Geant4 treatment of Ion/Ion physics relevant to International Space Station and interplanetary exploration

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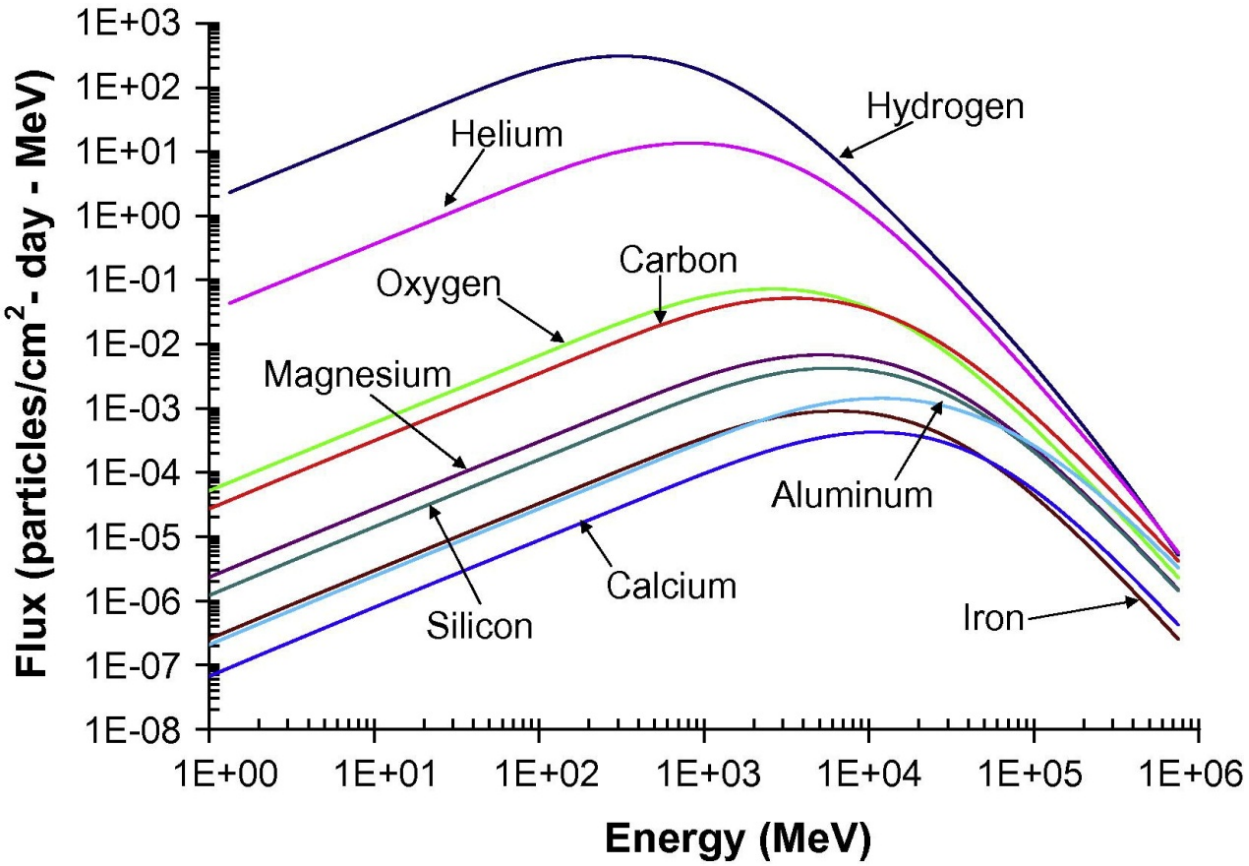
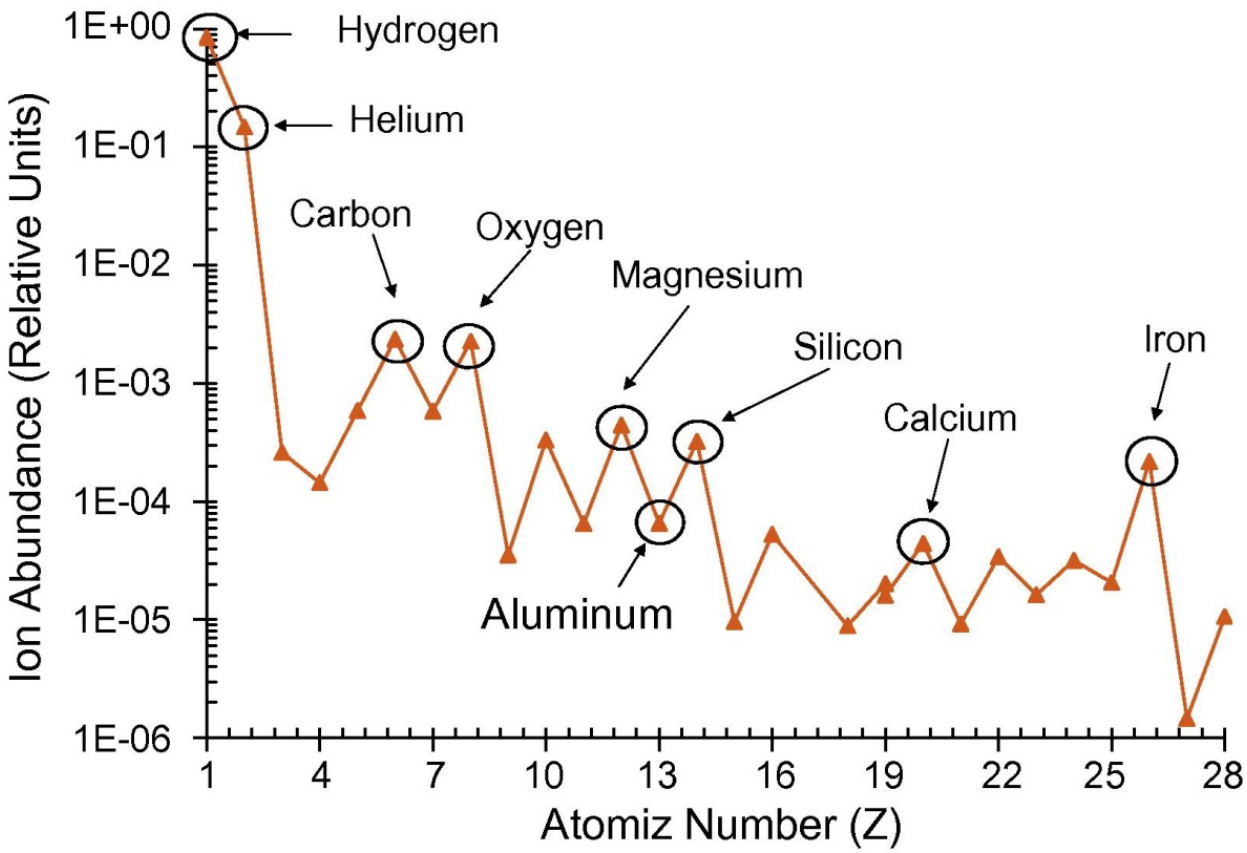
Calculated Ion flux in space (Aghara et al. 2009)



