Multi-Fragmentation of Nuclei by Photons: New Approaches and Results

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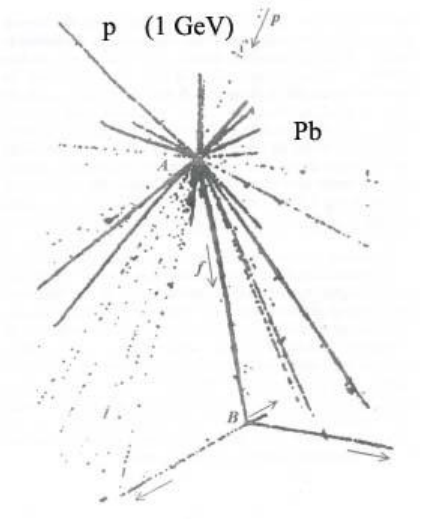
Previous experiments

Photon induced multifragmentation reactions were not observed nor by emulsion nor another methods

300 GeV p + W (66 tracks) Akhorov O. e.a. **JINR** R1=9963 (1976)

1 GeV p + Pb,Th,U Gorshkov B.L.,e.a. Ecplosion reaction in 238-U, 232-Th and 197-Au by 1 GeV protons. JETF letters,37.60-63, (1983). ***LPI***

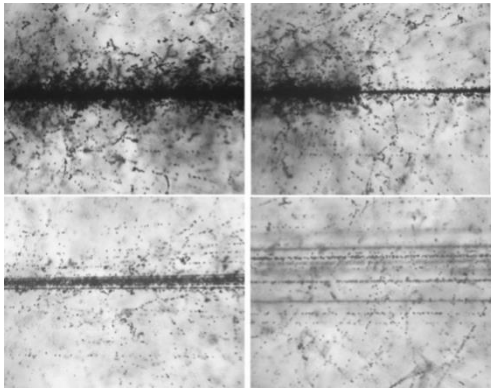


p, α-particles Lips V.,e.a. ***FASA.*** JINR, TH, Darmstadt (1993), IKDA 3/7, p1-11 (1993).

Relativistic ions **Au + emulsion target**

[http://**becquerel**.jinr.ru.]

A.S.Botvina e.a. ***ALADIN*** collaboration @ SIS, Multifragmentation of spectators in relativistic heavy-ion reactions, NP A 584 , 4 (1995) 737.



Theory interpretation :

Phase transition between nuclear matter and gas of nucleons

Threshold behavior : E* is comparable to binding energy

A.S.Botvina, A.S.Iljinov, I.N.Mishustin. Multifragmentation of nuclei by high energy protons. JETF letters, 42, 11, 462-464 (1985).

Kamaukhov V.A. On nuclear liquid gas phase transition via multifragmentation and fission. ЯФ. 1997. Т. 60. С. 1780-1783.

RELDIS Cascade Evaporation MODEL :

I. Pshenichnov et.al., Physical Review C57 (1998) 1920. , Physics of particles and nuclei, 42 (2011) 215, Eur. J. Phys. A 24 (2005) 69.

A2 : Double photoproduction off nuclei – are there effects beyond final-state interaction arXive:1304.1918v1 [nucl.ex] 6 Apr 2013

Fission & Fragmentation at Lower Energies

Photo-neutron reactions,

Cluster effects.

Kharkov, Erevan etc. 50 years ago.

V.Nedorezov, Yu.N.Ranuk. Photofission above the Giant resonance, Naukova Dumka,1984 Kiev.

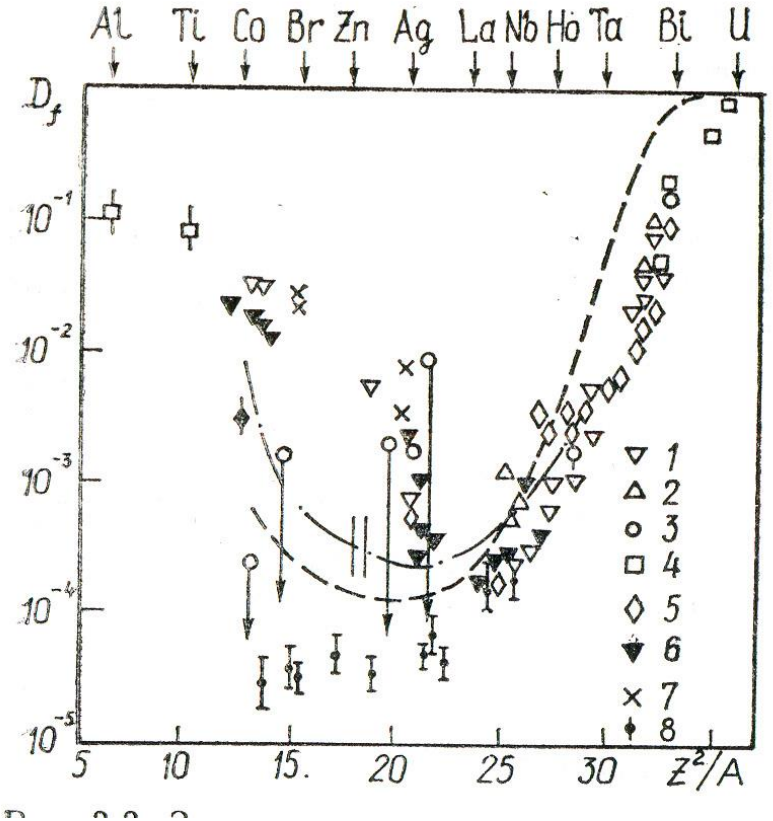
Recent new results:

Size of a-claster in Li-6 is smaller on 20%

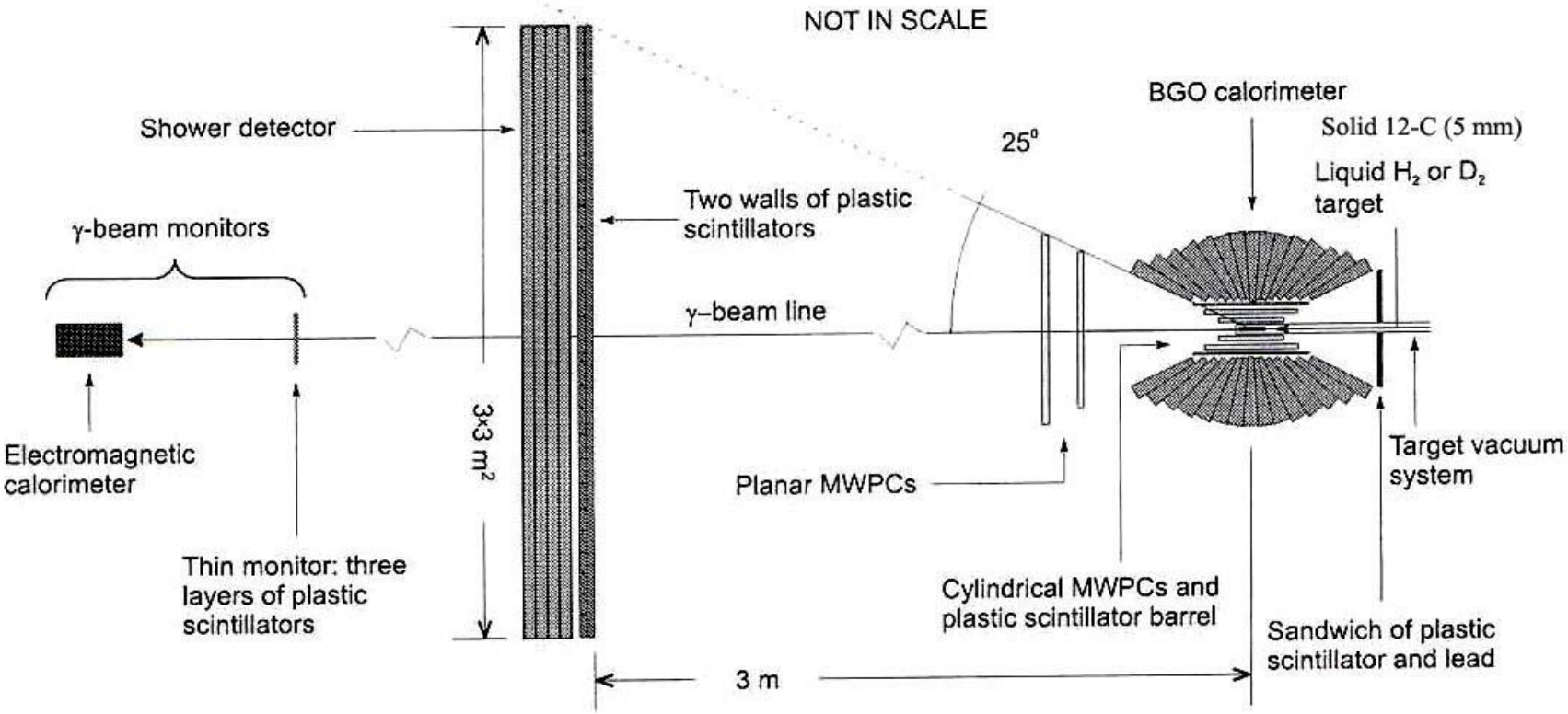
Than that of free a – particle.

T.Yamagata e.a. “Medium effects in the photoexcitation of a cluster in Li-6”.

NPNCP – **2014,** Japan.

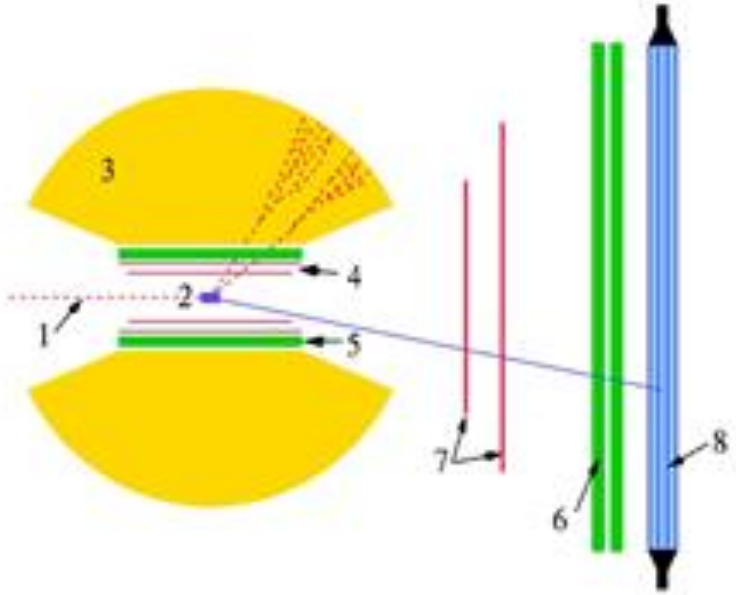


GRAAL experiment



LAGRANγE Detector

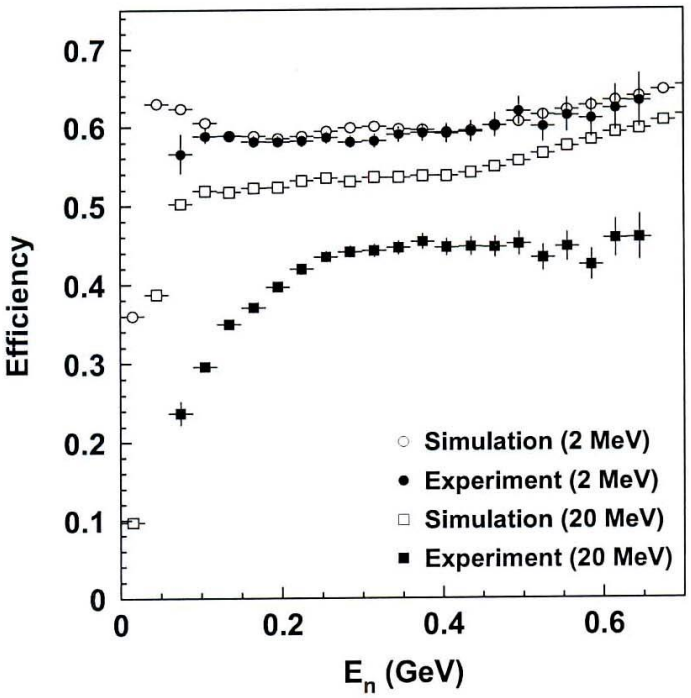
1: Compton gamma beam , 2: Liquid H2/D2 target , 3: BGO Calorimeter
4: Cylindrical MWPC's , 5: Plastic Barrel , 6: Plastic Wall, 7:Plane MWPCs, 8: Shower Wall



