Alpha particles produced by protons in B-11 (Geant4)

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We discuss the Geant4 prediction for alpha particle produced by 100-200 MeV protons in B-11 and medical phantoms (water, …)

Motivation

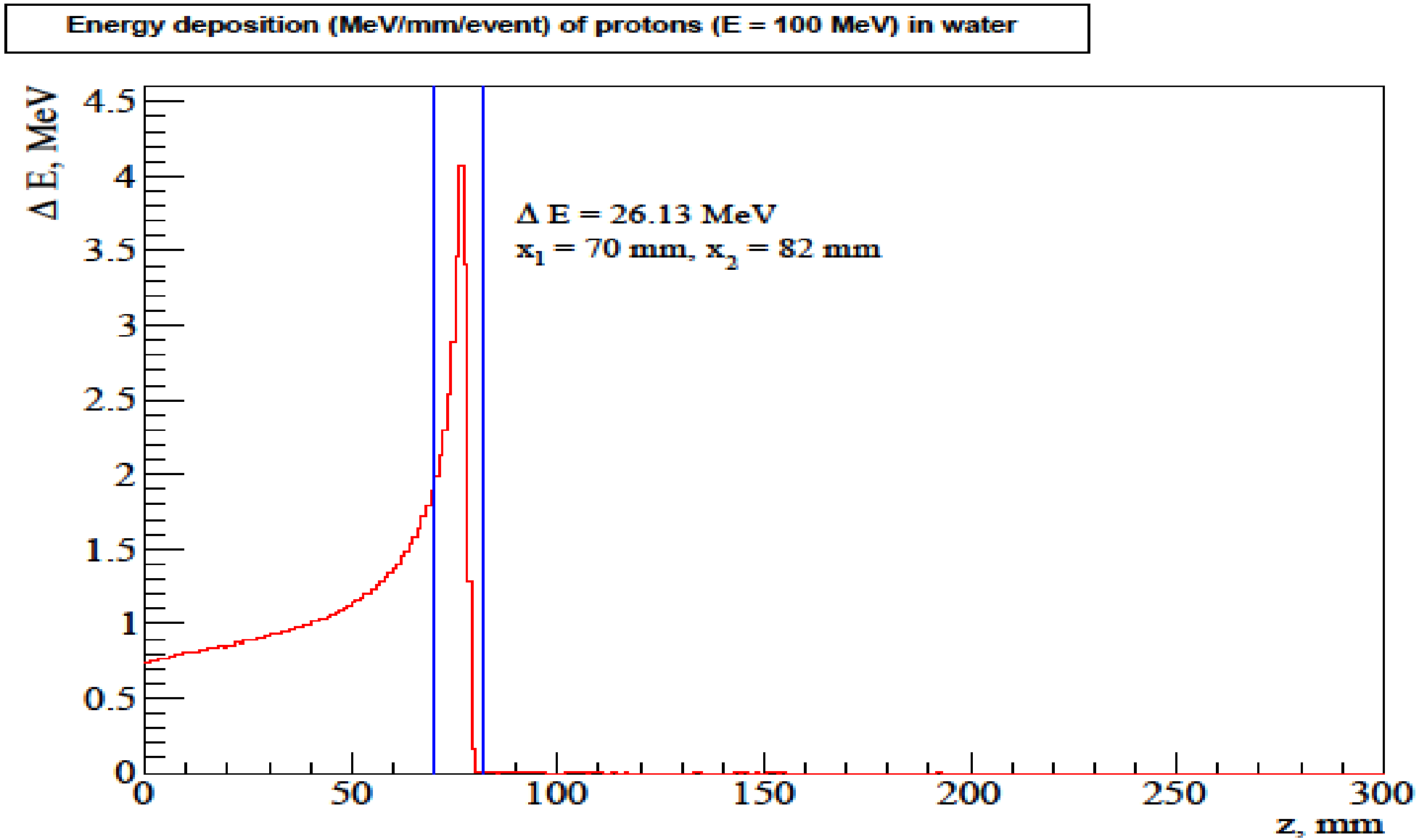
- Proton (ion) therapy is becoming more and more popular for the cancer treatment.
- It were proposed a number of methods to enrich the energy deposition in the Bragg peak, in particular to utilize,

  $p+^{11}B \rightarrow \alpha+^{8}Be^{*}$, $^{12}C^{*} \rightarrow 3\ \alpha + 8.7(9)$ MeV, reaction (INFN, Catania).
- A new Geant4 model is described for the reaction above.
- In addition, the Geant4 predictions for the alpha yield background are discussed.

It was R&D (Balakin's lab) at LPI concerning the proton accelerator for the cancer treatment (one is mounted at the Massachusetts General Hospital, Boston, USA). It is compact, efficient and reliable. The proton energy is up to ~300 MeV.

Prof Balakin near the medical phantom and the proton medical accelerator

Geant4 QBBC simulation in water showing the Bragg peak energy deposition.



New model, $p+^{11}B \rightarrow \alpha+^{8}Be^{*} \rightarrow 3\,\alpha + 8.7(9)$ MeV, in the framework of Geant4

- Integral XS is implemented according to the Catania proposal (data (?) EXFOR).
- The final state is created according the momentum and energy conservation including the binding energy of Be-8 released.
- The first emitted alpha get all the proton momentum.
- 2^{nd} and 3^{rd} alphas emitted isotropically have equal energy and opposite momenta satisfying the total energy balance.
- The model and XS are activated in the local QBBC constructor.

First experimental proof of Proton Boron Capture Therapy (PBCT) to enhance protontherapy effectiveness

G. A. P. Cirrone[1], L. Manti[2,3], D. Margarone[4], G. Petringa[1,5], L. Giuffrida[4], A. Minopoli[2], A. Picciotto[6], G. Russo[7,1], F. Cammarata[7,1], P. Pisciotta[1,5], F. M. Perozziello[2,3], F. Romano[8,1], V. Marchese[1], G. Milluzzo[1,5], V. Scuderi[1,4], G. Cuttone[1] & G. Korn[4]

