Neutron capture cross sections around neutron-rich magic nuclei for astrophysical purposes

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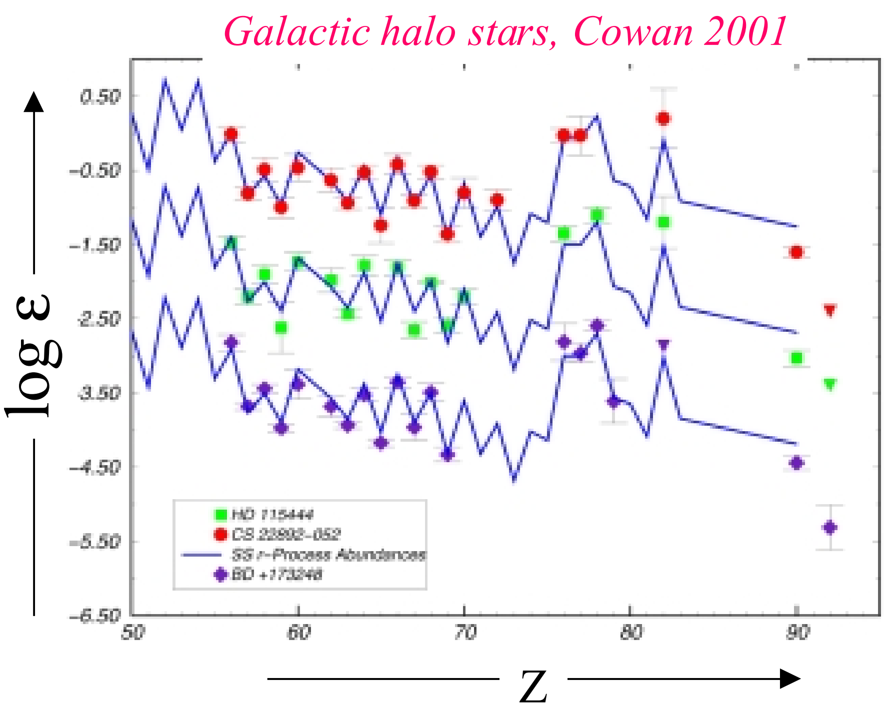
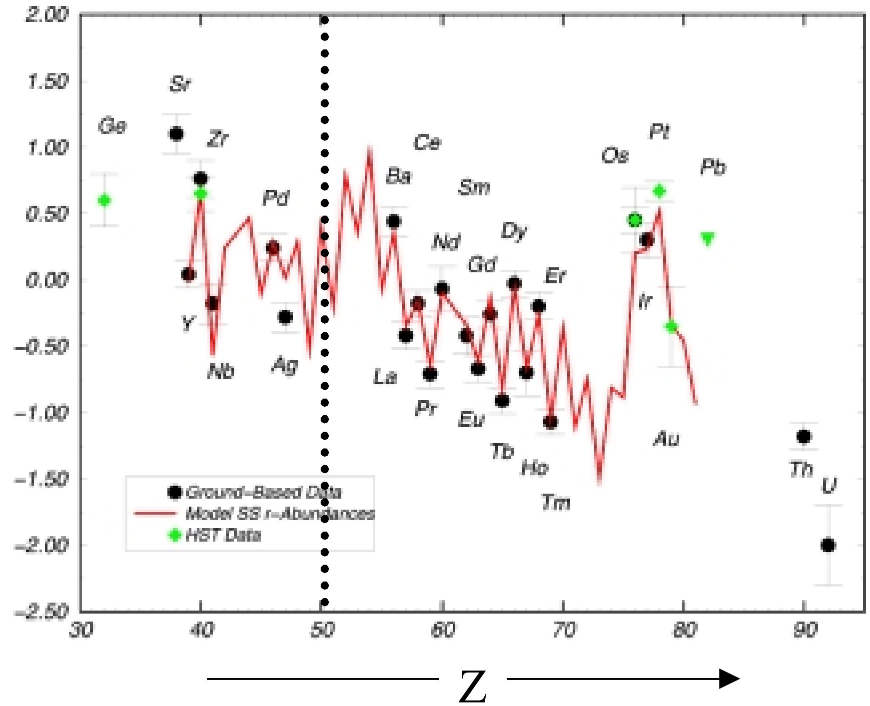
- Abundances observations
  - Astrophysical process
  - Experimental β-decay studies
- Neutron captures mechanisms
- Neutron captures on $^{46}Ar_{28}$

Observations in UMP Stars





r abundances similar to solar system for Z>54, A>130

Same abundance pattern in 3 different stars from the galactic halo

Very robust r-process for A>130

For Z<54 : non solar

Weak r-process (weak neutron fluxes) responsible for production of A<130 elements

Observations in inclusions of meteorites

^{48}Ca : -the last stable neutron rich nucleus in Ca chain
-two neutrons richer than ^{46}Ca which is also stable

-on Earth ^{48}Ca/^{46}Ca~50 >> 1

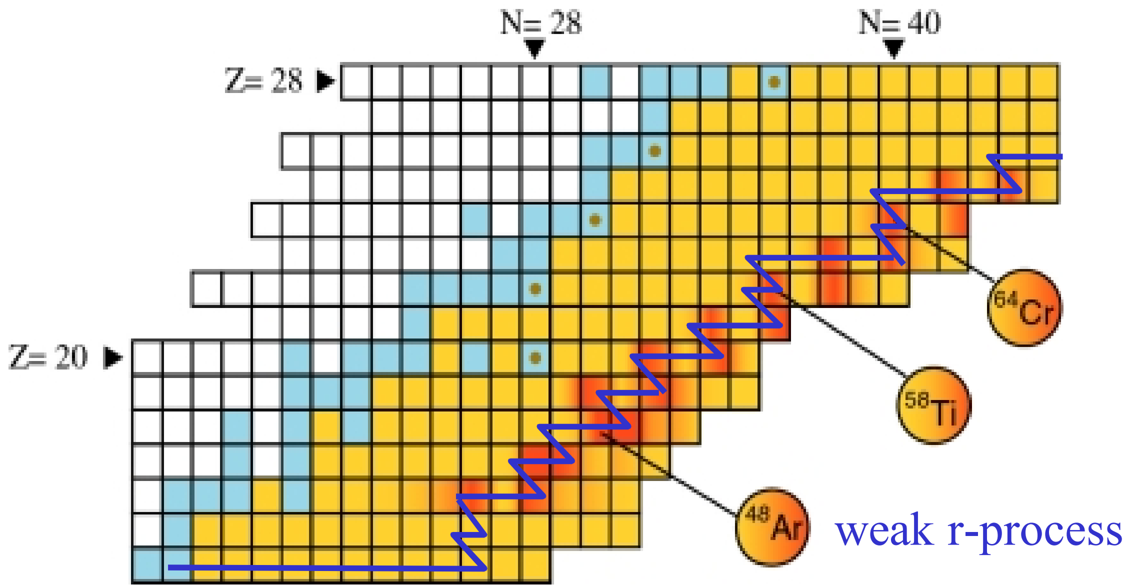
BUT :

