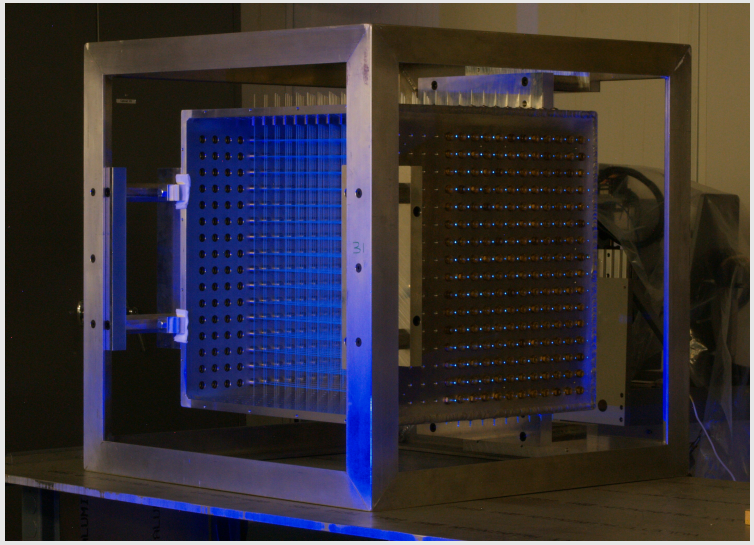
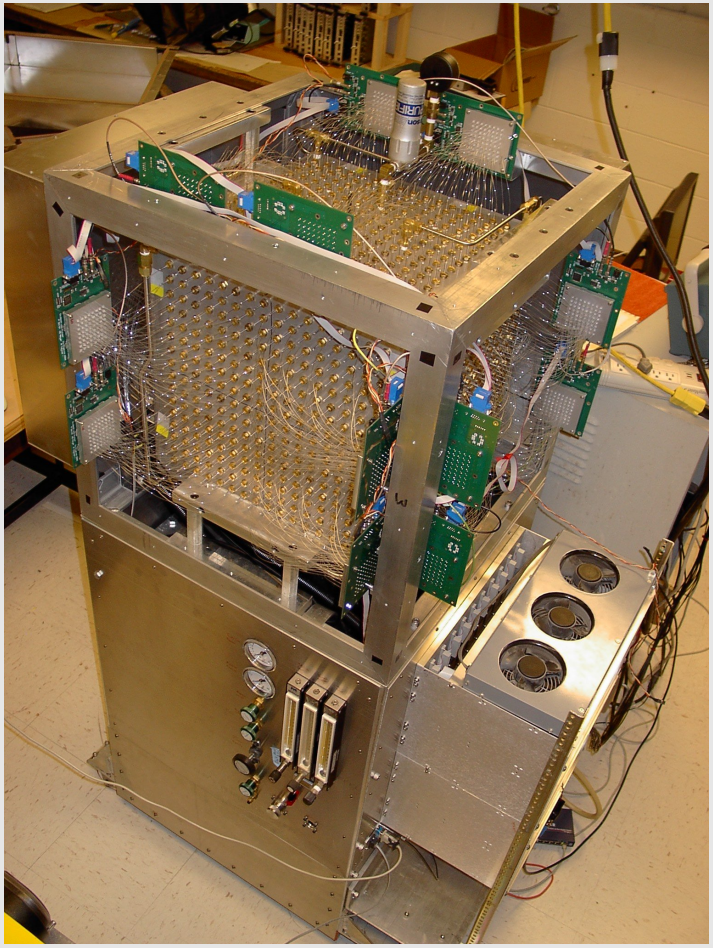
SciBath: A neutral particle detector technology (perhaps) for n - $\bar{n}$ experiments

INDIANA UNIVERSITY

Outline:
- motivation
- operating principle
- prototypes and tests
- status
- possible application to n - $\bar{n}$





R. Tayloe, Indiana U.
PXPS workshop
FNAL, 6/12

Motivation

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

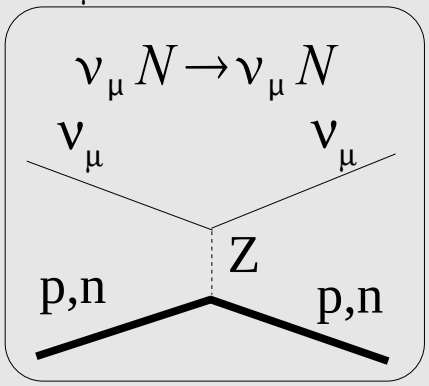
- Experimental signature: single ~100MeV proton track

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

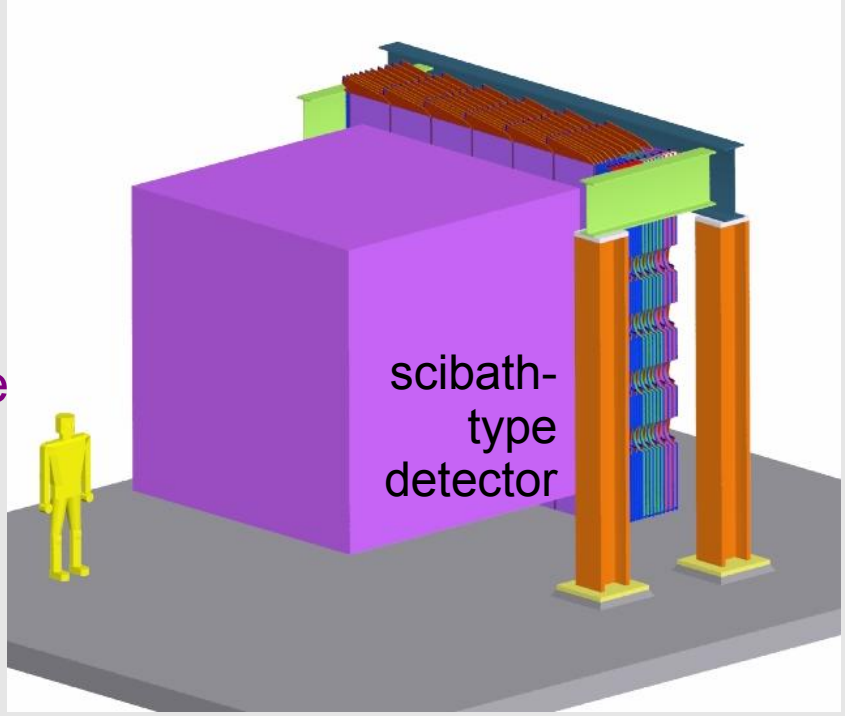
- Proposed FINeSSE experiment utilized SciBath technology:
  3D grid of wavelength-shifting fibers immersed in liquid scintillator

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

ν_μ NC elastic



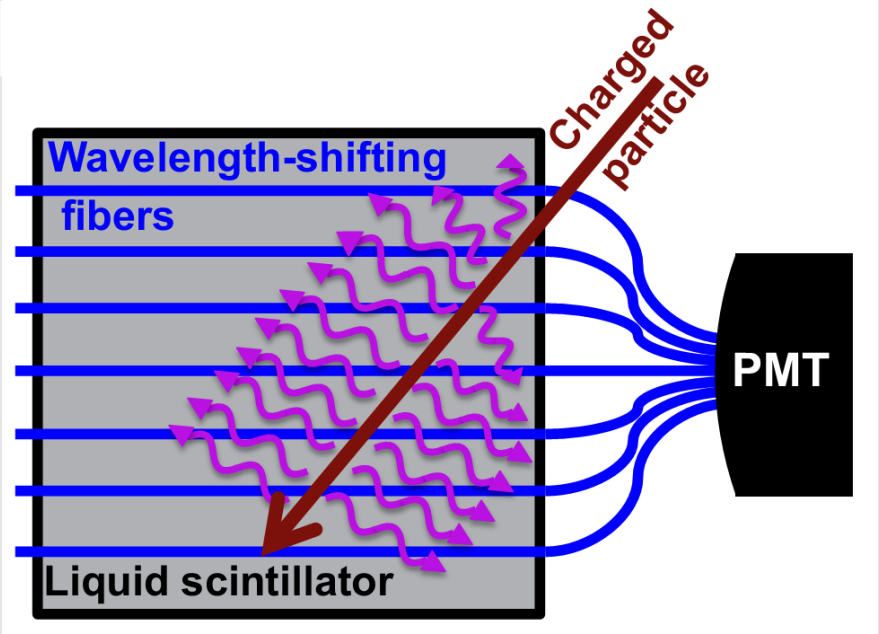
proposed FINeSSE experiment



Principle of operation

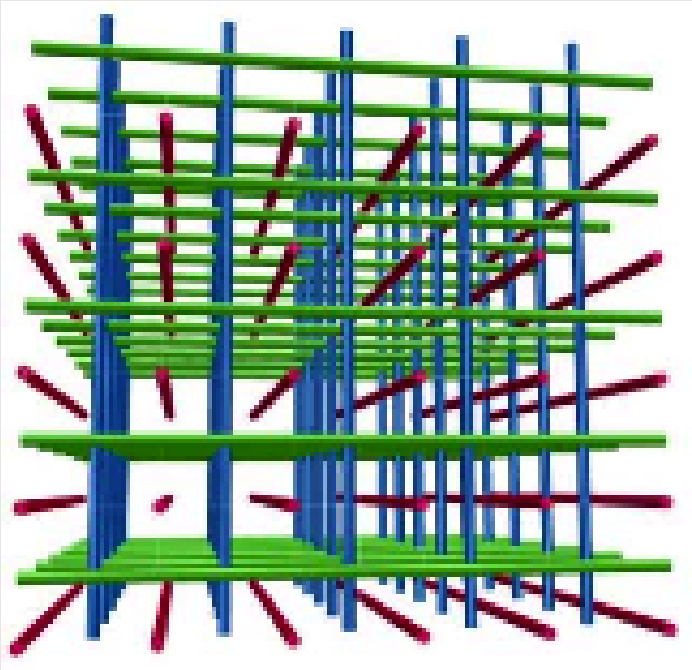
SciBath method:

- 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%

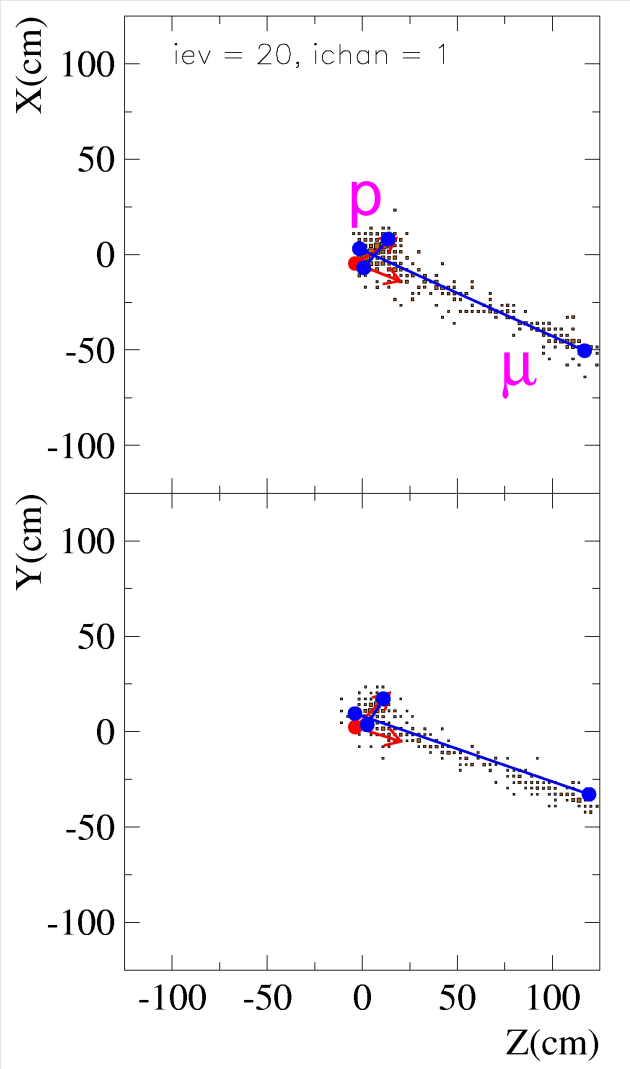


Physics simulation results

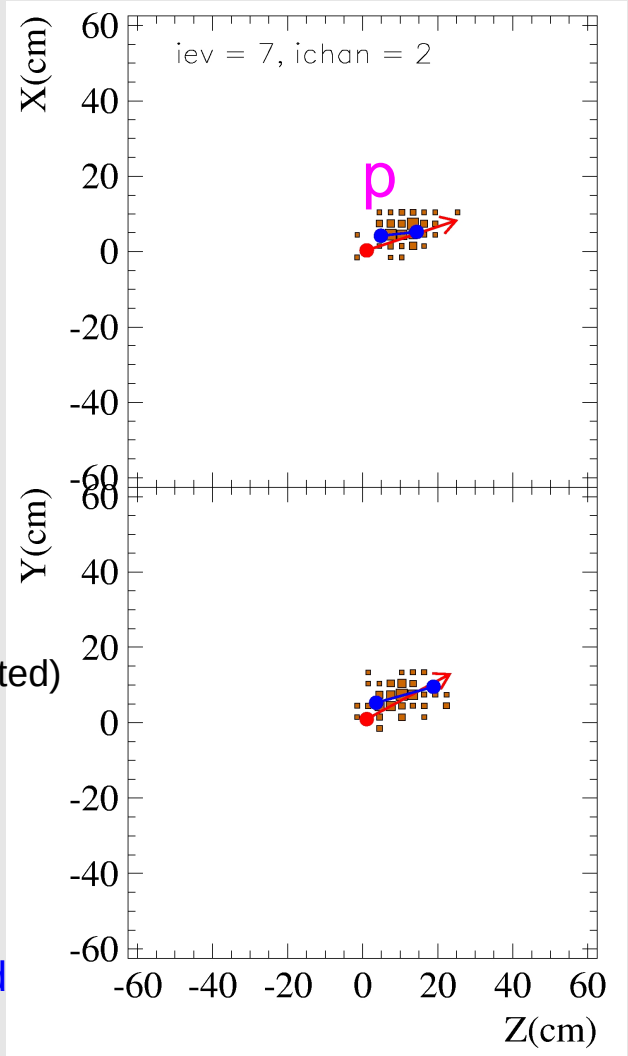
Simulation of large detector showed excellent reconstruction of ν events via proton, muon tracks

simulated hits and reconstructed tracks in the FINeSSE Detector

CCQE event



NCp event



fiber hits, (size ∝ # γ collected)

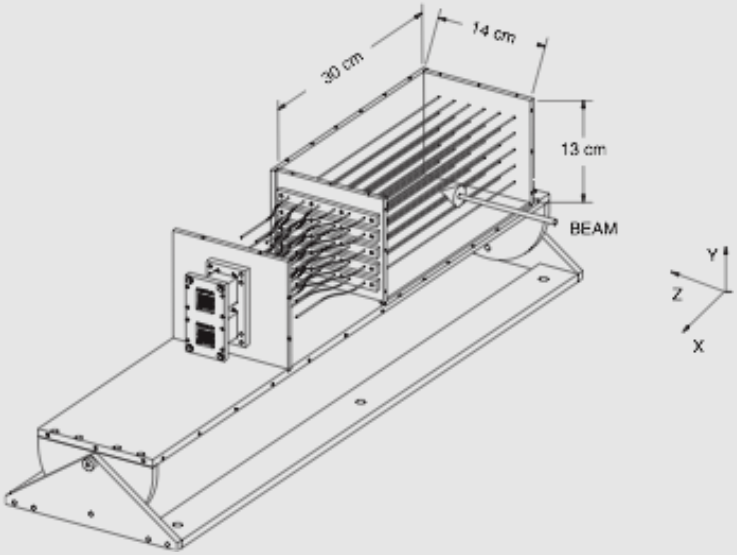
generated

reconstructed

Prototype I: SciBath-30

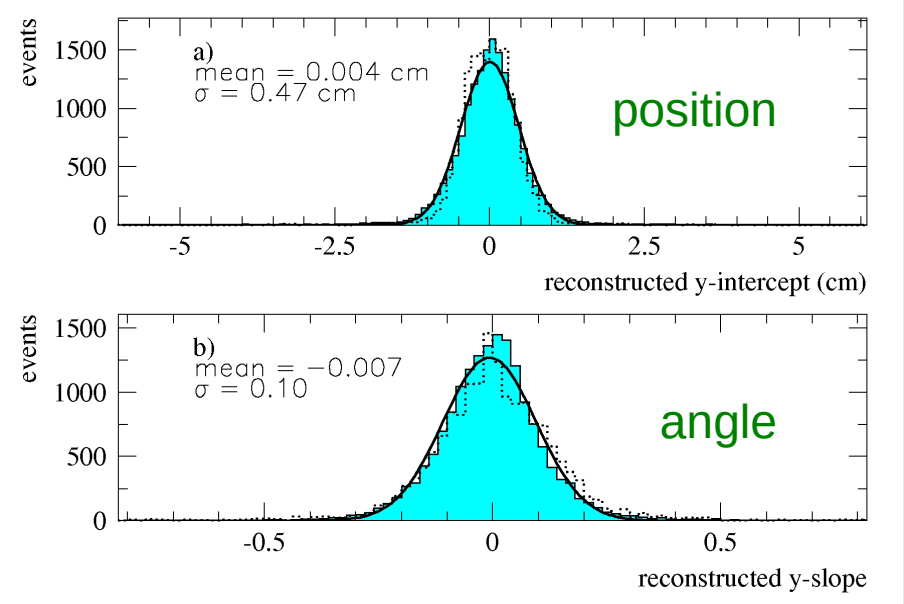
A proof-of-principle device was built
- 30 wls fibers in 1 orientation
- tested with 200 MeV protons.

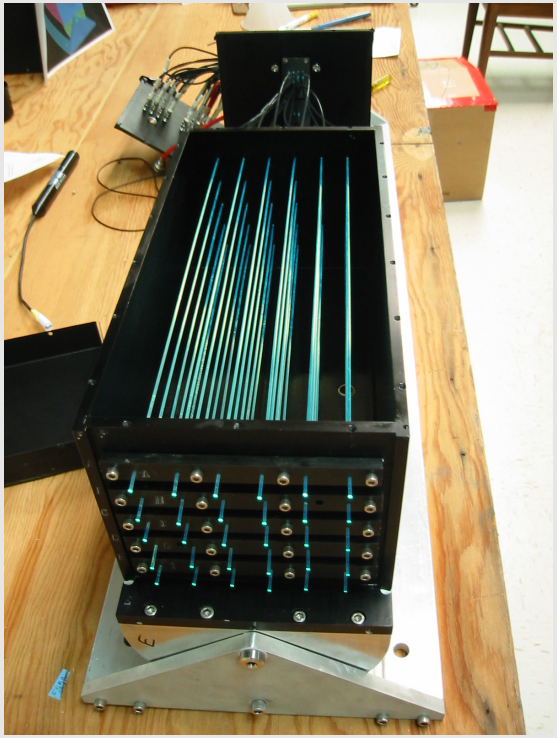
"A large-volume detector capable of charged-particle tracking",
R. Tayloe et al., Nucl.Instrum.Meth.A562:198-206,2006.



