Hadronic Models:
How accurate are they for ion therapy?

Investigating the accuracy of hadronic models for ion therapy

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Outline

Relevance of Hadronic Models for HT
Scope of the Comparison
Details of the Experiment and Simulation
Results
Summary and Outlook

Relevance of Hadronic Models for HT

Conventional and proton therapy

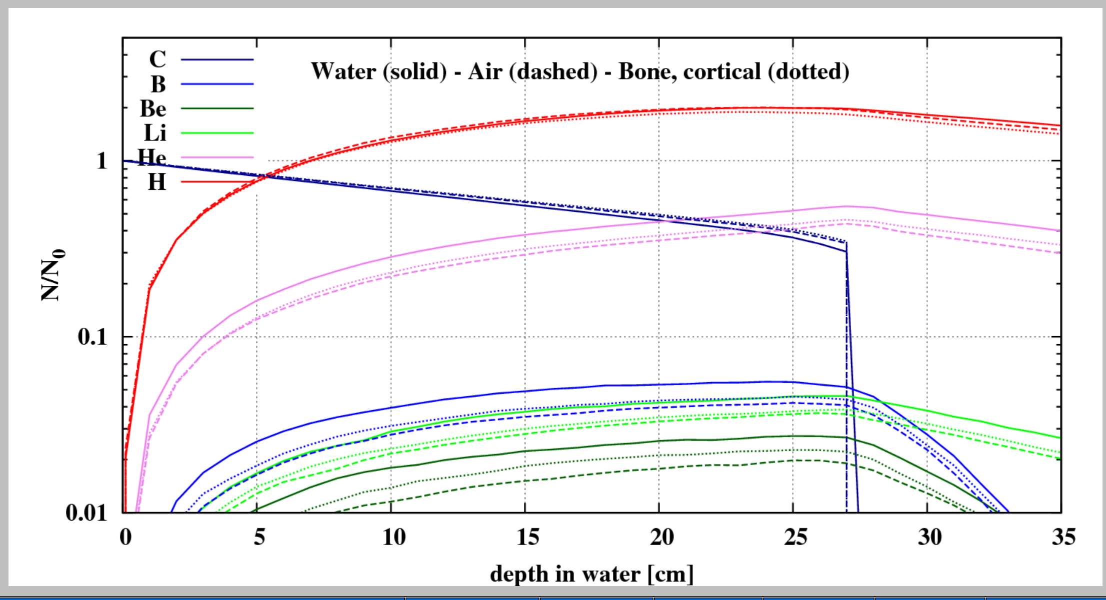
- Quality of dosimetric algorithms can be mostly assessed by its dose distributions
- Hadronic interactions introduce for proton therapy changes of some %GyE

Ion therapy

Additional complexity:

- Significant dependence of biologic effectiveness on LET
- Mixed radiation fields due to projectile fragmentation inside patient

400MeV/n C on water and bone



H2O at 25 cm	H	He	Li	Be	B	C
Dose fraction [%]	12.3	7.3	1.4	1.8	5.9	71.3

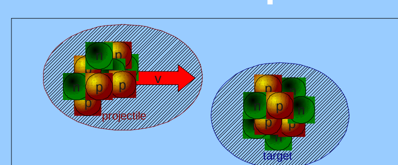
MC Codes for Hadron Therapy

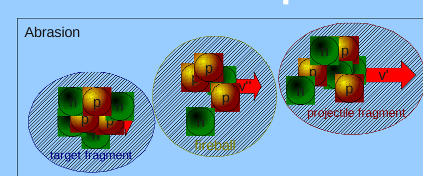
Applications of MC codes in ion therapy:

- (Pre-)treatment verification of analytic treatment planning systems (TPS)
- Database generation for analytic TPS (see talk G. Russo)
- Online/offline monitoring of dose delivery with PET
- ...

A key requirement of MC codes:

Accurate description of hadronic processes





Scope of the Validation

Presented comparison:

- Integral check for hadronic models
- Regime relevant for carbon therapy

Experiment: (Haettner 2006 [1,2], GSI)

- Thick-target experiment, 400MeV/u carbon on water
- Data types:
  - Integral charged fragment fluences over depth
  - Double-differential charged fragment fluences

Geant 4

Fair comparisons:

- Same conditions: geometry, materials, scoring, post analysis
- most suitable physics models/configurations

FLUKA

Thanks to:
V Ivantchenko, G Folger, J-M Quesada, A Ferrari !

