MCNP6 Simulation of Light and Medium Nuclei Fragmentation at Intermediate Energies

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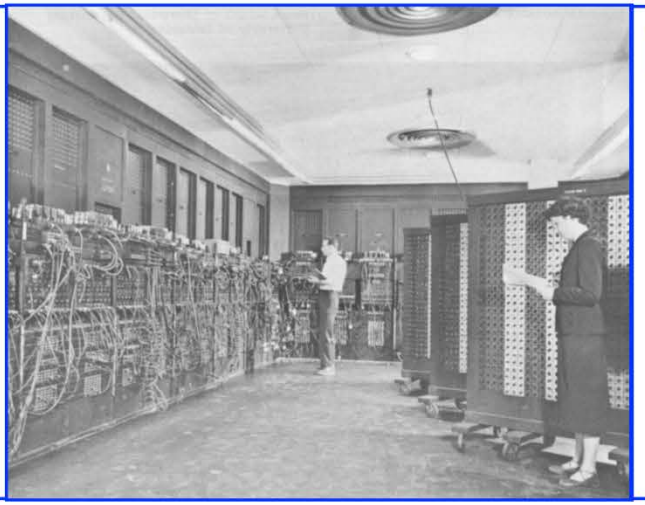
1. Introduction; MCNP6 History
2. A Brief Survey of the CEM and LAQGSM Physics
3. Validation and Verification of MCNP6 Fragmentation using CEM and LAQGSM
4. Summary

Monte Carlo & MCNP History

mcnp Monte Carlo Codes Group XCP-3, LANL

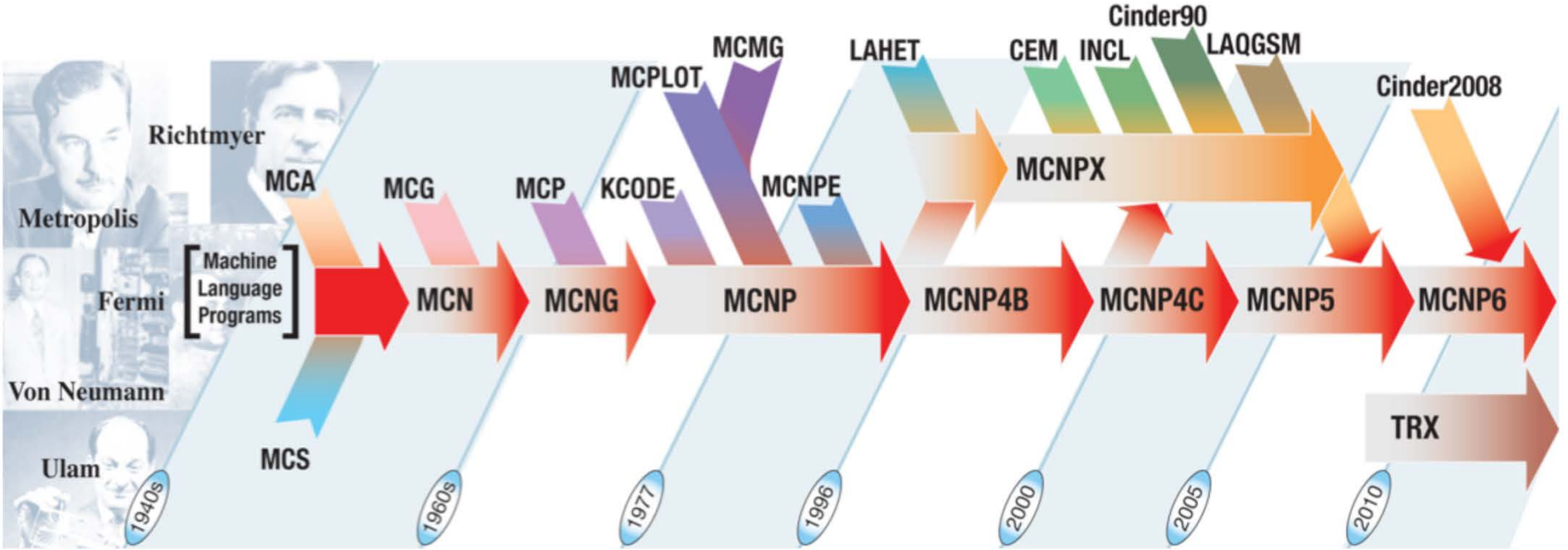
ENIAC – 1945

- 30 tons
- 20 ft x 40 ft room
- 18,000 vacuum tubes
- 0.1 MHz
- 20 word memory
- patchcords



Manhattan Project – 1945...

- Discussions on using ENIAC
- Ulam suggested using the "method of statistical trials"
- Metropolis suggested the name "Monte Carlo"
- Von Neumann developed the first computer code

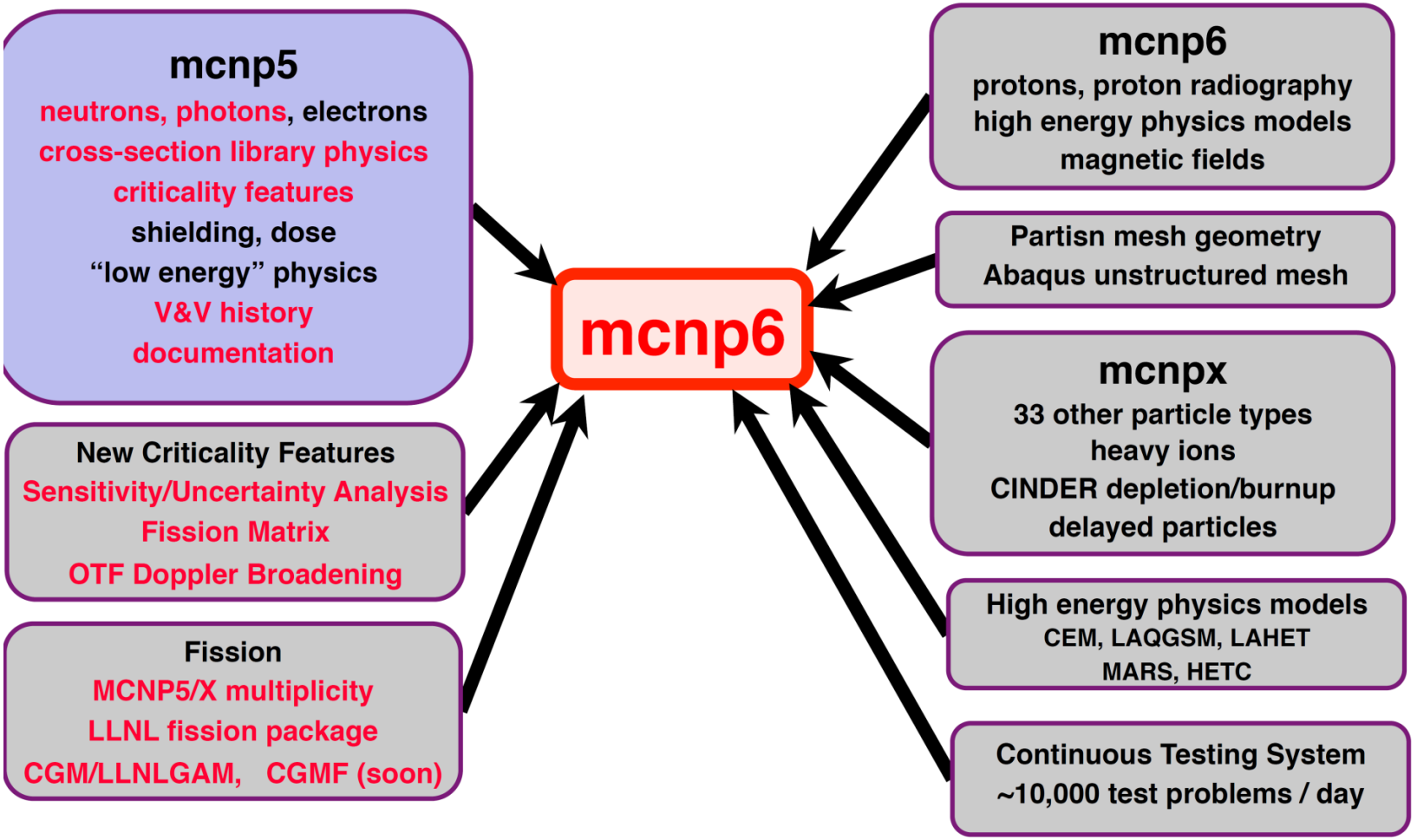


Forrest B. Brown, LA-UR-14-27694

T. Goorley, M. James, T. Booth, F. Brown, J. Bull, L. J. Cox, J. Durkee, J. Elson, M. Fensin, R. A. Forster, J. Hendricks, H. G. Hughes, R. Johns, B. Kiedrowski, R. Martz, S. Mashnik, G. McKinney, D. Pelowitz, R. Prael, J. Sweezy, L. Waters, T. Wilcox, T. Zukaitis, Initial MCNP6 Release Overview. MCNP6 version 0.1, Nuclear Technology, vol. 180, No. 3, Dec. 2012, pp. 298-315.

MCNP6 Features

mcnp Monte Carlo Codes Group XCP-3, LANL



mcnp5 – 100 K lines of code
mcnp6 – 500 K lines of code

mcnp6.1 – 2013
mcnp6.1.1b – 2014

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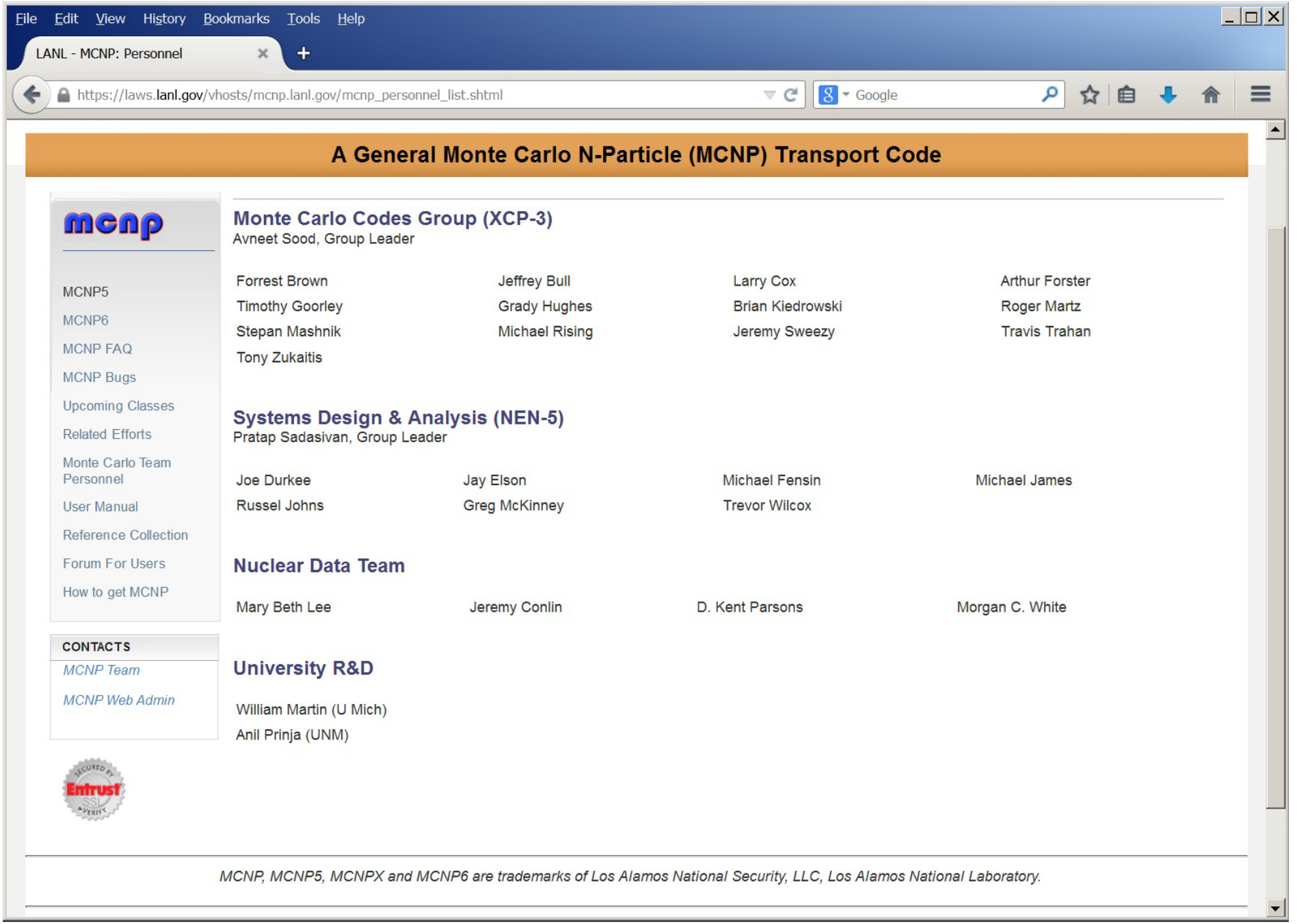

