Single and double charge exchange reactions in ^{12}C fragmentation at 300 MeV/nucleon



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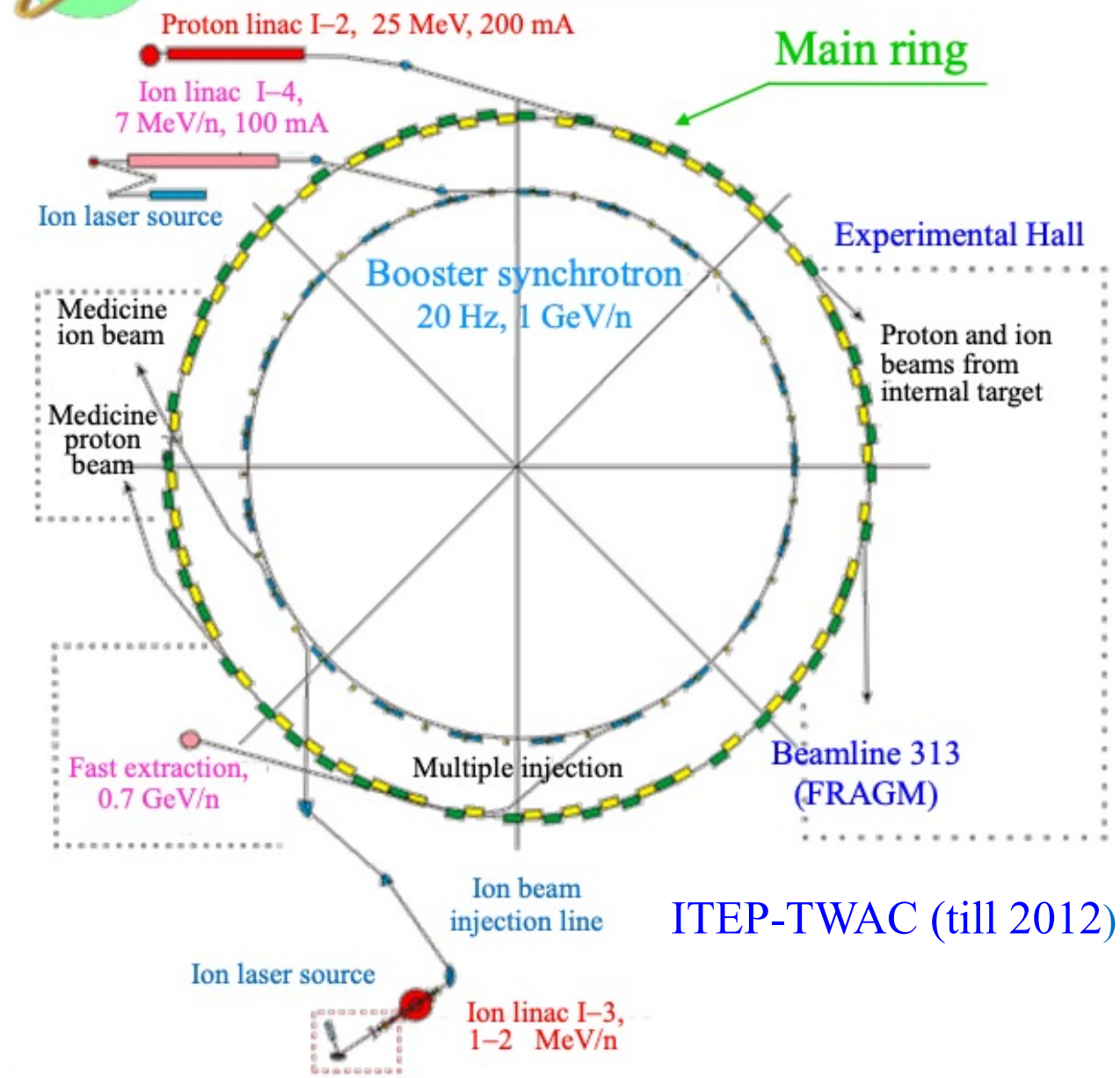
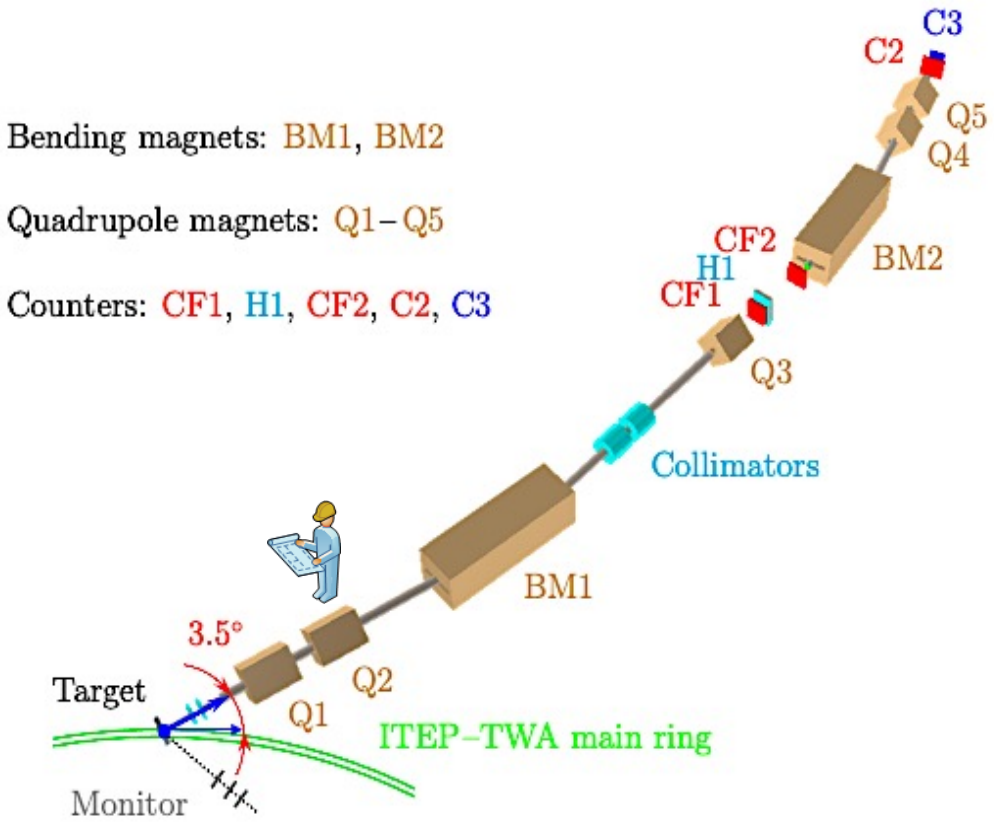
VIth International Conference on Particle Physics and Astrophysics (ICPPA-2022), 29 November – 2 December 2022, Moscow, Russia

