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Title: Preequilibrium Emission of Light Fragments in Spallation Reactions

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Preequilibrium Emission of Light Fragments in Spallation Reactions

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2013 International Conference on Nuclear Data for Science & Technology (ND2013), (New York, New York, United States)

Why This Research Is Important



Single Event Upsets (SEUs)

•October 2008, Airbus en route from Perth to Singapore¹

¹Necia Grant Cooper, "The Invisible Neutron Threat", National Security Science Feb. 2012: 13.

•Cold war satellite malfunctioned, detected nuclear missile launch²

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

Why This Research Is Important, cont.

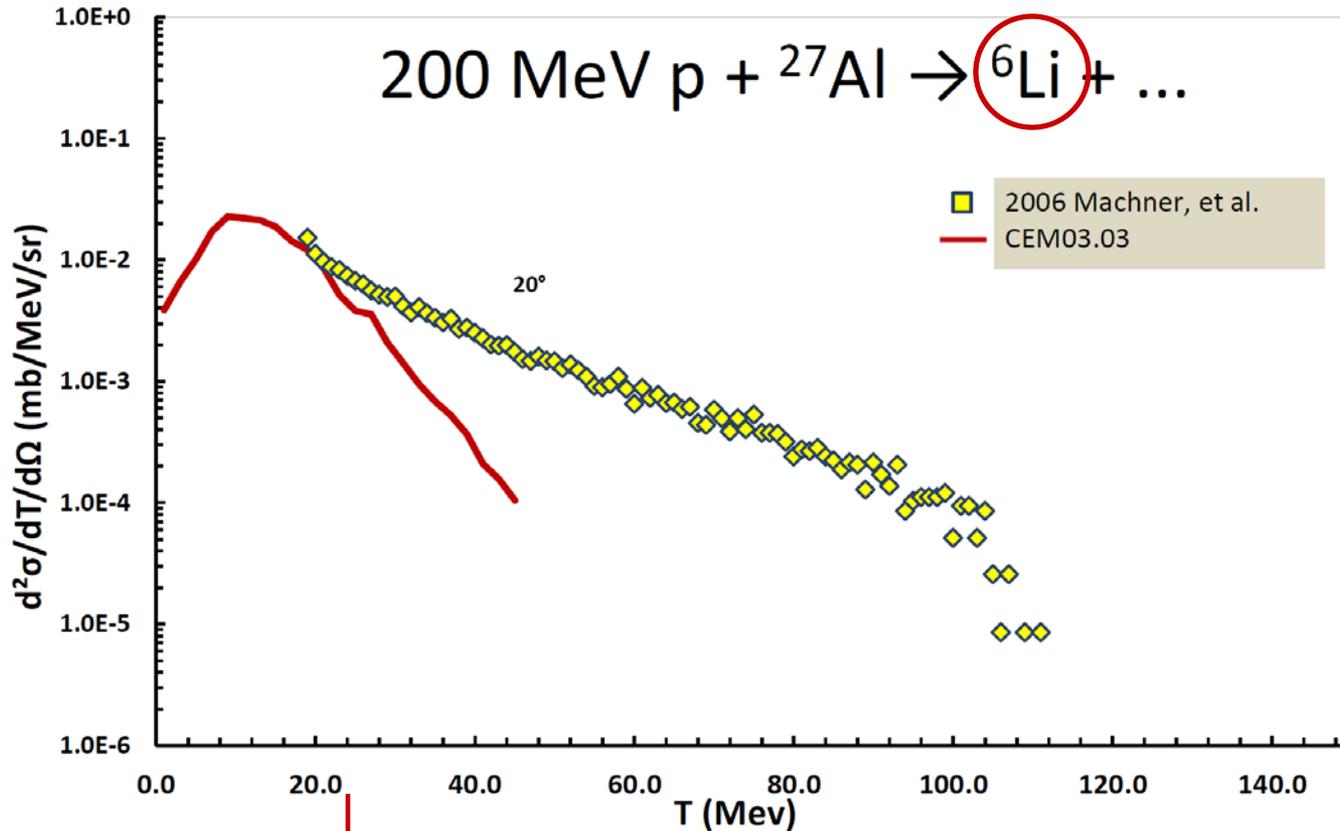
Also Important in

- 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 ^4He ^{3,4}
- 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.
- 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



