# Capture cross sections with DANCE for s-process

T. Kawano

- Introduction
- Theories for capture of nucleon — $\gamma$-ray emission, Level density, DSD capture
- Applications to nucleosynthesis — Neutron capture cross sections for Zr-isotopes
- Concluding Remarks

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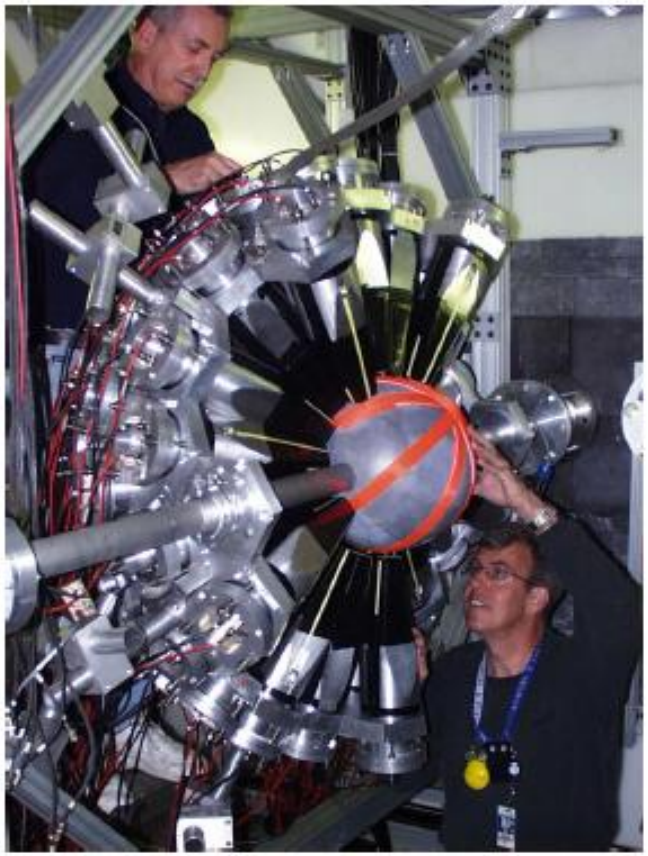
# DANCE

http://wnr.lanl.gov/dance/

- LANSCE Lujan Center
- DANCE is a $4\pi$ detector array that consists of up to 160 elements of $BaF_2$ crystals.
- It is designed to study capture reactions on small quantities of radioactive isotopes (down to 1 mg or up to 1 Ci)

## Capture Measurements at DANCE

- $^{95}$Zr capture cross section is needed for astrophysics.
- Measurements for $^{93}$Zr capture can be done with the DANCE detector.
- We estimate the $^{95}\mathrm{Zr}(n,\gamma)$ cross section, taking advantage of our nuclear modelling capability and LANSCE/DANCE experiments.



