Large-Area Picosecond Photosensor-based Neutrino Detector

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Problem

• For future neutrino detectors we would like to improve performance by increasing the detector coverage, granularity, timing resolution and quantum efficiency and/or reduce the cost of technology.

Approach

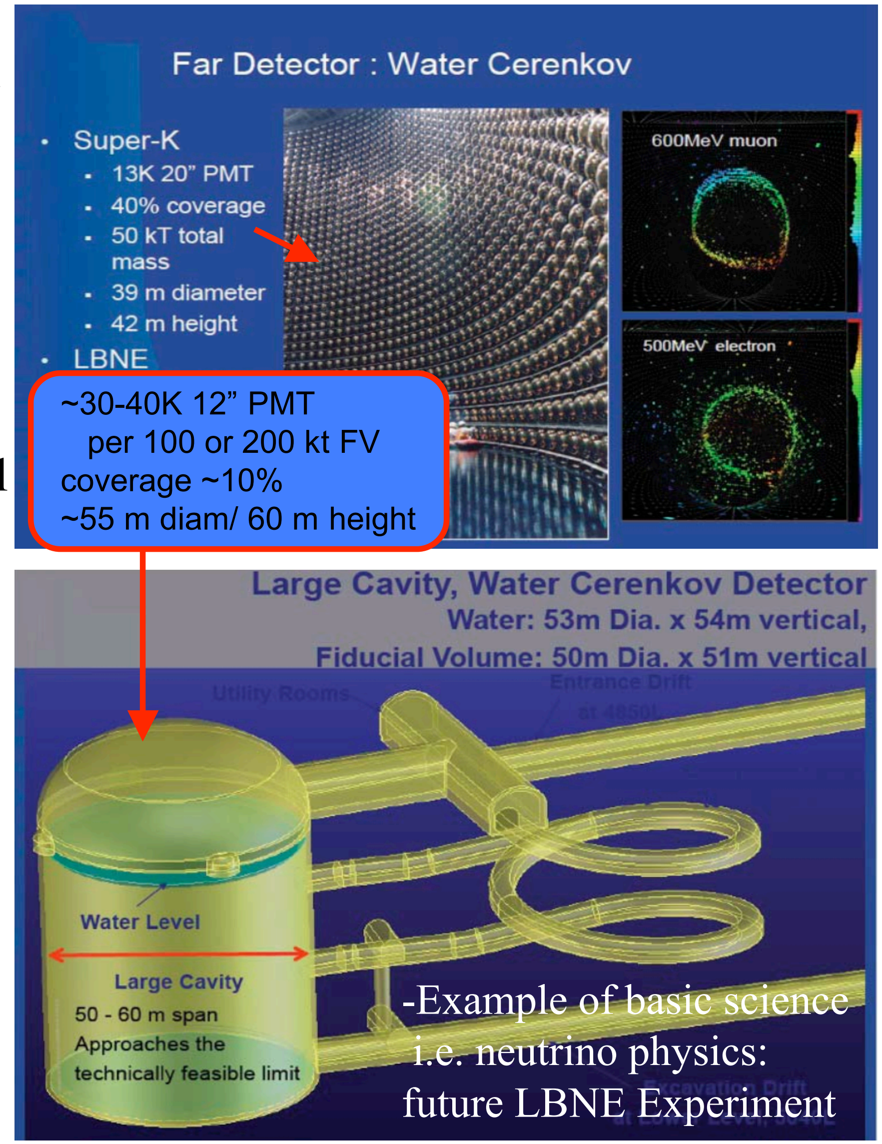
• Use Large Area Picosecond Photo-Detectors (LAPPD) currently under development at ANL/UC: MCP-based, potentially cheap, scalable, flat panel photo-detectors with a high precision time and spatial resolution.

Goal

• Develop a staged approach to neutrino applications of this technology.

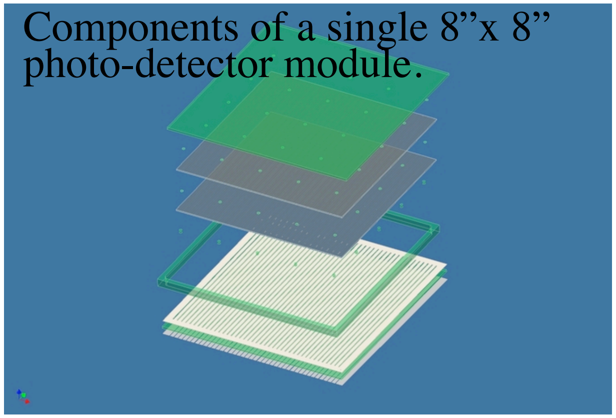
• Explore applications that could result in game-changing experiments in the field.

