GEMINI++

Today's Daily Overview for Gemini
You might have a problem that gets between your career and your family obligations. Of course you do the right thing, but it may turn out to be for the best in pretty much every way once it's all behind you.
You can depend on your people today -- they should come through for you in a way that reinforces your faith in them. Plans are firm and nobody should be late unless it's inescapable.
You're not in the loop -- but nobody else is, at least not consciously! You may find that there's a lot more going on under the surface of your interactions than usual, but you may not understand it until next week.

Two sets of calculations

INCL- GEMINI
Isabel – GEMINI

Disclaimer
The ability of GEMINI++ to predict correctly depends on the compound nucleus Z,A,Ex,J distributions from INCL/Isabel

Useful to compare to INCL/Isabel-ABLA/SMM variants

GEMINI++ is married to INCL and Isabel in the intercomparison

Gemini (the twins) is a very complex and confusing sign. To some people you can seem like a wonderful friend, while to others you will seem two-faced and sneaky. You will act like a child for most of your life. That includes both the good and bad characteristics of children. You are happy and energetic when things go right for you. However, when things go wrong, you can be passive-aggressive and very mean. You find decisions hard to make, since you can never stay with the one that you originally choose. You tend to fight loosing battles for something that you call a "moral" cause (even though you know it isn't). One quality (you decide whether it's good or bad) you have is the ability to lie and appear that you are telling the complete truth. You prefer to use someone else's solution to a problem than thinking of your own. Many of Gemini's poorer traits are due to your lack of self-esteem. It is very tough to get your attention. You will be thinking about many things at a time and you can't concentrate on any particular thing at one time. You may be praising somebody but at the same time you will be thinking against him(her). But the most intelligent people on the earth are Geminians.

Romantic behavior:
The uncertainty of the Gemini temperament does not favor lasting affairs and is the cause of much friction in their love life. You are little swayed by passion, and the only way to retain your fidelity is to meet your varying moods constantly in a fair and unsuspecting manner. You prefer light relationships to more lasting ones.

GEMINI++

Statistical-model decay code.
Only binary decays – no multifragmentation.

Hauser-Feshbach for *n,p,d,t*,^{3}He,α,Li emission
Bohr-Wheeler for symmetric fission when there is a fission peak
Moretto for imf's
Gamma-ray emission at low excitation energies.

Fission Mass distributions from systematics of Rusanov *et al.*
Fission and asymmetric imf barriers from Sierk's Finite-Range calculations.
(interpolation and extrapolation)

GEMINI++ was developed for heavy-ion fusion reaction which have high spins.
We have tried to develop code that works for both spallation and heavy-ion reactions

The Hauser Feshbach formalism is CPU intensive
Is it needed for spallation?

Statistical model parameters

Level densities and transmission coeffs. (inverse cross sections) adjusted to reproduce heavy-ion induced fusion data

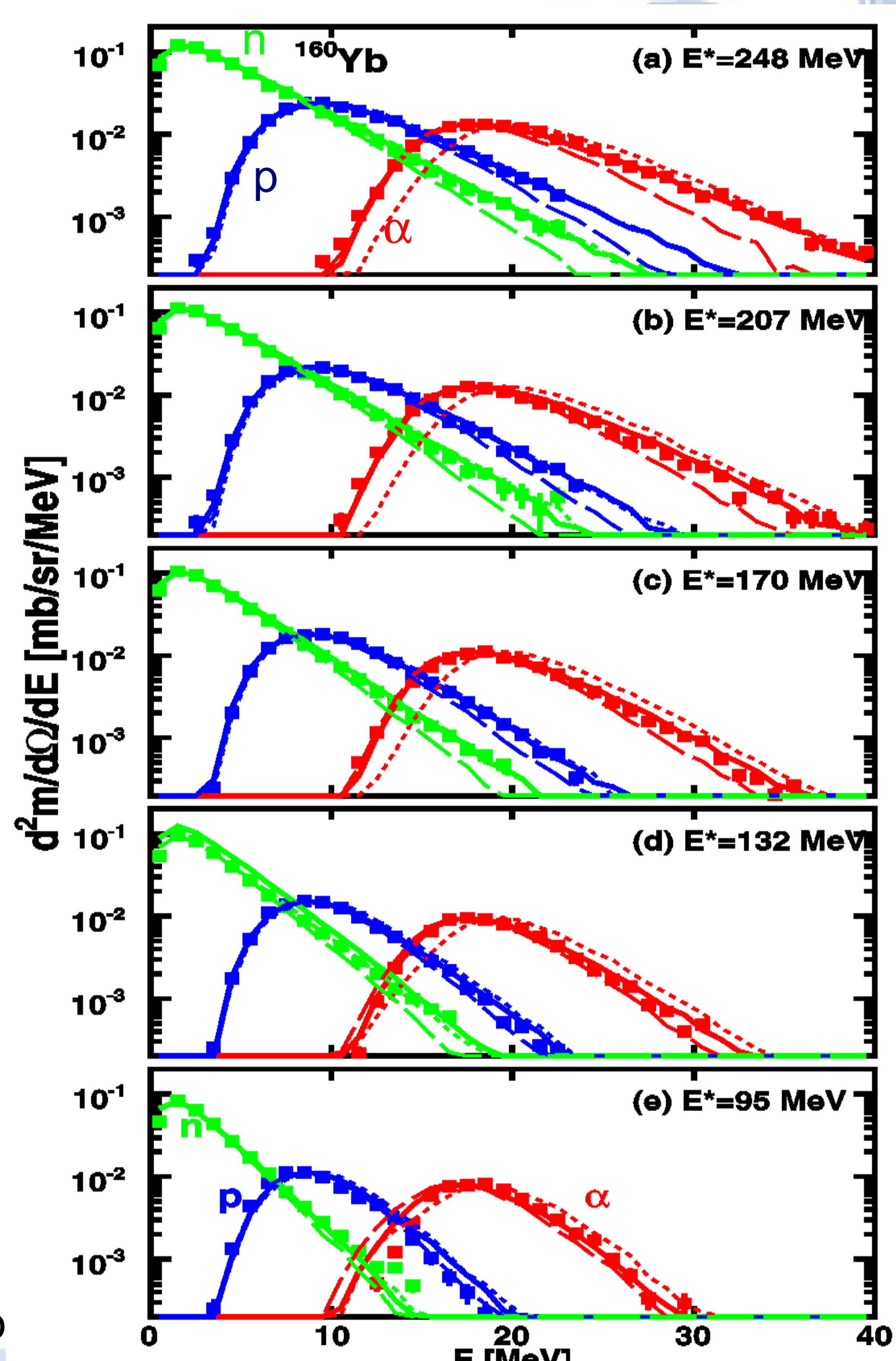
Excitation-energy dependent level-density parameter

a) low energies – washing out of shell effects (Ignatyuk)

b) larger energies – washing out of long-range correlations (collectivity). Strongly mass dependent.

Transmission coeff.

Include a distribution of Coulomb barriers due to thermal fluctuations. width~sqrt(T) (needed for α and heavier fragments)

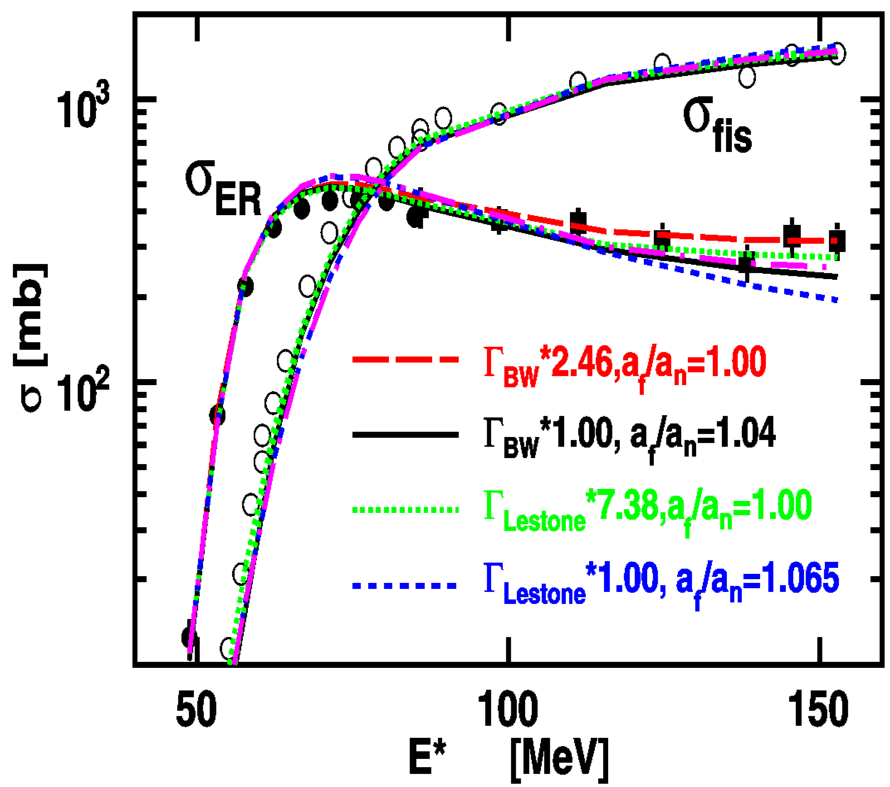


^{60}Ni+^{100}Mo->^{160}Yb

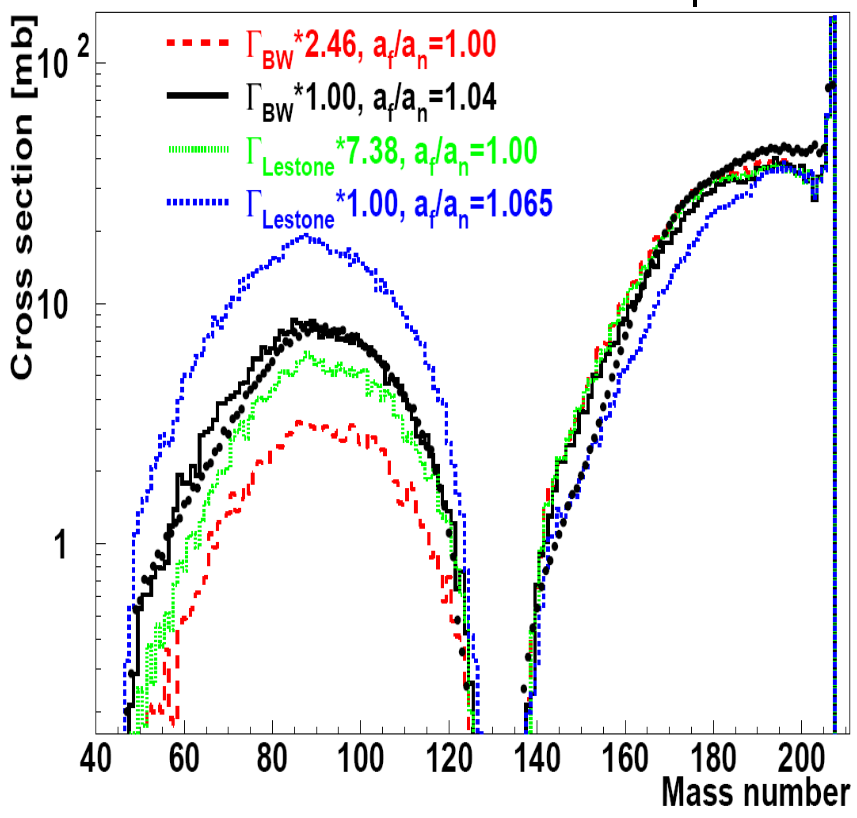
Fission Probability

Bohr – Wheeler decay width
$a_f/a_n = 1.04$
Sierk fission barriers
no fission transients
Gives a consistent description
of heavy-ion fusion-fission and Spallation data

$^{19}F+^{181}Ta \rightarrow ^{200}Pb$



1GeV p + Pb



n,p,d,t,3He,α differential xsections

General considerations

Statistical multiplicities for 1 GeV p+Pb using input from INCL

Neutron = 10.7
Proton = 0.313
Deuteron = 0.233
Triton = 0.251
3He = 0.012
α = 0.591

Neutrons are the dominant light-particle decay mode and remove most of the excitation energy.