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

protoype test tracking distributions

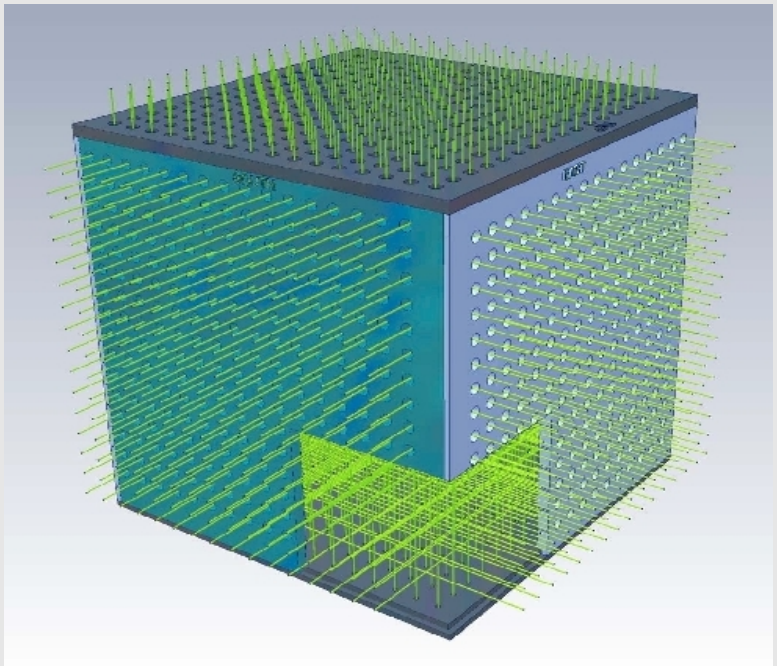


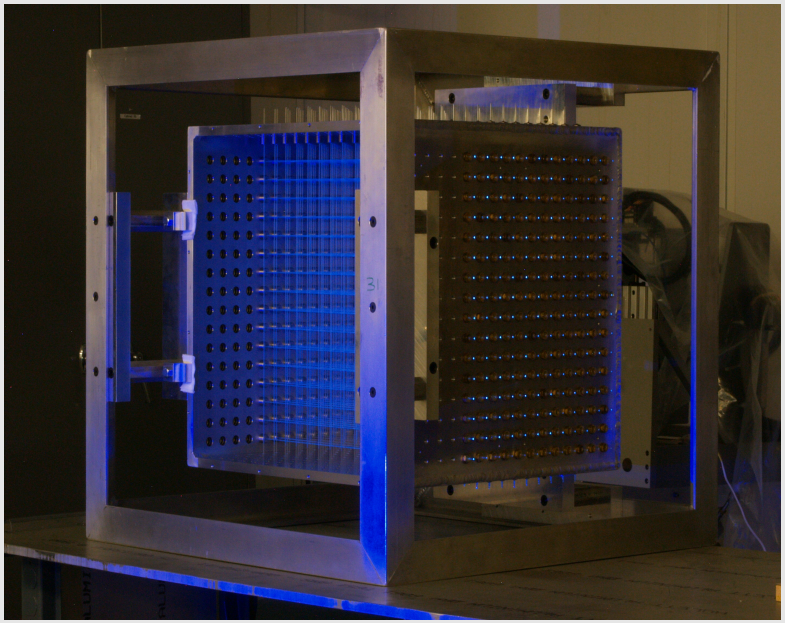


Next step: build a larger prototype with a 3D grid of fibers to:
- demonstrate 3D tracking
- develop and build economical, high channel-density readout
- pursue neutron detection applications

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

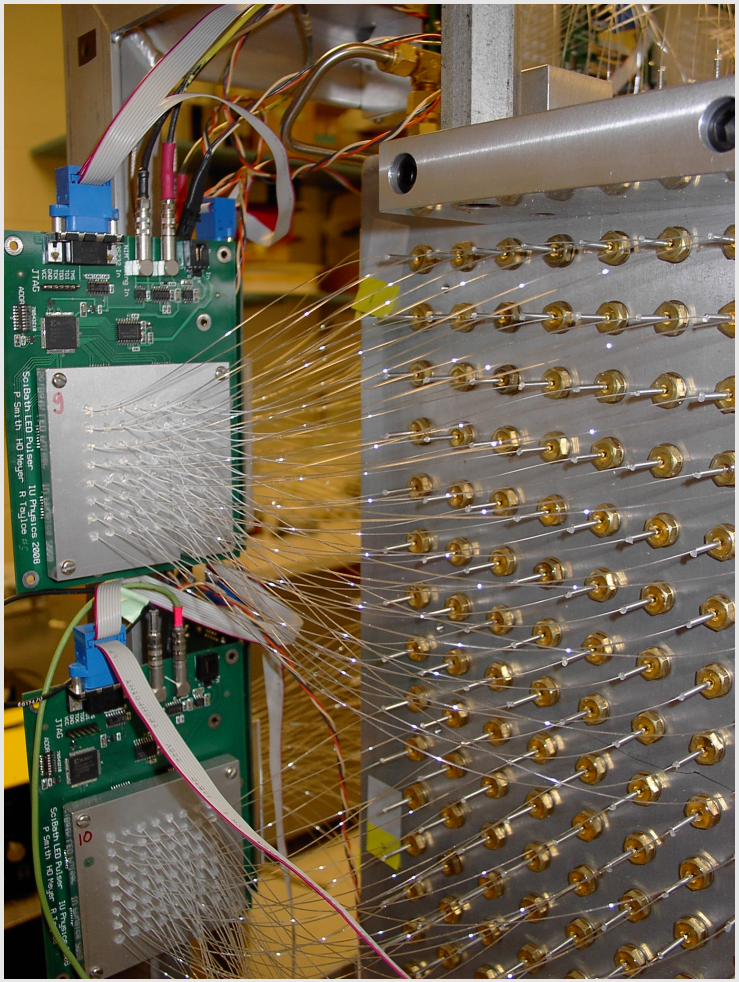




Prototype II: SciBath-768

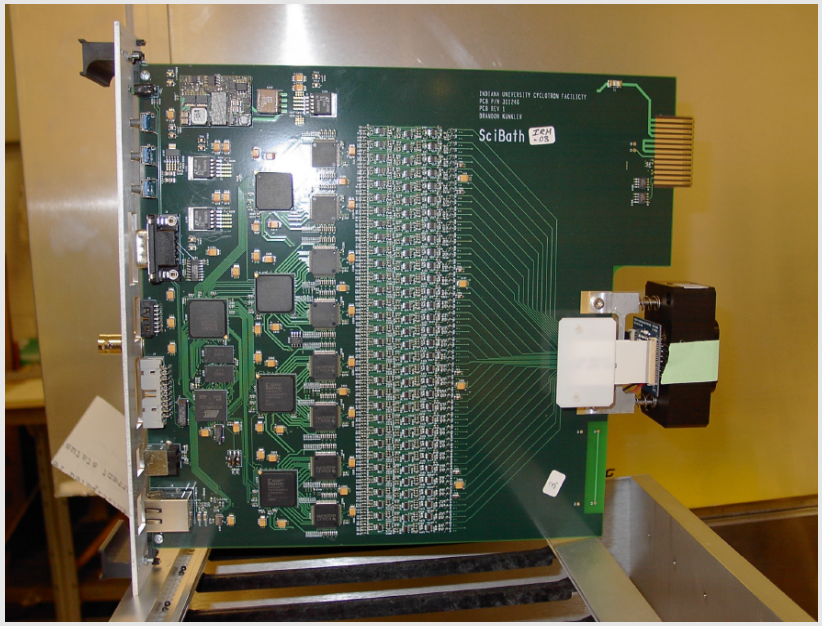
Specifications (cont):

