PROGRESS IN EXPERIMENTAL STUDIES OF THE BGO-OD COLLABORATION AT BONN

V. Nedorezov for the BGO-OD collaboration

INR RAS, Moscow

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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.

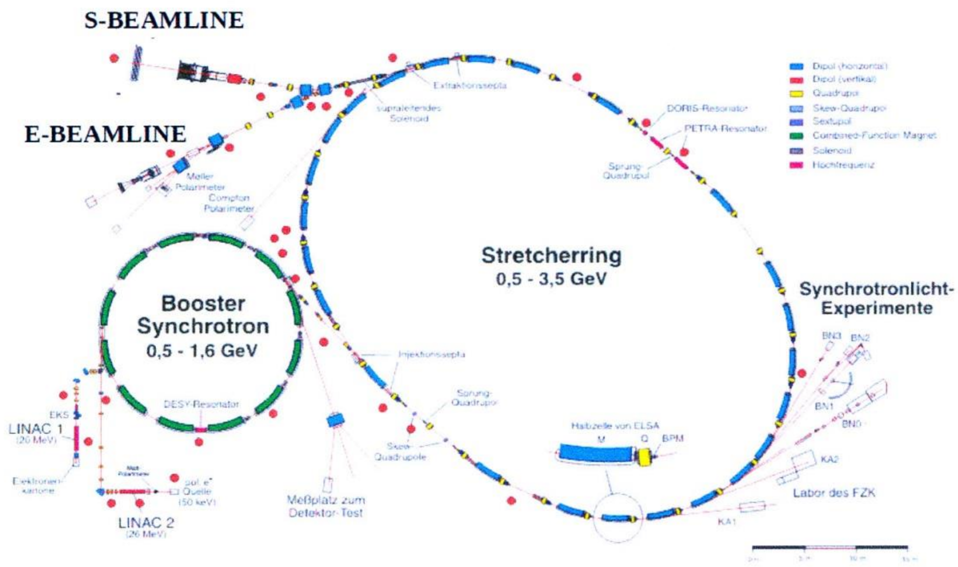
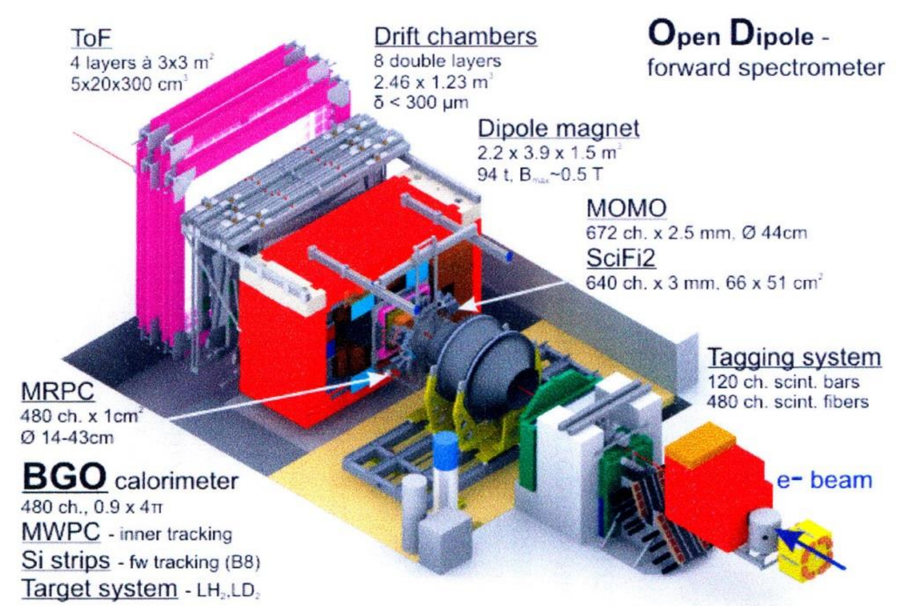


Figure 1. Elsa Facility.



General Information

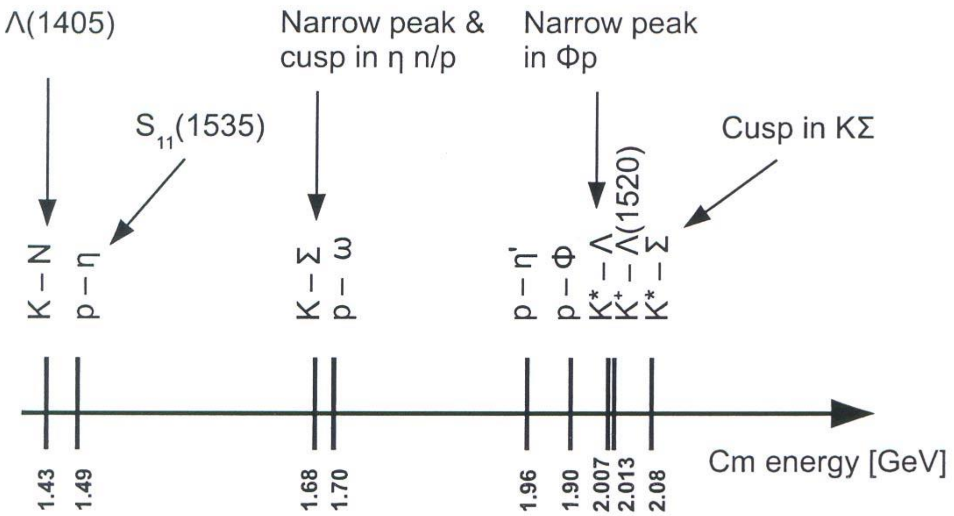
T. Jude The proceedings from the recent HYP2018 conference

- The BGO-OD experiment at the ELSA accelerator facility uses an energy tagged bremsstrahlung photon beam to investigate the excitation spectrum of the nucleon. The setup consists of a highly segmented BGO calorimeter surrounding the target, with a particle tracking magnetic spectrometer
- at forward angles. BGO-OD is ideal for investigating the photoproduction of hadrons of non-zero strangeness. The high momentum resolution at forward angles covers a kinematic region.
- where t-channel exchange mechanisms play a dominant role. Access to this low momentum transfer region also allows the investigation of degrees of freedom not derived from constituent.

Strangeness Photoproduction at the BGO-OD Experiment

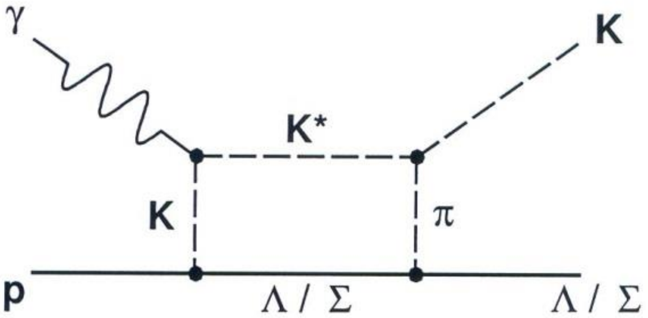
Meson-baryon dynamics may be expected to be especially important at thresholds, e.g. through (subthreshold) re-scattering effects.

Many unresolved structures seem associated with such production or decay thresholds,

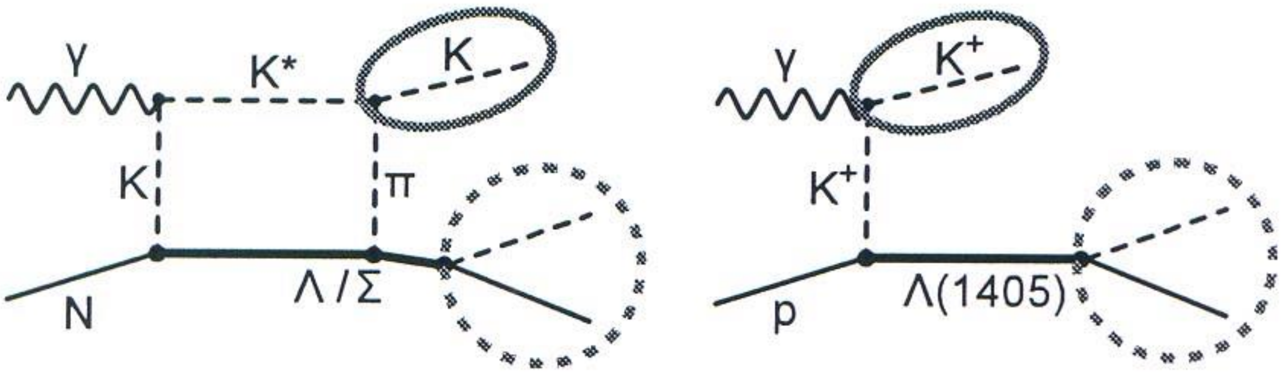


Strangeness Photoproduction at the BGO-OD Experiment

t-exchange diagram for K^0 photoproduction with an intermediatee K* and pion rescattering through subsreshold decay.



Strangeness Photoproduction at the BGO-OD Experiment



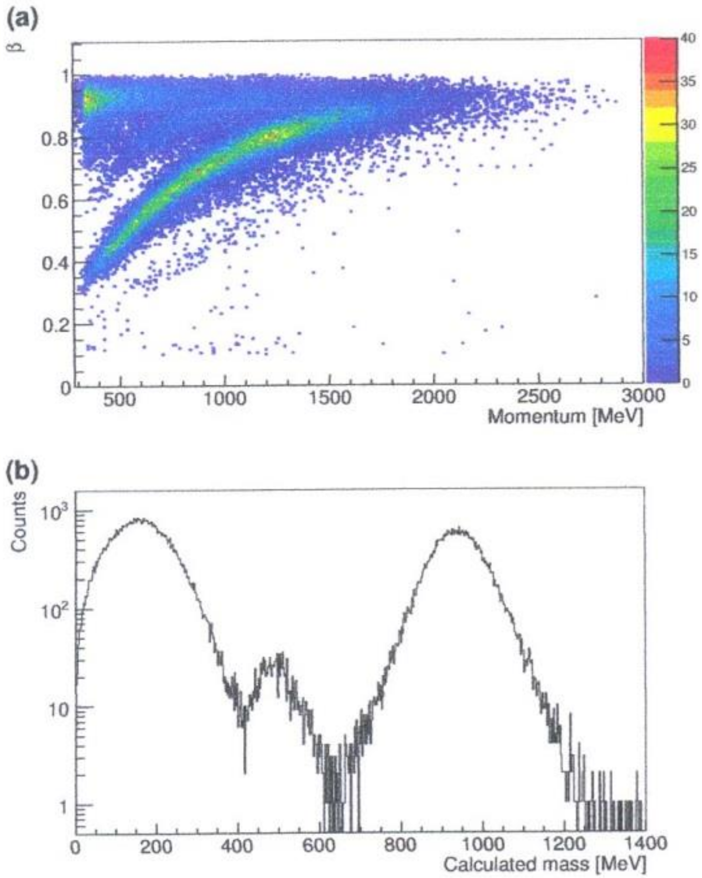
Kinematics of characteristic K^+, K^0 photoproduction

Strangeness Photoproduction at the BGO-OD Experiment

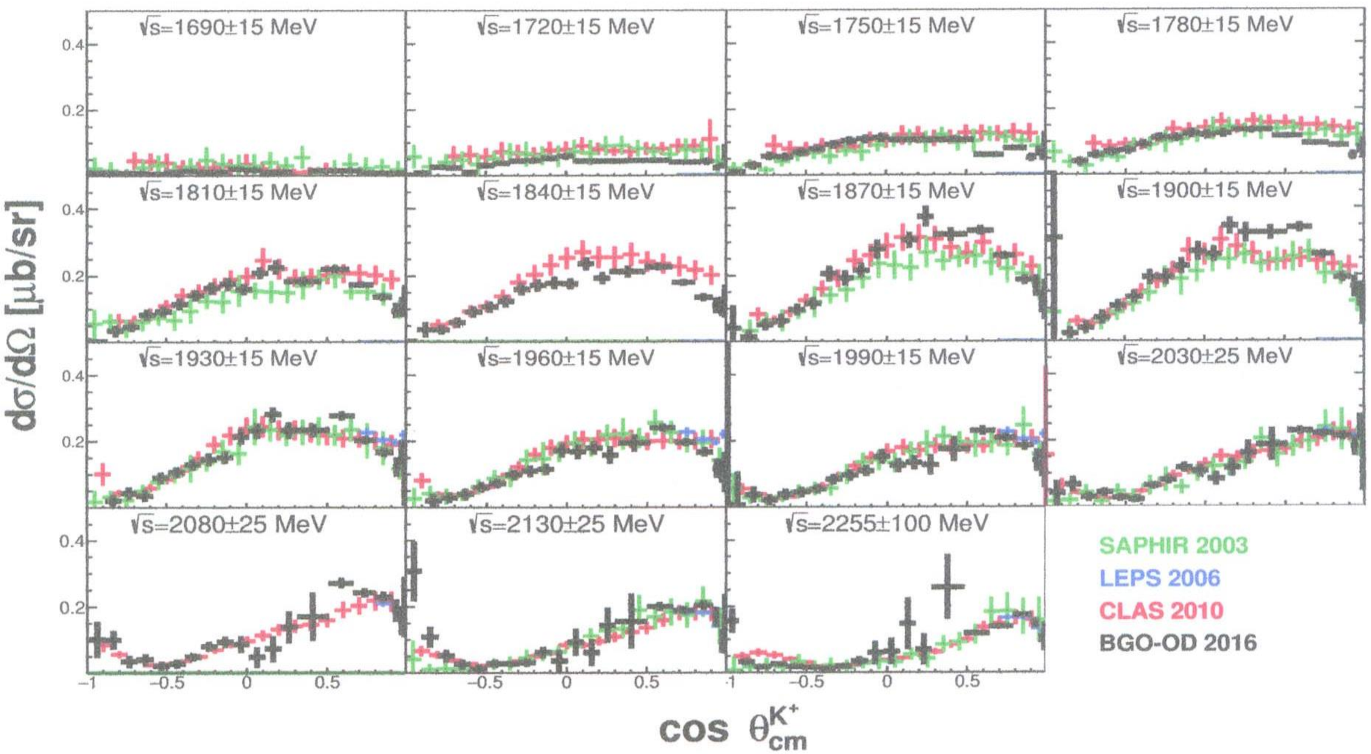
K$^+$ selection in the forward spectrometer.

