Validation of Geant4 models

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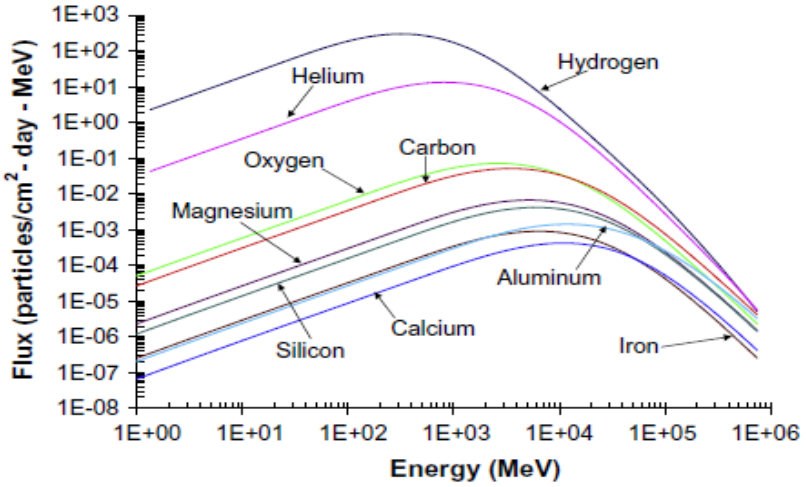
(under the ESA Technology Research Program)

Outline

- Introduction
- Testing suite extension with Ion/Ion validation
- Selected results
  - Ion interactions
  - Protons interactions in thick targets
- Conclusions

Space applications of Geant4 Ion/Ion models (ESA project A06041)



Ions flux on the Earth orbit

- Proton component of Cosmic Rays dominates
  - Geant4 simulation for proton incident is reasonable
- Radiation damage provided by ions is significant
  - Simulation precision for Geant4 Ion/Ion interactions is lower than that for protons
  - Validation of ion/ion interactions was limited
- This work is also useful for other applications:
  - LHC experiments
  - NA61 (requested for DPMJET interface)
  - Hadron therapy communities

Testing suite extension with Ion/Ion interactions

- First Ion/Ion settings were in IAEA benchmark since 2009
- Current work has been started in 2010
- Existing tests were extended and new tests are created

Tests used for validation of ion/ion interactions

- **IAEA spallation benchmark -** thin targets
  - Isotope production
  - 0.5-2 GeV/u
- **Test30** – thin target - neutron production
  - d, He4, C12, Ne20, Cl37, Ar40 projectile
  - 10-600 MeV/u
- **Test45ion** – thick target - neutron production
  - d, He4, C12, Ne20, Ar40, Fe56 projectile
  - 20-800 MeV/u
- **HADR02** – fragmentation – cross section
  - O16, S32, Fe56 projectile
  - 1-200 GeV/u

Models and Physics Lists tests for ion/ion interactions

- **Model level tests (test30, IAEA)**
  - BIC_ion
  - QMD
  - CHIPS
  - INCL
- **Physics List tests (test45ion, Hadr02)**
  - QBBC
  - QGSP_BIC
  - Shielding
  - CHIPS
  - INCL_ABLA
  - DPMJET-II.5 on top of any Physics List
  - FTFP_BERT

Data added for ion/ion validation

Test45ion – neutron yield on thick targets: experimental data from HIMAC (Japan) in 2001 – "Reevaluation of secondary neutron spectra…"

Projectile type and energy (MeV/nucleon)	Target and thickness (cm)			
He(100)	C(5.0)	Al(4.0)	Cu(1.5)	Pb(1.5)
He(180)	C(16.0)	Al(12.0)	Cu(4.5)	Pb(5.0)
C(100)	C(2.0)	Al(2.0)	Cu(0.5)	Pb(0.5)
C(180)	C(6.0)	Al(4.0)	Cu(1.5)	Pb(1.5)
C(400)	C(20.0)	Al(15.0)	Cu(5.0)	Pb(5.0)
Ne(100)	C(1.0)	Al(1.0)	Cu(0.5)	Pb(0.5)
Ne(180)	C(4.0)	Al(3.0)	Cu(1.0)	Pb(1.0)
Ne(400)	C(11.0)	Al(8.0)	Cu(3.0)	Pb(3.0)
Ar(400)	C(7.0)	Al(5.5)	Cu(2.0)	Pb(2.0)
Fe(400)	C(4.0)	Al(3.0)	Cu(1.5)	Pb(1.5)
Xe(400)	C(3.0)	Al(2.0)	Cu(1.0)	Pb(1.0)
Si(800)	C(23.0)		Cu(6.5)	

Test30 – thin target test: experimental data from RIKEN (Japan) – "Measurements of double differential neutron production…", DDXS

Target and thickness (mm)	Projectile type and energy (MeV/nucleon)	Energy loss in the target (MeV/nucleon)	Ratio of the energy loss in the target to the beam energy (%)
C (1.0)	He (135)	0.84	0.62
	C (135)	2.5	1.9
	Ne (135)	4.2	3.1
	Ar (95)	8.7	9.2
Al (0.6)	He (135)	0.74	0.55
	C (135)	2.2	1.6
	Ne (135)	3.7	2.7
	Ar (95)	7.7	8.1
Cu (0.3)	He (135)	1.1	0.79
	C (135)	3.2	2.4
	Ne (135)	5.3	3.9
	Ar (95)	11	11
Pb (0.3)	He (135)	0.98	0.73
	C (135)	2.9	2.2
	Ne (135)	4.9	3.6
	Ar (95)	10	11
Polyethylene (1.0)	He (135)	0.60	0.44

Test30 – thin target test: experimental data from HIMAC (Japan) – "Double differential cross sections …", DDXS

