LISE $^{++}_{cute}$: v.17.17.54-17.18

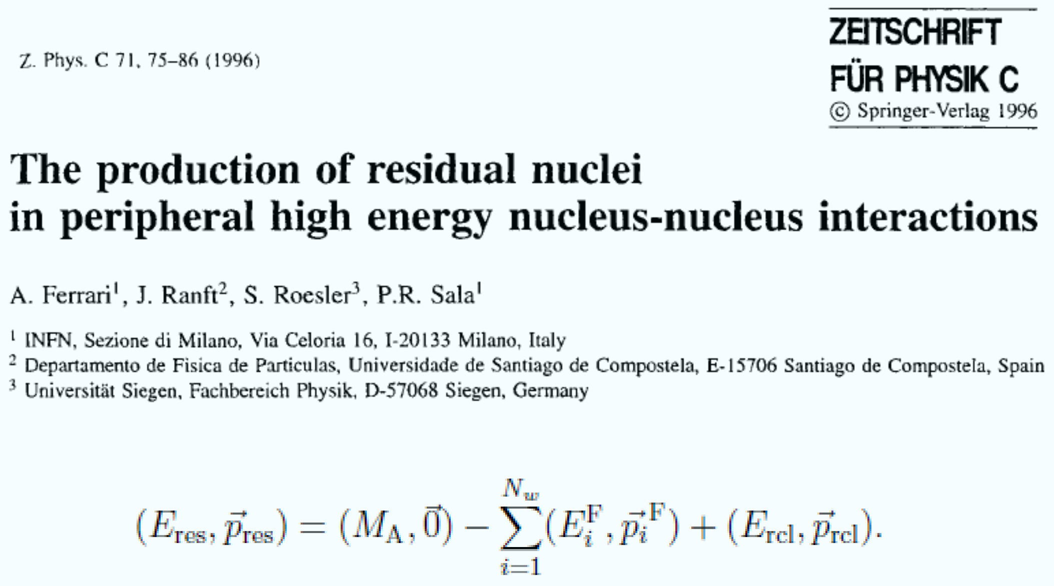
From 01/04/26

Executive summary

This note documents the incremental LISE++ modifications from v17.17.54 through v17.18.0, with emphasis on the new excitation-energy model IME-Hole (a.k.a. IME-Holes). The model reconstructs the residue excitation energy event-by-event from removed nucleon holes (separation energy + Fermi-motion kinetic energy) and then enforces on-shell 4-momentum consistency by overwriting the residue energy component.

Version log (as implemented)

Version	Date	Notes
17.17.54	12/29/2025	cap(gag) in L_Trans_angle: if (!std::isfinite(ig_aa)) ig_aa = 1;
		L_Distr1_convolute was re-written to vector. No new, no delete
17.17.55	12/30/2025	New proton-rich isotopes from RIKEN
17.17.56	12/30/2025	2D-plot: q vs. A/q
17.17.57	01/02/2026	New excitation-energy model: IME-Hole (initially only for plots)
17.17.58	01/03/2026	d_Apf_excitation: adaptation for IME_EE
17.17.59	01/03/2026	IME_EE: reconstruction, update, new functions
17.17.60	01/03/2026	IMEparams structure in L_initOptions
17.17.61	01/04/2026	IME-Hole model in d_Apf_excitation completed
17.17.62	01/04/2026	IME-Hole model plots in d_Apf_excitation
17.18.0	01/04/2026	Middle version changed


Z. Phys. C 71, 75–86 (1996)

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The production of residual nuclei in peripheral high energy nucleus-nucleus interactions

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$$(E_{\rm res},\vec{p}_{\rm res}) = (M_{\rm A},\vec{0}) - \sum_{i=1}^{N_w}(E_i^{\rm F},\vec{p}_i^{\,\rm F}) + (E_{\rm rcl},\vec{p}_{\rm rcl}).$$

IME-Hole excitation energy model

1 Naming

Recommended short name in LISE++ UI/logs: IME-Hole

Meaning:

- IME = "Invariant-Mass Enforced" (the residue 4-vector is made on-shell after computing E*)
- Hole = excitation built from removed nucleon holes (separation + kinetic energy)

2 Motivation

In the INC–IME stage, the residue four-momentum Pres is constructed from a sampled set of wounded nucleons. If the excitation energy is derived as E* = M_res − M0_res using an invariant mass M_res computed directly from Pres, numerical and/or off-shell inconsistencies can yield unphysical negative E*. IME-Hole avoids this by computing E* from physically positive hole contributions, then enforcing a consistent on-shell energy.

3 Core idea (physics picture)

Abrasion removes ΔA nucleons from the projectile. Each removed nucleon corresponds to a 'hole' in the projectile Fermi sea. The excitation of the residue is approximated as the sum of:

- separation energy S1 (S1p or S1n) for each removed nucleon
- kinetic energy associated with the sampled hole momentum (Fermi motion)

Optionally, an additive Coulomb term may be included.

4 Event-by-event algorithm

- Inputs: residue isotope (Z_res, A_res), abrasion losses ΔZ, ΔN (ΔA = ΔZ + ΔN), and model parameters.
- Sample which of the ΔA removed nucleons are protons vs neutrons (exactly ΔZ protons and ΔN neutrons).
- For each removed nucleon, sample a 3-momentum $\vec{p}$ from a Fermi distribution (or uniform Fermi sphere) with an optional scaling α_Fmod.
- Compute each hole excitation contribution:
  e_hole = T($\vec{p}$) + S1, where S1 is S1p or S1n from the mass database (or 0 if unavailable).
- Sum over holes: E_holes = Σ e_hole (always ≥ 0 with the usual positive-S1 convention).
- Apply global scaling/offset and Coulomb term:
  $E^* = ((E_{holes} \cdot \kappa + E_0) \cdot \lambda) + (\Delta E_{coul} \cdot s_{Coul})$
- Build an excited residue mass:
  M_exc = M0_res + E*
- Keep the residue 3-momentum from abrasion ($\vec{p}$_res taken from Pres), but overwrite the energy component to enforce on-shell kinematics:
  $Pres.E = \sqrt{M_{exc}^2 + |\vec{p}_{res}|^2}$
- Optional: store debug/diagnostic quantities (ΔA, E_holes, E*, M0_res, M_exc, |$\vec{p}$_res|).

5 Relativistic vs non-relativistic kinetic energy

For a hole with momentum magnitude p = |$\vec{p}$| and nucleon mass m (proton or neutron):

- non-relativistic: $T_{nr} = p^2 / (2 m)$
- relativistic: $T_{rel} = \sqrt{p^2 + m^2} - m$

At typical Fermi momenta (≈ 250 MeV/c), the relativistic correction is modest but non-negligible. IME-Hole can use either, but consistency across the codebase is recommended (same unit system everywhere).

6 Parameter meanings (recommended notation)

Model parameters used in the implementation:

Plain-text formula (Unicode math):

$E^* = ((E_{holes} \cdot \kappa + E_0) \cdot \lambda) + (\Delta E_{coul} \cdot s_{Coul})$

Symbol	*Meaning*
α_Fmod	Fermi-momentum scale factor applied to sampled hole momenta (dimensionless).
τ	Effective interaction time (or time-scale) parameter if used in the sampling/relaxation (s or fm/c depending on convention).
κ	Scale applied to the summed hole excitation E_holes before other scaling (dimensionless).
λ	Global excitation scaling factor (dimensionless).
E_0	Additive offset (MeV). Can represent missing contributions not captured by holes.
ΔE_coul	Coulomb excitation/energy-shift term (MeV).
s_Coul	Additional multiplicative Coulomb scaling (dimensionless).

IME-Hole excitation energy model implementation in $LISE^{++}$

1 Where the key change is made

The essential FORTRAN-consistent patch is localized to compute_EE_INC(...) (and/or the internal routine used by computeEstar_INC_IME_MeV(...)). The change is:

- Stop using M_res = invariantMass_MeV(Pres) to define E* in INC-IME
- Instead, after the hole loop compute E_holes, then M_exc = M0_res + E* and overwrite Pres.E with sqrt($M\_exc^2 + p^2$).

2 Why this guarantees positive excitation energy

Because each hole contribution is e_hole = T + S1 with T ≥ 0 and S1 ≥ 0 (in the standard separation-energy convention), E_holes is non-negative. If κ, λ are chosen non-negative and E_0 is not strongly negative, then E* stays ≥ 0 by construction. The on-shell enforcement step removes the prior inconsistency where the sampled 4-vector implied an invariant mass smaller than M0_res.

3 Debugging/validation checklist

- Print (or store) per-event: ΔA, ΔZ, ΔN, E_holes, E*, M0_res, M_exc, p^2, and M_invariant(Pres).
- Verify: M_invariant(Pres) ≈ M_exc (up to rounding).
- Verify: E* distribution changes smoothly with α_Fmod, κ, λ, E_0.
- Check corner cases where S1 is missing (BadValue): verify it defaults to 0 and does not crash.
- If you add a Coulomb term, verify its sign and scaling against your intended convention.

4 Expected behavior of width σ(E*)

If you observe a small σ(E*) (e.g., ~15 MeV around a mean ~240 MeV), common reasons are:

- ΔA is fixed (or narrowly distributed), so only Fermi-motion fluctuations contribute
- α_Fmod is small, reducing kinetic-energy variance
- κ and λ are set such that they compress the spread

To increase σ(E*) in a controlled way, introduce event-by-event fluctuations in ΔA (impact-parameter dependence), use a broader momentum sampling, or tune α_Fmod/κ/λ.

5. Notes on proton/neutron removal sampling (flags + shuffle)

A common implementation pattern for sampling exactly ΔZ protons among ΔA removed nucleons is:

- Create an array flags[0..ΔA−1] initialized to 0
- Set flags[i]=1 for i<ΔZ
- Randomly permute flags with std::shuffle

After shuffling, each position has an equal probability of being a proton-removal (flag=1), while preserving the exact counts.

This does distribute them randomly. If you need a different notion of 'randomly set distribute them' (e.g., correlated proton/neutron removal, or Z-dependent removal probability), replace the shuffle with a weighted draw without replacement.

6. References (background)

The IME-Hole model is inspired by standard abrasion–ablation hole pictures and by practical implementations in transport codes.

Suggested citations to include in documentation/manuscripts:

1) J.-J. Gaimard and K.-H. Schmidt, "A reexamination of the abrasion-ablation model for the description of the nuclear fragmentation reaction", Nucl. Phys. A 531 (1991) 709.

