Исследование сцинтилляторов прототипа мюонного годоскопа спектрометра ОКА

1. Введение
2. Материал сцинтиллятора :
   1. Полистирол производства Харьков
   2. Полистирол производства BASF
3. Волокно : Y11 диаметром 1мм
4. SiPM – силиконовый фотоумножитель с размером кристалла 1x1мм^2
5. Усилитель – с калориметра H1

SiPD schematic structure

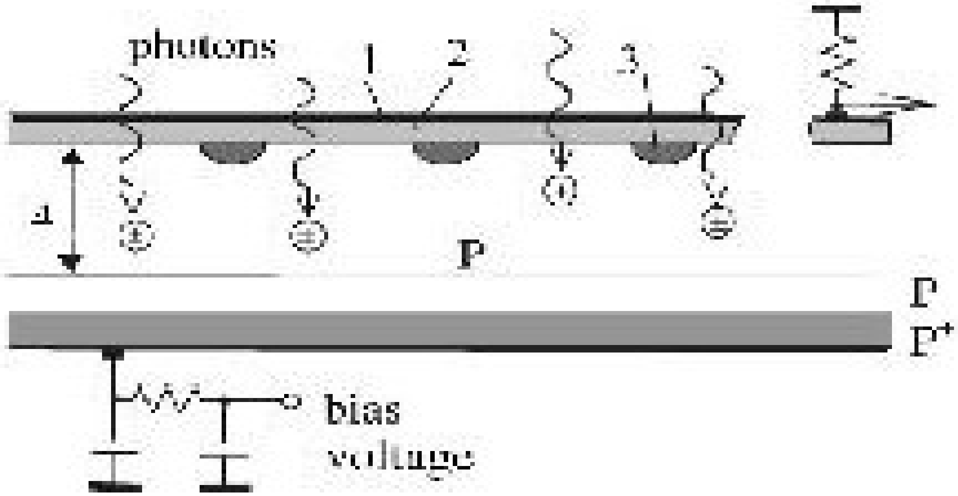


Fig. 1. The schematic photodiode structure (1) semitransparent metal contact (Ti), $d \approx 100$ Å; (2) SiC layer, $d \approx 0.15$ μm, $\rho = 10^5$–10^7 Ω cm; (3) n^+, r or hemisphere ≈ 1.5 μm; (4) depletion region (epitaxial layer).

pixels work together on common load, so the output is a sum of the signals from all pixels fired [7]:

$$n_{\text{pixels fired}} = n_{\text{pixels total}}(1 - e^{-\epsilon N_{\text{photons}}/n_{\text{pixels total}}})$$

where ϵ is the photon detection efficiency. The LGP topology which is shown on Fig. 1 we will refer below as a modification "0".

2. The improvement of the LGP topology

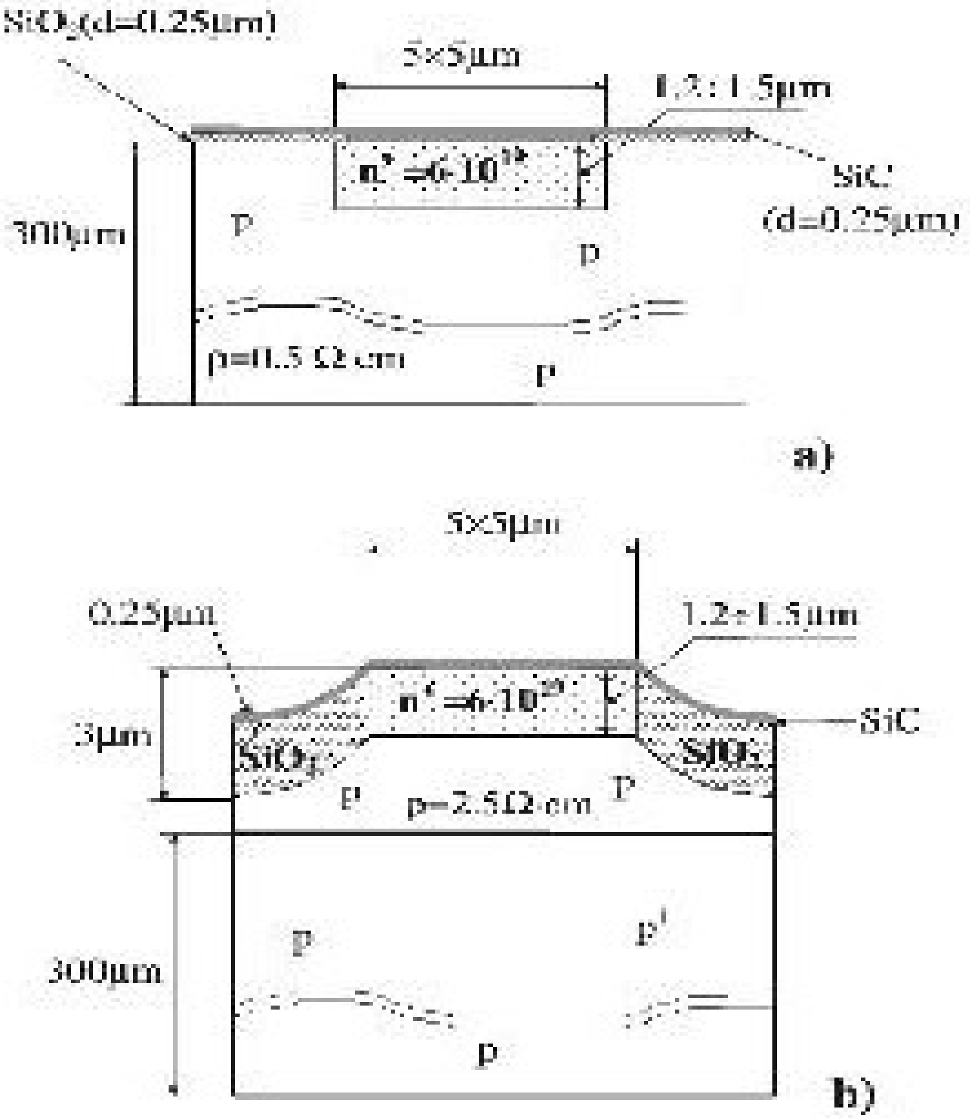


Fig. 2. Improved LGP topology: (a) Plane geometry (modification 1); (b) Mesotopology with p-epitaxy (modification 2).

Silicon Photomultiplier description

1 Silicon Photomultiplier (SiPM) description

The Silicon Photomultiplier (SiPM) is described in details in ref. [1–3]. The SiPM is a new type of photodetector based on silicon. It is a combined product of MEPhI [1] and the "Pulsar" enterprise in Moscow and has been developed in cooperation with DESY [2]. In figure 1 a schematic view of a SiPM is shown.

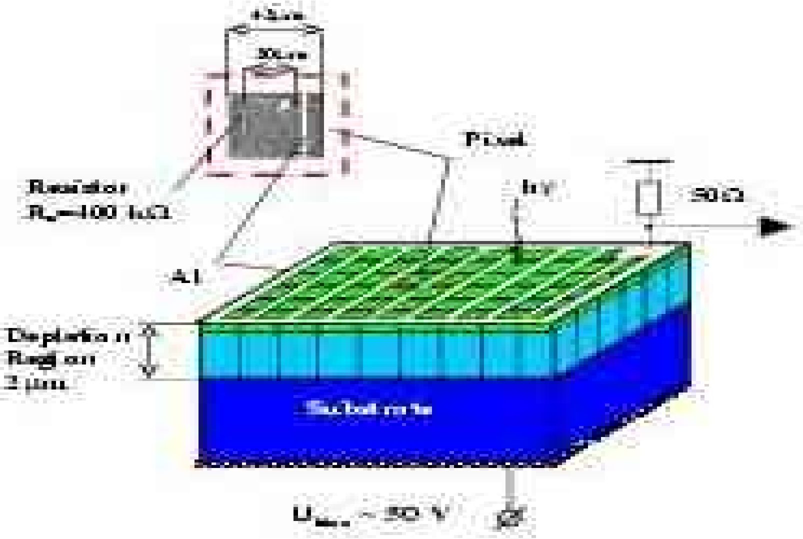


Figure 1: *Schematic view of a multipixel Silicon Photomultiplier. One SiPM covers the area of 1 mm² and consists of up to approximately 10^3 silicon micro pixels. The given pixel dimensions are only valid for a total number of pixels of 576.*

thick depletion region is needed to collect the produced pairs. Although the individual pixels are separated from each other, there is still the possibility to have optical crosstalk between the pixels. During the active time of one pixel electrons are produced in the Geiger discharge. These electrons produce photons (10^5 photons / electron), which then can initiate a discharge in a neighboring pixel. The photon detection efficiency of 10 - 20 % in a wavelength range between 400 and 700 nm and the high gain of 10^6 at a working bias voltage of approximately 60 V provide the SiPM with an output signal comparable to that of a conventional vacuum Photomultiplier tube. It also provides the possibility to resolve the photoelectron structure of the output signal, which is shown in figure 2, if a preamplifier is used additionally.

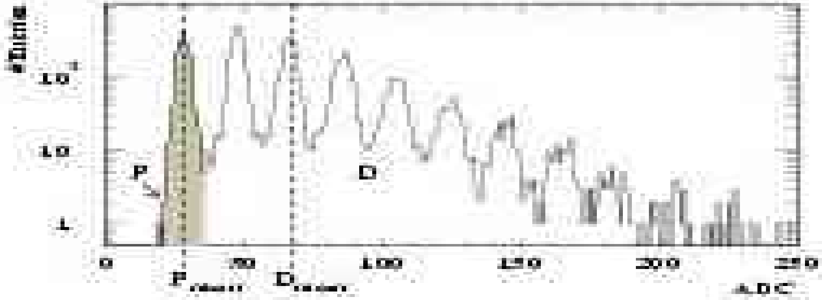


Figure 2: *SiPM pulse height spectrum D with photoelectron structure and mean value D_{mean}. The grey area indicates the pedestal P with mean value P_{mean}.*

