Dynamics of nuclear cascades in photoproduction of light neutral mesons

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GENERAL MOTIVATION

To answer the questions :

– How unstable mesons (π^0, η, ρ, ω etc) interact with nuclear media, in what reactions, what are the interaction products etc ?

  Different theoretical models are trying to subtract such information .

– We propose to study elastic and inelastic interactions of unstable mesons and nucleons with nuclear media by the model independent way, directly in the experiment.

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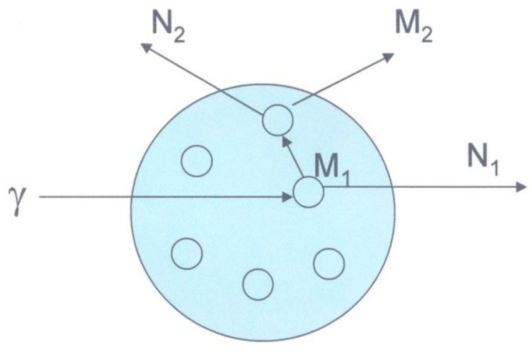
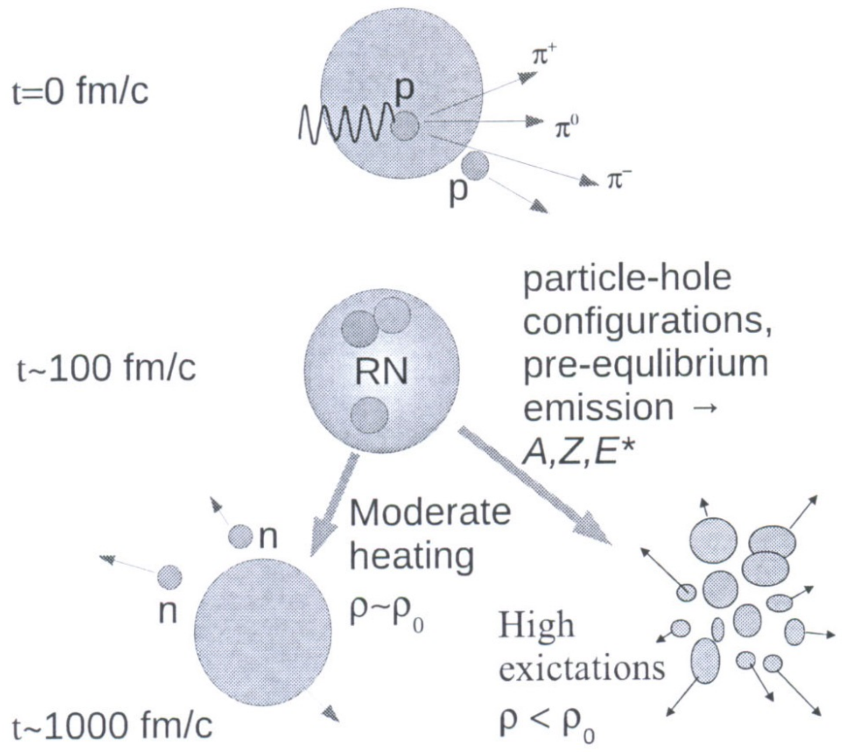


Experimental facilities (GRAAL, BGO-OD) allow to solve such problems

Theoretical RELDIS predictions:: I.A.Pshenichnov, NP. A940 (2015) 264



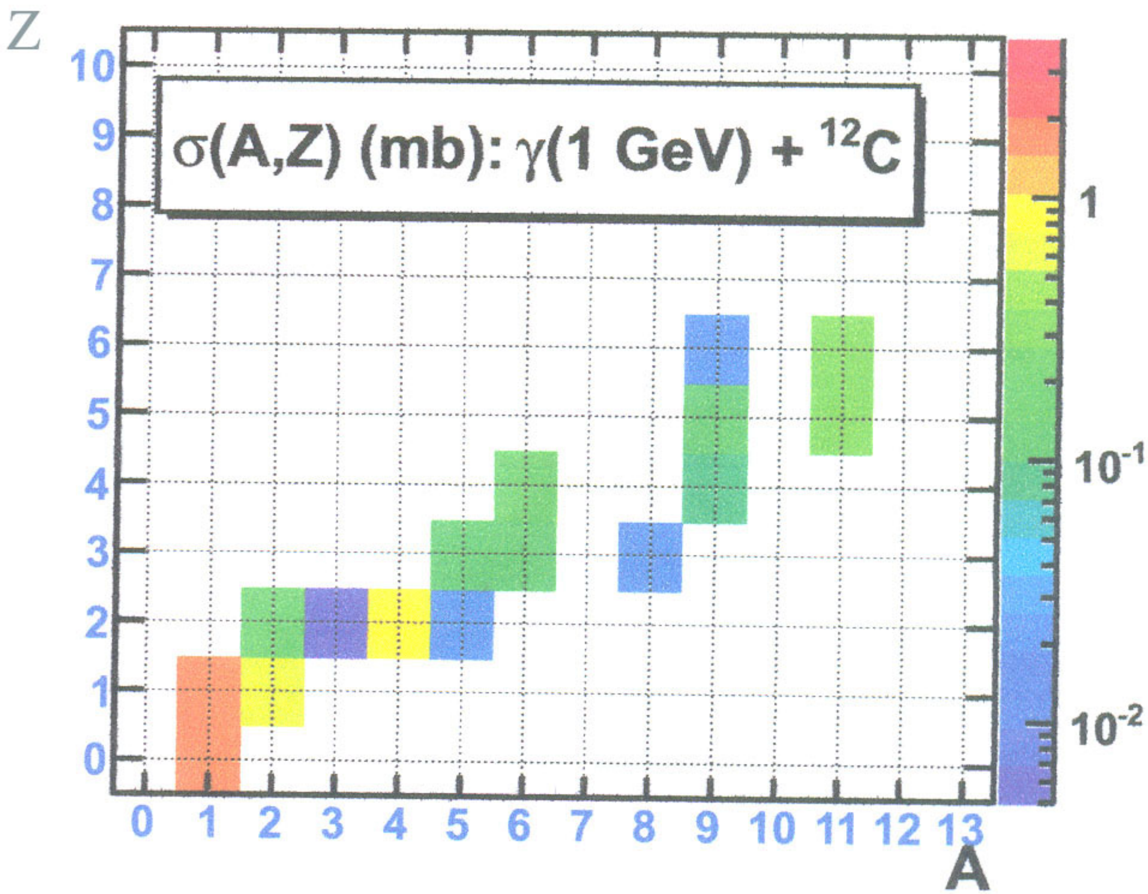
Photon TOF through a nucleus (10 fm diameter) is near $3*10^{-23}$ s,

100 fm/s equals $3*10^{-22}$ s.

Fragmentation of ^{12}C nucleus
by intermediate energy photons

RELDIS simulation : I.A. Pshenichnov , NP A940 (2015) 264

Exclusive process



Inclusive reactions

Selection of the primary recoil nucleon:

(data for C-12 from the GRAAL experiment)

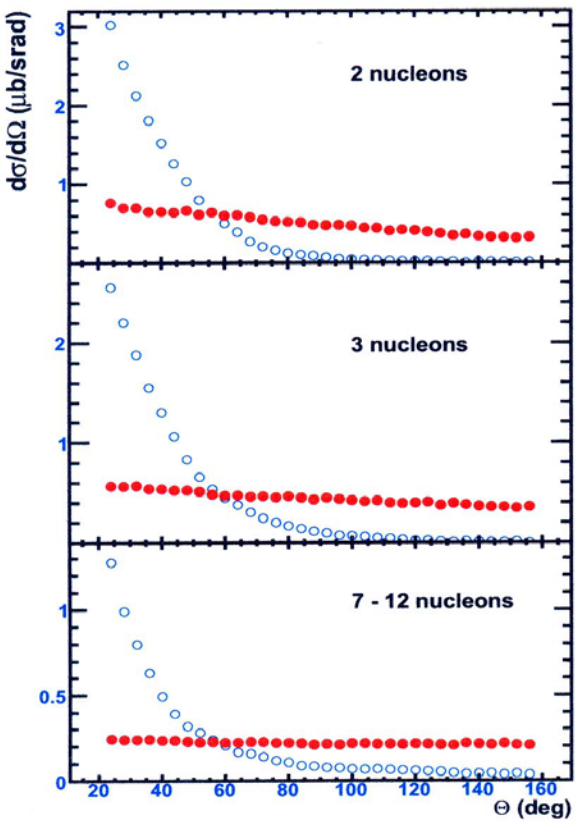


Figure 6: Measured angular distributions of nucleons produced in photodisintegration of ^{12}C in the laboratory system in events with two (top panel), three (middle panel), seven and more fragments (bottom panel). In all cases the angular distribution for the leading most energetic proton in each event is presented by open circles, while the distributions for all other nucleons in the same event are presented by solid circles.

