What Do We (I?) Know About Efficiency And Backgrounds in ν_e Appearance Studies with a Large Liquid Argon Detector?

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The Allure of Large Liquid Argon Detectors

A Liquid Argon TPC is an "Electronic Bubble Chamber".

Detailed tracking information $\Rightarrow$ Superior particle identification (e/π^0 separation, slow proton identification) $\Rightarrow$ Well suited for $\nu_\mu \rightarrow \nu_e$ charged-current studies.

Cost effective in large volumes.

Could operate with a magnetic field.

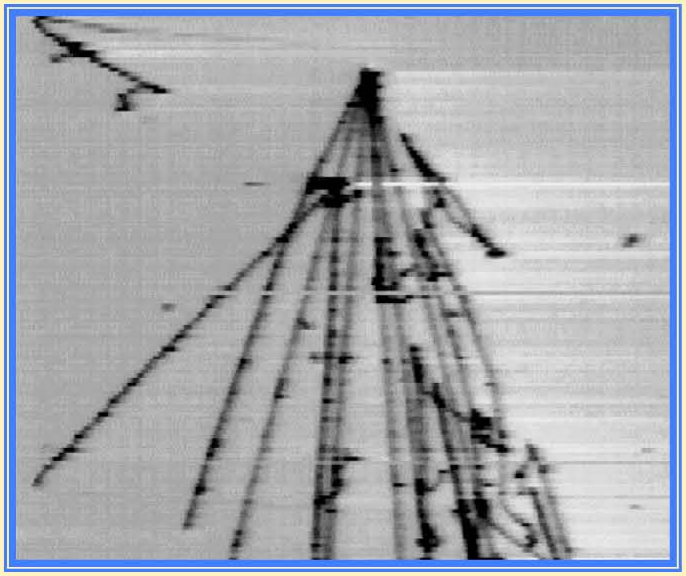
But, how well do we know the performance of LAr TPC for analysis of ~ 1 GeV neutrino interactions? [Efficiency for $\nu_e n \rightarrow p e^- X$; Rejection of $\nu_\mu n(p) \rightarrow n(p)\pi^0 X$]

A. Rubbia (Sept. 2005)

Why 2km LAr TPC? (1)

- **Fully active, homogeneous, high-resolution device** ⇒ high statistics neutrino interaction studies with bubble chamber accuracy .

