A Resonance Structure in the $\gamma\gamma$ Invariant Mass Spectrum in pC- and dC-Interactions

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Abstract

Along with π^o and η mesons, a resonance structure in the invariant mass spectrum of two photons at $M\gamma\gamma = 360 \pm 7 \pm 9$ MeV is observed for the first time in the reaction $dC \rightarrow \gamma + \gamma + X$ at momentum 2.75 GeV/c per nucleon.

Estimates of its width and production cross section are $\Gamma = 49.2 \pm 18.6$ MeV and $\sigma_{\gamma\gamma} = 98 \pm 24 + 93 - 67$ μb, respectively.

The collected statistics amount to 2339 ± 340 events of 1.5 · 10^{6} triggered interactions of a total number ~ 10^{12} of dC- interactions.

This resonance structure is not observed in pC collisions at the beam momentum 5.5 GeV/c.

Possible mechanisms of this ABC-like effect are discussed.

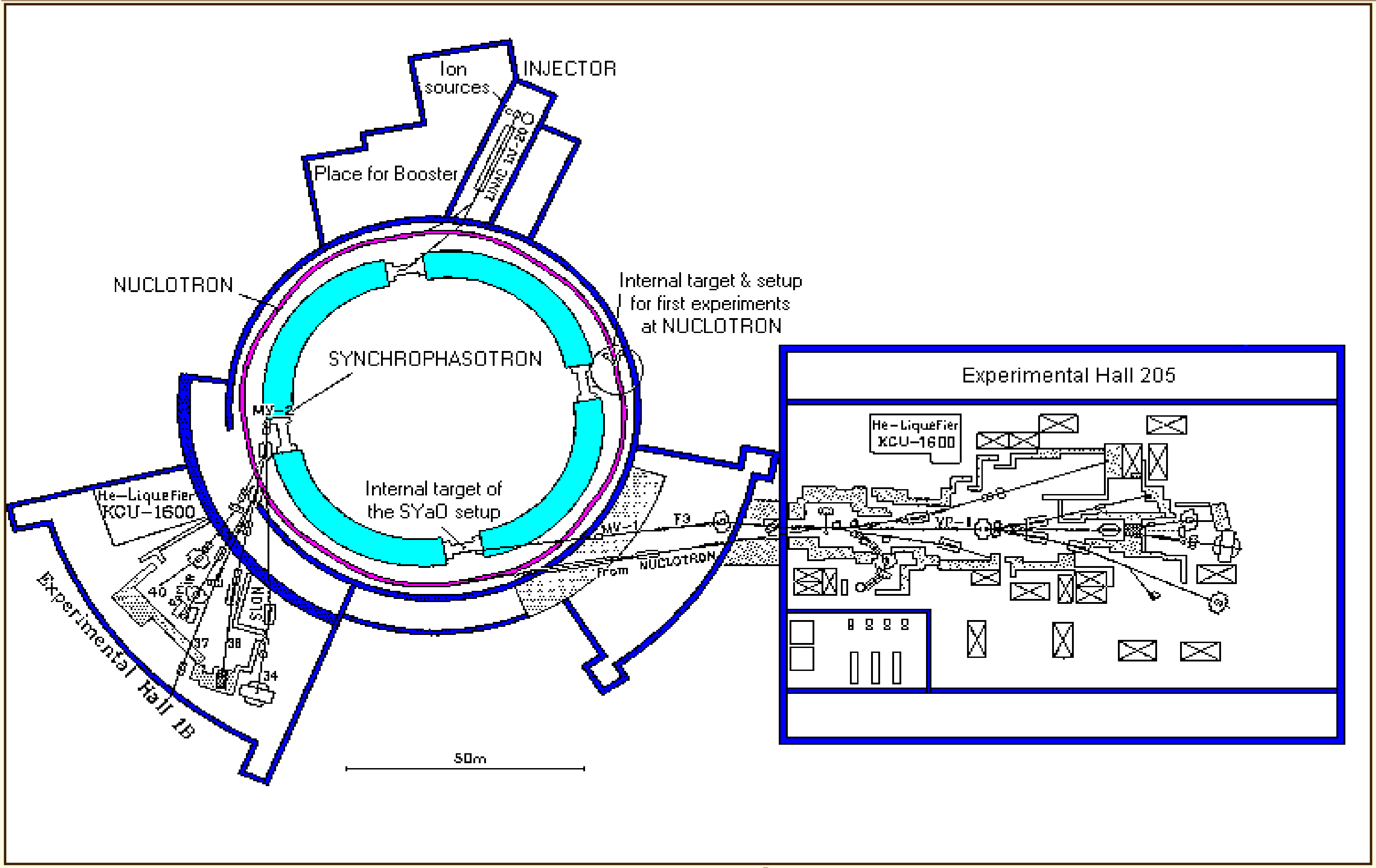
The aim

Dynamics of near-threshold production of the lightest mesons and their interactions: to study whether the known low-$\pi\pi$ mass anomaly in *pp* and *p*d systems can survive in heavier systems in the $\gamma\gamma$ channel.

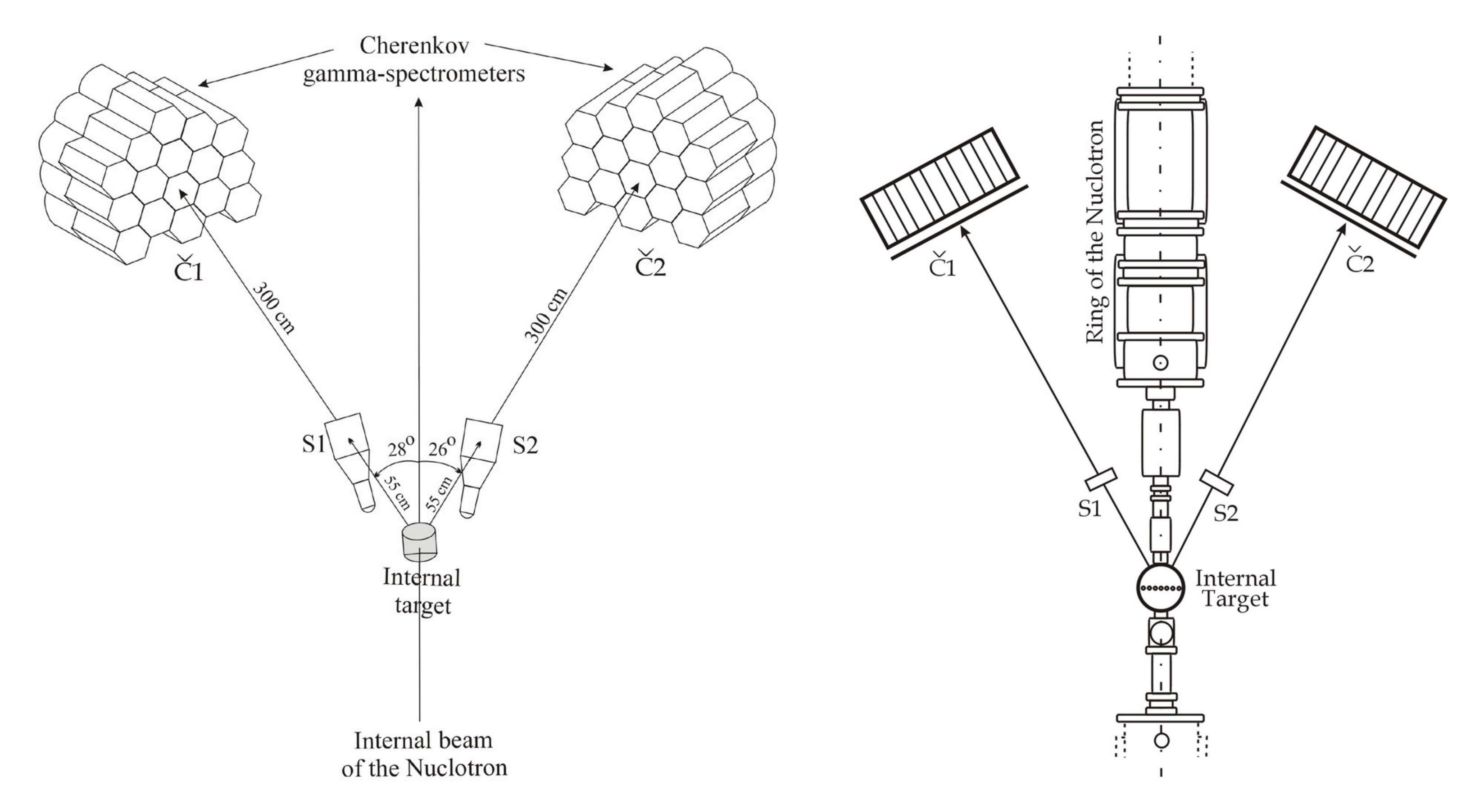
The plan of the report

1. The experiment
2. Measured invariant mass spectra of two-photon pairs
3. Similar analysis within the wavelet method
4. Different mechanisms of the observed $\gamma\gamma$ pair enhancement
5. Experimental estimates for production cross sections and widths of η mesons and hypothetical R resonance

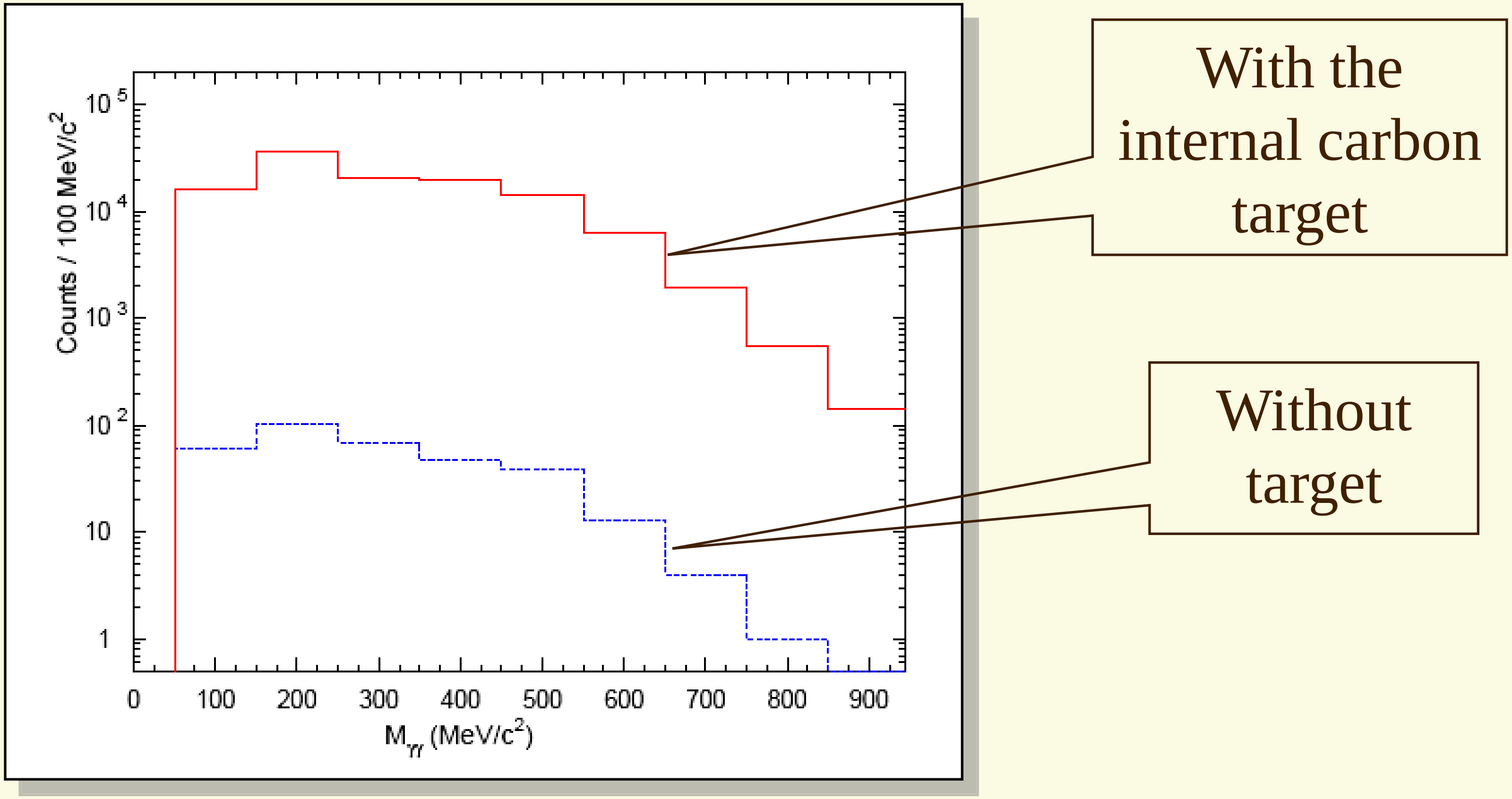
PHOTON-2 setup on internal beams of the NUCLOTRON



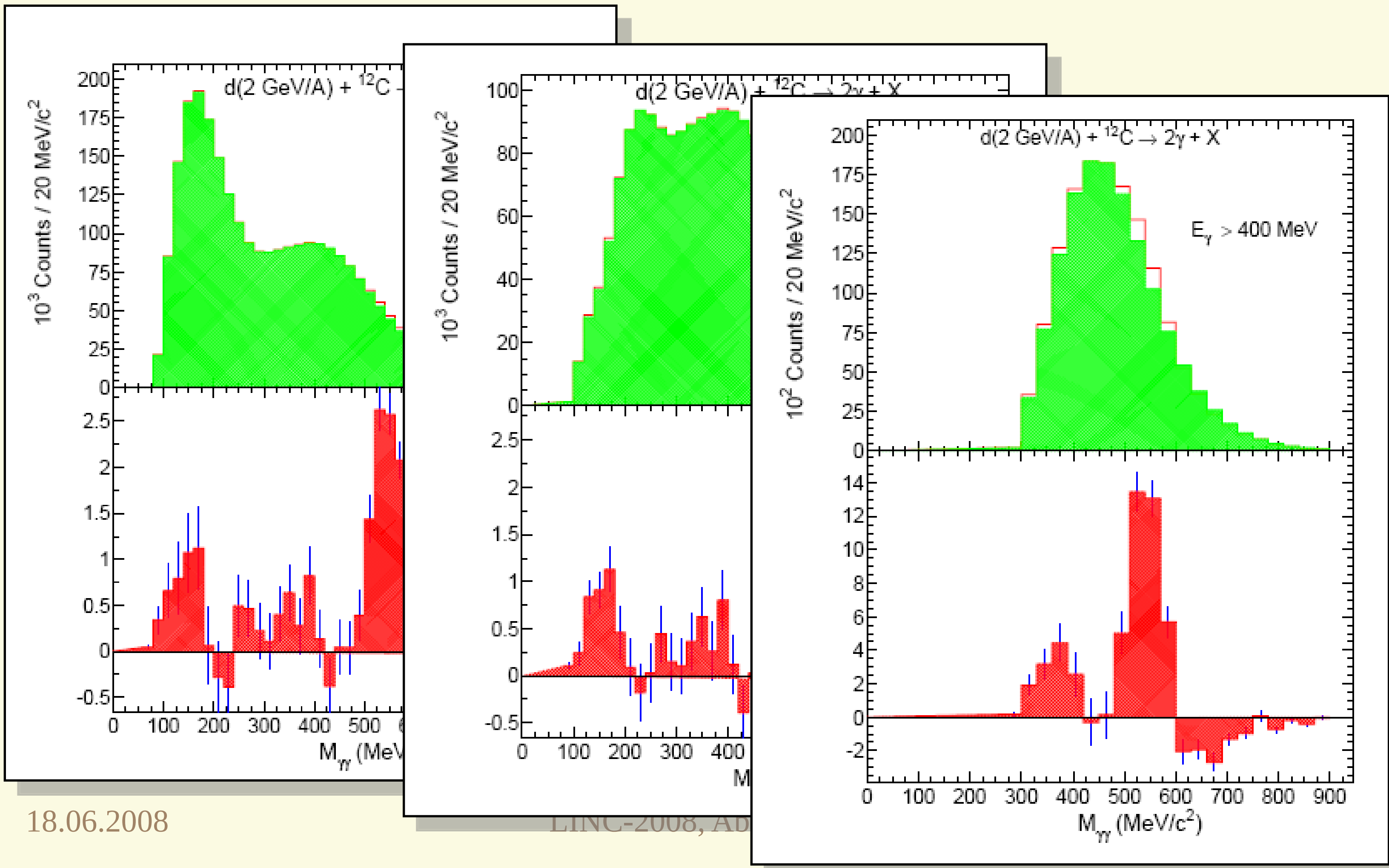
PHOTON-2 setup on internal beams of the NUCLOTRON



Invariant mass distributions of γγ pairs in two different runs of measurement under condition $E\gamma \geq 50$ MeV: with the empty target (dashed histogram) and with the internal carbon target (solid histogram) in the reaction $dC = \gamma + \gamma + X$ at 2.75 GeV/c per nucleon.



Invariant mass distribution of γγ pairs from the reaction dC → γ + γ + X at 2.75 GeV/c per nucleon for two values of the cut energy of photons. The top shaded histograms show the background contribution. The bottom histograms are invariant spectra after the background subtraction.



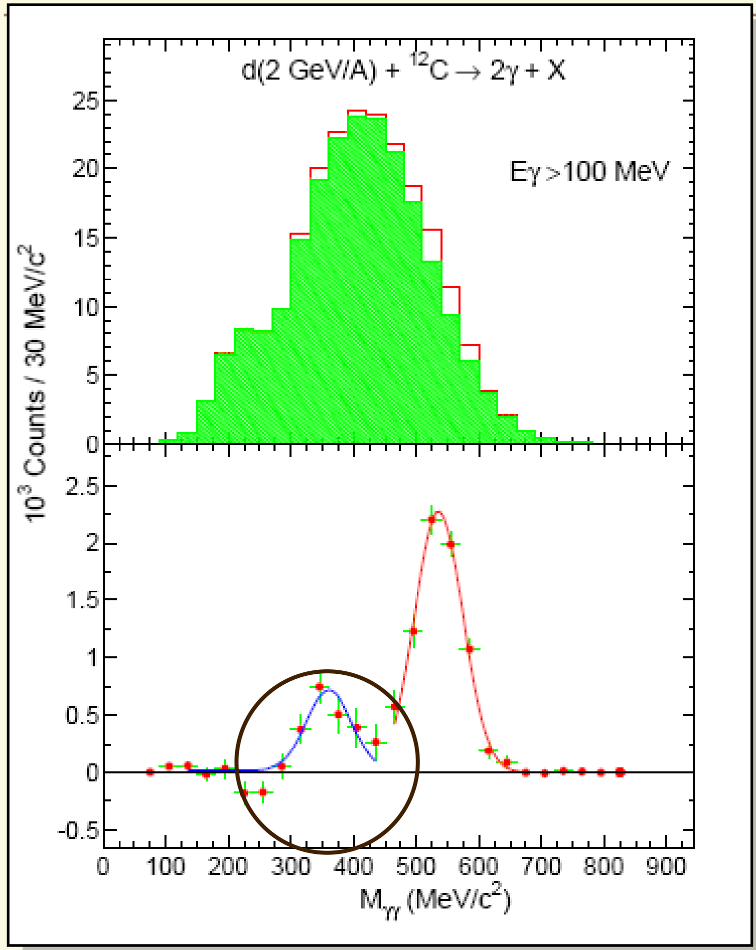
The optimal conditions

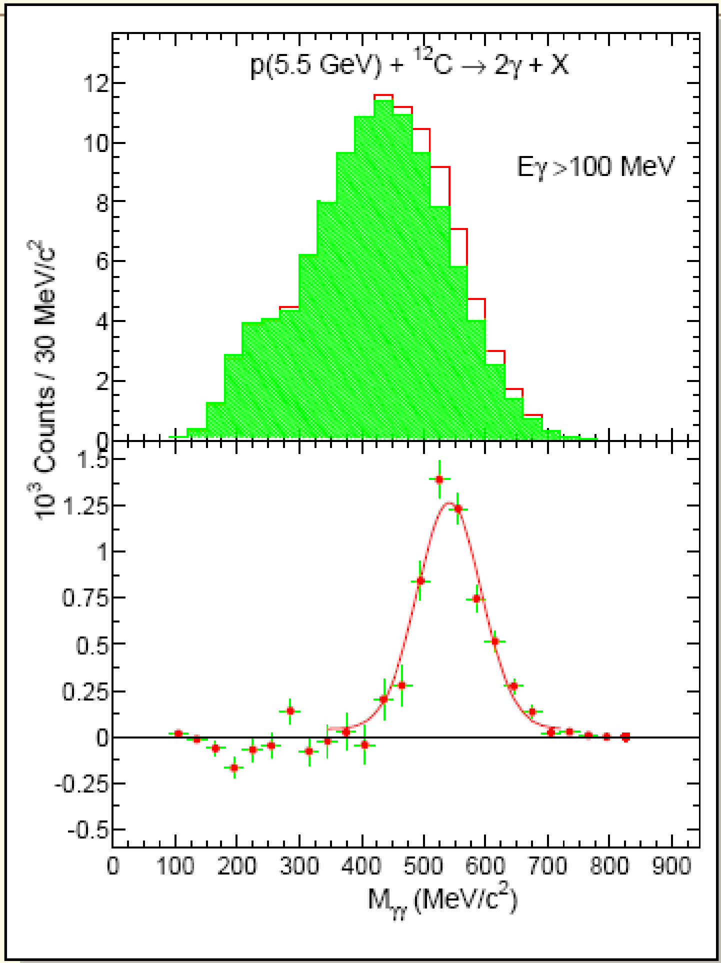
(1) the number of photons in an event, $N\gamma = 2$

(2) the energies of photons, $E\gamma \geq 100$ MeV

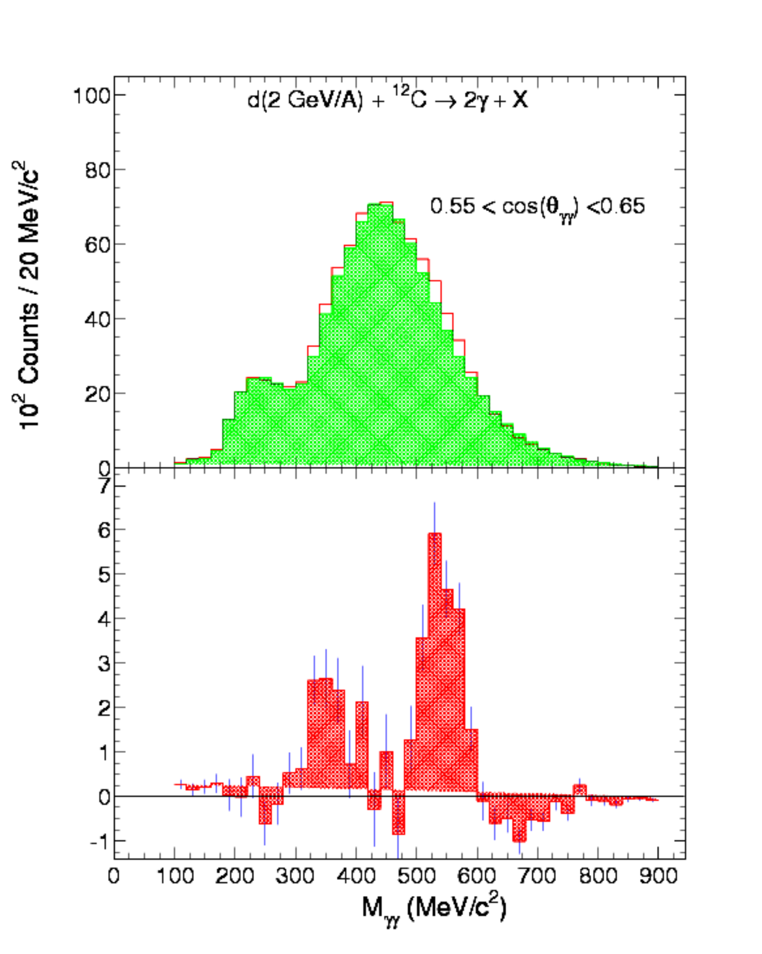
(3) the summed energy in real and random events ≤ 1.5 GeV

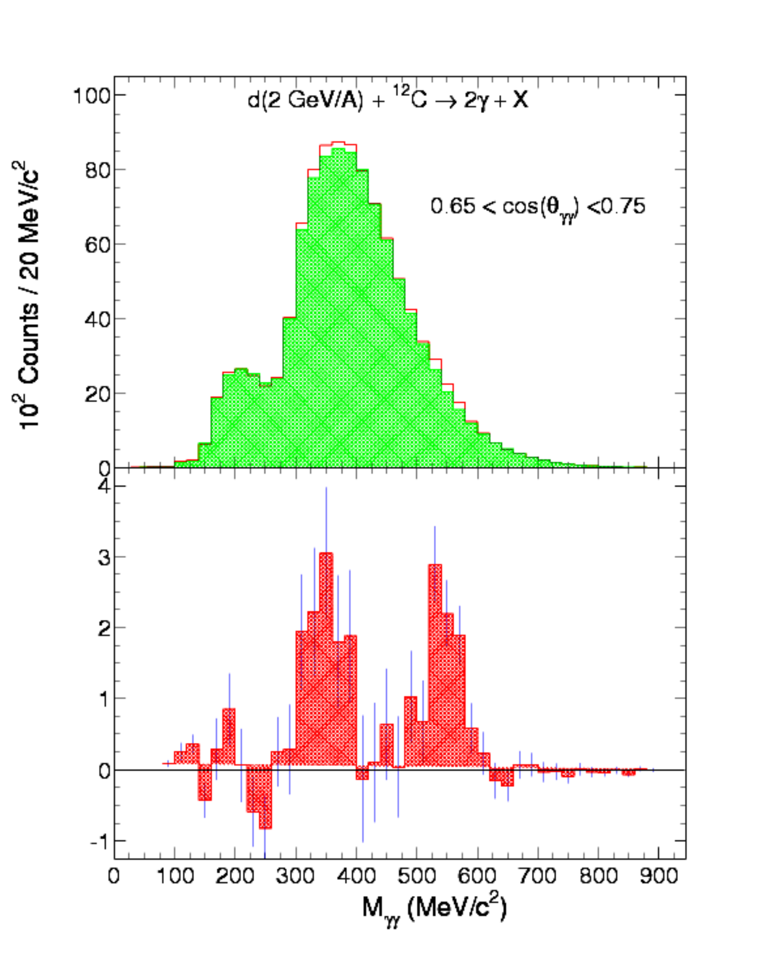
Invariant mass distributions of γγ pairs satisfying criteria (1) − (3) without (upper panel) and with (bottom panel) the background subtraction. The curves are the Gaussian approximation of experimental points



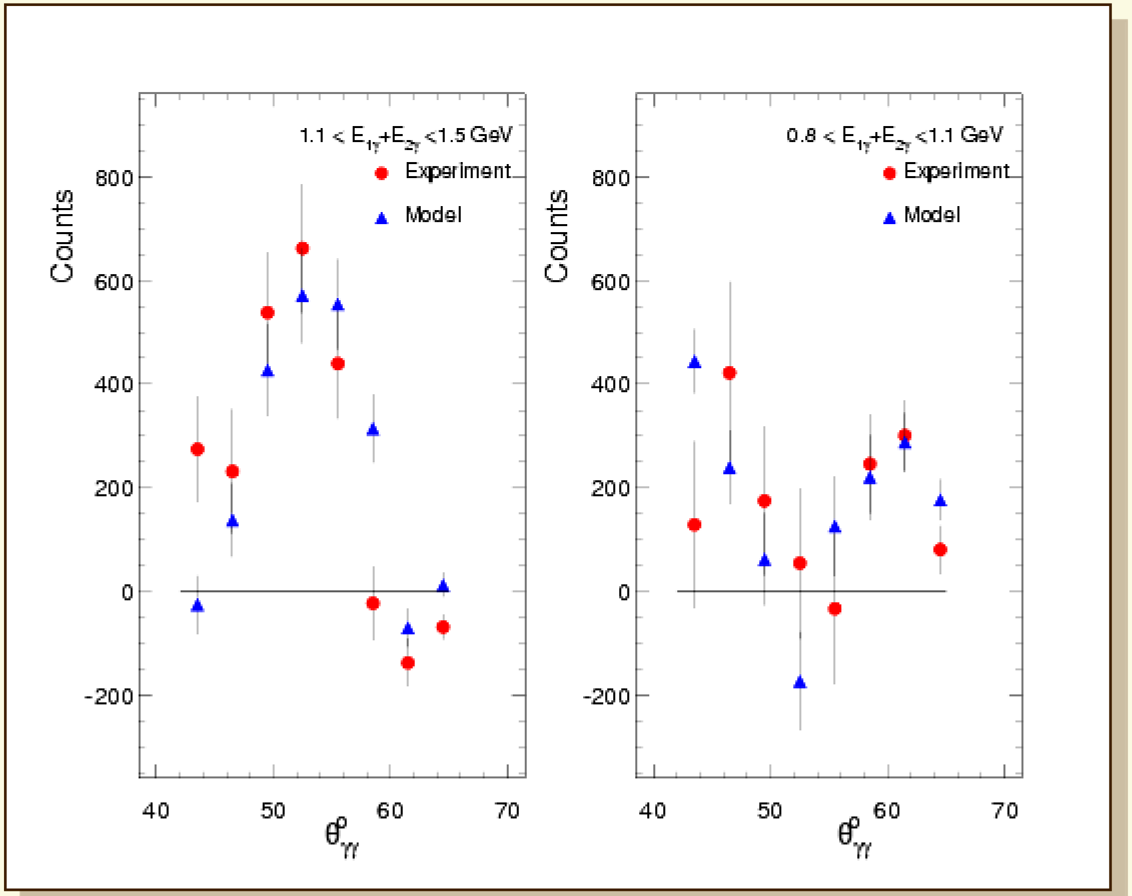


The invariant mass distributions of two photons for the opening angles 0.55 < cos (Θγγ) < 0.65 (left) and 0.65 < cos (Θγγ) < 0.75 (right) under the selection criteria (1) − (2).

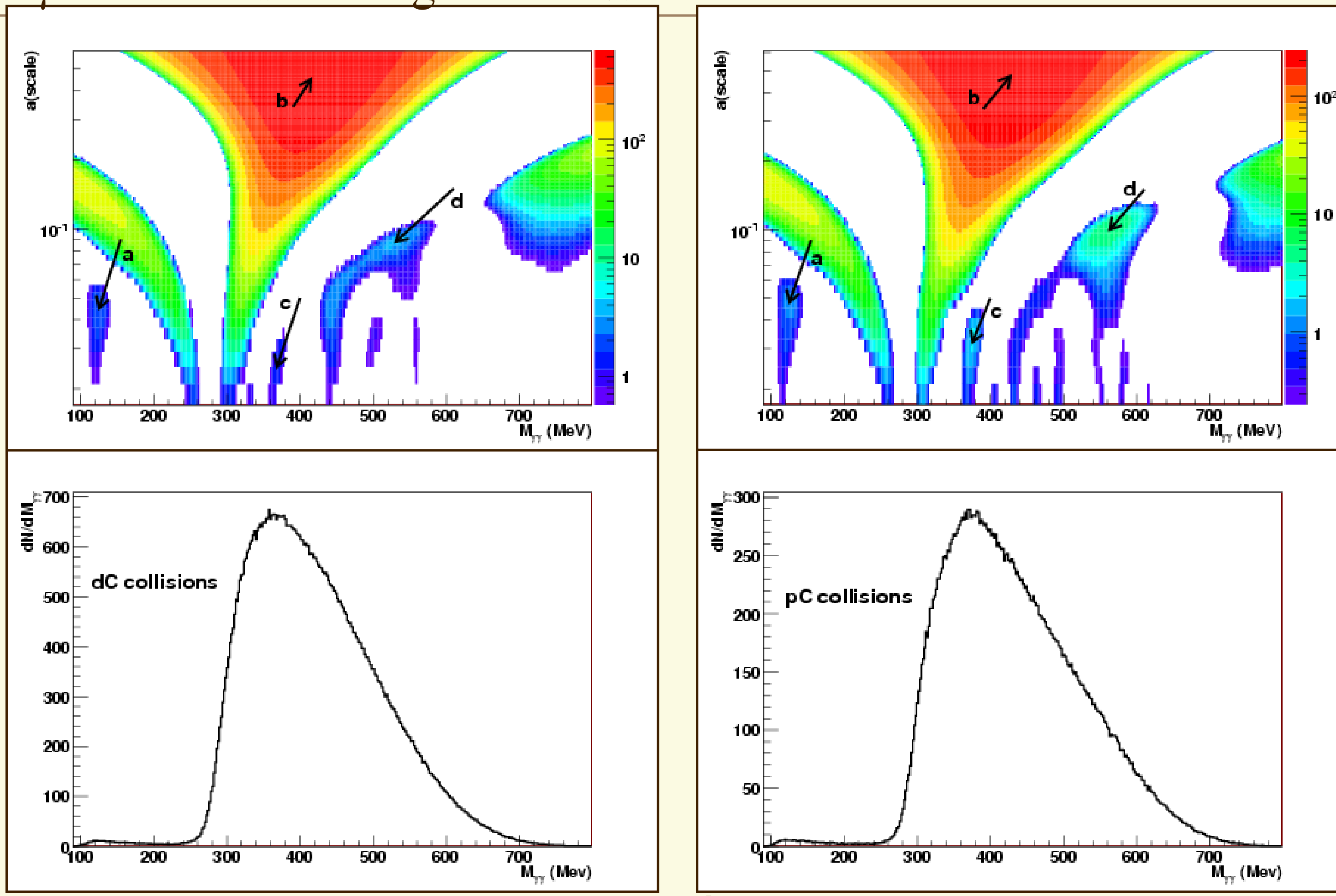




Distribution of the opening angle of γγ pairs in dC collisions for the two selections of (E1γ + E2γ).