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



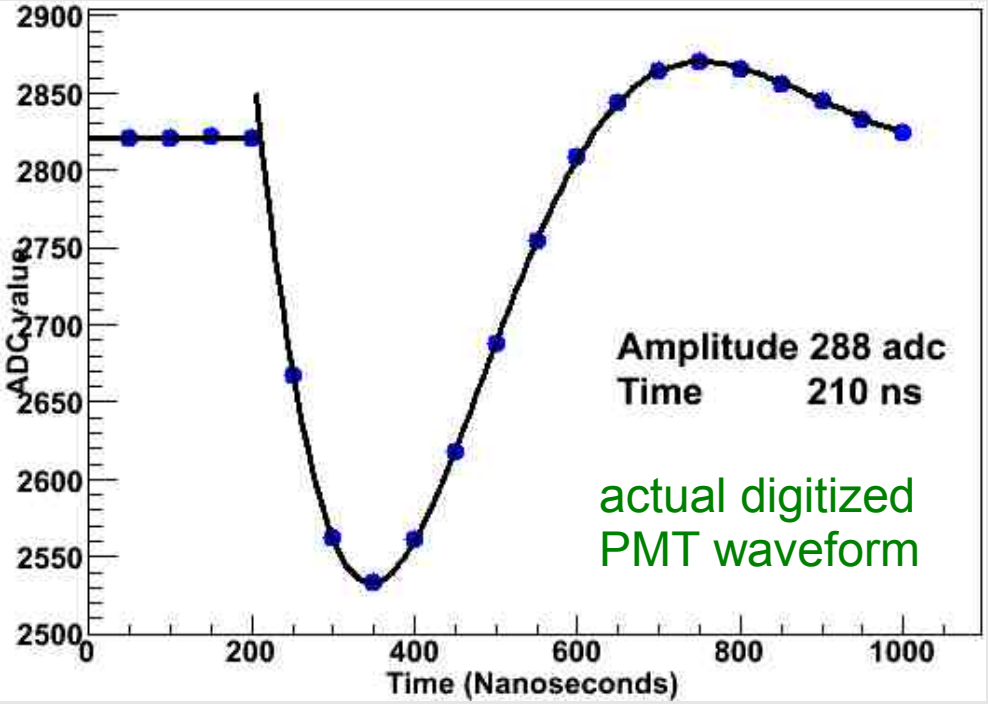
SciBath-768 readout electronics

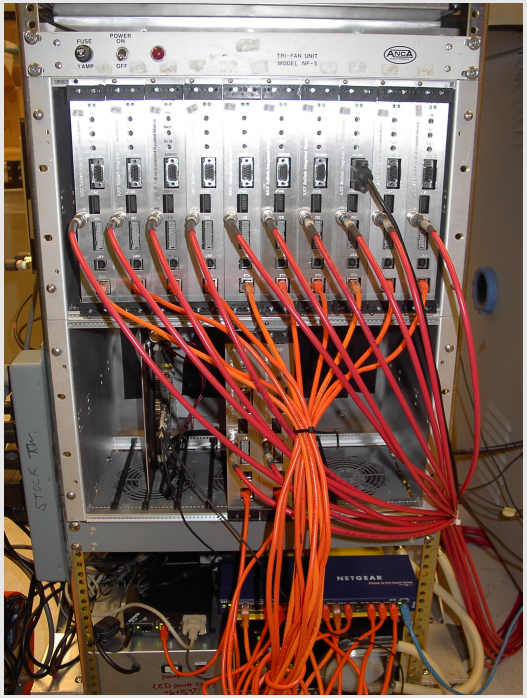
IRM with attached PMT



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)

- possible readout for SciNOvA

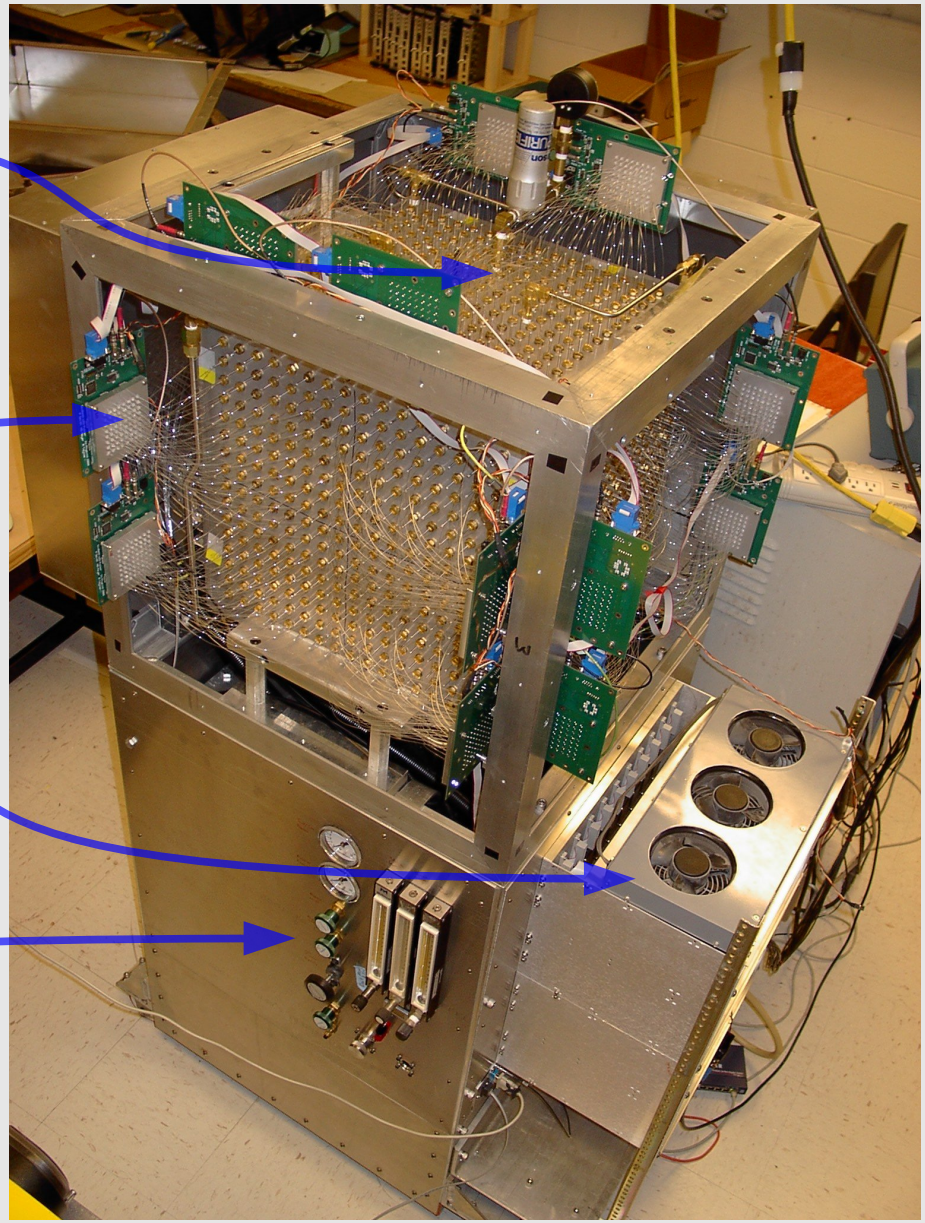
Prototype II: SciBath-768

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

- Pulsed LED calibration system

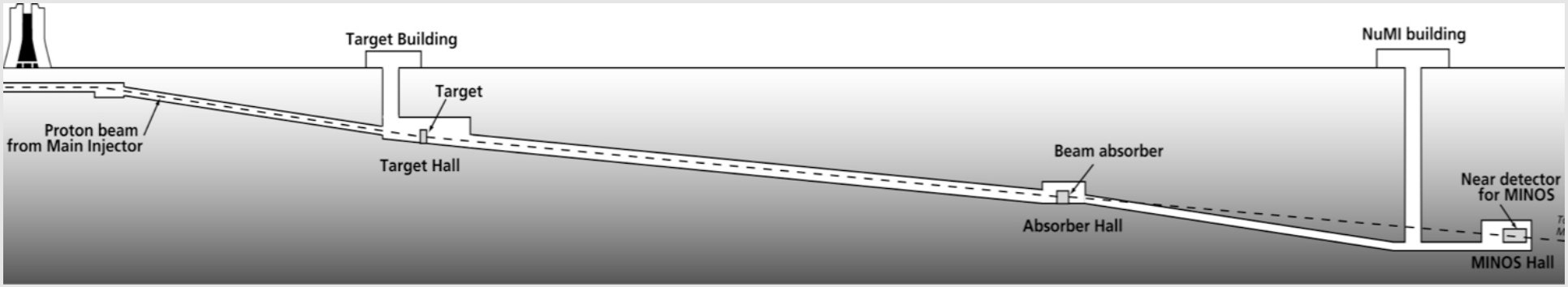
- Electronics crate w/readout including IRMs / PMTs

- liquid scintillator plumbing controls and gauges



SciBath-768 status

- detector is assembled and running
- ran for 3 months, fall'11 in MINOS near detector area (100m overburden)



to measure: neutrino events, underground n-flux, beam related neutrons

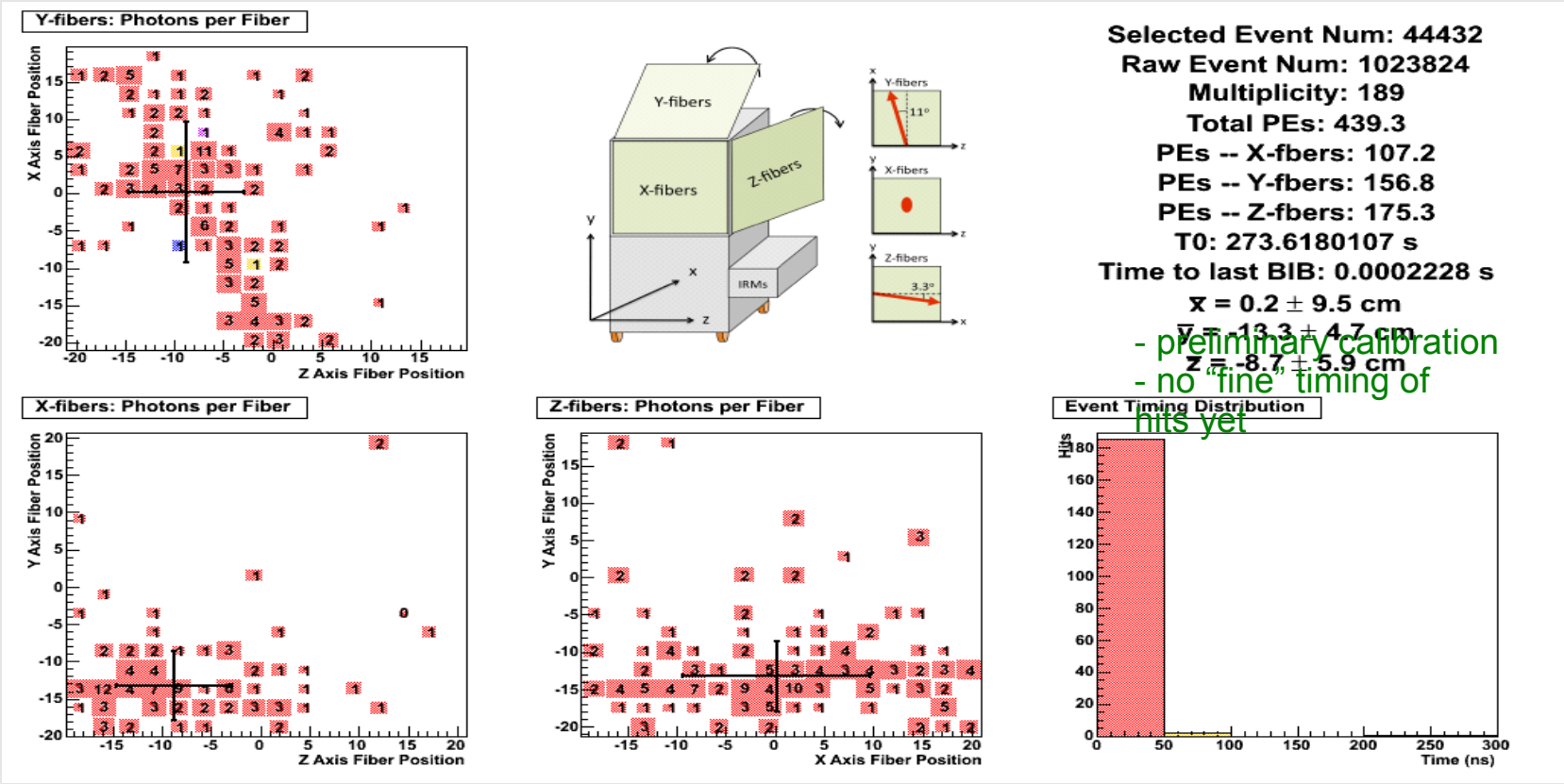
- then ran ~2months, spring'12 in MI12 area to measure beam-related neutron background for possible neutrino-Argon elastic scattering measurement.

