CPAD Instrumentation Frontier Meeting, University of Texas Arlington

How to capitalize on single electron sensitivity in liquid noble TPCs

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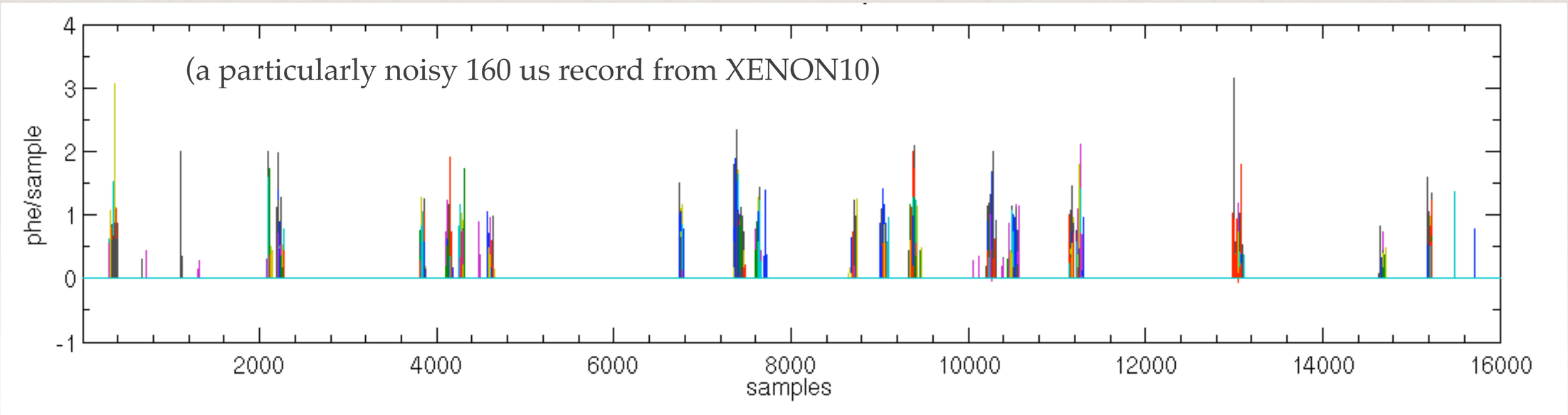
Single electrons: blessing, curse

- Ultimate detection threshold for electronic signals: single electron. check!
  - A unique capability among massive, low-background detectors
  - Thanks to internal amplification via proportional scintillation
  - Has enabled new physics searches/analyses
- But! UV photons: robust signal, relentless noise source

Near-threshold noise: “electron trains”

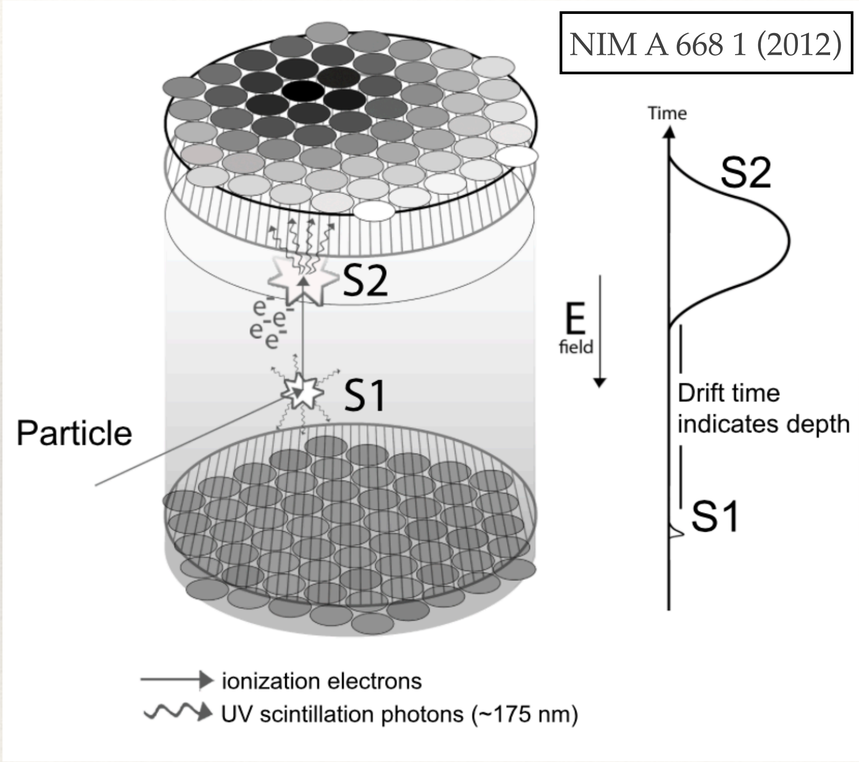
- XENON10 S2-only analysis identified a “new” background: electron trains
- Complicates identification of few-electron signals

