Comparison between the SMM and GEMINI++ de-excitation models

D. Mancusi[1] J. Cugnon[1] A. Boudard[2] S. Leray[2]
A. Botvina[3] R. Charity[4]

[1]IFPA, University of Liège, Belgium

[2]SPhN, IRFU, CEA, Saclay, France

[3]Reactions and nuclear astrophysics, GSI, Darmstadt, Germany

[4]Department of Chemistry, Washington University, St. Louis, MO, U.S.A.

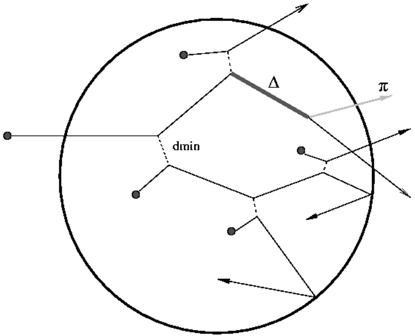
5th May 2009 — Satellite Meeting on Spallation Reactions
AccApp'09, Vienna (Austria)

Université de Liège

Outline

1. Physical ingredients
   - Cascade stage
   - De-excitation stage
2. Results
   - Residue cross sections
   - Neutron spectra
   - Light clusters
3. Conclusions

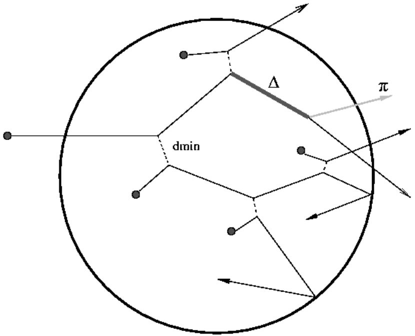
INCL4.5



Features

- INCL
- Developed by ULg@Liège, CEA@Saclay
- Binary nucleon-nucleon collisions
- Nucleus (remnant) left in an excited state
  - Must be coupled to a pre-equilibrium / de-excitation code

INCL4.5

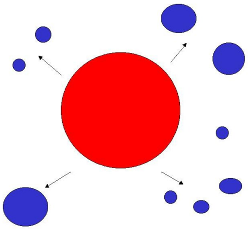


Features

- INCL
- Developed by ULg@Liège, CEA@Saclay
- Binary nucleon-nucleon collisions
- Nucleus (remnant) left in an excited state
  - Must be coupled to a pre-equilibrium / de-excitation code

The SMM model

SMM = Statistical Multifragmentation Model

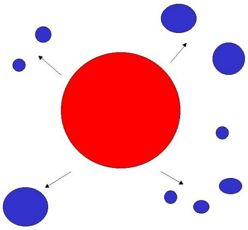


De-excitation mechanisms

- Simultaneous break-up
  - Thermodynamical configuration weights
  - Remnant splits in several “chunks”
- Fragment de-excitation
  - Fermi break-up
  - Evaporation $Z \leq 2$ (Weisskopf-Ewing)
  - Fission (Bohr-Wheeler)

The SMM model

SMM = Statistical Multifragmentation Model

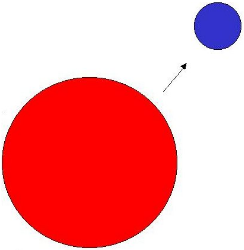


De-excitation mechanisms

- Simultaneous break-up
  - Thermodynamical configuration weights
  - Remnant splits in several “chunks”
- Fragment de-excitation
  - Fermi break-up
  - Evaporation $Z \leq 2$ (Weisskopf-Ewing)
  - Fission (Bohr-Wheeler)

Université de Liège

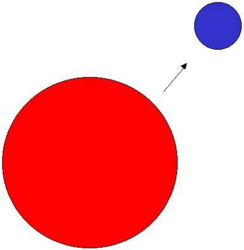
The GEMINI++ model



De-excitation mechanisms

- No simultaneous break-up
- Sequence of binary decays
- Evaporation $Z \leq 3$ (Hauser-Feshbach)
- Asymmetric fission $Z > 3$ (Moretto)
- Symmetric fission (Bohr-Wheeler)

The GEMINI++ model

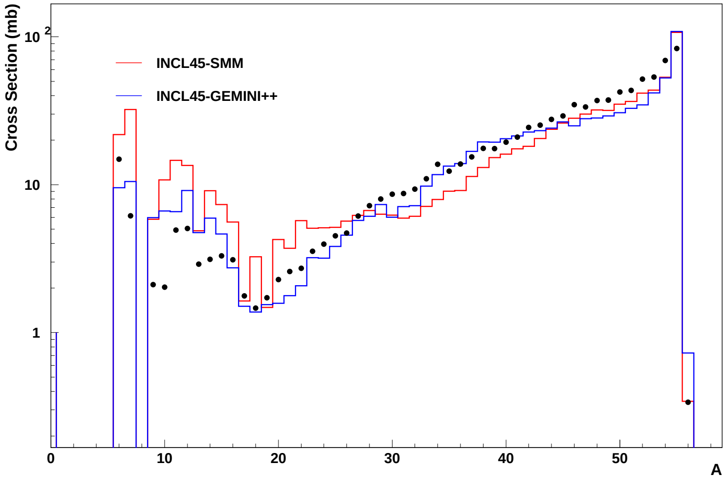


De-excitation mechanisms

- No simultaneous break-up
- Sequence of binary decays
- Evaporation $Z \leq 3$ (Hauser-Feshbach)
- Asymmetric fission $Z > 3$ (Moretto)
- Symmetric fission (Bohr-Wheeler)

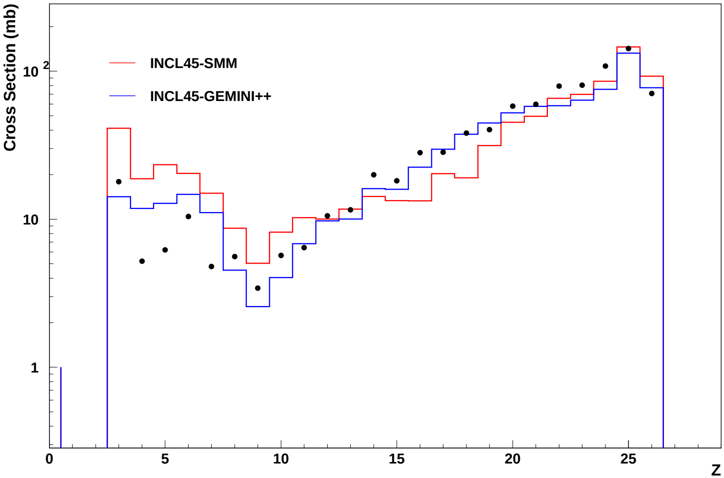
Université de Liège

1-GeV p + ^{56}Fe

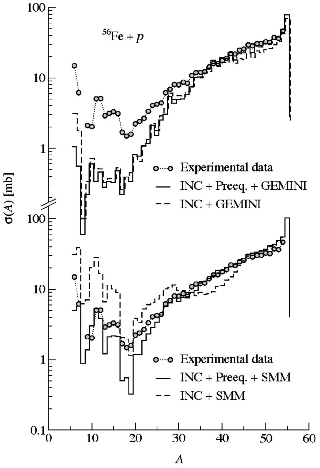


Université de Liège

1-GeV p + ^{56}Fe


Cross Section (mb)
10^2
10
1
INCL45-SMM
INCL45-GEMINI++
0
5
10
15
20
25
Z

1-GeV p + ^{56}Fe



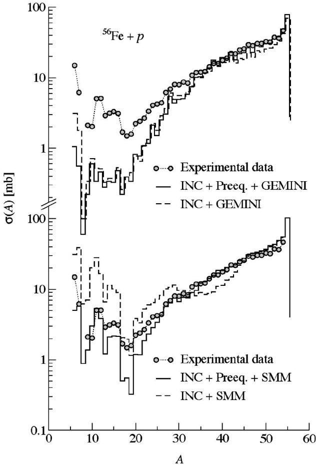
P. Napolitani *et al.*, PRC70 (2004)

