Gamma-Gamma Angle Correlation

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The beta-disaggregation of Cobalt-60 produces 2 gamma quants which energy spectrum and angle correlation will be examined.

Contents

1 Theory

1.1 Decay of 60-cobalt

The nuclear of 60-cobalt atom decays in process of β-decay to excited 60-nickel atom. The left energy will be emitted to 2 γ quants at almost same time as you can see at figure 1.

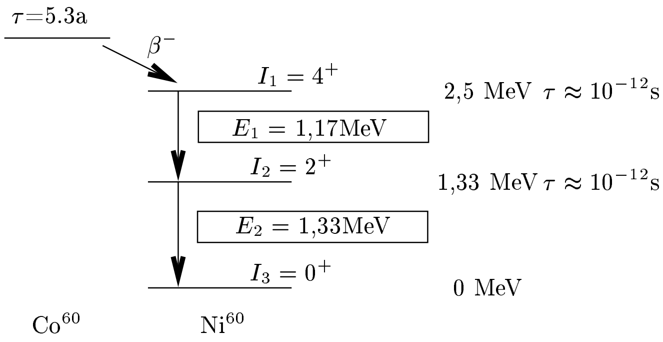

Figure 1: The Energy sheme of 60-cobalt decay

1.2 Interaction of Gamma quants

There are interactions of gamma quants in the detector: The photo effect and the compton effect. At the compton effect a gamma quant is scattered elastic at a quasi free electron. A part of energy is comitted to electron the other part leaves the matter of detector. This interaction produces a continious background. The difference of energy ΔE can be calculated with

$$\Delta E = E_0 \frac{2\Lambda \sin^2 \frac{1}{2}\varphi}{\lambda_0 + 2\Lambda \sin^2 \frac{1}{2}\varphi} \tag{1.1}$$

At the formular: φ the angle of scattering, Λ =2,426$\cdot 10^{-12}$ m the compton wavelength of electron, E_0 the start energy of γ-quant and λ_0 the wavelength of γ-quant. The maximal energy E_{max} at the angle of 180° is

$$\Delta E_{max} = \frac{2E_0^2}{2E_0 + 511\,\mathrm{keV}}.$$

For the two values of $\gamma-$energies there are

$$E_0 = 1{,}12\,\mathrm{MeV} \qquad \text{for } E_2 = 1{,}33\,\mathrm{MeV}$$
$$E_0 = 0{,}96\,\mathrm{MeV} \qquad \text{for } E_3 = 1{,}17\,\mathrm{MeV}$$

The minimal remainder energy $E_0 - \Delta E_{max}$ can be examined at he mirror figure of compton edge. The values are:

$$E_0 - \Delta E_{max} = 215\,\mathrm{keV} \qquad \text{for } 1{,}33\,\mathrm{MeV}$$
$$E_0 - \Delta E_{max} = 210\,\mathrm{keV} \qquad \text{for } 1{,}17\,\mathrm{MeV}$$

The theoretical values for the coefficients are depends definitely on nuclear angular momentum I_1, I_2, I_3 and the multipolarity L_1 and L_2 of radiation. Look at table 1

Multipol Type	I_1	L_1	I_2	L_2	I_3	A'_2	A'_4
1	4	2	2	2	0	0,102	0,0091
2	2	2	2	2	0	-0,0765	0,326
3	4	3	2	2	0	-0,268	0,032
4	2	1	2	2	0	0,25	0

Table 1: The development coefficients of angle correlation function for selected angular momentums

1.3 Angle correlation

The orientation of nuclear angular momentum is equal for both γ–emissions and the direction of quants are correlated. The fields of radiation to other one has a relative orientation. We can find out a normed correlation function

$$W(\Theta) = 1 + A_2 + \mathrm{P}_2(\cos\Theta) + A_4\,\mathrm{P}_4(\cos\Theta)$$

At this formular P_i is the Legendre polynom, A_2 and A_4 are the developmente coefficient for nuclear anglear momentum and Θ the angle of 90°, 136° and 180°.
The developement coefficients A_i are calculated by coincidence rates $K(\Theta)$ for each angle: K_{90}, K_{135} and K_{180}.

$$\begin{aligned} A'_2 &= \frac{10}{7}\frac{-9K_{90} + 4K_{135} + 5K_{180}}{6K_{90} + 8K_{135} + K_{180}} \\ A'_4 &= \frac{48}{7}\frac{K_{90} - 2K_{135} + K_{180}}{6K_{90} + 8K_{135} + K_{180}} \end{aligned}$$

Correlation function The coincidence rate is proportial to correlations function.

$$K(\Theta) = \frac{C(\Theta)}{A(\Theta)B(\Theta)} - C_a(\Theta) \tag{1.2}$$

At this formular you can find the number of registrated quants $A(\Theta)$ and $B(\Theta)$, the number of registrated coincidences $C(\Theta)$ and the number of incidental coincidences $C_a(\Theta)$.

Limited detector angle In an experiment like this the detectors have got a limited length. The γ–quant pass a different way in cristal - so they have a different probability of absorption. Because of this the development coefficients at measure (symbol A'_2 and A'_4) will be connected with an extenuated coefficient Q. The extenuated coeffizients are Q_2=0,893 and Q_4=0,672 - given by literature.

$$\begin{aligned} A_2 &= \frac{A'_2}{Q_2^2} = \frac{A'_2}{0,797} \\ A_4 &= \frac{A'_4}{Q_4^2} = \frac{A'_4}{0,457} \end{aligned} \tag{1.3}$$

2 Assembly

The source of radation is radioactive 60-cobalt. There are two γ–detector at a certain distance: detector A fixed, detector B is moveable on a circle. The position of detector B is signed at values 90°, 135° and 180°. The detector consists of szintilations cristalls made of sodium iodid. At the side photomultipliers are installed. The singals of are transmitted to discriminator, which permit to pass only energy of a determed range. The coincidence step is installed to prove the concomitance of signals and to count the number of signal A and B in a time period. The detailed step of experiment are listed in the script of [1].

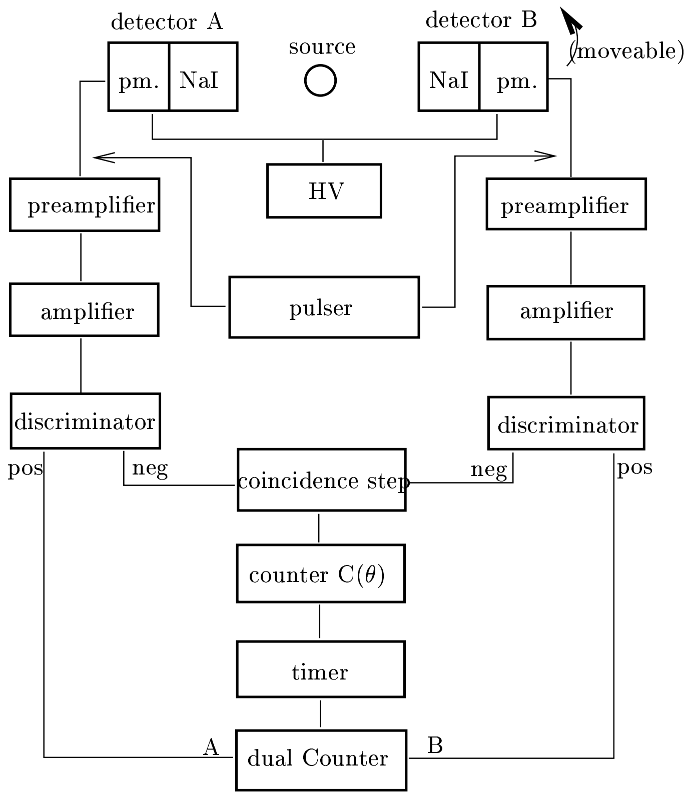

Figure 2: The Assembly for γ angle correlation. With photo multiplier (pm), high voltage source (HV), sodium iodid (NaI) and the counter for coincidences $C(\Theta)$

3 Implementation

At first we checked the temporal structure of pulses. The amplifier ist adjusted to send bipolar pulses with 4 volts to the SCA. The gross measure of pulses is given by an anlogue ratemeter - the exact counting will be done by dual counter. The scale of lower boarder for discriminator has an offset of 0,1 volts. We recommend to make measure of energy spectrum and coincidence in one unit. Else you will loose the dependence of voltage and energy by changing of delay time and windows width of disriminator.