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LANL - MCNP: Personnel

https://laws.lanl.gov/vhosts/mcnp.lanl.gov/mcnp_personnel_list.shtml

Google

A General Monte Carlo N-Particle (MCNP) Transport Code

mcnp

MCNP5
MCNP6
MCNP FAQ
MCNP Bugs
Upcoming Classes
Related Efforts
Monte Carlo Team Personnel
User Manual
Reference Collection
Forum For Users
How to get MCNP

CONTACTS
MCNP Team
MCNP Web Admin

Monte Carlo Codes Group (XCP-3)

Avneet Sood, Group Leader

Forrest Brown	Jeffrey Bull	Larry Cox	Arthur Forster
Timothy Goorley	Grady Hughes	Brian Kiedrowski	Roger Martz
Stepan Mashnik	Michael Rising	Jeremy Sweezy	Travis Trahan
Tony Zukaitis			

Systems Design & Analysis (NEN-5)

Pratap Sadasivan, Group Leader

Joe Durkee	Jay Elson	Michael Fensin	Michael James
Russel Johns	Greg McKinney	Trevor Wilcox	

Nuclear Data Team

Mary Beth Lee	Jeremy Conlin	D. Kent Parsons	Morgan C. White

University R&D

William Martin (U Mich)
Anil Prinja (UNM)

Entrust SSL

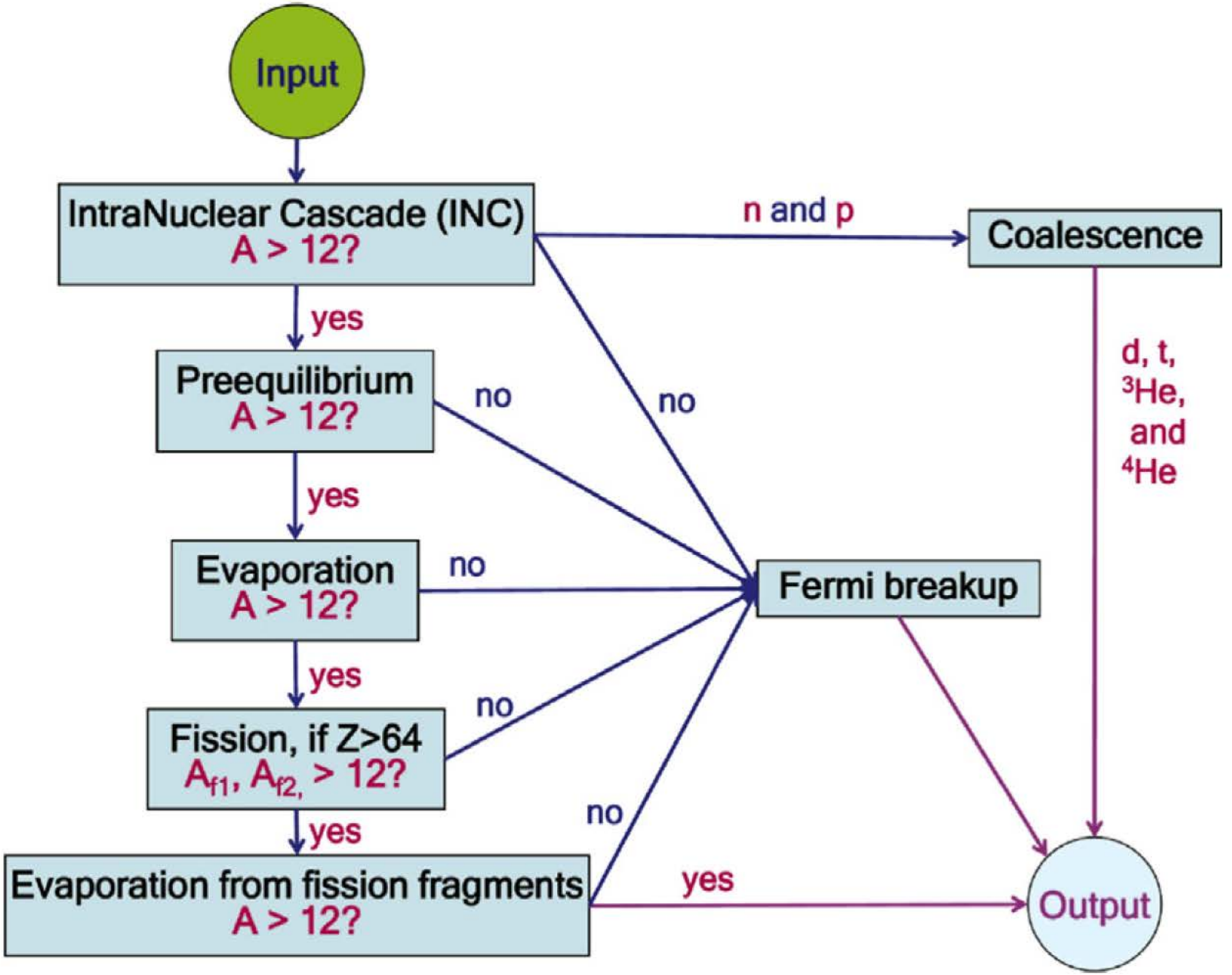
MCNP, MCNP5, MCNPX and MCNP6 are trademarks of Los Alamos National Security, LLC, Los Alamos National Laboratory.

INC Model Options in MCNP6

mcnp

Variable	Bertini	Isabel	CEM (default)	INCL	LAQGSM
Lower Energy	20-150 MeV	20-150 MeV	~ 10 MeV	~ 100 MeV (not in MCNP: ~ 5 MeV/A)	~ 100 MeV/A (not in MCNP: ~a few MeV/A)
Upper Energy	3.5 GeV (nuc-nuc) 2.5 GeV (pion-nuc)	1 GeV	5 GeV	2 GeV (not in MCNP: ~ 15 GeV)	~ 1 TeV/A (not in MCNP: ~ 20-100 TeV)
Target Nuclei	All	All	A ≥ 4	All	All
Incident particles	h, n, pions	h, n, $A \leq 4$ $\bar{h}, \bar{n}$ (not in MCNP: also A>4)	h, n, pions, γ	h, n, $A \leq 4$ (not in MCNP: ~ A<16)	Almost all particles & ions

Flow chart of nuclear-reaction calculations by CEM03.03 and LAQGSM03.03



Many people participated in development of the Cascade-Exciton Model (CEM) and Los Alamos version of the Quark-Gluon String Model (LAQGSM) over their more than 40-year history.

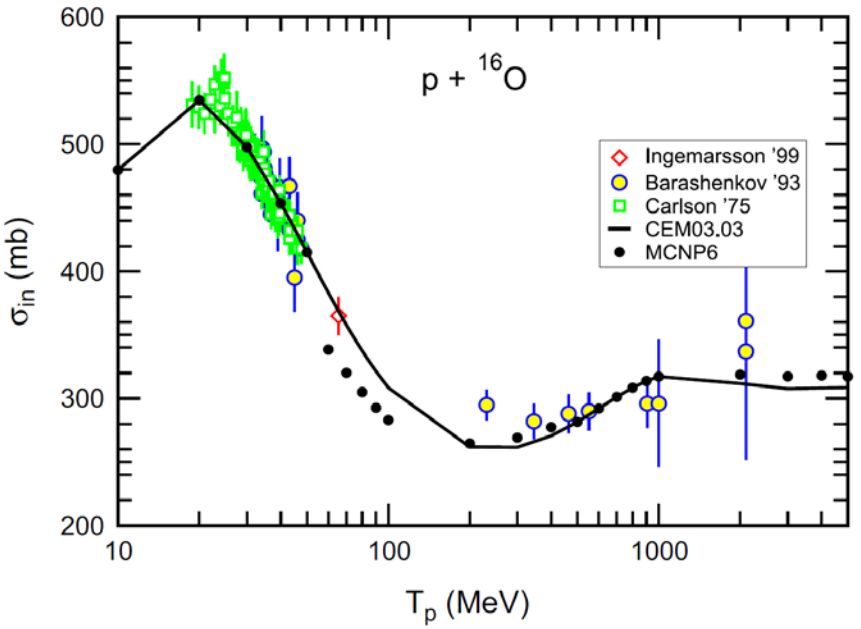
The current/recent contributors are:

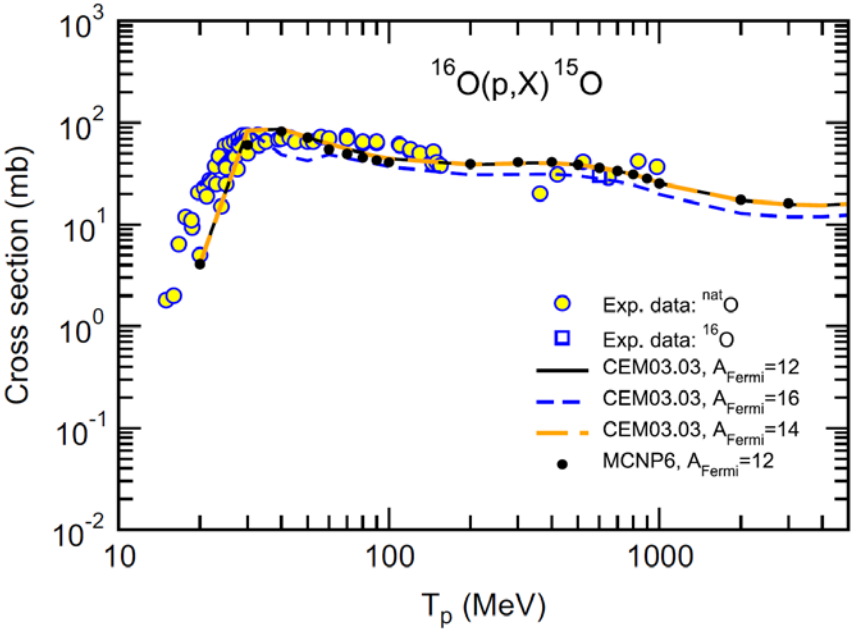
S. G. Mashnik, K. K. Gudima, A. J . Sierk, L. M. Kerby,
M. I. Baznat, R. E. Prael, N. V. Mokhov.

