SciBath: A novel tracking detector for measuring neutral particles underground

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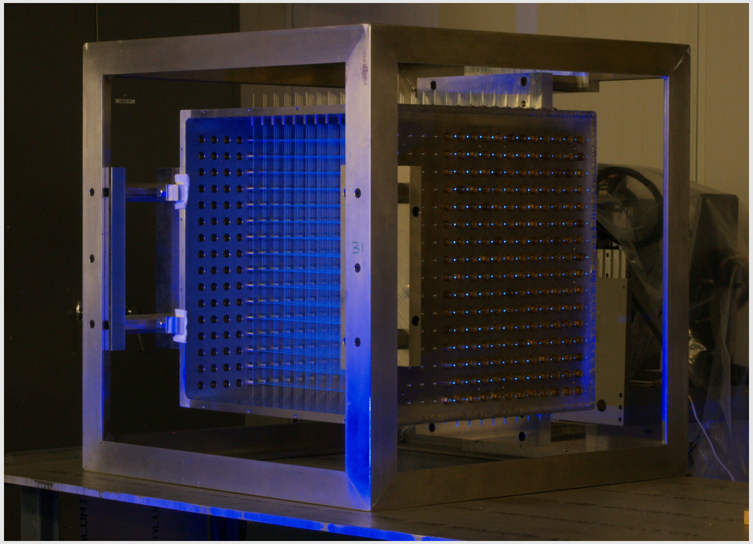
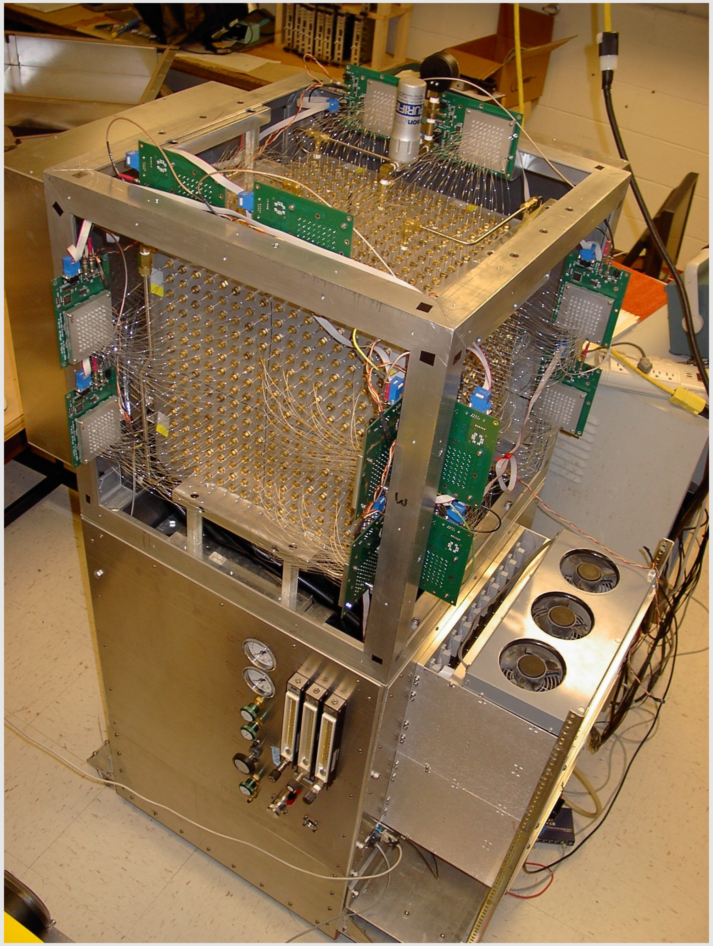
Outline:
- motivation
- operating principle
- prototypes and tests
- status
- future plans





R. Tayloe, Indiana U.
APS-DPF 2011
Providence, RI, 8/11

Motivation

- Motivated by desire to measure neutrino NC elastic scattering for strange quark contribution to spin of nucleon, FINeSSE experiment.

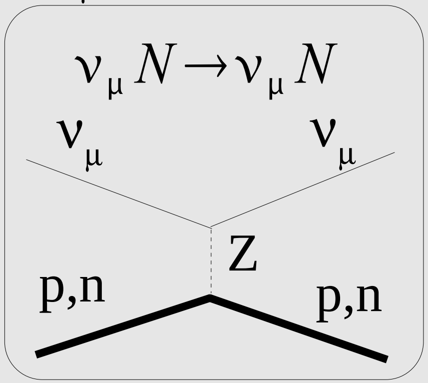
- Experimental signature: single ~100MeV proton track

- This requires large, O(10 tons), tracking neutrino detector.

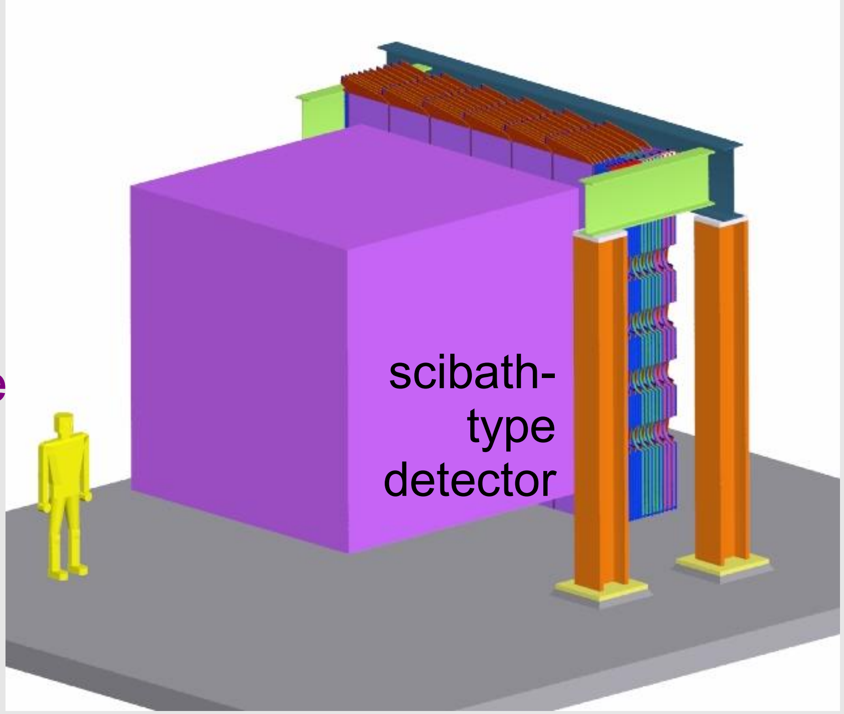
- Proposed FINeSSE experiment utilized SciBath technology:
  3D grid of wavelength-shifting fibers immersed in liquid scintillator

This method increases the performance/price ratio for neutrino detectors and will allow a ~10 ton, high-resolution, economical device.

ν_μ NC elastic



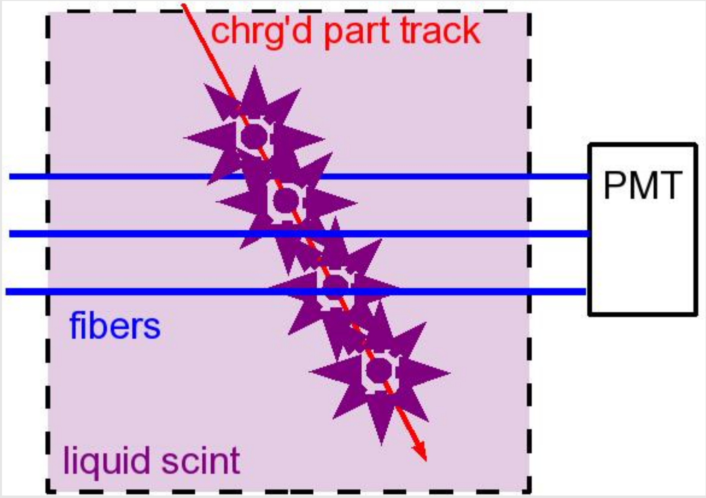
proposed FINeSSE experiment



Principle of operation

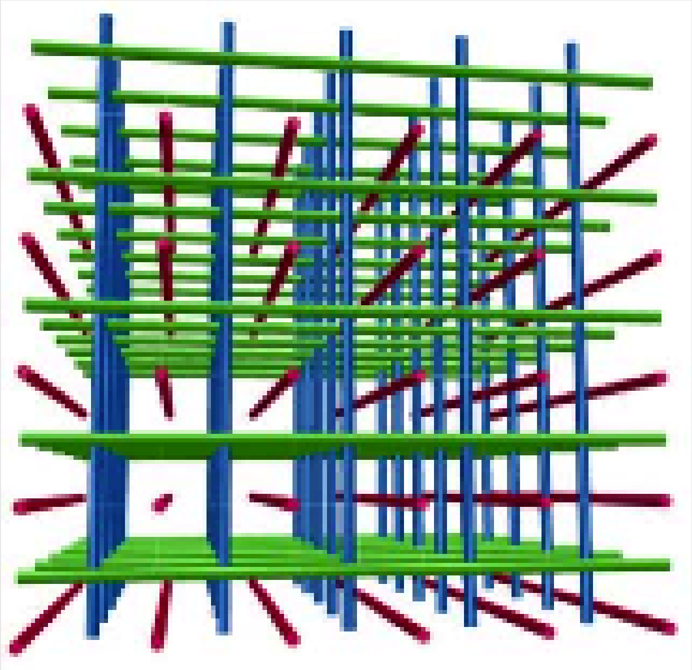
SciBath method:

- wavelength-shifting fibers immersed in liquid scintillator
- no optical barriers between fibers
- arranged in 3D grid for isotropic efficiency of charged particle tracks



Parameters:

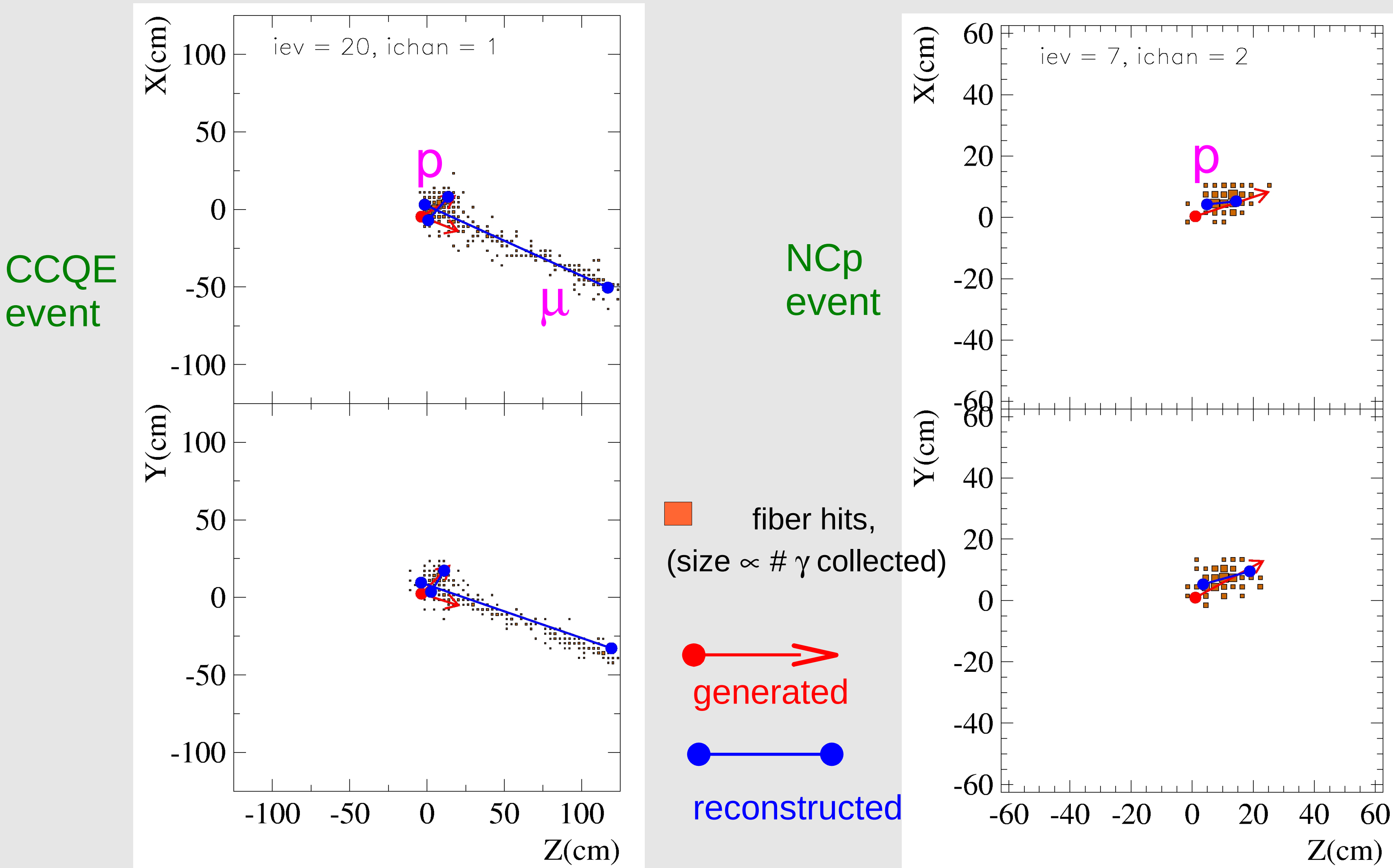
- Scintillation
  ~5000 photons / MeV
  λ emission ~ 350 – 400nm
  Single λ shifter used
  ~50cm attenuation length
- Wavelength Shifting (wls) Fibers:
  Absorb: λ ~ 320 – 370nm
  Emit: λ ~ 410 – 480nm
- PMTs:
  QE ~ 20%



Physics simulation results

Simulation of large detector showed excellent reconstruction of ν events

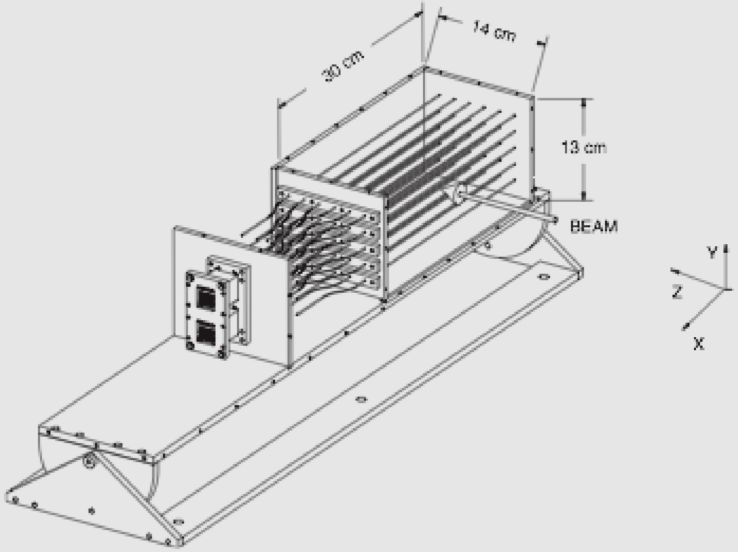
simulated hits and reconstructed tracks in the FINeSSE Detector



Prototype I: SciBath-30

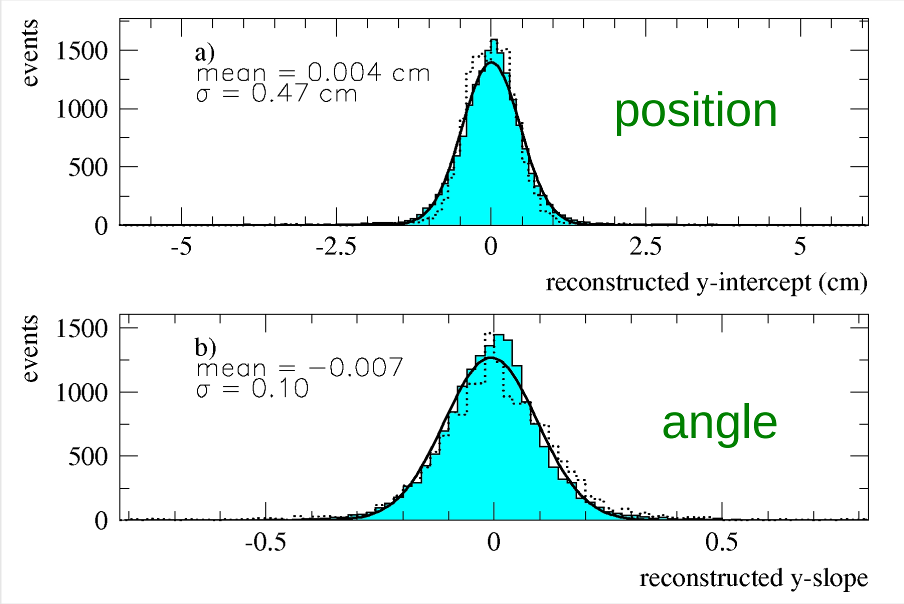
A proof-of-principle device was built
- 30 wls fibers in 1 orientation
- tested with 200 MeV protons.