Calculated Ion abundances in space (Aghara et al. 2009)



Ion/Ion models in Geant4 and Physics Lists updated to the g4.9.5

- **Models**
  - BIC_ion (0 – 5 GeV/u)
  - QMD (0.01 – 10 GeV/u)
  - INCL++ (0.15 – 3 GeV/u)
  - Abrasion (0.1 – 10 GeV/u)
  - CHIPS (0 – 100 TeV)
  - FTF (3 GeV/u - 10 TeV/u)
  - DPMJET-II.5 – external library
  - UrQMD – recentely
- **Physics Lists with detailed ion/ion simulation**
  - QBBC
  - FTFP_BERT
  - Shielding
  - QGSP_INCLXX
  - CHIPS

How one can validate Geant4 Ion/Ion models

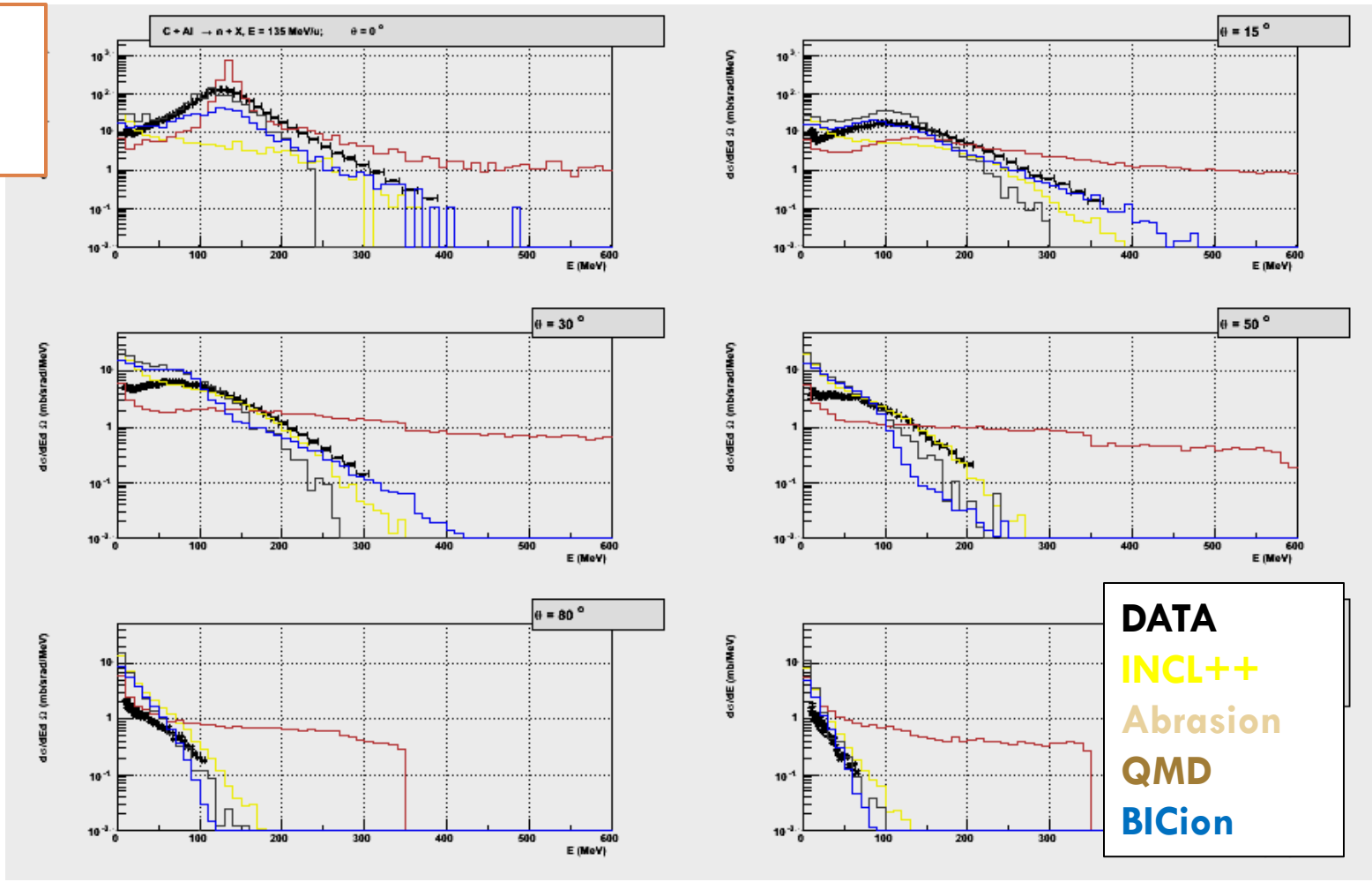
- **Hadronic Testing suite in Geant4 verification repository**
  - Hadronic cross sections test
    - Ions
  - Thin targets test, neutrons spectra (test30)
    - E = 0.1 – 1 GeV/u
    - (He4 to Ar40) on (C to Pb)
  - Thin targets fragmentation test, fragments cross sections (IAEAion)
    - E = 0.1 – 1 GeV/u
    - (He4 to Fe56) on (H to Pb)
  - Thick targets shielding test, neutrons spectra (test45ion)
    - E = 0.1 – 1 GeV/u
    - (D to Xe131) on (C to Pb)