Code Versions and Hadronic Models

Geant 4

Physics settings:

EM physics

- G4EmStandardPhysics_option3
- δ-ray prod. and transport cuts: 1mm

Hadronic physics

- QGSP_BIC_HP (recommended for HT)
  - using Tripathi light, Tripati, and Shen
- 2 Modes: G4BinaryLightIon <-> G4QMD
- G4RadioactiveDecayPhysics

De-excitation models added optionally:

- G4StatMF, G4FermiBreakUp, and “Hybrid”-Evaporation

Version: 9.3 beta01, including most recent improvements in G4FermiBreakUp and G4StatMF models and some bug fixes (9.3ref07, and more)

Recent changes: 9.2 -> 9.3

Significant improvement concerning:

- step-size dependence of final range (improved interpolation of stopping power-tables)
- bug fix slowing down simulations
- improvements of de-excitation models (J-M Quesada)
- new "Hybrid" option for evaporation (V Ivantchenko):G4Evaporation (Z<3, A<5)+G4GEM (2<Z<13,4<A,29)

FLUKA

Version: 2008.3

Physics settings:

Using “HADROTHErapy” setting

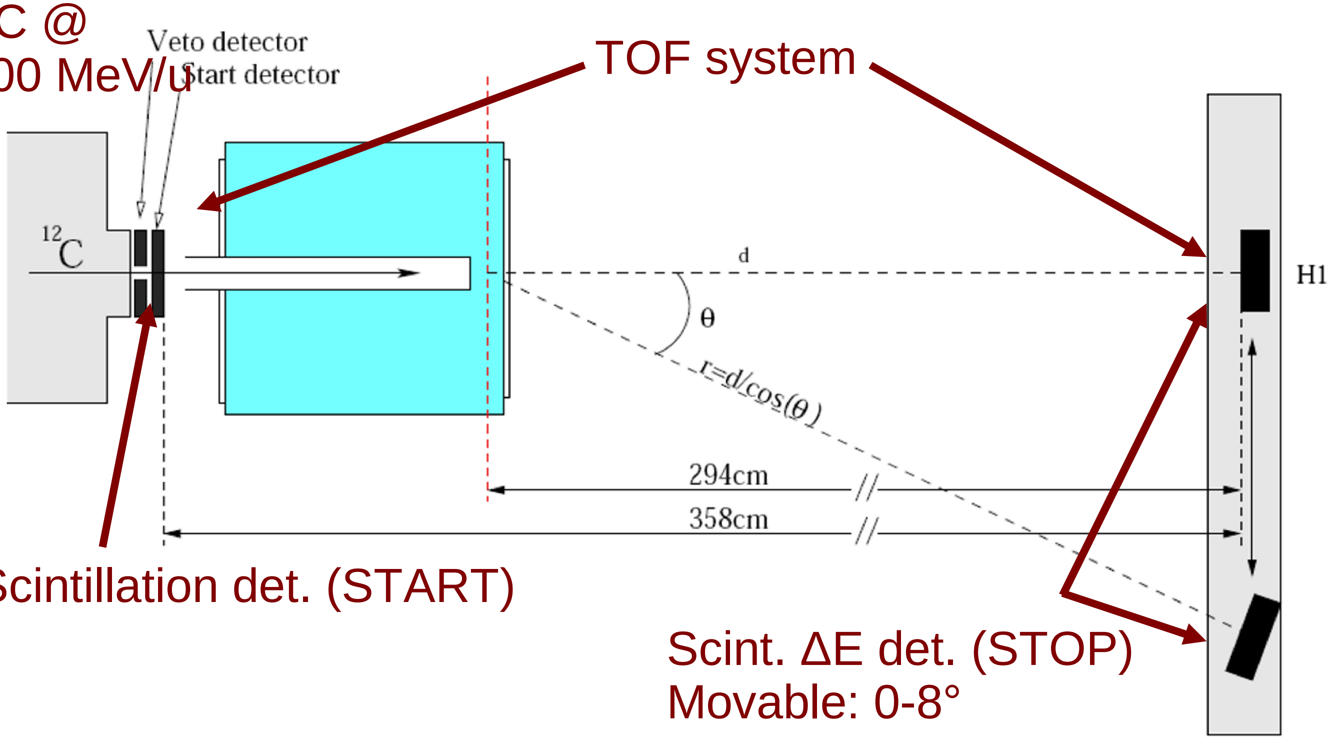
δ-ray prod. and transport cuts: 100keV

rQMD3.0>100MeV/n>BME, evaporation/fission/fragm. module

Details of the Experimental Set-up

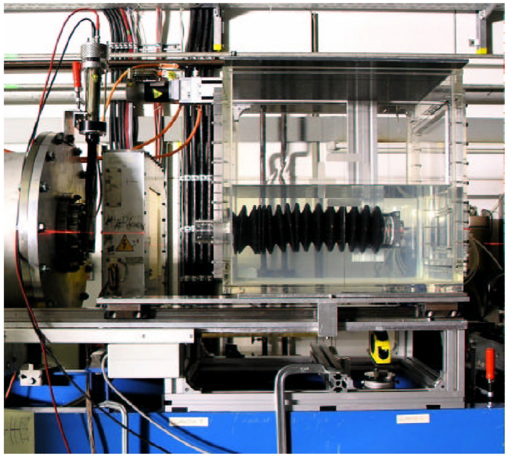
^{12}C @
400 MeV/u

TOF system



Scintillation det. (START)

Scint. ΔE det. (STOP)
Movable: 0-8°



Variable water column
Thickness: 6 -35cm

Source: [1]

Particle identification: TOF-ΔE plots
Particle energy: by TOF:

$$T(t)=\left(\frac{1}{\sqrt{1-\left(l/(ct)\right)^2}}-1\right)mc^2$$

Simulation:

