6th Workshop on Nuclear Level Density & Gamma Strength, Oslo, May 8-12, 2017
[http://tid.uio.no/workshop2017/]

Realistic radiative strength functions within analysis of fast-neutron induced reactions in the mass range A~90

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Content

1. **Motivation: - newest (α,γ), (p,γ), (α,n) reaction c.s. - suitable account**
   (framework)
   - α-OMP consistent analysis [Astrophysics & EUROfusion]
2. **E1 RSF model/parameters within (α,γ), (α,x): A~60, A~110, A~160,**
3. **E1 RSF model/parameters within (n,γ), (p,γ): A~90** [$^{90-92,94,96}$Zr(n,x), (n,α)]
4. Conclusion

1.1 Method, tools, IP [Nuclear data *consistent* model calculations]

[E.D. Arthur – P.G. Young, LANL, '80]

[e.g., Nucl. Sci. Eng. 76, 137 (1980)]

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[IAEA/NDS RCs (12), Bucharest, 1982-2011]

YES

i. **unitary use of *common model parameters* for different mechanisms**

ii. **use of *consistent sets* of input parameters - determined by *analyses of various independent* experimental data**

iii. **unitary account of *whole body* of related experimental data for *isotope chains* and *neighboring elements***

[activation & particle-emission spectra]

[enlarged incident-energy range]

NO re-normalization or free parameters, widely-used within ND libraries, *e.g.:*

1.2 Method, tools, IP

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OPTICAL MODEL : prime tool for all cross section calculations

- **Phenomenological OMP (global parameter sets): still extensively used**
- **Microscopic OPs: reduced uncertainties (e.g., OM ambiguities)**

- **Pure elastic scattering OP analysis**

  SCAT2 [O. Bersillon]

  - phenomenological OP

    + semi-microscopic (DF) OP

    (local version)

*Phys. Rev. C**62** (2000) 017001*
*Nucl. Phys. **A693** (2001) 616*
*Eur. Phys. J. **A12** (2001) 399*
Int. J. of Mod. Phys. E, 11 (2002) 249
*Nucl. Phys. **A**723 (2003) 104*
*Nucl. Phys. **A** 759 (2005) 327*
*Nucl. Phys. **A** 764 (2006) 246*

- **Coupled Reaction Channel (CRC)**

  FRESCO-2003 [I.J. Thompson]

- **Composite system equilibration**
  - **Geometry Dependent Hybrid** (GDH) preequilibrium-emission model
  - **Hauser-Feshbach** (HF) statistical model

  STAPRE-H95 [V. Avrigeanu, M. Avrigeanu]

  (updated)

1.3.1 Method, tools, IP

LOCAL APPROACH:

STAPRE-H95 (updated-2014) [OM/PE/SM: SCAT2, GDH, HF]

- **neutron- spherical OMP** [Koning-Delaroche, Nucl.Phys. **A713**, 231 (2003)]
- **p-, α- spherical OMP:** [Johnson+ (1968), V. Avrigeanu+, PRC **49**, 2125 (1994),
  V. Avrigeanu+, PRC **90**, 044612 (2014)]
- **γ-ray strength functions:** E1[EGLO/OCL:**PRC 93,045810(2016),** *ibid.* **94**,025804(2016)]
  M1(SLO, 1990 [RIPL-1])
- **PE: Geometry Dependent Hybrid model** [M. Blann+, PRC **28**, 1493 (1984)]
  - **+ α-particle emission** [Z.Phys. A **329**,177(1988)]
  - **+ J^{π}-conservation** [Z.Phys. A **329**,177(1988)]
  - **+ g_{FGM}(e), A_K(p,h), $f_K(p,h,E,F_1(l,E_i)$** [Phys. Rev. C **58**, 295 (1998)]

- **Nuclear-level density** ($E>E_d$ [**ENSDF**]): **BSFG:**
  - **+ $E^*<B_n$: (a,Δ) from fit of [D_0 (RIPL-3), N_d (ENSDF,RIPL3)]**
  - **+ $E^*>B_n$: $a(E^*)$** [A.R. Junghans+, NP**A629**, 635 (1998);
    A.J. Koning, M.B. Chadwick, PRC **56**, 970 (1997)]
  - **+ I/I_r: 0.5(g.s.)-0.75(B_n)-1(15 MeV)** [V.Avrigeanu+, JNST **S2**,746 (2002)]

1.3.2 Method, tools, IP: α-particle OMP

PHYSICAL REVIEW C **90**, 044612 (2014)

F4E-GRT-168.01-5.1

Further explorations of the α-particle optical model potential at low energies for the mass range $A \approx 45$–209

PHYSICAL REVIEW C **91**, 064611 (2015)

F4E-GRT-168.02-8.1

Consistent optical potential for incident and emitted low-energy α particles

PHYSICAL REVIEW C **94**, 024621 (2016)

F4E-GRT-168.02-8.1

Analysis of uncertainties in α-particle optical-potential assessment below the Coulomb barrier

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Background: Recent high-precision measurements of α-induced reaction data below the Coulomb barrier have pointed out questions about the α-particle optical-model potential (OMP) which are still unanswered within various mass ranges.
Purpose: The applicability of previous optical potential and eventual uncertainties and/or systematic errors of the OMP assessment at low energies can be further considered on this basis.
Method: Nuclear model parameters based on the analysis of recent independent data, particularly γ-ray strength functions, have been involved within statistical model calculation of the (α,x) reaction cross sections.
Results: The above-mentioned potential provides a consistent description of the recent α-induced reaction data with no empirical rescaling factors of the γ and/or nucleon widths.
Conclusions: A suitable assessment of α-particle optical potential below the Coulomb barrier should involve the statistical-model parameters beyond this potential on the basis of a former analysis of independent data.

DOI: 10.1103/PhysRevC.94.024621

arXiv:1605.05455

2.1 HF analysis (α,γ), (α,x): based on RSF data (A~160)

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V. AVRIGEANU, M. AVRIGEANU, AND C. MĂNĂILESCU PHYSICAL REVIEW C 90, 044612 (2014)

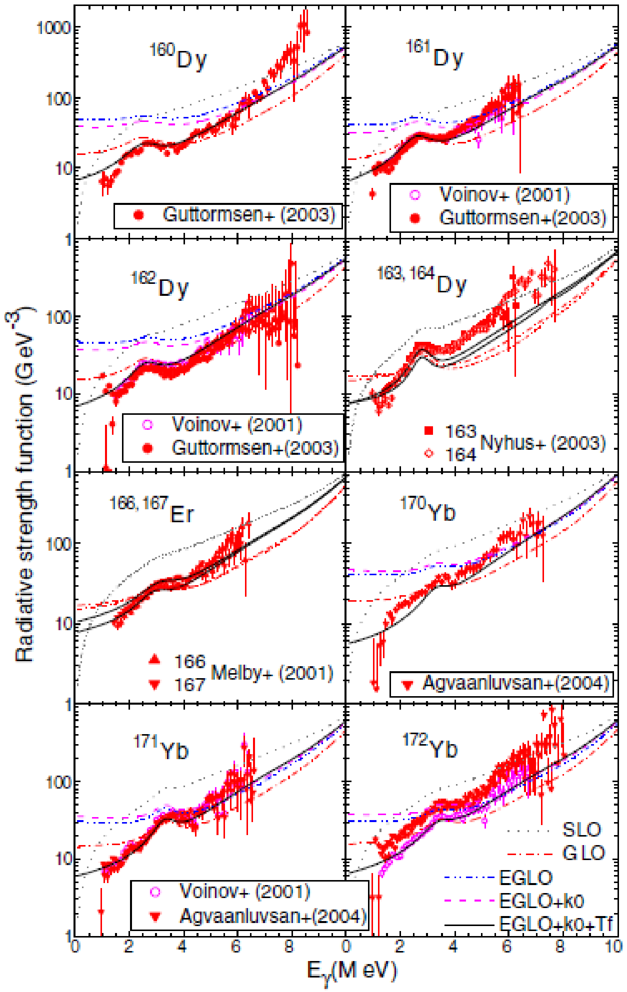

FIG. 3. (Color online) As Fig. 2 but for the sum of γ-ray strength functions of the $E1$ and $M1$ radiations for the $^{160-164}$Dy, ^{166,167}Er, and $^{170-172}$Yb nuclei.

