# CLUSTER DENSITIES WITHIN THE IWAMOTO-HARADA COALESCENCE / PICKUP MODEL FOR PRE-EQUIL. REACTIONS (STATISTICAL PICTURE OF DIRECT REACTIONS)

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- **Light clusters: d to α**
- **Coalescence model:**

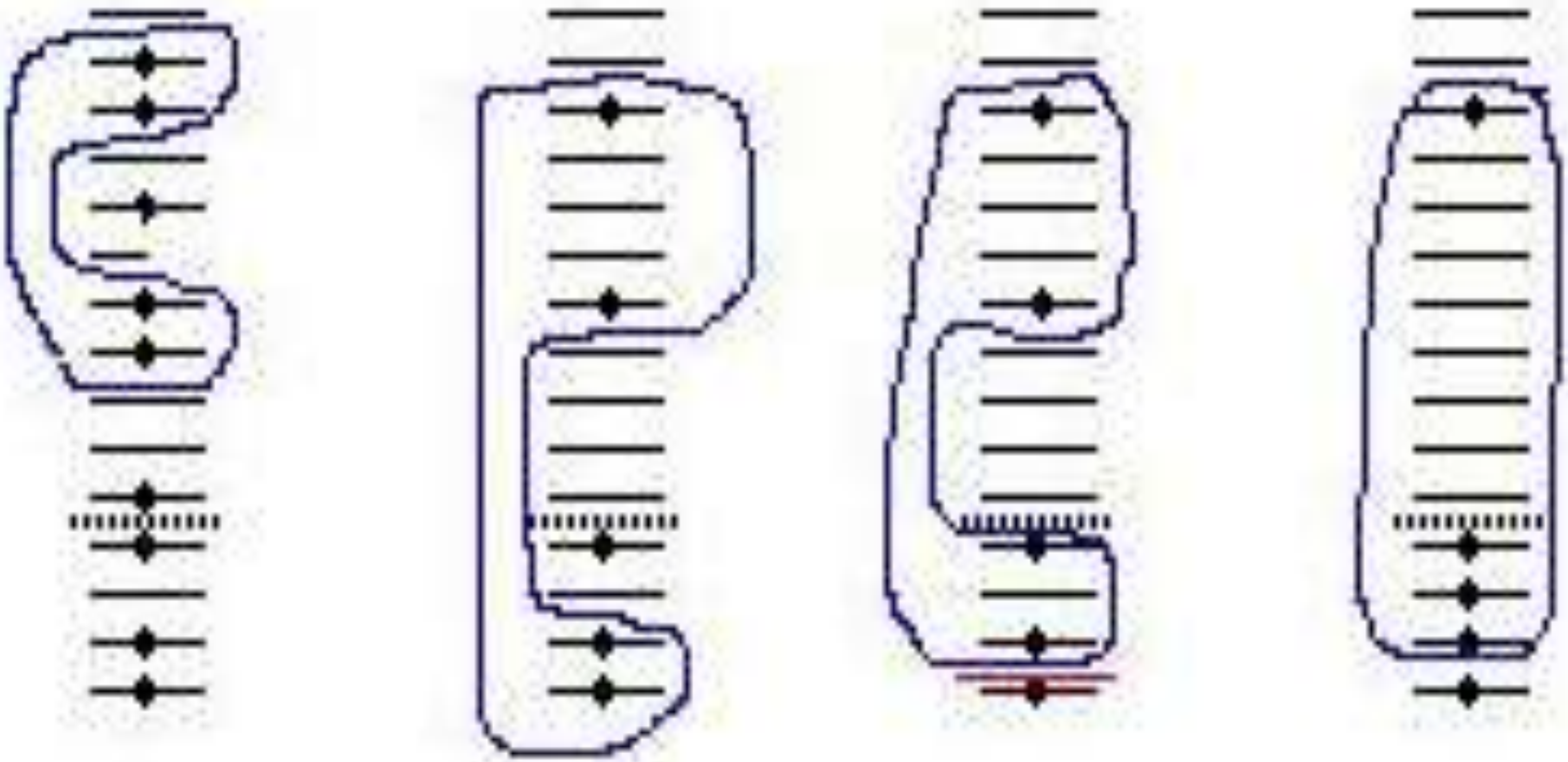
*Blann & Lanzafame, Kalbach (Cline), Ribanský & Obložinský*

Nucleon emision rate :

$$\lambda_x^c(n,E,\varepsilon_x) = \frac{2s_x+1}{\pi^2\hbar^3}\ \mu_x\varepsilon_x\sigma_{INV}^{*}(\varepsilon_x)\frac{\omega(p-1,h,U)}{\omega(p,h,E)}R_x(p)$$

Coalescence clusters:

$$\lambda_x^c(n,E,\varepsilon_x) = \frac{2s_x+1}{\pi^2\hbar^3}\ \mu_x\varepsilon_x\sigma_{INV}^{*}(\varepsilon_x)\frac{\omega(p-p_x,h,U)}{\omega(p,h,E)}R_x(p)\gamma_x\frac{\omega(p_x,0,\varepsilon_x+B_x)}{g_x}$$



*coalescence* *IH model* *IHB model* *knock-out*

INITIAL STAGE IN NUCLEON-INDUCED REACTIONS IS *N=1 (1P0H)**. HOWEVER, CLUSTERS CAN BE EMITTED ALSO FROM THIS VERY EARLY STAGE (NOT ALLOWED IN THE SIMPLE CLUSTER COALESCENCE PICTURE).

