Second Advanced Workshop on Model Codes for Spallation Models.
Saclay, 8-11 Feb. 2010

Results with INCL4.5.(20)

J. CUGNON (Ulg) and the INCL4 Collaboration

- Introduction
- From INCL4.2 to INCL4.5
- Results INCL4.5 (coupled to ABLA07)
- Conclusion

1. Introduction

INCL4.2:

-parameter-free, nucleon d.o.f., minimum distance of approach
-good description of data (with ABLA_v3p)

But:

- no composite emission
- no pion potential
- problems residue distributions
- problems at low energy

2. From INCL4.2 to INCL4.5

1. Introduction of a dynamical coalescence model for composites (INCL4.3)
   satisfactory at high energy

2. Development of INCL4.5 (and of ABLA07) in EUROTRANS

Main features of INCL4.5

Known phenomenology

- Isopin and energy-dependence of the nucleon mean field
- Pion potential
- Curved trajectories in the Coulomb field (in & out)

Cluster emission

- check for a particle trying to escape with E>Ethr (position)
- potential clusters are constructed (compactness criteria, a parameter per cluster for light clusters A>5)
- the most bound (per nucleon) cluster is emitted provided it tunnels through the Coulomb barrier (otherwise the driving nucleon is emitted, if it satisfies the same criterion)
- A≤4 clusters are not emitted if the direction of propagation is too tangential (cos ϑ >0.3) (except for 1st cluster...)
- Short-lived clusters (ex: ^{5}Li) are forced to decay

Pauli blocking

- Two nucleons below Fermi level do not interact
- Strict Pauli blocking on the first collision

Soft collisions and low energy

- No soft collisions (below $\sqrt{s}$ =1910 MeV)
- No restriction on the first collision
- “localE”: correction of local Fermi energy on the first collision

Fuzzy Fermi surface or imperfect quasi-particles

- if after a collision or a Δ-decay, a nucleon has $E<E_F+\zeta$ (18 MeV), it is considered as a spectator again
- cascade is stopped if $t>t_{fin}$ or if $N_{part} = 0$ and N_{π} (inside)=0

3. Analysis of the INCL4.5 results

Neutron cross sections

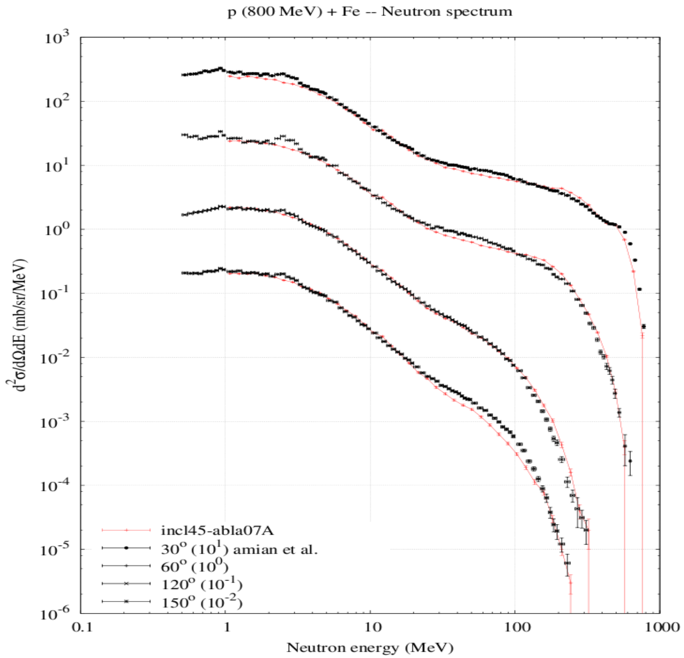
Results shown (in figures): coupling to ABLA07

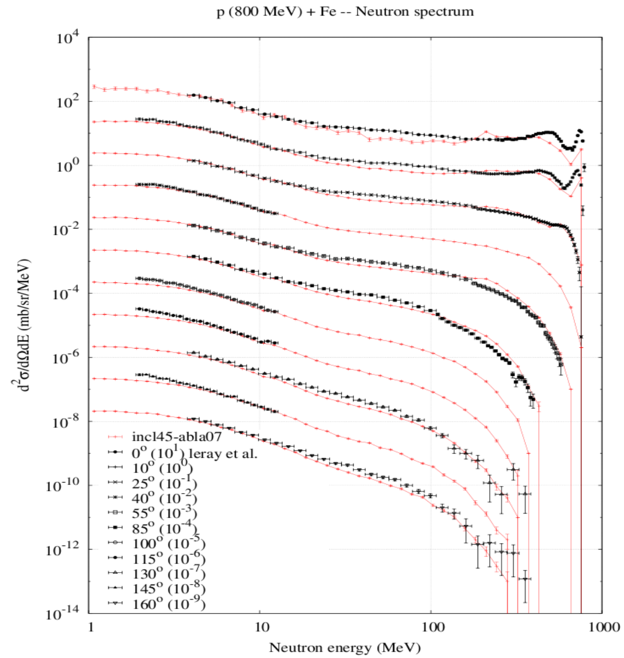
INC contribution easily isolated

amian

Saturne

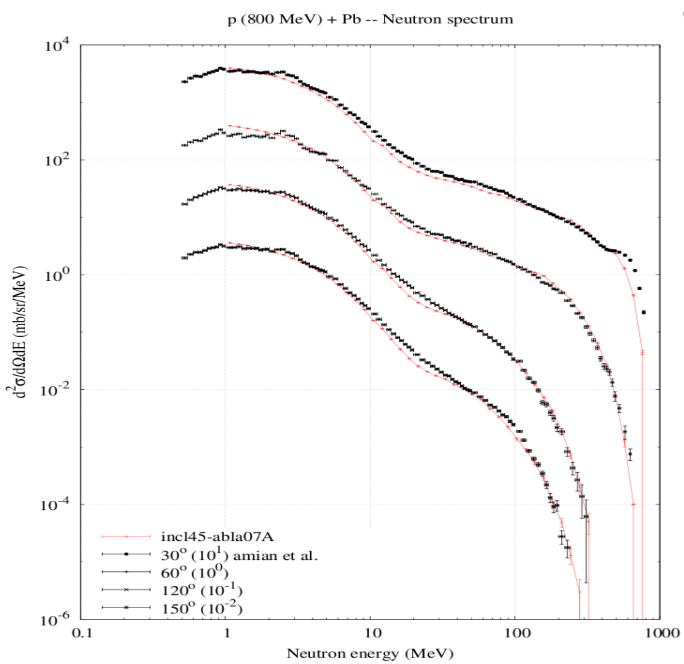
Fe

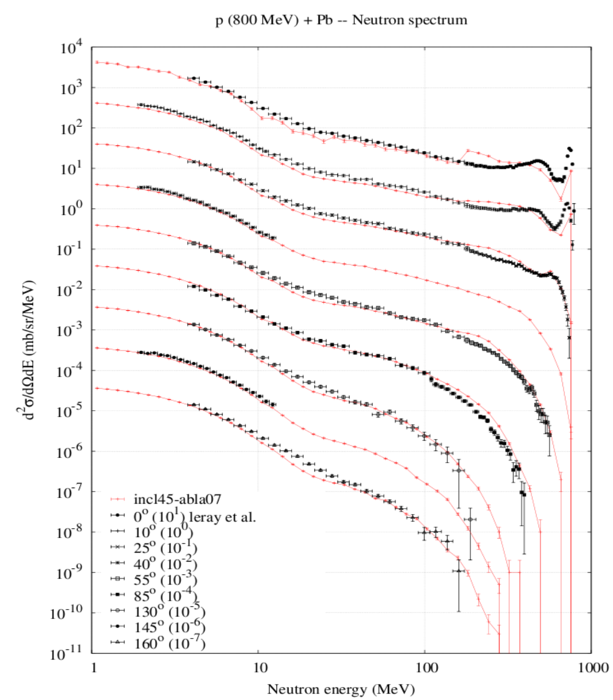




800 MeV

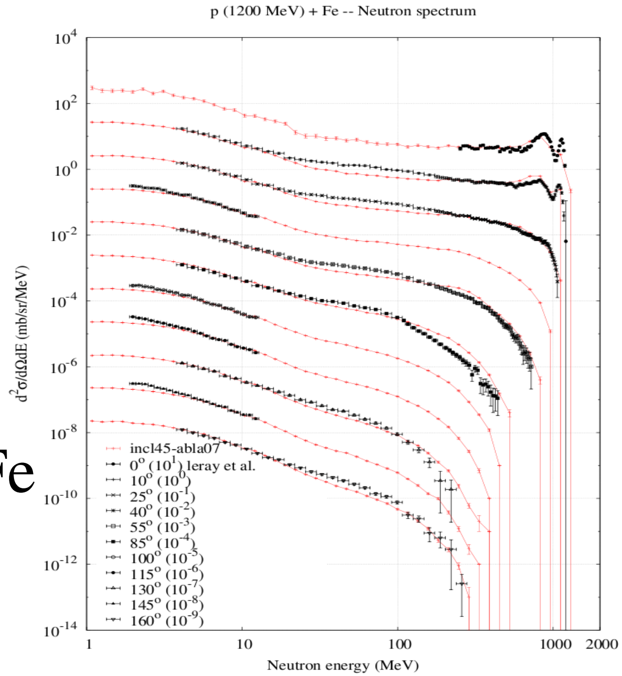
Pb

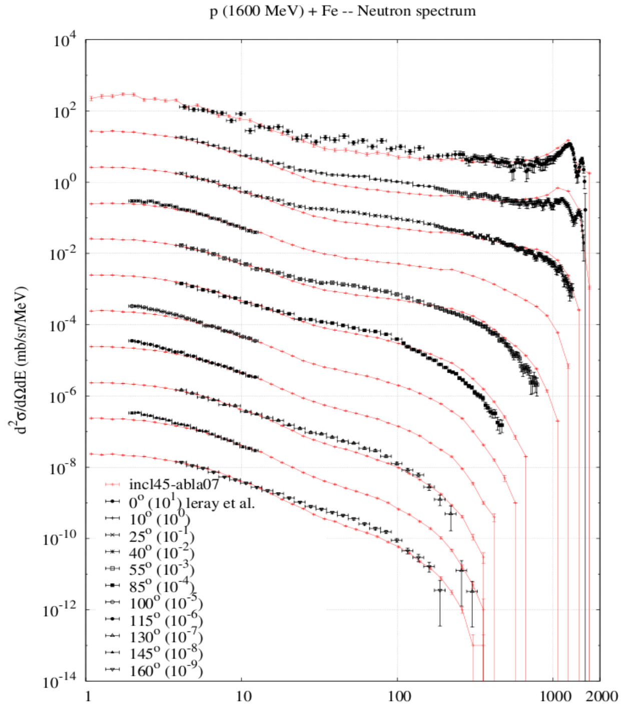


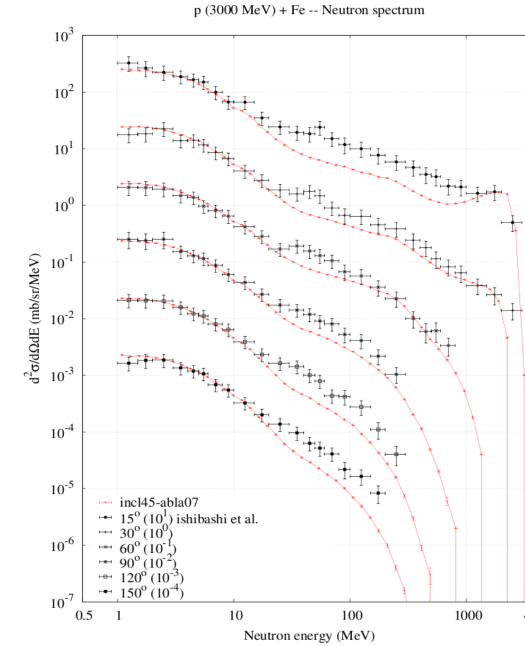


800 MeV | 1200 MeV | 3 GeV

Fe







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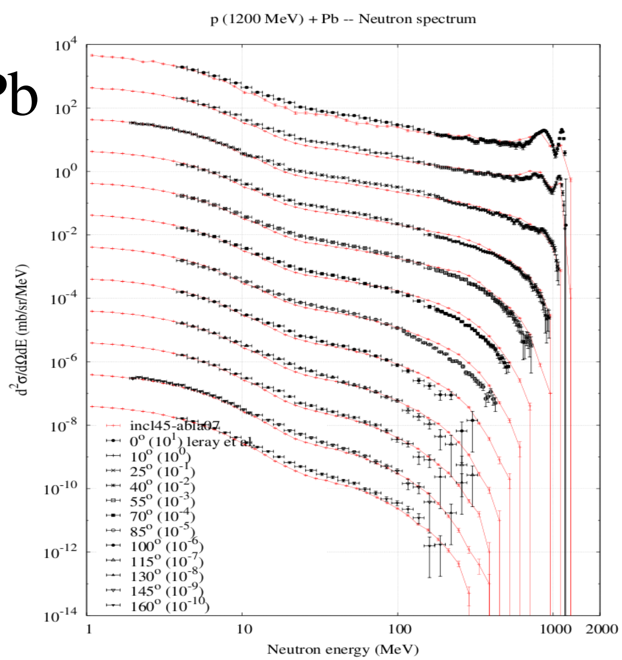
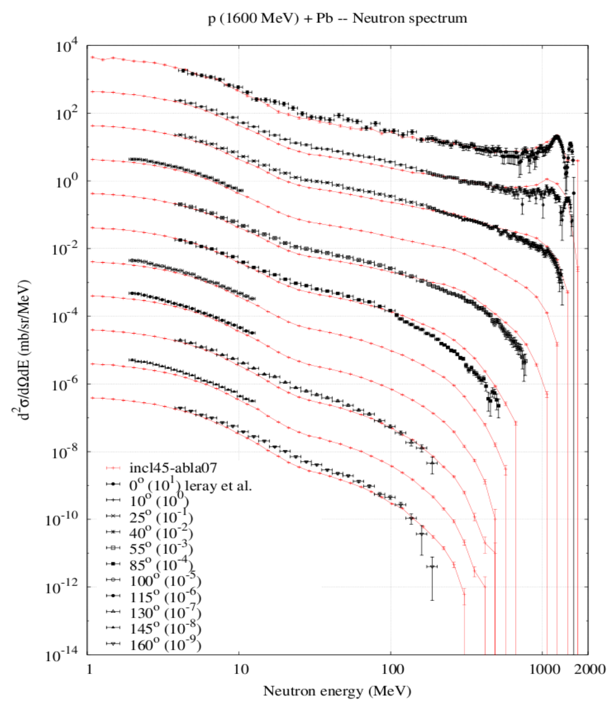
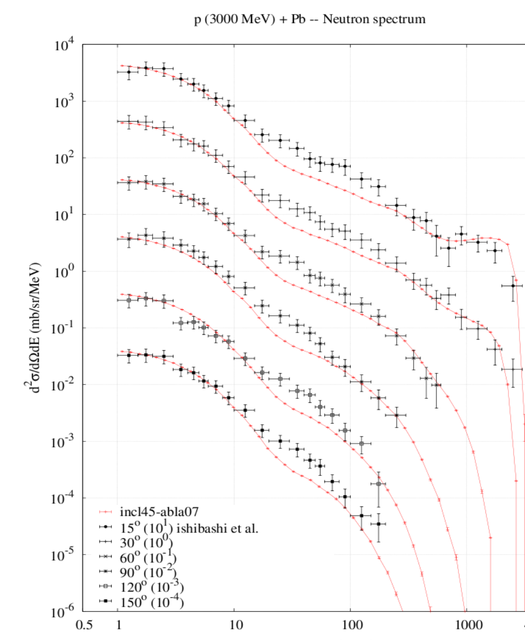
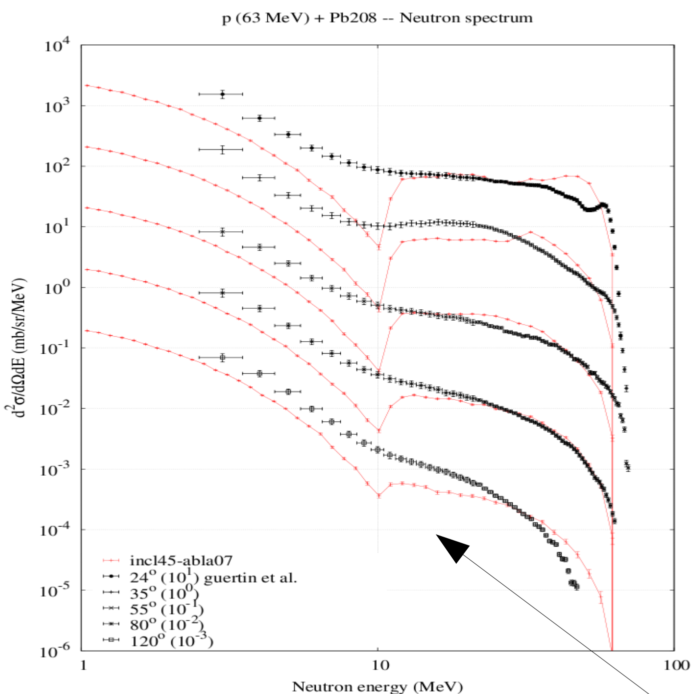
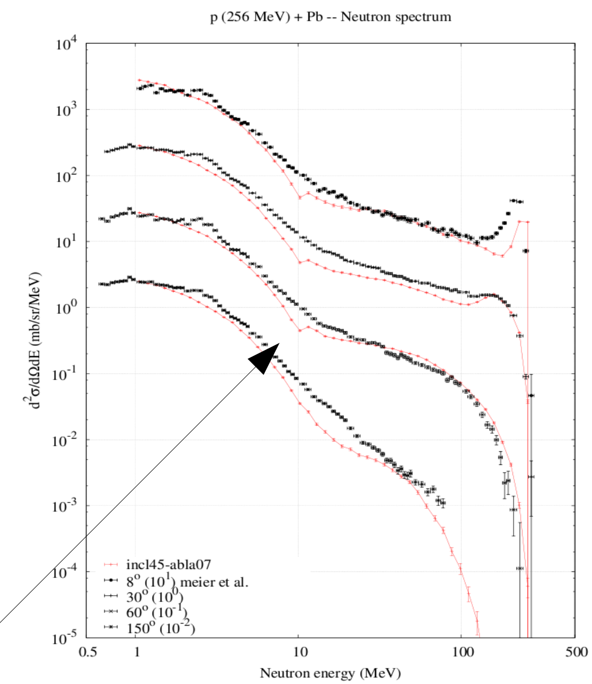
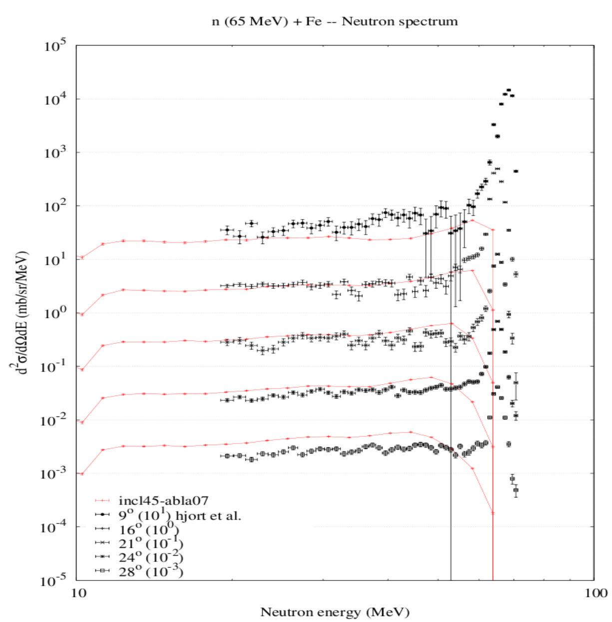












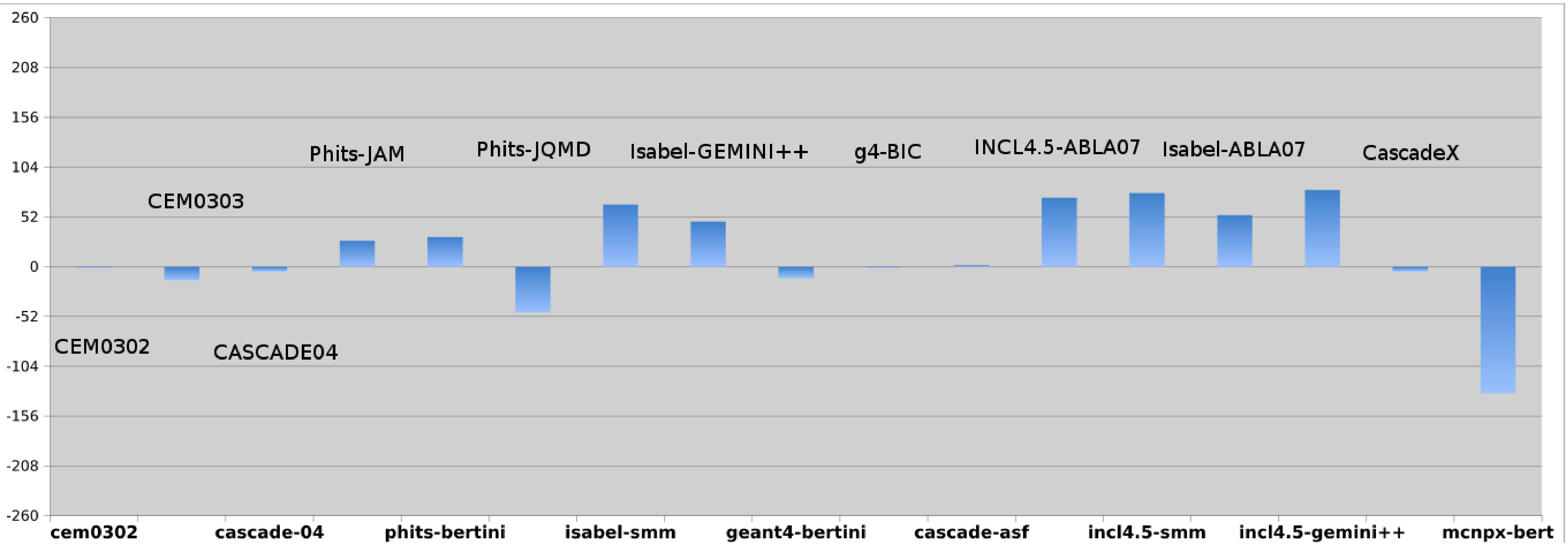
- The Isabel trick!

Change of slope

Strong points:

- good overall predicting power
- evaporation spectra

A. Boudard (notes with penalties)



	Isabel	INCL4.5
SMM	60	71
GEMINI++	44	74
ABLA07	50	67

Weak points:

- underprediction of spectra in the energy range “above evaporation”
  due to either cascade or cluster formation

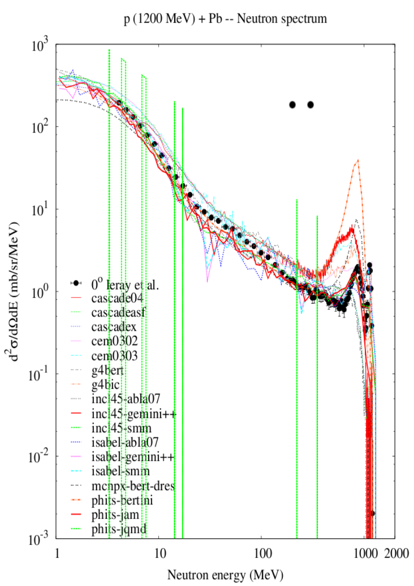
- overprediction at small angles and above 180 MeV
  probably due to energy-dependent potentials

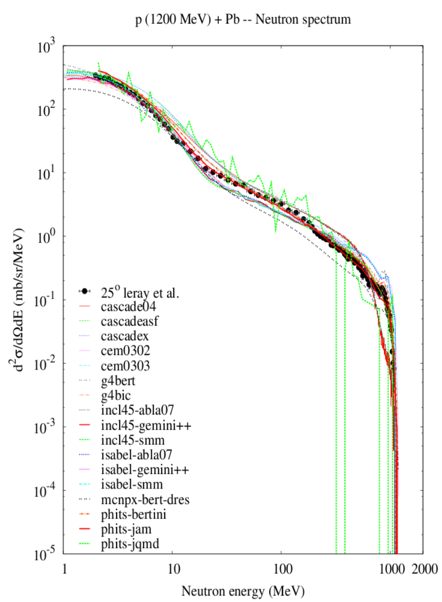
- quasi-inelastic (Delta) region: shift which decreases with incident energy
  and with the target mass

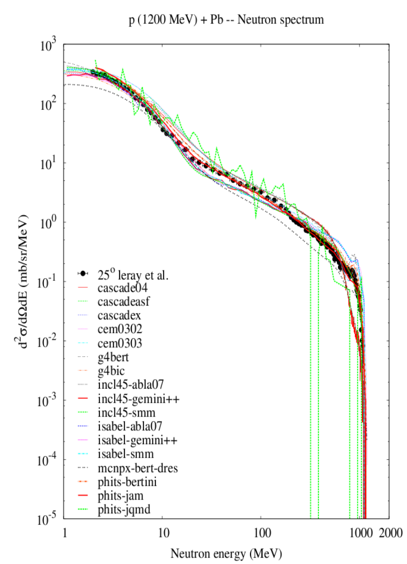
- ”accident at 10 MeV” only “visible” at low incident energy
  solution: remove (or smoothen) the “Isabel trick”

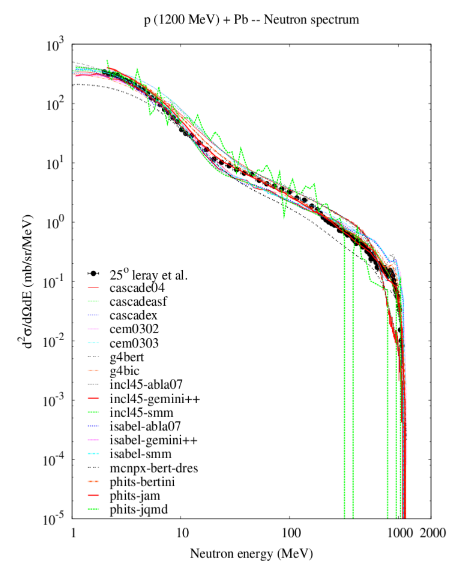
Trends:

- Agreement generally improves with increasing angles (except at very large angles)
- QE and QI peaks are less well described than the multi-collision contribution: a paradoxical theoretical problem
- Dispersion between models behaves as point 1 : another theoretical issue.