Motivation

- Nucleon charge exchange processes during ion fragmentation are poorly studied. There are only a few experiments performed in the energy range 1–2 GeV/nucleon. Such measurements at energy of 300 MeV / nucleon was measured for the first time
- During the fragmentation of ^{12}C carbon ions after a single nucleon charge exchange, three long-lived isotopes can be formed: ^{11}Be (7 neutrons), ^{12}B (7 neutrons), ^{12}N (7 protons) and one with a double charge exchange of ^{12}Be
- New experimental data can check theoretical models of ion-ion interactions (BC, QMD, INCL, LAQGSM, etc.) and indicate ways to calibrate them



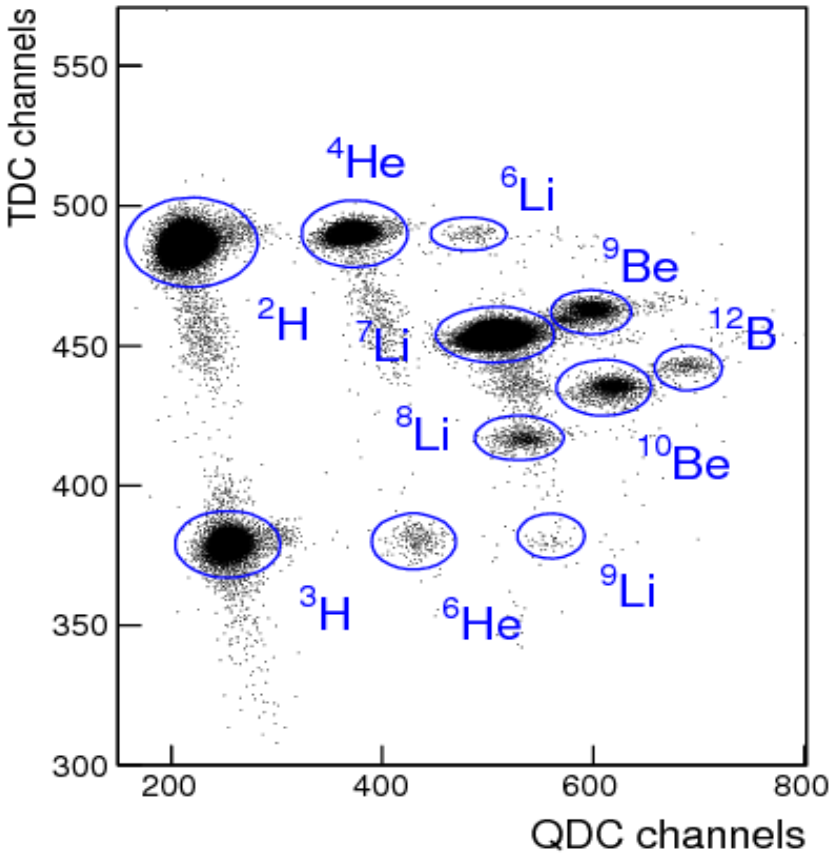
ITEP-TWAC (till 2012)



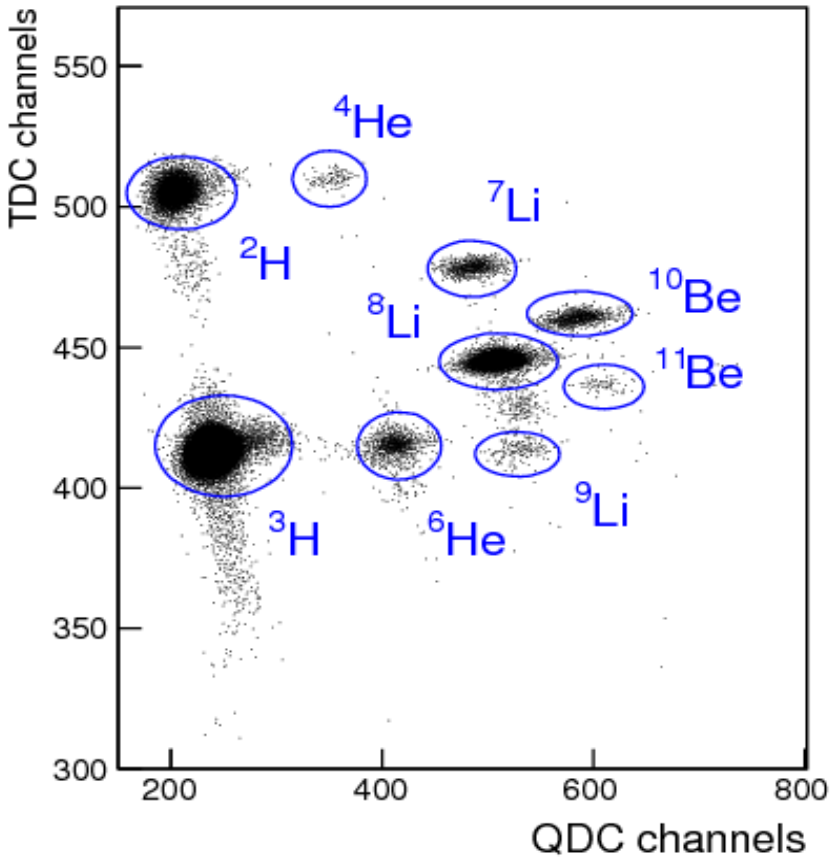
Experimental setup FRAGM

Fragment separation in the magneto – optical channel

Channel rigidity (p / Z) : 1.85 GeV/c



Channel rigidity (p / Z) : 2.05 GeV/c



✓ Correlation 2Dim distribution: QDC (function of dE/dx and Z of the fragment, determined by the counter CF1) from TDC (TOF – function of the atomic mass number, measured between CF1 and C2). TDC channel = 0.2 ns