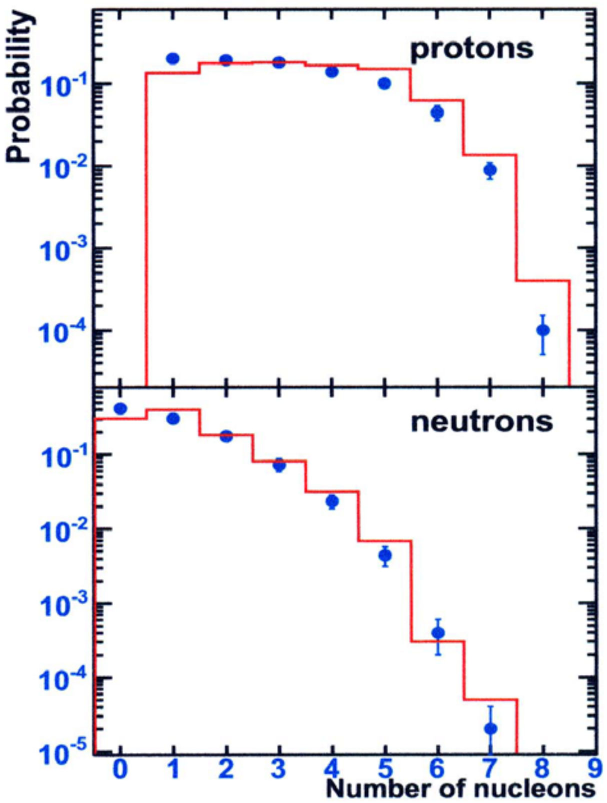
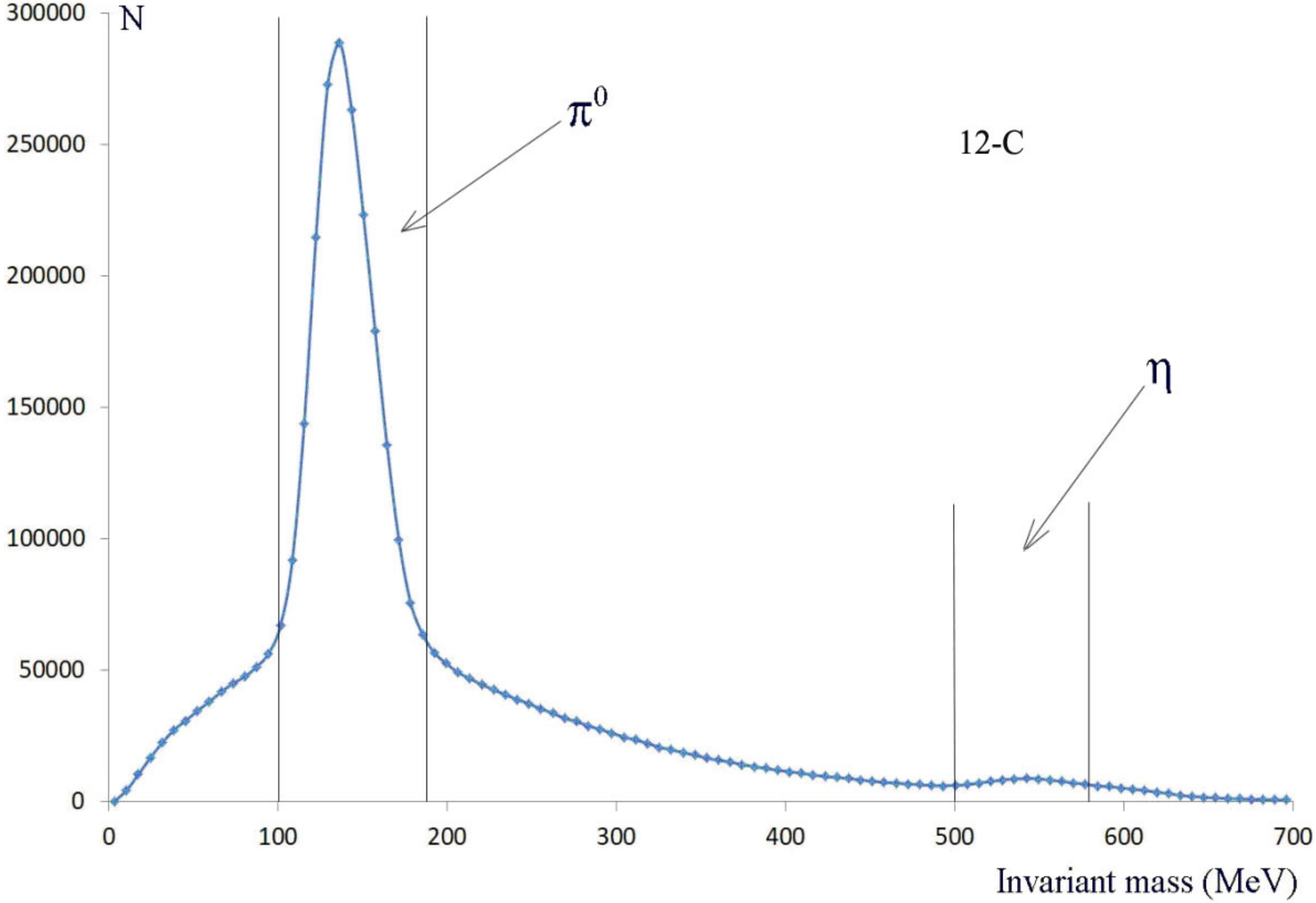


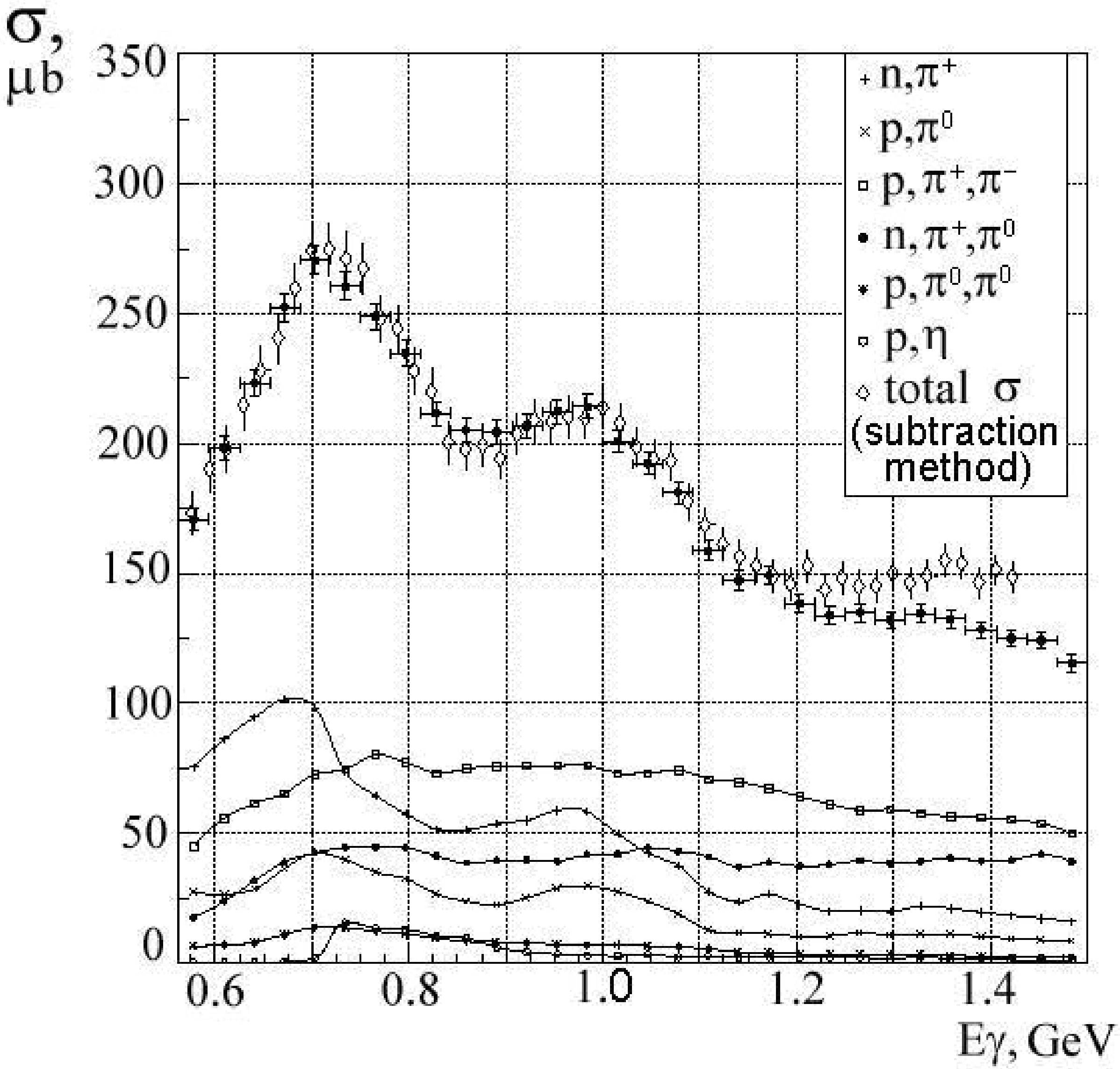
Figure 8: Measured (points) and calculated (histograms) probabilities of photodisintegration events of ^{12}C at 0.7–1.5 GeV with a given number of protons (top) and neutrons (bottom). Only statistical uncertainties of measurements are shown.

ALGORITHM:
Separation of partial meson photoproduction channels using invariant mass analysis and measurement of recoils in coincidences



INC generator

Total photoabsorption [GRAAL data}



History and current status of experimental works

Akhorov O. e.a. JINR **300 GeV p + W** (*Emulsion method*, 1976)

Gorshkov B.L.,e.a **PNPI** , **1 GeV p + Pb,Th,U** (*Emulsion method*, 1983)

Relativistic ions **emulsion method**

P.Zarubin e.a. **JINR**, BECQUEREL collaboration , *Emulsion method*.