-EK-1-4-1 ^{48}Ca/^{46}Ca~250

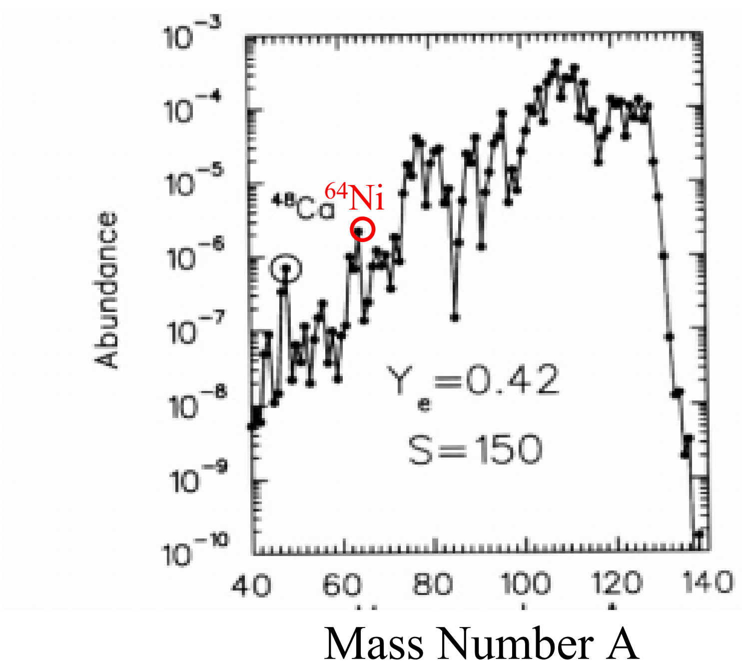
And also correlated isotopic anomalies in neutron-rich nuclei ^{50}Ti- ^{54}Cr- ^{58}Fe- ^{64}Ni

Could be explain by a "weak" r-process

The weak r-process : Production of A<130 elements



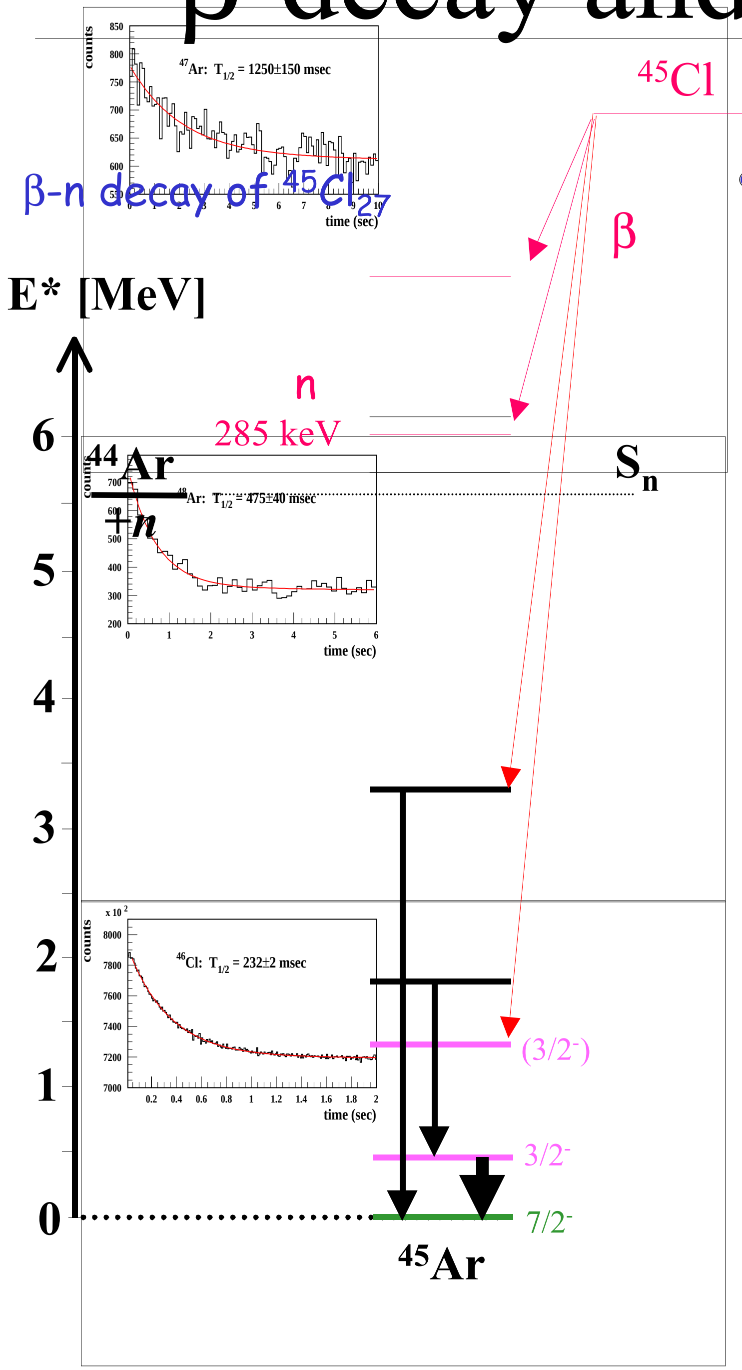
- Explosive environment
- Involves neutron rich nuclei
  - Neutron captures
  - β decays



