Deuteron breakup on medium nuclei and induced activation analysis for the IFMIF EVEDA

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- Motivation
- Elastic Scattering (OMP)
- **Breakup**
- **Direct reactions**
- Pre-equilibrium
- Evaporation
- **Activation cross sections calculations**

Motivation: Data Needs

IFMIF

(International Fusion Material Irradiation Facility)

D-Li neutron source for testing fusion reactor candidate materials

General purpose : Activation/transmutation data library

[U. Fischer: "Nuclear Data Libraries for Advanced Systems: Fusion Devices", Nov 2007, IAEA, Vienna]

- Urgent need for qualified IFMIF reference data library
- IEAF/EAF : (n, p, **d**), to be further developed, improved and validated
- **Cross section measurements & calculations required for**
  - ***neutrons (E >20 MeV): Cr, Co, V, W, Ta, Pb, Bi, Au, Mn***
  - ***deuterons (E < 40 MeV): Cu, Al, Nb, Co***
  - ***protons (E < 12 MeV): Cu, Al, Nb, Ta, W, Au, Pb***
- **Evaluations (n, p, d) to be further developed, improved and validated**

Reliable gas production cross-section data (H, He)

Dosimetry data file to be developed for E > 20 MeV (IRDF)

Nuclear Model Calculations

❑ Pure elastic scattering OP analysis

SCAT2 [O. Bersillon]

- phenomenological OP

+ semi-microscopic (DF) OP

(local version)

DFOLD [M. Avrigeanu]

- double folding method

Microscopic Optical Model Potential

$$U(E,R)= \int dr_1 \int dr_2\ \rho_1(r_1)\ \rho_2(r_2)\ v_{eff}(\rho,E,s=R+r_1-r_2)$$

- $\rho_{1,2}$ - **density distributions** of projectile (1) and target (2)
- **v**(r) - **effective NN-interaction**:
  isoscalar and **isovector** components of
  direct and **exchange** parts of **M3Y** interaction
  (**g**-matrix using **Reid/Paris NN** potential)

*M. Avrigeanu et al., PRC **62** (2000) 017001; EPJ **A 12** (2001) 399 ; NP **A723** (2003) 104; NP **A764** (2006) 246; PRC **79** (2009) 044610; At. Data Nucl. Data Tables **95** (2009) 501*

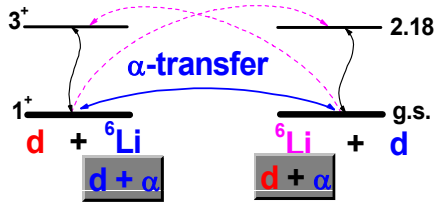
❑ Direct reactions

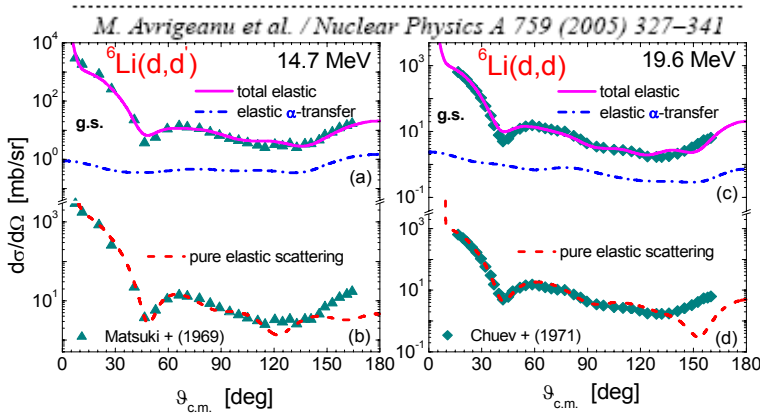
FRESCO-2003 [I.J. Thompson]

- breakup: elastic component (CDCC)

- elastic transfer: weakly bound systems

- stripping & pick-up: (d,p), (d,n), (d,t)





❑ Composite system equilibration

STAPRE-H95 [V. Avrigeanu, M. Avrigeanu] (updated)

- OMP:SCAT2000; preequilibrium: **GDH / EXCITON;** evaporation: **Hauser-Feshbach**

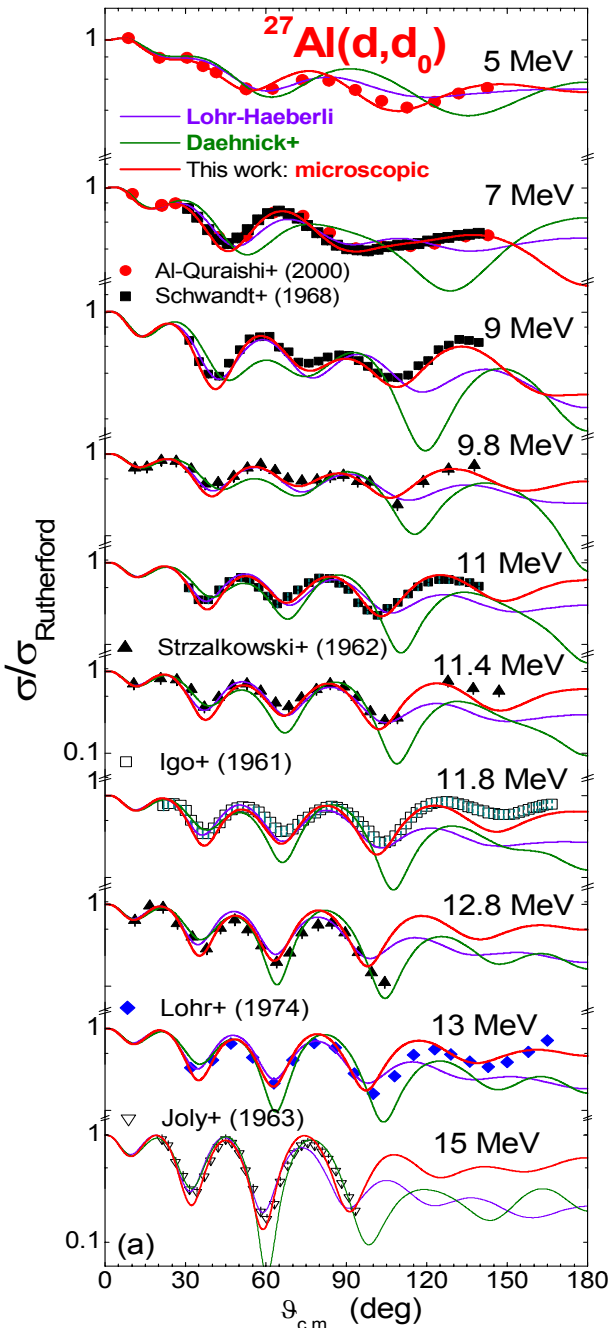
TALYS - 1.0; TALYS - 1.2 [A. Koning, S. Hilaire, M. Duijvestijn]

