RoentDek

UHV-Detectors Handels GmbH
Supersonic Gas Jets
Multifragment Imaging Systems

Application Note:

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Hexanode application for enhancing the count rate in pulsed operation

A Hexanode can be used for enhancing the data acquisition efficiency for ionization processes with pulsed beams, for example in case of laser-induced ionization in low-repetition pulsed mode.

The total acquisition speed of a RoentDek Delay-line detector is about 1-2 million particles per sec. However, there is a dead-time limitation during a 40-150 ns long period("anode dead-time", depends on anode size) which affects applications with pulsed beams, e.g. from high-power lasers where several particles per pulse can be ionized in the target and are detected by the micro-channel plate stack (MCP). While an MCP-stack can potentially produce decent charge amplification also for several simultaneous particles, the delay-line anode cannot always cope with that and does produce a unambiguous pulse sequence to recover position and time of several particles arriving within the anode dead-time.

Although all RoentDek delay-line anodes will distinguish events with only one or several particles detected during the anode dead-time interval, a DLD will only allow to safely determine the time and position of a single particle in this period. Already events with two particles may not be reconstructed correctly even if an advance reconstruction algorithm is applied.

Applying the same algorithm for a Hexanode detector will push the system performance to being able of reconstructing two-particle events in most case (for details see a detailed discussion of the Hexanode in literature) but three-particle events may not be unambiguously reconstructed in many cases and/or only with inferior resolution.

Therefore, we usually do not recommend the use of a Hexanode instead of a DLD with the *only* purpose of increasing the count rate capability. The gain in count rate may only be a factor of 2, while the "price" for this is the introduction of an elaborated and reconstruction routine which will work during on-line acquisition up to a limited count rate (and only off-line for high rate data acquisition). Still, the Hexanode has superior performance even for so-called single-hit operation and is the best choice if the need for maximum performance ranks higher than budgetary constraints. Furthermore, if the only option to increase count rate and thus reducing the data acquisition time is doubling the number of particles that can be detected per shot, employing the Hexanode is the method of choice.

In the following, the operation limits of Hexanode and DLD for pulsed operation is discussed quantitatively.

The statistics for pulsed operation mode is determined by the Poisson distribution:

The likelihood P that zero, one or more (n) particles are detected is a function of λ which is the expectation value, i.e. the mean particle number per pulse.

$$P(n, \lambda) = \lambda^n/n! \cdot e^{-\lambda}$$

Clearly, the number n for a specific pulse can only be integer, i.e. n = 0, 1, 2,… while λ can have any positive value and scales in this example with the intensity of the ionizing pulse and/or the ionization cross section and/or the target density.

n	p(n , λ=0.2)
0	0,81873075
1	0,16374615
2	0,01637462
3	0,00109164
4	5,4582E-05
5	2,1833E-06
6	7,2776E-08
7	2,0793E-09
1+2	0,18012077

n	p(n , λ=2)
0	0,13533528
1	0,27067057
2	0,27067057
3	0,18044704
4	0,09022352
5	0,03608941
6	0,0120298
7	0,00343709
1+2	0,54134113