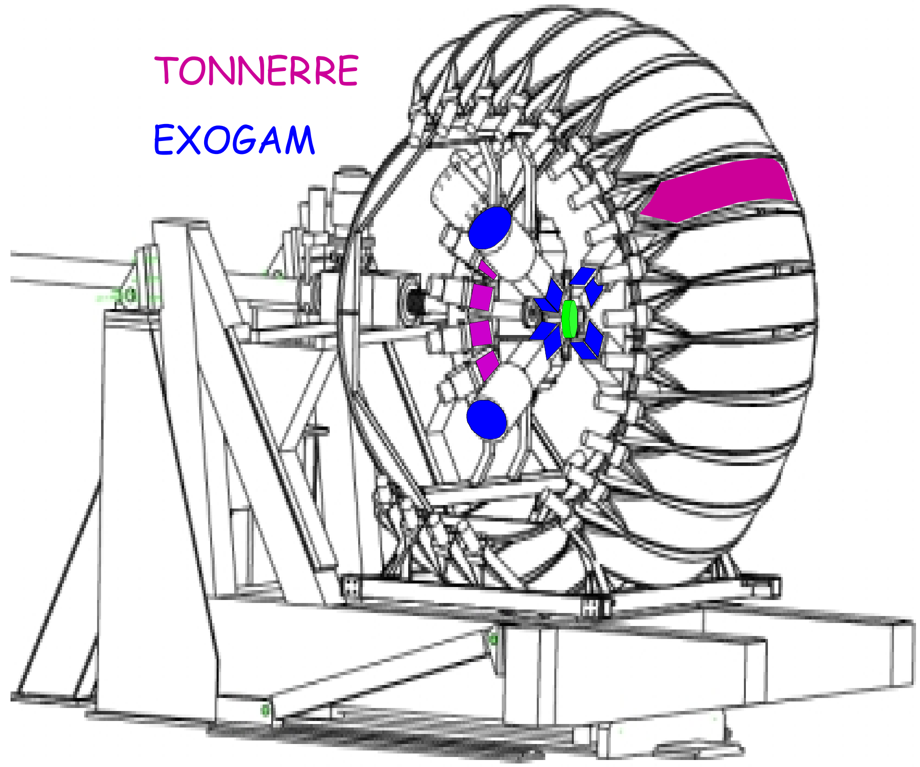
- Production of nuclei with A<130
- Overproduction of ^{48}Ca & ^{64}Ni

K.L. Kratz et al. Proc. Della Societa Astronomica Italiana 2000

β-decay and spectroscopy studies



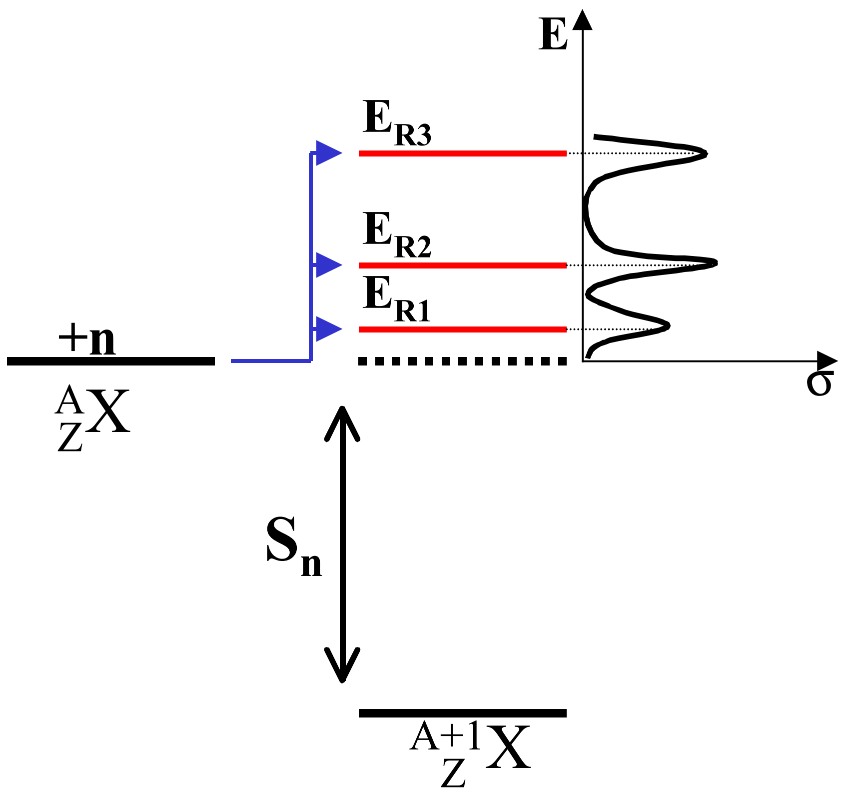
- **Some states could contribute to the direct capture**



S. Grévy, private comm., LPC Caen

Neutron capture mechanisms

Compound nucleus : resonant captures

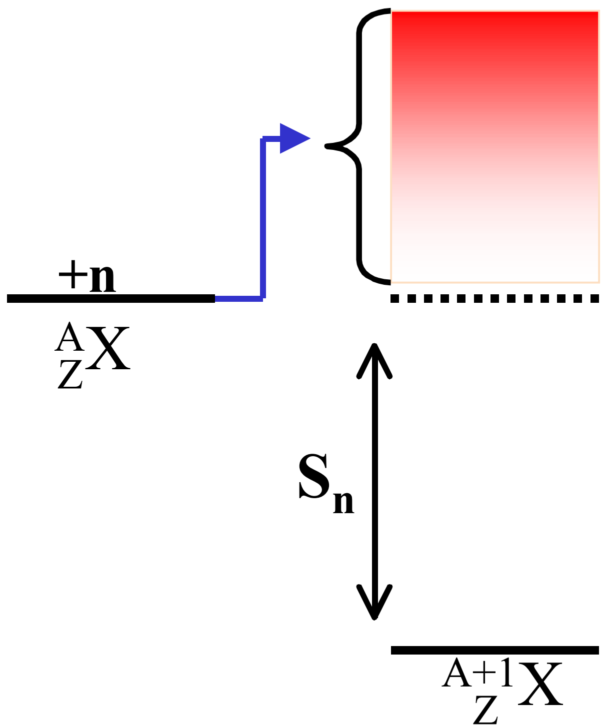


- If few resonances above the threshold : resonant capture
  =>application of Breit-Wigner formalism
- Captures only possible for given neutron energies : $E_n = S_n + E_R$
- Strong variation of the cross-section with the neutron energy depending on quantum numbers of the final states