3.1 Energy Spectrum

We have set the window width at 0,5 volts for detector A and 10,5 volts for detector B. The amplifiers have a value of 200 volts and the Photomultiplier a value of 1200 volts. The time of each measure are 20 seconds.

3.2 Coincidence

The step of coincidence is set to 15 ns. The SCA will be used in integration mode.

3.2.1 Delay and Coincidence

To examine the delay of both channels we set the delay at 11,78 volts (A) and 3,18 volts (B). In this state there are not any coincidences. Step be step the value of delay will be increased. It is important, that the peak of 1,17 MeV and 1,33 MeV will be passed by system. Sometimes we have to readjust the delay of channels.

3.2.2 Coincidence of Angles

Each measure has a time period of 200 seconds. We repeat the sequence 30°, 135° and 180° for 25 times. At the end of measure the number of incidental coincidences is measure at a time period of 400 seconds is counted.

4 Interpretation

4.1 Energy spectrum

4.1.1 Calibration of spectrum

The values of measure are listed in table 3 and 4. With these values we made a plot of volate in figure 4. You can find the full energy peaks of γ–quant look at figure 5 and 6. The voltage has an error of $\Delta U = 0,01\,\mathrm{V}$ and an offset of 0,01 V which must be reduced from each value.

	voltage A	voltage B
$E_1 = 1,17\,\mathrm{MeV}$	0,76	1,33
$E_2 = 1,33\,\mathrm{MeV}$	0,90	1,53

The lower voltage and energy should be proportional. But we have established the more exact way: Find the difference of the energy peak of $E_1 = 1,17\,\mathrm{MeV}$ and $E_2 = 1,33\,\mathrm{MeV}$. We introduce a linear dependence between voltage and energy with factor b and a constant number a:

$$\begin{aligned}
b &= \frac{E_2 - E_1}{U_2 - U_1} \\
\Delta b &= \sqrt{\frac{\Delta E_1^2}{(U_1 - U_2)^2} + \frac{\Delta E_2^2}{(U_2 - U_1)^2} + \frac{(E_2 - E_1)^2 \Delta U_1^2}{(U_1 - U_2)^4} + \frac{(E_1 - E_2)^2 \Delta U_2^2}{(U_1 - U_2)^4}} \\
E_2 &= b \cdot U_2 + a \\
a &= E_2 - b \cdot U_2 \\
\Delta a &= \sqrt{\Delta E_2^2 + U_2^2 \Delta b^2 + b^2 \Delta U_2^2} \\
E(U) &= b \cdot U + a \\
\Delta E(U) &= \sqrt{U^2 \Delta b^2 + b^2 \Delta U^2 + \Delta a^2}
\end{aligned}$$

$$\begin{aligned} b_A &= 1,143\,{}^{\mathrm{MeV}}/\mathrm{V} & b_B &= 0.800\,{}^{\mathrm{MeV}}/\mathrm{V} \\ \Delta b_A &= 0,115\,{}^{\mathrm{MeV}}/\mathrm{V} & \Delta b_B &= 0,056\,{}^{\mathrm{MeV}}/\mathrm{V} \\ a_A &= 0,301\,\mathrm{MeV} & a_B &= 0,106\,\mathrm{MeV} \\ \Delta a_A &= 0,105\,\mathrm{MeV} & \Delta a_B &= 0,087\,\mathrm{MeV} \end{aligned}$$

So we get for each detector:

$$E_A(U) = 1,143\,{}^{\mathrm{MeV}}/\mathrm{V}U + 0,301\,\mathrm{MeV} \qquad E_B(u) = 0,8\,{}^{\mathrm{MeV}}/\mathrm{V}U + 0,106\,\mathrm{MeV}$$

With this formular we created an energy spectrum in figure 3.

4.1.2 The compton edge

Looking at figure 7 and 8 the compton edge can be found at value 0,6 V and 1,05 V. So we get

$$\begin{aligned} E_A &= 1,143\,{}^{\mathrm{MeV}}/\mathrm{V}0,6\,\mathrm{V} + 0,301\,\mathrm{MeV} & E_B &= 0,8\,{}^{\mathrm{MeV}}/\mathrm{V}1,05\,\mathrm{V} + 0,106\,\mathrm{MeV} \\ &= 0,987\,\mathrm{MeV} \pm 0,126\,\mathrm{MeV} & &= 0,946\,\mathrm{MeV} \pm 0,060\,\mathrm{MeV} \end{aligned}$$

These are good values for emission of $E_1 = 1,17\,\mathrm{MeV}$ coming close to theoretical value of 0,96 MeV. The compton edge for emission of $E_2 = 1,33\,\mathrm{MeV}$ can be seen weakly - but its covered by the full peak of E_1–peak.

4.1.3 Back scattering peak

Looking at figure 9 and 10 the back scattering value can be found at value 0,05 V and 0,2 V. So we get

$$\begin{aligned} E_A &= 1,143\,{}^{\mathrm{MeV}}/\mathrm{V}0,05\,\mathrm{V} + 0,301\,\mathrm{MeV} & E_B &= 0,8\,{}^{\mathrm{MeV}}/\mathrm{V}0,2\,\mathrm{V} + 0,106\,\mathrm{MeV} \\ &= 0,358\,\mathrm{MeV} \pm 0,105\,\mathrm{MeV} & &= 0,266\,\mathrm{MeV} \pm 0,013\,\mathrm{MeV} \end{aligned}$$

There are rather unsharp values. There is neither clear assignment to 215 MeV nor to 210 MeV of the peaks.

4.2 Delay of both channels

We have set the window width to 20 ns. At the delay of 11,78 ns for detector A and delay of 3,18 ns the number of coincidence are zero. The mode of SCA is switched to integration. Changing the delay the figure 11 is measured and plotted at figure 12.

4.3 Measure of coincidences

The measured data are listed in table 5, 6 and 7. For the error handling we must take care for poisson statistic. To measure the coincidence rate $K(\Theta)$ we calculate for each measure step $K_0 = \frac{k}{AB}$. Conclusing 25 single measure the average and $\overline{K}_0$ with standard deviation

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(K_{0i} - \overline{K}_0)^2}$$