SMM improves with pre-equilibrium

IMF production

- SMM → multifragmentation
- GEMINI++ → asymmetric fission
- The question is not settled

1-GeV p + ^{56}Fe



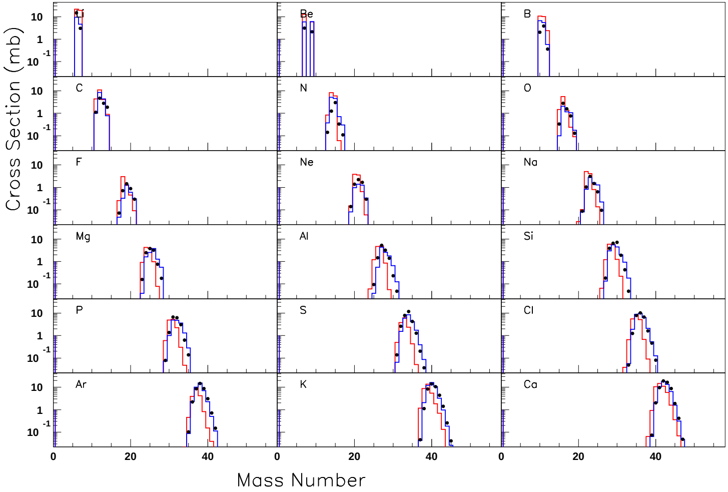
P. Napolitani *et al.*, PRC70 (2004)

`SMM` improves with pre-equilibrium

IMF production

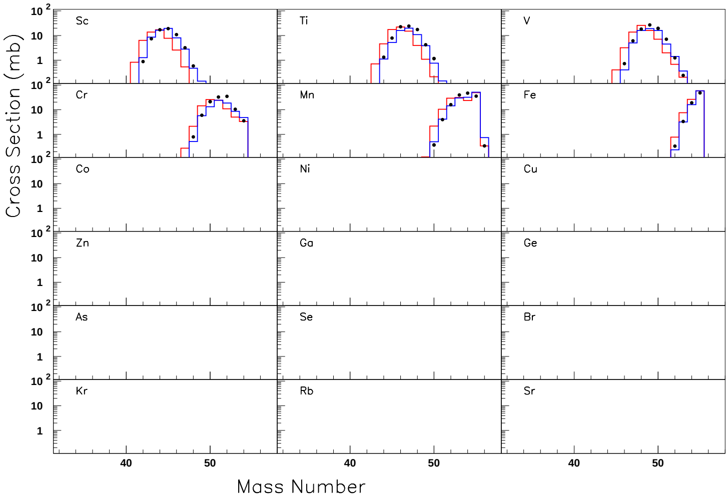
- `SMM` → multifragmentation
- `GEMINI++` → asymmetric fission
- The question is not settled

1-GeV p + ^{56}Fe



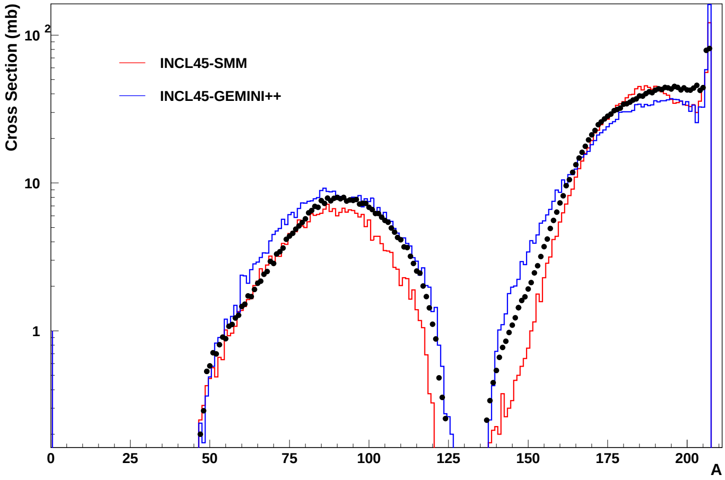
Université de Liège

1-GeV p + ^{56}Fe



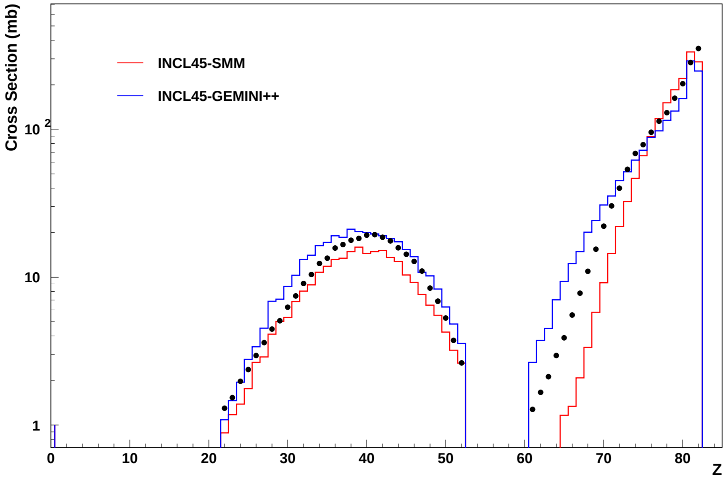
Université de Liège

1-GeV p + ^{208}Pb



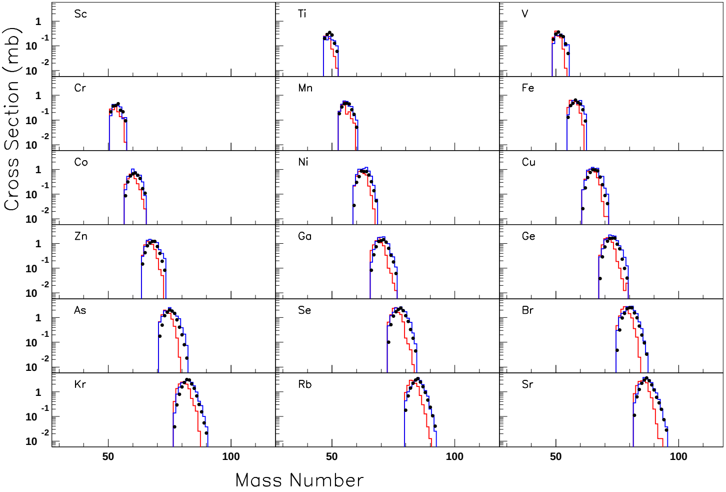
Université de Liège

1-GeV p + ^{208}Pb

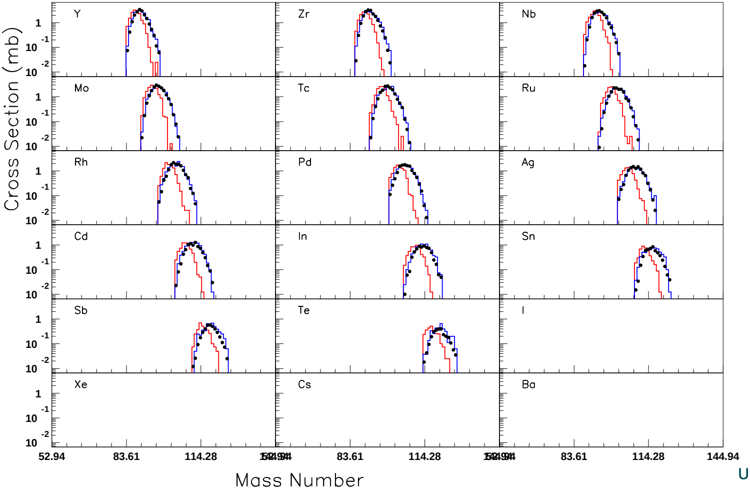


Université de Liège

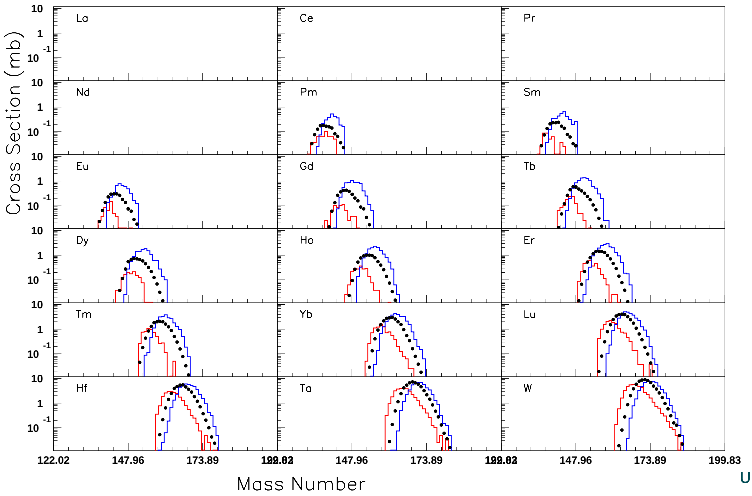
1-GeV p + ^{208}Pb


Sc
Ti
V
Cr
Mn
Fe
Co
Ni
Cu
Zn
Ga
Ge
As
Se
Br
Kr
Rb
Sr
Cross Section (mb)
Mass Number
50
100