a – β vs momentum for positively charged particles.

b – separation of K$^+$, pions and protons



Preliminary results



$\gamma p \to K^+ \Sigma^o$ differential cross sections

in comparison with

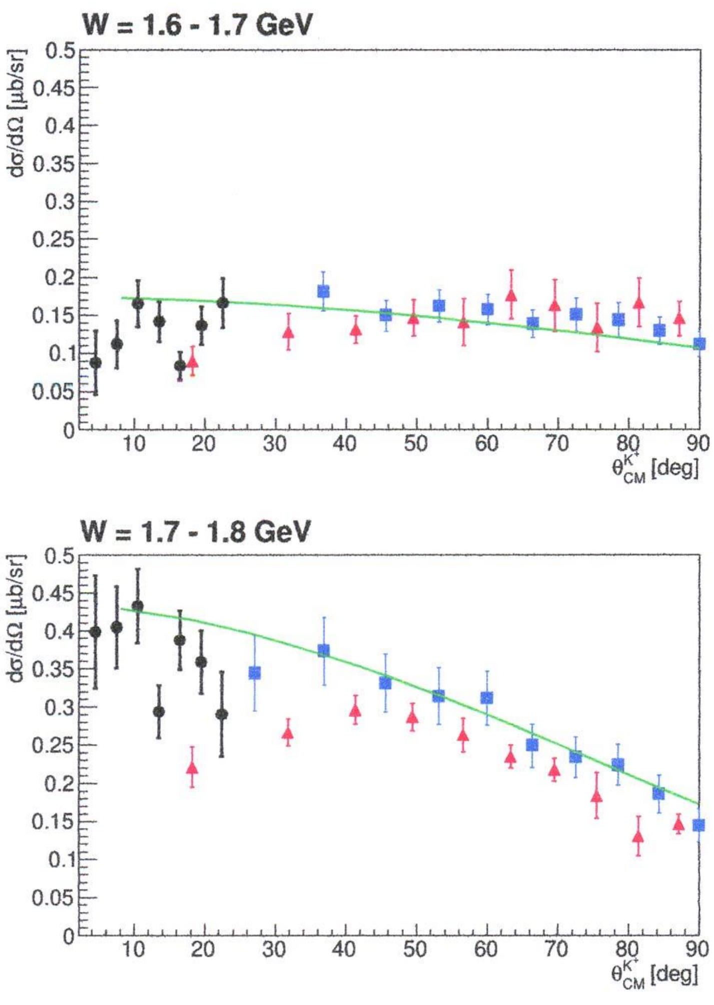
SAPHIR (green), LEPS (blue) and CLAS (red) data

Preliminary results

γ p -> K^+ Λ

differential cross sections in comparison with CLAS (blue) and SAPHIR (red) data.

Green line is the PWA Bonn-Gatchina parametrisation.



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

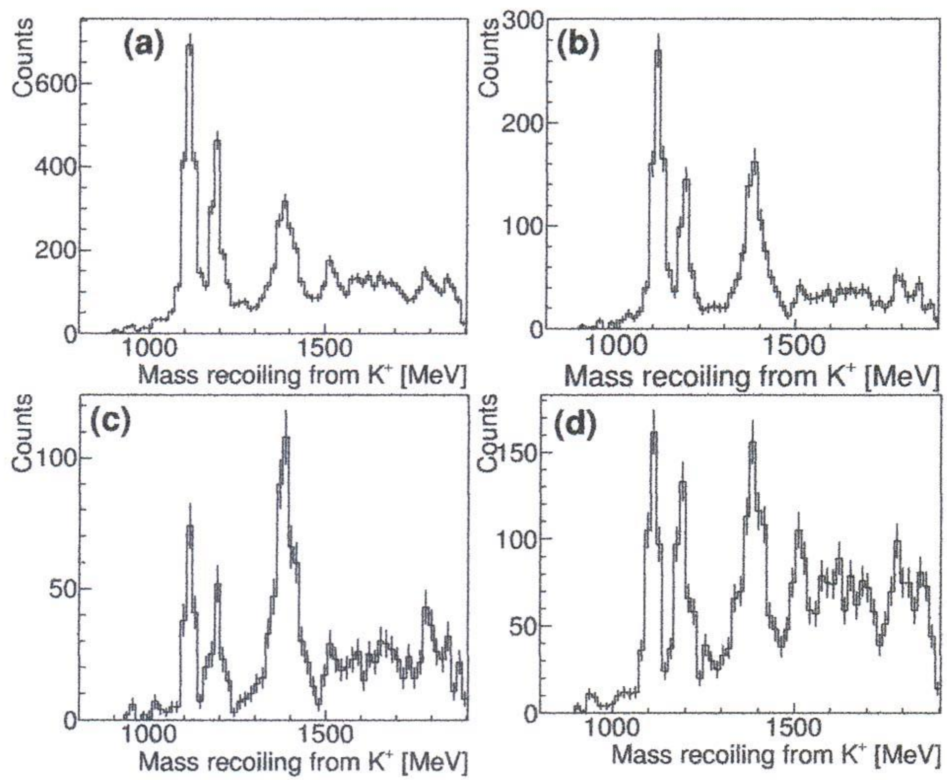
Λ(s=-1) : 1115 MeV

(S_{01}) 1405

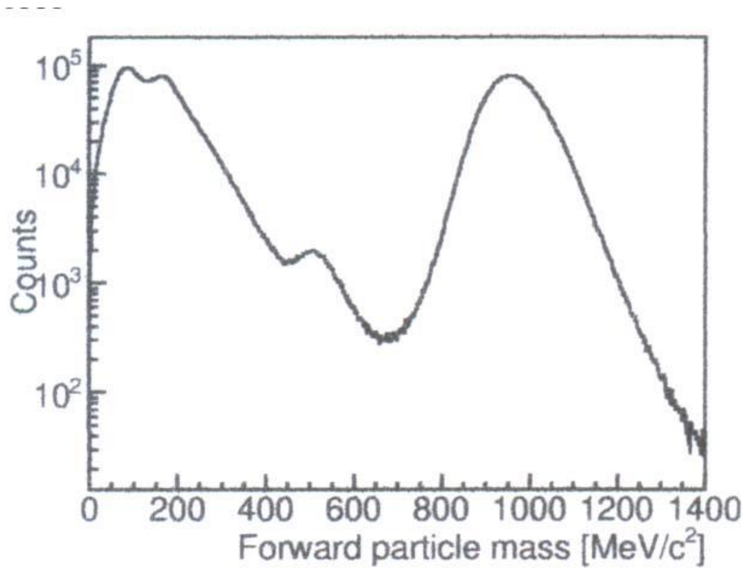
12 resonances

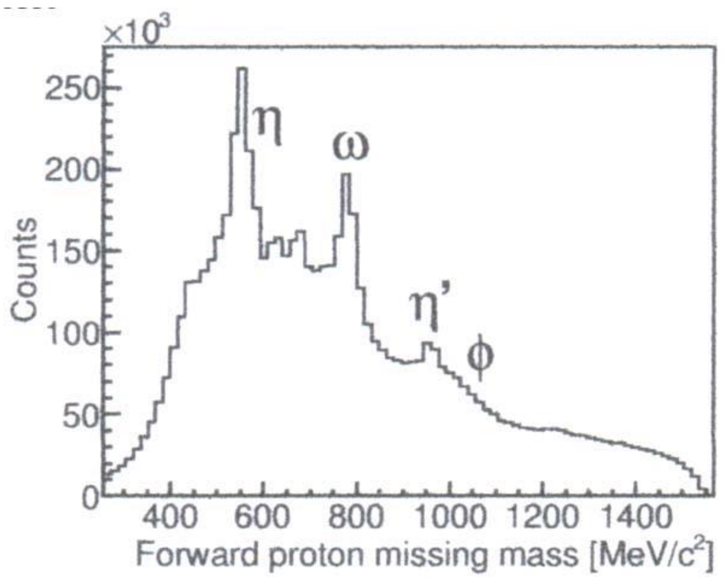
1500 - 2350 MeV

Σ^0 (s=-1) 1192 MeV



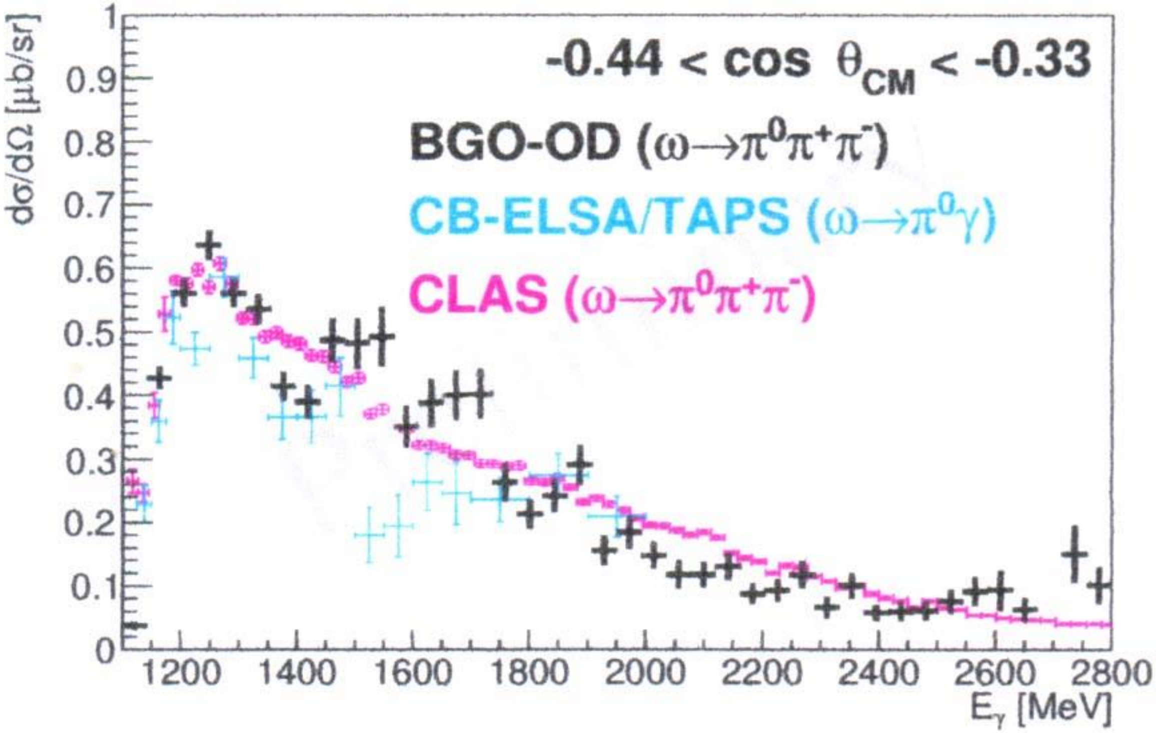
Preliminary results :





left – particle mass calculated from velocity and momentum
right – missing mass from forward protons

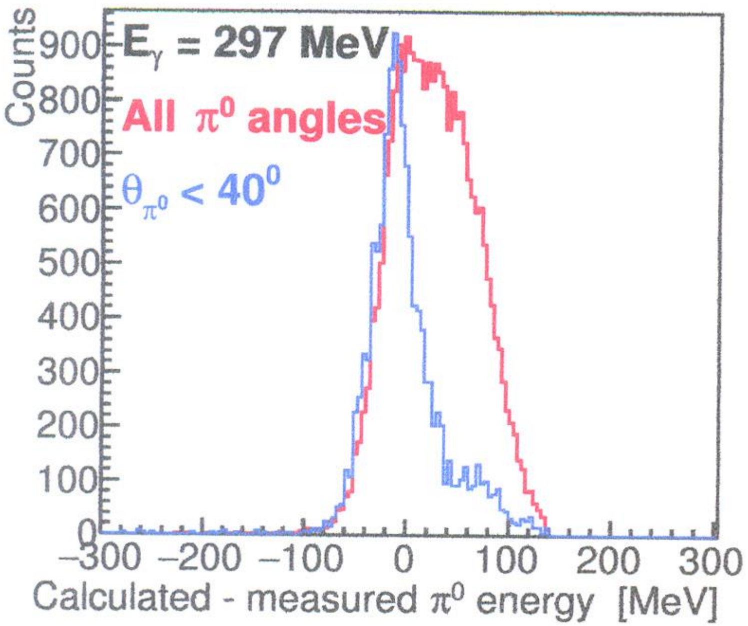
Preliminary results



Differential cross section for $\gamma p \rightarrow \omega p$ reaction

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.

