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Title: Preequilibrium Emission of Light Fragments in Spallation Reactions

Author(s): Kerby, Leslie M
Mashnik, Stepan G
Sierk, Arnold J

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Preequilibrium Emission of Light Fragments in Spallation Reactions

Leslie M. Kerby[1,2], Stepan G. Mashnik[1], and Arnold J. Sierk[1]
[1]Los Alamos National Laboratory
[2]University of Idaho

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Why This Research Is Important

Single Event Upsets (SEUs)

- **October 2008, Airbus en route from Perth to Singapore[1]**

[1]Necia Grant Cooper, “The Invisible Neutron Threat”, National Security Science Feb. 2012: 13.

- **Cold war satellite malfunctioned, detected nuclear missile launch[2]**

[2]Countdown to Zero, dir. Lucy Walker, perf. Graham Allison, James Baker III, DVD, Magnolia, 2010.

Why This Research Is Important, cont.

Also Important in

- Radiation Shielding
- Medical applications (proton and ion therapy for cancer)
- Understanding better the mechanisms of nuclear reactions

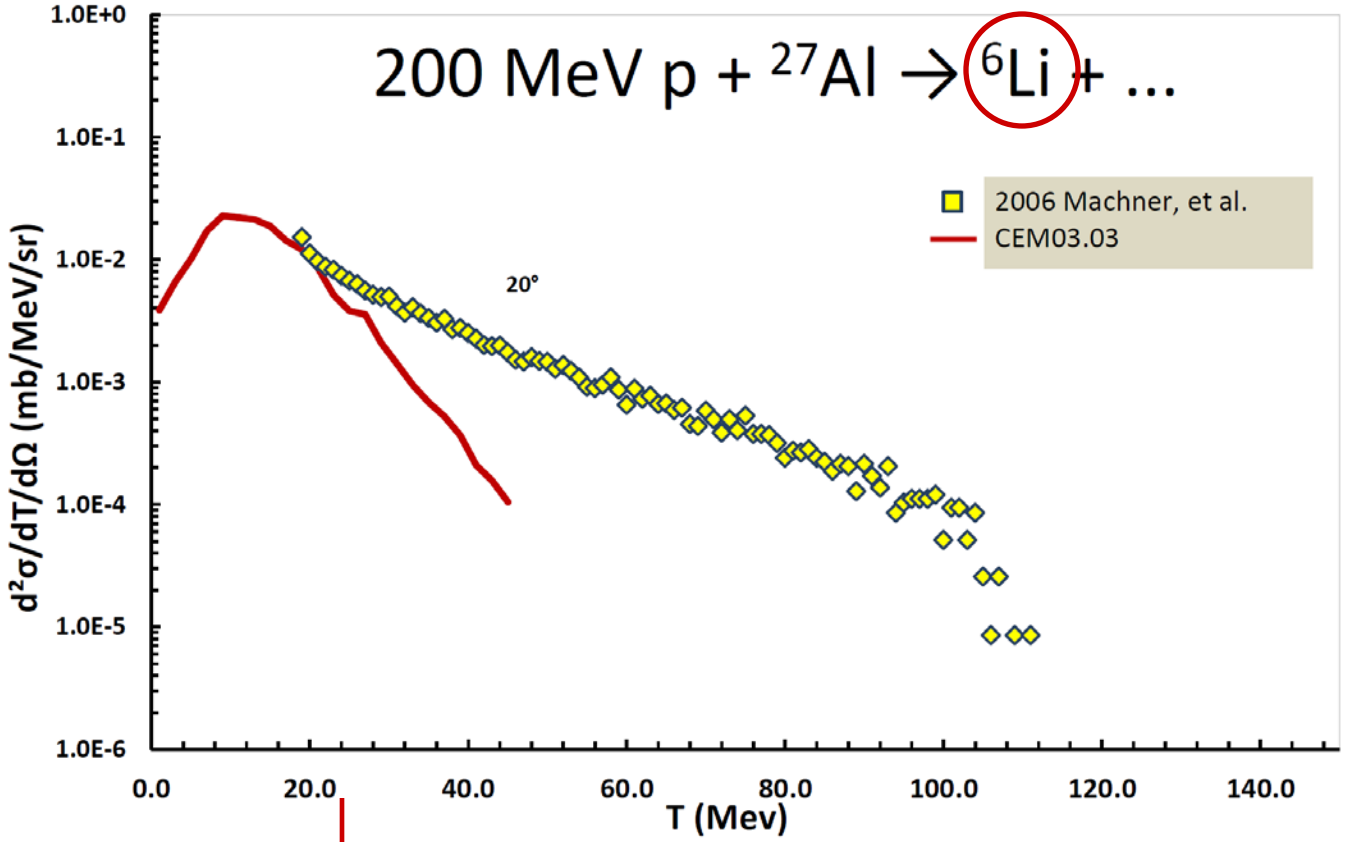
The 2008-2010 IAEA Benchmark of Spallation Models

- Recommended considering preequilibrium emission (and maybe also coalescence production) of fragments heavier than ^{4}He [3,4]

- [3] S. G. Mashnik et al., "Second Advanced Workshop on Model Codes for Spallation Reactions", CEA-Saclay, France, 8-11 Feb 2010, LA-UR-10-00510.