Beam (MeV)	Thickness (g/cm^2) C target	Cu target	Pb target
C at $E/A = 290$	1.80	4.47	2.27
C at $E/A = 400$	9.00	13.4	9.08
Ne at $E/A = 400$	1.80	4.47	2.27
Ne at $E/A = 600$	3.60	4.47	4.54
Ar at $E/A = 400$	0.720	1.34	1.70
Ar at $E/A = 560$	1.08	1.79	2.27

NEW

IAEA benchmark – thin target test: experimental data from HIMAC (Japan) and NRSL (USA)– "Fragmentation cross sections of medium-energy…", Fragmentation XS

Ion species	E_{beam} (MeV/nucleon)
^{35}Cl	650, 1000
^{40}Ar	290
^{40}Ar	400
^{40}Ar	650
^{40}Ar	650
^{48}Ti	1000

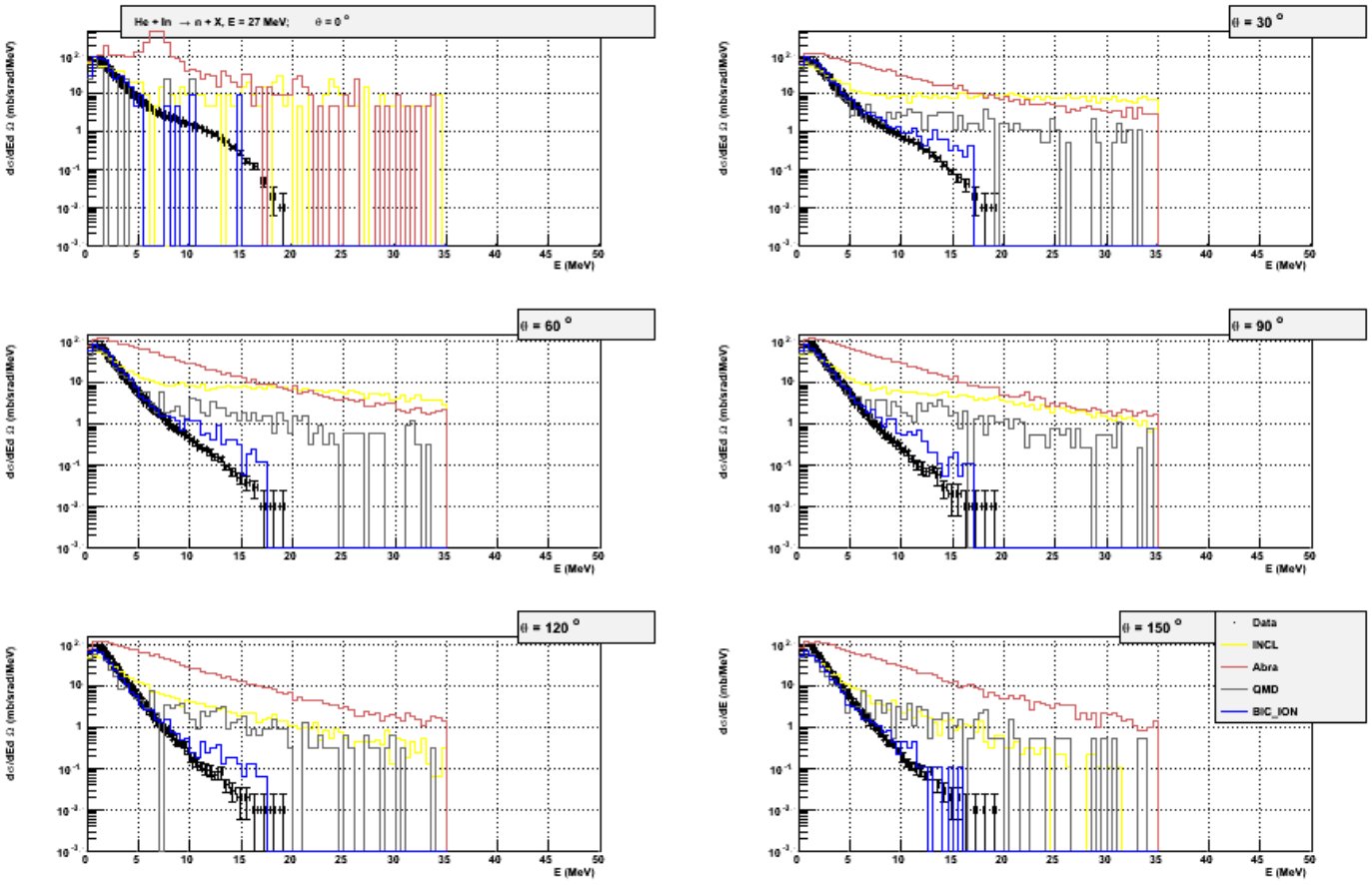
HADR02 – high energy test

- Hadr02 was created to test DPMJET in Geant4
- Can be used now for all energies and Physics lists
- Now we added the data of fragmentation XS
  - S32 and O16 of 1, 60, 200 GeV/u
  - Fe56 of 1.88 GeV/u