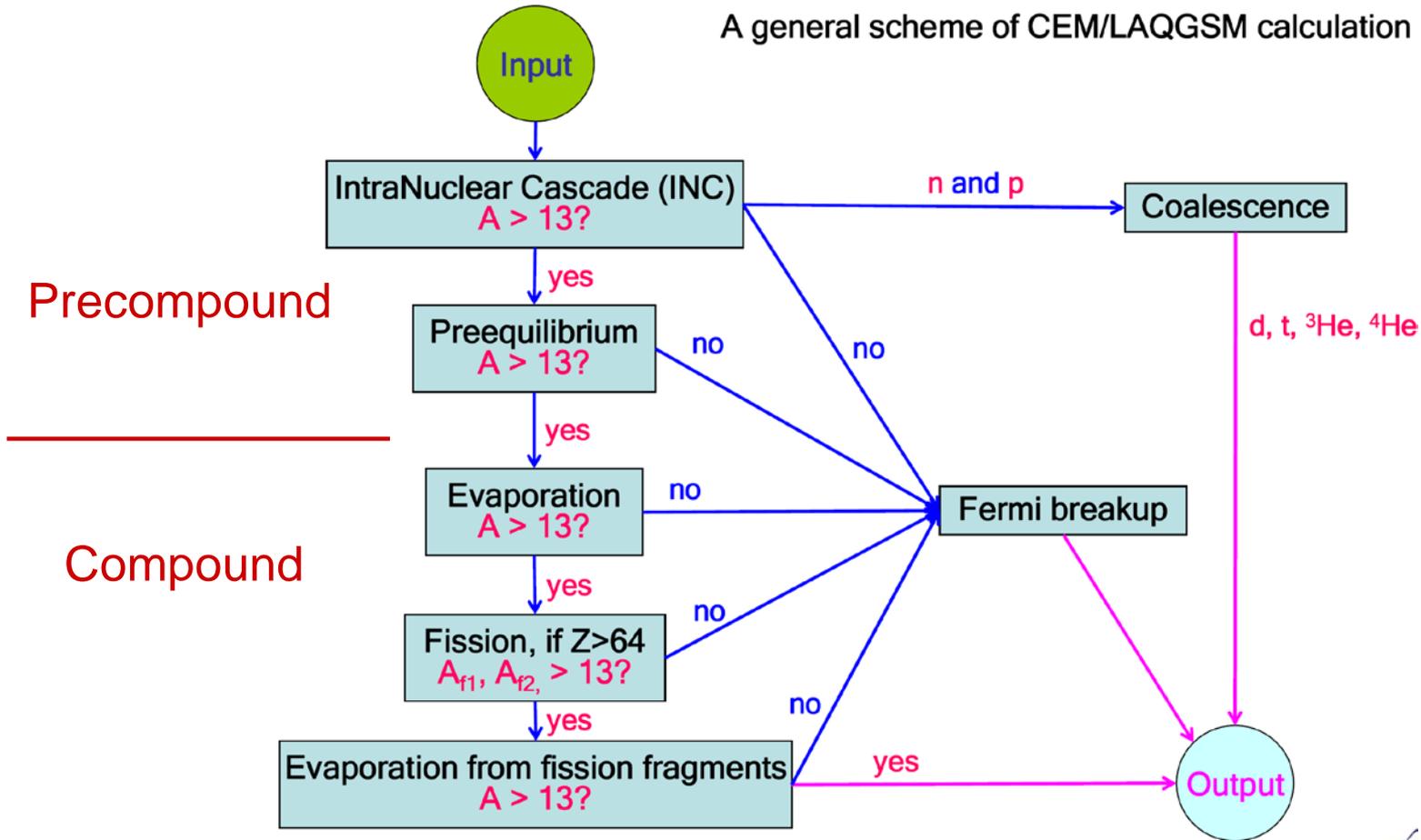
Evaporation

Precompound

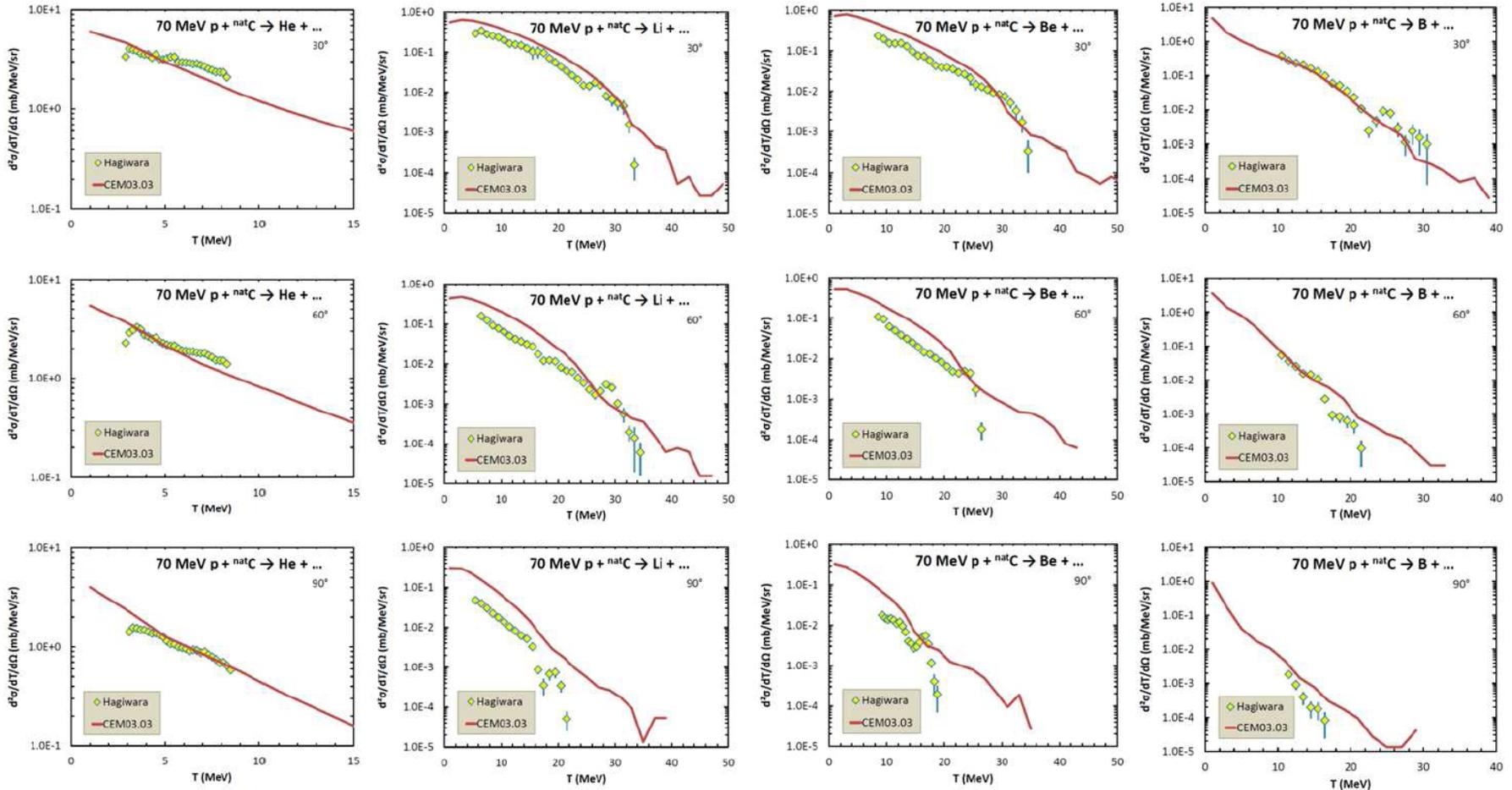
Machner et al., Phys. Rev. C 73 (2006) 044606.