✓ Different fragments can be easily separated by analyzing the correlation distribution

✓Binary Cascade (BC, GEANT4 toolkit, G. Folger *et al*., EPJA 21 (2004) 407) :

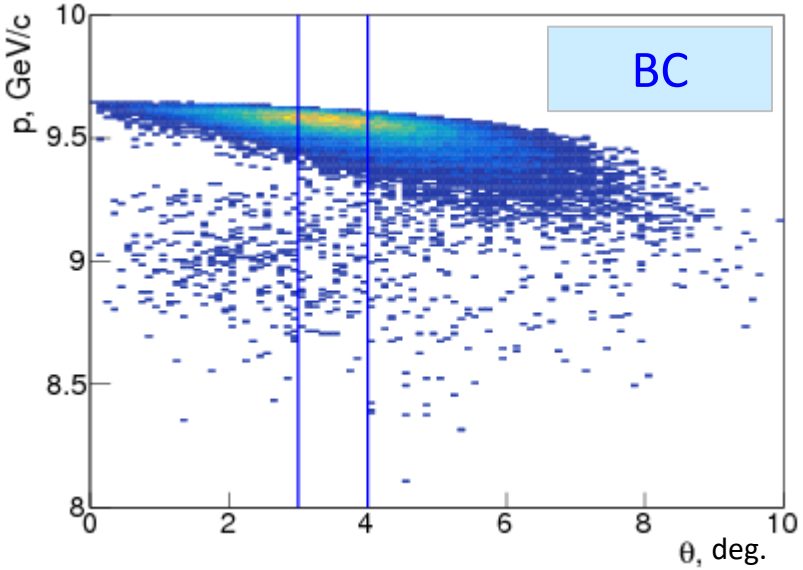
✓Quantum Molecular Dynamics (QMD, GEANT4 toolkit) T. Koi *et al*., AIP Conf. Proc. 896 (2007) 21:

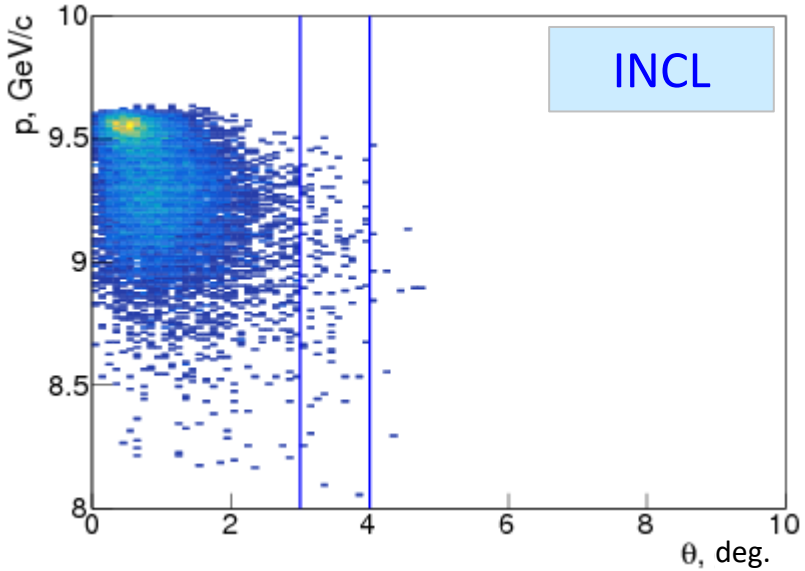
✓Liege Intranuclear Cascade (INCL++, J. Dudouet *et al*., PR **C**89 (2014) 054616) :

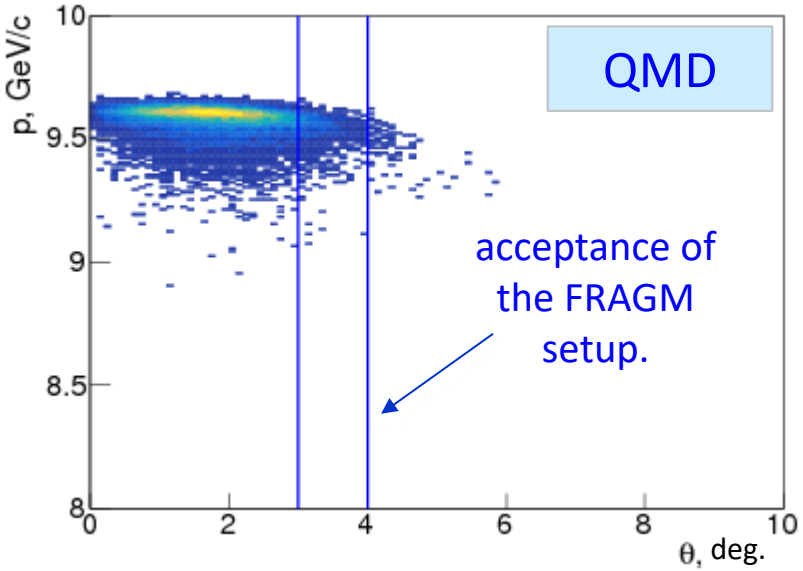
✓Los Alamos version of Quark Gluon String Model (LAQGSM03.03) LA-UR-11-01887, presented by M.I. Baznat (Academy of Sciences of Moldova)

Generally, all models work on the same principle. When ions collide, individual nucleons with the Fermi momentum, are creating intermediate prefragments. After the intranuclear cascade, prefragment is formed, decay of the excited prefragment is considered differently in each model.