The invariant mass distribution of γγ pairs and the biparametric distribution of the GW of the 8-th order for dC (left) and pC (right) interactions.
The distribution is obtained with an additional condition for photon energies $E\gamma 1/E\gamma 2 > 0.8$ and binning in 2MeV.



Data simulation

To simulate pC and dC reactions we use a transport code consisting of two phases At high energies it is the Quark-Gluon String Model (QGSM) and at the energy of a few GeV the string dynamics is reduced to the earlier developed Dubna Cascade Model (DCM) with upgrade of elementary cross sections involved.

The following γ-decay channels are taken into account:

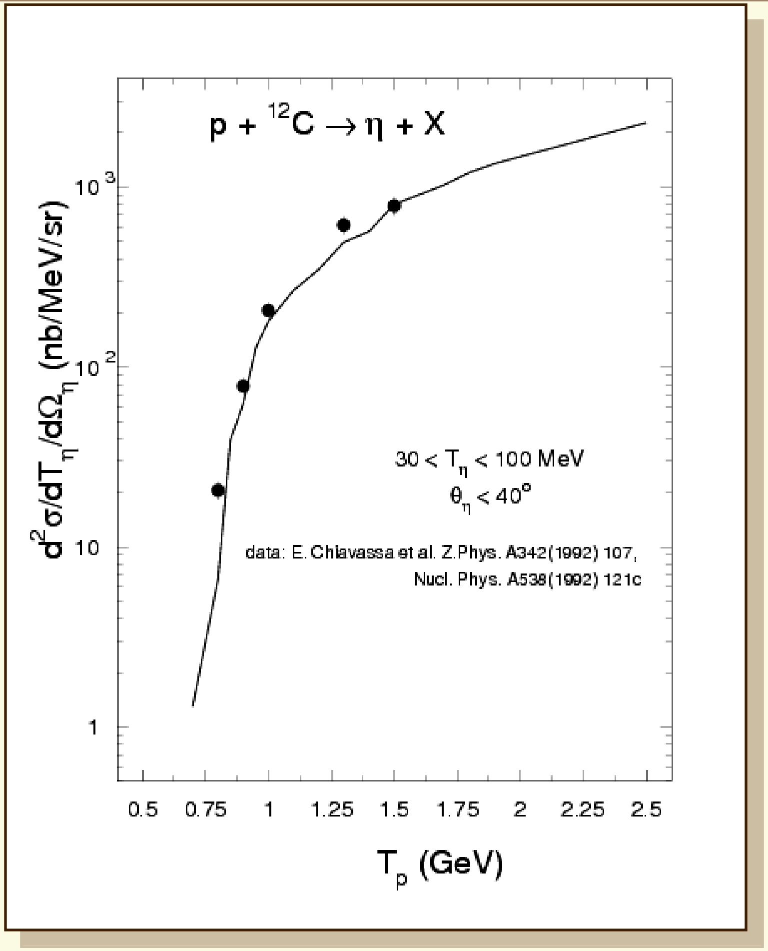
the direct decays of π^o,η,ή hadrons into two γ's;

$\omega \rightarrow \pi^o\gamma$; $\Delta \rightarrow N\gamma$ and the Dalitz decay of $\eta \rightarrow \pi\pi\gamma$,

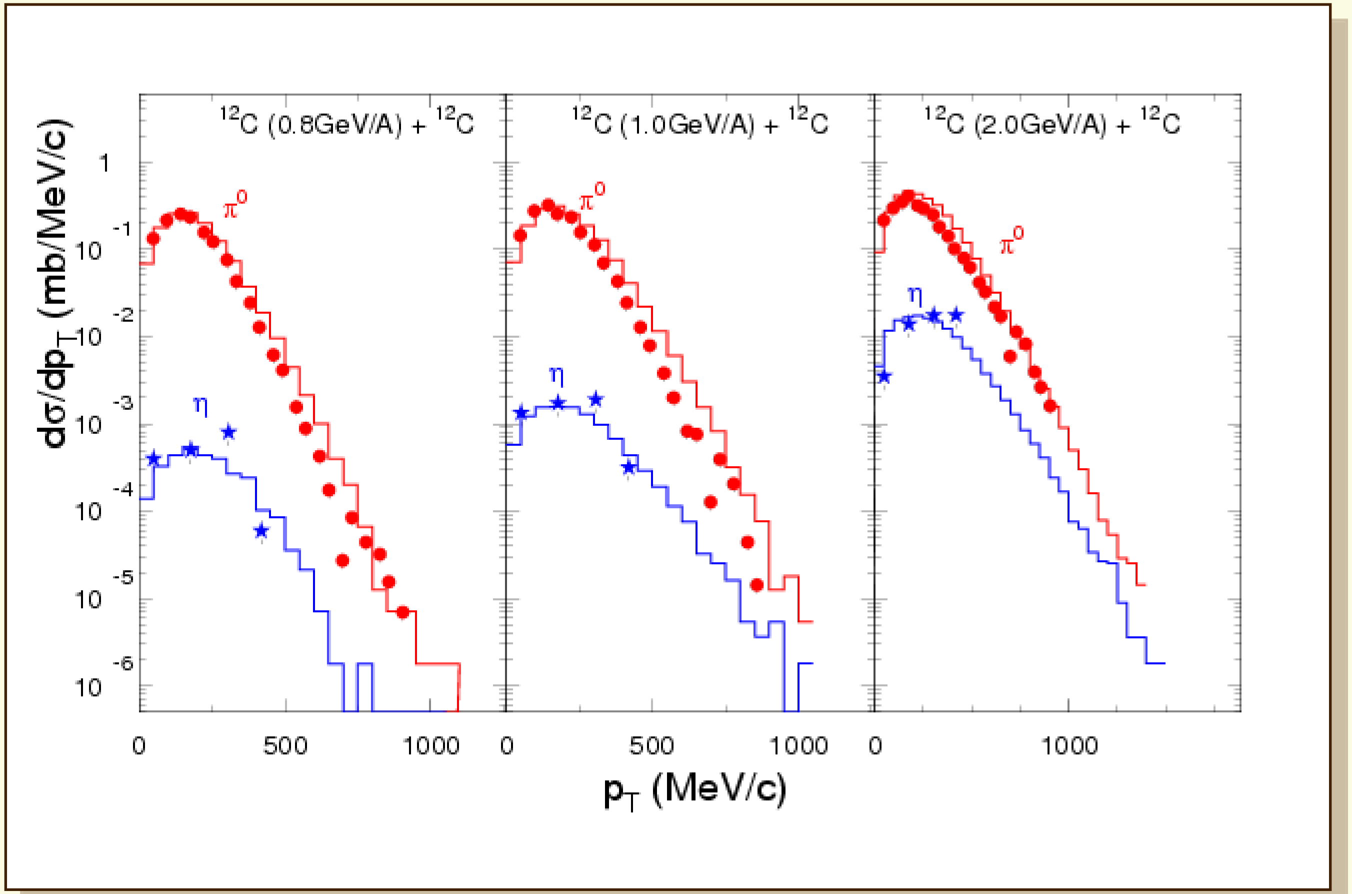
$\eta \rightarrow \gamma ee$ and $\pi^o \rightarrow \gamma ee$; the $ή \rightarrow \rho^o\gamma$, the $\Sigma \rightarrow \Lambda\gamma$,

the πN and NN-bremsstrahlung.

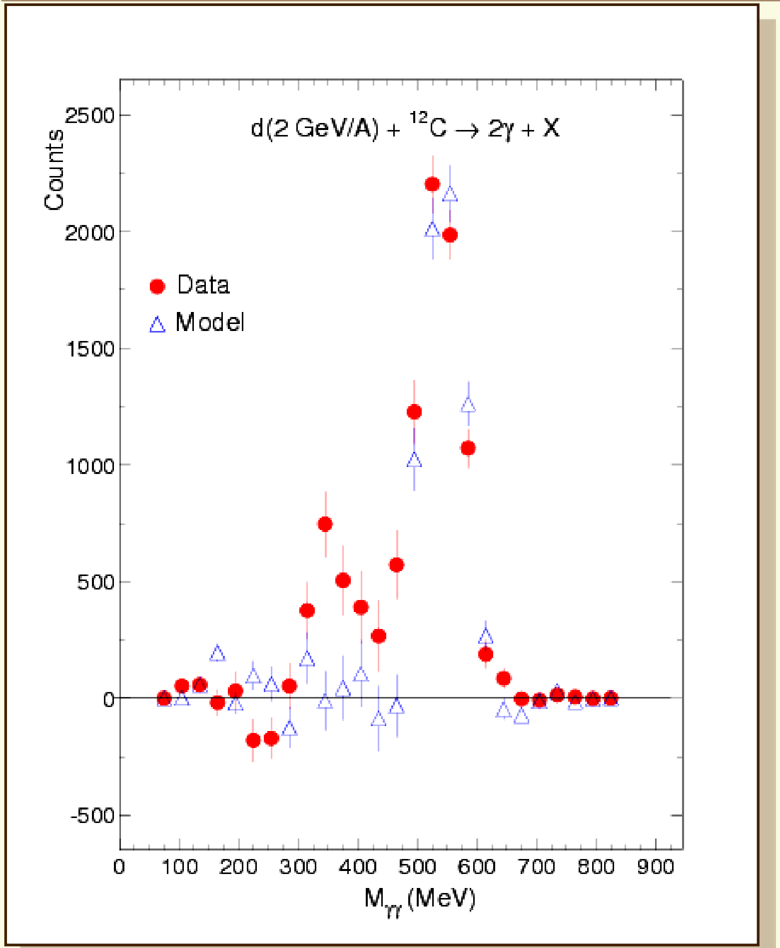
The proton energy dependence of the double differential cross section for the η production in pC collisions.

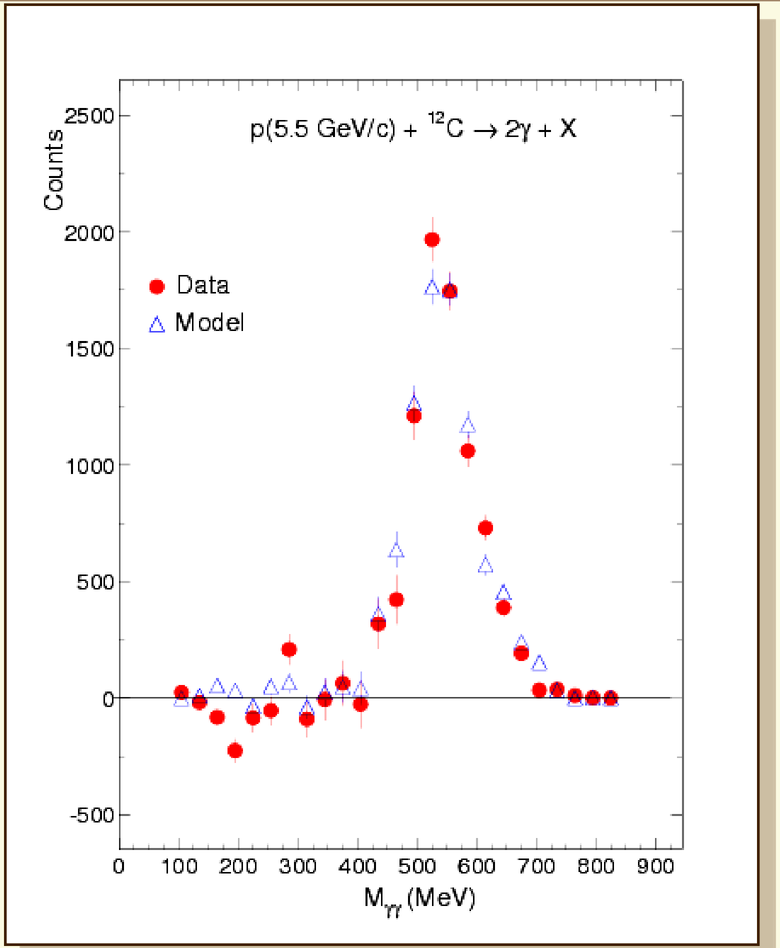


Transverse momentum distributions of π and η in the middle rapidity range from CC collisions at different energies. Experimental points are from the TAPS Collaboration [R.Averbeck et al Z.Phys.A 359 (1997)65]

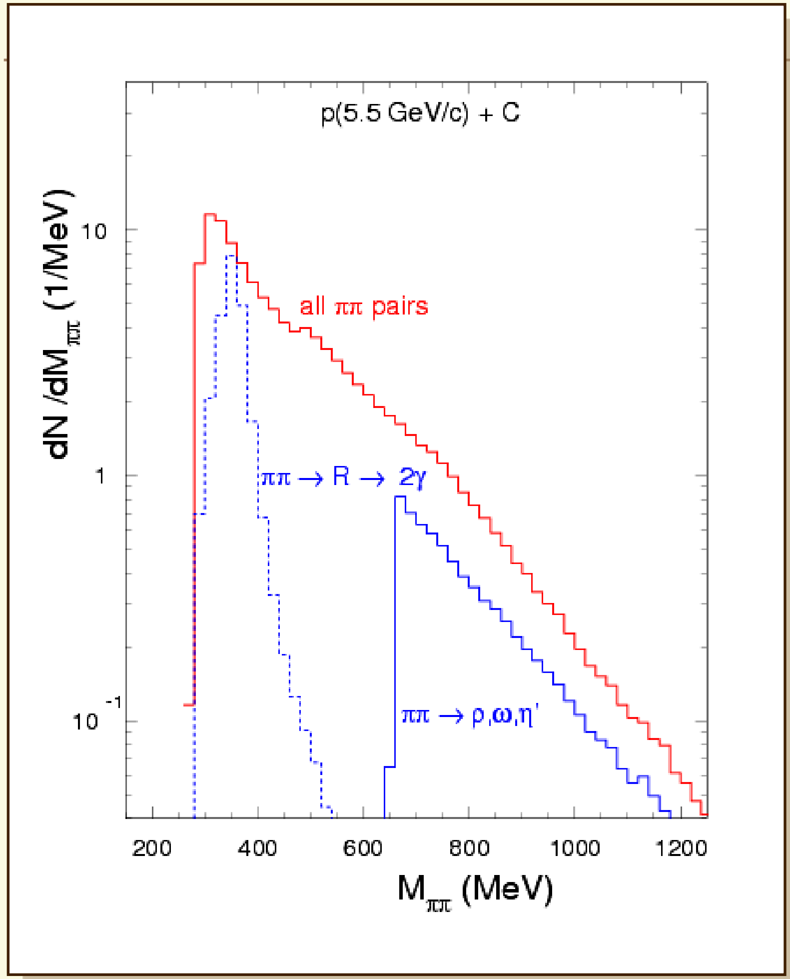


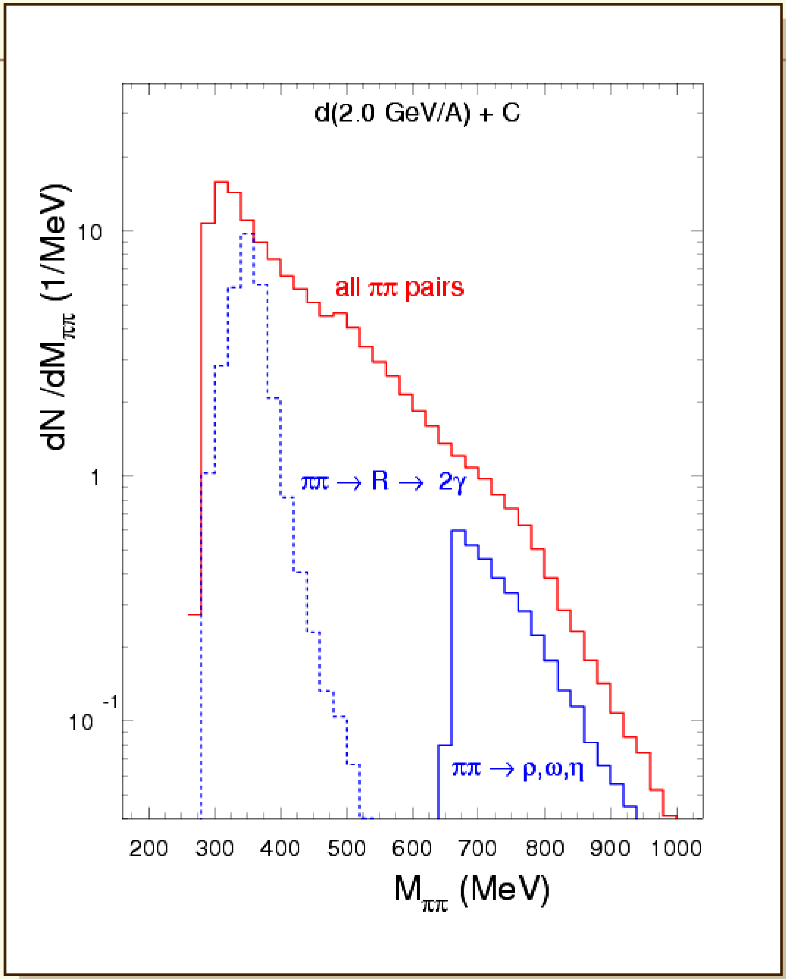
The invariant mass distributions of γγ pairs from the dC (left) and pC (right) reactions after background subtraction.



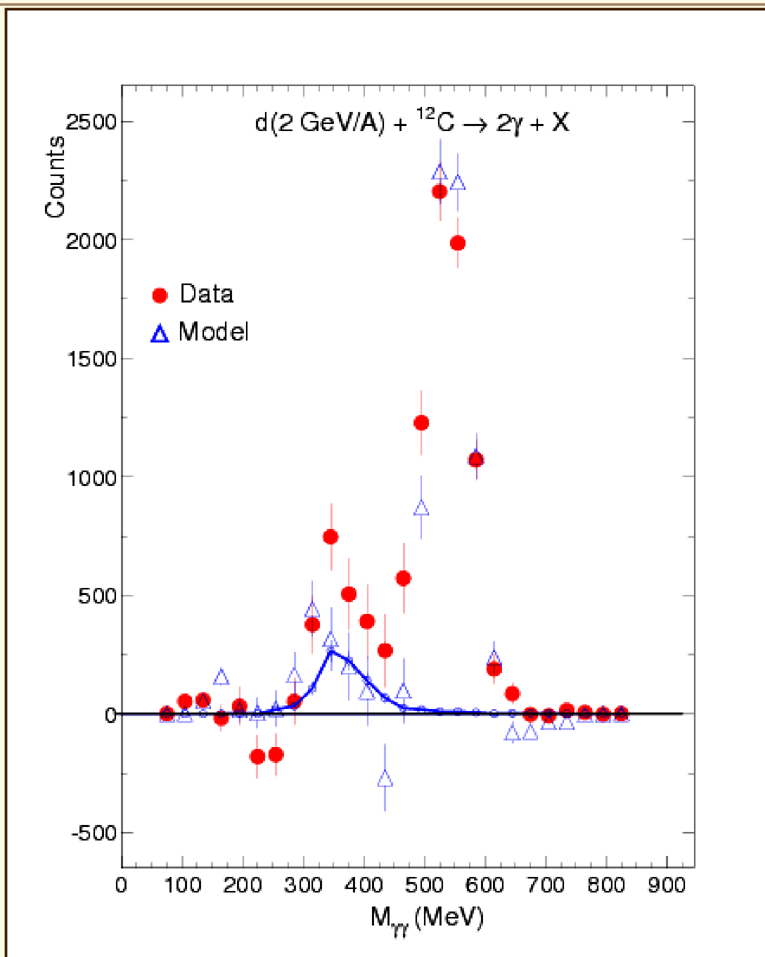


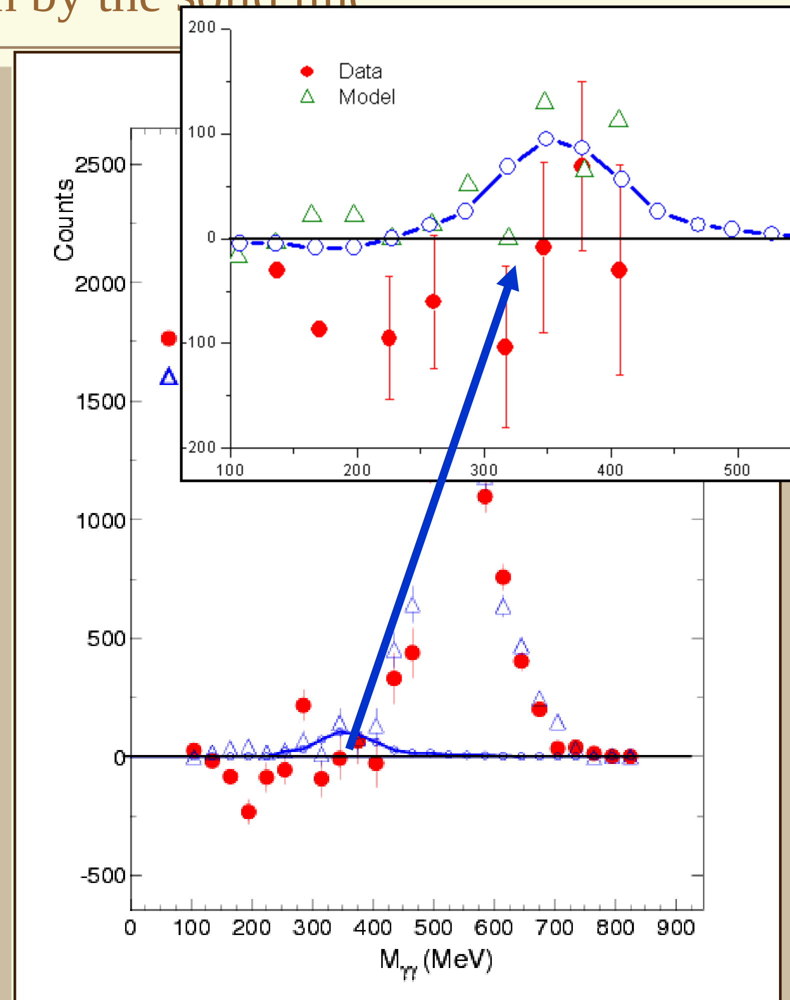
Invariant mass distribution of pion pairs from ππ interactions in pC and dC collisions.



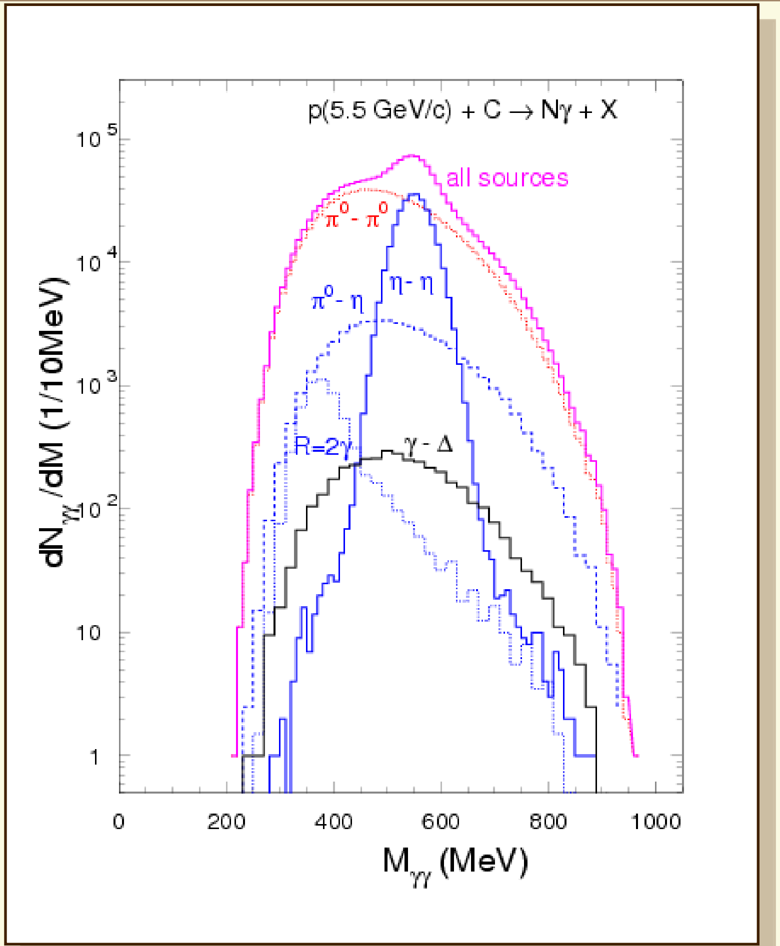


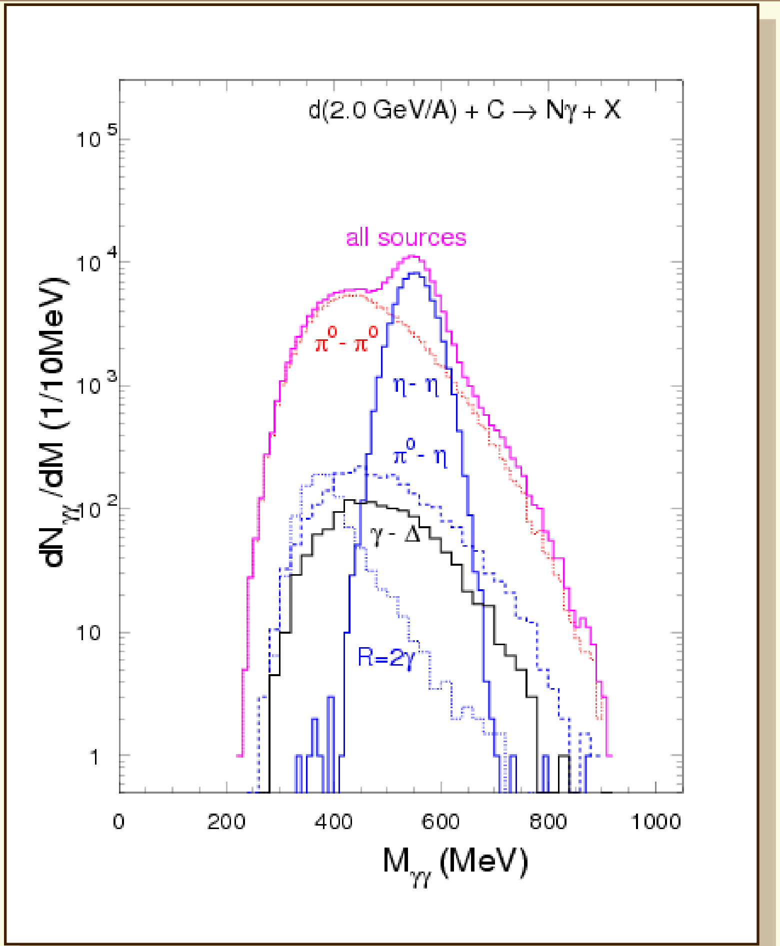
Invariant mass distributions of γγ pairs from the pC and dC reactions after background subtraction. Both experimental (circles) and simulated (triangles) points are obtained under the same conditions. The contribution of photons from the R decay is shown by the solid line



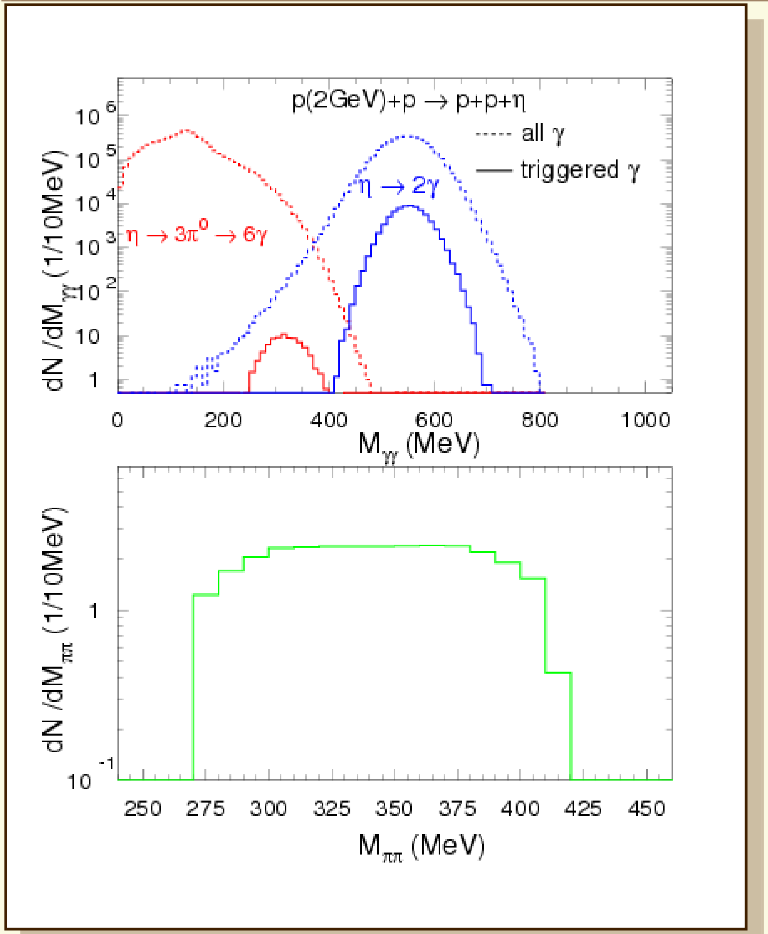


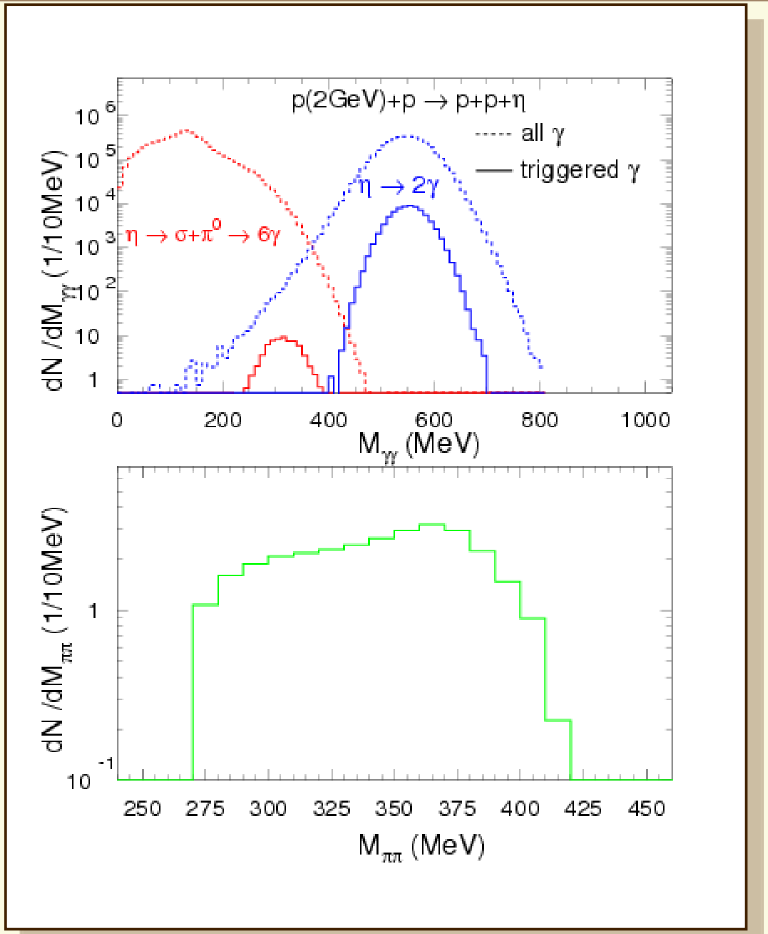
The calculated γγ invariant mass distribution in pC and dC collisions for selected events with Nγ = 2.