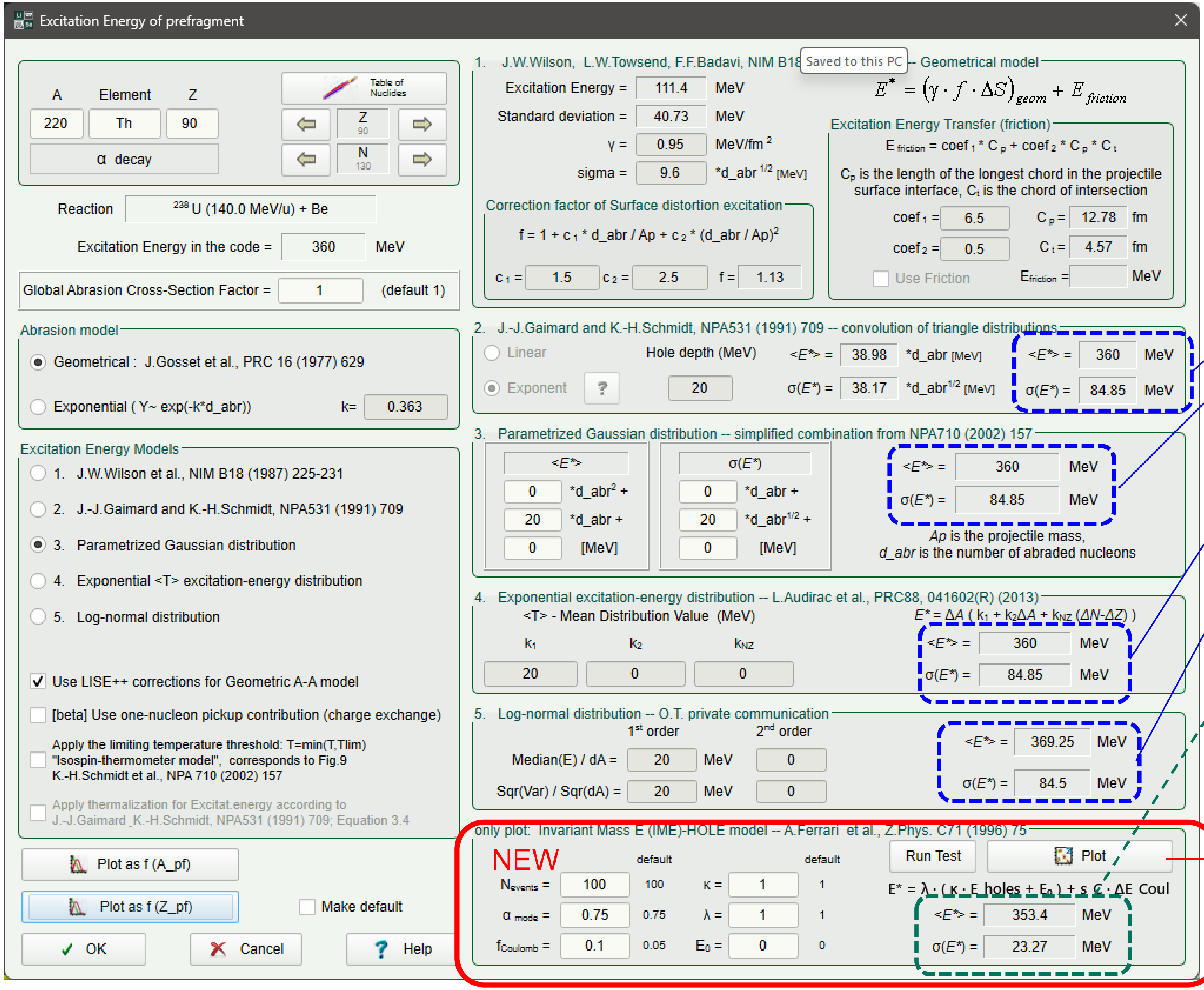
2) See also summaries of the hole-excitation prescription in ABRABLA implementations (e.g., thesis-level descriptions).

Note: A thesis summary of the ABRABLA hole approach states that the residue excitation energy is determined from the number of created holes and their energies, with typical average values quoted per abraded nucleon; consult your preferred ABRABLA/fragmentation reference list for the most appropriate primary citation.

3) H. Alvarez-Pol et al. / A. Kelic-Heil et al. (ABRABLA07 literature): discussions of an empirical excitation-energy scaling factor applied to the abrasion hole prescription to reproduce fragment observables.

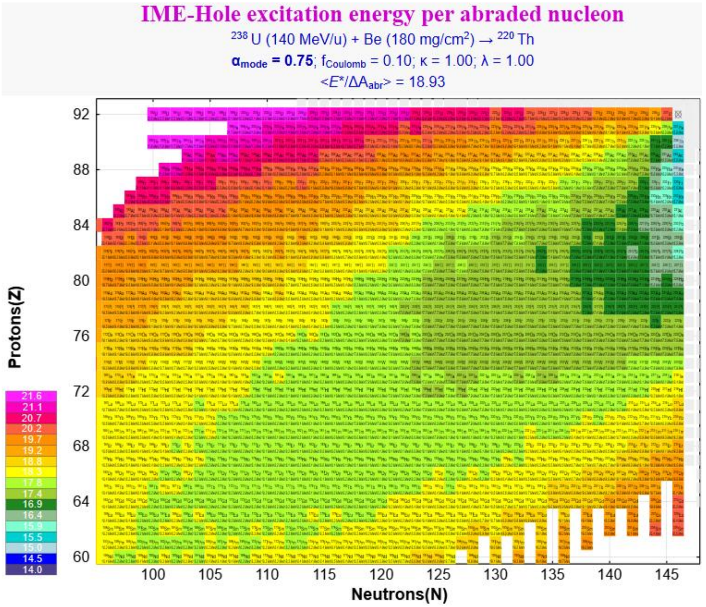
4) M. Ordonez (PhD thesis, TUM, 2017): pedagogical description of ABRABLA abrasion excitation from hole energies and the role of final-state interactions in increasing the average excitation per abraded nucleon (useful secondary reference).

IME-Hole EE in LISE++



the same result at 20 MeV for <E*> and Sigma

For α_{mode} = 0.75 (corresponds to A.Ferrari et al., Z.Phys. C71 (1996) 75-86)
<E*> as models 2-5, but too narrow.
To change it, BeAGLE uses the LogNormal insert (see the next slide)



LogNormal excitation-energy distribution in BeAGLE

(EstarFix / ESFDEV stub);

Mathematics + practical parameter mapping for LISE/ABRABLA-style workflows

Context. In BeAGLE/DPMJET3 workflows, a simple placeholder ("repair") sampler is sometimes used to force the excitation energy E* to be positive when an upstream model produces Eexc < 0. The width knob is often called ESFDEV (a dimensionless "log-space sigma").

1. Sampler definition (what the code actually draws)

Let g be a standard normal random variable: $g \sim \mathcal{N}(0, 1)$.

The stub sampler returns (variable names as commonly seen in the FORTRAN snippets):

$E^* = \text{mean} \times \exp(\text{dev} \times g)$

where dev is wired to ESFDEV, and g is a Gaussian random deviate (often called gaus).

Important: despite the variable name "mean", this multiplicative prefactor is the MEDIAN parameter of the LogNormal distribution, not the true mean, unless dev = 0.

Equivalently, taking logarithms:

$\ln(E^*) = \ln(\text{mean}) + \text{dev} \times g$

so ln(E*) is Gaussian and E* is LogNormal.

2. LogNormal mathematics (closed-form moments)

Assume $E^* \sim \text{LogNormal}(\mu, \sigma_{log}^2)$ with:

$\mu = \ln(m)$ where m is the median parameter (in the FORTRAN stub: m ≡ mean)

$\sigma_{log} = \text{dev} = \text{ESFDEV}$

Then:

- Median:

$\text{median}(E^*) = \exp(\mu) = m$

- Mean:

$\langle E^* \rangle = \exp(\mu + \sigma_{log}^2 / 2) = m \times \exp(\sigma_{log}^2 / 2)$

- Variance:

$\text{Var}(E^*) = (\exp(\sigma_{log}^2) - 1) \times \exp(2\mu + \sigma_{log}^2)$

- Standard deviation:

$\sigma(E^*) = \langle E^* \rangle \times \text{sqrt}(\exp(\sigma_{log}^2) - 1)$

- Coefficient of variation (relative width):

$CV = \sigma(E^*) / \langle E^* \rangle = \text{sqrt}(\exp(\sigma_{log}^2) - 1)$

3. Practical parameter mapping (how to pick ESFDEV and the scale)

3.1 Choose ESFDEV from a desired relative width

If you want a target relative width $CV = \sigma/\langle E^* \rangle$, use: $\text{dev} = \sigma_{log} = \text{sqrt}(\ln(1 + CV^2))$

Rule of thumb: dev sets multiplicative 1σ fluctuations by a factor exp(dev).

- dev = 0.1 → exp(dev) ≈ 1.11 (≈ ±10%)
- dev = 0.3 → exp(dev) ≈ 1.35 (×/÷ 1.35)
- dev = 0.5 → exp(dev) ≈ 1.65 (×/÷ 1.65)
- dev = 1.0 → exp(dev) ≈ 2.72 (×/÷ 2.7)

3.2 If you want the distribution to have a desired TRUE mean

If you want $\langle E^* \rangle = \bar{E}_{target}$ for a chosen dev, set the multiplicative prefactor to:

$m = \bar{E}_{target} / \exp(\text{dev}^2 / 2)$ and sample $E^* = m \times \exp(\text{dev} \times g)$.

4. Where it typically applies (why ESFDEV may not change global σ)

In the common BeAGLE logic, the lognormal replacement is applied only when:

(i) the computed excitation energy is negative (Eexc < 0), and

(ii) a repair/fix flag is enabled (e.g., ESFIXTYP > 0).

Therefore, if most events already have Eexc > 0, changing ESFDEV changes only the subset of "repaired" events, so the global σ(E*) across ALL events may appear small.