Half of DANCE array with $^{6}$LiH ball

J.L. Ullmann, DANCE workshop, Feb. 2004

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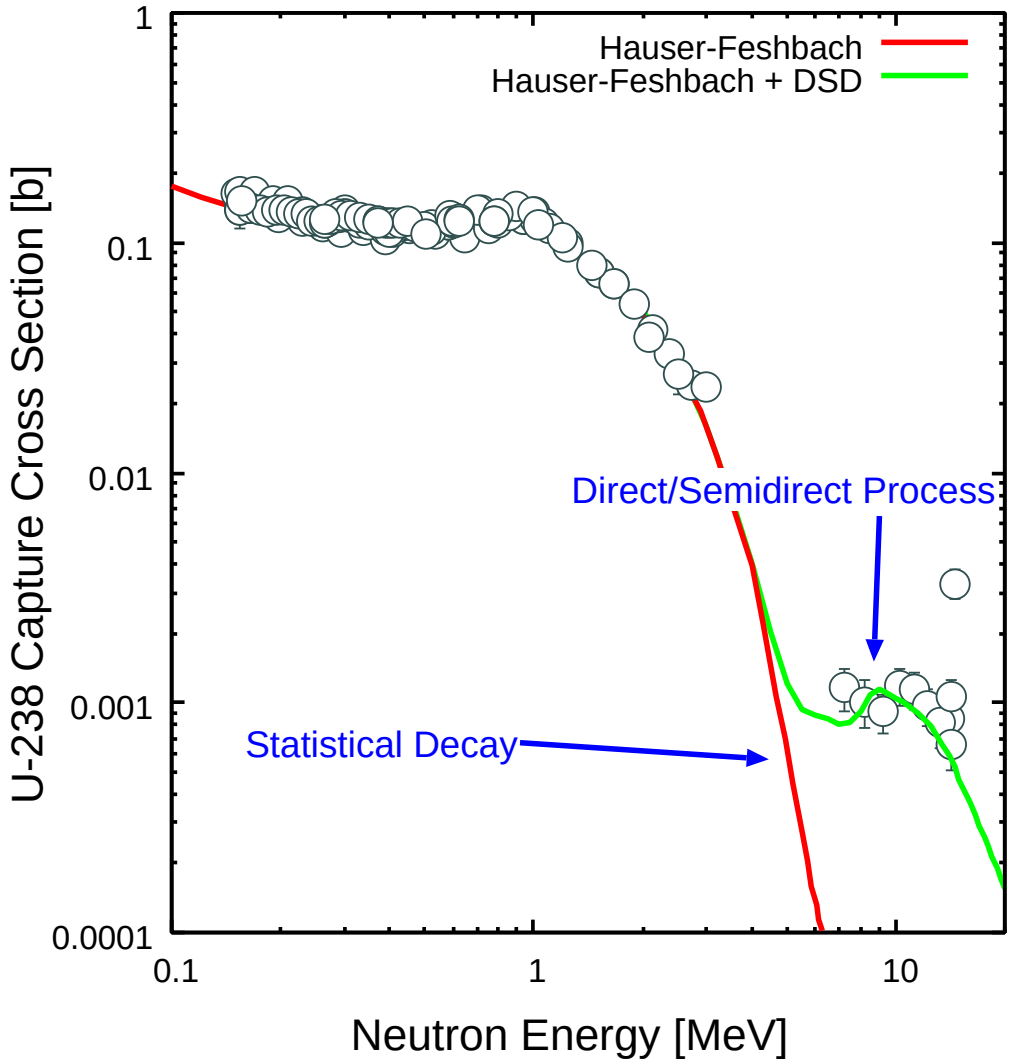
# Neutron Capture Process

## Compound Reaction

- Incident neutron and target form a compound nucleus, and decay.
- Hauser-Feshbach model, with width fluctuation.
- Capture cross section decreases rapidly when many neutron inelastic channels open.

## Direct/Semidirect Capture

- Direct transition to one of the single-particle state.
- Giant Dipole Resonance (GDR)

