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Title: CEM03.01 and LAQGSM03.01 Improvement for Gas-Production Cross Section Calculations

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CEM03.01 and LAQGSM03.01 Improvement for Gas-Production Cross Section Calculation

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- Introduction
- Complex Particle and Fragment Production Mechanisms in CEM03.01 and LAQGSM03.01
- Particle Spectra
- Total Production Cross Sections (Yields)
- Summary

- Gas-production cross sections are needed for ADS applications to estimate the material damage
- Complex particle spectra are needed to design portable high-energy neutron spectrometers
- Kinetic Energy Released in Matter (KERMA) is needed for radiotherapy and radiation protection
- Complex-particle and light-fragment data are needed for astrophysics
- • • •

- CEM and LAQGSM were developed initially without a special care about complex-particle production

CEM and LAQGSM describe complex-particle and light-fragment production via:

- Intra-Nuclear Cascade (INC) nucleons → coalescence
- Preequilibrium and evaporation
- Fission-like binary-decay
  (“G” versions of our codes; “G” stands for GEMINI)
- Multifragmentation
  (“S” versions of our codes; “S” stands for SMM)
- Fermi Break-up of light nuclei (A<12)
- Residual nuclei produced after all stages of reactions

The Coalescence Model

$$W_d(\vec{p}, b) = \int\int d\vec{p}_p d\vec{p}_n \rho^C(\vec{p}_p, b)\rho^C(\vec{p}_n, b)\delta(\vec{p}_p + \vec{p}_n - \vec{p})\Theta(p_c - |\vec{p}_p - \vec{p}_n|),$$

LAQGSM:

$P_0(d)$ = 90 MeV/c; $P_0(t) = P_0(^3He)$ = 108 MeV/c; $P_0(^4He)$ = 115 MeV/c

CEM:

$P_0(d)$ = 150 MeV/c; $P_0(t) = P_0(^3He)$ = 175 MeV/c; $P_0(^4He)$ = 175 MeV/c

The Exciton Model

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

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

$$\gamma_j \simeq p_j^3(V_j/V)^{p_j-1} = p_j^3(p_j/A)^{p_j-1}$$

$$<\sigma> \rightarrow <\sigma> F(\Omega) \ ,$$

$$F(\Omega) = \frac{d\sigma^{free}/d\Omega}{\int d\Omega' d\sigma^{free}/d\Omega'}$$

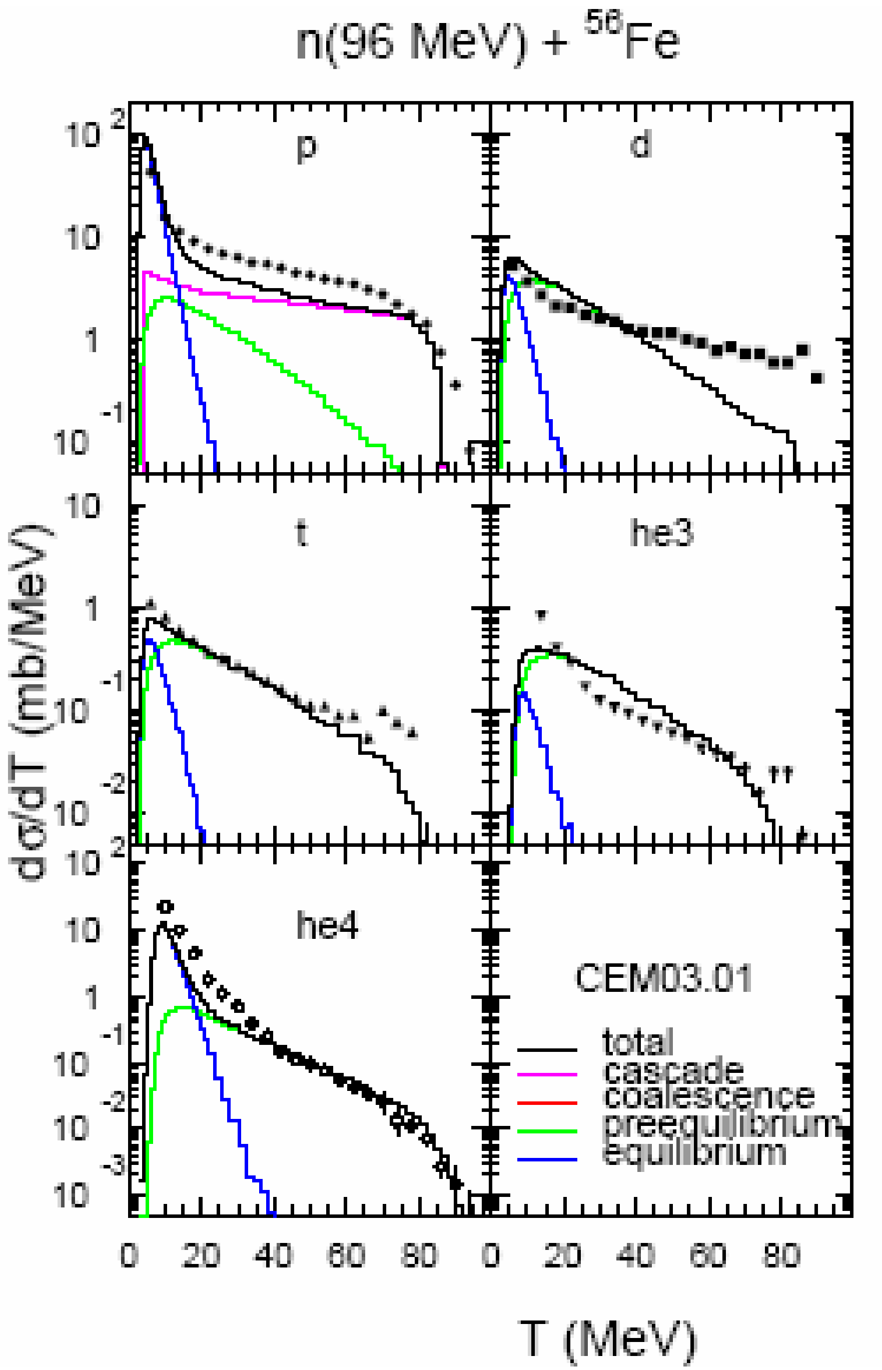
1) γ_j was fitted for proton-induced reactions

2) Kalbach systematics for angular distribution of preequilibrium particles was incorporated at energies below 210 MeV to replace the CEM approach

