Test frame for reactions on flight in Geant4: photons.

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1. Creation of tests/test19 directory for reactions on flight in Geant4.
2. CHIPS universal process G4QCollision for nuclear interactions.
3. The “photon” (GDR region), “gamma” (60-150 MeV) subdirectories.

Test19 is the second tool of “19/29” club in Geant4.

- geant4/tests/test29 & geant4/test/test19 contain CHIPStest executable;
- separate files: test19_c.cc for CHIPS processes and test19_g.cc for GHAD processes (test19_f.cc for FLUKA C++ wrappers?);
- the first tests are the existing tests of photo-nuclear reactions;
- projectile PDG Code = 0 in chipstest.in means “all projectiles”;
- target PDG Code = 0 in chipstest.in means “all targets”;
- PAW kumac files start CHIPStest=test19 with a chipstest.in input file and convert the output ASCII files to ntuples for plotting;
- if GHAD has two or more processes for the same projectile, one can edit the test19_g.cc file and select the necessary process;
- one can collect new data and create a new test19 subdirectory.

Universal G4QCollision CHIPS process for all hadrons.

- CHIPS has one G4QCollision process for all hadrons;
- CHIPS conserves energy, momentum, charge, and baryon number;
- test19 checks conservation of E, p, Q, and B for each event;
- test19 defines a special (Z, N) monoisotopical G4Element;
- target nuclei are defined by the 9SPPPNNN code (C12=90006006);
- projectiles are defined by PDG codes, energy/momentum are in MeV;
- virtual projectiles (e.g. γ^*, π^*, or K^*) can have nonzero kinetic energy (if the kinetic energy is 0, it is calculated from the momentum);
- nuclear clusterization and s-suppression regulate multiplicities.

Sequence of the input data in the chipstest.in file.

Tcritic s2ud etaS nop mom en pPDG targPDG nEv frN frDb clPr VaM solA

180.00 0.30 0.30 152 1000. 0. -211 90006006 100 0.75 0.05 5.00 9.00 0.70

- Tcritic - CHIPS critical temperature, important only for high energies;
- s2ud - s-quark suppression, important for strange particles production;
- etaS - suppression of η mesons, important for secondary photons;
- nop - secondary clusters 122:A<5(minimum), 152:A<9, 182:A<13...;
- mom - momentum in MeV/c, it can be zero for the Capture At Rest;
- en - total energy (MeV), if en=0, it is calculated from m and mom;
- pPDG - particle code of the projectile (e.g. γ=22, π^-=-211, p=2212);
- targPDG - nuclear code for the target isotope (can be 10SZZZAAAI);

Sequence of the input data in the chipstest.in file (continue).

Tcritic s2ud etaS nop mom en pPDG targPDG nEv frN frDb clPr VaM solA

180.00 0.30 0.30 152 1000. 0. -211 90006006 100 0.75 0.05 5.00 9.00 0.70

- nEv - the number of events to be simulated (it can be changed by kumac's according to the input parameter regulating statistics);
- frN - a percentage of quasi-free nucleons on the nuclear surface;
- frDb - a percentage of quasi-dinucleons on the nuclear surface;
- clPr - clusterization parameter for the dense part (1-freN-freD);
- VaM - Vacuum/NuclearMatter ratio for the Quark Fusion (vacuum) and Quark Exchange (nuclear matter) hadronizations mechanisms;
- solA - the $cos(\theta)$ definition of the absorption solid angle for secondary mesons after antibaryon annihilation at rest on nuclear surface;

Non-relativistic evaporation package 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):

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

$$\frac{dN}{\sqrt{T}dE} \propto \left(1 - \frac{T}{W_n}\right)^{\frac{3}{2}n-4}.$$

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

Nuclear clusterization parameters

Quark exchange forces clustering nuclei.

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

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

Parameters found for pion capture in Eur. Phys. J. 9 (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

Inclusive CHIPS, invariant phase space, K-variable.

