TPC Response Simulation Overview

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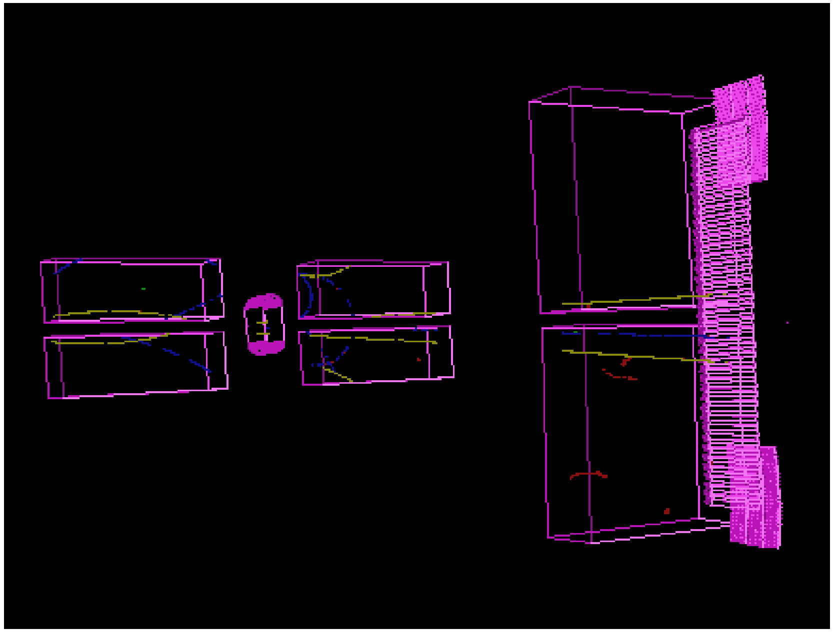
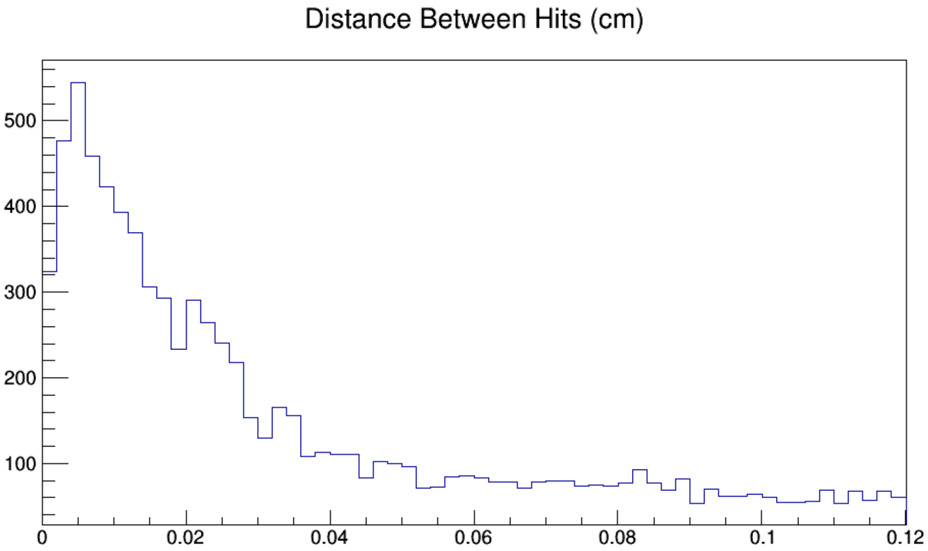
Outline

- Geant4 hits
- Drifting
  - Linear (MTPCs, FTPCs)
  - ExB (VTPCs, GTPC)
- Sample Generation
  - Sampling Resolution
  - Diffusion (X, Y)
  - Sample placement (Z)
- Response Simulation
  - Electrons Generated
  - Pad response/resolution (x, t)
  - Pad ADC values