Hadr02– extended example

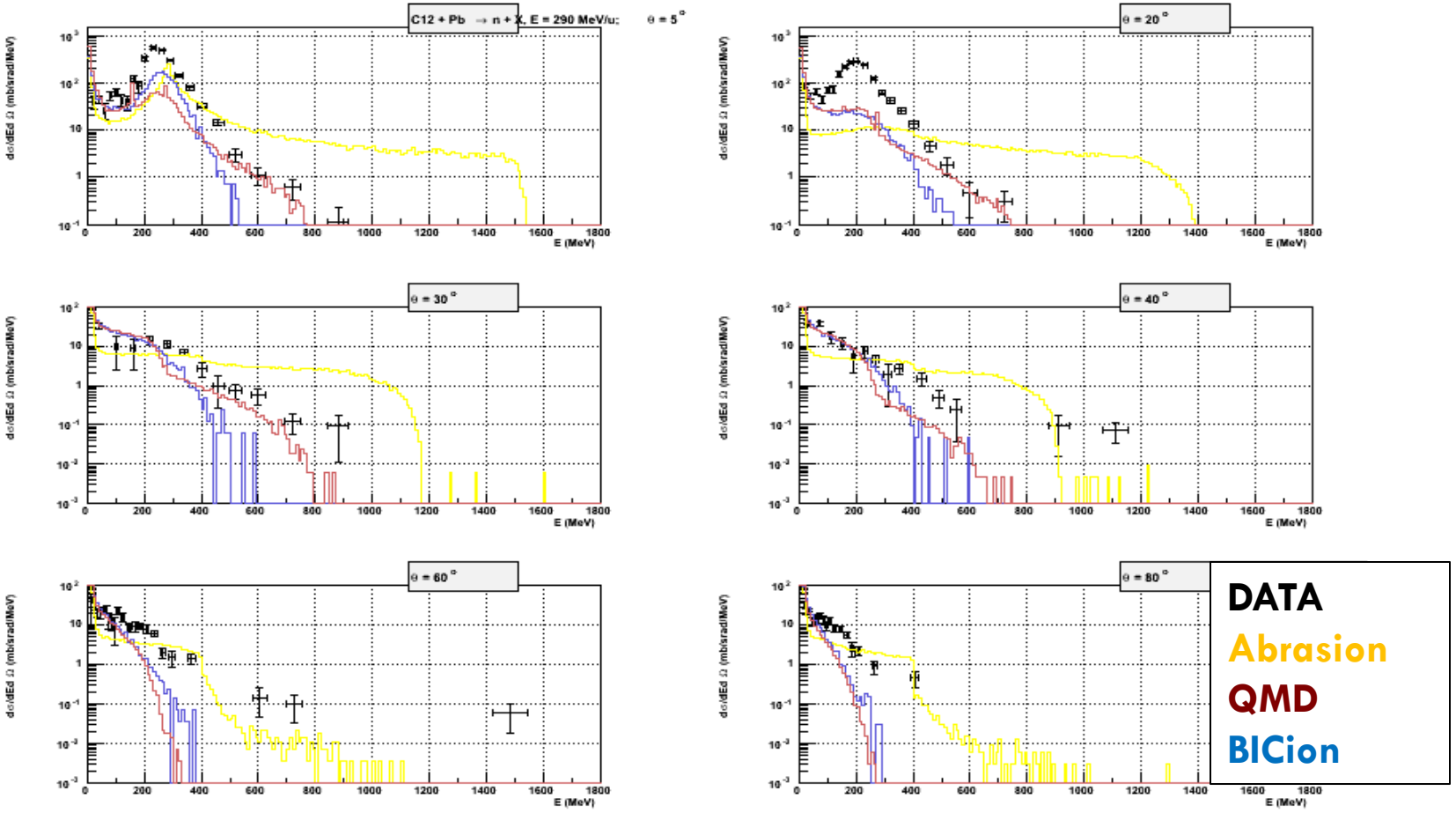
- It demonstrates how ion/ion physics can be invocated with interface of DPMJET-II.5
- It was requested at CERN by several users
- Implementation is based on experiences with GRAS
  - Following general structure of Geant4 examples
    - In geant4/examples/extended/hadronic/Hadr02
  - Extra subdirectory “dpmjet2_5”
  - Extra data set G4DPMJET2_5DATA
  - DPMJET-II.5 or FTF can be used for ion/ion
- Our favorite is the FTF model