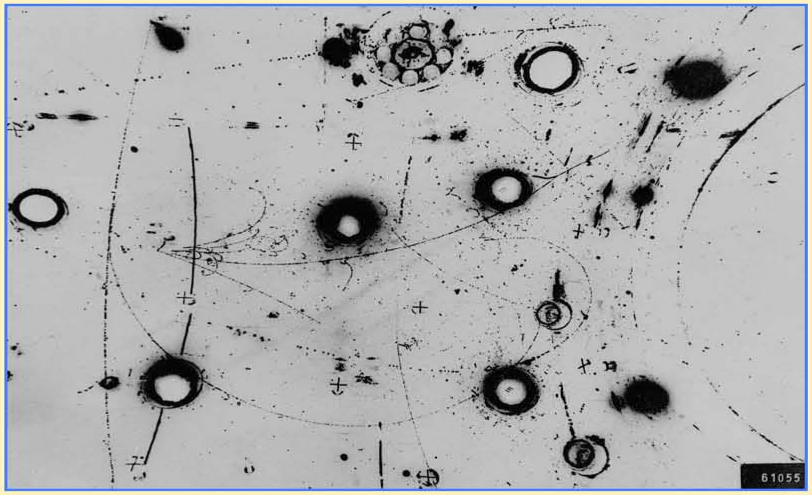
Real event in ICARUS



High granularity: Sampling = 0.02 X_0

"bubble" size ≈3×3×0.4 mm^3

Gargamelle bubble chamber

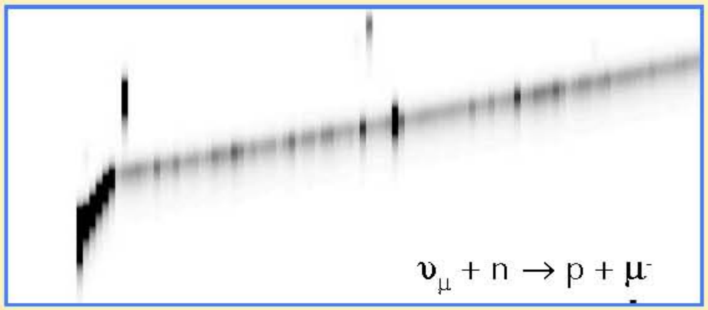


bubble diameter ≈3mm

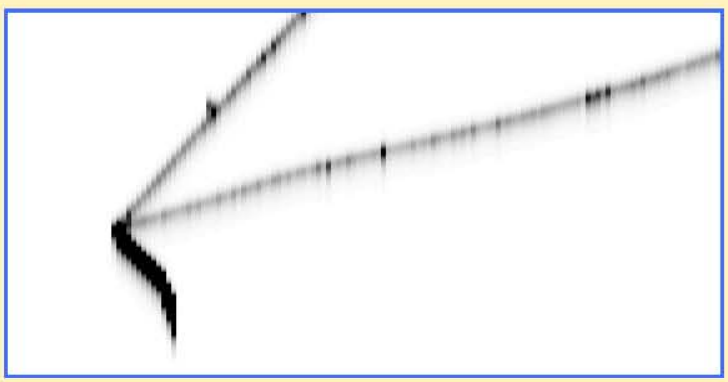
Capable of 1-event discovery…

Why 2km LAr TPC? (2)

- Reconstruction of low momentum hadrons (below Cherenkov threshold), especially recoiling protons.
- Independent measurement of off-axis flux and QE/nonQE event ratio.



MC QE event.
Proton momentum = 490 MeV/c



MC nQE event.
Pion+ momentum = 377 MeV/c, Proton momentum = 480 MeV/c

Protons

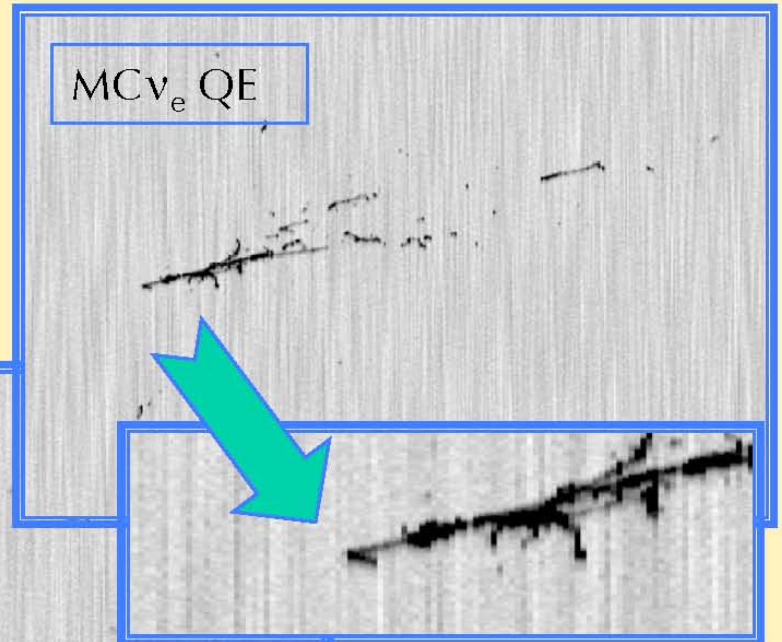
Kinetic energy T (MeV)	Momentum p (MeV/c)	Range in LAr (cm)
10	43	0.14
40	280	0.93
70	370	4.19
100	446	7.87
300	813	51.9
500	1094	116

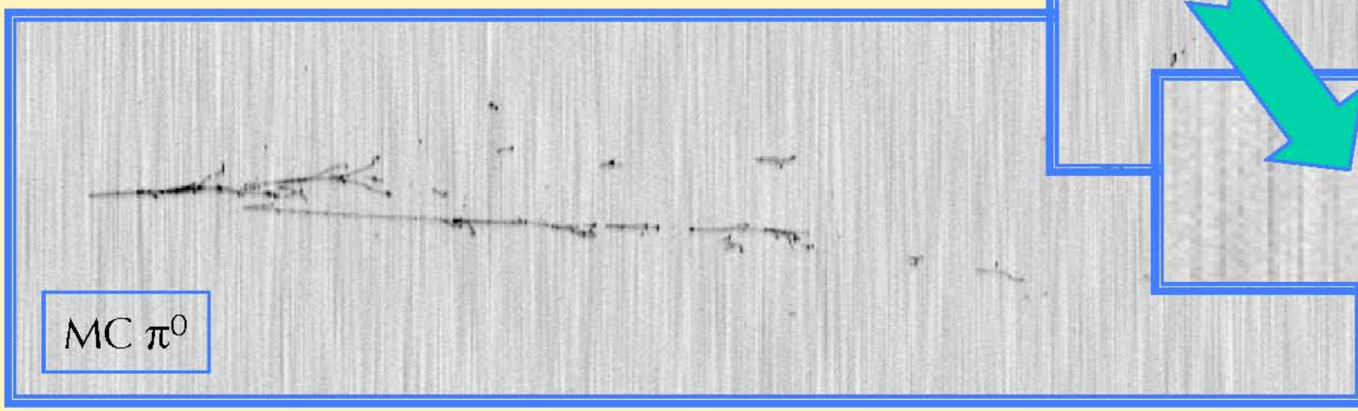
Cherenkov threshold in Water p = 1070 MeV/c

A. Rubbia (Sept. 2005)

Why 2km LAr TPC? (3)

- Exclusive measurement of νNC events with clean π^0 identification for an independent determination of systematic errors on the NC/CC ratio.
- Measurement of the intrinsic ν_eCC background.