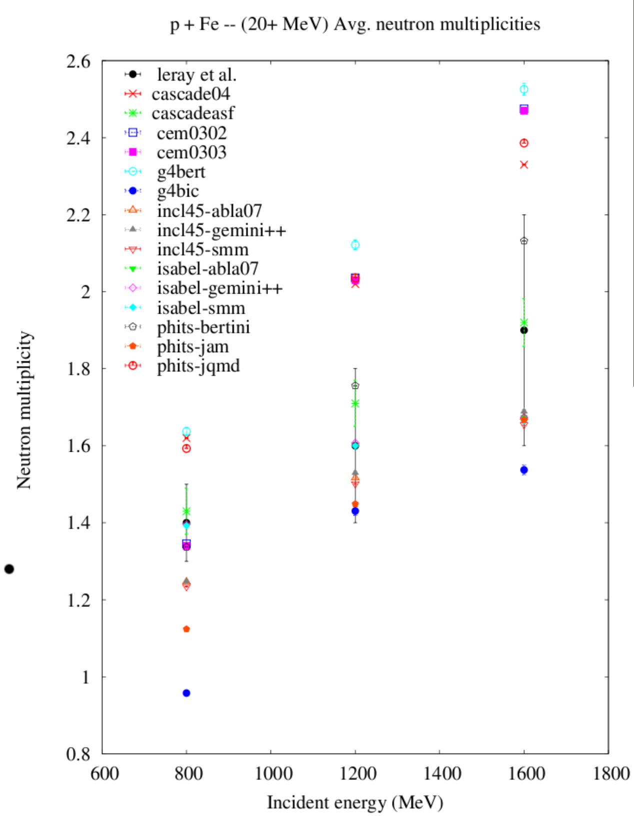


Neutron multiplicities (E>20MeV)

Average multiplicities

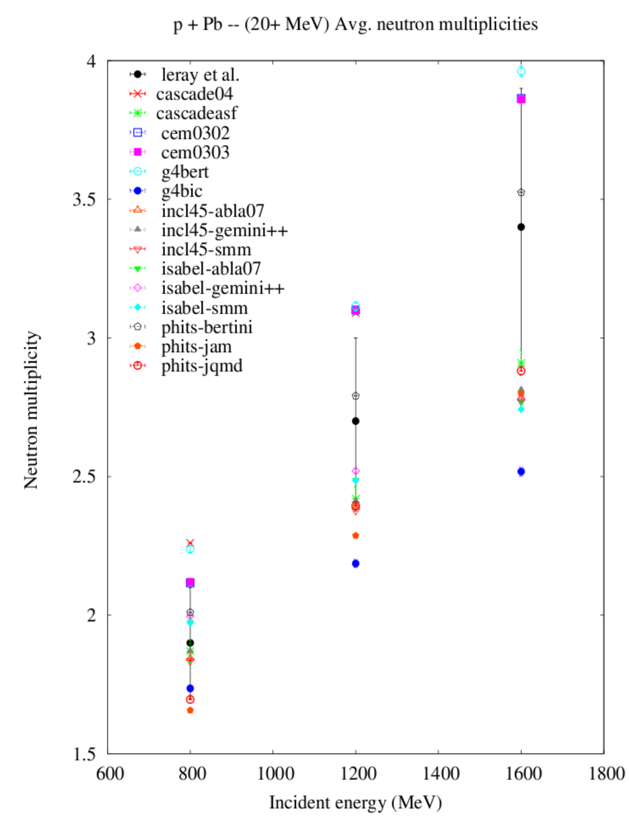
Ideal $\chi^2 \leq 0.75$

Fe



CEM02	104
CEM03	100
Isabel	1.6
INCL4.5	3.3
Phits	9.0
Cascade asf	0.39

Pb



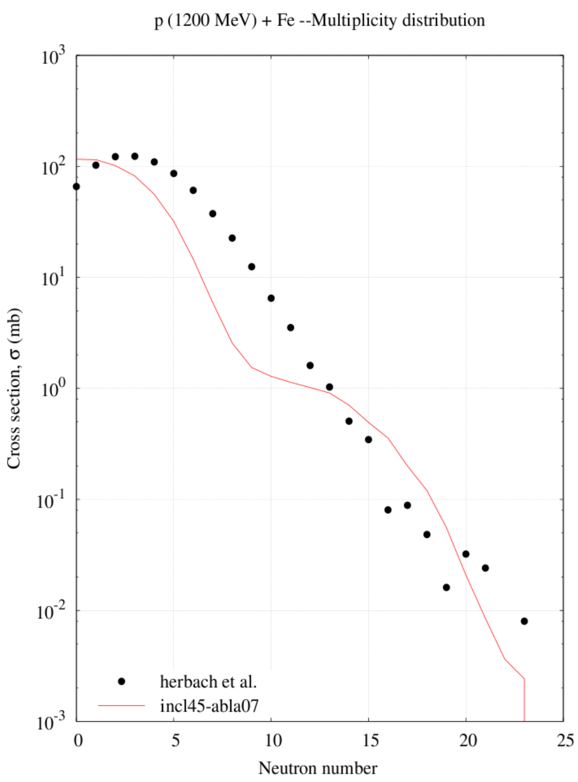
CEM02	3.7
CEM03	
Isabel	2.4
INCL4.5	2.9
Phits	4.7
Cascade asf	1.84

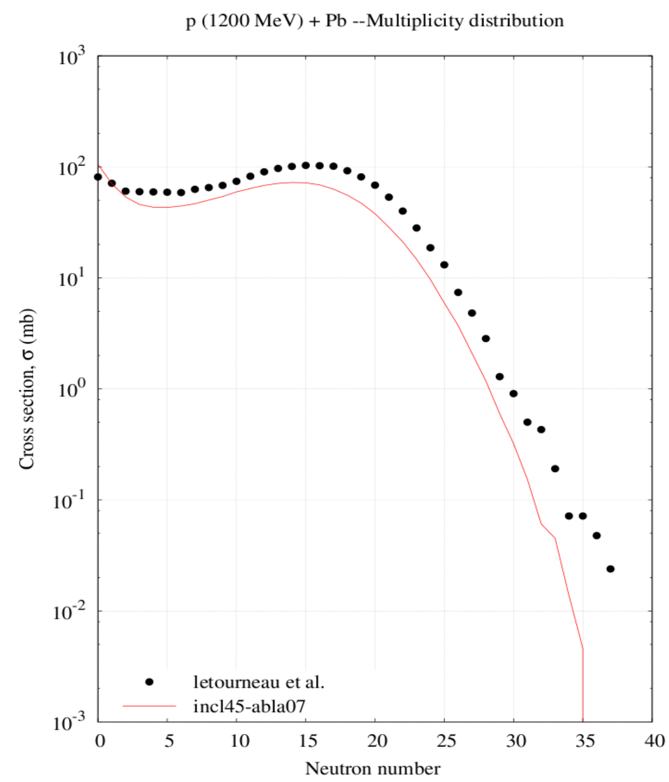
Exp. Unc. σ/<n> 7% 12% 16%

Exp. unc. 10% 11% 15%

Multiplicity distributions

•

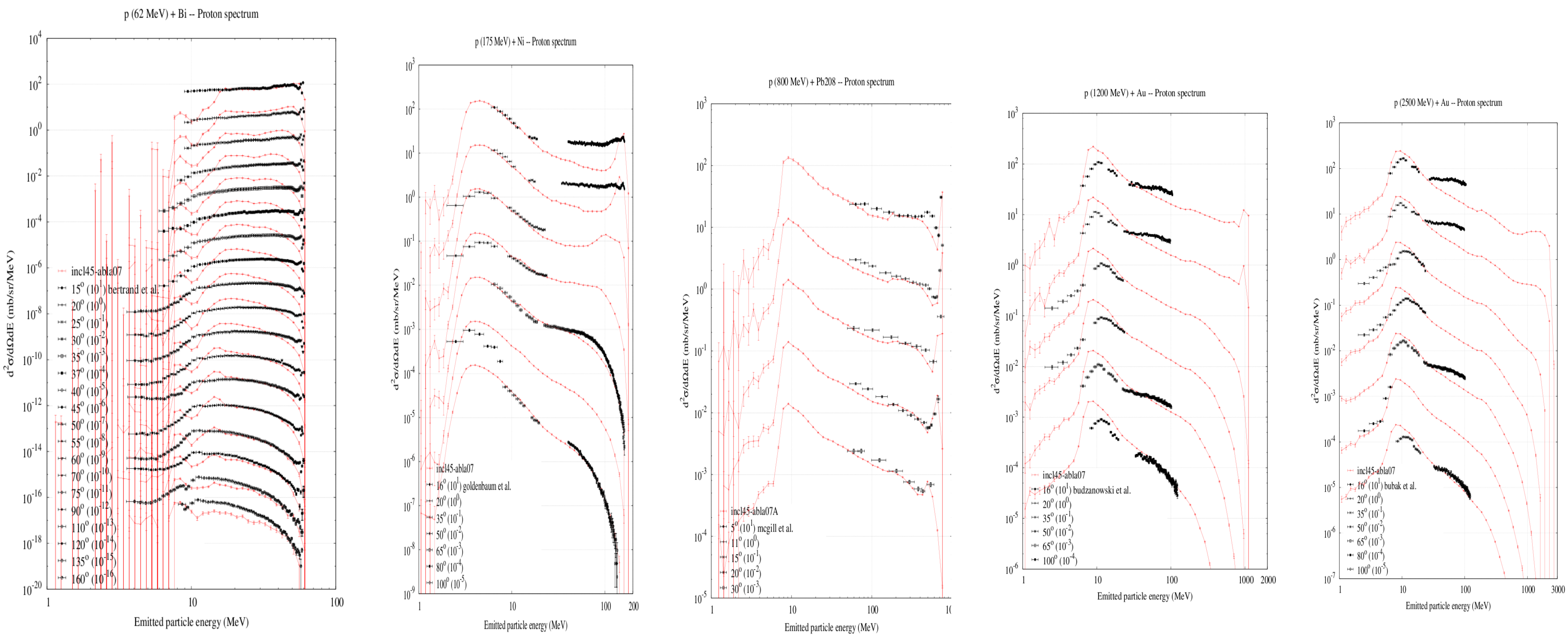




Light charged particles

p

Overall satisfactory agreement(+good QE), but
- underprediction above the evaporation at small angles (composite formation)
- overprediction at low excitation energy
- ”hole” at 10MeV

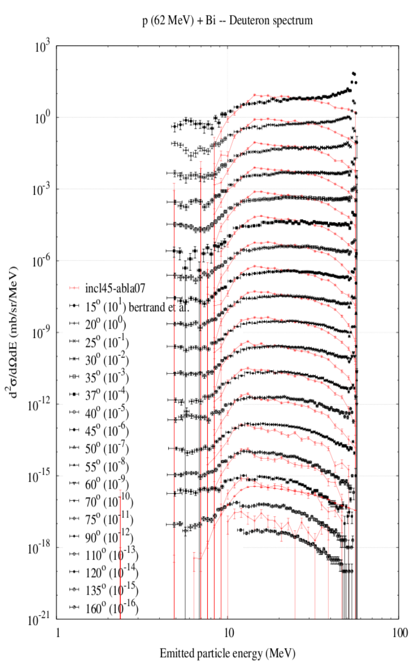


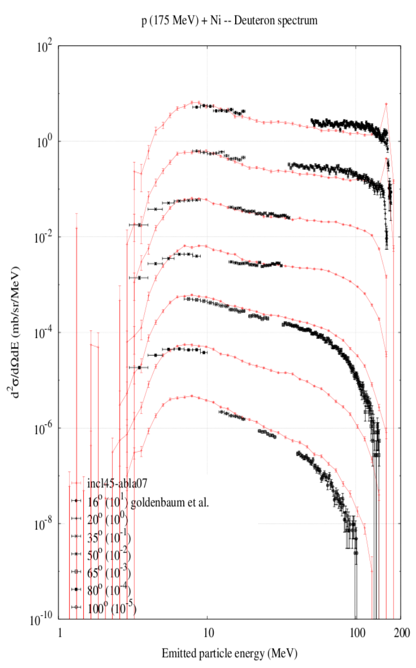
d

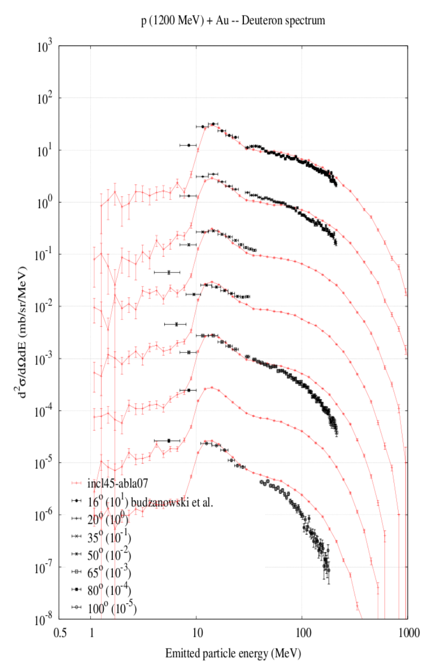
Overall satisfactory agreement

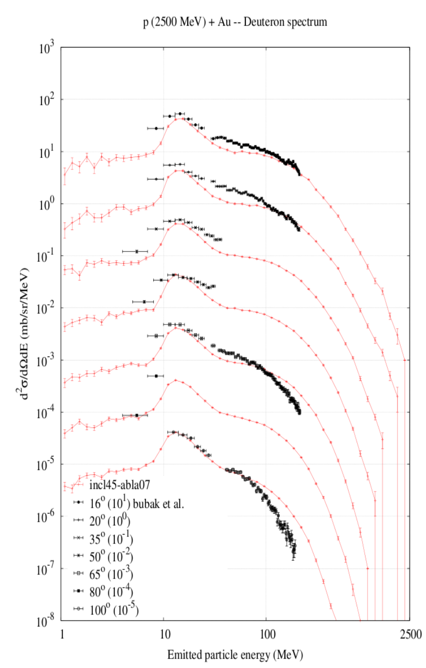
Peak-up too large

Small angles are less good





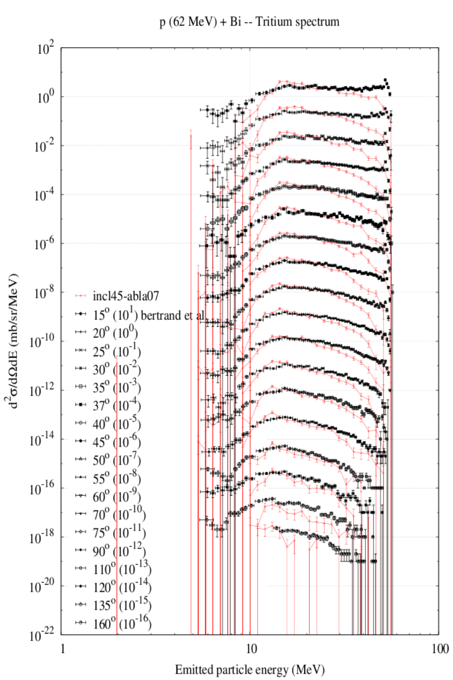


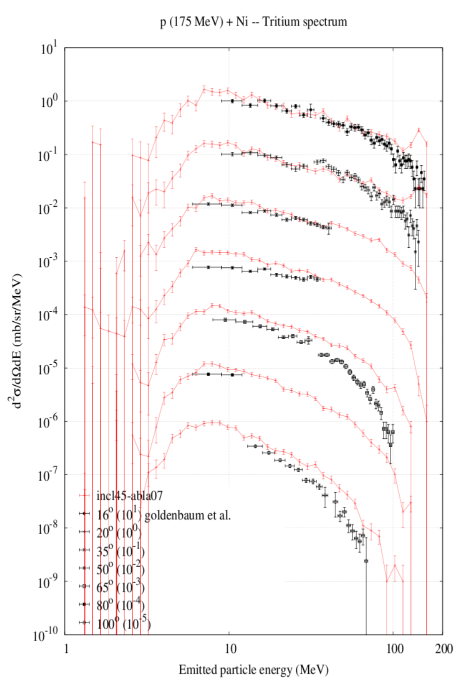


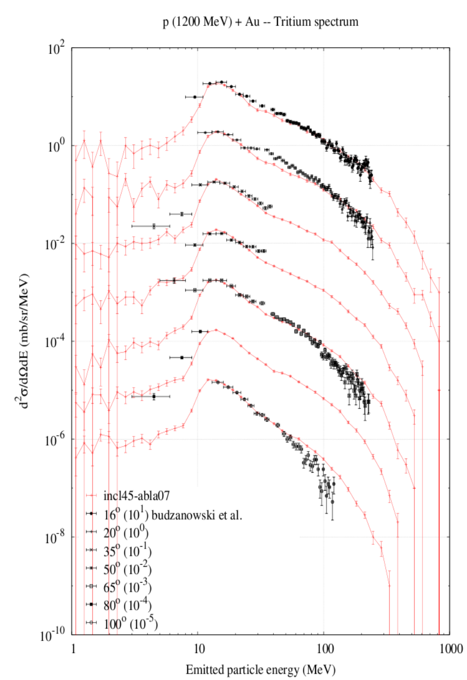
t

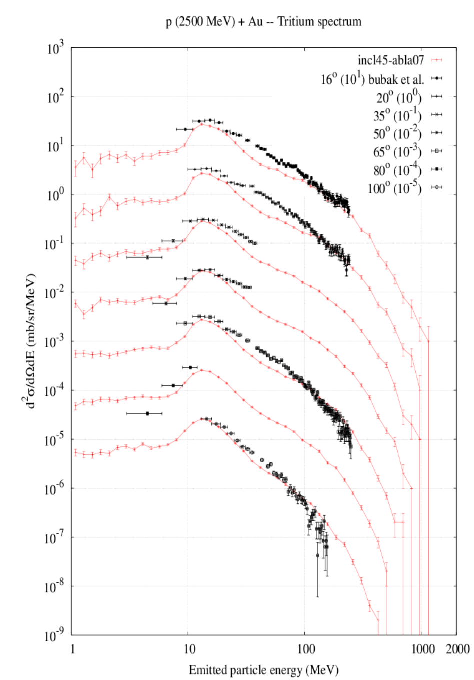
Overall satisfactory agreement

- Peak-up too large
- Small angles are less good
- 2.5 GeV results are less good





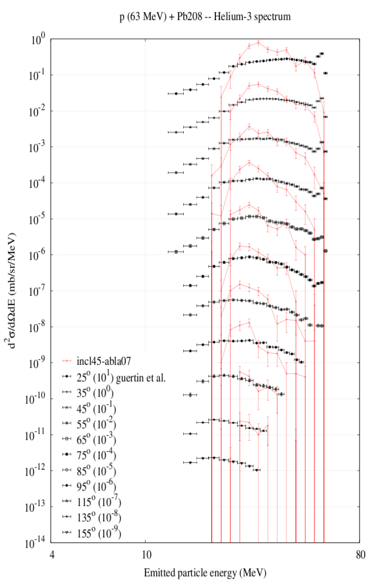


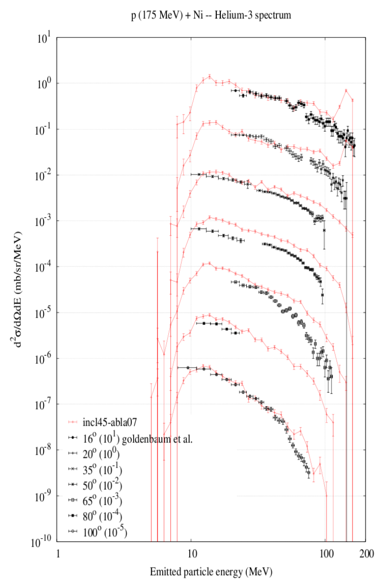


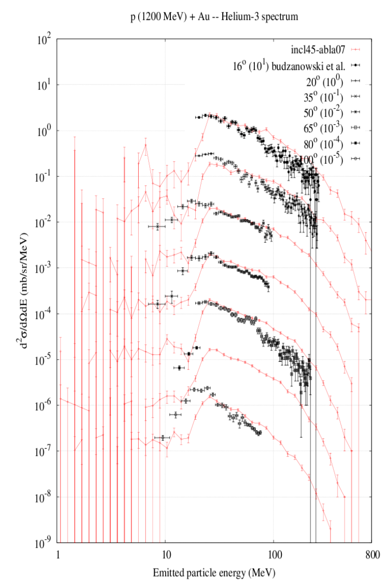
^3He

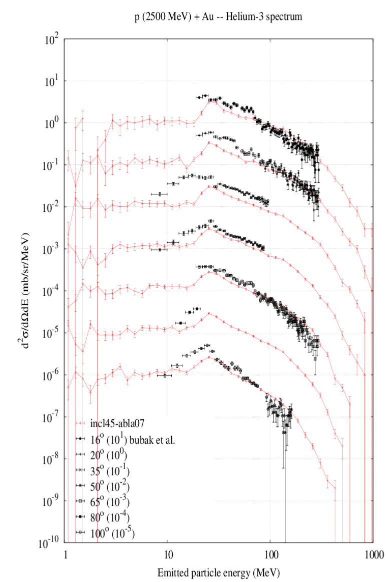
Overall satisfactory agreement

- Bad shapes at low energy
- Peak-up too large
- Barrier and/or evaporation?





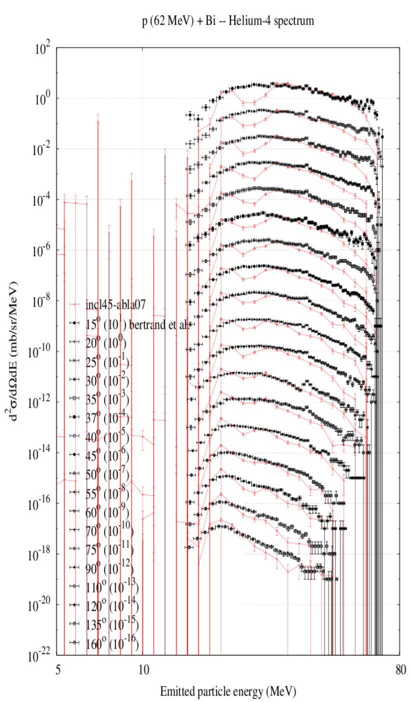


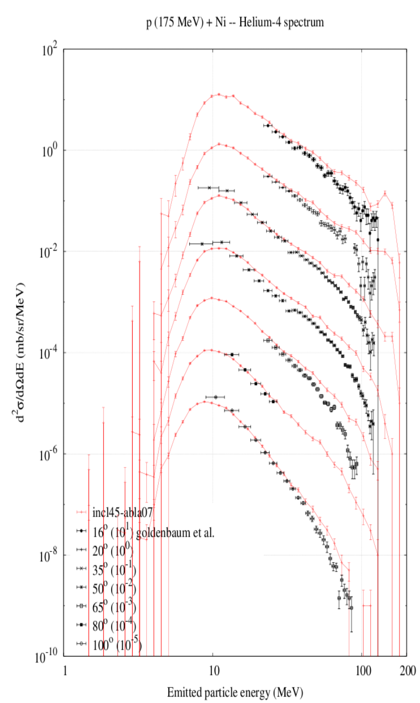


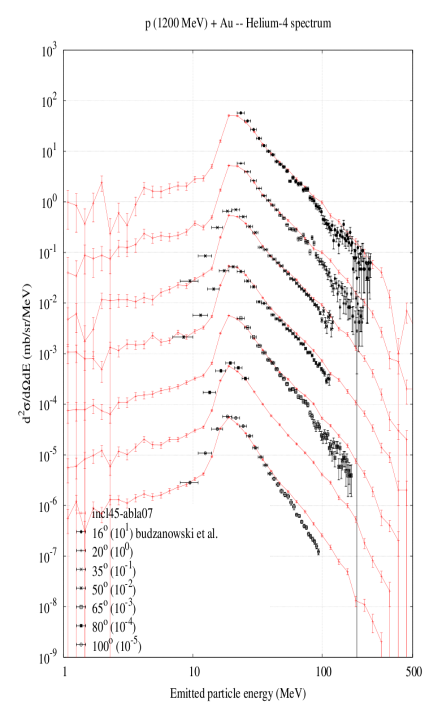
α

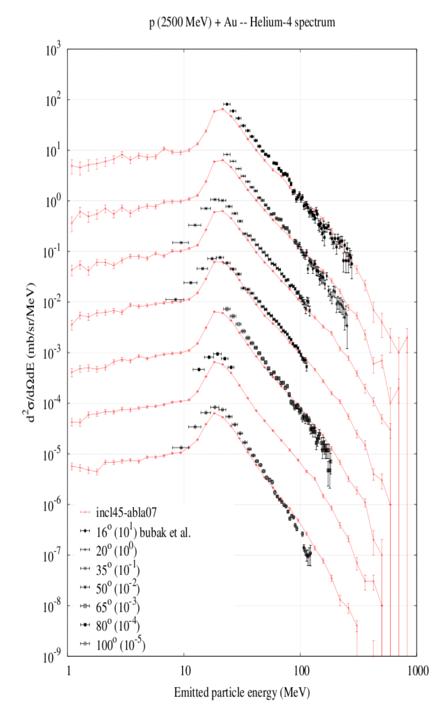
Overall satisfactory agreement

- Bad shapes at low energy
- Peak-up too large?
- Barrier and/or evaporation?