Input: Geant4 Hits

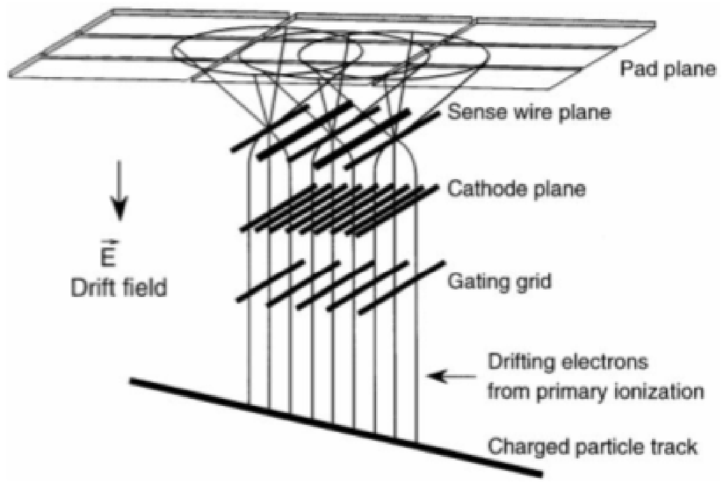
- Provided information:
  - Global hit location (x,y,z)
  - Time of hit
  - Energy deposited
  - Particle momentum at hit
- Small step size between hits





Linear Drifting

- MTPCL/R, GTPC
- Electric field assumed to be homogeneous, vertical
- Drift velocities ~1-2 cm/μs
  - MTPC drift length: up to 111 cm → ~80 μs!
    - Data acquisition for only 51.2 μs (256 x 200 ns or 512 x 100 ns



Crossed E, B Field Drifting

- Non-negligible B-field distortions in VTPC1/2, GTPC
- Solve Langevin Eq. In this region using 5th-order Runge-Kutta (~1000 steps)

$$m\frac{d\boldsymbol{v}}{dt}=e\,\boldsymbol{E}+e\left[\boldsymbol{v}\,x\,\boldsymbol{B}\right]-K\,\boldsymbol{v}$$

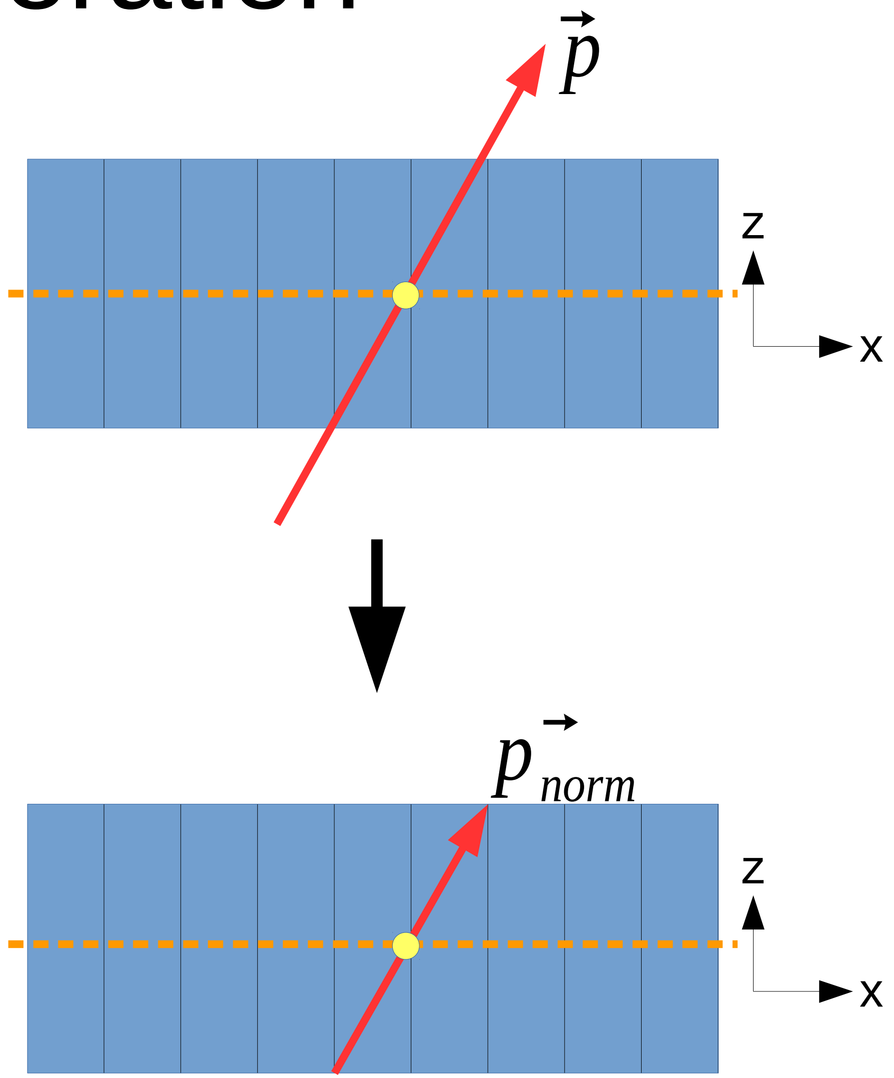
t >> τ:

$$\frac{d\,\boldsymbol{r}}{dt}=\frac{-v_{drift}}{|\boldsymbol{E}|}\frac{1}{1+(\omega\,\tau)^2}\left(\boldsymbol{E}+\frac{\omega\,\tau}{|\boldsymbol{B}|}\left[\boldsymbol{E}\,x\,\boldsymbol{B}\right]-\left(\frac{\omega\,\tau}{|\boldsymbol{B}|}\right)^2(\boldsymbol{E}\cdot\boldsymbol{B})\,\boldsymbol{B}\right)$$

$$\tau=\frac{m}{K}\;,\;\;\omega=\frac{e\,|\boldsymbol{B}|}{m}$$

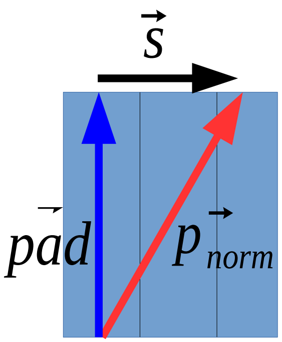
Sample Generation

- Drift positions at wire planes re-centered over padrows in order to create “energy deposition paths”
- Momentum normalized to pad length (z)



Sample Generation

- Signal Spread Length $|\vec{s}|$: Difference between normalized momentum vector and pad direction vector



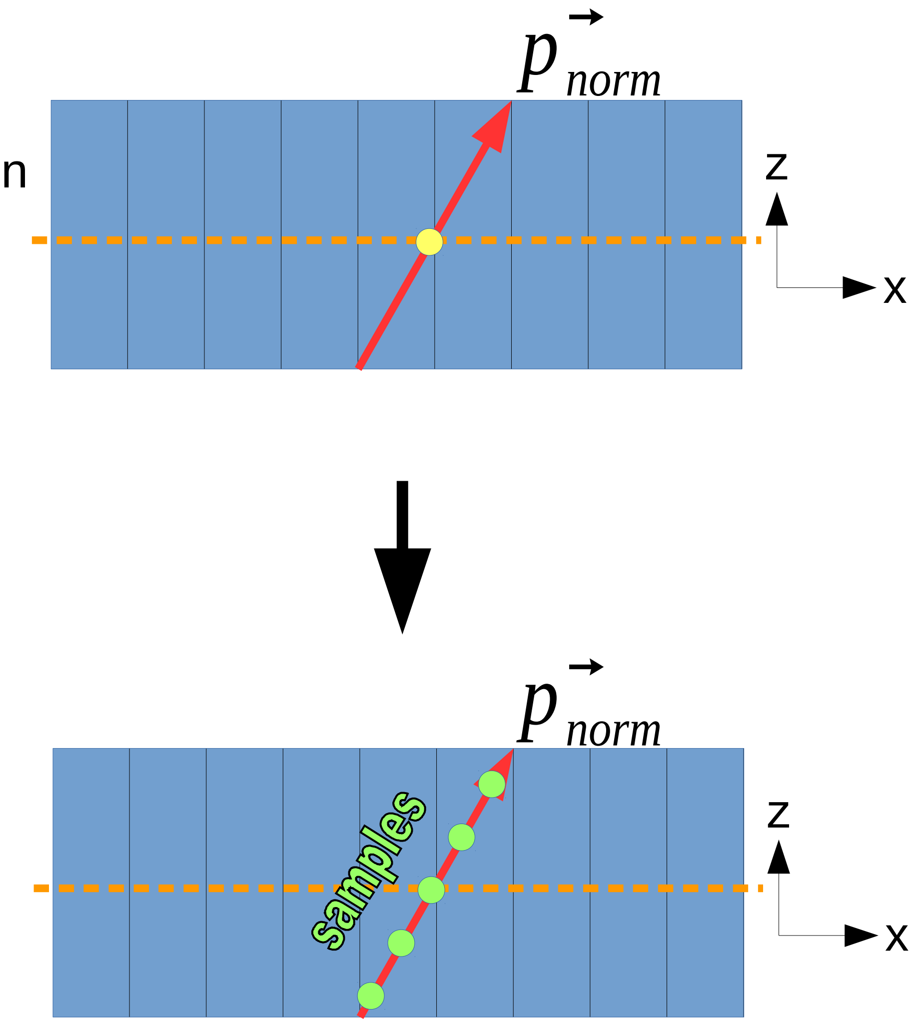
- Sampling Resolution R: largest of these two! *(Note: diffusion constant units in config file are cm^1/2!)*