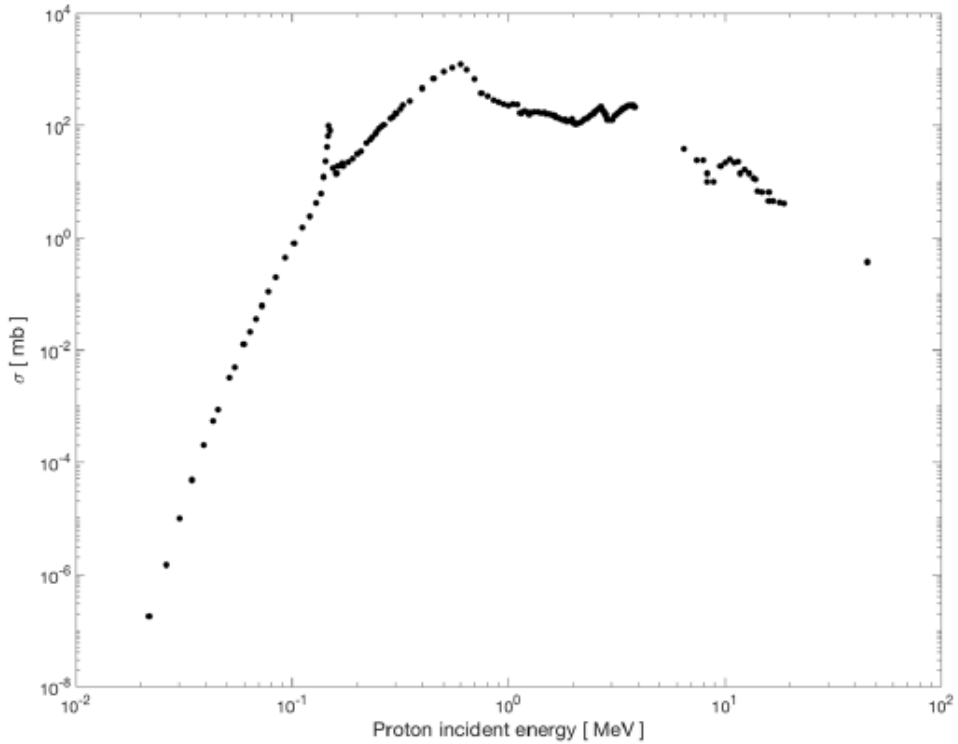
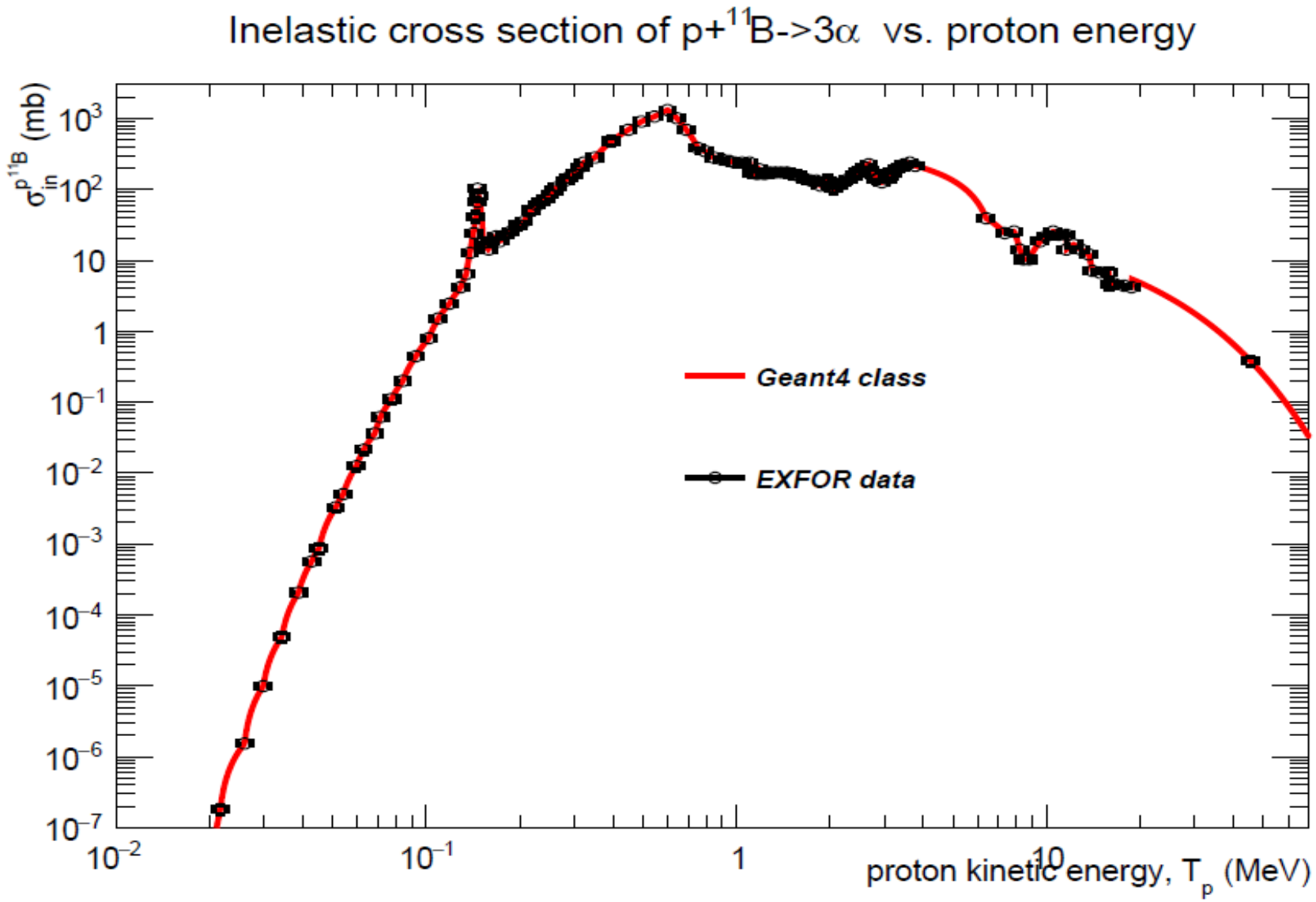