When vertex known, combine with probability to convert within 1 cm:

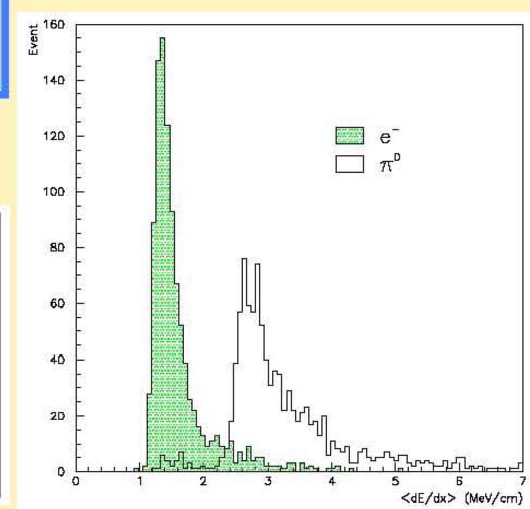
⇒ 5.4%

Combined, aim at:

⇒ 0.2% π^0 efficiency by imaging for 90% electron efficiency

dE/dx cut efficiency:

Energy (GeV)	π^0 efficiency (%)	$< dE/dx >_{cut}$ (MeV/cm)
0.25	6.5	2.13
0.5	5.5	2.19
1	3.7	2.21
2	2.7	2.10



A. Curioni (Aug. 2006)

$\nu_e n \rightarrow p e^- X$ Efficiency ~ 90%

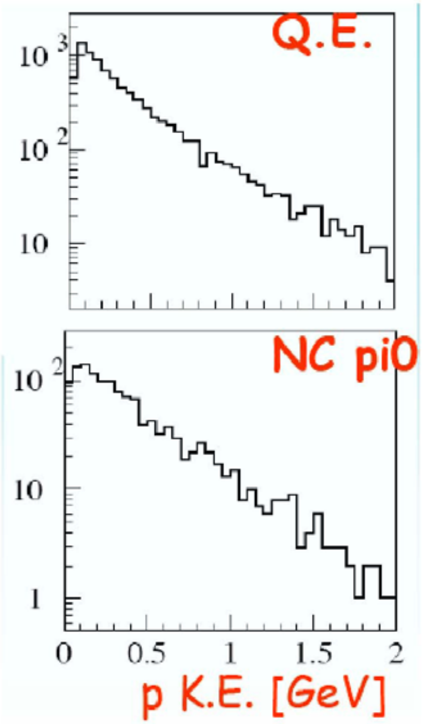
Require E_{proton} > 50 MeV).

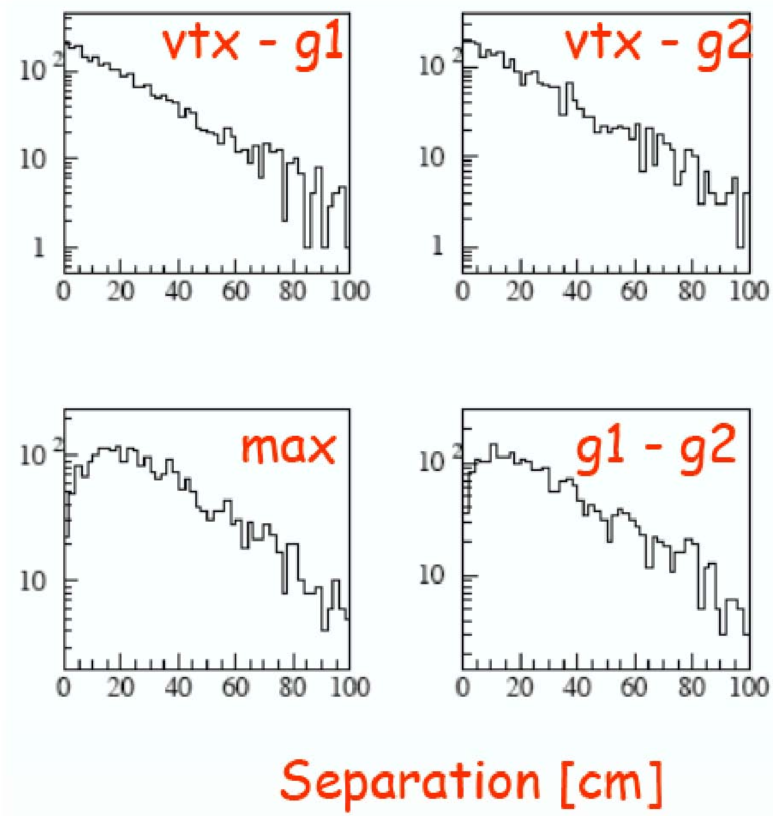
Rejection of $\nu_\mu n(p) \rightarrow n(p)\pi^0 X$ ~ 200:1