- analysis on these data sets underway....

Data analysis/Event reconstruction

- for each WLS fiber, PMT channel charge/time is recorded with triggerless, deadtime less DAQ
- Provides track “image” (= particle track convoluted with light spread function)
- can extract position, direction, energy
- also record associated delayed events (eg muon-decays, n-capture, beta-decay)
- particle-ID possible via:
    - de/dx, eg: mu vs proton)
    - event “topology”, eg: mu vs neutron
    - delayed event “tags”, eg: mu-decay, n-capture

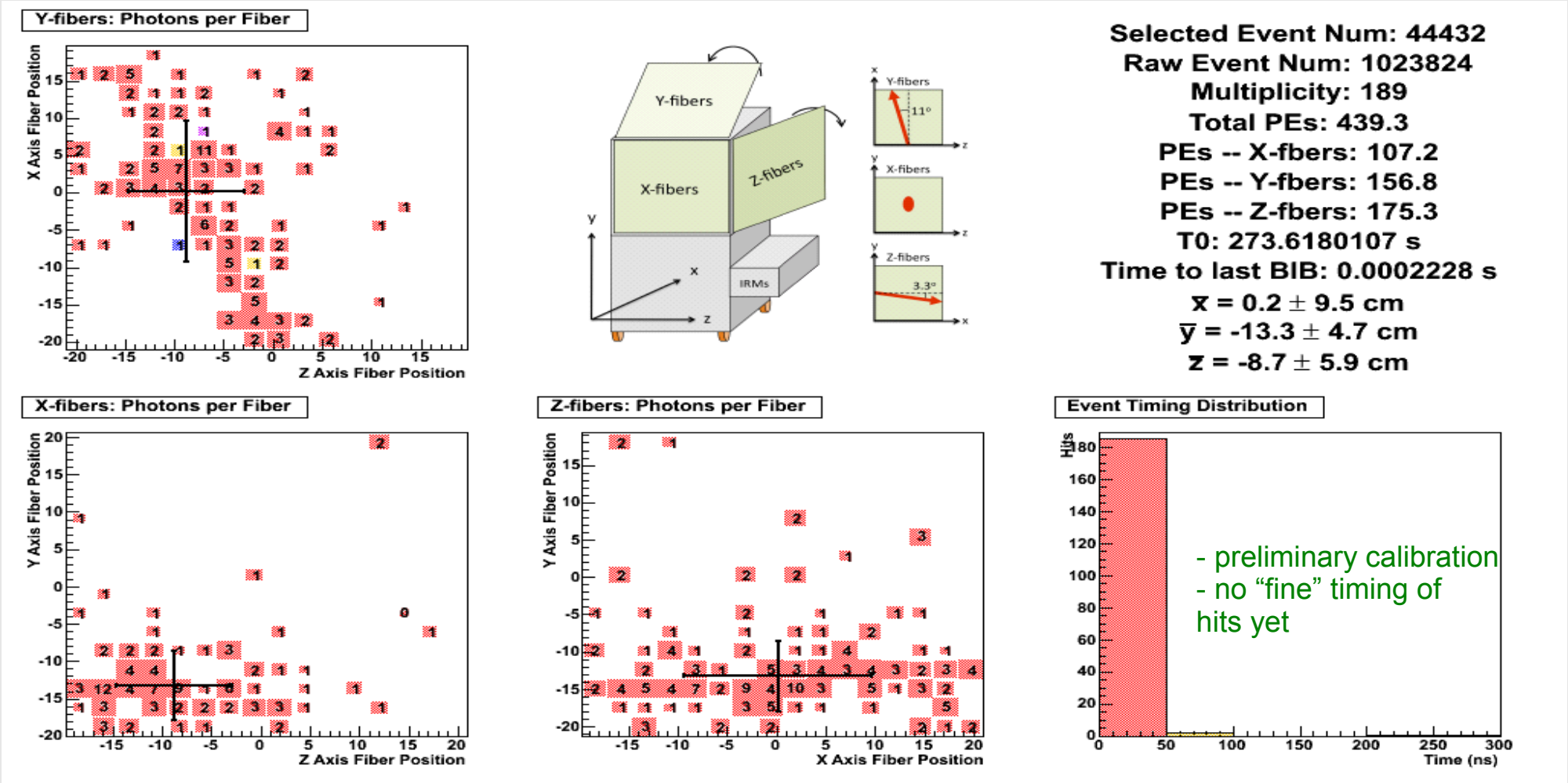
data: muon candidate event



- preliminary calibration