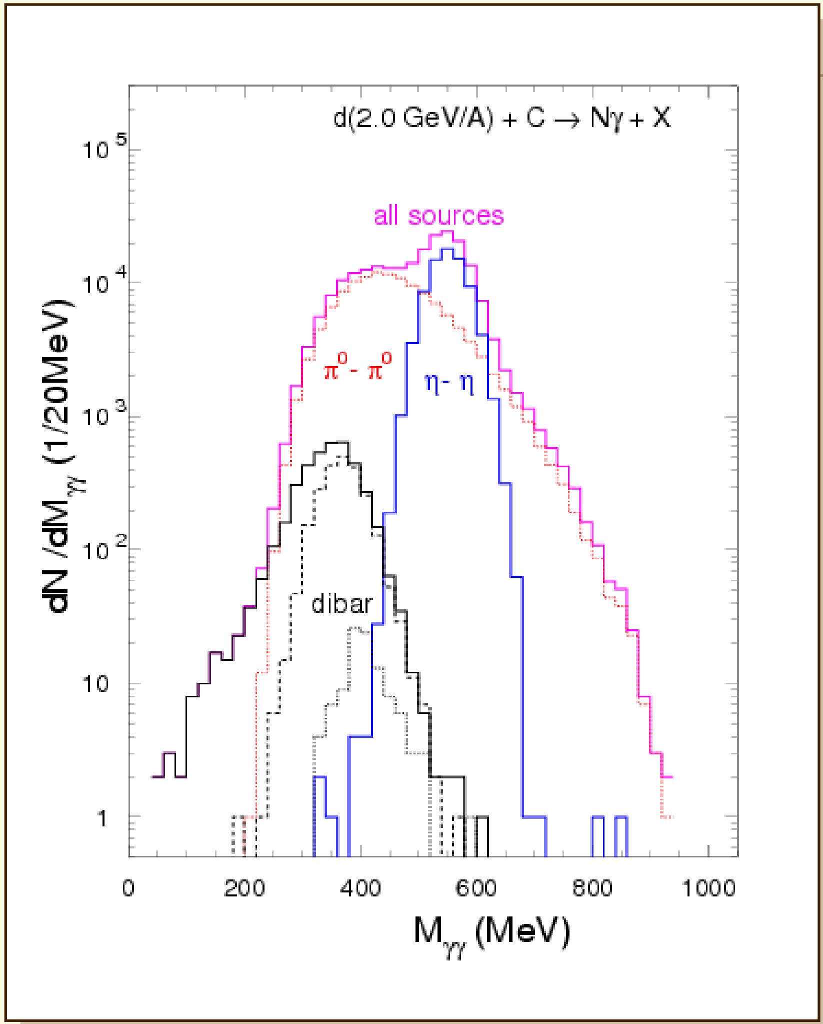


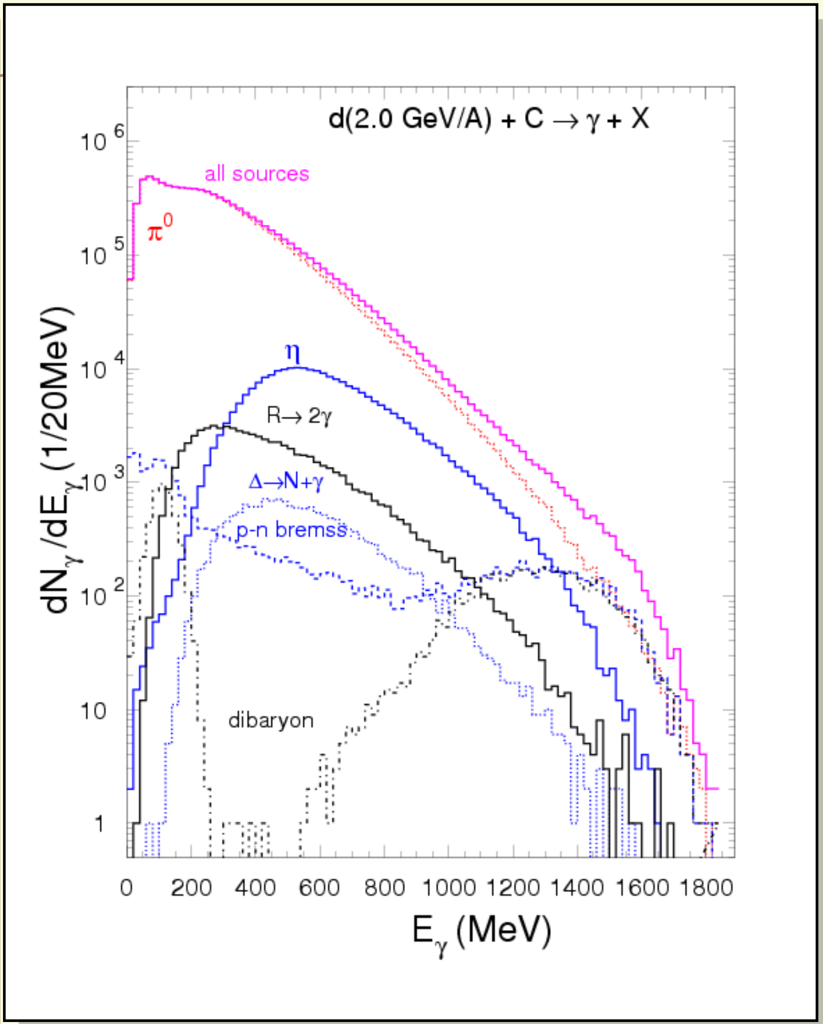
The γγ (top) and ππ(bottom) invariant mass distributions for the η decay through the $\eta \rightarrow \gamma\gamma$ and $\eta \rightarrow 3\pi$ channels.



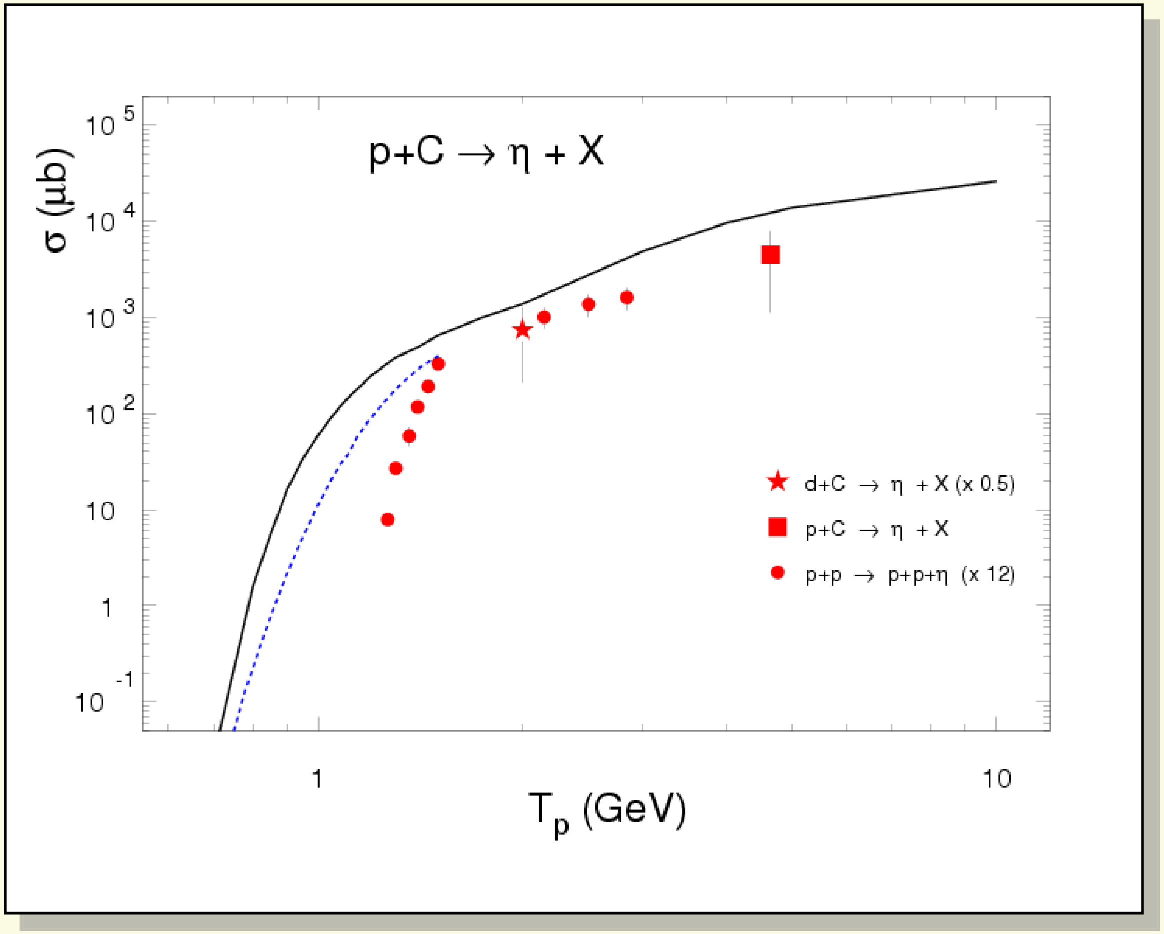


The γγ invariant mass distribution (left) and energy spectra of photons (right) calculated for dC collisions with inclusion of the dibaryon mechanism.

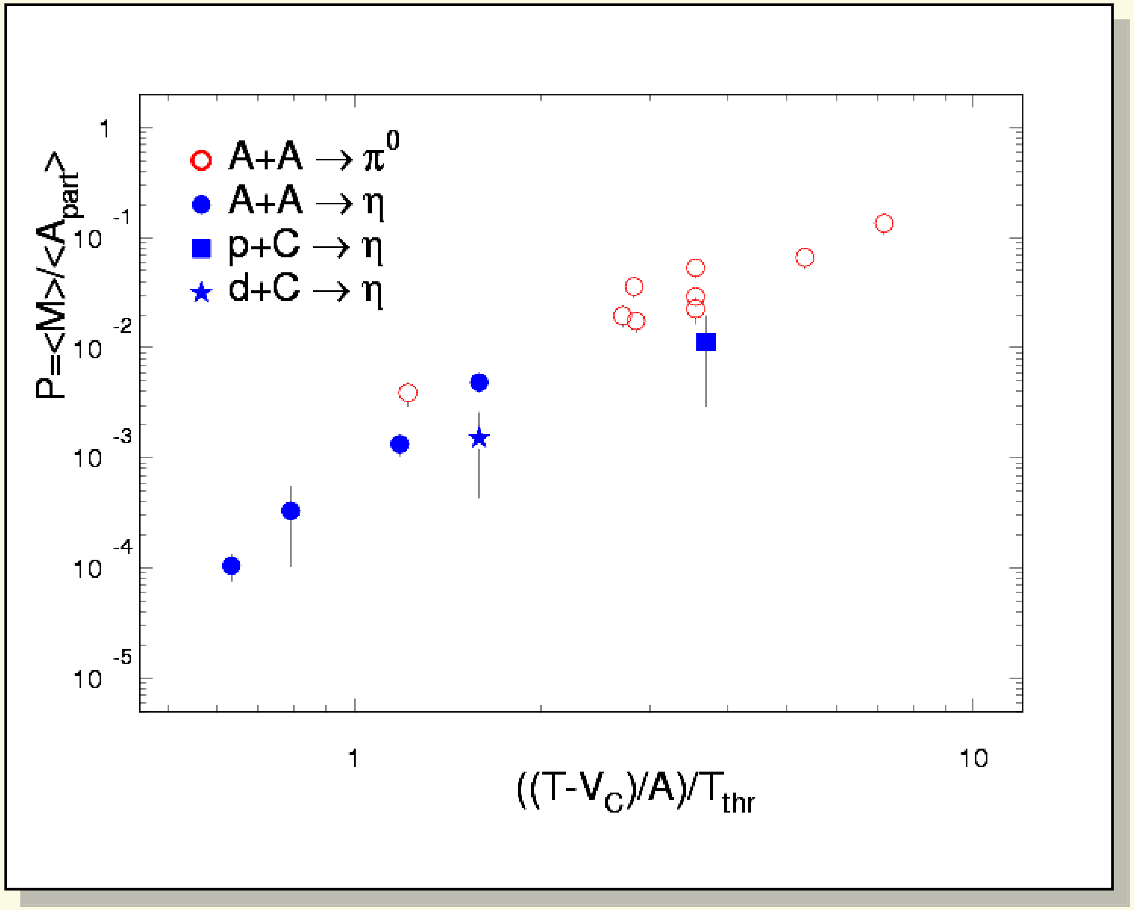


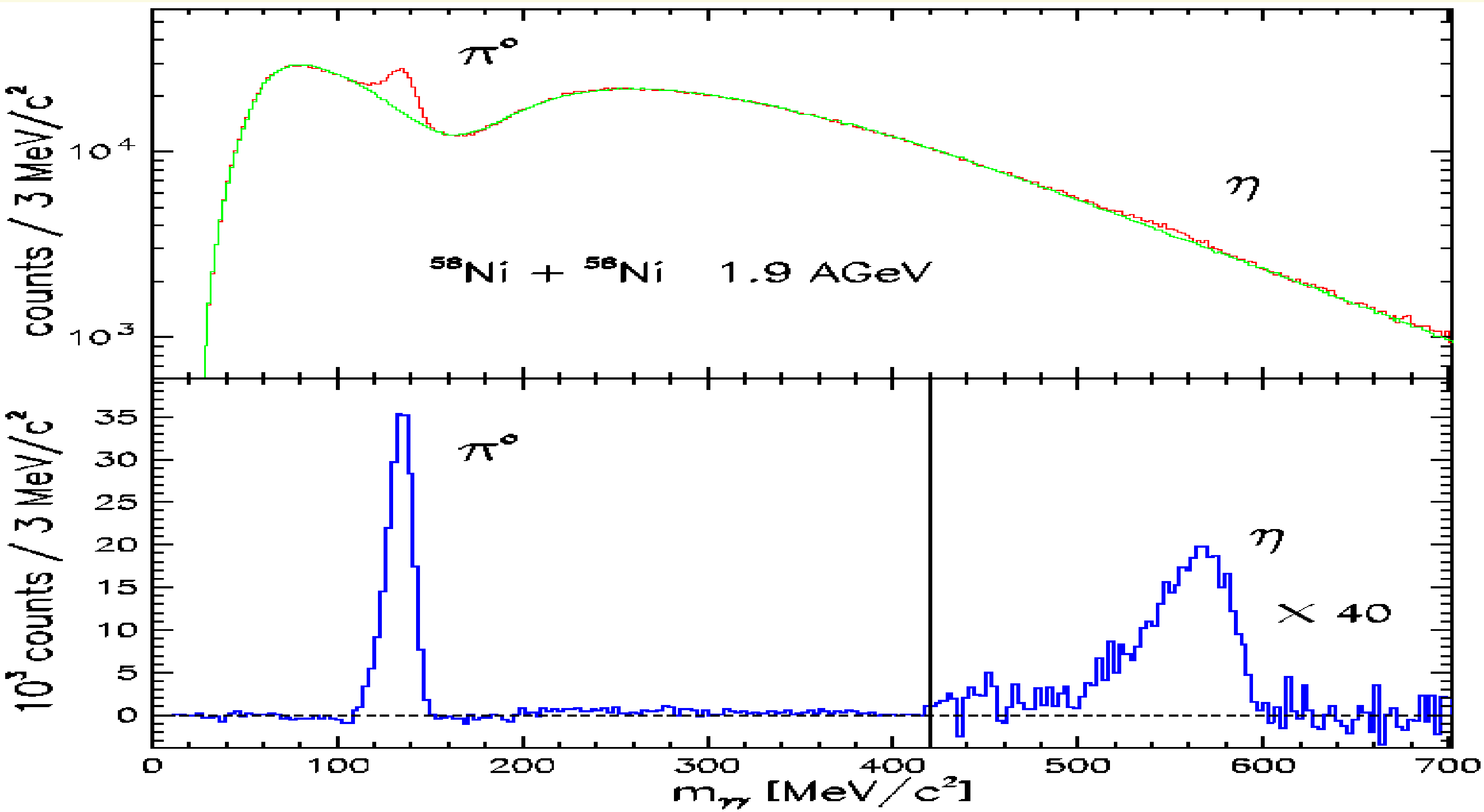


Excitation function for production in pC collisions calculated by Cassing (dotted curve) and within our DCM model (solid line).
Circles show the cross section for elementary collisions pp → ppη, multiplied by the factor of 12.



Meson production probability as a function of bombarding energy per nucleon normalized to the meson production threshold.





- A.Taranenko et.all, Czech.J.Phys. 50S4 (2000) 139, nucl-ex/9910002.
- Results of the invariant-mass analysis of photon pairs (TAPS). The upper frame shows the invariant-mass spectrum which corresponds to the η trigger in the experiment 58Ni+58Ni at 1.9 AGeV. The combinatorial background (dotted line) was determined by event mixing. The lower frame shows the invariant-mass distribution after background subtraction and demonstrates the quality of the background determination.

Comparison with experiments on the “TAPS”

1. Z.Phys.A359, 65(1997): C+C reaction, 2.0A GeV

	TAPS	PHOTON-2
Opening angles	65º-102º	42º-66º
η energies (GeV)	> 0.70	> 1.01
Mean values	0.85	1.21
O.R. energies	> 0.457	> 0.652
Mean values	0.552	0.782
Total cr. sect. (b)	2.021	0.612
Arm’s area (m^2)	0.578	0.424
Arm’s solid angle (sr)	0.257	0.047
En.res. σ/E (m.v.,%)	3.0	6.1
Sig./B. in 300-420:	~ 0.0014 [a] (<0.004)	0.027

[a] Sig. ~ √6 · 10^5

Necessary statistics for same observation in the experiment on TAPS (Z.Phys.A359, 65(1997): C+C reaction, 2.0A GeV)

$\sim 3\cdot 10^{12} \cdot (\Delta\Omega_{PHOTON} / \Delta\Omega_{TAPS})^2 \cdot (\Delta M_{PHOTON} / \Delta M_{TAPS})^2 \cdot [(S/B)_{PHOTON} / (S/B)_{TAPS}]^2$

S/B=0.0014

$\sim 3\cdot 10^{12} \cdot (0.047 / 0.257)^2 \cdot (3.0 / 6.1)^2 \cdot (0.027 / 0.0014)^2$

= 9 · 10¹² interactions,

S/B<0.004 :

> 1.1 · 10¹² interactions.

$N_{cycle} > (1.1 \cdot 10^{12}) / (5 \cdot 10\hat{}6 \cdot \omega) =$

= 4 500 000 accelerator cycles,

$\omega = \rho x\cdot(N_A / A)\cdot \sigma(CC) = 0.049, \quad \rho x = 0.487\ g/cm^2$

For indication (+3 st.err.) : > 550 000 acceler. cycles

Concluding remarks

1. Thus, based on a thorough analysis of experimental data measured at the JINR Nuclotron and statistics of 2339 340 events of 1.5·10^6 triggered interactions of a record total number 2·10^{12} of dC-interactions there was observed a resonance-like enhancement at the mass $M_{\gamma\gamma}$=360 7 9 MeV, with the width Γ=49 19 MeV. The production cross section $\sigma_{\gamma\gamma}$ ~ 98 μb is estimated preliminary in the invariant mass spectrum of two photons produced in dC-interactions at momentum of incident deuterons 2.75 GeV/c per nucleon. A structure like this is not observed in the $M_{\gamma\gamma}$ spectrum from pC (5.5 GeV/c) interactions while the η meson is clearly seen in both the cases. These results, obtained by means of the mixing event background, are confirmed by the wavelet analysis.

Concluding remarks

2. To certain extent this enhancement at $M_{\gamma\gamma}$ ~(2-3)M_{π} is similar to the puzzling ABC effect observed for two-pion pairs from nucleon-nucleon and lightest nuclei collisions at the near threshold energy. In the given work we see that it exists in the $\gamma\gamma$ channel and measurements are extended to a heavier system. It means that this resonance-like structure is a quite stable object which even survives in the nuclear surrounding.

Concluding remarks

3. To understand the origin of the observed structure, several dynamic mechanisms were attempted: production of the hypothetic *R* resonance in $\pi\pi$ interactions during the evolution of the nuclear collision, formation of the *R* resonance with participation of photons from the Δ decay, the $\pi^o\pi^o$ interaction effect in the $3\pi^o$ channel of the η decay, and a particular decoupled dibaryon mechanism. Unfortunately, none of these mechanisms is able to explain the measured value of the resonance-like enhancement, though they contribute to the invariant mass in the region of interest.

Concluding remarks

4. The carbon target is really the heaviest one used in experiments where ABC-like structure has been observed. In contrast with all other experiments considered here, one may expect some manifestation of in-medium effects. The prominent feature of the η meson is that the η-nucleon system couples dominantly to the N*(1535)(S^{11})resonance at the threshold energies. Hence, due to the η coupling to N*(1535)-nucleon-hole modes, one could expect the eta meson nuclear dynamics to be sensitive to modification of nucleon and N* properties in medium. As was shown [E.E.Kolomeitsev et al. arXiv:0801.4834], the η spectral function at normal nuclear density has a second maximum near Mη ~ 400 MeV which may be associated to a partial chiral symmetry restoration. Its two-photon decay inside a nucleus might give a rise to a maximum close to the measured value of *R*. Unfortunately, we cannot perform transport calculations with taking into account the in-medium modification of hadron properties.

Concluding remarks

5. The recent data of the wasa-celsius Collaboration provide a strong support to the idea of a nontrivial dibaryon state. An attractive candidate for its realization may be a model of the intermediate σ-dressed dibaryon. In this model the short-range *NN*-interaction, described by the standard *t*-channel σ exchange between two nucleons, is replaced with the respective *s*-channel σ exchange associated with the intermediate dibaryon production treated as a σ-dressed six-quark bag. The strong scalar σ-field arises around the symmetric 6*q* bag, because the change in the symmetry of six-quark state in the transition from the *NN* channel to the intermediate dressed-bag state. Due to a strong attraction of the σ meson to quarks, this intensive σ gield squeezes the bag and increases its density. The contribution of the *s* channel mechanism would be generally much larger than

Concluding remarks

5. the conventional *t*-channel one due to a resonance-like enhancement. The high quark density in the symmetric 6*q* state enhances meson field fluctuations around the multiquark bag and thereby partially restores the chiral symmetry. Therfore, the mass of σ meson gets much lower and has been estimated to be the value $M\sigma$ ~ 350   380 MeV. In its turn, it should enhance the near-threshold pion and double-pion production. In addition, a large varietyof nuclear data, in particularproperties of short- and intermediate-range of *NN* and 3*N* potentials, has been explained within this model; however, still there is no direct quantitative calculations of the ABC-like effects.

Concluding remarks

6. From the experimental side it is highly desirable to determine more accurately the mass, width, and cross section of the observed resonance structure by enlarging the acceptance. To verify the above conclusions new experiments are required to be carried out under conditions appropriate for registration of pairs of two photons within the invariant mass interval of 300-400 MeV. In this respect experiments on proton and carbon targets with proton and deuteron beams at the same energy per nucleon would be very useful. Some scanning in the beam energy will clarify the possible resonance structure of this effect. By varying the opening angle of the PHOTON-2 spectrometer it is possible to get information about momentum spectra of the produced resonance-like structure which could be a delicate test of the *R* production mechanism.

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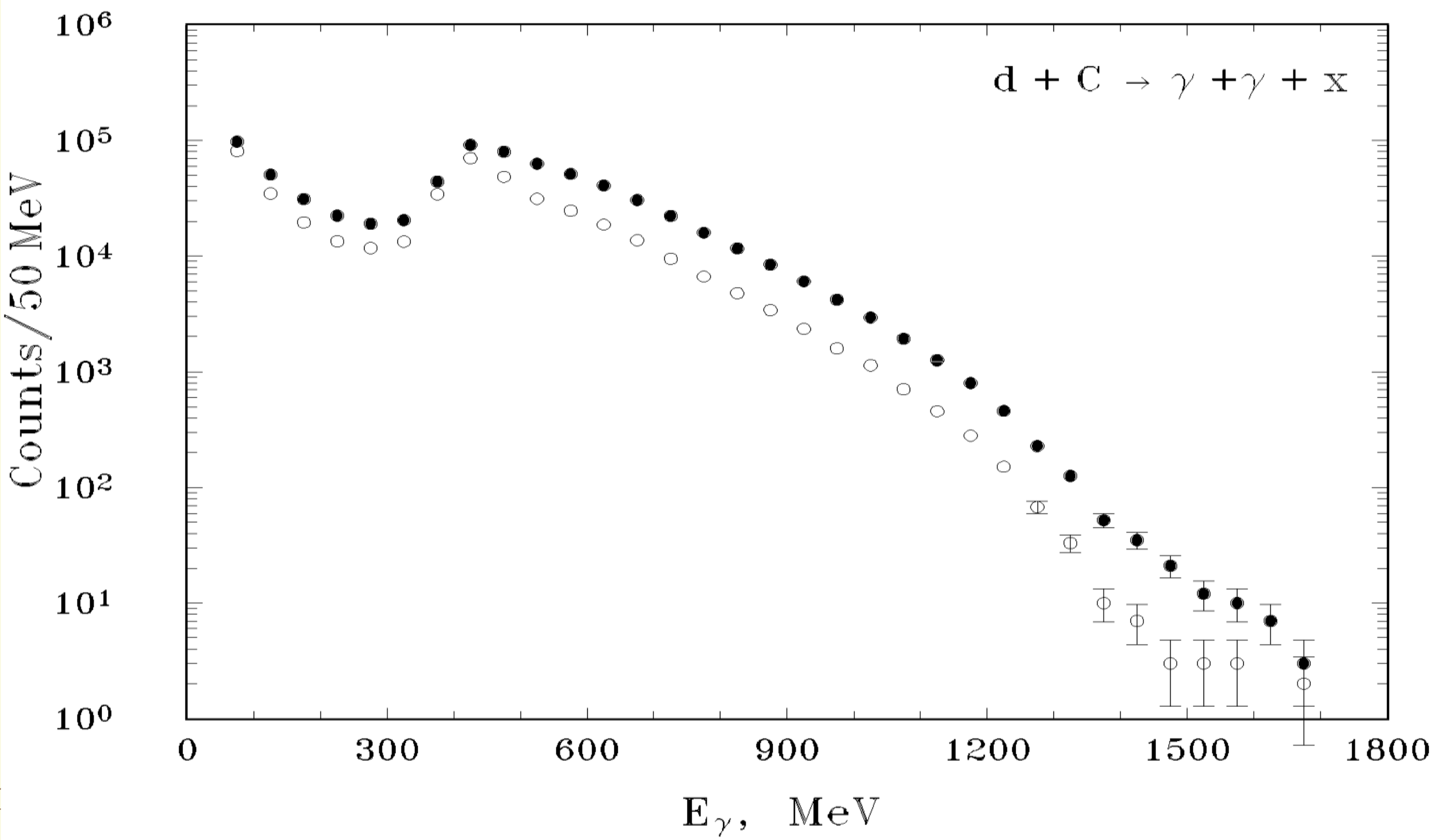
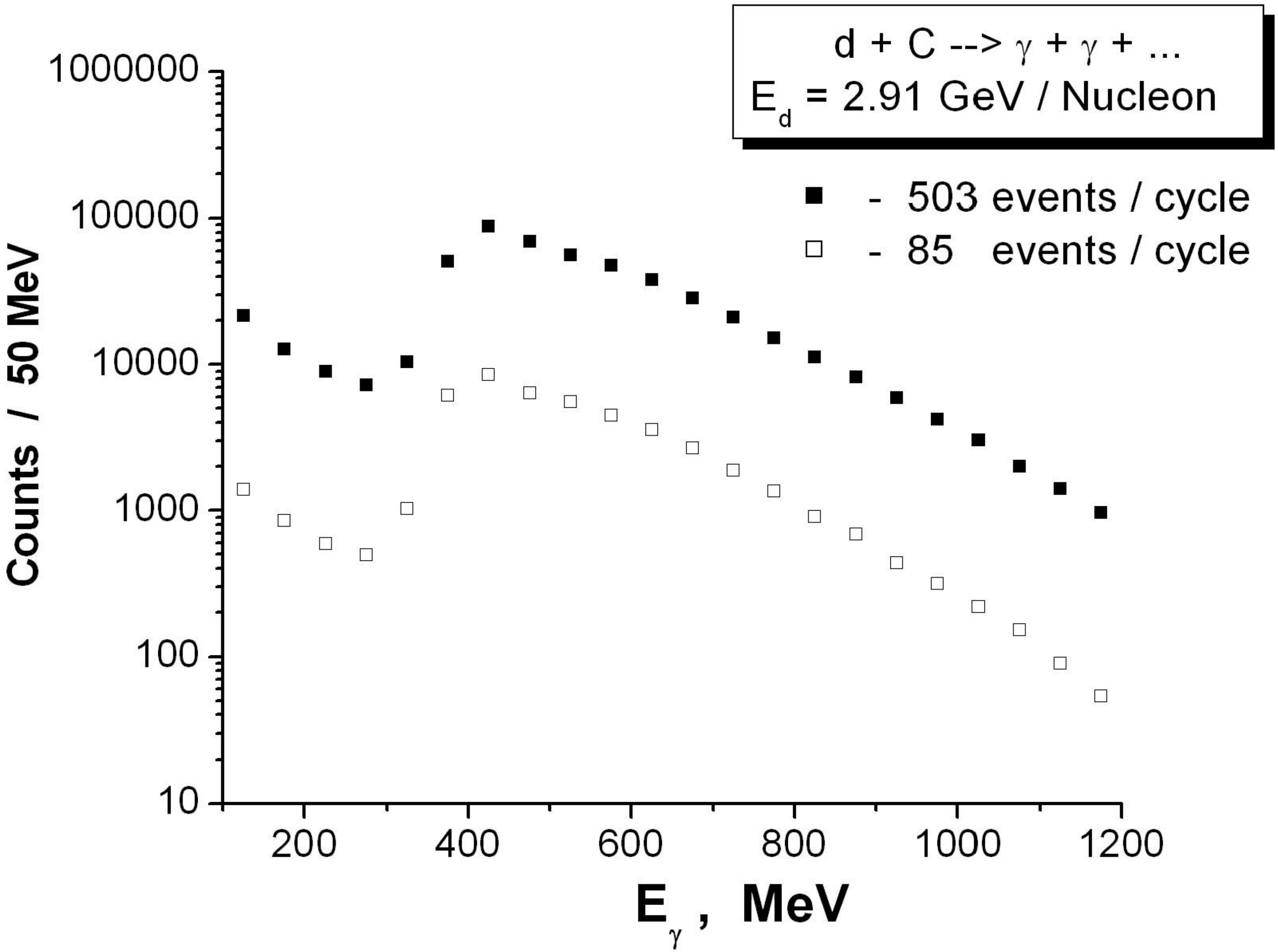
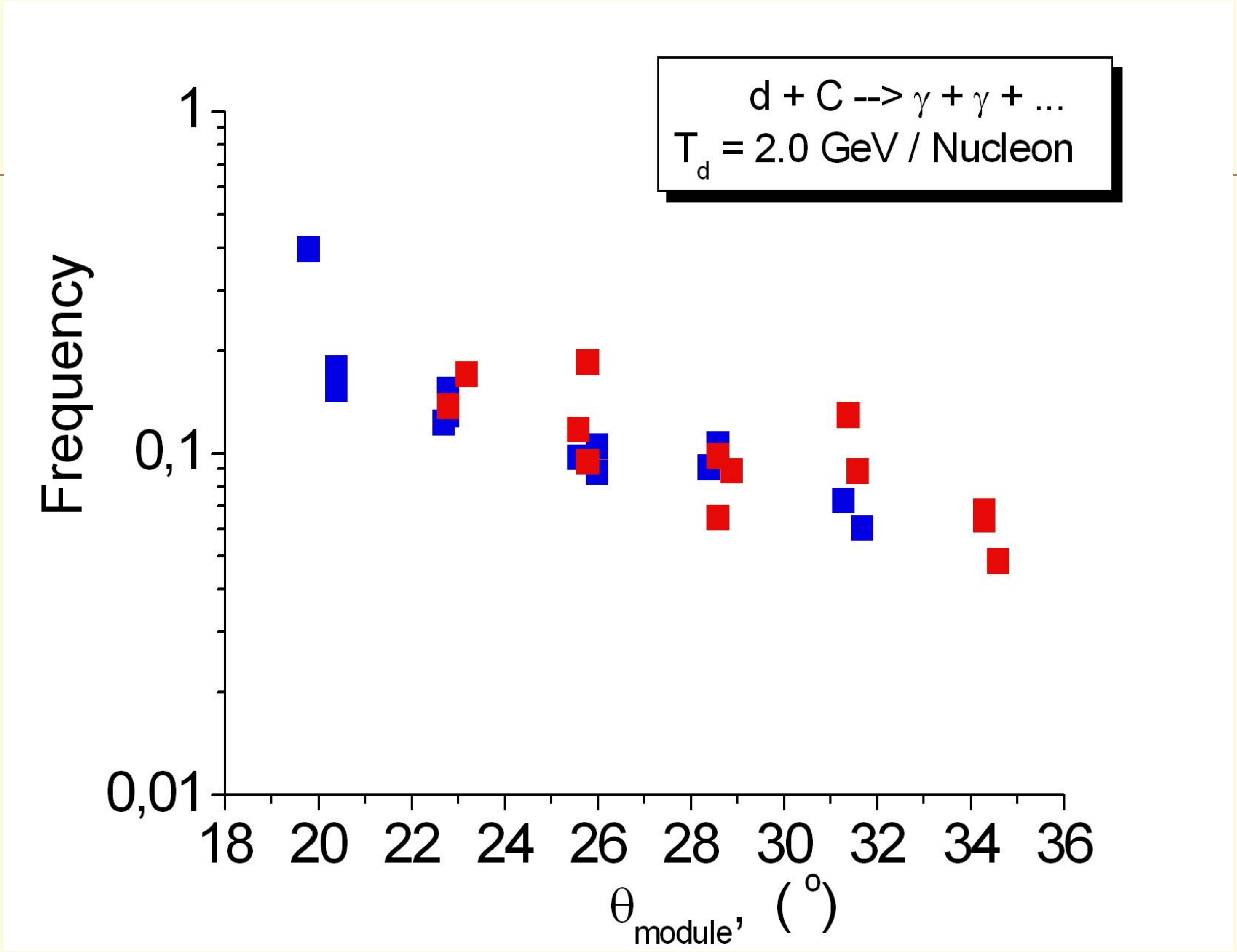
Thank you !

