FLUCTUATION IN ELECTROMAGNETIC CASCADES PRODUCED BY GAMMA-QUANTA OF 100-3500 MeV ENERGY IN DENSE AMORPHOUS MEDIA

B.Słowiński[1,2], P.Duda[1] and P.Hladki[1]

[1]Faculty of Physics, Warsaw University of Technology, Poland

[2]Institute of Atomic Energy, Otwock-Świerk, Poland

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OUTLINE OF THE TALK

- MOTIVATION
- ABSTRACT
- SHORT HISTORY
- EXPERIMENTAL REALITY
- RESULTS OF MODELING OF FLUCTUATION:
  - LONGITUDINAL PROFILES
  - TRANSVERSE PROFILES
- SUMMARY AND CONCLUSION

Motivation

- Longitudinal and lateral profiles of electromagnetic cascades (EMC) produced in heavy amorphous media by high enough energy gamma quanta and electrons (or positrons) are the basic characteristics of the phenomenon both from cognitive and application viewpoints.
- Such are relevant fluctuations of these profiles since the process of EMC is of strongly expressed stochastic nature that is especially perceptible at not too high energies (i.e. hundredths MeV to several GeV).
- The fluctuations determine the energy resolution and accuracy of flight direction of particles initiating EMC.
- The information about fluctuations of EMC is needed for electromagnetic calorimeters under construction such as PANDA (GSI).

Abstract

We study the longitudinal fluctuation of electromagnetic cascades (EC) produced in liquid xenon, PWO and BGO by gamma quanta of energy from 100 MeV to 3.5 GeV at different cut-off energies within the interval 0.1-3 MeV. The work has been performed using GEANT and EGS modeling codes.

The ultimate objective of this investigation is to obtain exhaustive and concise information about fluctuations in EC suitable for experiments.

Basic steps in the investigation of electromagnetic cascades (EMC):

1. **Rossi B. Phys. Zs., 1932, vol.33, p.304 - discovery of the phenomenon.**
2. **Rossi B. High-Energy Particles. Prentice-Hall, New York, 1952 - one-dimensional theory of EMC.**
3. **Longo E., Sestili J. Nucl. Instr. Meth., 1975, vol.128, p.283 – computer model of EMC** *(neither EGS4, nor GEANT)*.
4. **De Angelis A. Nucl. Instr. Meth. A., 1988, vol.271, p.455 - computer model of EMC** *(neither EGS4, nor GEANT)*.
5. **Słowiński B. Phys. Part. Nucl. 25 (2), March-April 1994 - overview of experimental and theoretical description of EMC.**
6. **Modern description of EMC is needed urgently** *(with EGS4 and GEANT)*.

Integral description of EMC fluctuation
(as an estimation of energy resolution)

$$\frac{\sigma}{E} \propto \frac{\sqrt{t}}{\sqrt{E}},$$

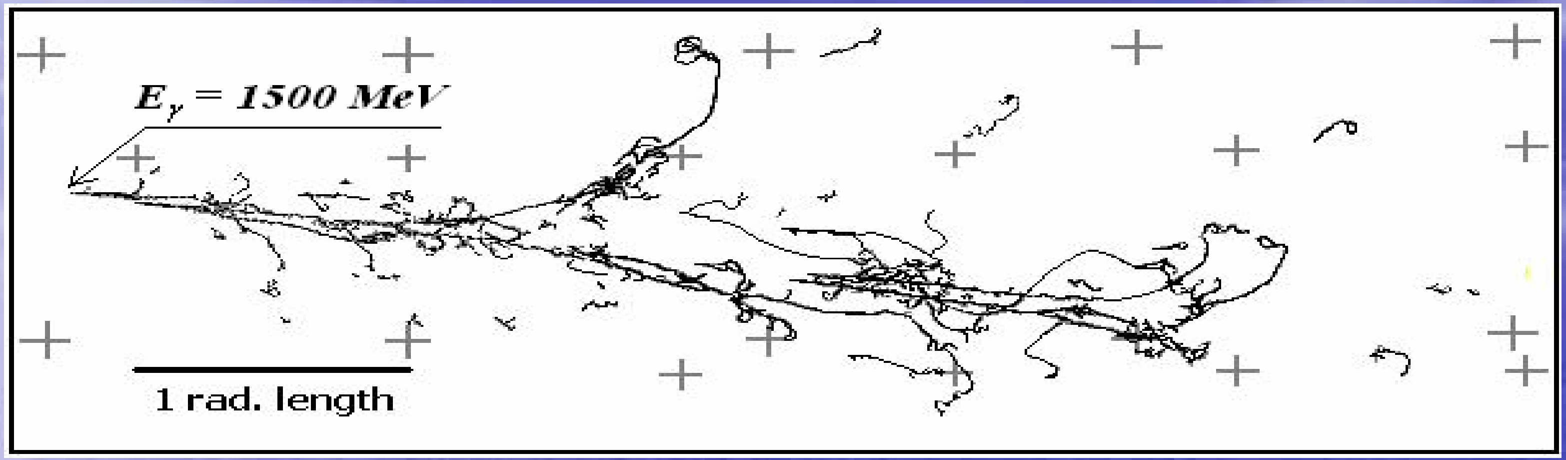
t is the step of sampling in units of r.l.

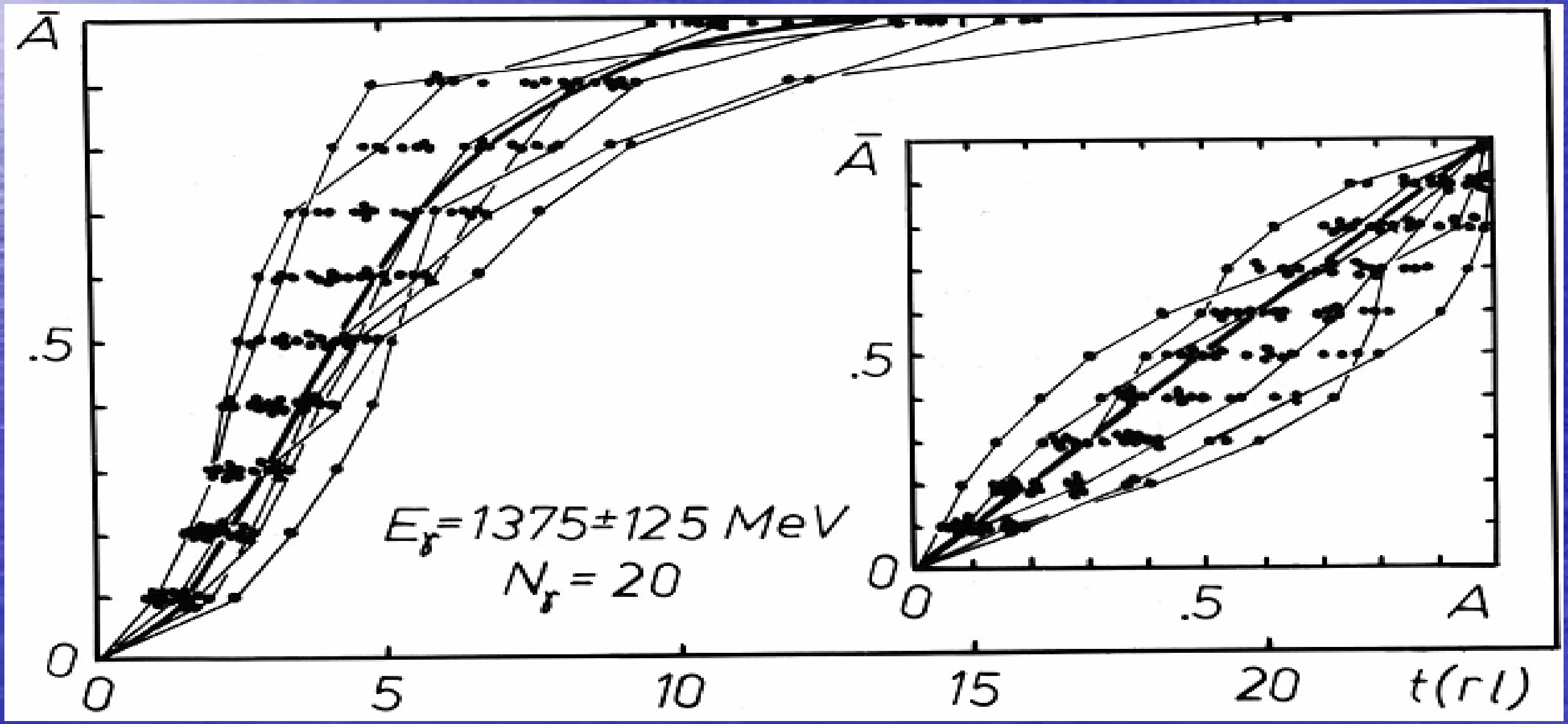
(C.Grupen. Particle detectors. Cambridge University Press. 1996)

$$\frac{\sigma_E}{E} = (\frac{a^2}{E^2} + \frac{b^2}{E} + c^2)^{1/2}$$

E is in GeV *(for $PbWO_4$ – PWO; ALICE experiment)*

Experimental reality after the picture from the 26 liter Xenon Bubble Chamber (LHE JINR)

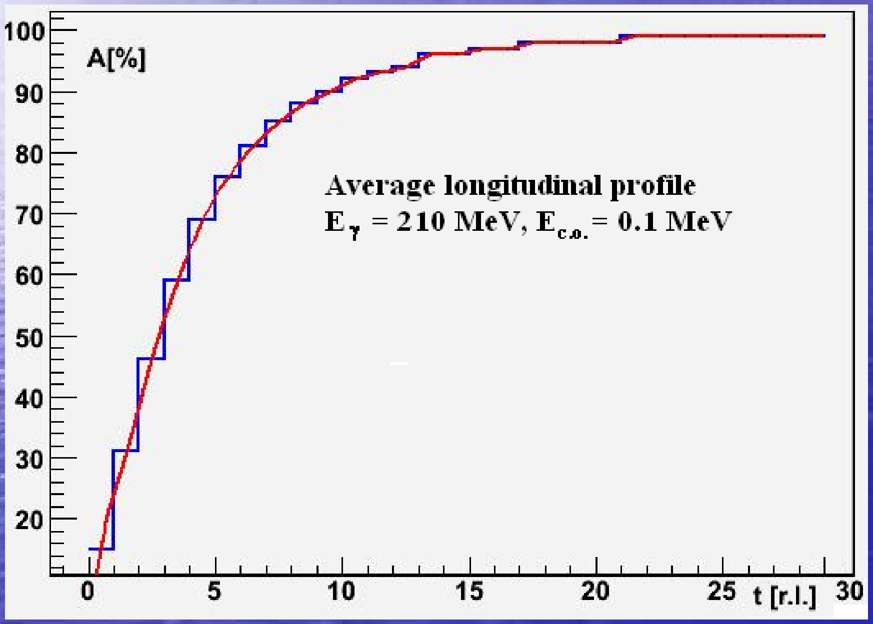


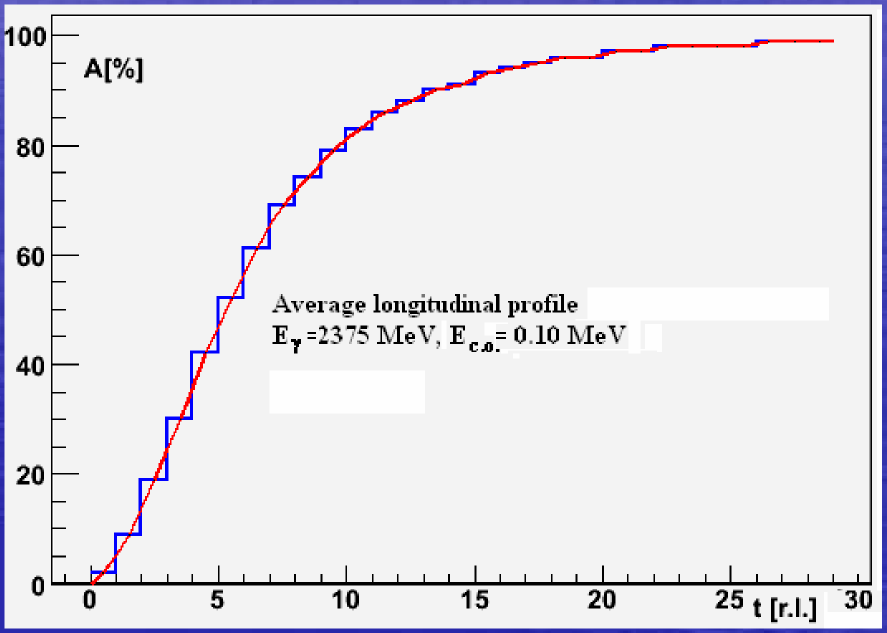


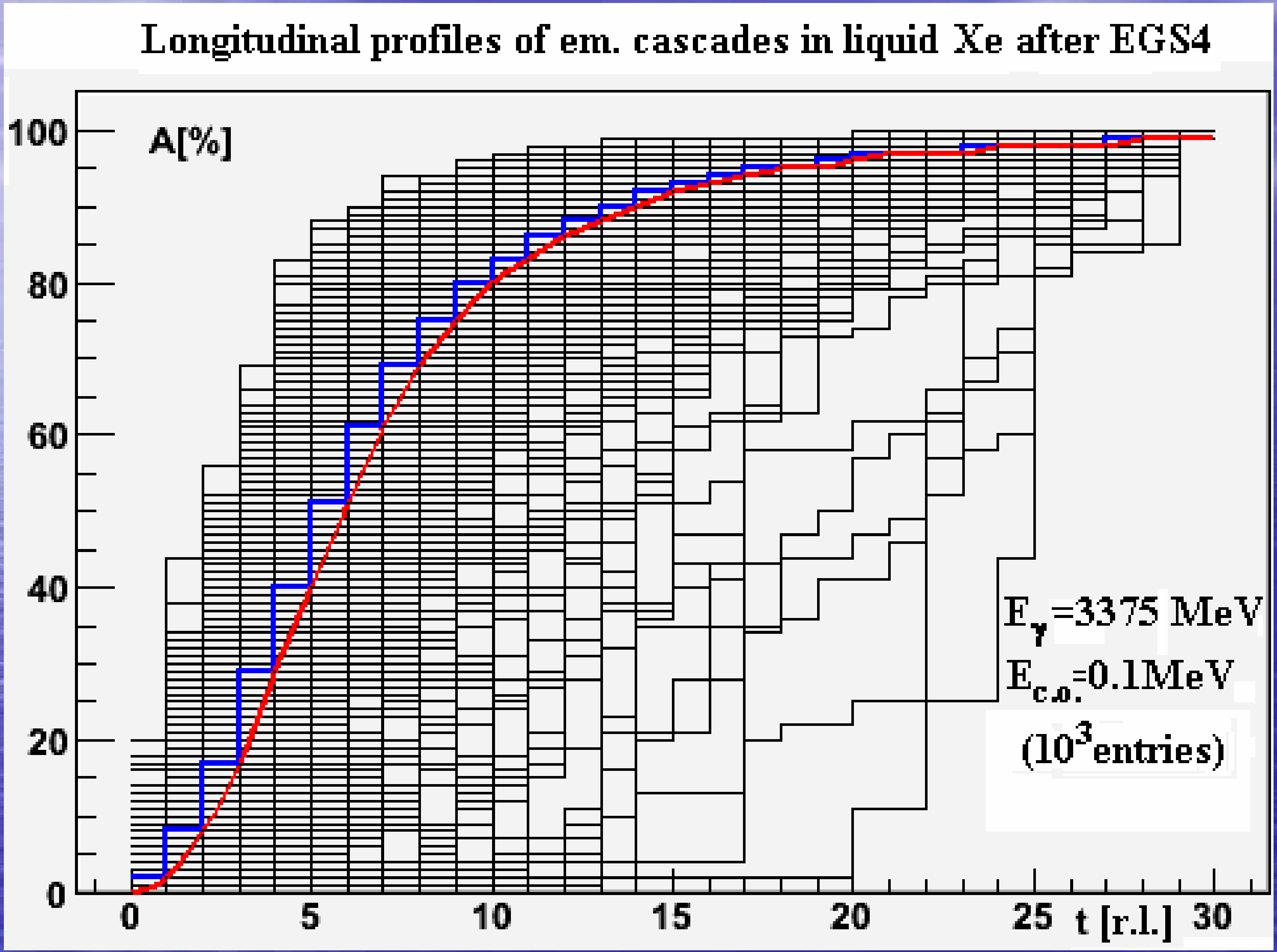
LONGITUDINAL PROFILES

Two examples of average longitudinal profile of EMC produced in liquid xenon by gammas of energy 210 and 2375 MeV

(after EGS4 code)



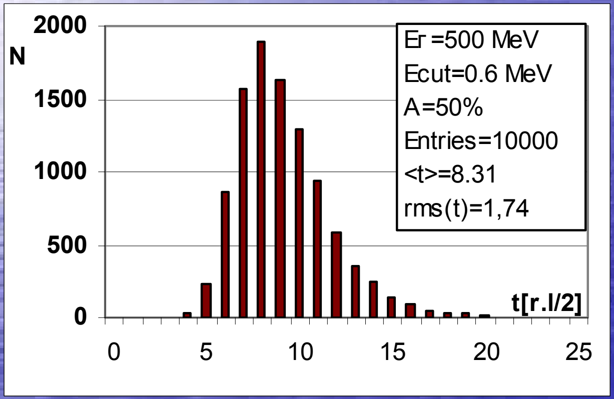


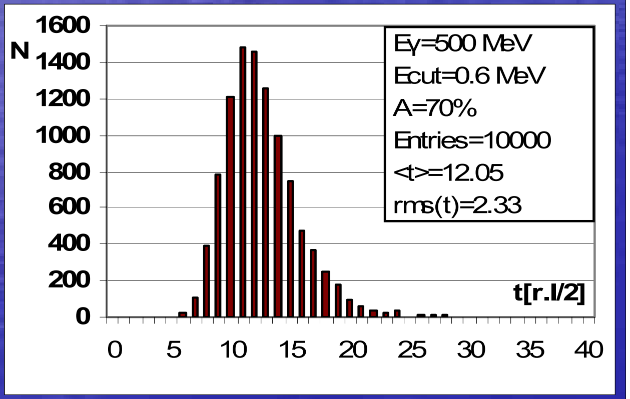

Longitudinal profiles of em. cascades in liquid Xe after EGS4
A[%]
100
80
60
40
20
0
0
5
10
15
20
25
t [r.l.]
30
E_γ=3375 MeV
E_c.o.=0.1MeV
(10^3 entries)

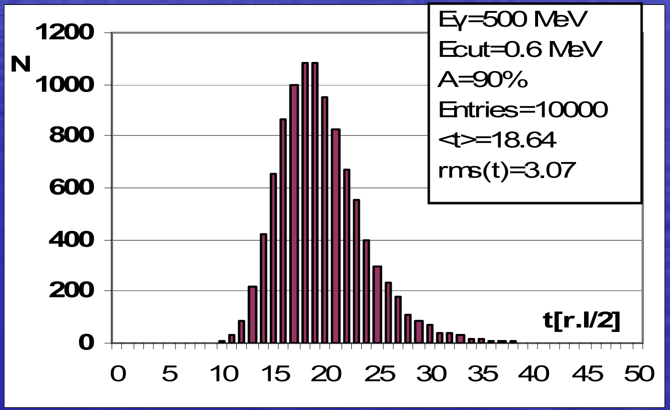
Distributions of the depth t at which a fraction A(%) of the total EMC energy loss is released in PWO ($PbWO_4$) as seen by GEANT and EGS code.

An example of EMCs produced by gamma quanta of energy E_γ =500 MeV at $E_{c.o.}$ = 0.6 MeV in PWO ($PbWO_4$) as calculated by EGS4 code at three different thresolds A of average energy release :

0.5, 0.7 and 0.9.







Results of modeling of EMC longitudinal fluctuation for PWO and BGO

(modelled using GEANT code)

Modelled are events of EMC produced by gamma quanta of energy E_γ = 100, 200, 500, 1000, 2500, 3000 and 3500 MeV at the cut-off range of cascade electrons: 0.01, 0.1 and 2mm, and three values of average cascade depths: A = 0.5, 0.7 and 0.9.