Charge exchange reaction to the model test





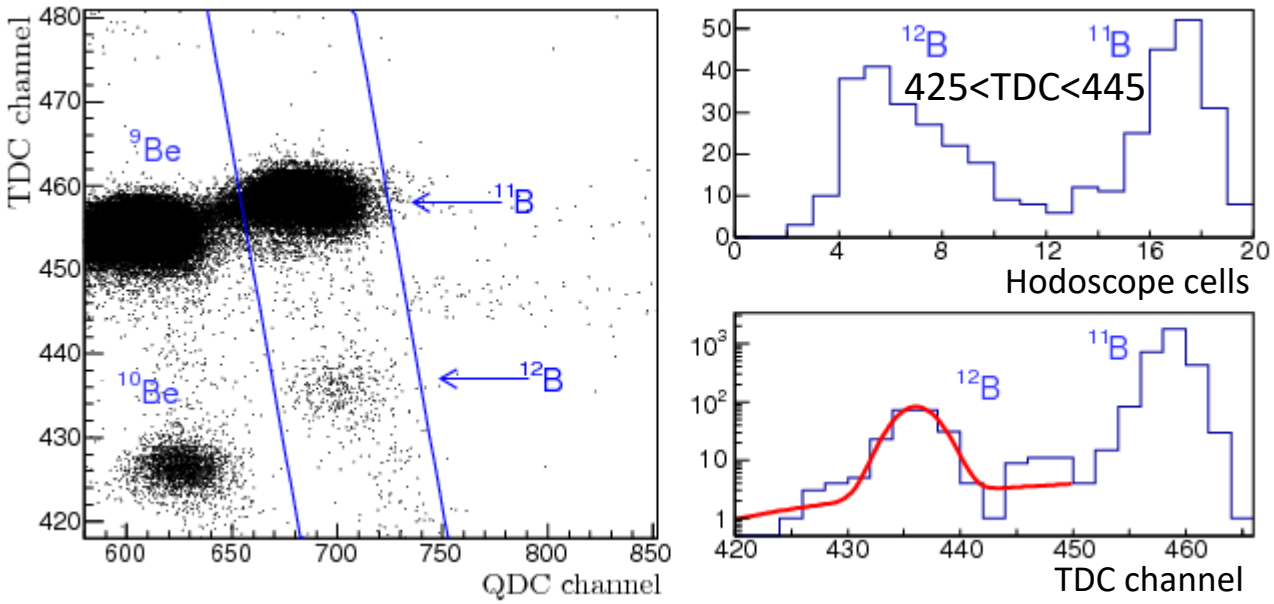


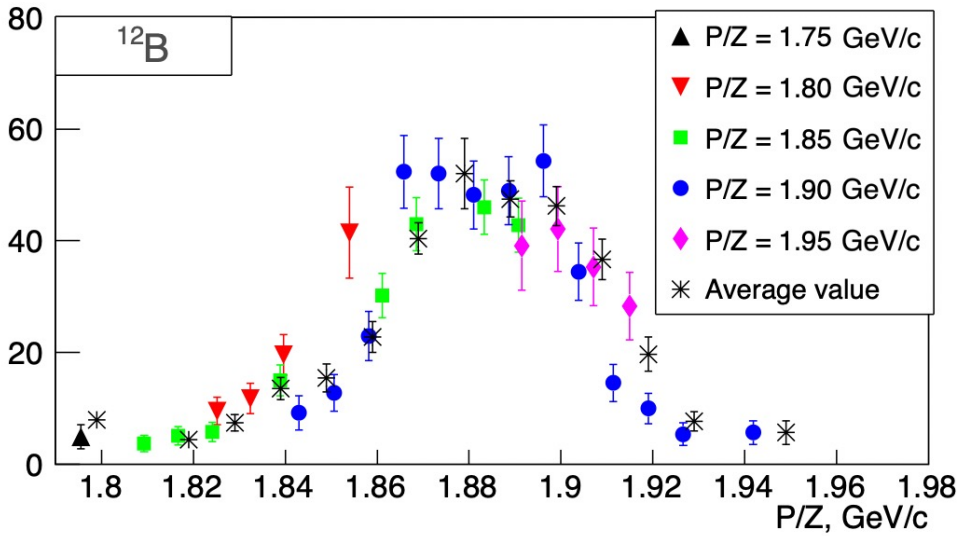
✓ BC and QMD models have distributions, but different kinematic descriptions of ^{12}B

✓ INCL reproduces the production of ^{12}B, but has an inaccurate angular distribution

✓ LAQGSM does not reproduce fragments resulting from the charge exchange reaction