*CLINE, NUCL. PHYS. A193 (1972), 417;
AGASSI, WEIDENMUELLER, MANTZOURANIS, PHYS. REP. C22 (1975), 145;
GADIOLI, GADIOLI ERBA, SAJO-BOHUS, TAGLIAFERRI, RIV. N. CIM. 6 (1976), 1

## Generalized (coalescence + pickup)

*Iwamoto & Harada, Dobeš & Běták, Bisplinghoff*

$$\omega(p-p_x,h,U)\,\omega(p_x,0,\varepsilon_x+B_x)$$

$$\to$$

$$\sum_{p^*=1}^{p_x}\int_{\varepsilon_x+B_x}^{E}\omega(p-p^*,h,E-\varepsilon_1)\,\omega(p^*,0,\varepsilon_1)\,\omega(0,p_x-p^*,\varepsilon_2)\,d\varepsilon_1$$

***EMISSION RATE PROPORTIONAL to the CLUSTER FORMATION PROBABILITY***

***SINGLE-CLUSTER DENSITY INVERSELY PROPORTIONAL to the CLUSTER FORMATION PROBABILITY***

## Generalized (coalescence + pickup)

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$$\omega(p-p_x,h,U)\omega(p_x,0,\varepsilon_x+B_x)$$

$$\rightarrow$$

$$\sum_{p^*=1}^{p_x}\int_{\varepsilon_x+B_x}^{E}\omega(p-p^*,h,E-\varepsilon_1)\omega(p^*,0,\varepsilon_1)\omega(0,p_x-p^*,\varepsilon_2)d\varepsilon_1$$

***EMISSION RATE PROPORTIONAL to the CLUSTER FORMATION PROBABILITY***

***SINGLE-CLUSTER DENSITY INVERSELY PROPORTIONAL to the CLUSTER FORMATION PROBABILITY***

***THEREFORE the result is PARAMETERLESS !***

- *Bisplinghoff*

  Pickup limited by the binding energy of nucleons in the cluster (i.e. about 28 MeV for alphas and 2 MeV for deuterons)

- ***Now***

  Limitation due to binding energy for all clusters

  Only low-exciton configurations with pickup (CN limit!)