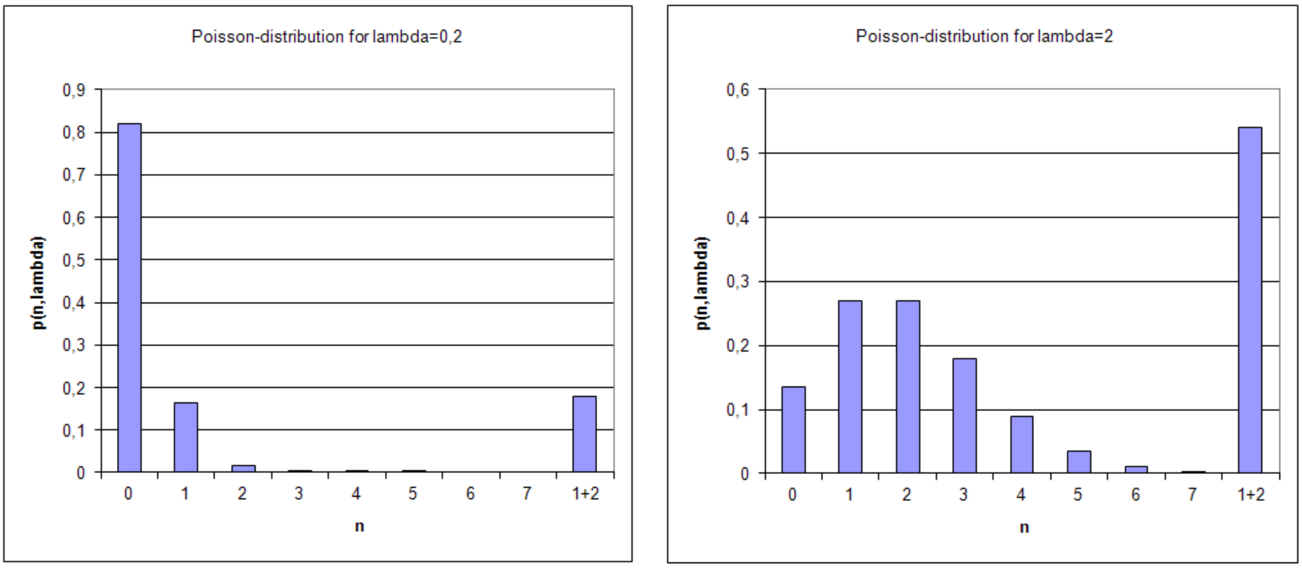

Figure 1: Probability distribution of the number of particles as function of λ.

In figure 1 two examples for such probability distributions as function of λ = 0.2 and λ = 2 are given. Note that depending on the type of particles, there can be a difference between the number of particles reaching the MCP and those that are detected. The following considerations account only the *detected* particles. The ratio of detected particles versus impinging particles is given by the quantum efficiency (QE) of the MCP for a certain particle species and impact energy, i.e. usually < 70%. For calculating the effective probability for detecting a certain number of particles, the expectation value for arriving particles has to be multiplied by QE.

Generally, P(n) has the maximum probability compared to all other probabilities if λ = n, however, their sum will always exceeds the maximum's number. An interesting value in these considerations is the sum of P(1) and P(2), which describes the probability for "good" (useful) events for a Hexanode, i.e. where either one or two particles are detected, while for the DLD only events for n = 1 are useful.

Figure 2 shows the probability function P(n,λ)for several numbers n of detected particles as function of λ (x-axis) and also for the sum P(1,λ) + P(2,λ). For k> 0 these curves show a maximum at the expection value, i.e. the green curve for n = 1 at λ = 1 and for n = 2 at λ = 2 (blue curve). The red curve (probability for detecting one *or* two particles) peaks λ = √2, which is obviously the ideal expectation value for a Hexanode, compared to λ = 1 for a DLD.

n	p(n , λ=√2)
0	0,24316866
1	0,34384049
2	0,24309522
3	0,11457888
4	0,04050363
5	0,01145443
6	0,00269943
7	0,00054528
1+2	0,58693571

If probabilities for λ = 1 λ = √2 are compared it is becomes obvious that a Hexanode can ideally only detect about twice as many particles as the DLD, even if the incoming particle rate (i.e. λ) can be optimized:

$$P(1,\lambda=\sqrt{2}) + P(2, \lambda=\sqrt{2}) = 0.59, \qquad P(1,\lambda=1) = 0.27$$

This neglects the fact that some of the two-particle events on the Hexanode will have to be rejected due to occasional timely and spatial overlap beyond the multi-hit capabilities of a Hexanode. On the other hand, a portion of three-particle events may be reconstructed additionally.