Needs structural informations of unbound states in the final nucleus

Neutron capture mechanisms

Compound nucleus : statistical treatment



- **High level density above the threshold : overlap between resonances =>application of Hauser-Feshbach formalism**

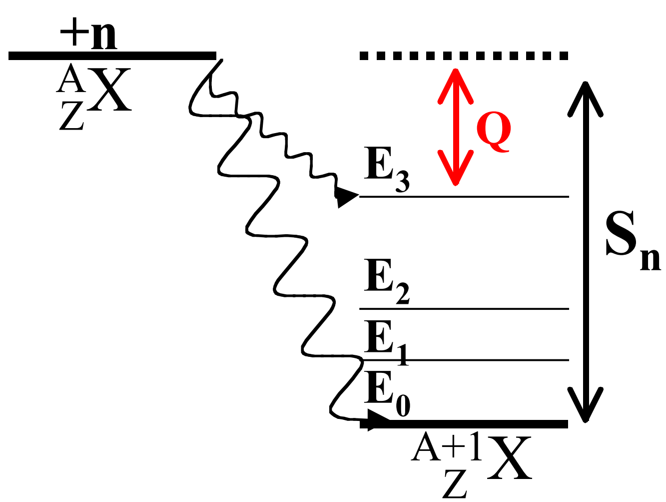
- **Captures possible for all neutron energies above the threshold**

- **Smooth variation of the cross-section with the neutron energy**

Determination of the cross section via statistical models : applicability (structure, S_n)?

Neutron capture mechanisms

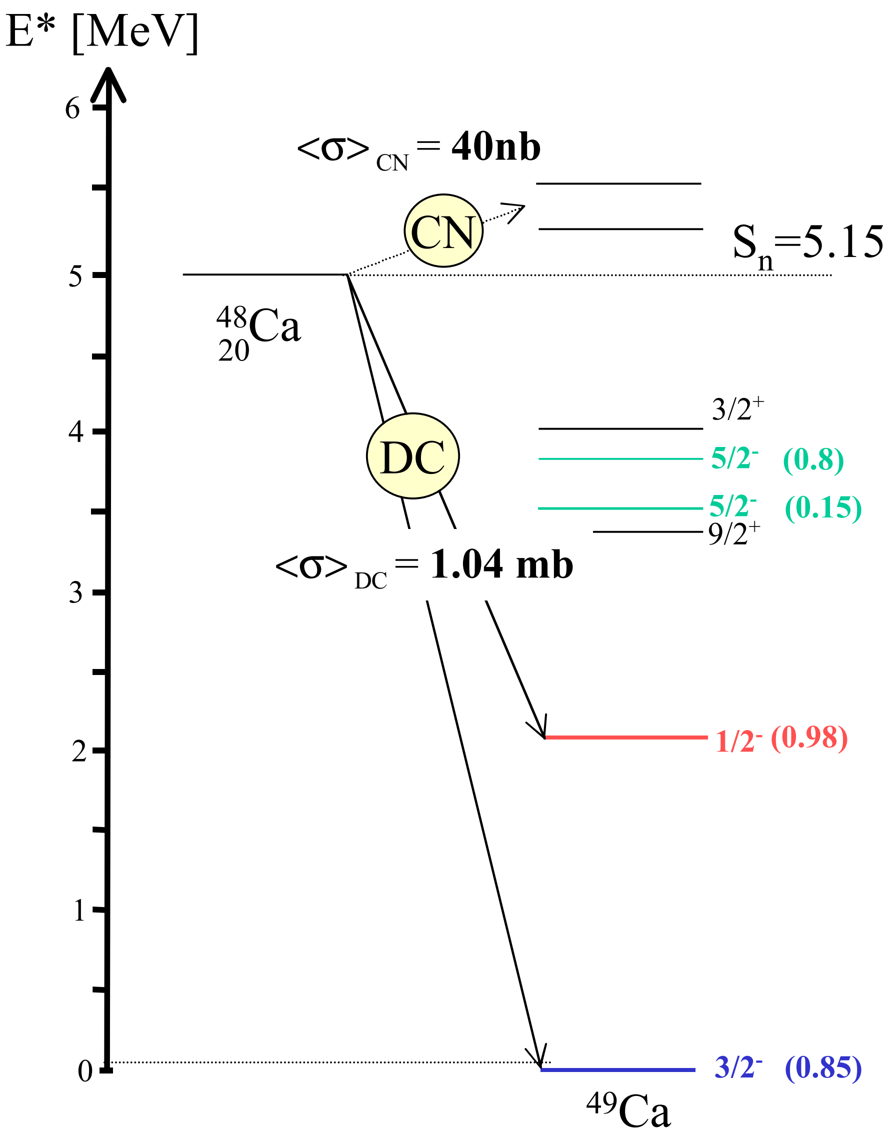
Direct capture



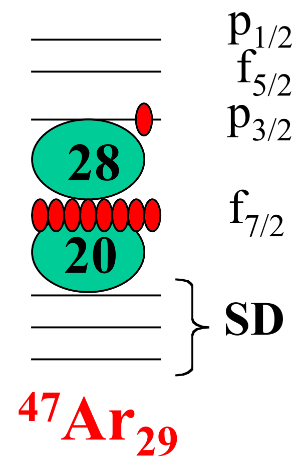
- Captures on bound levels in final nucleus
- Captures possible for all neutron energies
- Smooth variation of the cross-section with the neutron energy depending on l, Q and S of final state

Needs strutural informations of low energy bound states : spectroscopic factors accessible by transfer reactions