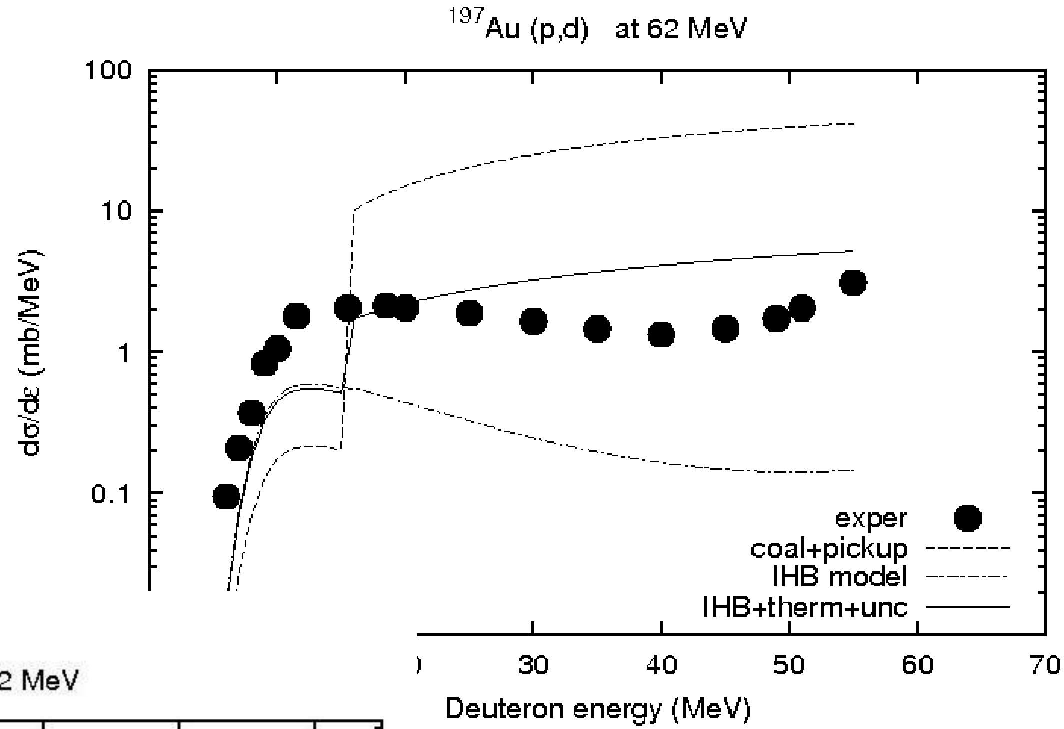
  Thermal "blurring" considered

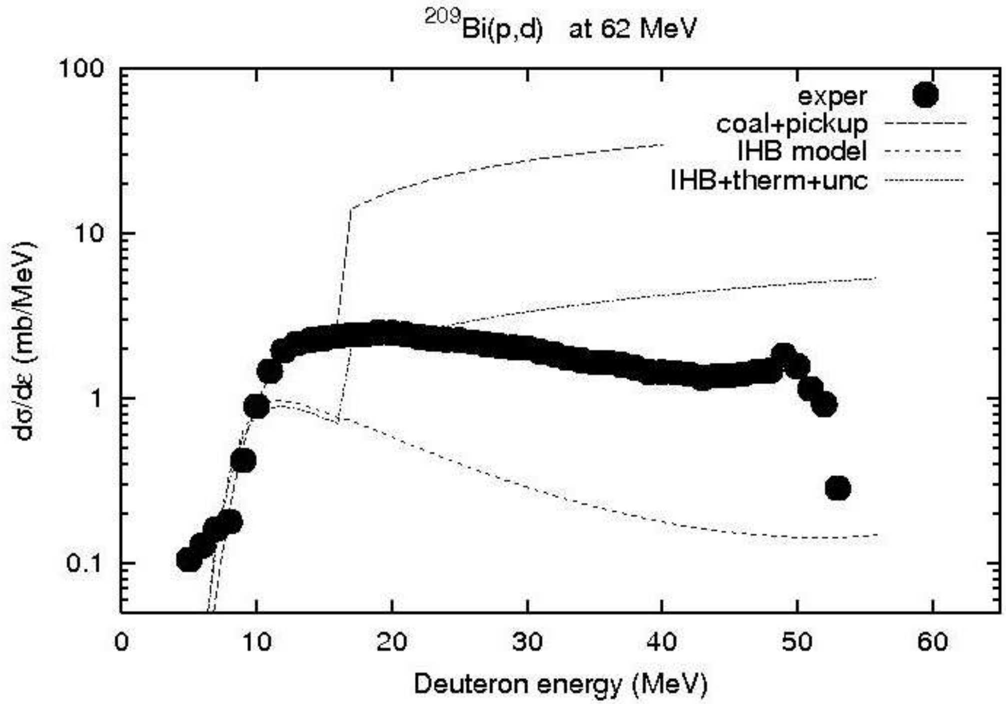
  Possibility of knockout (initial stage only) for alphas

$$\propto \int_0^E \omega(0,4,U-\varepsilon)\omega(1,0,\varepsilon)d\varepsilon$$