Future analysis of missing mass structure

Missing resonances

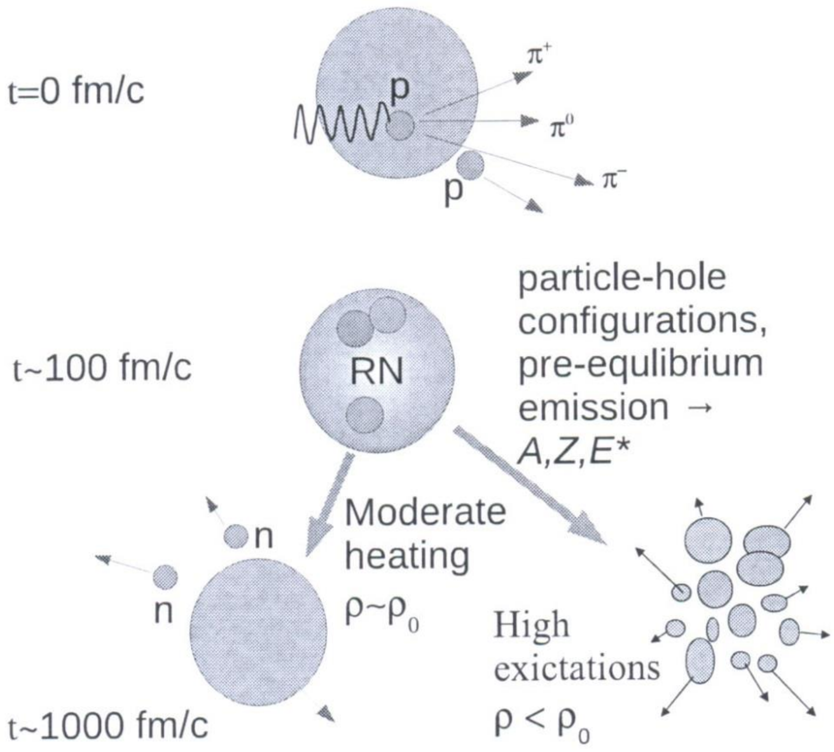
Exotic structure nucleons

Σ beam asymmetry

Polarization studies

Traditional interest to Nuclear excitation dynamics

Light nuclei



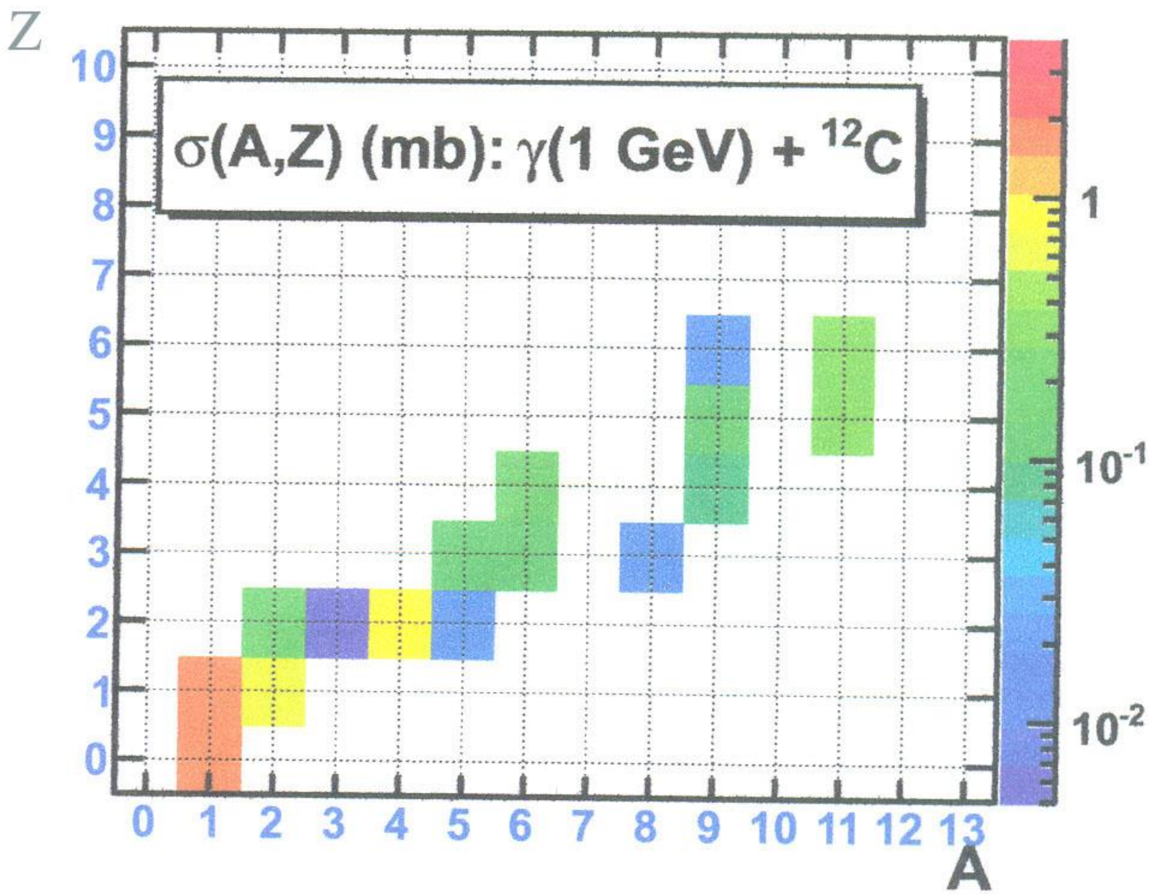
Photon TOF through a nucleus (10 fm diameter) is near $3*10^{-23}$ s,

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

Multifragmentation : Theoretical predictions

RELDIS simulation : I.A.Pshenichnov in paper: Nucl.Phys. A940 (2015) 264-278

Stable particles & Exotics



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.

Positive features and principal problems.
Why the PHOTON beam ?

- a a nucleus is transparent for photons (universal curve) ,

- background reactions (elastic and multiple scattering of projectiles) are negligible,

- multiplicity of products is relatively small ,

- possibility to distinguish the primary and secondary recoils by the energy and angular measurement.

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First results for 12-C nuclei (GRAAL experiment)

V.Nedorezov e.a. Nucl.Phys. A940 (2015) 264-278.

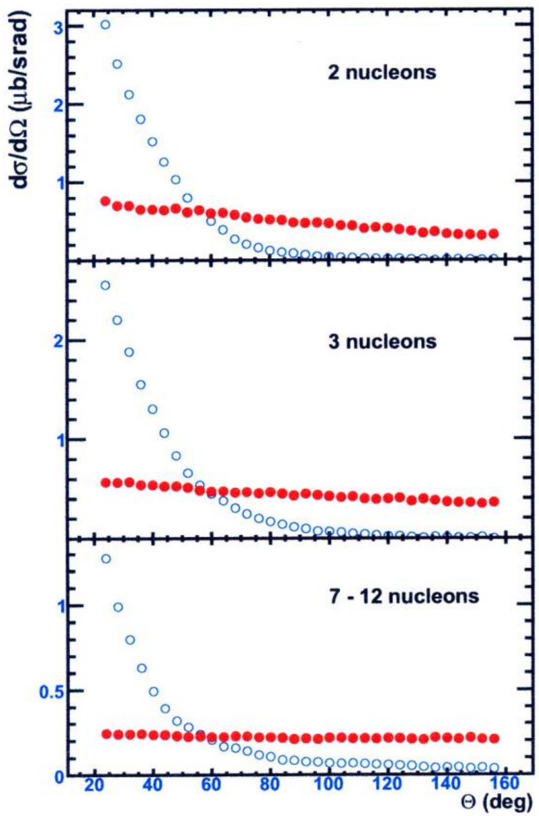


Figure 6: Measured angular distributions of nucleons produced in photodisintegration of ^{12}C in the laboratory system in events with two (top panel), three (middle panel), seven and more fragments (bottom panel). In all cases the angular distribution for the leading most energetic proton in each event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

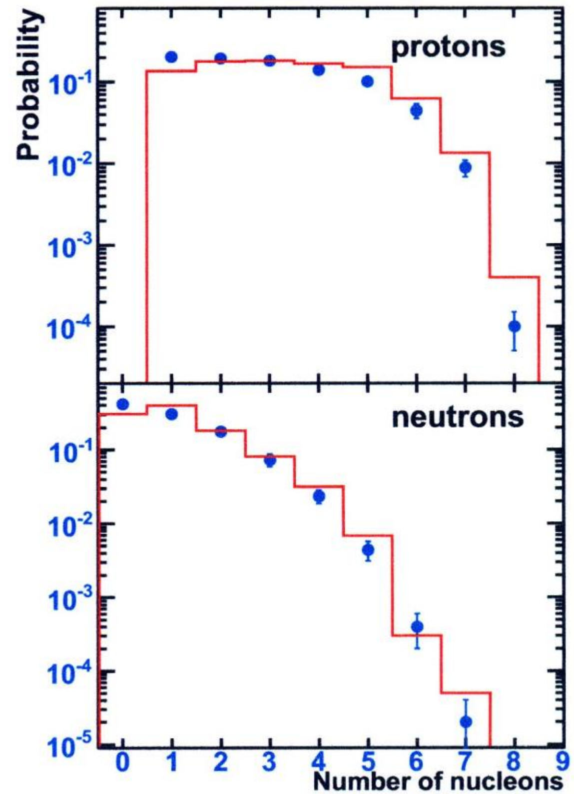
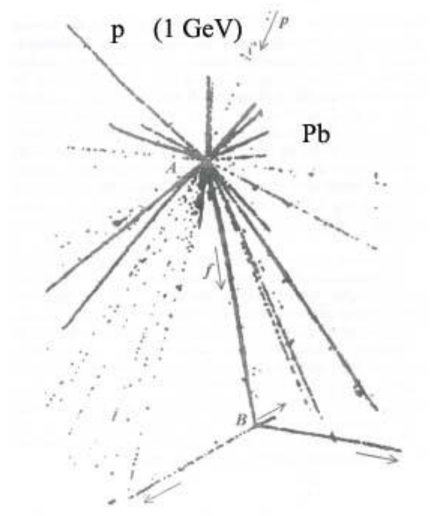


Figure 8: Measured (points) and calculated (histograms) probabilities of photodisintegration events of ^{12}C at 0.7–1.5 GeV with a given number of protons (top) and neutrons (bottom). Only statistical uncertainties of measurements are shown.

Fragmentation of light nuclei by real and virtual photons

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***

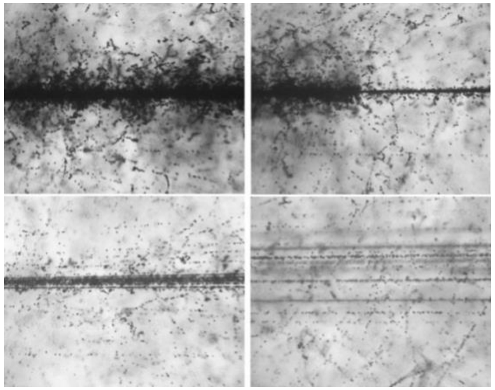


p, α-particles Lips V.,e.a. ***FASA.*** JINR, TH, Darmstadt (1993), IKDA 3/7, p1-11 (1993).

Relativistic ions

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

Au + emulsion target



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 añd 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

Study of $\eta n \rightarrow \pi^- p$ 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

GENERAL MOTIVATION

- To answer the question :

- 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 with nuclear media by the model independent way, directly in the experiment.

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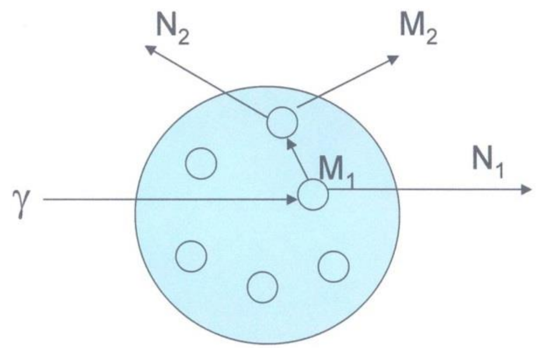


Short living mesons:

Meson type	Life time τ (s)	Relativistic range in vacuum $c\tau$ (fm)	Width Γ (MeV)
π^0	$8 * 10^{-17}$	$2.5 * 10^7$	$8 * 10^{-6}$
η	$5 * 10^{-19}$	$1.5 * 10^5$	10^{-3}
η'	$3 * 10^{-21}$	$0.9 * 10^3$	0.2
ρ	$4 * 10^{-24}$	1.2	149
ω	$7 * 10^{-23}$	20	8.43

Transparency 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

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

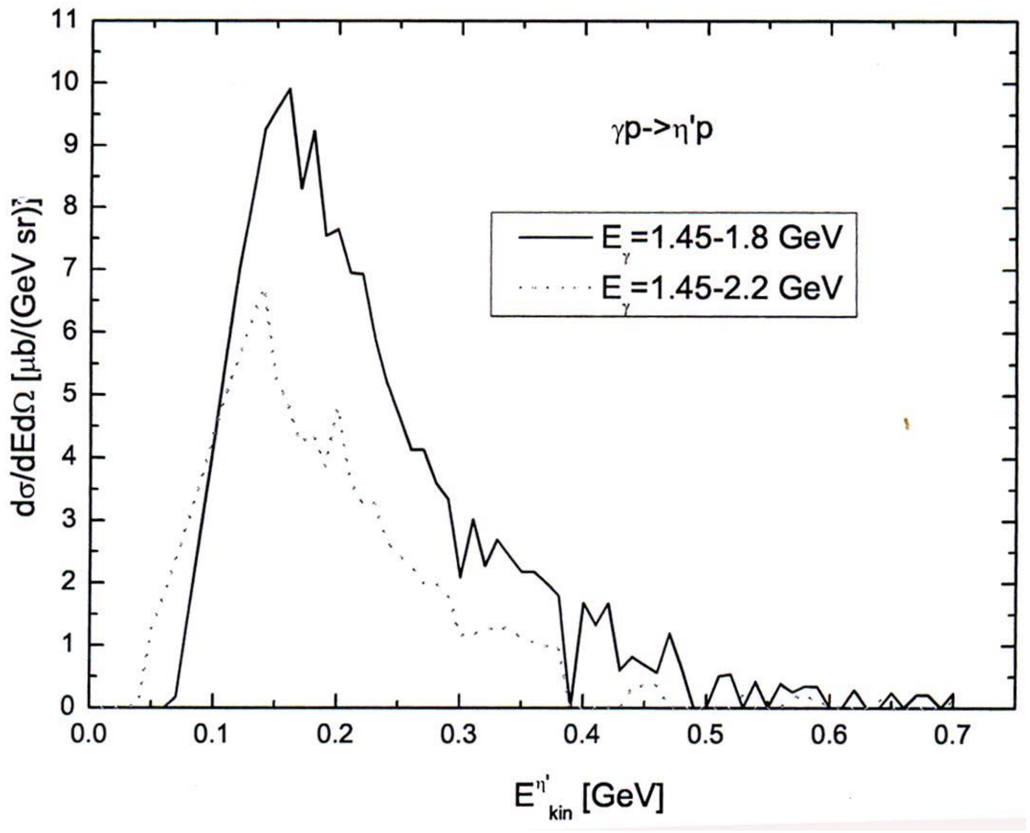
Evaluated inelastic $\sigma_{\eta' n}$ = 10.3 ± 1.4 mb.

