Light Particle Kinematics in LISE^{++}

Status after today's analysis: LISE^{++} v18.5.14

Goal: understand and fix the low / too-narrow proton momentum distribution used by the Prompt Radiation utility.

Contents

- Momentum-model limitations for light charged particles: projectile-fragment models vs. de-excitation products.
- CM → Lab tests for ^{79}Ge* and ^{60}Ca*: fixed CM angles, all-angle spectra, and TKE / MeV/u checks.
- PHITS-inspired reference plots are qualitative only; component contributions are not normalized.

Main result

- Problem found: 1H used Apf = 1, giving sigparB ≈ 194 and a direct-like, too-narrow distribution.
- Neighboring light particles used evaporation-parent-like APF ≈ 27–29, giving sigparB ≈ 834–848.
- Fix: SearchPrefragment() now uses a temporary 2H seed for requested 1H, while keeping final product = 1H.

Discussion / next checks

- Validate v18.5.14 spectra against requested PHITS/JQMD output from Tom before using absolute yields.
- Keep channel bookkeeping explicit: target-like evaporation, projectile-residue de-excitation, participant / pre-equilibrium.
- Recommendation: present v18.5.14 as a physics-motivated width correction, not only as a code patch.

Recommendation on the Convolution Model for Light-Particle Momentum Distributions in LISE^{++}

Main recommendation:

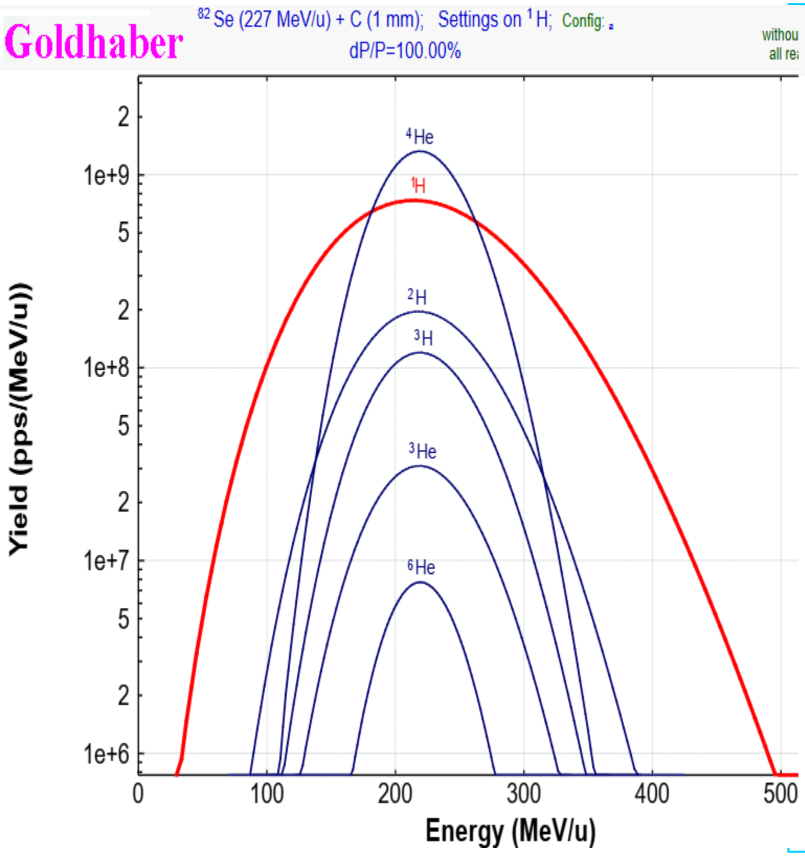
Develop and implement a new mechanism-dependent model for light-particle momentum and energy distributions in LISE^{++}. The existing models were developed mainly for projectile-fragmentation residues and do not explicitly include projectile de-excitation, participant/pre-equilibrium emission, target evaporation, breakup, and coalescence.
The Convolution model and the v18.5.14 correction improve the present calculations, but they represent only an interim solution.