Overview of CEM Model

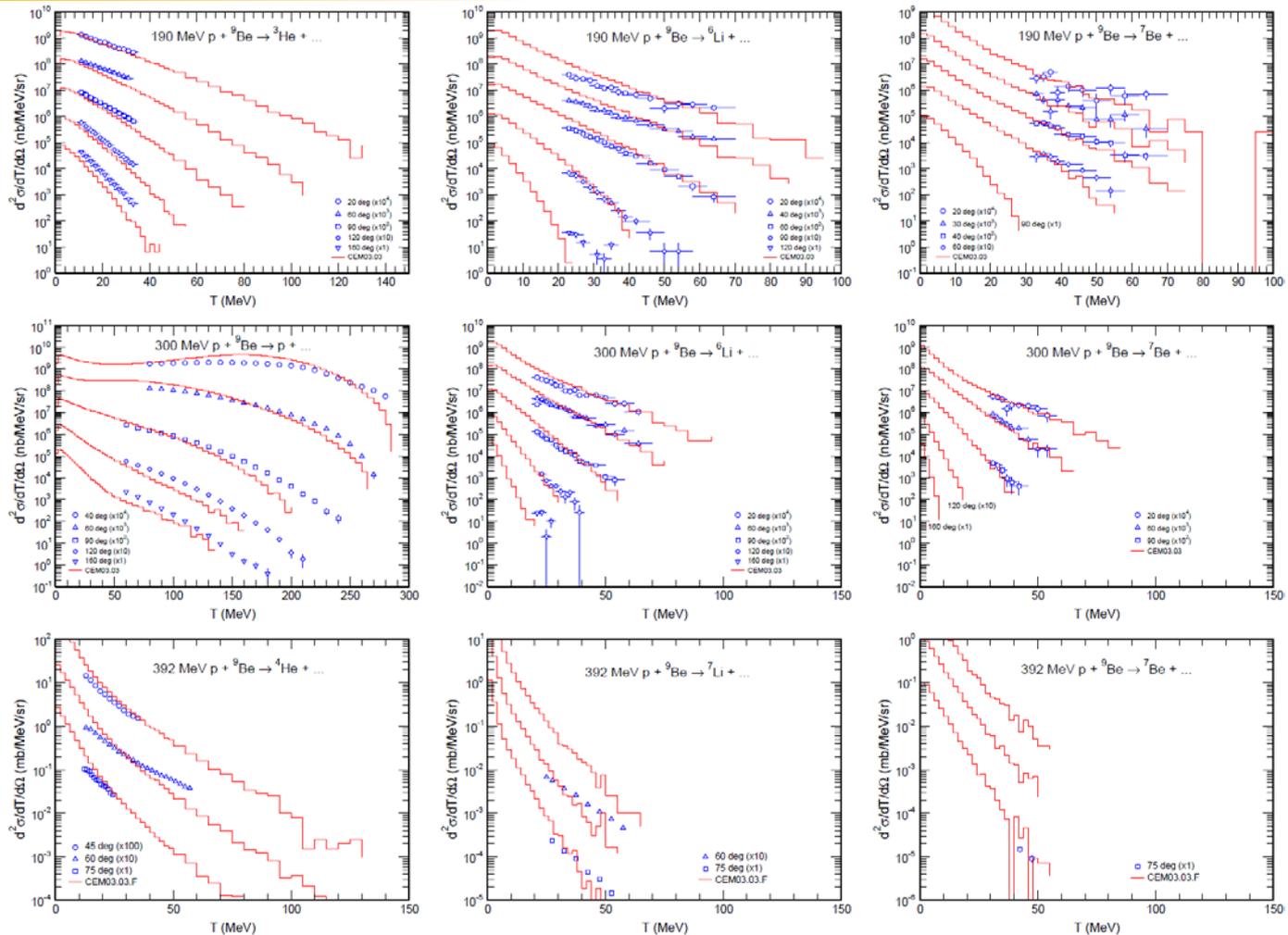
A general scheme of CEM/LAQGSM calculation



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)



Modified Exciton Model of Preequilibrium Emission

The Modified Exciton Model (MEM) used by CEM⁵ calculates Γ_j , the emission width (or probability of emitting particle fragment j) as

