FRAGM

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Test of nuclear fragmentation models with carbon fragmentation at 0.3 GeV/n

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Introduction and motivation

Experiment FRAGM at ITEP TWAC (Moscow)

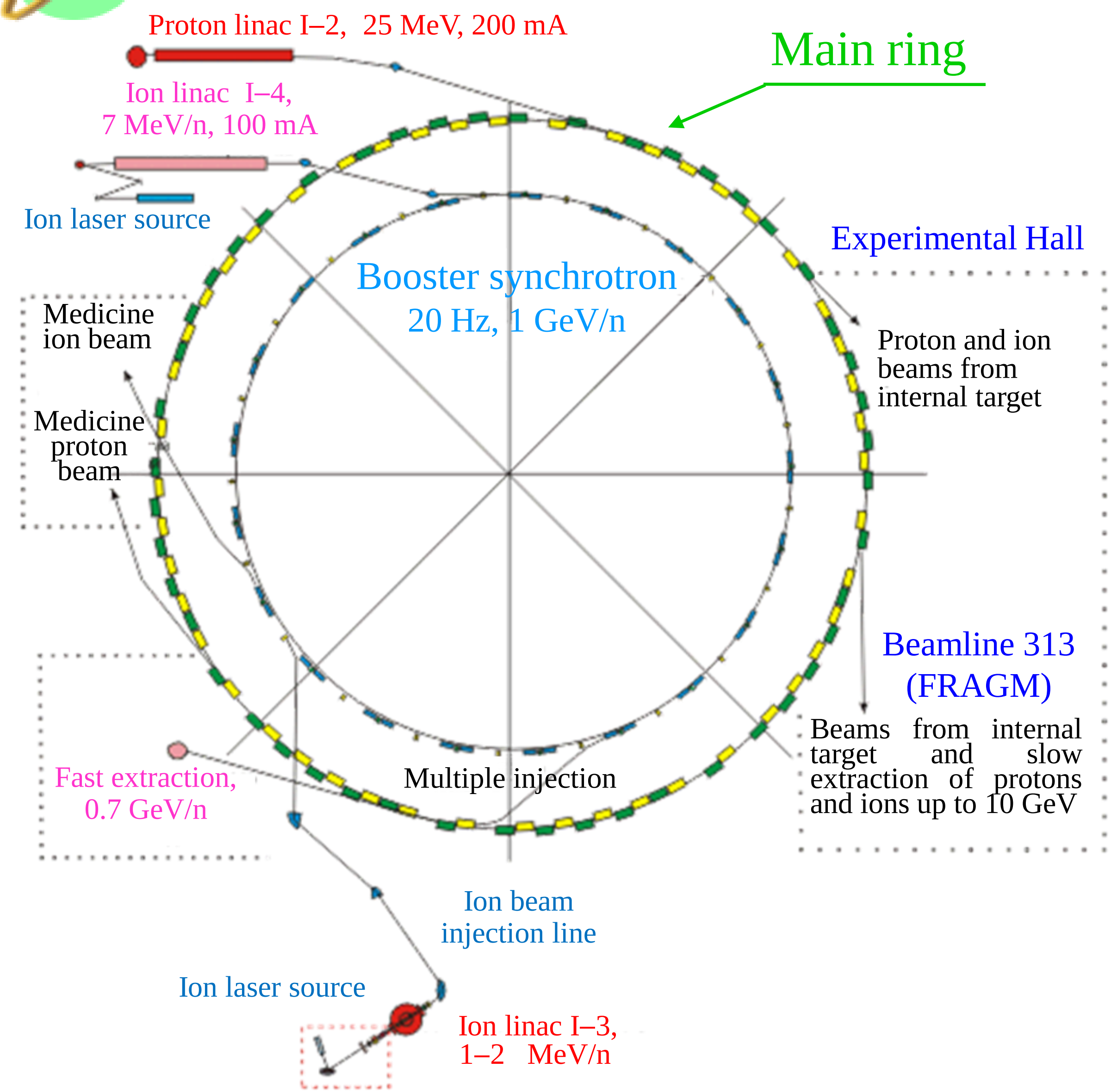
$^{12}C + A \rightarrow f + X$ (inverse kinematics)

fragments:	p, d, t, ^{3}He, ^{4}He, ^{6}He, ^{6}Li,…, ^{10}C, ^{11}C, ^{12}C
^{12}C kinetic energy:	0.2 – 3.2 GeV/nucleon
fragment angle:	3.5^o with respect to ^{12}C beam
different targets:	Be, Al, Cu, Ta for ^{12}C beam of 0.3 GeV/n
sensitivity:	up to 6 orders of the cross section magnitude

I will focus on the results of the run with different targets at 0.3 GeV/n

- good data for carbon fragmentation are needed for overall understanding of nucleus-nucleus collisions
- the carbon fragmentation in this energy region is also important for application in ion therapy where fragmentation is a main source of irradiation behind Bragg peak
- few ion-ion interaction models exist that aim at precise description of fragmentation processes. They have to be tested at different processes.