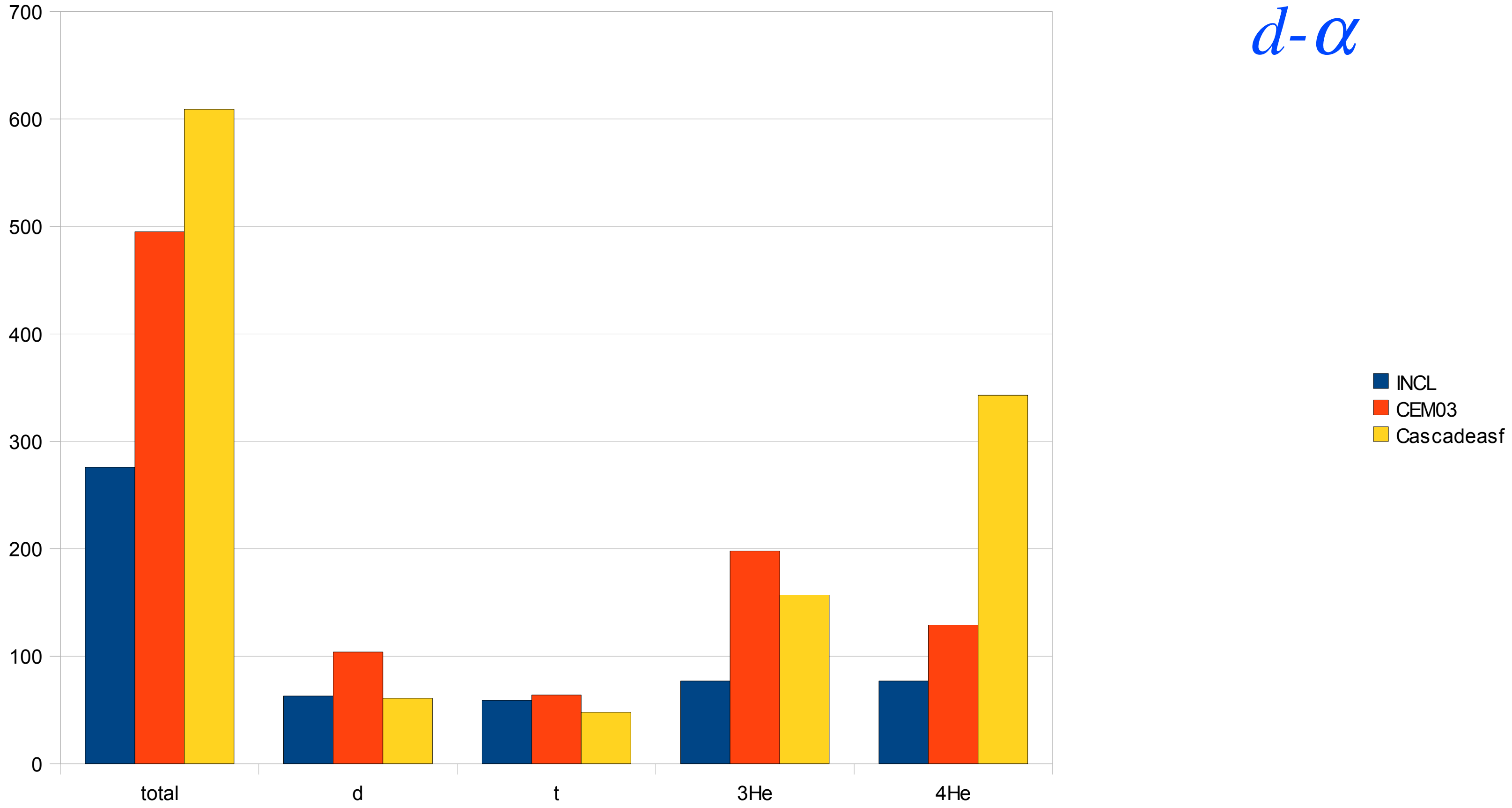






Statistics of the F-factors for spectra above 20 MeV

d-α

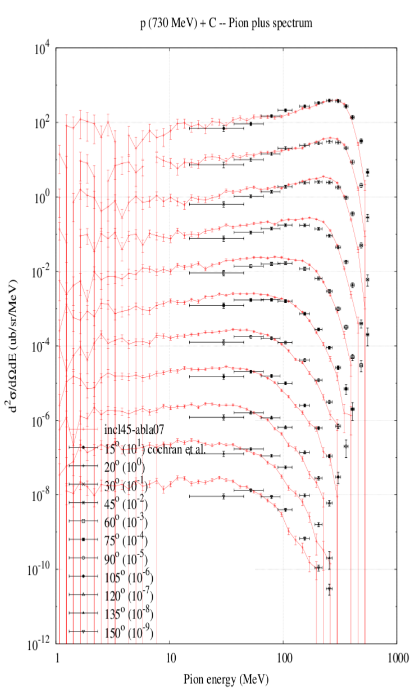


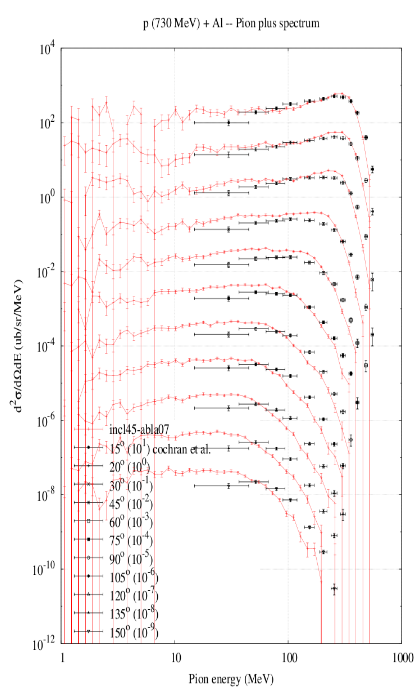
Pions

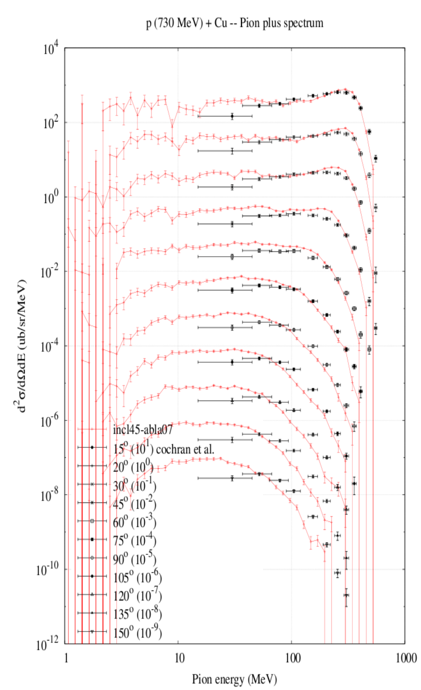
π^+

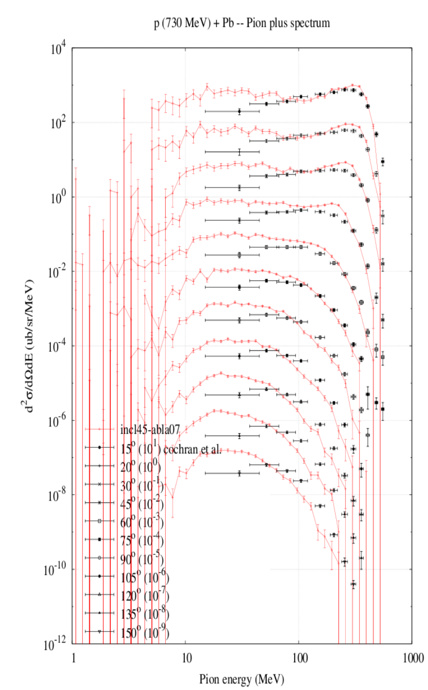
Overall good agreement

Overprediction at low energy for heavy targets





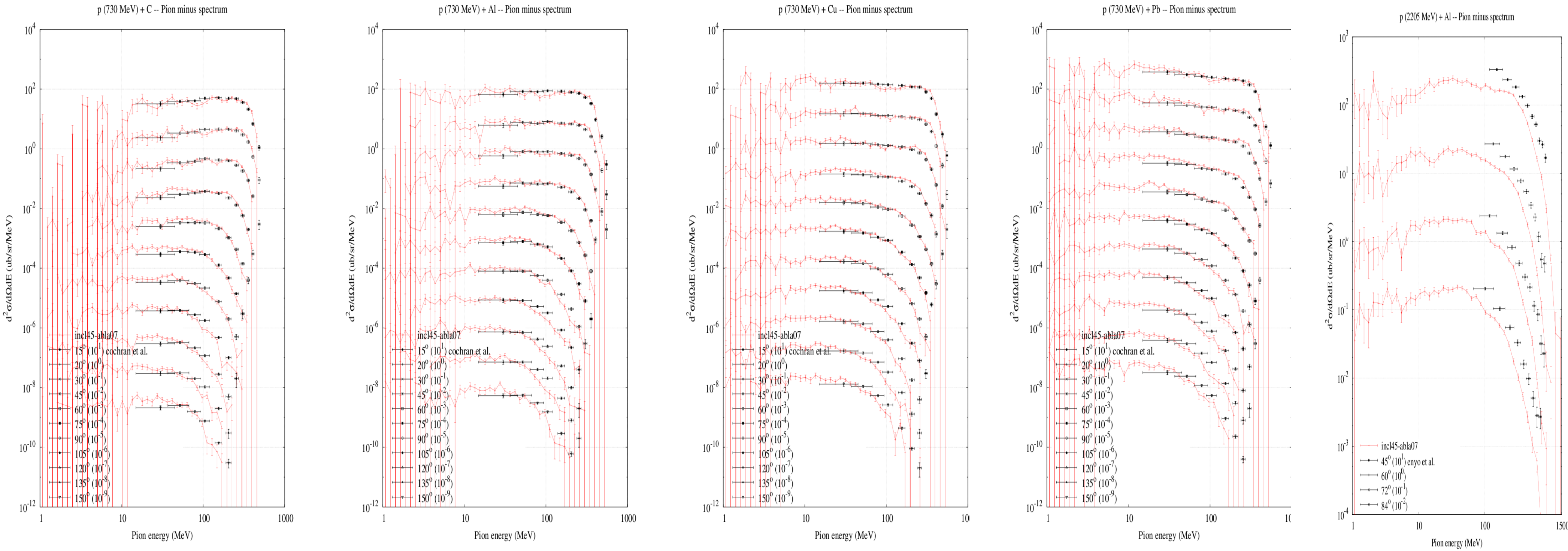




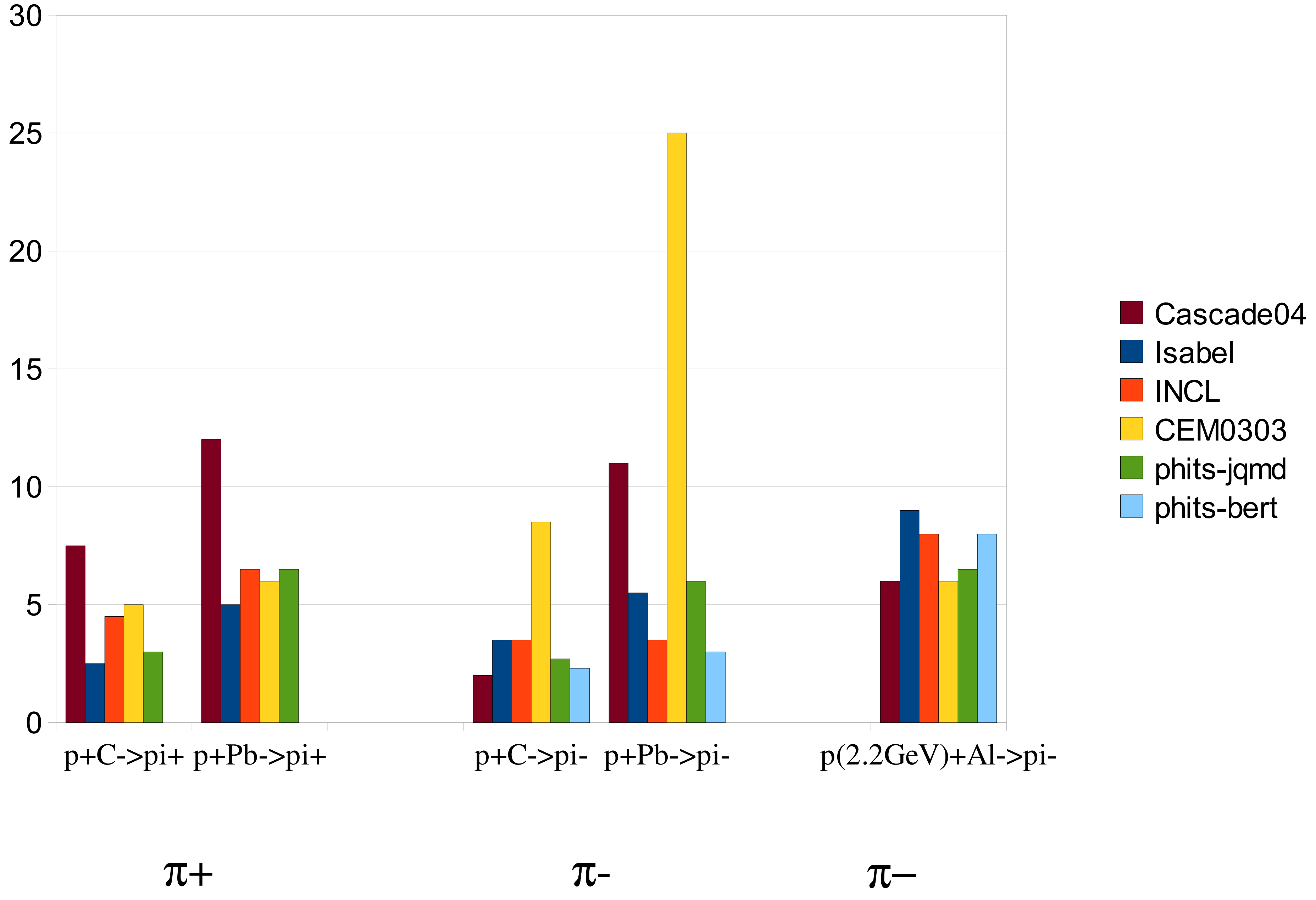
π⁻

General good agreement
Better than for positive pions
Good isospin and Coulomb effects

Underprediction at 2.2 GeV (multi pion production)



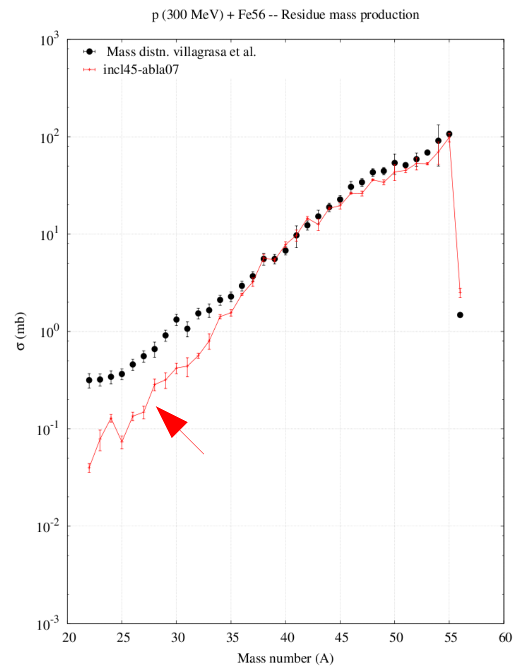
Average H-factors

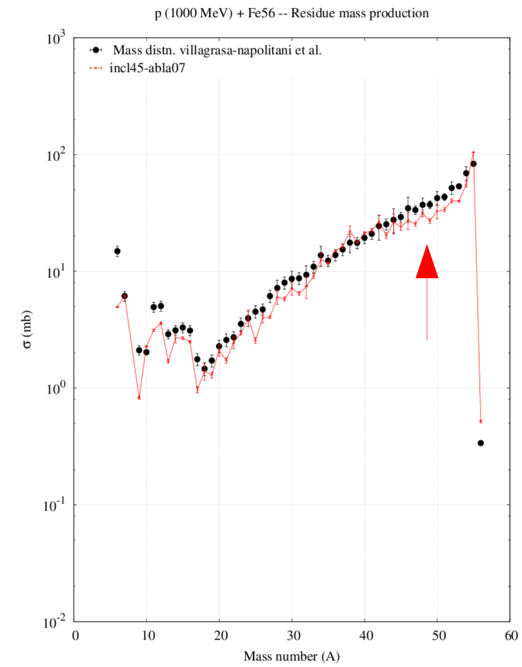


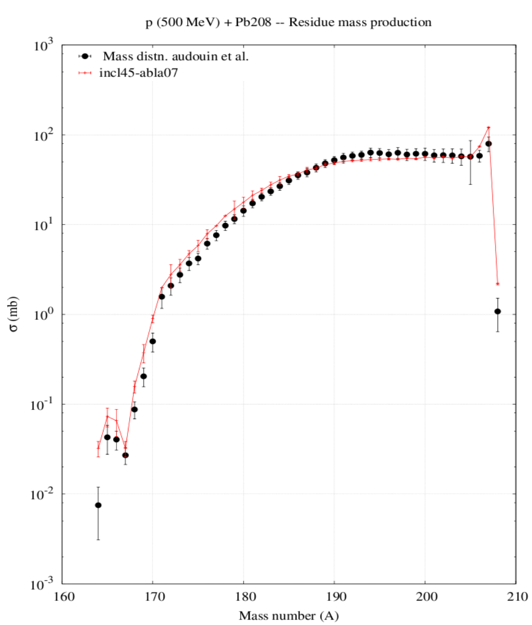
Residues

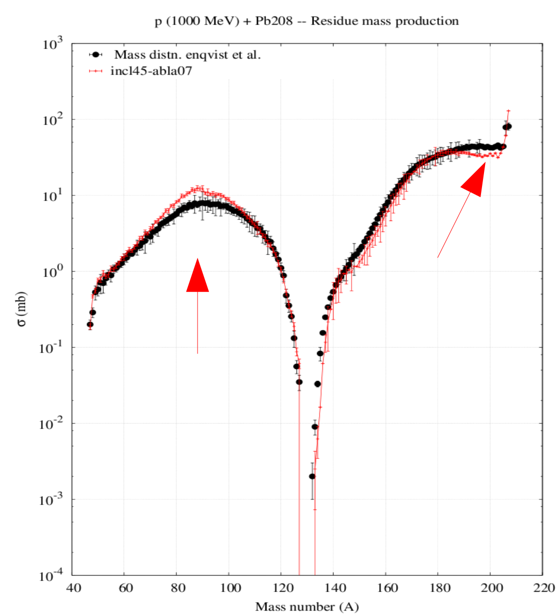
A-distributions

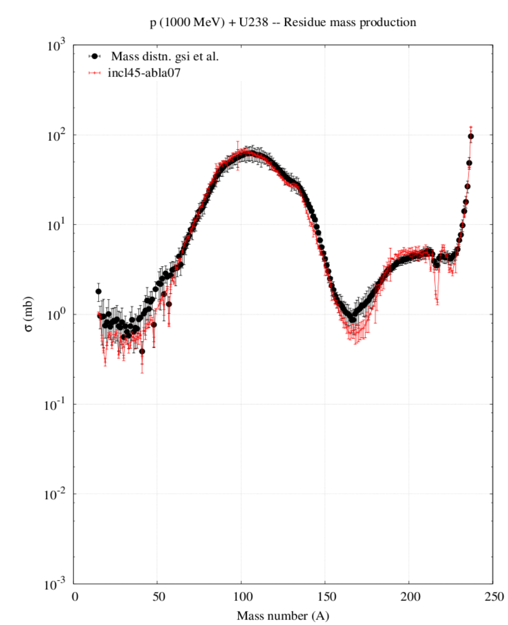
Overall good agreement
Also in details:
A_T-residues, IMF, odd-even effects, low-A end of ER,..





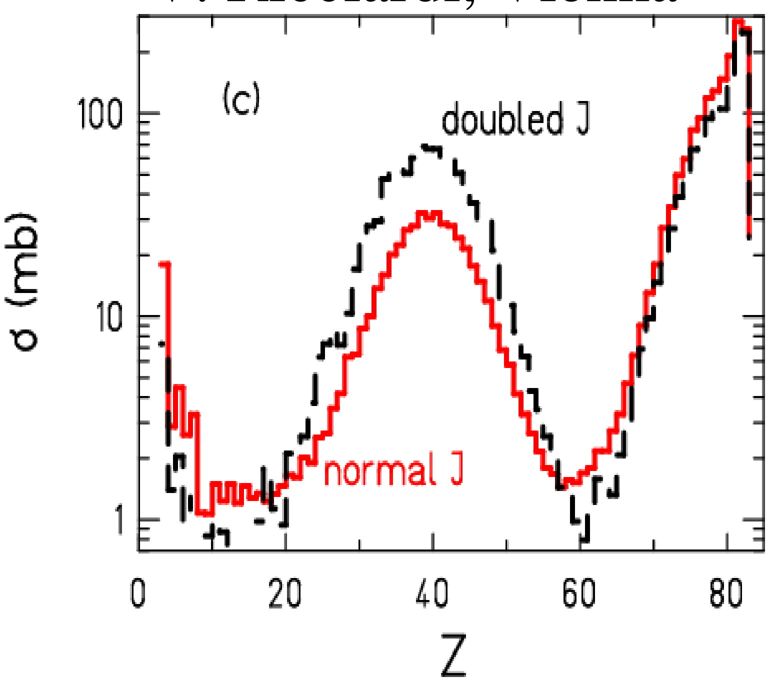


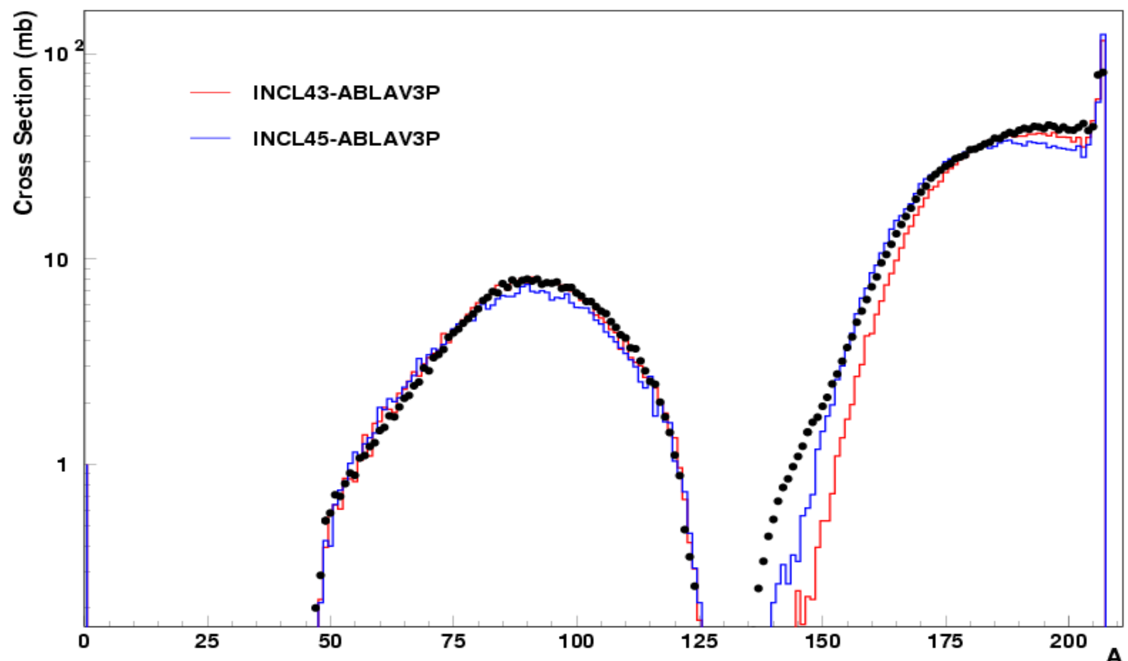




For this kind of observables, there is a definite (and limited) influence of the cascade stage

V. Ricciardi, Vienna





It is hard to identify the respective merits of INCL4.5 and ABLA07:
A deficiency of one may be compensated by an opposite deficiency of the other

Low mass end of ER (in Pb @1GeV):

-more large E* events in INCL4.5 ← composite, V(E), V(pion), ?

-emission of IMF in ABLA07

NB: 1. reconciled with results at 500 MeV

2. still not satisfactory @300 MeV

High mass end of ER (in Fe, Pb @1 GeV)

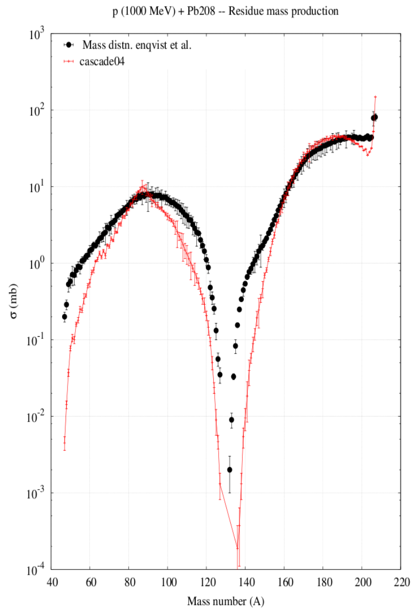
-too few events with small E* ← 1collision, either X-sections or INCL model

- not the case at lower energy and for U

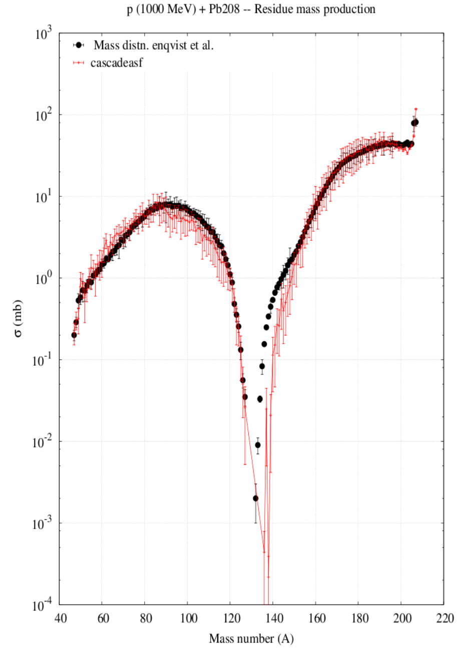
Fission: too high (1.5) for Pb @ 1GeV

Either E* or x distributions of INCL4.5,

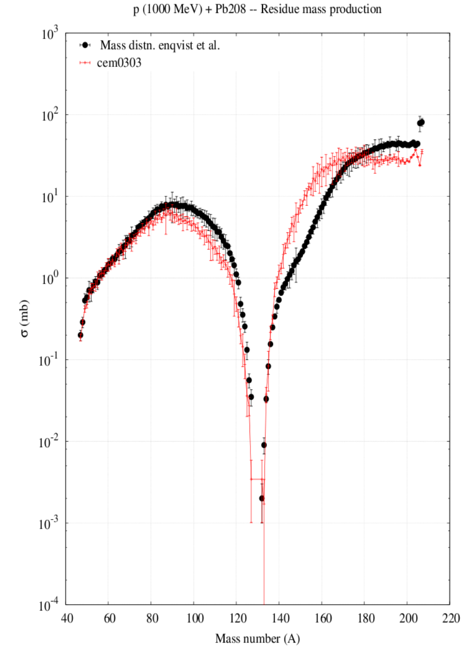
Or fission model of ABLA (fission yield depends on many parameters) casc04