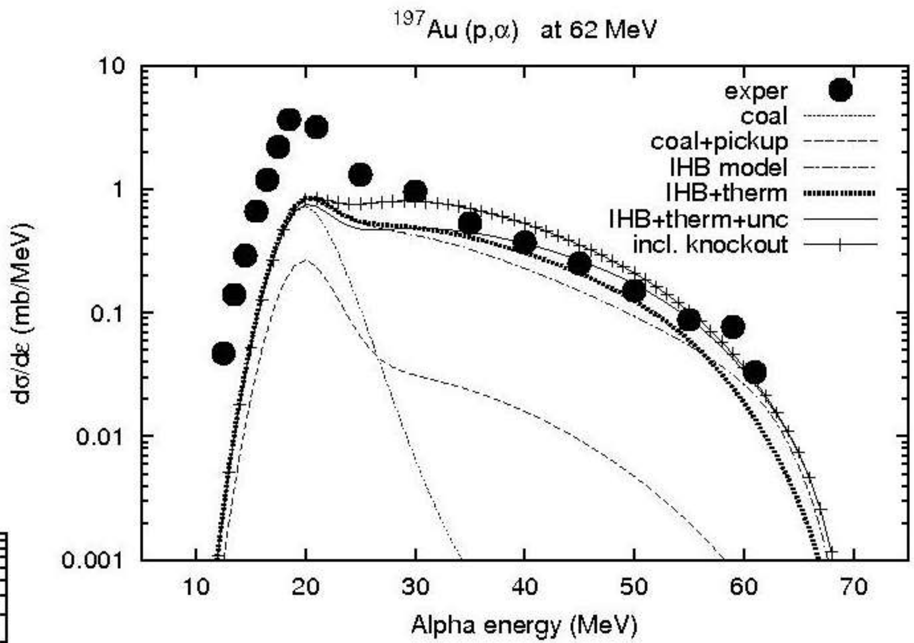
**Calculations without spin (old)**

**a) deuterons**

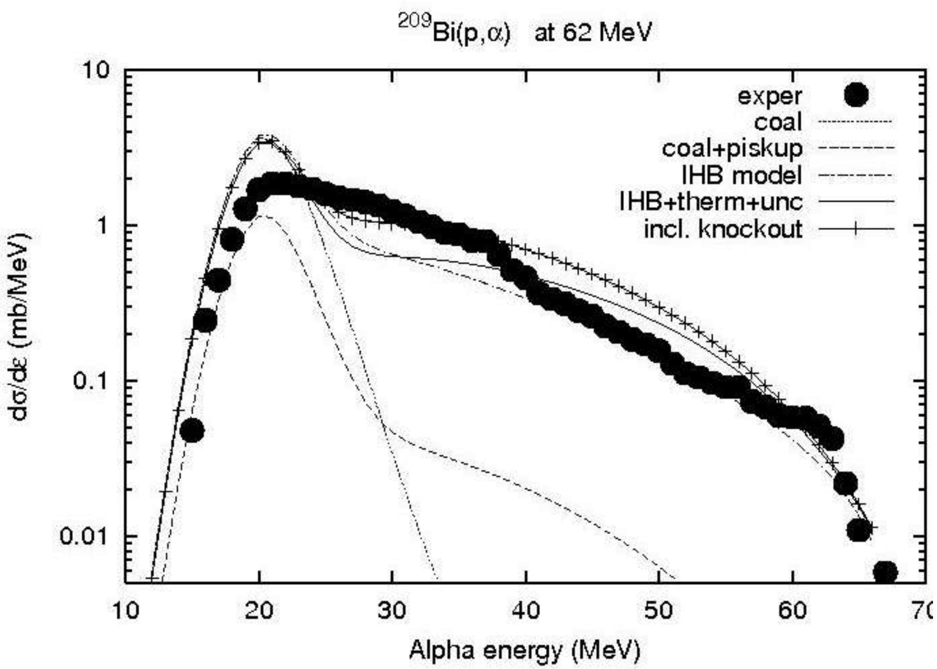


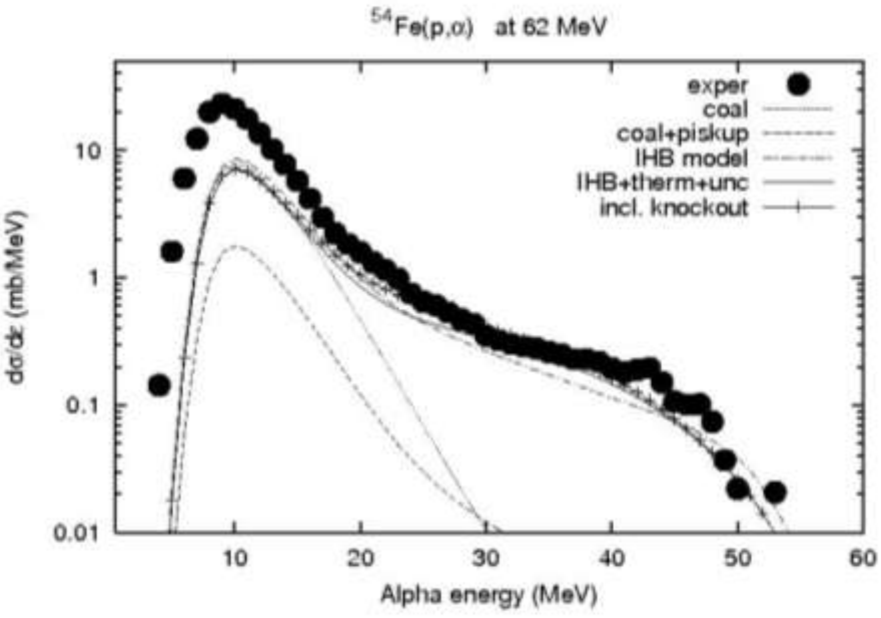
## b) alpha



$^{197}$Au (p,α) at 62 MeV
exper
coal
coal+pickup
IHB model
IHB+therm
IHB+therm+unc
incl. knockout
dσ/dε (mb/MeV)
Alpha energy (MeV)