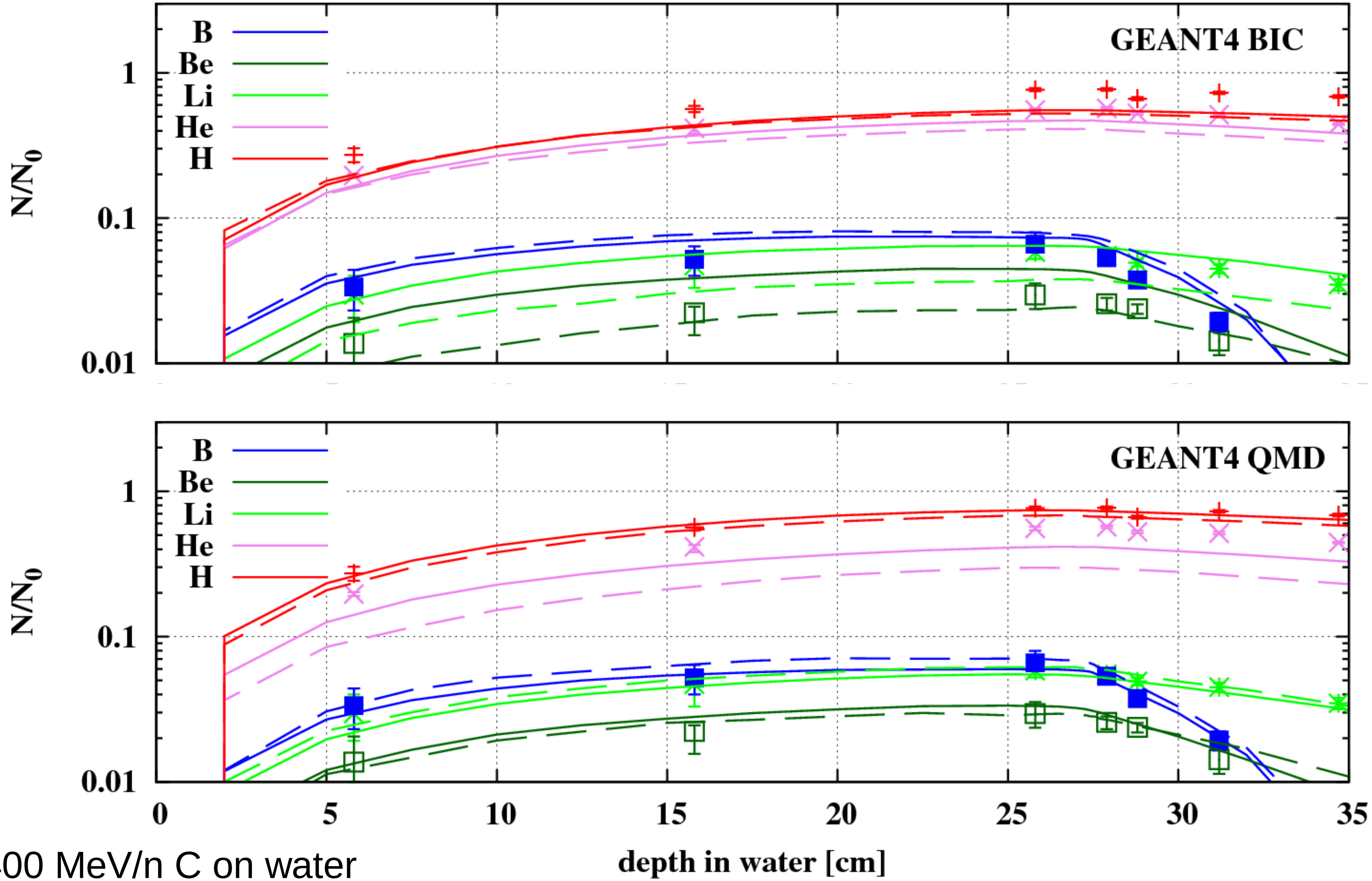
- Detailed modeling of set-up
- Reproducing TOF measurement technique (and associated errors!)

Results: Integral Fragment Yields

Build-up of secondaries

for particles with angles <10°

Points: Haettner 2006
Dashed lines: Geant4
Solid lines: G4 with Fermi Break-Up and MultiFrag