You cannot double the number of neutrons and still conserve energy. Neutrons are thus constrained by energy conservation and are least sensitive to the statistical-model ingredients.

Excitation-energy dependence

Average excitation-energy of immediate parent associated with evaporation

Neutron = 111 MeV
Proton = 184 MeV
Deuteron = 244 MeV
Triton = 251 MeV
3He = 312 MeV
α = 166 MeV

Average compound nucleus E* = 162 MeV.

Decay width $\Gamma \sim \exp(E_{cost}/T)$, Temperature $1/T = d \ln(\rho)/dE^*$

E_{cost} = separation energy + Coulomb barrier

Costly particles such α *t*,*d*,3He require large temperatures to get a non-negligible decay width, so these are heavily biased to events with large excitation energies. These particle are thus sensitive to the statistical-model parameters at large excitation energies.

Statistical-model parameters important for differential xsections

Level-density and Coulomb barriers (inverse cross section, transmission coeff)

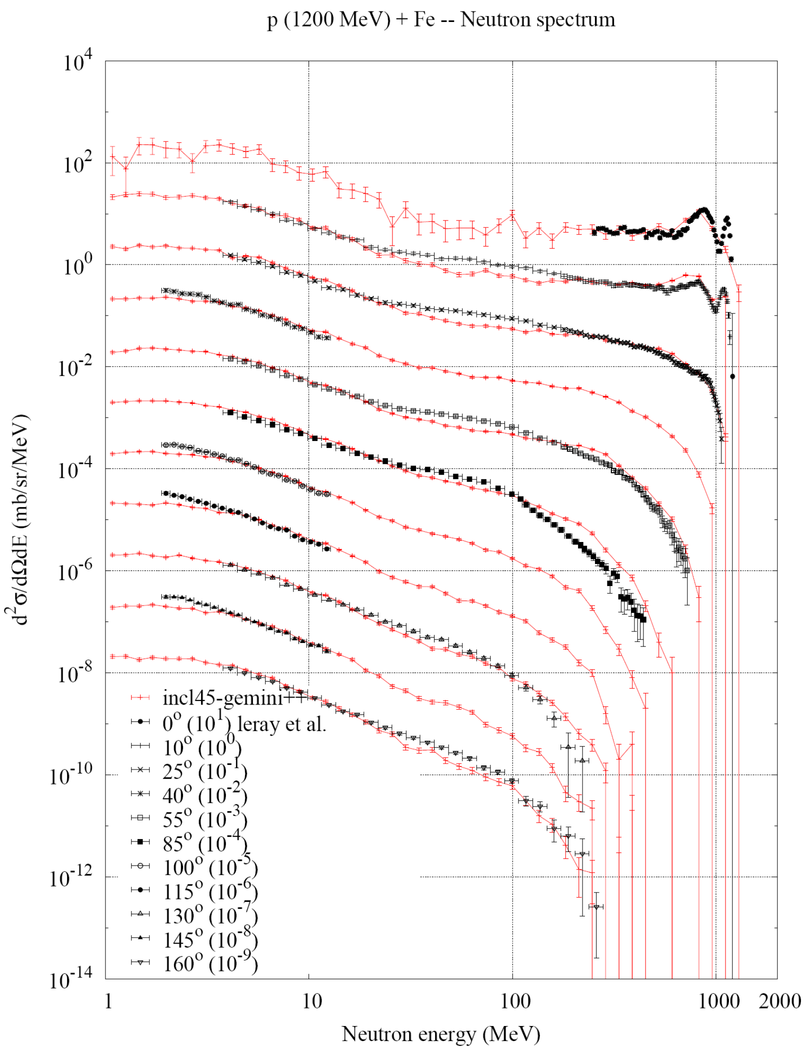
Costly particles are very sensitive to nuclear temperature (level density)

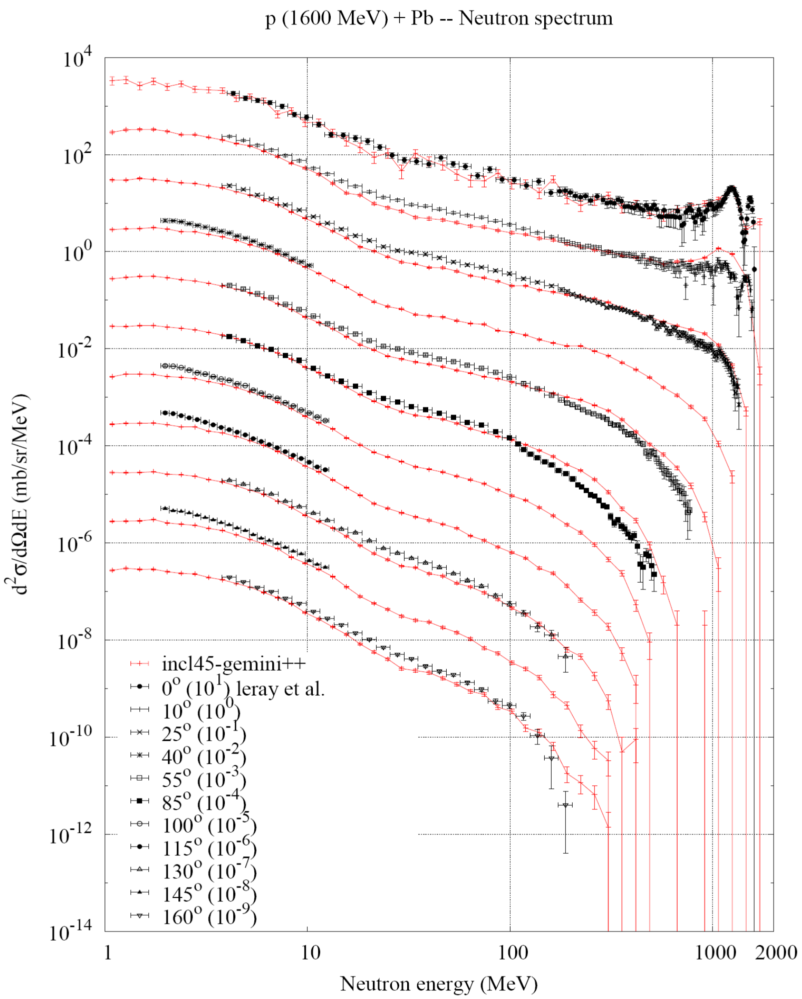
Increase in multiplicities for $a=A/7.3$ to $a=A/11$ MeV^{-1}
Using INCL 1 GeV *p*+Pb compound nuclei

Neutrons = -8%
Protons = 13%
Deuterons = 52%
Tritons = 51%
3He = 118%
α = 49%
Fission = -20%