A.S.Botvina e.a**.** **GSI** , ***ALADIN*** collaboration

N.Vonta e.a. ***Michigan*** microtron 20 MeV/n [Neutron-rich rare isotope production from projectile fission of heavy beams in the energy range of 20 MeV/nucleon]

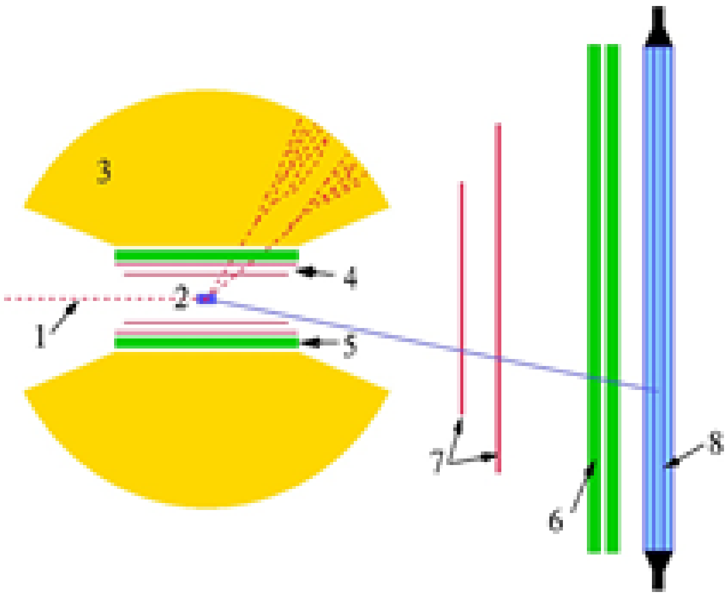
V.A.Karnaukhov e.a**. JINR, GeV p, d, α + Au etc.** (*FASA – spectrometer* 1993-2015).

The multifragmentation time scale is measured for d(4.4 GeV) + Au collisions by the analysis of the relative angle correlation function for the intermediate-mass fragments. Multifragmentation of a target spectator is measured to be 100 fm/c (CL > 99.5%) delayed in relation to the collision moment.

GRAAL EXPERIMENT

LAGRANγE Detector

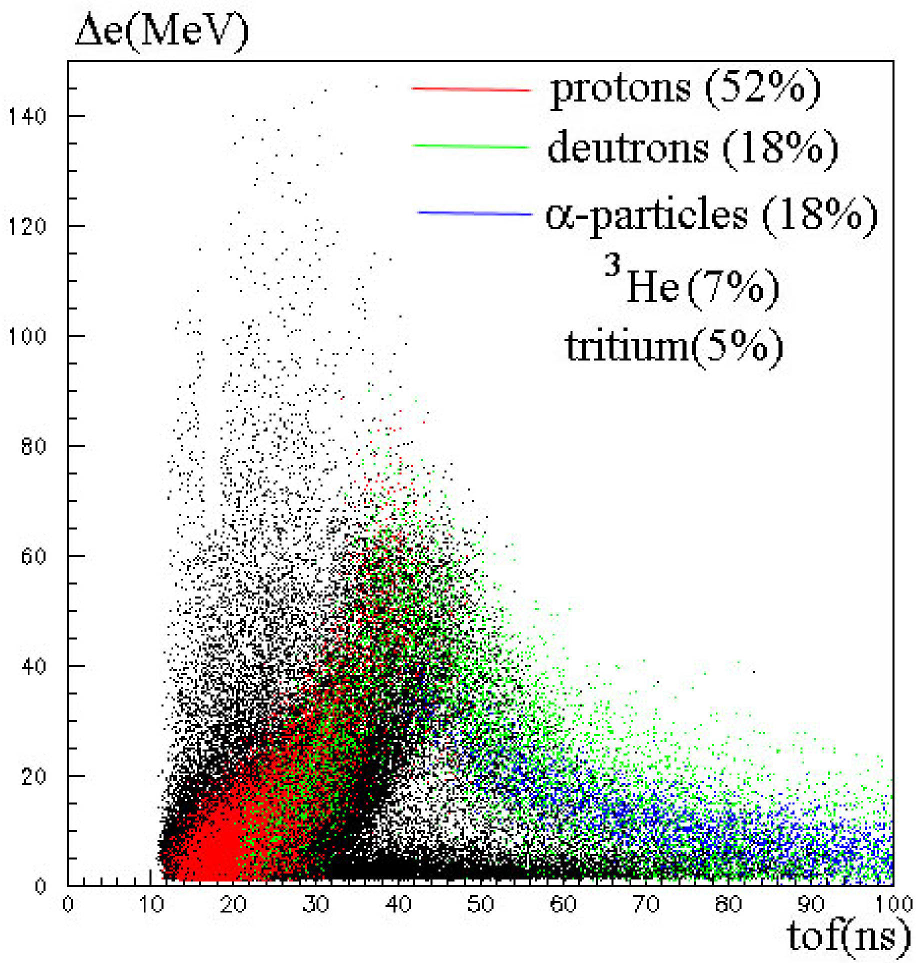
1: Compton gamma beam , 2: Liquid H2/D2 target , 3: BGO Calorimeter
4: Cylindrical MWPC's , 5: Plastic Barrel , 6: Plastic Wall, 7:Plane MWPCs, 8: Shower Wall



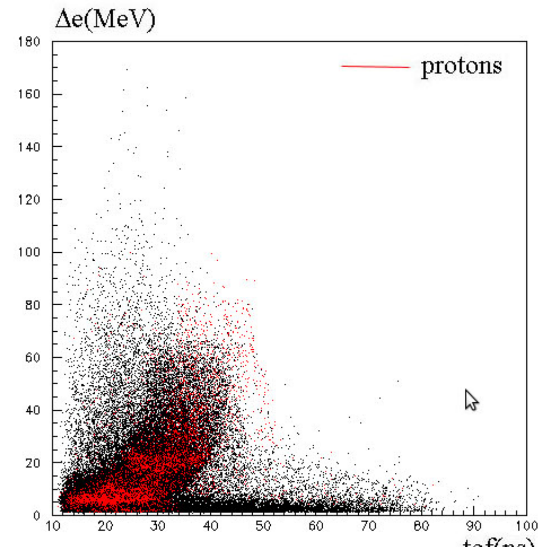
- <u>Shower Wall</u>
- neutron efficiency 20 %
- γ / neutron PID

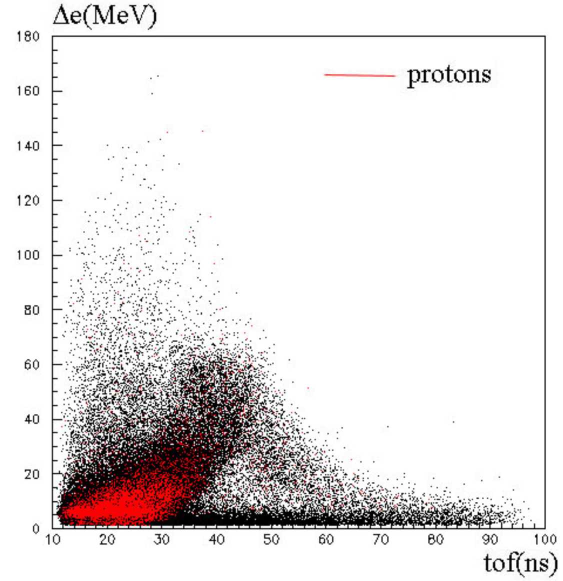
Simulations :

12-C



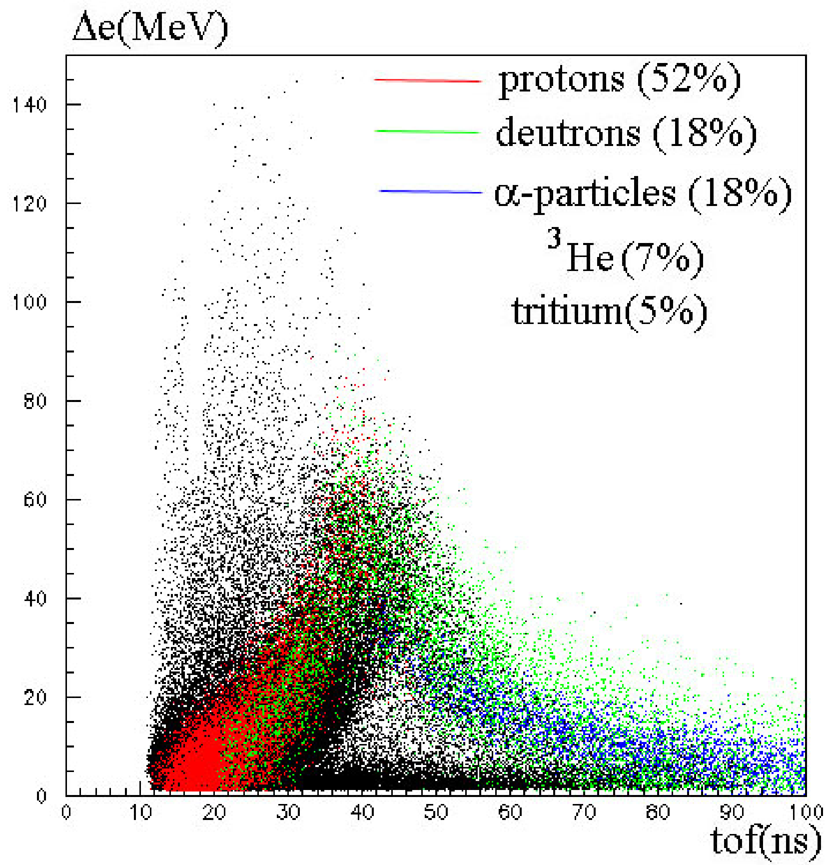
proton and deuteron

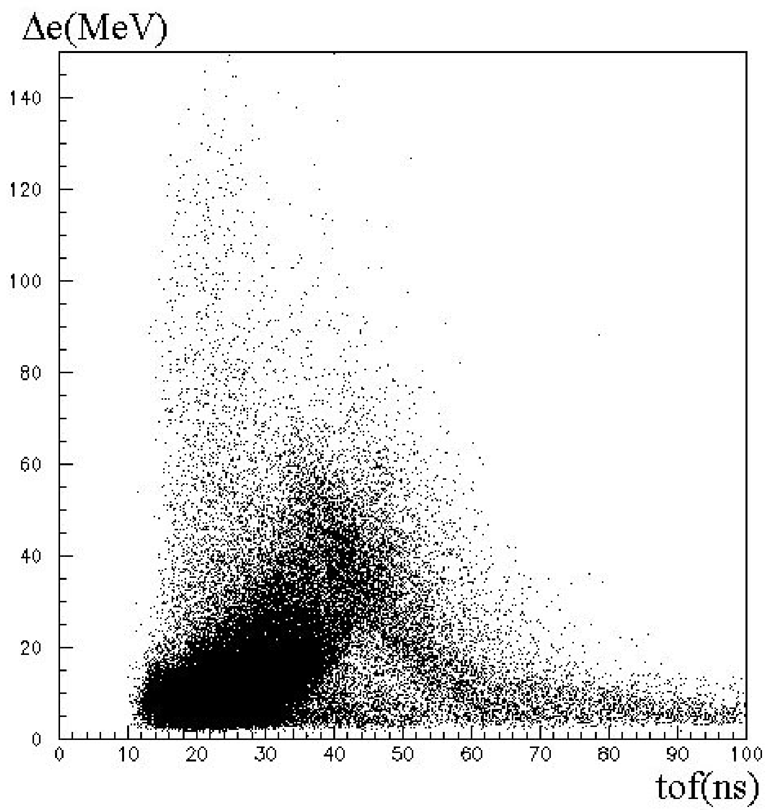




Simulation and experiment

12-C target





BGO-OD at ELSA

Principal improvement as compared with GRAAL can be done due to the magnetic spectrometer placed downstream of the target to distinguish charge mesons, protons, deuterons and other charge products.