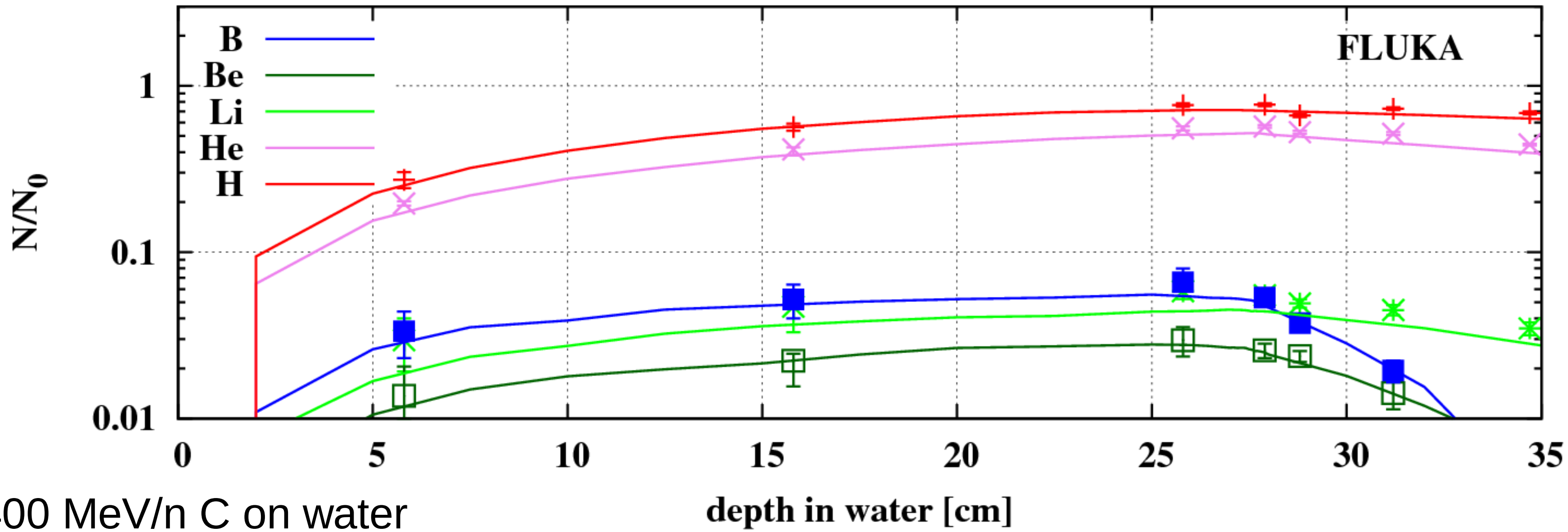
400 MeV/n C on water

Results: Integral Fragment Yields

Build-up of secondaries

for particles with angles <10°

Points: Haettner 2006
Solid lines: FLUKA



400 MeV/n C on water

Observations:

- Improvement when including Fermi Break-Up and Multifragmentation Model
  - most notably due to Fermi Break-Up
  - “Hybrid Model” yields negligible changes ~1%-scale
- BIC model: fluences of H and He underestimated max. by ~20-30%, Be o.e. 50%
- QMD model: better agreement than BIC & FLUKA, except for He (u.e ~30-40%)
- FLUKA: agreement within ~30%