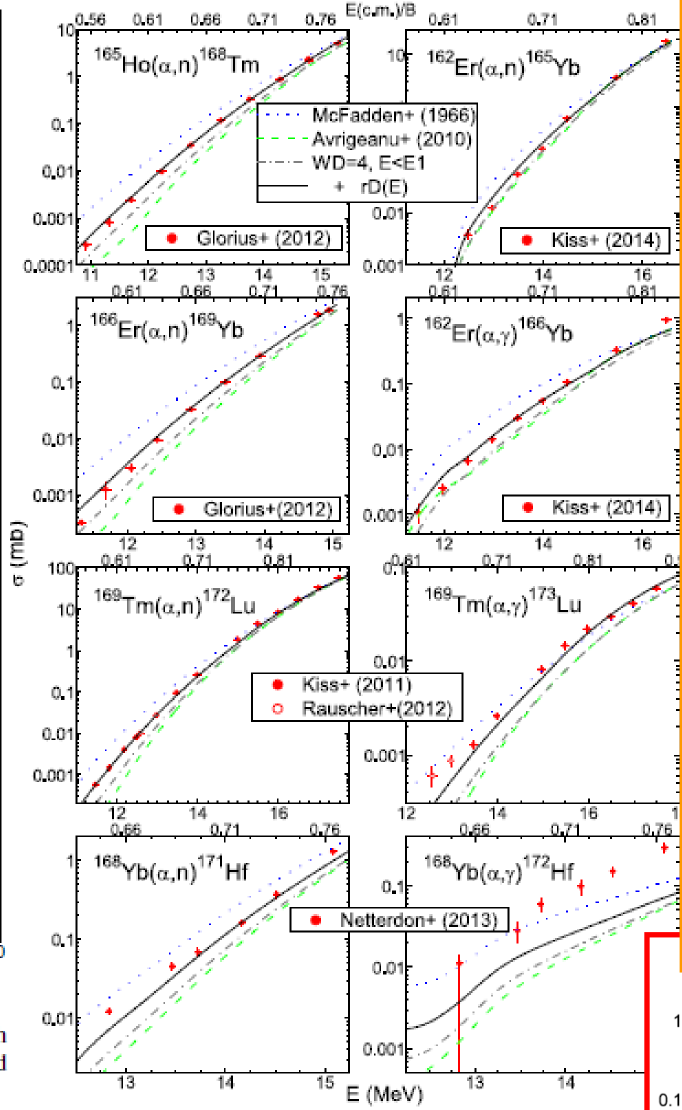

FIG. 6. (Color online) As Fig. 4 but for ^{165}Ho [10], ^{162}Er ^{166}Er [10], ^{169}Tm [12,13], ^{168}Yb [14], and SM calculations using the OMP of this work without the ~7% larger radius for the su imaginary potential (dash-dotted curves).

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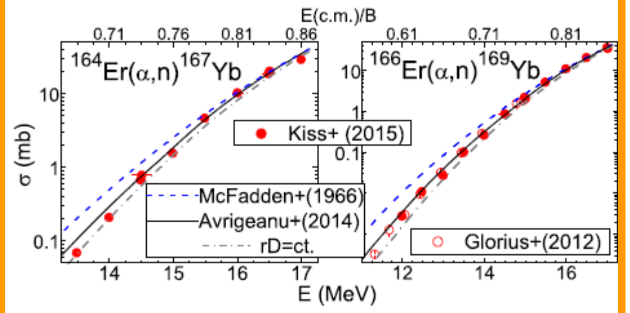


FIG. 8. Comparison of recently measured (α,n) reaction cross sections for ^{164,166}Er [5,57] with the calculated values using the α-particle OMPs of Refs. [17] (dashed curves) and [7] with (solid curves) as well as without (dash-dotted curves) the energy-dependent

PHYSICAL REVIEW C 94, 024621 (2016)

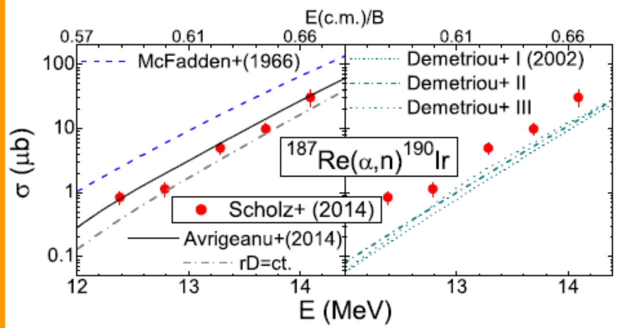
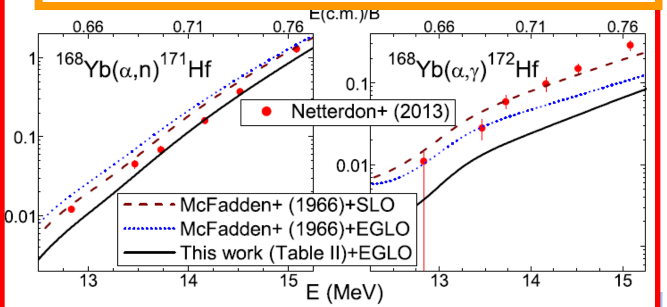


FIG. 9. As Fig. 8 but for ^{187}Re [6] (left), and the OMPs I–III of Ref. [16] (short dotted, short dash-dotted, and short dashed curves, respectively) (right).