Test30. Thin target neutron spectra. Al(C12, NN) 135 MeV/u

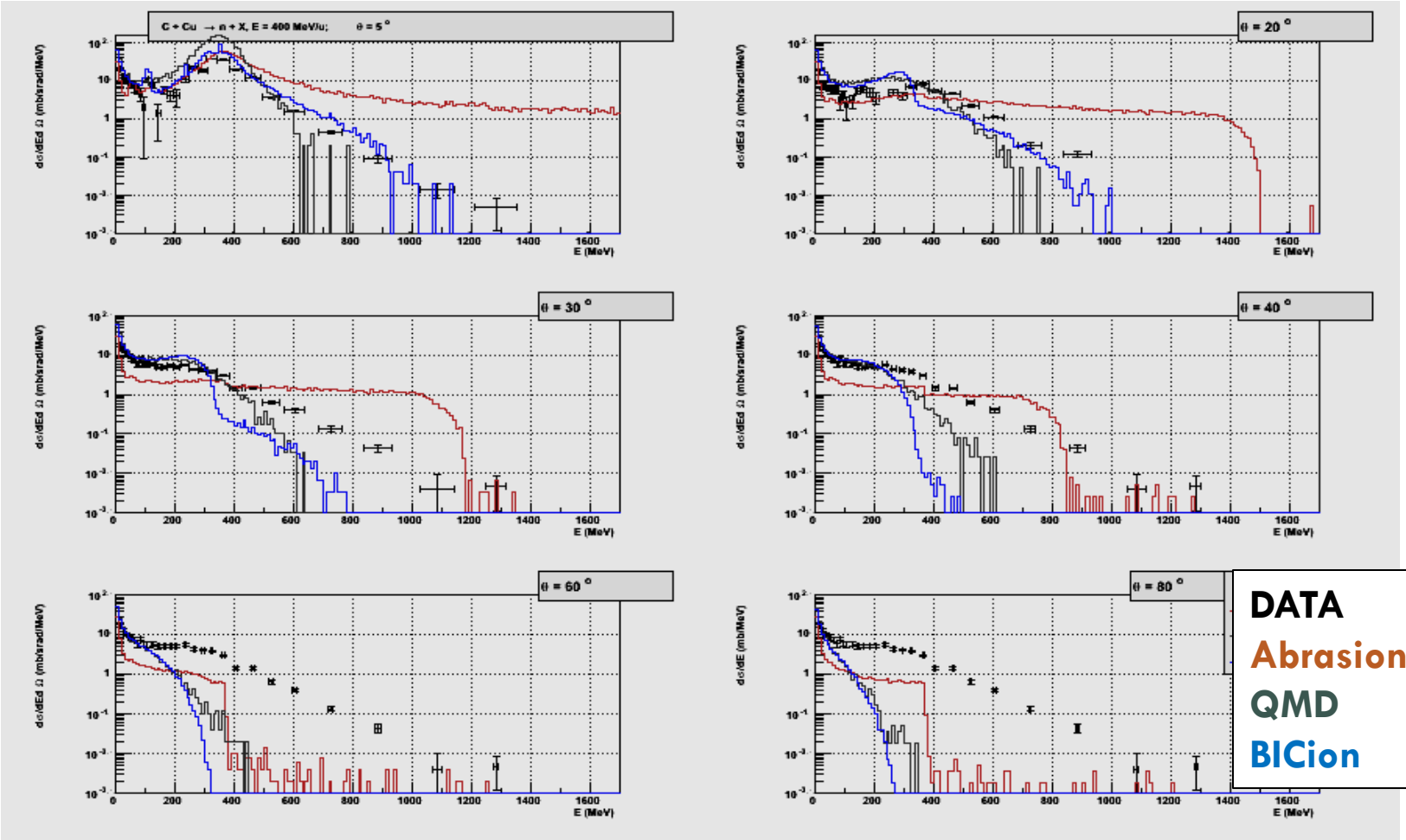
Typical for thin targets
0° is wrong



Test30. Thin target neutron spectra. Pb(C12, NN) 290 MeV/u