Neutron capture on ^{46}Ar



E. Krausmann at al. PRC 53 (1996) 469.
R. Abegg et al. NPA 303 (1978) 121.

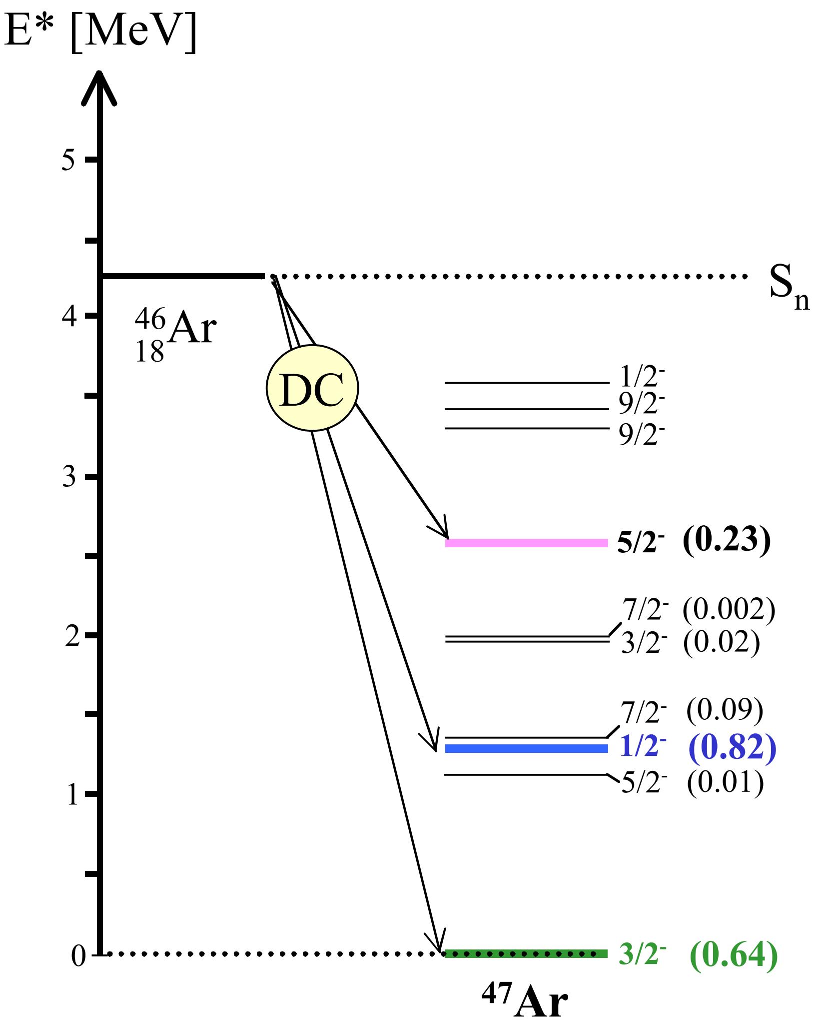


- **N=28** magic number
- Low neutron separation energy

The level density around S_n assumed to be low : necessity to consider direct capture

