Using Large-Area Picosecond Photosensors in Water Cherenkov Detectors

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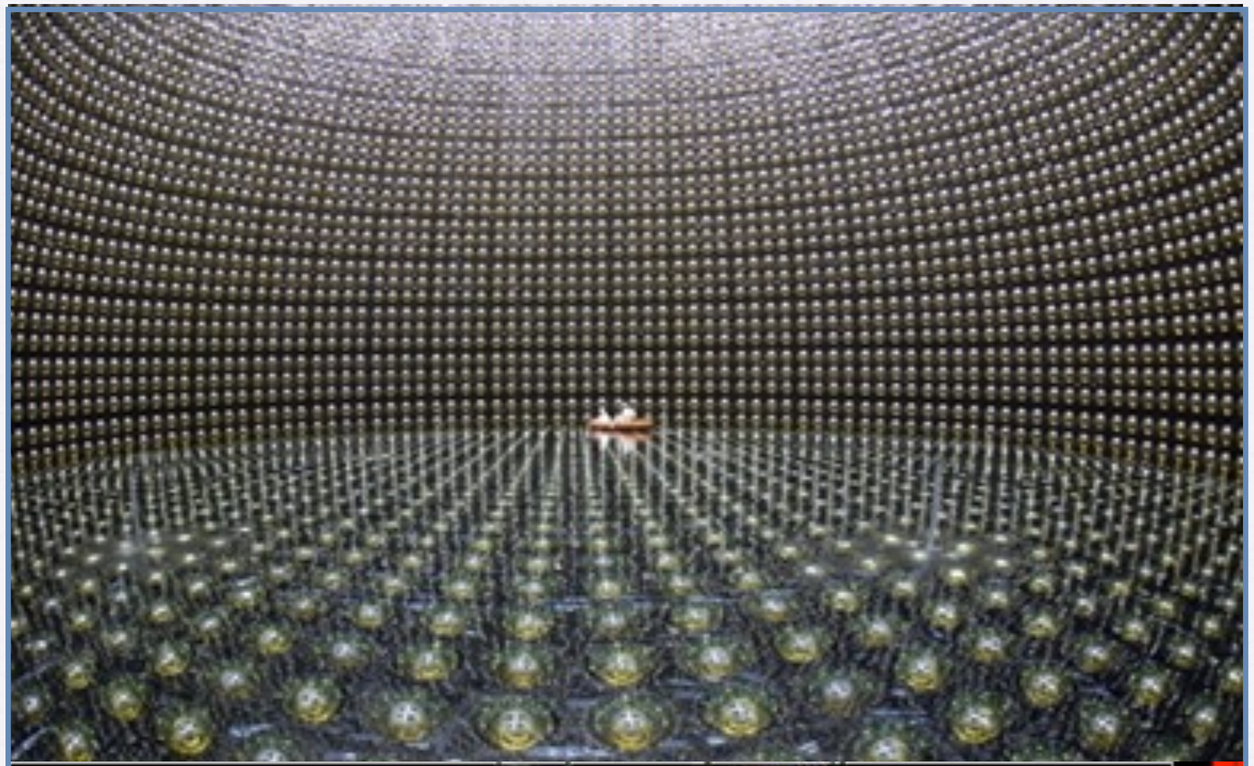
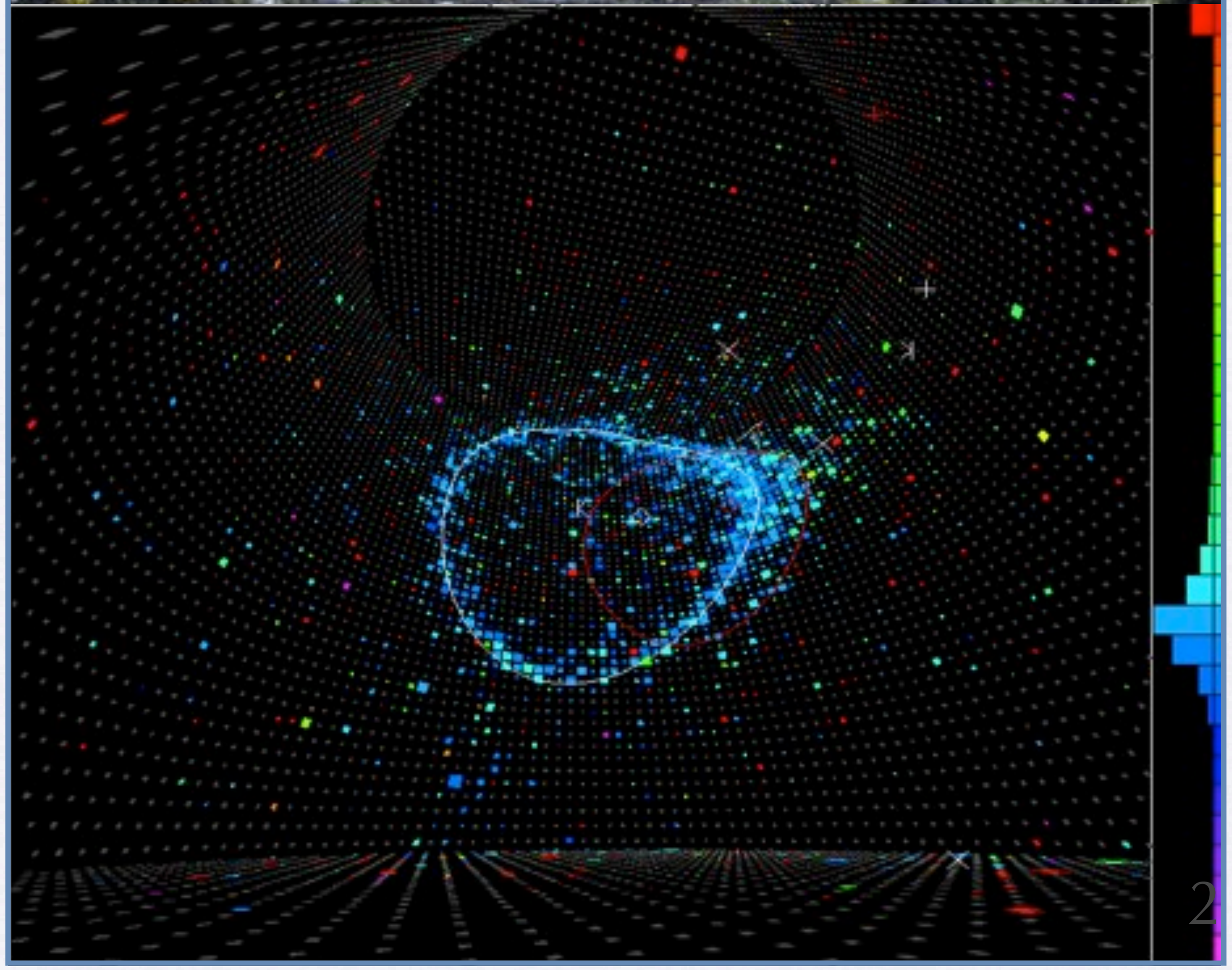
Motivation I

- The next generation of neutrino experiments will require massive detectors to reach the sensitivities needed to measure CP violation in the lepton sector and the neutrino mass hierarchy.
- One or several well instrumented large water Cherenkov (WCh) detectors provides the mass required for a broad physics program in LBNE.
- The biggest challenge for the WCh is to instrument very large surfaces with traditional photomultiplier technology due to cost.





Motivation II

- In neutrino physics, there is also a need for smaller and/or higher intensity detectors.
- Recent results have a series of low significance “anomalies” that might need to be resolved and/or measured in a short-baseline beam.
- This could be an excellent opportunity to put this technology to the test before a large deployment.
- Other interesting uses: a possible Near Detector for LBNE, nuclear non-proliferation, etc.

