Technical Note
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Setting the Gain in BSD Counters

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Abstract

Analysing the analog signal (*adc*) from the BSD detector it is observed that the position of the maximum of the *adc* distributions varies with the counter number. This is corrected by finding the relative gain constants that make integrated *adc* spectra equal to one chosen reference counter. In addition, it is seen that average gain depends on pixel position. It decreases exponentially as pixel index increases, independent of the trigger type. Comparing standard and minimum-bias data it is concluded that the observed gain dependence comes from the attenuation of light along the BSD paddle. The gain dependence on pixel index is best described by a superposition of one falling exponential and one increasing linear function. Fit to the pixel gain distributions yields coefficients that can be used to correct for attenuation losses. These coefficients have similar values for different BSD counters.

1 Introduction

The main purpose of the Barrel Scintillation Detector (BSD) is to increase the acceptance of the Radphi experiment for the slow protons recoiled from γp interactions. In combination with the Barrel Gamma Veto (BGV) detector, which wraps around the BSD, it can be used to increase the acceptance for photons. The BSD detector consists of 48 scintillating paddles, with attached PMTs, grouped in three layers. The inner two layers have 12 paddles each, organized as right-hand (the first) and left-hand spirals (the second layer), while the third set consists of 24 straight paddles. The scintillating paddles are numbered, according to their layer, as BSD channels R0 - R11, L12 - L23 and S24 - S47. Coincidence between overlapping BSD channels forms a pixel. Coordinates of pixels are defined by straight paddle and pixel index. Pixel index is numbered 0 - 7 from upstream to downstream. These two coordinates allow us to form spatial distributions of detected particles.

In this technical note we analyze the analog (adc) signal from the BSD detector. For the given layer, we should not expect that signal above some well defined threshold depends on the counter number (azimuth dependence). The way to ensure this is to match relative gain within layers. In the next section the matching procedure is explained and the gain constants used to match relative gains are given. Analysis of the adc signal within particular BSD counter shows that average gain decreases as pixel index increases (polar angle dependence). One interpretation is that signal is decreasing because of attenuation of light along a BSD counter. In the last section this assumption is justified and the pixel gain distributions, before and after attenuation correction, are presented.

2 Setting the relative gain

Event distributions of analog signals from different BSD counters are similar in shape, but due to different counter characteristics, such as threshold, light collection efficiency etc., the position and height of the maximum of the distribution varies from counter to counter (see Fig. 1a). However, all BSD counters should have tails of adc spectra (aBSD $\geq$ 200) that are similar both in shape and magnitude. Thus, instead of matching maxima or mean values of adc distributions, it is preferable to match the tails of distributions by matching integrated adc spectra to some chosen reference counter within each layer. This method makes the matching insensitive to distortions of the spectra at low pulse height that come from discriminator thresholds.

The first step in setting relative gains is to choose some point e_0 above threshold in the adc distribution of the reference channel and calculate the integral from this point to infinity. The second step is to find the appropriate value of e from each other counter so that the corresponding integrals are equal to the reference one

$$\int_e^\infty \frac{dN}{de} de = I^{ref} = \int_{e_0}^\infty \frac{dN}{de} de. \tag{1}$$

The next step is to scale the gain of each counter so that e lines up with e_0. In general, the signal is proportional to some gain constant g when pedestal p is subtracted

$$e' = g(e - p). \tag{2}$$

If the pedestal value is already subtracted, then from Eq. 2 we can get the gain coefficient needed to make scales equal ($e' = e_0$)

$$g = \frac{e_0}{e}. \tag{3}$$

We decided to calculate g for two different integration limits e_0 and to take the average value of g. Counter R03 is chosen to be the reference one for all other counters. In Table 1 are given gain constants obtained for two chosen reference values $e_{0_1} = 80$, and $e_{0_2} = 120$. Multiplying adc signal by the corresponding $\bar{g}$ one can set gains in different BSD counters relative to the chosen one. In Fig. 1b one can see adc spectra from several straight counters after their relative gain has been applied.

3 Attenuation of light along BSD paddles

The adc signal from a BSD counter is proportional to the amount of collected light, or in other words to the deposited energy. When one compares different pixels in a given counter, it can be seen that peak position

Table 1: Gain constants set relative to counter R03.