Cherenkov counter

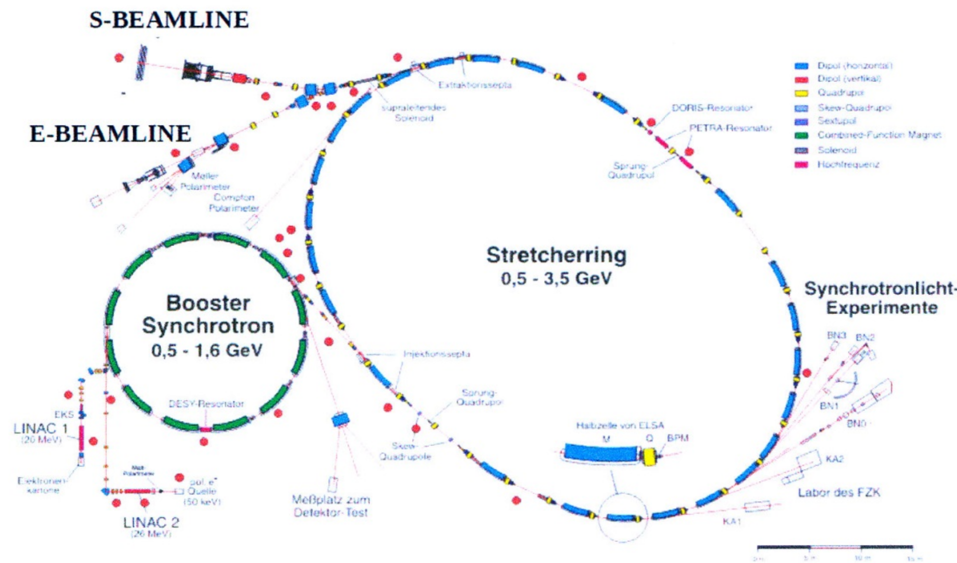
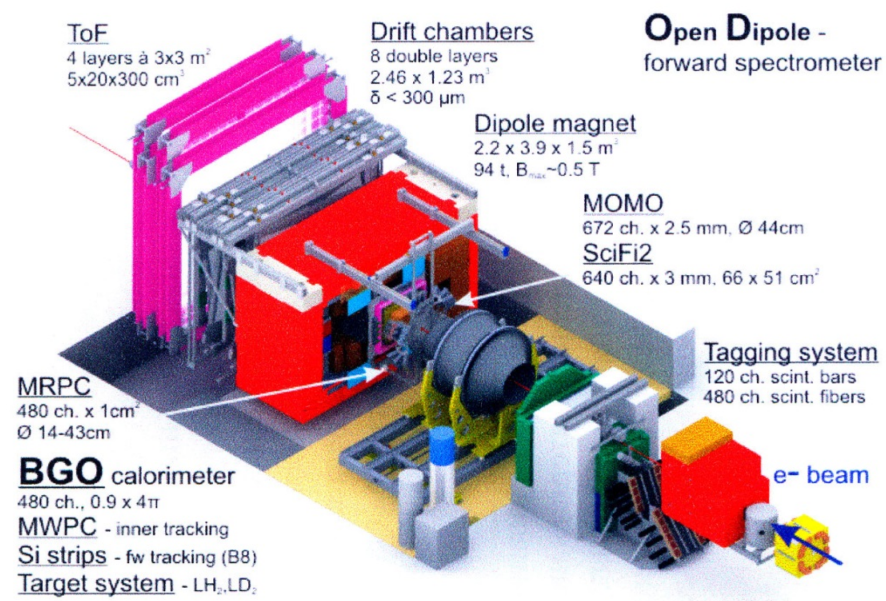


Figure 1. Elsa Facility.



Preliminary results

Missing mass recoiling from a forward K^+ Momentum range of 500 - 800 MeV.

a – all data

b – p in BGO

c – p 0 & at least one additional charged particle.

d - at least two additiona charged particles

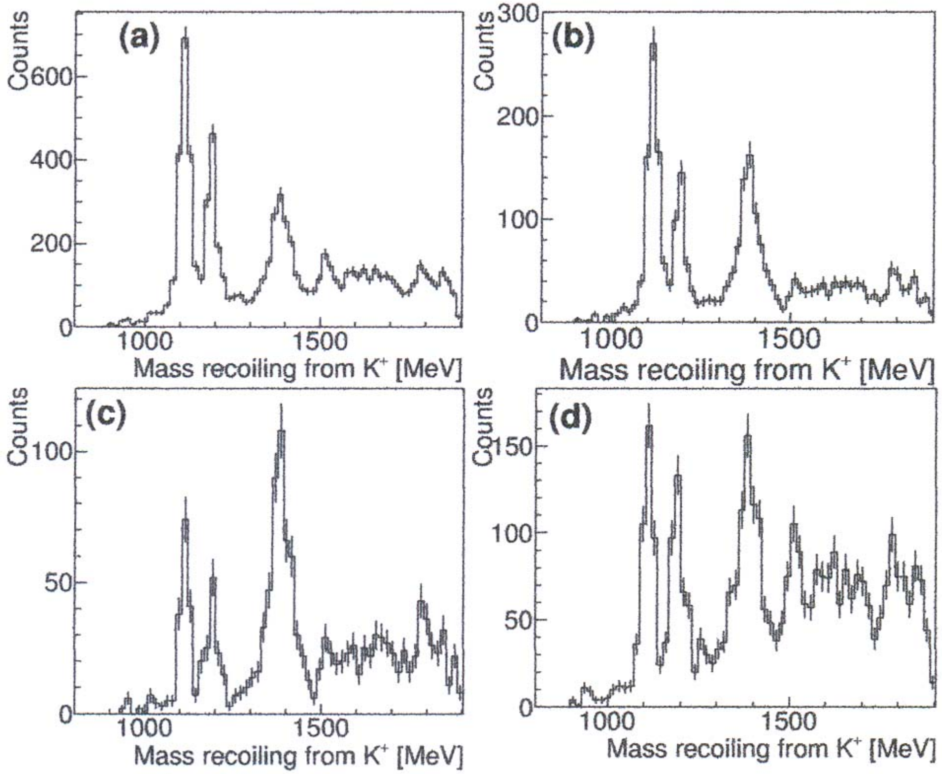
Λ**(s=-1)** : 1115 MeV

(S_{01}) 1405

12 resonances

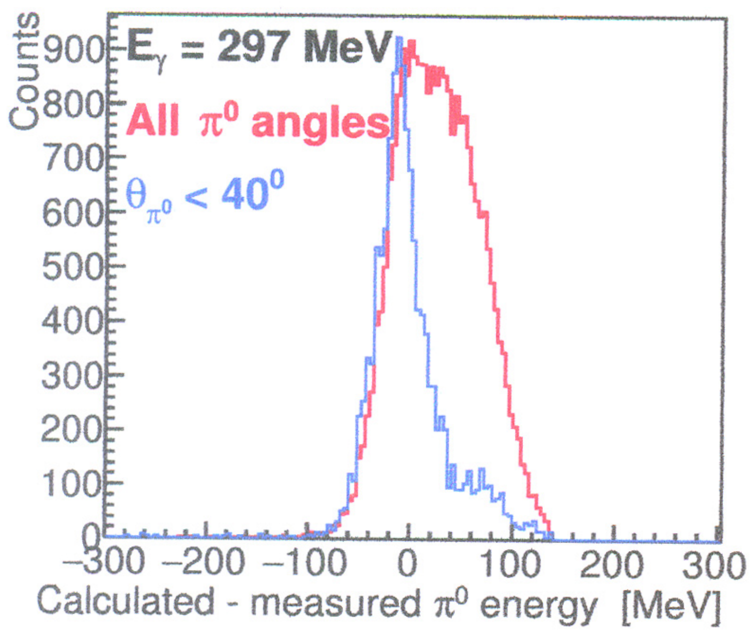
1500 - 2350 MeV

Σ^0 **(s=-1)** 1192 MeV



Coherent photoproduction off carbon.

Potential opportunities in hypernuclei research.



Difference between calculated and measured p^0 energy with a beam energy of 297 MeV for all angles and polar angles smaller than 40^0.

A peak at zero indicates coherent events.

Recoil nucleon is a tagger of the partial meson photoproduction

Multiplicity **n = 1**

Nuclear elastic scattering reactions induced by unstable mesons, The recoil nucleon is emitted fin forward direction .

n=2

Inelastic interactions; first candidate could be ηn -> $\pi^- p$, search for bound states of mesons with a nucleus.

n > 2

Multifragmentation - phase transition between nuclear matter and gas of nucleons and fragments.

n = 0

Coherent interaction - Debruck scattering. Low energy and momentum transfer photofission reactions etc.