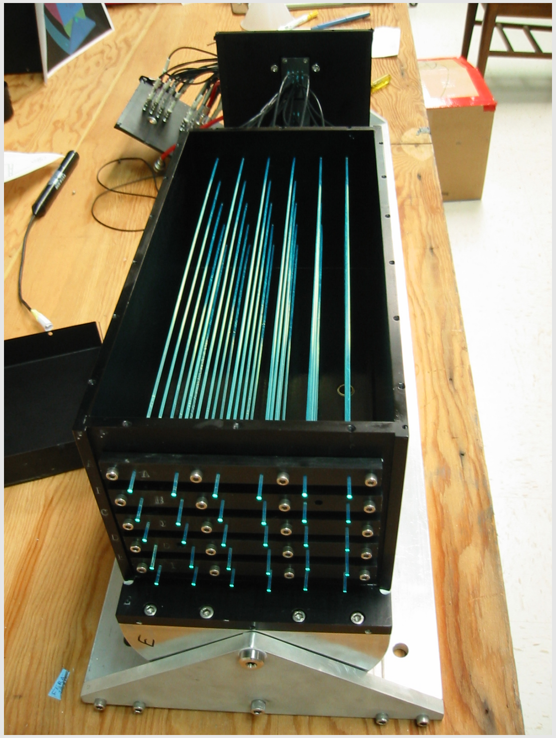
"A large-volume detector capable of charged-particle tracking", R. Tayloe et al., Nucl.Instrum.Meth.A562:198-206,2006.



Measured position/angular resolution (for protons): 5 mm/6°

protoype test tracking distributions

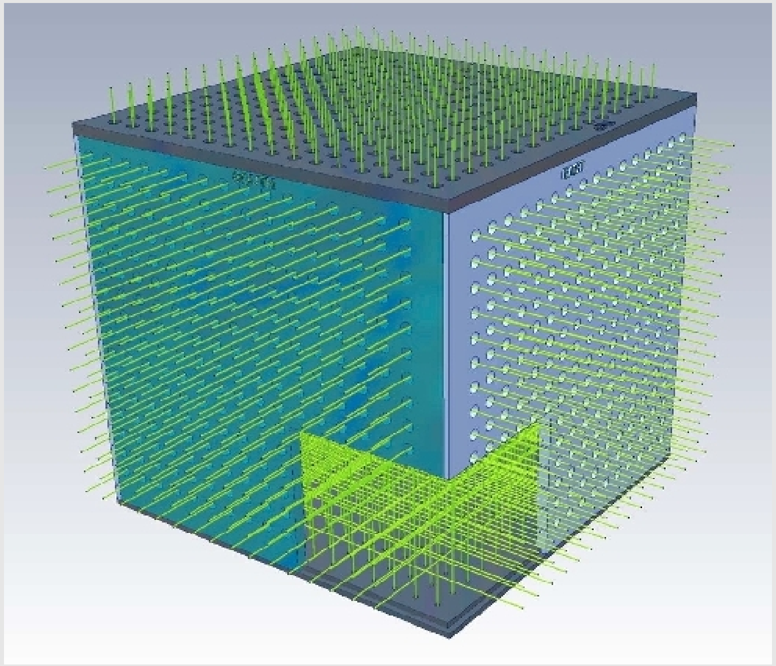


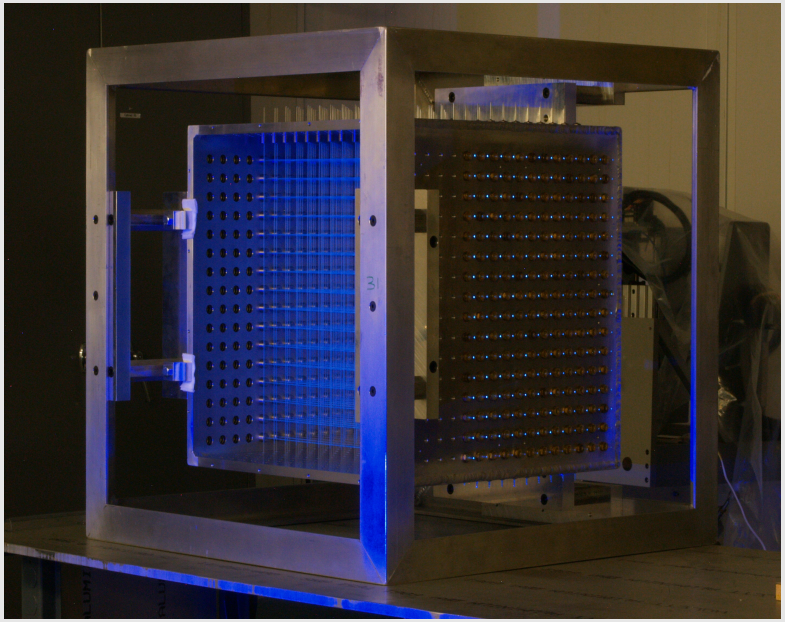


Next step: build a larger prototype with a 3D grid of fibers to:
- demonstrate 3D tracking
- develop and build economical, high channel-density readout
- pursue neutron detection applications

Prototype II: SciBath-768

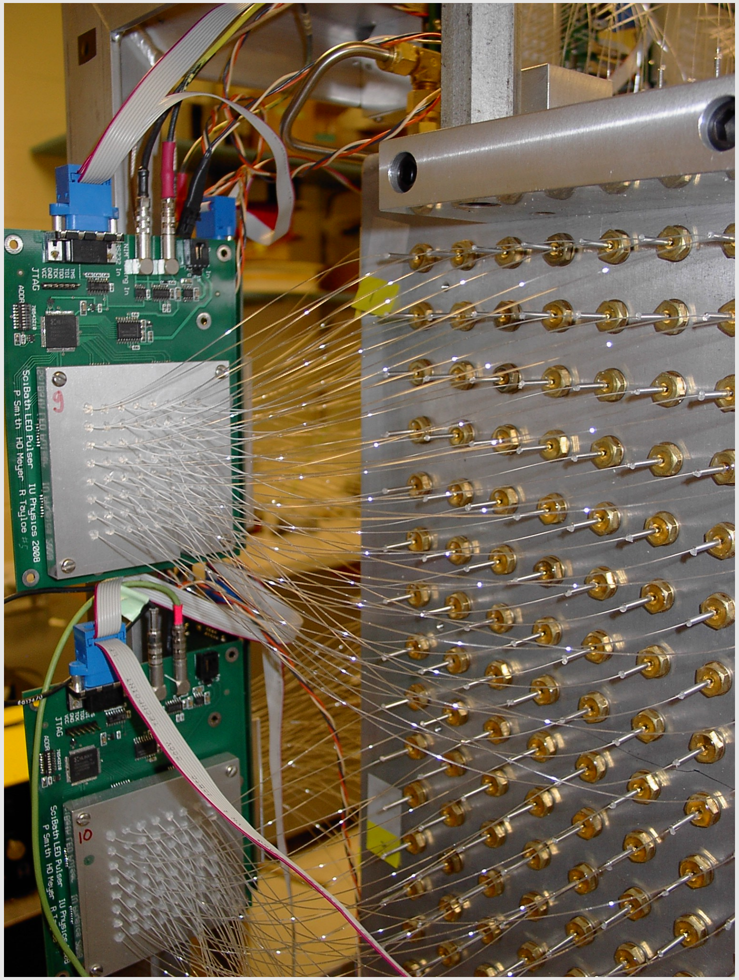
Specifications:
- $(45cm)^3$ volume containing...
- 82 liters of liquid scintillator:
  mineral oil, 11% pseudocumene, + PPO
- 3-16x16 grids, in x,y,z (768 total), 2.5cm spacing,
  1.5mm wavelength-shifting (WLS) fibers (UV->blue)
- coupled to clear plastic fibers, routed to readout