Selected results for 9.5beta

mainly new plots and problematic results are shown

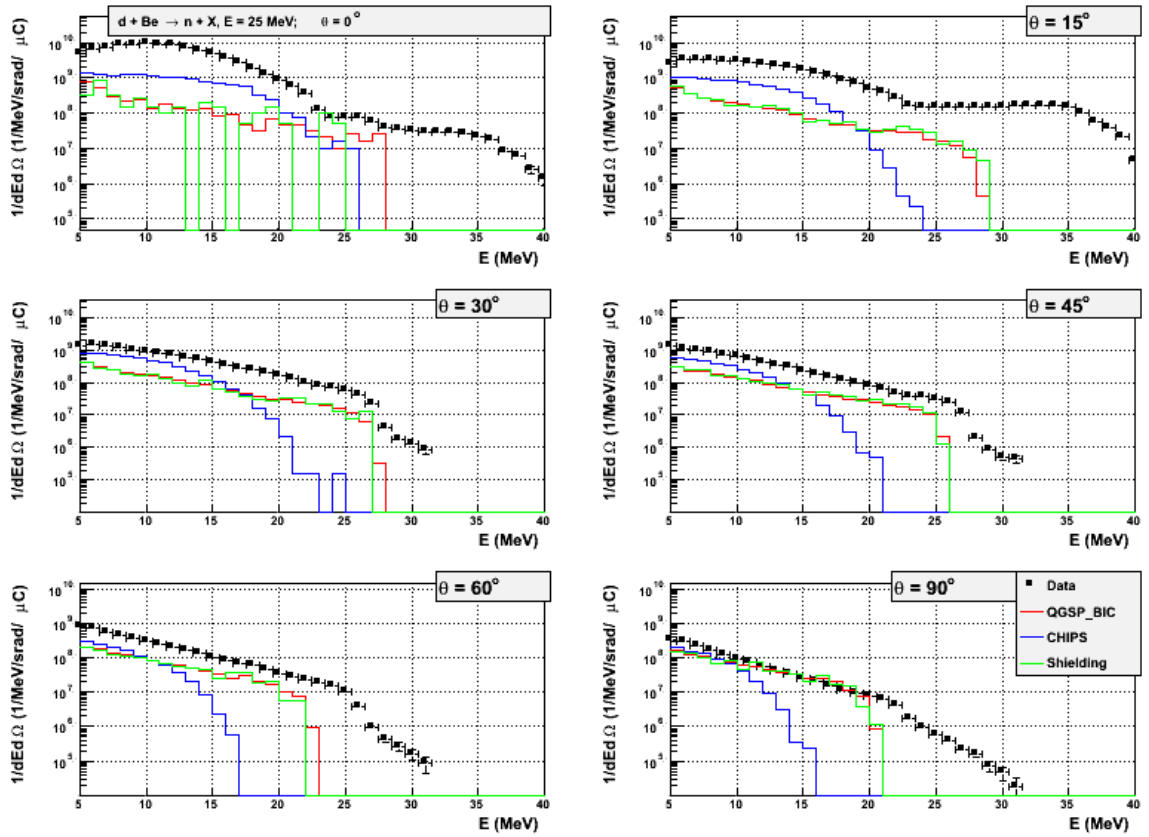
Thin target neutron DDXS: In-115(He,n) at 26.8 MeV



