Theory Alliance
FACILITY FOR RARE ISOTOPE BEAMS

FRIB-TA Topical Program: Statistical Nuclear Properties in the AI/ML Era: Advances, Challenges, and Synergies for FRIB Science

June 29, 2026 to July 10, 2026
Facility for Rare Isotope Beams
America/New_York timezone

- Overview
- Registration
- Timetable
- Participant List
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- Airports
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- Parking
- U.S. Visa and Health Insurance Information
- FRIB Theory Alliance Code of Conduct
- Past FRIB Theory Alliance Topical Programs

Contact

ta-programs@frib.msu.edu

Statistical nuclear properties from the shell model and reduced-order fitting schemes

Jul 7, 2026, 10:30 AM
1h
1221A/B (Facility for Rare Isotope Beams)

Speaker

Oliver Gorton (Lawrence Livermore National Laboratory)

Presentation materials

There are no materials yet.

FRIB-TA Topical Program: Statistical Nuclear Properties in the AI/ML Era: Advances, Challenges, and Synergies for FRIB Science
FRIB 1221A/B,10:30 AM – 11:30 AM July 6, 2026

Statistical properties from the shell model and reduced-order fitting schemes

Oliver Gorton, postdoc | Lawrence Livermore National Laboratory, California, USA

Reaction Theory for R-process Observables (RETRO) Collaboration:
Jutta Escher[1] (PI), Jeffrey M. Berryman[1], Jonathan Cabrera Garcia[2], Erika M. Holmbeck[1], Atul Kedia[3], Kostas Kravvaris[1], Gail C. McLaughlin[3], Cole D. Pruitt[1], Andre Sieverding[1], and Rebecca Surman[2]

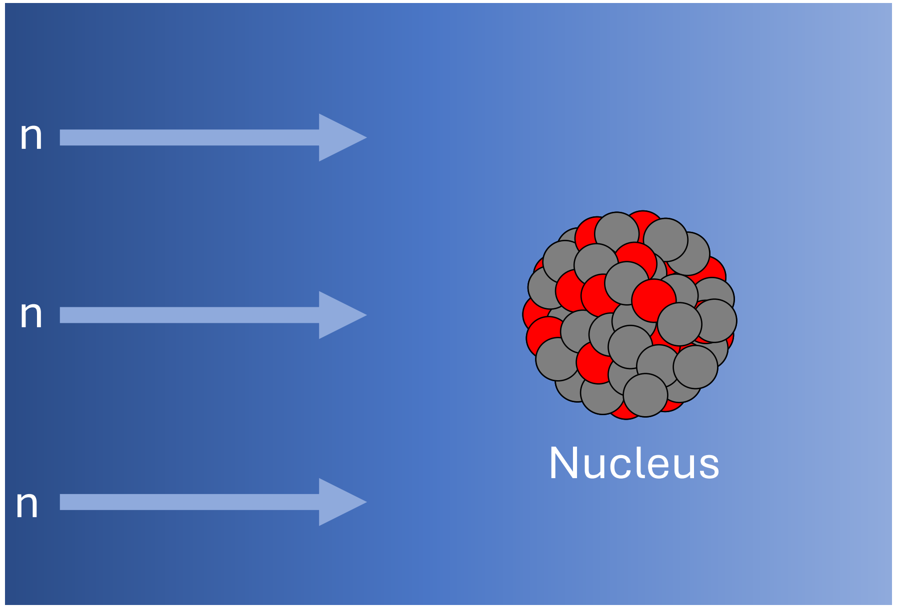
[1]LLNL, [2]U. Notre Dame, [3]North Caroline State University

Prepared by LLNL under Contract DE-AC52-07NA27344.

How and where are heavy elements formed?

Answer "Extreme radiation environments with ultra-high neutron fluxes"

Neutron star merger

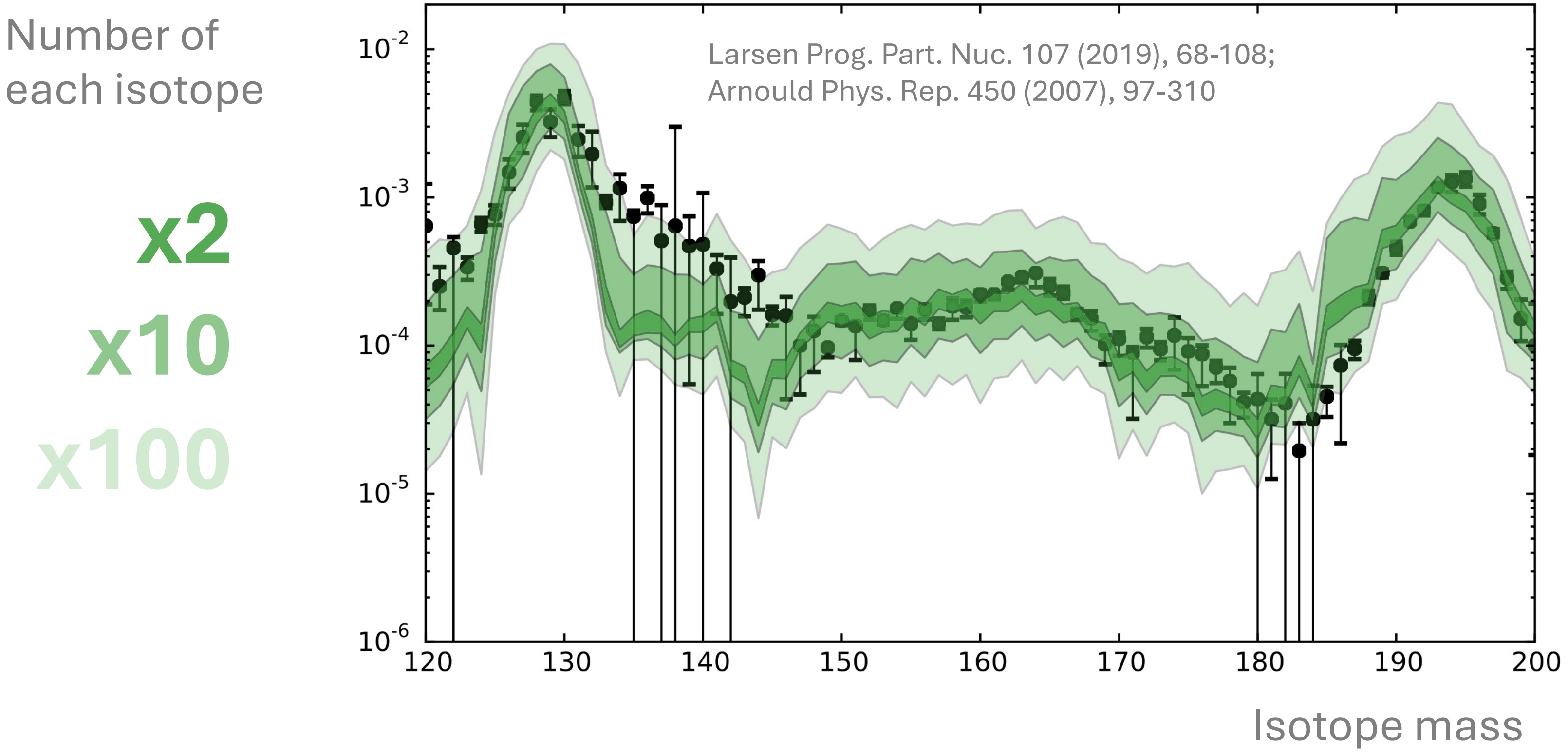


Flux > 10^{37}/cm^2/s
(Neutron density >10^{29}/cm^3 @ 1GK)

Isotopic “fallout” from extreme events

The task

Given **radiochemical evidence**,
determine the **event** (neutron source) that produced it

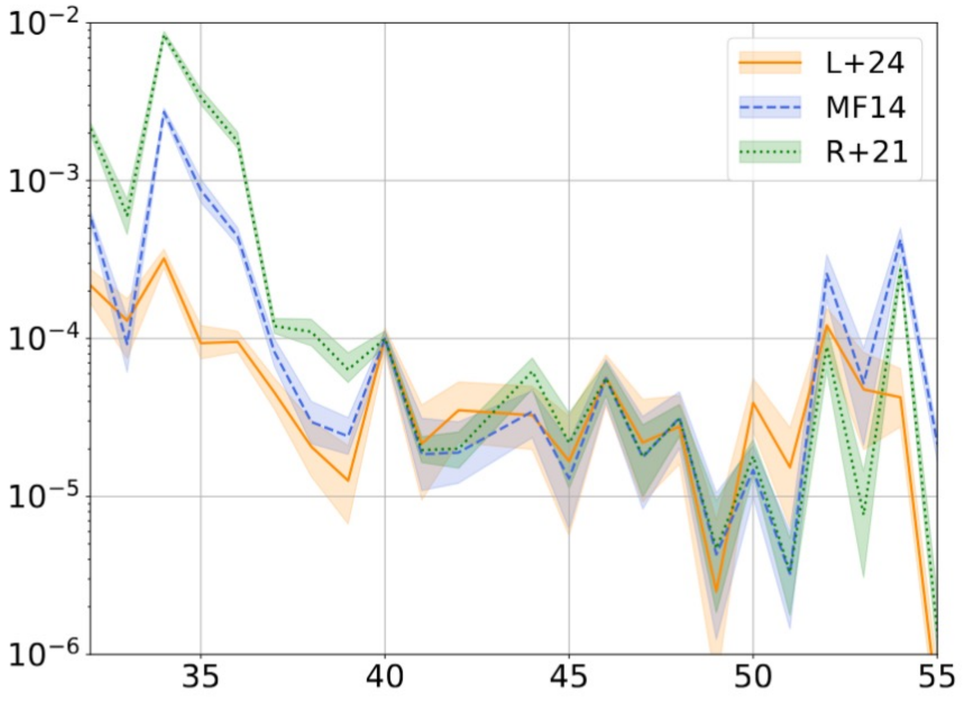


Hydrodynamics versus nuclear physics uncertainty

Task Given **radiochemical evidence**, determine the **event** that produced it

3 hydro simulations (2 NS mergers, 1 supernova) + 1 source of nuclear uncertainties*

Amount of isotope produced



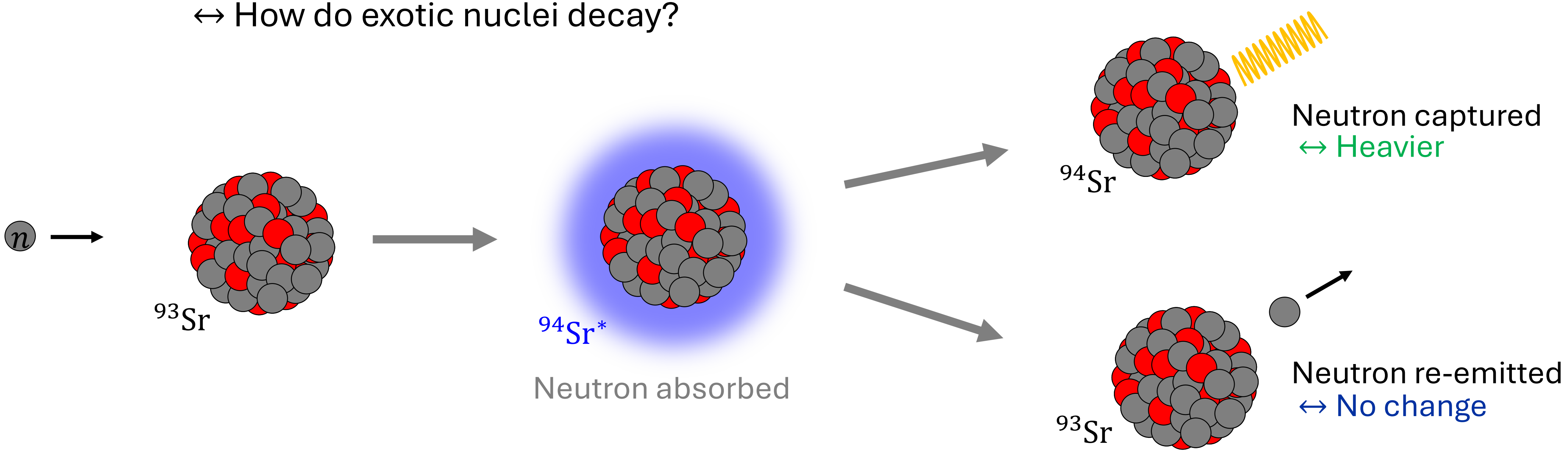
Isotope Z

Figure from Atul Kedia (NCSU) arXiv:2602.12428 (under review for PRC)

*neutron optical model

Nuclear physics needs

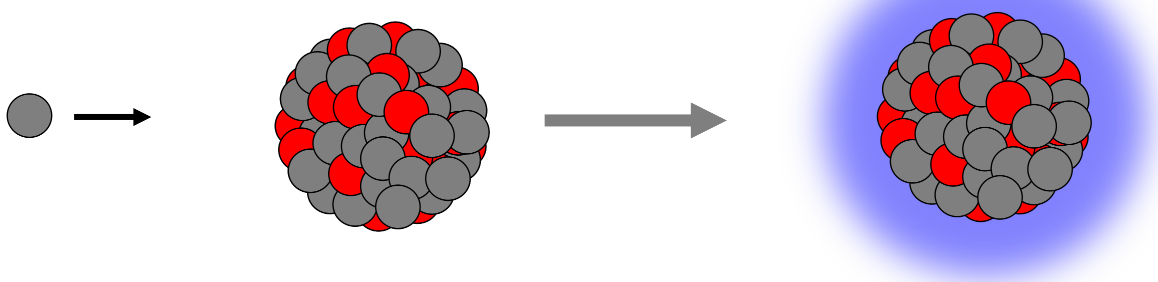
Need to know: How do exotic nuclei get heavier?
↔ How do exotic nuclei decay?