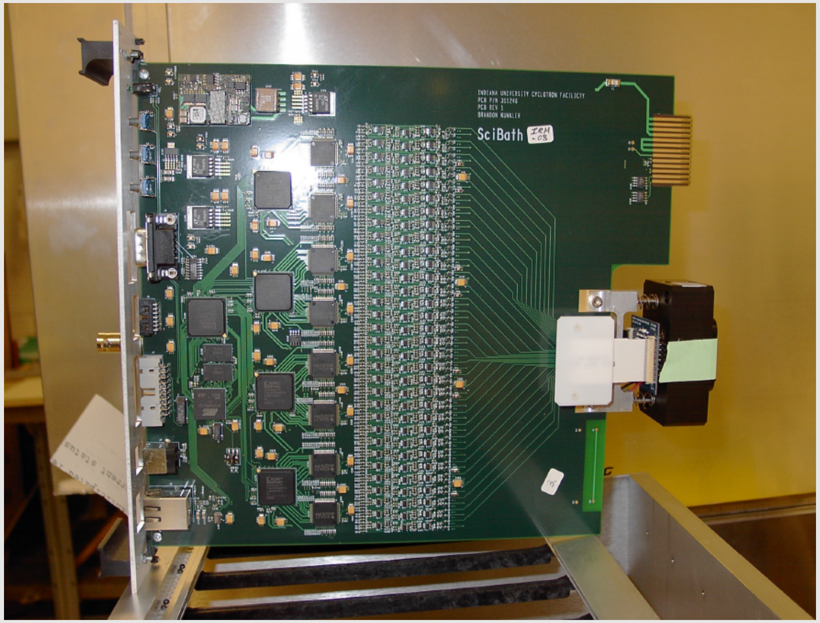
Prototype II: SciBath-768

Specifications (cont):
- 1.5mm plastic clear fibers, routed to readout
- pulsed LED calibration system (custom-built)
- 12 Hamamatsu 64-anode PMTs
- custom-built readout system “IRM”



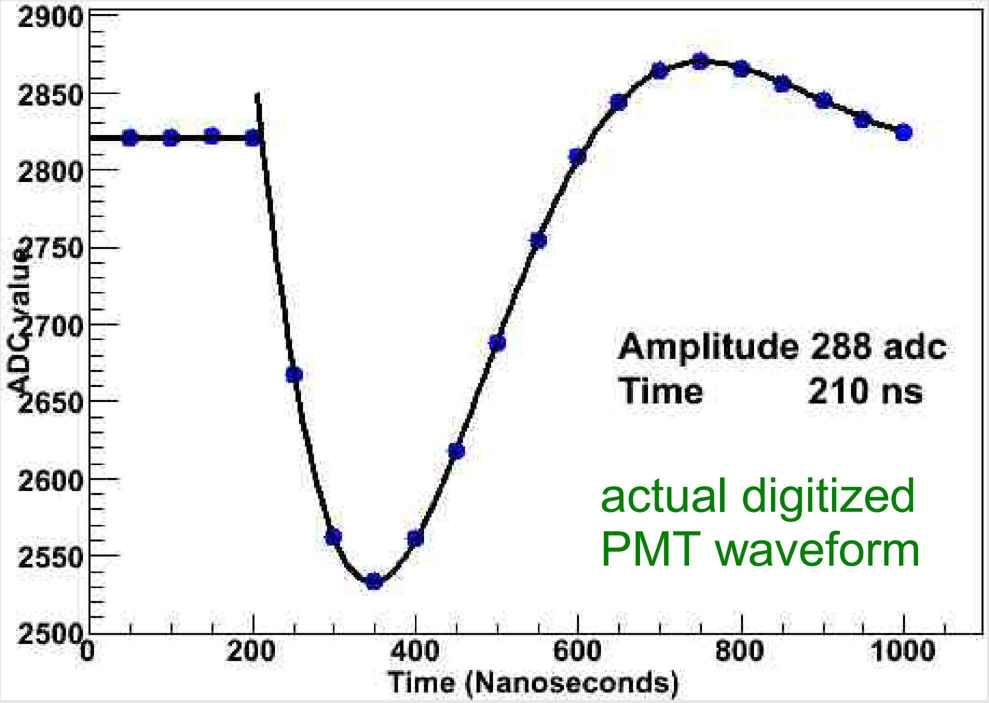
SciBath-768 readout electronics

IRM with attached PMT



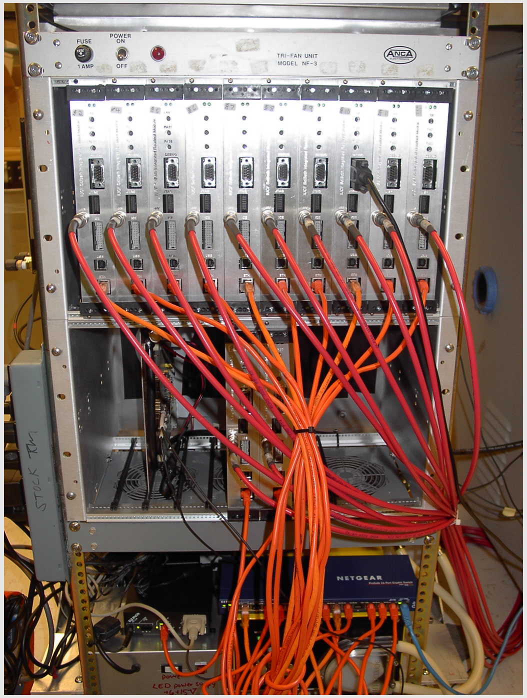
IU Integrated Readout Modules (IRMs):

- 6U VME formfactor with integrated 64 anode MAPMT
- VME backplane not used, only VME crate "shell"
- frontend:
  - "ringing integrator" into 12-bit flash ADC (20 MHz),
  - allows Q,T (to ~1 ns) info from 1 ADC



- 5 FPGAs, ARM9 microcontroller, e-net readout
- ~$70/channel (including PMT)

- default readout for SciNOvA (see X. Tian talk of thurs)