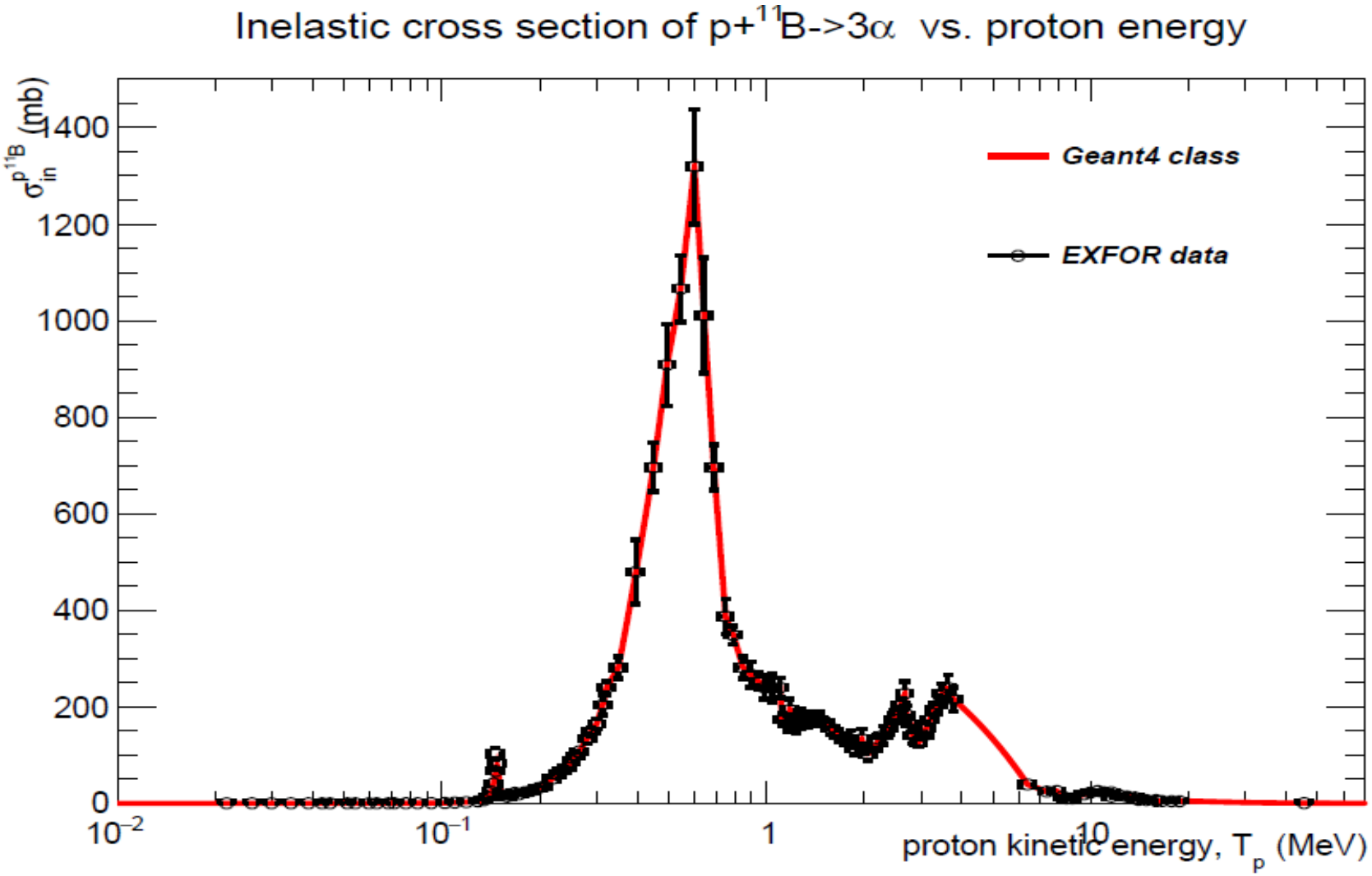
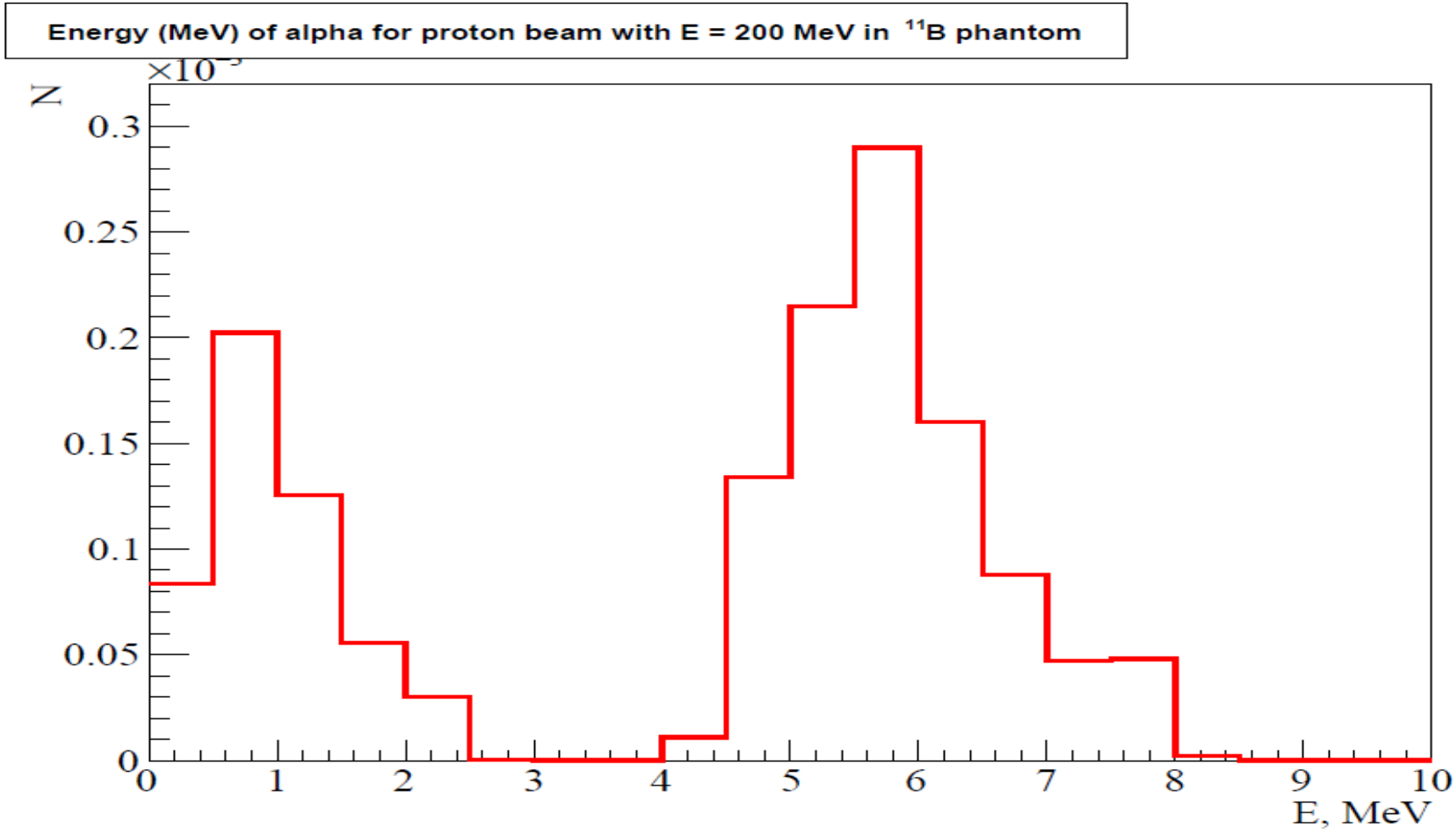


