Results of the de-excitation code ABLA07

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Layout

- Improvements in ABLA07
- Stages of a spallation reaction
- Influence of the 1^{st} stage on the results
- Comparison of ABRA, INCL4, ISABEL + ABLA07
- Conclusions

Improvements
in
ABLA07

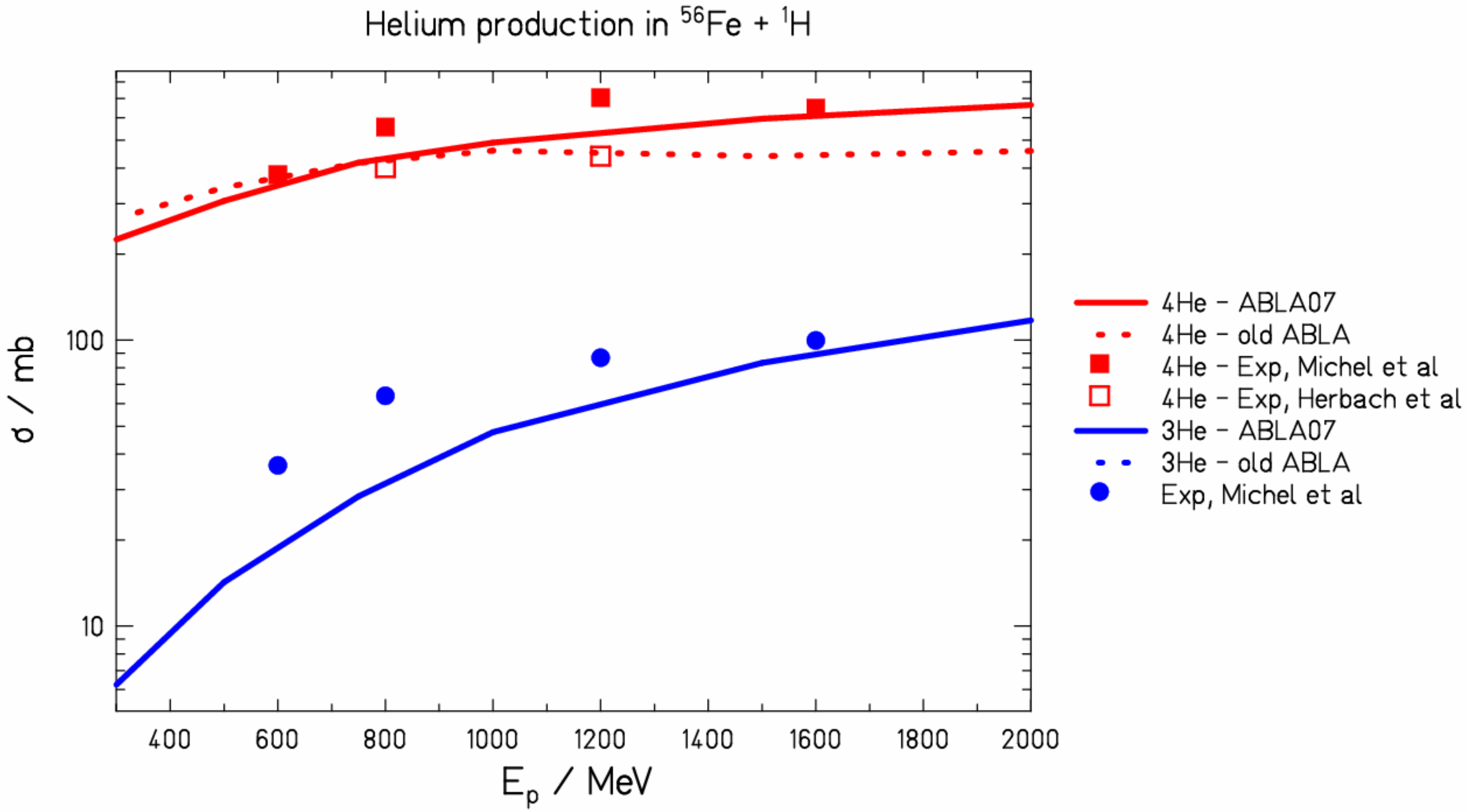
see proceedings of the
“Joint ICTP-IAEA Advanced Workshop on Model Codes for Spallation Reactions„
held in Trieste, Italy, 4-8 January 2008

ABLA07

New features (with moderate increase of computing time):

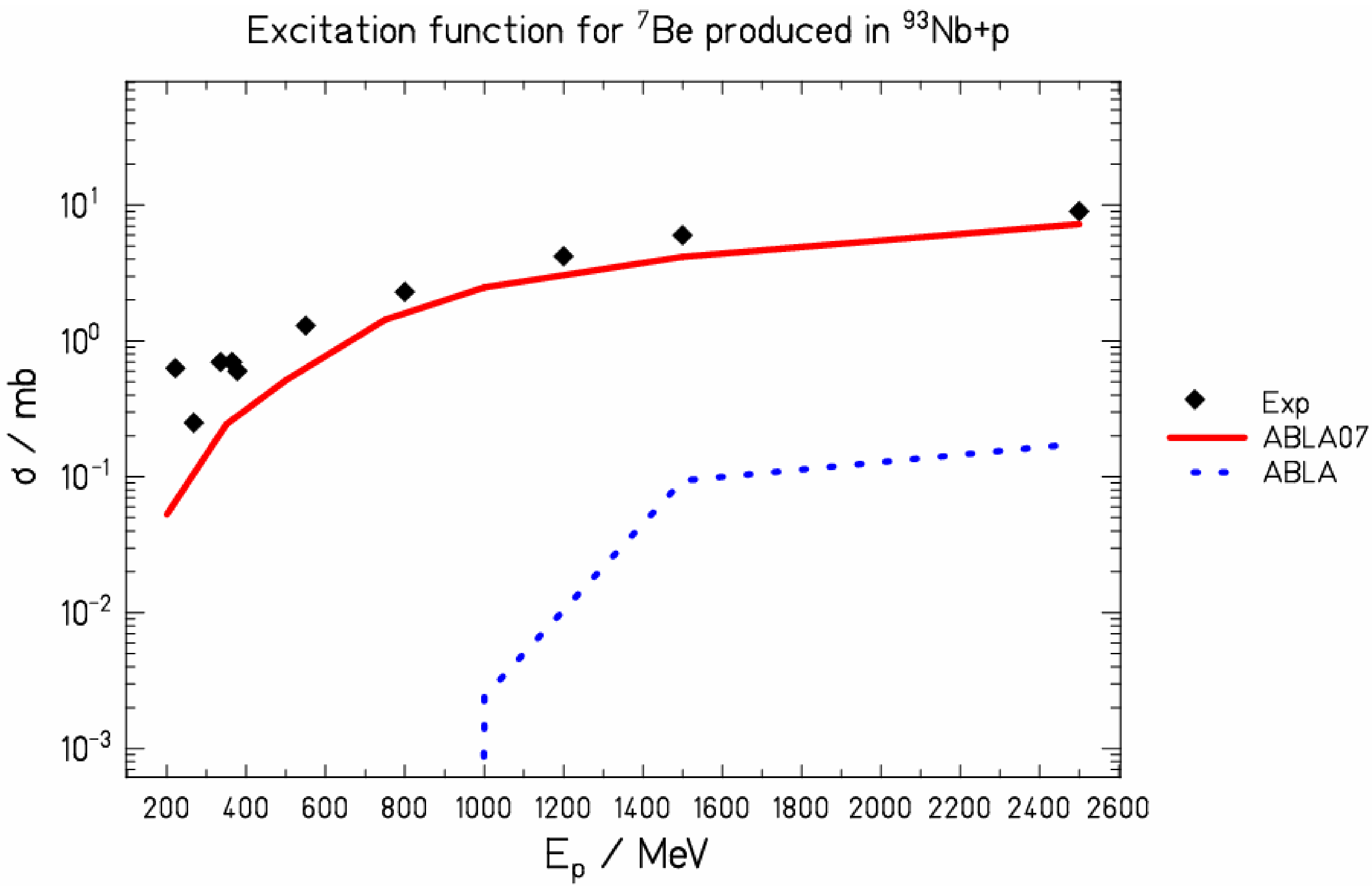
- Multifragmentation
- CN-decay channels γ, n, p, LCP, IMF, fission (continuous)
  - inverse x-sections from nuclear potential
  - treatment of angular momentum
  - fission transients from Fokker-Planck equation
  - barrier structure in low-energy fission
  - nuclide production in fission with 1 parameter set
    - from spontaneous fission to high E* for all CN
  - evaporation on fission path

Production of helium



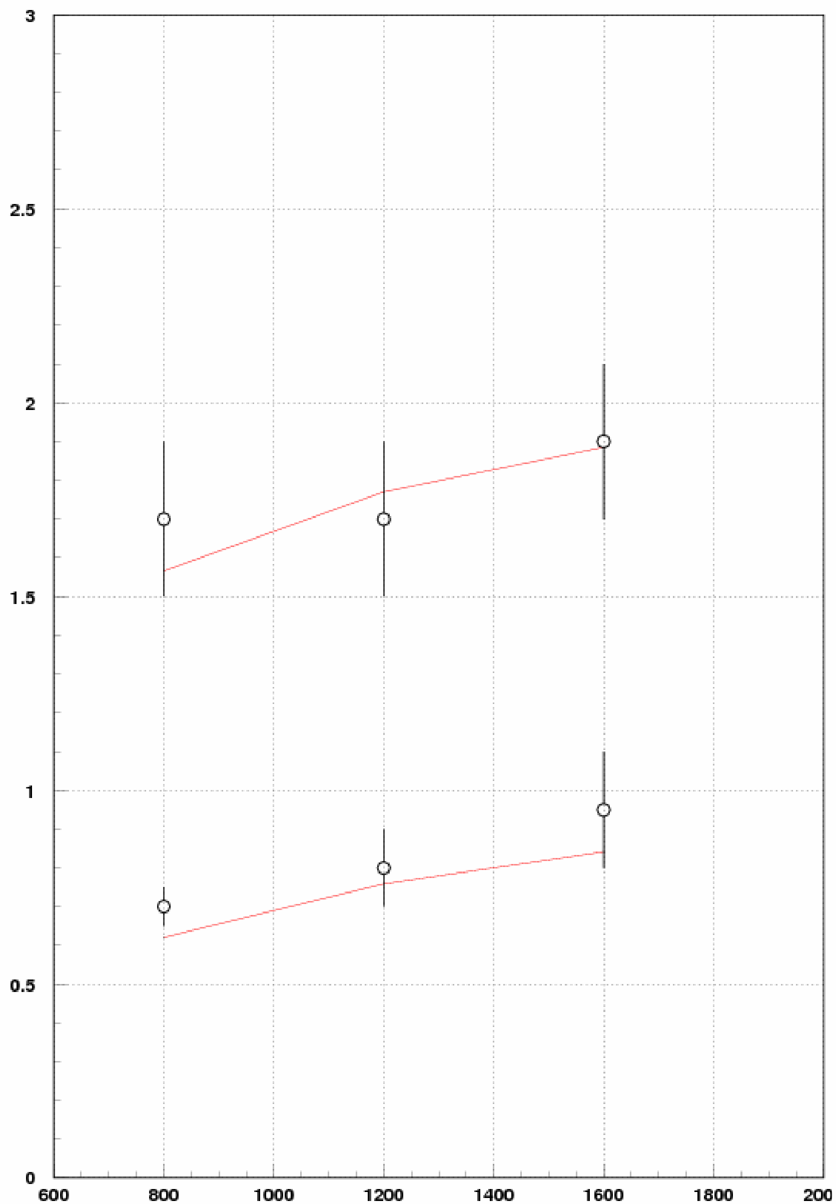
Data: R. Michel et al., NIM B 103,
C. M. Herbach et al., Proc SARE-5 meeting, 2000

Production of ^7Be



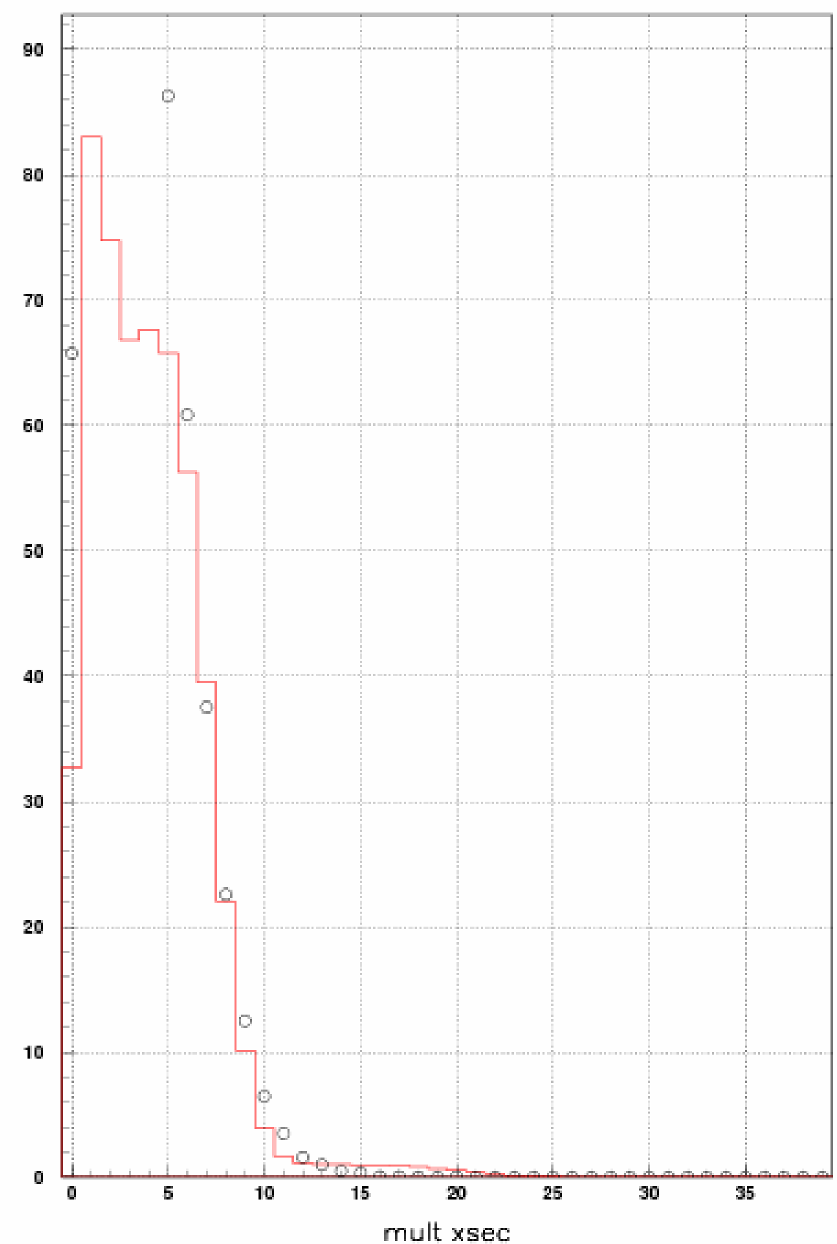
2009/05/01

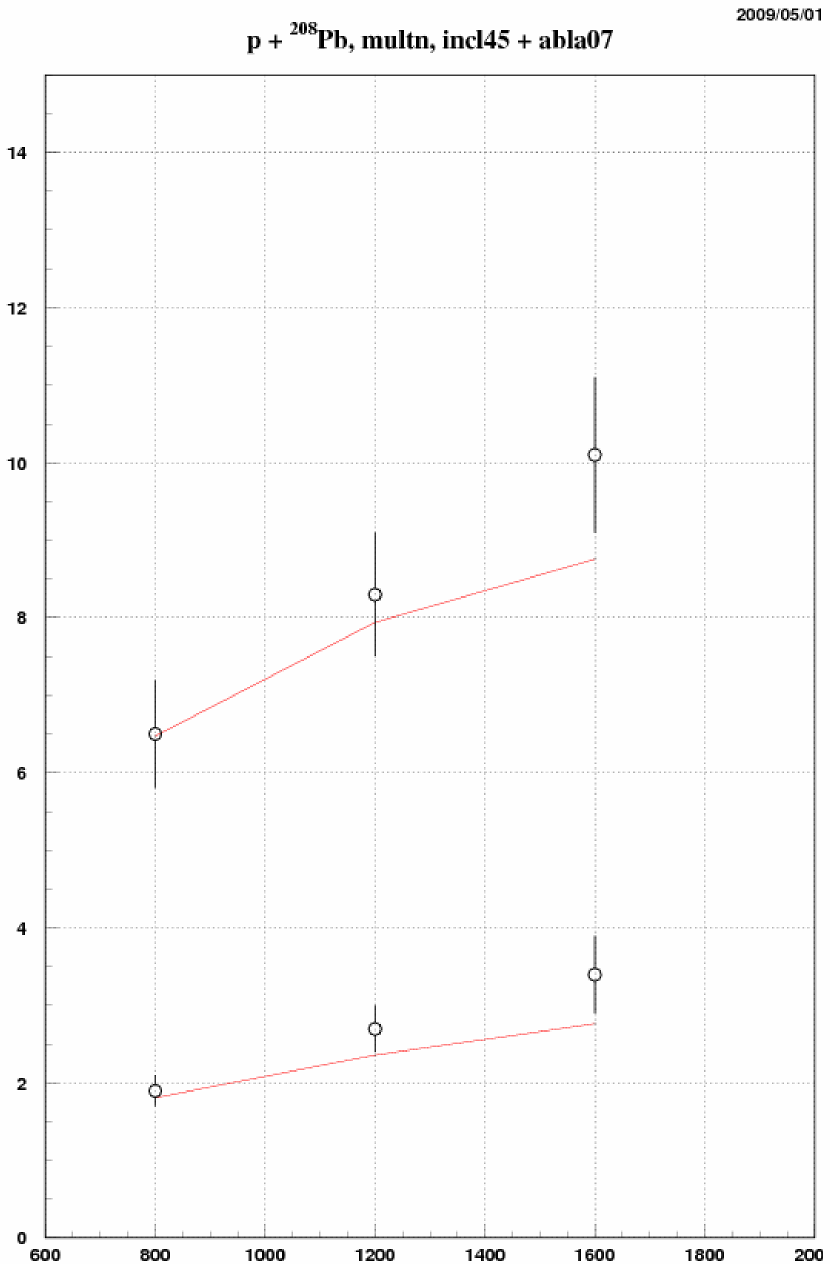
p + ^{56}Fe, multn, incl45 + abla07



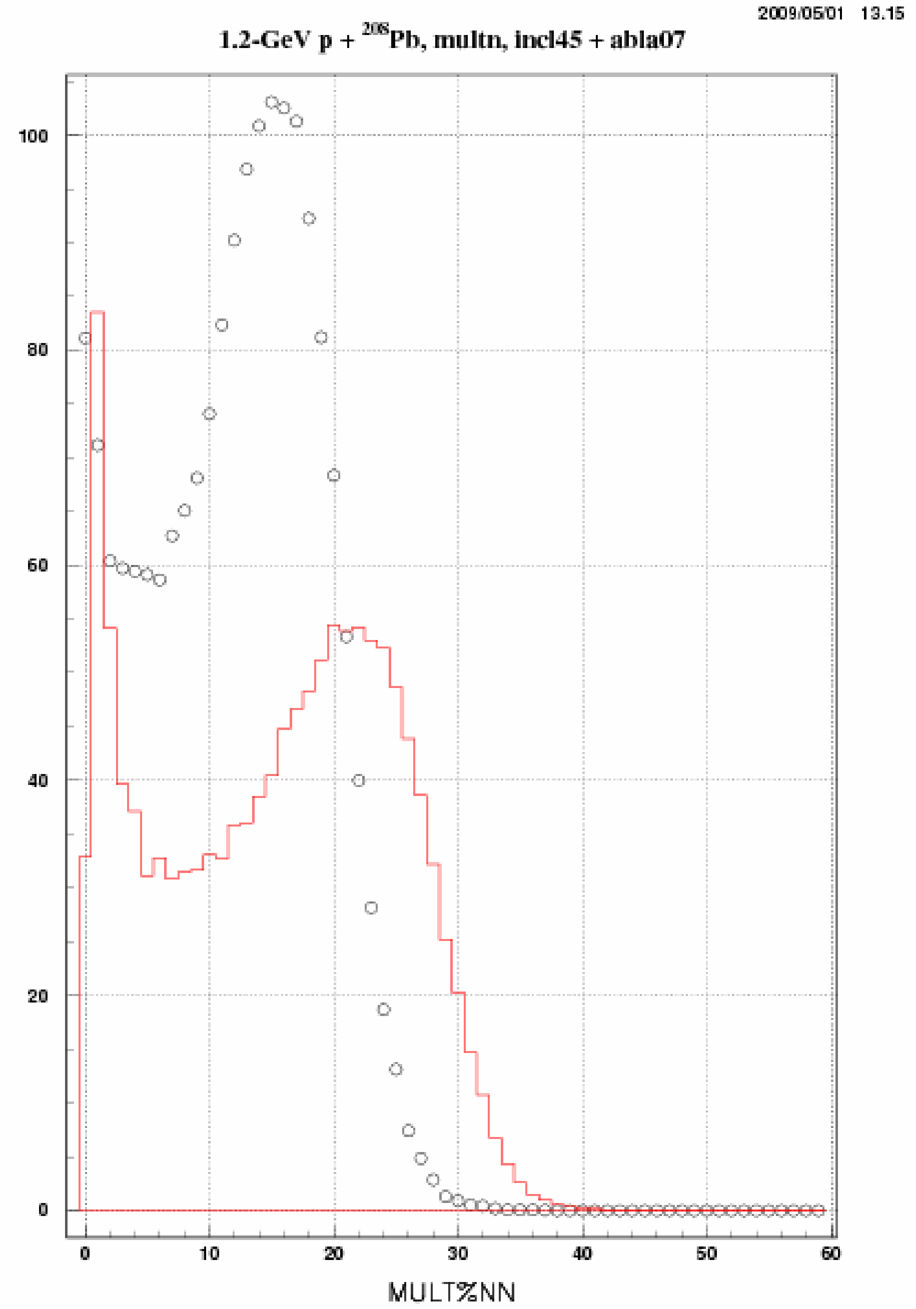
2009/05/01 13.12

p + ^{56}Fe, multn, incl45 + abla07





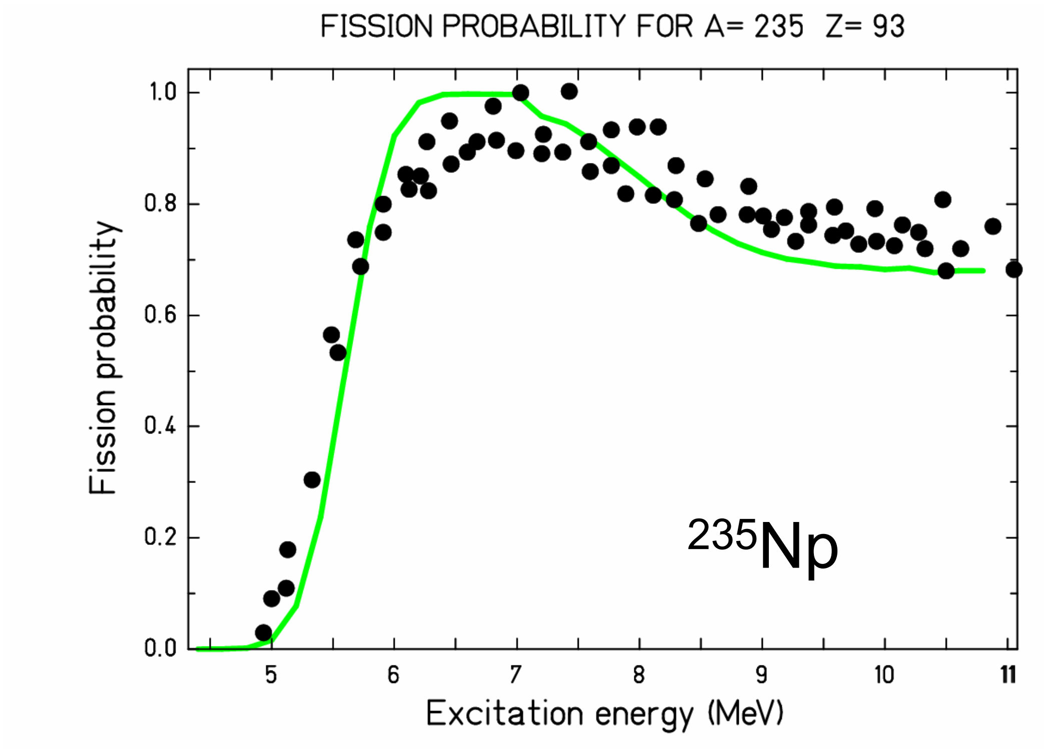
2009/05/01
p + ^{208}Pb, multn, incl45 + abla07
0
2
4
6
8
10
12
14
600
800
1000
1200
1400
1600
1800
200



