INCL4.5-Abla07: What's new for the assessment of spallation target activation?

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irfu cea saclay

INCL4.5 and Abla07

INCL4 Intra-Nuclear Cascade Liège (CEA and U-Liège)
Abla Deexcitation (GSI)
Break-up; evaporation; fission

(~150 MeV → 3 GeV)

Emitted particles

INCL4.2	n, p, π
Abla	n, p, α

INCL4.5 and Abla07

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

INCL4.5 and Abla07

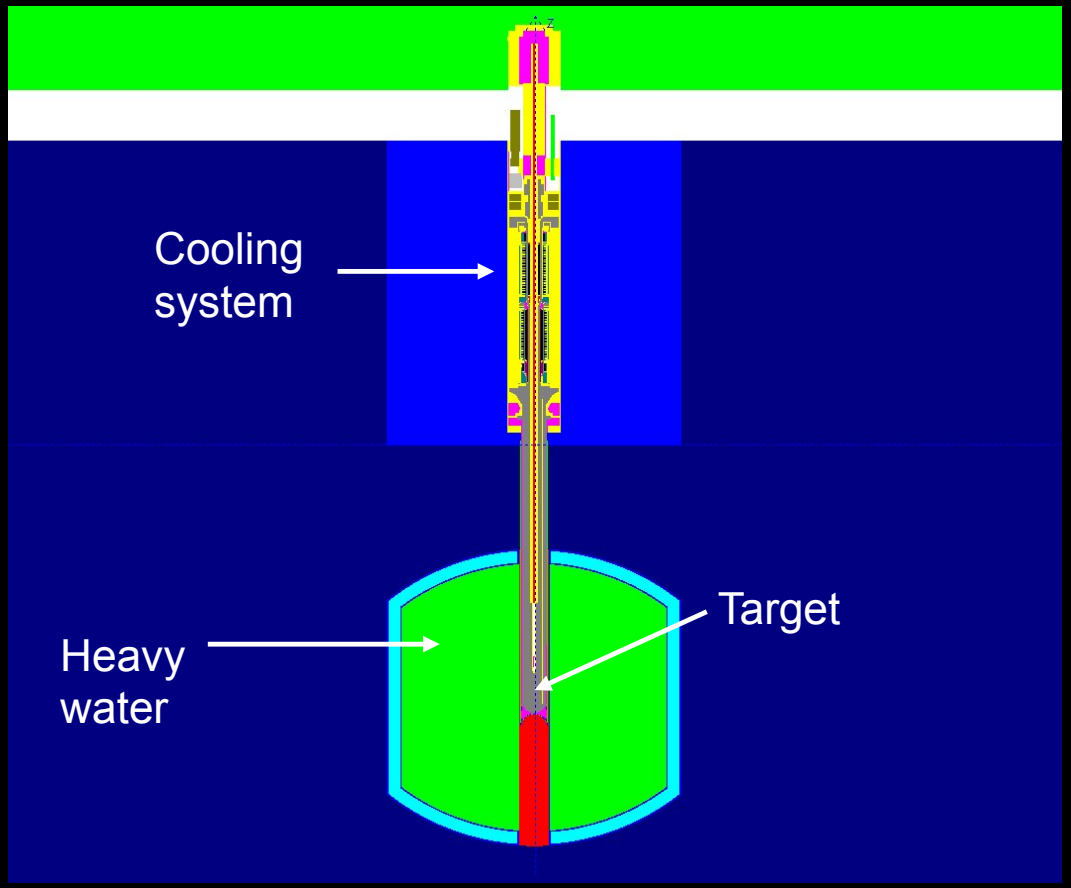
INCL4	Intra-Nuclear Cascade Liège	(CEA and U-Liège)
Abla	Deexcitation Break-up; evaporation; fission	(GSI)

And INCL4.5-Abla07 in a MCNPX beta version

Emitted particles

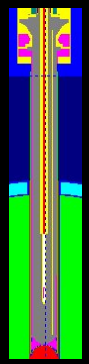
INCL4.2	n, p, π
Abla	n, p, α
INCL4.5	n, p, π, d, t, ^{3}He, α and A $\leq$ 8
Abla07	n, p, d, t, ^{3}He, α and IMF

MegaPie



- Demonstrator for liquid Pb-Bi target
- Within SINQ (PSI)
- operated in 2006
- Proton beam
- 575 MeV and 1.4 mA (~0.8 MW)

MegaPie



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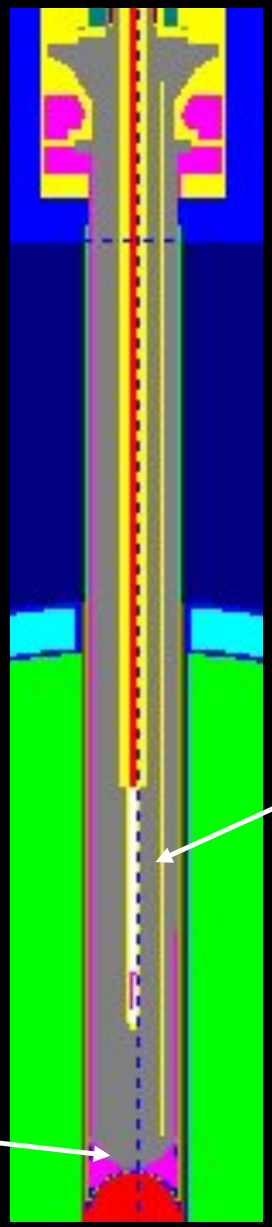

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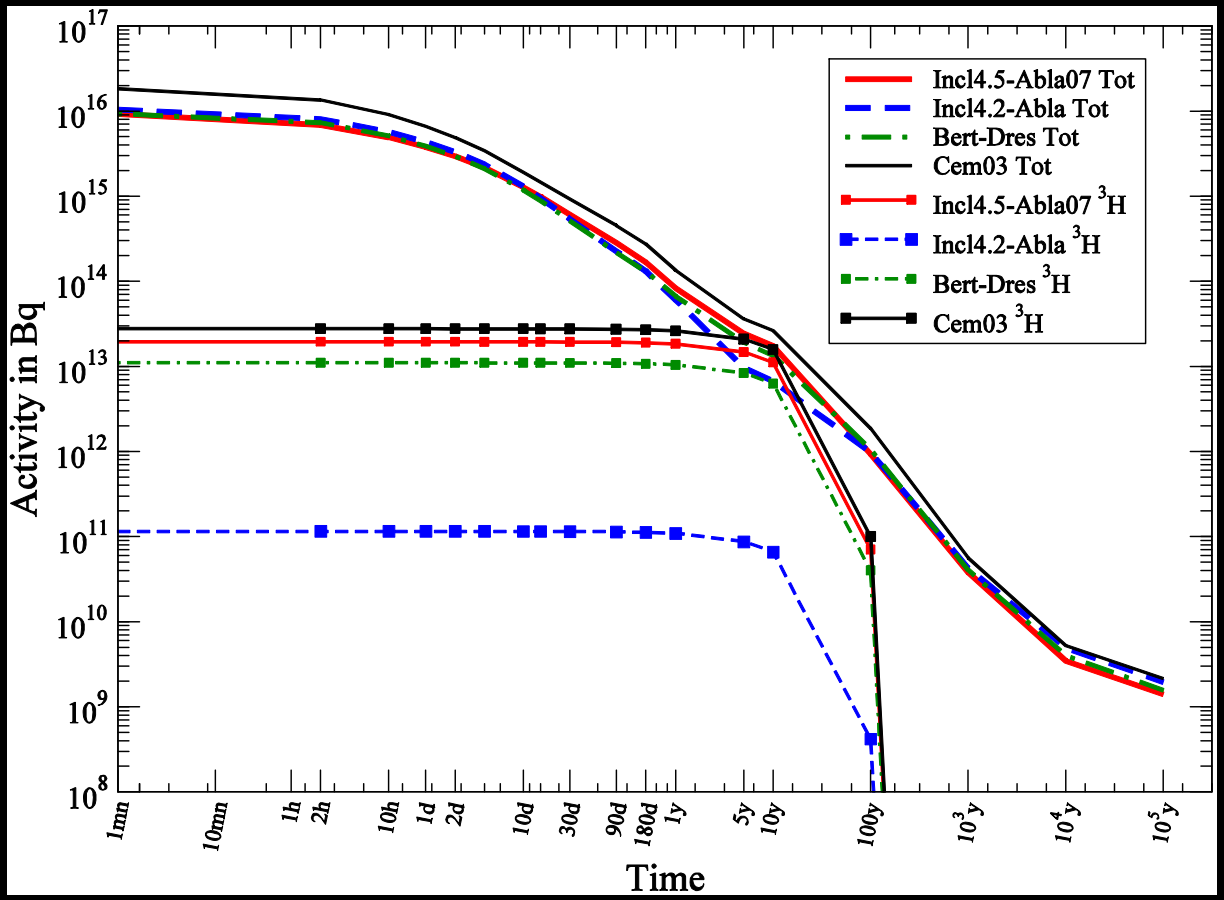
Activity LBE

