Workshop on TALYS/TENDL Developments

IFIN-HH EUROfusion

On deuteron-induced reactions with TALYS

Marilena Avrigeanu and Vlad Avrigeanu

Horia Hulubei National Institute for Physics & Nuclear Engineering (IFIN-HH), Bucharest, Romania

- Update of the modelling capabilities of the nuclear model code TALYS by implementation of an alternative deuteron breakup model

- Deuteron cross section data analysis involving TALYS code
  - Importance of the Direct Interaction (DI) mechanisms
  - FINAL RESULTS versus TENDL-2015

Breakup mechanism d+^{27}Al ⟶ ^{29}Si*

elastic breakup: ^{27}Al + d ⟶ ^{27}Al + n+ p — no n/p – target interaction

Inelastic breakup enhancement

inelastic breakup: (^{27}Al+n) + p ⟶ ^{28}Al*

BF Breakup fusion

inelastic breakup: (^{27}Al+p) + n ⟶ ^{28}Si*

	$E_{n/p}$; $Q_{n/p,x}$	E_d; $Q_{d,x}$
γ	^{27}Al(n,γ)^{28}Al	^{27}Al(d,p)^{28}Al
n	^{27}Al(n,n')^{27}Al	^{27}Al(d,np)^{27}Al
p	^{27}Al(n,p)^{27}Mg	^{27}Al(d,2p)^{27}Mg
α	^{27}Al(n,α)^{24}Na	^{27}Al(d,αp)^{24}Na
γ	^{27}Al(p,γ)^{28}Si	^{27}Al(d,n) ^{28}Si
n	^{27}Al(p,n)^{27}Si	^{27}Al(d,2n)^{27}Si
p	^{27}Al(p,p')^{27}Al	^{27}Al(d,pn)^{27}Al
α	^{27}Al((p,α)^{24}Mg	^{27}Al(d,αn)^{24}Mg

Breakup

Fusion Engineering and Design 84 (2009) 418–422

Contents lists available at ScienceDirect

Fusion Engineering and Design

PHYSICAL REVIEW C **82**, 037601 (2010)

Improved deuteron elastic breakup energy dependence via the continuum-discretized coupled-channels method

M. Avrigeanu*

"Horia Hulubei" National Institute for Physics and Nuclear Engineering, P.O. Box MG-6, R-077125 Bucharest-Magurele, Romania

A. M. Moro†

Departamento de FAMN, Universidad de Sevilla, Apartado 1065, E-41080 Sevilla, Spain

PHYSICAL REVIEW C **95**, 024607 (2017)

Additive empirical parametrization and microscopic study of deuteron breakup

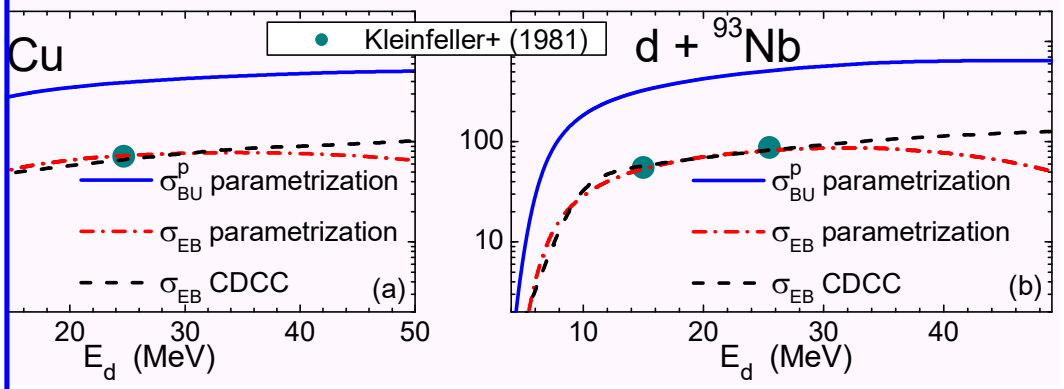
M. Avrigeanu* and V. Avrigeanu

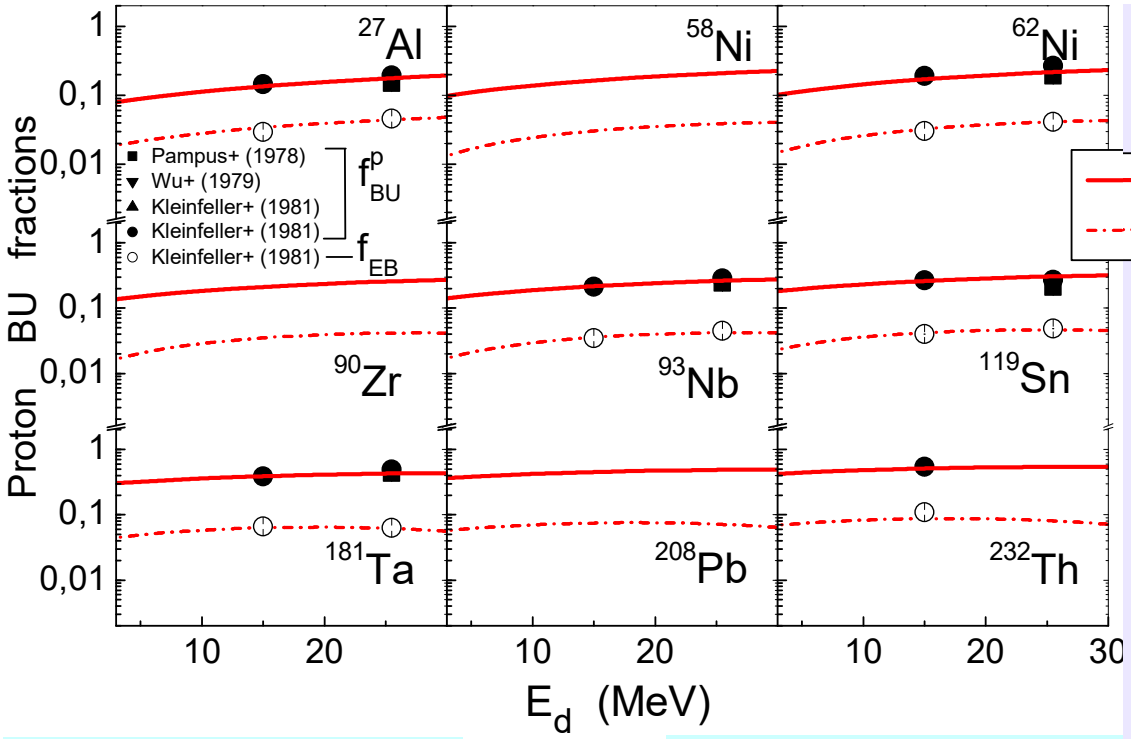
Horia Hulubei National Institute for Physics and Nuclear Engineering, P.O. Box MG-6, R-077125 Bucharest-Magurele, Romania

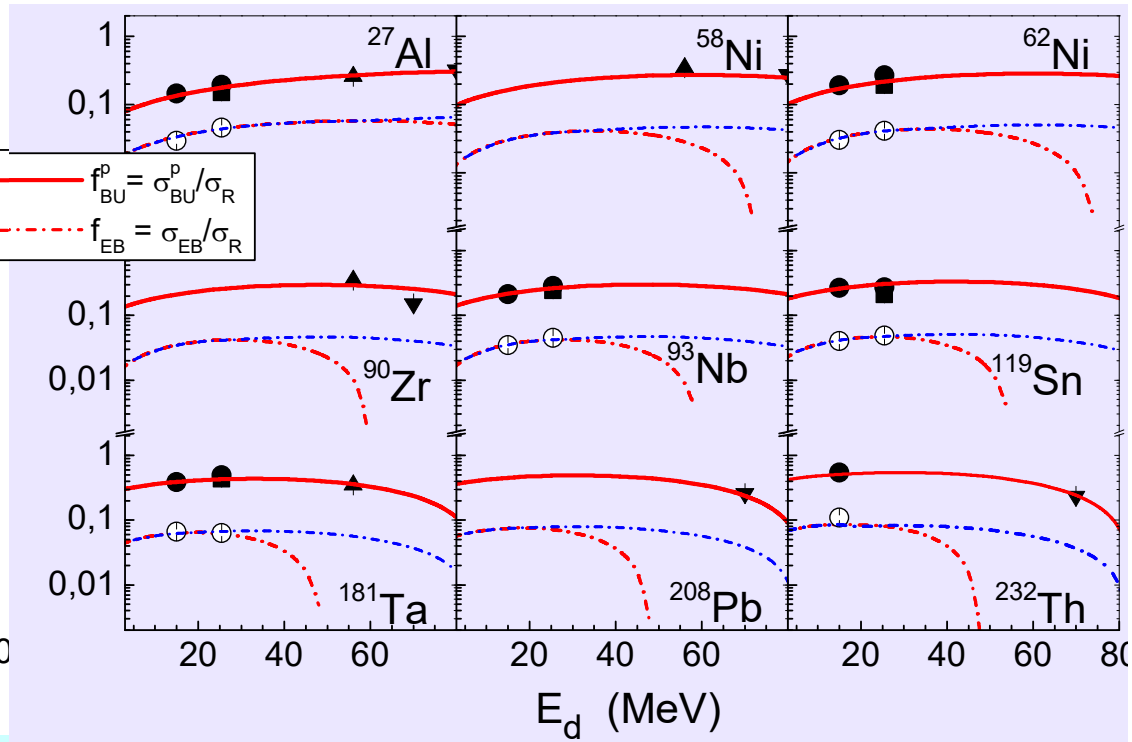
(Received 16 January 2017; published 14 February 2017)

$$f_{EB}^{norm}(E) = f_{BU}^{n/p}(E)\frac{f_{EB}(E_{max})}{f_{BU}^{n/p}(E_{max})}, \quad E > E_{max}$$

the microscopic calculations, the cross-section difference should be considered within the objectives of further measurements.







Alternative breakup formalism in TALYS-1.65

April 2015

JEFF Fusion WG, April 29-30, 2015, EFFDOC-1251

M. Avrigeanu et al.,
[1] Fus. Eng. Design 84, 418 (2009)
[2] Phys. Rev. C 85, 034603 (2012)
[3] Phys. Rev. C 88, 014612 (2013)
[4] Nucl. Data Sheets 118, 301 (2014)
[5] Phys. Rev. C 89, 044613 (2014)
[6] Phys. Rev. C 94, 014606 (2016)
[7] Phys. Rev. C 95, 024607 (2017)

NEW subroutines: breakupAVR.f called by preeqcomplex.f

calculates - BU fractions (TOTAL, inelastic & elastic)
[Eqs. (1)-(3), Phys. Rev. C 88, 014612]

$$f_{\rm BU}^{(n/p)} = 0.087 - 0.0066Z + 0.00163ZA^{1/3} + 0.0017A^{1/3}E - 0.000002ZE^2,$$

$$f_{\rm EB} = 0.031 - 0.0028Z + 0.00051ZA^{1/3} + 0.0005A^{1/3}E - 0.000001ZE^2.$$

$$f_{\rm BF}^{(n/p)} = f_{\rm BU}^{(n/p)} - f_{\rm EB},$$

- BU cross sections (TOTAL, inelastic & elastic)
[Eqs. (2)-(5), Phys. Rev. C 89, 044613]

$$\sigma_{BU}^{p/n} = [0.087 - 0.0066Z + 0.00163ZA^{1/3} + 0.0017A^{1/3}E - 0.000002ZE^2]\sigma_R,$$

$$\sigma_{EB} = [0.031 - 0.0028Z + 0.00051ZA^{1/3} + 0.0005A^{1/3}E - 0.000001ZE^2]\sigma_R,$$

$$\sigma_{BF}^{p/n} = \sigma_{BU}^{p/n} - \sigma_{EB}$$

checkBU called by breakupAVR.f

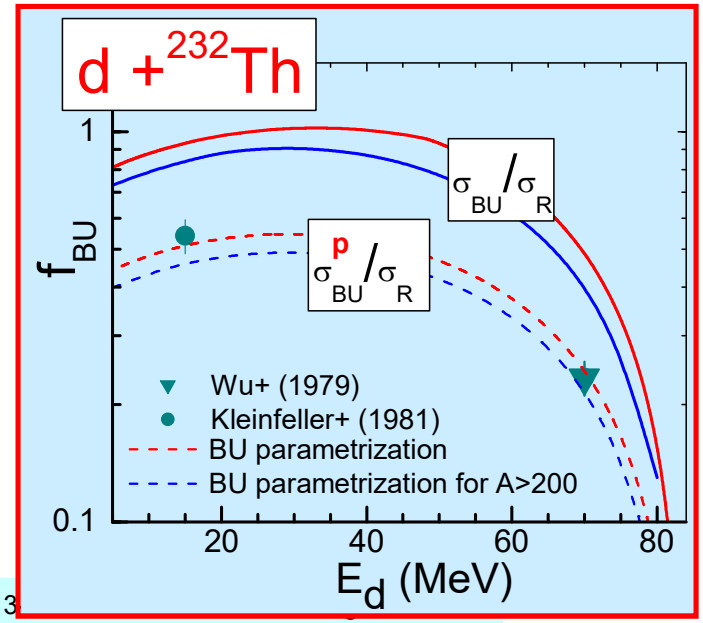
Deuteron EB normalization

Eq. (3), Phys. Rev. C 95, 024607

$$f_{\rm EB}^{\rm norm}(E) = f_{\rm BU}^{n/p}(E)\frac{f_{\rm EB}(E_{\rm max})}{f_{\rm BU}^{n/p}(E_{\rm max})}, \quad E > E_{\rm max}.$$