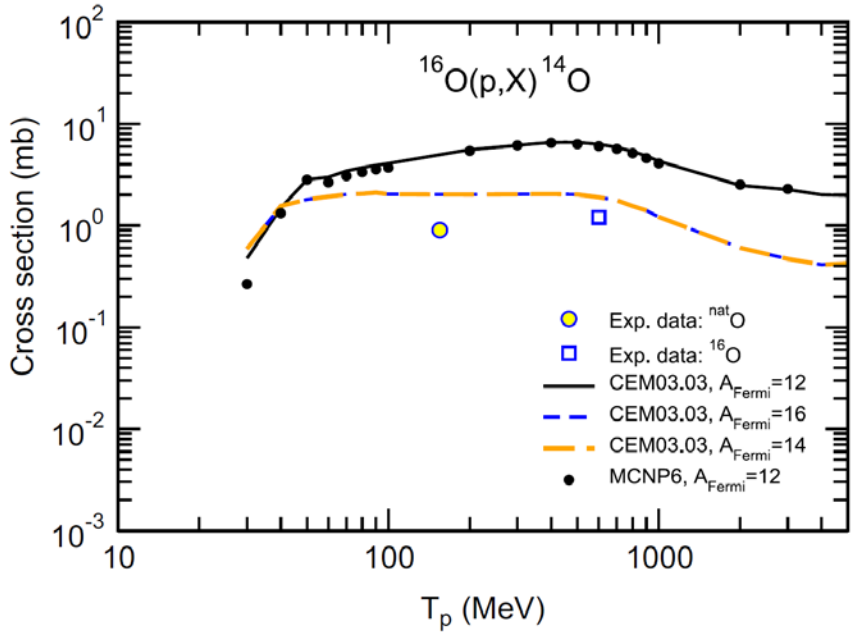
A recent lecture with many references on our work may be found in:

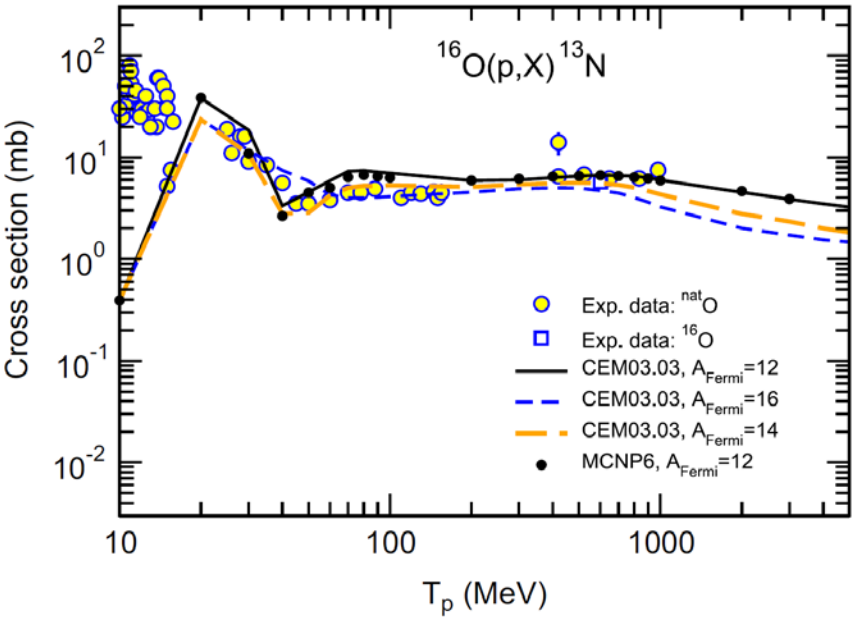
S. G. Mashnik, K. K. Gudima, R. E. Prael, A. J. Sierk, M. I. Baznat, and N. V. Mokhov, CEM03.03 and LAQGSM03.03 Event Generators for the MCNP6, MCNPX, and MARS15 Transport Codes, Joint ICTP-IAEA Advanced Workshop on Model Codes for Spallation Reactions, February 4-8, 2008, ICTP, Trieste, Italy, LA-UR-08-2931, Los Alamos (2008), E-print: arXiv:0805.0751.

S.G. Mashnik, L.M. Kerby / Nuclear Instruments and Methods in Physics Research A764 (2014) 59-81









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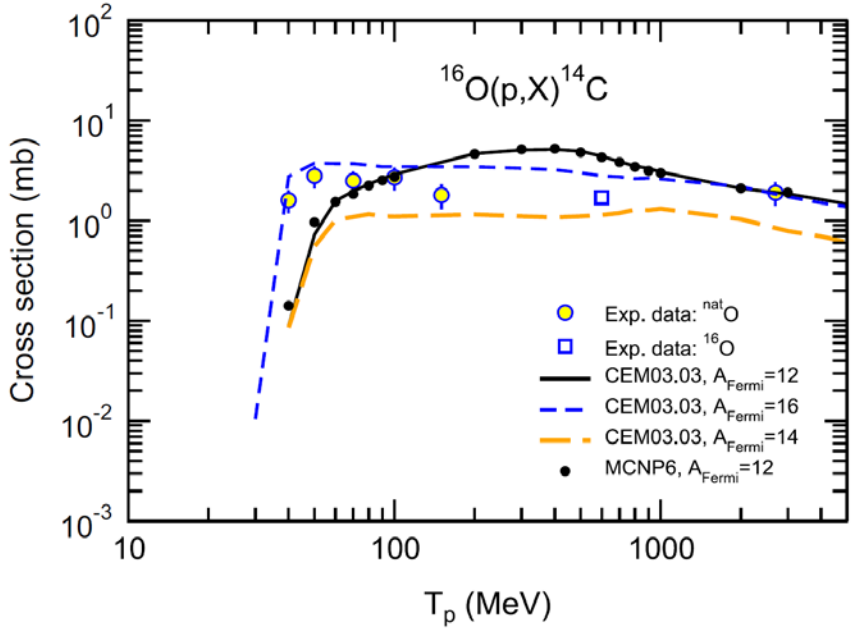

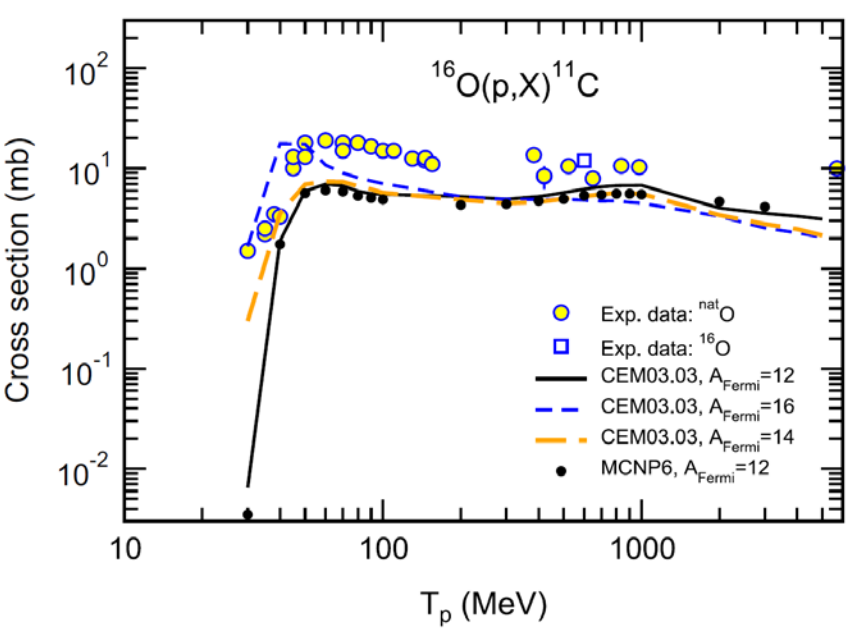

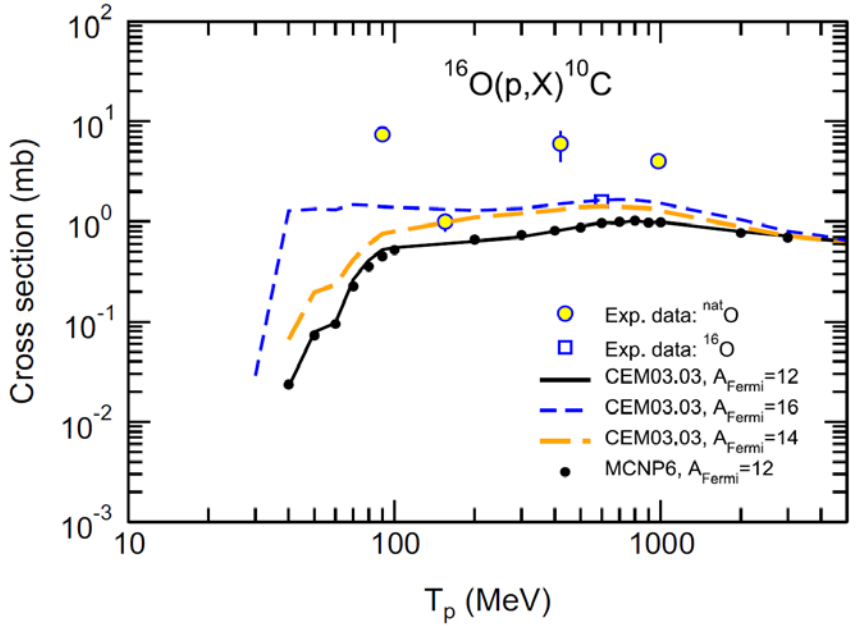

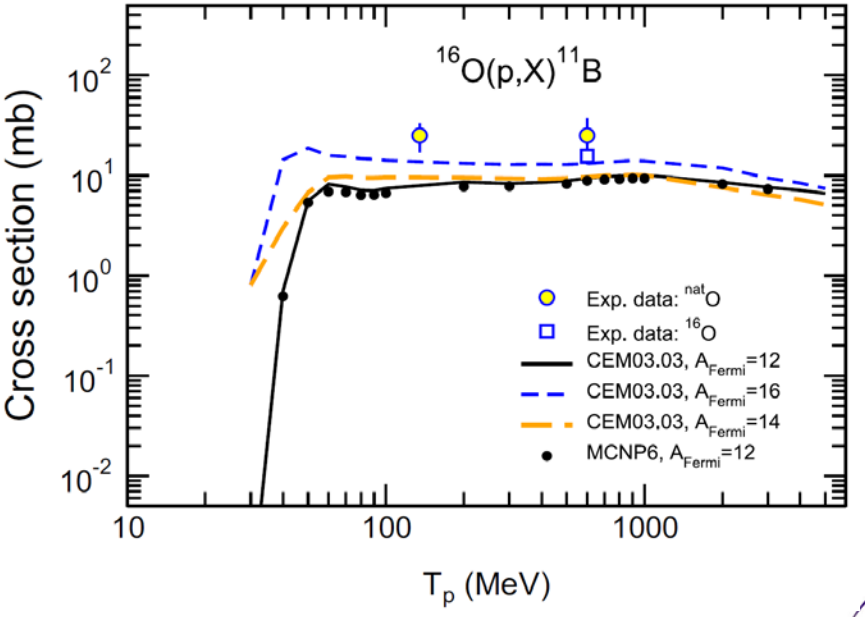

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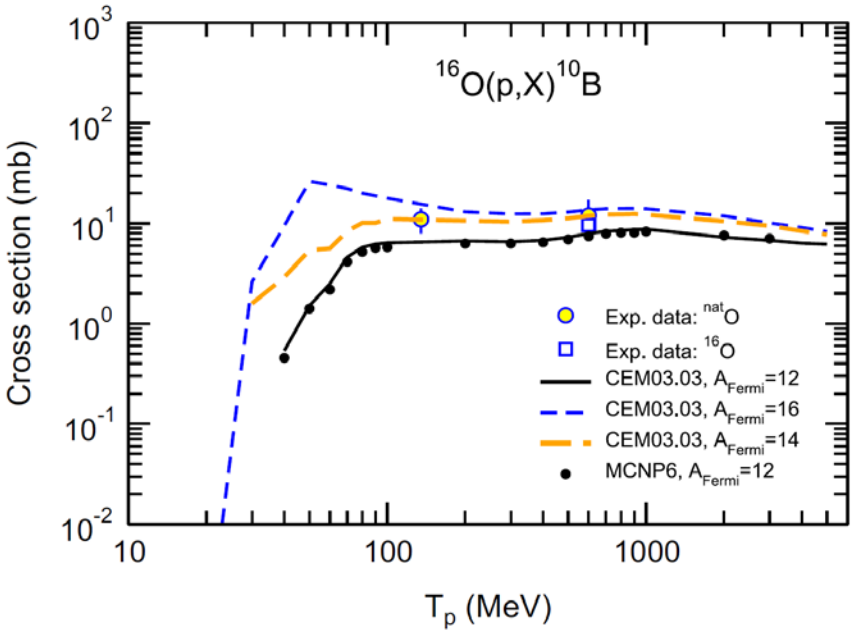