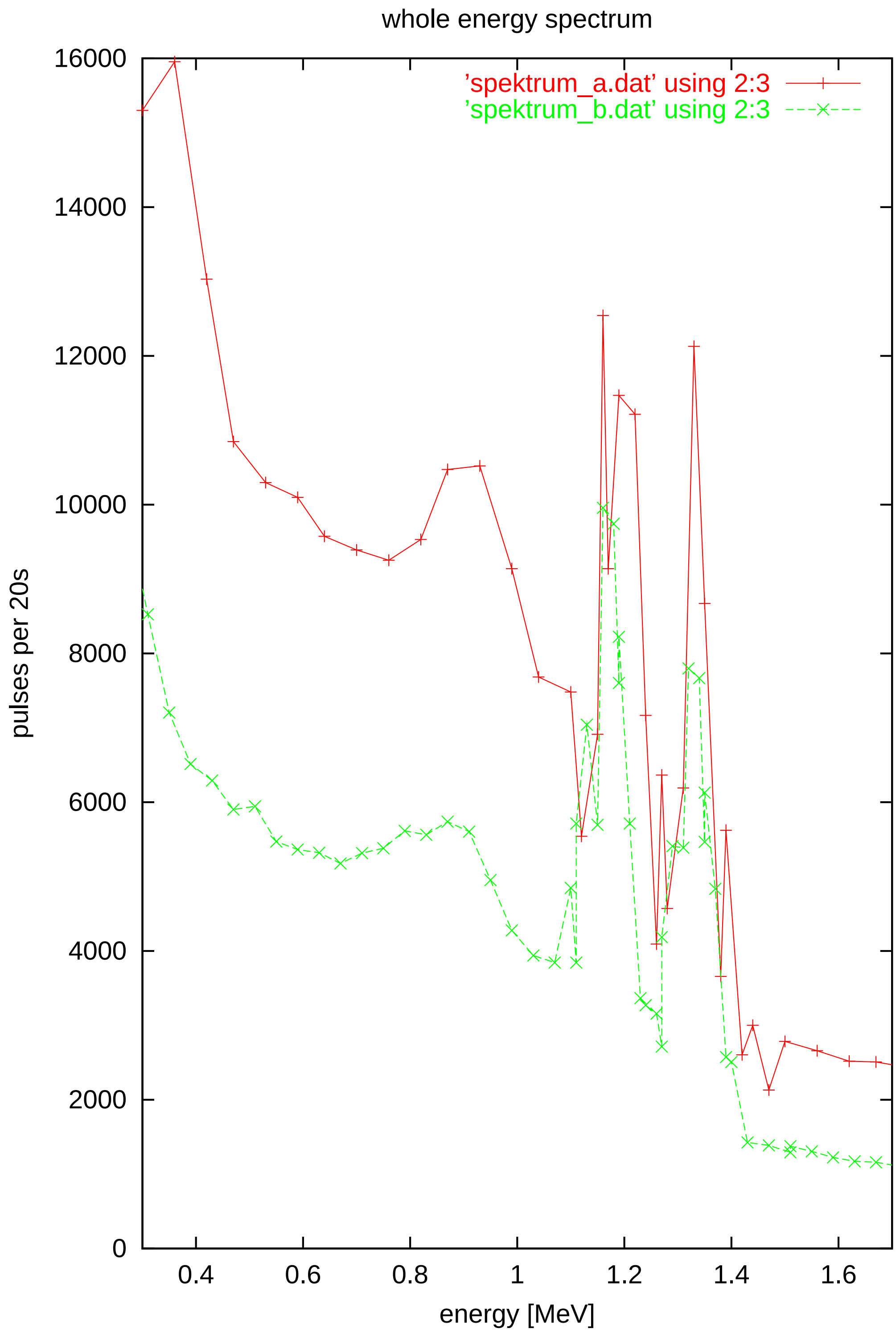

Figure 3: Whole spectrum of energy for detector A and B

is found out. For the number of incidental coincidences a measure with 400 s is used. So the number is halved. For the absolute error of each counted number we use the standard deviation of poisson distribution. The average $\overline{K}$ of a measure is equal to measured value only for one measure - the number of counted rates n.

$$\sigma = \sqrt{\overline{K}} = \sqrt{n}$$

For the errors it means $\Delta A = \sqrt{A}$, $\Delta B = \sqrt{B}$, $\Delta k = \sqrt{k}$. The number of counted rated are high enough for gaussian error propagation.

$$\Delta K_Z = \sqrt{\left(\frac{k}{A^2 B}\Delta A\right)^2 + \left(\frac{k}{AB^2}\Delta B\right)^2 + \left(\frac{1}{AB}\Delta k\right)^2}$$

So we can find out the coincidence rate rather exactly

$$\begin{aligned} K(\Theta) &= \overline{K}_0 - K_Z \\ \Delta K(\Theta) &= \sqrt{\Delta \overline{K}_0^2 + \Delta k_Z^2} \end{aligned}$$

All coincidence rate are collected in the table 2.

angle$\Theta[°]$	$K(\Theta)$	$\Delta K(\Theta)$
90	$8,28 \cdot 10^{-9}$	$1,31 \cdot 10^{-10}$
135	$8,92 \cdot 10^{-9}$	$1,59 \cdot 10^{-10}$
180	$9,63 \cdot 10^{-9}$	$1,63 \cdot 10^{-10}$

Table 2: Collected values of coincidence rates

4.3.1 Calculation of lengendre coefficients

Each value of table 2 well be handled by formular 1.3 and the gaussian error propagation that we get following values

$$\begin{aligned} A_2' &= 0,101783 \\ \Delta A_2' &= \frac{1}{(6K_{90} + 8K_{135} + K_{180})^4}\Big(5.58 \cdot 10^{-16} K_{90}^2 + 1.52 \cdot 10^{-16} K_{90} K_{135} + 3.93 \cdot 10^{-16} K_{135}^2 - \cdots \\ & \quad 3.57 \cdot 10^{-16} K_{90} K_{180} + 2.62 \cdot 10^{-16} K_{135} K_{180} + 1.20 \cdot 10^{-16} K_{180}^2\Big) \\ &= 0,0171 \\ A_4' &= 0,00367 \\ \Delta A_4' &= \frac{1}{(6K_{90} + 8K_{135} + K_{180})^4}\Big(5.07 \cdot 10^{-16} K_{90}^2 + 1.25 \cdot 10^{-16} K_{90} K_{135} + 4.48 \cdot 10^{-16} K_{135} + \cdots \\ & \quad 4.75 \cdot 10^{-16} K_{90} K_{180} - 1.61 \cdot 10^{-16} K_{135} K_{180} + 1.39 \cdot 10^{-16} K_{180}^2\Big) \\ &= 0,020 \end{aligned}$$

$$A_2 = \frac{A_2'}{0,797} = \frac{0,101783}{0,797} = 0,128 \qquad \Delta A_2 = \Delta A_2' = 0,017$$
$$A_4 = \frac{A_4'}{0,457} = \frac{0,017154}{0,457} = 0,008 \qquad \Delta A_4 = \Delta A_4' = 0,020$$

5 Conclusion

The spectrum of 60–nickel of state $I_1 = 4^+$ has two characteristic energy peaks at 1,17 and 1,33 MeV. The compton edge of 1,17 MeV and the roughly rage of back scattering peak can be find out at this work. The coefficients of correlations function

$$W(\Theta) = 1 + A_2 \,\mathrm{P}\cos\Theta + A_4 \,\mathrm{P}\cos\Theta$$

are calculated at the values of

$$A_2 = 0,128 \pm 0,017 \qquad \text{theoretical}: A_2 = 0,102$$
$$A_4 = 0,008 \pm 0,020 \qquad \text{theoretical}: A_4 = 0,00091$$

In comparison to table 1 there is examinated mulipol type 1, which is an electric quadrupol. So we can rather good confirm the energy transition from $I_2 = 2^+$ to $I_3 = 0^+$.