Counter	$g_1 = \frac{e_{o1}}{e_1}$	$g_2 = \frac{e_{o2}}{e_2}$	$\bar{g}$	$\lvert g_1 - g_2 \rvert$
R00	0.8081	0.8219	0.8150	0.0138
R01	0.6897	0.7018	0.6957	0.0121
R02	0.6504	0.6704	0.6604	0.0200
R03	1.0000	1.0000	1.0000	0.0000
R04	0.5369	0.5333	0.5351	0.0036
R05	0.9091	0.9375	0.9233	0.0284
R06	0.9091	0.9231	0.9161	0.0140
R07	0.9756	0.9917	0.9837	0.0161
R08	1.0667	1.0909	1.0788	0.0242
R09	0.7143	0.7229	0.7186	0.0086
R10	0.7018	0.6977	0.6997	0.0041
R11	0.8696	0.9023	0.8859	0.0327
L12	1.3333	1.3483	1.3408	0.0150
L13	1.1765	1.2000	1.1882	0.0235
L14	1.1594	1.1538	1.1566	0.0056
L15	1.2500	1.2903	1.2702	0.0403
L16	0.8989	0.8824	0.8906	0.0165
L17	1.0526	1.0435	1.0481	0.0092
L18	1.0811	1.0909	1.0860	0.0098
L19	1.3115	1.3333	1.3224	0.0219
L20	0.9639	0.9756	0.9697	0.0118
L21	1.1111	1.1215	1.1163	0.0104
L22	0.8247	0.8163	0.8205	0.0084
L23	0.9877	0.9524	0.9700	0.0353
S24	0.9302	0.9023	0.9162	0.0280
S25	1.0127	1.0526	1.0326	0.0400
S26	1.0959	1.1321	1.1140	0.0362
S27	1.1111	1.1429	1.1270	0.0317
S28	1.1594	1.1881	1.1738	0.0287
S29	1.1765	1.1765	1.1765	0.0000
S30	0.7921	0.7643	0.7782	0.0277
S31	0.7339	0.7547	0.7443	0.0208
S32	1.2903	1.2903	1.2903	0.0000
S33	0.8247	0.8571	0.8409	0.0324
S34	0.8989	0.9231	0.9110	0.0242
S35	0.8889	0.9023	0.8956	0.0134
S36	0.8989	0.9160	0.9075	0.0172
S37	1.0811	1.0811	1.0811	0.0000
S38	0.8602	0.8759	0.8681	0.0157
S39	1.0390	1.0345	1.0367	0.0045
S40	1.0127	1.0256	1.0191	0.0130
S41	0.8247	0.7843	0.8045	0.0404
S42	1.0127	0.9836	0.9981	0.0291
S43	1.2698	1.2903	1.2801	0.0205
S44	1.0526	1.0619	1.0573	0.0093
S45	0.8791	0.8571	0.8681	0.0220
S46	1.0667	1.0811	1.0739	0.0144
S47	1.1111	1.1215	1.1163	0.0104

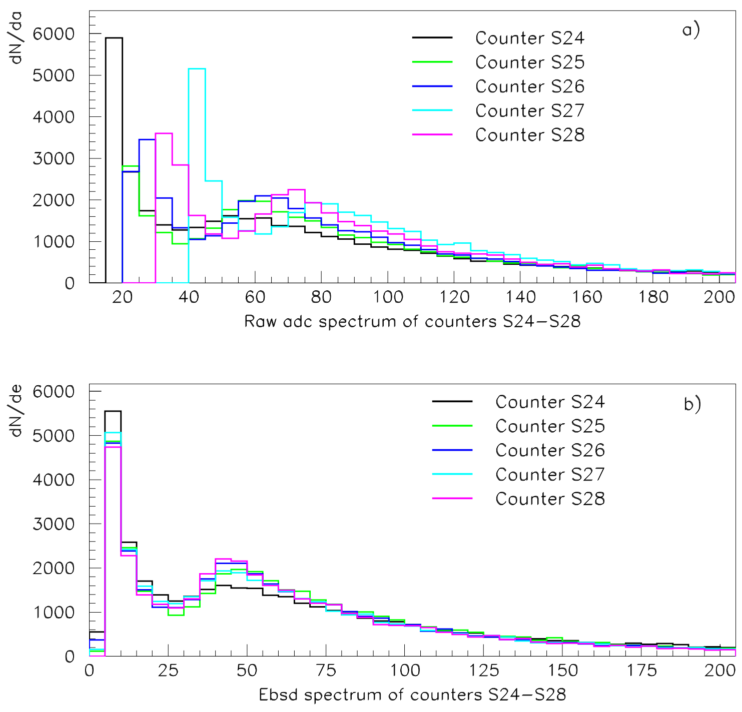

Figure 1: Event distribution of *adc* signal for counters S24-S28 plotted on top of each other before (a) and after (b) gain is matched to the reference channel (R03).

shifts toward lower values for higher pixel index (see Fig 2). The reason for that might be polar angle energy dependence or attenuation of light along the BSD counters. Since the same dependence is observed in both minimum-bias and standard data, it is concluded that attenuation of light is responsible for the observed gain dependence on pixel index. If the effect were due to the dependence of the particle spectrum on polar angle, the gain vs. pixel curve should be different for hadronic (standard) and electromagnetic (minimum-bias) backgrounds.

In order to explore this dependence, the distribution of mean *adc* gain as a function of pixel number is formed for every BSD counter. All distributions of pixel gains show the same characteristics (see Fig. 3): fast exponential drop for the first three pixels and a rather flat tail at higher pixels. An exponential drop would be expected from attenuation, while flattening might be due to reflection from the end of the counter. Thus, the sum of one falling and one increasing exponential function could be used to describe the data

$$g(z) \sim [exp(-bz) + C\,exp(bz)], \tag{4}$$

where z is given in pixel units. The constant b is inversely proportional to the attenuation length while C takes care of the reflection coefficient and length of the paddle. Alternatively, one might explain the flattening of the gain curve at smaller angles by the increasing path length of the particle passing through the counter

$$gain \sim L = a/sin(\theta) \sim \sqrt{r^2 + z^2},$$

where a is the thickness of a paddle, θ is the angle from the beam axis ($\theta \sim 30^0$ near the end of the detector), and r is the radius of a given layer. Taking into account these effects leads to following equation