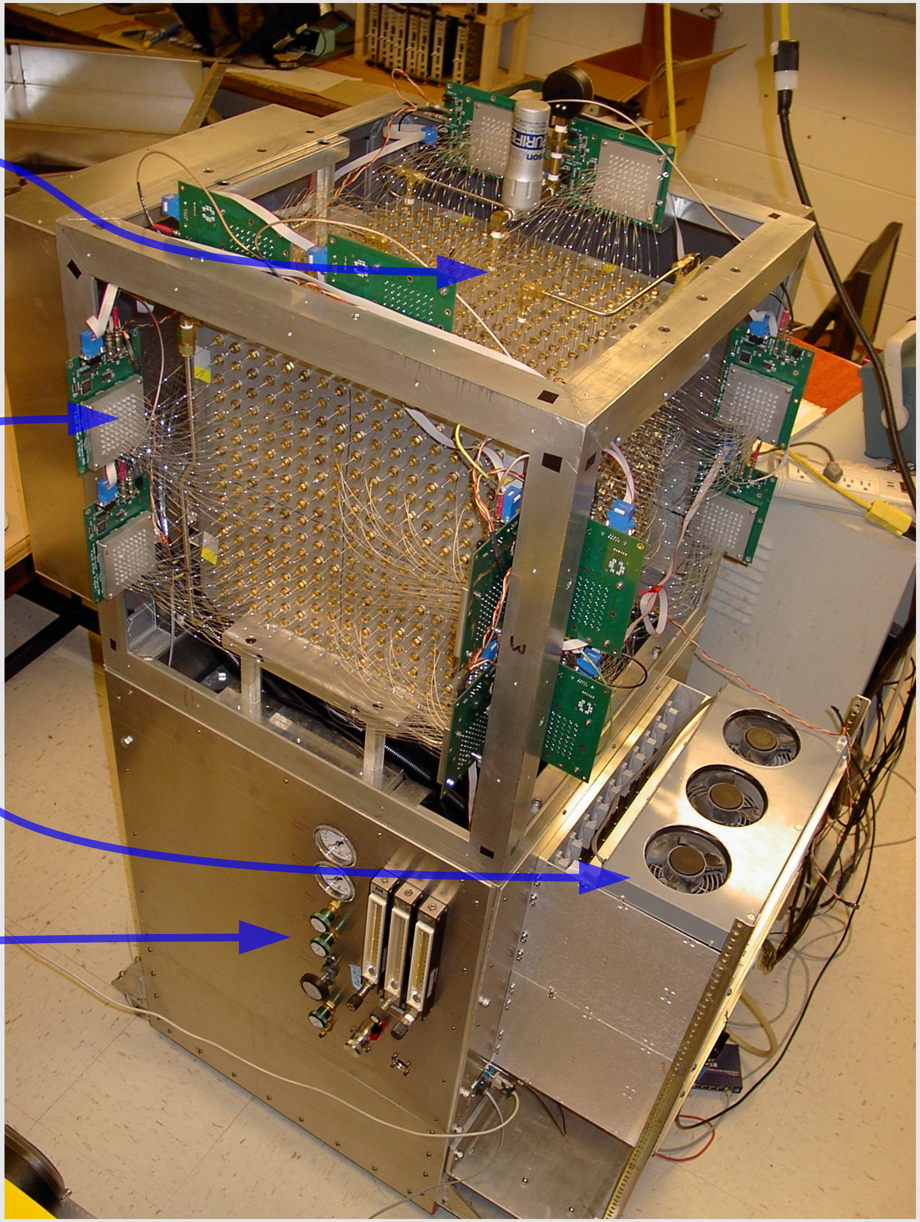
Prototype II: SciBath-768

- 80L Tank
- 70kg Liquid Scintillator
- 768 WLS Fibers in 3D

- Pulsed LED calibration system

- Electronics crate w/readout including IRMs / PMTs

- liquid scintillator plumbing controls and gauges



SciBath-768 status

- detector is assembled and running
- DAQ system in operation
- V1 of analysis/simulation programs in use

- ongoing work:
  - collecting/analyzing cosmic ray (muon) data
  - calibration with LEDs
  - upgrading DAQ software
  - developing PID algorithms

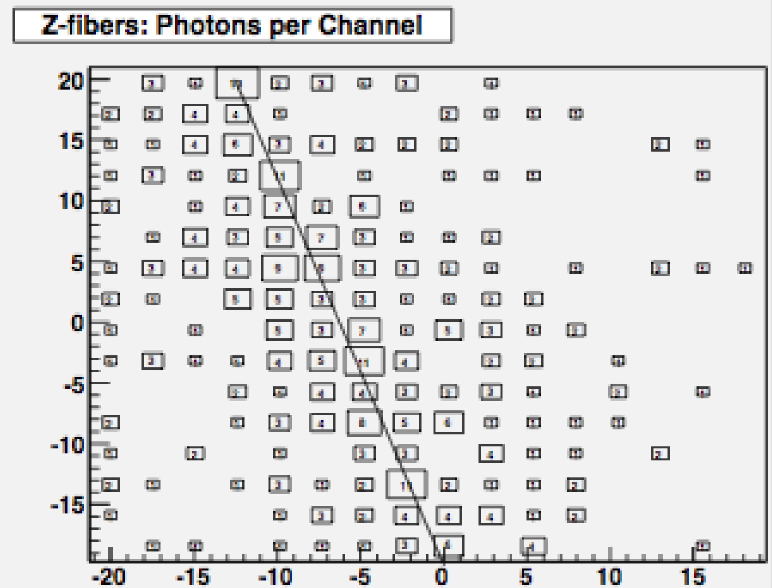
- preparing for 3-month run this fall at Fermilab in MINOS near-detector area (100m underground)

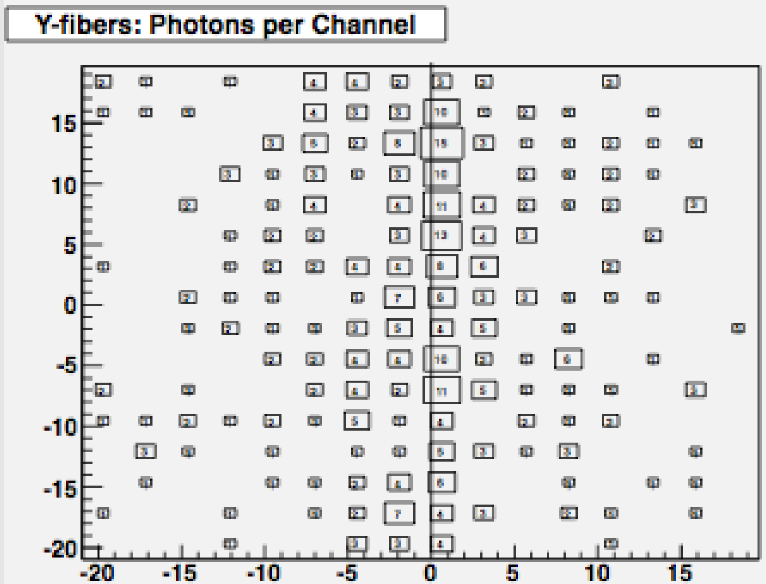
Event reconstruction

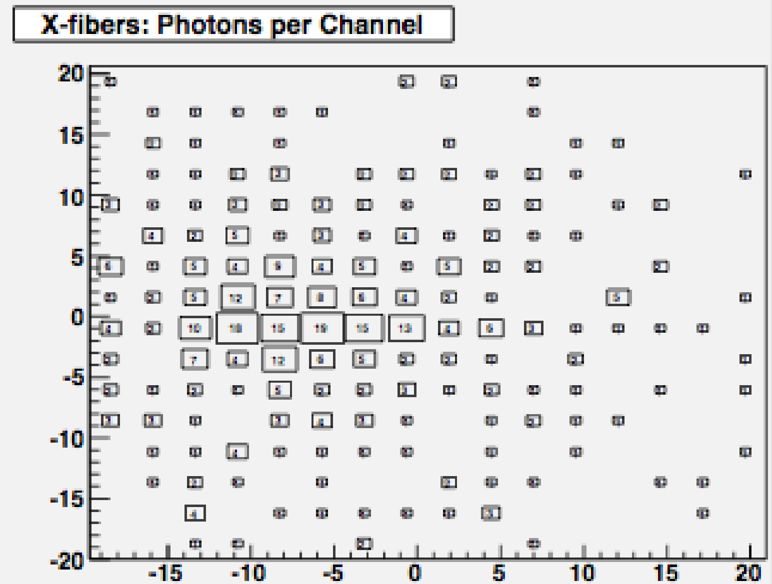
- each WLS fiber, PMT channel records a “pixel” of image (particle track convoluted with light spread function)
- allows track (or tracks) reconstruction

MC simulated μ
with reconstructed track

expected position/angle resolution:
from simulation, guided with previous measuments: ~0.5cm, 5deg