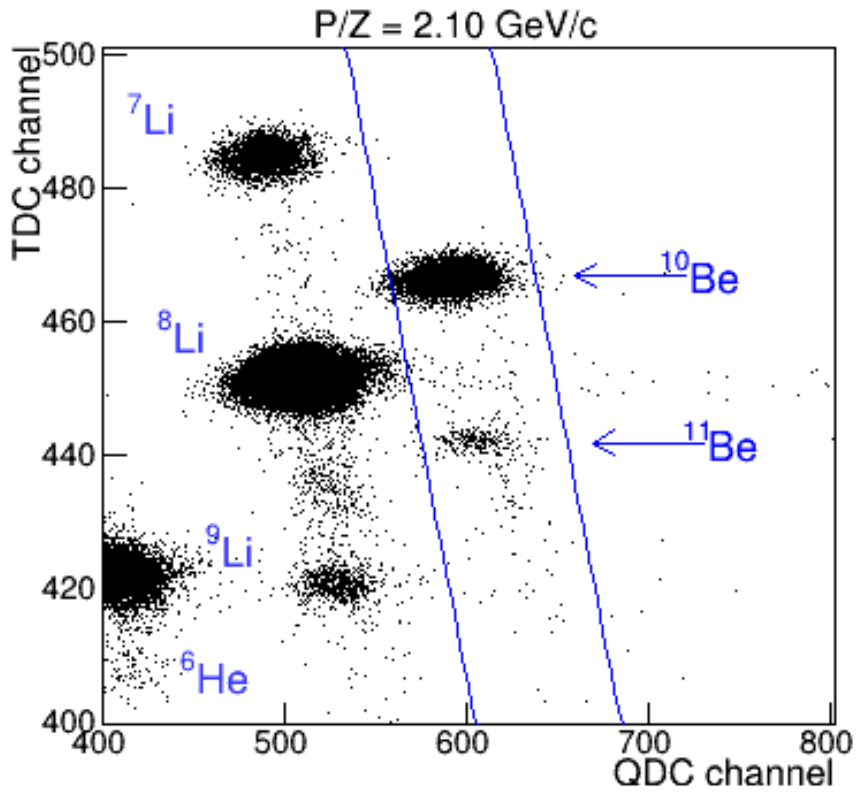
Rigidity: p / Z = 1.8 GeV/c

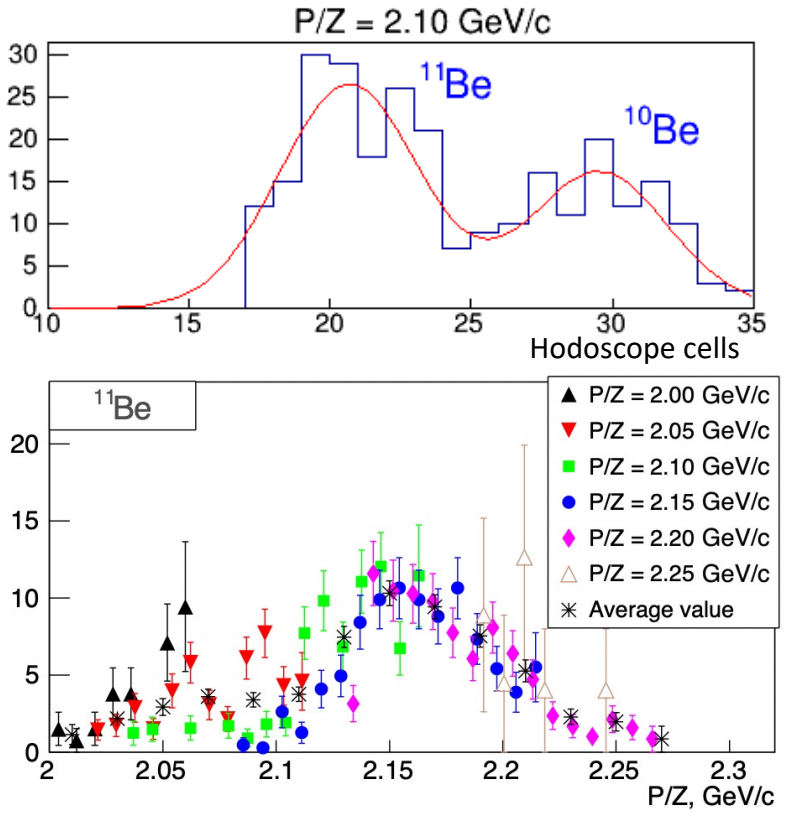




- ^{12}B extraction algorithm at a channel rigidity of 1.8 GeV/c: time-of-flight (TDC) and signal amplitude (QDC) correlation distributions (left); distribution by the cell number of hodoscope counter and by TDC channels (right)
- Background to effect gives ^{11}B, yield of signal is obtained using a fit procedure
- For the summation of ^{12}B points, a rigidity step of 10 MeV was chosen