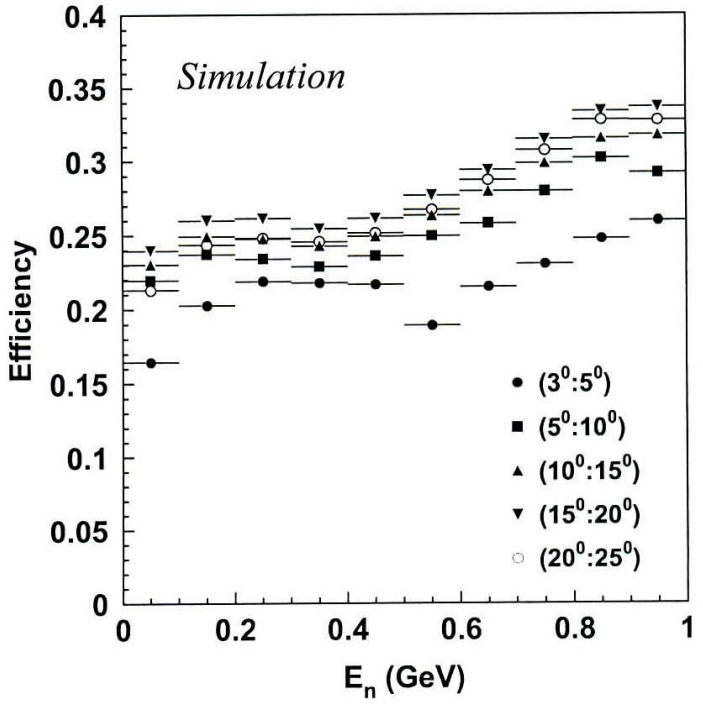
- <u>Shower Wall</u>
- neutron efficiency 20 %
- γ / neutron PID

Neutron measurement efficiency for BGO ball

O. Bartalini , A.Mushkarenkov et.al., NIM A 448, 12 (2006).



(а)



(б)

GRAAL

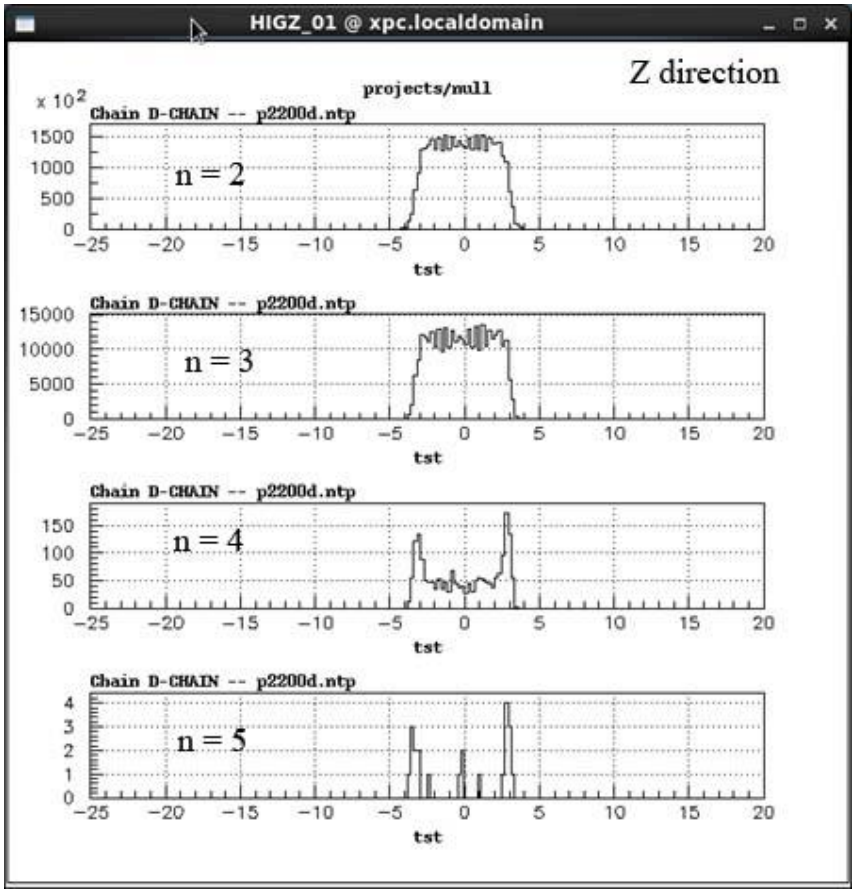
Target : 8 cm LD + 100 μm mylar windows ($C_{10}H_8O_4$)

γ Beam

0.6-1.5 GeV

Cylindrical 4π MWPCs:

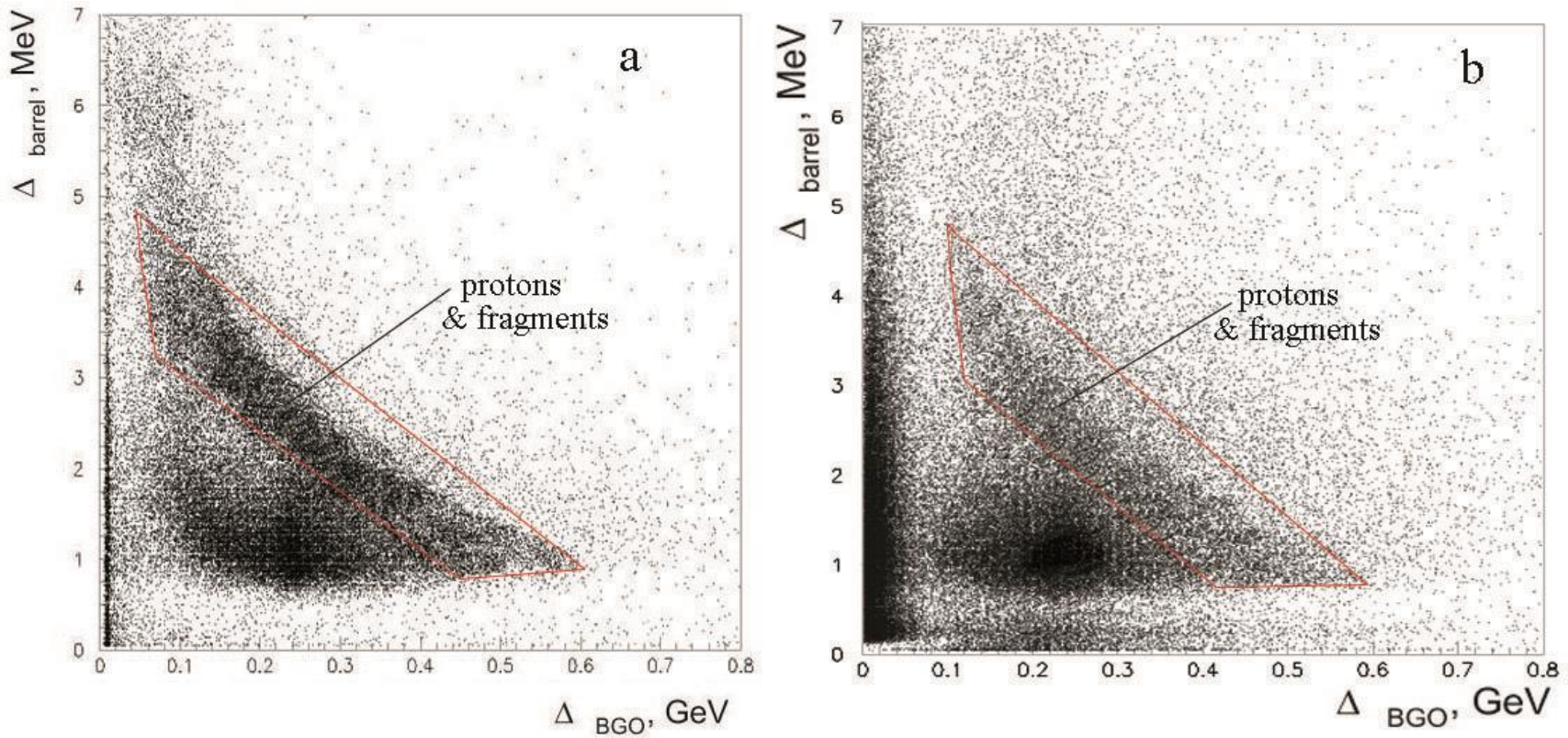
Yield of charged particles from the mylar windows (LD target) with different multiplicity (n=2,3,4,5)