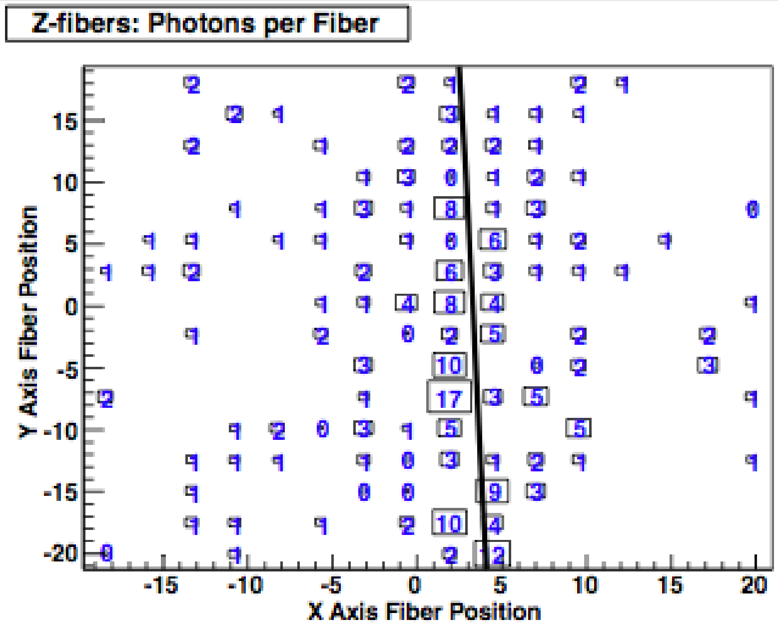


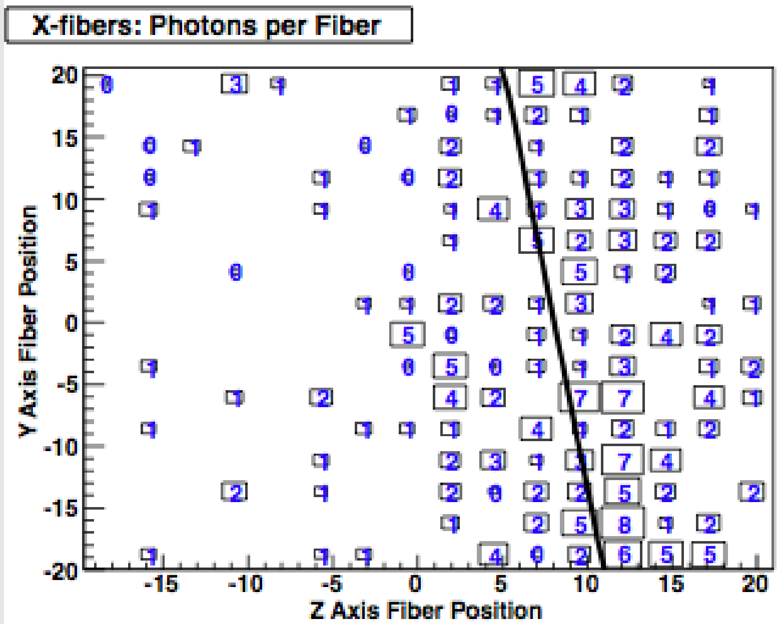


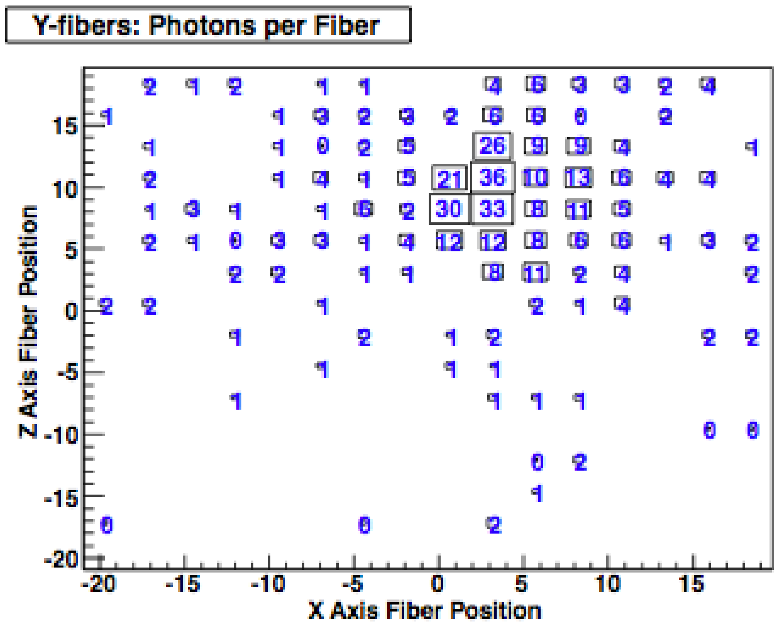
Event reconstruction

cosmic ray (data) μ with reconstructed track

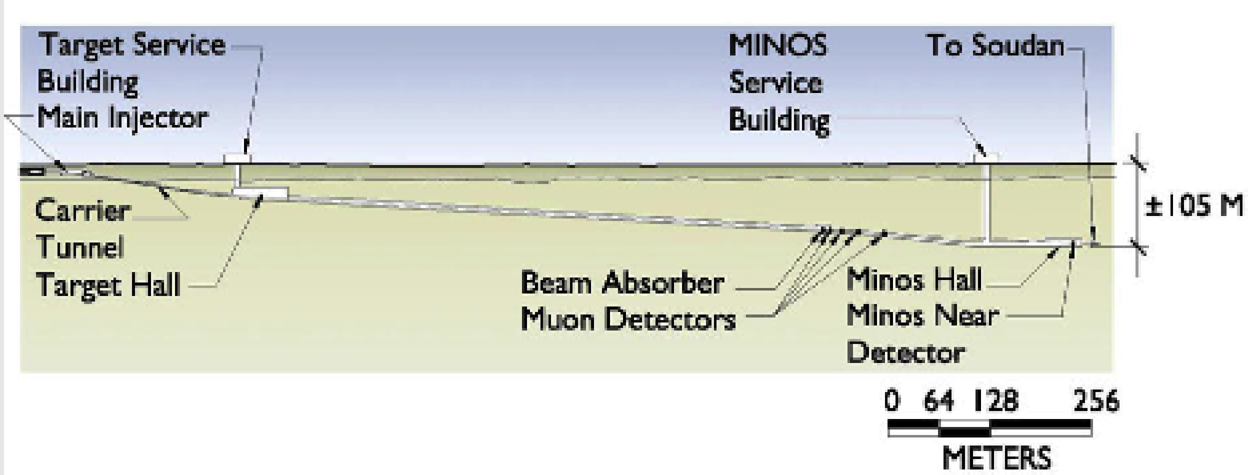
(with first, rough calibration)







SciBath-768 plans



- Fall 2011 run at FNAL
  - in MINOS near detector hall
  - 100m overburden

Goals:

- demonstrate ν event reconstruction
  - in 3-month run (2-month livetime) expect 10^2-10^4 events depending on beam configuration, ν channel
- cosmic-induced fast (1-100 MeV) neutron flux measurement:
  - very poorly known, important for underground/low-backgd physics (eg: COUPP)
  - expect ~20 events/day
- ν beam-induced n measurement

Expected ν/ $\bar{\nu}$ events in SciBath at 5mrad off-axis location

Beam Configuration	ν CC inclusive	ν CCQE
neutrino: Low E	550	100
neutrino: Med E	12000	1400
antineutrino: Low E	200	30
antineutrino: Med E	4000	1300

- Then, assuming successful demo at FNAL underground:
  Run in underground lab (eg: WIPP) to measure fast neutron flux for double-β decay, dark matter background estimates.

SciBath-768: neutron measurements

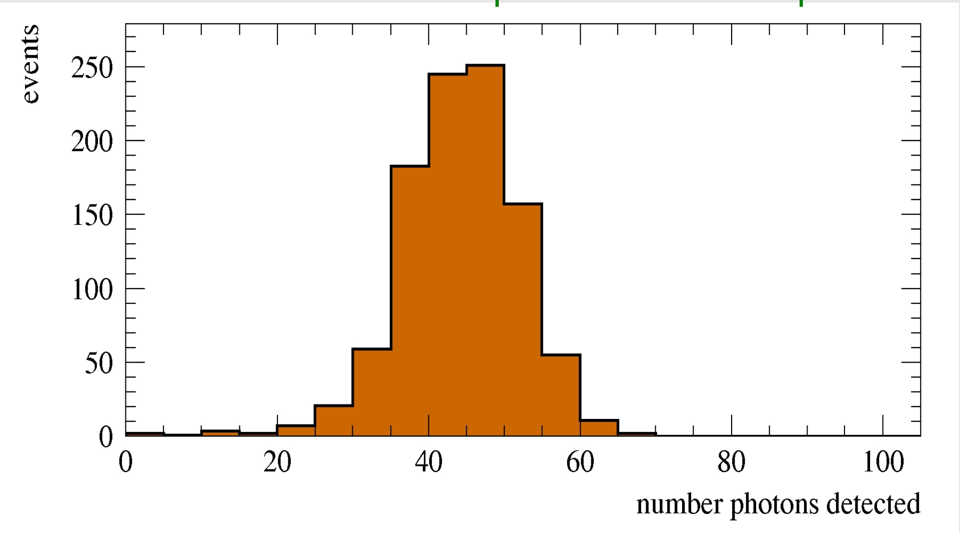
- SciBath detector is sensitive to fast (1-100MeV) n via prompt np elastic and nC inelastic scattering

- n may be tagged via delayed (~200μs) n-capture γ (2.2 MeV).
  - Enables 30% energy resolution 30% efficiency in 1-10 MeV range