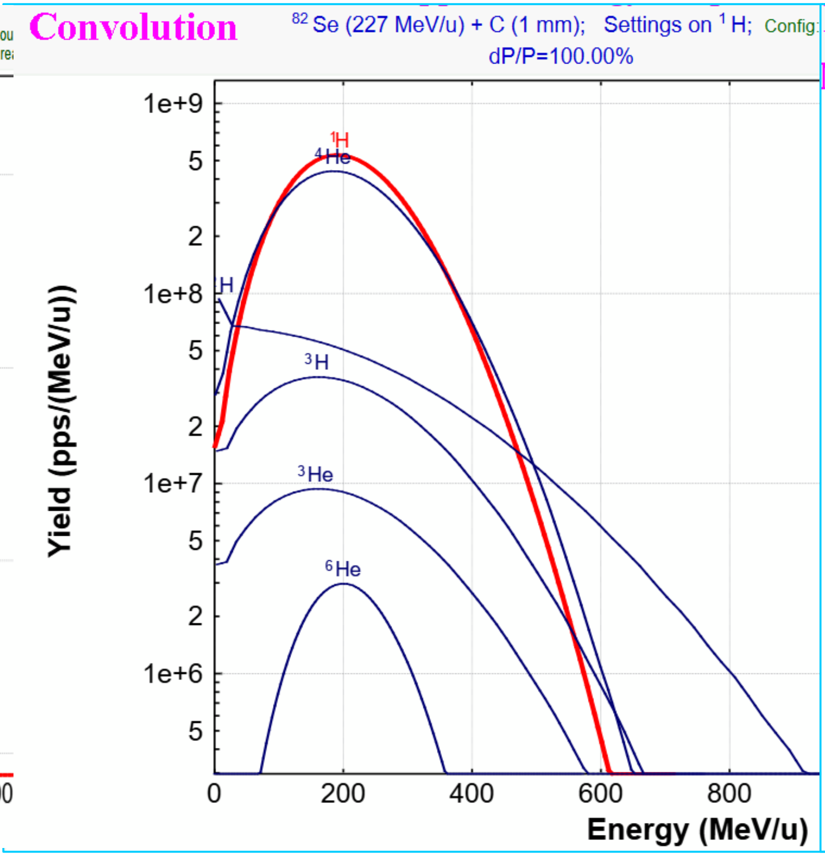
Momentum distribution models in LISE++

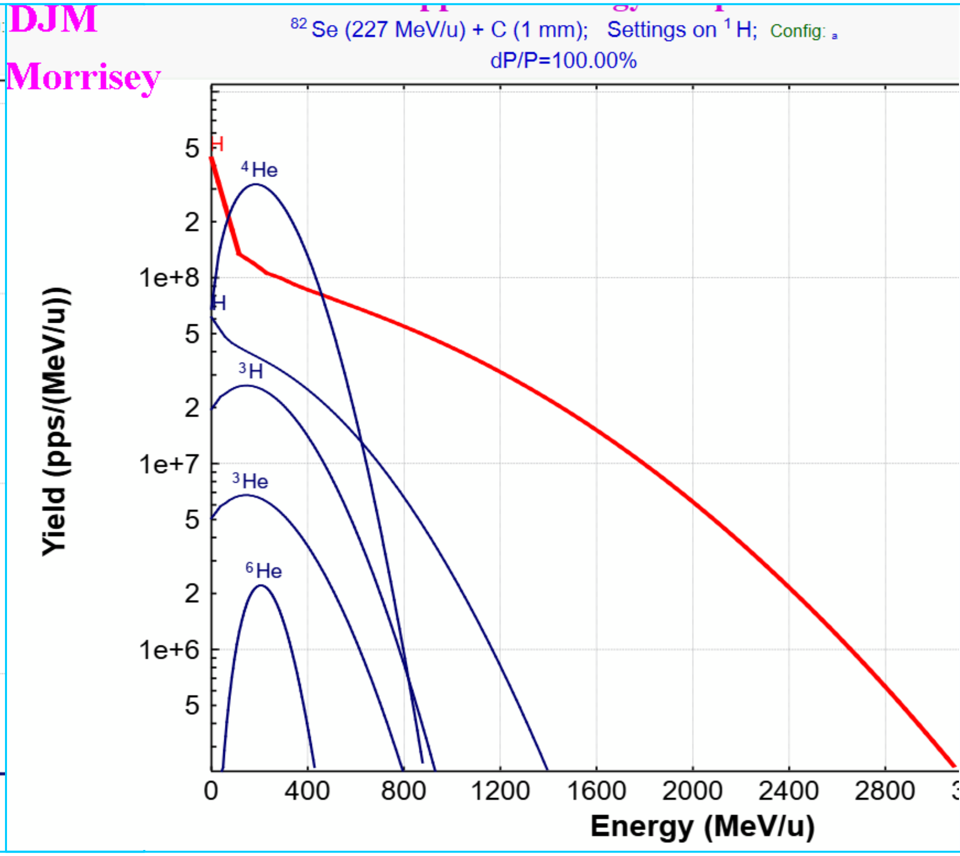
Too narrow for de-excitation particles

1P = 4He .. Not so good

Too high production of 1H for 3 GeV



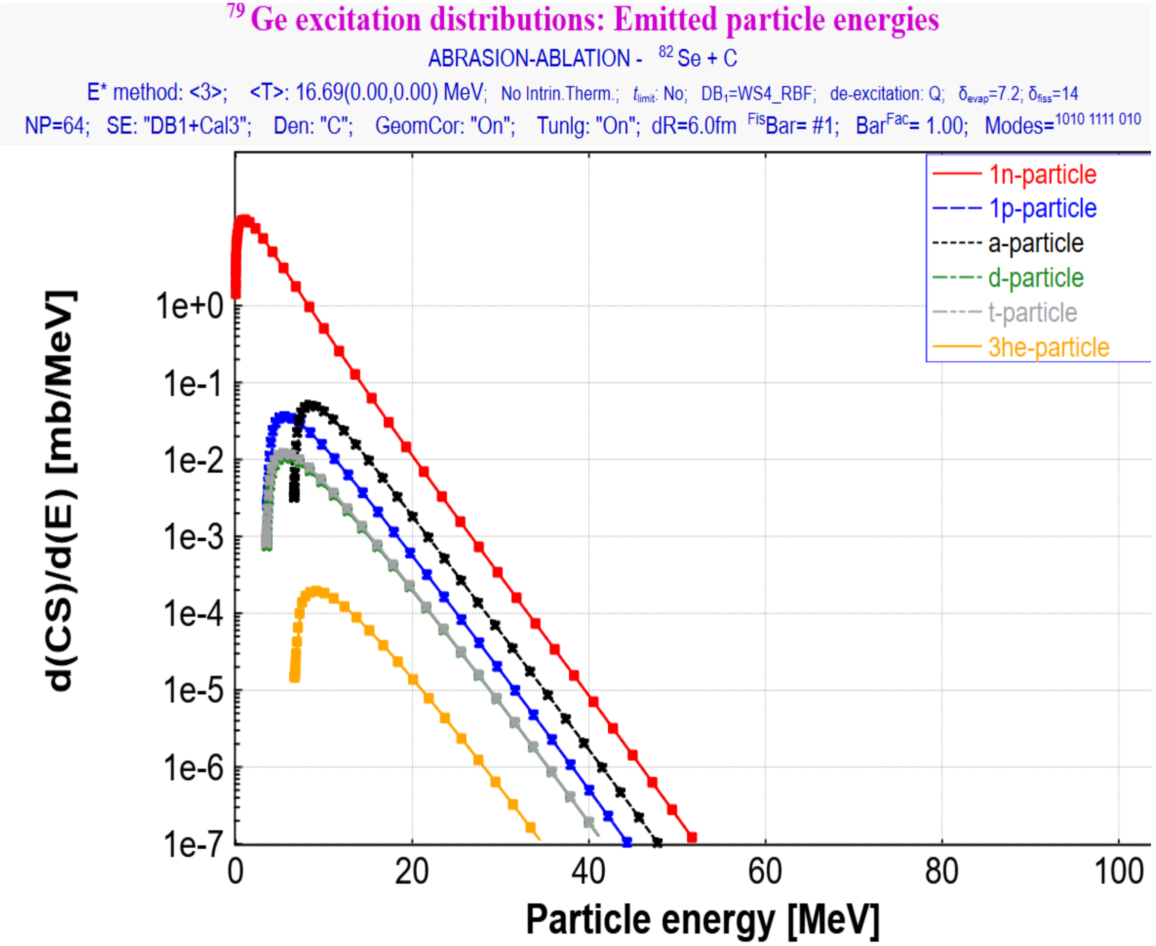


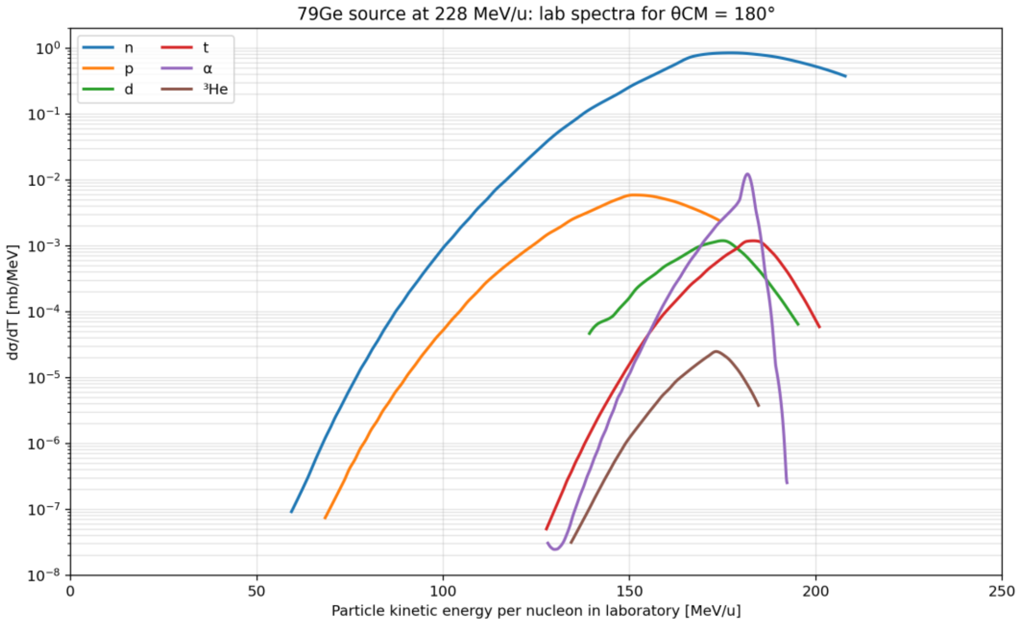


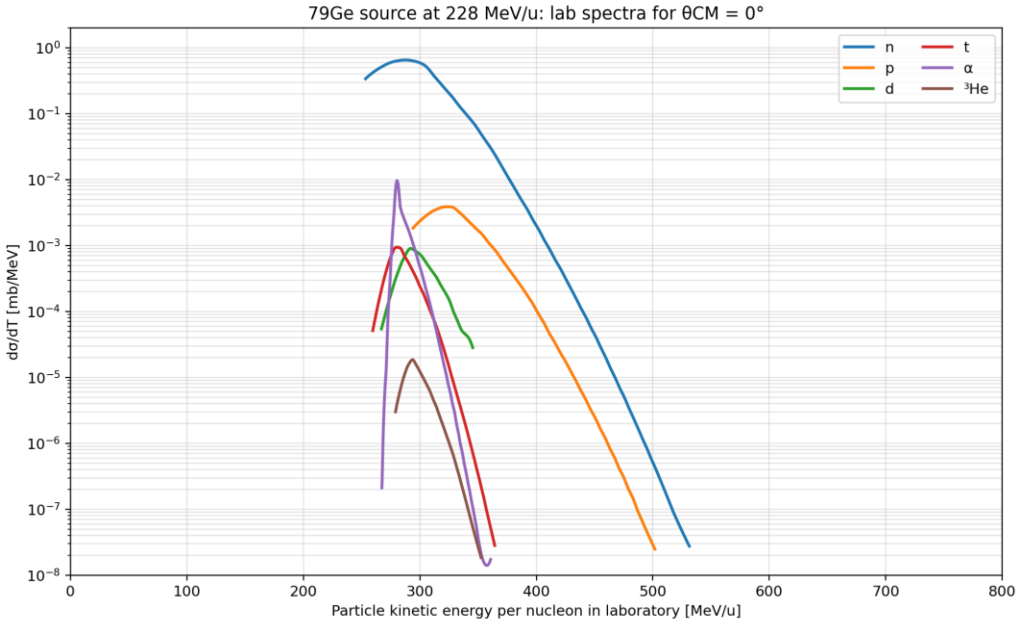
These models are developed for projectile fragmentation products, but most of light charge particles come from de-excitation