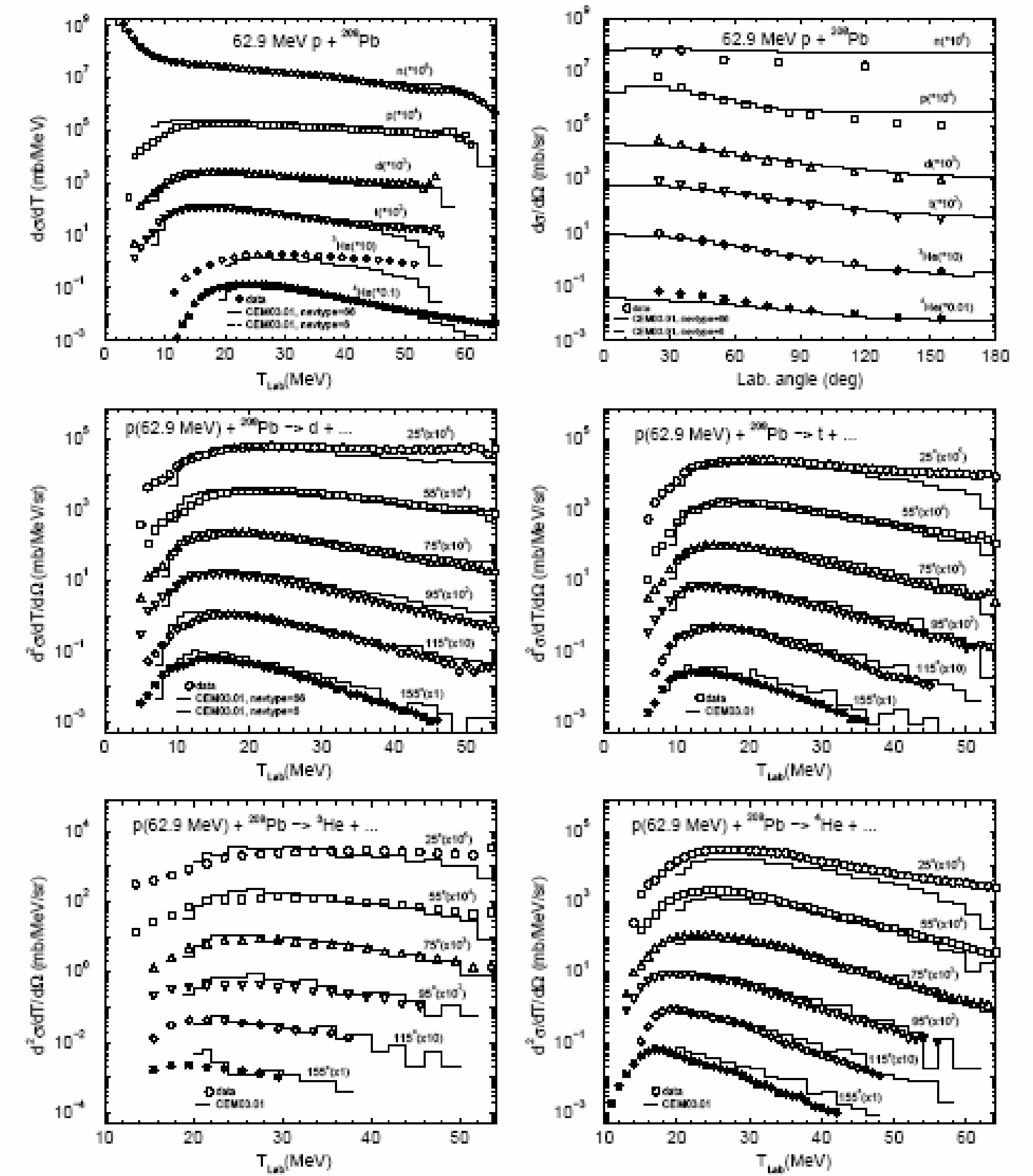
The Evaporation Model

$$P_j(\epsilon)d\epsilon = g_j \sigma_{inv}(\epsilon) \frac{\rho_d(E - Q - \epsilon)}{\rho_i(E)} \epsilon d\epsilon,$$

Z_j	Ejectiles						
0	n						
1	p	d	t				
2	^{3}He	^{4}He	^{6}He	^{8}He			
3	^{6}Li	^{7}Li	^{8}Li	^{9}Li			
4	^{7}Be	^{9}Be	^{10}Be	^{11}Be	^{12}Be		
5	^{8}B	^{10}B	^{11}B	^{12}B	^{13}B		
6	^{10}C	^{11}C	^{12}C	^{13}C	^{14}C	^{15}C	^{16}C
7	^{12}N	^{13}N	^{14}N	^{15}N	^{16}N	^{17}N	
8	^{14}O	^{15}O	^{16}O	^{17}O	^{18}O	^{19}O	^{20}O
9	^{17}F	^{18}F	^{19}F	^{20}F	^{21}F		
10	^{18}Ne	^{19}Ne	^{20}Ne	^{21}Ne	^{22}Ne	^{23}Ne	^{24}Ne
11	^{21}Na	^{22}Na	^{23}Na	^{24}Na	^{25}Na		
12	^{22}Mg	^{23}Mg	^{24}Mg	^{25}Mg	^{26}Mg	^{27}Mg	^{28}Mg



Data: V. Blideanu *et al.*, Phys. Rev. C **70** (2004) 014607



Data: A. Guertin *et al.*,
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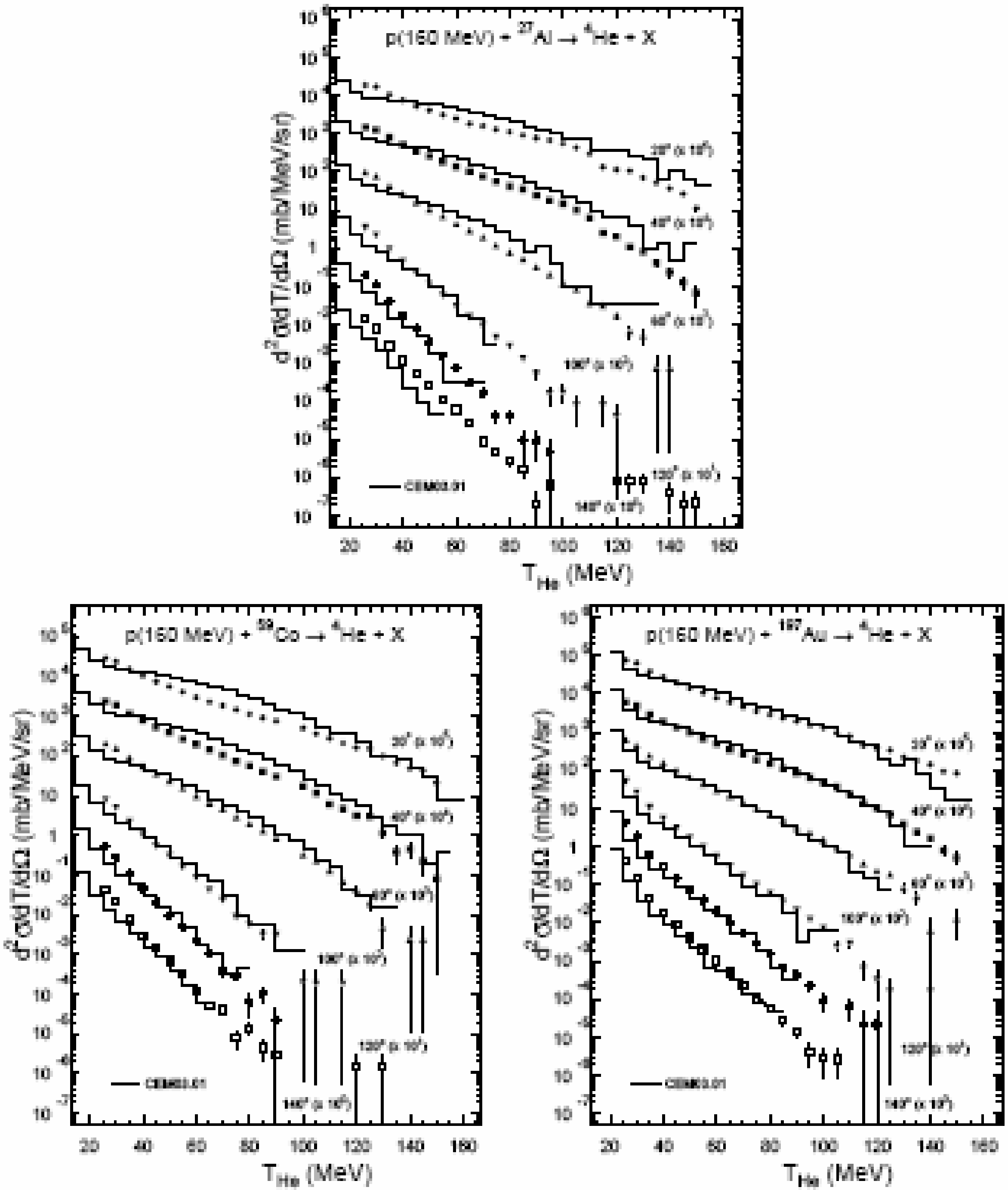