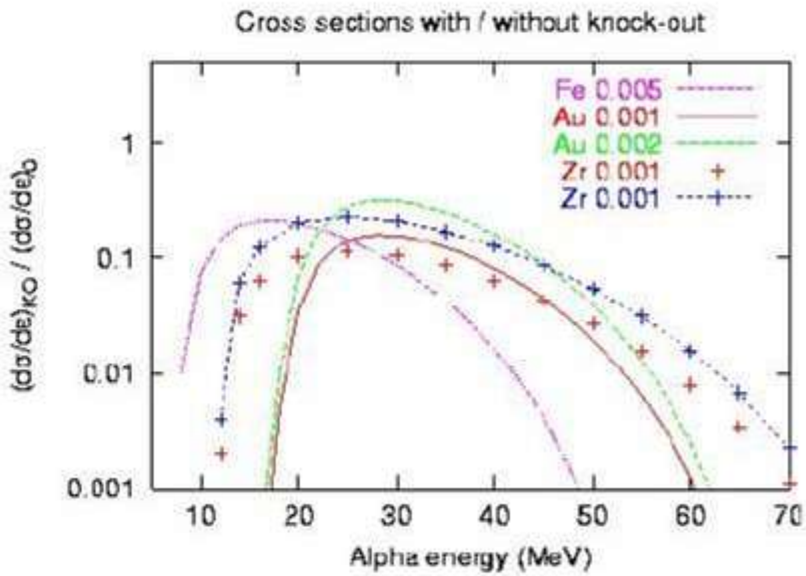



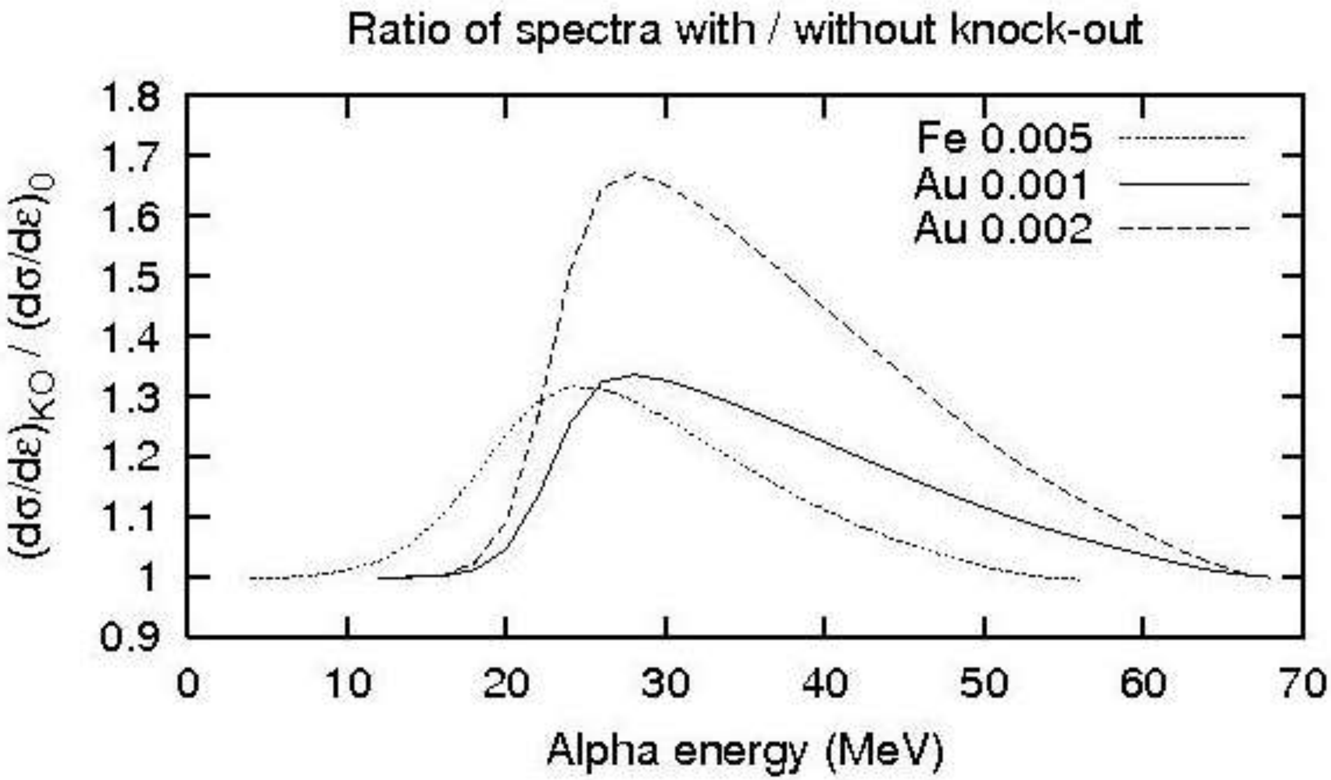
$^{209}$Bi(p,α) at 62 MeV
exper
coal
coal+piskup
IHB model
IHB+therm+unc
incl. knockout
dσ/dε (mb/MeV)
Alpha energy (MeV)

$^{54}$Fe(p,α) at 62 MeV
exper
coal
coal+piskup
IHB model
IHB+therm+unc
incl. knockout
dσ/dε (mb/MeV)
Alpha energy (MeV)