- [4] S. Leray et al., "Results from the IAEA Benchmark of Spallation Models", Journal of the Korean Physical Society Vol. 59, No. 2 (2011), 791-796.

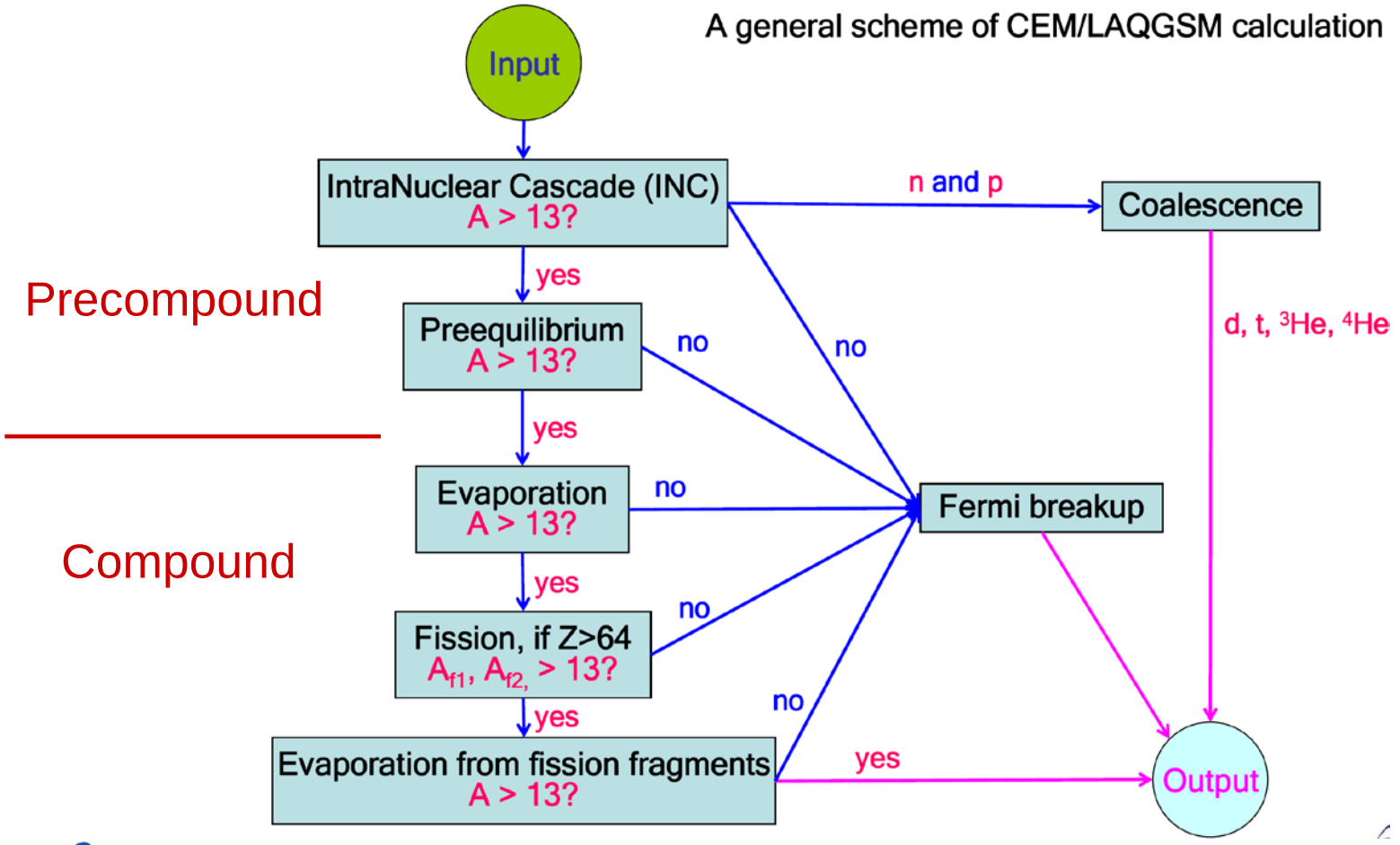
Current Capabilities of CEM03.03



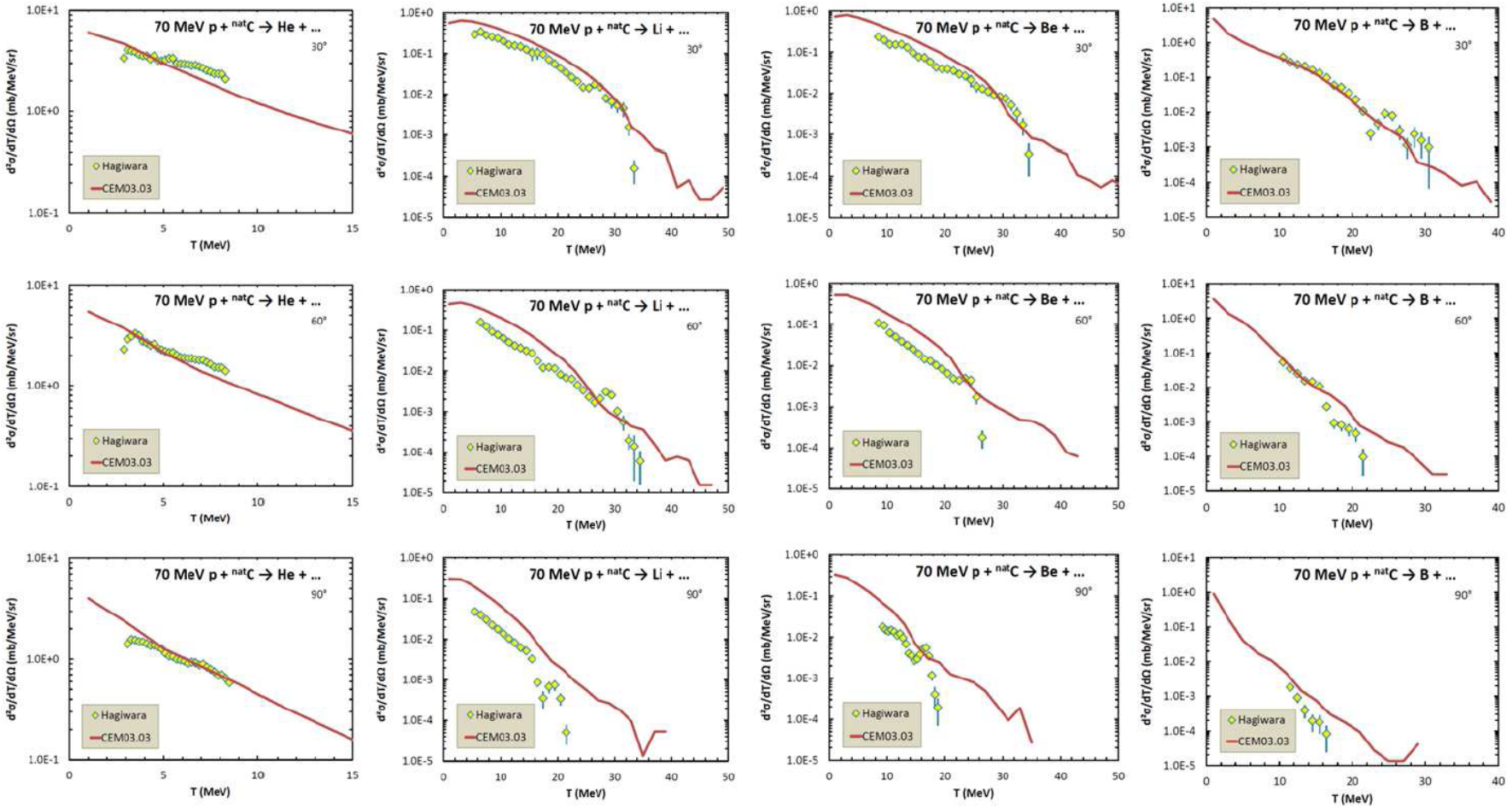
Evaporation | Precompound

Machner et al., Phys. Rev. C 73 (2006) 044606.

