CHIPS-specific verification.

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1. Basic ideas of CHIPS nuclear fragmentation.
2. Verification of spectra of nuclear fragments.
3. Verification of hadronic spectra near kinematic limits.
4. Verification of kinematic correlations of hadronic yield.

Basic ideas of CHIPS nuclear fragmentation.

- The projectile creates high energy nuclear excitations (SU(3) symmetric quasmons) in nuclear matter adopting not more than $A^{\frac{1}{3}}\ GeV$ (depends on impact parameter b) of the projectile energy.
- The quark exchange short range interaction mechanism creates multi-nucleon clusters in the dense part of the nucleons.
- Quark exchange between the quasmons and the surrounding clusters dissipates energy of quasmons and yields nuclear fragments.
- Mesons can be produced by the quark fusion mechanism.
- The CHIPS algorithm is a decay in nuclear matter and not a cascade.
- CHIPS has internal non-relativistic phase space evaporation.
- The generated secondaries can take part in final state interaction.

Relativistic and non-relativistic packages in CHIPS

Ultra-relativistic phase space of 3D partons:

$$\Phi_n(E) = \int \delta(\sum_{i=1}^{n} E_i - E)\, \delta^3(\sum_{i=1}^{n} \vec{p}_i) \prod_{i=1}^{n} \frac{d^3\vec{p}_i}{2E_i} \propto s^{n-2},$$

$$\frac{dN}{pdE} \propto \left(1 - \frac{2k}{\sqrt{s}}\right)^{n-2}.$$

Non-relativistic phase space of protons and neutrons (no fragments):

$$\tilde{\Phi}_n(W_n) = \int \tilde{\Phi}_{n-1}(W_{n-1}) \cdot \delta(W_n - W_{n-1} - T)\sqrt{T} dT\, dW_{n-1} \propto W_n^{\frac{3}{2}n - \frac{5}{2}}$$

$$\frac{dN}{\sqrt{T}dE} \propto \left(1 - \frac{T}{W_n}\right)^{\frac{3}{2}n-4},\ \ W_n\ is\ total\ energy\ of\ n\ nucleons.$$

$$W_A = U \cdot A + E_{\mathrm{excitation}},\ \ U = 1.7\ MeV\ (a\ parameter).$$

Verification of spectra of nuclear fragments: Spectra.

Baryons (one dimensional consideration of quark exchange):

$$k + M = E + q, \quad k = p - q \quad \rightarrow \quad k = \frac{E - M + p}{2}$$

Mesons (one dimensional consideration of quark fusion):

$$k + q = E, \quad k - q = p \quad \rightarrow \quad k = \frac{E + p}{2}$$

Anti-baryons (antiquark-antidiquark fusion):

$$k + q = M + E, \quad k - q = p \quad \rightarrow \quad k = \frac{E + M + p}{2}$$

$$\frac{Ed\sigma}{d^3p} \propto \frac{d\sigma}{pdE} \propto EXP\left\{-\frac{(k - \Delta)[1 - v \cdot cos(\theta)]}{T\sqrt{1 - v^2}}\right\}$$

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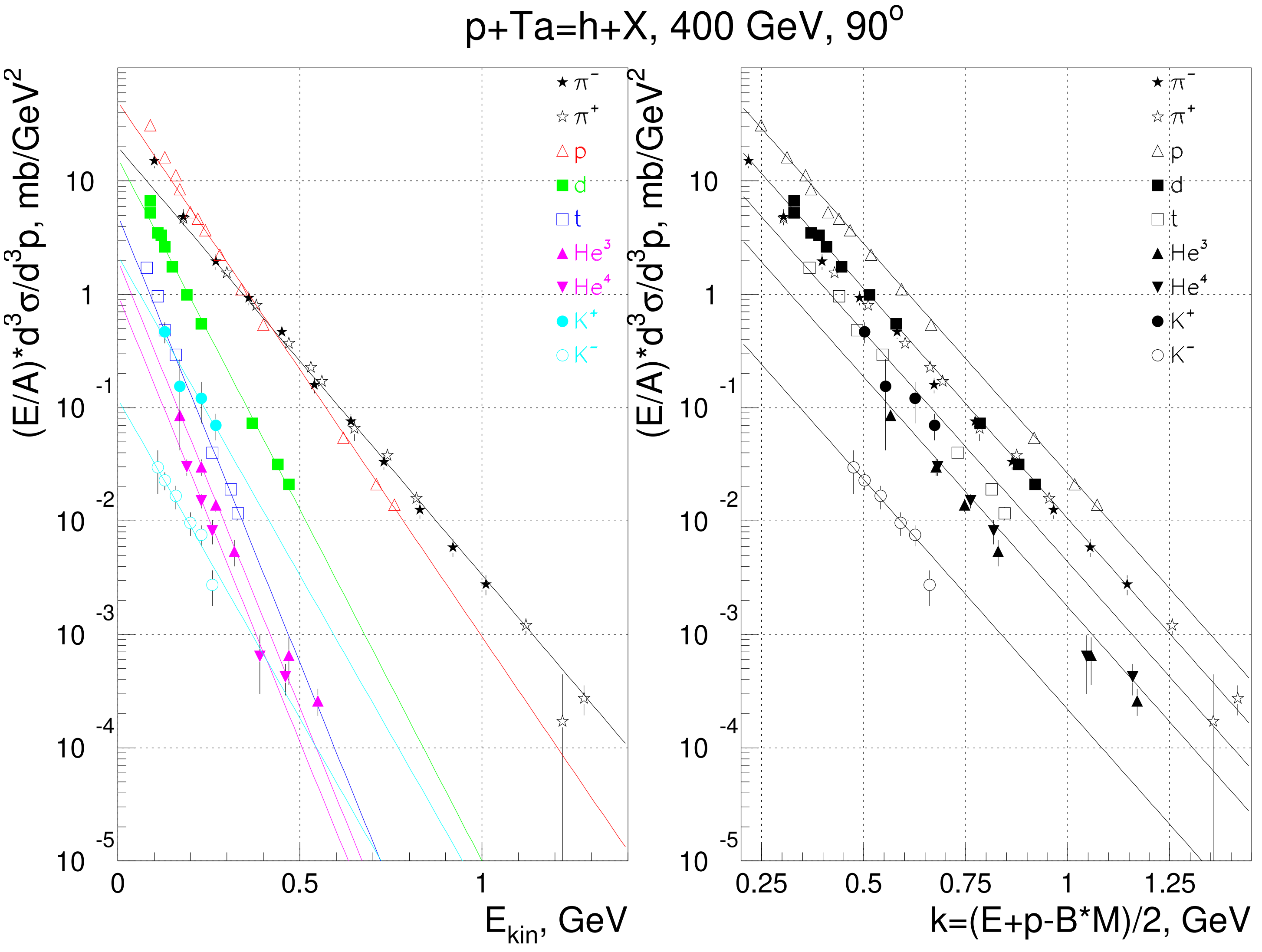