for n = 5
they are not mesons,
not primary recoils

Most probably they are cascade protons - results of intra-nuclear interaction

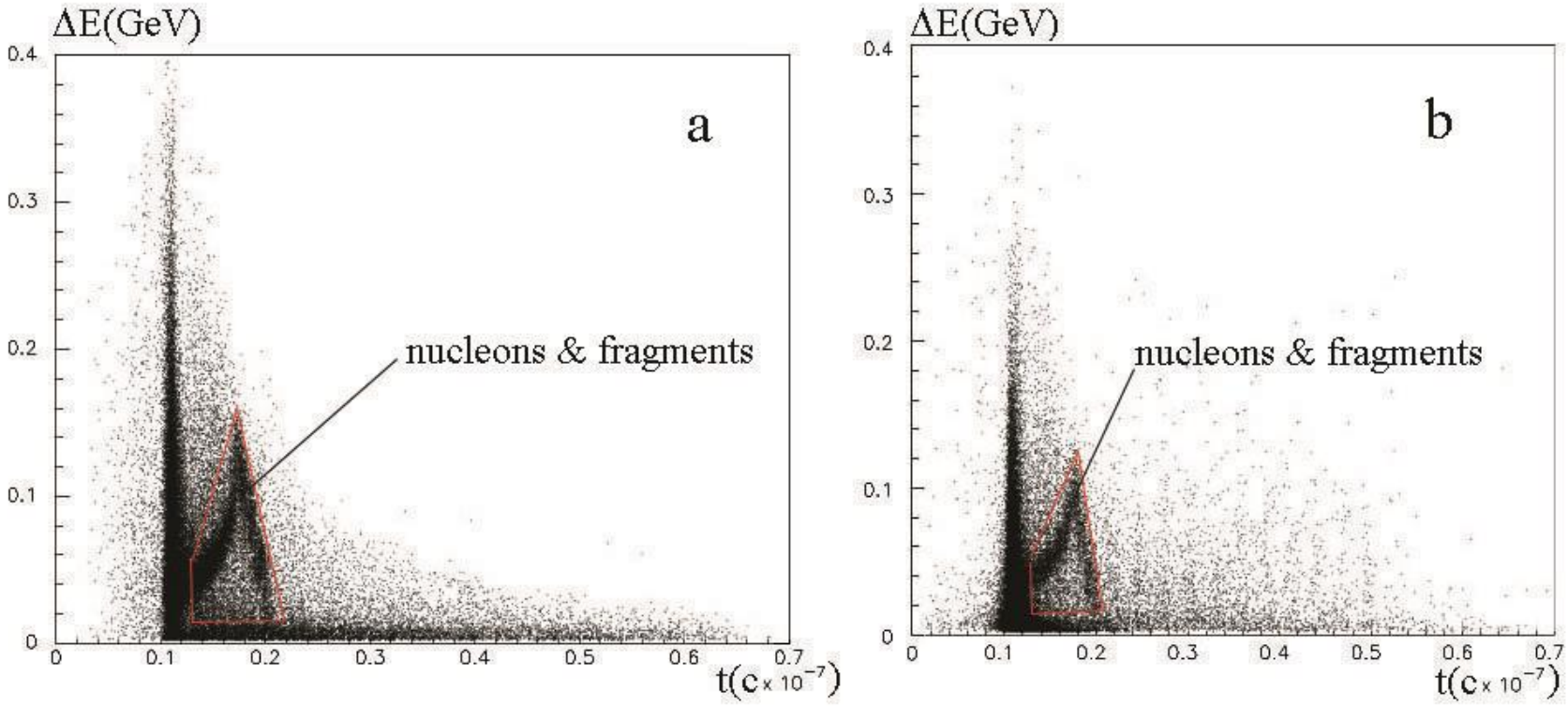
Carbon target:
ΔE barrel – ΔE BGO Identification in the 4π



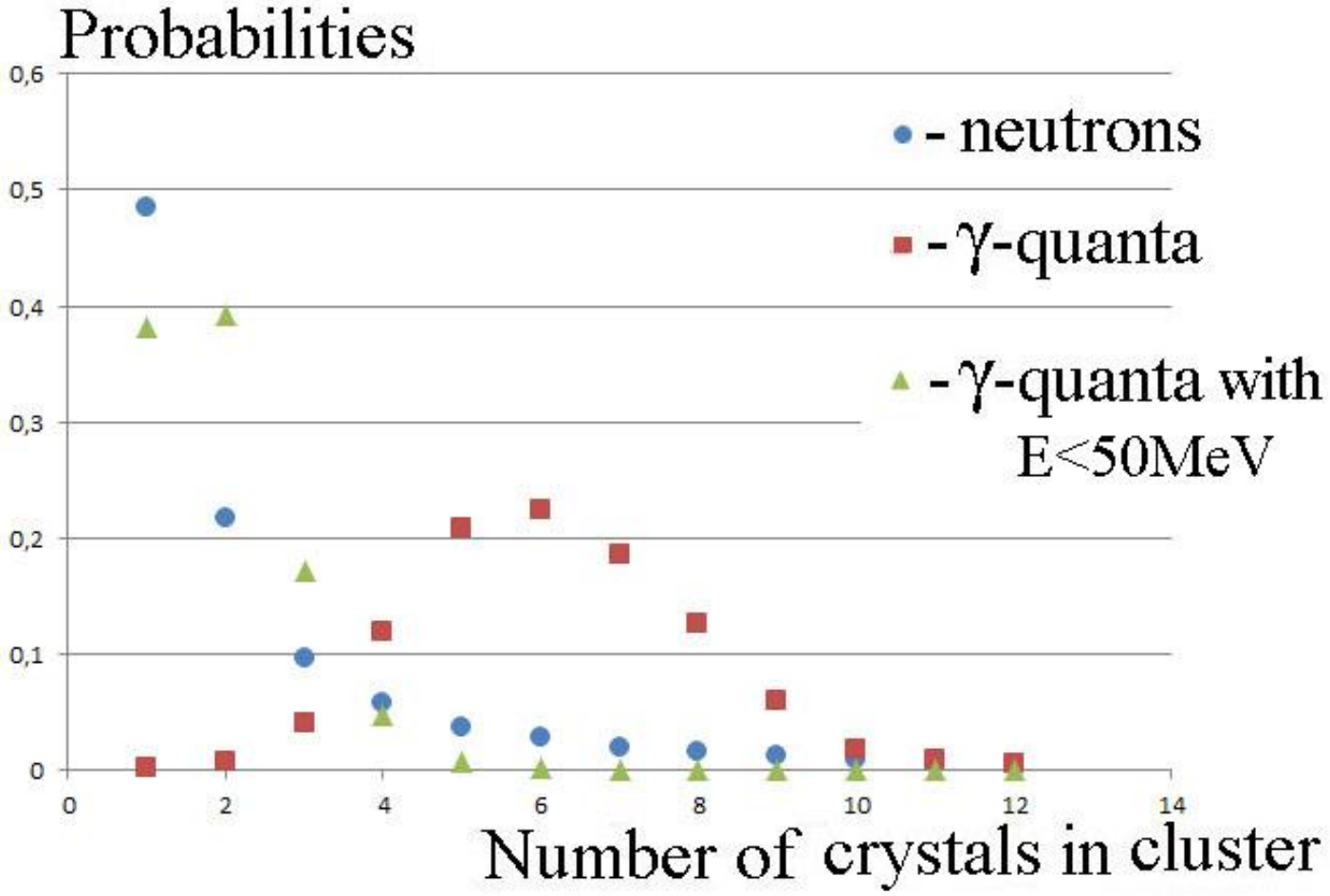
a – simulations , b – experiment

Carbon target:

TOF –ΔE Identification in the forward direction



Additional identification methods for BGO



Experimental results :

Table 1: Average numbers of charged nuclear fragments and neutrons registered in the forward direction and BGO ball, respectively

	Protons and fragments	Neutrons
Forward Direction	0.35±0.01	0.04±0.01
BGO ball	2.05±0.03	0.57±0.01

Total photo-absorption cross section for ^{12}C.

Crosses - **GRAAL data,**

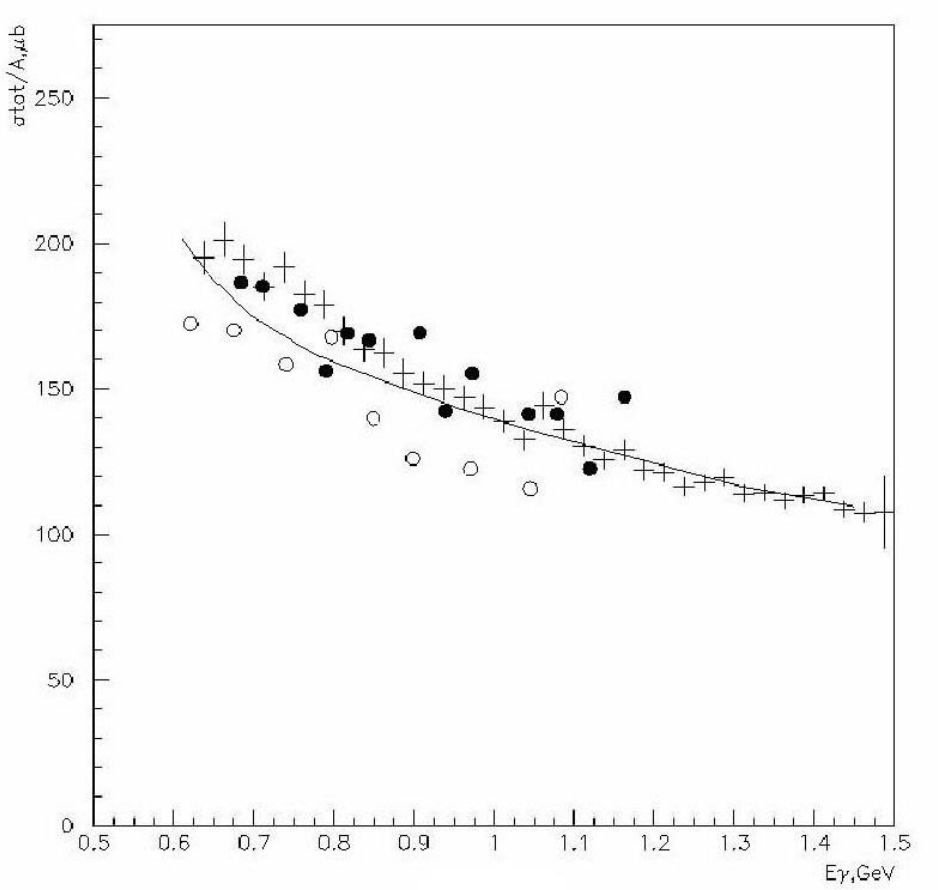
full points – **Bianchi e.a. [4]**

open points - **Mirazita e.a. [5]**

[4] M. Mirazita et.al., Phys.Lett. B 407, 225 (1997).