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

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

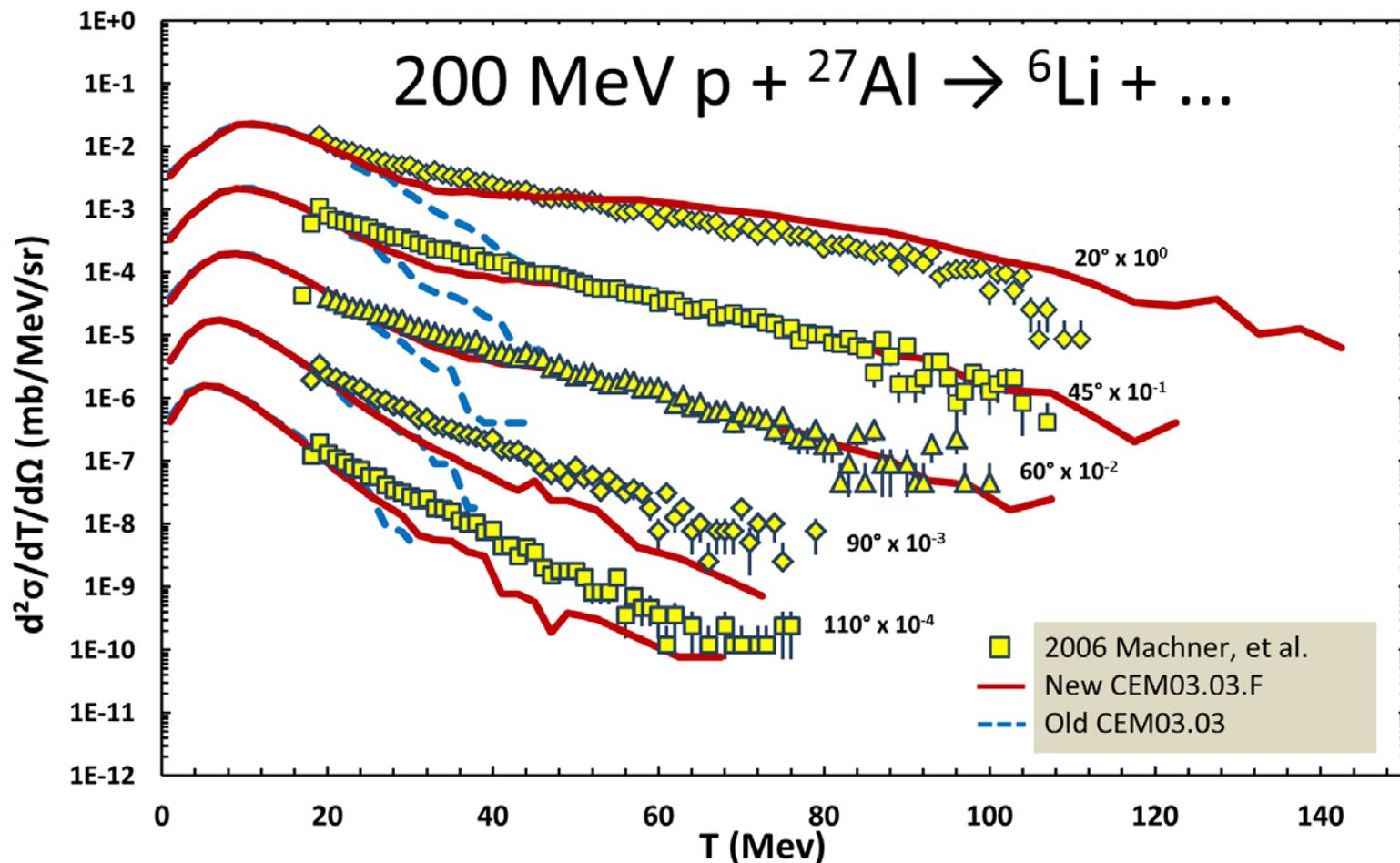
$$\lambda_c^j(p, h, E, T) = \frac{2s_j + 1}{\pi^2 \hbar^3} \mu_j \Re(p, h) \frac{\omega(p-1, h, E - B_j - T)}{\omega(p, h, E)} T \sigma_{inv}(T) \quad (2)$$