Deuteron BU additional constraint, A>200

f_{BU} should not exceed **0.90**



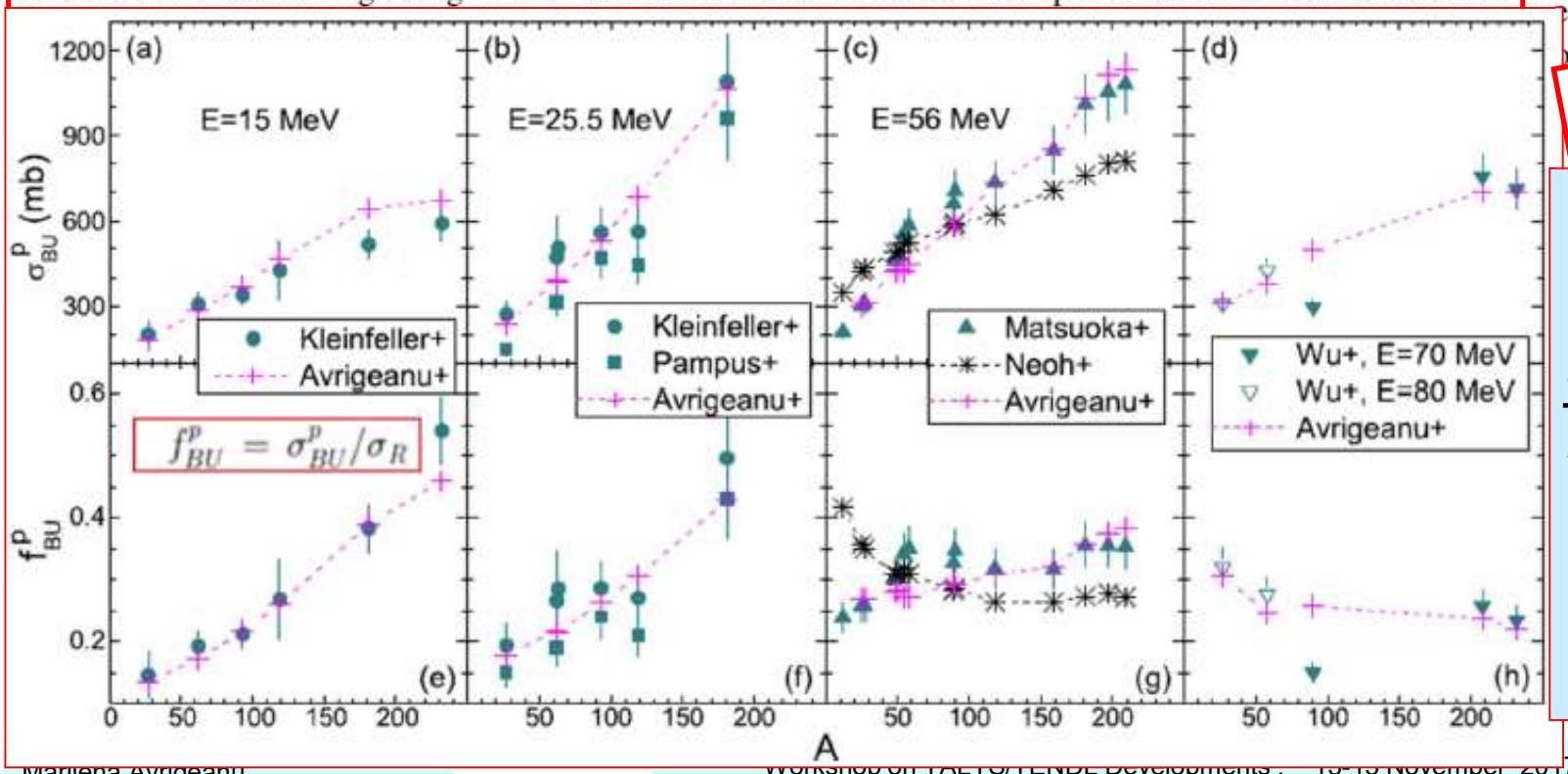
Empirical parametrization versus microscopic predictions

PHYSICAL REVIEW C 95, 024607 (2017)

Additive empirical parametrization and microscopic study of deuteron breakup

M. Avrigeanu* and V. Avrigeanu
ulubei National Institute for Physics and Nuclear Engineering, P.O. Box MG-6, R-077125 Bucharest-Magurele, R
(Received 16 January 2017; published 14 February 2017)

Comparative assessment of the total breakup proton-emission cross sections measured for 56 MeV deuteron interaction with target nuclei from ^{12}C to ^{209}Bi, with an empirical parametrization and recently calculated microscopic neutron-removal cross sections was done at the same time with similar data measured at 15, 25.5, 70, and 80 MeV. Comparable mass dependencies of the elastic-breakup (EB) cross sections provided by the empirical parametrization and the microscopic results have been also found at the deuteron energy of 56 MeV, while the assessment of absolute-values variance up to a factor of two was not possible because of the lack of EB measurements at energies higher than 25.5 MeV. While the similarities represent an additional validation of



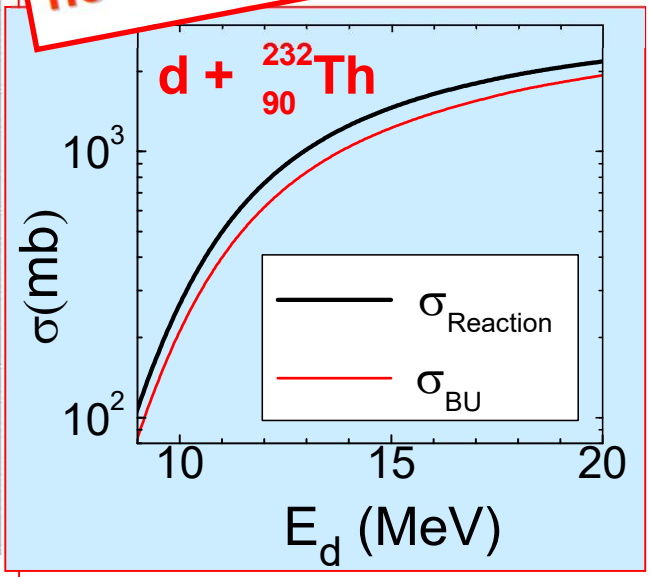
044619 (2016)

r deuteron-induced reactions

Minomo, and Kazuyuki Ogata
iversity, Ibaraki 567-0047, Japan
ptember 2016; published 27 October 2016)

eron-induced reactions. A reaction model space
ere *A* is the target nucleus, and the nucleon-target
n effective nucleon-nucleon interaction in nuclear
scattering wave function in the model space is
DCC) method, and the eikonal reaction theory
neutron removal cross sections. Elastic
ral energies are

breakup dominance for heavy nuclei and $E_d \sim V_c$



April 2016 BU-ENHANCEMENT

JEFF/EFF Meeting, OECD/NEA, 27-28 April 2016, EFFDOC-1285

[Eq. (7), Phys. Rev. C 89, 044613]

BUenhance.f called by residualout.f :

$$\sigma_{BF}^{p,x}(E_d) = \sigma_{BF}^{p}(E_d) \int dE_p \frac{\sigma_{(p,x)}(E_p)}{\sigma_R^p} \frac{1}{(2\pi)^{\frac{1}{2}} w} exp[-\frac{(E_p - E_p^0(E_d))^2}{2w^2}]$$

GENERATION OF EXTERNAL FILES, $\frac{\sigma_{(p,x)}(E_p)}{\sigma_R^p}$

STEPS:

a) read from **TENDL** activation cross sections corresponding to:

- n+ **Atarget** , $\sigma^n(Z,A,E_n)$; p+ **Atarget** , $\sigma^p(Z,A,E_p)$ .../tendl2014/n_file/(p_file)/EL/A/residual/rpZA.tot

  rpZA.tot ($E_{n/p}$) populating the **same** residual (Z,A) nuclei of d + **Atarget**

- n + **Atarget** , $\sigma_{tot}(Z_T,A_T,E_n)$: .../tendl2014/neutron_file/EL/A/total/totalxs.tot

- p + **Atarget** , $\sigma_R(Z_T,A_T,E_n)$: .../tendl2014/proton_file/EL/A/total/nonelastic.tot

b) divide rpZA(E_n) / totalxs(E_n)
rpZA(E_p) / nonelastic.tot(E_p) → enhancing ratios ENHratioN/P.dat (type,Z,N,ien)

c) Interpolate the ratios along $BU_{nucleons}$ **energy** 0.1:60 MeV, ebin=0.1 MeV

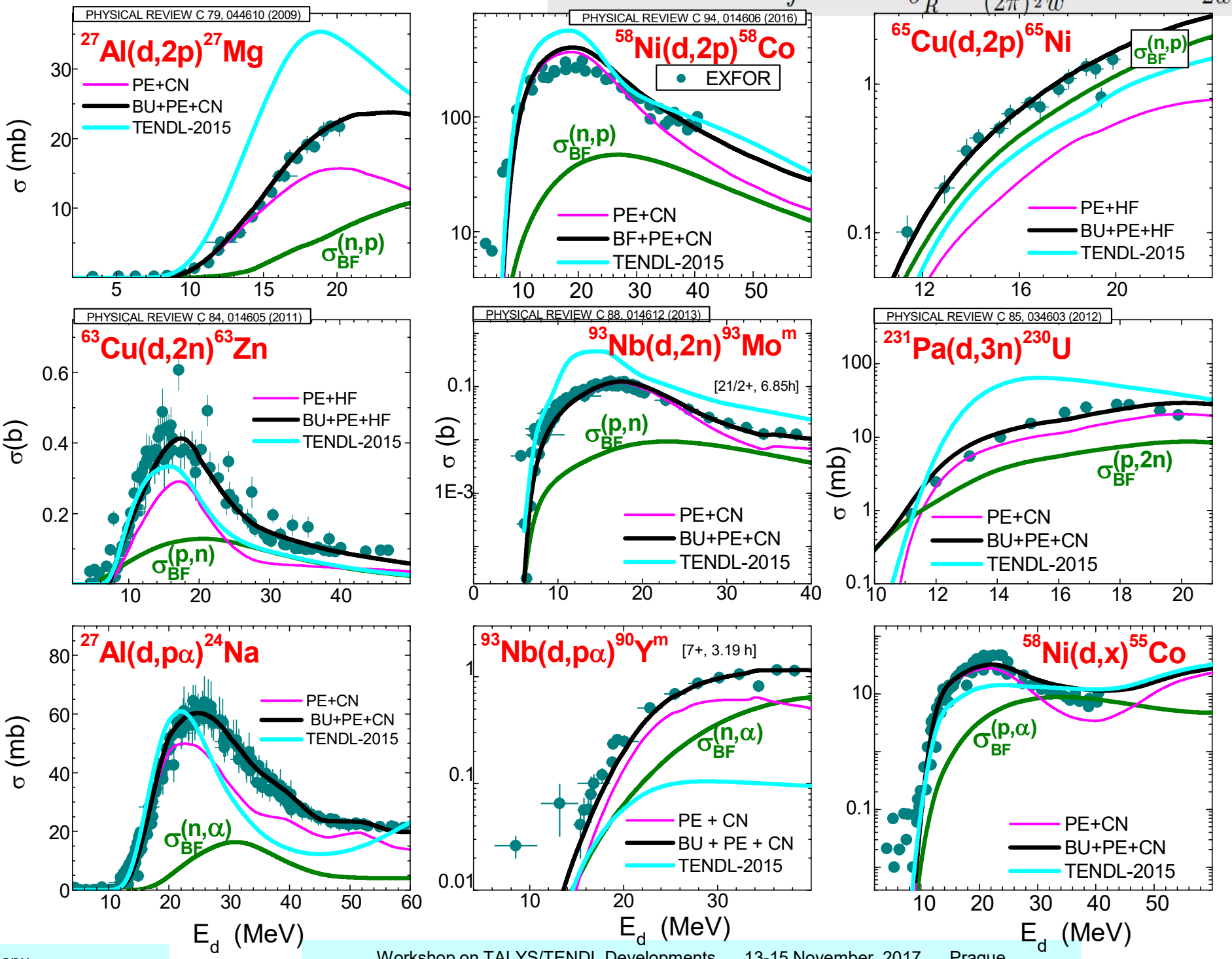
d) Create a new sub-directory in STRUCTURE for writing/reading ENHratiosN/P

NPxsratios.f called by talysreactions.f
reads ENHratiosN/P from:

structure/TENDL-npxs/neutrons/ENHratioN.dat
structure/TENDL-npxs/protons/ENHratioP.dat

BREAKUP ENHANCEMENT:

$$\sigma_{BF}^{p,x}(E_d) = \sigma_{BF}^{p}(E_d) \int dE_p \; \frac{\sigma_{(p,x)}(E_p)}{\sigma_R^p} \frac{1}{(2\pi)^{\frac{1}{2}} w} exp[-\frac{(E_p - E_p^0(E_d))^2}{2w^2}]$$



Deuteron interaction analysis: Nuclear Models & CODES

Motivation: Nuclear Data Needs (FENDL, EURATOM, F4E, EUROfusion)

❖ITER, IFMIF, SPIRAL2, Breeder Reactors

❑REQUIRED deuteron reaction cross sections measurements & calculations

(E ~ 50 MeV): Al, Cu, Nb, Co, Mn, Fe, Cr, Ni, C.. Th, U,

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

Dosimetry data file for E > 20 MeV (IRDF)

Surrogate reactions (d,pγ), (d,pf) on Th, U,…

❑ **Deuteron breakup**

BREAKUP [M. Avrigeanu, V. Avrigeanu]

- total, elastic and inelastic breakup c.s.: M. Avrigeanu *et al.*, **Fusion. Eng. Design, 84, 418 (2009);**
  M. Avrigeanu and V. Avrigeanu, **Phys. Rev. C 95, 024607 (2017).**
- inelastic breakup enhancements : P. Bém *et al.,* **Phys. Rev. C 79, 044610 (2009);**
  E. Šimečková *et al.*, **Phys. Rev. C 84, 014605 (2011);**
  M. Avrigeanu *et al.,* **Phys. Rev. C 85, 034603 (2012); 88, 014612 (2013);**
  89, 044613 (2014); **92**, 02160(R) (2015), **94**, 0146-6 (2016).

❑ **Direct reactions**

FRESCO (Version FRES 2.9, September 2011) [I.J. Thompson]

- **breakup:** elastic component (CDCC): M. Avrigeanu, A.M. Moro, **Phys. Rev. C 82, 037610 (2010).**
- **elastic transfer:** weakly bound systems: M. Avrigeanu *et al.,* **Nucl. Phys. A 759, 327 (2005).**
- **stripping & pick-up:** (d,p), (d,n), (d,t), (d,α)

❑ **Composite system equilibration for both deuteron and breakup nucleon reactions**

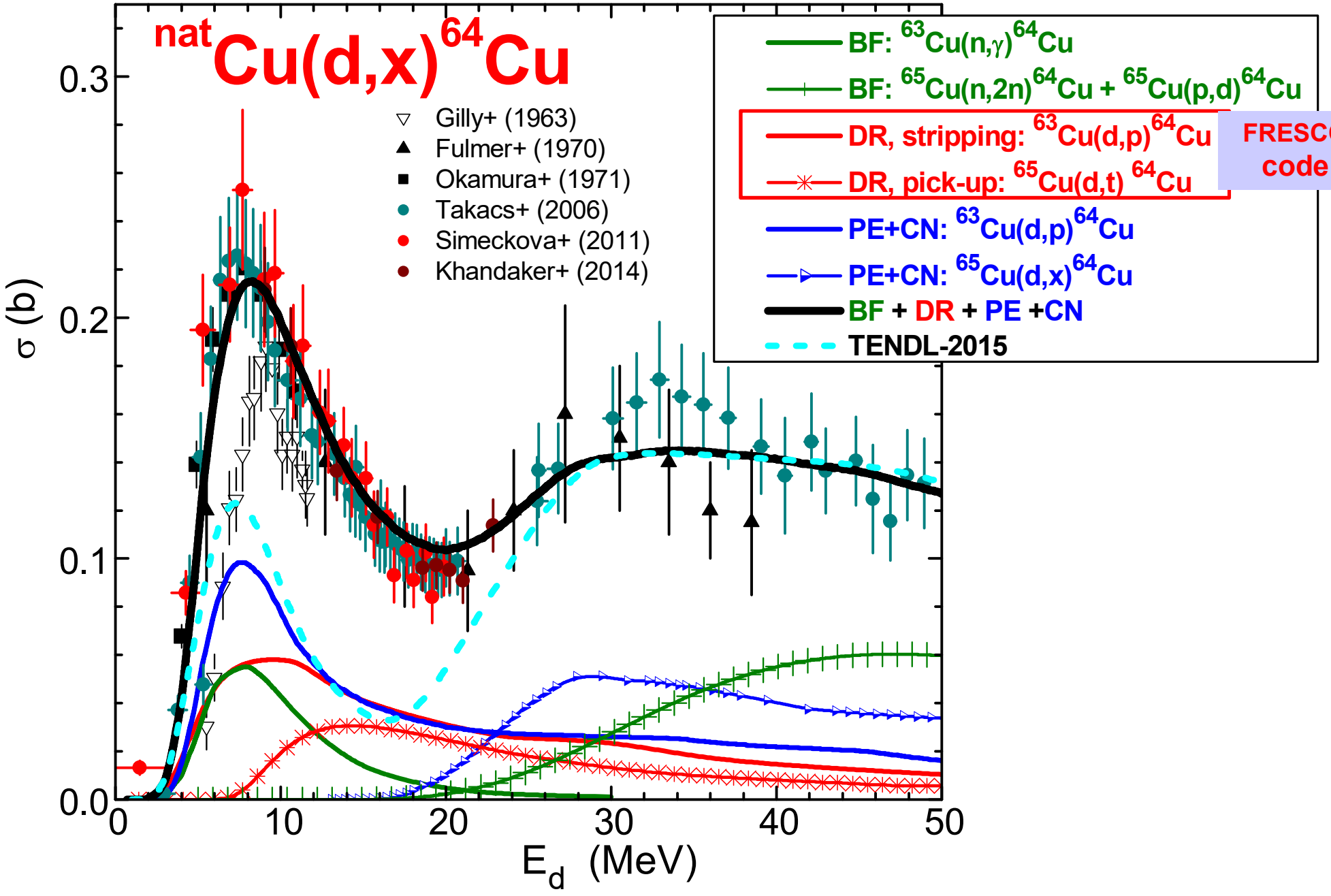
STAPRE-H95 [V. Avrigeanu, M. Avrigeanu] (updated)