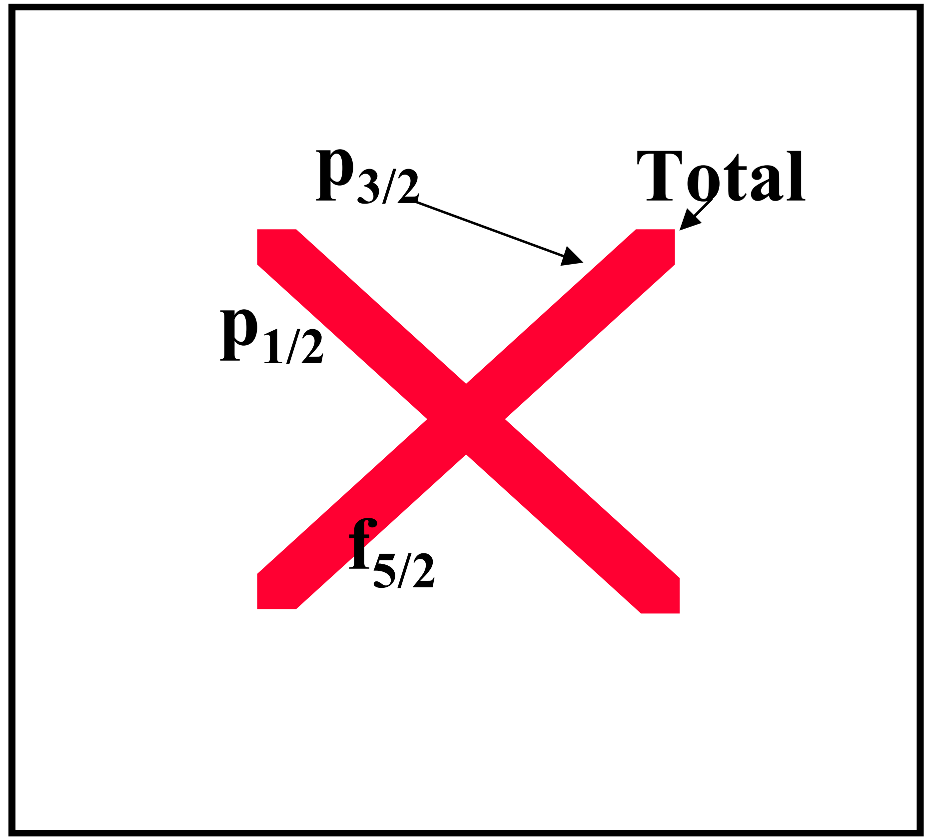
95% of the cross section is DC

Neutron capture on ^{46}Ar



Shell Model results

ANTOINE



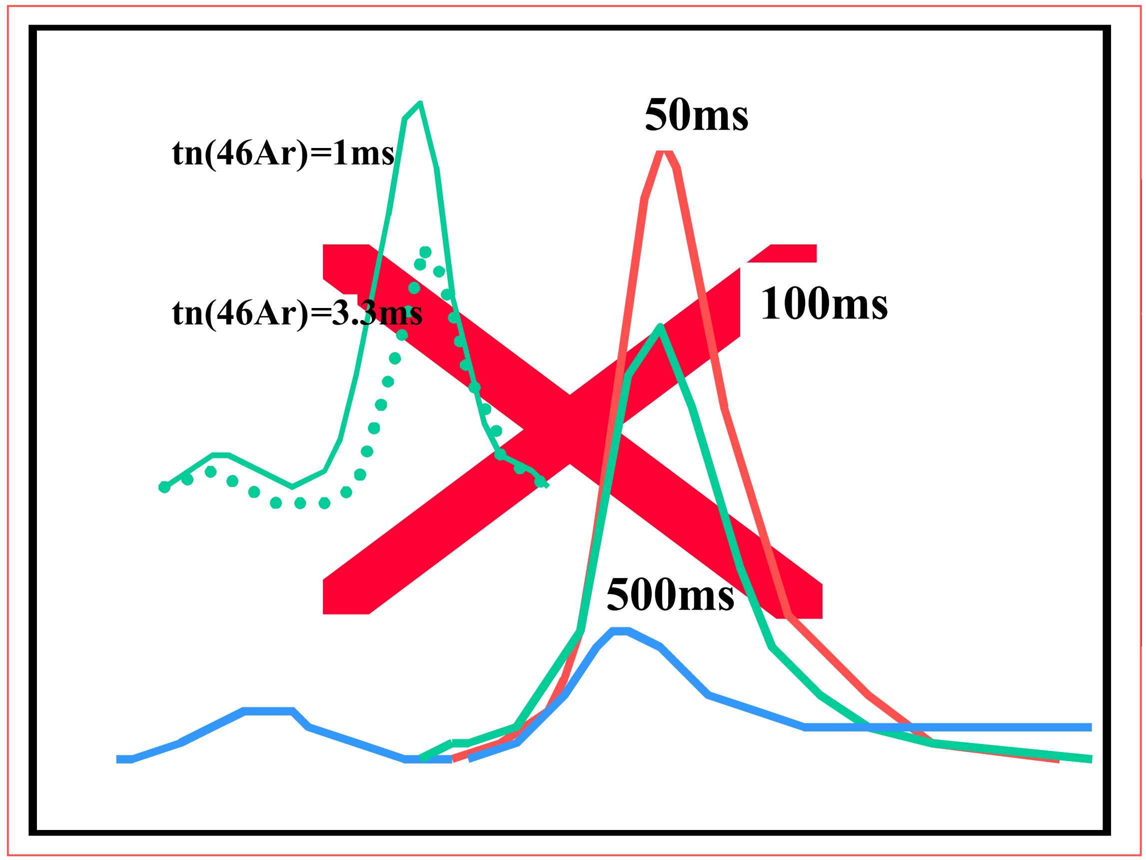
Nuclear structure of ^{47}Ar enhances neutron capture on ^{46}Ar which is a N=28 closed shell nucleus

Weak r-process network simulation

Including : β-decays, neutron captures for nuclei from stability
to neutron drip-line

Require to solve more than 1000 coupled differential equations.

Not yet time dependent :
T_9=cst, d_n=cst



Conclusion & outlooks

• Weak r-process could be responsible for production of low mass neutron rich nuclei

• Needs of β half-lives, neutron capture cross-sections for prediction of the weak r-process final abundances

• Neutron-rich magic nuclei => mainly direct capture mechanism

$\Rightarrow$ low energy structure in final nucleus

• Complementarity of β-decay-γ-spectroscopy and tranfer reaction

=> energy of low lying states

=> spins & spectroscopic factors

Coming soon :

Transfer reaction at GANIL, in June : $^{44,46}Ar(d,p)$

=> energy, spins, spectro. fac.(to be compared with already measured levels in ^{45}Ar)

=> size of the N=28 gap

Collaboration

Isotopic anomalies :

O. Sorlin, L. Gaudefroy (Institut de Physique nucléaire)
K.L. KRATZ (Institut für Kerchemie; Mainz university)
T. Rauscher (Departement für Physik und astronomy; Basel university)

Transfer reaction in Ar isotopes :

Institut de Physique nucléaire
CEA Saclay
GANIL
LPC Caen
Institute of Nuclear Research (Hungary)
FLNR-Dubna (Russia)
NBI (University of Copenhagen)

Direct neutron capture : TEDCA

$$\frac{f\sigma}{f\Omega} \propto S \left| \; \Phi_f \, \Theta_{EM} \, \Phi_i \, d\vec{r} \right|^2$$

Φ_f , Φ_i : coming from resolution of Schrödinger equation with a potential obtained by double folding

Θ_{EM} : E1, E2, M1 electromagnetic operator

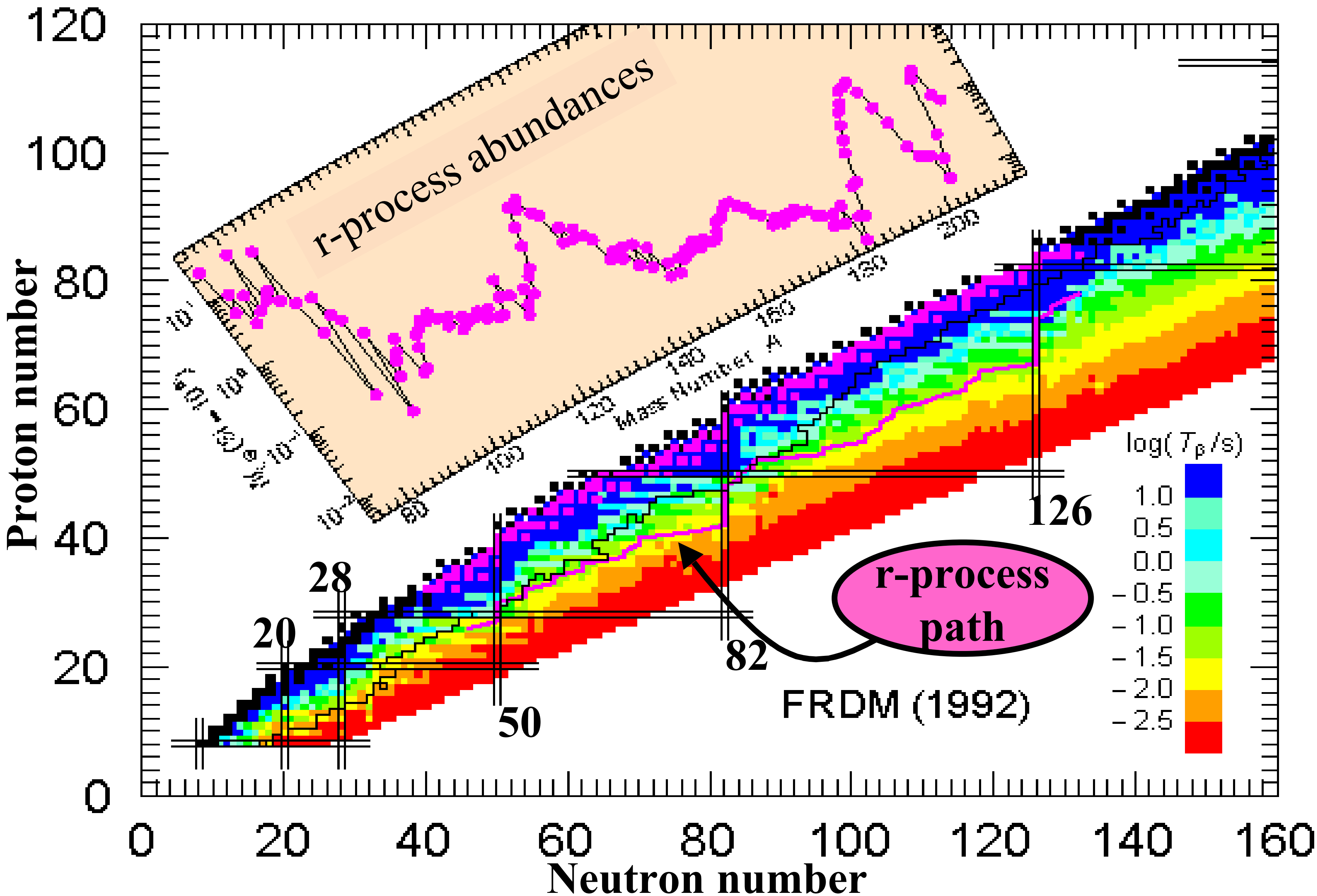
$$V = \lambda \quad \rho_n(\vec{r}_n)\,\rho_A(\vec{r}_A)\,v_{eff}(E,\rho_n,\rho_A)\,d\vec{r}_n\,d\vec{r}_A$$

