Results of the de-excitation code ABLA07

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Layout

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

Improvements
in
ABLA07

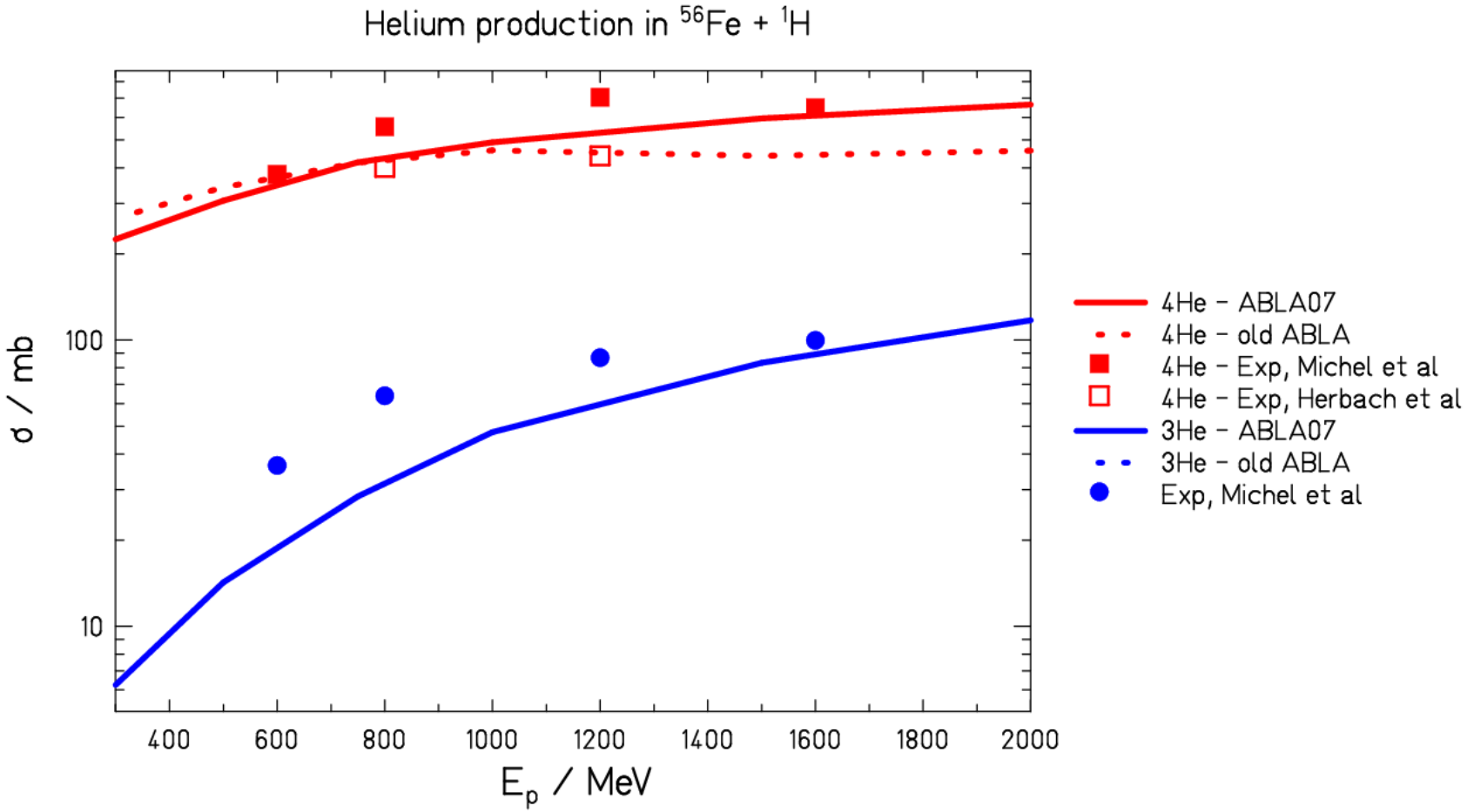
see proceedings of the
“Joint ICTP-IAEA Advanced Workshop on
Model Codes for Spallation Reactions„
held in Trieste, Italy, 4-8 January 2008

ABLA07

New features (with moderate increase of computing time):

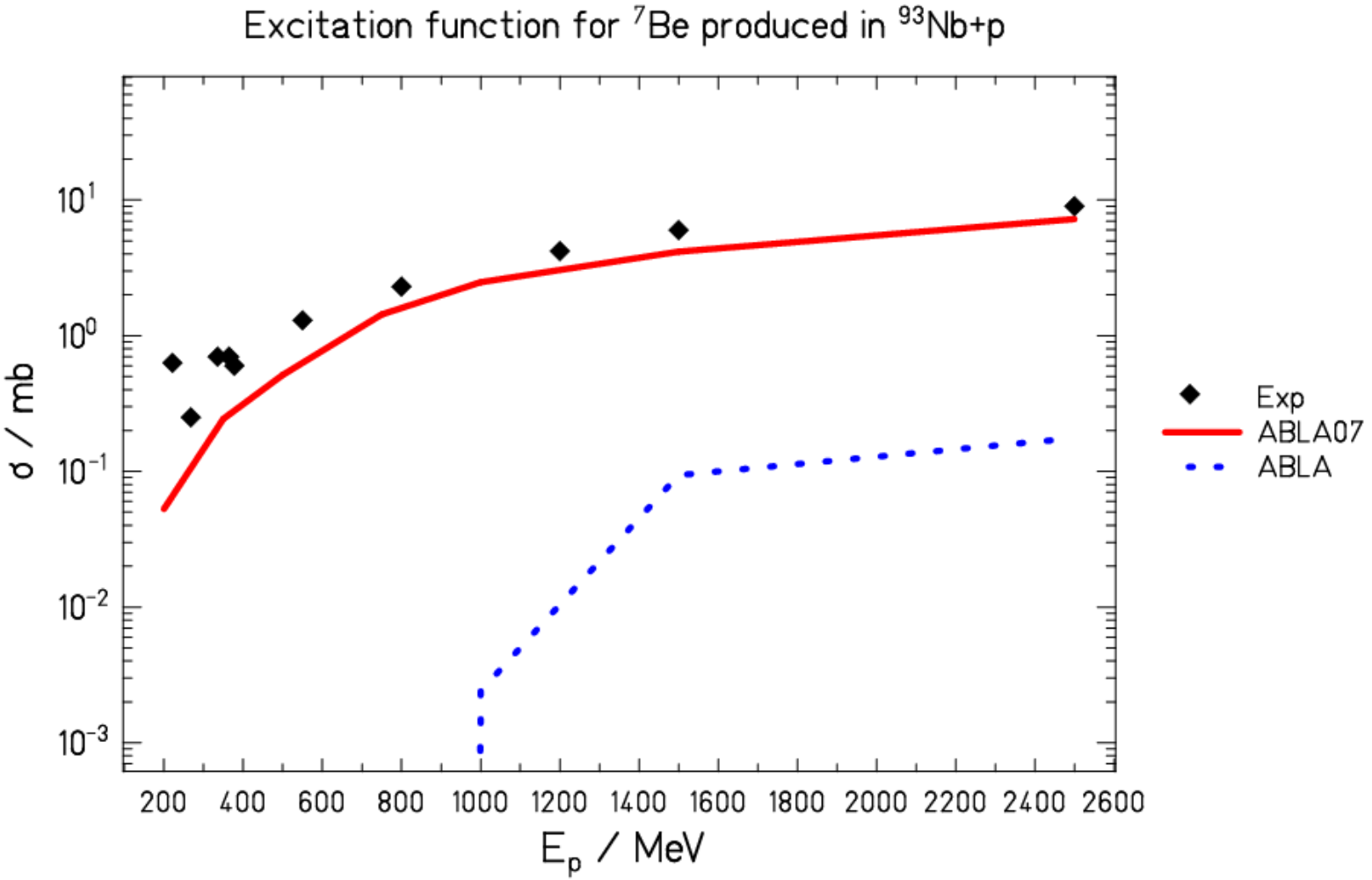
- Multifragmentation
- CN-decay channels γ, n, p, LCP, IMF, fission (continuous)
  - inverse x-sections from nuclear potential
  - treatment of angular momentum
  - fission transients from Fokker-Planck equation
  - barrier structure in low-energy fission
  - nuclide production in fission with 1 parameter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

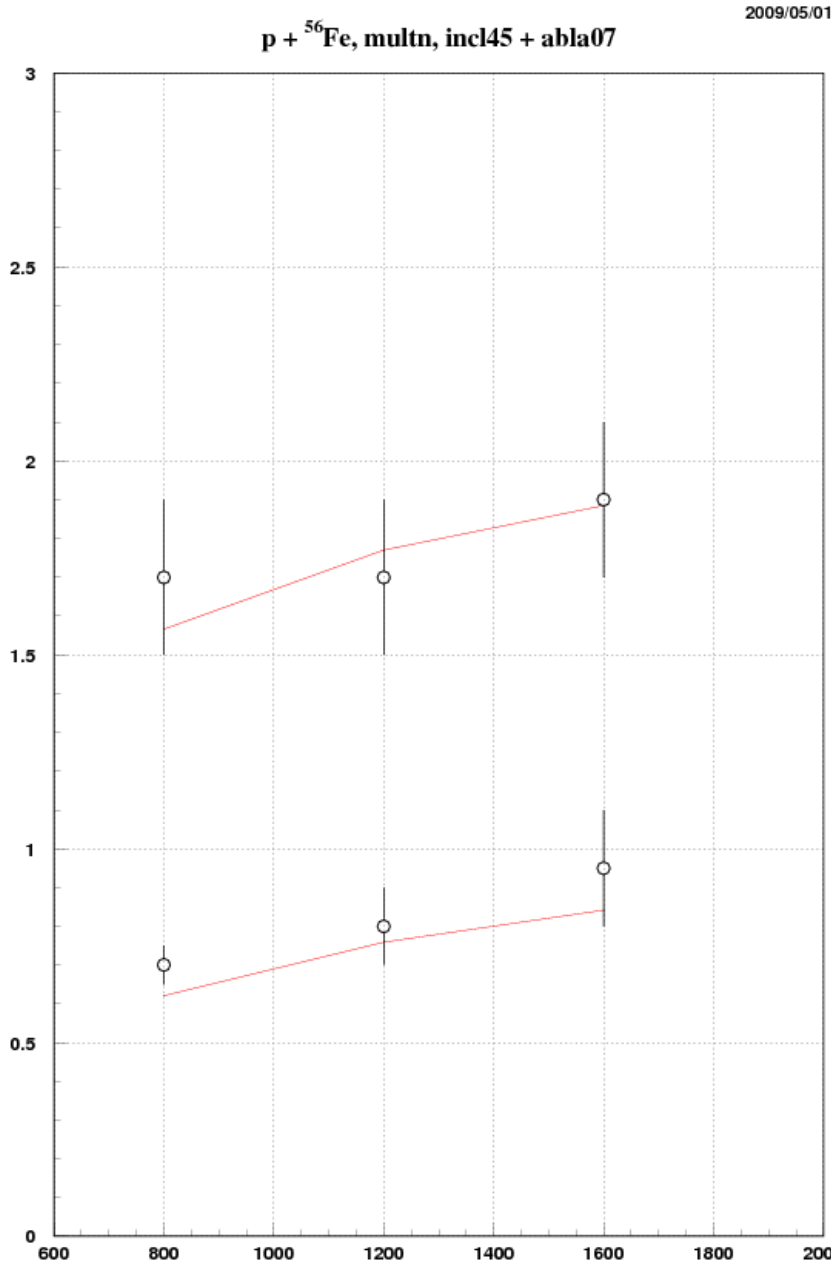
Production of helium

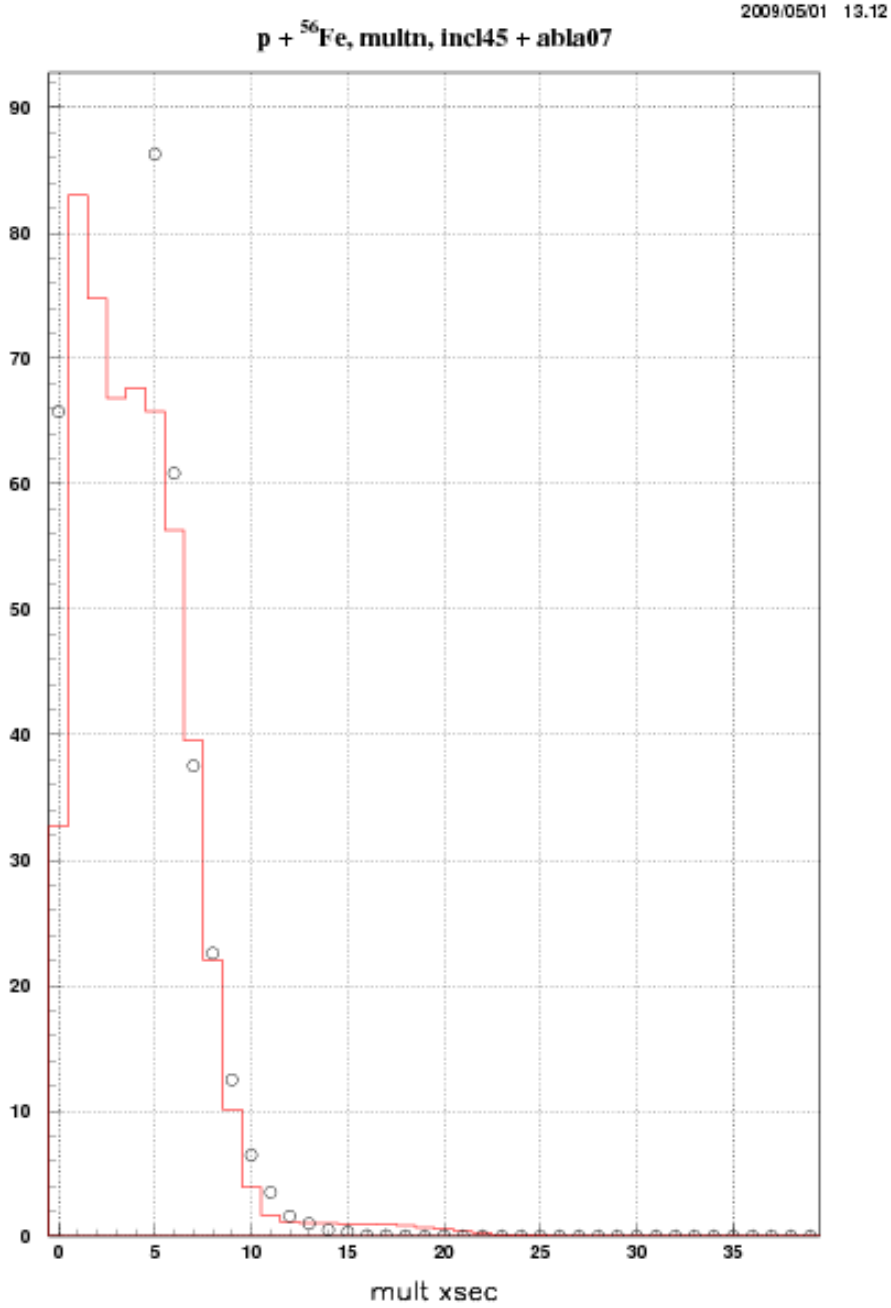


Data: R. Michel et al., NIM B 103,
C. M. Herbach et al., Proc SARE-5 meeting, 2000

Production of ^{7}Be

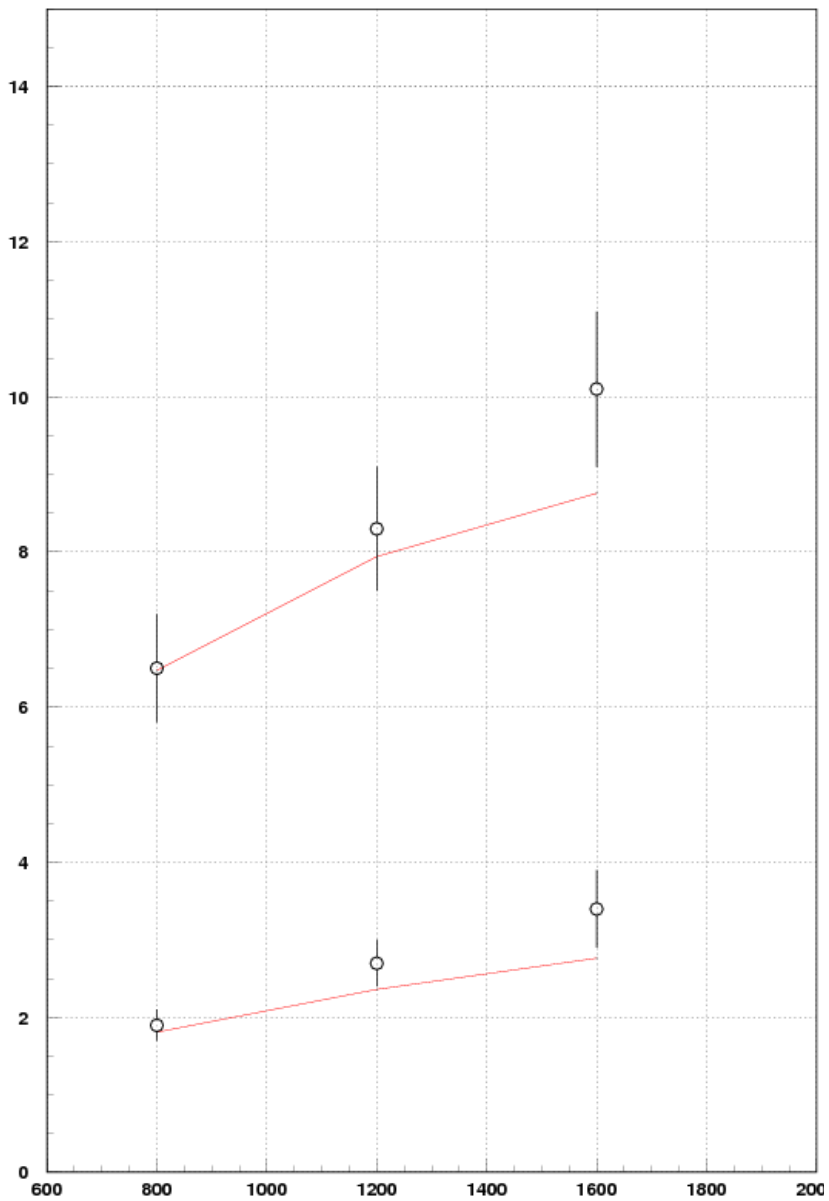



2009/05/01
p + 56Fe, multn, incl45 + abla07
3
2.5
2
1.5
1
0.5
0
600
800
1000
1200
1400
1600
1800
200


2009/05/01 13.12
p + 56Fe, multn, incl45 + abla07
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
mult xsec