In the case of liquid xenon:

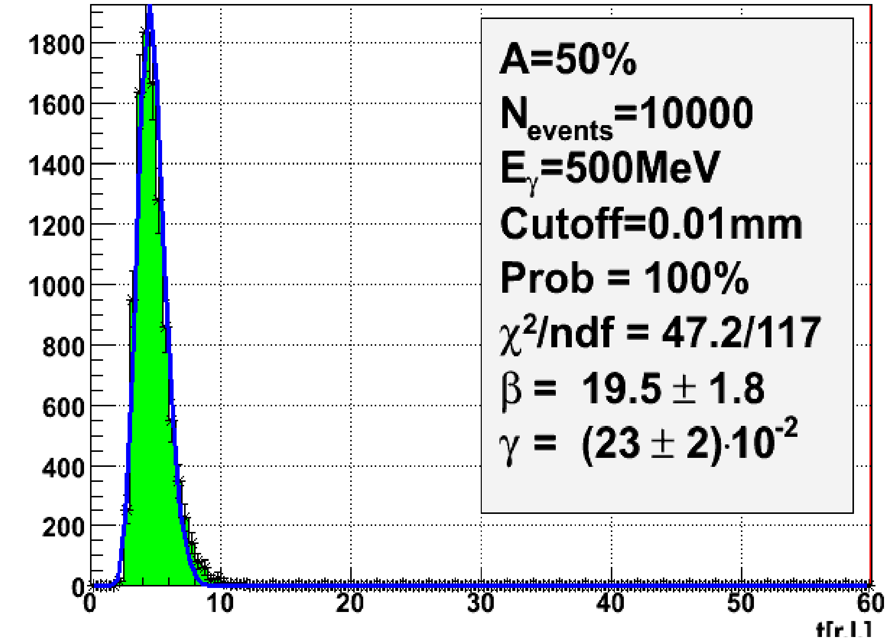
E_γ = 210, 555, 875, 1625, 2375 and 3125 MeV at the cut-off energy

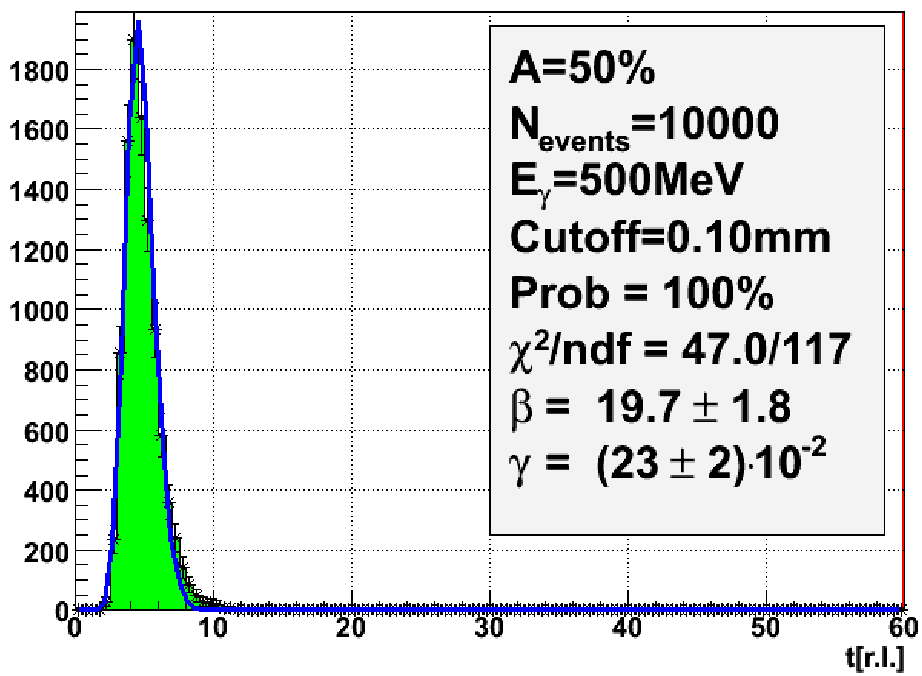
$E_{c.o.}$ = 0.1, 0.5, 0.9, 1.8, 3.0 and 6.8 MeV,

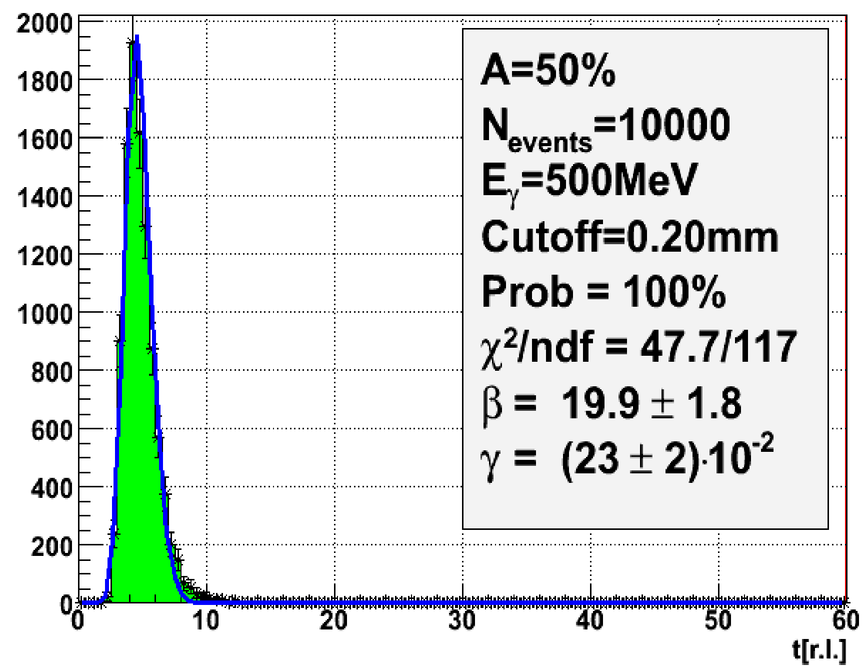
A = 0.5, 0.7 and 0.9.

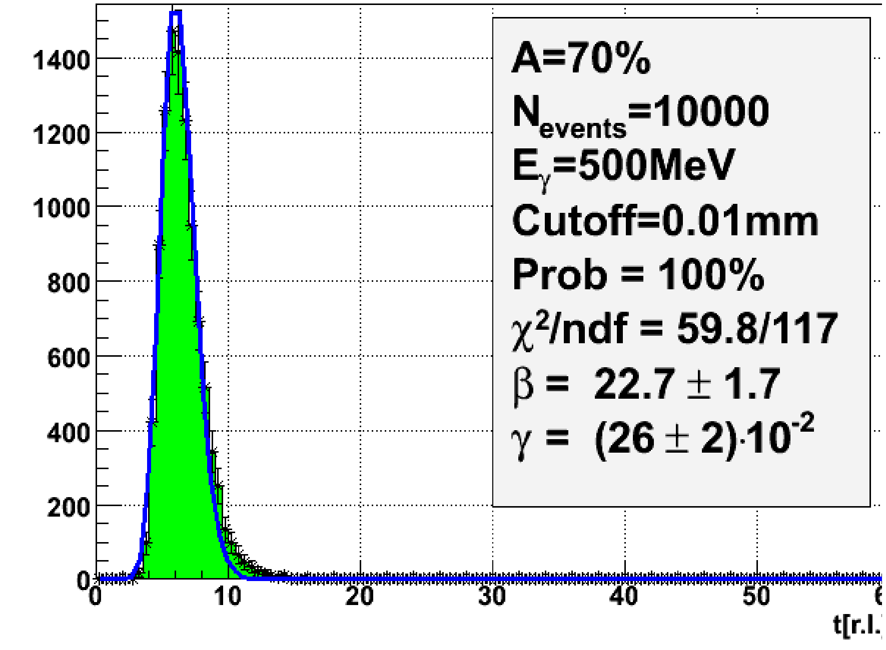
Fitting function for longitudinal fluctuation of EMC in PWO:

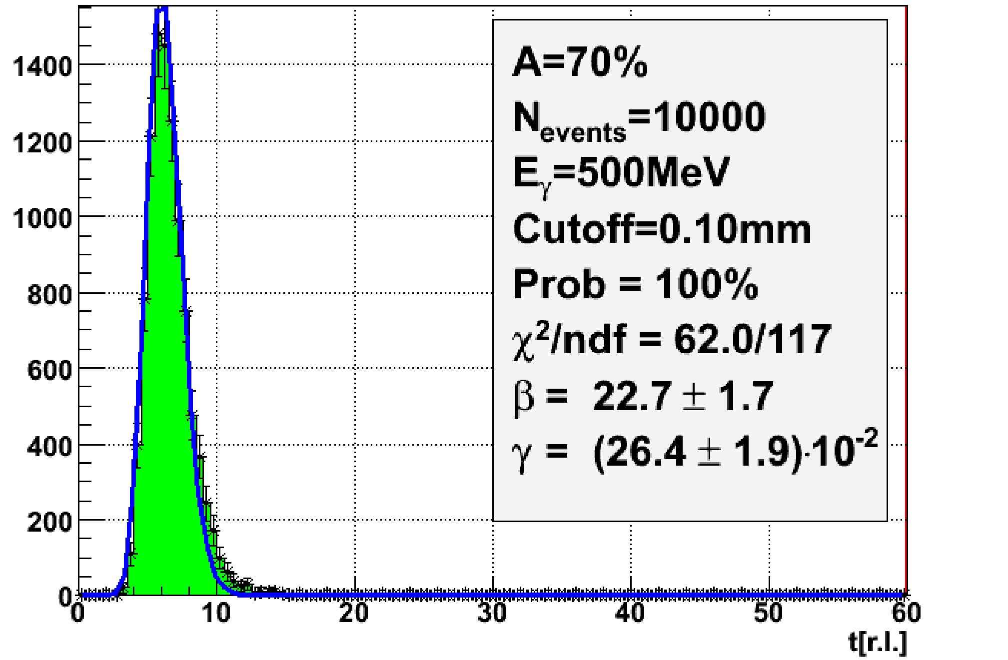
$$P(t_A) = \alpha \cdot t_A^{\beta} \exp(-t_A / \gamma)$$

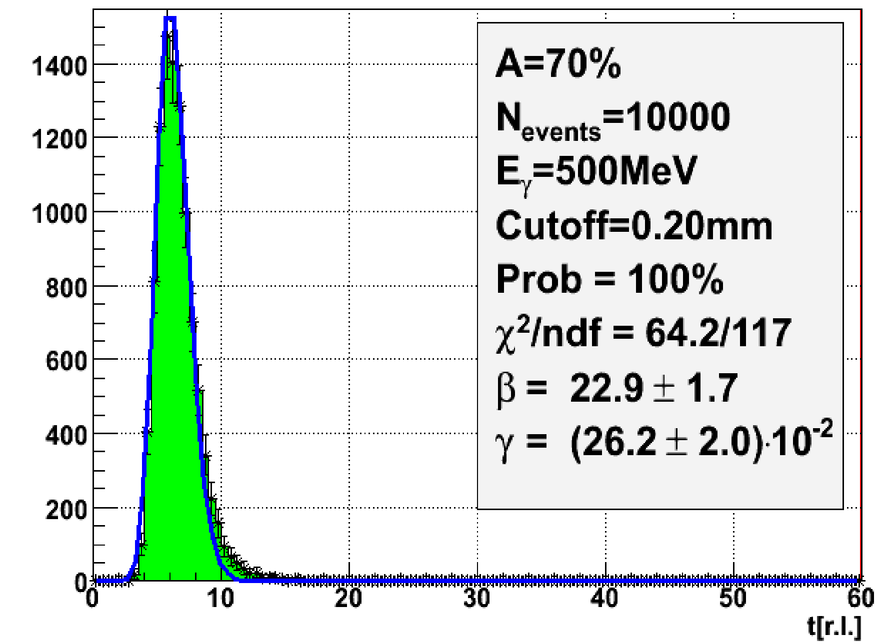




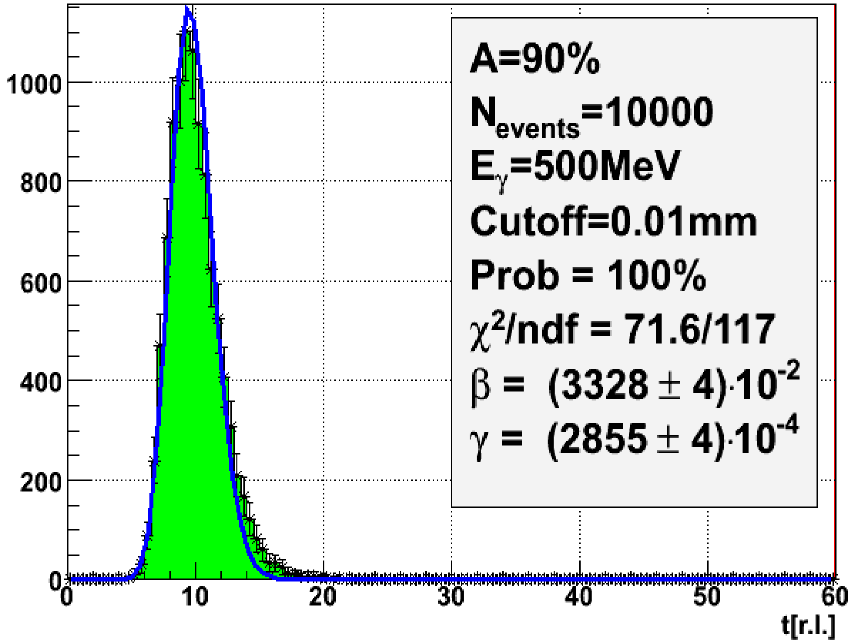


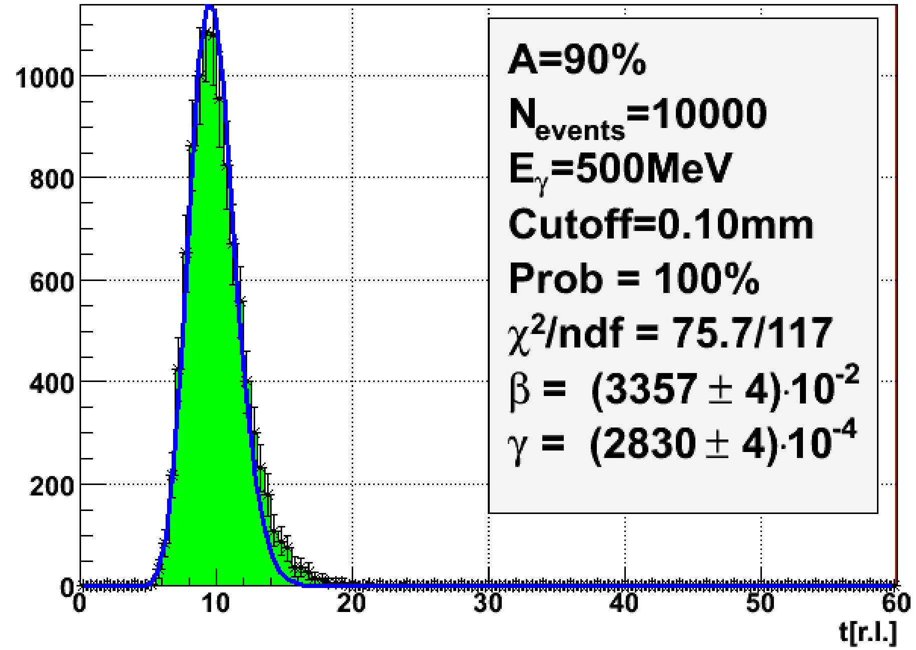


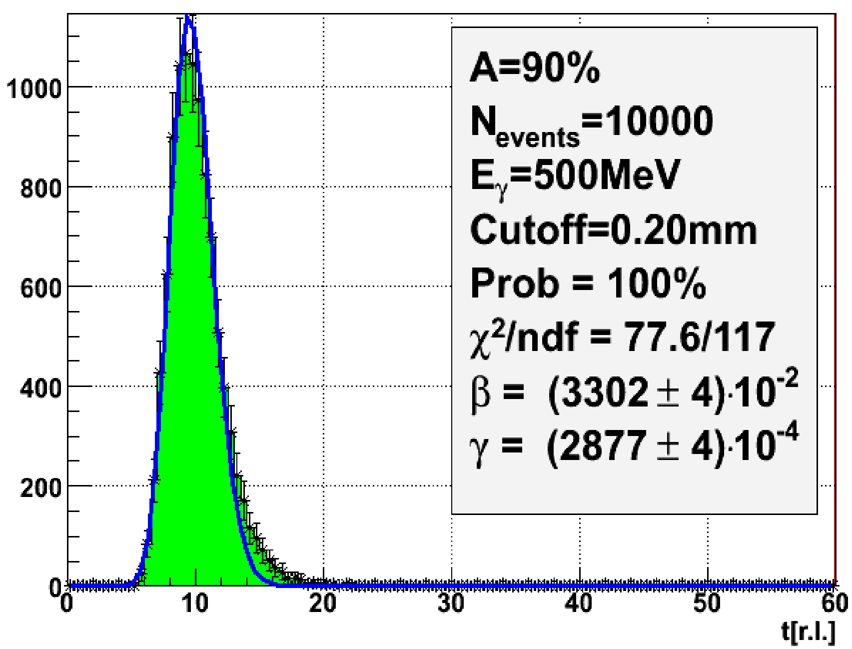




Distributions of the shower depth t_A at which a fixed part A of average cascade energy is released when the cascade is initiated in PWO by gamma quanta of energy Eγ = 500 MeV and detected with the cut-off length 0.01mm, 0.1mm and 0.2 mm (histograms). Smooth curves demonstrate the fitting function (3) with the corresponding values of the parameters α, β and γ and test statistics $\chi2$/ndf.