2009/05/01 13.15
1.2-GeV p + ^{208}Pb, multn, incl45 + abla07
0
20
40
60
80
100
0
10
20
30
40
50
60
MULT%NN

Fission cross sections

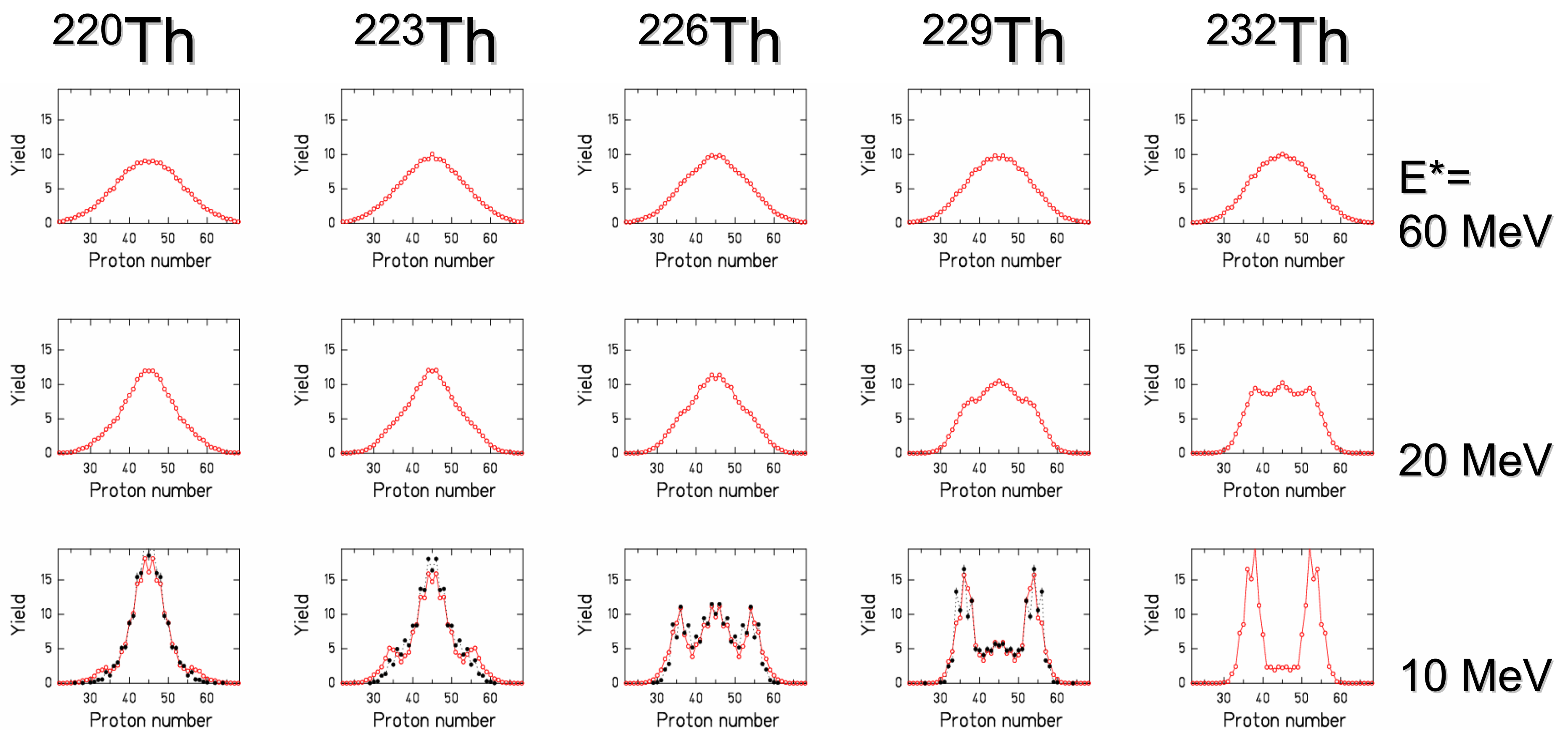
Low-energy fission → influence of double-humped structure in fission barriers of actinides and symmetry classes at saddle



● exp data - Gavron et al., PRC13

—— ABLA07

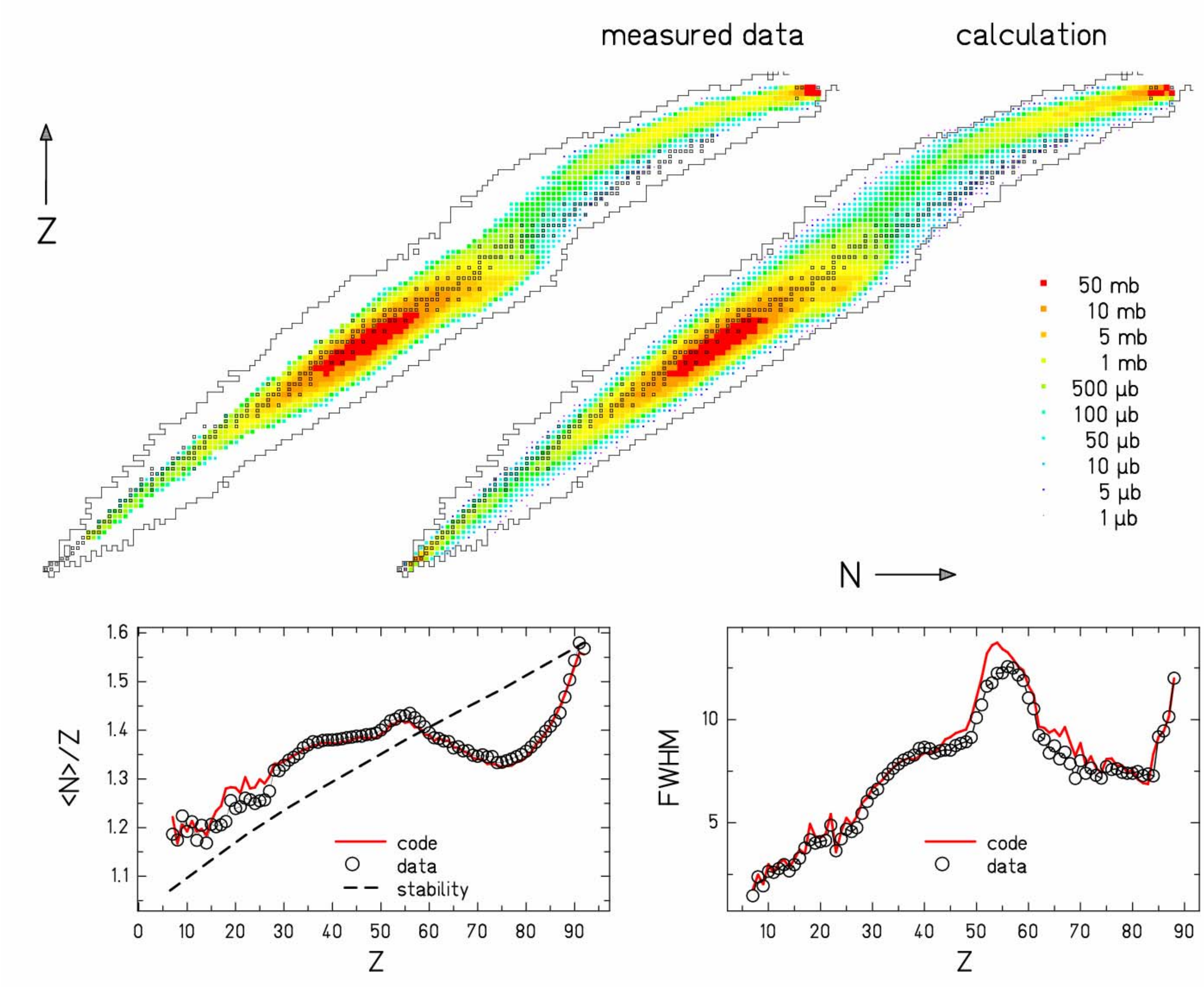
Multimodal fission around ^{226}Th



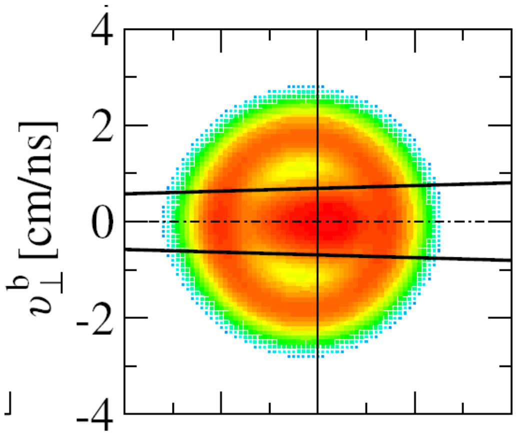
Black: experimental data (GSI experiment)
Red: model calculations (N=82, Z=50, N=92 shells)

Possible fissionning systems in spallation of ^{238}U!

Spallation ^{238}U (1 A GeV) + ^{1}H



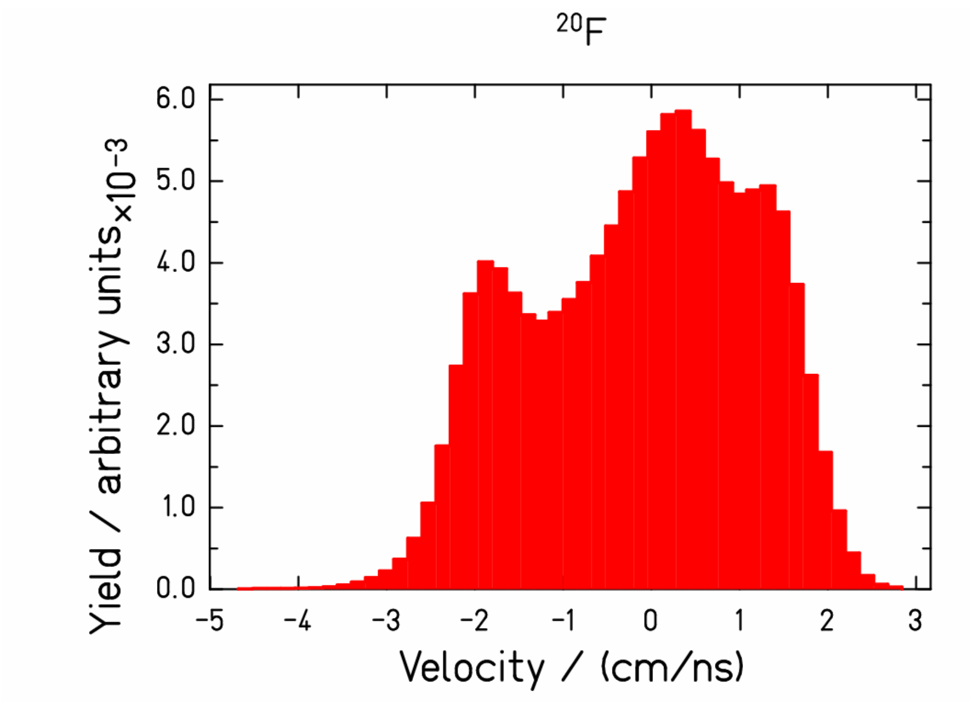
Multifragmentation



Longitudinal cuts in velocity

$^{136}Xe + {}^{1}H$
1 A GeV

Multifragmentation: One central component due to expansion of an homogenous source.

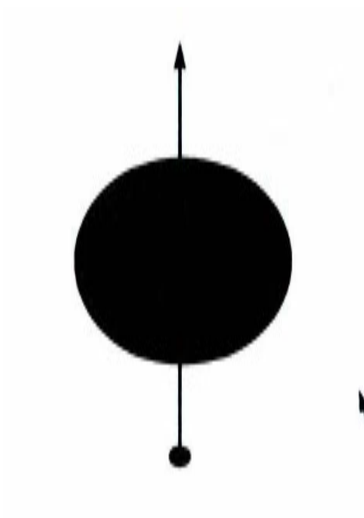


Binary decay: 2 separated forward and backward components due to Coulomb repulsion.

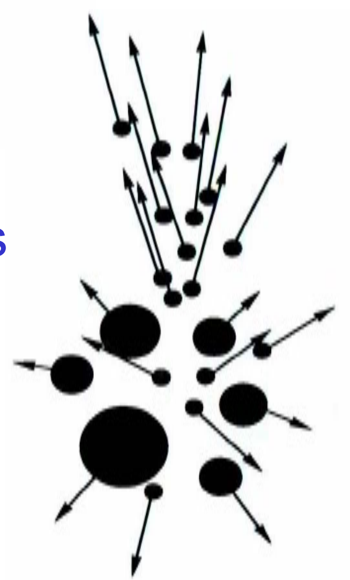
PhD, P. Napolitani

Stages of a spallation reaction

Stages of a spallation reaction



Primary collisions



Final residues

1st stage

- Primary collisions (≈10 fm/c = 3.3 10^{-23} s)
  - ► Distorted nuclear system
- Thermalisation of nucleonic motion (≈100 fm/c)
  - ► Compound nucleus

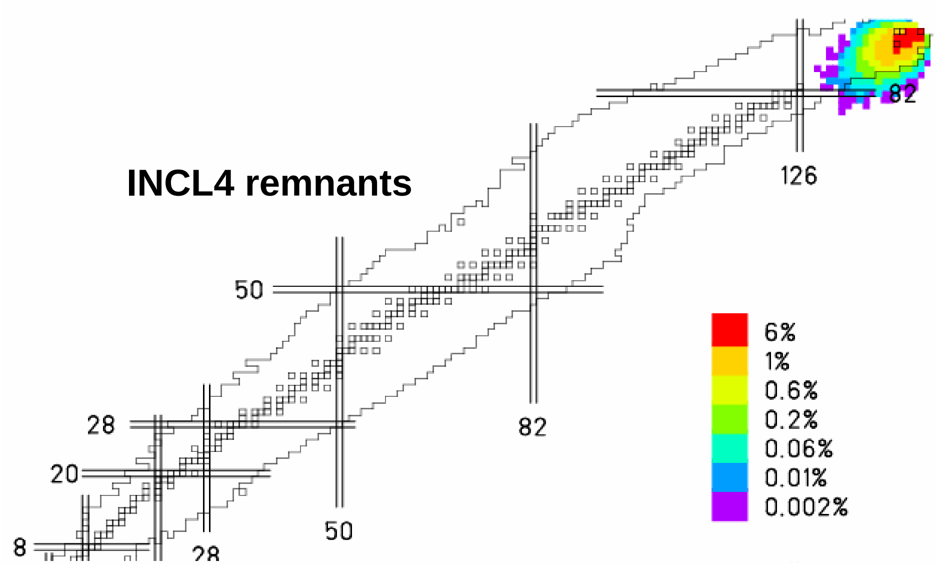
<u>ABLA07 starts here</u>

2nd stage

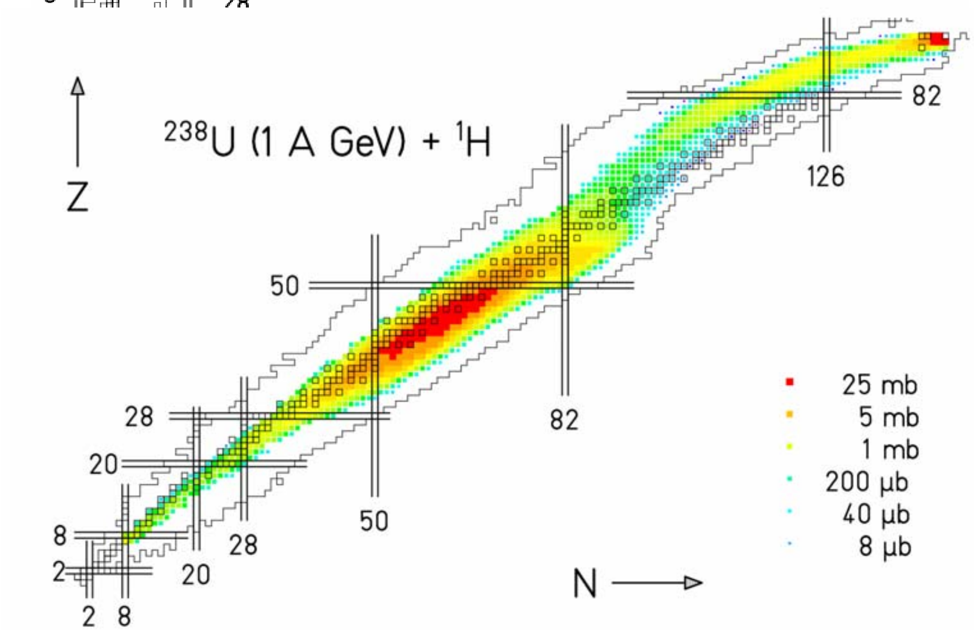
- Expansion (a few 100 fm/c)
  - ► Thermal instabilities
- Shape evolution (≈1000 fm/c)
  - ► Fission delay
- De-excitation (up to ≈10^7 fm/c)
  - ► Final residue

ABLA07 is 2nd part of ABRABLA07 (Abrasion-ablation code).

Fingerprints of the de-excitation process



The situation after the primary collision process can be expressed by the parameters of the compound nucleus.
They define the starting point of the de-excitation process.