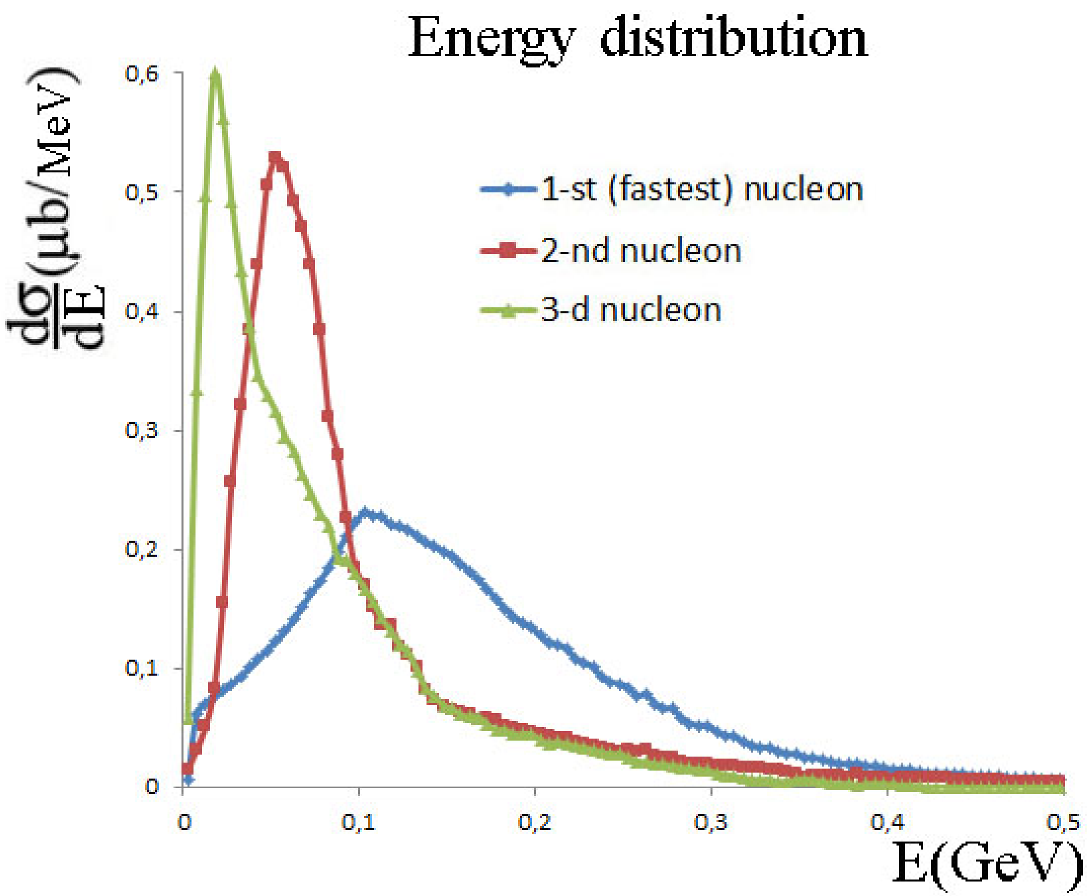
- Polarization effects can play an important role in such kind experiments.

Study of ηn -> $\pi^- p$ reaction in ^{12}C nucleus using recoil protons as a tagger, based on photo-multi-disintegration measurement

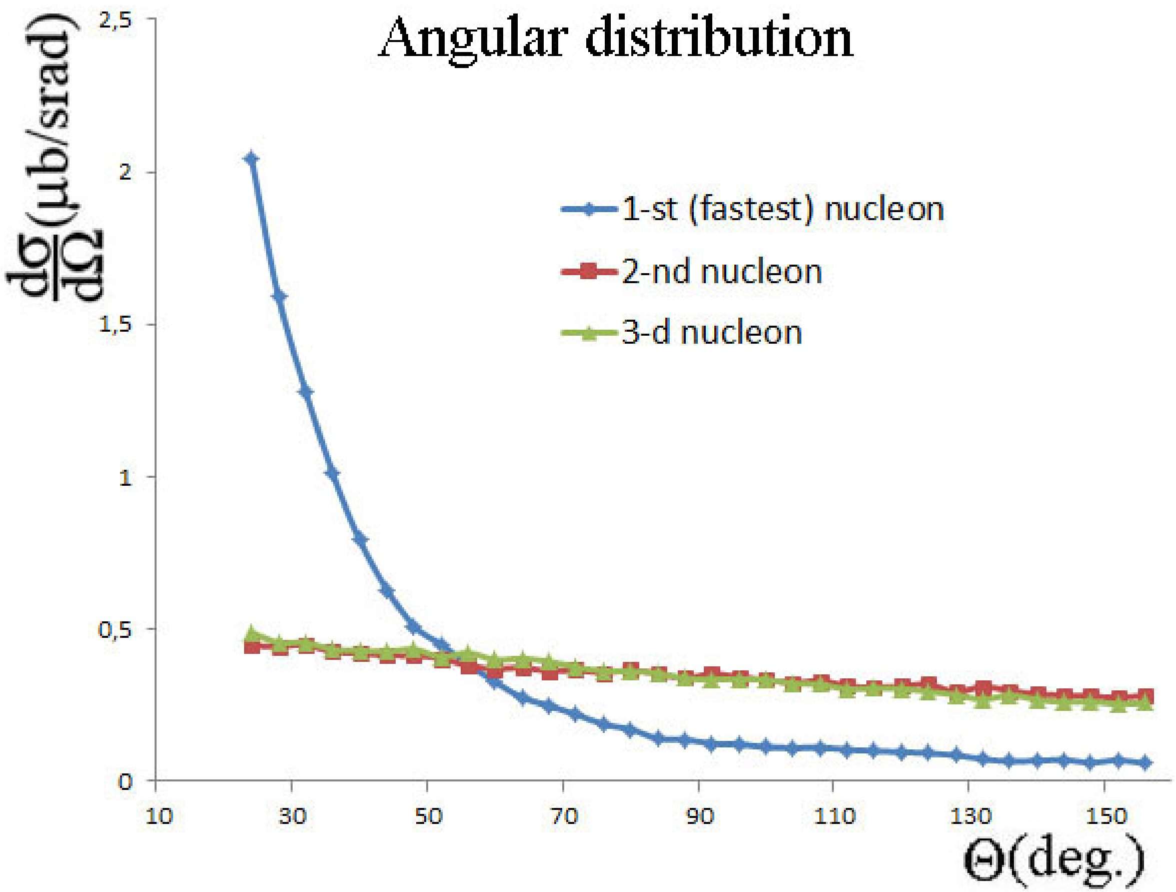
A.Lapik, A.Mushkarenkov, V.Nedorezov, A.Turinge, N.Rudnev
for GRAAL & BGO-OD collaborations

Institute for Nuclear Research, RAS, Moscow

Principal feature to select the primary recoil proton: BGO energy loss distribution



Selection of the primary recoil nucleon: angular distribution

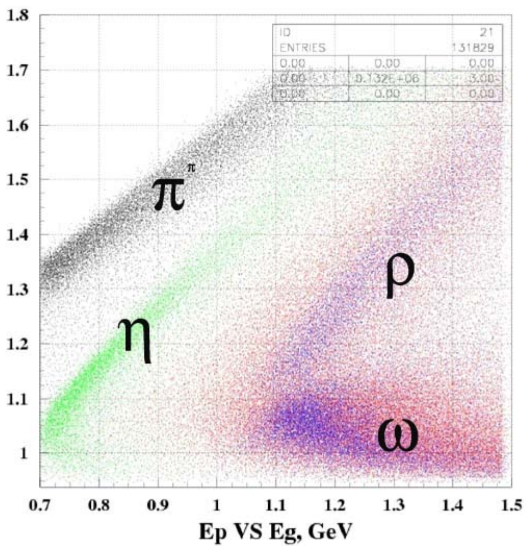


Meson Tagging by recoil protons: Simulation for ^{14}N

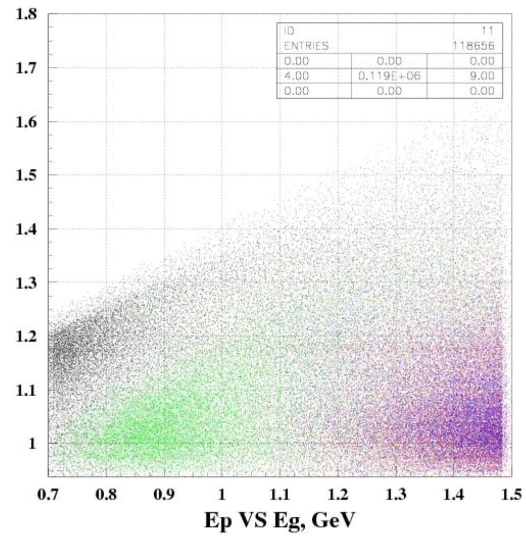
Variable parameters Ep, $E\gamma$, Fixed parameter θ_p

Ideal case: (no backgrounds, ideal resolution but intranuclear cascade is included) :