2.2 HF analysis (α,γ), (α,x): based on RSF data (A ~ 60)

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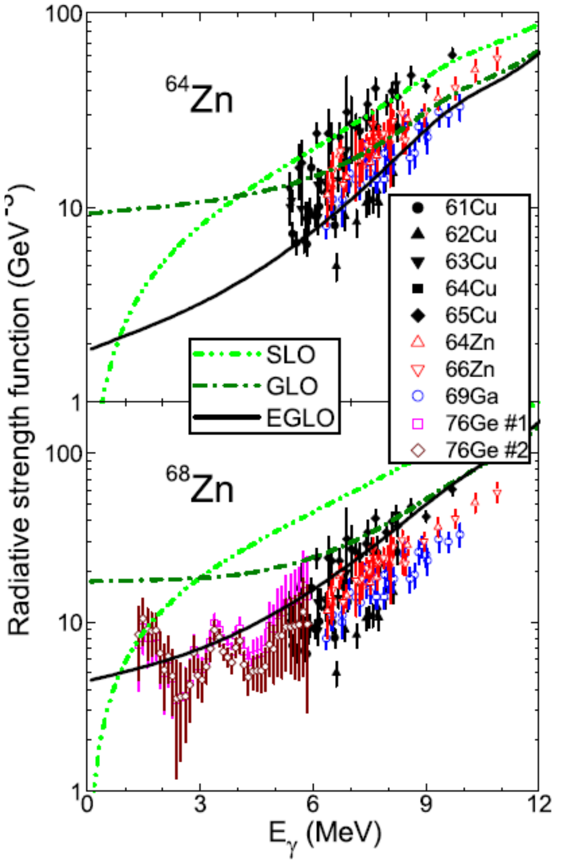
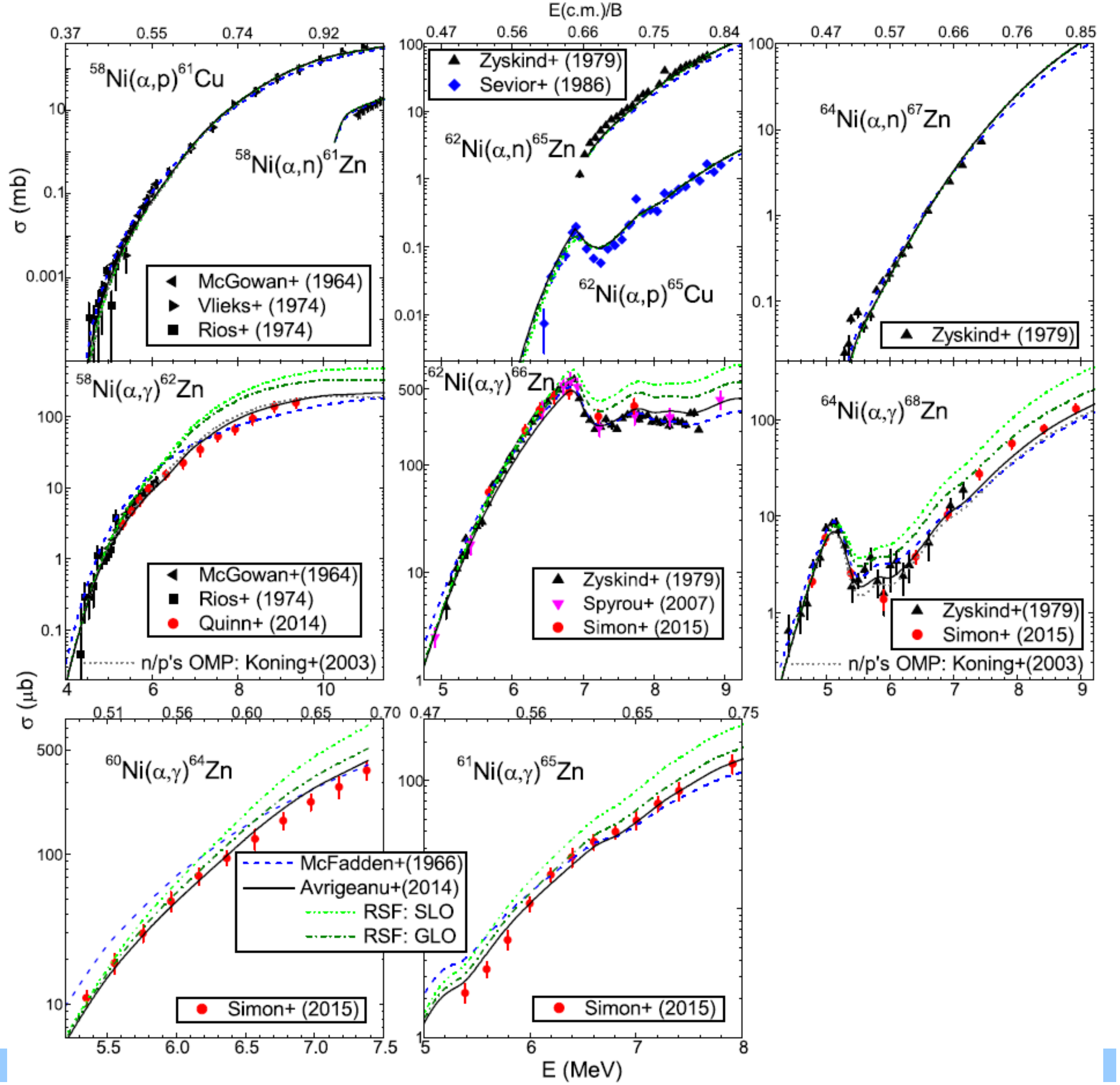


IG. 2. Comparison of the sum of calculated γ-ray strengt
ions of the $E1$ and $M1$ radiations for ^{64}Zn and ^{68}Zn nuclei, usin
: SLO (dash-dot-dotted curves), GLO (dash-dotted curves), an
O (solid curves) models for $E1$ radiations and the SLO model fc
adiations. Also shown are the measured dipole γ-ray strengt
ions for ^{61,62,63,64,65}Cu, ^{64,66}Zn, ^{69}Ga, and ^{76}Ge nuclei [27–33].