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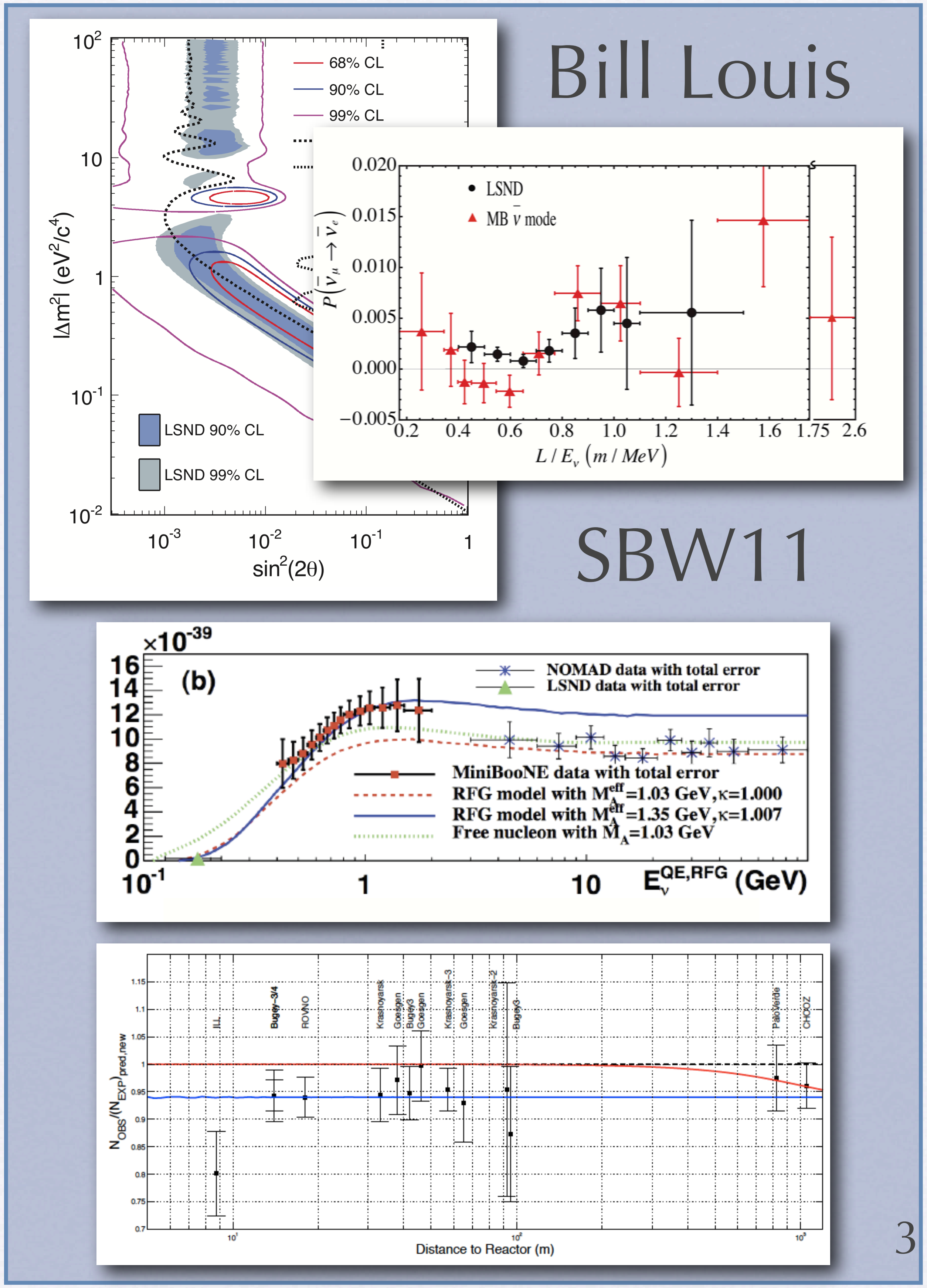
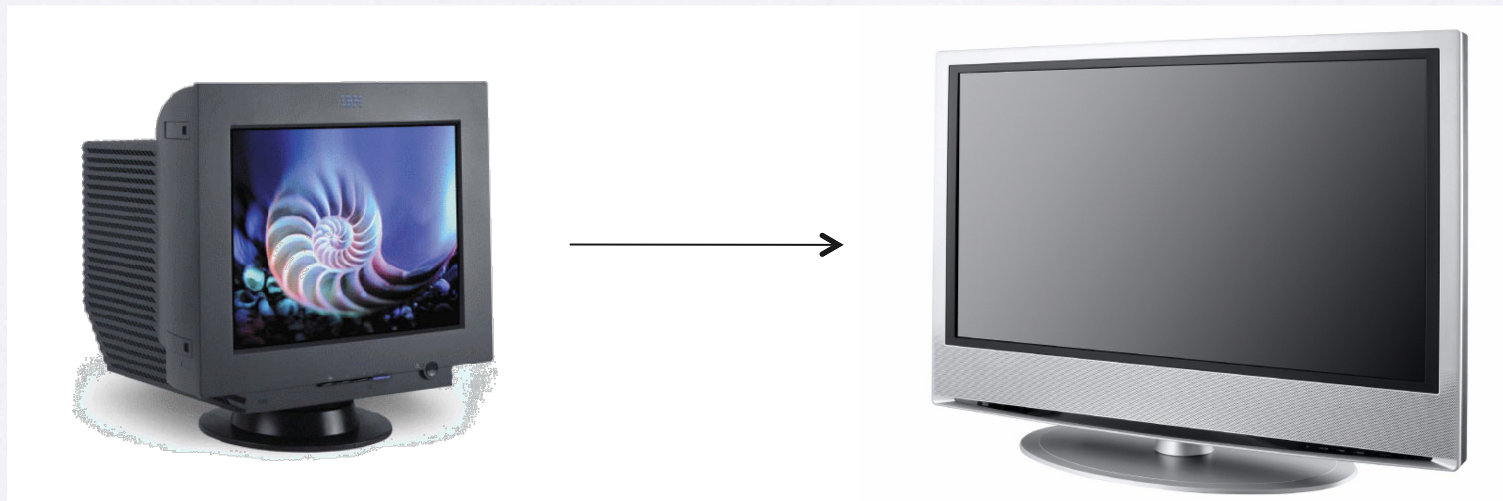
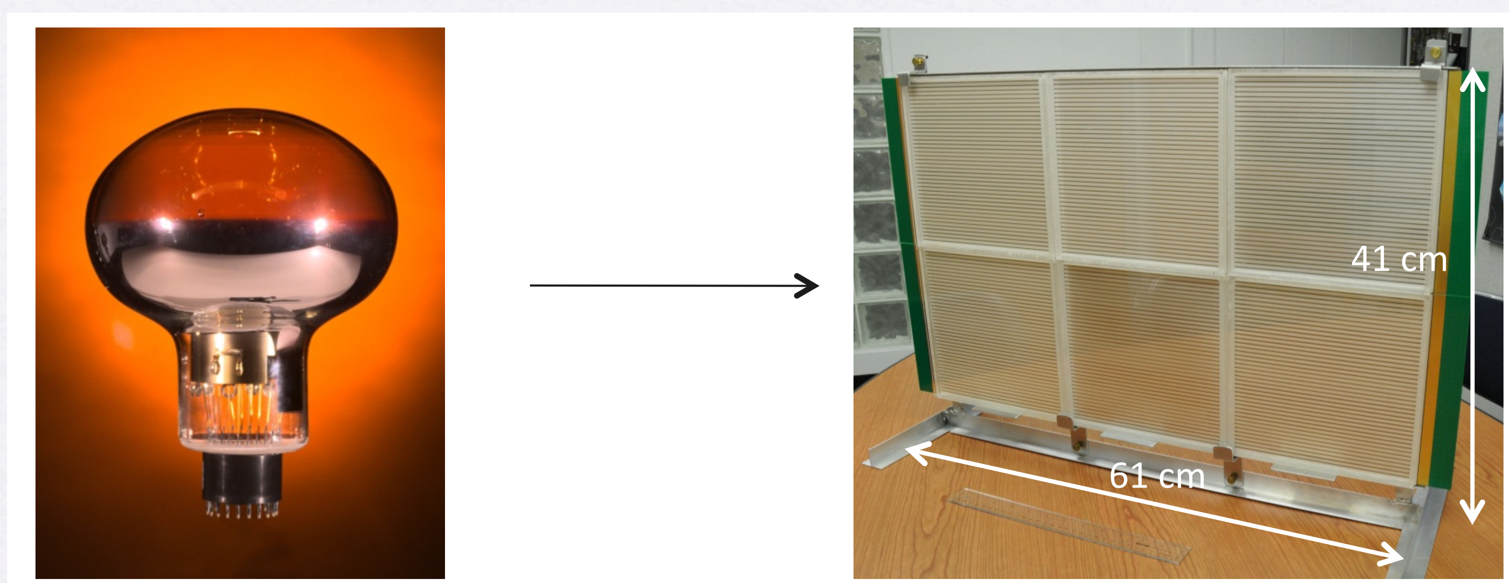


A LAPPD for neutrinos

who can resist a cool analogy?





A LAPPD for neutrinos

Proposed design / Wish list

- Multichannel plate photosensor in 8x8″ tiles arranged in 24x16″ super-module.
- Scaled photocathode or new material such as nano-structured photocathodes. Higher than 25%?
- Timing resolution of ~100 psec.
- Channel count optimized to large area/desired granularity.
- Integrated double sided readout.
- Large-area flat panel may be resistant to high pressure environment.
- No magnetic susceptibility.

The Neutrino Application

yes, it might be cheaper but...