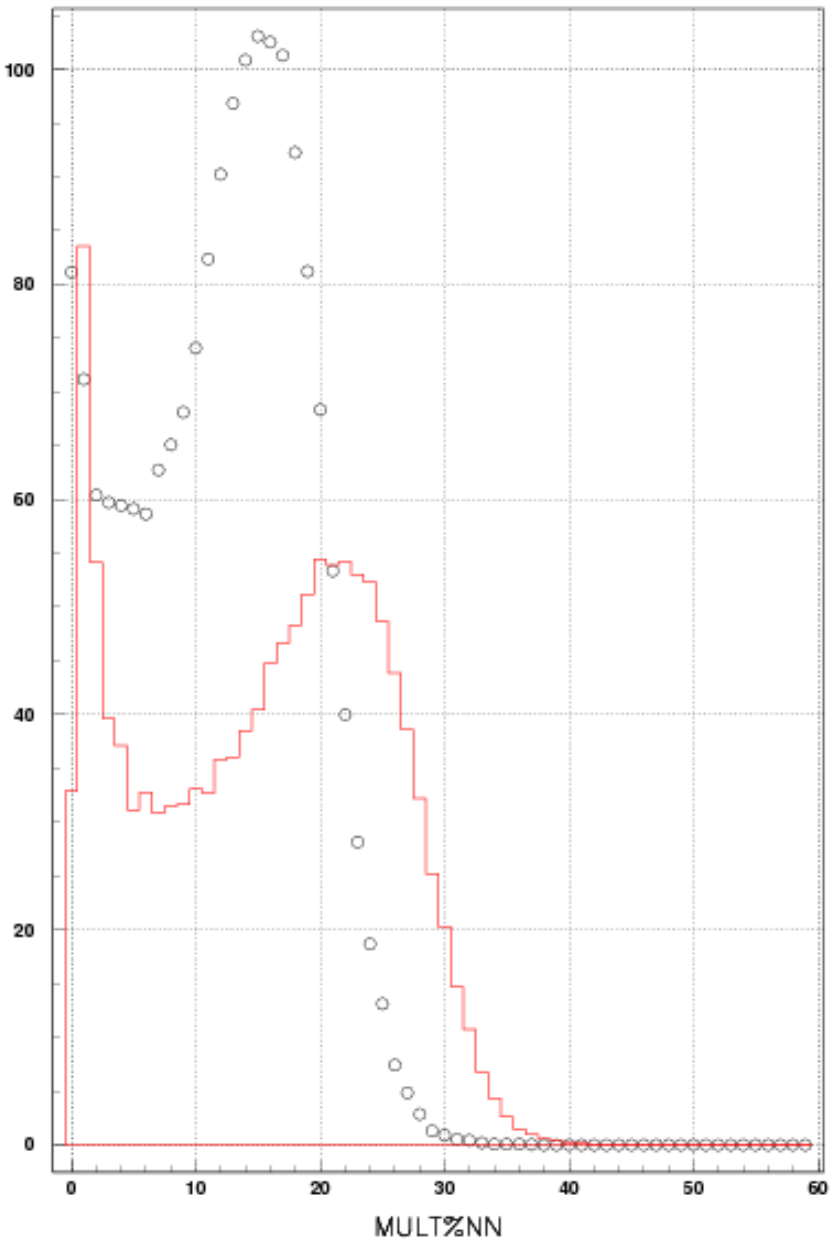
2009/05/01

p + ^{208}Pb, multn, incl45 + abla07



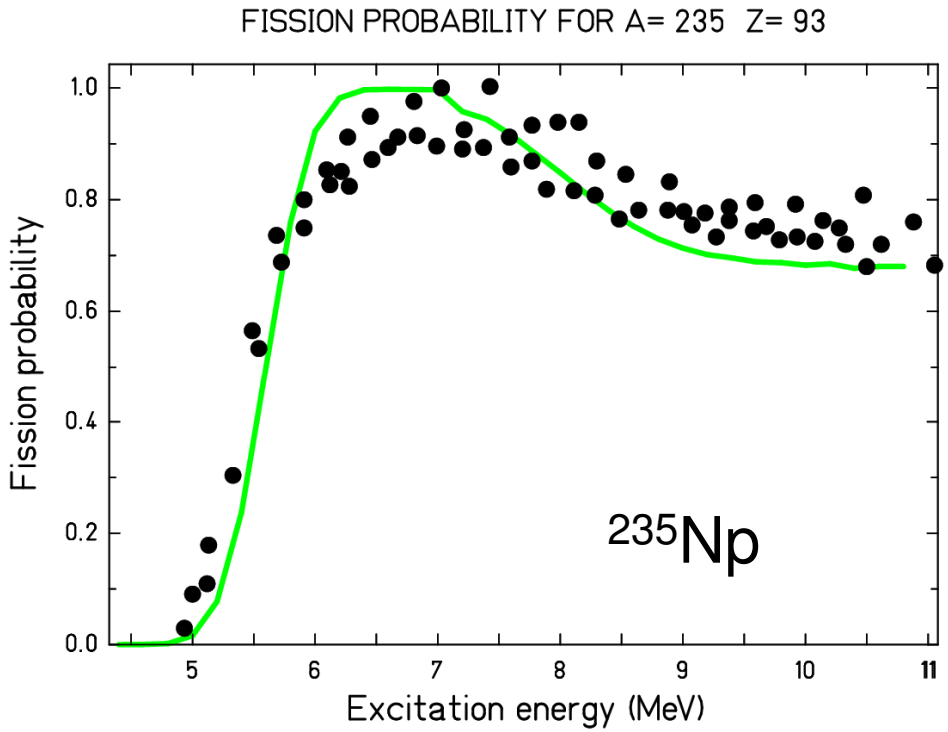
2009/05/01 13.15

1.2-GeV p + ^{208}Pb, multn, incl45 + abla07



Fission cross sections

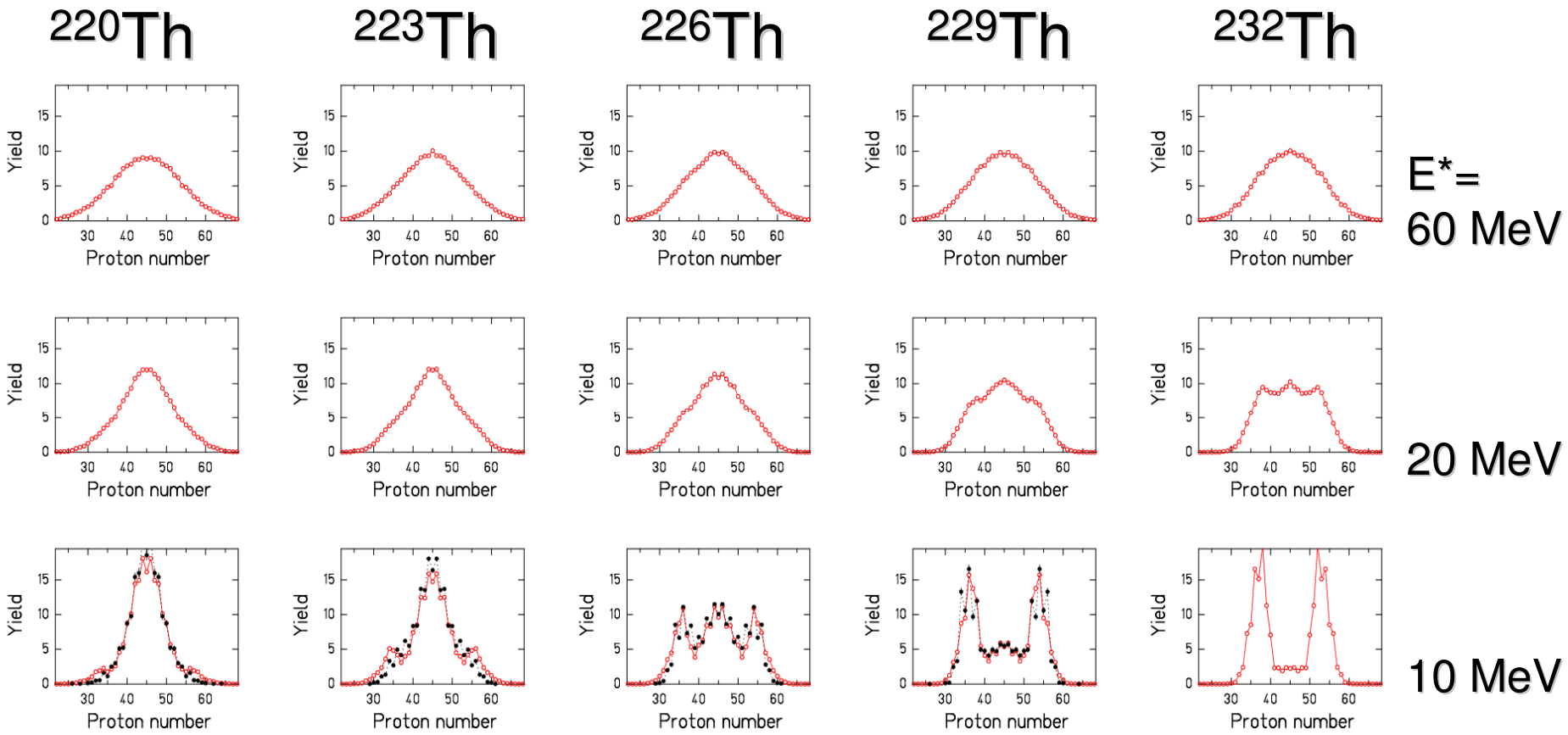
Low-energy fission → influence of double-humped structure in fission barriers of actinides and symmetry classes at saddle



● exp data - Gavron et al., PRC13

— ABLA07

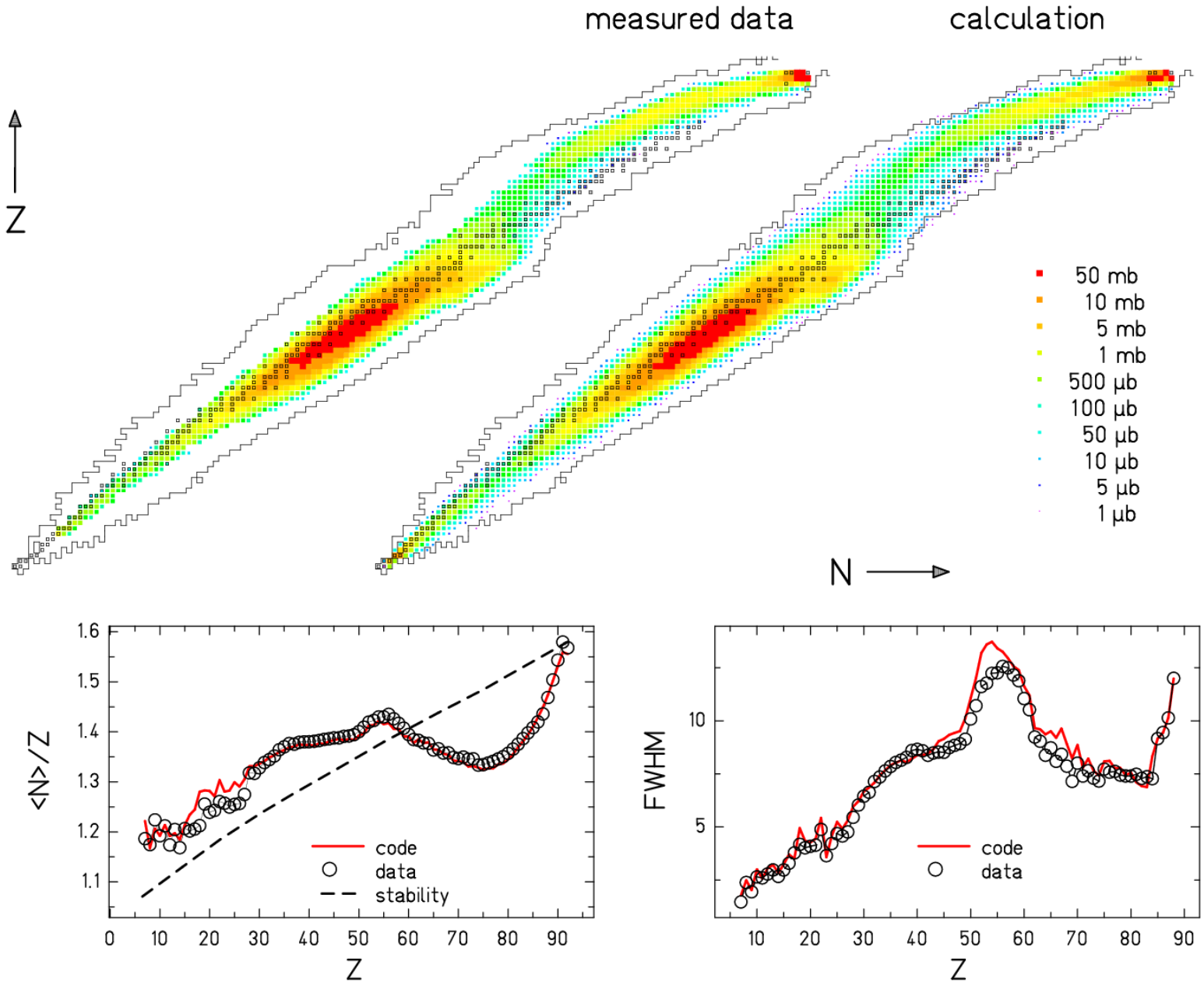
Multimodal fission around ^{226}Th



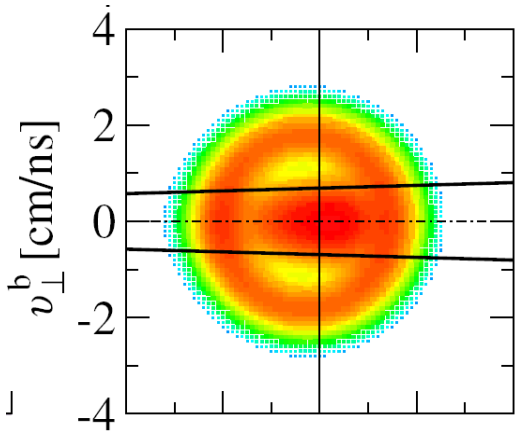
Black: experimental data (GSI experiment)
Red: model calculations (N=82, Z=50, N=92 shells)

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

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



Multifragmentation

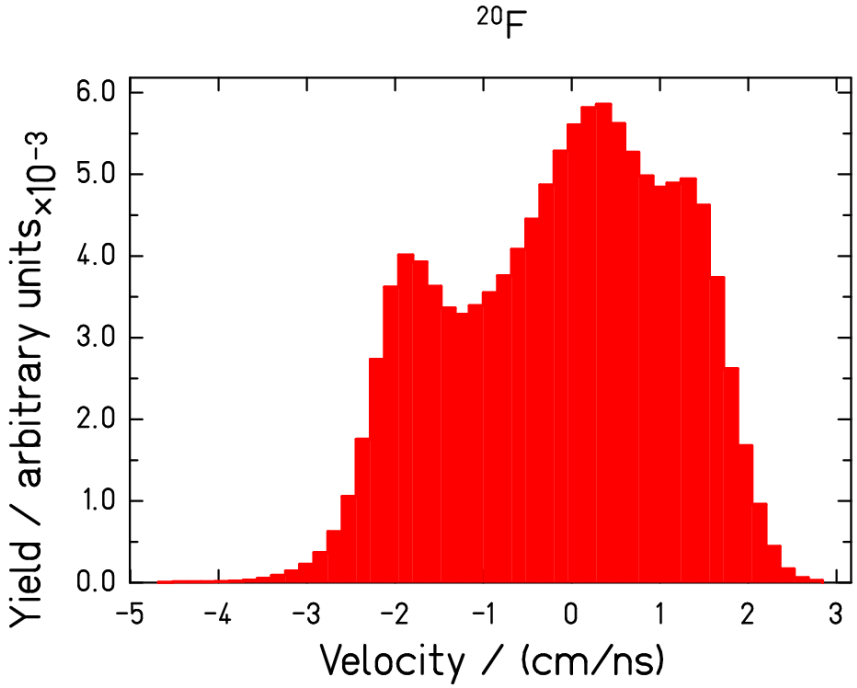


$^{136}Xe + {}^{1}H$
1 A GeV

Longitudinal cuts in velocity

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

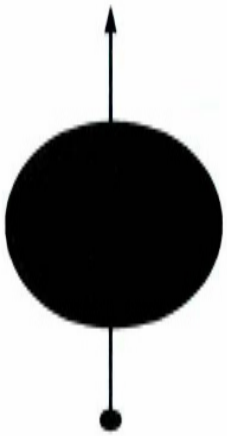
Binary decay:
2 separated forward and backward components due to Coulomb repulsion.



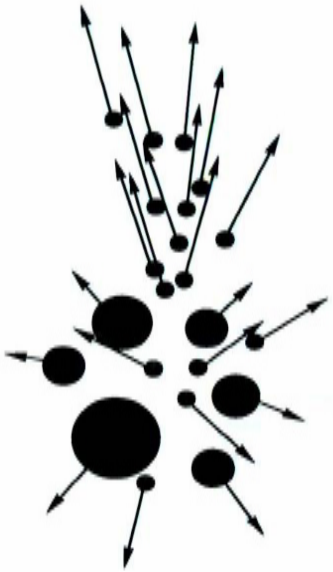
PhD, P. Napolitani

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

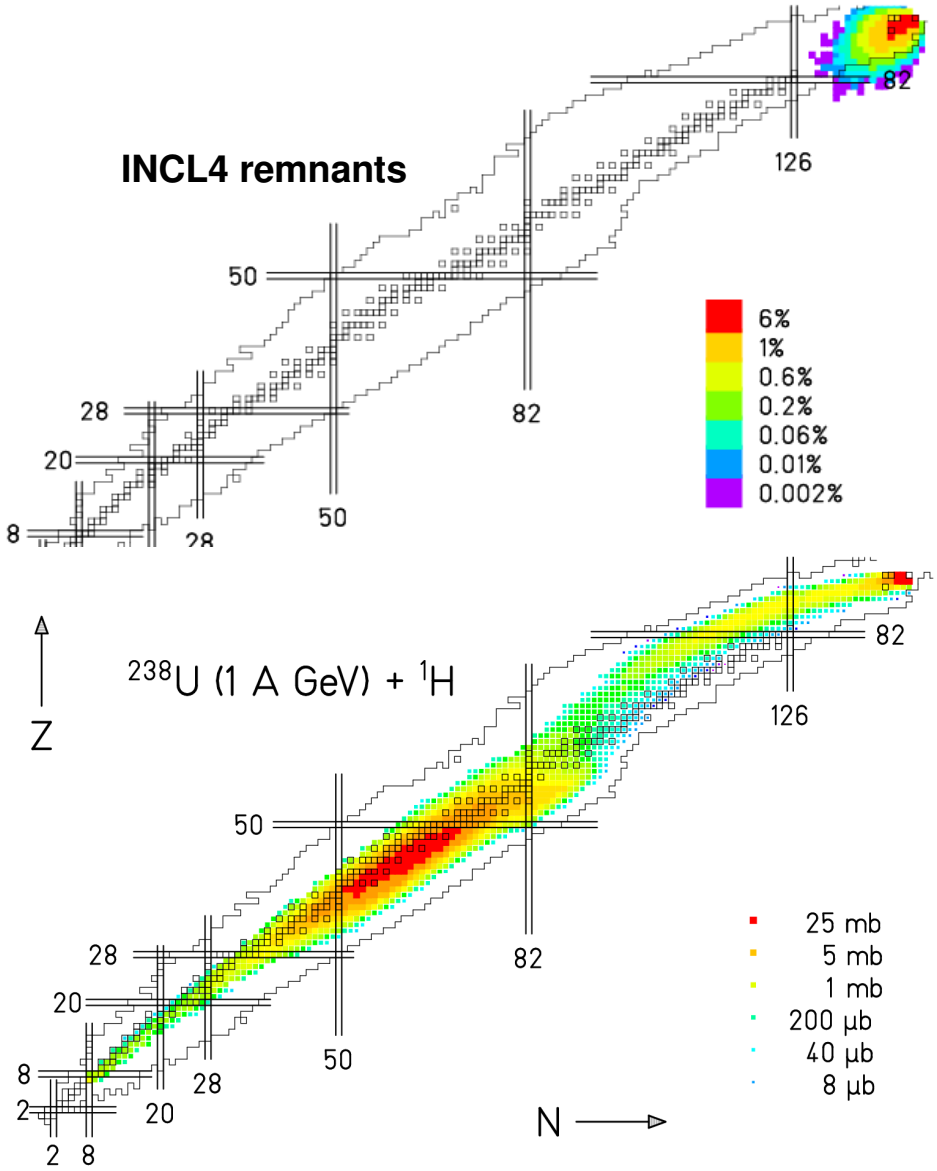
ABLA07 starts here

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



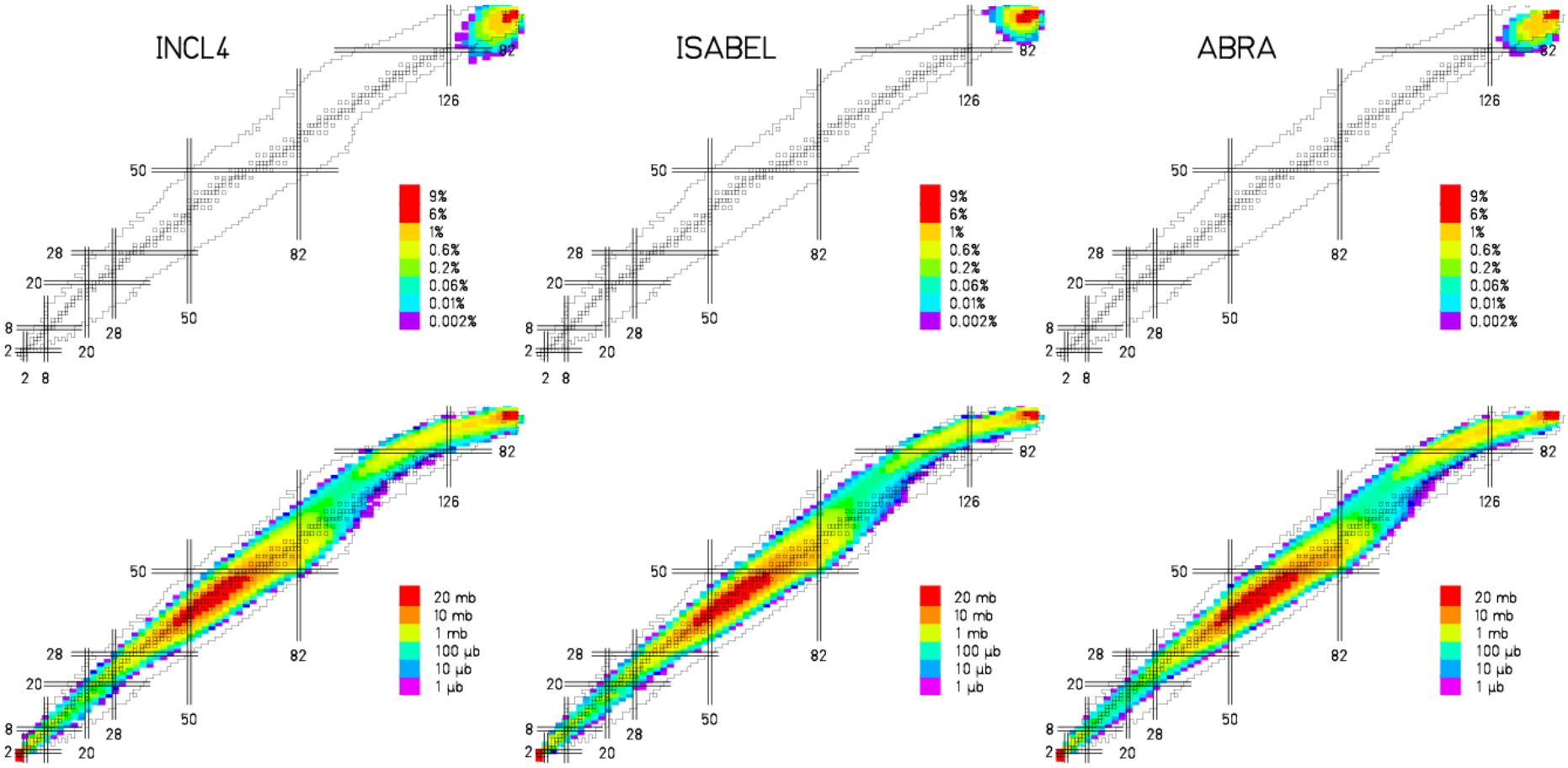
Experimental data (P. Armbruster et al., PRL 93 (2004) 212701)

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.

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



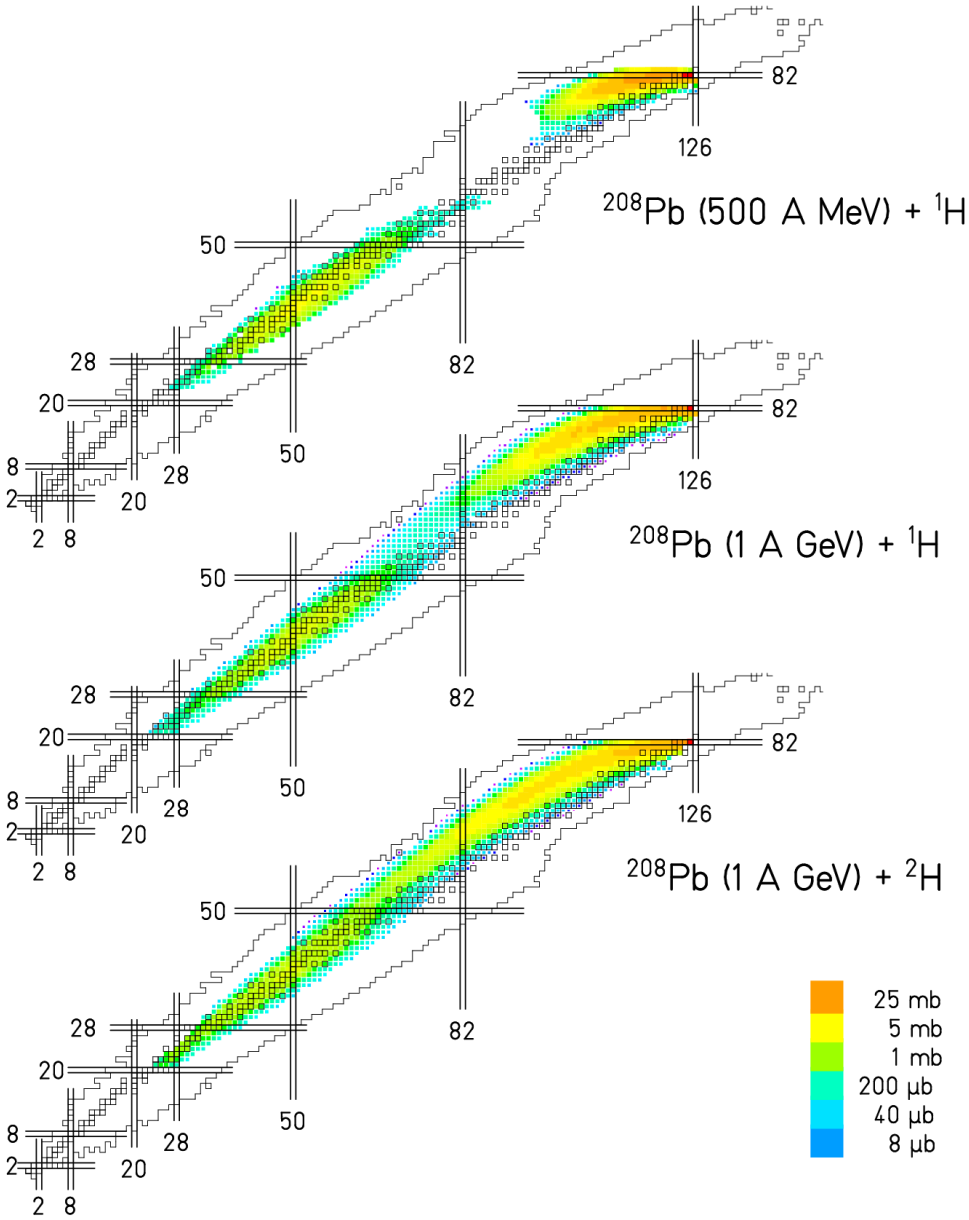
At first glance, nothing seems to change among the different 1st stage models, however ...

