DIY Particle Detector

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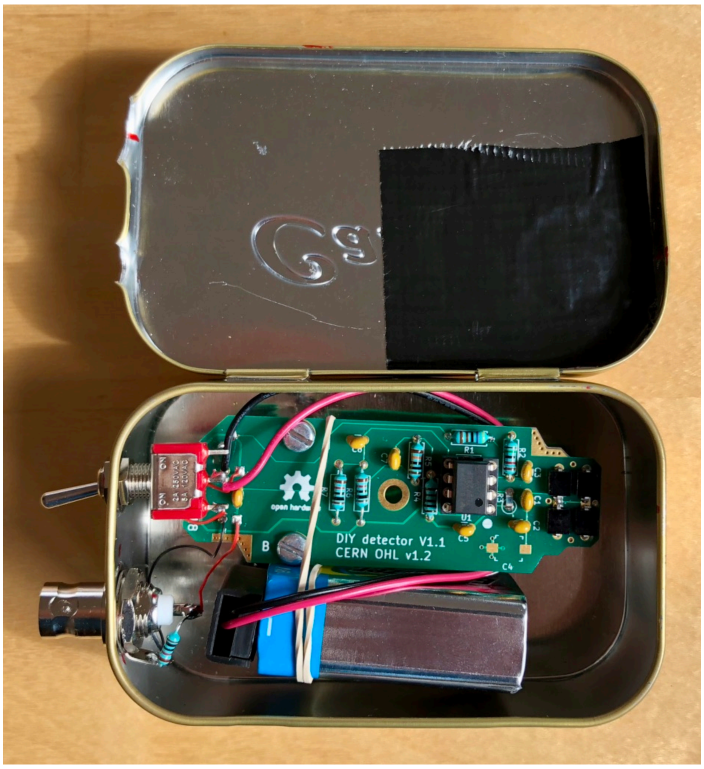
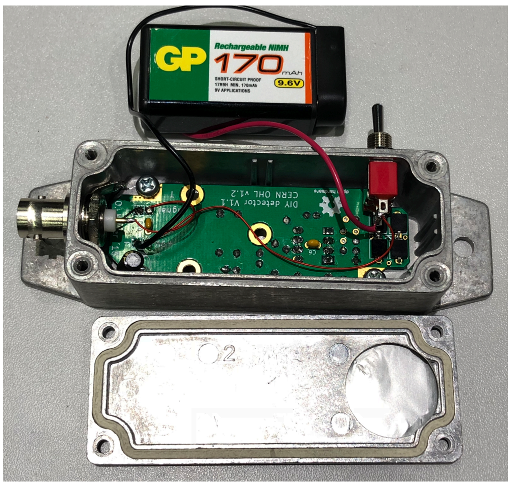
Working Principle:

Ionizing radiation liberates charges in the silicon lattice structure of four low-cost commercial p-i-n diodes, BPW 34 - sold as photo diodes in different variants. The chip's sensitive layer depth is about 100 μm [2] which makes if a good detector for electrons from beta decays of natural radioactivity. Detection efficiency in such a silicon sensor is about 100 % for up to 100 keV electrons.
Small current peaks induced in the diodes are amplified with a dual stage amplification circuit. The first stage is a transimpedance amplifier configuration applying a factor of 10^7 followed by a second inverting stage, amplifying the signal again by a factor of 100. The output is AC-coupled and can be directly connected to an oscilloscope or the microphone input of a computer (see notes on schematic about optional R8).
Alpha particles cannot be detected unless the plastic package of the diodes, covering the silicon chip, is removed. The probability detecting gamma or X-ray photons is very low.

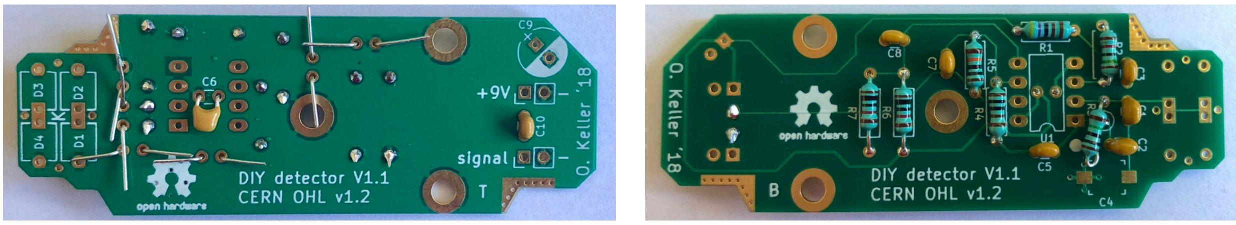
Casing Choices:



A metallic case (tin boxes for candies work great, see above) that closes completely and can fit the board together with a 9V battery block. It is important to shield the circuit from any light as good as possible and and block electro-magnetic interferences (hence the metal box as Faraday cage).
A small whole in the case (about 2 cm diameter) in front of the diodes is useful to improve the sensitivity towards particles. However, any light entering from outside must be blocked rigorously with black tape and/or aluminum tape covering the hole.
For professional aluminium die-cast cases (c.f. image on the right) that fit the board precisely please refer to the part numbers stated on the schematic.