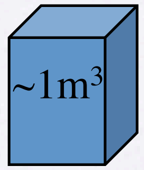
- The application of this new technology for neutrino Water Cherenkov detectors could enhance background rejection and vertex resolution by **improving spatial and timing information**. It could also broaden the low energy physics capabilities of the detectors by **providing higher coverage** than what is currently planned.
- These benefits need to be demonstrated with simulations, characterization and calibration design for these devices.
- Design of the photosensors is being kept reasonably generic as there are many possible applications.
  - LAPPD collaboration partnering with groups interested in applications. This is one such partnership (lab/university).
  - Direct feedback to the baseline design of these devices is needed by defining and optimizing the specifications.
- For the large LBNE Water Cherenkov detectors, at this time this technology is seen as a possible upgrade path. A talk was presented to the Marx committee.

➡ Collaboration of Iowa State (ISU), Argonne and UChicago has already started.

A phased approach

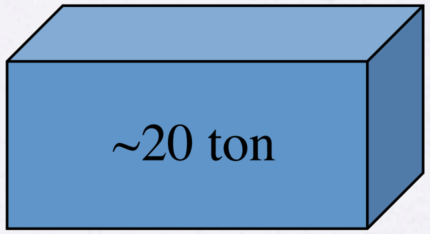
Philosophy: build something small, then something big

- Short term: design, build and operate ~2m^3 detector. Application: "proof of principle", homeland security, etc.

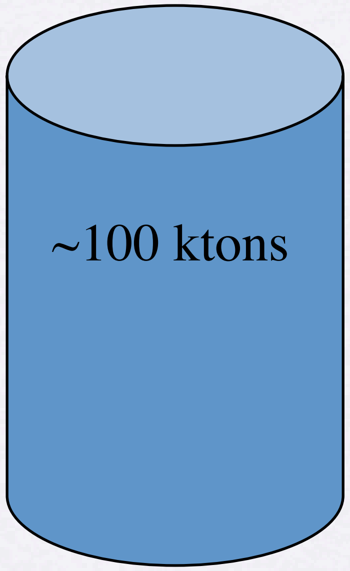


  - Submitted as a LDRD (Djurcic, et. al) last week.

- Intermediate term: build a ~20-ton detector. Application: short-baseline neutrino physics (oscillation tests and cross-section measurements), LBNE-like Near Detector, low-background counting facility (if placed underground).



- Long term: apply to large ~100 kton detectors. Application: long-baseline neutrino physics, proton decay, super-nova detection, solar neutrinos, etc.



  - Concept being explored under NSF Career (Sanchez).

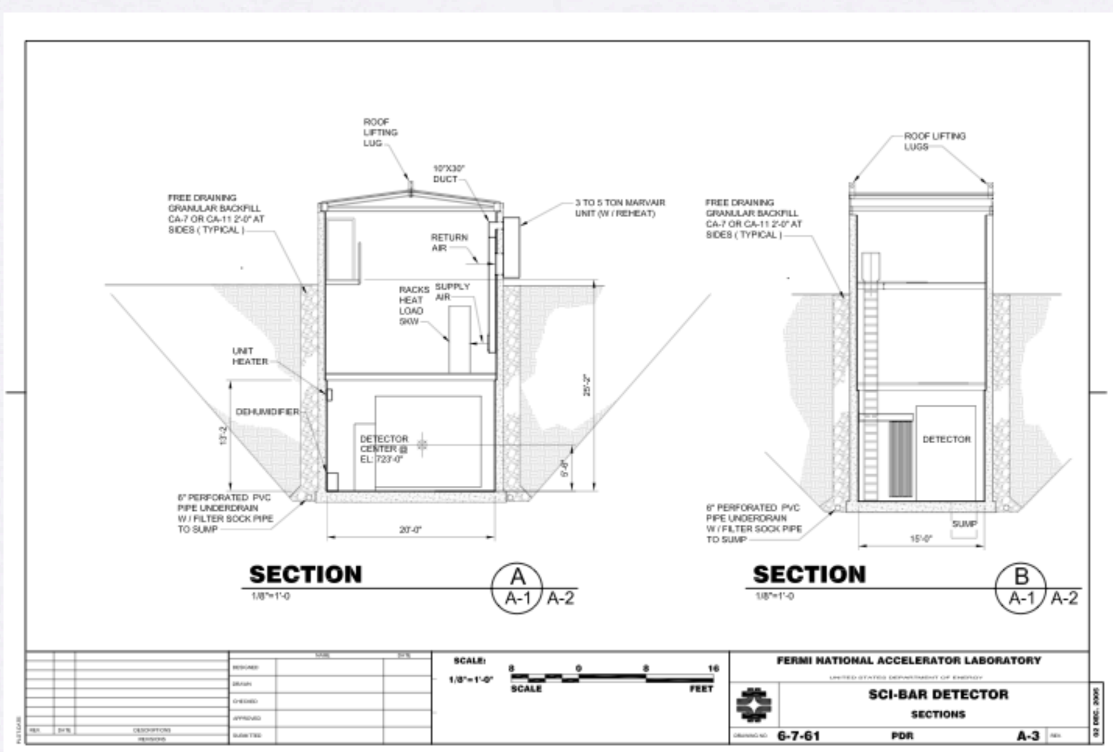
Short term plan

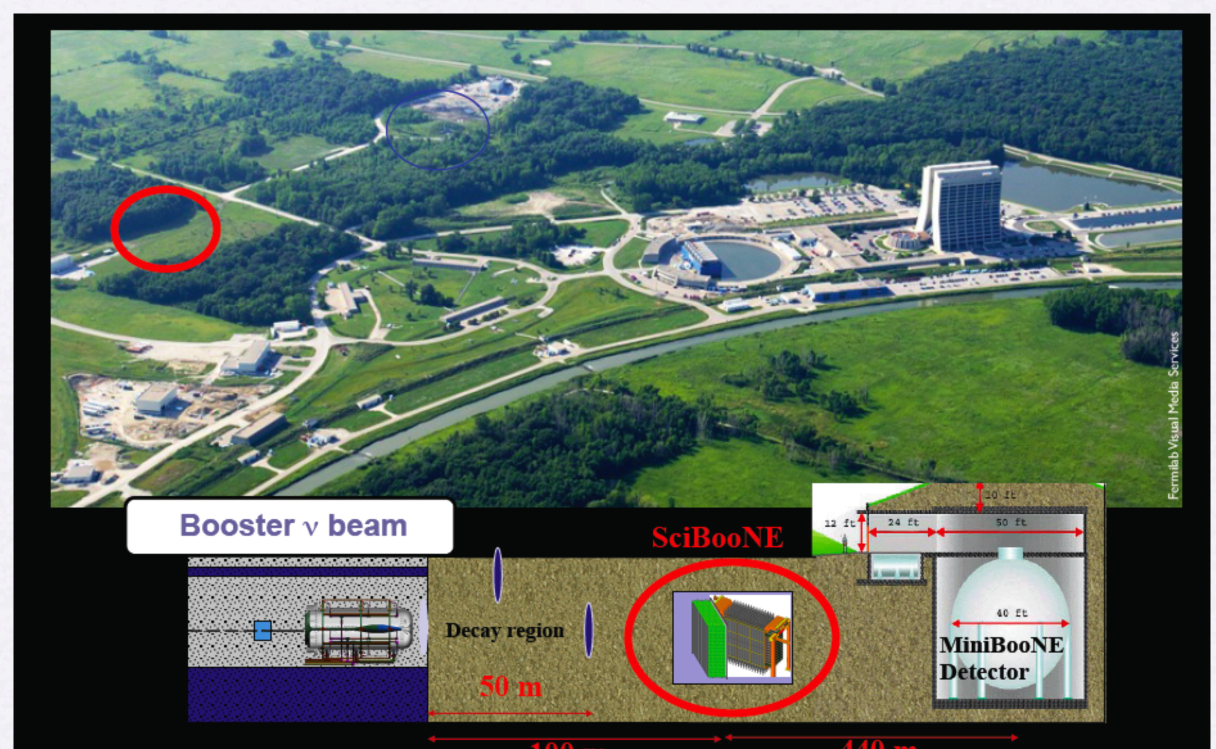
- **Design, build and operate a ~2m^3 detector.**
- *1st stage*: characterize and design LAPPD-based detector: simulate and quantify the benefits of position and time resolution, understand particle ID and background rejection capabilities.
    - Recently there has been progress in producing cheap, high-light yield water-based scintillator (Minfang Yeh/BNL). Thus additional goal characterize water versus water-based liquid scintillator advantages for this application.
- *2nd stage*: Begin building a prototype of such detector with modules available: design the liquid and photodetector containment vessel, understand the LAPPD module/liquid interface and design readout scheme.
- *3rd stage*: Application and operation of LAPPD in various liquids. Initial testing and operation will be done using cosmic rays. Operation in Fermilab test beam. Complete proposal to place in Fermilab neutrino beam.

➡ Submitted as LDRD by Djurcic, Demarteau, Frisch, Sanchez, Wetstein.