DATA
INCL
Abrasion
QMD
BICion

Example where BICion is the only working model

Thick target neutron yield: Be(d,n) at 25 MeV



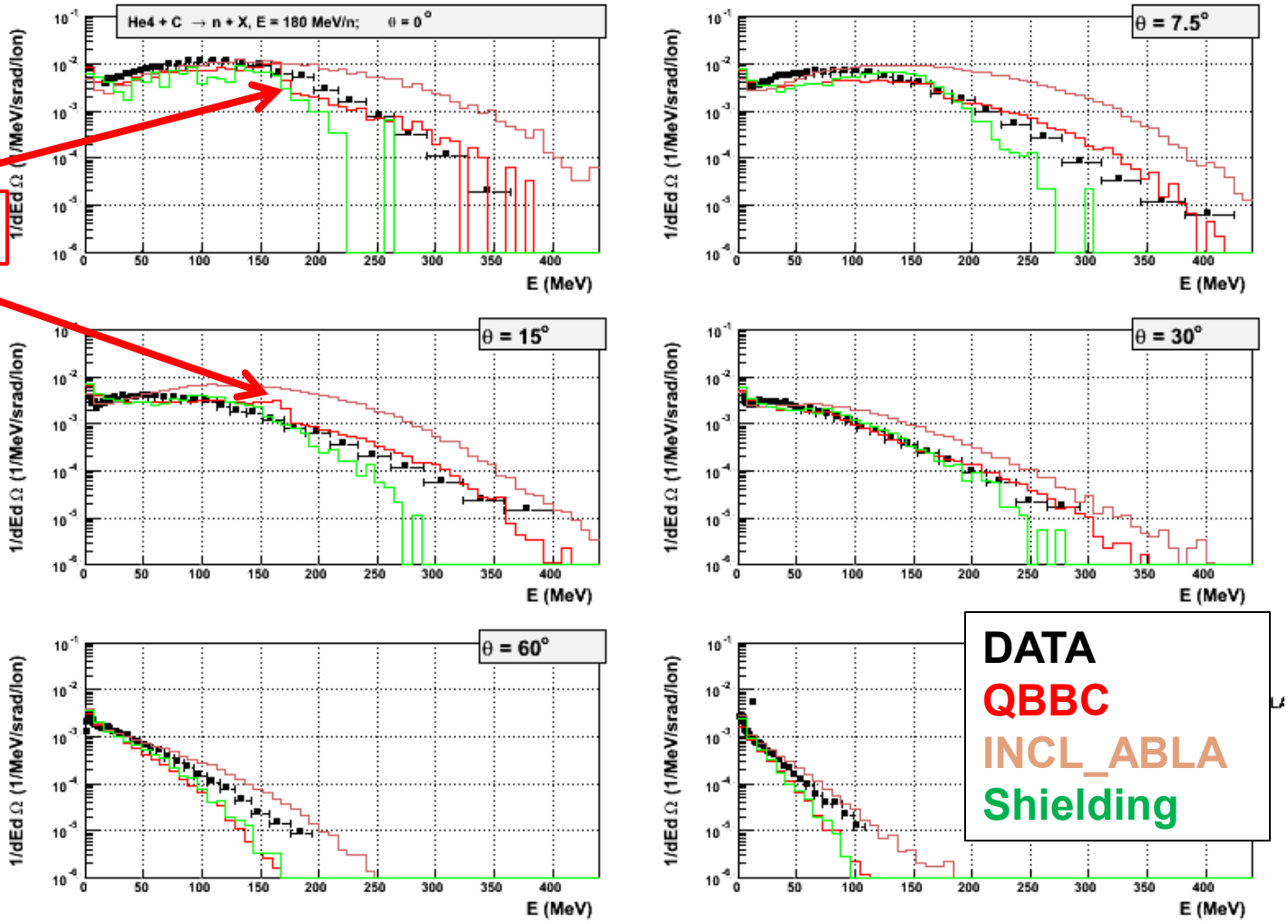
DATA
QGSP_BIC
Shielding
CHIPS

Geant4 models cannot reproduce experiment

Thick targets neutron yield: C(He4,n) 180 MeV/u

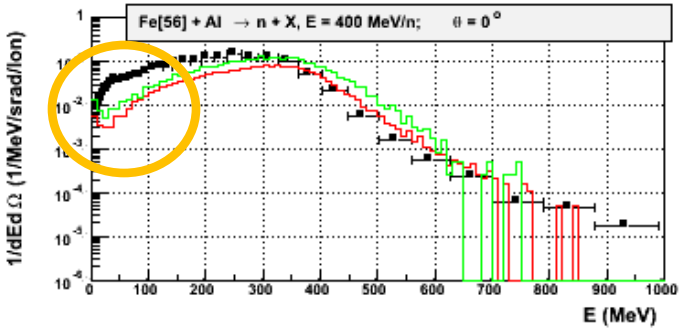
Steps in BICion

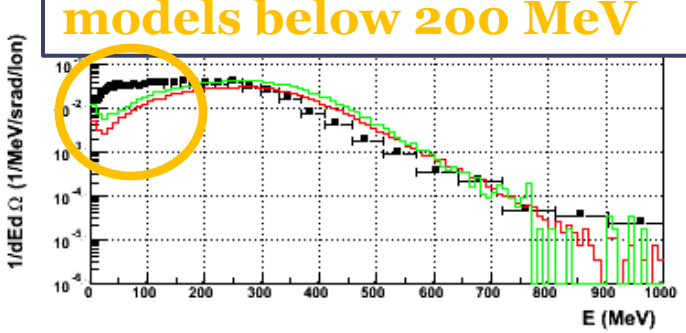
QMD needs CPU time

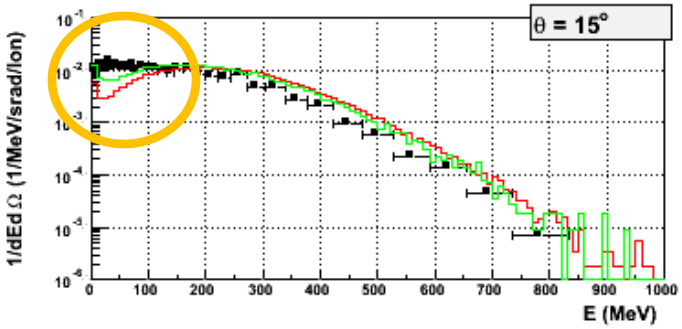


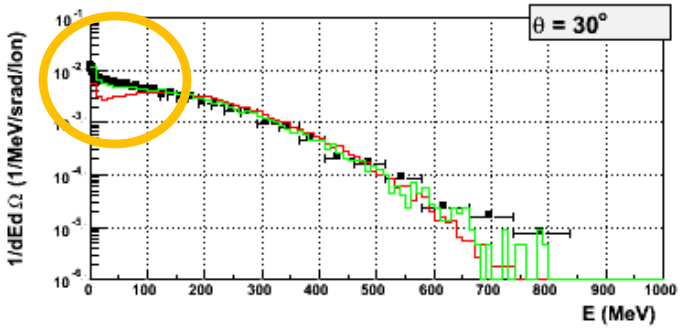
Thick target neutron yield: Al(Fe56,n) at 400 MeV/u

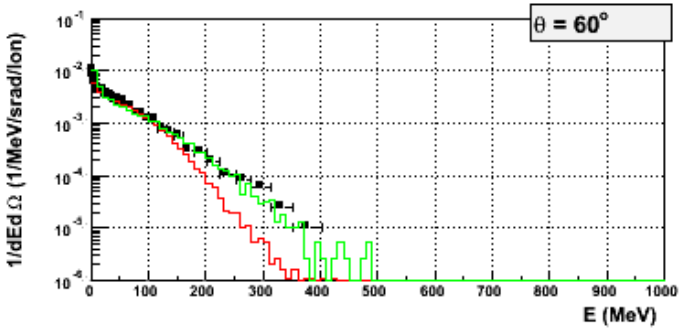
Very typical problem for all models below 200 MeV

