Results of the SMM model

A. Botvina[1] D. Mancusi[2]

[1]Institute for Nuclear Research, Moscow, Russia

[2]University of Liège, Liège, Belgium

Second Advanced Workshop on
Model Codes for Spallation Reactions

Saclay (France), 10th February 2010

Université de Liège

Outline

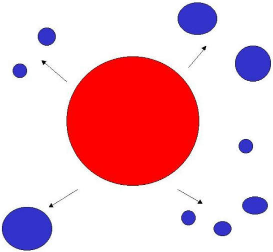
1. About SMM
   - Structure
   - Multifragmentation in spallation reactions
2. Results
   - Neutrons
   - LCP
   - Residue cross sections
3. Conclusions

Outline

1. About SMM
   - Structure
   - Multifragmentation in spallation reactions
2. Results
   - Neutrons
   - LCP
   - Residue cross sections
3. Conclusions

The SMM model

SMM = Statistical Multifragmentation Model

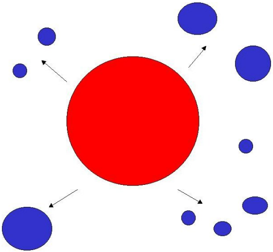


De-excitation mechanisms

- Multifragmentation stage
  - Thermodynamical configuration weights
  - Several hot fragments
- Secondary de-excitation (compound nucleus)
  - Fermi break-up
  - Evaporation $Z \leq 2$ (Weisskopf-Ewing)
  - Fission (Bohr-Wheeler)

The SMM model

SMM = Statistical Multifragmentation Model

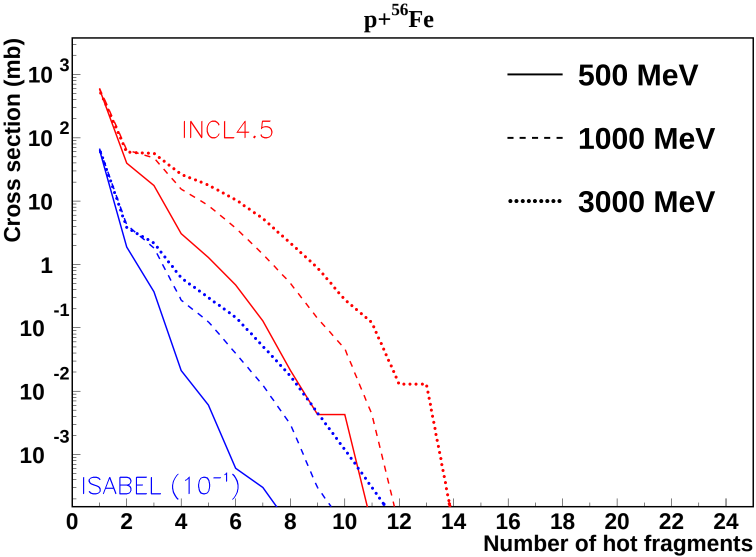


De-excitation mechanisms

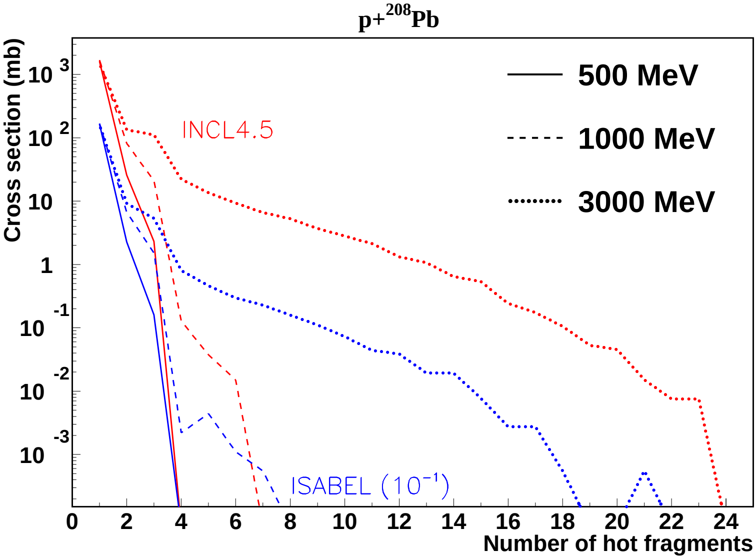
- Multifragmentation stage
  - Thermodynamical configuration weights
  - Several hot fragments
- Secondary de-excitation (compound nucleus)
  - Fermi break-up
  - Evaporation $Z \leq 2$ (Weisskopf-Ewing)
  - Fission (Bohr-Wheeler)

