Particle tracking at light speed with quantum dots

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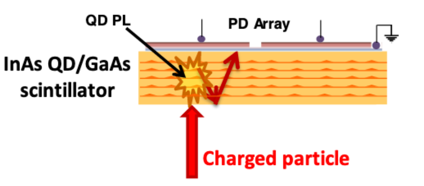
A blue skies question

Can we transition beyond the charge-drift paradigm a la Si?

- What if we could use light collection for trackers and/or fast timing?

- Thin detector (small X_0)
- Small pitch
- Fast light emmission (< 1 ns)
- High light yield
- Integrated photodetector
- Low power
- Radiation hard

Lab-grown InAs quantum dots (QDs) embedded in GaAs semiconductor

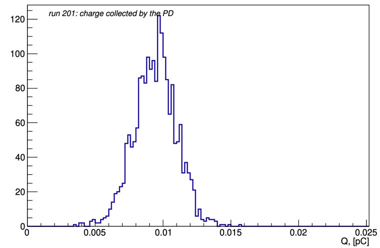


1. Quantum Dot Scintillator (QDS) — shown in orange
   - Thin layers of QDs sandwiched between thin layers of GaAs semiconductor
   - Total detector thickness of ∼20 μm
   - Ionizing particle produces e^-/h pairs in GaAs
   - Charges quickly absorbed by QDs (∼few ps)
   - Excited state QDs emmit photons as they transition to ground state
   - QD emission time of ∼ 1 ns
   - 1.1 eV emitted photons resulting in low photon self-absorption (∼ 1 cm^{-1})
2. Photosensor — physically integrated ∼1 μm thick InGaAs photodiodes

Phase α: QDS performance with 5.5 MeV α's (P. Murat, CPAD 2019)

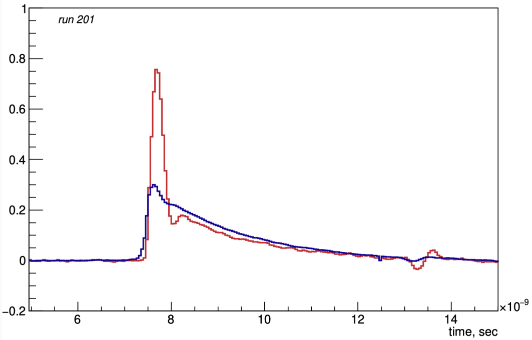
Energy

Energy resolution for 5.5 MeV α-particles



- charge on PD $\sim$ 1pC - corresponds to collection efficiency $\sim$ 8%
- observed energy resolution $\sim$ 10-15% ? - expected much better even for 8% efficiency

Timing



Measured 10^4 e^- / MeV with $\sim$100 ps rise times (in photovoltaic mode!)

$\rightarrow$ Fastest and highest light-yield of any known scintillator

Back to earth

Understand physics of uncommon sensor

- We need to understand our inefficiencies
  - Where does our ∼10% energy resolution limit come from?
    - Perhaps nonuniformities in MBE growth?
    - Other ideas not yet thought of?
  - How can we improve our light collection efficiency?
    - Design new sensors with larger PD coverage

Feasibility for HEP applications

- We need to demonstrate effectiveness in MIP detection
- Start with transition from 5 MeV → 60 keV line from Am-241
- Will require longer integration times for short term measurements
- Sophisticated electronics and readout required for fast MIP detection
  - Expect signals of thousands of e^- in 100s ps

Building a tracker: "One → Few → Many"

- Big near-term goal: Demonstrate 2 channel coincidence