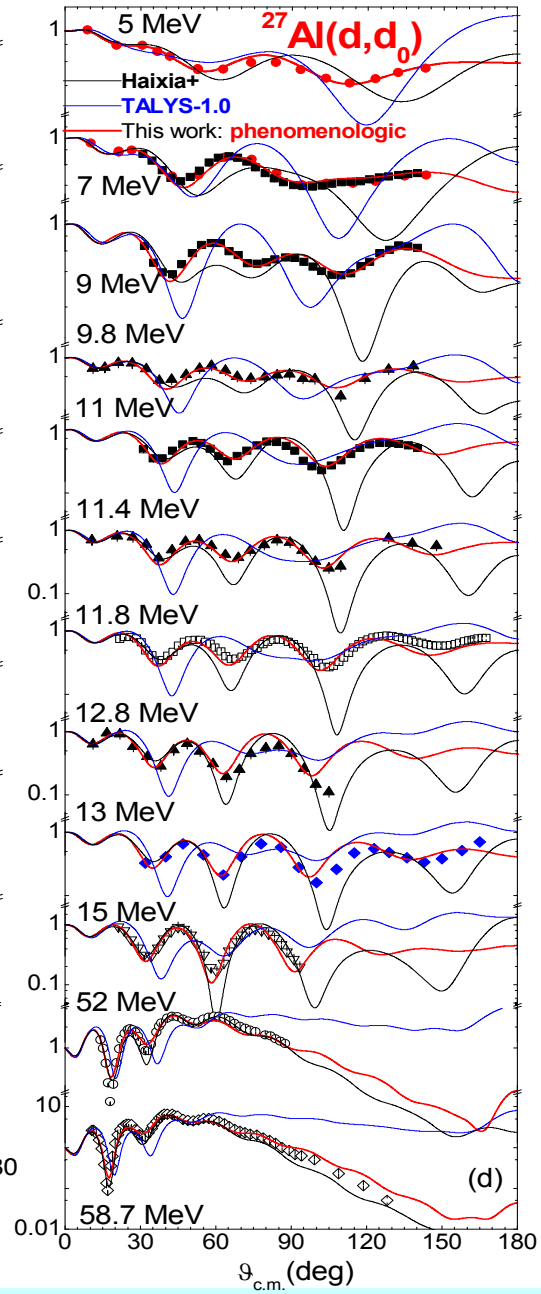
- OMP:ECIS'97; preequilibrium: **MSD / EXCITON;** evaporation: **Hauser-Feshbach**

Optical Model Potential

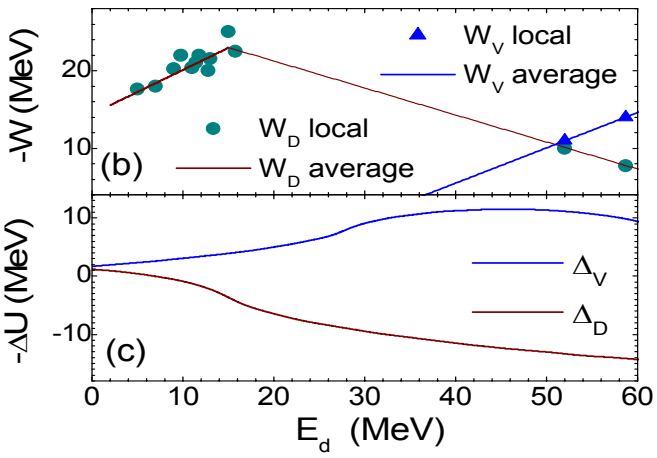
- NO GLOBAL OPTICAL MODEL POTENTIAL (OMP) for d + Nucleus (A<27)
- COMPARATIVE ANALYSIS of global OMPs for d + ^{27}Al, ^{63,65}Cu, ^{54,56,58}Fe, ^{93}Nb, ^{59}Co
  - Lohr-Haeberli (1974): A~40-209, E=8-13 MeV
  - Perey-Perey (1963,1976): A~40-208, E=12-25 MeV
  - Daehnick et al. (1980): A~27-238, E=11.8-90 MeV
  - Bojowald et al. (1988): ^{27}Al, ^{89}Y, ^{120}Sn, and ^{208}Pb at E_d=58.7 and 85 MeV
- None of these global OMP describes data at E<15 MeV
- Semi-microscopic OMP by using realistic nucleon-nucleon interaction
  U_{DF}, & more accurate parameterization for W_V, W_D, V_{SO}
- Phenomenological OMP : parameterization for U_R (frozen W&V_{SO})
- Cross-Sections calculations

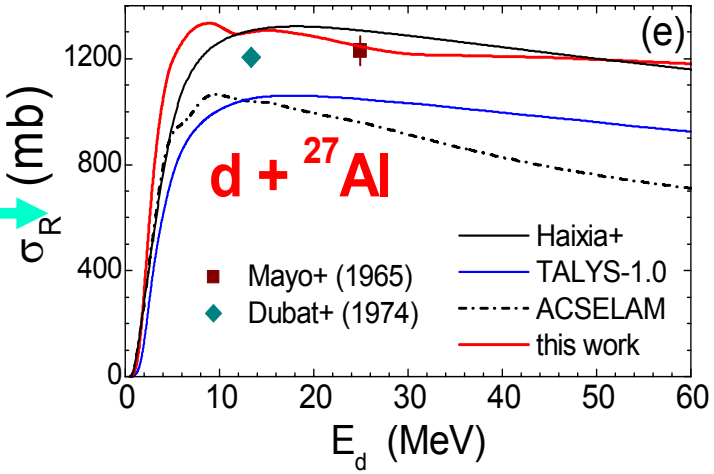
DF-real & phenomenological imaginary/s.o. potentials → Phenomenological OMP



