Cosmic rays & their interstellar medium environment
CRISM-2011

Spallation modelling
What's new on nuclei production with INCL4.5-Abla07?

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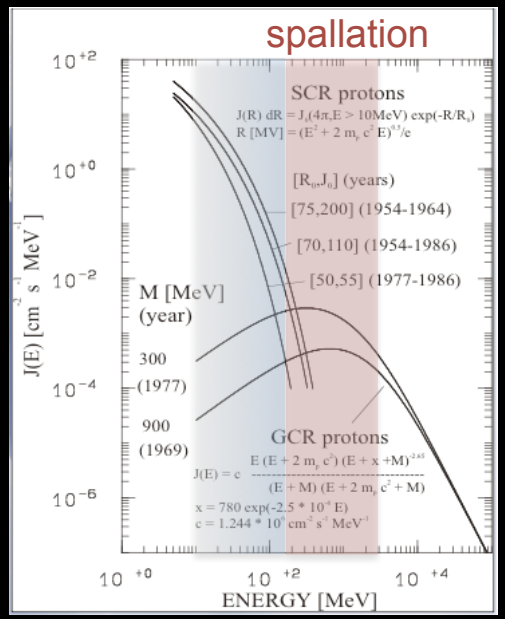
Spallation modelling
What's new on nuclei production with INCL4.5-Abla07?

Spallation modelling

A. Boudard
S. Leray — CEA-Saclay (F)
J.-C. David

J. Cugnon
D. Mancusi — U. Liège (B)

A. Kelic
M.V. Ricciardi — GSI (G)



Meteorites Cosmogenic Nuclides

R. Michel — U. Hannover (G)

I. Leya — U. Bern (CH)

Co-signed papers

Main conclusion: spallation models (were) not yet good enough (Exp. data needed)

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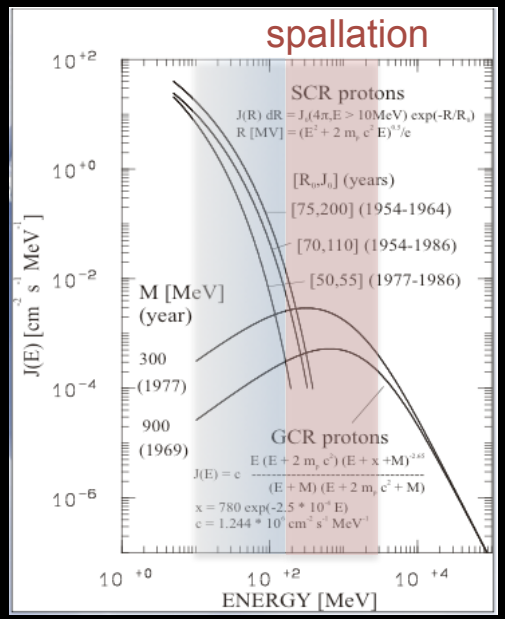

Meteorites Cosmogenic Nuclides

R. Michel — U. Hannover (G)

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Main conclusion: spallation models not yet good enough (Exp. data needed)

… → 2010-2011 great improvements in the modelling

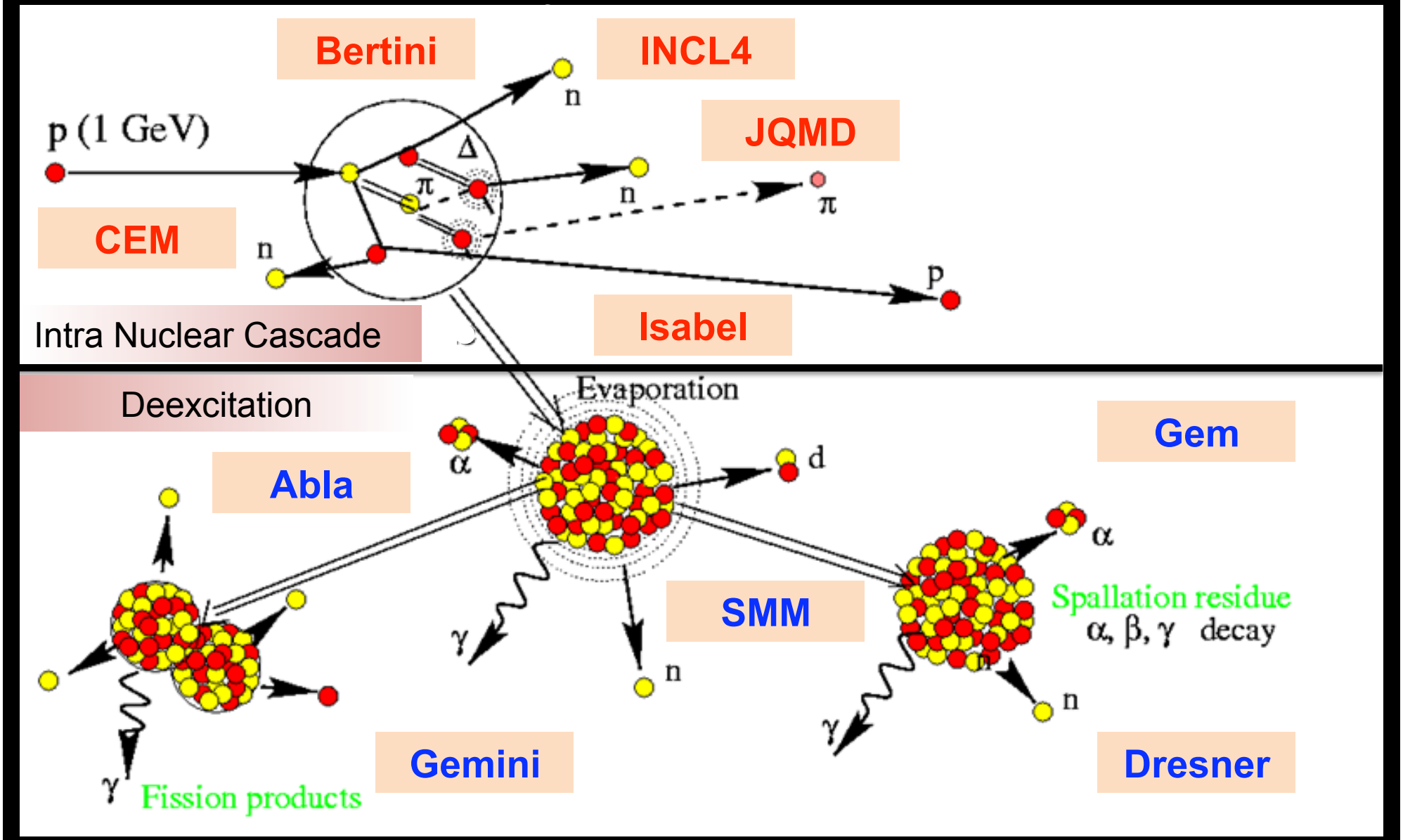
What are the new performances for cosmogenic nuclides in meteorites?!

Spallation modelling
What's new on nuclei production with INCL4.5-Abla07?

Definition

MODELS

Spallation modelling
What's new on nuclei production with INCL4.5-Abla07?



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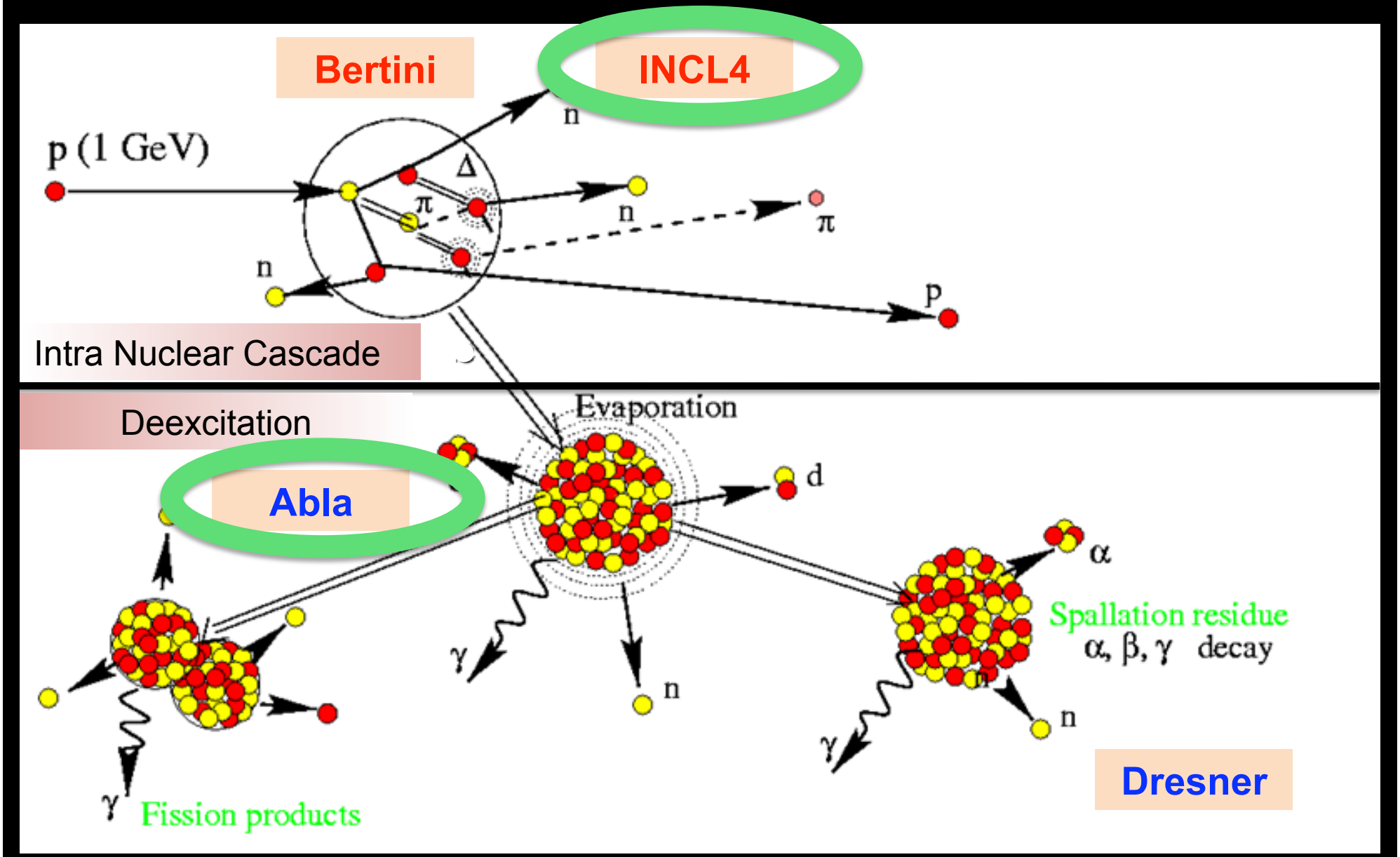