Outline

Incidence of multifragmentation



Incidence of multifragmentation



Multifragmentation events

$$\text{Multifragmentation} \stackrel{\text{def}}{=} \text{3+ hot fragments}$$

MF probability

p + Fe

E_p (MeV)	INCL4.5	Isabel
500	3.47%	0.60%
1000	10.42%	3.07%
3000	16.27%	4.51%

p + Pb

E_p (MeV)	INCL4.5	Isabel
500	0.14%	0.10%
1000	1.18%	0.86%
3000	10.12%	4.32%

$\langle N_{\text{fragments}} \rangle$

p + Fe

E_p (MeV)	INCL4.5	Isabel
500	1.14	1.04
1000	1.37	1.13
3000	1.59	1.17

p + Pb

E_p (MeV)	INCL4.5	Isabel
500	1.02	1.02
1000	1.07	1.06
3000	1.41	1.18

Multifragmentation events

$$\text{Multifragmentation} \stackrel{\text{def}}{=} 3\text{+ hot fragments}$$

MF probability

p + Fe

E_p (MeV)	INCL4.5	Isabel
500	3.47%	0.60%
1000	10.42%	3.07%
3000	16.27%	4.51%

p + Pb

E_p (MeV)	INCL4.5	Isabel
500	0.14%	0.10%
1000	1.18%	0.86%
3000	10.12%	4.32%

$\langle N_{\text{fragments}} \rangle$

p + Fe

E_p (MeV)	INCL4.5	Isabel
500	1.14	1.04
1000	1.37	1.13
3000	1.59	1.17

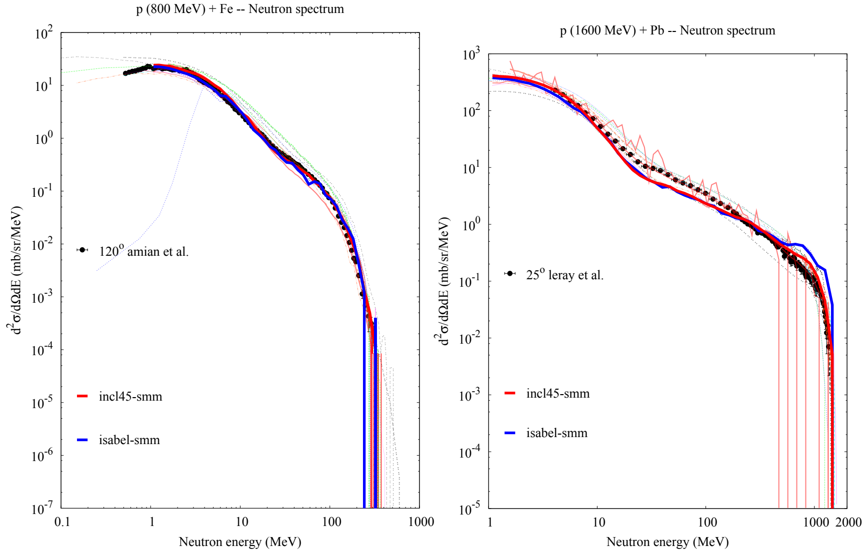
p + Pb

E_p (MeV)	INCL4.5	Isabel
500	1.02	1.02
1000	1.07	1.06
3000	1.41	1.18

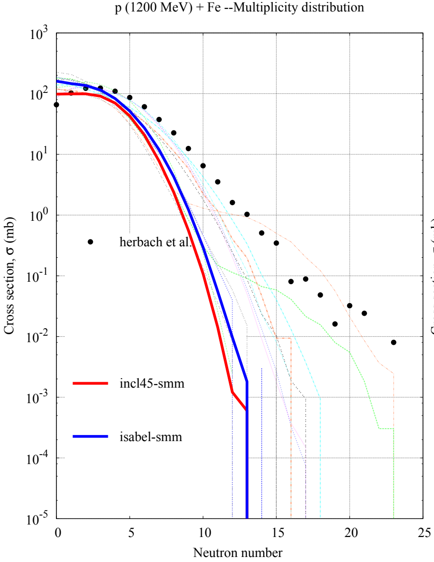
Outline

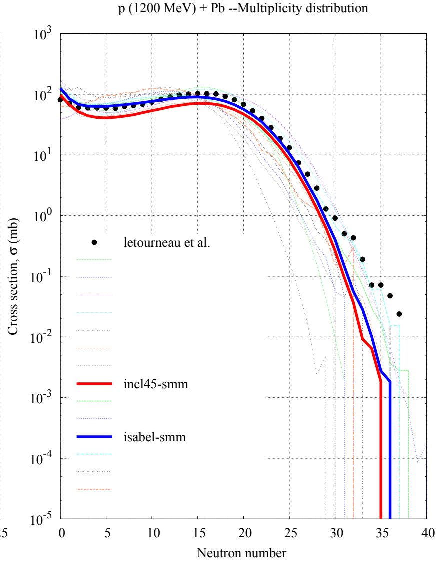
1. About SMM
   - Structure
   - Multifragmentation in spallation reactions
2. Results
   - Neutrons
   - LCP
   - Residue cross sections
3. Conclusions