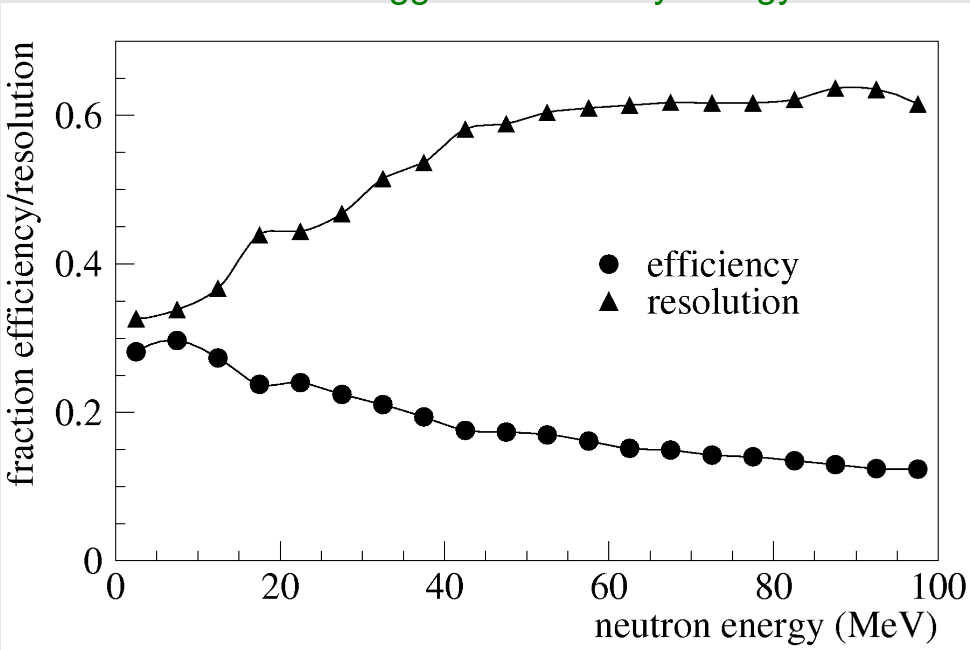
- some direction information should be possible

- investigating possibility of ^{6}Li or Gd loading to increase neutron tagging efficiency

Detector Response to 2.2 MeV photon



detector tagged-n efficiency/energy resolution

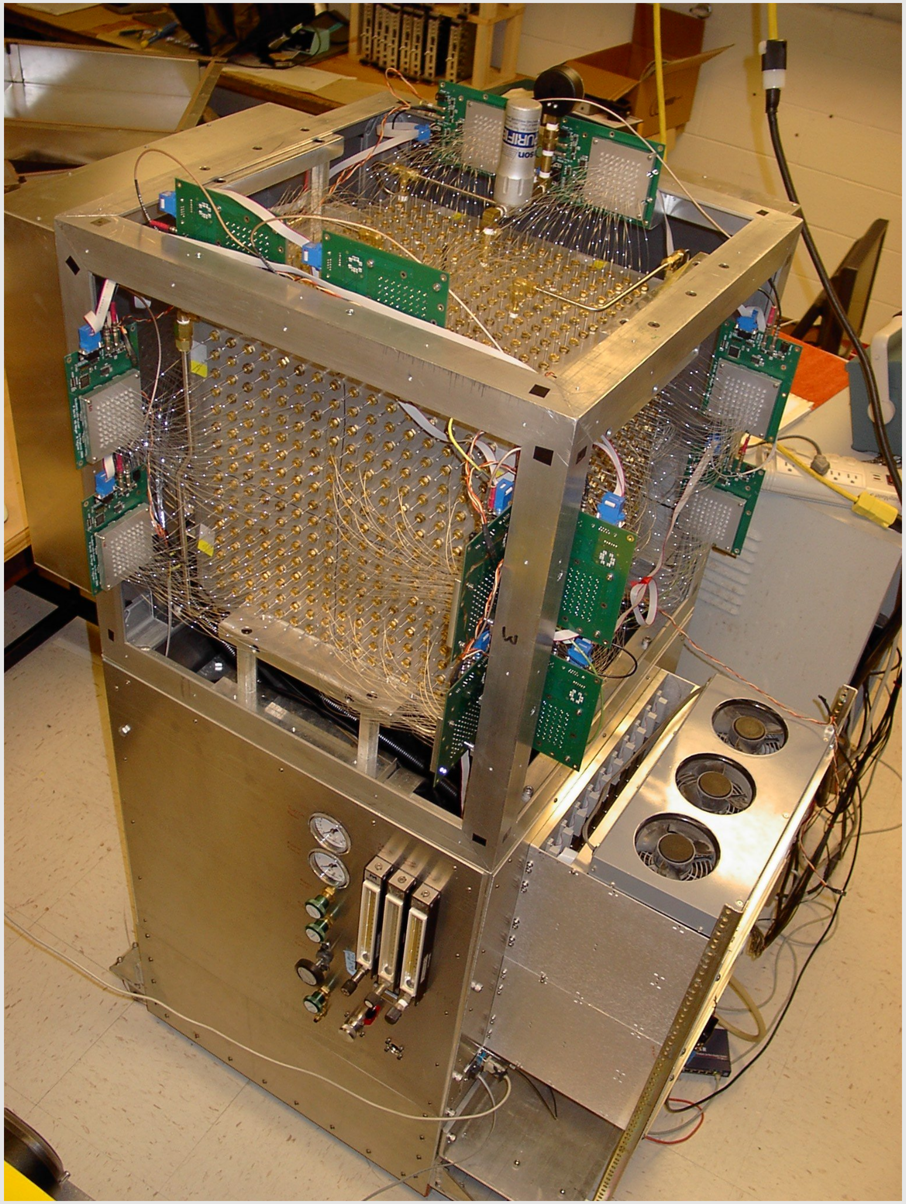


Conclusions

- SciBath-768 detector is built and commissioned

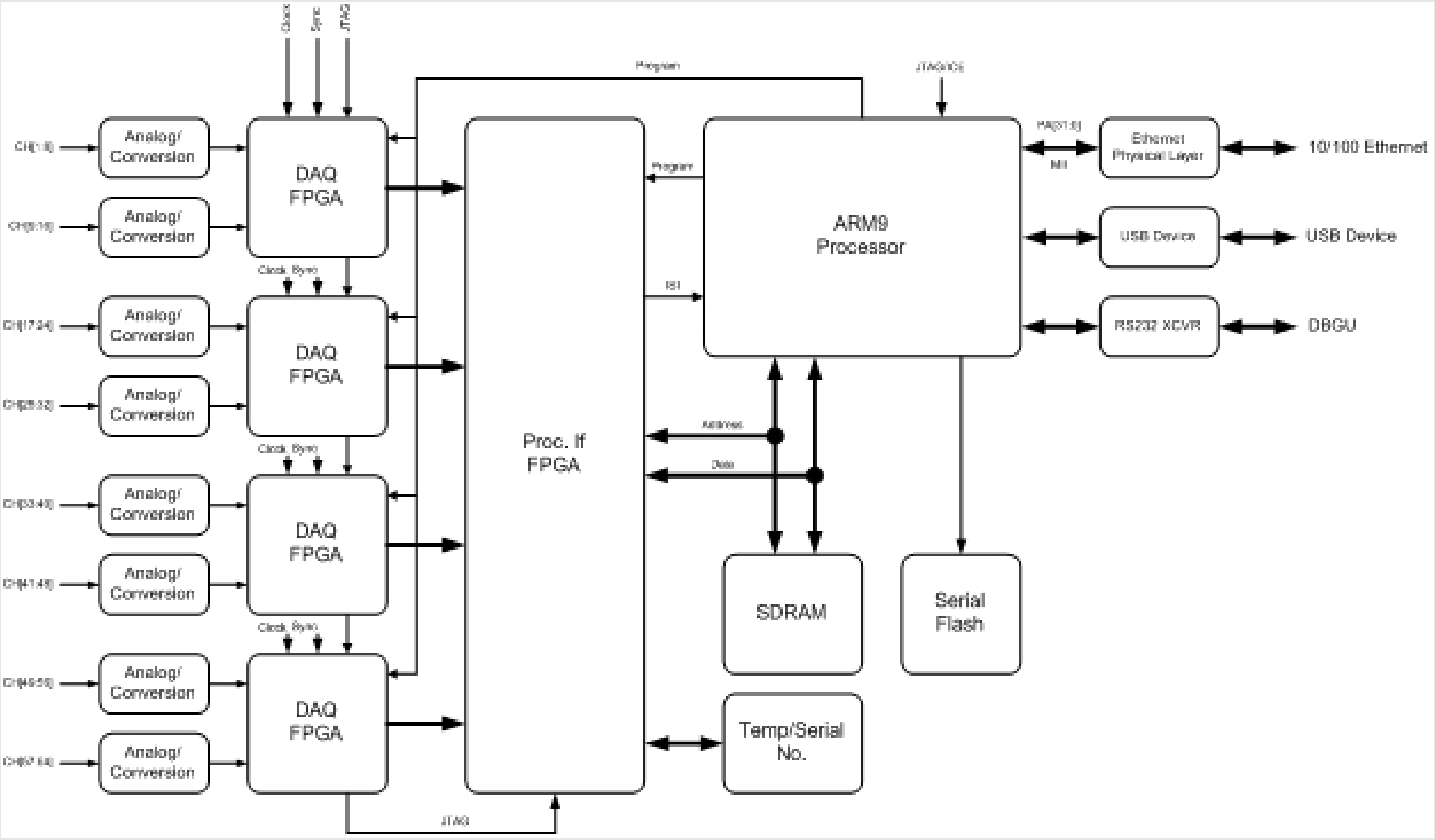
- Run planned for this fall at Fermilab in underground MINOS hall to
  - demo neutrino event reconstruction
  - measure cosmic- and beam-related neutron fluxes