Вид кристалла в корпусе со снятым окном

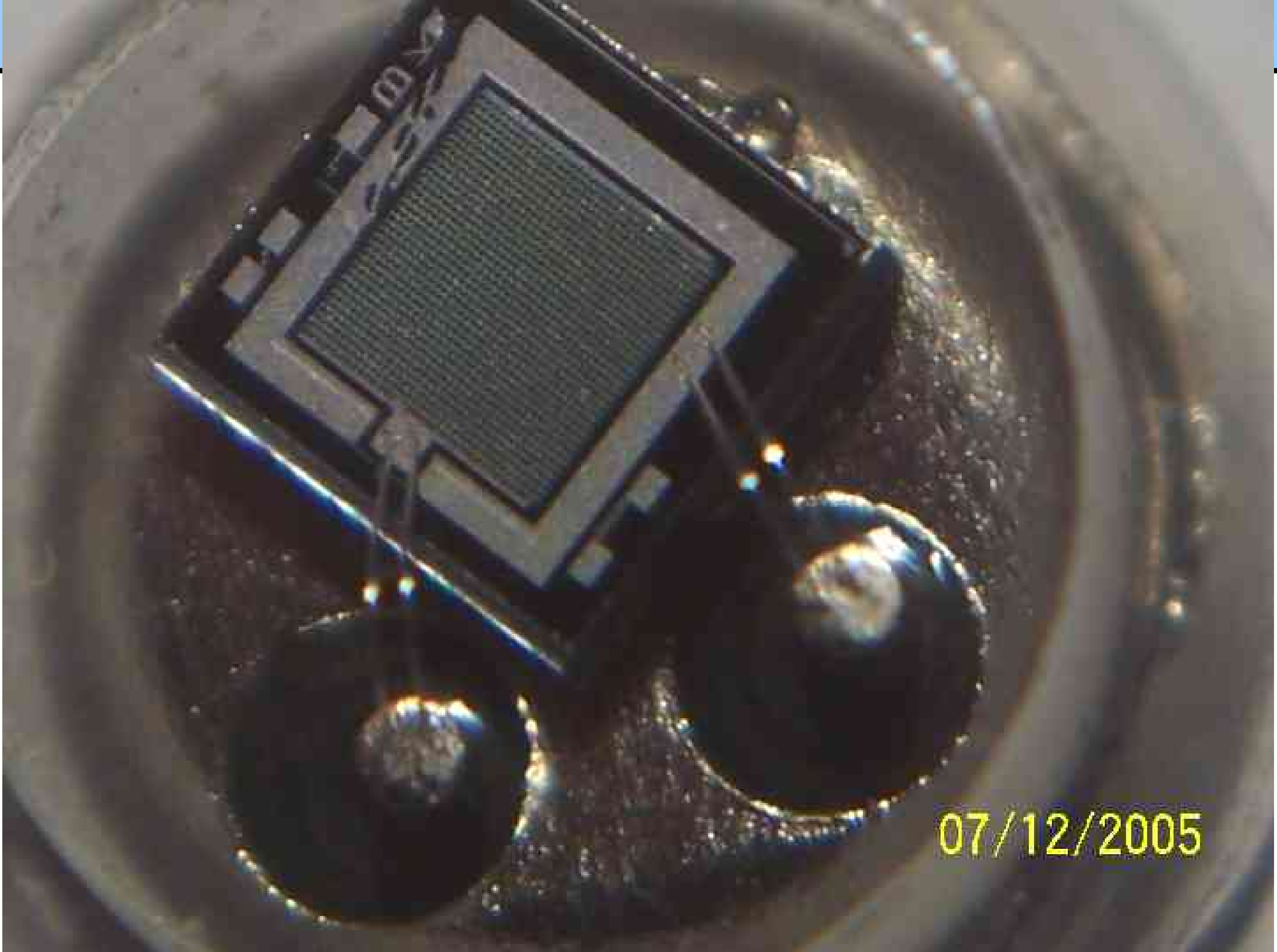

07/12/2005

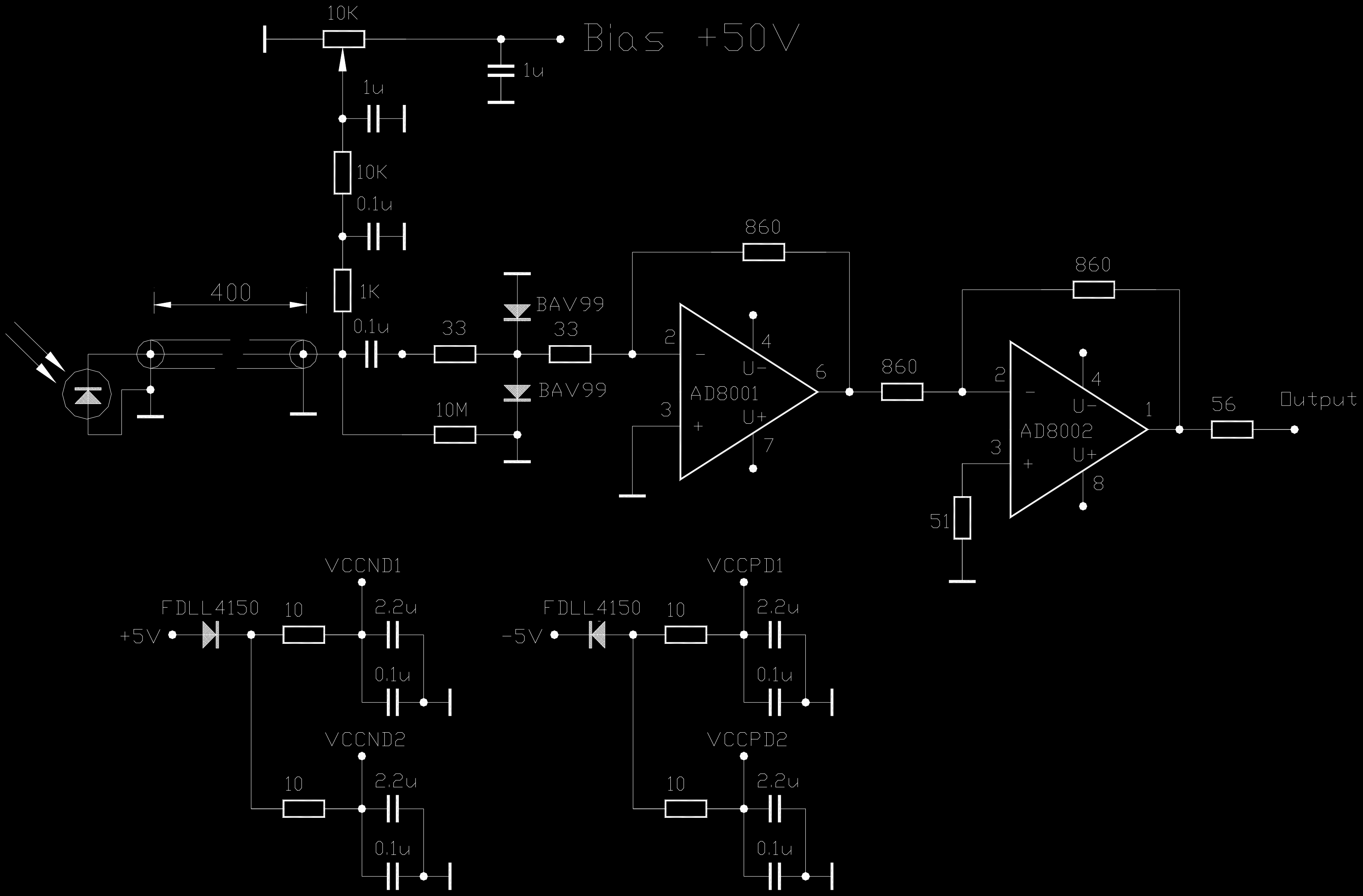
Фото сцинтиллятора с волокном

Установка фотодиода на сцинтиллятор

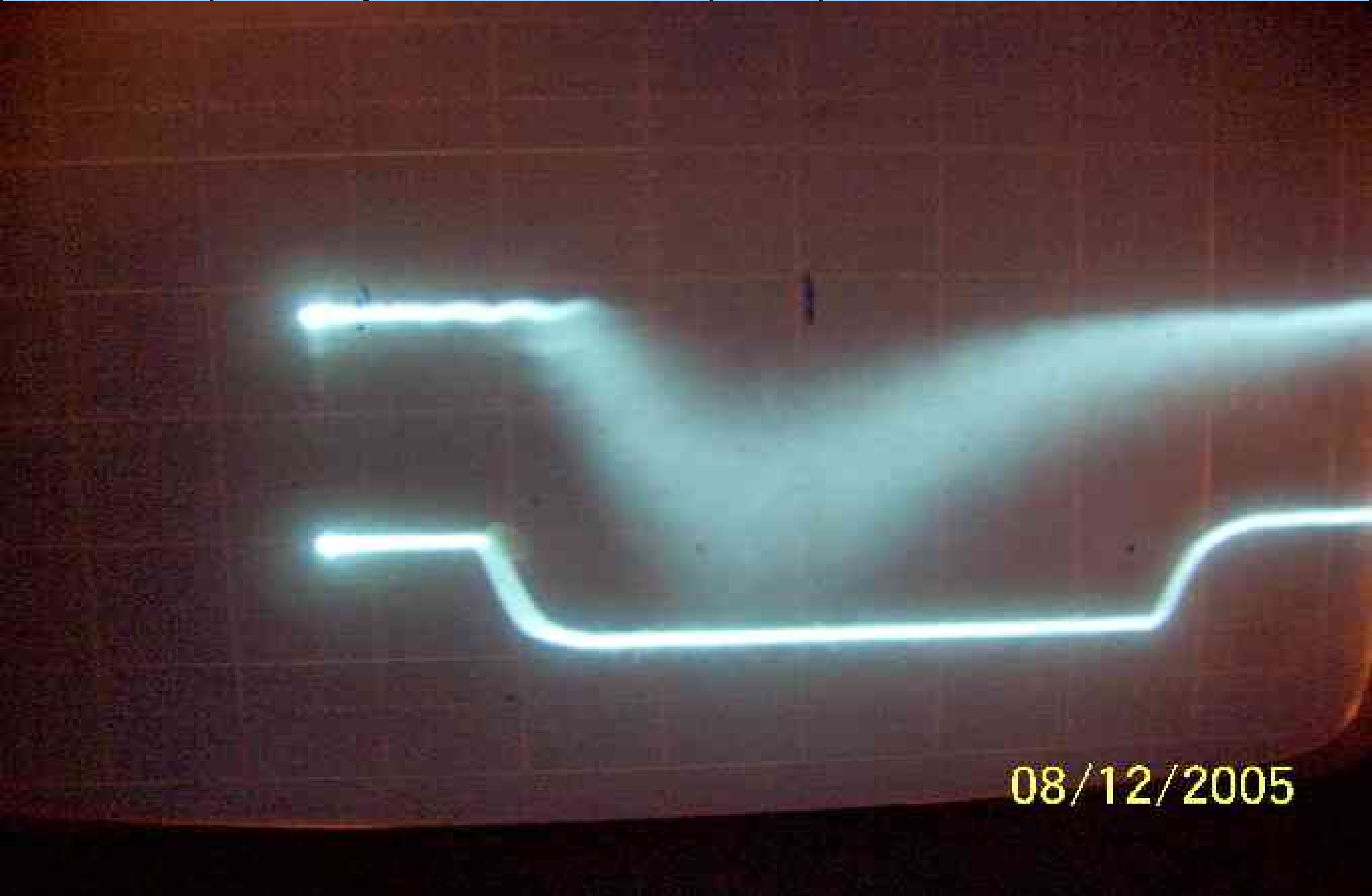
20/12/2005

Схема установки для измерения сцинтиллятора на космике

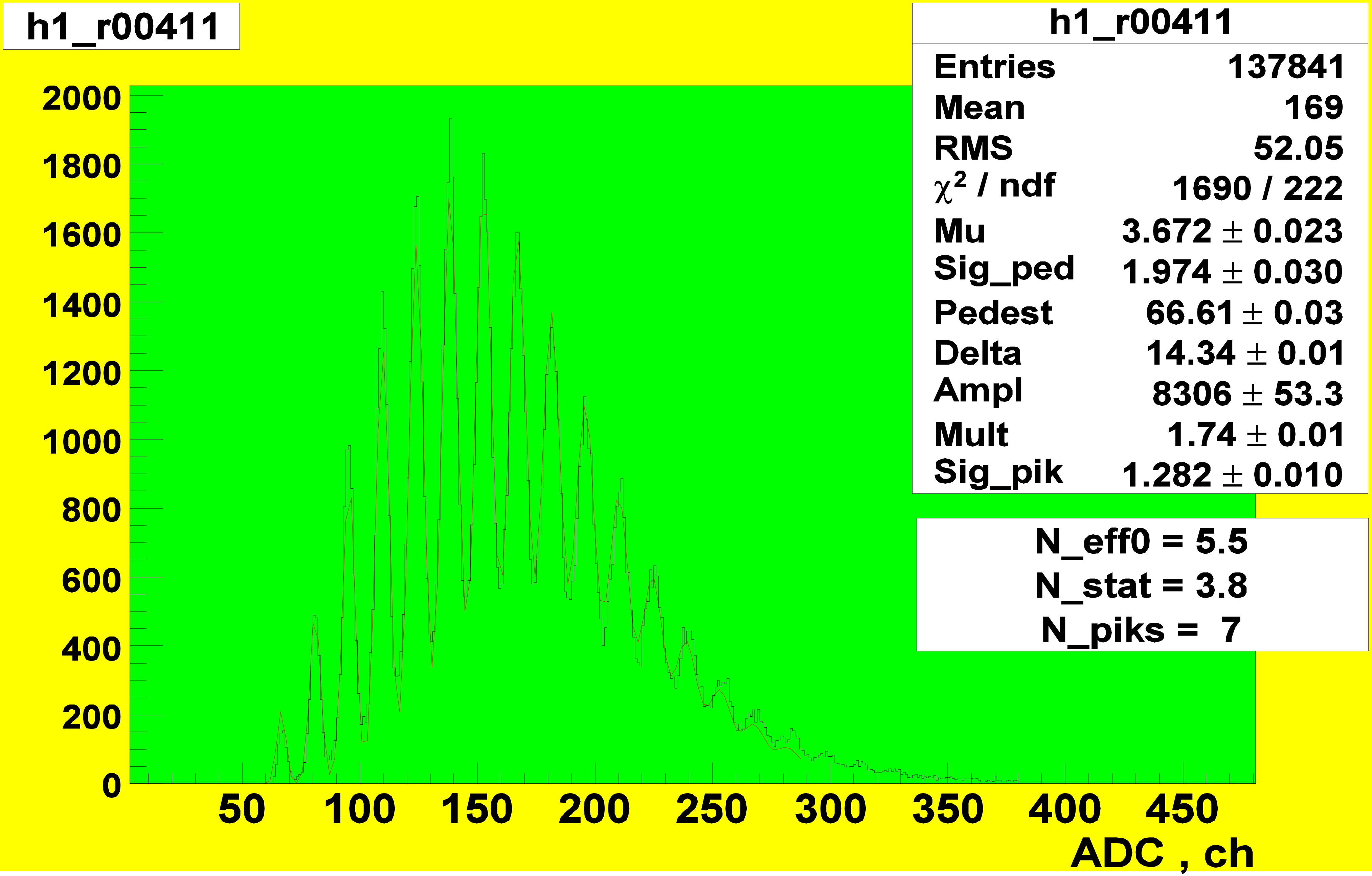
Схема усилителя и включения фотодиода



Форма импульса PD от LED, развертка20 нс/кл, 50мВ/кл



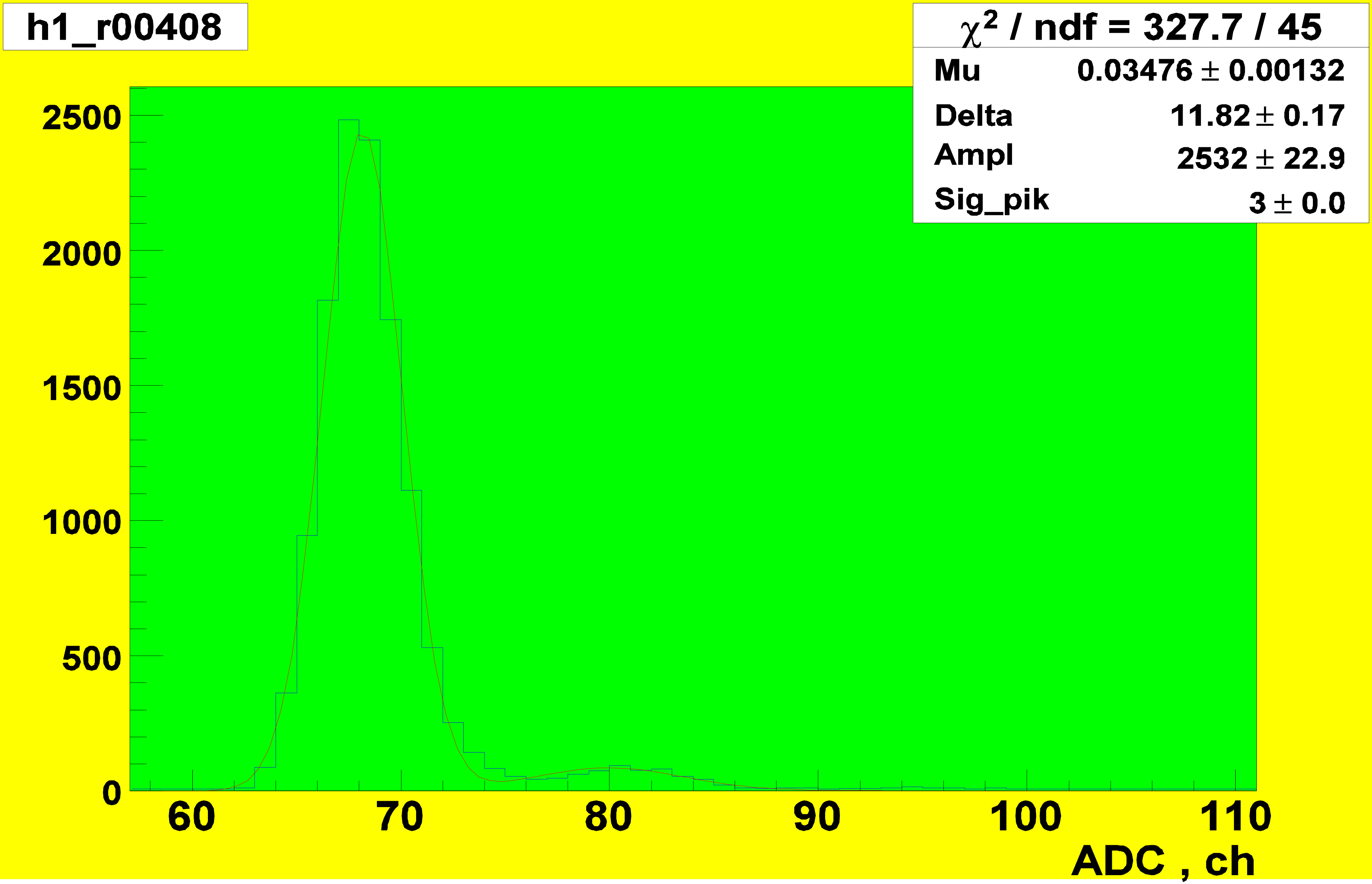
Спектр LED , t=-10



h1_r00411	
Entries	137841
Mean	169
RMS	52.05
χ^2 / ndf	1690 / 222
Mu	3.672 ± 0.023
Sig_ped	1.974 ± 0.030
Pedest	66.61 ± 0.03
Delta	14.34 ± 0.01
Ampl	8306 ± 53.3
Mult	1.74 ± 0.01
Sig_pik	1.282 ± 0.010