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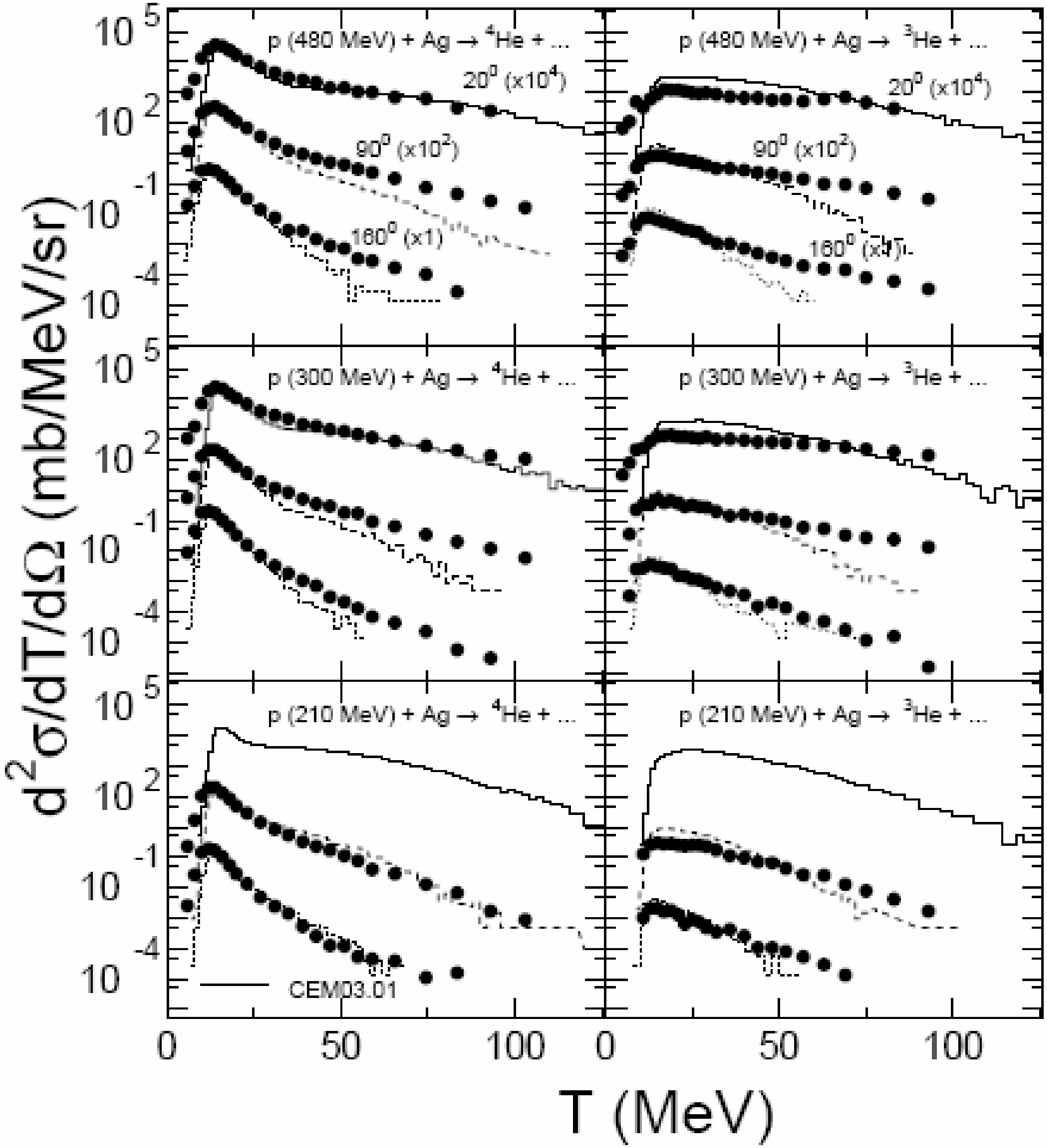

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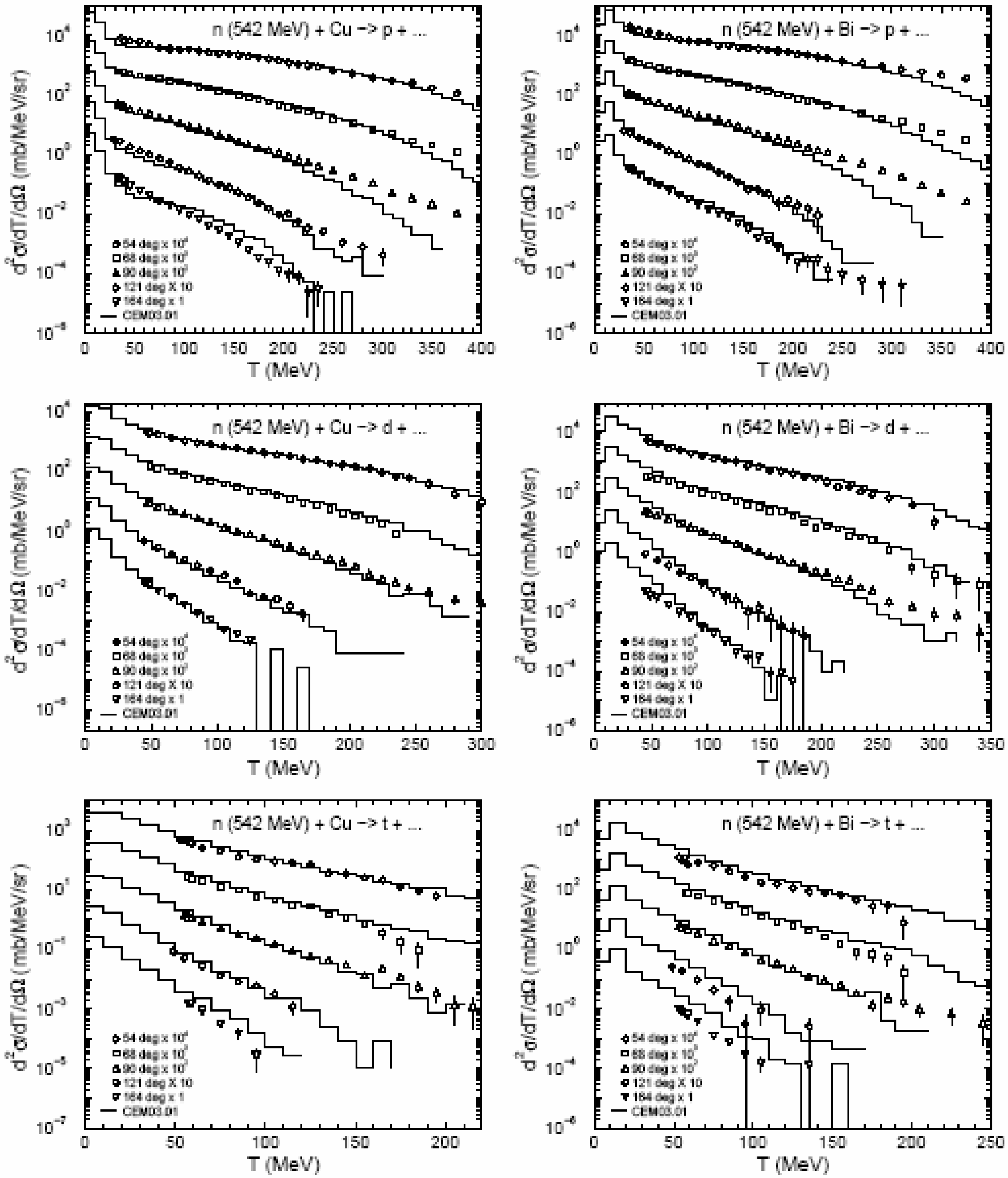