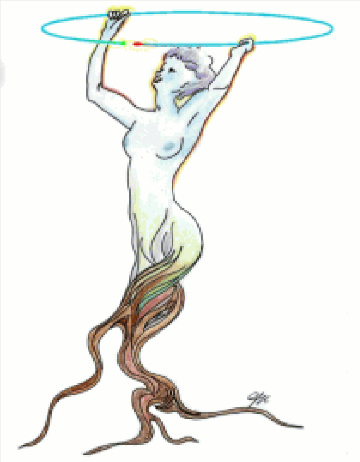
- Planning for future runs to help understand underground neutron fluxes for low-background experiments (eg: double-β decay, dark matter)



backup slides

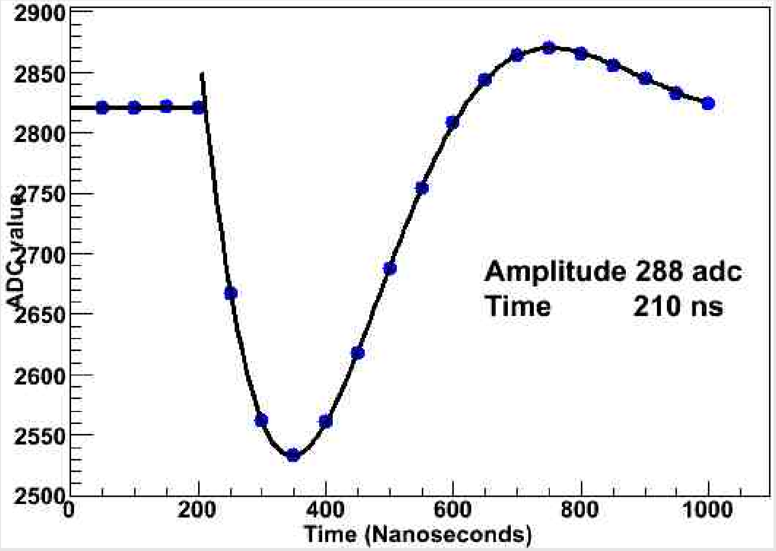
SciBath-768 readout electronics





Analysis Method

SciBath ADC versus time



- Hits time ordered, fitted, and grouped into "events"
- Resulting data stored in ROOT trees
- Baseline = average of pre-pulse adc samples
- Charge = baseline – minimum of fit function
- Hit time, t, from fit
- Charge resolution: fraction of a PE
- Time resolution: ~ 5 ns

$$fit(x) = -[amp] \cdot \exp\left(-\frac{(x-[t])}{[decay]}\right) \cdot \sin\left(\frac{(x-[t])}{[osc]}\right) + baseline$$

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D.~Mei and A.~Hime,
  %``Muon-induced background study for underground laboratories,''
  Phys.\ Rev.\  D {\bf 73}, 053004 (2006)
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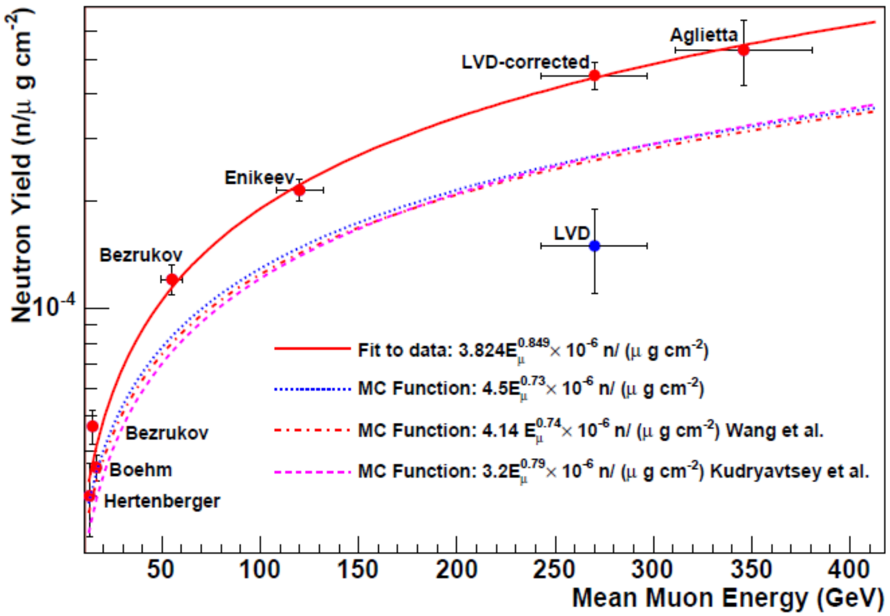
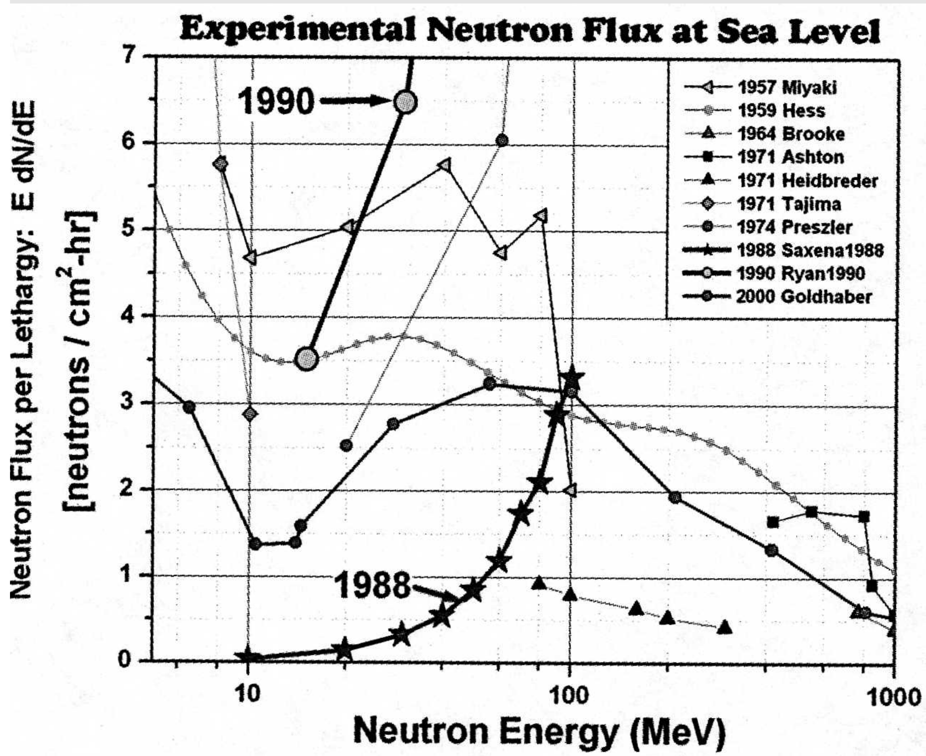


FIG. 8: The neutron production rate in liquid scintillator versus the mean muon energy. Data points with uncertainties are experimental measurements from Hertenberger [29], Boehm [30], Bezrukov [31], Enikeev [32], the LVD data [34] and Aglietta [33]. The solid curve is our global fit to the data after correcting the LVD data point for quenching effects described in the text. Our global fit curve describes the data well but the FLUKA simulations tend to underestimate the neutron production rate by about 35%.



Ref: L.T. John et al., Terrestrial Thermal Neutrons , IEEE Trans. Nucl. Sci. **50**, 2060 (2003)