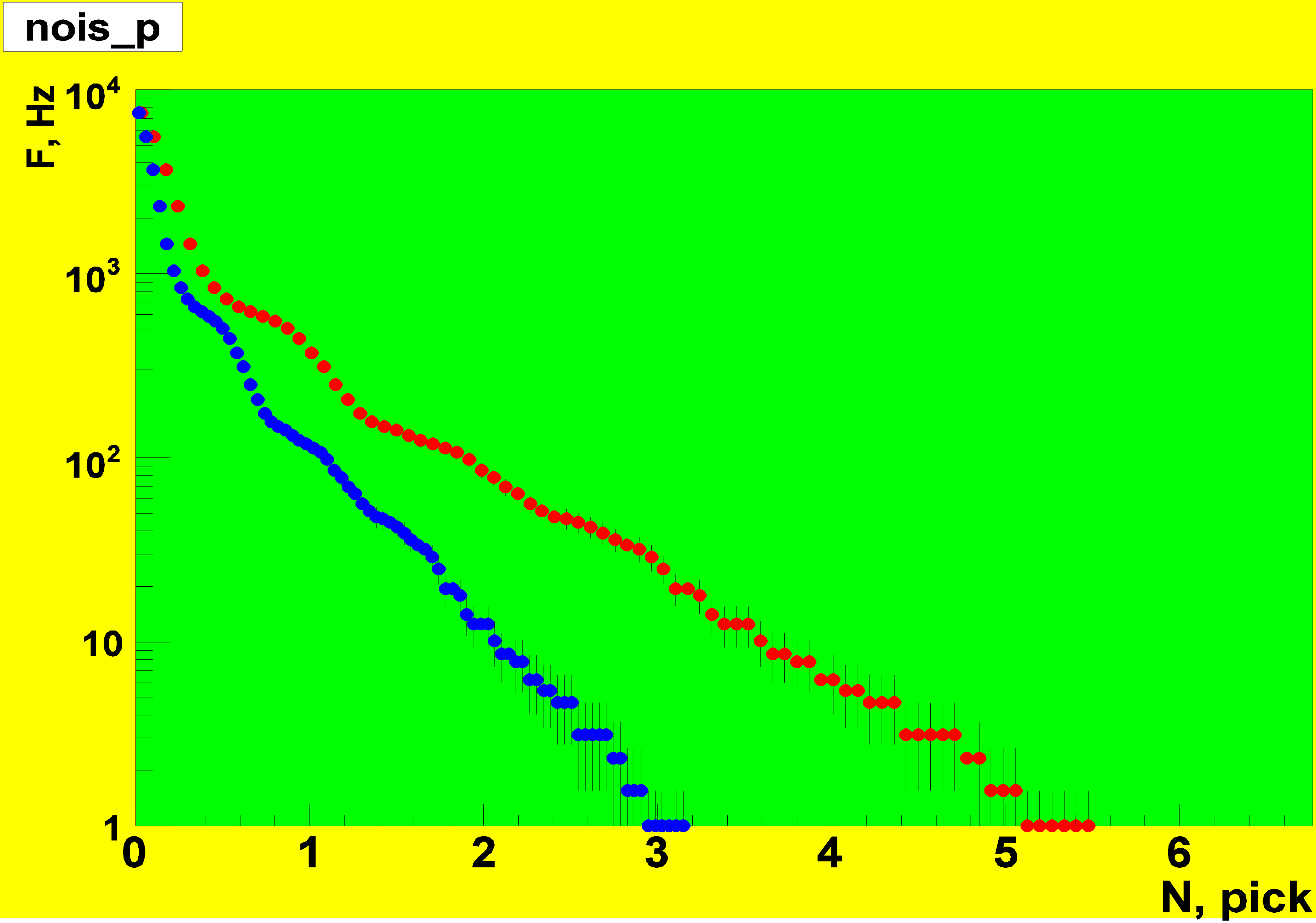
N_eff0 = 5.5
N_stat = 3.8
N_piks = 7

Пьедестал , t=-10

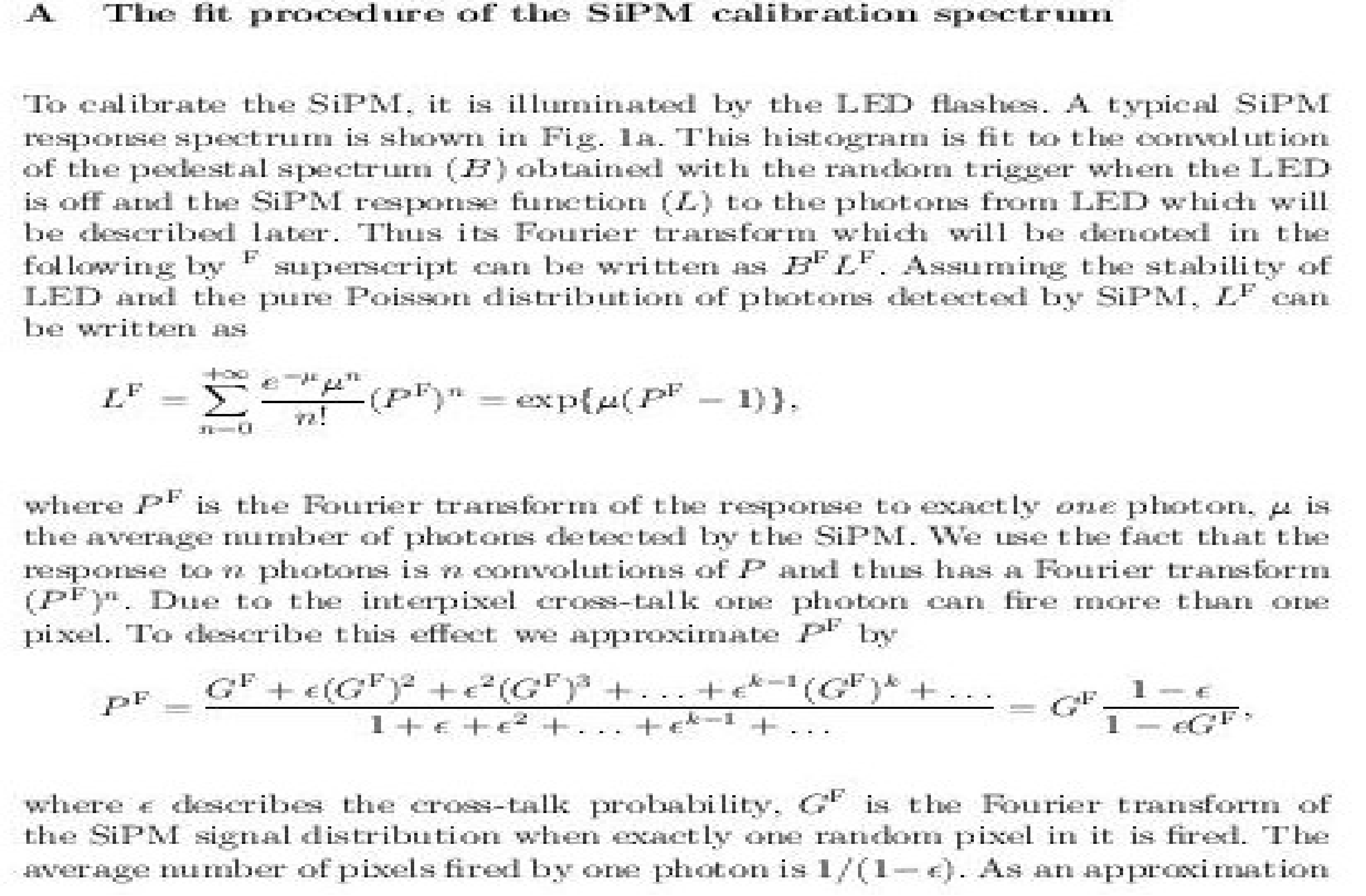


χ^2 / ndf = 327.7 / 45	
Mu	0.03476 ± 0.00132
Delta	11.82 ± 0.17
Ampl	2532 ± 22.9
Sig_pik	3 ± 0.0

Noise vs threshould , t=-10



The fit procedure of the SiPM spectra



A The fit procedure of the SiPM calibration spectrum

To calibrate the SiPM, it is illuminated by the LED flashes. A typical SiPM response spectrum is shown in Fig. 1a. This histogram is fit to the convolution of the pedestal spectrum (B) obtained with the random trigger when the LED is off and the SiPM response function (L) to the photons from LED which will be described later. Thus its Fourier transform which will be denoted in the following by $^{\mathrm{F}}$ superscript can be written as $B^{\mathrm{F}}L^{\mathrm{F}}$. Assuming the stability of LED and the pure Poisson distribution of photons detected by SiPM, L^{F} can be written as

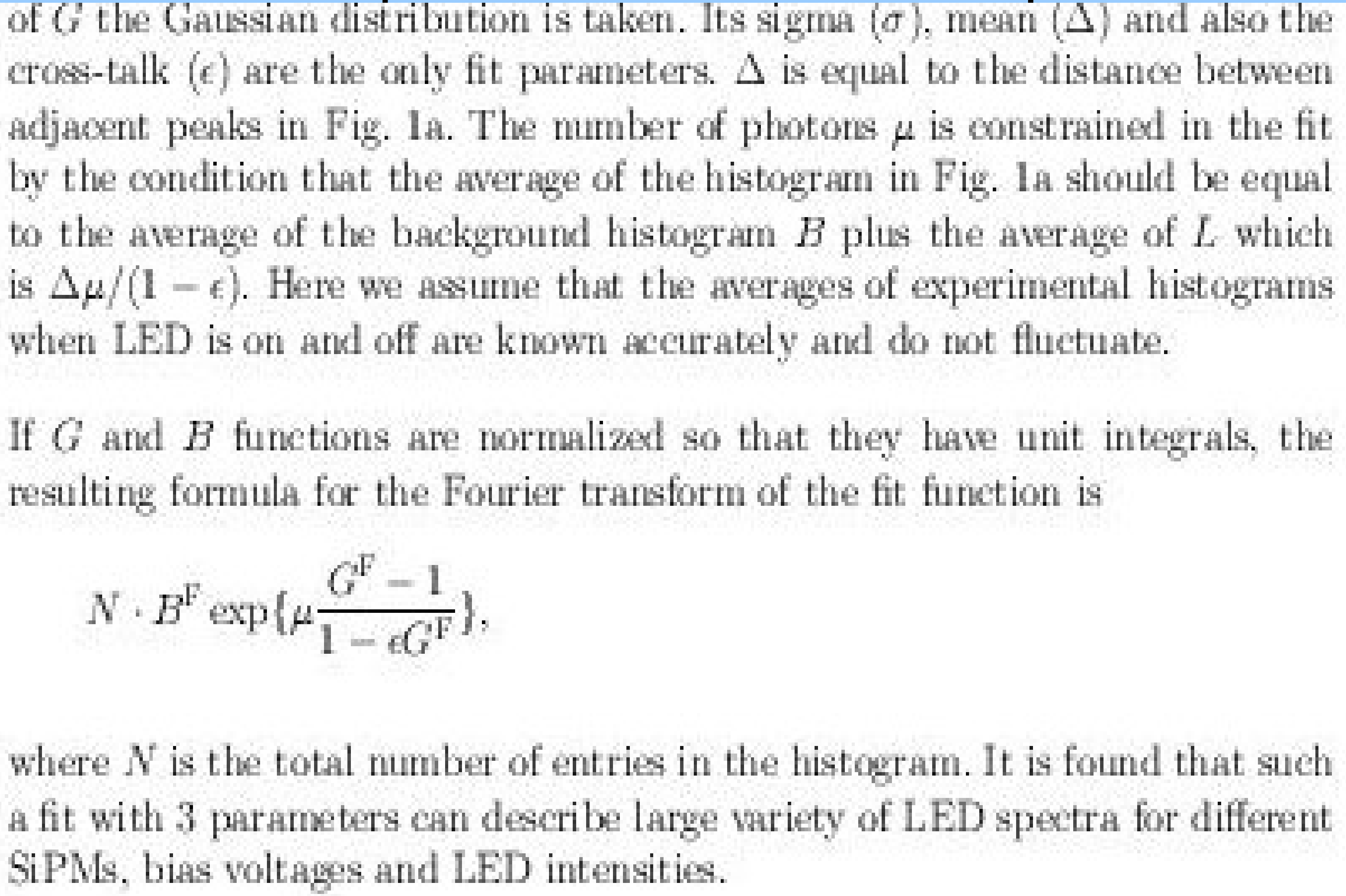
$$L^{\mathrm{F}} = \sum_{n=0}^{+\infty} \frac{e^{-\mu}\mu^{n}}{n!}(P^{\mathrm{F}})^{n} = \exp\{\mu(P^{\mathrm{F}} - 1)\},$$

where P^{F} is the Fourier transform of the response to exactly *one* photon, μ is the average number of photons detected by the SiPM. We use the fact that the response to n photons is n convolutions of P and thus has a Fourier transform $(P^{\mathrm{F}})^{n}$. Due to the interpixel cross-talk one photon can fire more than one pixel. To describe this effect we approximate P^{F} by

$$P^{\mathrm{F}} = \frac{G^{\mathrm{F}} + \epsilon(G^{\mathrm{F}})^{2} + \epsilon^{2}(G^{\mathrm{F}})^{3} + \ldots + \epsilon^{k-1}(G^{\mathrm{F}})^{k} + \ldots}{1 + \epsilon + \epsilon^{2} + \ldots + \epsilon^{k-1} + \ldots} = G^{\mathrm{F}}\frac{1-\epsilon}{1-\epsilon G^{\mathrm{F}}},$$

where ϵ describes the cross-talk probability, G^{F} is the Fourier transform of the SiPM signal distribution when exactly one random pixel in it is fired. The average number of pixels fired by one photon is $1/(1-\epsilon)$. As an approximation