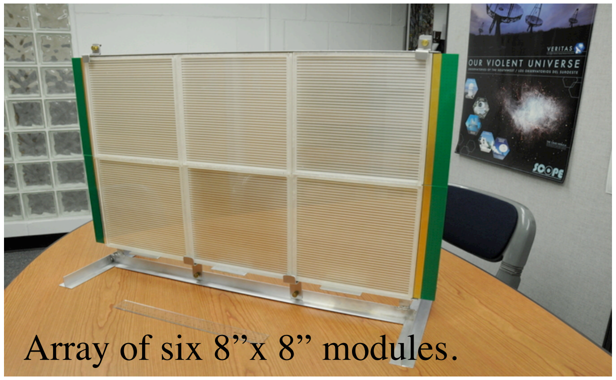
• First application of LAPPD-based detector in a liquid scintillator (LS), pure water or water-based LS detector.



Potential Advantages of Large Area Picosecond Photo Detectors over PMTs

- mm spatial resolution
- <100 pico-second time resolution
- potential 100% coverage
- reduced cost


Components of a single 8”x 8” photo-detector module.


Array of six 8”x 8” modules.

Potential LAPPD-based Detector Applications

Generic Application:

Measure radiation in a variety of applications.

- Medical imaging.
- National and homeland security.
- Border security.
- Nuclear plant safety.

Basic Science

- Neutrino application of this new technology to neutrino Liquid Scintillator/Water detectors:
    - It could enhance background rejection and vertex resolution by improving spatial and timing information (track reconstruction).
    - It would enhance low energy physics capabilities of the detectors by providing higher coverage than what is currently planned.
- Low-background counting facility: position a material sample within detector.

LAPPD Project Status

- The goal of the LAPD project is to develop a commercializable planar detector module with 100 pico-second time resolution and one cm spatial resolution across the area of the module.
- However, the project does not include design and/or realization of a particular experiment or applications.
- The approach is to partner with groups that might be interested in using the technology.
- Neutrino and related detectors would be such a group.

• Status/Goals of LAPPD-PMT production?
• Possible delivery of modules for a small scale experiments.
• Overlap among current proposals/projects:
    • ANL/UC/LLNL: "Centimeter spacial and 100ps temporal resolution in cubic meter liquid scintillator detectors".
    • CalTech/FNAL/ANL: "Development of Cost-Effective Crystals with
    • Dual-Readout for the Homogeneous Hadron Calorimetry".
    • Mayly's NSF Career award: "Next generation Neutrino Water Cherenkov Detectors Using Large-Area Fast Photosensors" (already funded, more on this later).
• What is the time scale for supplying LAPPDs to all these proposals, if funded?
• Is there common detector simulation work, LAPPD characterization work etc. to be done?