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



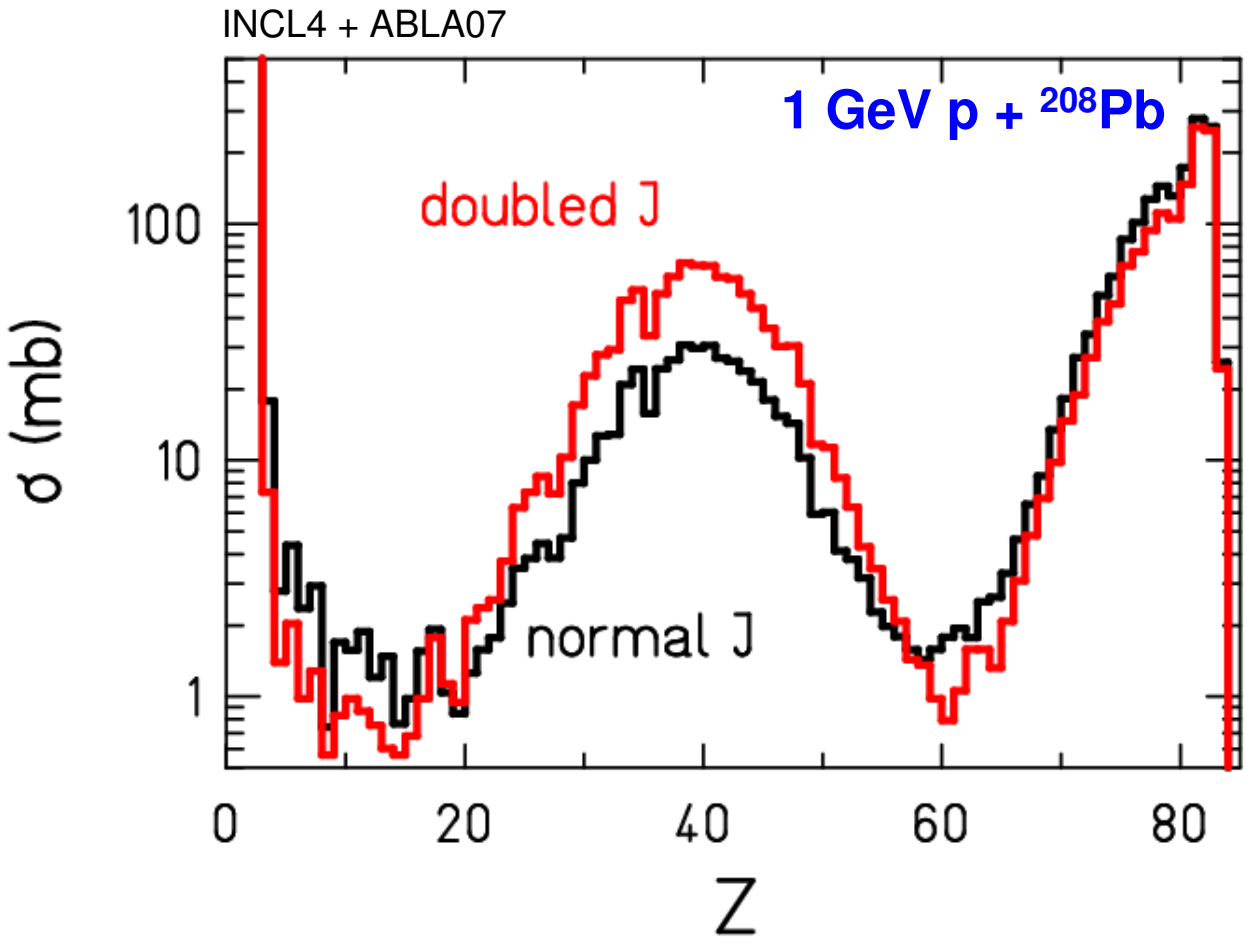
Increase of beam energy leads to higher excitation energies after INC and to larger mass loss in evaporation.

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



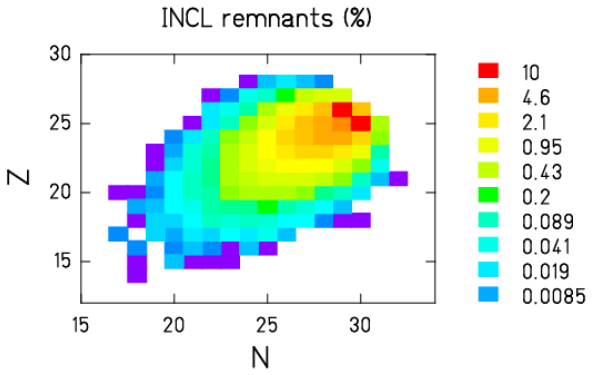
Comparison of

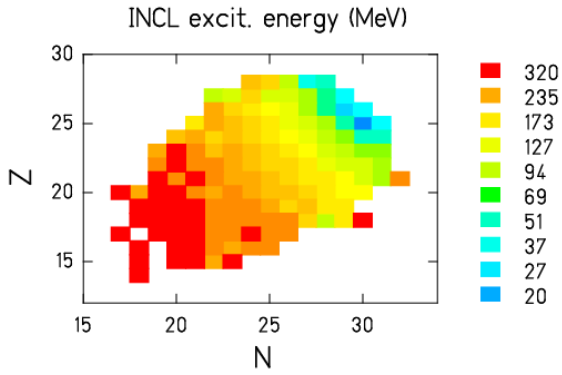
INCL4
ISABEL
ABRA

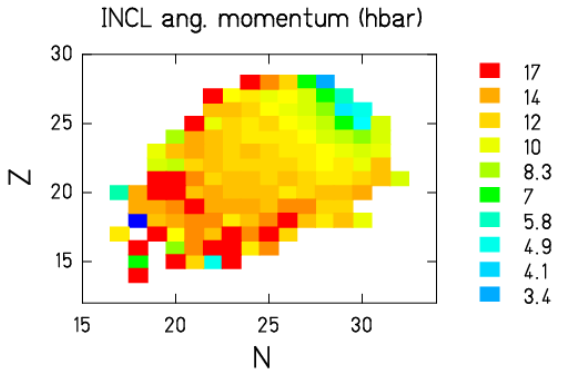
for

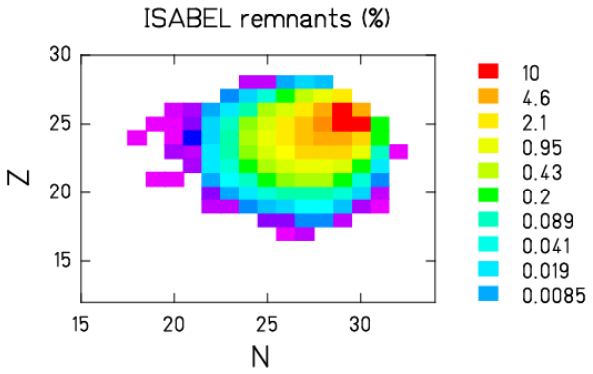
1 GeV p + ^{56}Fe, ^{208}Pb, ^{238}U

1 GeV p + ^{56}Fe


INCL remnants (%)
Z
N
10
4.6
2.1
0.95
0.43
0.2
0.089
0.041
0.019
0.0085


INCL excit. energy (MeV)
Z
N
320
235
173
127
94
69
51
37
27
20


INCL ang. momentum (hbar)
Z
N
17
14
12
10
8.3
7
5.8
4.9
4.1
3.4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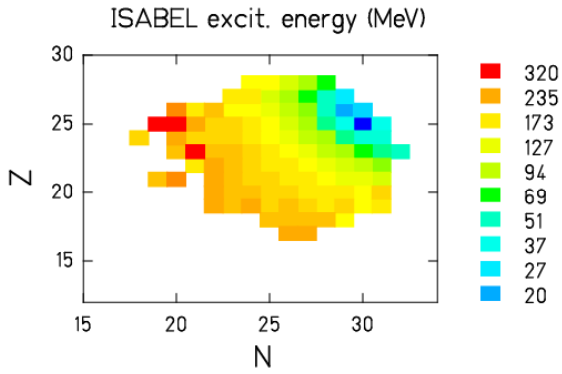
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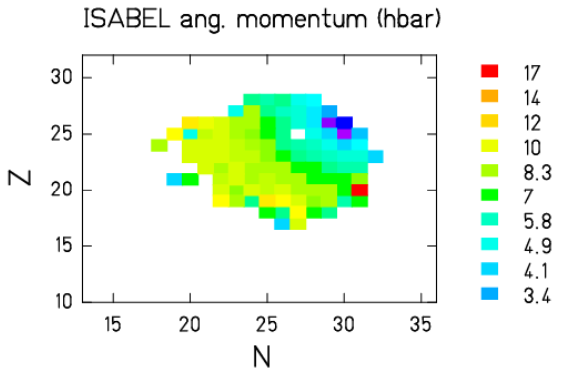
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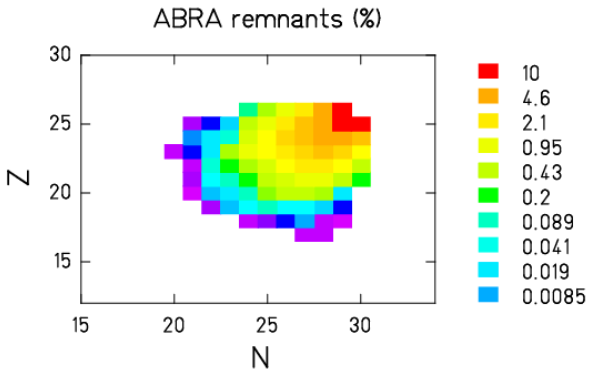
ABRA remnants (%)
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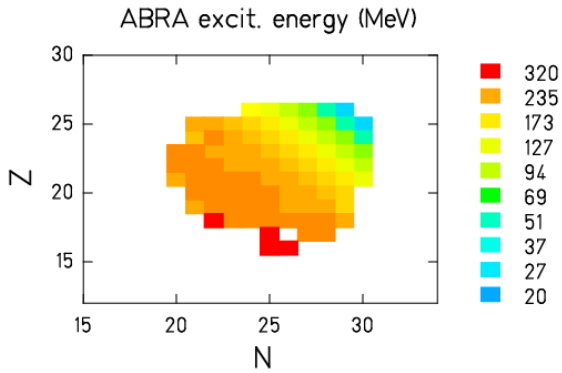
ABRA excit. energy (MeV)
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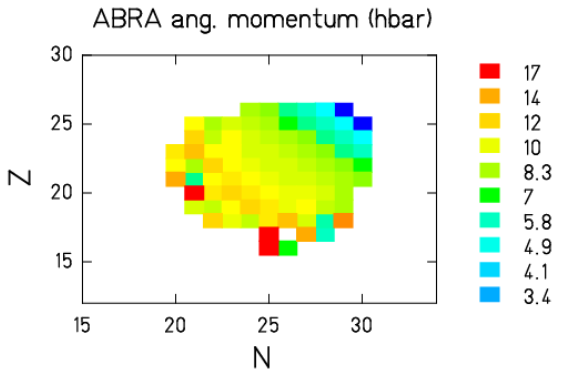
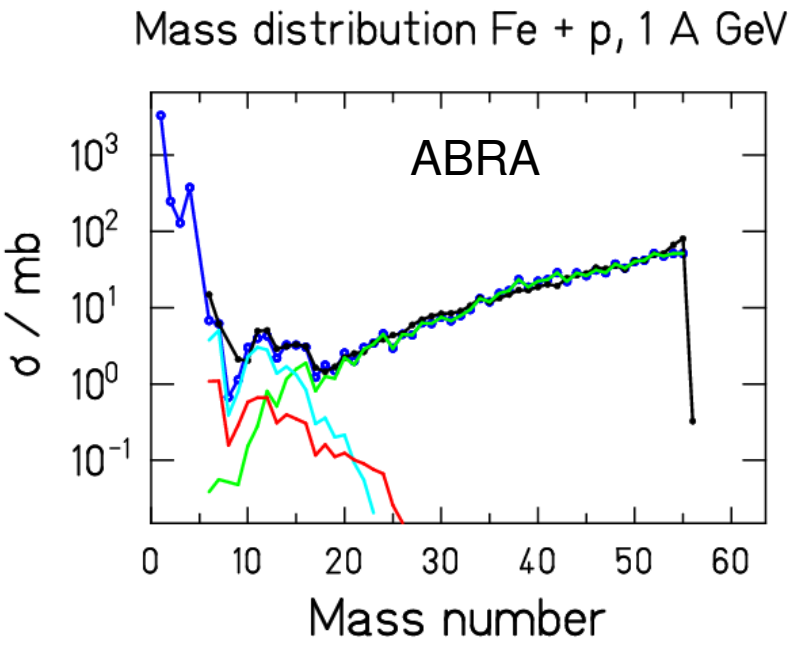
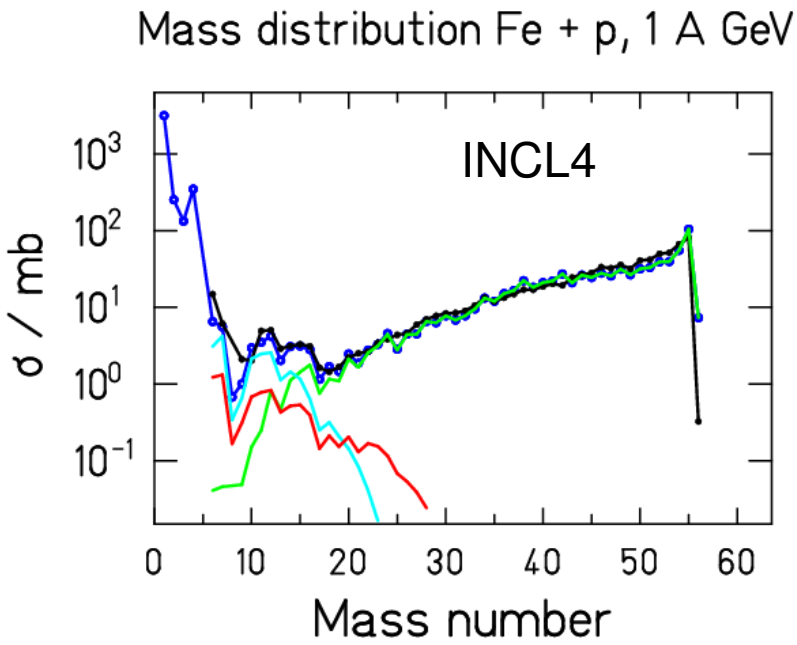
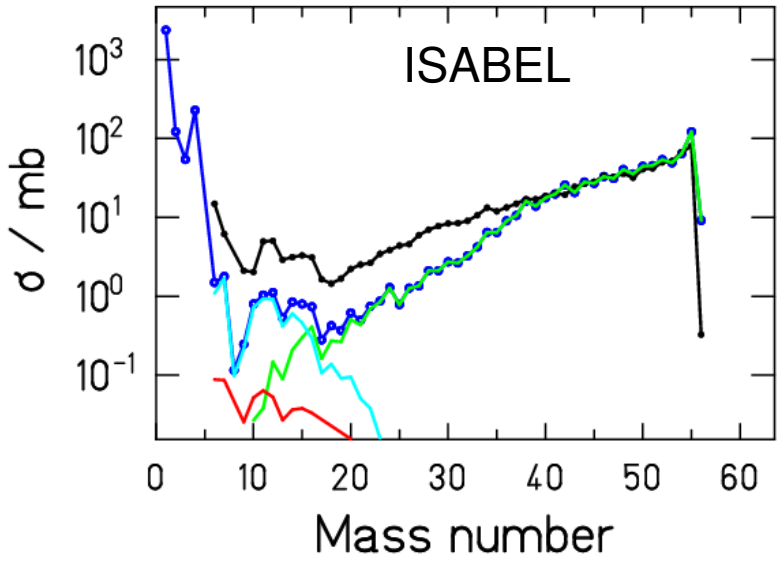