Search of ^{11}Be



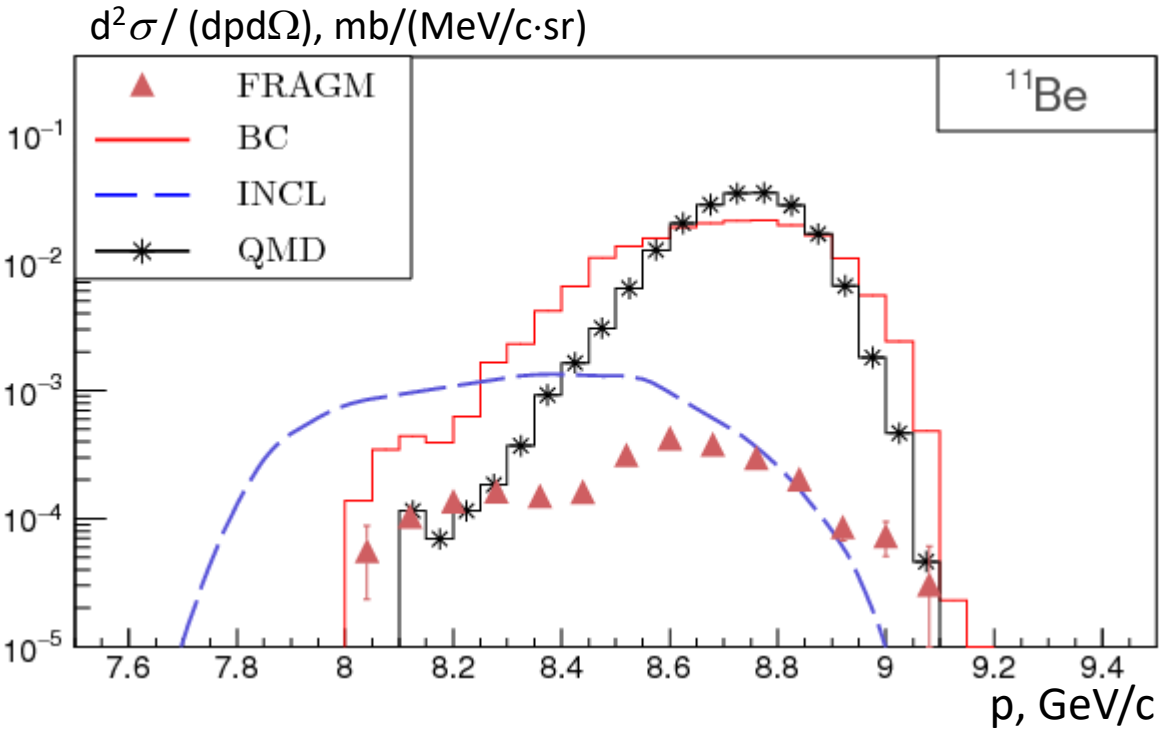


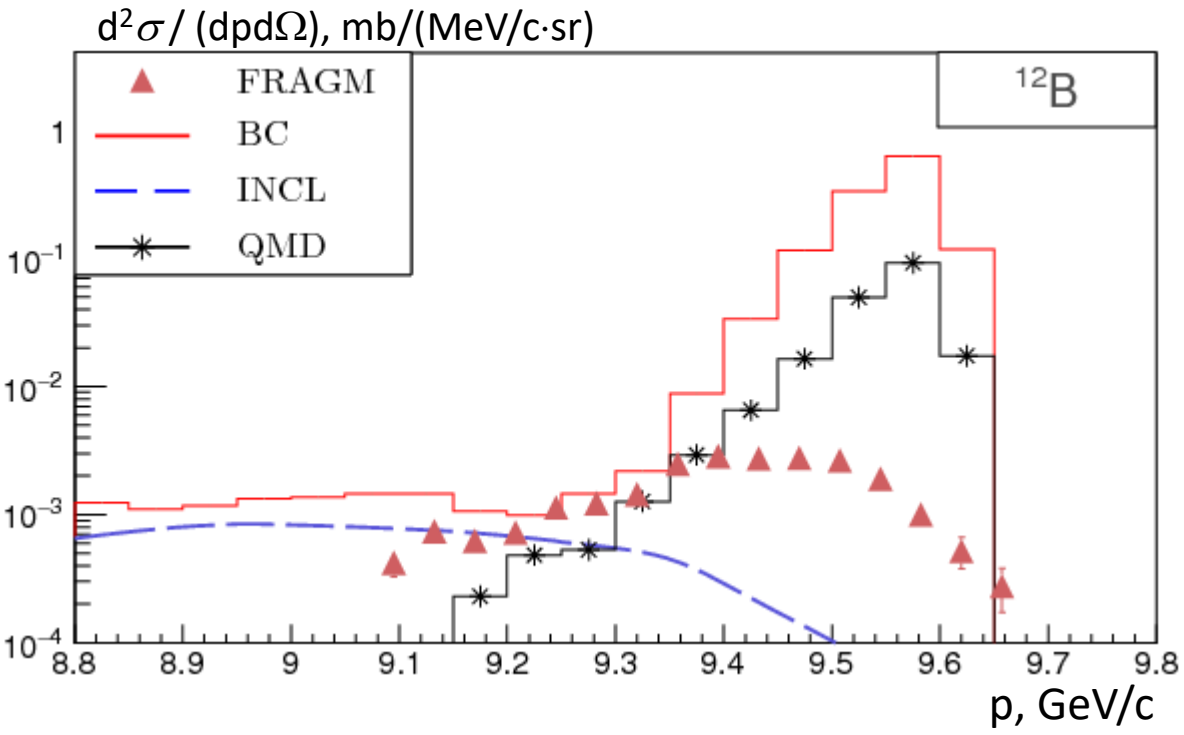
✓Procedure of the fragments selection: correlation distribution of the time-of-flight from the time-to-digital converter (TDC) and the signal amplitude from the charge-to-digital converter (QDC) at the rigidity of the magneto-optical channel 2.1 GeV/c (left). The rigidity range was selected from 2 to 2.25 GeV/c

✓Distribution of the selected events in the ^{11}Be production region over the hodoscope cell has shown on right upper plot. Background for ^{11}Be is rejected due to the Gaussian fit. To sum the ^{11}Be points, a rigidity step of 20 MeV was chosen (right lower plot).

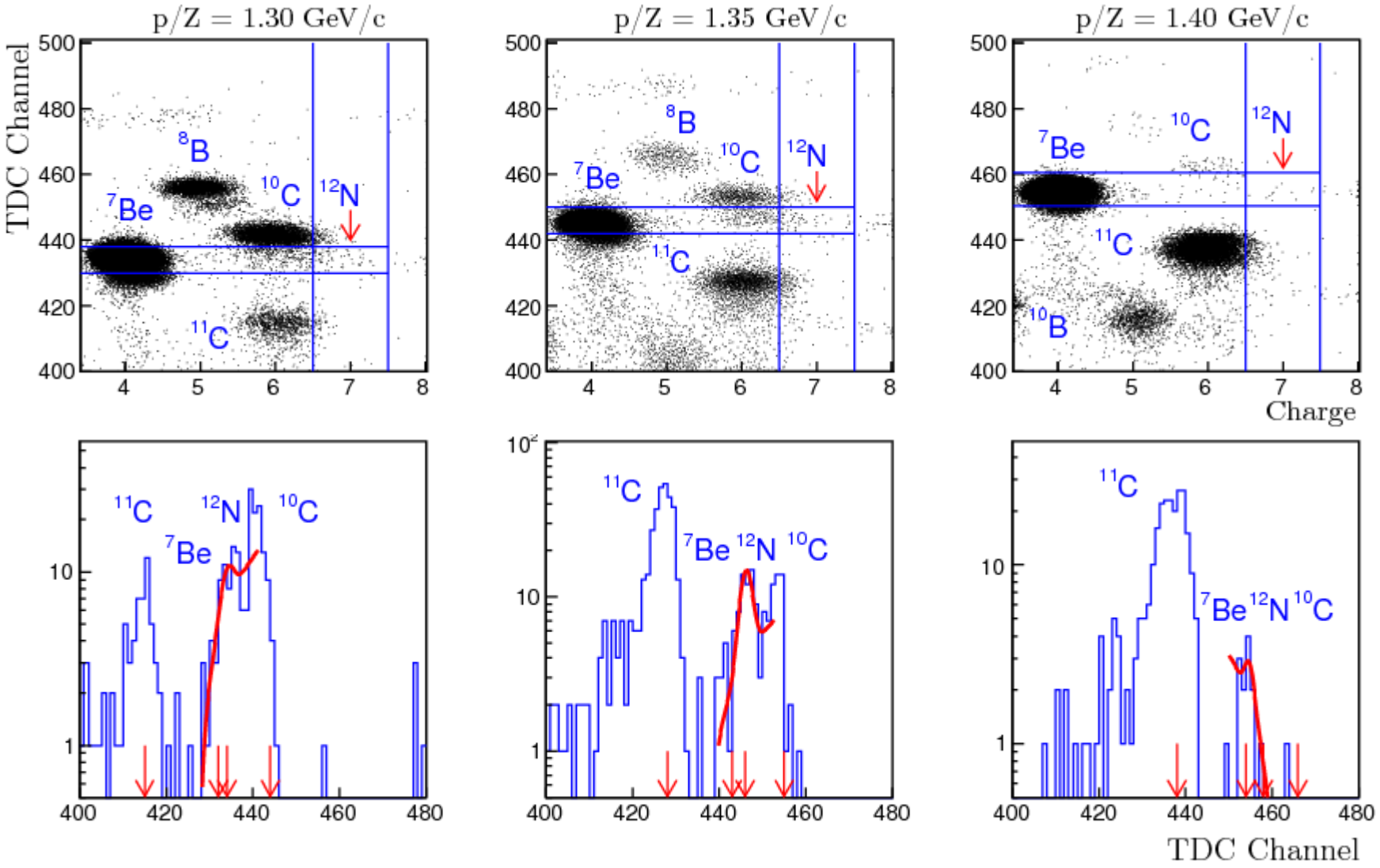
Differential cross section of ^{11}Be and ^{12}B