- no “fine” timing of hits yet

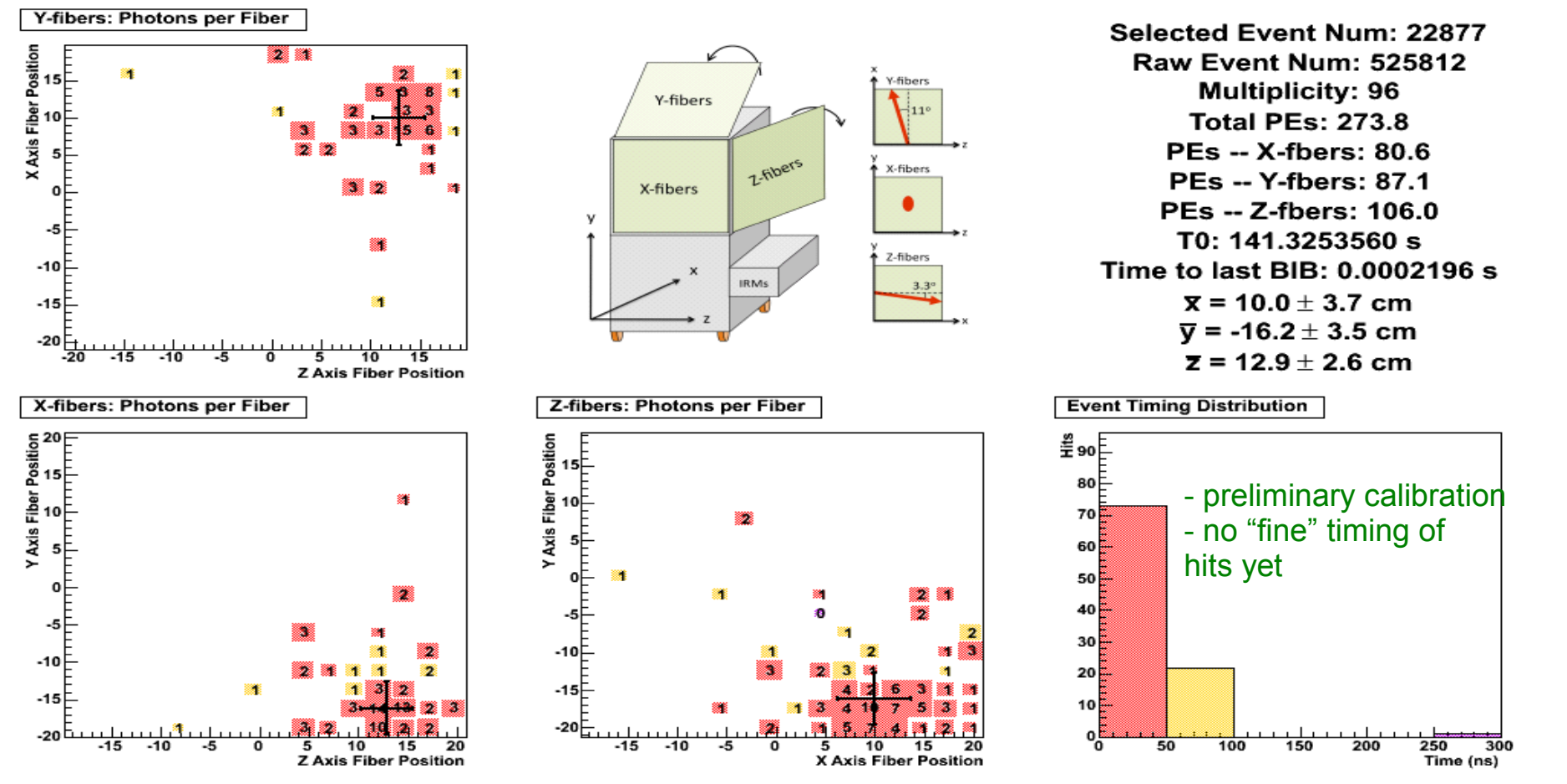
Event reconstruction

MINOS data: muon candidate event



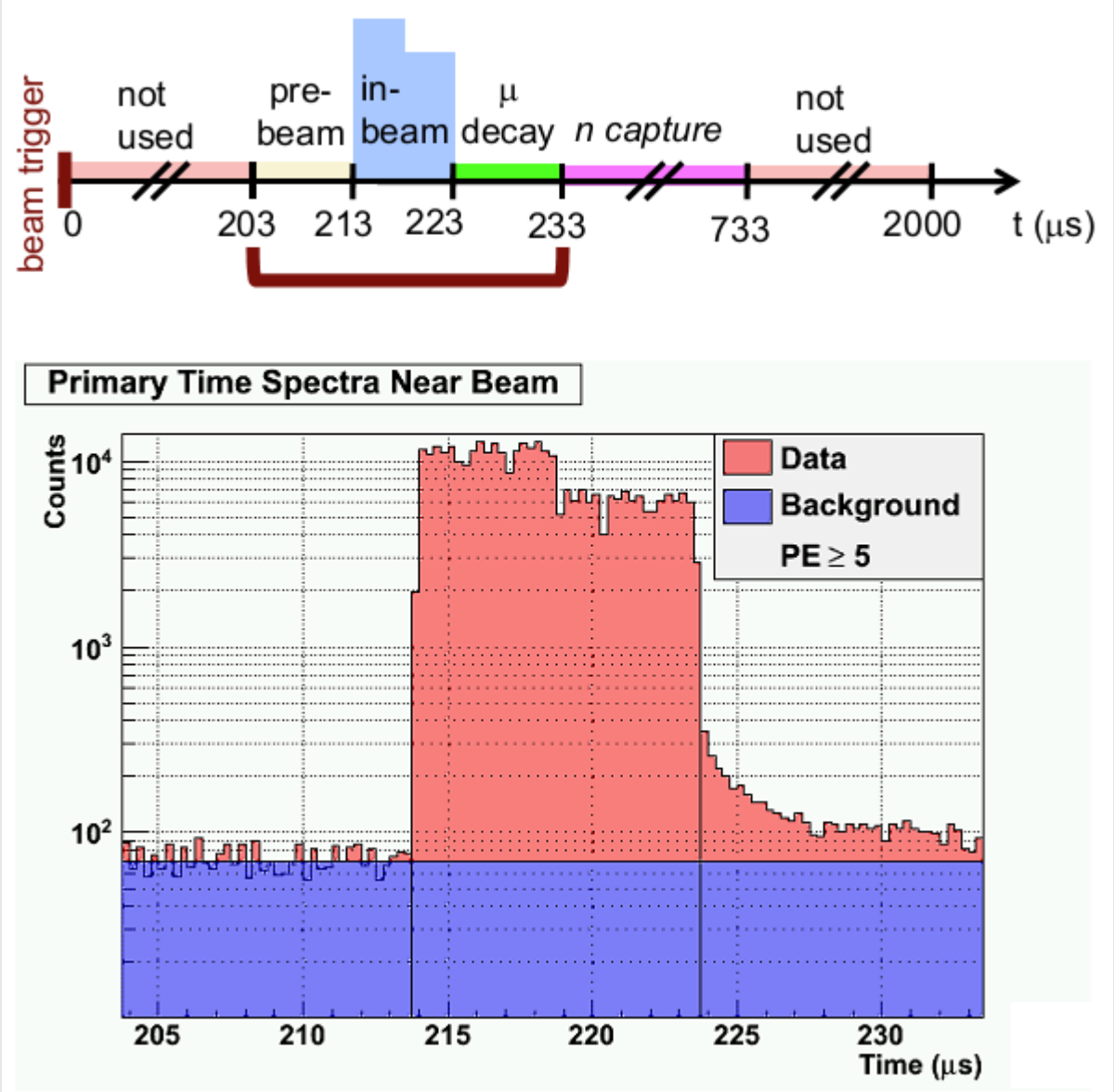
Event reconstruction

MINOS data: neutron candidate event



Preliminary results: MINOS area data beam related muons

- Primary near beam
- Multiplicity > 6 cut
- 41 days of data
- 1.5×10^6 beam spills
- Beam window:
  - 10 μs @ 0.5 Hz
  - 23% of beam windows have events



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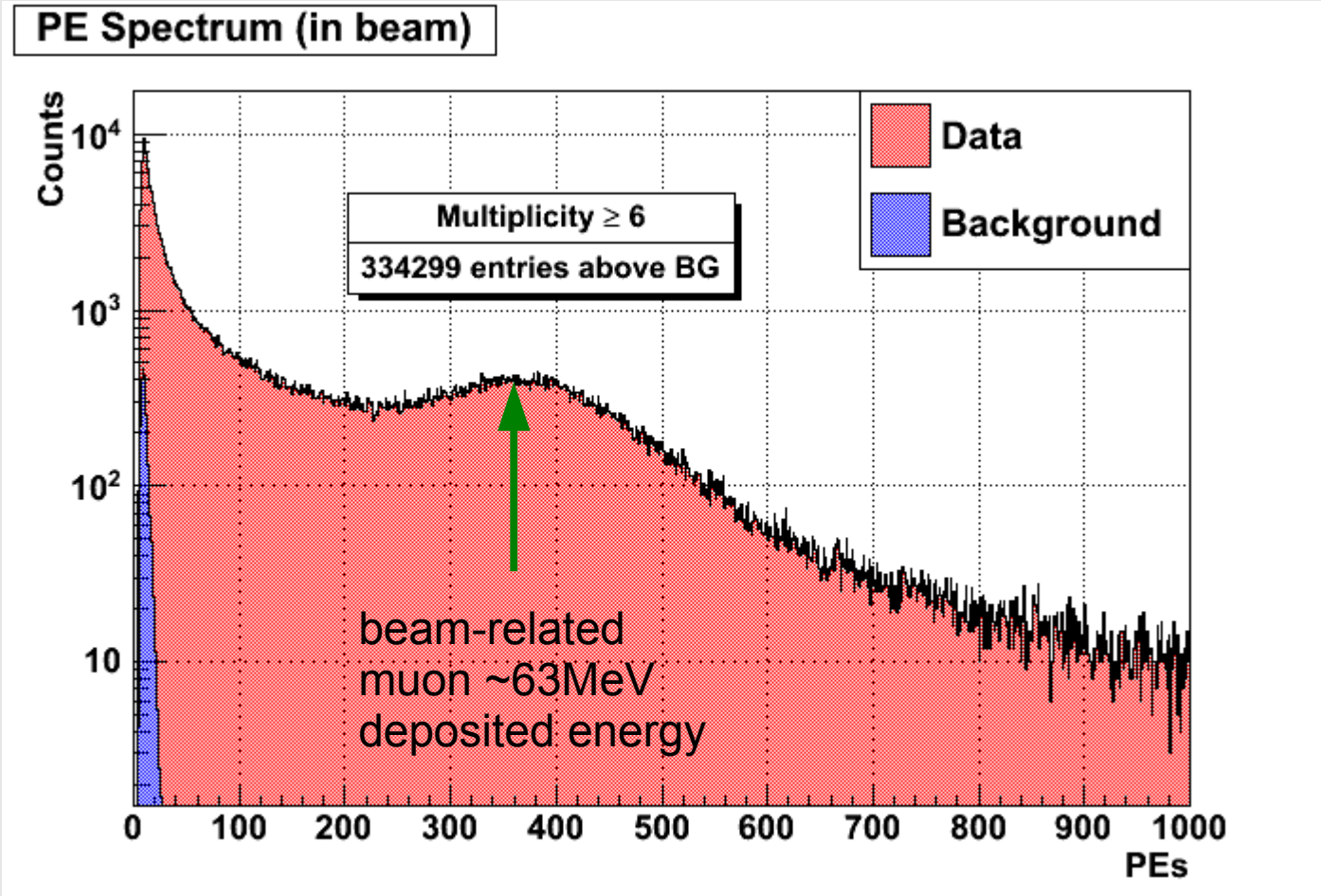
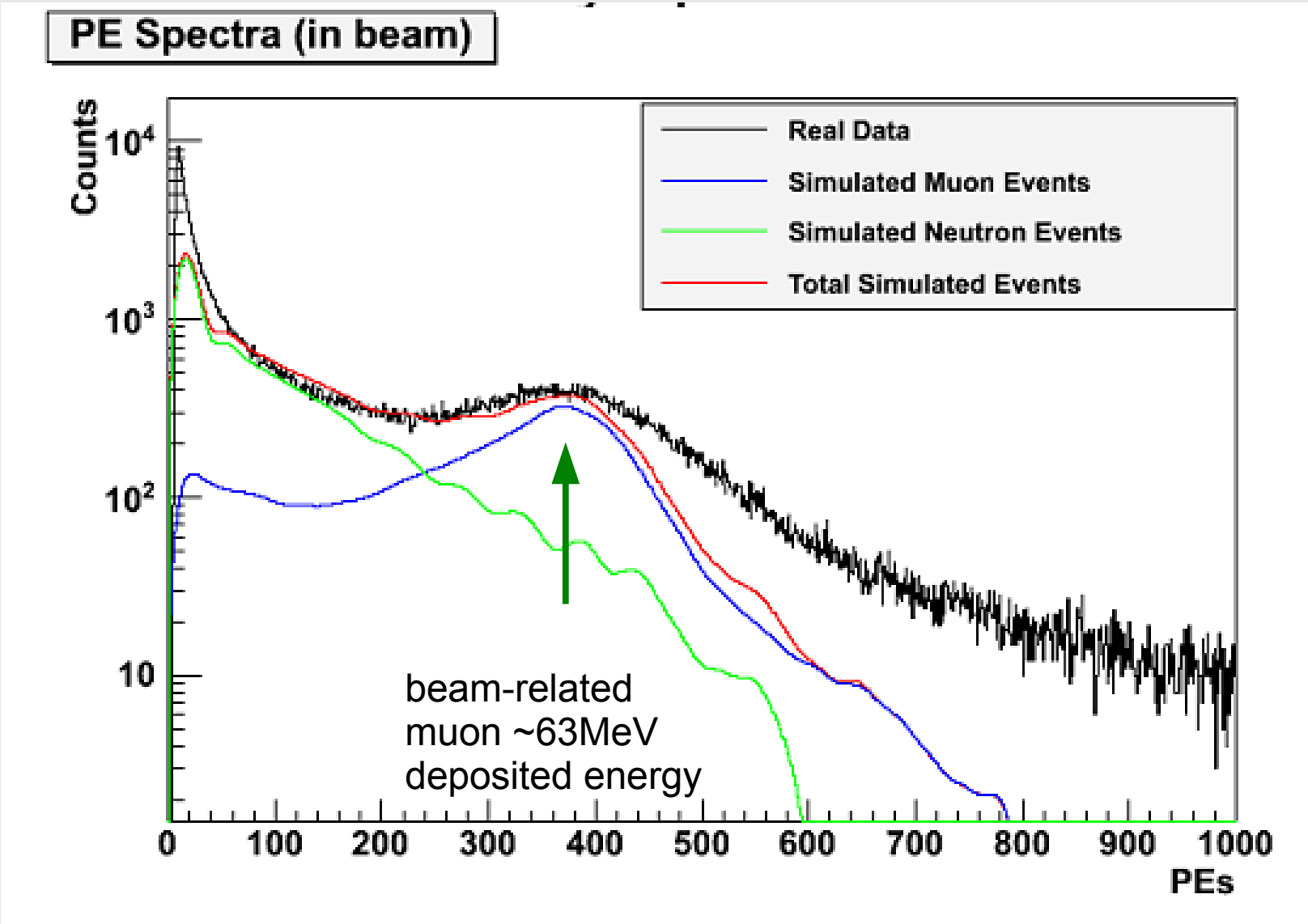
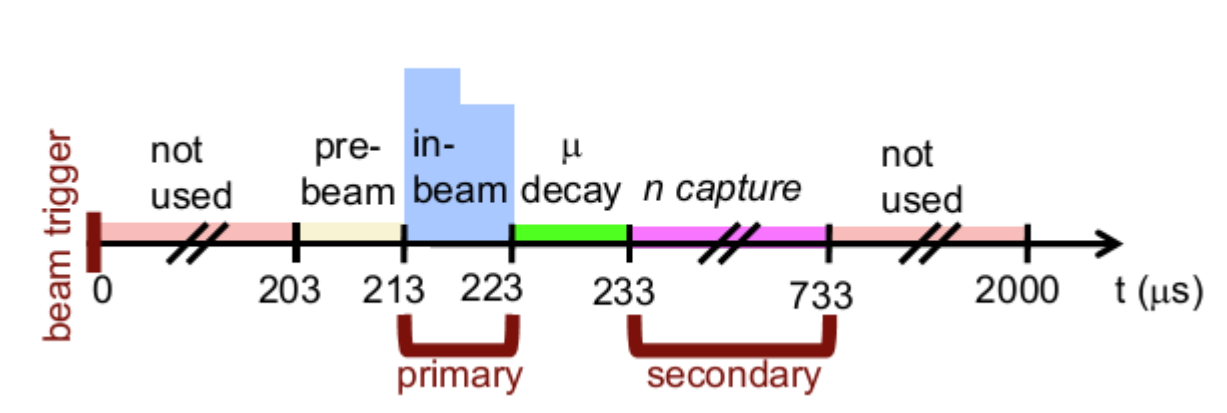