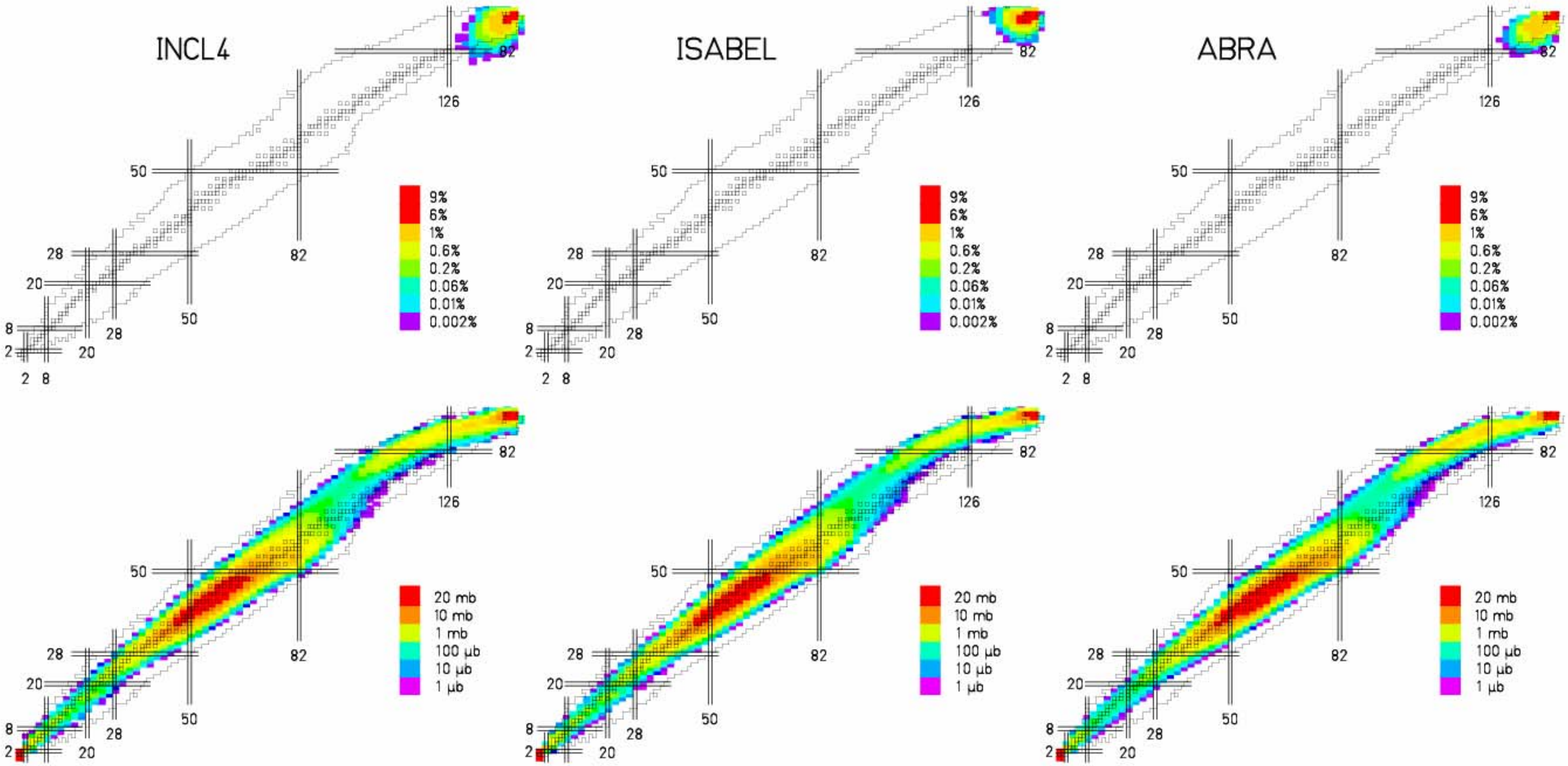


Experimental data (P. Armbruster et al., PRL 93 (2004) 212701)

The de-excitation process wipes out most of the properties of the heated thermalised system.
Most of the characteristics of the final residues are fingerprints of the de-excitation process.

Fingerprints of the de-excitation process

1 GeV p + ^{238}U **INCL4, ISABEL, ABRA + ABLA07**



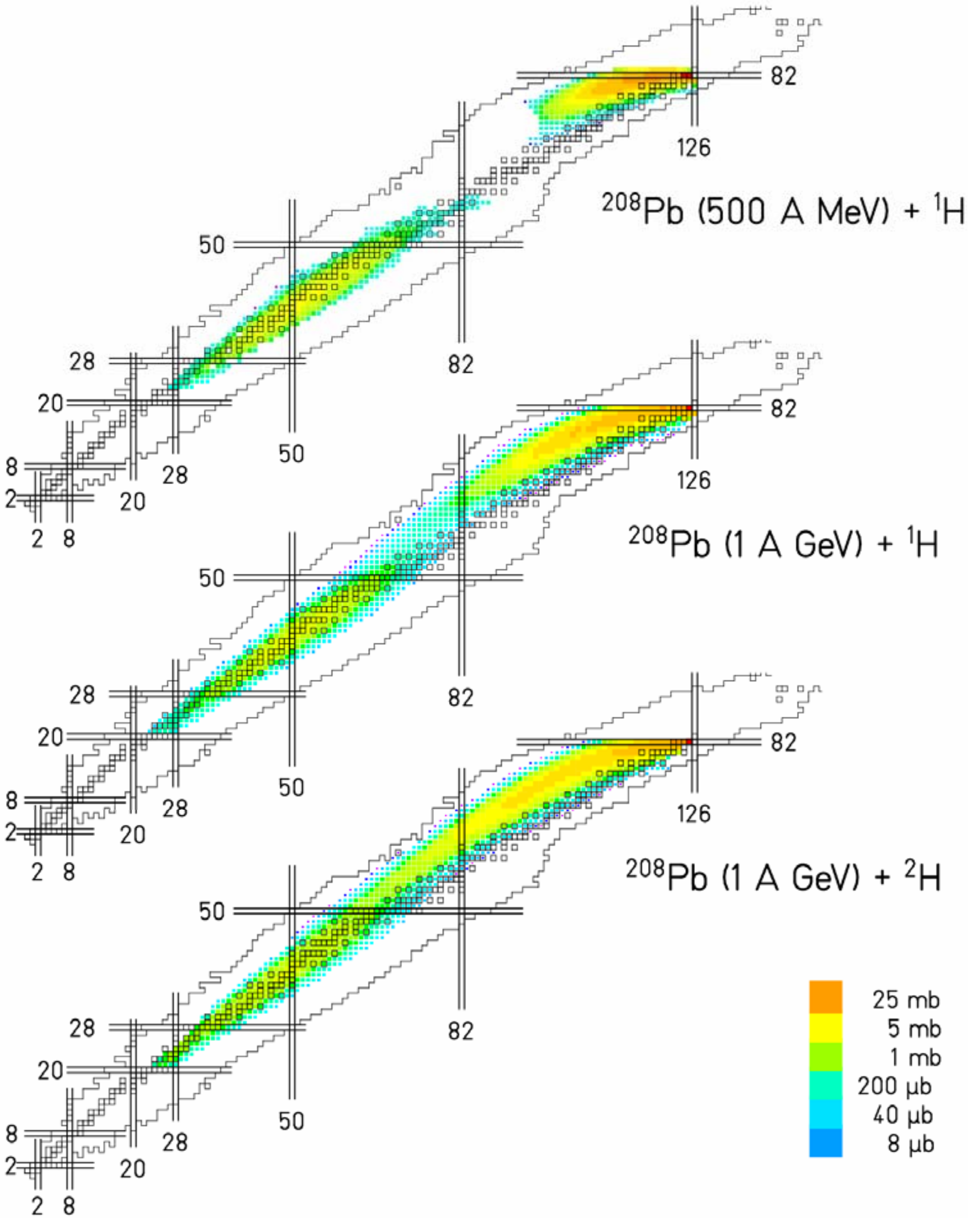
At first glance, nothing seems to change among the different 1st stage models, however ...

Influence of the 1st stage of the reaction

Parameters of the compound nucleus

- Composition in A and Z
  - Starting point on the chart of the nuclides
  - Fluctuations in N/Z
- Thermal excitation energy
  - Influence on emission rates
  - Reduced in de-excitation
- Angular momentum
  - Influence on barriers (mostly fission)
  - Modified in de-excitation
- Linear momentum
  - No influence on de-excitation
  - Signature of reaction channel
- Volume (extended)
  - Response to heating - breakup

Excitation energy



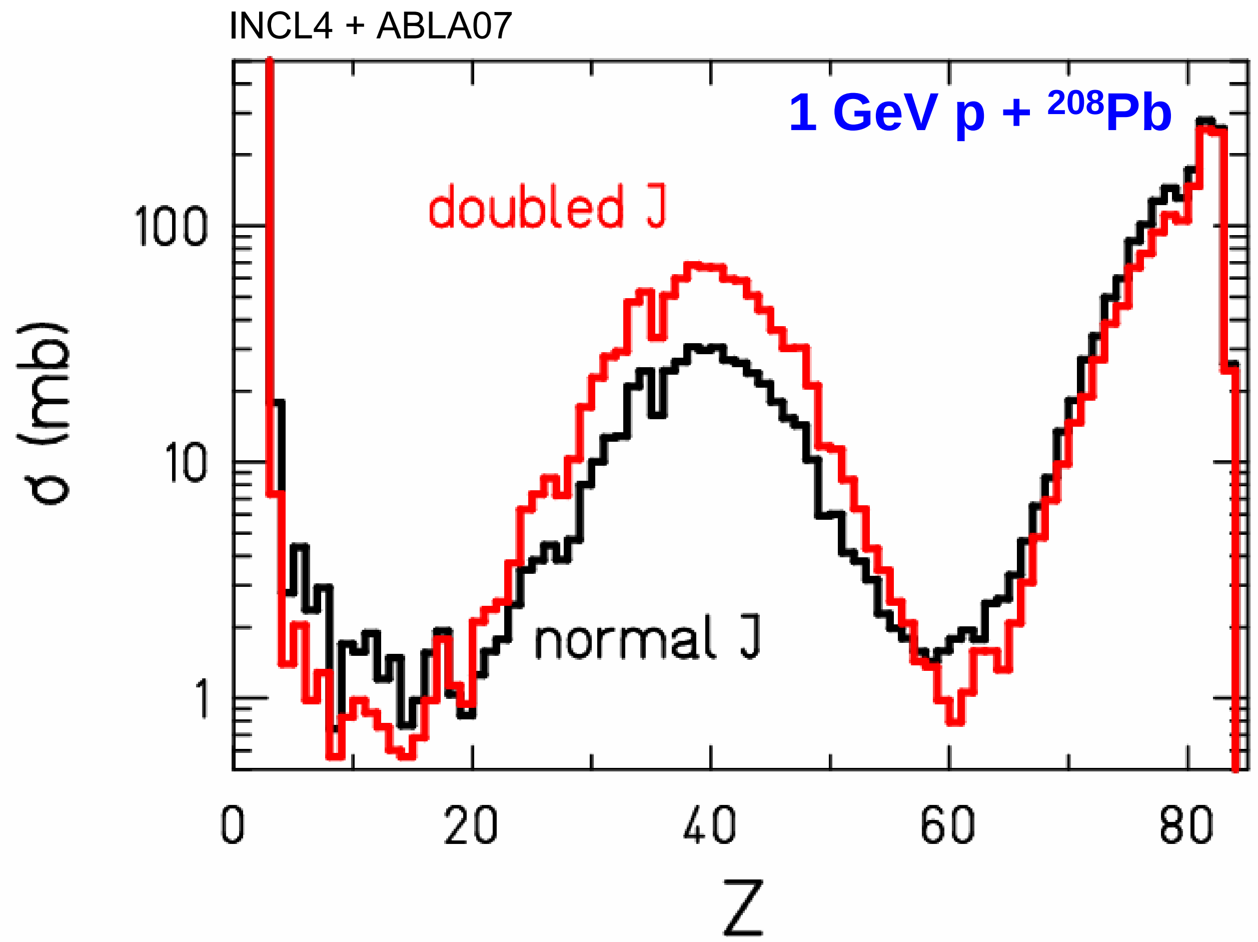
Increase of beam energy leads to higher excitation energies after INC and to larger mass loss in evaporation.

Experimental Data

T. Enqvist et al., NPA 686, 481, NPA 703, 435
B. Fernandez et al., NPA 747, 227
L. Audouin et al., NPA 768, 1

Angular momentum

- Influence on barriers (mostly fission)
- Modified in de-excitation



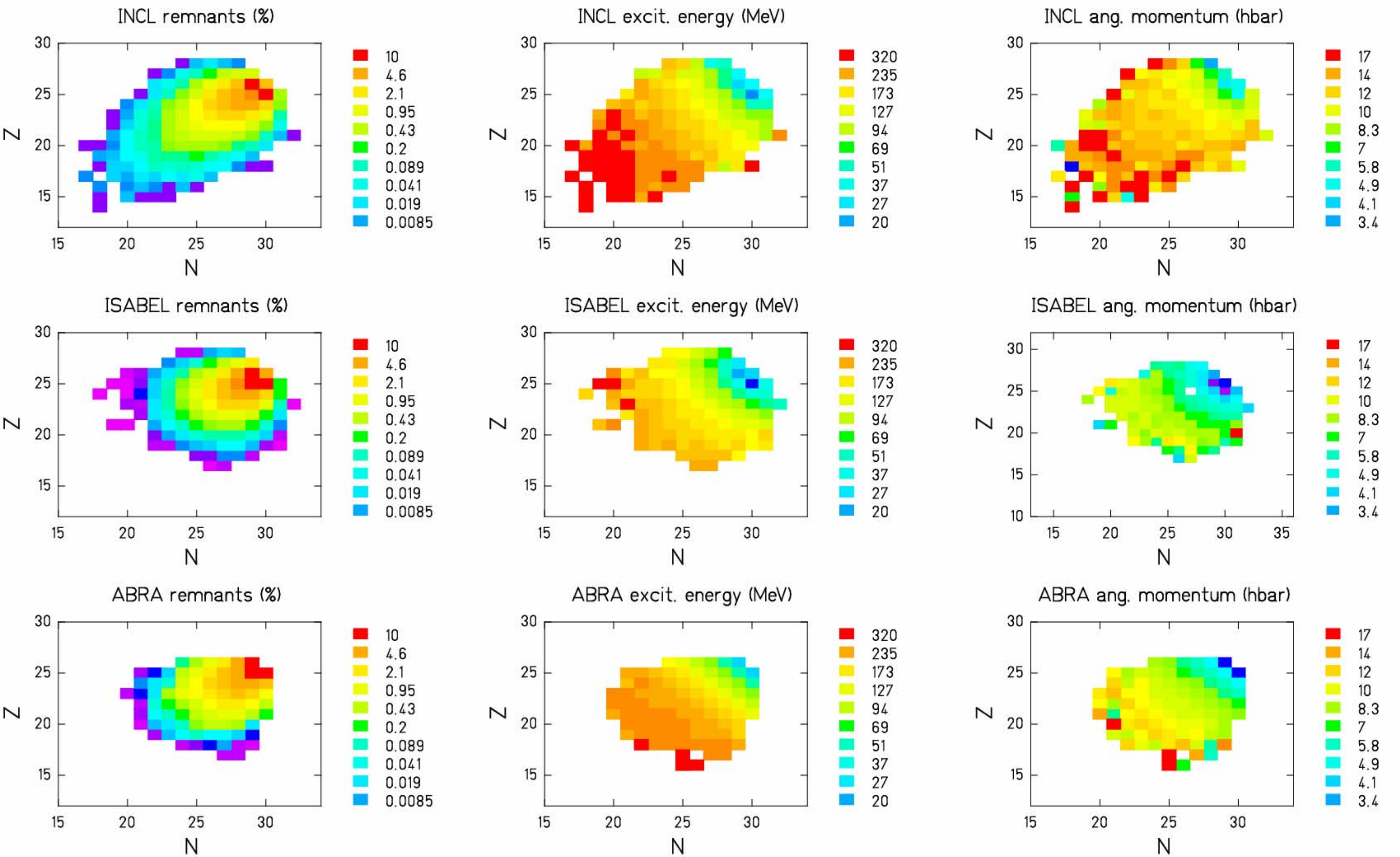
Comparison of

INCL4
ISABEL
ABRA

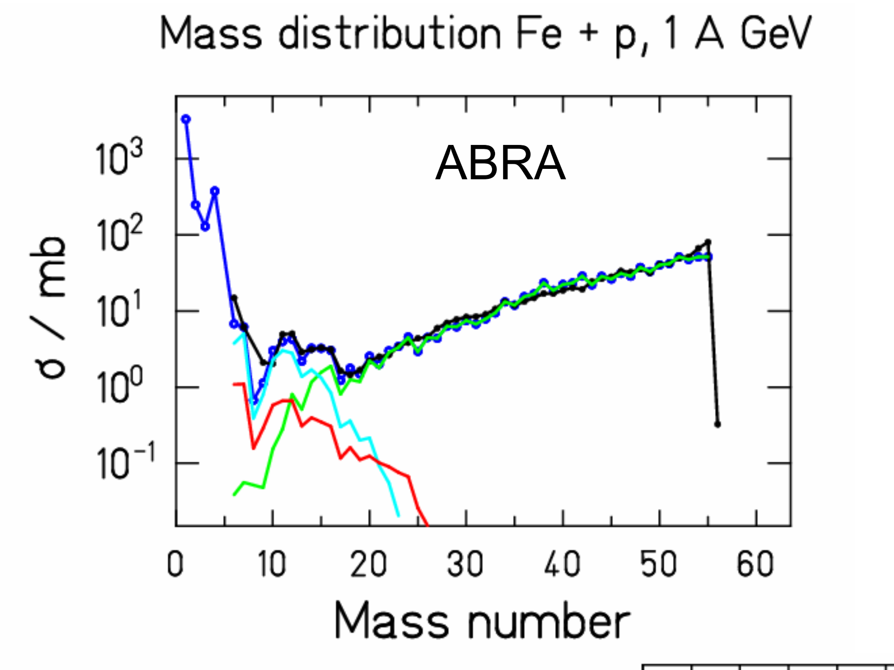
for

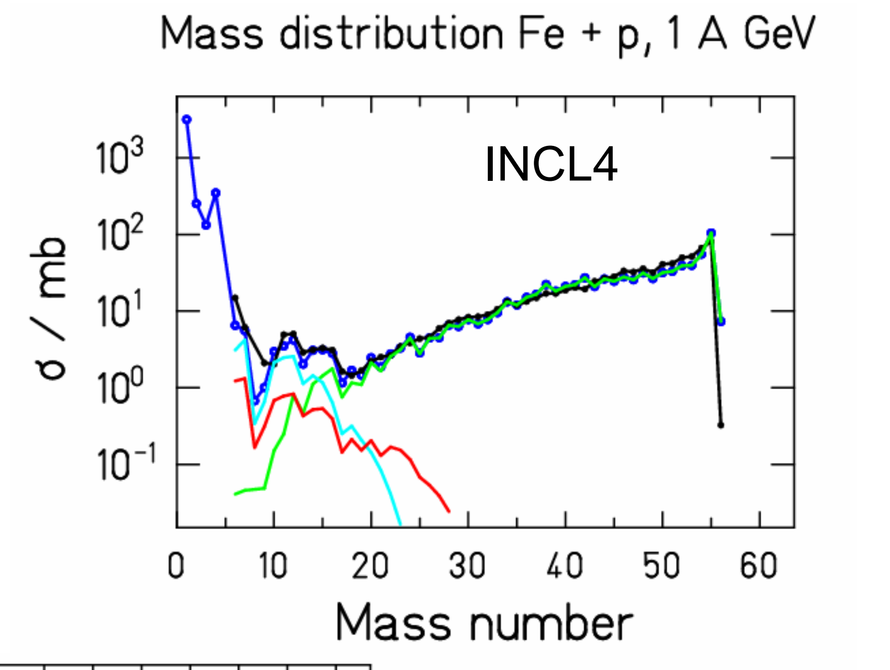
1 GeV p + ^{56}Fe, ^{208}Pb, ^{238}U

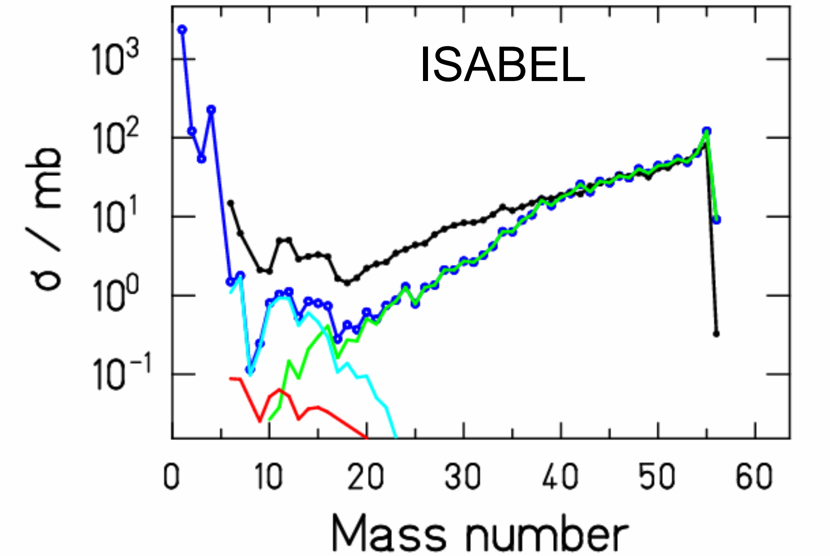
1 GeV p + ^{56}Fe


INCL remnants (%)
INCL excit. energy (MeV)
INCL ang. momentum (hbar)
ISABEL remnants (%)
ISABEL excit. energy (MeV)
ISABEL ang. momentum (hbar)
ABRA remnants (%)
ABRA excit. energy (MeV)
ABRA ang. momentum (hbar)
Z
N
10 4.6 2.1 0.95 0.43 0.2 0.089 0.041 0.019 0.0085
320 235 173 127 94 69 51 37 27 20
17 14 12 10 8.3 7 5.8 4.9 4.1 3.4