Build Instructions:
Use the parts overview page as a guide. The assembly should start with soldering the smallest components, all resistors followed by the small yellow capacitors. Their pins should be carefully bend closely to the package to make them fit into the narrow footprints. The image below shows all resistors and yellow capacitors in place. Note how the pins of C6, mounted on the opposite side to U1, are cut very close to the board (right image) in order to provide enough space for U1 which will be placed right above. R3 is bent to the side here but could be also mounted standing upright, depending on available space in the chosen case.

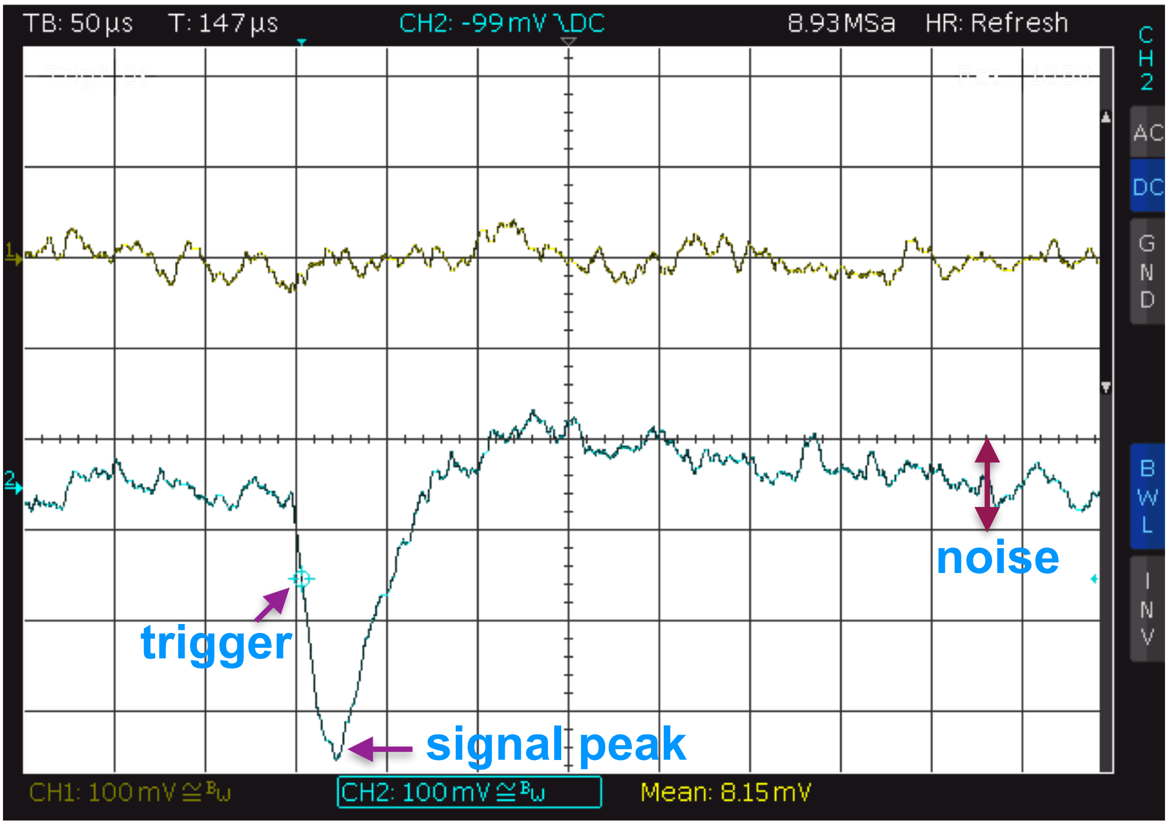


Top and bottom side with all resistors and small yellow capacitors placed. Bending the pins as show on the left picture keeps the components in place and simplifies soldering. Cut them as short as possible with side-cut pliers afterwards.

