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PPAC for luminosity monitor

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Abstract

The development of the PPAC (Parallel Plate Avalanche Chamber) for use in calorimeters for measuring high-energy particles is described. The nanosecond waveform of a PPAC signal is presented.

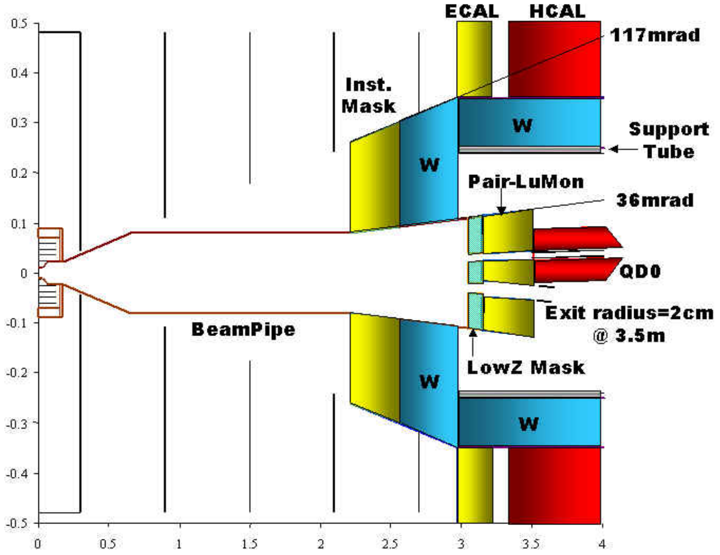
Introduction:

The luminosity monitor requires a detector that is fast (sub nanosecond), not damaged by a radiation dose of several Grad, and subdivided into sections of area no larger than 0.25 cm^2. One, and possibly the best, detector for this application is a low pressure Parallel Plate Avalanche Chamber (PPAC).[1]

A typical PPAC is two flat plates separated by 2 mm with a voltage of 750 V between them with a filling gas of 20 torr of isobutane. The charged particles passing through the gas produce ionization and the multiplication is achieved by applying a sufficiently large voltage to cause each electron to produce an avalanche. The avalanche results in current gains of several orders of magnitude. Because of its simple, "lowtech" design, a PPAC is an inexpensive device that can be made to be radiation hard.

The electrical signal is generated and amplified in the detector itself. There is no need for photodetectors. To achieve a fast signal, the capacitance (proportional to the area) must be kept small so that the RC time constant is smaller than the electron collection time. The detector is connected directly to a 50-ohm transmission line. The electron collection time is of the order of one ns and depends on the applied voltage, the cathode-anode spacing, and the gas pressure and type. The signal is generated by the motion of charges between the plates. The positive ions move slowly and in most applications make no observable contribution to the signal.

This note is primarily concerned with the use of PPACs in the Pair-luminosity monitor (Pair-LuMon in diagram below) and the Instrumented Mask; but suitably designed PPACs could also be used in ECAL and HCAL. The NLC bunch structure is 120 Hz trains with 192 bunches/train with 1.4 ns bunch spacing.



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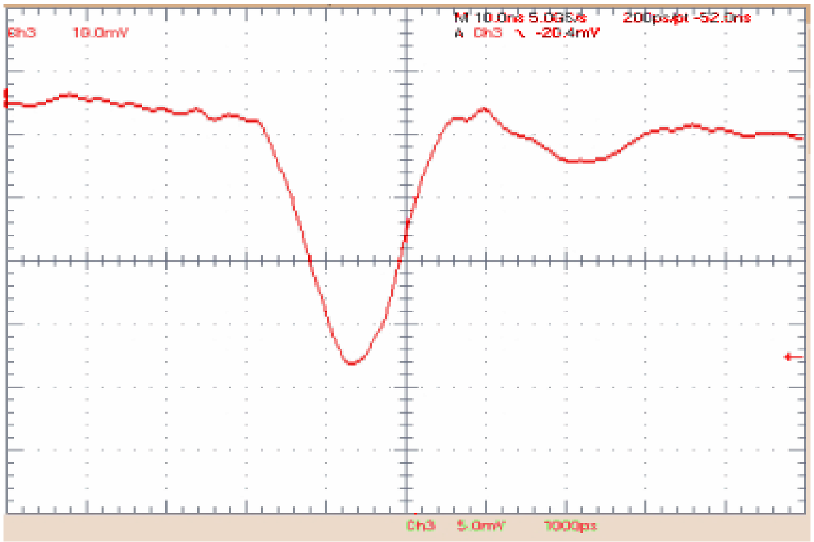
Parts of LuMon will try to measure the energy of 200-250 GeV electrons in a background of 1000 e^+/e^- per cm^2. This is a difficult task that will require a clever design of the calorimeter with extensive simulation. Whatever the design of the calorimeter, PPACs can provide adequate sampling of the ionization in the shower.