Baryons (one dimensional consideration of quark exchange):

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

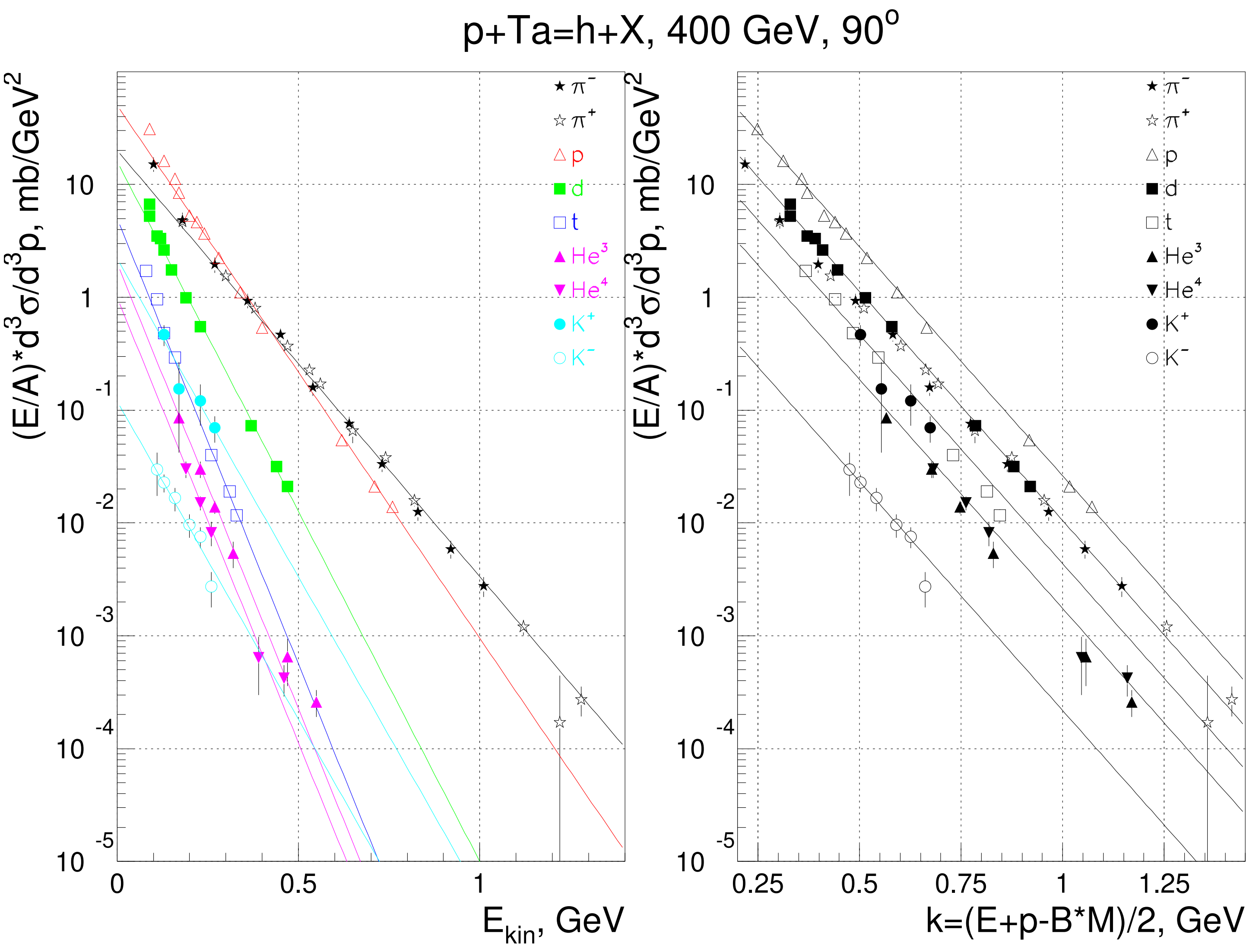
Mesons (one dimensional consideration of quark fusion):

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

Antibaryons (antiquark-antidiquark fusion):

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

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


p+Ta=h+X, 400 GeV, 90°
(E/A)*d³σ/d³p, mb/GeV²
E_kin, GeV
k=(E+p-B*M)/2, GeV
π⁻
π⁺
p
d
t
He³
He⁴
K⁺
K⁻