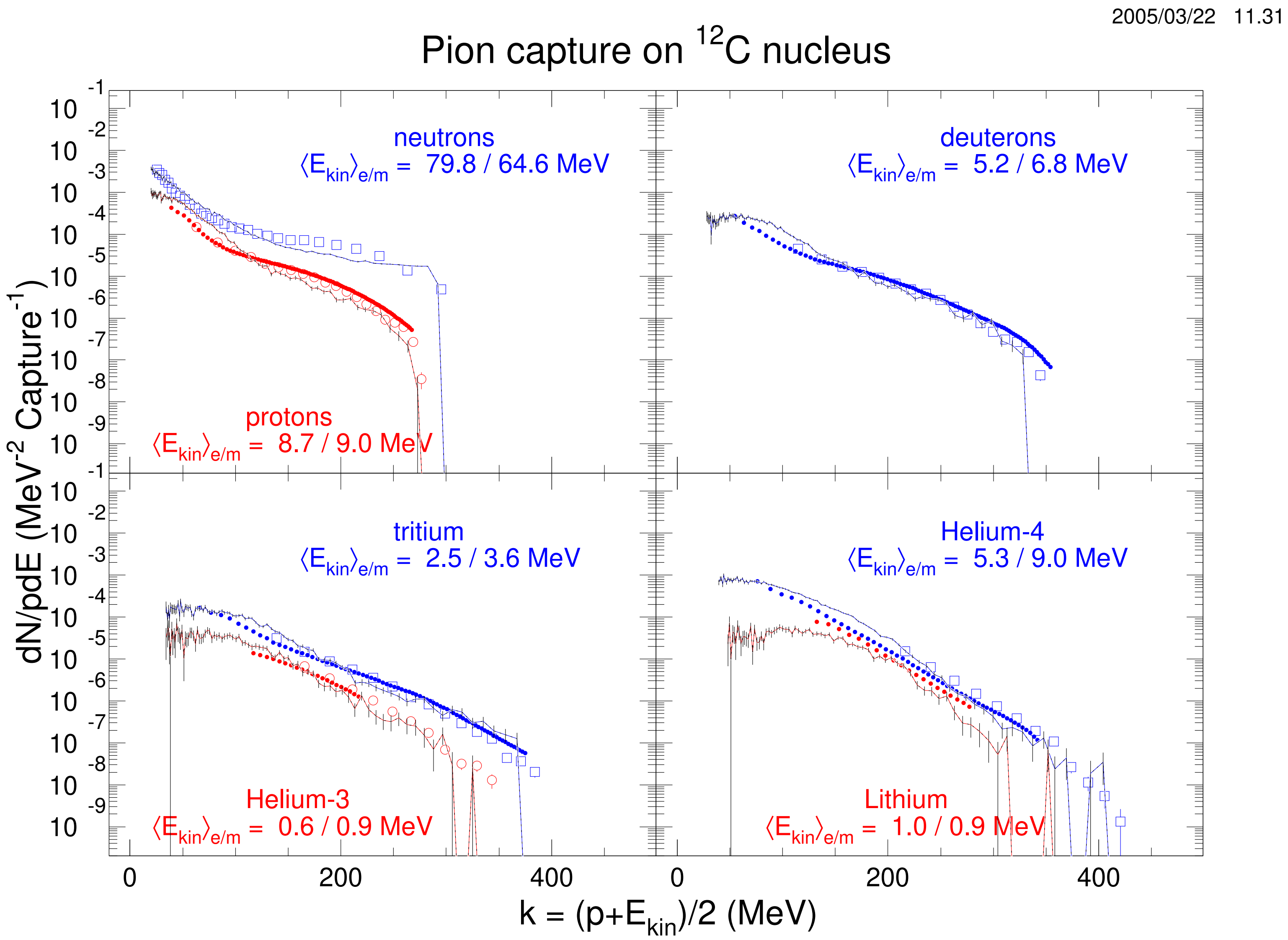
Verification of spectra of nuclear fragments: Clusters.