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

TALYS - 1.4 - 1.8 [A. Koning, S. Hilaire, M. Duijvestijn]

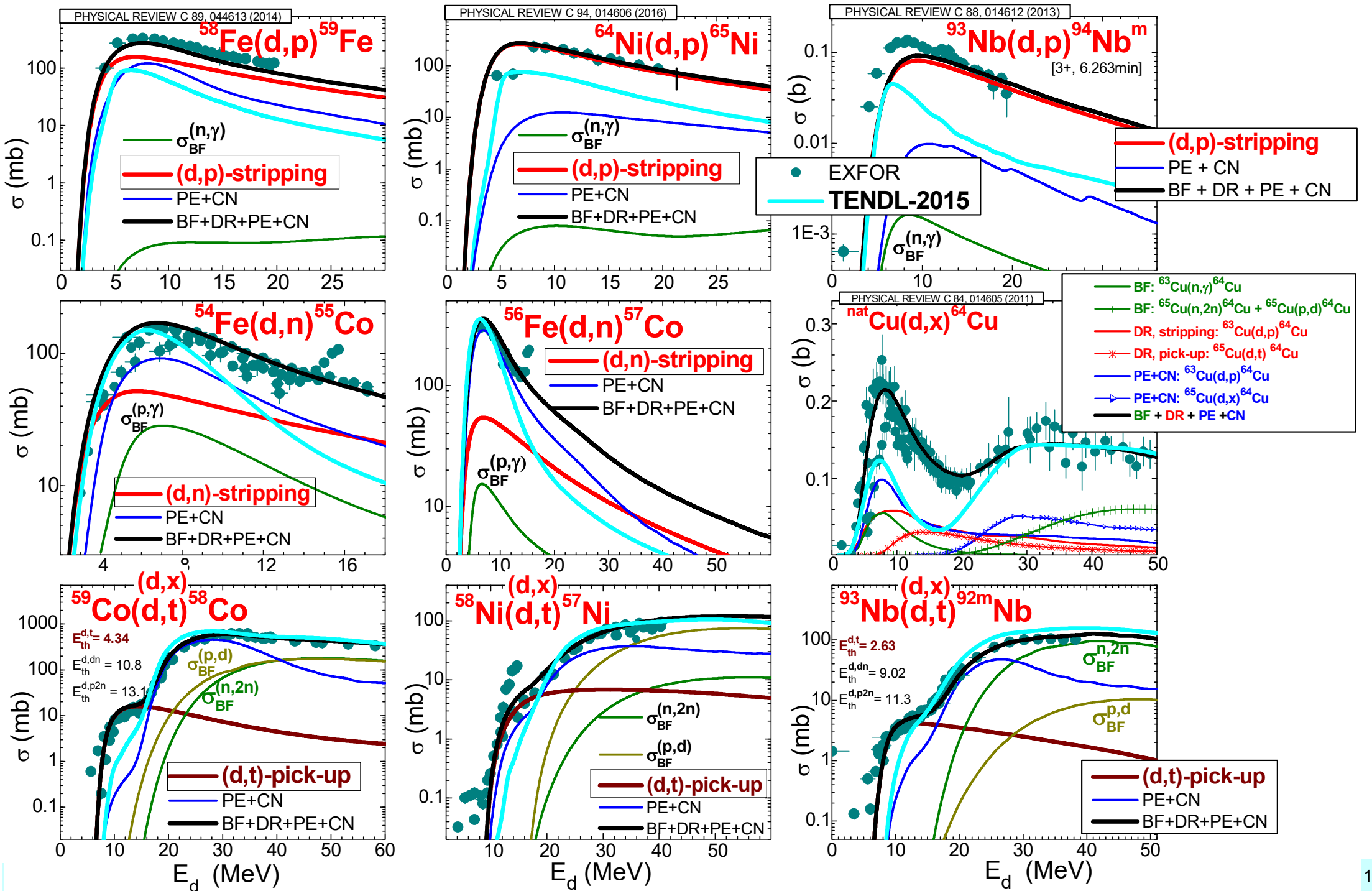
- **OMP:ECIS'97;** breakup, preequilibrium: **MSD / EXCITON;** evaporation: **Hauser-Feshbach**

REACTION MECHANISMS INVOLVED in $^{nat}Cu(d,x)^{64}Cu$ PROCESS

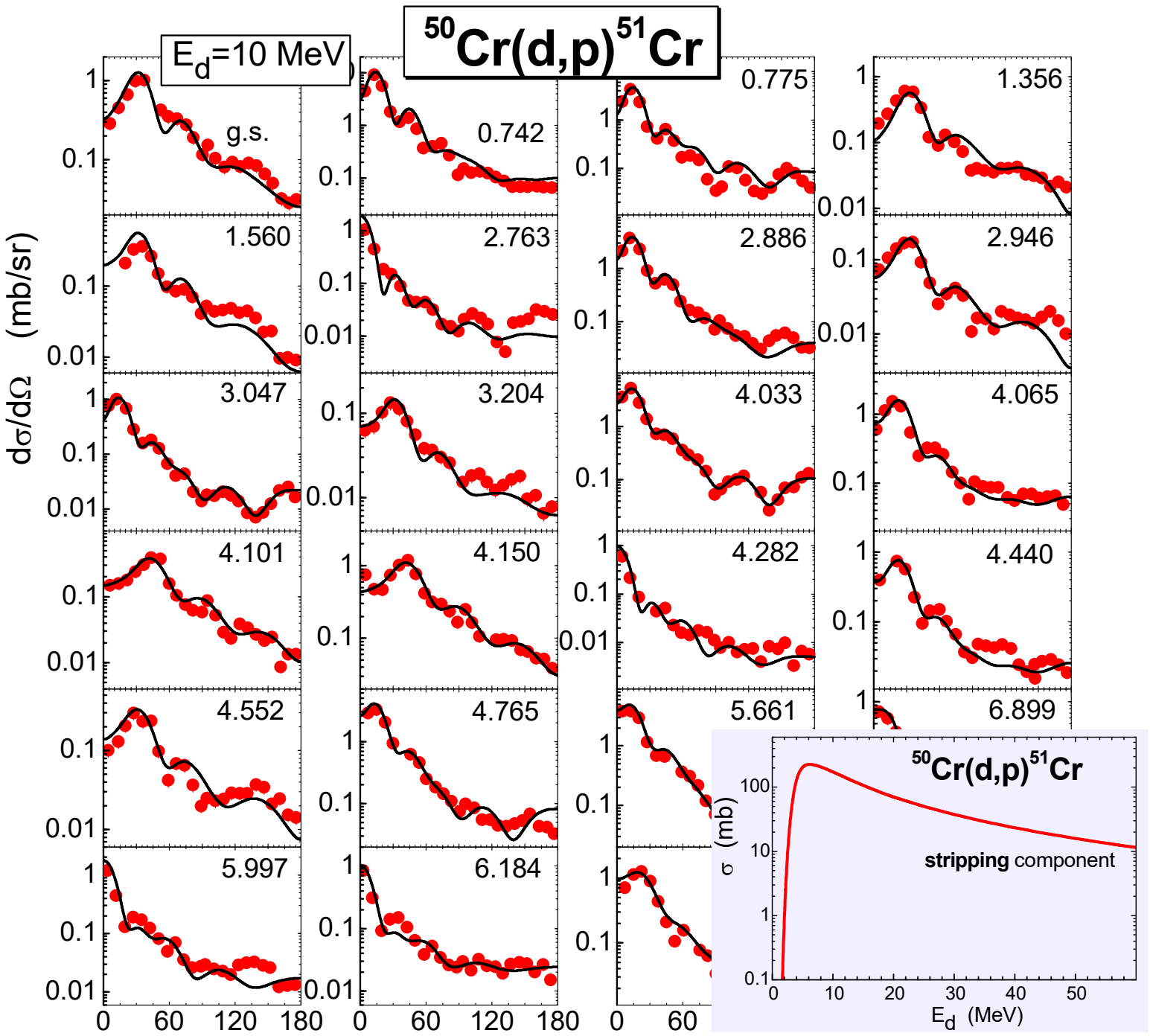


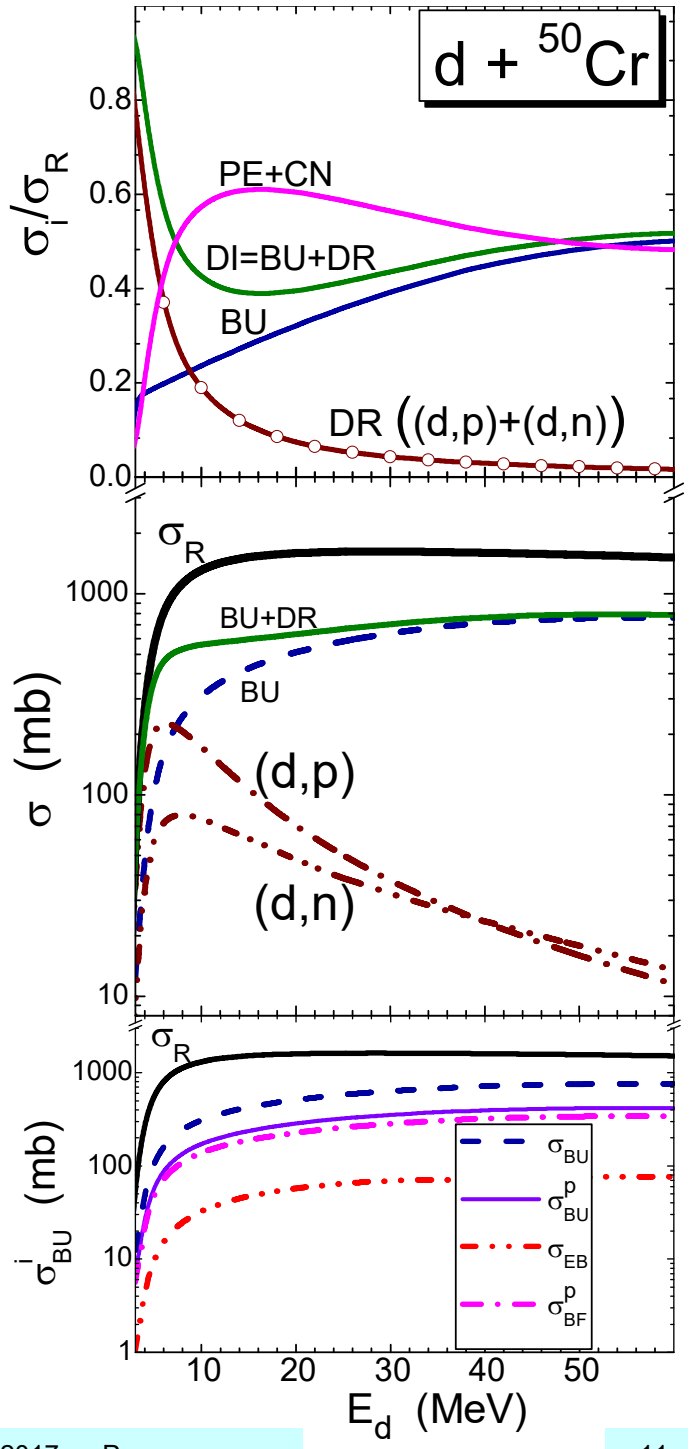
ROLE OF DIRECT REACTIONS: STRIPPING & PICK-UP

Important for the first-chance emitted particle, NOT INCLUDED IN TALYS !!!