## c) α-knockout admixtures from the fit to the data



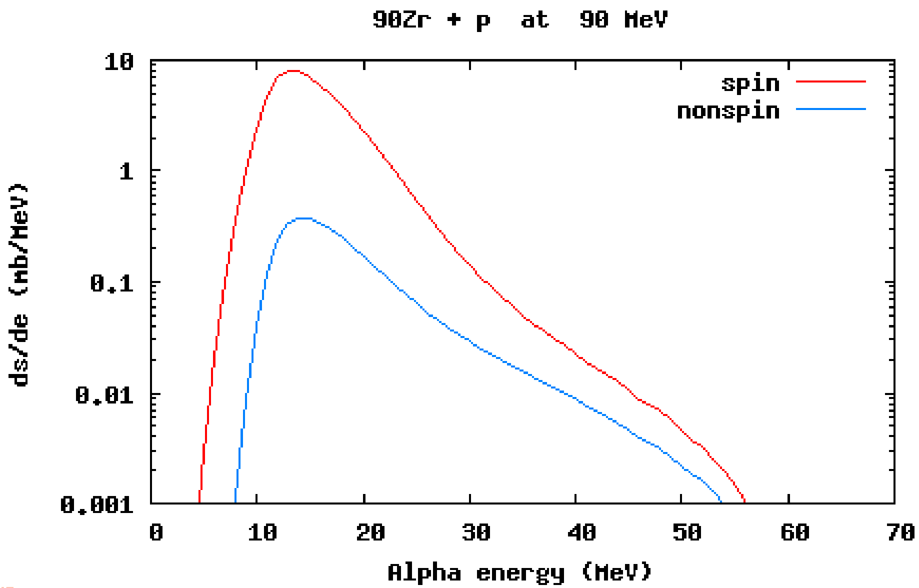



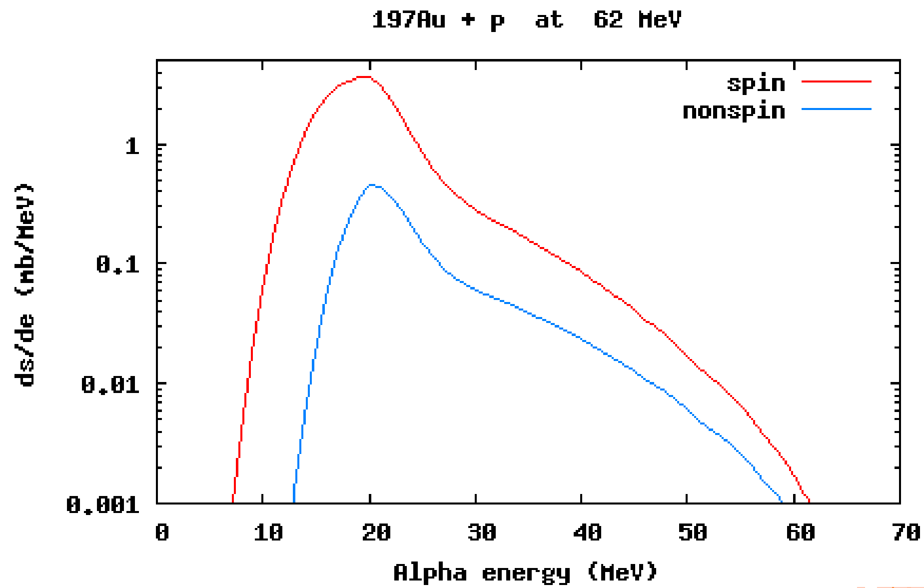
# Spin variables:

*Coupling of nucleons to form a coalescence or pickup cluster  may be – in a very rough approximation –considered included in the formation probability.*

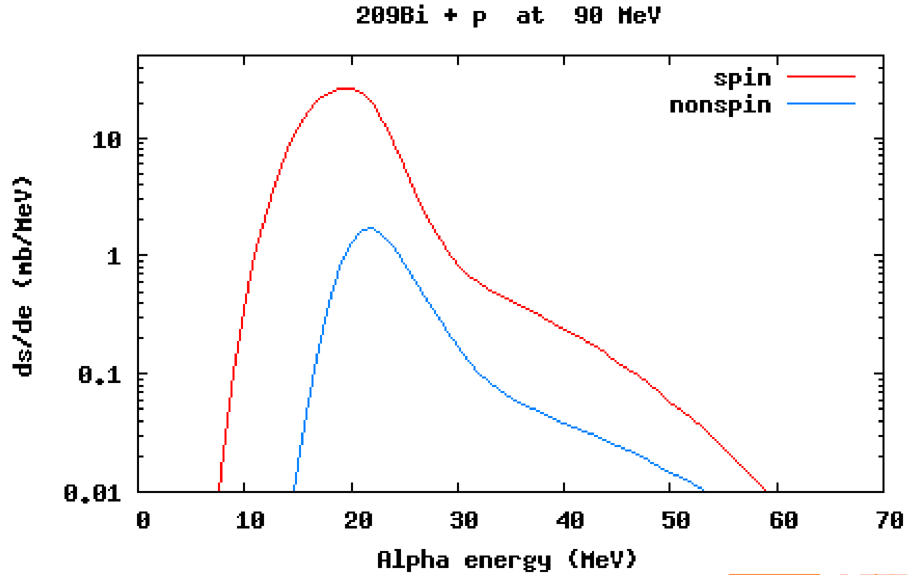
***Therefore, no additional couplings appear in the emission rates and the only place affected by the angular momentum are different transition coefficients and via competitions to other (nucleon,γ) channels.***