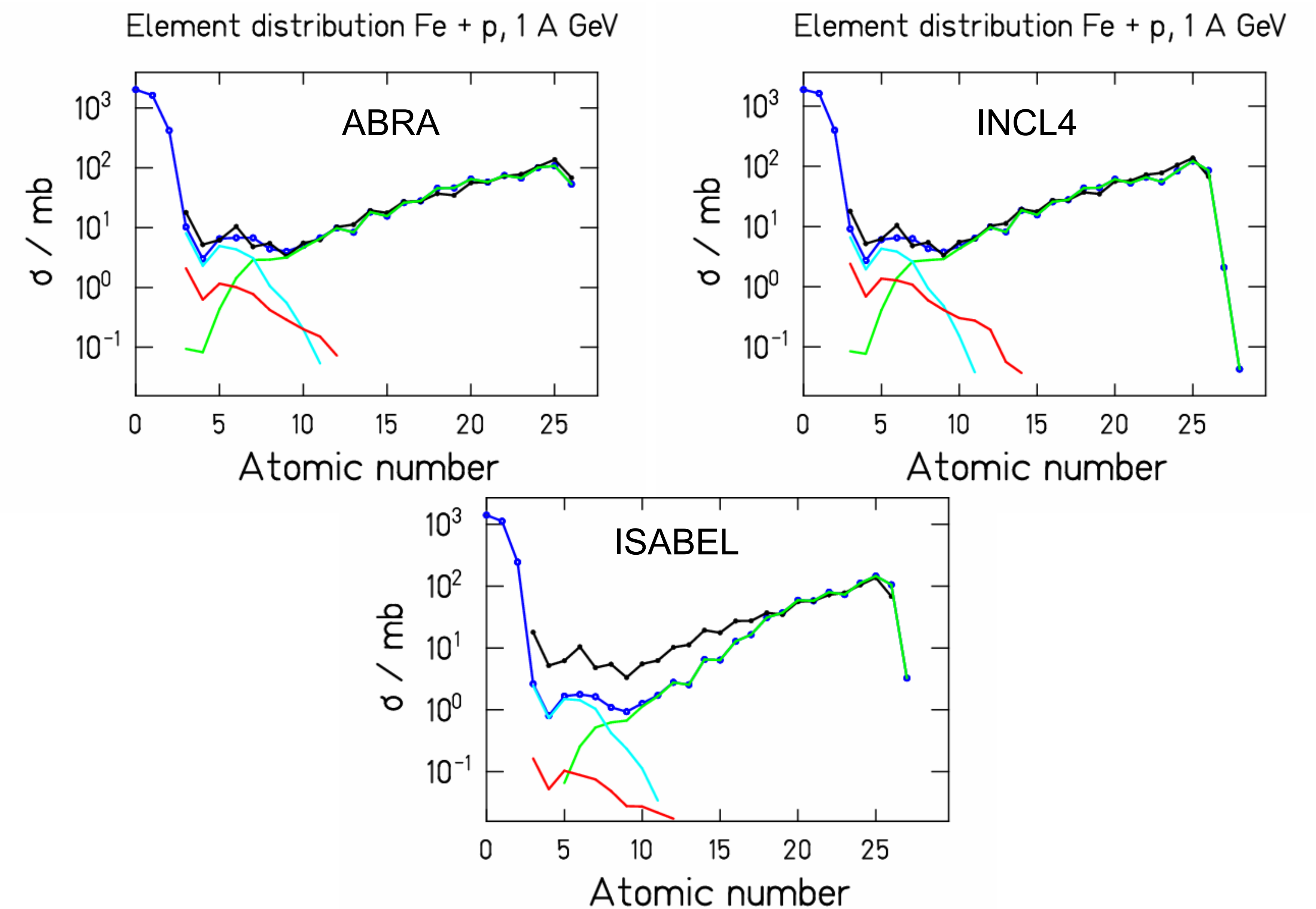
1 GeV p + ^{56}Fe


Mass distribution Fe + p, 1 A GeV
ABRA
σ / mb
Mass number


Mass distribution Fe + p, 1 A GeV
INCL4
σ / mb
Mass number

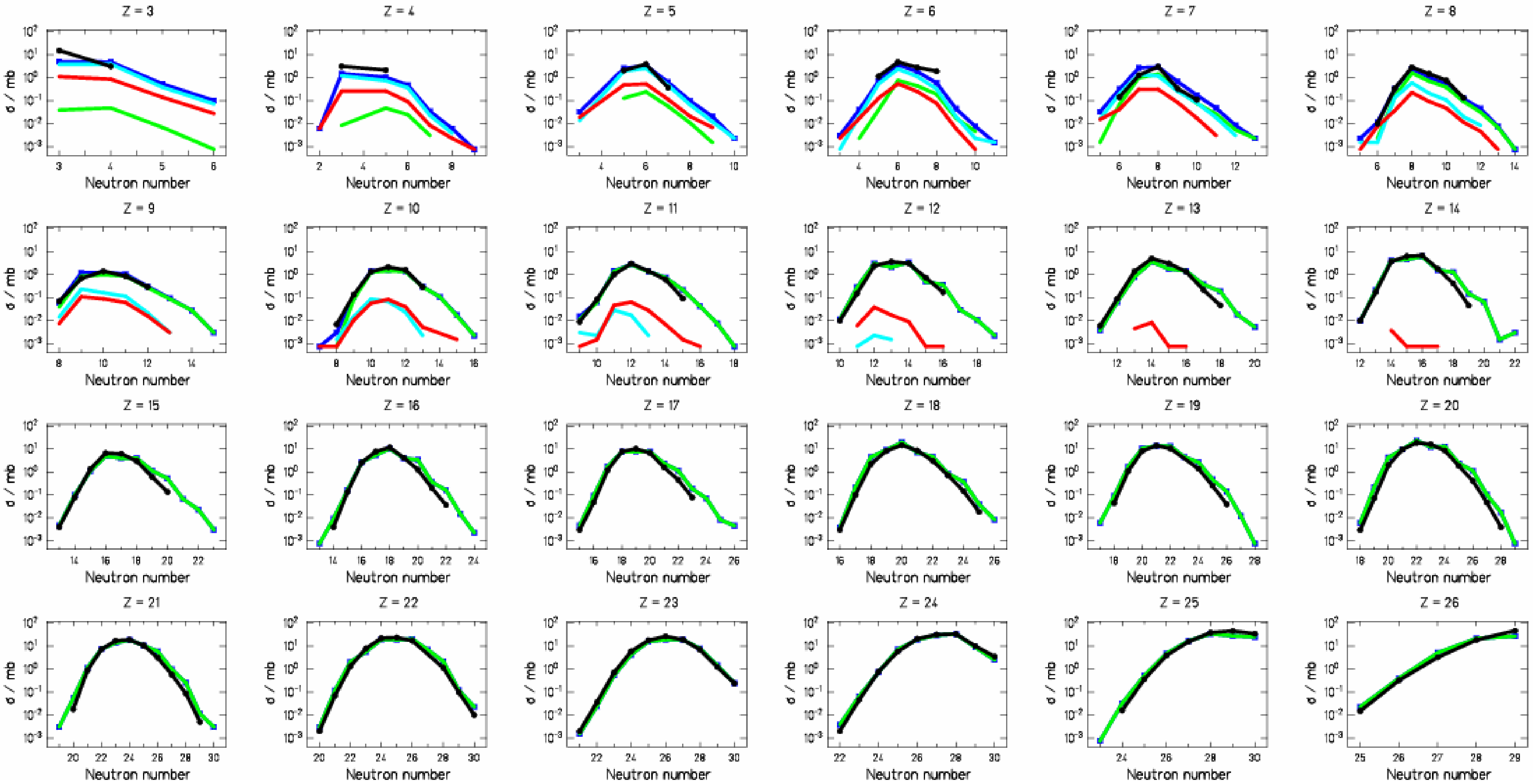

ISABEL
σ / mb
Mass number

1 GeV p + ^{56}Fe

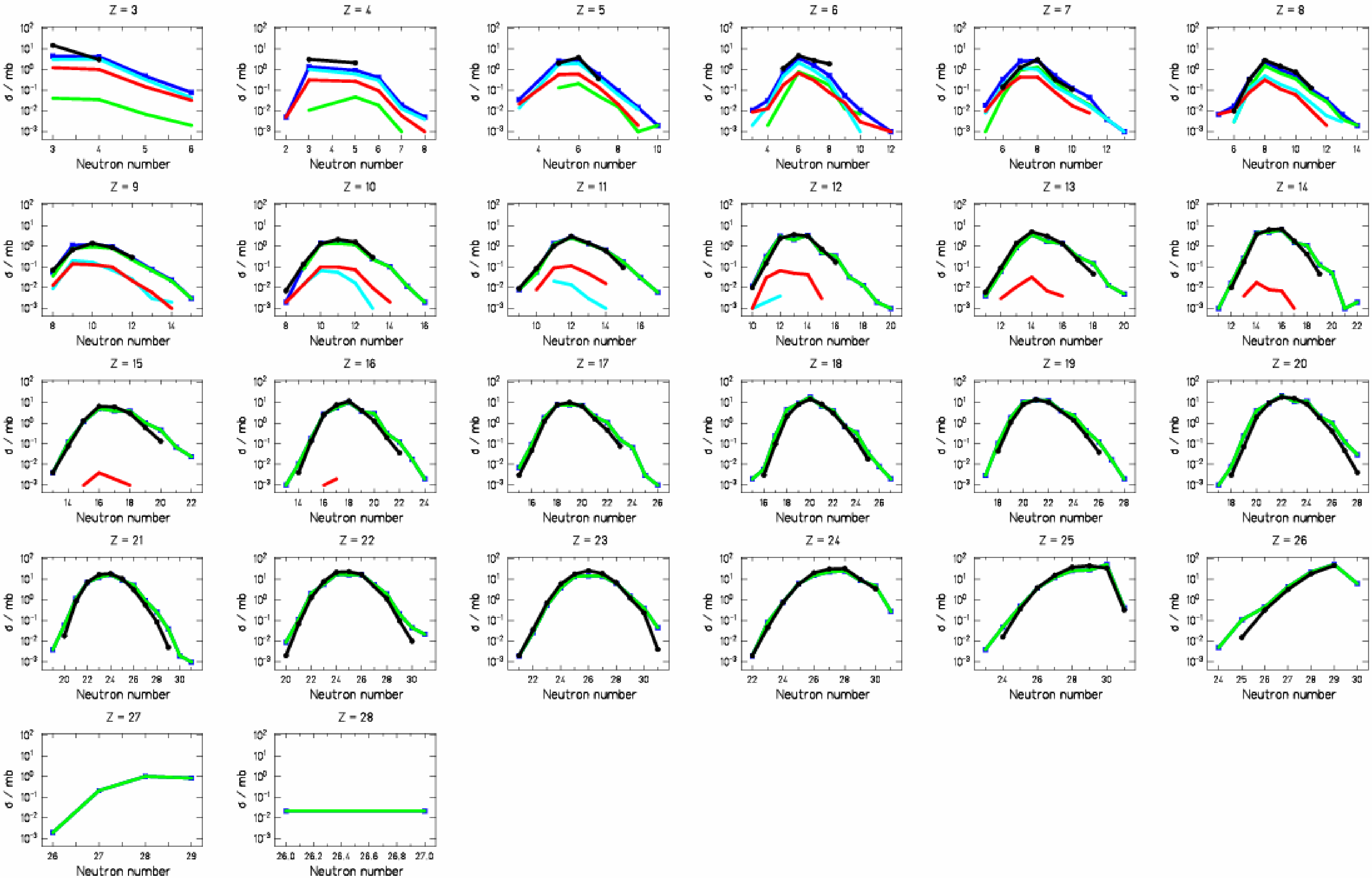


Element distribution Fe + p, 1 A GeV
ABRA
σ / mb
Atomic number
Element distribution Fe + p, 1 A GeV
INCL4
σ / mb
Atomic number
ISABEL
σ / mb
Atomic number