$$g(z) = A\sqrt{r^2 + z^2}[exp(-z/B) + Cexp(z/B)]. \tag{5}$$

This function has three parameters A, B, and C, where B is now proportional to the attenuation length. By fitting the distributions of pixel gains using this function with three free parameters it is possible to obtain good agreement with the data. However, it is found that a fit of equal quality can be obtained using a simpler function that is the sum of a falling exponential and a linearly increasing function (see Fig 3)

$$g(z) = A[exp(-z/B) + Cz]. \tag{6}$$

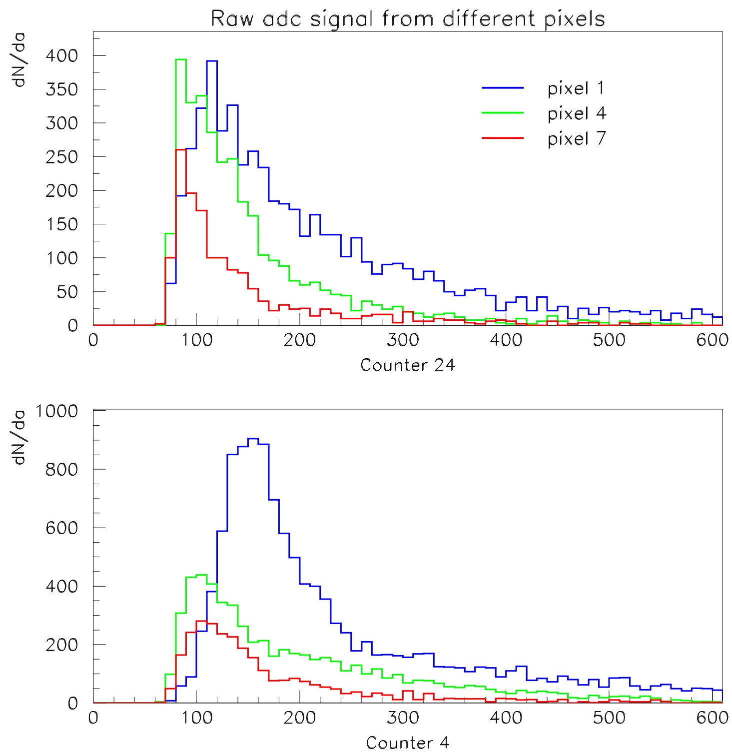

Figure 2: Raw *adc* signal from counters S24 and R04 for several chosen pixels, minimum-bias data.

This parametrization is found to yield parameters with smaller fluctuations from counter to counter than are obtained using Eq. 5. In Table 2 are given results of three and two-parameter fits, as well as average and r.m.s values of fitting parameters for the two different types of BSD paddles. After the fit, the parameter A is discarded since it can be absorbed into the gain. One can see that there are more variations of B for three than for two-parameter fit, and even negative values of C in the case of three-parameter fit. When parameter C is kept fixed (one value for spirals and one for straights), similar values of B are obtained for all BSD counters within particular layer. Because of the similarity of the pixel gain distributions from standard and minimum-bias data, and the larger statistics of standard data, we decided to take standard data to obtain the calibration constants,

$$cor(z) = \frac{g(0)}{g(z)} = \frac{1}{exp(-z/B) + Cz}. \tag{7}$$

Values of B and C used to correct pixel gains are given in the last two columns of Table 2. and they are obtained using standard run r8003. In Figs. 4 - 7 are shown pixel gain distributions, before (dashed crosses) and after corrections for attenuation (solid crosses) for all 48 BSD counters. As an example of how the attenuation correction procedure is checked, in Fig. 8 is given the pixel gain distribution of the first layer of BSD counters from the standard run r8600. The calibration constants were obtained from run r8003.

In conclusion, the analog signal from the BSD detector is analysed. It is observed that all BSD paddles have similar *adc* distributions. However, because of different characteristics of the counters, the position of the maximum varies from counter to counter. In order to correct for this, relative gain constants are found so that integrated spectra are matched to one chosen reference counter. In addition, it is seen that average gain depends on pixel position. Average gain decreases exponentially as pixel index increases, independent of the trigger type. Comparing standard and minimum-bias data it is concluded that the observed gain dependence comes from the attenuation of light along the BSD paddle. The gain dependence on pixel index is best described by a superposition of one falling exponential and one increasing linear function. Fit to the pixel gain distributions yields coefficients that can be used to correct for attenuation losses. These coefficients have similar values for different BSD counters.