For complex particles, an extra factor γ_j is introduced:

$$\gamma_j \approx p_j^3 \left(\frac{p_j}{A} \right)^{p_j - 1} \quad (3)$$

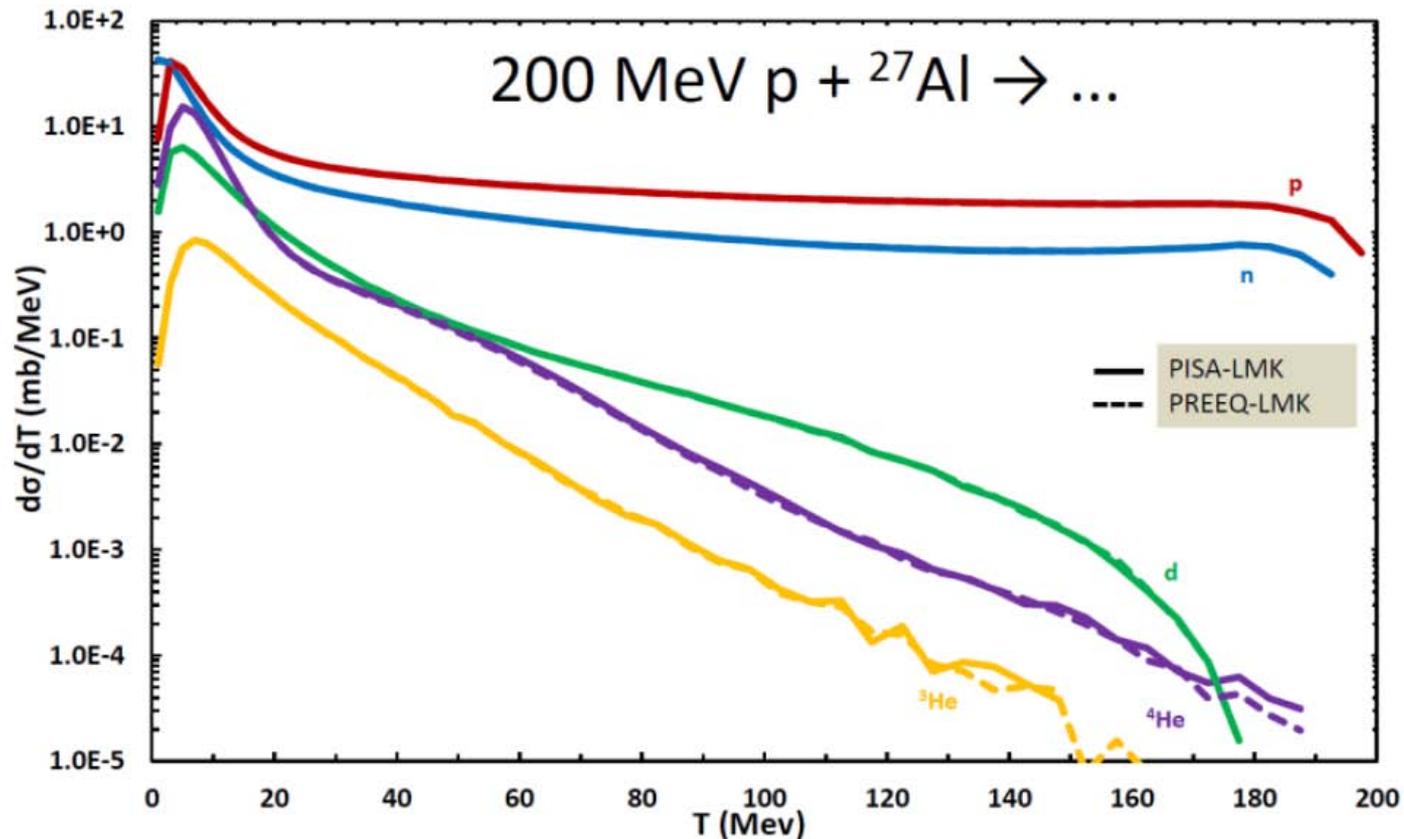
⁵K. K. Gudima, S. G. Mashnik, and V. D. Toneev, "Cascade-Exciton Model of Nuclear Reactions," Nuclear Phys. A401 (1983) 329-361.