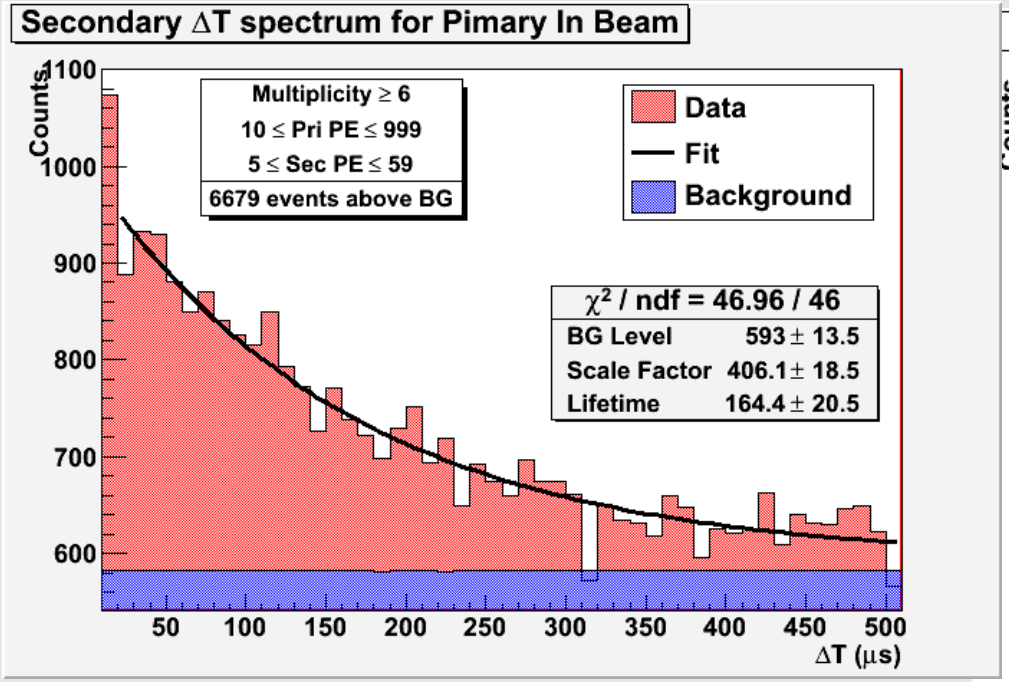
Preliminary results: beam related muons

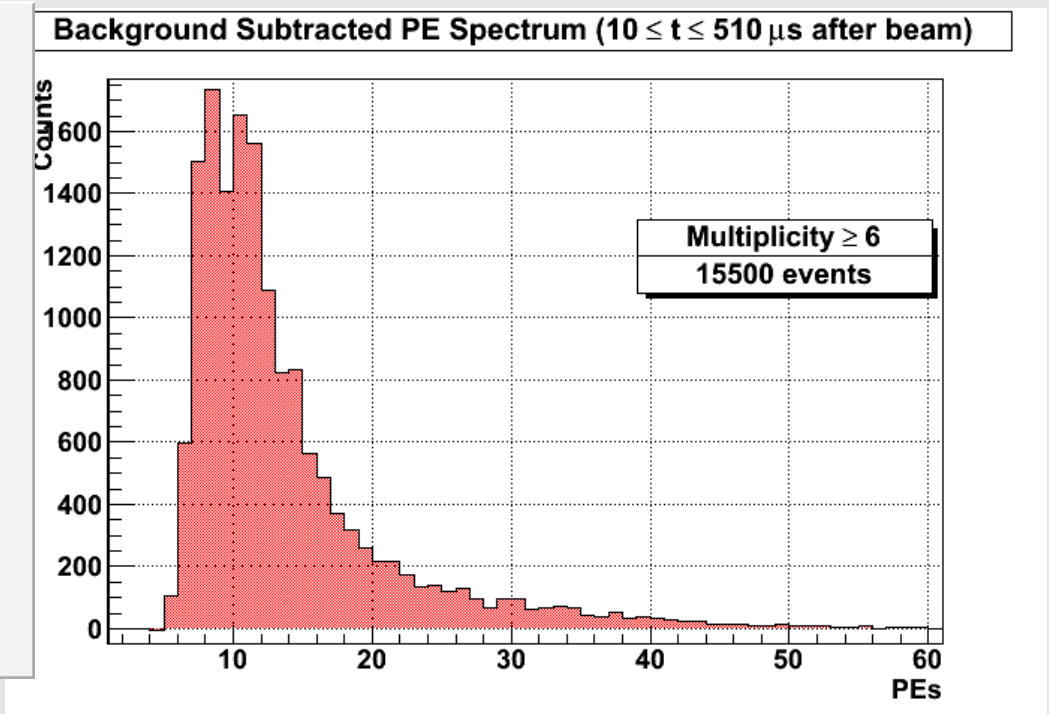
- MC-simulated muons/neutrons compared to data