1-GeV p + ^{208}Pb

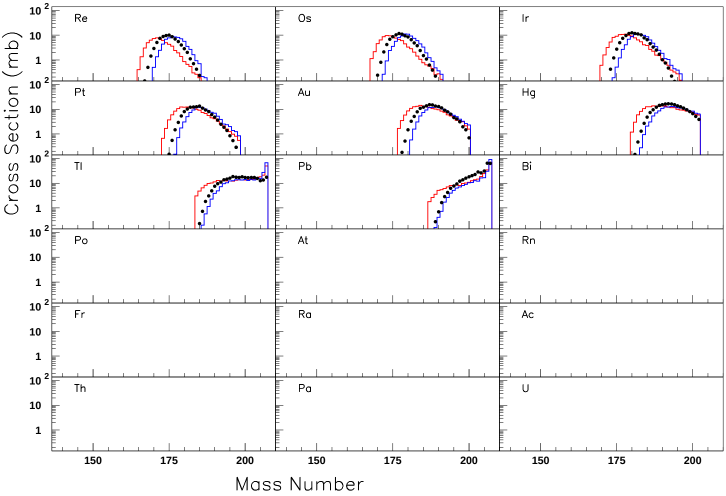

Y
Zr
Nb
Mo
Tc
Ru
Rh
Pd
Ag
Cd
In
Sn
Sb
Te
I
Xe
Cs
Ba
1
10^-1
10^-2
52.94
83.61
114.28
144.94
Cross Section (mb)
Mass Number

1-GeV p + ^{208}Pb

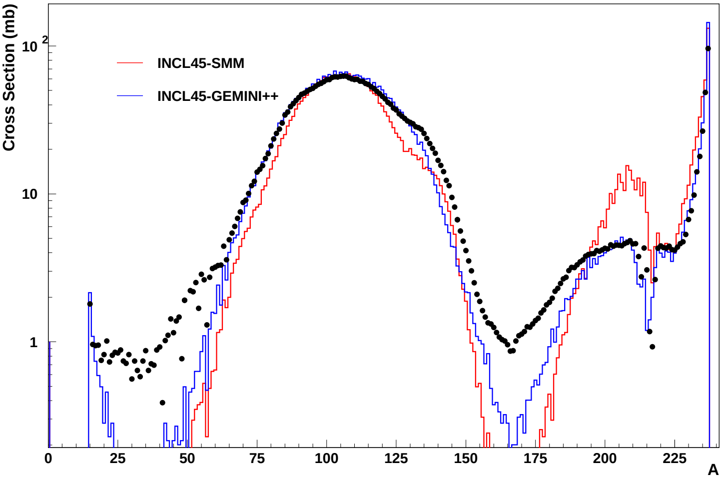


Université de Liège

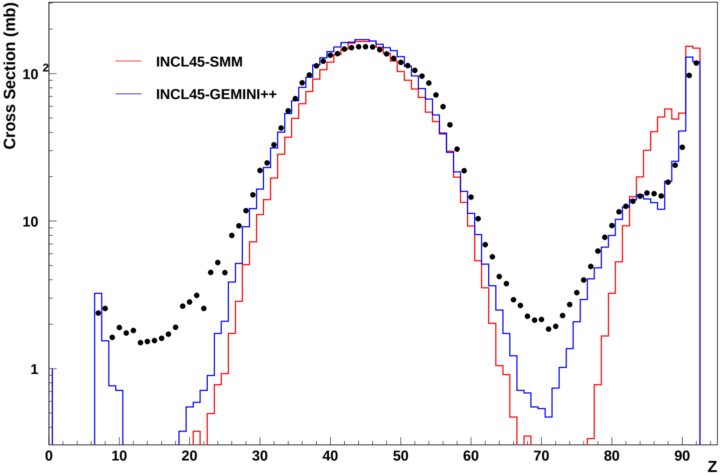
1-GeV p + ^{208}Pb


Re
Os
Ir
Pt
Au
Hg
Tl
Pb
Bi
Po
At
Rn
Fr
Ra
Ac
Th
Pa
U
Cross Section (mb)
10^2
10
1
150
175
200
Mass Number

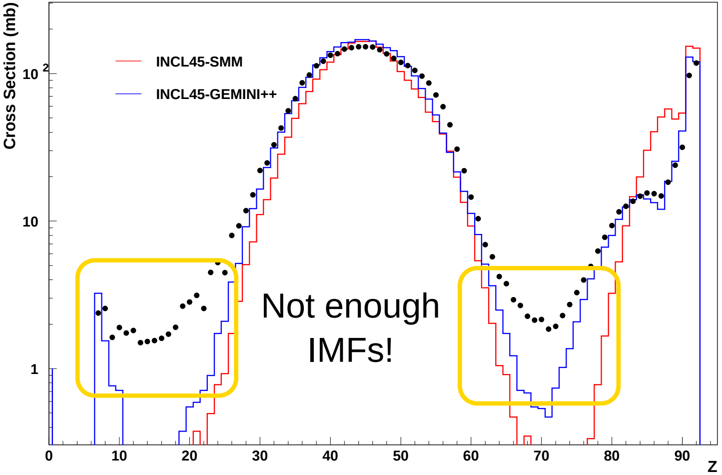
1-GeV p + ^{238}U


Cross Section (mb)
10^2
10
1
INCL45-SMM
INCL45-GEMINI++
0
25
50
75
100
125
150
175
200
225
A

1-GeV p + ^{238}U

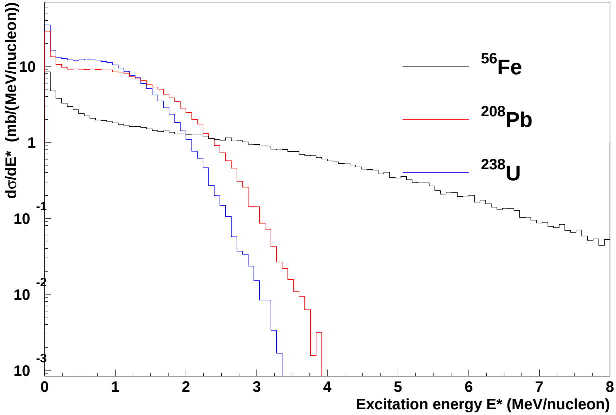

INCL45-SMM
INCL45-GEMINI++
Cross Section (mb)
10^2
10
1
0
10
20
30
40
50
60
70
80
90
Z