Neutron spectra



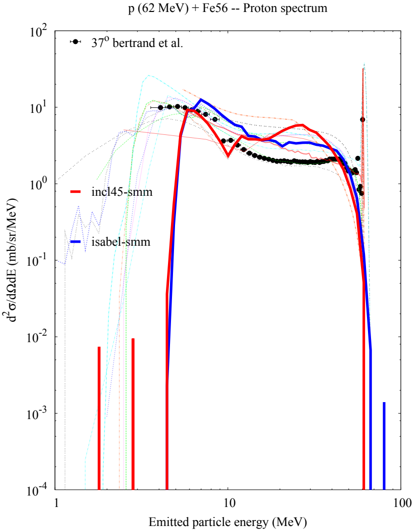
Neutron multiplicity distributions

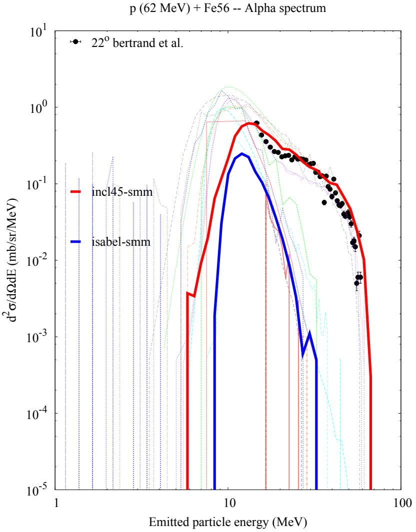




Outline

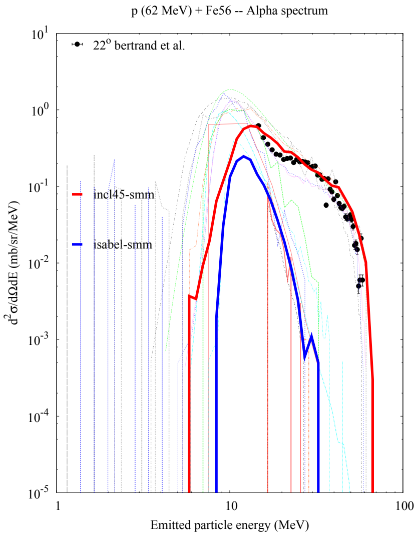
Low-energy systems



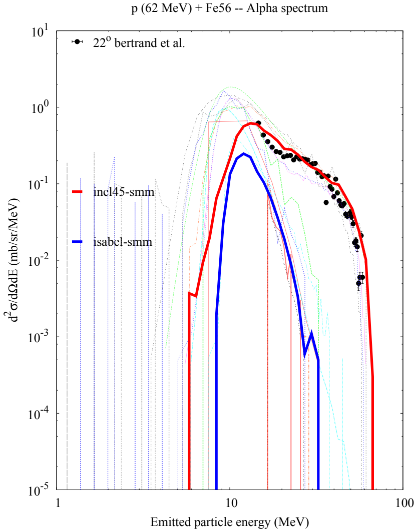


Low-energy systems

- De-excitation $\ll$ INC
- $E \lesssim$ INC theoretical limit



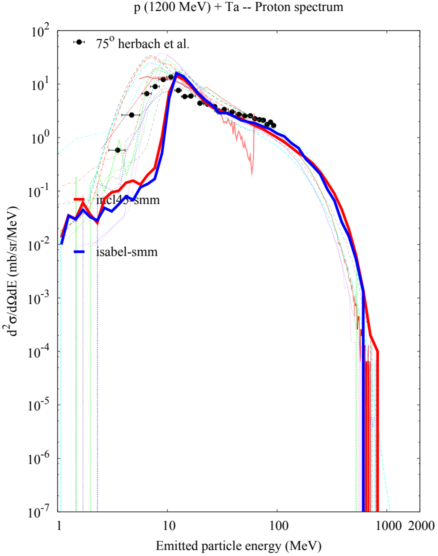
Low-energy systems

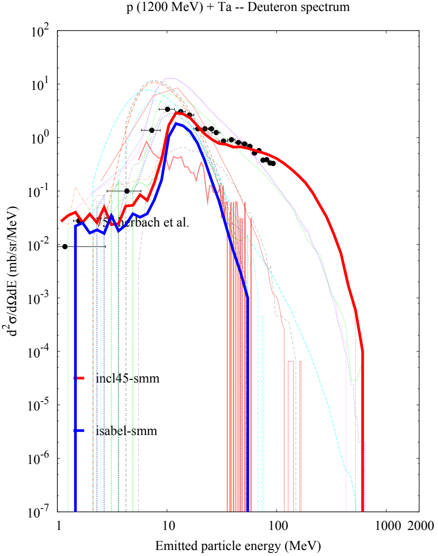


No pre-equilibrium clusters from Isabel!