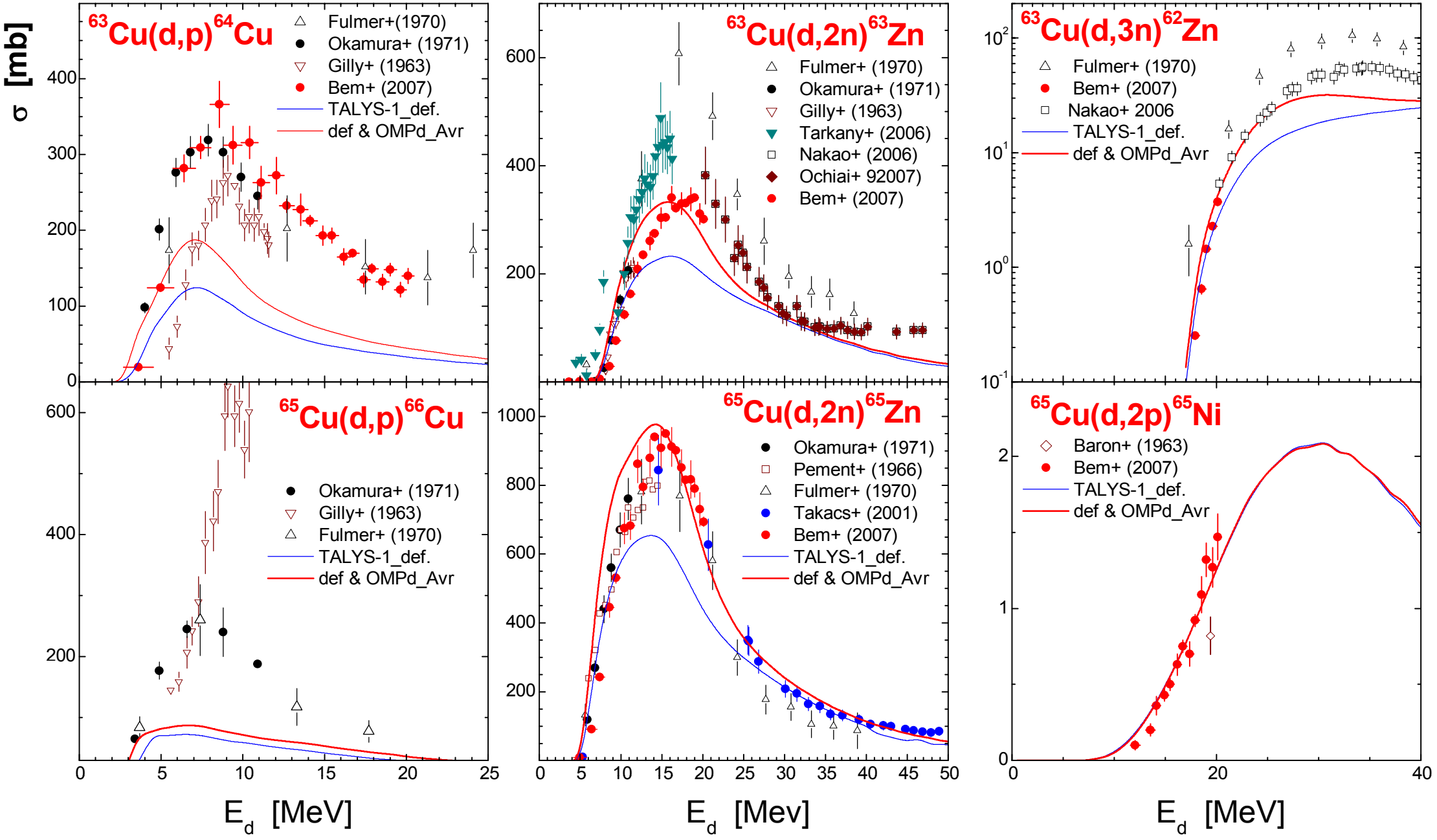


M. Avrigeanu *et al.*, Fus. Eng. Des. 84, 418 (2009)





d + ^{63,65}Cu: activation cross sections first step: d-OMP



d + ^{63,65}Cu: activation cross-sections

EPJ Web of Conferences **2**, 01004 (2010)
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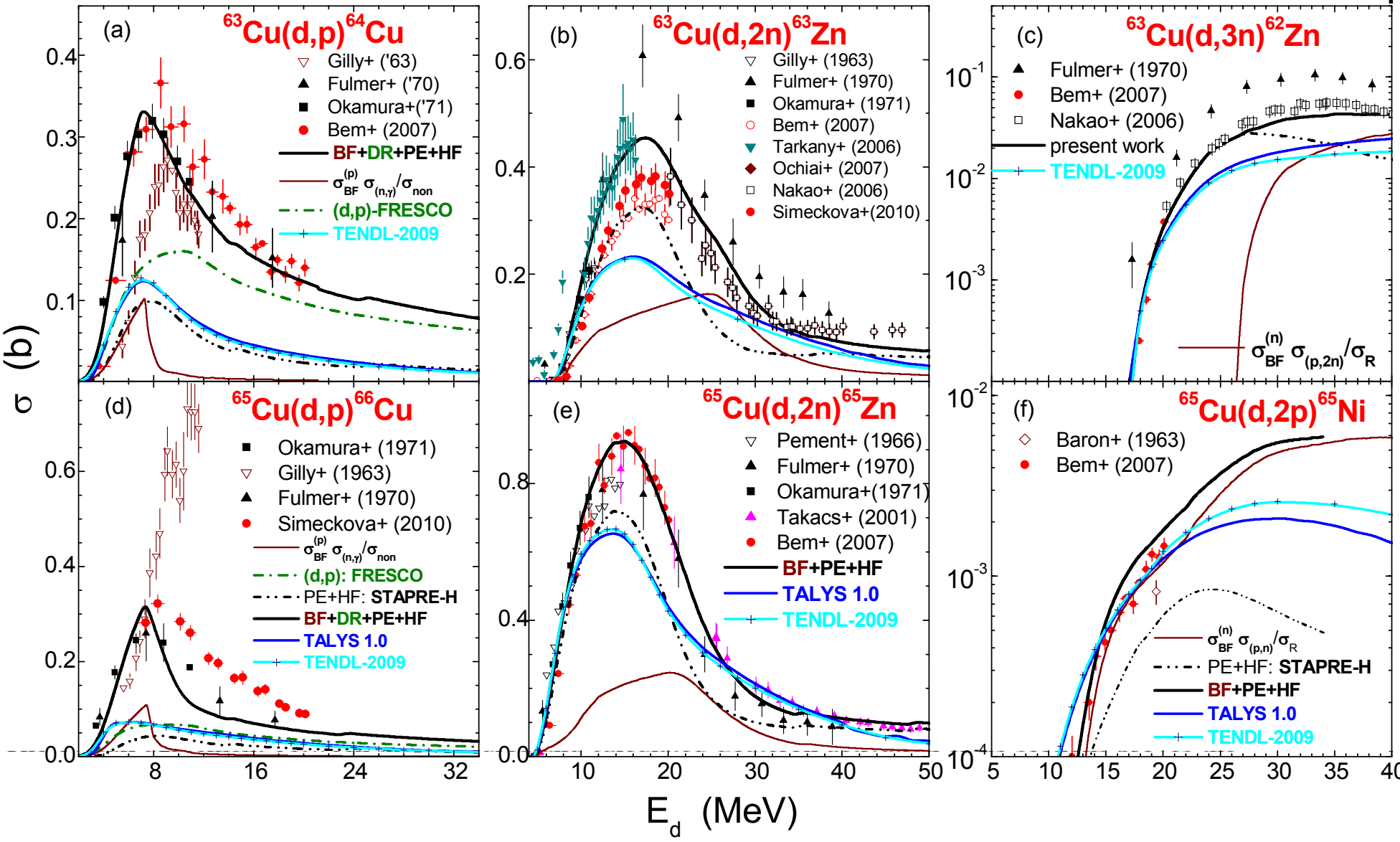
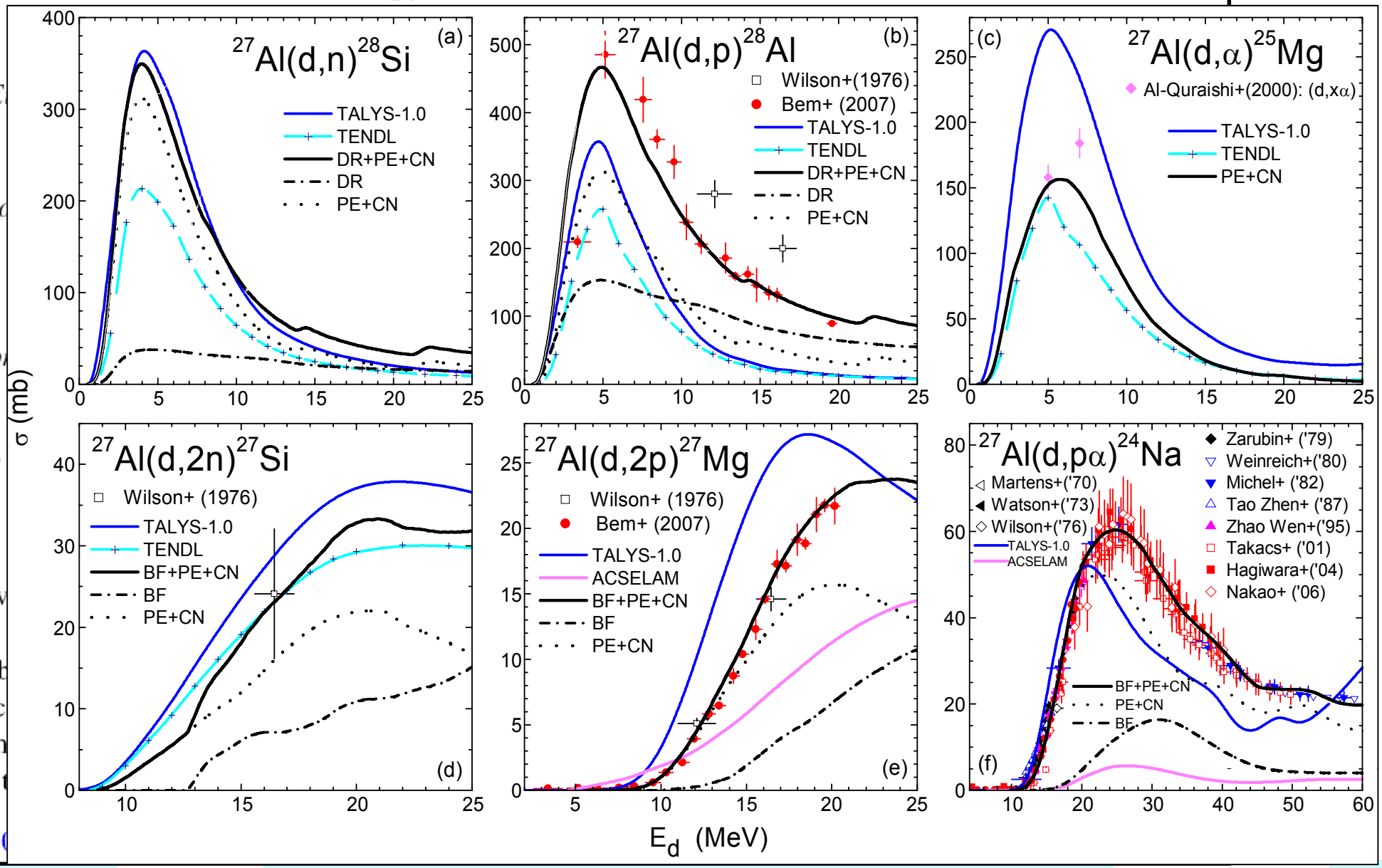


d + ^{27}Al: activation cross-sections

PHYSICAL REVIEW C **79**, 044610 (2009)

Low and medium energy deuteron-induced reactions on ^{27}Al



d breakup involvement : d+^{93}Nb ⋯⋯→ ^{95}Mo*

elastic ^{93}Nb + d → ^{93}Nb + n+ p

inelastic (^{93}Nb + n) + p → ^{94}Nb* + p

$\sigma^{BU\text{-}Inelastic} * \sigma_{n,x} / \sigma^{n}_{R}$

^{94}Nb + γ + p (γp ch. of ^{95}Mo*)

^{93}Nb + n + p (np ch. of ^{95}Mo*)

^{93}Zr + p + p (2p ch. of ^{95}Mo*)

^{90}Y + α + p (αp ch. of ^{95}Mo*)

inelastic (^{93}Nb + p) + n → ^{94}Mo* +n

$\sigma^{BU\text{-}Inelastic} * \sigma_{p,x} / \sigma^{p}_{R}$

^{94}Mo + γ + n (γn ch. of ^{95}Mo*)

^{93}Mo + n + n (2n ch. of ^{95}Mo*)

^{93}Nb + p + n (pn ch. of ^{95}Mo*)

^{90}Zr + α + n (αn ch. of ^{95}Mo*)

Empirical breakup components f^{BU} systematics

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Q{Al(d,p)} = 5.5 MeV

Analysis of deuteron elastic scattering and induced activation cross-sections of light and medium nuclei for IFMIF EVEDA

