Update on the compilation and assessment of experimental PSF

IAEA Consultants' Meeting on Evaluation of Photon Strength Function Data, 12-14 Nov. 2025, Vienna, Austria

Kgashane L. Malatji, T. Laplace, M. Wiedeking *et al.*,
Nuclear Data Program, LBNL & Nuclear Engineering Department, UCB
klmalatji@berkeley.edu
http://nucleardata.berkeley.edu

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Outline

- ✓ 2025 PSF database update
- ✓ Quality indications:
  - ✓ Full exp. uncertainty budget
  - ✓ Model-dependent uncertainties
  - ✓ Constraints by D_0 & Gg
  - ✓ Shape Method
- ✓ Challenges in Data Compilation & Assessment
- ✓ Recommendations

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Photon Strength Function Database

2013: Consultancy 's meeting at IAEA with recommendation on PSF database
2016-2019: IAEA Coordinated Research Project
Photonuclear Data and Photon Strength Functions F41032

https://www-nds.iaea.org/PSFdatabase/

Eur. Phys. J. A (2019) **55**: 172
DOI 10.1140/epja/i2019-12840-1

THE EUROPEAN PHYSICAL JOURNAL A

Review

Reference database for photon strength functions

S. Goriely[1], P. Dimitriou[2,a], M. Wiedeking[3], T. Belgya[4], R. Firestone[5], J. Kopecky[6], M. Krtička[7], V. Plujko[8], R. Schwengner[9], S. Siem[10], H. Utsunomiya[11], S. Hilaire[12], S. Péru[12], Y.S. Cho[13], D.M. Filipescu[14], N. Iwamoto[15], T. Kawano[16], V. Varlamov[17], and R. Xu[18]

IAEA Coordinated Research Project on Updating Nuclear Level Densities for Applications F41034, **2024-2028**

Data updated annually as of 2024

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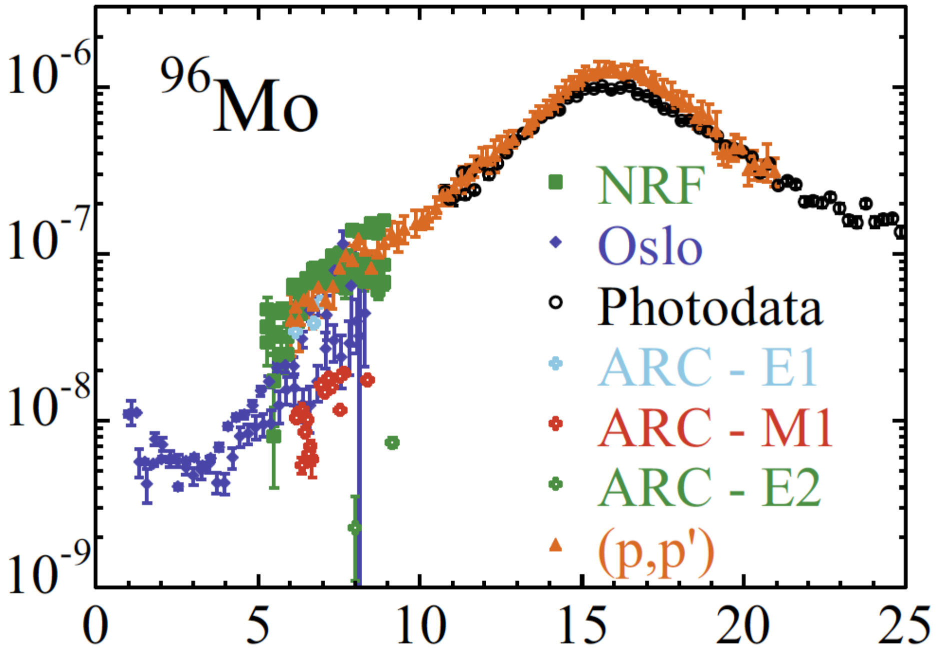
PSF: How are these data measured?