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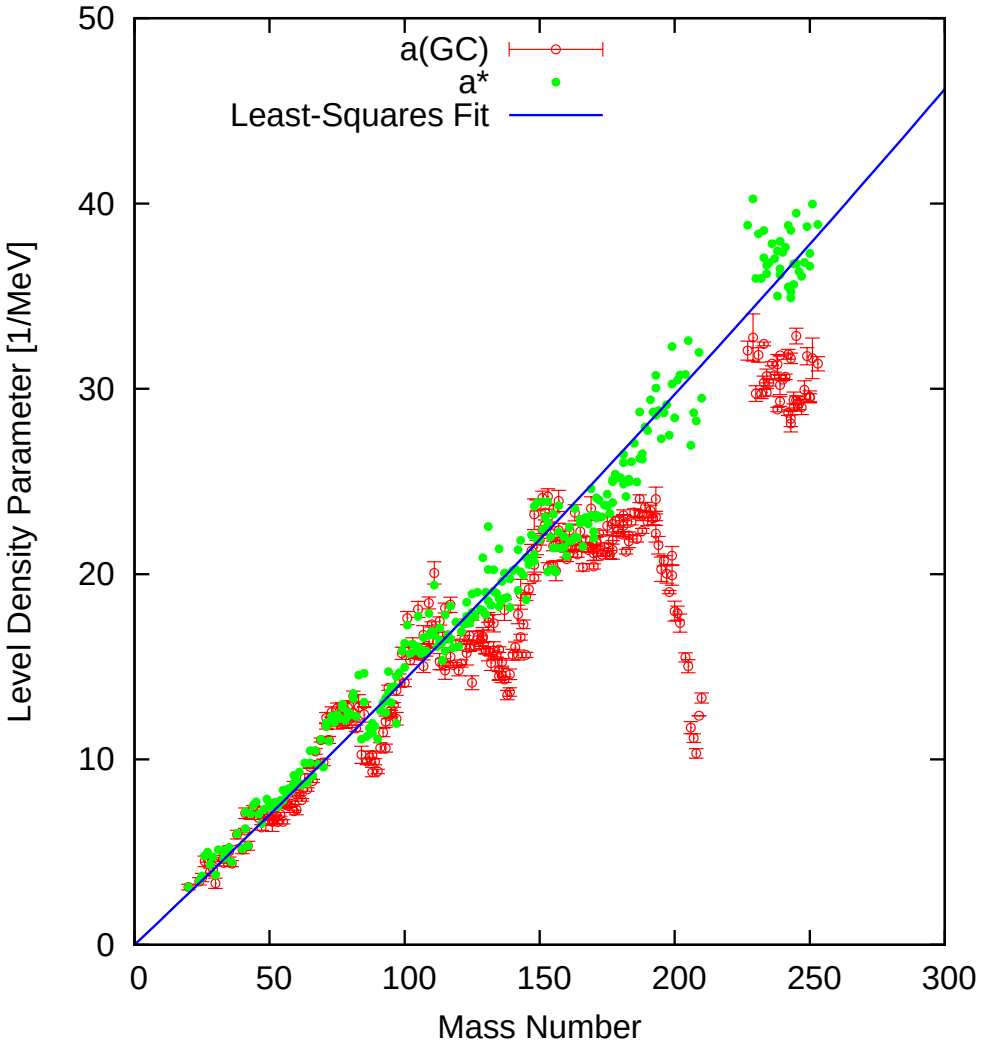
# Level Density Parameter

## Washing-out of Shell Effects




- The level density is given by

$$\rho(U+\Delta) \propto \exp\left\{\sqrt{2a(U+\Delta)}\right\},$$

where $a$ is the level density parameter.

- Shell correction ($\delta W$) and pairing energies ($\Delta$) are needed to wash-out the shell effects.

$$a = a^*\left\{1+\frac{\delta W}{U}\left(1-e^{-\gamma U}\right)\right\}$$

- We still see the shell effects (green dots), when $\delta W$ and $\Delta$ are taken from KTUY(04) mass formula.