Optical model

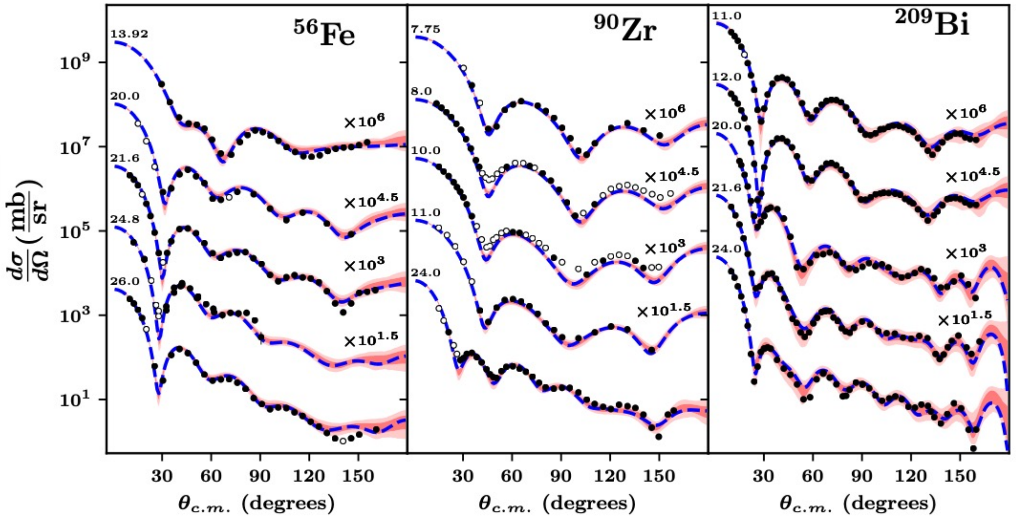
Radiative strength functions,
Level densities,
Optical model

Optical potentials with uncertainties have led the way for physics-informed UQ in reactions



Optical model

KDUQ global optical potential



From Pruitt, Escher, Rahman PRC 107 014602 (2023)

Physics-informed UQ in reactions: learn physical parameters, predict observables

$L\left(\frac{d\sigma}{d\Omega}\right)$: Scattering data, $O(10^4)$

$P(\omega)$ OMP parameters ω, $O(10^2)$

$p[y'(\theta)]$: Global nucleon transmissibility, $O(10^{>3})$

Optical model

Astrophysics applications with 500+ cross sections from physics-informed uncertainties

Neutron-capture rates with UQ from the KDUQ potential*

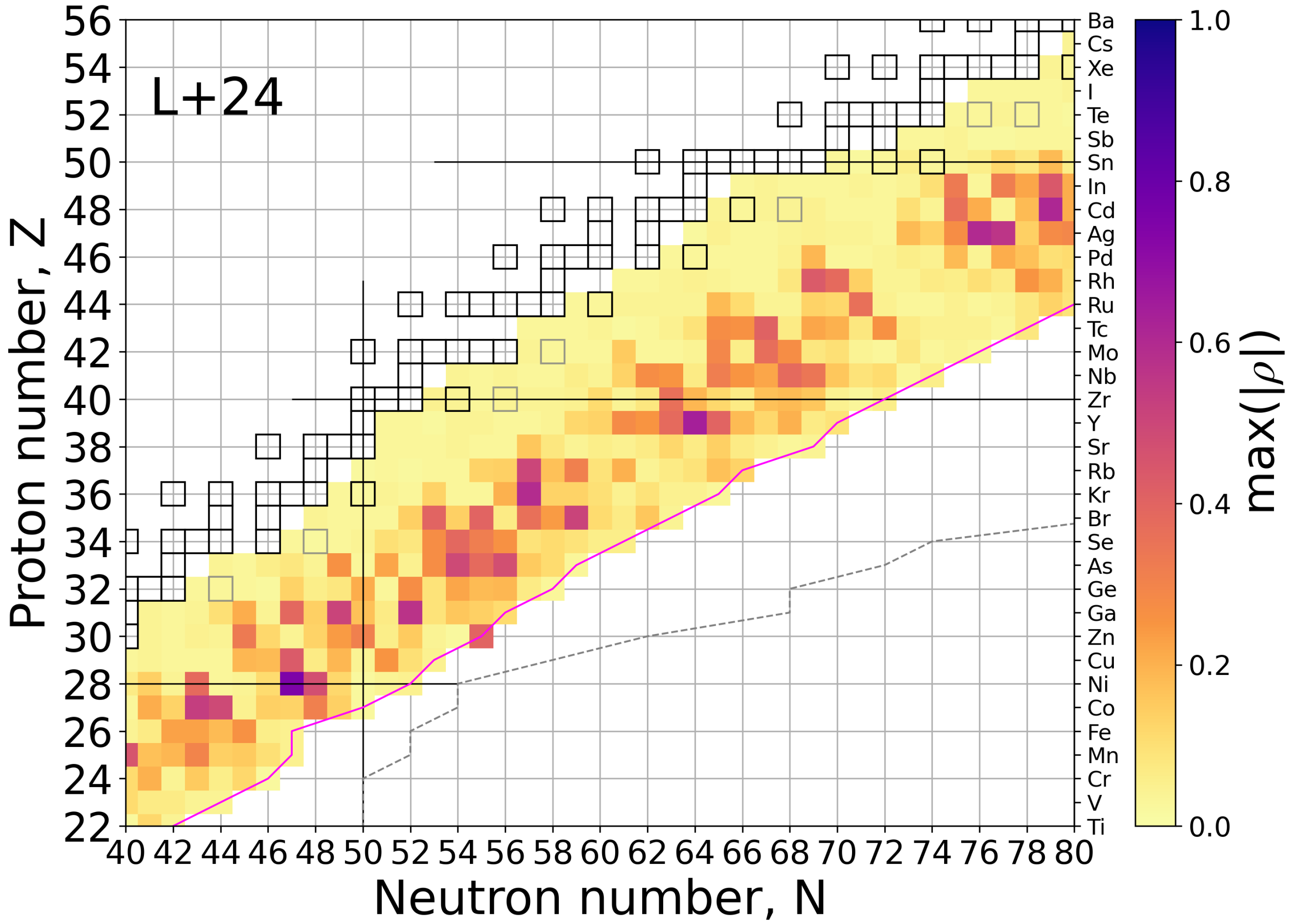


Figure from Atul Kedia (NCSU)
arXiv:2602.12428
(under review for PRC)

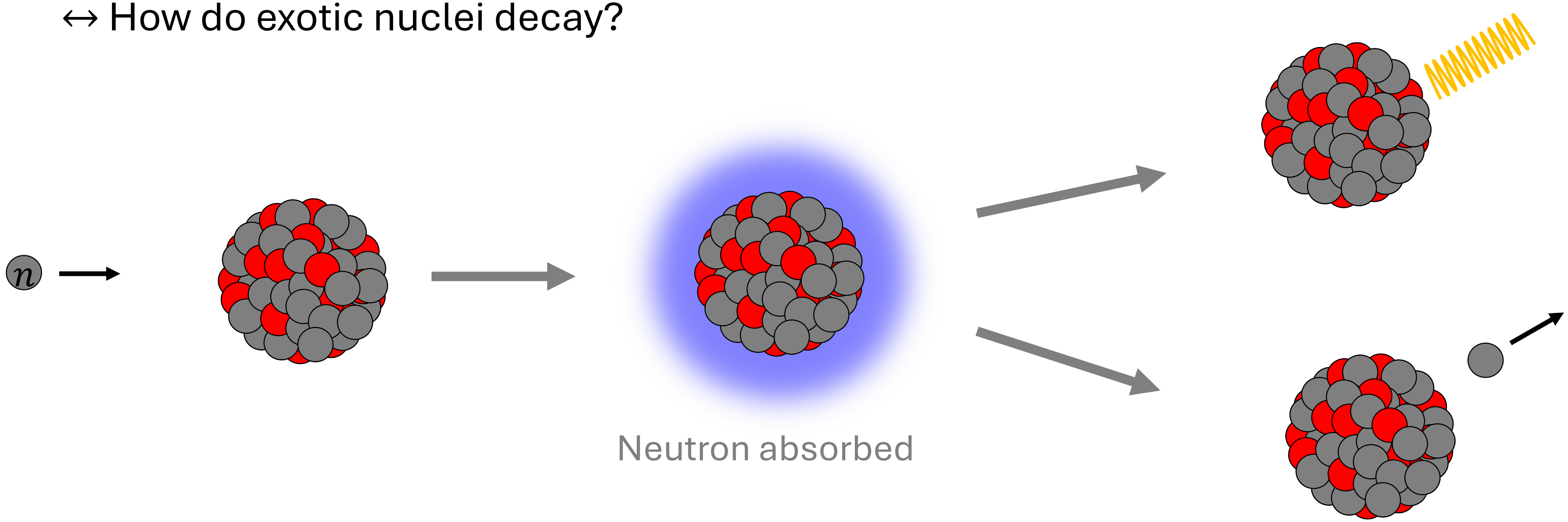
*neutron optical model

LLNL-CFPRES-2021587

The other inputs for nuclear reactions

Need to know: How do exotic nuclei get heavier?

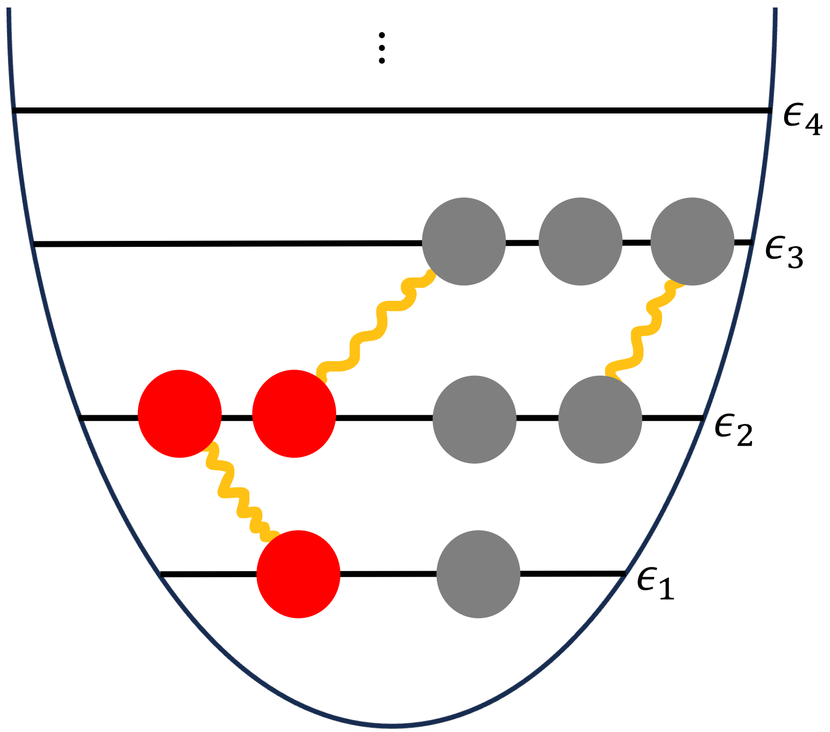
↔ How do exotic nuclei decay?

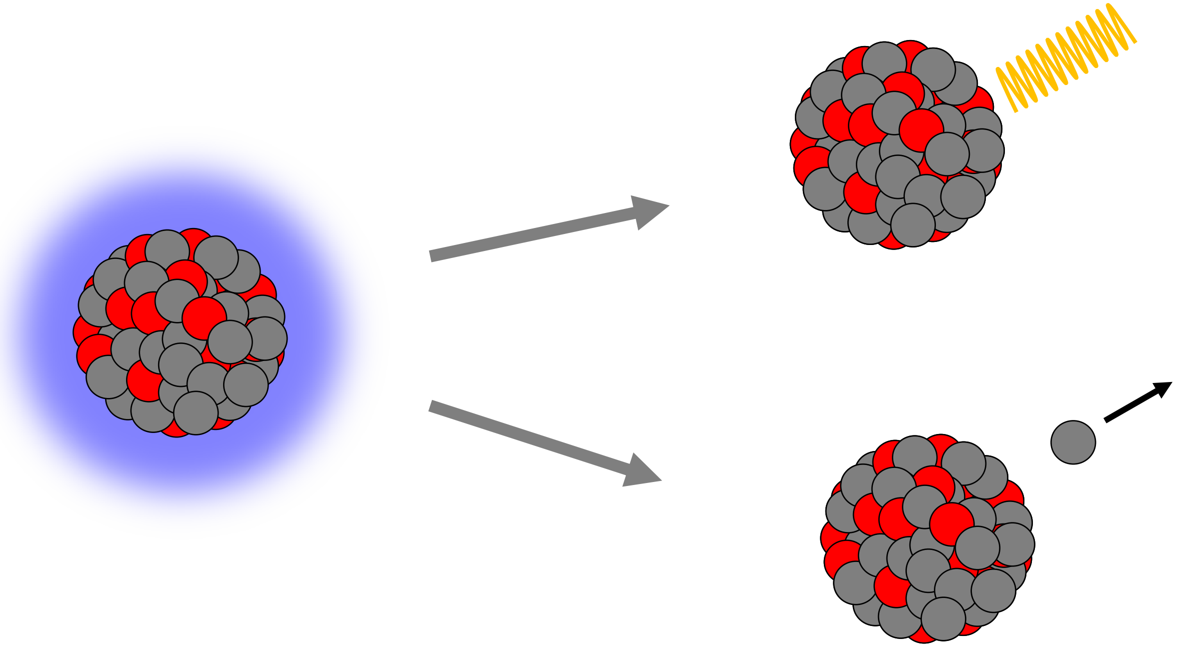


Optical model

Radiative strength functions,
Level densities,
Optical model

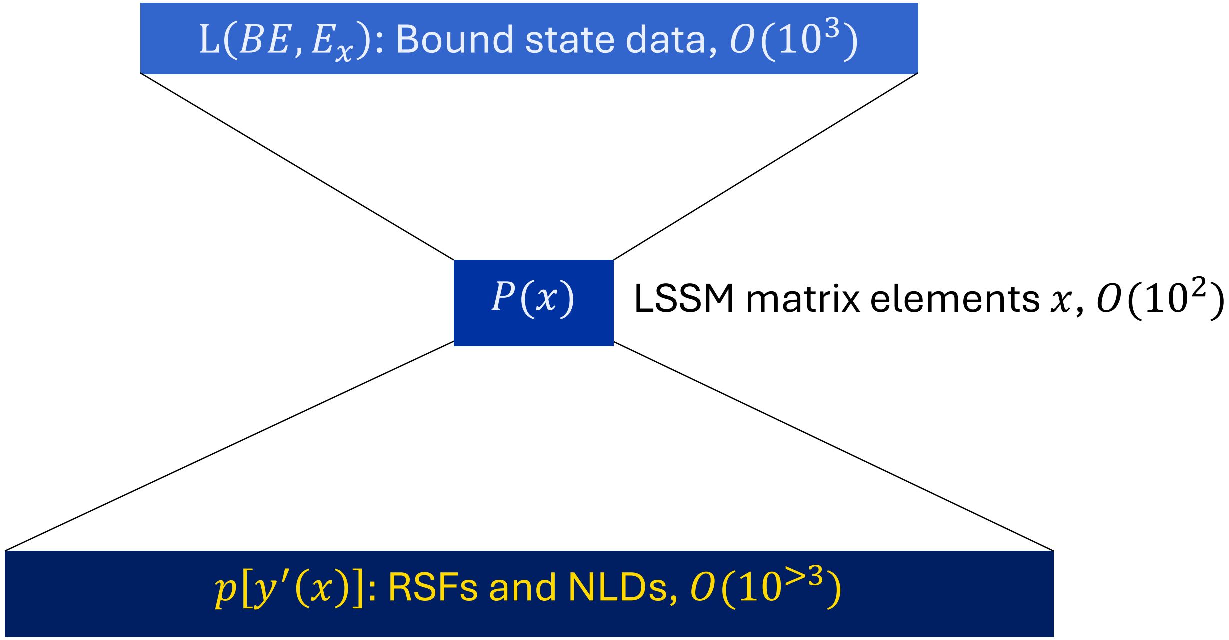
Large-scale nuclear shell model (LSSM) can provide these inputs