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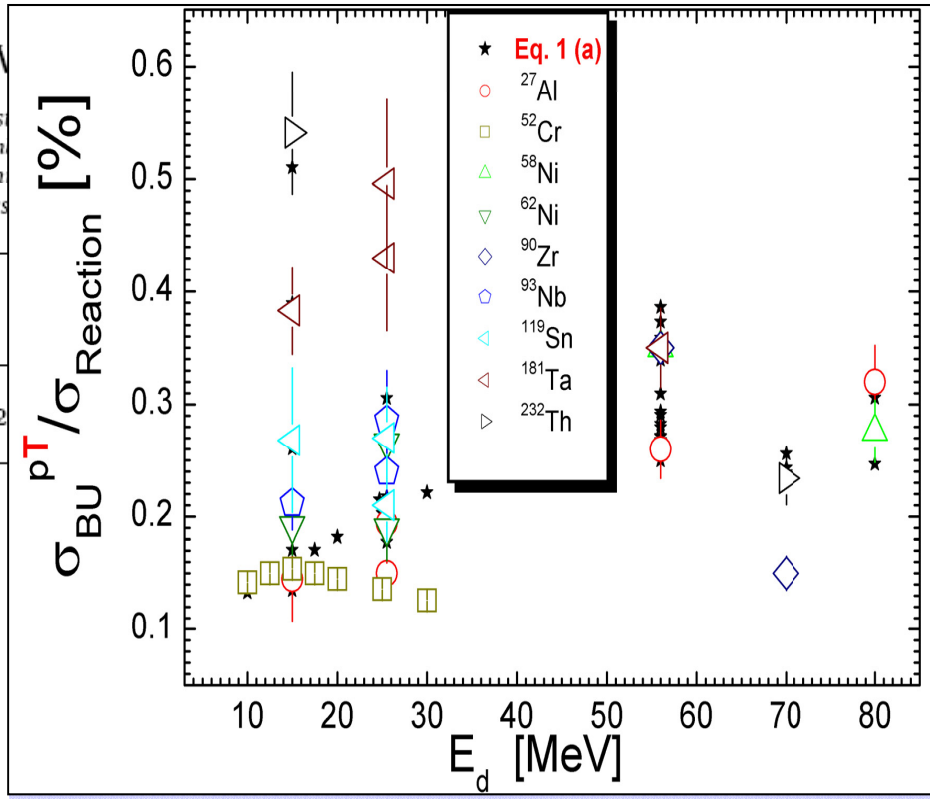
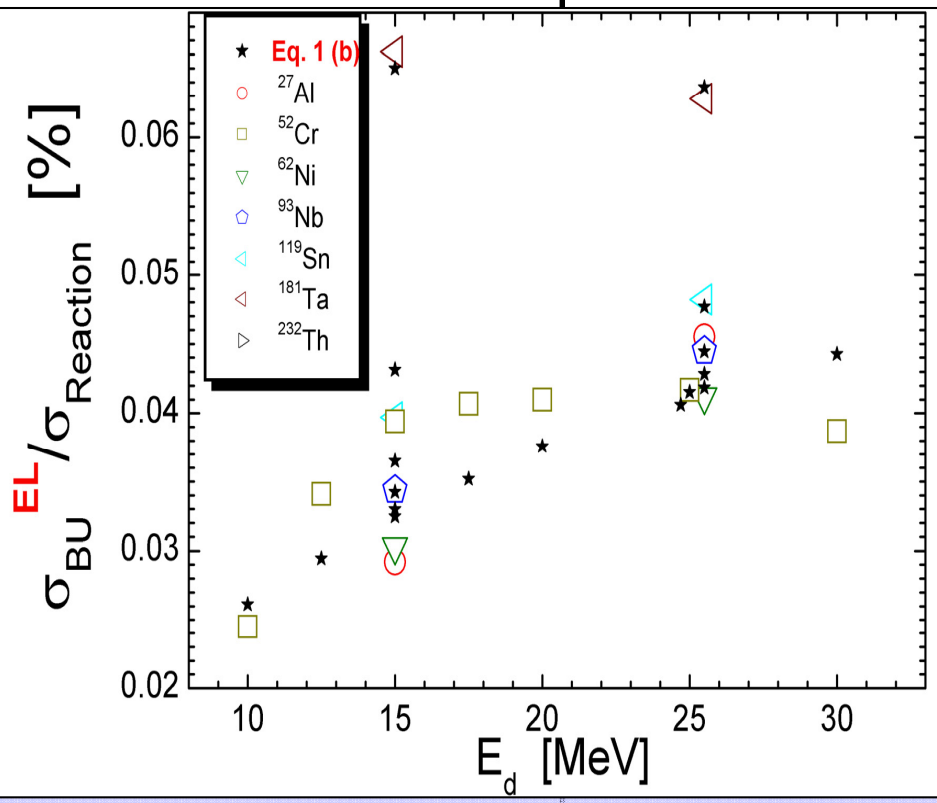




$$f^{pT}_{BU} = 0.087 - 0.0066\,Z + 0.00163\,Z\,A^{1/3} + 0.0017\,A^{1/3}E - 2E\text{-}6\,ZE^2$$

$$f^{EL}_{BU} = 0.031 - 0.0028\,Z + 0.00051\,Z\,A^{1/3} + 0.0005\,A^{1/3}E - 1E\text{-}6\,ZE^2$$

STRIPPING calculations details (FRESCO)

M. Avrigeanu *et al.*, Fus. Eng. Des. 84, 418 (2009)

- **neutron-proton interaction**:
  $\langle\varphi(d),\varphi(p/n)\rangle$; $V=V_0e^{-(r/rd)2}$
  V_0=72.15 MeV; rd=1.484 fm
  M. Kamimura *et al.*, Prog. Theor. Phys. Suppl. 80 (1986) 1

- **nucleon bound state**:
  $\langle\varphi(\text{Target}),\varphi(\text{Residual})\rangle$
  real-WS: V_0; r_0=1.25; a=0.65

- **spectroscopic factors**, S^{IJ}_{lsj}:
  experimental proton/neutron angular distributions
  $\Psi_{JM}(\xi,r)\sim\sum_{lsj}A^{IJ}_{lsj}[\varphi^{I}_{target}(\xi)\ \varphi_{lsj}]_{JM}$;