$$a^* \simeq 0.138A + 5.34\times 10^{-5}A^2$$

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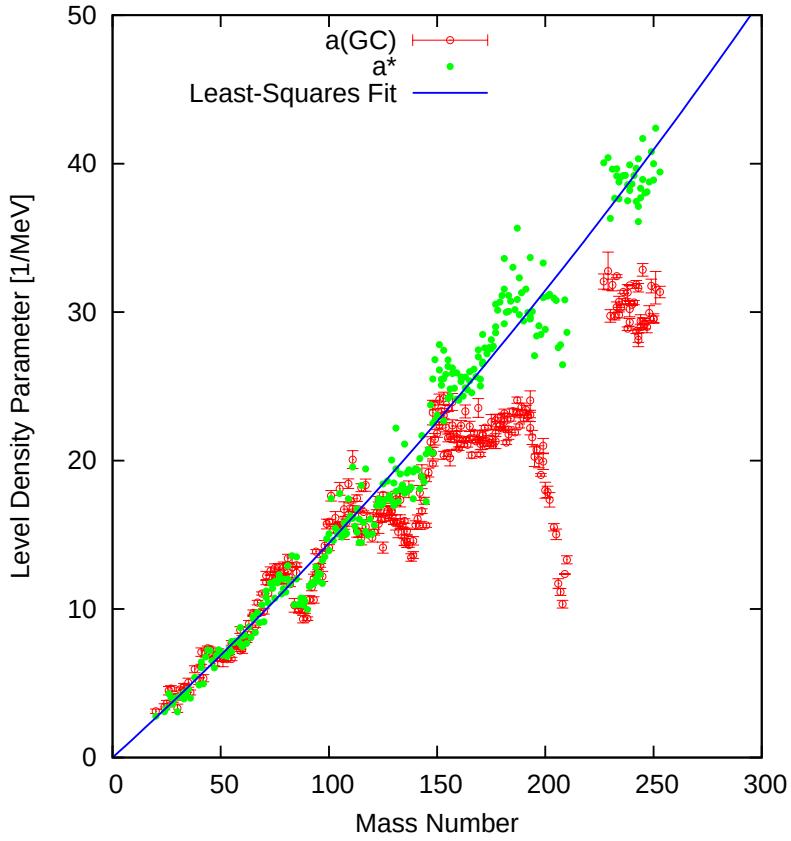
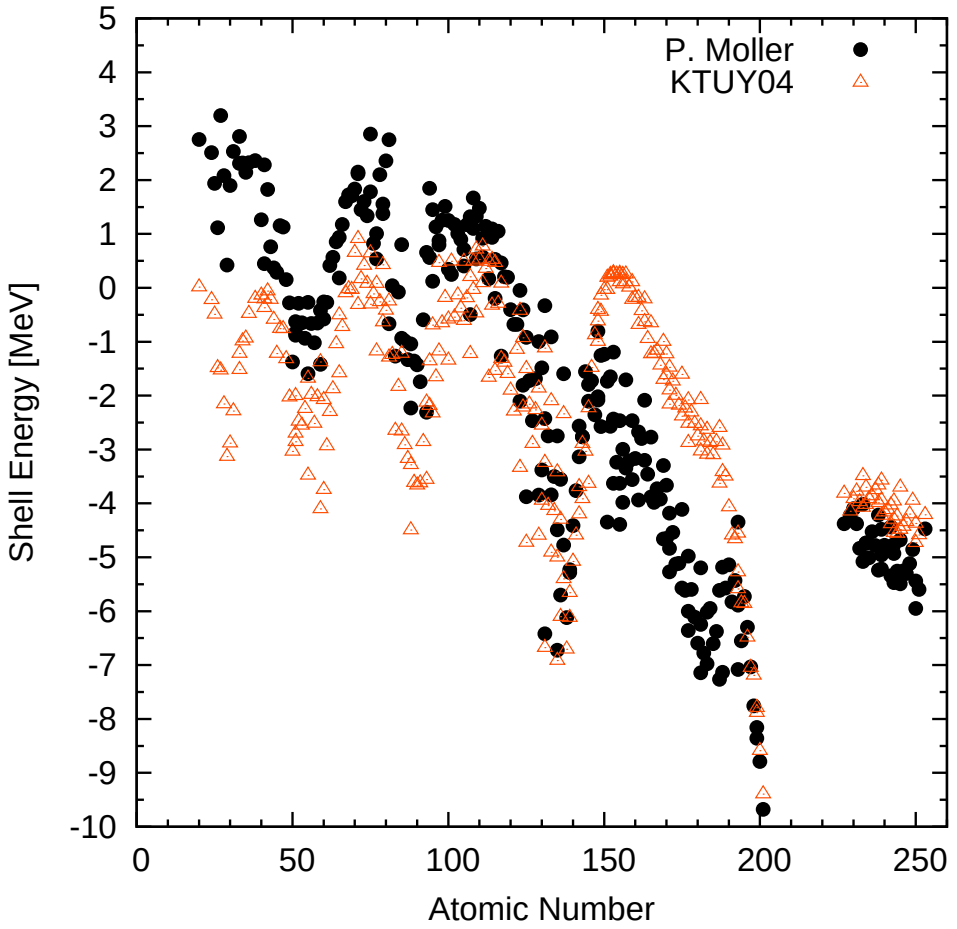
# Level Density Parameter, cont'd