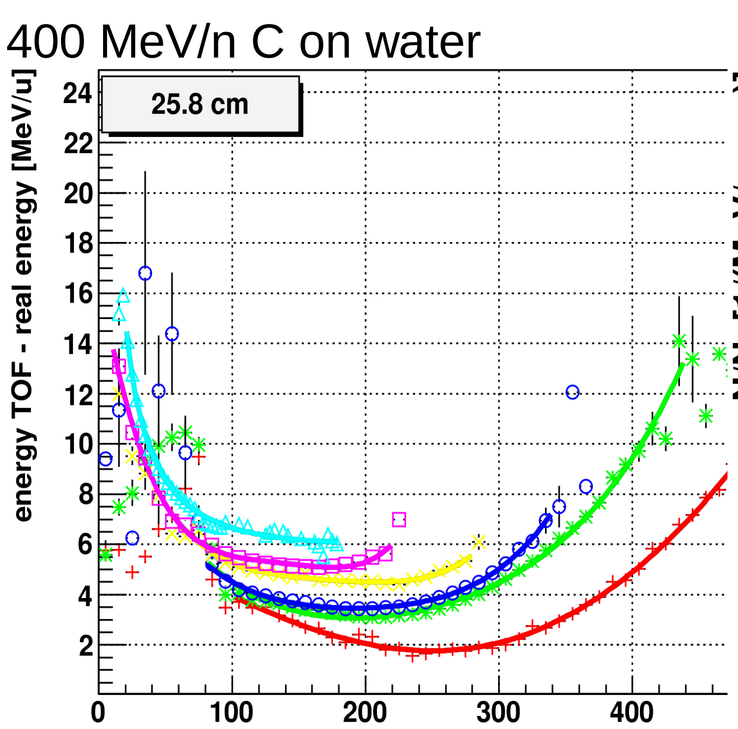
Simulating Measurement Techniques

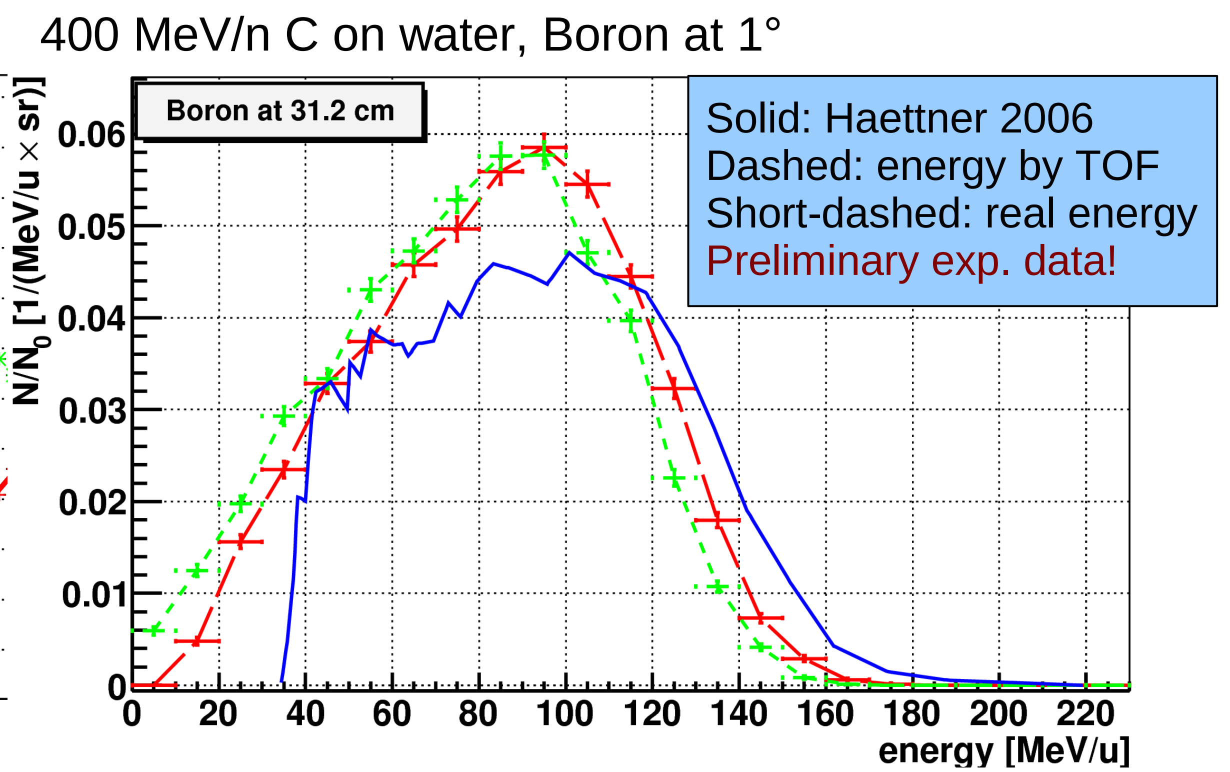
Influences of measurement uncertainties on the energy spectra:

- TOF measurement technique → reproduced by simulation
- Limited time resolution → introduced by Gaussian uncertainty

Impact on the energy spectra:

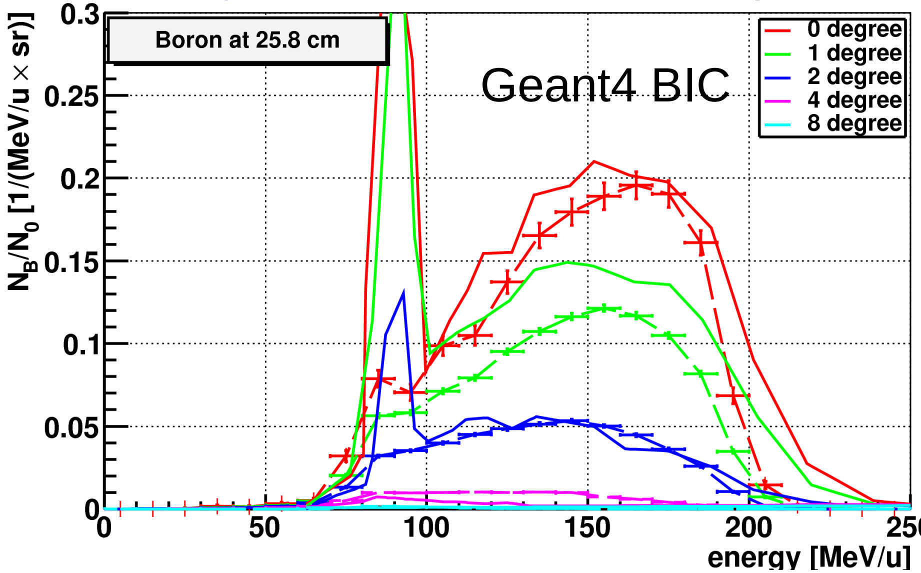
- Systematic shift of the energies by ~10MeV/u
- Slight broadening, “blurring”