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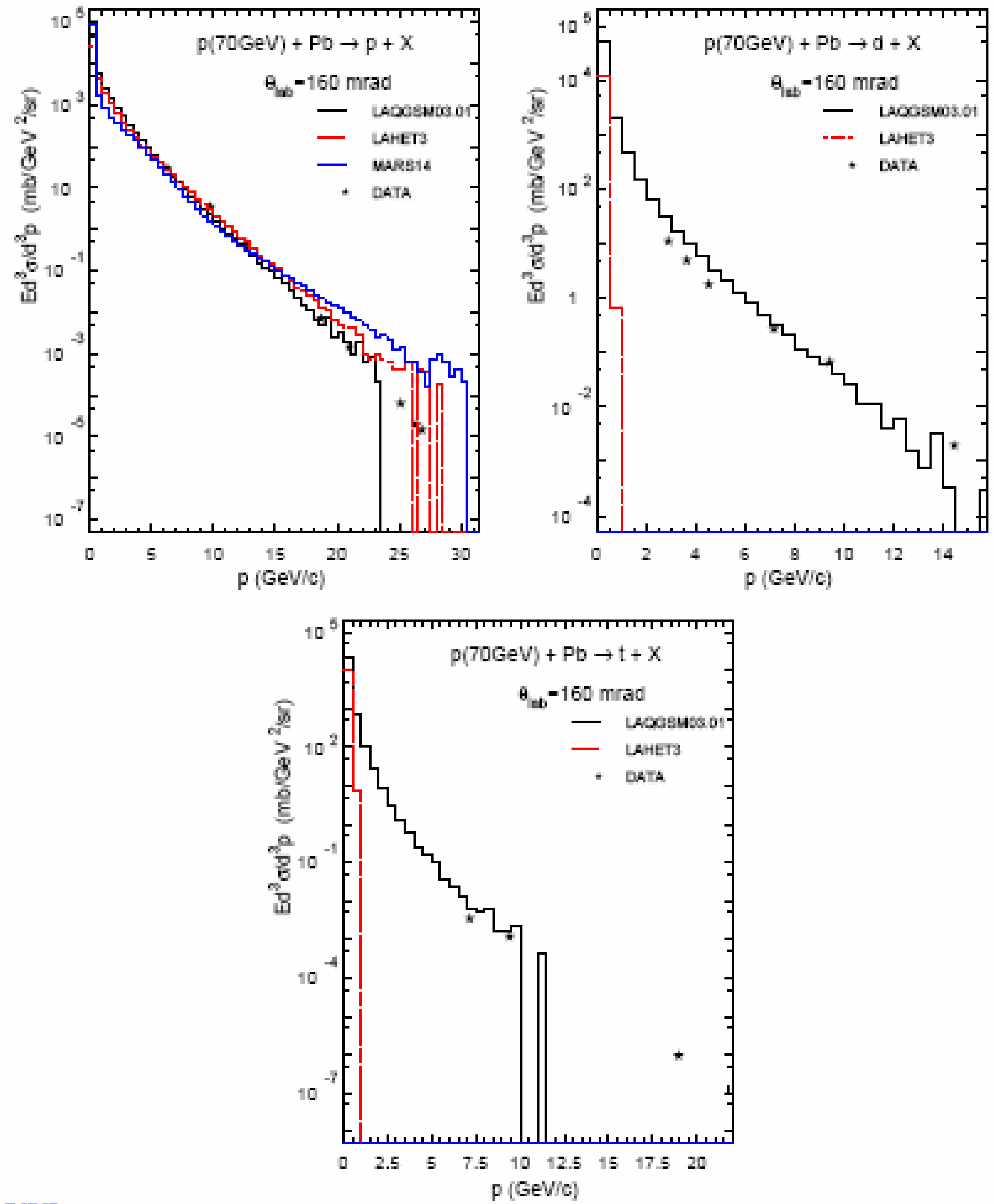
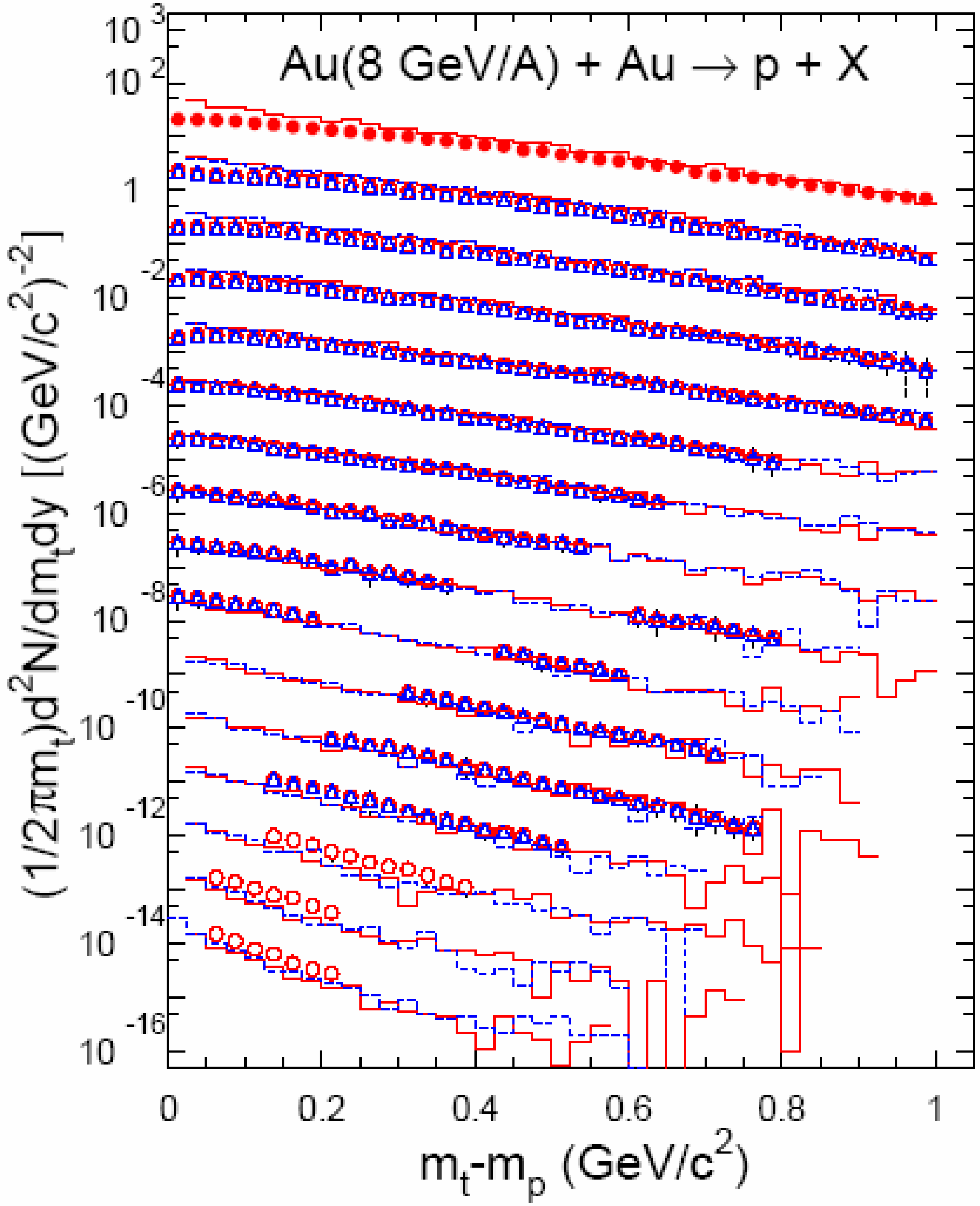
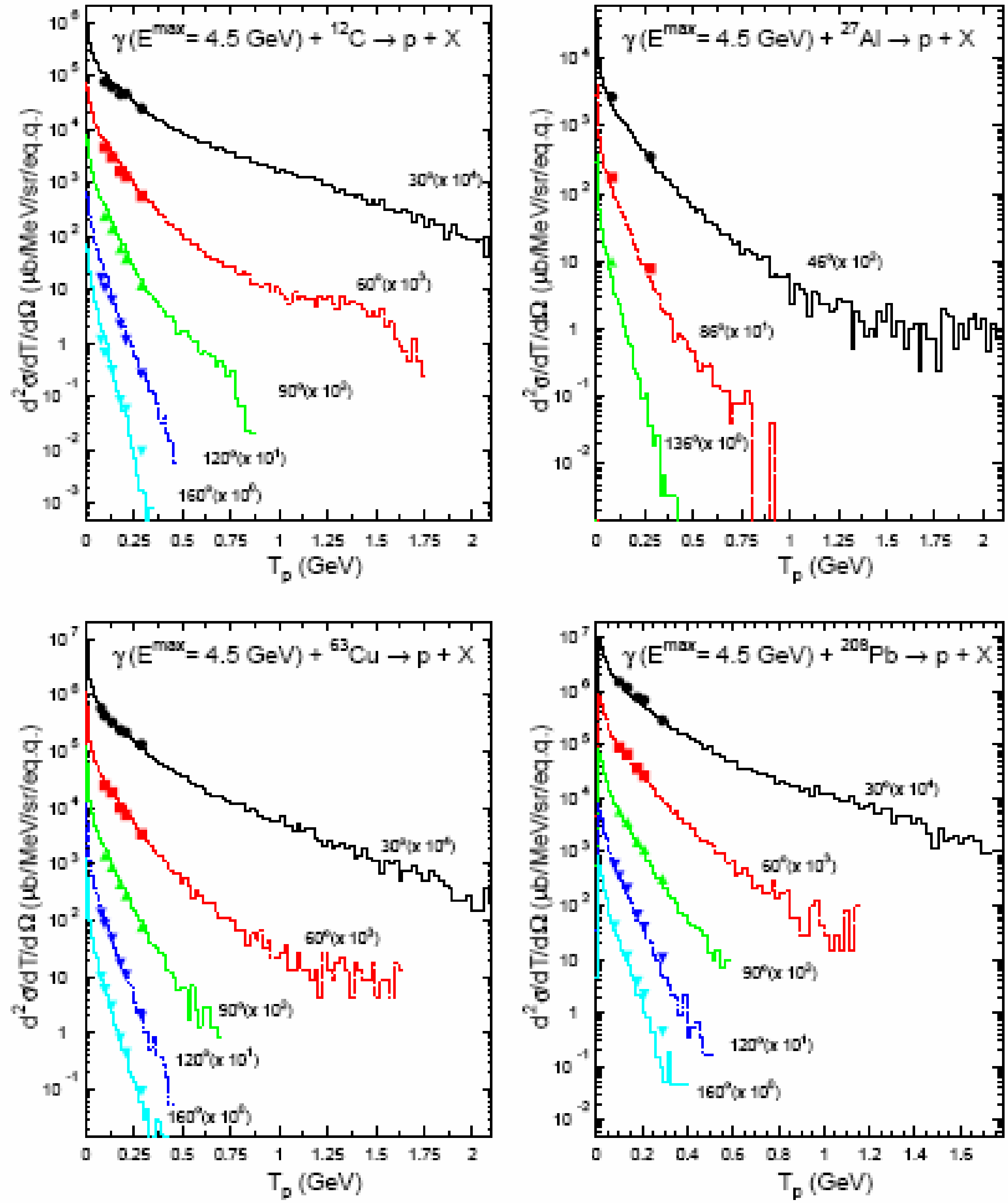