Oslo, beta-Oslo, inverse Oslo Methods (<S_n)

Ratio/Shape Methods (<S_n)

Nuclear Resonance Fluorescence (<S_n)

Inelastic p scattering with polarized beam (<S_n & >S_n)

Primaries from p-capture (>S_p and <S_n)

Primaries from charged particle reactions (<S_n)

Two-step cascade, n/p capture (<S_n)

Photonuclear Reactions (>S_n)

Primaries from n-capture (>S_n)

Goriely, Dimitriou, Wiedeking et al., Eur. Phys. J A 55, 172 (2019)

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Data in the PSF database 2024

Experimental data:
324 unique nuclides (1071 datafiles) for all experimental methods

154 nuclides	Z = 2-94	(337 files)	Photonuclear
103 nuclides	Z = 21-94	(133 files)	**Oslo Methods**
58 nuclides	Z = 9-90	(137 files)	Thermal neutron capture
63 nuclides	Z = 9-94	(115 files)	Absolute Photonuclear
54 nuclides	Z = 33-94	(123 files)	Average Resonance Capture
52 nuclides	Z = 9-94	(99 files)	Discrete Resonance Capture
27 nuclides	Z = 26-82	(34 files)	**Nuclear Resonance Fluorescence**
22 nuclides	Z = 22-40	(37 files)	**Proton capture**
11 nuclides	Z = 26-66	(31 files)	**Ratio and Shape Method**
8 nuclides	Z = 42-82	(25 files)	**Proton scattering**

Theoretical
Two models validated and recommended to perform global calculations of
E1 and M1 PSFs for all nuclides across the nuclear chart: D1M-QRPA and SMLO.

PSF database 2025 Update

Added assessed data for 34 nuclei:

^{51}Ti: 2 files, bOM, OM

^{56,57,58,60}Fe: 22 files, bOM, OM, SM

^{59}Co: 1 file, NRF

^{67}Ni: 1 files, iOM

^{66}Zn: 1 file, NRF

^{76}Ge: 1 file, SM

^{88}Kr: 2 files, bOM, SM

^{111,112,113,114,116,117,118,119,120,122,124}Sn: 7 files, OM

^{128,130}Te: 5 files, OM, NRF

^{140}Ba: 1 file, bOM

^{147,149}Sm: 2 files, OM

^{161,162,163,164}Dy: 4 files, OM

^{186}W: 1 file, OM

^{195}Pt: 1 file, OM

^{198}Au: 2 files, OM

^{239}U: 1 file, OM

Additional new isotopes to each method

5 nuclides	OM
4 nuclides	bOM
3 nuclides	SM
1 nuclides	iOM
1 nuclides	NRF

53 new data files and
53 new readme files

Corrected previously published files: 20
Change file labels: 528

Sent to IAEA for dissemination (Dec 2025)

PSF database format

```
# f1_exp_026_056_OM_1.dat
#
# Z = 26, A = 56
# No. of entries: 74
# Col 1: photon energy E in MeV
# Col 2: bin width dE in MeV
# Col 3: dipole strength f1 in MeV^-3
# Col 4: uncertainty df1 in MeV^-3
# Format: 2f10.3, 2e12.3
# Author: A. C. Larsen et al., J. Phys. G: Nucl. Part. Phys. 44, 064005
(2017)
# Compiler: K.L Malatji, T.A. Laplace, M. Wiedeking and V.W. Ingeberg
#     E         dE        f1          df1
    2.119     0.124     2.910e-08   1.345e-09
    2.244     0.124     2.291e-08   1.256e-09
    2.368     0.124     1.894e-08   1.125e-09
    2.491     0.124     1.127e-08   8.272e-10
    2.615     0.124     2.245e-08   9.846e-10
    2.740     0.124     1.802e-08   9.124e-10
    2.864     0.124     1.497e-08   7.458e-10
    2.987     0.124     1.400e-08   6.710e-10
    3.111     0.124     1.286e-08   6.331e-10
    3.236     0.124     1.751e-08   6.753e-10
    3.360     0.124     1.277e-08   6.481e-10
    3.483     0.124     1.524e-08   7.051e-10
    3.607     0.124     1.227e-08   6.104e-10
    3.732     0.124     8.691e-09   5.142e-10
    3.856     0.124     1.168e-08   4.962e-10
    3.979     0.124     8.796e-09   5.114e-10
    4.104     0.124     9.851e-09   4.653e-10
    4.228     0.124     1.048e-08   5.700e-10
    4.351     0.124     1.130e-08   5.168e-10
```