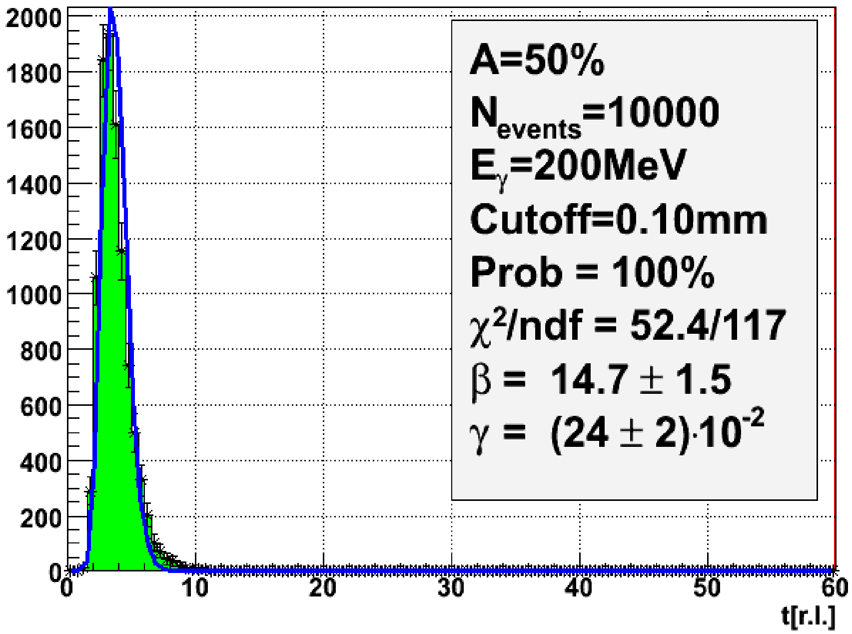


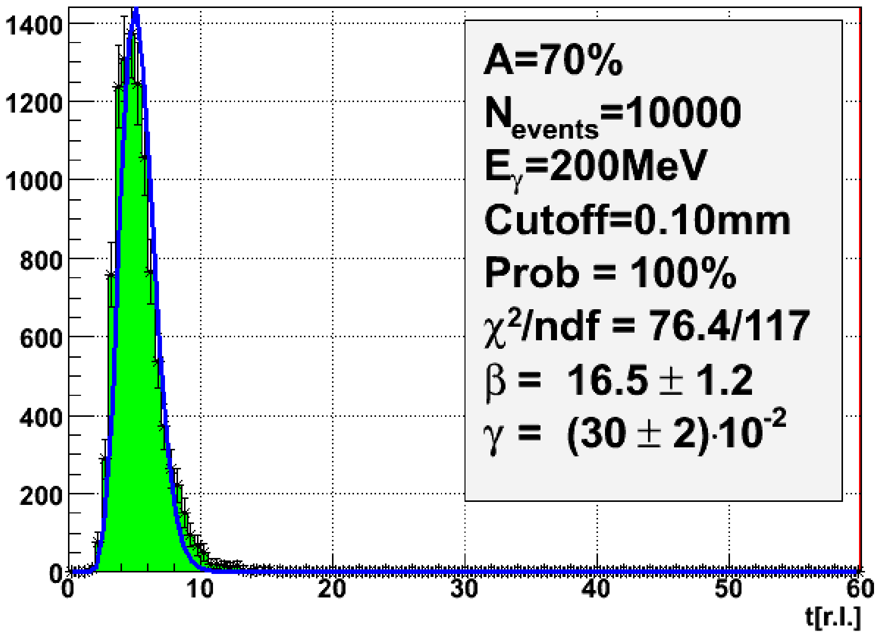


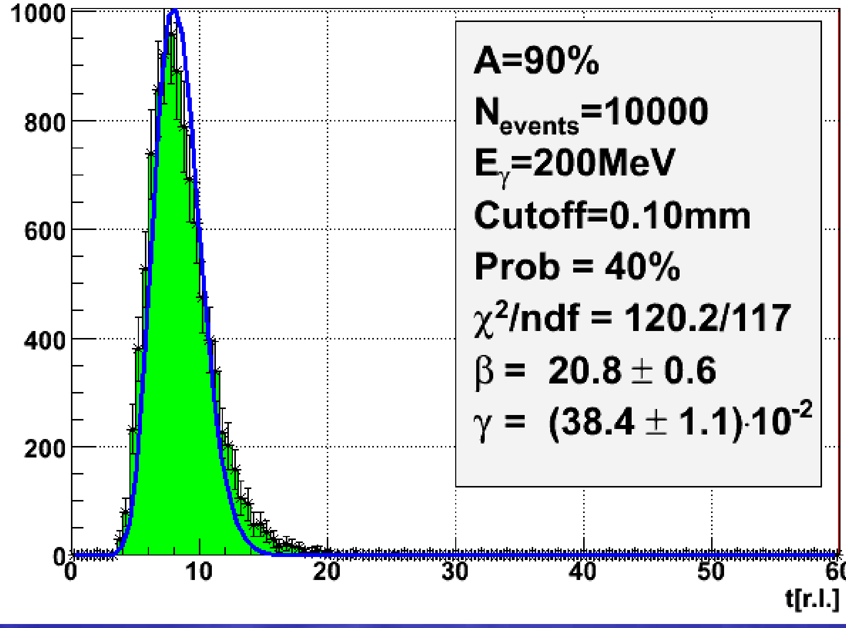


Modelled by using GEANT code in PWO

Eγ=500 MeV

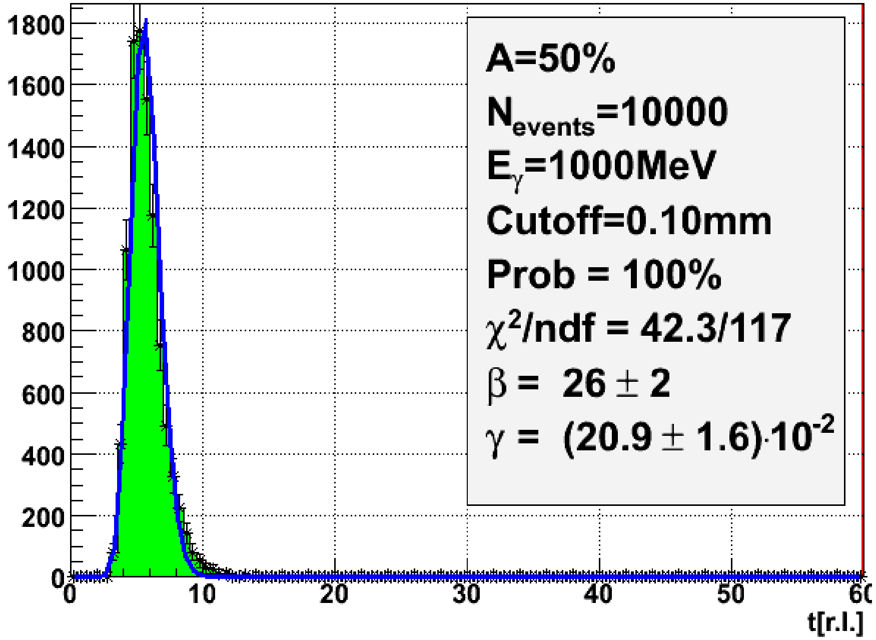


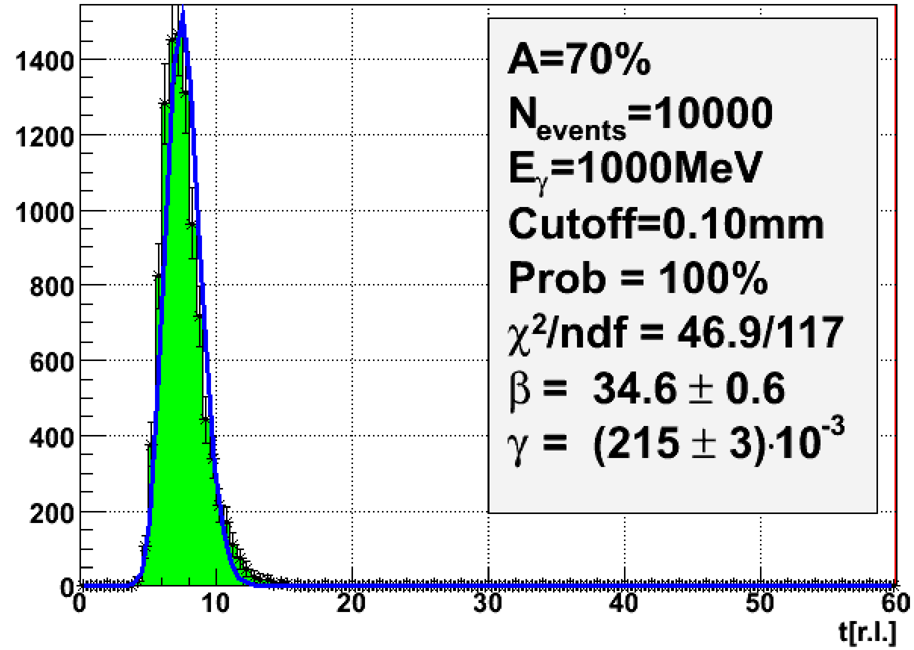


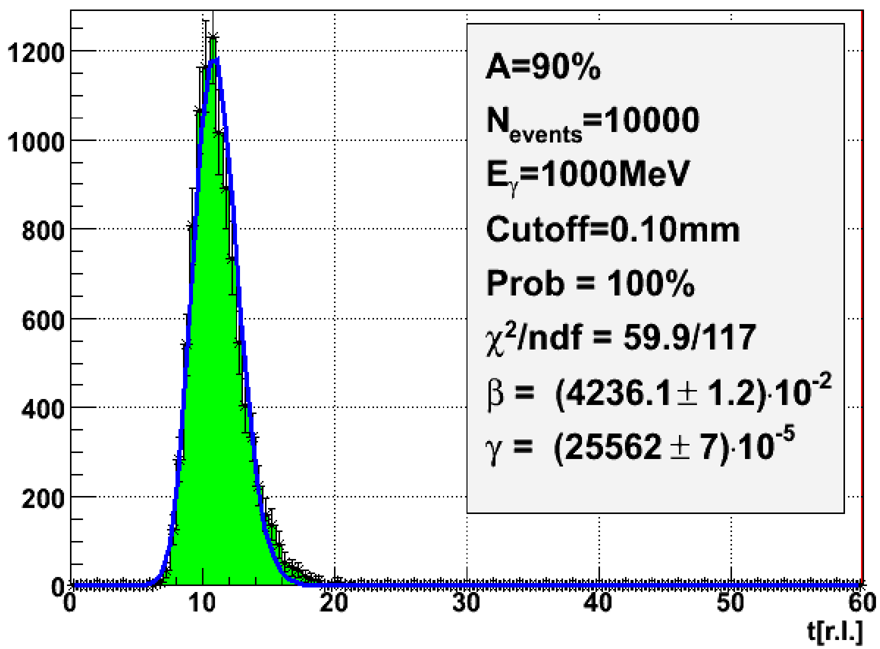


Modelled by using GEANT code in PWO

$E\gamma$=200MeV

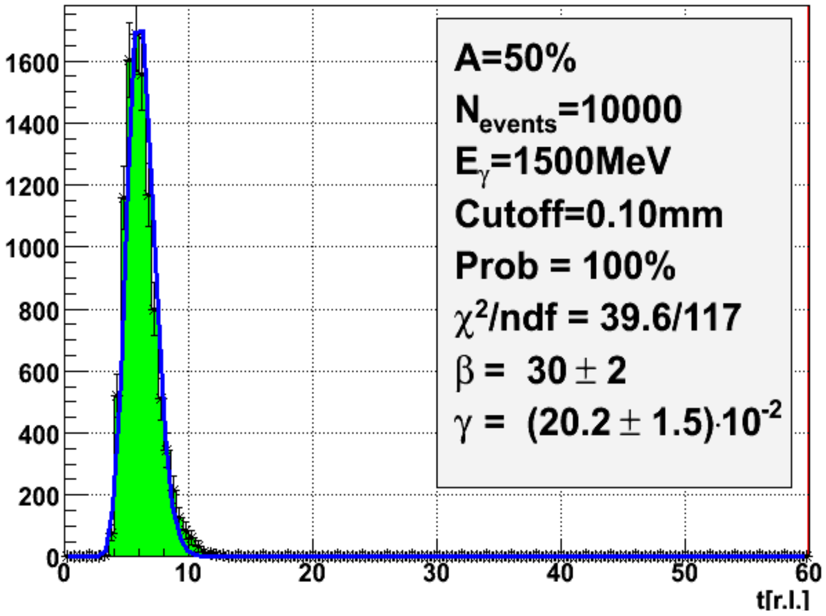


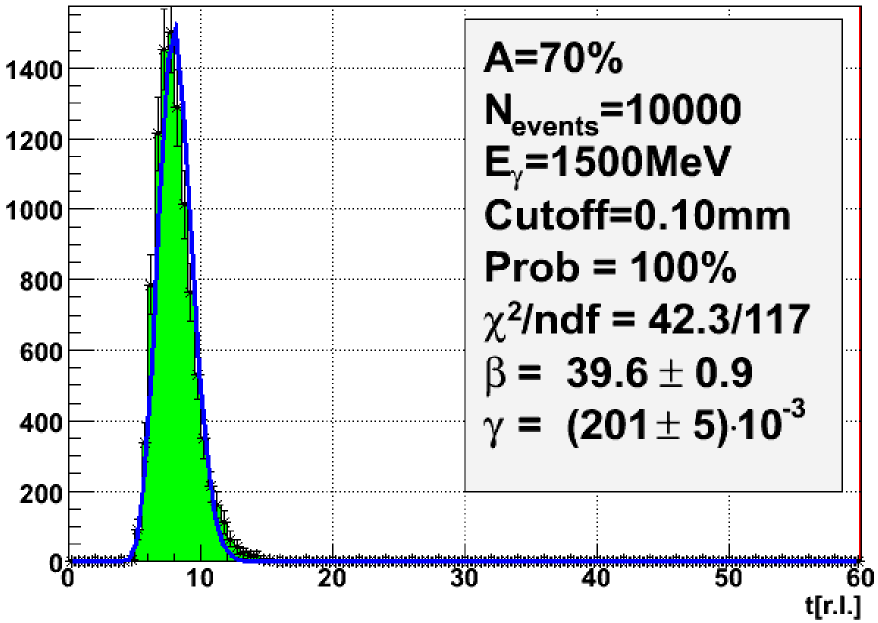


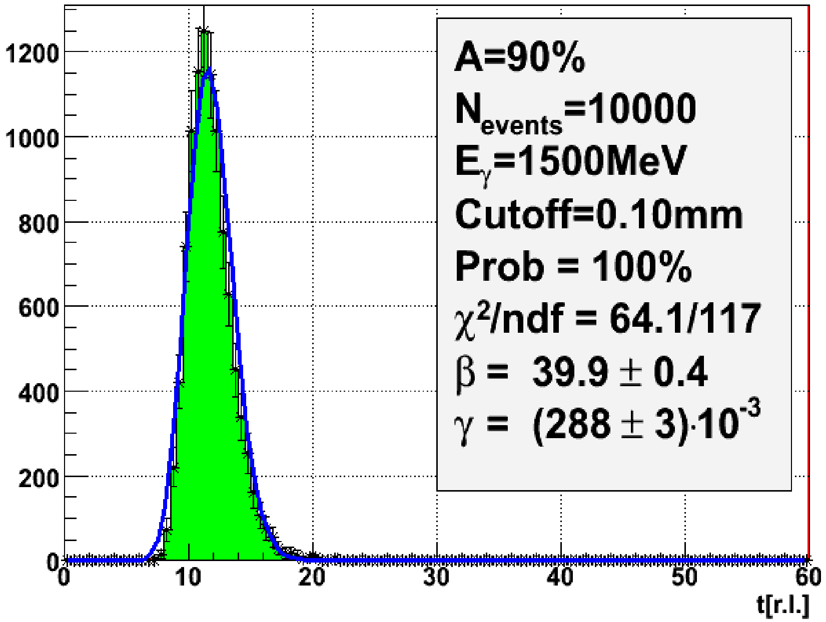


Modelled by using GEANT code in PWO

E_γ=1000MeV

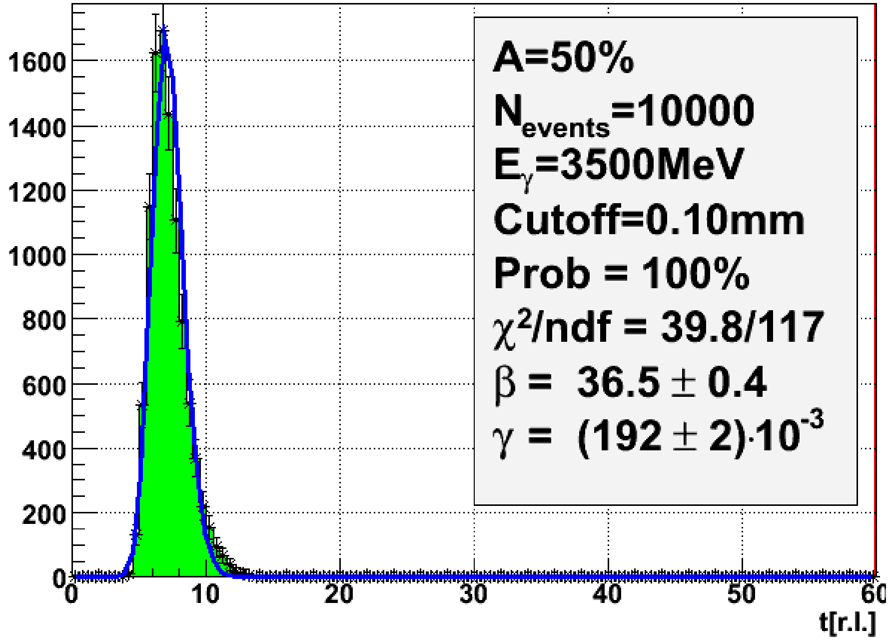


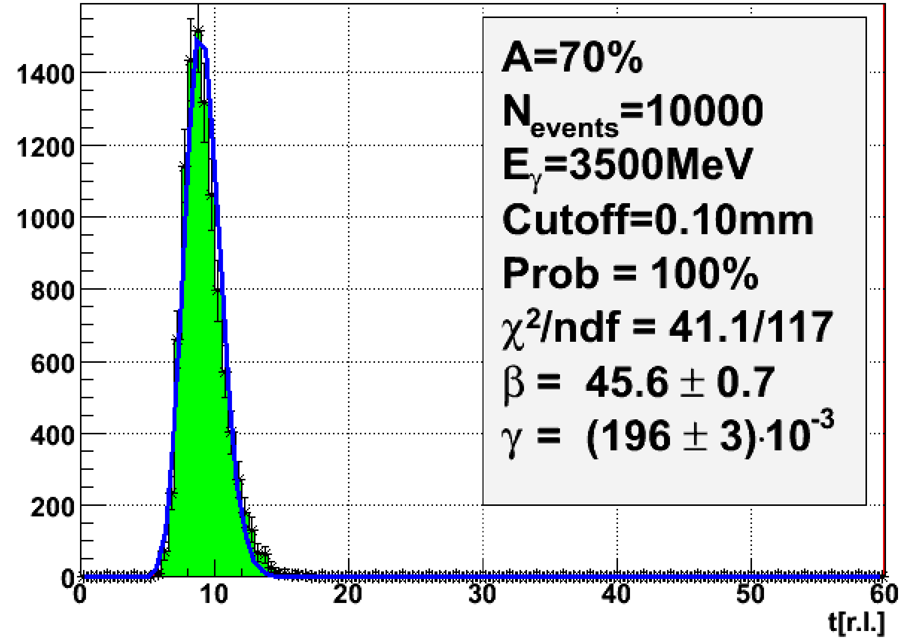


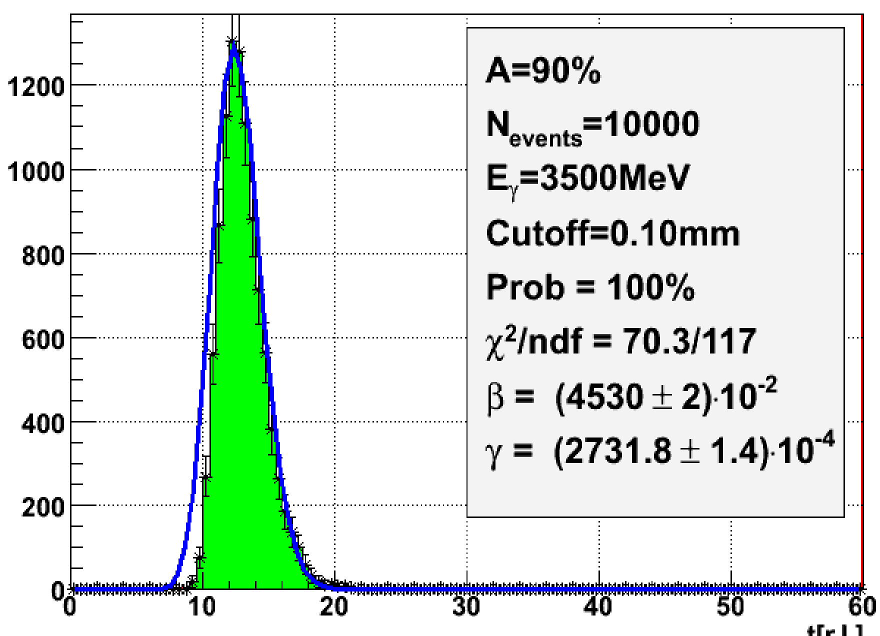


Modelled by using GEANT code in PWO

Eγ=1500MeV

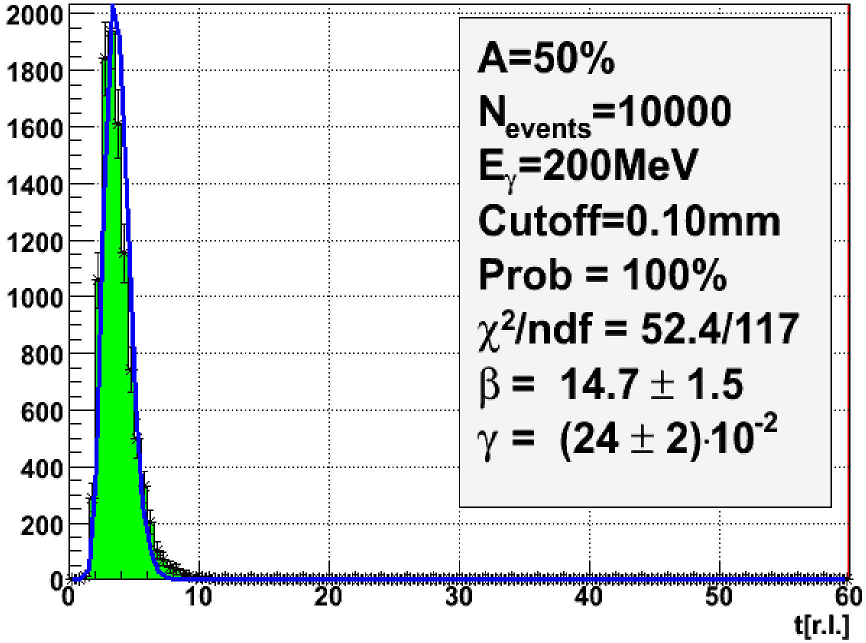


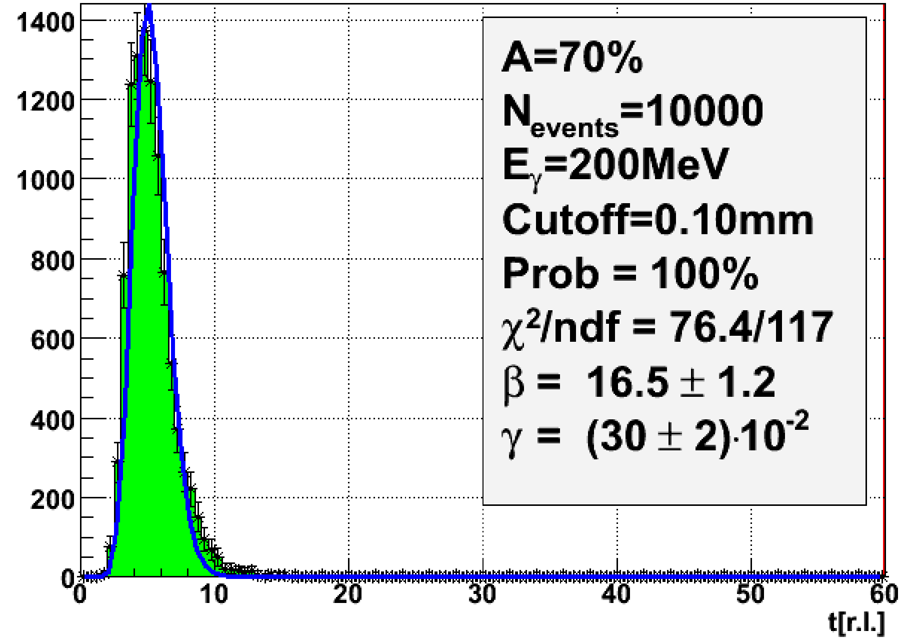