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

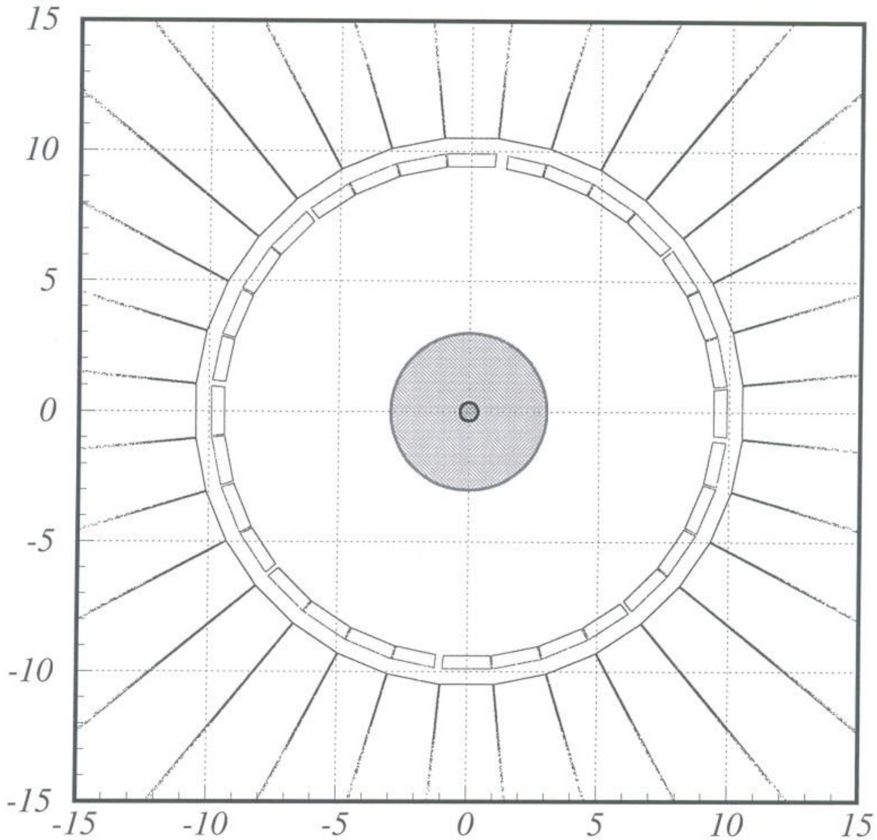
Numerous data on A-dependence of meson photoproduction are available : V.Nedorezov, Yu.N.Ranyuk. Photofission above the giant resonance. Naukova dumka, Kiev, 1989.

Differential cross section for η’ + ^{12}C in the full solid angle vs $E^{\eta'}_{kin}$
(in coincidences with protons within $\theta = 1^0 - 11^0$)
Vo = - 50 MeV

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

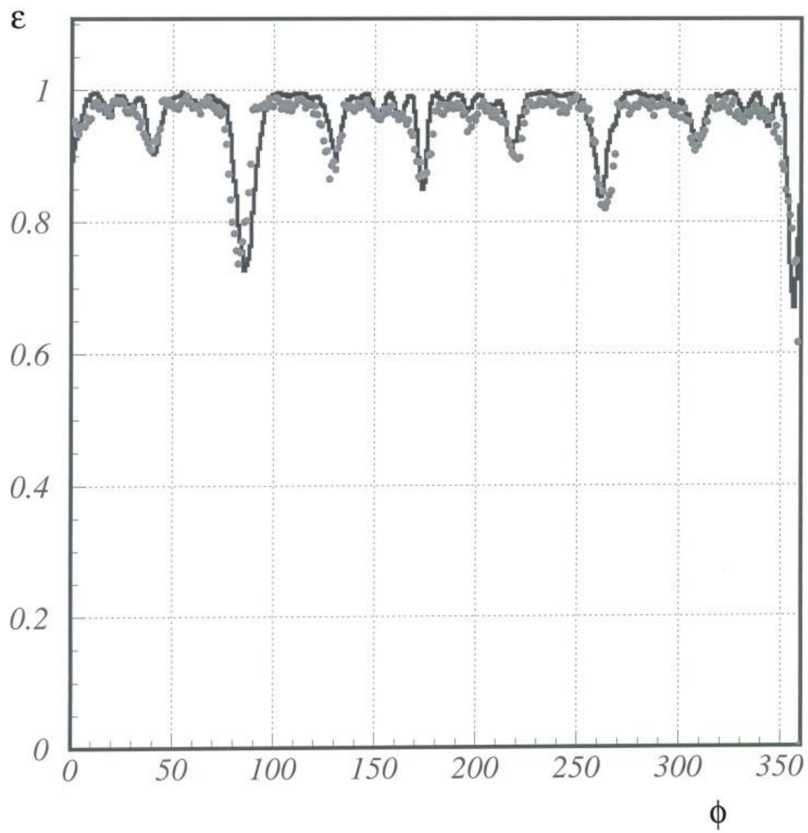


Experiment : new requirements
Precise evaluation of the proton measurement efficiency using $\gamma\ p > \pi^0\ p$ reaction



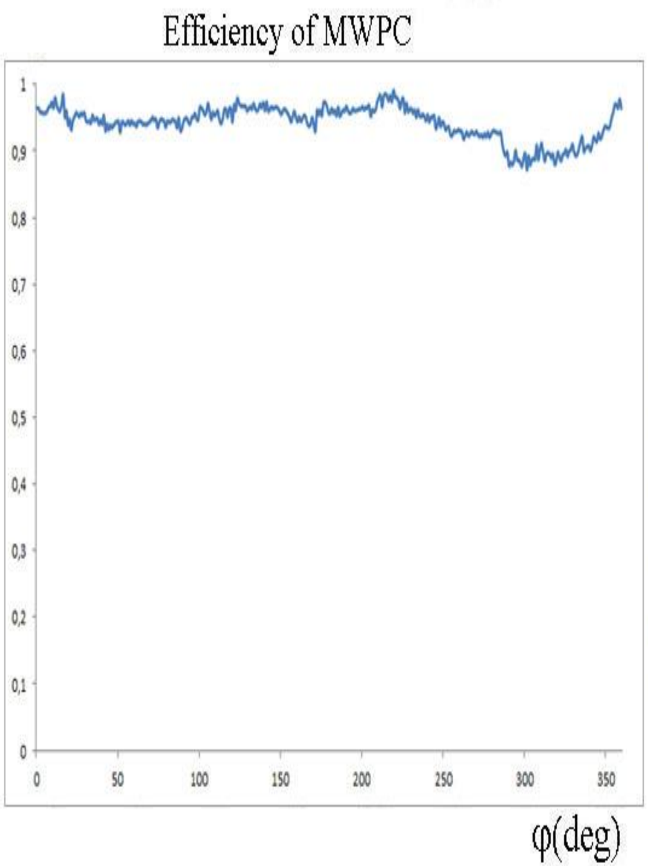
BGO & Barrel geometry in ϕ plane

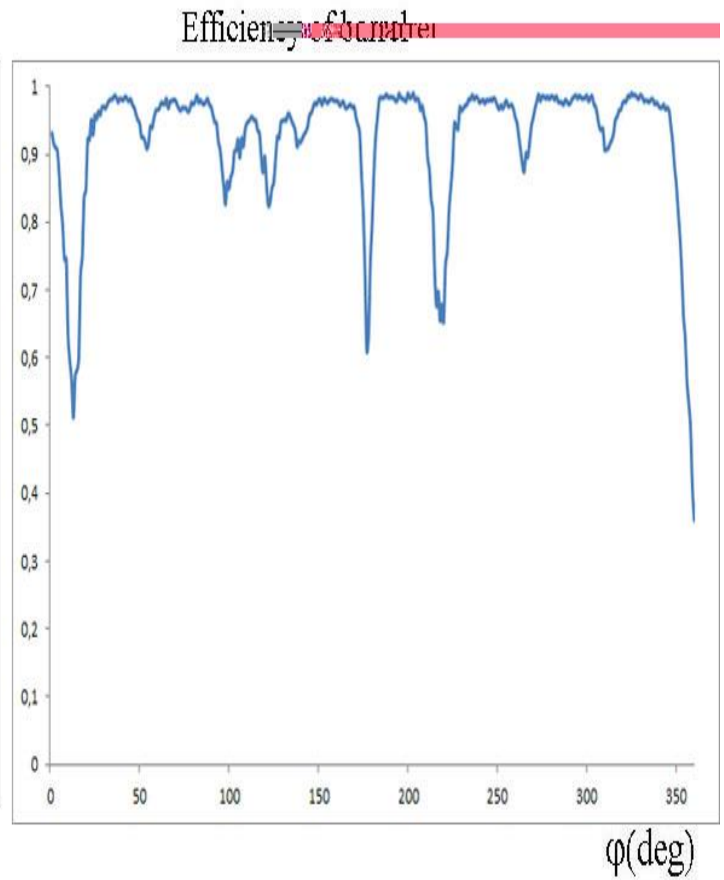
Proton measurement efficiency in the Barrel as function of ϕ