Data File

Investigate ways to make data machine readable

```
# f1_NLD_exp_026_056_OM_1.readme
#
# Data were published by A. C. Larsen et al., J. Phys. G: Nucl. Part. Phys. 44, 064005 (2017)
#
# Reaction 56Fe(p,p)56Fe with beam energy 16.0 MeV
# at Oslo Cyclotron Laboratory (OCL).
#
# Particle - gamma coincidences were measured in CACTUS/SiRi and the
# resulting coincidence spectra was unfolded [M. Guttormsen et al. NIM Phys. Res. A 374, 371 (1996)]
# with the response of CACTUS.
# The first generation matrix is then found using an iterative
# method [M. Guttormsen et al., NIM Phys. Res. A 255, 518 (1987)]
#
# The functional shape of the level density and the gamma-ray transition coefficient
# is extracted from the first generation matrix using a chi-square
# minimalization method [A. Schiller et al., NIM Phys. Res. A 447, 498 (2000)].
#
# Data taken with LaBr3:Ce (From HECTOR, Uni. Milano)
#
# Absolute value of the level density and transmission coefficient is
# found by normalization to known values.
#
# The level density is normalized to:
#       (i) The level density at the neutron separation energy.
#       (ii) Known discrete levels at low energy.
#
# The transmission coefficients are normalized with the process
# described in [A. Voinov et al., Phys. Rev. C 63, 044313 (2001)]
#
#
# Inputs used for the normalization:
#       (i) Spin cutoff model of [T. von Egidy and D. Bucurescu, Phys. Rev. C 80, 054310 (2009)]
#       (ii) Level density at the neutron separation energy
#               rho(Sn) = 2.180e+03 ± 5.900e+02 1/MeV is found using
#               the neutron resonance spacing D0 = 3.36 ± 1.24 keV
#               estimated from systematics (see publication for more details).
#       (iii) Average radiative width <Gg0> = 1900.0 ± 600.0 meV
#               estimated from systematics (see publication for more details).
#
# The reaction will populate primarily the quasi-continuum
# such that most transitions are assumed to be dipole, such
# that the dipole strength is found by f1(Eg) = T(Eg)/(2*pi*Eg**3).
#
#
#
# The uncertainties of the resulting level density
# and photon strength function are statistical errors only.
```

Readme File

Challenges in Data Compilation, Assessment, and Outlier Analysis

About 21 datasets with 5 column files

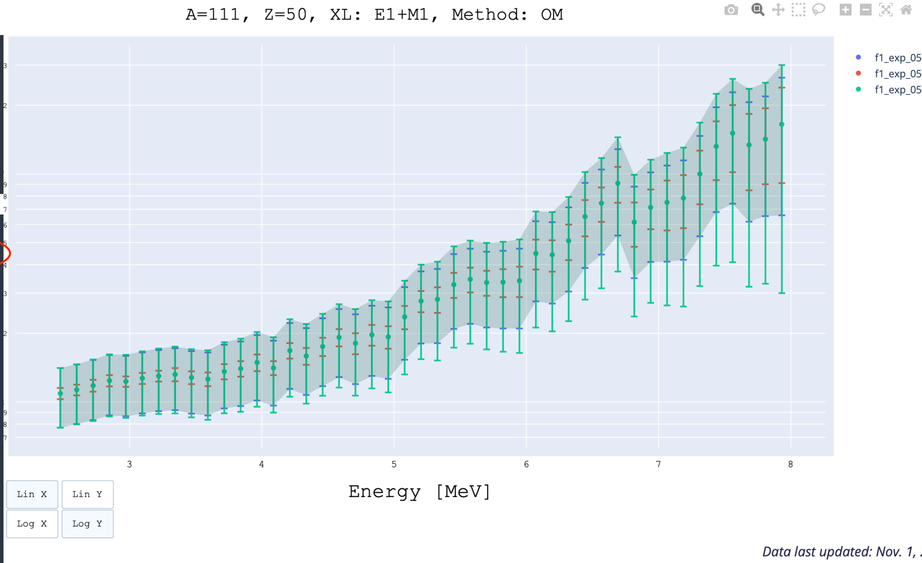
Two cases:

✓ Only statistical vs total (statistical vs. systematics)

✓ Lower and Upper error bands

E	dE	f1	df1(stat)	df1(tot)
1.500	0.250	2.490e-08	4.100e-09	7.410e-09
1.750	0.250	1.920e-08	2.460e-09	5.270e-09
2.000	0.250	1.500e-08	2.020e-09	4.080e-09