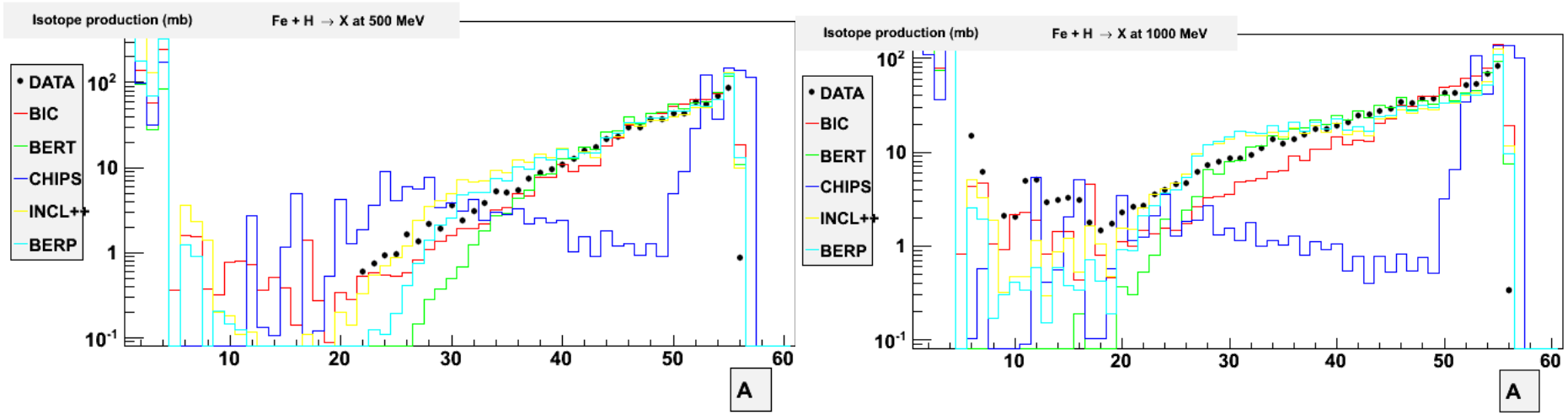


Test30: Thin target neutron spectra. Cu(C12,NN) at 400 MeV/u



High-E spectra typically is not reproduced

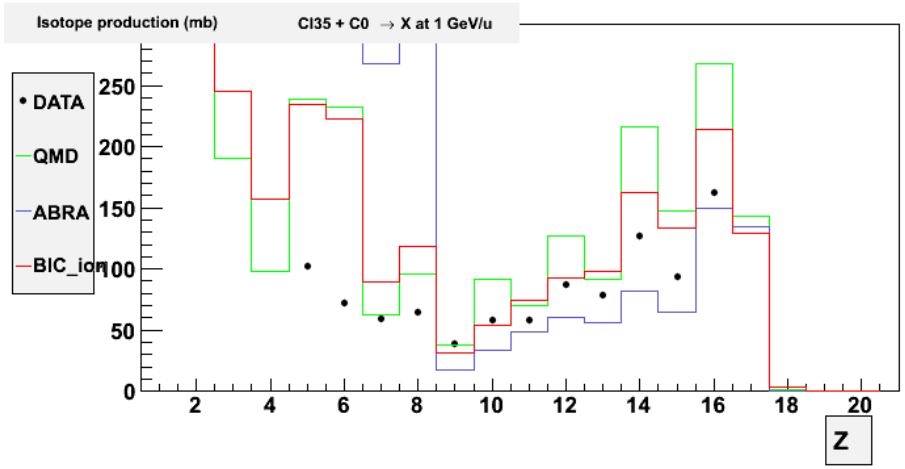
Spallation benchmark. Isotopes production.