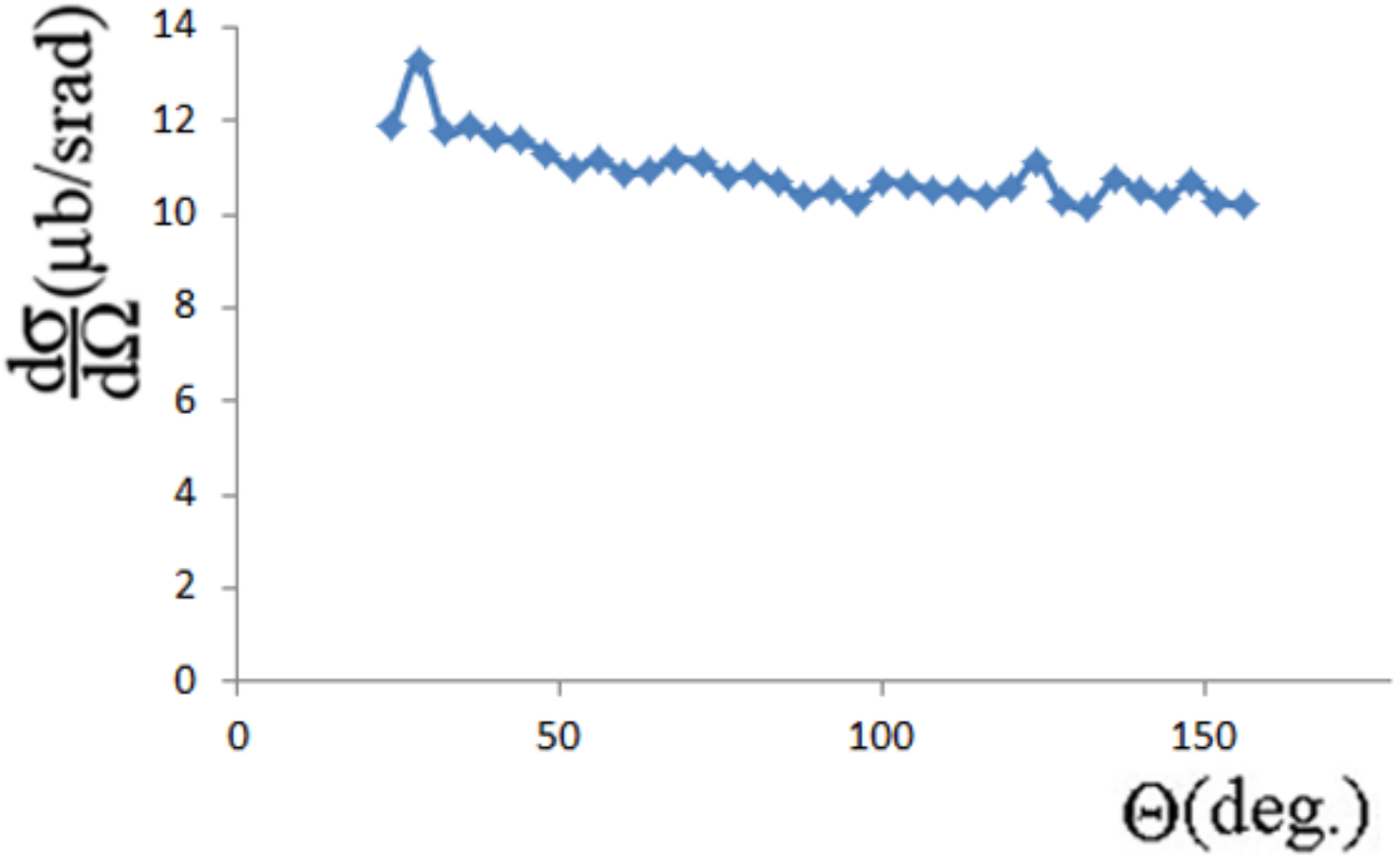
[5] N. Bianchi et.al., Phys.Lett. B 309, 5 (1993).

“Universal curve” - full line.



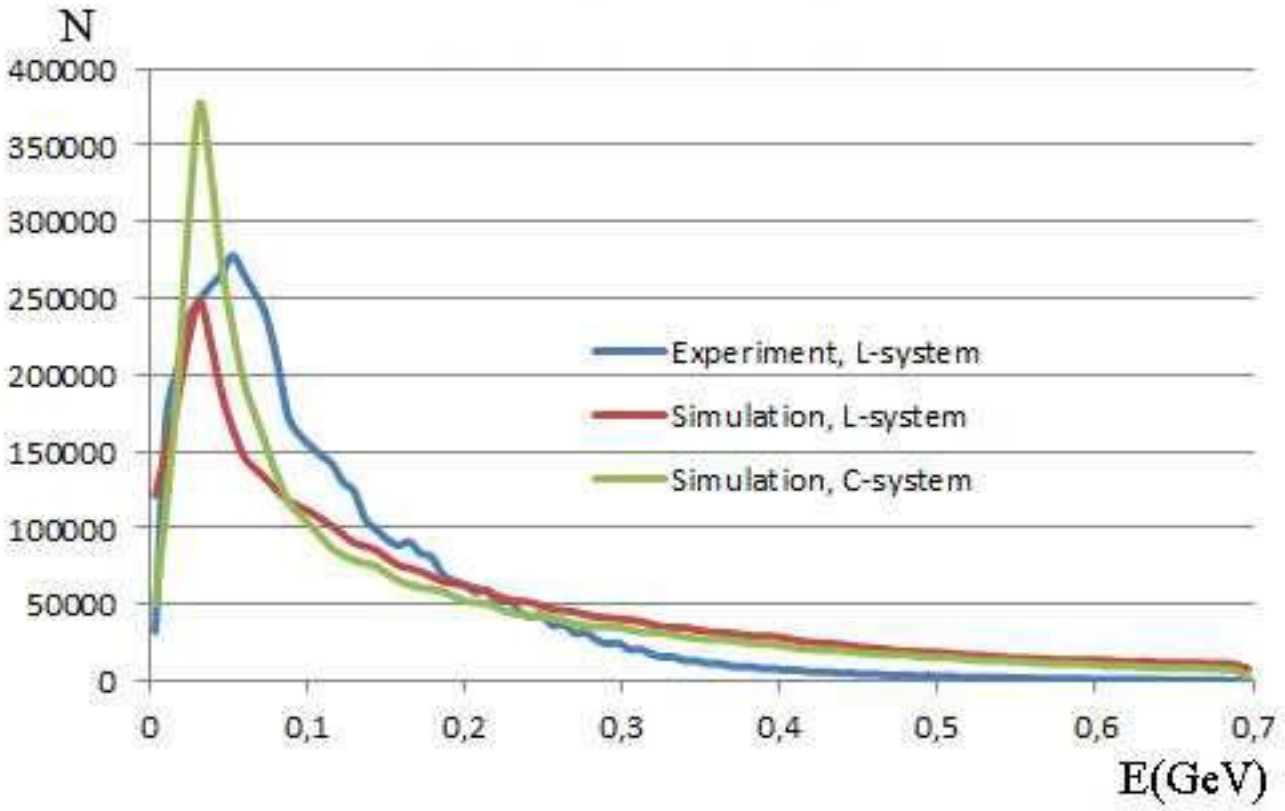
Angular distribution of products from ^{12}C

Multiplicity n > 7, $E\gamma$ = 0.7 – 1.5 GeV

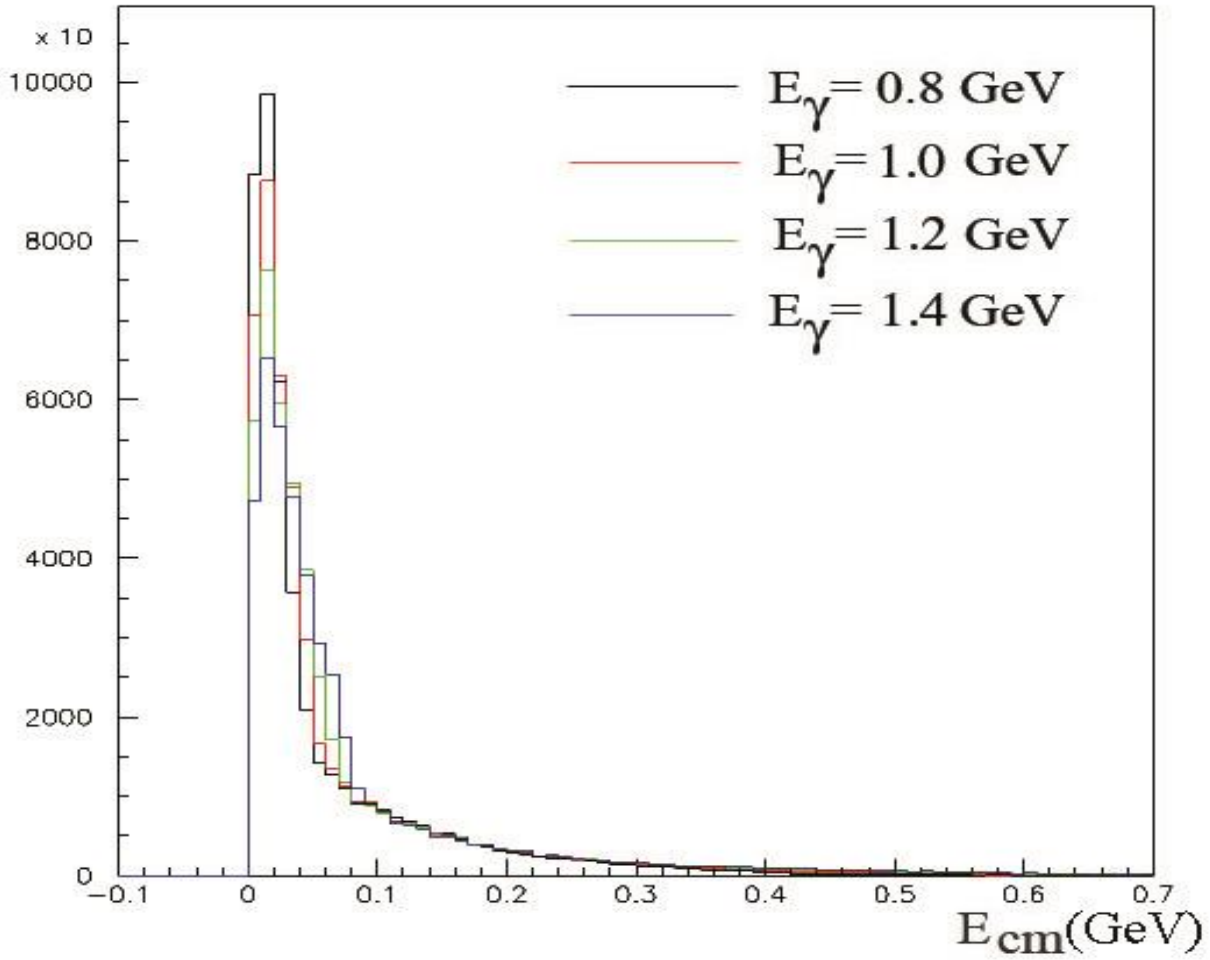


Energy distributions of nucleons produced in photodisintegration of 12-C.