#	E	dE	f1	df1(stat)	df1-(tot)	df1+(tot)
#	1.732	0.124	0.108E-07	2.917E-10	4.245E-09	4.328E-09
#	1.856	0.124	0.105E-07	2.941E-10	4.124E-09	4.208E-09
#	1.980	0.124	0.106E-07	2.709E-10	4.153E-09	4.243E-09
#	2.104	0.124	0.105E-07	2.843E-10	4.115E-09	4.209E-09
#	2.228	0.124	0.995E-08	2.825E-10	3.916E-09	4.011E-09
#	2.352	0.124	0.108E-07	2.951E-10	4.252E-09	4.363E-09
#	2.476	0.124	0.135E-07	3.477E-10	5.329E-09	5.477E-09
#	2.600	0.124	0.123E-07	3.124E-10	4.878E-09	5.023E-09
#	2.724	0.124	0.121E-07	3.052E-10	4.787E-09	4.940E-09
#	2.848	0.124	0.128E-07	3.298E-10	5.069E-09	5.243E-09
#	2.972	0.124	0.128E-07	3.071E-10	5.077E-09	5.264E-09
#	3.096	0.124	0.137E-07	3.196E-10	5.449E-09	5.665E-09
#	3.220	0.124	0.140E-07	3.287E-10	5.585E-09	5.823E-09
#	3.344	0.124	0.137E-07	3.376E-10	5.476E-09	5.725E-09
#	3.468	0.124	0.130E-07	3.356E-10	5.214E-09	5.469E-09
#	3.592	0.124	0.143E-07	3.289E-10	5.757E-09	6.059E-09
#	3.716	0.124	0.147E-07	3.339E-10	5.926E-09	6.257E-09



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Challenges in Data Compilation, Assessment, and Outlier Analysis

22	44	OM	E1+M1	27	2.173	8.241	A. C. Larsen et al.	2012	f1_exp_022_044_OM_1
22	44	OM	E1+M1	27	2.173	8.241	A. C. Larsen et al.	2012	f1_exp_022_044_OM_2
22	46	OM	E1+M1	69	1.790	9.800	M. Guttormsen et al.	2011	f1_exp_022_046_OM_rec
22	46	PG	E1+M1	40	7.100	13.160	I.I. Zalyubovskij et al.	1994	f1_exp_022_046_PG_1994Zal
22	46	PG	E1+M1	61	6.518	13.140	I.D. Fedorets et al.	2008	f1_exp_022_046_PG_2008Fed

46	108	OM	E1+M1	51	2.160	8.160	T. K. Eriksen et al.	2014	f1_exp_046_108_OM
48	112	SM	E1+M1	17	4.990	6.962	PRC	2022	f1_exp_048_112_SM_1
48	112	SM	E1+M1	12	5.104	7.559	PRC	2022	f1_exp_048_112_SM_2
48	105	OM	E1+M1	57	1.004	7.947	A. C. Larsen et al.	2013	f1_exp_048_105_OM

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Challenges in Data Compilation, Assessment, and Outlier Analysis

OM: Assign quality indicator as a measure of reliability since the method is changing over time