V_{eff} : DDM3Y interaction
Neutron density ρ_n : δ function
Target nucleus density ρ_A : mean field theory (HFB)

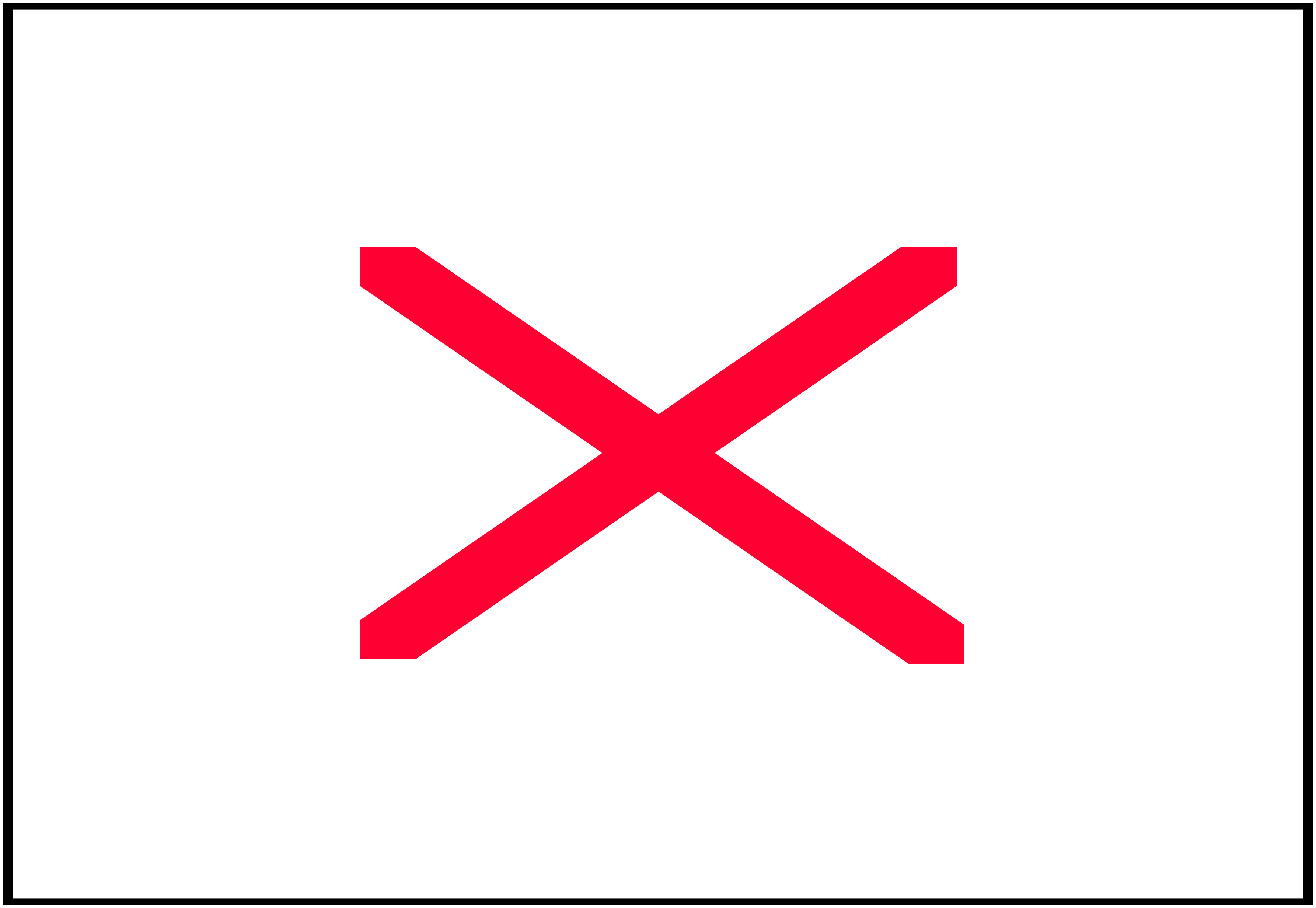
Free parameter λ :

- Entrance channel : fixed to reproduced neutron scattering
- Exit channel : fixed to reproduce neutron separtion energy