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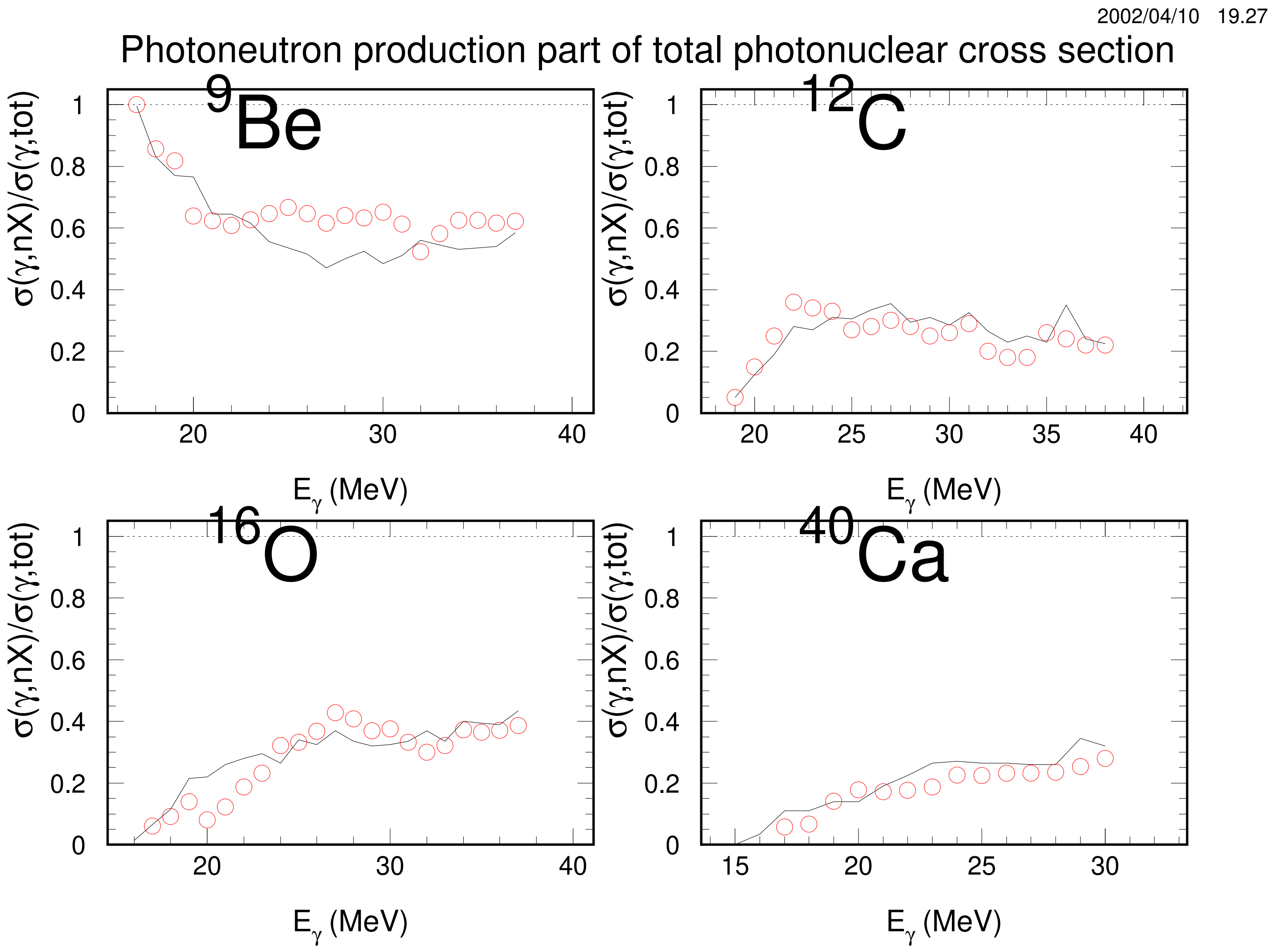