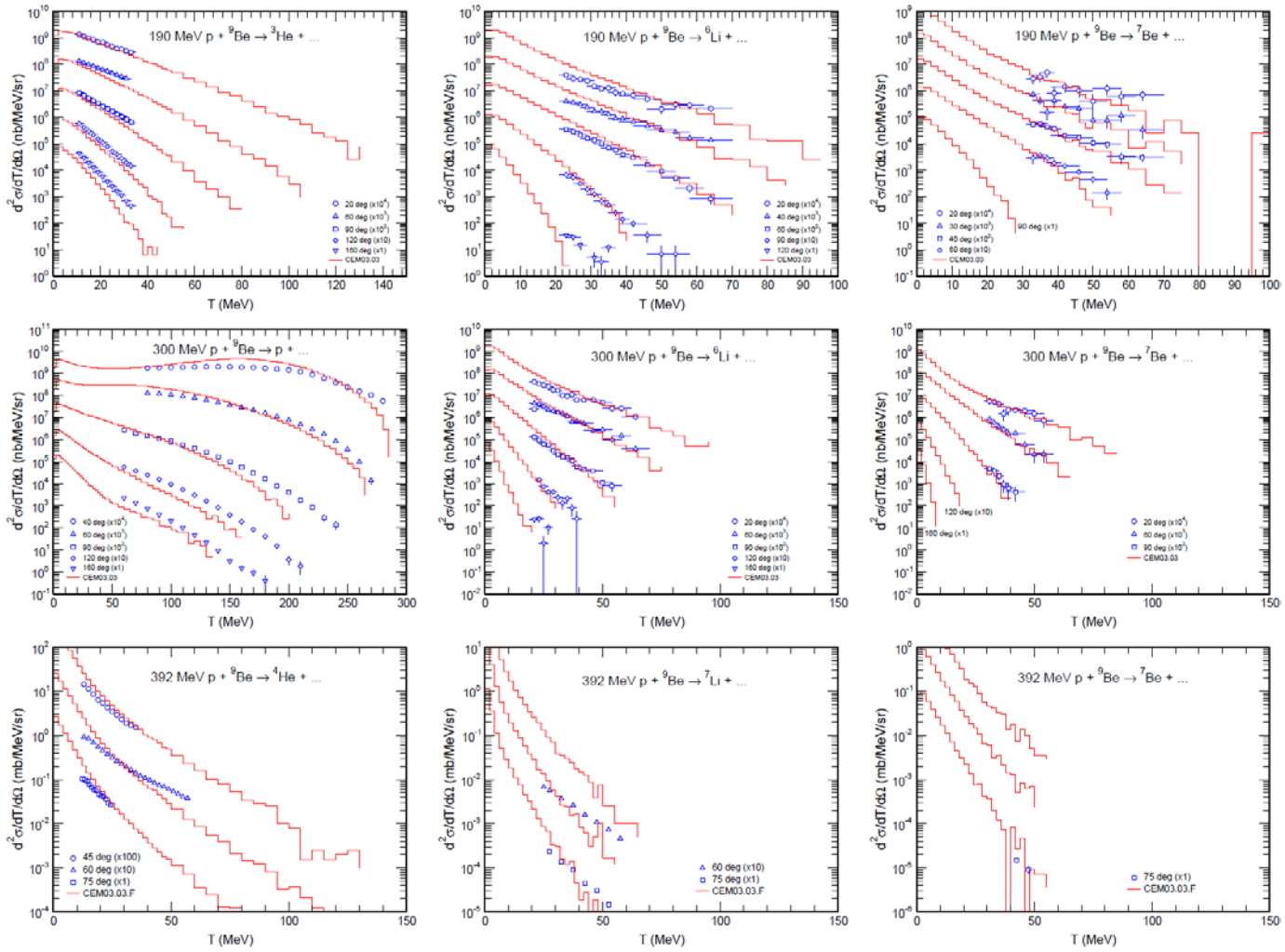
Overview of CEM Model



Examples of fragment spectra calculated with the Fermi Break-up model used by CEM/LAQGSM; Exp. data are from: M. Hagiwara et al., J. Nucl. Sci. Technol. 49, 571-587 (2012)



Example of light fragment spectra calculated with the Fermi Break-up model used by CEM/LAQGSM; Exp. data from: Y. Uozumi et al., NIM A571, 743 (2007) and R. E. L. Green et al., Phys. Rev. C 35, 1341 (1987)



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Modified Exciton Model of Preequilibrium Emission

The Modified Exciton Model (MEM) used by CEM[5] calculates Γ_j, the emission width (or probability of emitting particle fragment j) as