The fit procedure of the SiPM spectra



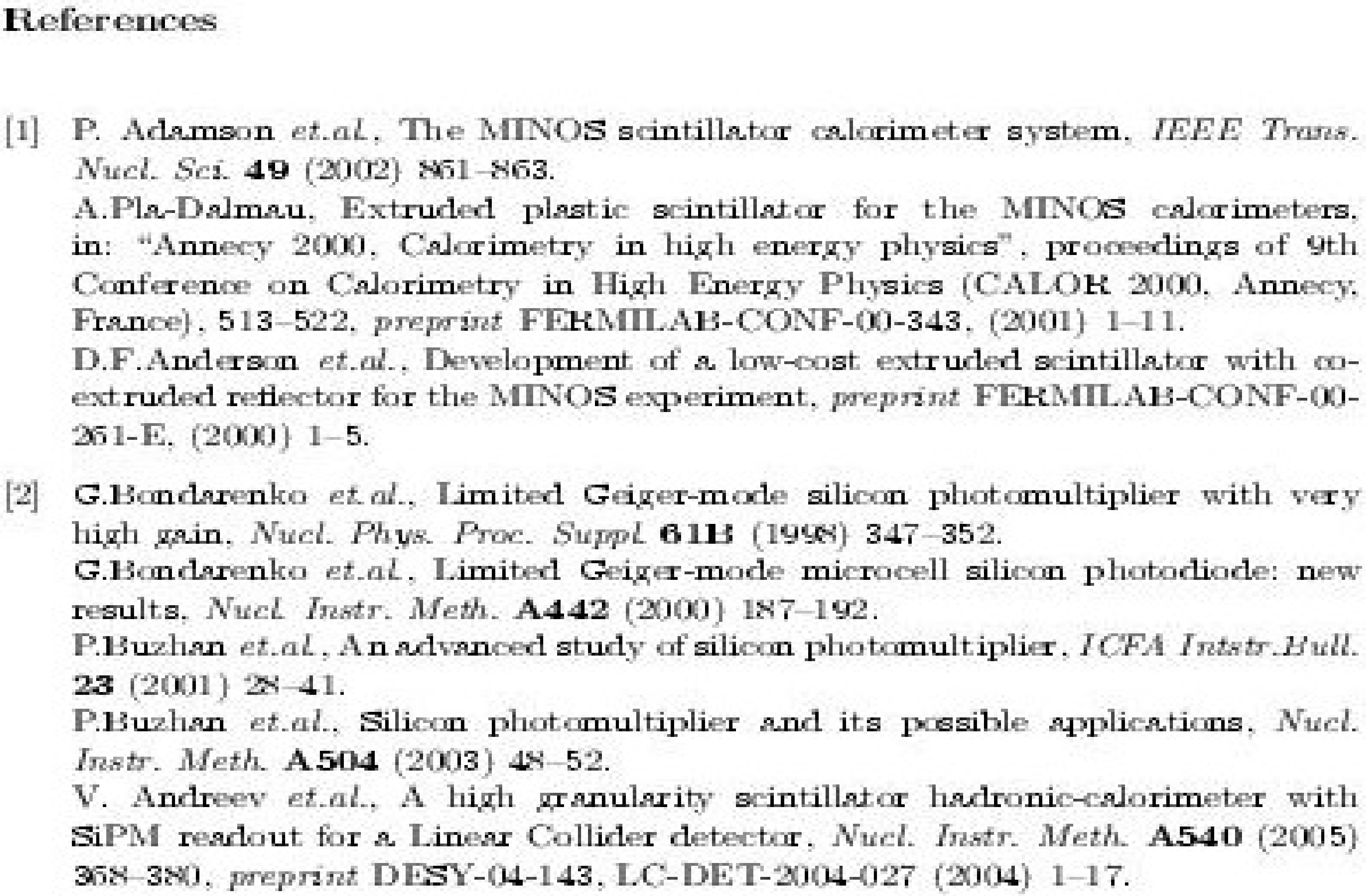
of G the Gaussian distribution is taken. Its sigma (σ), mean (Δ) and also the cross-talk (ϵ) are the only fit parameters. Δ is equal to the distance between adjacent peaks in Fig. 1a. The number of photons μ is constrained in the fit by the condition that the average of the histogram in Fig. 1a should be equal to the average of the background histogram B plus the average of L which is $\Delta\mu/(1-\epsilon)$. Here we assume that the averages of experimental histograms when LED is on and off are known accurately and do not fluctuate.

If G and B functions are normalized so that they have unit integrals, the resulting formula for the Fourier transform of the fit function is

$$N \cdot B^{\mathrm{F}} \exp\{\mu \frac{G^{\mathrm{F}} - 1}{1 - \epsilon G^{\mathrm{F}}}\},$$

where N is the total number of entries in the histogram. It is found that such a fit with 3 parameters can describe large variety of LED spectra for different SiPMs, bias voltages and LED intensities.

References



References

[1] P. Adamson *et.al.*, The MINOS scintillator calorimeter system, *IEEE Trans. Nucl. Sci.* **49** (2002) 861–863.
A.Pla-Dalmau, Extruded plastic scintillator for the MINOS calorimeters, in: "Annecy 2000, Calorimetry in high energy physics", proceedings of 9th Conference on Calorimetry in High Energy Physics (CALOR 2000, Annecy, France), 513–522, *preprint* FERMILAB-CONF-00-343, (2001) 1–11.
D.F.Anderson *et.al.*, Development of a low-cost extruded scintillator with co-extruded reflector for the MINOS experiment, *preprint* FERMILAB-CONF-00-261-E, (2000) 1–5.

[2] G.Bondarenko *et.al.*, Limited Geiger-mode silicon photomultiplier with very high gain, *Nucl. Phys. Proc. Suppl.* **61B** (1998) 347–352.
G.Bondarenko *et.al.*, Limited Geiger-mode microcell silicon photodiode: new results, *Nucl. Instr. Meth.* **A442** (2000) 187–192.
P.Buzhan *et.al.*, An advanced study of silicon photomultiplier, *ICFA Intstr.Bull.* **23** (2001) 28–41.
P.Buzhan *et.al.*, Silicon photomultiplier and its possible applications, *Nucl. Instr. Meth.* **A504** (2003) 48–52.
V. Andreev *et.al.*, A high granularity scintillator hadronic-calorimeter with SiPM readout for a Linear Collider detector, *Nucl. Instr. Meth.* **A540** (2005) 368–380, *preprint* DESY-04-143, LC-DET-2004-027 (2004) 1–17.

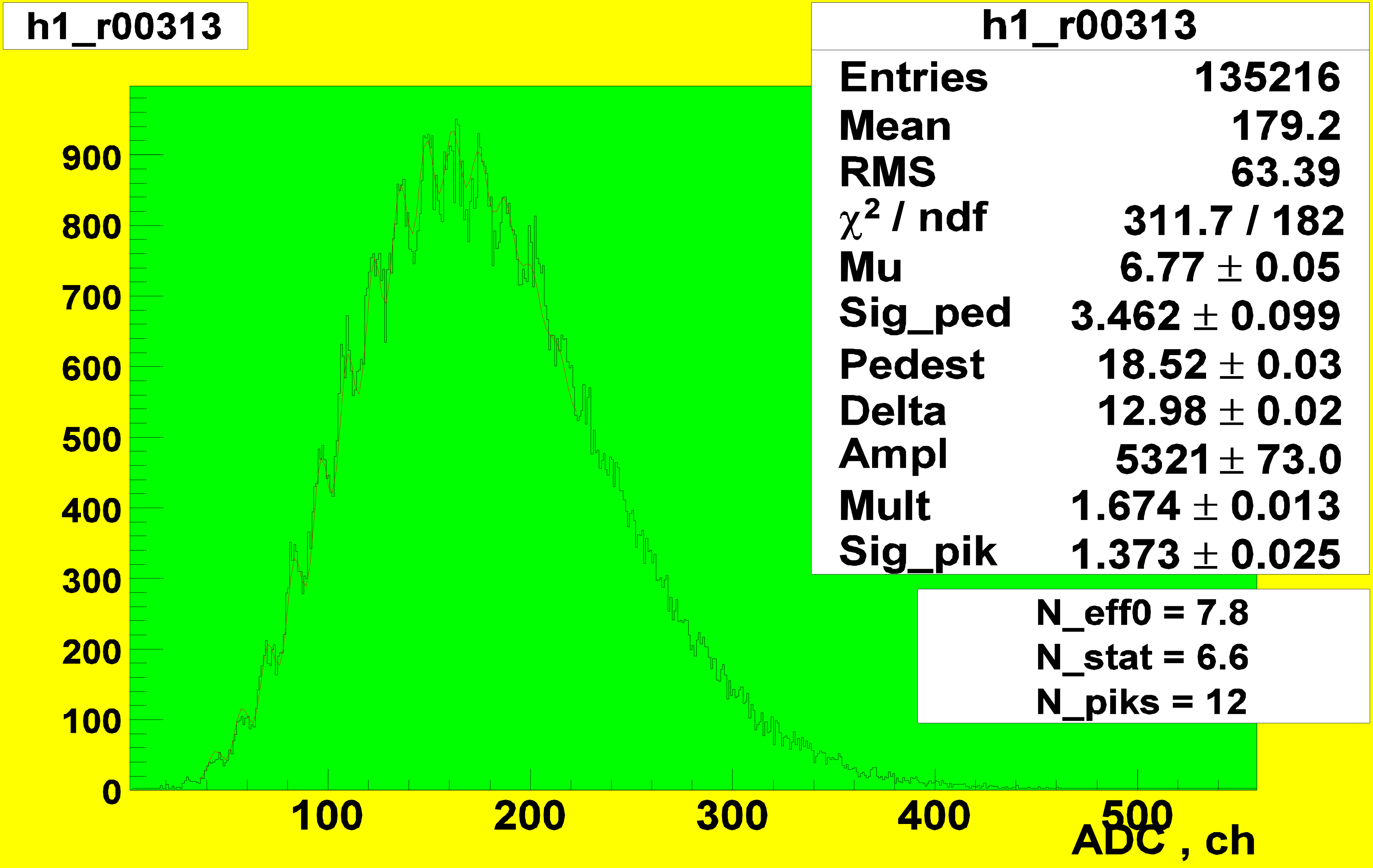
Функция для фитирования спектров SIPM

```
Double_t fitf(Double_t *x, Double_t *par)
{
Double_t    mu              = par[0];                   //   npe for poisson          // fixed
Double_t     sig_ped2    = par[1]*par[1];             //   width of pedestal         // fixed
Double_t     offset          = par[2];                   //   pedestalls position      // fixed
Double_t     delta           =  par[3];                   //  delta = step of picks
Double_t     norm            = par[4];                   //  normalization factor
Stat_t          n0                = (Stat_t)par[5];            // n –for poisson loop       // fixed
Double_t     mult1           = par[6];                   //  multiplisyti
Double_t     sig_pik2       = par[7]*par[7];             //  sigma pik**2

Double_t arg = 0.
for  (Double_t n=0.; n<n0; n++) {
Double_t mmm1 = mean_led/delta/multi;                              // mean for poisson//

Double_t      mean =  n * delta + offset;                    // mean for gaus
Double_t     sigma =  sqrt(sig_ped2 + n*sig_pik2);       // sigma for picks
Double_t gaus1=(TMath::Gaus( x[0],mean,sigma)  );
Double_t pois1 =(TMath::Poisson( n/mult1 , mu )  );
arg=arg+gaus1*pois1;
 }
Double_t fitval = arg * par[4];
return  fitval;}
```