## The microscopic / macroscopic approach for $\delta W$ and $\Delta$ of P.Möller




$$a^* \simeq 0.132A + 1.29 \times 10^{-3} A^2$$

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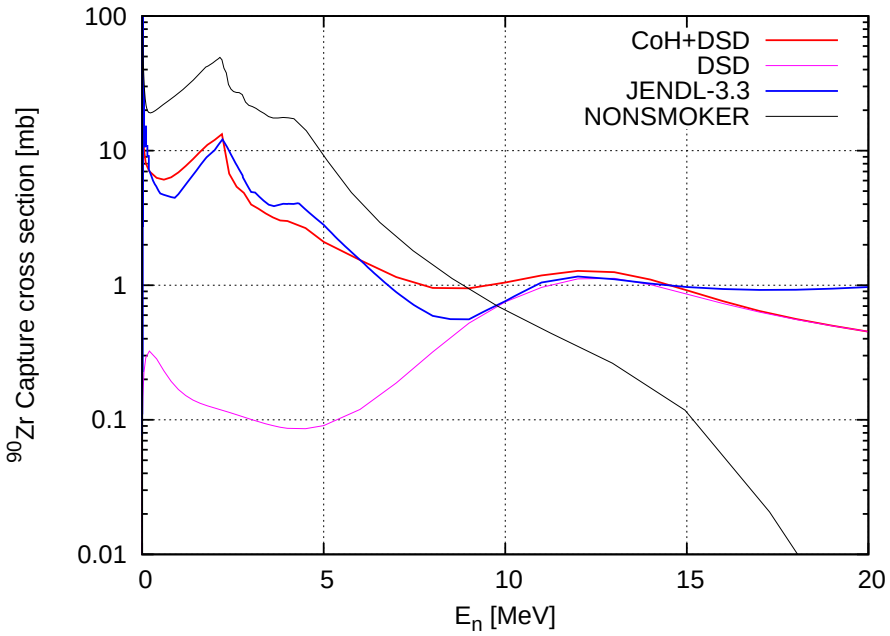
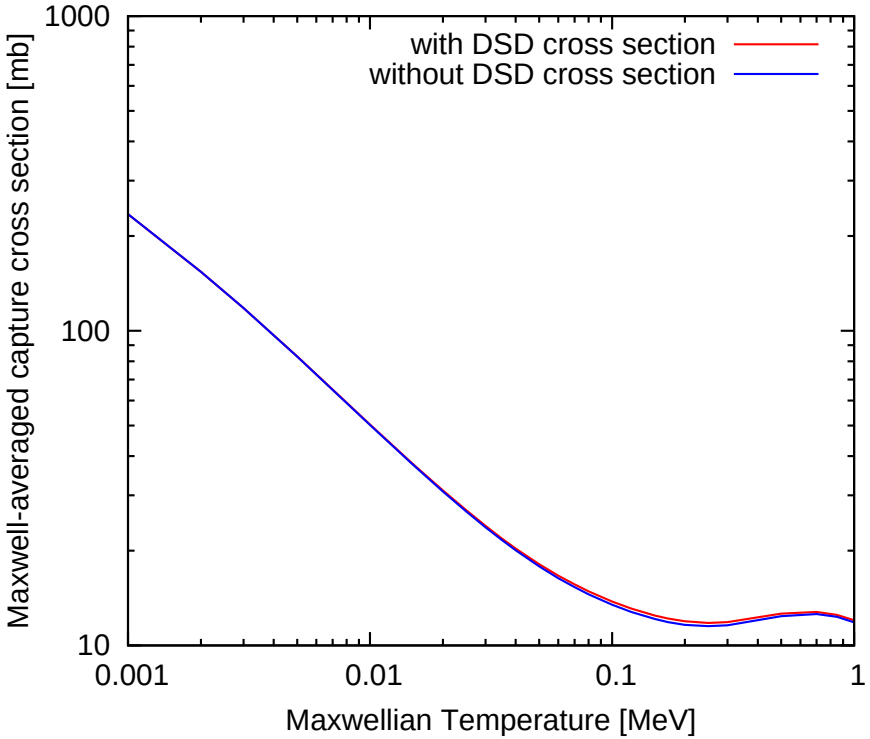
# DSD Contribution to MACS

## Cross Section

$$\sigma(l_1 j_1; l_0 j_0) = \frac{8\pi\mu}{9k\hbar^2}\left(\frac{E_\gamma}{\hbar c}\right)^3 |T_d + T_{sd}|^2$$