Figure 8. Experimental cross sections. Proton-^{11}B total reaction cross section for the most probable α_1 channel decay (from EXFOR database).

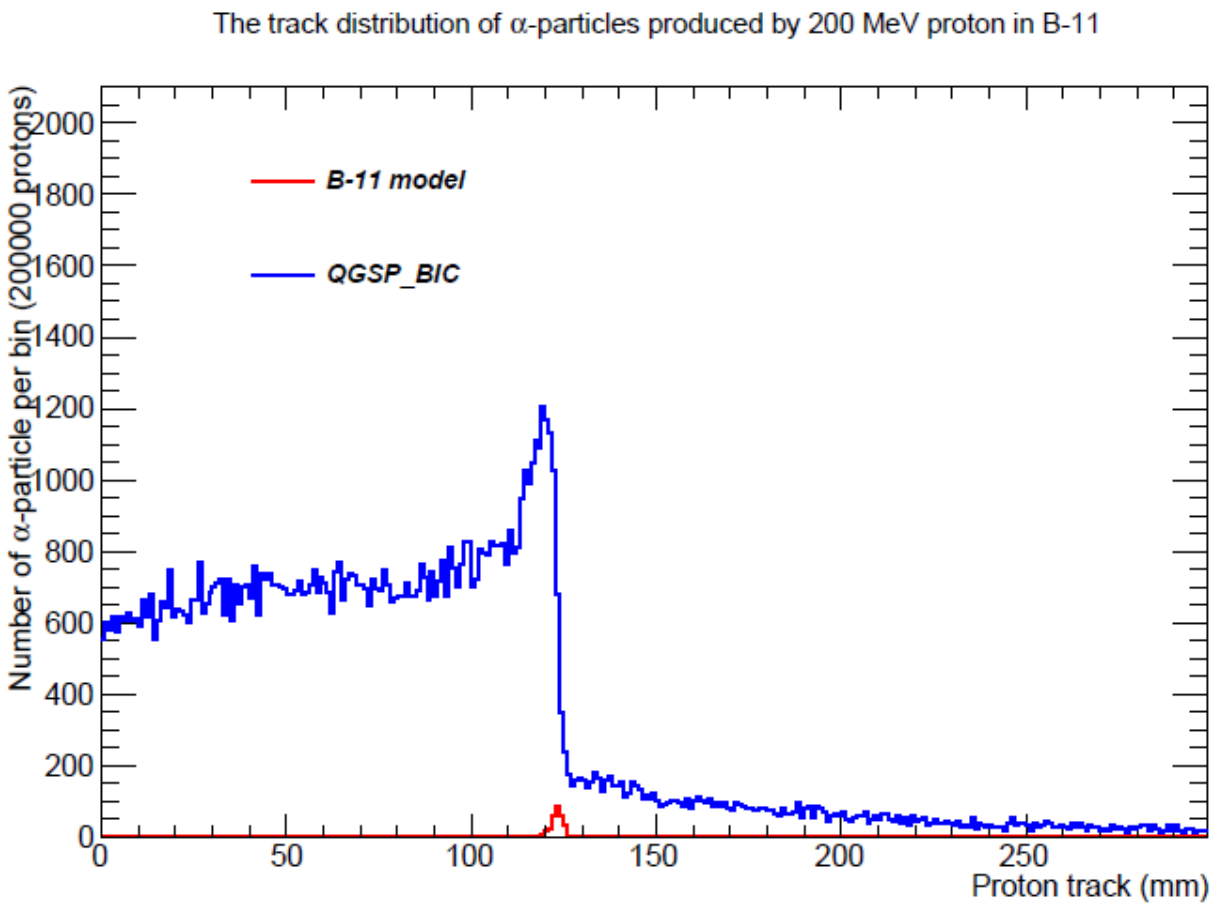

Inelastic cross section of p+11B->3α vs. proton energy
σ in p 11B (mb)
10^3
10^2
10
1
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-2
10^-1
1
10
proton kinetic energy, T p (MeV)
Geant4 class
EXFOR data


Inelastic cross section of p+^{11}B->3α vs. proton energy
$\sigma_{in}^{p^{11}B}$ (mb)
1400
1200
1000
800
600
400
200
0
10^{-2}
10^{-1}
1
10
proton kinetic energy, T_p (MeV)
Geant4 class
EXFOR data

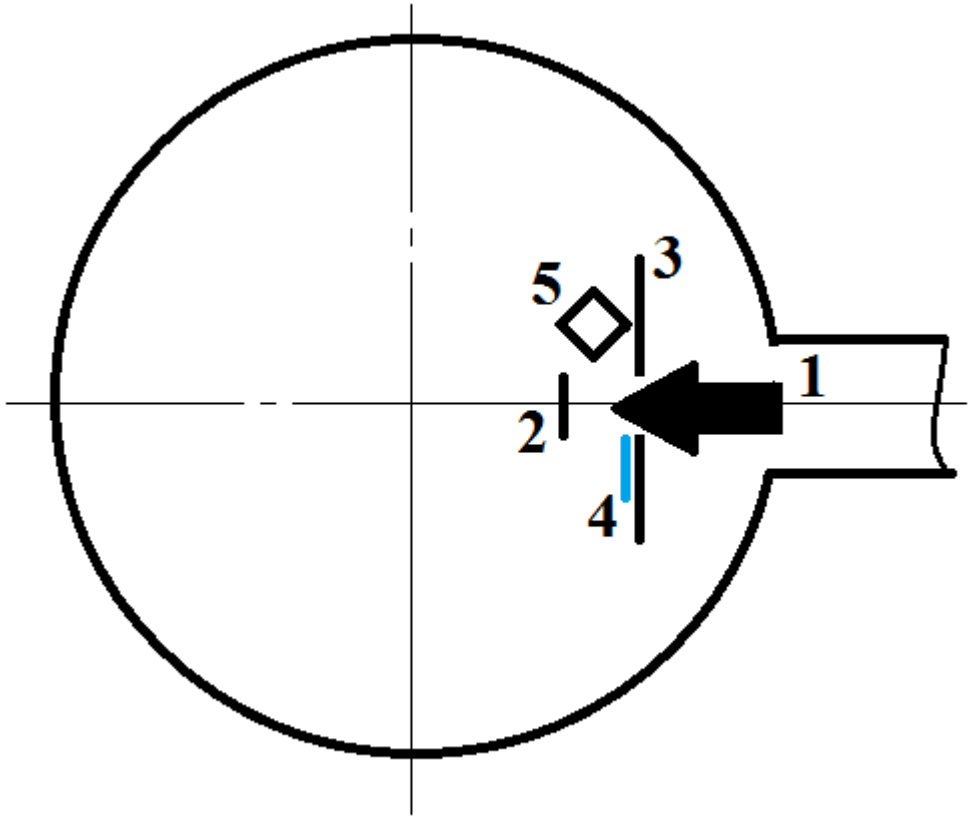
The alpha particle spectrum according to the model in B-11
(the integral output is about 0.015 alpha/proton at the natural density 2.34 g/cm3)