Spallation modelling
What's new on nuclei production with INCL4.5-Abla07?

Definition

MODELS

~150 MeV < E < 3 GeV

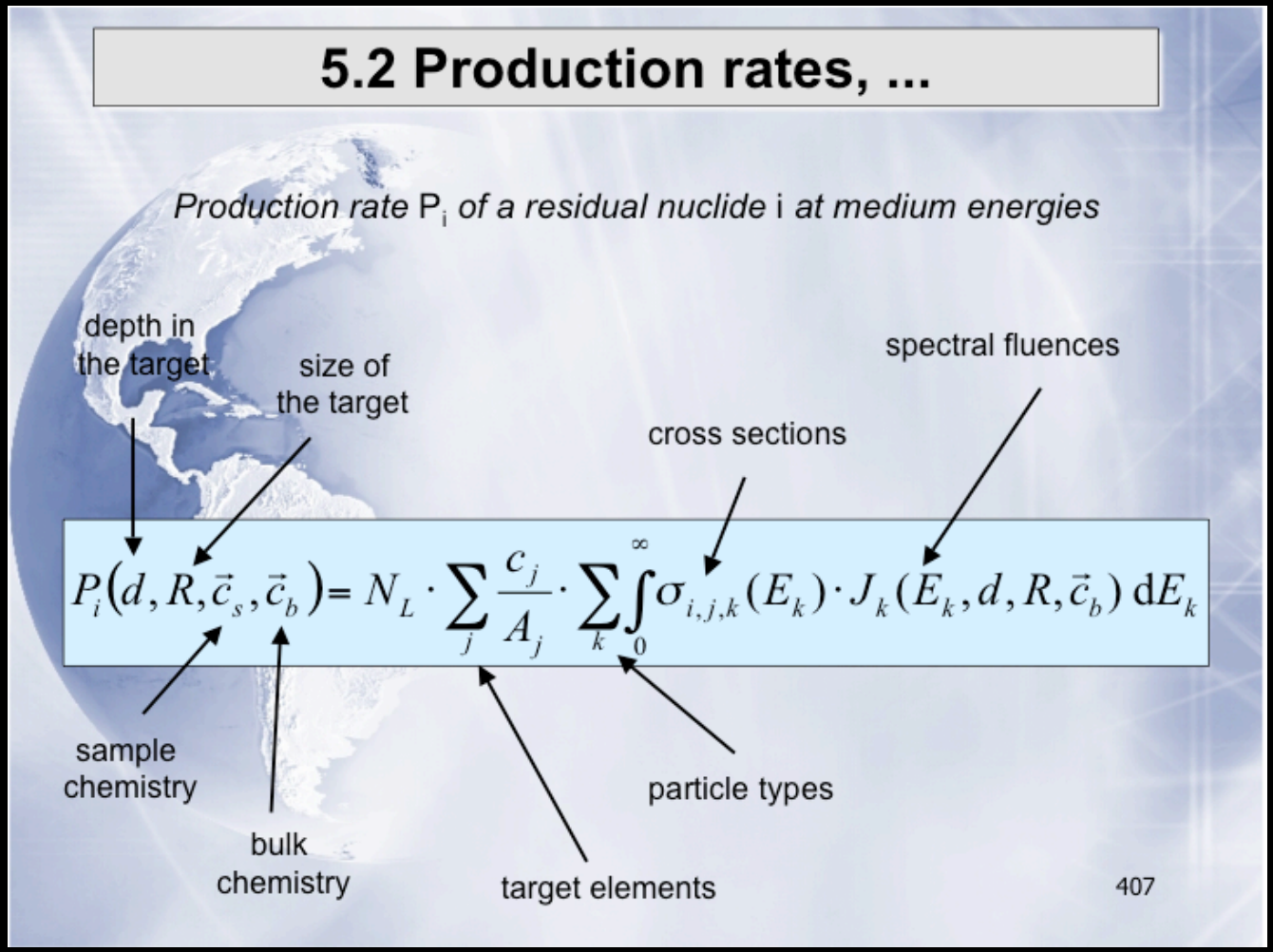
• INCL4.2 / INCL4.5 *old* / *new*	Intra Nuclear Cascade Liège	*old* in MCNPX *new* could be in MCNP6
• Abla / Abla07	Deexcitation (evap. – fission – *break-up*)	
• Bertini	Intra Nuclear Cascade	default model in (LAHET – MCNPX)
• Dresner	Deexcitation (evap. – fission)	used by astrophysics

E < ~200 MeV

• TENDL10	**T**ALYS-based **E**valuated **N**uclear **D**ata **L**ibrary	used by astrophysics

Definition

Ingredients

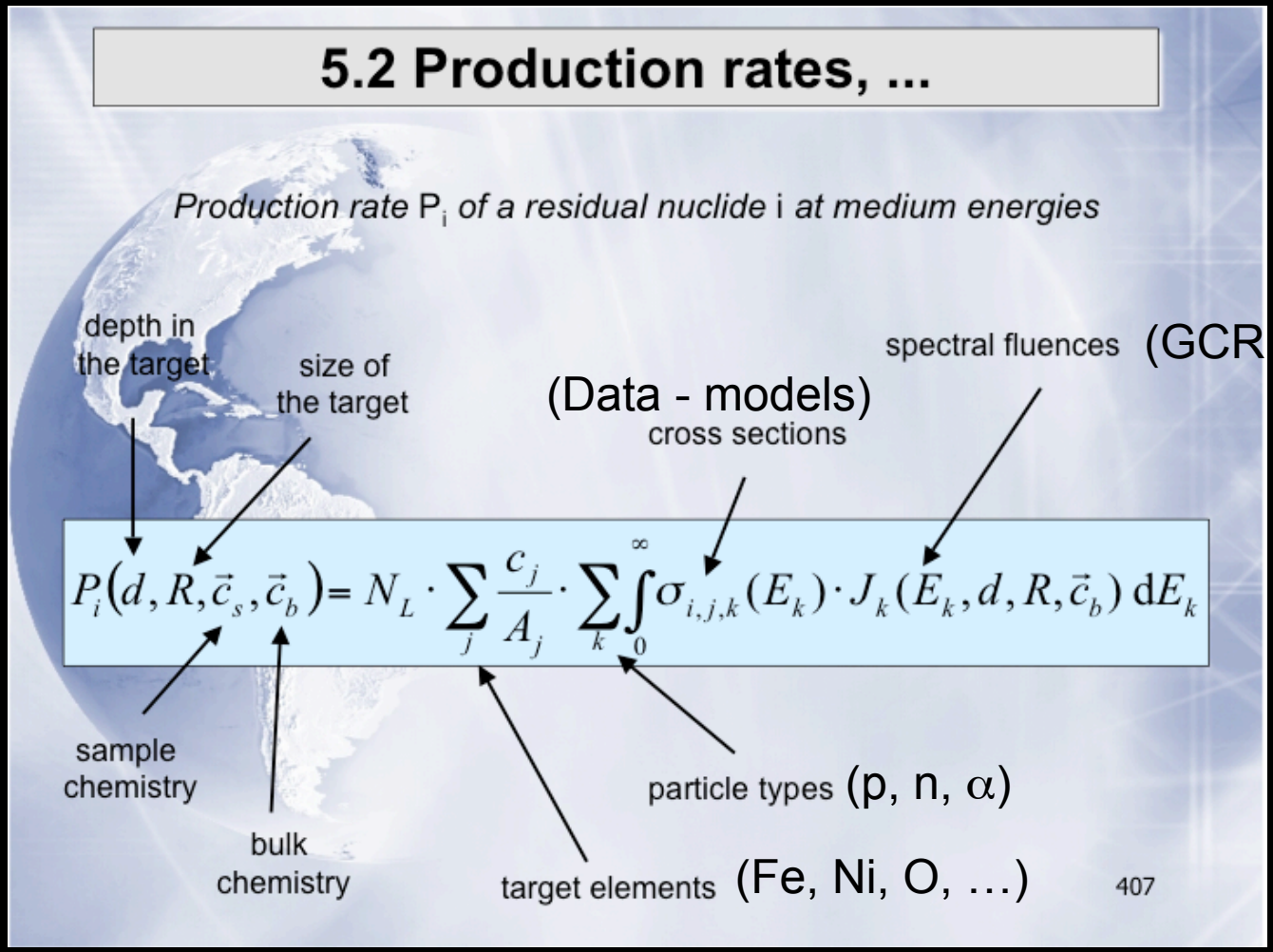


from http://noblegas.unibe.ch/index.php?content=teaching/meteorites_ess (Chapter 5)