$2^0<\theta_p<10^0$



$2^0<\theta_p<40^0$

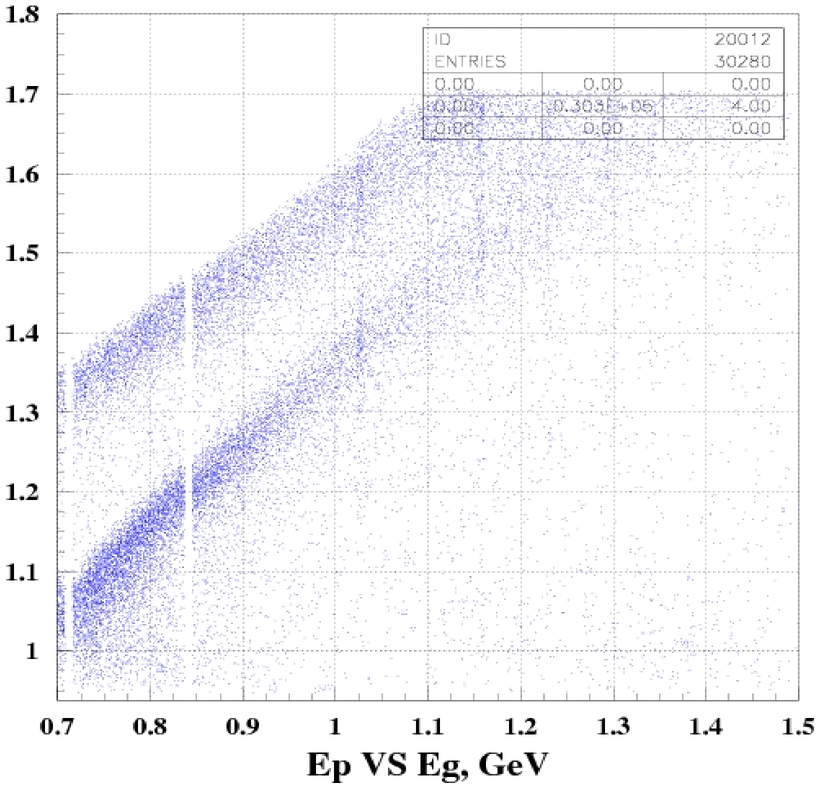


Multiple ($n \leq 4$) meson production and INC is included

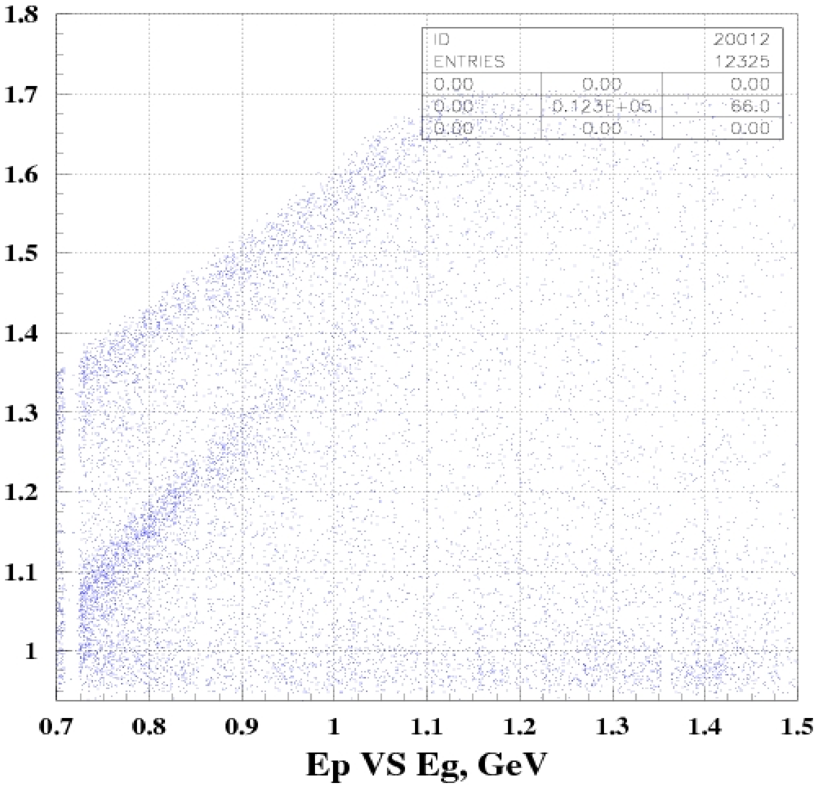
A.Ignatov e.a. New experimental and simulated results on nuclear media effects in meson photoproduction off nuclei. Prog.Part.Nucl.Phys.(2008) 61:253-259,2008.

•First GRAAL experimental results
•Deuteron target
•2^0<theta<10^0

•simulation



•Experiment
•Kinematics is not included

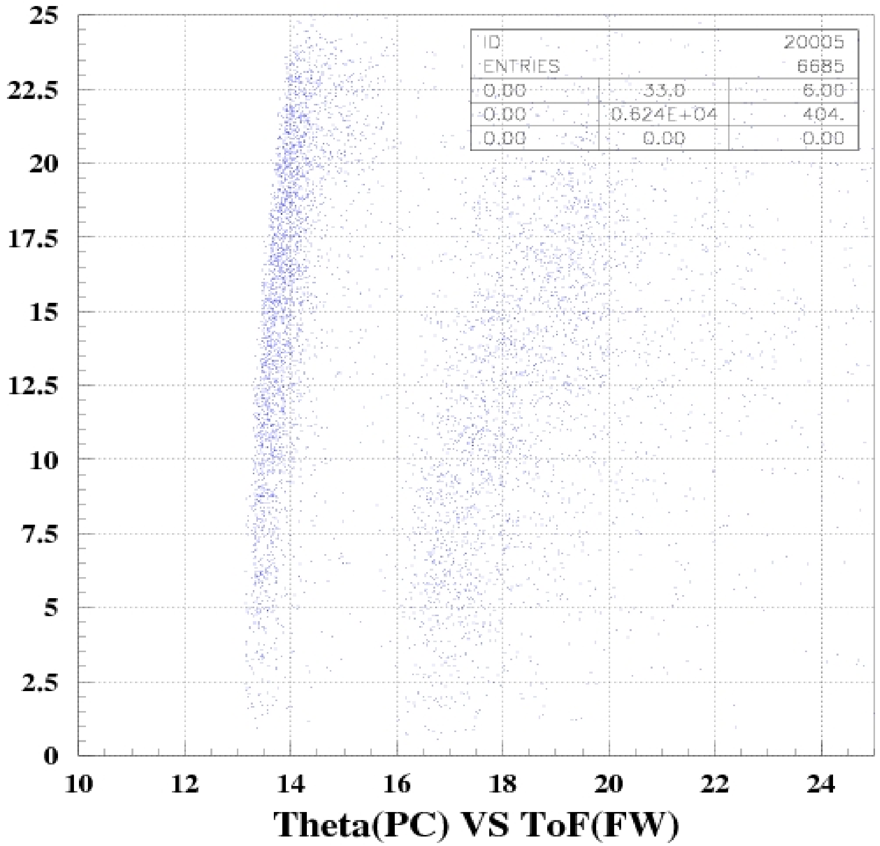


Separation of π^0 and η meson production by the recoil proton from C-12

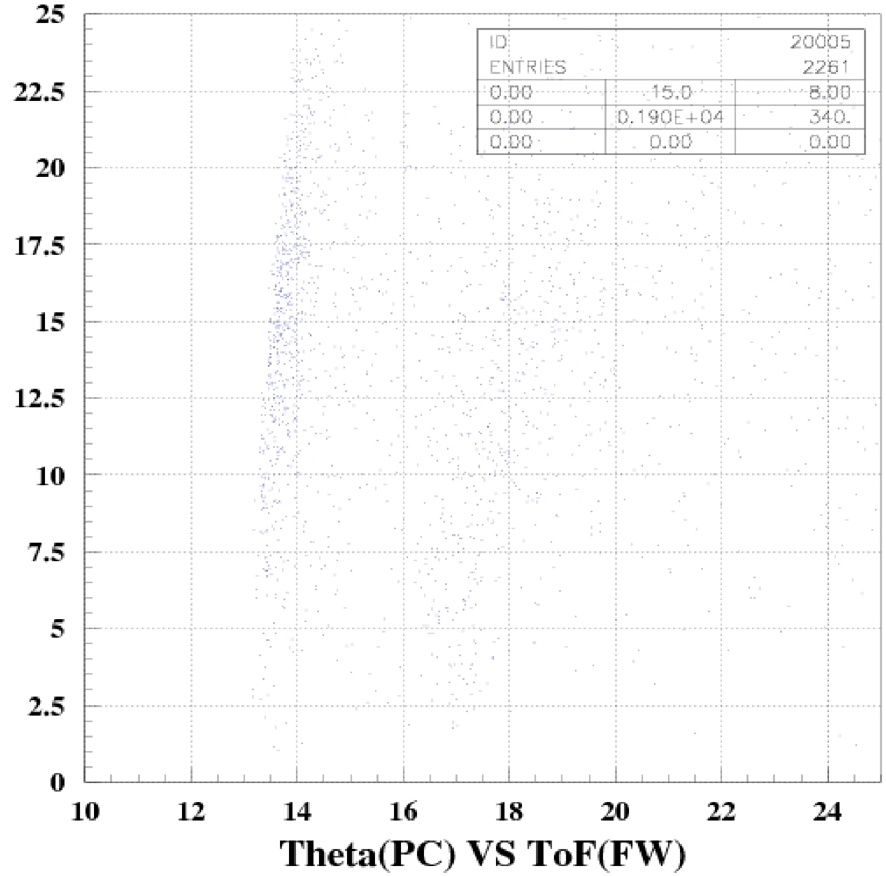
Number of the charged tracks in forward >= 1 Number of the neutral clusters in BGO = 2