5. Implementation notes / pitfalls

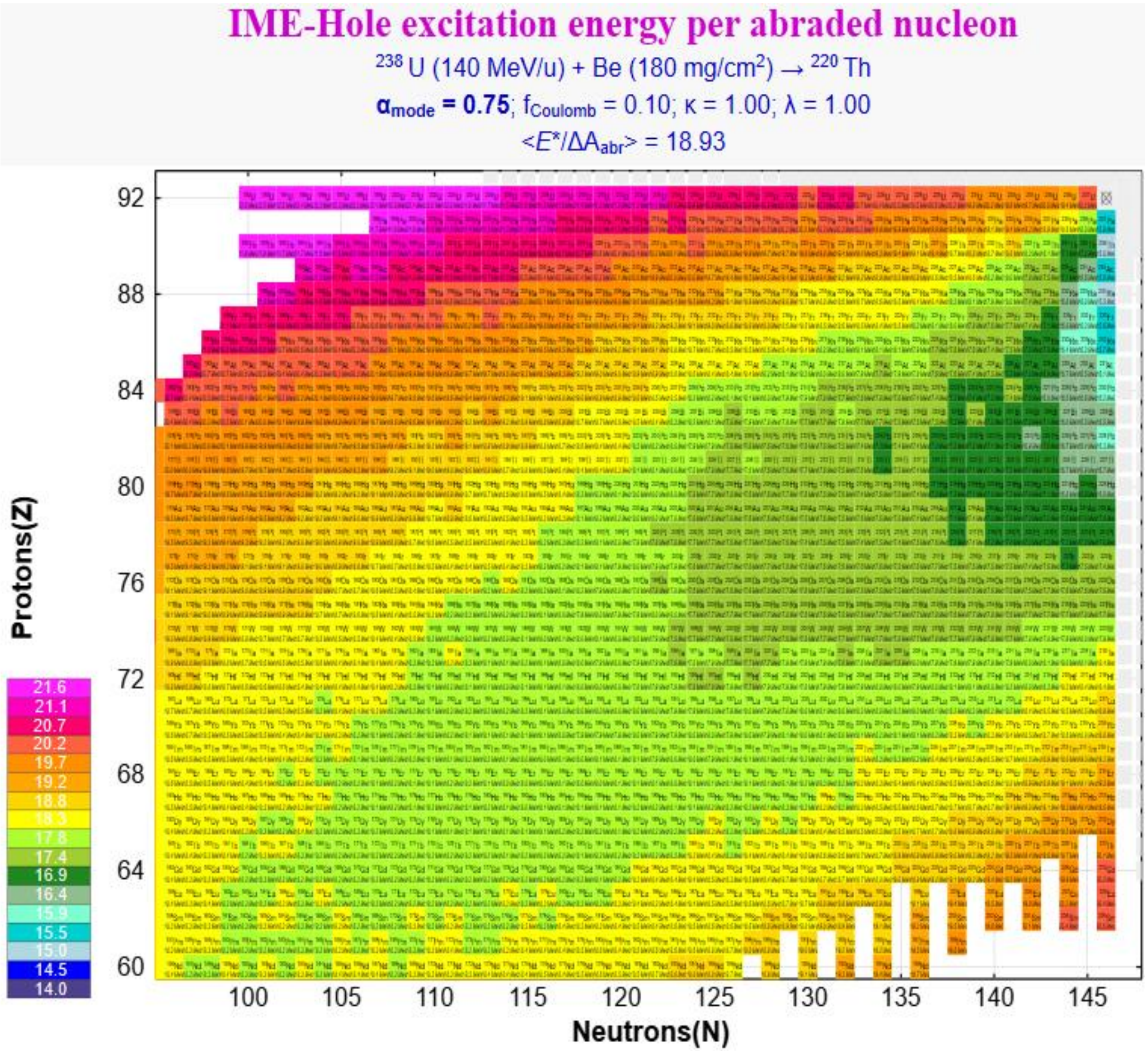
- Units: ESFDEV (dev) is dimensionless; it is stddev of ln(E*).
- Median vs mean: the stub's multiplicative parameter (called "mean" in some code) is actually the median parameter.
- Positivity: the lognormal draw is strictly > 0 (before any optional clipping).
- Diagnostics: Monte Carlo σ depends on which subset you include; check "repaired-only" vs "all events".

Quick reference formulas

```
g ~ 𝒩(0, 1)
E* = m × exp(dev × g)
median(E*) = m
⟨E*⟩ = m × exp(dev²/2)
CV = sqrt(exp(dev²) - 1)
dev = sqrt( ln(1 + CV²) )
m = Ē_target / exp(dev²/2)
```

IME-Hole EE vs. BeAGLE results: ^{238}U

Courtesy of I. Richardson, B. Schmookler, J.L.R.Sanchez



BeAGLE tau=10

<E*> = 22.3

tau = 10

Sum of ModeLogN/dA, dZ \ dN	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0				25.18	24.80	27.13	25.84	26.05	26.03	25.29	25.14	24.86	24.43	23.55	22.78	21.15	18.90		
1			24.46	25.66	25.99	25.66	24.53	24.90	24.63	24.21	24.08	23.56	23.19	22.40	21.67	20.41	19.05	16.29	
2		24.45	24.08	24.88	24.15	24.23	24.37	24.56	23.99	23.85	23.64	23.20	22.84	22.16	21.62	20.53	19.53	17.64	15.20
3		24.23	24.42	24.35	24.60	24.14	23.97	23.93	23.62	23.46	23.16	22.77	22.54	21.91	21.33	20.39	19.46	18.05	16.75
4	24.18	25.07	23.77	24.31	24.52	23.84	24.13	23.67	23.52	23.22	23.00	22.62	22.39	21.78	21.39	20.56	19.90	18.72	18.44
5	24.51	24.29	24.09	22.93	23.63	23.56	23.55	23.25	23.42	22.99	22.63	22.32	22.22	21.62	21.14	20.49	19.76	19.33	18.83
6	21.98	22.10	24.32	23.24	23.17	23.34	23.30	23.16	23.19	22.77	22.65	22.22	22.11	21.52	21.07	20.50	20.08	19.54	19.65
7	24.58	23.44	22.91	23.76	23.80	23.12	23.42	22.91	22.61	22.57	22.36	21.90	21.88	21.52	20.98	20.42	20.35	19.35	19.89
8	22.22	25.14	21.44	23.23	22.70	23.36	23.04	22.62	22.85	22.34	22.15	21.96	21.64	21.23	20.90	20.72	20.74	19.49	20.69
9	23.45	23.27	23.22	23.45	22.70	22.73	22.82	21.99	22.23	22.70	22.01	21.62	21.76	21.27	21.06	20.49	19.64	18.86	15.49
10		24.56	23.54	22.70	22.75	22.06	22.85	22.85	22.35	22.04	21.90	21.37	20.62	21.32	20.59	20.43	20.75	16.67	
11			22.87	22.78	20.85	22.79	21.58	21.56	21.97	22.81	21.96	21.24	19.88	19.78	20.11	21.26	17.52		
12					21.39	21.59	21.26	20.41	20.22	21.32	21.76	21.73	20.72	18.87	18.72				

BeAGLE tau=20

Sum of ModeLogN/dA, dZ \ dN	10	9	8	7	6	5	4	3	2	1	0
0		21.42	21.71	21.82	20.99	20.38	19.90	18.32	16.26		
1	19.49	20.55	20.10	20.91	20.11	19.72	18.88	17.89	16.49	14.00	
2	20.58	20.40	20.85	20.30	20.06	19.11	18.95	18.00	17.09	15.39	12.98
3	22.13	19.93	20.53	20.03	19.59	19.11	18.76	17.65	17.35	15.73	14.46
4	20.61	21.77	20.13	19.69	19.57	19.44	18.61	18.02	17.59	16.48	15.89
5		19.81	20.35	18.80	18.95	18.75	18.56	17.74	16.89	17.02	17.85
6			20.15	18.63	18.86	18.49	18.82	18.04	18.08	17.35	15.98
7				19.51	19.89	19.00	16.39	18.91	16.51	12.92	