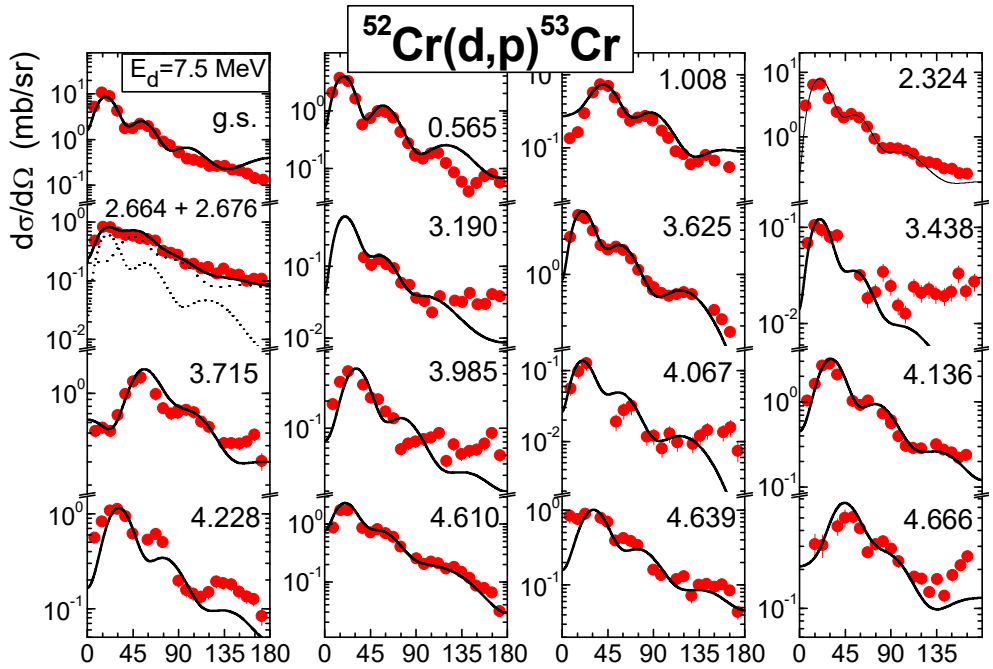


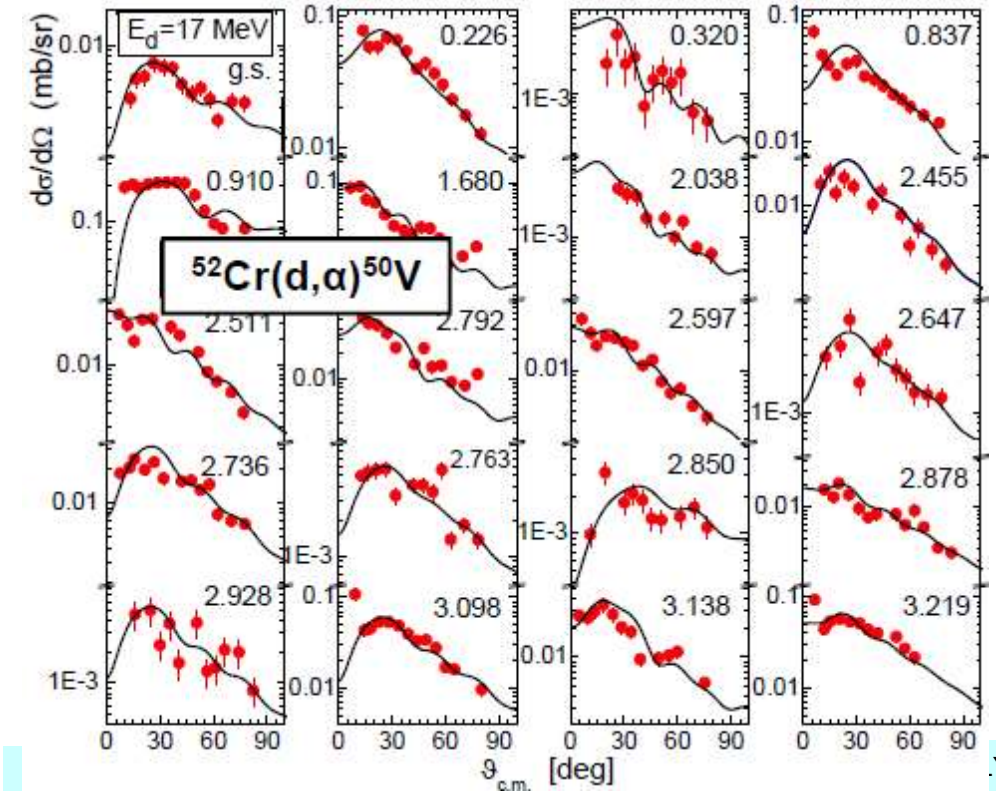
DIRECT INTERACTIONS COMPONENTS OF THE DEUTERON INTERACTION: ^{50}Cr

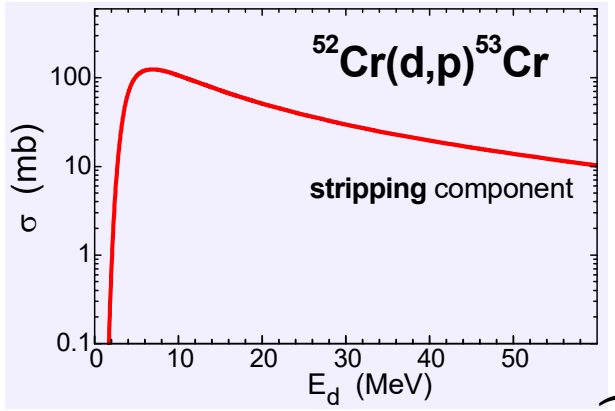


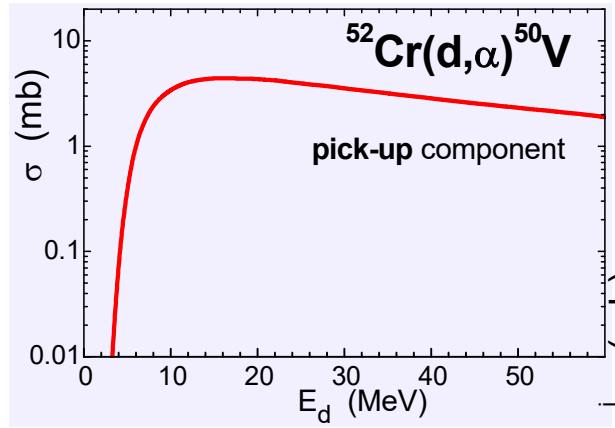


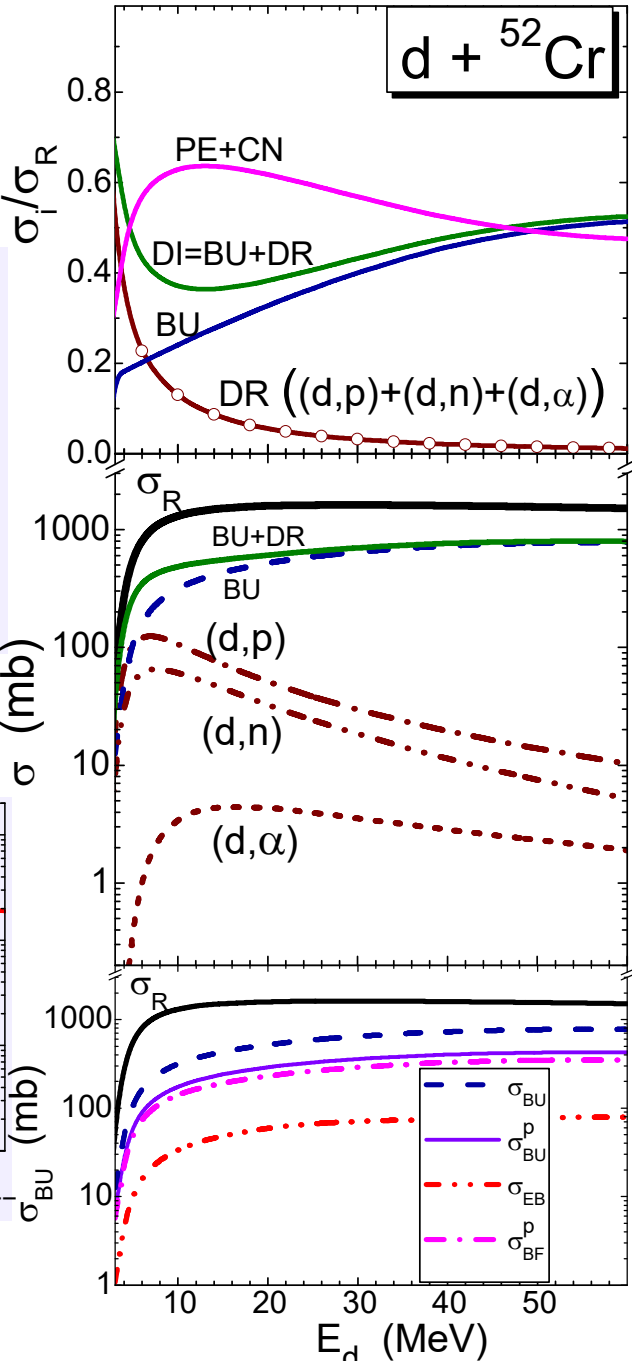
DIRECT INTERACTIONS COMPONENTS OF THE DEUTERON INTERACTION: ^{52}Cr



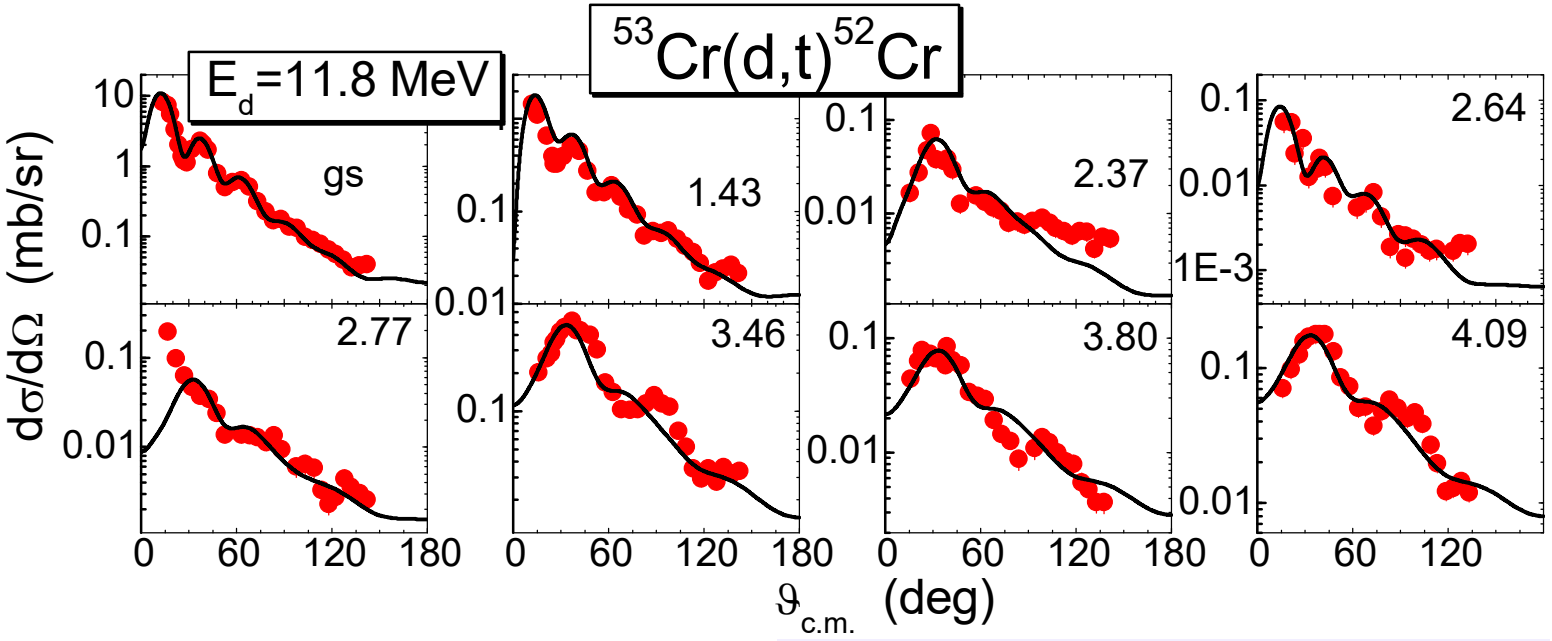


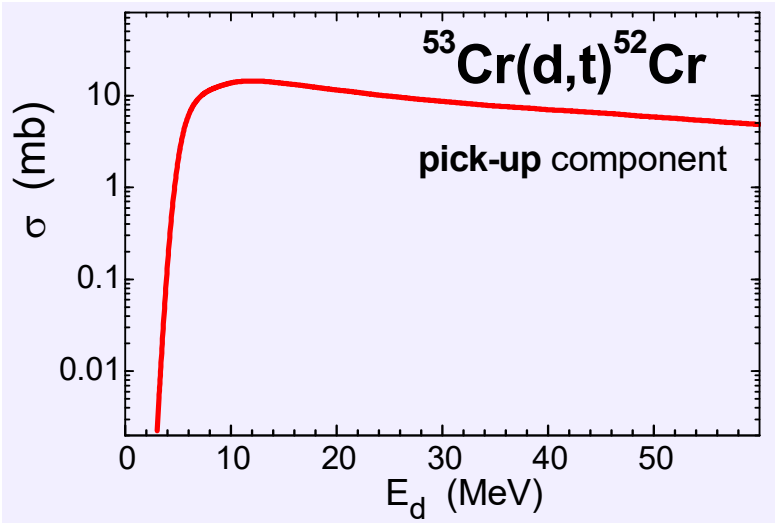


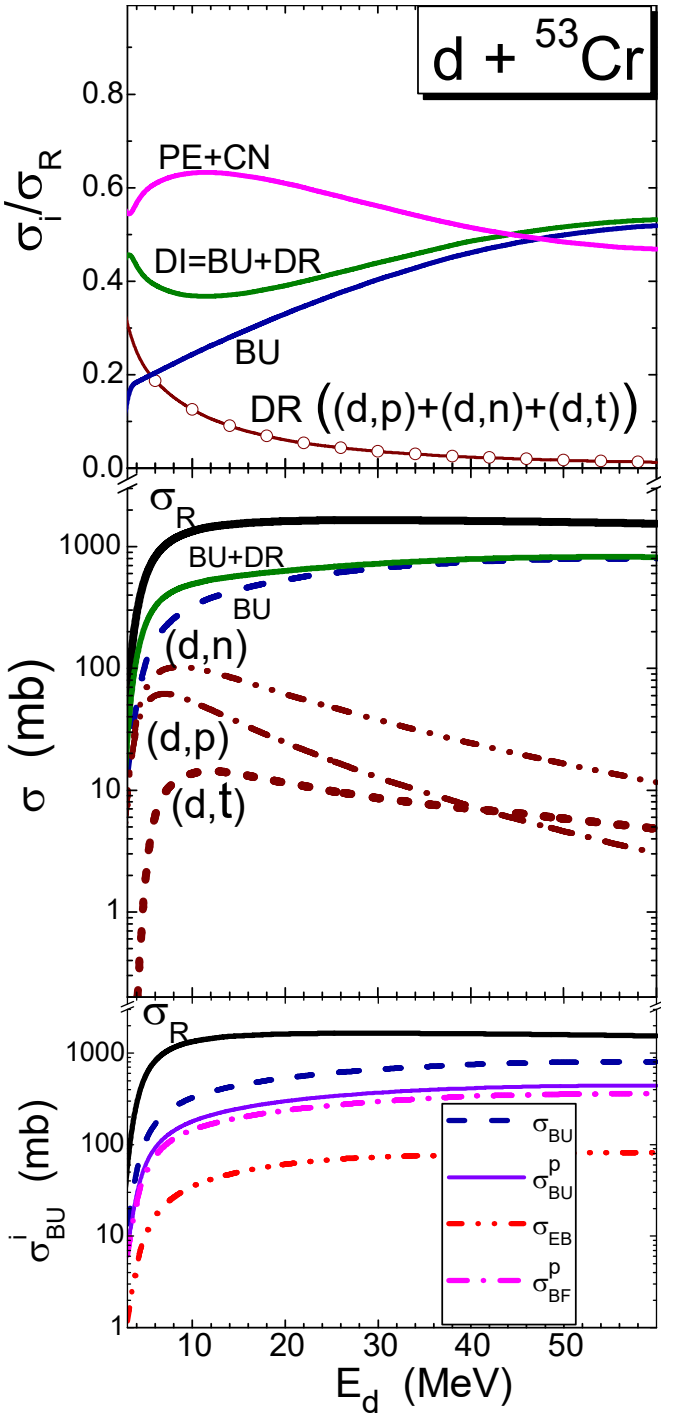




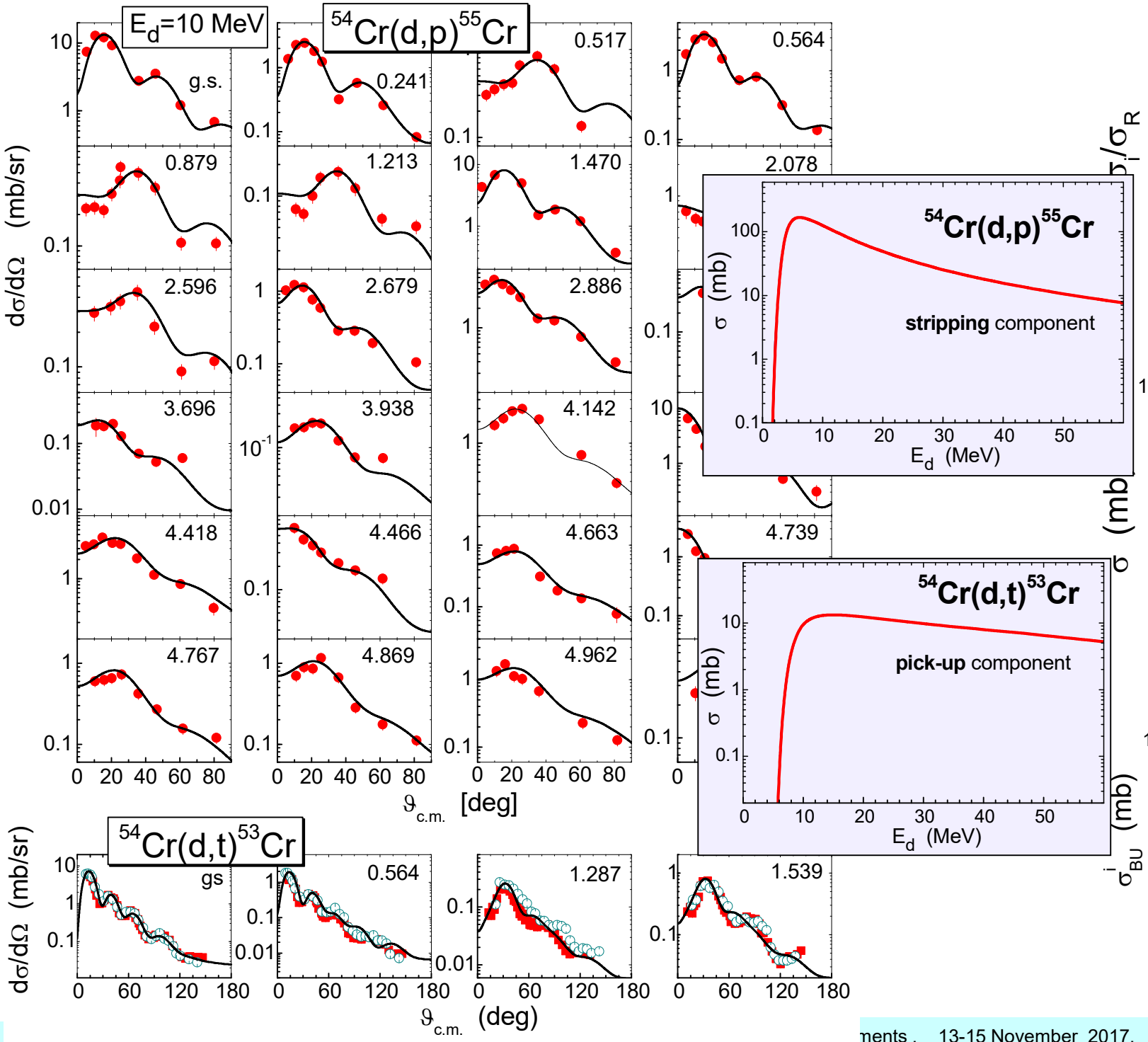