The alpha output in the limits of the model activity from the G4 cascade is about 30 times bigger



The experimental vacuum set-up sketch:
1 – 1 MeV proton beam,
2 – natural boron target,
3 – collimator,
4 – tracking detector (CR39),
5 – Si detector.
Preliminary (unpublished) experimental yield is 2.8x10-5 alpha/proton to the rear semi sphere (the model – 2.2x10-5). The difference is about 35-40%. And about 25 times less than the Geant4 cascade alpha yield



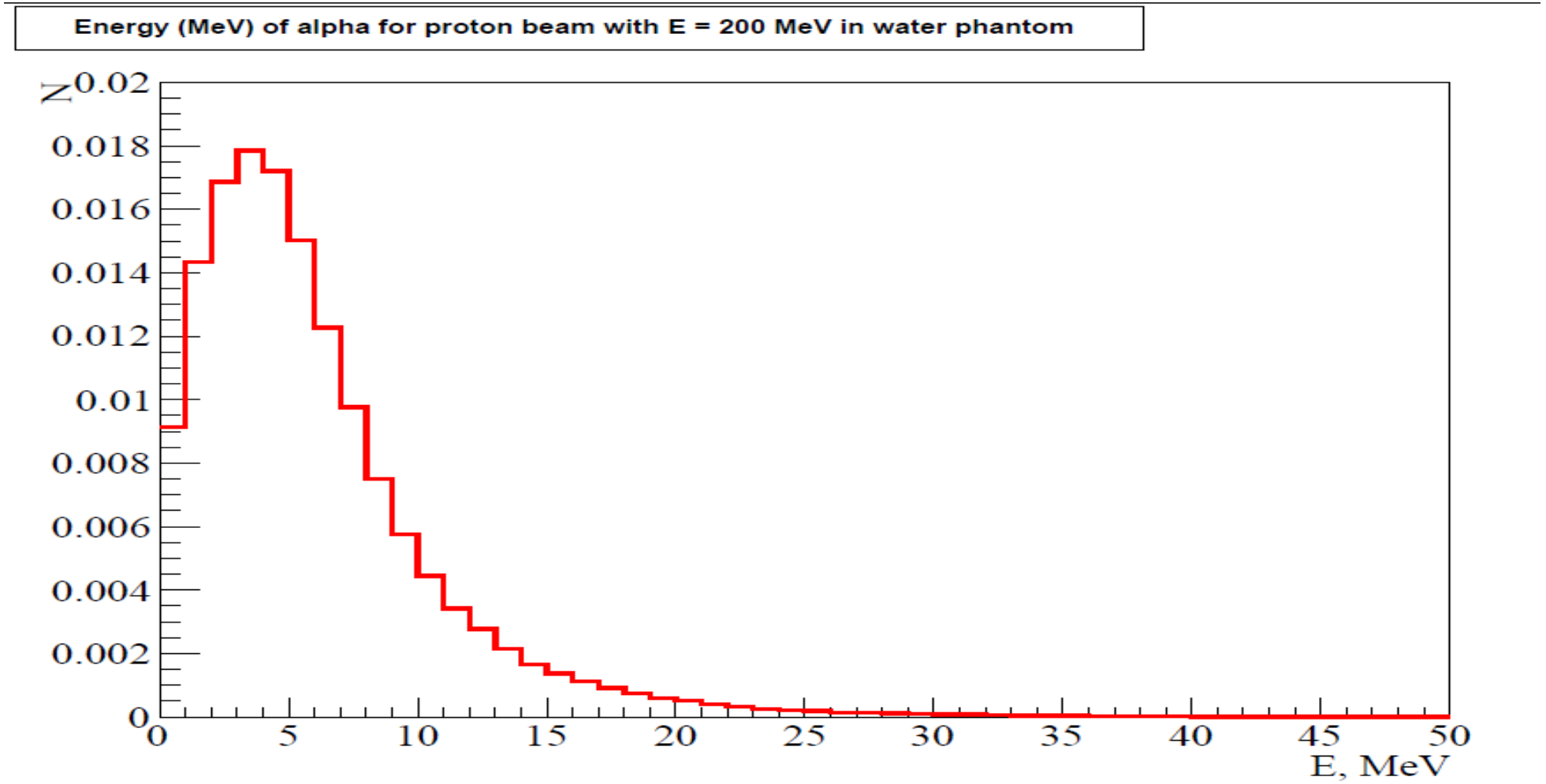
Discussion

- According to the Geant4 cascades 100-200 MeV protons produce remarkable amount of alpha particles (much more in total compared with special model for B-11).
- It looks like the Geant4 nuclear evaporation is responsible for that (?).
- Any additional experimental data?