Radiative strength functions,
Level densities,
Optical model

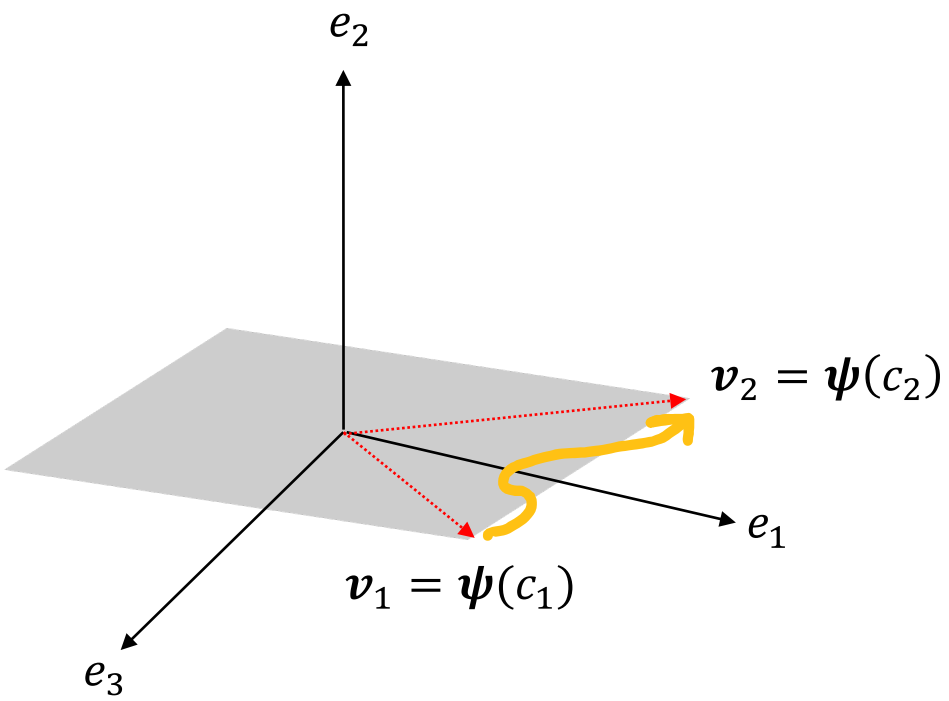
Physics-informed UQ from shell model: learn physical parameters, predict observables

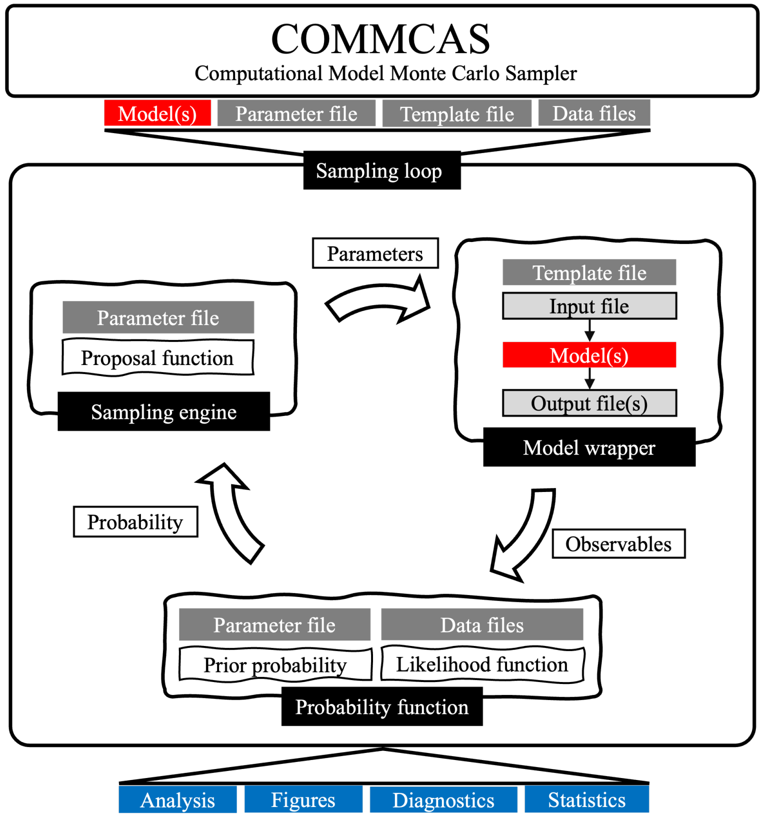


Gorton, Kravvaris PRC 112, 014302 (2025)

Reduced-order models (eigenvector continuation) accelerate MCMC parameter inference

Shell model emulator + **MCMC parameter inference**

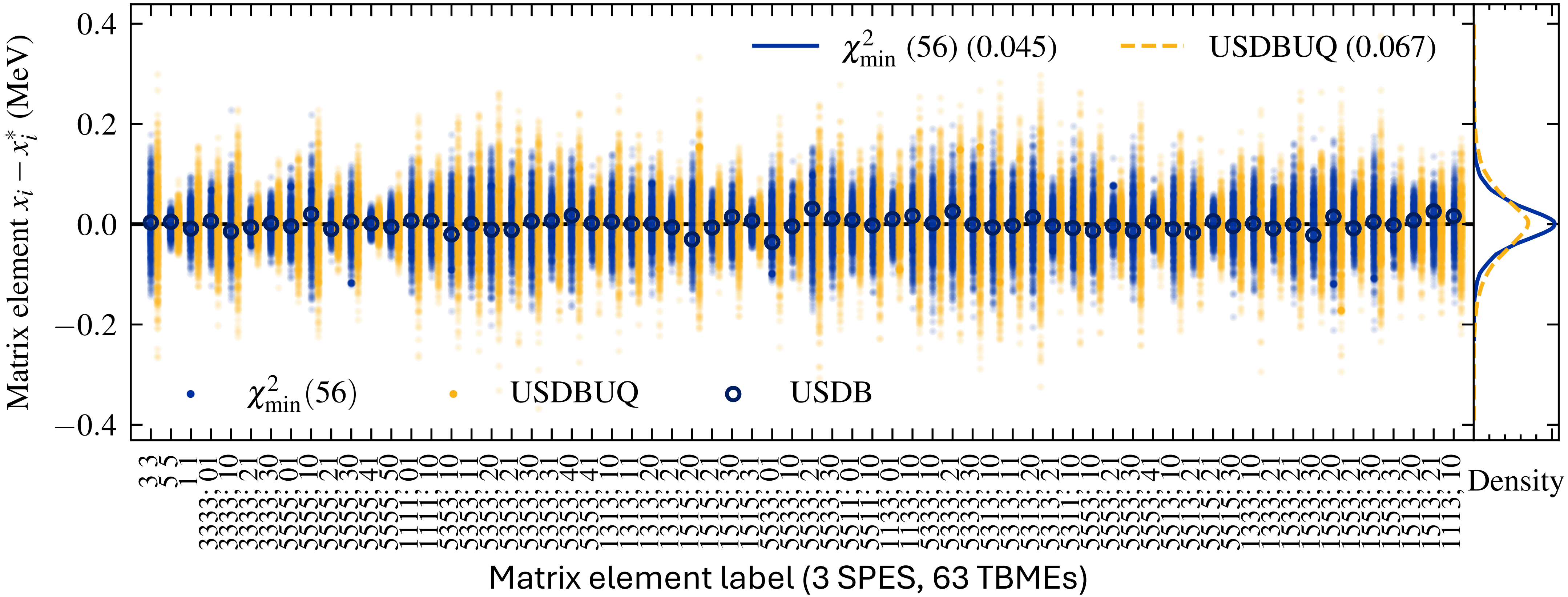




Gorton, Kravvaris PRC 112, 014302 (2025)

We published the first shell model interaction with uncertainties

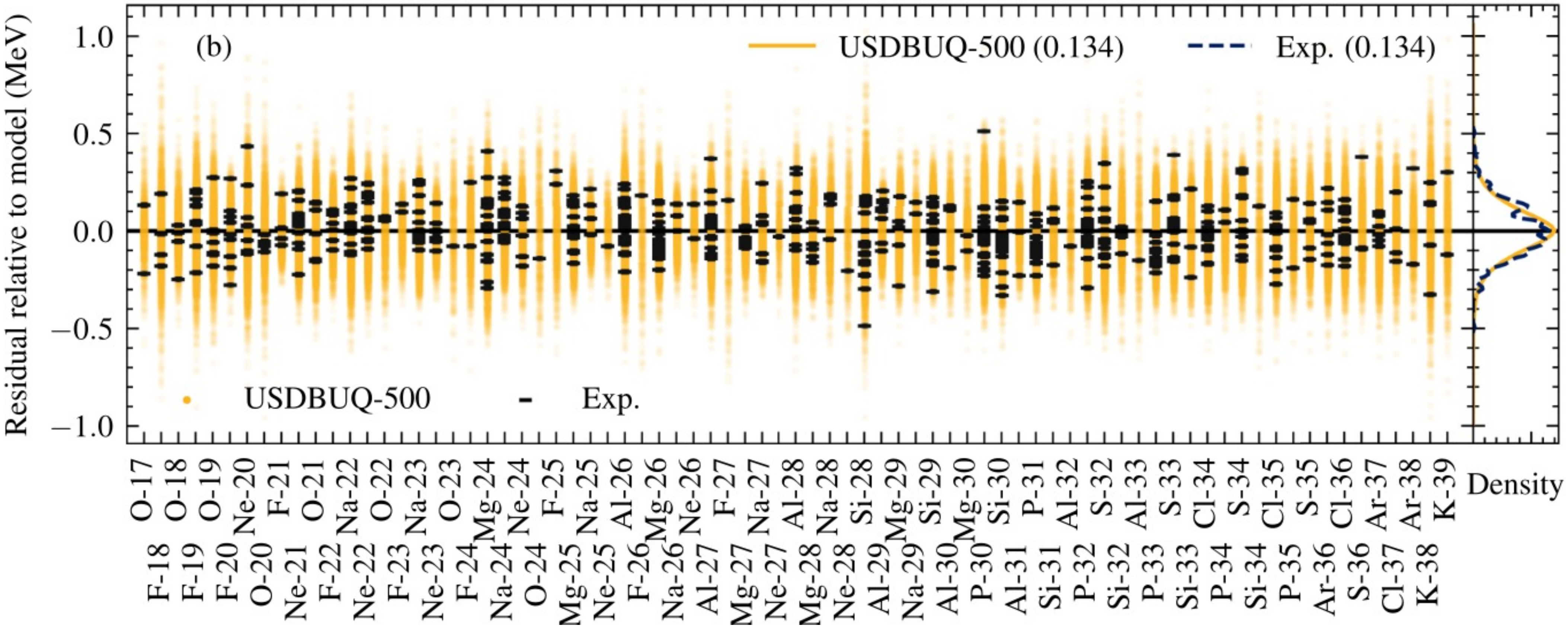
Distribution of effective-interaction matrix elements



Gorton, Kravvaris PRC 112, 014302 (2025)

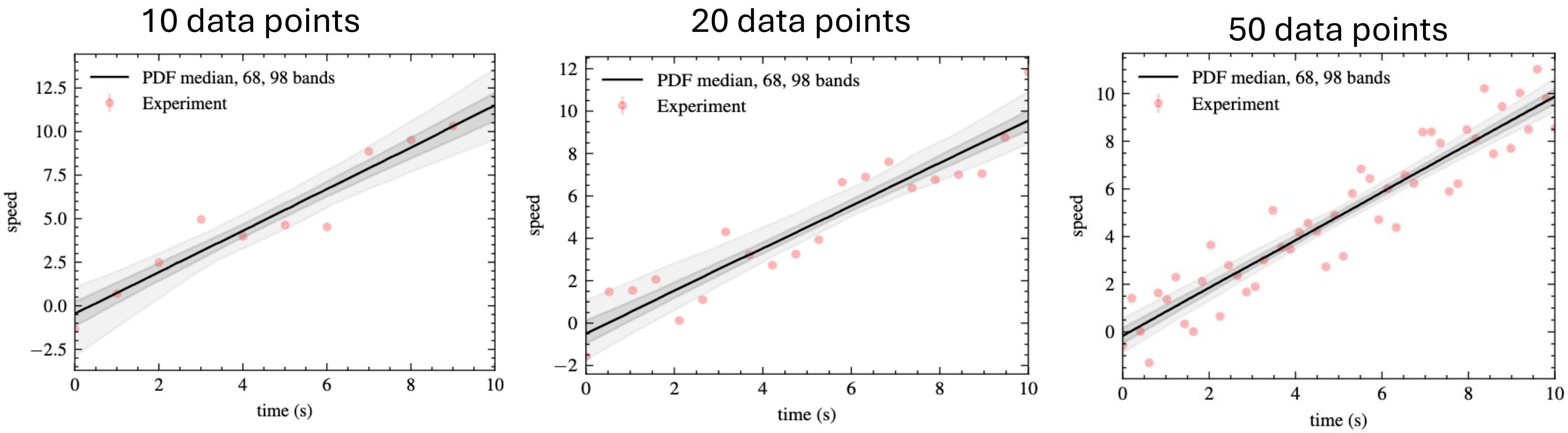
We published the first shell model interaction with uncertainties

Distribution of energy-level predictions



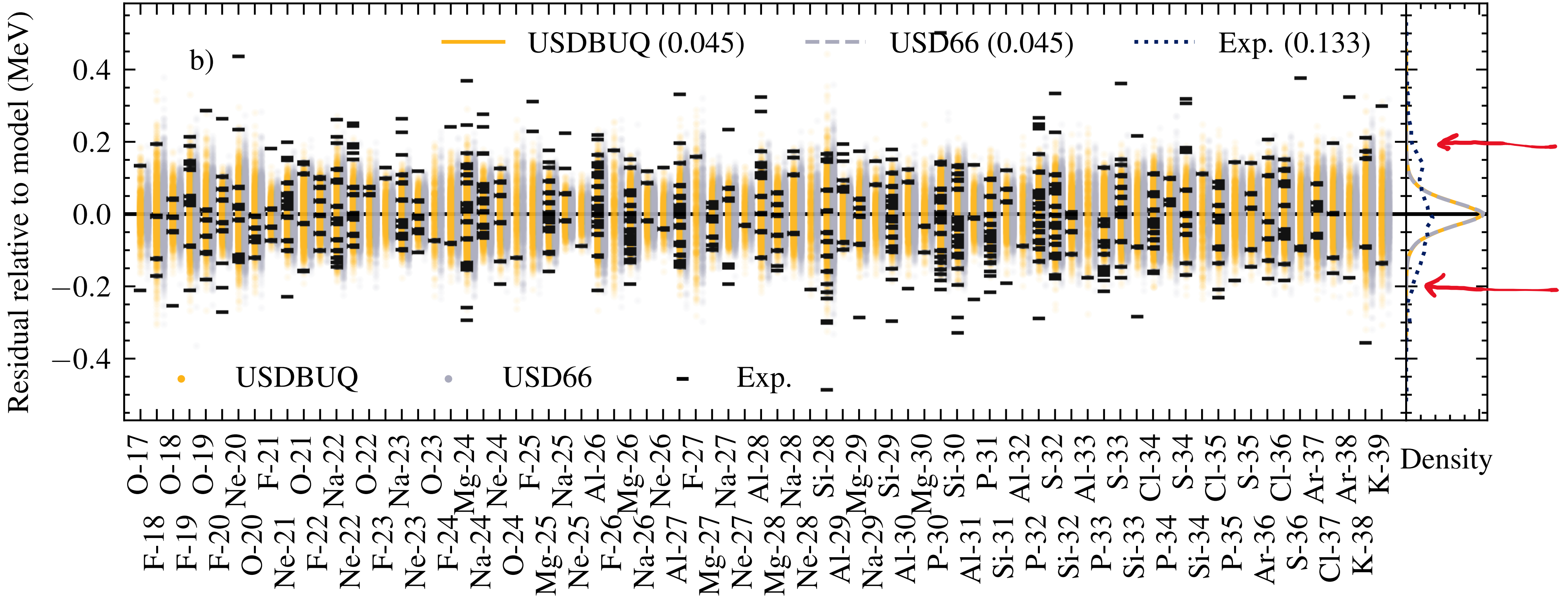
Gorton, Kravvaris PRC 112, 014302 (2025)

With uncorrelated noisy measurements, **confidence intervals shrink** with number of data



“Noise from flawed measurements are washed out”

Residual is dominated by *systematic* and *correlated* model defect, NOT noisy measurement!