DIRECT INTERACTIONS COMPONENTS OF THE DEUTERON INTERACTION: ^{53}Cr



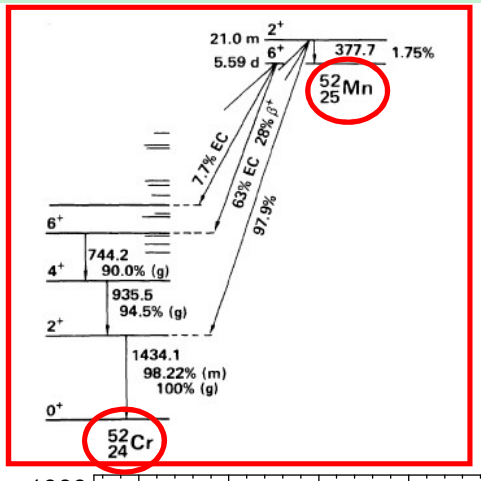


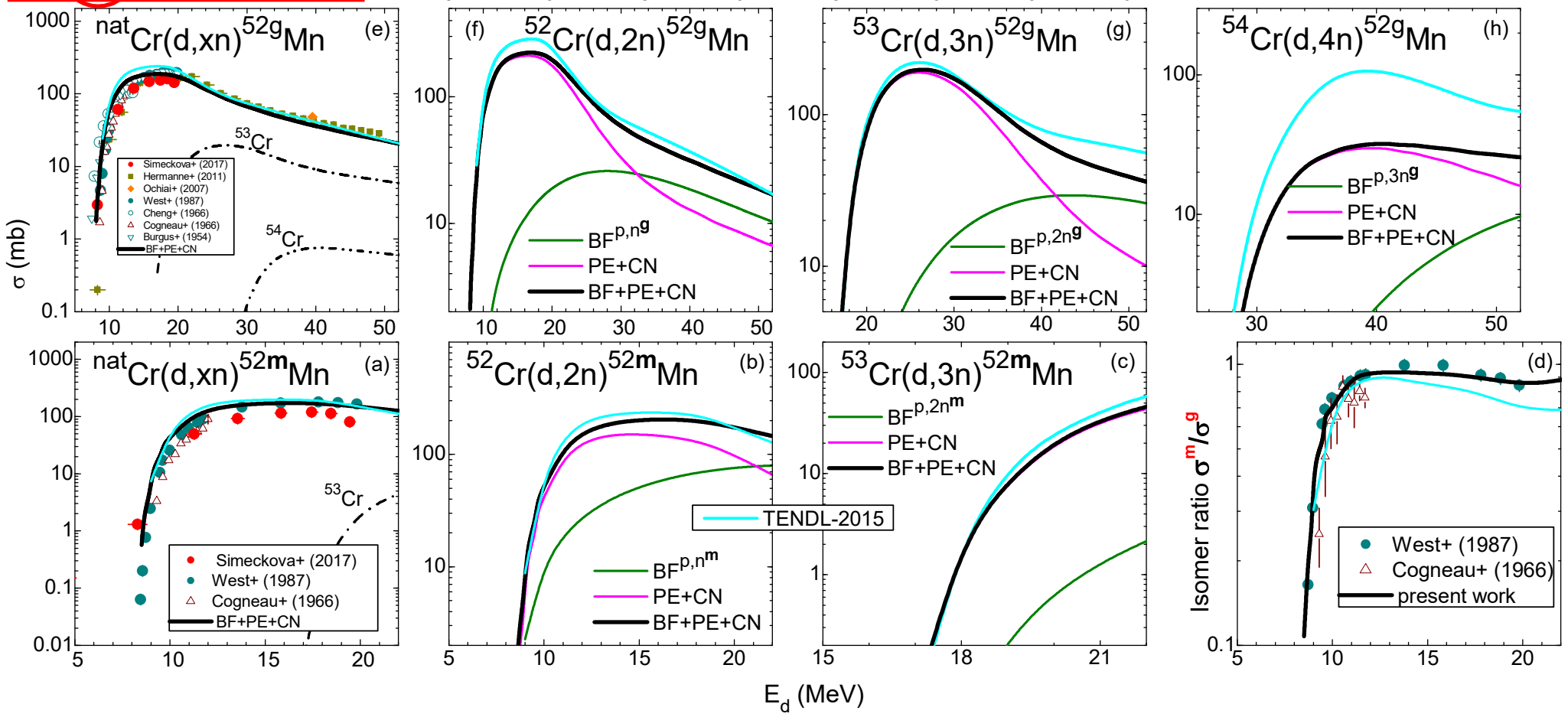


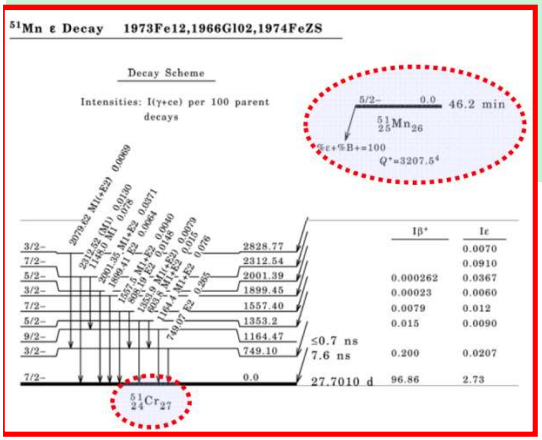
DIRECT INTERACTIONS COMPONENTS OF THE DEUTERON INTERACTION: ^{54}Cr



$^{nat}Cr(d,xn)^{52g,m,(g+m)}Mn$ Activation Cross Sections Analysis

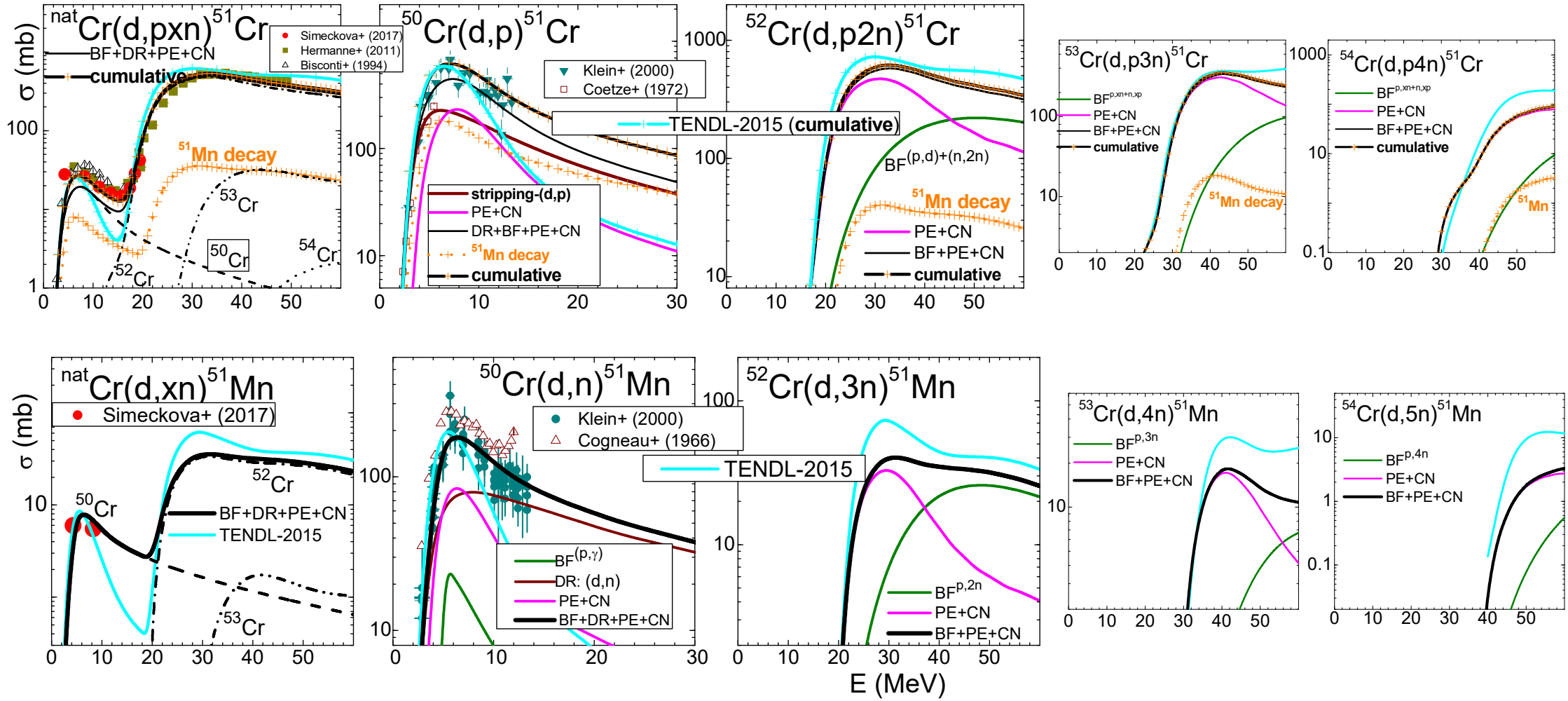




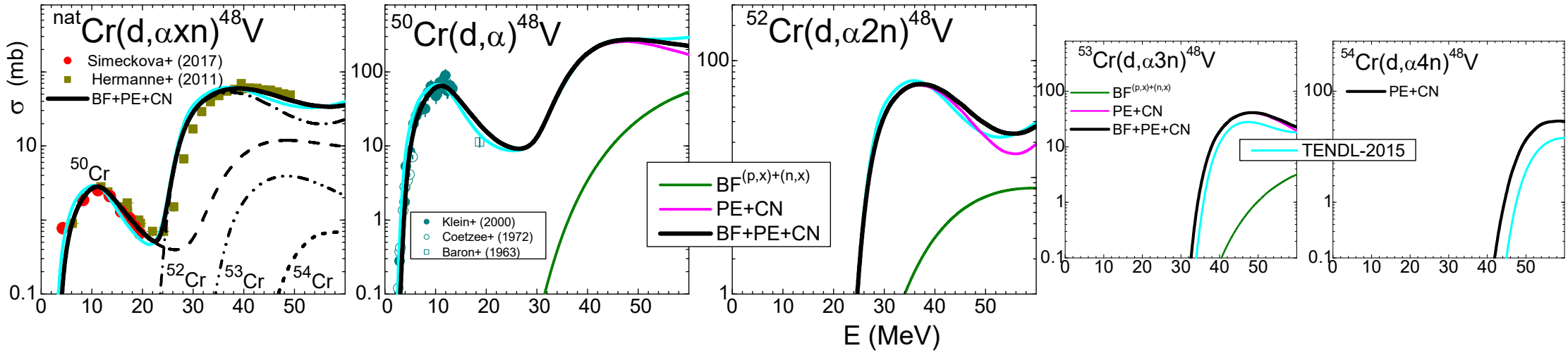


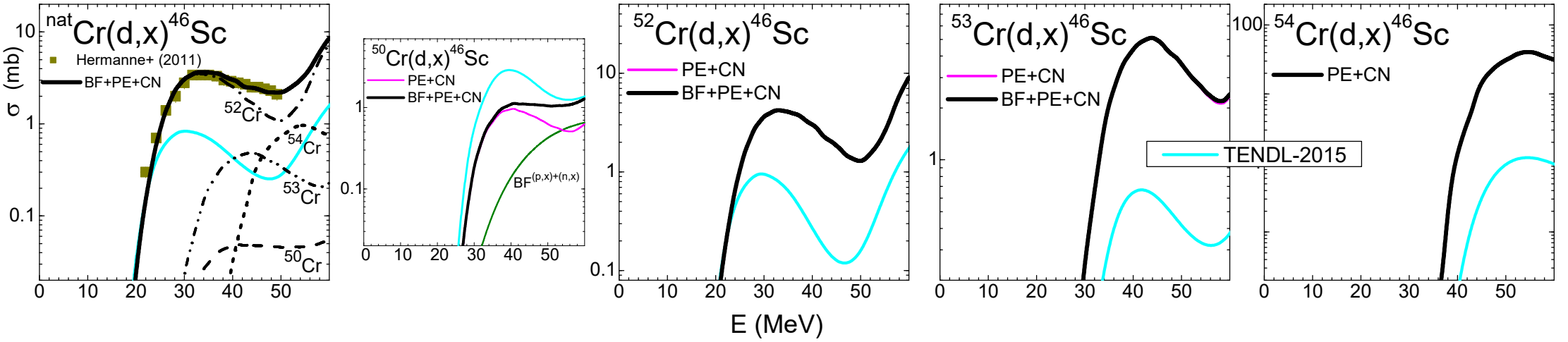
$^{nat}Cr(d,x)^{51}Cr$ Activation Cross Sections