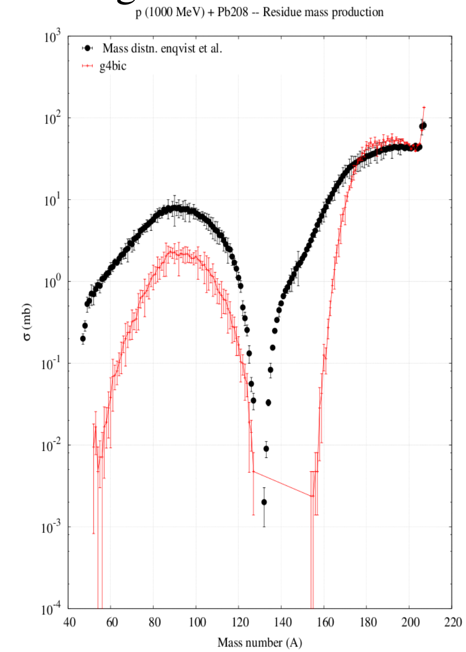
casc-asf



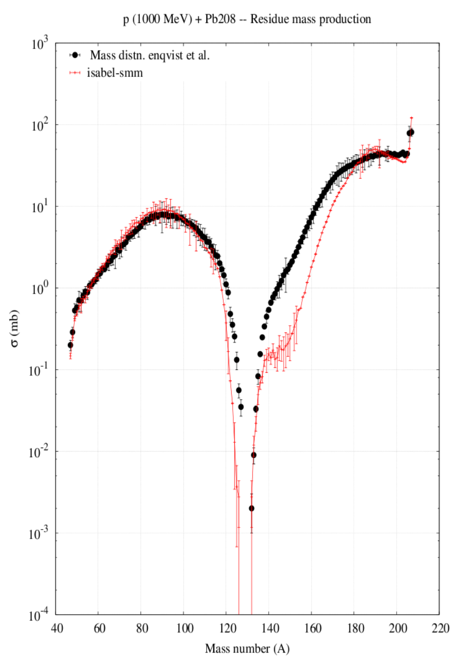
cem0303



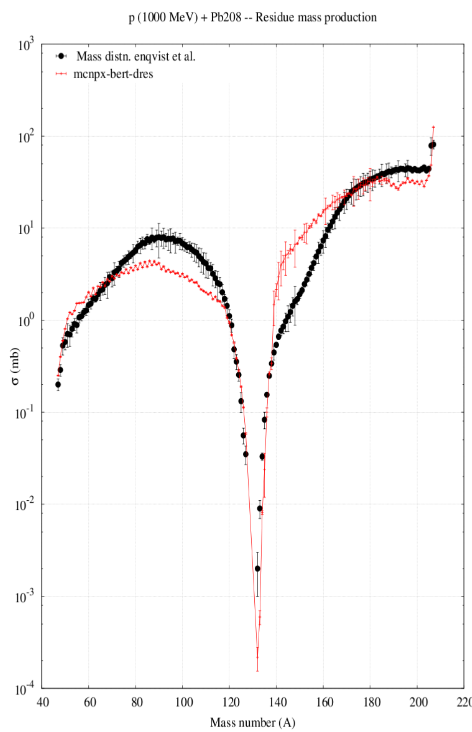
g4-BIC



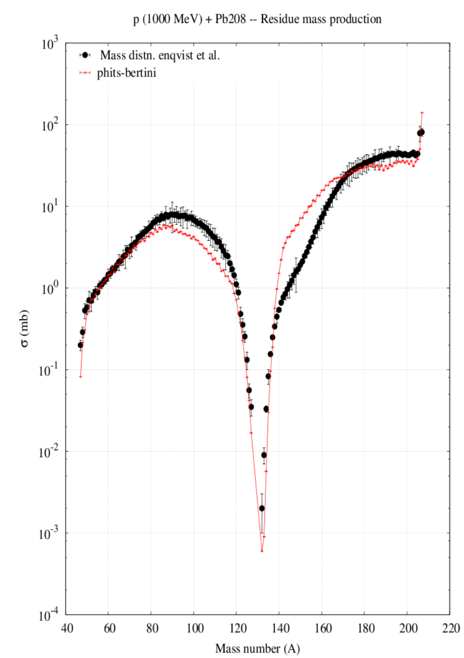
Isabel-SMM



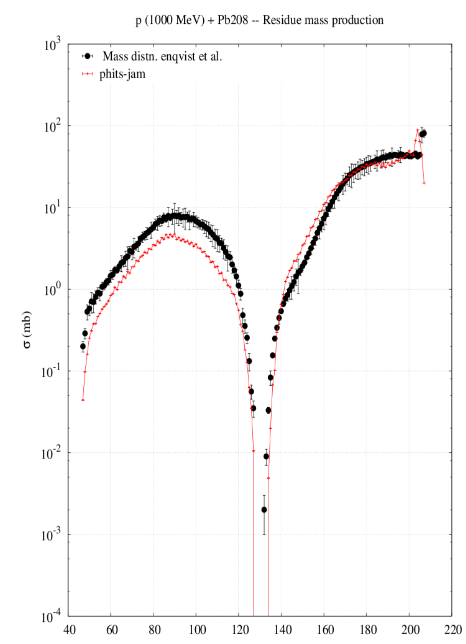
MCNPX-Bert



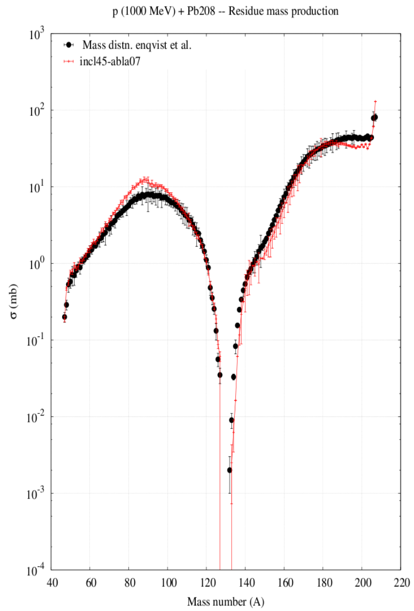
PHITS-BERT



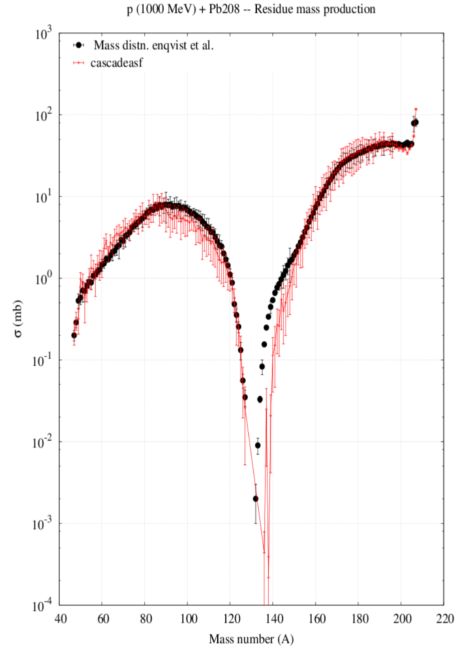
PHITS-jam



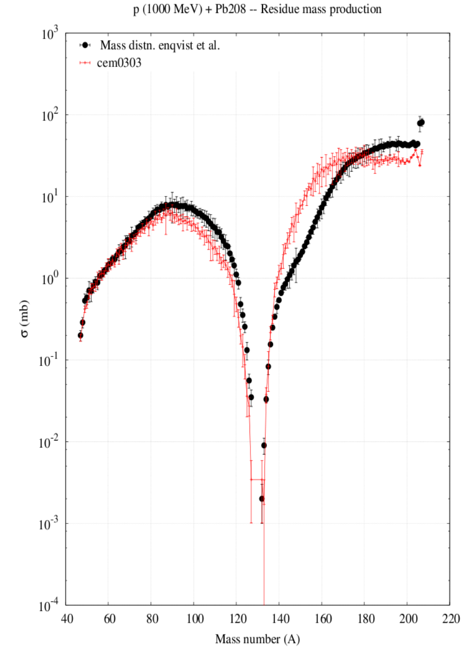
INCL-ABLA



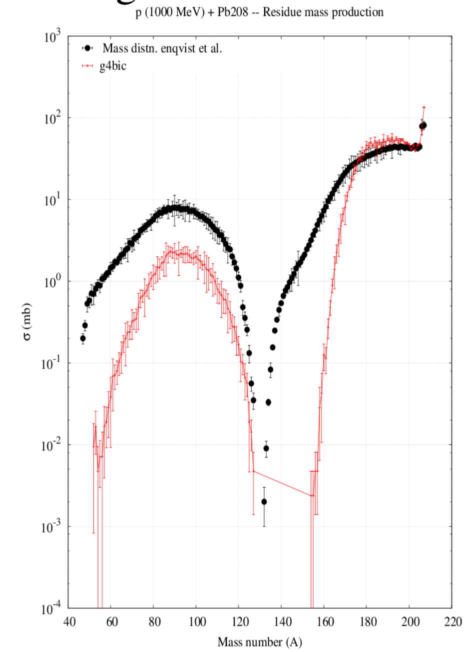
casc-asf



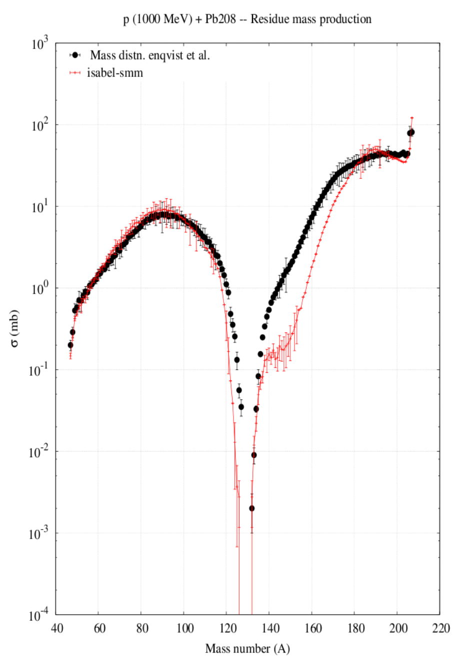
cem0303



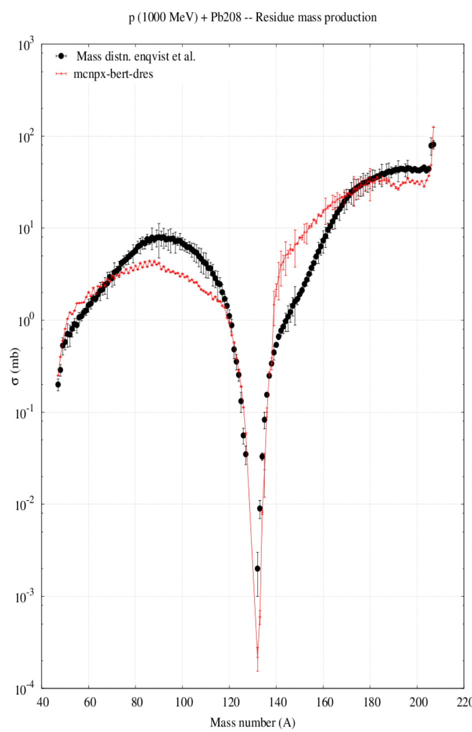
g4-BIC



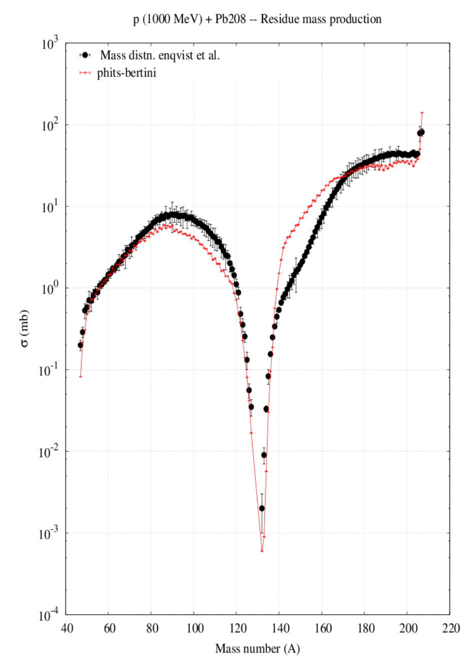
Isabel-SMM



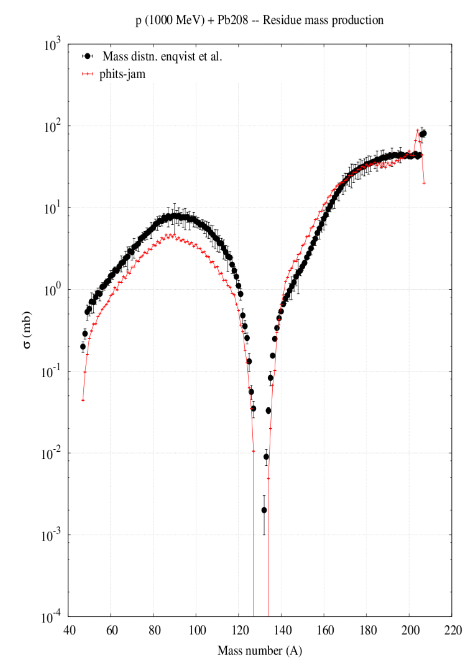
MCNPX-Bert



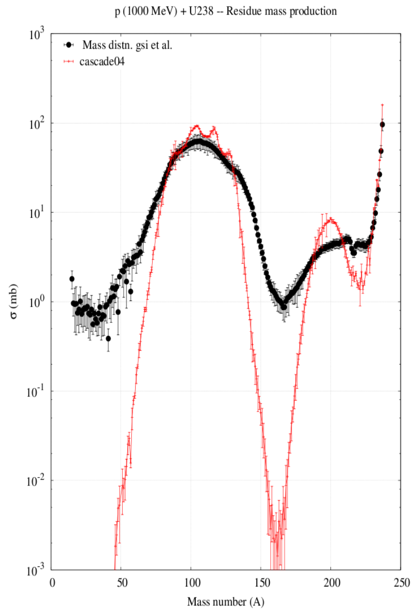
PHITS-BERT



PHITS-jam



casc04



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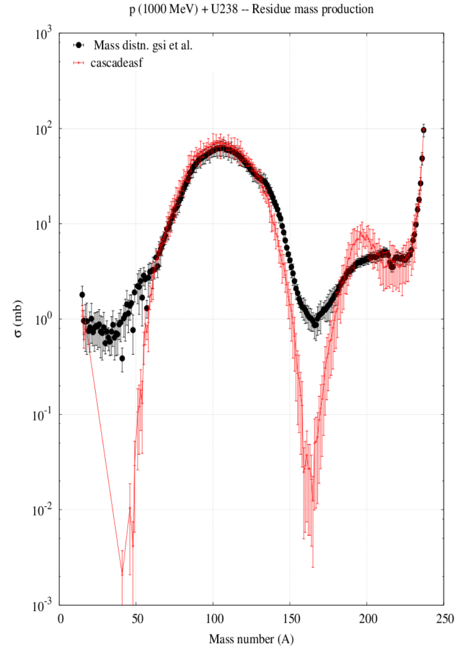

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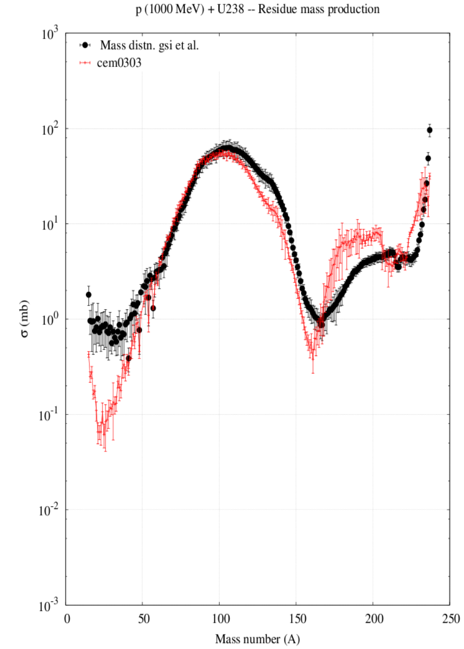

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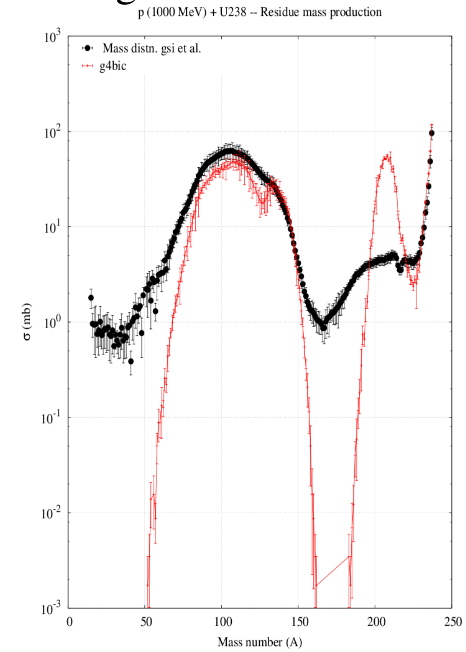
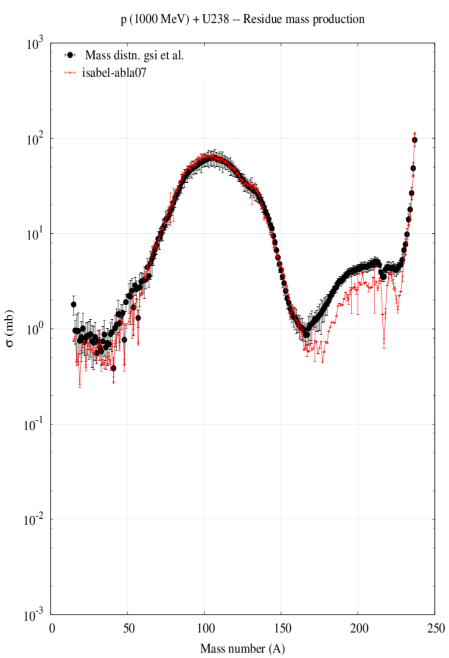
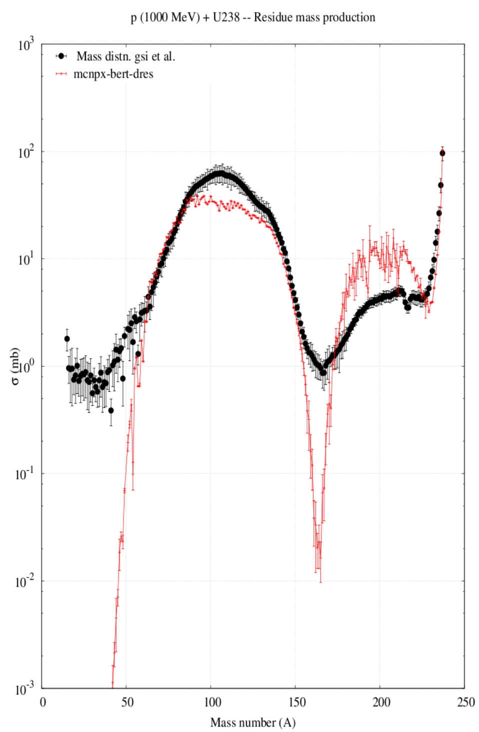


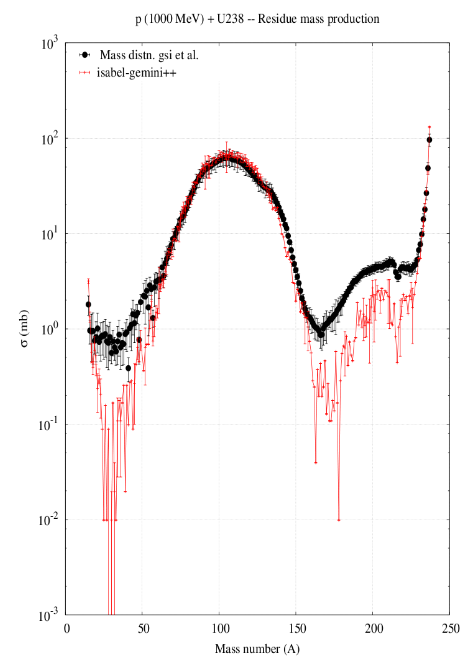
Isabel-ABLA



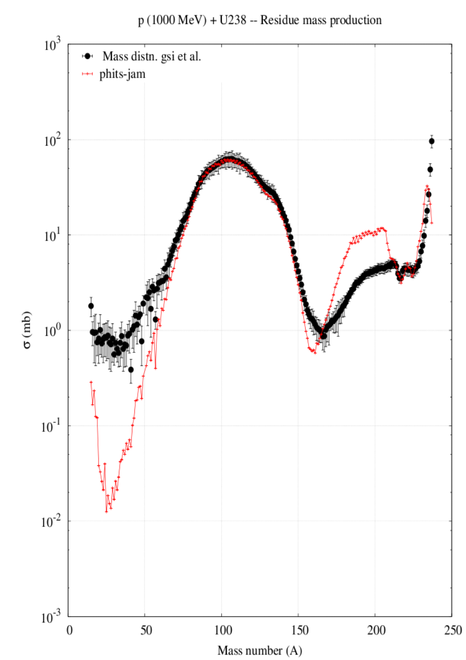
MCNPX-Bert



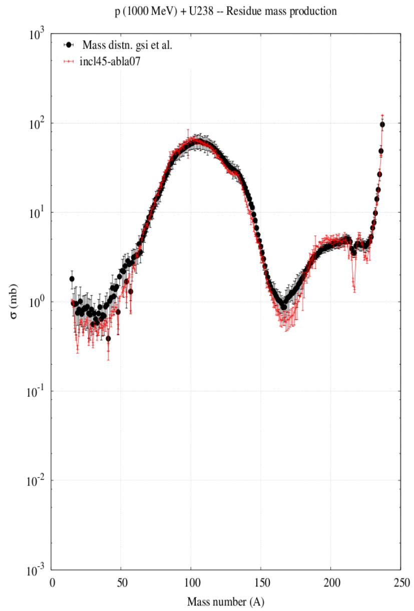
PHITS-BERT



PHITS-jam



INCL-ABLA



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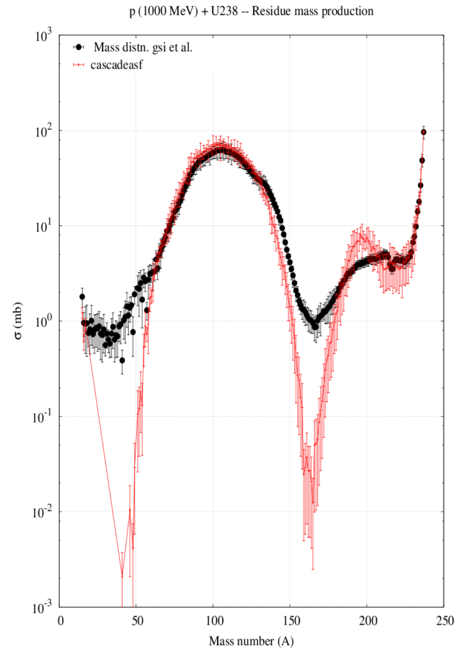
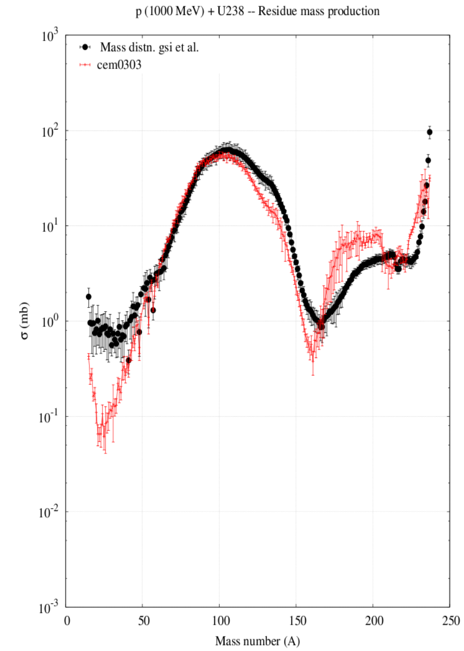
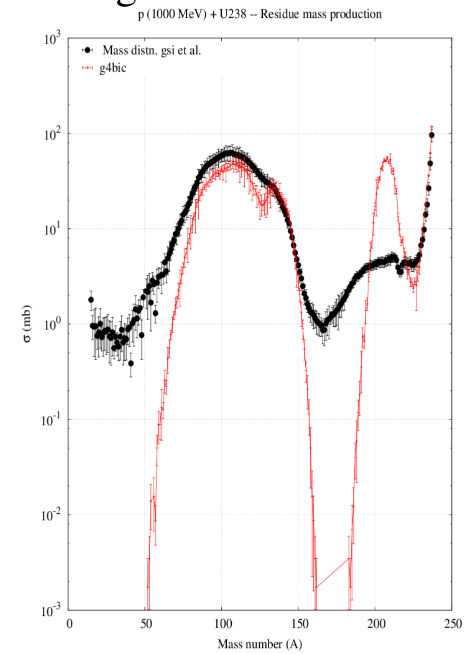


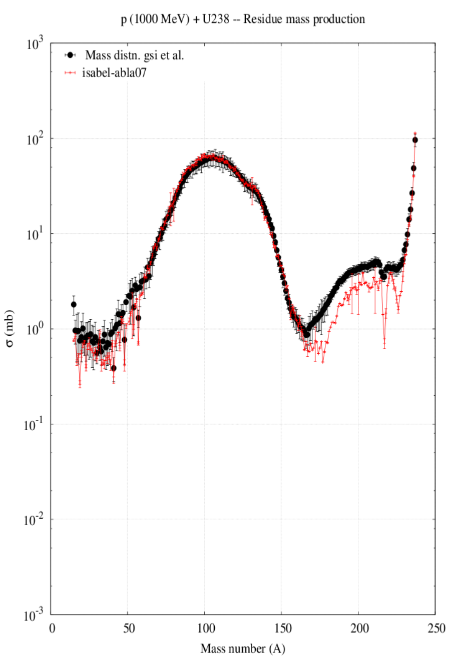
cem0303



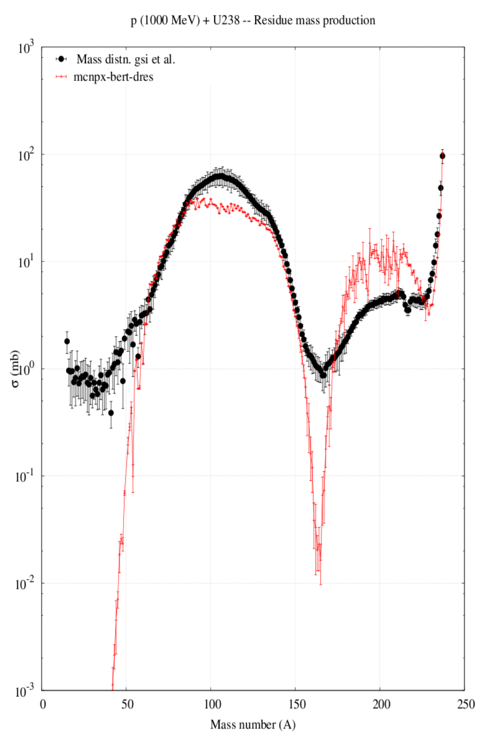
g4-BIC



Isabel-ABLA



MCNPX-Bert



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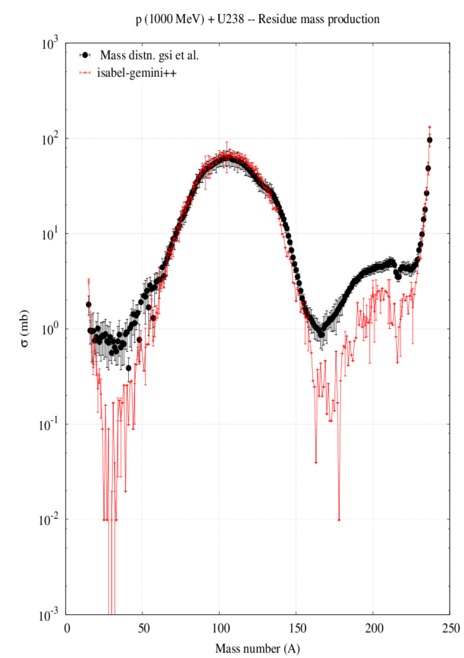
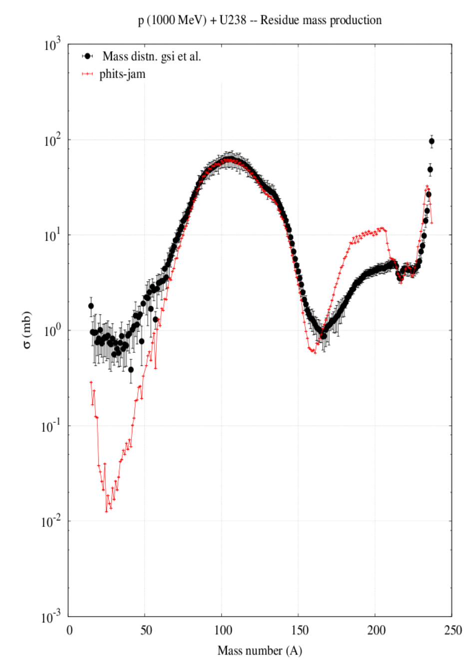
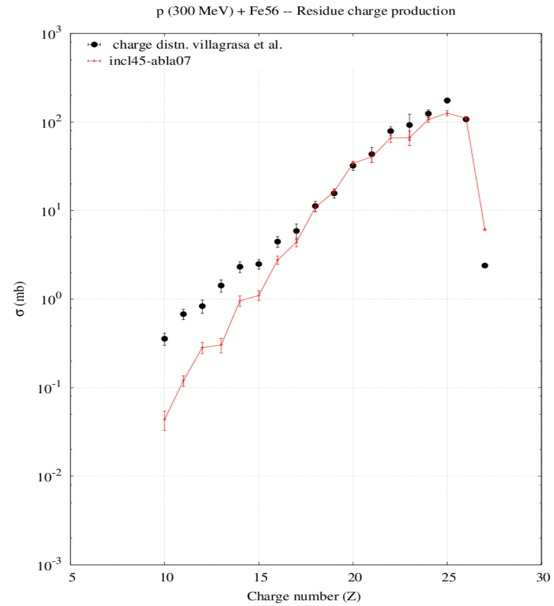