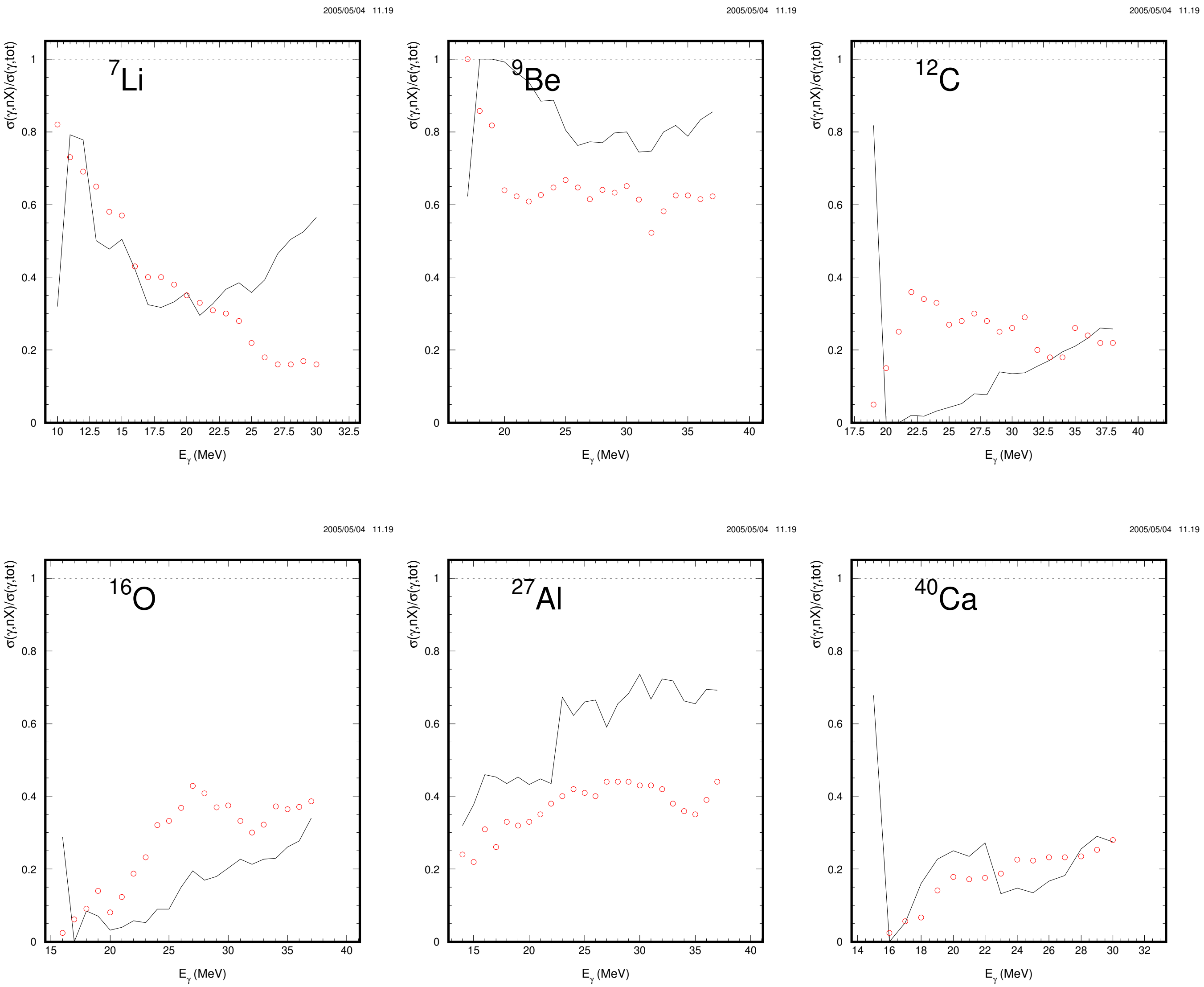
γA in the GDR region ("photon" subdirectory).