1-GeV p + ^{238}U



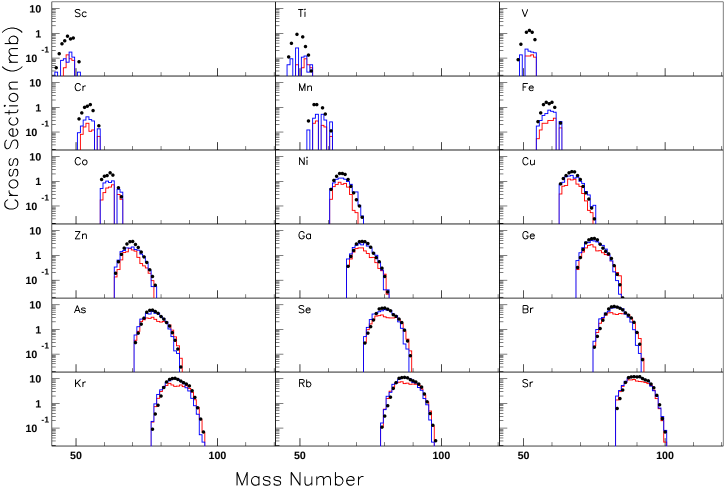
Cross Section (mb)
10 2
10
1
INCL45-SMM
INCL45-GEMINI++
Not enough IMFs!
0
10
20
30
40
50
60
70
80
90
Z

1-GeV p + ^{238}U

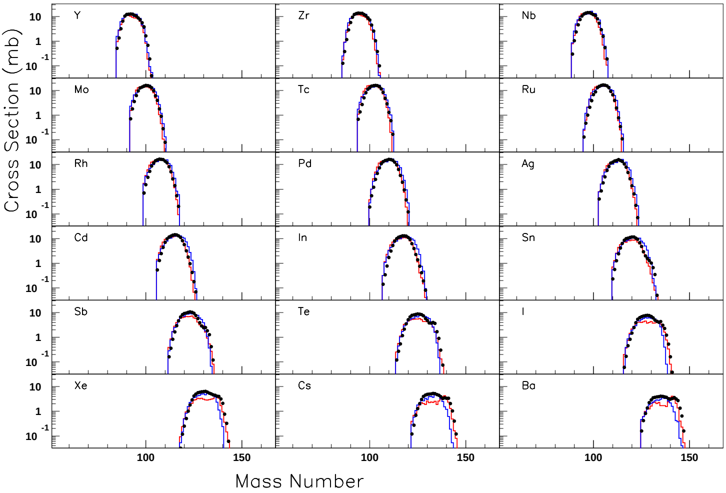


No break-up
in Pb and U!

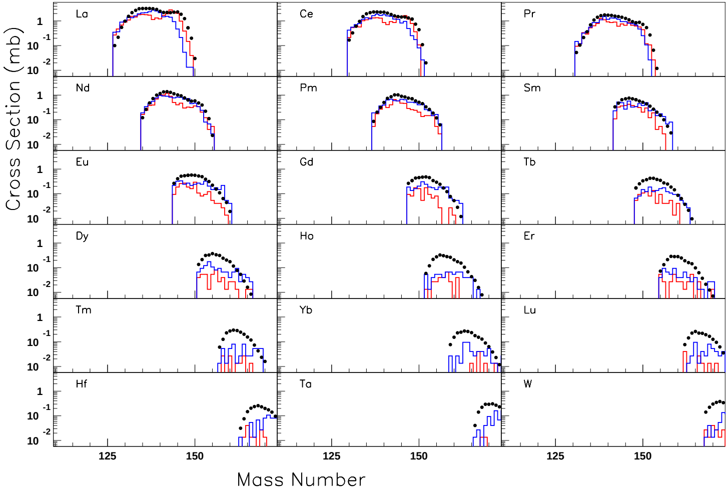
1-GeV p + ^{238}U


Sc
Ti
V
Cr
Mn
Fe
Co
Ni
Cu
Zn
Ga
Ge
As
Se
Br
Kr
Rb
Sr
Cross Section (mb)
10
1
10
-1
50
100
Mass Number

1-GeV p + ^{238}U

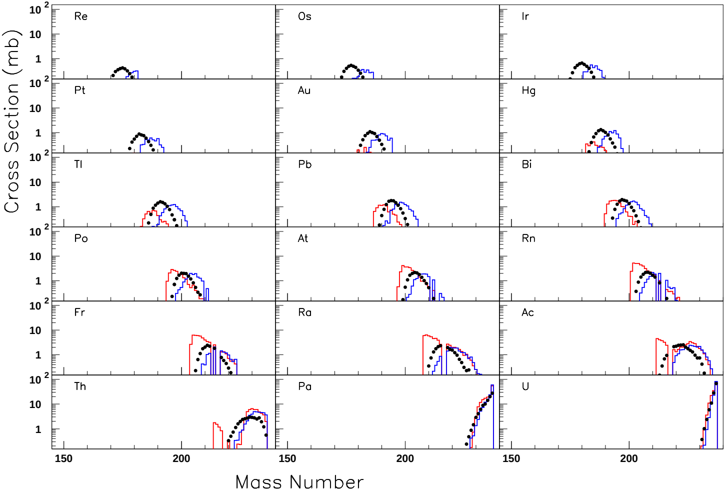

Y
Zr
Nb
Mo
Tc
Ru
Rh
Pd
Ag
Cd
In
Sn
Sb
Te
I
Xe
Cs
Ba
10
1
10^-1
100
150
Cross Section (mb)
Mass Number

1-GeV p + ^{238}U



La
Ce
Pr
Nd
Pm
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
Hf
Ta
W
Cross Section (mb)
1
10 -1
10 -2
125
150
Mass Number

1-GeV p + ^{238}U



Université de Liège

In short

- `GEMINI++` has good fission and spallation yields
- `SMM` less good for fission
  - `SMM` prefers pre-equilibrium + de-excitation
- IMF production mechanism?

In short

- GEMINI++ has good fission and spallation yields
- SMM less good for fission
    - SMM prefers pre-equilibrium + de-excitation
- IMF production mechanism?

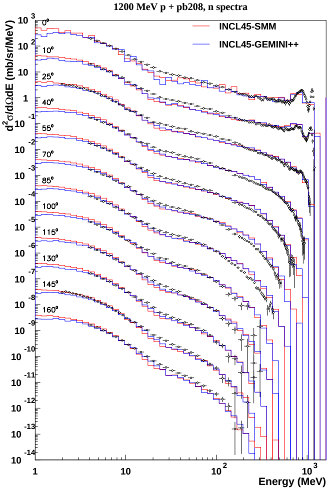
In short

- GEMINI++ has good fission and spallation yields
- SMM less good for fission
  - SMM prefers pre-equilibrium + de-excitation
- IMF production mechanism?

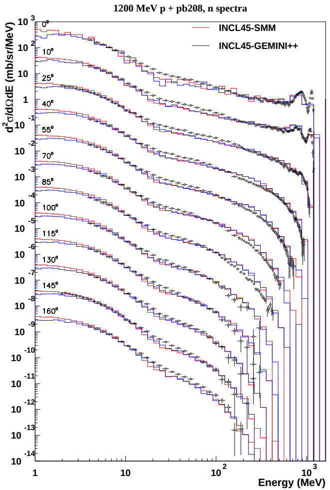
In short

- GEMINI++ has good fission and spallation yields
- SMM less good for fission
  - SMM prefers pre-equilibrium + de-excitation
- IMF production mechanism?