Solid line – experiment, points – simulation

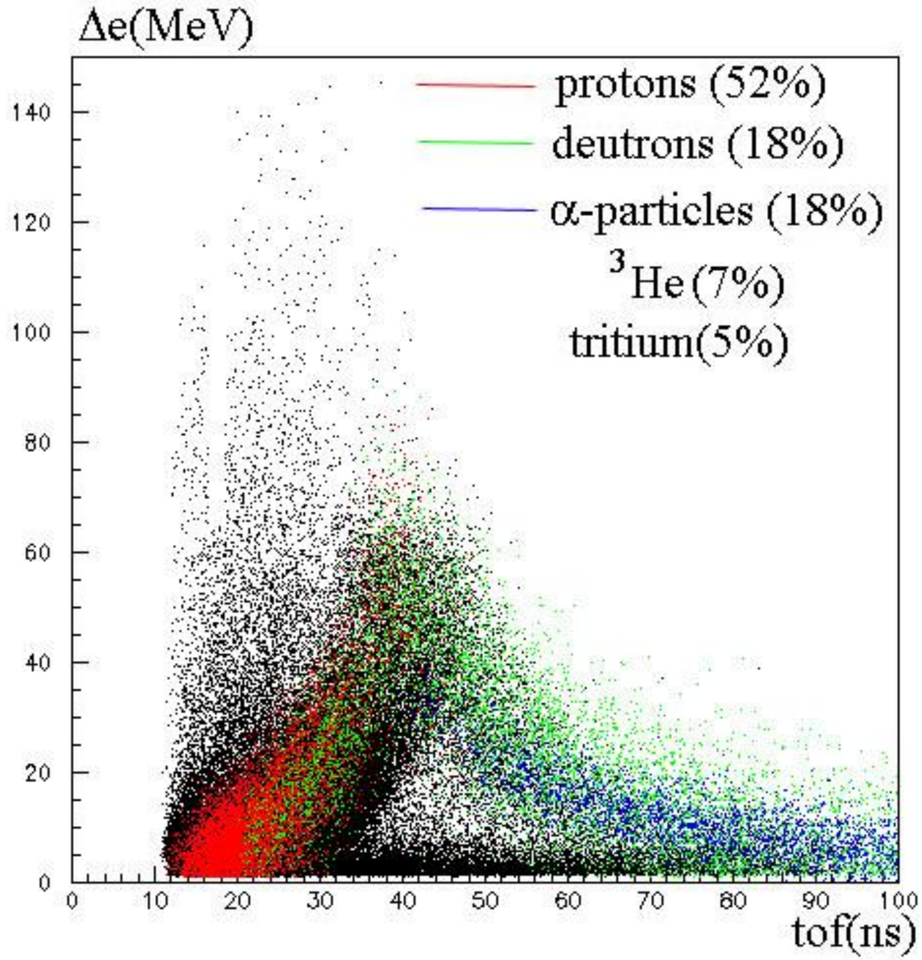
Proton measurement efificiency



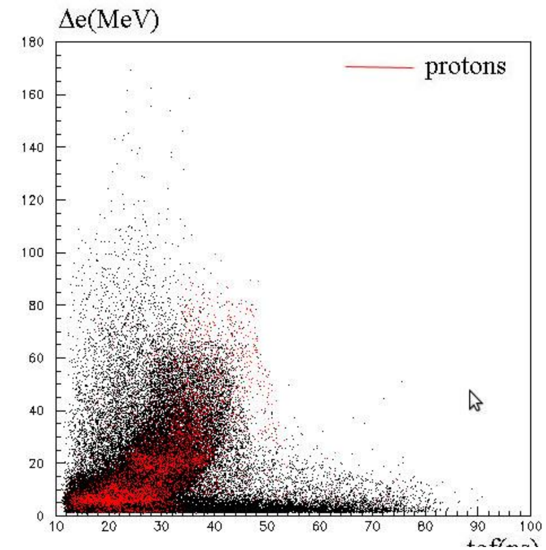


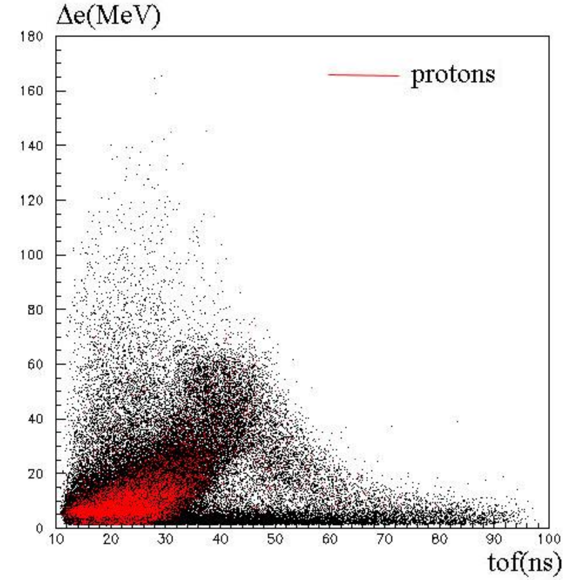
Simulations (GRAAL) :

12-C



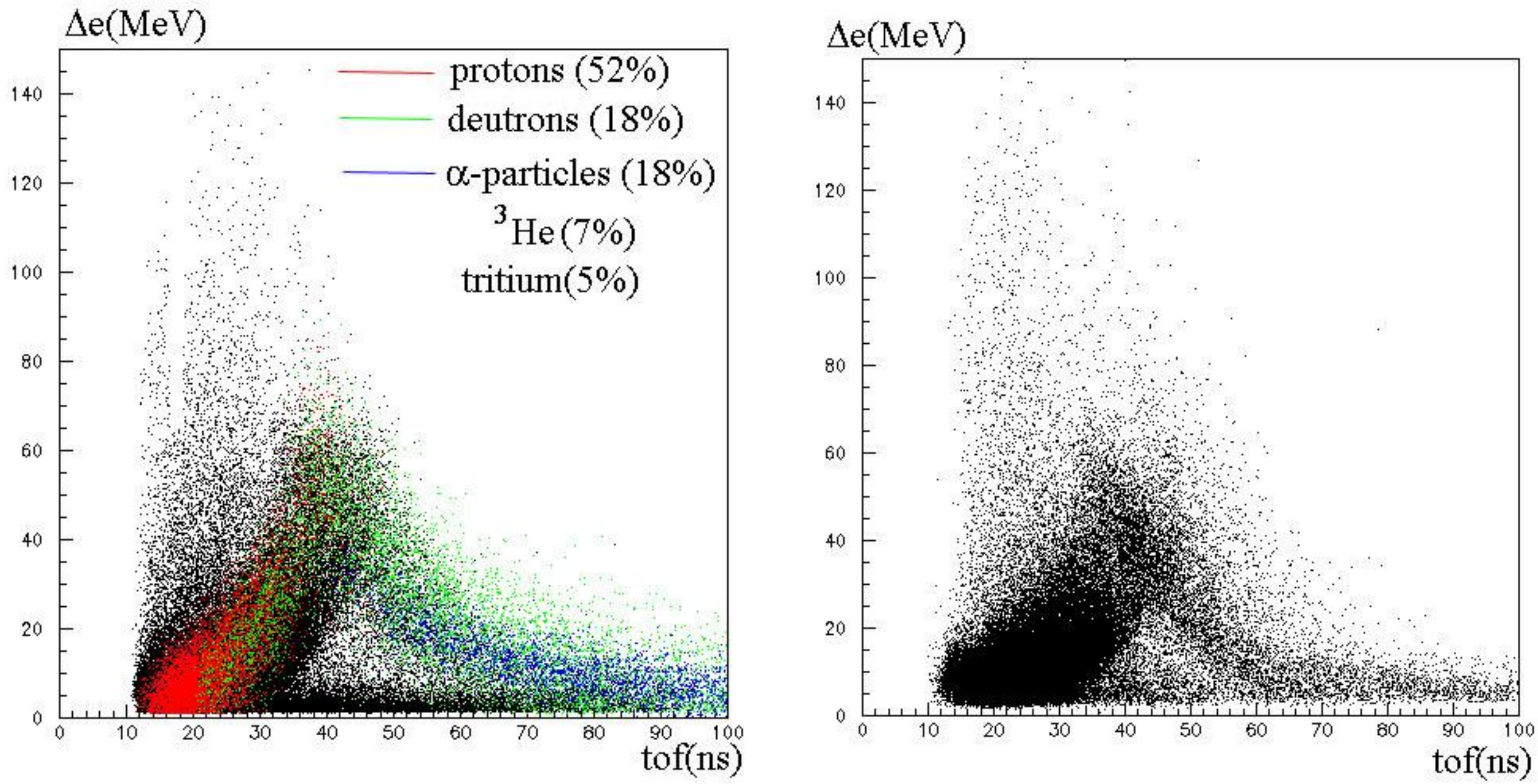
proton and deuteron





Simulation and experiment (GRAAL)

^{12}C target

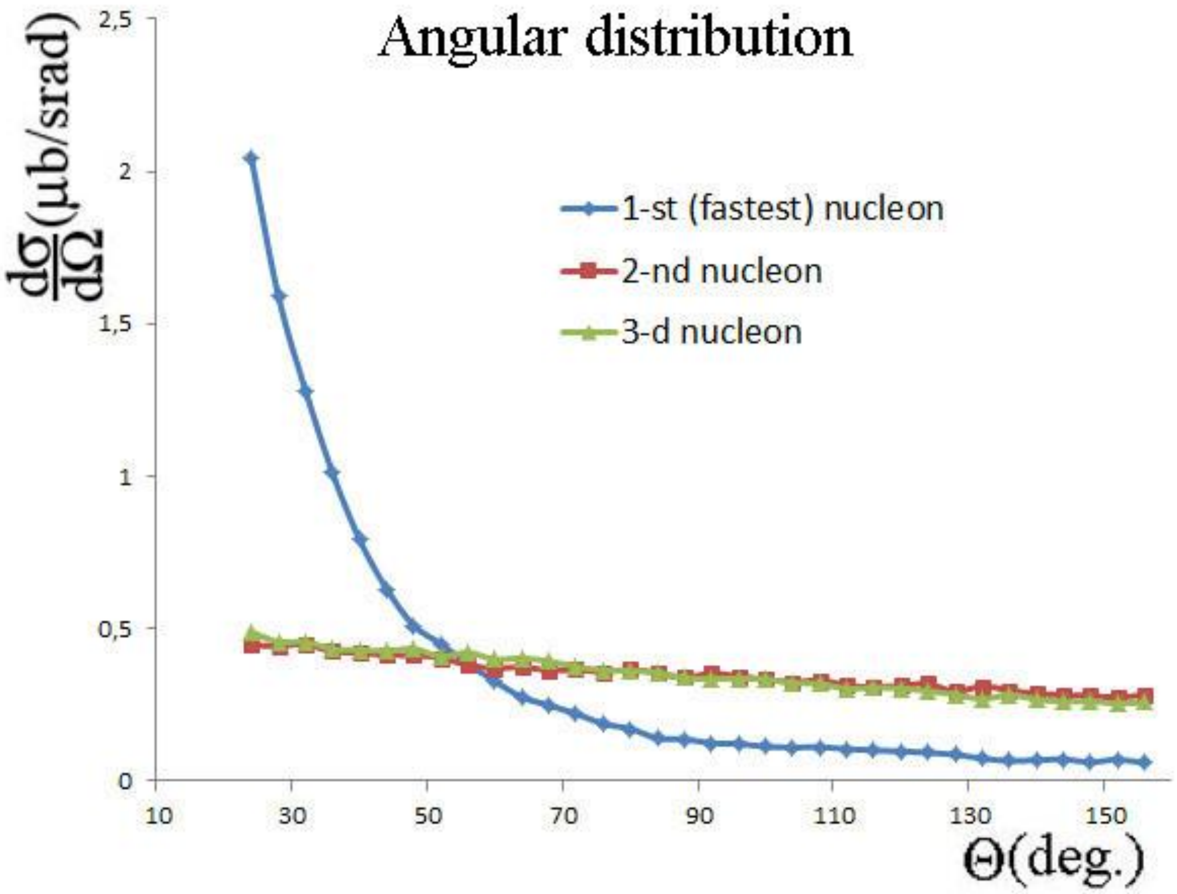


Results

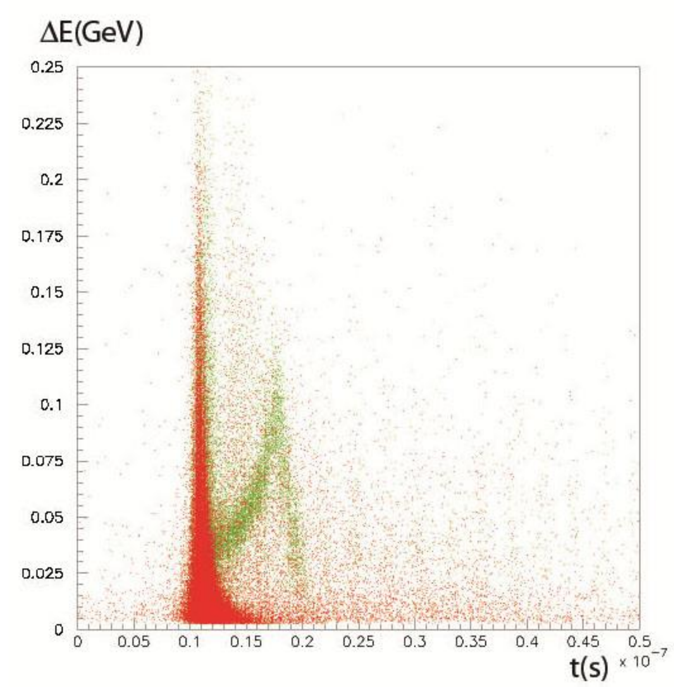
GRAAL BECQUEREL

	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 %)

Selection of the primary recoil nucleon: angular distribution

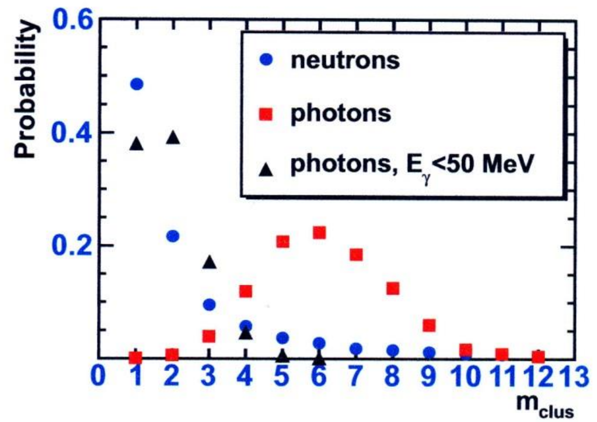


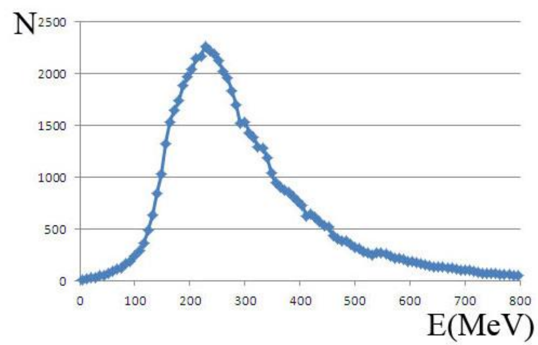
Separation of neutral particles in the GRAAL experiment [1]:



In forward direction (EM-calorimeter) TOF-ΔE Is similar to protons but Efficiency is in 5 times less

Mclus dependence:





Eγ energy spectrum from all partial channels

Expected contribution of low energy photons (E_γ < 50 MeV) does not exceed 2%

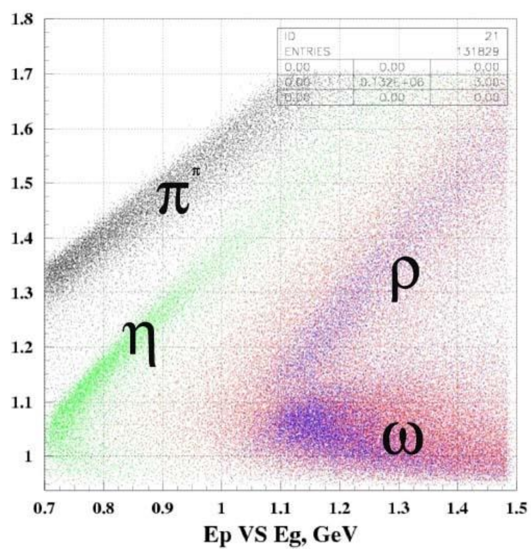
Additional efforts to exclude complementary neutral clusters in BGO : *TOF in BGO*

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

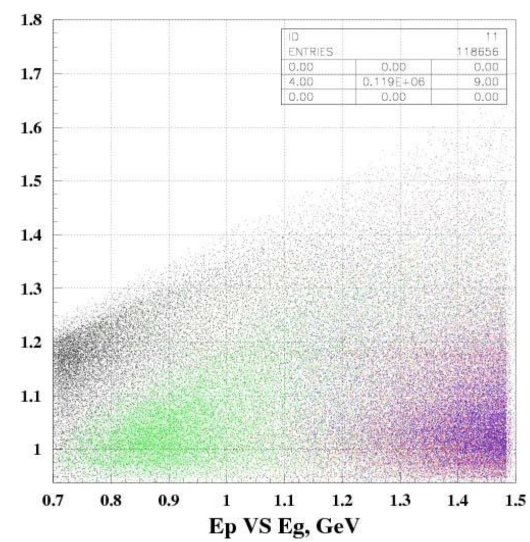
Variable parameters Ep, Eγ , Fixed parameter θ_p

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

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



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

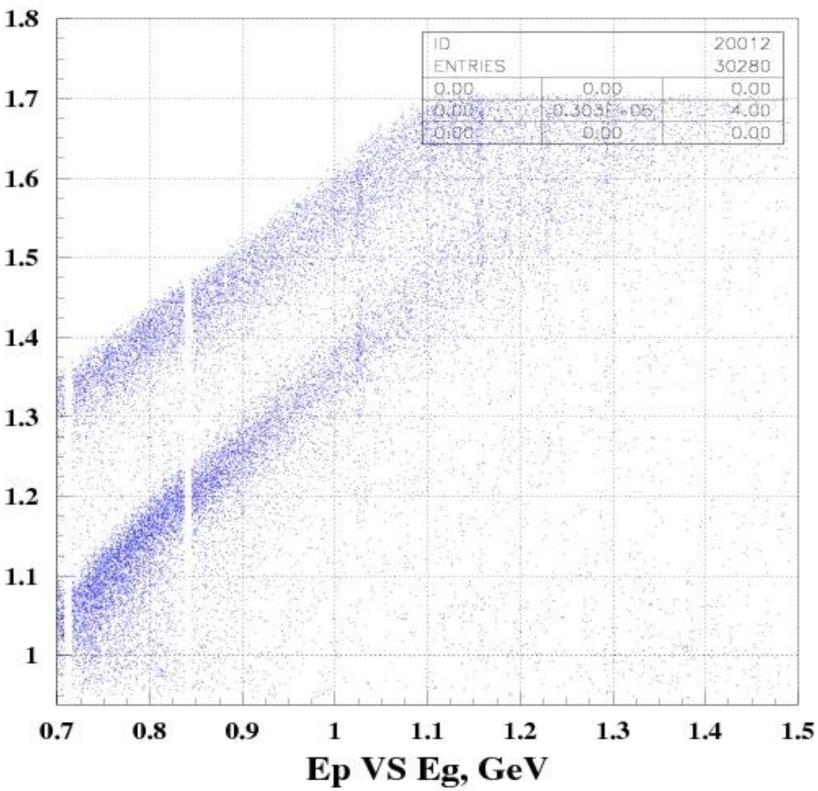


Multiple (n ≤4) meson production and INC is included

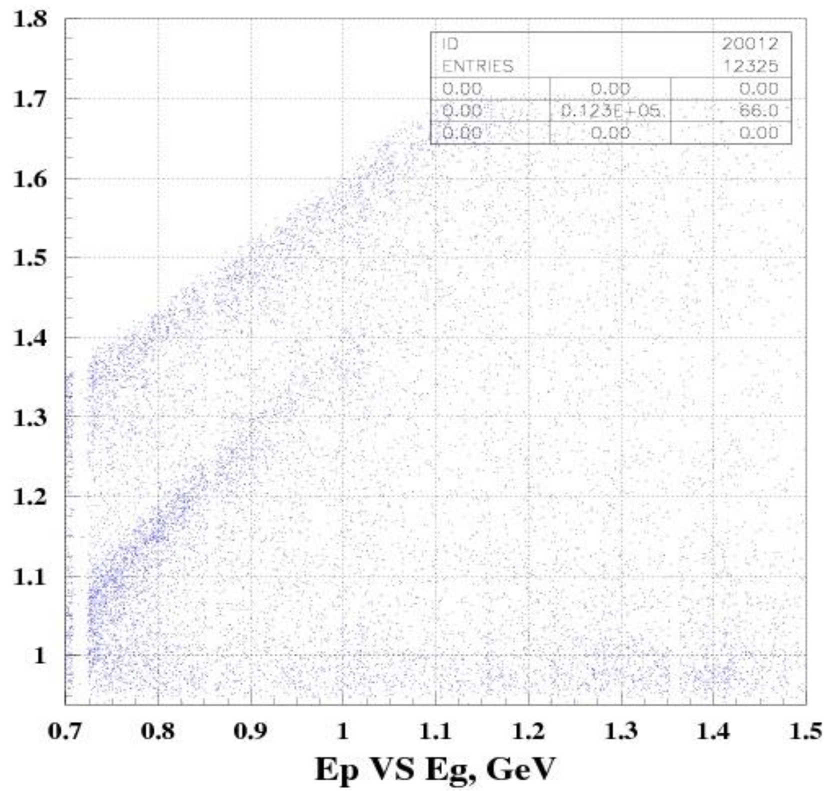
A.Ignatov e.a. New experimental and simulated results on nuclear media effects in meson photoproduction off nuclei. Prog.Part.Nucl.Phys.(2008) 61:253-259,2008.

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

- simulation



- Experiment
- Kinematics is not included



Magnetic spectrometer

Separation of charged particles (pions, kaons, protons, light nuclei) in forward direction

$\theta = 1^0 - 11^0$

$\Delta P/P$ = 1% is much better than at GRAAL (10%)

TOF in BGO

1 ns would be enough to distinguish p,d, a particles because the energy of secondary particles is relatively small

Complementary neutral clusters from neutron scattering can be rejected

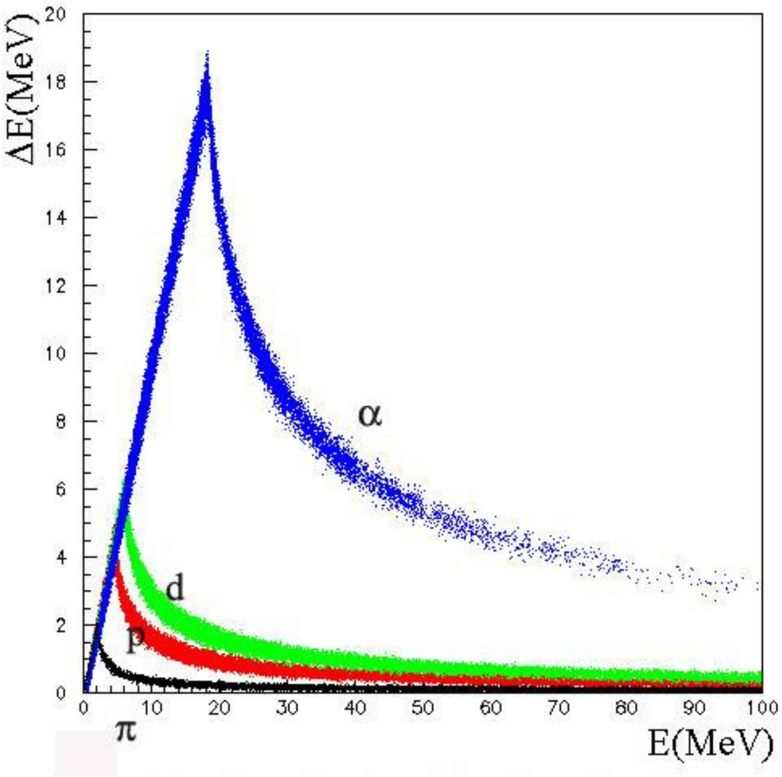
Analog ΔE signal from MWPC

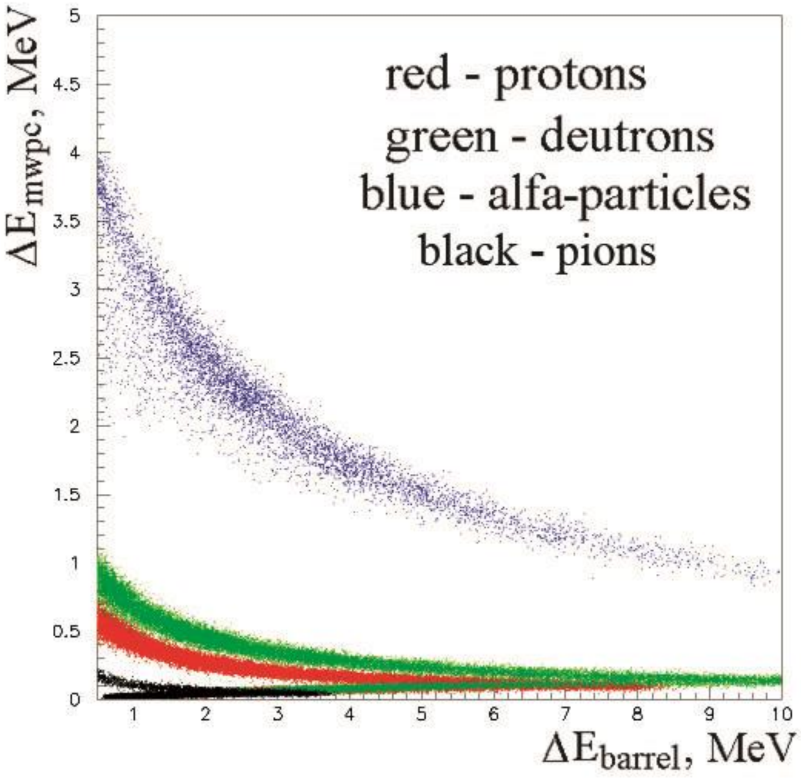
Simulation of energy loss in MWPC and barrel for π, p, d, α particles,

Angular range - $80^0 - 100^0$,energies are evaluated by RELDIS model for E_γ = 1 GeV, ^{12}C target

(A.Turinge, private communication)

Energy loss in MWPC





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

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

□ Beam Eγ = 0.6-1.5 GeV

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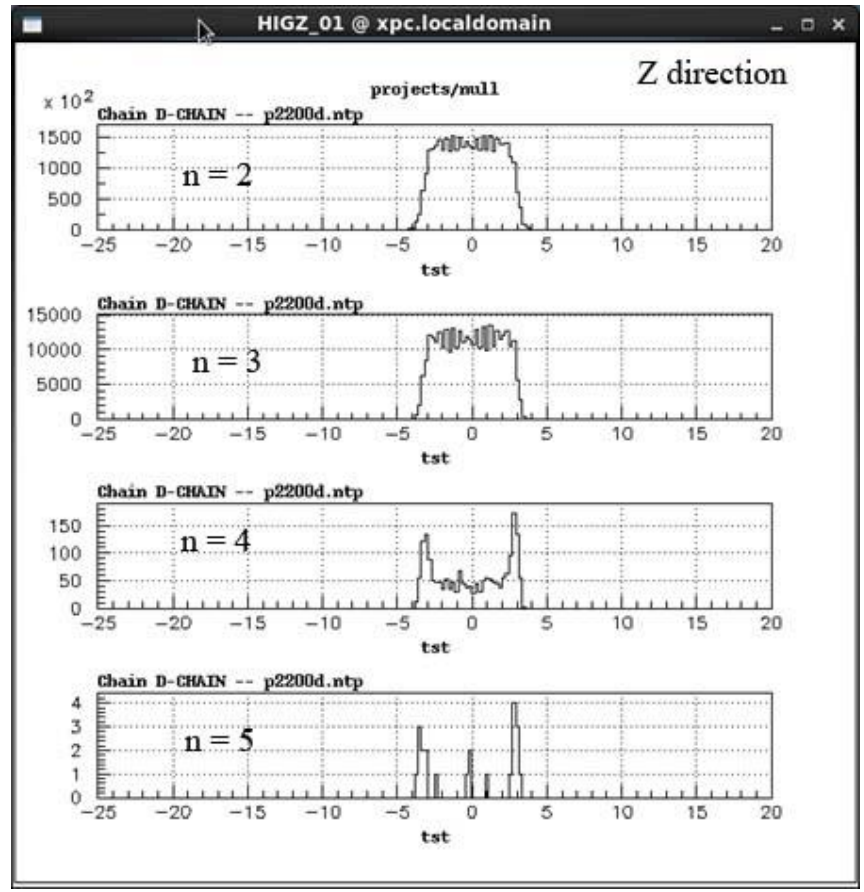


