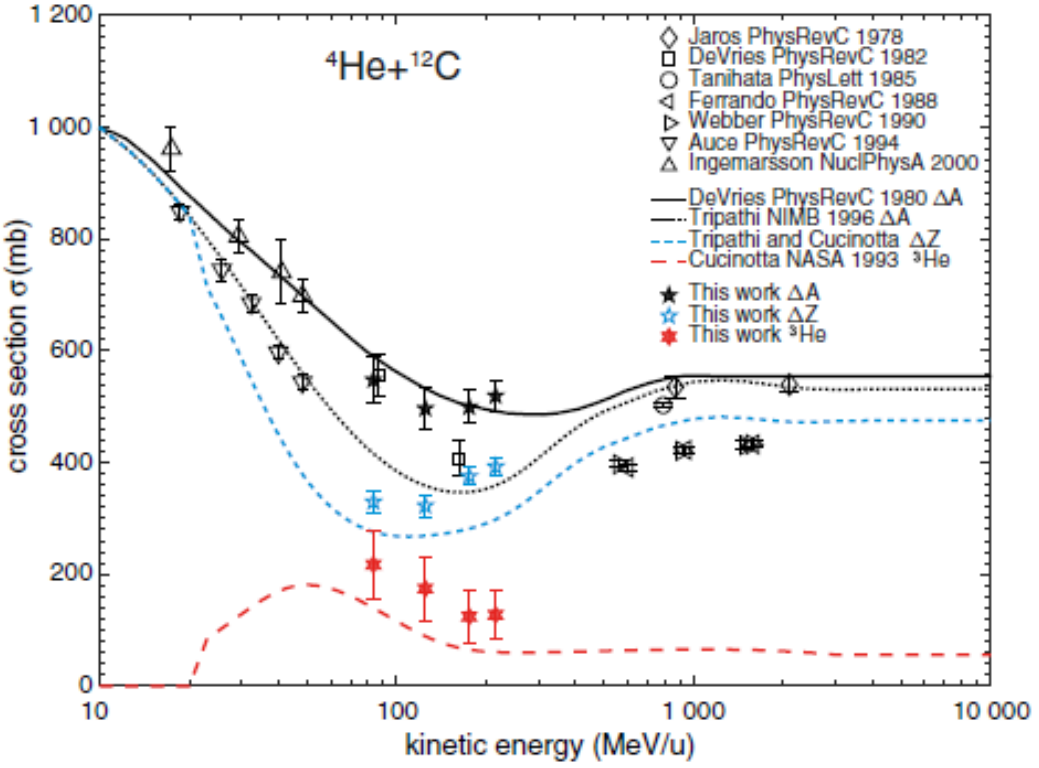
Identification of the transmitted ions and generated fragments by correlation of the detector signals and fit methods.

F. Horst et al. **Phys. Rev. C** 96 (2017)

Fragmentation experiment at HIT: Results



The primary ^{4}He fluence decreases with increasing depth due to nuclear reactions.