H1(Fe56,IsoXS) 500 and 1000 MeV

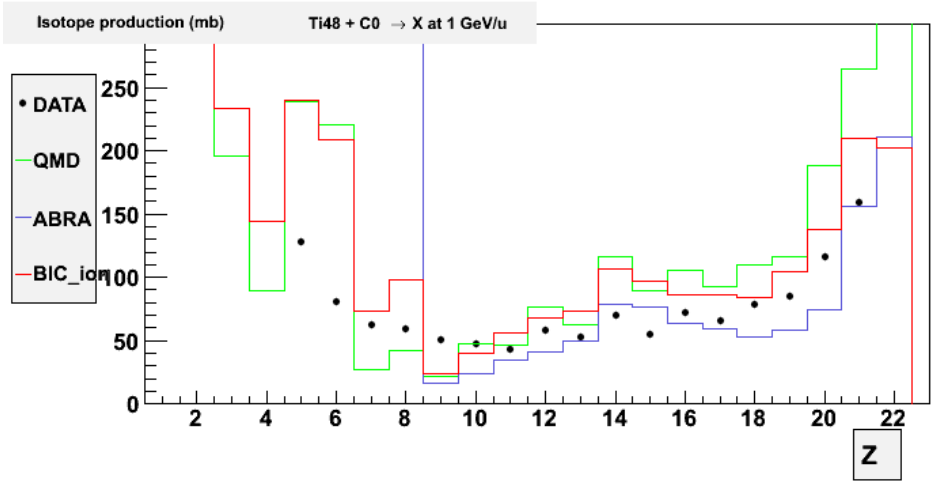
BERP and INCL++ are the most accurate

Thin targets. Fragmentation Cross Sections



- C(Cl35,Fxs) 1GeV/u

DATA
Abrasion
QMD
BICion



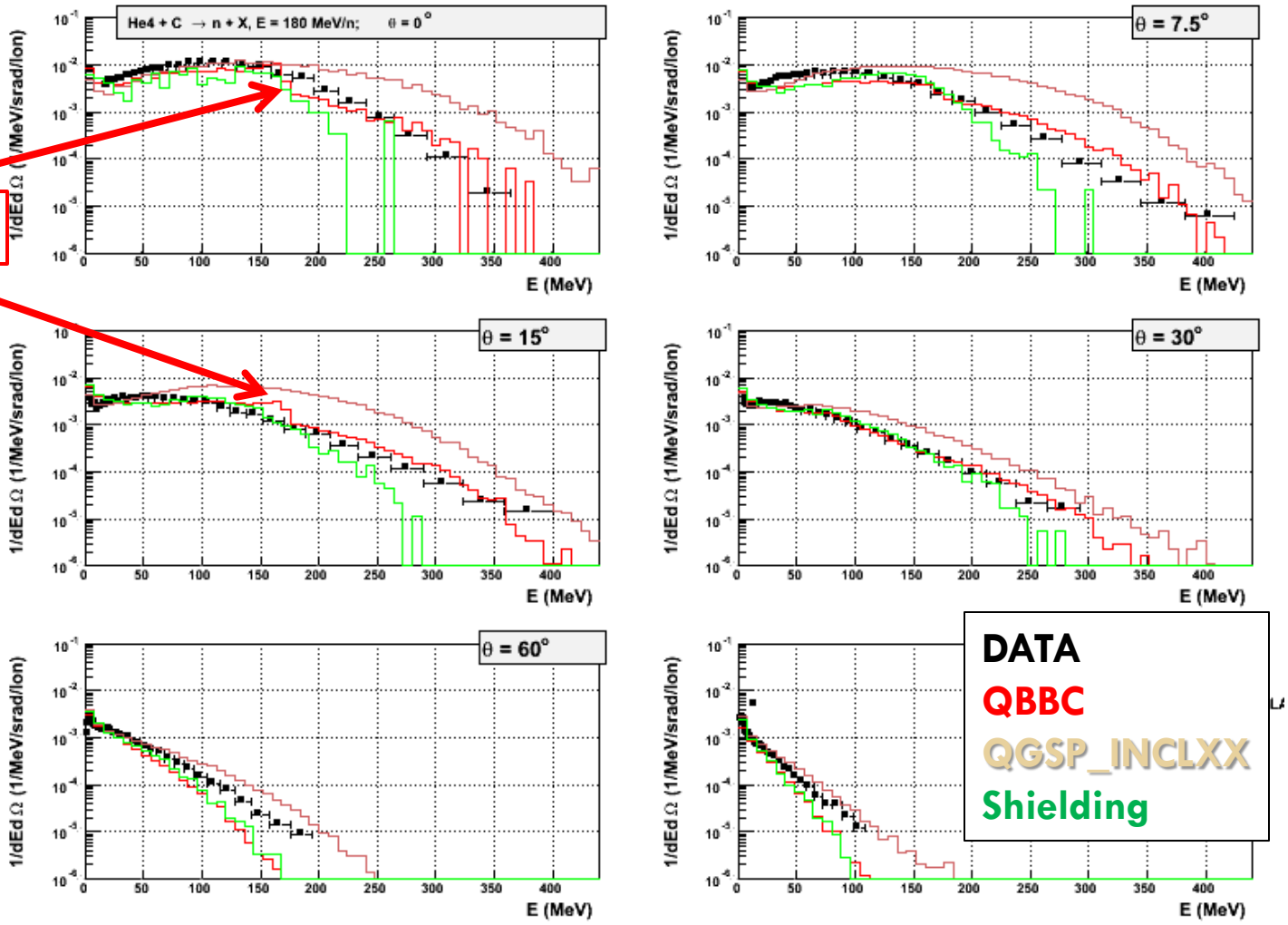
- C(Ti48,Fxs) 1GeV/u

DATA
Abrasion
QMD
BICion

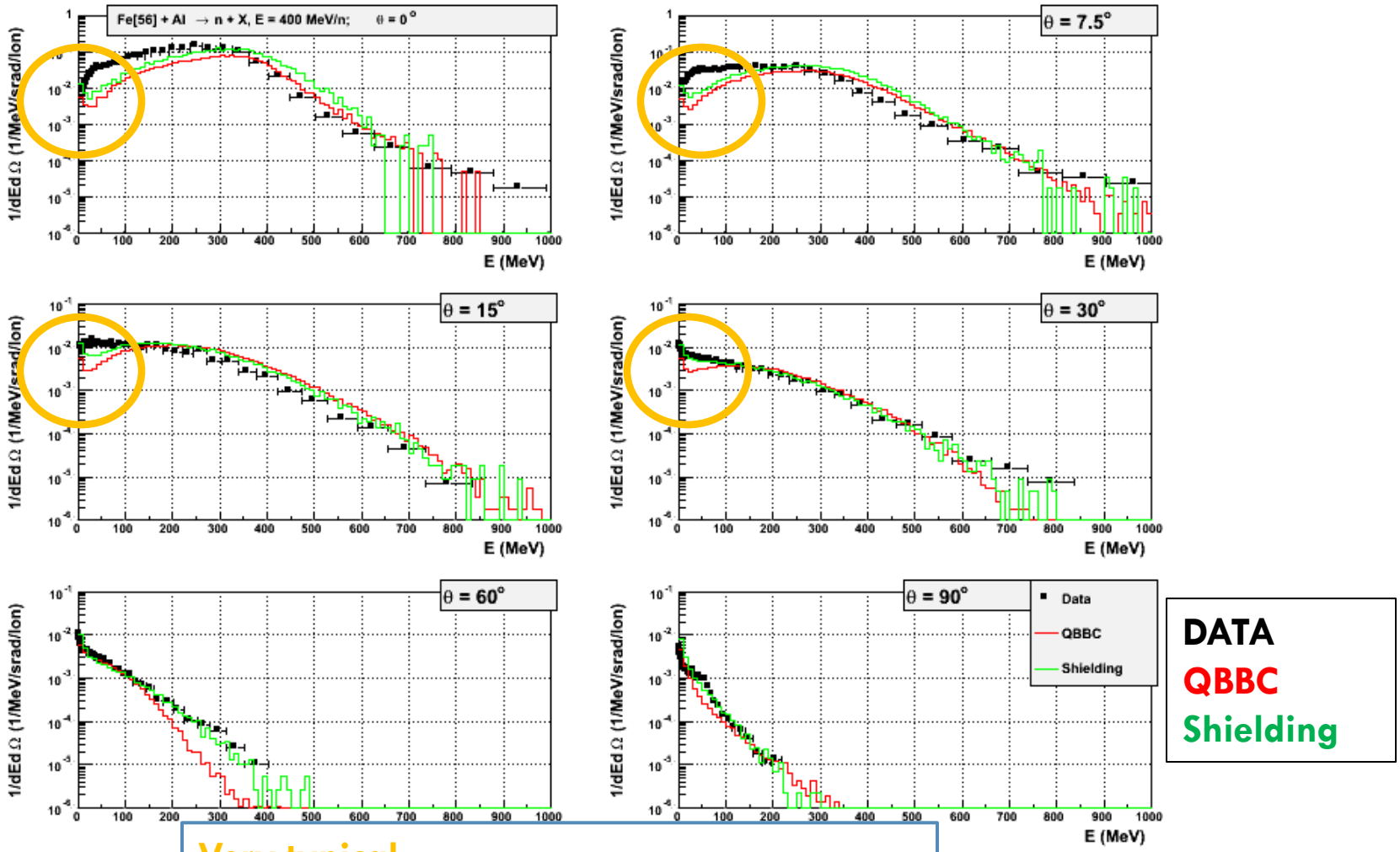
Test45ion. Thick targets neutron yield: C(He4,NN) 180 MeV/u

Steps in BICion

Shielding Needs higher CPU time



Test45ion. Thick target neutron yield: Al(Fe56,NN) at 400 MeV/u



CPU results for g4.9.5.ref07 test30 (regular run)

Model	Pb(Ne20) 400 MeV/u	C(Ne20) 400 MeV/u	Pb(C12) 400 MeV/u	Zr91(He4) 27 MeV
BICion	1.0	1.0	1.0	1.0
QMD	5.1	23.2	66.3	2980*
INCL++	0.7	0.45	0.9	93**
Abrasion	1.1	1.3	1.5	192

- * - QMD has infinite loop on most of 27 MeV interactions He4
- ** - INCL++ has many warnings on many events of 27 MeV interactions He4

Conclusions

- BICion is a good model for the space science

Ion/Ion development perspectives

- Geant4 Ion/Ion cross sections should be studied and improved (especially Elastic and EM dissociation XS of ions are not well established in Geant4)
- Improvements Geant4 models
  - Binary cascade needs improvements:
    - Internal elastic cross sections and generators
    - Coalescence model to sample production of high energy d, t, He3,He4
    - Design and implementation of utility classes which are responsible for CPU
  - Pre-compound model
    - Study on CPU performance and possible speed up
    - Improvements of internal cross sections
  - De-excitation models
    - GEM model requires review and redesign because is responsible for underestimation of light fragment production and CPU overhead
    - Multi-fragmentation model requires review and redesign
    - Isotope production data can be used to tune de-excitation models
  - Binary light ion cascade
    - Needs to be tuned to existing experimental data: new data at 62 MeV/u; old data already included in the testing suite on neutron production and fragmentation; extra data from recent experiments
  - Elastic models need extension of testing suite