References

[1] Institut für Atomare Physik und Fachdidaktik, *Skript über Gamma-Gamma Winkelkorrelation*, TU Berlin, 2000

A Data of measures

voltage [V]	energy [MeV]	rates in 40 s
0	0. 3	15300
0. 05	0. 36	15955
0. 1	0. 42	13031
0. 15	0. 47	10849
0. 2	0. 53	10297
0. 25	0. 59	10099
0. 3	0. 64	9574
0. 35	0. 7	9391
0. 4	0. 76	9253
0. 45	0. 82	9533
0. 5	0. 87	10473
0. 55	0. 93	10520
0. 6	0. 99	9139
0. 65	1. 04	7683
0. 7	1. 1	7482
0. 72	1. 12	5543
0. 74	1. 15	6912
0. 75	1. 16	12544
0. 76	1. 17	9139
0. 78	1. 19	11469
0. 8	1. 22	11215
0. 82	1. 24	7167
0. 84	1. 26	4093
0. 85	1. 27	6366
0. 86	1. 28	4570
0. 88	1. 31	6190
0. 9	1. 33	12129
0. 92	1. 35	8672
0. 94	1. 38	3659
0. 95	1. 39	5623
0. 98	1. 42	2604
1	1. 44	3002
1. 02	1. 47	2130
1. 05	1. 5	2784
1. 1	1. 56	2660
1. 15	1. 62	2517
1. 2	1. 67	2508
1. 25	1. 73	2435
1. 3	1. 79	2328
1. 35	1. 84	2273
1. 4	1. 9	2317
1. 45	1. 96	2242
1. 5	2. 02	2159
1. 55	2. 07	2062
1. 6	2. 13	2048
1. 65	2. 19	2007
1. 7	2. 24	1932
1. 75	2. 3	1958
1. 75	2. 3	1962
1. 8	2. 36	1965
1. 85	2. 42	1931
1. 9	2. 47	1948
1. 95	2. 53	1947
2	2. 59	1838
2. 05	2. 64	1833
2. 1	2. 7	1871
2. 15	2. 76	1826
2. 2	2. 82	1885
2. 25	2. 87	1909
2. 3	2. 93	1942
2. 35	2. 99	1986
2. 4	3. 04	1984

Table 3: The values for spectrum detector A

voltage [V]	energy [MeV]	rate in 40 s
0	0. 11	6805
0. 05	0. 15	7321
0. 1	0. 19	7811
0. 15	0. 23	9228
0. 2	0. 27	9902
0. 25	0. 31	8527
0. 3	0. 35	7205
0. 35	0. 39	6514
0. 4	0. 43	6291
0. 45	0. 47	5902
0. 5	0. 51	5944
0. 55	0. 55	5471
0. 6	0. 59	5363
0. 65	0. 63	5320
0. 7	0. 67	5178
0. 75	0. 71	5316
0. 8	0. 75	5380
0. 85	0. 79	5616
0. 9	0. 83	5562
0. 95	0. 87	5738
1	0. 91	5604
1. 05	0. 95	4954
1. 1	0. 99	4277
1. 15	1. 03	3940
1. 2	1. 07	3843
1. 24	1. 1	4847
1. 25	1. 11	3845
1. 26	1. 11	5714
1. 28	1. 13	7041
1. 3	1. 15	5696

voltage [V]	energy [MeV]	rate in 40 s
1. 32	1. 16	9957
1. 34	1. 18	9744
1. 35	1. 19	7602
1. 36	1. 19	8224
1. 38	1. 21	5713
1. 4	1. 23	3366
1. 42	1. 24	3270
1. 44	1. 26	3157
1. 45	1. 27	2714
1. 46	1. 27	4186
1. 48	1. 29	5408
1. 5	1. 31	5389
1. 52	1. 32	7798
1. 54	1. 34	7669
1. 55	1. 35	5467
1. 56	1. 35	6128
1. 58	1. 37	4836
1. 6	1. 39	2574
1. 62	1. 4	2507
1. 65	1. 43	1427
1. 7	1. 47	1386
1. 75	1. 51	1294
1. 75	1. 51	1377
1. 8	1. 55	1306
1. 85	1. 59	1225
1. 9	1. 63	1172
1. 95	1. 67	1160
2	1. 71	1109
2. 05	1. 75	1161
2. 1	1. 79	1087
2. 15	1. 83	1016
2. 2	1. 87	1056
2. 25	1. 91	987
2. 3	1. 95	947
2. 35	1. 99	959
2. 4	2. 03	908

Table 4: The values for spectrum detector B

Versuch	G	A	B	K	C
1	90	197882	179626	290	8,159E-09
2	90	197910	179637	270	7,595E-09
3	90	197587	179707	294	8,280E-09
4	90	197330	179737	322	9,079E-09
5	90	197412	179097	326	9,221E-09
6	90	197118	178968	302	8,561E-09
7	90	195387	179236	314	8,966E-09
8	90	196074	179080	288	8,202E-09
9	90	194898	178515	336	9,657E-09
10	90	194791	178100	304	8,763E-09
11	90	193174	177384	316	9,222E-09
12	90	192830	176594	288	8,457E-09
13	90	192049	177128	244	7,173E-09
14	90	191105	173858	292	8,789E-09
15	90	191424	177219	282	8,313E-09
16	90	191139	177318	300	8,852E-09
17	90	190170	177198	232	6,885E-09
18	90	189744	177679	288	8,543E-09
19	90	187995	176763	302	9,088E-09
20	90	187610	176994	284	8,553E-09
21	90	187702	176843	297	8,947E-09
22	90	187879	176760	307	9,244E-09
23	90	187892	176627	286	8,618E-09
24	90	187729	177036	291	8,756E-09
25	90	187733	176687	284	8,562E-09
				Mittelwert	8,58E-009
				StandardAbw	6,37E-010
				Stat Fehler	1,27E-010
Zufällige Koinzidenzen					
200s	90	185450	178077	10	3,028E-10
400s	90	374100	354756	12	3,617E-10
				Mittelwert	3,322E-10
				Fehler	3,03E-011
Koinzidenzrate					8,28E-009
				Fehler	1,31E-010

Table 5: The coincidences at the angle of 90 degrees

Versuch	G	A	B	K	C
1	135	197041	179876	347	9,790E-09
2	135	197122	180027	361	1,017E-08
3	135	197083	179654	340	9,603E-09
4	135	197104	180081	410	1,155E-08
5	135	196661	178649	326	9,279E-09
6	135	196703	179568	320	9,060E-09
7	135	195359	179072	272	7,775E-09
8	135	195826	177585	342	9,834E-09
9	135	194945	177691	292	8,430E-09
10	135	194159	176322	290	8,471E-09
11	135	193638	176370	288	8,433E-09
12	135	192528	176612	332	9,764E-09
13	135	192113	176524	308	9,082E-09
14	135	190451	165944	278	8,796E-09
15	135	190920	177299	336	9,926E-09
16	135	189408	173596	314	9,550E-09
17	135	189021	177180	310	9,256E-09
18	135	189519	176652	286	8,543E-09
19	135	187638	177330	284	8,535E-09
20	135	187623	178683	276	8,233E-09
21	135	187697	177269	299	8,986E-09
22	135	188107	176891	302	9,076E-09
23	135	187894	176439	314	9,472E-09
24	135	187901	176642	289	8,707E-09
25	135	187687	177022	292	8,789E-09
				Mittelwert	9,16E-009
				StandardAbw	7,81E-010
				Stat Fehler	1,56E-010
Zufällige Koinzidenzen					
200s	135	185065	178254	8	2,425E-10
400s	135	372905	355647	20	6,032E-10
				Mittelwert	4,229E-10
				Fehler	3,03E-011
Koinzidenzrate					8,92E-009
				Fehler	1,59E-010