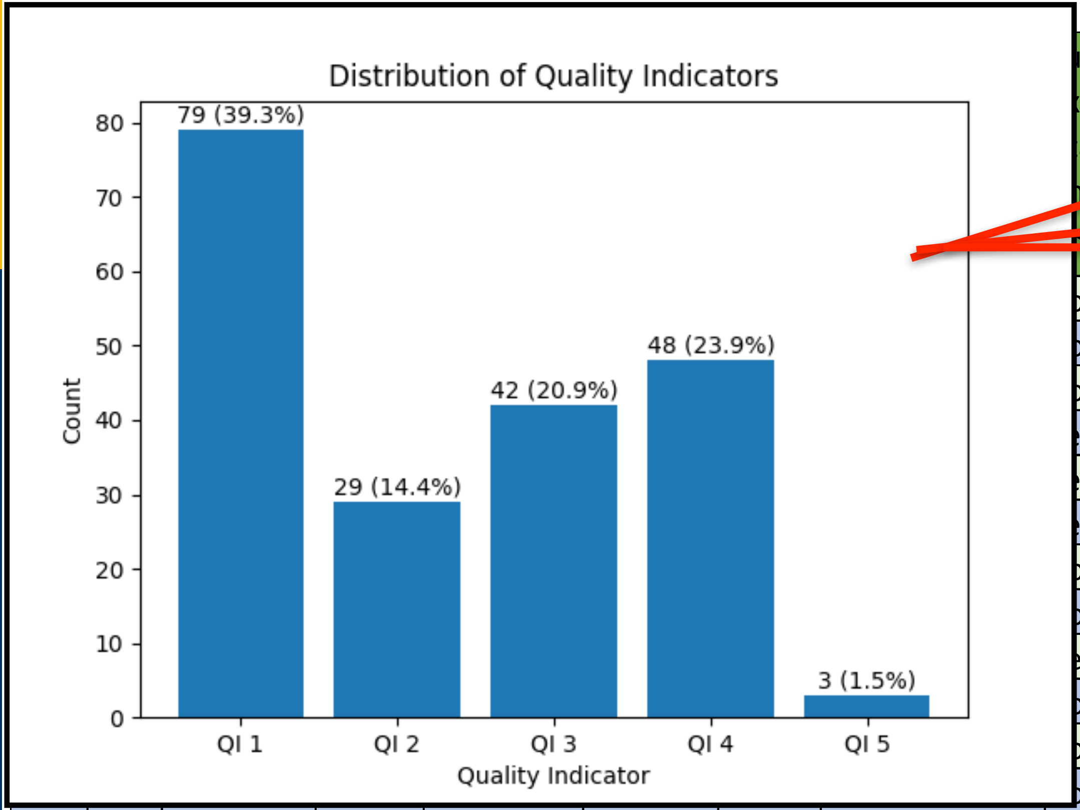
- Criteria for assigning Quality Indicators

A	Z	Residual	Target	projectile	ejectile	Ebeam	PSF_ref	Full experimental uncertainties	Full model uncertainties	D02	Gg	Shape Method	After March 2014	Quality indicator 1 to 5
44	21	Sc	Sc	3he	a	38.0	A. C. Larsen et al	no	No	Yes	No	No	no	1
45	21	Sc	Sc	3he	3he	38.0	A. C. Larsen et al	no	No	Yes	No	No	no	1
43	21	Sc	46Ti	a	p	32.0	A. Bürger et al., F	no	No	Yes	No	No	no	1
46	22	Ti	Ti	p	p	15.0	M. Guttormsen e	yes	no	no	no	No	no	1
46	22	Ti	Ti	p	p	15.0	M. Guttormsen e	yes	no	no	no	No	no	1
46	22	Ti	Ti	p	p	15.0	M. Guttormsen e	yes	no	no	no	No	no	1
44	22	Ti	Ti	p	t	32.0	A. C. Larsen et al	no	Yes	no	no	No	no	2
44	22	Ti	Ti	p	t	32.0	A. C. Larsen et al	no	Yes	no	no	No	no	2
51	22	Ti	Ti	p	d	12.5	Liddick et al, Phy	Yes	No	yes	yes	no	yes	4
51	22	Ti				0	Liddick et al, Phy	no	no	yes	yes	no	yes	3
50	23	V	V	3he	a	30.0	A. C. Larsen et al	no	no	no	no	no	no	1
51	23	V	V	3he	3he	30.0	A. C. Larsen et al	no	no	Yes	Yes	no	no	1

Challenges in Data Compilation, Assessment, and Outlier Analysis

OM: Assign quality indicator as a measure of reliability since the method is changing over time

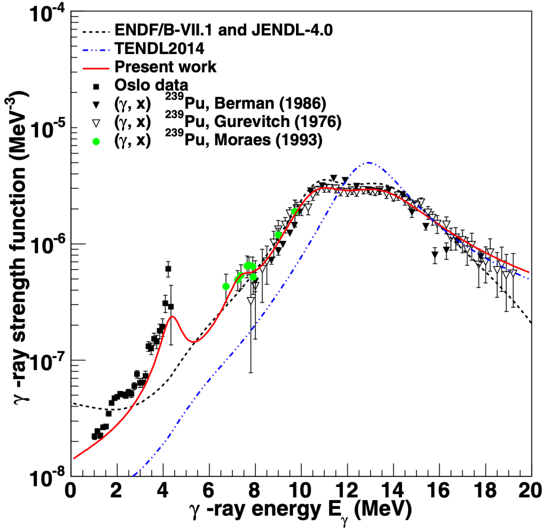
- Criteria for assigning Quality Indicators