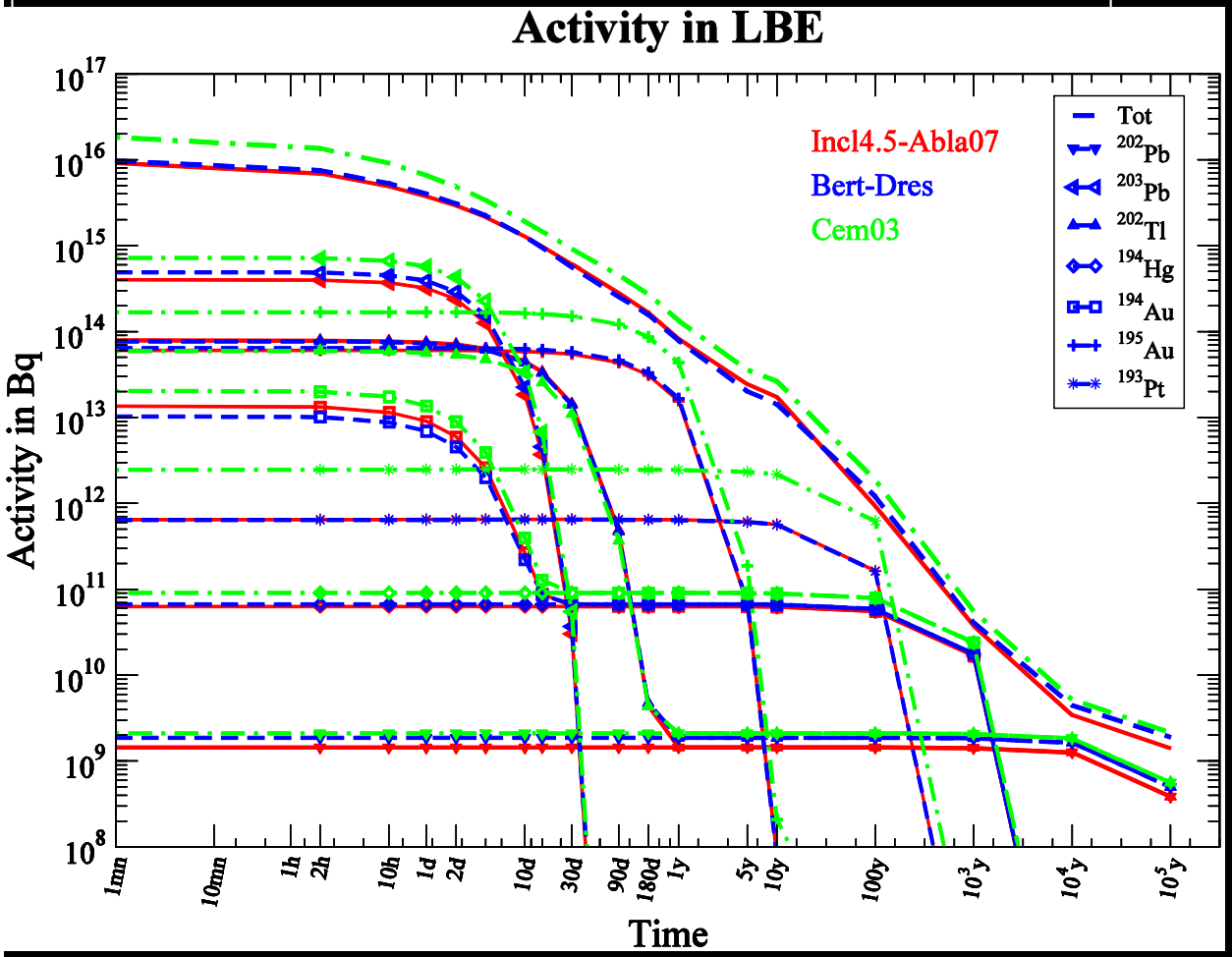


Main differences:

- Tritium contribution
- CEM03 higher

Activity LBE

Main contributors



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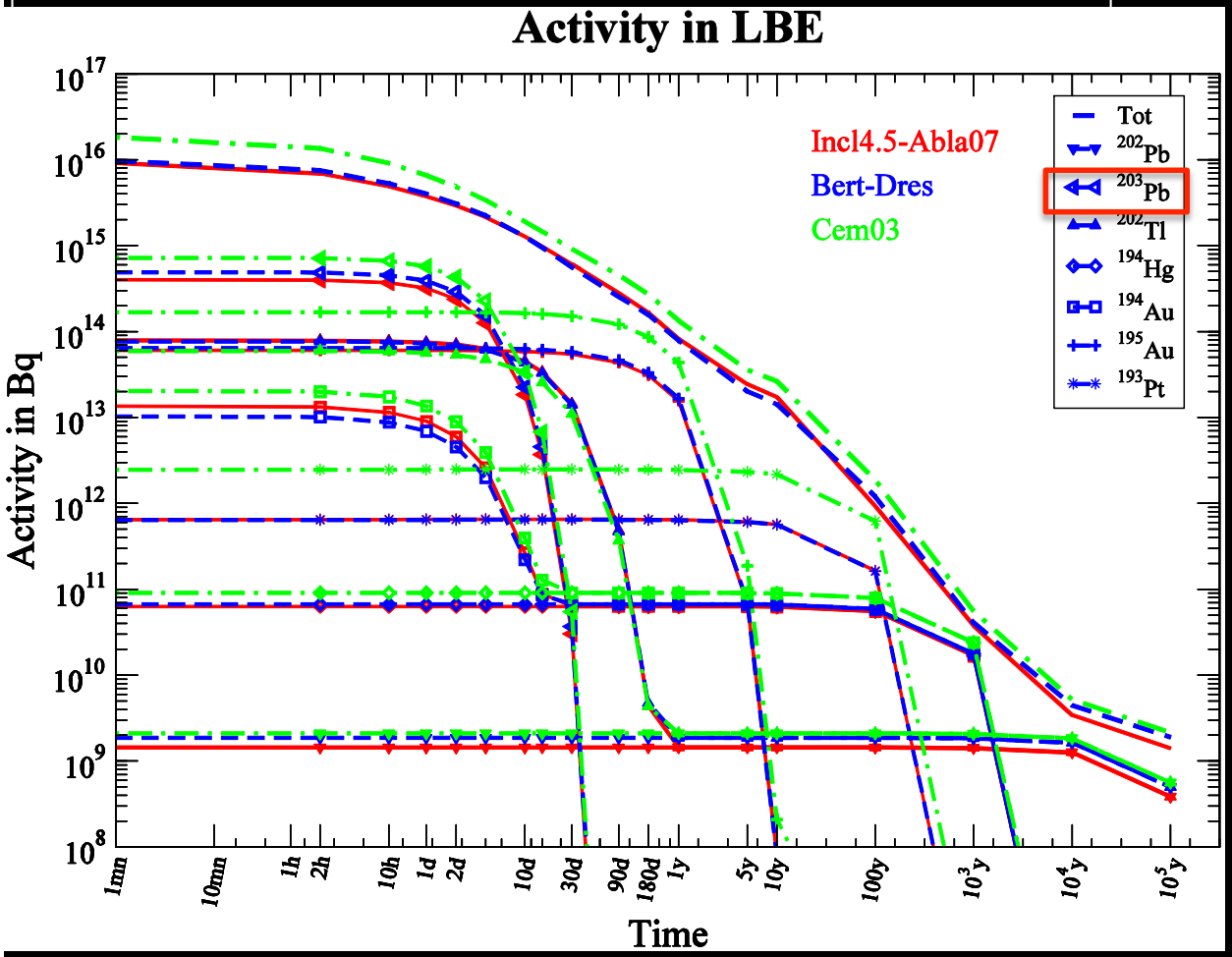
Activity LBE