***Exception: knock-out – a-particle is not formed during reaction, but it is already present in the target nucleus.***



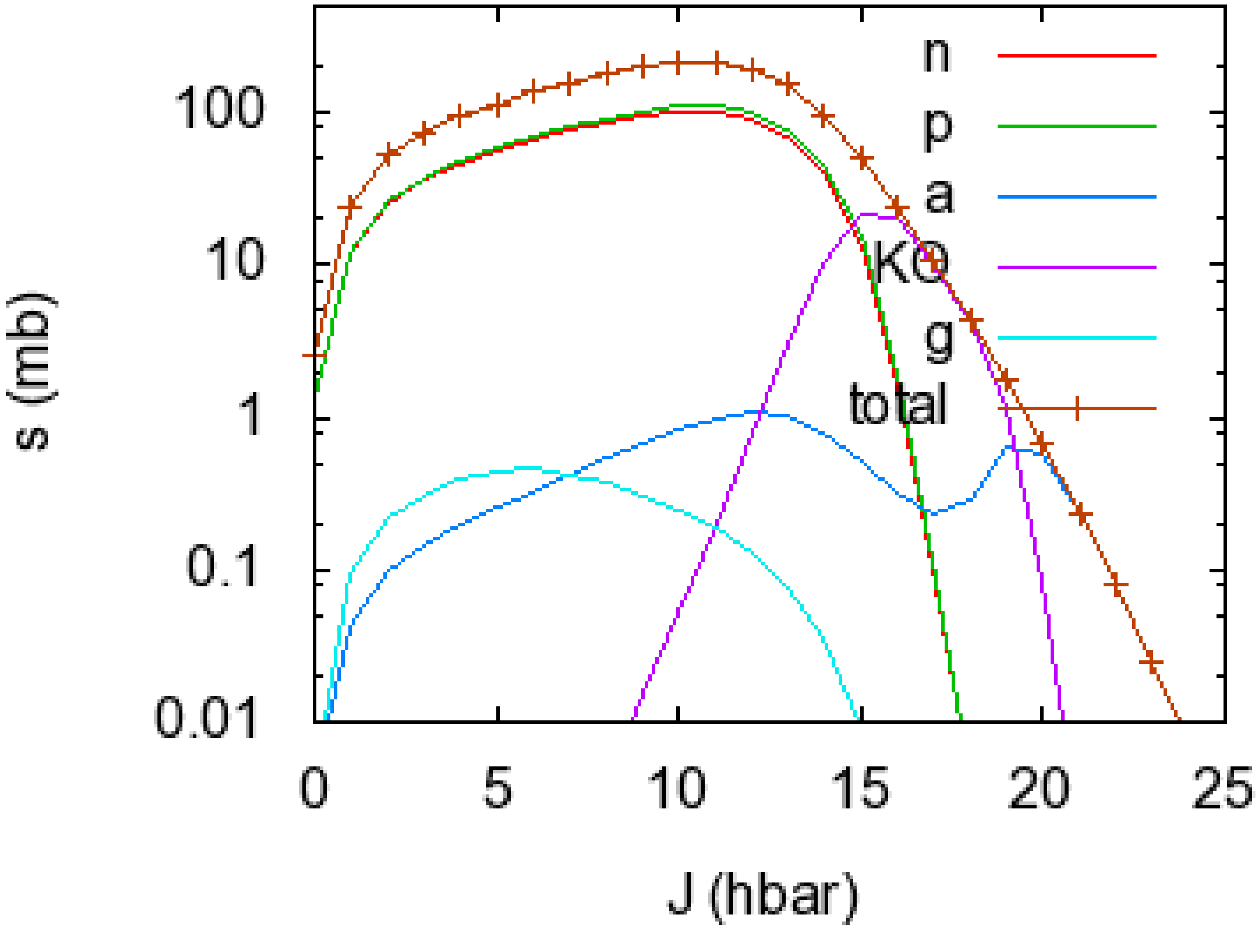



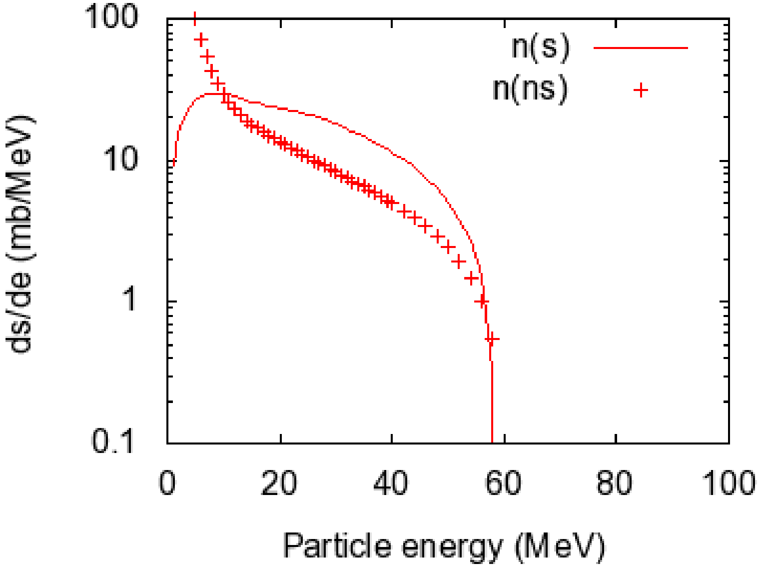

Effect of $T_l$ on the α emission spectra (knock-out, thermal blurring, etc. are not included here). First emission only!