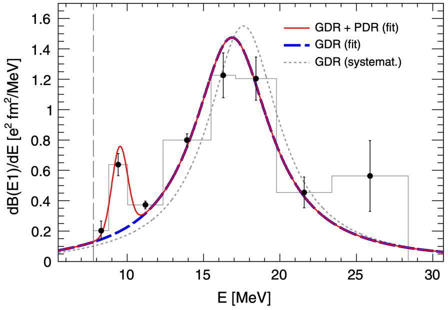


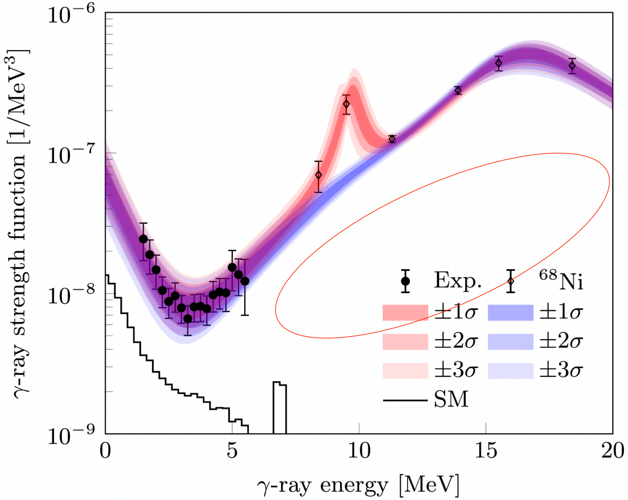
...ll ...xperime ...al ...ncertaint ...s	Full model uncertainties	D02	Gg	Shape Method	After March 2014	Quality indicator 1 to 5
...o	No	Yes	No	No	no	1
...o	No	Yes	No	No	no	1
...o	No	Yes	No	No	no	1
...es	no	no	no	No	no	1
...es	no	no	no	No	no	1
...es	no	no	no	No	no	1
...o	Yes	no	no	No	no	2
...o	Yes	no	no	No	no	2
...es	No	yes	yes	no	yes	4
...o	no	yes	yes	no	yes	3
...o	no	no	no	no	no	1
...o	no	Yes	Yes	no	no	1

Challenges in Data Compilation, Assessment, and Outlier Analysis

- ✓ Maybe not enough reduction factor due to close to Coulomb barrier? See cases ^{155}Sm, ^{181}Ta and others…

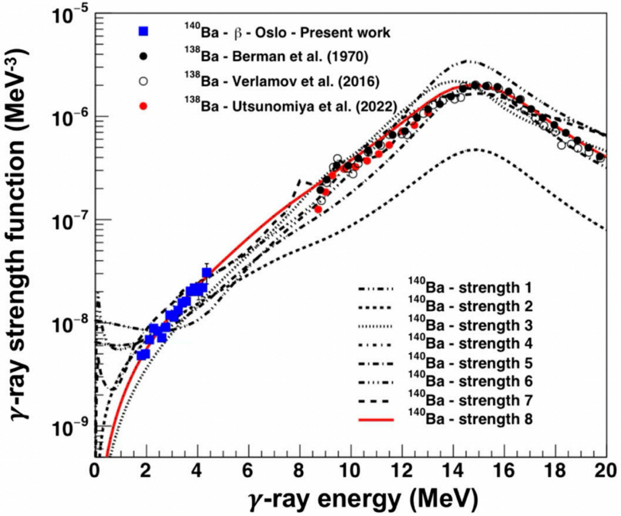






- ✓ ^{68}Ni from relativistic Coulex, D. M. Rossi, et al., Phys. Rev. Lett. 111, 242503 (2013). **Add to database?**