Intermediate plans

- **Build a ~20-ton detector.**
- Short baseline neutrino workshop 2011 at Fermilab. Discussed recent short-baseline anomalies.
- One idea is using Neutrinos from the Booster beamline in the SciBooNE pit.
- Total neutrinos at this site ~10K/ton/10^{20}POT.





Long term plan

- **Apply to large ~100 kton detectors.**
- *1st stage*:
  - Study interplay of coverage, timing, granularity, quantum efficiency for expanding the physics capabilities of the next generation of Water Cherenkov detectors.
  - 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 parameters, relative timing, vertex and angular resolution as well as particle ID efficiency.

Funded as NSF Career (5 year project)
Hiring joint Argonne/Iowa State postdoc for this work.

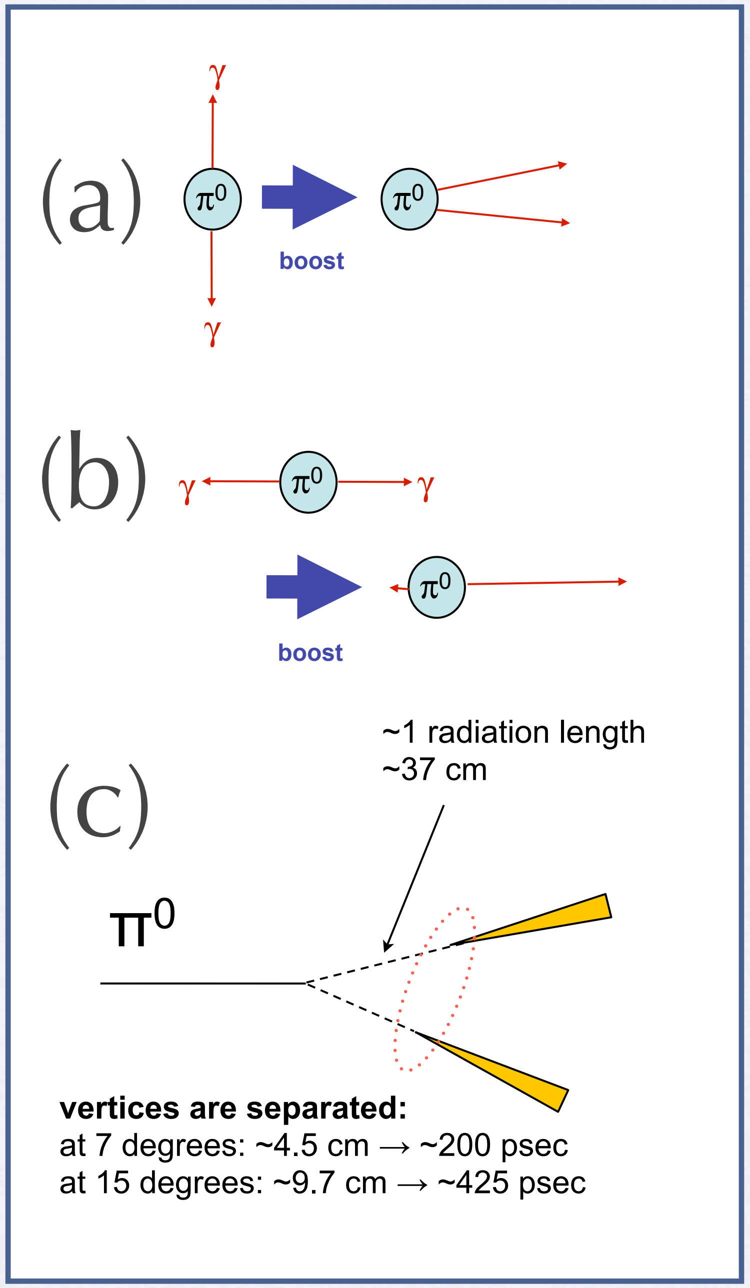
Improving background rejection

- For the long baseline neutrino application, we want to obtain better background rejection:

  (a) Higher granularity and larger coverage improves angular resolution between the two photons in forward π^0 decays (typically smaller than 15°).

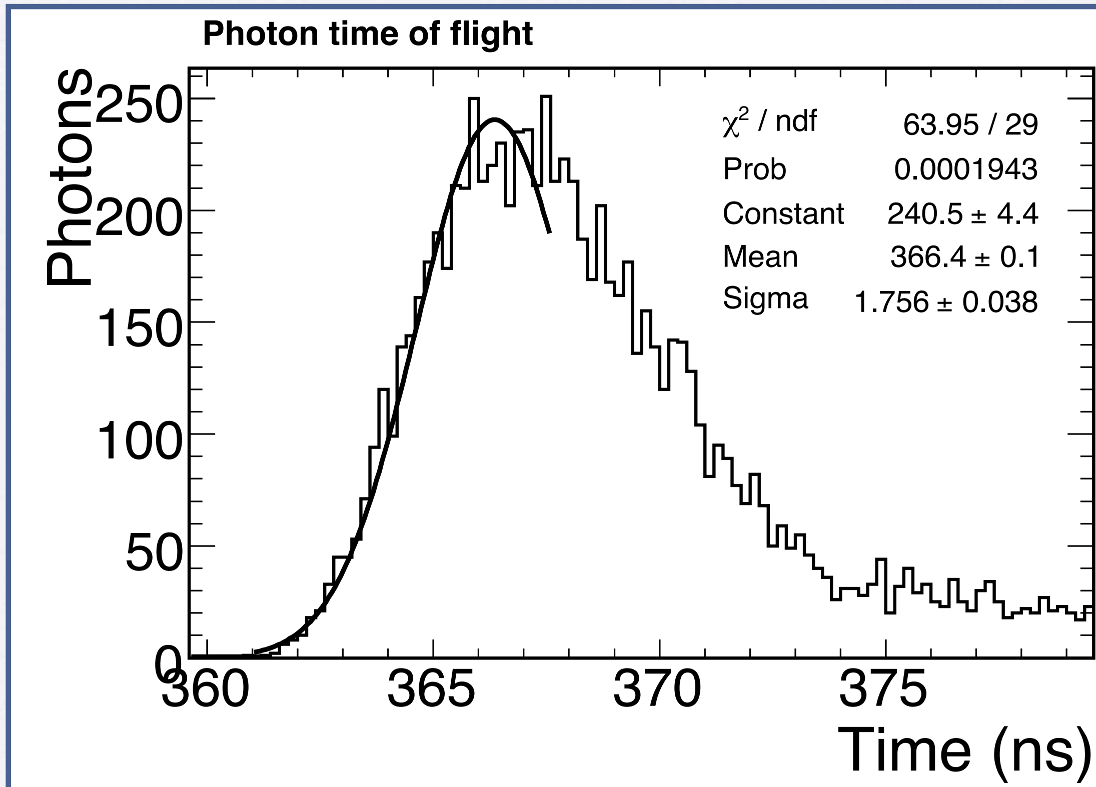
  (b) Larger area coverage/higher QE could increase the efficiency of detecting the less energetic photon in an asymmetric π^0 decay.

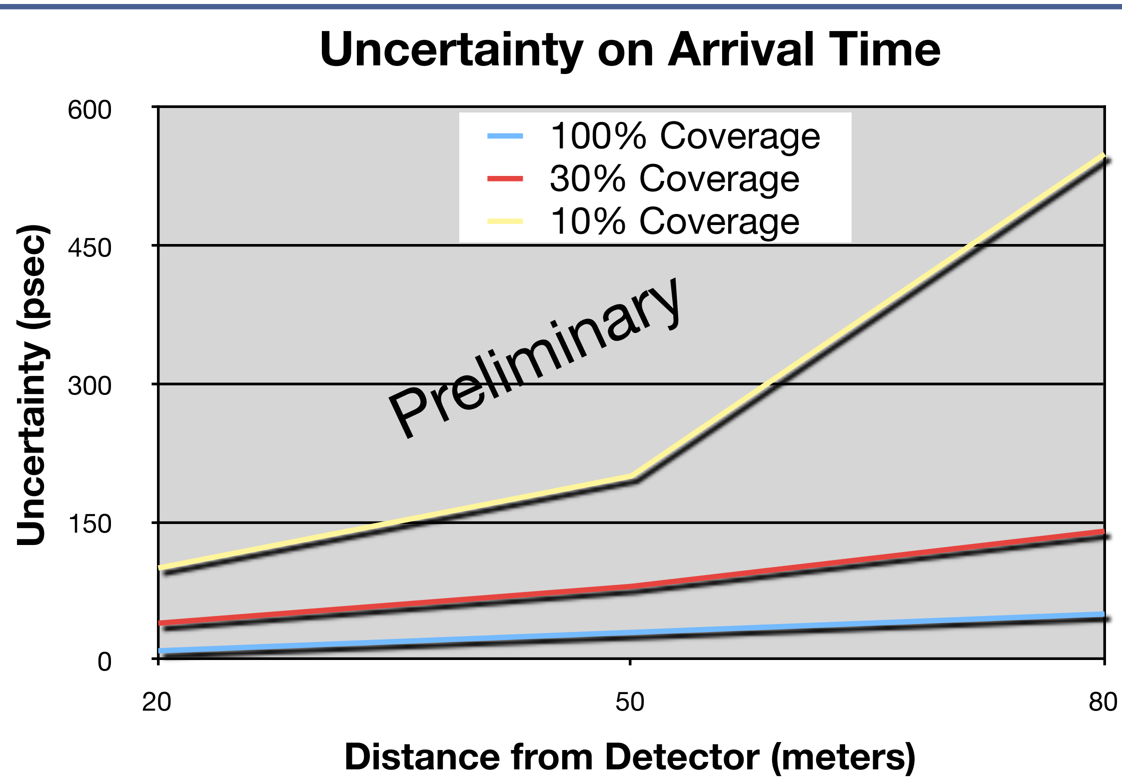
  (c) Faster timing can improve vertex resolution down to a few cm, permitting the separation of the conversion points of the π^0 for some events.