## Calculated Zr-90 Capture

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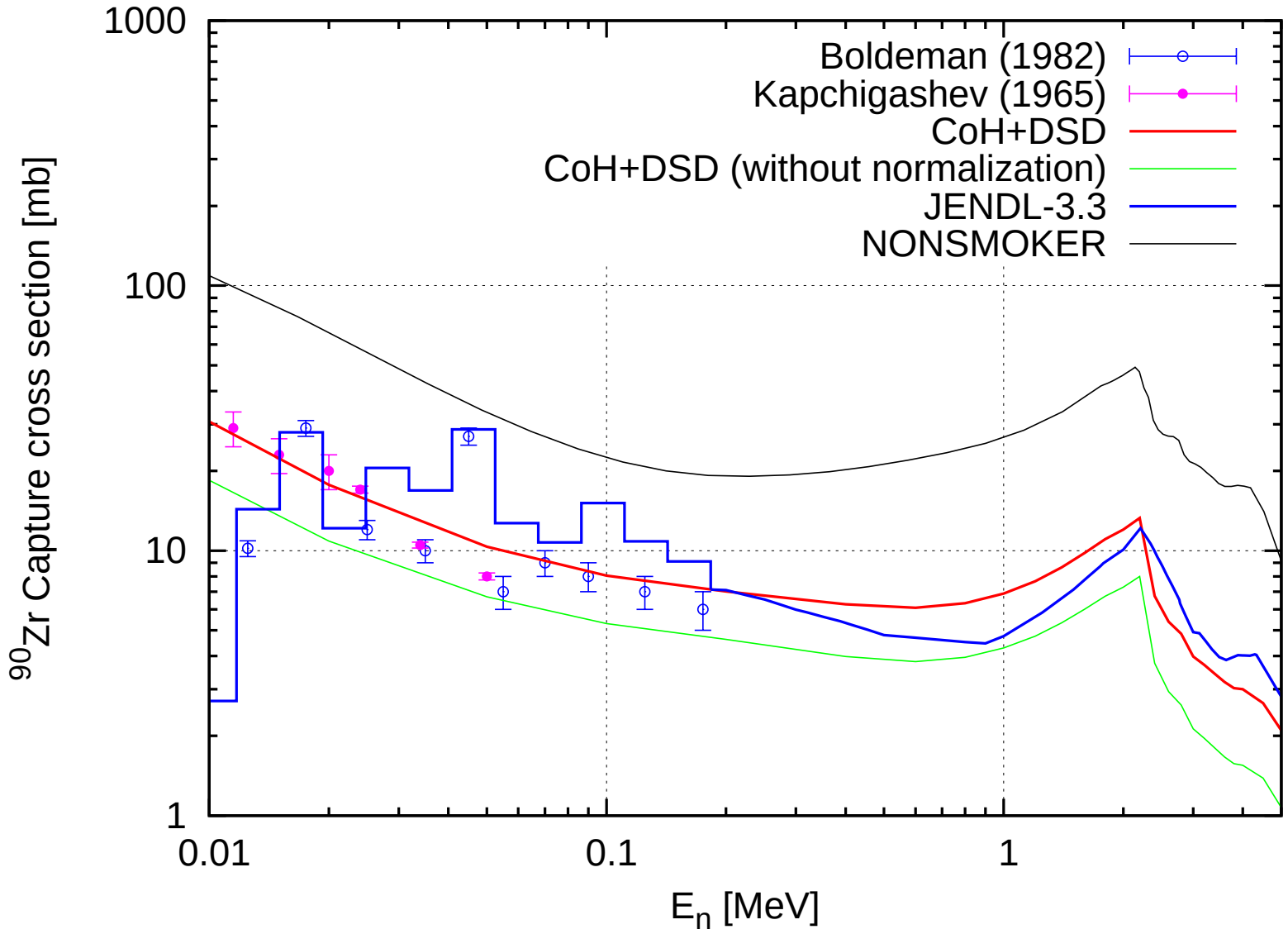
# Zr-90 Neutron Capture Cross Section