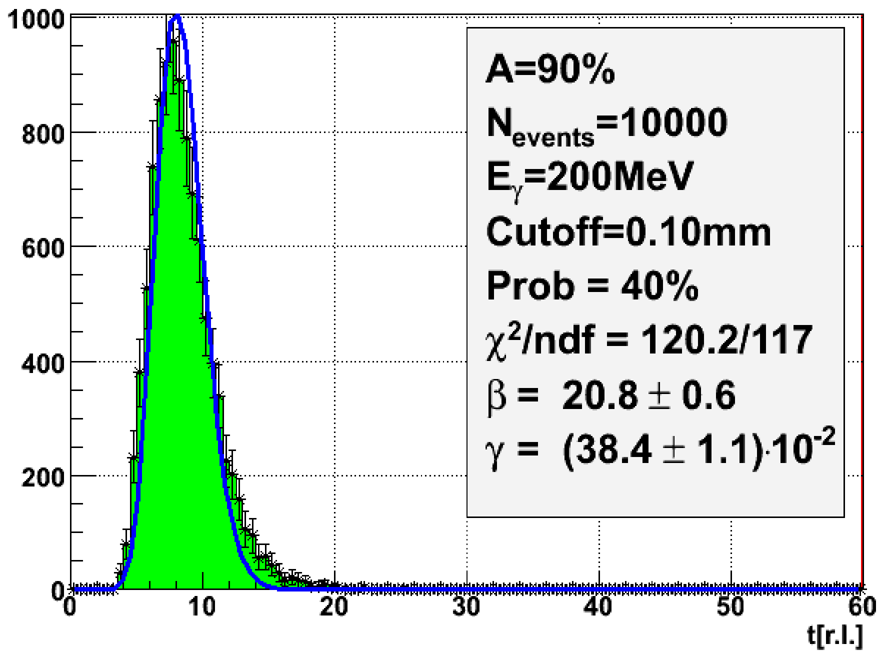


Modelled by using GEANT code in PWO

E_γ=3500MeV

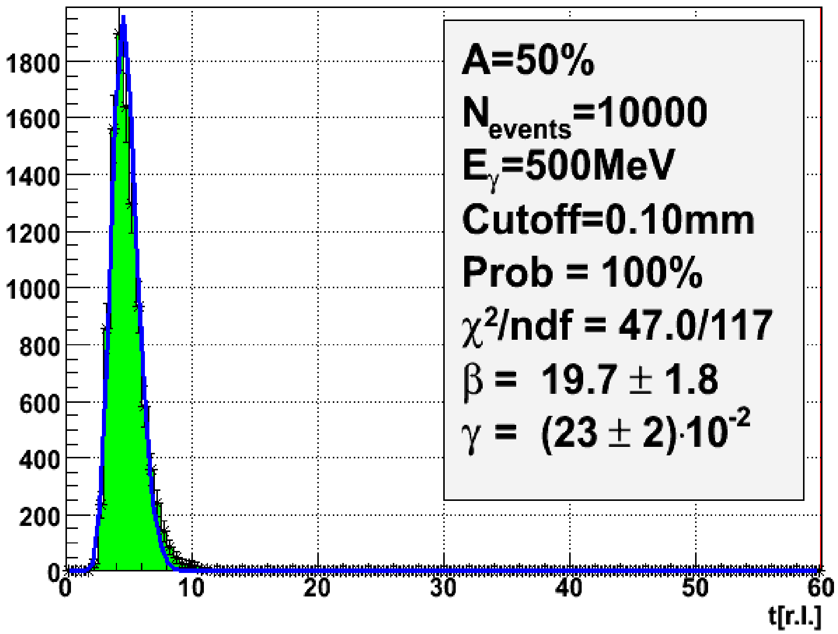


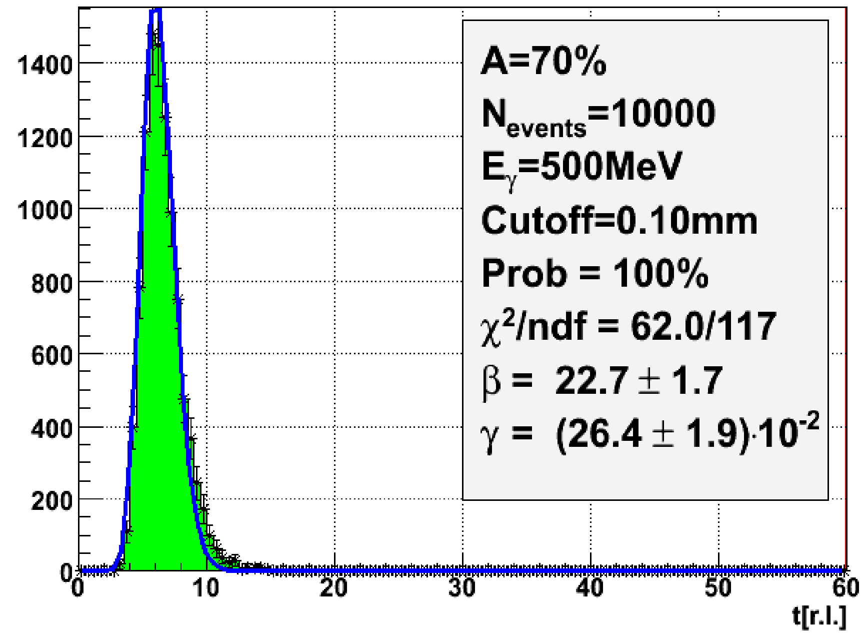


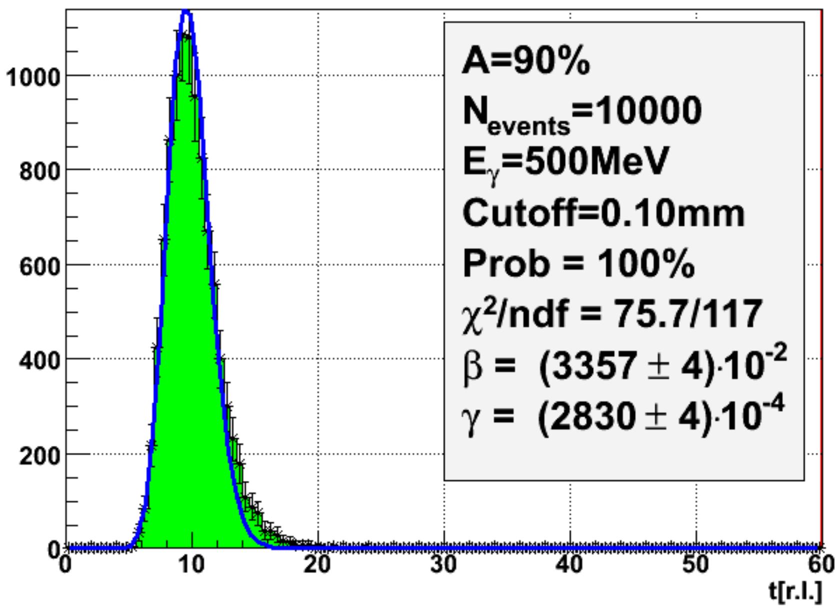


Modelled by using GEANT code in BGO

$E\gamma$=200MeV

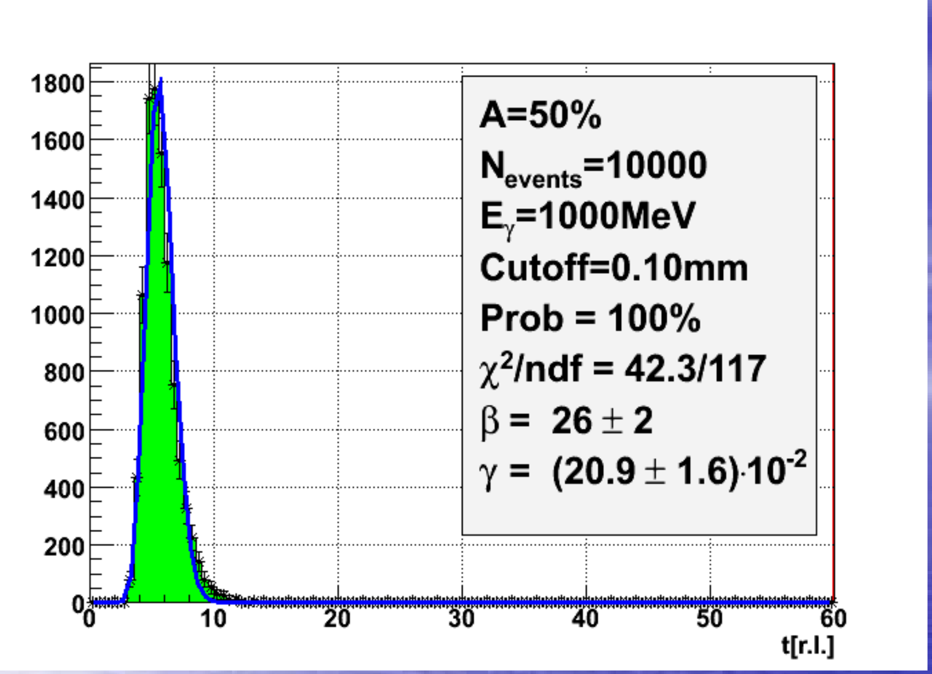


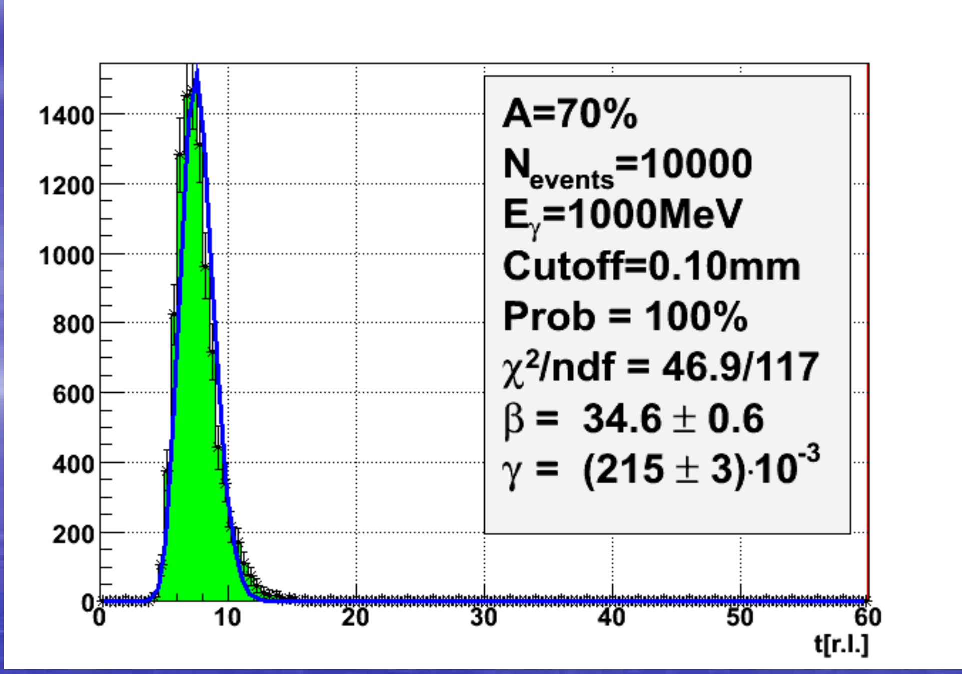


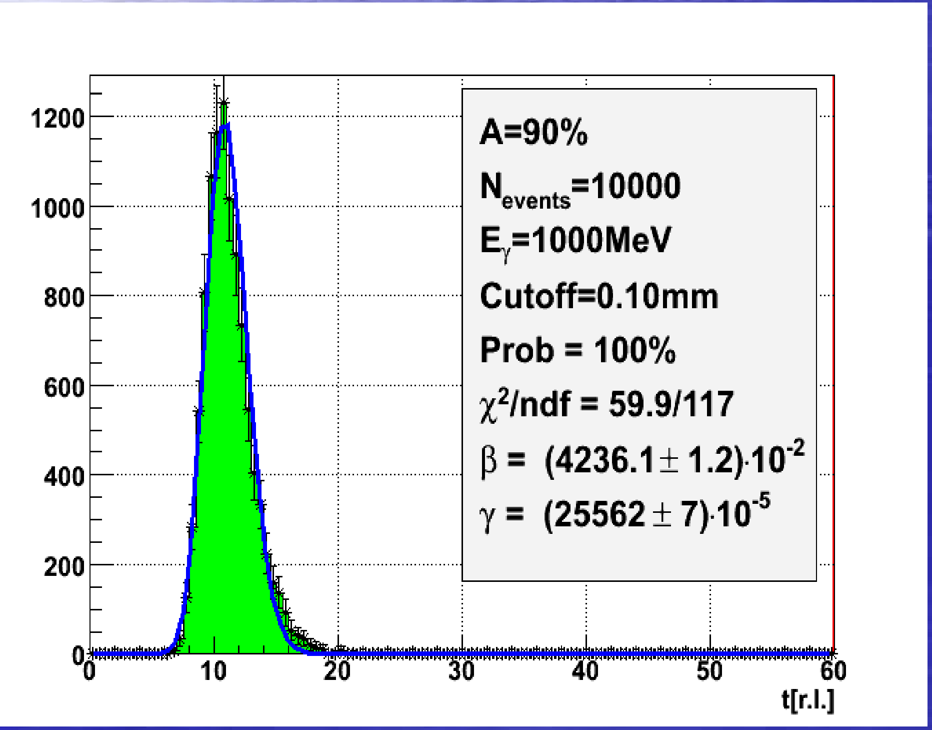


Modelled by using GEANT code in BGO

$E\gamma$=500 MeV

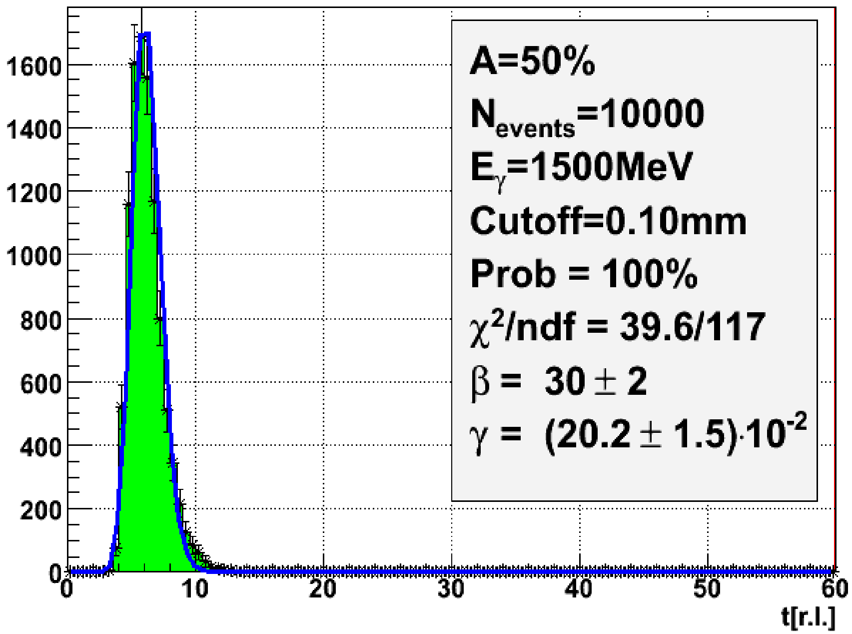


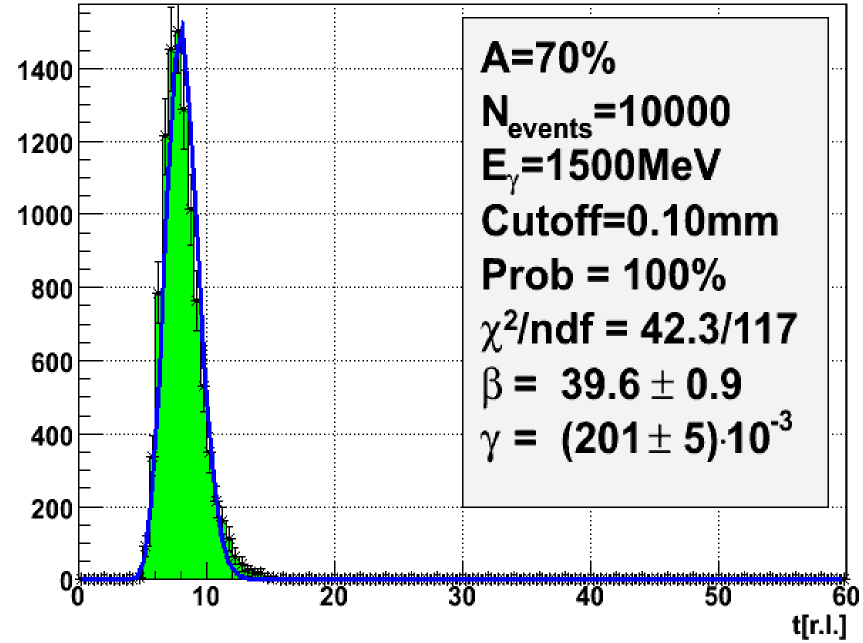


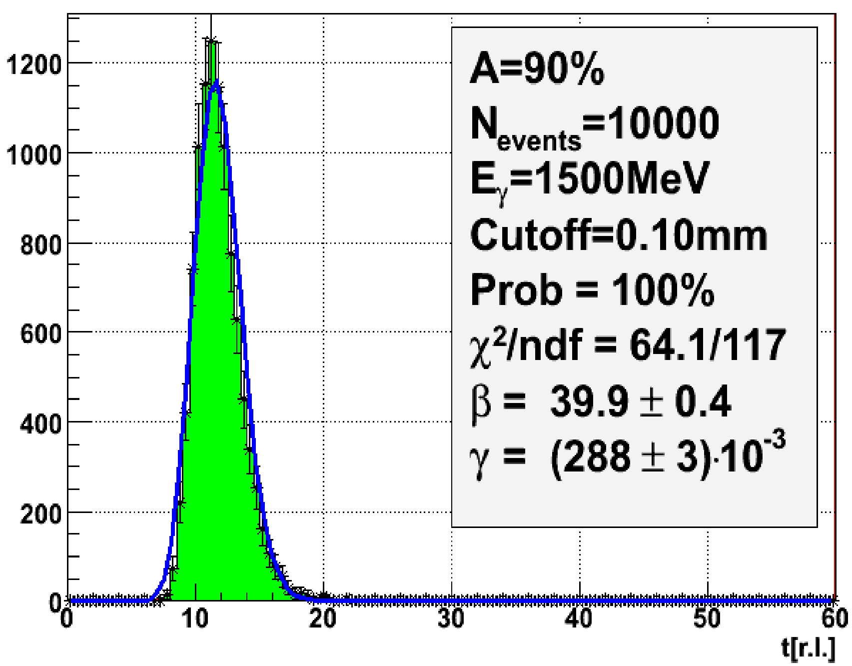


Modelled by using GEANT code in BGO

Eγ=1000 MeV

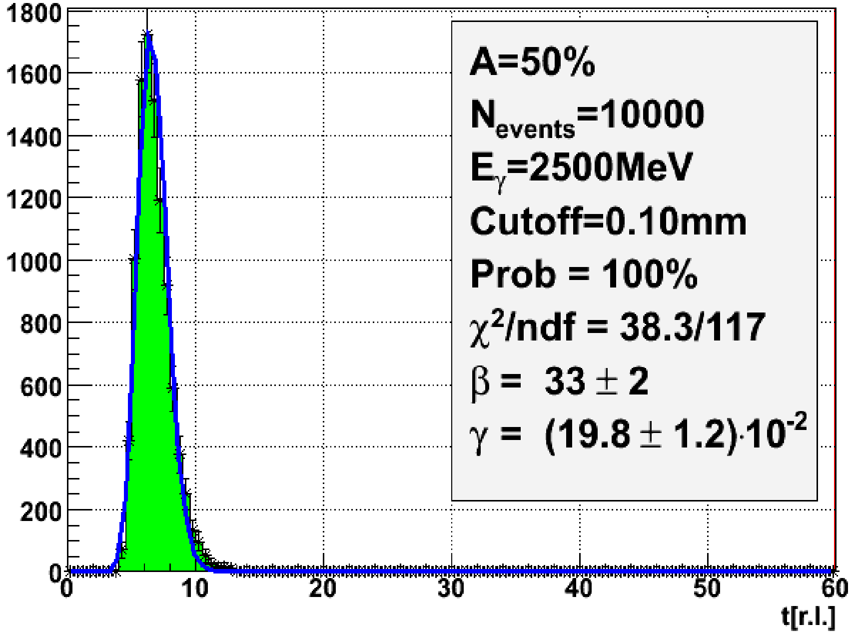


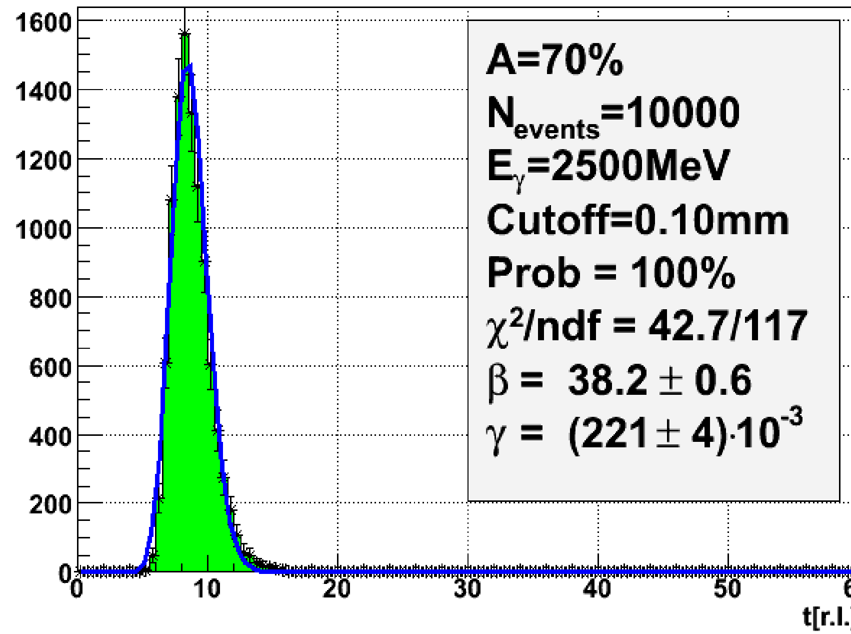


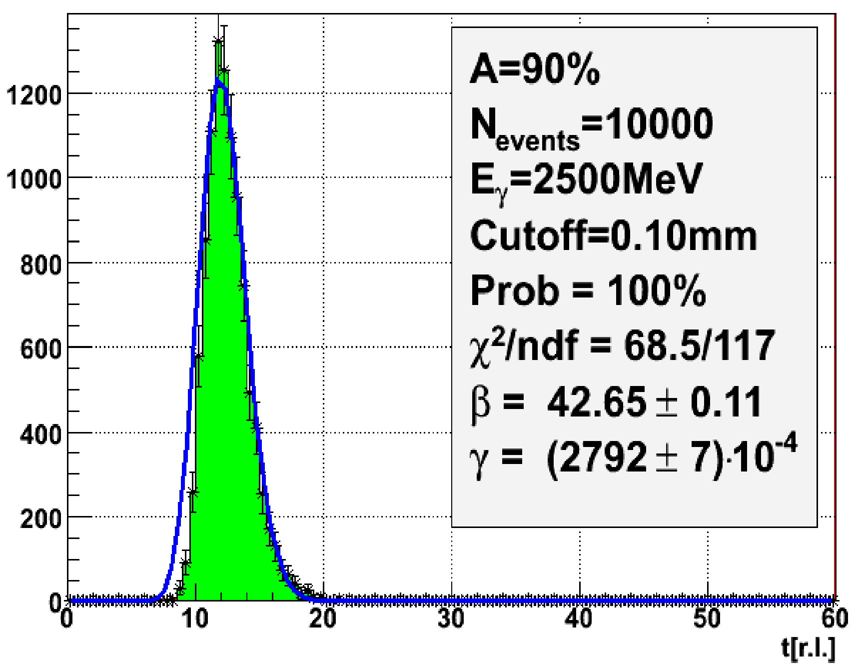


Modeled by using GEANT code in BGO

$E\gamma$=1500 MeV