ABRA ang. momentum (hbar)
Z
N
17
14
12
10
8.3
7
5.8
4.9
4.1
3.4

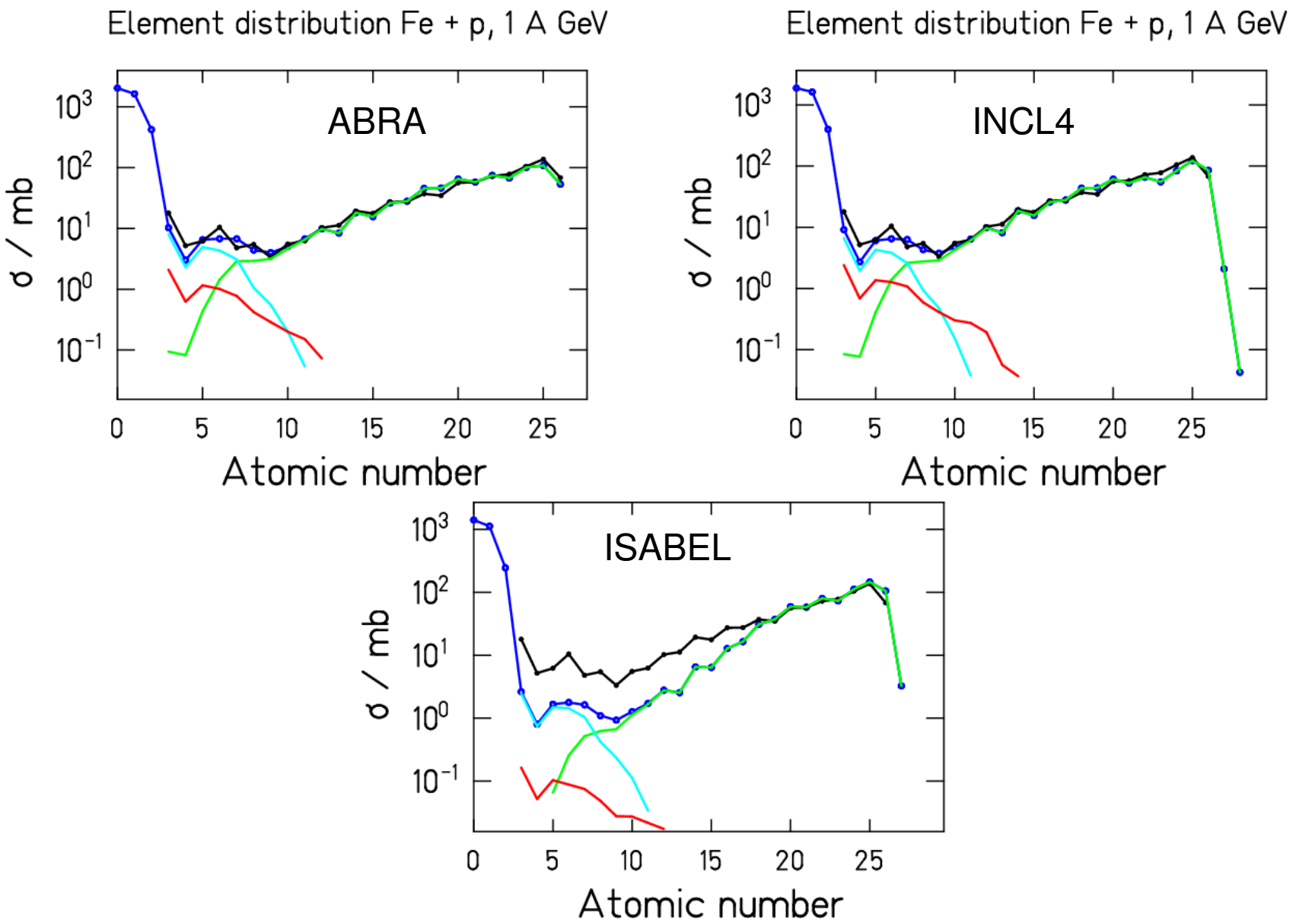
1 GeV p + ^{56}Fe


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

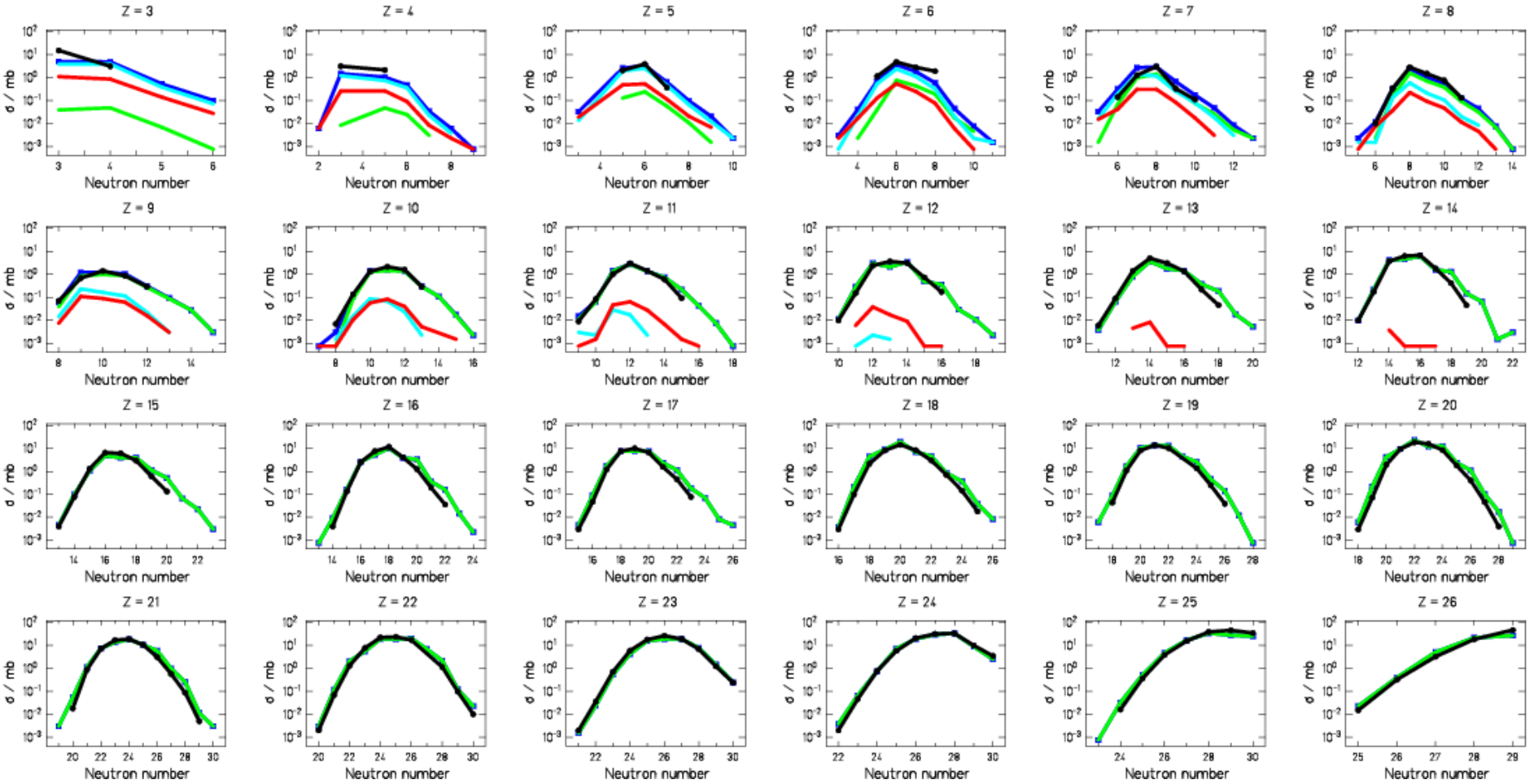

Mass distribution Fe + p, 1 A GeV
INCL4
σ / mb
Mass number


ISABEL
σ / mb
Mass number

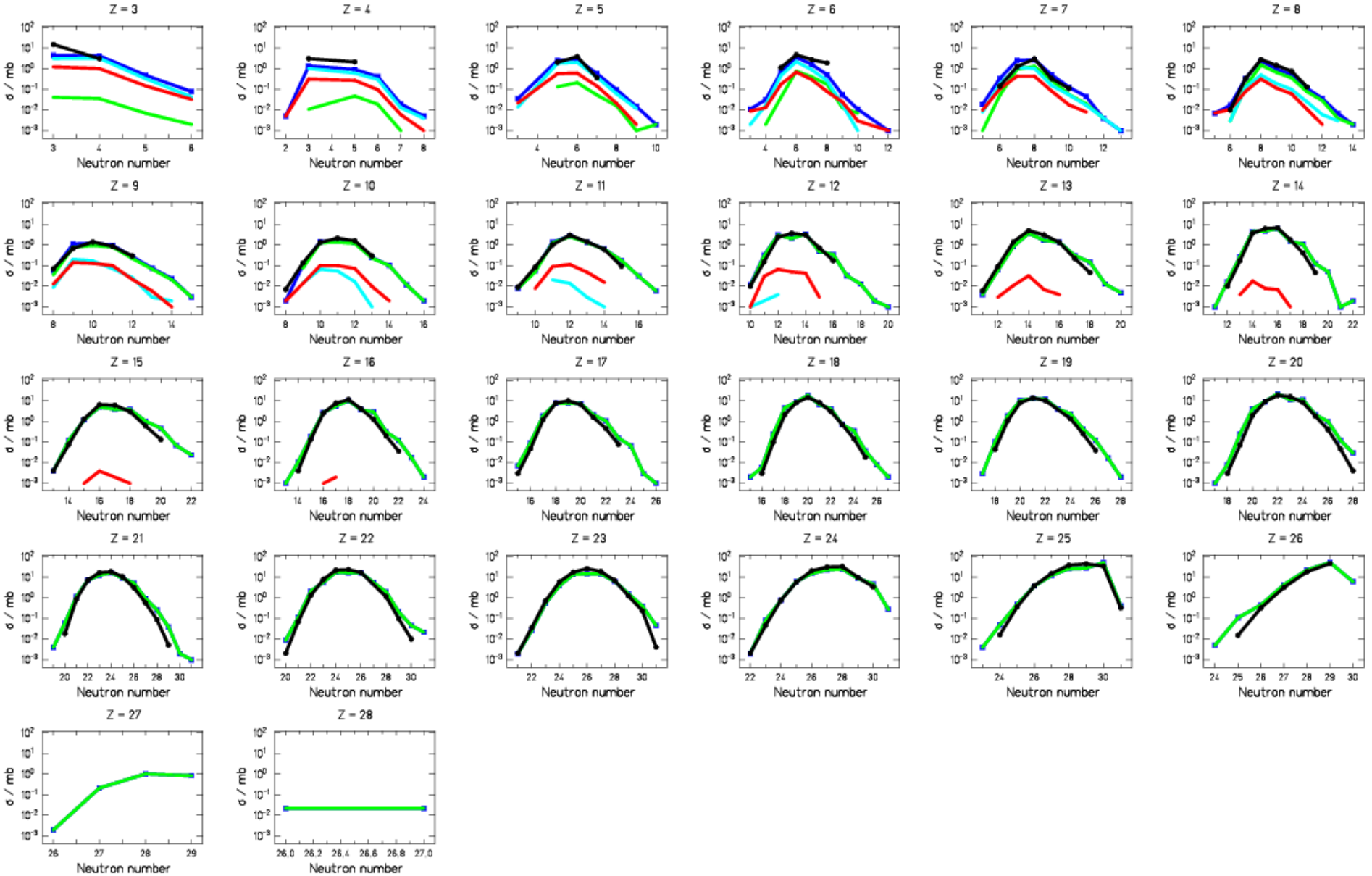
1 GeV p + ^{56}Fe


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

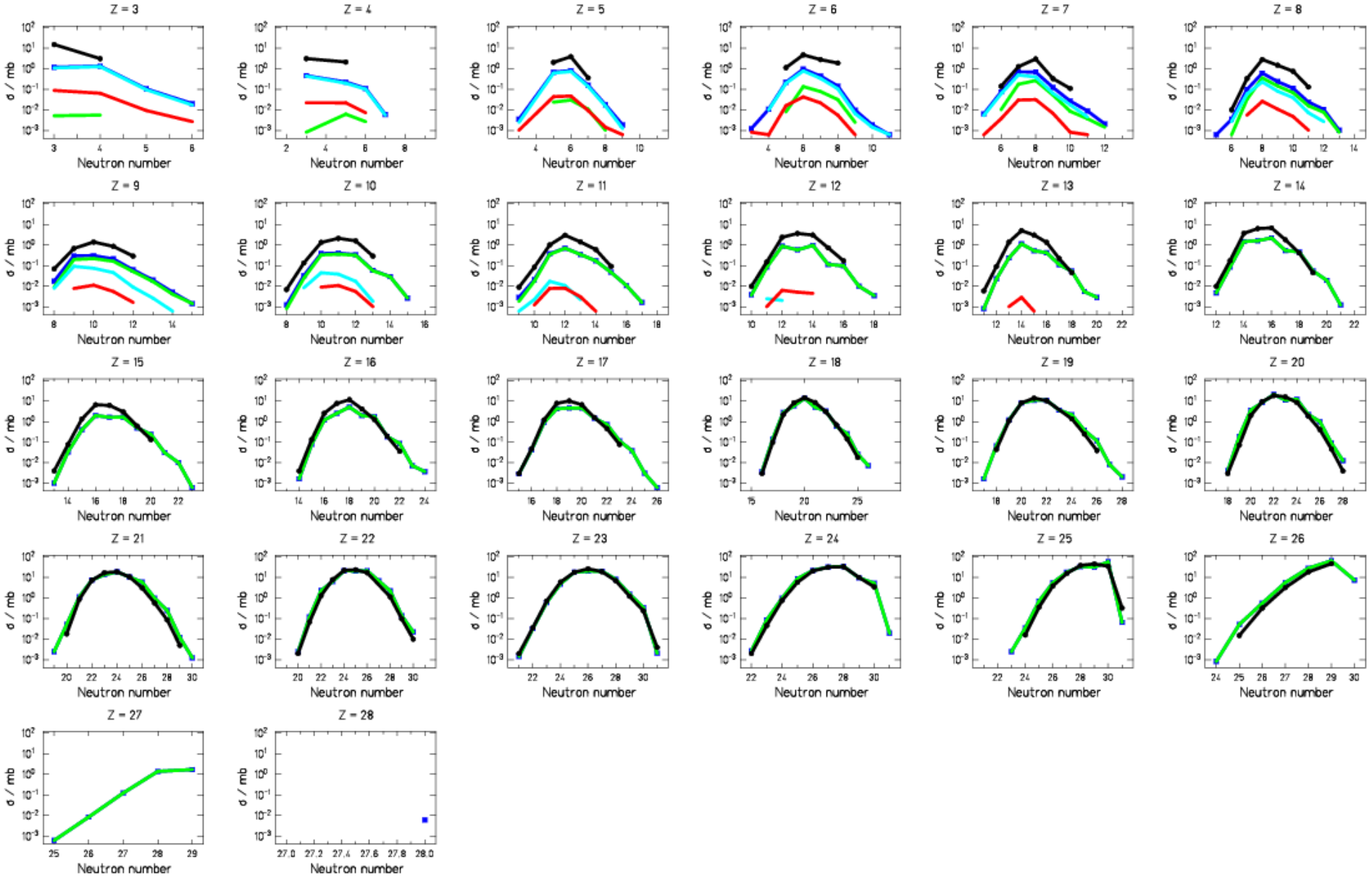
1 GeV p + ^{56}Fe ABRABLA07



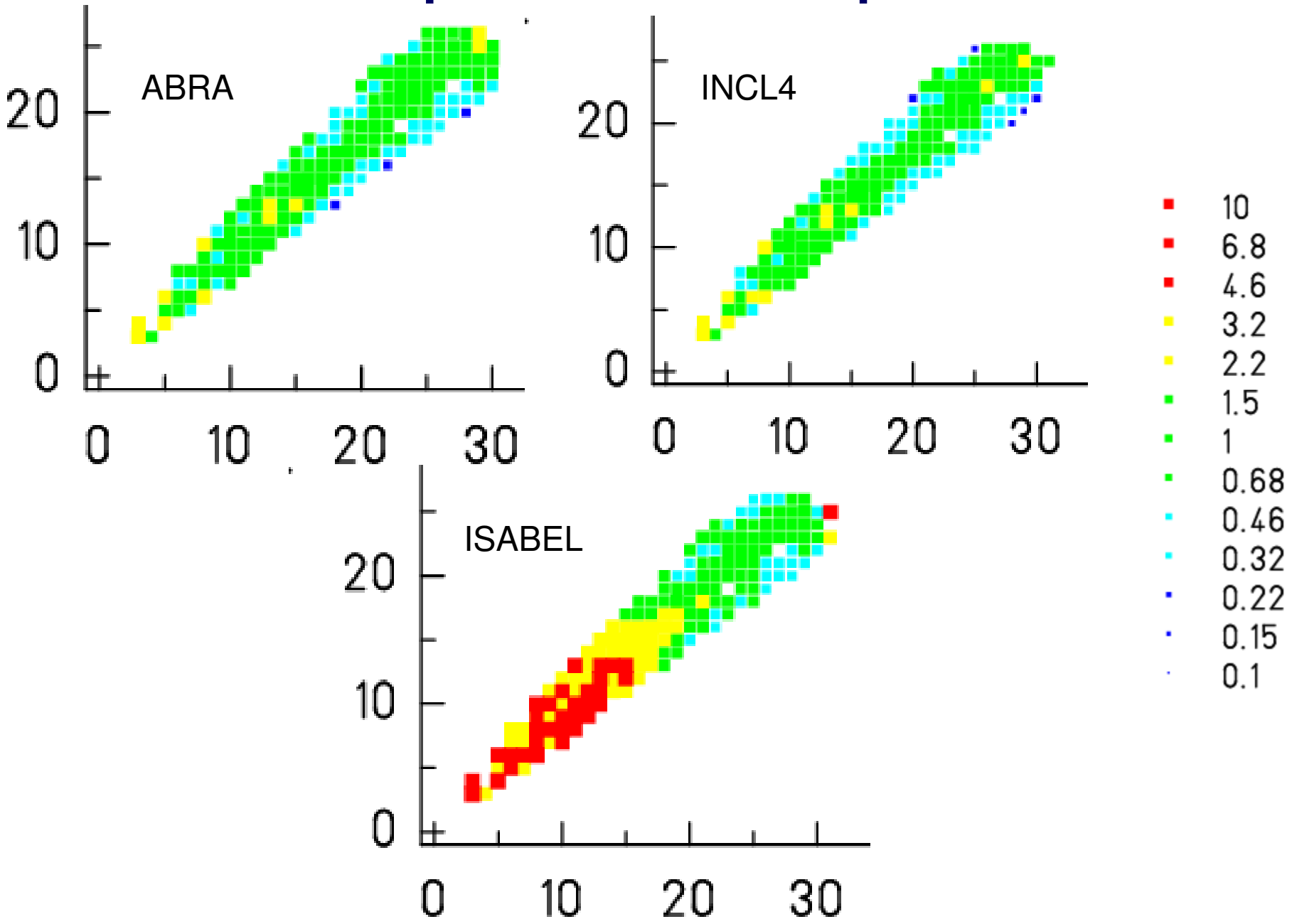
1 GeV p + ^{56}Fe INCL4+ABLA07



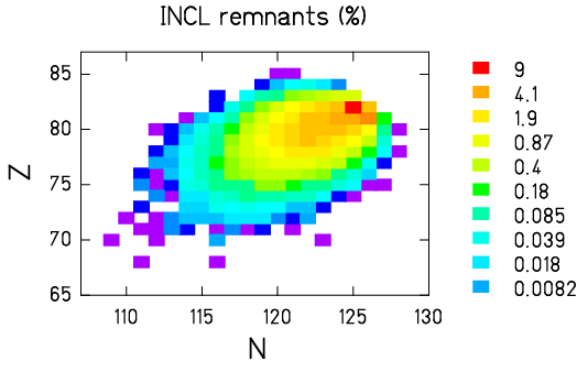
1 GeV p + ^{56}Fe ISABEL+ABLA07

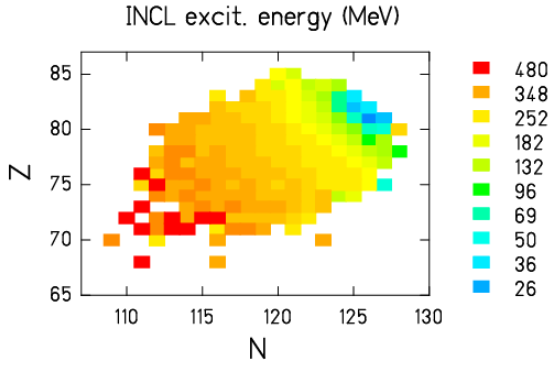


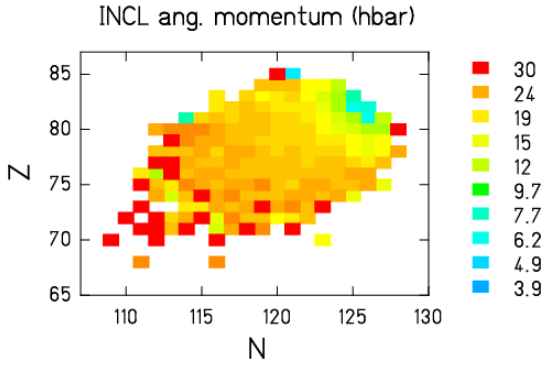
1 GeV p + ^{56}Fe ratio exp/calc

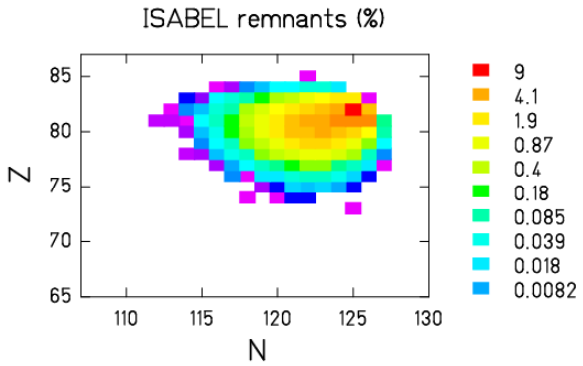


1 GeV p + ^{208}Pb


INCL remnants (%)
Z
N
9
4.1
1.9
0.87
0.4
0.18
0.085
0.039
0.018
0.0082


INCL excit. energy (MeV)
Z
N
480
348
252
182
132
96
69
50
36
26


INCL ang. momentum (hbar)
Z
N
30
24
19
15
12
9.7
7.7
6.2
4.9
3.9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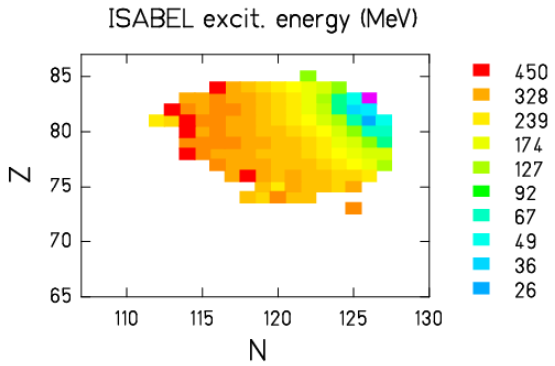
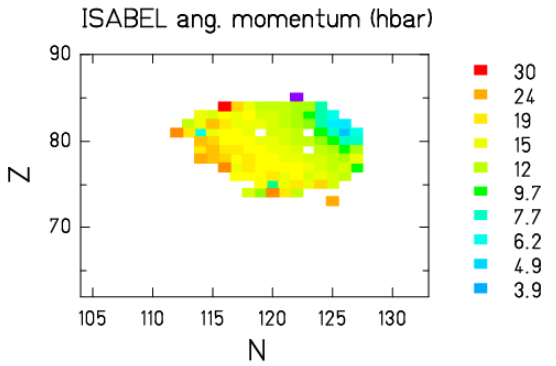