Reject whenever one or both γ more than 2 cm from primary vertex (100:1)

Require E_{proton} > 50 MeV (2:1)

[Predictions similar to those of Rubbia group.]





Visual Scan of 450 Monte Carlo Events (2005)

Estimation of Signal Efficiency and Background Rejection for a Liquid Argon Detector in the NuMI Off-Axis Beam

H. Gallagher, B. Bowler, S. Gangotena, A. Hall, W. A. Mann, J. Schneps, A. Para, J. Weiner

May 25, 2005

Abstract

In this note we describe a small study carried out at Tufts University to evaluate the signal efficiency and background rejection capabilities of liquid argon detectors for sub-dominant $\nu_\mu \rightarrow \nu_e$ searches in the NuMI beam. The analysis is based on a blind scan of 450 events.

		N	pass	ϵ	η
NC		290	4	-	73±31
signal ν_e	CC	32	26	0.81±0.07	-
Beam ν_e	CC	24	14	0.58±0.10	-
	NC	8	0	-	/
Beam $\overline{\nu}_e$	CC	13	10	0.77 ± 0.09	-
	NC	19	0	-	/
ν_μ	CC	32	0	-	/
$\overline{\nu}_\mu$	CC	32	1	-	/

$\varepsilon = 81 \pm 7$ % for ν_e appeareance.

Rejection factor = 73 ± 31 for neutral current events with a π^0.

ν_e Charged Current Appearance Events with Clear Electron Showers

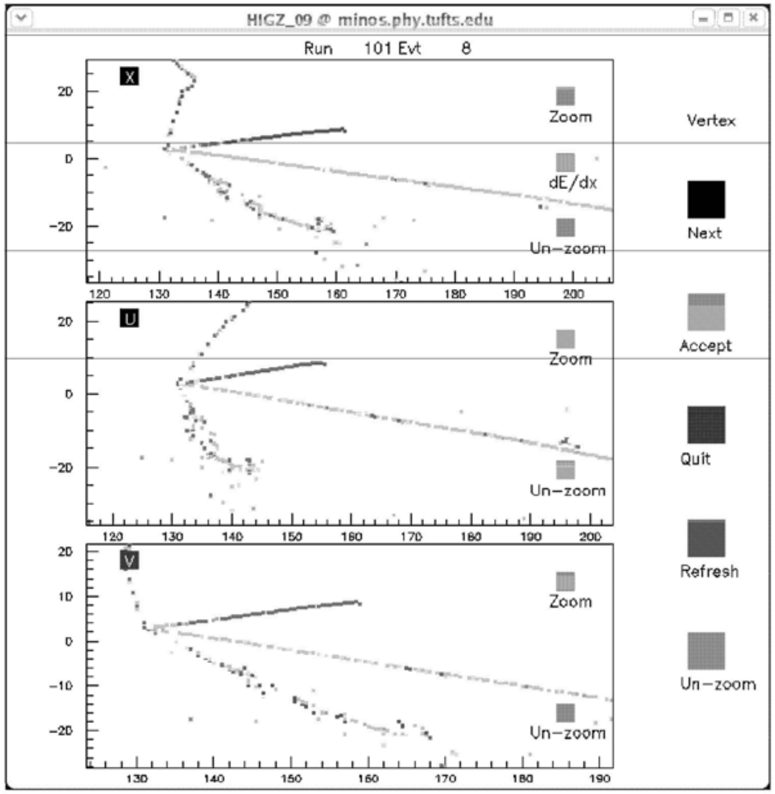


Figure 6: Signal event selected, 2.2 GeV DIS ν_e CC with y=0.89. The electron shower is clearly visible.