<E*> = 19.14

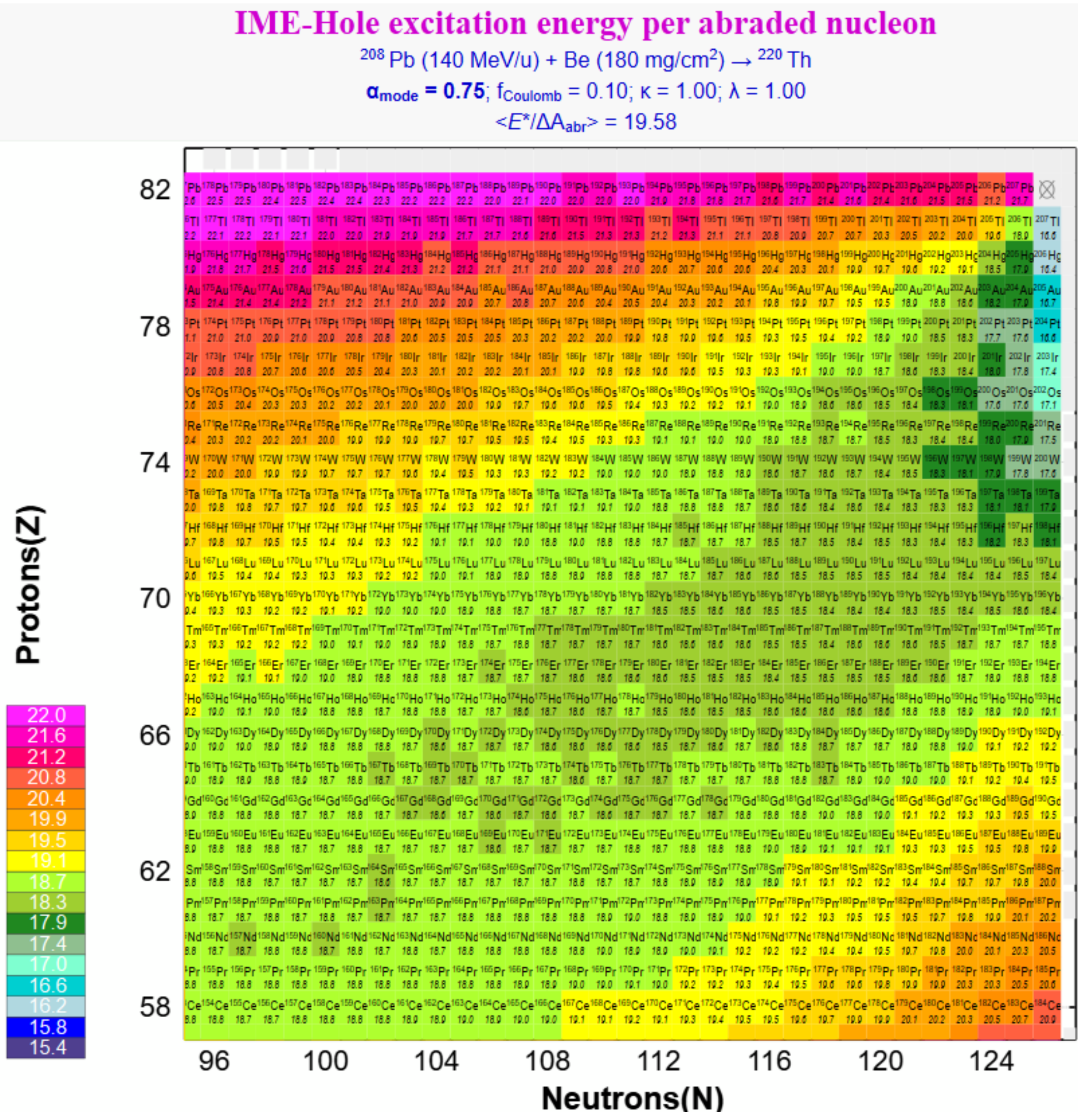
Liege

<E*> = 19.7

Sum of Mod, dZ \ dN	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0						24.26	24.58	26.50	27.72	28.73	29.58	30.07	28.17	26.28	20.34	12.01		
1				20.97	18.87	23.36	23.49	25.30	25.44	26.50	26.93	27.57	26.45	24.59	20.64	15.53	10.01	
2				20.68	21.13	21.42	22.33	23.33	23.90	25.14	25.45	25.75	25.29	24.09	21.81	17.66	13.70	10.01
3			19.24	19.60	20.13	20.24	20.78	21.86	22.39	23.10	23.51	23.51	23.85	23.26	21.85	20.31	17.20	13.27
4		[illegible]	16.48	18.19	18.93	18.98	20.25	20.28	21.11	22.06	21.97	22.45	22.41	22.39	21.87	21.60	18.79	16.07
5		16.26	16.73	18.23	17.88	18.85	18.94	19.23	19.99	20.07	20.82	21.00	21.09	21.29	20.97	20.79	19.12	23.86
6		15.09	15.68	17.08	17.65	17.73	18.09	19.03	18.77	19.27	19.57	19.42	19.90	19.63	21.82	20.27	20.16	22.12
7		15.67	15.80	16.45	17.11	17.01	17.40	17.93	18.06	18.13	19.55	18.35	18.85	19.57	19.96	18.66	19.70	18.15
8	13.65	15.10	15.84	15.68	16.29	16.28	16.76	17.60	17.80	17.91	18.33	17.70	17.92	18.24	19.37	18.05	15.22	
9		13.42	15.56	15.72	15.31	15.67	16.28	17.44	16.90	16.83	17.43	17.22	16.23	17.82	13.52	15.17		
10		13.94	15.37	14.89	14.61	15.82	15.90	16.46	16.58	15.87	16.02	15.71	16.99	14.61				
11			14.99	15.39	14.14	15.96	14.81	16.04	15.13	15.45	15.02	13.41						
12			14.34	13.14	14.30	14.81	13.98	15.86	13.25	13.23								

IME-Hole EE vs. BeAGLE results: ^{208}Pb

Courtesy of I. Richardson, B. Schmookler, J.L.R.Sanchez



BeAGLE <E*> = 18.3

Sum of ModeLogN/dA dZ \ dN	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0					20.55	22.52	21.67	21.27	21.49	20.84	20.17	20.10	19.74	18.87	18.14	16.56	14.69		
1				21.05	21.45	20.53	21.19	19.98	20.32	19.97	19.67	19.31	18.93	18.20	17.51	16.33	15.14	13.13	
2			19.77	20.56	20.43	20.03	20.09	19.82	19.69	19.39	19.38	18.91	18.76	18.07	17.67	16.63	15.77	14.12	11.91
3		19.13	21.05	19.93	19.70	20.16	20.05	19.87	19.59	19.14	19.06	18.84	18.47	18.01	17.45	16.74	15.86	14.68	13.39
4		20.50	18.88	19.96	19.74	19.48	19.89	19.31	19.75	19.33	18.79	18.68	18.42	17.97	17.70	16.77	16.22	15.49	14.79
5		18.61	19.96	19.65	19.18	19.49	19.51	19.26	19.38	18.91	18.46	18.56	18.24	17.93	17.37	16.92	16.39	15.57	15.31
6	19.93	20.23	20.03	19.42	19.79	19.43	19.10	18.95	18.97	19.28	18.88	18.39	17.97	17.93	17.71	16.87	17.00	16.30	15.83
7	19.50	19.72	18.33	18.97	19.80	19.24	19.10	19.19	18.51	18.58	18.48	18.36	18.13	17.42	17.24	16.53	16.44	15.99	15.99
8	18.60	18.73	19.67	19.15	19.18	18.94	18.95	19.13	18.94	18.49	18.13	18.54	17.81	17.69	17.60	16.95	16.45	16.71	16.14
9			19.05	18.96	19.37	18.84	18.34	19.09	18.69	18.38	18.58	17.95	17.94	17.41	17.27	17.43	16.04	16.79	15.87
10			19.41	20.41	19.94	19.14	18.90	17.89	19.15	18.56	18.24	18.08	18.03	17.81	17.15	16.41	17.05	8.45	23.22
11					18.84	18.96	19.43	18.73	17.83	18.02	17.54	17.75	17.52	17.14	17.02	18.08	17.24		
12					18.09	17.80	18.34	18.85	18.40	17.65	18.19	18.80	17.34	17.41	15.99	17.71			
13									18.09	16.23	17.55	18.68	15.94						

Liege <E*> = 19.14

Sum of ModeLogN/dA dZ \ dN	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0				22.83	21.96	24.90	27.30	28.61	28.63	28.78	27.21	24.71	19.38	11.79		
1				21.81	22.52	24.14	24.49	25.91	26.36	26.44	25.70	24.09	20.83	15.50	9.56	
2			22.13	21.40	21.98	22.78	23.39	23.99	24.79	25.17	24.58	23.73	21.27	17.70	13.83	10.01
3		18.87	18.53	19.67	20.50	21.99	22.06	22.69	22.92	23.37	23.20	22.69	21.66	19.63	17.01	13.82
4		18.37	19.06	19.25	19.75	20.09	21.01	21.49	21.94	21.82	22.31	21.91	20.85	20.42	19.81	17.11
5	18.27	17.59	17.17	18.32	18.75	19.41	19.53	19.94	20.08	20.97	20.57	20.84	21.95	20.65	19.38	17.77
6	16.31	16.17	16.93	17.66	18.00	18.29	18.70	19.01	19.38	19.42	20.79	19.85	20.69	20.25	20.59	16.65
7	15.57	16.88	16.12	16.89	17.14	18.03	17.76	18.01	17.96	19.27	19.23	19.29	18.96	18.27	17.36	14.15
8	15.76	15.90	16.00	16.20	17.02	16.75	16.98	17.54	18.31	18.42	18.87	17.78	18.33	19.69	16.35	
9	16.01	14.80	15.46	15.05	16.18	16.88	16.78	16.96	17.49	17.20	18.09	16.22	16.15			
10		13.65	15.42	15.57	15.70	14.99	16.49	17.37	16.37	15.86	17.02	15.67				
11			14.60	16.28	15.73	14.54	15.13	15.26	15.52							
12		12.86		14.55												

IME-Hole EE vs. BeAGLE results: ^{136}Xe

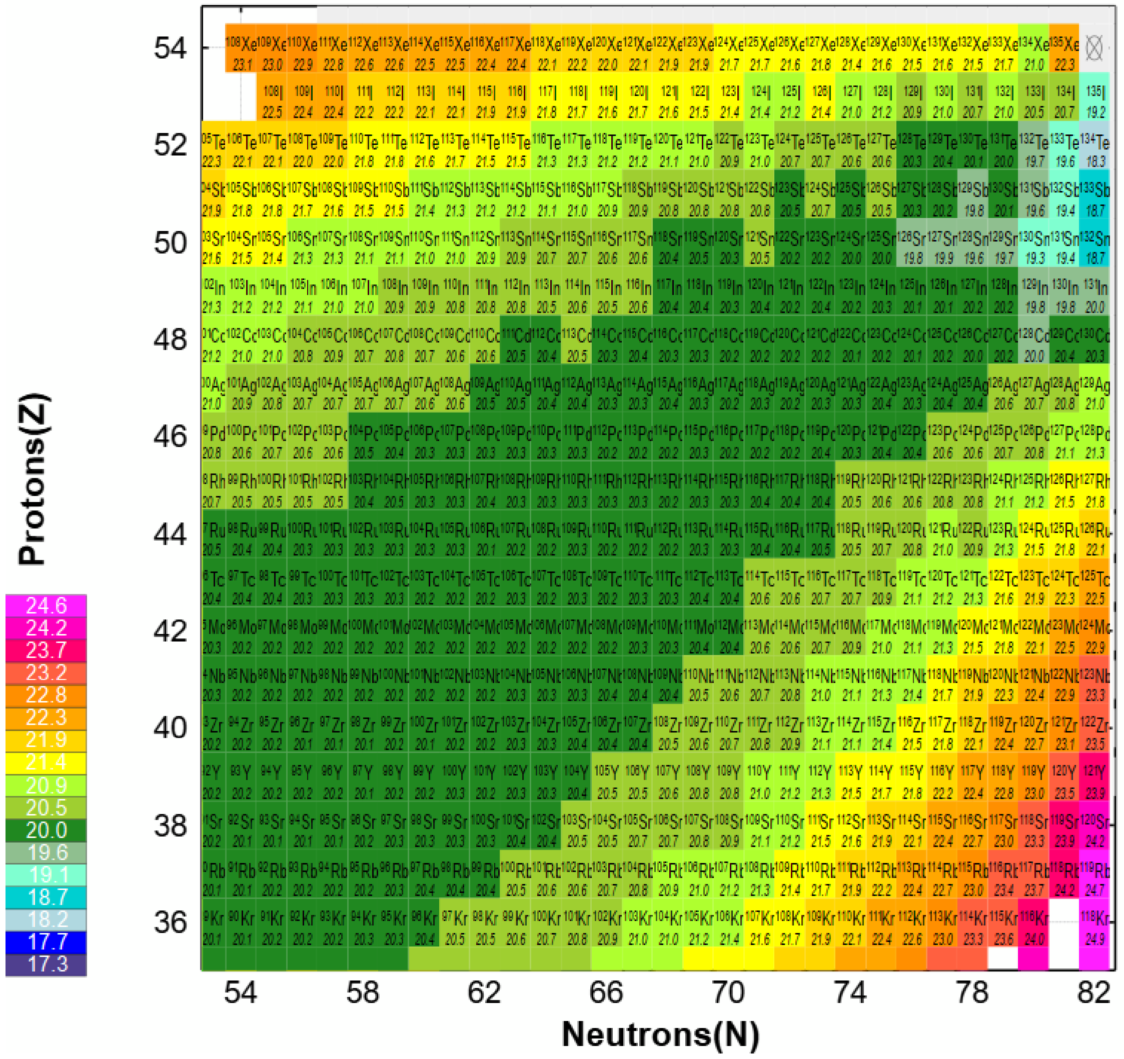
Courtesy of I. Richardson, B. Schmookler, J.L.R.Sanchez

IME-Hole excitation energy per abraded nucleon

^{136}Xe (140 MeV/u) + Be (180 mg/cm^2) → ^{122}Cd

α_{mode} **= 0.75**; $f_{Coulomb}$ = 0.10; κ = 1.00; λ = 1.00

$\langle E^*/\Delta A_{abr} \rangle$ = 20.85



BeAGLE

<E*> = 20.49

Sum of ModeLogE dN												
dZ	11	10	9	8	7	6	5	4	3	2	1	0
0		23.02	25.39	25.01	24.36	23.70	23.23	22.76	20.98	19.42		
1		24.03	23.48	23.69	23.58	22.69	21.87	21.25	20.14	19.12	16.75	
2	24.72	24.03	24.00	22.76	22.53	22.41	21.75	21.45	20.39	19.65	17.81	16.05
3	24.23	22.41	22.97	23.13	21.97	22.28	21.47	20.81	19.91	19.19	18.00	17.22
4	24.82	22.73	22.69	22.23	21.24	21.93	21.82	20.82	19.94	19.44	18.47	18.59
5	24.23	22.12	22.97	21.62	22.17	21.28	20.25	19.84	19.14	19.05	18.10	18.03
6		22.53	24.70	22.02	21.37	20.68	21.01	20.37	19.98	18.82	17.92	17.06
7			21.61	17.25	20.12	20.23	20.03	20.34	19.94	19.44	18.04	17.07
8				16.79	18.80	21.76	20.02	20.54	19.90	19.75	17.99	