Распределения по энергии всех кластеров (темные кружки) и кластеров, состоящих из одного модуля

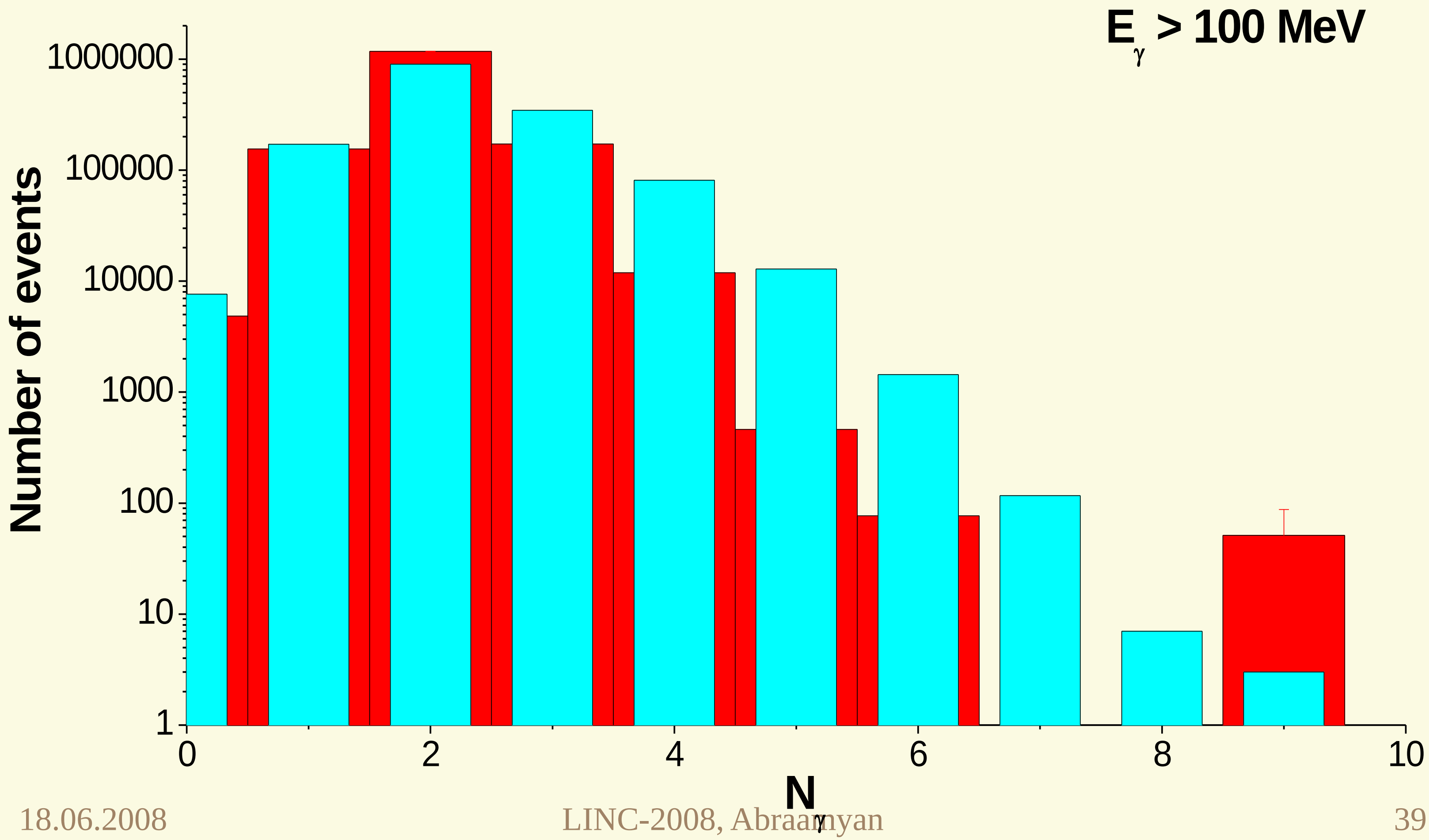




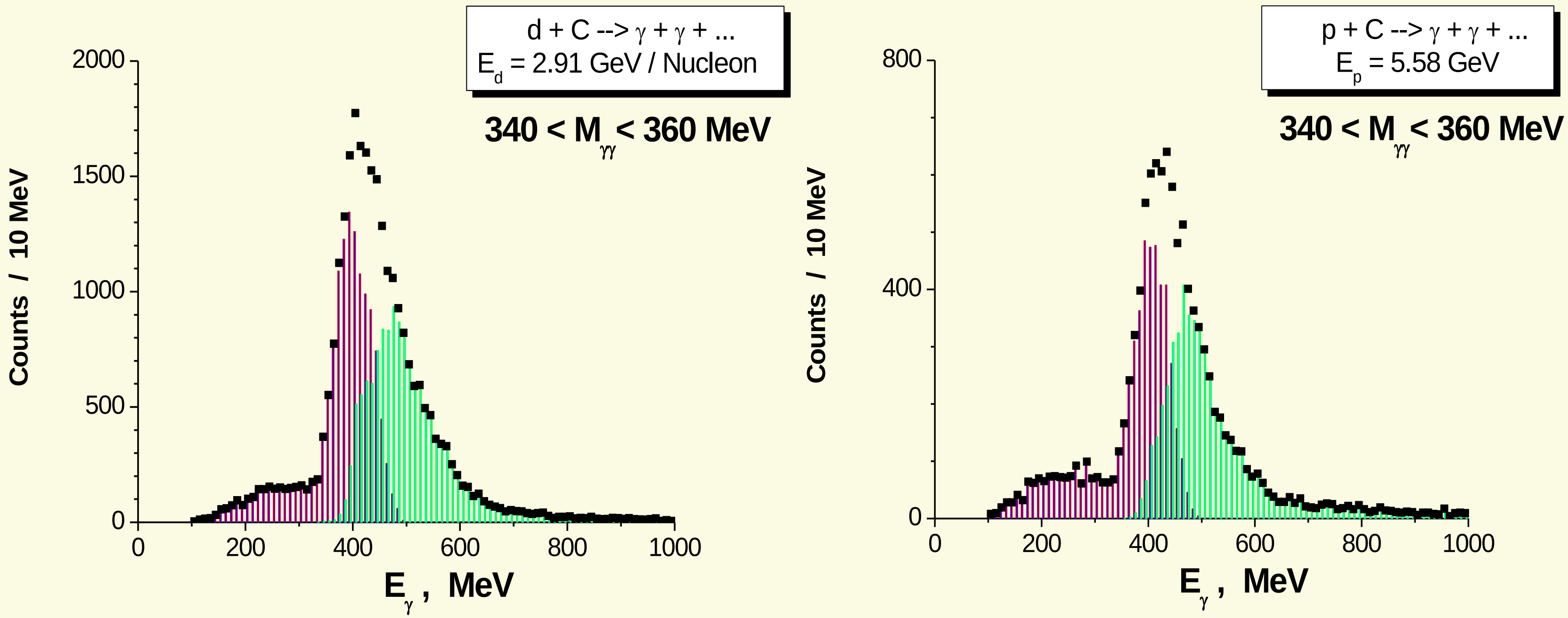
d + C --> γ + γ + ...
E_d = 2.91 GeV / Nucleon
- 503 events / cycle
- 85 events / cycle
Counts / 50 MeV
1000000
100000
10000
1000
100
10
200
400
600
800
1000
1200
E_γ , MeV


d + C --> γ + γ + ...
T_d = 2.0 GeV / Nucleon
Frequency
1
0,1
0,01
18
20
22
24
26
28
30
32
34
36
θ_module, (°)

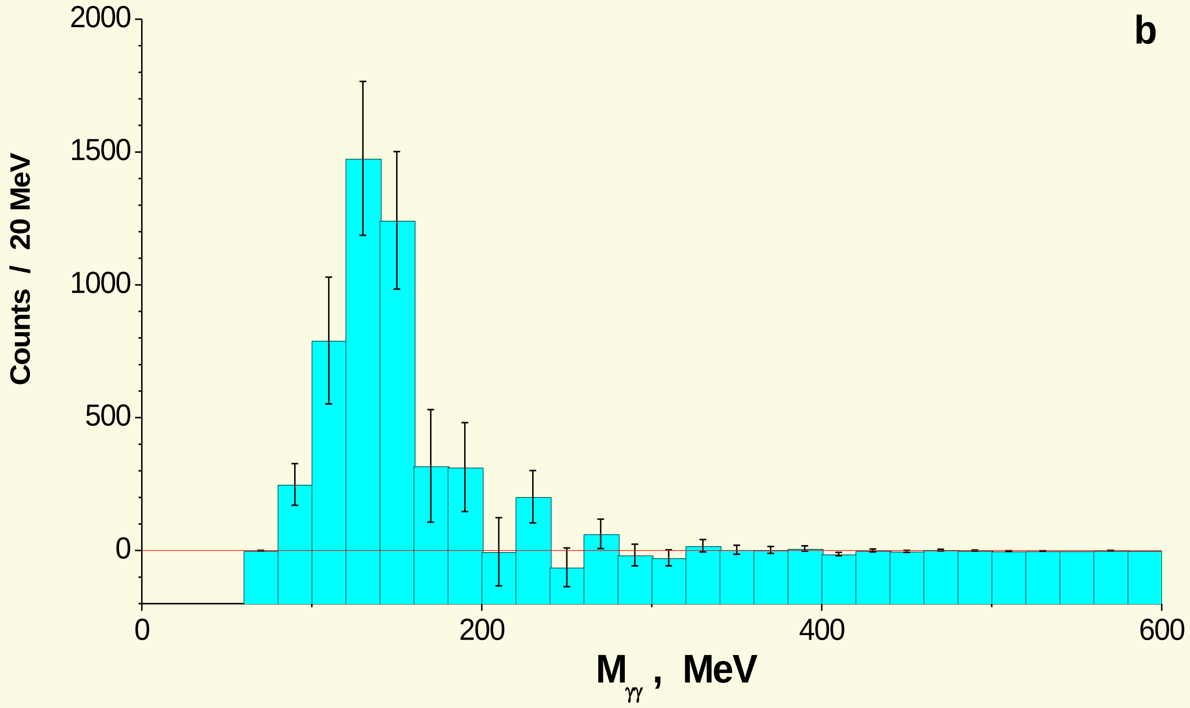
Зависимость множественности от интенсивности (загрузки): Син.- 503соб./цикл; Кр.- 85соб./цикл.



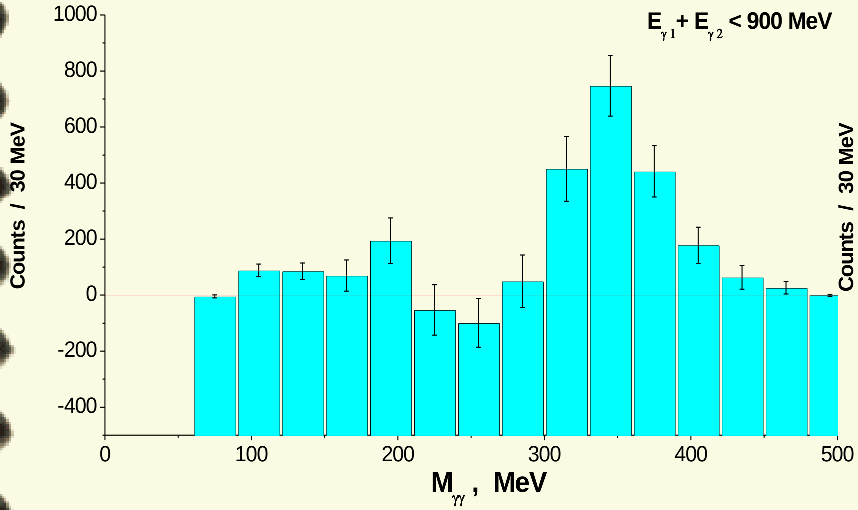
Распределения по энергии γ-квантов в комбинациях с эффективной массой в интервале 340 ÷ 360 МэВ. Отдельные гистограммы представляют распределения для γ-квантов с наименьшей и наибольшей энергией в каждой паре.

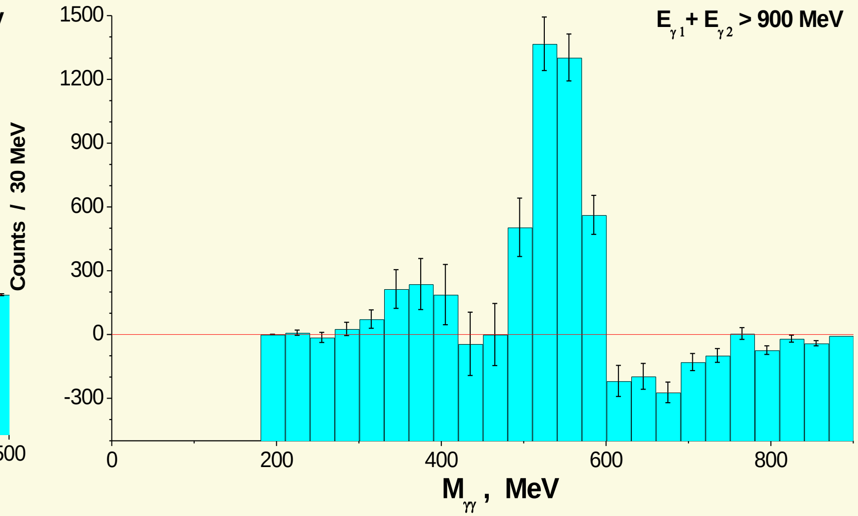


Спектр эффективных масс пар γ-квантов за вычетом фона в реакции **d + C→ γ + γ + x,** E_d = 1.98 ГэВ/н, E_γ > 100 МэВ. D_i = 50mV

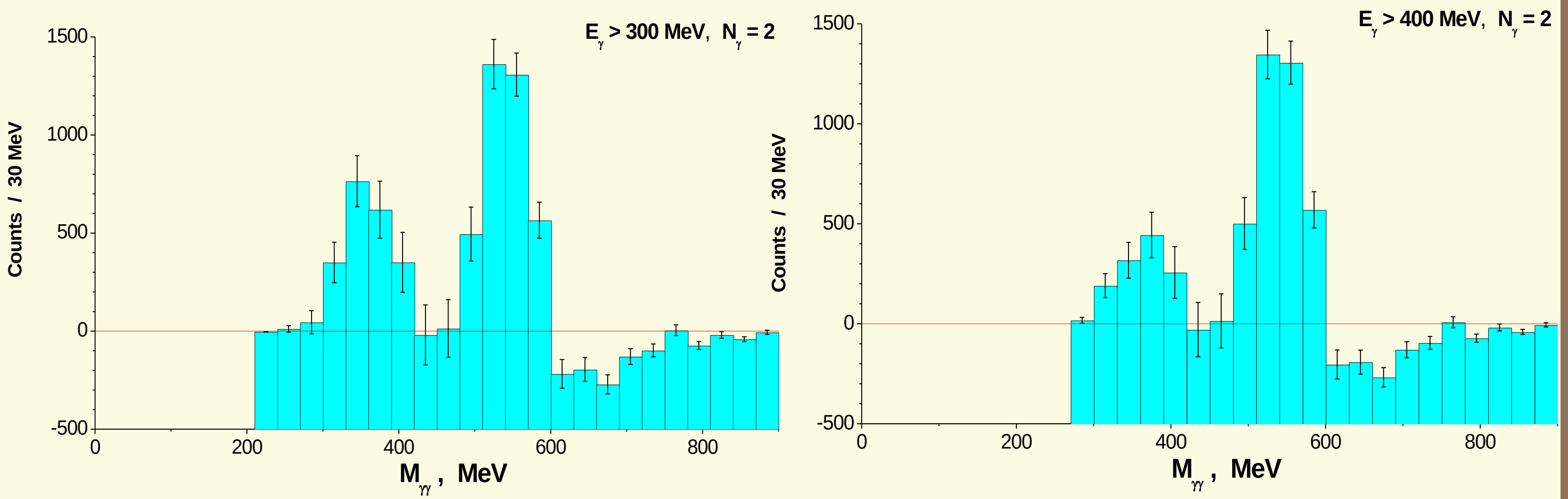


Спектр эффективных масс пар γ-квантов за вычетом фона в реакции **d + C→ γ + γ + x,** Ed = 2.91 ГэВ/н, в различных интервалах по сумме энергий двух γ-квантов.

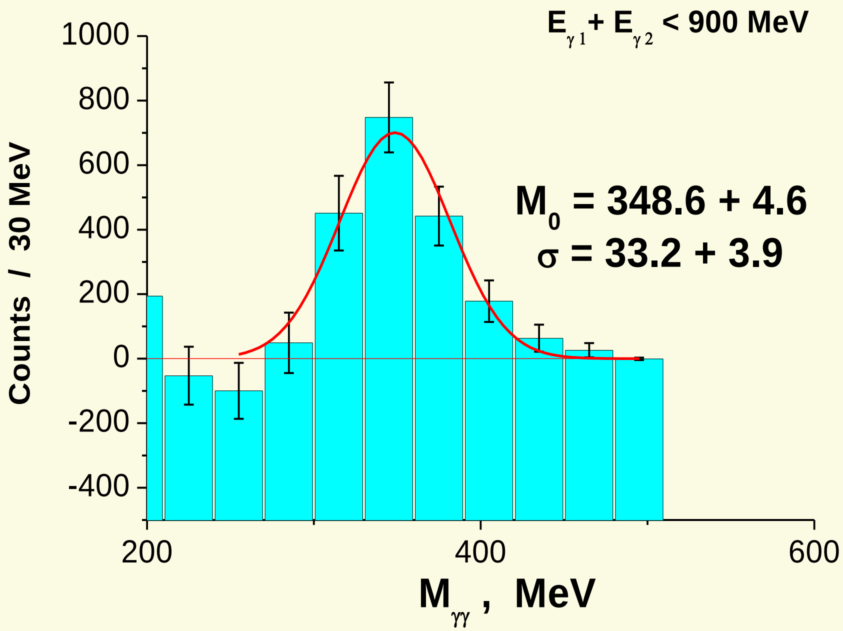


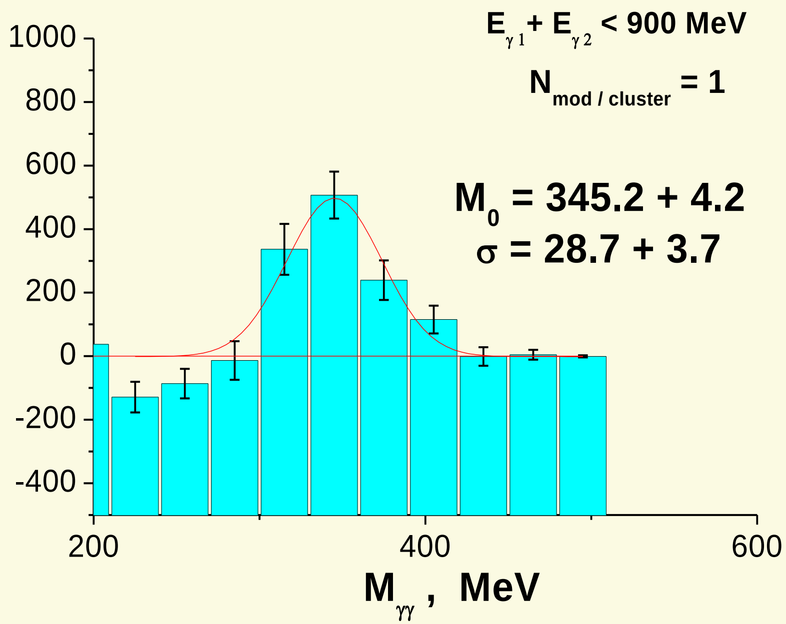


Спектр эффективных масс пар γ-квантов за вычетом фона в реакции d + C→ γ + γ + x, Ed = 2.91 ГэВ/н, при различных уровнях отбора γ-квантов по энергии.

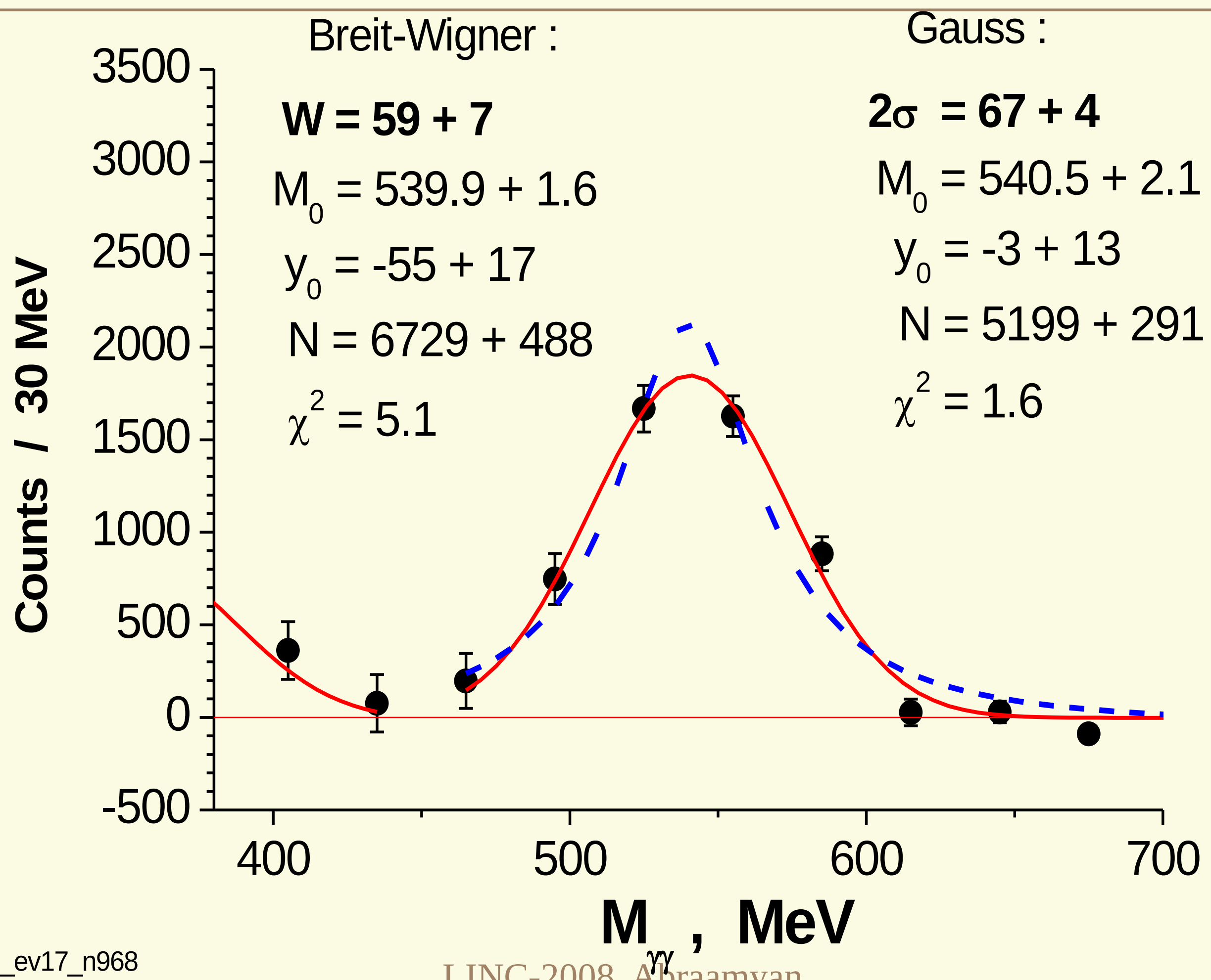


Спектр эффективных масс пар γ-квантов за вычетом фона в реакции **d + C→ γ + γ + x,** E_d = 2.91 ГэВ/н, при условиях: E_γ > 100 МэВ, N_γ = 2, E_1+E_2 < 900 МэВ.





$d + C \rightarrow \gamma + \gamma + x$, $E_d = 2.91$ GeV/N



ПТЭ, № 6, 1996, с. 5.

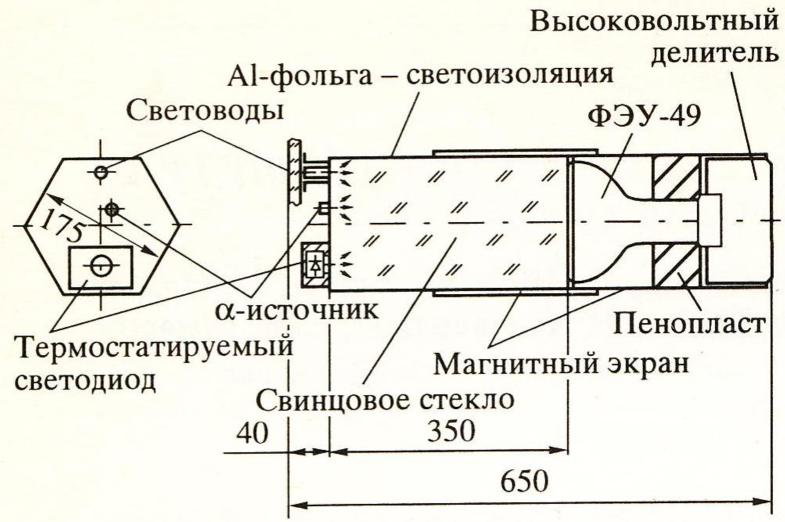


Рис. 2. Схема модуля черенковского γ-спектрометра.

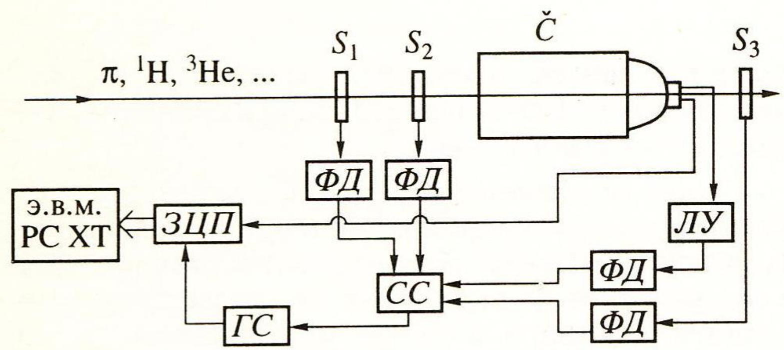
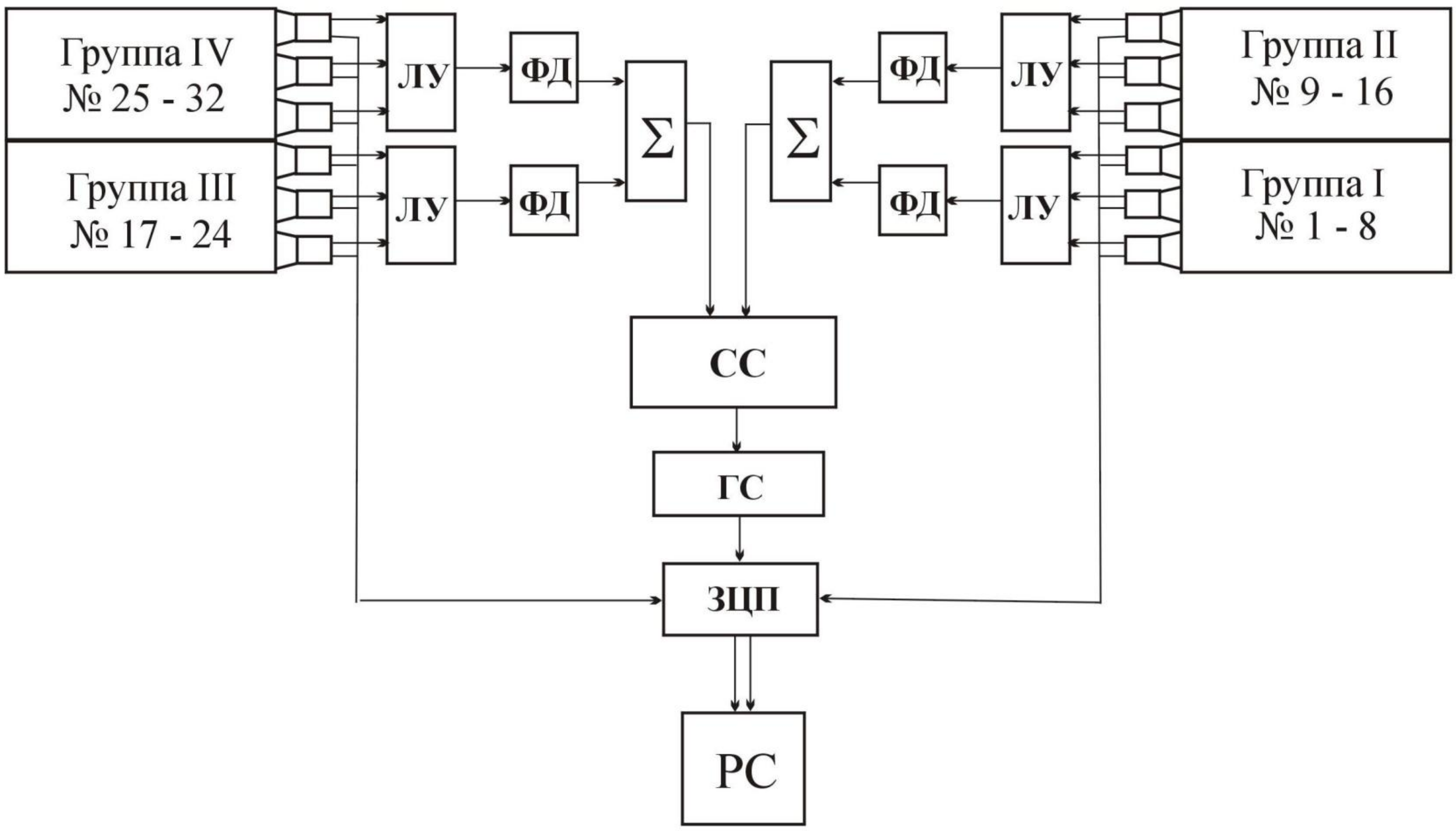


Рис. 3. Блок-схема электронного устройства γ-спектрометра. S_1–S_3 – сцинтилляционные счетчики, $\check{C}$ – γ-спектрометр, *ФД* – формирователи-дискриминаторы, *ЛУ* – линейный усилитель, *СС* – схема совпадений, *ГС* – генератор строба, *ЗЦП* – зарядово-цифровой преобразователь.