ITEP accelerator complex TWAC



TWAC= TeraWatt Accumulator Complex

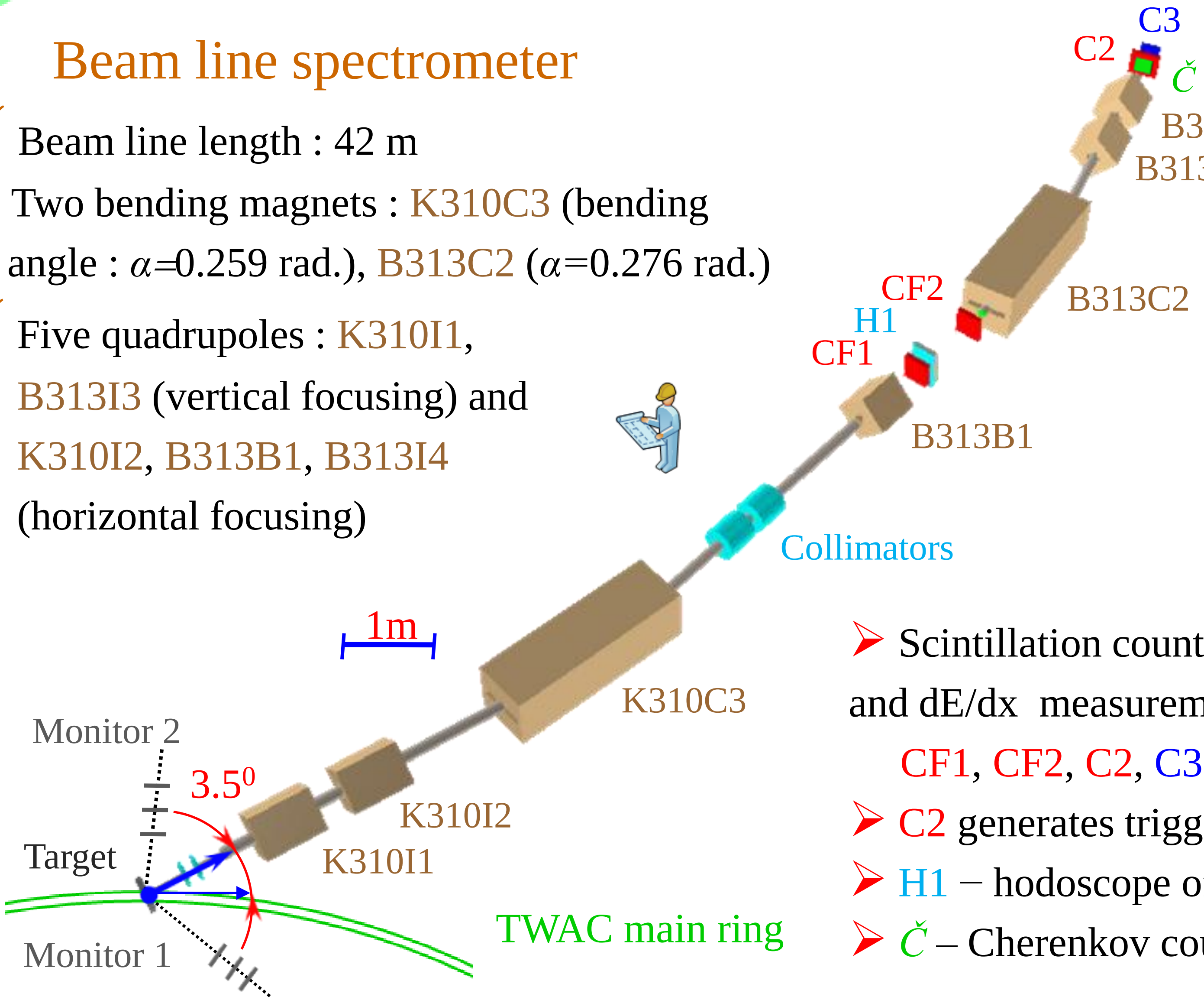
TWAC current parameters

- ✓ Proton acceleration : 50 – 10000 MeV
- ✓ Ion acceleration : up to 4 GeV/nucleon
- ✓ Ion accumulation : up to 700 MeV/nucleon
- ✓ Accelerating ions : up to ^{56}Fe
- ✓ Typical intensity : 10^{11} nucleons / s

Experiment FRAGM

Beam line spectrometer

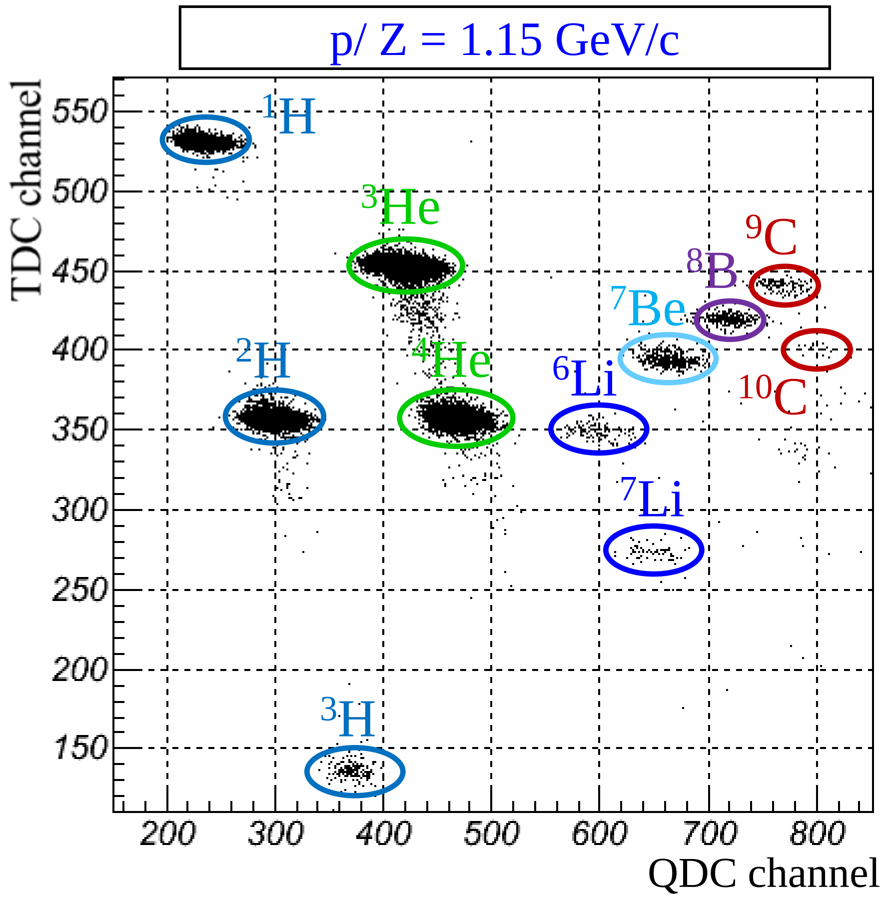
- ✓ Beam line length : 42 m
- ✓ Two bending magnets : K310C3 (bending angle : α=0.259 rad.), B313C2 (α=0.276 rad.)
- ✓ Five quadrupoles : K310I1, B313I3 (vertical focusing) and K310I2, B313B1, B313I4 (horizontal focusing)