Coverage and timing

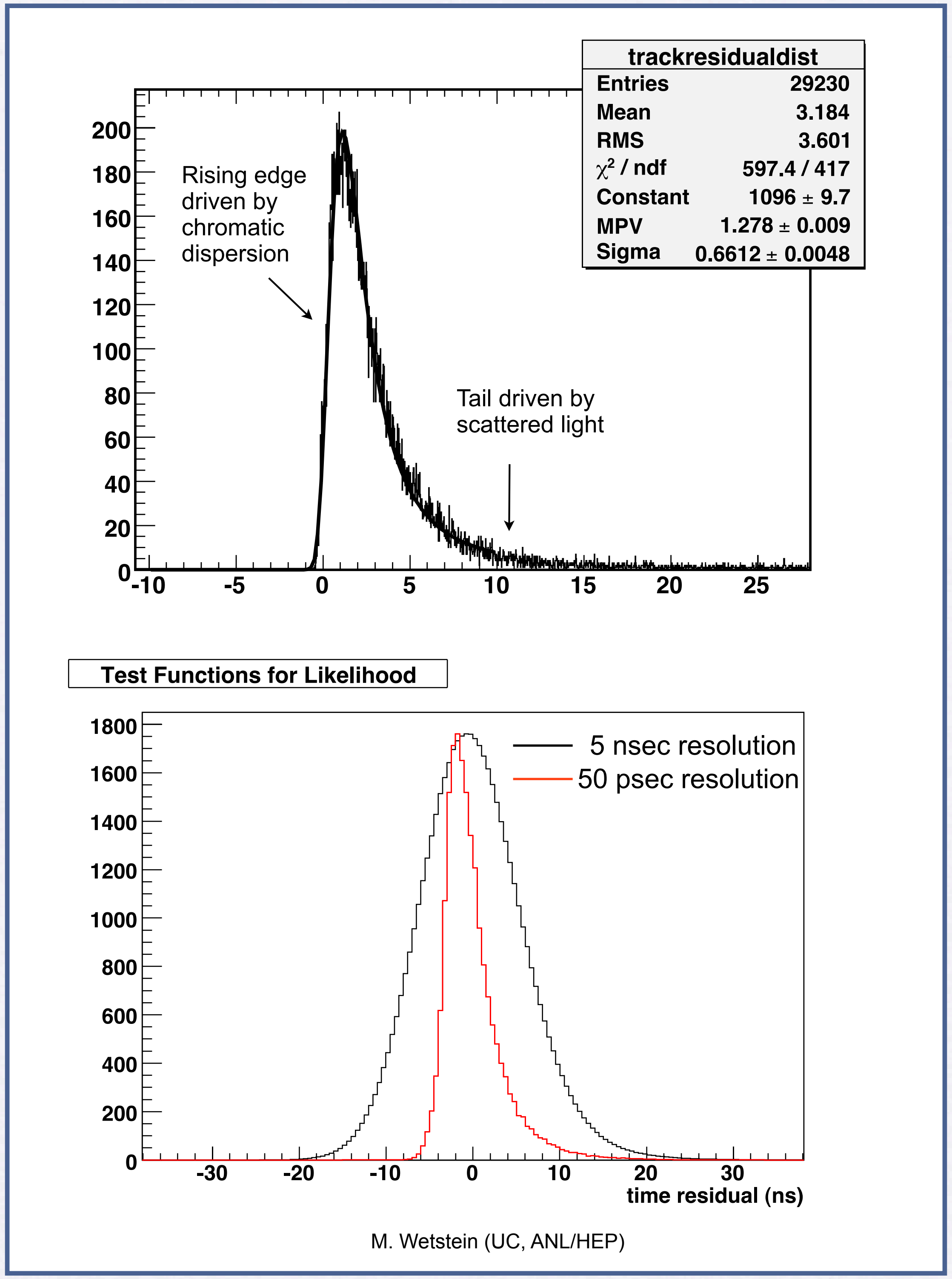
- A concern in using fast timing in large detectors are the effects of frequency dependent dispersion, scattering and absorption.
- Using a fast toy MC originally developed by J. Felde (UCDavies) we study the time of arrival for photons in an spherical detector.
- For a 50m detector with 100% coverage, 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 and faster timing allows for better use of timing information in Water Cherenkov detectors.





First algorithms

- 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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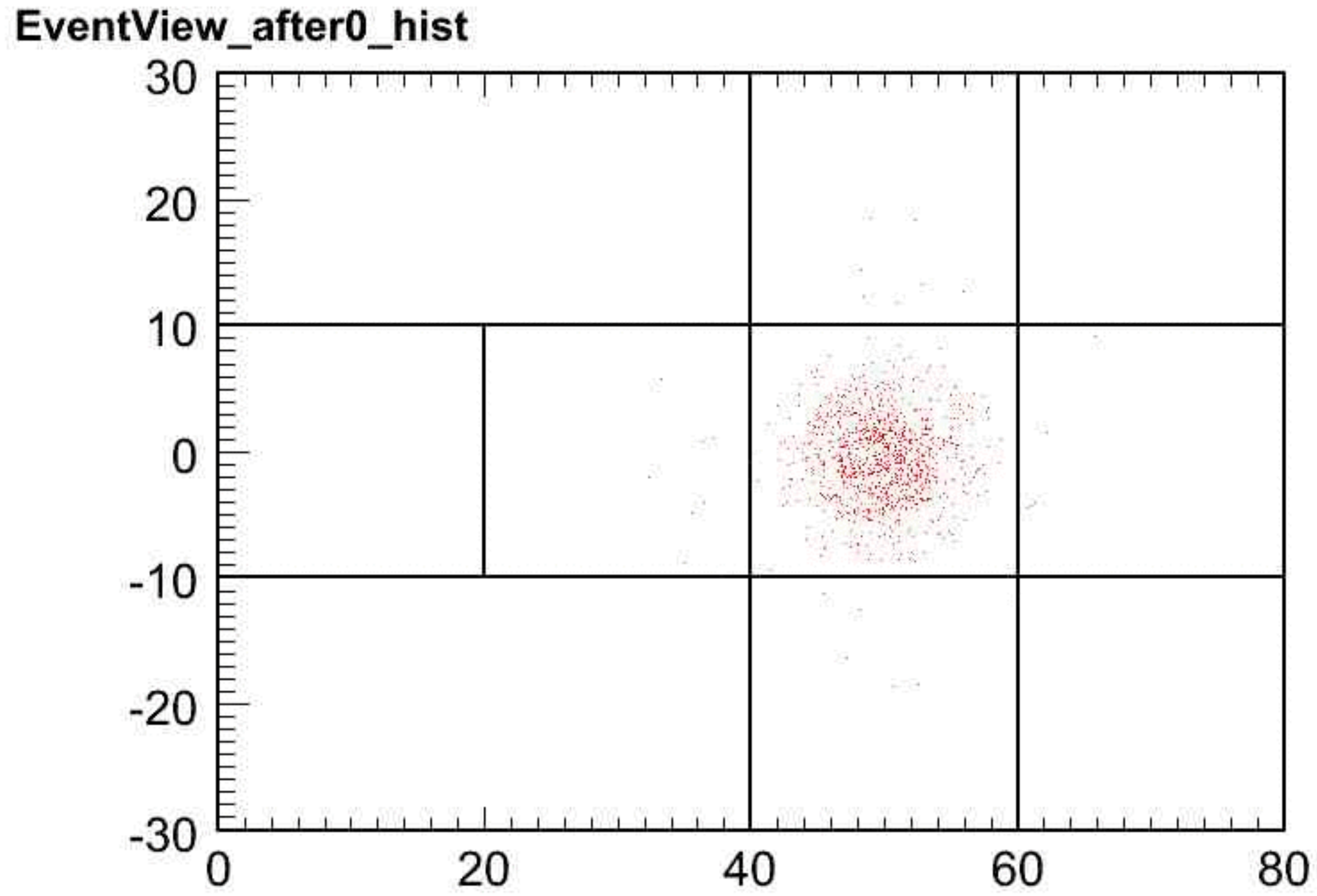
Work being done within LBNE contributing reconstruction algorithms to the collab.