1.2-GeV p + ^{208}Pb

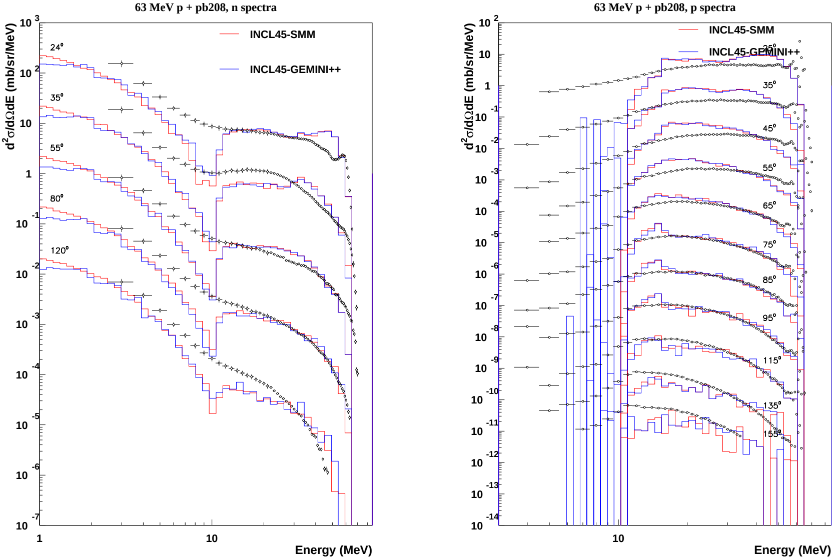


In short

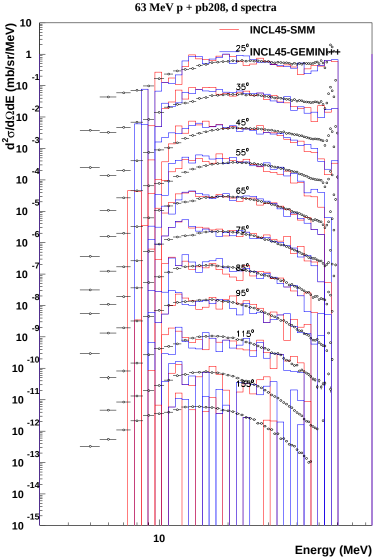


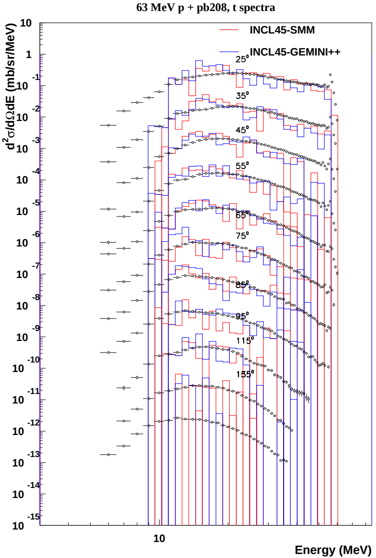
SMM spectra look too cold
. . . pre-equilibrium might help

63-MeV p + ^{208}Pb (low energy)

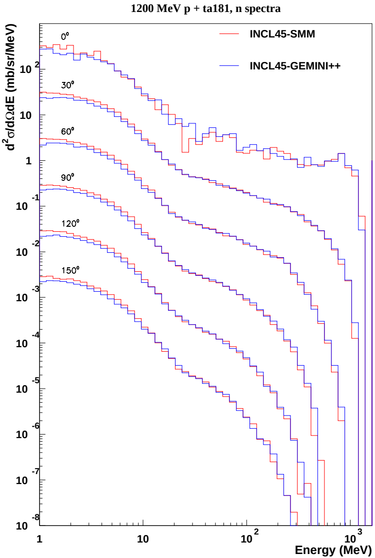


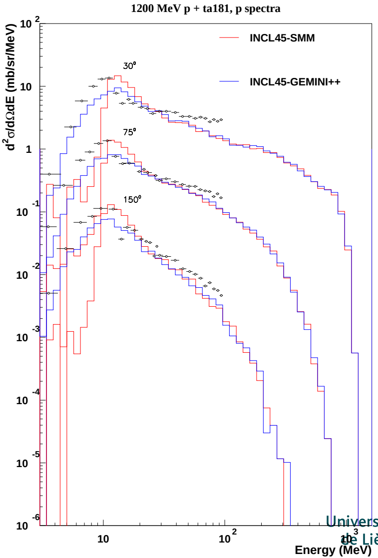
63-MeV p + ^{208}Pb (low energy)



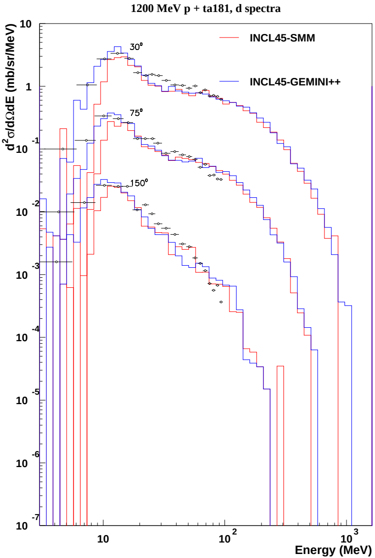


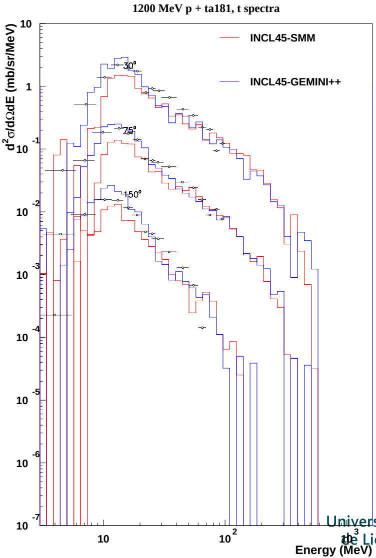
1.2-GeV p + ^{181}Ta (high energy)



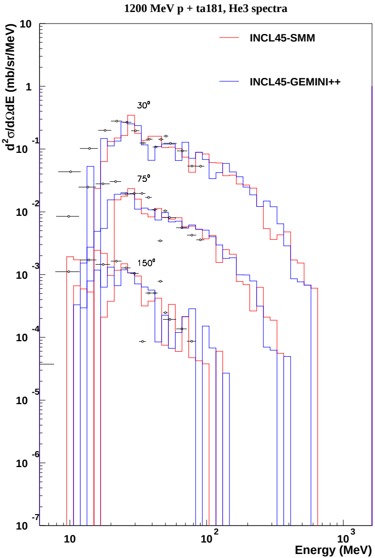


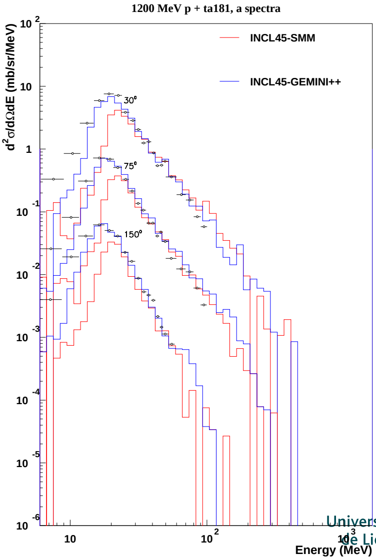
1.2-GeV p + ^{181}Ta (high energy)





1.2-GeV p + ^{181}Ta (high energy)





In short

- Low-energy LCP yields are insensitive to de-excitation
- Very little ^{3}He in de-excitation
- `GEMINI++` sensibly better than `SMM`
    - No multifragmentation
    - More accurate evaporation model

In short

- Low-energy LCP yields are insensitive to de-excitation
- Very little ^{3}He in de-excitation
- GEMINI++ sensibly better than SMM
  - No multifragmentation
  - More accurate evaporation model

In short

- Low-energy LCP yields are insensitive to de-excitation
- Very little ^{3}He in de-excitation
- `GEMINI++` sensibly better than `SMM`
  - No multifragmentation
  - More accurate evaporation model

In short

- Low-energy LCP yields are insensitive to de-excitation
- Very little ^{3}He in de-excitation
- `GEMINI++` sensibly better than `SMM`
  - No multifragmentation
  - More accurate evaporation model

In short

- Low-energy LCP yields are insensitive to de-excitation
- Very little ^{3}He in de-excitation
- `GEMINI++` sensibly better than `SMM`
  - No multifragmentation
  - More accurate evaporation model

Summary

- SMM needs a pre-equilibrium model
- GEMINI++ has accurate physics
  - ...but it is ~20 times slower than SMM!
- IMF production could be improved

Summary

- SMM needs a pre-equilibrium model
- GEMINI++ has accurate physics
  - ...but it is ∼20 times slower than SMM!
- IMF production could be improved

Summary

- SMM needs a pre-equilibrium model
- GEMINI++ has accurate physics
  - . . . but it is ∼20 times slower than SMM!
- IMF production could be improved