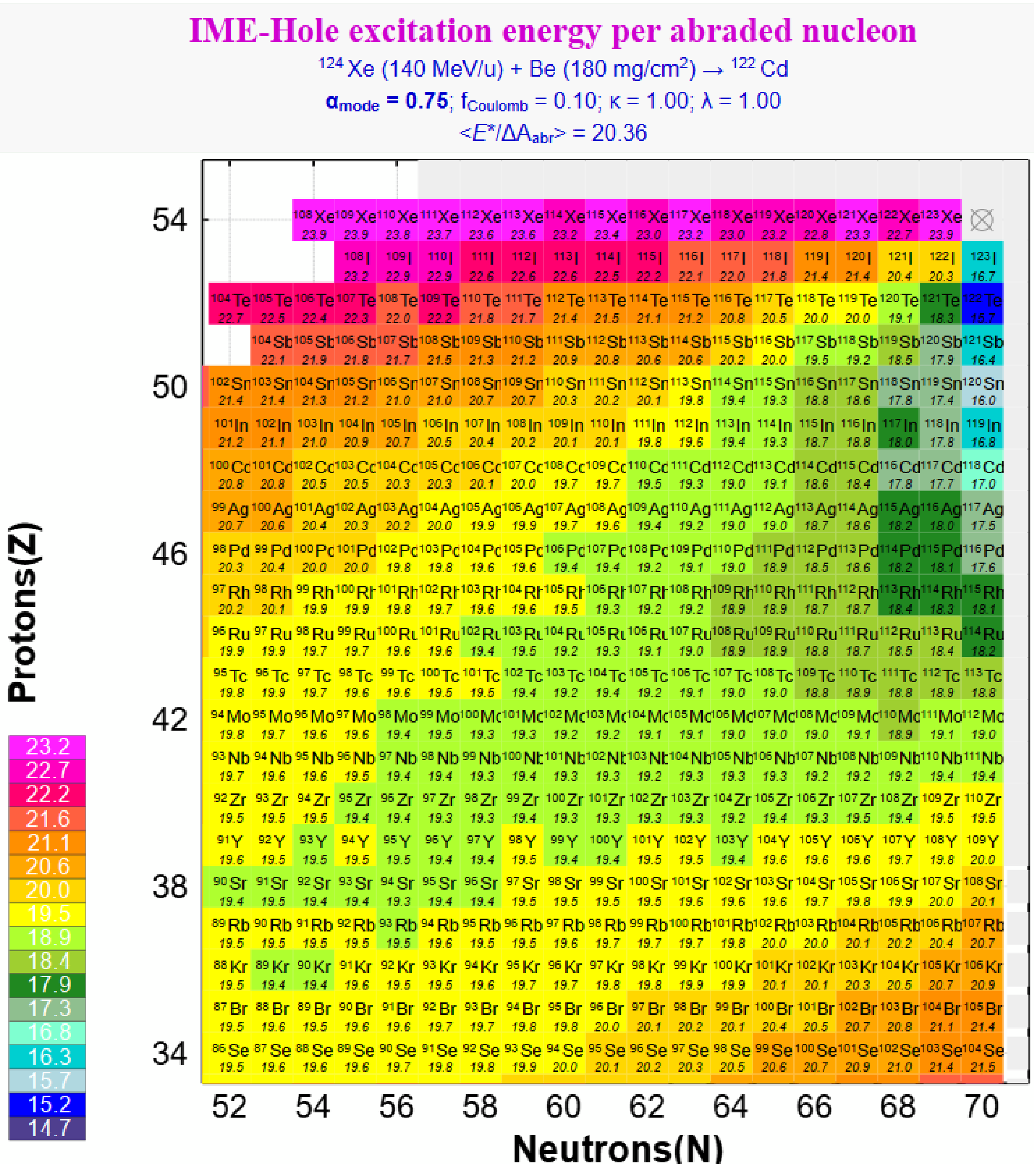
Liege

<E*> = 17.34

Sum of Mode dN																
dZ	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0					19.32	21.66	23.34	23.68	25.21	24.74	23.79	21.52	17.20	10.45		
1				19.05	21.07	21.88	22.82	22.33	22.87	22.62	22.09	20.52	17.61	13.33	8.67	
2			16.59	18.26	18.64	20.46	21.14	20.81	21.32	21.45	20.84	20.24	18.14	15.82	12.21	9.01
3			17.74	18.67	19.32	18.94	19.25	19.95	20.12	20.57	19.96	19.70	18.42	17.13	14.97	12.59
4		16.70	16.23	17.64	17.53	18.19	18.59	19.40	19.11	19.48	19.19	19.38	19.03	17.71	16.38	16.45
5	14.07	15.28	16.82	16.73	17.33	17.90	18.02	17.91	18.46	18.21	18.83	19.00	18.48	17.95	17.36	13.84
6		15.69	16.93	16.34	16.67	17.30	17.30	17.45	17.76	18.20	18.00	18.27	17.94	17.58	17.90	17.78
7		15.89	15.63	15.75	16.37	16.88	16.56	17.34	16.51	17.40	17.26	16.99	16.83	15.02	20.89	
8		14.17	15.46	15.30	15.38	16.64	16.61	16.46	16.26	16.18	17.11	15.44	15.53	18.12		
9	13.22	14.56	13.50	16.50	15.54	14.72	16.18	15.20	15.49	15.40	16.59	12.93				
10			14.50	14.37	14.12	15.48	14.33	14.29	15.33	9.35						
11						13.46	10.59	16.42								

IME-Hole EE vs. BeAGLE results: ^{124}Xe

Courtesy of I. Richardson, B. Schmookler, J.L.R.Sanchez



BeAGLE

<E*> = 21.3

Sum of ModeLogN/dA	dN											
dZ	11	10	9	8	7	6	5	4	3	2	1	0
0			22.26	24.60	22.89	22.79	22.04	21.75	20.02	18.47		
1		19.62	23.11	23.78	21.94	21.94	21.20	21.00	20.12	19.38	17.06	
2		22.90	22.07	22.76	22.72	22.72	21.65	21.50	20.68	20.16	18.71	17.71
3		22.24	22.84	23.12	21.91	21.86	21.44	21.53	21.01	20.09	19.54	18.85
4	21.91	22.29	22.82	23.53	22.56	22.36	21.90	21.58	21.04	20.90	20.29	20.14
5		20.50	22.44	23.12	23.83	21.32	21.95	21.97	21.11	20.34	19.72	20.58
6		21.37		22.15	23.15	23.20	21.60	21.83	21.06	20.84	20.80	20.10
7				21.75	21.99	21.73	20.81	21.11	20.27	20.19	20.28	19.53
8					22.57	21.62	21.26	20.22	20.86	20.70	21.08	
9						21.05	22.22			20.98		

IME-Hole EE vs. BeAGLE results: ^{86}Kr

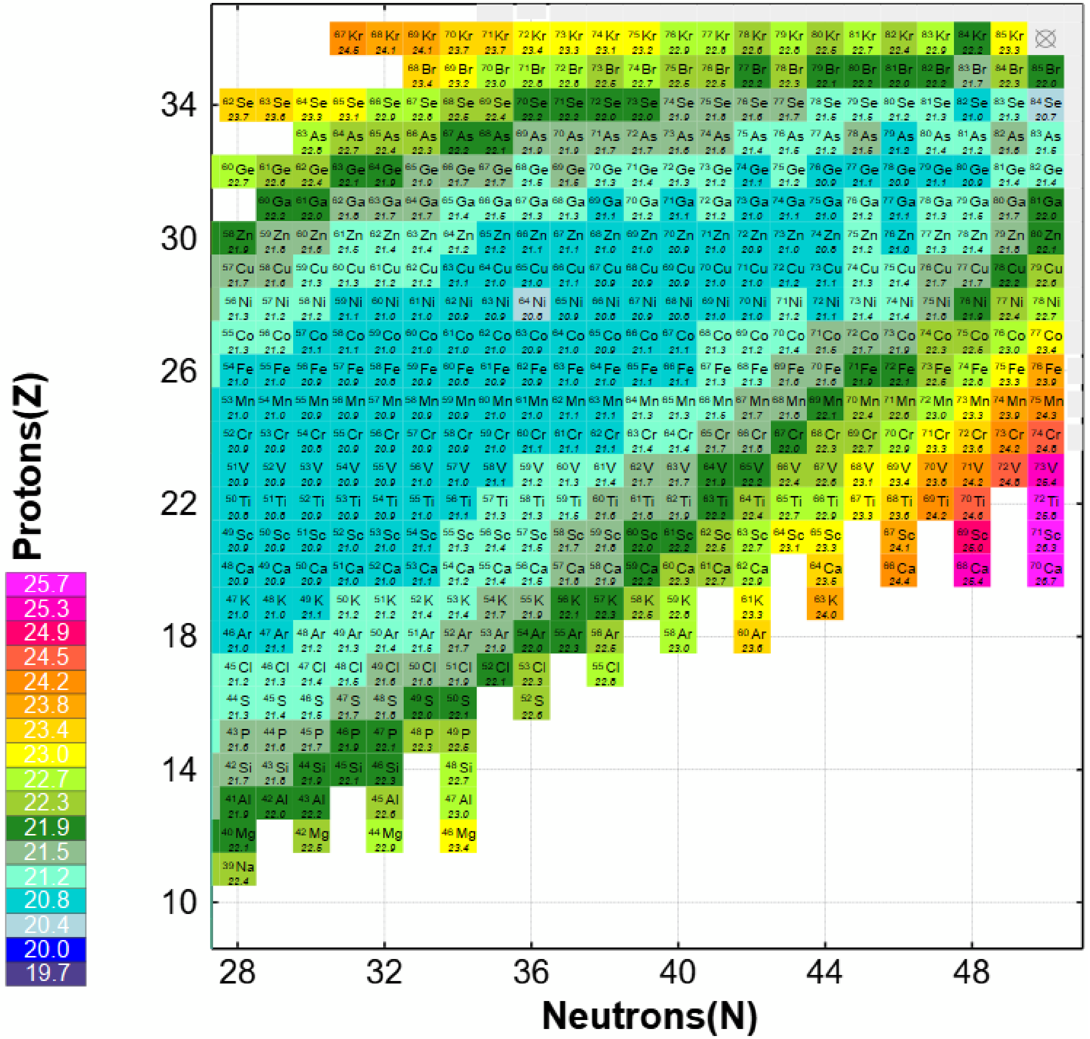
Courtesy of I. Richardson, B. Schmookler, J.L.R.Sanchez