Table 6: The coincidences at the angle of 135 degrees

Versuch	G	A	B	K	C
1	180	197698	176327	367	1,053E-08
2	180	197703	176337	351	1,007E-08
3	180	197679	176211	334	9,589E-09
4	180	197056	176310	370	1,065E-08
5	180	195551	175974	364	1,058E-08
6	180	197033	176534	356	1,023E-08
7	180	195411	176081	358	1,040E-08
8	180	195229	175475	386	1,127E-08
9	180	193853	173525	338	1,005E-08
10	180	193893	173419	336	9,993E-09
11	180	193144	173608	319	9,513E-09
12	180	191663	155202	268	9,009E-09
13	180	191194	170812	312	9,553E-09
14	180	191162	172771	320	9,689E-09
15	180	190854	173989	326	9,817E-09
16	180	189354	173597	314	9,552E-09
17	180	188829	173712	334	1,018E-08
18	180	187794	173728	318	9,747E-09
19	180	187647	174410	300	9,167E-09
20	180	187435	174647	322	9,837E-09
21	180	187587	174603	317	9,678E-09
22	180	187614	174537	316	9,650E-09
23	180	187404	174501	317	9,694E-09
24	180	187701	174489	324	9,893E-09
25	180	187507	174589	330	1,008E-08
				Mittelwert	9,94E-009
				StandardAbw	4,93E-010
				Stat Fehler	9,87E-011
Zufällige Koinzidenzen					
200s	180	185450	178077	10	3,028E-10
400s	180	374100	354756	12	3,617E-10
				Mittelwert	3,322E-10
				Fehler	3,03E-011
Koinzidenzrate					9,63E-009
				Fehler	1,03E-010