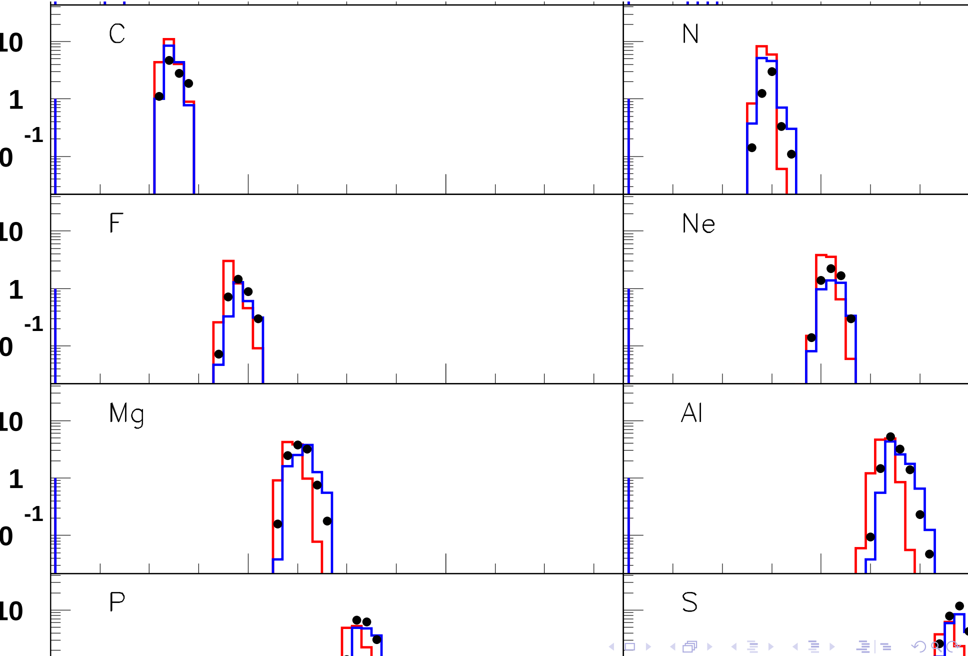
Summary

- SMM needs a pre-equilibrium model
- GEMINI++ has accurate physics
  - ...but it is ~20 times slower than SMM!
- IMF production could be improved

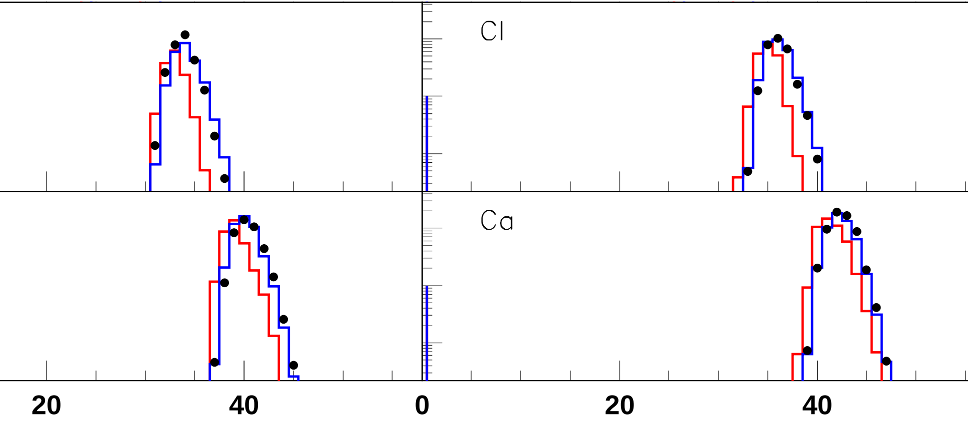
The end

Thank you for your attention!