Блок-схема электронной аппаратуры



ПТЭ, № 1, 1989, с. 57.

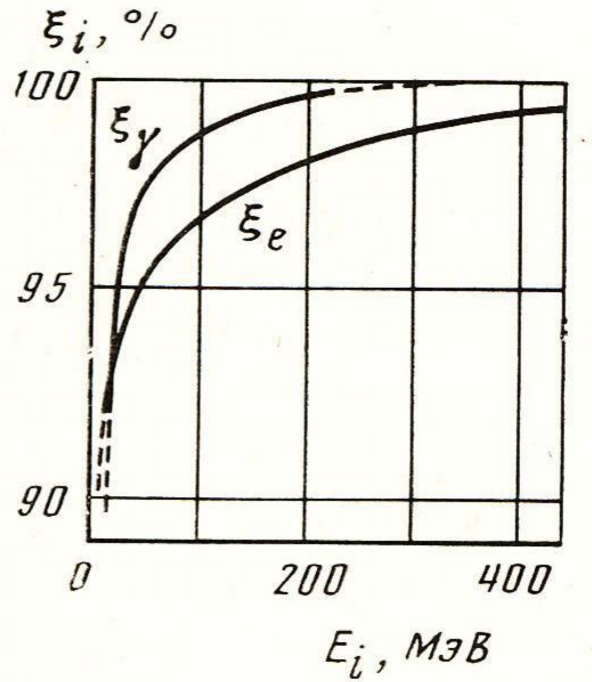
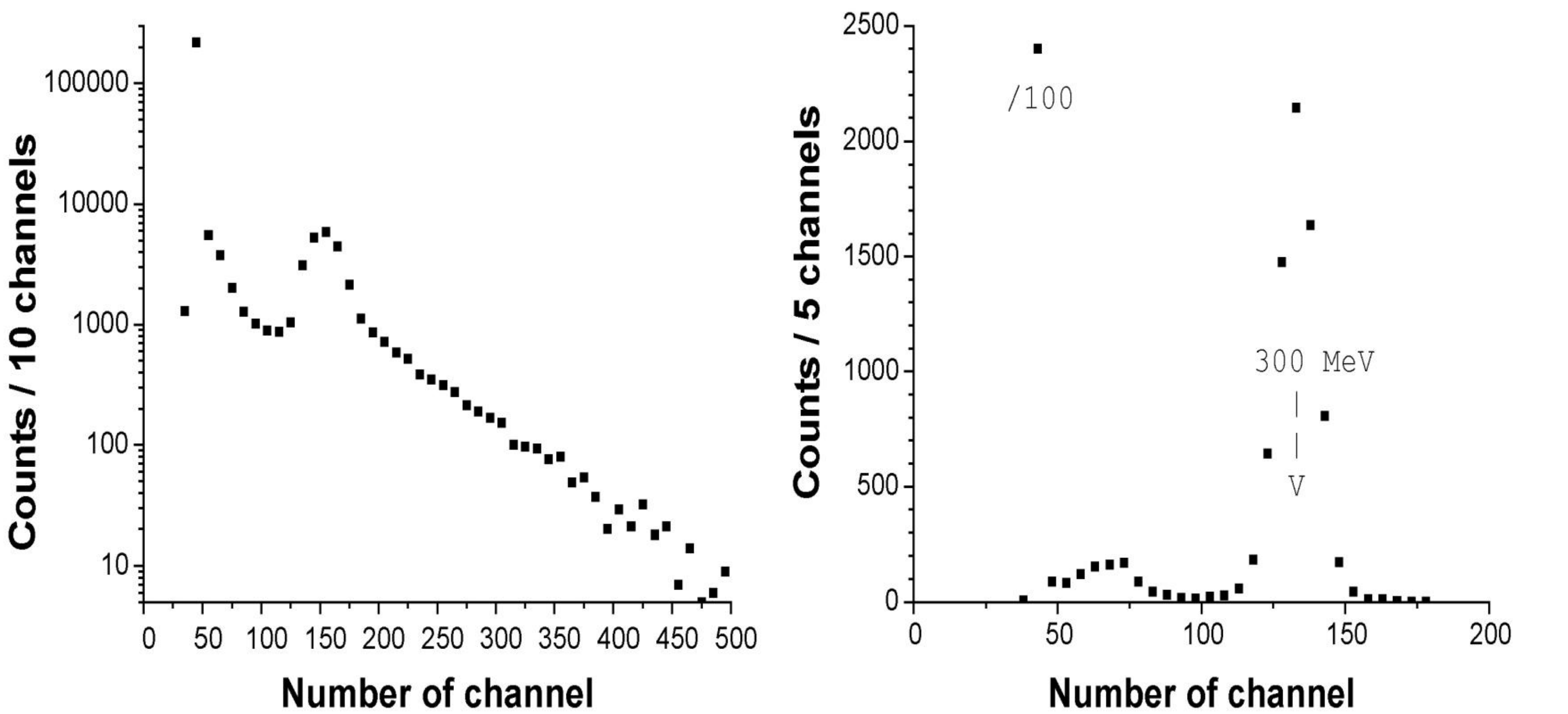
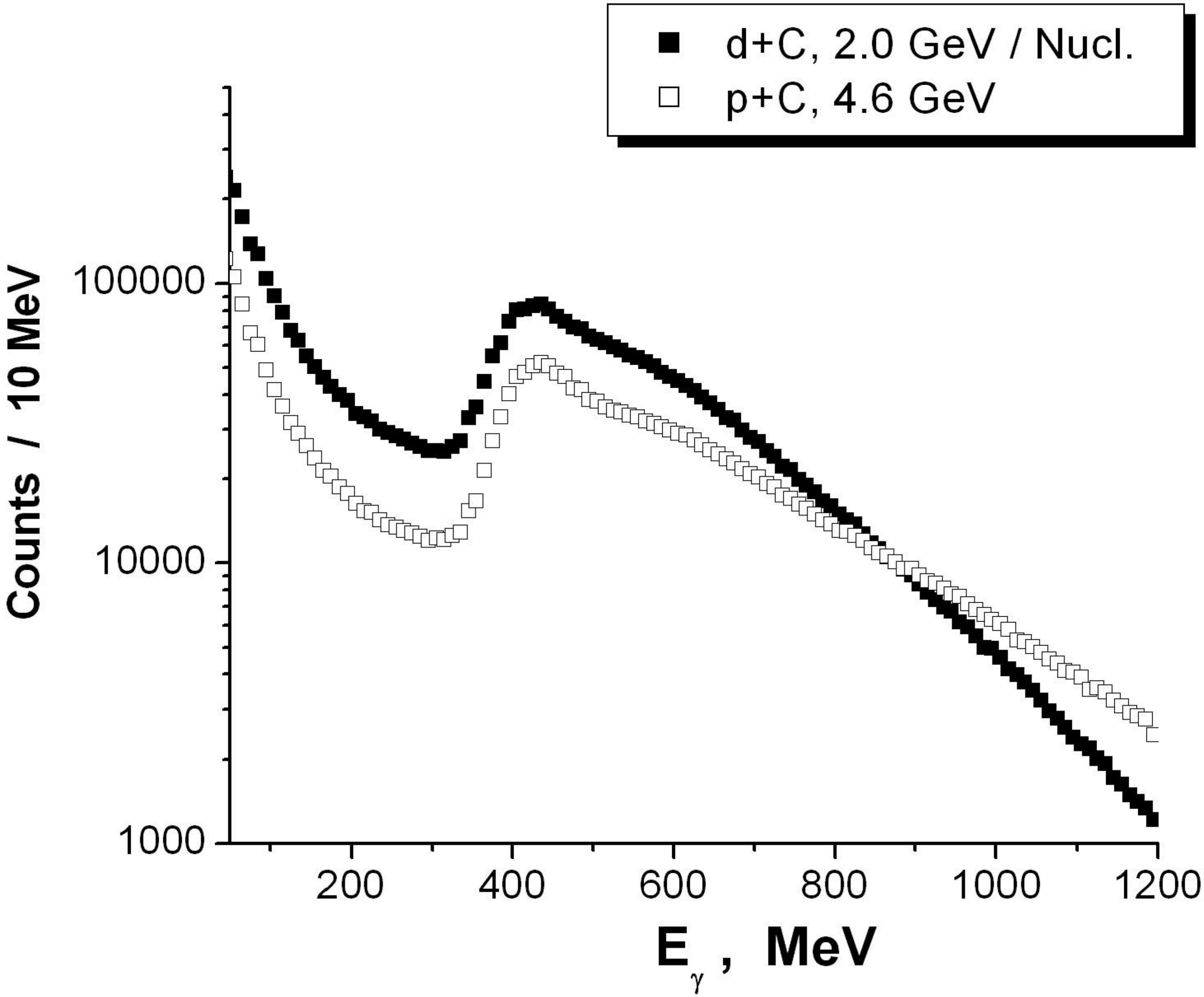


Рис. 2. Зависимости ξ_i (E_i) для γ-спектрометра с радиатором из стекла ТФ-1 толщиной 14 рад. ед.

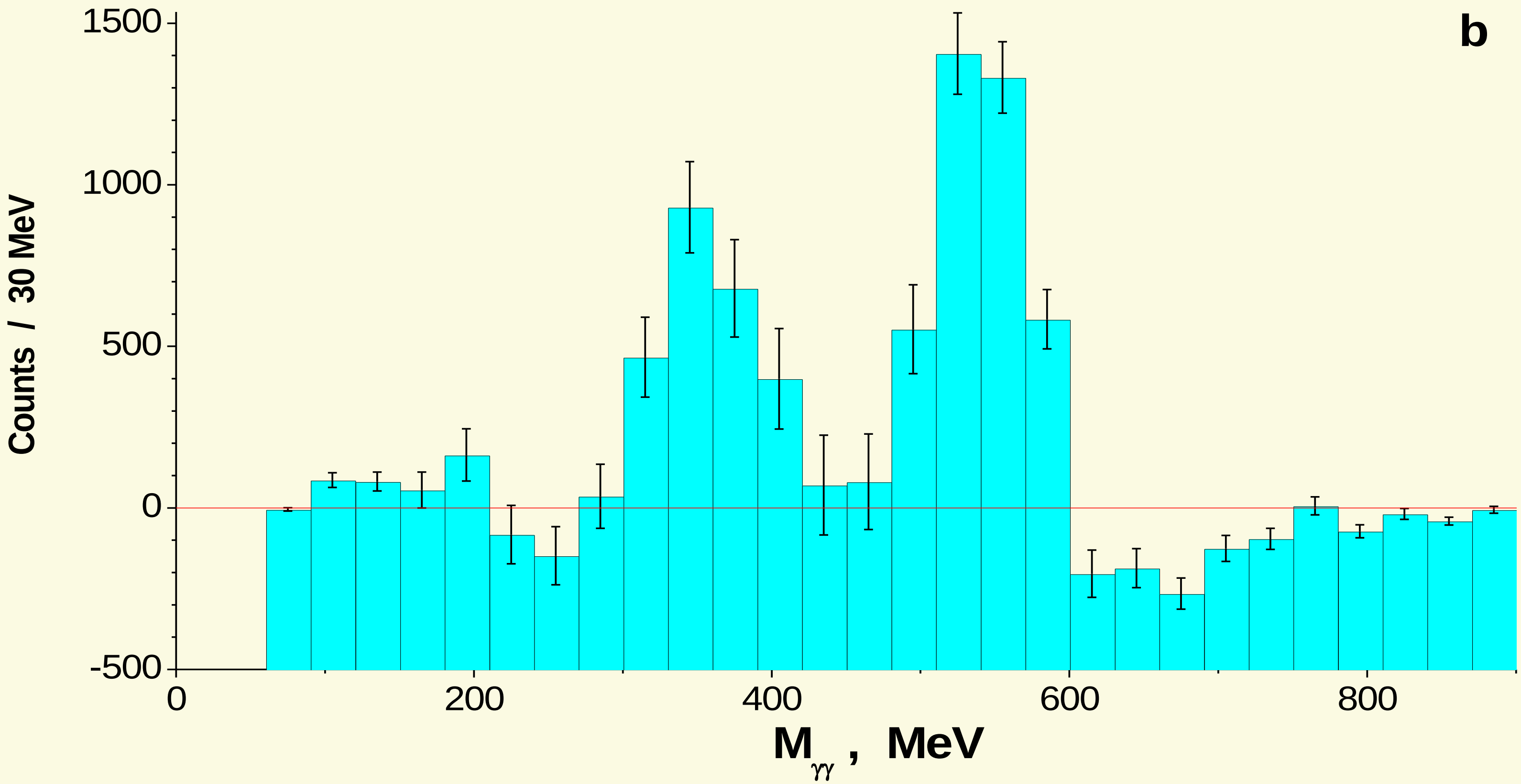
Амплитудный спектр в модуле N25 в реакции p + C $\rightarrow \gamma + \gamma + x$, Pp = 5.5 ГэВ/c.



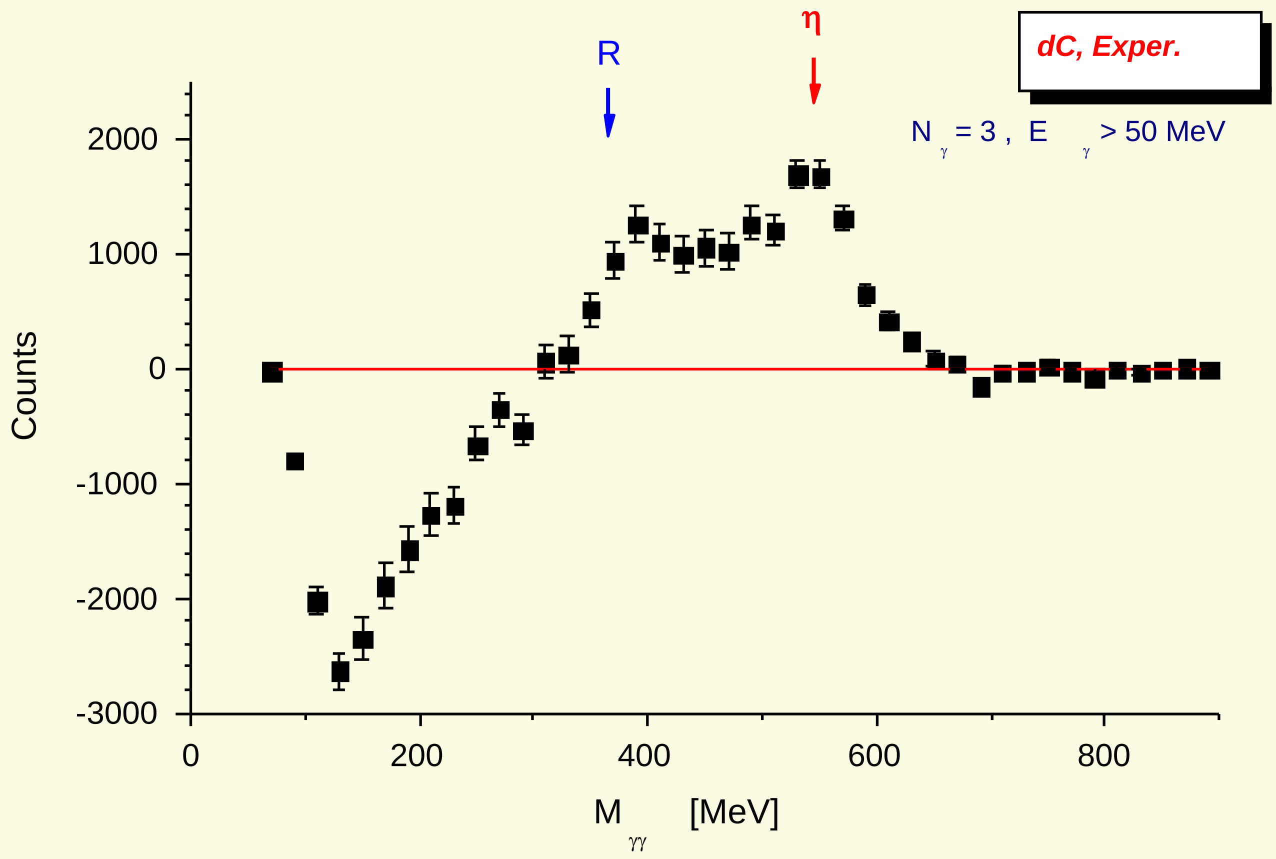
$$E = [(A - П) / (A\alpha - П)] \cdot E\alpha экв$$


d+C, 2.0 GeV / Nucl.
p+C, 4.6 GeV
Counts / 10 MeV
100000
10000
1000
200
400
600
800
1000
1200
E_γ , MeV

Invariant mass distribution of pairs of γ-quanta in the reaction d + C⟶ γ + γ + x after background subtraction under the selection criteria (1)-(2).

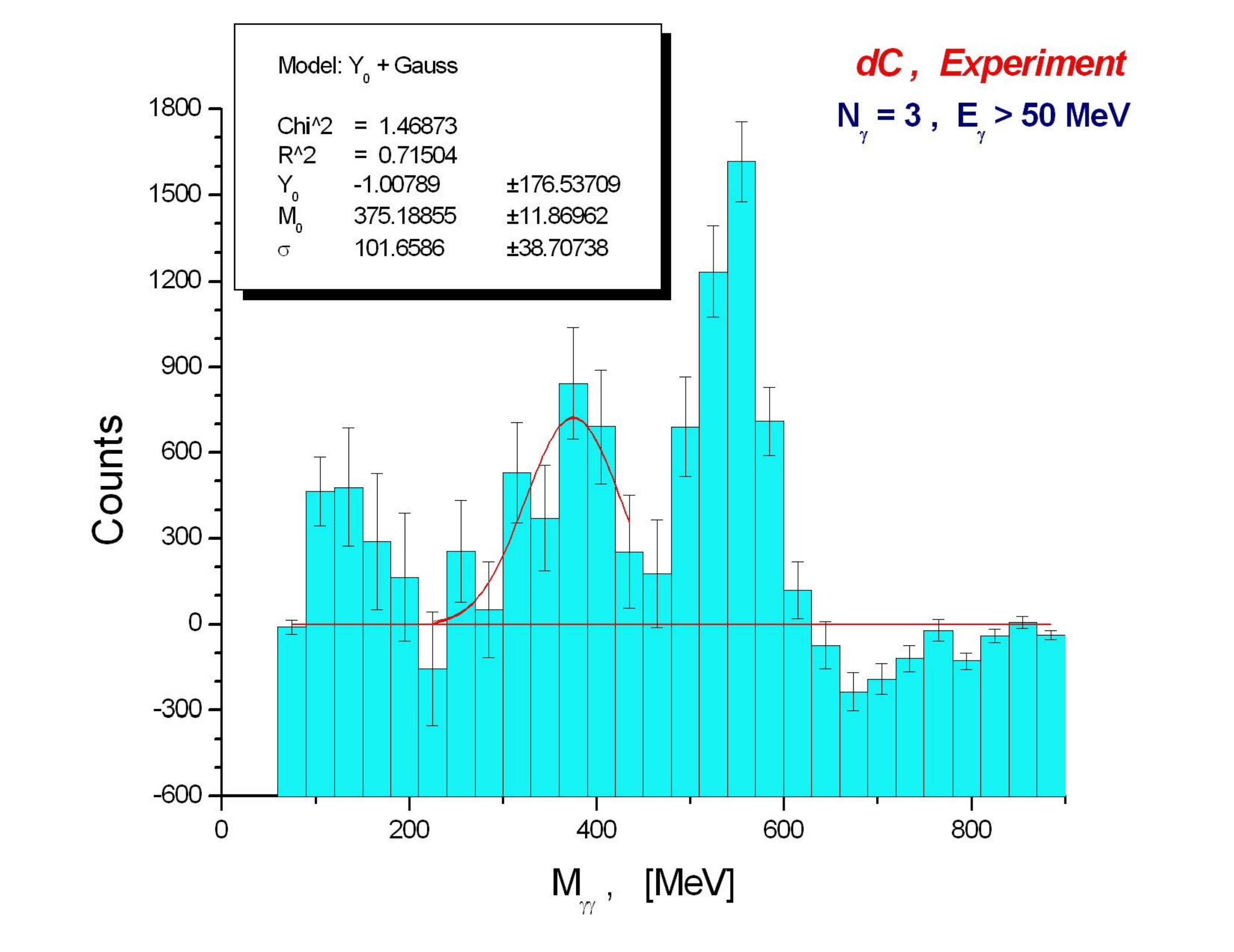


Nγ=3

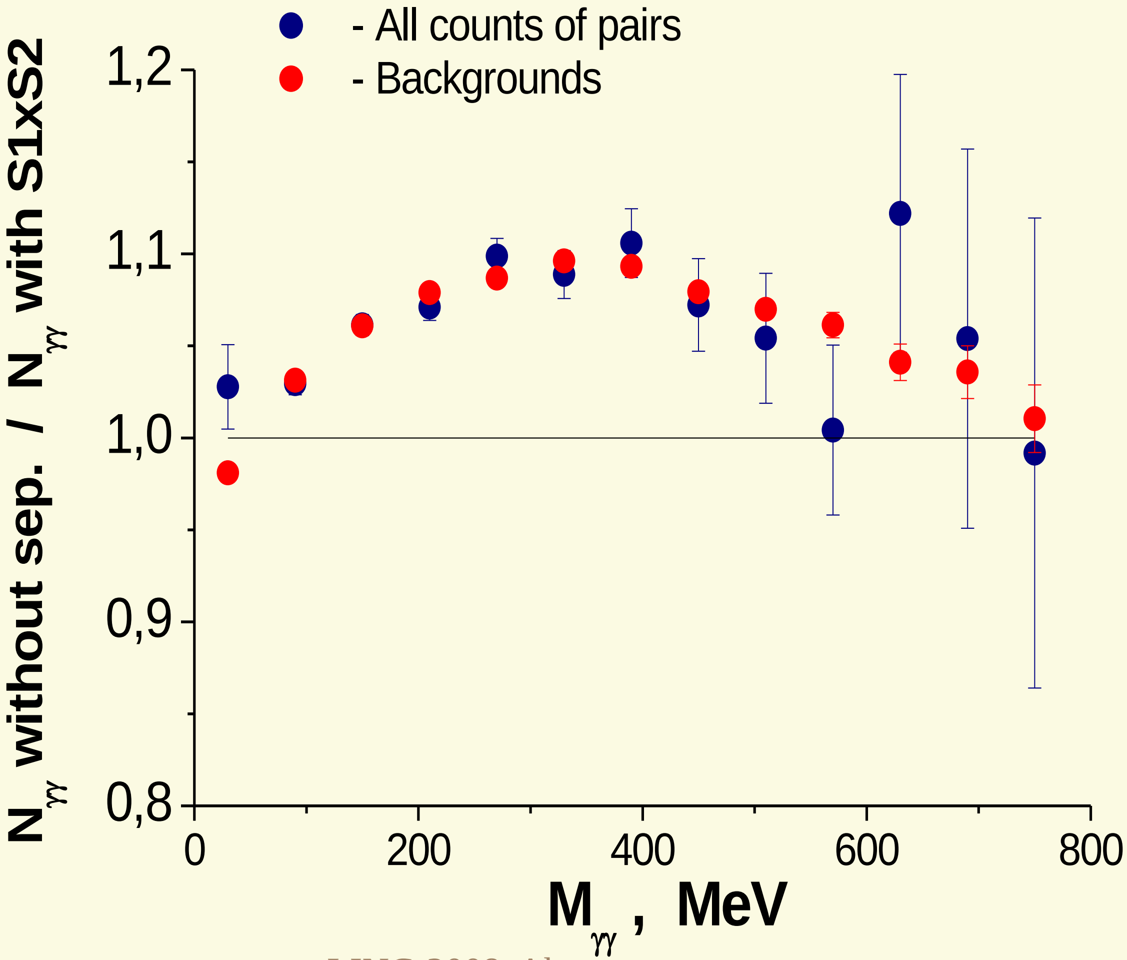


η
R
dC, Exper.
N γ = 3 , E γ > 50 MeV
2000
1000
0
-1000
-2000
-3000
Counts
0
200
400
600
800
M γγ [MeV]

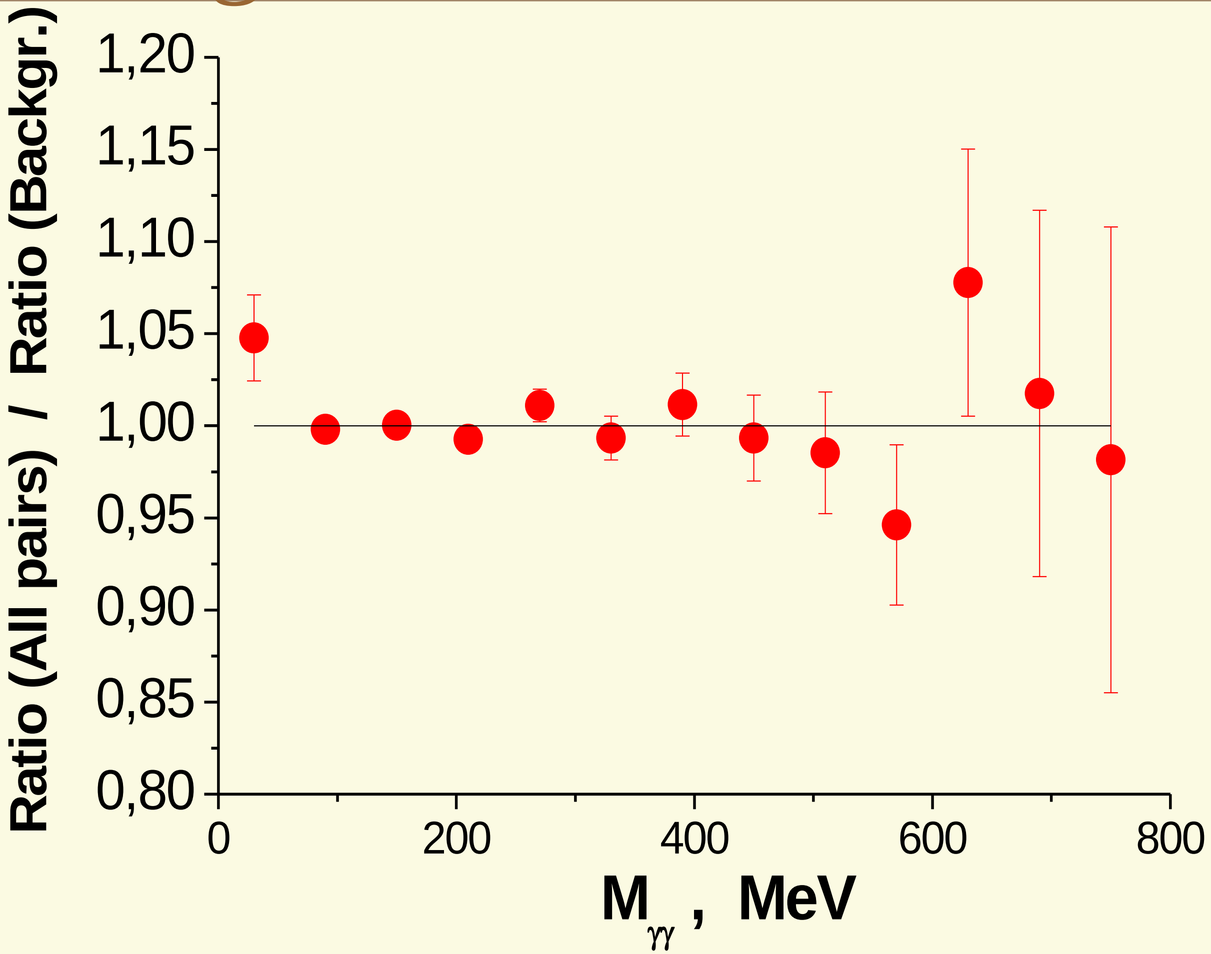
Nγ=3: 1γ in the L.Arm, 2γ in the R.Arm + 2γ in the L.Arm, 1γ in the R.Arm