2.3.2 HF analysis (α,γ), (α,x): based on RSF data (A ~ 110) (1/4)

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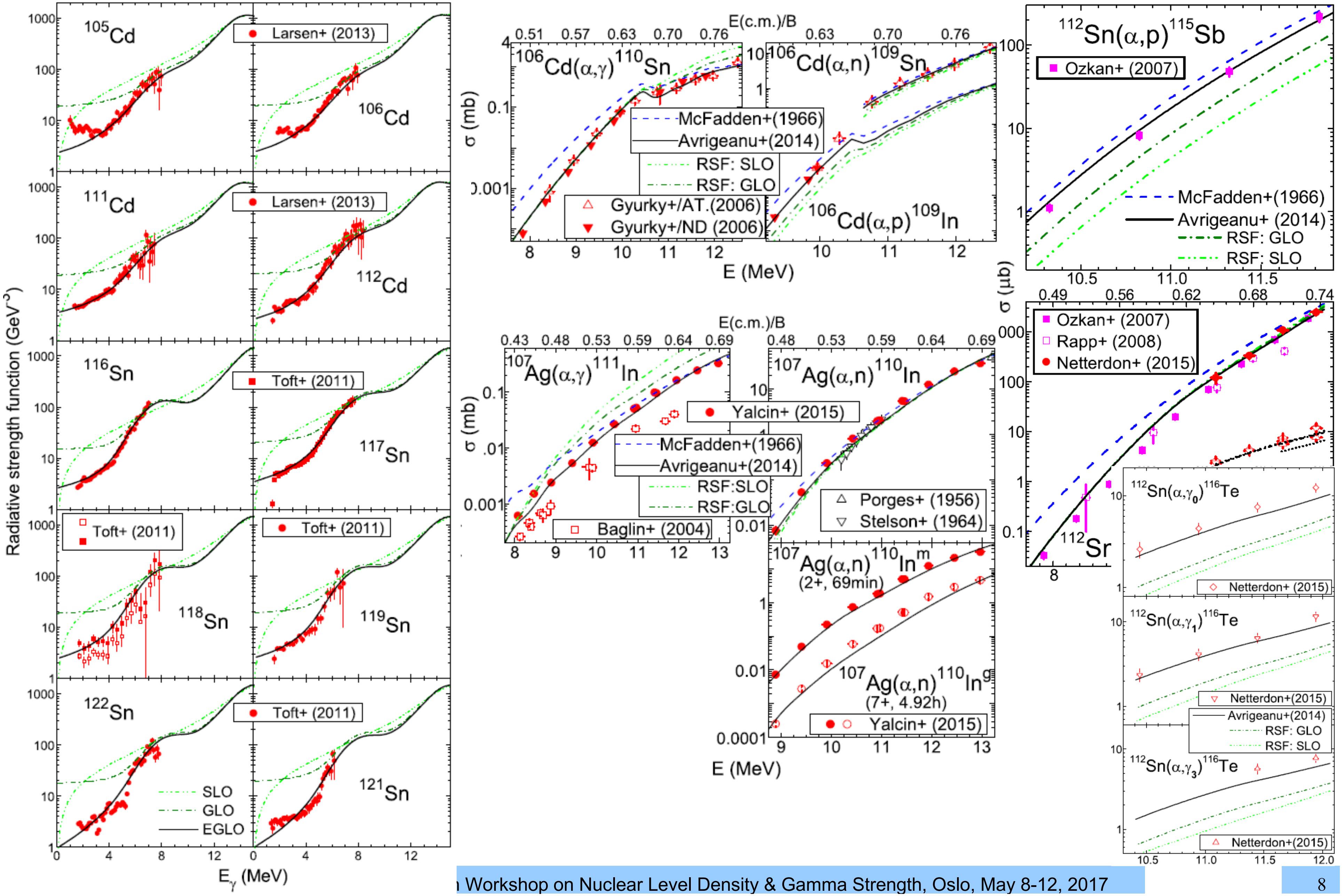
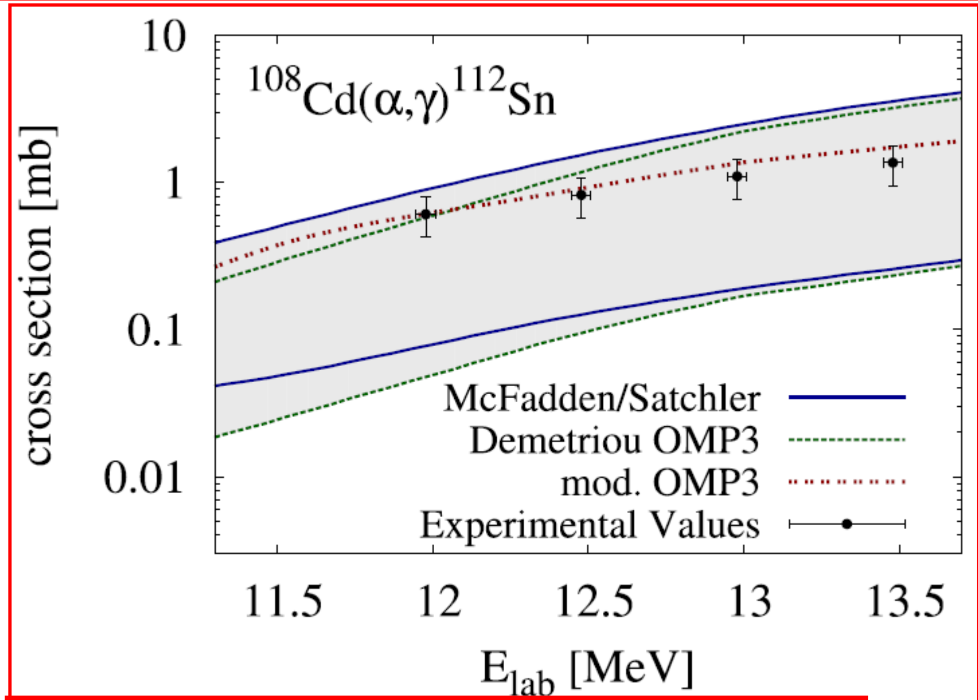
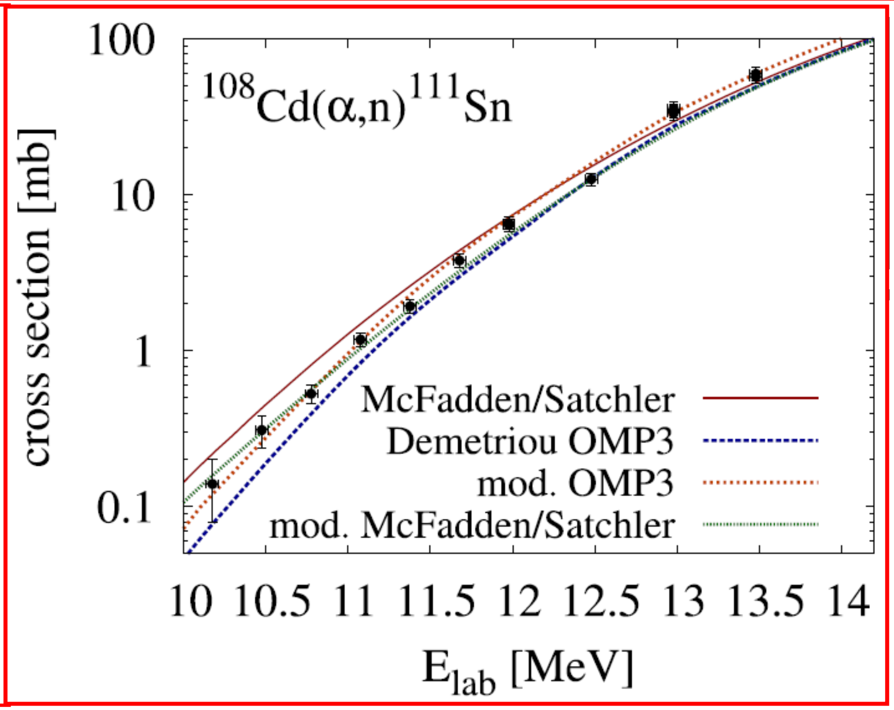
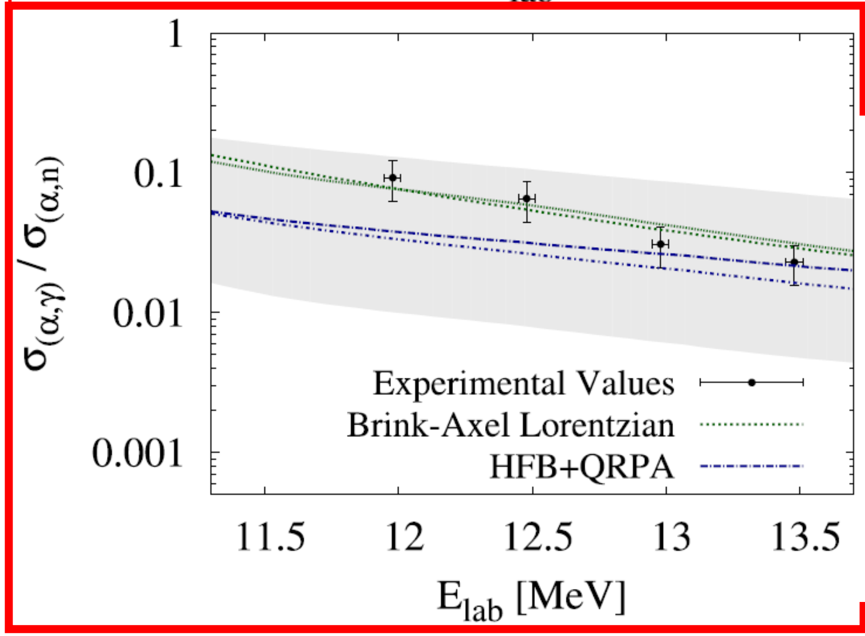