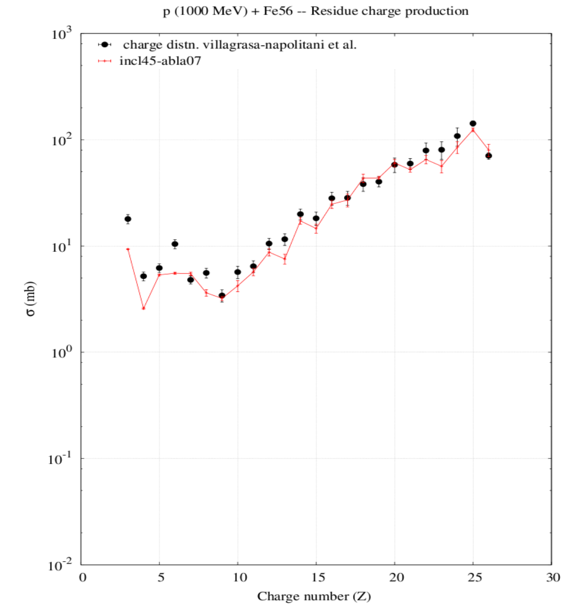
PHITS-jam

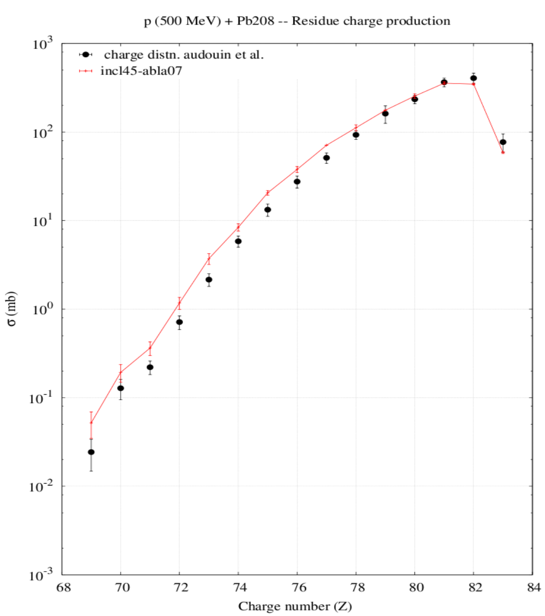


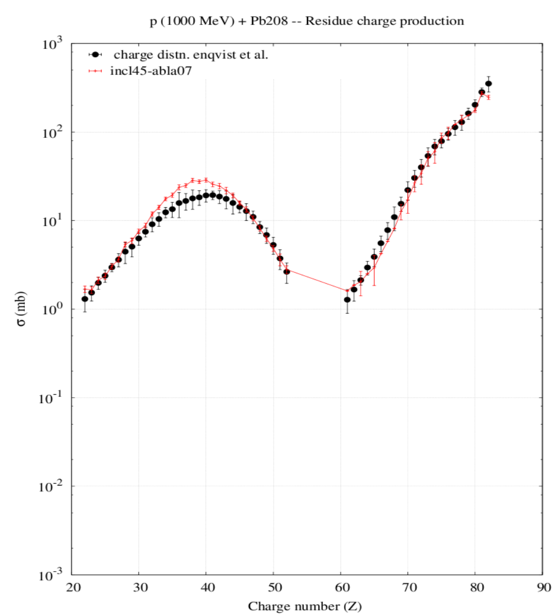
Z-distributions

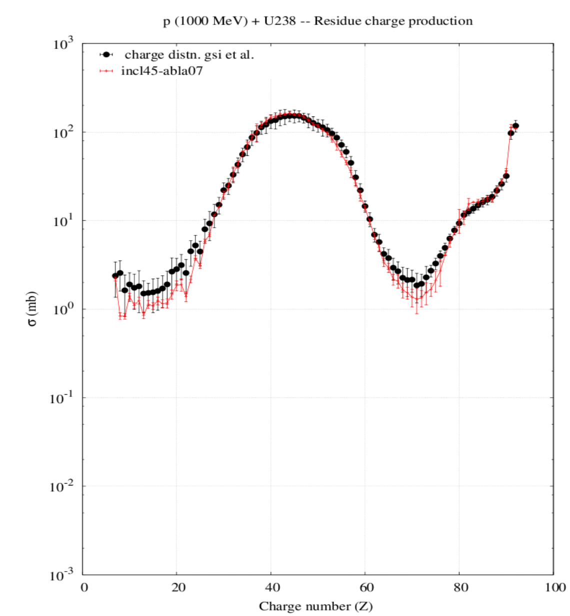
Same conclusions







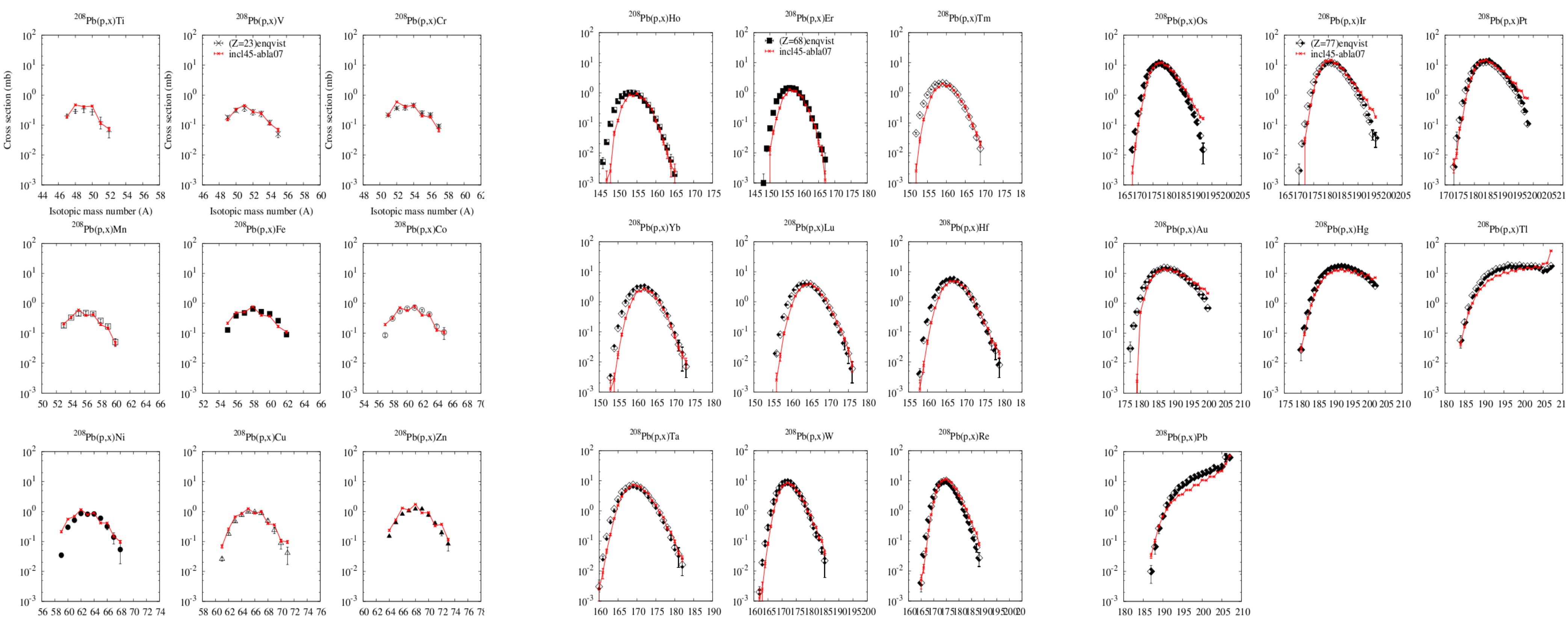




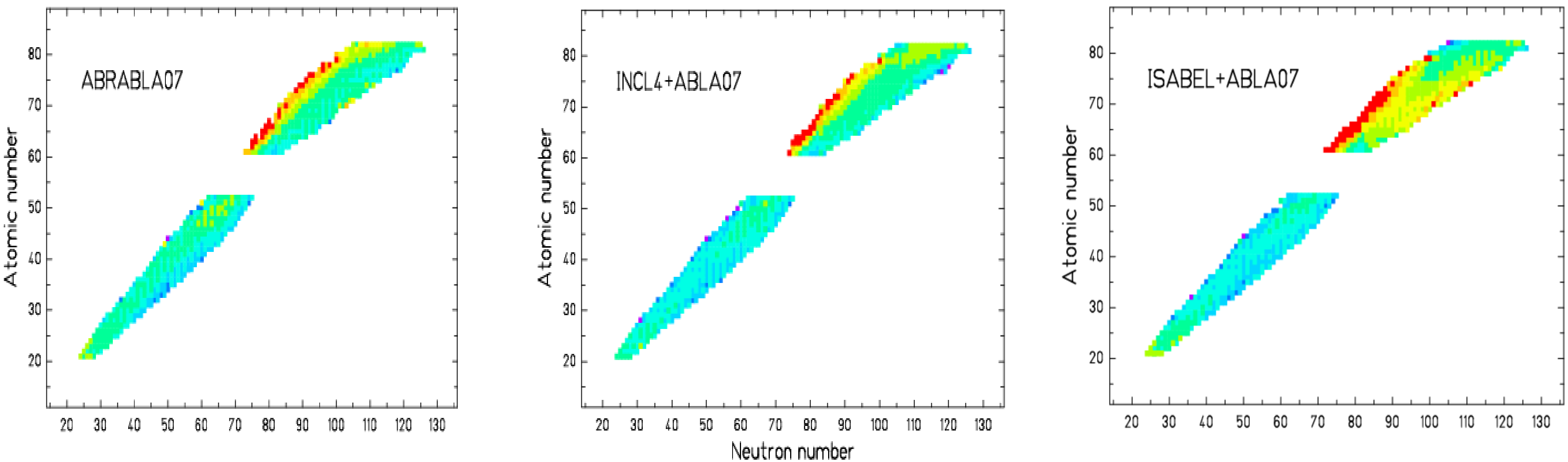
Isotopic distributions

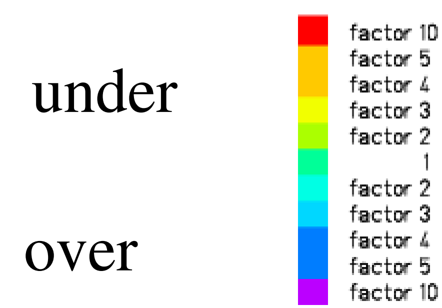
Shift in the middle of the ER peak toward n-rich side
Pb and Tl distributions are depleted

Too many protons are emitted in the cascade and/or evaporation



p(1GeV)+Pb

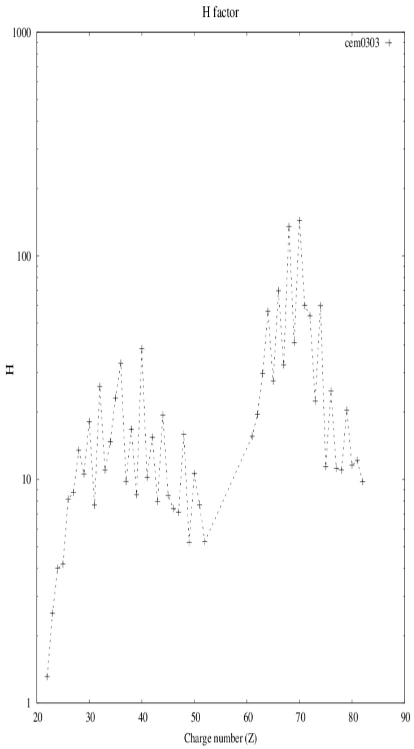


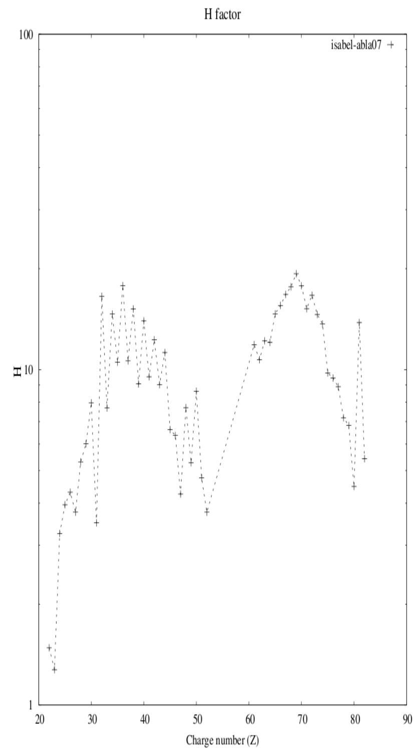


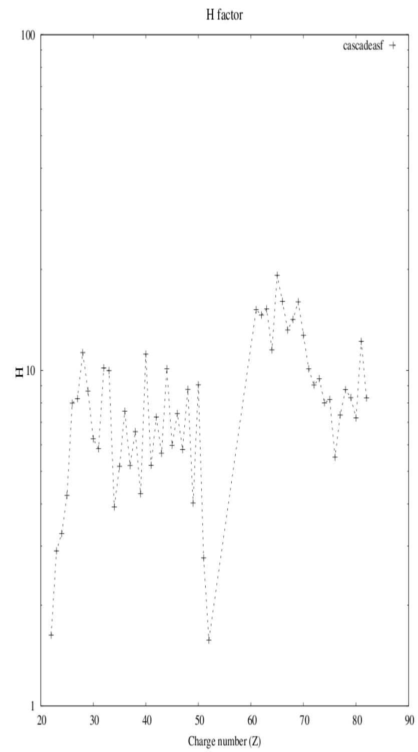
V. Ricciardi, Vienna

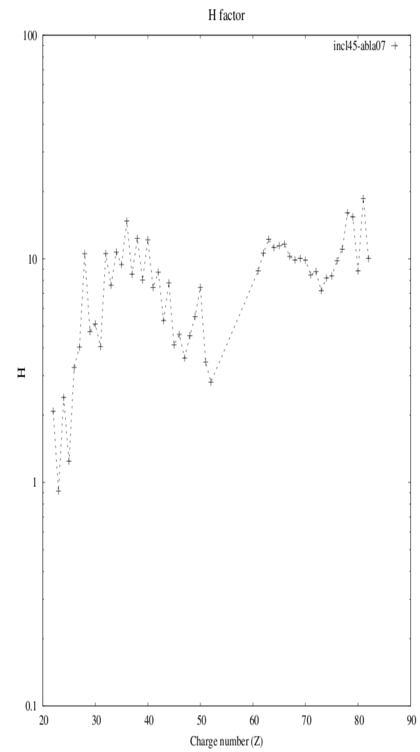
p (1GeV) + Pb

H-factor





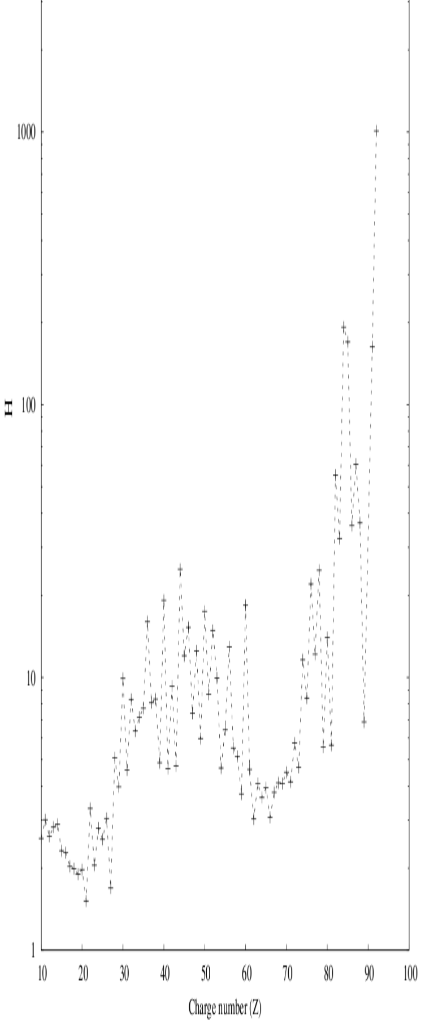




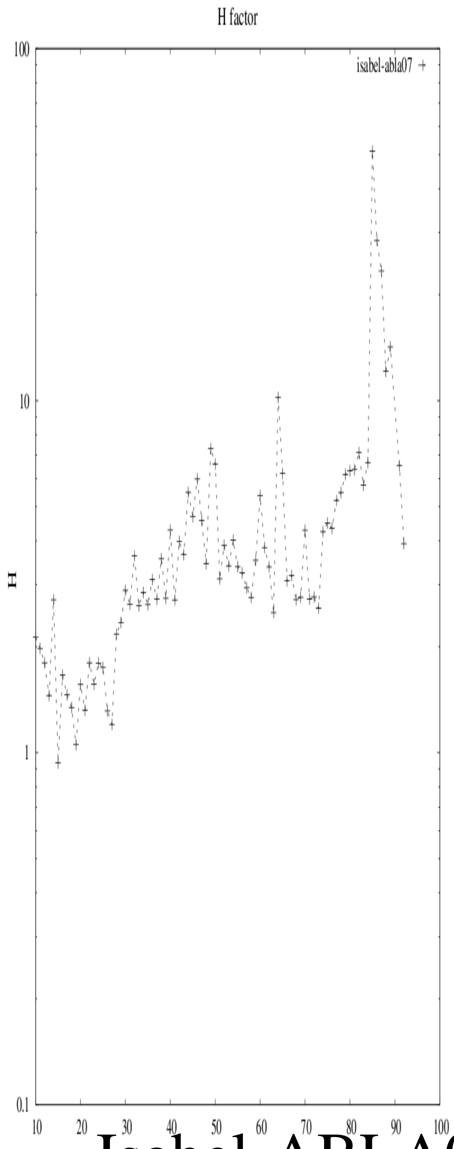
CEM0303 Isabel-ABLA07 Cascade-asf INCL4.5-ABLA07