^{79}Ge* → Emitted particles in CM → Lab

LISE^{++} AA

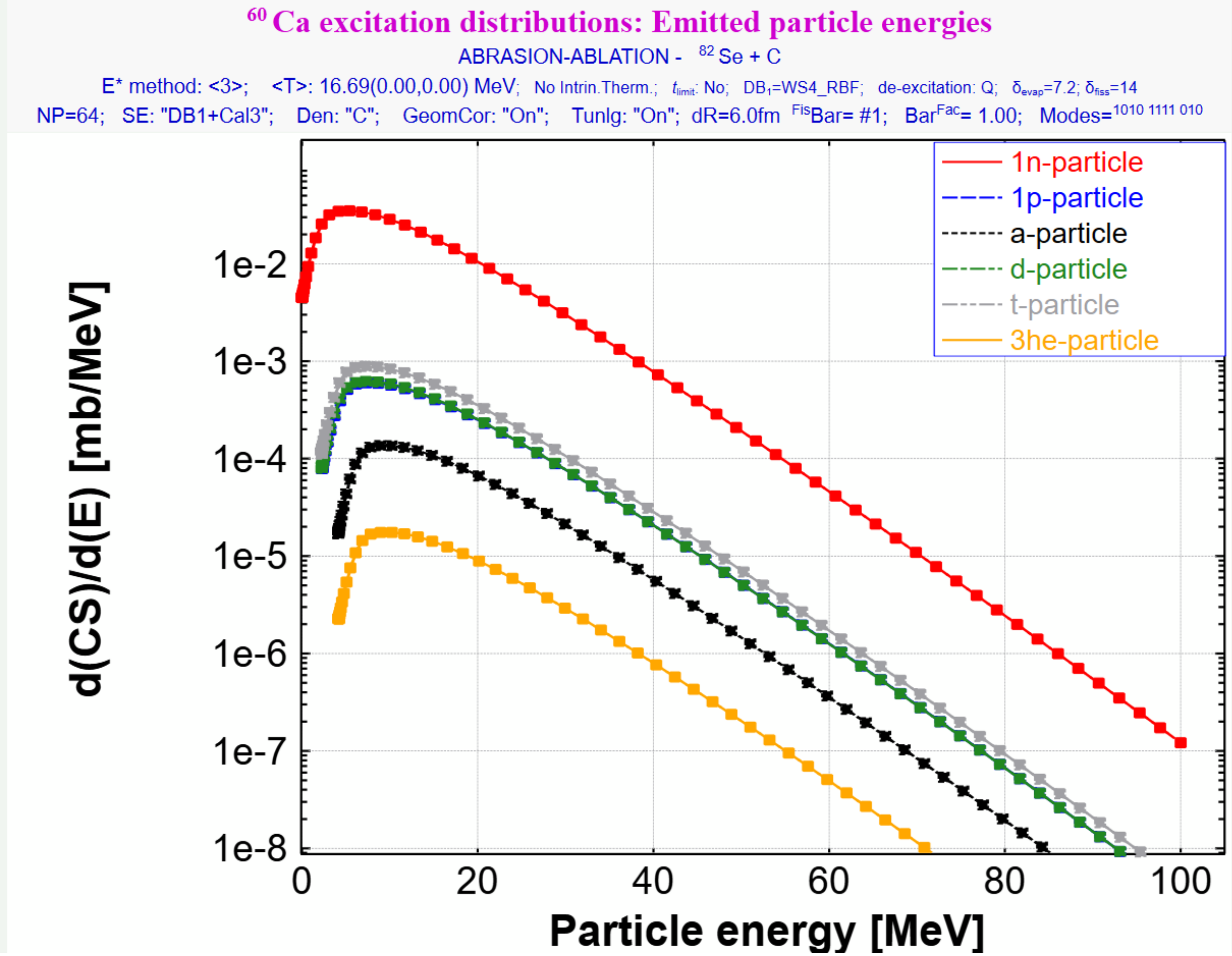


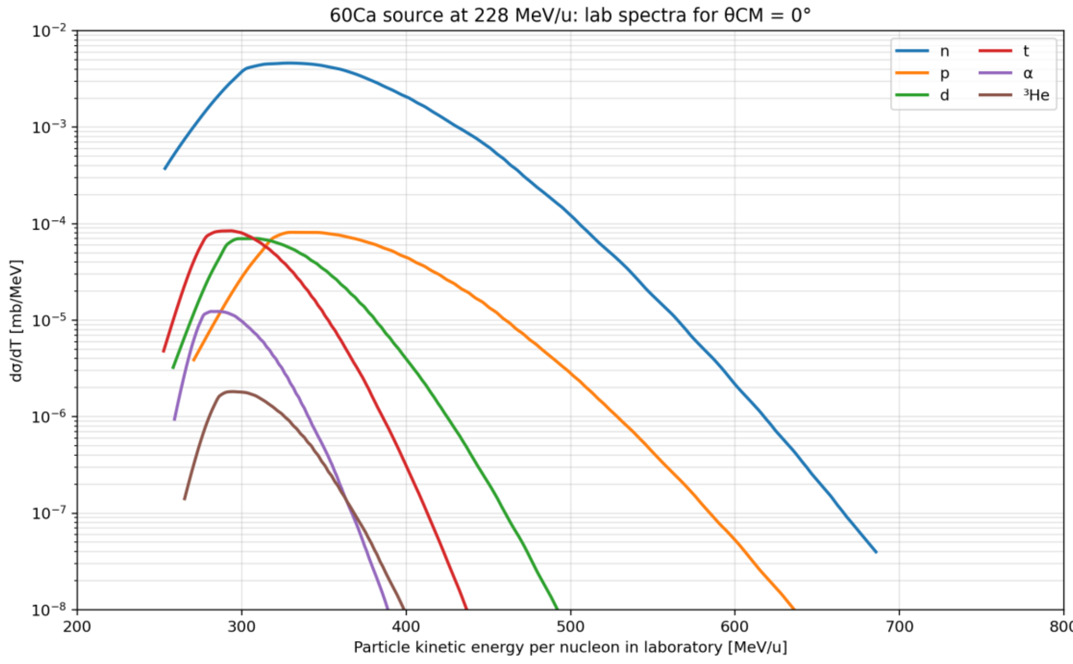


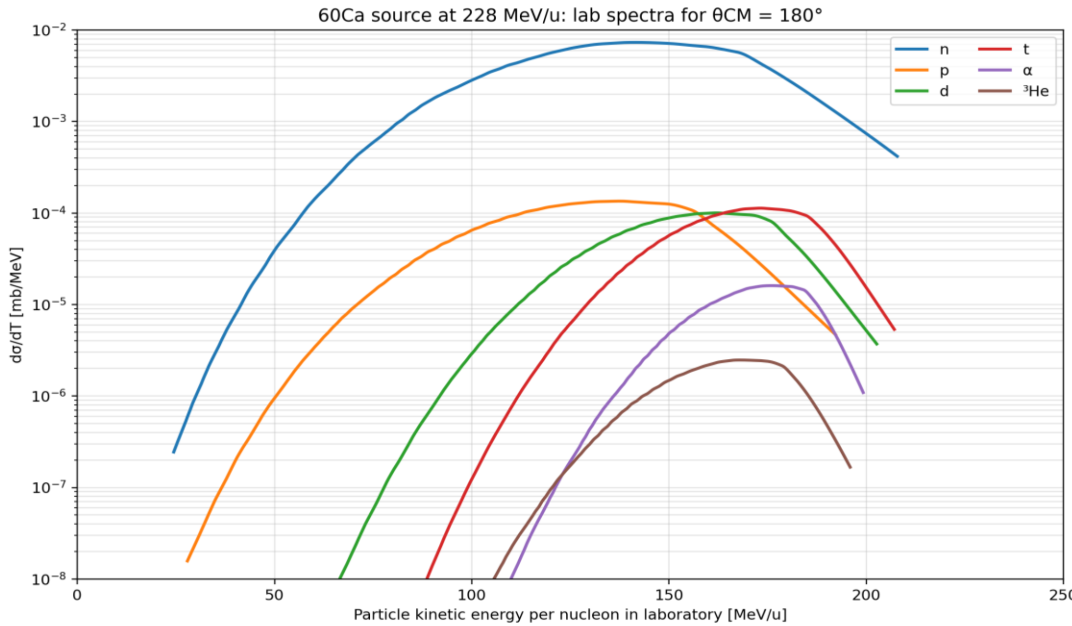


^{60}Ca* → Emitted particles in CM → Lab (0 degree)