Possible explanation → **Elementary data**

Main contributors



Activity LBE

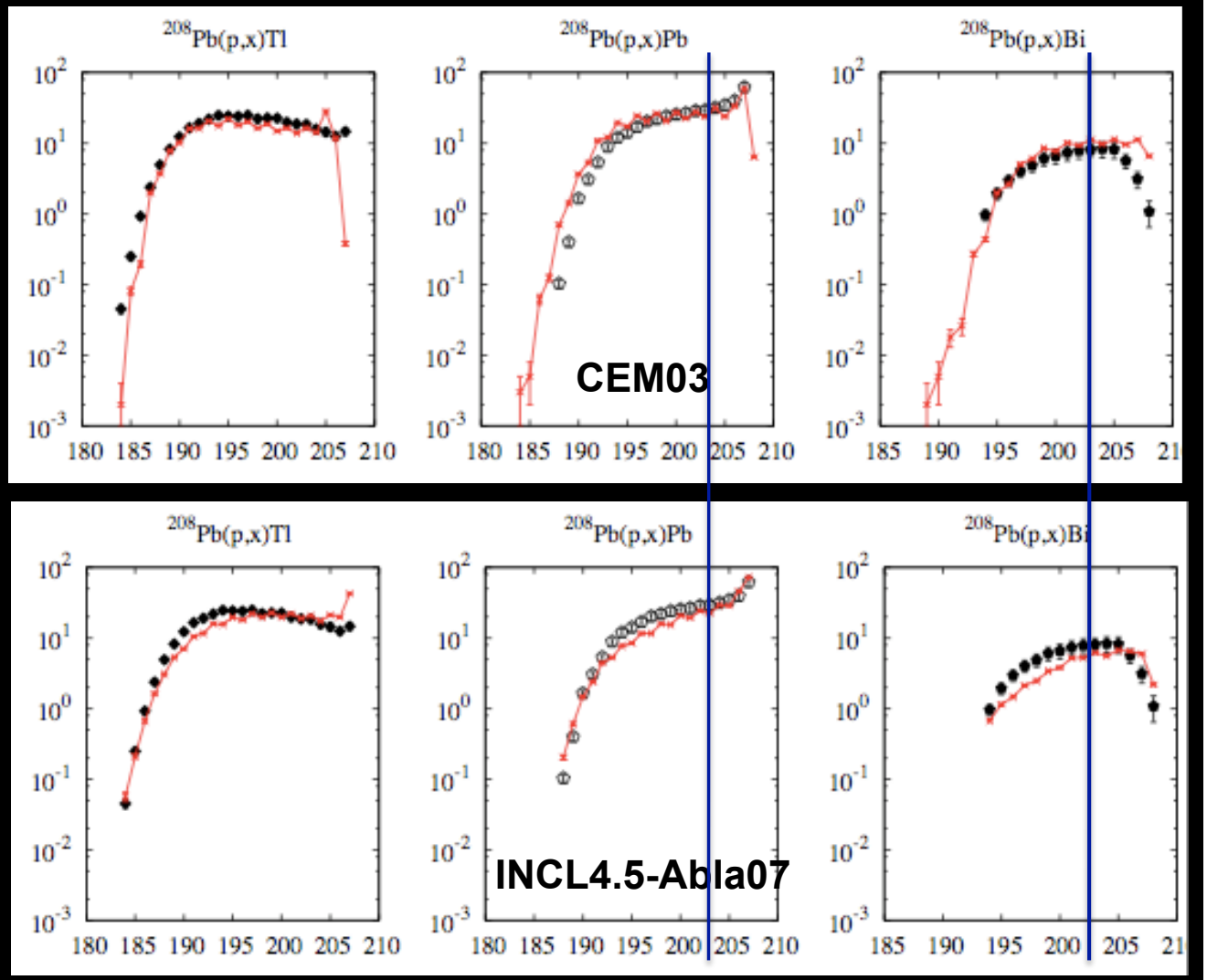
Possible explanation → **Elementary data**

Ex. ^{203}Pb contribution

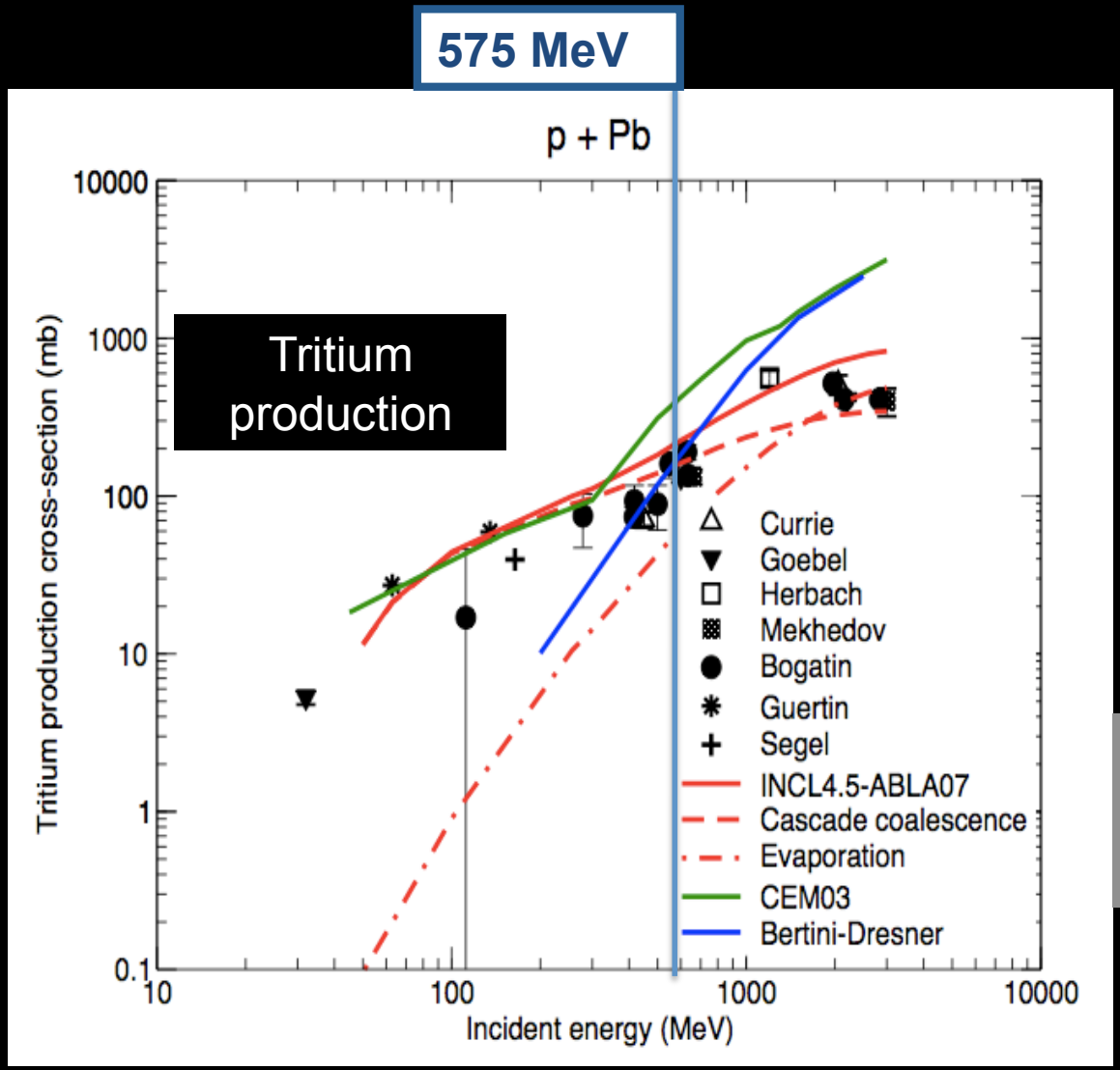
p+^{208}Pb @500MeV
INCL4.5-Abla07 ≈ CEM03

But…
@~500MeV
^{203}Pb= 80% ^{203}Pb
20% ^{203}Bi
@~70MeV
^{203}Pb= 50% ^{203}Pb
50% ^{203}Bi

… same story with ^{202}Pb



Activity LBE



Main differences:

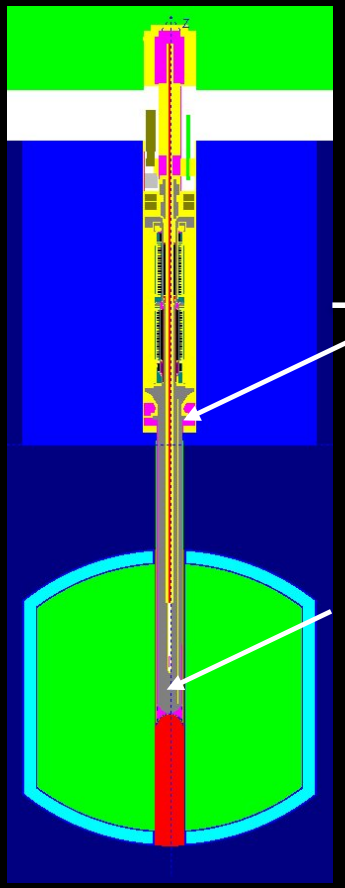
- Tritium contribution
- CEM03 higher

INCL4.5-Abla07 better than the other codes in the MegaPie energy range

Delayed Neutrons in LBE

Neutrons:
- prompt (reaction)
- delayed (decay of precursors)