$$P_\nu = \frac{C_\nu^a \cdot \omega^{\nu-1}}{(1+\omega)^{a-1}} + \varepsilon_\nu, \quad \omega \; is \; a \; clusterization \; parameter,$$

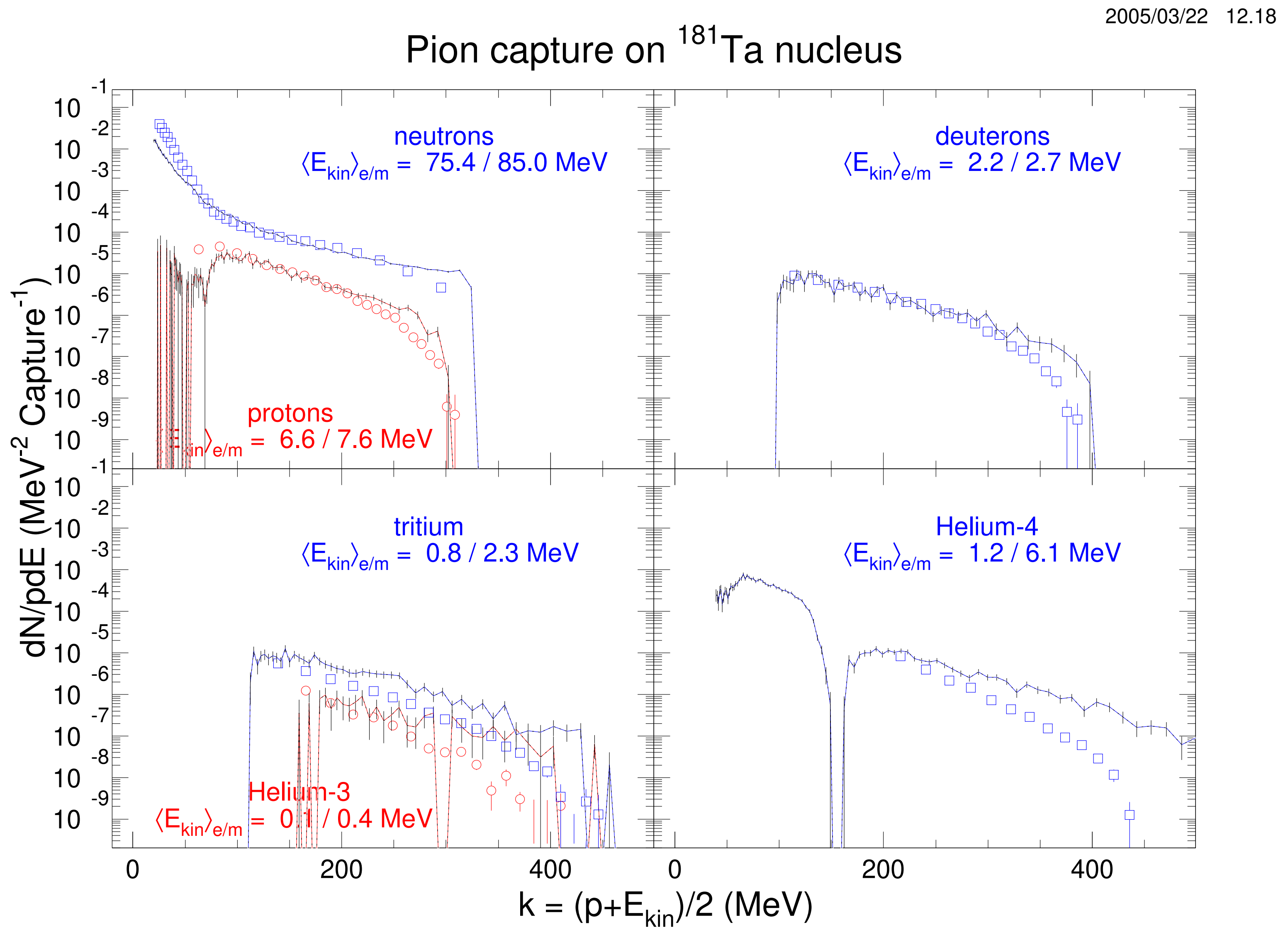
ε_ν - clusterization on nuclear surface, $\varepsilon_{\nu>2} = 0.$ $a = 1 - \sum_{i=1}^{n} \varepsilon_i$

Parameters found for pion capture in Eur. Phys. J. A9 (2000) 411:

	^{9}Be	^{12}C	^{28}Si	^{59}Co	^{181}Ta
ε_1	0.45	0.40	0.35	0.33	0.33
ε_2	0.15	0.15	0.05	0.03	0.02
ω	5.00	5.00	5.00	5.00	5.00



2005/03/22 11.31
Pion capture on 12C nucleus
neutrons
⟨Ekin⟩e/m = 79.8 / 64.6 MeV
protons
⟨Ekin⟩e/m = 8.7 / 9.0 MeV
deuterons
⟨Ekin⟩e/m = 5.2 / 6.8 MeV
tritium
⟨Ekin⟩e/m = 2.5 / 3.6 MeV
Helium-3
⟨Ekin⟩e/m = 0.6 / 0.9 MeV
Helium-4
⟨Ekin⟩e/m = 5.3 / 9.0 MeV
Lithium
⟨Ekin⟩e/m = 1.0 / 0.9 MeV
dN/pdE (MeV-2 Capture-1)
k = (p+Ekin)/2 (MeV)
0
200
400