$$\Gamma_j(p,h,E) = \int_{V_j^c}^{E-B_j} \lambda_c^j(p,h,E,T)dT \tag{1}$$

where the partial transmission probabilities, λ_c^j, are equal to

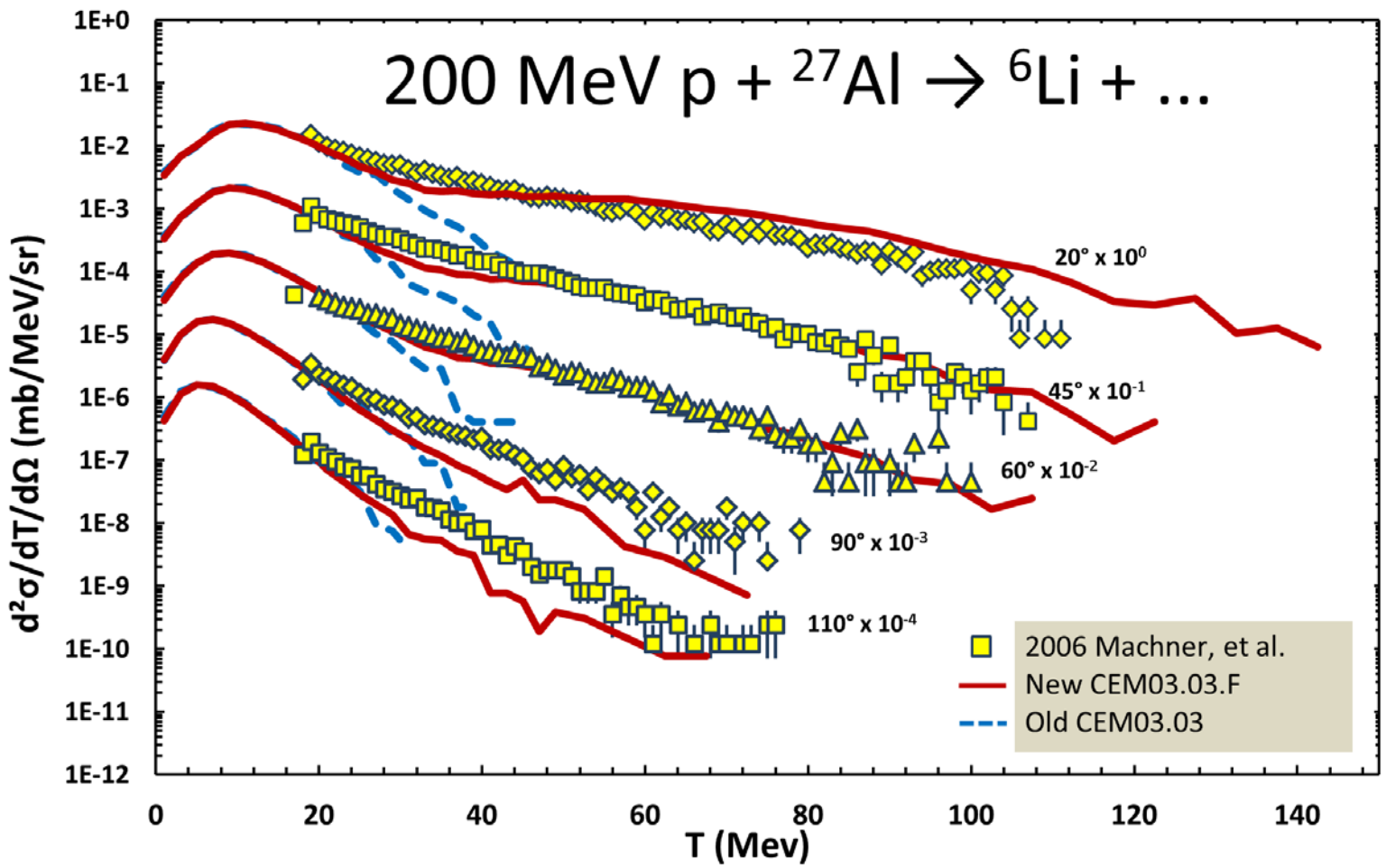
$$\lambda_c^j(p,h,E,T) = \frac{2s_j+1}{\pi^2\hbar^3}\mu_j\Re(p,h)\frac{\omega(p-1,h,E-B_j-T)}{\omega(p,h,E)}T\sigma_{inv}(T) \tag{2}$$