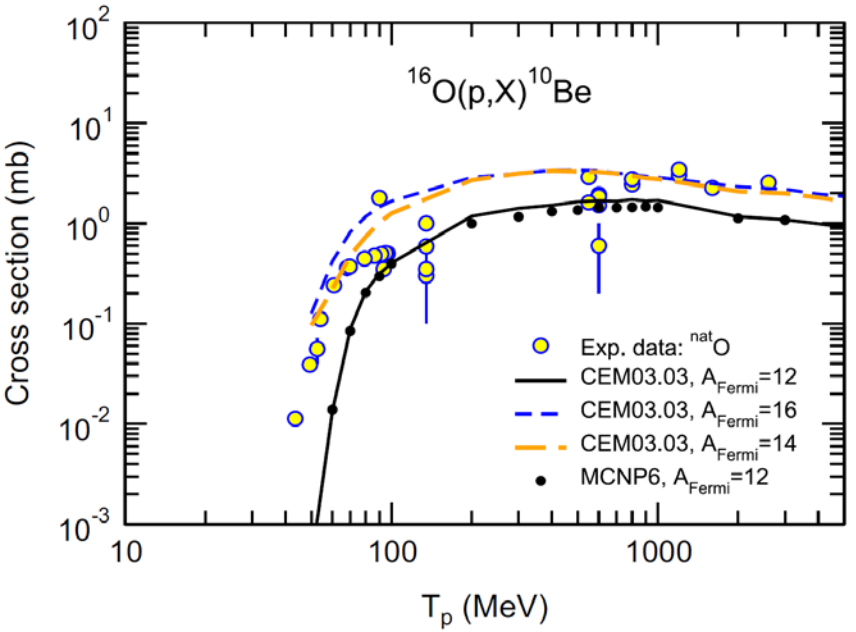

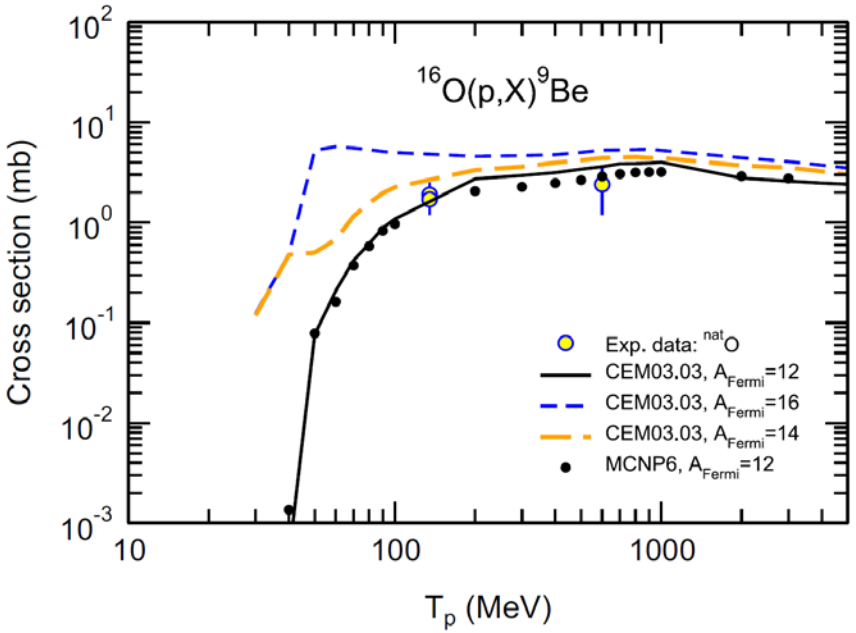

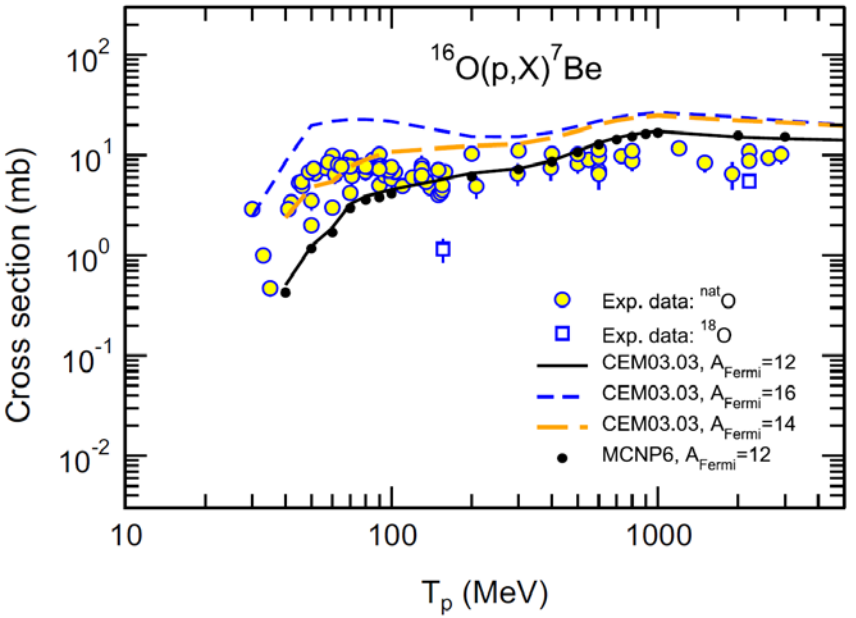

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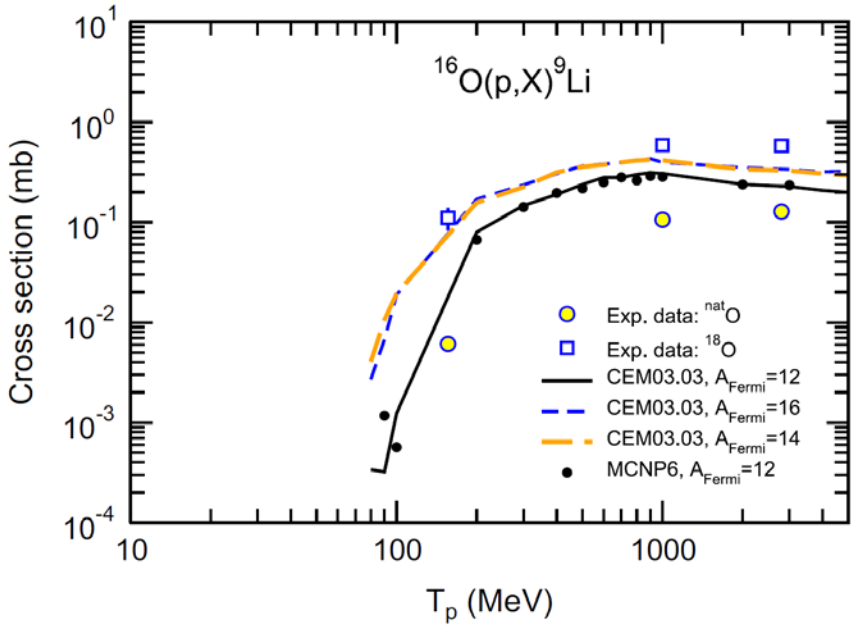