Phased Approach

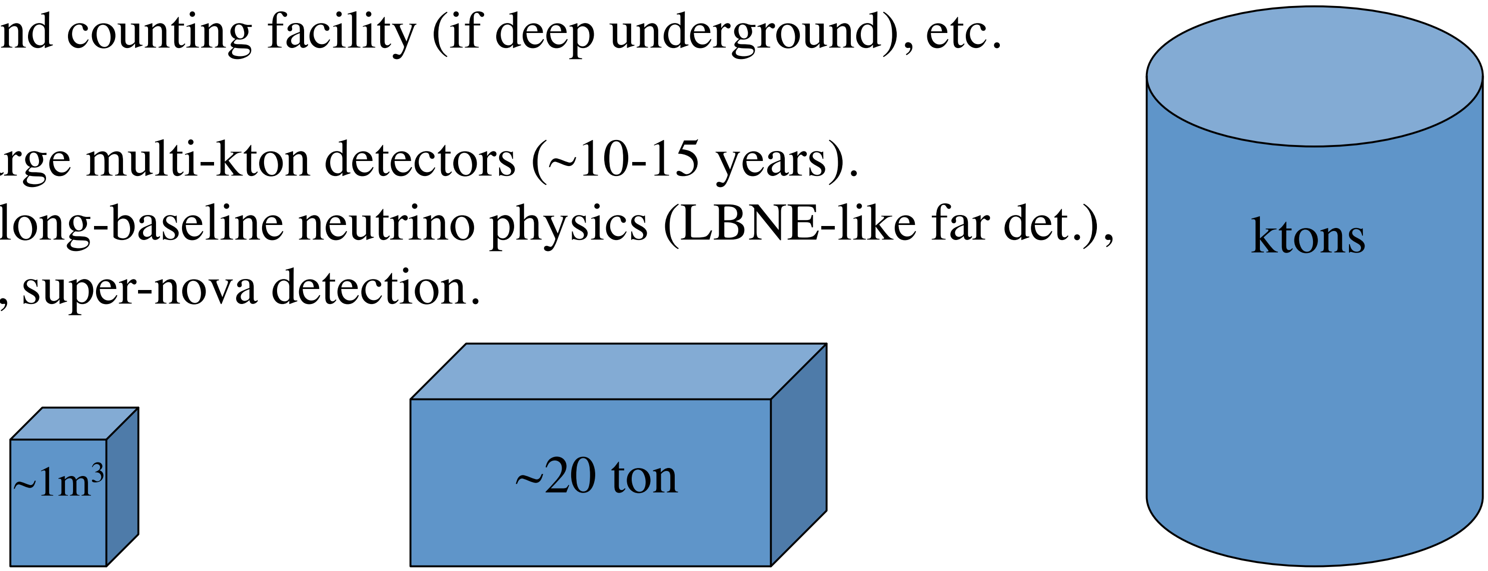
Philosophy: First build something small, then build something big.

Phased Approach in Technology Development

- Short-term: design, build and operate ~1m^3 detector (~3 years).
  Application: "proof of principle", homeland security, physics?

- Intermediate-term: build a 20 ton LAPD-based detector (~4-6 years).
  Application: short-baseline neutrino physics (oscillation tests and cross-section measurements), LBNE-like near detector, low-background counting facility (if deep underground), etc.

- Long-term: large multi-kton detectors (~10-15 years).
  Application: long-baseline neutrino physics (LBNE-like far det.), proton decay, super-nova detection.



Liquid Choice

- The LAPD-based detector could detect a particle interaction in:
  - water (cherenkov light).
  - liquid scintillator (ideally both cherenkov and scintillator light).
  - water based liquid scintillator.

- Liquid scintillator advantages:
  - open possibilities to detect physics below Cherenkov threshold.
  - proton decay channel $p \rightarrow K$ becomes accessible.
  - no need for purification (contrary to Water Cherenkov detectors).

- Cherenkov detector advantages:
  - Simpler optical model (less uncertainty).
  - Scalable to larger detectors due to longer attenuation.
  - Length than oil, cheaper than oil.

- Best of both worlds?

Possibility to use the water-based liquid scintillator - Minfang Yeh/BNL.

Detector Size Features

- Large detector concept:
  - complete shower development (beam physics).
  - containment dictates the size of the detector.
  - effects of light propagation: attenuation, scattering, absorption, dispersion.
  - physics dictates photo-detector coverage.
  - use of timing tied to coverage.

- Small Detector concept:
  - showers not contained if limited size (both water and oil have dE/dx~2MeV/cm).
  - seeing only first few radiation lengths (both water and oil have $X_0 \sim 40$cm).
  - timing is essential for pattern recognition/vertex resolution.
  - high hit rate/photon density might be an issue (saturation?).

- Detailed technical discussion on these points this afternoon.

Possible Short-term Goals: design, build and operate ~1m^3 detector (~3 years).
Application: "proof of principle", homeland security, any physics?