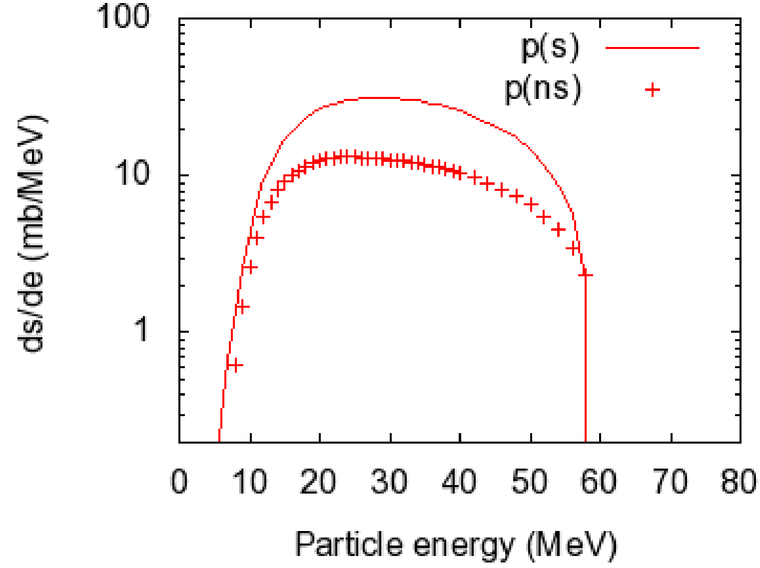


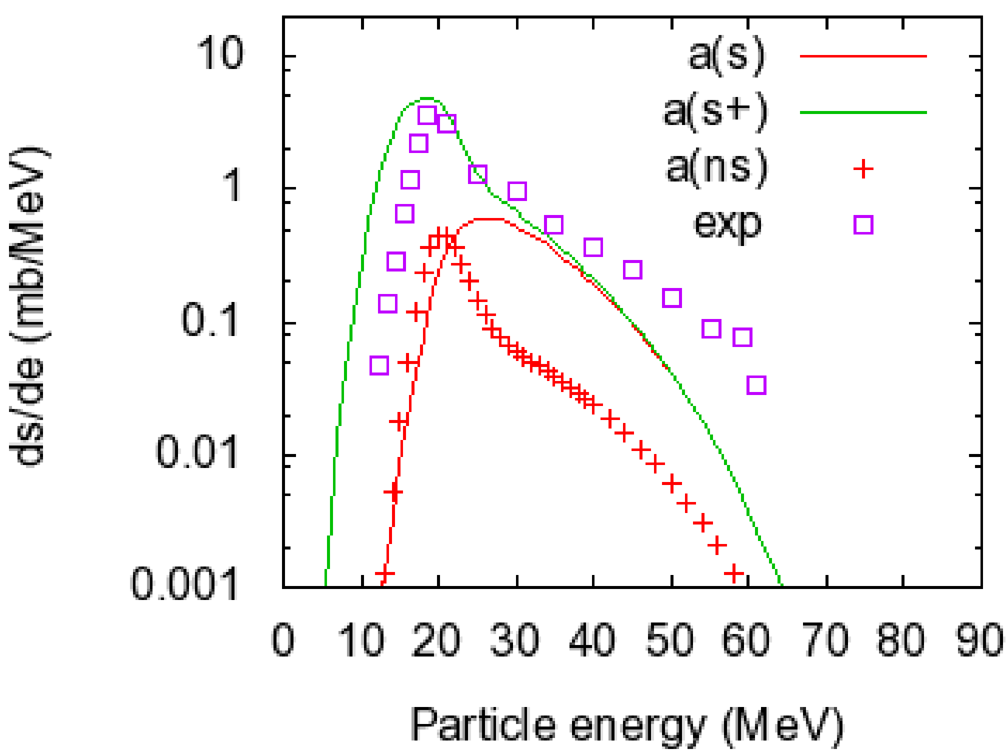
# $^{197}Au(p,\alpha)$ @ 62 MeV

**From which spin of the composite nucleus proceeds the first (particle or γ) emission** ***(knock-out contribution is not in absolute scale).***




n(s)
n(ns)
ds/de (mb/MeV)
Particle energy (MeV)
100
10
1
0.1
0
20
40
60
80
100


p(s)
p(ns)
ds/de (mb/MeV)
Particle energy (MeV)
100
10
1
0
10
20
30
40
50
60
70
80


a(s)
a(s+)
a(ns)
exp
ds/de (mb/MeV)
Particle energy (MeV)
10
1
0.1
0.01
0.001
0
10
20
30
40
50
60
70
80
90

# *CONCLUSIONS*

- Clusterization itself **parameterless**
- Effective only at initial stages, what enables proper equilibrium (compound nucleus) limit
- Thermal blurring of nucleons allowed
- Pickup (IHB) generalized to all types of clusters
- For strongly bound ejectiles knockout possible:
- Included angular momentum, but the couplings are hidden in cluster formation probability
- Introduction of spin variables enhances the cluster emission compared to spin-independent case. *(It plays similar role as deformation according to Blann & Komoto)*
- ***All calculations presented here are just with default parameters (level densities, inverse c.s., transition matrix element)!***

# ISTROS

## Isospin STructure, Reactions and energy Of Symmetry

Častá-Papiernička (near Bratislava, Slovakia)

23 – 27 September 2013

http://istros.sav.sk

# Thank you