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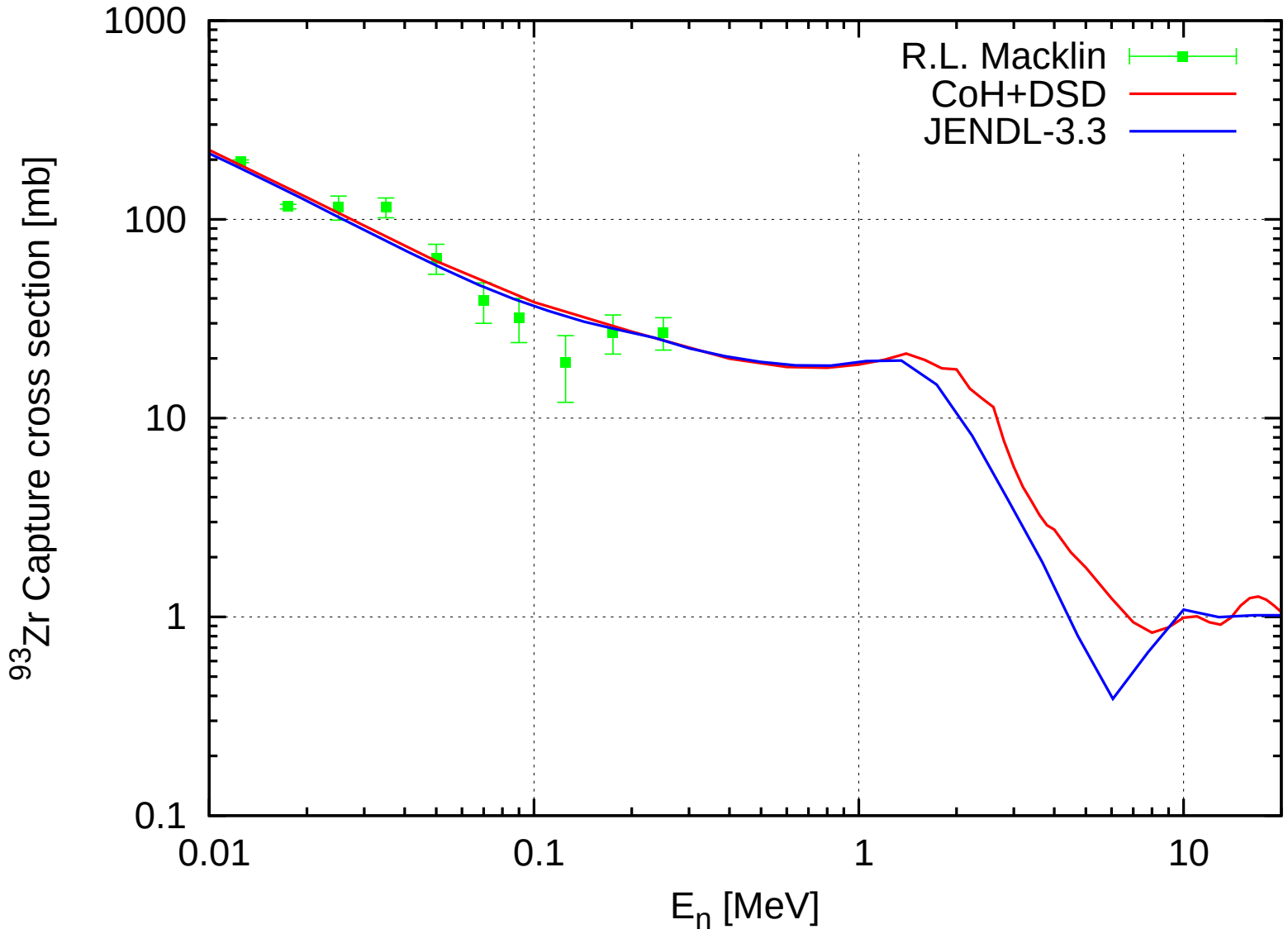
# Zr-93 Neutron Capture Cross Section