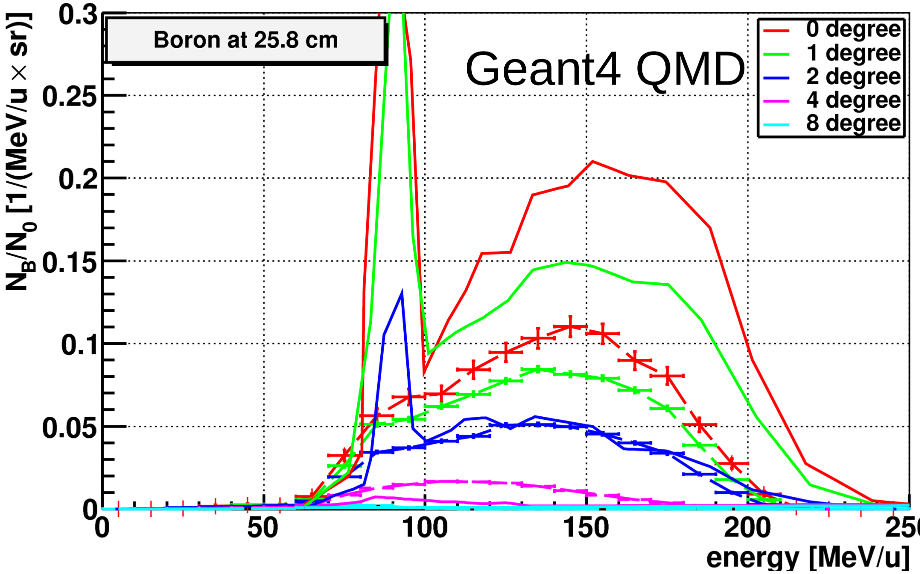


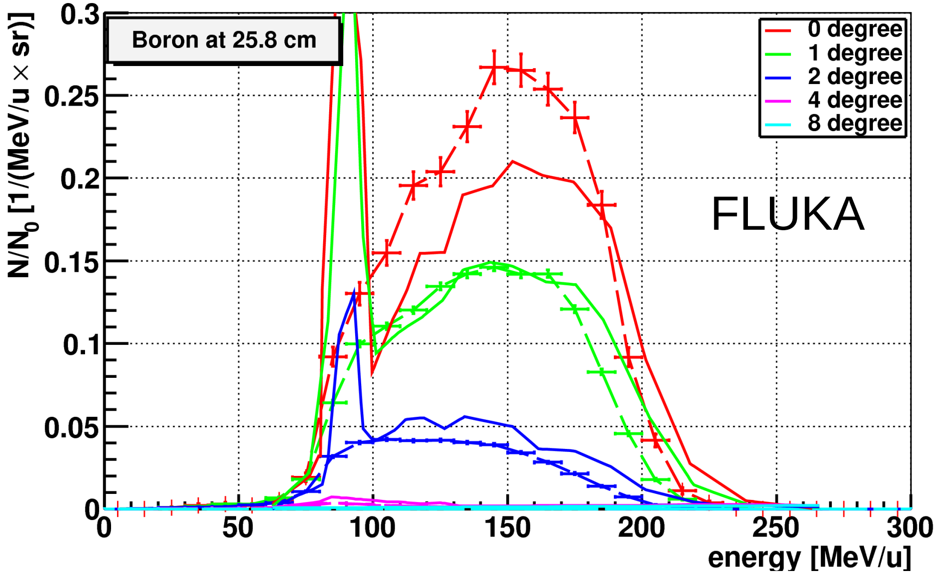


Results: Double-Differential Fluences

Boron fragments at 25.8cm WE depth for 400 MeV/n C on water

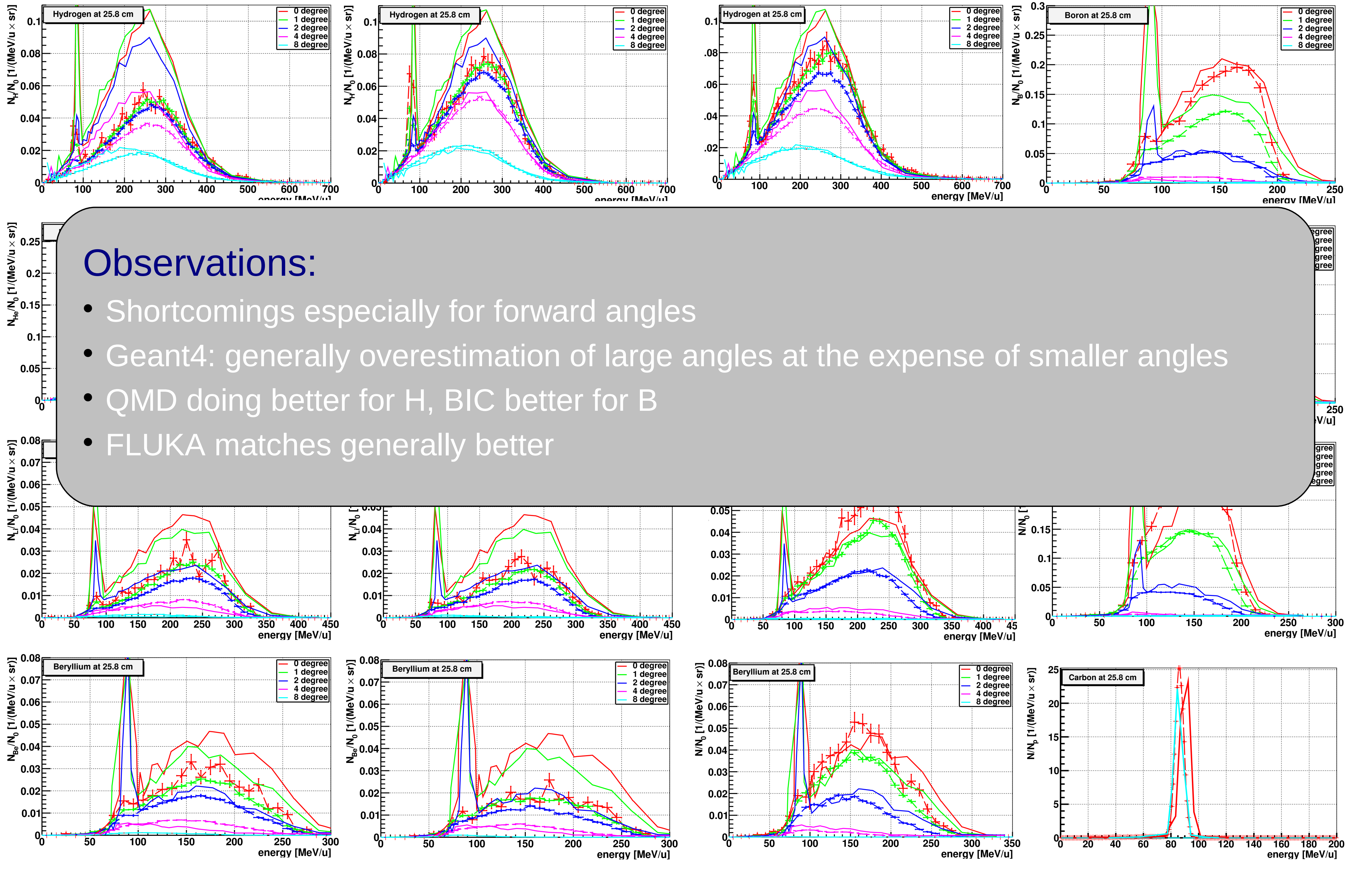






Solid: Haettner 2006
Dashed with errorbars: Simulations
Preliminary exp. data!

Results: Double-Differential Fluences



Observations:

- Shortcomings especially for forward angles
- Geant4: generally overestimation of large angles at the expense of smaller angles
- QMD doing better for H, BIC better for B
- FLUKA matches generally better

Summary

Fragmentation compared with Geant4 and FLUKA

- Thick-target, 400MeV/u carbon on water

Approximations in Experiment

- due to the TOF technique and limited time resolution
- introduce small corrections in energies of exp. spectra (~10MeV/n)