H-factor

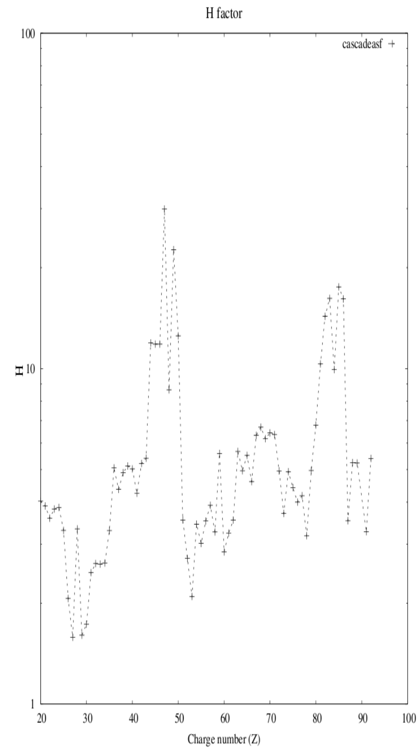
p (1GeV) + U



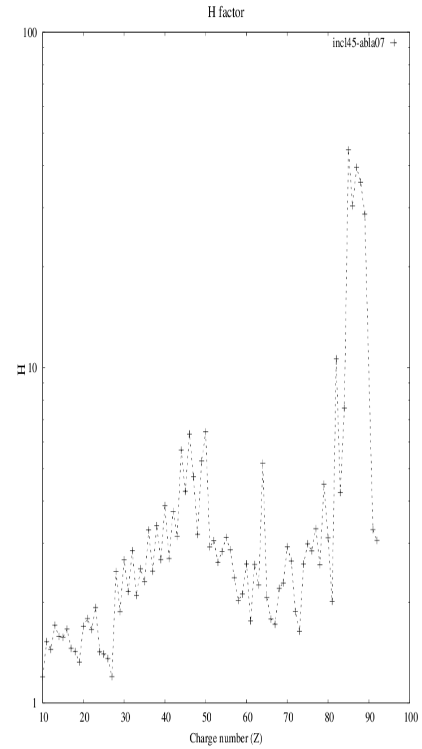
CEM0303



Isabel-ABLA07

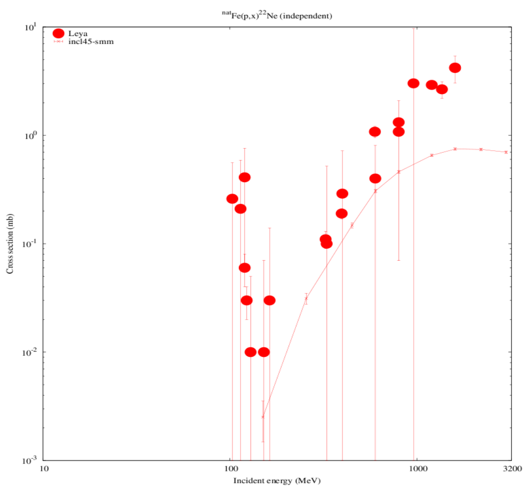


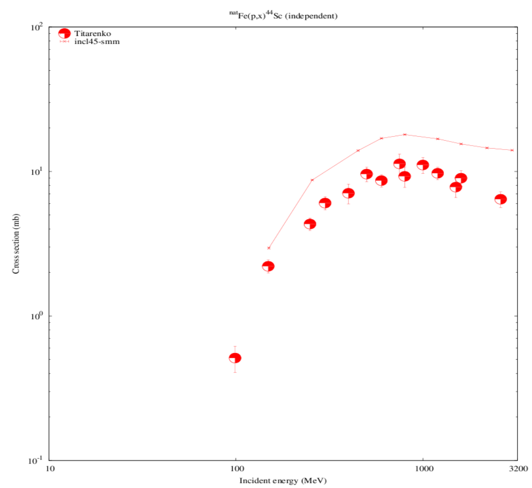
Cascade-asf

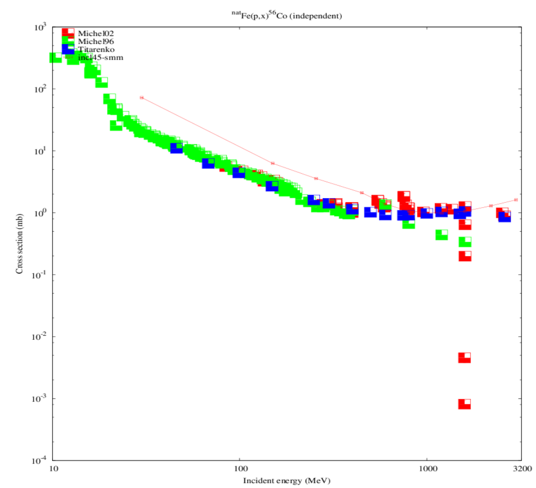


INCL4.5-ABLA07

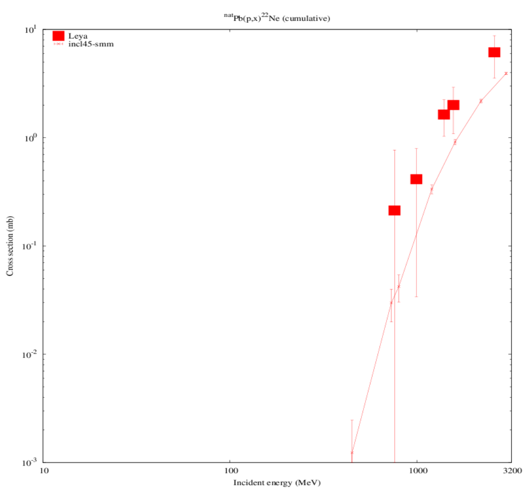
Excitation functions

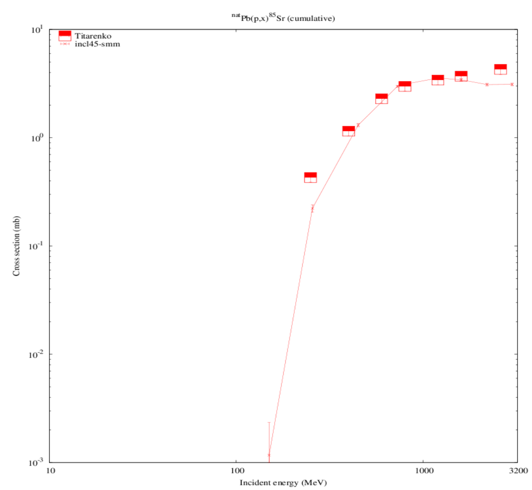


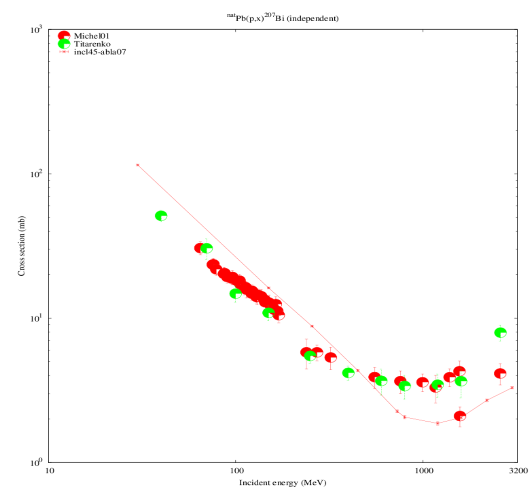




p+^{nat} Fe



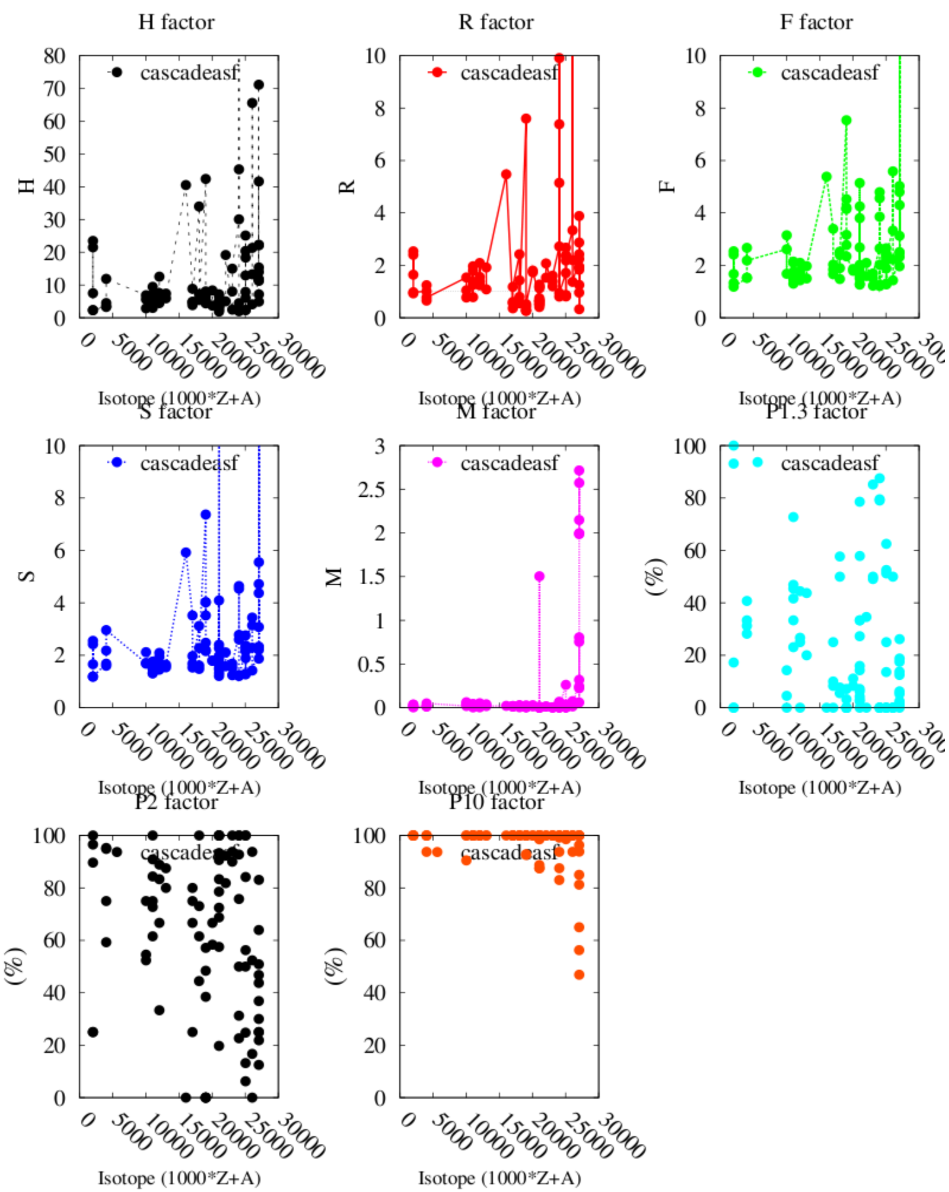




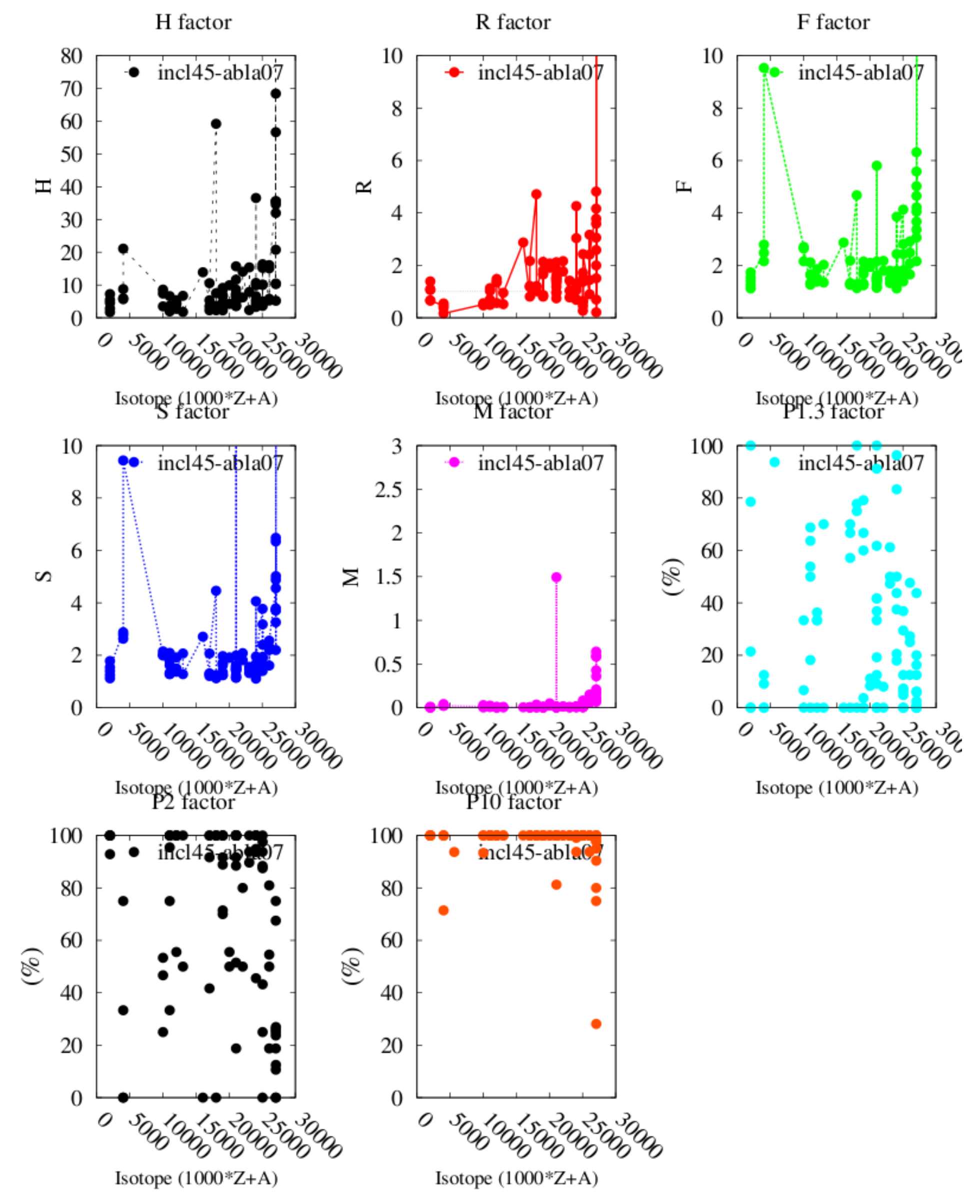
p+^{nat} Pb

Fe

cascade-asf

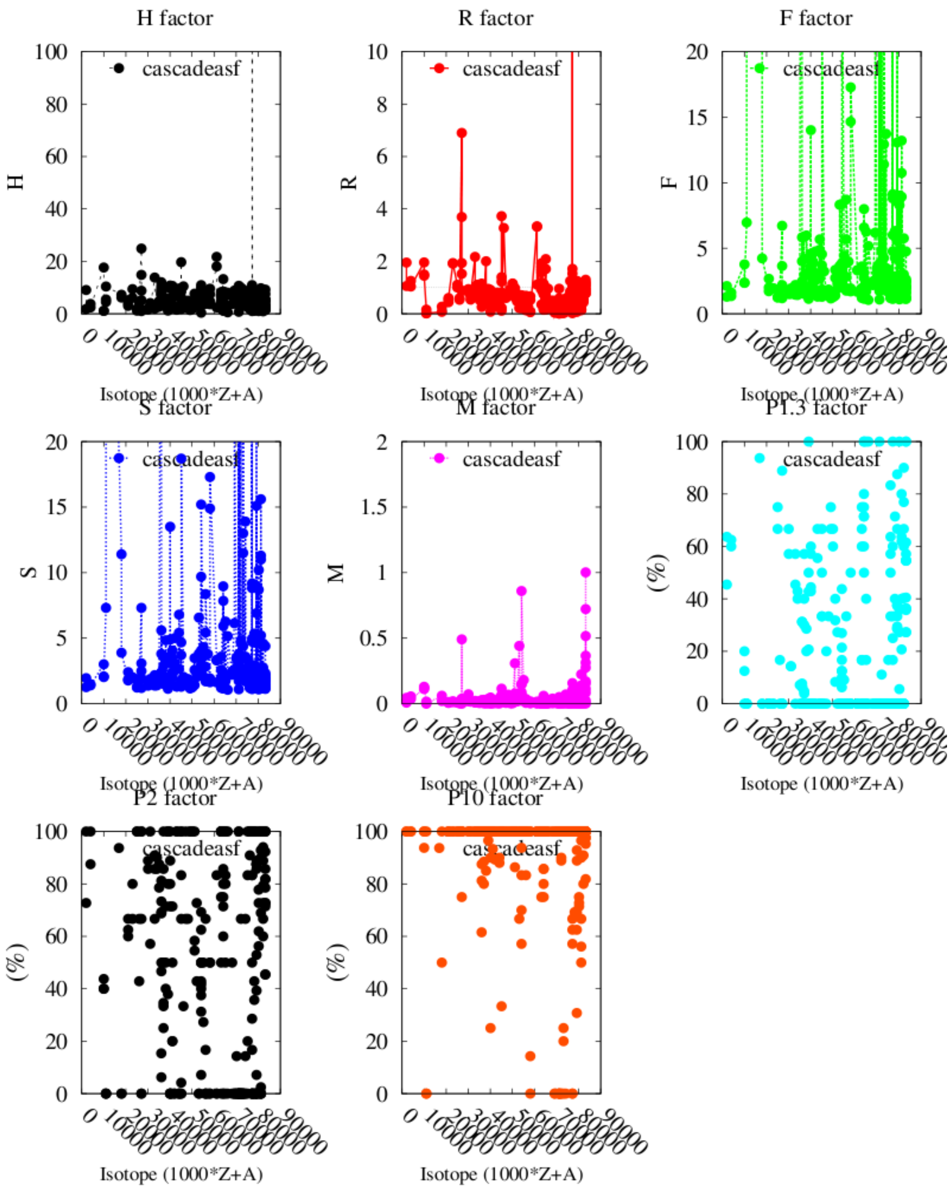


INCL4.5-ABLA07

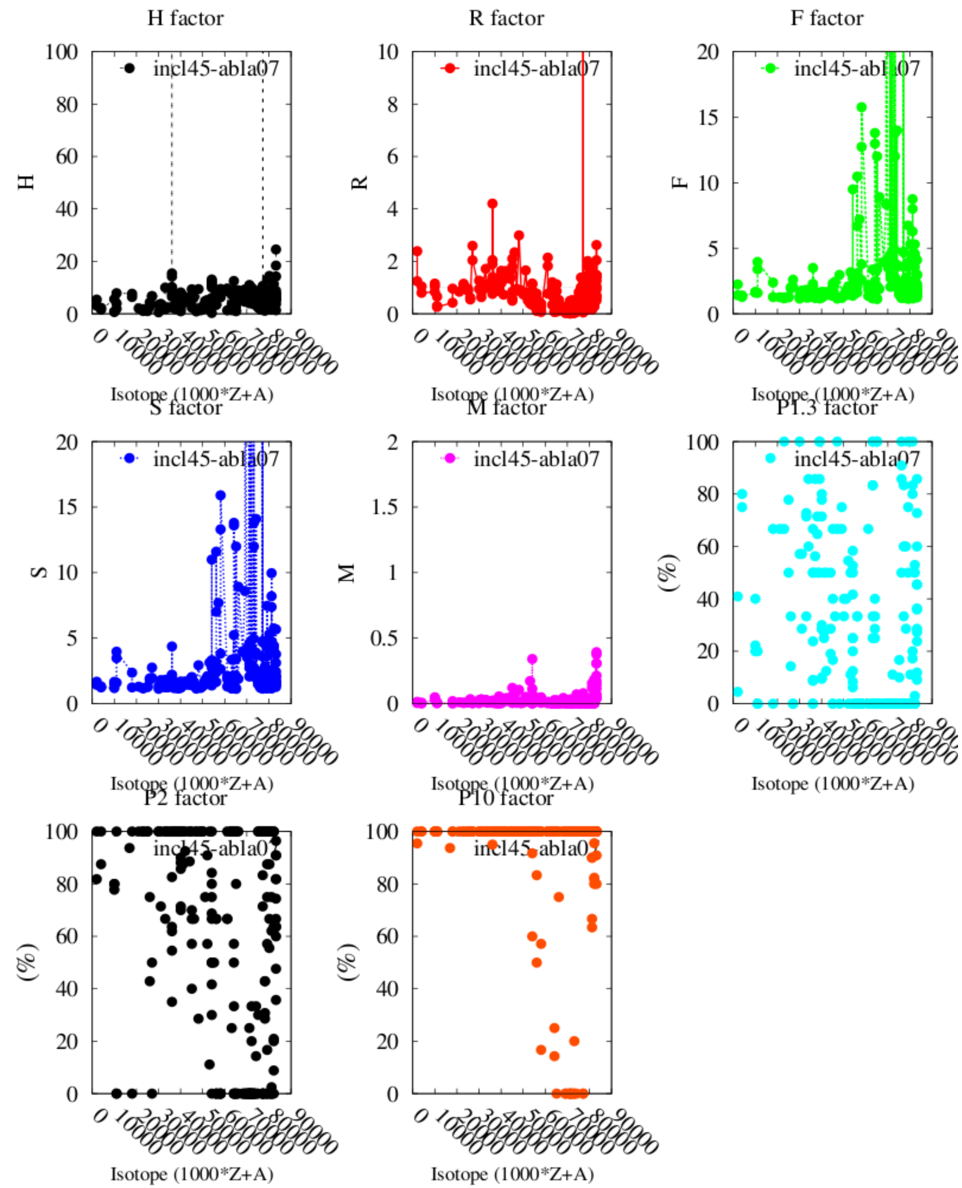


Pb

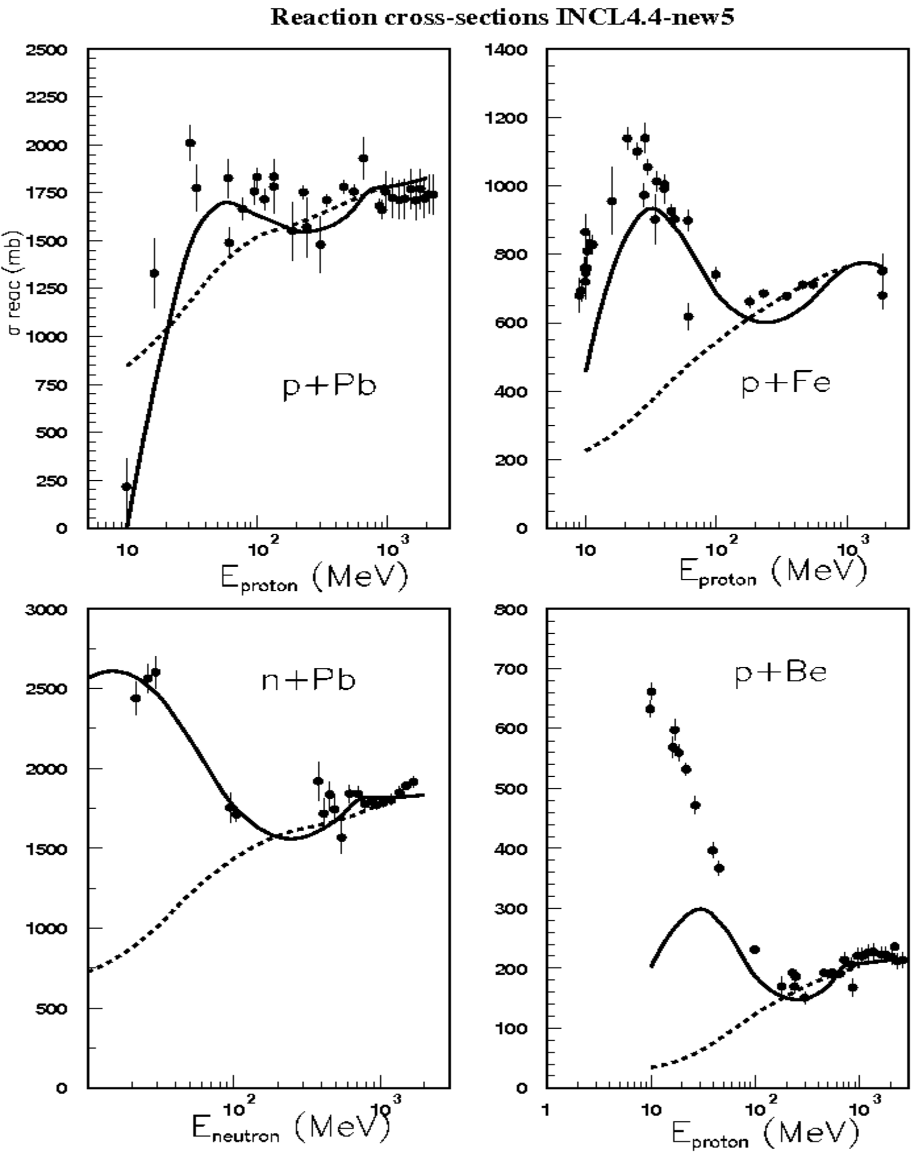
cascade-asf



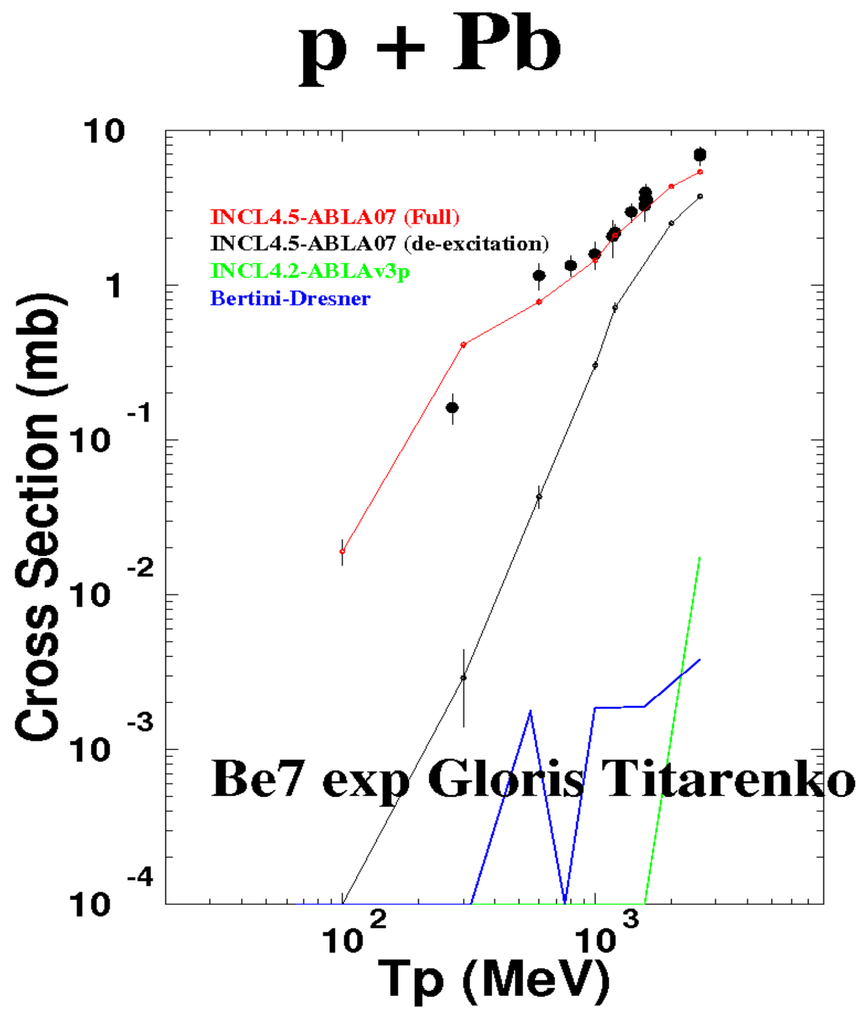
INCL4.5-ABLA07



Plus



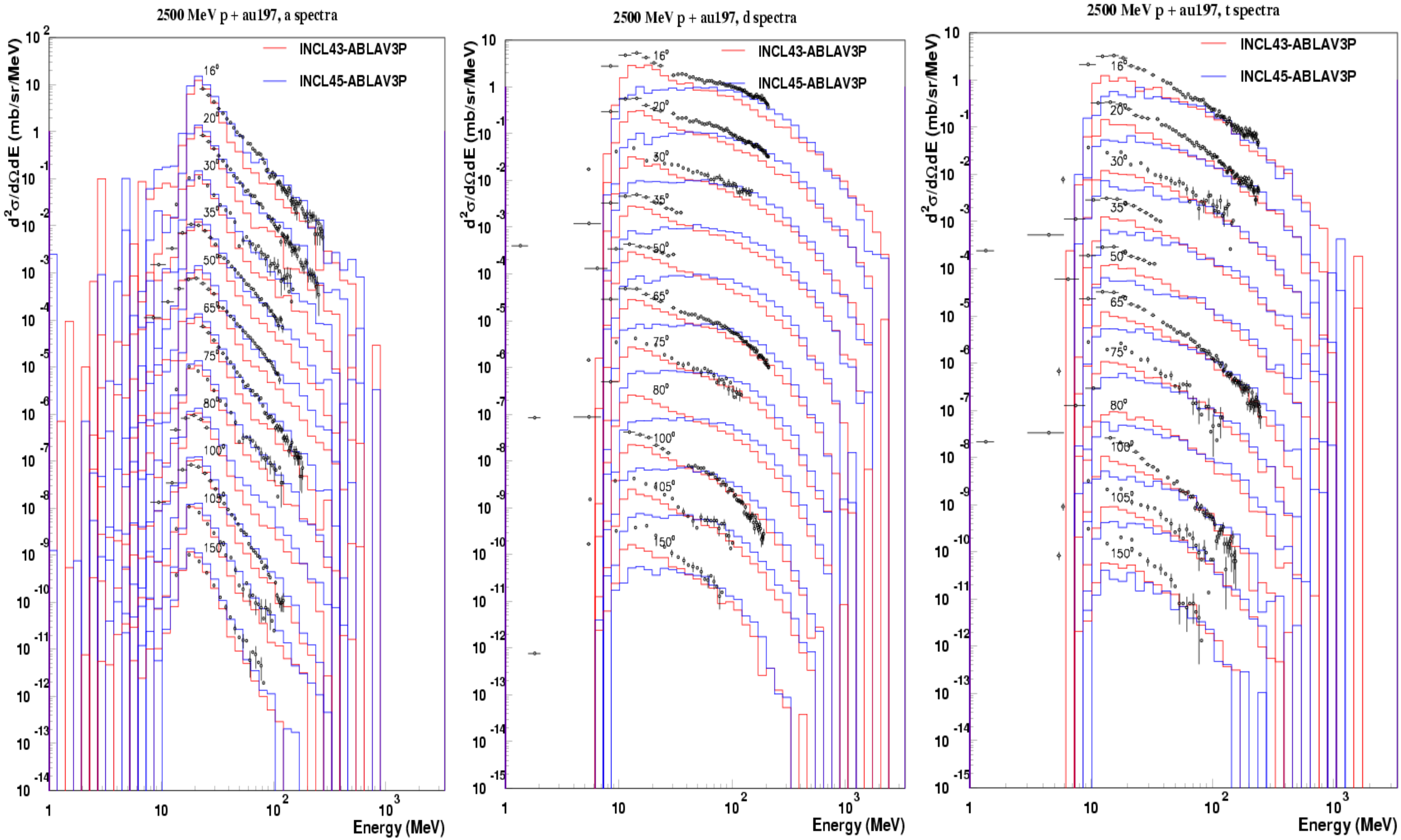
Reaction cross-sections INCL4.4-new5
σ reac (mb)
p+Pb
p+Fe
n+Pb
p+Be
E proton (MeV)
E neutron (MeV)



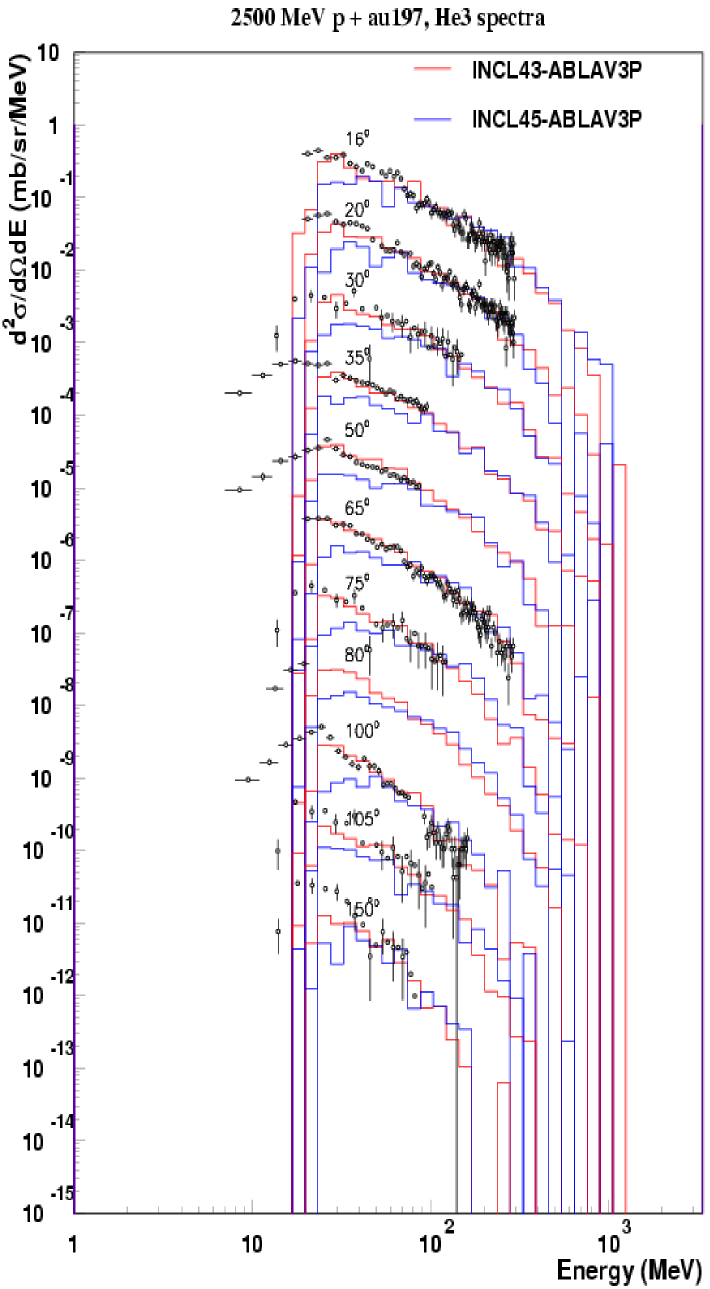
p + Pb
INCL4.5-ABLA07 (Full)
INCL4.5-ABLA07 (de-excitation)
INCL4.2-ABLAv3p
Bertini-Dresner
Be7 exp Gloris Titarenko
Cross Section (mb)
Tp (MeV)