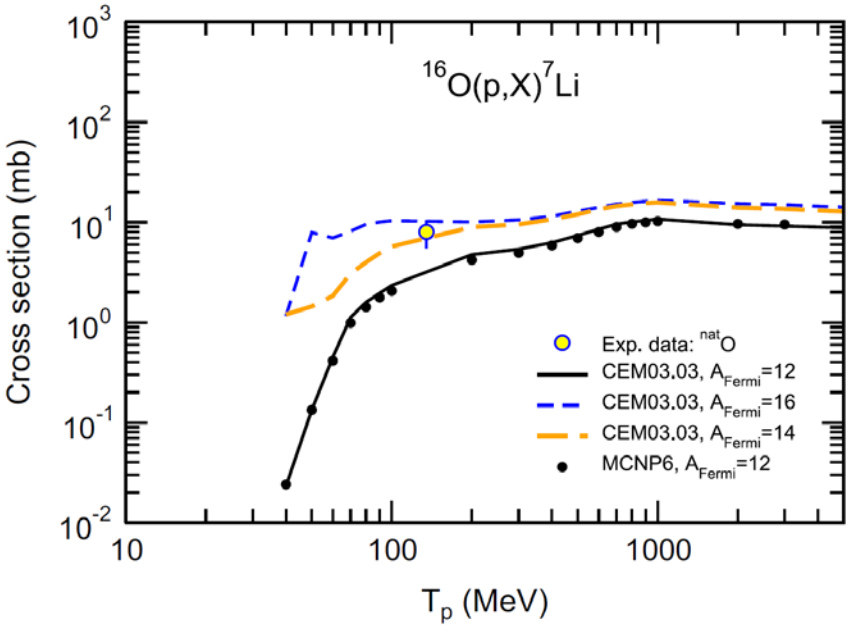

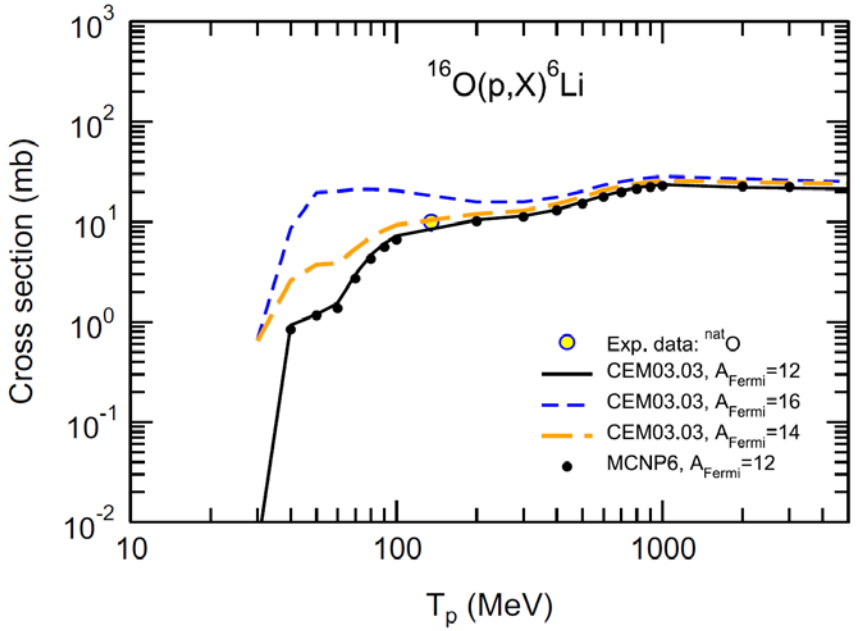

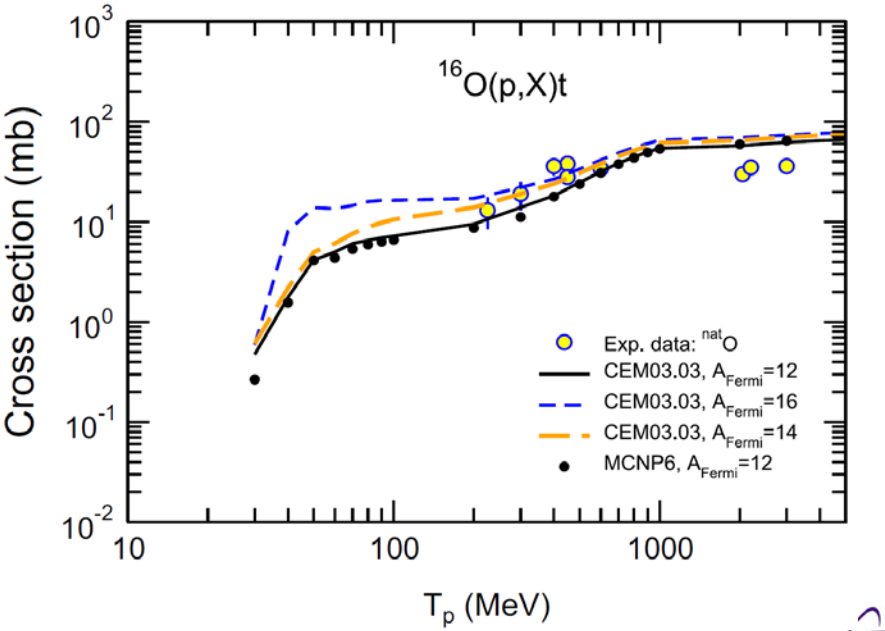

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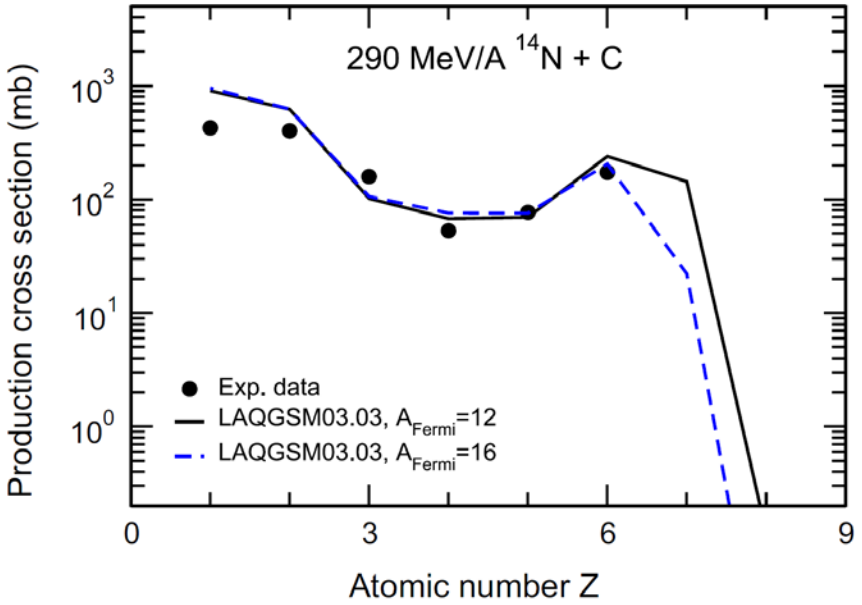

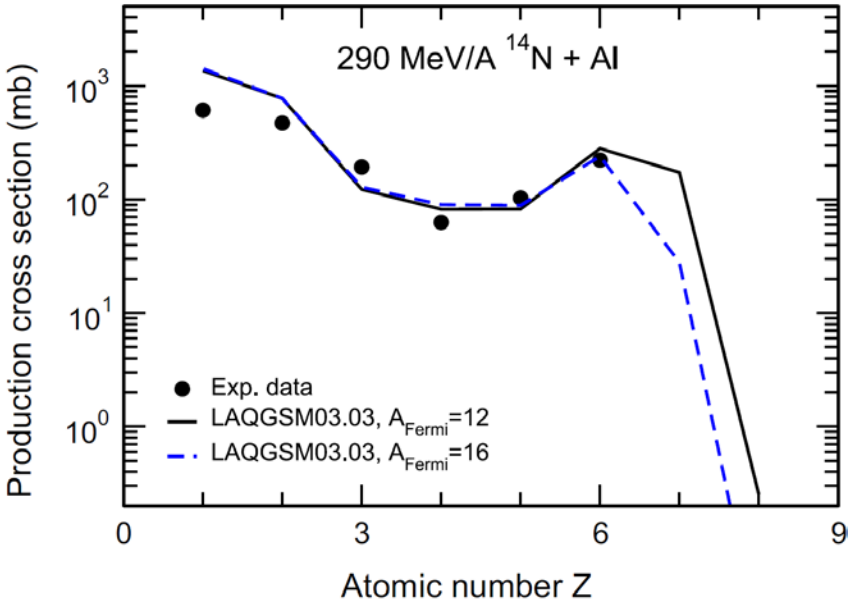

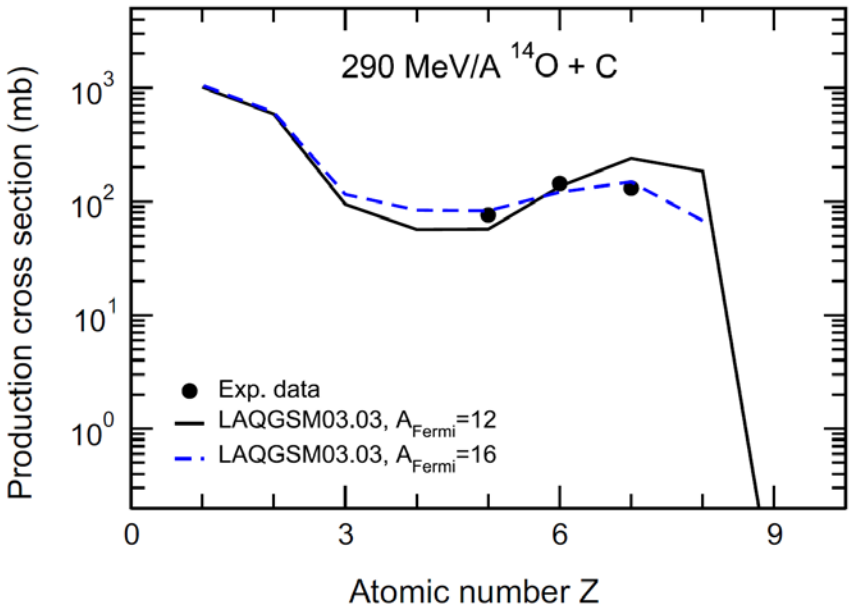

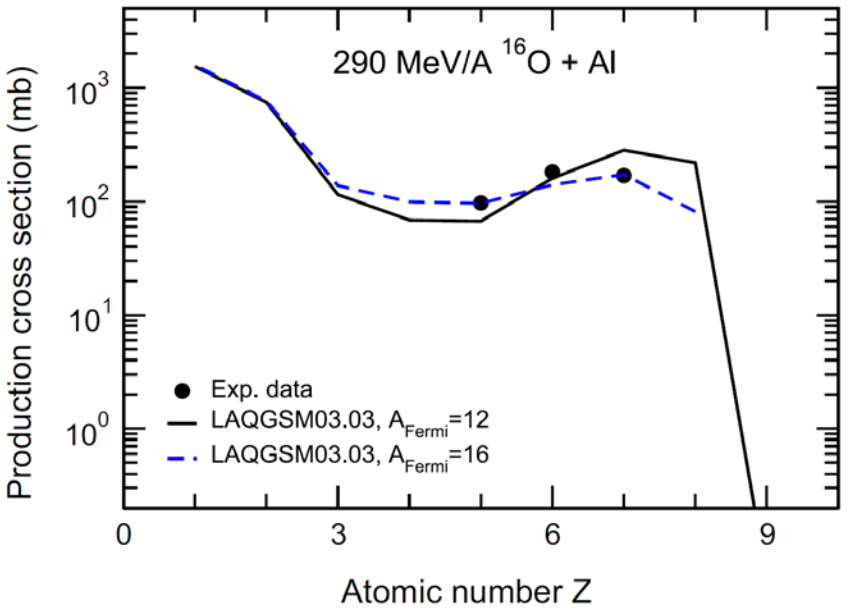

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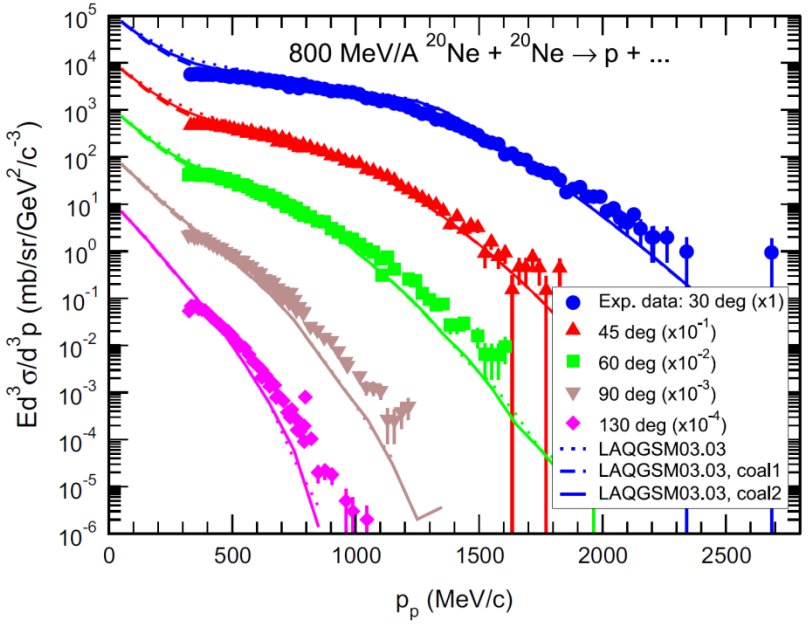