Table 7: The coincidences at the angle of 180 degrees

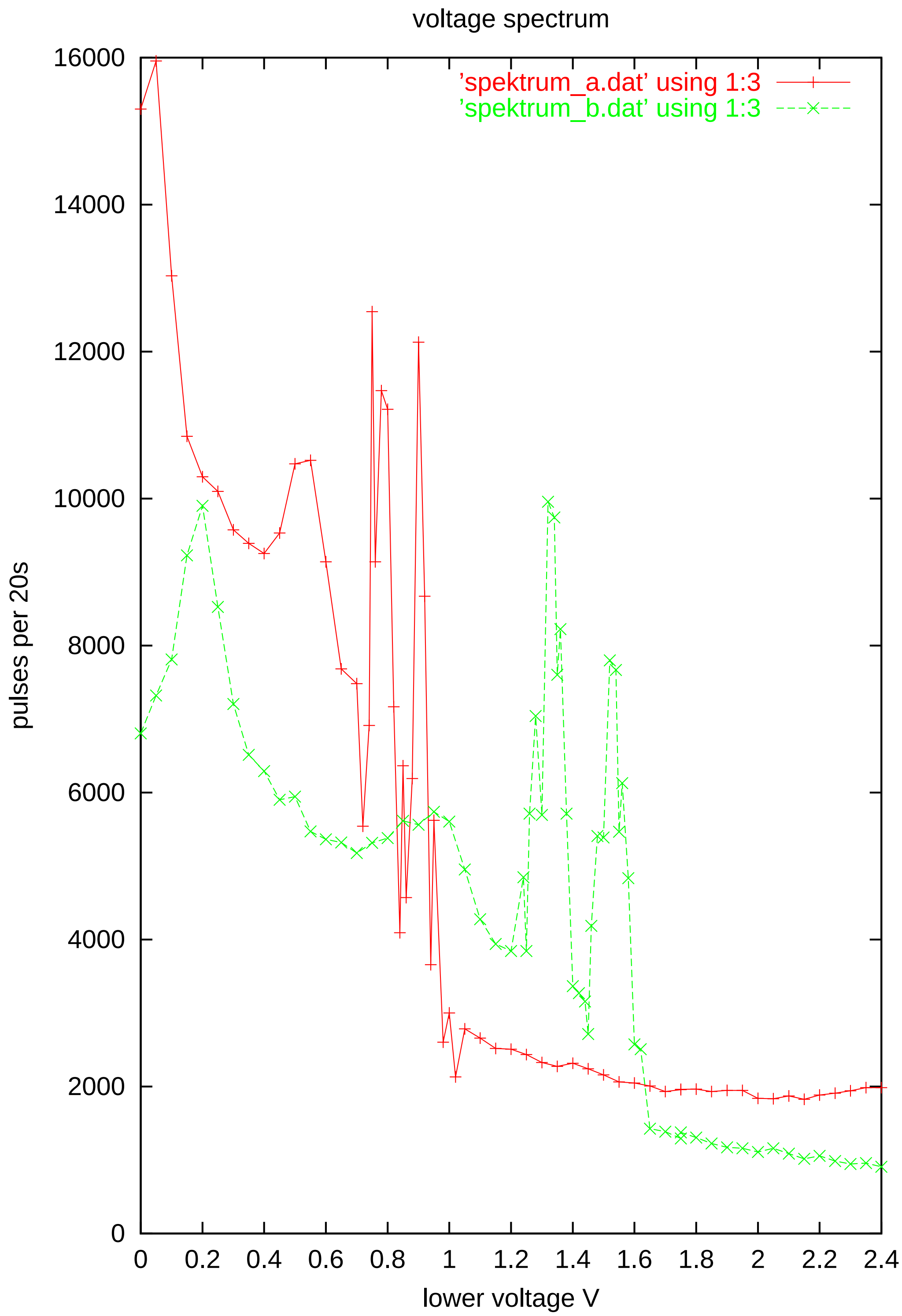

Figure 4: The voltage spectrum with two pregnant γ–peaks

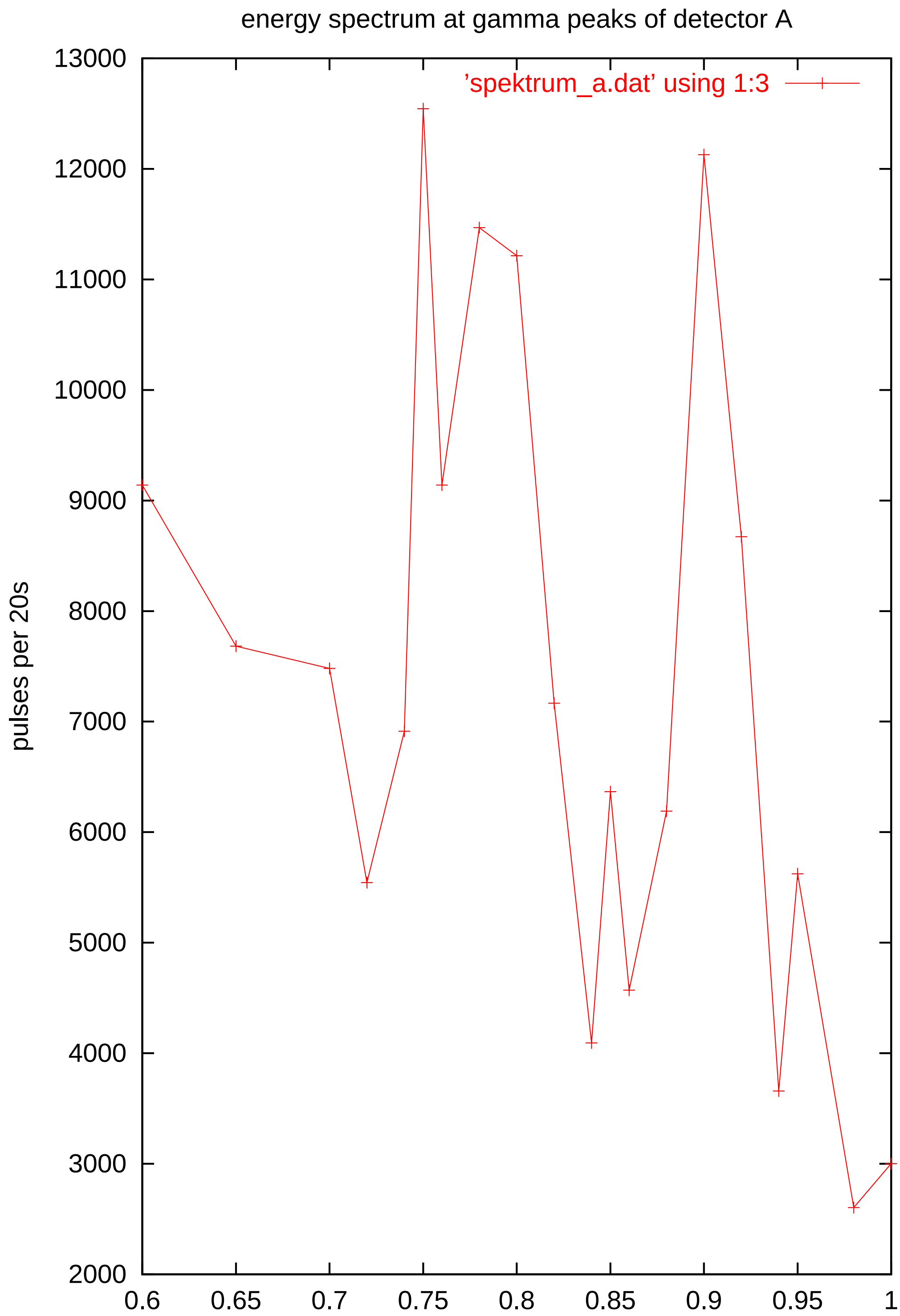

Figure 5: The γ–peaks for spectrum detector A

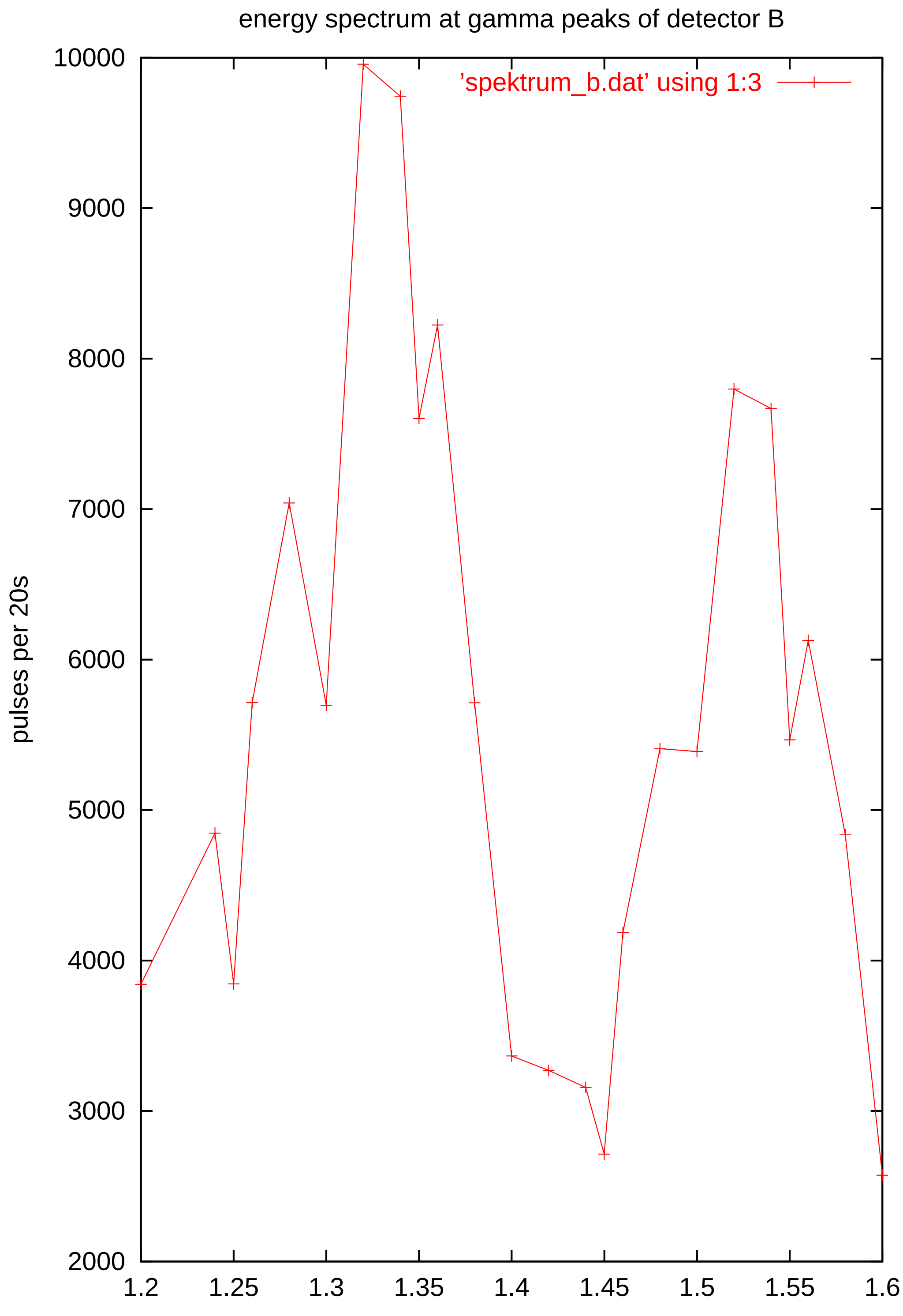

Figure 6: The γ–peaks for spectrum detector B

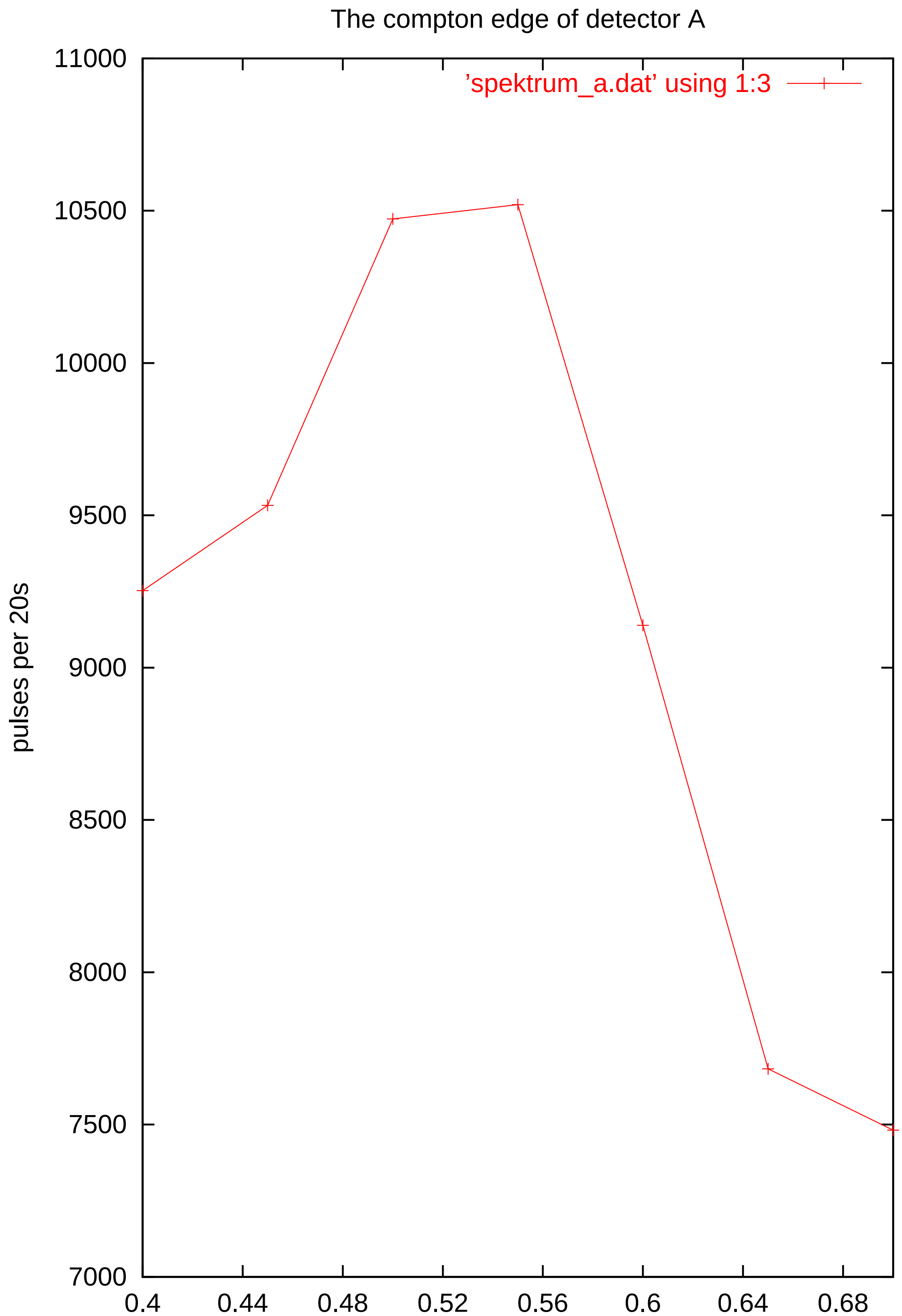

