XV. Detectors and Electronics – Summary

1. There is no ideal detector.

   Many types of detectors have evolved and all of them have an appropriate place (even if it may just be a niche).

   The choice depends on

   - the specific application,
   - the available technical resources and
   - the technical sophistication of the user.

2. Two basic configurations exist:

   - direct conversion of energy into electrical signal

     ionization chambers
     (gaseous, solid-state)
     internal gain devices
     (proportional counters, avalanche diodes)
     cryogenic devices

   - indirect detection

     scintillators + light detectors

     photomultiplier tubes
     photodiodes
     photocathodes + gas proportional chambers

     Cherenkov radiation + light detectors

   The choice of materials for direct conversion is limited
   (semiconductors – Si, Ge, ... or gases)

   Indirect detection allows a wide range of absorber materials with greater stopping power dE/dx (density, atomic number)

3. Properties and applications of some detector types

Thin semiconductor detectors (up to ~ 1 mm thick)

- high resolution charged particle and x-ray spectroscopy
- ultra-fast timing
- high resolution position sensing (~ μm)
- highly-segmented arrays
- sophisticated technology
  - good match to monolithic integrated circuits
  - expensive for large areas

Large-volume semiconductor detectors (especially Ge)

- high-resolution gamma ray spectroscopy
  (good efficiency to several MeV)
- typically cooled to liquid nitrogen temperature

Scintillation Detectors

- high-efficiency photon detection (> 1 MeV)
- fast timing (plastic scintillators)
- sensitive to magnetic fields

Gas proportional chambers

- large-area position sensing
- large-area x-ray detection
- bulky, require gas systems

Cryogenic Detectors

- ultra-high energy resolution

detection of weakly ionizing particles

- slow
- require cooling to mK temperatures

4. Detectors consist of

   - sensors +
   - electronics

   and both must be considered together.

5. Maximize the signal

   Maximizing the signal also implies reducing the capacitance at the electronic input node. Although we want to measure charge, the primary electric signal is either voltage or current, both of which increase with decreasing capacitance.

6. Select the appropriate shaper and shaping time

   Depends on required rate capability and timing performance.

   In general, short shaping times will require higher power dissipation for a given noise level than long times.

   The shaper can be optimized with respect to either current or voltage noise (important in systems subject to radiation damage)

   The choice of shaping function and time can significantly affect the sensitivity to external pickup.

7. Choose the input transistor to match the application.

   At long shaping times FETs (JFETs or MOSFETs) are best.
   At short shaping times, bipolar transistors tend to prevail.

8. Position-sensitive detectors can be implemented using either interpolation techniques or direct readout. Interpolating systems reduce the number of electronic channels but require more complex and sophisticated electronics. Direct readout allows the greatest simplicity per channel, but requires many channels, often at high density (good match for monolithically integrated circuits).

9. Segmentation improves both rate capability and noise (low capacitance). It also increases radiation resistance.

10. Timing systems depend on slope-to-noise ratio, so they need to optimize both rise-time and capacitance.

    Relatively long rise-times can still provide good timing resolution (<< rise-time), if the signal-to-noise ratio is high.

    Variations in signal transit times and pulse shape can degrade time resolution significantly.

11. Electronic noise in practical systems can be predicted and understood *quantitatively*.

12. From the outset, systems must consider sensitivity to spurious signals and robustness against self-oscillation.

    Poor system configurations can render the best low-noise front-end useless, but proper design can yield “laboratory” performance in large-scale systems.

13. Although making detectors “work” in an experiment has relied extensively on tinkering and “cut-and-try”, understanding the critical elements that determine detector performance makes it much easier to navigate the maze of a large system.

    It is more efficient to avoid problems than to fix them.

    A little understanding can go a long way.