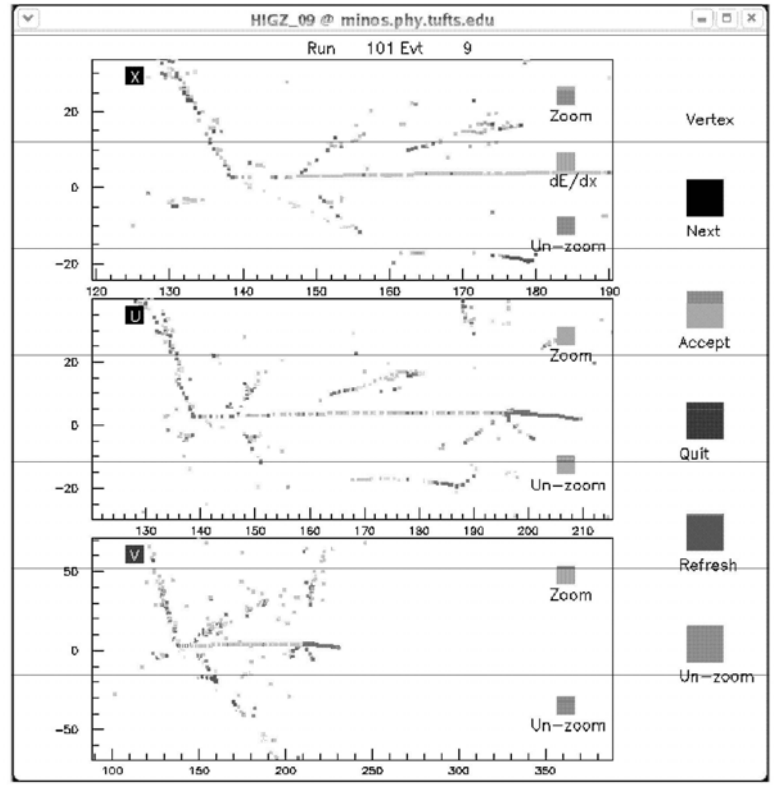


Figure 7: Signal event selected, 2.4 GeV DIS ν_e CC with y=0.87. The electron shower is clearly visible.

ν_e Appearance Events with Poorly Developed Electron Showers

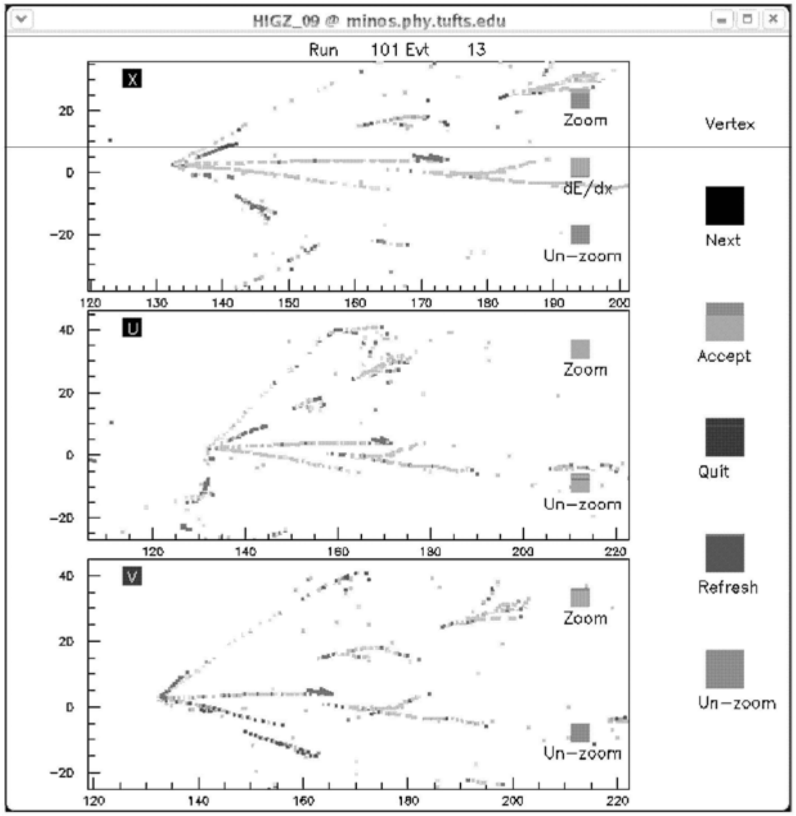


Figure 9: Signal event failing the scan, scored as a "2" and a "1" by the scanners. The event is a 2.3 GeV DIS event with y = 0.88. The electron showers early.