2005/03/22 12.18
Pion capture on ^{181}Ta nucleus
neutrons
$\langle E_{kin}\rangle_{e/m}$ = 75.4 / 85.0 MeV
protons
$\langle E_{kin}\rangle_{e/m}$ = 6.6 / 7.6 MeV
deuterons
$\langle E_{kin}\rangle_{e/m}$ = 2.2 / 2.7 MeV
tritium
$\langle E_{kin}\rangle_{e/m}$ = 0.8 / 2.3 MeV
Helium-3
$\langle E_{kin}\rangle_{e/m}$ = 0.1 / 0.4 MeV
Helium-4
$\langle E_{kin}\rangle_{e/m}$ = 1.2 / 6.1 MeV
dN/pdE (MeV^{-2} Capture^{-1})
k = (p+E$_{kin}$)/2 (MeV)

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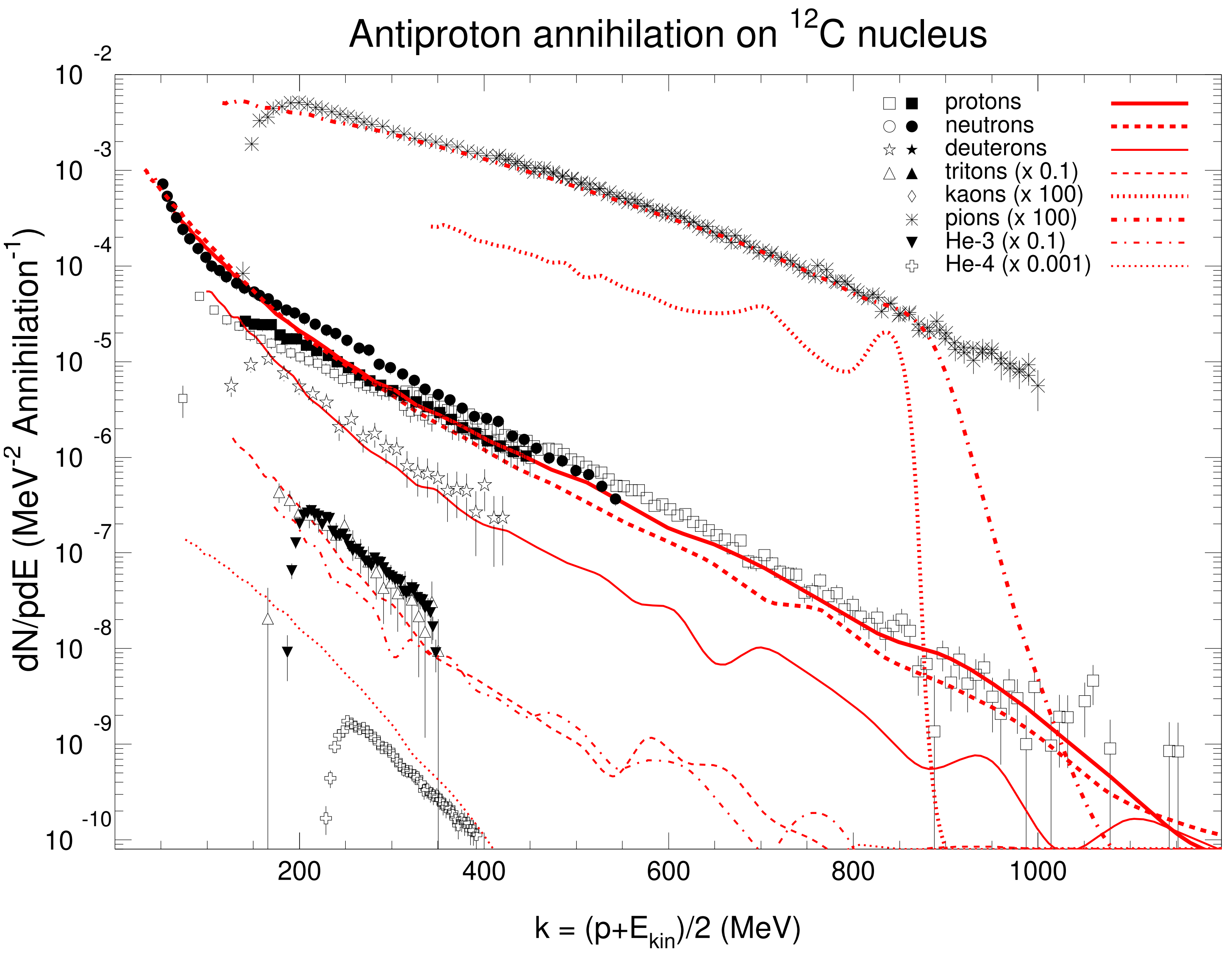
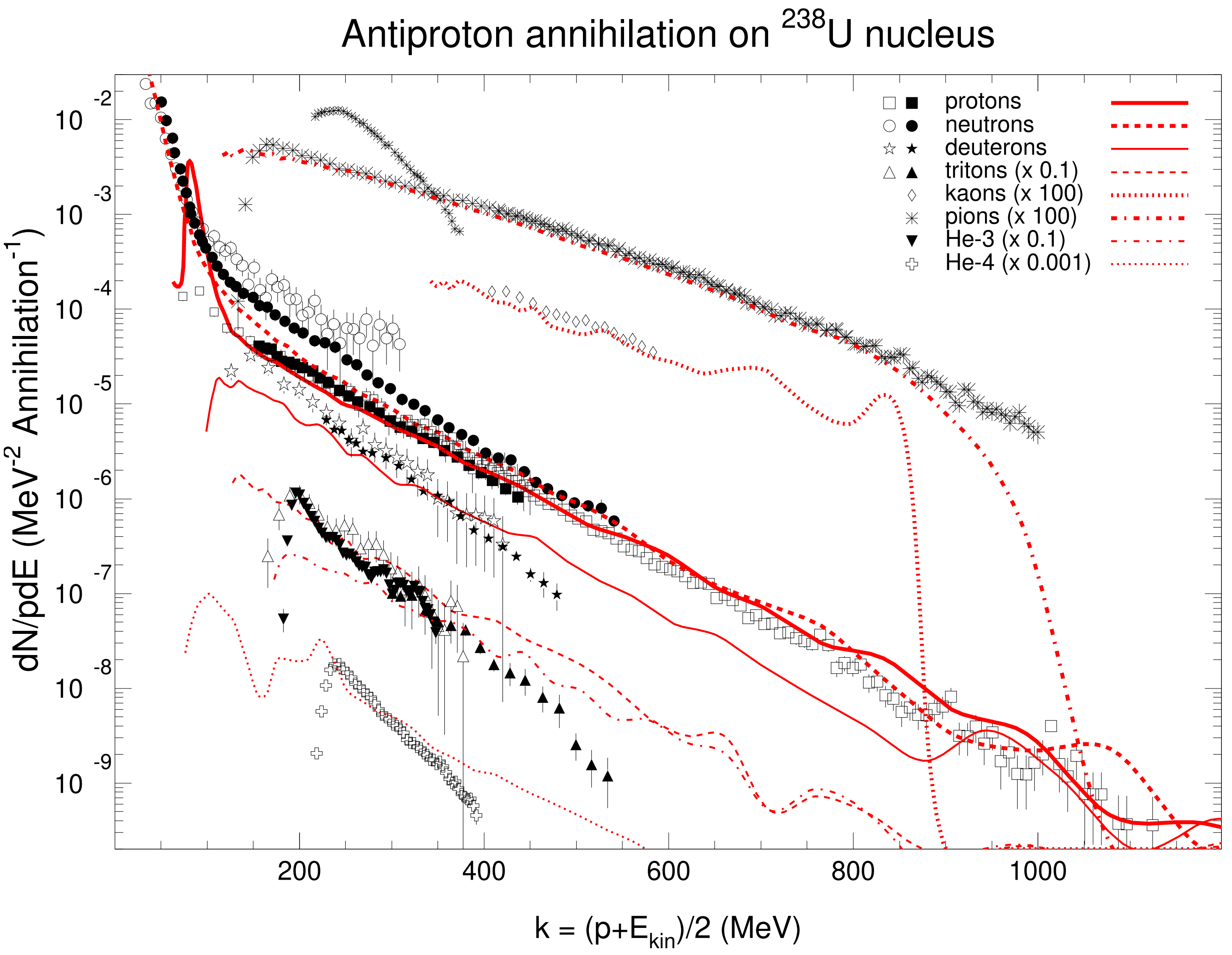