- Cylindrical 4π MWPCs
- of the detector LAγRANGE:

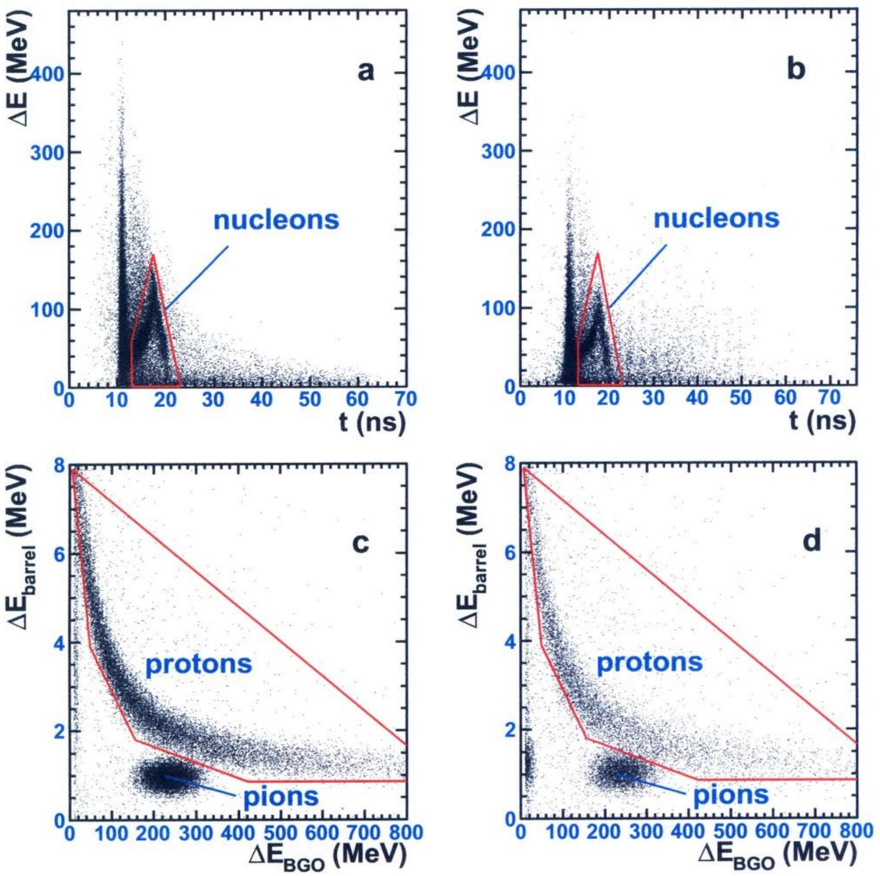
- for n = 5 measured particles
- are not mesons, not primary
- recoils,
-
- Most probably they are cascade
- protons from intra-nuclear
- interaction
-

:

Separation of charged particles in the GRAAL experiment
[V.Nedorezov e.a. (GRAAL collaboration) NP, A (2015), pp. 264-278]

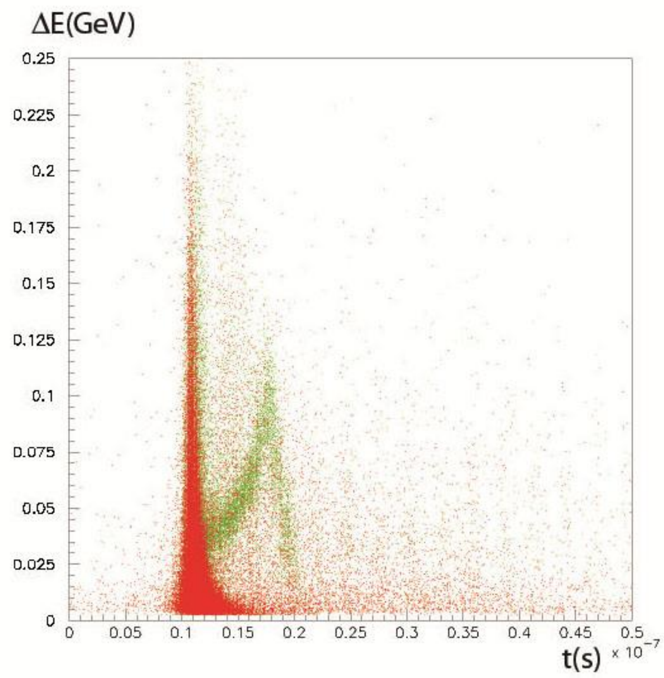
a – simulation,   b – experiment

- *Forward detector*
- *(plastic wall   (ΔE – TOF)*
- *ΔE (barrel) – ΔE (BGO)*



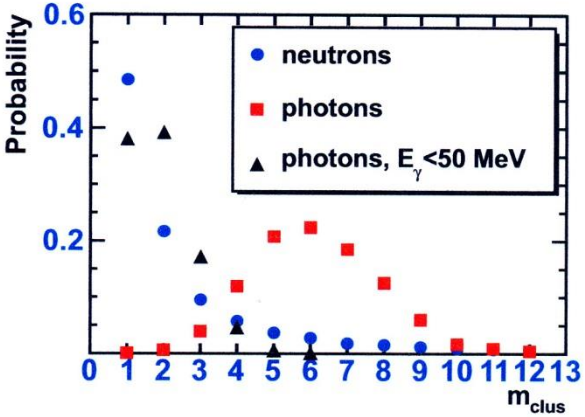
Additional efforts to identify charger particles in BGO :
vertex : star picture from the target, selection of files

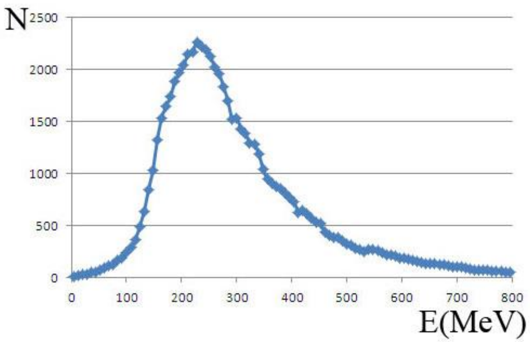
Separation of neutral particles in the GRAAL experiment [1]:



In forward direction (EM-calorimeter) TOF-ΔE Is similar to protons but Efficiency is in 5 times less

Mclus dependence:



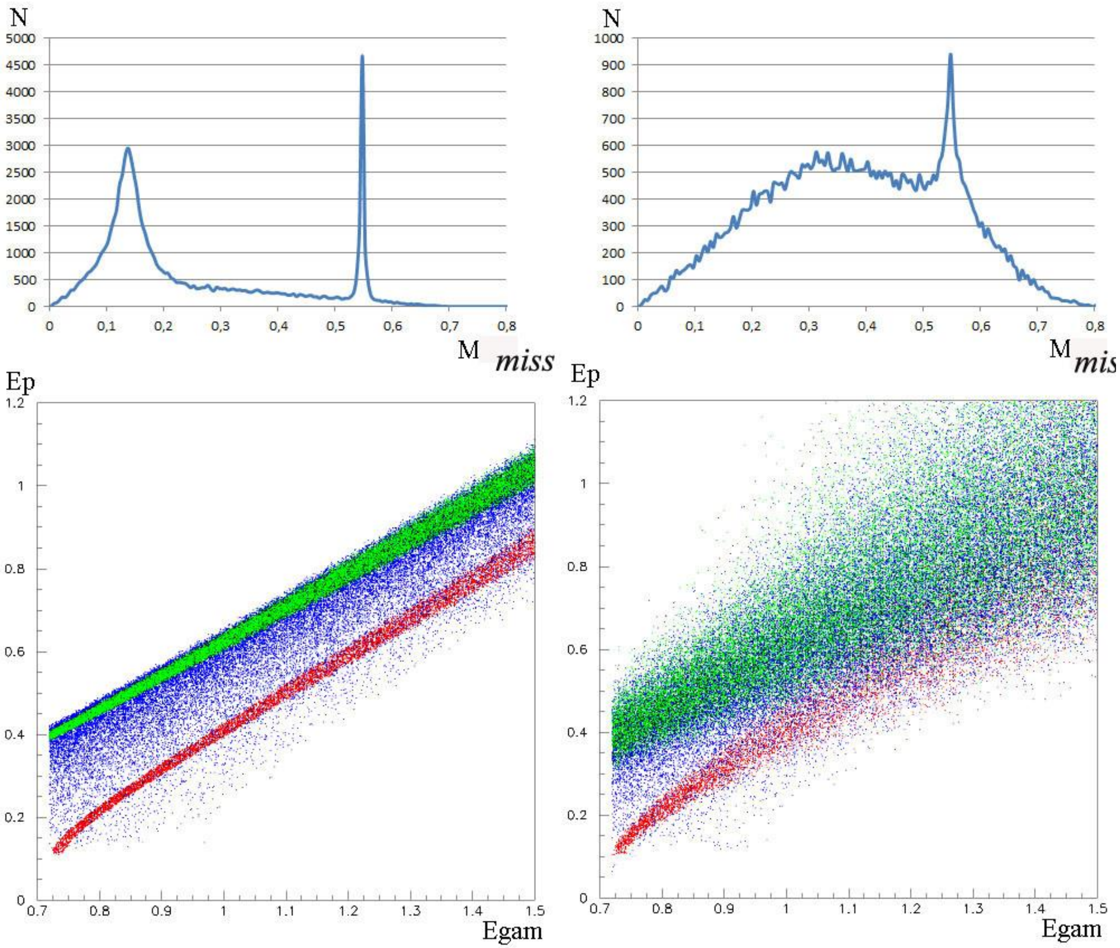


Eγ energy spectrum from all partial channels

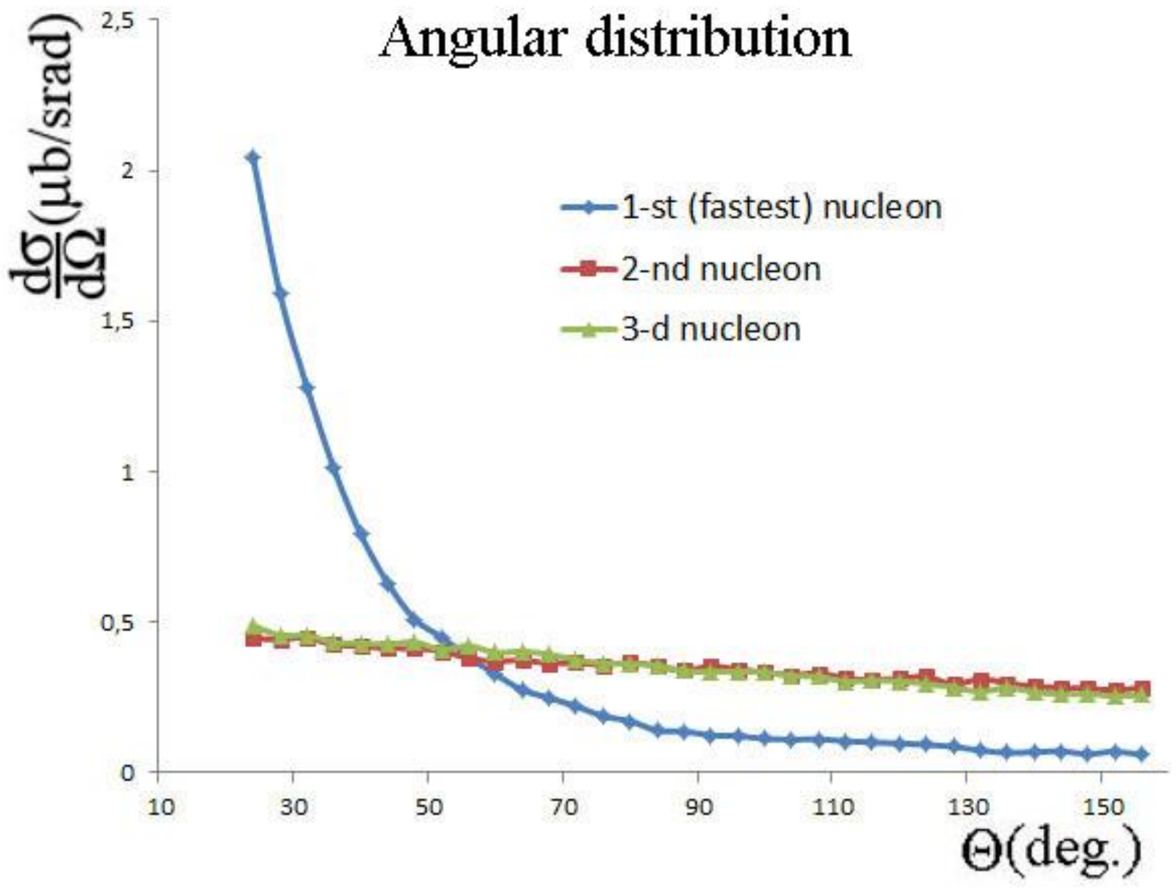
Expected contribution of low energy photons (E_γ < 50 MeV) does not exceed 2%

Additional efforts to exclude complementary neutral clusters in BGO : *TOF in BGO*