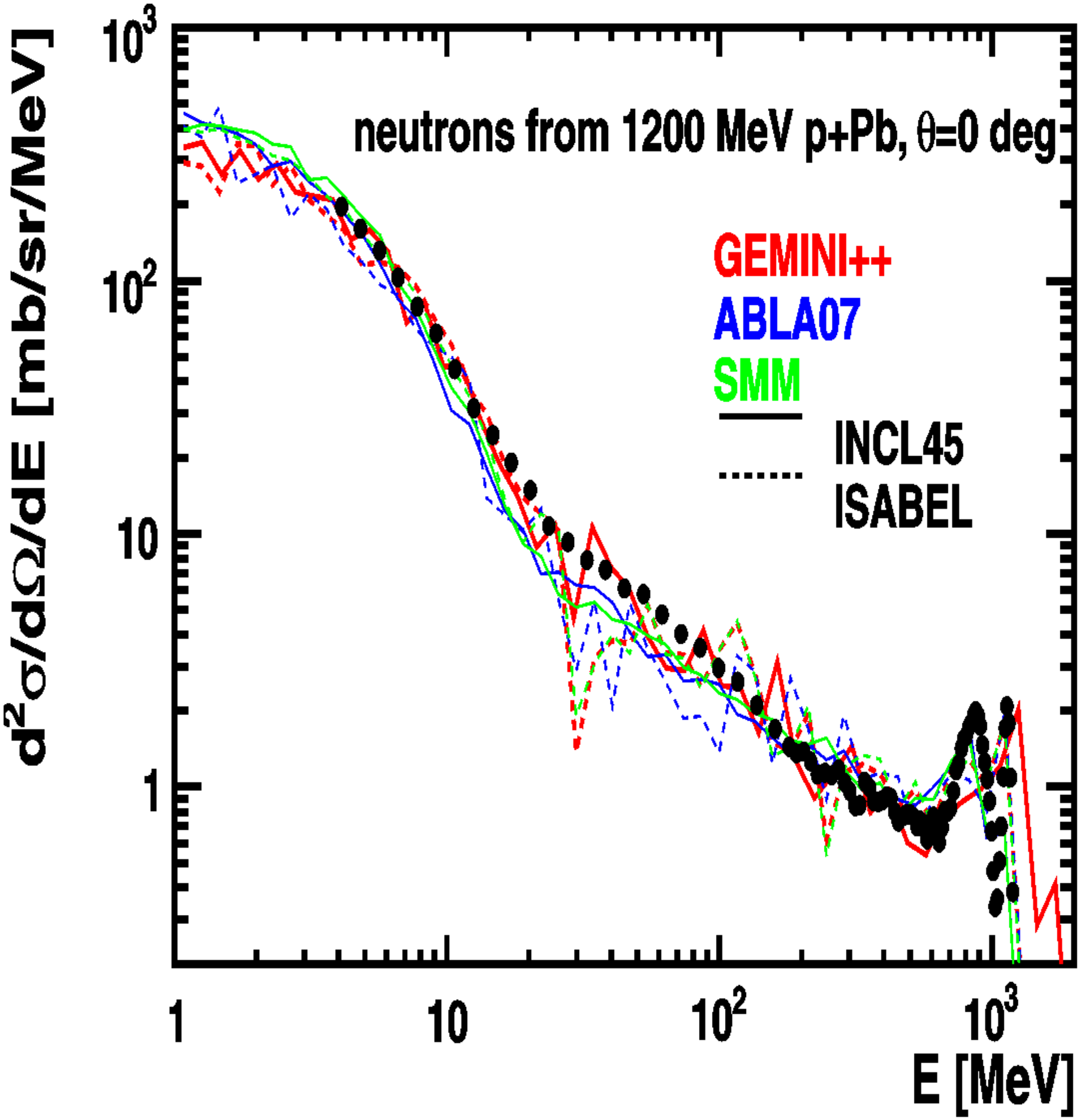
Neutrons differential xsections

Evaporation component found at low energies
Good agreement



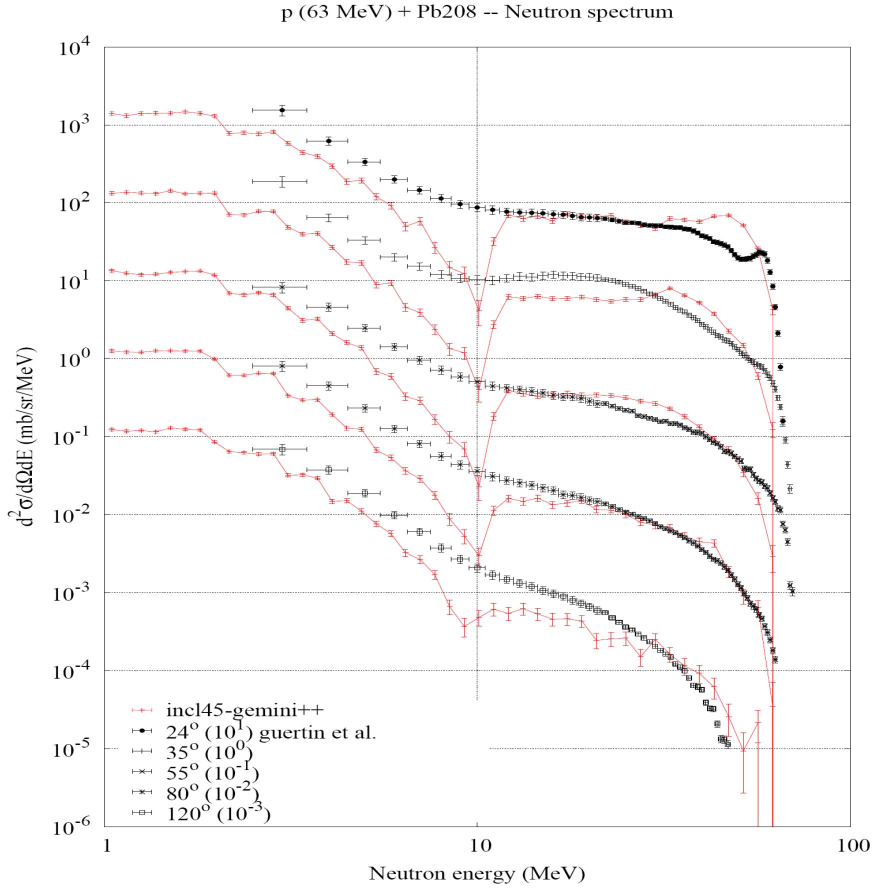


No dependence on GEMINI++/ABLA/SMM as expected

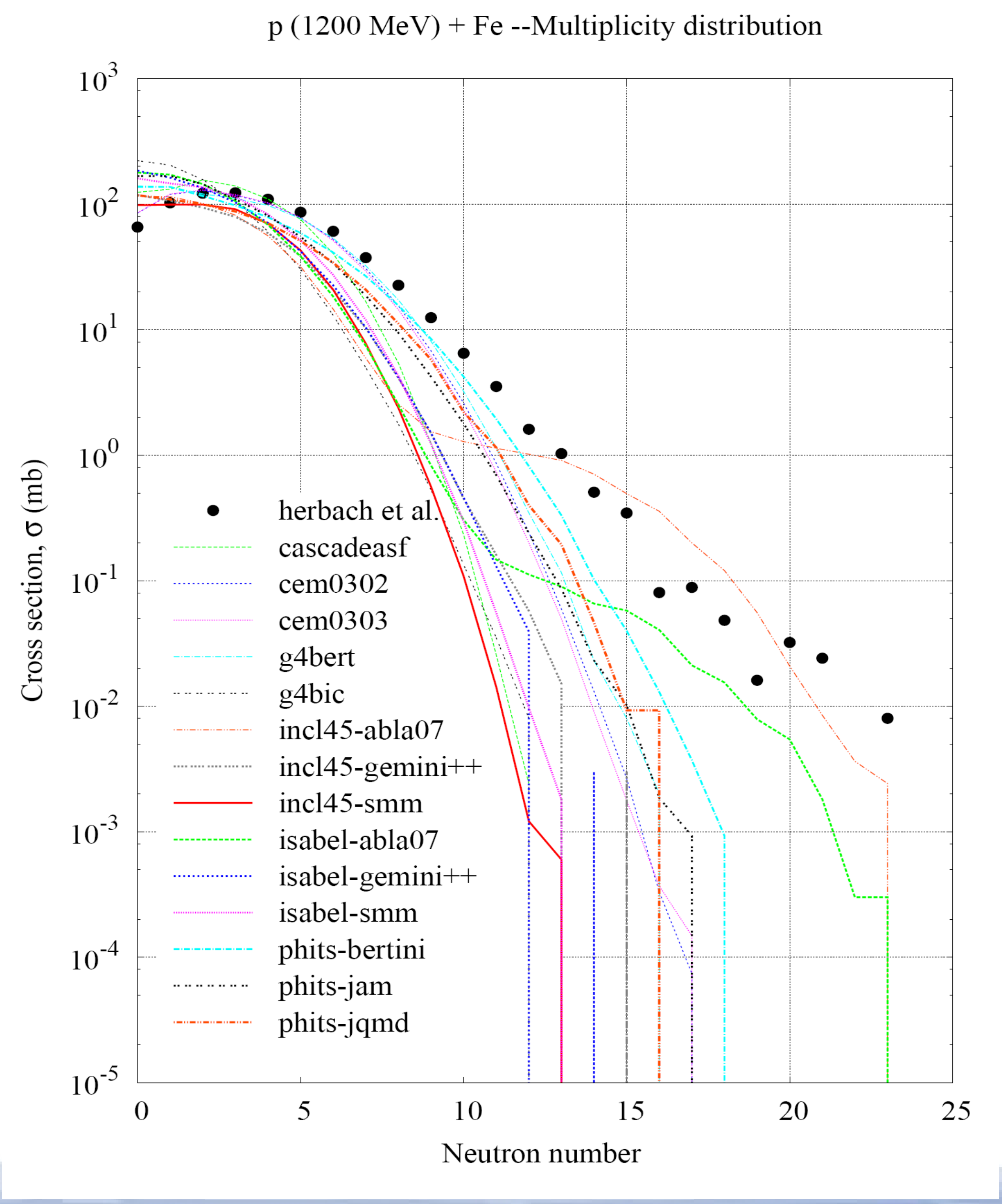


Low bombarding energies

At low bombarding energies, I trust GEMINI++ the most and INCL/Isabel the least



N-multiplicities



INCL/GEMINI
and Isabel/GEMINI
both two narrow?

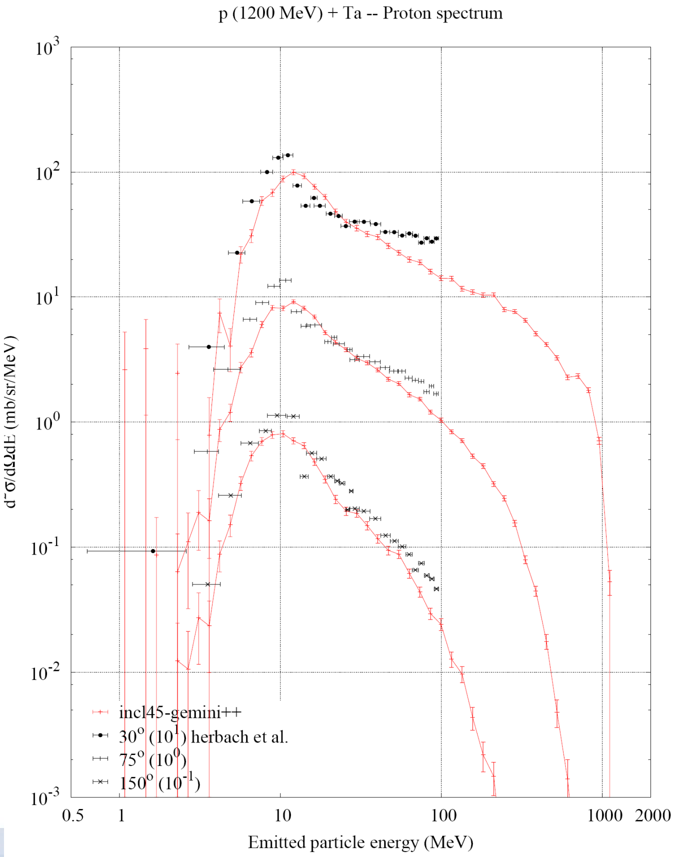
Is this a problem with the initial stage or GEMINI?

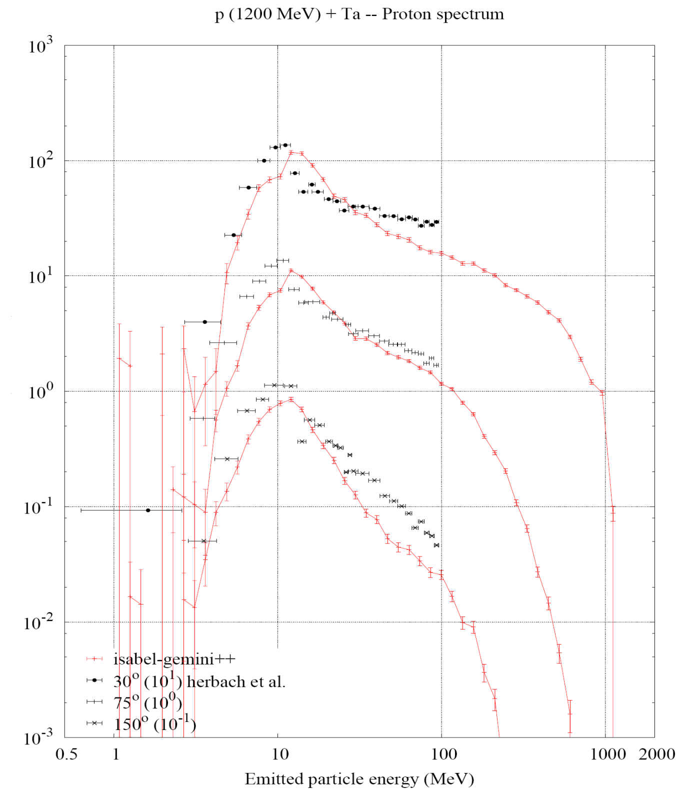
Protons

GEMINI++ does do very well

Coulomb barrier is wrong?

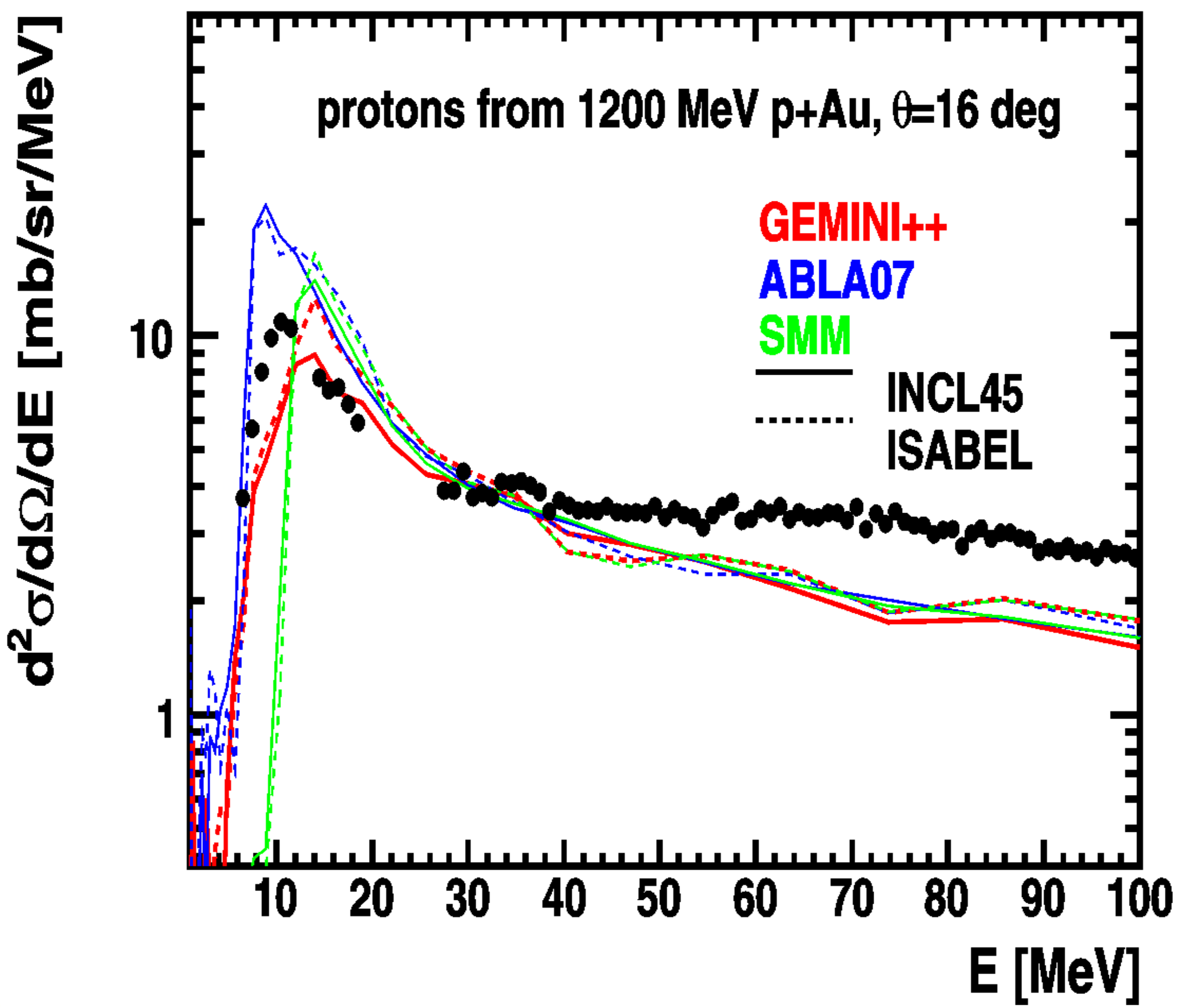
GEMINI gets this right for
protons from heavy-ion fusion reactions