LISE^{++} AA

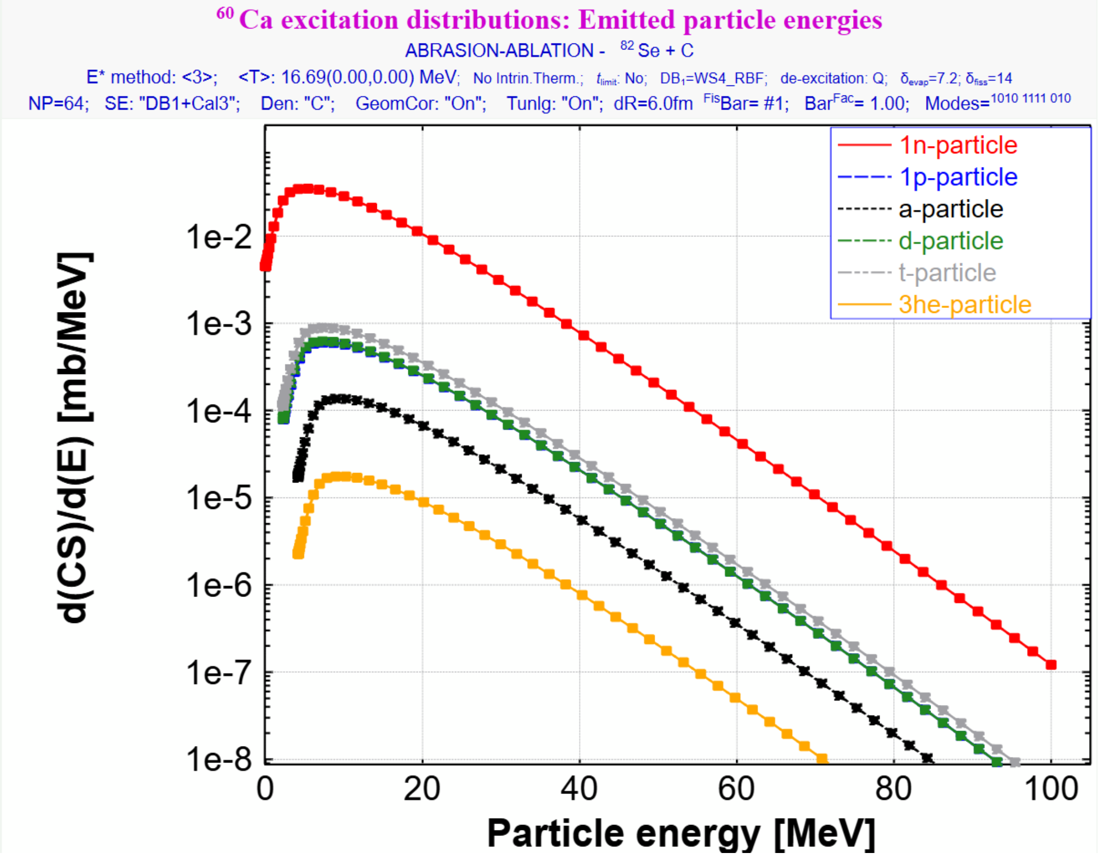


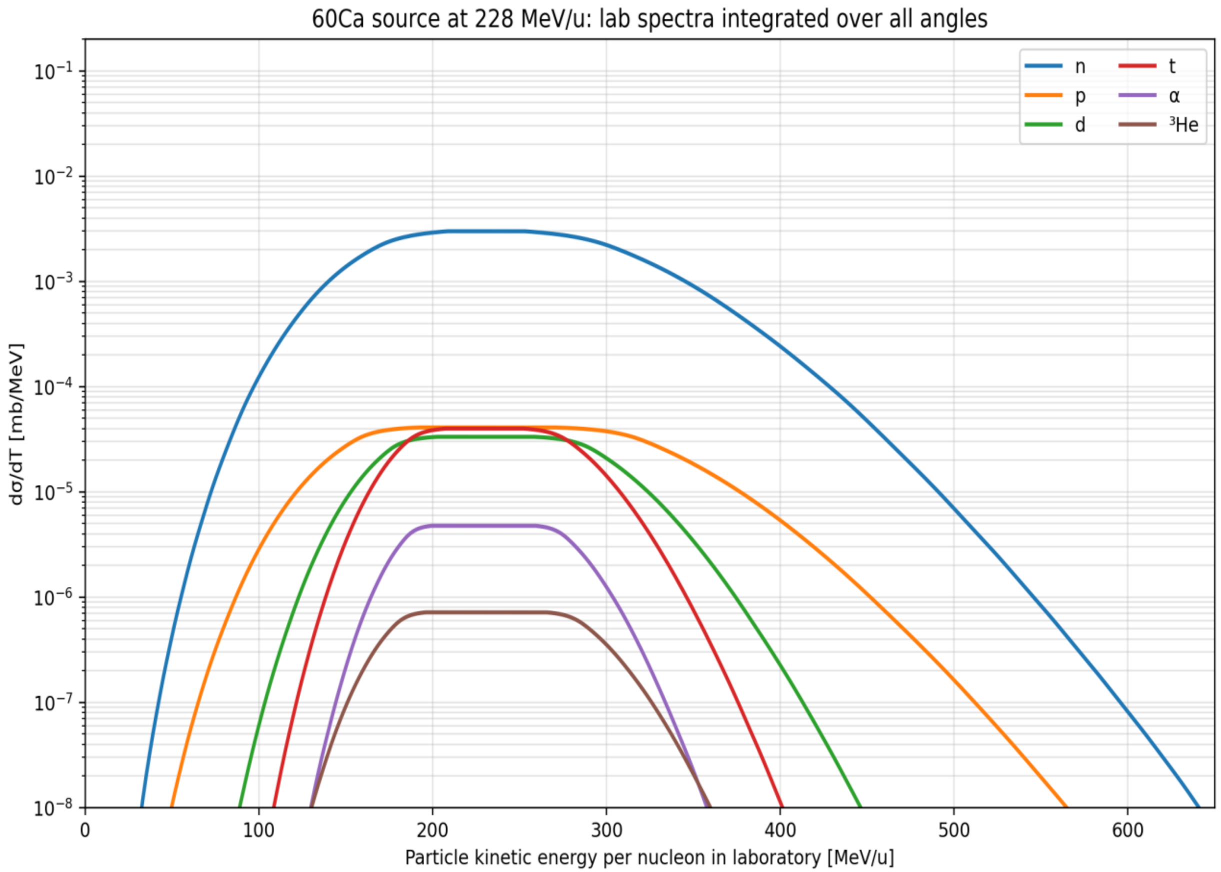




^{60}Ca* → Emitted particles in CM → Lab (total)