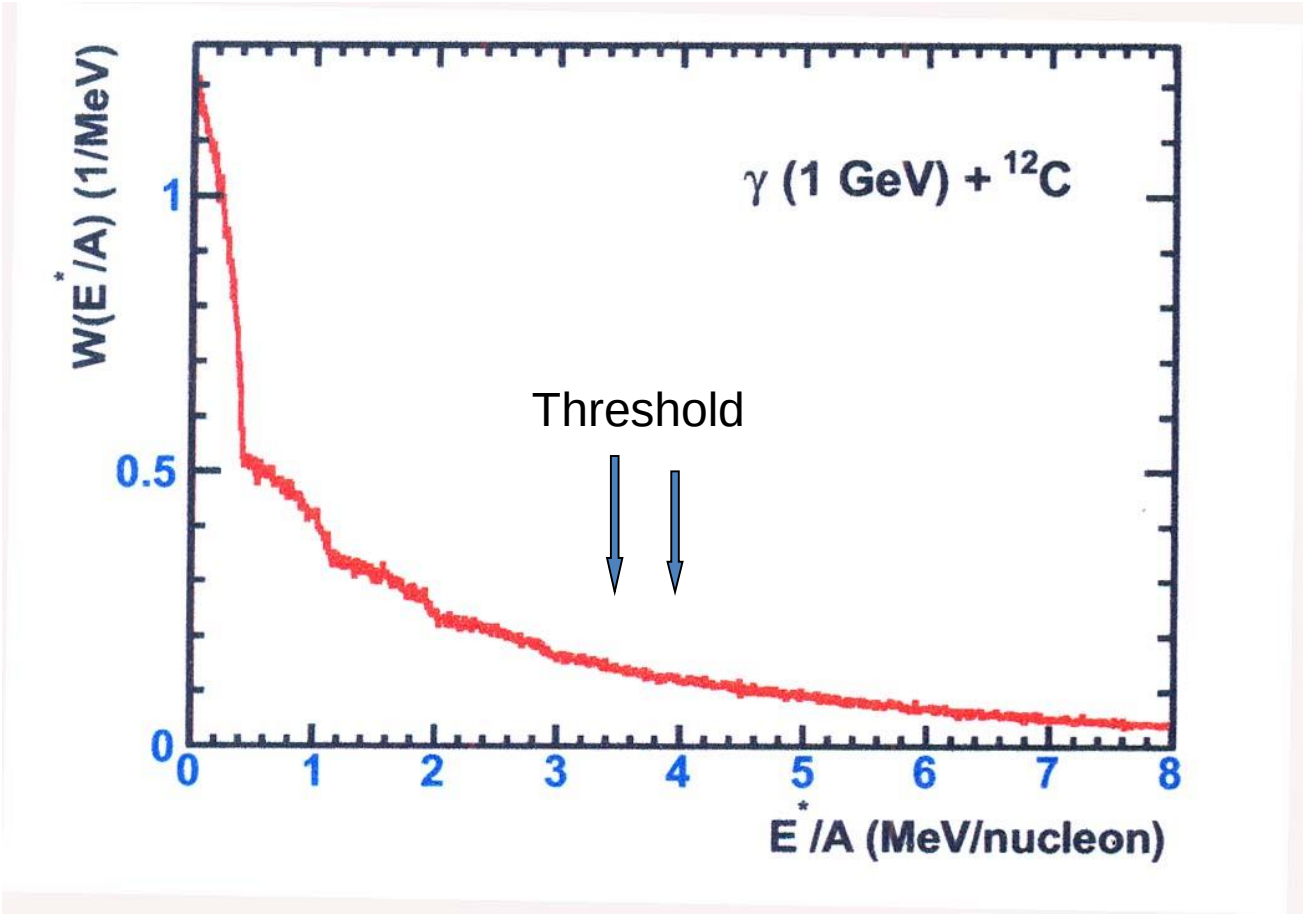
In comparison with RALDIS predictions



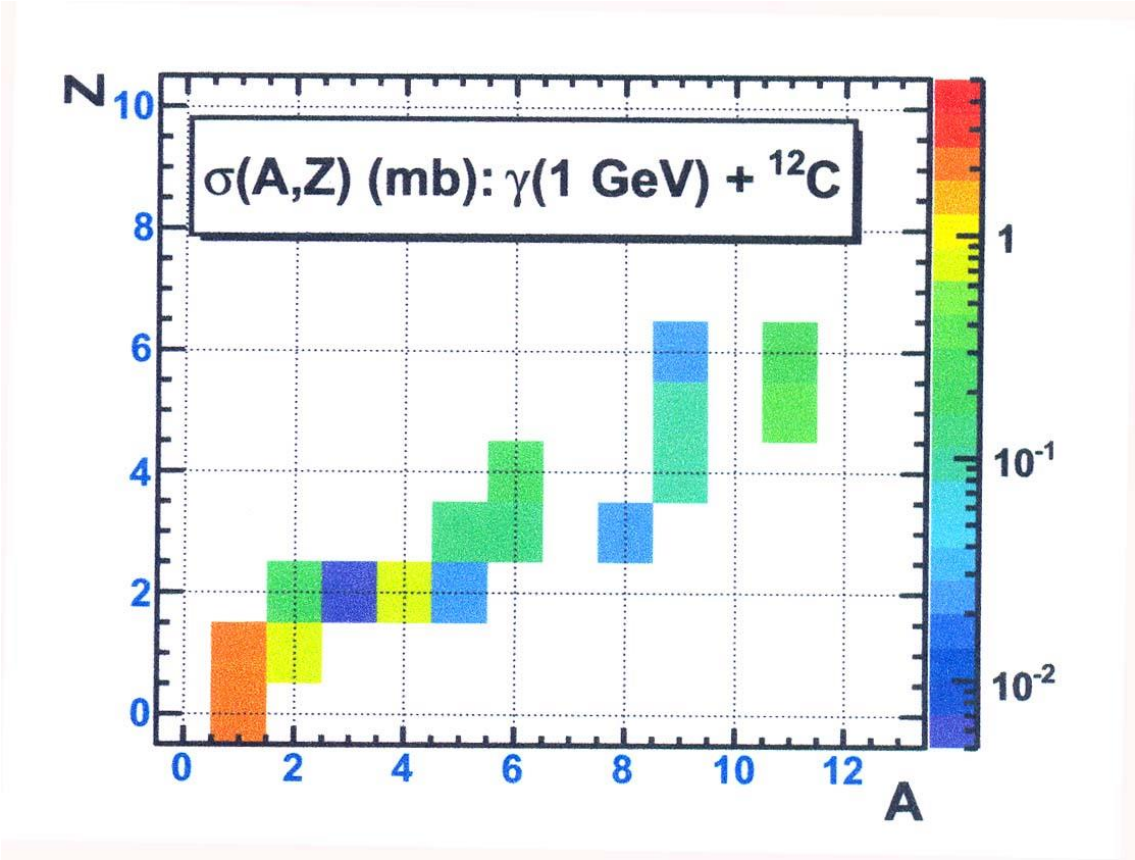
The same as function of Eγ :
Energy distributions of nucleons (RELDIS predictions) :



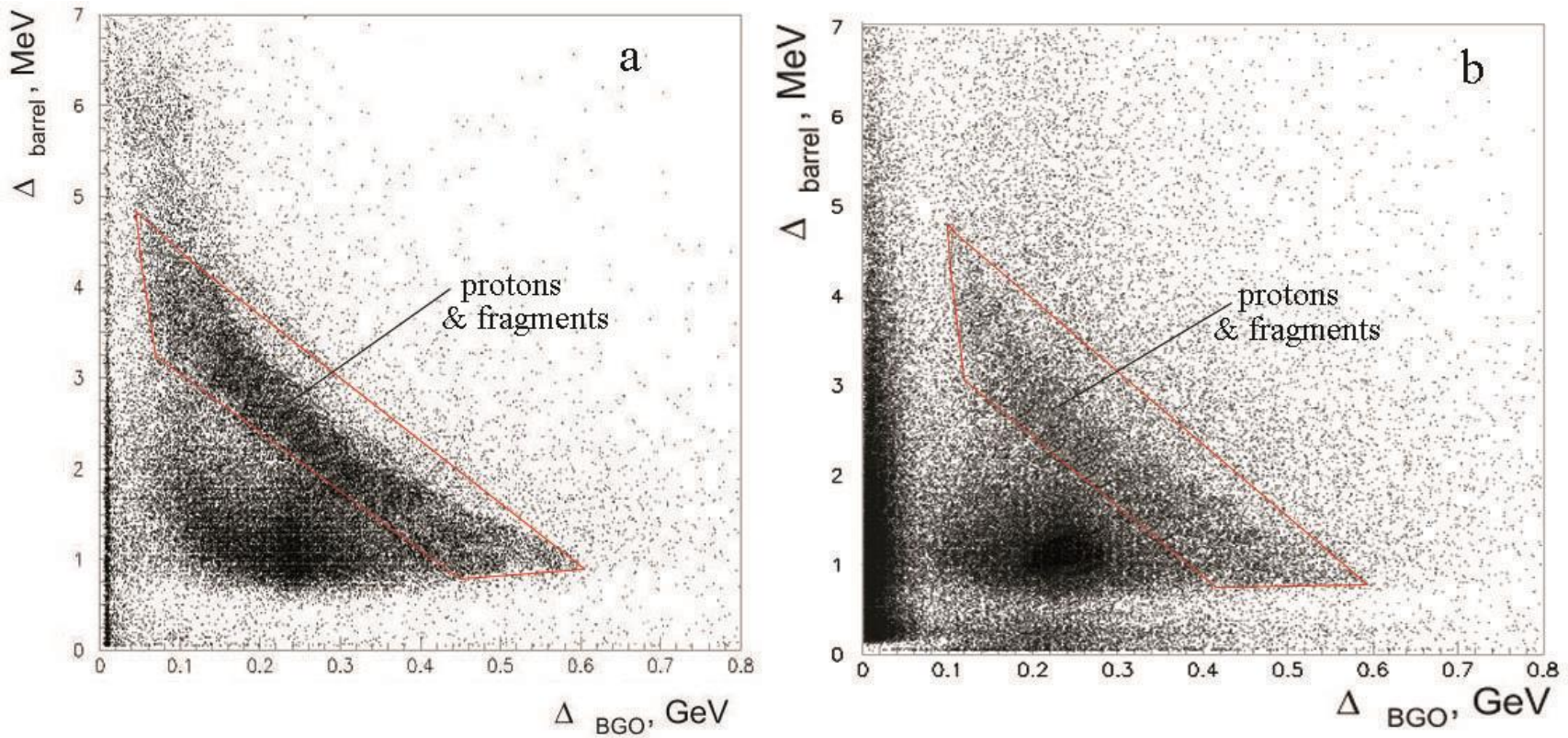
Probability to create a residual nucleus with a given excitation energy per nucleon, $E^{\star}/A$, in the absorption of 1 GeV photons by 12-C, calculated by the RELDIS model.



Calculated inclusive cross section to create a nuclear fragment with a mass number *A* and a charge *Z* in the absorption of 1 GeV photons by 12C.