Figure 7: The compton edge for detector A

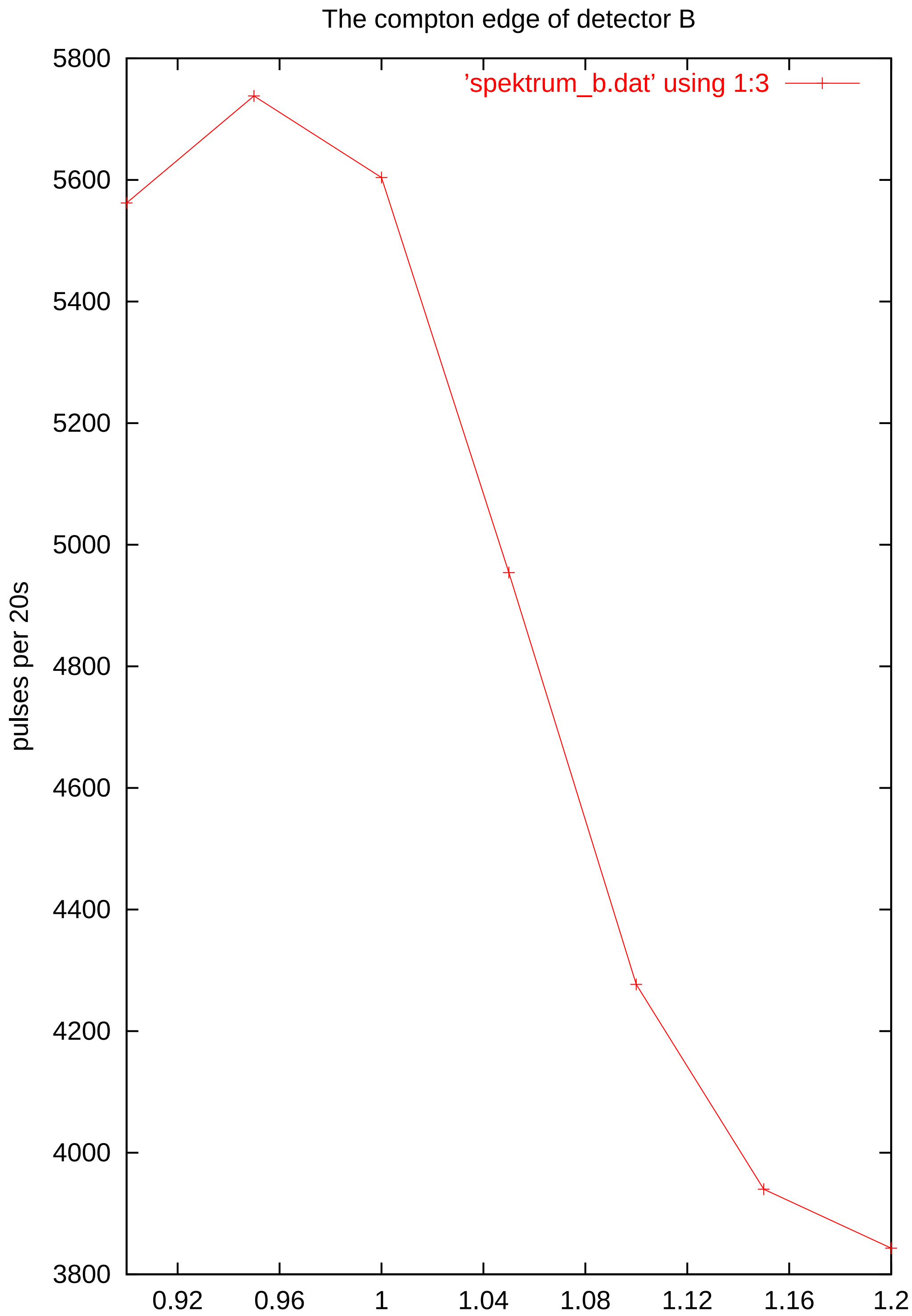

Figure 8: The compton edge for detector A

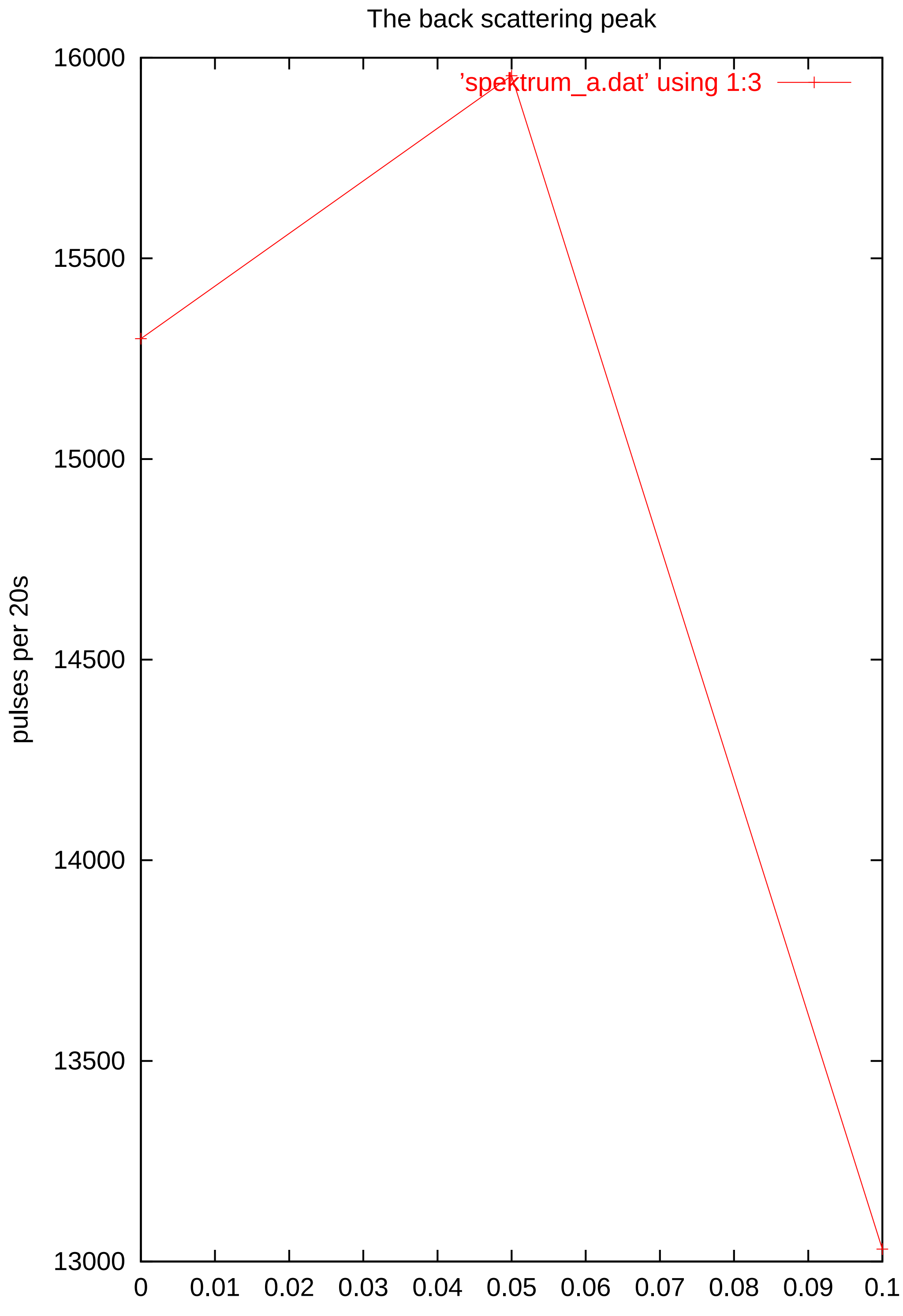

Figure 9: The back scatterin peak for detector A

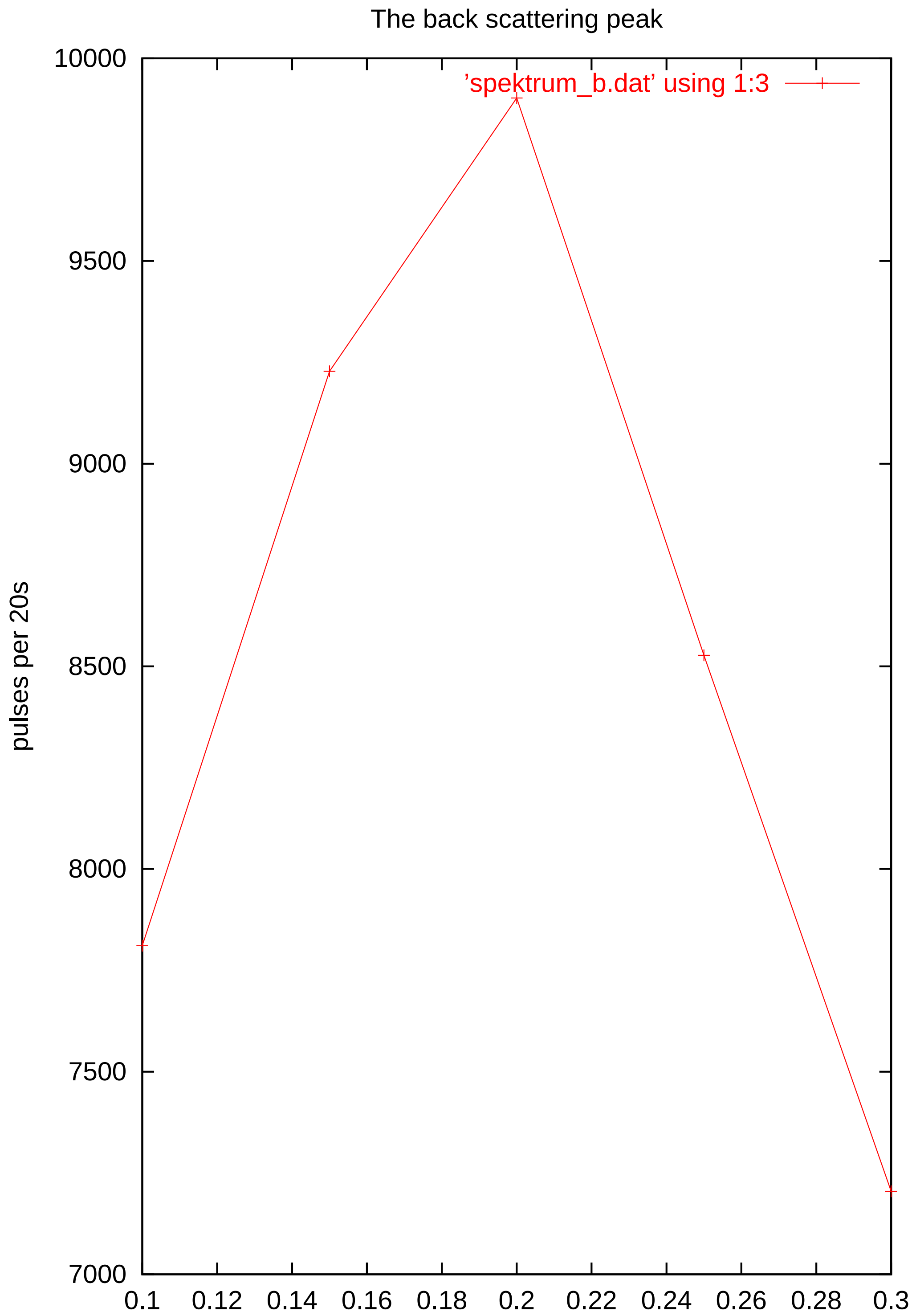

Figure 10: The back scatterin peak for detector B

dekay [ns]	number of coincidences
2. 96	0
2. 98	2
3. 00	8