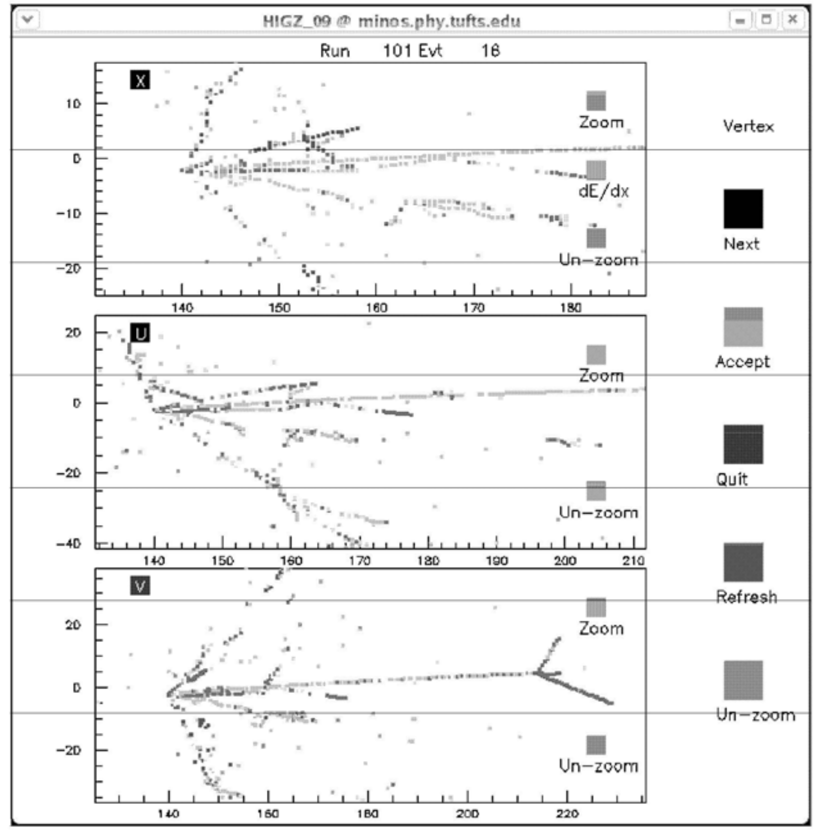


Figure 10: Signal event failing the scan, scored as a "4" and a "2" by the scanners but rejected by the "experts". The event is a 2.3 GeV DIS event with y = 0.87.

ν_μ Charge Current Events with $\pi^0 \to \gamma\gamma$ Showers That Fake an Electron Shower

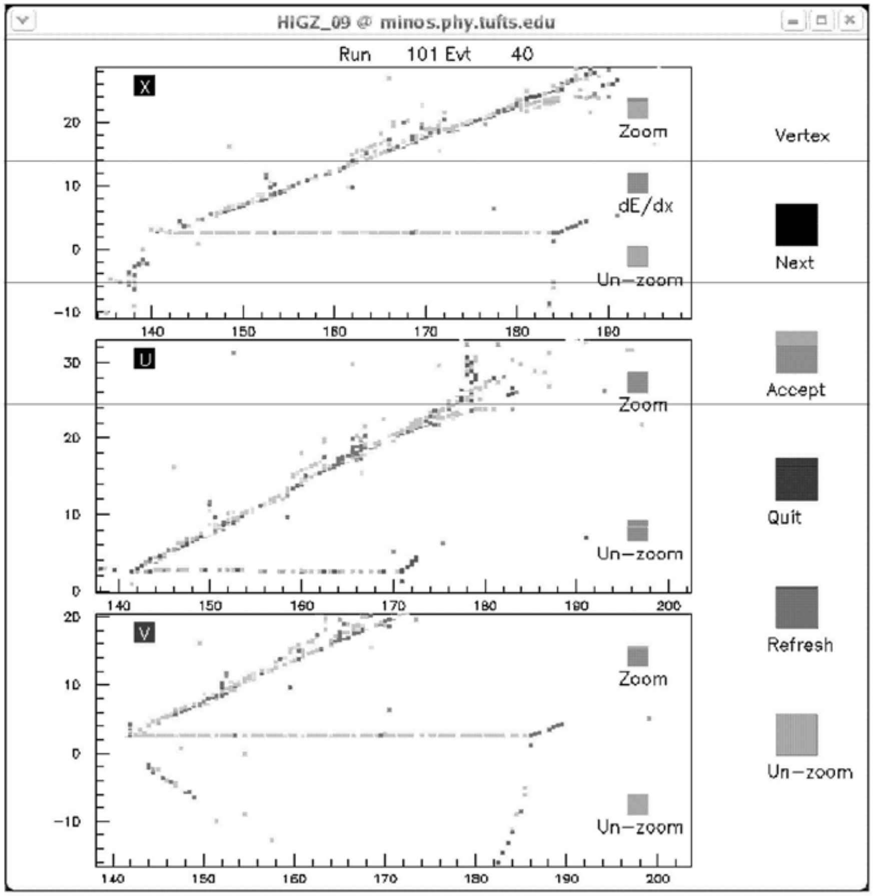


Figure 11: NC event called signal in the scan.