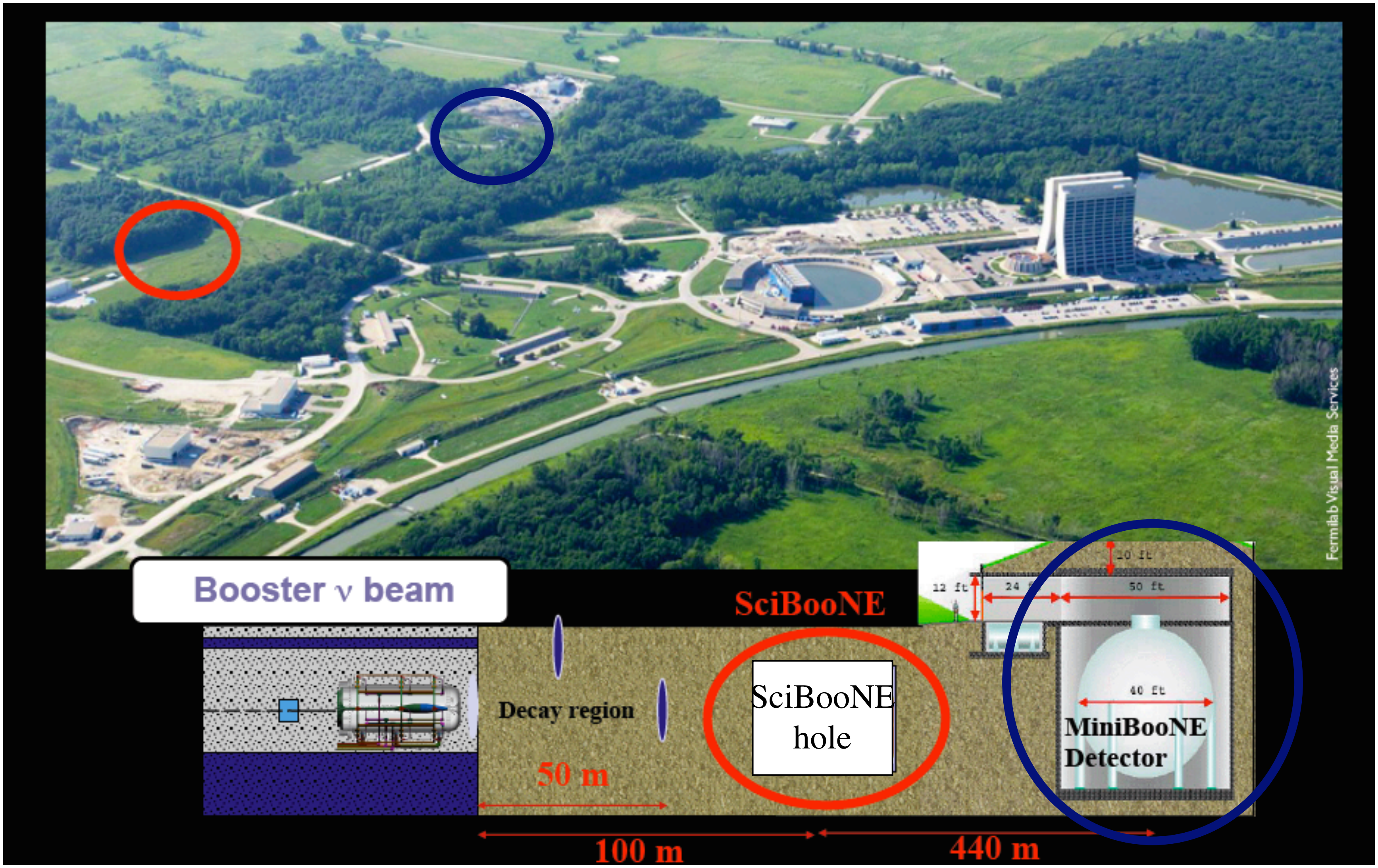
- 1st year: characterize and design LAPD-based detector: simulate and quantify the benefits of a precise position and time resolution, understand particle ID and background rejection capabilities.
- 2nd year: LAPD module available, start building a prototype of LAPD based detector: understand the LAPD module/liquid interface, design containment vessel, readout scheme (test wireless).
- 3rd year: application and operation of LAPD in LS, water, or water-based LS detector: data analysis and comparison with expectation.

This could be funded through LDRD, DOE detector R&D, Early Career.