ISABEL excit. energy (MeV)
Z
N
450
328
239
174
127
92
67
49
36
26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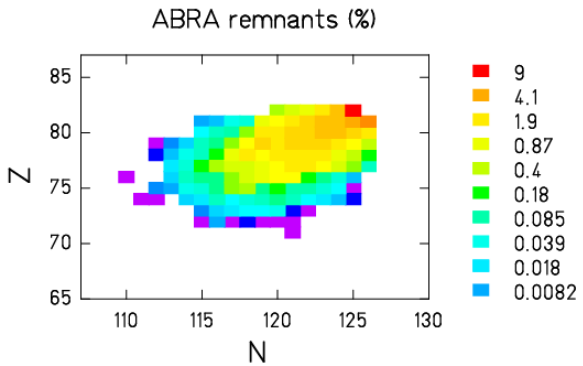
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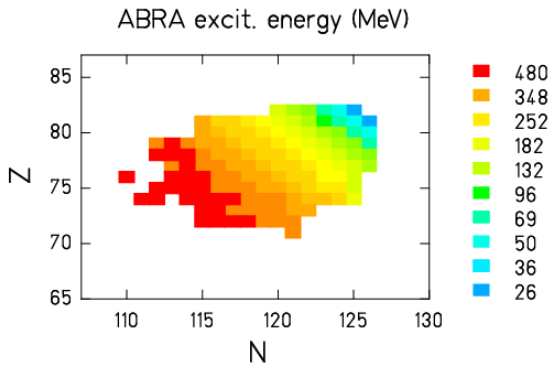
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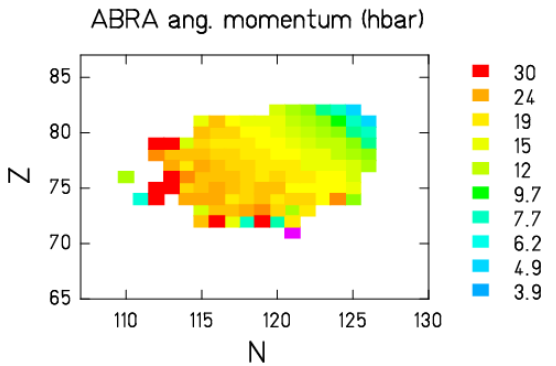
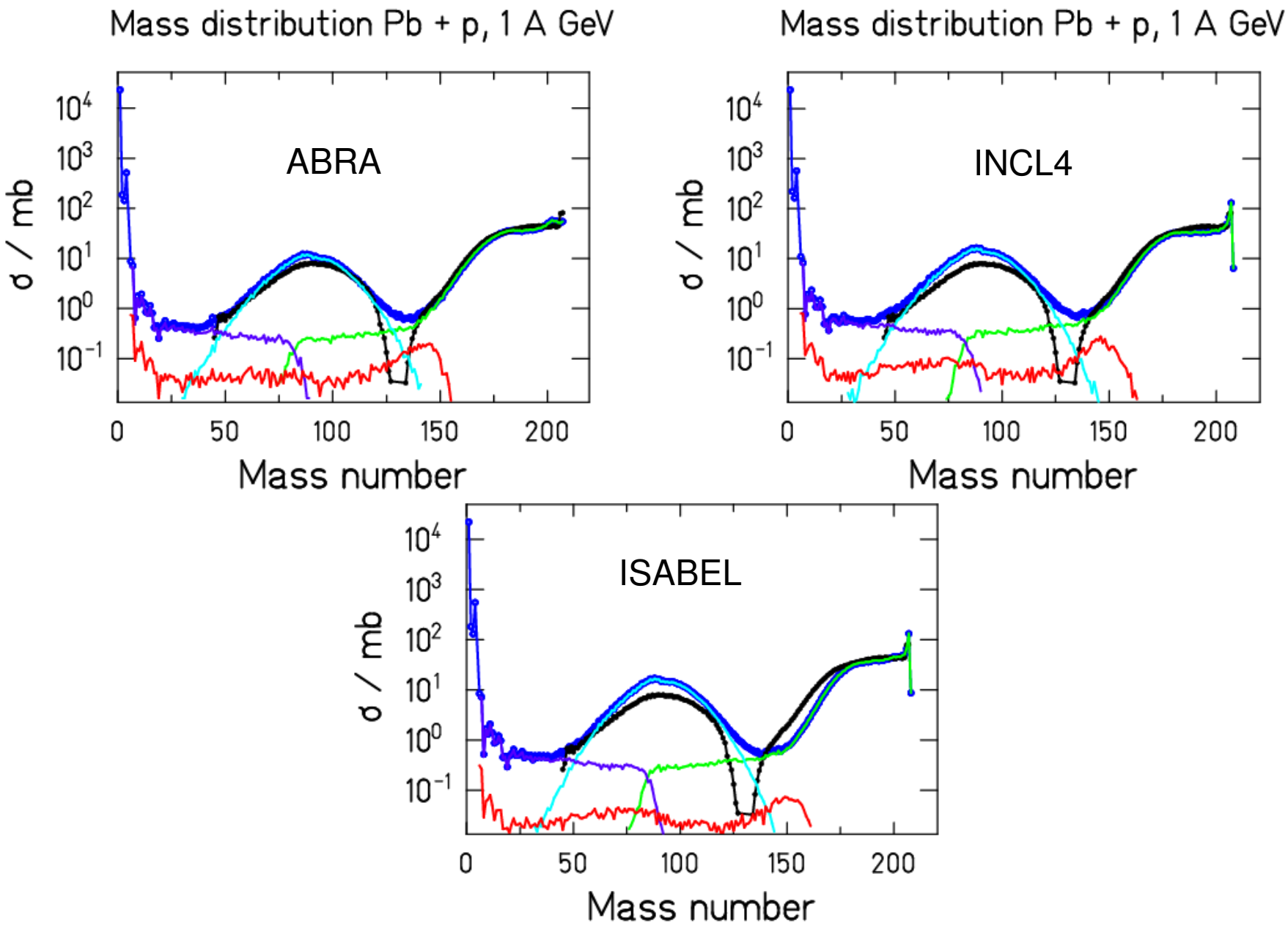
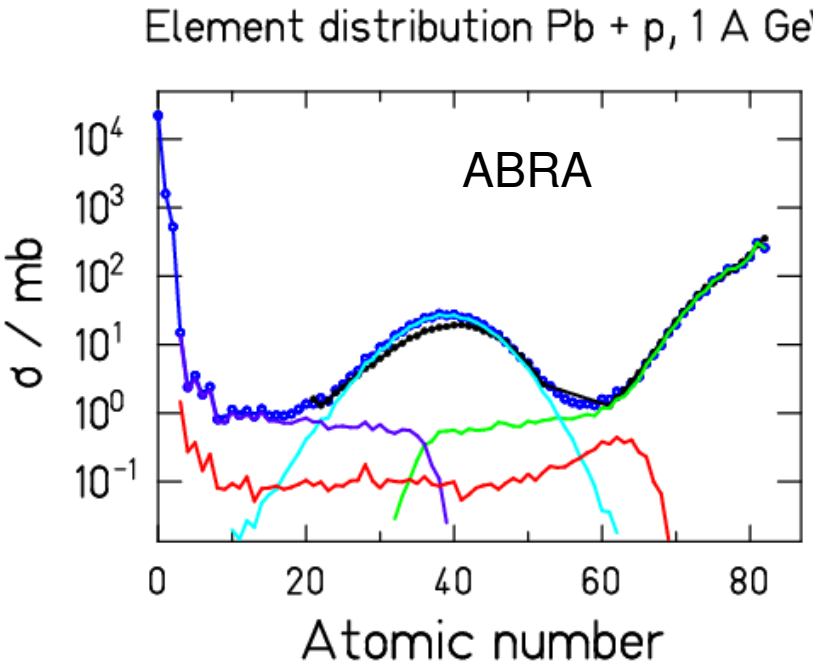
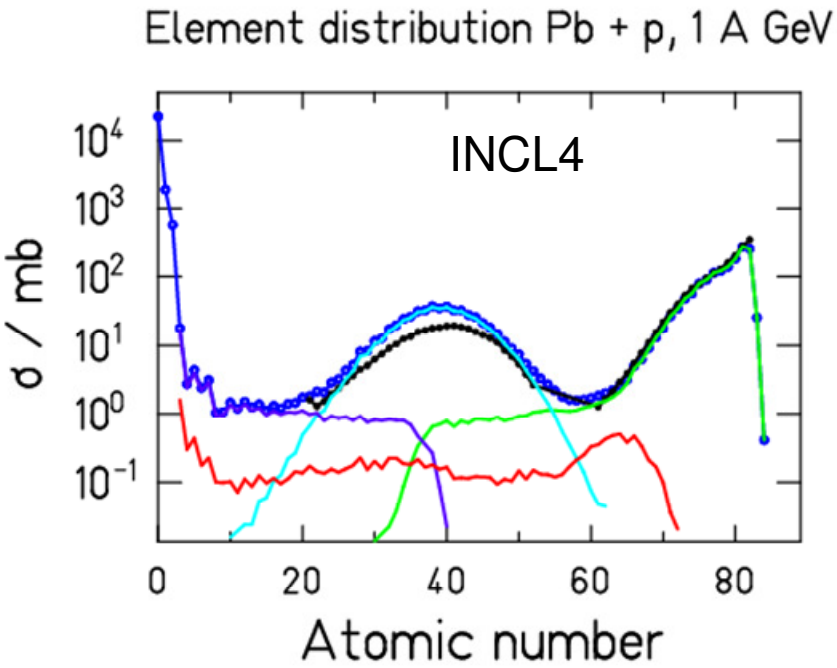