  $|A^{IJ}_{lsj}|^2 = S^{IJ}_{lsj}$

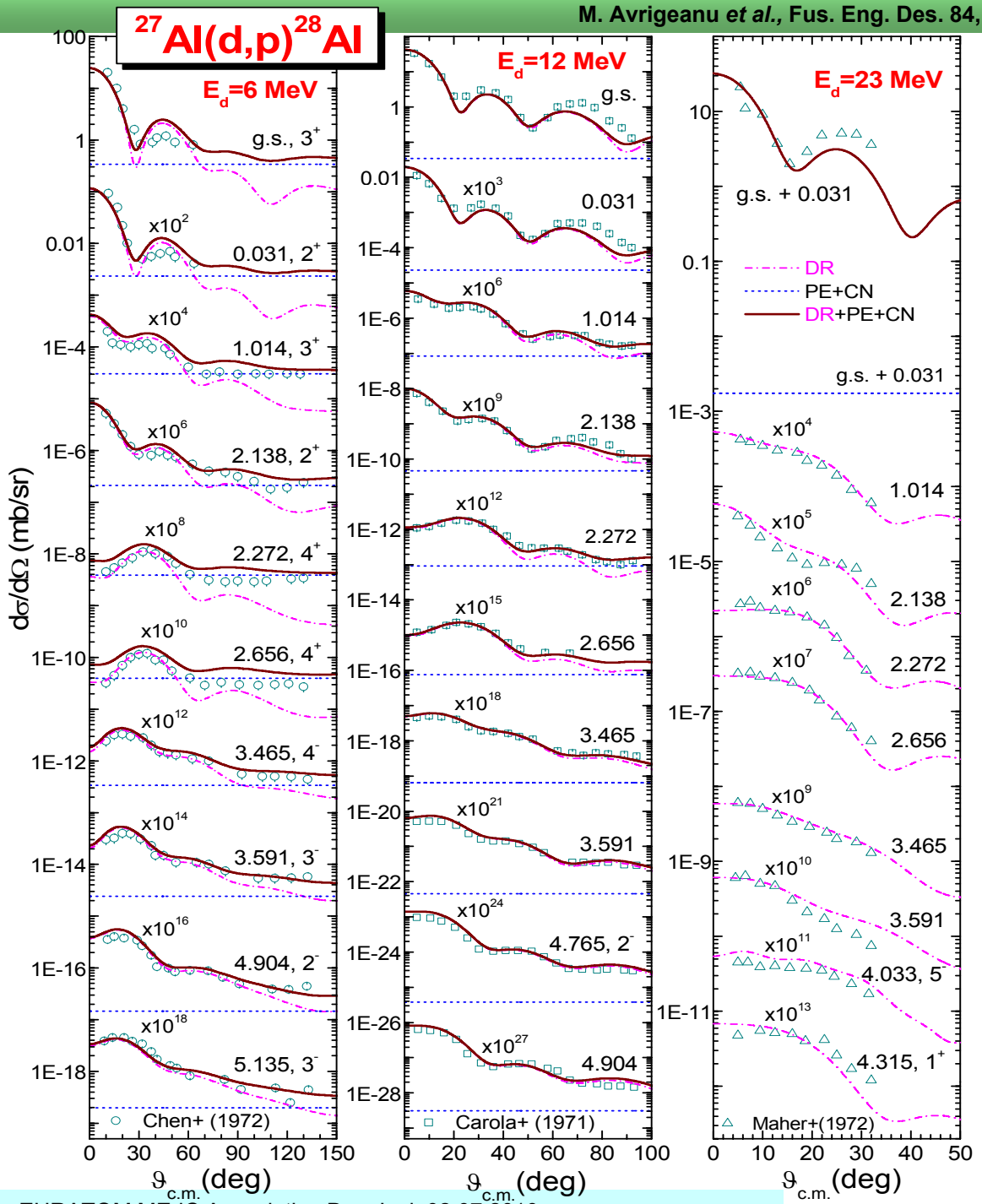
35 levels up to **5.135 MeV** for the **odd-odd** ^{28}Al (^{27}Al(d,p)^{28}Al)

24 levels up to **11.4 MeV** for the **even-even** ^{28}Si (^{27}Al(d,n)^{28}Si)

63 levels up to **3.030 MeV** for the **odd-odd** ^{64}Cu (^{63}Cu(d,p)^{64}Cu)

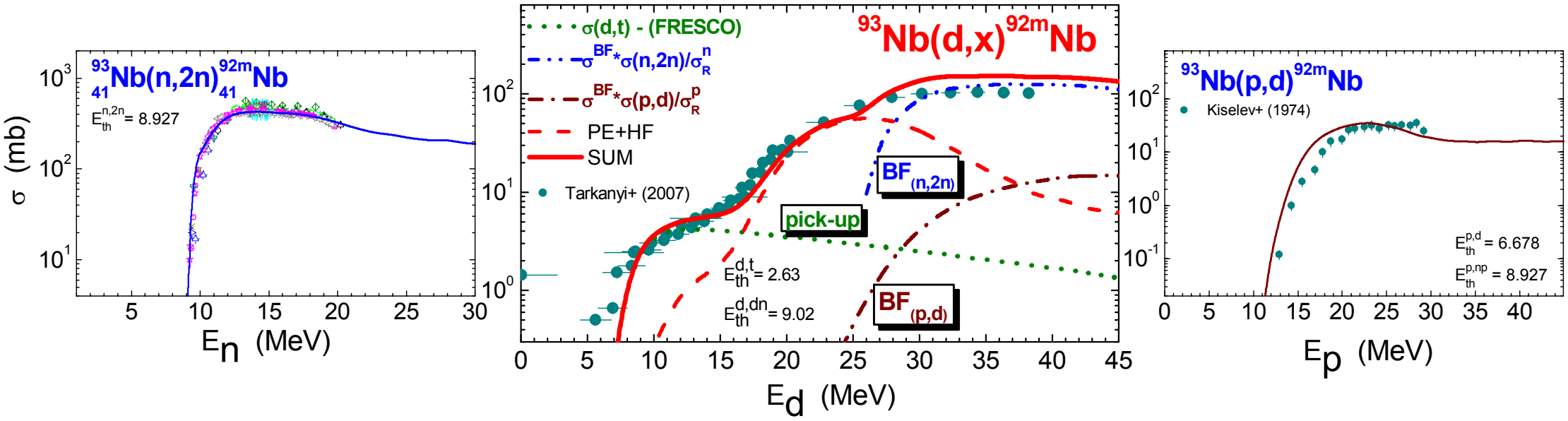
52 levels up to **3.080 MeV** for the **odd-odd** ^{66}Cu (^{65}Cu(d,p)^{66}Cu)