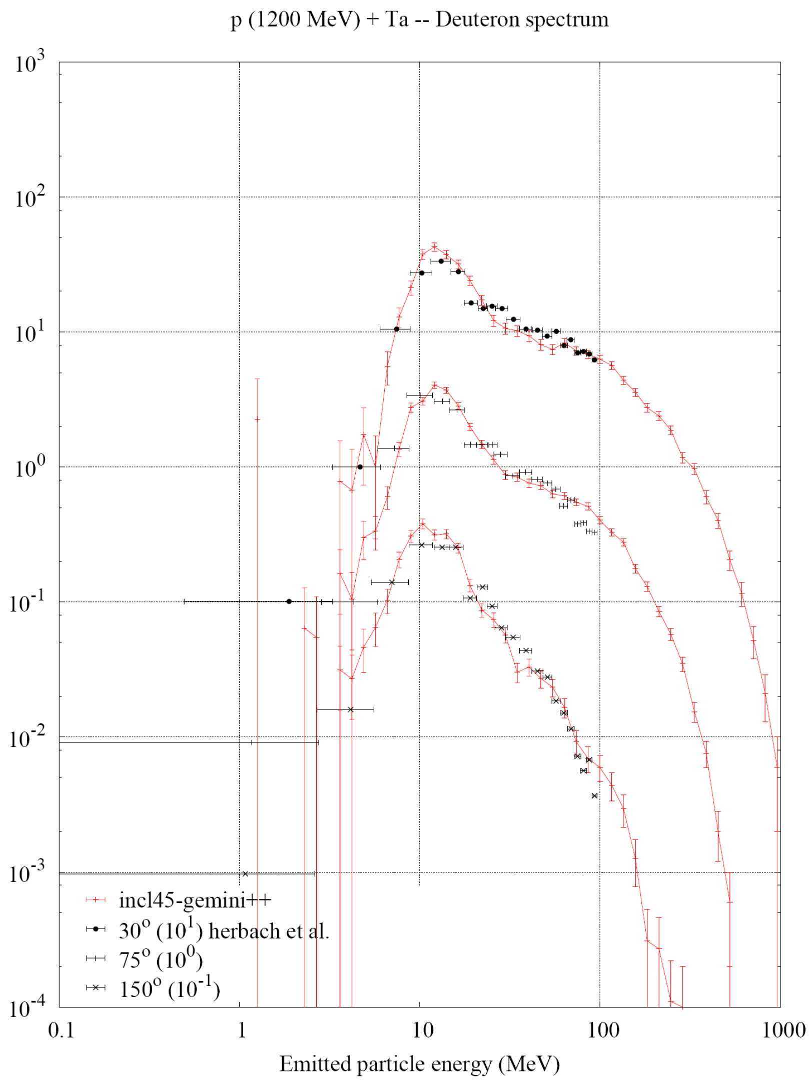
Proton differential xsections

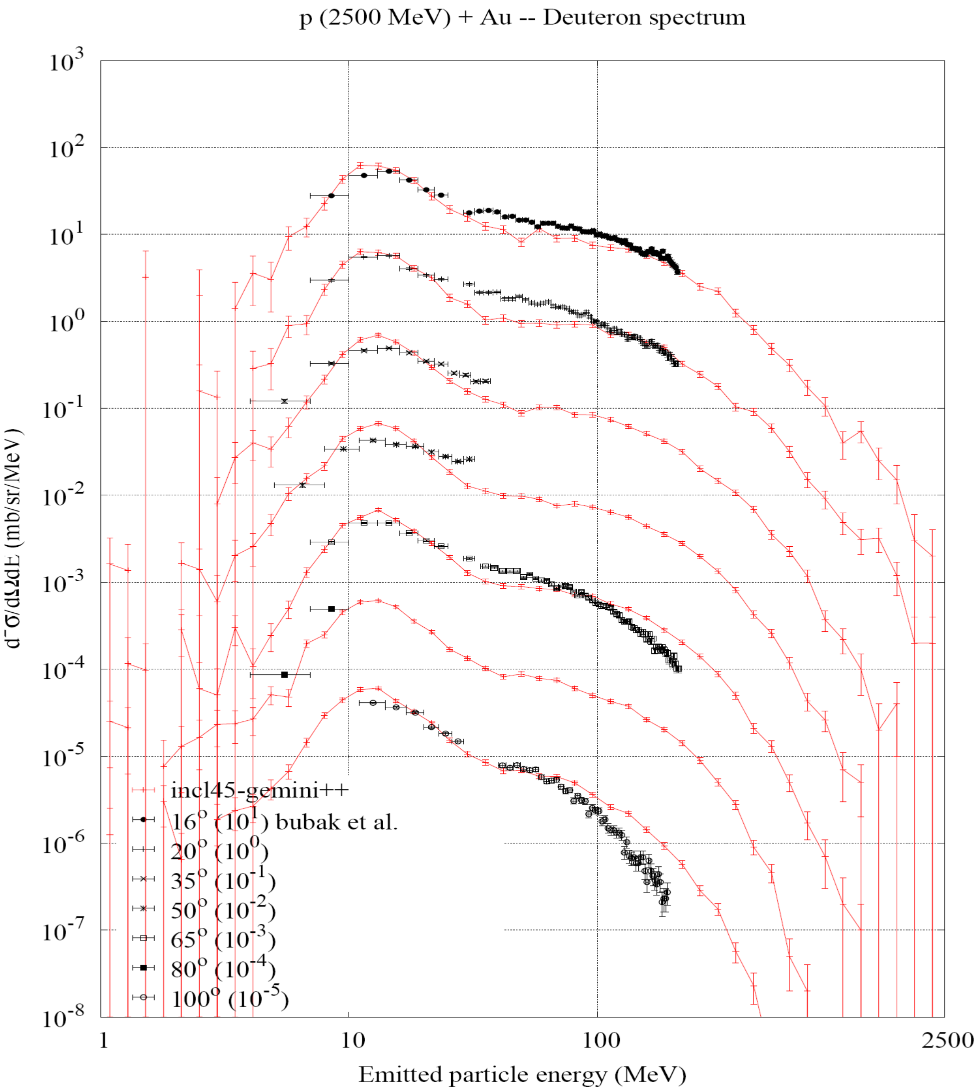
Too few statistical protons – need ~50% more



deuteron

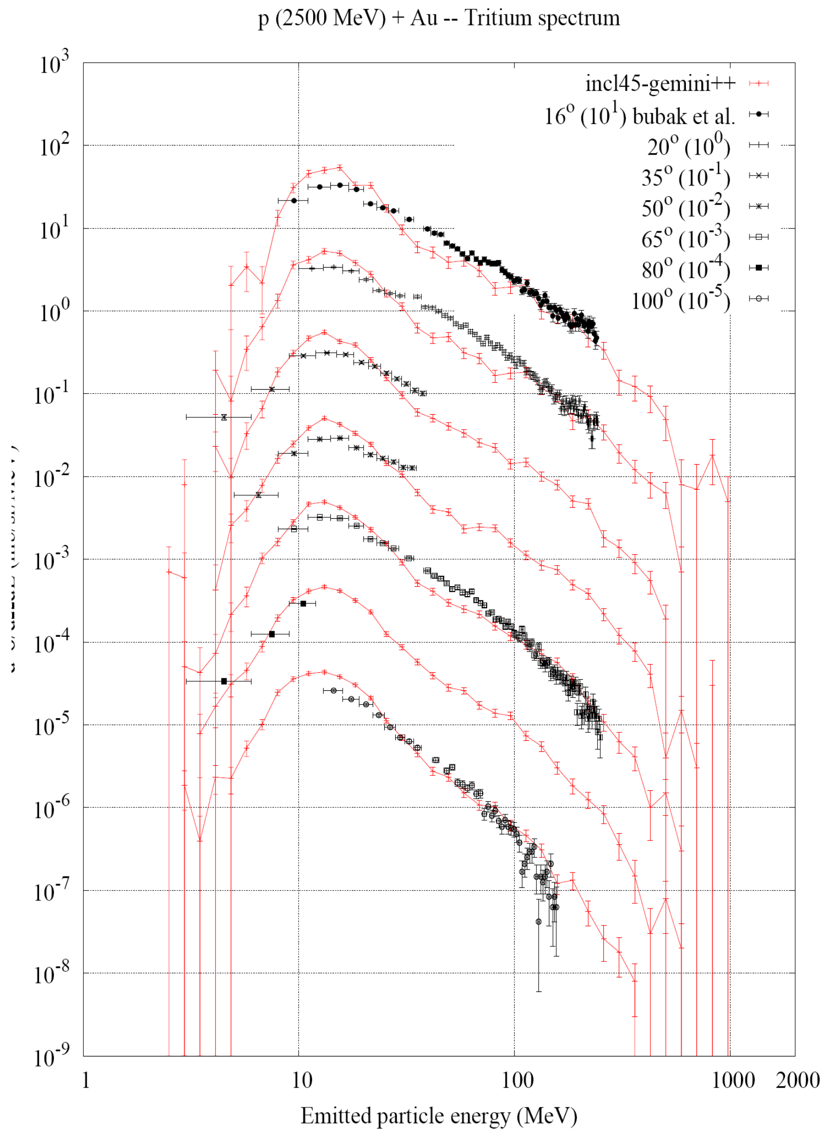
GEMINI is reasonable – predicts slightly too many deuterons