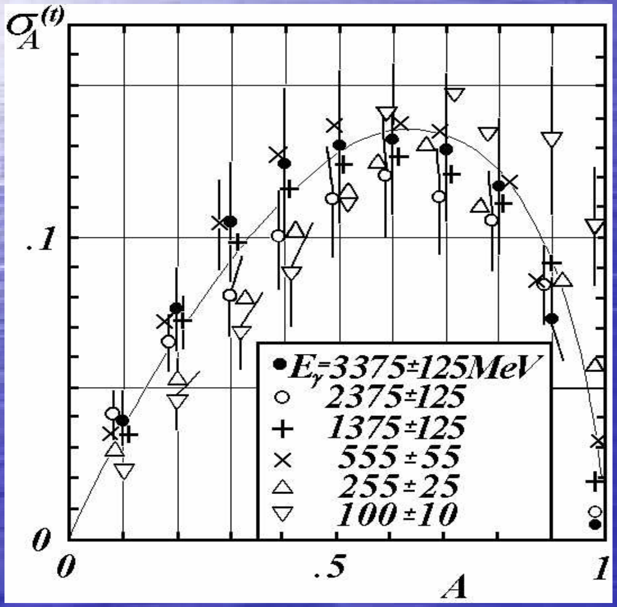




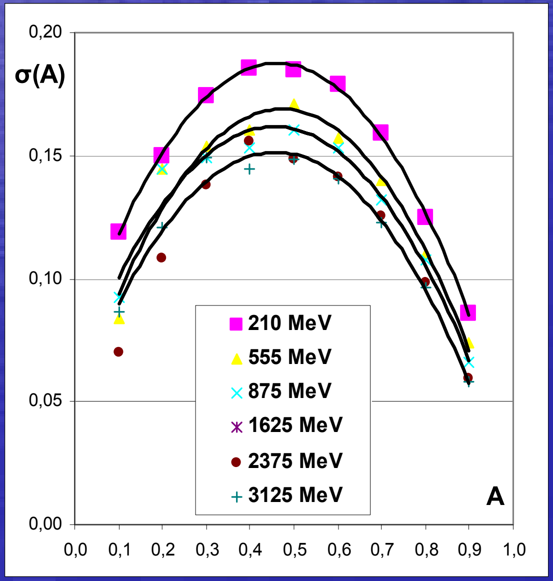
Modelled by using GEANT code in BGO

Eγ=2500 MeV

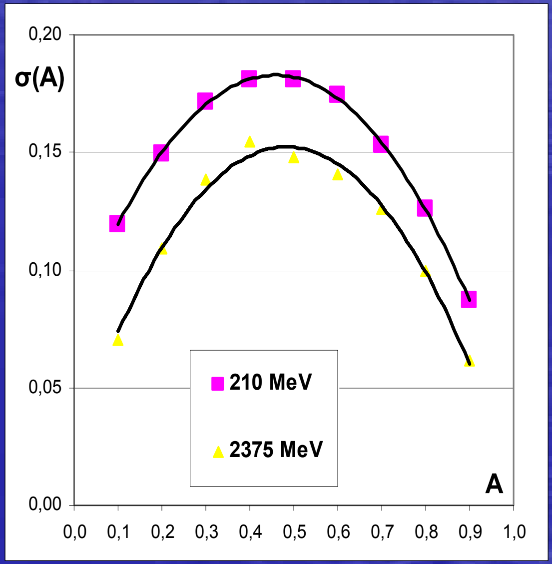
Rms dependence on the threshold A for longitudinal fluctuation in liquid xenon



Experiment

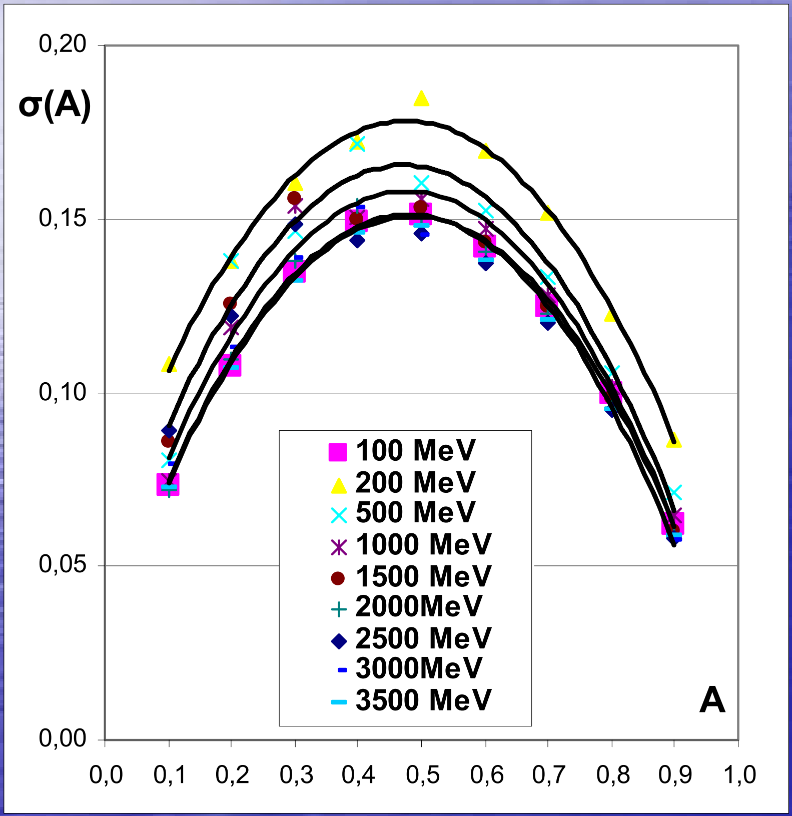


Modeling by GEANT

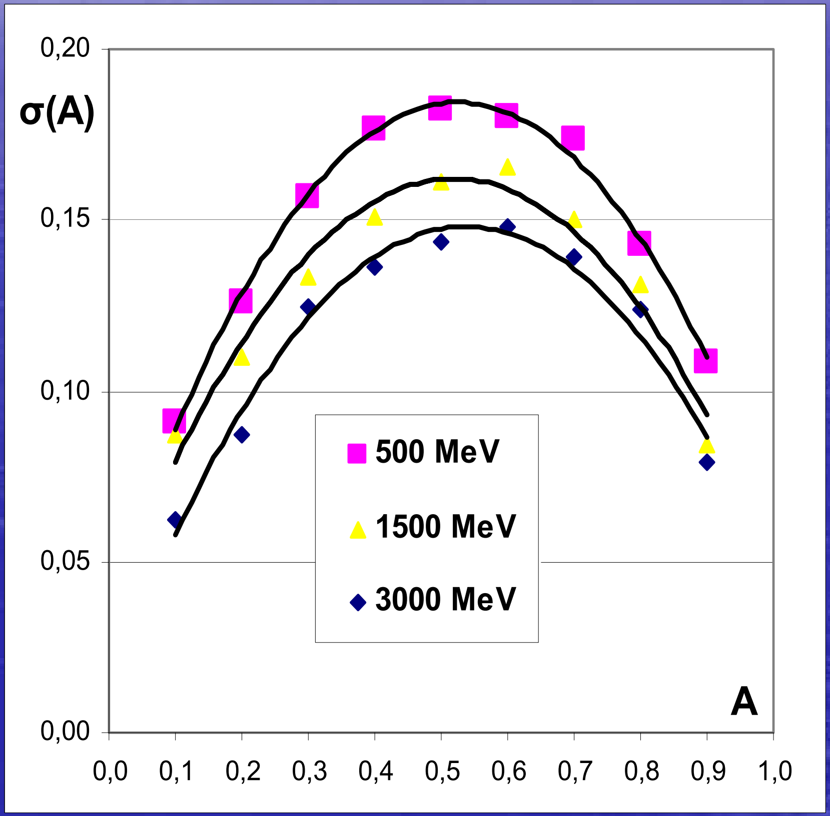


Modeling by EGS

Rms dependence on the threshold A for longitudinal fluctuation in PWO

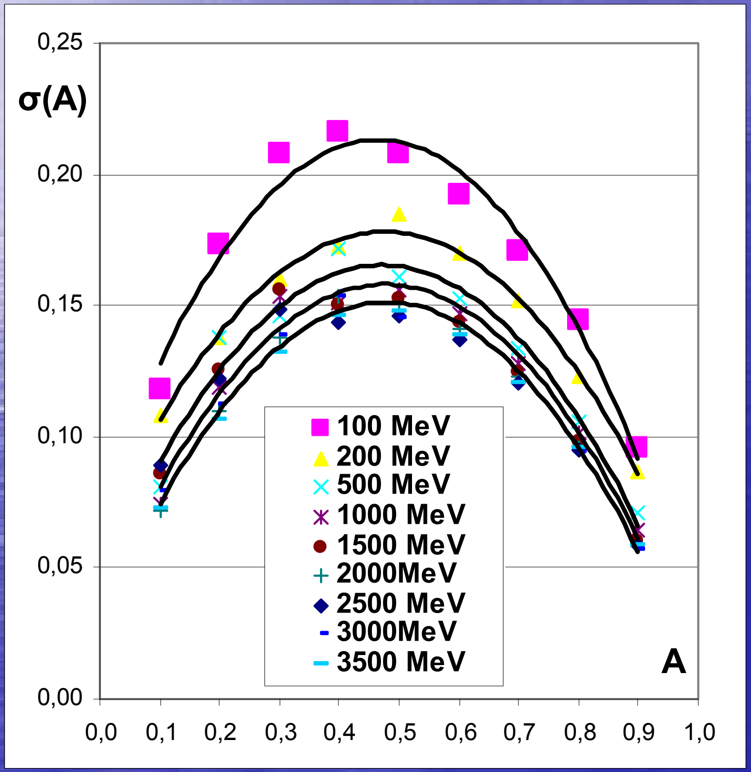


Modeling by GEANT

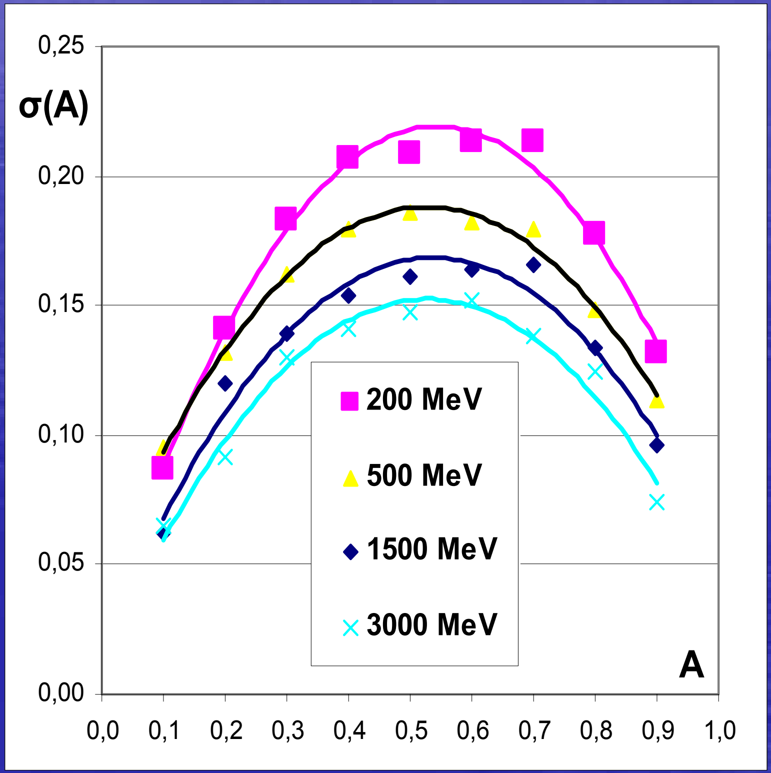


Modeling by EGS

Rms dependence on the threshold A for longitudinal fluctuation in BGO



Modeling by GEANT



Modeling by EGS

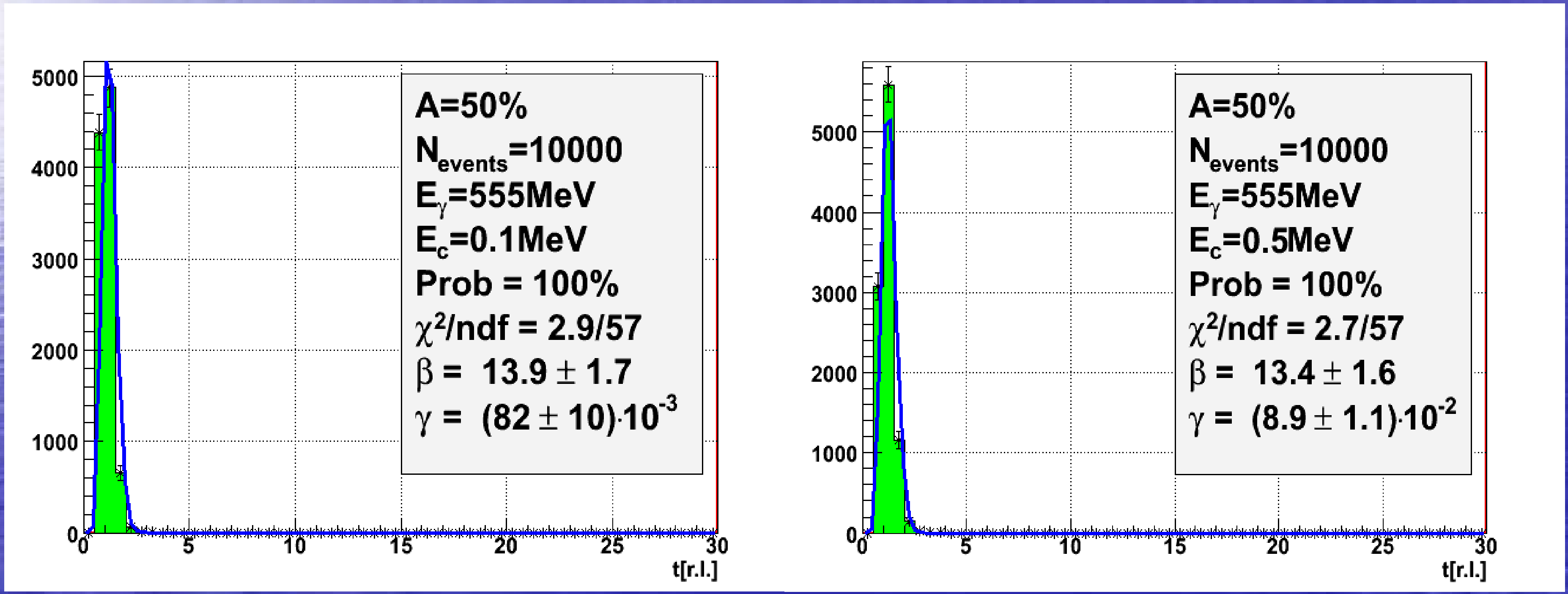
Results of modeling of EMC transverse fluctuation for liquid xenon, PWO and BGO