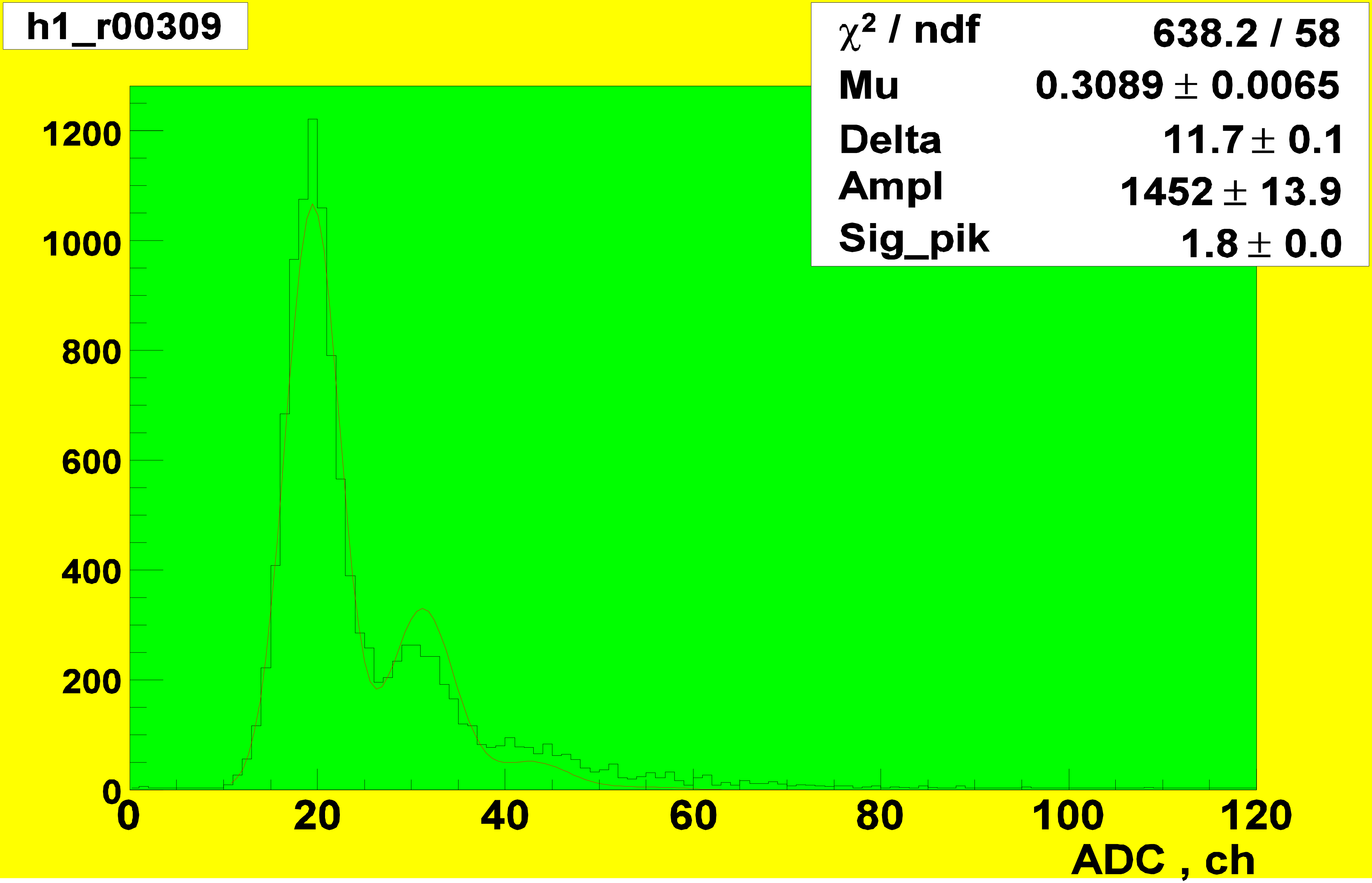
Спектр LED , t=+20



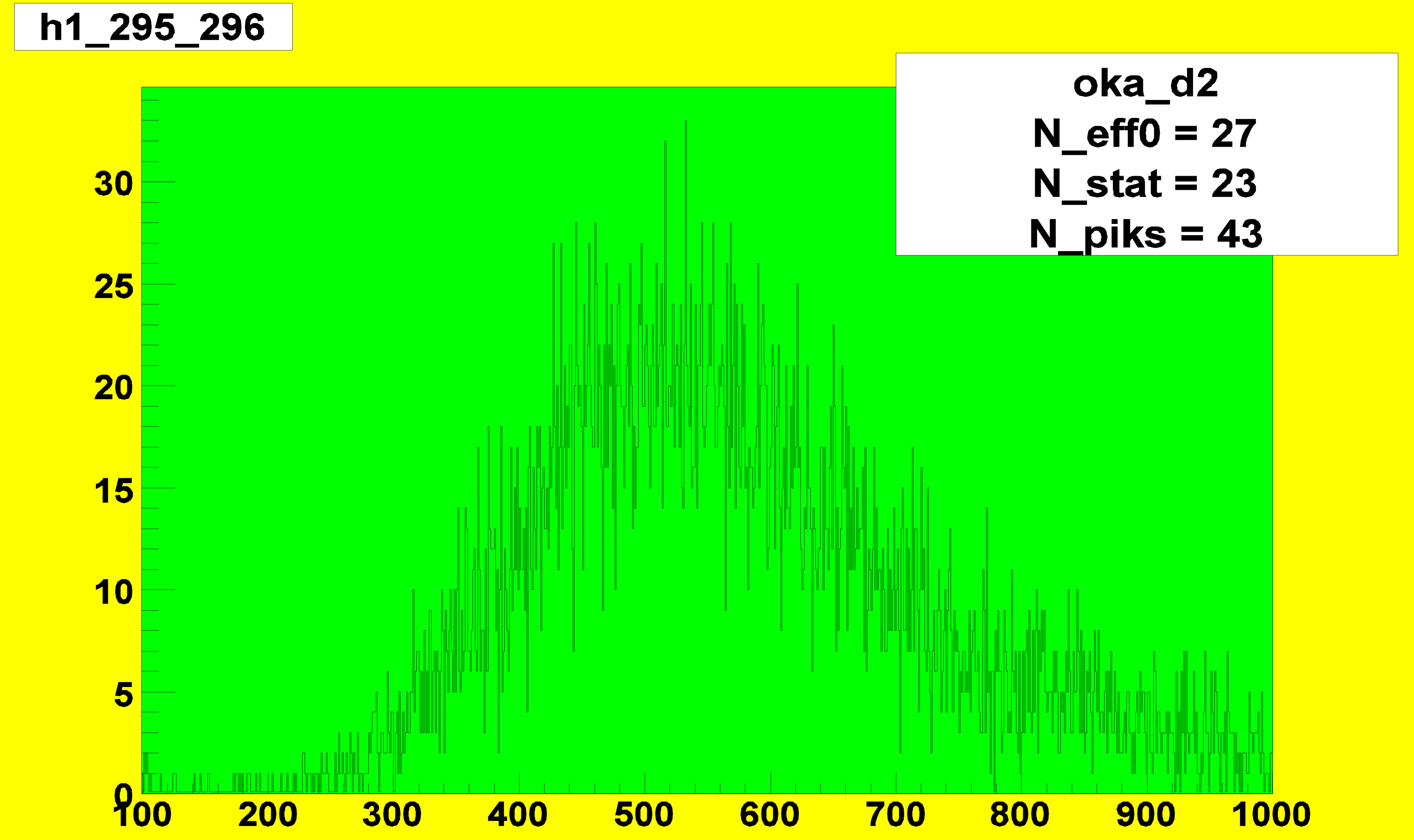
h1_r00313	
Entries	135216
Mean	179.2
RMS	63.39
χ^2 / ndf	311.7 / 182
Mu	6.77 ± 0.05
Sig_ped	3.462 ± 0.099
Pedest	18.52 ± 0.03
Delta	12.98 ± 0.02
Ampl	5321 ± 73.0
Mult	1.674 ± 0.013
Sig_pik	1.373 ± 0.025