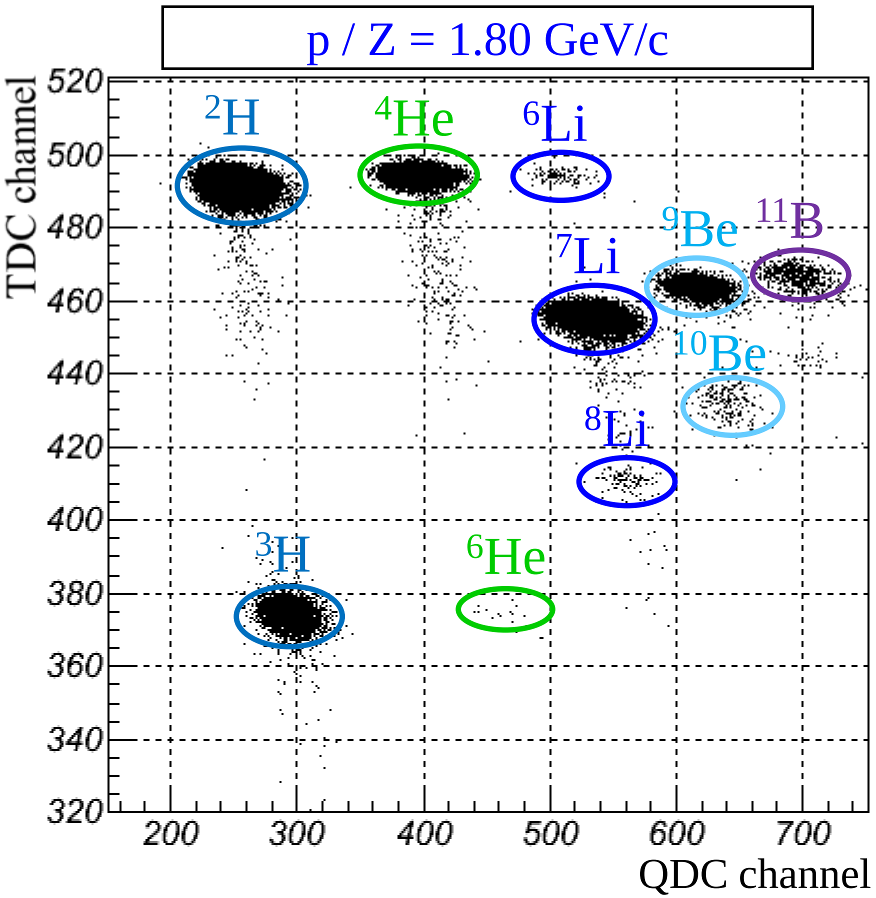


Max. rigidity 6 GeV/c

- Scintillation counters for TOF and dE/dx measurement: CF1, CF2, C2, C3
- C2 generates trigger
- H1 – hodoscope of 20 elements
- Č – Cherenkov counter

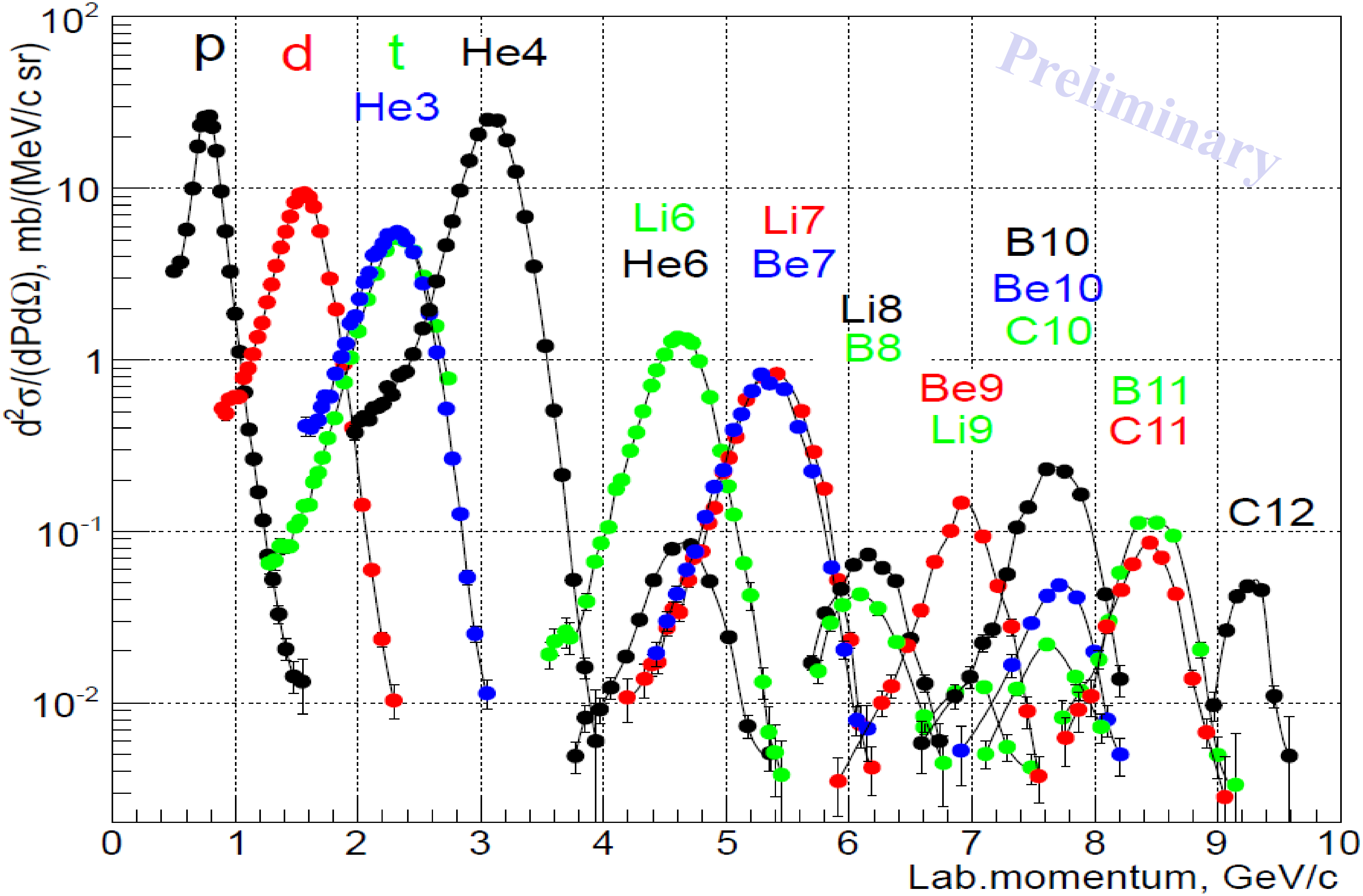
Example of fragment selections at 0.3 GeV/nucleon