Liquid metal target → Precursors can move →



Measurement of DN @ MegaPie in 2006

Attempt to calculate DN with INCL4.5-Abla07

D. Ridikas et al., Proc. of PHYSOR2006, Vancouver, Canada

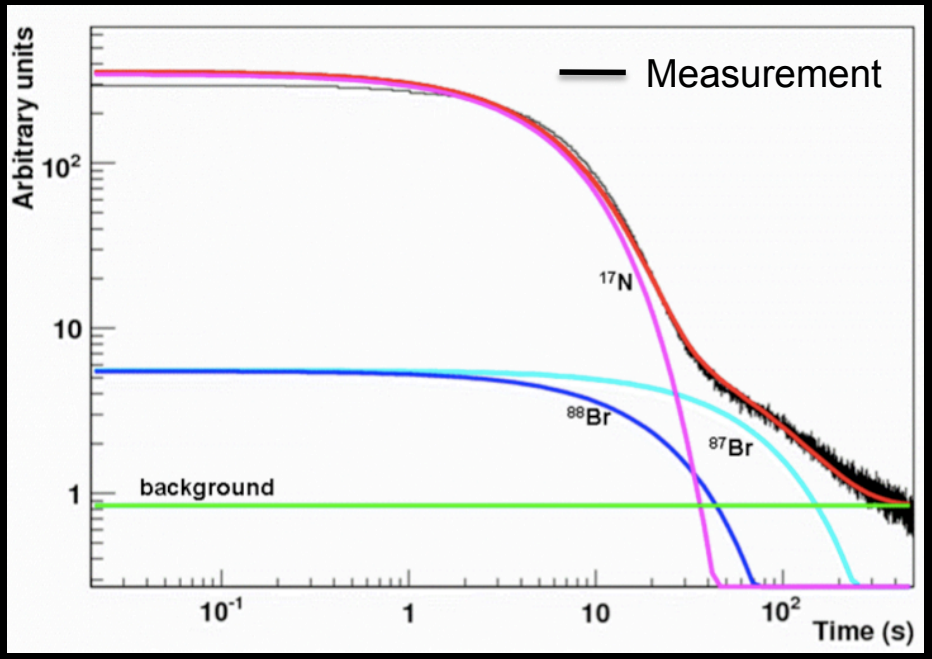
Delayed Neutrons in LBE

Experiment

DN flux (a) and contributors (a_i)

$$a(x) = \sum_{i=1}^{n} a_i(x) = \sum_{i=1}^{n} a_i^a \frac{1-\exp(-\lambda_i \tau_a)}{1-\exp(-\lambda_i T)} \exp(-\lambda_i \tau_d(x))$$

- τ_a activation time
- T (total) circulation time
- τ_d transit (decay) time
- "i" precursor #i



Fit of DN measurement with 3 precursors

Group	Precursor	Half-life (s)	a_i, %
1	^{87}Br	55.6	4.3
2	^{88}Br	16.3	3.3
3	^{17}N	4.16	92.4

…^{17}N is produced now in INCL4.5-Abla07…

Delayed Neutrons in LBE

Calculation

$$a(x) = \sum_{i=1}^{n} a_i(x) = \sum_{i=1}^{n} a_i^a \frac{1-\exp(-\lambda_i \tau_a)}{1-\exp(-\lambda_i T)} \exp(-\lambda_i \tau_d(x))$$

	a_i Ratios	
	INCL4.5-Abla07	Experiment
$^{17}N/^{87}Br$	2.26	21.49
$^{17}N/^{88}Br$	4.06	28.00
$^{87}Br/^{88}Br$	1.80	1.30

@ 1 GeV	^{17}N (mb)	^{88}Br (mb)	^{87}Br (mb)
Gatchina exp.	493 ± 17	40 ± 12	30 ± 11
INCL4.5-Abla07	233 ± 10	82 ± 6	10 ± 2
Phits	249 ± 17	52 ± 8	8 ± 3

^{17}N, ^{87}Br, ^{88}Br: <u>difficult to estimate</u>

- ^{87}Br, ^{88}Br: very rich neutron Br isotopes
- ^{17}N: 2 mechanisms

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INCL4.5-Abla07 has to improved N/Br ratios…
But able to calculate them!

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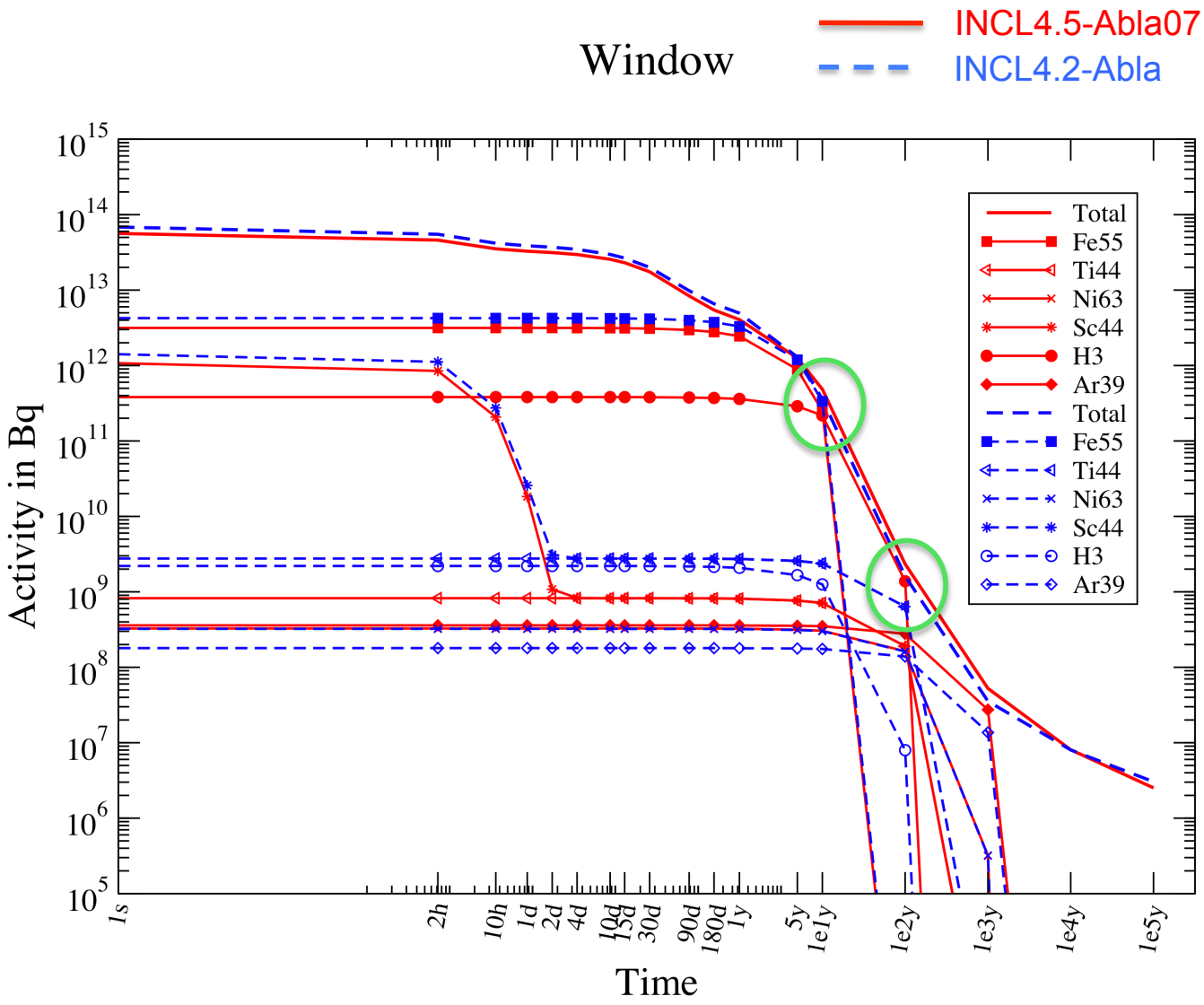
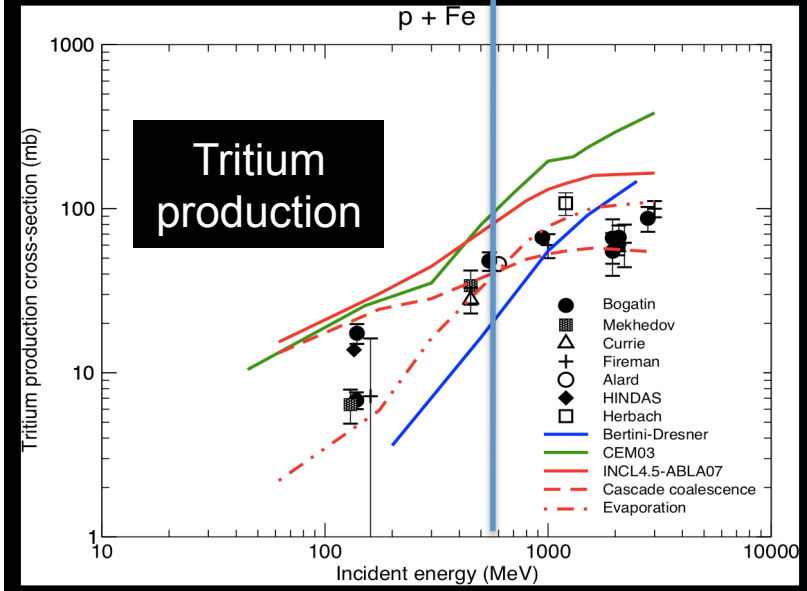
Activity Window



- ~no difference…
- except Tritium!?