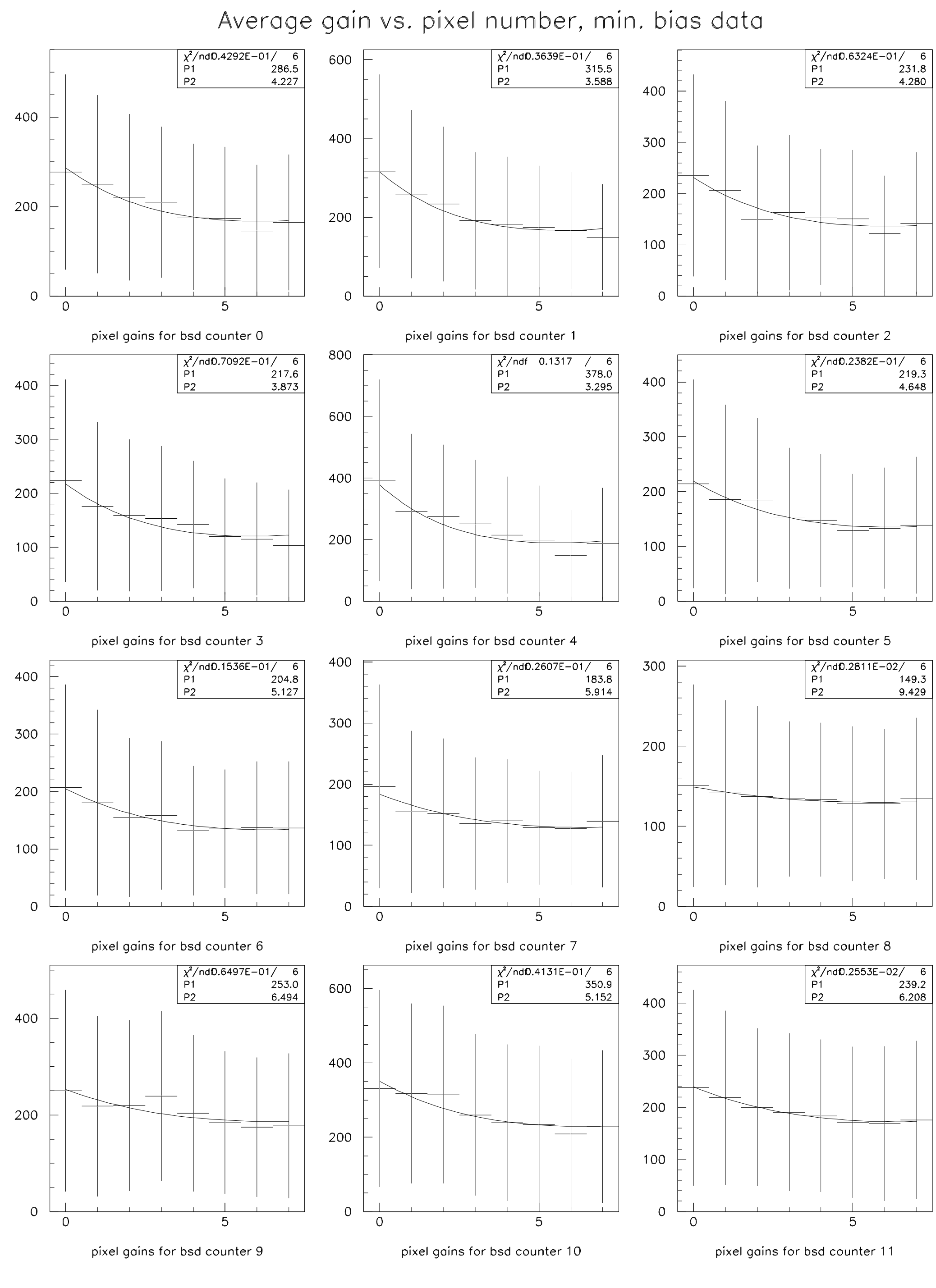

Figure 3: Pixel gain distributions for the first layer of BSD counters (channels R0-R11). Solid lines represent the best fit obtained with three free parameters.

Table 2: Attenuation of light in the BSD counters: the best fit results in the case of three and two fitting parameters. The normalization parameter A is discarded.

	Minimum-bias data							Standard data		
	Three parameters				Two par.			Two par.		
Counters	B		C		B		C (fix.)	B		C (fix.)
R00	5.93		.034		4.23		.055	4.33		.057
R01	4.74		.038		3.58			3.85		
R02	4.49		.054		4.27			4.01		
R03	6.80		.020		3.87			3.49		
R04	4.85		.029		3.29			3.12		
R05	5.58		.046		4.64			4.87		
R06	4.64		.063		5.13			4.17		
R07	4.44		.073		5.91			4.42		
R08	7.87		.066		9.42			5.98		
R09	15.67		.008		6.49			4.49		
R10	7.57		.032		5.15			3.72		
R11	5.95		.059		6.21			5.06		
L12	10.99		.026		6.26			5.83		
L13	7.54		.051		6.74			5.33		
L14	5.75		.058		5.88			3.69		
L15	5.77		.071		7.36			5.19		
L16	3.45		.062		3.77			2.97		
L17	4.35		.065		5.02			3.99		
L18	3.69		.068		4.49			3.81		
L19	5.59		.062		6.24			5.12		
L20	7.76		.033		5.19			4.64		
L21	6.63		.044		5.40			4.74		
L22	5.89		.029		3.96			3.97		
L23	9.81		-.001		3.95			3.49		
average/rms	6.49	2.61	.05	.02	5.27	1.4		4.35	0.8	
S24	4.88		.048		5.88		0.035	4.16		.037
S25	16.91		.015		10.50			8.03		
S26	19.81		.003		9.25			7.42		
S27	11.23		.021		8.18			6.45		
S28	20.86		.001		9.38			7.67		
S29	6.12		.039		6.31			5.09		
S30	4.26		.041		4.59			3.60		
S31	5.79		.049		7.33			6.65		
S32	14.22		.018		9.67			8.69		
S33	43.43		-.021		9.17			7.67		
S34	47.81		-.036		7.35			6.36		
S35	48.22		-.029		8.31			6.54		
S36	23.32		-.012		7.83			6.87		
S37	8.64		.031		7.66			5.97		
S38	21.97		-.030		5.84			6.49		
S39	19.88		-.025		5.79			5.74		
S40	31.65		-.030		6.86			6.56		
S41	6.14		.014		4.32			3.54		
S42	12.74		-.007		5.74			4.73		
S43	22.98		.001		9.91			6.96		
S44	19.45		.013		11.24			6.23		
S45	8.80		.019		6.47			4.35		
S46	11.21		.034		10.33			7.77		
S47	8.65		.038		8.84			6.07		
average/rms	18.28	12.76	.008	.02	7.79	1.89		6.24	1.4	