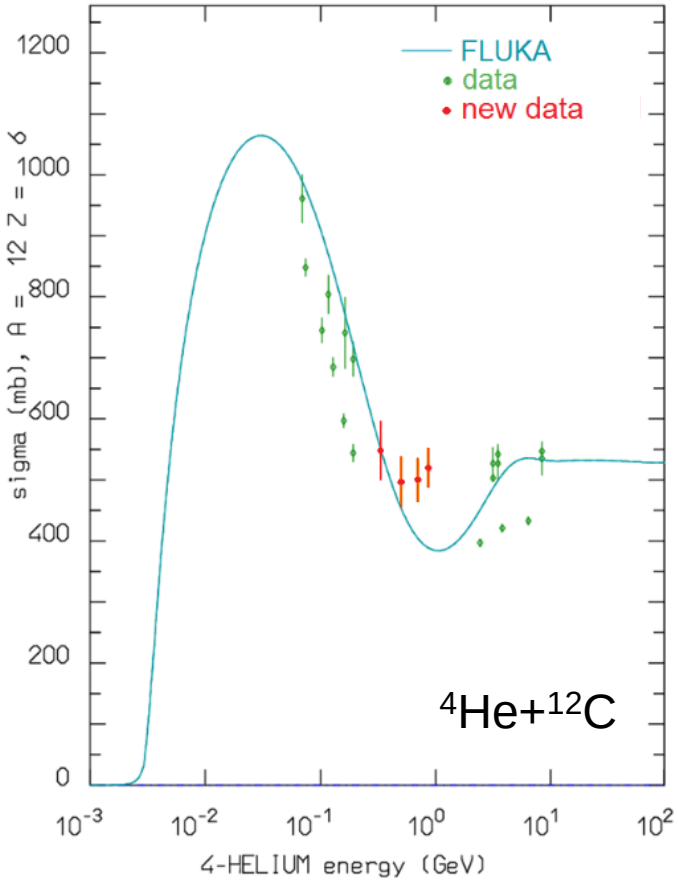


Tripathi cross section parametrization under-estimates the ^{4}He+^{12}C reaction cross section by up to 30%.

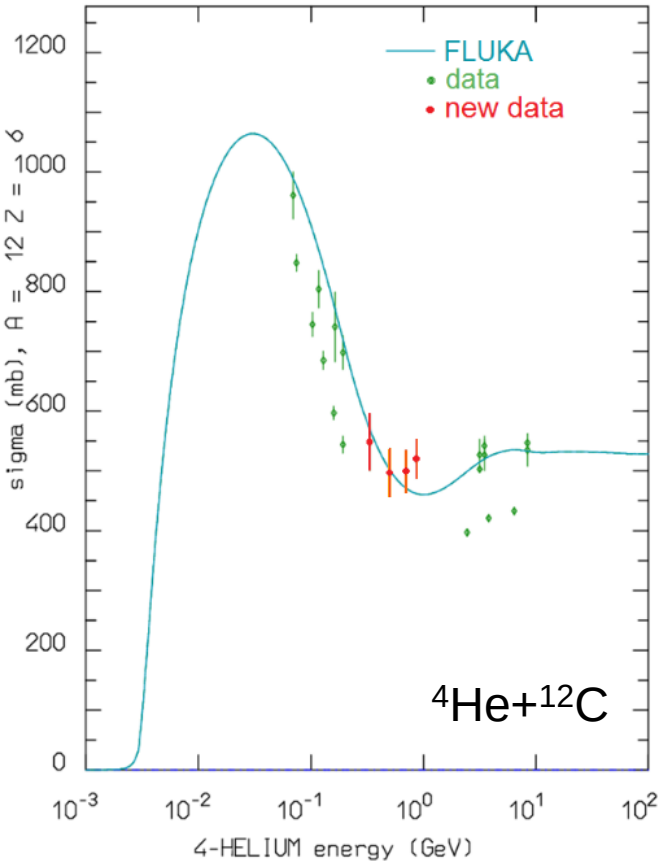
F. Horst et al. **Phys. Rev. C** 96 (2017)