Spallation modelling
What's new on nuclei production with INCL4.5-Abla07?

Definition

Ingredients



GCR

p	87%
α	12%
heavy ions	1%

from http://noblegas.unibe.ch/index.php?content=teaching/meteorites_ess (Chapter 5)

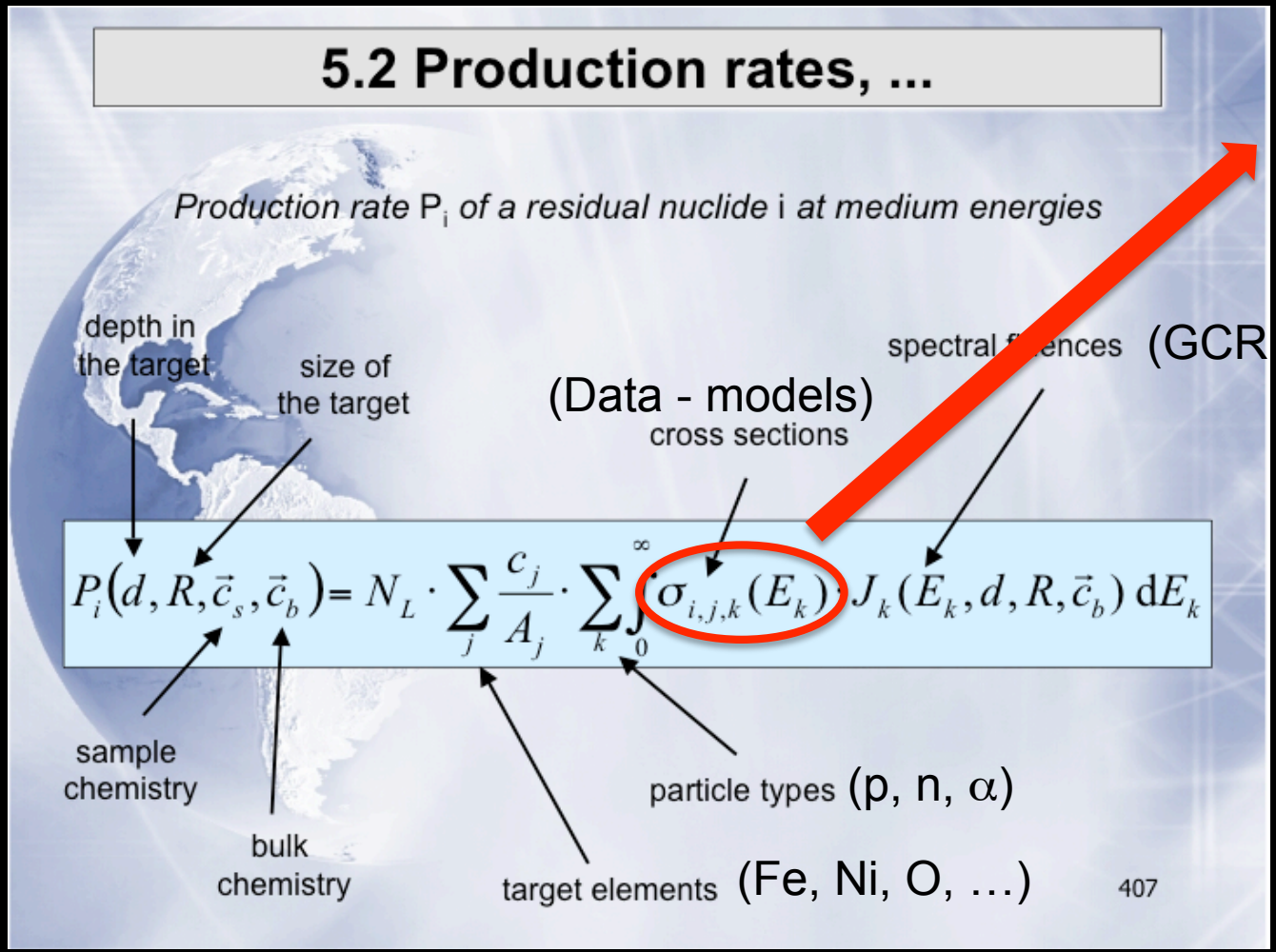
Spallation modelling
What's new on nuclei production with INCL4.5-Abla07?

Definition

Ingredients

σ can be

- **independent (no progenitor)**
- **cumulative (progenitors)**



GCR

p	87%
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Improvements in the modelling

Emitted particles

INCL4.2	n, p, π
Abla	n, p, α
INCL4.5	n, p, π, d, t, ^{3}He, α and A ≤ 8
Abla07	n, p, d, t, ^{3}He, α and IMF

Other refinement – extensions

- V_N = cst → $V_N(E,T_3)$ Improves charge exchange quasi-elastic and quasi-inelastic events
- V_π = 0 → $V_\pi(T_3)$ Improves pion production cross section
- Extension to Low Energy (Coulomb distorsion - compound nucleus)

Spallation modelling
What's new on nuclei production with INCL4.5-Abla07?

Results

Results

Which isotopes? - Which targets?

Cosmogenic Nuclides in Extraterrestrial Matter

Nuklid	$T_{1/2}$	Targetelemente
^{14}C	5.73 ka	N, O, Mg, Al, Si, S, P, Ca, Ti, Fe, Ni
^{59}Ni	75. ka	Fe, Ni
^{41}Ca	103. ka	Ca, Ti, Fe, Ni
^{81}Kr	210. ka	Rb, Sr, Y, Zr
^{36}Cl	300. ka	Cl, Ar, Ca, Ti, Fe, Ni
^{26}Al	716. ka	Mg, Al, Si, Ar, S, P, Ca, Ti, Fe, Ni
^{60}Fe	1.5 Ma	Ni
^{10}Be	1.51 Ma	C, N, O, Mg, Al, Si, S, P, Ca, Ti, Fe, Ni
^{53}Mn	3.7 Ma	Fe, Ni
^{129}I	15.7 Ma	Te, Ba, Xe, REE
^{40}K	1.28 Ga	Ca, Ti, Fe, Ni
He	stable	C, O, Mg, Al, Si, S, P, Ca, Ti, Fe, Ni
Ne	stable	Na, Mg, Al, Si, S, P, Ca, Ti, Fe, Ni
Ar	stable	Cl, Ca, Fe, Ni
Kr	stable	Br, Rb, Sr, Y, Zr
Xe	stable	Te, I, Ba, REE

from http://noblegas.unibe.ch/index.php?content=teaching/meteorites_ess (Chapter 5)

Results

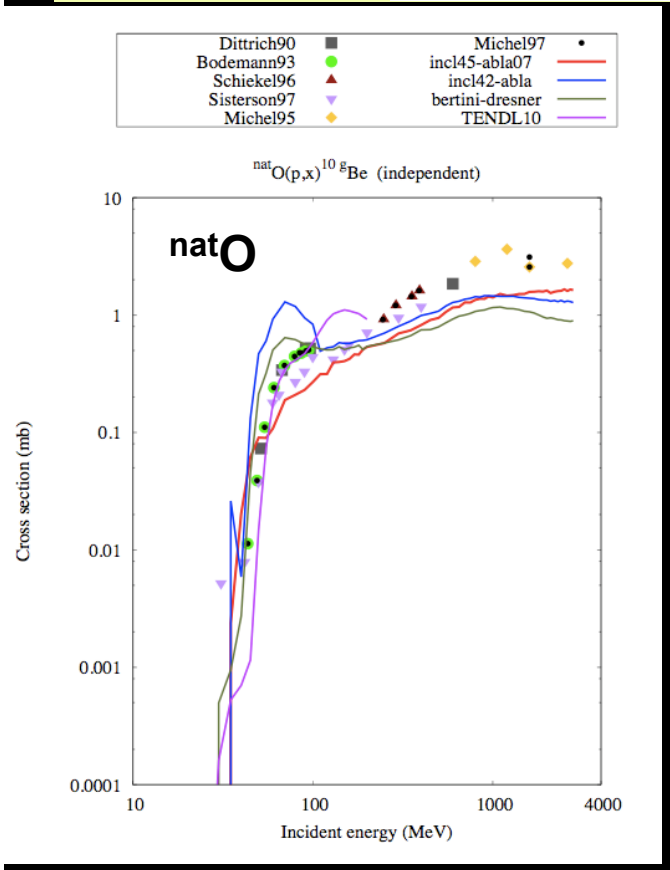
Which? - What for?