2.3.2 Recent (α,γ), (α,x) data /analysis: A ~ 110 (2/4)







in TALYS is indicated by a gray shaded area. The best reproduction of the measured ratios was obtained by the combination of the Brink-Axel Lorentzian model for the γ-ray strength function an the Back-shifted Fermi gas model for the nuclear-level density. Please note that this does not imply directly that these models are the best in describing the nuclear level density or the γ-ray strength functions in the compound nucleus ^{112}Sn but have only been found in combination to reproduce the ratio of the γ- and

2.3.2 HF analysis (α,γ), (α,x): based on RSF data (A ~ 110) (3/4)

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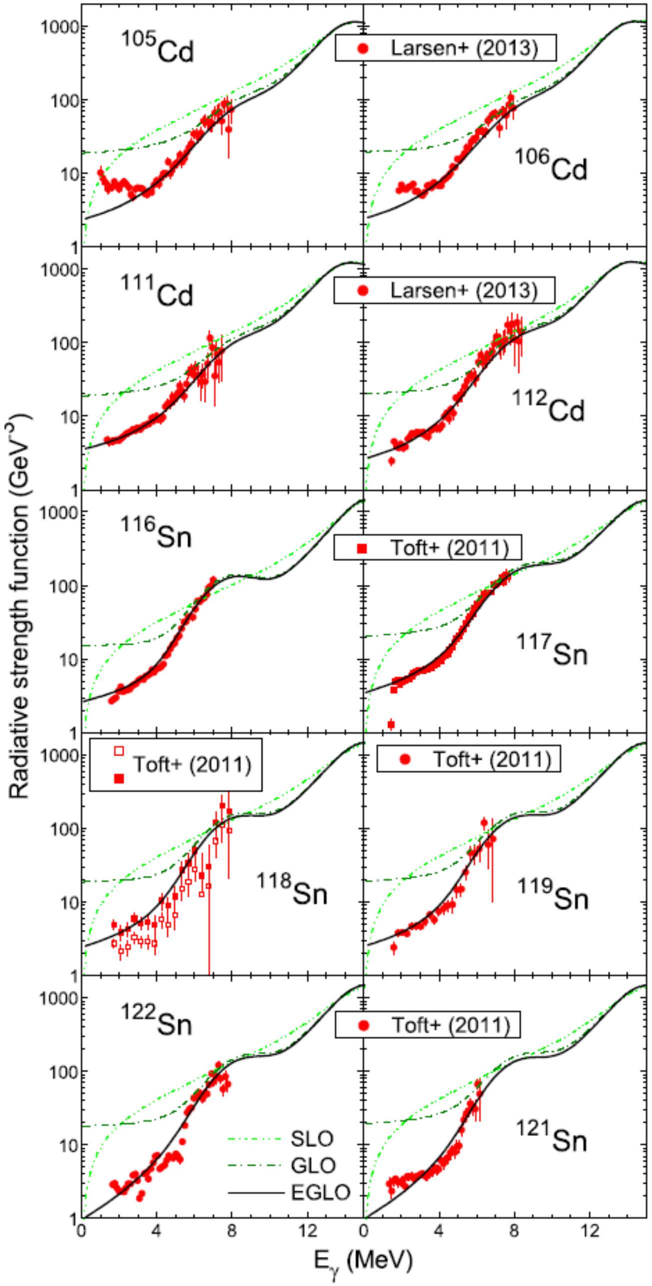
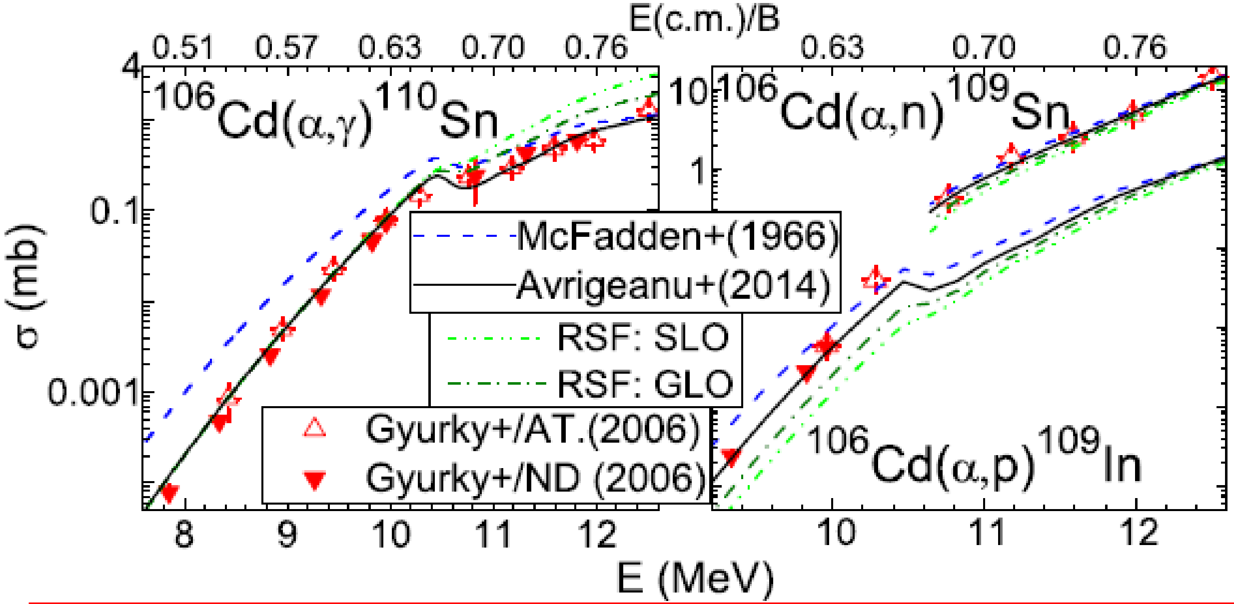
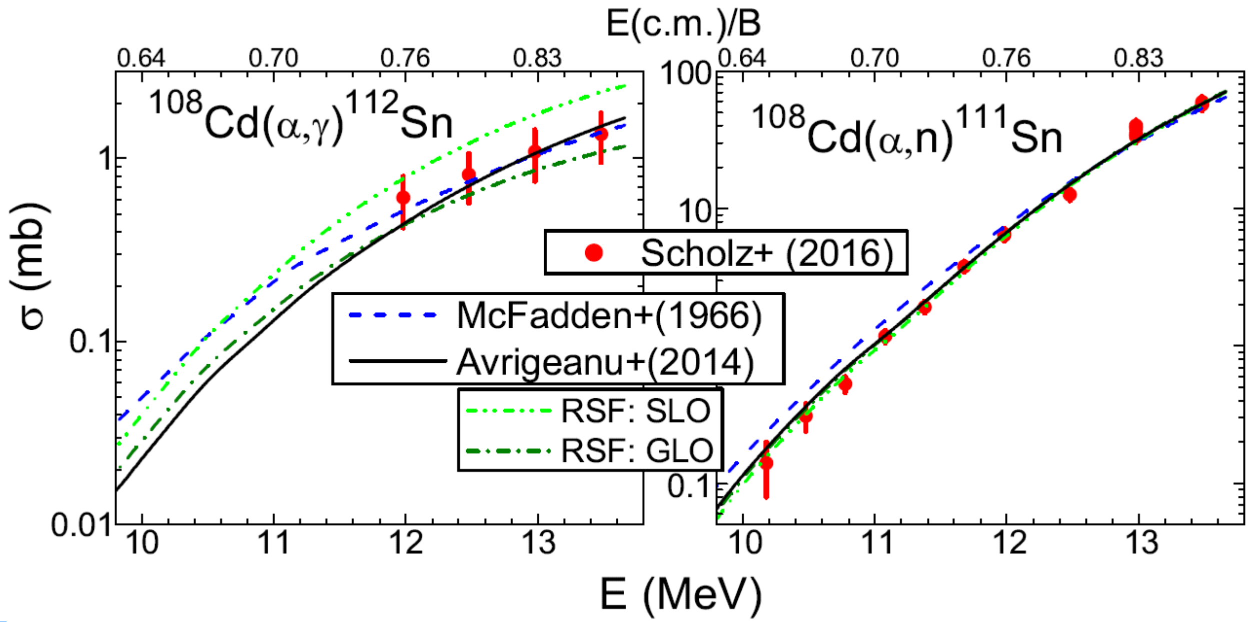
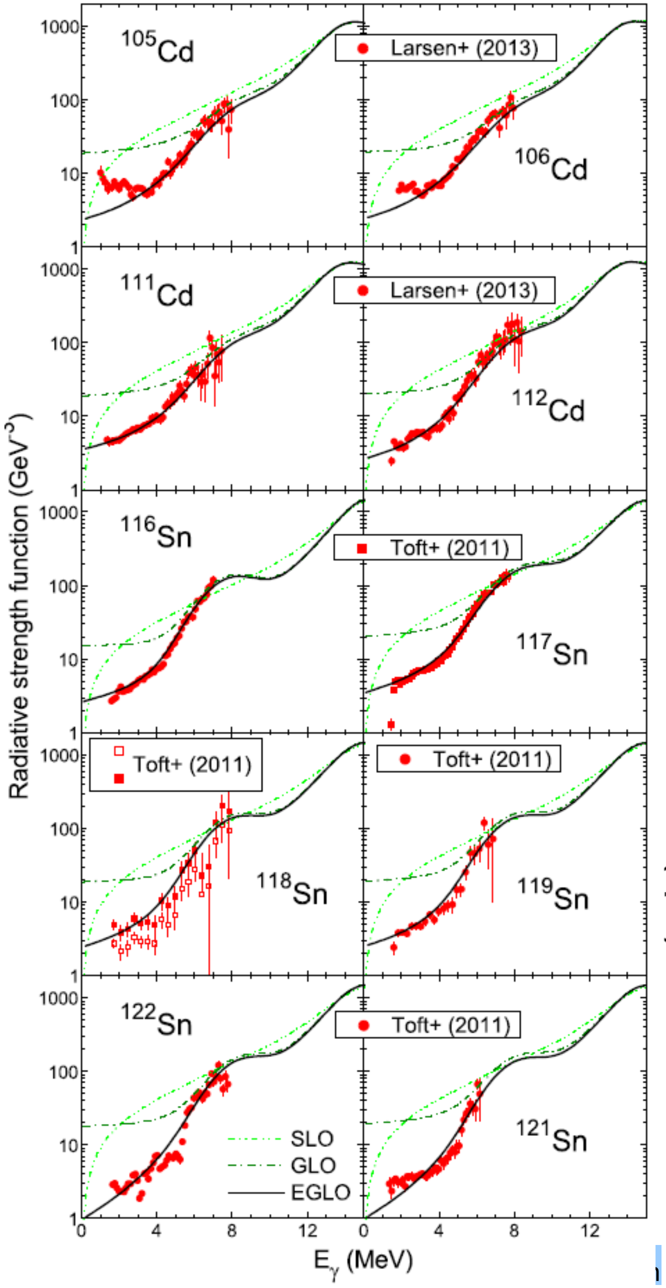
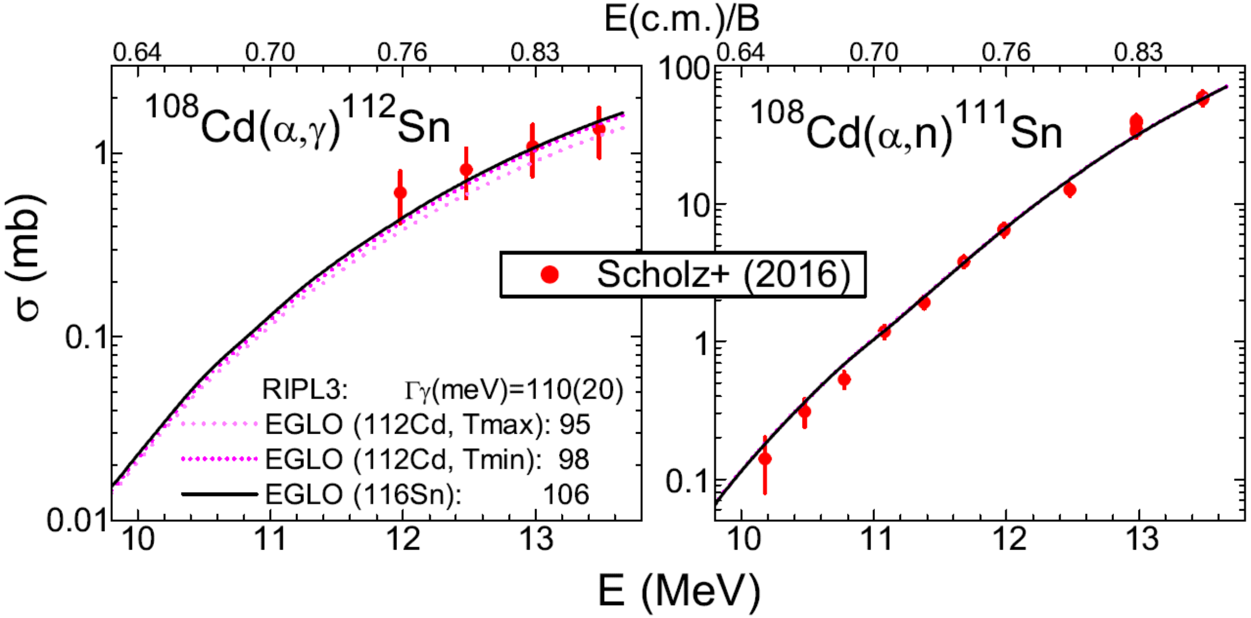