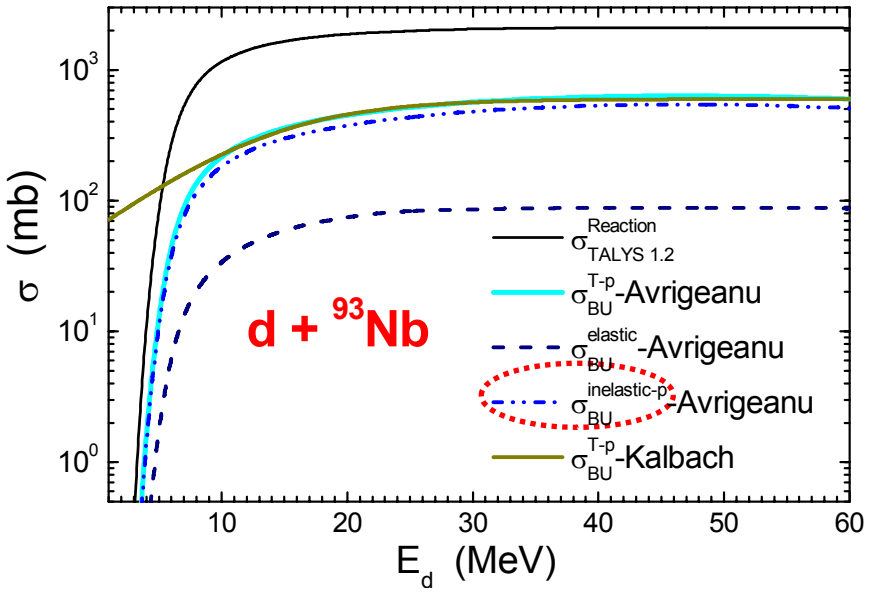
119 levels up to **6 MeV** for the **odd-odd** ^{59}Co (^{59}Co (d,p) ^{60}Co)