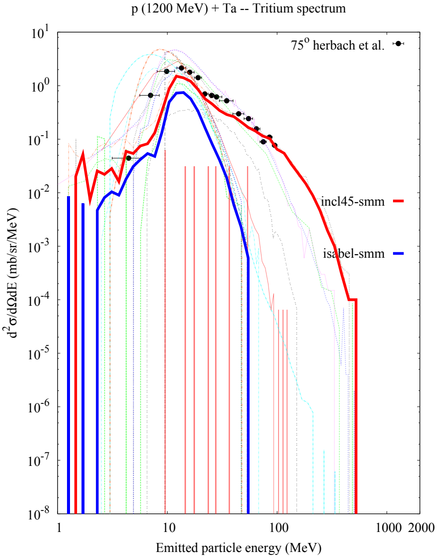
- Difficult to assess the cascade contribution
- Meaningful comparison only with INCL4.5

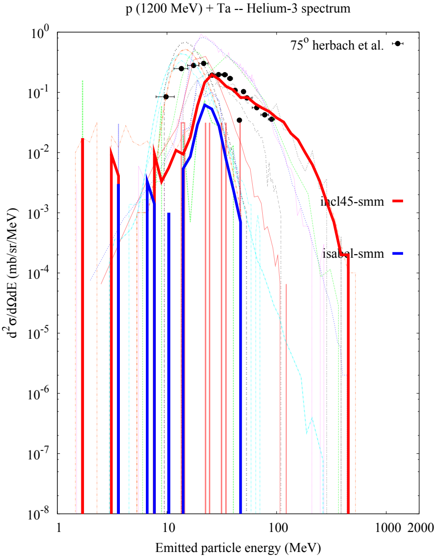
High-energy systems



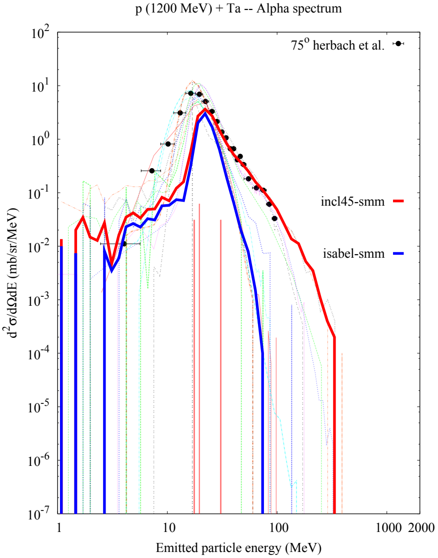


High-energy systems





High-energy systems



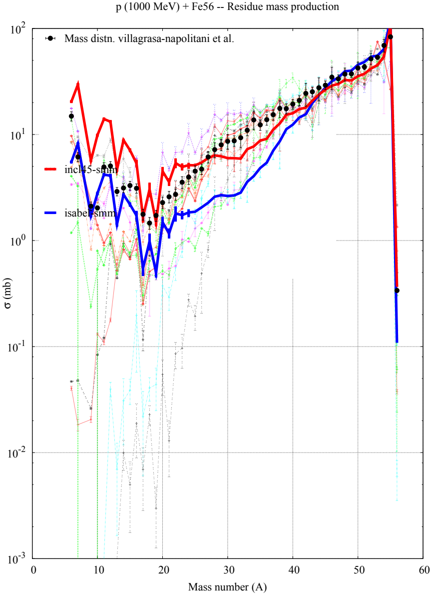
LCP spectra

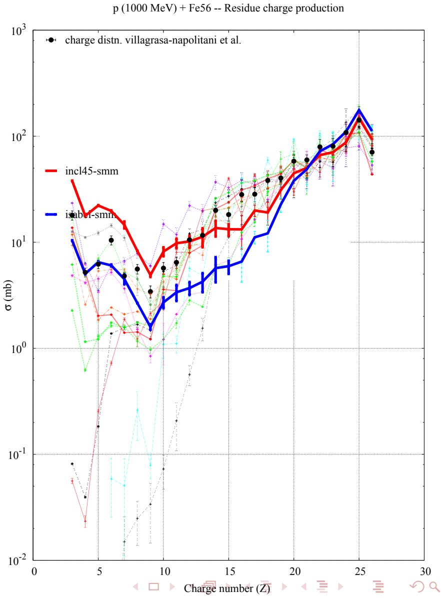
- Yields OK within a factor of 2
- Barriers are too sharp!
  - On the to-do list