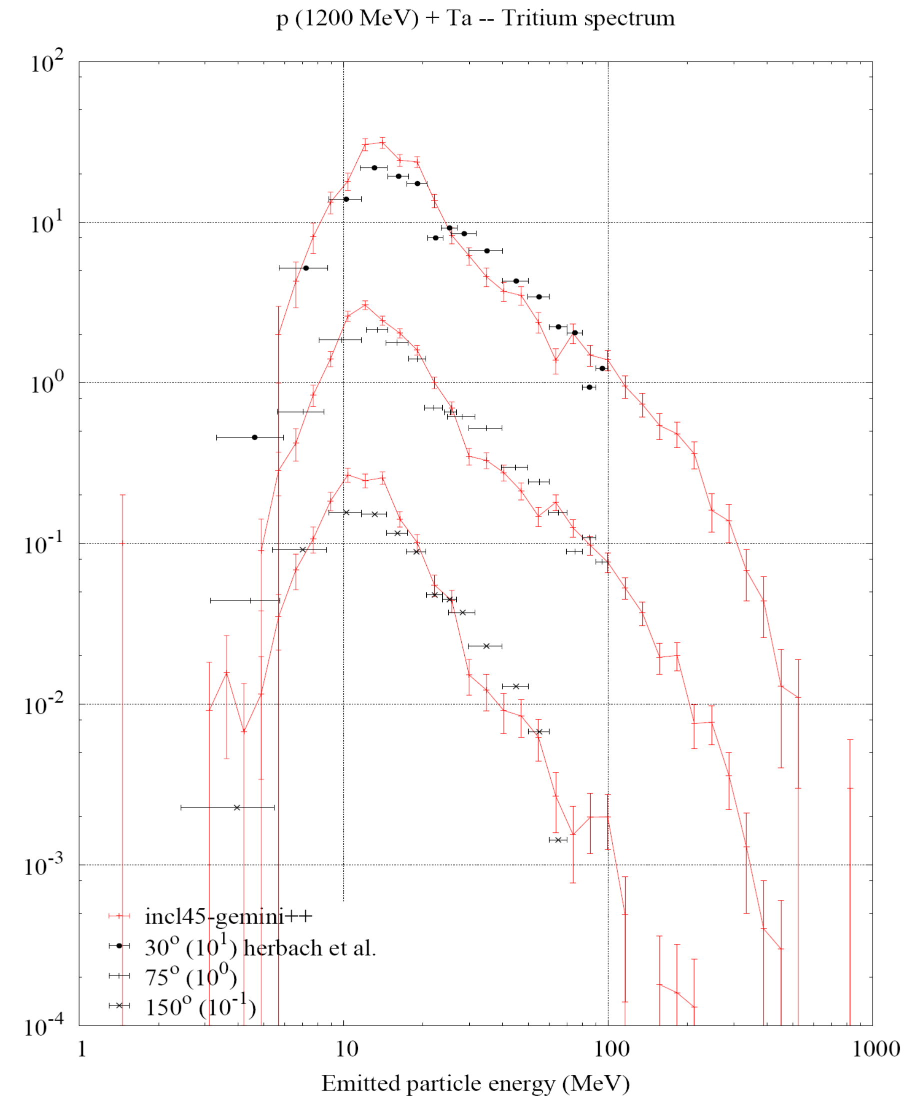




tritons

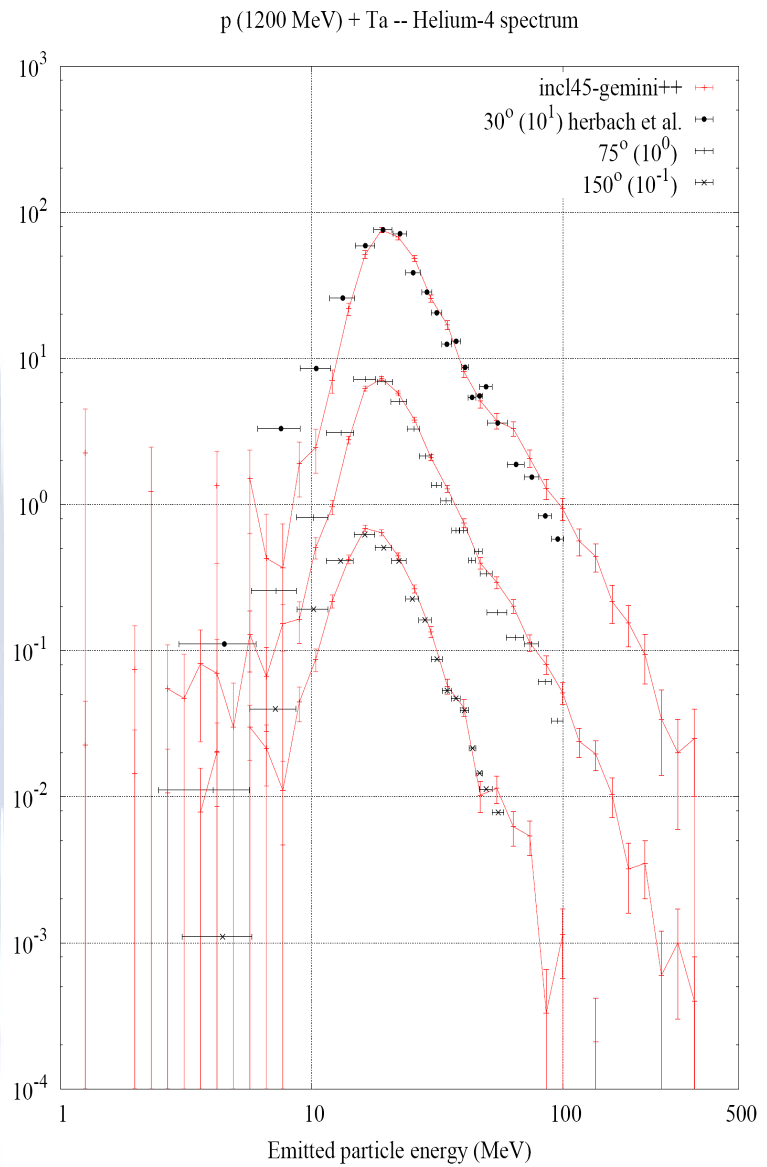
GEMINI predicts too many tritons (factor of <2)