Preliminary results: n-capture signal



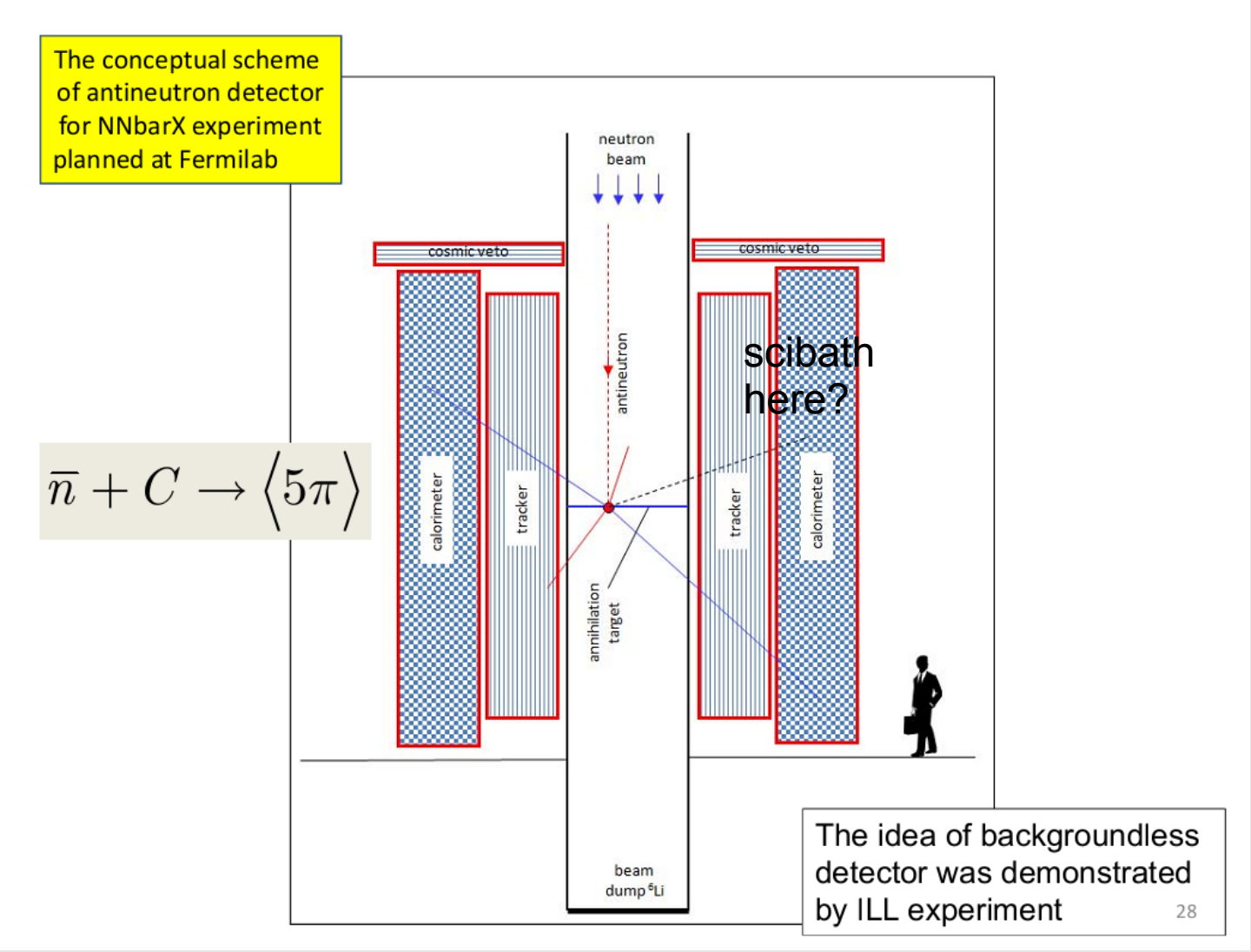




SciBath for n-$\bar{n}$?

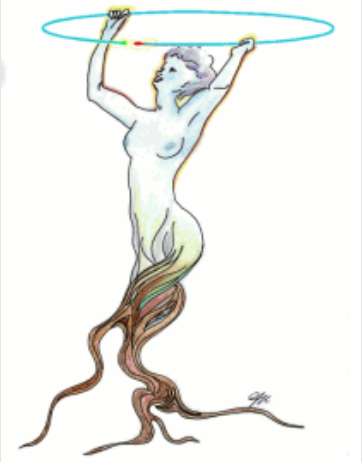
- A SciBath detector could combine the tracker and calorimeter functions

- may be an economical option.



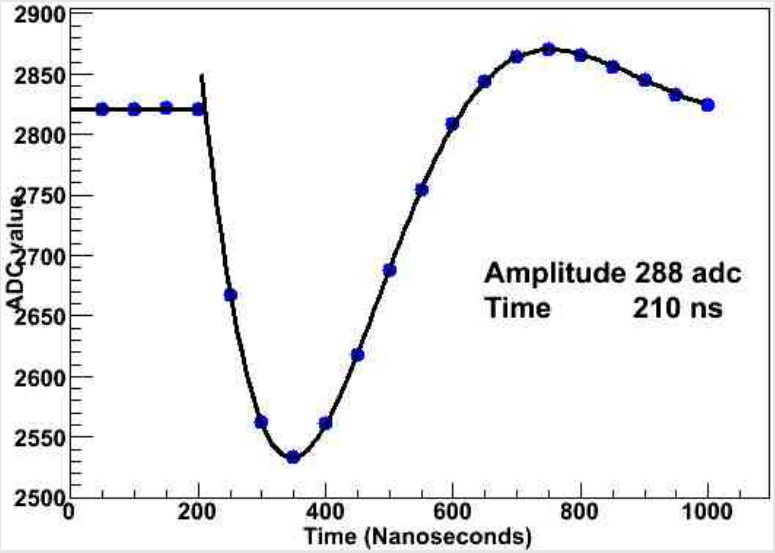
$$\bar{n} + C \rightarrow \langle 5\pi \rangle$$

backup slides



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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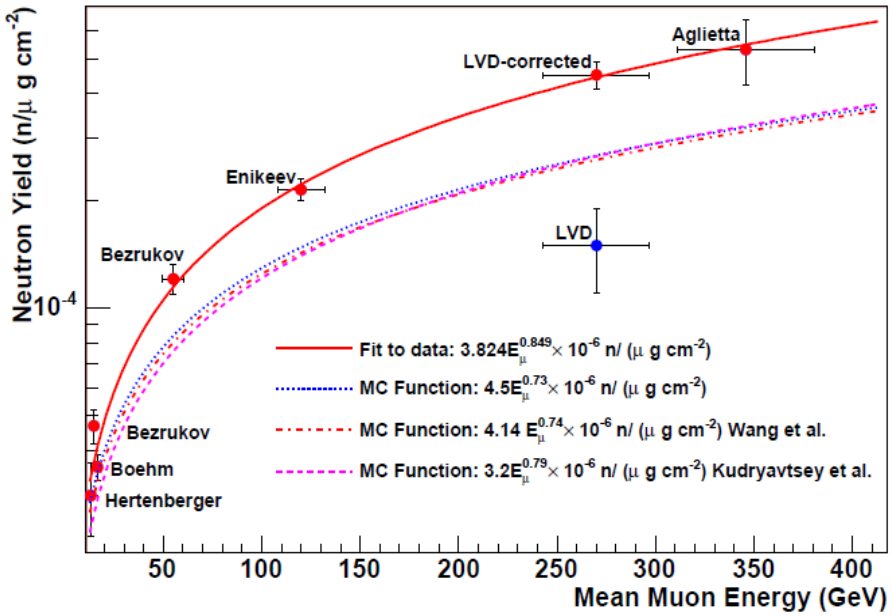
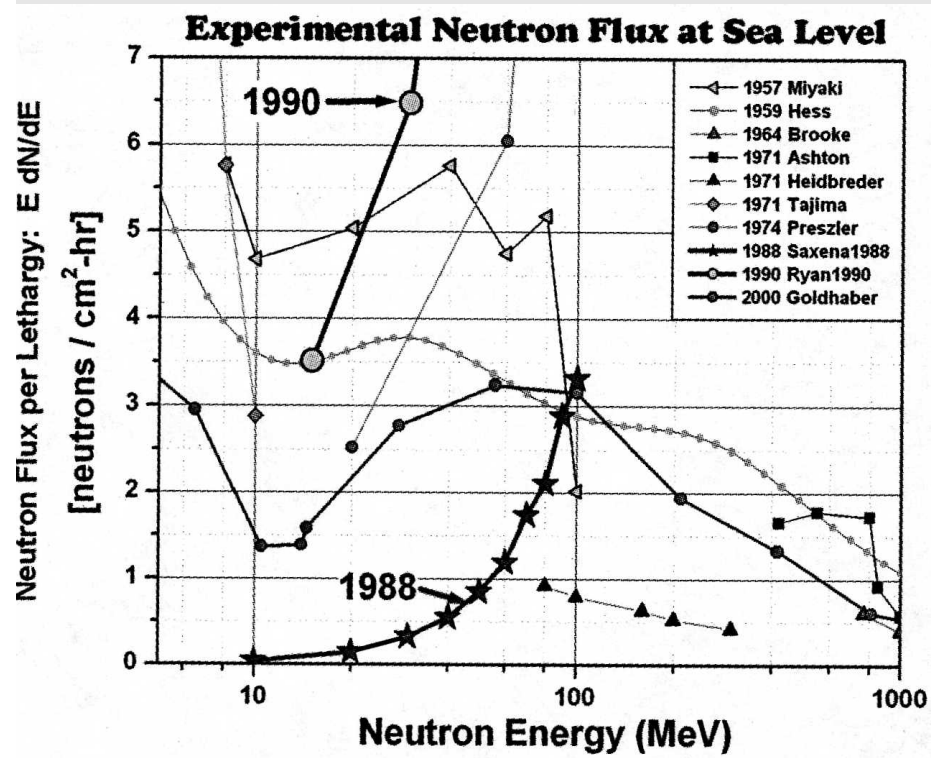


FIG. 8: The neutron production rate in liquid scintillator versus the mean muon energy. Data points with uncertainties are experimental measurements from Hertenberger [29], Boehm [30], Bezrukov [31], Enikeev [32], the LVD data [34] and Aglietta [33]. The solid curve is our global fit to the data after 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)