Preliminary Results



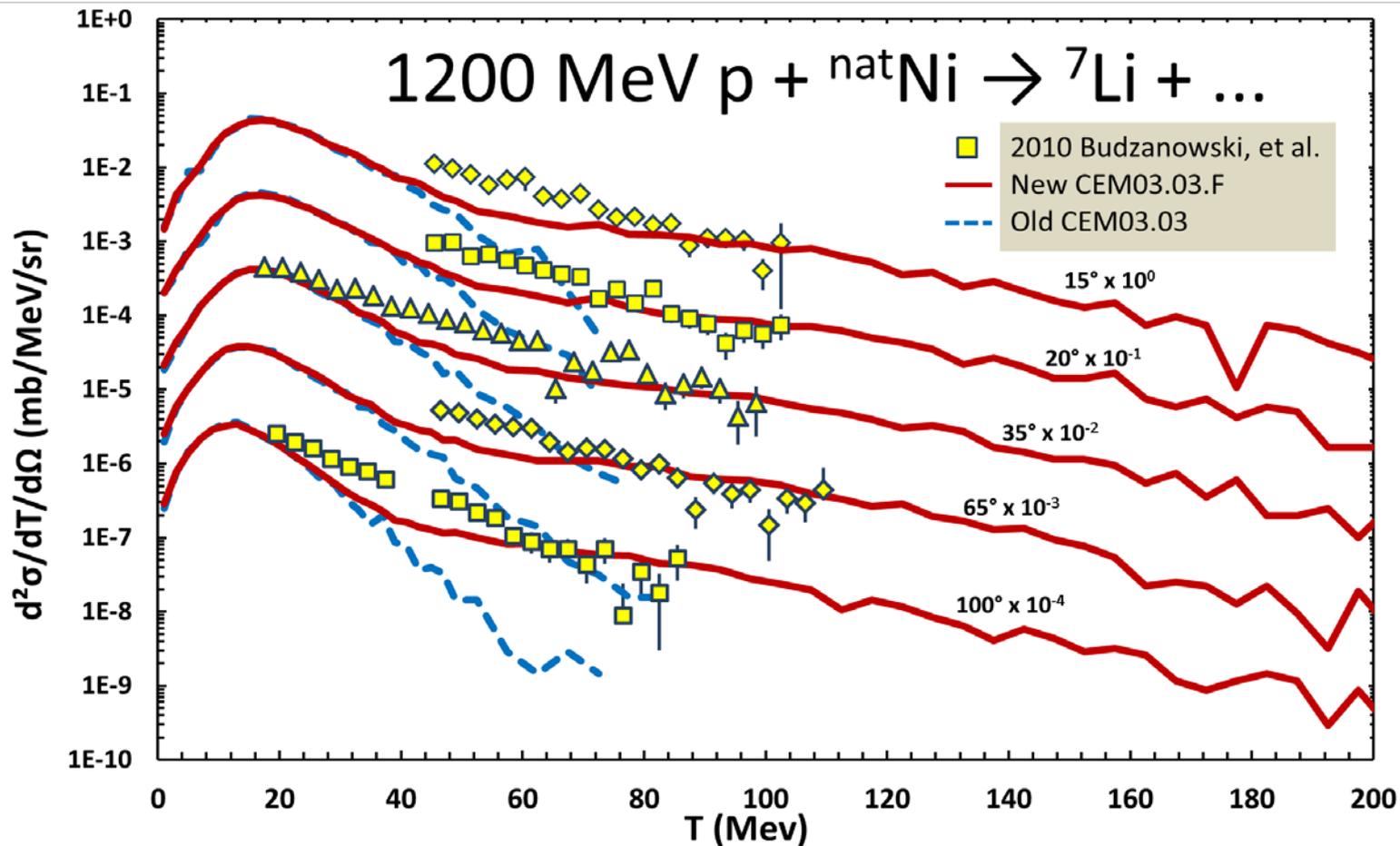
Machner et al., *Phys. Rev. C* **73** (2006) 044606.