575 MeV

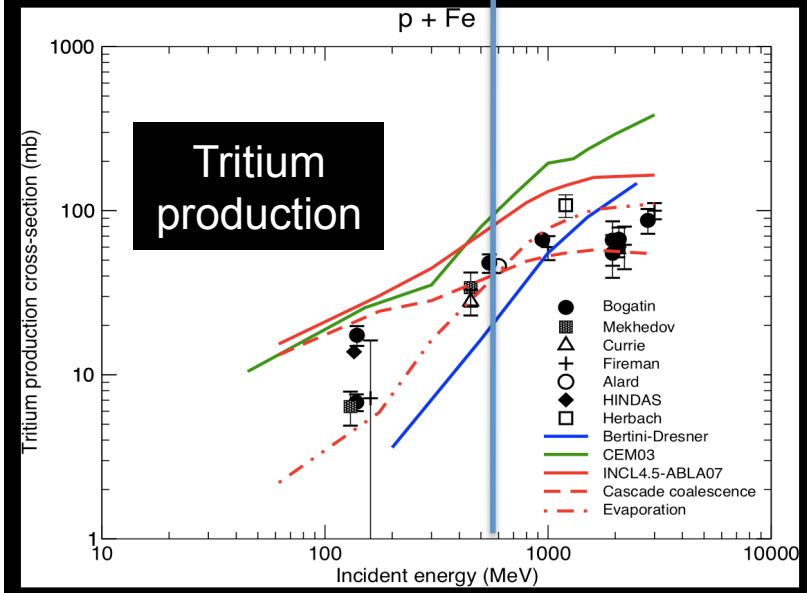
Tritium in Window



Tritium is directly produced and with the right rate

575 MeV

Tritium in Window



Tritium is directly produced and with the right rate

BUT comes also from low energy neutrons:

- ^{3}He 29.7%
- ^{6}Li 1.6%

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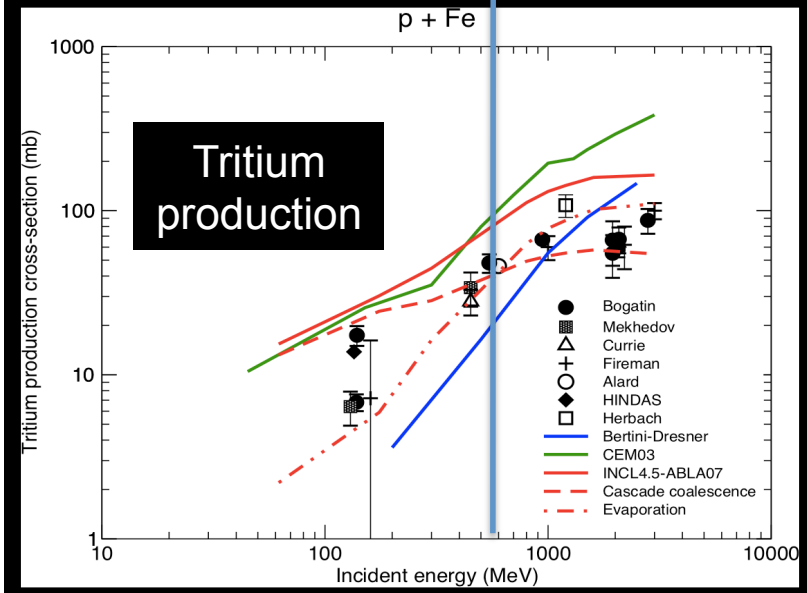
saclay

575 MeV

Tritium in Window



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σ (barn)	$80\ 10^{-3}$	850	150
flux (particle/proton/cm2)	$2\ 10^{-3}$	$3\ 10^{-2}$	$3\ 10^{-2}$

By hand:

- ^{3}He 20.5%
- ^{6}Li 0.4%

irfu cea saclay

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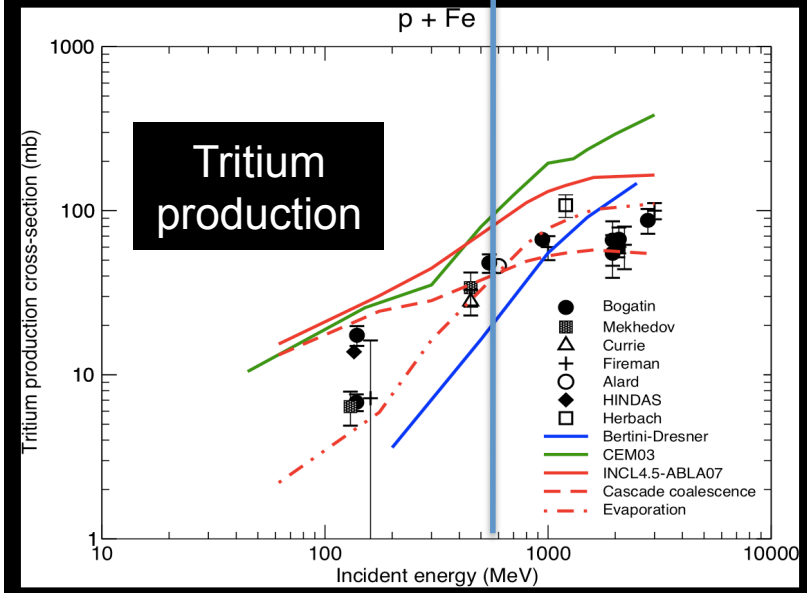
Tritium in Window



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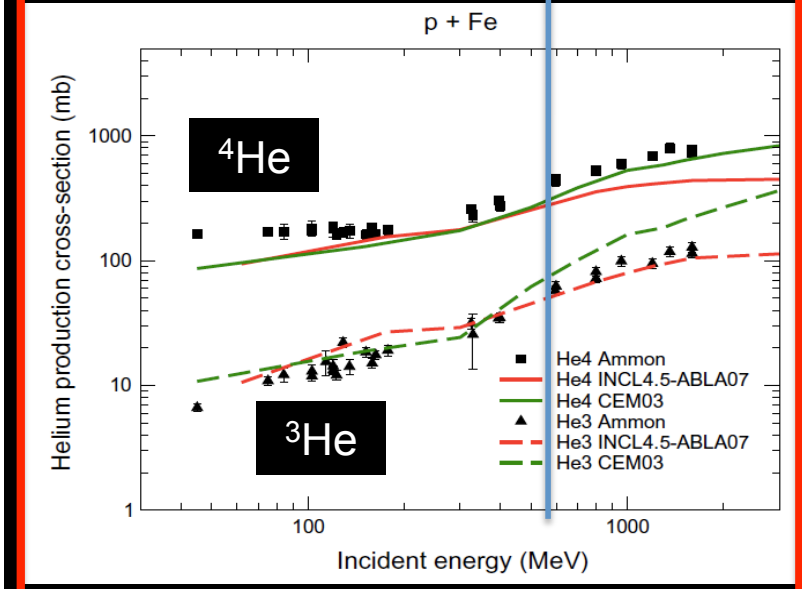