cumulative

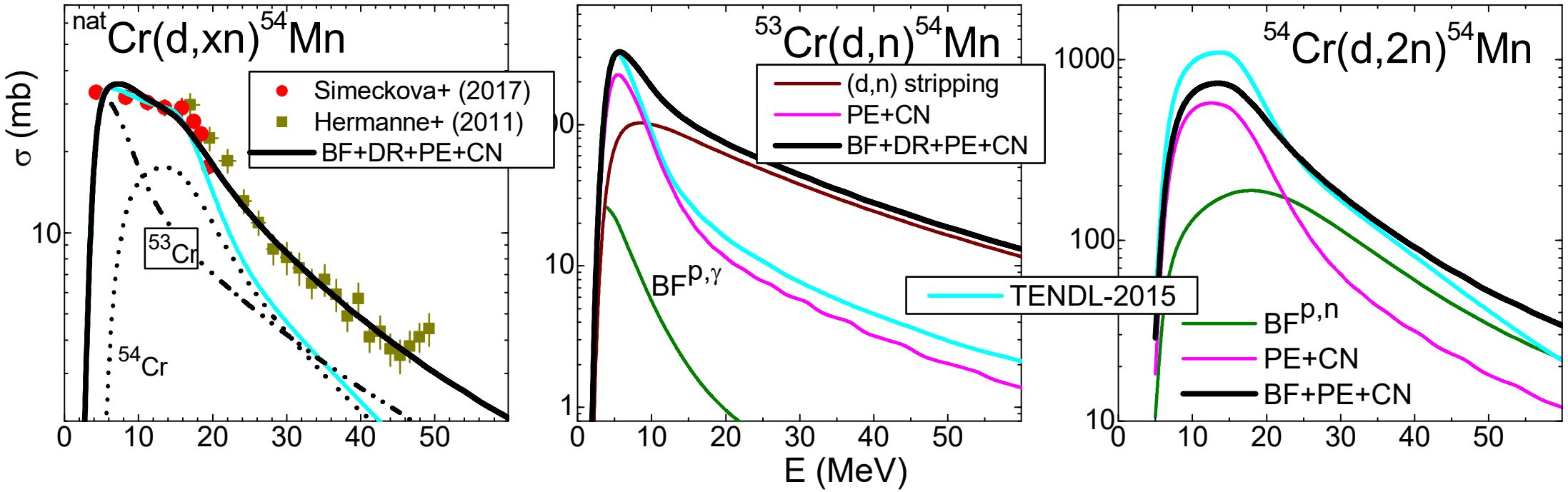


^{nat}Cr(d,x)^{48}V & ^{nat}Cr(d,x)^{46}Sc Activation Cross Sections





$^{nat}Cr(d,xn)^{54}Mn$ Activation Cross Sections Analysis



Conclusions of CRP on Nuclear Data for Charged-particle Monitor Reactions and Medical Isotope production (1)

Table 3: Cross-section studies of monitor reactions.

Cross sections	Agreed responsibilities, status and actions	January 2017
$^{27}Al(d,x)^{22,24}Na$	Accept Pade 21 fit for ^{22}Na up to 100 MeV. For ^{24}Na, some points were excluded. Accept Pade 12 fit up to 100 MeV.	NO accompanying figure

vs.

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

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

P. Bém,* E. Šimečková, and M. Honusek
Euratom/IPP.CR Fusion Association, Nuclear Physics Institute, 25068 Řež, Czech Re

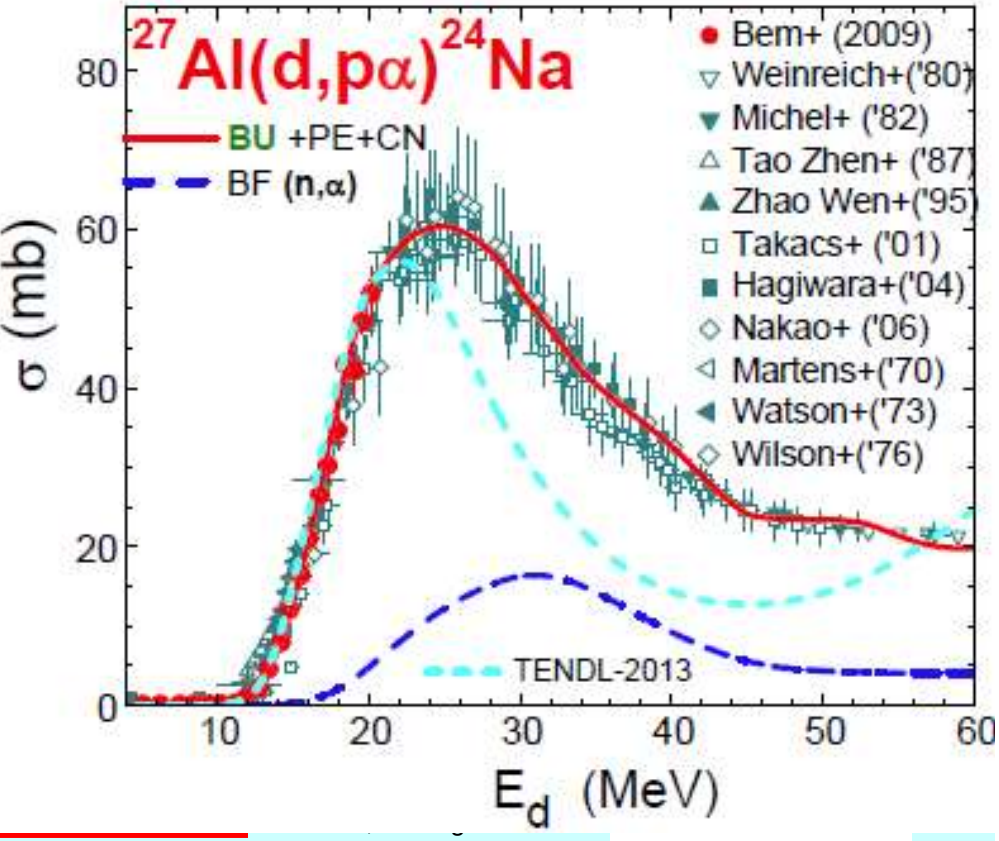
U. Fischer and S. P. Simakov
Euratom/FZK Fusion Association, Forschungszentrum Karlsruhe, Hermann-von-Helmho
76344 Eggenstein-Leopoldshafen, Germany

R. A. Forrest
Euratom/UKAEA Fusion Association, Culham Science Centre, Abingdon OX14 3DB, Unit

M. Avrigeanu,† A. C. Obreja, F. L. Roman, and V. Avrigeanu
'Horia Hulubei' National Institute for Physics and Nuclear Engineering, P. O. Box MG-6, Bucharest

(Received 30 January 2009; published 30 April 2009)

The activation cross sections of (d,p), $(d,2p)$, and $(d,p\alpha)$ reactions on ^{27}Al were measur range from 4 to 20 MeV using the stacked-foils technique. Following a previous extended a scattering, breakup, and direct reaction of deuterons on ^{27}Al, for energies from 3 to 60 MeV, th and statistical emissions are considered in the same energy range. Finally, all deuteron-induced including the present data measured up to 20 MeV deuteron energy are properly described due t analysis of the elastic scattering and reaction data.



Conclusions of CRP on Nuclear Data for Charged-particle Monitor Reactions and Medical Isotope production (2)

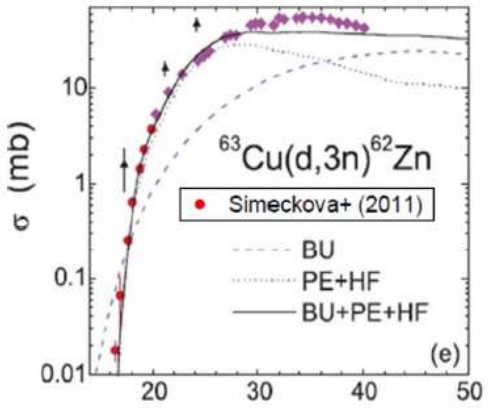
January 2017

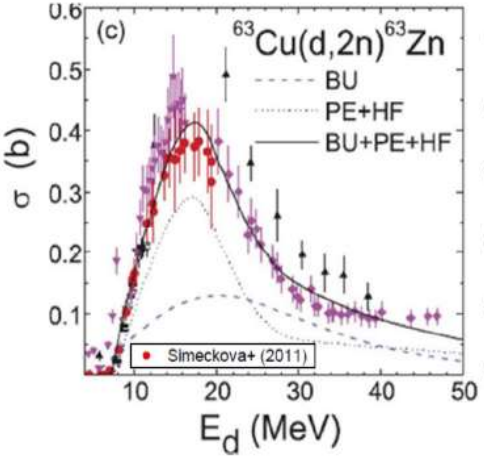
Table 3: Cross-section studies of monitor reactions.

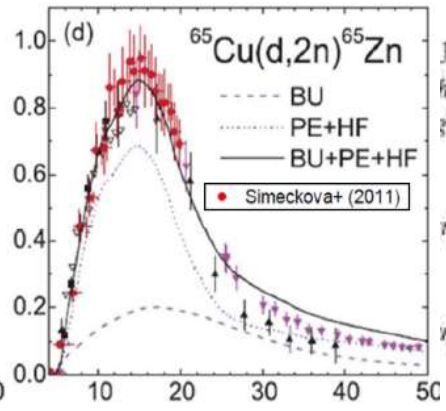
Cross sections	Agreed responsibilities, status and actions
$^{nat}Cu(d,x)^{62}Zn$	Accept Pade 9.
$^{nat}Cu(d,x)^{63}Zn$	CRP will not recommend due to deviation at 20 MeV and at 45 MeV. However, accept Pade 12.
$^{nat}Cu(d,x)^{65}Zn$	Accept Pade 13C uncertainties to be increased to 6%.

NO accompanying figure in the Report or in presentations

vs.







PHYSICAL REVIEW C **84**, 014605 (2011)

Low and medium energy deuteron-induced reactions on ^{63,65}Cu nuclei

E. Šimečková,* P. Bém, M. Honusek, and M. Štefánik
Euratom/IPP.CR Fusion Association, Nuclear Physics Institute (NPI), 25068 Řež, Czech Republic

J. Fischer and S. P. Simakov
he Institute of Technology (KIT), Hermann-von-Helmholtz-Platz, 1, 76344 genstein-Leopoldshafen, Germany

R. A. Forrest
rnational Atomic Energy Agency, A-1400 Vienna, Austria

A. J. Koning
ncy Group, P.O. Box 25, NL-1755 ZG Petten, The Netherlands

J.-C. Sublet
ldham Centre for Fusion Energy, Abingdon OX14 3DB, United Kingdom

M. Avrigeanu,† F. L. Roman, and V. Avrigeanu
"Horia Hulubei" National Institute for Physics and Nuclear Engineering, P.O. Box MG-6, RO-077125 Bucharest-Magurele,

(Received 11 May 2011; published 12 July 2011)

The activation cross sections of (d,p), $(d,2n)$, $(d,3n)$, and $(d,2p)$ reactions on ^{63,65}Cu were measured in the energy range from 4 to 20 MeV using the stacked-foil technique. Then, following the available elastic-scattering data analysis that provided the optical potential for reaction cross-section calculations, an increased effort was devoted to the breakup mechanism, direct reaction stripping, and pre-equilibrium and compound-nucleus

Conclusions of CRP on Nuclear Data for Charged-particle Monitor Reactions and Medical Isotope production (3)

Table 3: Cross-section studies of monitor reactions. January 2017

Cross sections	Agreed responsibilities, status and actions
$^{nat}Fe(d,x)^{56}Co$	Hermanne to de-select Nakua 2006 data, and re-send to Ignatyuk for re-fitting by July 1, 2016. !

NO accompanying figure

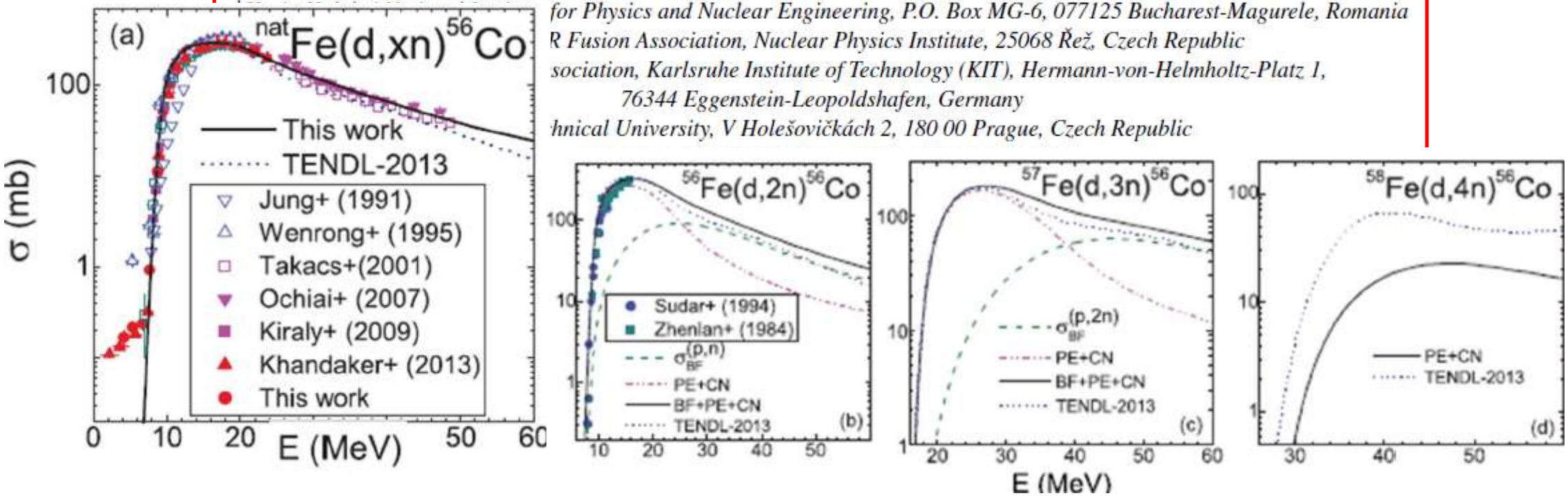
vs.

PHYSICAL REVIEW C 89, 044613 (2014)

Low energy deuteron-induced reactions on Fe isotopes

M. Avrigeanu,[1,*] V. Avrigeanu,[1] P. Bém,[2] U. Fischer,[3] M. Honusek,[2] K. Katovsky,[4] C. Mănăilescu,[1] J. Mrázek,[2] E. Šimečková,[2,†] and L. Závorka[2]

for Physics and Nuclear Engineering, P.O. Box MG-6, 077125 Bucharest-Magurele, Romania
R Fusion Association, Nuclear Physics Institute, 25068 Řež, Czech Republic
sociation, Karlsruhe Institute of Technology (KIT), Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany
hnical University, V Holešovičkách 2, 180 00 Prague, Czech Republic



Conclusions of CRP on Nuclear Data for Charged-particle Monitor Reactions and Medical Isotope production (4)

Table 3: Cross-section studies of monitor reactions.