N_eff0 = 7.8
N_stat = 6.6
N_piks = 12

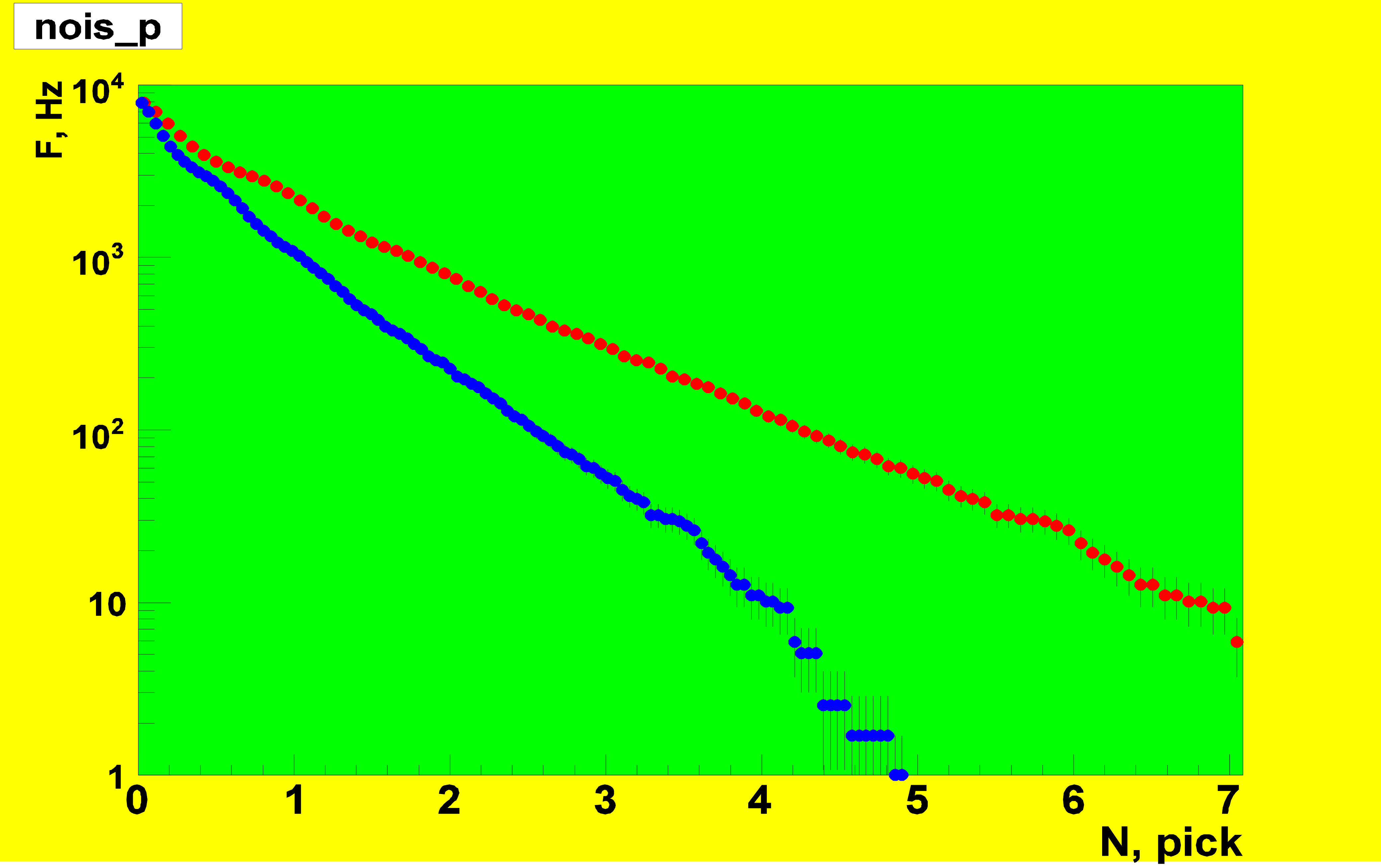
Пьедестал , t=+20



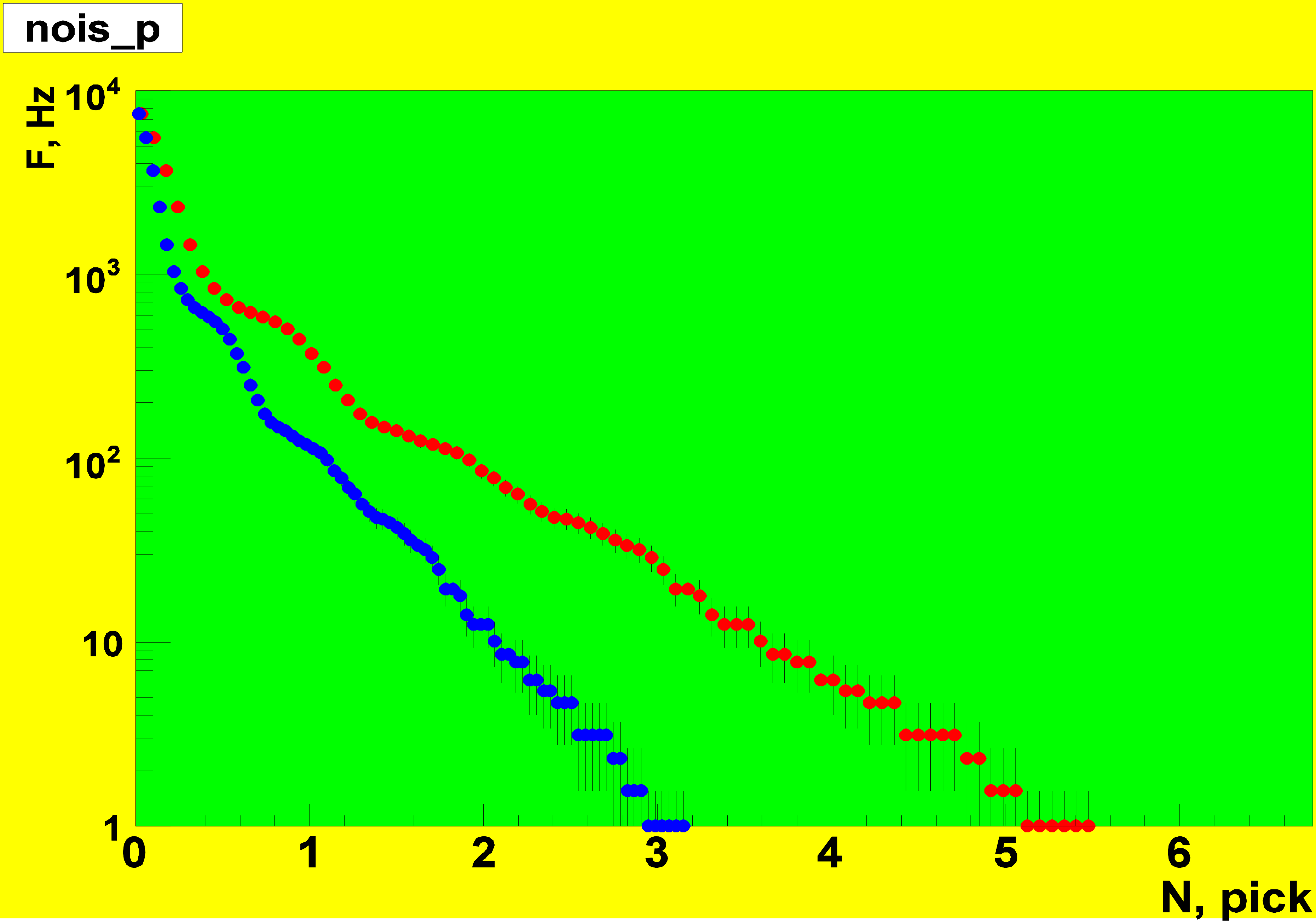
Cosmic spectra



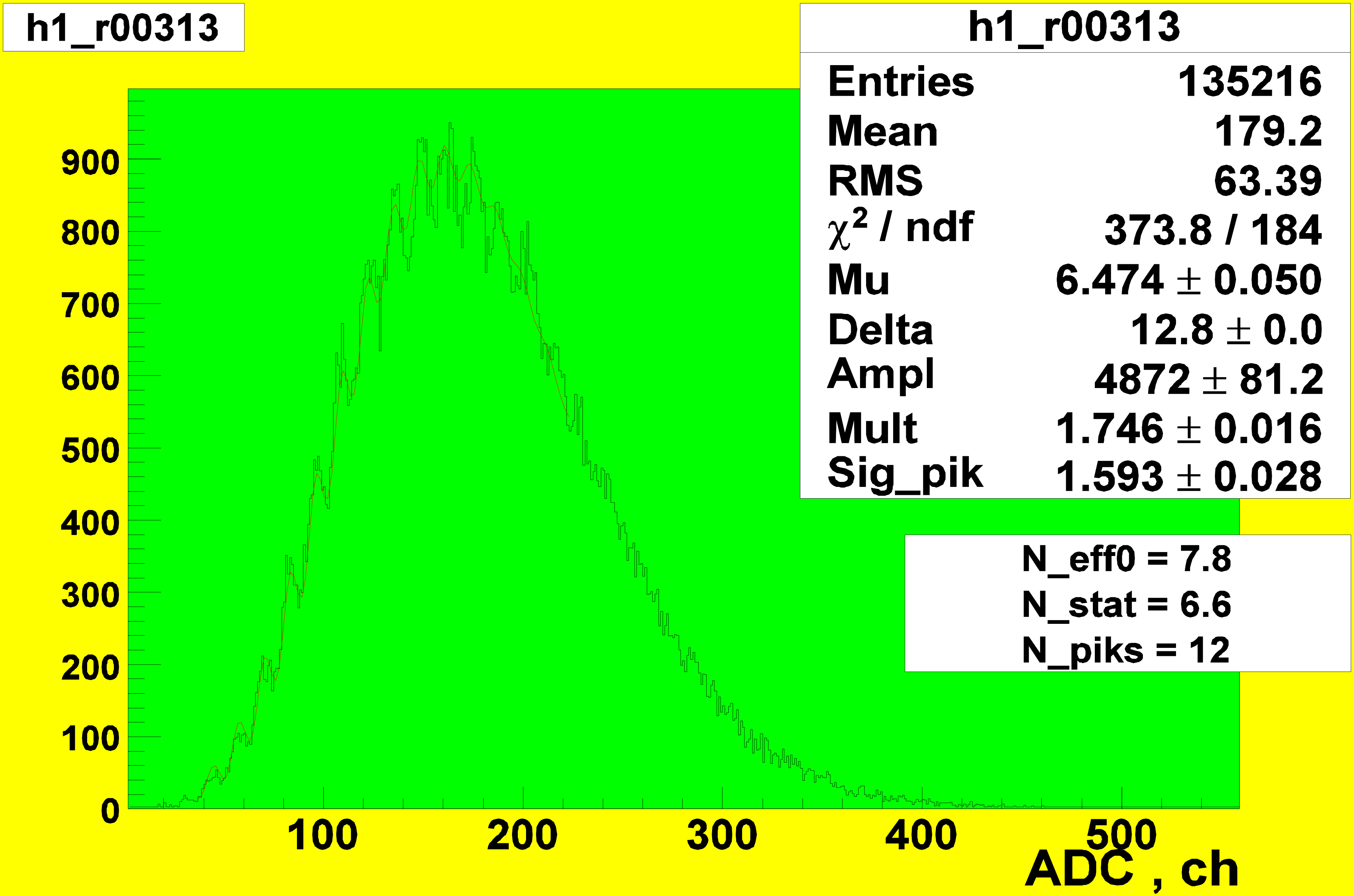
Noise vs threshould , t=+20



Noise vs threshould , t=-10



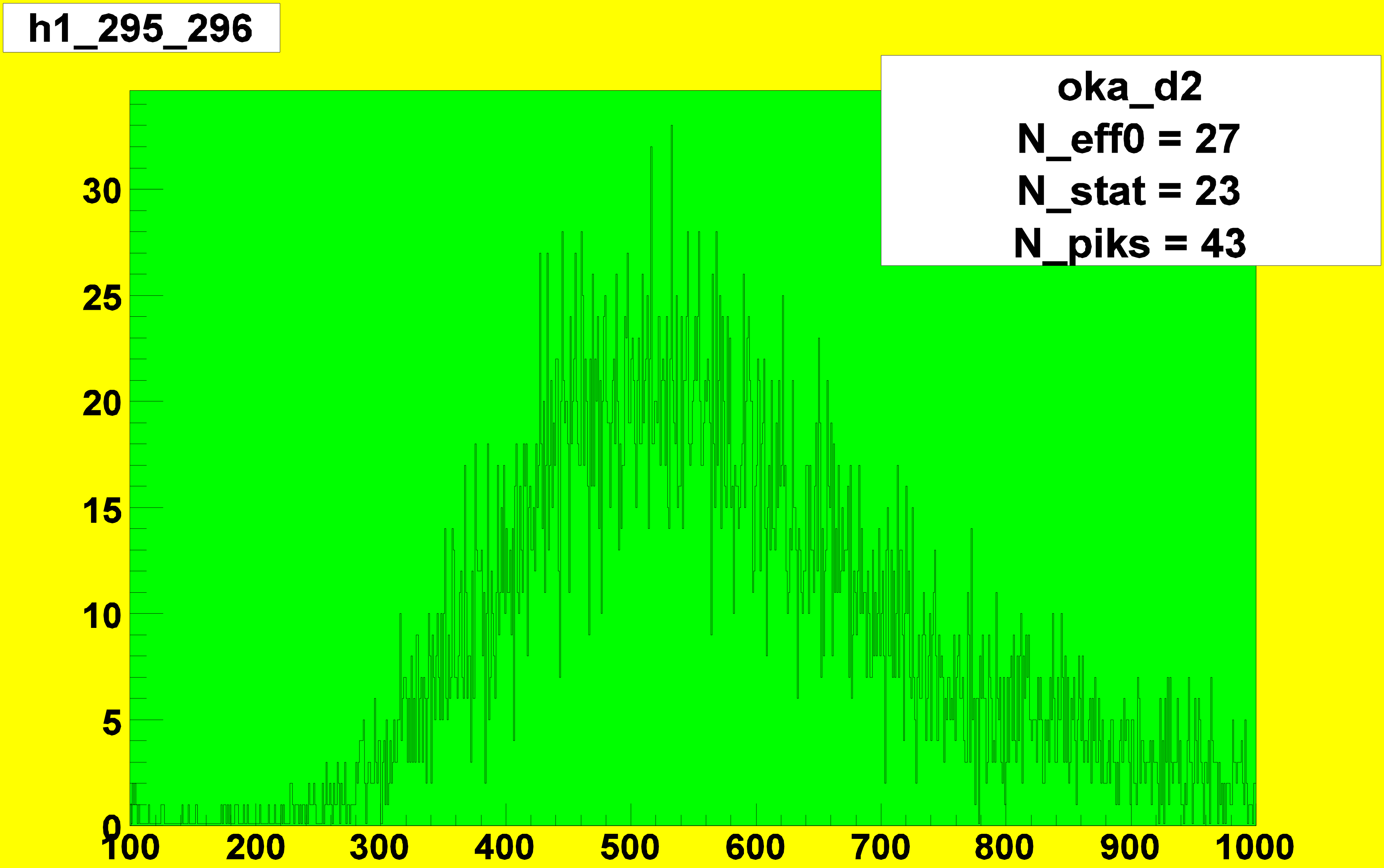
Светодиод, ОКА пластик Харьков, PD_1 , U=38.5В



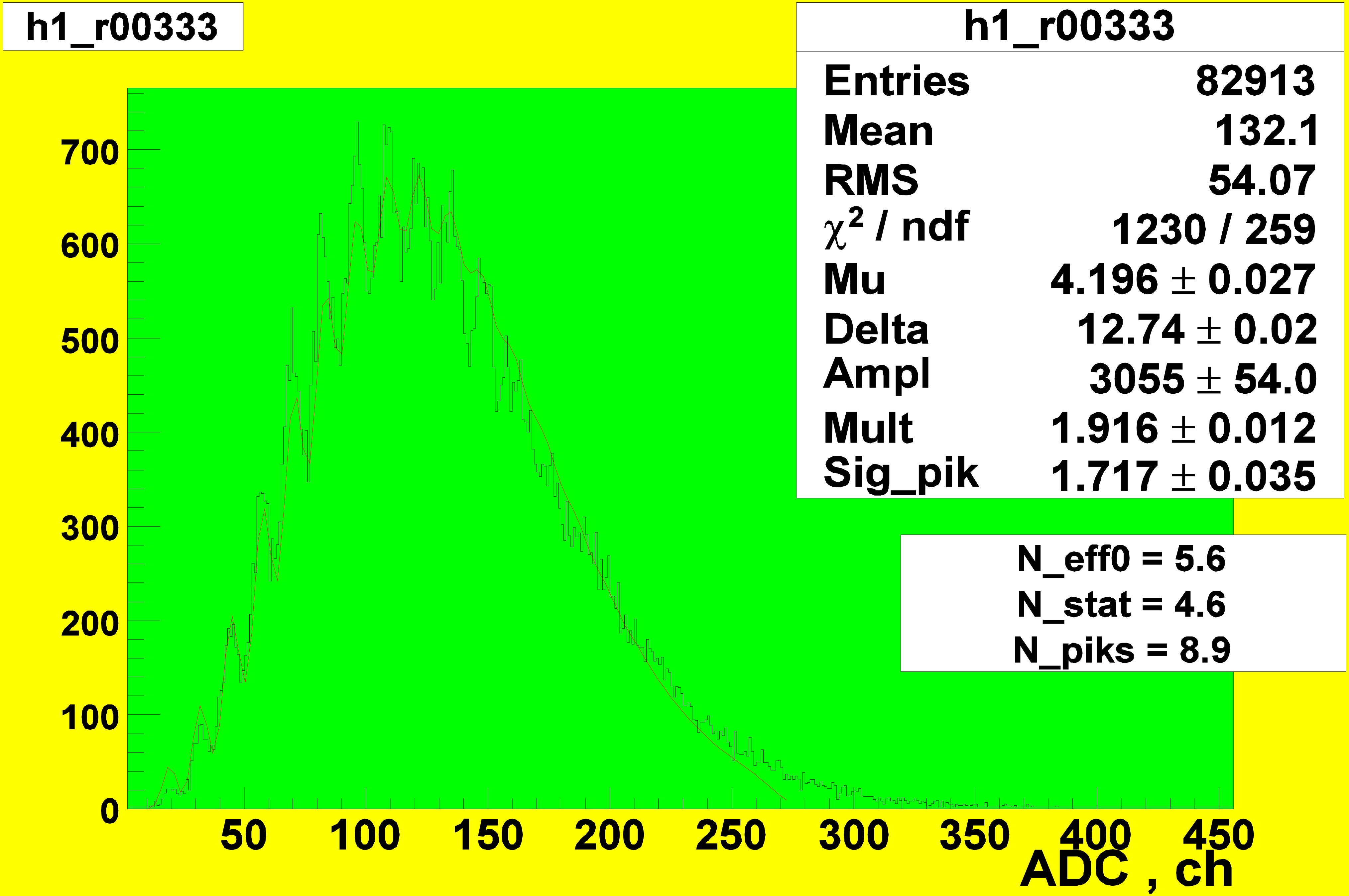
h1_r00313	
Entries	135216
Mean	179.2
RMS	63.39
χ^2 / ndf	373.8 / 184
Mu	6.474 ± 0.050
Delta	12.8 ± 0.0
Ampl	4872 ± 81.2
Mult	1.746 ± 0.016
Sig_pik	1.593 ± 0.028