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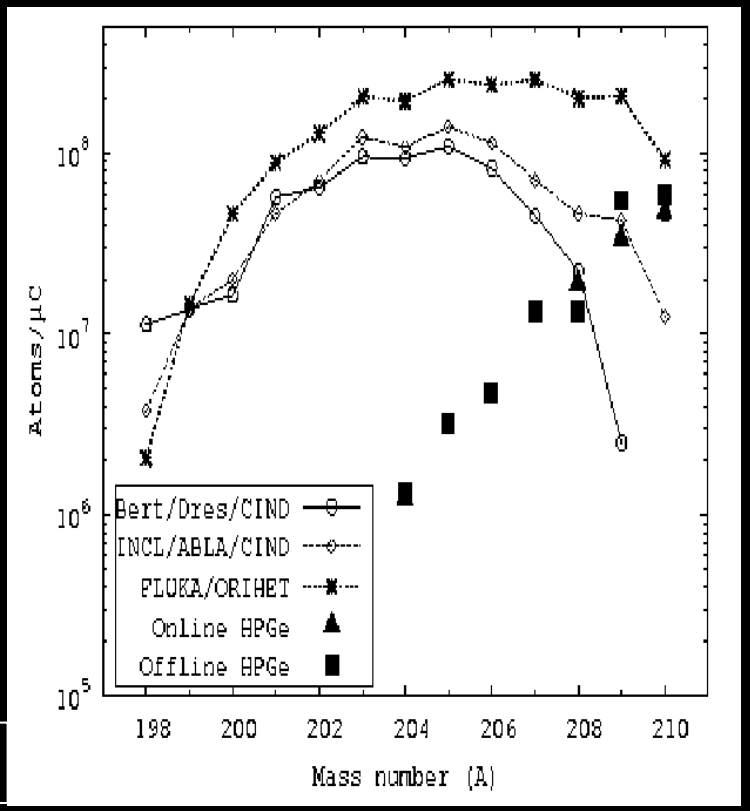
Astatine @ ISOLDE

Release of volatiles in Pb/Bi has been studied at ISOLDE (Ep = 1.4 GeV)
… and **At** were measured (Y. Tall et al., ND2007)

At is produced with low rates, but:

- **At** decays to Po (α emitter)
- **At** more volatile than Po

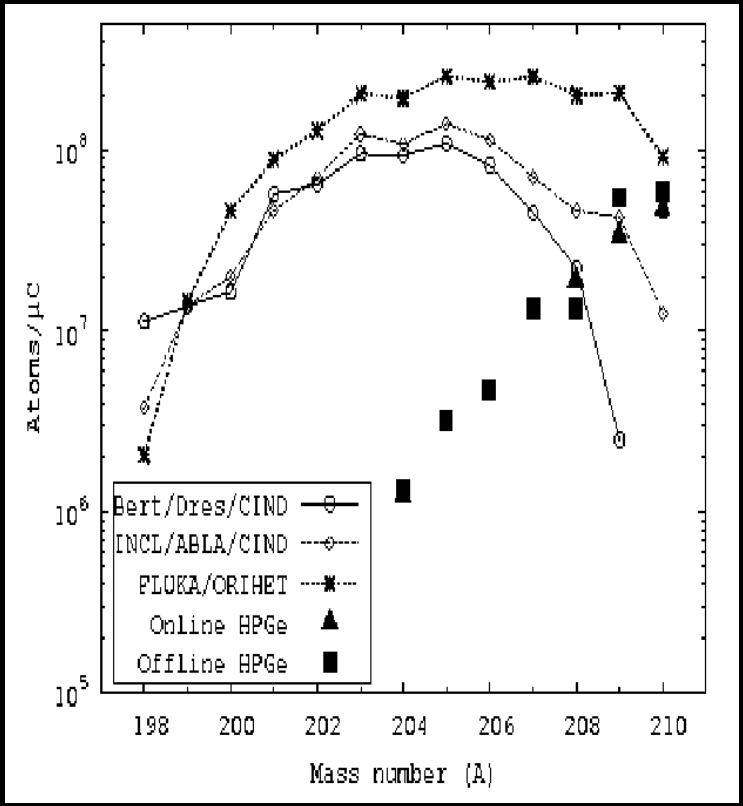
→ **At** can become a safety issue



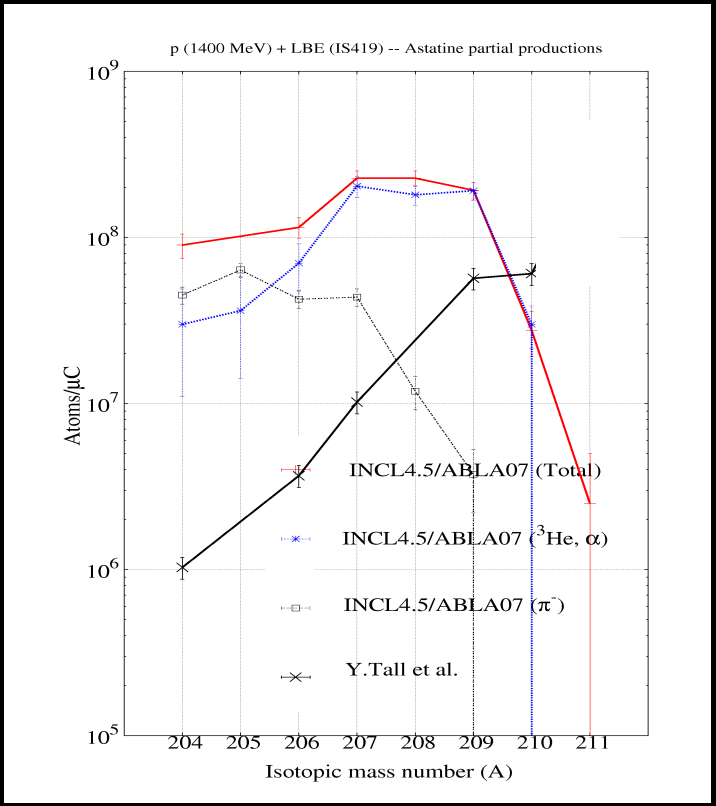
No model was able to reproduce **At** production

Astatine @ ISOLDE

2007



2010



INCL4.5-Abla07 seems not really better (shape!)… ??? Why?

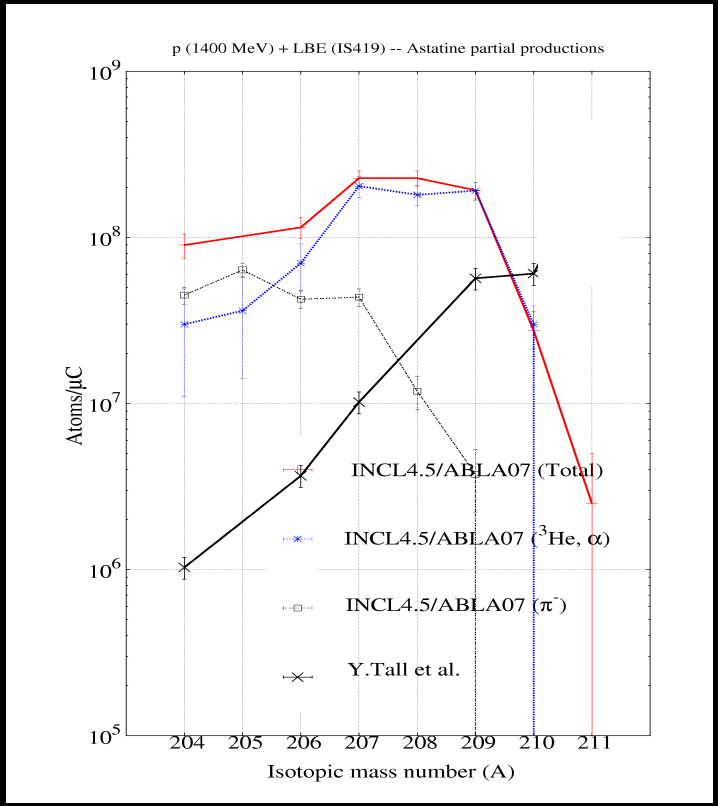
- Model?
- Data? ……→ data=measurement / calculation=in-target !!!

Astatine @ ISOLDE

Two production channels:

- Bi (p,π⁻) for light isotopes
- secondary reactions induced by He for heavy isotopes
  - ↪ wrong shape of calculation!