Neutron captures in the (weak) r-process

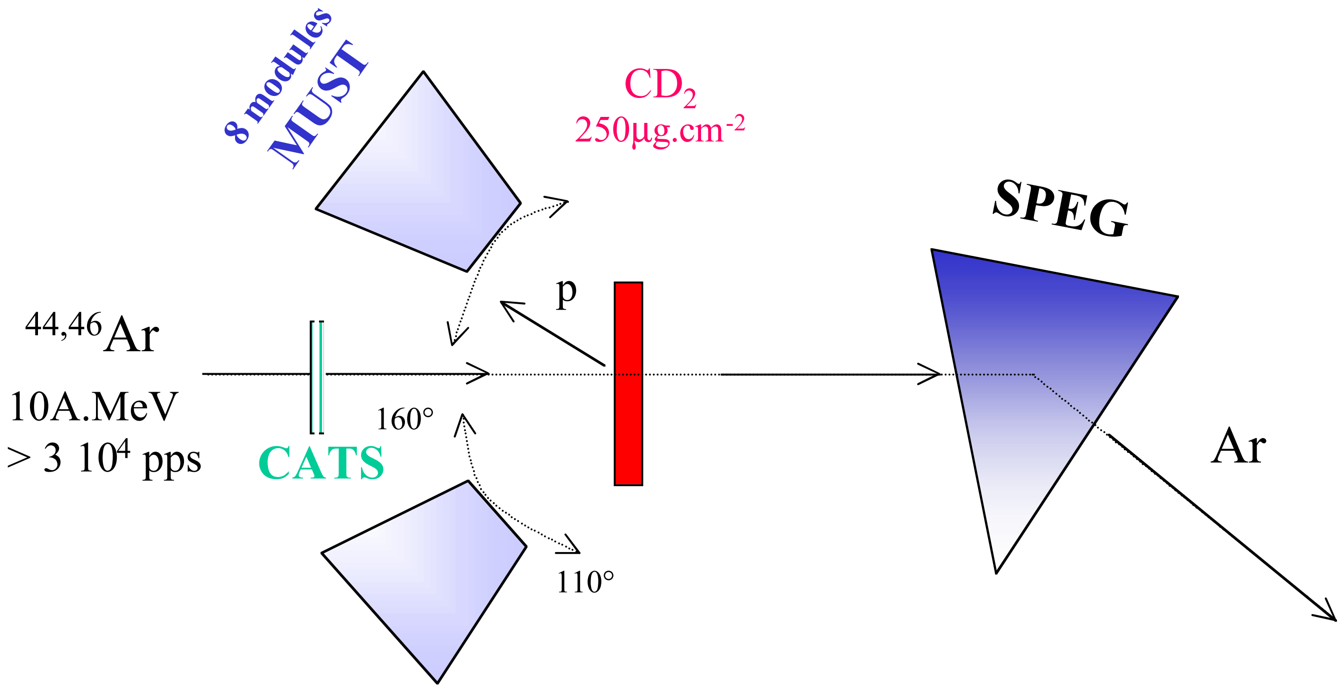


Neutron captures in the (weak) r-process



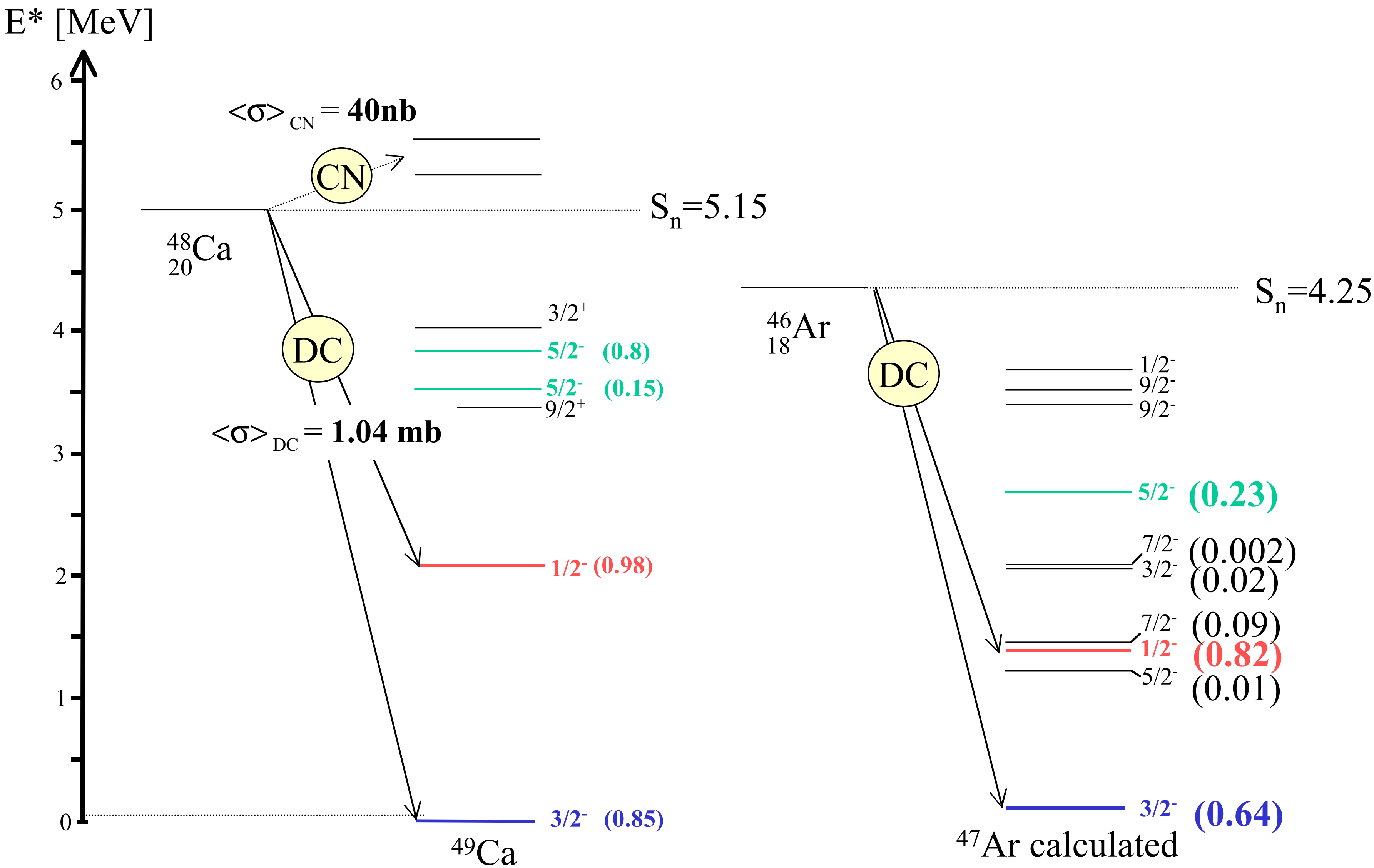
Neutron capture on $^{44,46}Ar$ (Experiment)

- **Experiment in June at GANIL**



Study of the $p_{3/2}$, $p_{1/2}$ and $f_{5/2}$ states: energy, spec. factor, spin

Neutron capture on $^{44,46}Ar$



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95% of the cross section is DC

Similar behaviour expected in ^{46}Ar