Event display: electron

Back to a small detectors

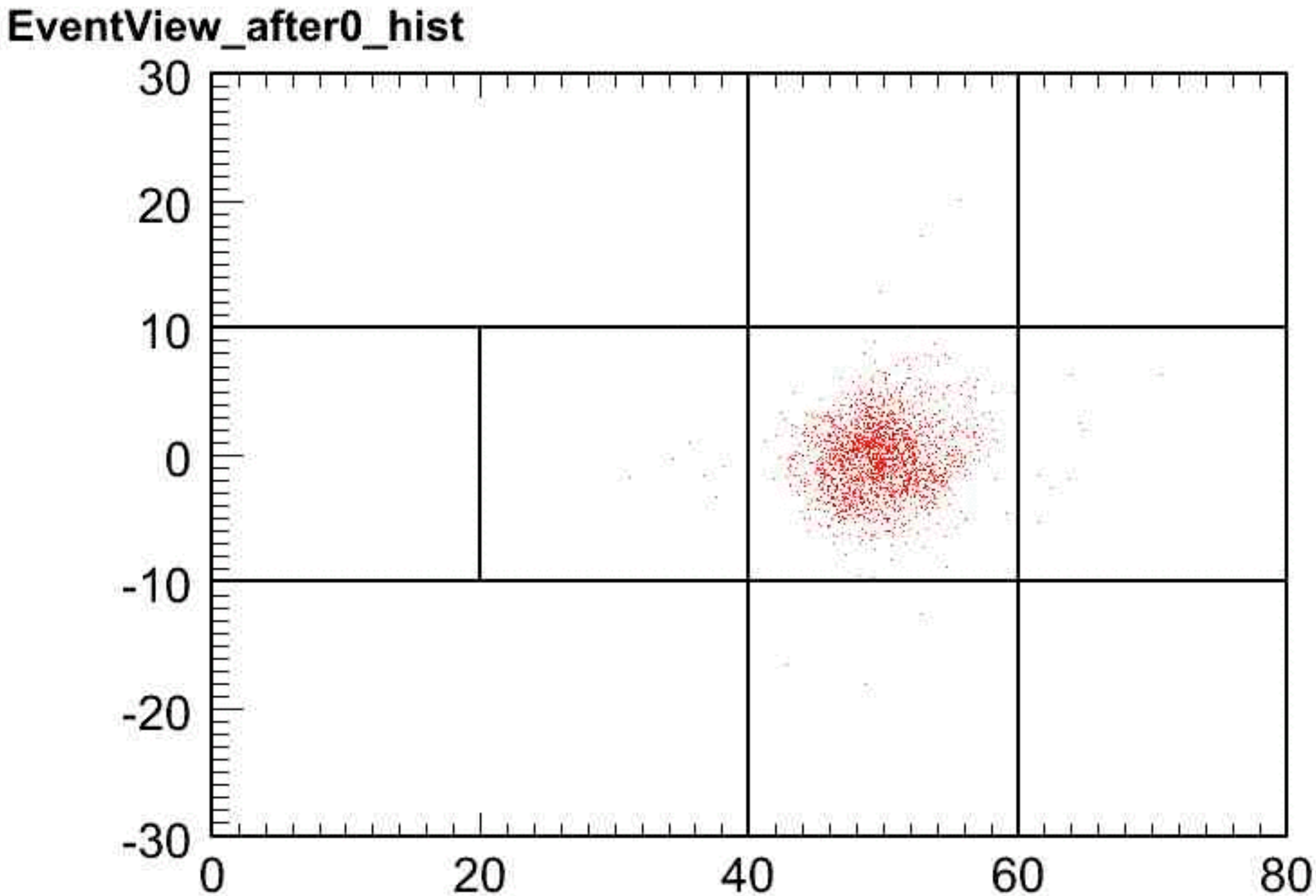


http://www.hep.anl.gov/mcsanchez/EventDisplays/animatedelectron_2ns.gif

Simulation: 750 MeV particle in 2 nsec steps

Event display: π^o

Back to a small detectors

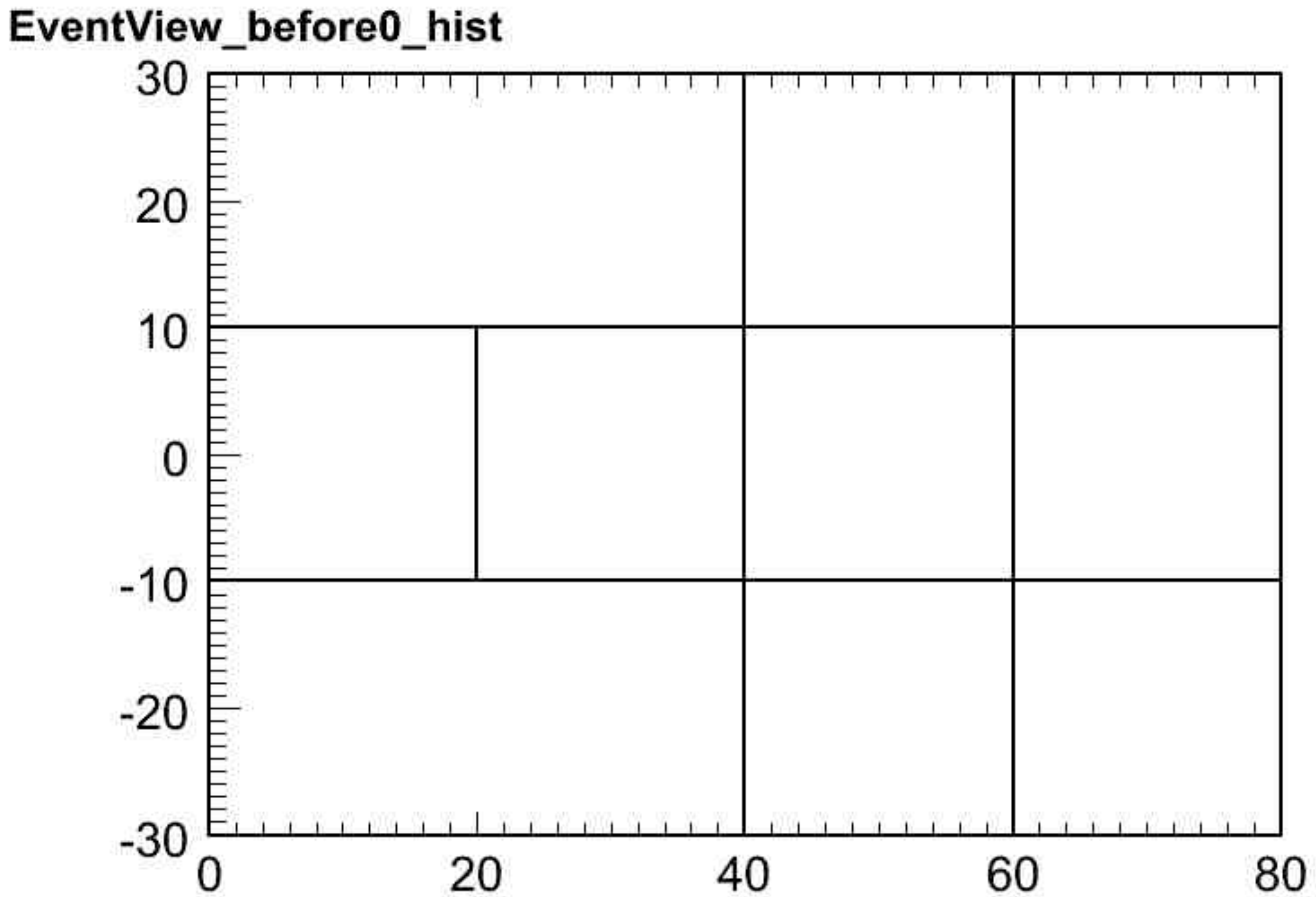


http://www.hep.anl.gov/mcsanchez/EventDisplays/animatedpizero_2ns.gif

Simulation: 750 MeV particle in 2 nsec steps

Event display: electron

Back to a small detectors

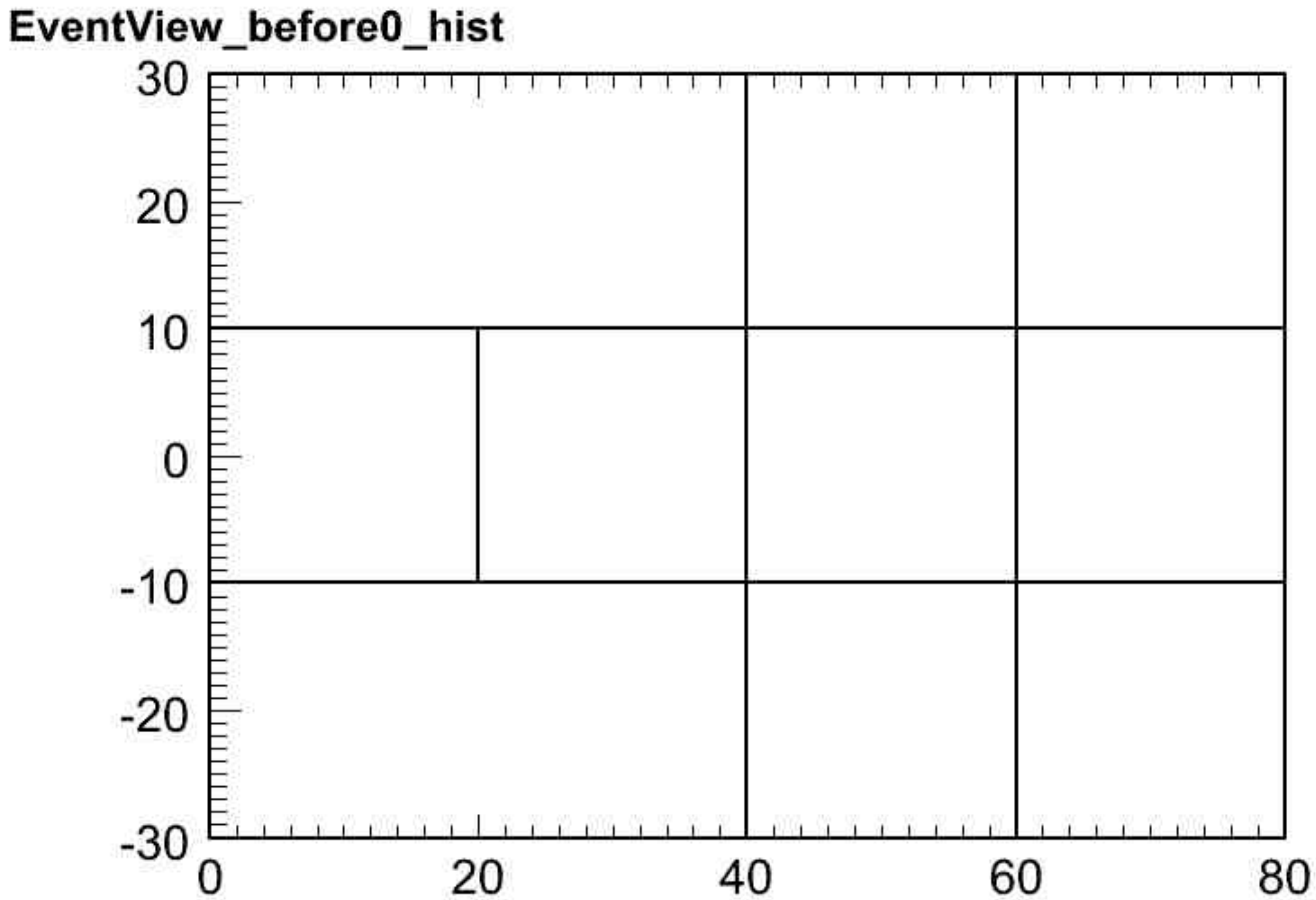


http://www.hep.anl.gov/mcsanchez/EventDisplays/animatedelectron.gif

Simulation: 750 MeV particle in 100 psec steps

Event display: π^o

Back to a small detectors



http://www.hep.anl.gov/mcsanchez/EventDisplays/animatedpizero.gif

Simulation: 750 MeV particle in 100 psec steps

Conclusions

- The new devices have the potential of improving the physics capabilities of the next generation of WCh detectors by providing better timing and higher coverage.
- We have started a program simulating these detectors within the LBNE WCh framework as well as developing algorithms that allow us to exploit the features of the new photosensors.