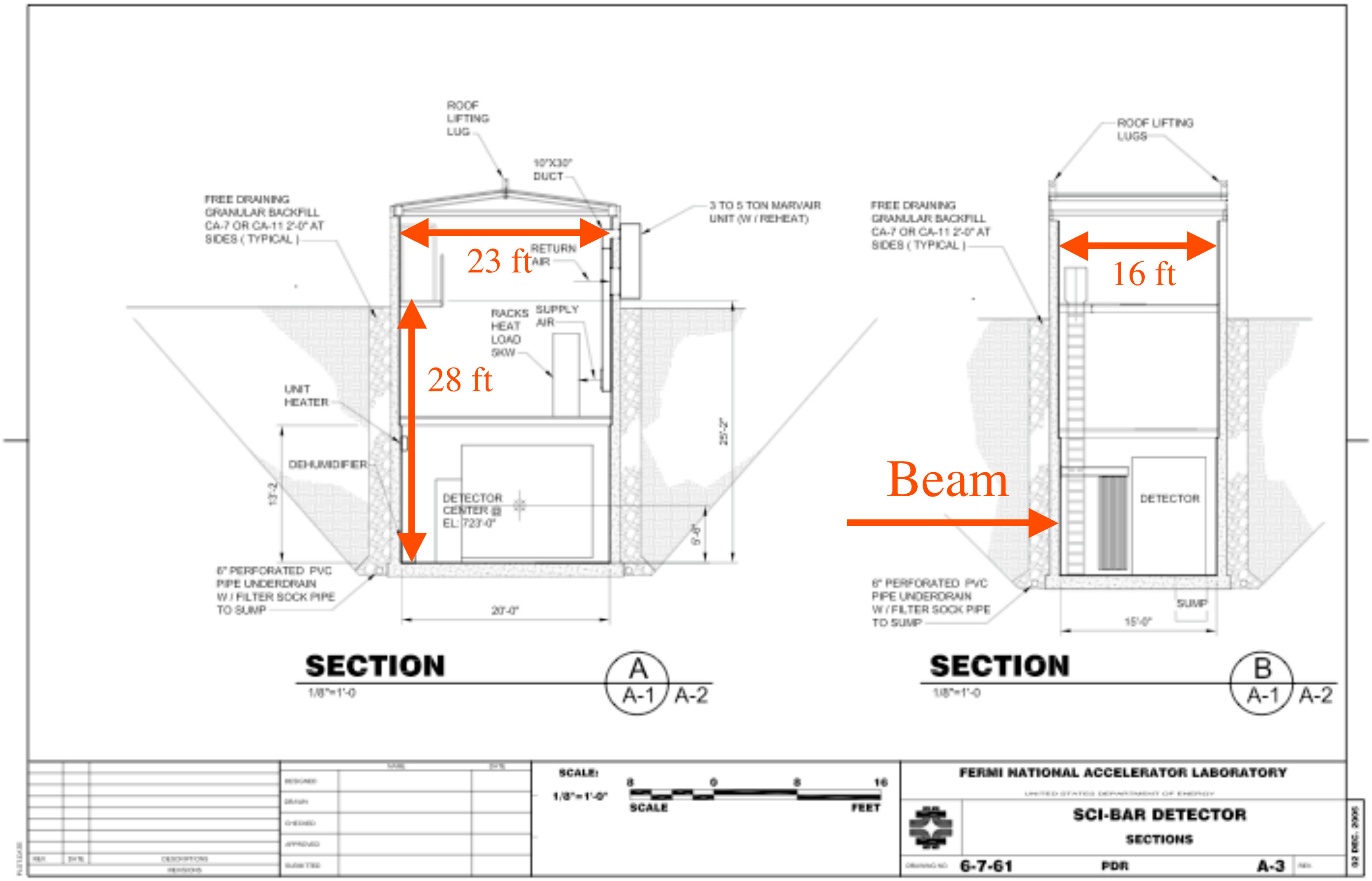
Possible Intermediate-term: build a 20 ton LAPD-based detector (~4-6 years).
Application: short-baseline neutrino physics (oscillation tests and cross-section measurements).

-Short-baseline Neutrino Workshop 2011 (May12-14, FNAL): discuss interest, ideas.

-One idea is using Neutrinos from the Booster Beamline in the SciBooNE pit:



SciBooNE Enclosure Drawings



Rates Expected with $1x10^{20}$ POT exposure at SciBooNE pit

	Total Events [1/1ton/10^{20}POT]	ν-type	Total (per ν-type)	Charged Current	Neutral Current
Booster Beam (ν-mode, Target = CH_2)	10419	ν_μ	10210	7265	2945
		anti-ν_μ	133	88	45
		ν_e	72	52	20
		anti-ν_e	4.4	3	1.4
Booster Beam (ν-mode, Target = H_2O)	10612	ν_μ	10405	7443	2962
		anti-ν_μ	129	85	44
		ν_e	73	53	20
		anti-ν_e	4.6	3.0	1.6