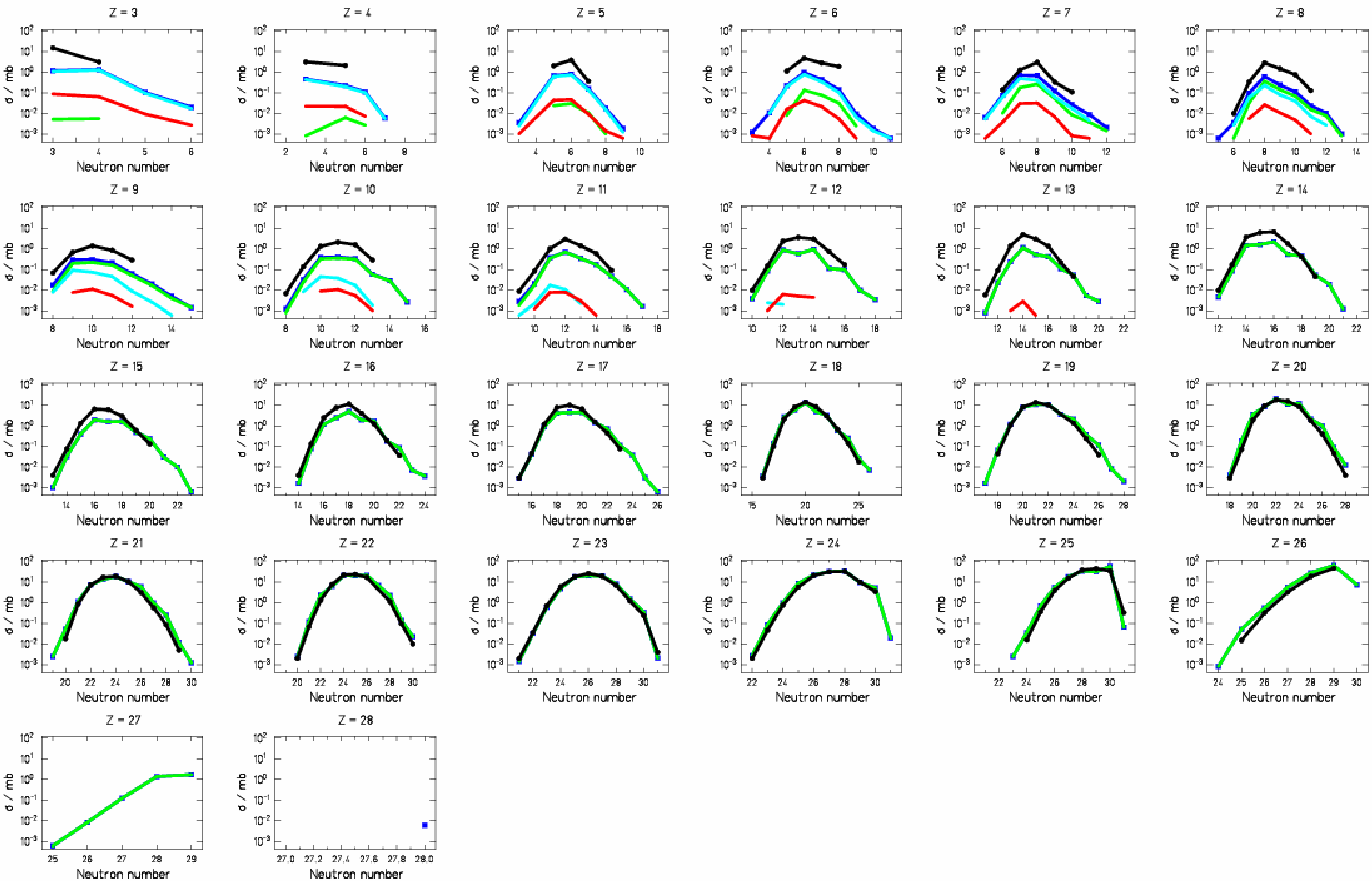
1 GeV p + ^{56}Fe ABRABLA07



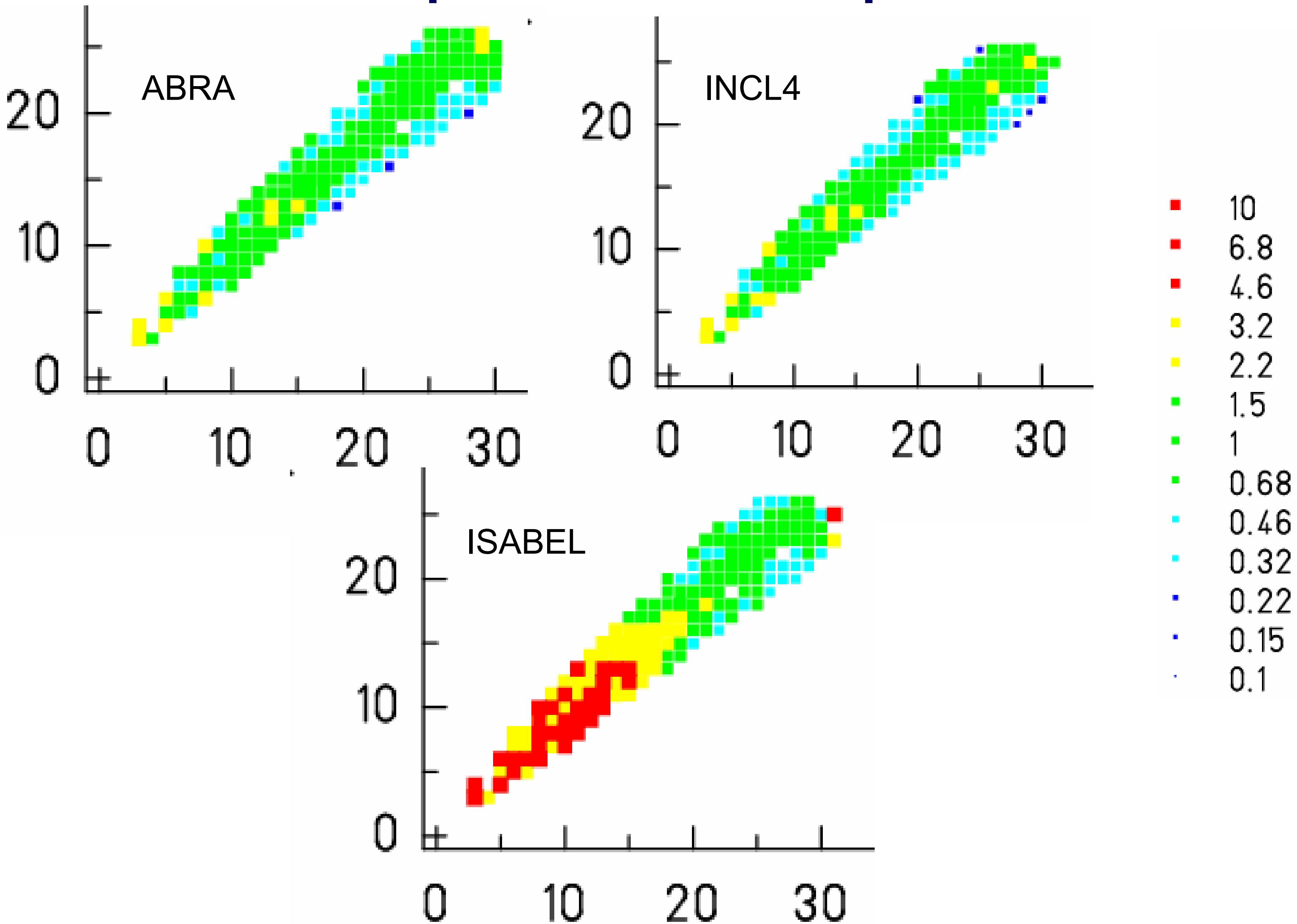
1 GeV p + ^{56}Fe   INCL4+ABLA07



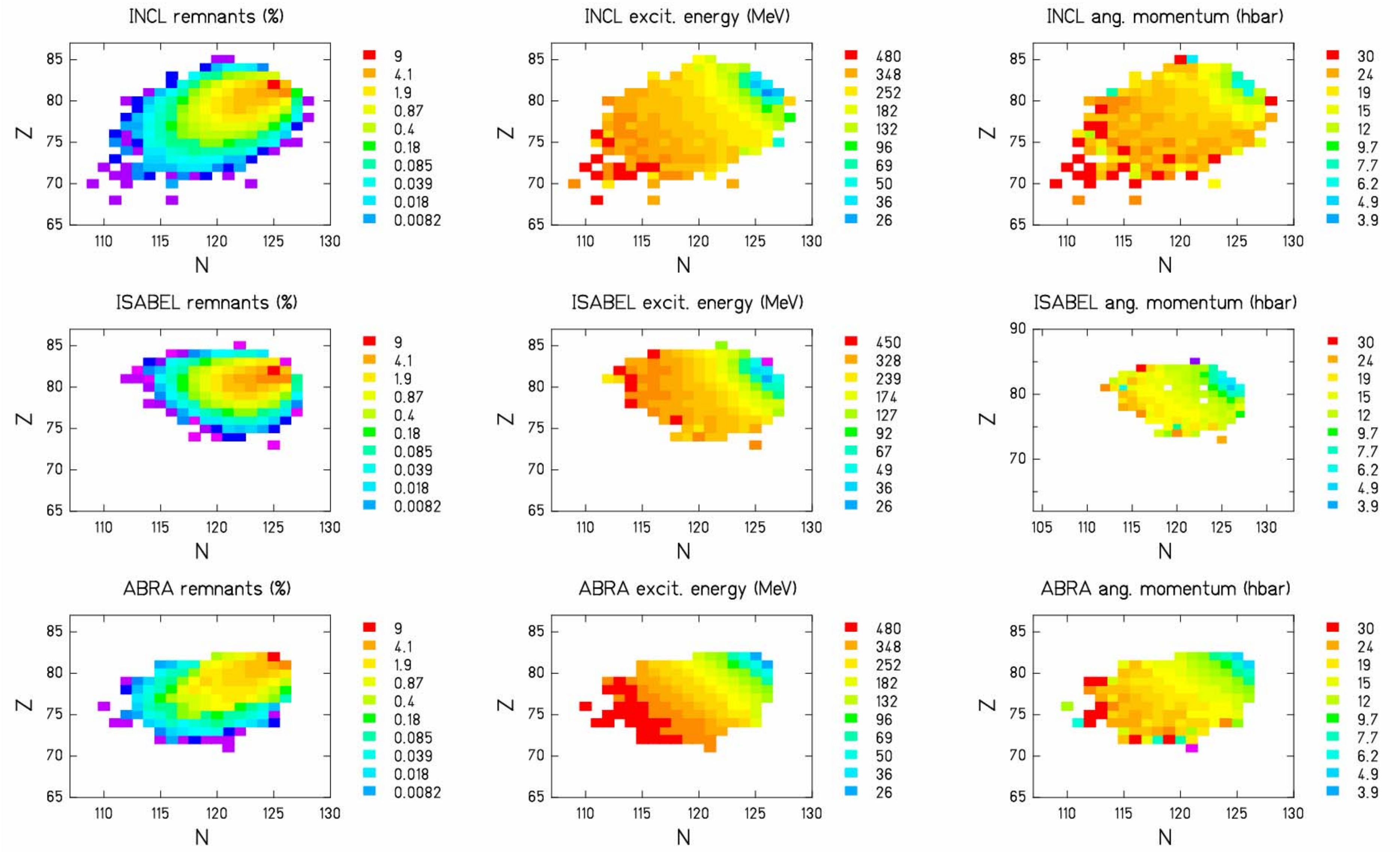
1 GeV p + ^{56}Fe   ISABEL+ABLA07



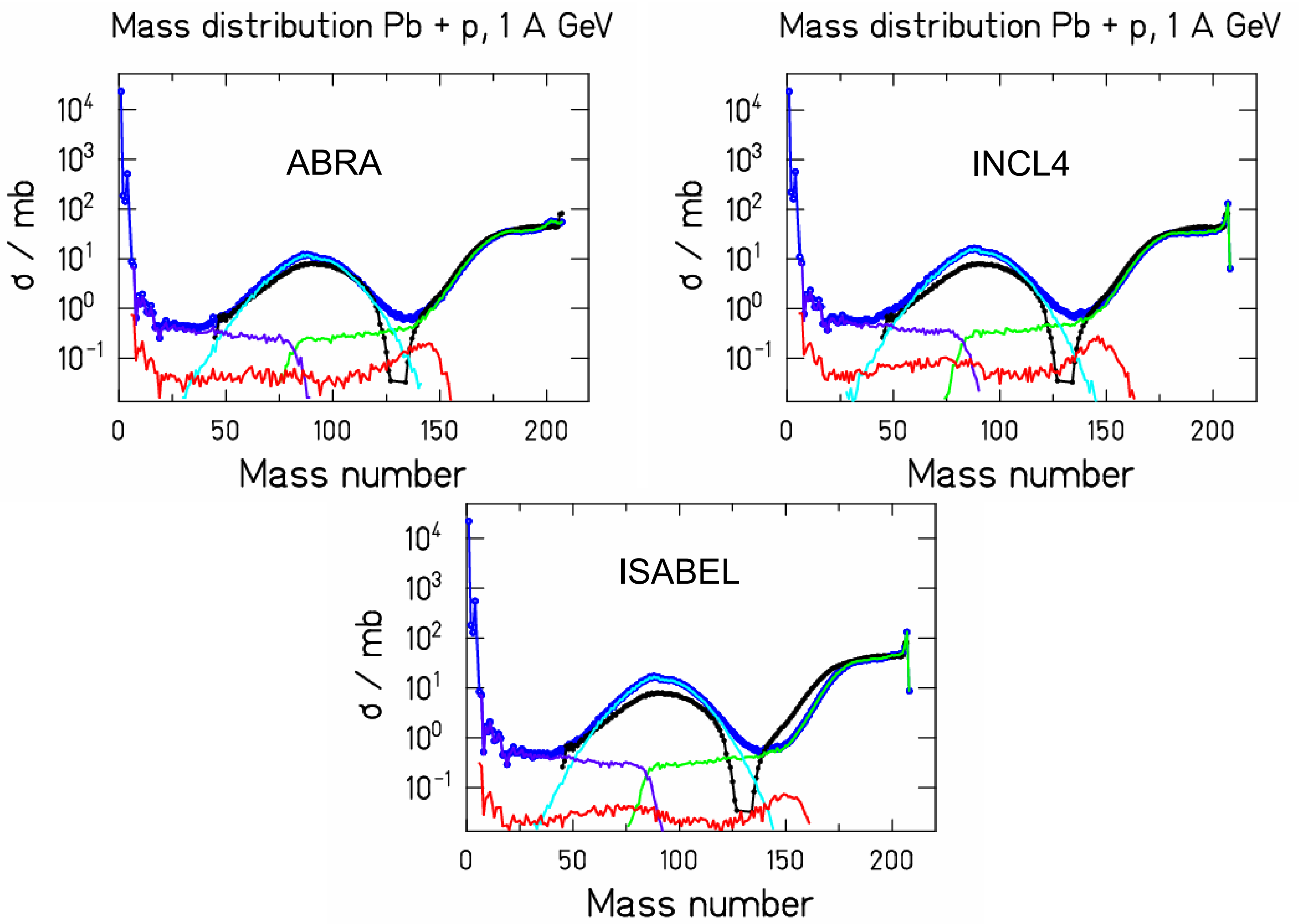
1 GeV p + ^{56}Fe ratio exp/calc



1 GeV p + ^{208}Pb

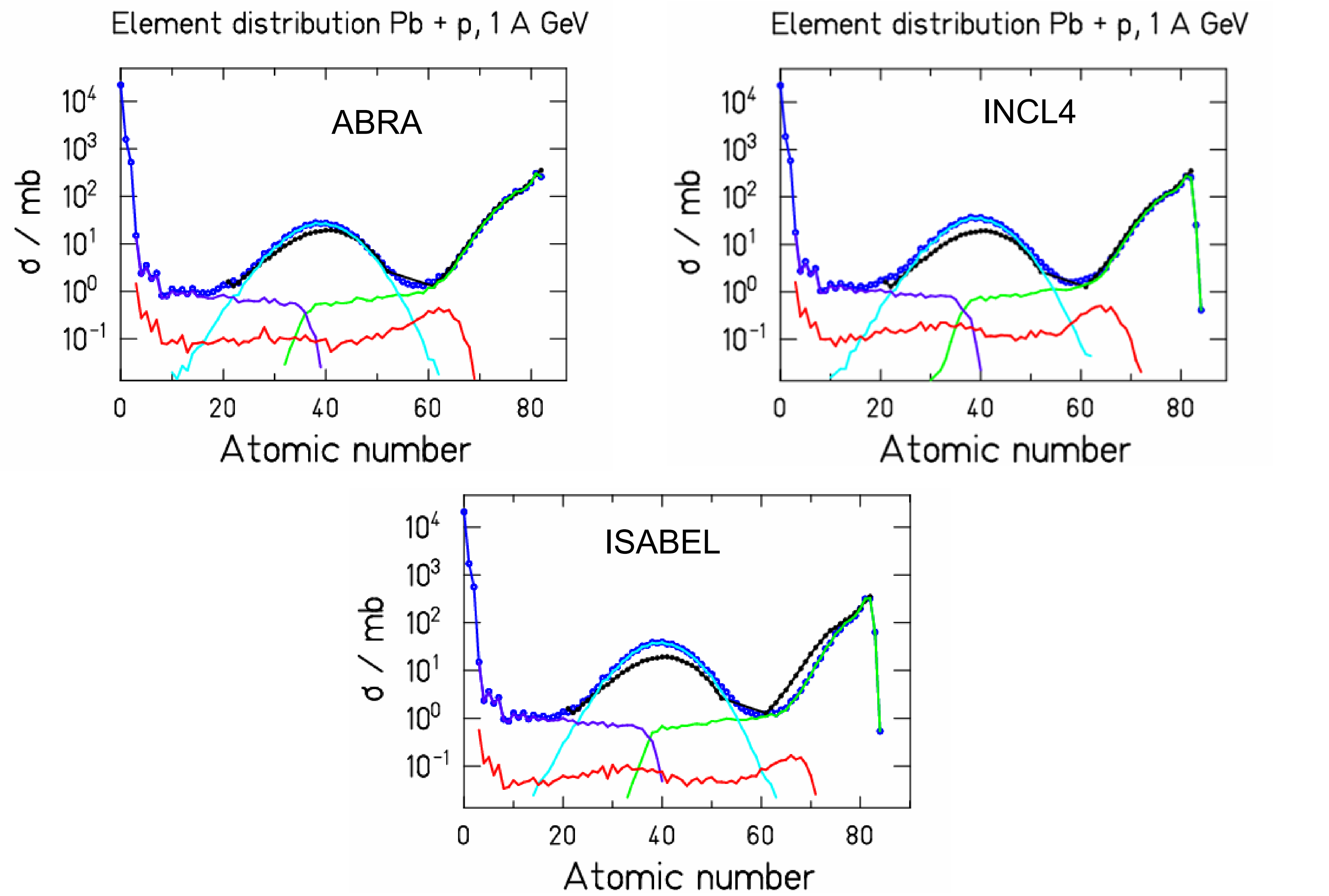

INCL remnants (%)
INCL excit. energy (MeV)
INCL ang. momentum (hbar)
ISABEL remnants (%)
ISABEL excit. energy (MeV)
ISABEL ang. momentum (hbar)
ABRA remnants (%)
ABRA excit. energy (MeV)
ABRA ang. momentum (hbar)
Z
N
9
4.1
1.9
0.87
0.4
0.18
0.085
0.039
0.018
0.0082
480
348
252
182
132
96
69
50
36
26
450
328
239
174
127
92
67
49
36
26
30
24
19
15
12
9.7
7.7
6.2
4.9
3.9

1 GeV p + ^{208}Pb

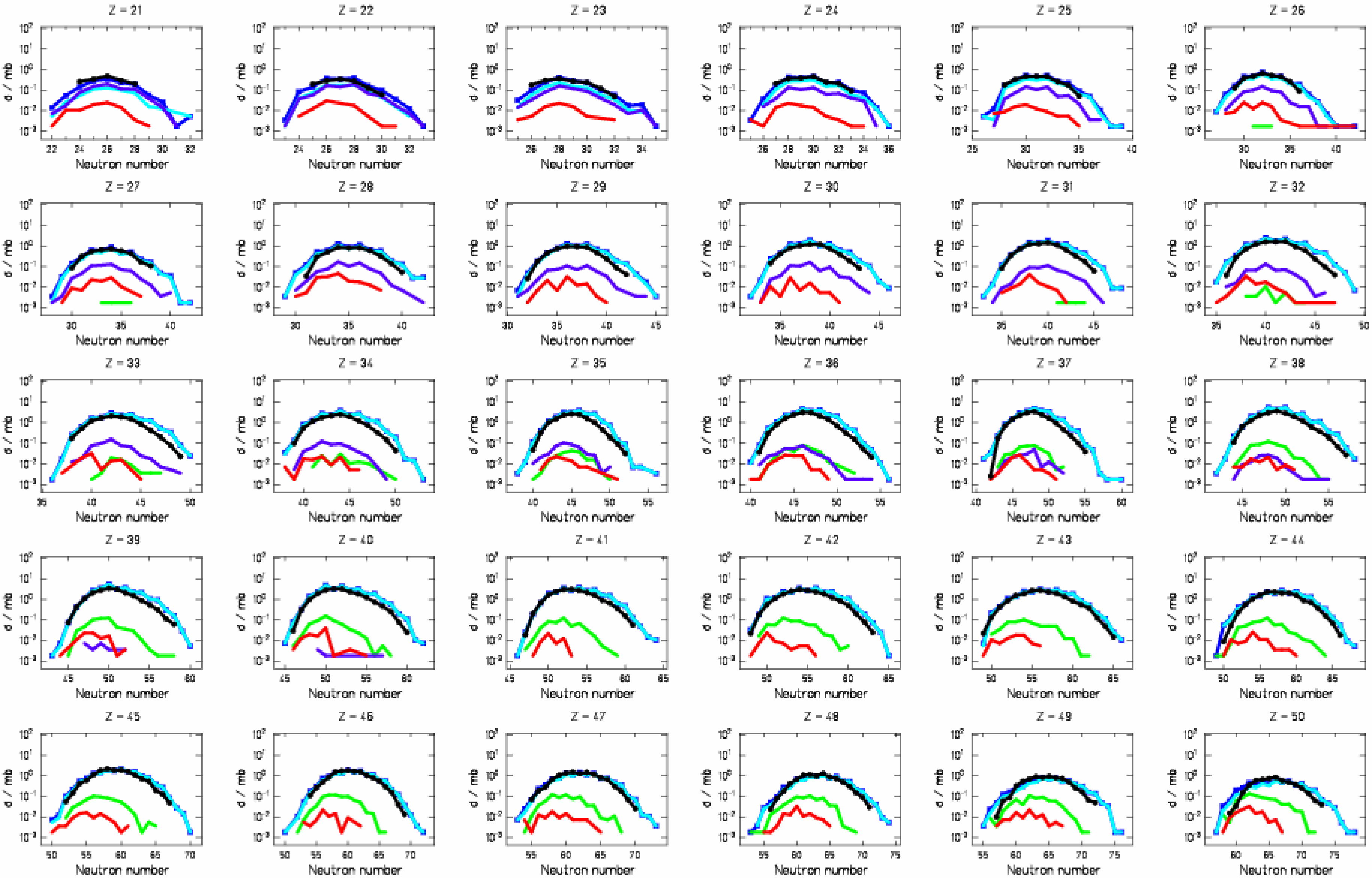


Mass distribution Pb + p, 1 A GeV
ABRA
σ / mb
Mass number
Mass distribution Pb + p, 1 A GeV
INCL4
σ / mb
Mass number
ISABEL
σ / mb
Mass number

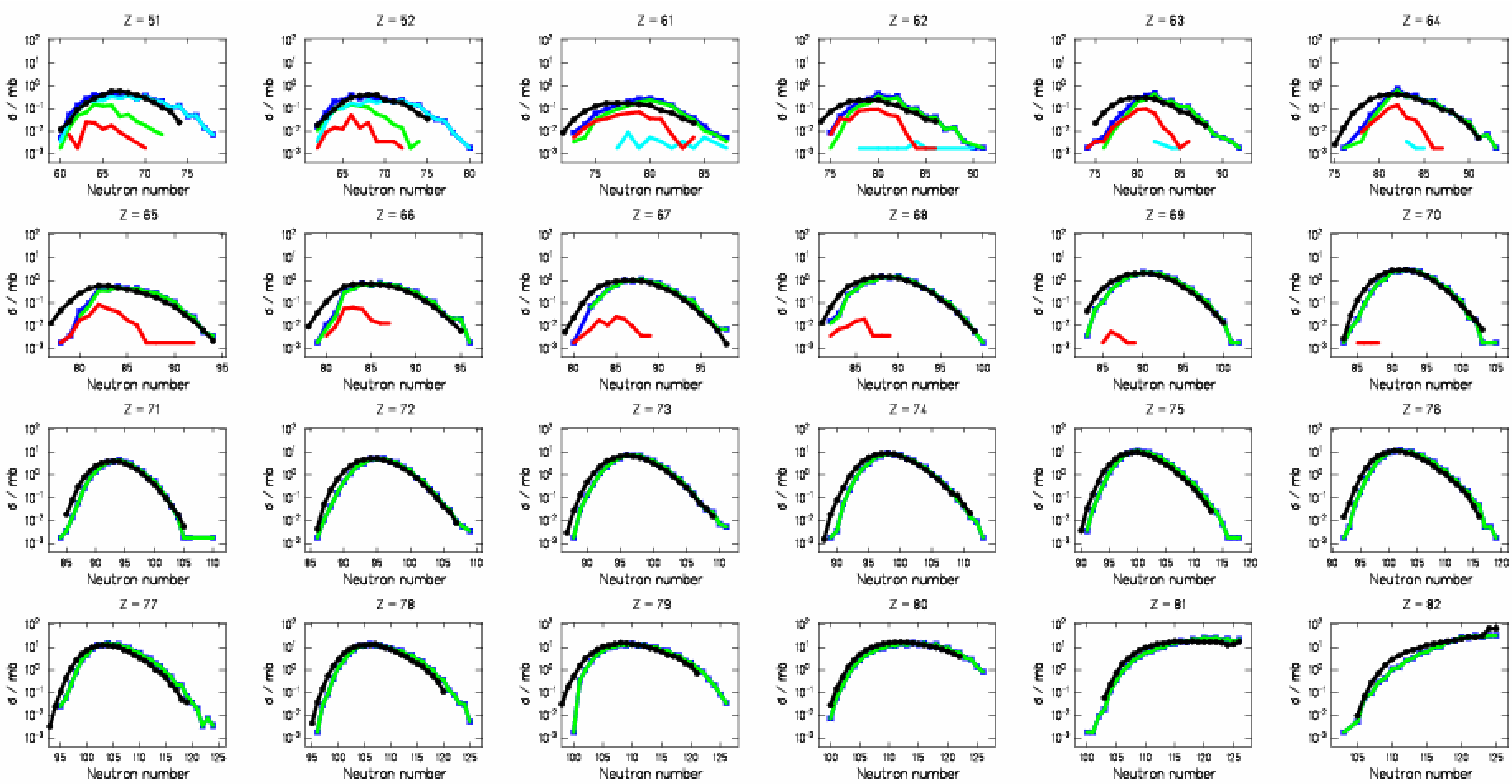
1 GeV p + ^{208}Pb


Element distribution Pb + p, 1 A GeV
ABRA
σ / mb
Atomic number
Element distribution Pb + p, 1 A GeV
INCL4
σ / mb
Atomic number
ISABEL
σ / mb
Atomic number

