Characteristics of detectors

Electrical detectors used, if possible

- Sensitivity
- Detector response
- Energy resolution
- Response function
- Response time
- Detector efficiency
- Dead time
Sensitivity

Capability of detecting a given type of radiation

Depends on:
- Cross section for ionization
- Detector mass and volume
- Level of noise
- Absorber
- Collimation and surroundings
Detector response

(energy <-> detector signal)

\[ E \propto Q = \int_{0}^{\text{some } \mu s} I(t) \, dt \]

\[ E \propto \max(I(t)) \]
Energy resolution
(Poisson case)

Usual Gaussian shape
FWHM = 2.35 σ

Let \( w \) = energy of one ionization:

\[
E = Jw
\]

\[
R_{\text{std.dev.}} = \frac{\Delta E_{\text{std.dev.}}}{E} = \frac{\sigma_J}{J} = \frac{\sqrt{J}}{J} = \sqrt{\frac{w}{E}}
\]

\[
R_{\text{FWHM}} = \frac{\Delta E_{\text{FWHM}}}{E} = 2.35 \frac{\sigma_J}{J} = 2.35 \sqrt{\frac{w}{E}}
\]
Energy resolution
(non-Poisson case)

If full energy is deposited in the detector, the Poisson statistics is incorrect. Since (almost) all energy is detected, constraints are imposed on the number of ionizations $J$. We modify the expressions using the Fano factor $F$, typically $F = 0.1 - 0.2$.

$$\sigma^2 = FJ$$

$$R_{FWHM} = \frac{\Delta E_{FWHM}}{E} = 2.35 \frac{\sigma_J}{J} = 2.35 \sqrt{\frac{F_W}{E}}$$

In addition to the contribution from the detector itself, several other effects may contribute:

$$(\Delta E_{tot})^2 = (\Delta E_{det})^2 + (\Delta E_{electr})^2 + (\Delta E_{beam})^2 + \ldots$$
Response function

Unfolded $u$

Raw $r$

$N_\gamma$

$N_e$

$E_\gamma$

$E_e$

incoming

measured
Response time

The time the detector takes to form the signal after arrival of the radiation

- **dead time**
- **sharp timing**
- **pile-up at high rate**
Detector efficiency(I)

\[ \Omega_{\text{tot}}(E) = \frac{\text{Events registered}}{\text{Events emitted by source}} \]

\[ \Omega_{\text{tot}}(E) = \Omega_{\text{geom}} \cdot \varepsilon_{\text{instr}}(E) \]
Detector efficiency (II)

$\varepsilon_{\text{instr}}(E)$ may also depend on geometry:

\[
\varepsilon_{\text{instr}}(E, x) = \varepsilon_{\text{instr}}(E) \left[ 1 - \exp\left(\frac{-x}{\lambda}\right) \right]
\]

More complex set-ups require simulations (Geant4)
Dead time

The time to process a signal, often associated with the duration of a signal in the detector.

However, the detector, the signal processing and the acquisition CPU all have different dead times and with different implications for the experiment.

• Electron (hole) collection time in detector: $1 \text{ns} - 1 \text{us}$
• Signal processing (pre- and main-amp.): $1 \text{us} - 5 \text{us}$
• ADCs and eventbuilder (CPU): $1 \text{us} - 100 \text{us}$

Typically $10,000 \text{ c/s per detector} \Rightarrow 100 \text{ us}$
Paralyzed (extendable) model for dead time (I)

Single event dead time = $\tau$
By high count rate the detector may be paralyzed for more than $\tau$ due to overlapping dead times. We loose 4 events out of 8 => 50% dead time.
Paralyzed (extendable) model for dead time (II)

True count rate (1/s) : \( m \)

Observed counts in time \( T \) : \( k \)

Single dead time (s) : \( \tau \)

Probability of one event is : \( P(t) = \frac{1}{m} \exp(-mt) \)

\[
k = mT \cdot P(t > \tau) = mT \cdot \frac{1}{m} \int_{\tau}^{\infty} \exp(-mt) dt = mT \exp(-m\tau)
\]
Non-paralyzed (non-extendable) model for dead time (I)

Single event dead time = $\tau$

By high count rate the detector restarts after $\tau$ and is ready for a new event. We lose 3 events out of 8 => 38% dead time.
Non-paralyzed (non-extendable) model for dead time (II)

True count rate (1/s): \( m \)

Observed counts in time \( T \): \( k \)

Single dead time (s): \( \tau \)

The total dead time in a period \( T \) is: \( k\tau \)

The true number of counts is: \( mT = k + mk\tau \)
Dead time measurements

Dead time is usually measured in %: \( R_{\text{dead}} = \frac{k}{mT} \)

Try not to run with more than 10% dead time.

**Measurement:**
- Count the true number of counts (red) with a fast preamp., giving \( k \) within, say, 1 min.
- Count in the same period the number of events (green) registered \( mT \).