- The distributions for charge-exchange reactions occurring with the production of ^{11}Be and ^{12}B are given
- Experimental data and model calculations are quite different relative to each other
- It should be noted, that the experimental data are close to the binary cascade (BC) model in terms of the width and shape of distributions, but diverge from the models in absolute values





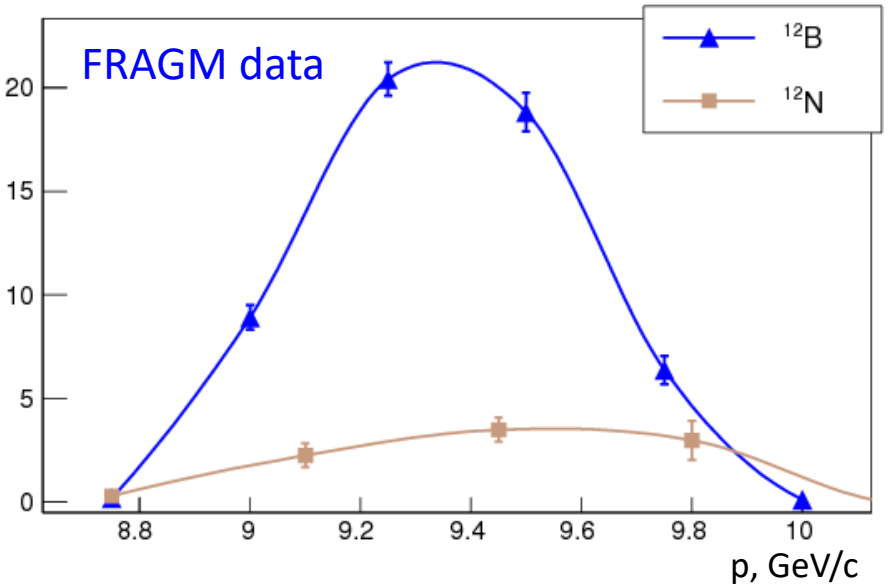
Search of ^{12}N / I

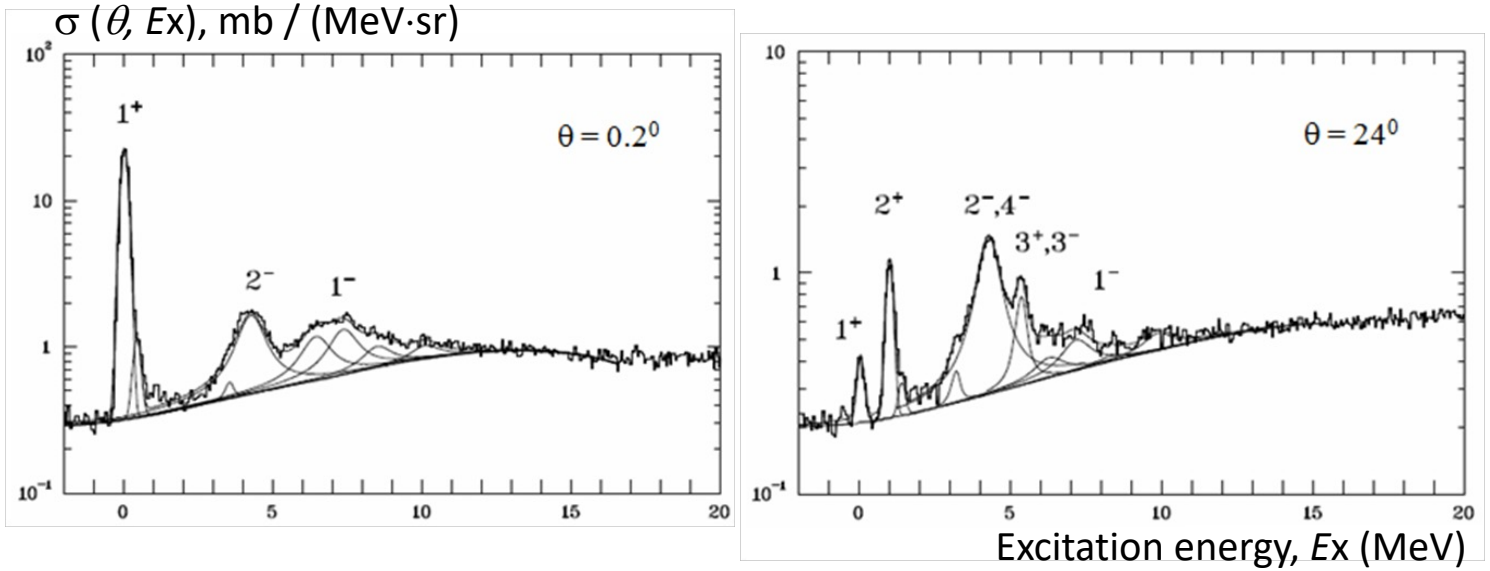


✓The search for ^{12}N at the rigidity range: 1.25 to 1.45 GeV/c

✓Not enough statistical data to search ^{12}N by hodoscope

✓ Possible candidates to ^{12}N can be found by fitting of the TDC channel projection with charge selection (vertical blue lines)





✓ Comparative ratio of the yield of the ^{12}B isotope and the yield of ^{12}N candidates (ground state) to estimating the upper limit for detecting ^{12}N by the experimental setup