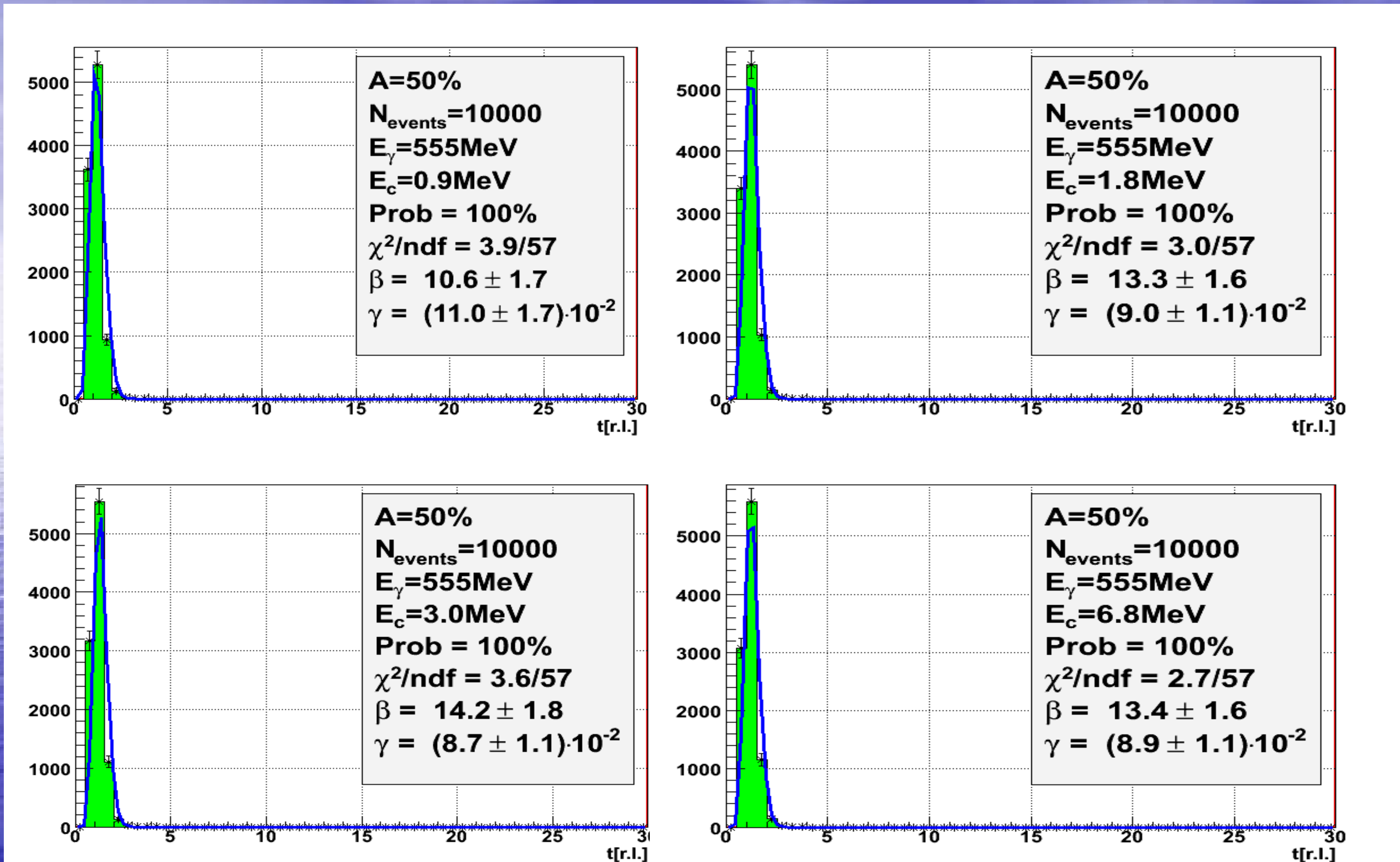
(modelled using GEANT code)

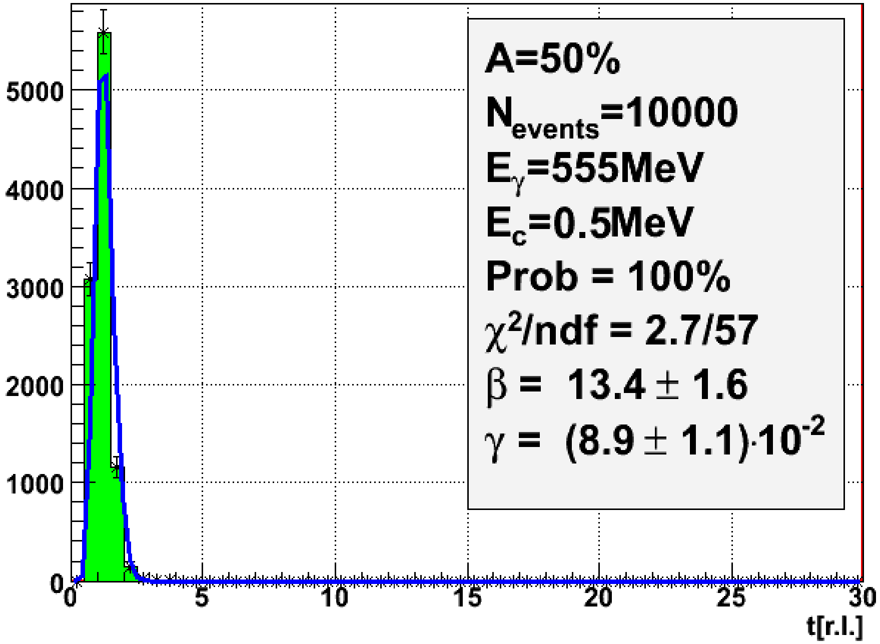
Fitting function for transwerse EMC fluctuation:

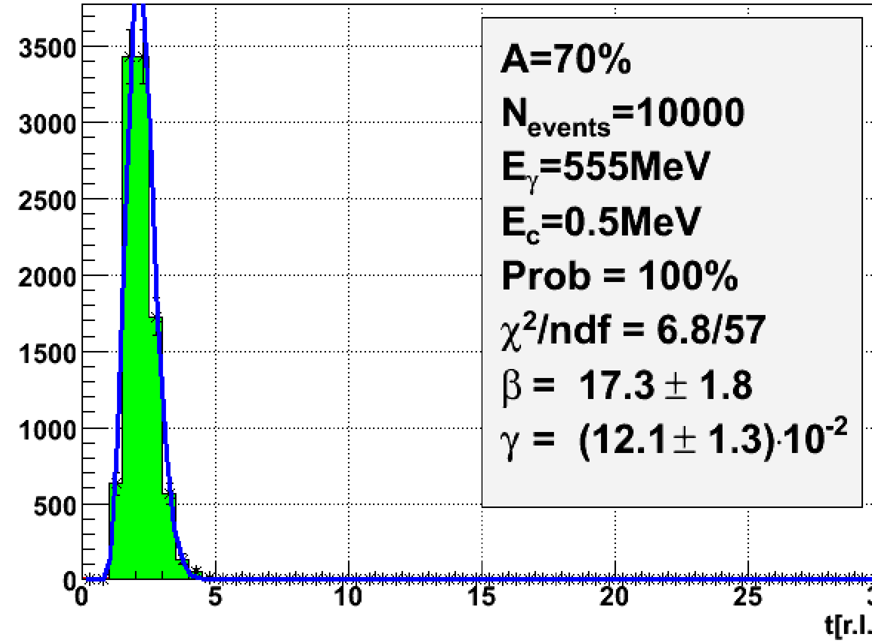
$$P(t_A) = \alpha \cdot t_A^{\ \beta} \exp(-t_A / \gamma)$$

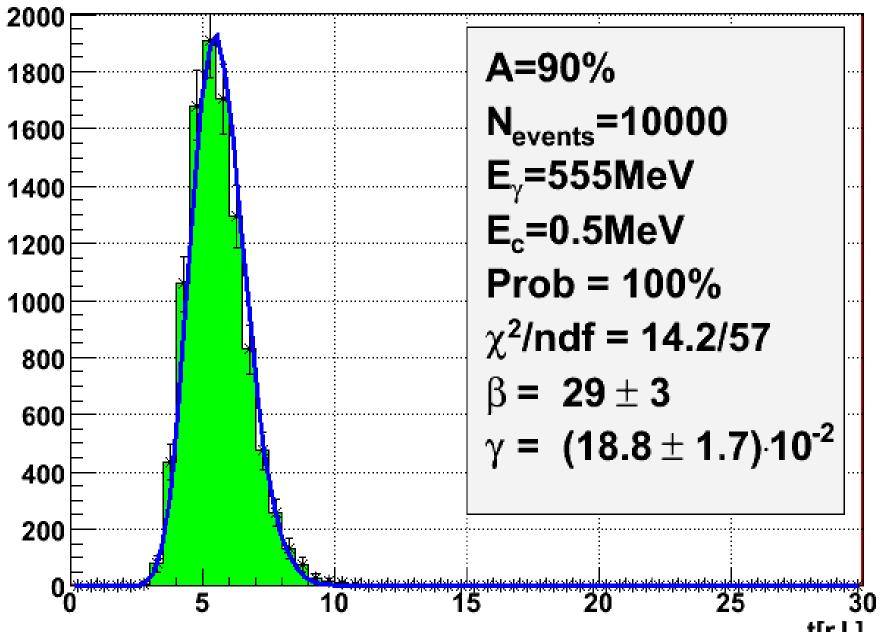
EMC in liquid Xe



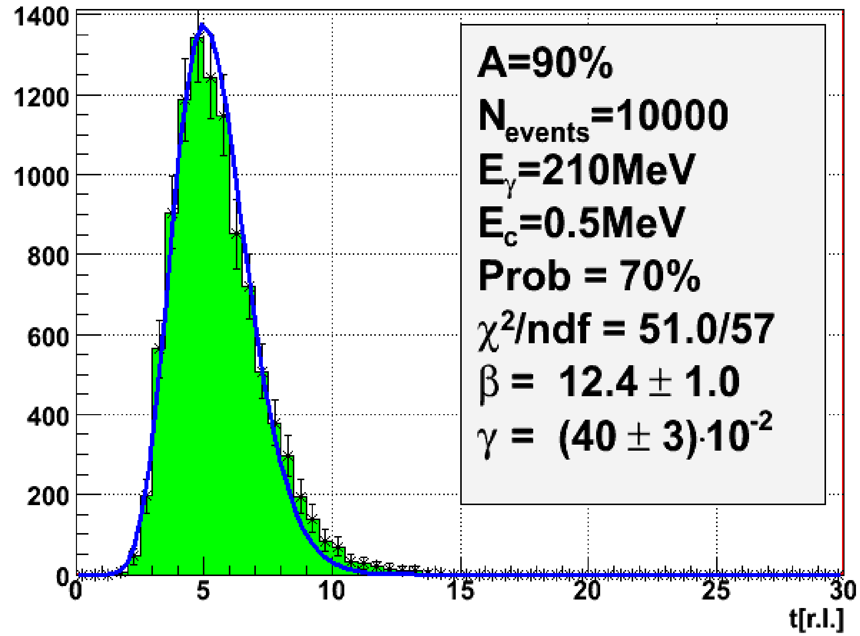

A=50%
N_events=10000
E_γ=555MeV
E_c=0.9MeV
Prob = 100%
χ²/ndf = 3.9/57
β = 10.6 ± 1.7
γ = (11.0 ± 1.7)·10⁻²
t[r.l.]
A=50%
N_events=10000
E_γ=555MeV
E_c=1.8MeV
Prob = 100%
χ²/ndf = 3.0/57
β = 13.3 ± 1.6
γ = (9.0 ± 1.1)·10⁻²
t[r.l.]
A=50%
N_events=10000
E_γ=555MeV
E_c=3.0MeV
Prob = 100%
χ²/ndf = 3.6/57
β = 14.2 ± 1.8
γ = (8.7 ± 1.1)·10⁻²
t[r.l.]
A=50%
N_events=10000
E_γ=555MeV
E_c=6.8MeV
Prob = 100%
χ²/ndf = 2.7/57
β = 13.4 ± 1.6
γ = (8.9 ± 1.1)·10⁻²
t[r.l.]







Modelled by using GEANT code in liquid xenon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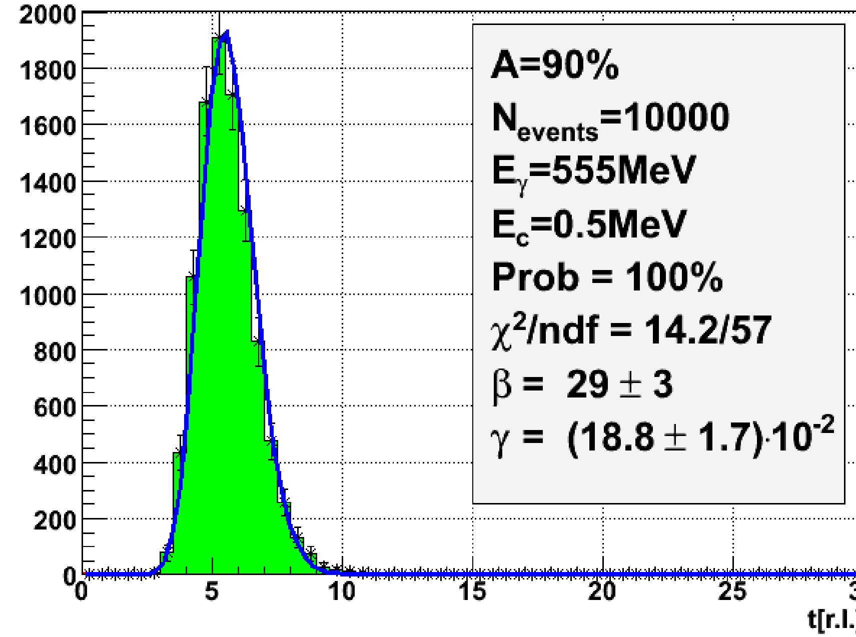
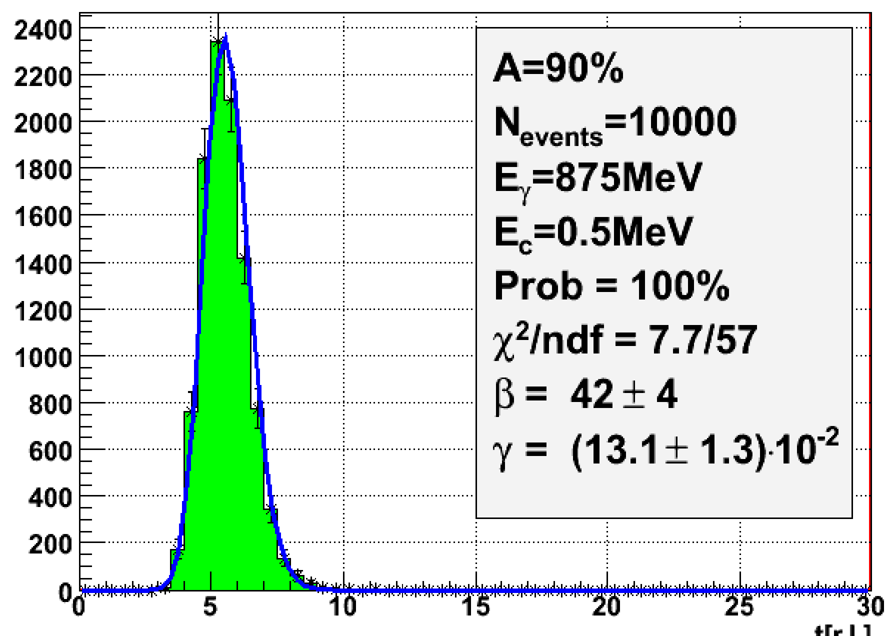
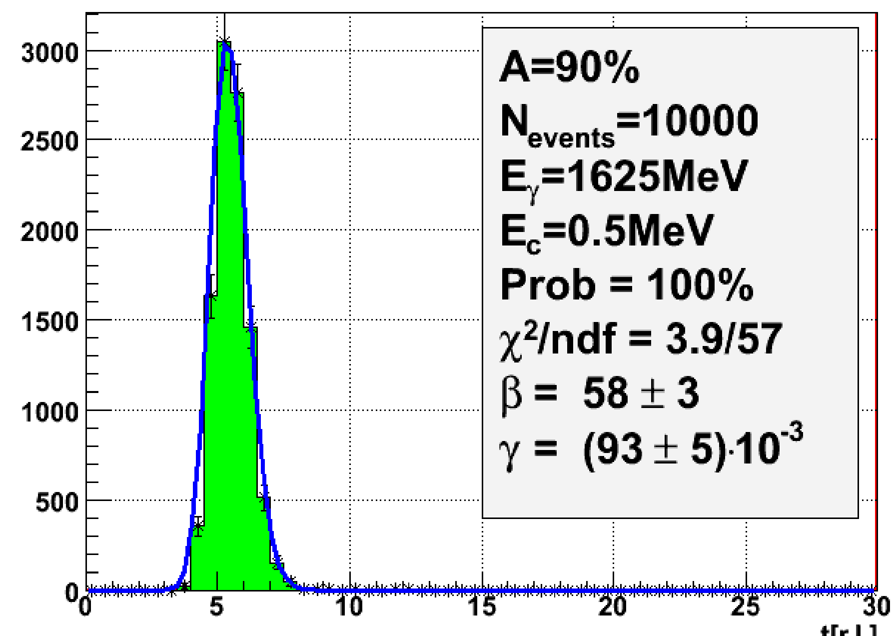
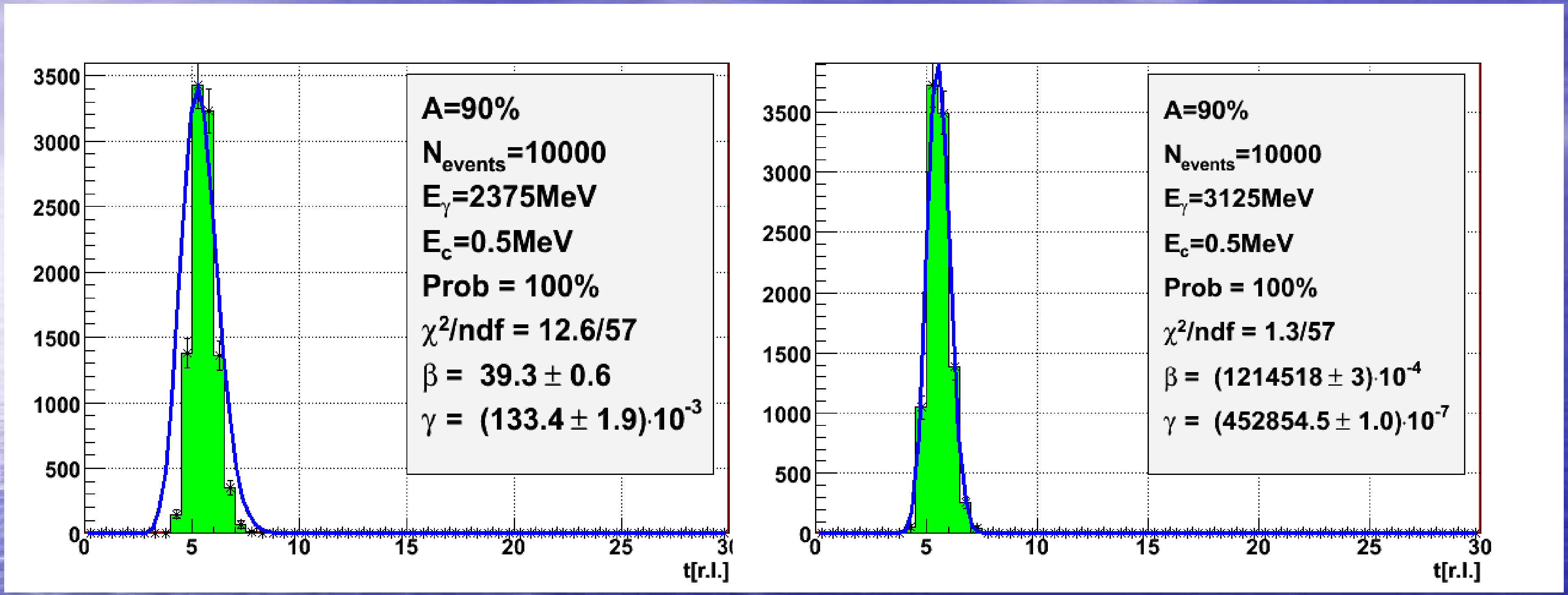
N_events=10000
E_γ=210MeV
E_c=0.5MeV
Prob = 70%
χ²/ndf = 51.0/57
β = 12.4 ± 1.0
γ = (40 ± 3)·10^-2
t[r.l.]