Antiproton annihilation on ^{12}C nucleus
dN/pdE (MeV^{-2} Annihilation^{-1})
k = (p+E$_{kin}$)/2 (MeV)
protons
neutrons
deuterons
tritons (x 0.1)
kaons (x 100)
pions (x 100)
He-3 (x 0.1)
He-4 (x 0.001)
200
400
600
800
1000


Antiproton annihilation on ^{238}U nucleus
dN/pdE (MeV^{-2} Annihilation^{-1})
k = (p+E$_{kin}$)/2 (MeV)
protons
neutrons
deuterons
tritons (x 0.1)
kaons (x 100)
pions (x 100)
He-3 (x 0.1)
He-4 (x 0.001)
200
400
600
800
1000
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}

Verification of hadronic spectra near kinematic limits.

- The projectile energy can be absorbed by a cluster, so the mass of the quasmon is big and the fragmentation can reach kinematic limits.
- The degrees of freedom of the model is "How many surrounding nucleons can compensate virtuality of the recoil quasmon?".
- Before the hadronic tuning it was decided to let all nucleons of the nucleus to compensate the virtuality of the recoil quasmon.
- The energetic fragmentation is faster but it must be tuned to describe real multiplicities of the secondary hadrons.
- Near kinematic limits the excited states of the residual nuclei can be important (e.g. GDR residual excitation).
- The spectra near kinematic limits can be sensitive to initial interaction of the projectile (multiplicity of quasmons created by a projectile).