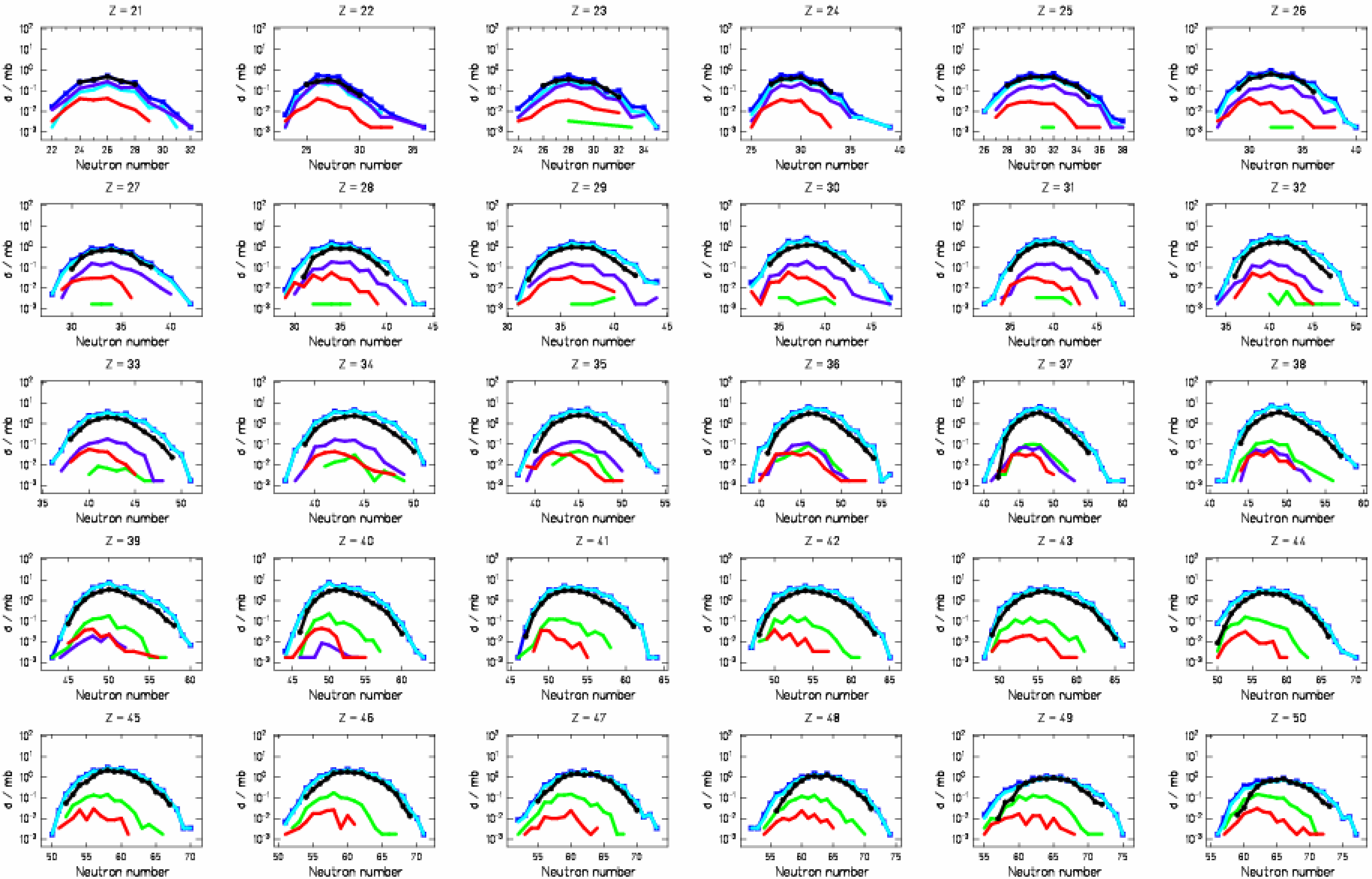
1 GeV p + ^{208}Pb ABRABLA07



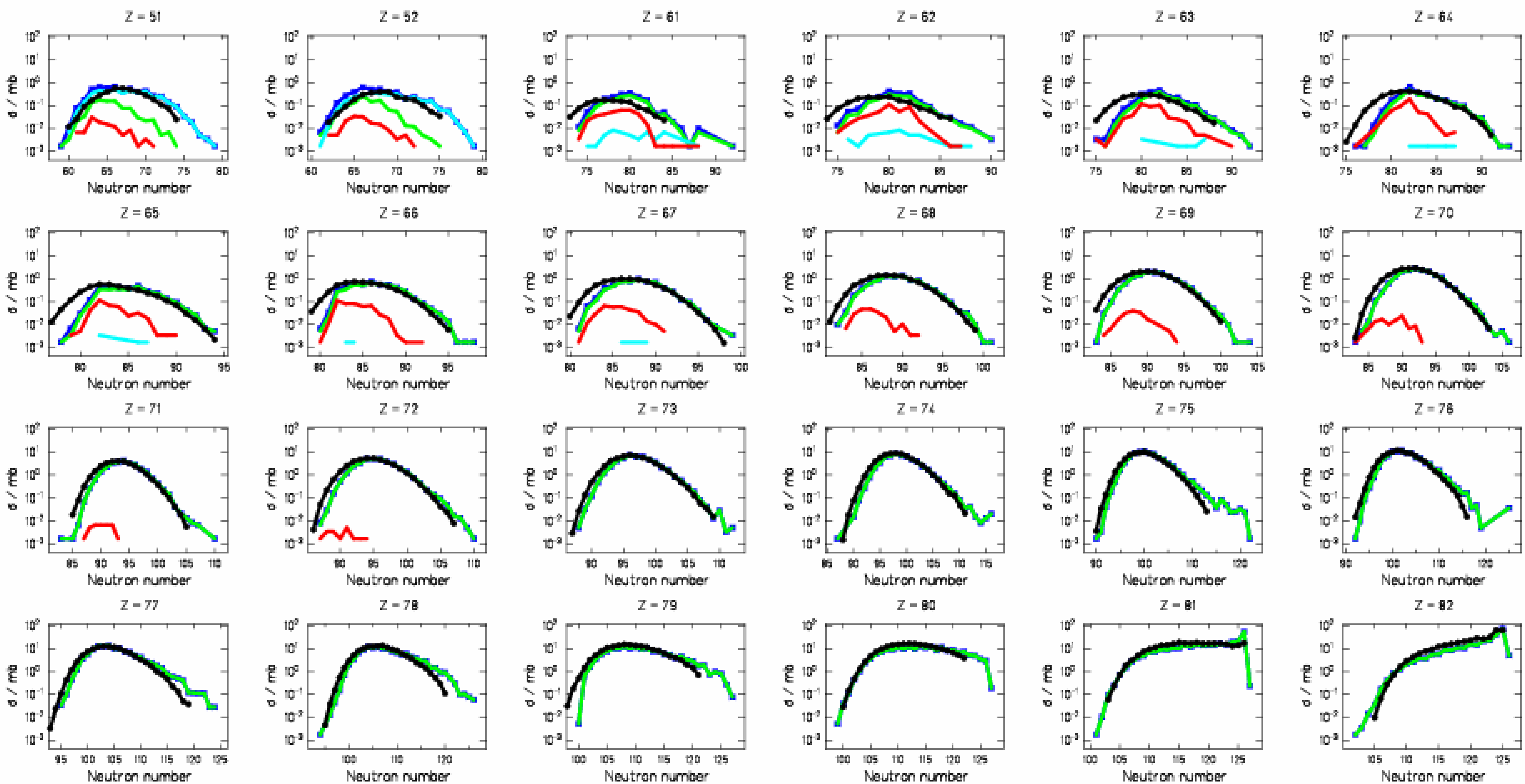
1 GeV p + ^{208}Pb ABRABLA07



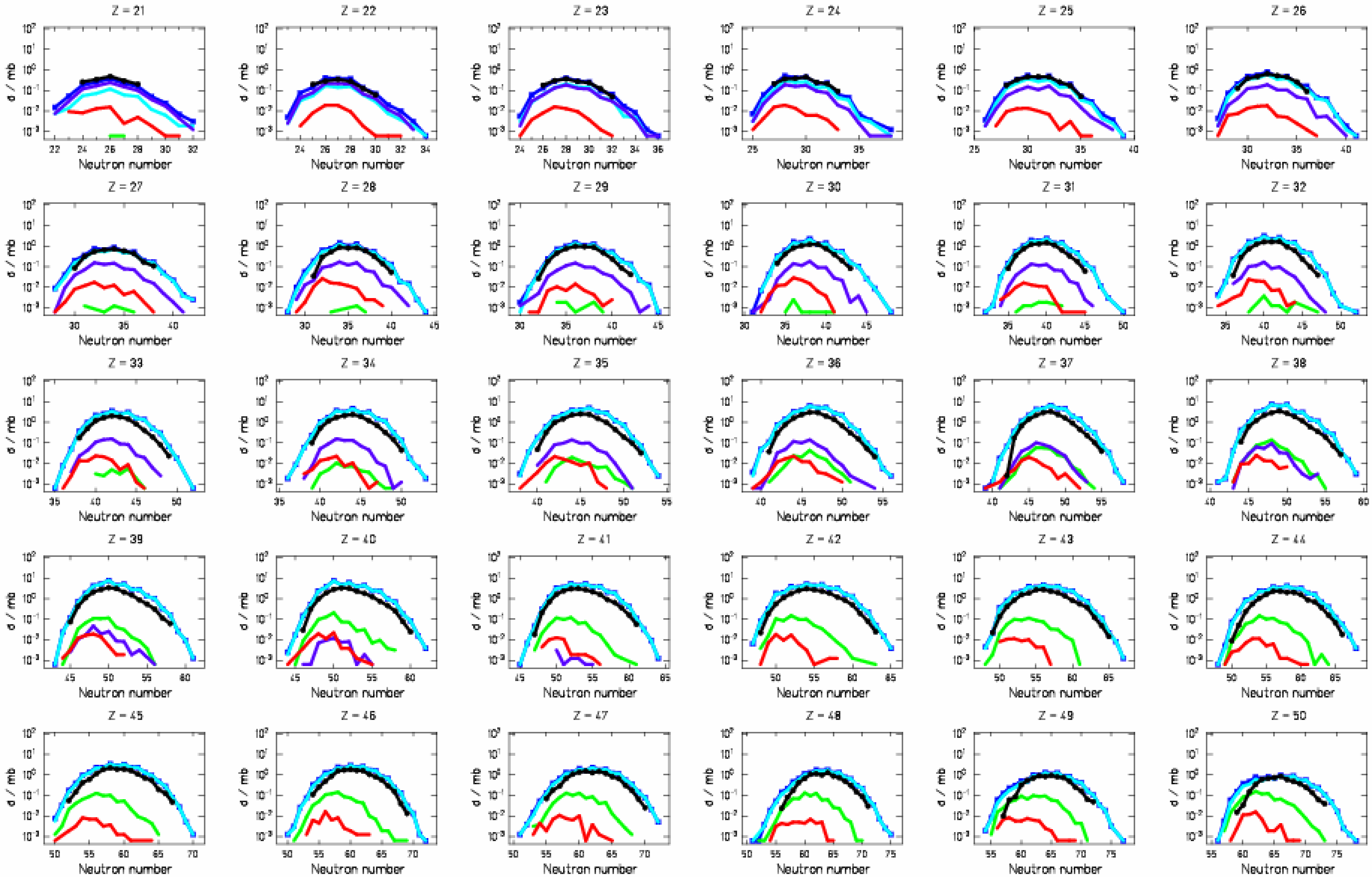
1 GeV p + ^{208}Pb INCL4+ABLA07



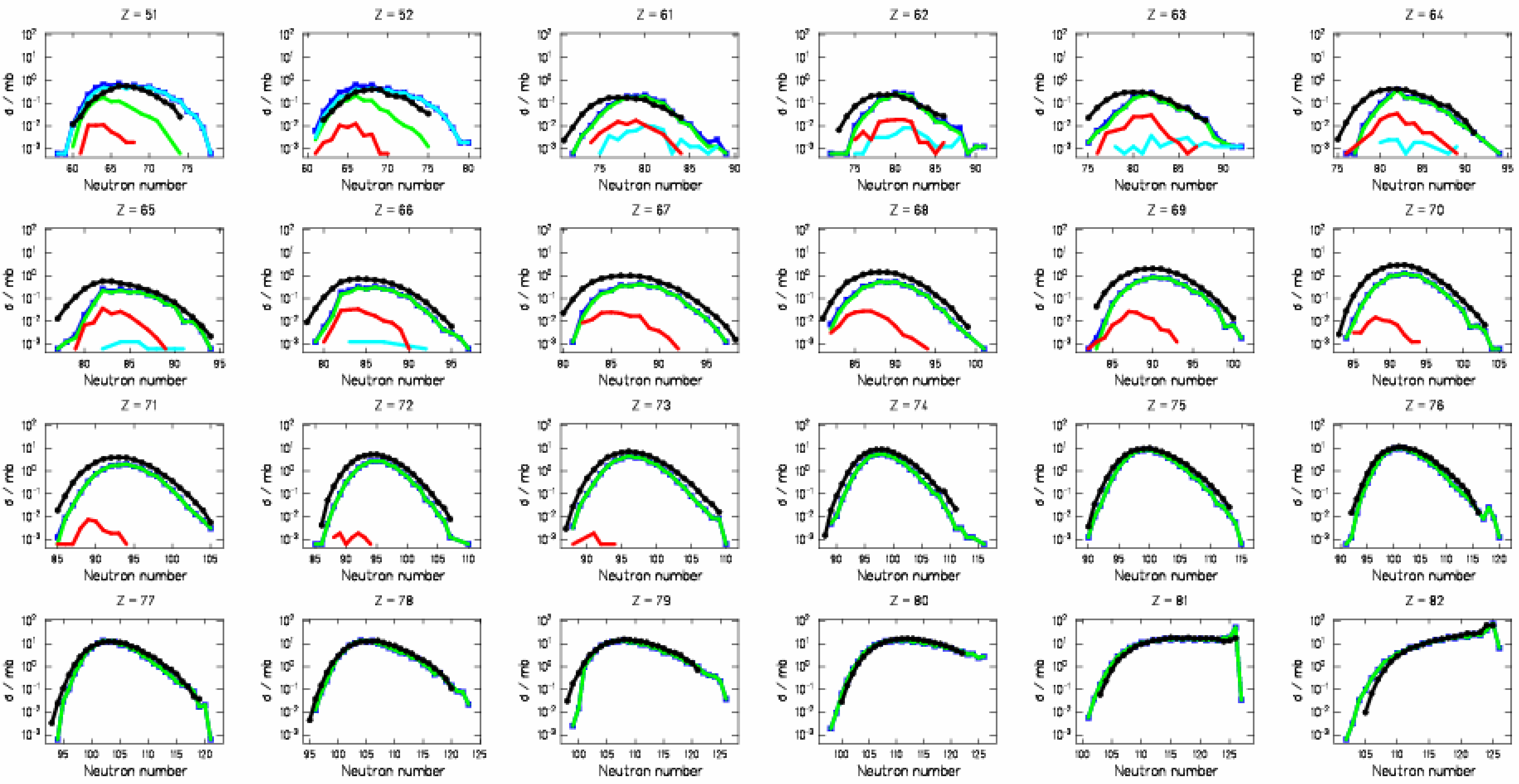
1 GeV p + ^{208}Pb INCL4+ABLA07



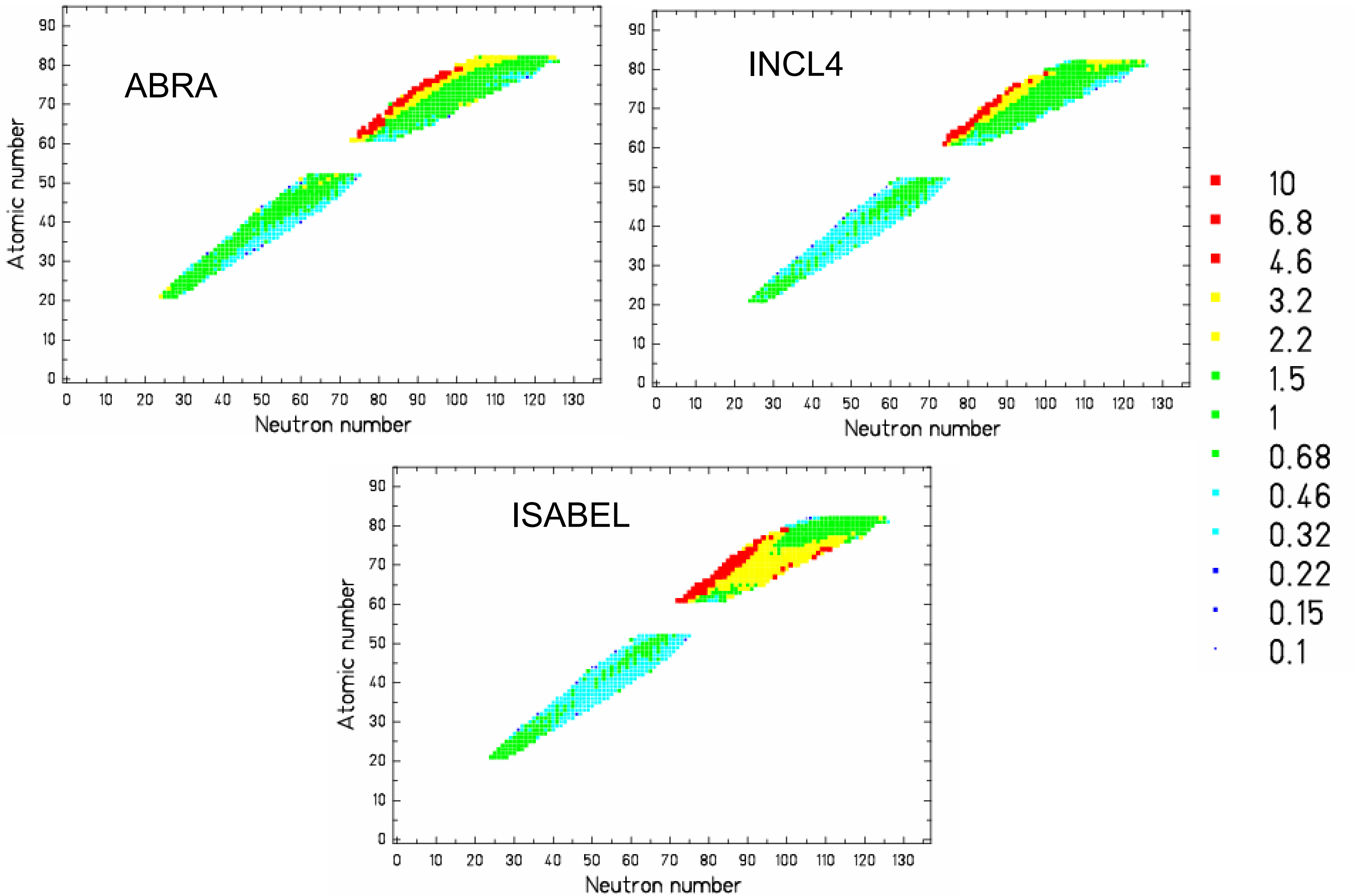
1 GeV p + ^{208}Pb ISABEL+ABLA07



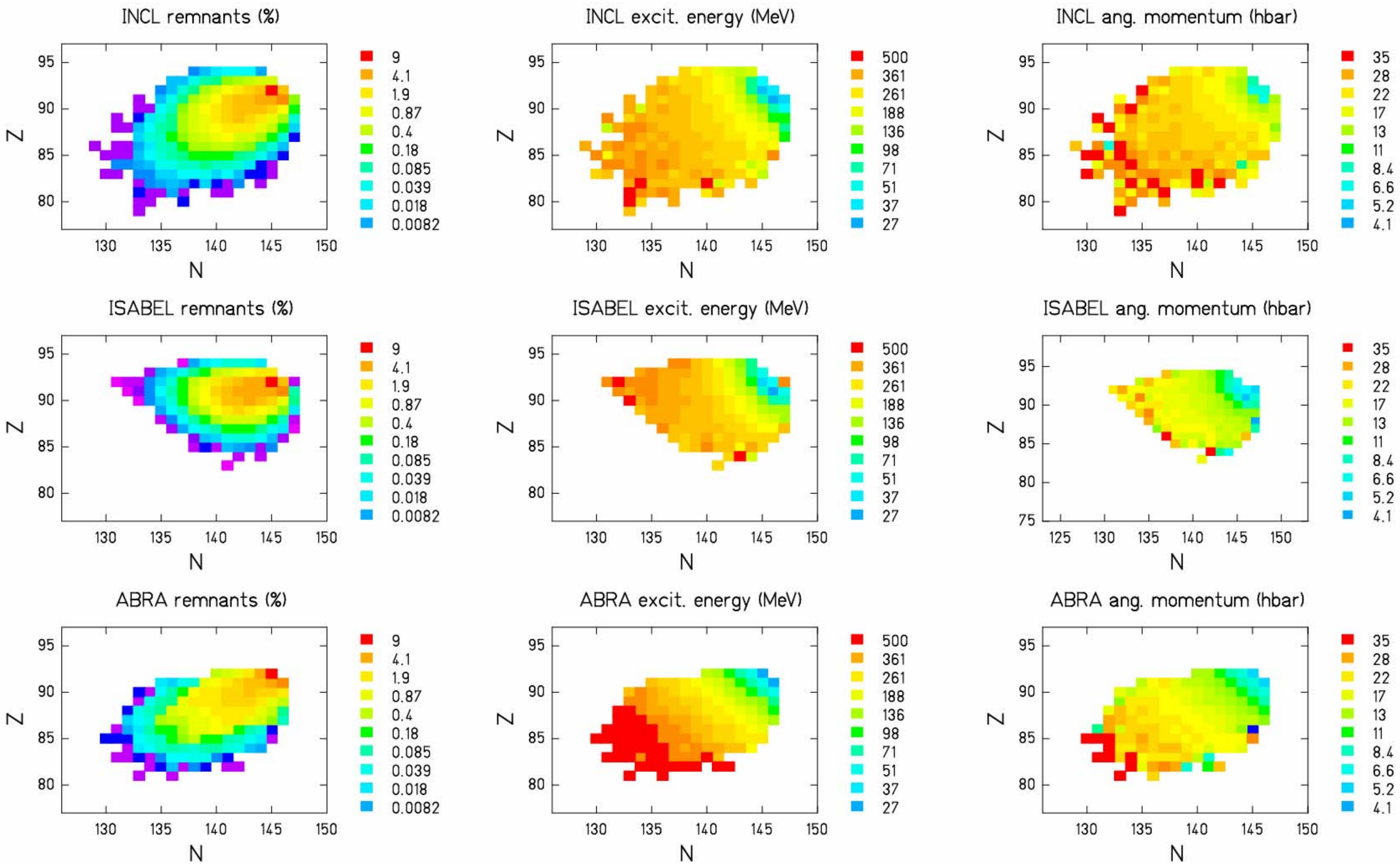
1 GeV p + ^{208}Pb ISABEL+ABLA07



1 GeV p + ^{208}Pb ratio exp/calc



1 GeV p + ^{238}U



INCL remnants (%)
INCL excit. energy (MeV)
INCL ang. momentum (hbar)
ISABEL remnants (%)
ISABEL excit. energy (MeV)
ISABEL ang. momentum (hbar)
ABRA remnants (%)
ABRA excit. energy (MeV)
ABRA ang. momentum (hbar)
Z
N
9
4.1
1.9
0.87
0.4
0.18
0.085
0.039
0.018
0.0082
500
361
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136
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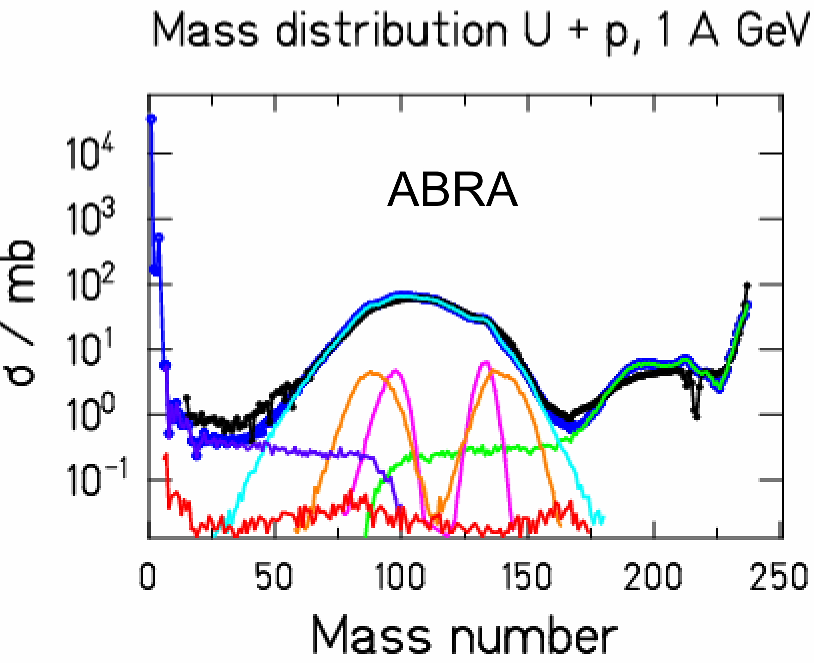
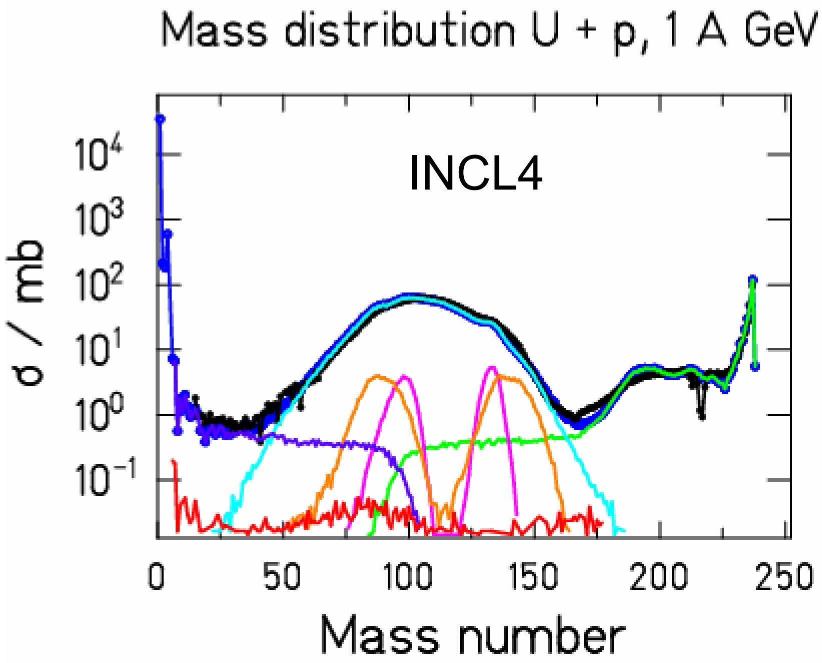
35
28
22
17
13
11
8.4
6.6
5.2
4.1