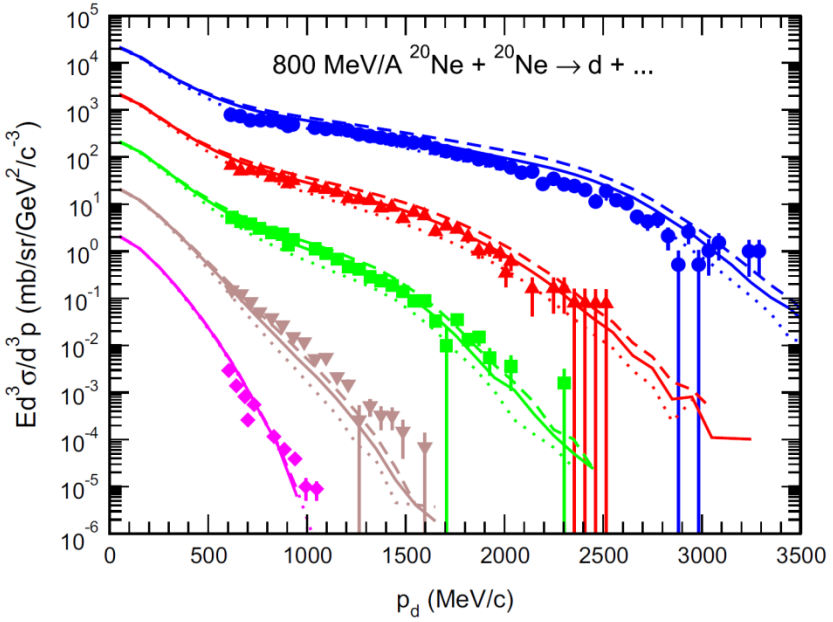

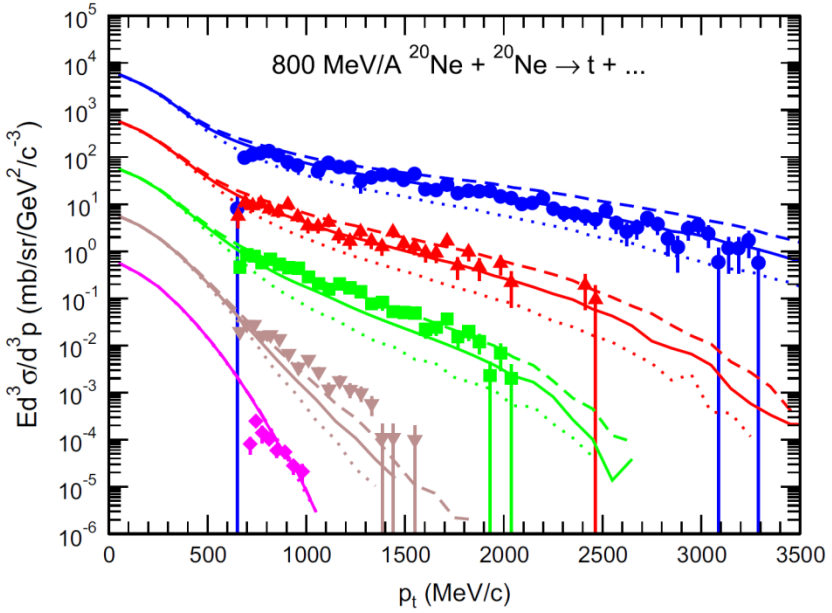

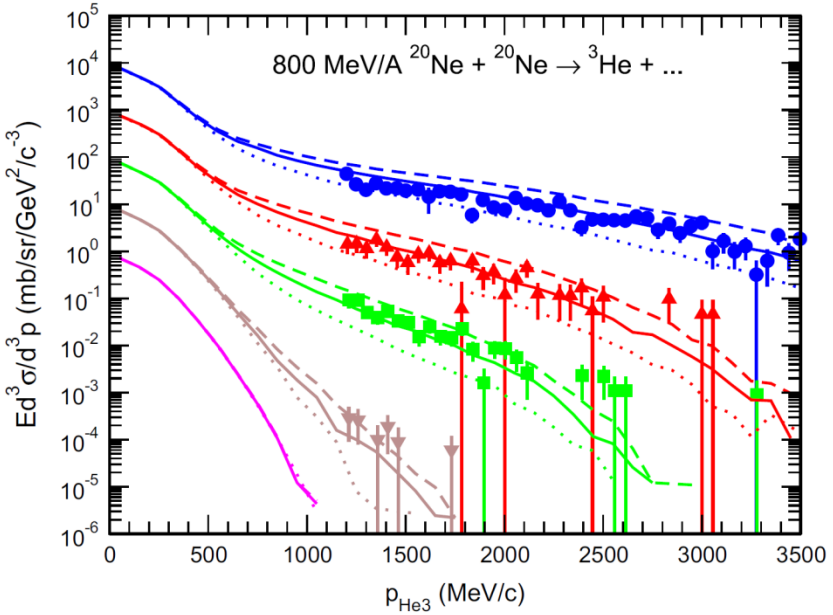

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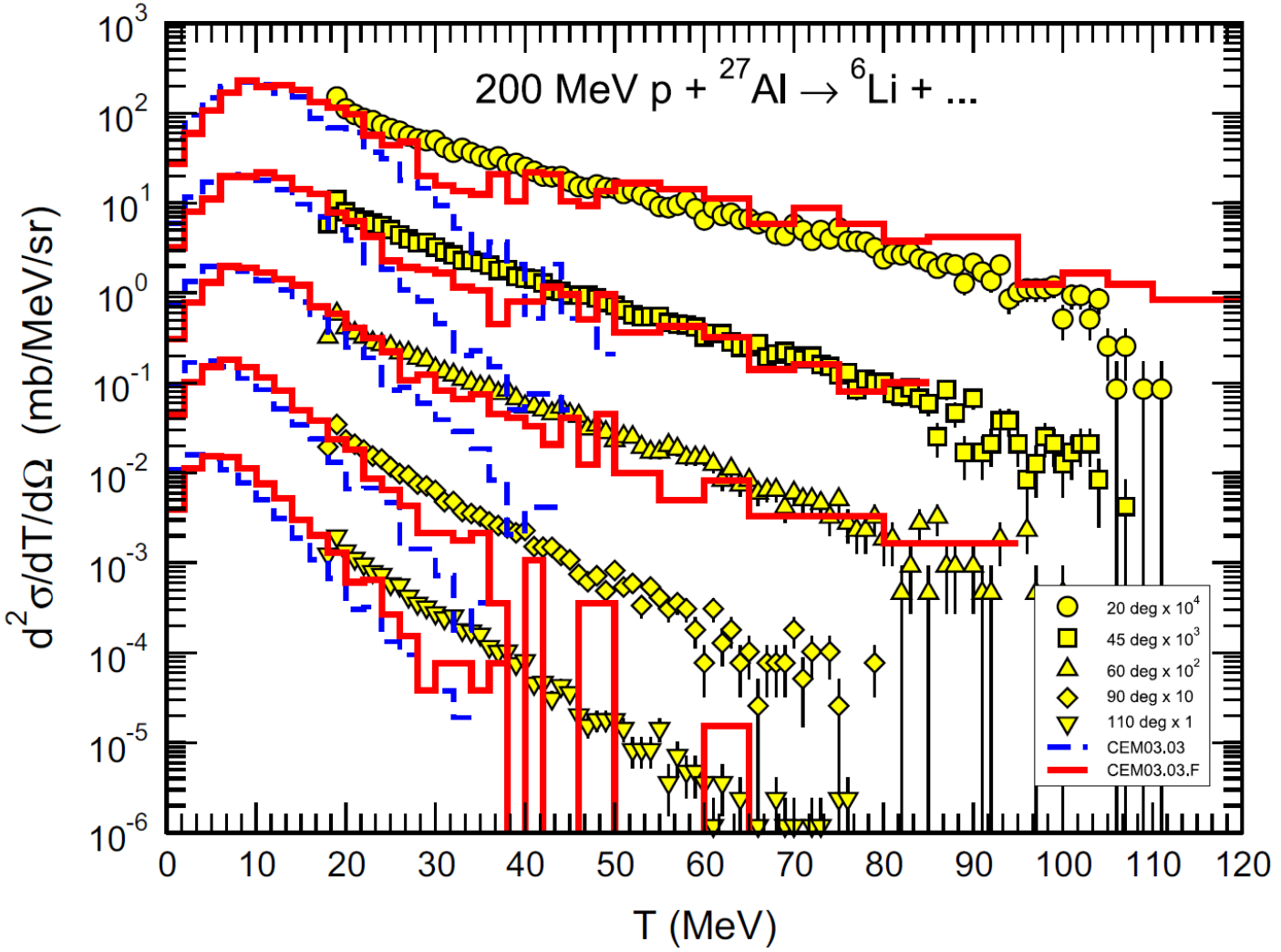


Fig. 27. Comparison of experimental ^{6}Li spectra at 20, 45, 60, 90, and 110° by Machner et al. [61] (symbols) with calculations by the unmodified CEM03.03 (dashed histograms) and preliminary results with the modified MEM in CEM03.03. F (solid histograms), as indicated.