- this is a low energy reaction where mesons can not be produced;
- the low energy photon is absorbed by a quark, not by a nucleon;
- after the quark level hadronization (Quark Exchange) is exhausted, the nonrelativistic evaporation package of CHIPS starts;
- G4QCollision has a new interface to CHIPS for γA reactions;
- as GHAD photonuclear interfaces had problems, on the threshold just 50% protons and 50% neutrons are radiated (must be corrected);
- the results can be worse because the detailed nuclear masses data base of CHIPS was changed recently (for the energy/momentum conservation test) to the rough Geant4 data base;
- tests for contributions of other channels are necessary.


2002/04/10 19.27
Photoneutron production part of total photonuclear cross section
⁹Be
¹²C
¹⁶O
⁴⁰Ca
σ(γ,nX)/σ(γ,tot)
Eγ (MeV)
0
0.2
0.4
0.6
0.8
1
15
20
25
30
35
40

Test frame for reactions on flight in Geant4: photons.



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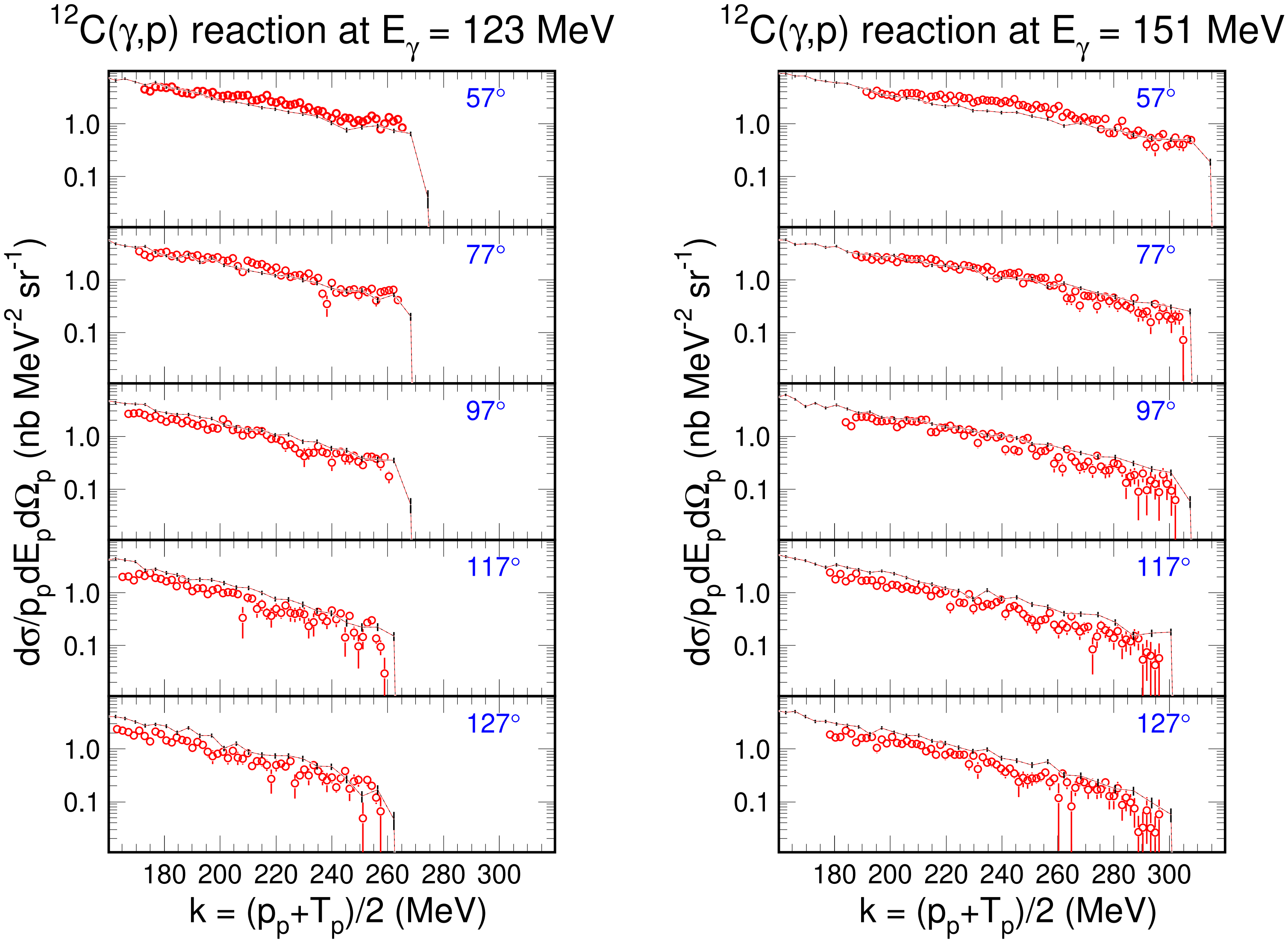
γA below π meson threshold ("gamma" subdirectory).

Published in Eur. Phys. J. A9 (2000) 411, and 421.

- the VaM parameter (vacuum/matter) isn't used as there is no mesons.
- the cross section values are not used yet (they are hardwired).
- an angular dependence is still there, but the hard part is overestimated;
- the low energy photonuclear reactions need additional tuning;
- no comparison with GHAD because it uses CHIPS for γA reactions, but some difference can be there because GHAD uses different parameters of CHIPS;
- more comparison with data are needed above the π meson threshold;
- one test is going to be prepared for a few hundred MeV.



$^{12}C(\gamma,p)$ reaction at E_γ = 123 MeV
$^{12}C(\gamma,p)$ reaction at E_γ = 151 MeV
$d\sigma/p_p dE_p d\Omega_p$ (nb MeV^{-2} sr^{-1})
57°
77°
97°
117°
127°
1.0
0.1
180 200 220 240 260 280 300
$k = (p_p+T_p)/2$ (MeV)