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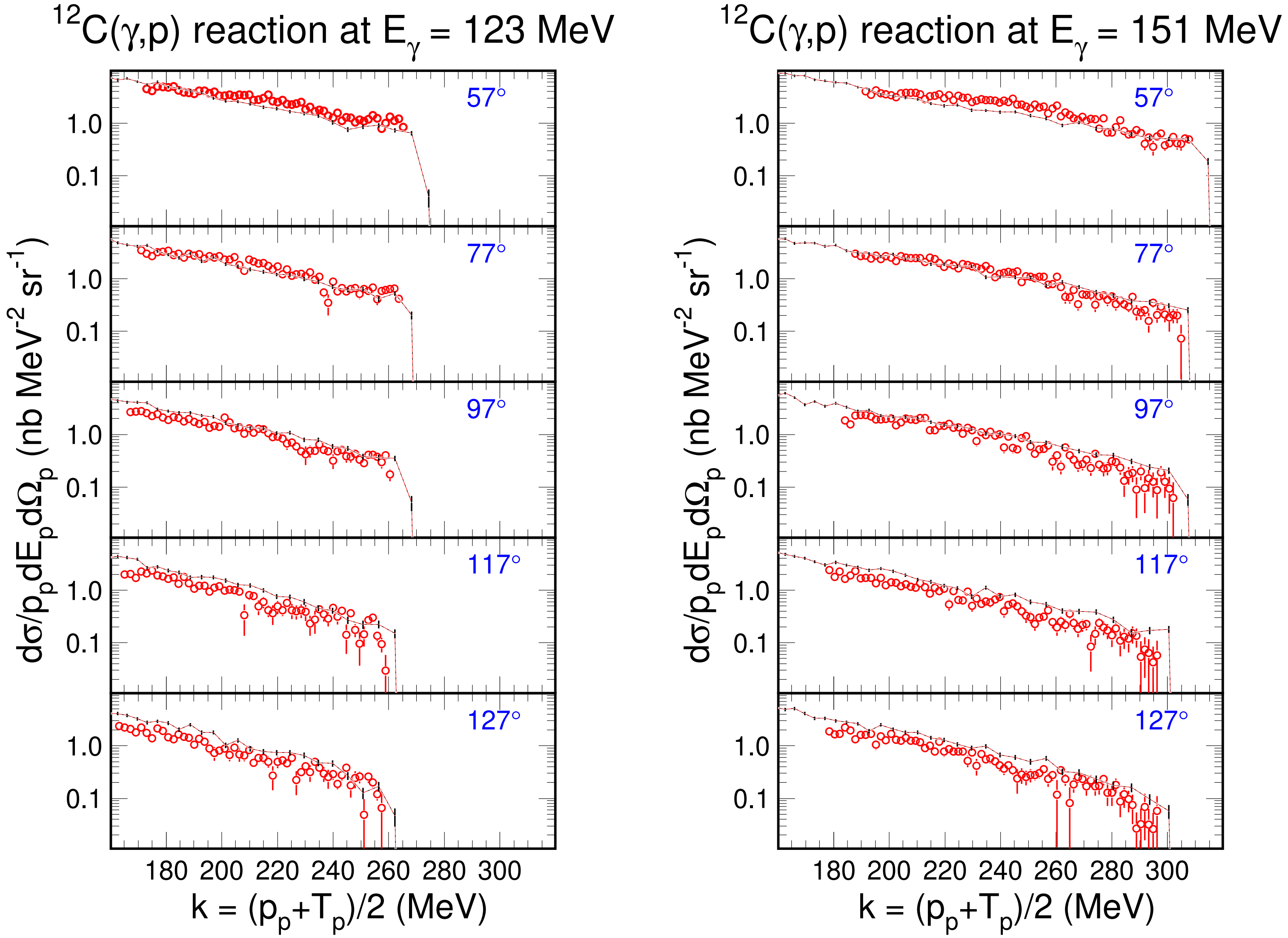
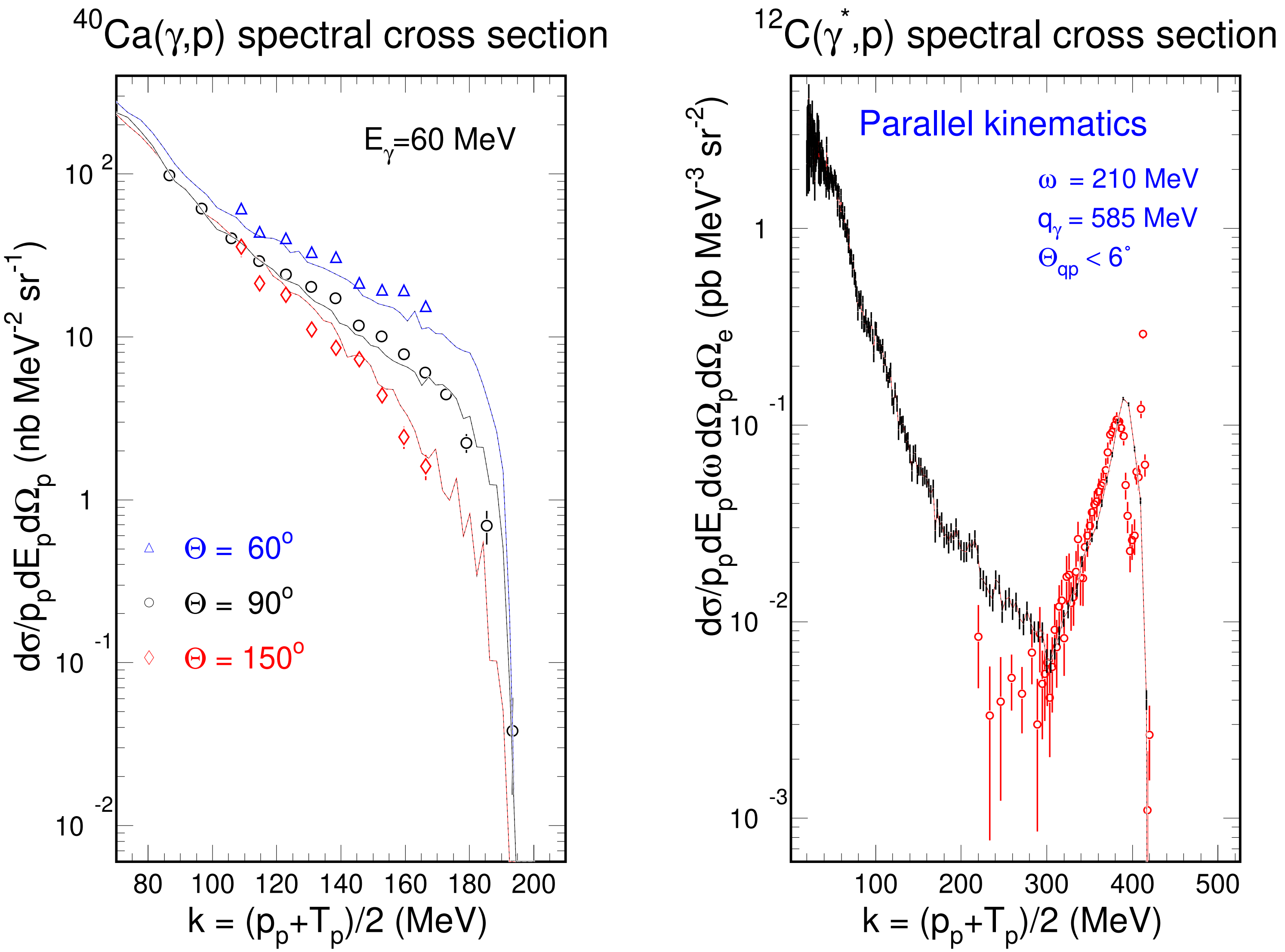