L.M. Kerby , and S.G. Mashnik, LA-UR-15-20323, ANS Transactions, 2015

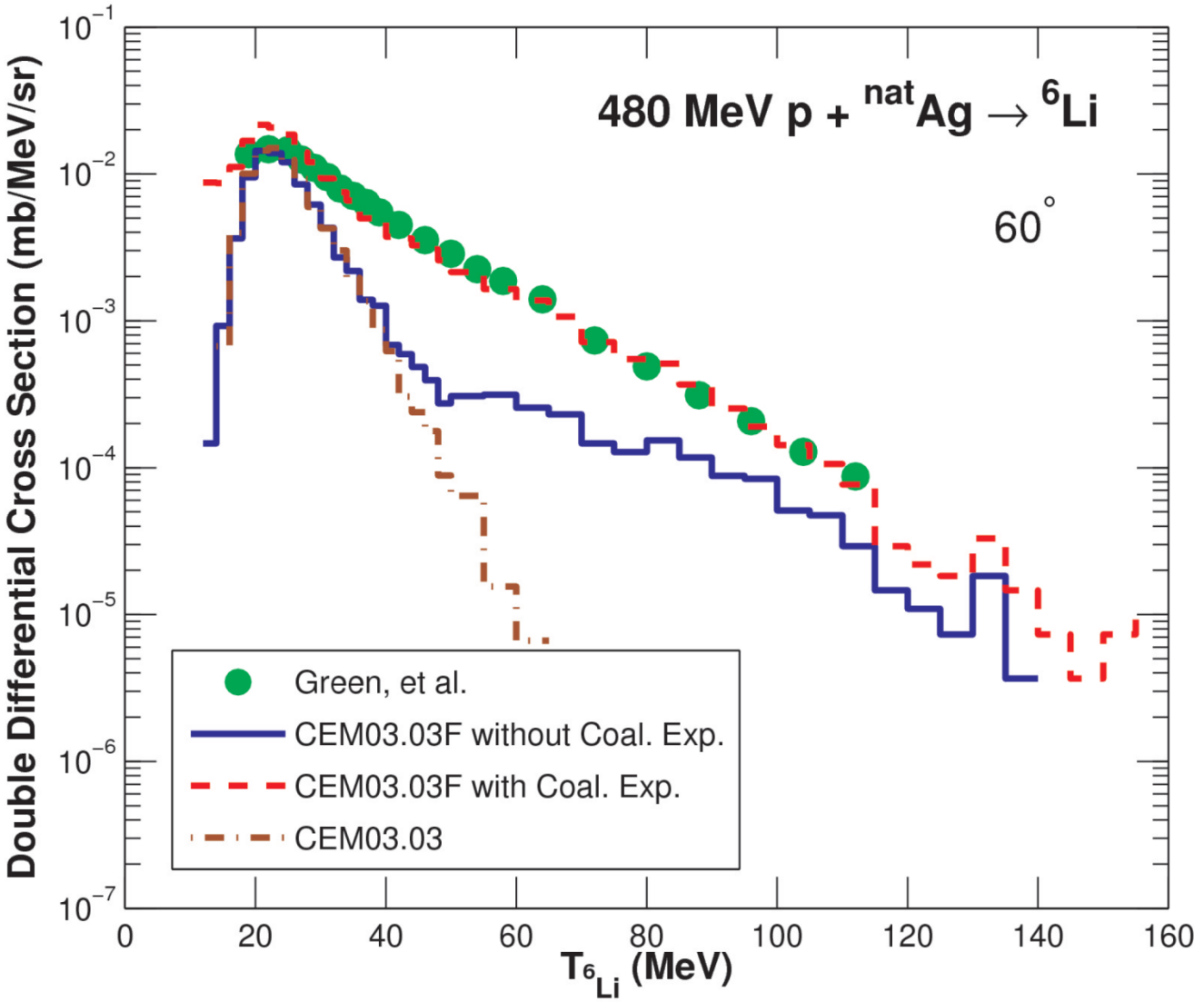
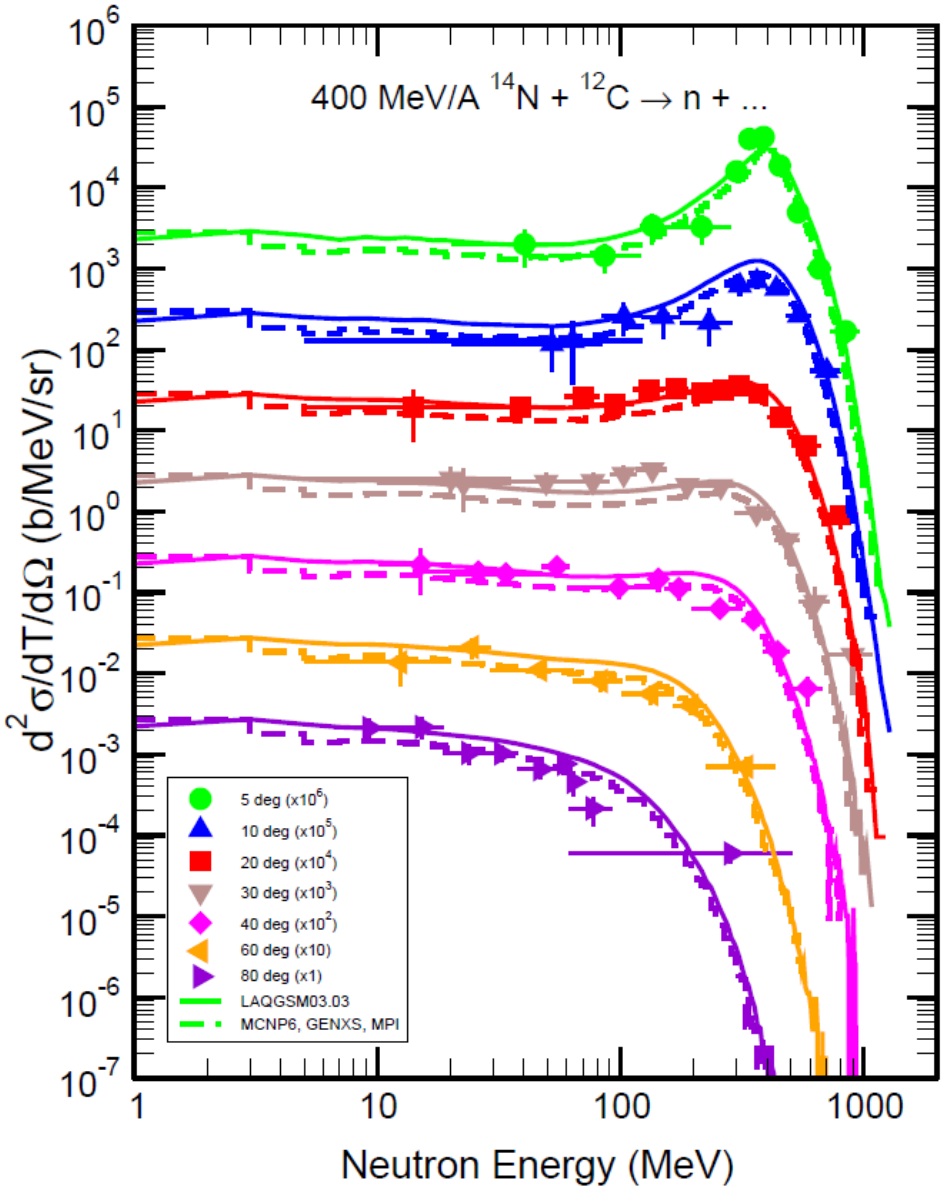
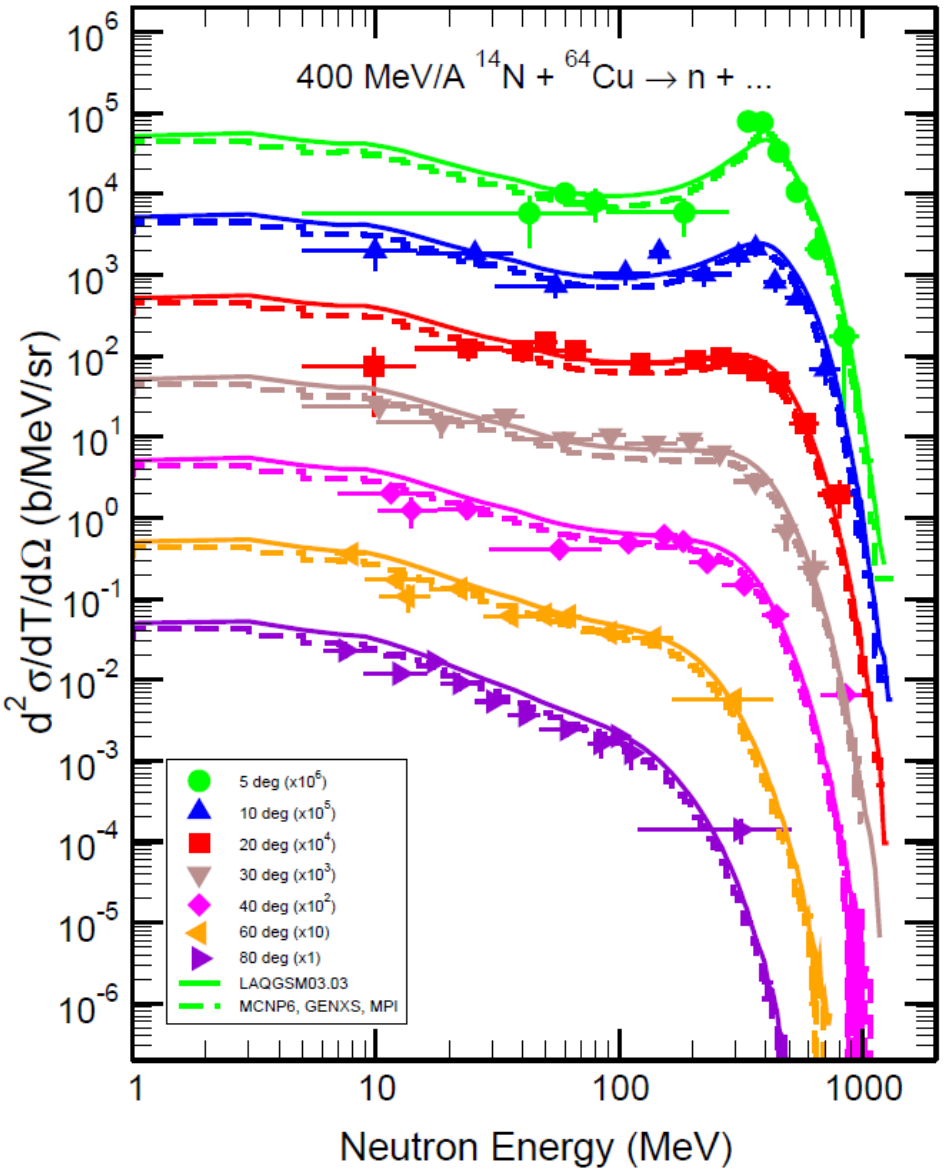


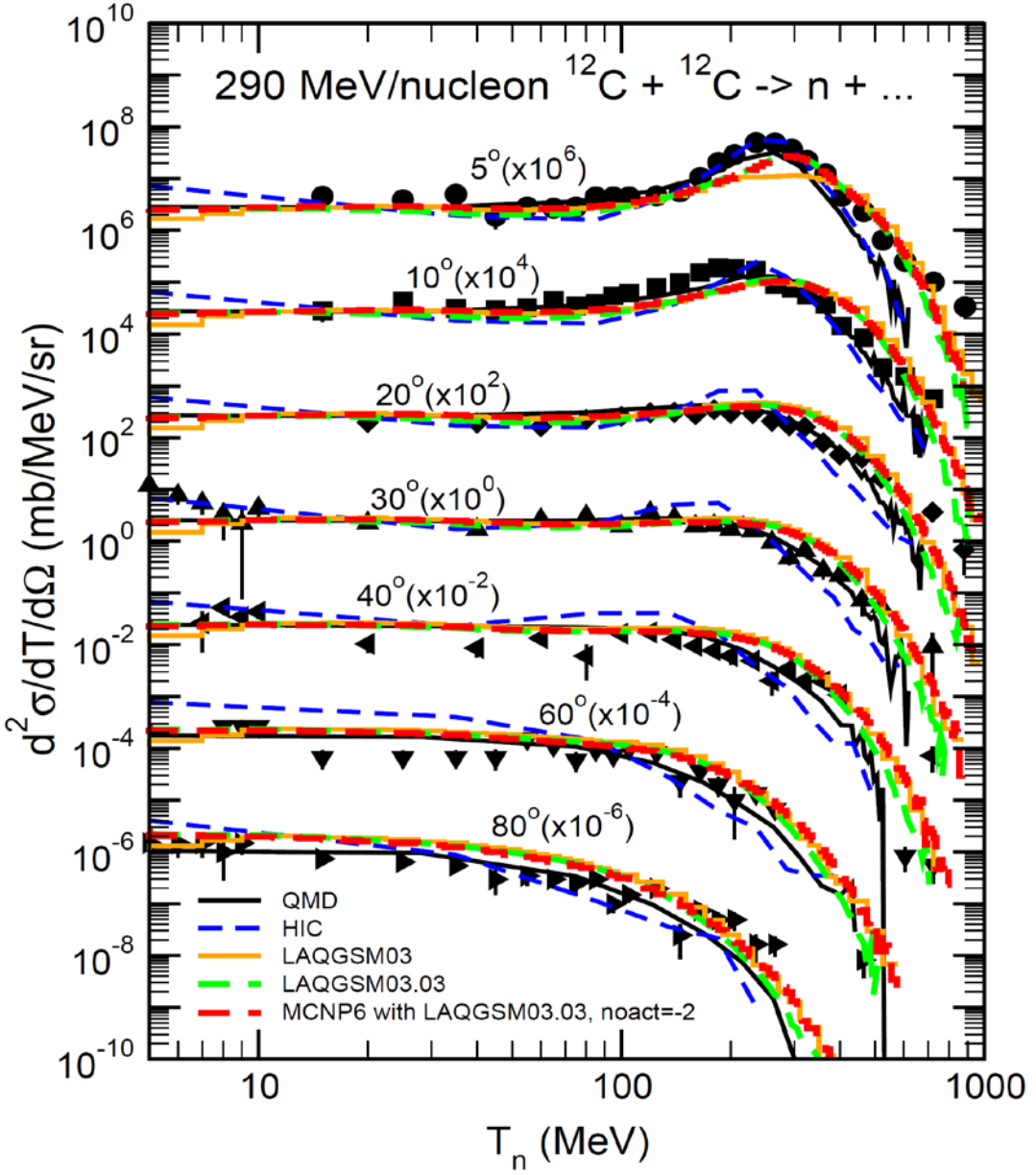
Fig. 3. Comparison of experimental results of the reaction 480 MeV p + ^{nat}Ag → ^{6}Li at 60° by Green *et al.* [17] (green circles), with simulations from the original CEM03.03 (brown dashed-dotted lines), CEM03.03F without coalescence expansion (blue solid lines) and the CEM03.03F with coalescence expansion (red dashed lines).

S.G. Mashnik, Proc. 2nd International Conference on Advances in Radioactive Isotope Science (ARIS 2014), June 1-6, 2014, Tokyo, Japan; JPS Conference Proceedings, 2015; arXiv:1407.2832





Experimental data are from: Y. Iwata et al., Phys. Rev. C64 (2001) 054609;
QMD, HIC, and LAQGSM03 results are from: H. Iwase et al., AIP 769 (2005) 1066



S.G. Mashnik, K. K. Gudima, N. V. Mokhov, and R. E. Prael, LAQGSM03.03 Upgrade and Its Validation, LA-UR-07-6198; E-print: arXiv:0709.1736 [nucl-th] 12 Sep 2007