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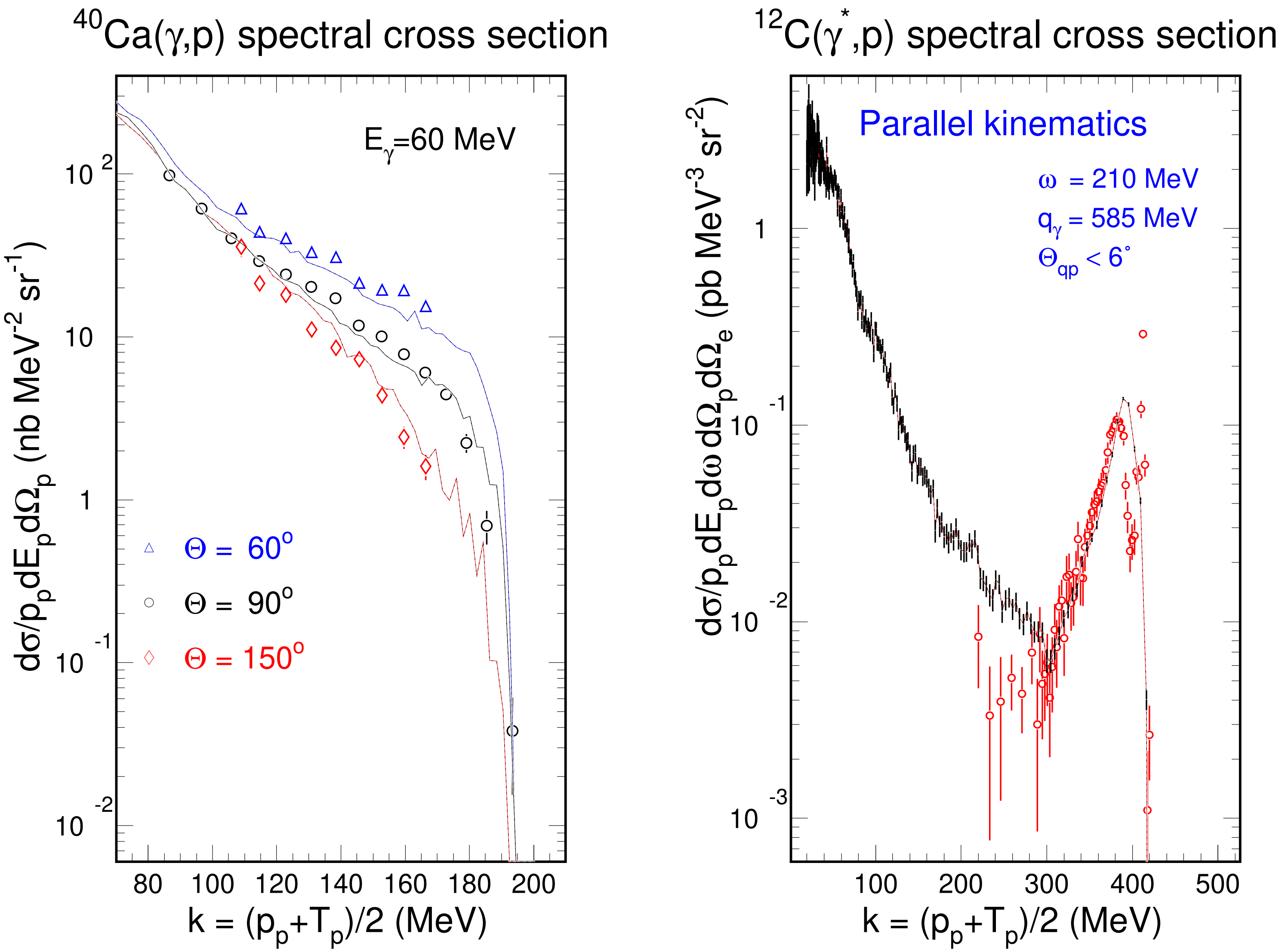
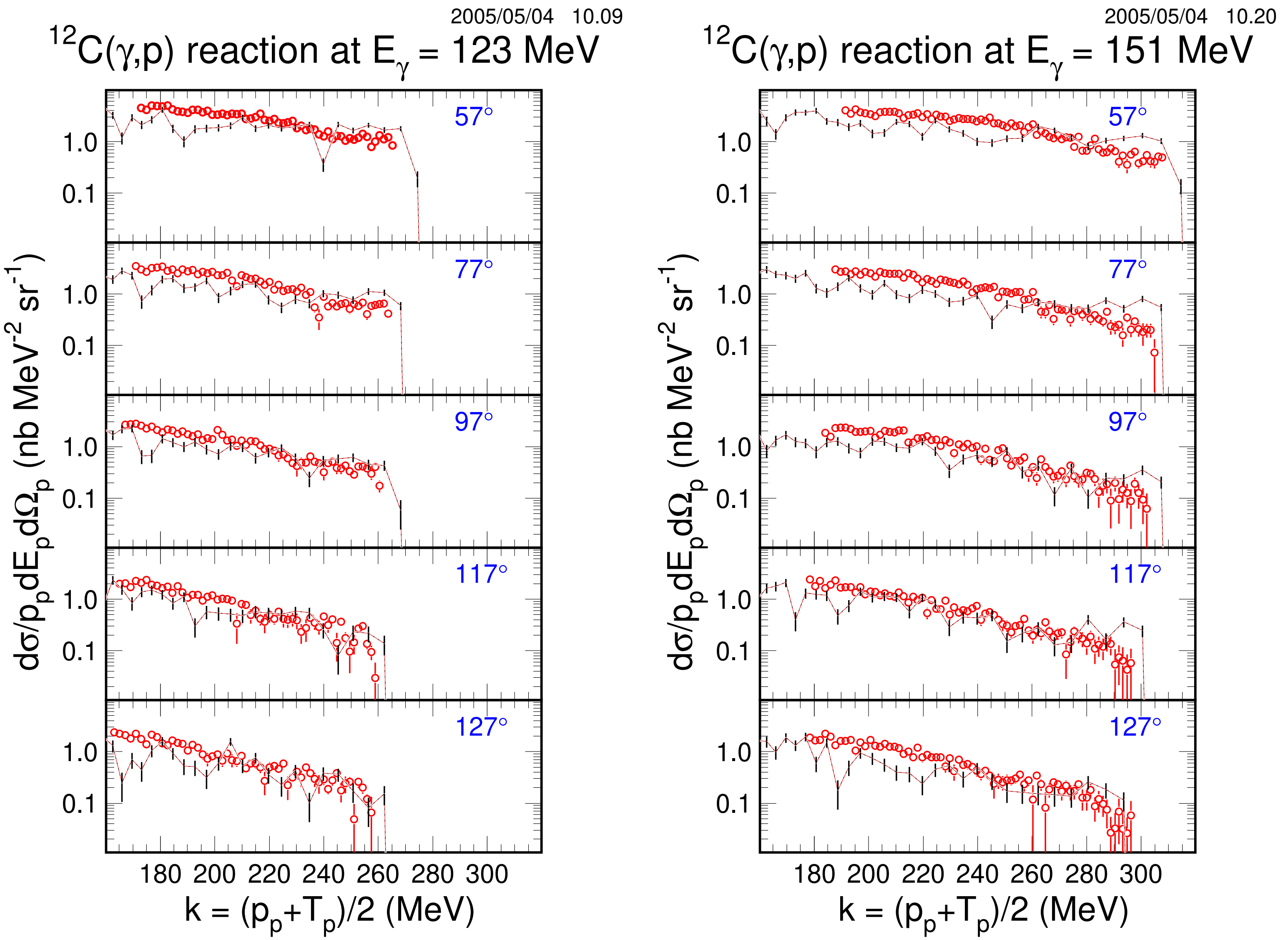