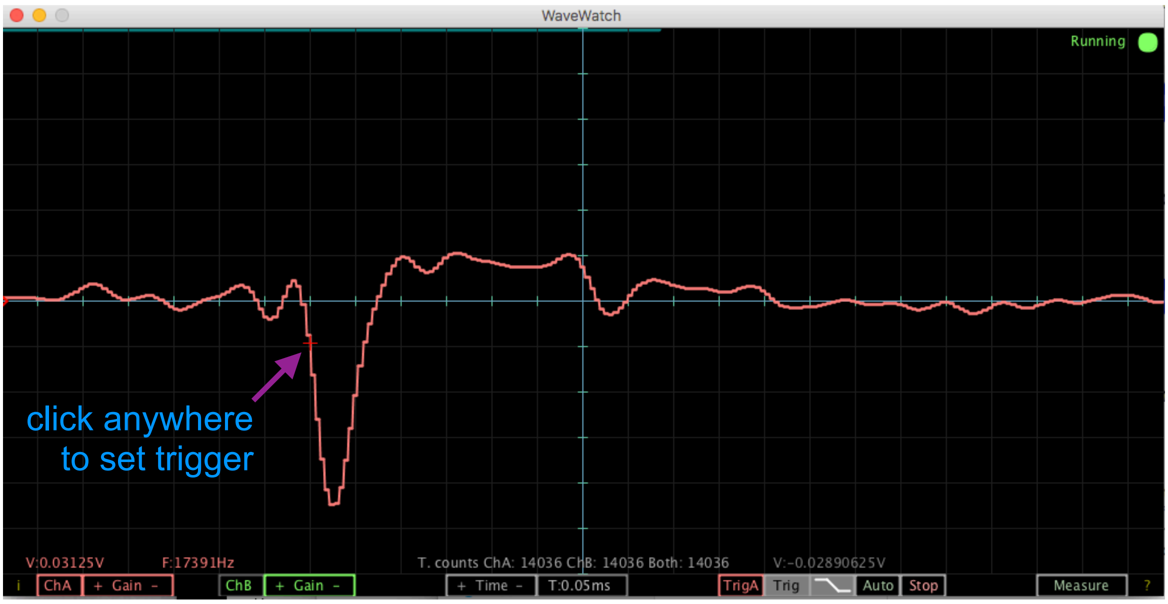
When placing U1, D1 – D4 and C9, their polarities must be respected. Pin number one of U1 is marked with a white circle on the board that needs to be aligned with the circle mark on the chip's package. The diodes D1, D2, D3 and D4 can be mounted on either side, depending on what is more convenient in respect to the available casing. The diodes should be close to the wall of the case, ideally behind a thin 'window' covered only by light-tight black tape. The cathode pin of the BPW 34 diode is marked with a little notch (see drawing in parts overview) and must be aligned with the holes for the diodes in the middle of the board (marked with 'K' for 'Kathode'). The large polarized capacitor C9 should be mounted last and can be placed upright or flat on either side of the board as long as its short pin (on the capacitor marked with a white stripe) is aligned with the white half-circle on the board.
The switch should be connected between the red wire of the battery clip and the '+9V' input marking on the board. The board connection marked with 'signal' is soldered to the central pin of the wall-mounted BNC socket. The '-' connection next to the signal output can be used to connect the ground plane of the circuit with the metallic case at the BNC socket. The three big mounting holes in the middle of the board (forming a triangle) are compatible with M3 screws and are as well connected to the ground plane of the board.
After all soldering is finished, the 9 V power rail should be checked for any short circuit. An ohmmeter should show initially about 9 - 10 kOhm when measuring across the two connections of the battery clip.

Using the DIY Detector:
After connecting the battery, close the case and be sure no daylight or artificial light reaches inside. Connect the BNC output to an oscilloscope input, configured to 1 MOhm impedance, DC coupled, timebase 50 - 100 us per div, voltage scale 50 - 100 mV per div. Once the power switch of the detector is flipped, the oscilloscope should show a large change of output voltage on the screen.
With a brand new battery (voltage above 9 V) the expected output noise floor is +/- 50 mV around zero. The signal pulses can be triggered at - 80 to - 100 mV (the signal is negative!) using a falling slope edge trigger. Once the battery voltage drops to 8 V and below, the noise floor is typically reduced to +/- 20 mV and the signal pulses can be triggered reliably at around - 35 mV. Since the circuit draws only a few milliampere it will operate for several hours. The upper screenshot one the next page shows a typical signal trace. The area of the signal confined by the pulse shape is proportional to the energy that was deposited by the ionising radiation hitting the sensor (most likely electrons; photoelectric absorption or Compton scattering of energetic gamma or X-ray photons can be observed, but will be very rare).
If an oscilloscope is not at hand, the pulses can be recorded using the audio input of a computer! In this case the optional output resistor R8 must be populated in parallel to the BNC socket. A value of 10 kOhm works well for most multi-functional inputs dedicated to headphones and headset microphones (e.g. most modern laptops). Refer to the schematic for the wiring diagram showing a 4-pin 'TRRS' compatible jack connection.

Outlook:
The complete design, including experiment descriptions, will be soon published under the CERN Open Hardware License in an education oriented physics journal. The files will appear on www.github.com/ozel.
The author is available and will happily respond to any kind of inquires (oliver.michael.keller@cern.ch).



Oscilloscope screenshot showing a typical signal trace on channel 2.



Screenshot from the WaveWatch sketch, made for the programming environment Processing.
To run this nice oscilloscope program which includes trigger functionality, download version 3 from www.processing.org, install the missing 'Minim' library via 'Sketch' menu / 'Import Library…' / 'Add Library…'.
Download my sketch from https://github.com/ozel/WaveWatch/archive/master.zip, unzip and open the file WaveWatch-master/WaveWatch/WaveWatch.pde in Processing.

References:
[1] Bernd Laquai, www.opengeiger.de
[2] Federico Ravotti et al. (2008) BPW34 Commercial *p-i-n* Diodes for High-Level 1-MeV Neutron Equivalent Fluence Monitoring. IEEE TRANSACTIONS ON NUCLEAR SCIENCE, Vol. 55, No. 4