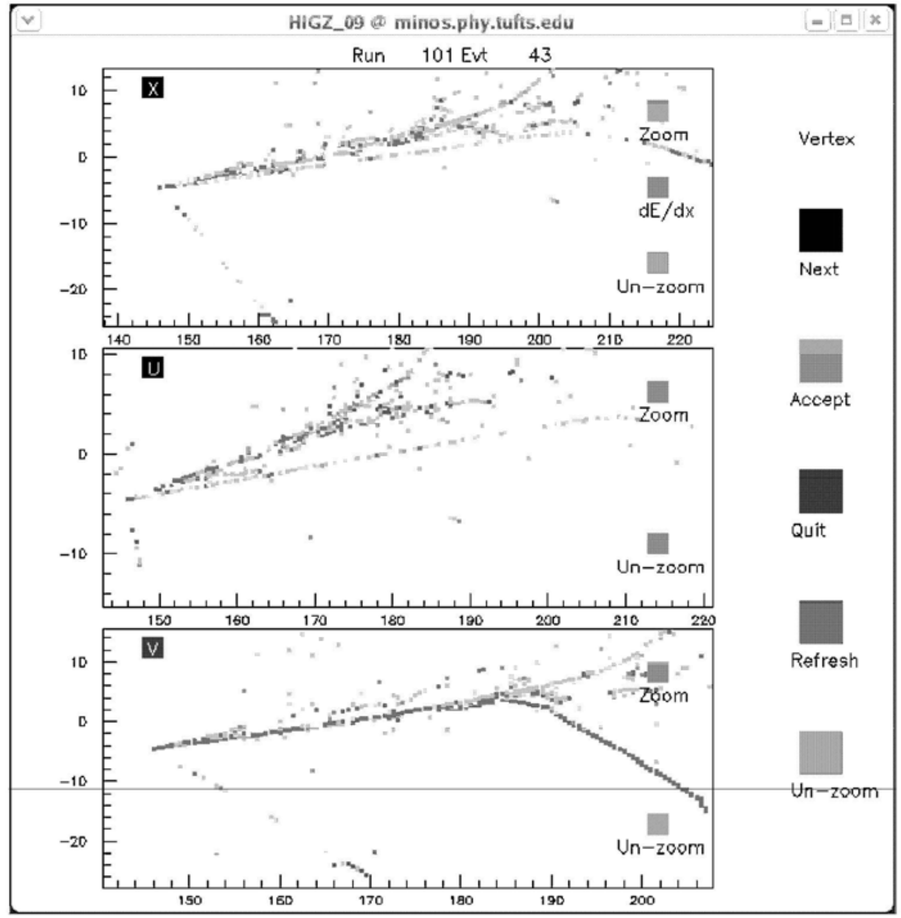


Figure 12: NC event called signal in the scan. Overlapping track and shower are evident

More ν_μ Charge Current Events with $\pi^0 \rightarrow \gamma\gamma$ Showers That Fake an Electron Shower