1-GeV p + ^{56}Fe

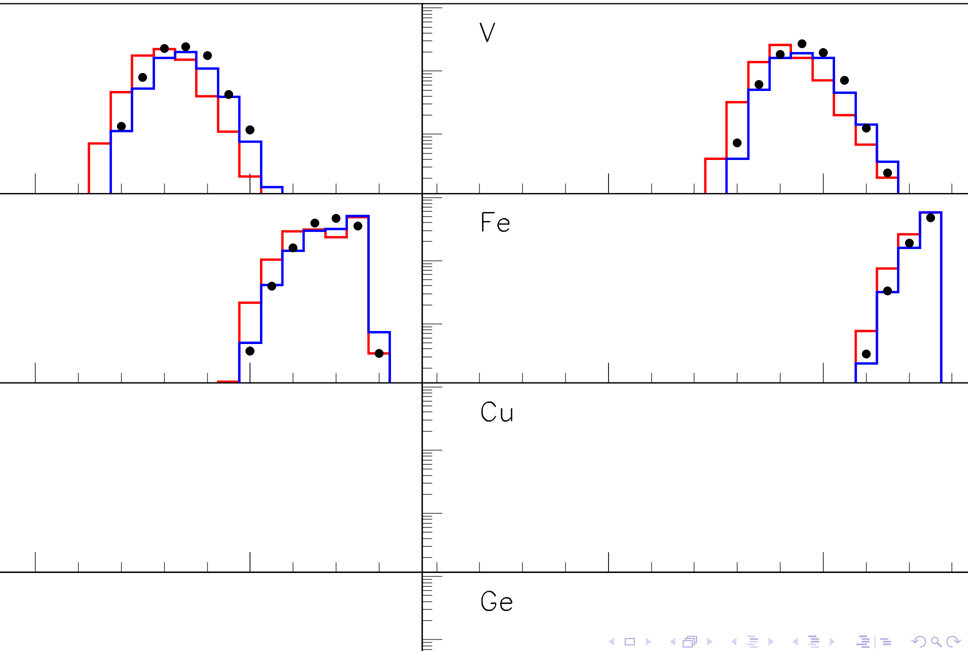


1-GeV p + ^{56}Fe

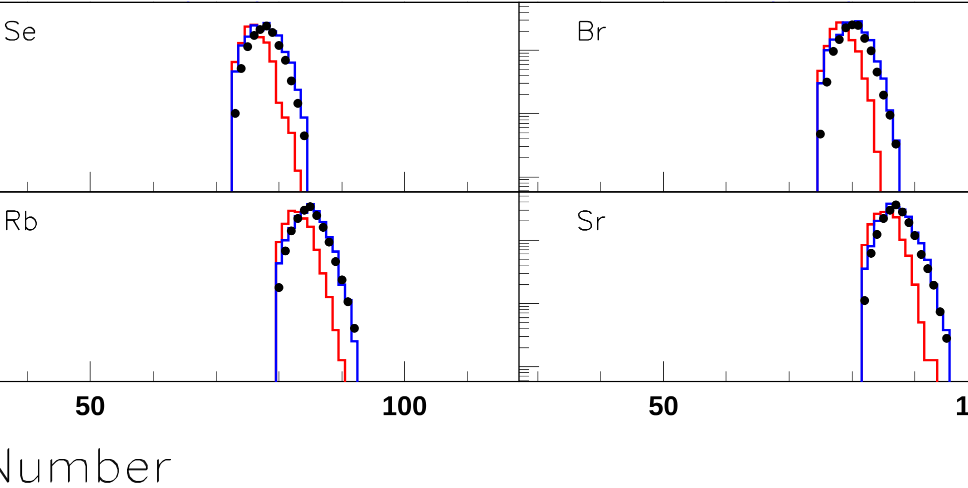


ber

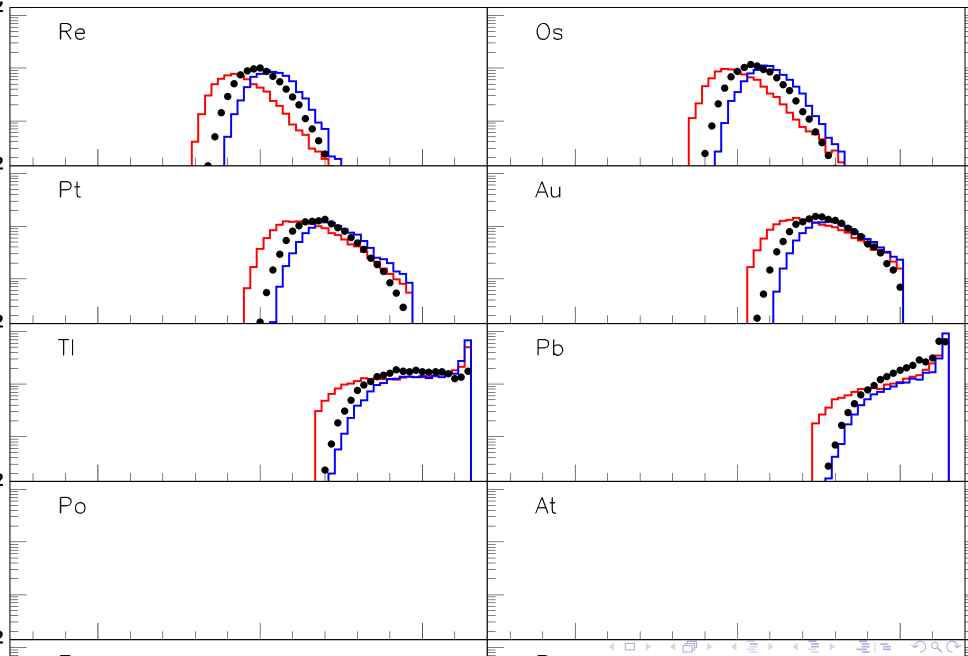
1-GeV p + ^{56}Fe



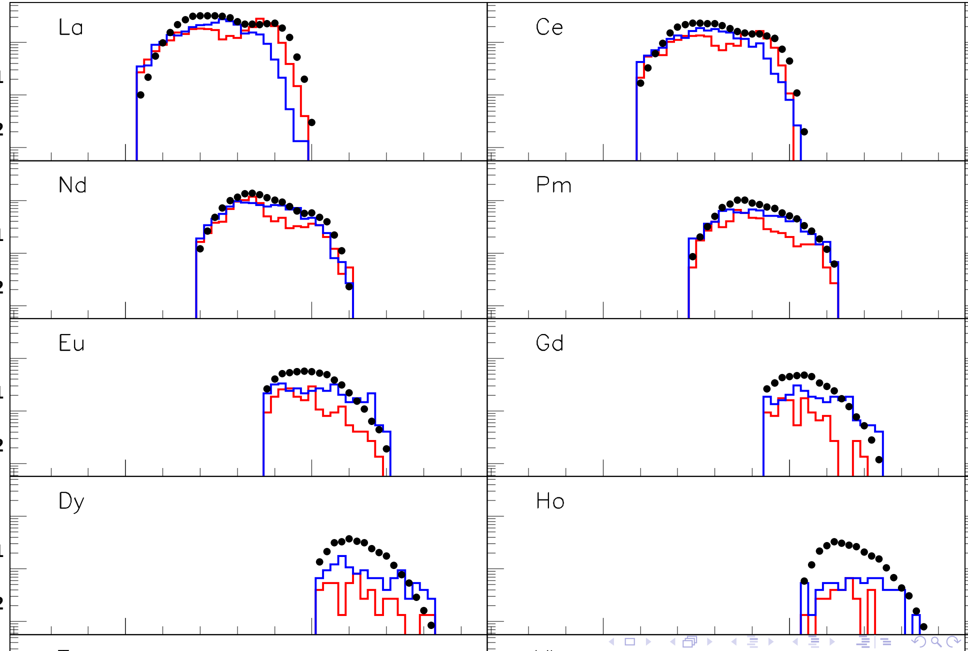
1-GeV p + ^{208}Pb



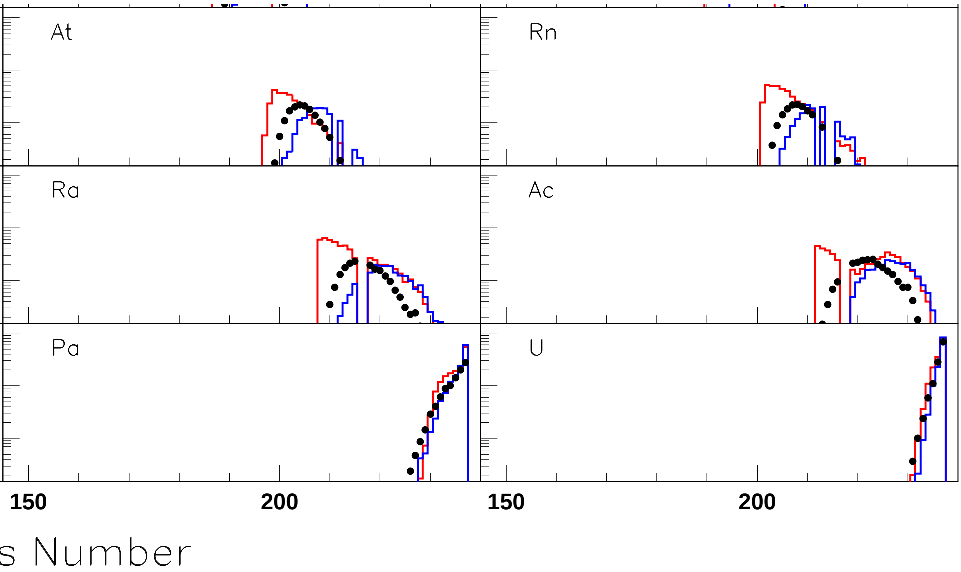
1-GeV p + ^{208}Pb



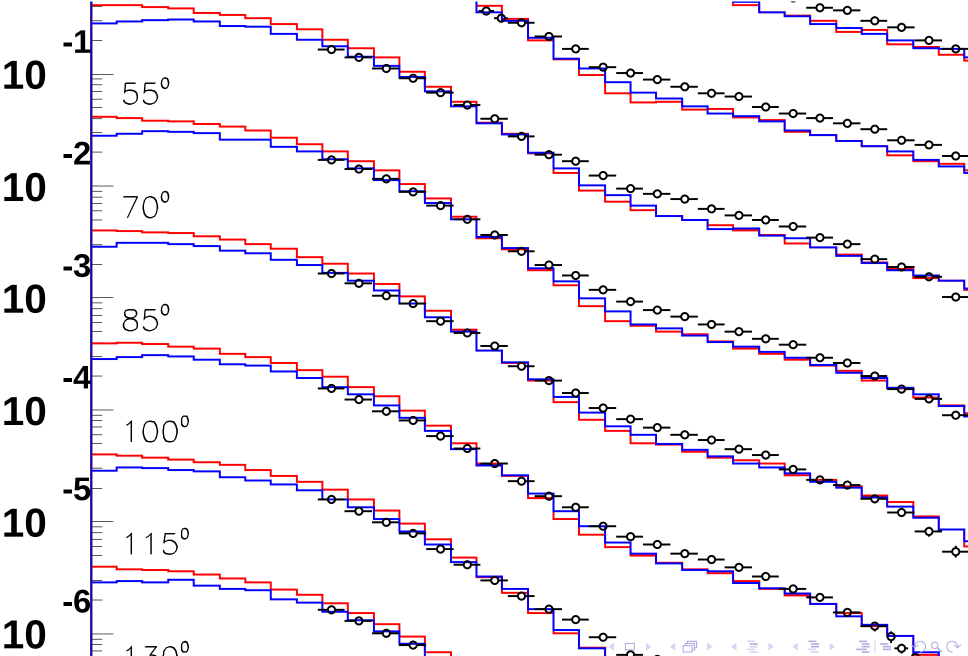
1-GeV p + ^{238}U