- ✓ QDC (from CF1) vs TOF between CF1 and C2
- ✓ Regions of the different fragments are well separated
- ✓ TOF is a function of A, QDC is a function of Z

Fragment momentum spectra, Be target, 300 MeV/n



Ion – ion interaction models for test

- From GEANT4 package (supported by CERN)
  - Binary Cascade (BC) : (G. Folger *et al.*, EPJA 21 (2004) 407)
  - Quantum Molecular Dynamics (QMD): (T. Koi *et al.*, AIP Conf. Proc. 896 (2007) 21)
  - Liege Intranuclear Cascade (INCL++) : (J. Dudouet *et al.*, PR **C**89 (2014)054616)
  - 10M ion – ion interactions have been generated for each model
- Los Alamos version of the Quark Gluon String Model (LAQGSM03.03) (by courtesy of

  S. Mashnik, and K.Gudima) : (LA-UR-11-01887)
- A simple statistical approach to projectile fragmentation
  - Gaussian shape of fragment momentum spectra
  - Widths of the fragment momentum spectra in projectile rest frame are independent from projectile energy and target nucleus (limiting fragmentation)
  - Parabolic law for the width (Goldhaber 1974)

Structure of ion-ion interactions model

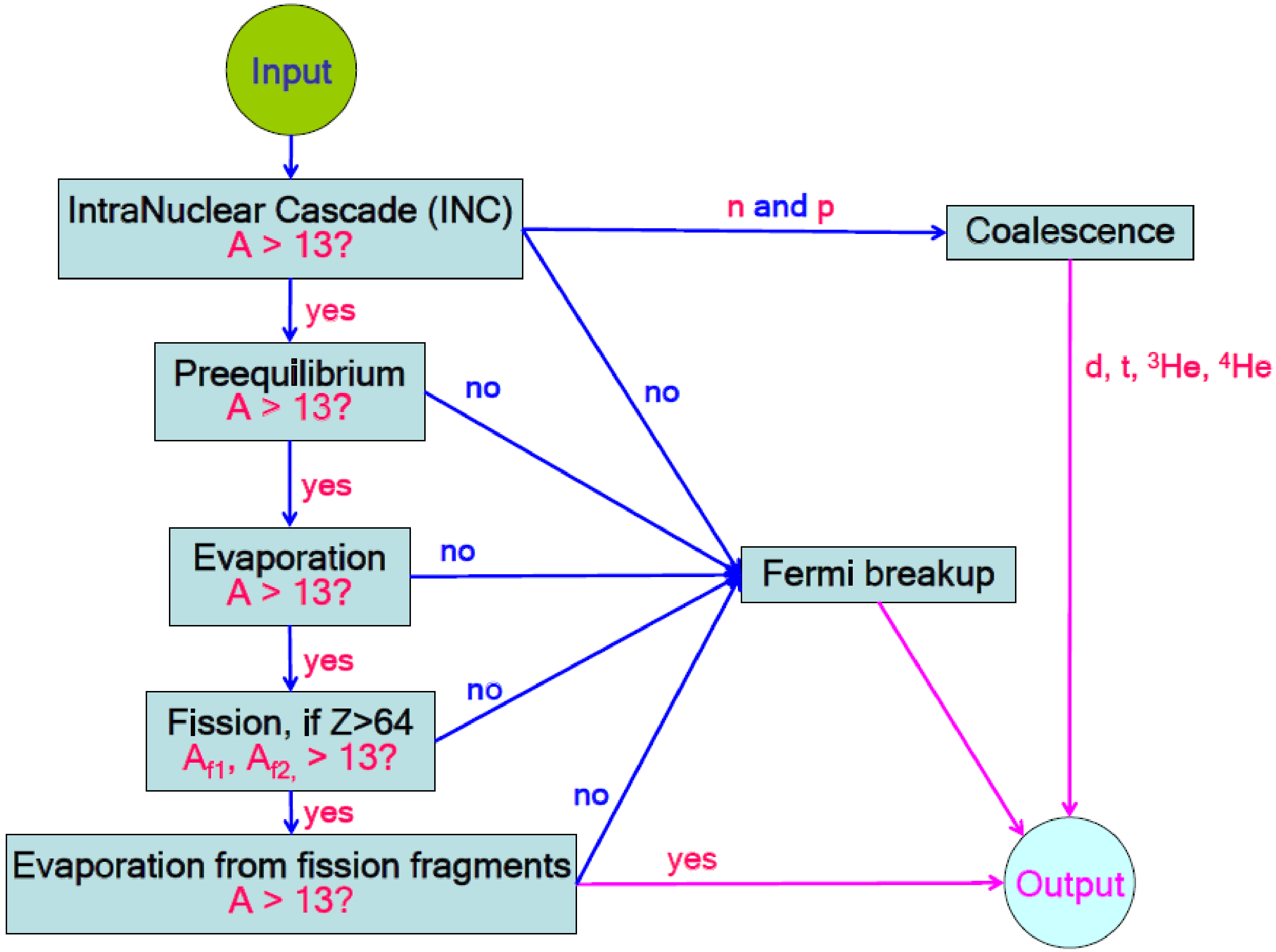
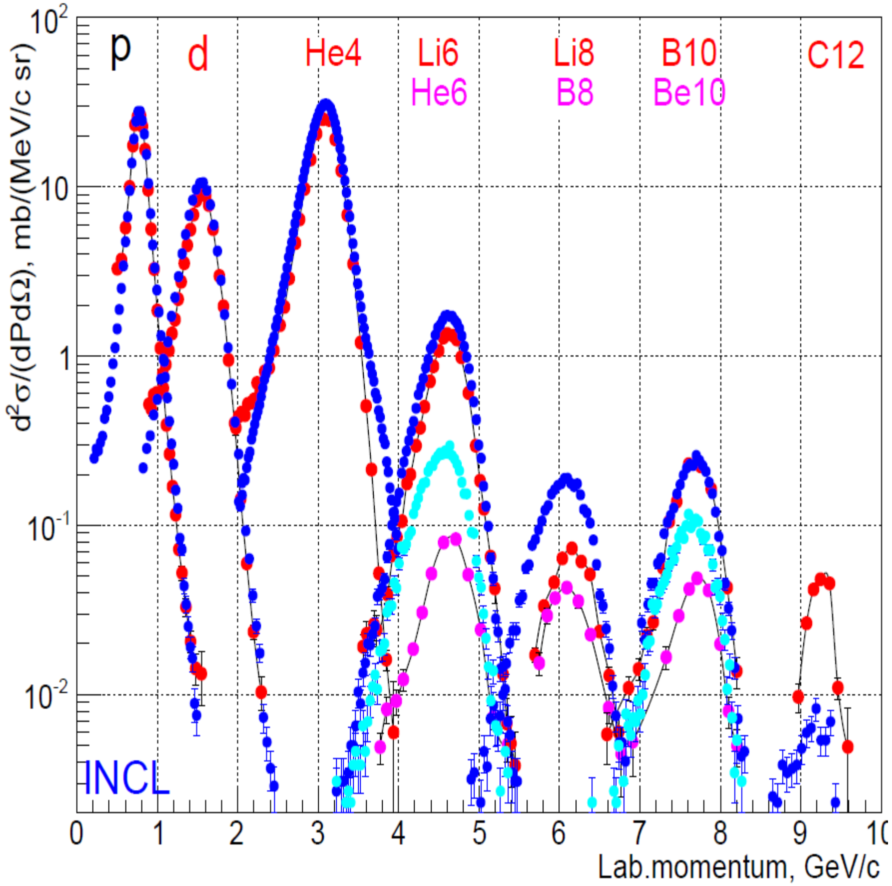
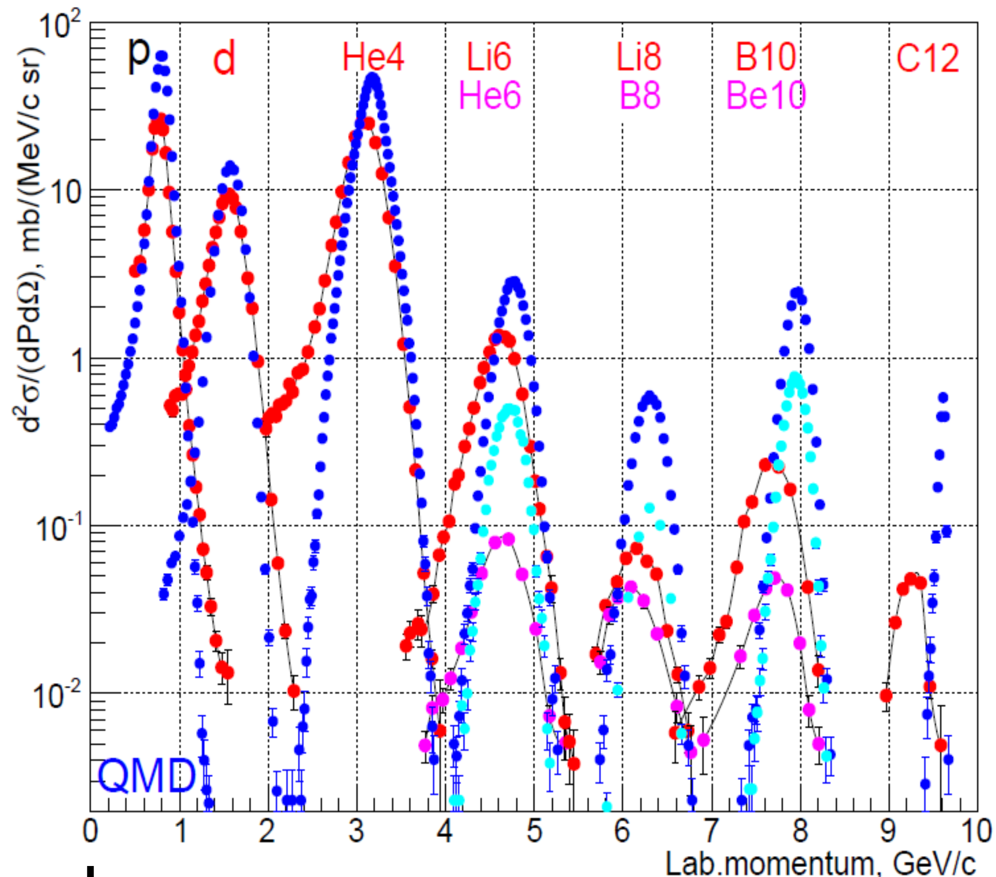


Figure 1: General scheme of nuclear reaction calculations by LAQGSM03.03.

FRAGM data (red/pink) vs INCL and QMD (blue)