For complex particles, an extra factor γ_j is introduced:

$$\gamma_j \approx p_j^3(\frac{p_j}{A})^{p_j-1} \tag{3}$$

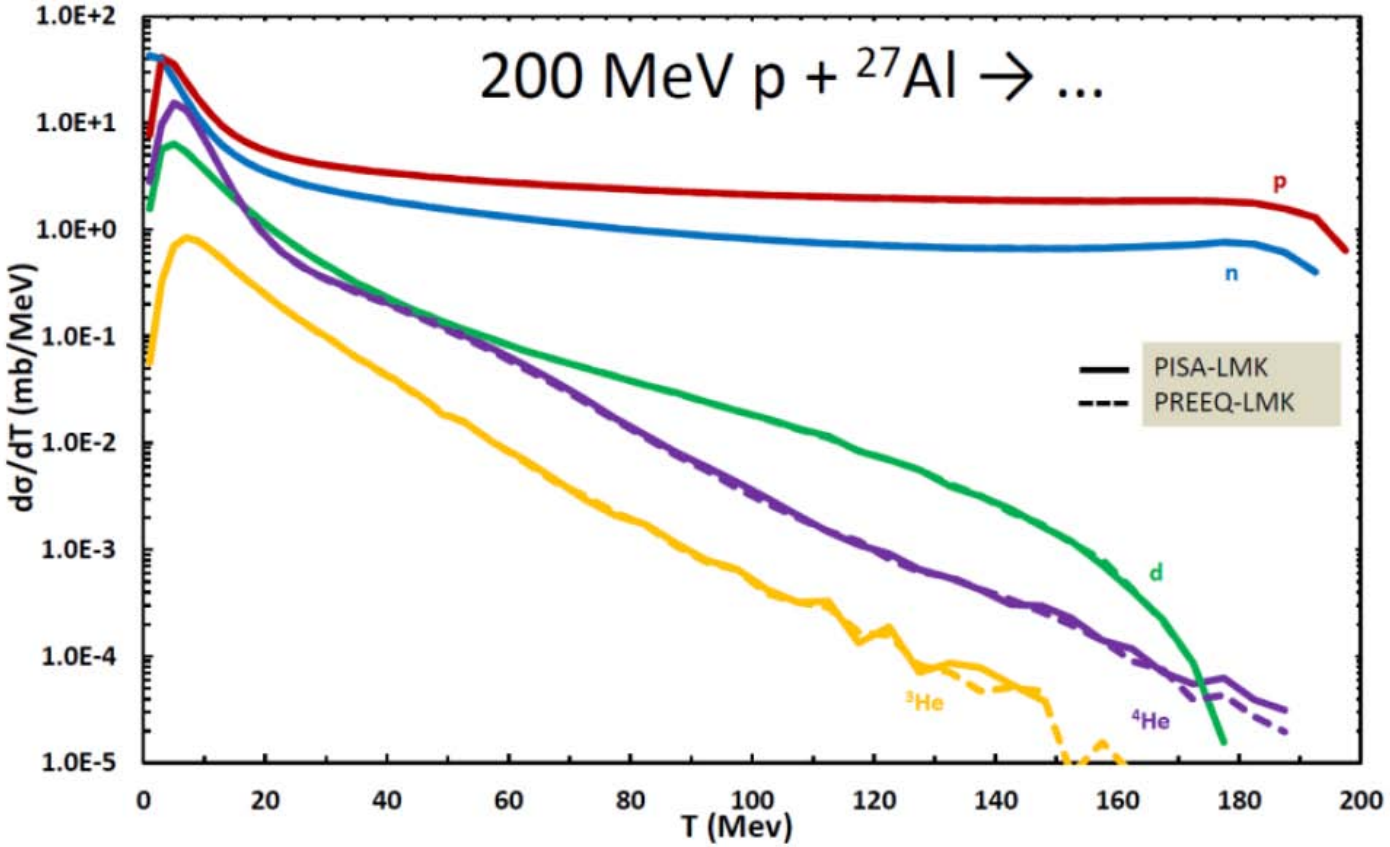
[5]K. K. Gudima, S. G. Mashnik, and V. D. Toneev,"Cascade-Exciton Model of Nuclear Reactions," Nuclear Phys. A401 (1983) 329-361.