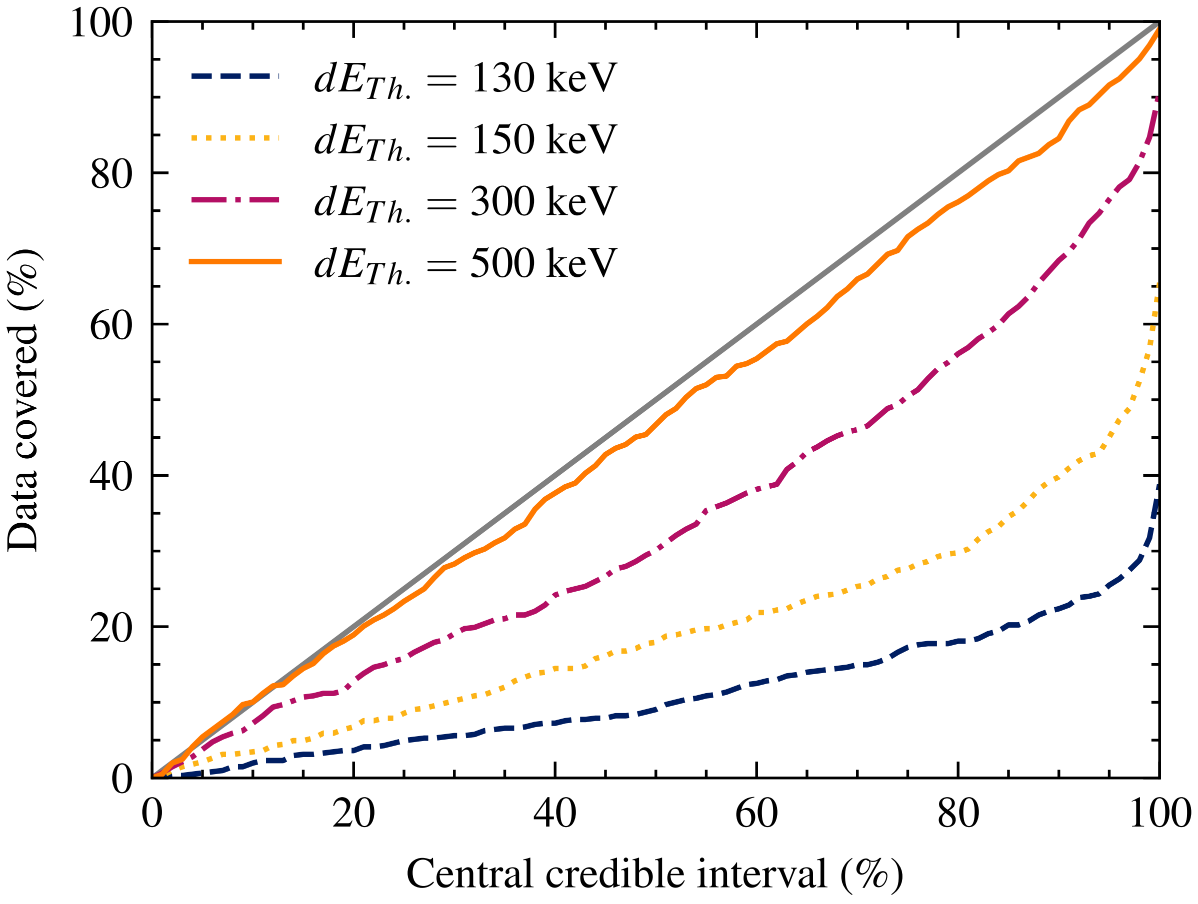
$$\sigma_i^2 = \sigma_i^2(Experiment) + \sigma_i^2(Theory)$$

a few keV << 130 keV

We do NOT want **confidence intervals** to decrease with # of data

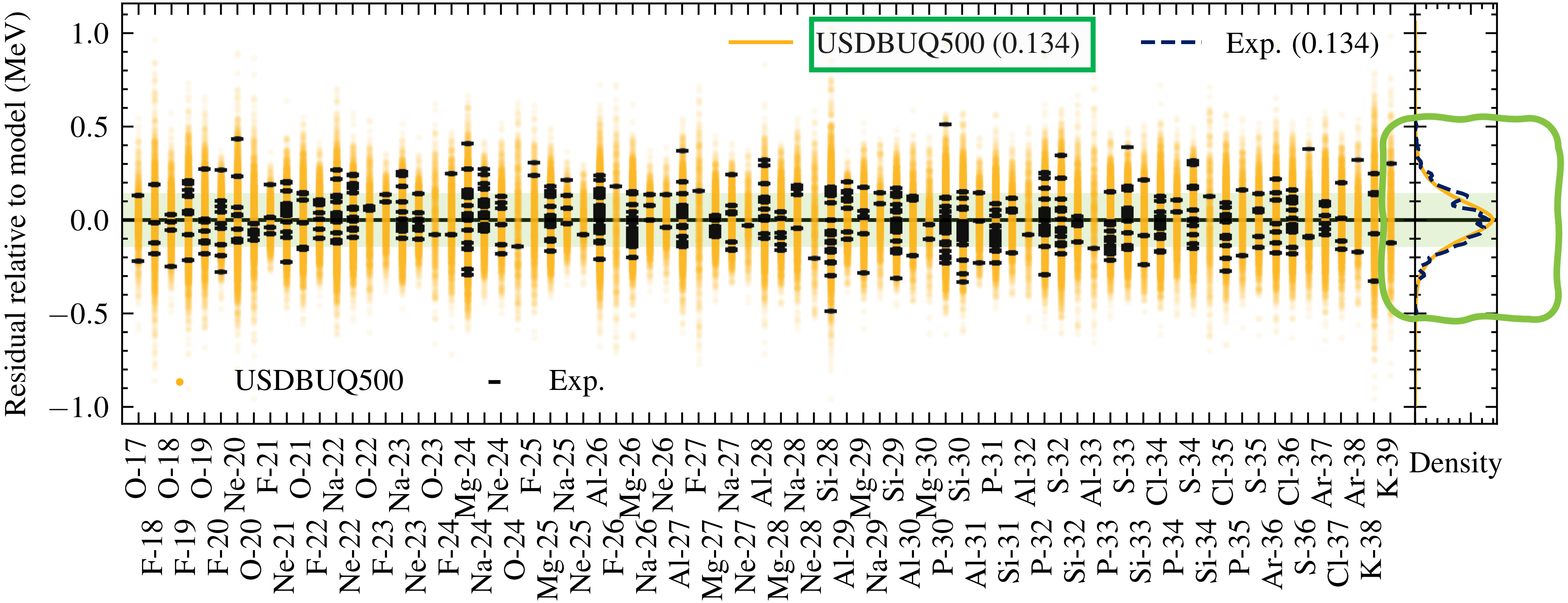
This sets the size of error bars

Working solution: empirical data coverage test



Does this mean the Shell model uncertainty is 500 keV instead of 130 keV?

Takeaway: be careful when applying “textbook” statistics to real problems



500 keV is not actual uncertainty

USDBUQ500 stat sheet

Standard error of **random prediction**:

- 190 keV (USDB is 130 keV)

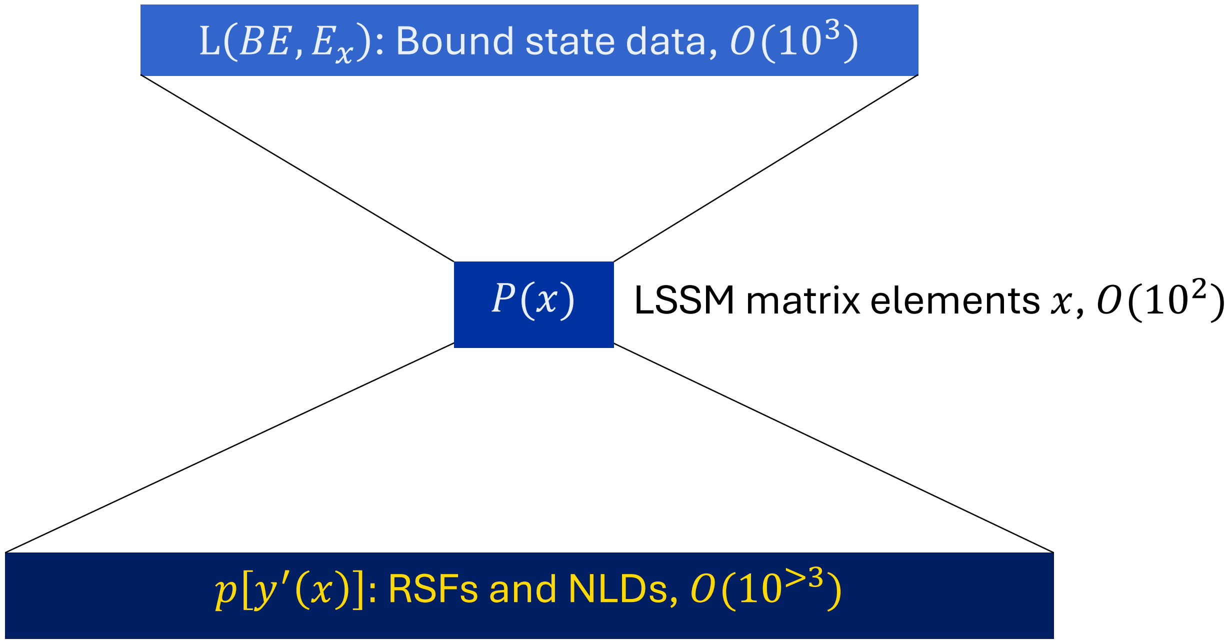
Standard error of **averaged prediction:**

- 134 keV

Average half-width of **error bar**:

- 134 keV

Physics-informed UQ from shell model: learn physical parameters, predict observables

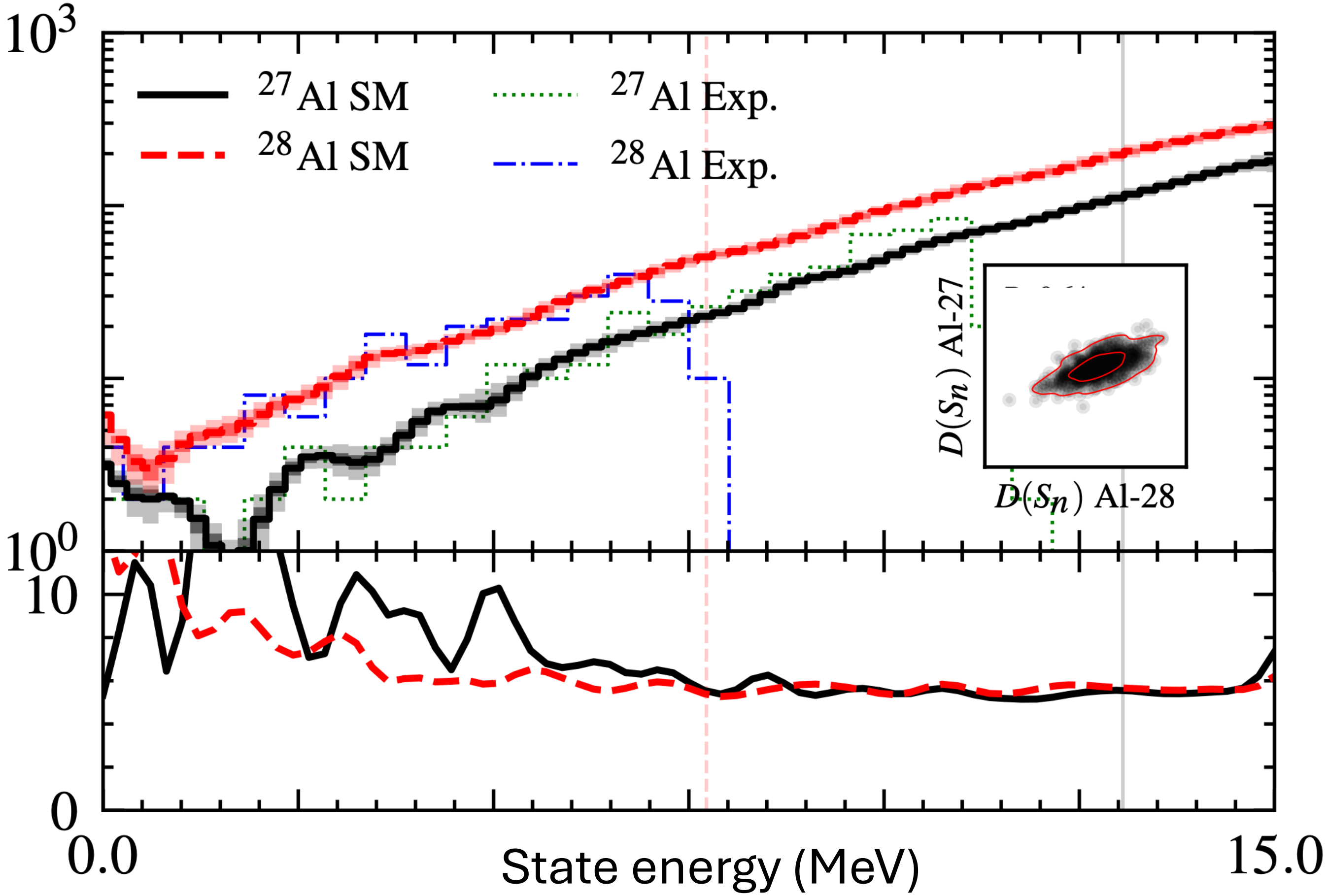


Gorton, Kravvaris PRC 112, 014302 (2025)