$$X_{samp} = 2\sqrt{x_{resolution}^2 + x_{radius}^2} \qquad x_{radius} = \sigma_{x-diff}\sqrt{d}$$

$$Y_{samp} = 2\sqrt{y_{resolution}^2 + y_{radius}^2} \qquad y_{radius} = \sigma_{y-diff}\sqrt{d}$$

- Number of Samples:

$$n_{samp} = 1 + \frac{|\vec{s}|}{R}$$



Response Simulation

- For each sample: $n_{electrons} = 1 + \left(\frac{n_{elec}}{z_{unit}}\right)\left(\frac{|\vec{pad}|}{n_{samp}}\right)$, $\quad n_{pads} = 2\frac{\sigma_x}{|\vec{pad}|}$

$\left(\frac{n_{elec}}{z_{unit}}\right)$ Is a configuration parameter. Reasonable values?

- X-response σ_x:

$$\sigma_x = \sqrt{\sigma^2_{x-intrins} + \sigma^2_{x-diff} + \sigma^2_{x-cross} + \sigma^2_{Lorentz}}$$

  - Affects number of pads signal is distributed over

- X-resolution r_x:

$$r_x = \sqrt{r^2_{x-intrins} + \frac{\sigma^2_{x-diff}}{n_{elec}} + \frac{r^2_{x-cross}\, n_{samp}}{eff_{pad}} + r^2_{Lorentz}}$$

  - Affects adjusted sample x-position

- Y-response σ_y:

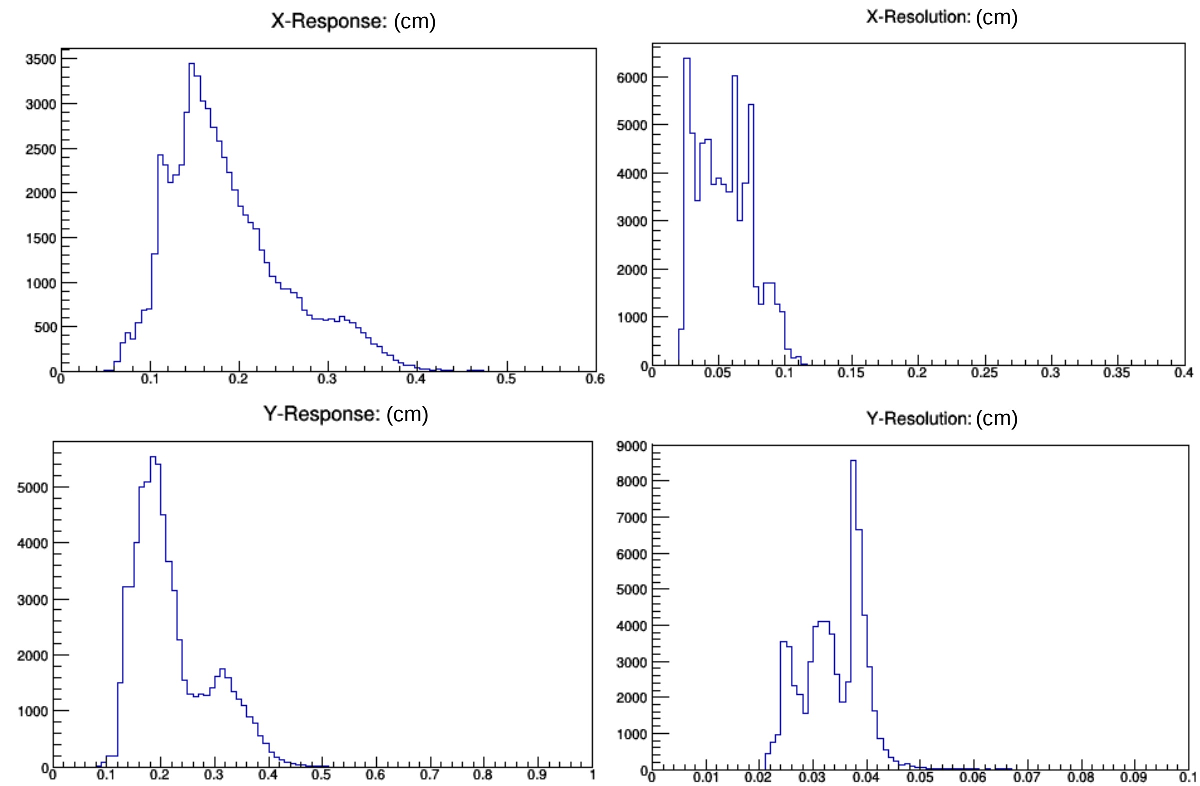
$$\sigma_y = \sqrt{\sigma^2_{y-intrins} + \sigma^2_{y-diff} + \sigma^2_{y-cross}}$$