IME-Hole excitation energy per abraded nucleon

^{86}Kr (140 MeV/u) + Be (180 mg/cm^2) → ^{70}Kr

α_{mode} = **0.75**; $f_{Coulomb}$ = 0.10; κ = 1.00; λ = 1.00

$\langle E^*/\Delta A_{abr} \rangle$ = 21.65



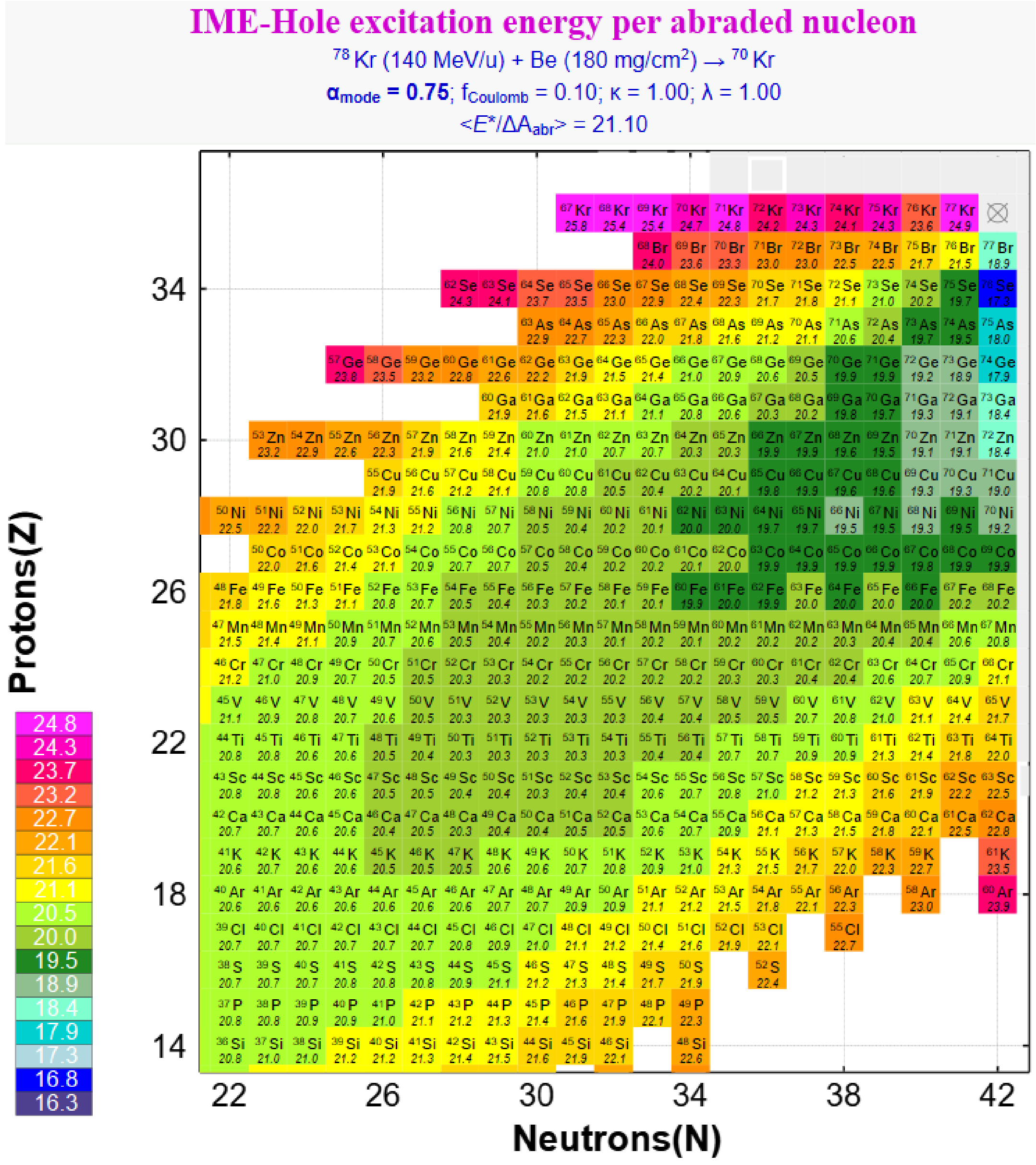
Liege

<E*> = 16.6

Sum of M dN														
dZ	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0				19.45	18.94	20.83	20.85	21.02	20.43	19.44	14.94	9.79		
1			17.98	18.19	19.31	20.03	20.12	19.89	19.00	18.57	15.61	12.34	8.01	
2			17.48	18.72	18.38	19.15	19.07	19.27	18.72	18.38	16.61	14.24	11.16	8.67
3		16.50	17.30	17.71	17.72	18.17	18.25	18.32	17.86	17.72	16.82	15.50	13.92	11.65
4	16.30	17.74	16.77	17.02	17.28	17.53	17.67	17.75	17.41	17.32	17.08	16.48	15.51	14.22
5	13.87	16.02	16.27	16.30	16.68	16.63	16.82	16.93	16.80	16.93	16.26	16.68	15.94	15.64
6	15.67	15.50	15.61	15.84	16.25	16.29	16.64	16.69	16.72	16.80	16.58	16.13	15.28	17.60
7	14.49	15.51	15.76	15.71	16.25	15.69	15.92	16.07	16.38	15.68	16.51	15.39	17.25	
8	15.50	15.31	15.82	15.54	15.67	15.46	15.40	15.80	15.39	15.35	14.38	14.46		
9	14.42	14.99	15.36	15.35	15.06	15.10	14.56	15.23	16.02	15.17	16.74			
10		16.24	11.56	15.73	13.62	13.56	14.42	12.86	13.09					

IME-Hole EE vs. BeAGLE results: ^{78}Kr

Courtesy of I. Richardson, B. Schmookler, J.L.R.Sanchez



BeAGLE, tau=10

<E*> = 19.9

Sum of ModeLogN dN									
dZ	8	7	6	5	4	3	2	1	0
0	22.65	19.97	21.48	19.77	19.40	18.01	17.03		
1	20.11	20.14	20.55	19.82	19.79	18.78	18.28	16.08	
2	20.02	20.44	20.76	20.72	20.66	19.79	19.44	18.06	17.12
3	20.51	20.55	21.13	20.43	20.45	19.79	19.58	18.26	17.80
4	20.42	21.96	20.96	21.35	21.03	20.40	20.10	19.11	19.56
5	21.58	20.90	21.08	20.95	20.73	20.16	19.92	19.19	19.31
6		21.10	21.11	21.43	21.13	20.32	19.65	19.34	20.46
7			21.16	20.12	19.64	20.53	19.32	18.86	17.72
8				22.47	19.11	19.19	20.08	21.16	

Liege (Be 1Gev))