CHIPS-specific verification.



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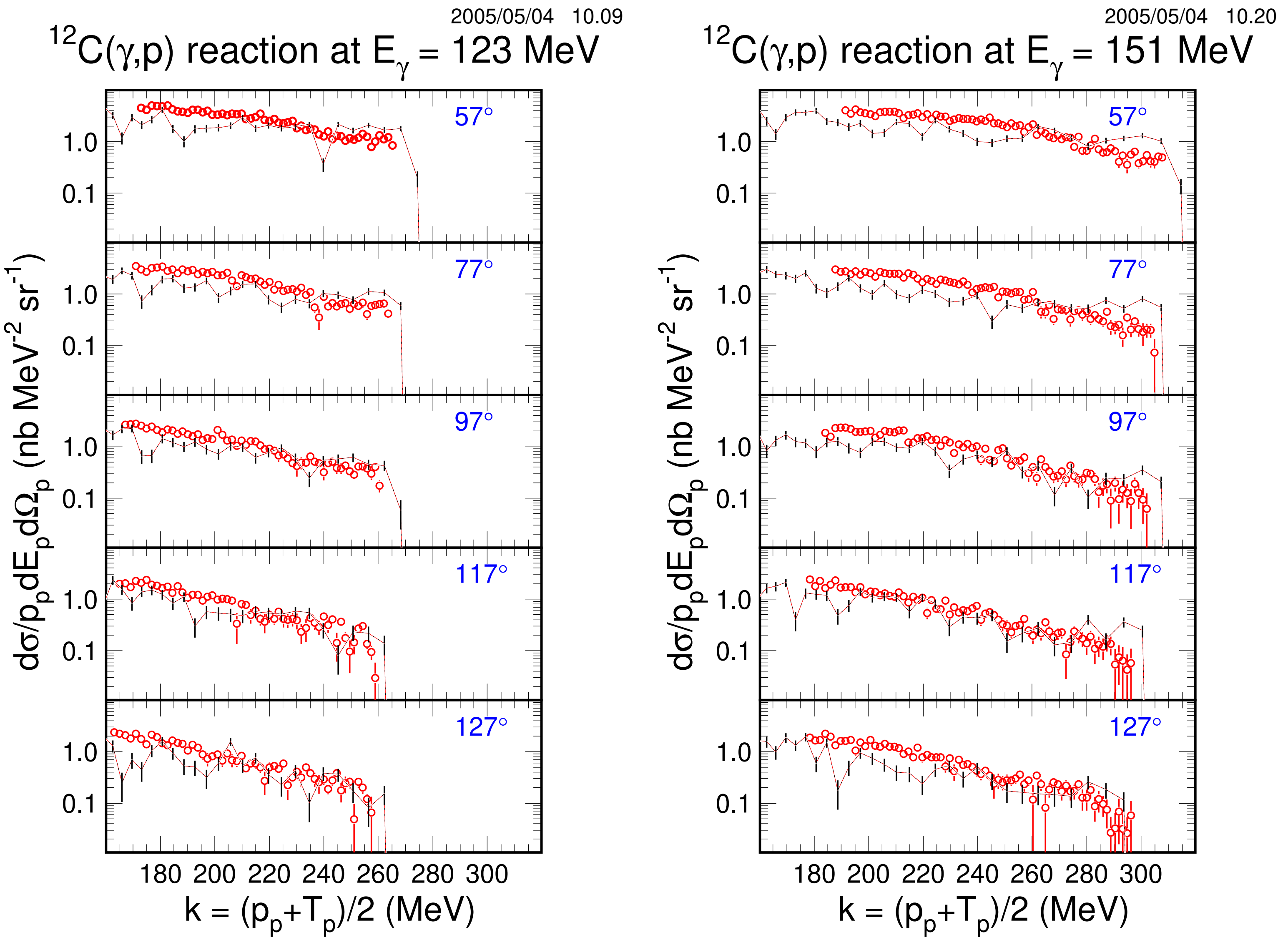
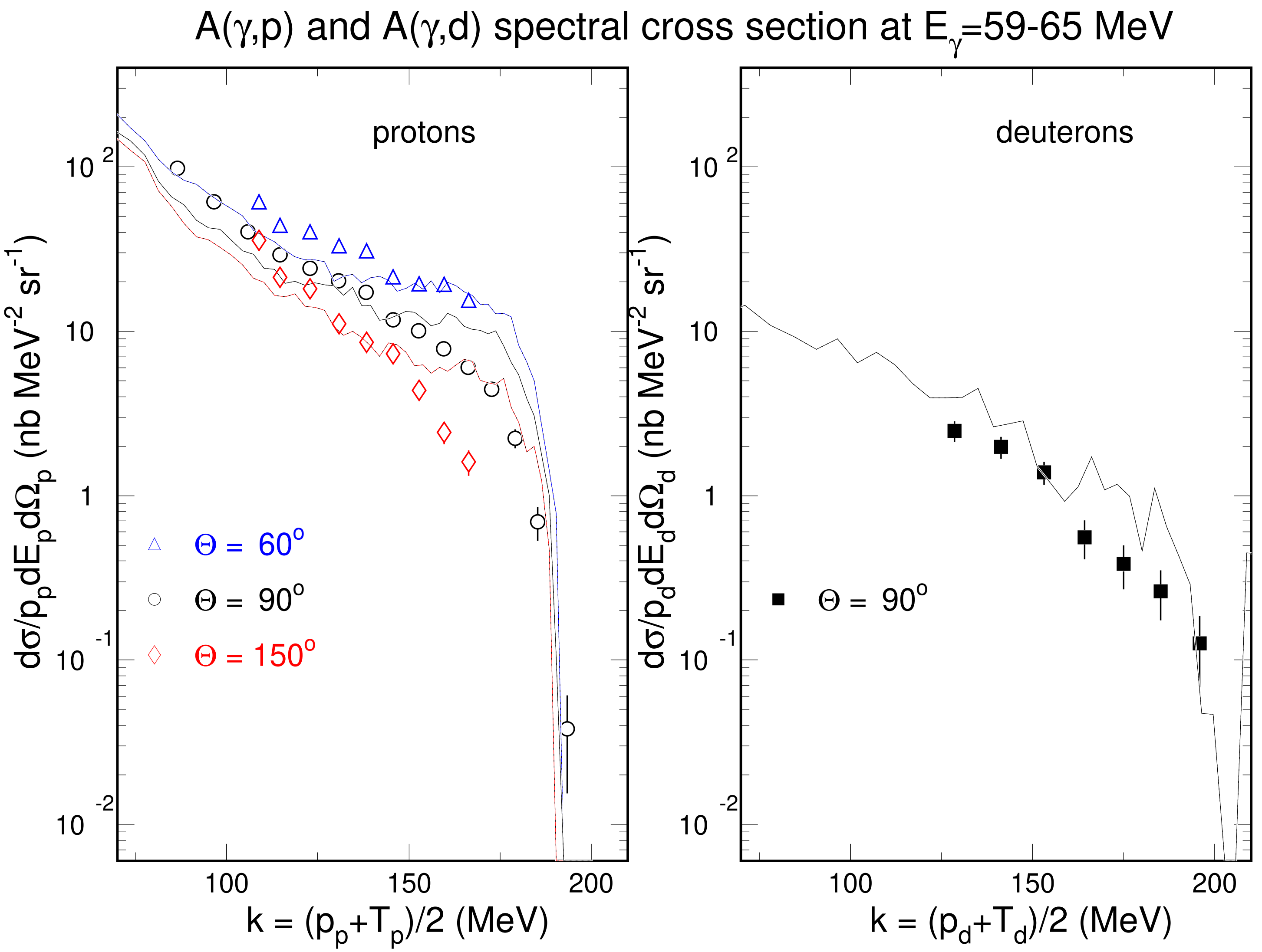
CHIPS-specific verification.