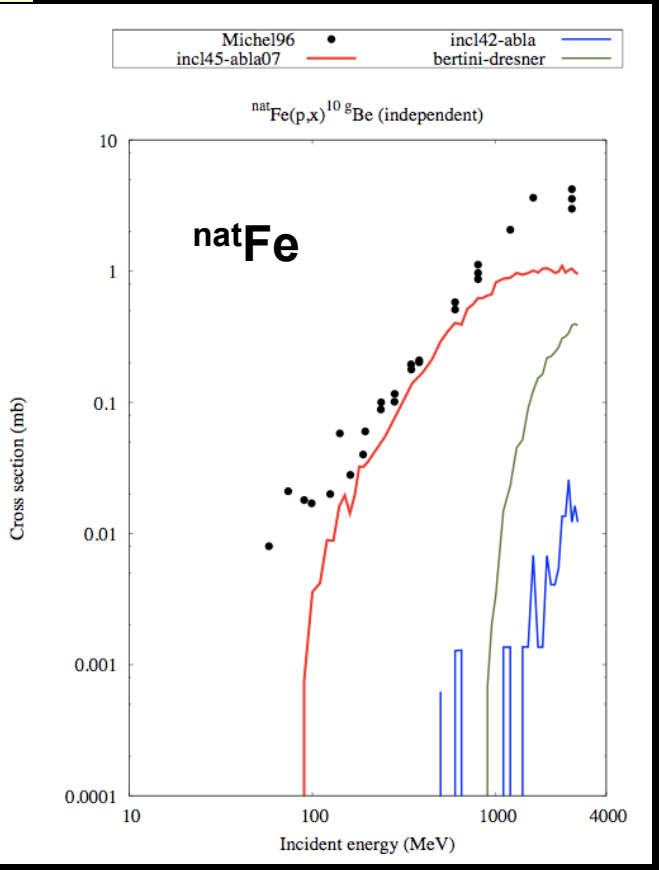
- p+Fe,Ni,O — Comparison with other Models; Comparison with Experimental Data
- p+Fe — Composition and Cumulative effects
- n+Fe,Ni,O — Comparison with p as projectile; Comparison with Experimental Data
- α+Fe — Comparison with Experimental Data; Comparison with 2p+2n approximation

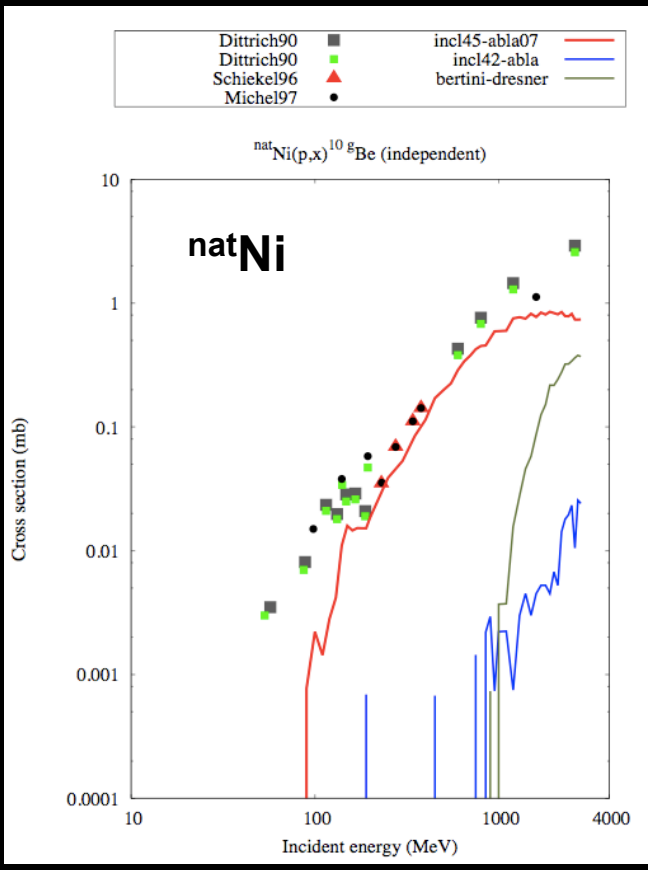
Spallation modelling
What's new on nuclei production with INCL4.5-Abla07?

Light isotope p+X → ^{10}Be

Results







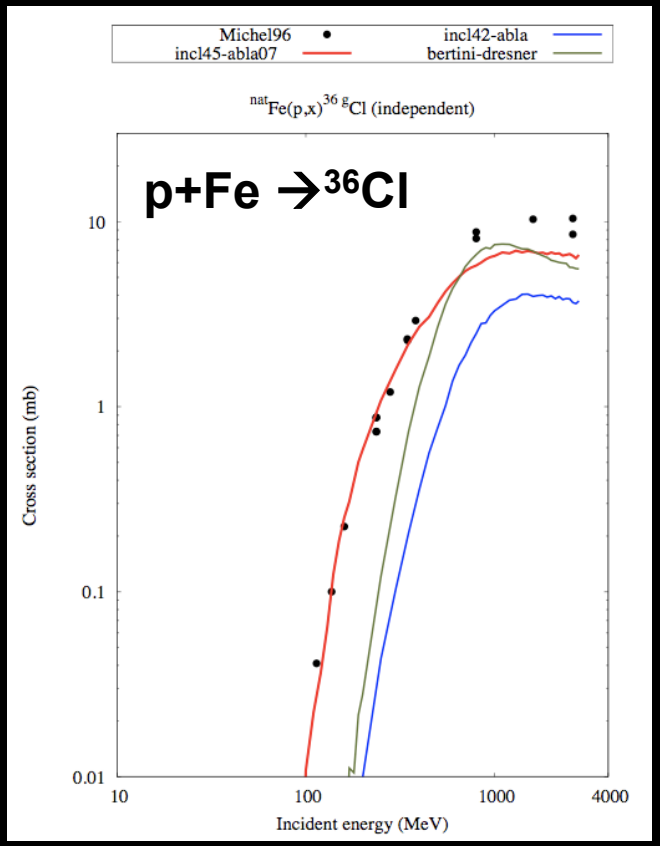
- Two types of mechanism: evap. (O) and possibly Break-up (Fe-Ni)
- INCL4.5-Abla07 much better on Fe/Ni
- … but threshold and high energy (> ~1GeV) must be better understood

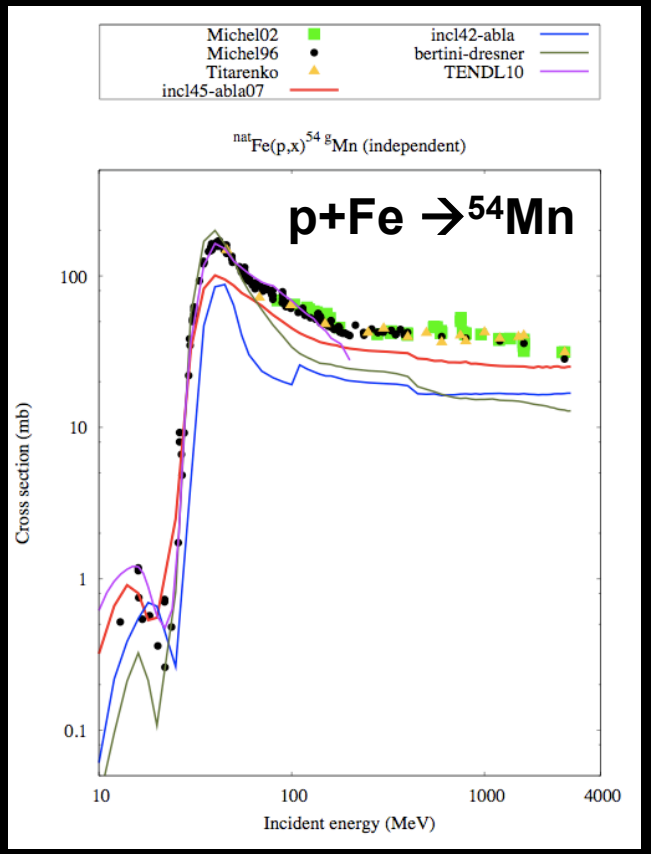
Spallation modelling
What's new on nuclei production with INCL4.5-Abla07?