ABRA ang. momentum (hbar)
Z
N
30
24
19
15
12
9.7
7.7
6.2
4.9
3.9

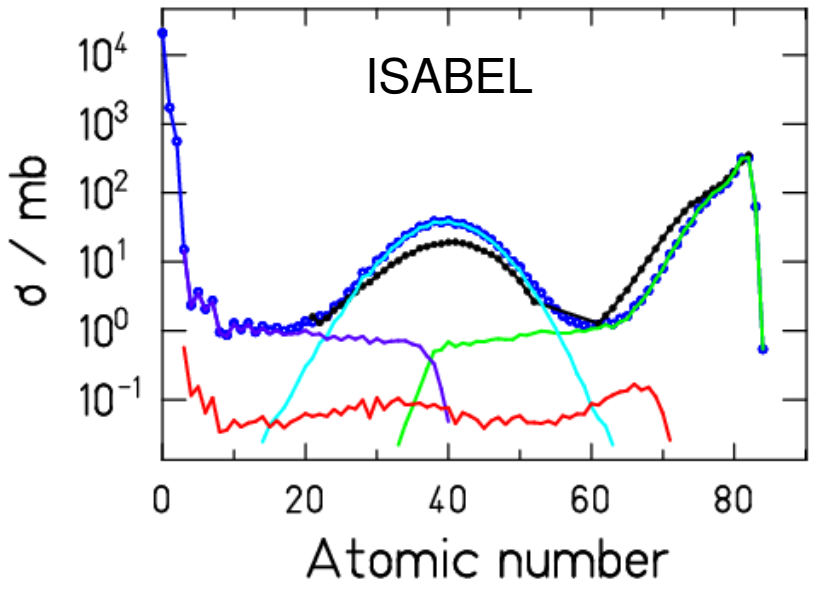
1 GeV p + ^{208}Pb


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

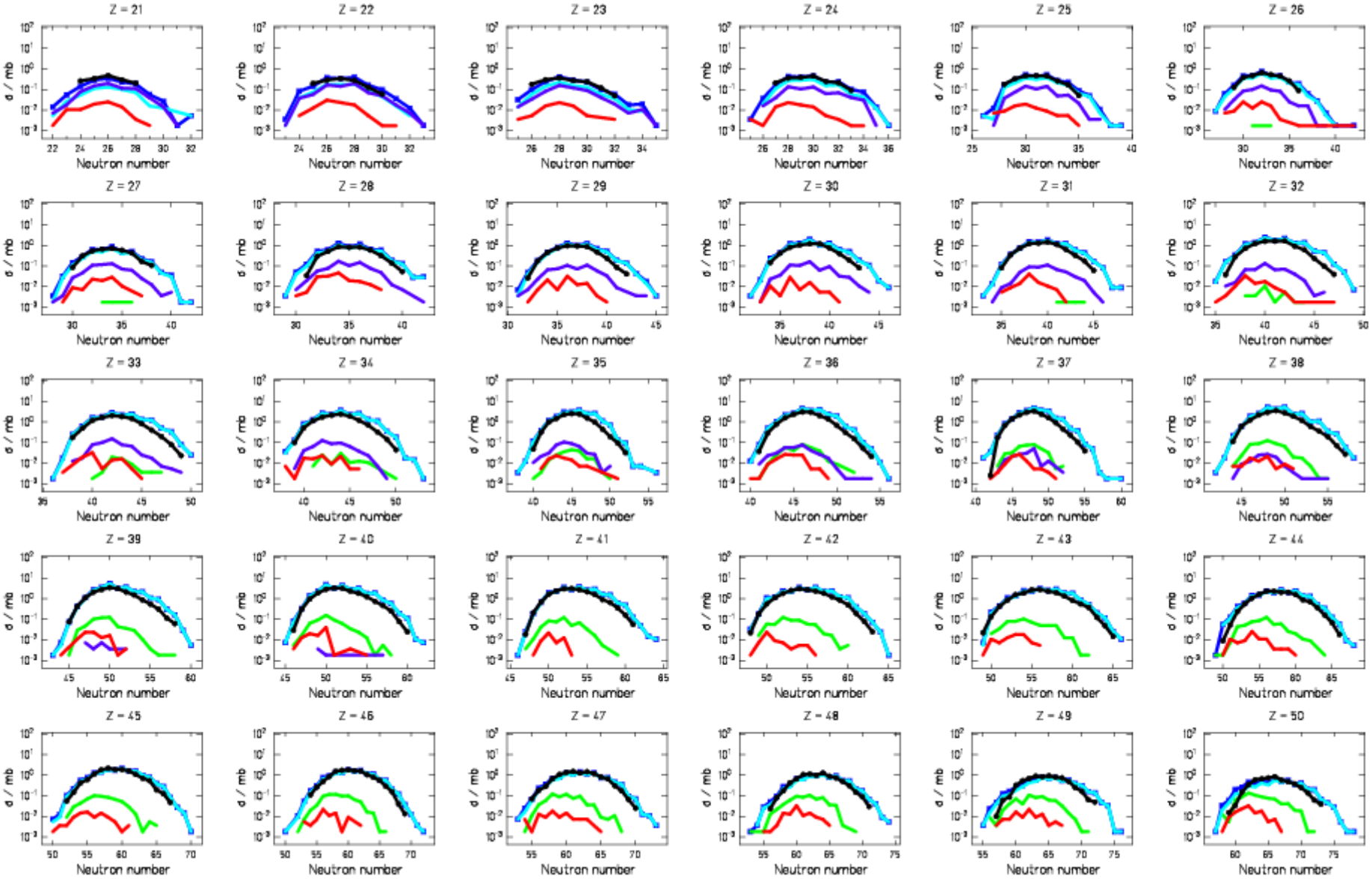
1 GeV p + ^{208}Pb


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

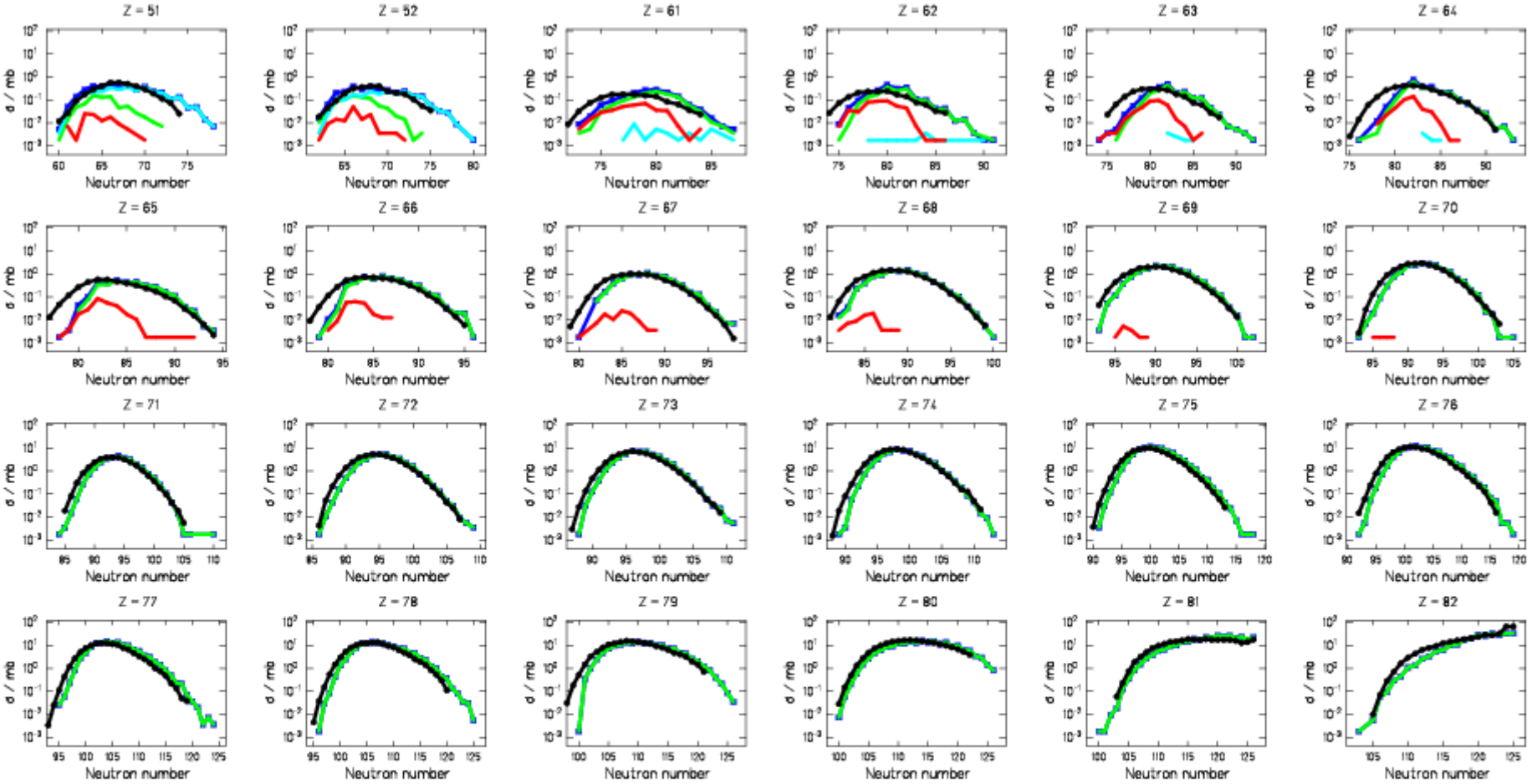

Element distribution Pb + p, 1 A GeV
INCL4
σ / mb
Atomic number


ISABEL
σ / mb
Atomic number

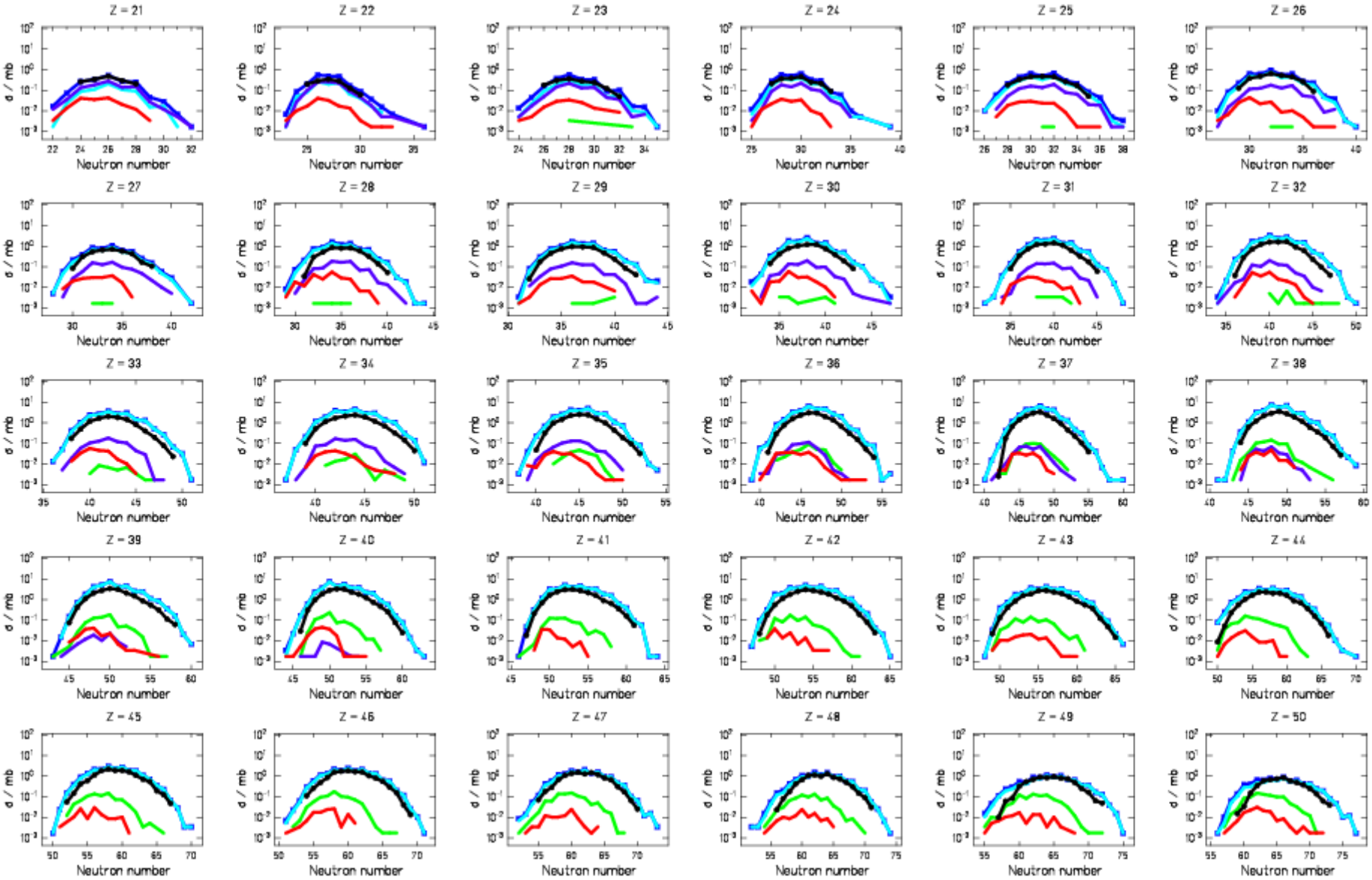
1 GeV p + ^{208}Pb ABRABLA07



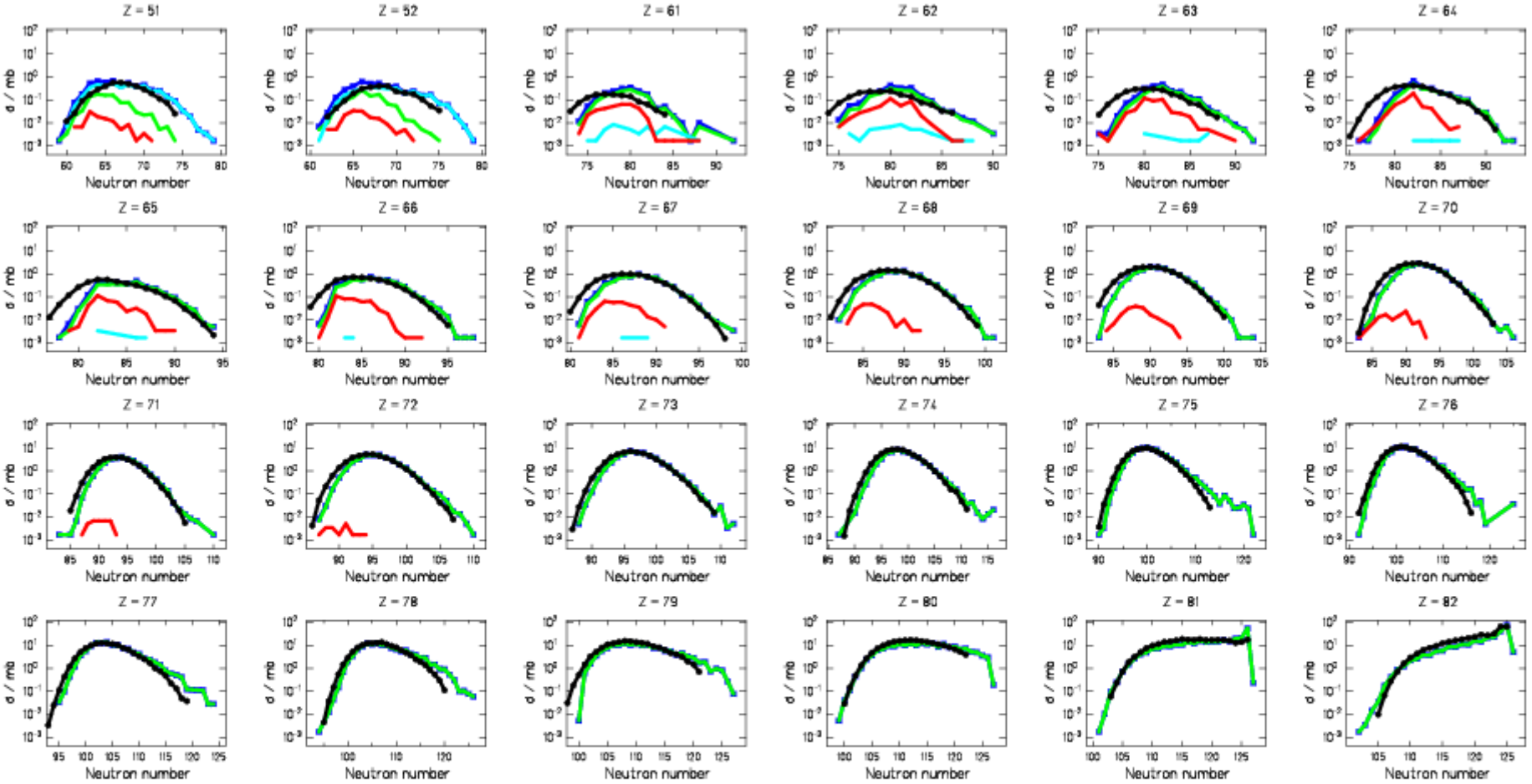
1 GeV p + ^{208}Pb ABRABLA07



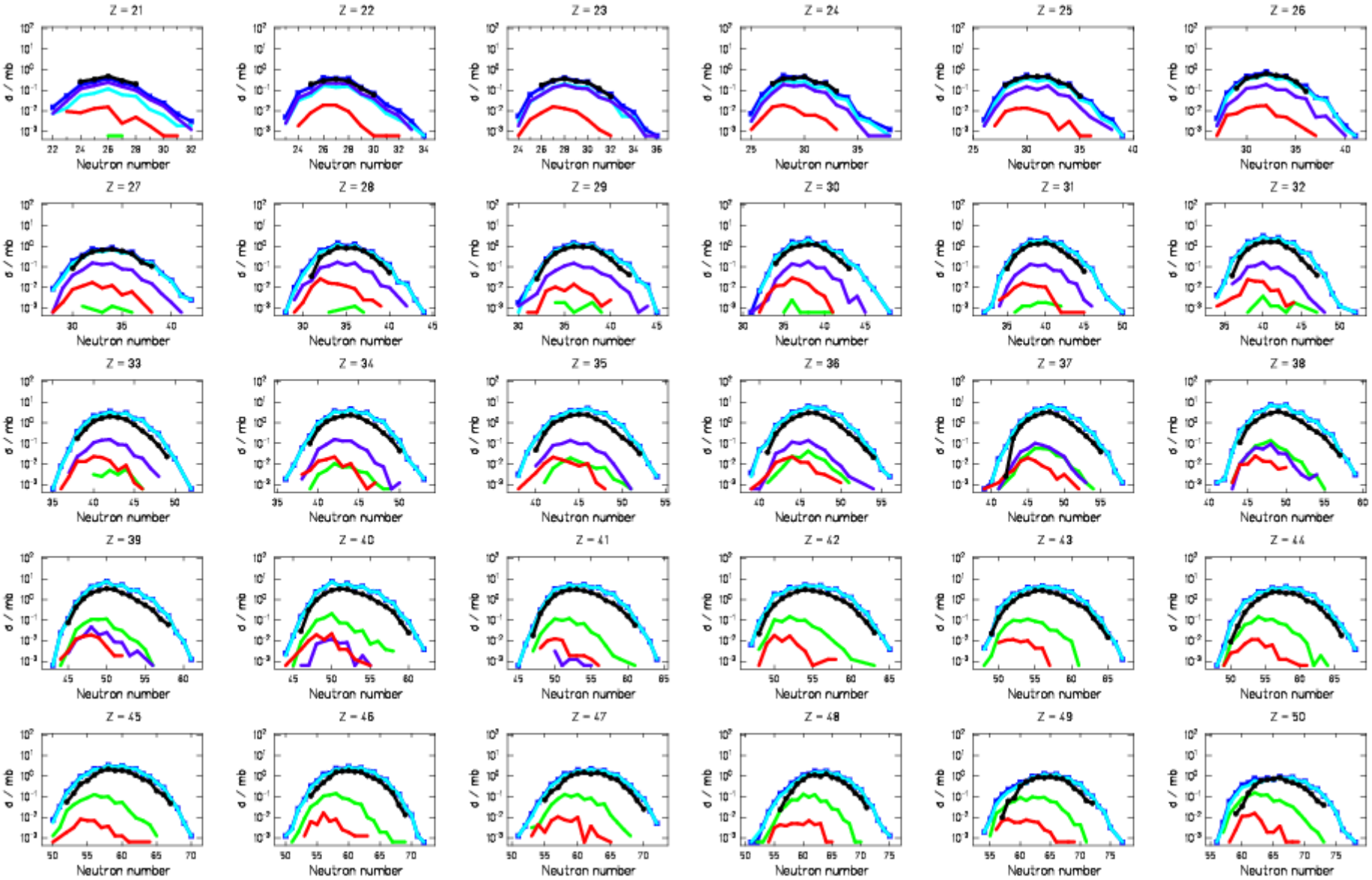
1 GeV p + ^{208}Pb INCL4+ABLA07



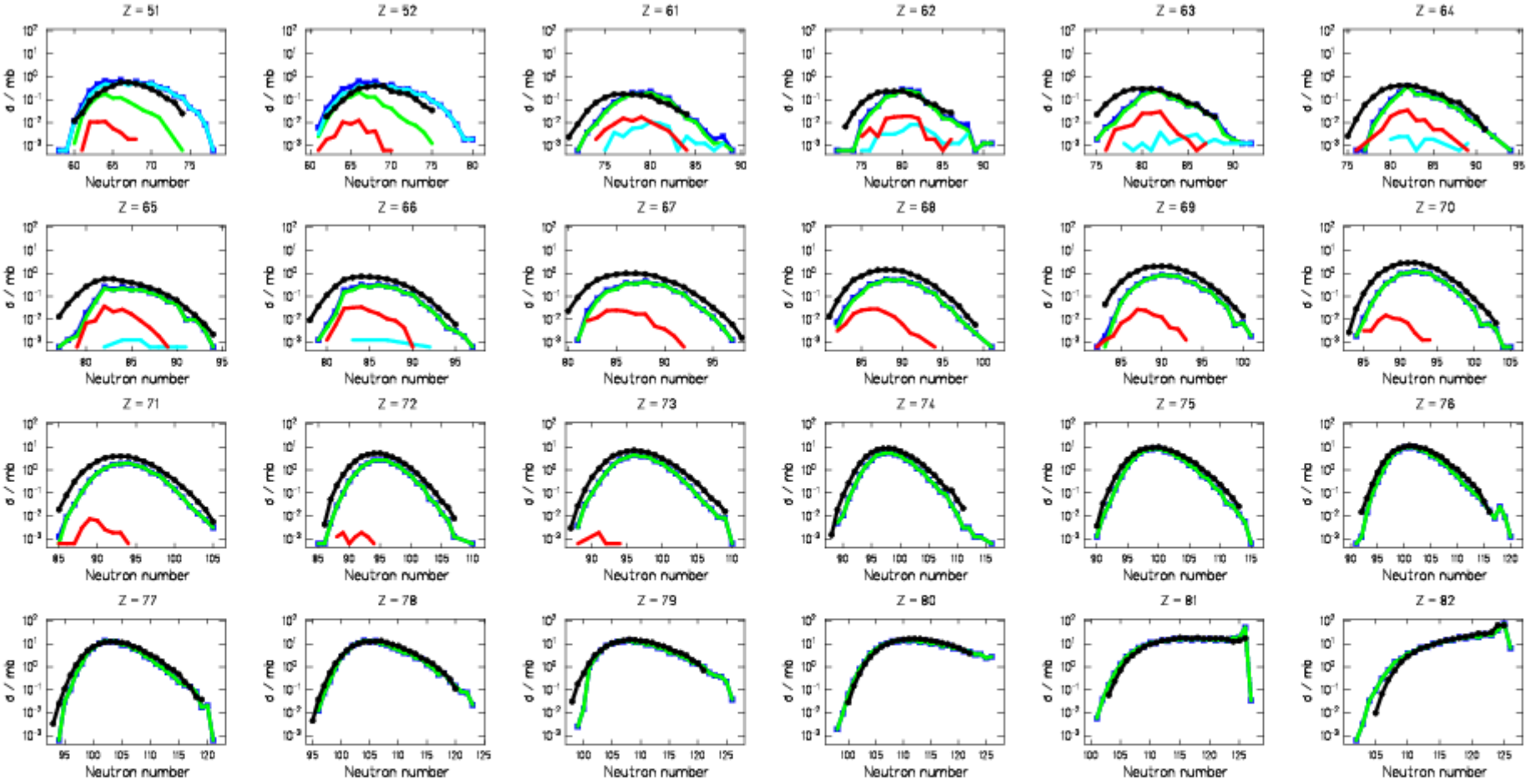
1 GeV p + ^{208}Pb INCL4+ABLA07



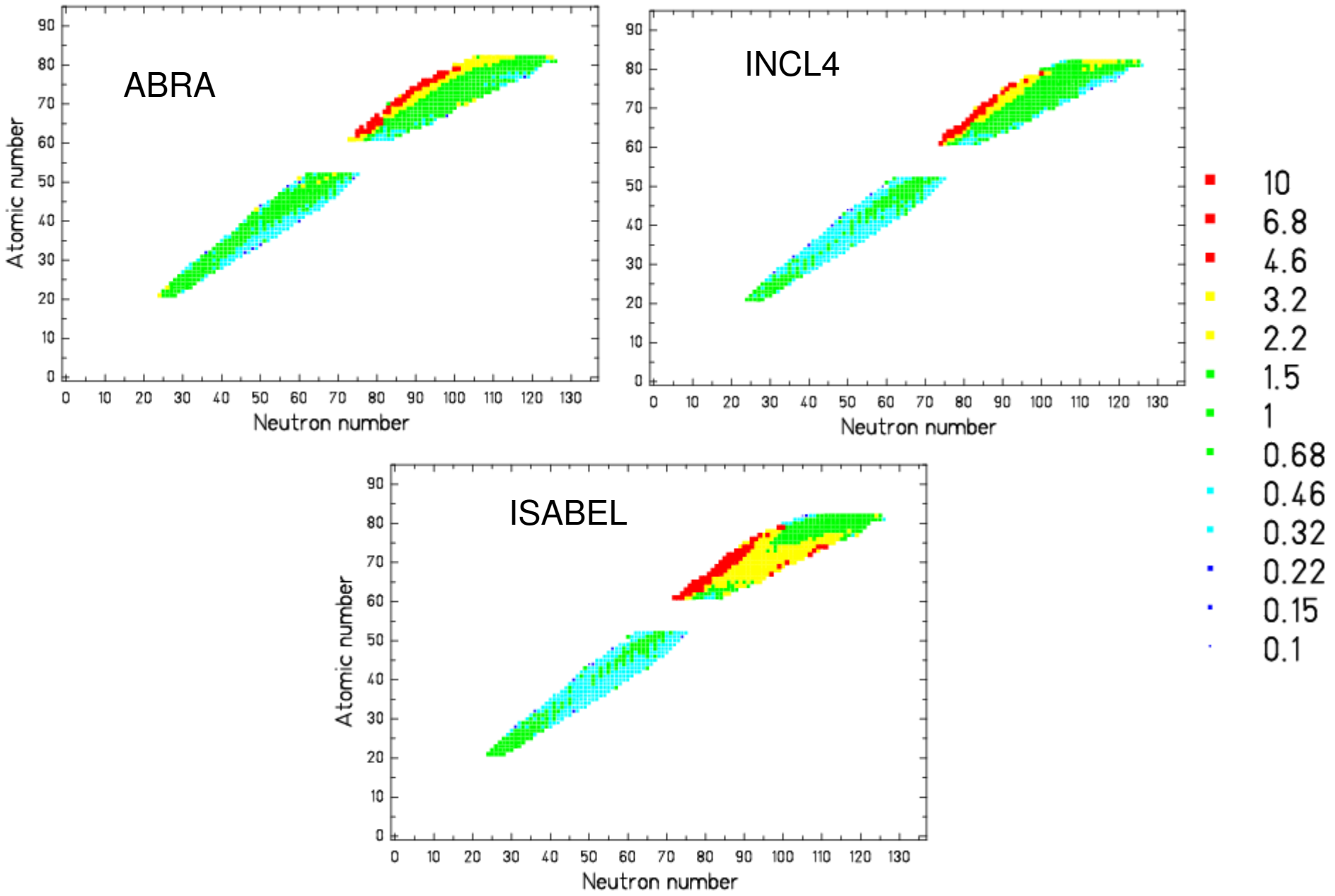
1 GeV p + ^{208}Pb ISABEL+ABLA07



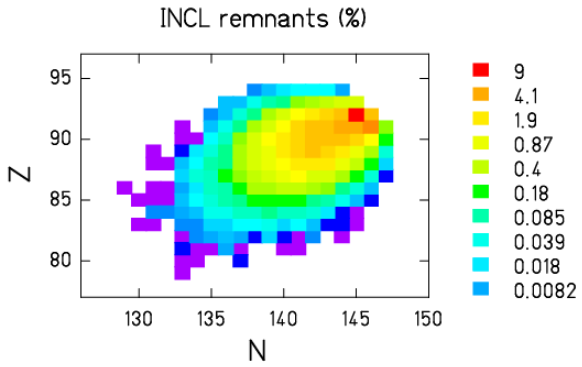
1 GeV p + ^{208}Pb ISABEL+ABLA07

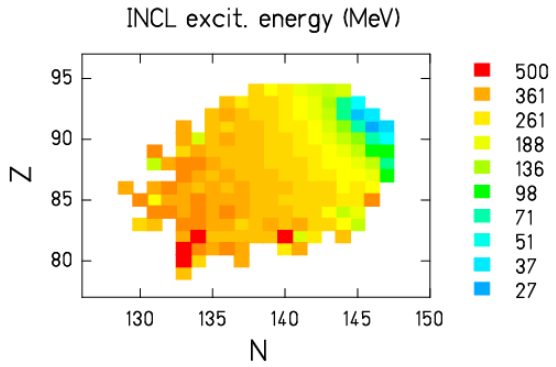


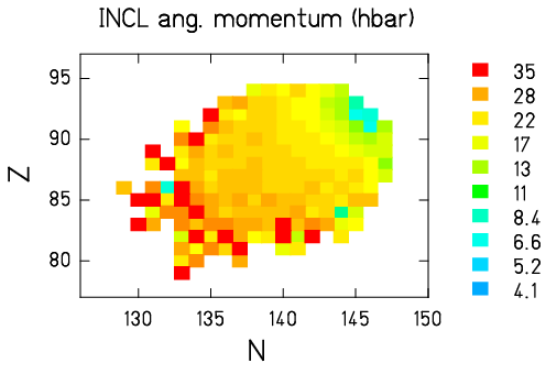
1 GeV p + ^{208}Pb ratio exp/calc

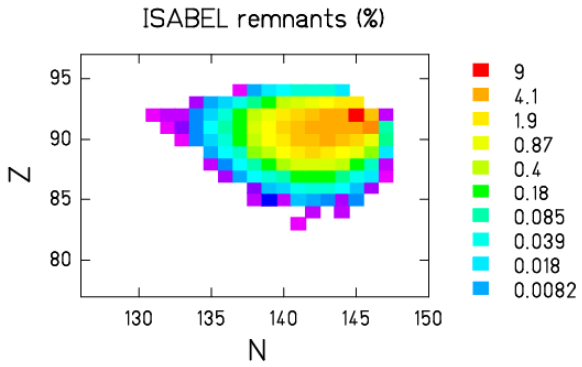