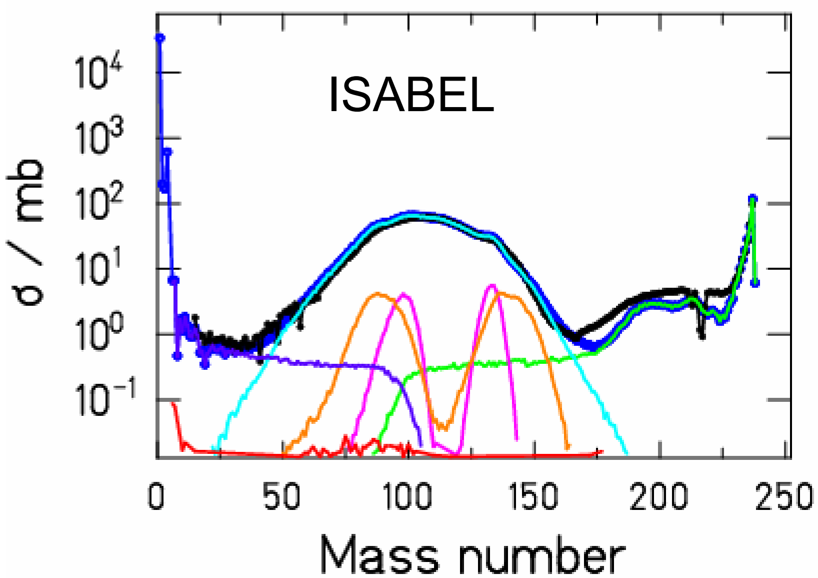
1 GeV p + ^{238}U



Mass distribution U + p, 1 A GeV
ABRA
σ / mb
Mass number

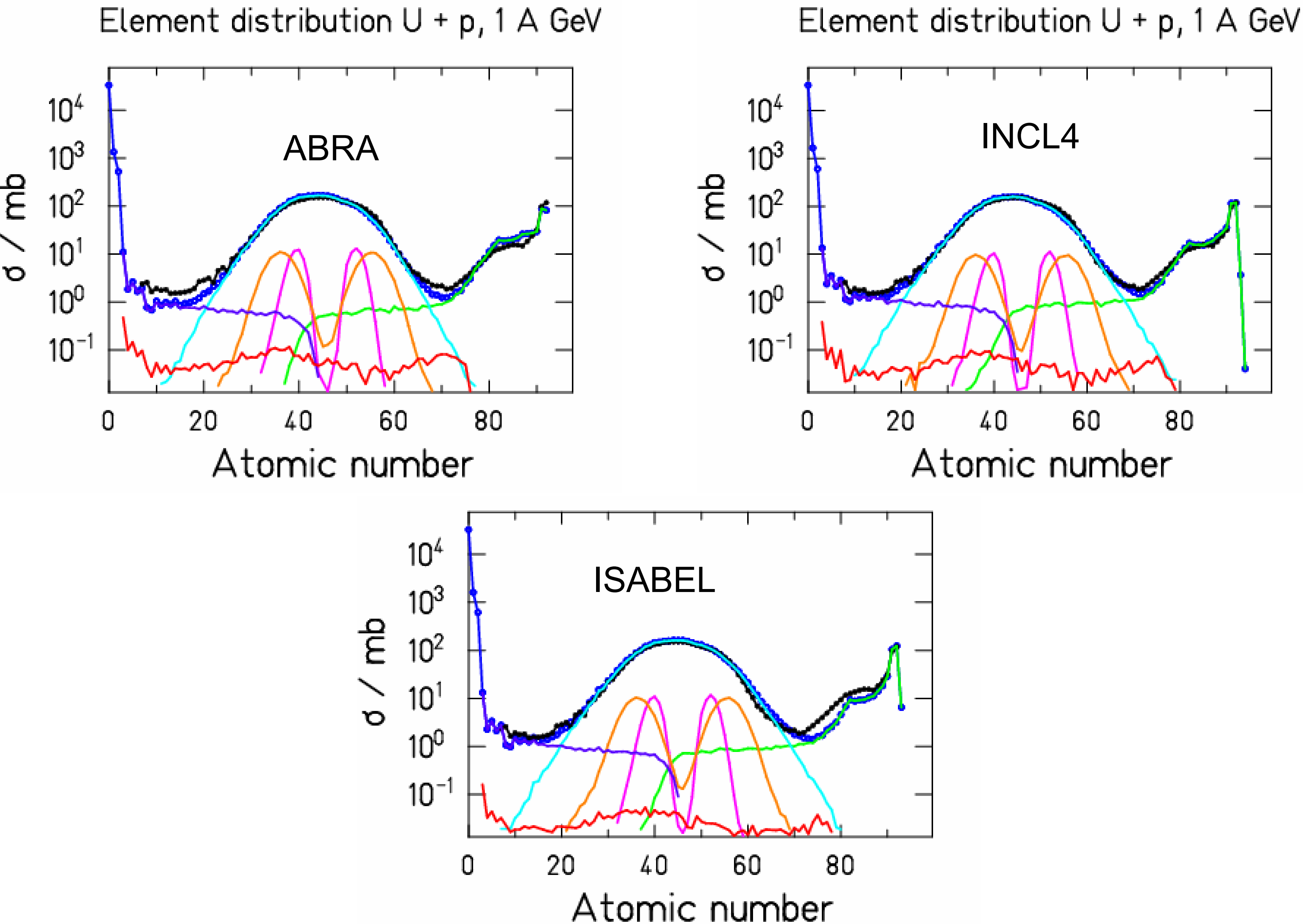


Mass distribution U + p, 1 A GeV
INCL4
σ / mb
Mass number



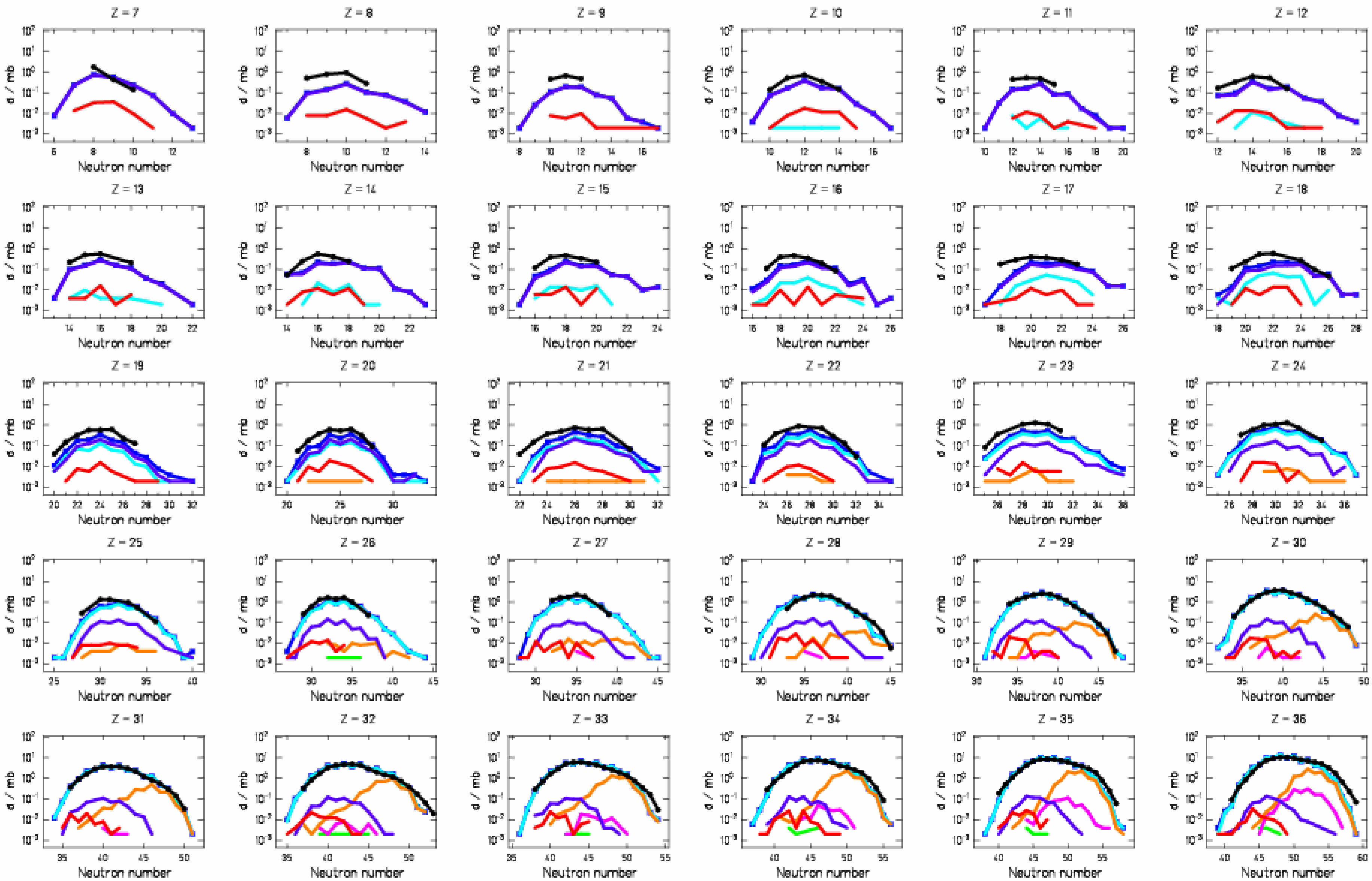
ISABEL
σ / mb
Mass number

1 GeV p + ^{238}U

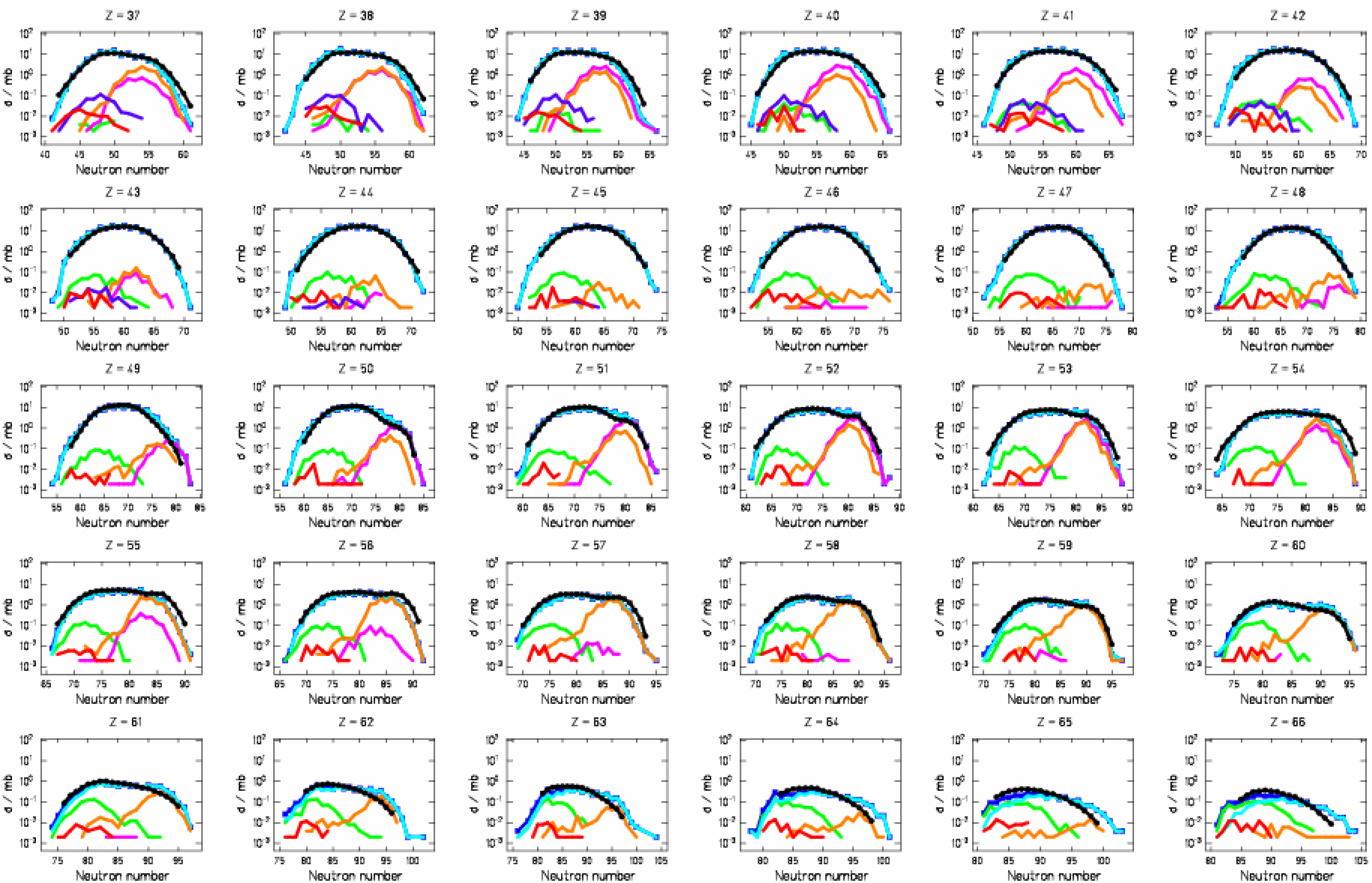


Element distribution U + p, 1 A GeV
ABRA
σ / mb
Atomic number
Element distribution U + p, 1 A GeV
INCL4
σ / mb
Atomic number
ISABEL
σ / mb
Atomic number