Preliminary Results



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

1200 MeV p + ^{nat}Ni

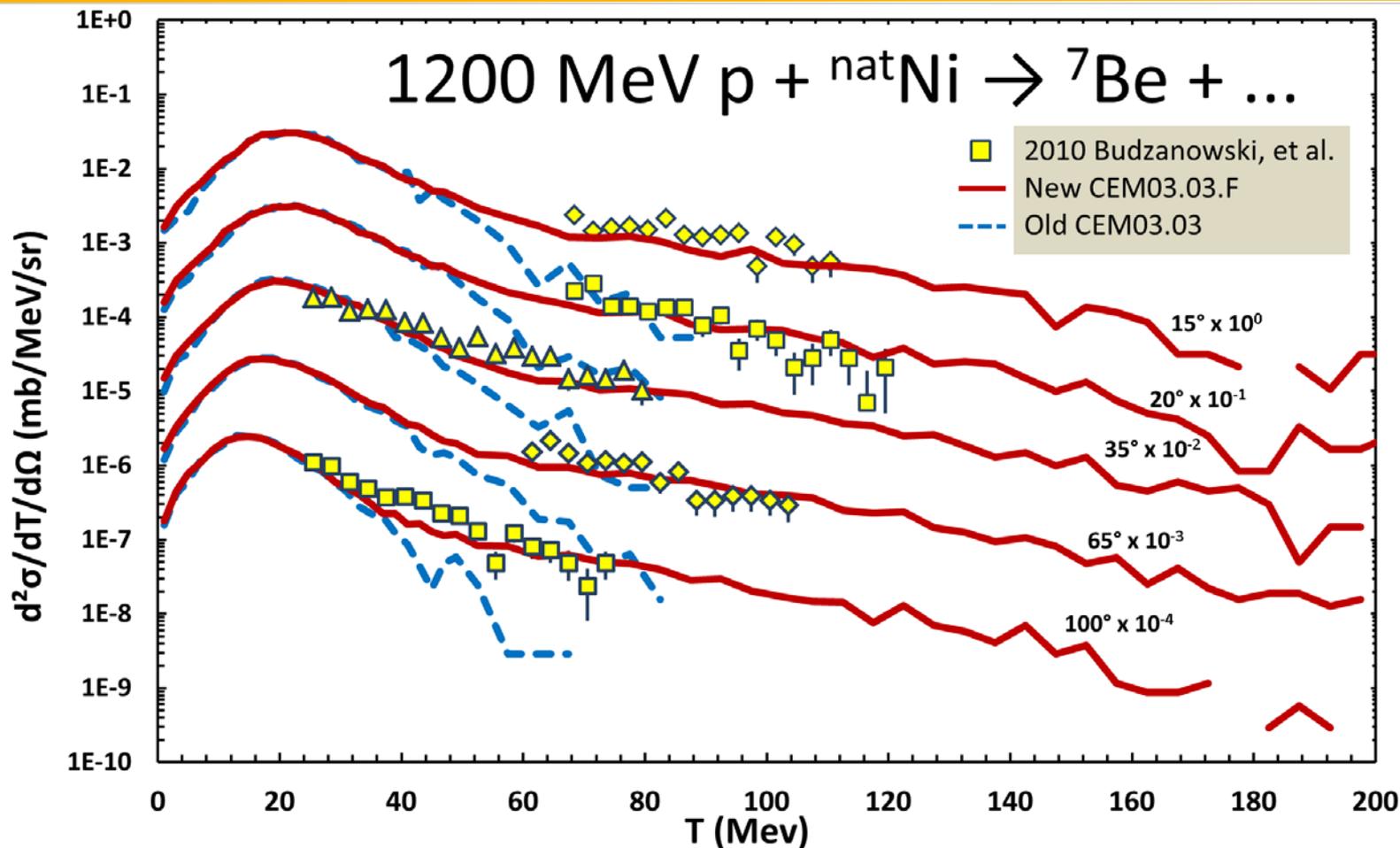


A. Budzanowski et al., Phys. Rev. C **82**, 034605 (2010)

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1200 MeV p + ^{nat}Ni cont.