Data: L. M. Barkov *et al.*,
Sov. J. Nucl. Phys.
35 (1982) 694;
37 (1983) 732;
41 (1985) 227



Data: J. L. Klay *et al.*, Phys. Rev. Lett., **88** (2002) 102301



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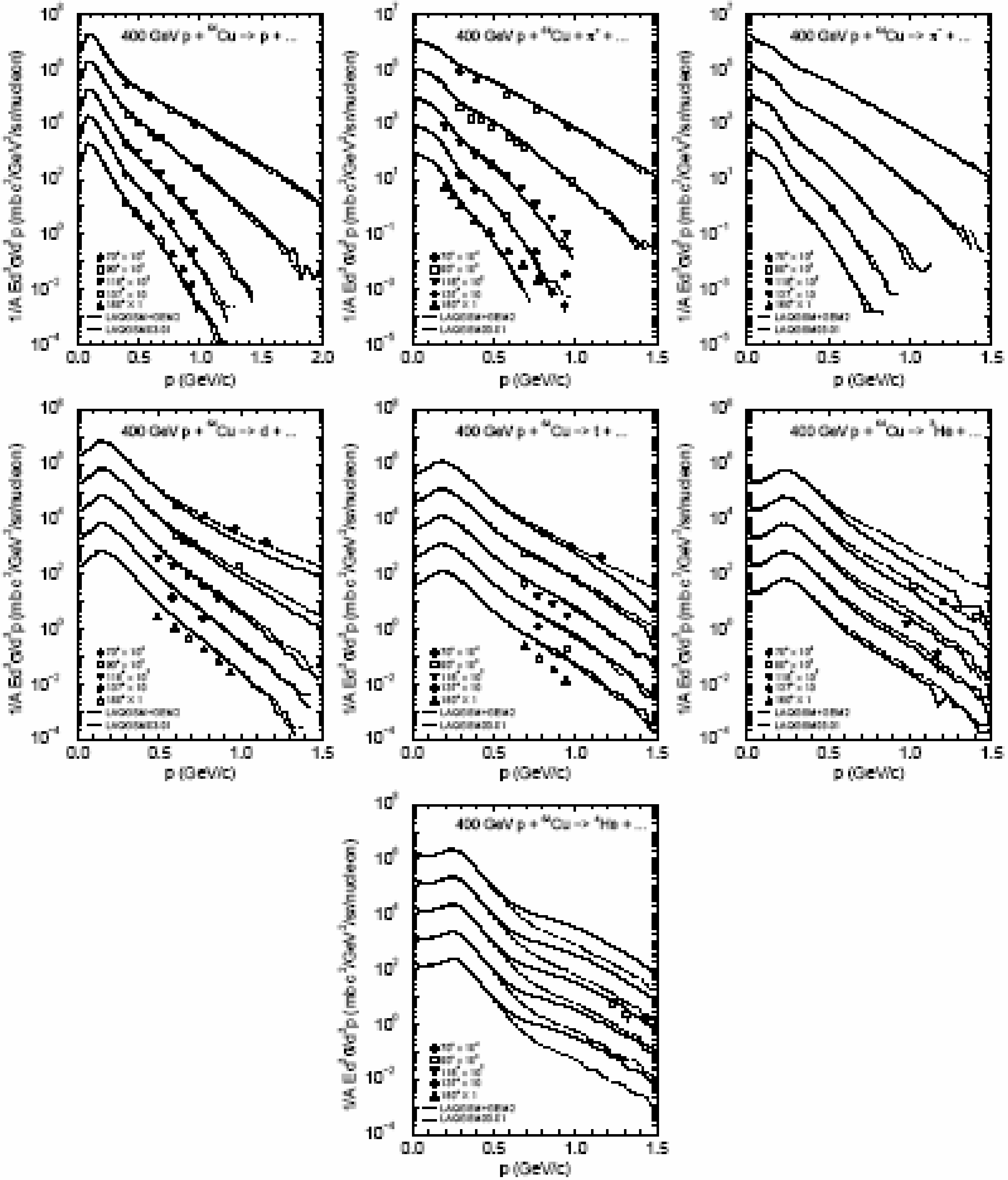

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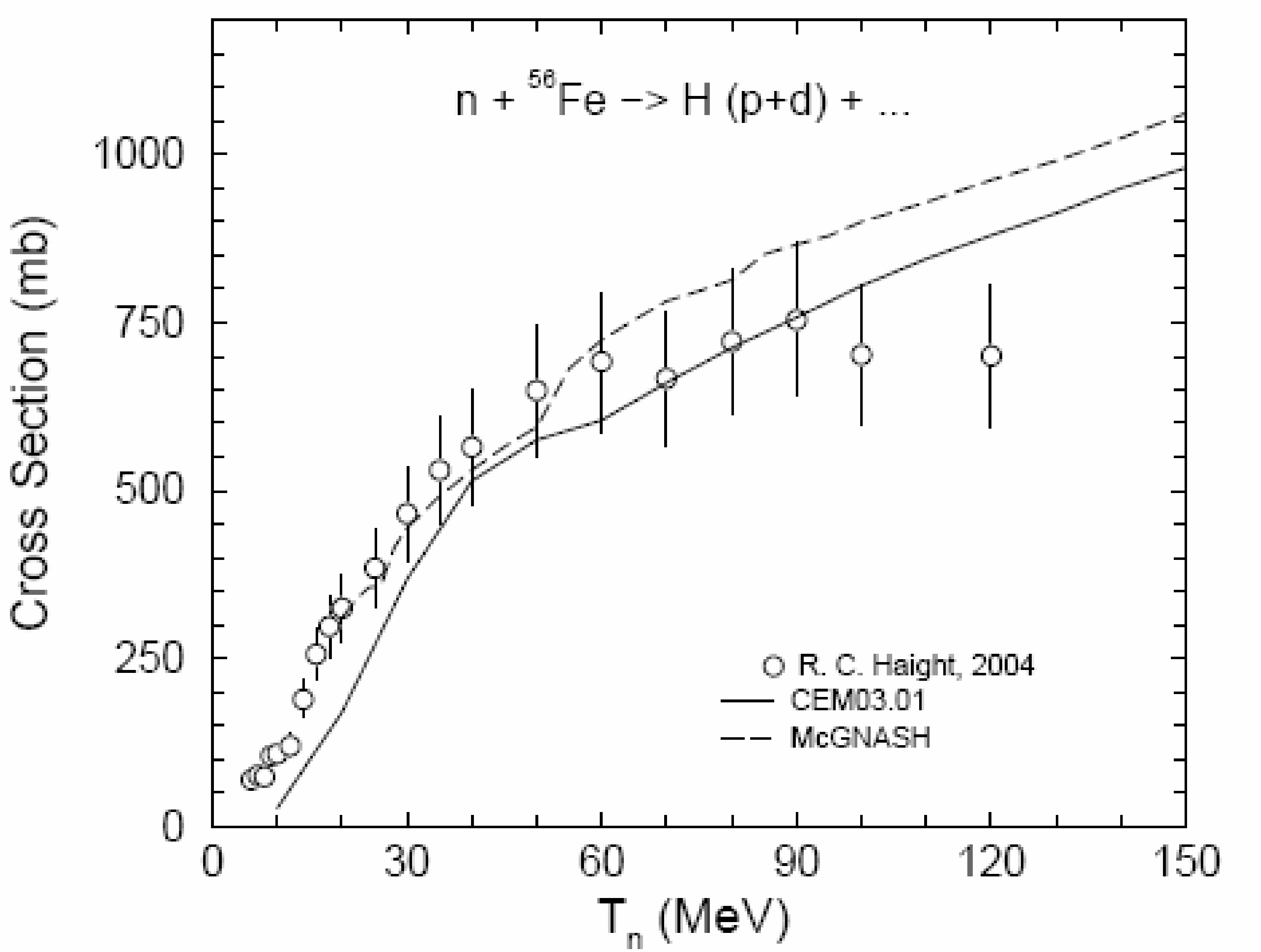