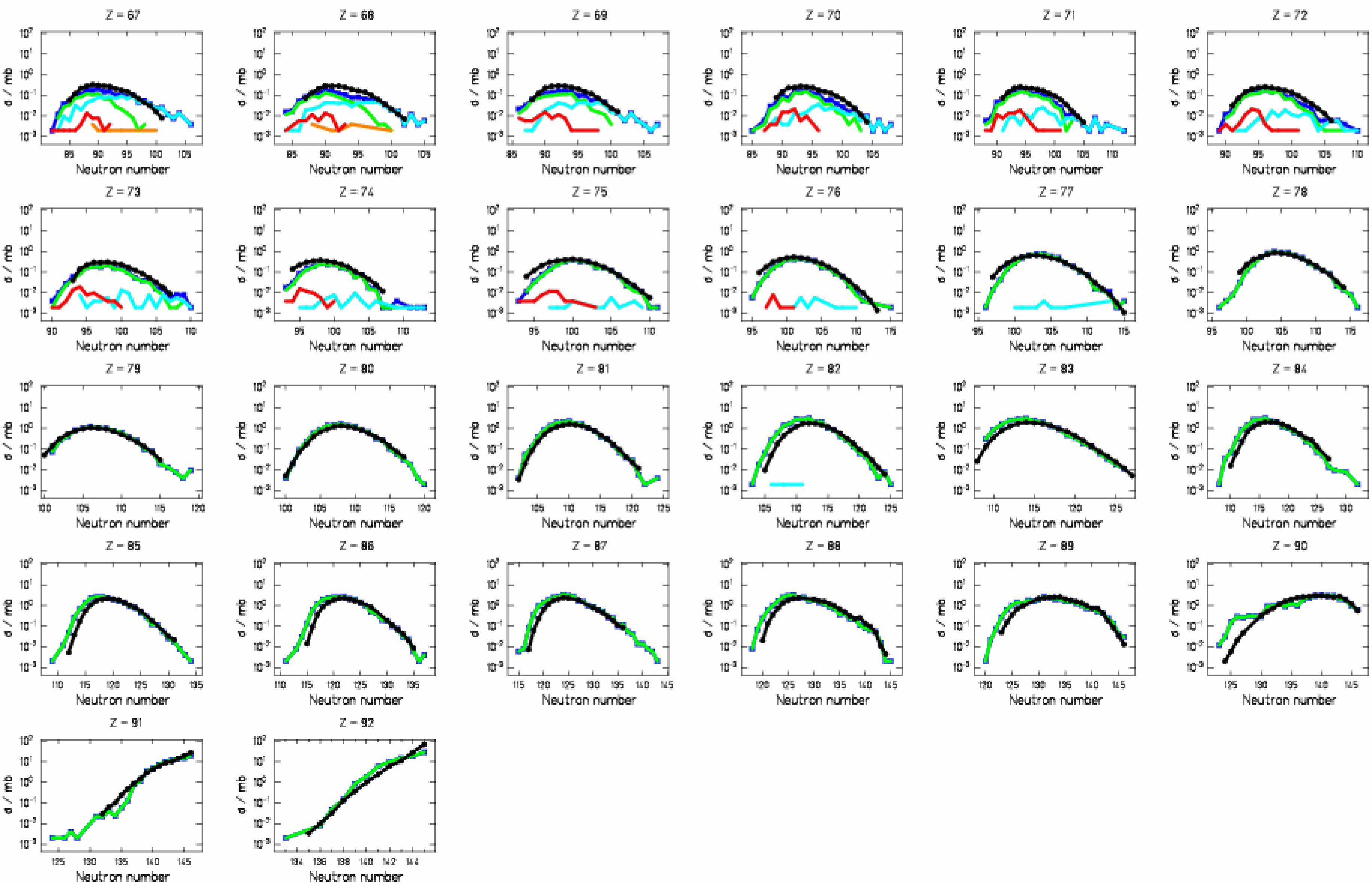
1 GeV p + ^{238}U ABRABLA07



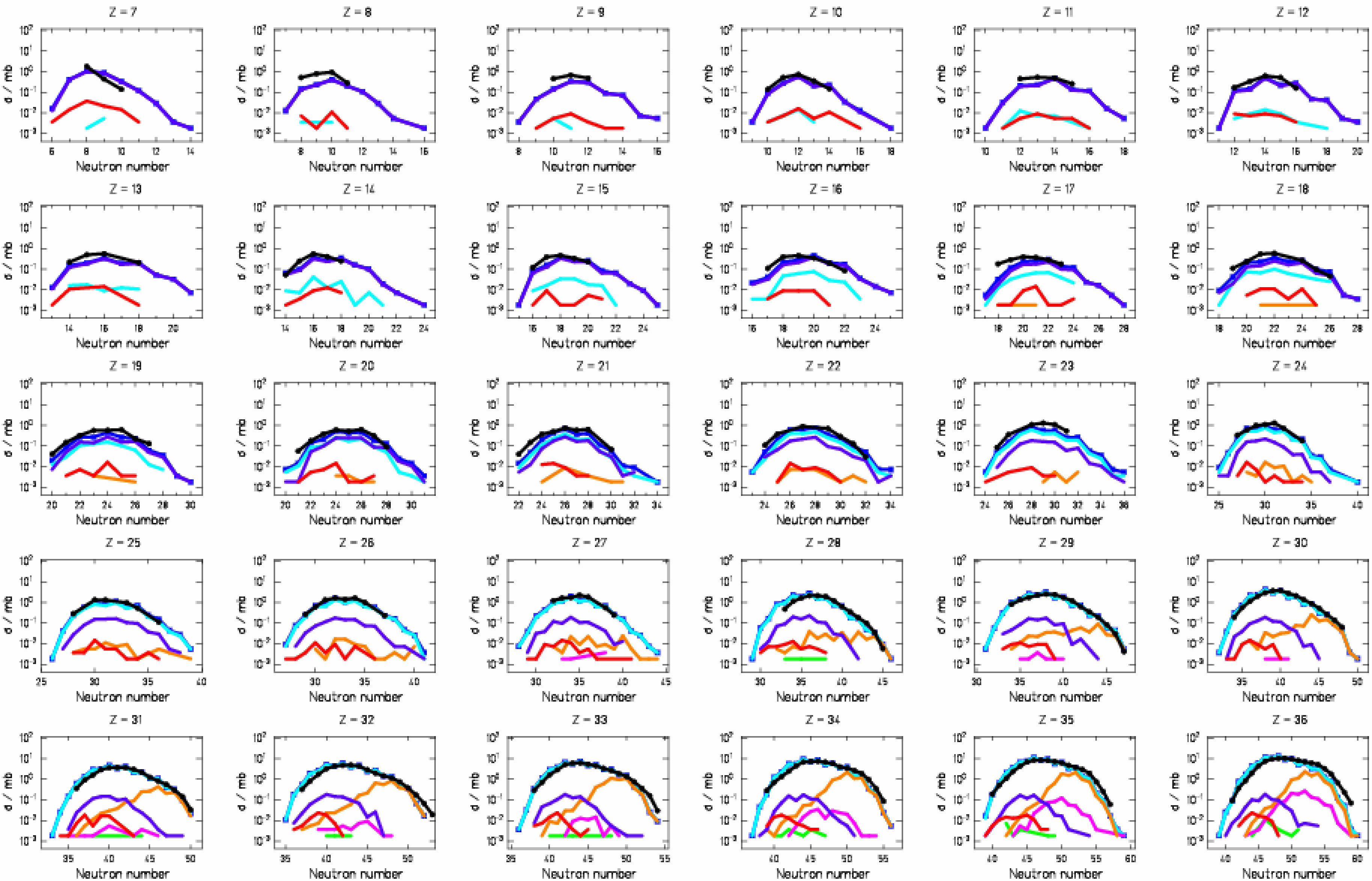
1 GeV p + ^{238}U ABRABLA07



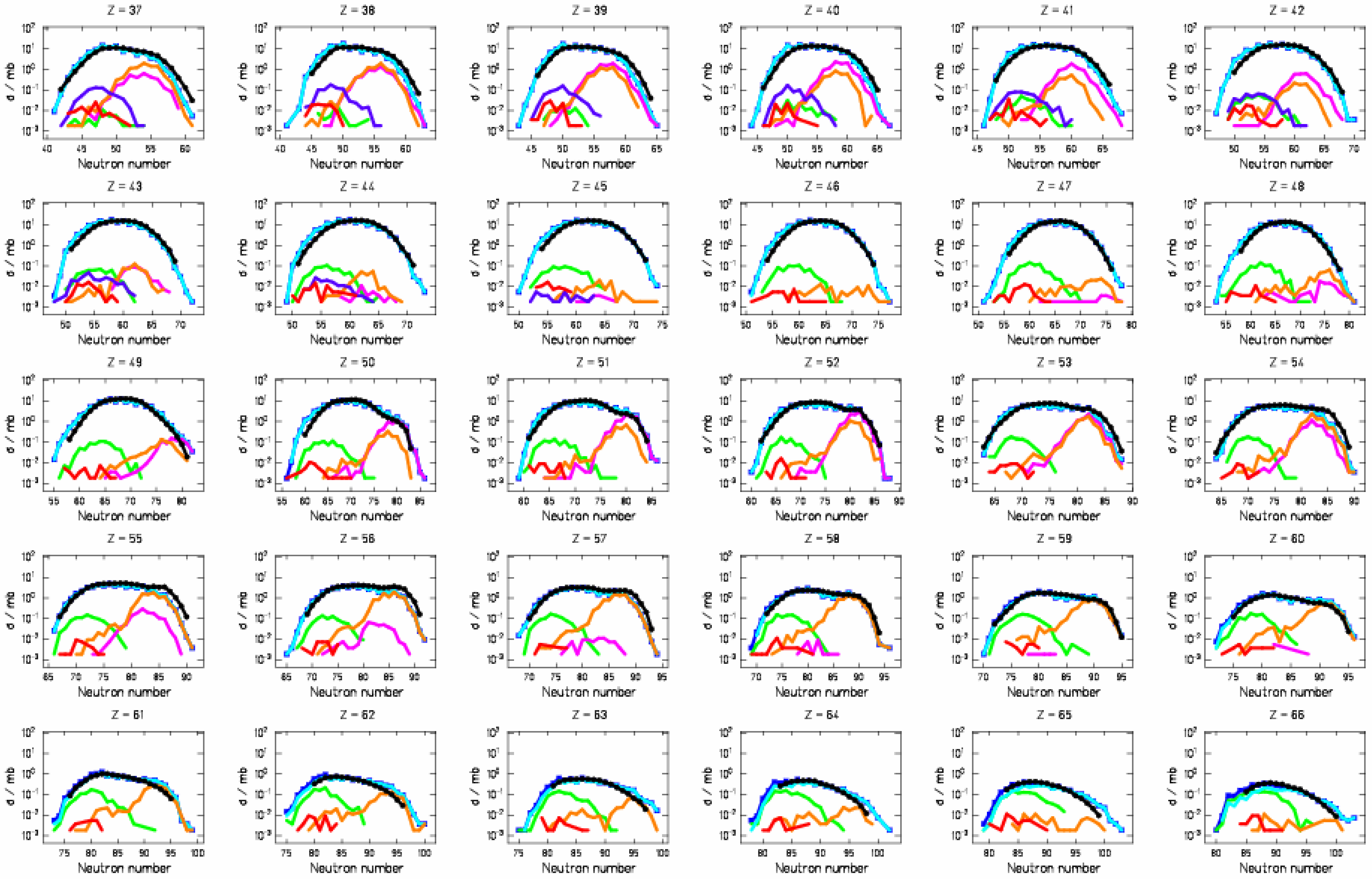
1 GeV p + ^{238}U ABRABLA07



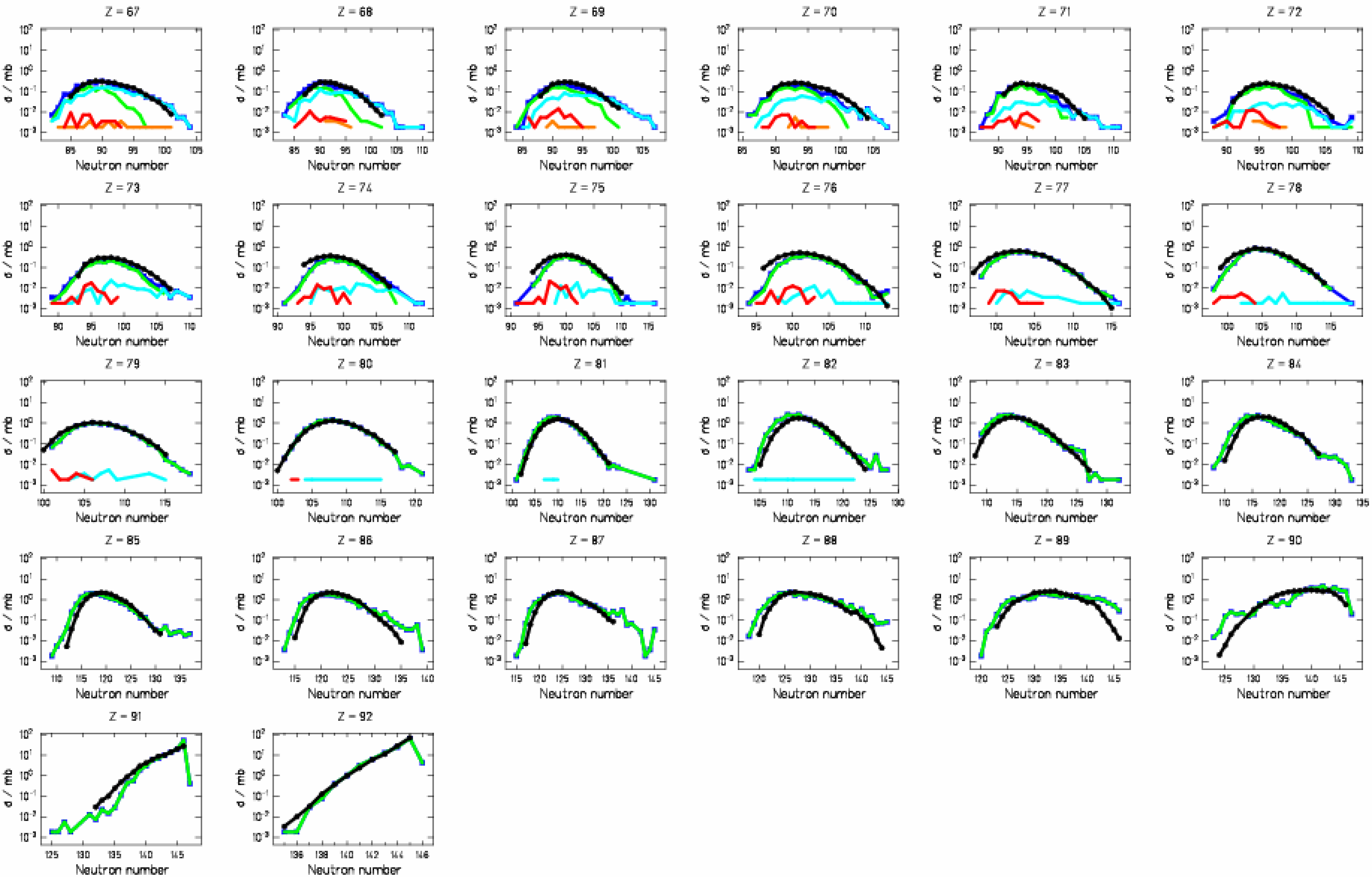
1 GeV p + ^{238}U   INCL4+ABLA07



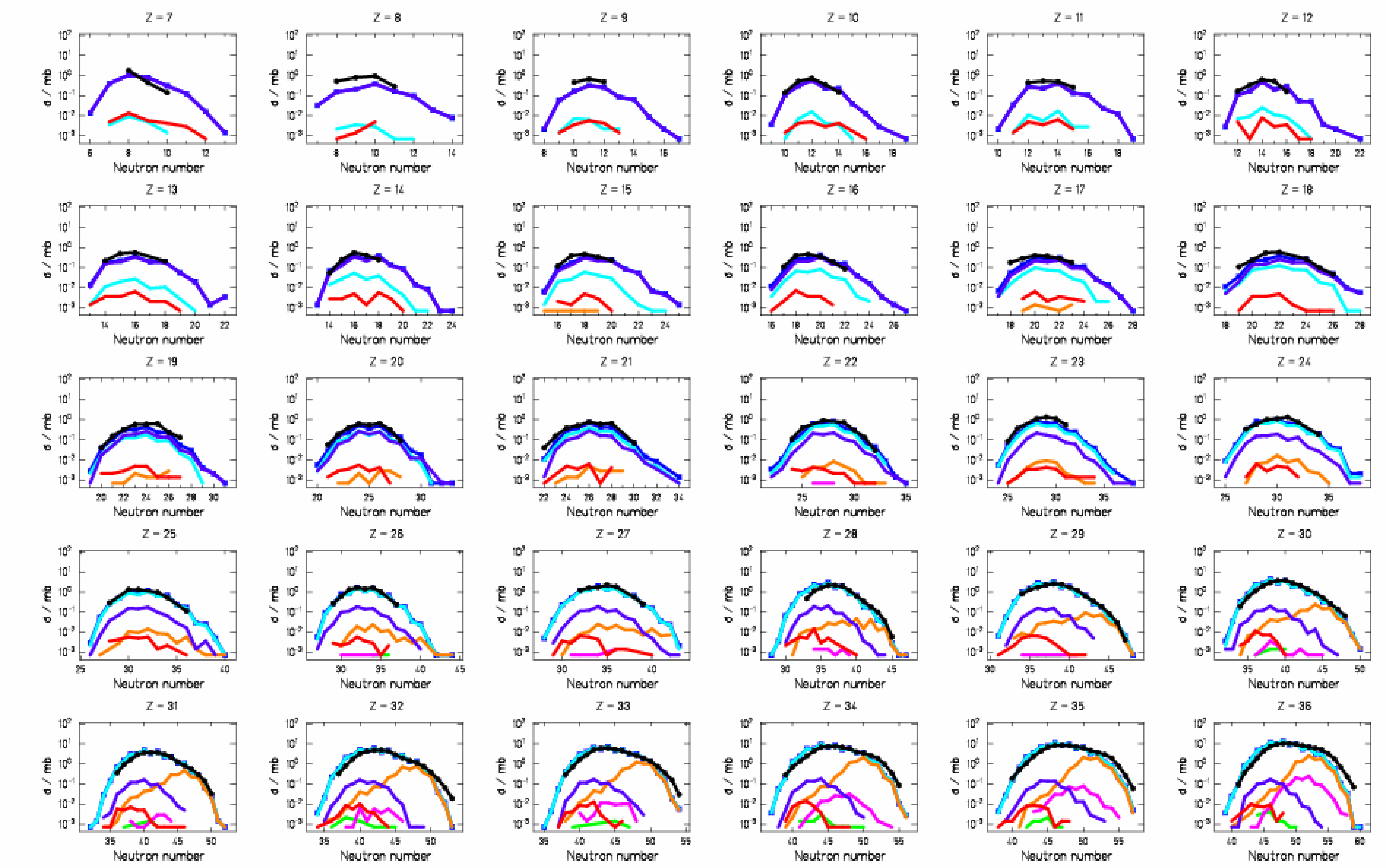
1 GeV p + ^{238}U   INCL4+ABLA07



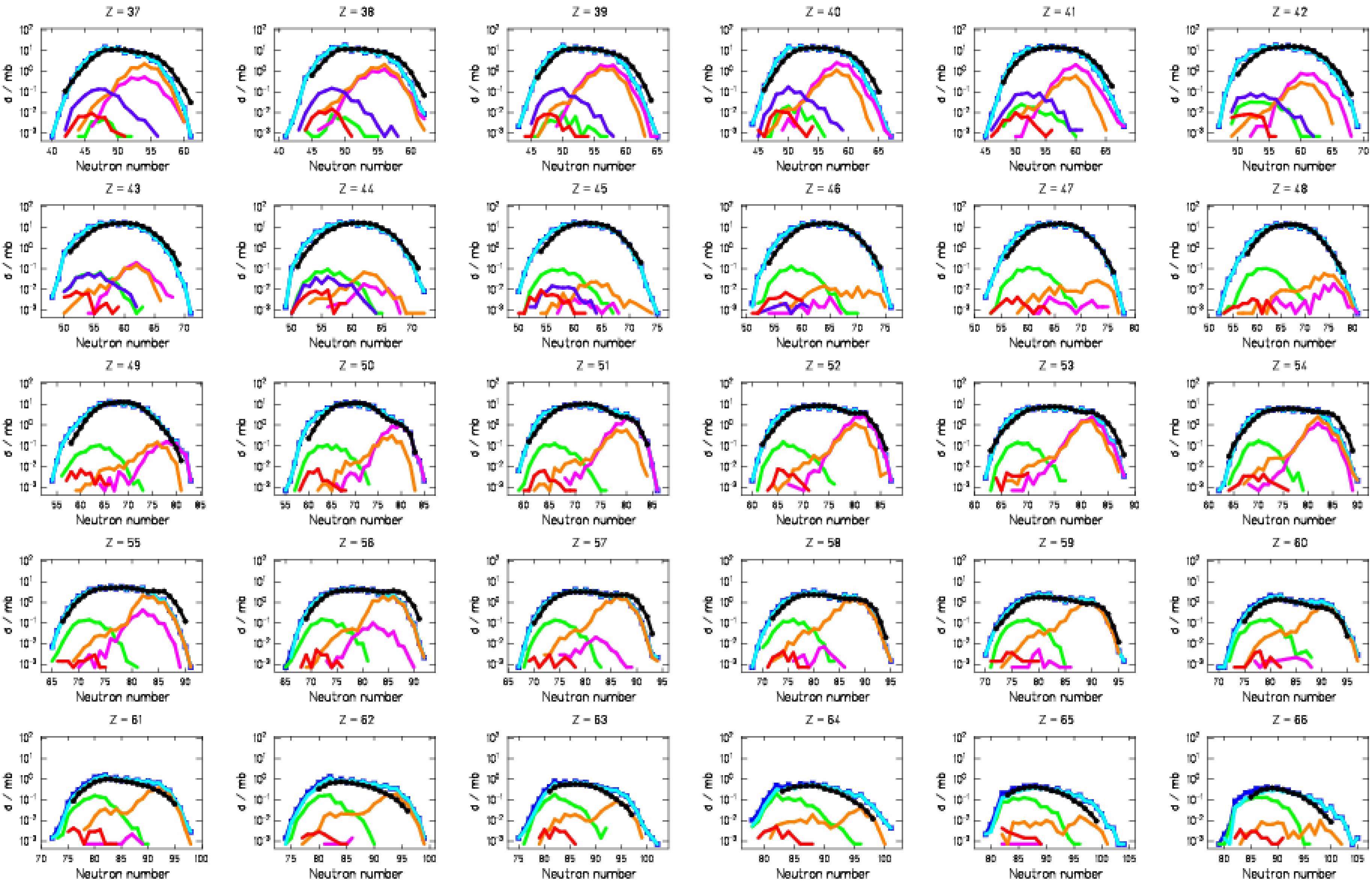
1 GeV p + ^{238}U INCL4+ABLA07



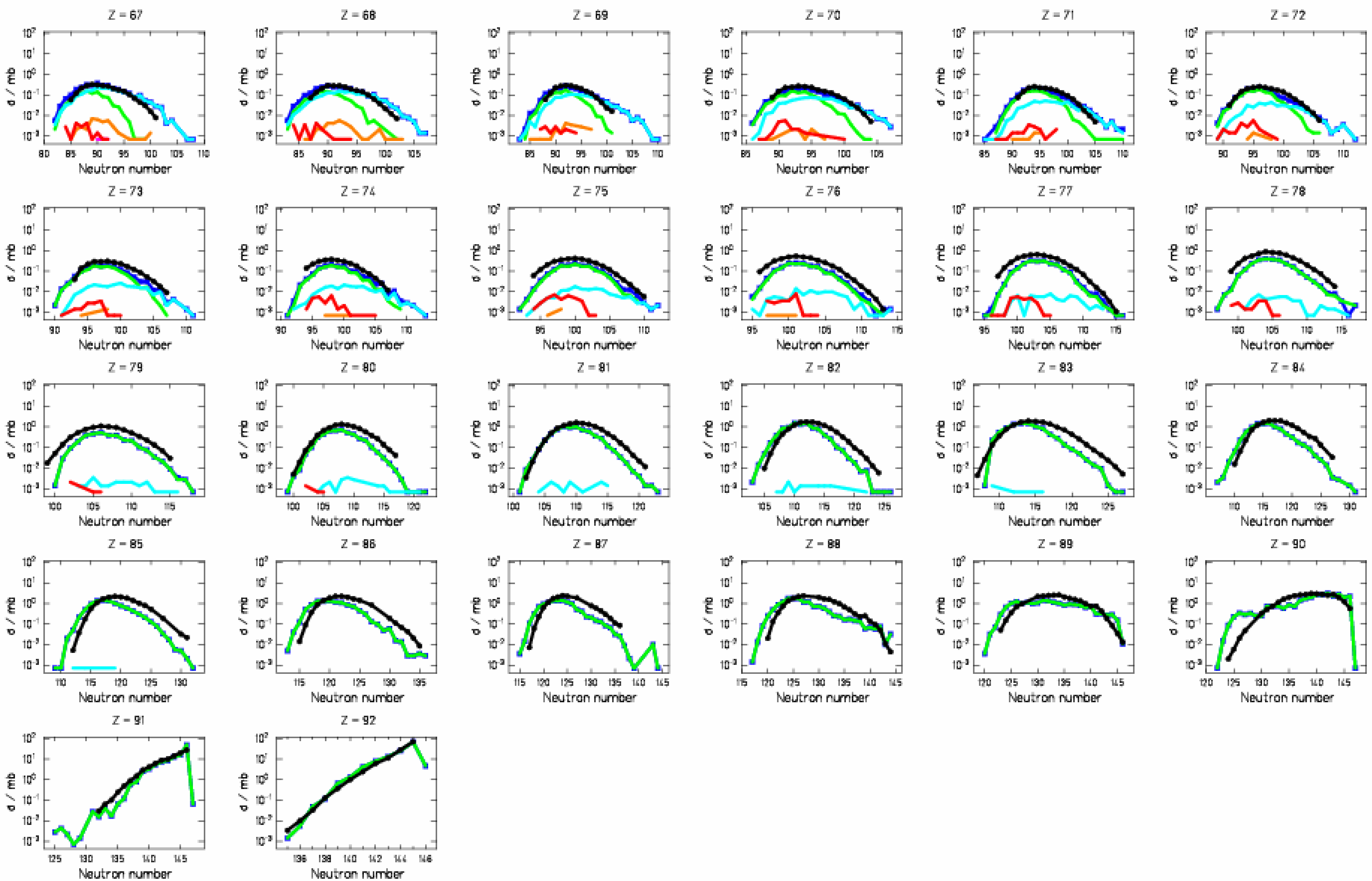
1 GeV p + ^{238}U ISABEL+ABLA07



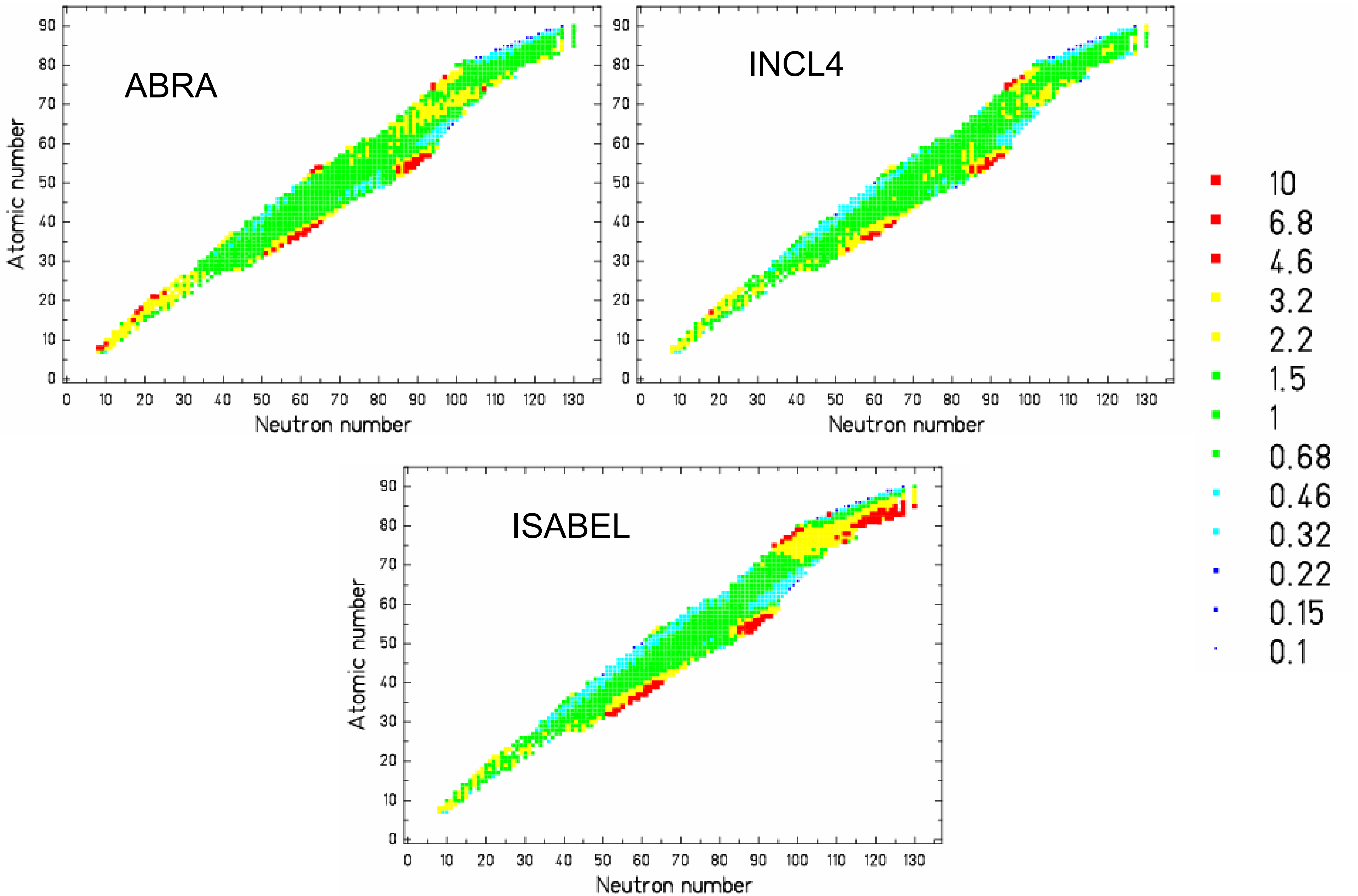
1 GeV p + ^{238}U ISABEL+ABLA07



1 GeV p + ^{238}U ISABEL+ABLA07



1 GeV p + ^{238}U   ratio exp/calc



Conclusions

What can still be done in ABLA:

- Improvement of even-odd effect
- More physics content in the break-up stage (not so important for spallation reactions)

Further improvements:

- Necessity of fixing the initial conditions of the de-excitation process → Spaladin experiments