Medium Mass isotope

Results

Close to the Mass target





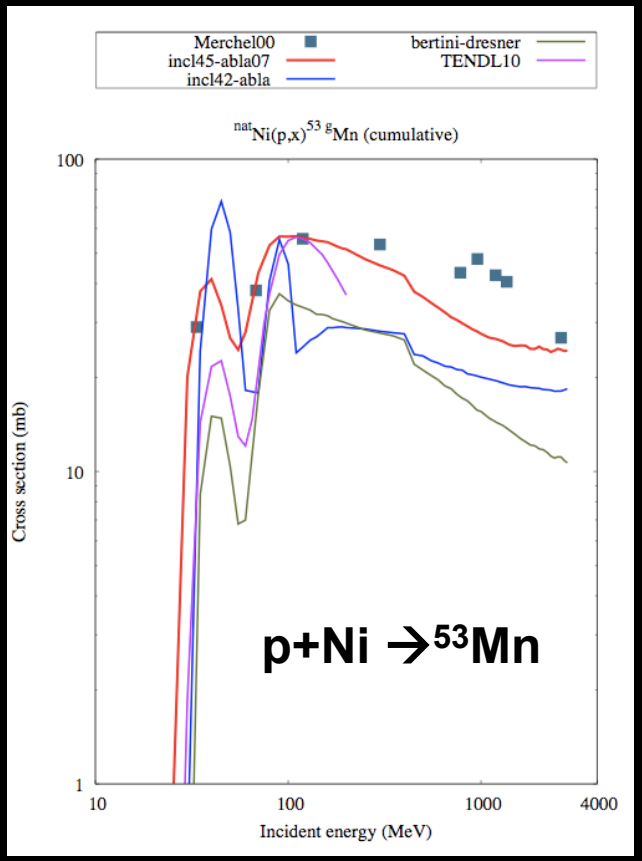
^{36}Cl very well reproduced (except high E)

Low Energy ~OK (see later)

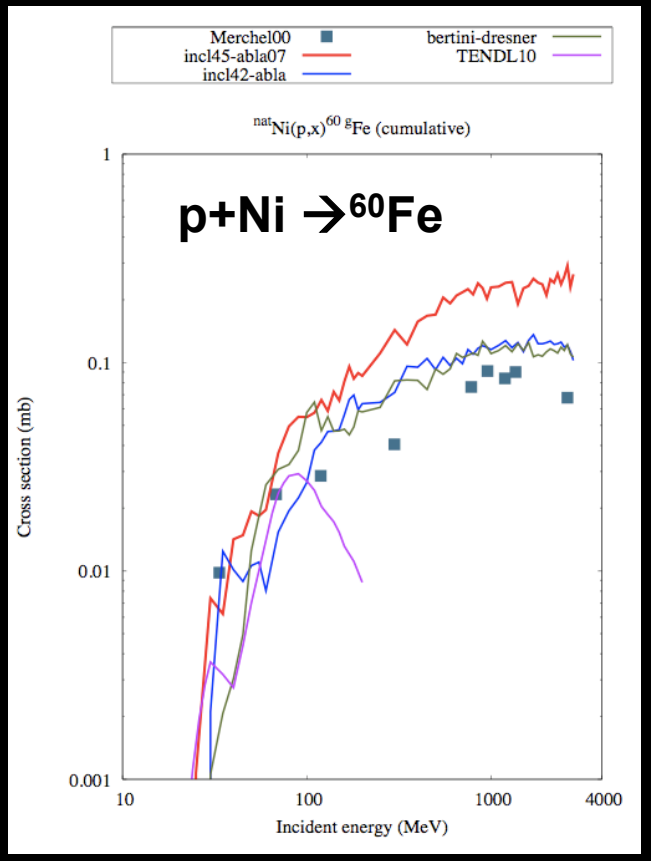
INCL4.5-Abla07 has the best shape on the whole E range

Spallation modelling
What's new on nuclei production with INCL4.5-Abla07?

Results



Close to the Mass target



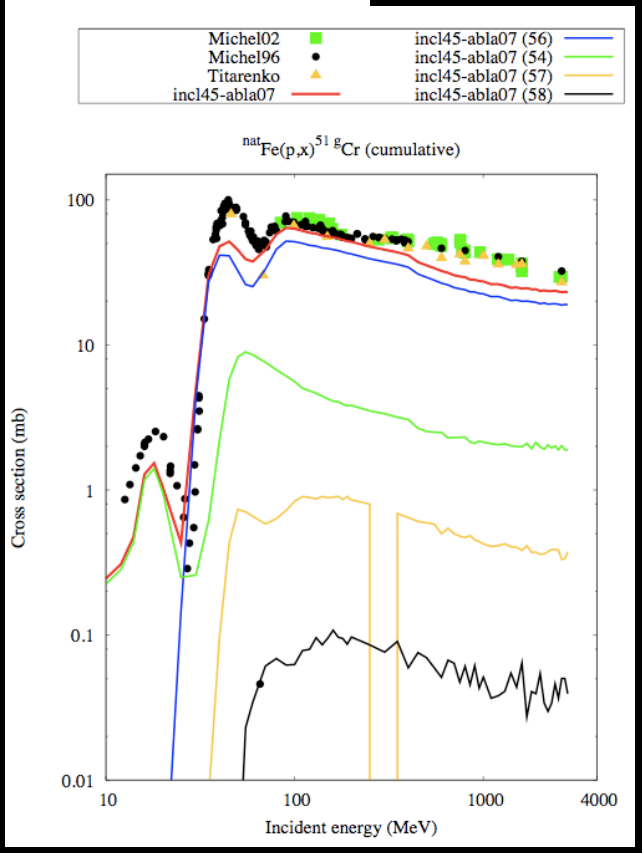
- Low Energy *perfect* (2 data…)
- High E: normalization…(?)

E ↗: overestimation (???)

In some specific cases (here ^{60}Fe) INCL4.5-Abla07 can still be improved

Spallation modelling
What's new on nuclei production with INCL4.5-Abla07?