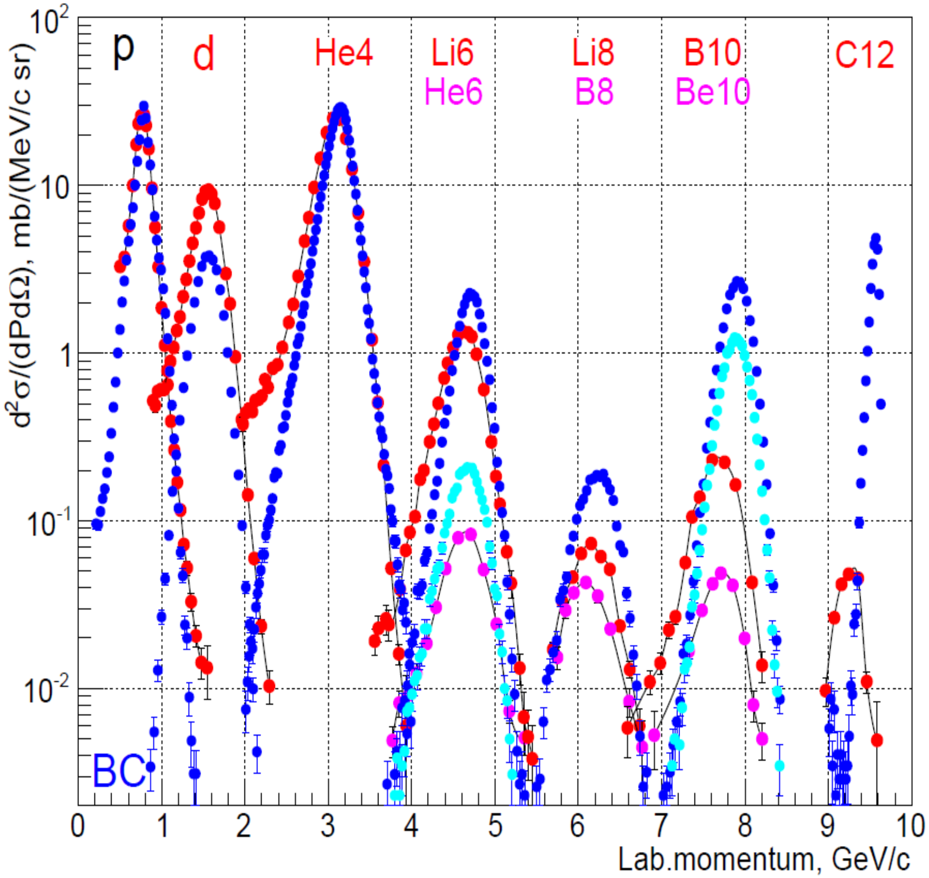


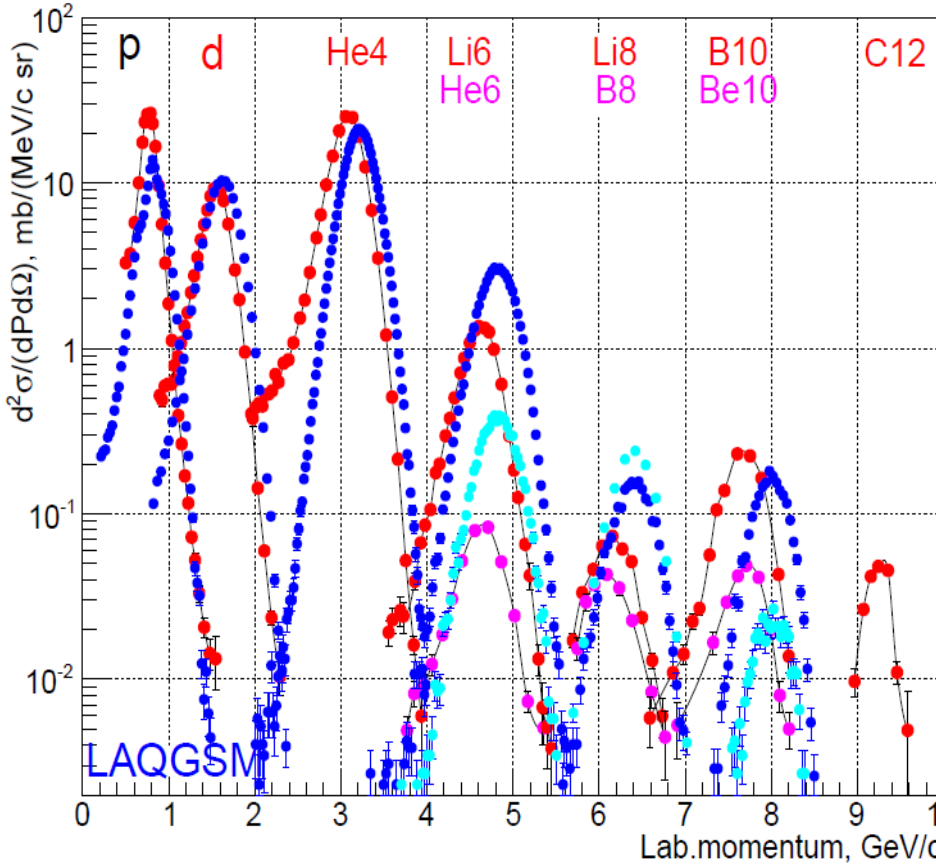


Very good agreement for p,d,He4, Li6,B10, reasonable for He6,Li8,Be10, bad for B8(absent in this scale), C12

Reasonable for p-Li6, for all others production is strongly overestimated

FRAGM data (red/pink) vs BC and LAQGM(blue)