Now we compute structure inputs for reactions: **Nuclear Level Densities (NLDs)**

Density of states
(1/MeV)

Predicted uncertainty
(%)

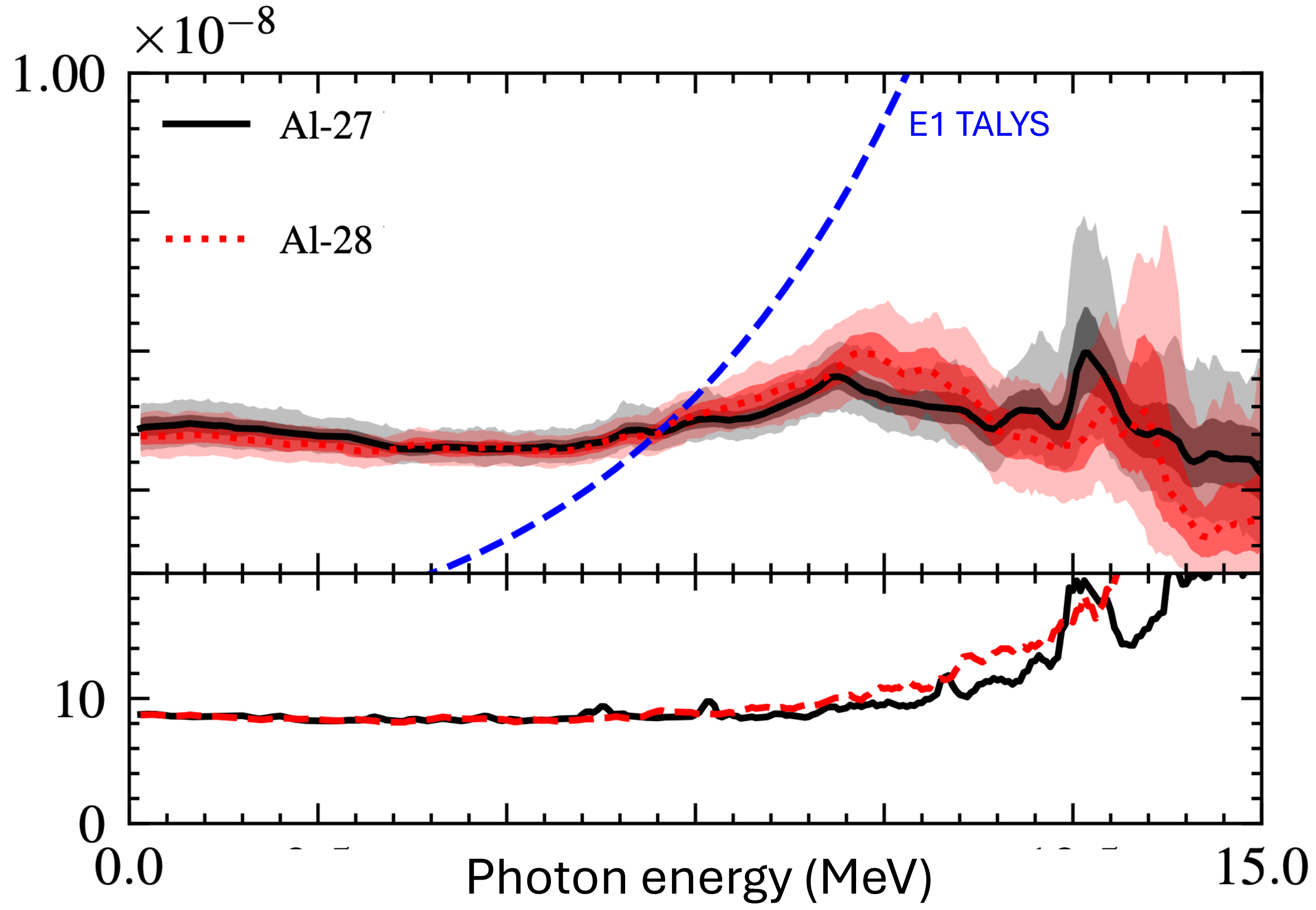


Gorton and Kravvaris (2026) arXiv:2604:09935

Now we compute structure inputs for reactions: **Radiative Strength Functions (RSFs)**

Photon strength function
(1/MeV³)

Predicted uncertainty
(%)



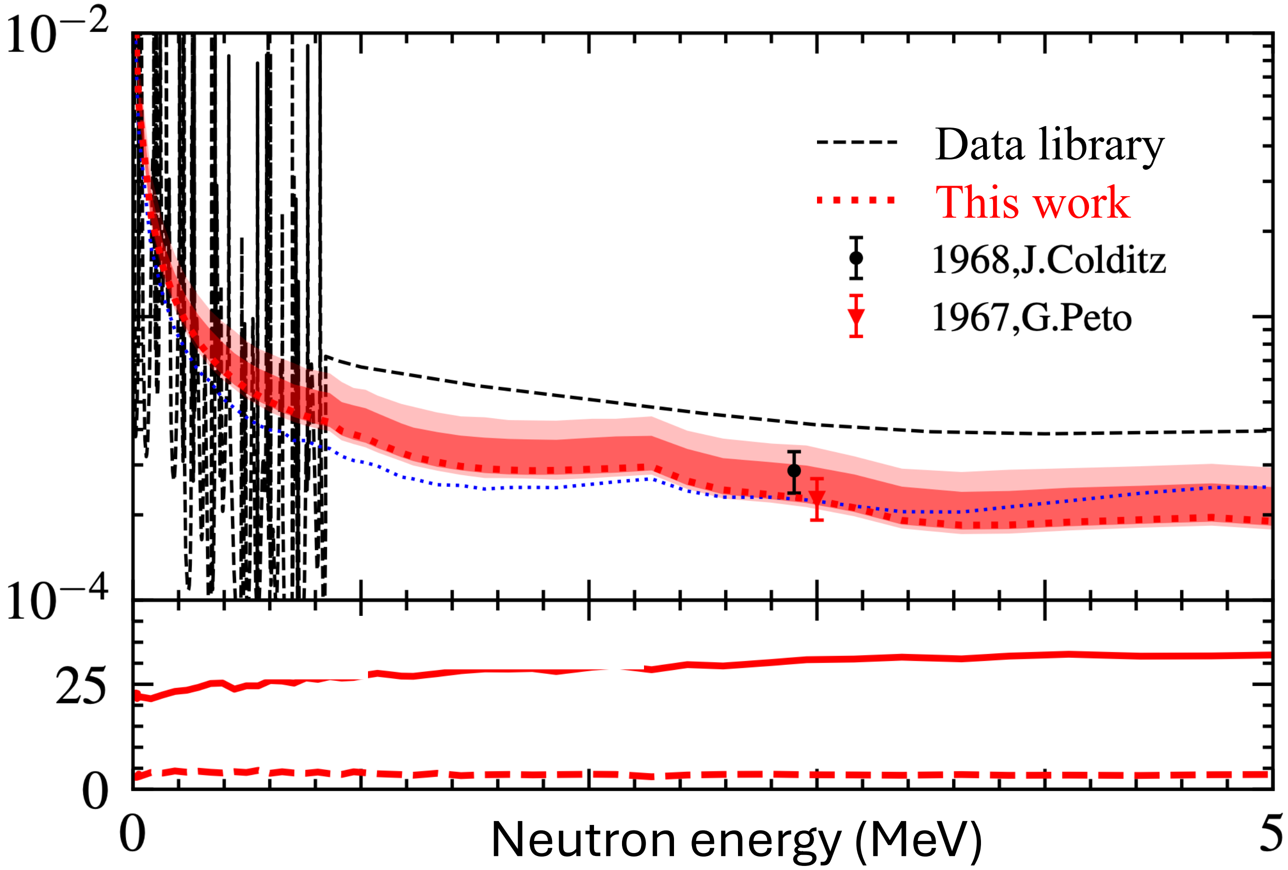
Gorton and Kravvaris (2026) arXiv:2604:09935

Developing workflows to propagate uncertainty from microscopic theory to applications

Capture cross section
(10^{-24} cm^2)

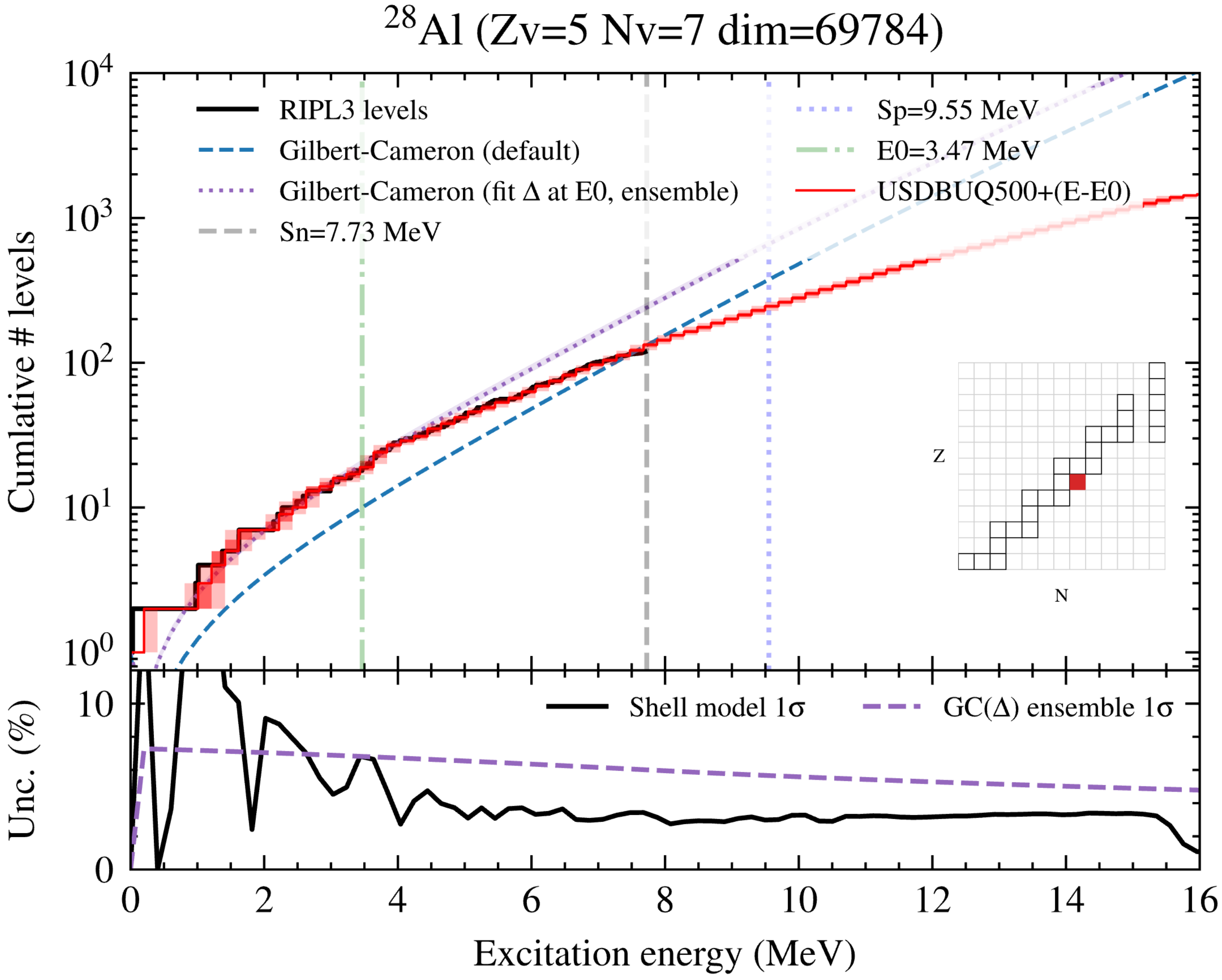
Modern
statistical methods
enhance credibility

Predicted uncertainty
(%)



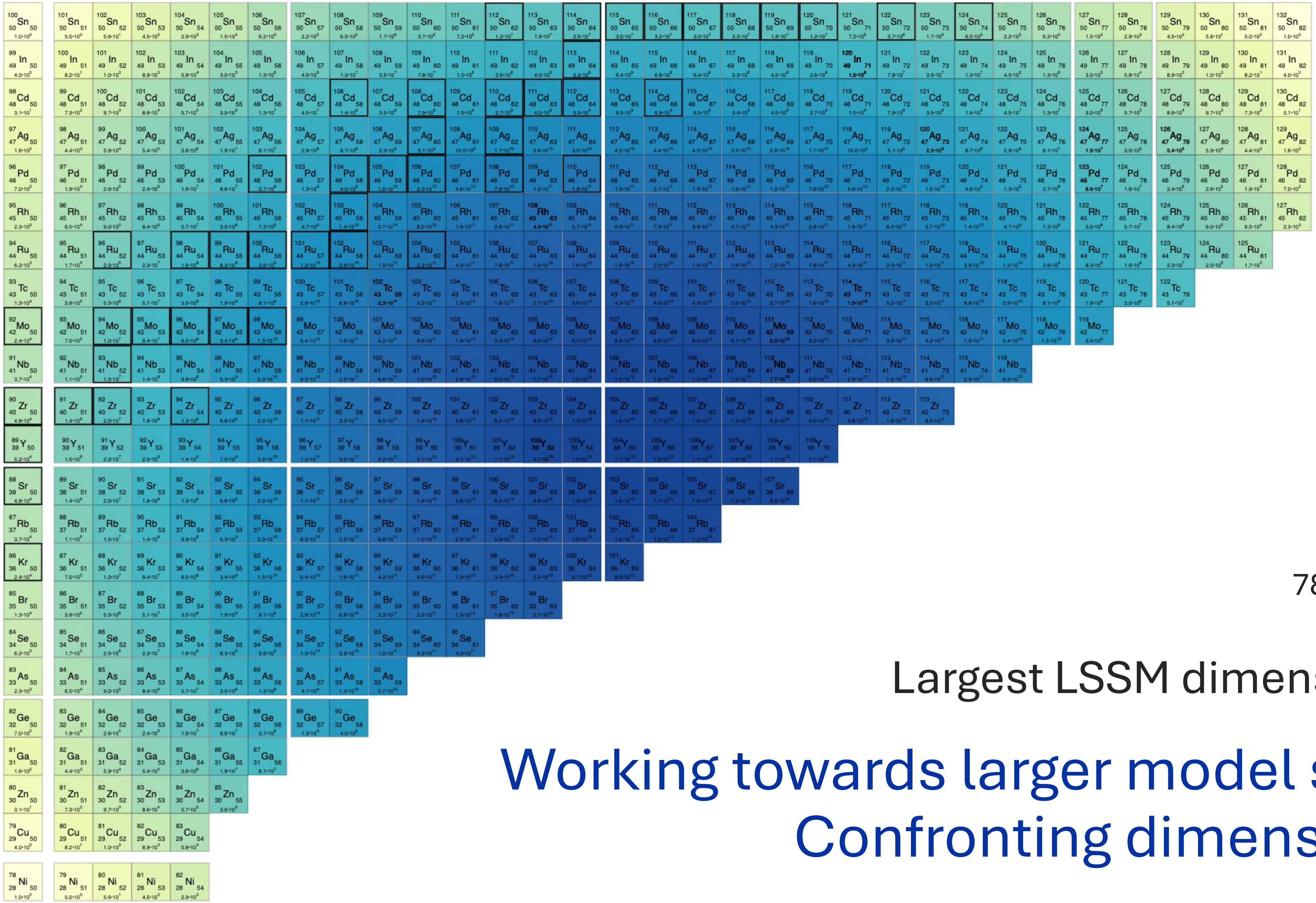
Gorton and Kravvaris (2026) arXiv:2604:09935

