NuDot: Double-Beta Decay with Direction Reconstruction in Liquid Scintillator

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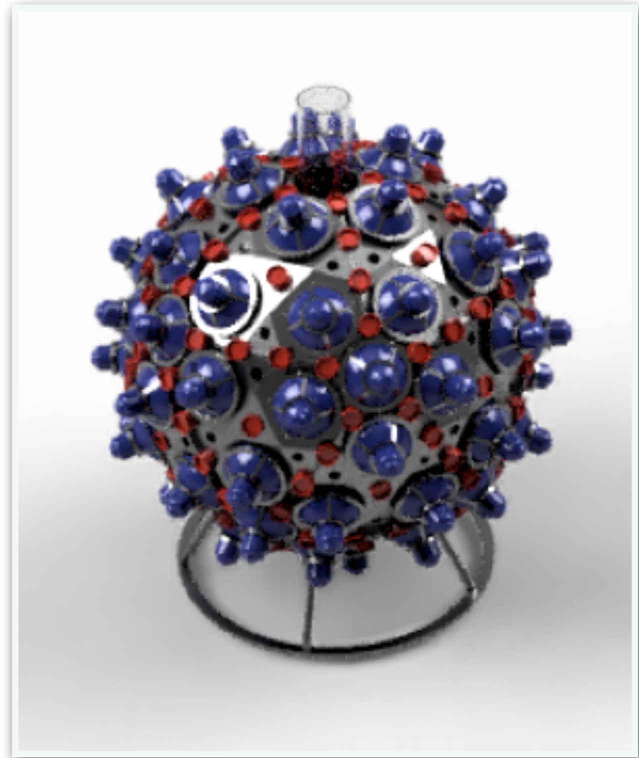
Liquid Scintillator and the Future of 0νββ Searches:

- Liquid scintillator experiments have demonstrated field-leading sensitivity
- Monolithic approach can be scaled to kiloton scale
- "Irreducible backgrounds" like ^{8}B solar neutrinos will become problematic for future experiments

NuDot Goals:

- Develop hardware, DAQ, and analysis techniques required for sub-nanosecond timing in liquid scintillator
- Demonstrate Cherenkov signal momentum reconstruction of ~1 MeV electrons
- Conduct proof-of-concept measurements:
  - with calibration sources at MIT's Bates Laboratory
  - 2νββ half-life measurement at LNGS
- Test novel liquid scintillator cocktails, including quantum dot wavelength shifters

Hardware and Design:



- High light-collection efficiency: 72 x 8" PMTs
- Fast timing: 140 x 2" PMTs
  - Hamamatsu R13089's have demonstrated TTS of 140ps
- 1m diameter inner sphere of isotope-doped scintillator
- Submerged in mineral oil to provide shielding
- DAQ system combines CAEN v1724 (5Gs/s) with v1725 (250 Ms/s): high-freq. sampling with low dead-time

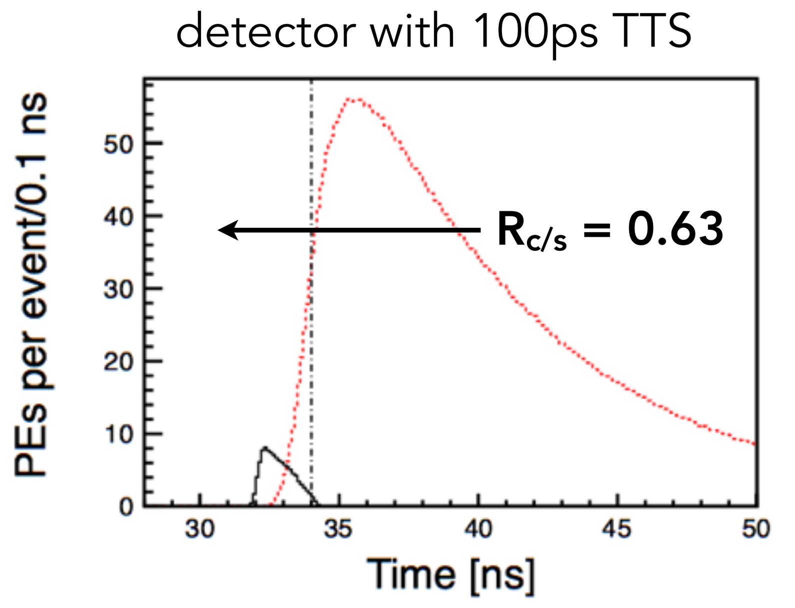
Status and Schedule:

- FlatDot paper in preparation
- NuDot construction, July-September 2018
- Surface data-taking, 2018-19. Operation at LNGS, 2019-20

Timing-Based Cherenkov Separation:

- All charged particles excite the scintillator, leading to isotropic light emission
- Charged particles moving faster than the speed of light in the medium also produce Cherenkov light
  - Double-β decay gives 2 e⁻ above the Cherenkov threshold, ^{8}B solar νs produce only one
- Long-wavelength Cherenkov light is not absorbed, so it retains directional information

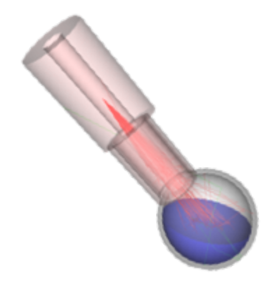
Simulation of KamLAND-style detector with 100ps TTS

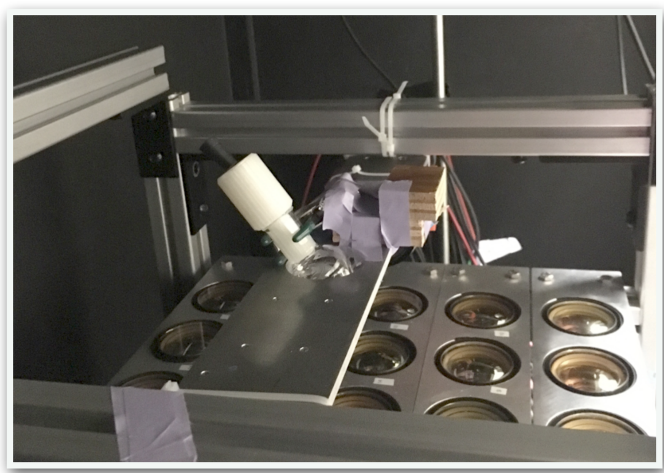


- Scintillators have inherent rise time, so Cherenkov light is produced first
- Longer wavelength Cherenkov light travels faster in scintillator, so timing separation improves in larger detectors
- Quantum dots could be used to improve separation by tuning and narrowing emission

FlatDot Test-Stand:

- 25-PMT array with 2 trigger PMTs and muon veto paddle (all R13089)
- ^{90}Sr "β gun" source can be shifted and tilted
- Cuvette holds any liquid

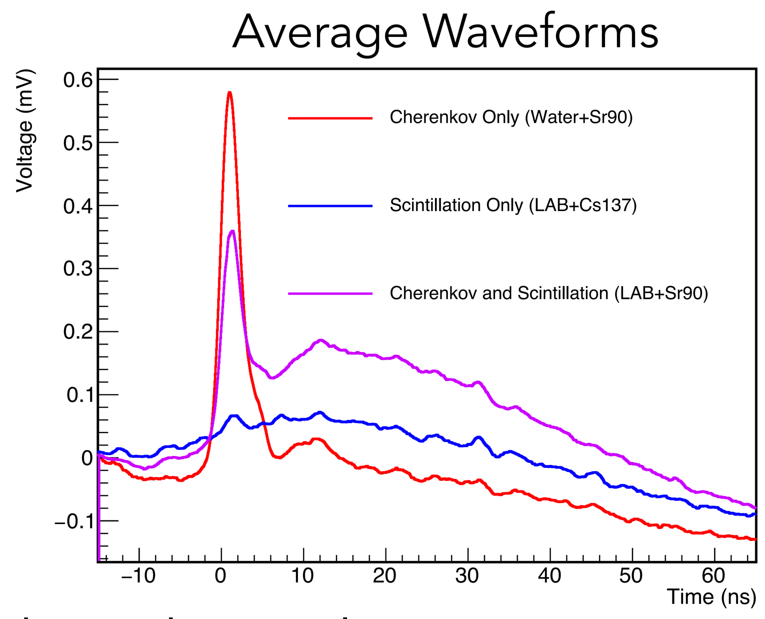




FlatDot Timing Performance:

- Demonstrated Cherenkov/ scintillation light separation for ^{90}Y βs (Q = 2.28 MeV) in LAB

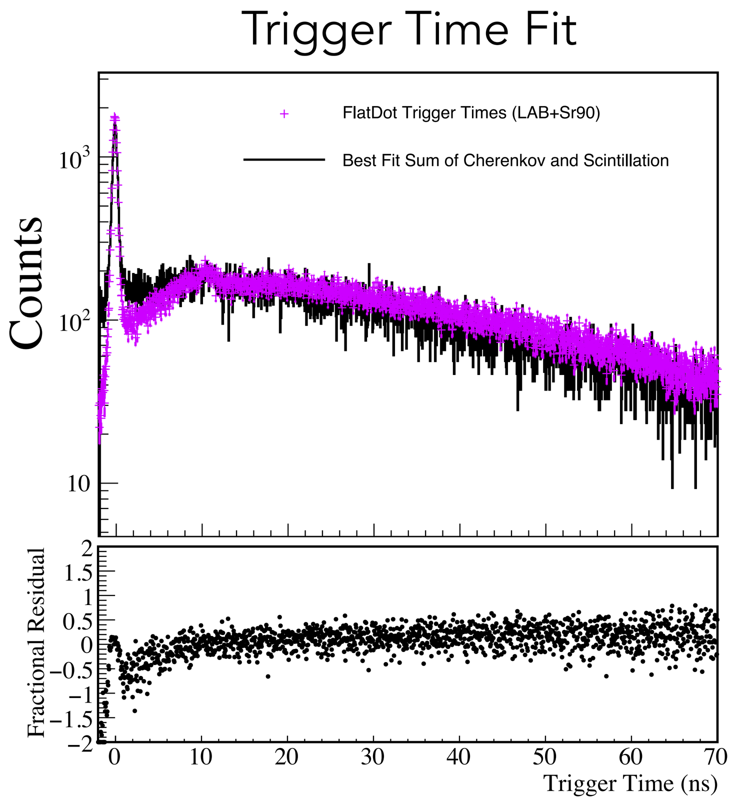
Average Waveforms



- Data-driven fit:
  - ^{90}Sr + Water for Cherenkov-only timing curve
  - ^{137}Cs + LAB for scintillation-only timing curve
  - Signal fit to a sum of the two curves
- Fit from -2 to 70 ns, excluding region with significant dead time loss (1.5-8 ns)
- $R_{c/s}$ = 74±7% in Cherenkov window

	Cherenkov Window (|t|<0.4ns)	Scintillation Window (t>2ns)
Fraction of Total Cherenkov Light	70%	13%
Fraction of Total Scintillation Light	3%	92%