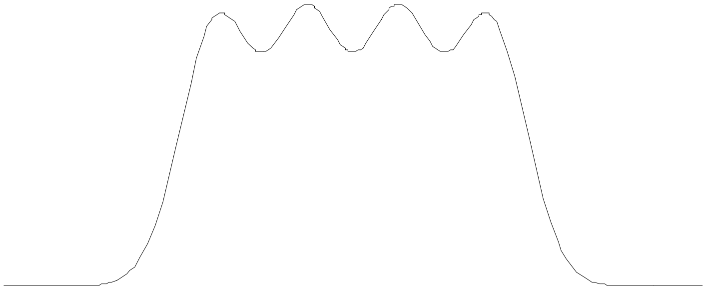
Wave Form

We expect the luminosity monitor to be made of layers of tungsten metal or tungsten alloy (to keep the Molière radius small) interleaved with layers of detector to sample the shower. PPACs could be used in pairs, the pair consisting of three plates. The center one would be the high voltage electrode and would be as thick as possible while being suspended inside of the gas volume. This HV plate would be part of the absorber. The outer walls of the PPAC pair would also be of tungsten or tungsten alloy and would be faced with an insulating circuit board covered with small conducting pads that are connected to 50 ohm strip lines that take the signals to edge connectors. Only a single pad is needed to demonstrate the characteristics of the output signals.

We show here the signal shape from a PPAC, of area 0.25 cm^2, with a spacing between the plates of 1.0 mm, filled with 30 torr of isobutane, at a voltage of 650 volts. The signal requires 1.0 ns to reach its peak value and has a FWHM of 1.3 ns. Everything in the trace below, except the main peak, is noise. The relative amount of noise is large because of the small size of the signal using our ^{137}Cs source. With the much larger signals with the NLC the noise will be negligible.



The width of the signal from a single bunch does not allow the signal to go to zero between bunches separated by 1.4 ns, but there is sufficient separation to allow measurement of bunch to bunch fluctuations. The figure below shows the signal from a train of four equal bunches separated by 1.4 ns.



Positive ions

There is a positive ion formed for each electron, but because they move slowly and do not produce avalanches, they can generally be ignored. With 192 electron pulses in a time short compared with the ion collection time, the pulses from electrons will ride on top of a rising signal from the positive ions from individual pulses. This background level should rise to about 20% of the amplitude of the electron pulses. As a first approximation, the background rises linearly to the amplitude that can be measured just after the last pulse. The extent to which the positive ions are collected during the pulse train can be measured by observing the fall of the positive-ion background at the end of the pulse train. The positive ion current for a single, fast pulse can be measured by using a charge-integrating amplifier.

The voltage between the plates must be kept low enough so that the accumulation of positive ions does not cause a nonlinearity in the energy response of the detector. This is easily done since the nonlinear regime is usually accompanied by sparking in the detector.

Tests and future plans

We have studied the characteristics of a pair of large area, 170 cm^2, PPACs that are constructed as a single unit. On the outside are two heavy, grounded plates to withstand atmospheric pressure. Between them there are three thin plates, the middle one grounded and the other two at high voltage. The signals are taken from the two thin plates at high voltage. In a calorimeter there are considerable differences between one shower and the next. The double PPAC provides two independent measurements of the same part of the same shower. A comparison of the signal from the two sides allows a measurement of the energy and time resolution of the detector.

The following describes the tests of the double PPAC:

1. Tests at the Advanced Photon Source, at Argonne National Laboratory, using 80 ps pulses of 7 GeV positrons to create electromagnetic showers.

   Electromagnetic showers were generated by allowing the halo of the beam to strike the beam pipe. The number of electrons contributing to the shower was varied by making small changes in the beam-line magnets. Since all of the electrons in the bunch were essentially simultaneous, the signals in the detector were the same as signals from particles of much higher energy. The energy resolution, determined by comparing signals from the two sides of the device, was about 1%. The PPAC signal from a shower is generated by hundreds of simultaneous but independent ionization events. This allows the PPAC to produce a large signal without any part of it becoming saturated.

2. Test of PPAC at Fermilab test beam facility with 120 GeV protons.

   This test will provide an energy calibration for the double PPAC for hadronic showers. This test is scheduled for July 2004.

3. Test of PPAC at CERN-CMS test beam facility with protons and pions of energy between 20 and 300 GeV.

   This test of the double PPAC will provide more detailed information about the detector and will sample the infrastructure at CERN.

We need to test the small PPAC with showers from single electrons. This can be done in mid 2005 at SLAC or perhaps sooner using 6 GeV electrons at JLAB. If funding becomes available we would make a complete prototype detector, with multiple pads. This could be used in 2005 at SLAC to determine the energy resolution of a luminosity monitor using such detectors. In this case, the electronics is the major cost. For the test we would use borrowed electronics.

We are planning to search for a gas to use in a PPAC that will not be subject to aging problems.

A PPAC can be constructed of materials that are extremely resistant to radiation, i.e. metals and ceramics. However under extreme radiation conditions isobutane can polymerize to form non-volatile materials. These can be removed by cleaning the detector, but it would be better if they were not formed in the first place. There are many promising gas mixtures. A small PPAC suspended in a large, 2 liter, gas volume and provided with a weak alpha particle source has been constructed for the gas studies. The study will begin in the near future.

E. Norbeck has had considerable experience with low-pressure gas detectors. Part of this experience is given in his paper on heavy gases in charged particle detectors.[2]

Conclusions

A PPAC with pads that are small compared with 1 cm^2 provides signals that are suitable for use in the proposed LC luminosity monitor. We expect that the cost of such a device would be a small fraction of the cost of any competing technology that provides comparable performance.

References

1. University Program of Accelerator and Detector Research for the Linear Collider (vol. II), December 2003;
   http://www.hep.uiuc.edu/LCRD/pdf_docs/LCRD_UCLC_Big_Doc/
   see LCRD Proposal 3.2 in this document, *R&D for a Luminosity Monitor*.

2. E. Norbeck et al., *Heavy gases, iso-octane and C_3F_8 in charged particle detectors* **,** Nucl. Instr. Meth. **A314**, 620 (1992).