Preliminary Results



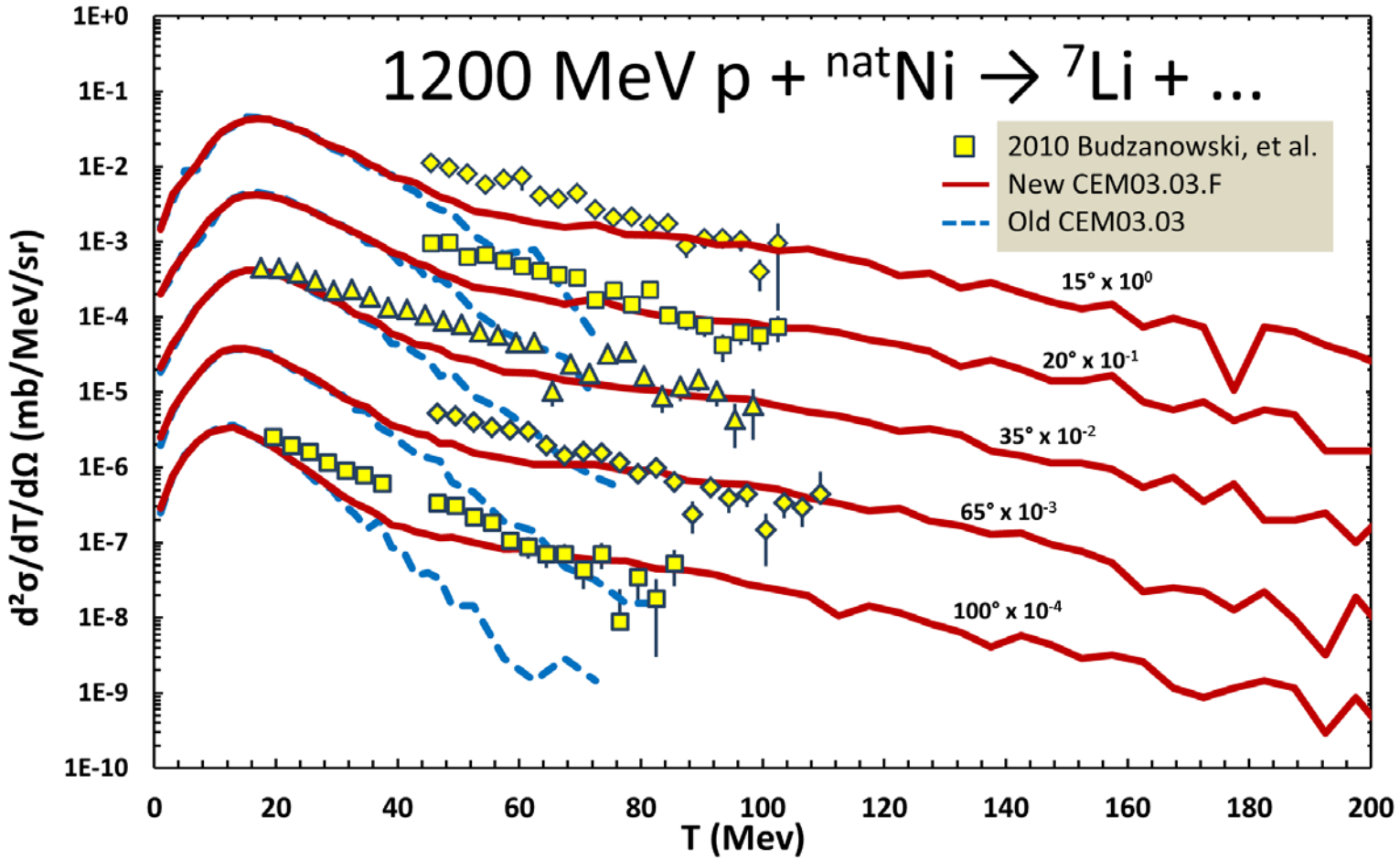
Machner et al., Phys. Rev. C **73** (2006) 044606.