Agreement with experimental data reasonable

- QMD better than BIC (time factor ~2 (C on H2O))
- better agreement needed! (PET dose monitoring, …)

Recent (on-going) improvements in Geant4

- especially for de-excitation models (mainly Fermi Break-Up)
- in better shape for ion therapy applications

Outlook

Very limited experimental data for HT

- both thin- and thick-target, for validation and as input for hadronic models

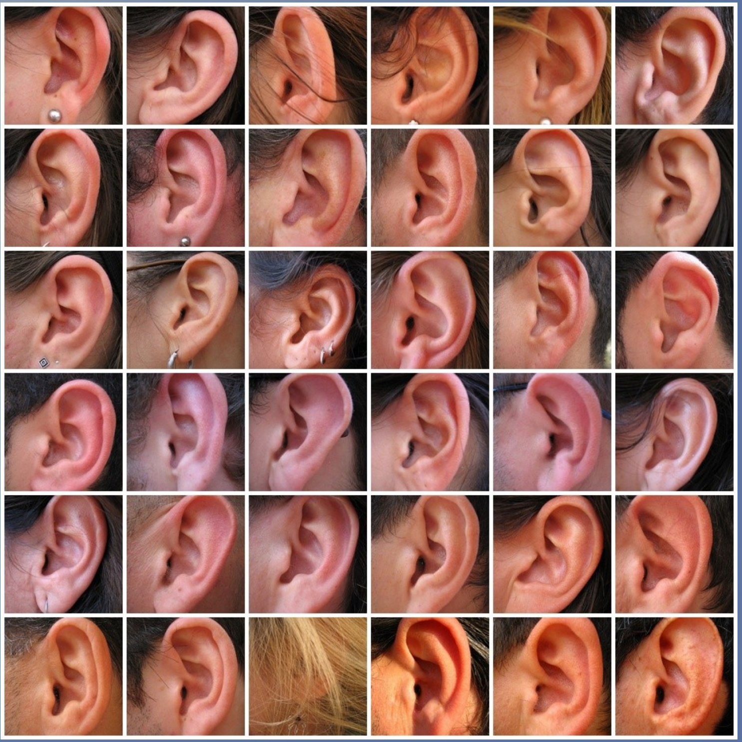
More cross-section data needed!

- for regimes relevant to ion therapy

Effort in the community under way

- LNS: up to 80AMeV (collab. with Ganil 100MeV/n), cross-sections
- HIMAC, BNL: (Benton E, Shiver L, Scampoli P), charge-changing cross-sections
- HIMAC: Emulsion Cloud Chambers (Toshito T), charge-changing cross-sections
- GSI: FIRST project, ...
- …

Thanks for attentive ...