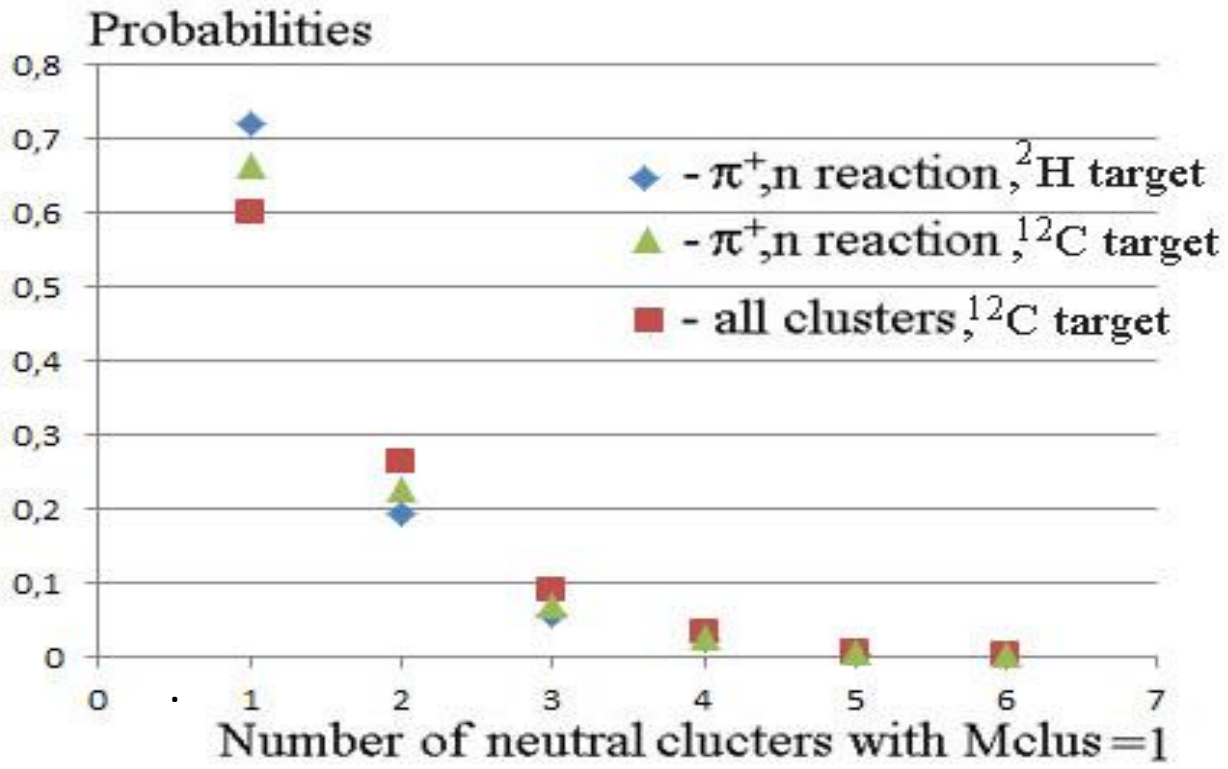


Carbon target:
ΔE barrel – ΔE BGO Identification in the 4π

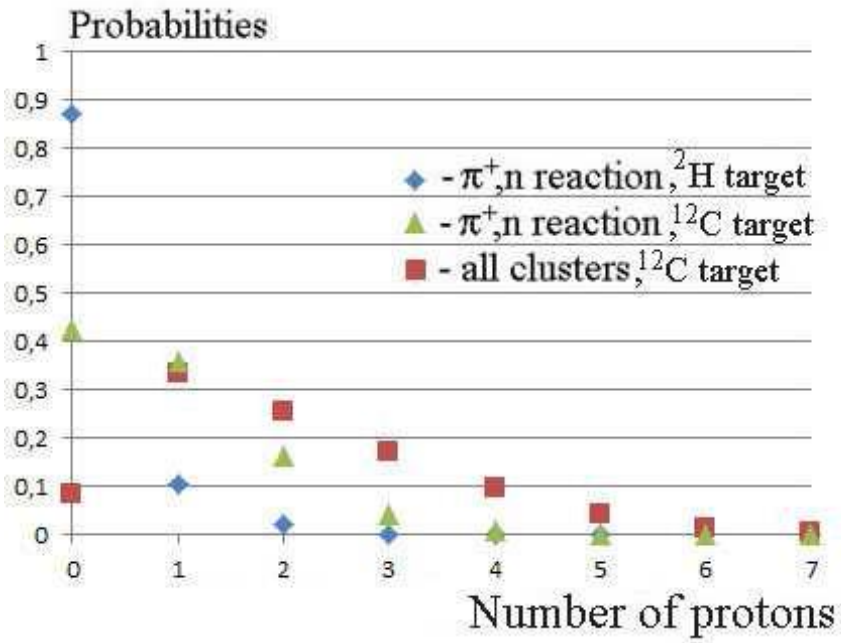


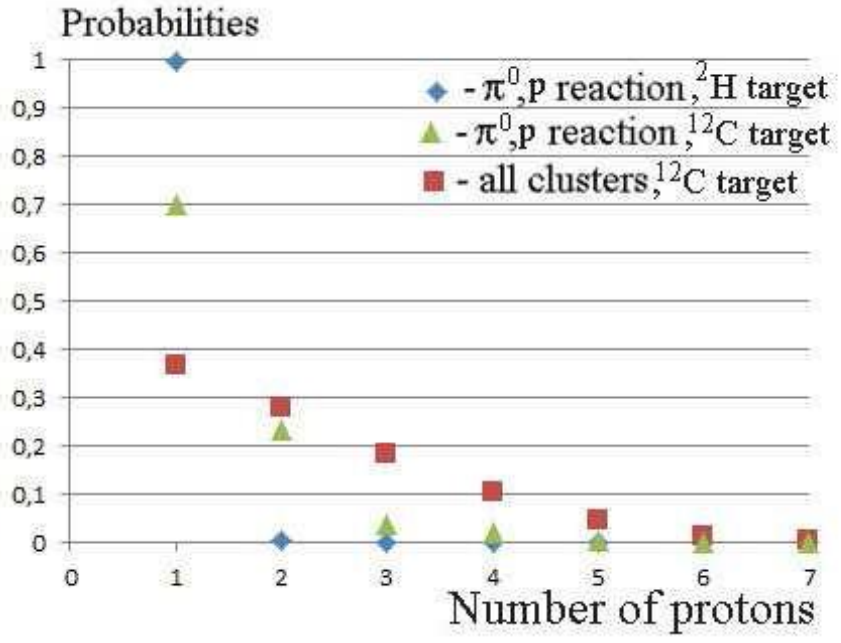
a – simulations , b – experiment

Probability of neutral cluster (neutron) production in different partial reactions [GRAAL results]

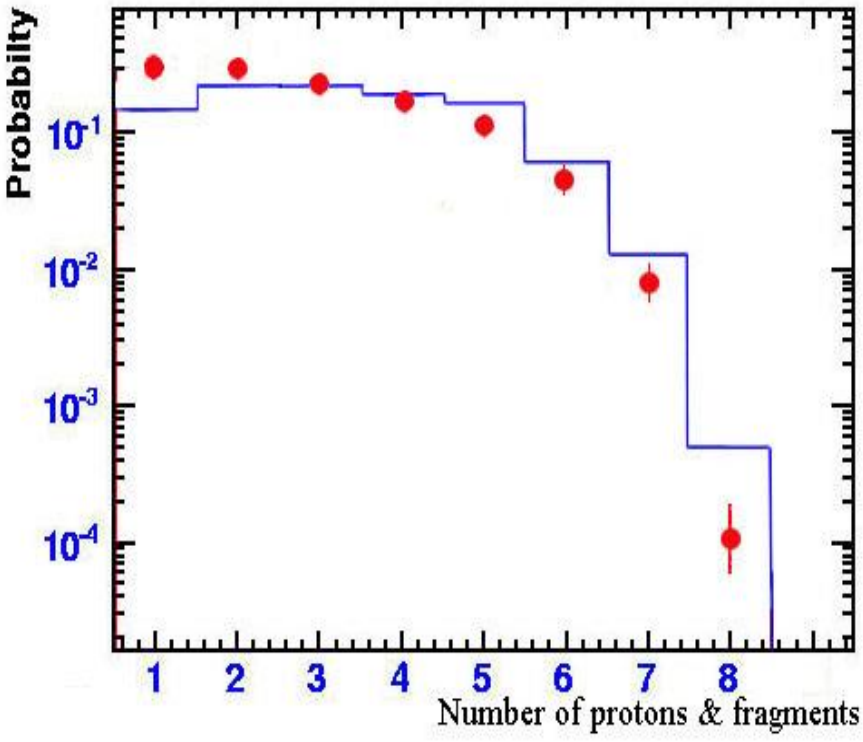


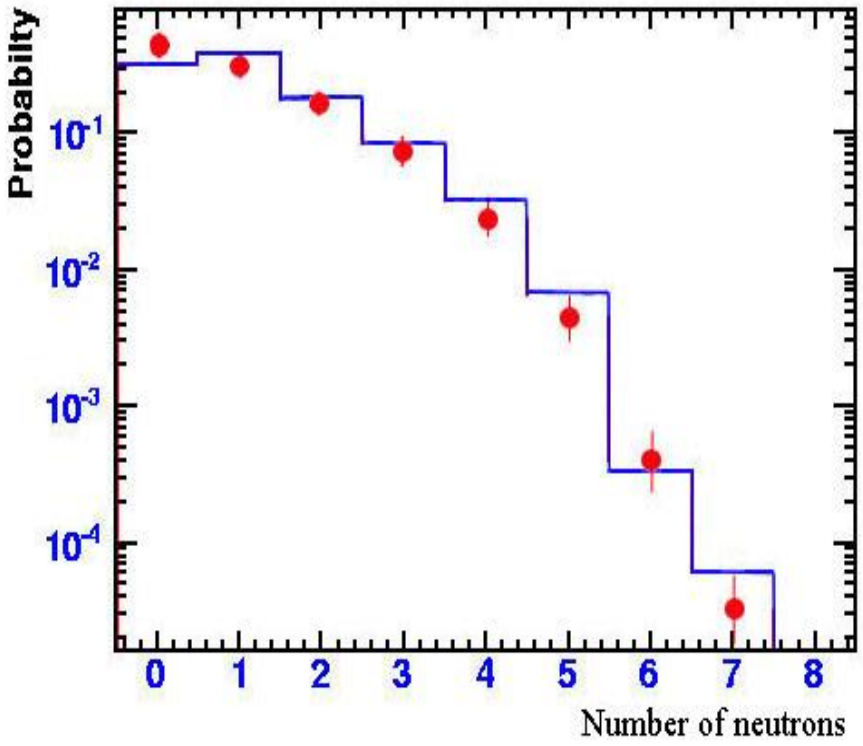
Probabilities of proton emission together with π+*n* (left panel) and π◦ *p* (right panel) in photodisintegration of 12-C.



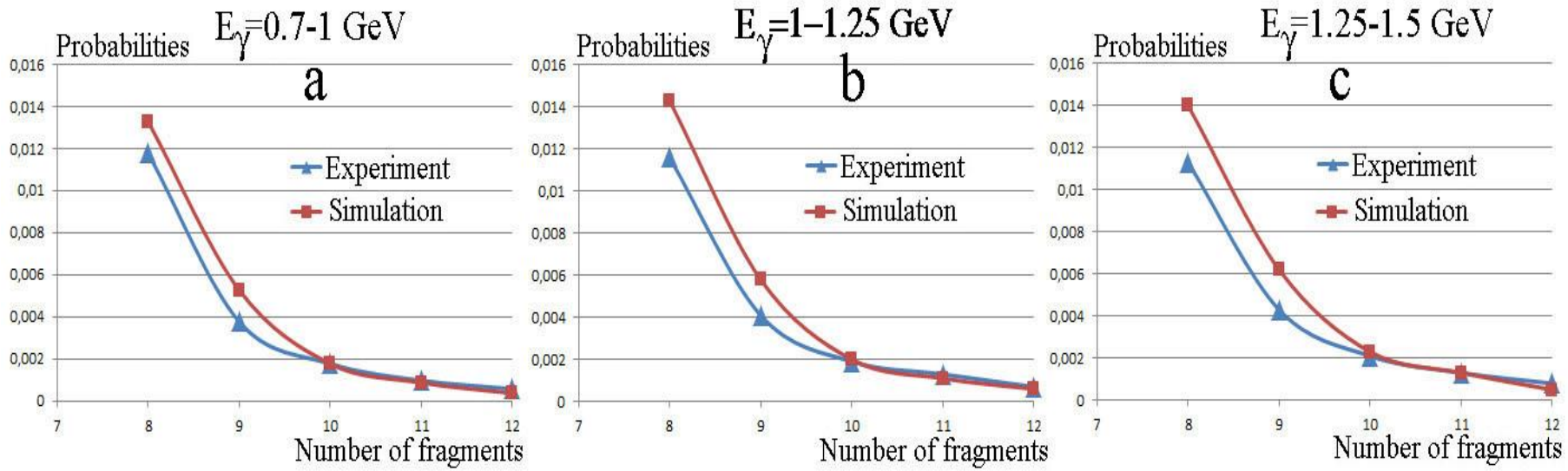


Probability of emission of protons and neutrons from ^{12}C target.
Points – GRAAL results, histograms – RELDIS predictions.
Statistical errors are presented.