^{40}Ca(γ,p) spectral cross section
E_γ=60 MeV
$d\sigma/p_pdE_pd\Omega_p$ (nb MeV^{-2} sr^{-1})
Θ = 60°
Θ = 90°
Θ = 150°
k = $(p_p+T_p)/2$ (MeV)
^{12}C(γ*,p) spectral cross section
Parallel kinematics
ω = 210 MeV
q_γ = 585 MeV
Θ_{qp} < 6°
$d\sigma/p_pdE_pd\omega d\Omega_pd\Omega_e$ (pb MeV^{-3} sr^{-2})
k = $(p_p+T_p)/2$ (MeV)

Test frame for reactions on flight in Geant4: photons.



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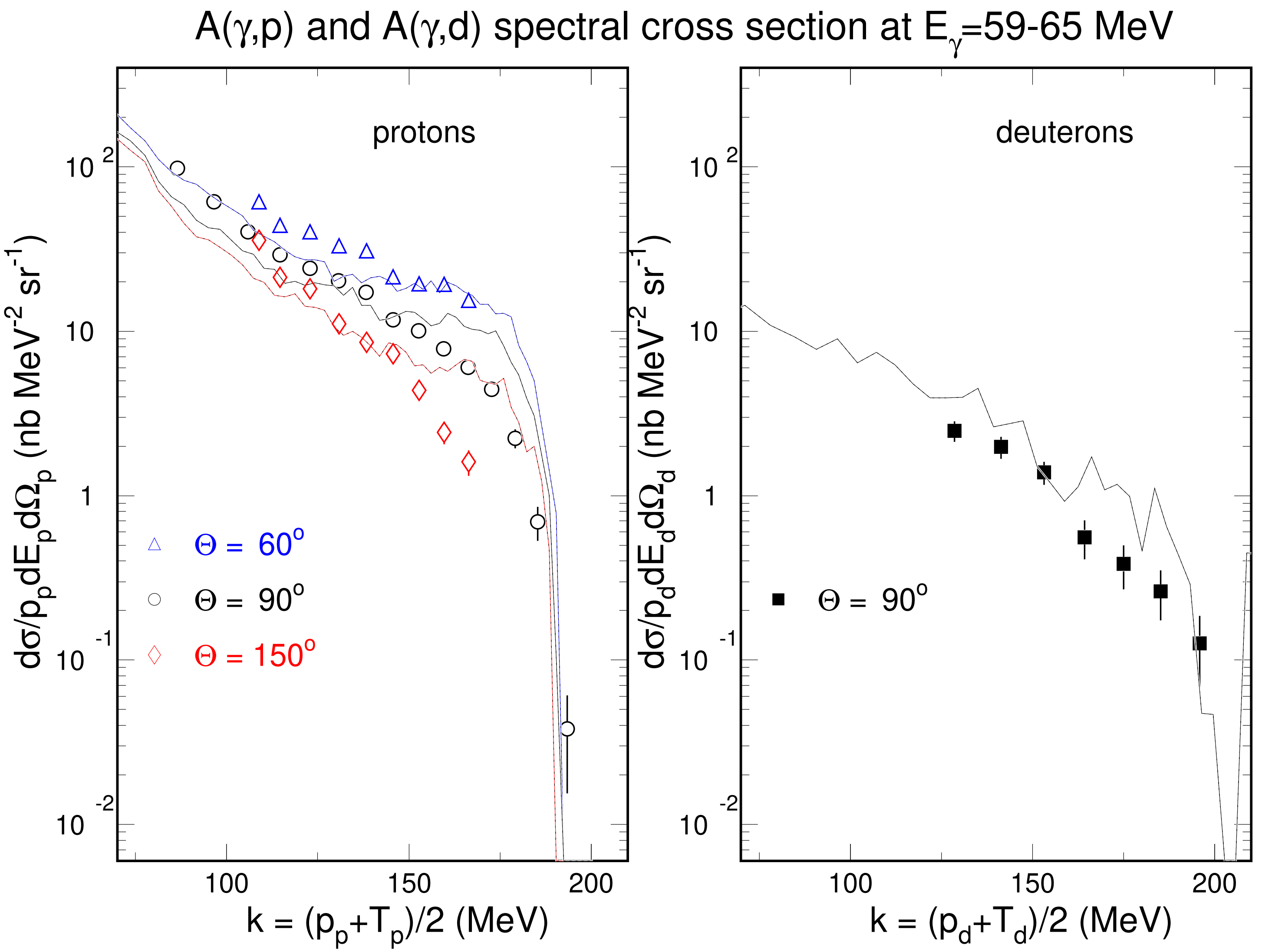
A(γ,p) and A(γ,d) spectral cross section at Eγ=59-65 MeV
protons
deuterons
dσ/p_p dE_p dΩ_p (nb MeV^-2 sr^-1)
dσ/p_d dE_d dΩ_d (nb MeV^-2 sr^-1)
Θ = 60°
Θ = 90°
Θ = 150°
Θ = 90°
10^2
10
1
10^-1
10^-2
100
150
200
k = (p_p+T_p)/2 (MeV)
k = (p_d+T_d)/2 (MeV)

Conclusion

- "19/29" club is open for contribution of users, which are interested in particular energy range of particular hadron-nuclear interactions;
- Test29 includes the projectile and target loops and it is stable.
- The normalization by total cross-sections in test19 is not yet done;
- Photo-nuclear tests for higher energies and an energy dependence of multiplicities for antiproton-nuclear reactions are going to be added;
- For the low energy tests the exact nuclear masses values are very important, so these values must be improved in Geant4;
- Test of all hadrons, all energies, and all targets in a loop as a performance test should be added to test19;
- "19/29" tests can be used as physics tests for new Geant4 releases/

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