p+Fe → $^{51}Cr_c$



Results

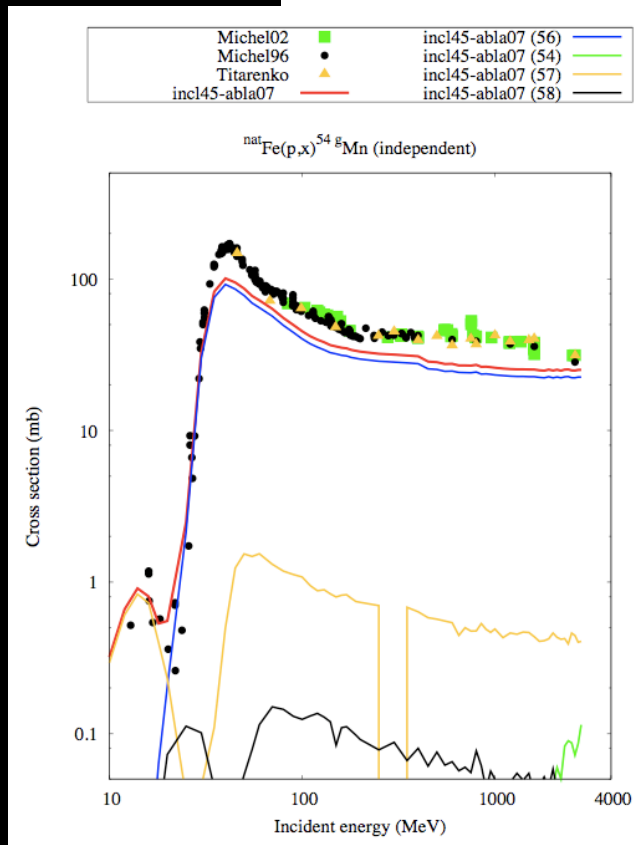
← *Matrix* →

&

← Cumulative

Effects

p+Fe → ^{54}Mn

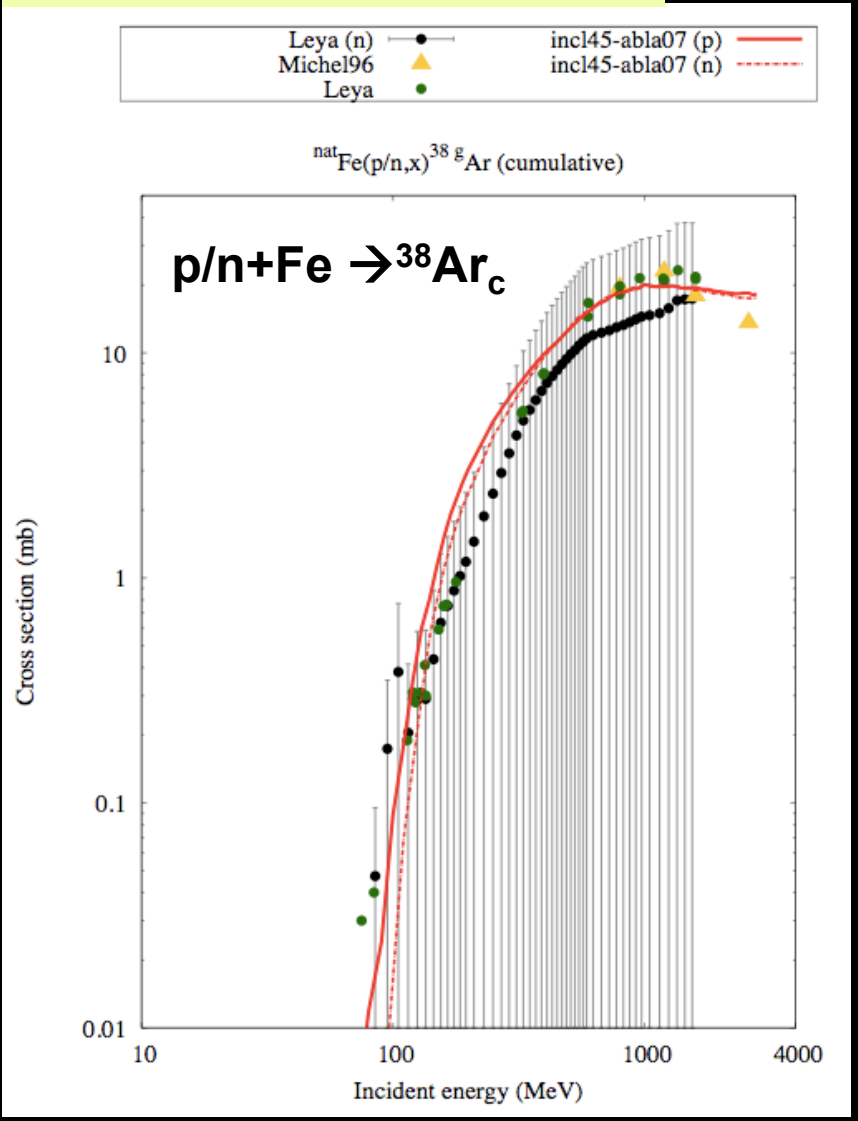


- $^{51}Cr_c$ = ^{51}Cr + ^{51}Mn
- 1st bump: p + ^{54}Fe → ^{51}Mn + α
- 2nd / 3rd bumps: p + ^{56}Fe → ^{51}Cr/^{51}Mn + X

- 1st bump: p + ^{57}Fe → ^{54}Mn + α
- 2nd bump: p + ^{56}Fe → ^{54}Mn + X

Spallation modelling
What's new on nuclei production with INCL4.5-Abla07?

Medium Mass isotope



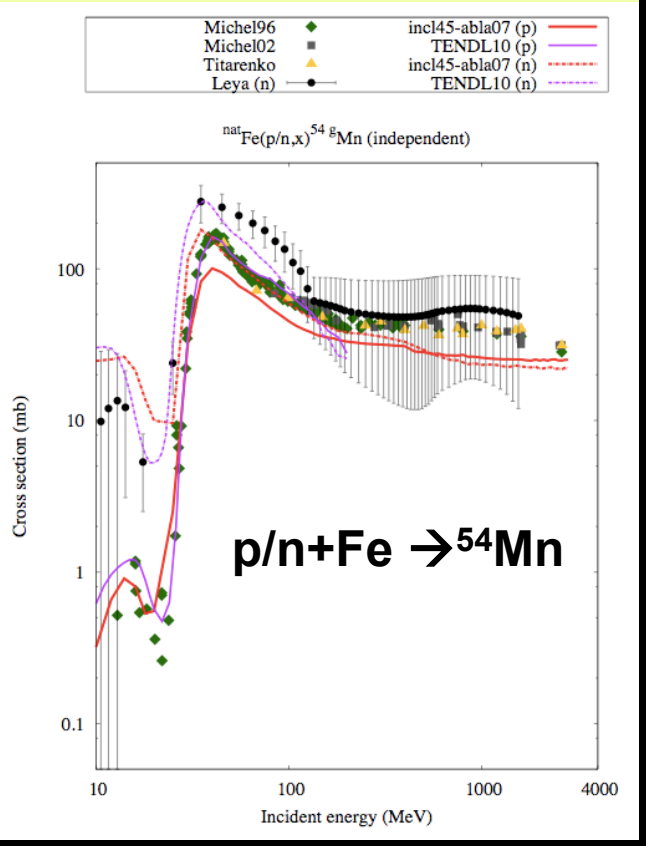
Results

- n-induced data difficult to obtained
- Here n ≈ p assumption is valid
- INCL4.5-Abla07 OK for both

neutron data from I. Leya and submitted to NIM B last Monday

Spallation modelling
What's new on nuclei production with INCL4.5-Abla07?

Close to the Mass target

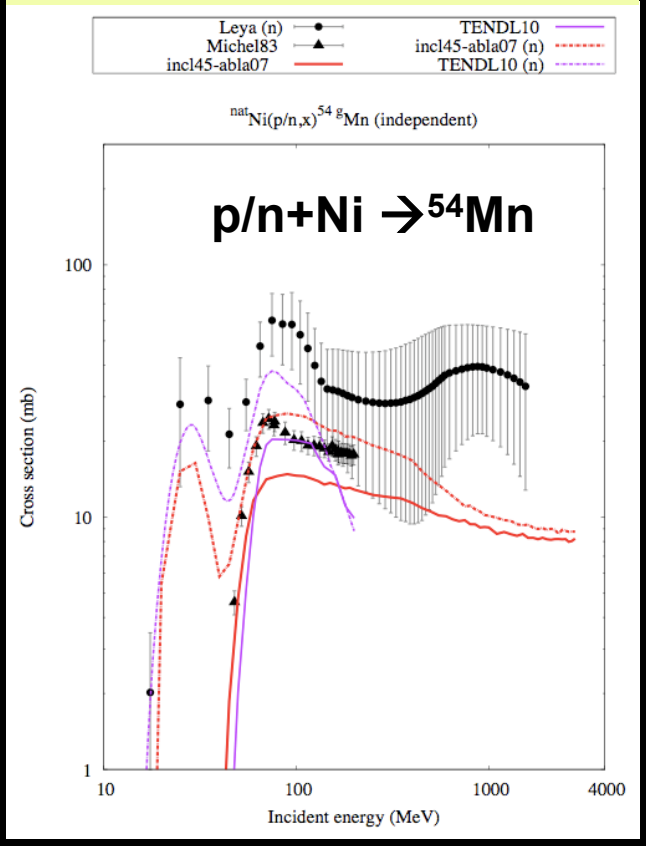


Results

n ≈ p assumption

no more valid!

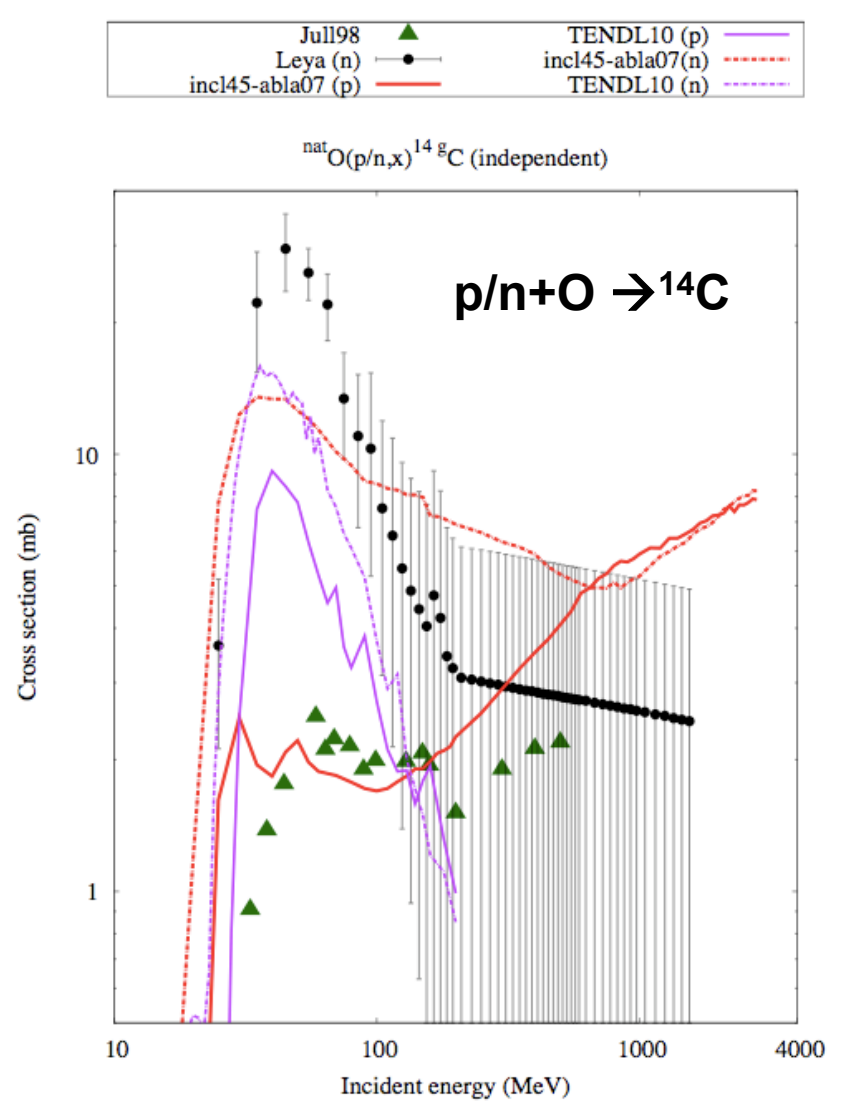
Low Energy



- INCL4.5-Abla07 seems to have the right shape for p and n when both are different
- Next goal: reduce the ratio Exp./Cal. when needed

Spallation modelling
What's new on nuclei production with INCL4.5-Abla07?

