Taking CCDs to the ultimate performance for low Energy Threshold Experiments

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CCDs & Low Energy Threshold Experiments

DAMIC: Dark Matter in CCDs

CONNIE: Coherent neutrino nucleus experiments.
Noise in CCD

\[ V_{\text{out}} = \frac{Q}{C} \]
\[ C_{\text{equiv}} \approx 0.046 \text{pf} \]
\[ V_{\text{out}} \approx 3 \mu\text{V/e}^- \]

Parasitic capacitances decrease the gain, and therefore SNR making it harder to measure electrons.

250\mu m > 1.5e^-
650\mu m > 1.7e^-
650\mu m << 1e^-
Electronic sources of noise

- The first stage is a transistor in a source follower configuration that sense the charge on the SN.
- The JFET driver is used for fast read-out.
- The pre-amplifier, is a AD8065 in non inverting configuration with gain 2, it matches the output impedance to 50Ω.
- At all stages, noise is added to the signal, degrading SNR

Pixel value $[e^-]$

The Noise is $\sigma \approx 2e^-$

The threshold is $4\sigma \approx 30eV$ (3.77eV/e$^-$)
Low Noise Alternative

- The JFET driver was removed. This reduces the total noise but readout is slower.
- The amplifier was replaced by a LN version with a gain of 4.5, reducing the impact of the Monsoon electronics noise.

The Noise is $\sigma \approx 1.7 e^{-}$

The threshold is $4\sigma \approx 25.6 eV$
Spurious Charge

- During the shifting of the charge packets, the clock signals can release some electrons from the channel stops, and then by impact ionization those electrons can generate holes that are collected in the wells.
- The amount of generated charge depends on the:
  - Voltage swing of the clocks
  - Rise/fall times
- This phenomenon was observed in two CCD designs
- Reading the whole CCD from only one side, it is possible to detect the presence of spurious charge
Spurious Charge in 5.2g CCDs

The clock voltages have been optimized to generate no spurious charge.
X-rays, WIMPS and Neutrinos generate charge in a small space (<1μm), and in the image look like points (hits)
Conformation of point events

- The holes generated by the event are drifted by the electric field to the collection well of the pixel.
  There is a repulsion effect and a diffusion effect.

\[ \sigma^2 = D \cdot T \]

D depends on the material
T depends on the electric field
Experimental Results with X-rays

There is a dependency of the size of the hit with number of electrons (x-ray energy), due to charge repulsion effects.

The maximum size ($\sigma$) that the events can achieve depends on their energy.
Measurement of the depth and $\sigma$ relationship

Knowing the depth in the bulk of the CCD is a background rejection tool. Low energy surface events can be filtered and the ones in the middle of the bulk can be taken as candidate events.
Conclusions

• Electronic noise of the read-out system can be minimized; the noise introduced by the CCD MOSFET is still the dominant source of noise.
• Spurious charge can be eliminated.
• The size of point-like events depend on charge repulsion and diffusion.
• It is possible to relate the depth and the size of the events, in order to produce a background subtraction tool.

Thank you!
Backup
ML estimator of DLH parameters

\[
L(Q_T, \sigma_D, \mu_x, \mu_y) = \prod_{j=1}^{N} \sum_{i=1}^{Q_T} \frac{Q_T! \lambda^i (1 - \lambda)^{Q_T-i} e^{-(q_j-i)^2 / 2\sigma^2_N}}{i!(Q_T-i)!}
\]

\[
\lambda_i = \frac{Q_T}{2\pi\sigma_D} \int_{x_i}^{x_{i+1}} \int_{y_i}^{y_{i+1}} e^{-\frac{(x-\mu_x)^2 + (y-\mu_y)^2}{2\sigma_D^2}} \, dx \, dy
\]

- Noise from the read-out electronics
- Binomial distribution of the total charge on each event pixel
- Pixelation

- Simulation of 1000 of Cu-Ka events at three pixel positions an different diffusion
Point events of 400e− at three different depths