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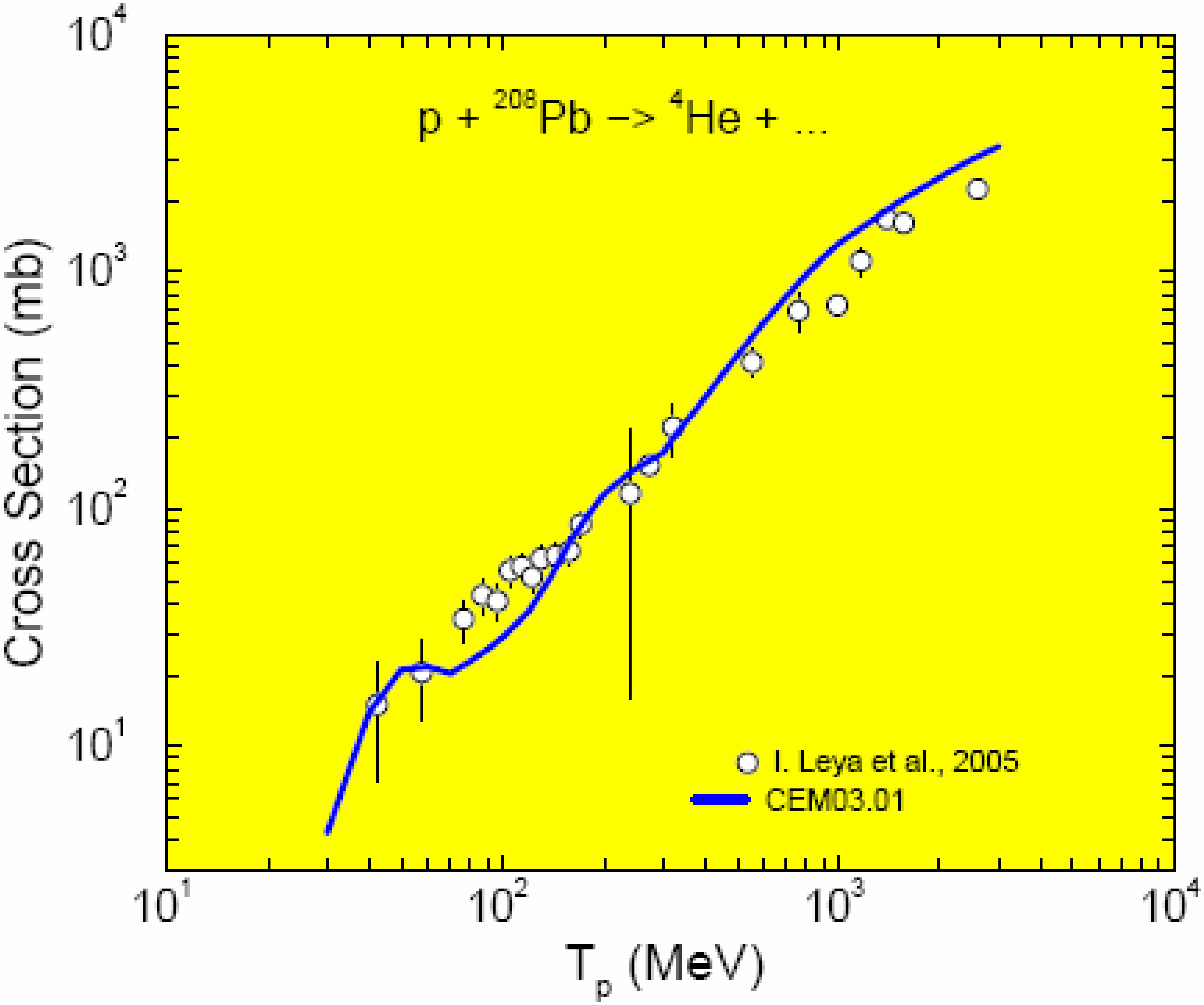