LISE^{++} AA



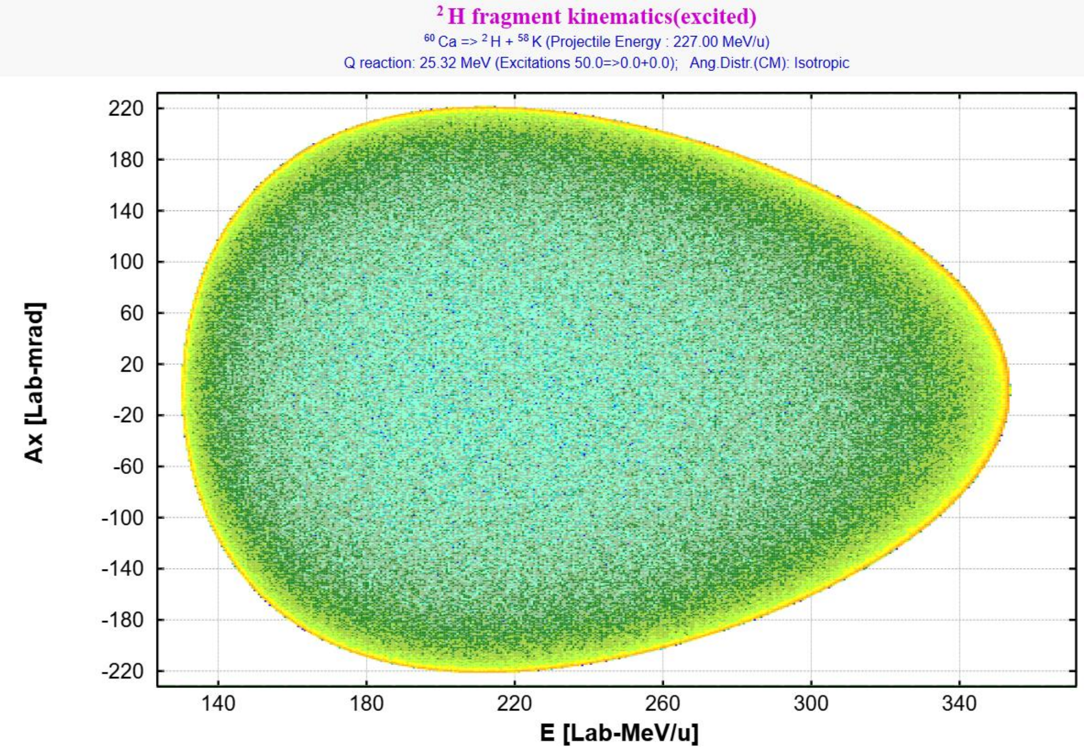


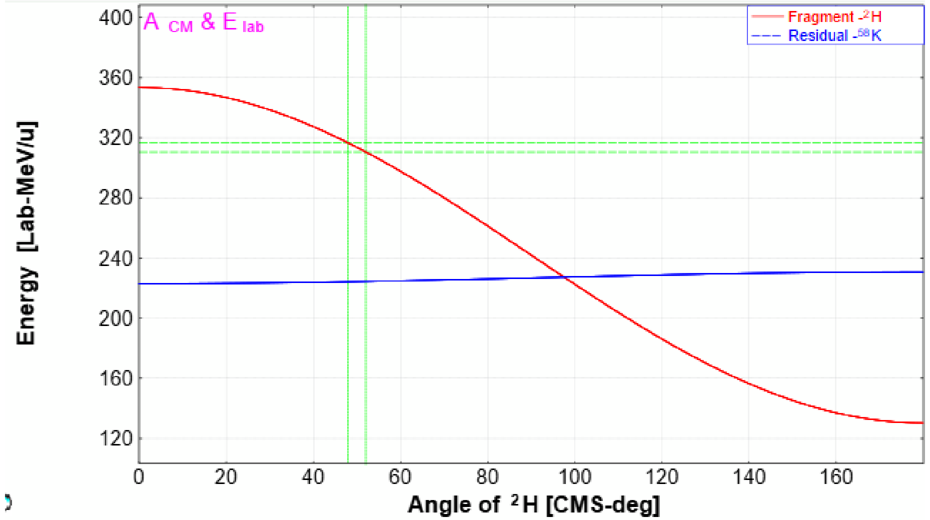
LISE++ Kinematics Calculator

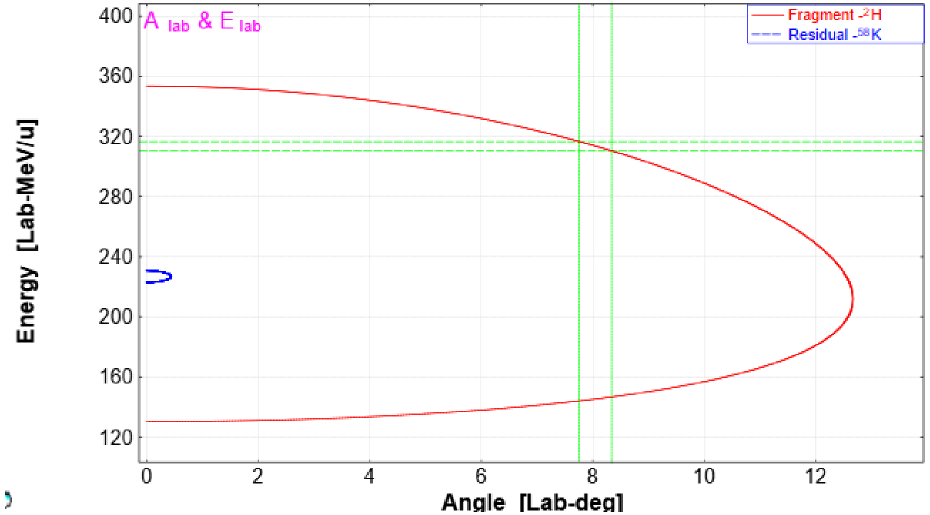
Participants

			ME [MeV]	Excitation Energy
A	Beam	^{60}Ca	12.28	50
B	Target	^{12}C		
C	Fragment	^{2}H	13.14	0
D	Residual	^{58}K	23.82	0.001