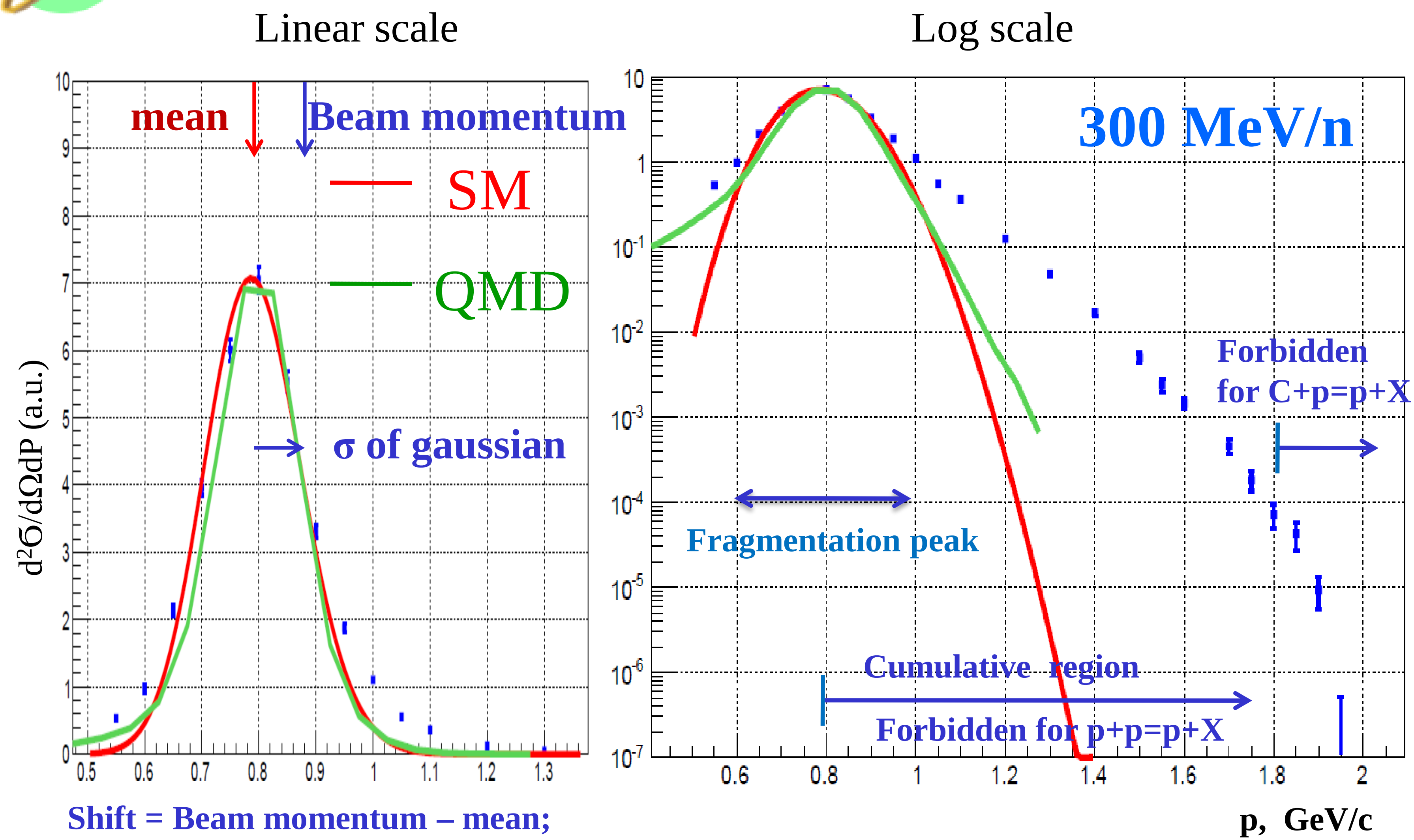




p-normalization, good agreement for all apart from B10,Be10,C12(overestimated B8(absent in this scale)

Reasonable for all fragments, peaks are slightly shifted to higher momentum, for C12 there is no prediction