Hybrid approach to level densities



sd shell

Z \ N	8	9	10	11	12	13	14	15	16	17	18	19	20
Ca (20)								^{35}Ca $1.2\cdot10^{2}$	^{36}Ca $8.1\cdot10^{1}$	^{37}Ca $3.7\cdot10^{1}$	^{38}Ca $1.4\cdot10^{1}$	^{39}Ca $3.0\cdot10^{0}$	^{40}Ca $1.0\cdot10^{0}$
K (19)					^{31}K $8.2\cdot10^{2}$				^{35}K $8.2\cdot10^{2}$	^{36}K $3.9\cdot10^{2}$	^{37}K $1.3\cdot10^{2}$	^{38}K $2.8\cdot10^{1}$	^{39}K $3.0\cdot10^{0}$
Ar (18)				^{29}Ar $1.9\cdot10^{3}$	^{30}Ar $4.2\cdot10^{3}$	^{31}Ar $6.5\cdot10^{3}$	^{32}Ar $7.6\cdot10^{3}$	^{33}Ar $6.5\cdot10^{3}$	^{34}Ar $4.2\cdot10^{3}$	^{35}Ar $1.9\cdot10^{3}$	^{36}Ar $6.4\cdot10^{2}$	^{37}Ar $1.3\cdot10^{2}$	^{38}Ar $1.4\cdot10^{1}$
Cl (17)				^{28}Cl $6.1\cdot10^{3}$	^{29}Cl $1.3\cdot10^{4}$	^{30}Cl $2.1\cdot10^{4}$	^{31}Cl $2.4\cdot10^{4}$	^{32}Cl $2.1\cdot10^{4}$	^{33}Cl $1.3\cdot10^{4}$	^{34}Cl $6.1\cdot10^{3}$	^{35}Cl $1.9\cdot10^{3}$	^{36}Cl $3.9\cdot10^{2}$	^{37}Cl $3.7\cdot10^{1}$
S (16)			^{26}S $4.2\cdot10^{3}$	^{27}S $1.3\cdot10^{4}$	^{28}S $2.9\cdot10^{4}$	^{29}S $4.4\cdot10^{4}$	^{30}S $5.2\cdot10^{4}$	^{31}S $4.4\cdot10^{4}$	^{32}S $2.9\cdot10^{4}$	^{33}S $1.3\cdot10^{4}$	^{34}S $4.2\cdot10^{3}$	^{35}S $8.2\cdot10^{2}$	^{36}S $8.1\cdot10^{1}$
P (15)			^{25}P $6.5\cdot10^{3}$	^{26}P $2.1\cdot10^{4}$	^{27}P $4.4\cdot10^{4}$	^{28}P $7.0\cdot10^{4}$	^{29}P $8.0\cdot10^{4}$	^{30}P $7.0\cdot10^{4}$	^{31}P $4.4\cdot10^{4}$	^{32}P $2.1\cdot10^{4}$	^{33}P $6.5\cdot10^{3}$	^{34}P $1.3\cdot10^{3}$	^{35}P $1.2\cdot10^{2}$
Si (14)	^{22}Si $1.4\cdot10^{2}$	^{23}Si $1.5\cdot10^{3}$	^{24}Si $7.6\cdot10^{3}$	^{25}Si $2.4\cdot10^{4}$	^{26}Si $5.2\cdot10^{4}$	^{27}Si $8.0\cdot10^{4}$	^{28}Si $9.4\cdot10^{4}$	^{29}Si $8.0\cdot10^{4}$	^{30}Si $5.2\cdot10^{4}$	^{31}Si $2.4\cdot10^{4}$	^{32}Si $7.6\cdot10^{3}$	^{33}Si $1.5\cdot10^{3}$	^{34}Si $1.4\cdot10^{2}$
Al (13)	^{21}Al $1.2\cdot10^{2}$	^{22}Al $1.3\cdot10^{3}$	^{23}Al $6.5\cdot10^{3}$	^{24}Al $2.1\cdot10^{4}$	^{25}Al $4.4\cdot10^{4}$	^{26}Al $7.0\cdot10^{4}$	^{27}Al $8.0\cdot10^{4}$	^{28}Al $7.0\cdot10^{4}$	^{29}Al $4.4\cdot10^{4}$	^{30}Al $2.1\cdot10^{4}$	^{31}Al $6.5\cdot10^{3}$	^{32}Al $1.3\cdot10^{3}$	^{33}Al $1.2\cdot10^{2}$
Mg (12)	^{20}Mg $8.1\cdot10^{1}$	^{21}Mg $8.2\cdot10^{2}$	^{22}Mg $4.2\cdot10^{3}$	^{23}Mg $1.3\cdot10^{4}$	^{24}Mg $2.9\cdot10^{4}$	^{25}Mg $4.4\cdot10^{4}$	^{26}Mg $5.2\cdot10^{4}$	^{27}Mg $4.4\cdot10^{4}$	^{28}Mg $2.9\cdot10^{4}$	^{29}Mg $1.3\cdot10^{4}$	^{30}Mg $4.2\cdot10^{3}$	^{31}Mg $8.2\cdot10^{2}$	^{32}Mg $8.1\cdot10^{1}$
Na (11)	^{19}Na $3.7\cdot10^{1}$	^{20}Na $3.9\cdot10^{2}$	^{21}Na $1.9\cdot10^{3}$	^{22}Na $6.1\cdot10^{3}$	^{23}Na $1.3\cdot10^{4}$	^{24}Na $2.1\cdot10^{4}$	^{25}Na $2.4\cdot10^{4}$	^{26}Na $2.1\cdot10^{4}$	^{27}Na $1.3\cdot10^{4}$	^{28}Na $6.1\cdot10^{3}$	^{29}Na $1.9\cdot10^{3}$	^{30}Na $3.9\cdot10^{2}$	^{31}Na $3.7\cdot10^{1}$
Ne (10)	^{18}Ne $1.4\cdot10^{1}$	^{19}Ne $1.3\cdot10^{2}$	^{20}Ne $6.4\cdot10^{2}$	^{21}Ne $1.9\cdot10^{3}$	^{22}Ne $4.2\cdot10^{3}$	^{23}Ne $6.5\cdot10^{3}$	^{24}Ne $7.6\cdot10^{3}$	^{25}Ne $6.5\cdot10^{3}$	^{26}Ne $4.2\cdot10^{3}$	^{27}Ne $1.9\cdot10^{3}$	^{28}Ne $6.4\cdot10^{2}$	^{29}Ne $1.3\cdot10^{2}$	^{30}Ne $1.4\cdot10^{1}$
F (9)	^{17}F $3.0\cdot10^{0}$	^{18}F $2.8\cdot10^{1}$	^{19}F $1.3\cdot10^{2}$	^{20}F $3.9\cdot10^{2}$	^{21}F $8.2\cdot10^{2}$	^{22}F $1.3\cdot10^{3}$	^{23}F $1.5\cdot10^{3}$	^{24}F $1.3\cdot10^{3}$	^{25}F $8.2\cdot10^{2}$	^{26}F $3.9\cdot10^{2}$	^{27}F $1.3\cdot10^{2}$	^{28}F $2.8\cdot10^{1}$	^{29}F $3.0\cdot10^{0}$
O (8)	^{16}O $1.0\cdot10^{0}$	^{17}O $3.0\cdot10^{0}$	^{18}O $1.4\cdot10^{1}$	^{19}O $3.7\cdot10^{1}$	^{20}O $8.1\cdot10^{1}$	^{21}O $1.2\cdot10^{2}$	^{22}O $1.4\cdot10^{2}$	^{23}O $1.2\cdot10^{2}$	^{24}O $8.1\cdot10^{1}$	^{25}O $3.7\cdot10^{1}$	^{26}O $1.4\cdot10^{1}$		

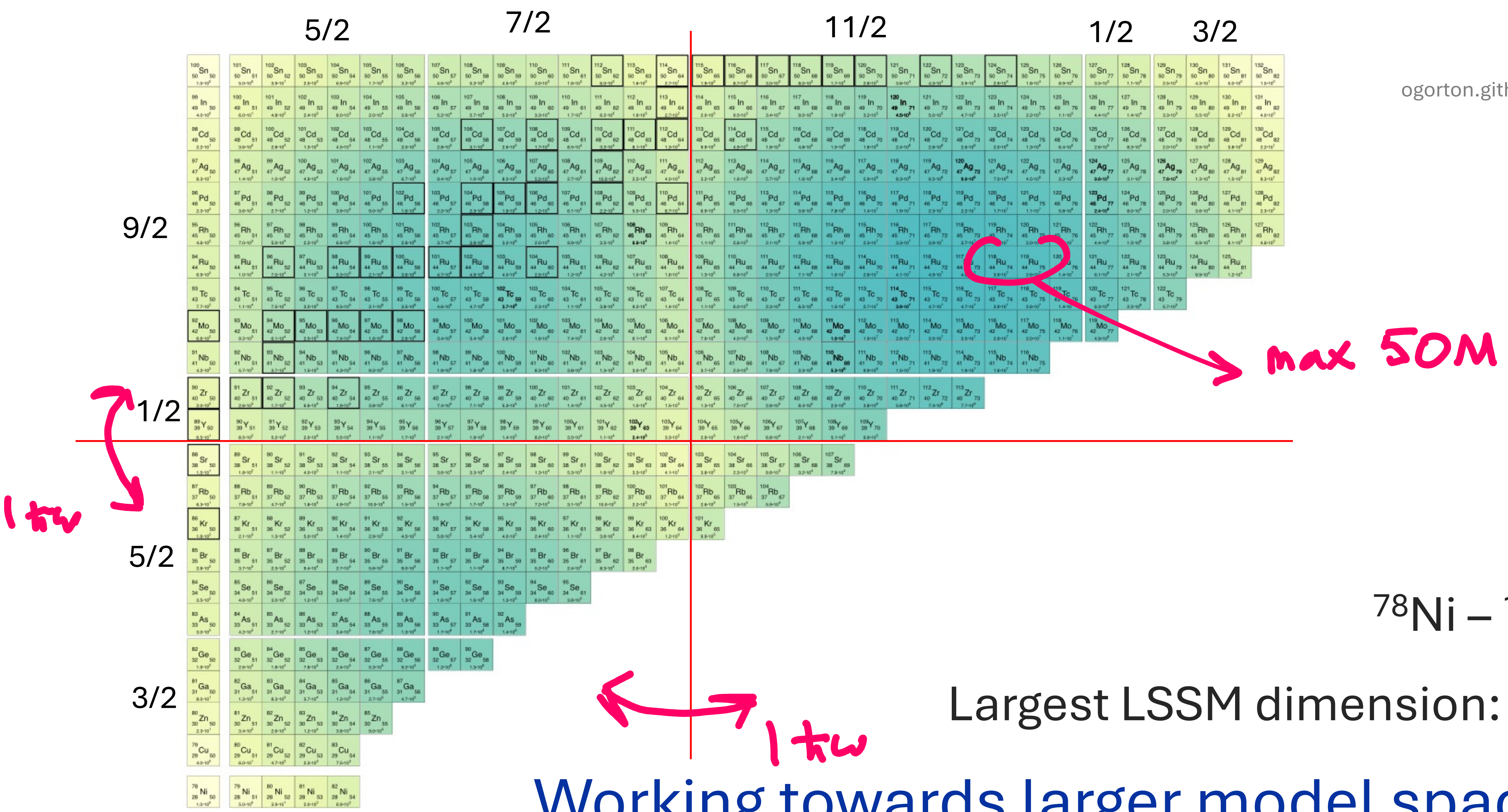


ogorton.github.io/nuclearchart

^{78}Ni – ^{132}Sn

Largest LSSM dimension: 10^{13}

Working towards larger model spaces; Confronting dimensionality



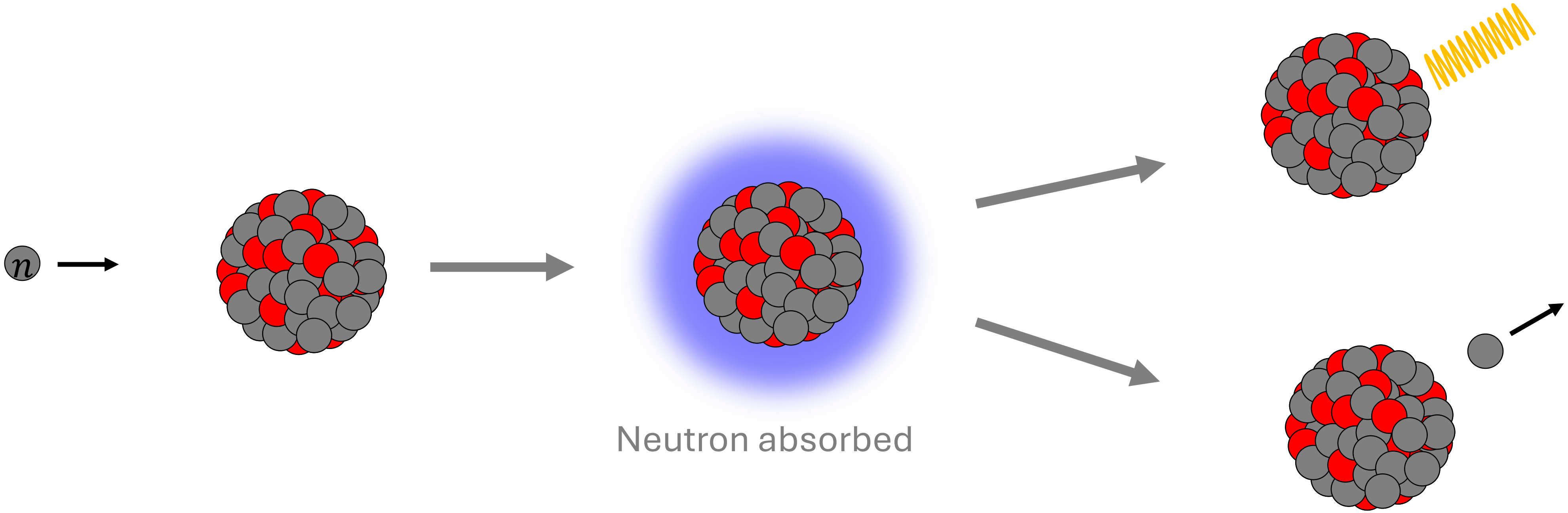
ogorton.github.io/nuclearchart

^{78}Ni – ^{132}Sn

Largest LSSM dimension: 10^{13}

Working towards larger model spaces; Confronting dimensionality

How to compute Radiative Strength Functions with the LSSM



Optical model

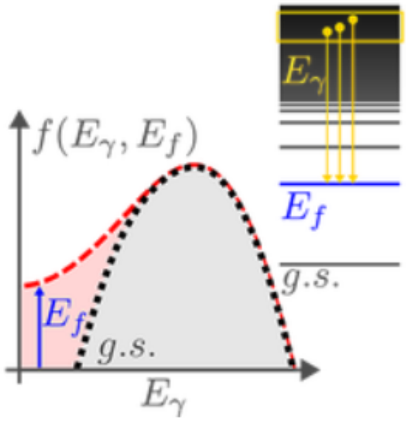
Radiative strength functions,
Level densities,
Optical model