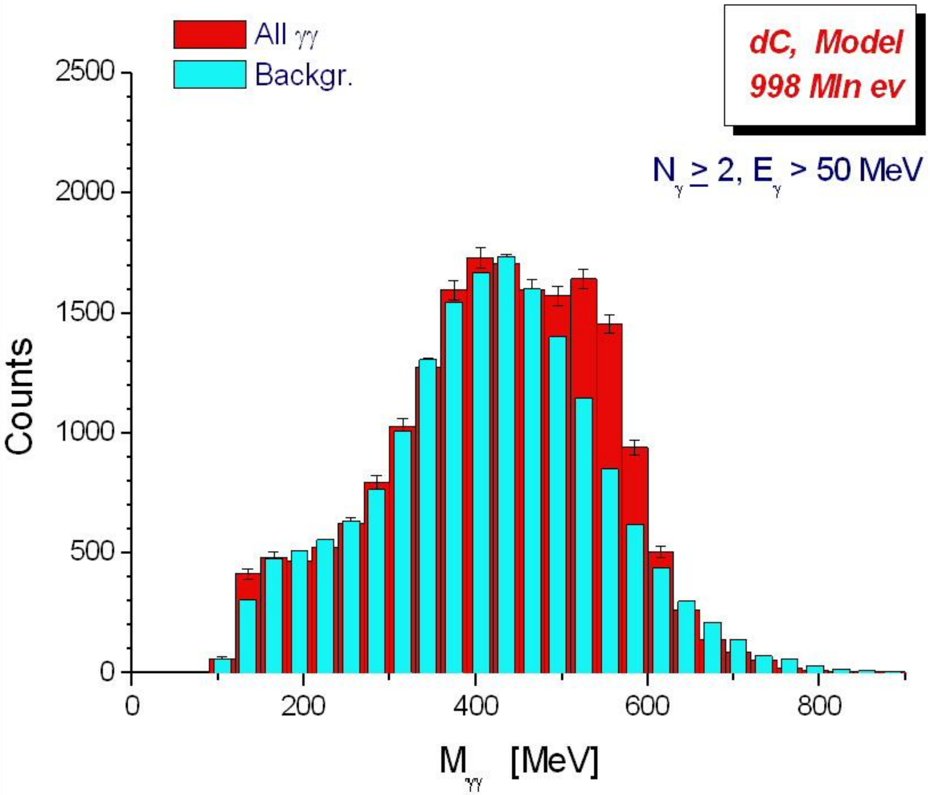


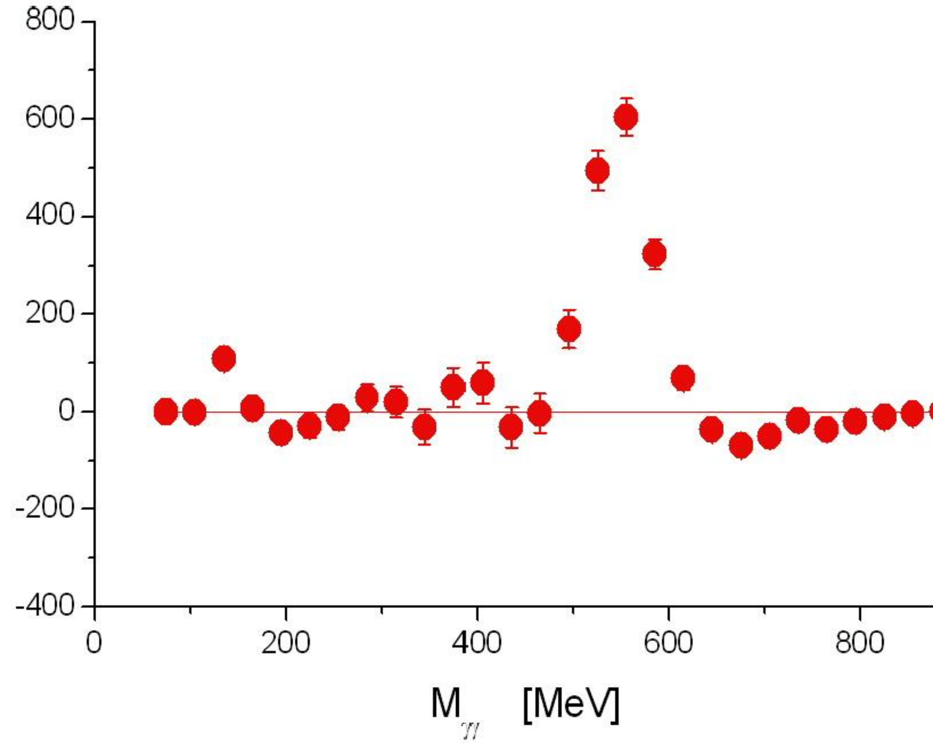
Charged particles contribution



Charged particles contribution after background subtraction

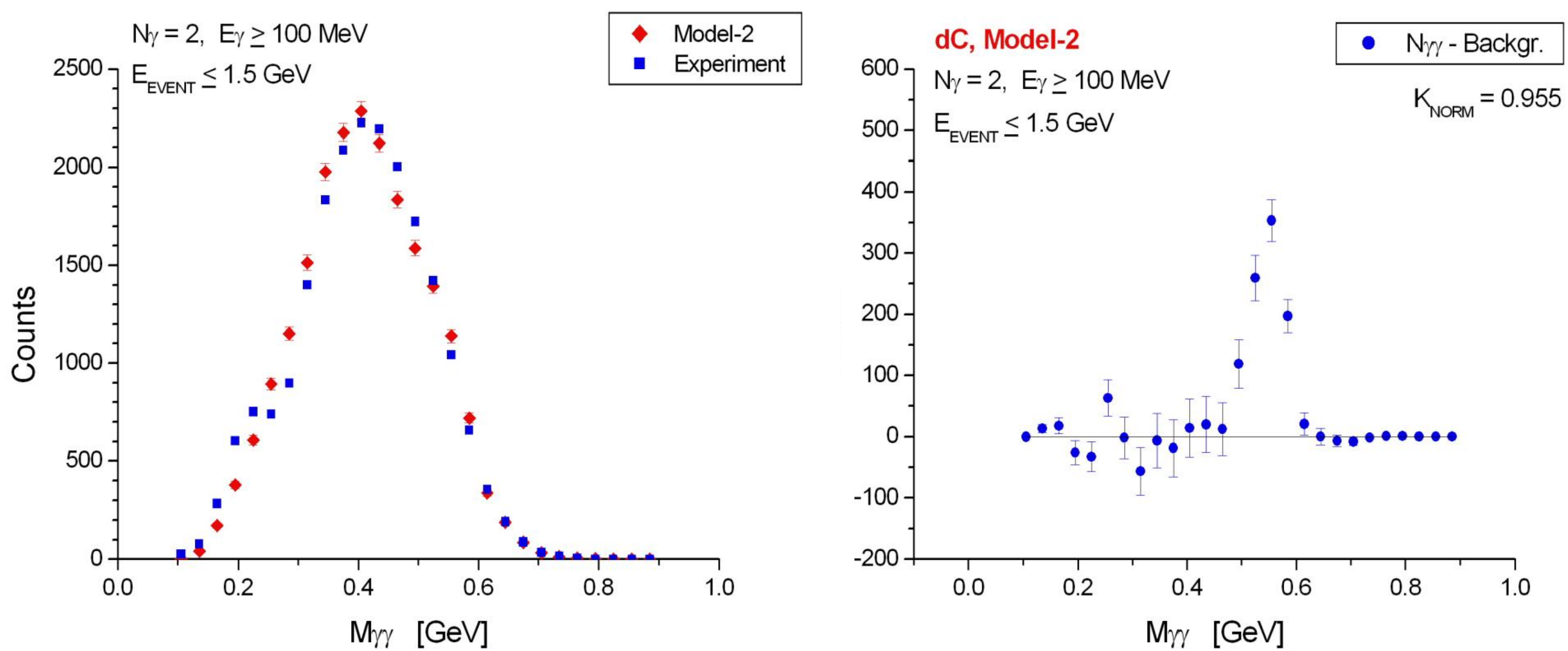


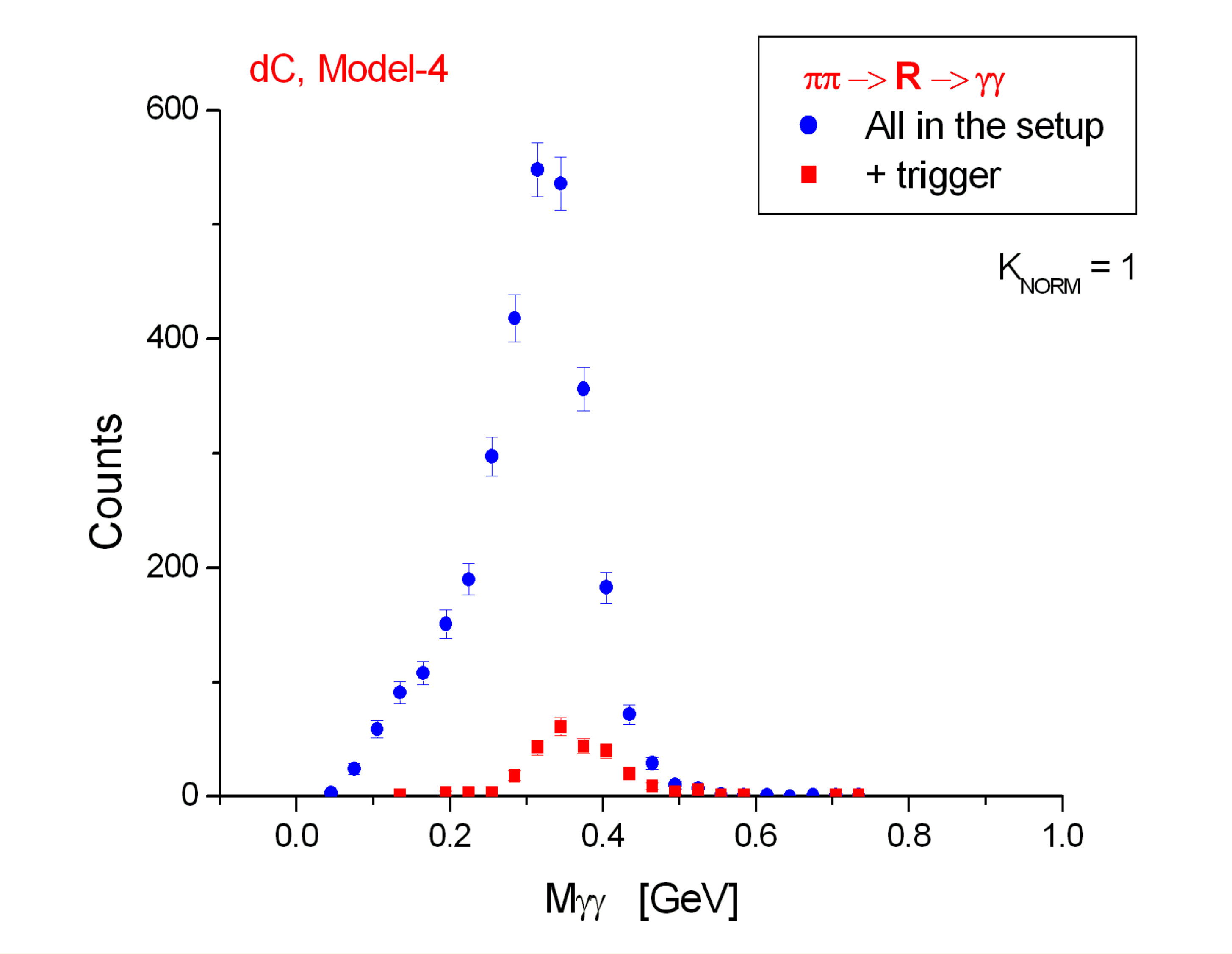

All γγ
Backgr.
dC, Model
998 Mln ev
N_γ ≥ 2, E_γ > 50 MeV
Counts
2500
2000
1500
1000
500
0
0
200
400
600
800
M_γγ [MeV]


800
600
400
200
0
-200
-400
0
200
400
600
800
M_γγ [MeV]

Распределение по инвариантной массе пар γ-квантов до и после вычитания фона: моделированные данные в реальных условиях эксперимента, без включения резонанса.

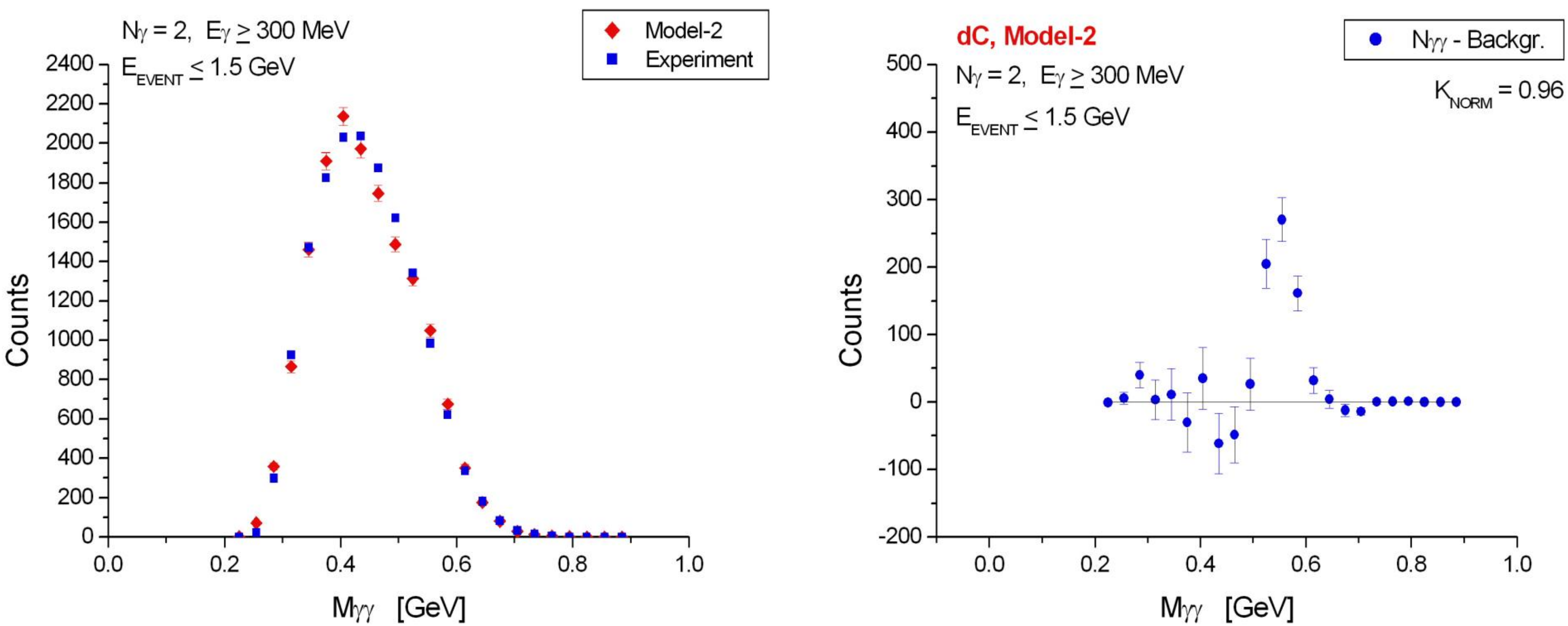
D_g2_1_kazh2ev15




dC, Model-4
ππ –> R –> γγ
All in the setup
+ trigger
K_NORM = 1
Counts
600
400
200
0
0.0
0.2
0.4
0.6
0.8
1.0
Mγγ [GeV]

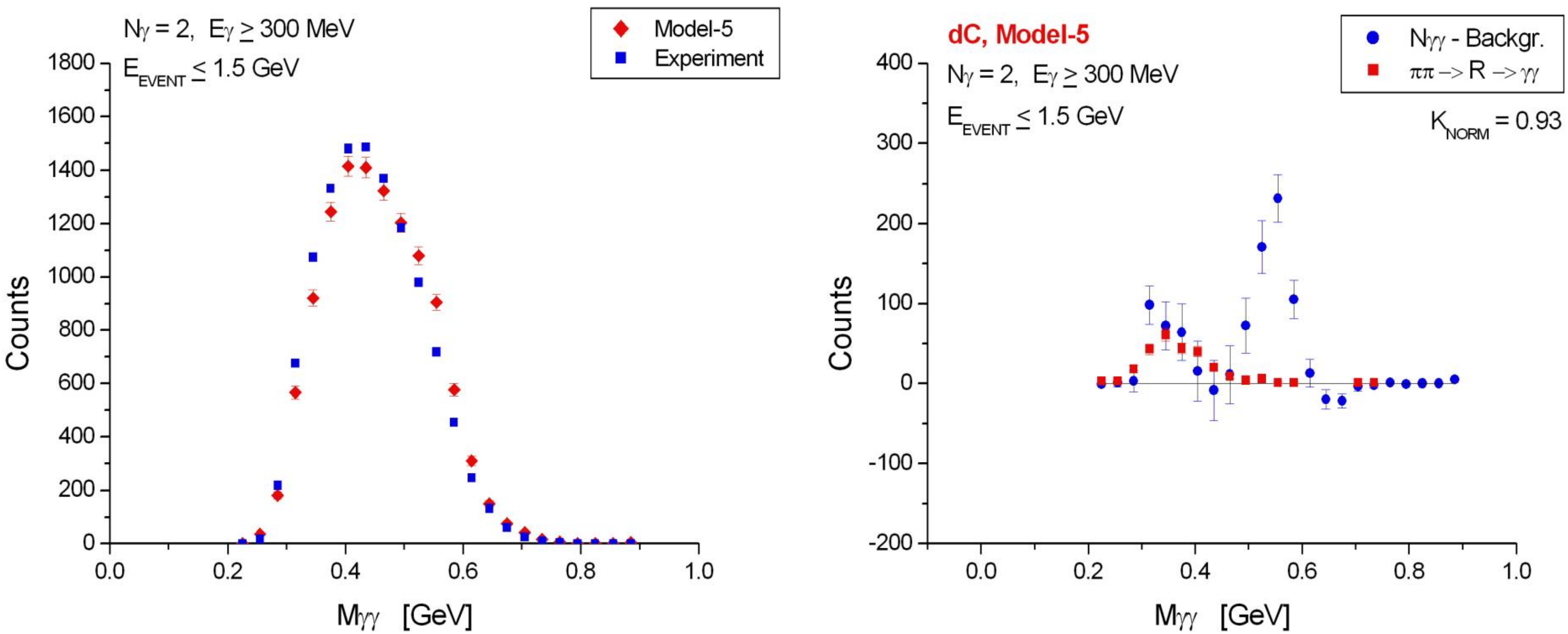
Распределение по инвариантной массе пар γ-квантов до и после вычитания фона: моделированные данные в реальных условиях эксперимента, без включения резонанса.

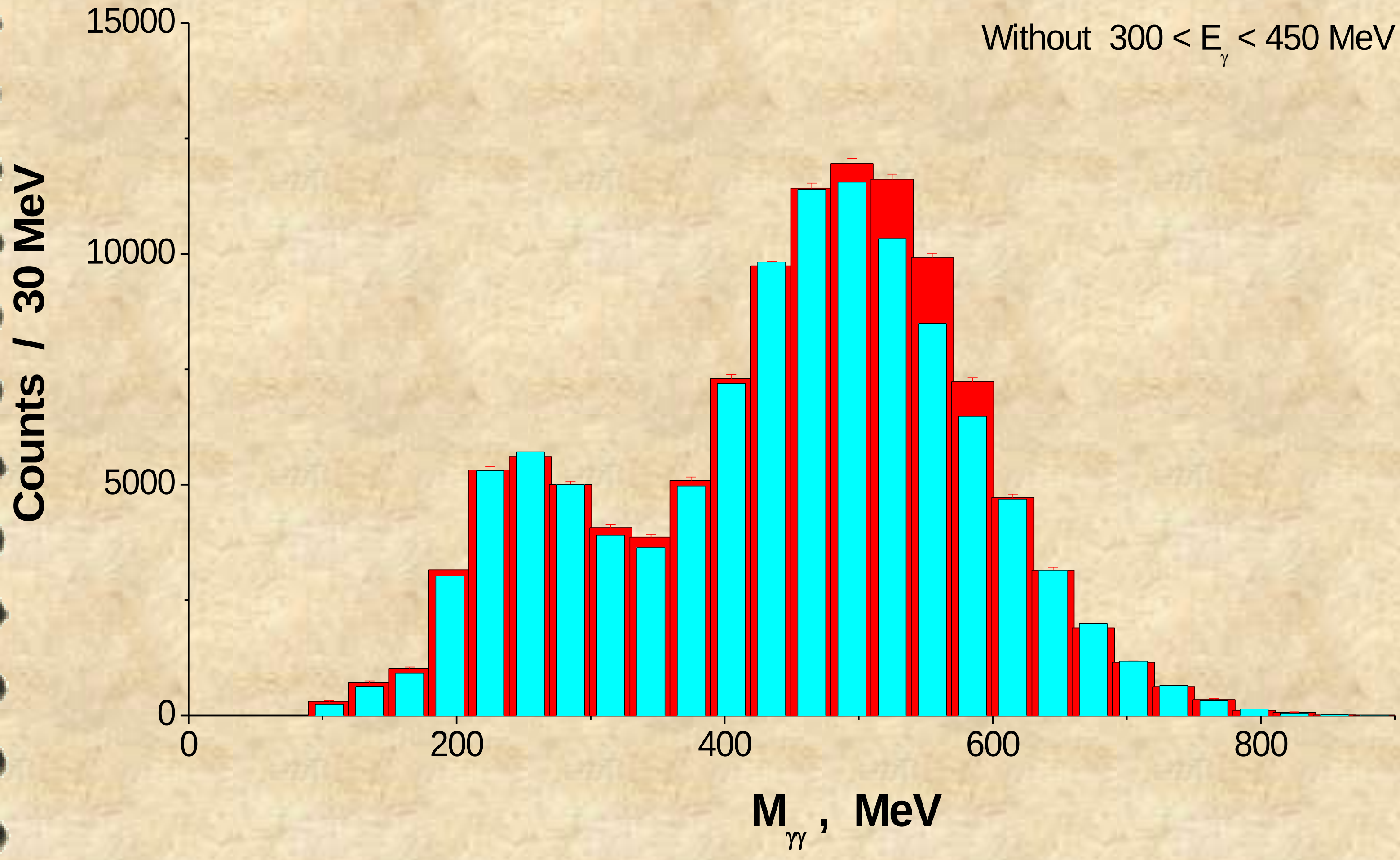
D_g2_3_kazh3i14ev15



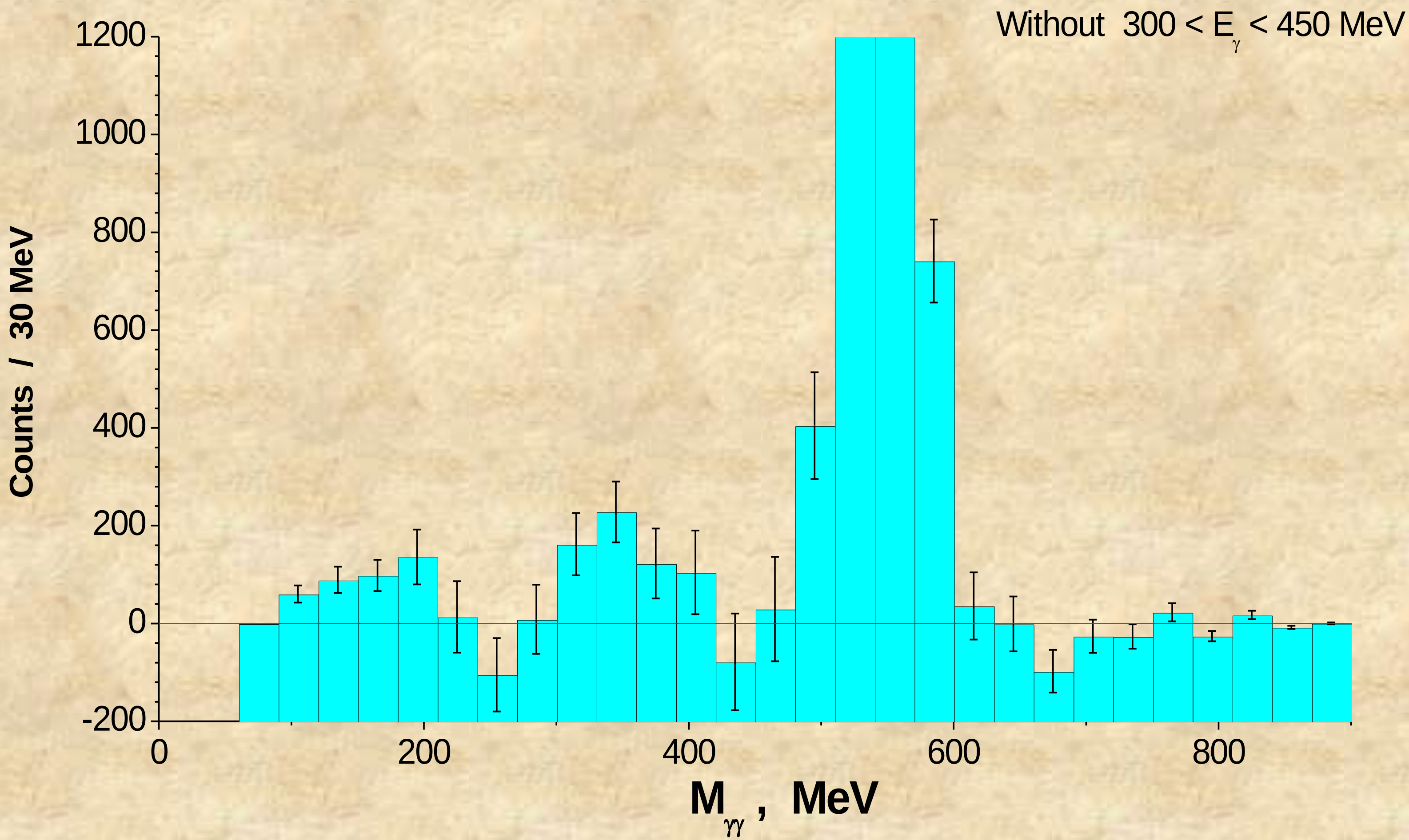
Распределение по инвариантной массе пар γ-квантов до и после вычитания фона: моделированные данные в реальных условиях эксперимента, с включением резонанса.

Cbr5_g2_3_kazh4ev15

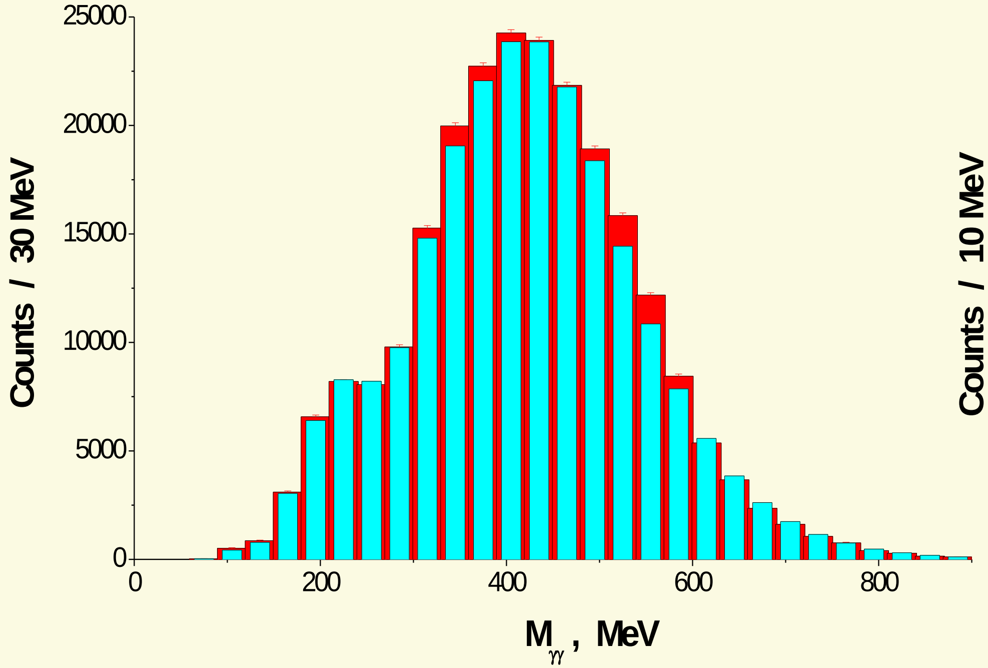


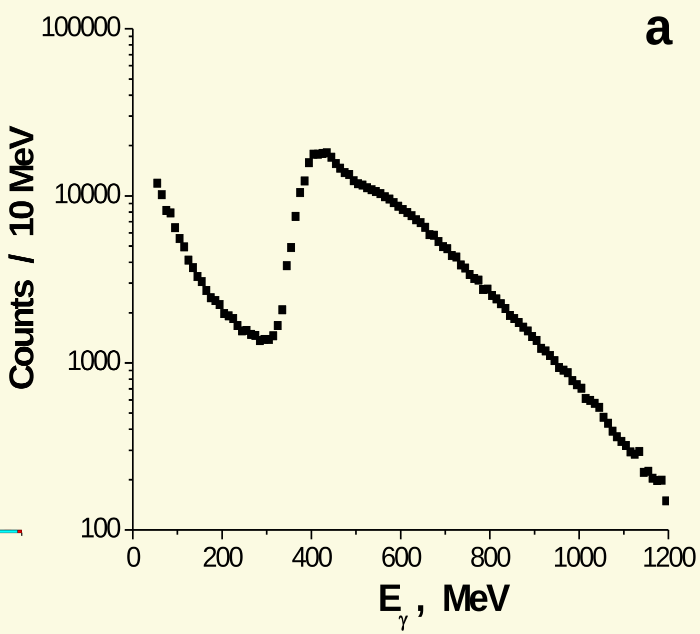


Without 300 < E_γ < 450 MeV
Counts / 30 MeV
15000
10000
5000
0
0
200
400
600
800
$M_{\gamma\gamma}$, MeV

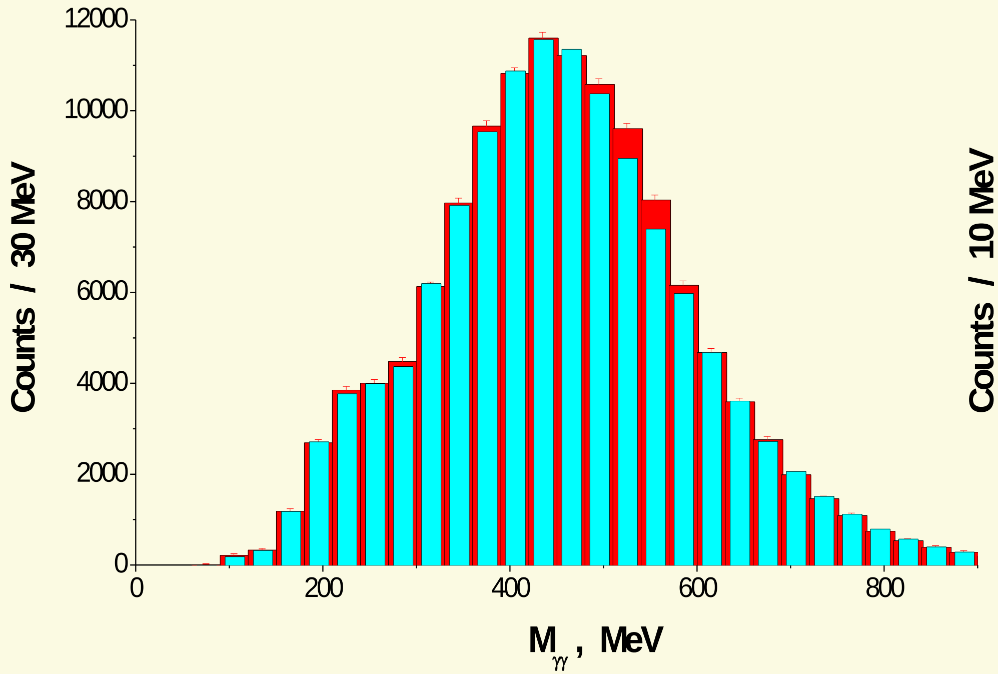

Without 300 < E γ < 450 MeV
Counts / 30 MeV
1200
1000
800
600
400
200
0
-200
0
200
400
600
800
M γγ , MeV

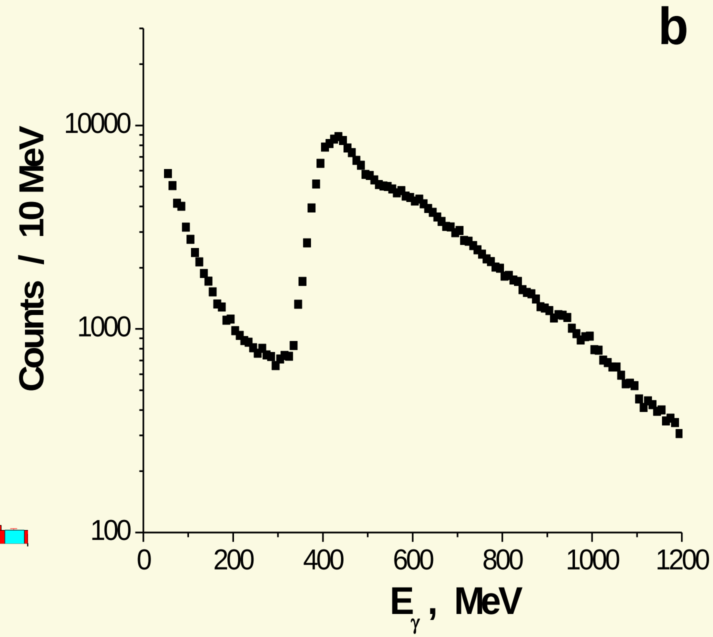
Распределение γ-квантов по энергии в событиях с Nγ = 2 , в реакции d + C→ γ + γ + x, Ed = 2.91 ГэВ/нуклон.