Egamma = 790-810 MeV

simulation



experiment

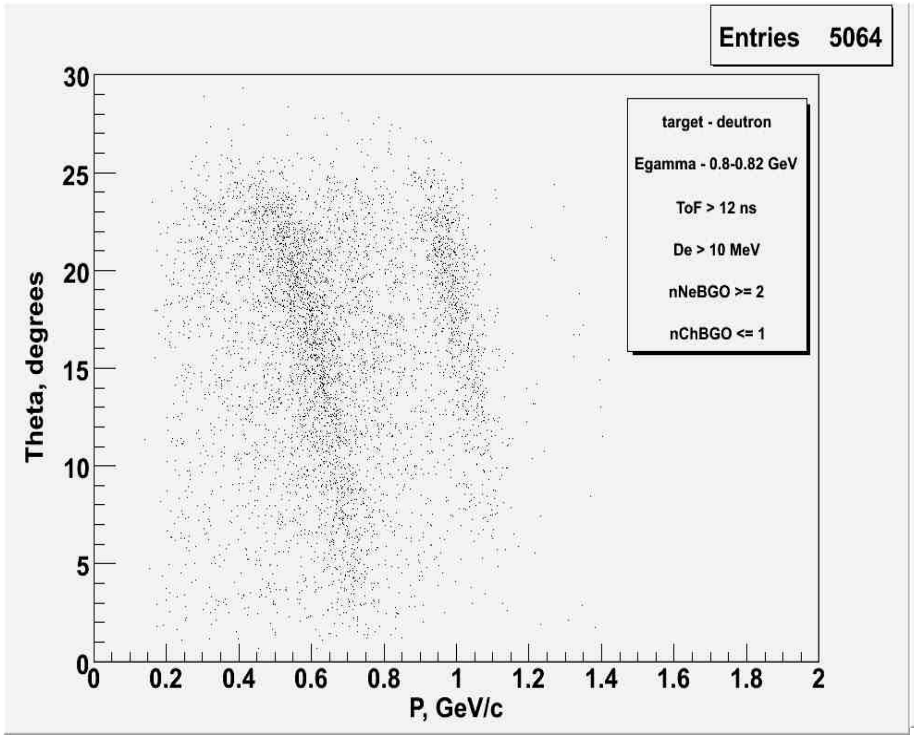


Separation of π^0 and η meson production by the recoil proton

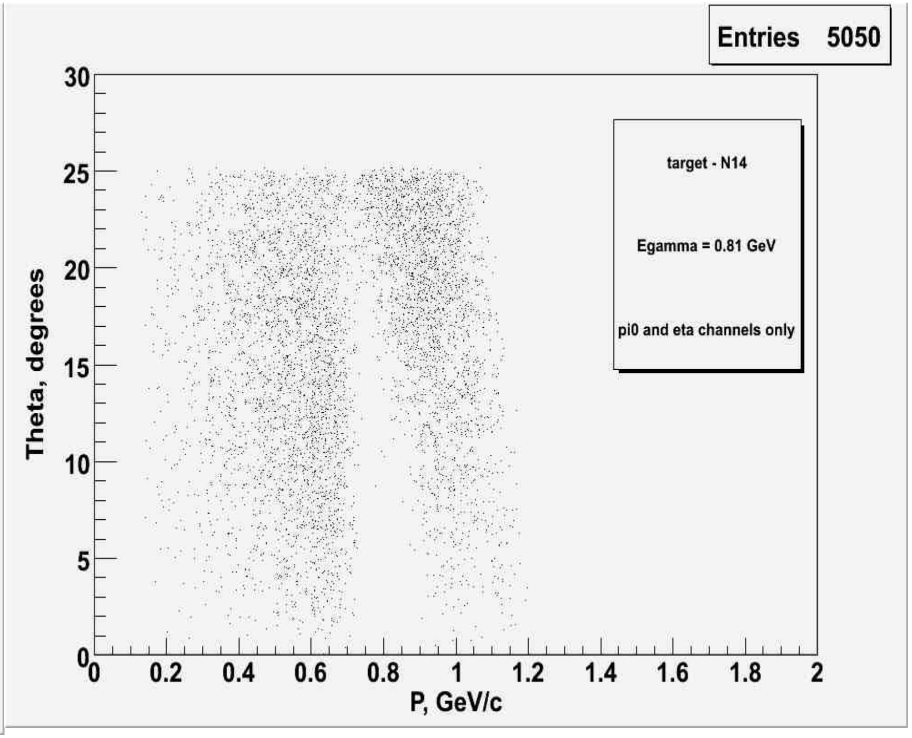
Number of the charged tracks in forward = 1 Number of the neutral clusters in BGO = 2