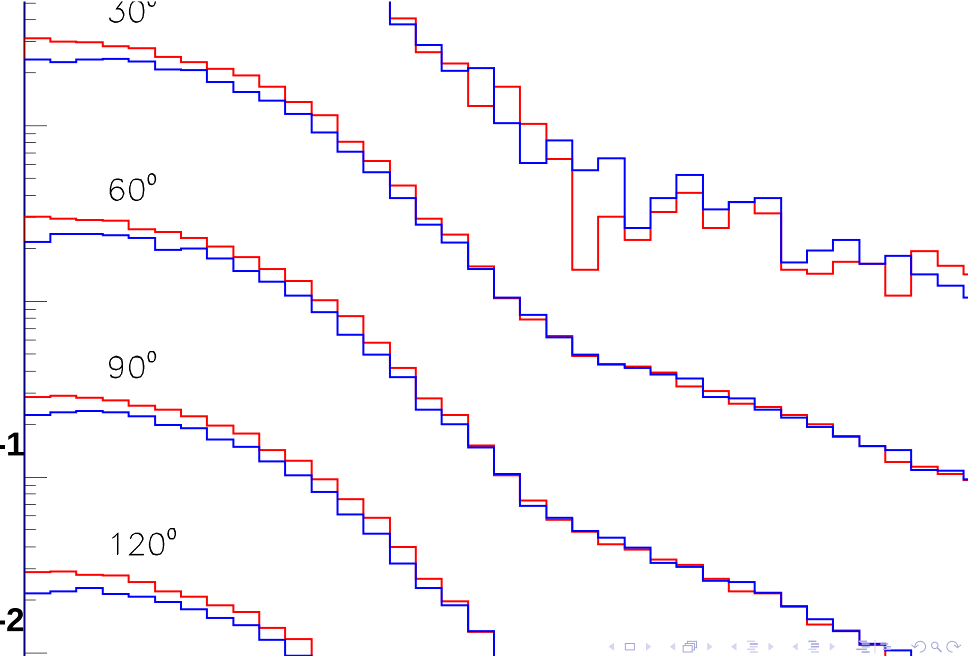
1-GeV p + ^{238}U



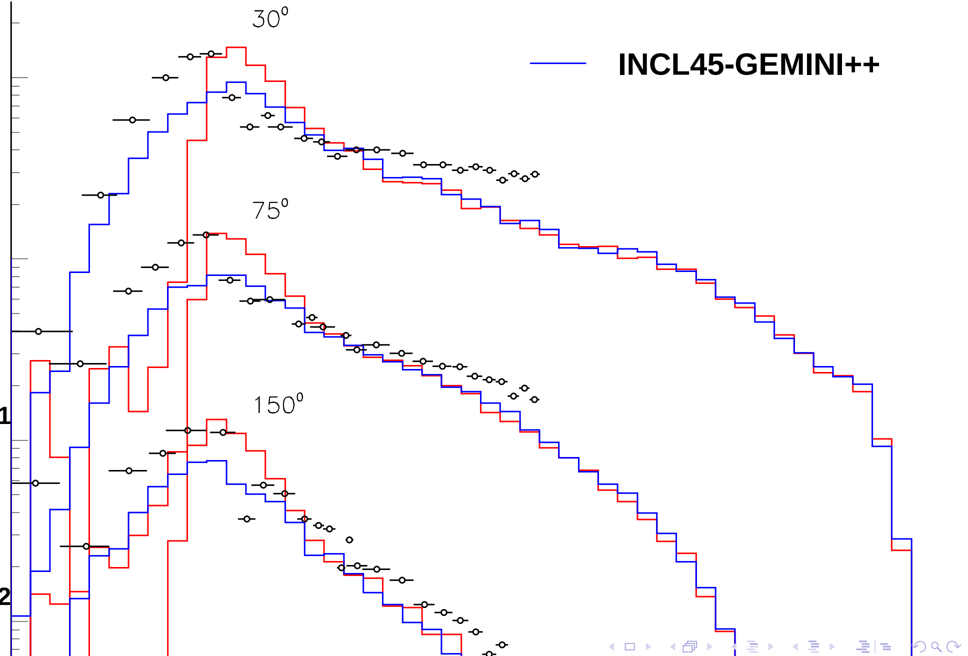
1.2-GeV p + ^{208}Pb



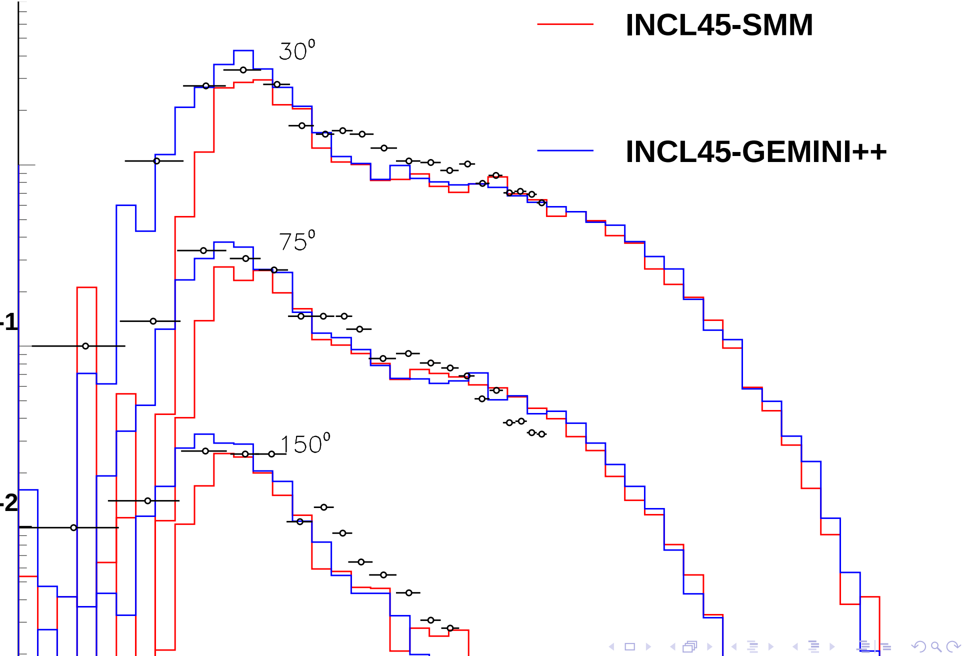
1.2-GeV p + ^{181}Ta (high energy)



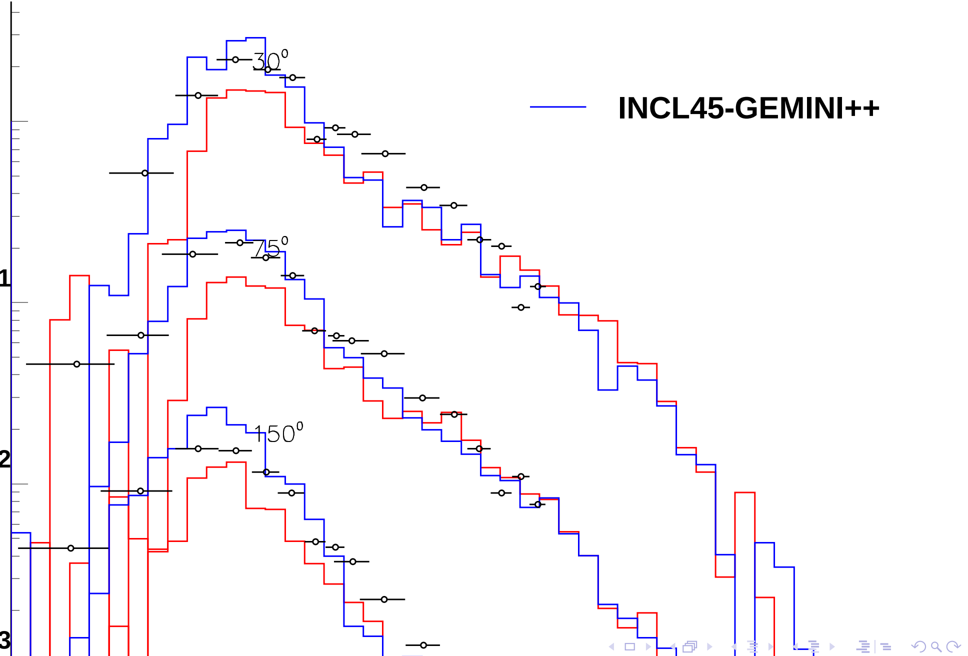
1.2-GeV p + ^{181}Ta (high energy)



1.2-GeV p + ^{181}Ta (high energy)



1.2-GeV p + ^{181}Ta (high energy)



1.2-GeV p + ^{181}Ta (high energy)