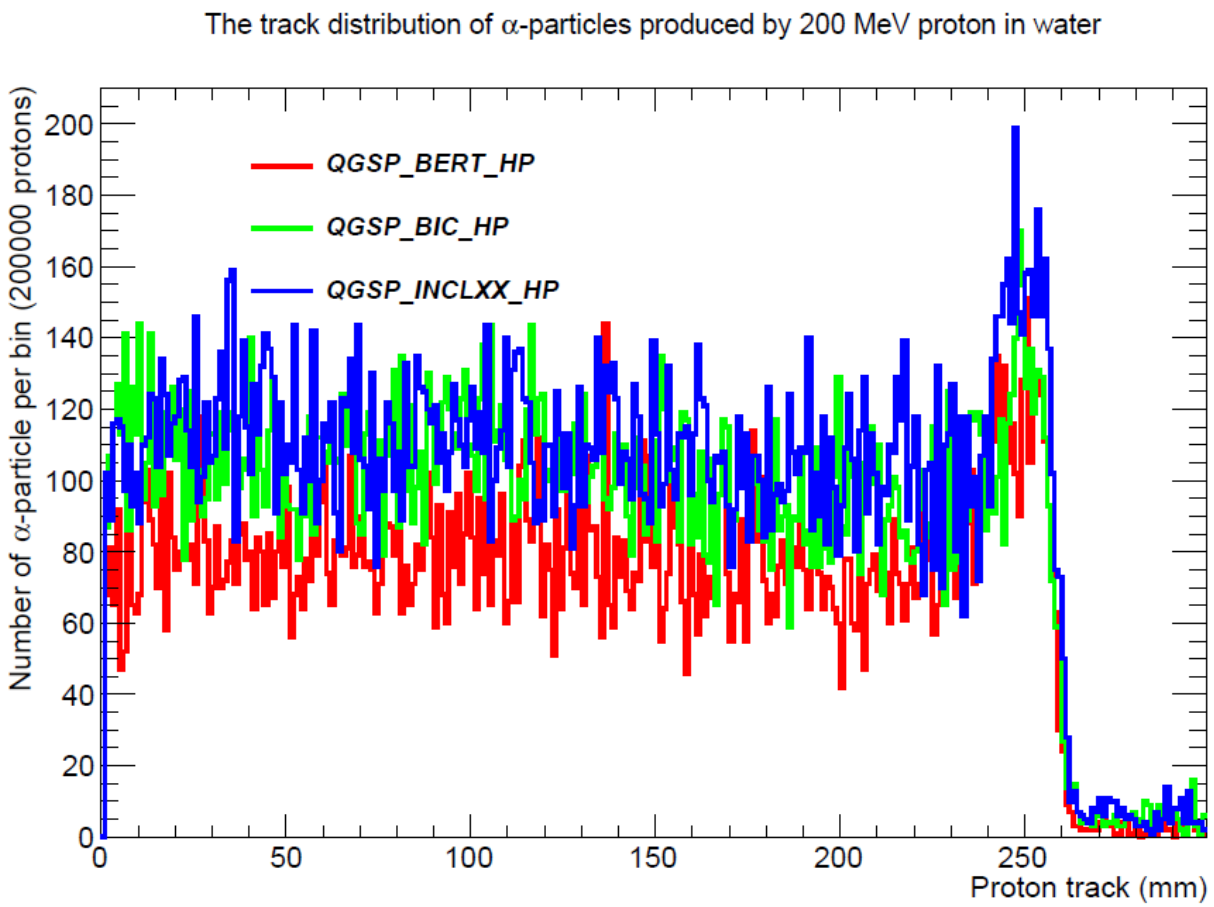
Thank you

Back-up slides

Alpha particle spectrum produced by 200 MeV protons in water (~0.15 alpha by 1 proton over all track), inelastic of primary proton -76% , radioactive decay -17%, and inelastic of secondary neutrons - 7%



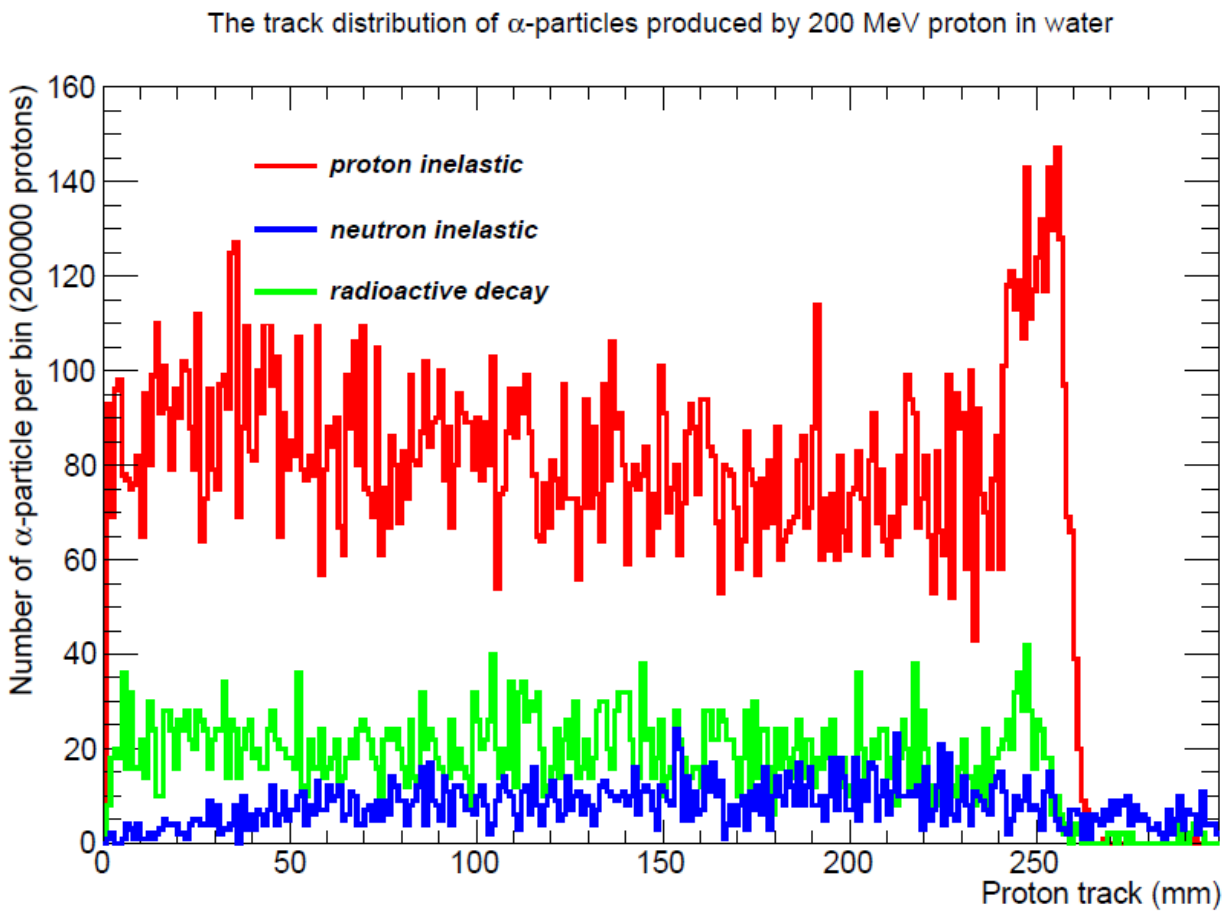
Alpha particle production along 200 MeV proton in water track (hadronic cascade comparison, BERT, BIC, INCLXX)