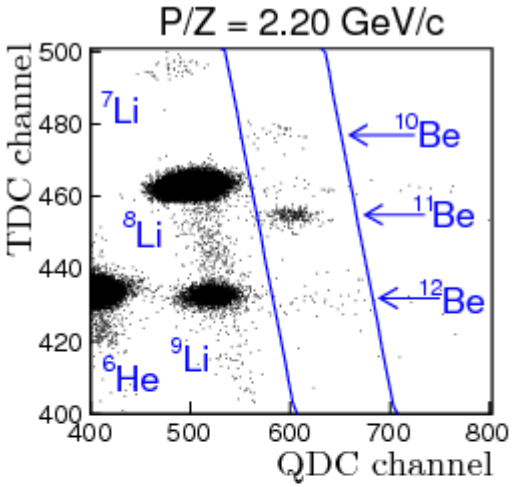
✓ At maximum the ratio of ^{12}N / ^{12}B is around 1/7 can be defined as upper limit

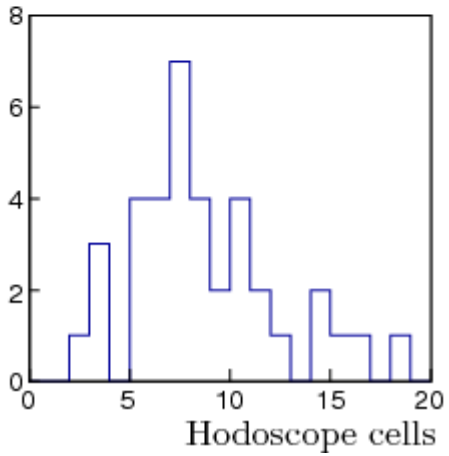
➢ Experimental data of the ^{12}N were obtained at the Indiana University Cyclotron Facility in reaction ^{12}C(p,n)^{12}N at T_{kin} = 135 MeV

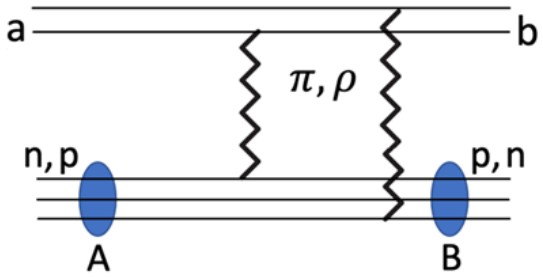
➢ Two plots show yields of ^{12}N for two registration angles : θ = 0.2⁰ and θ = 24⁰ plots. In inverse kinematic (projectile – ^{12}C, target – proton), second plot is equivalent to θ ~ 2⁰ and ground state of ^{12}N is suppressed in comparison with zero angle

➢ Other short-lived ^{12}N excited states decaying through the p + ^{11}C channel

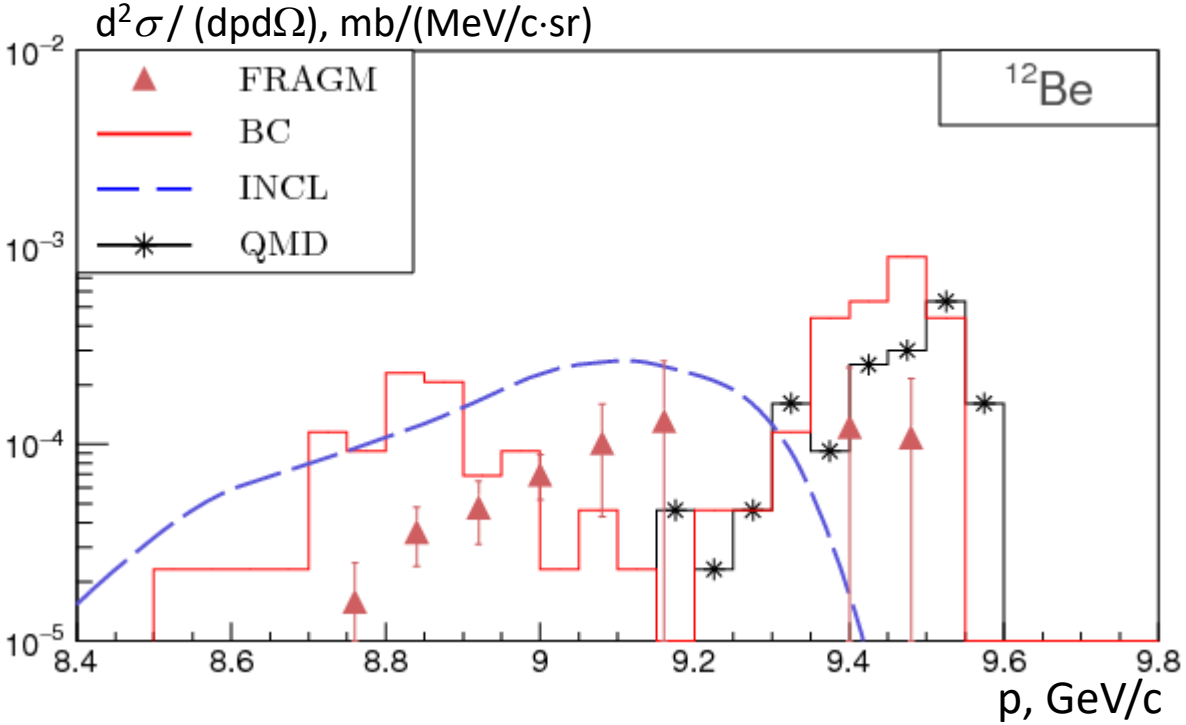
Search of ^{12}Be







✓Double charge exchange reaction : usually associated with pion exchange between projectile and target nucleons



- The search of ^{12}Be was carried out in the range of rigidity from 2.15 to 2.45 GeV/c
- Two peaks can be found in the experimental data corresponding to virtual and real pion emission
- Better description of the ^{12}Be momentum shape gives BC model demonstrating two different peaks. Other models have shown only one

Conslusion

- Using this method, ^{11}Be, ^{12}Be, and ^{12}B isotopes were detected and their differential cross section as a function of the momentum were measured. For ^{12}N, which is produced predominantly in the form of an excited and short-lived state, the upper limit of this reaction was estimated
- Different models of ion-ion interactions were considered from the point of view of their applicability to the description of charge exchange processes
- The best description of the studied reactions is provided by the binary cascade (BC) model


Thank You