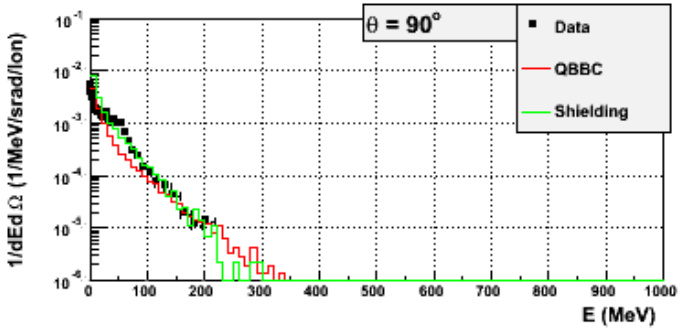








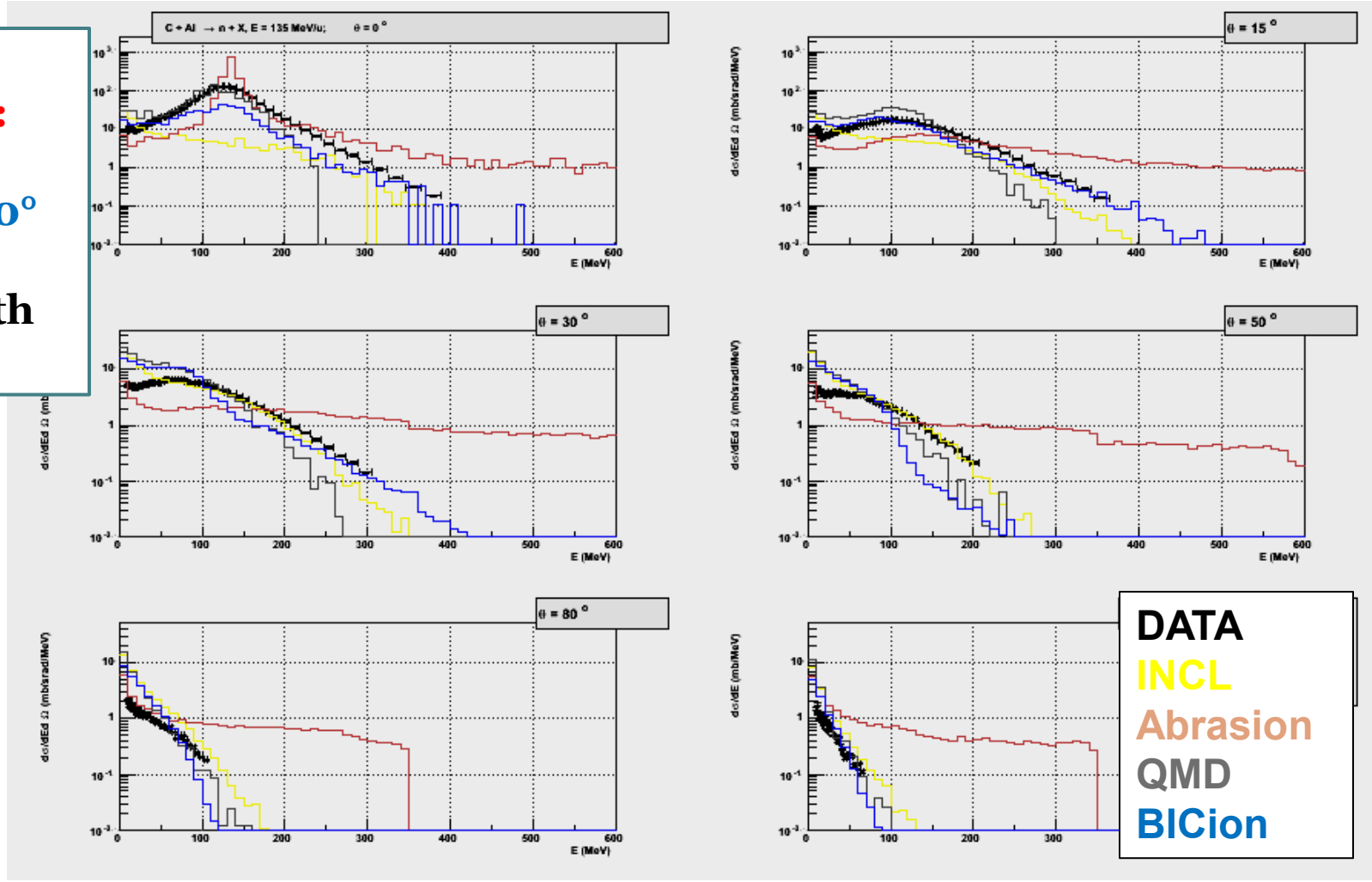




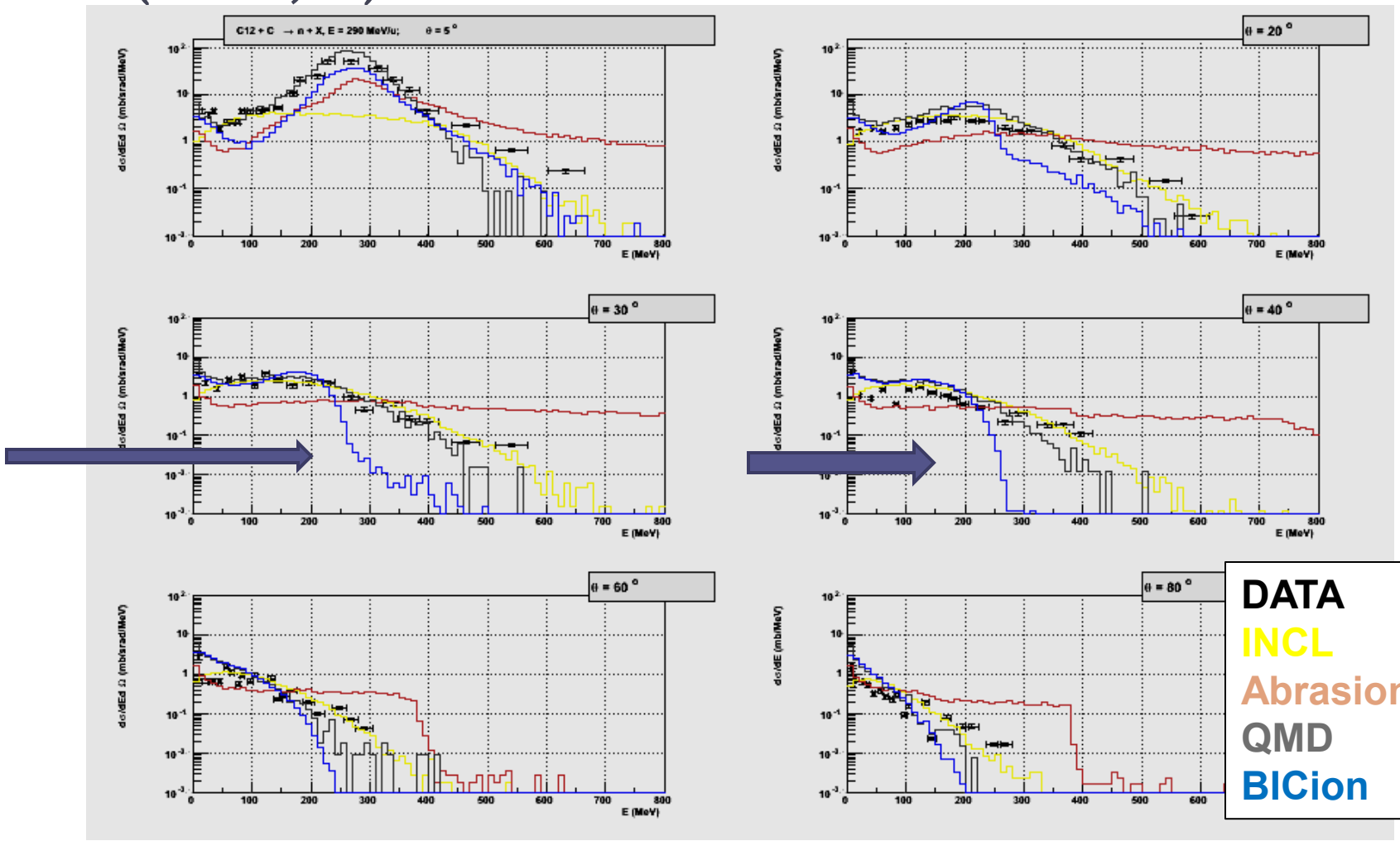
DATA
QBBC
Shielding

Thin target neutron DDXS: Al(C12,n) at 135 MeV/u

Typical for thin targets:
BIC has problem at 0°
QMD has problem with the tail

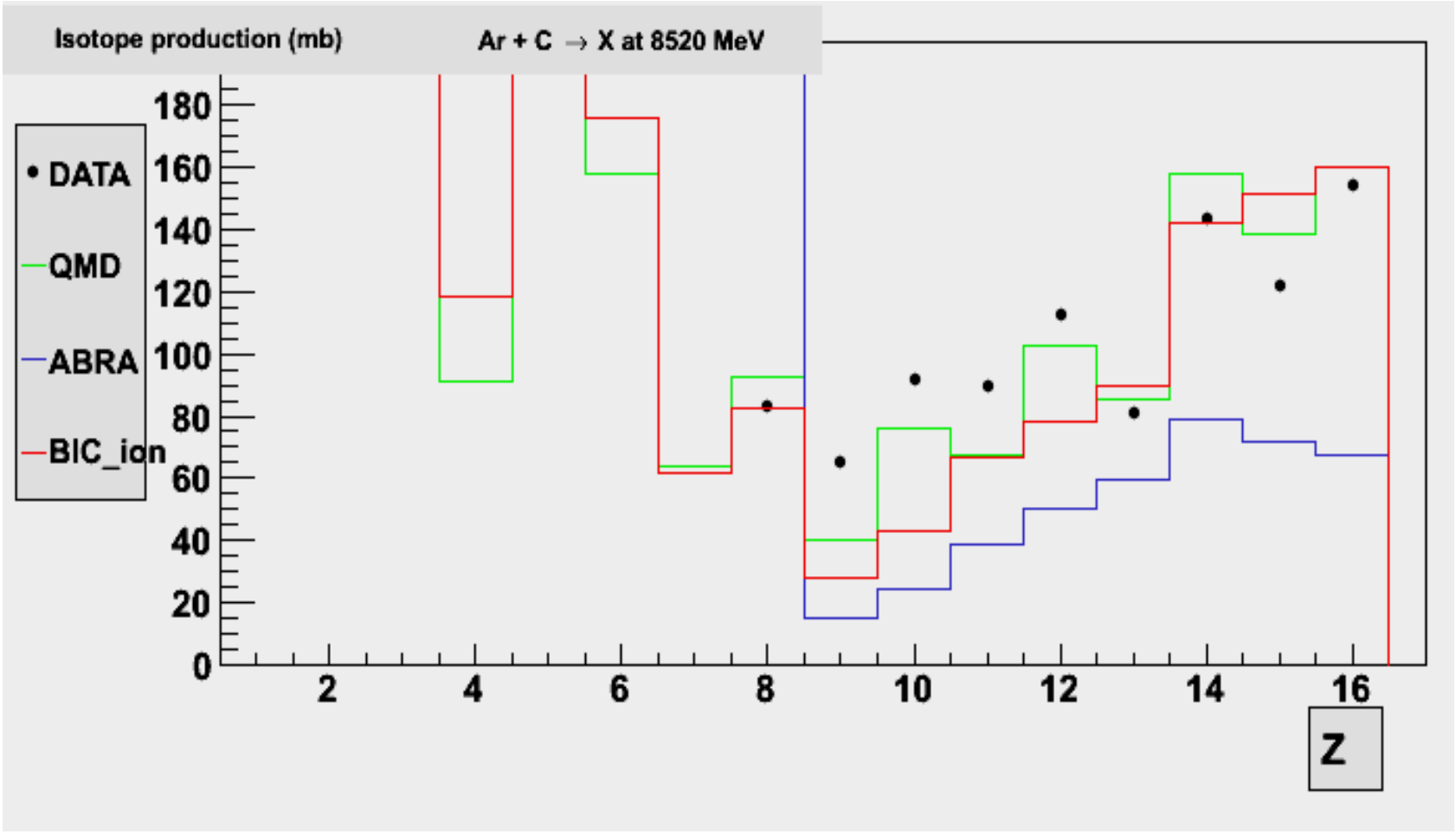


Thin target neutron DDXS: C0(C12,n) at 290 MeV/u