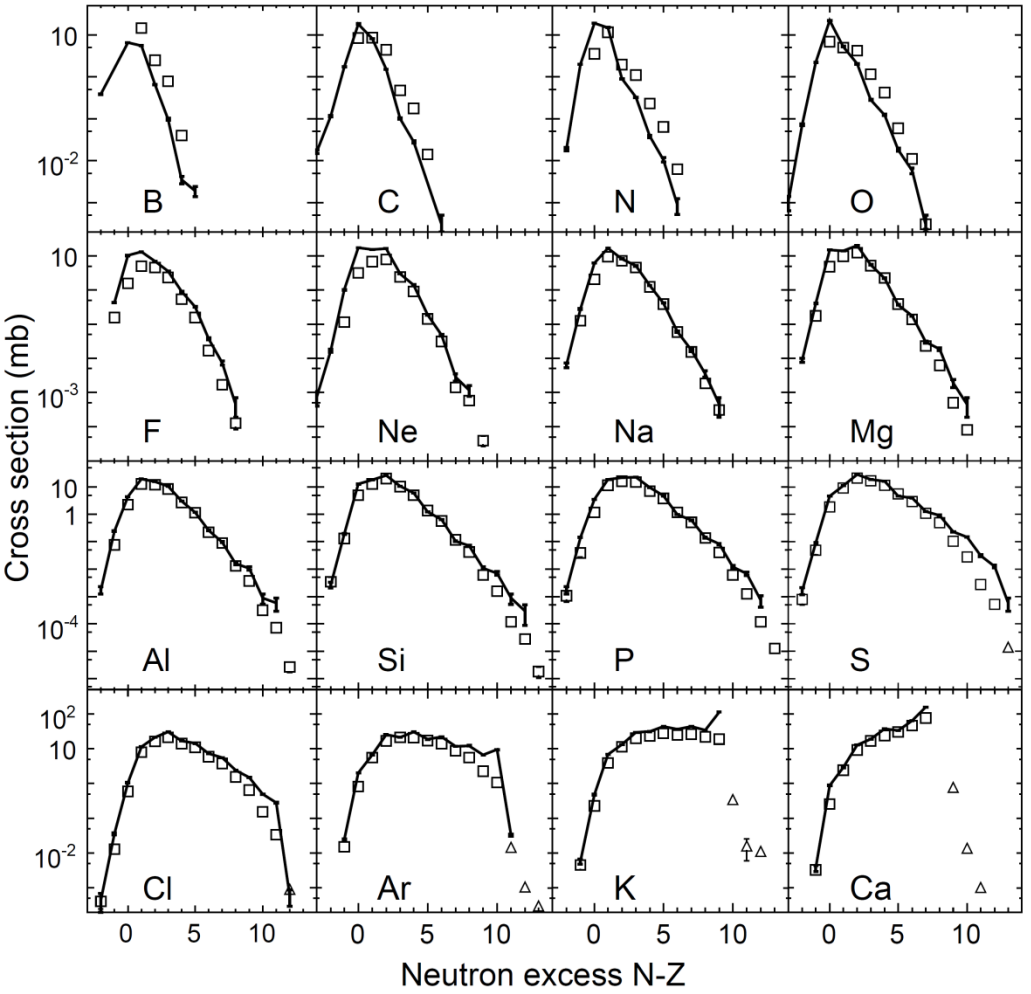


Figure 12: Measured cross sections for ^{48}Ca fragmentation on ^{9}Be at 140 MeV/nucleon [49,50] compared with LAQGSM03.03 predictions.

S.G. Mashnik, J. S. Bull, H. G. Hughes, R. E. Prael, A. J. Sierk, Proc. 11th Conference on the Intersections of Particle and Nuclear Physics (CIPANP 2012), St. Petersburg, FL, May 29 - June 3, 2012, AIP Conf. Proc. 1560, 706 (2013); arXiv:1207.5076

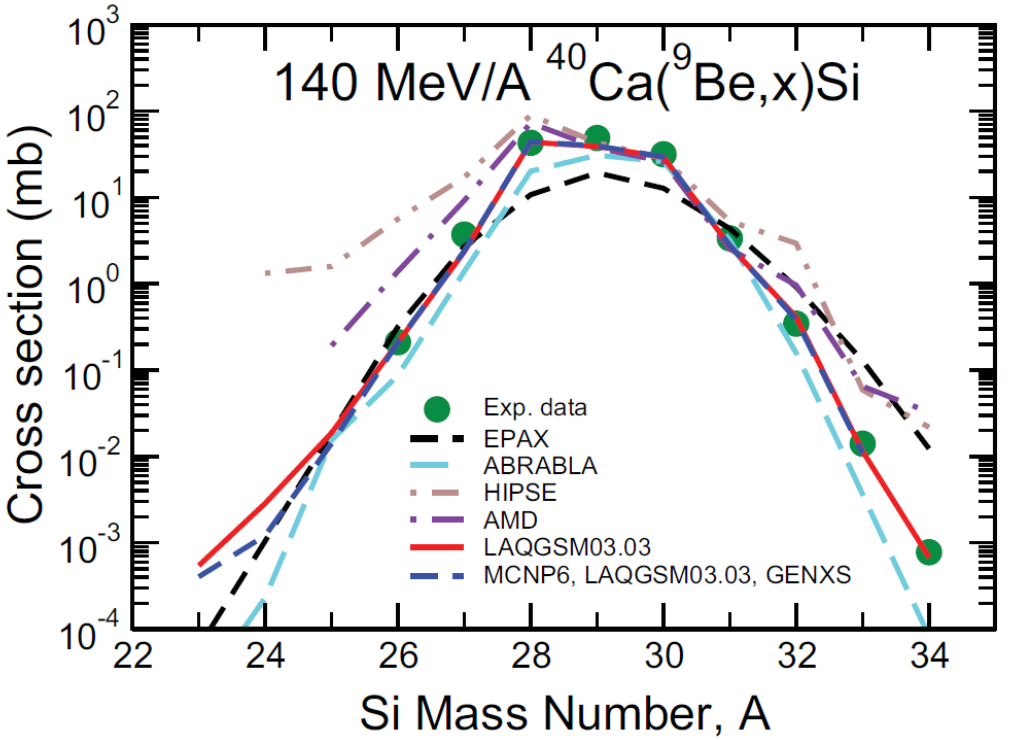
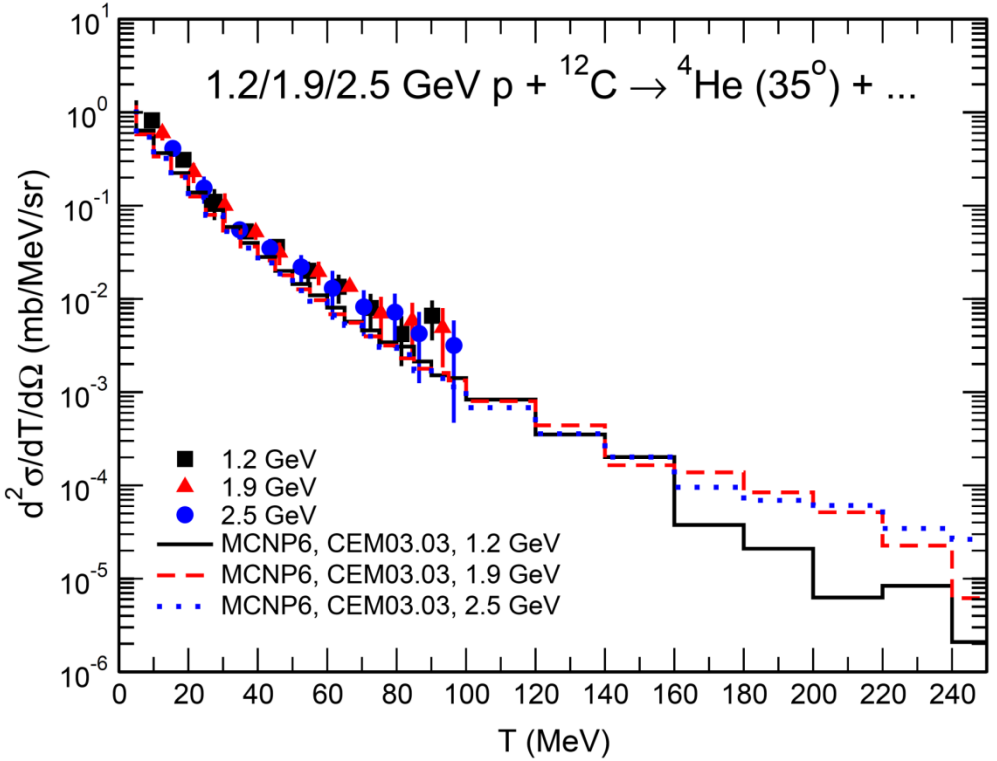
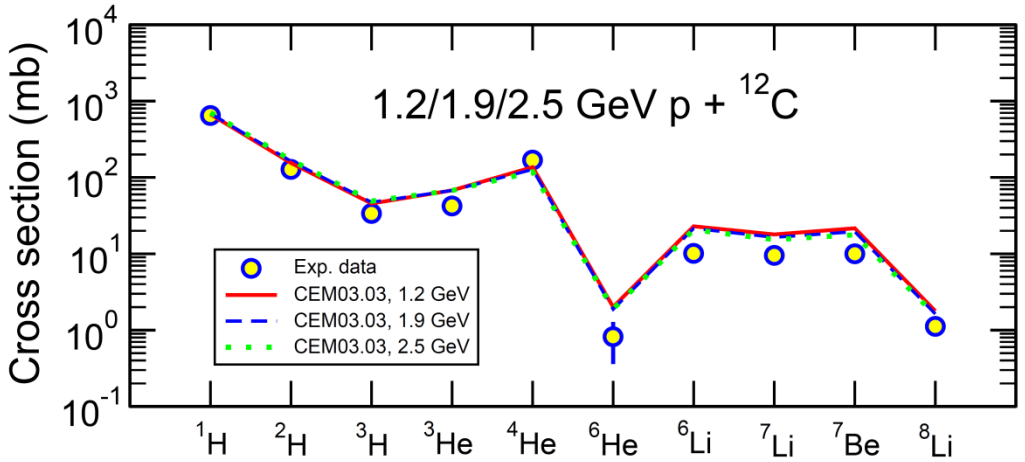
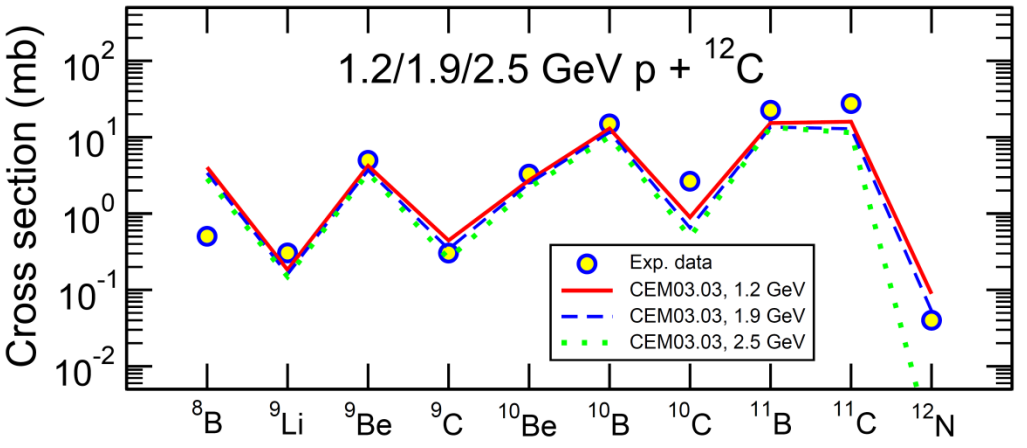


FIGURE 2. Experimental [18] mass-number yields of Si isotopes produced from 140 MeV/A ^{40}Ca + ^{9}Be (green filled circles) compared with results from EPAX [19], ABRABLA [14], HIPSE [20], and AMD [21] from [18], as well as with predictions by LAQGSM03.03 used as a stand alone code and by MCNP6 using the LAQGSM03.03 event-generator, as indicated.

Exp. Data are from: M. Fidelus, for PISA collaboration, "Total production cross section for p+^{12}C reactions in the limiting fragmentation range"; PhD thesis, Cracow, 2010







Summary

- MCNP6, the latest and most advanced LANL Monte Carlo transport code, representing a merger of MCNP5 and MCNPX, is actually much more than the sum of those two computer codes; MCNP6 is available to the public via RSICC at Oak Ridge, TN, USA.

- In the present work, we Validated and Verified (V&V) MCNP6 against different experimental data on intermediate-energy fragmentation reactions, and results by several other codes, using mainly the latest modifications of the Cascade-Exciton Model (CEM) and of the Los Alamos version of the Quark-Gluon String Model (LAQGSM) event generators CEM03.03 and LAQGSM03.03.

- We found that MCNP6 using CEM03.03 and LAQGSM03.03 describes well fragmentation reactions induced on light and medium target nuclei by protons and light nuclei of energies around 1 GeV/nucleon and below and can serve as a reliable simulation tool for different applications, like cosmic-ray-induced single event upsets (SEU's), radiation protection, and cancer therapy with proton and ion beams, to name just a few. Future improvements of the predicting capabilities of MCNP6 for such reactions are possible and discussed in our work.