A=90%
N_events=10000
E_γ=555MeV
E_c=0.5MeV
Prob = 100%
χ²/ndf = 14.2/57
β = 29 ± 3
γ = (18.8 ± 1.7)·10^-2
t[r.l.]


A=90%
N_events=10000
E_γ=875MeV
E_c=0.5MeV
Prob = 100%
χ²/ndf = 7.7/57
β = 42 ± 4
γ = (13.1 ± 1.3)·10^-2
t[r.l.]


A=90%
N_events=10000
E_γ=1625MeV
E_c=0.5MeV
Prob = 100%
χ²/ndf = 3.9/57
β = 58 ± 3
γ = (93 ± 5)·10^-3
t[r.l.]

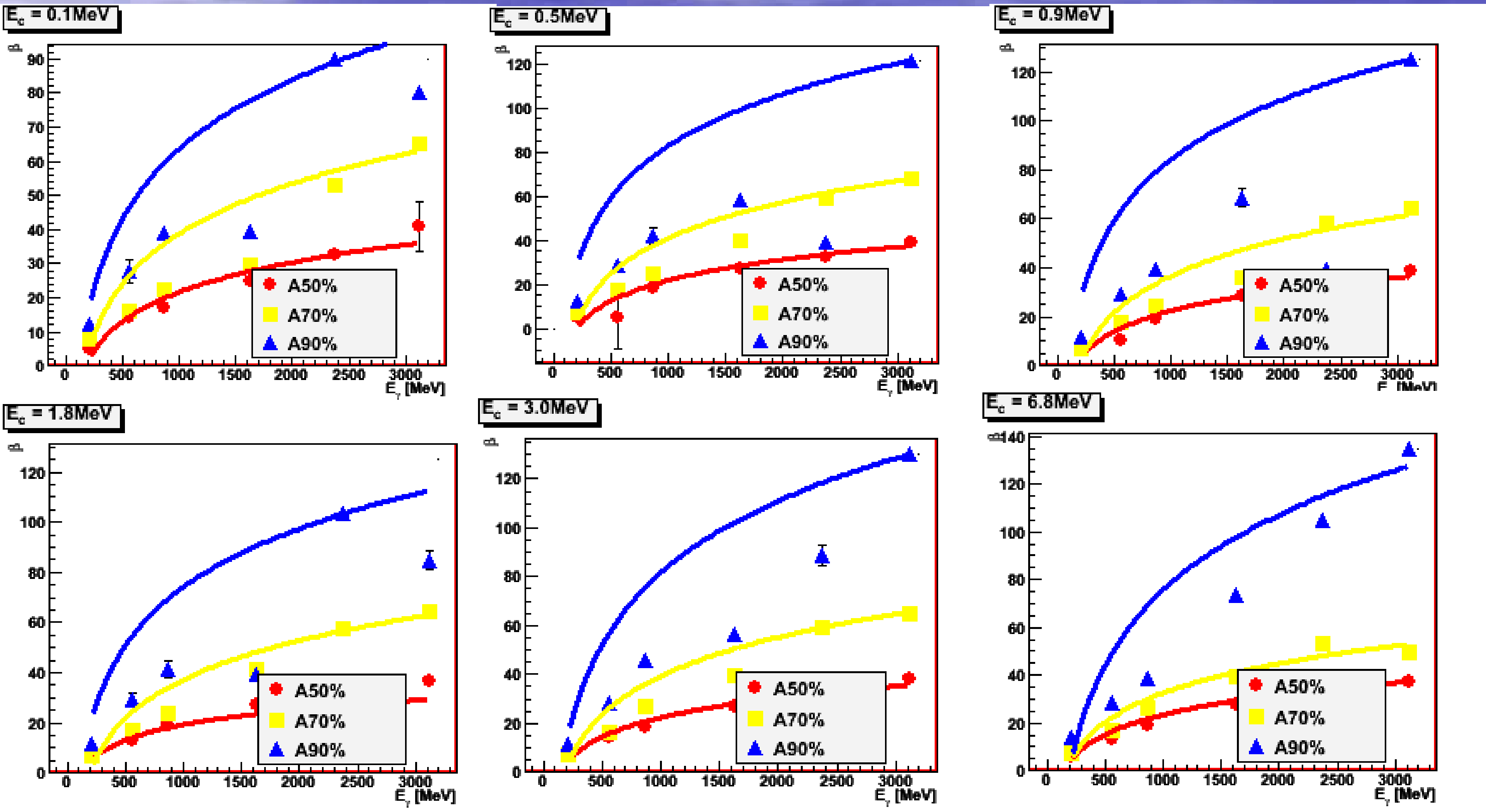


Modelled by using GEANT code in liquid xenon

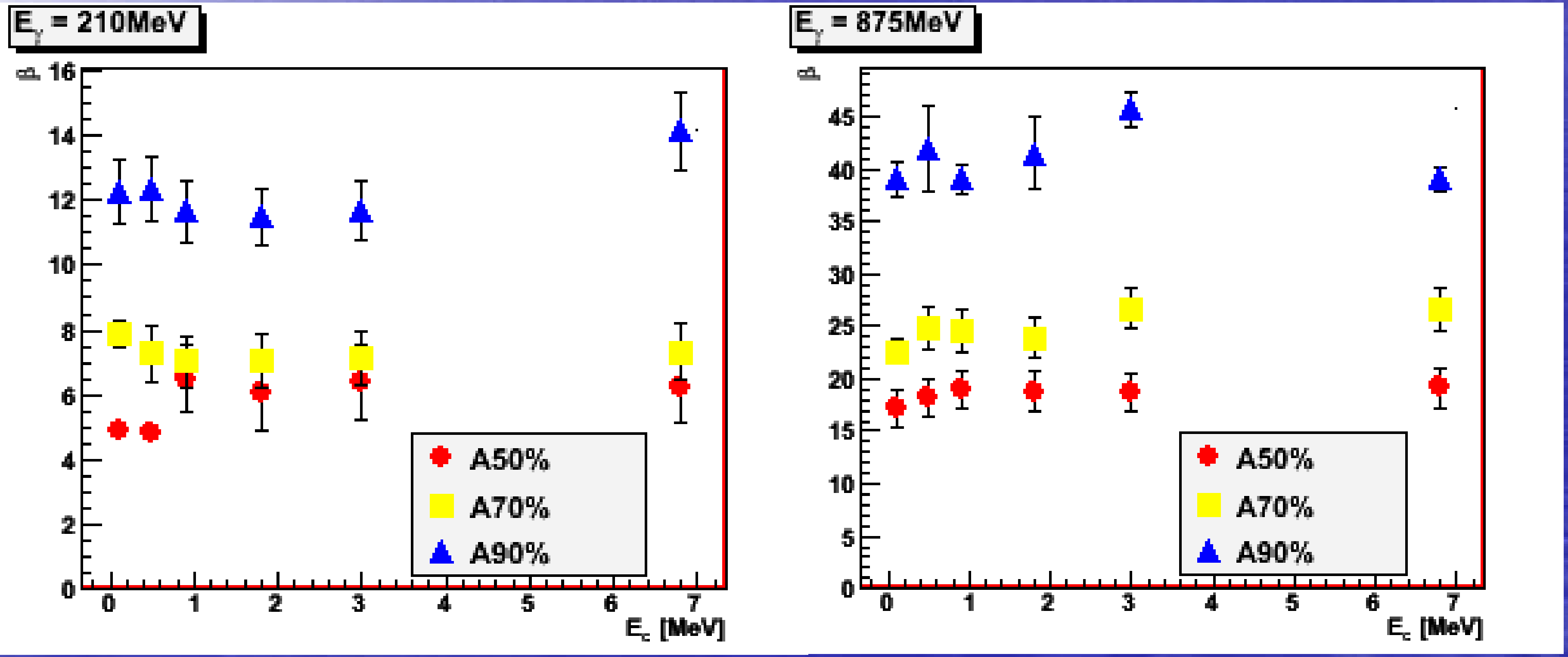
Energy dependence of fitting function parameters β and γ

$$P(t_A) = \alpha \cdot t_A^{\beta} \exp(-t_A / \gamma)$$

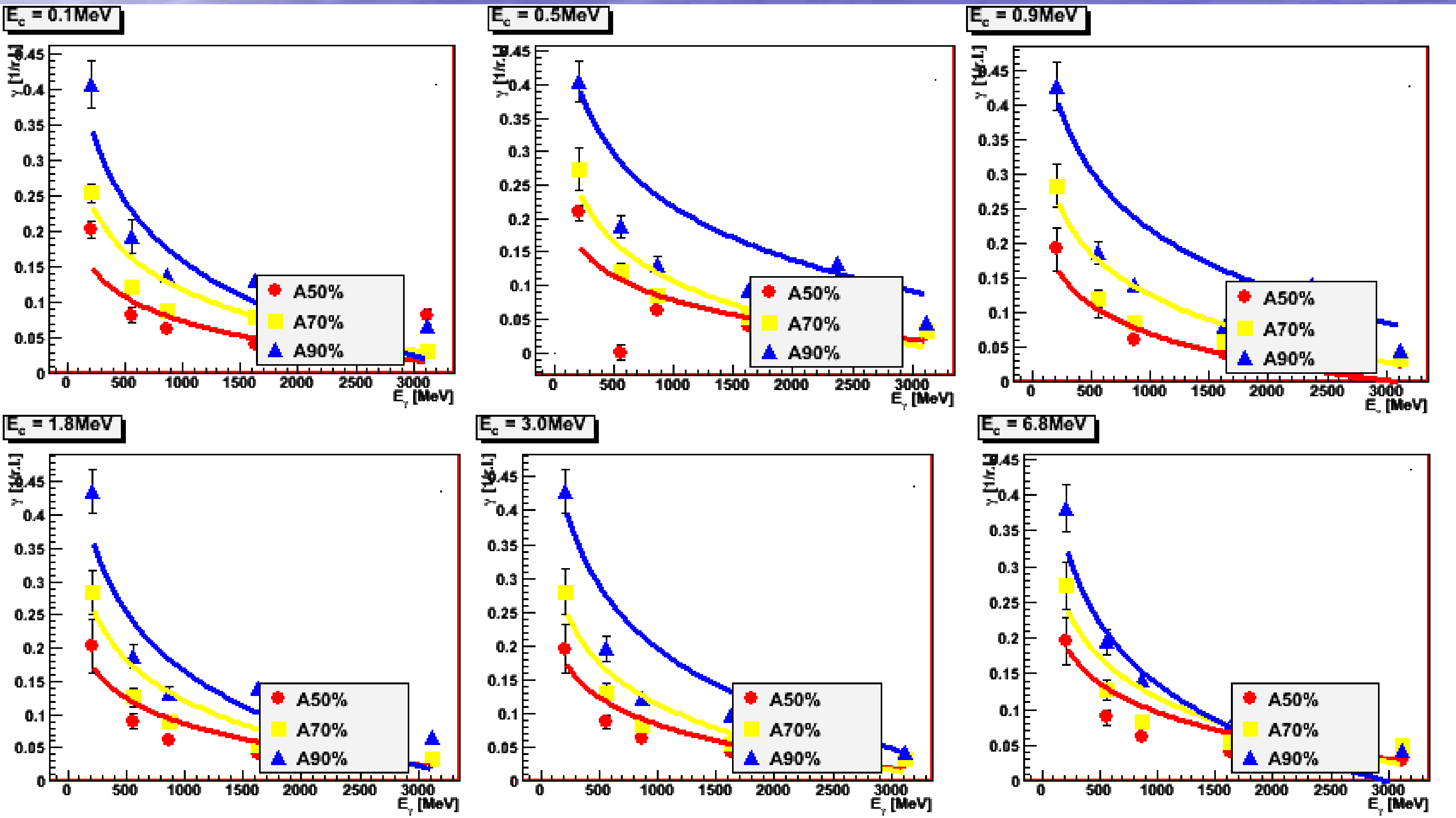
Energy dependence of the parameter β for liquid xenon at different cut-off energy E_c and threshold A.



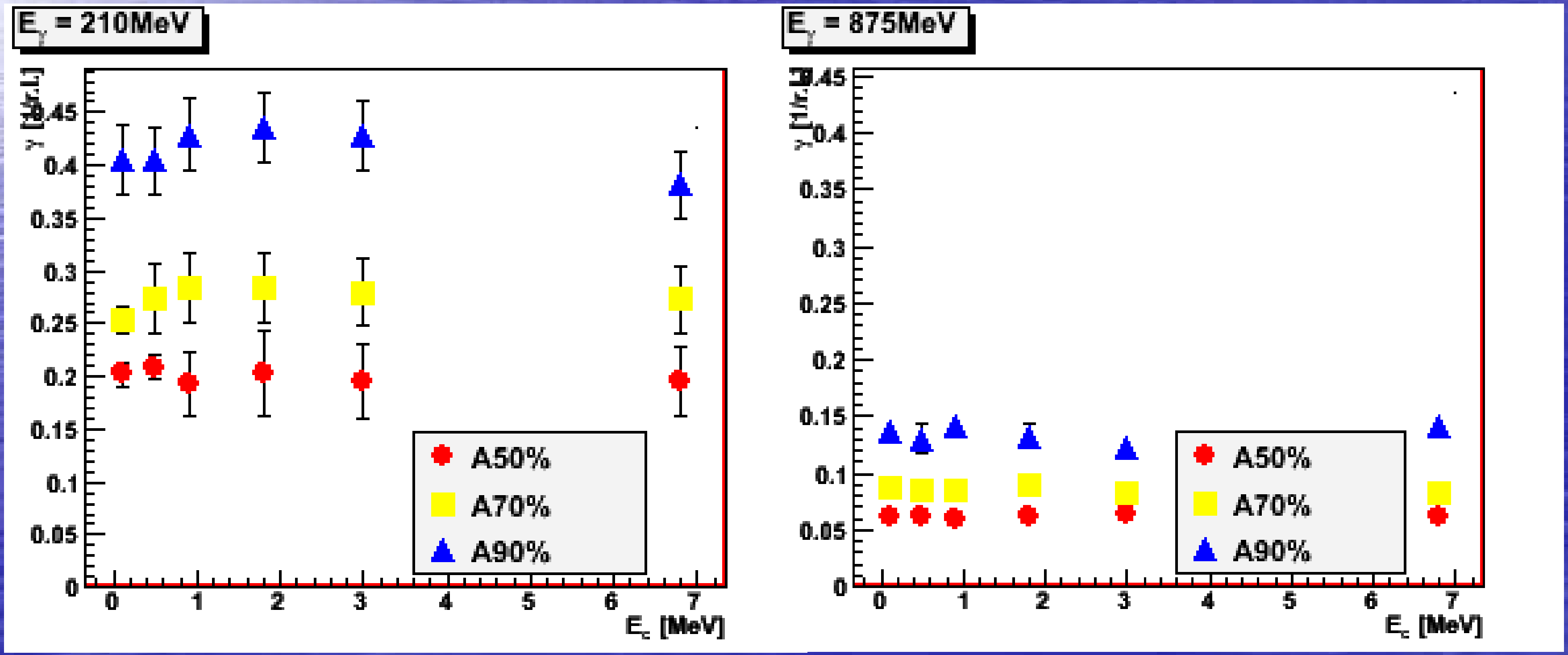
Cut-off energy E_c dependence of the parameter β for liquid xenon at different thresholds A and gamma quanta energy E_γ.



Energy dependence of the parameter γ for liquid xenon at different cut-off energy E_c and threshold A.



Cut-off energy Ec dependence of the parameter γ for liquid xenon at different thresholds A and gamma quanta energy Eγ.