Preliminary Results



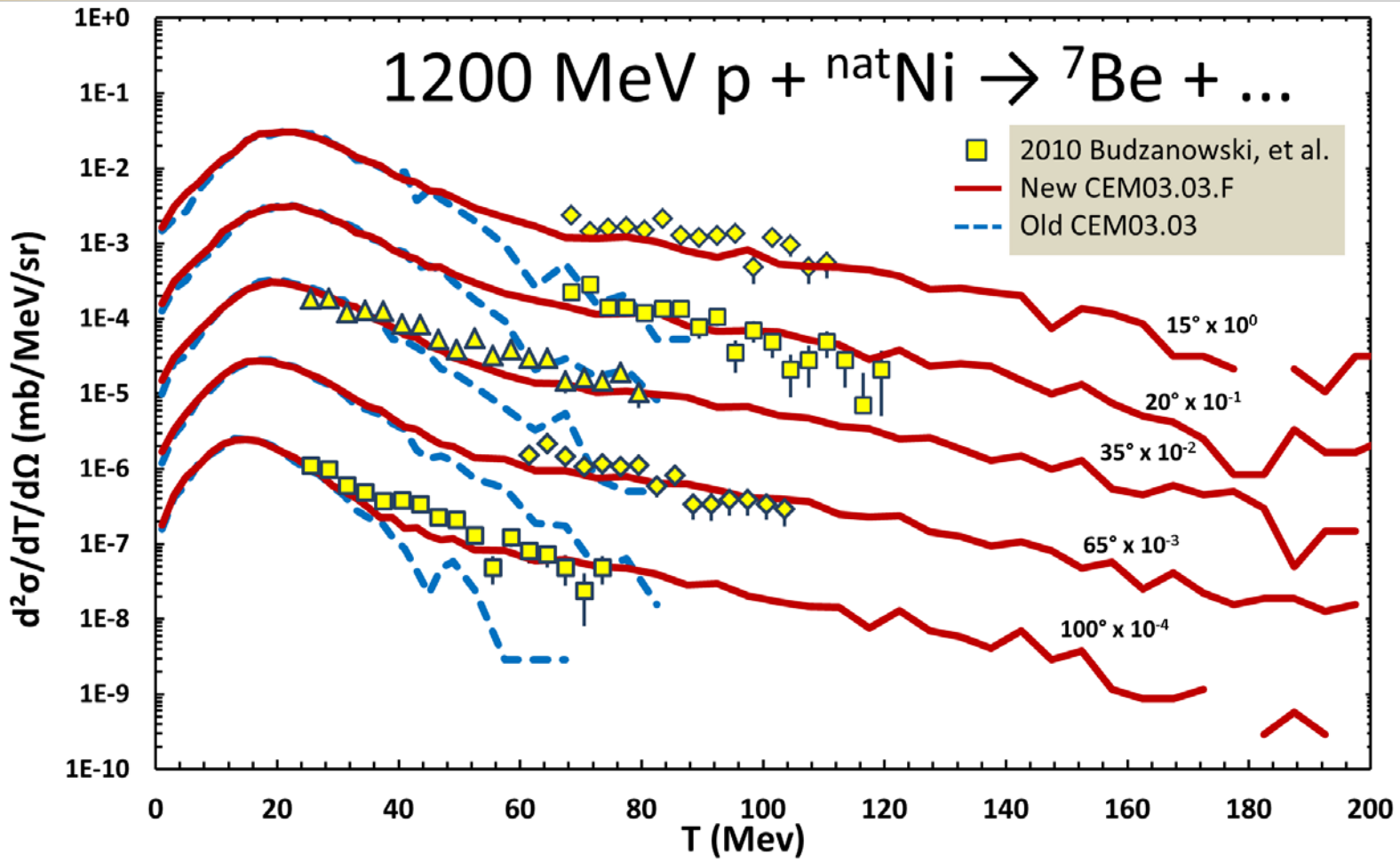
High-energy tails of light fragments were obtained without changing significantly spectra of n, p, d, t, ^{3}He, and ^{4}He