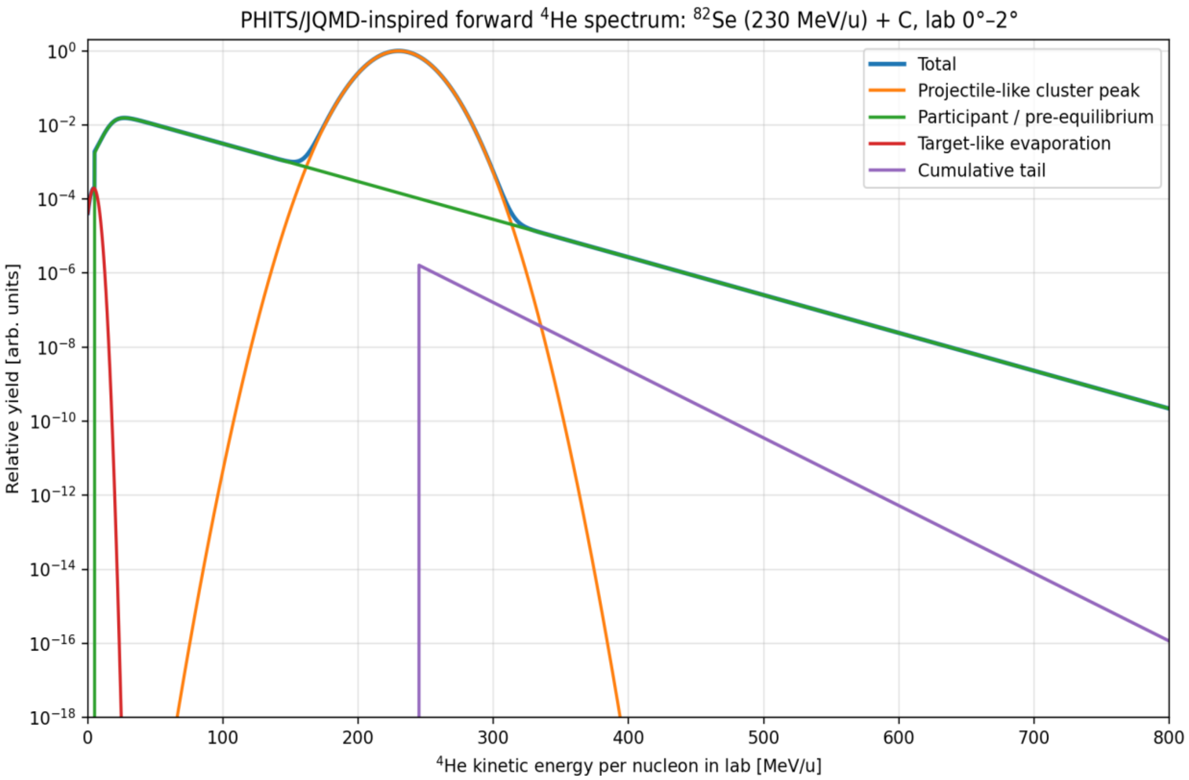
Deuteron emission at E*= 50 MeV

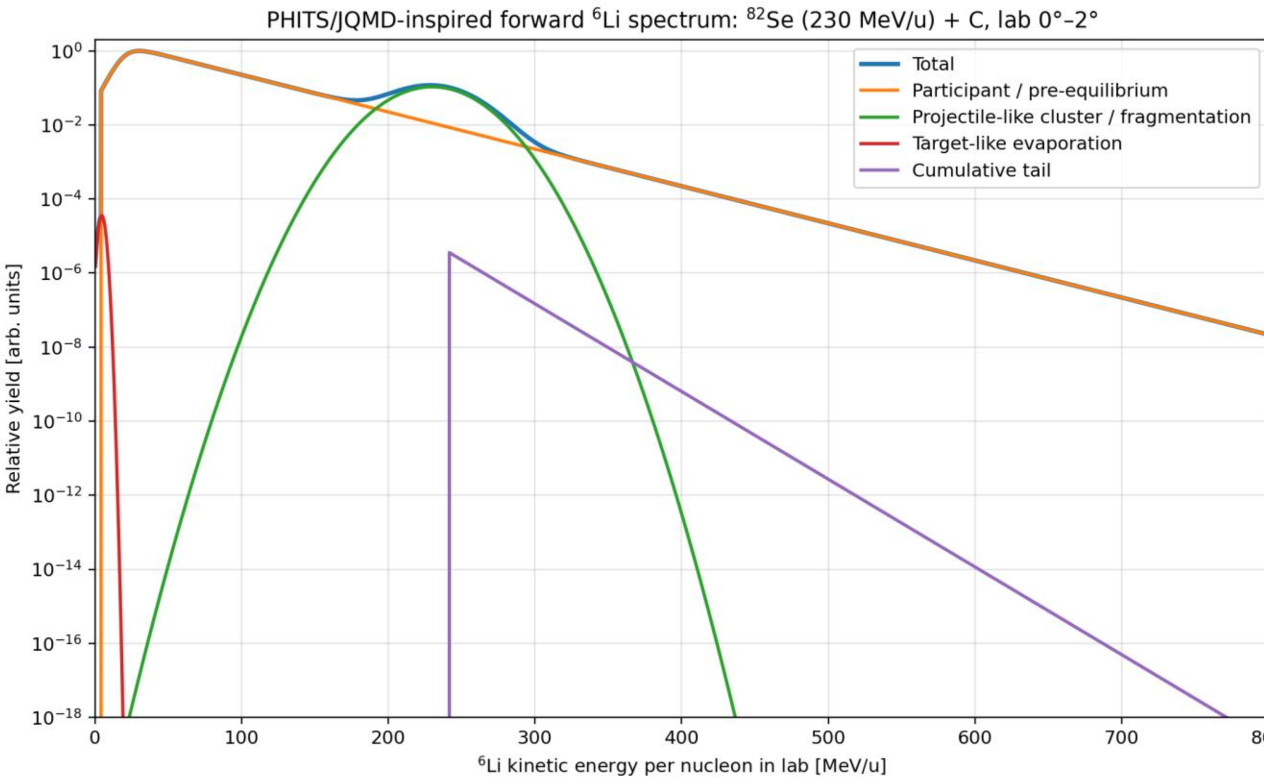






Important: Component contributions are not normalized





The request has been sent to Tom generate energy spectra directly from PHITS

ChatGPT reference to PHITS : ^{1}H, ^{2}H (0-degree)

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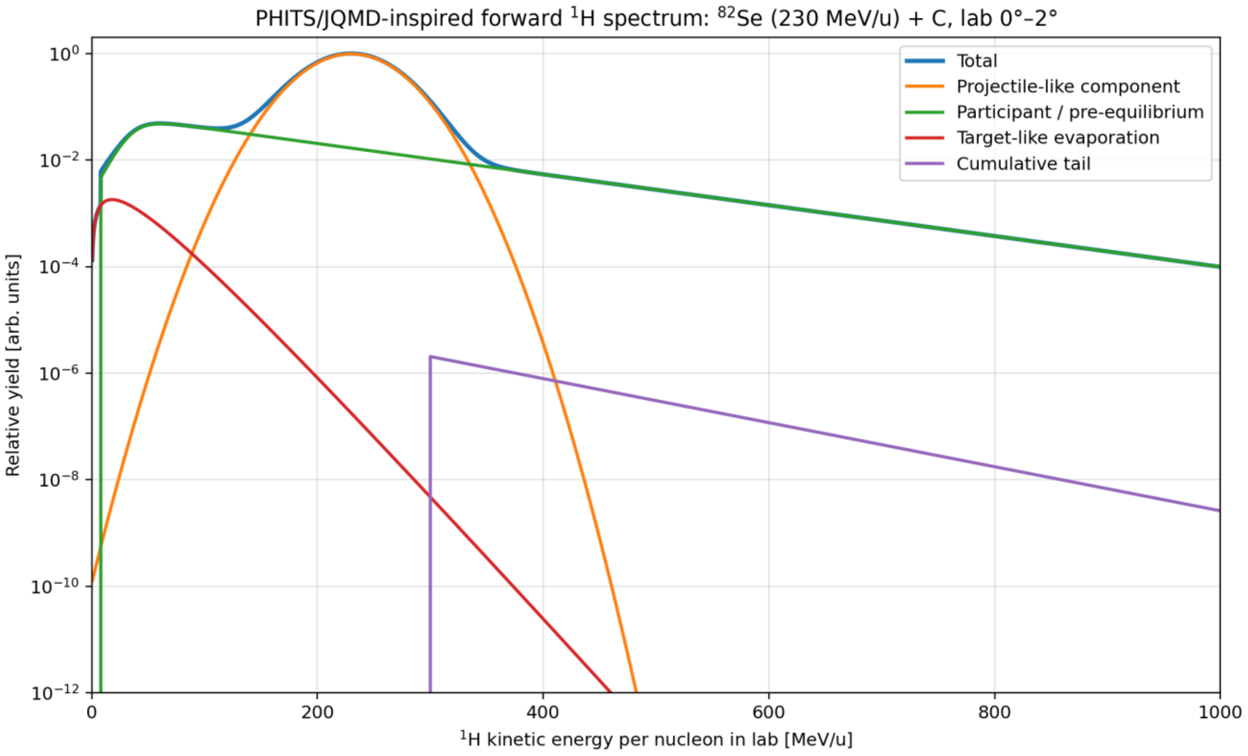
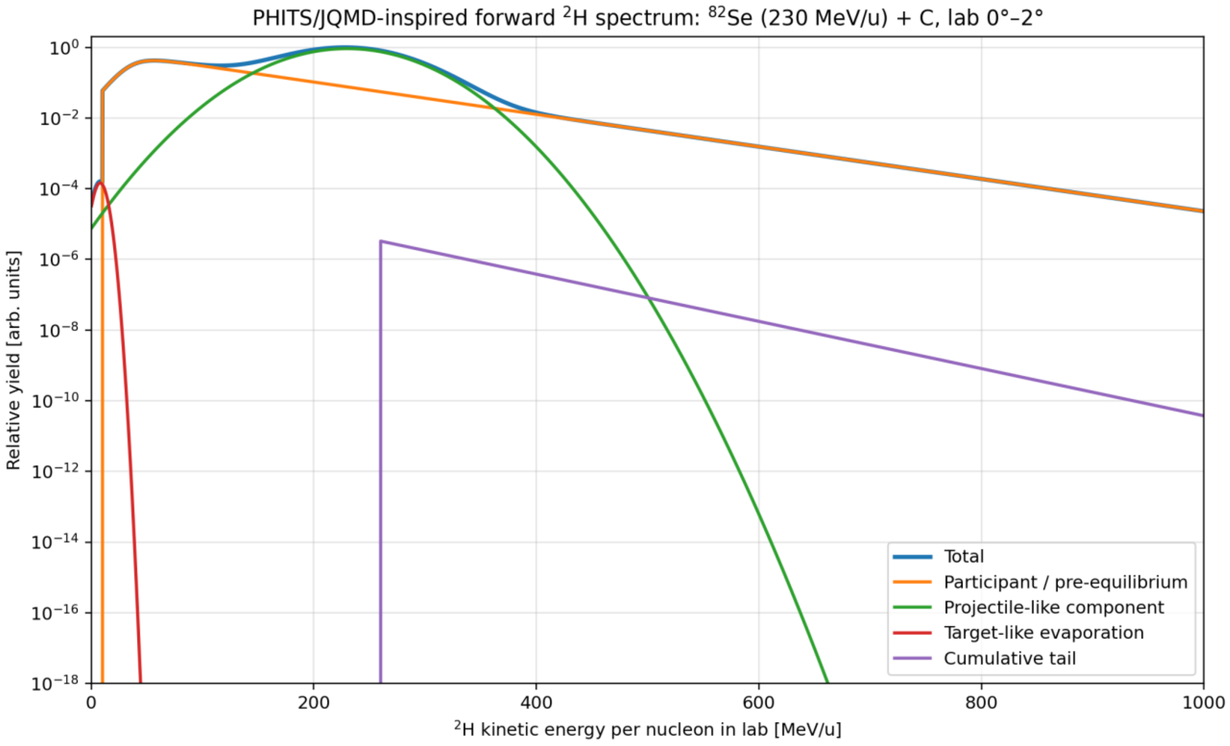
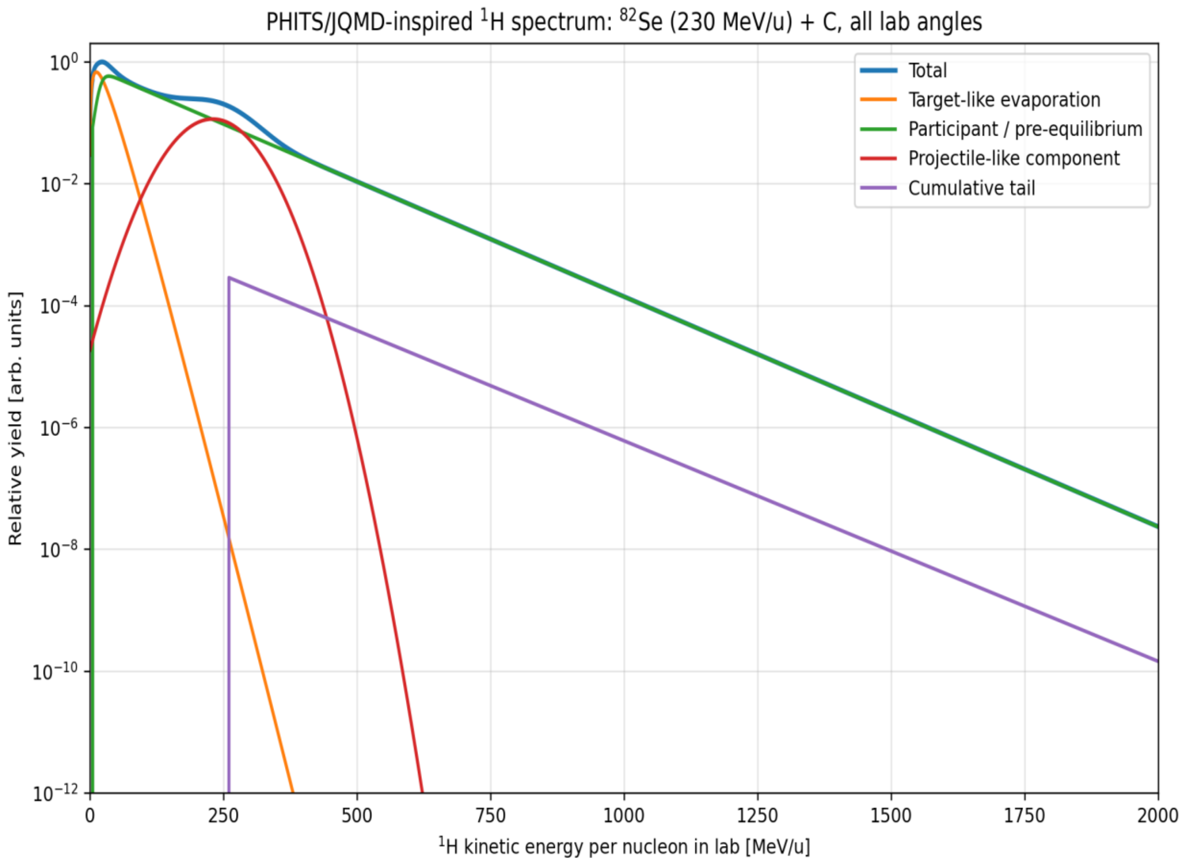