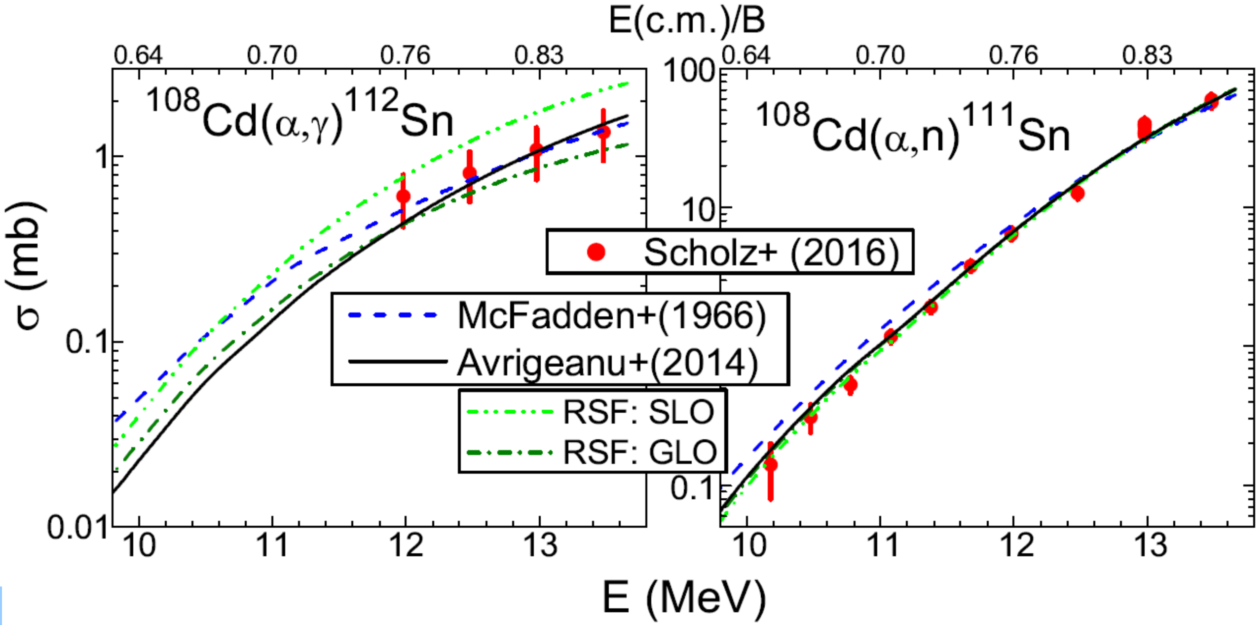


2.3.2 HF analysis (α,γ), (α,x): based on RSF data (A ~ 110) (4/4)





112Cd: A. C. LARSEN *et al.* PHYSICAL REVIEW C **87**, 014319 (2013)
116Sn: H. K. TOFT *et al.* PHYSICAL REVIEW C **83**, 044320 (2011)



3.1 HF analysis (n+Zr): RSF/OMP(p) vs. σ(p,γ) , σ(p,n)

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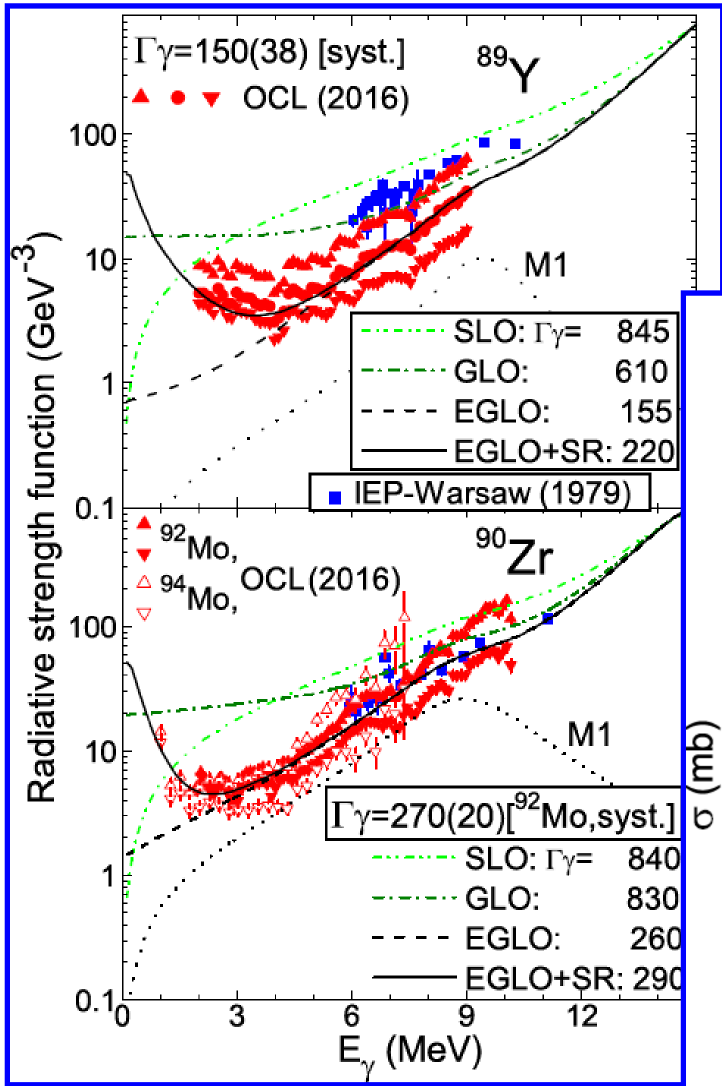
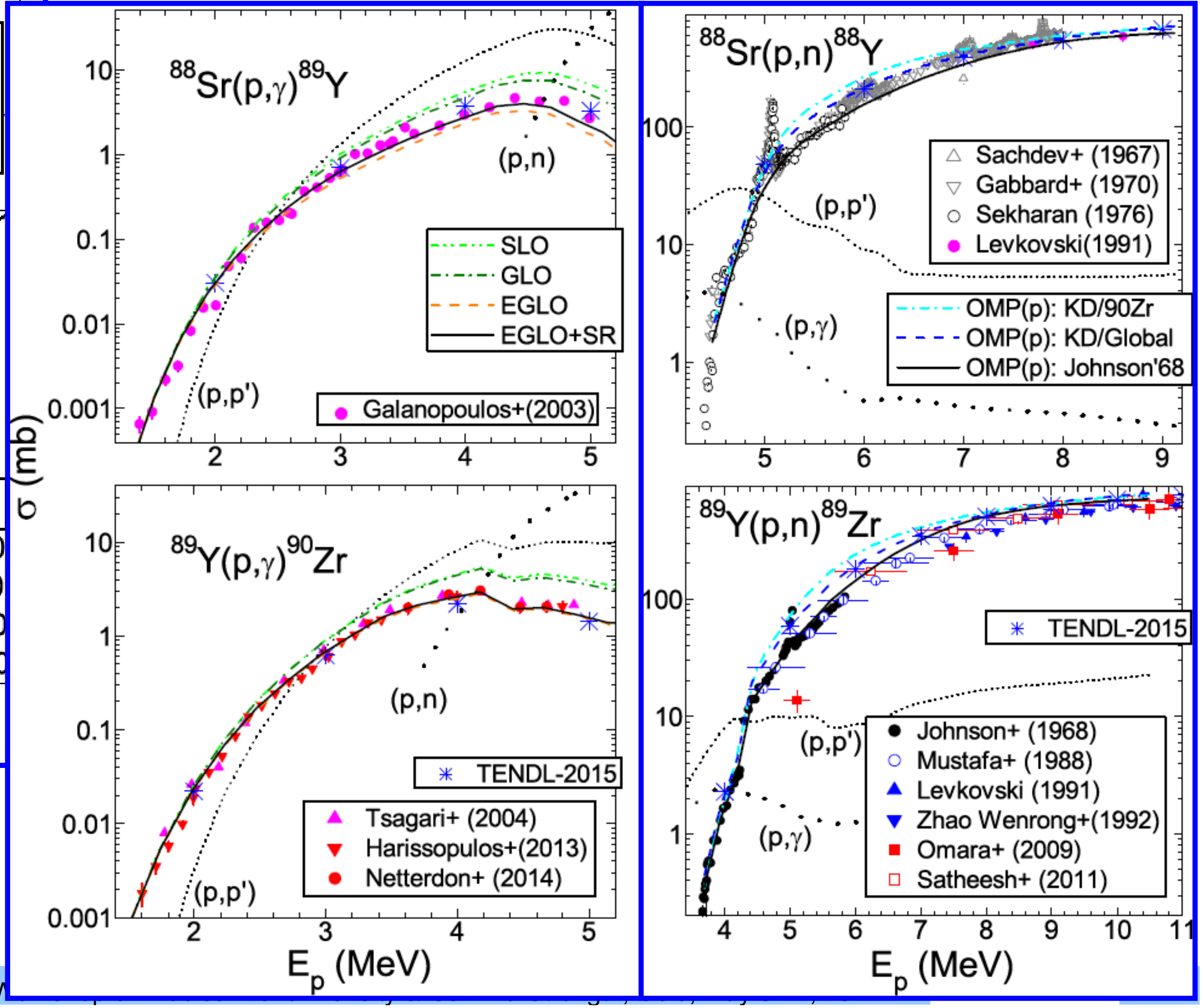