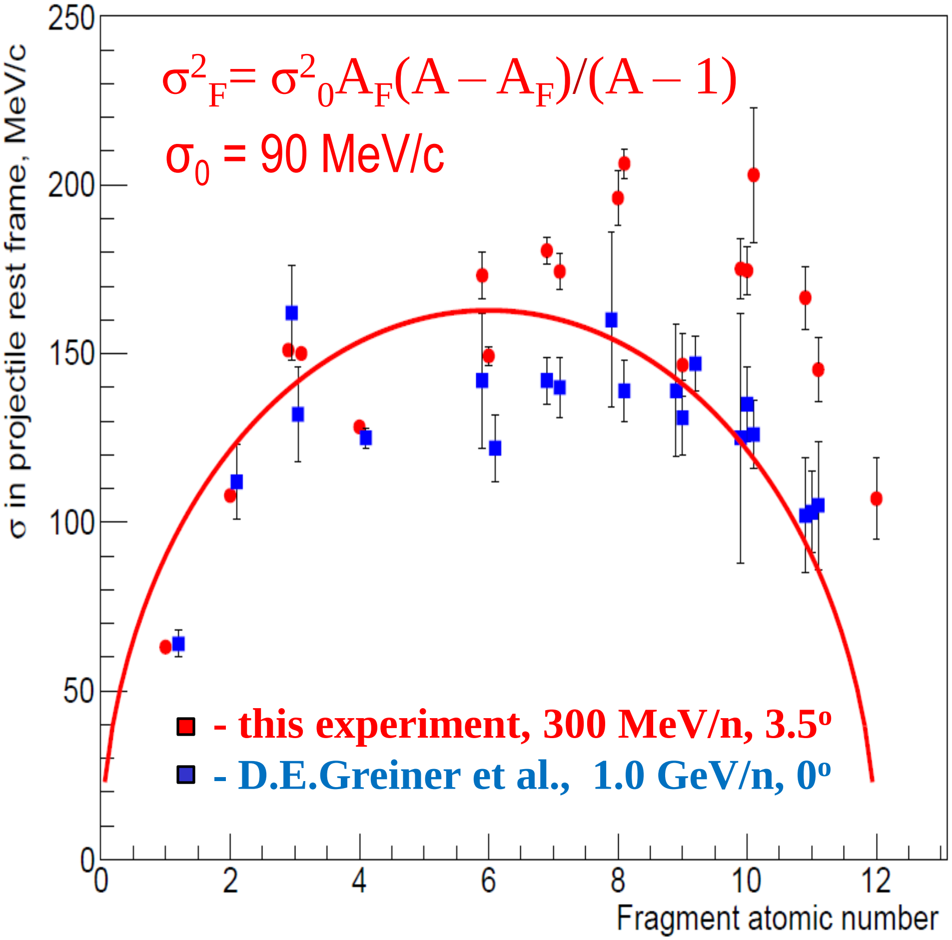
Proton momentum spectrum

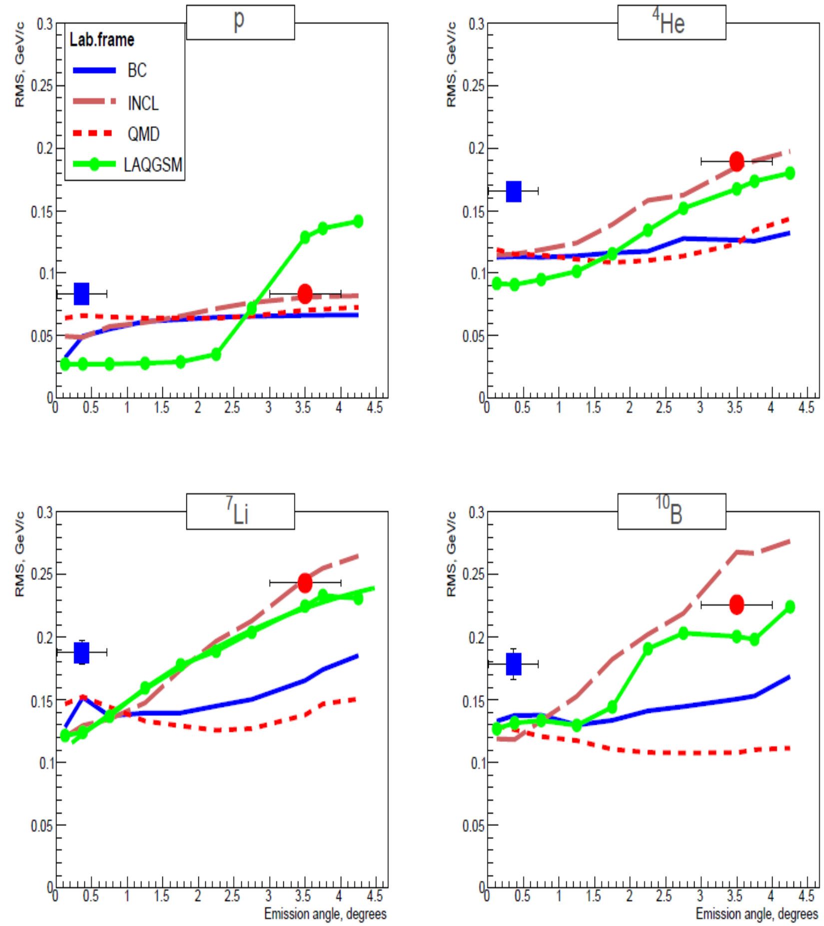


Shift = Beam momentum – mean;

σ will be called "width" of the peak

Test of Goldhaber parabolic law

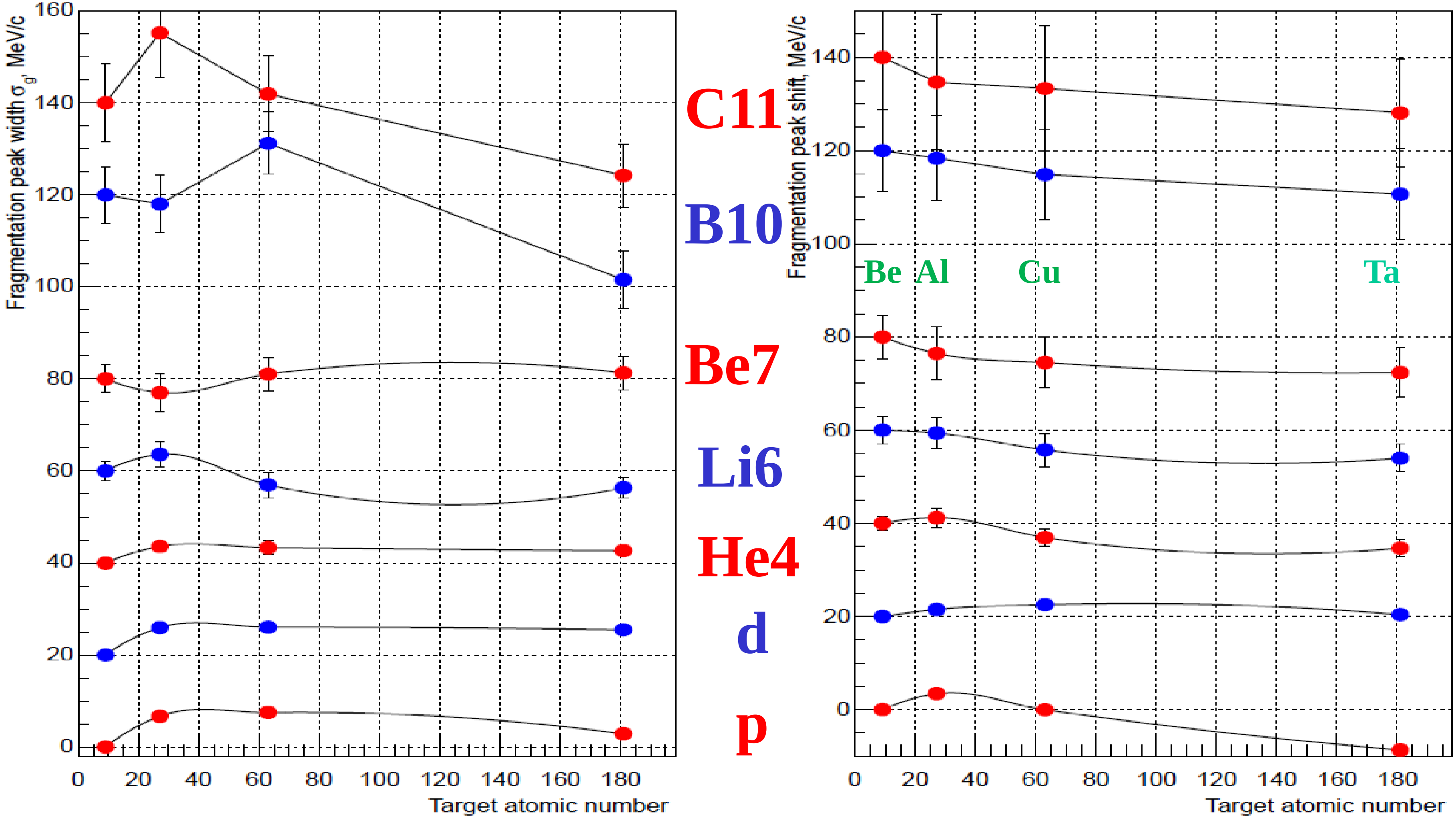




Dependence of fragmentation peak width
On fragment emission angle in MC models

Widths depend only on A, not on Z
Limiting fragmentation is valid even for 300 MeV/n
Widths depend on fragment emission angle

Target dependence of fragmentation peak width/shift



Widths are independent of target nuclei with accuracy of 5 MeV/c for light and 15 MeV/c for heavy fragments

Shifts per nucleon have a tendency to decrease for Ta-target by 5-10 MeV/c per nucleon

Conclusion

- Fragment momentum spectra from ^{12}C fragmentation at 300 MeV/n were measured with high precision on four target nuclei.

- The spectra were compared to predictions of four transport codes: BC, INCL, LAQGSM and QMD. All models give the description of fragmentation peaks from very good to reasonable except for few above mentioned points.

- 2) Main terms of simplest statistical models have been tested and found valid even for 300 MeV/n.

Thank You