3. 02	38
3. 04	384
3. 06	576
3. 08	834
3. 10	946
3. 12	996
3. 14	1000
3. 16	1000
3. 18	998
3. 20	1000
3. 22	1000
3. 24	996
3. 26	942
3. 28	678
3. 3	540
3. 32	48
3. 34	0
3. 36	0
3. 36	4
3. 38	0
3. 4	0

Figure 11: Measure of detector delay and number of coincidences

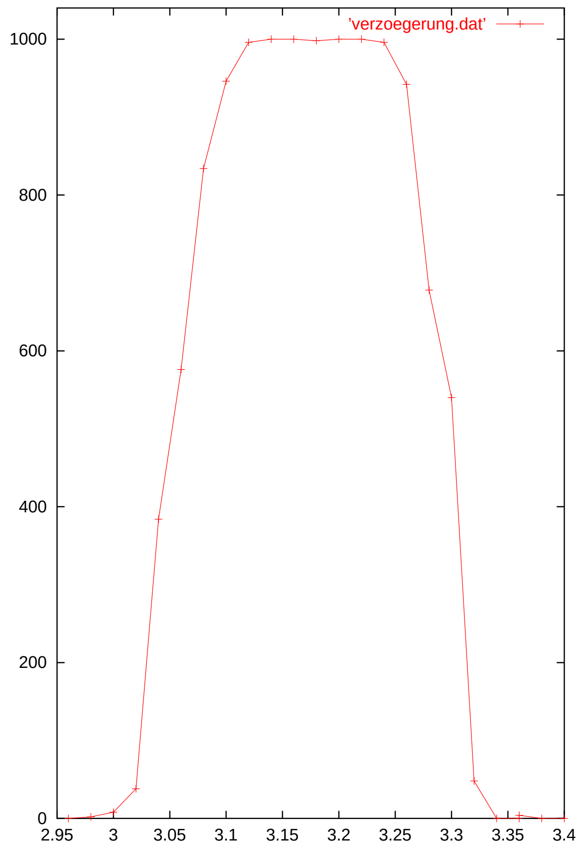

Figure 12: The dependence detector delay and number of coincidences