Outline

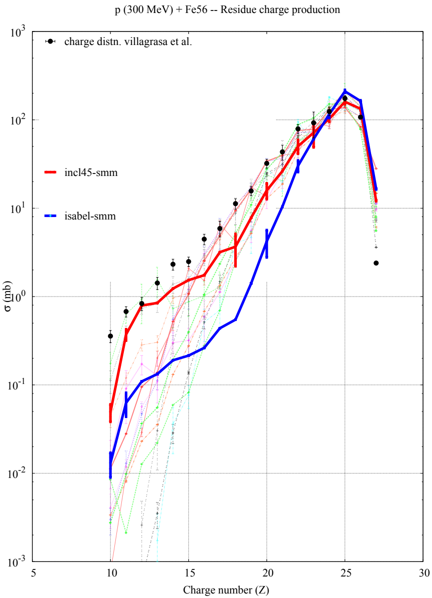
1. About SMM
   - Structure
   - Multifragmentation in spallation reactions
2. Results
   - Neutrons
   - LCP
   - Residue cross sections
3. Conclusions

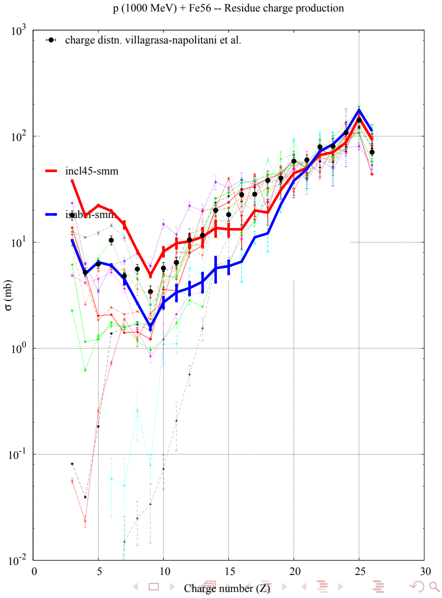
$p + {}^{56}$Fe, Z distributions





$p + {}^{56}Fe$, Z distributions





p + ^{56}Fe, Z distributions

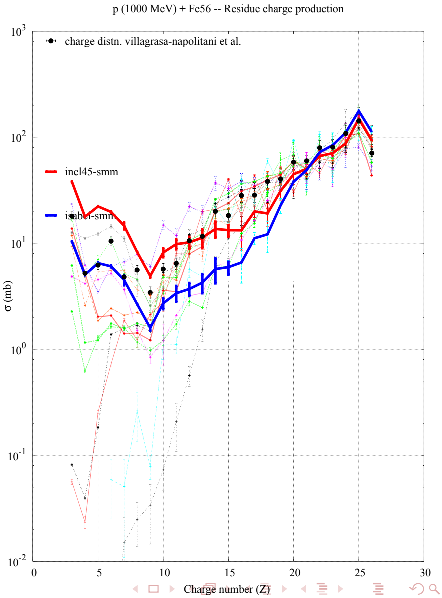
Sensitivity to INC

Isabel:

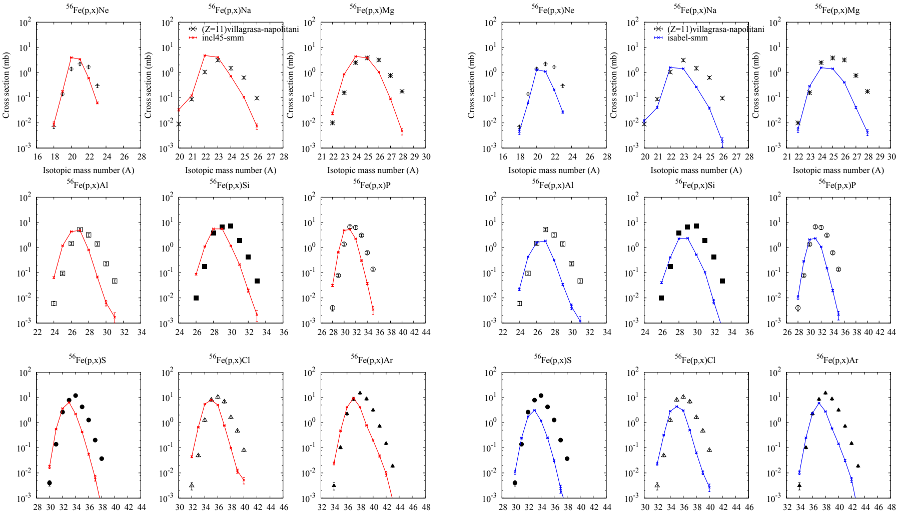
- ✗ not enough evaporation products
- ✓ IMFs ∼ OK

INCL4.5:

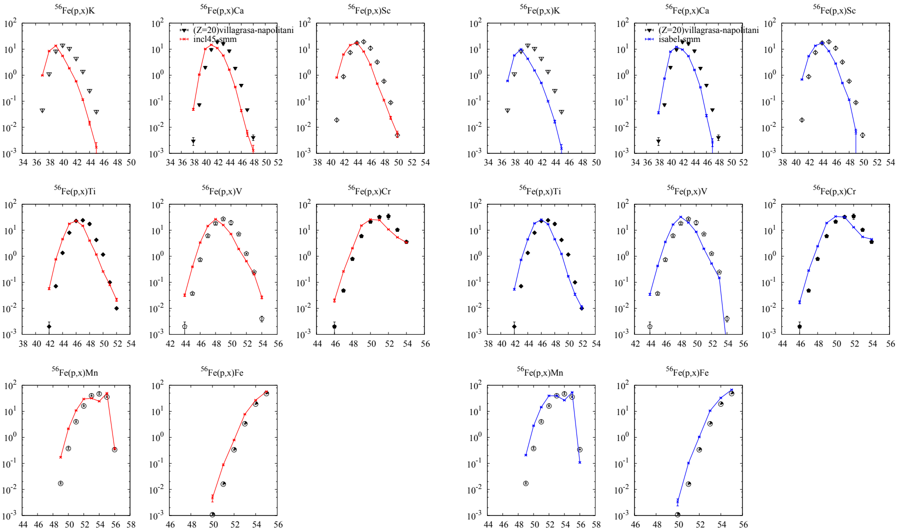
- ✓ evaporation products ∼ OK
- ✗ too many IMFs