Angle vs momentum correlation of primary recoil proton

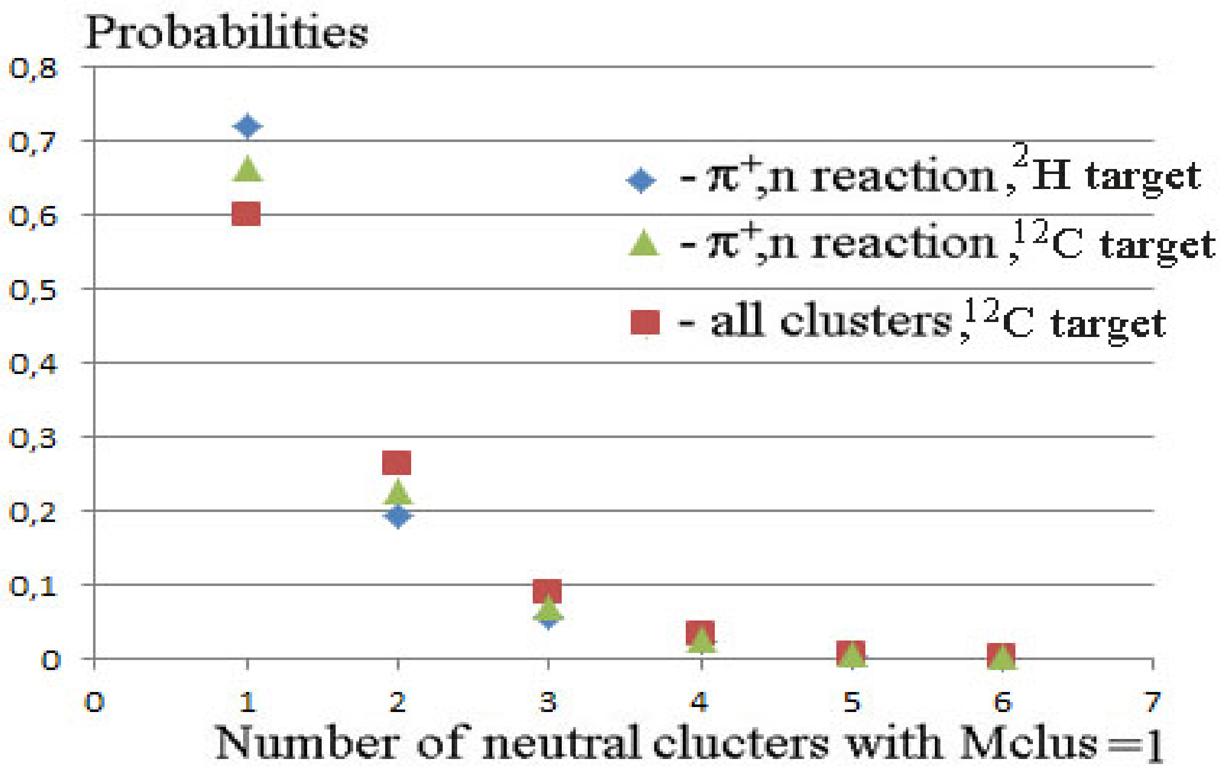
Experiment on deutron

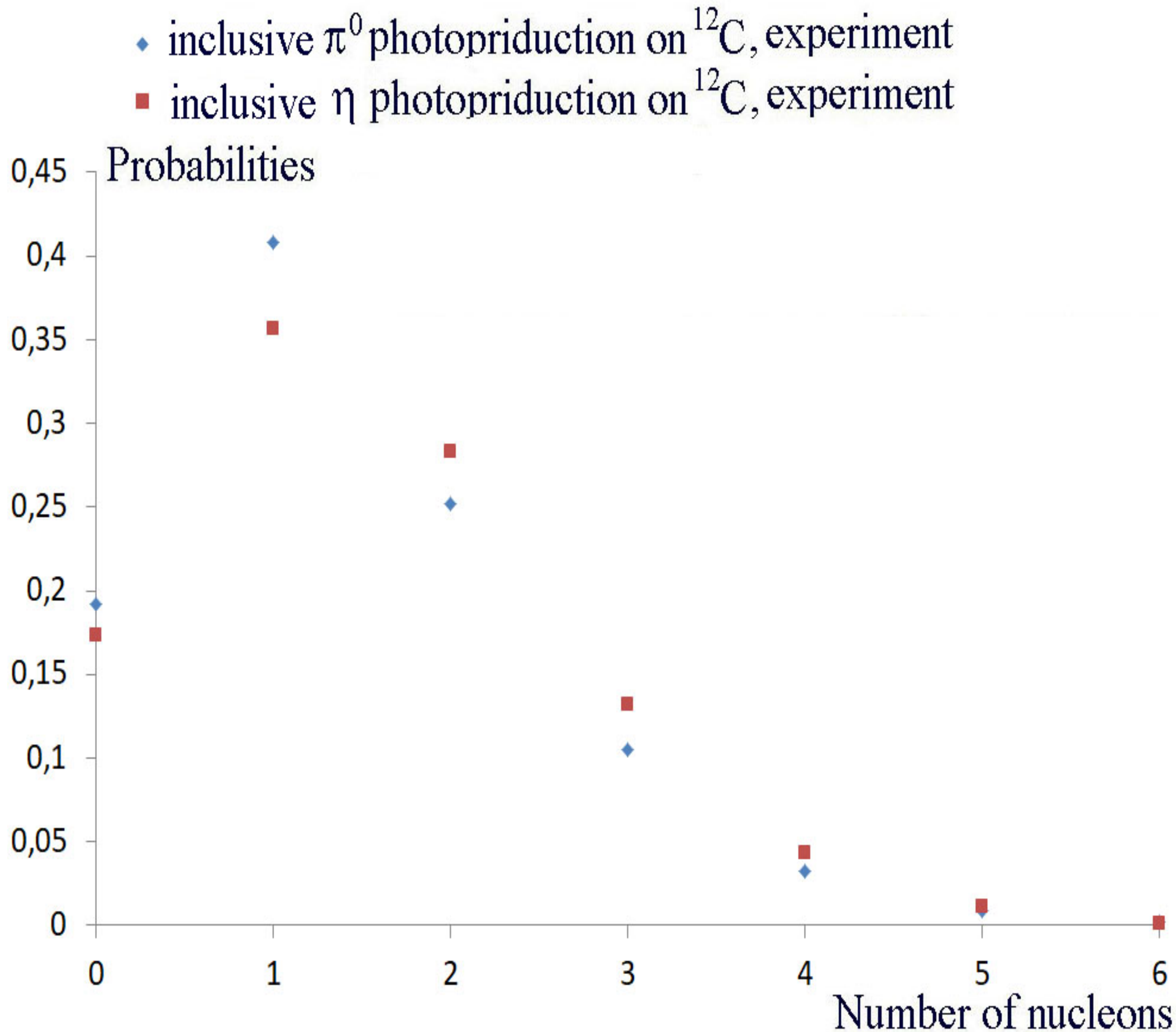


Simulations with INC code on ^{14}N nucleus

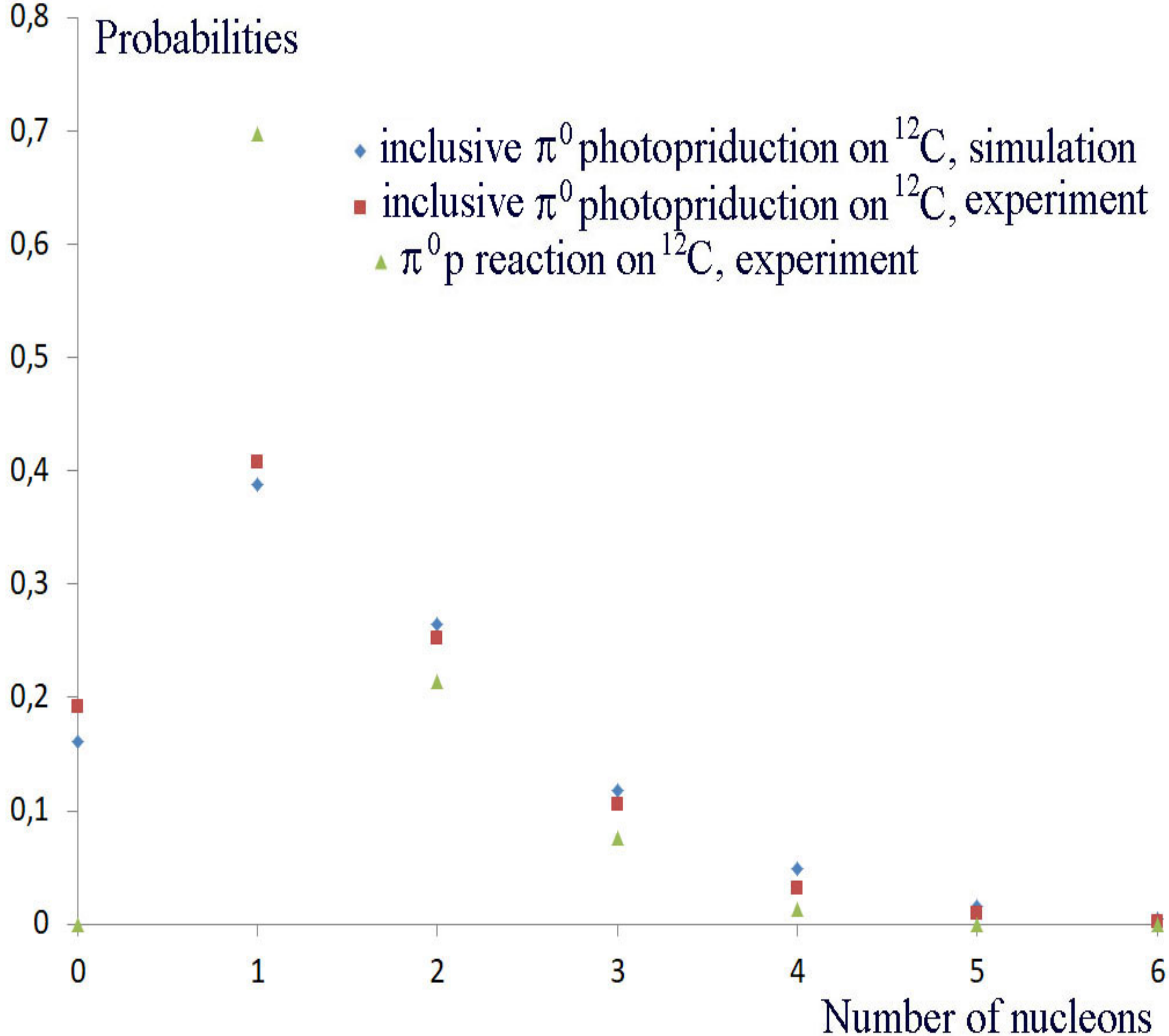


Probability of neutral cluster (neutron) production in different partial reactions [GRAAL results]





inclusive π^0 photopriduction on ^{12}C, experiment
inclusive η photopriduction on ^{12}C, experiment
Probabilities
0,45
0,4
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
0
1
2
3
4
5
6
Number of nucleons



Probabilities
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
inclusive π0 photopriduction on 12C, simulation
inclusive π0 photopriduction on 12C, experiment
π0p reaction on 12C, experiment
0
1
2
3
4
5
6
Number of nucleons

Real and virtual photon experiments

GRAAL BECQUEREL(JINR)

	Real photons		Virtual photons (Coulomb dissociation)	
	^{12}C (simulation)	^{12}C (experiment)	^{12}N [12]	^{11}C [12]
Протон	52 %	53 %	184 (68 %)	204 (48 %)
Дейтрон	18 %	20 %	0	0
H-3	5 %	18 %	0	0
He-3	7 %	5 %	0	0
He-4	18 %	4 %	75 (32 %)	221 (52 %)

Transparency of nuclei for η-mesons in **Glauber model with eikonal approximation**

[P.Muhlich, U.Mosel, NP A 773 (2006) 156]

Definition
$$\tilde{T}_A = \frac{\sigma_{\gamma A \to \eta' A'}}{A \sigma_{\gamma N \to \eta' N}} \, .$$

Normalized to ^{12}C

$$T_A = \frac{\pi R^2}{A\sigma_{\eta' N}} \left\{ 1 + \left(\frac{\lambda}{R}\right) \exp\left[-2\frac{R}{\lambda}\right] + \frac{1}{2}\left(\frac{\lambda}{R}\right)^2 \left(\exp\left[-2\frac{R}{\lambda}\right] - 1\right) \right\}$$

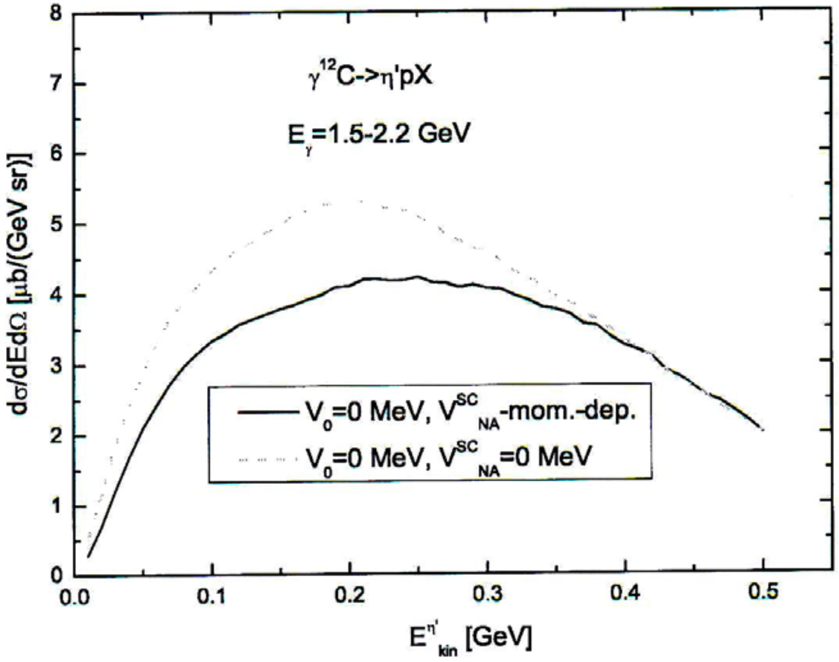
Evaluated inelastic $\sigma_{\eta' n} = 10.3 \pm 1.4$ mb.

[M.Nanova e.a.(BGO-OD collaboration) Phys.Lett. B710 (2012) 600-606]

Numerous data on A-dependence of meson photoproduction are available :
V.Nedorezov, Yu.N.Ranyuk. Photofission above the giant resonance. Naukova dumka, Kiev, 1989.

Differential cross section for η’ + ^{12}C in the full solid angle vs $E^{\eta'}_{kin}$
for momentum dependent nuclear potential
(in coincidences with protons within $\theta = 1^0 - 11^0$)

E.Ya.Paryev, Study of in-medium η’ properties in the (γ,η’p) reaction on nuclei.
arXiv:1503.09007 [nucl-th], Mar 31, 2015



Perspectives

- Difference in real and virtual photon fragmentation ,
- Exotic fragment production,
- Time scale of nuclear dynamics in separated photoproduction channels,
- Nuclear reactions induced by short living mesons.

Conclusion:

Positive features of the PHOTON beam can be realized :

- **nucleus is transparent for photons (universal curve) ,**
- **background reactions (elastic and multiple scattering of projectiles) are negligible,**
- **multiplicity of products is relatively small.**

Modern photonuclear facilities like BGO-OD at Bonn are suitable to solve the assigned tasks.

Thank you for attention