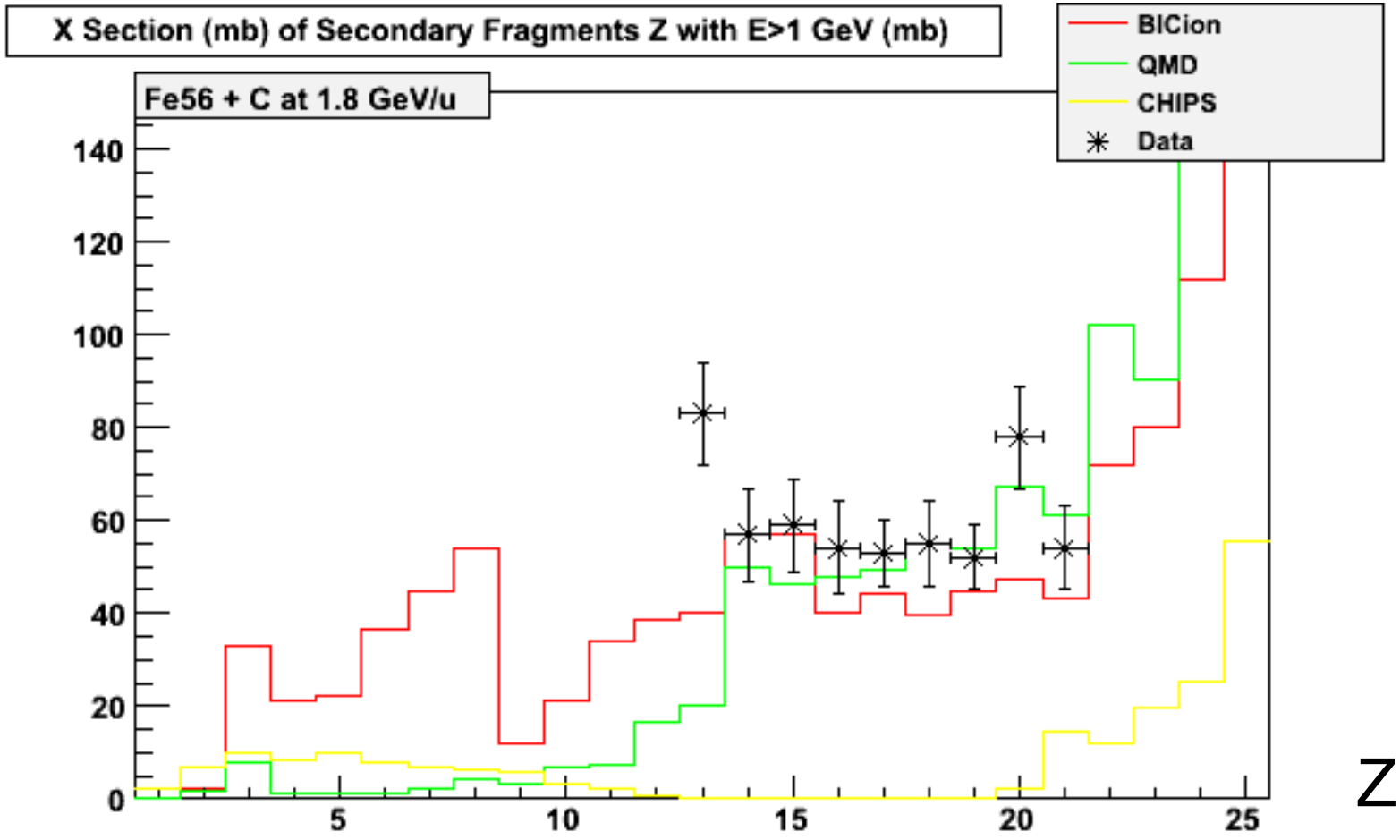


Long tail typically is not reproduced by BICion

IAEA: fragmentation XS, C(Ar40, Iso) at 213 MeV/u

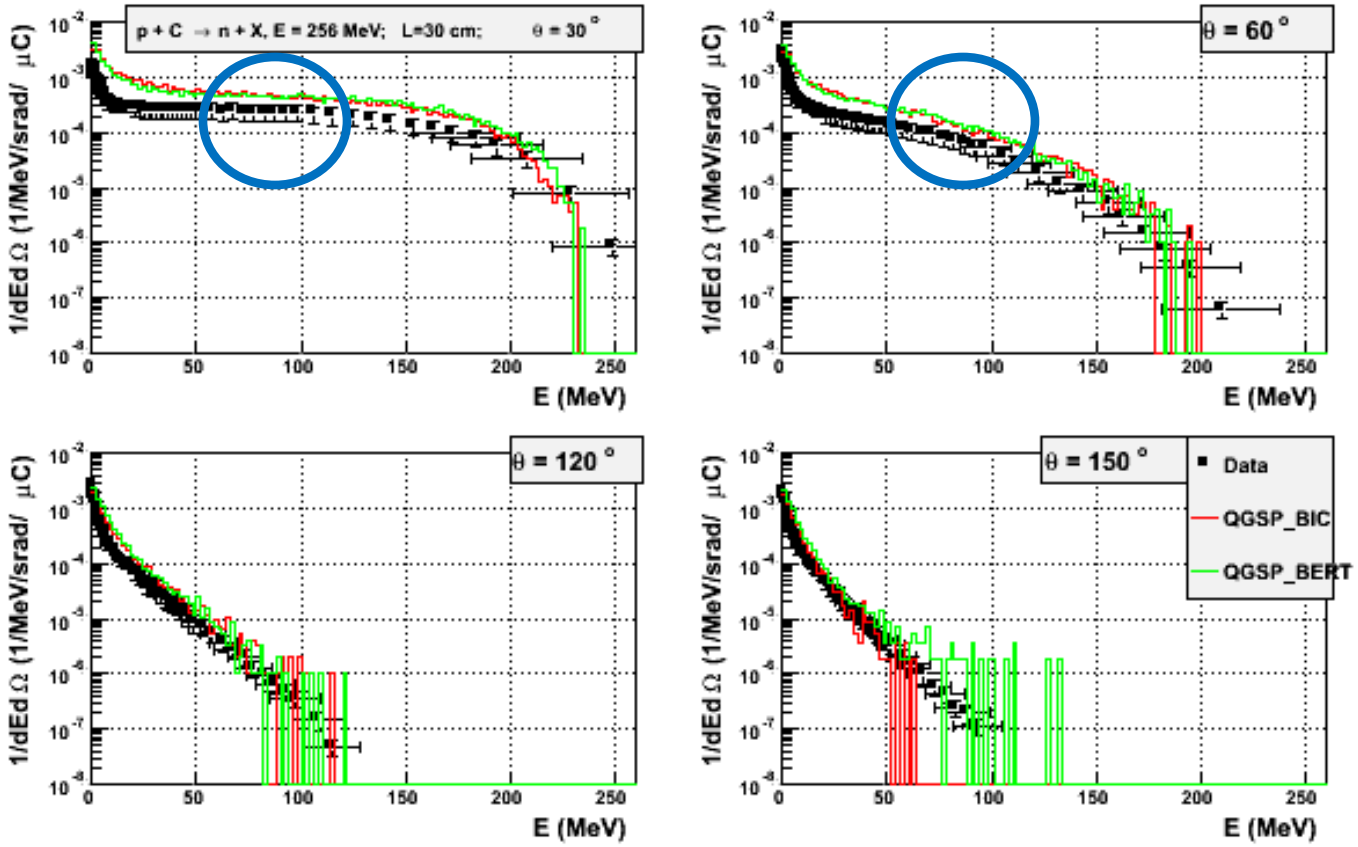


Fe56 on Carbon (37 mm) at 1.8 GeV/u (9.4.ref07)



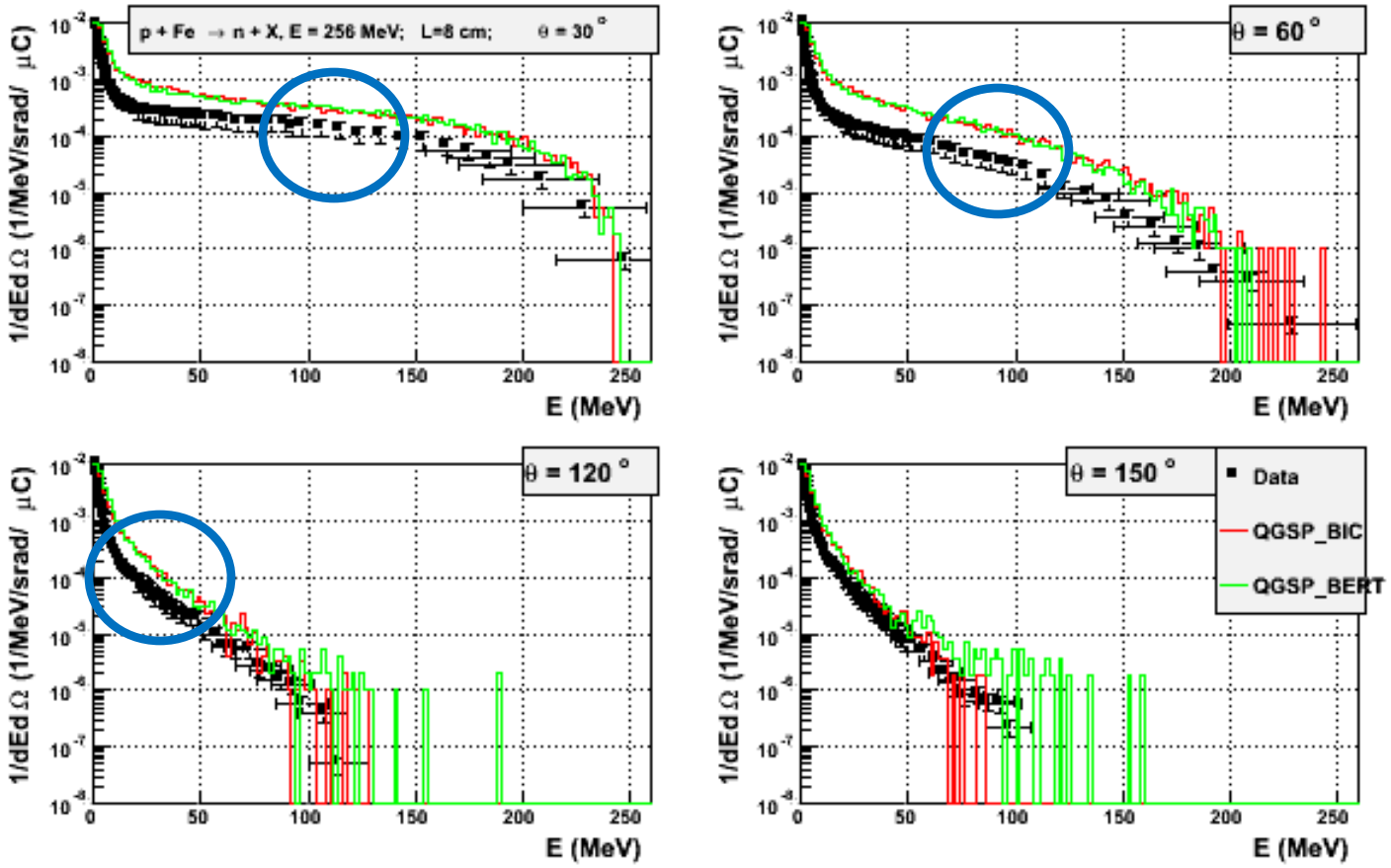
Protons interactions in thick targets (new IAEA benchmark)

Thick target neutron yield: C(p,NN) 256 MeV (30 sm)



Problems in forward angles for both of BIC and BERT
Good agreement at large angles

Thick target neutron yield: Fe(p,NN) 256 MeV (30 sm)



Problems in forward angles for both of BIC and BERT
Good agreement at 150° only

Conclusions

- Testing suite for Ion/Ion interaction validation significantly extended
  - neutron production below 1 GeV/u is available
  - fragmentation XS at low and high energies
- There are problems in Geant4 models for Ion/Ion interactions
  - At low energy (>100 MeV/u) in all models
  - At high energy – FTF cannot provide fragmentation
  - DPMJET-II.5 has limitation (projectile Z < 27)
- Thick target benchmark proposed by IAEA some time ago show problems in interpretation of data at forward angles