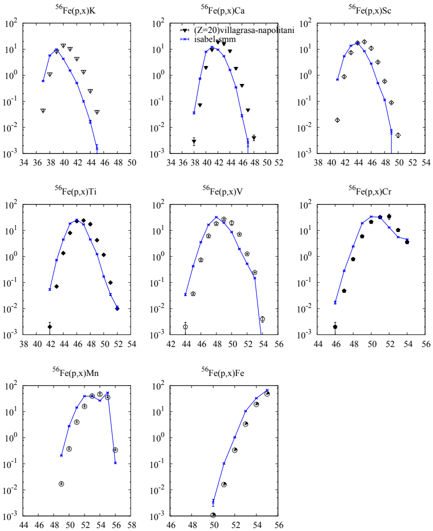
p + ^{56}Fe, isotopic distributions



p + ^{56}Fe, isotopic distributions



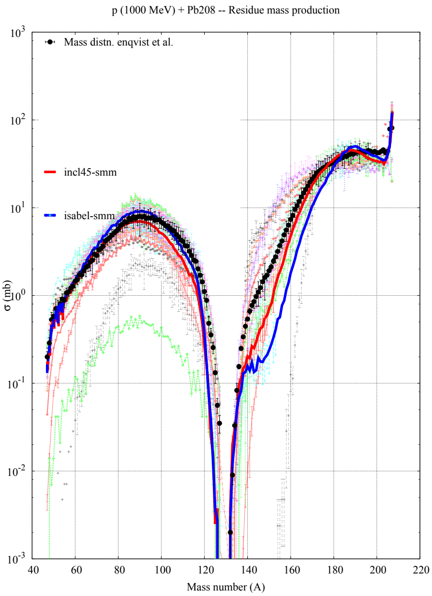
$p + {}^{56}$Fe, isotopic distributions

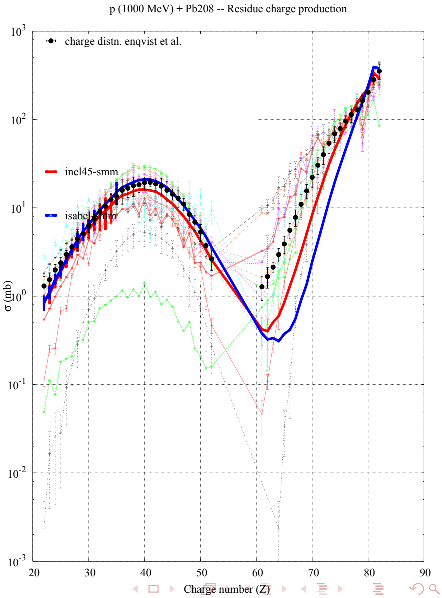


Solid result

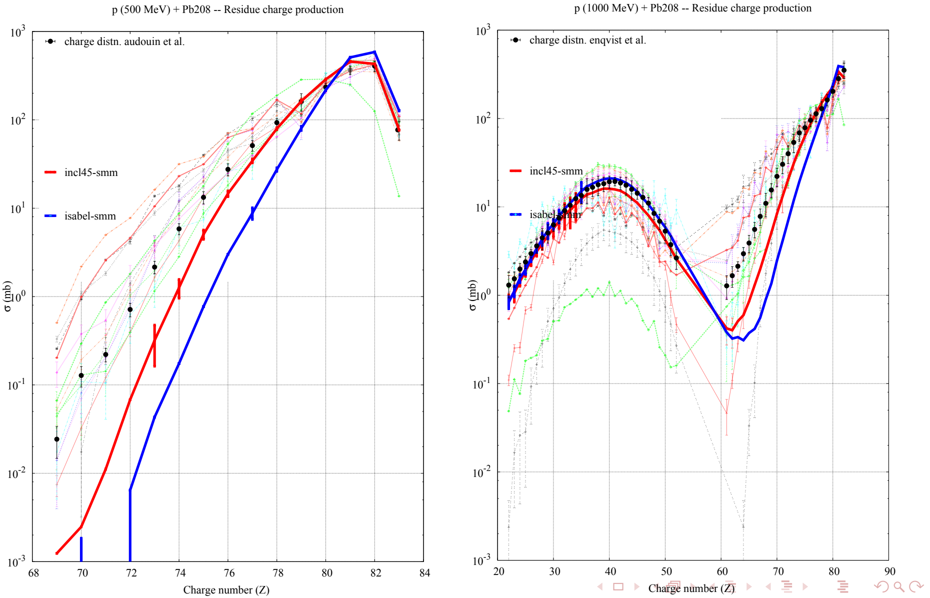
Residues are too neutron-poor

$p + {}^{208}$Pb, Z distributions





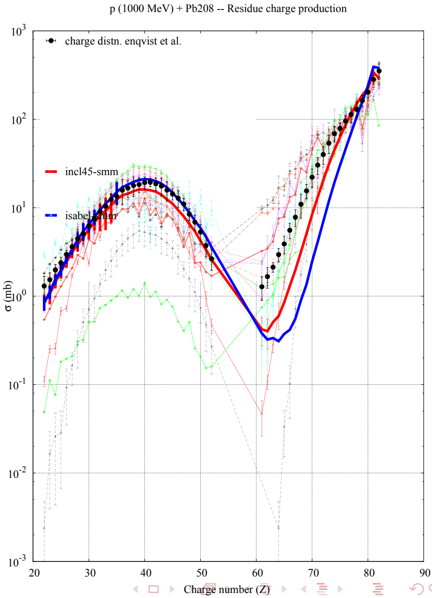
p + ^{208}Pb, Z distributions



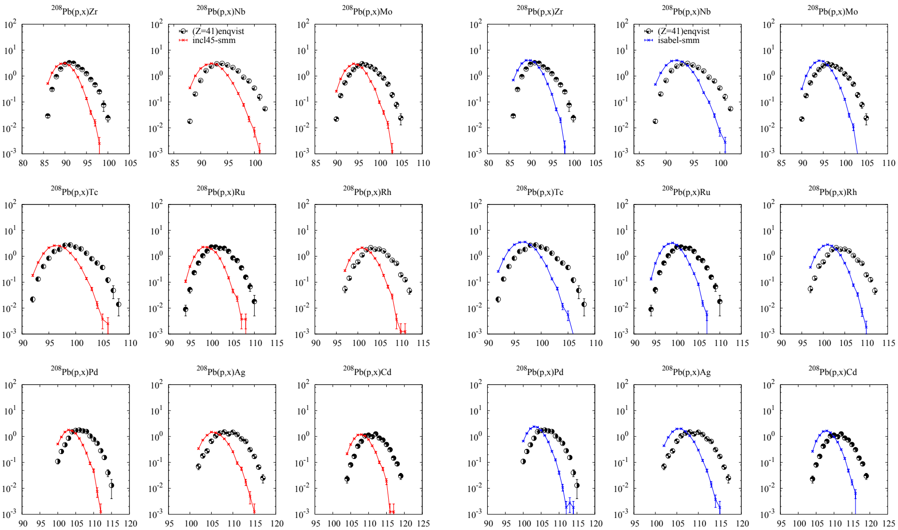
$p + {}^{208}$Pb, Z distributions

Solid results

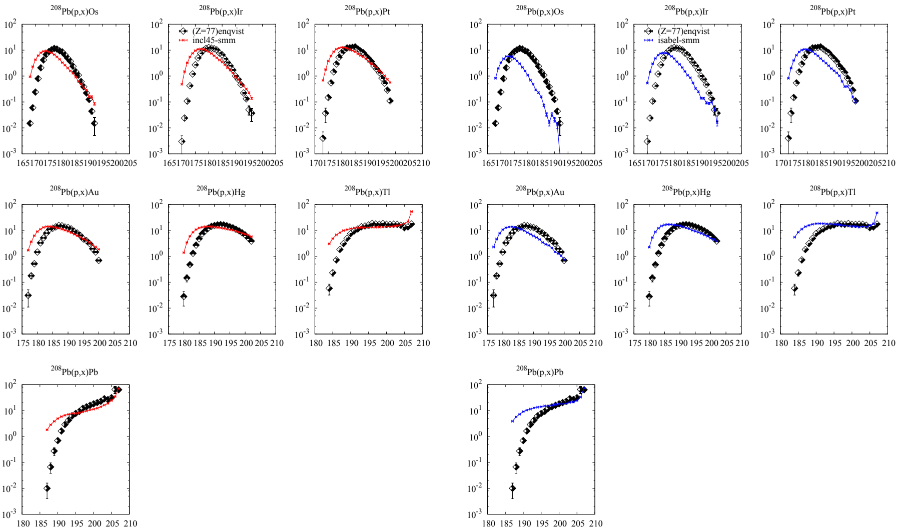
- ✓ Fission XS ∼ OK
- ✗ Evaporation shoulder
  - IMF emission?