- ✓ No systematic uncertainty resulting from different PSF models, no error band



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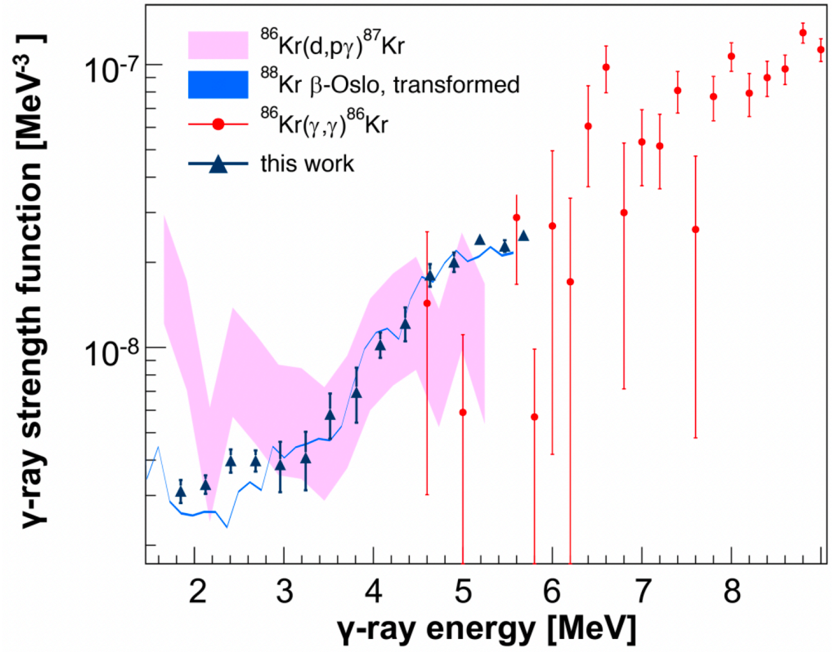
Challenges in Data Compilation, Assessment, and Outlier Analysis

Induced Uncertainties from Digitized Data:

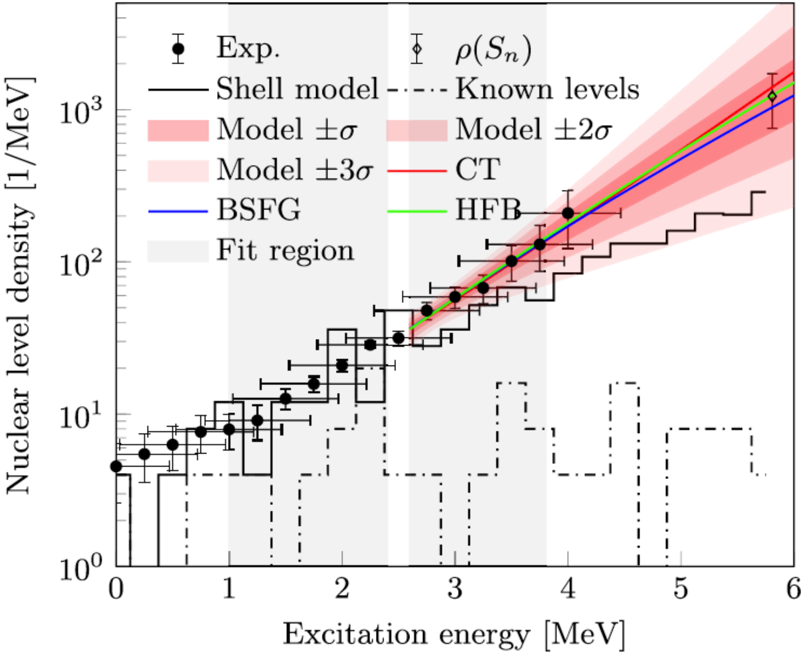
- Small error bars
- Overlapping points
- Line tracing errors

✓ ^{88}Kr (transformed): Statistical uncertainties only.



Full model uncertainties

✓ Full model uncertainties: Bayesian analysis (unavailability of exp. D_0 & Γ_γ) provide additional model constraint? Add to QI criterion?