Phys Rev Lett **107** 051301 (2011)



Few-electron signals are more difficult to localize

- S2 signal: 1 electron => ~200 UV photons => ~25 photoelectrons
- S2 UV photon hit pattern returns larger (x,y) uncertainty for small signals
- Shrinks the usable self-shielded fiducial target mass



This noise scales with detector size

- $O(10^6)$ UV photons per second from proportional scintillation
- They photo-ionize ~ppb bulk impurities and detector materials (bigger detector, more targets)
- Electrons drift to liquid-gas interface
- Electron extraction time constants (2+ !) not well known, but mostly ~ns with residual ~ms JETP 55 5 (1982)
- ∴ Constant, uncorrelated trickle of electrons

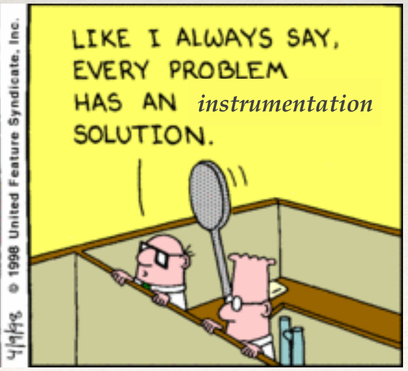
Which parties might this crash?

- Low-mass WIMP search — Phys Rev Lett **107** 051301 (2011)
- Sub-GeV dark matter search — Phys Rev Lett **109** 021301 (2012)
- 8B solar neutrino measurement via coherent scatter — future LZ publication
- Neutrino magnetic moment search — future LZ publication
- Probably others…

"Every problem has an instrumentation solution"

- Quench the UV photons — methane is a natural choice
  - Will erode primary scintillation (S1) sensitivity — that's OK
  - Will erode proportional scintillation (S2) — also OK
  - Will require new purification technology — doable
- Use thick GEMs to detect single electrons
  - Reduces uncertainty on (x,y) reconstruction via segmented anode
  - additional suppression of UV

NIM A 686 106 (2012)



Towards a drop-in upgrade

- R&D on Xe-CH_4 (and possibly other UV-quenching mixtures)
- R&D on thick GEMs in Xe-CH_4 at 175 K (previous work with GEMs have only obtained x200 amplification, need x10^5) NIM A 556 273 (2006)
- Goal would be a future "drop-in" upgrade for an existing large detector (like, say, LZ)
- e.g. replace the top array of PMTs with thick GEMs, and add a UV quencher

S2-only operation offers unique benefits

- Can sharpen (or outright enable) our sensitivity for the searches mentioned on slide 6
- But also appears to require a unique tweak in order to function in larger detectors
- This R&D would be parallel and complementary to G2 dark matter and aligned with P5

Extra slide

- methane purification — commercial solution from SAES: PS3-MT3-337 removes all “usual suspect“ electronegative impurities. Similar to PS4-MT3-R-1 except also passes CH_4.
- methane solubility — triple point 91 K versus 161 K for xenon. Expect roughly x10 preference for gas phase at 173 K (normal operating temperature of LUX-like detectors)

Raether limit

- Rather unfortunate reality of avalanches
- Qc ~ 1e7 electrons above which discharges are inevitable
- But we have some tools at our disposal:
  - HV switching based on S1 detection
  - increased diffusion to spread avalanche laterally