2010



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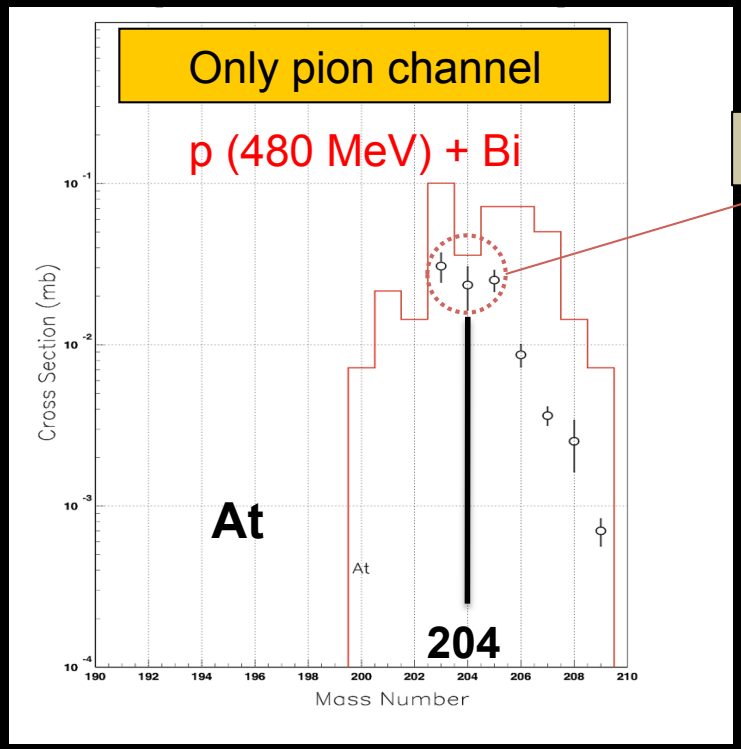
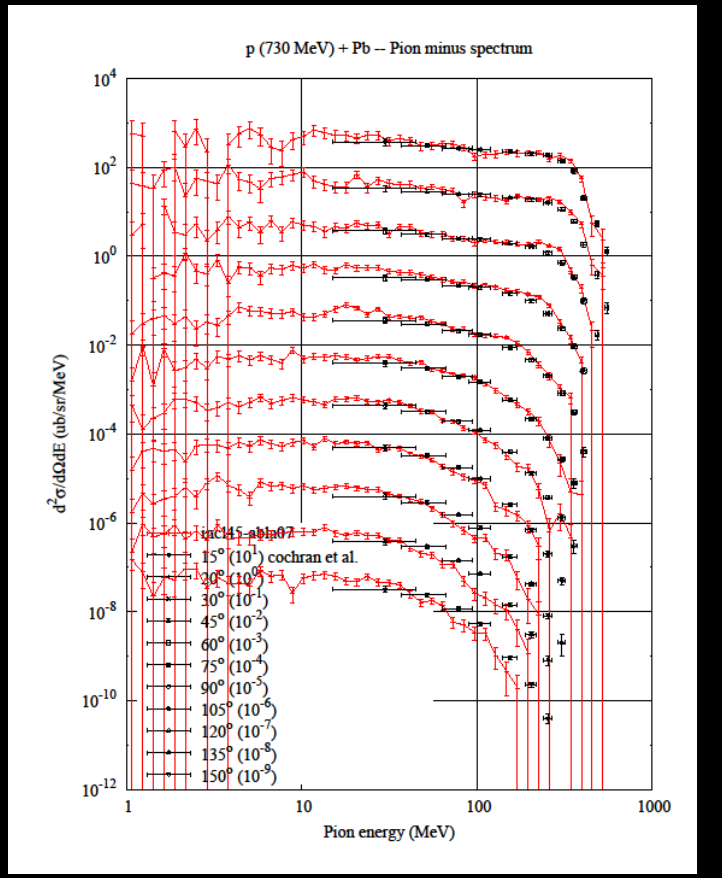


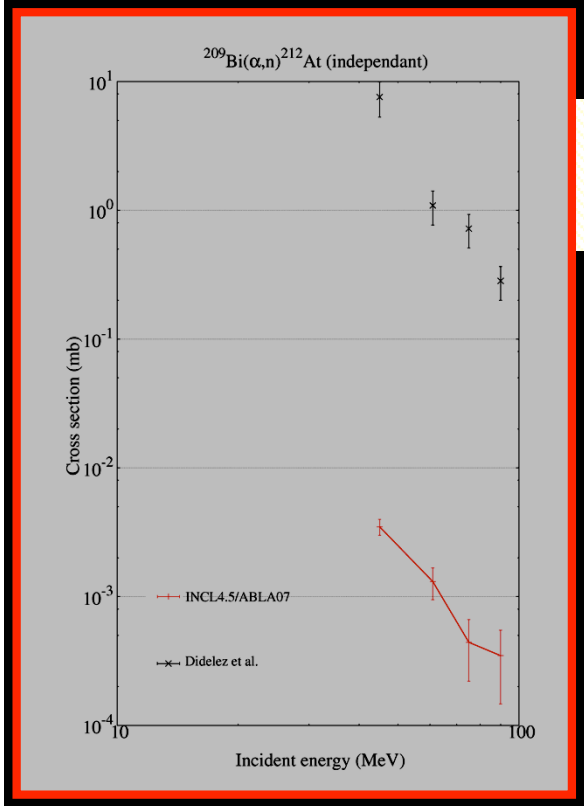


- π spectra: OK!
- **At** production (π channel only) not so bad

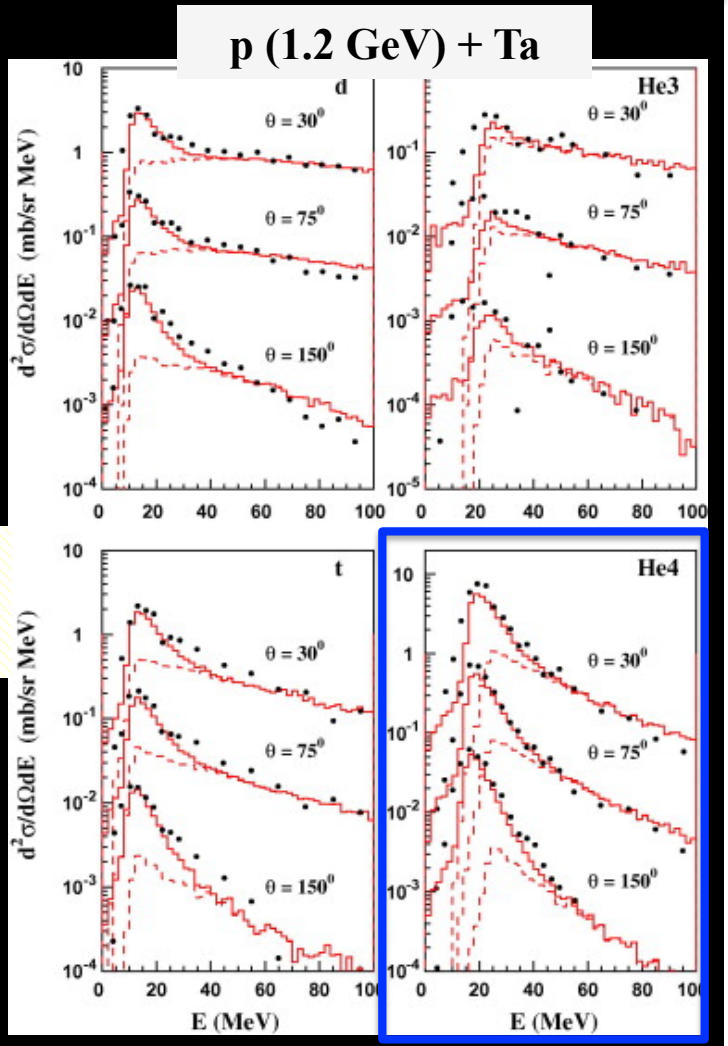
Astatine @ ISOLDE

Two production channels:

- Bi (p,π⁻) for light isotopes
- **secondary reactions induced by He for heavy isotopes**
  - ➥ **wrong shape of calculation!**