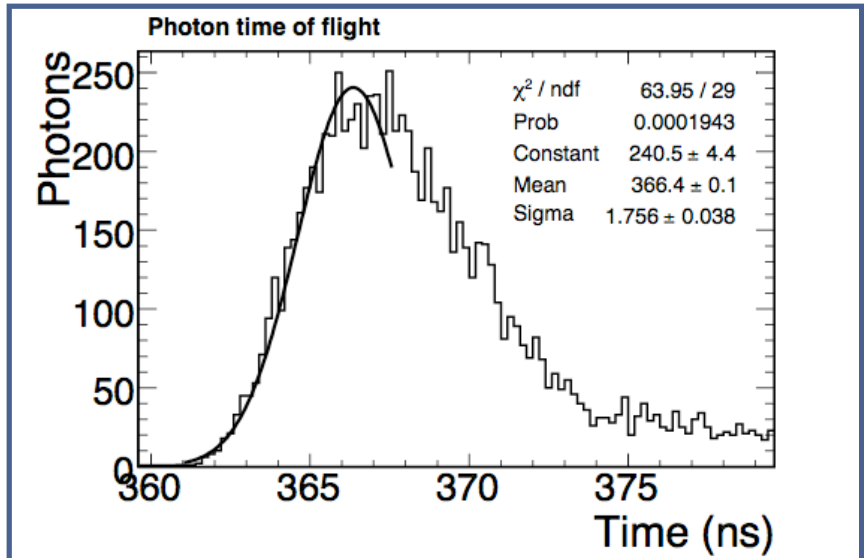
Possible Long-term: large multi-kton detectors (~10-15 years).
Application: long-baseline neutrino physics (LBNE-like far det.), proton decay, super-nova detection.

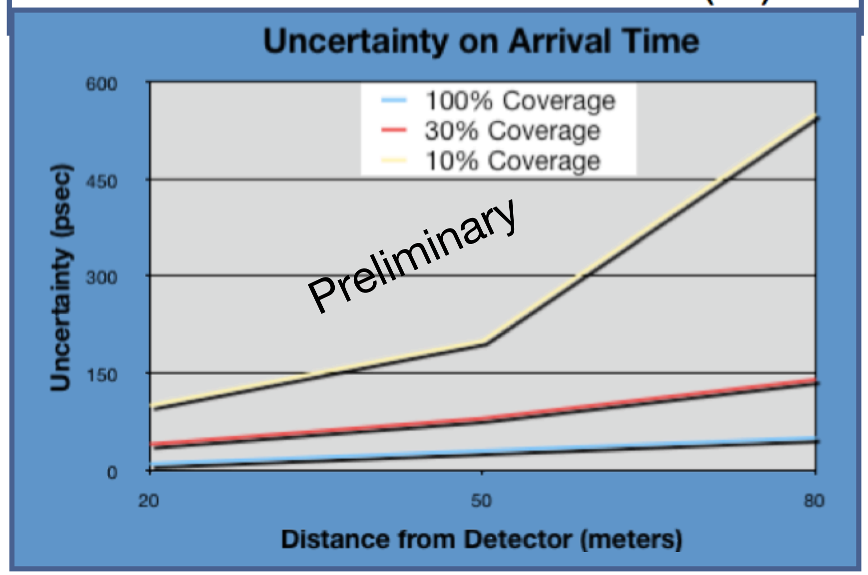
- Investigation of issues related to large water detector funded through Mayly's NSF CAREER grant (5 year project).
- 1st stage:
  - Study the interplay of coverage, timing, granularity, quantum efficiency for expanding the physics capabilities of the next generation of water cherenkov detectors using LAPPDs.
  - Develop algorithms to make use of new photosensors.
- 2nd stage: Characterize LAPPDs at ISU for specific features required for this measurement.
- 3rd stage: Develop calibration design for the use of LAPPDs:
  - Optical params: light scattering and attenuation length.
  - Relative timing.
  - Vertex and angular resolution.
  - Particle ID efficiency.

See this afternoon discussion on progress on this.