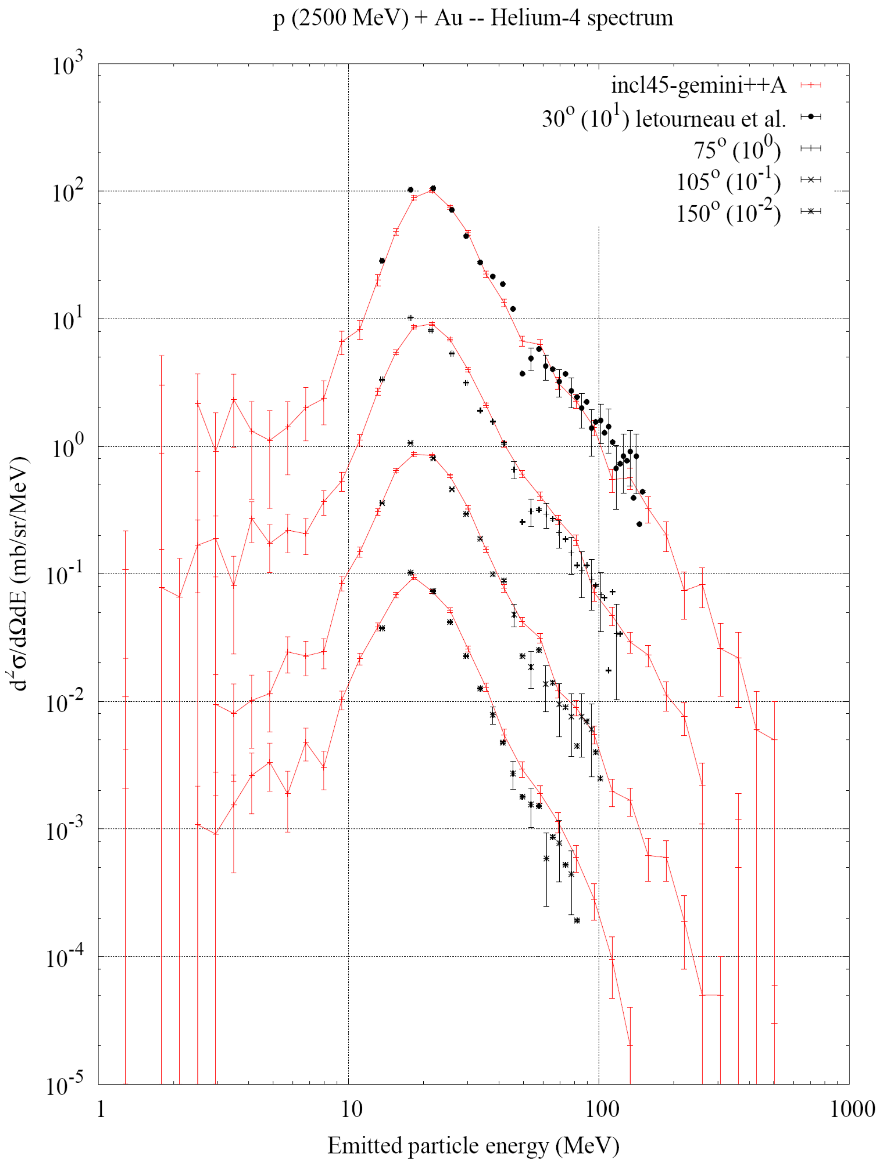




alpha

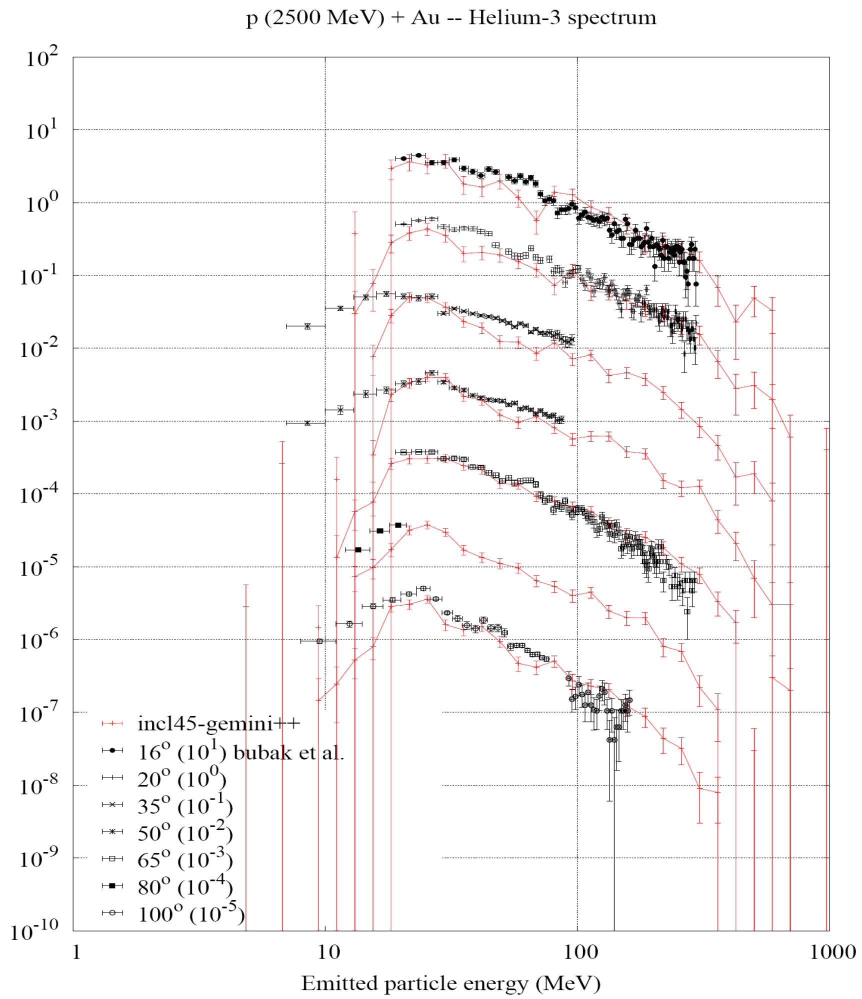
Good reproduction

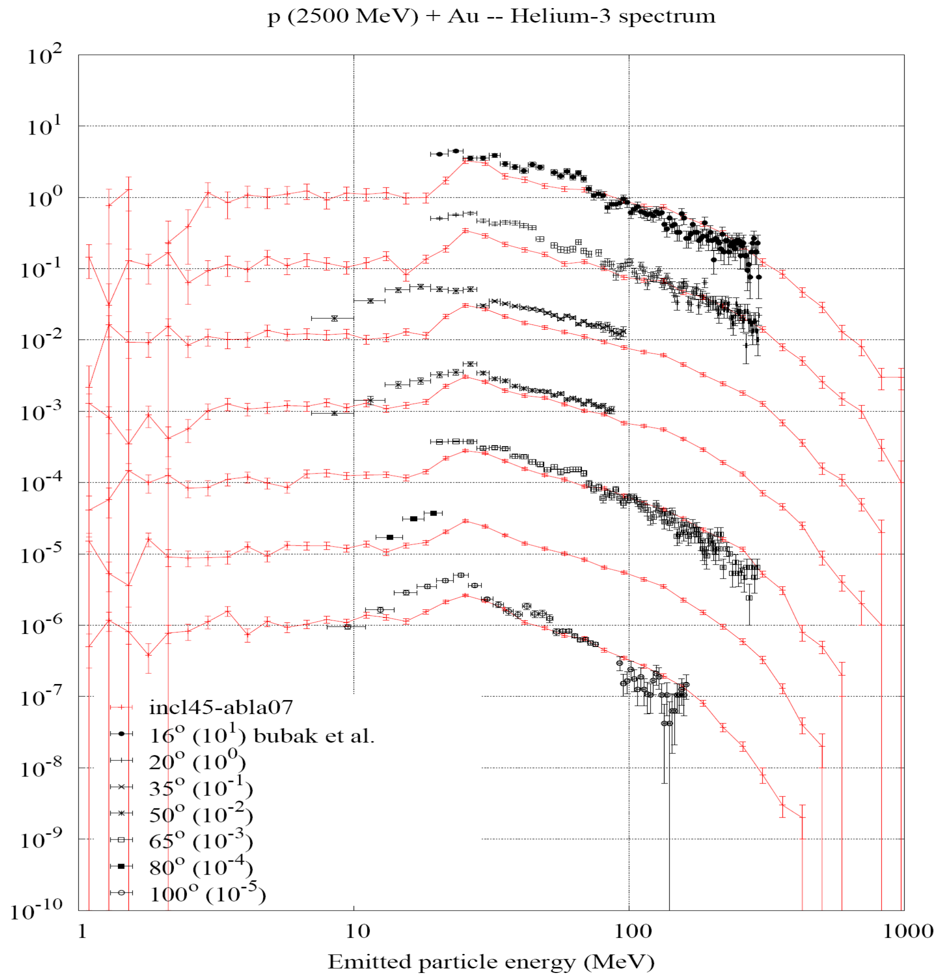




^{3}He

Very little statistical emissions.
No Coulomb bump





Summery of differential xsections

Neutrons and alpha predictions are good.

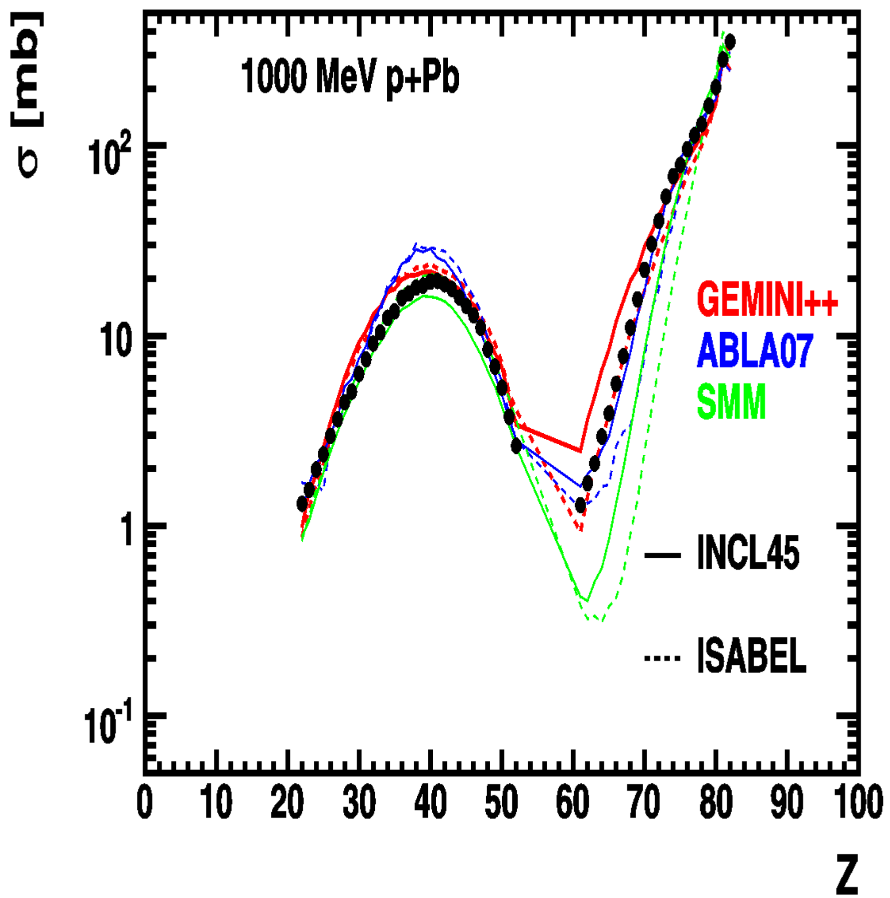
Biggest discrepancy for protons –
Need reduced Coulomb barriers?

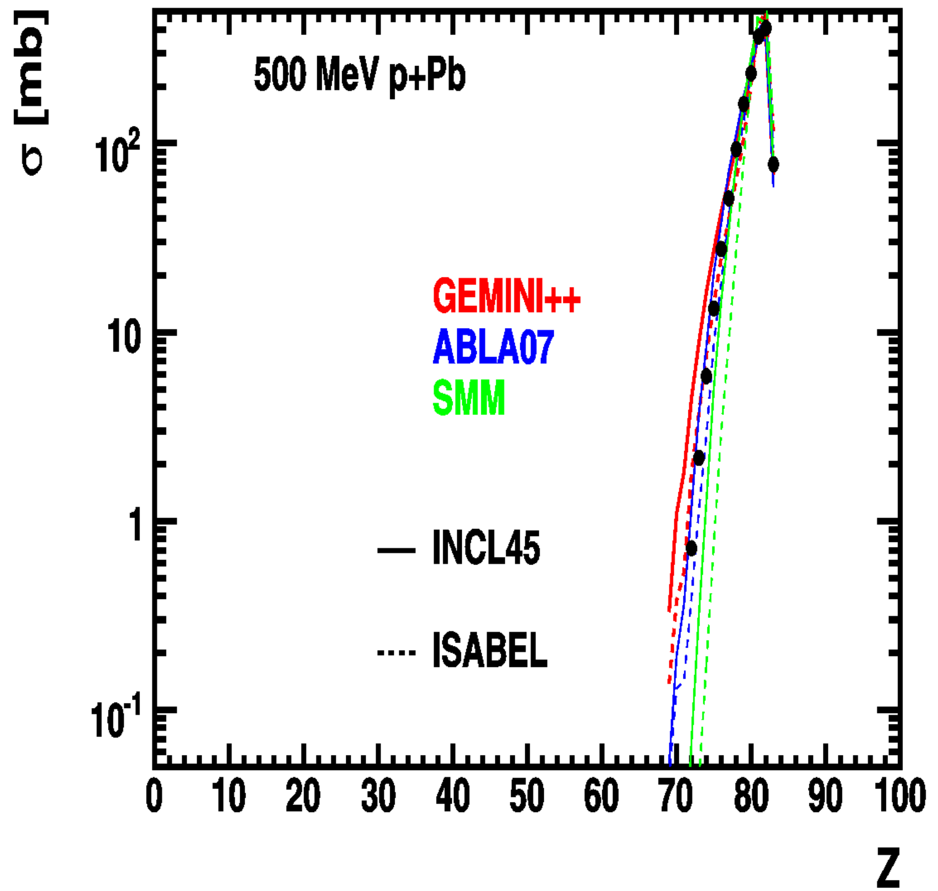
Or last chance subbarrier proton emissions,
For daugter nuclei with $Ex < S_n < S_p + B_{coul}$, $Ex > S_p$
In GEMINI++, these produce the lowest energy protons,
Sensitive to nuclear structure.

Not consistent with heavy-ion fusion reactions.
(N-Z)/A dependence of level-density parameter and Coulomb barriers?

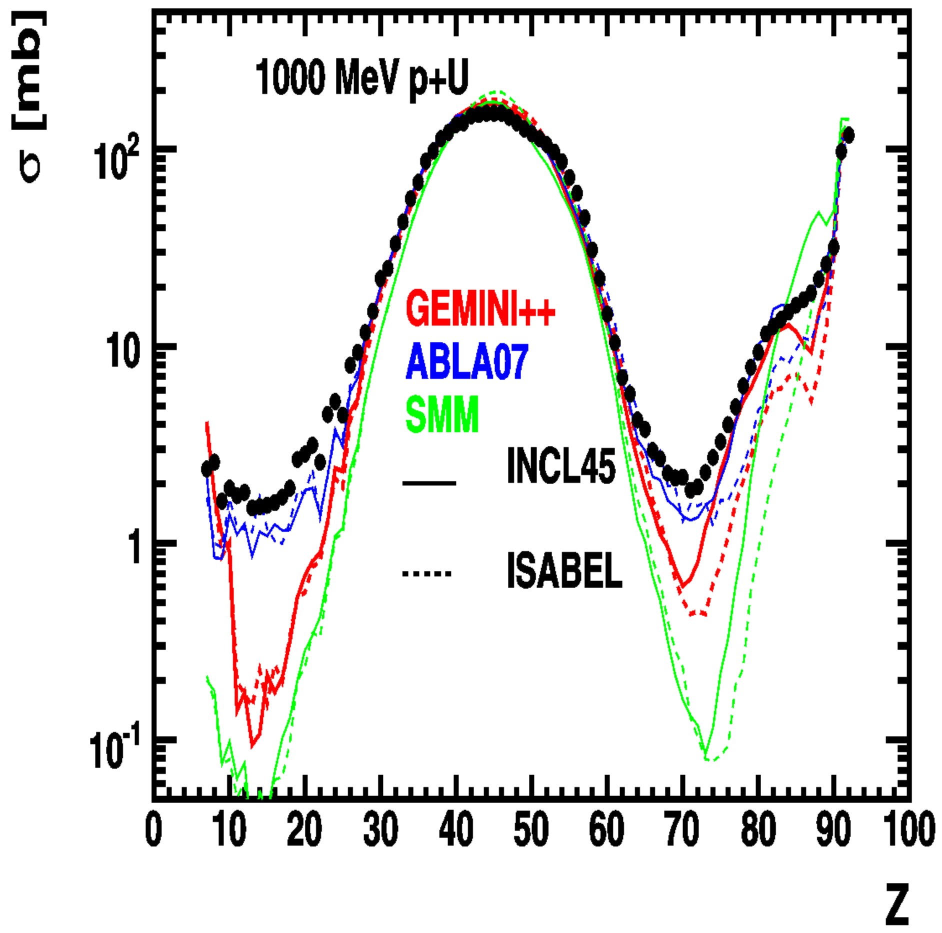
d,*t* predictions are a little too large – any attempt to reduced these by changing the nuclear temperature (level-density) Will also reduce the alpha yield.
d,t,^{3}*He* are typically overpredicted in heavy-ion fusion reactions as well.
May need preformation factors.