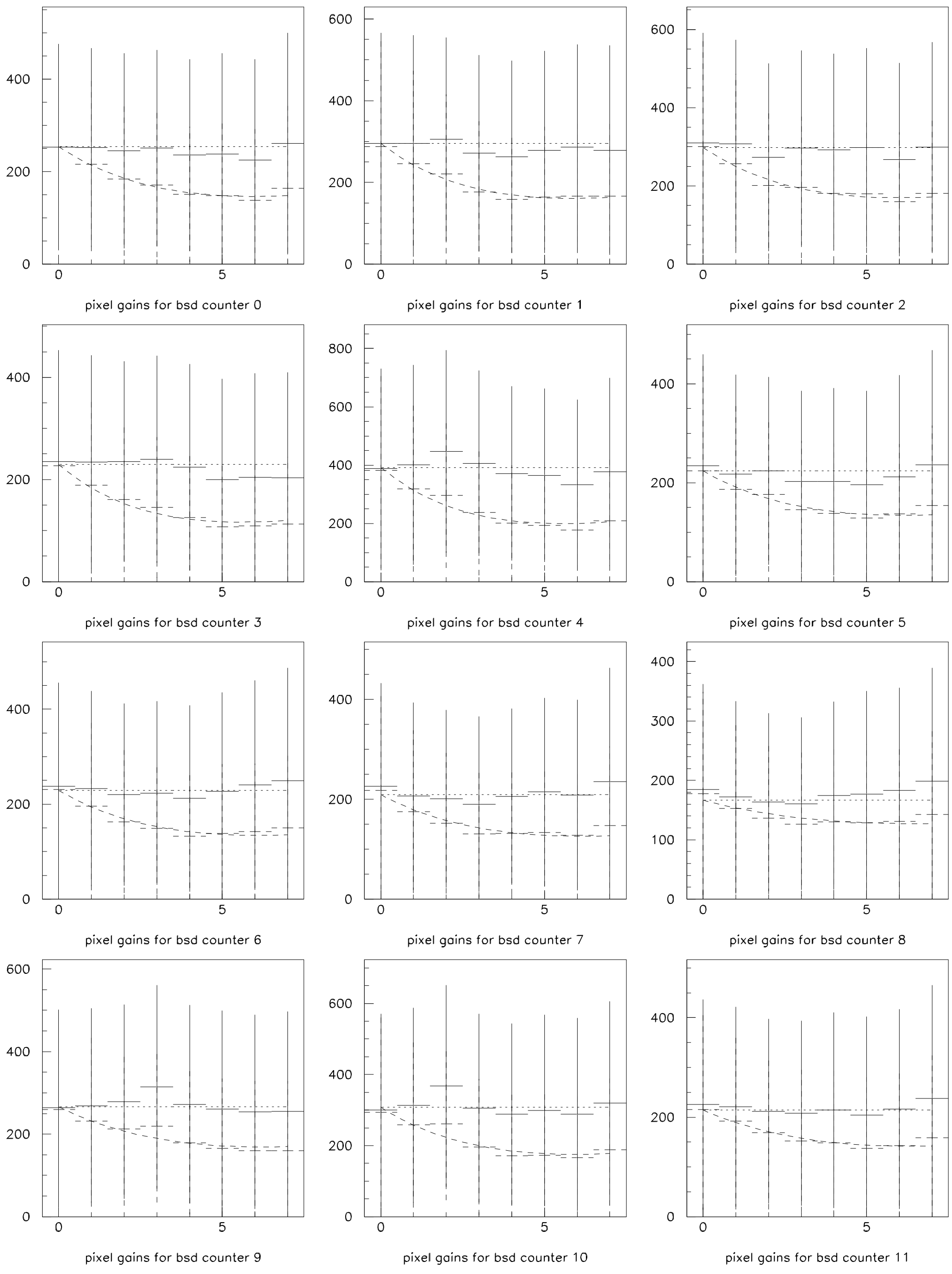

Figure 4: Pixel gain distributions for channels R0-R11 after attenuation corrections. Dashed crosses represent gains before corrections. The dashed line represents the best fit obtained by use of Eq. 6 when C is kept fixed (see Table 2). The dotted line represents the expected gain level following the attenuation correction.