Results

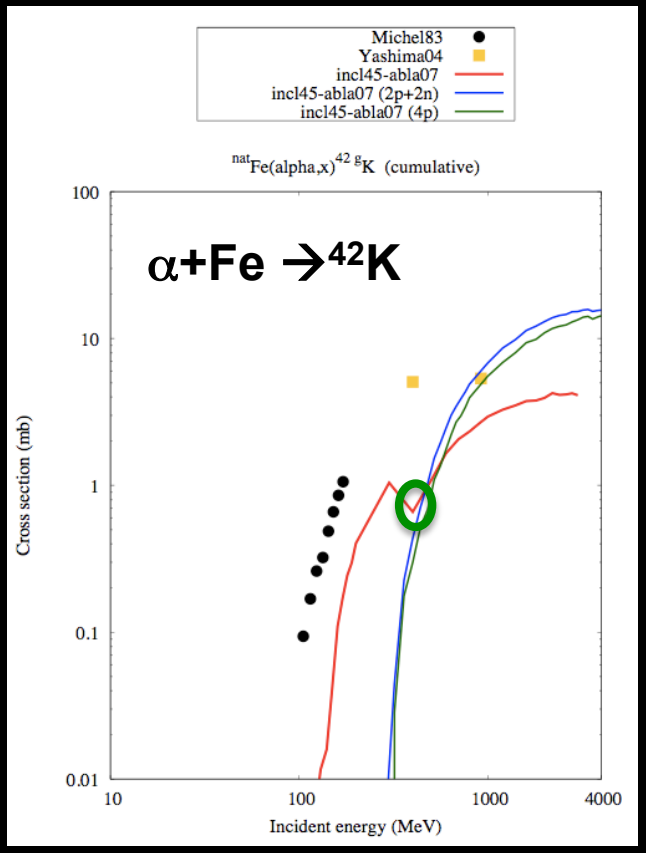


INCL4.5-Abla07 give also promising results even for light nuclei at low energy

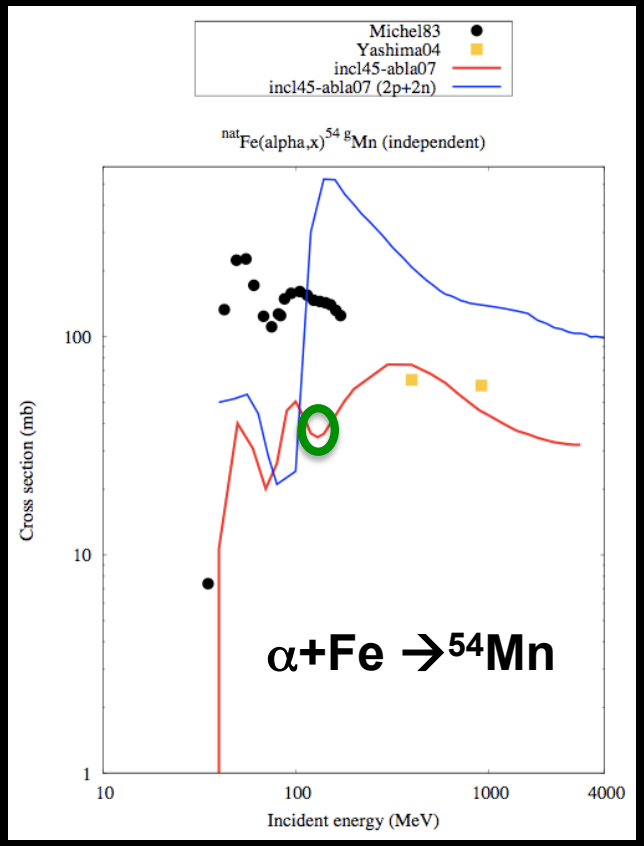
… competitive with other dedicated models

Spallation modelling
What's new on nuclei production with INCL4.5-Abla07?

Results



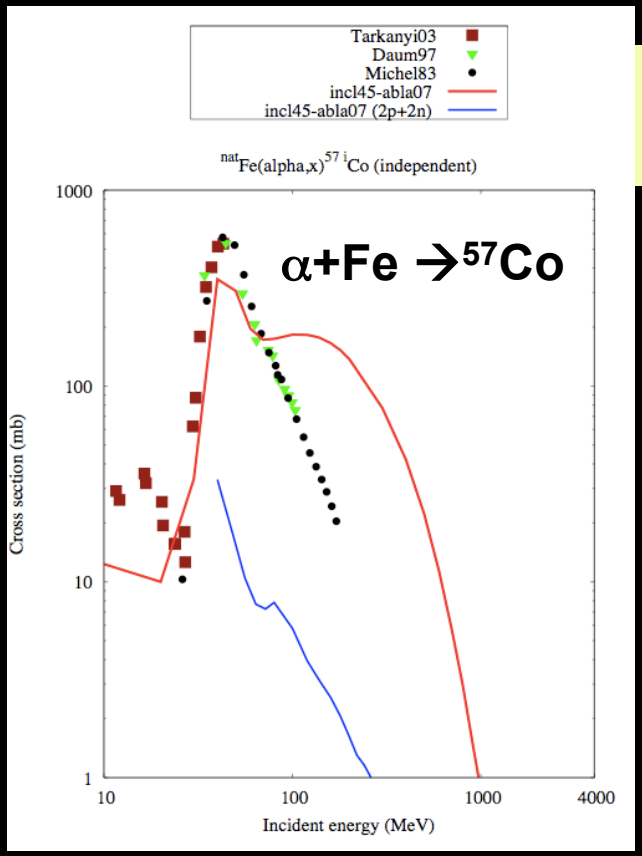
- Few data with α as projectile
- α = 4p / α = 2p+2n crude approx.



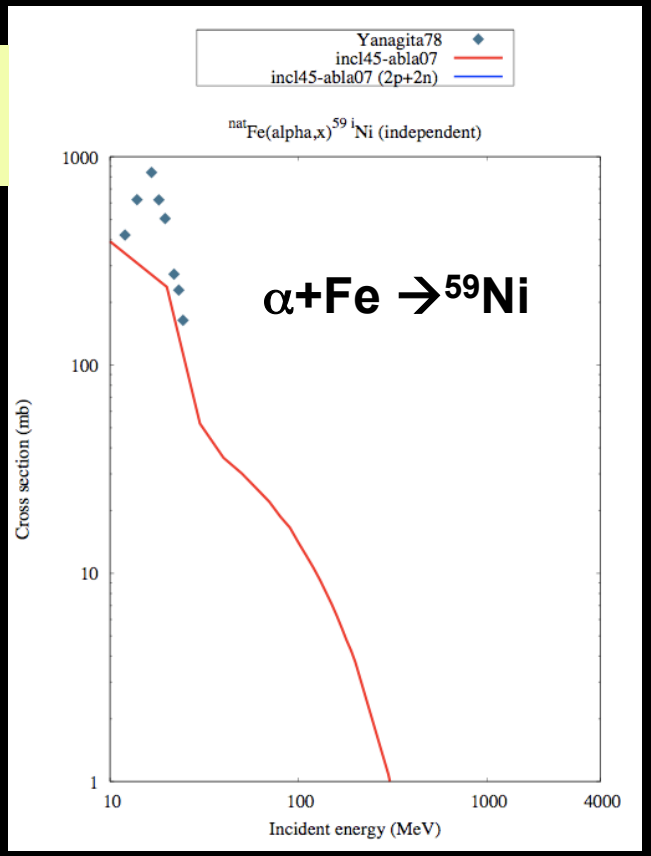
- Once again INCL4.5-Abla07 has the right shape
- But
  - Compound nucleus formation has to be refined (transition O)
  - Start production at lower energy (?)

Spallation modelling
What's new on nuclei production with INCL4.5-Abla07?