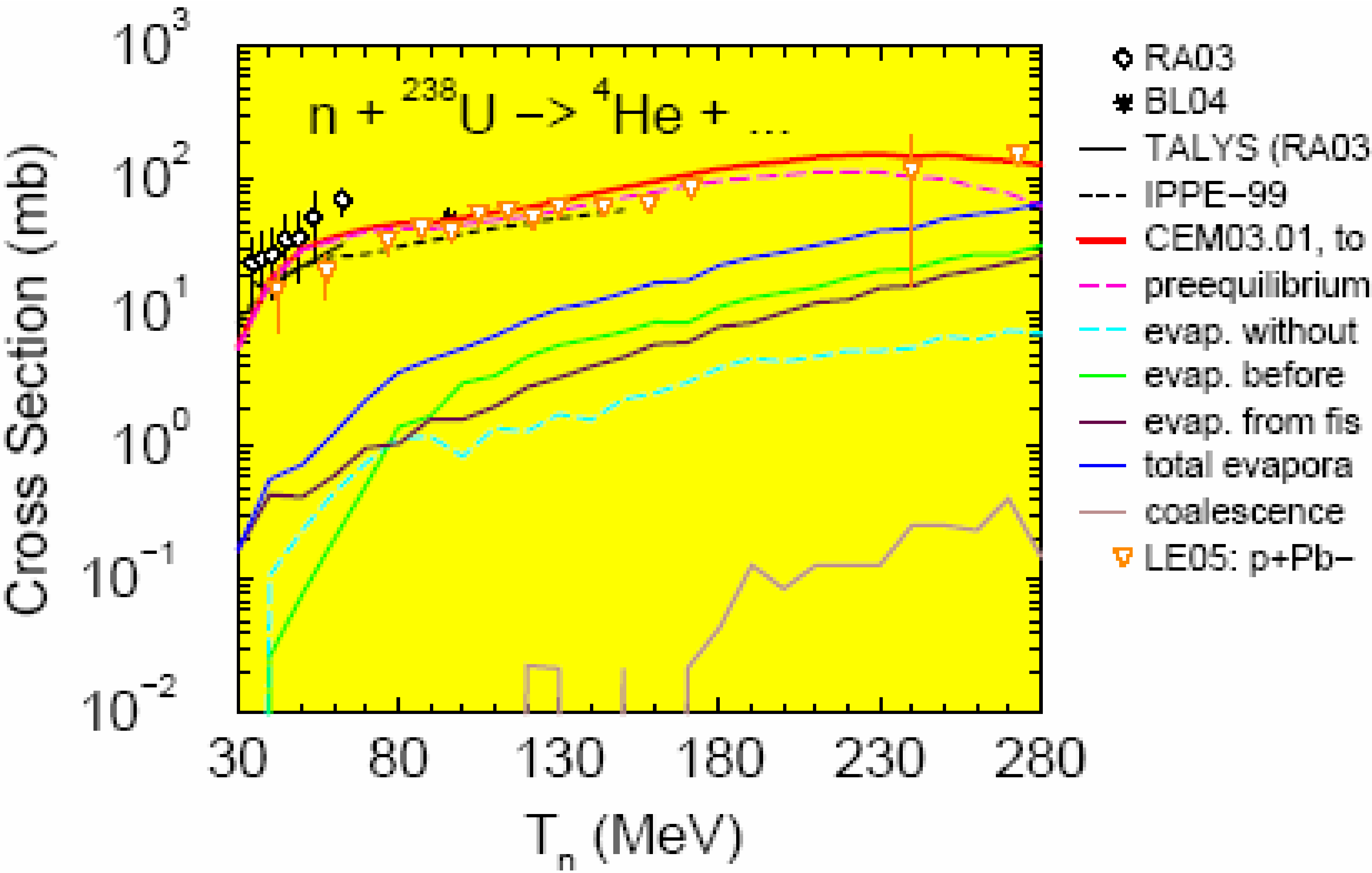
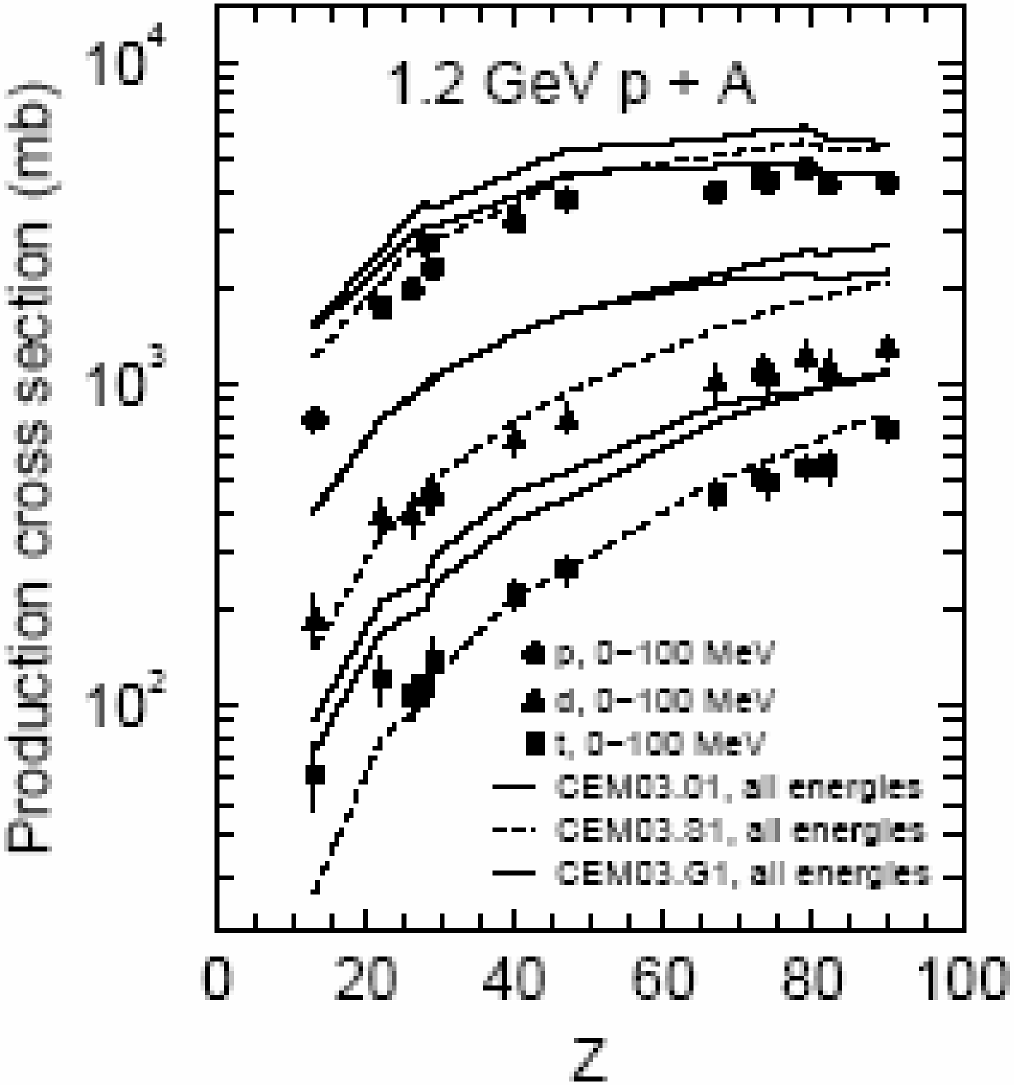
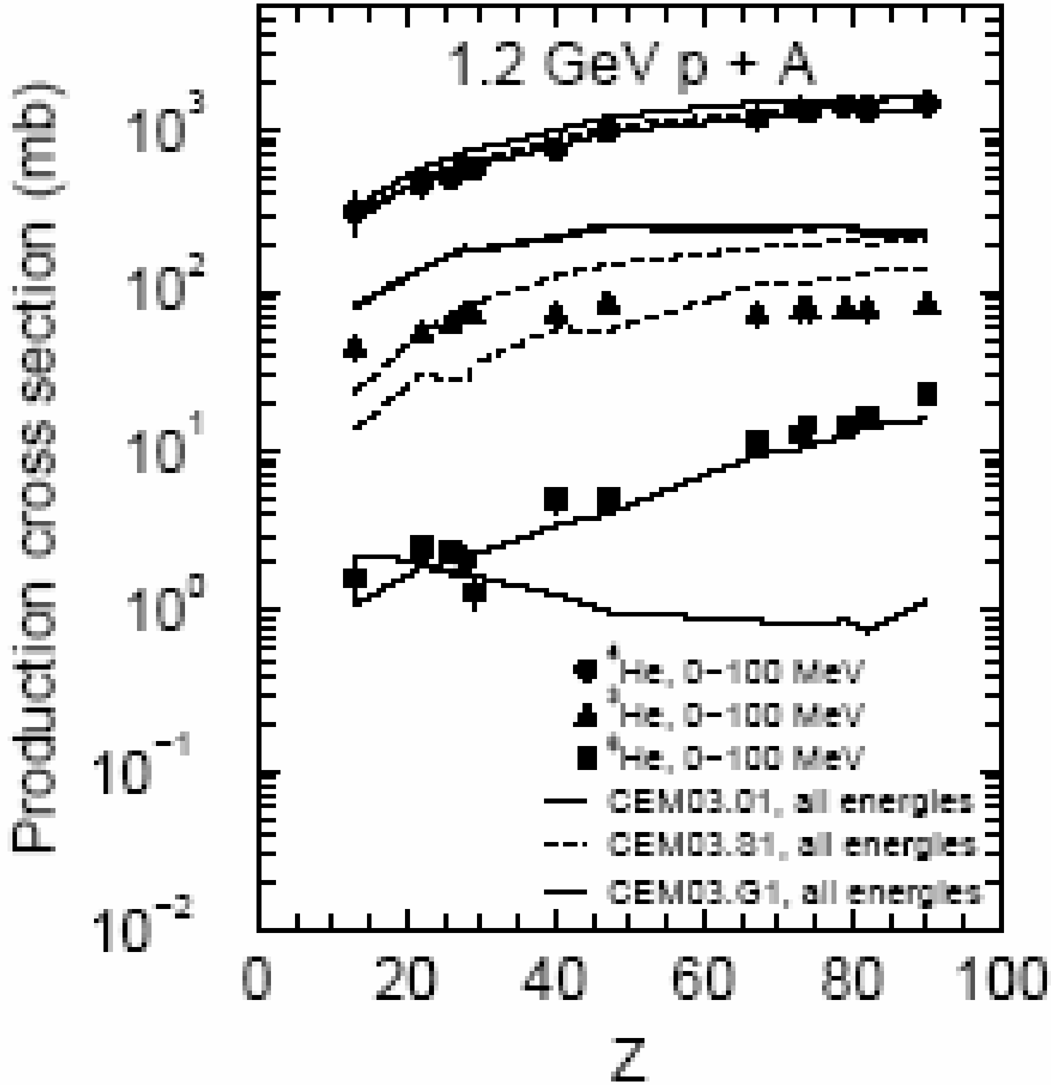