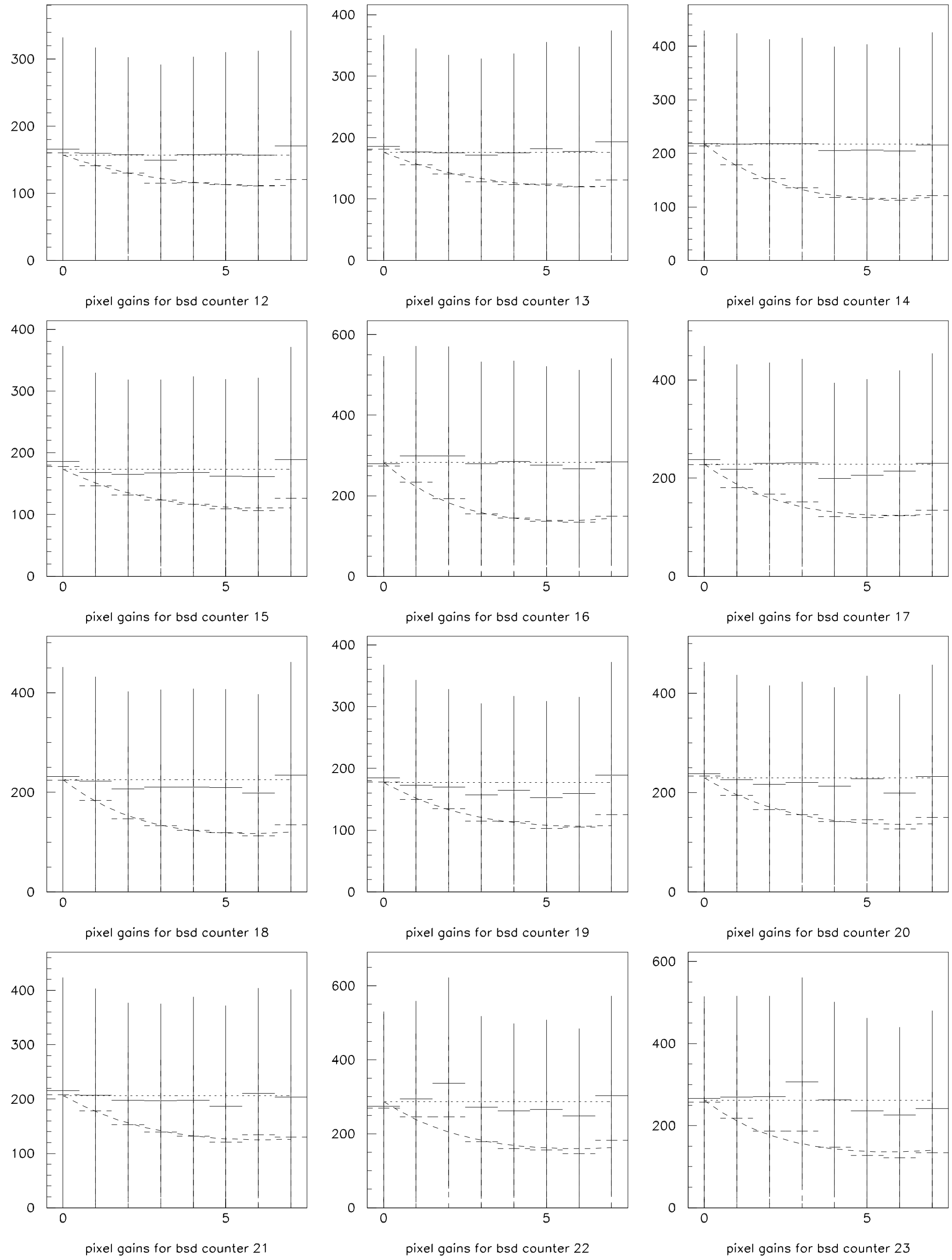

Figure 5: The same as Fig. 4 but for the left counters L12 -L23.