CHIPS-specific verification.



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Verification of kinematic correlations of hadronic yield.

- CHIPS conserves energy, momentum, and quantum numbers (charge, baryon number, strangeness) and describes kinematic correlations.
- The qualitative effect of the kinematic correlations is higher yield of hadrons in the opposite direction to the detected secondary hadron.
- The azimuthal correlations $R(\Delta\phi)$ are studied at fixed θ.
- The polar correlations $R(\Delta\theta)$ are studied at fixed ϕ.

$$R(\bar{p}_1, \bar{p}_2) = \frac{\sigma_{in} \cdot \frac{d\sigma}{d\bar{p}_1 d\bar{p}_2}}{\frac{d\sigma}{d\bar{p}_1} \cdot \frac{d\sigma}{d\bar{p}_2}}$$

Conclusion

- CHIPS is a new generation of the SU(3) symmetric quark level simulation codes for hadron-nuclear interactions at high energies.
- Application of CHIPS to the capture at rest reactions and to low energy photo-nuclear reactions shows that CHIPS works starting E=0.
- CHIPS approach can help to understand even masses of hadrons (EPJ A14(2002)265) considering massless u and d quarks.
- CHIPS naturally produces nuclear fragments avoiding final state fusion of nucleons which is usually used in the cascade codes.
- CHIPS has a tunable (virtual recoil quasmon) mechanism for fitting of nuclear spectra near kinematic limits of the reaction.
- CHIPS can be used for simulation of kinematic correlations, which are not described in the parameterized models like LHEP of Geant4.