Large Detector application concepts

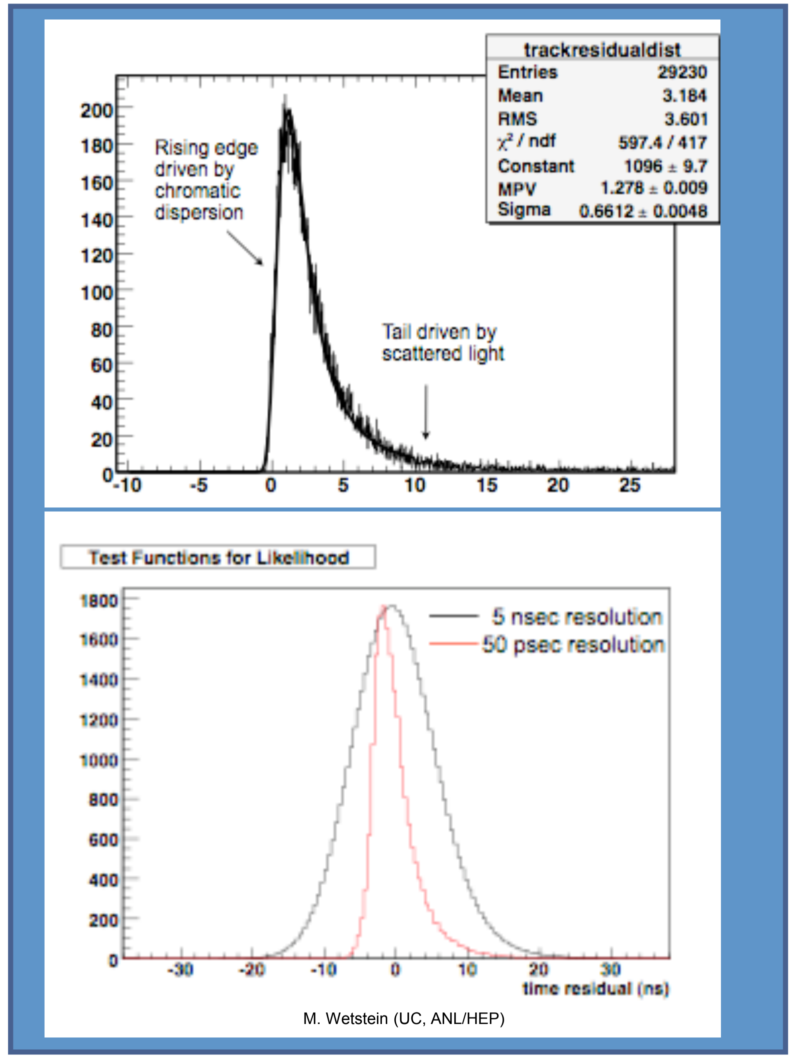
- A concern in using fast timing are the effects of frequency dependent dispersion, scattering and absorption.
- Using a fast toy MC originally developed by J. Felde we study the time of arrival for photons in an spherical detector.
- For a 50m detector with 100% coverage, the rise time (t_{90}-t_{10}) is of the order of 2 ns which cannot be sampled with standard PMT technology.
- For a given detector size, the rise time stays constant and the uncertainty in the position of the leading edge becomes smaller if larger photodetector coverage is considered.
- A combined improvement in photodetector coverage (for reduced uncertainty in risetime) and faster timing (to better sample the risetime) allows for better use of timing information in Water Cherenkov detectors.





Large Detector application concepts

- Collaboration among the hi-res WCh working group has produced a new platform for testing algorithms on WCh detectors with interactively modifiable photodetector properties.
- These efforts have already identified promising features in observables, such as timing residuals, that could potentially be used to improve track reconstruction and better identify π^o backgrounds.
- GEANT-based studies are being done in less idealized conditions: Including effects of temperature, pressure, Mie scattering, higher order chromatic dispersion and wavelength shifting.



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Long-term: large multi-kton detectors (~10-15 years).
Application: long-baseline neutrino physics (LBNE-like far det.), proton decay, super-nova detection.

- The alternative is a different design detector from the standard LBNE water cherenkov that could do similar or more interesting physics.
- Use of liquid scintillator or water-based scintillator needs:
  - Simulation of the scintillation component based on other experiments.
  - Different reconstruction algorithms.
  - Different scale/geometry.
  - Magnetic field?
- This is a large project that would need significant manpower to realize.
- New direction?

- Other proposals with overlapping physics interests:
  - LBNE WC
  - DAEdALUS
  - LENA
  - MEMPHYS
  - light collection in LAr detectors?