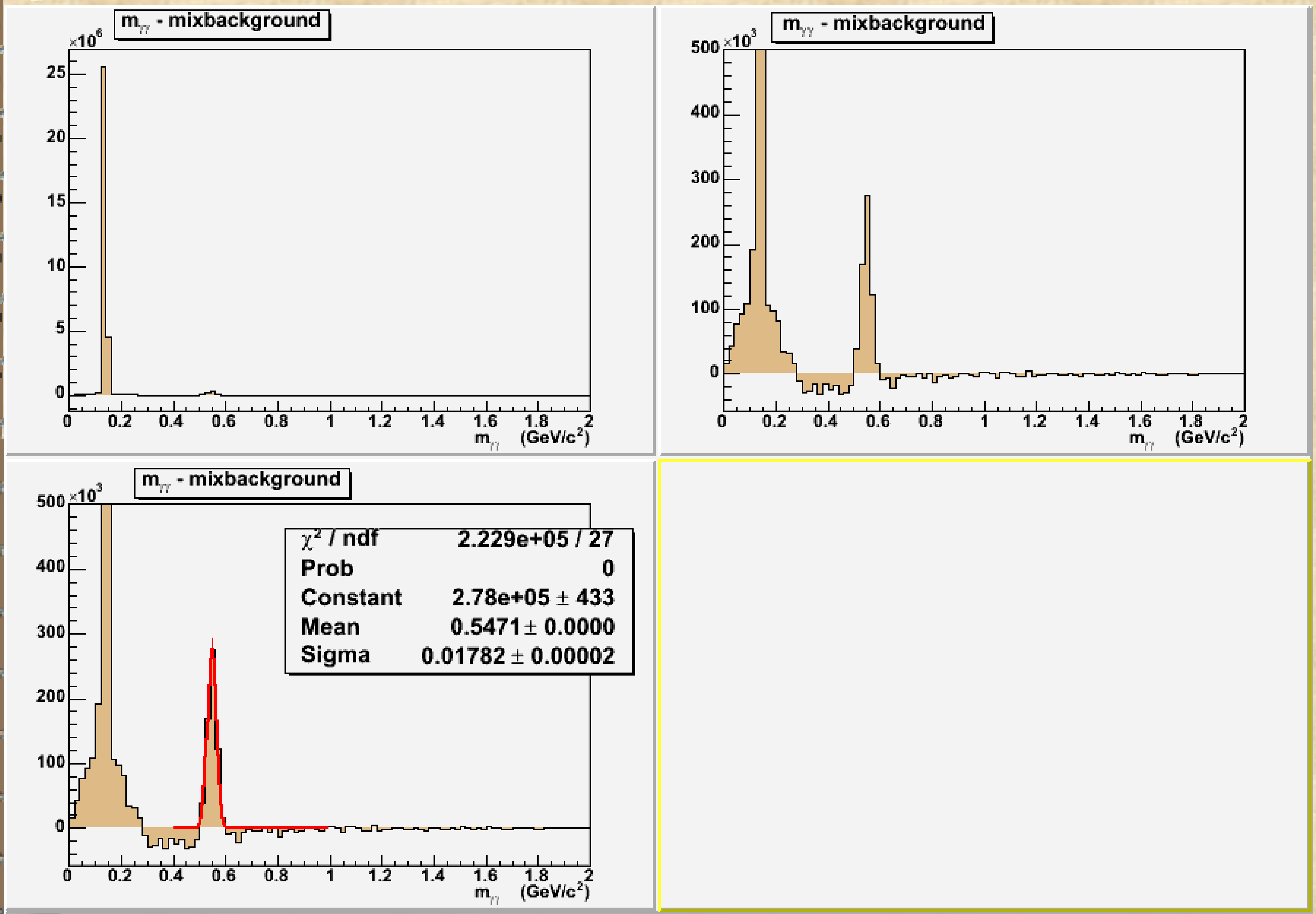




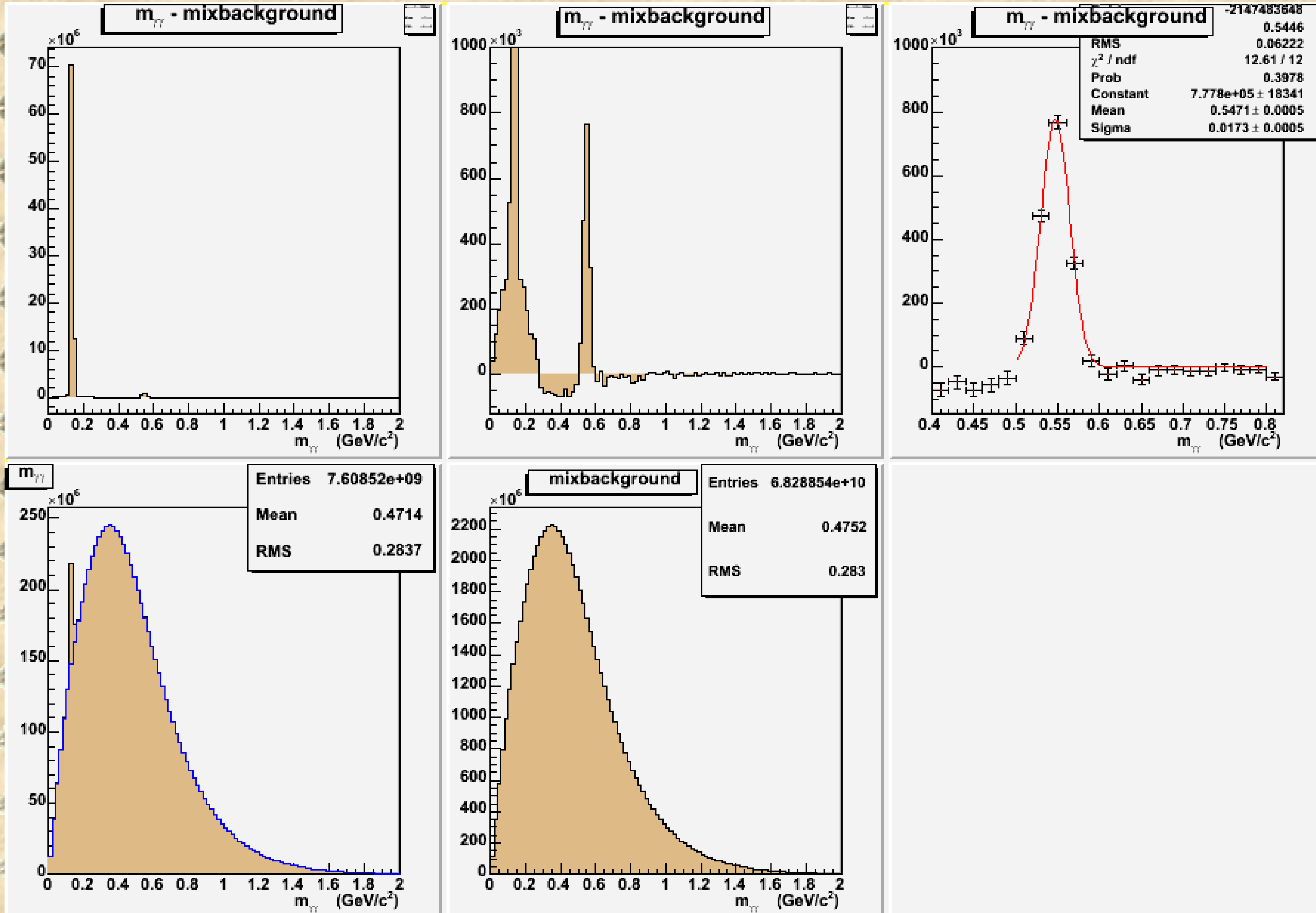
Распределение γ-квантов по энергии в событиях с $N\gamma = 2$, в реакции $p + C \rightarrow \gamma + \gamma + x$, Ep = 5.58 ГэВ.



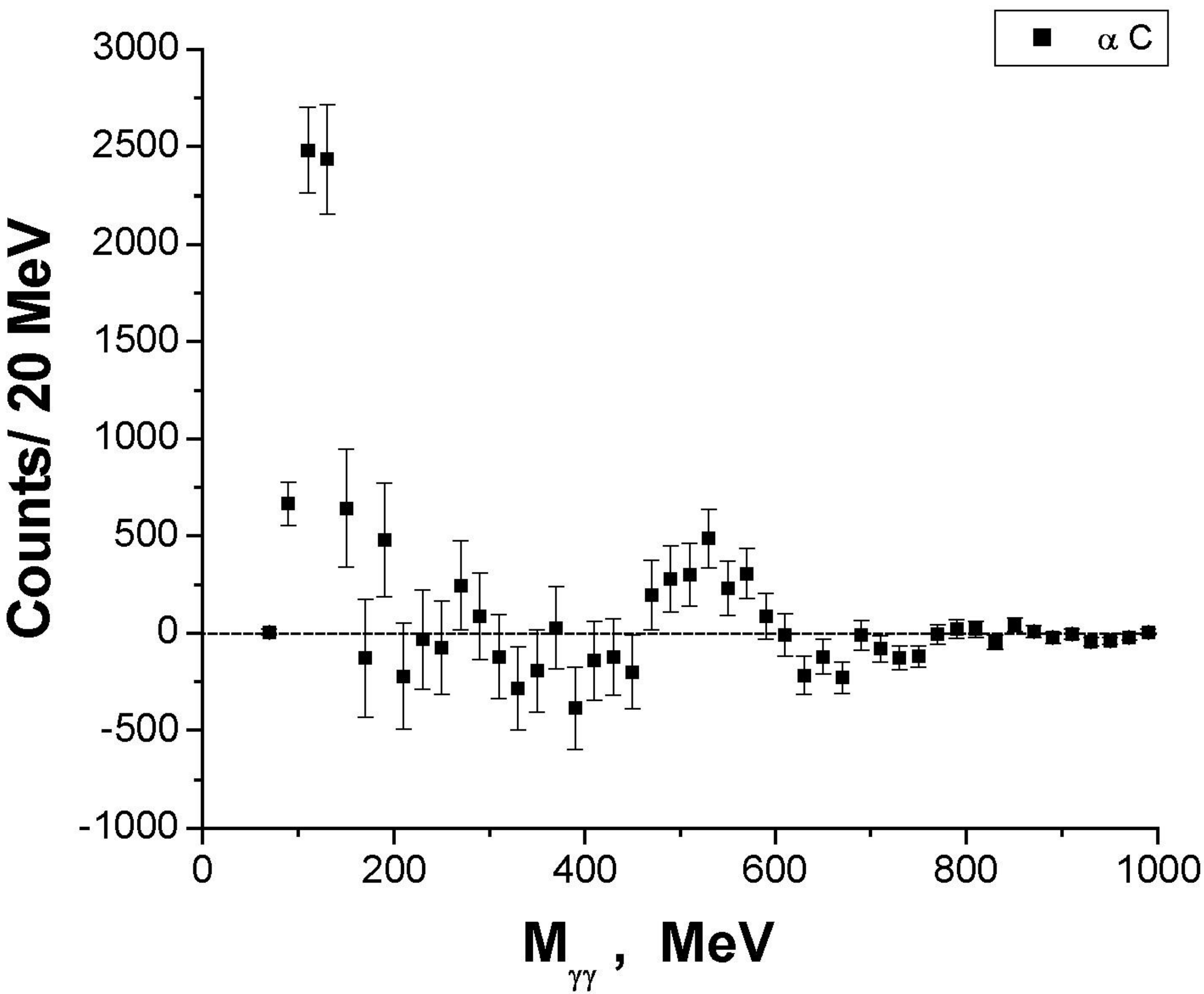




m_γγ - mixbackground
×10^6
25
20
15
10
5
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
m_γγ (GeV/c²)
m_γγ - mixbackground
500 ×10^3
400
300
200
100
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
m_γγ (GeV/c²)
m_γγ - mixbackground
500 ×10^3
400
300
200
100
0
χ² / ndf 2.229e+05 / 27
Prob 0
Constant 2.78e+05 ± 433
Mean 0.5471 ± 0.0000
Sigma 0.01782 ± 0.00002
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
m_γγ (GeV/c²)

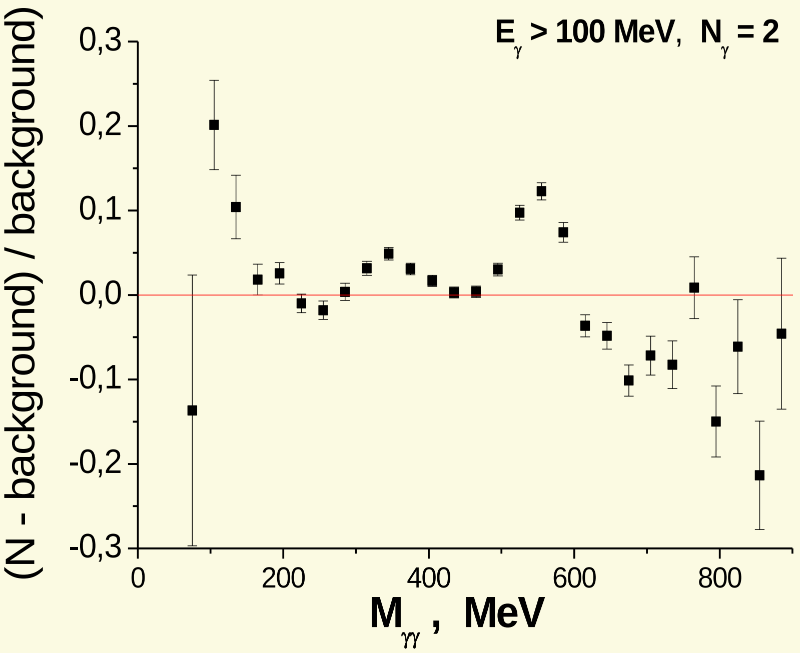


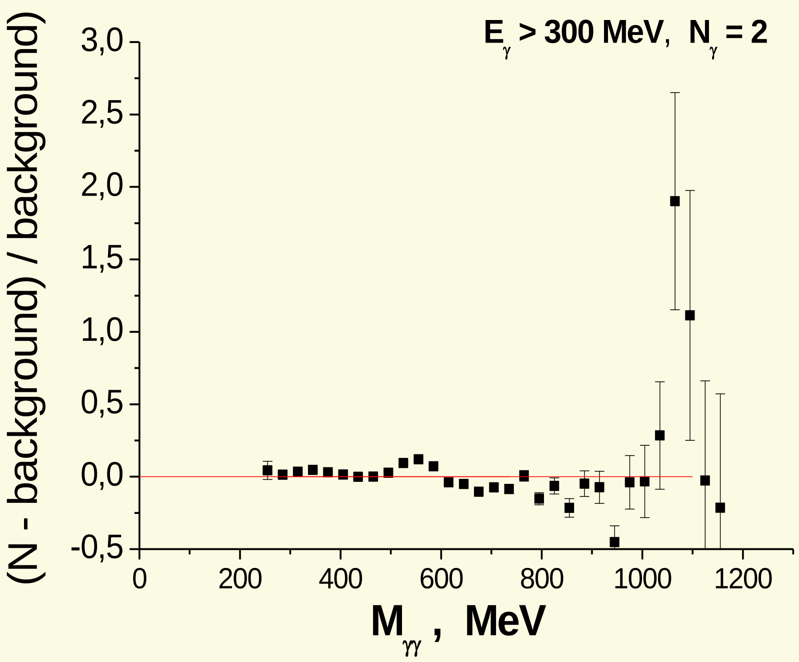
mγγ - mixbackground
mγγ (GeV/c²)
mγγ - mixbackground
mγγ (GeV/c²)
mγγ - mixbackground
-2147483648
0.5446
RMS 0.06222
χ² / ndf 12.61 / 12
Prob 0.3978
Constant 7.778e+05 ± 18341
Mean 0.5471 ± 0.0005
Sigma 0.0173 ± 0.0005
mγγ (GeV/c²)
mγγ
Entries 7.60852e+09
Mean 0.4714
RMS 0.2837
mγγ (GeV/c²)
mixbackground
Entries 6.828854e+10
Mean 0.4752
RMS 0.283
mγγ (GeV/c²)



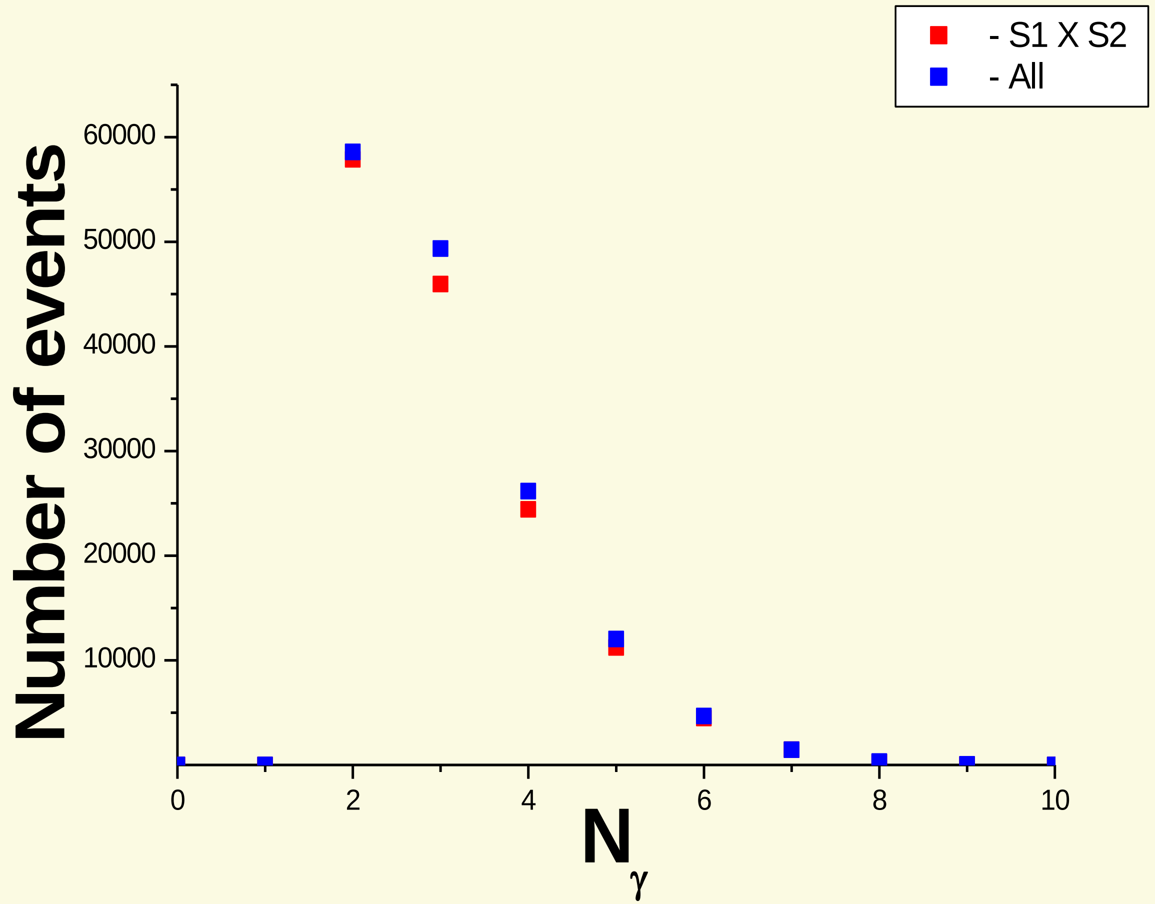
αC
Counts/ 20 MeV
3000
2500
2000
1500
1000
500
0
-500
-1000
0
200
400
600
800
1000
Mγγ , MeV

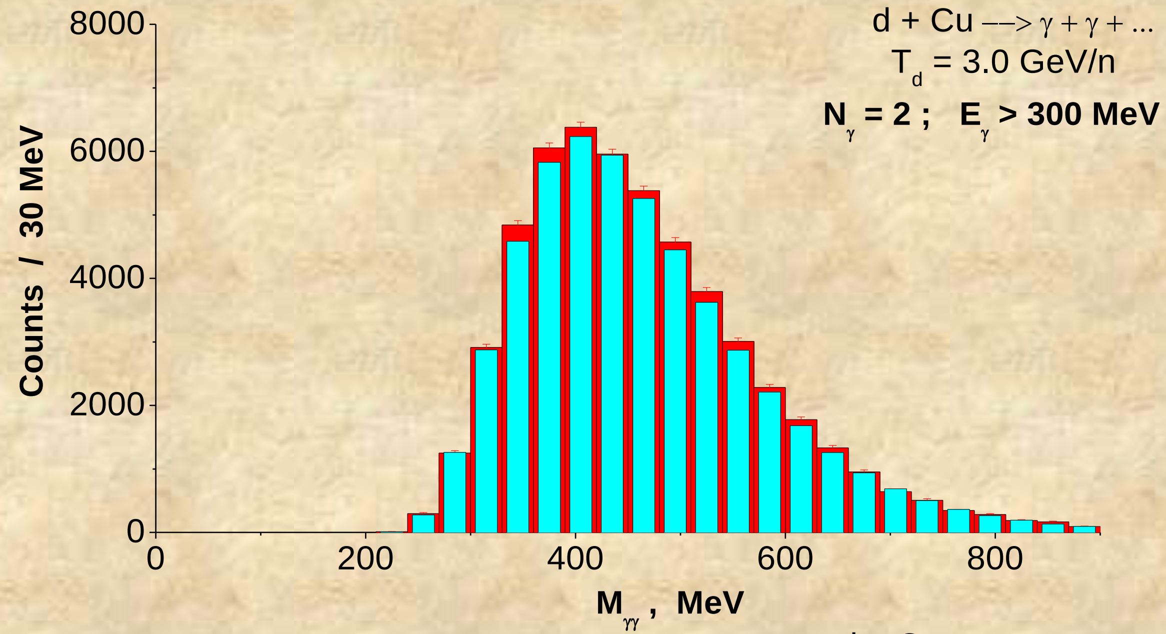
Отношение числа пар γγ за вычетом фона к числу фоновых пар

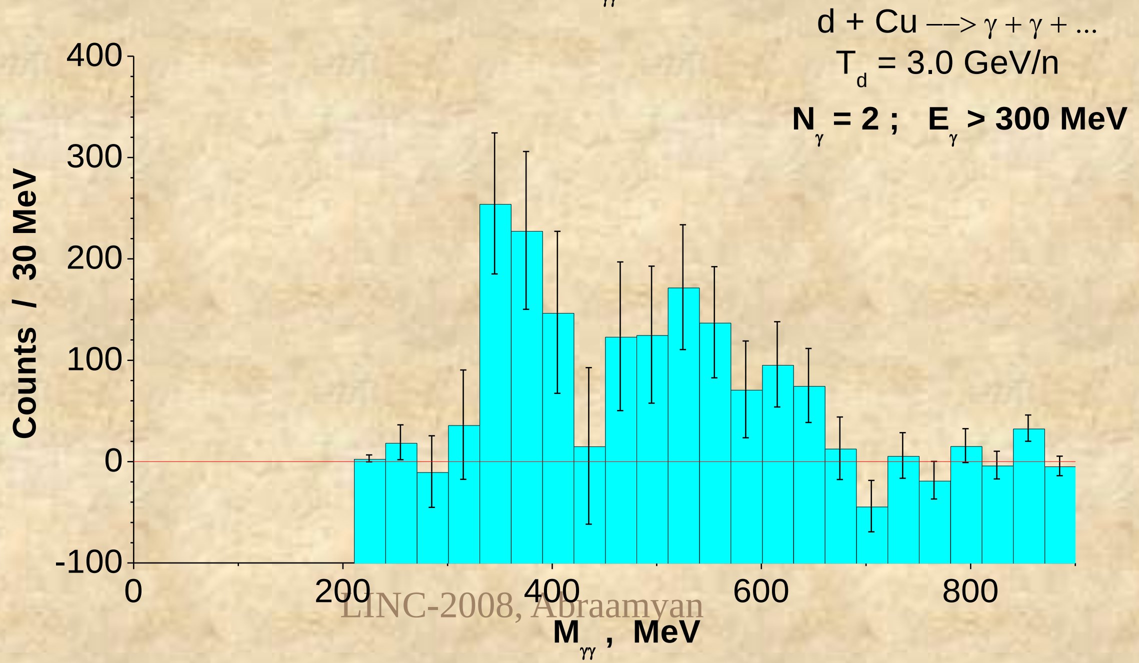


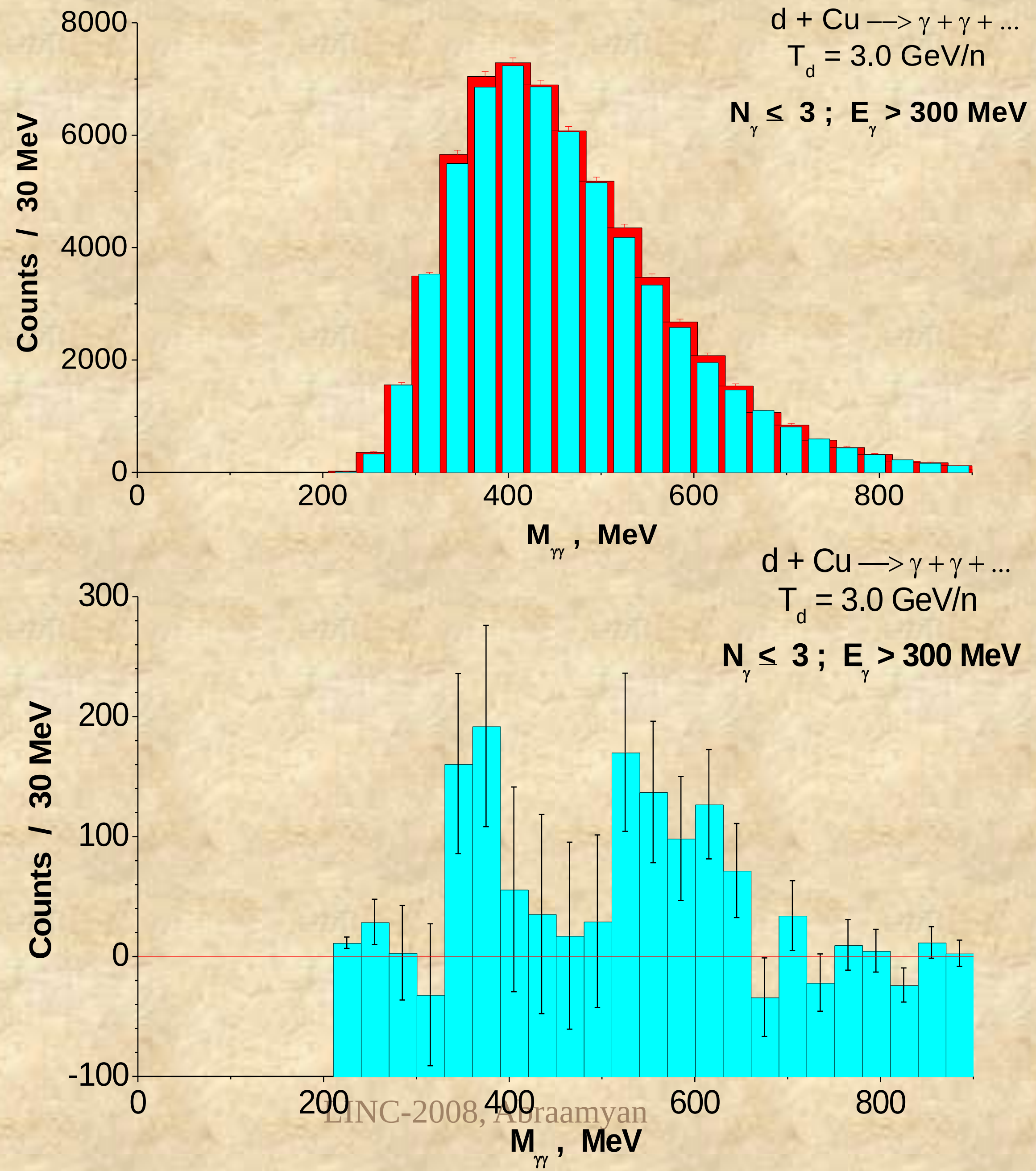


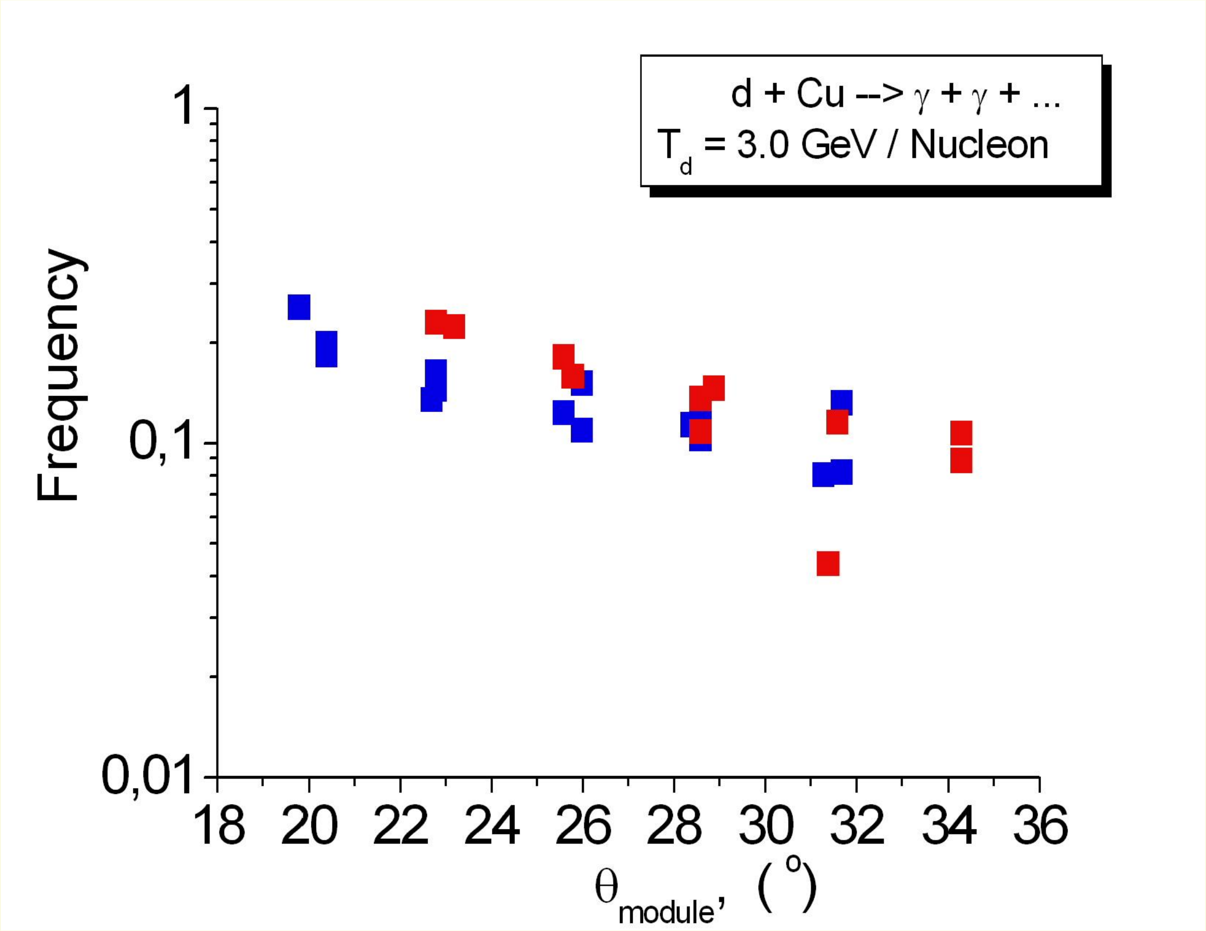
Распределение событий по множественности в реакции α + C при импульсе 3.8 ГэВ/с, без сцинтилляционных счетчиков (синие точки) и с сцинтилляционными счетчиками в антисовпадении