Particle Training Network for European Radiotherapy

http://cern.ch/partner

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Bibliography

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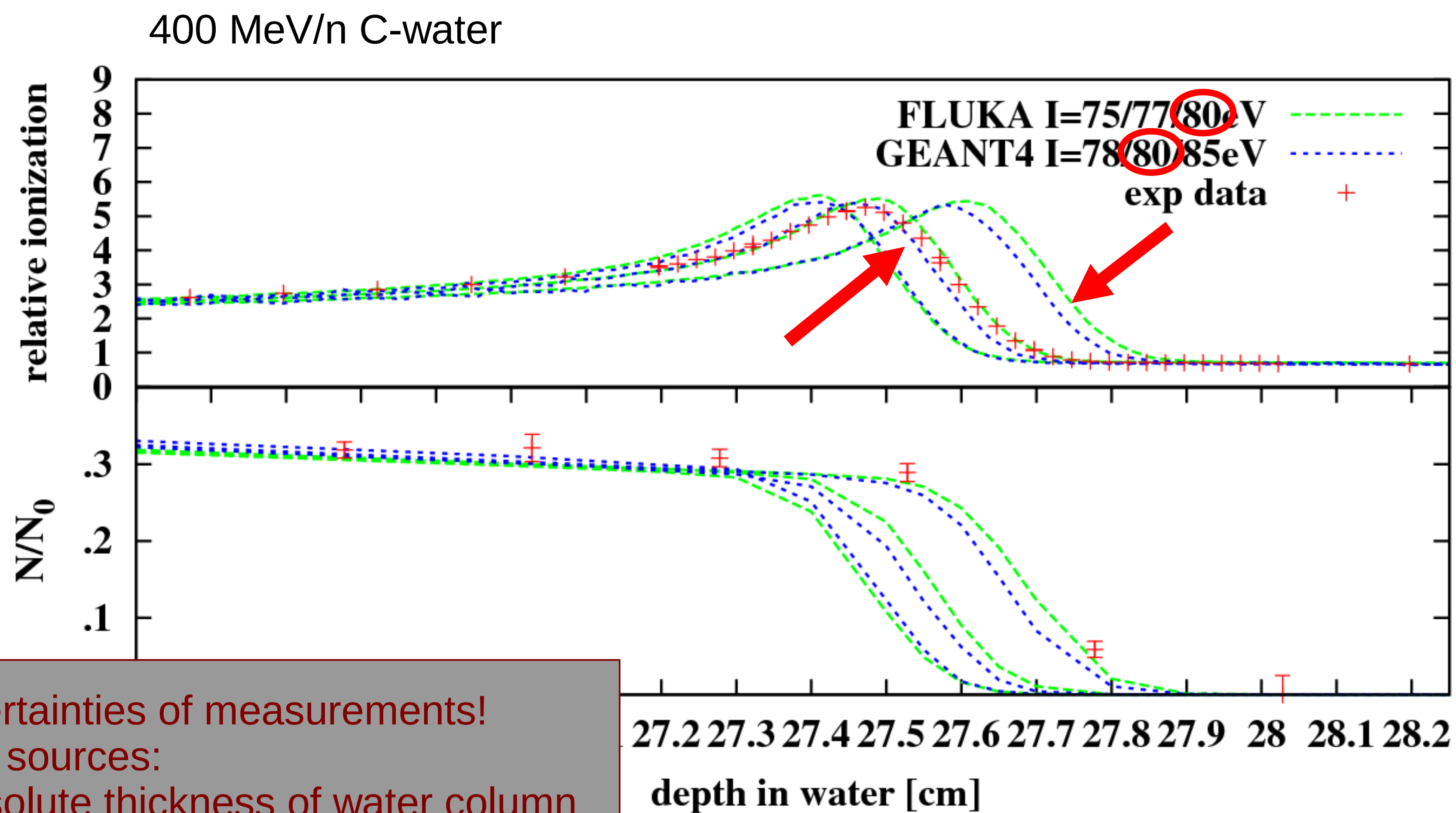
2) Haettner E et al., 2006, “EXPERIMENTAL FRAGMENTATION STUDIES WITH 12C THERAPY BEAMS”, Radiation Protection Dosimetry, Vol. 122, No. 1–4, pp. 485–487
3) Toshito T et al., 2007, “Measurements of total and partial charge-changing cross sections for 200- to 400-MeV/nucleon 12C on water and polycarbonate. Phys. Rev. C 75, 054606”
4) Toshito T et al., 2007, “Measurements of total and partial charge-changing cross sections for 200- to 400-MeV/nucleon 12C on water and polycarbonate. Phys. Rev. C 75, 054606”
5) Toshito T et al., 2008, “Measurements of projectile-like 8B and 9B production in 200-400 MeV/nucleon 12C on water”, Phys. Rev. C 78, 067602
6) INFN, 2008, “The Treatment Planning System (TPS) Project”, INFN, internal document

Adjustment of Ionization Potential (Add.)

The story with the ionization potential ...



Uncertainties of measurements!
Main sources:

- Absolute thickness of water column (+/- 0.5 mm)
- Attenuation: thickness of detector to be taken into account (WE ~13mm)

MC code comparisons (Add.)

Lateral profiles