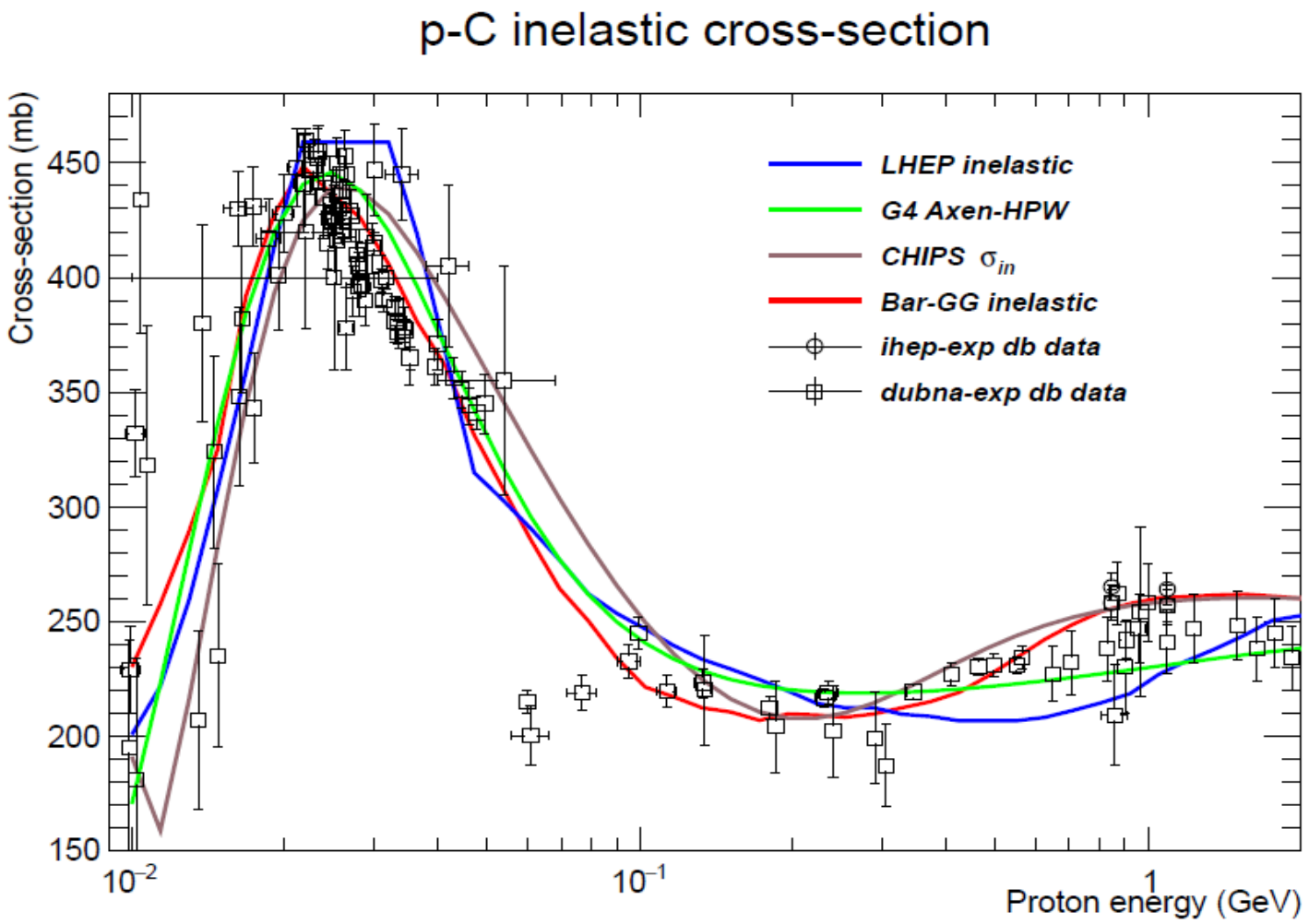
Relative number (%) of alpha particle produced by 200 MeV proton in water for different cascades

Physics list	QGSP_BIC_HP	QGSP_BERT_HP	QGSP_INCLXX_HP
Proton inelastic	76	71	75
Neutron inelastic	7	6	8
Radioactive decay	17	23	17
Alpha particle yield by 1 proton	0.15	0.1	0.17