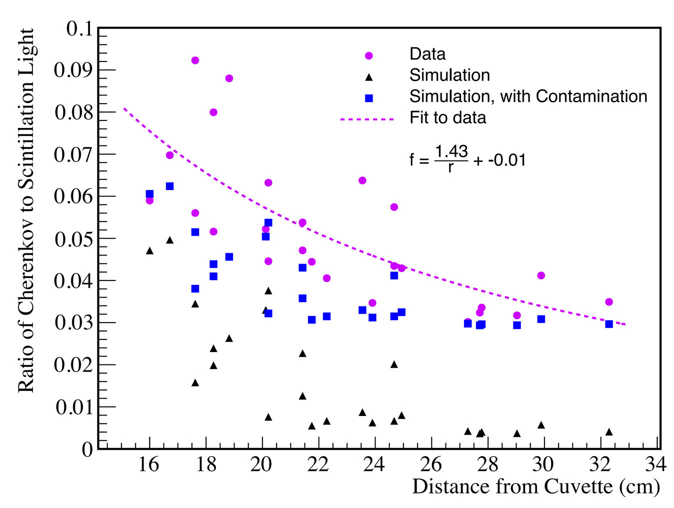
Trigger Time Fit



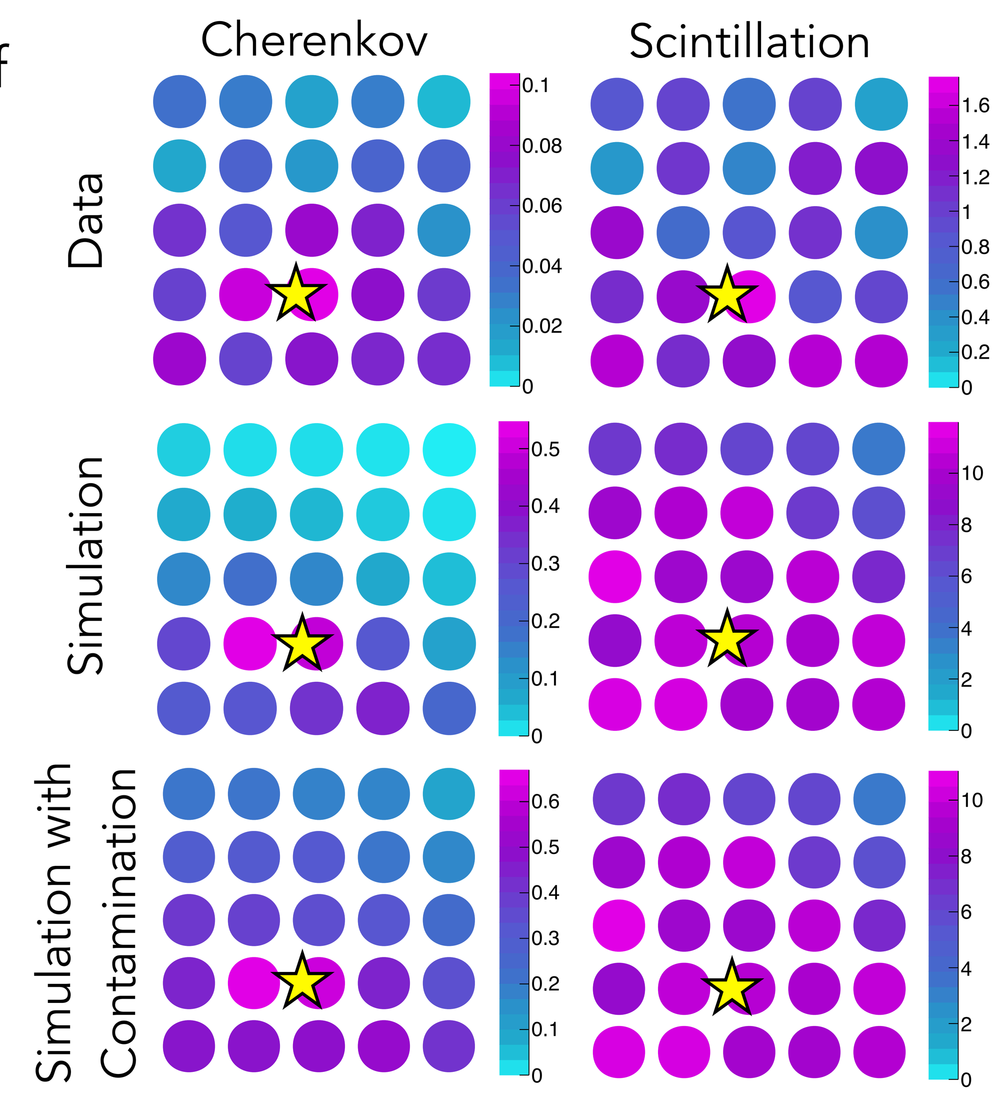
FlatDot Spatial Distribution:

- Compared average distribution of Cherenkov and scintillation light to Geant4 simulation for off-center and tilted collimator
- Simulation distributions corrected for expected contamination, determined from timing fit result

Cherenkov to Scintillation Ratio



Average Photoelectrons per Event



☆ Source position, tilted towards bottom row by 35°

For more information, see:

Deep Learning for Liquid-Scintillator-Based Double-β Decay Searches (Monday, Wall #70)
Perovskite Quantum Dots in Liquid Scintillator (Wednesday, Wall #153)
Comparing Spherical Harmonics Analysis and Machine Learning Techniques for Double-β Decay Identification in a Large Liquid Scintillator Detector (Wednesday, Wall #151)
The Road to Theia (Monday, Wall #122)
The Discovery Potential of Theia (Monday, Wall #123)