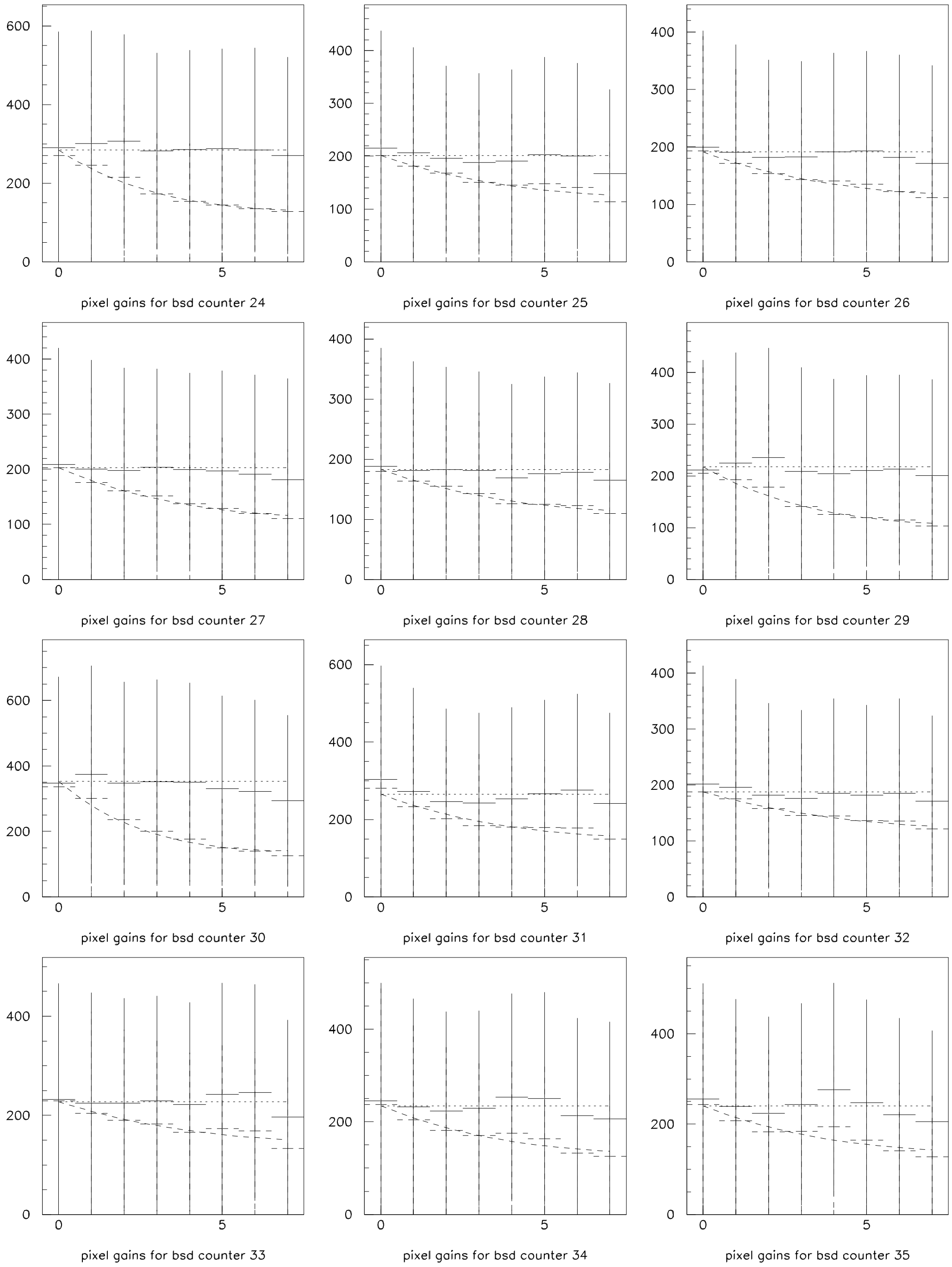

Figure 6: The same as Fig. 4 but for the straight counters S24 -S35.