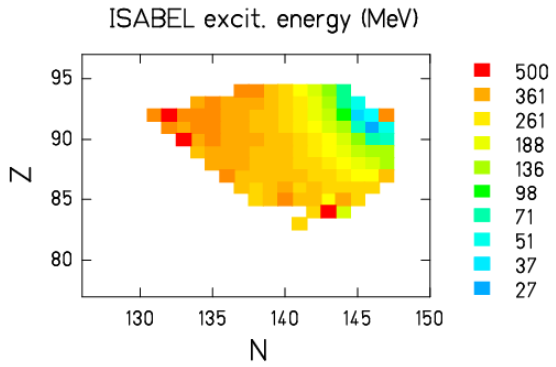
1 GeV p + ^{238}U

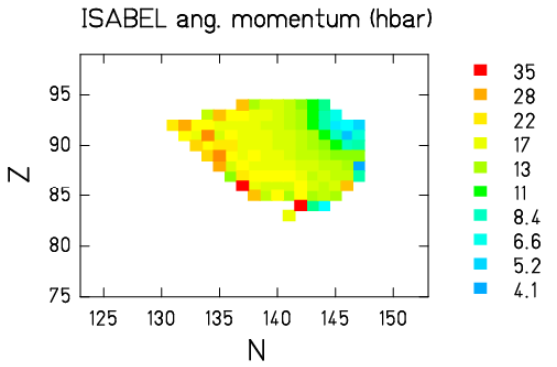

INCL remnants (%)
Z
N
9
4.1
1.9
0.87
0.4
0.18
0.085
0.039
0.018
0.0082

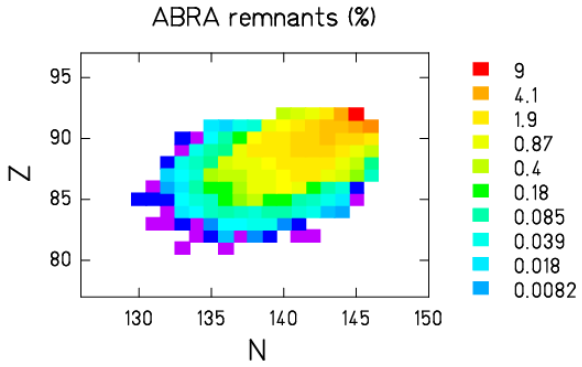

INCL excit. energy (MeV)
Z
N
500
361
261
188
136
98
71
51
37
27

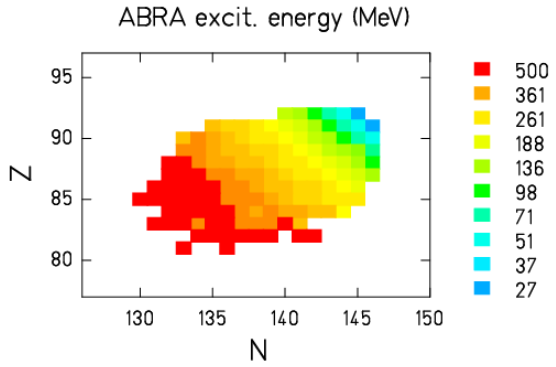

INCL ang. momentum (hbar)
Z
N
35
28
22
17
13
11
8.4
6.6
5.2
4.1

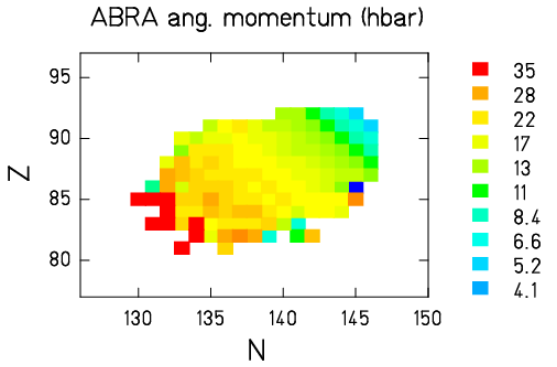

ISABEL remnants (%)
Z
N
9
4.1
1.9
0.87
0.4
0.18
0.085
0.039
0.018
0.0082


ISABEL excit. energy (MeV)
Z
N
500
361
261
188
136
98
71
51
37
27

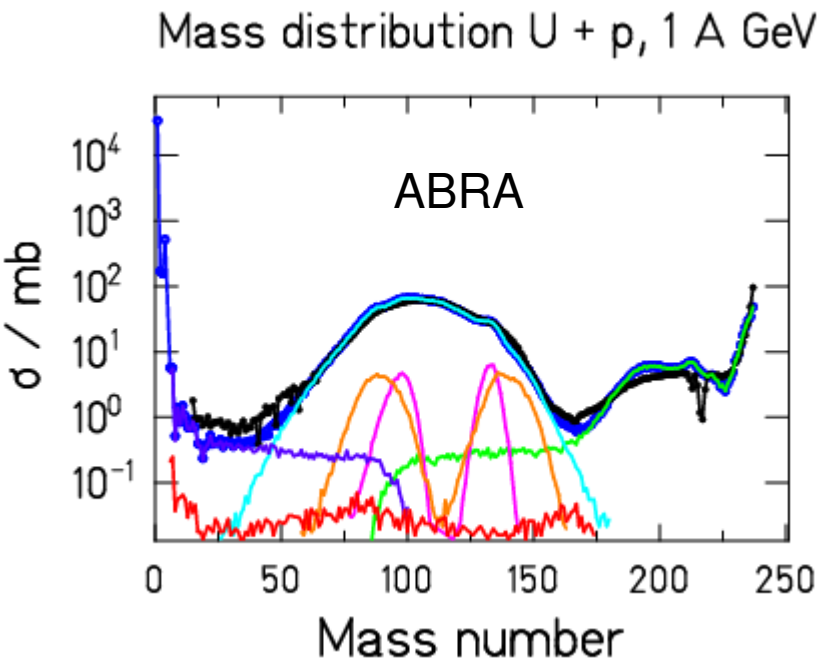

ISABEL ang. momentum (hbar)
Z
N
35
28
22
17
13
11
8.4
6.6
5.2
4.1

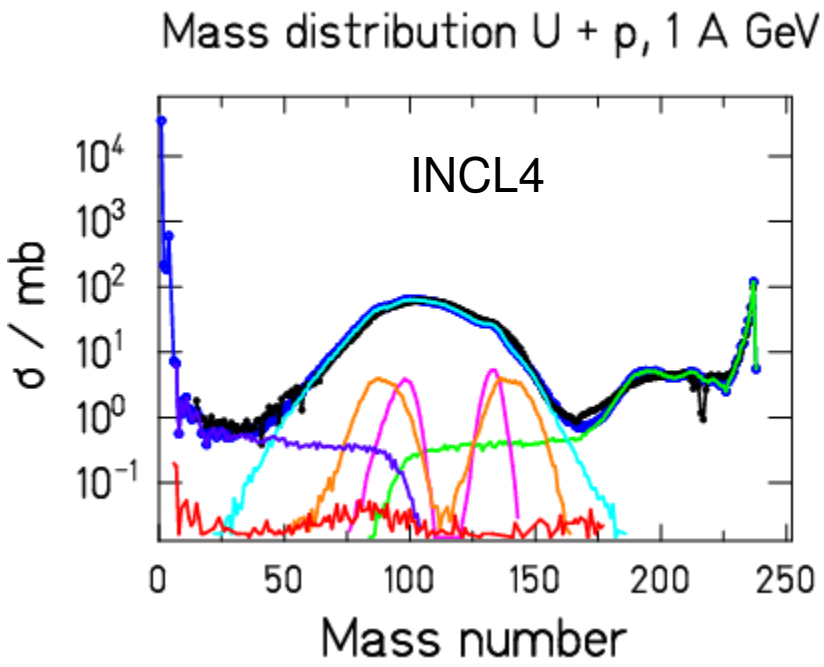

ABRA remnants (%)
Z
N
9
4.1
1.9
0.87
0.4
0.18
0.085
0.039
0.018
0.0082

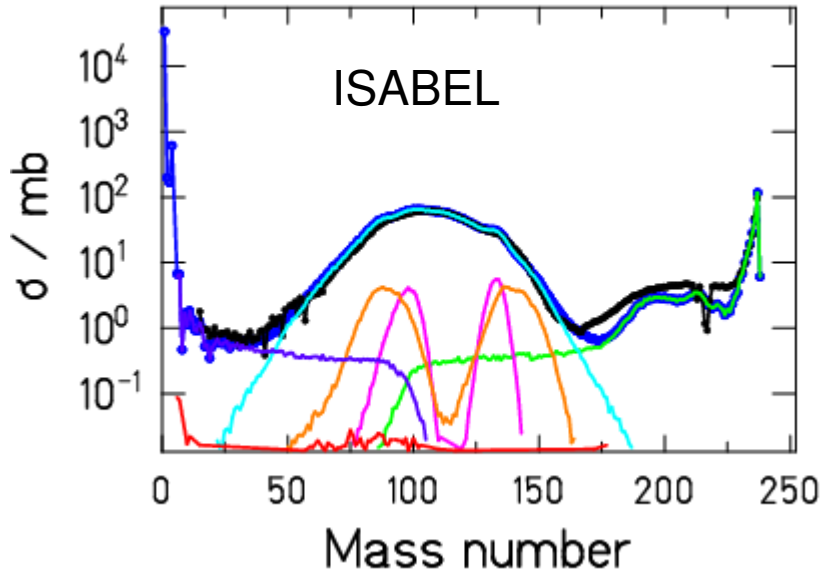

ABRA excit. energy (MeV)
Z
N
500
361
261
188
136
98
71
51
37
27


ABRA ang. momentum (hbar)
Z
N
35
28
22
17
13
11
8.4
6.6
5.2
4.1

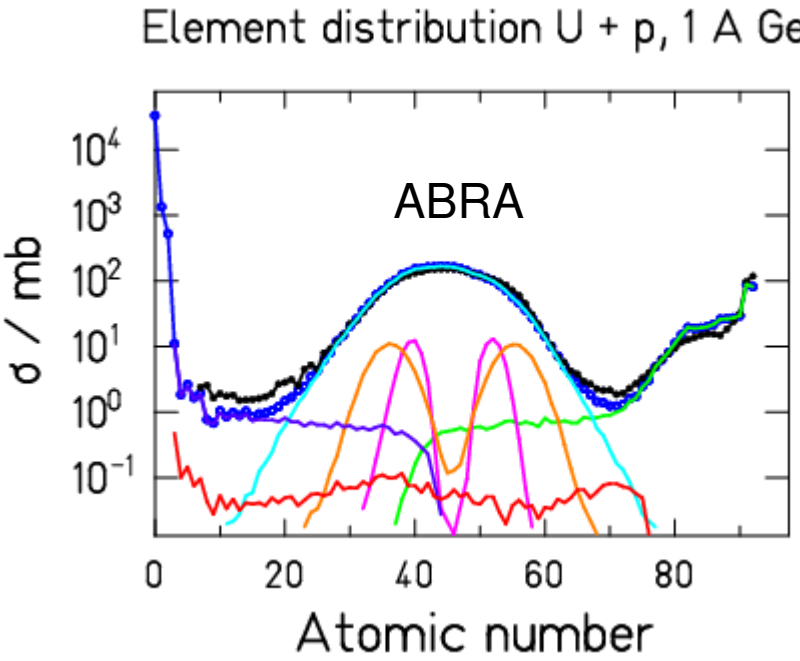
1 GeV p + ^{238}U

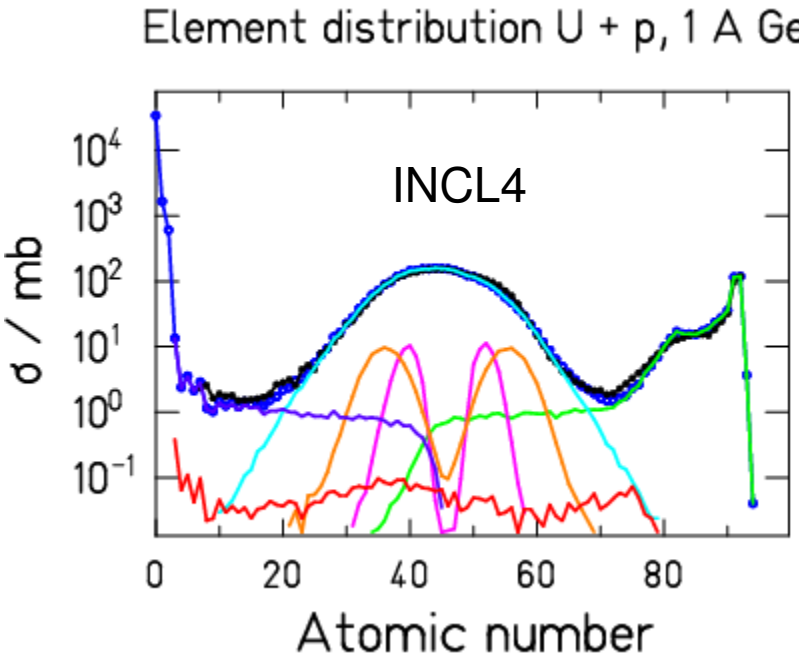

Mass distribution U + p, 1 A GeV