^{12}C multi-fragmentation probabilities (n = 8 – 12) at different Eγ energies in comparison with RELDIS predictions



Conclusion

First photonuclear experiment on multifragmentation of nuclei in the nucleon resonance energy region is sufficiently described by the cascade evaporation model RELDIS. An explosion mechanism of nuclear decay is available with small probability (≤ 0.1%). There is no difference for different projectiles (1 GeV photons, protons etc) for multifragmentation process.

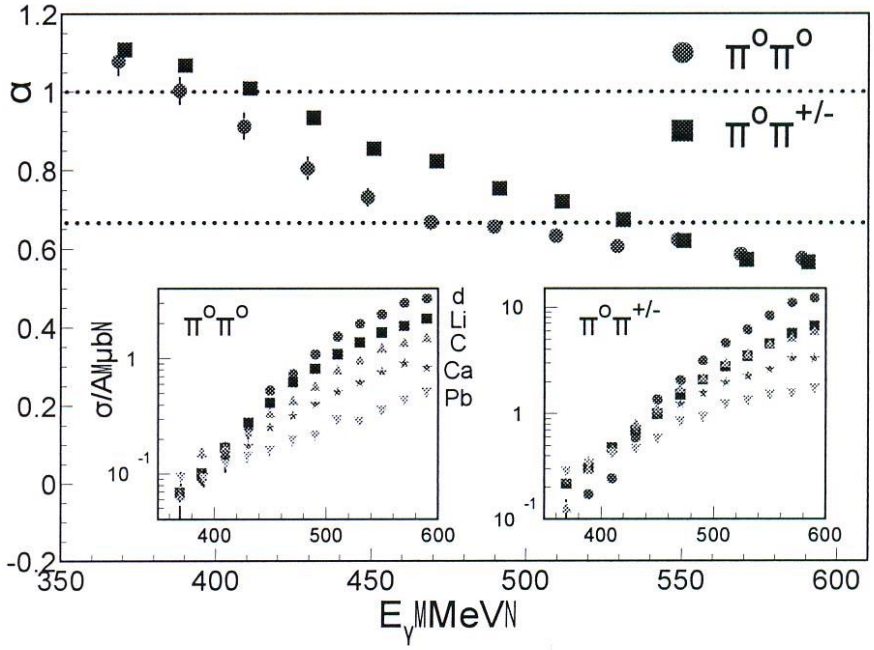
What follows? - Future photonuclear experiments

1. **Interaction of unstable mesons with nuclear medium.**
2. **Actinide nuclei.**
3. **Multiple meson production.**

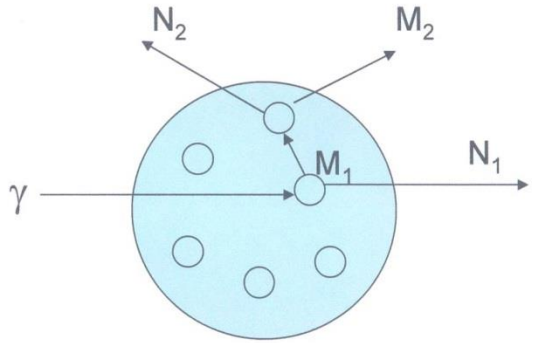
Multiple meson production

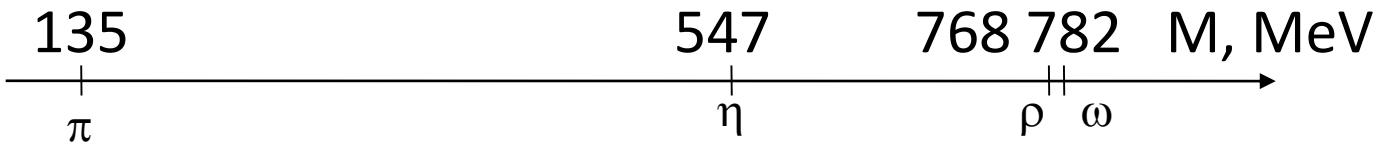
QA.Maghrbi e.a. (A2) Doublt pion production off nuclei – are there effects beyond final atate interaction? arXive:1304.1918v1 [nucl-ex] 6 apr 2013

$$\sigma(A,E_\gamma) \propto A^{\alpha(E_\gamma)}$$



Meson Photoproduction in Light Nucleus
Tagging of mesons by recoil nucleon



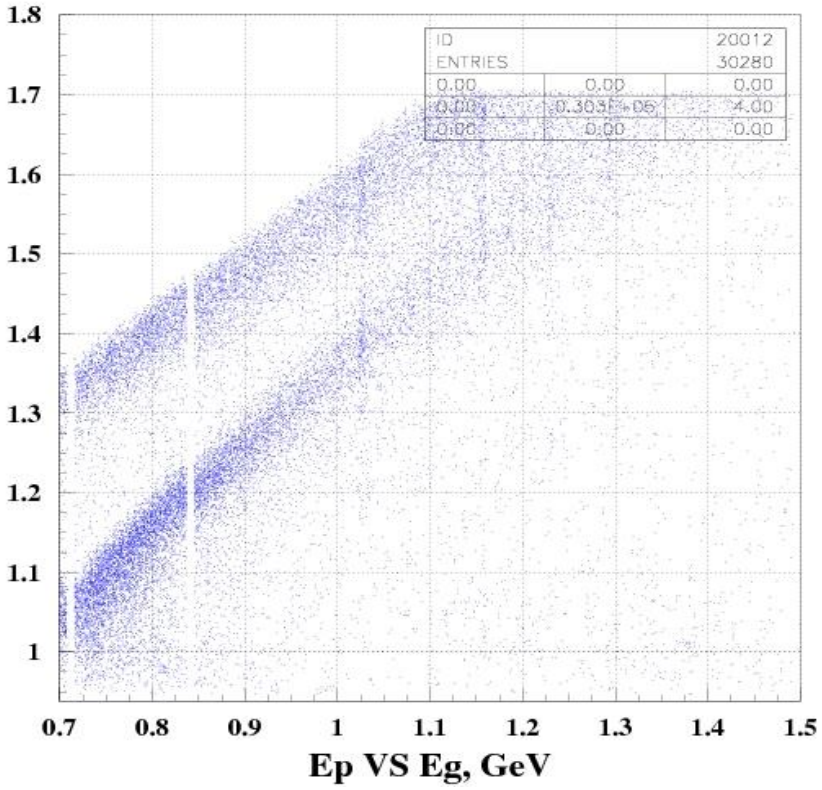


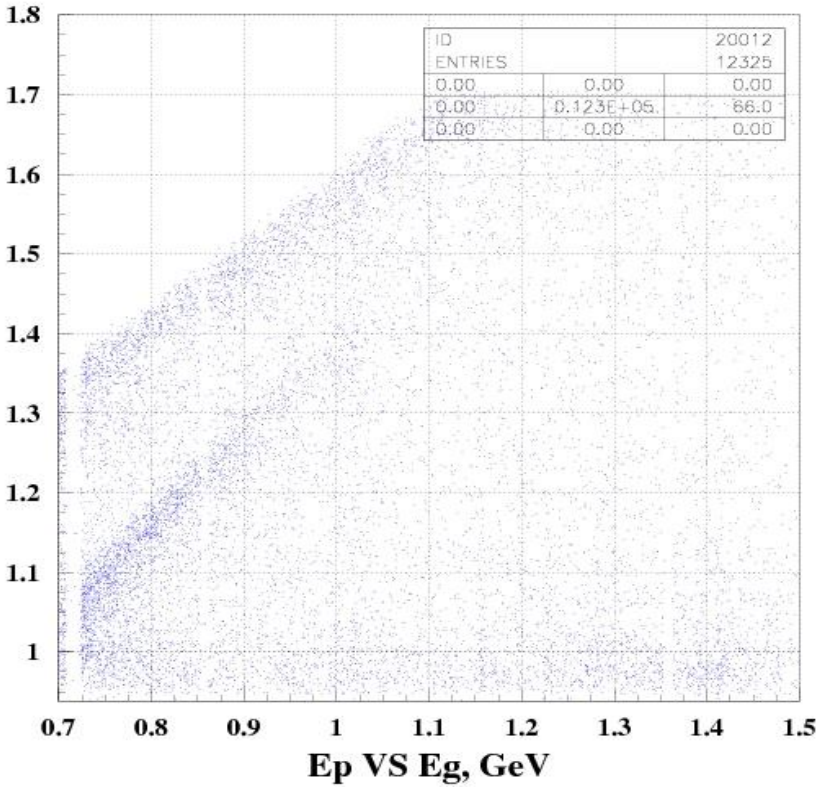
Number of the charged tracks in forward = 1
Number of the neutral clusters in BGO = 2

2^0<theta<10^0

simulation

Experiment
Kinematics is not included

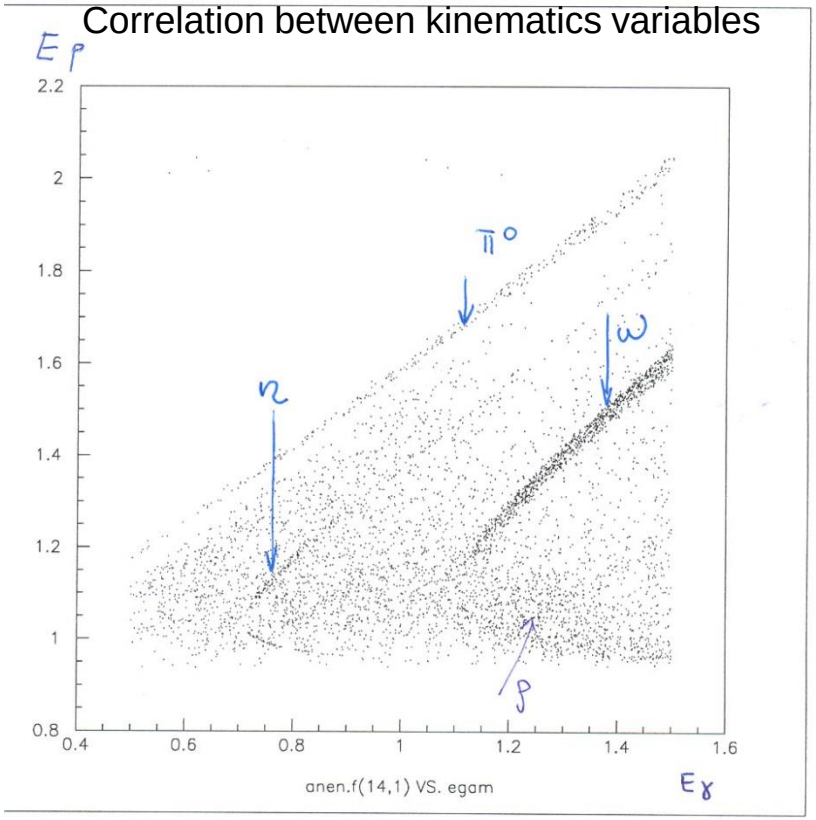




Signatures for inelastic scattering
Simulation for ideal case (no backgrounds, fine resolution)