January 2017

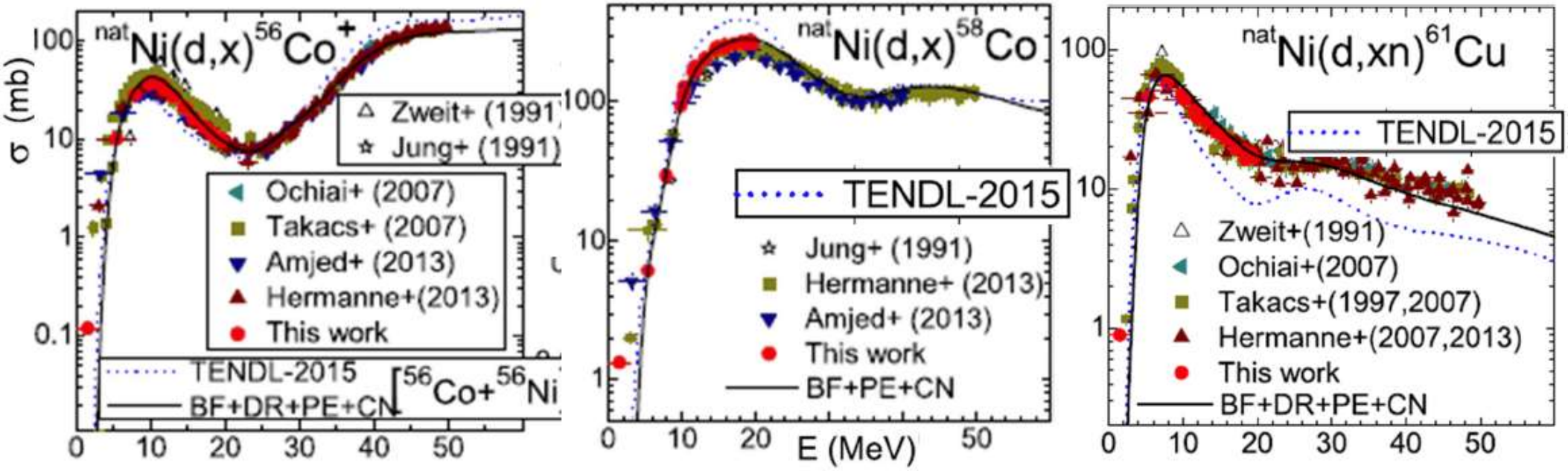
Cross sections	Agreed responsibilities, status and actions
$^{nat}Ni(d,x)^{56}Co$	CRP will recommend data up to 50 MeV. Accept Pade 11; fit uncertainties to be increased by Ignatyuk to at least 5%.
$^{nat}Ni(d,x)^{58}Co$	Accept Pade 12.
$^{nat}Ni(d,x)^{61}Cu$	Potential systematic shifts due to use of different gamma lines were considered. Accept Pade 10.

NO accompanying figure

PHYSICAL REVIEW C **94**, 014606 (2016)

Deuteron-induced reactions on Ni isotopes up to 60 MeV

M. Avrigeanu,[1,*] E. Šimečková,[2,†] U. Fischer,[3] J. Mrázek,[2] J. Novak,[2] M. Štefánik,[2] C. Costache,[1] and V. Avrigeanu[1]



Conclusions of CRP on Nuclear Data for Charged-particle Monitor Reactions and Medical Isotope production (5)

January 2017

Table 7: Cross-section studies for the production of therapeutic α emitters.

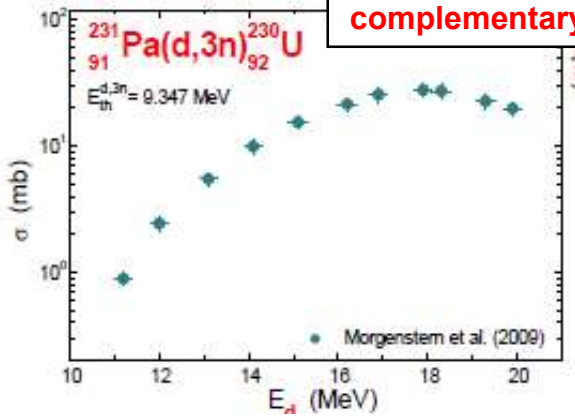
Cross sections	Agreed responsibilities, status and actions
^{231}Pa(d,3n)^{230}U	Ignatyuk to refit up to 30 MeV based on additional supporting theoretical calculations.

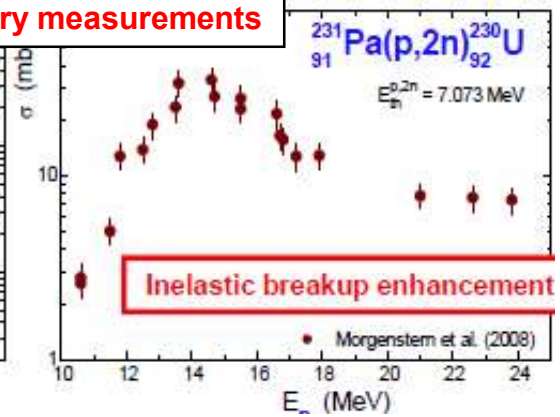
NO accompanying figure

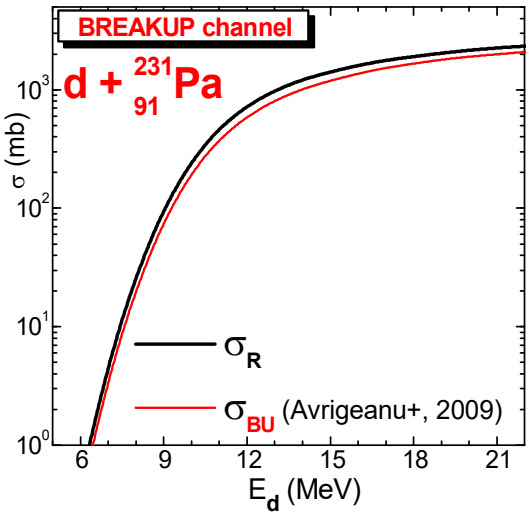
vs.

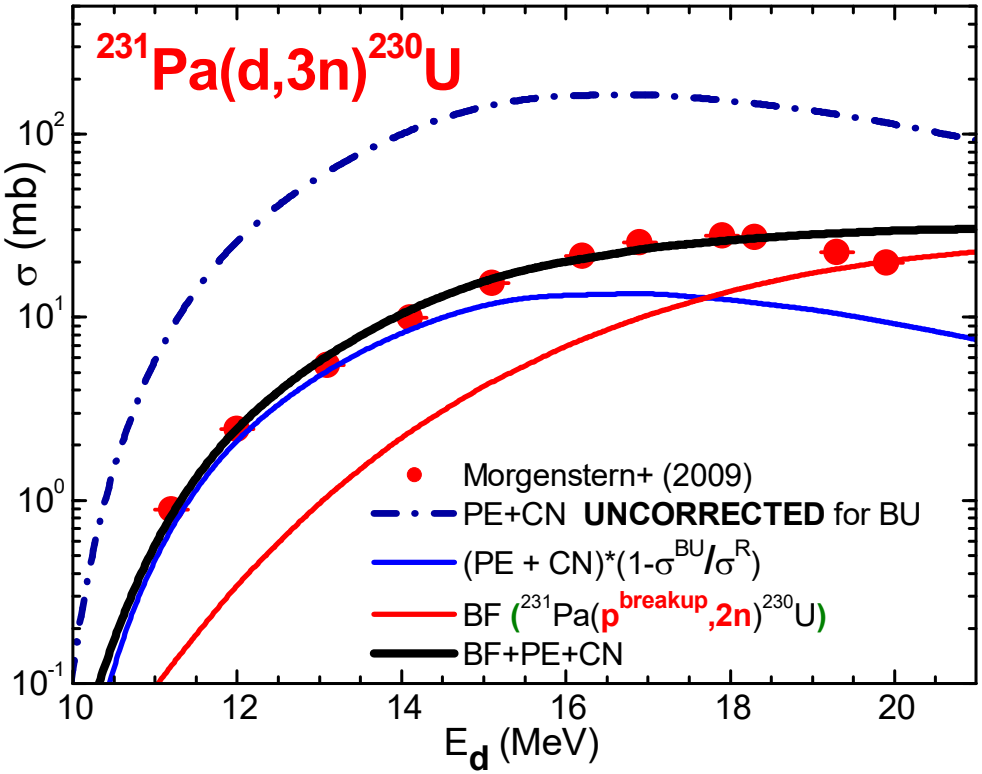
PHYSICAL REVIEW C

complementary measurements









$$\sigma_{BF}^{p,x}(E_d) = \sigma_{BF}^{p}(E_d) \int dE_p \frac{\sigma_{(p,x)}(E_p)}{\sigma_R^p} \frac{1}{(2\pi)^{\frac{1}{2}} w} exp[-\frac{(E_p - E_p^0(E_d))^2}{2w^2}]$$

CONCLUSIONS

Thank you!

deuteron induced reactions analysis

should consider

TALYS BREAKUP, **FRESCO** STRIPPING & PICK-UP, **TALYS** PE & CN MECHANISMS

- **DIRECT INTERACTIONS (DI):**

  BREAKUP & BREAKUP ENHANCEMENT of activation C.S.

  STRIPPING: (d,p), (d,n) & PICK-UP: (d,t) , (d,α)

- **PE & EVAPORATION cross sections corrected**

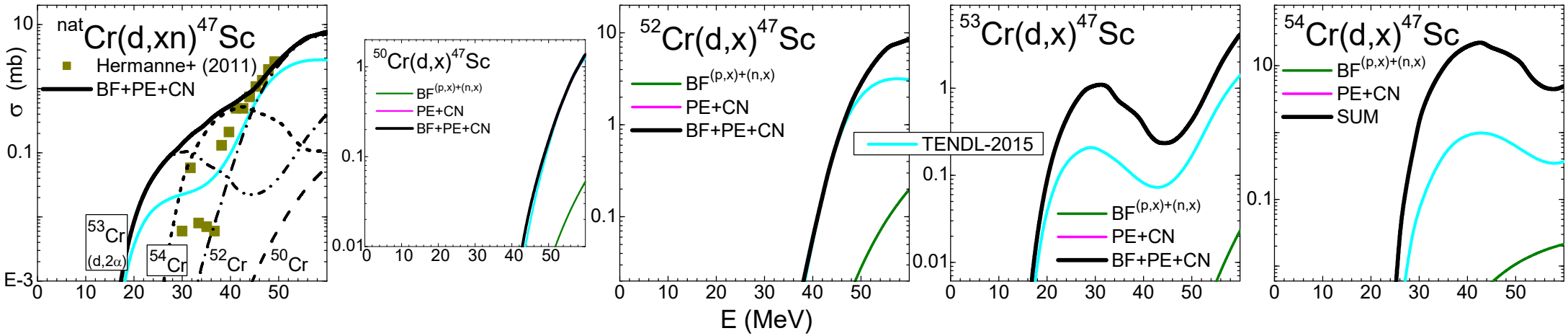
  for initial d-flux leakage towards DIRECT INTERACTIONS

??? PADE APPROXIMATIONS

as long as exist

Powerful Computers and Available Dedicated Codes ???

Deuteron activation cross sections analysis ^{47}Sc

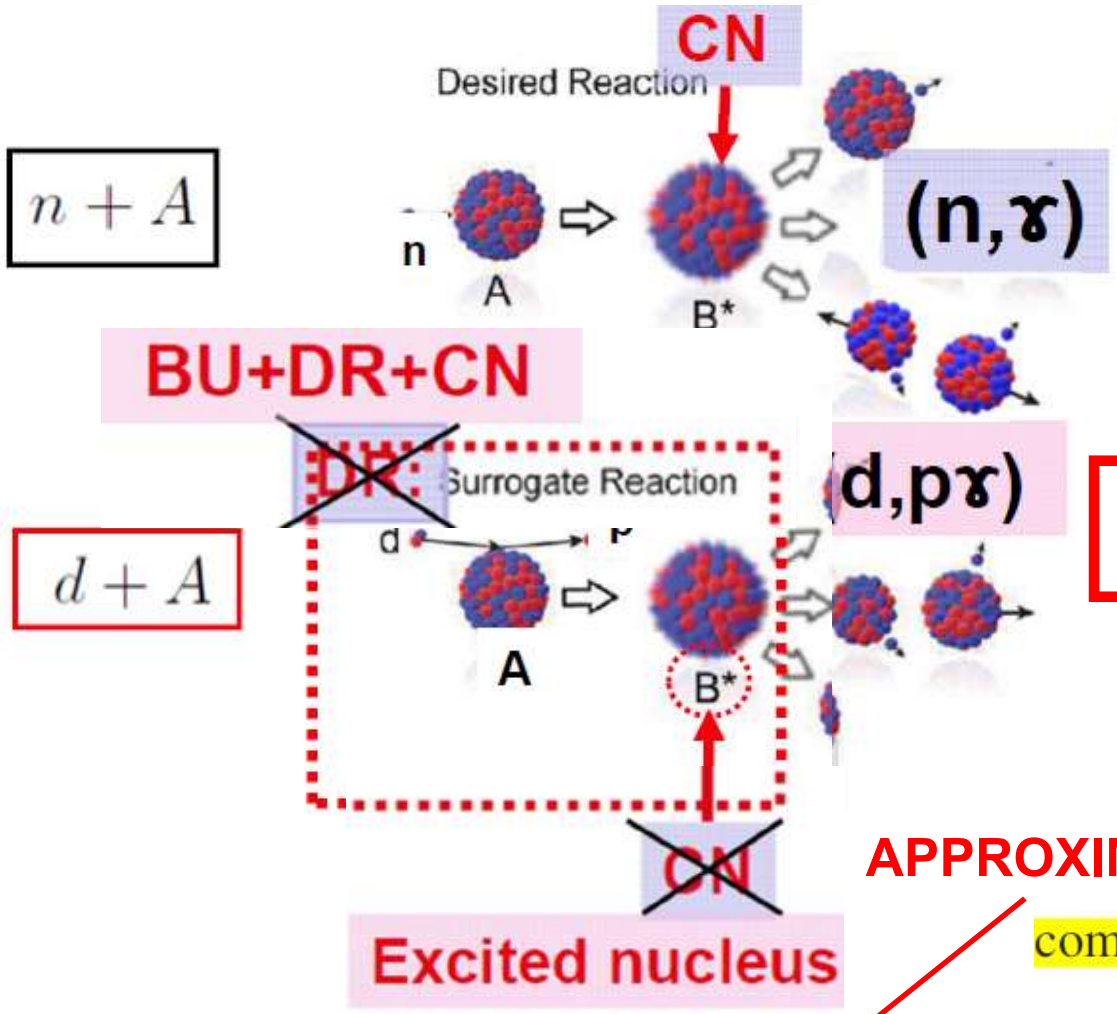


DEUTERON Surrogate Reactions

REVIEWS OF MODERN PHYSICS, VOLUME 84, JANUARY–MARCH 2012

Compound-nuclear reaction cross sections from surrogate measurements

Jutta E. Escher, Jason T. Burke, Frank S. Dietrich, Nicholas D. Scielzo,
Ian J. Thompson, and Walid Younes



$$\sigma_{n,\gamma}(E_n) = \Sigma_{\mathbf{J},\pi}\, \sigma_n^{CN}(E_{ex}, J, \pi) G_\gamma^{CN}(E_{ex}, J, \pi)$$

$$\sigma_n^{CN}(E_{ex}) \equiv \Sigma_{\mathbf{J},\pi}\, \sigma_n^{CN}(E_{ex}, J, \pi)$$

$$P_{d,p\gamma}(E_{ex}) = \Sigma_{\mathbf{J},\pi}\, F_{d,p}^{CN}(E_{ex}, J, \pi) G_\gamma^{CN}(E_{ex}, J, \pi)$$

$$P_{d,p\gamma}^{exp}(E_{ex}) = \frac{N_{p,\gamma}^{coincidences}(E_{ex})}{N_{d,p}^{surrogateevents}(E_{ex})}$$