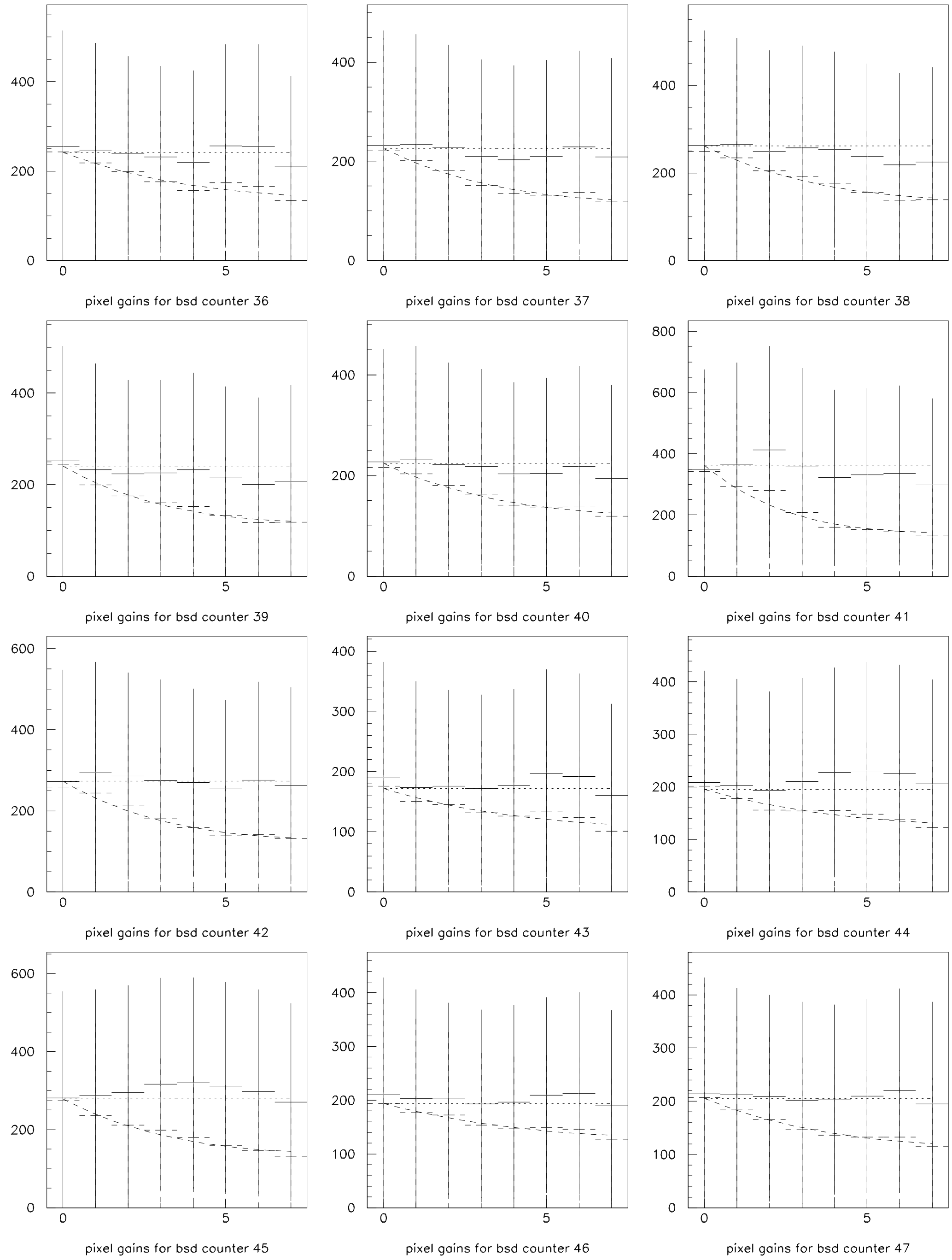

Figure 7: The same as Fig. 4 but for the straight counters S36 -S48.

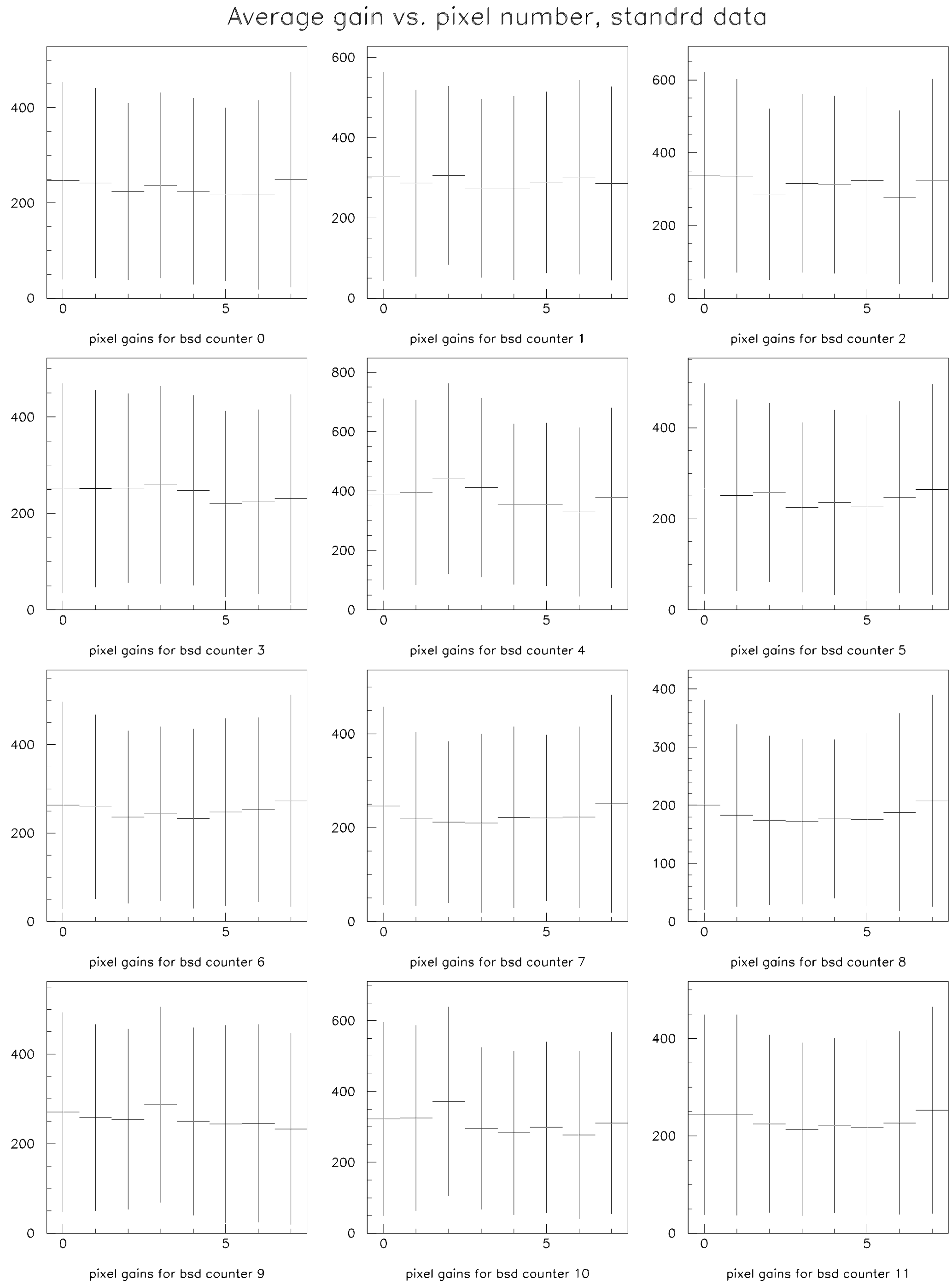

Figure 8: Standard run r8600: pixel gain distributions for channels R0-R11 after attenuation corrections performed using correction factors given in the last two columns of Table 2.