- **production of He OK**
- **wrong production of At**

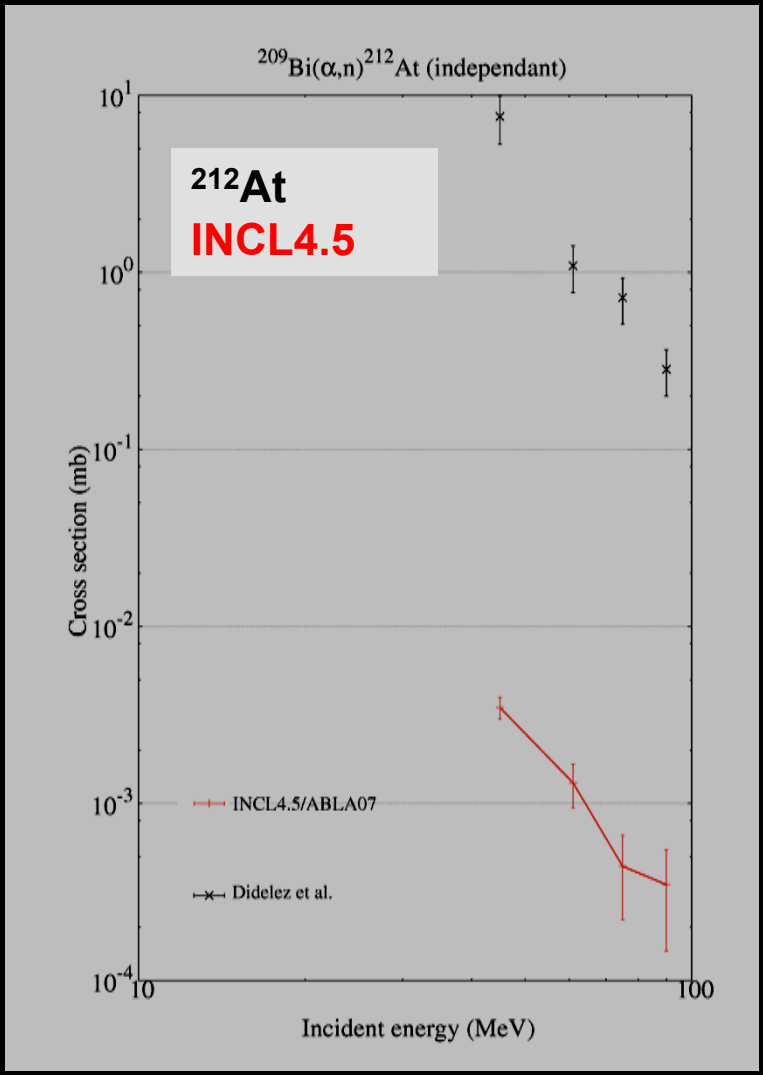


➥ **Exact reaction Q-values not taken into account**

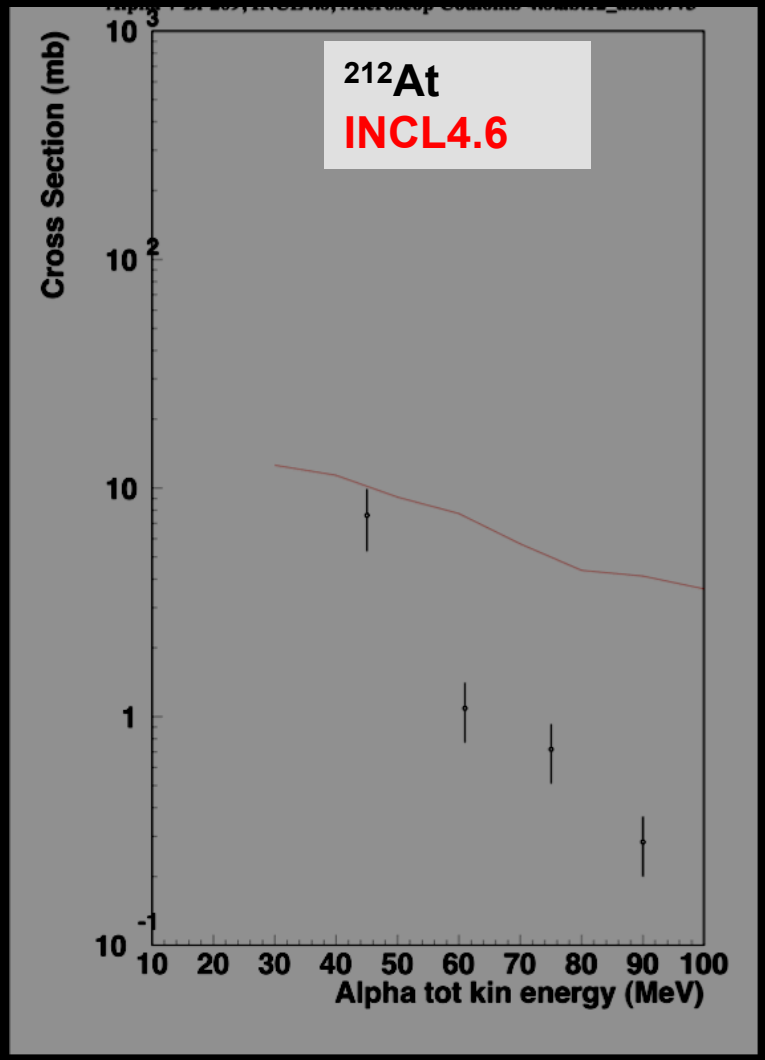
➥ **Coulomb deviation not done in He induced reactions**

Astatine @ ISOLDE

Improvement ?

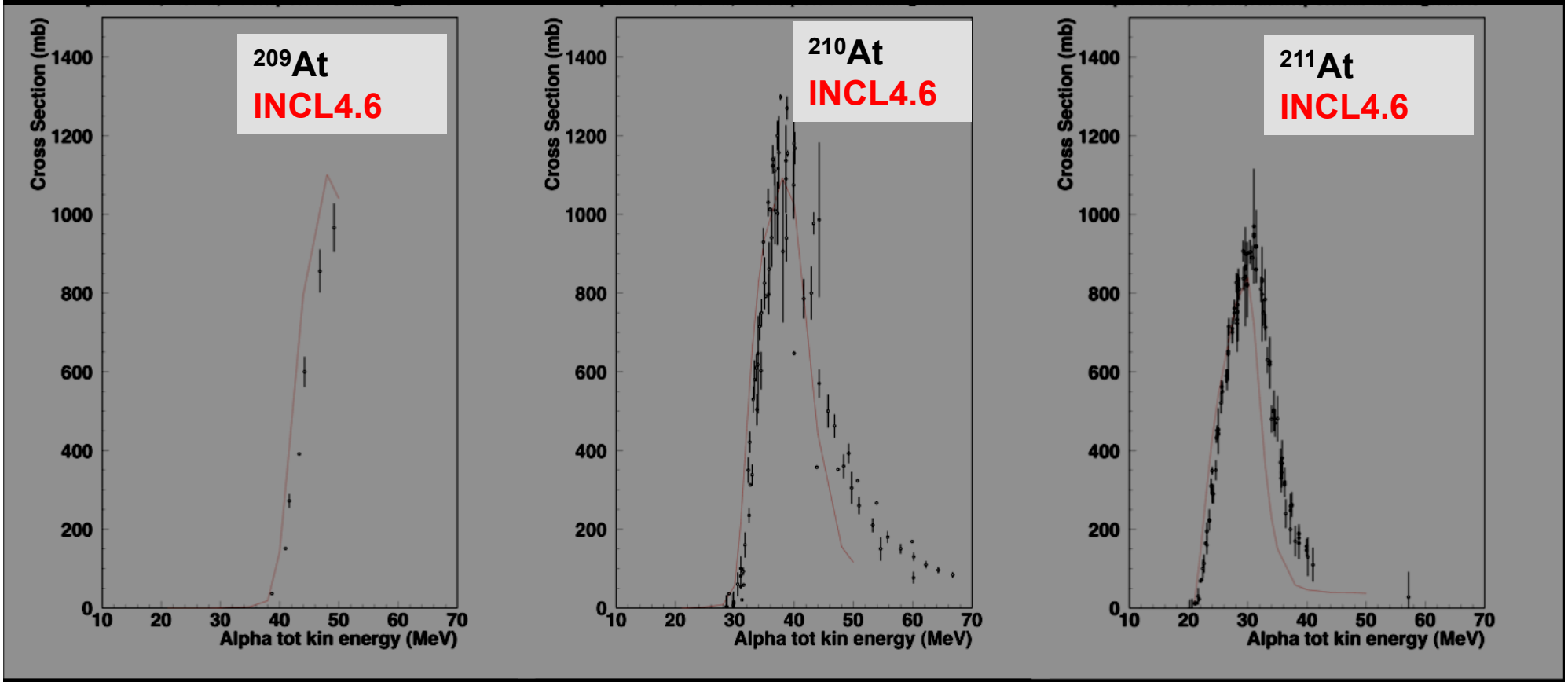


YES



Astatine @ ISOLDE

Improvement!



Astatine @ ISOLDE

Next steps

- Improvements into MCNP(X) → new ISOLDE calculation
- Status on the data: ^{211}At

Conclusion

We have seen that:

- **Need of Elementary Data to understand *macroscopic* results**
  AND taking into account all mechanisms
  - ^{203}Bi production for ^{203}Pb production (and at lower energies)
  - ^{3}He(^{6}Li) production for Tritium production

- **Delayed Neutrons tricky to estimates due to**
  - Combination of several mechanisms (evaporation/fission/break up)
  - Low probability channels

- **"Extented low energy" spallation needed**
  - Astatine (potential safety issue) from Helium ~40MeV (<< 150 MeV)

INCL4.5 and Abla07 (try to) become comprehensive codes with very encouraging results

INCL4.5-Abla07: What's new for the assessment of spallation target activation?

Authors

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