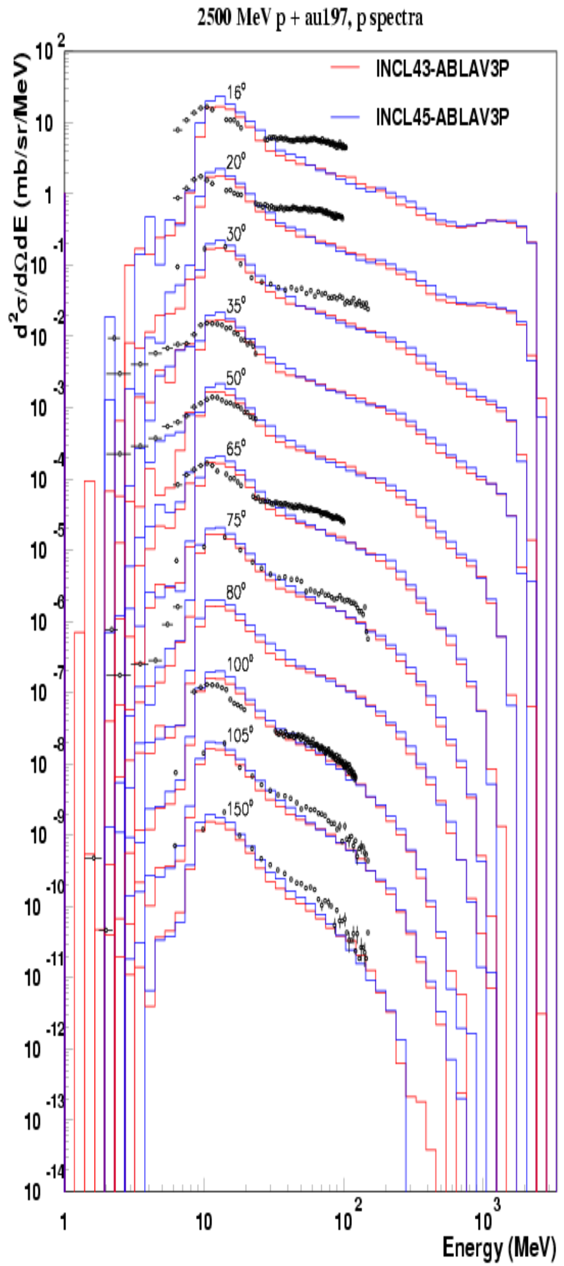
4. Conclusion

- *INCL4.5 generates good (and consistent) results*
- *Improves significantly over INCL4.2 (thanks to EUROTRANS)*
- *On: composites, pions, neutron multiplicities, excitation functions,..*
- *But not on: neutron spectra, residues (close to the remnant),...*
- *See the experts for evaluation*



p(2.5 GeV) + ^{197}Au

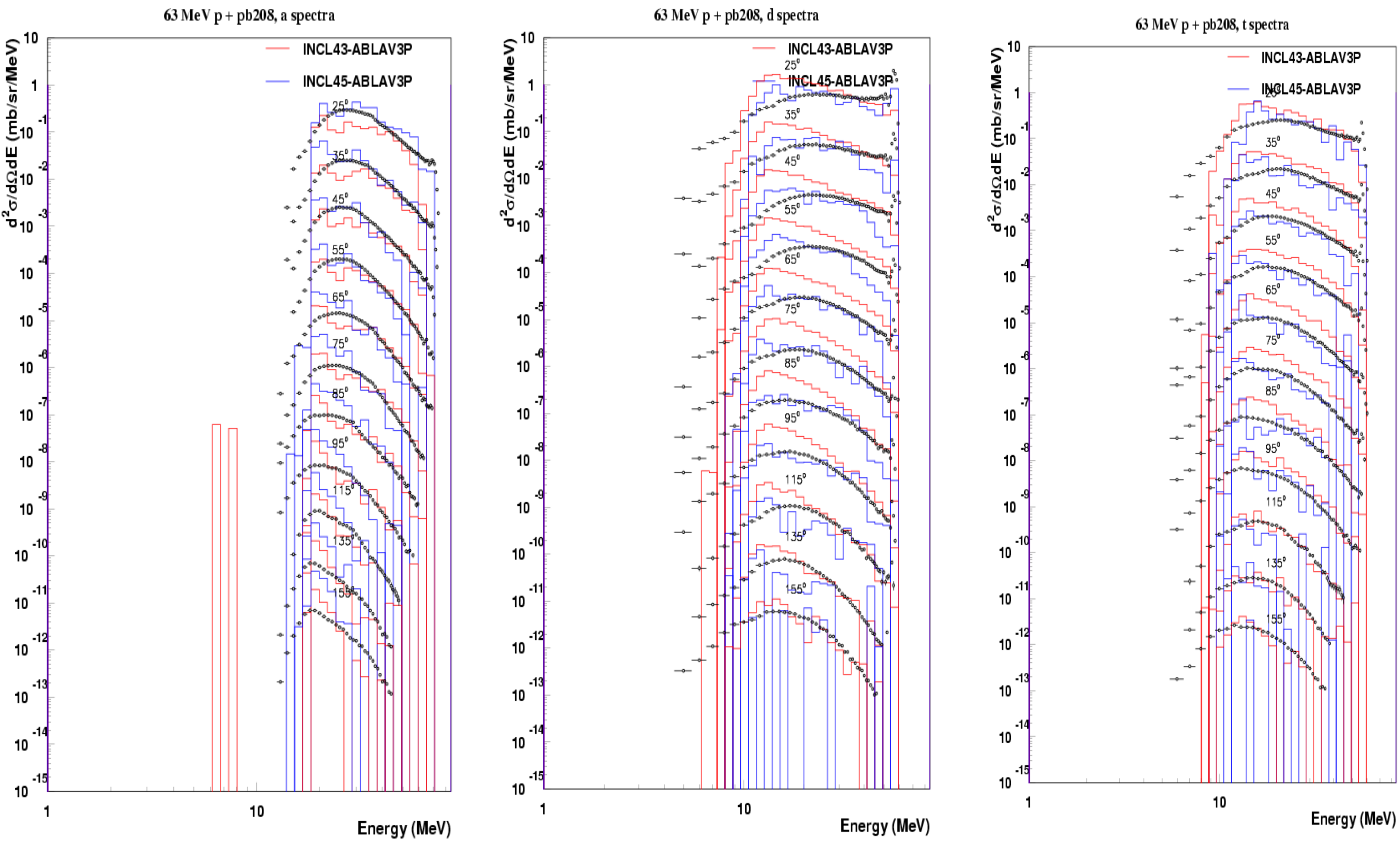




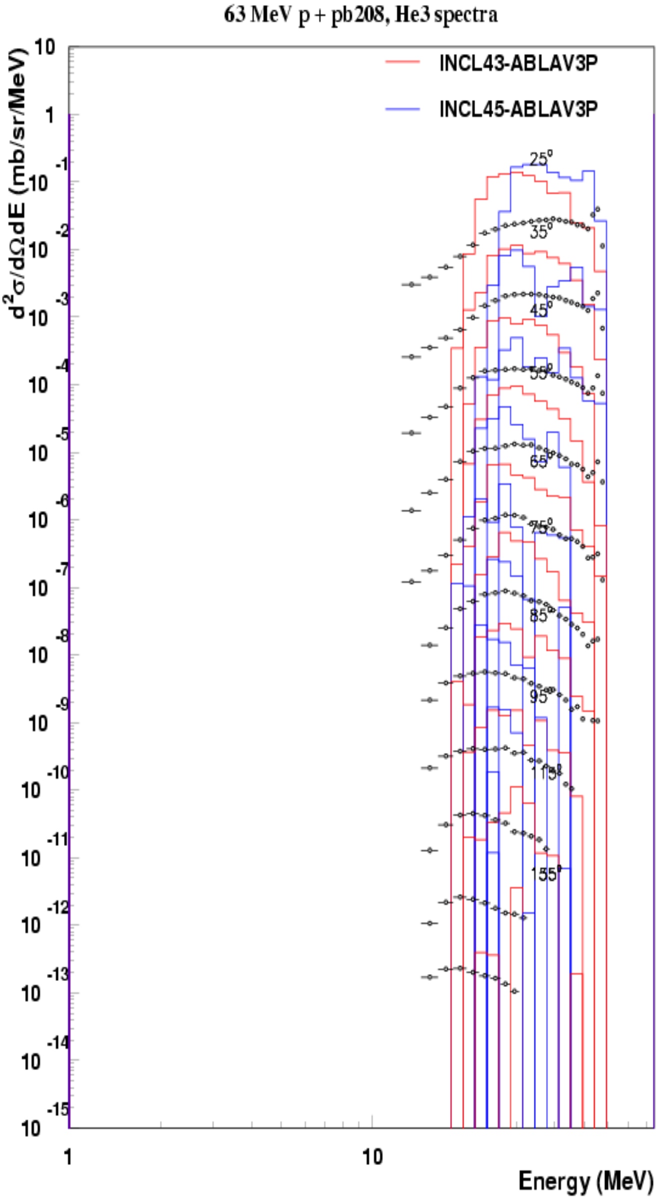
INCL4.5 is slightly better

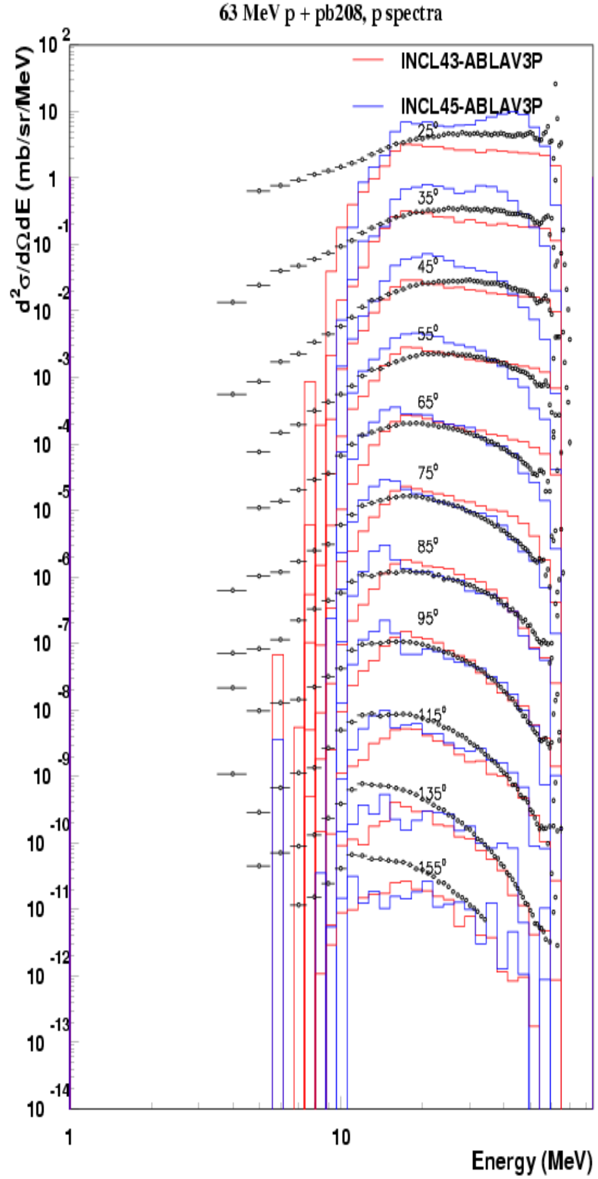
p underestimated

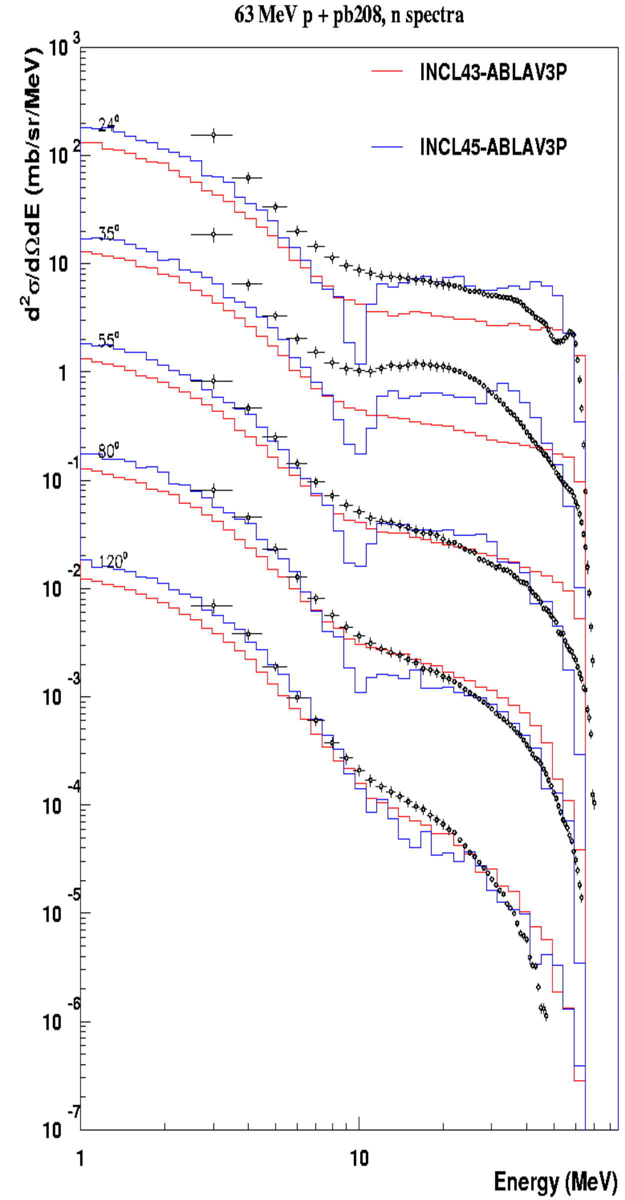
Similar results for p(1.2 GeV) on ^{197}Au and ^{181}Ta