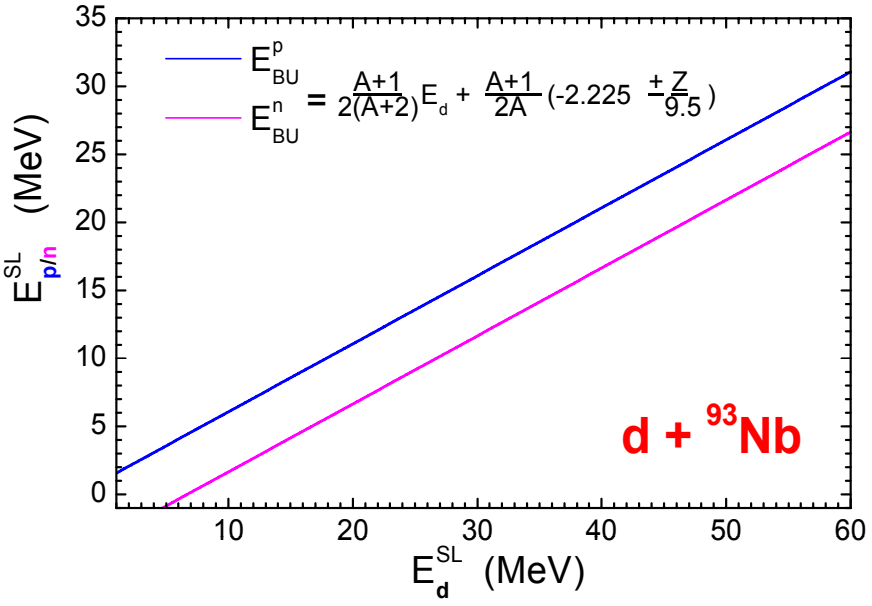


Breakup and Pick-up contributions to activation cross-sections

M. Avrigeanu, V. Avrigeanu, Int. Conf. on Nucl. Data for Sci. and Tech., Jeju-Korea, 26-30 April, 2010

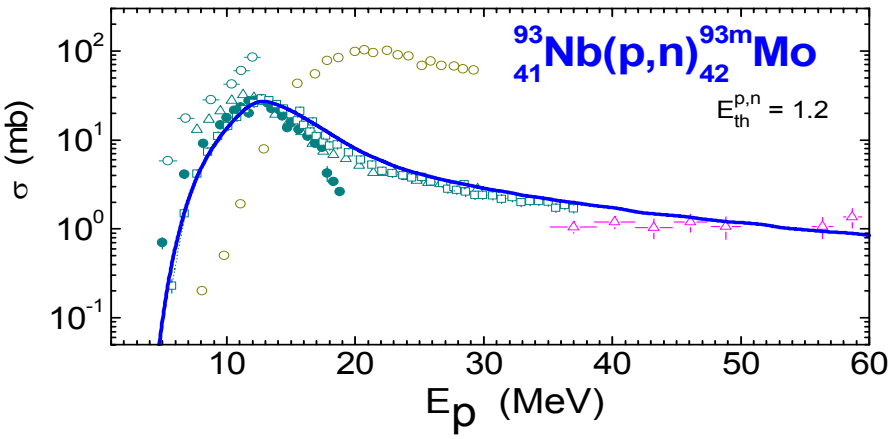


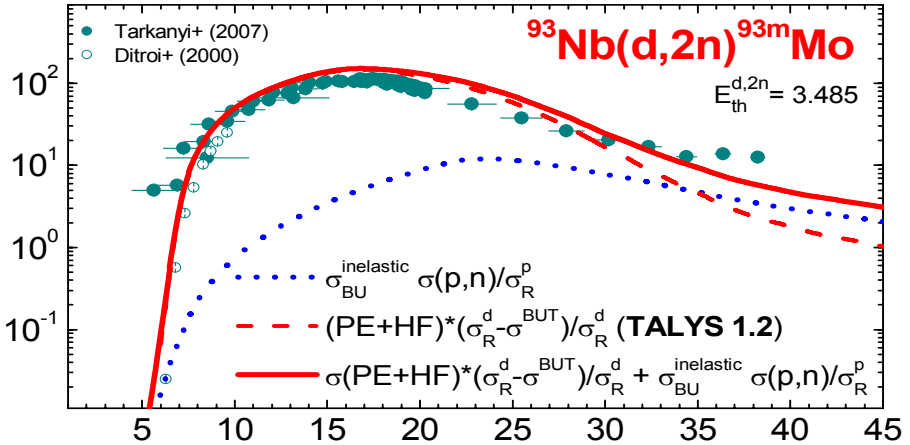


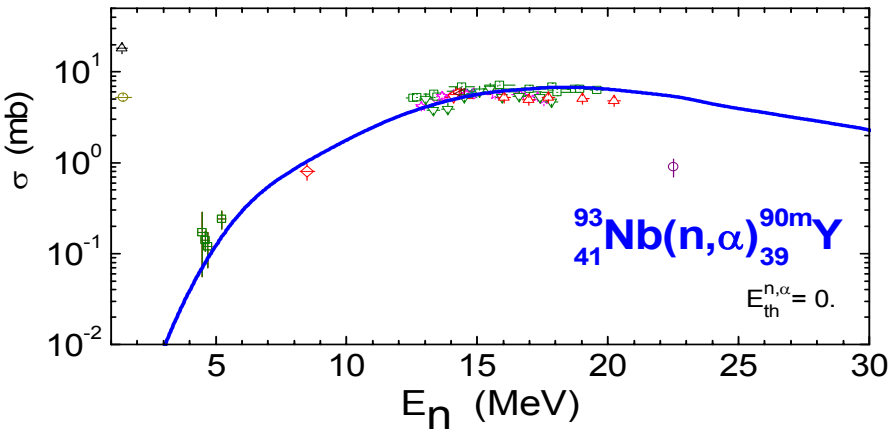


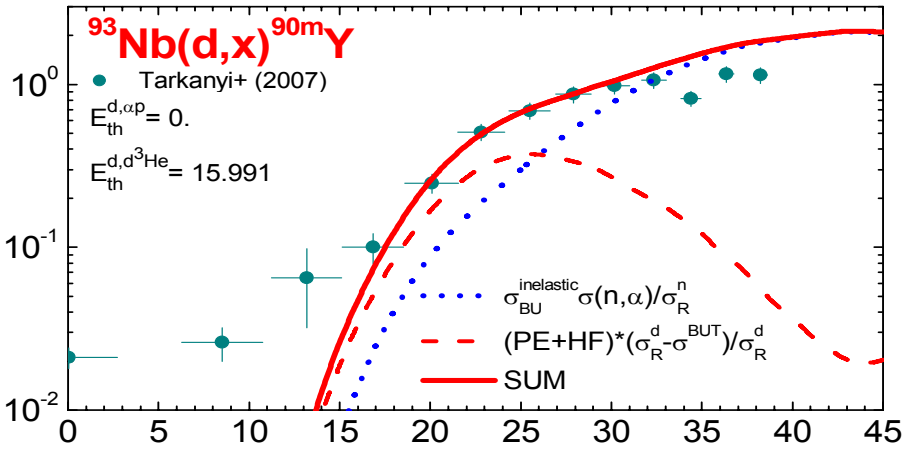
Deuteron breakup contribution to activation cross-sections

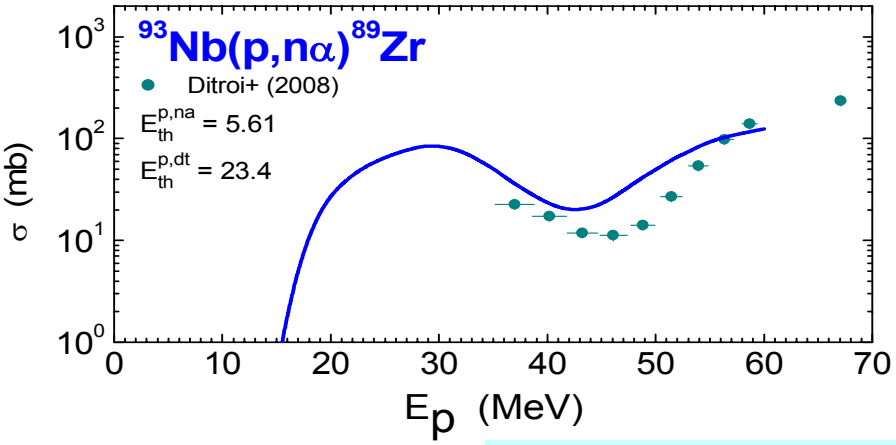
M. Avrigeanu, V. Avrigeanu, Int. Conf. on Nucl. Data for Sci. and Tech., Jeju, Korea, 26-30 April, 2010

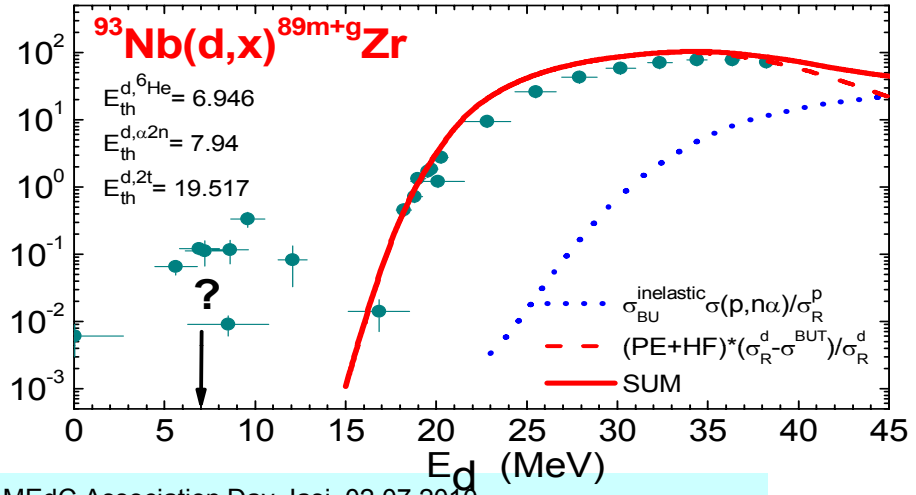












CONCLUSIONS

- **Semi-microscopic OMP analysis**
  - ❖ U_{DF}: ρ_d (charge) & ρ_{Al} (charge) & M3Y Paris-NN
  - ❖ W_D & V_{SO} phenomenological
  - ❖ improved agreement with data adding the dispersion corrections
- **Phenomenological OMP analysis for ^{27}Al, ^{63,65,nat}Cu, ^{93}Nb**
  - ❖ agreement with all available measured data
  - ❖ good description of (d,d) data vs. TALYS default OMPs
  - ❖ improved description of (d,d) data vs. global OMPs
- **Analysis of d interaction with ^{27}Al,^{63,65}Cu, ^{93}Nb, ^{59}Co**
  - ❖ BU, BF - Deuteron break-up mechanism contributions,
  - ❖ DR mechanism considered trough n & p stripping, pick-up
  - ❖ PE and evaporation mechanisms contributions
  - ❖ Comparison of d-activation with TENDL-2009 library
- **F4E-2008-GRT-06 (ES-AC) / Task 5b further work:**

FUSION FOR ENERGY

Annex B

DMS #	F4E_D_N10783		
Call #	F4E-2010-GRT-056		
Page	7 / 12	Rev.	00.0

– Task 5.2. Microscopic real optical potentials will be used for a final setup of improved model.

Latest measurements of deuteron induced reaction cross sections will be taken into account.

- **Deuteron activation c. s. calculations for EUROFER constituents**

Thank you !