EDITORS' SUGGESTION

Radiative strength functions from the energy-localized Brink-Axel hypothesis

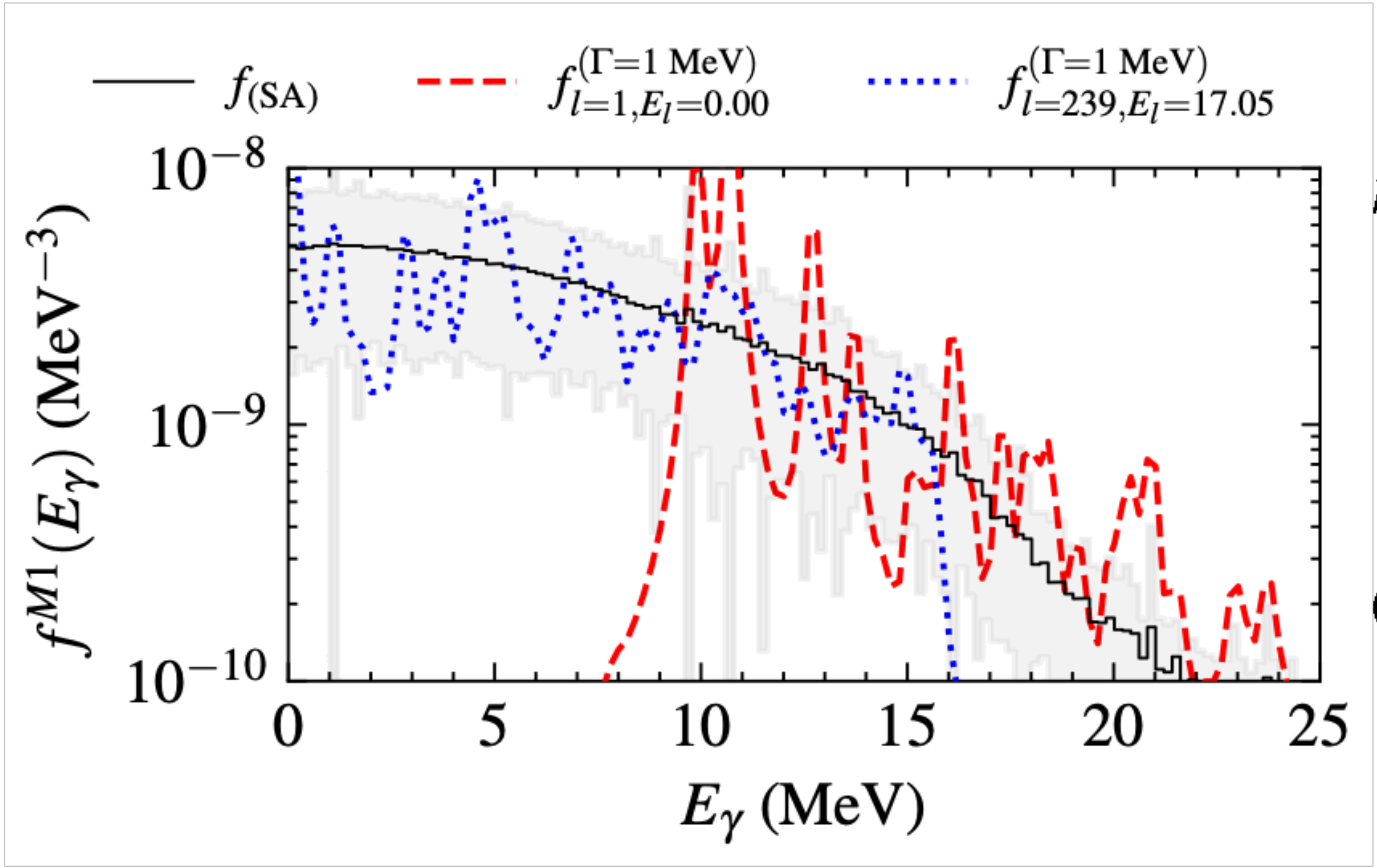
Oliver C. Gorton, Konstantinos Kravvaris, Jutta E. Escher, and Calvin W. Johnson

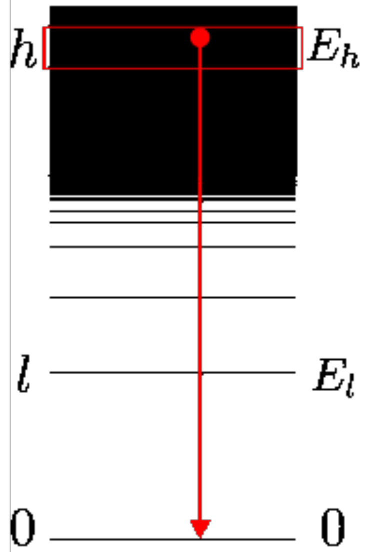
Phys. Rev. C **113**, 044327 (2026) - Published 29 April, 2026



Radiative strength functions (RSFs) are crucial inputs for statistical nuclear reaction codes but are difficult to calculate because they require wave functions of highly excited states. The authors used large-scale shell model calculations to identify a key result of the energy-localized Brink-Axel hypothesis: the shape of the RSF evolves smoothly with wave-function energy. Combined with an efficient Lanczos strength-function method, this insight leads to a practical new approach for computing RSFs which was validated for ^{24}Mg and provided novel results for ^{56}Fe. The method is expected to simplify RSF calculations while motivating the use of energy-dependent RSFs in modern reaction codes.

Radiative strength function depends on energy of residual state





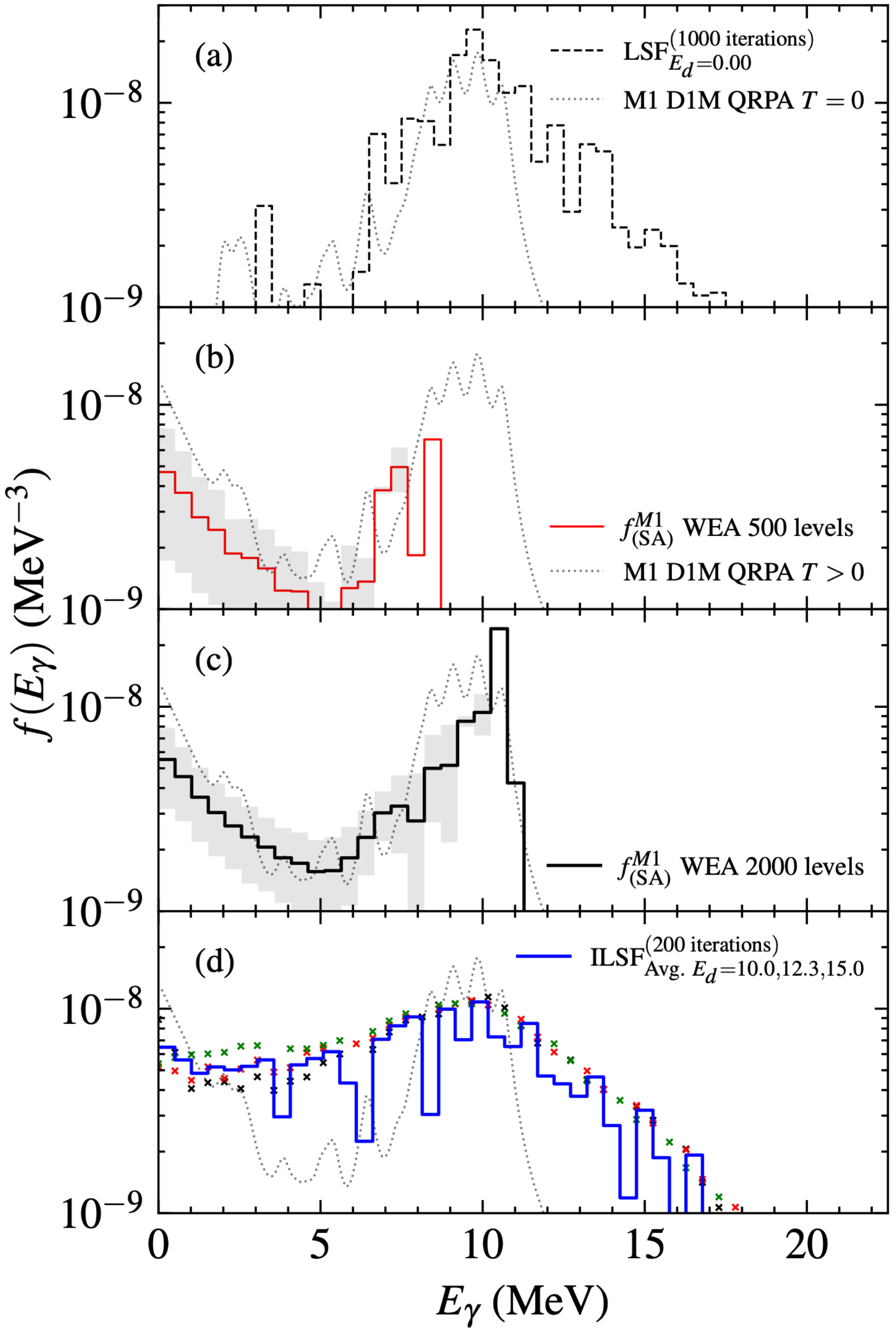
^{56}Fe M1 shape evoluation?

To ground state

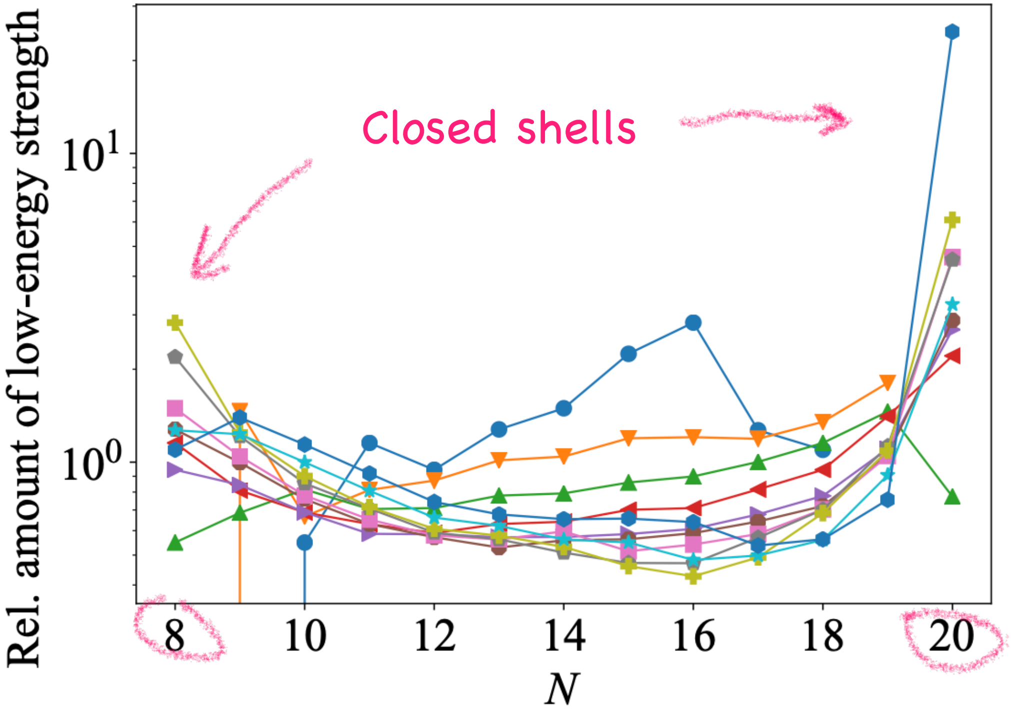
Average over first 500 levels

Average over first 2000 levels

Average over 3 high-energy levels



Evolution of low-energy M1 strength:
(1) nearness to closed shell
(2) restricted valence space