Nucleus N-14
$\theta_p = 2^0 – 10^0$

Multiple (n <= 4) meson production is included



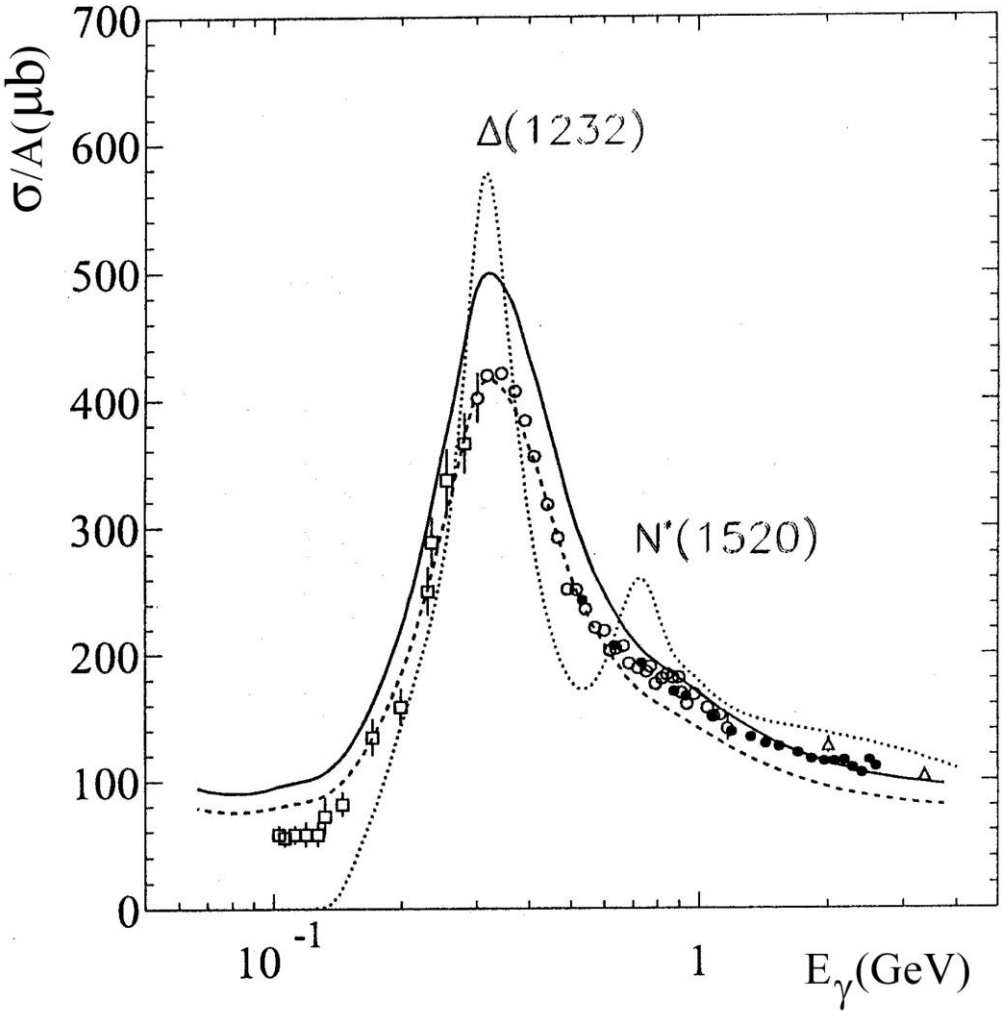
I.Pshenichnov e.a. Moscow, EMIN-2001, p.170

A.Ignatov e.a. Prog.Part.Nucl.Phys. 61 (2008) 306-307 .

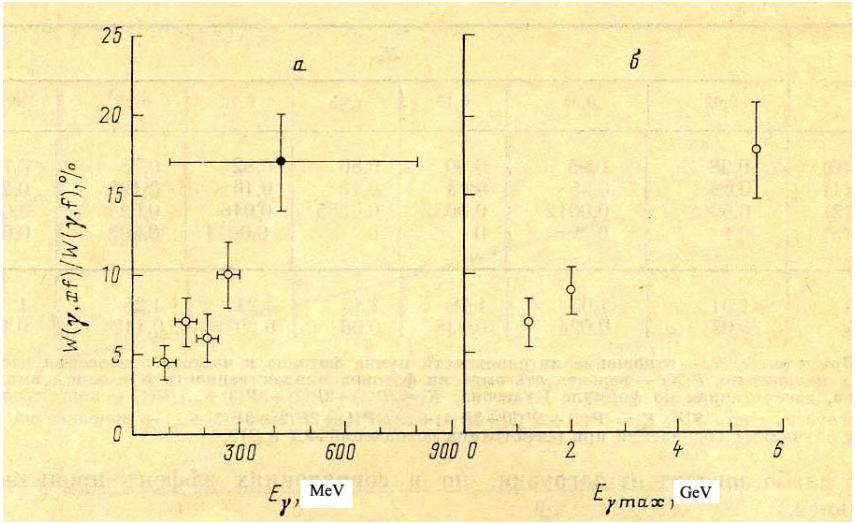
Total photoabsorption in actinide nuclei

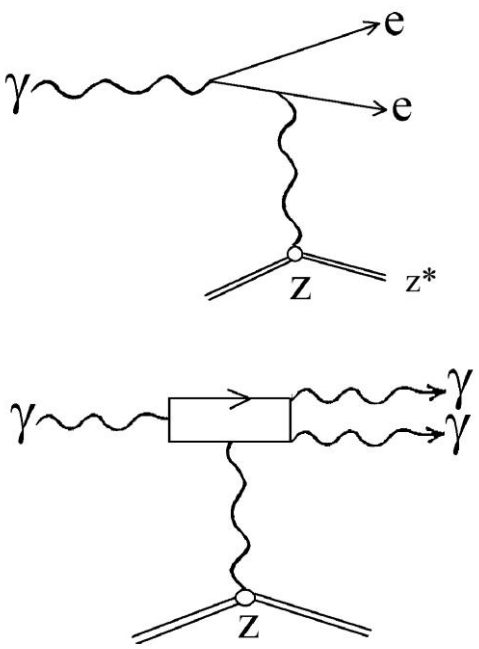
C. Cetina, P. Heimberg, B. L. Berman e.a.

Phys.Rev. C65 :044622, 2002.



Low energy and momentum transfer photonuclear reactions

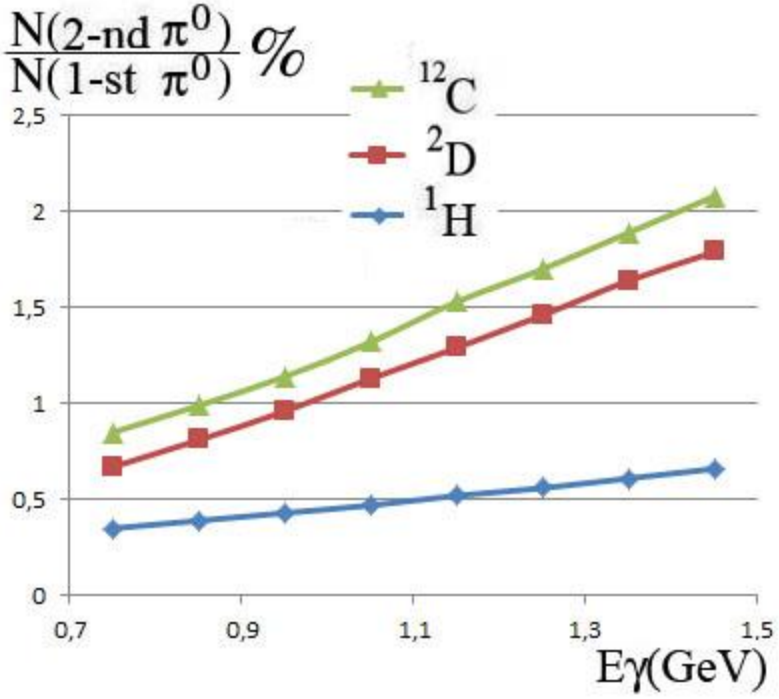


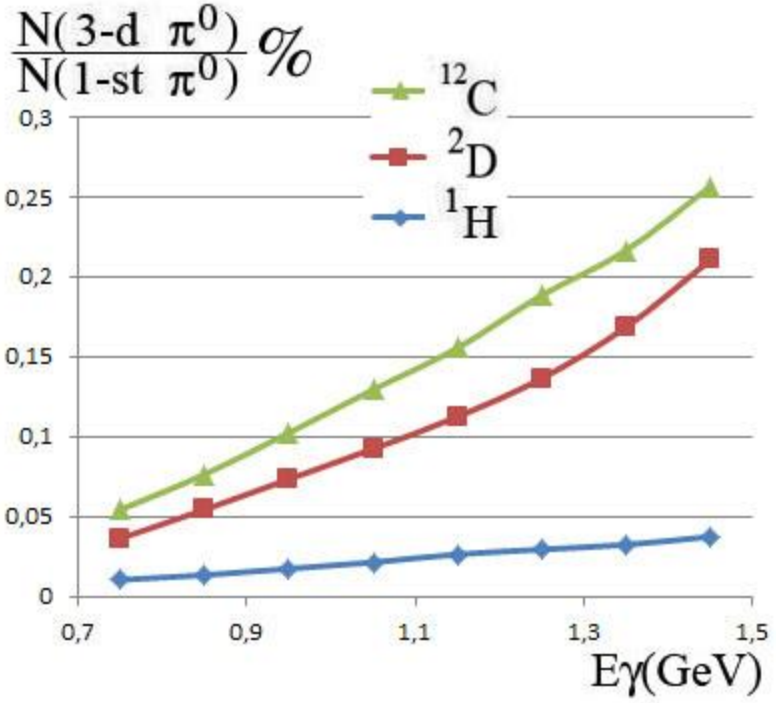


Probability of γ,xf reaction on U target

D.Ivanov e.a. Rus.J. Nucl.Phys. ЯФ 55, 1 (1993) 3.

GRAAL prelimiary data





Thanks for attention