ABRA
σ / mb
Mass number

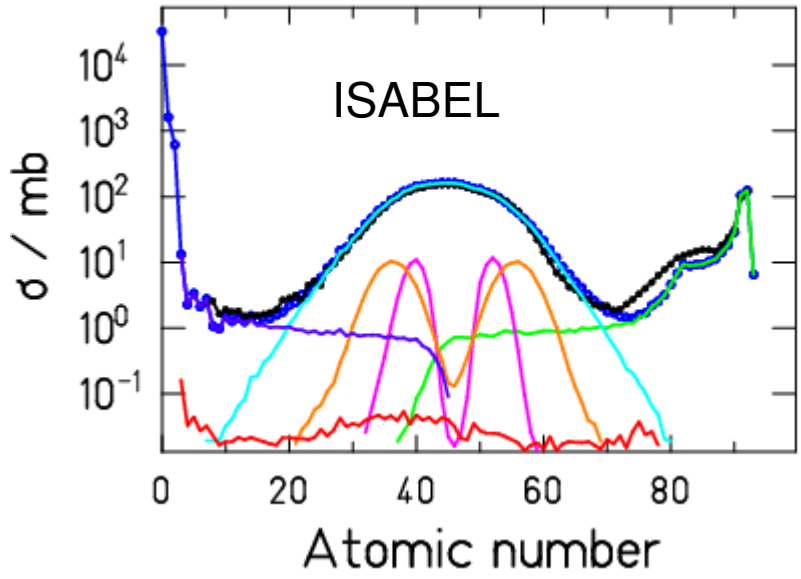

Mass distribution U + p, 1 A GeV
INCL4
σ / mb
Mass number


ISABEL
σ / mb
Mass number

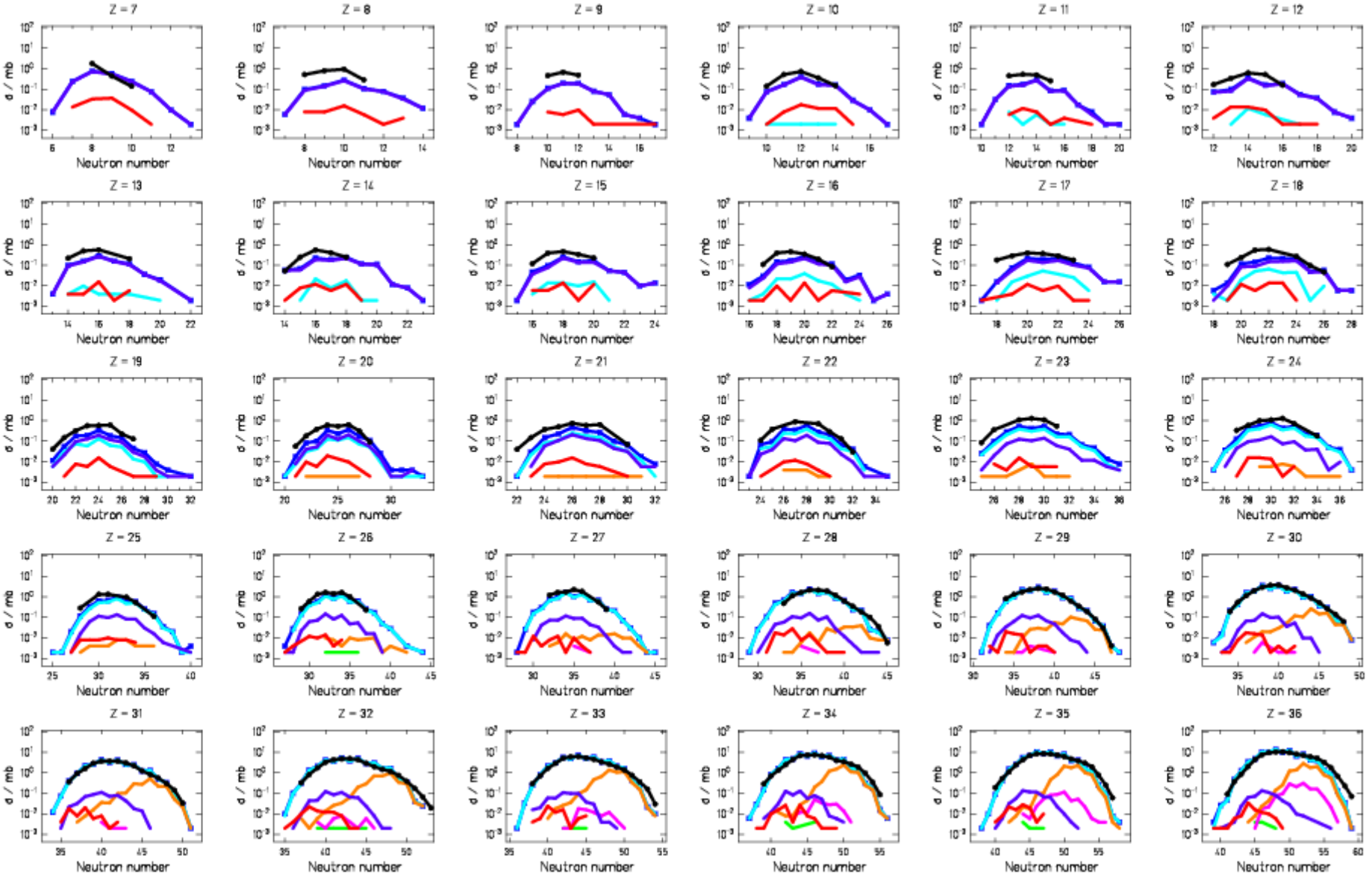
1 GeV p + ^{238}U


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

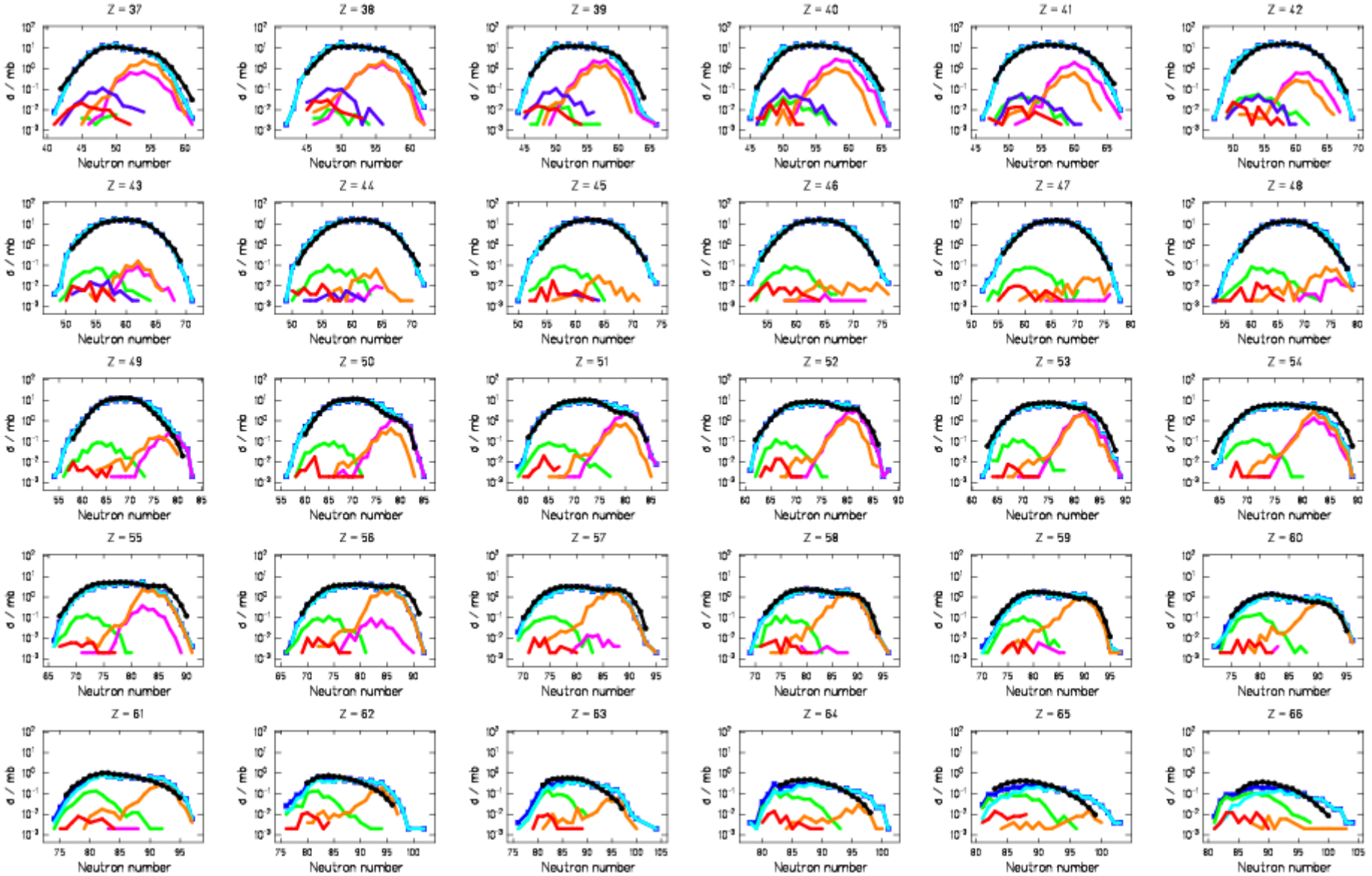

Element distribution U + p, 1 A GeV
INCL4
σ / mb
Atomic number


ISABEL
σ / mb
Atomic number

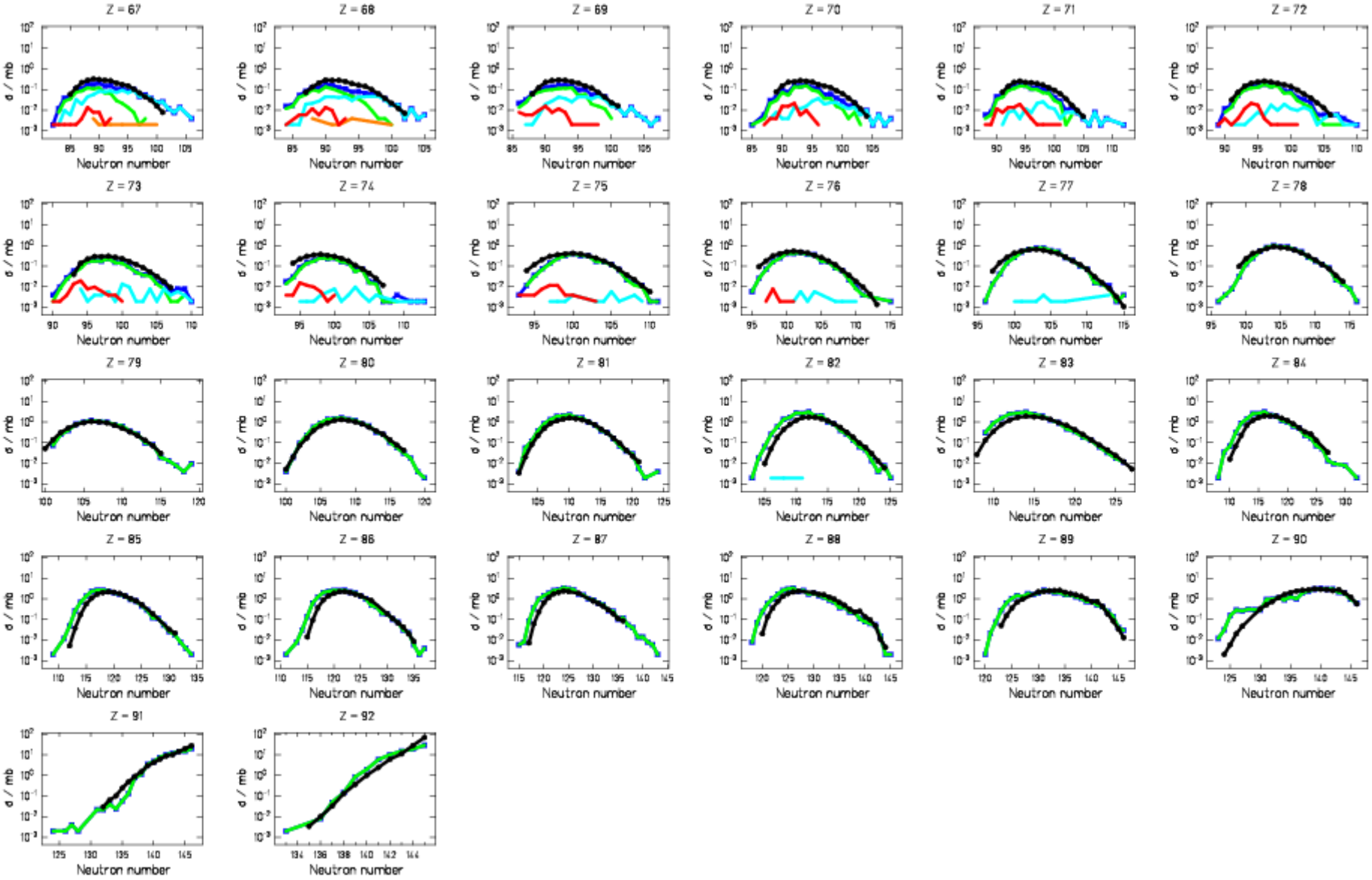
1 GeV p + ^{238}U ABRABLA07



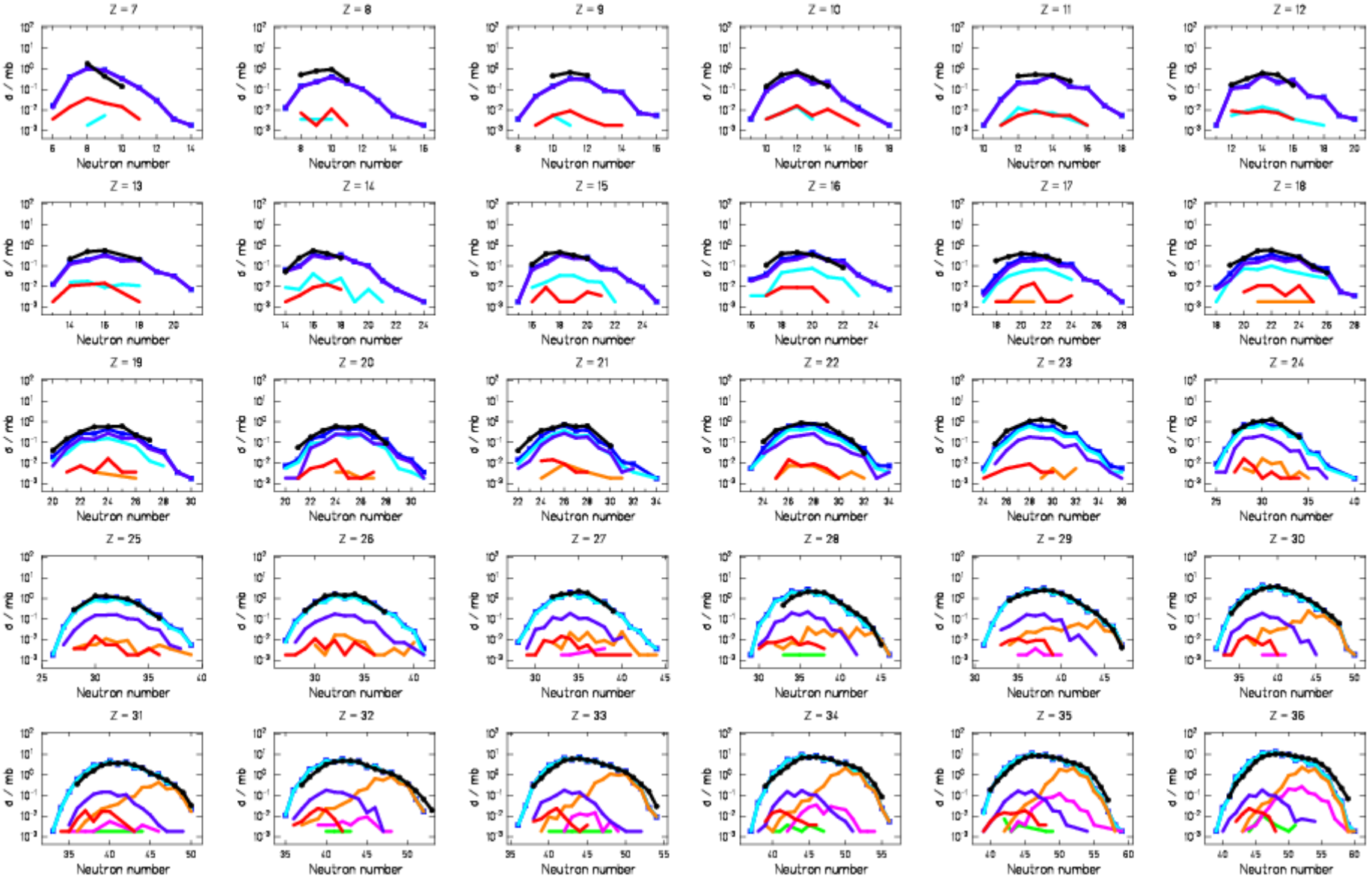
1 GeV p + ^{238}U ABRABLA07



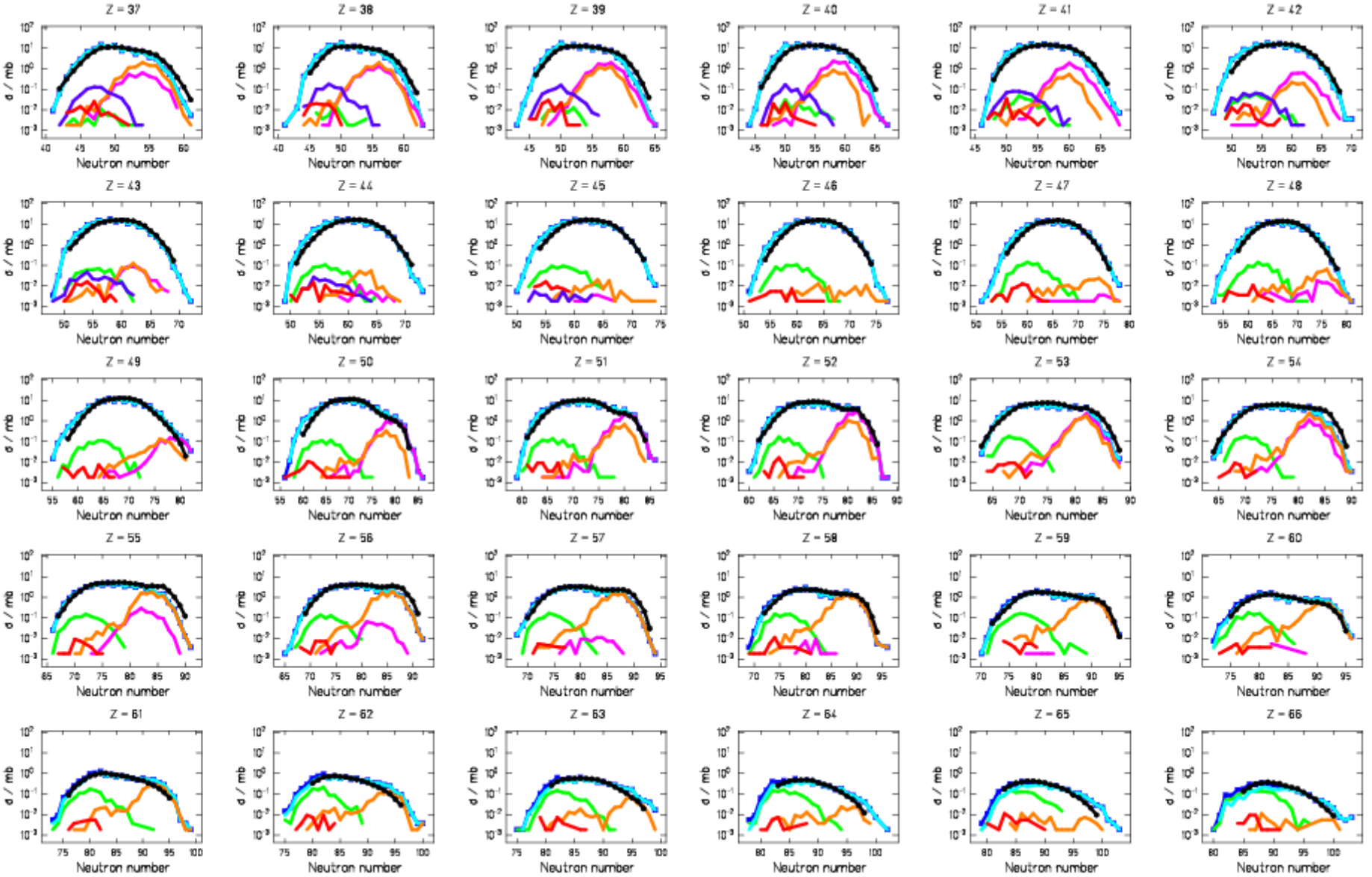
1 GeV p + ^{238}U ABRABLA07



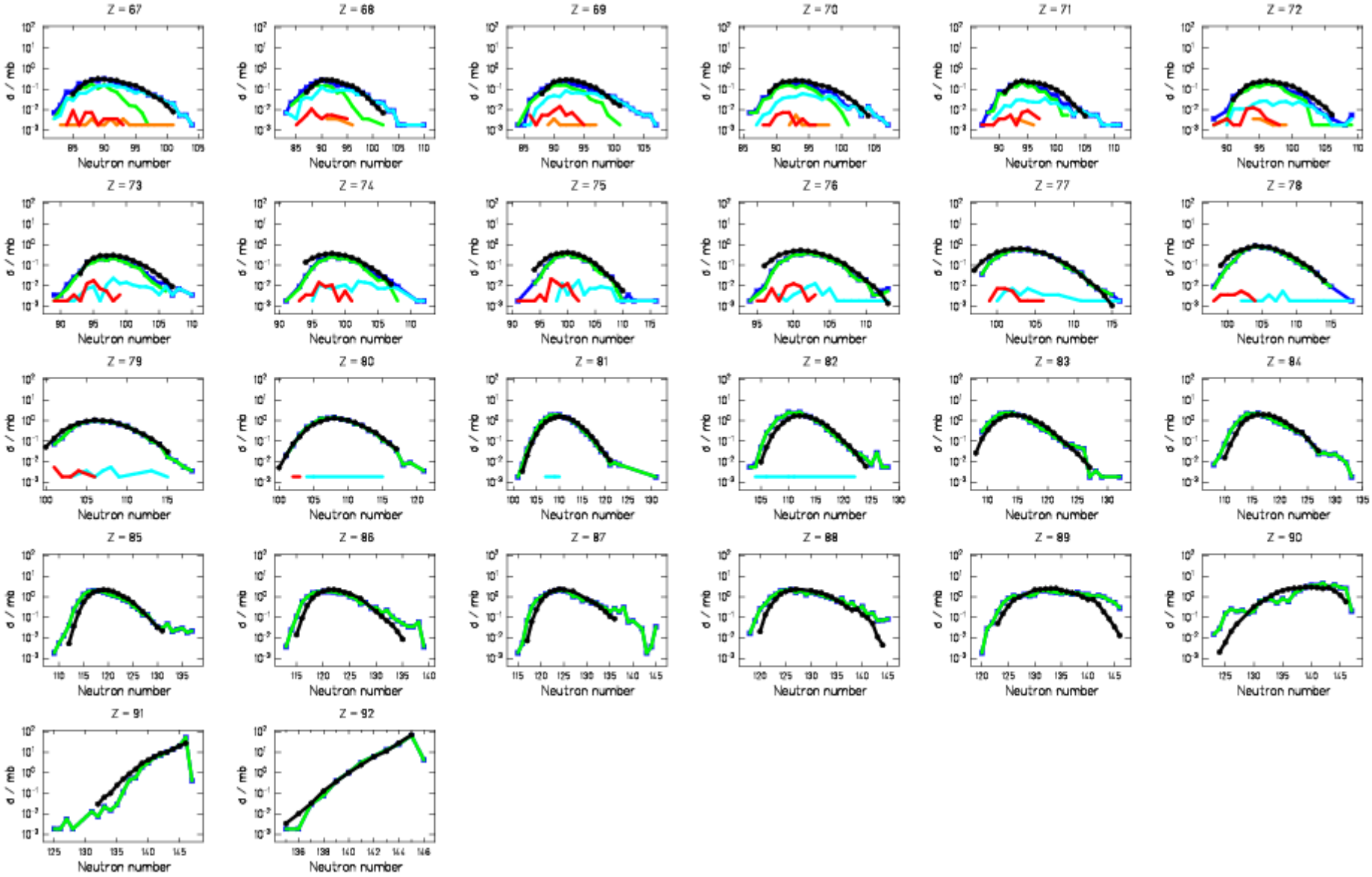
1 GeV p + ^{238}U INCL4+ABLA07



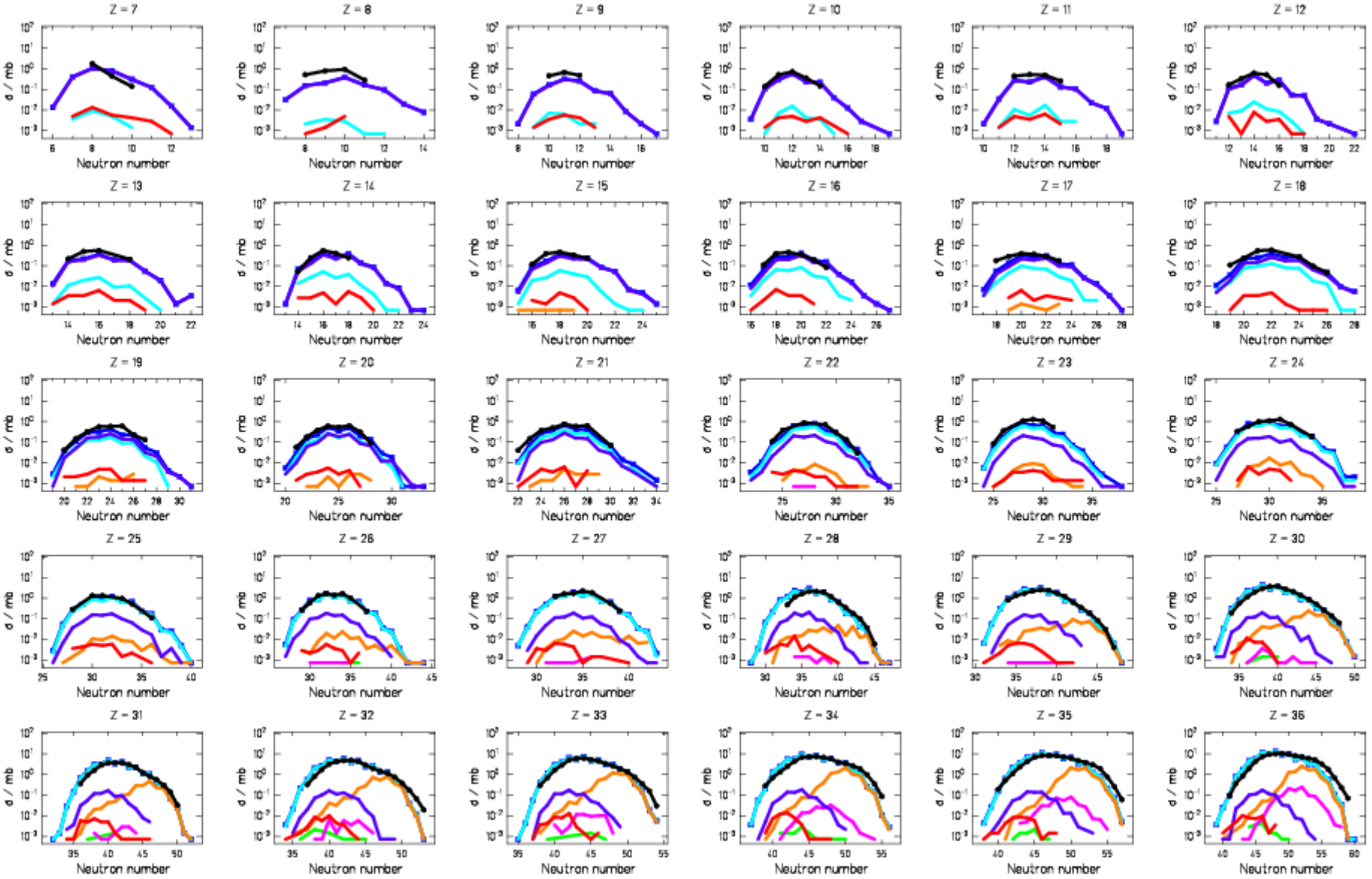
1 GeV p + ^{238}U INCL4+ABLA07



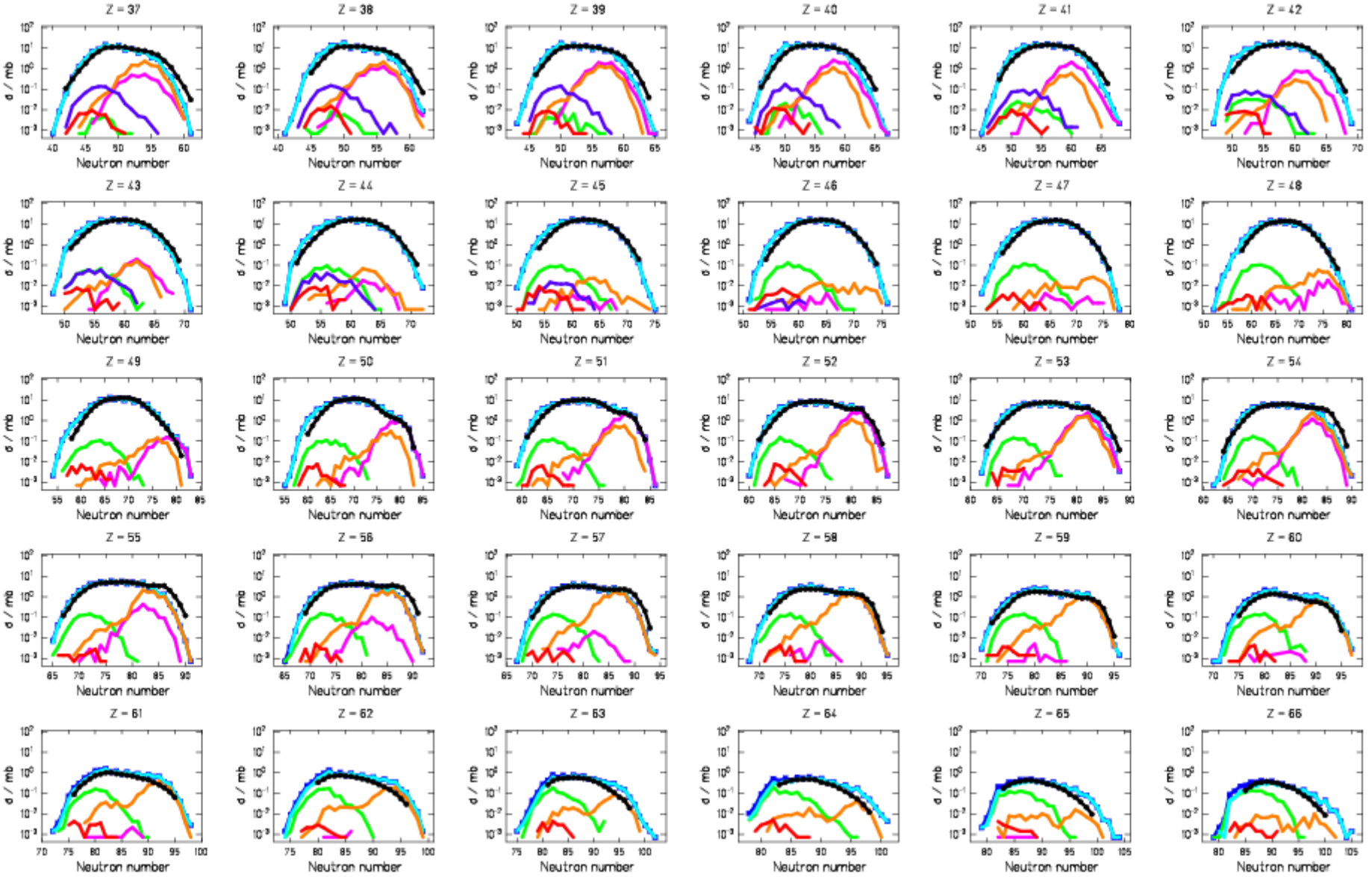
1 GeV p + ^{238}U INCL4+ABLA07



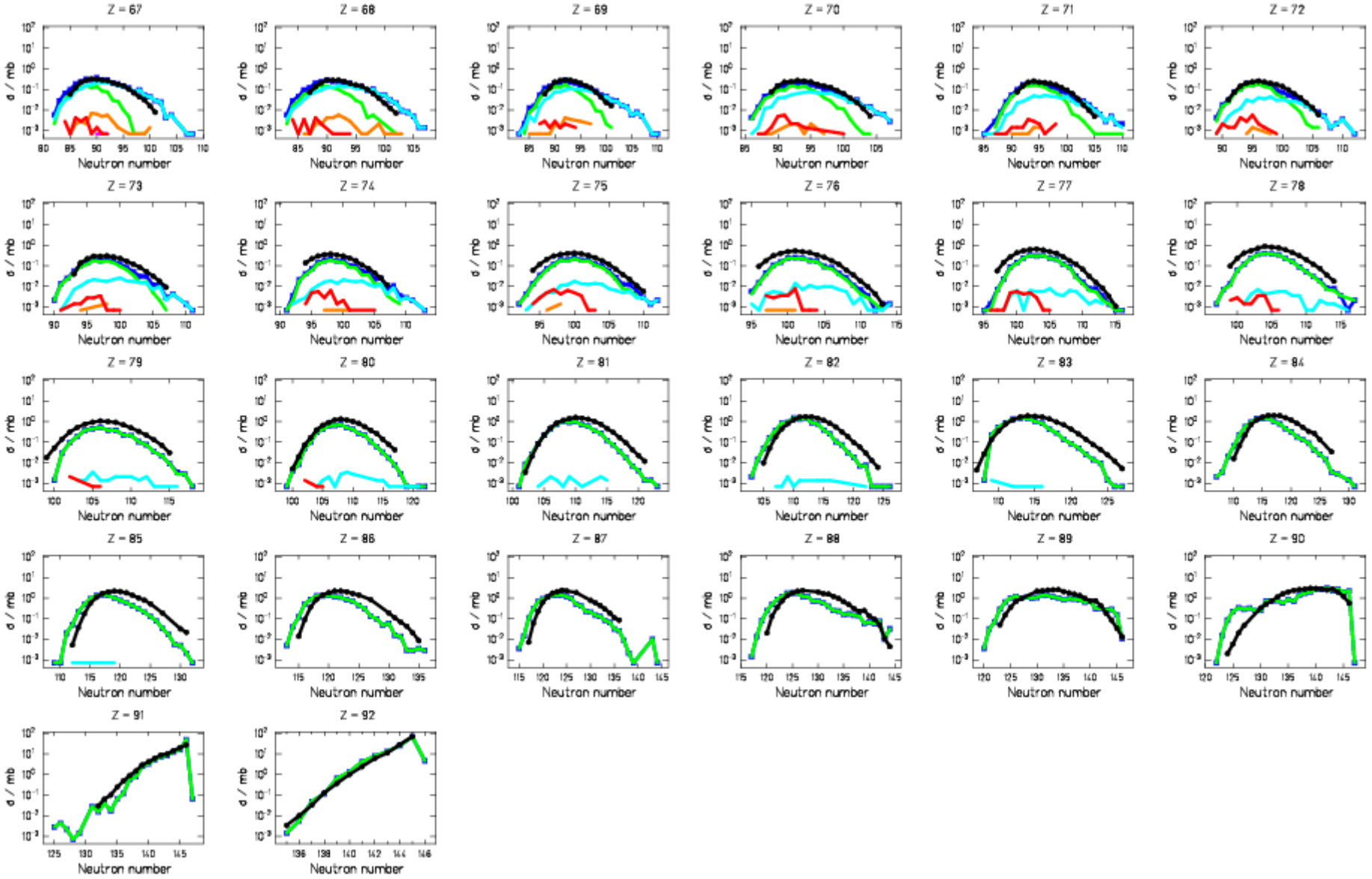
1 GeV p + ^{238}U ISABEL+ABLA07



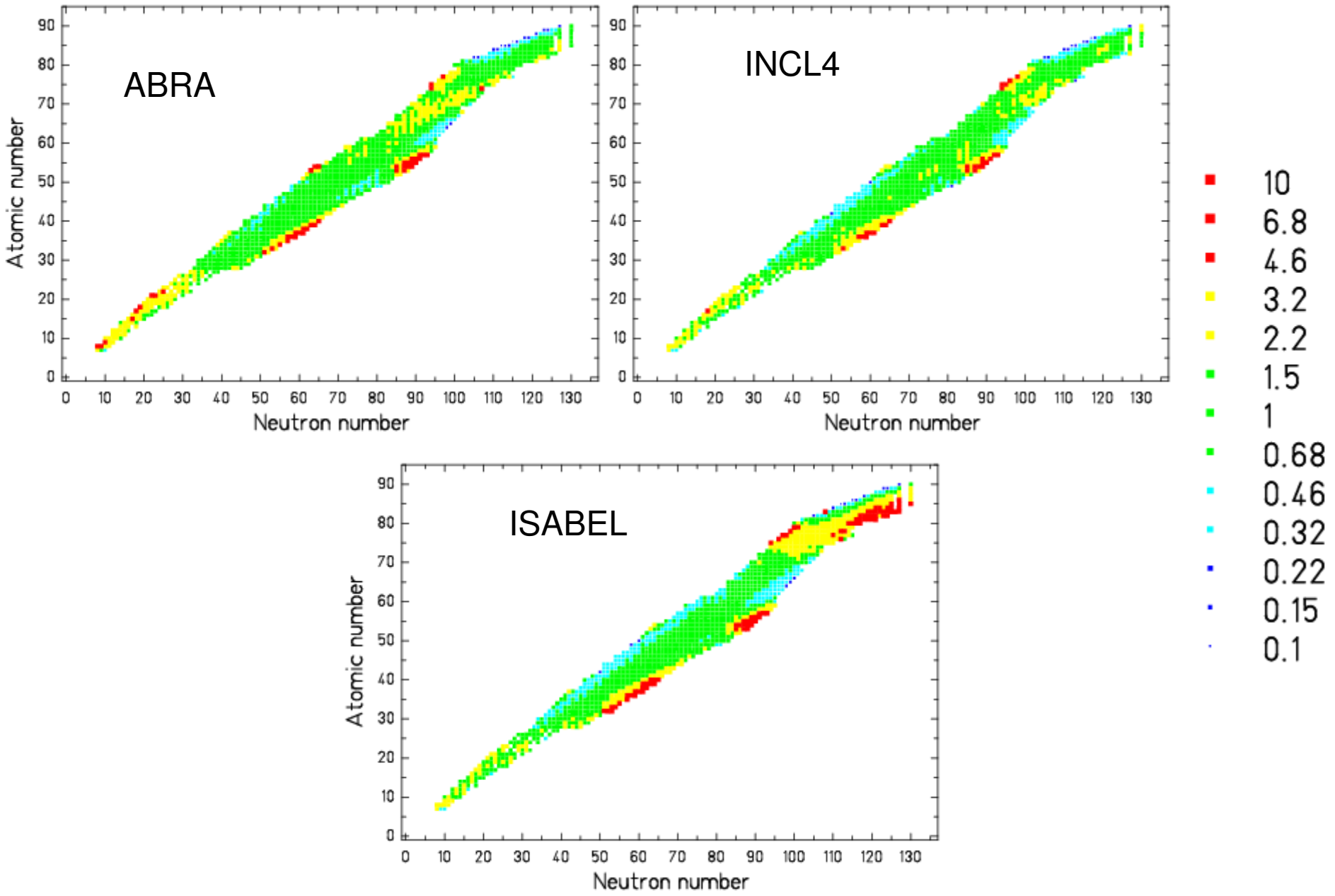
1 GeV p + ^{238}U ISABEL+ABLA07



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**