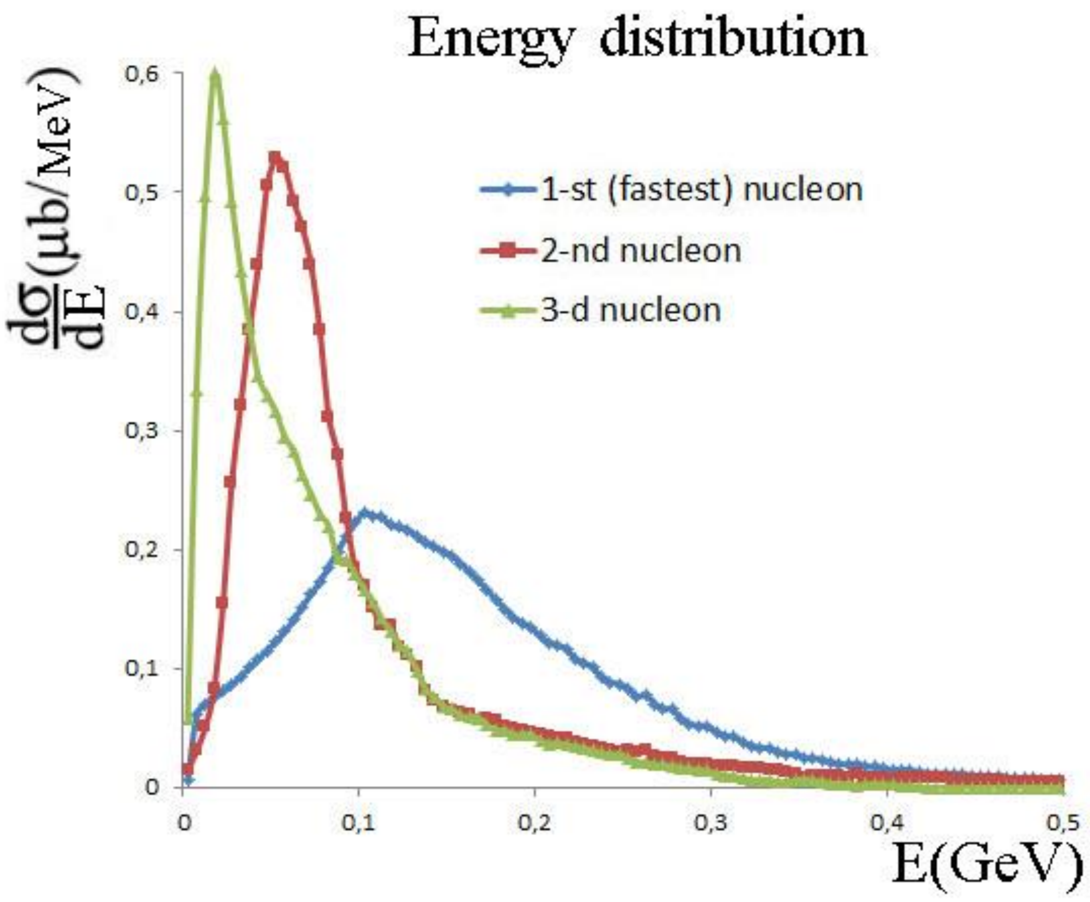
Simulation:
Left panel: resolution of 0.5% (BGO-OD)
Right panel: resolution of 10% (GRAAL)



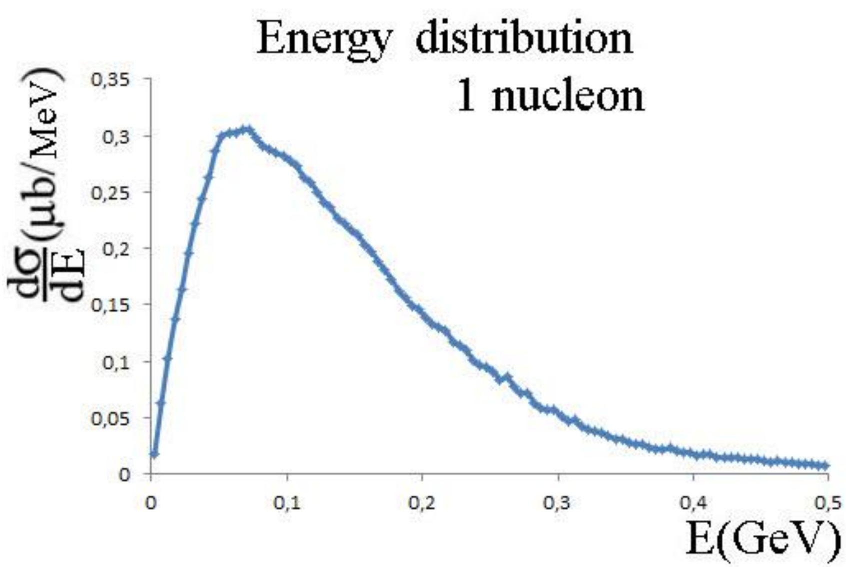
Selection of the primary recoil nucleon: angular distribution

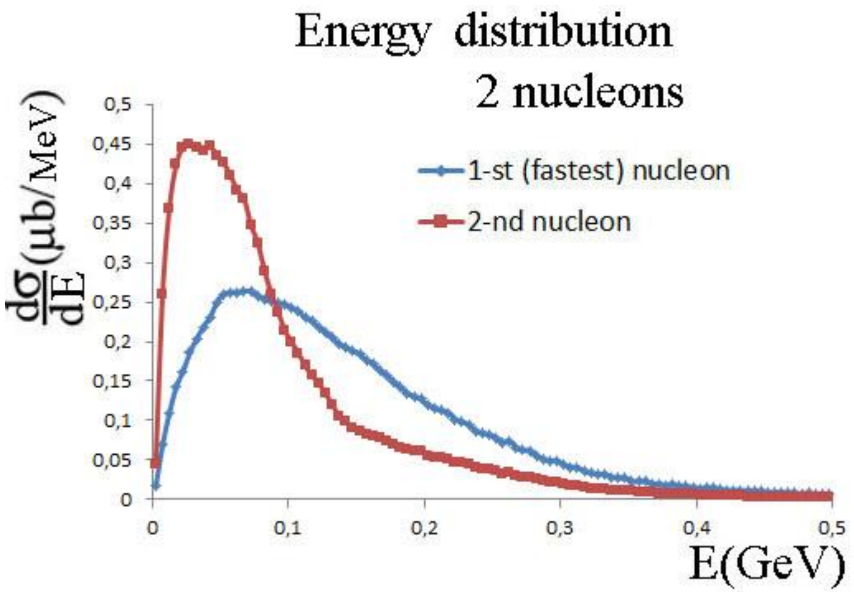


Principal feature to select the primary recoil proton: BGO energy loss distribution

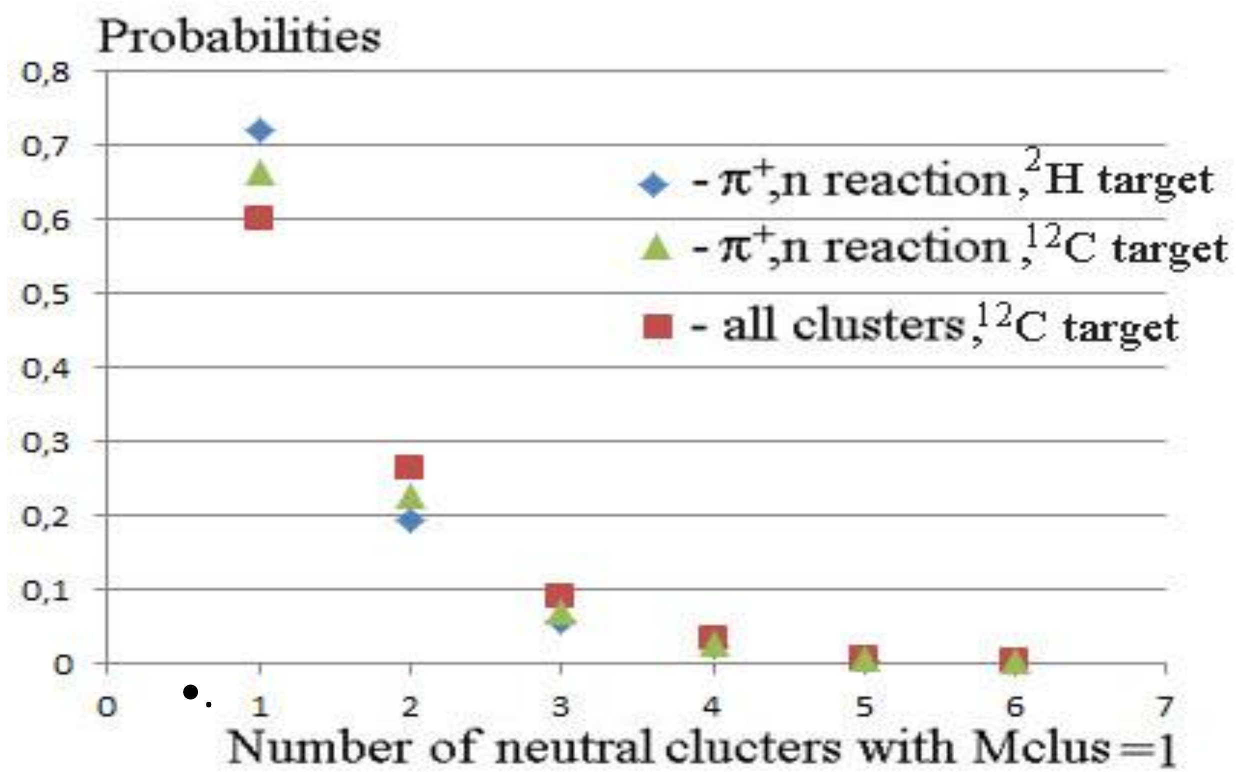


Principal feature to select the primary recoil proton:
BGO energy loss distribution

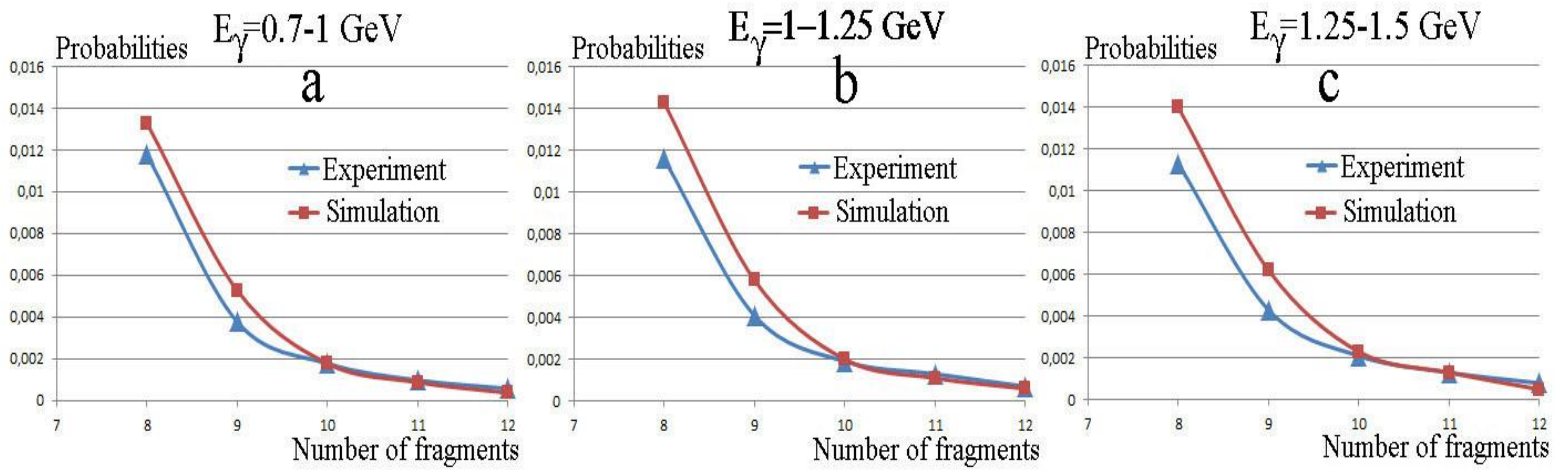




Probability of neutral cluster (neutron) production in different partial reactions [GRAAL results]



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



18-й International Seminar EMIN-2018,
Moscow , October 8-11 2018 г.
www/cpc.inr.ac.ru/~pnlab/emin2018

QCD and Hadron Physics.

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Polarization phenomena, spin physics.

Lebedev Institute, INR RAS, JINR & Mainz *University, BINP Novosibirsk, Japan Atomic Energy Agency*

Fragmentation of nuclei by real and virtual photons.

INR RAS & Bonn University, JINR, FAIR , Kioto University

Giant resonances and collective excitations of nuclei.

SINP, MEPHI, FTI Obninsk, RCNP, Osaka University

New developments and perspectives

SINP & ELI-NP Bukharest, BINP Novosibirsk, Japan Atomic Energy Agency

Conclusion
Future photonuclear experiments

BGO-OD perspectives

USA : Electron Ion Collider (EIC)

At BNL - the **eRHIC** utilizes a new electron beam facility based on an Energy Recovery Linac (ERL) to be built inside the RHIC tunnel in order to collide electrons with one of the RHIC beams.

At Jefferson Laboratory the Medium Energy Electron Ion Collider (**MEIC**) employs a new electron and ion collider ring complex, together with the 12 GeV upgraded CEBAF in order to achieve similar collision parameters.

CEBAF, TUNL HIGS …

Europe : **ELISe GSI , Bonn ELSA, Hamburg DESY, VEPP Novosibirsk, …**

Japan : **SPRING 8, SUBARU …**

CONCLUSION

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