  - Affects number of time bins signal is distributed over

- Y-resolution r_y:

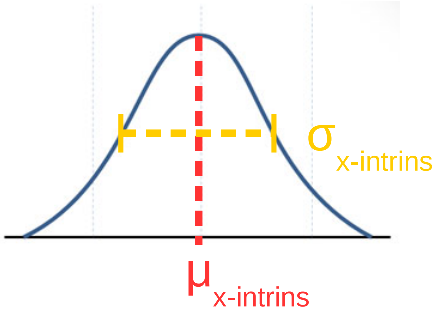
$$r_y = \sqrt{r^2_{y-intrins} + \frac{\sigma^2_{y-diff}\, n_{pads}}{n_{elec}} + \frac{\sigma^2_{y-cross}\, n_{samp}\, n_{pads}}{eff_{pad}}}$$

  - Affects central time bin (effectively sample y-position)

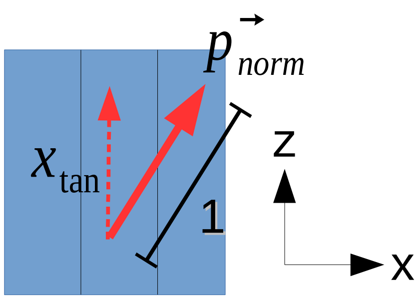


Response Simulation

- $\sigma_{x-intrins}$: Randomly selected from distribution



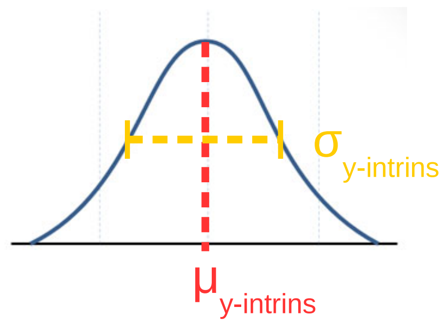
- $r_{x-intrins} = \mu_{x-intrins}$
- σ_{x-diff}: Diffusion coefficient
- $\sigma_{x-cross} = \frac{1}{12}\left(\frac{|\vec{pad}|\, x_{\tan}}{n_{samp}}\right)^2, \quad x_{\tan} = \left(\vec{p_{norm}}\right)\cdot\hat{x}$
- $r_{x-cross} = \sigma_{x-cross}\left(\frac{n_{samp}}{eff_{pad}}\right)$



- $\sigma_{Lorentz} = \frac{\gamma^2}{12\left(1+x_{\tan}^2\right)}$
- $r_{Lorentz} = \frac{\gamma^2}{12\left(eff_{wire}\, n_{wires}\right)\left(1+\tan(BA)^2\right)}$
- $\gamma^2 = \left(p\left(x_{\tan} - \theta_{Lorentz}\right)\right)^2$
- $\tan(BA) = \frac{x_{\tan-corr} - x_{\tan}}{1 + x_{\tan-corr}\, x_{\tan}}$
  - $x_{tan\text{-}corr}$ = corrected x_{tan} due to global pad tilt
  - p = sense wire pitch
  - $\theta_{Lorentz}$ = sector config parameter

Response Simulation

- $\sigma_{y-intrins}$:
  Randomly selected from distribution

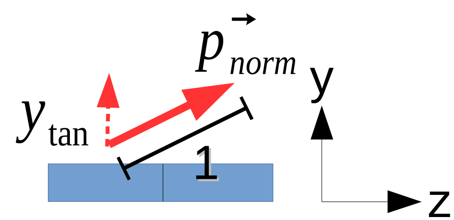


- $r_{y-intrins} = \mu_{y-intrins}$

No Lorentz Angle corrections for y-response / y-resolution!