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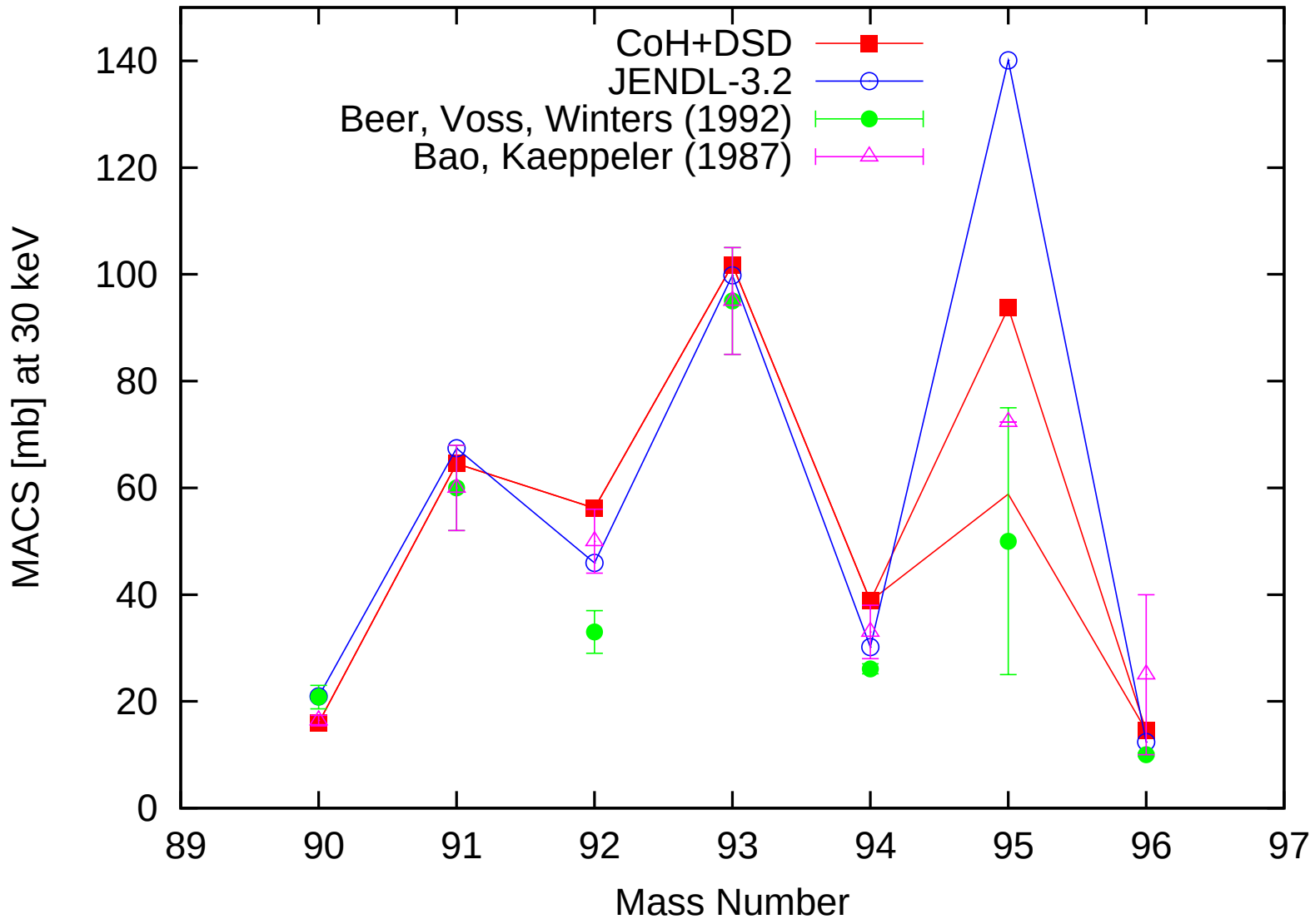
# MACS Mass Dependence

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# Concluding Remarks

## Theories Included

- Hauser-Feshbach statistical model with width fluctuation correction
- Direct-Semidirect capture process — Systematics for the strength

## Neutron Reaction (Capture) Data for Astrophysics

- Development of an automated cross section calculation system
  - Optical Model and Hauser-Feshbach-Moldauer Theory
  - linked to nuclear structure information
    - KTUY04 mass formula or P.Möller's shell/pairing energies
    - Level densities are also linked to the mass formulae
  - systemtatics/phenomenology — new parametrization
- Capture cross sections for Zr isotopes.
- Contribution of DSD process to the Maxwellean averaged capture cross section is very small.

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