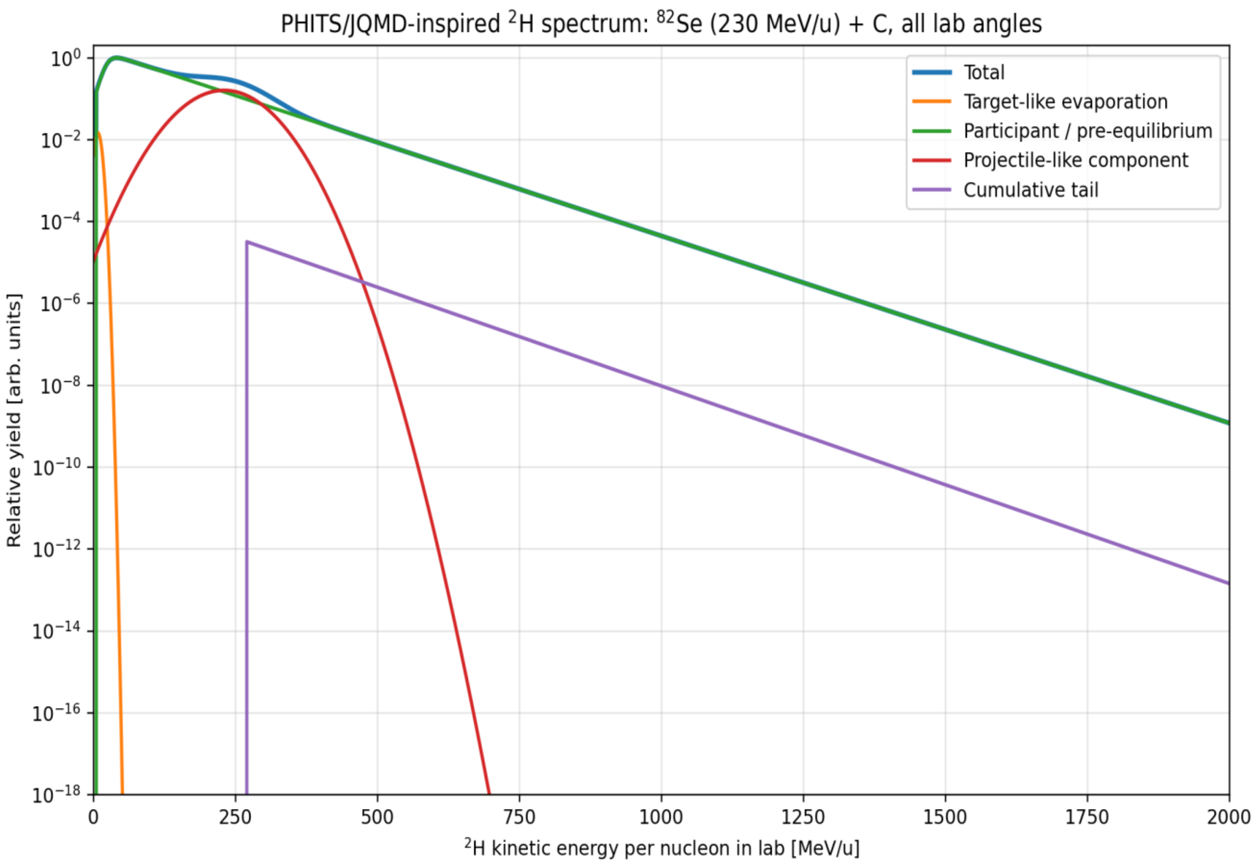


The request has been sent to Tom generate energy spectra directly from PHITS

ChatGPT reference to PHITS : ^{1}H, ^{2}H (all angles)

Important: Component contributions are not normalized





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LISE++ v.18.5.14: updates for proton momentum distributions

Version	Topic	Implementation Summary
18.5.14	Fireball prefragment search for 1H	SearchPrefragment() now uses a temporary 2H search seed when the requested product is 1H. This makes proton momentum distributions follow the same evaporation-parent APF behavior as 2H, instead of stopping with direct-like Apf=1.

- The momentum-width investigation showed that 1H had Apf=1, while 2H, 3H, and 4He were assigned evaporation-parent-like APF values near 27-29.
- The width expression uses sigparB proportional to sqrt(Apf * dA / dP), so Apf=1 made the proton distribution significantly narrower than neighboring hydrogen isotopes.

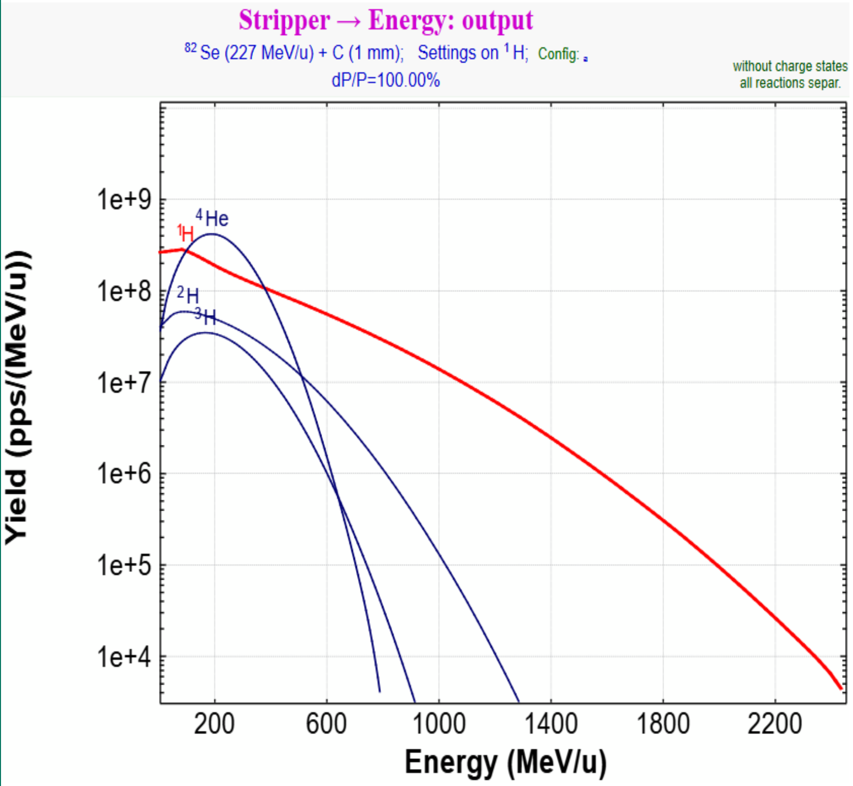
Using a temporary 2H seed only inside SearchPrefragment() keeps the original requested product as 1H while allowing the APF search to use the same parent-search path as deuterons.