- There is significant work to be done:
  - Complete and test simulations/reconstruction under progressively less ideal conditions. Expand reconstruction to do ring counting and particle ID. Compare to results in latest LBNE WCh design.
  - Provide feedback to the LAPPD collaboration to the design with an eye to improve the physics capabilities of the LBNE WCh detectors.
  - Start a characterization program once prototypes are available and if previous steps are successful develop the necessary calibration design to be able to use these detectors in a realistic scenario.
  - Test in a realistic scenario before commercial product is available, ~m^3 WCh prototype in a neutrino beam. Test in larger detector.

Backup

Intermediate plans

- **Build a ~20-ton detector.**

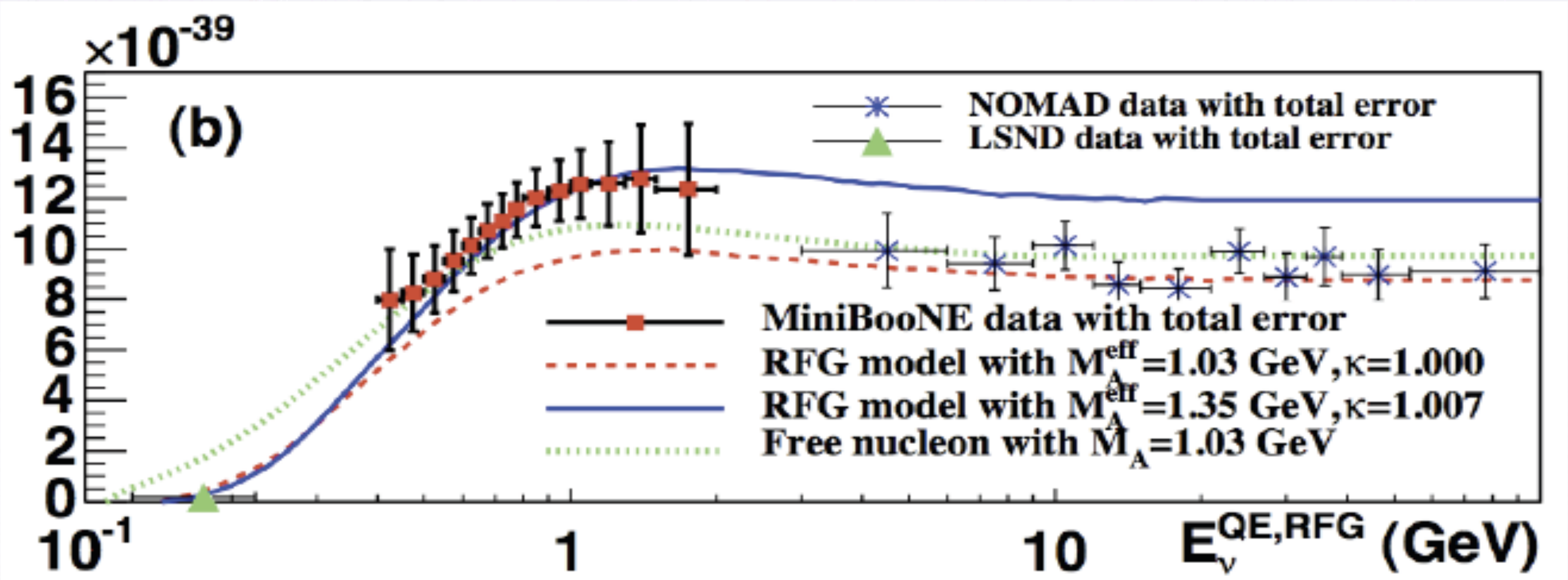
Rates Expected with 1x10^{20} POT exposure at SciBooNE pit

	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

Djurcic

Intermediate plans

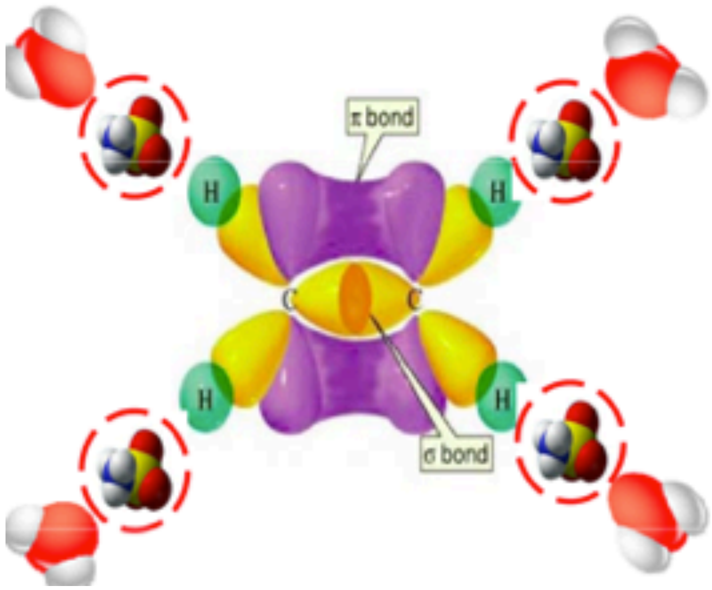
- **Build a ~20-ton detector.**
- What physics? Quasi-elastic charged current cross sections in water.