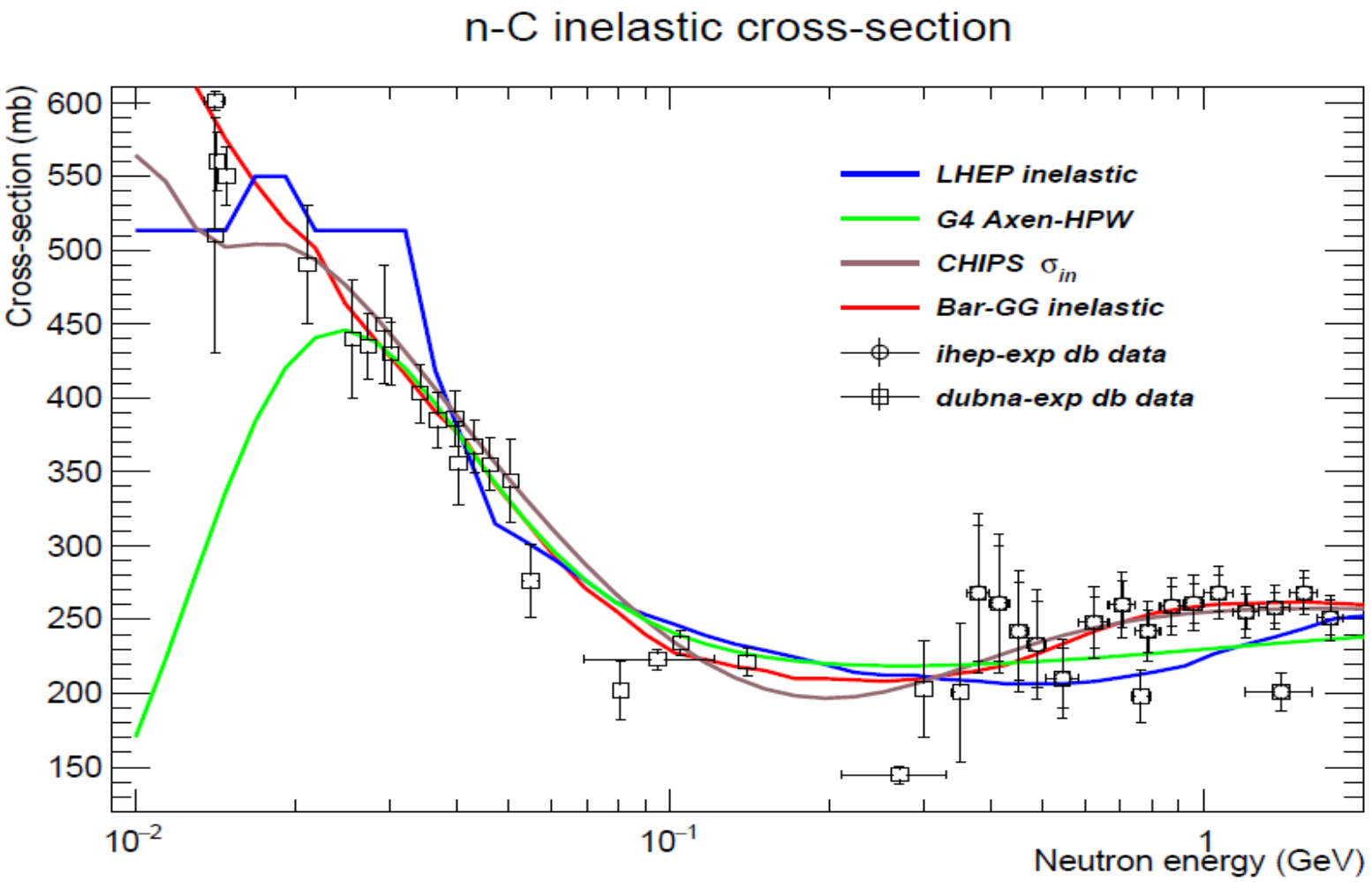
Alpha particle production along 200 MeV proton track (different processes)



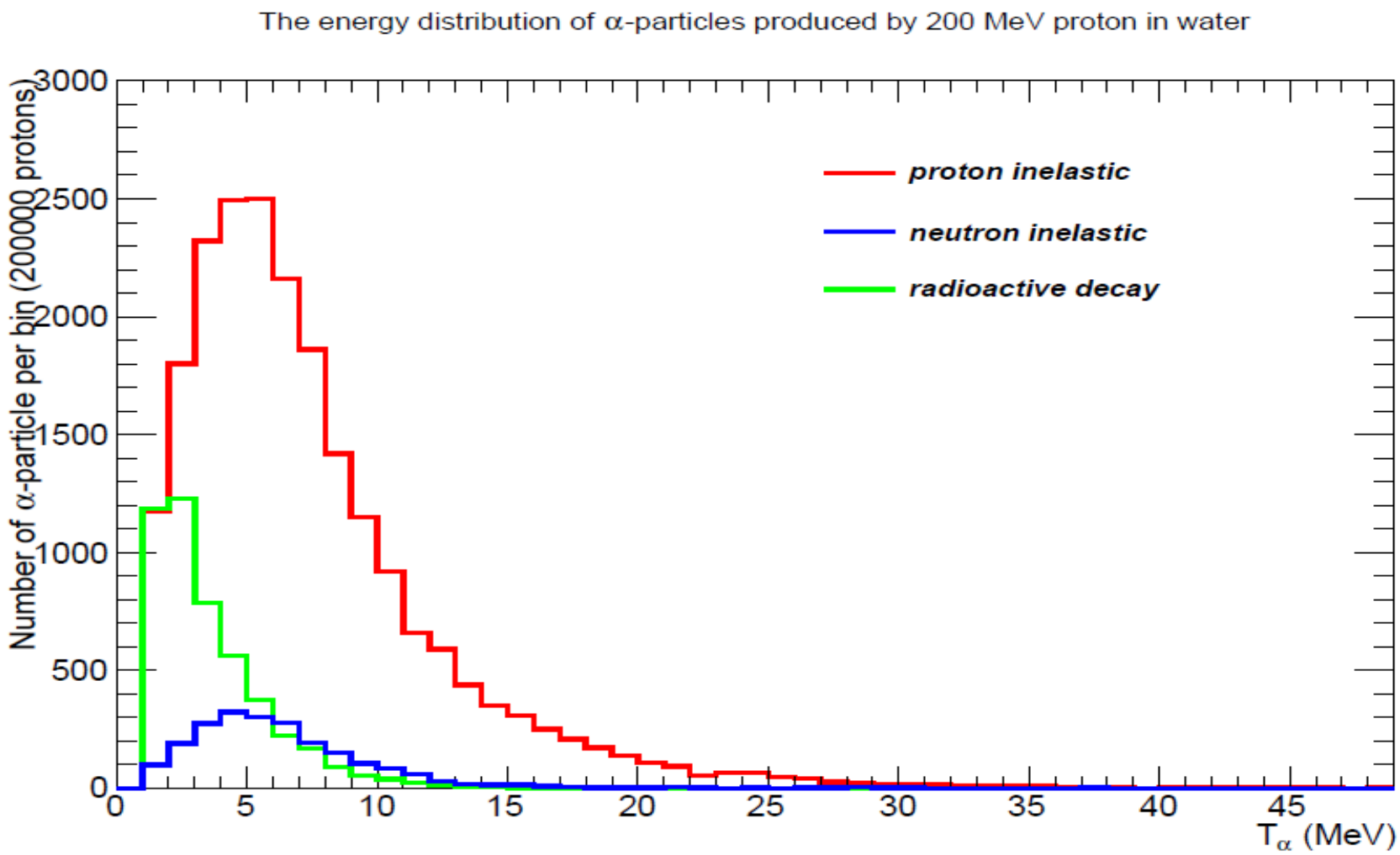
Integral inelastic proton-carbon cross section (maximum in the Bragg peak region)



Integral inelastic neutron-carbon cross section (maximum in the Bragg peak region)



Alpha particle spectra from 200 MeV protons in water (different processes)



Alpha particle spectra from 200 MeV protons in mean human body material (different processes)