Data: I. Leya *et al.*, NIM **B229** (2005) 1

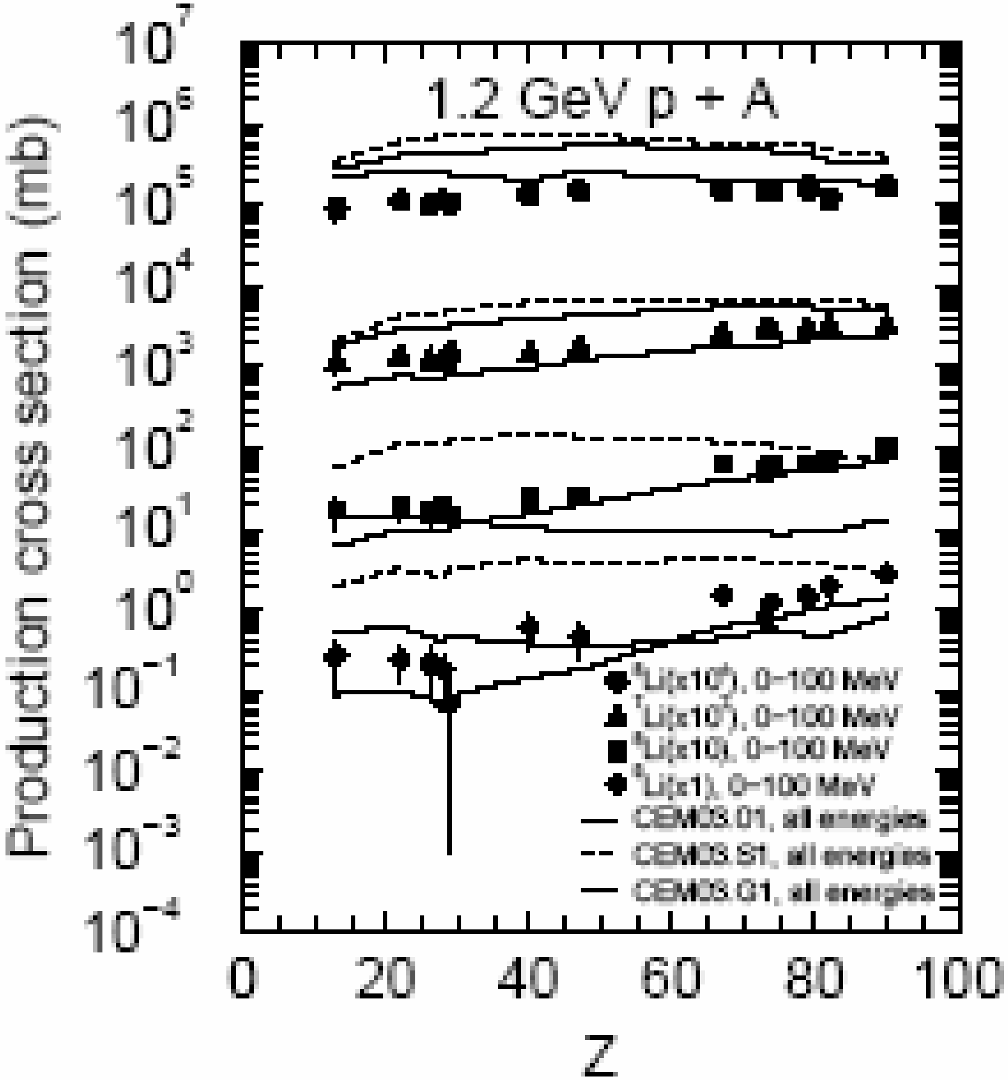


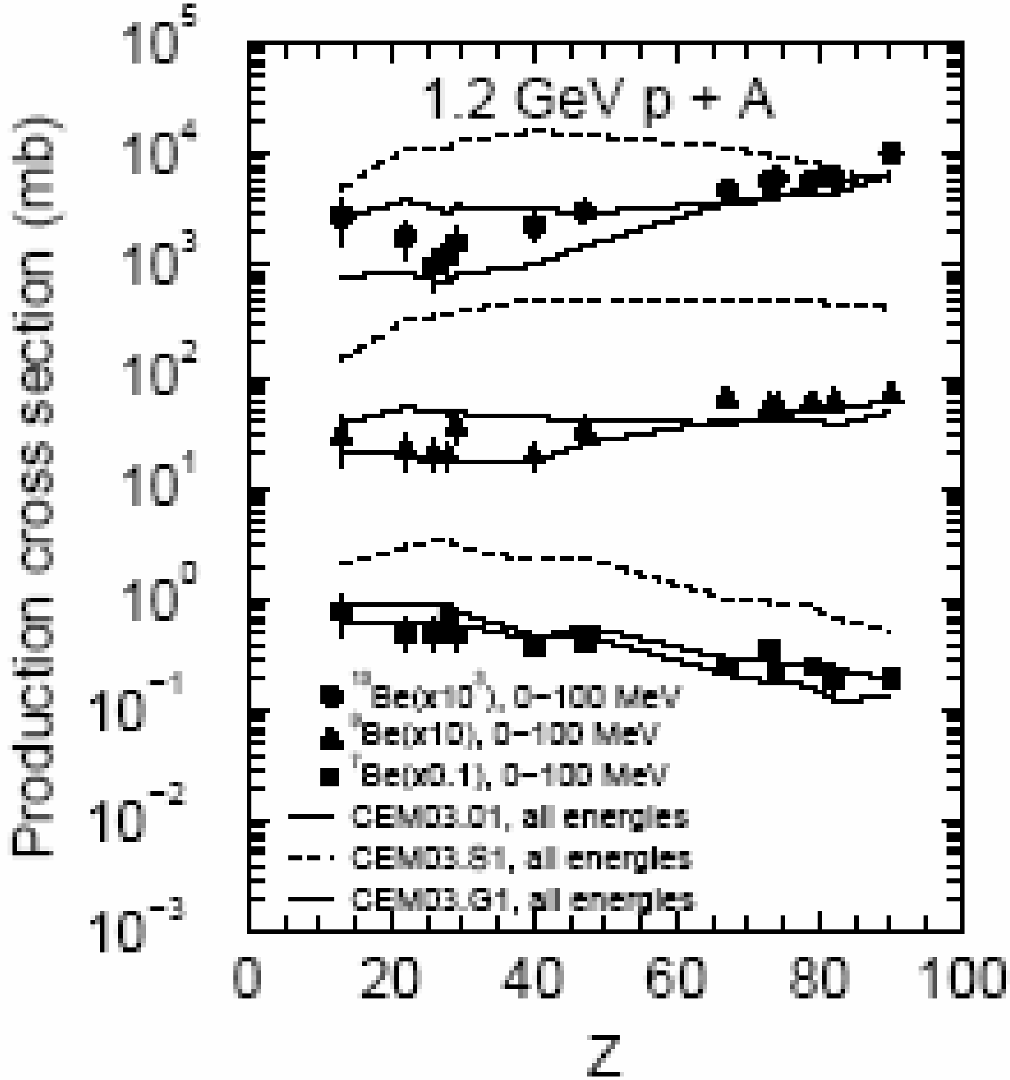
Data: **RA03**: E. Raeymackers *et al.,* Phys. Rev. **C68** (2003) 024604; **BL04**: V. Blideanu *et al.,* Phys. Rev. C70 (2004) 014607; **LE05**: I. Leya *et al.,* NIM **B229** (2005) 1 **(p+^{208}Pb)**





Data: L. Audouin *et al.*, Nucl. Phys. A768 (2006) 1





Data: L. Audouin *et al.*, Nucl. Phys. A768 (2006) 1

Summary

- CEM03.01 and LAQGSM03.01 and their “S” and “G” versions describe complex particles spectra and gas-production xsec much better than their precursors

- CEM03.01 is available now to users from RSICC

- CEM03.01 and LAQGSM03.01 are being (were) incorporated into MCNP6, MARS, and MCNPX, to be available to users from RSICC