N_eff0 = 7.8
N_stat = 6.6
N_piks = 12

Спектр от космики, ОКА пластик Харьков, PD_1, U=38.5В



Светодиод, ОКА пластик Харьков, PD_2, U=39.0В

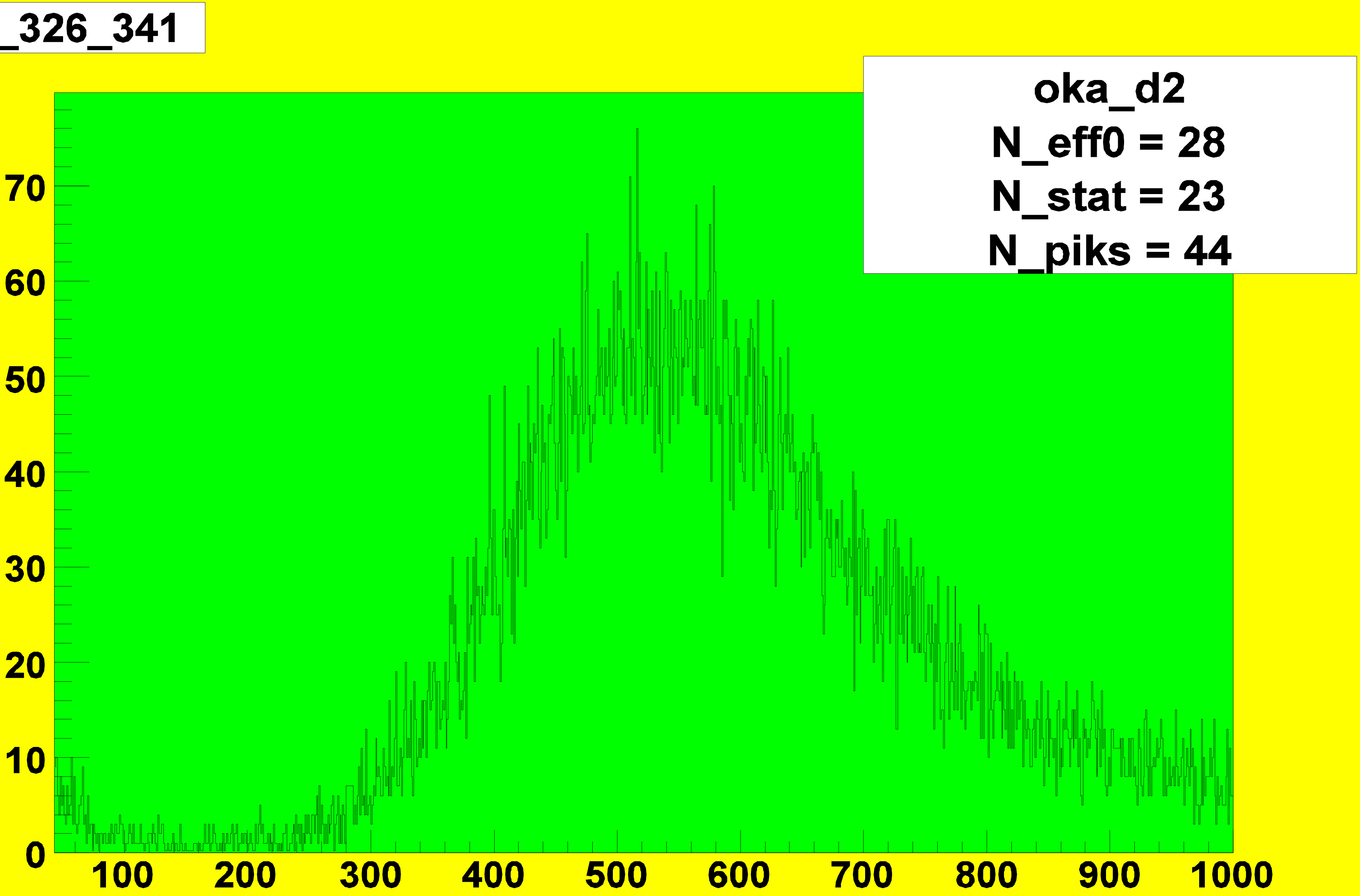


h1_r00333

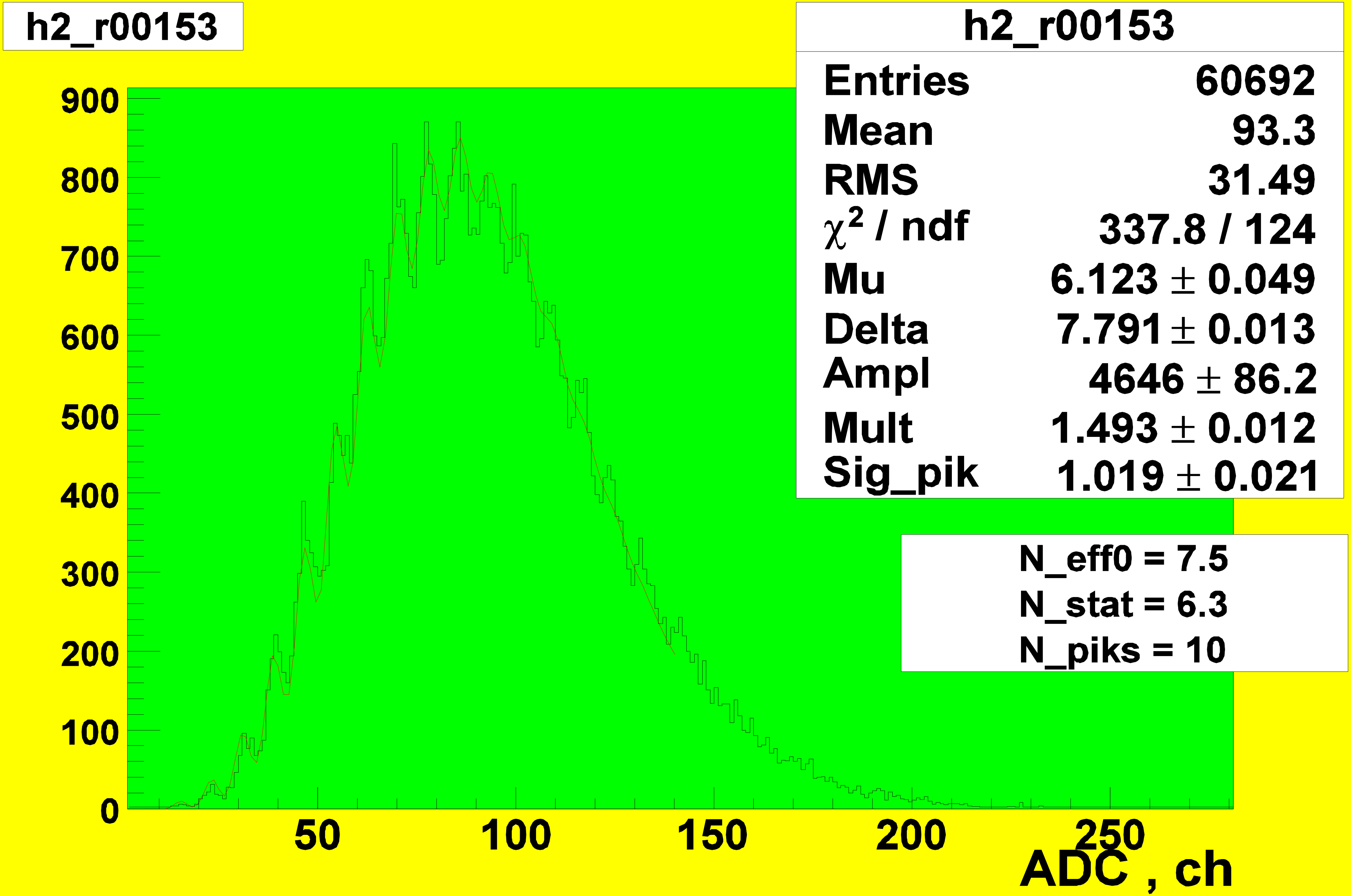
Entries	82913
Mean	132.1
RMS	54.07
χ^2 / ndf	1230 / 259
Mu	4.196 ± 0.027
Delta	12.74 ± 0.02
Ampl	3055 ± 54.0
Mult	1.916 ± 0.012
Sig_pik	1.717 ± 0.035

N_eff0 = 5.6
N_stat = 4.6
N_piks = 8.9

Спектр от космики, ОКА пластик Харьков, PD_2 , U=39.0B



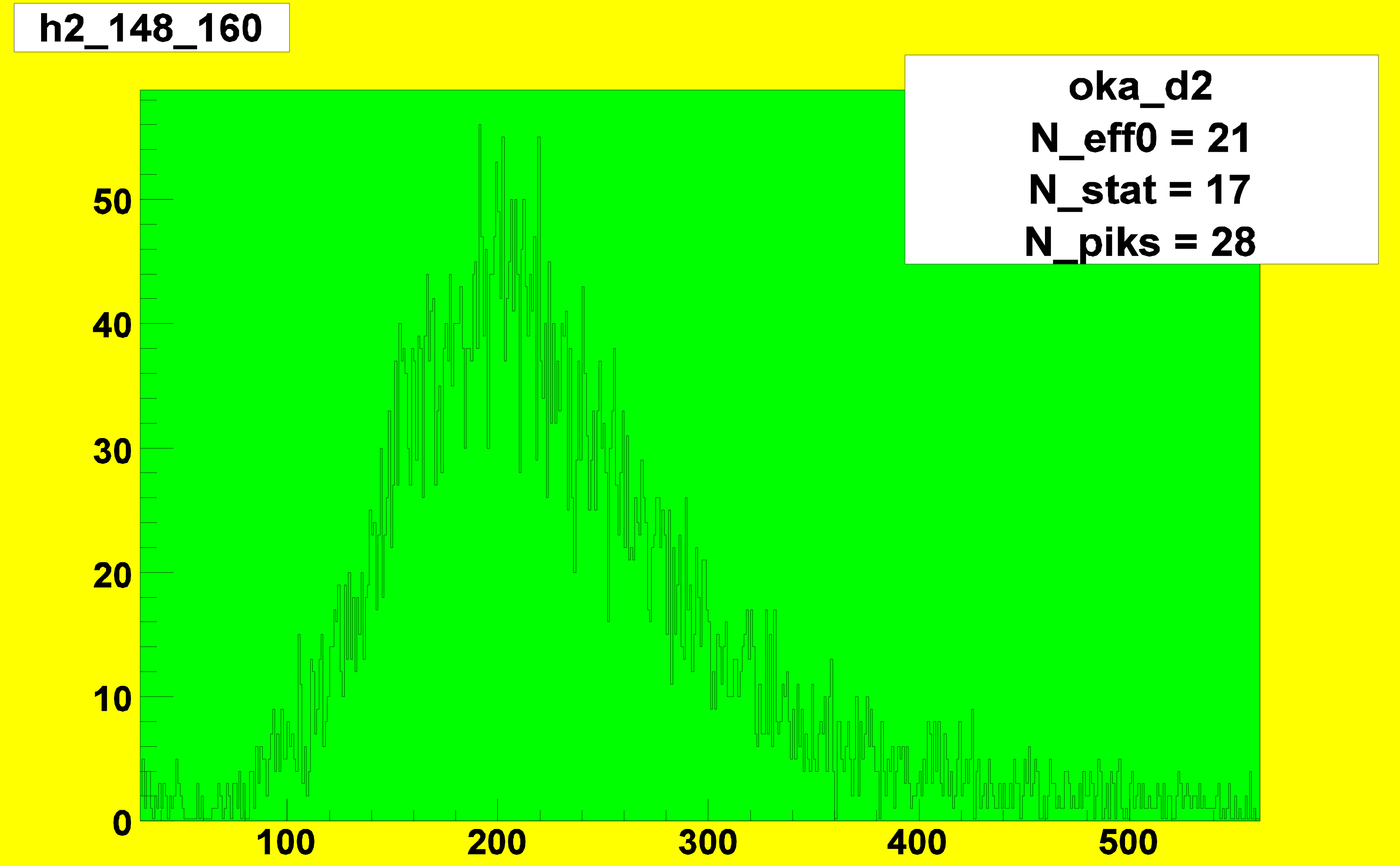
Светодиод, ОКА пластик BASF, PD_1 , U=39.0В



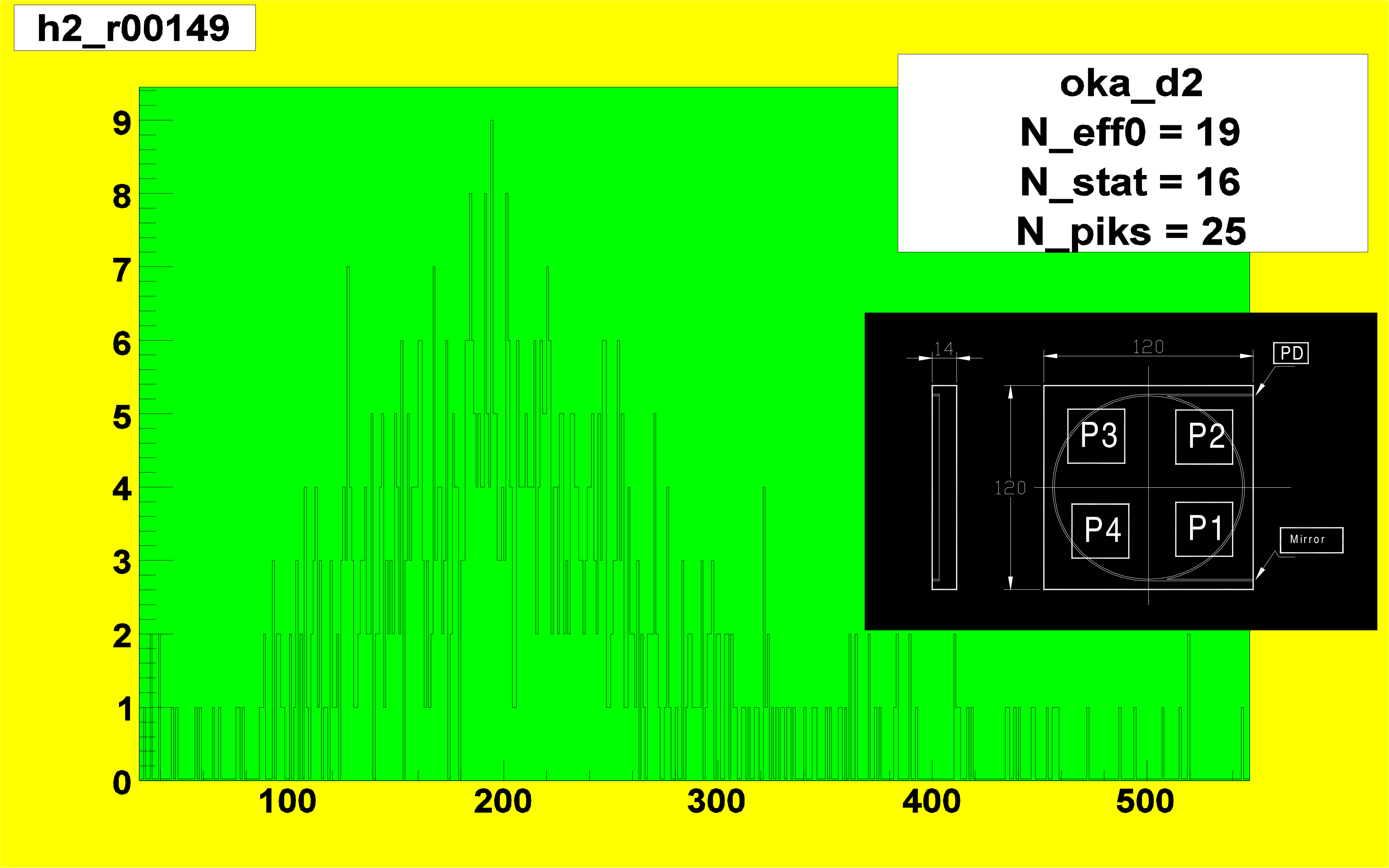
h2_r00153	
Entries	60692
Mean	93.3
RMS	31.49
χ^2 / ndf	337.8 / 124
Mu	6.123 ± 0.049
Delta	7.791 ± 0.013
Ampl	4646 ± 86.2
Mult	1.493 ± 0.012
Sig_pik	1.019 ± 0.021

N_eff0 = 7.5
N_stat = 6.3
N_piks = 10

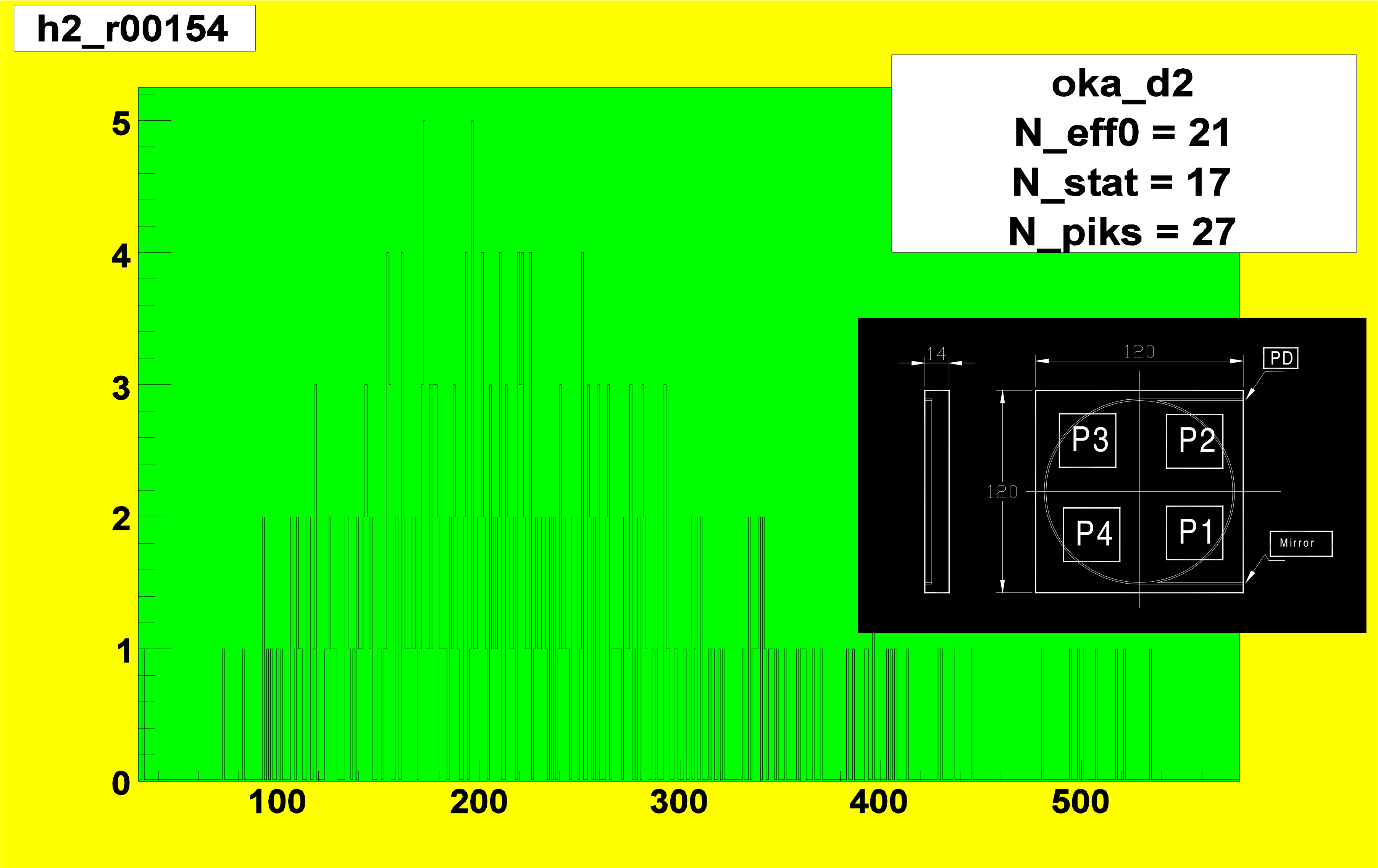
Спектр от космики, ОКА пластик BASF, PD_1 , U=39.0B