SR parameters for the model strength functions of ^{89}Y and ^{90}Zr nuclei.

Nucleus	E_{SR} (MeV)	Γ_{SR} (MeV)	σ_{SR} (mb)
^{89}Y	0.6	2.8	0.14
^{90}Zr	0.4	1.2	0.14



3.2 HF analysis (n+Zr): RSF vs. $\sigma(n,\gamma)$: ^{89}Y, $^{90-92,94,96}Zr$

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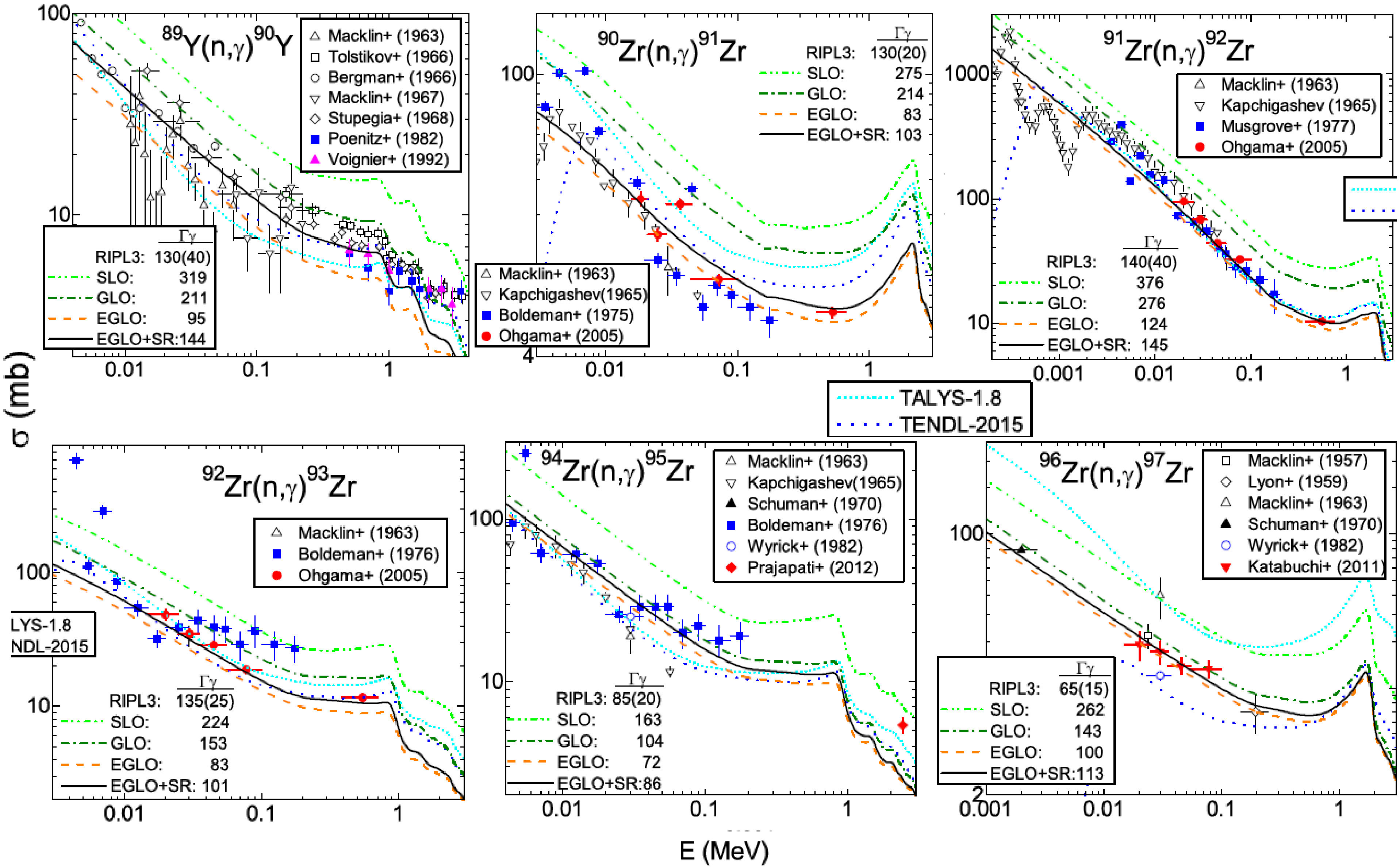
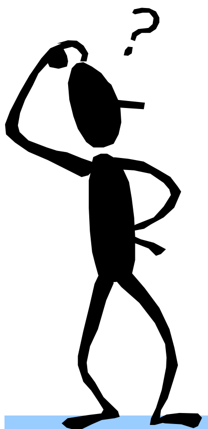


4. Conclusions

- **Consistent RSF: consistent (n,γ), (p,γ), (α,γ), (α,p) cross sections**
- **Consistent analysis of (n,x) reactions on ^{90,91,92,94,96}Zr** *(submitted)*
- **(n,α) analysis:** ⟹ { **α-absorption (E<B):** at surface / **(n,α) - emission (E<B):** in volume **?**

[PRC **91**,064611 (2015): **(p,α) – emission (E<B): at surface]**

Open Questions (?)



- **Additional (n,α) & (p,α) reaction c.s. consistent analysis**
- **Additional (n,α) & (n,αn) reaction c.s. consistent analysis**

Thank you for your attention !