Midtbø, Larsen, et al. (2018)
PRC 98, 064321

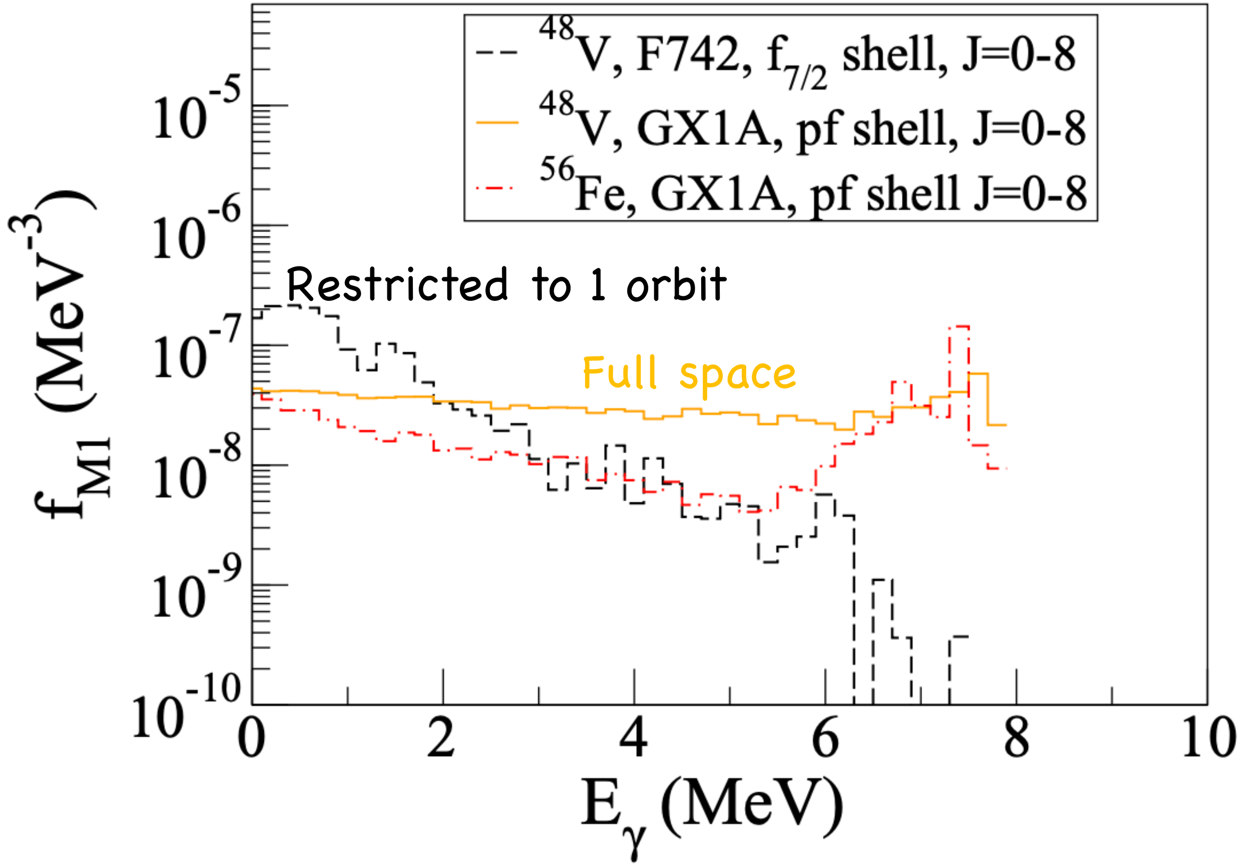
sd-shell: biggest M1 upturn near closed shells

LLNL-CFPRES-2021587

Evolution of low-energy M1 strength:

(1) nearness to closed shell

(2) restricted valence space



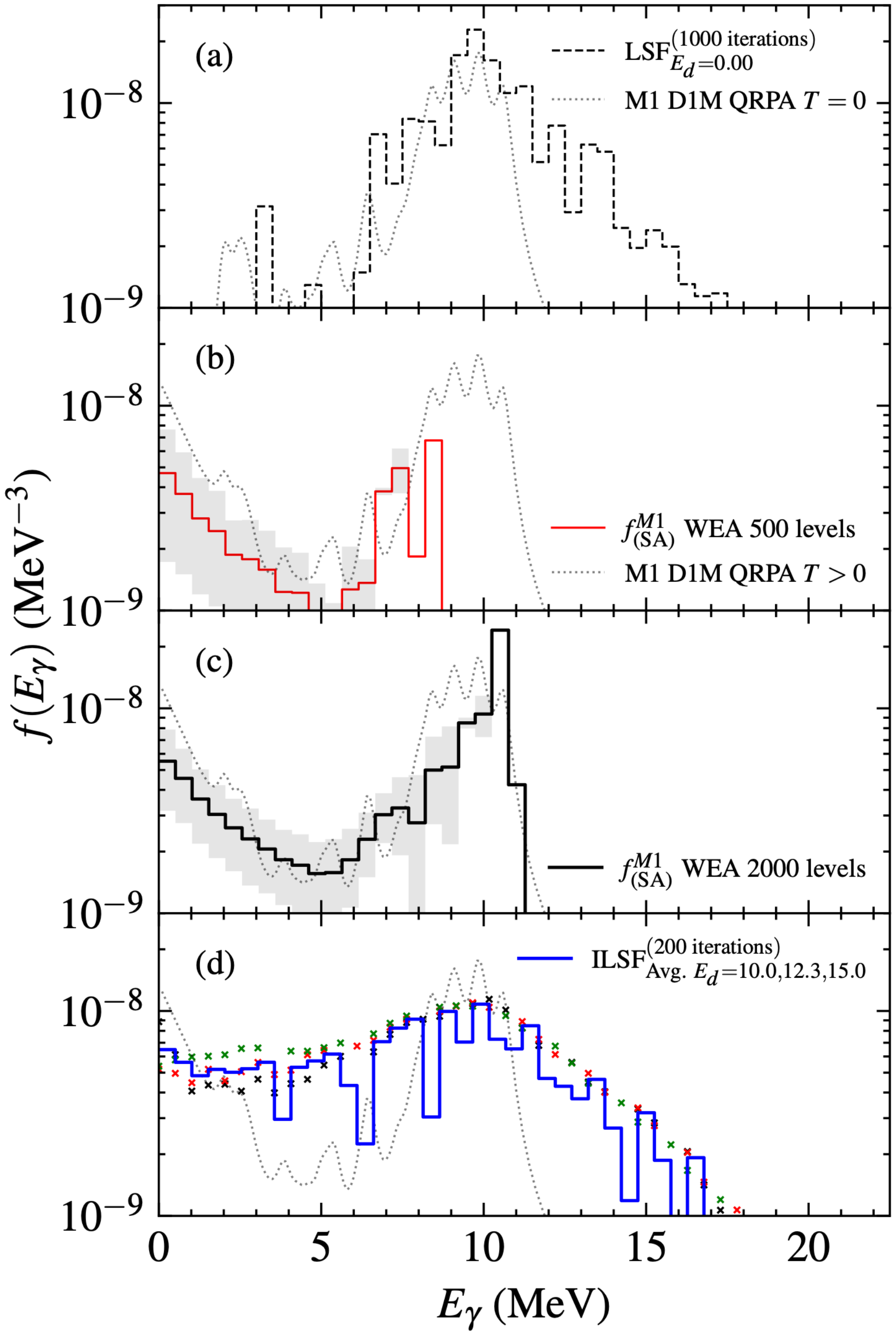
Karampagia, Brown, Zelevinsky (2017)
PRC 95, 024322

pf-shell: exponential shape damped by orbital mixing

M1 shape flattens with energy because single-particle orbits become entangled

^{56}Fe

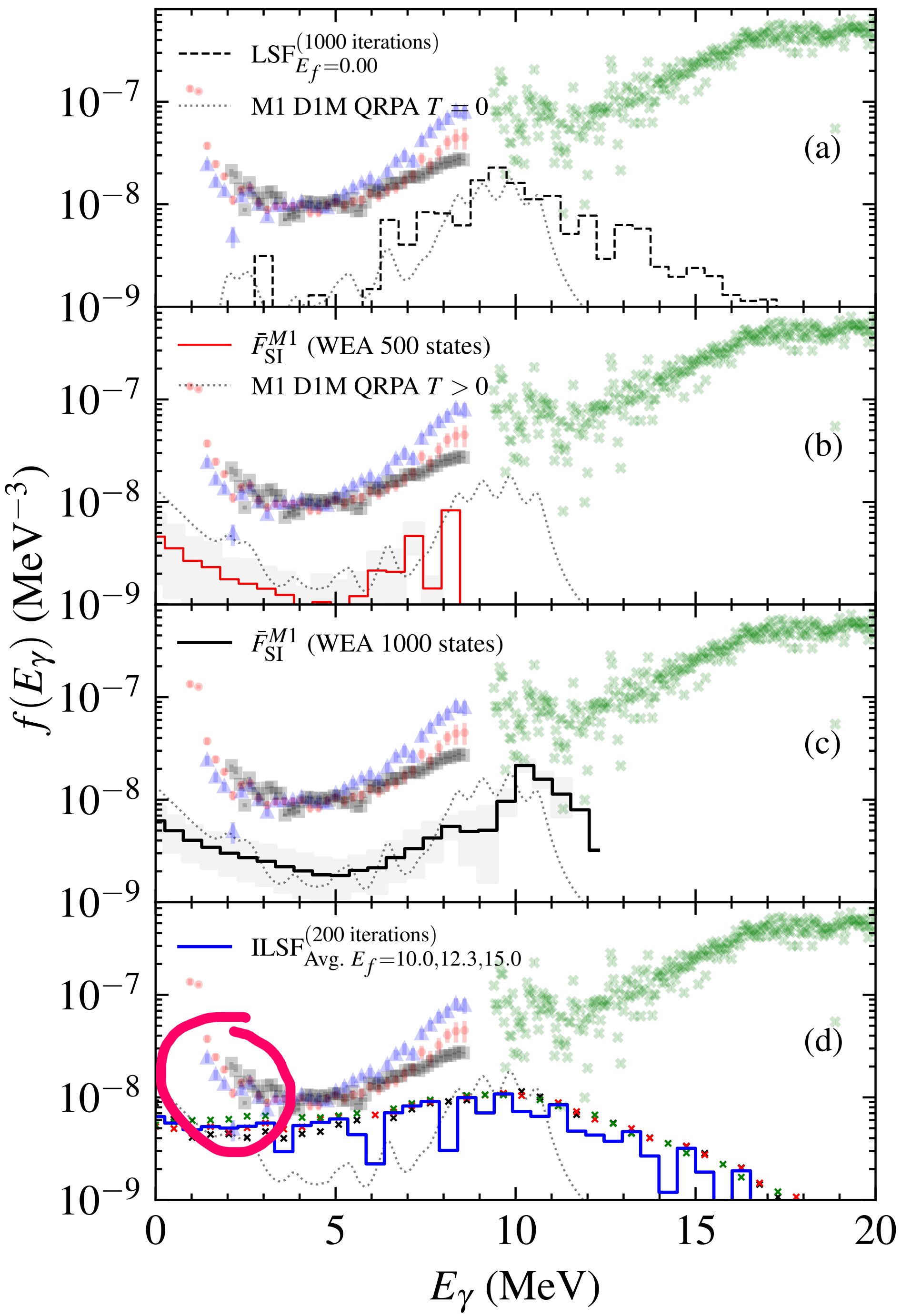
Strength flattens when decaying to excited states



What about the Oslo-type data?

^{56}Fe

M1 cannot explain observed up-turn according to LSSM



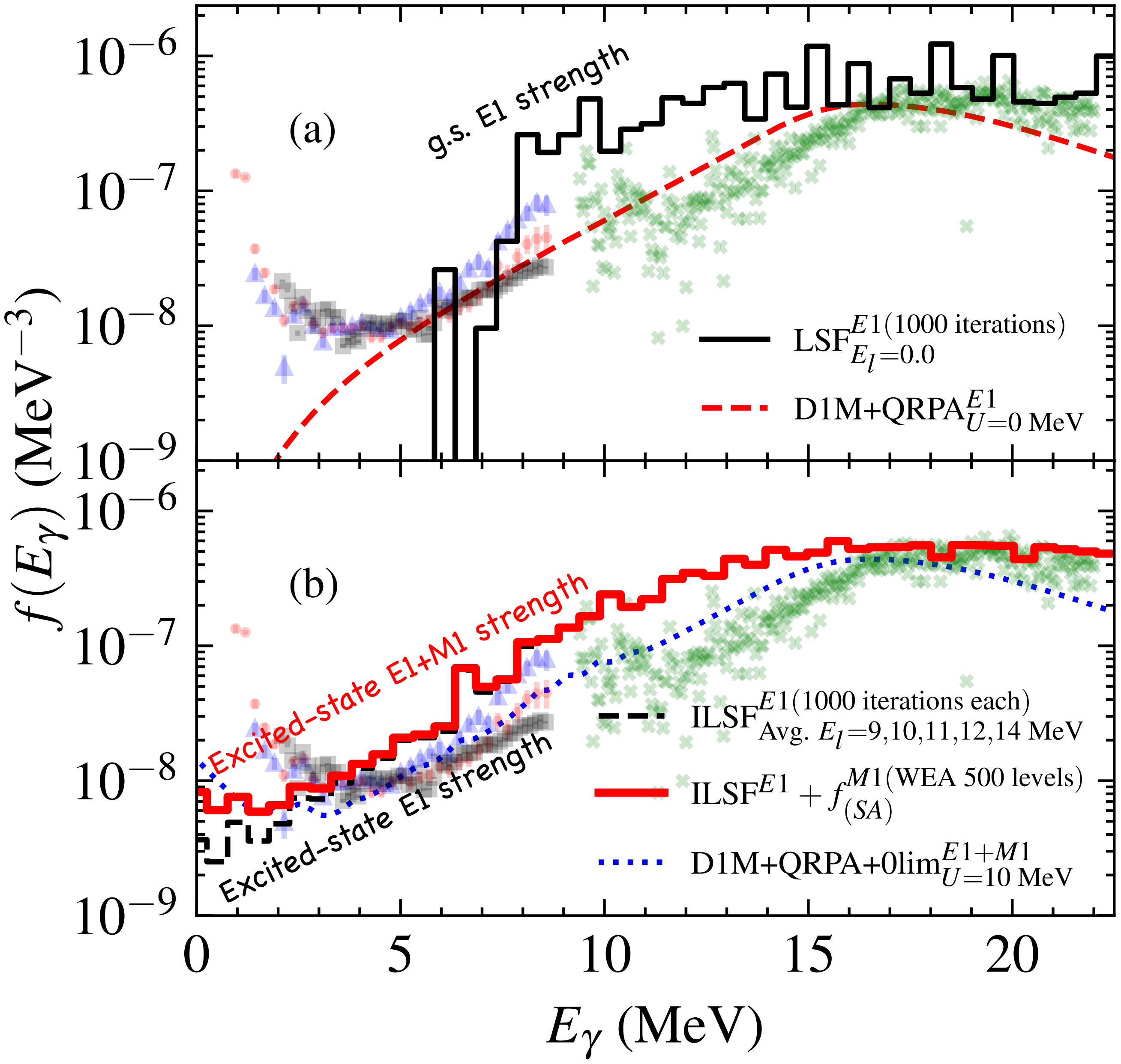
E1 RSF to excited states now possible with LSSM

Fe-56

No adjustment
No folding
sdpf model space (dimension 10^{15})
+ Energy-based configuration truncation (500 M)
+ ILSF method (5 semi-converged wave functions)

For your consideration:

- Interaction (sdpfmu-db) not tuned for pf nuclei
- Missing g9/2 orbit:
    - May shift E1 mean-energy up
    - Should not affect low-energy
- What could generate observed strength?
    - Would need to modify total M1



Radiative strength functions and ELBA hypothesis

Takeaways:

1. Radiative strength (E1 and M1) increases at low E_γ, relative to photo-absorption (see Kopecky-Uhl model)

2. Exponential shape (M1) related to single-shell transitions; changed by orbital **entanglement**:
   - Open shells (see Midtbø 2018, Karampagia 2017)
   - **Level energy E_f** (this work)

3. The **energy** of the level E_f matters, not the number of levels; use **Lanczos**!