<E*> = 18.8

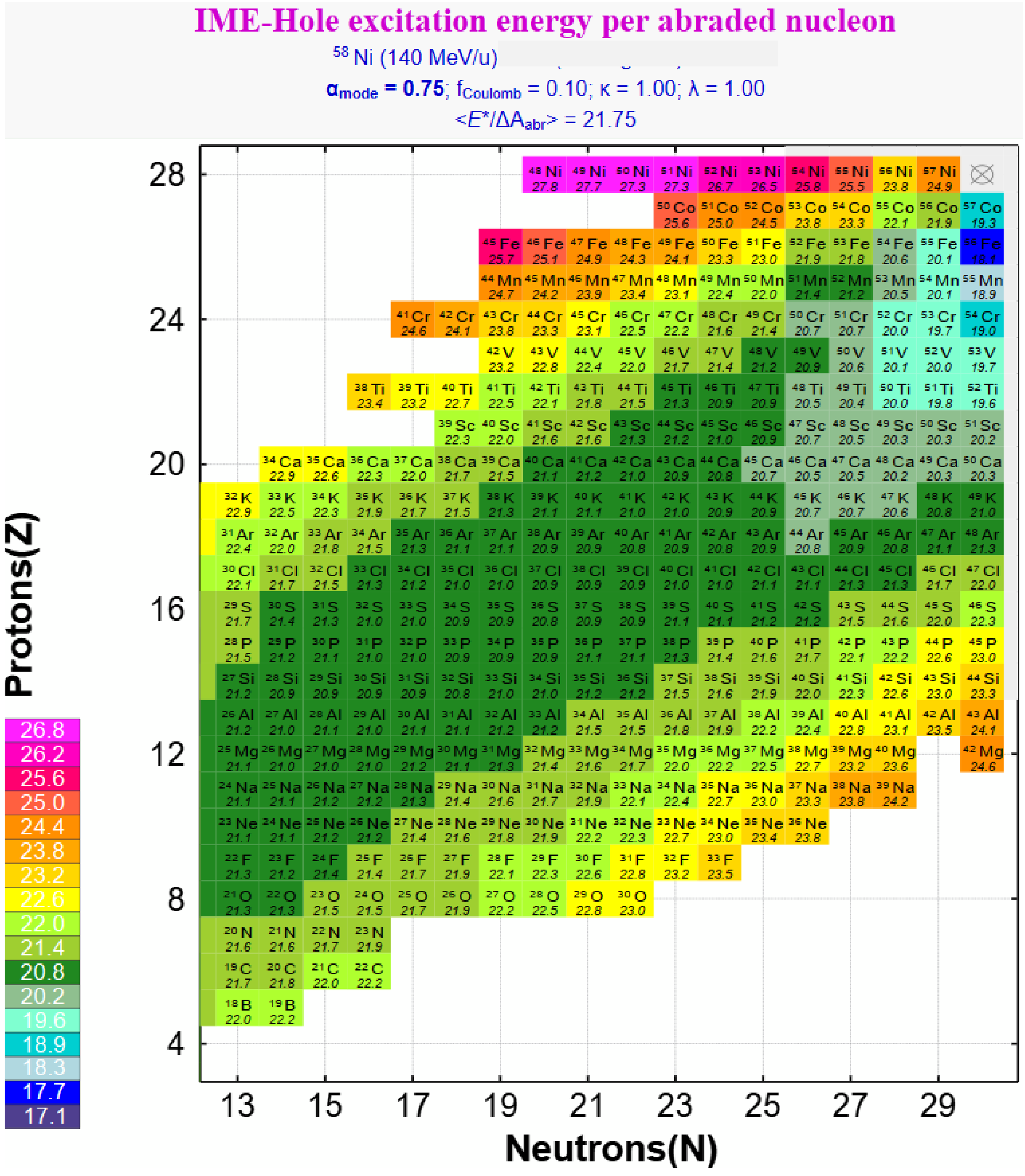
Sum of N dN																													
dZ	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0																		22.10	19.54	18.37	18.53	16.50	16.35	15.21	12.39	8.62	6.23		
1																	18.22	17.77	17.60	16.82	19.71	17.26	16.37	14.87	13.48	11.28	8.77	6.45	
2															15.37	11.61	21.12	17.75	20.29	18.89	18.50	17.23	16.49	15.24	14.88	13.03	11.63	9.15	8.34
3														20.37	19.48	20.31	20.91	19.67	19.54	18.33	18.33	17.21	16.71	15.57	15.54	14.09	13.36	11.72	10.72
4													17.89	19.95	20.75	20.37	19.56	19.62	19.21	18.76	18.15	17.64	17.29	16.24	15.98	15.25	15.26	13.69	14.06
5											19.51	21.17	17.50	19.91	20.43	20.31	19.51	19.86	19.03	18.50	18.23	17.42	17.27	16.78	16.40	15.88	15.87	15.00	14.21
6										21.39	18.66	21.35	21.10	20.81	20.42	19.09	19.56	19.11	19.20	18.47	18.60	17.84	17.81	17.23	17.59	16.55	16.70	16.06	17.22
7									20.81	19.07	20.17	19.93	20.75	20.29	20.27	19.49	19.52	19.41	19.37	18.70	18.76	18.40	18.05	17.84	17.95	17.34	17.57	17.34	20.51
8								20.22	20.84	19.90	20.19	19.73	20.00	20.14	20.20	19.49	19.54	19.09	19.18	19.17	18.60	18.52	18.75	18.49	18.62	18.24	17.83	17.62	17.84
9							18.77	18.82	19.95	19.70	20.39	20.13	20.45	19.88	19.50	19.66	19.64	19.20	19.05	19.01	19.22	18.87	18.76	18.65	19.33	19.21	18.15	19.25	20.81
10						19.72	20.01	20.94	19.87	20.31	20.72	20.41	19.87	20.03	20.13	19.49	19.67	19.16	19.35	19.46	19.57	19.36	19.67	19.67	18.78	19.64	19.37	19.31	
11					19.77	19.34	19.39	19.87	20.06	20.25	20.16	20.21	19.67	19.85	19.76	19.78	19.97	19.62	19.29	19.31	19.16	19.20	19.40	19.58	19.66	20.54	21.21		
12					19.79	20.06	20.06	19.35	20.24	20.22	19.92	19.87	20.18	19.79	20.13	19.80	19.86	19.96	19.86	19.61	19.68	20.29	19.71	20.23	20.23	19.73	22.31		
13				19.32	19.91	20.02	19.93	20.13	19.70	19.79	20.02	19.82	19.81	19.80	19.80	19.71	19.77	19.95	19.53	19.73	19.94	20.01	20.50	19.83	19.91	17.86			
14			18.56	19.20	19.67	20.00	19.75	19.75	19.54	19.64	19.97	19.71	19.89	19.83	19.82	19.71	19.84	19.68	19.87	19.47	19.98	20.59	19.26	20.86	18.53				
15			18.55	19.12	19.63	19.36	19.87	19.46	19.68	19.49	19.92	19.59	19.90	19.68	19.64	19.53	20.01	19.86	19.49	20.25	20.53	20.26	21.73	19.64					
16		18.79	18.82	18.71	19.50	19.79	19.11	19.42	19.47	19.48	19.48	19.51	19.90	20.13	19.82	20.01	19.60	19.73	20.29	20.66	21.10	20.36	19.23	18.85					
17		18.24	18.69	19.20	18.67	18.77	19.07	19.04	19.17	19.29	19.29	19.41	19.69	19.76	19.85	20.03	19.76	20.42	19.66	20.14	22.08	20.38							
18	19.41	17.82	19.63	18.69	18.72	18.63	19.08	18.94	19.46	19.06	19.46	19.47	19.75	19.36	19.95	19.52	20.46	20.65	20.17	20.29	9.10								
19	16.95	17.75	19.03	18.47	18.57	19.06	18.92	18.79	18.76	19.17	19.11	19.35	19.59	19.81	19.51	19.76	20.00	18.90	18.91	18.56									
20	15.51	18.38	18.29	18.27	18.24	18.73	18.98	19.02	19.07	19.05	19.27	19.60	19.62	19.97	19.64	20.52	19.91	19.67	22.39										
21	17.53	18.17	18.13	18.65	18.29	18.99	18.55	18.70	18.77	19.08	18.80	18.77	20.15	19.43	18.41	19.01	20.52												
22	16.02	17.77	18.33	17.82	18.54	18.65	18.46	18.51	18.83	19.01	19.16	19.16	19.00	18.33	14.55	18.23	18.59												
23		17.35	17.23	17.47	18.72	18.57	18.55	18.78	18.75	18.08	18.16	17.89	17.07	17.97															
24		15.99	17.52	17.15	17.24	18.38	17.57	18.57	18.32	17.94	18.54	18.36																	
25					17.26	17.99	18.03	17.13	18.61																				

Liege (p 1Gev))

<E*> = 16.0

Sum of Moc dN														
dZ	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0					17.62	17.48	19.18	19.18	18.88	18.37	13.84	9.34		
1				8.74	18.60	19.12	19.29	19.16	18.09	17.66	14.97	12.00	7.79	
2			15.74	17.51	18.21	18.05	18.12	18.23	17.88	17.34	15.73	14.01	11.12	8.45
3			15.44	16.75	16.91	17.57	17.52	17.82	17.08	17.24	16.03	15.26	13.66	12.37
4		15.04	16.90	16.26	16.84	16.95	16.76	17.09	17.01	16.91	16.42	16.39	15.34	14.61
5		14.12	15.91	16.19	15.91	16.44	16.27	16.37	16.52	16.59	16.43	16.82	15.76	16.55
6		15.04	15.81	15.59	15.92	16.06	16.29	16.34	16.25	16.78	16.04	16.42	16.86	18.02
7	14.77	15.50	14.96	15.03	15.72	15.67	15.63	16.28	15.87	16.07	15.93	16.82	16.03	17.17
8	13.21	15.46	14.54	15.22	15.09	15.45	15.79	16.16	15.34	15.67	15.41	16.45	18.84	
9	14.80	14.16	14.27	15.00	14.67	14.50	15.14	14.86	14.30	15.57	15.07	15.01		
10		13.39	14.53	14.51	14.22	15.38	14.56	15.74	14.26	12.51				
11					14.03	12.77	10.31	15.45						

IME-Hole EE vs. BeAGLE results: ^{58}Ni



Courtesy of I. Richardson, B. Schmookler, J.L.R.Sanchez

BeAGLE

<E*> = 17.8

Sum of Mode dN	8	7	6	5	4	3	2	1	0
dZ									
0		12.92	15.86	16.03	16.11	15.51	16.20		
1		16.17	15.84	17.44	17.14	17.07	17.24	16.04	
2	16.29	17.34	17.86	18.09	18.64	18.35	18.49	17.45	16.81
3	17.97	18.72	17.76	18.58	18.90	18.58	18.35	17.35	16.41
4		19.60	18.52	19.17	19.42	18.76	18.89	17.76	17.18
5			19.13	18.98	19.20	18.44	18.57	17.38	17.30
6			19.73	18.92	19.02	18.74	17.48	18.07	17.90
7				20.40	19.59	18.45	17.03	17.76	19.76
8							17.39		

Liege (C 1Gev))

<E*> = 17.7

Sum of Moc dN	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
dZ																							
0														13.97	17.53	16.08	16.34	14.63	12.14	9.16	6.35		
1												17.79	17.23	18.20	17.17	16.13	15.56	14.74	13.26	11.23	8.26	6.21	
2											18.18	18.72	19.01	17.98	18.10	16.89	16.13	15.16	14.50	12.50	11.17	8.80	7.09
3										18.51	21.15	18.67	18.42	17.84	17.15	16.70	16.69	15.49	15.03	13.66	13.16	11.30	9.43
4									17.18	20.36	19.36	18.67	18.34	17.93	18.17	17.10	17.01	16.23	15.48	14.91	14.22	13.24	11.96
5							20.36	19.01	19.40	19.33	19.81	18.31	18.53	17.55	17.77	17.39	17.00	16.49	16.02	15.37	15.62	14.56	13.26
6						20.27	19.85	19.83	19.81	19.36	19.23	18.55	18.55	18.00	17.93	17.53	17.51	16.79	17.08	16.59	16.26	15.08	16.40
7					19.27	20.13	19.35	19.16	19.44	18.83	18.98	18.71	18.46	18.36	17.95	17.73	17.50	17.02	17.22	16.87	16.72	15.77	17.04
8					16.04	20.50	18.86	18.84	19.13	19.00	18.79	18.65	18.58	18.40	18.34	18.21	18.19	17.83	17.94	17.74	17.92	16.86	16.39
9				18.22	18.61	19.40	19.63	19.22	19.21	18.83	18.70	18.60	18.72	18.33	18.45	18.26	18.38	18.34	17.80	18.14	18.24	18.22	11.40
10			17.89	18.56	18.72	18.86	19.08	18.90	18.91	18.72	18.85	18.63	18.96	18.62	18.36	18.32	18.76	19.06	18.33	19.56	20.46	18.32	
11		17.70	18.05	19.74	18.88	18.92	19.14	18.97	19.12	18.81	18.91	18.79	18.84	18.49	18.45	18.69	18.89	19.23	19.29	18.76	19.90		
12		17.73	19.01	18.94	19.13	19.02	19.11	19.04	18.80	18.85	18.90	18.59	19.00	18.50	18.95	19.07	18.73	18.85	18.12	20.07	15.30		
13	19.50	18.53	18.97	18.98	19.25	18.76	19.05	19.17	18.90	18.77	19.00	18.96	18.91	18.77	19.21	19.75	18.93	19.47	15.35				
14	17.68	18.38	18.83	18.94	18.83	19.10	19.09	18.99	18.89	19.05	18.96	19.07	19.19	19.00	19.42	19.08	20.19	19.72	18.64				
15	18.89	18.69	18.38	18.70	18.76	18.94	18.61	19.05	18.95	19.00	18.88	19.17	18.99	18.70	18.45	18.85	18.78	18.40					

Liege (p 1Gev))

<E*> = 15.2

Sum of Mod dN	11	10	9	8	7	6	5	4	3	2	1	0
dZ												
0				14.78	17.89	17.92	17.64	16.86	13.46	9.36		
1			14.91	17.82	17.20	17.48	17.24	16.25	14.26	11.67	7.56	
2		16.17	15.65	17.42	16.89	17.19	16.71	16.68	15.15	13.50	11.12	8.14
3		16.24	15.49	16.46	16.70	16.82	16.66	16.24	15.55	14.67	12.93	11.44
4		15.13	15.71	16.13	16.31	16.46	16.21	16.38	15.94	15.94	14.59	14.07
5	15.01	15.05	15.57	15.96	15.90	16.00	15.87	15.72	15.93	15.87	14.91	13.59
6	14.89	15.36	15.23	15.42	15.23	15.93	15.61	16.03	15.98	16.11	14.84	17.04
7	15.47	15.20	14.70	15.38	15.18	15.40	15.32	15.59	16.00	16.09	14.68	16.40
8	13.95	14.71	14.94	15.41	15.04	15.15	14.88	15.42	15.01	15.47	16.24	
9	13.96	13.49	13.55	15.12	14.56	14.78	16.02	15.06	11.46	16.21		
10		13.11	13.45	13.56	15.27	15.32	14.34	13.80				