Development II:
Water-Based Scintillation Light

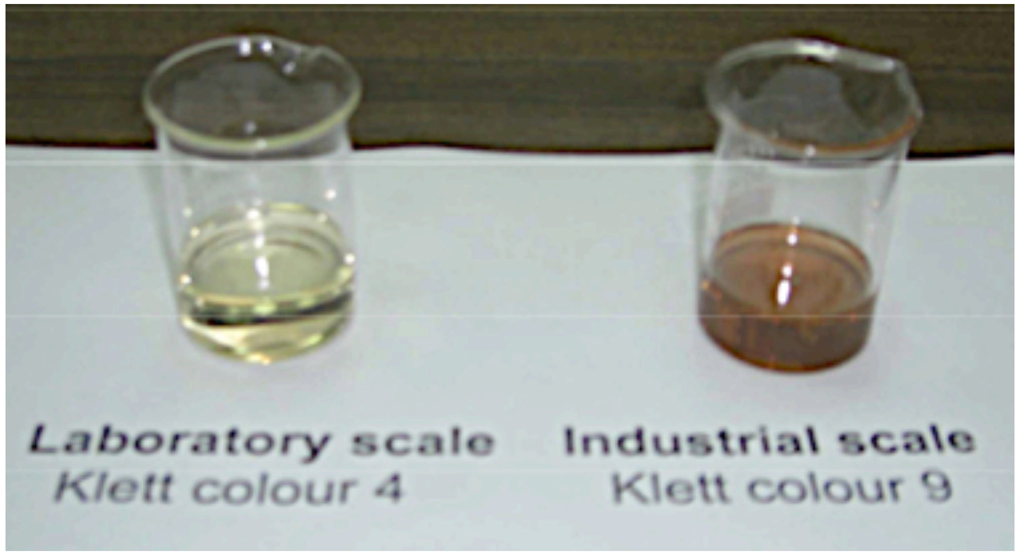
Linear Alkylbenzene (LAB) - Industrial detergent
Key innovations:

- ability to create stable solutions
- purification to achieve longer attenuation lengths



Ideal for large scale experiments

- Non-toxic
- Non-flammable
- Stable
- Cheap

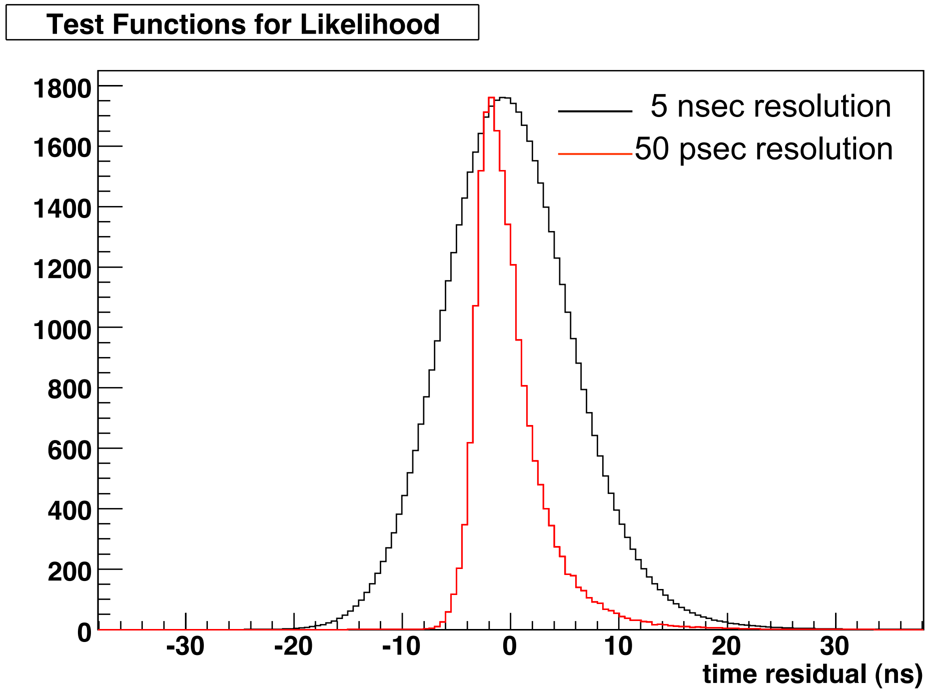


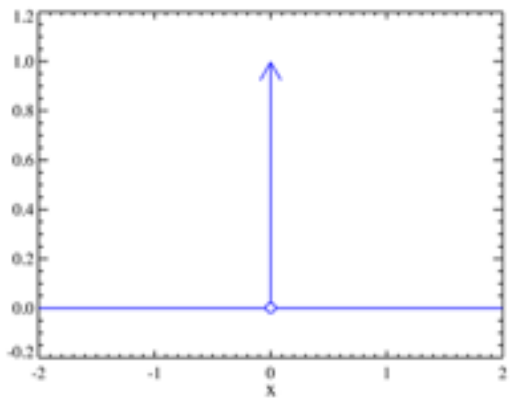
The scintillation light might be difficult to resolve with timing, but...

- It may be possible to have both Cherenkov and scintillation light, separated in time
- The spatial/statistical gains would be considerable.

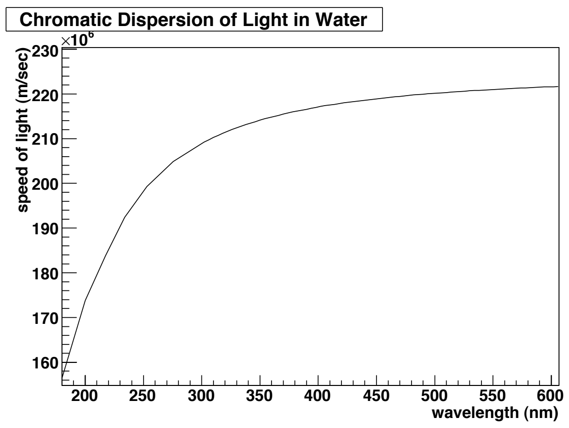
The Likelihood Test-Function

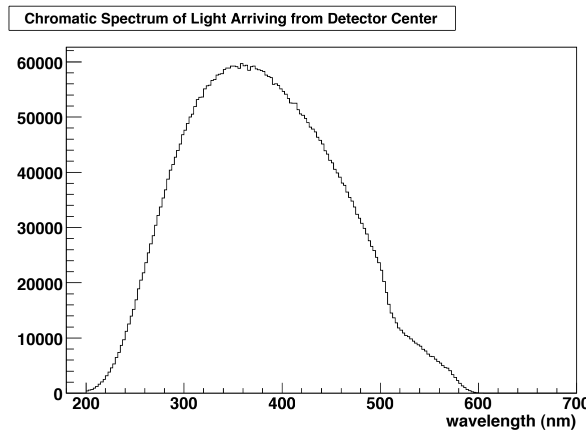
- Not necessarily symmetric (or analytic)
- At time resolutions below 1 ns, chromatic dispersion is significant
- Contains more shape information than just the width
- Sandbox has an algorithm to generate the effects of chromatic dispersion. It is not yet optimized for speed.



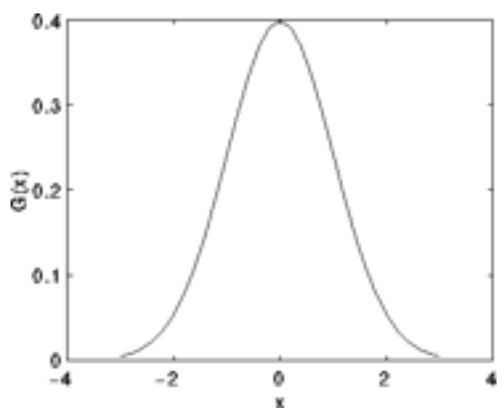


1. Start with a delta function to represent the time residual, corresponding to a fixed speed of light





2. Recalculate and sum the delta function at times corresponding to different speeds of light, weighted by the chromatic spectrum. One must use the hit positions and their distances from a hypothesized track.



3. Convolute with a gaussian resolution term.

Looking for signatures of multiple tracks

One interesting new idea to come out of our work is to look for systematic variations in width and peak of the timing residual distribution for different azimuthal slices of the Cherenkov ring.

Differences should be most pronounced on the plane of the two decay gammas from the pi0