APPROXIMATIONS:

compound nucleus produced in the transfer reaction

$$\sigma_{\mathrm{n},\gamma}^{\mathrm{WE}}(\mathrm{E_n}) = \sigma_{\mathrm{n}}^{\mathrm{CN}}(\mathrm{E_n}) \mathrm{P}_{\mathrm{d,p}\gamma}^{\mathrm{exp}}(\mathrm{E_{ex}})$$

Similar J, π distributions in both reactions

$$\mathrm{F_n^{CN}(E_{ex}, J, \pi) \approx F_{d,p}^{CN}(E_{ex}, J, \pi)}$$

Decay probabilities $G(E^*, J^\pi)$ independent of J, π

$$\mathrm{G_\gamma^{CN}(E_{ex}, J, \pi) = G_\gamma^{CN}(E_{ex})}$$

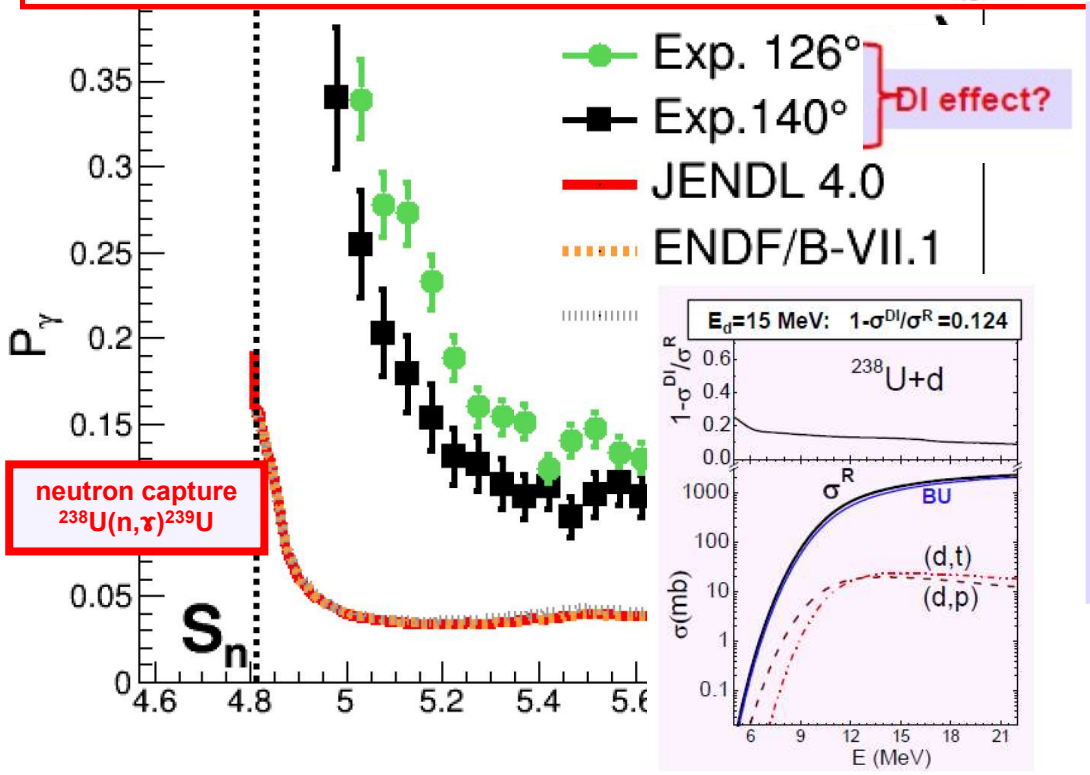
SURROGATE REACTIONS: STRONG EFFECTS OF THE DEUTERON BREAKUP (2)

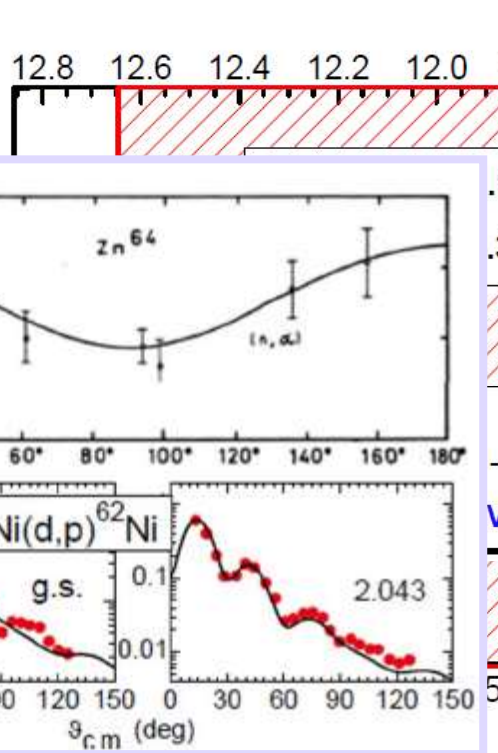
Investigation of the ^{238}U(d,p) surrogate reaction via the simultaneous measurement of γ-decay and fission probabilities

PHYSICAL REVIEW C 94, 024614 (2016)

Q. Ducasse,[1,2] B. Jurado,[1,*] M. Aïche,[1] P. Marini,[1] L. Mathieu,[1] A. Görgen,[3] M. Guttormsen,[3] A. C. Larsen,[3] T. Tornyi,[3] J. N. Wilson,[4] G. Barreau,[1] G. Boutoux,[5] S. Czajkowski,[1] F. Giacoppo,[3] F. Gunsing,[6] T. W. Hagen,[3] M. Lebois,[4] J. Lei,[7] V. Méot,[5] B. Morillon,[5] A. M. Moro,[7] T. Renstrøm,[3] O. Roig,[5] S. J. Rose,[3] O. Sérot,[2] S. Siem,[3] I. Tsekhanovich,[1] G. M. Tveten,[3] and M. Wiedeking[8]

$$\sigma^{WE}_{n,\gamma}(E_n) = \sigma^{CN}_{n}(E_n) P^{exp}_{d,p\gamma}(E_{ex}) = \sigma^{CN}_{n}(E_n) \frac{N^{coincidences}_{p,\gamma}(E_{ex})}{N^{surrogateevents}_{d,p}(E_{ex})}$$





$$P^{exp}_{d,p\gamma}(E_{ex}) = \frac{N^{coincidences}_{p,\gamma}(E_{ex})}{N^{surrogateevents}_{d,p}(E_{ex})}$$

$$P_{d,p\gamma}(E_{ex}) = \Sigma_{J,\pi} F^{CN}_{d,p}(E_{ex}, J, \pi) G^{CN}_{\gamma}(E_{ex}, J, \pi) \approx P^{exp}_{d,p\gamma}(E_{ex})$$

mechanism		model
^{239}U* : BF	$n^{BF}+^{238}U \rightarrow {}^{239}U^*$	phenomenologic
DR	$d+^{238}U \rightarrow p+^{239}U^*$	DWBA
	$^{238}U \rightarrow {}^{240}Np^* \rightarrow p+^{239}U^*$	H-F

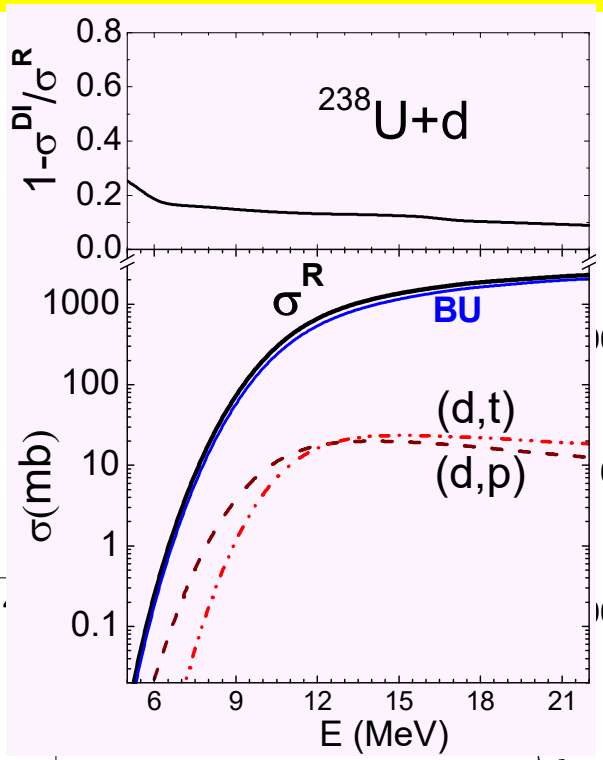
CN mechanism, too restrictive frame for d-surrogate

LARGE leakage of d flux through BU + DR before CN formation

SURROGATE REACTIONS: STRONG EFFECTS OF THE DEUTERON BREAKUP (1)
d+^{238}U INTERACTION

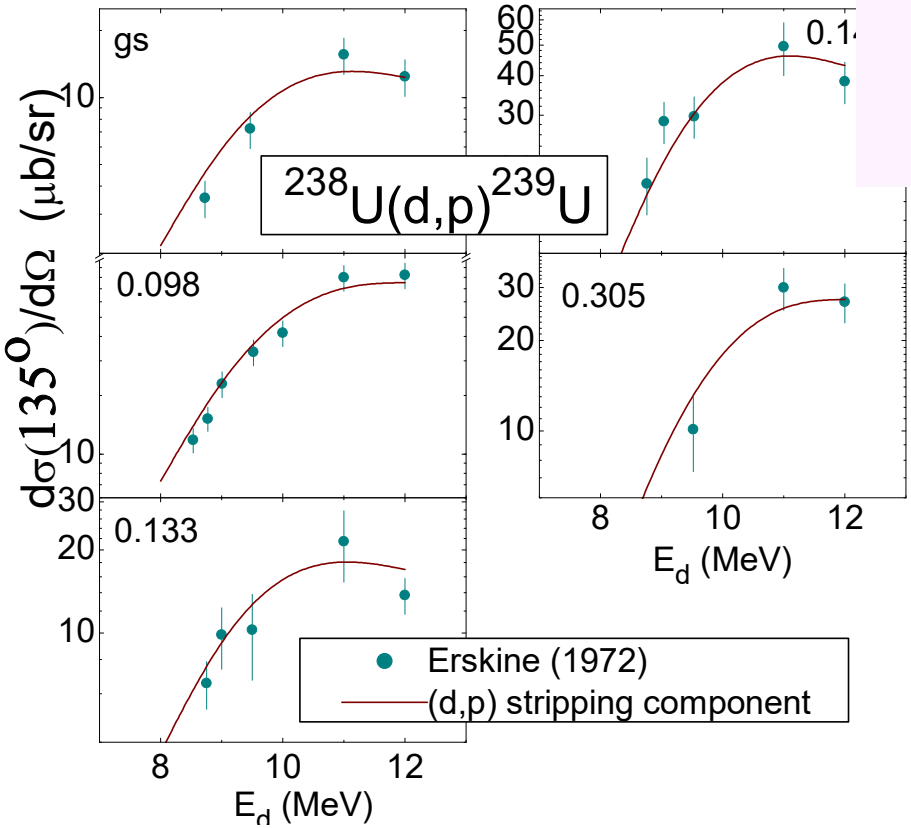
d-OMP: Haixia-Cai,
Phys. Rev. C73, 054605 (2006)

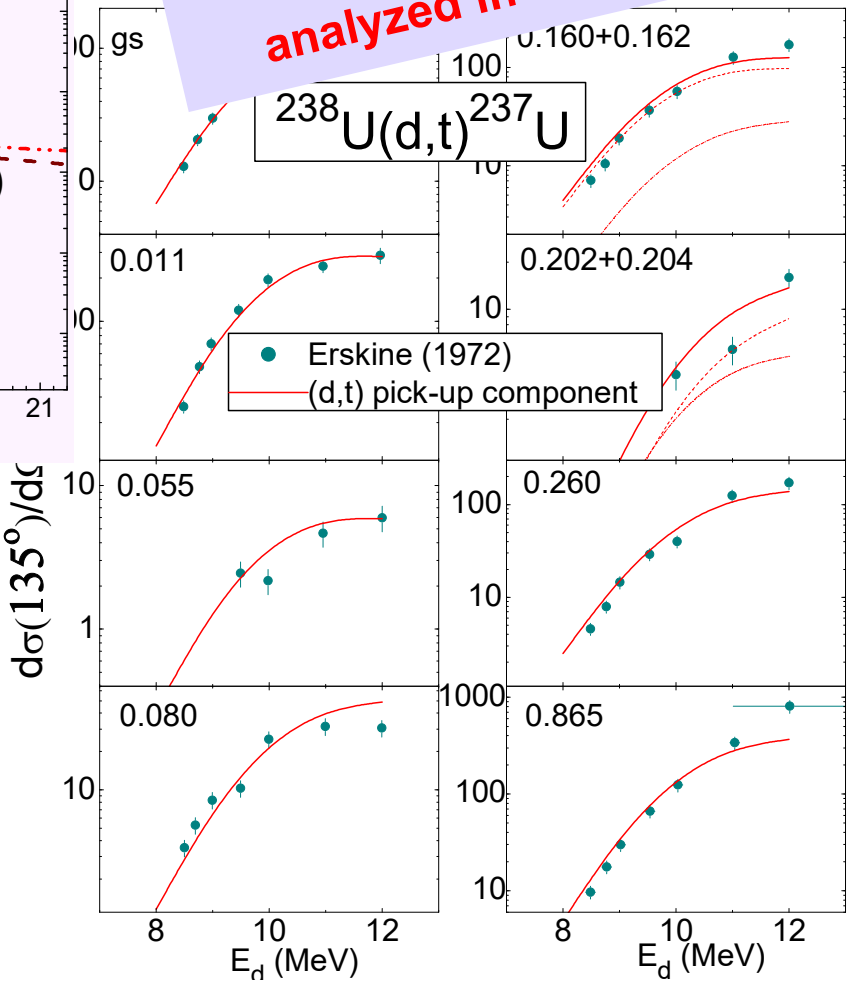
p-OMP: Capote-Soukhovitski,
J. Nucl. Sc.&Tech 45, 333 (2008)



E_d=15 MeV: $1-\sigma^{DI}/\sigma^{R}$ =0.124

BU dominance
Warning for d-surrogates analyzed in CN frame





Corrected P_γ by d-flux leakage through DI (frac=0.124)

$$P_{d,p\gamma}(E_{ex}) = \Sigma_{J,\pi} \mathbf{F}^{\mathbf{CN}}_{\mathbf{d,p}}(\mathbf{E_{ex}}, \mathbf{J}, \pi) G^{CN}_{\gamma}(E_{ex}, J, \pi) \approx P^{exp}_{d,p\gamma}(E_{ex})$$