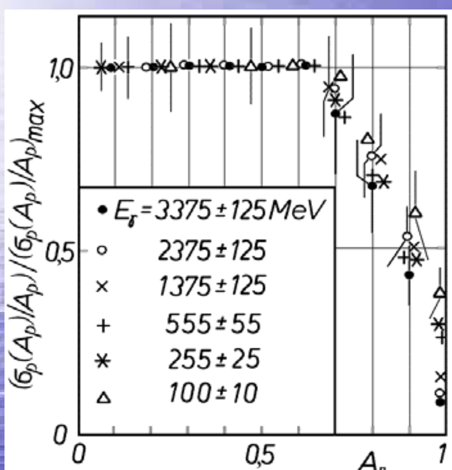


Parameterization on energy E_γ of paraters β and γ for trensverse fluctuation in liquid xenon at different thresholds A

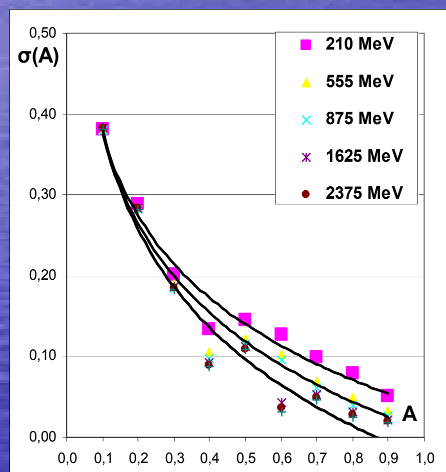
$$p(E_\gamma) = a_p \ln(E_\gamma) - b_p$$

E_c 0.5 MeV						
	A	a	Дa	b	Дb	ч^2/n
в	A50%	13,634	0,023	-72	22	291.0/5
в	A70%	23,603	0,000	-122	37	129.6/5
в	A90%	34,026	0,000	-152	46	18274.0/5
г	A50%	-0,033	0,010	0,454	0,002	12.6/5
г	A70%	-0,044	0,013	0,528	0,008	831.3/5
г	A90%	-0,105	0,031	1,081	0,005	179245.9/5

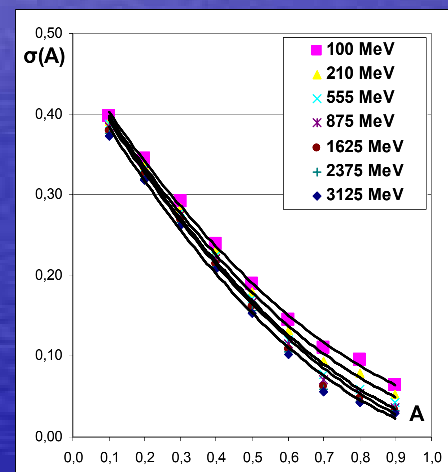
Rms dependence on the threshold A for transverse fluctuation in liquid xenon



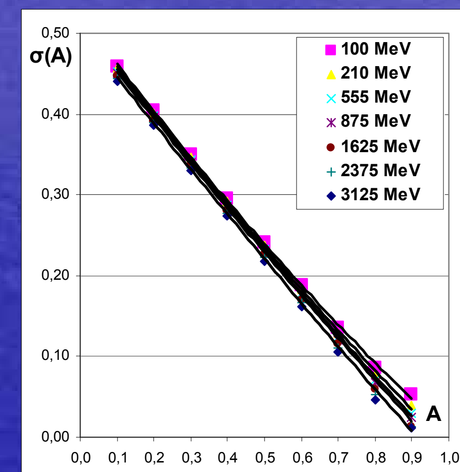
Experiment for plane projected tracks



Modeling by Geant for radial tracks distribution

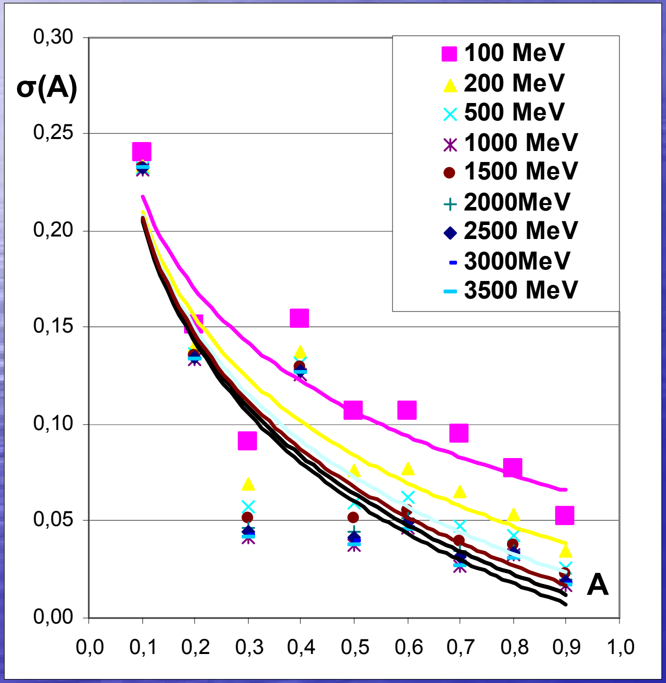


Modeling by Geant for radial tracks distribution

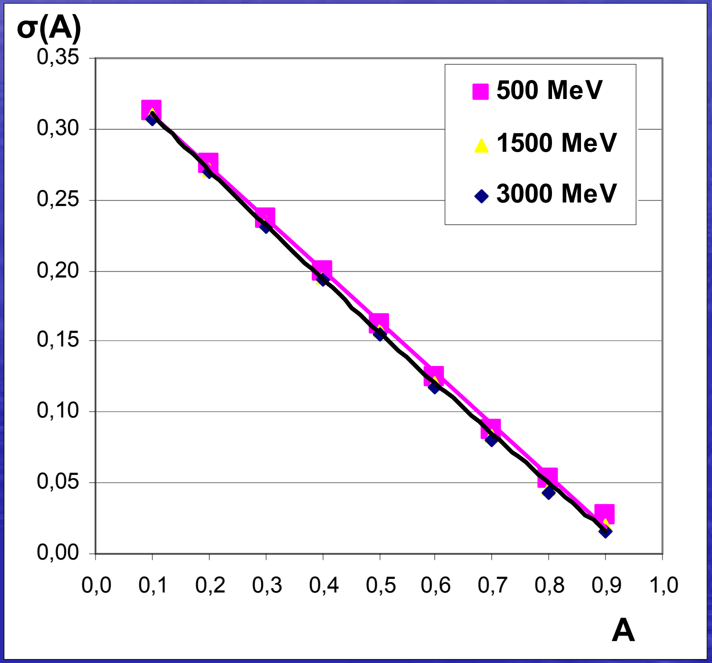


Modeling by EGS for plane projected tracks

Rms dependence on the threshold A for transverse fluctuation in PWO

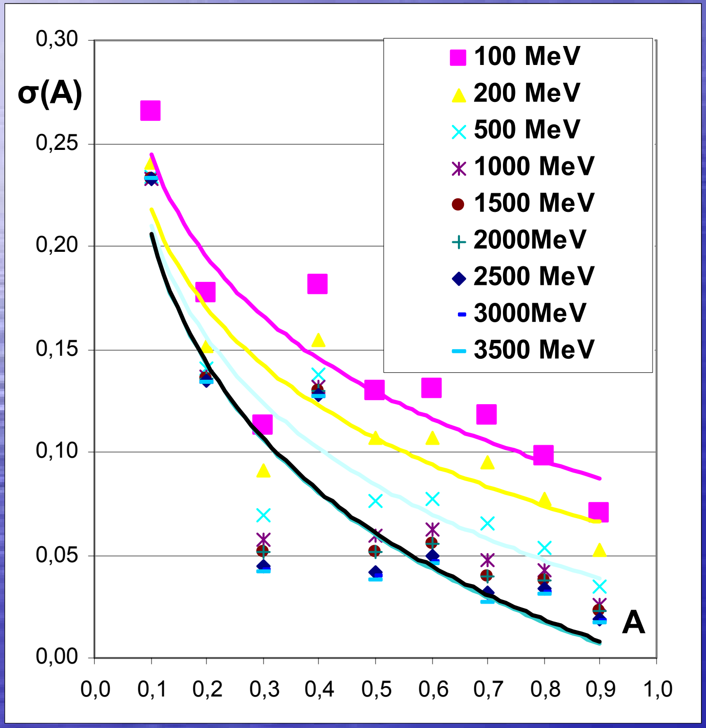


Modeling by Geant for radial tracks distribution

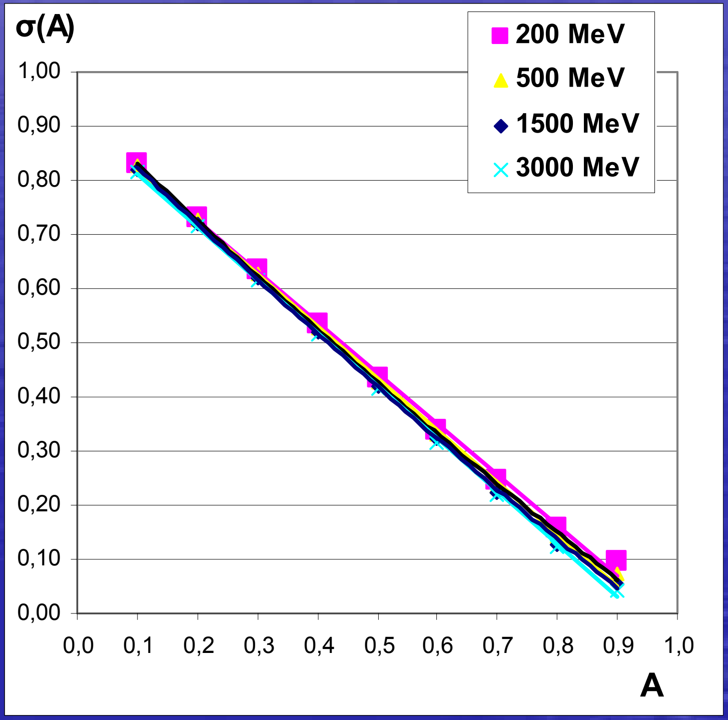


Modeling by EGS for plane projected tracks

Rms dependence on the threshold A for transverse fluctuation in BGO



Modeling by Geant for radial tracks distribution



Modeling by EGS for plane projected tracks

SUMMARY AND CONCLUSION

▲ The comprehensive analysis of longitudinal and lateral profiles of EMC initiated in: liquid xenon,PWO and BGO by qamma quanta of energy from 100 MeV up to 3500 MeV has been performed by using GEANT4 and EGS code at several values of cut-off energy beetwen 0.1 and 6.8 MeV, and three values of theshold depths at which an average energy loss equals A= 0.5, 0.7 and 0.9.

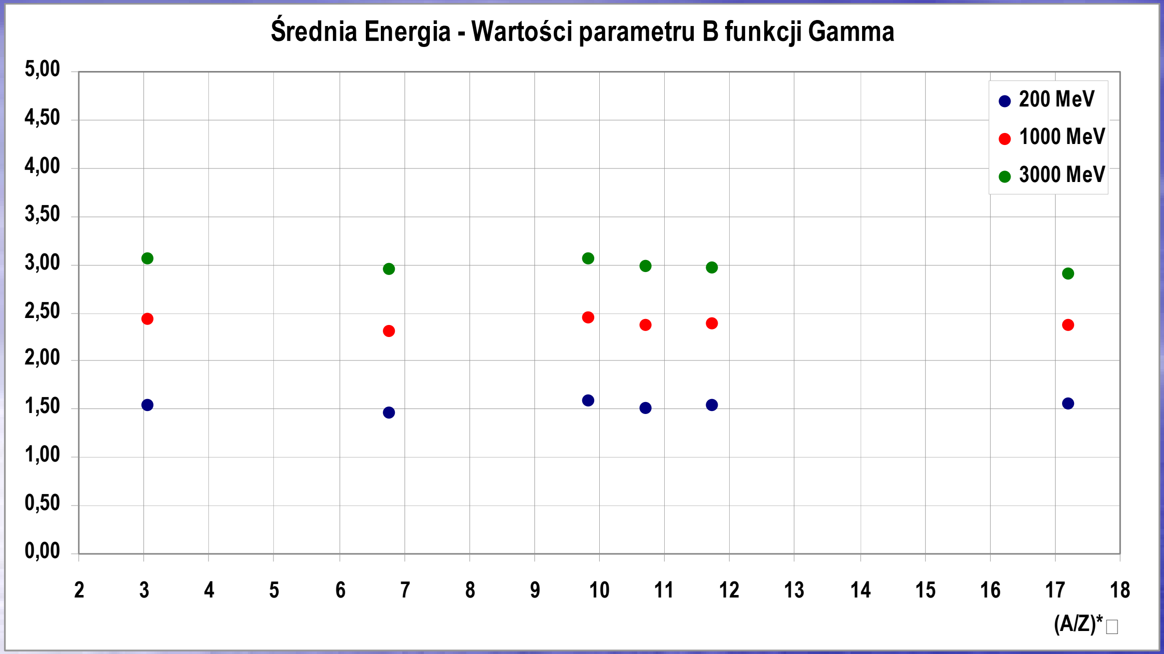
▲ **It was shown that there exists the possibility to describe such basic differential characteristics as the cascade's profiles and fluctuations in a simple concise analytic form.**

▲ The work aiming to describe the material dependence of the basic cascades characteristics is **in progress**.

THANK YOU

FOR

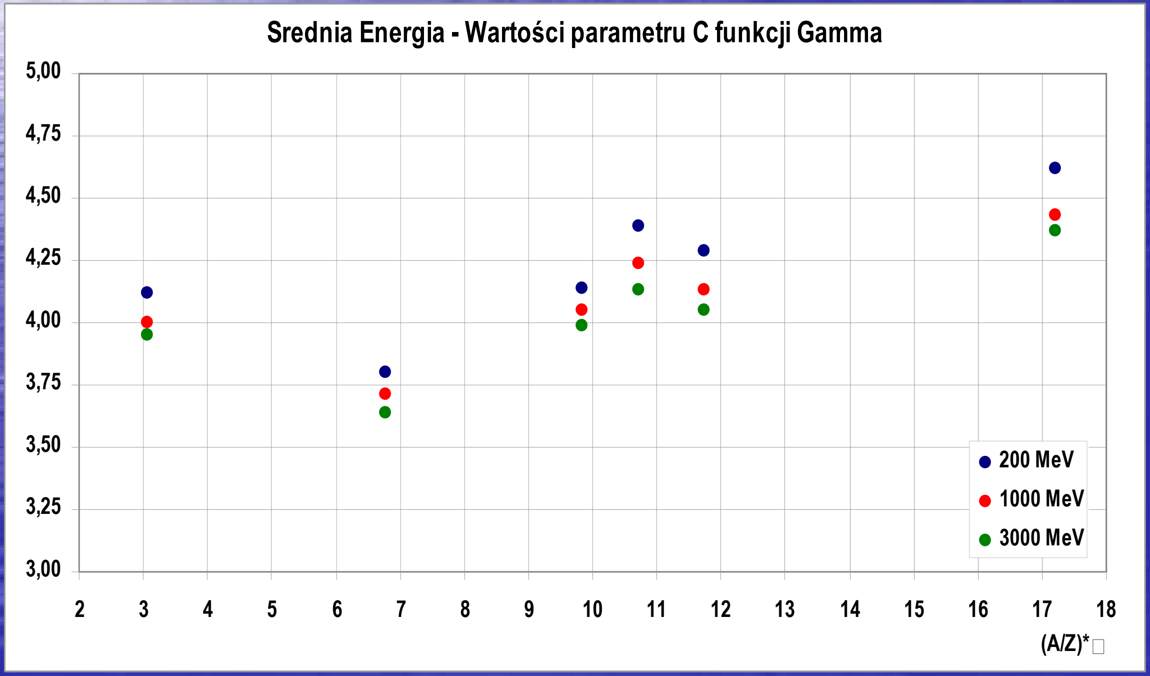
YOUR ATTENTION



Profil kaskady dofitowana do niego funkcja gamma

$$P(t_A) = \alpha \cdot t_A{}^{\beta} \exp(-t_A / \gamma)$$

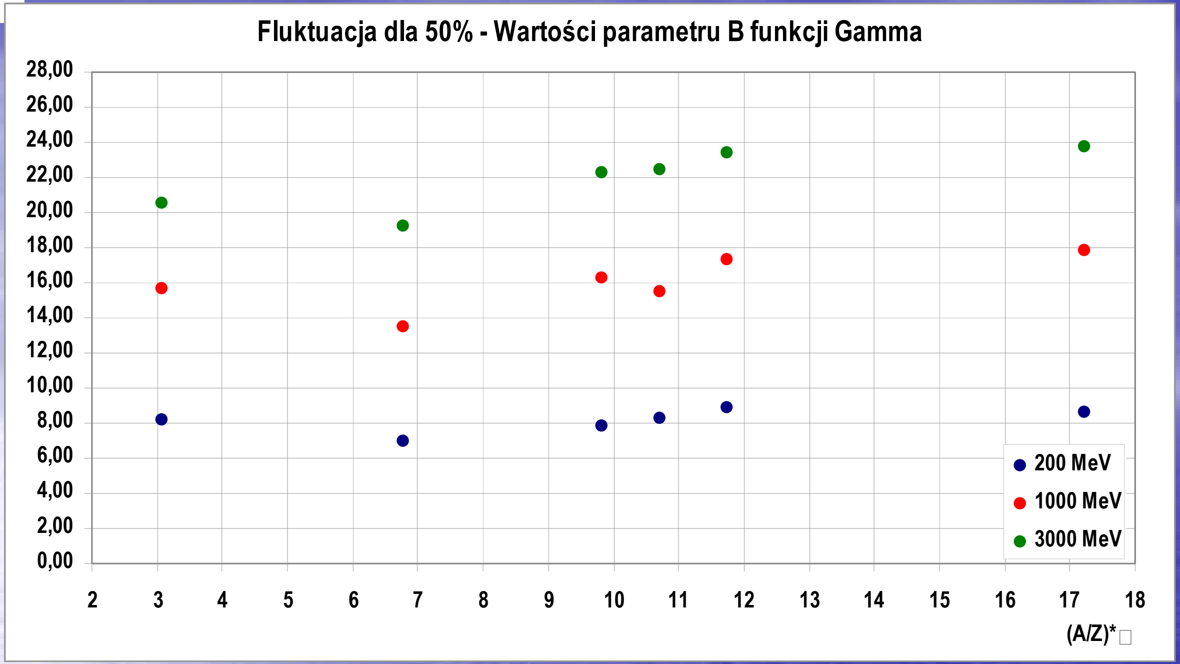
Zależność dofitowanego β od A/Z dla różnych energii Eγ



Zależność dofitowanego γ od A/Z dla różnych energii Eγ

Modelowanie wykonano dla materiałów takich jak: BGO, CWO (CdWO4), PWO, GaAS, Si, Pb, Xe i szkło ołowiowe

Cutoff = 0.1mm
Eγ=200MeV, 1000MeV, 3000MeV

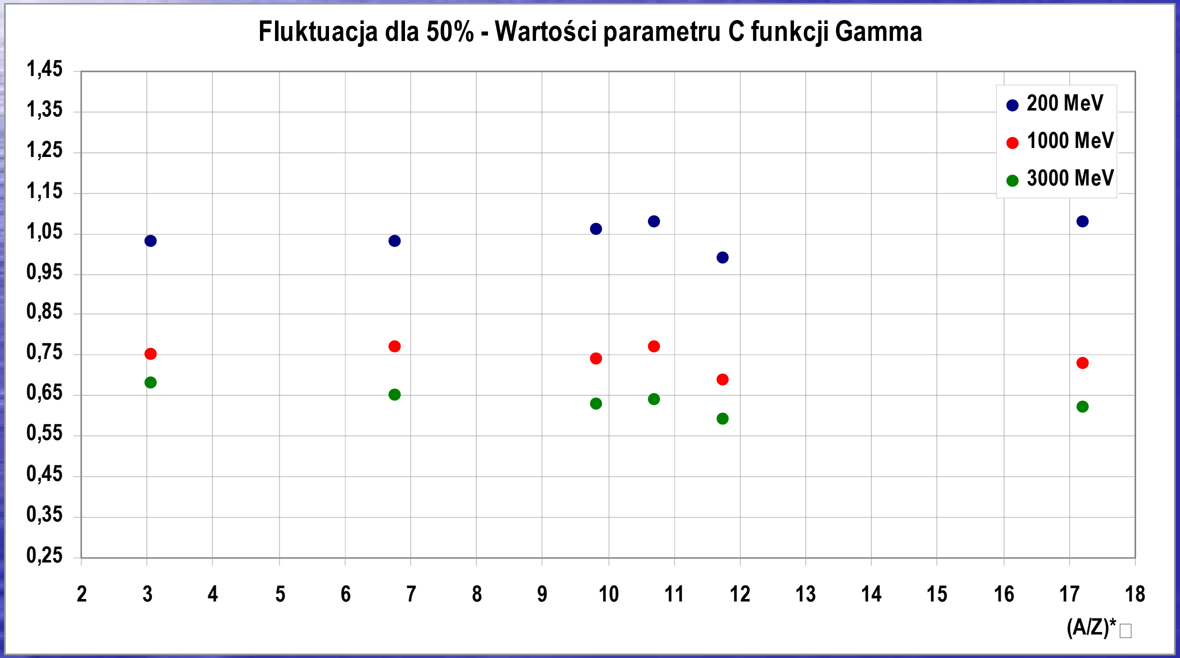


Fluktuacje podłużne A=50%
dofitowana funkcja gamma

Cutoff = 0.1mm

$$P(t_A) = \alpha \cdot t_A^{\beta} \exp(-t_A / \gamma)$$

Zależność dofitowanego β od A/Z dla różnych energii Eγ



Zależność dofitowanego γ od A/Z dla różnych energii Eγ