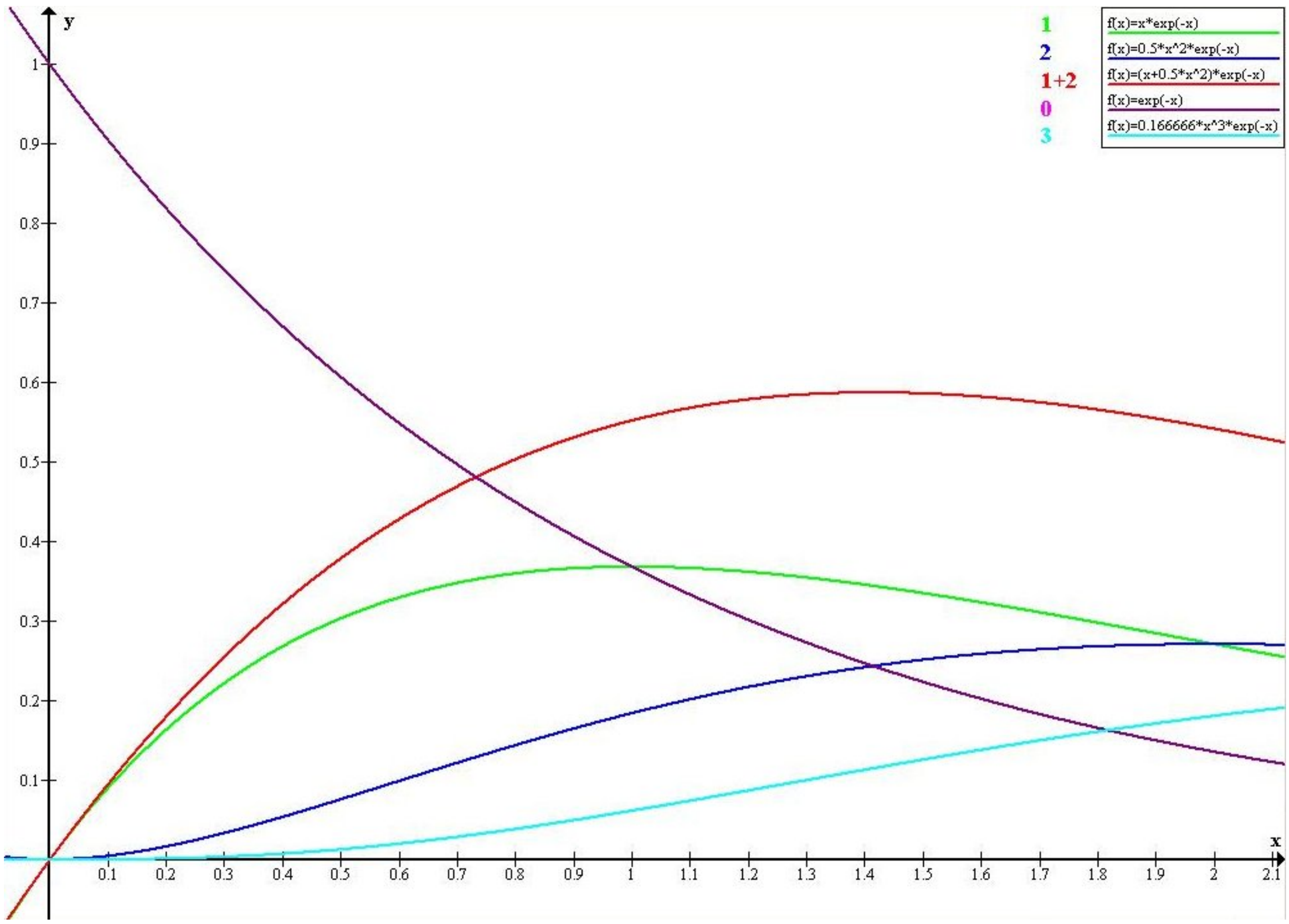

Figure2: Probability functions for detecting 0, 1,2,… particles (curves with different colors). The x-axis is λ.

This means that the Hexanode can improve the number of detected particles by a factor of two in an experimental situation where a pulsed source with a given (average) repetition rate sets the primary limit for the data acquisition speed. The improvement will be less if the mean number of emitted particles per shot cannot easily be adjusted for optimizing the effective λ.

It should be noted that the Hexanode can only improve the detection efficiency if incoming particles are uncorrelated. In an experiment where several particles from a certain event, e.g. from a breakup of an atom or molecule shall be analyzed, it is crucial that "single collision conditions" on the target are mostly maintained. Otherwise, fragments from breakup of different target entities will be mixed and the common origin of quasi-simultaneous arriving particles is not guaranteed. Therefore, λ must be kept well below 1 to assure a negligible contribution of n = 2 or higher events, which may not always be recognized as such and contribute a background in the data.