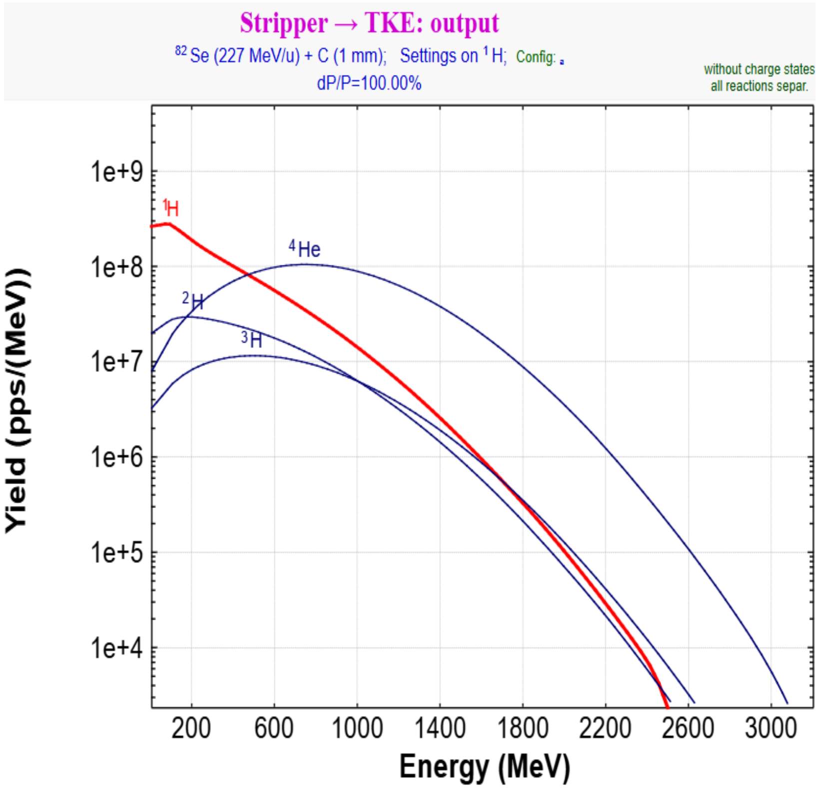
Diagnostic Values

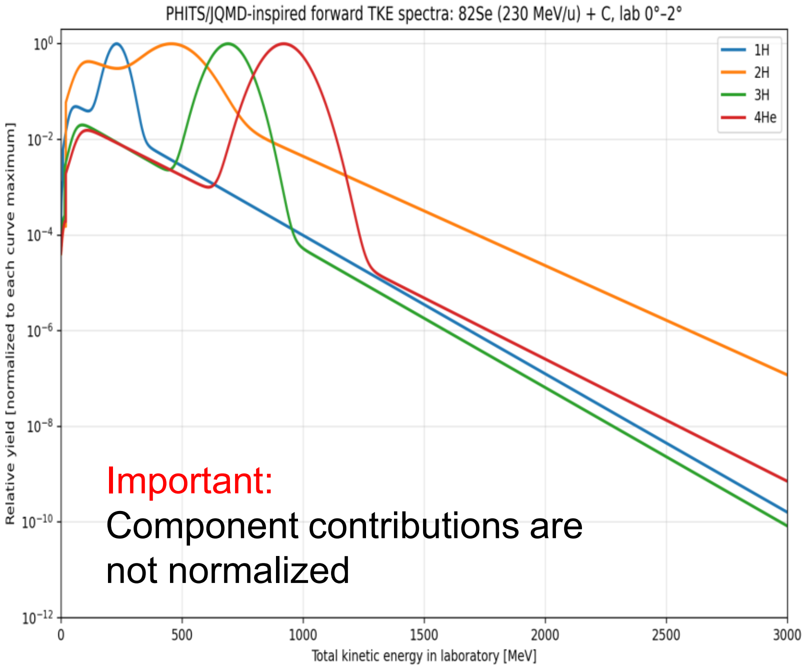
Product	Observed Before Change	Consequence
1H	Apf=1, sigparB=194.36	Direct-like APF produced a narrow proton spectrum.
2H	Apf=27, sigparB=833.762	Evaporation-parent-like APF produced a much wider distribution.
3H	Apf=28.2208, sigparB=843.458	Width consistent with the same APF behavior as 2H.
4He	Apf=29, sigparB=848.041	Width consistent with the light-particle evaporation-parent group.

See next slide for update results

v.18.5.14, Convolution #2







Important:
Component contributions are not normalized

Main recommendation

The Convolution model should not be regarded as universally superior to every other LISE++ momentum model. However, for light particles produced predominantly through de-excitation of an excited projectile-like fragment, it is conceptually more appropriate than models developed for direct projectile-fragmentation residues.

Why the Convolution model is appropriate in this case

For an ordinary projectile-fragmentation residue, the reaction can be represented schematically as:

Projectile → excited projectile-like fragment

For a light particle emitted later from that excited fragment, there are two kinematic stages:

Projectile → F* → R + x

where x = p, d, t, ^{3}He, α, and similar light particles.

The laboratory distribution of the emitted particle should therefore contain:

- the velocity and momentum distribution of the excited parent fragment F*;
- the particle-energy and angular distribution in the F* rest frame;
- the Lorentz transformation into the laboratory frame.

Conceptually, this is a convolution of the parent-fragment distribution with the decay kernel:

$$f_x^{lab}(p) = \int f_{F^*}(P)\, K_{F^* \to x}(p \mid P, E^*, \theta^*)\, dP$$

This is the central physics reason for preferring the Convolution model in the present context.

$$Y_{\text{light}} = Y_{\text{projectile fragmentation}} + Y_{\text{projectile de-excitation}} + Y_{\text{participant/pre-equilibrium}} + Y_{\text{target evaporation}}.$$

Recommended long-term LISE^{++} solution

A more defensible treatment would separate the light-particle spectrum into mechanisms rather than assign one effective momentum model to the entire yield:

- Projectile-residue decay: parent momentum distribution convolved with the CM de-excitation spectrum;
- Direct fragmentation: Goldhaber, Morrissey, or another fragmentation model;
- Participant or pre-equilibrium emission: a dedicated broad-source distribution;
- Target evaporation: a nearly stationary and approximately isotropic source.

This mechanism-separated approach would be more physically transparent than forcing all channels into one Gaussian or one empirical longitudinal distribution.

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Important limitation

The Convolution model should not automatically replace every other model for all light particles. A calculated light-particle yield can contain several physically distinct mechanisms:

- target-like evaporation;
- projectile-residue de-excitation;
- participant or pre-equilibrium emission;
- direct breakup, fragmentation, or coalescence.

The Convolution model mainly addresses the projectile-residue de-excitation component. It does not, by itself, provide a complete description of target evaporation, fireball emission, cascade processes, or pre-equilibrium production.

Comparison with other momentum-distribution models

Goldhaber-type model

This model is well suited to the momentum width of a direct projectile-fragmentation residue, where the width is generated mainly by the random removal of projectile nucleons. It becomes questionable when applied directly to p, d, t, or α particles that are secondary products emitted after equilibration.

Morrissey-type or empirical fragmentation models

These models are useful for centroids and widths of projectile-like residues across systematic fragmentation data. They describe the transported residue, not necessarily a light particle evaporated from that residue. Direct application may therefore generate an artificial narrow structure near projectile velocity.

Phenomenological light-fragment models

These may be useful when a light isotope is produced directly through breakup, coalescence, or multifragmentation. However, no single effective model can cleanly represent direct cluster removal, participant emission, pre-equilibrium emission, statistical de-excitation, and target-like evaporation at the same time.

Convolution model

The Convolution model is the most physically motivated starting point when the dominant process is projectile fragmentation followed by de-excitation emission. It naturally broadens the laboratory distribution because the decay recoil is folded with the momentum distribution of the moving parent fragment.

Recommended model-selection statement

Use the Convolution model as the default momentum treatment for light particles identified as secondary de-excitation products of projectile-like fragments. Use direct-fragmentation models only for an explicitly direct component, and avoid interpreting one effective model as representing the complete light-particle spectrum.