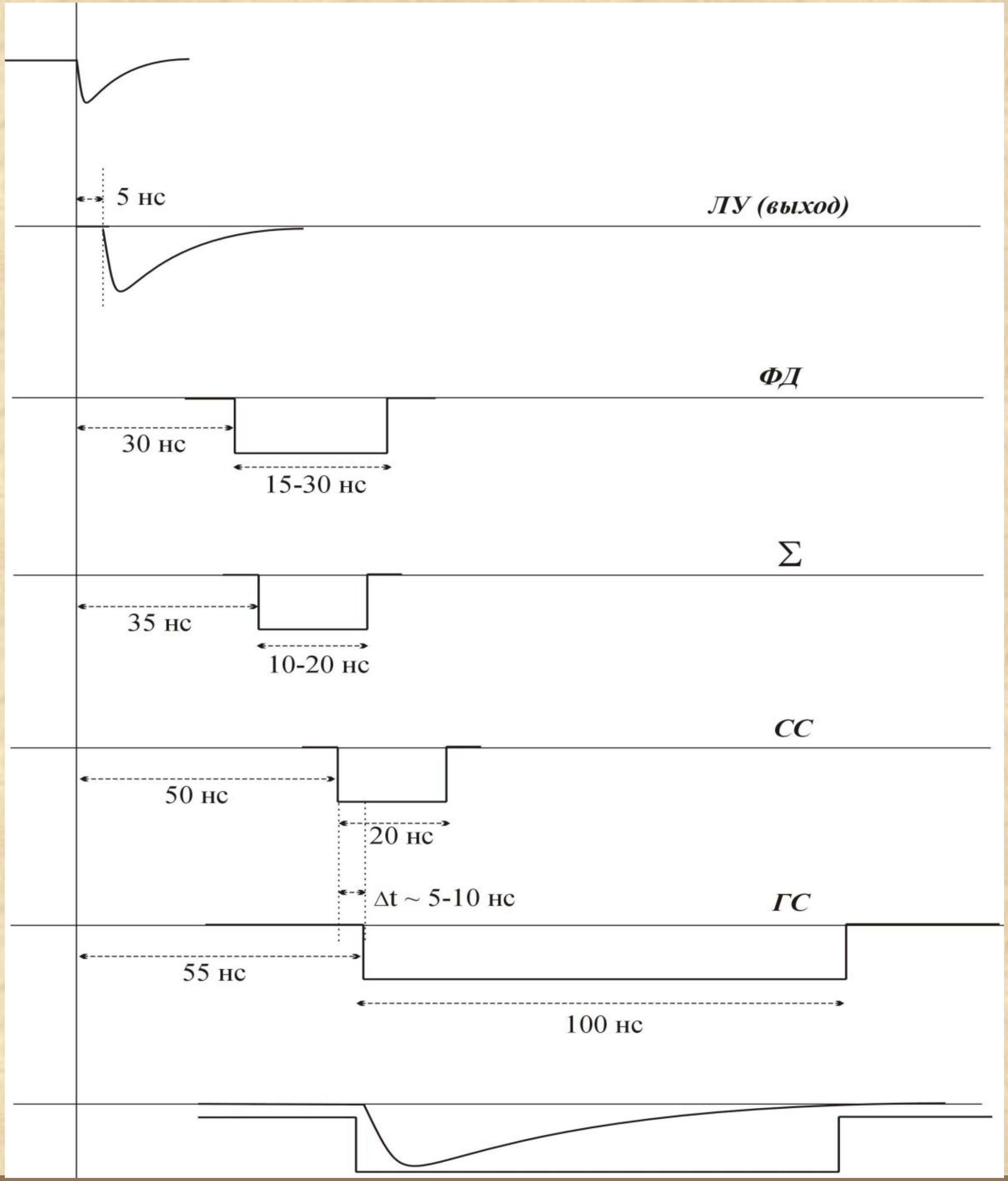


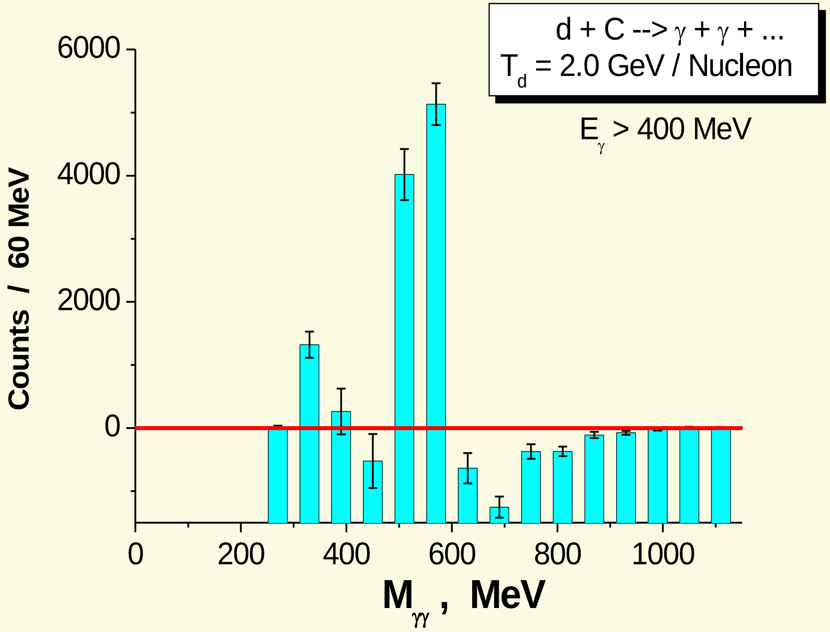

d + Cu ––> γ + γ + ...
T_d = 3.0 GeV/n
N_γ = 2 ; E_γ > 300 MeV
Counts / 30 MeV
M_γγ , MeV
0
2000
4000
6000
8000
0
200
400
600
800

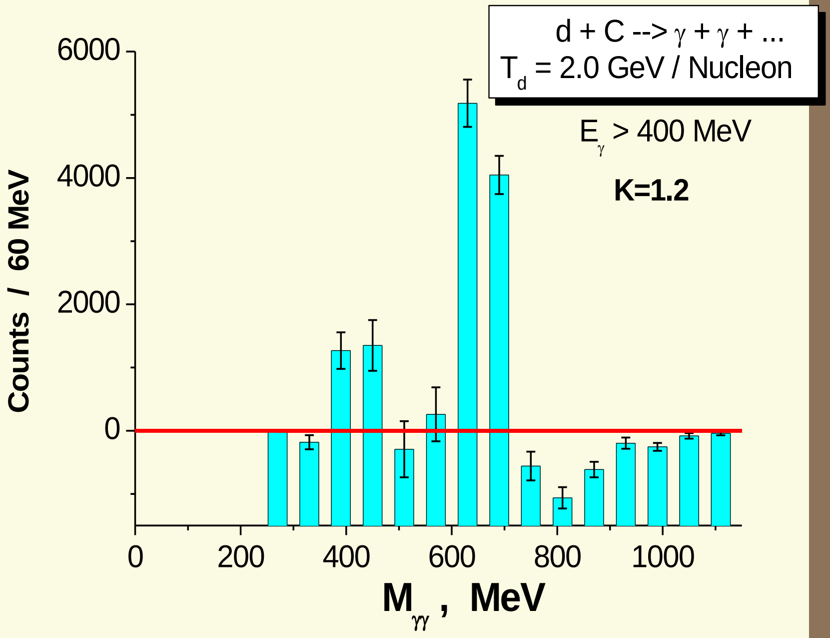

d + Cu ––> γ + γ + ...
T_d = 3.0 GeV/n
N_γ = 2 ; E_γ > 300 MeV
Counts / 30 MeV
M_γγ , MeV
-100
0
100
200
300
400
0
200
400
600
800


d + Cu —> γ + γ + ...
T_d = 3.0 GeV/n
N_γ ≤ 3 ; E_γ > 300 MeV
Counts / 30 MeV
M_γγ , MeV
8000
6000
4000
2000
0
200
400
600
800
d + Cu —> γ + γ + ...
T_d = 3.0 GeV/n
N_γ ≤ 3 ; E_γ > 300 MeV
Counts / 30 MeV
M_γγ , MeV
300
200
100
0
-100

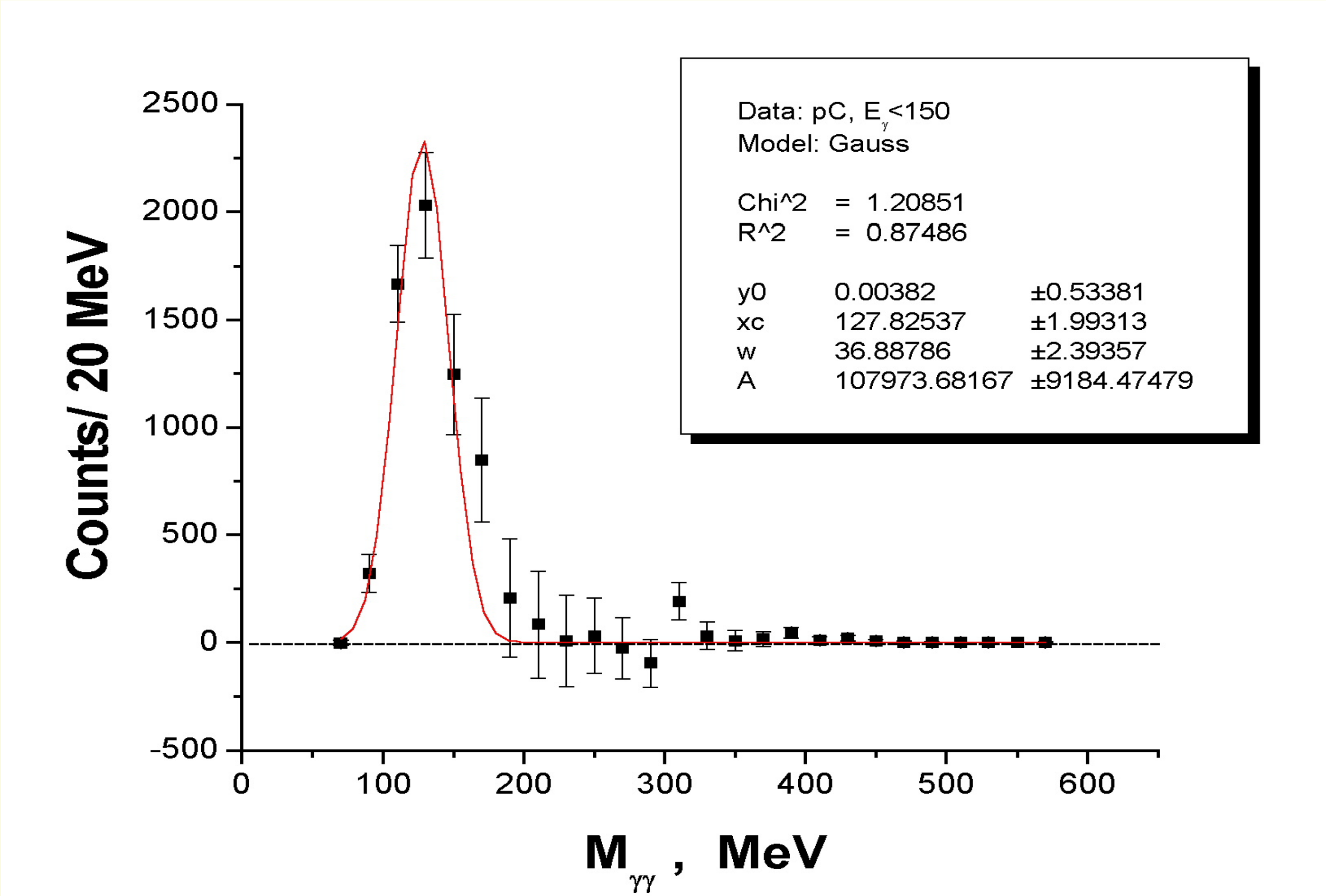

d + Cu --> γ + γ + ...
T_d = 3.0 GeV / Nucleon
Frequency
1
0,1
0,01
18 20 22 24 26 28 30 32 34 36
θ_module, (o)


5 нс
ЛУ (выход)
ФД
30 нс
15-30 нс
Σ
35 нс
10-20 нс
СС
50 нс
20 нс
Δt ~ 5-10 нс
ГС
55 нс
100 нс

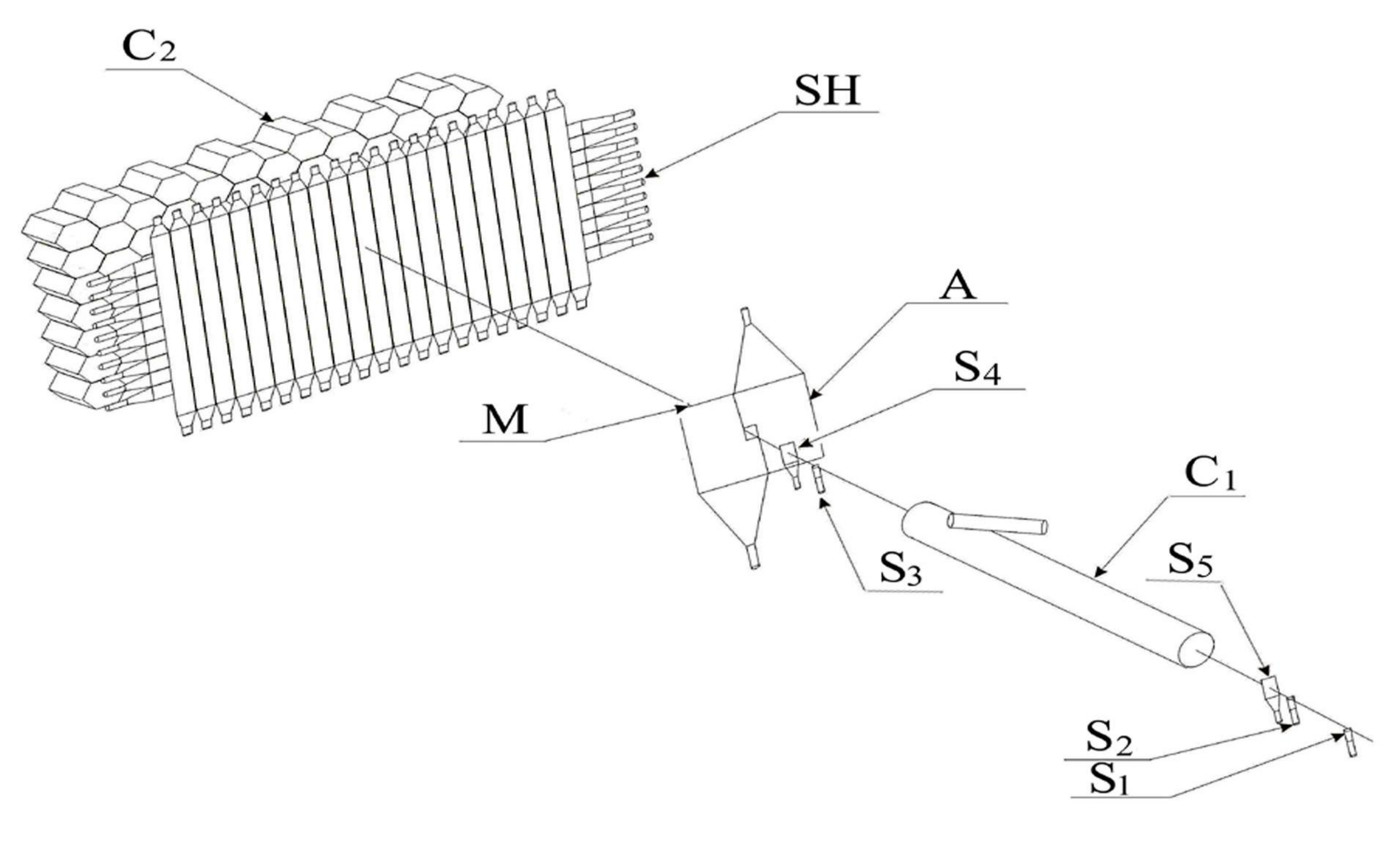

d + C --> γ + γ + ...
T_d = 2.0 GeV / Nucleon
E_γ > 400 MeV
Counts / 60 MeV
6000
4000
2000
0
200
400
600
800
1000
M_γγ , MeV

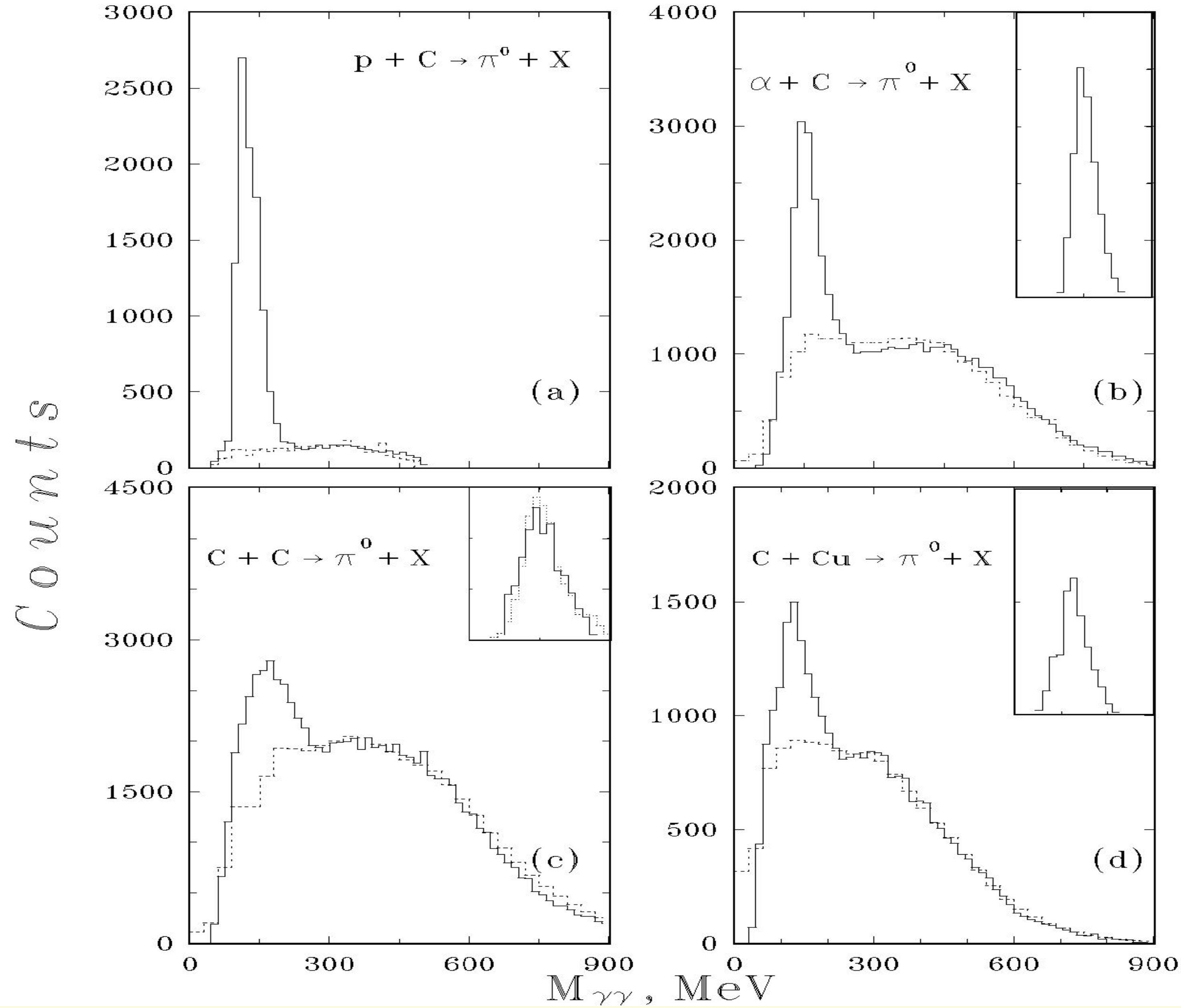

d + C --> γ + γ + ...
T_d = 2.0 GeV / Nucleon
E_γ > 400 MeV
K=1.2
Counts / 60 MeV
6000
4000
2000
0
200
400
600
800
1000
M_γγ , MeV

Registration of low energy γ-quanta

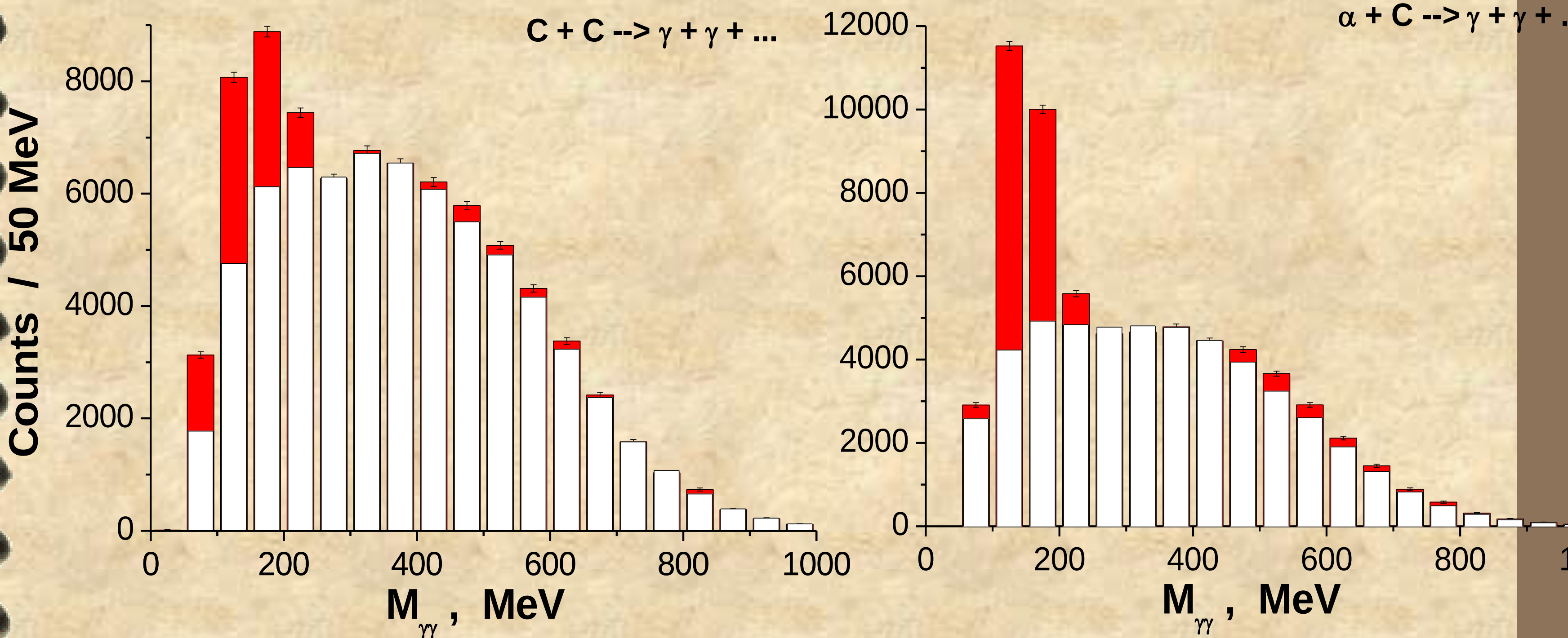


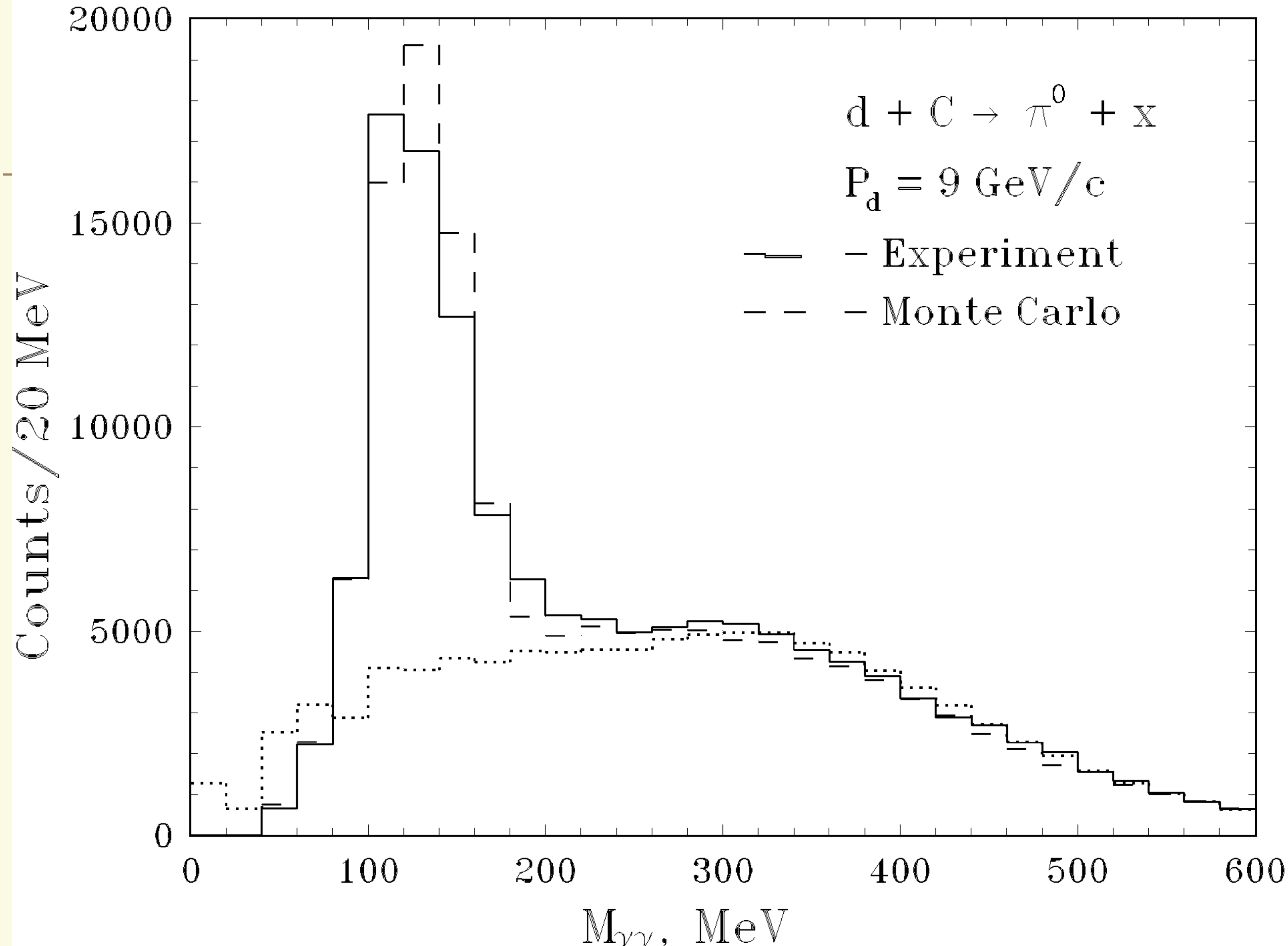
FOTON setup on beams of the Synchrophasotron



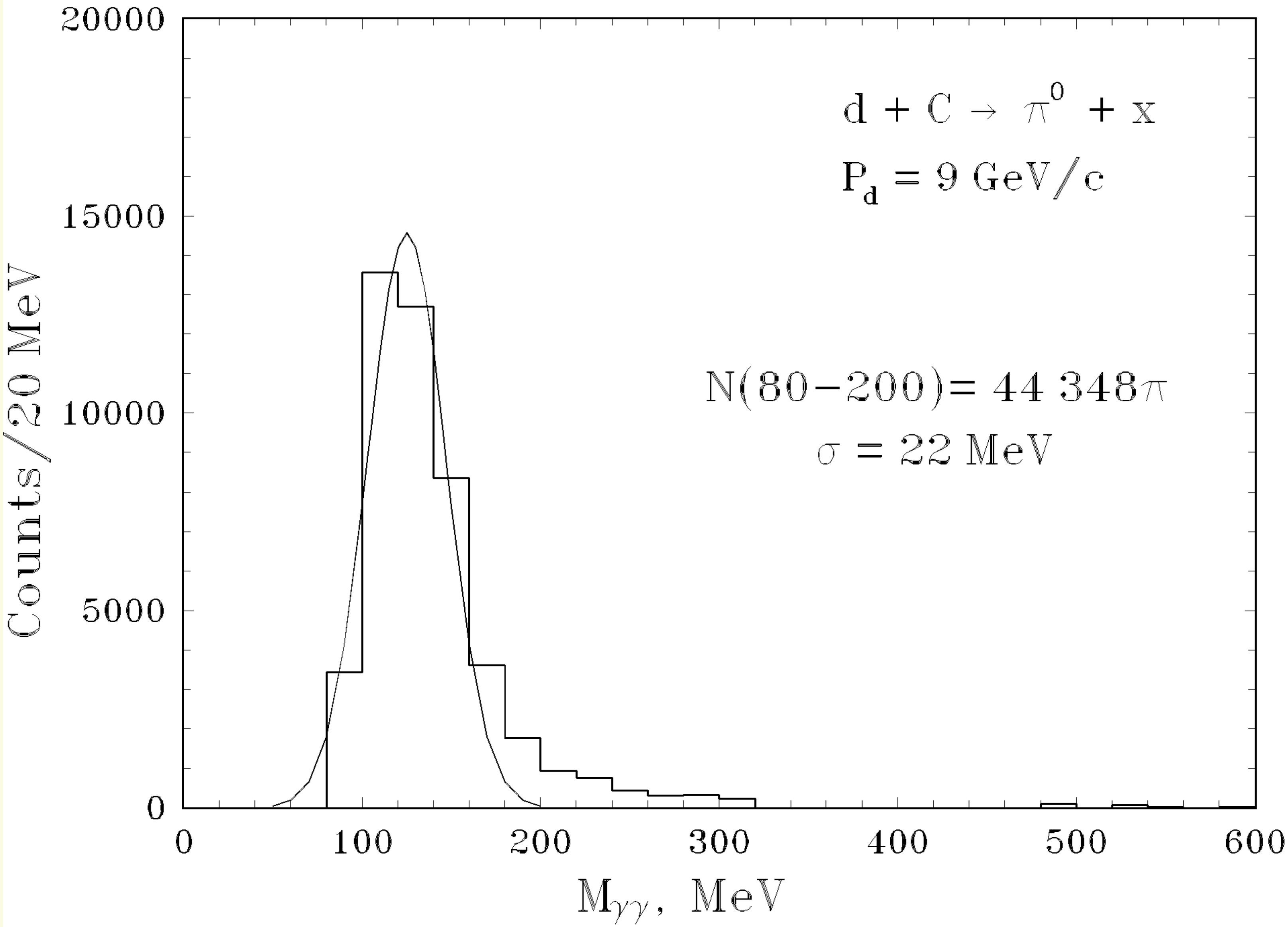


p + C → π⁰ + X
α + C → π⁰ + X
C + C → π⁰ + X
C + Cu → π⁰ + X
(a)
(b)
(c)
(d)
Counts
M γγ , MeV
0
300
600
900
500
1000
1500
2000
2500
3000
4000
4500


C + C --> γ + γ + ...
α + C --> γ + γ + ...
Counts / 50 MeV
M γγ , MeV
M γγ , MeV



d + C → π^0 + x
P_d = 9 GeV/c
– Experiment
– Monte Carlo
Counts/20 MeV
$M_{\gamma\gamma}$, MeV
20000
15000
10000
5000
0
0
100
200
300
400
500
600



20000
15000
10000
5000
0
Counts/20 MeV
0
100
200
300
400
500
600
$M_{\gamma\gamma}$, MeV
d + C → π^0 + x
P_d = 9 GeV/c
N(80−200)= 44 348π
σ = 22 MeV