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

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Summary

CEM extension, results:

- Extended CEM to include emission of light fragments (LF) heavier than ^4He (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:

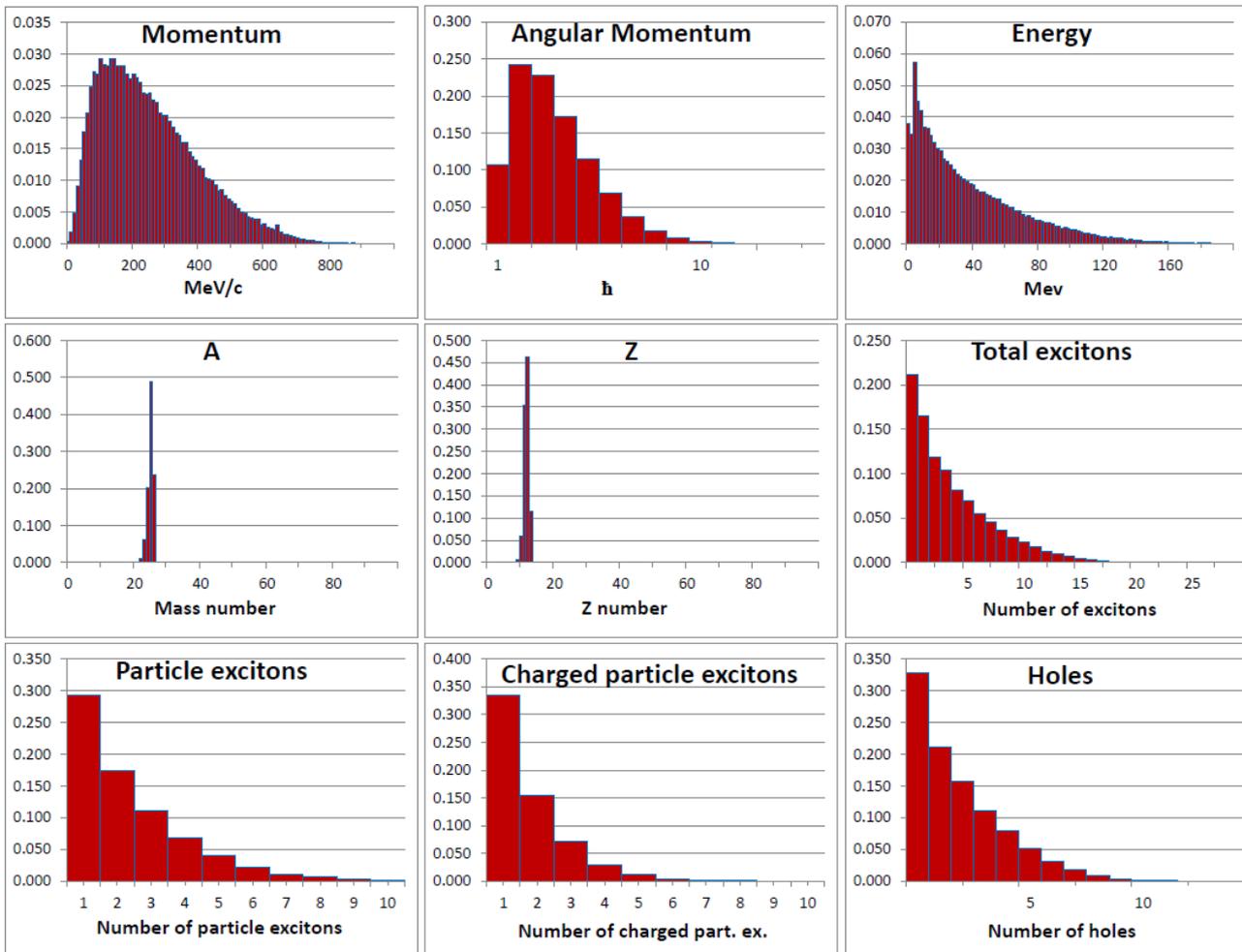
- Global γ_β ; investigate coalescence and Fermi break-up; upgrade evaporation model; **incorporation of CEM03.03.F**

Thank you for your attention!

200 MeV p + ²⁷Al (after INC)

**Residual
Nuclei
After INC**

Probability



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

Probability