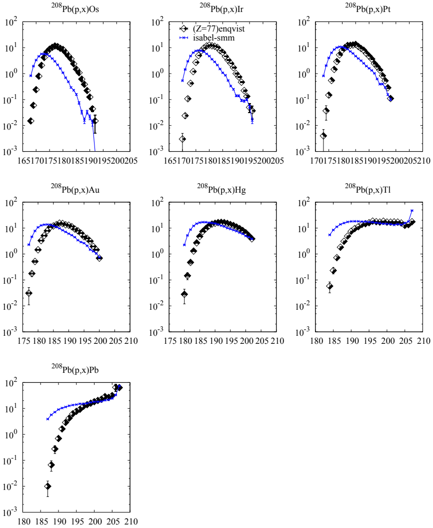
p + ^{208}Pb, isotopic distributions



p + ^{208}Pb, isotopic distributions



p + ^{208}Pb, isotopic distributions

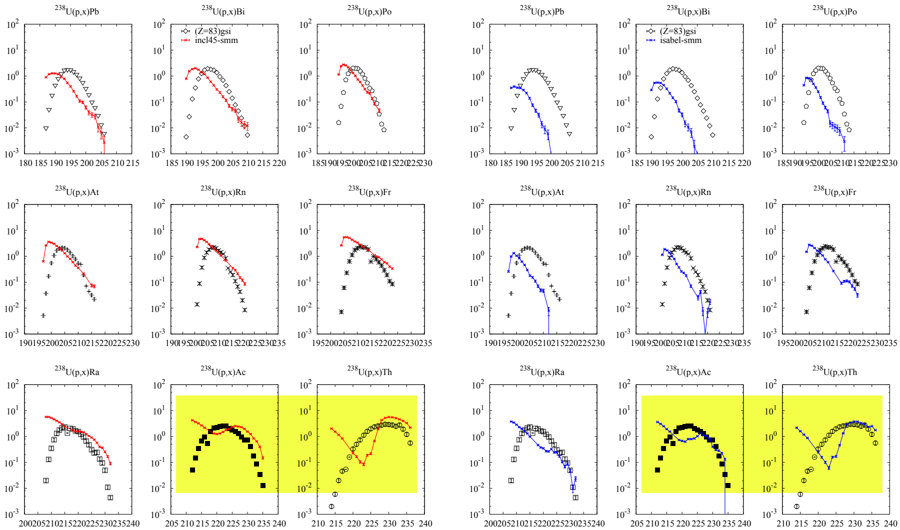


Solid result

Residues are too neutron-poor

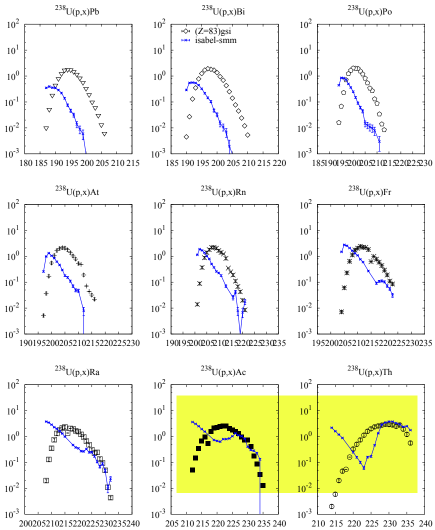
- Same conclusion can be drawn for Fe, Pb and U

$p + {}^{238}$U, isotopic distributions



$p + {}^{238}$U, isotopic distributions

A clue for the neutron-poor residues?



Conclusions

- Multifragmentation in SMM is frequent!
- ✓ Neutrons
- LCP
  - ✓ Yields
  - ✗ Barriers
- Residues
  - ✓ Fission
  - ?? Evaporation residues
  - ✗ Isospin

To do

- Quantify the importance of MF
- Refine CN de-excitation
- Correlations would make this task easier
  - Next intercomparison?

Conclusions

- Multifragmentation in SMM is frequent!
- ✓ Neutrons
- LCP
  - ✓ Yields
  - × Barriers
- Residues
  - ✓ Fission
  - ?? Evaporation residues
  - × Isospin

To do

- Quantify the importance of MF
- Refine CN de-excitation
- Correlations would make this task easier
  - Next intercomparison?

Thank you!