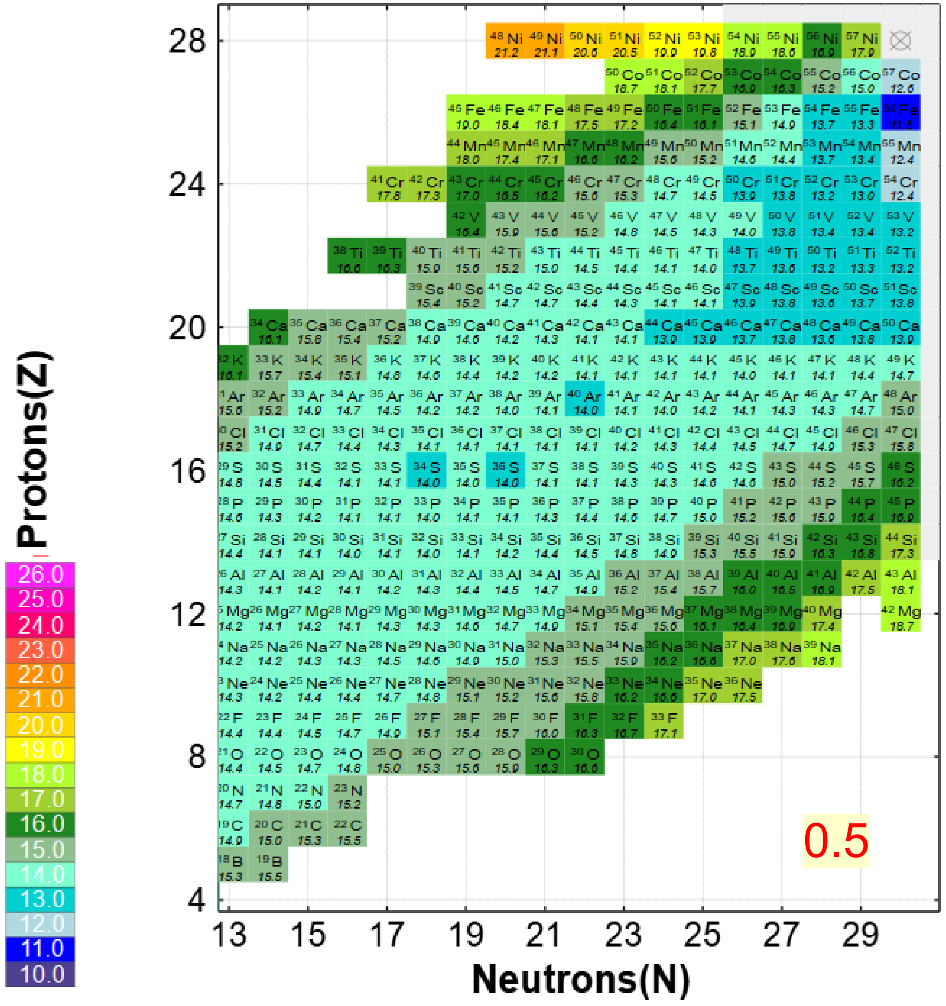
IME-Hole EE results as f(α_{mode})

IME-Hole excitation energy per abraded nucleon

^{58}Ni (140 MeV/u)

α_{mode} = **0.50**; $f_{Coulomb}$ = 0.10; κ = 1.00; λ = 1.00

$\langle E^*/\Delta A_{abr} \rangle$ = 14.99

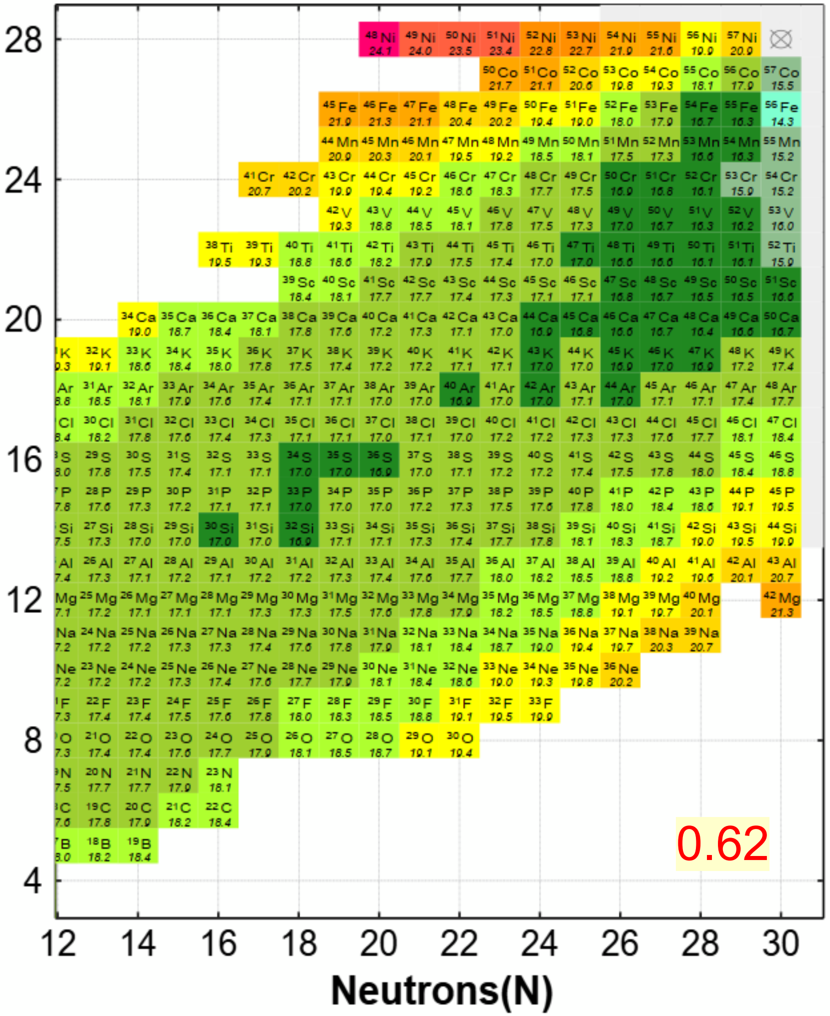


IME-Hole excitation energy per abraded nucleon

^{58}Ni (140 MeV/u)

α_{mode} = **0.62**; $f_{Coulomb}$ = 0.10; κ = 1.00; λ = 1.00

$\langle E^*/\Delta A_{abr} \rangle$ = 17.91

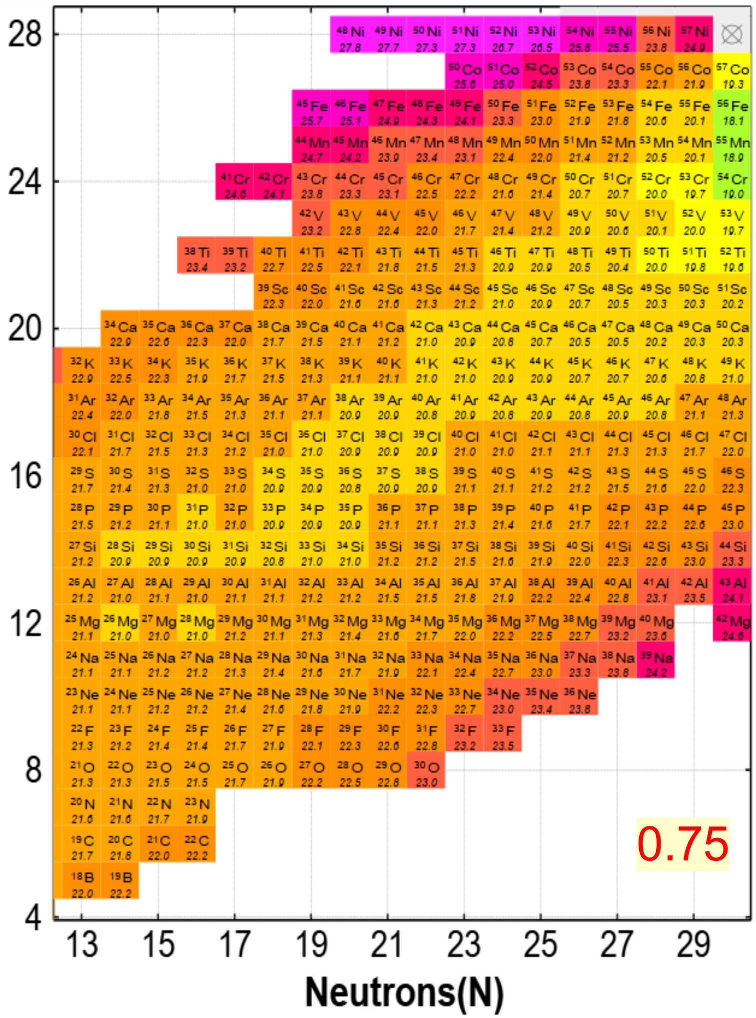


IME-Hole excitation energy per abraded nucleon

^{58}Ni (140 MeV/u)

α_{mode} = **0.75**; $f_{Coulomb}$ = 0.10; κ = 1.00; λ = 1.00

$\langle E^*/\Delta A_{abr} \rangle$ = 21.75



What is $alpha_{mode}$?

According to a paper from **1996** (Ferrari et al., Z. Phys. C), **α_mod** is an **empirical reduction factor** applied to the **Fermi momentum / nucleon momentum distribution** inside the nucleus, meant to mimic that the *real* momentum distribution is not perfectly described by a sharp uniform Fermi-gas picture (they explicitly mention **nuclear-skin effects**).

In practice:

- **What it does physically:** it **scales down the typical nucleon momenta** (and therefore the typical Fermi kinetic energies) used when estimating the "hole"/spectator excitation after nucleons are removed
- **Why it exists:** to absorb missing physics of the simplified nuclear model (surface/shell/skin, non-uniform density, etc.) into one knob
- **How they choose it:** they **tune α_mod to data**, specifically by comparing model predictions to **measured black-particle production**, and then fix it

In the **attached paper**, What the paper states is:

- **α_mod is fixed at 0.5** after tuning to a *larger data set* (hadron–A and nucleus–nucleus)

There is a note that in an **earlier work** they used **α_mod = 0.75** (together with τ0 = 2 fm/c), but that was based on **h–A data only**, and the "new" parameters are from a broader dataset