^{4}He reaction cross section in FLUKA

Current FLUKA parametrization



Preliminary attempt

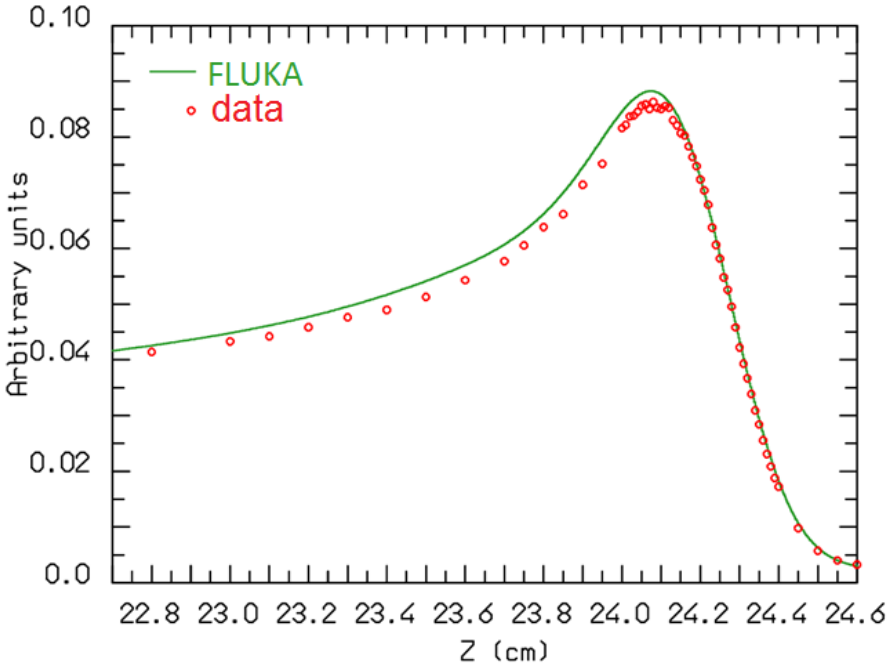


→ Extrapolation from ^{4}He+^{12}C to ^{4}He+^{16}O for dose calculations in water (H_2O) !

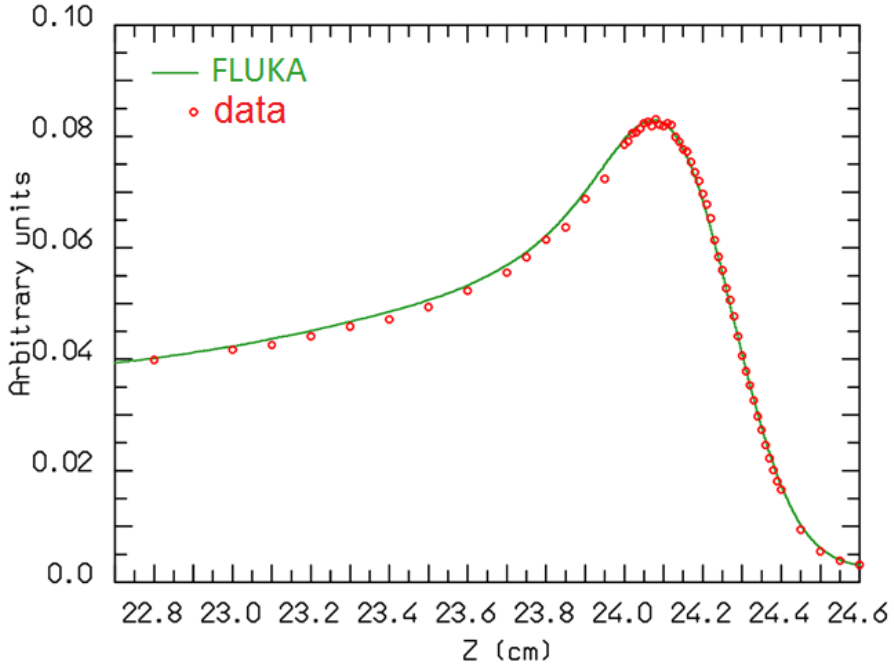
^{4}He Bragg curves using adjusted FLUKA model

Distal end of a 190 MeV/u ^{4}He Bragg curve in water calculated with the old and new cross section model vs. a measured Bragg curve:

Old model



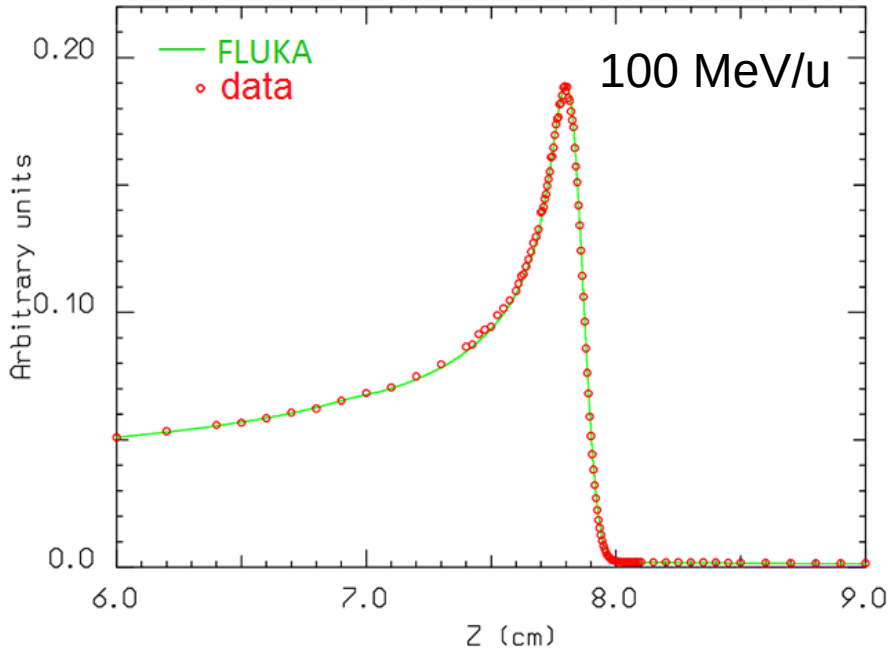
New adjusted model

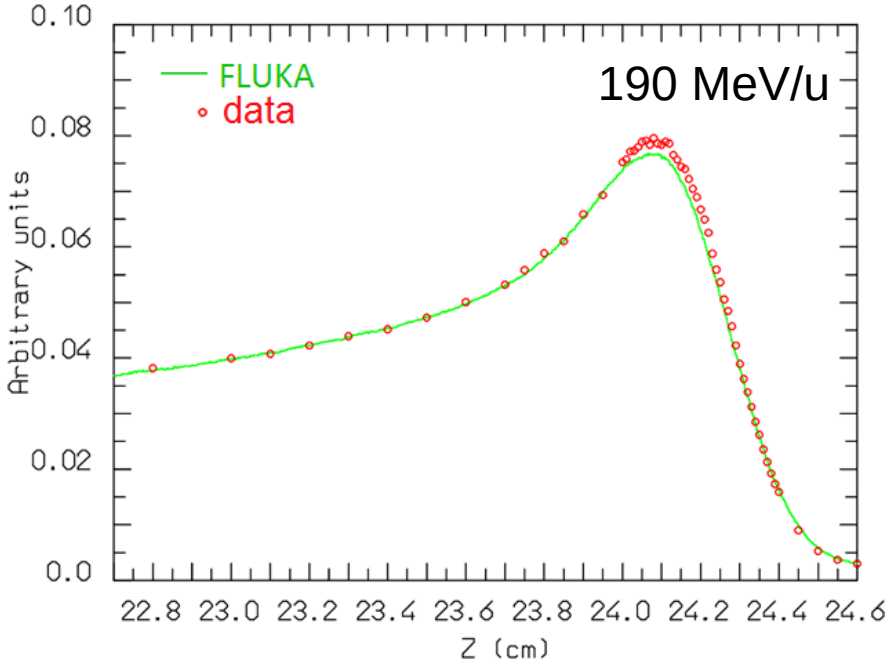


Experimental data
aquired at HIT

^{4}He Bragg curves using adjusted FLUKA model

Distal end of two ^{4}He Bragg curves in water calculated with a new cross section model also considering reactions without fragmentation of the projectile (which we did not measure in our experiment):





→ New cross section measurements on ^{16}O targets are required!

Experimental data aquired at HIT

Summary and Outlook

- Novel nuclear cross sections relevant for radiotherapy with ^{4}He ions were presented.

- Based on the new cross section data, first attempts to improve the FLUKA reaction cross section parametrization were performed. Significant effects on calculated depth dose profiles were observed.

- More experimental data in the therapeutical energy range will enable to better tune the FLUKA nuclear reaction models. Especially for dose calculation in water, cross section measurements for $^{4}He+^{16}O$ would be helpful.

- New measurements are planned to obtain cross section data for $^{4}He+^{16}O$ collisions using Si and SiO_2 targets.

Thanks for your attention !

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