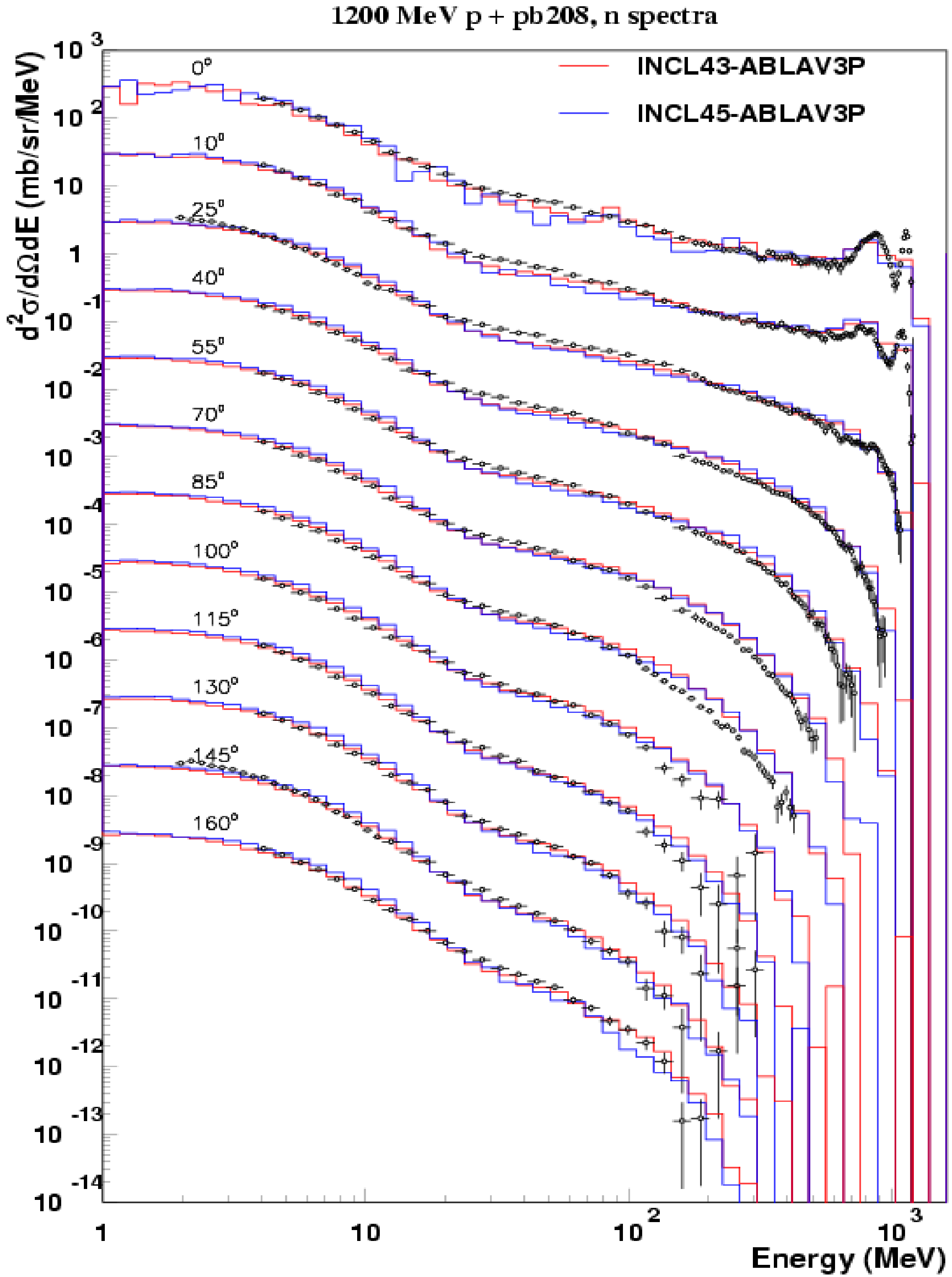
p (63 MeV) + ^{208} Pb



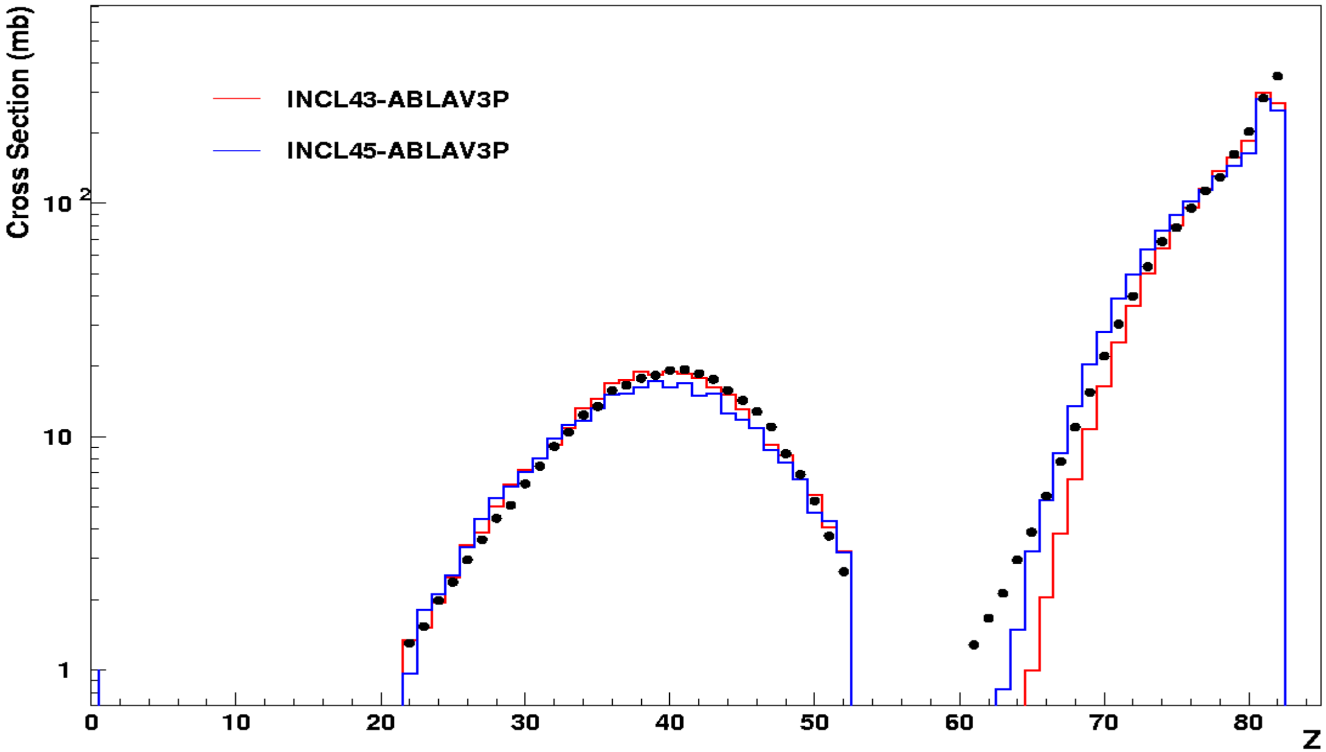


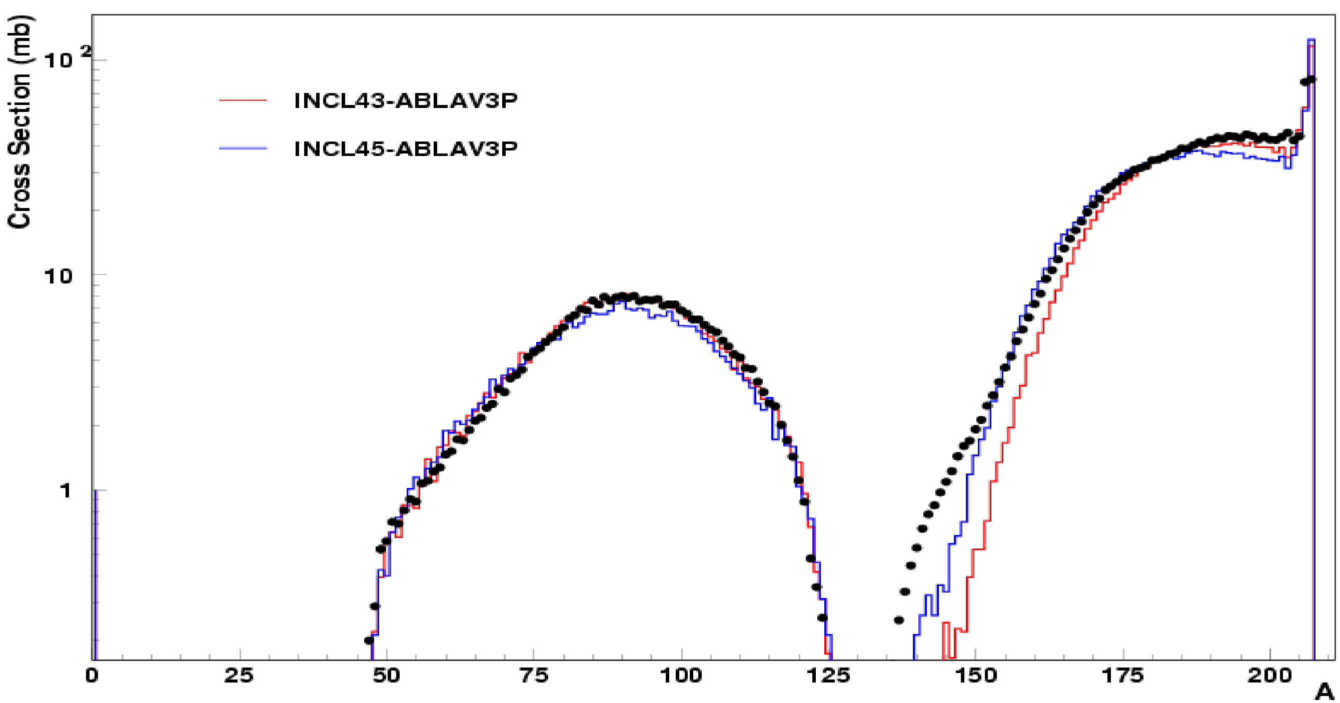


Conclusion (on composites): satisfactory results, except on p @HE and n @LE

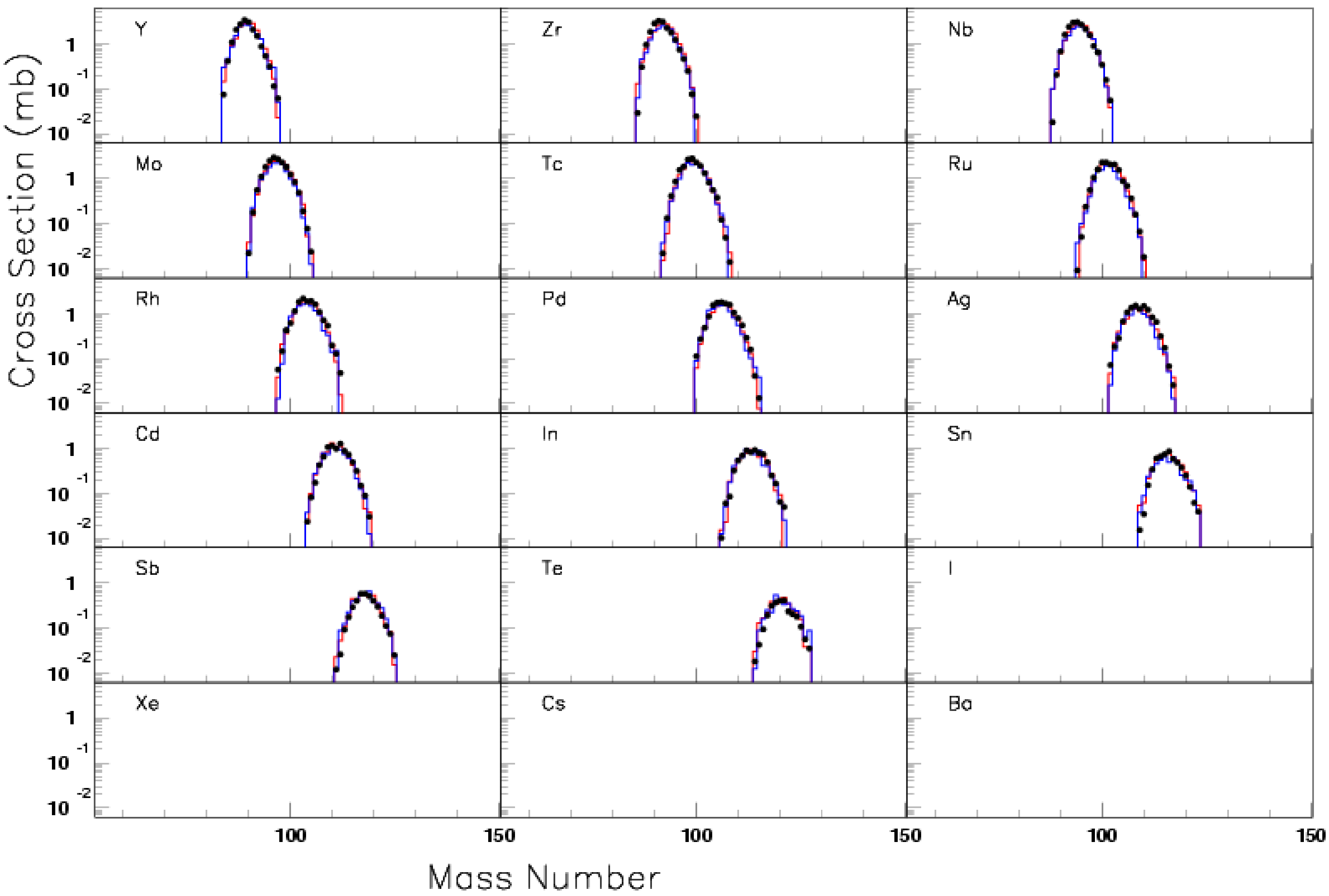


slightly less good

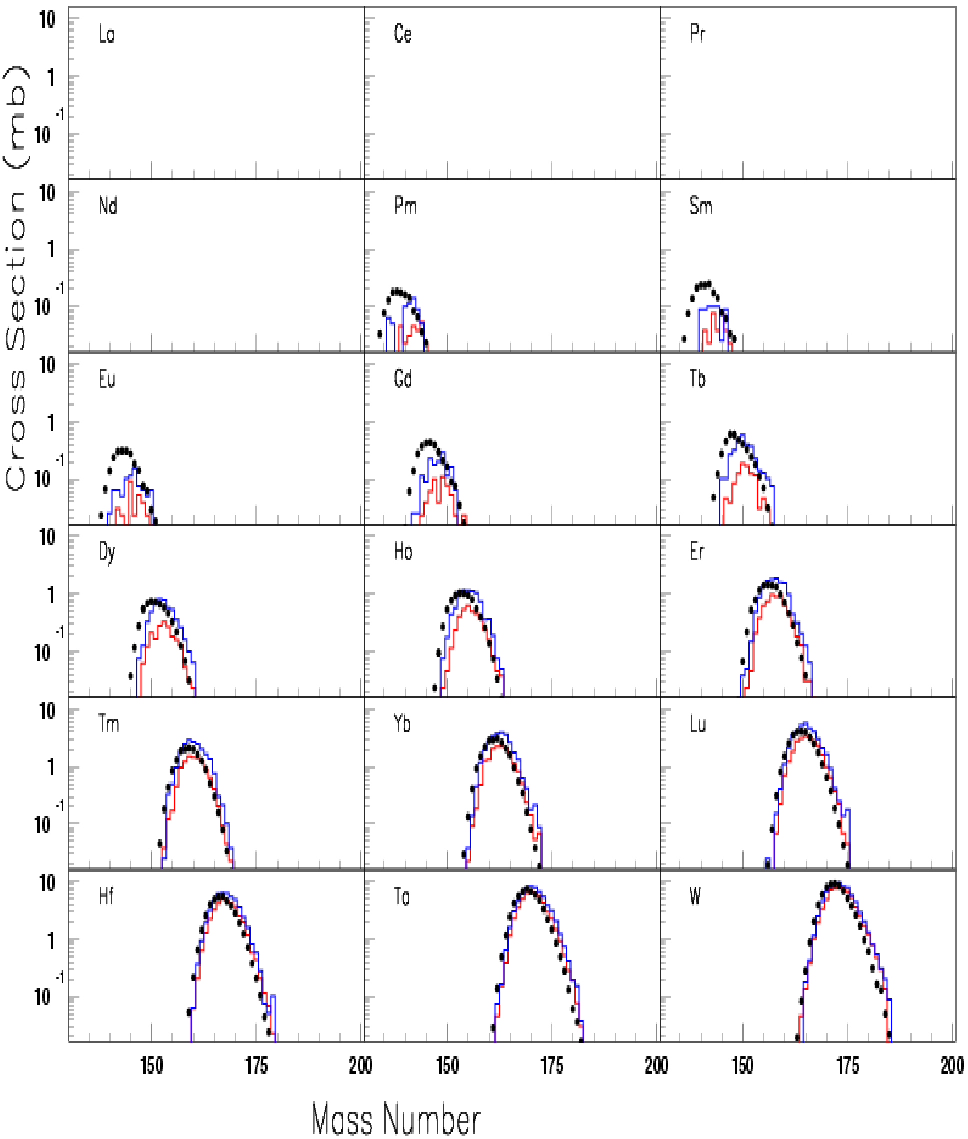


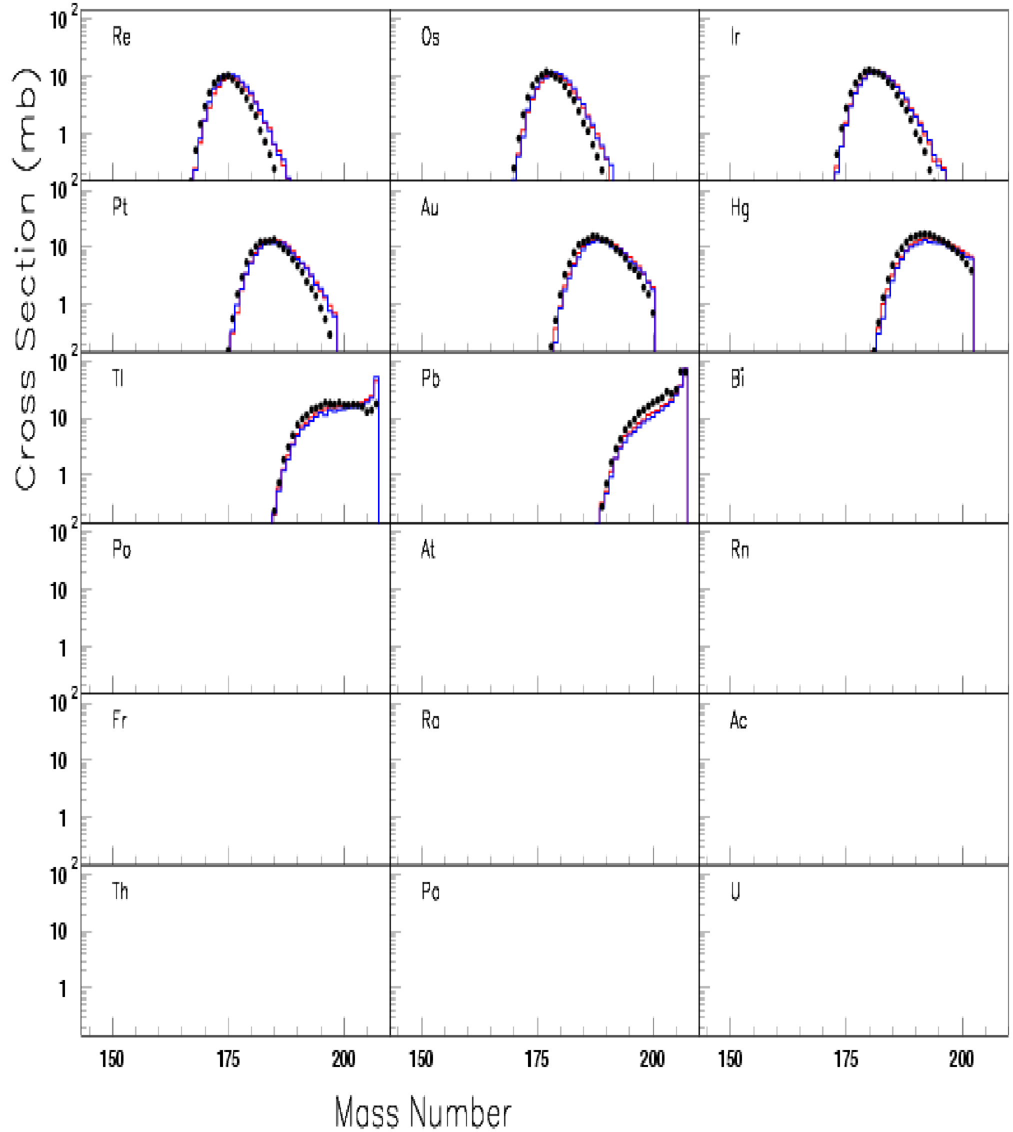


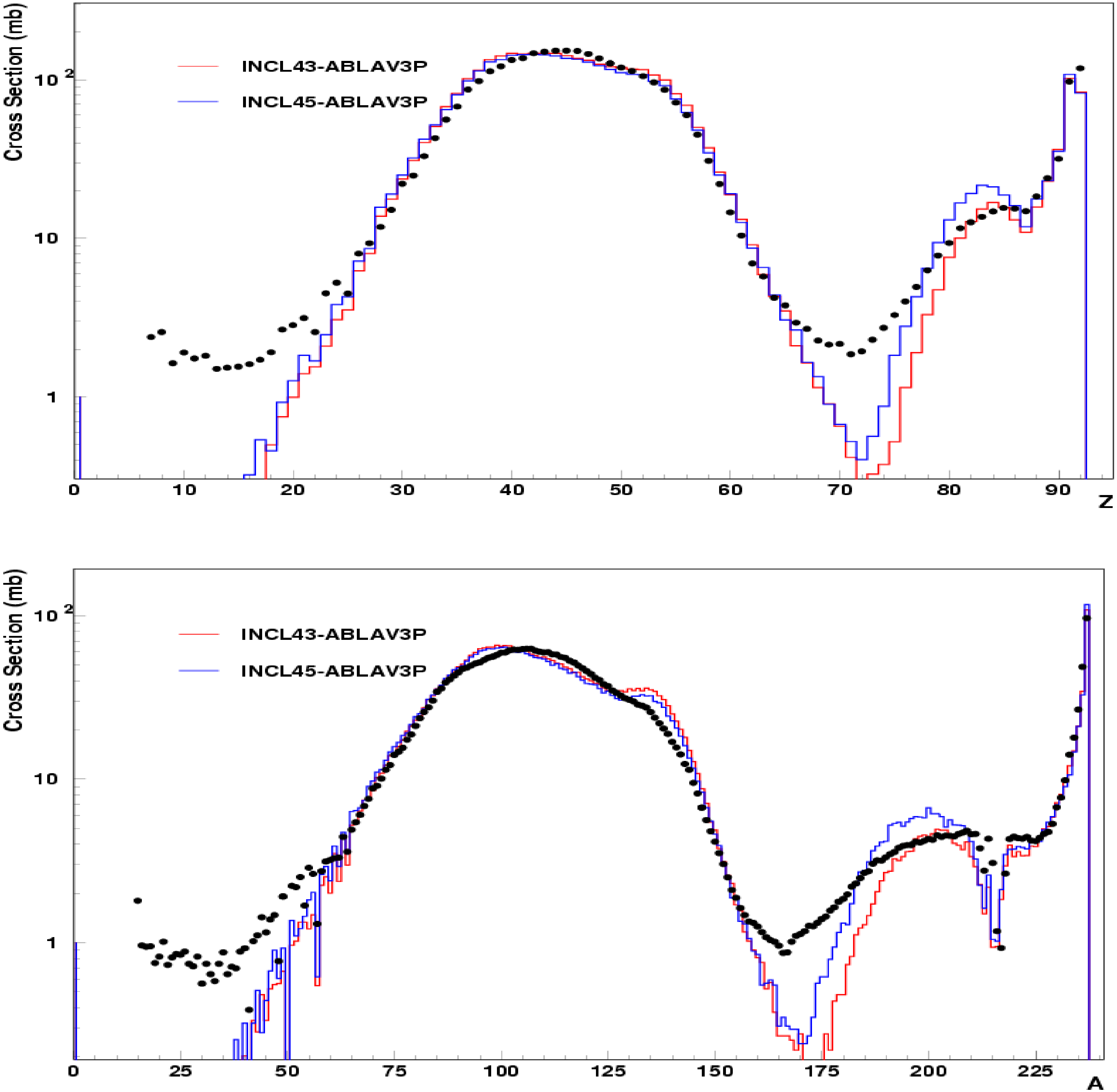
INCL4.5: better or not?



virtue of ABLA

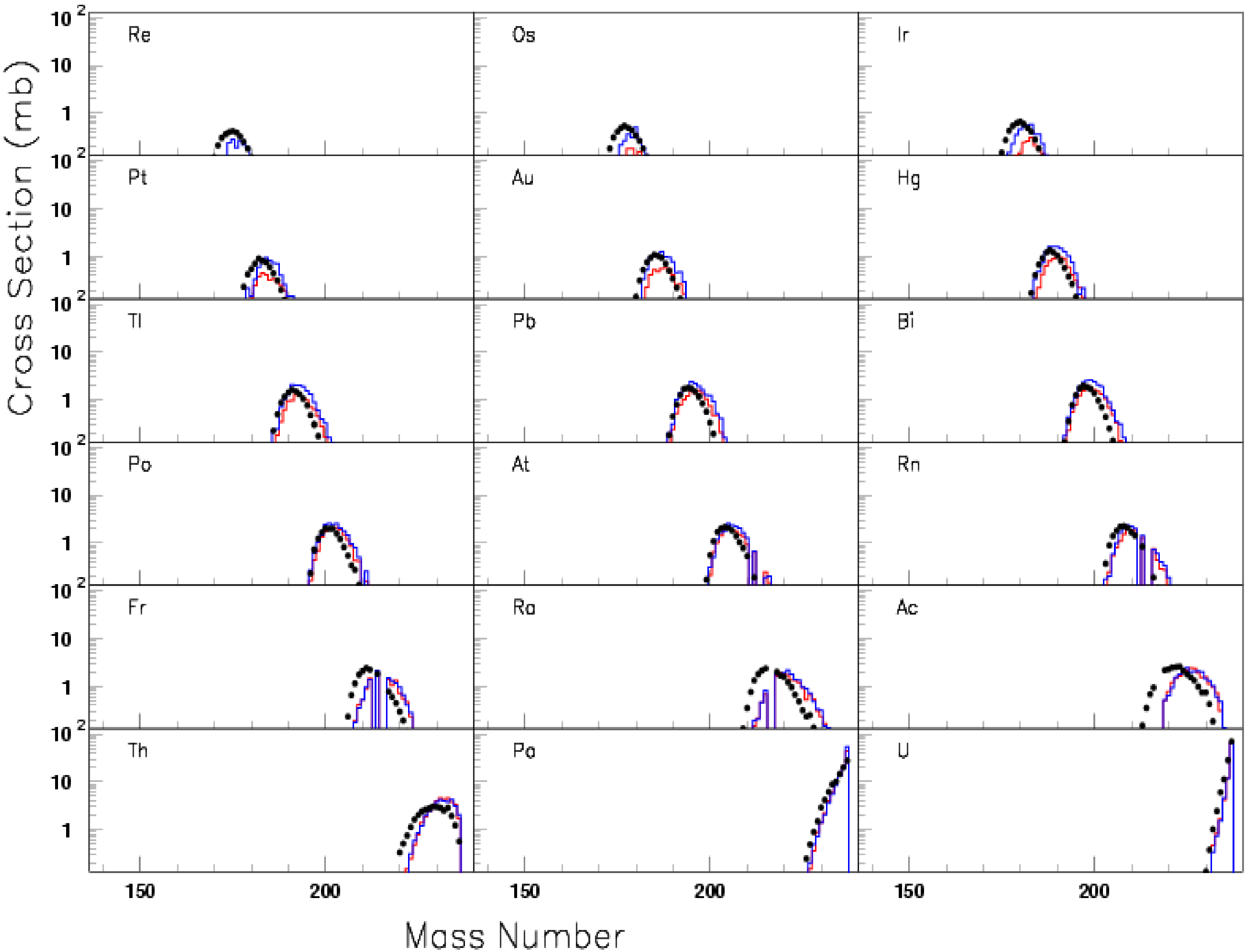

Cross Section (mb)
La
Ce
Pr
Nd
Pm
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
Hf
Ta
W
150
175
200
Mass Number


Cross Section (mb)
Re
Os
Ir
Pt
Au
Hg
Tl
Pb
Bi
Po
At
Rn
Fr
Ra
Ac
Th
Pa
U
150
175
200
Mass Number



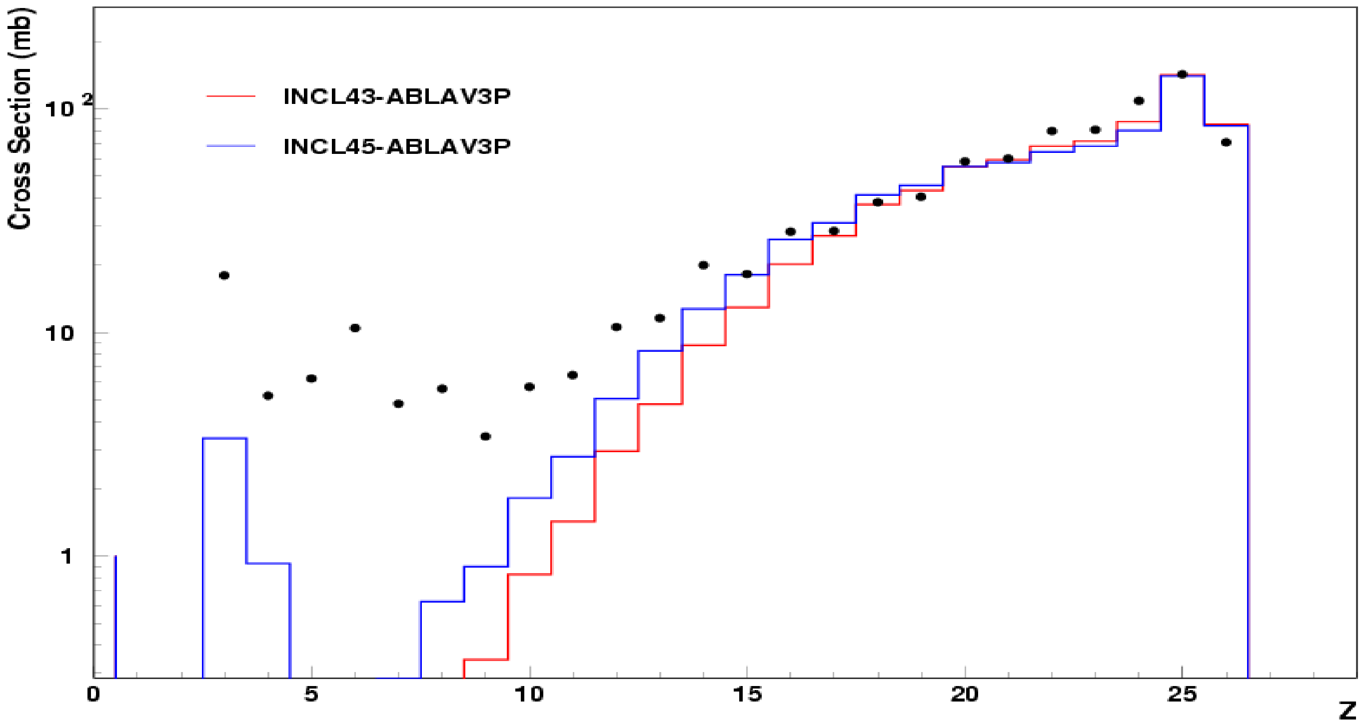
Cross Section (mb)
INCL43-ABLAV3P
INCL45-ABLAV3P
Z
Cross Section (mb)
INCL43-ABLAV3P
INCL45-ABLAV3P
A

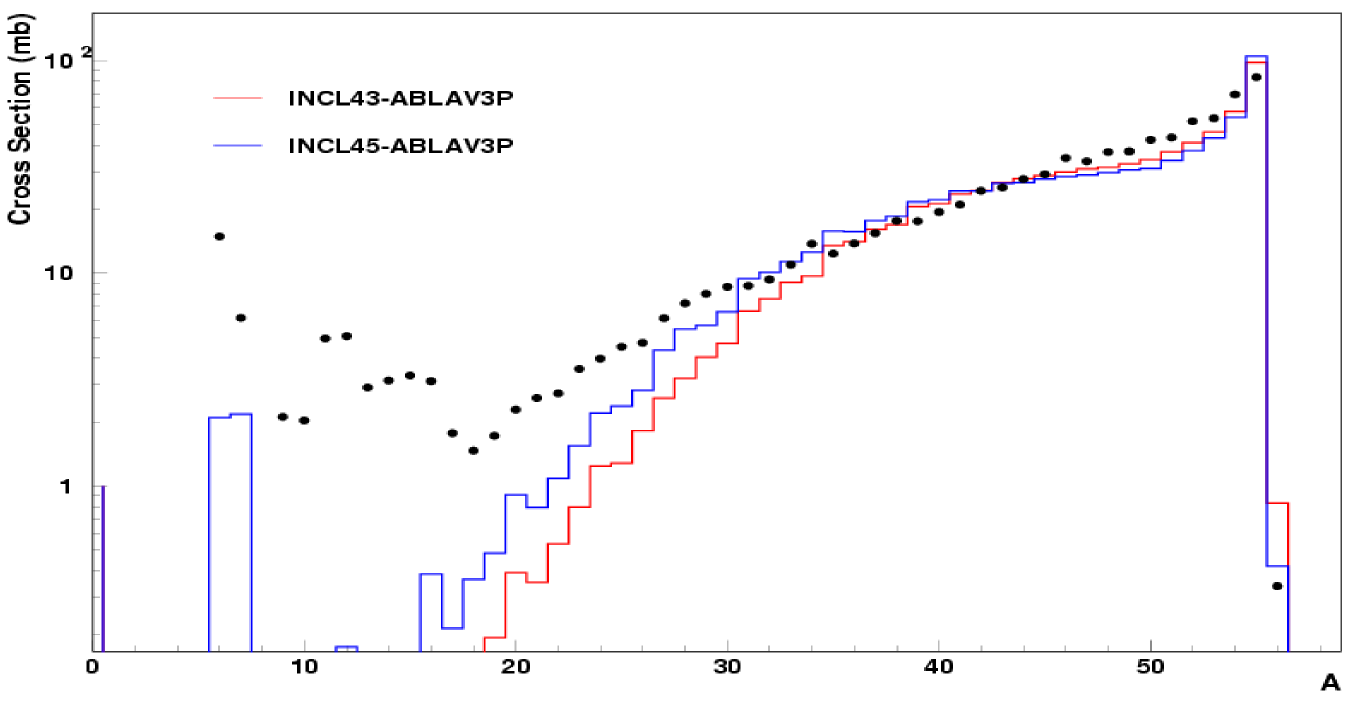
p(1GeV)+^{238}U

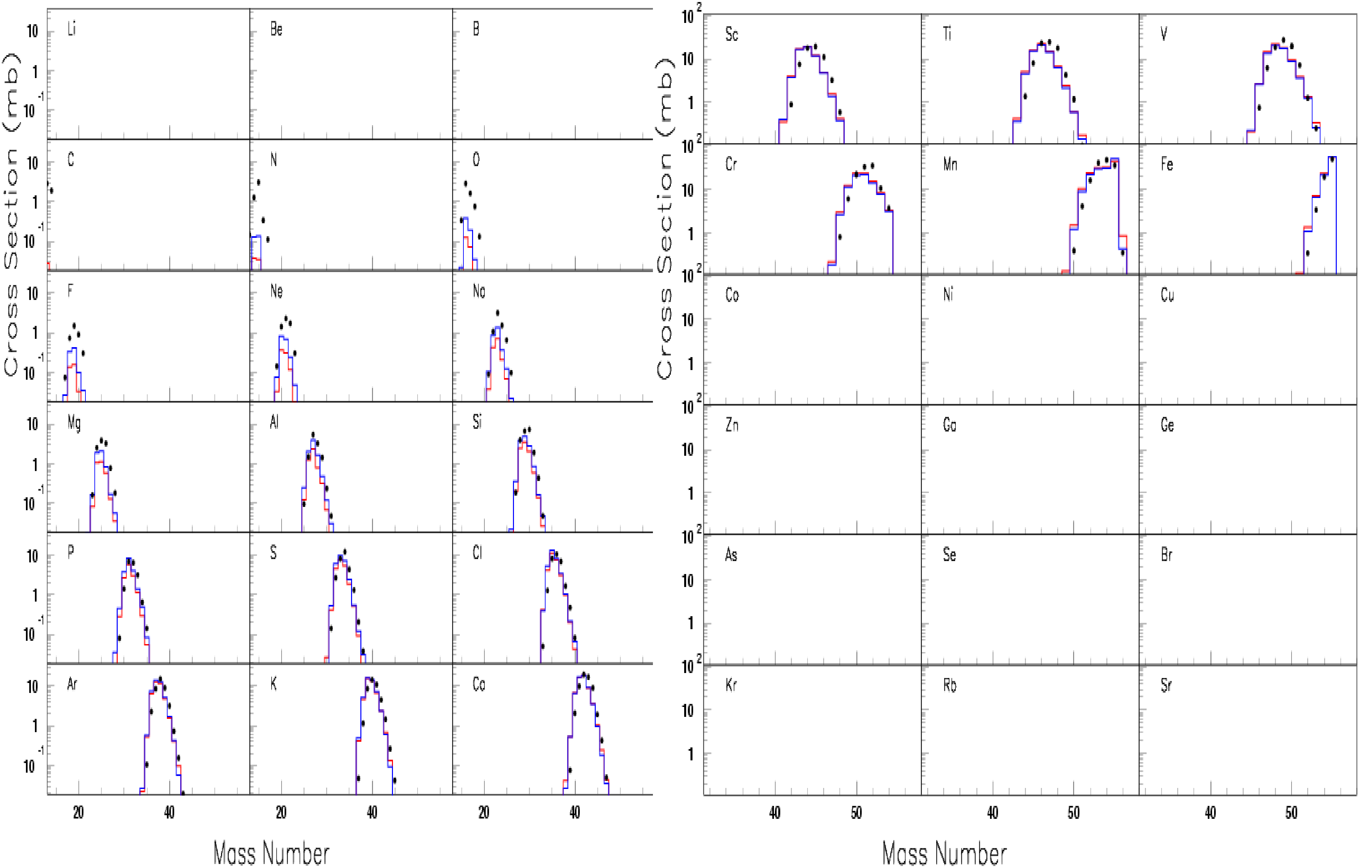


Re
Os
Ir
Pt
Au
Hg
Tl
Pb
Bi
Po
At
Rn
Fr
Ra
Ac
Th
Pa
U
Cross Section (mb)
Mass Number

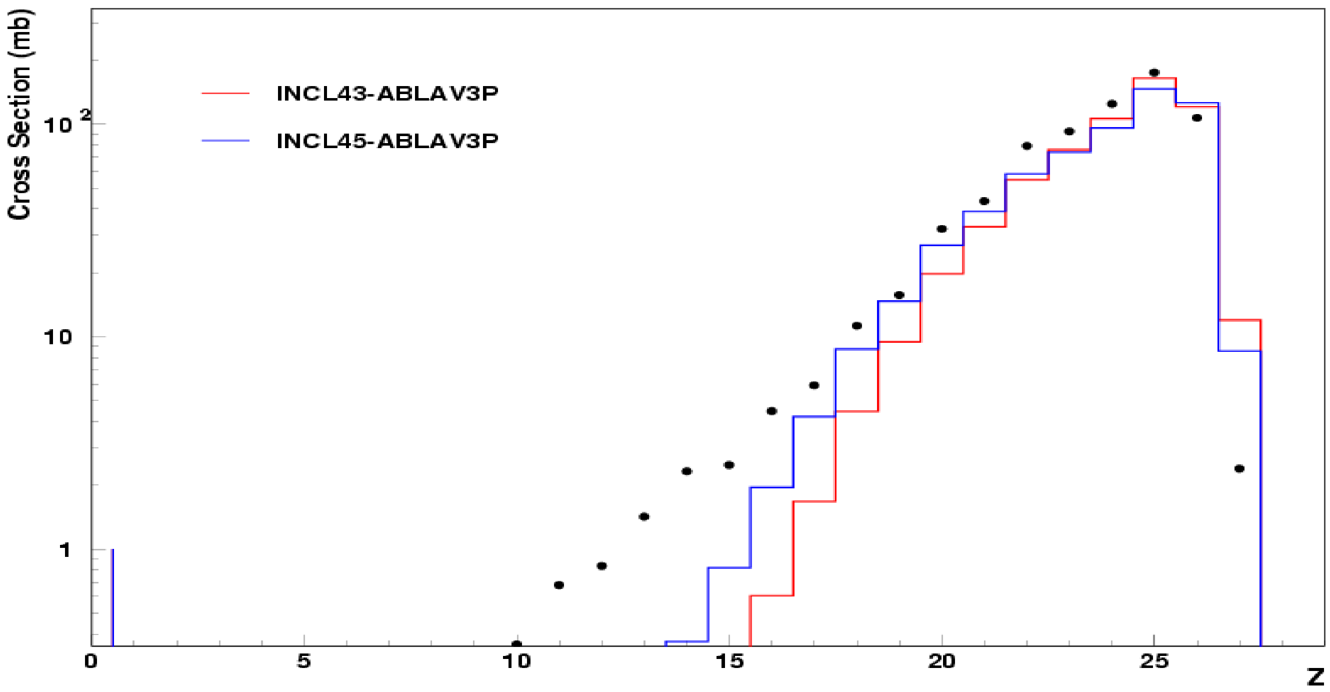
$p(1GeV)+^{56}Fe$

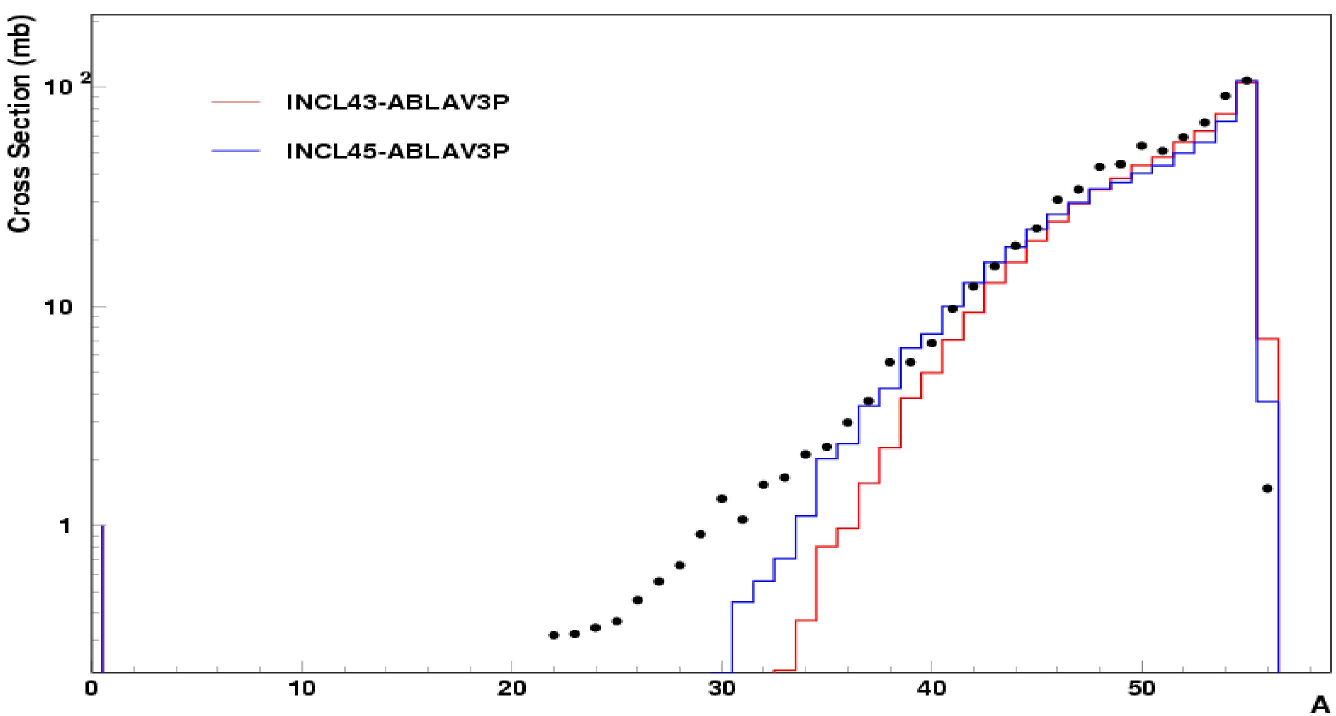

Cross Section (mb)
INCL43-ABLAV3P
INCL45-ABLAV3P
Z


Cross Section (mb)
INCL43-ABLAV3P
INCL45-ABLAV3P
A



Cross Section (mb)
Li
Be
B
C
N
O
F
Ne
Na
Mg
Al
Si
P
S
Cl
Ar
K
Ca
Mass Number
Sc
Ti
V
Cr
Mn
Fe
Co
Ni
Cu
Zn
Ga
Ge
As
Se
Br
Kr
Rb
Sr





p(300MeV)+^{56}Fe

Conclusion:

- INCL4.5 is slightly better
- persistent problem for residues close to the projectile
- end of spallation peak and IMF emission?

4. Conclusion

- INCL4.5: sophistication, empirism
- Cluster production is improved
- Nucleon spectra are less good
- Slight improvement on the residues (but this implies de-excitation models)
- Development is going on