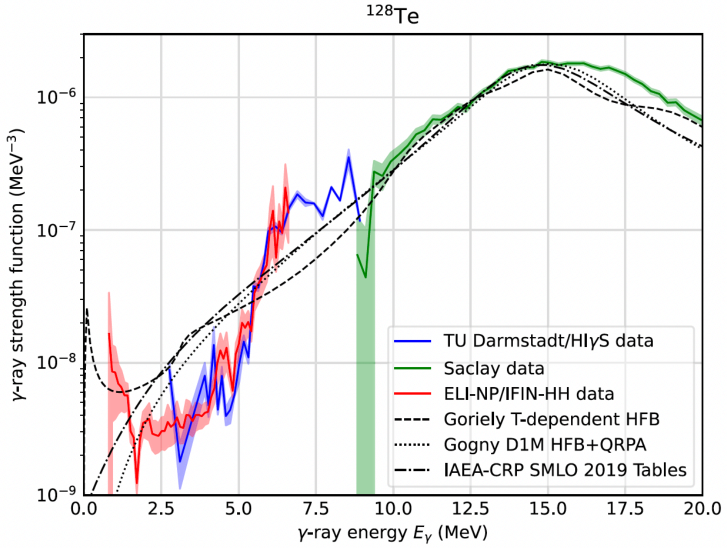


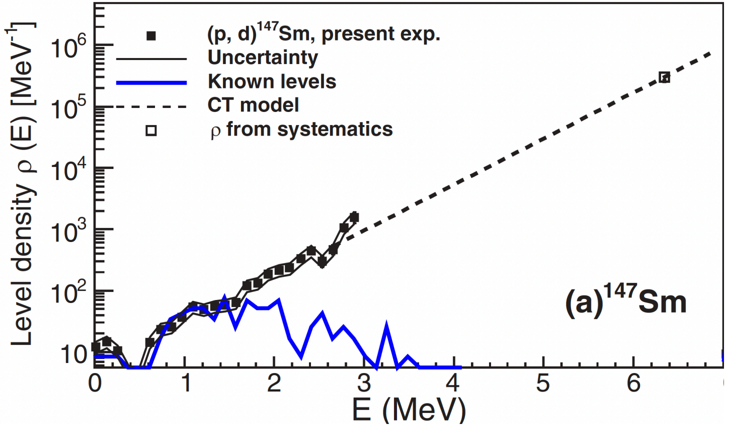
✓ PSF data normalized to NRF data (both absolute value and slope)

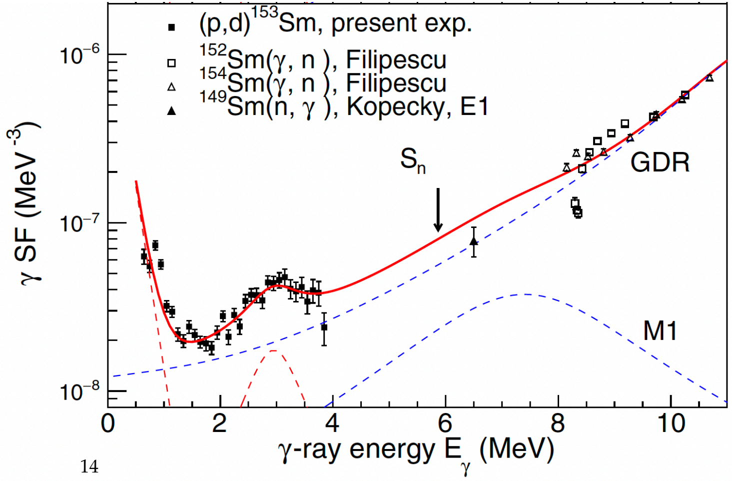
✓ Gg quoted is inconsistent with Mughabghab and RIPL-3.

✓ GEANT simulations for detector response do not match the data across a wide energy region.

✓ Exp. NLD data up-to 4 MeV, uncertain extrapolation and slope







Challenges in Data Compilation, Assessment, and Outlier Analysis

Additional:

- ✓ Identified a few good candidates (slope too steep), measured with (p,p), (d,p) for reanalysis with shape method or apply reduction factor.
- ✓ Gg only based on two resonances (^{65}Ni)
- ✓ Coulomb dissociation constrain OM data absolute value?
- ✓ Gg was not trusted and adjusted (^{73}Ge)
- ✓ Systematics for normalization? In some cases information missing from publication
- ✓ **Outlier Analysis** (See talk: **T. Laplace**)

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Recommendations

✓ A page or template for data submission to www-nds.iaea.org/PSFdatabase/??

✓ A PSF tag to journals or groups working on PSF

✓ Develop publication guidelines for NLD/PSF data to be incorporated in database

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Thank You!

Update on the compilation and assessment of experimental PSF

Work done under the Quasi-continuum Nuclear Data Evaluator Traineeship

Kgashane L. Malatji, T. Laplace, M. Wiedeking *et al.*,

Nuclear Data Program, LBNL & Nuclear Engineering Department, UCB

klmalatji@berkeley.edu

http://nucleardata.berkeley.edu

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