1200 MeV p + ^{nat}Ni



A. Budzanowski et al., Phys. Rev. C **82**, 034605 (2010)

1200 MeV p + ^{nat}Ni cont.



A. Budzanowski et al., Phys. Rev. C **82**, 034605 (2010)

Summary

CEM extension, results:

- **Extended CEM to include emission of light fragments (LF) heavier than ^{4}He (up to ^{28}Mg) in the preequilibrium stage**
- **Built a module to calculate residual nuclei physical properties, which can be inserted anywhere in the reaction process we want**
- **Preliminary results show much greater ability to describe high-energy tails and yields of LF**

Future work:

- **Global γ_{β}; investigate coalescence and Fermi break-up; upgrade evaporation model; incorporation of CEM03.03.F into MCNP6**

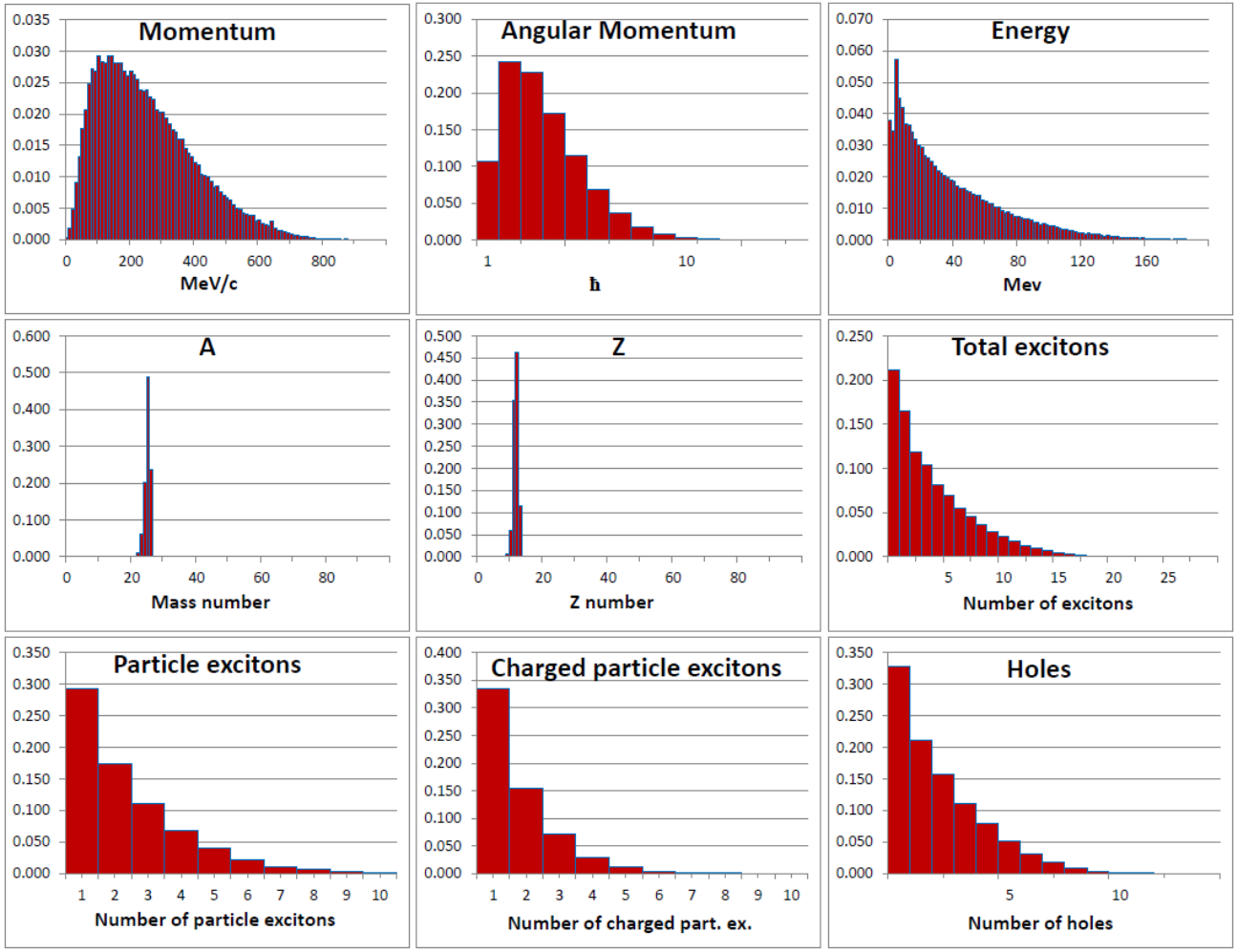
Thank you for your attention!

200 MeV p + ^{27}Al (after INC)

Residual Nuclei

After INC

Probability



Distributions of residual nuclei produced in 2.5 GeV p + ^{197}Al reaction directly after INC, before the preequilibrium stage