- σ_{y-diff} :
  Diffusion coefficient

- $\sigma_{y-cross} = \frac{1}{12}\left(\frac{|\vec{pad}|\, y_{\tan}}{n_{samp}}\right)^2, \quad y_{\tan} = (\vec{p_{norm}}) \cdot \hat{y}$

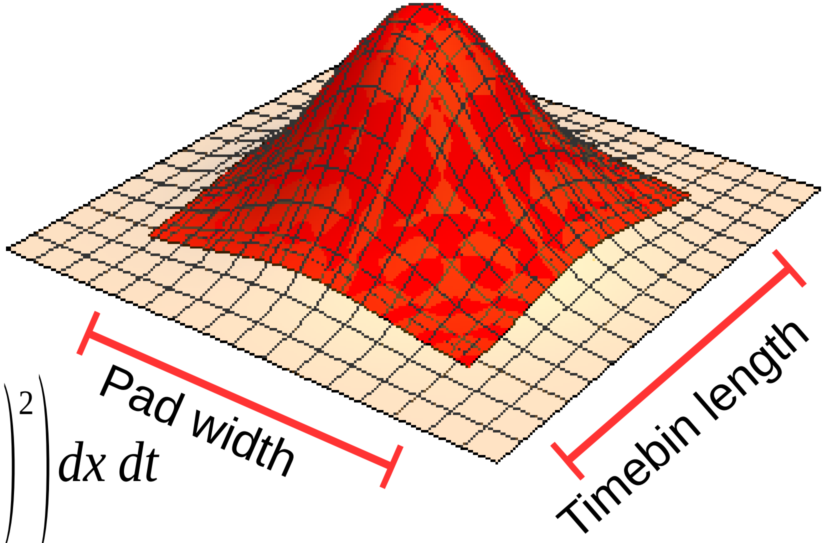


- $r_{y-cross} = \sigma_{y-cross}\left(\frac{n_{samp}}{eff_{pad}}\right)$

Unknown parameters!!
(eff_{pad}, eff_{wire})

Response Simulation

- ADC values written to pads: Integral of 2-D Gaussian in (x,t)



$$PadADC = adc \cdot \int_{-w/2}^{w/2} \int_{-T/2}^{T/2} \exp\left(-\left(\frac{\Delta x}{r_x}\right)^2\right) \exp\left(-\left(\frac{(\Delta y / v_d)}{(r_y / v_d)}\right)^2\right) dx\, dt$$

- w = pad width
- T = timebin length
- Δx, Δy = distance from sample center (pad farther from sample center recieves smaller ADC value)
- adc = ADC/dE factor (see next slide)

- X and Y resolution (r_x, r_y) are used to slightly shift final sample positions before ADC value calculation
- Pads within $3\sigma_x$ (x-response width) are written to

ADC Value Calculation

- Minimal dE Along Pad: Another integral over the same 2-D Gaussian, multiplied by pad length and a *factor*:
  - "MinimalDEPerLengthUnit"
    - How to obtain this factor?
- Total ADC for Geant4 hit: Multiply ADC/dE factor by energy deposited, spread evenly among samples

$$Min.\,dE = \frac{Min.\,dE}{pathLength} \cdot |\vec{pad}| \cdot \int_{-w/2}^{w/2} \int_{-T/2}^{T/2} \exp\left(-\left(\frac{\Delta x}{r_x}\right)^2\right) \exp\left(-\left(\frac{(\Delta y / v_d)}{(r_y / v_d)}\right)^2\right) dx\, dt$$

$$\frac{ADC}{dE} = \left(\sigma_{noise} \frac{S}{N}\right)\left(\frac{1}{(Min.\,dE)\, g_{y0}}\right)$$

$\frac{S}{N}$: Signal-to-noise ratio

σ_{noise} : "Noise sigma"

g_{y0} Gain at local y=0 inside chamber

Thanks!