Fission Yields good





Z distributions

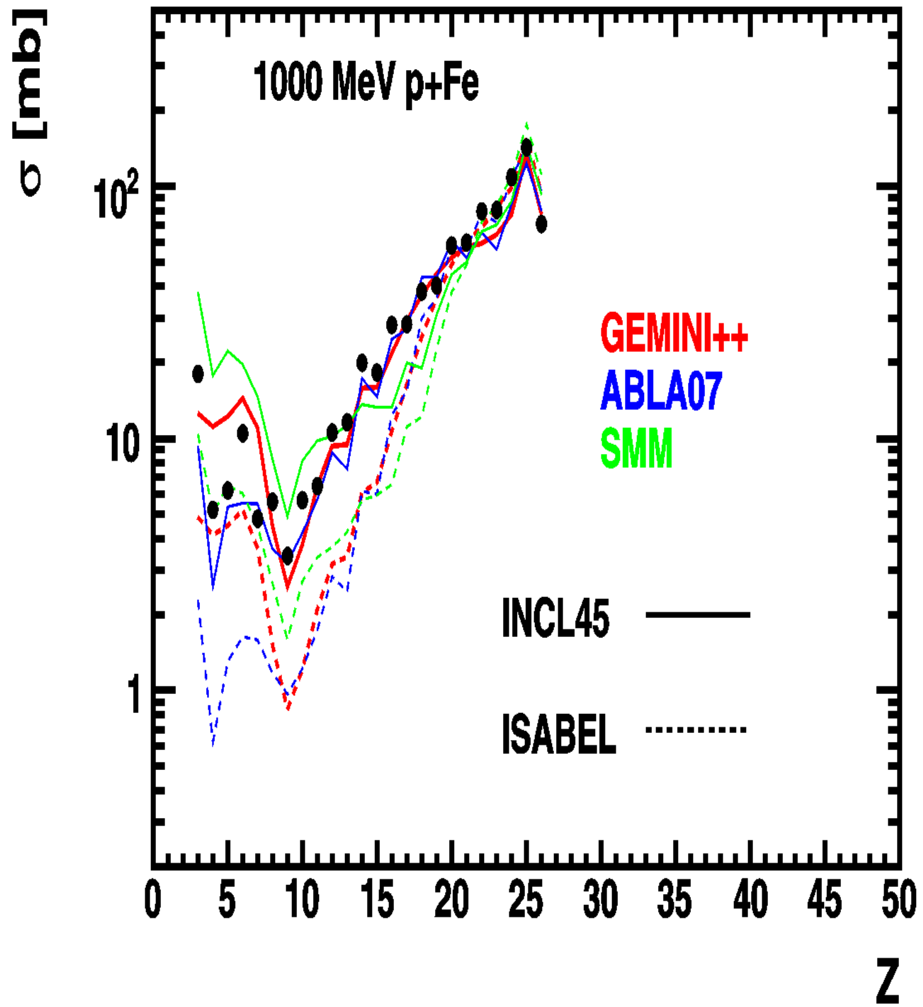


GEMINI++ assumes a parabolic asymmetry dependence of fission barriers with the width obtained from experimental systematics.

p+U fission is at lower excitation energies than p+Pb and we start to see structure in the Z distribution for fission

Need lower barriers for IMF emission 10<Z<20. (no calculations of asymmetric barriers for A>190 by Sierk)

IMF probabilities



Only case were we are sensitive to IMF yields.

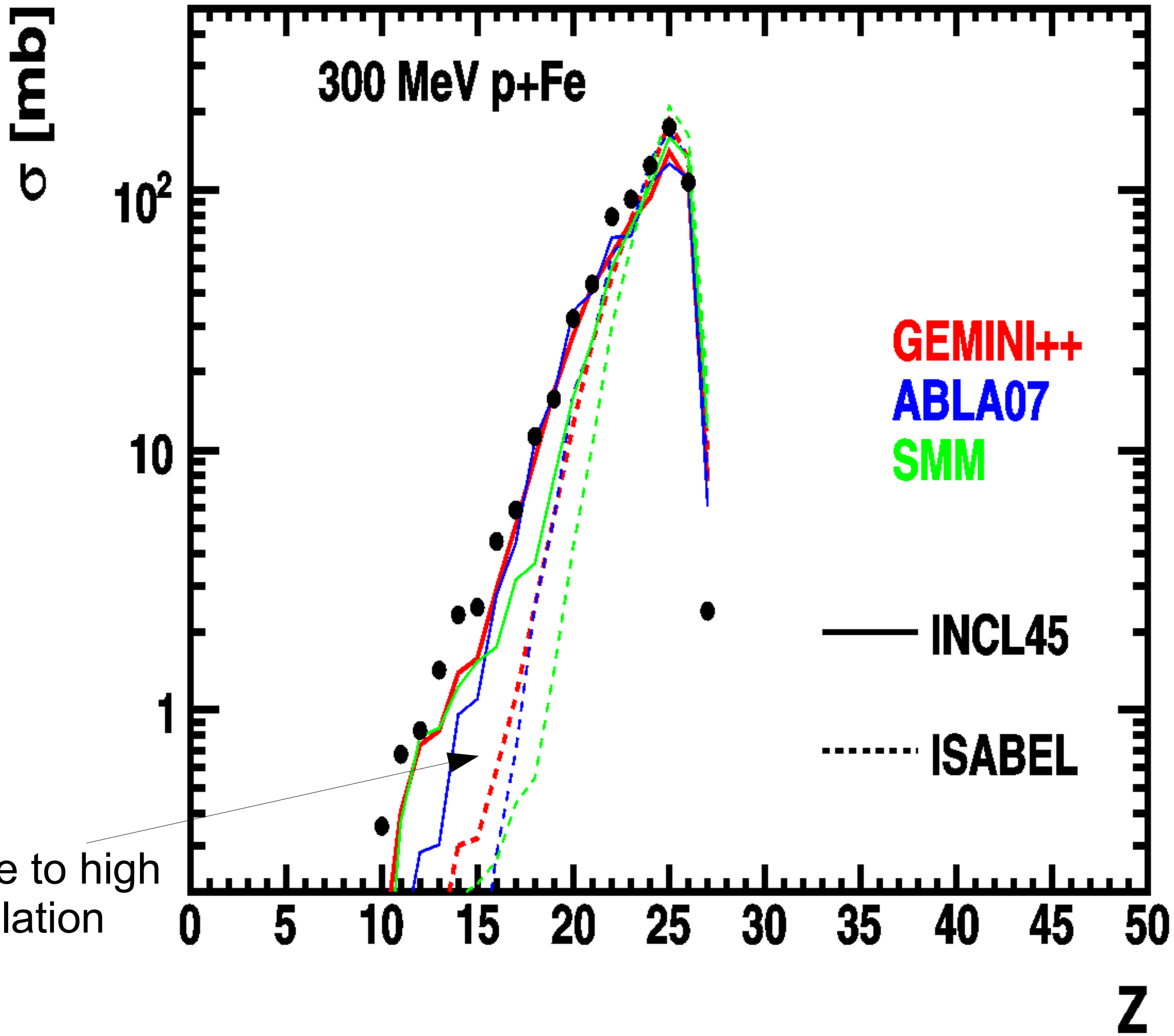
There was a mistake in GEMINI++ that depressed IMF emission.

Average excitation energy of intermediate nucleus that emitted fragment

n = 77 MeV
p = 80 MeV
d = 116 MeV
IMF = 250 MeV

IMF's are very sensitive to the population and level-density at high excitation energy.