Results



Heavier than the Mass target

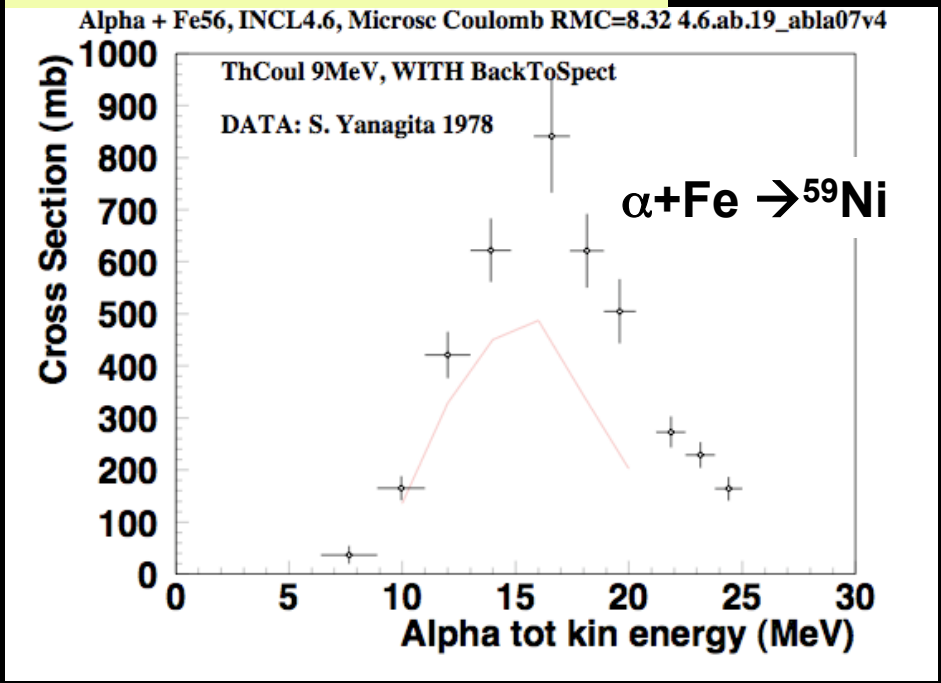


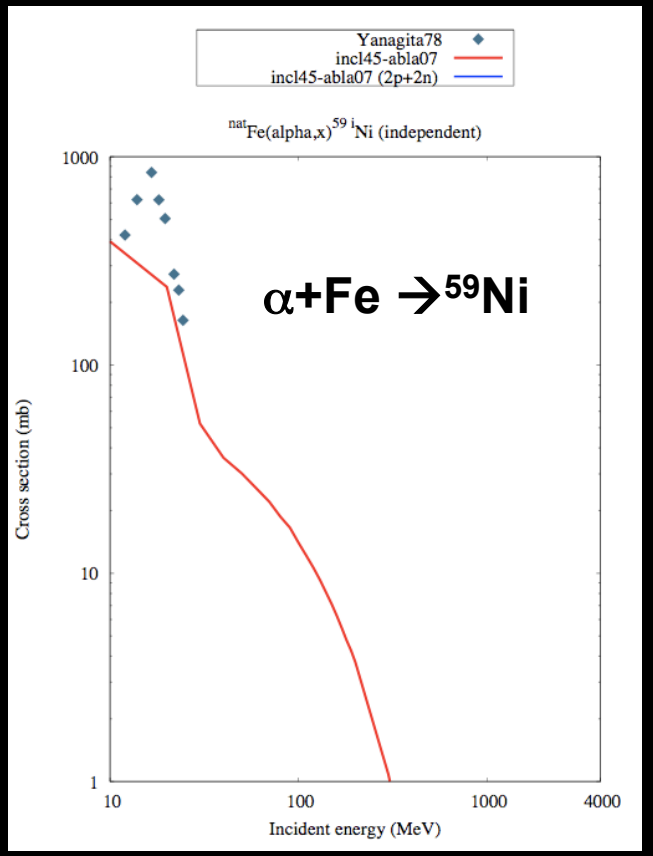
- INCL4.5-Abla07 not so bad - except the shoulder (CN nucleus - see before)

Spallation modelling
What's new on nuclei production with INCL4.5-Abla07?

Results

Better coulomb barrier…



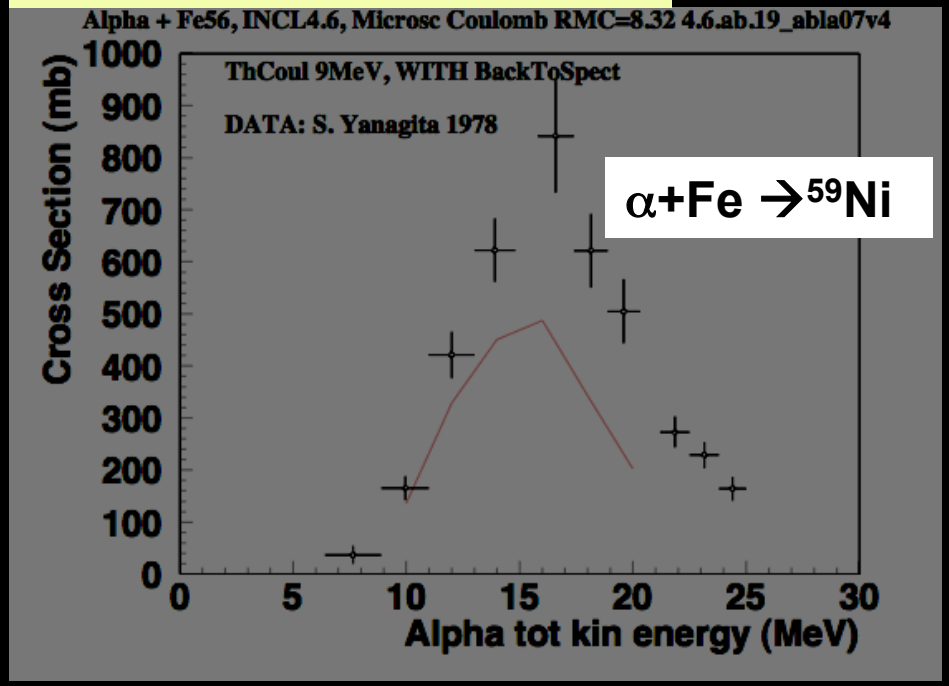


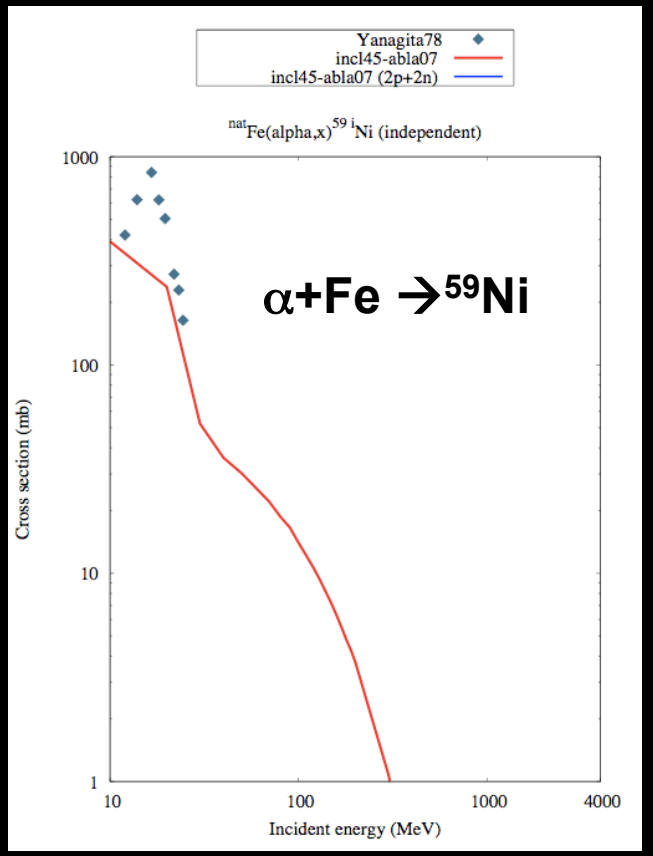
- INCL4.5-Abla07 not so bad - except the shoulder (CN nucleus - see before)
- … and results can be easily improved (figure on the left)

Spallation modelling
What's new on nuclei production with INCL4.5-Abla07?

Results

Better coulomb barrier…





- INCL4.5-Abla07 not so bad - except the shoulder (CN nucleus - see before)
- … and results can be easily improved (figure on the left)

Summary

✧ Great improvements of INCL4.5-Abla07 for residue production
(compared to other spallation model, see: http://www-nds.iaea.org/spallations)

✧ Extension to low energies and IMF production satisfactory

(Thesis on extensions to high energies (10 GeV) defended in September)

✧ Nevertheless details have to be refined/studied

→ **INCL4.5 and Abla07 become comprehensive codes**

And so could help:
- When data are missing
- To test/estimate/replace approximations: n=p; α=2p+2n or 4p

Until the day no more data will be necessary…

Thank you!

BACK UP

INCL4.5: New features

- Emitted particles: N, π → N, π, Light Charged Clusters (A < 9)
  A nucleon escaping can drag with him other nucleons (surface coalescence)

- V_N = cst → $V_N(E,T_3)$
  Improves charge exchange quasi-elastic and quasi-inelastic events

- V_π = 0 → $V_\pi(T_3)$
  Improves pion production cross section

- Extension to Low Energy
  . For a collision a test is made (E_{cm}>2M+cut_{NN}) to save time → except 1st one
  . Coulomb distorsion taken into account

- Pauli Blocking: statistic → statistic, except first collision (strict)
- Stopping time → Stopping time + Energy criterion (< E_F + 10 MeV) -- to save *time*

Abla07: all possible deexcitation channels