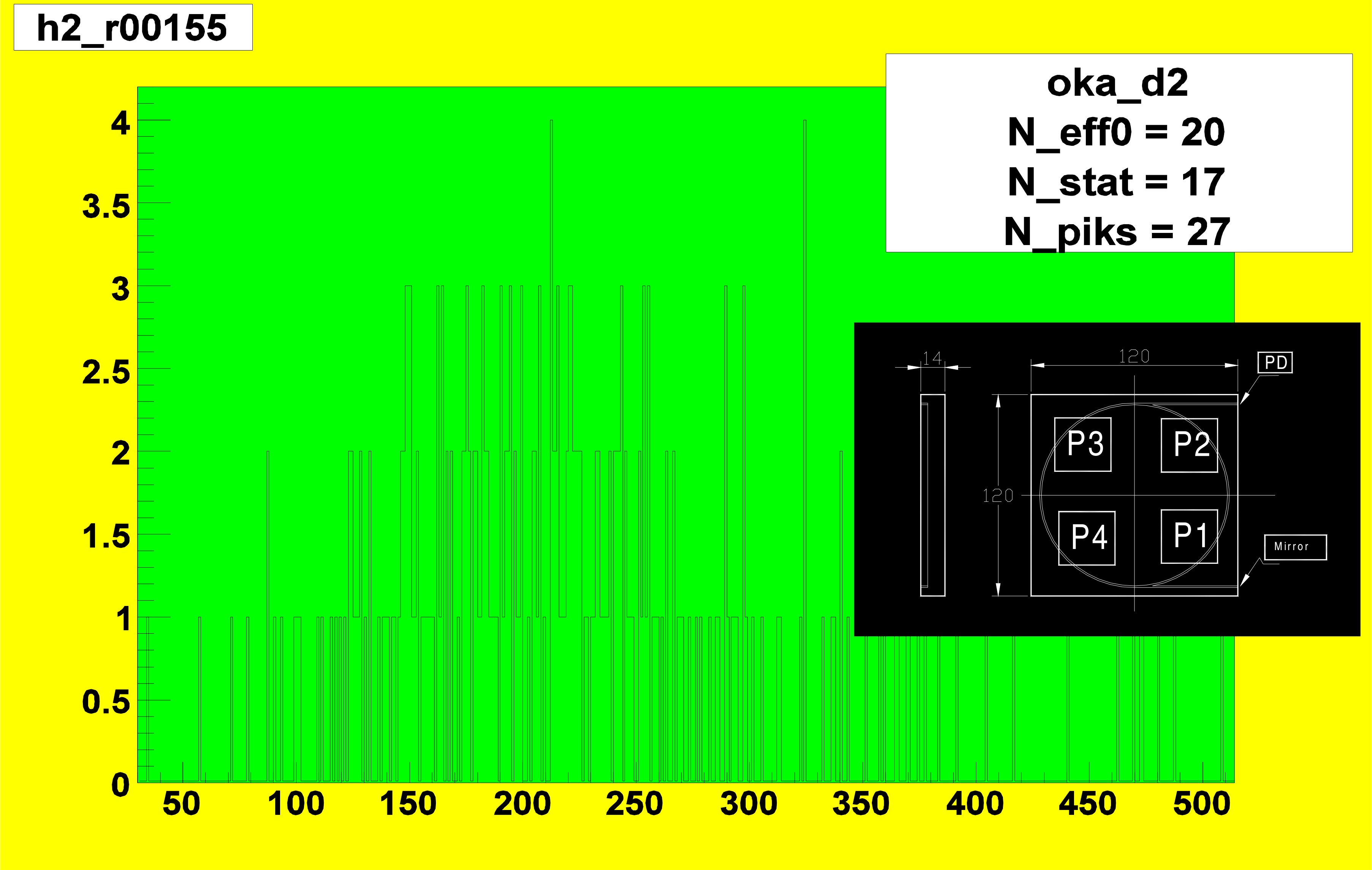
Позиция P1


h2_r00149
oka_d2
N_eff0 = 19
N_stat = 16
N_piks = 25
0
1
2
3
4
5
6
7
8
9
100
200
300
400
500
14
120
PD
120
P3
P2
P4
P1
Mirror

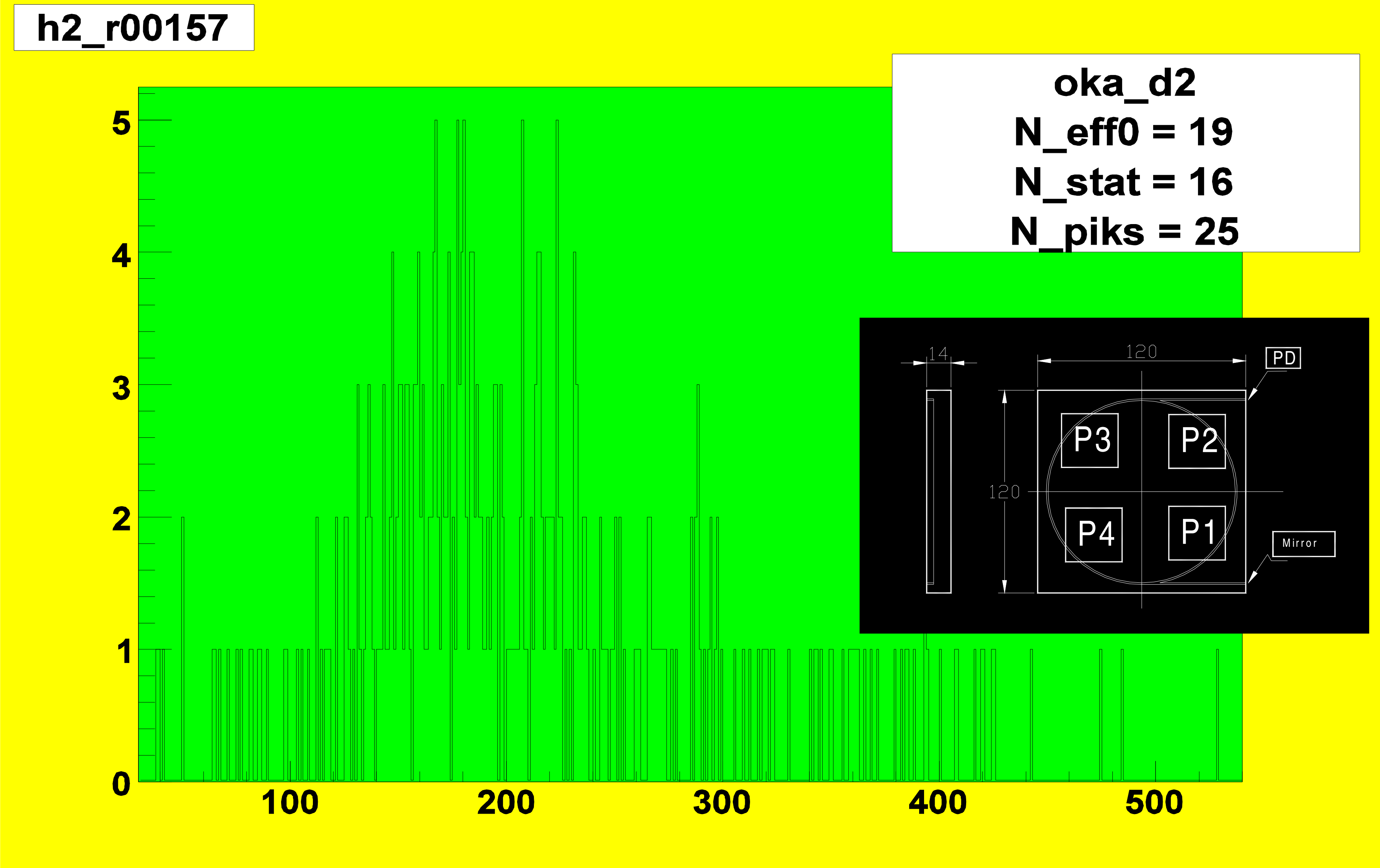
Позиция P2


h2_r00154
oka_d2
N_eff0 = 21
N_stat = 17
N_piks = 27
0
1
2
3
4
5
100
200
300
400
500
14
120
PD
120
P3
P2
P4
P1
Mirror

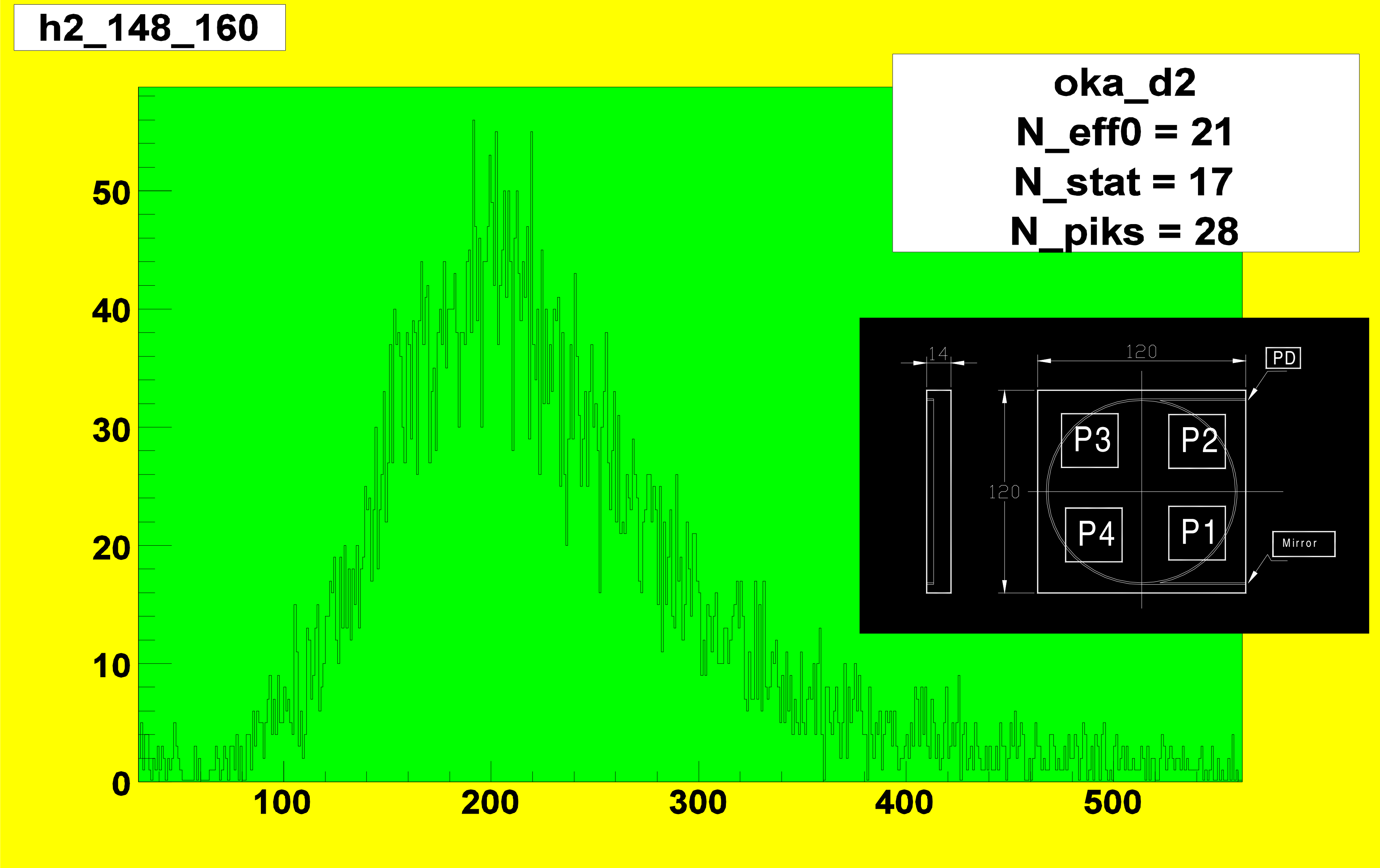
Позиция P3


h2_r00155
oka_d2
N_eff0 = 20
N_stat = 17
N_piks = 27
0
0.5
1
1.5
2
2.5
3
3.5
4
50
100
150
200
250
300
350
400
450
500
14
120
PD
120
P3
P2
P4
P1
Mirror

Позиция P4


h2_r00157
oka_d2
N_eff0 = 19
N_stat = 16
N_piks = 25
0
1
2
3
4
5
100
200
300
400
500
14
120
PD
120
P3
P2
P4
P1
Mirror

Позиция - центр



oka_d2
N_eff0 = 21
N_stat = 17
N_piks = 28

Заключение:

1. Величина сигнала при смещении на диоде +39В:
    1. 23 фотоэлектона или
    2. 43 фотопика
2. Амплитуда сигнала: 200 мВ на 1 MIP
3. Шум на пороге 8 фотопиков (5фотоэлектронов):
    1. 1.0 Hz при температуре +20 градусов
    2. 0.1 Hz при температуре -10 градусов
4. Материал сцинтиллятора : ПС- Харьков
5. Однородность: 2-3% по площади 120x120мм **2
6. Волокно : Y11 диаметром 1мм
7. SiPM – силиконовый фотоумножитель с размером кристалла 1x1мм ^{2}
8. Усилитель : NE55390