300 MeV p+Fe



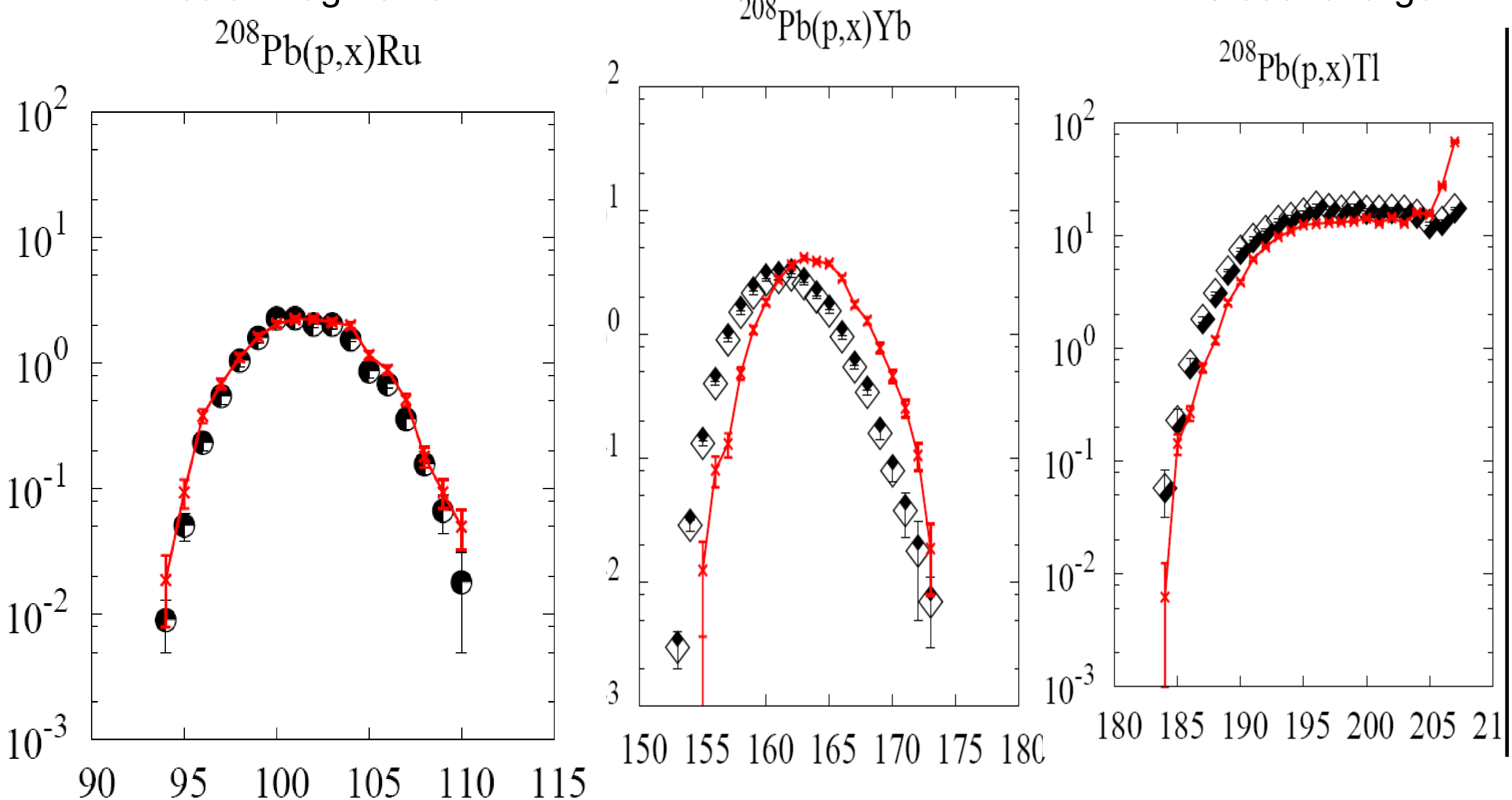
Sensitive to high
Ex population

Isotope distributions

Fission fragments

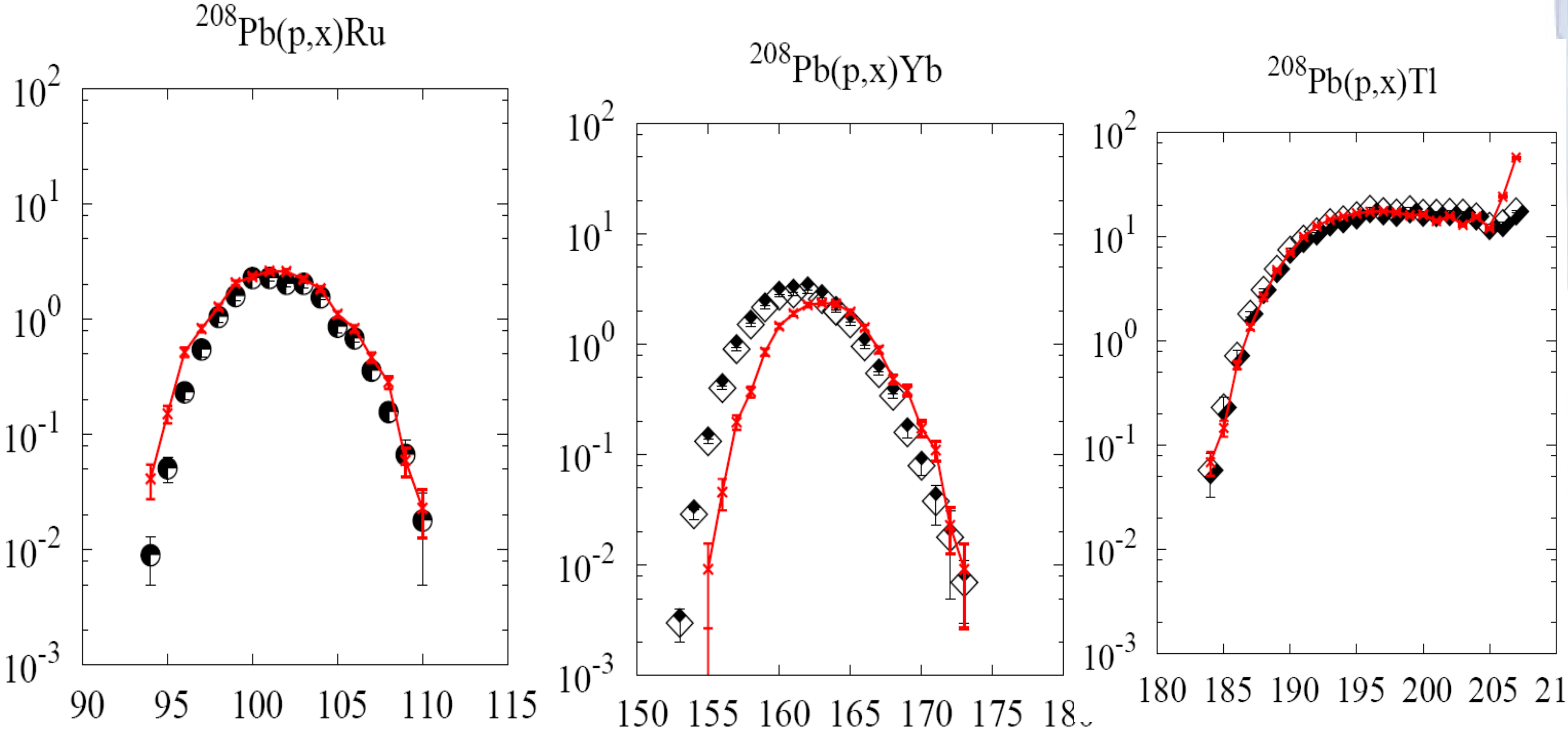
Too neutron rich

Close to target



INCL-GEMINI++

Same result for Isabel/GEMINI++

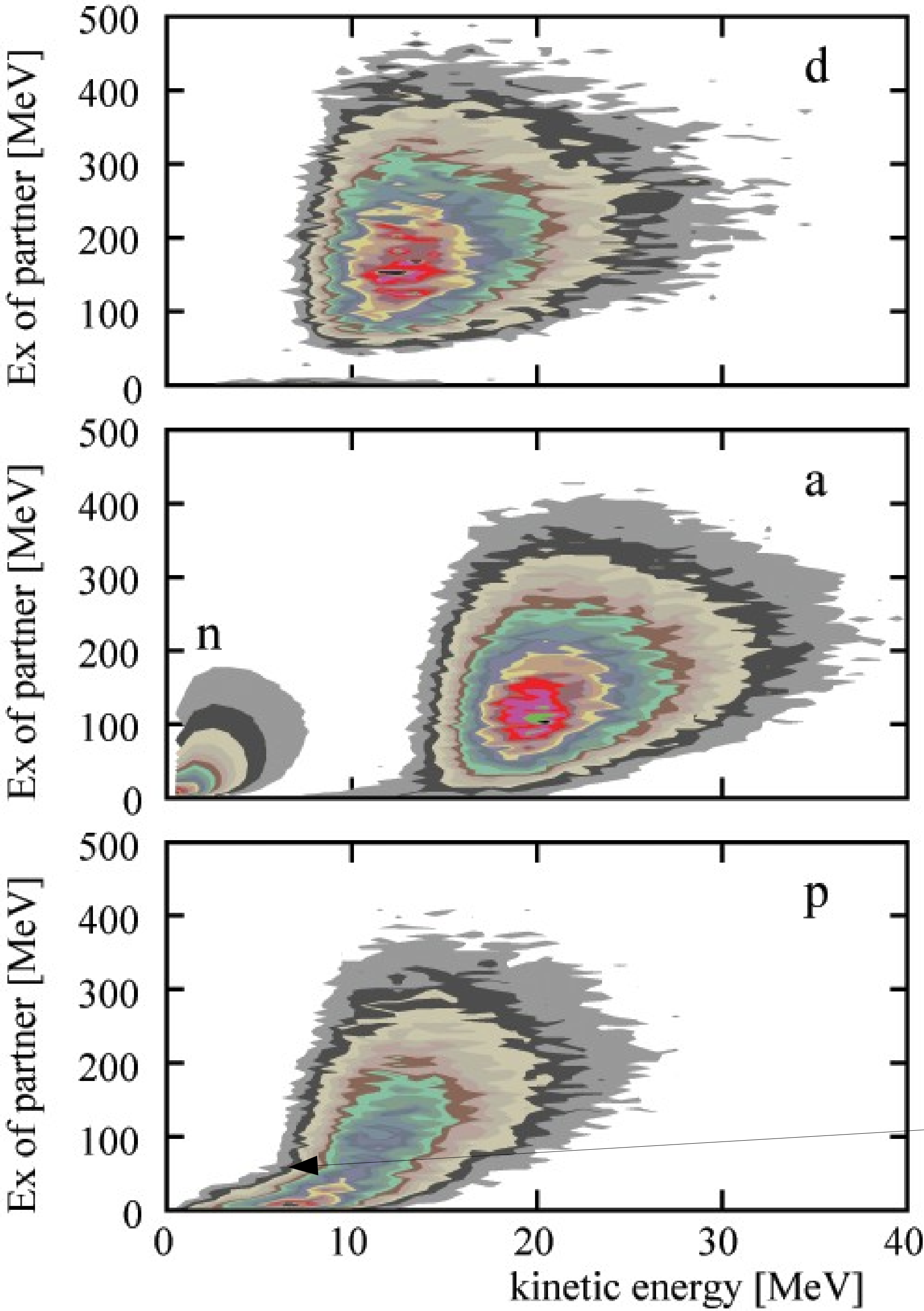


Conclusion for Z,A and isotopic distributions

a) Total fission yield and the fission isotopic distributions are well described.

b) IMF yields probe the high excitation-energy tail of the Excitation-energy distributions.
Problem in benchmark calculation was found and fixed.
Will readjust and get more consistent description of imf in both spallation and heavy-ion fusion reactions.

c) For other residues away from the target mass,
GEMINI predictions are too neutron rich.
Probably related to problems in reproducing proton differential xsections.



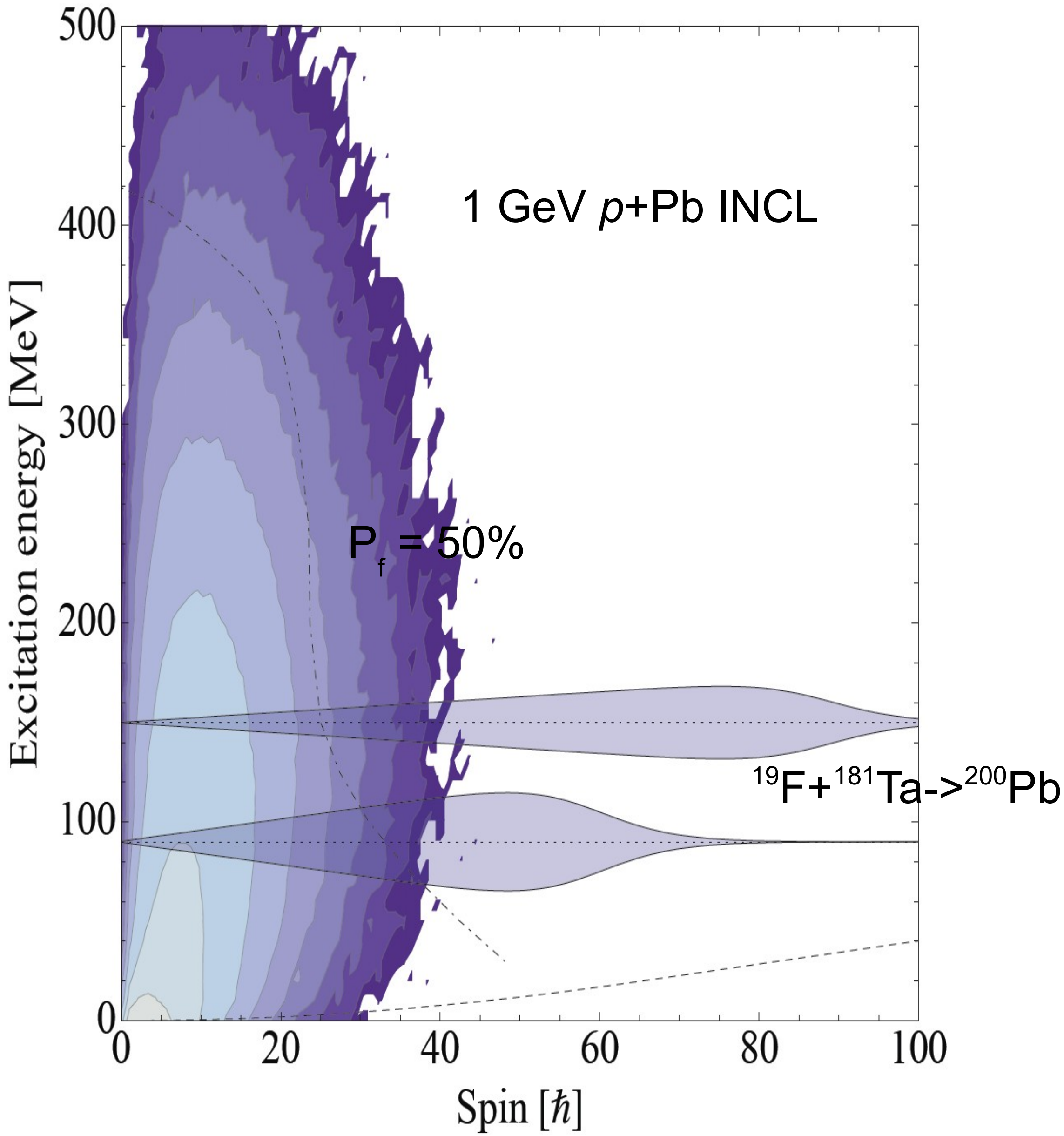
GEMINI does predict enough low-energy protons and the residuals are too neutron rich?

Lower Coulomb barriers?

Where are low energy protons emitted?

Last-chance subbarrier protons

Angular-momentum dependence



In spallation, fission comes from events in the high spin and high excitation-energy tails of the compound-nucleus population.

Average spin is small, not important for differential xsections.

It is important to consider spin, However for the n,p,d,t,α differential cross sections the Weisskopf formula is probably OK.