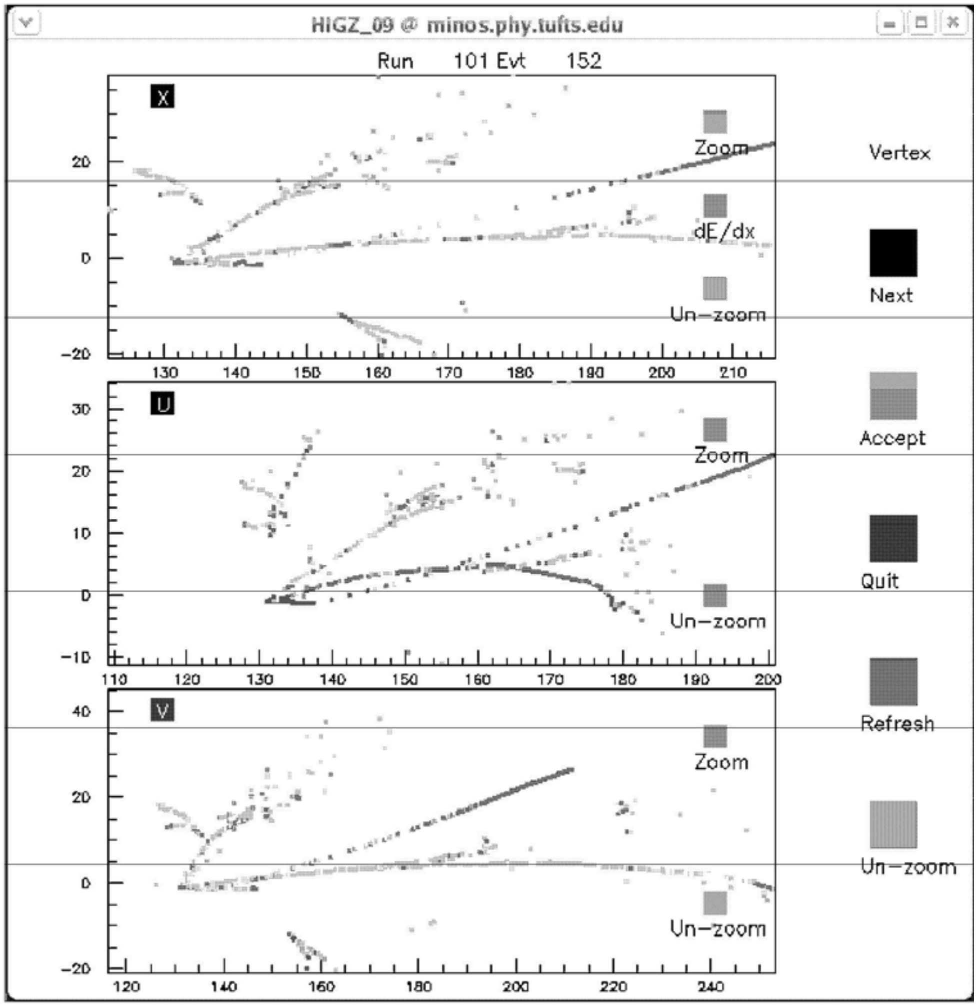


Figure 14: NC event called signal in the scan.

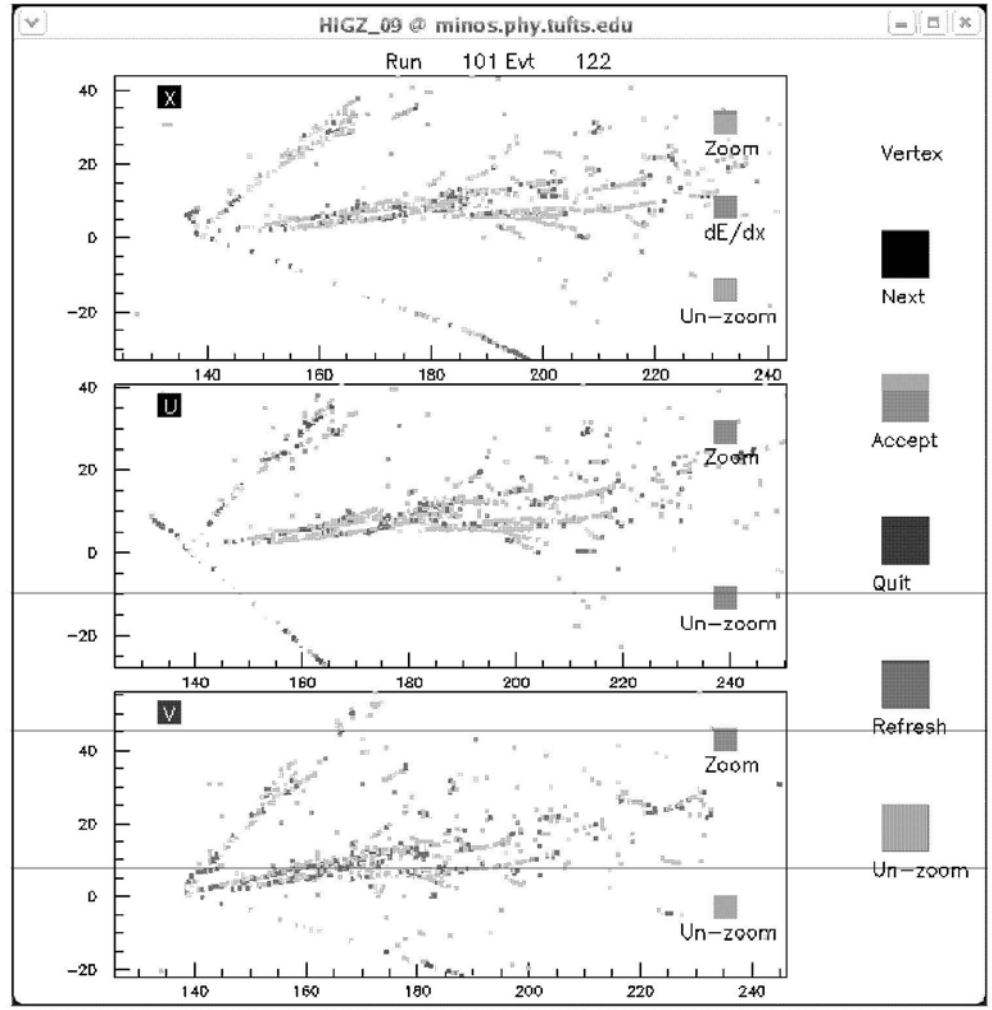
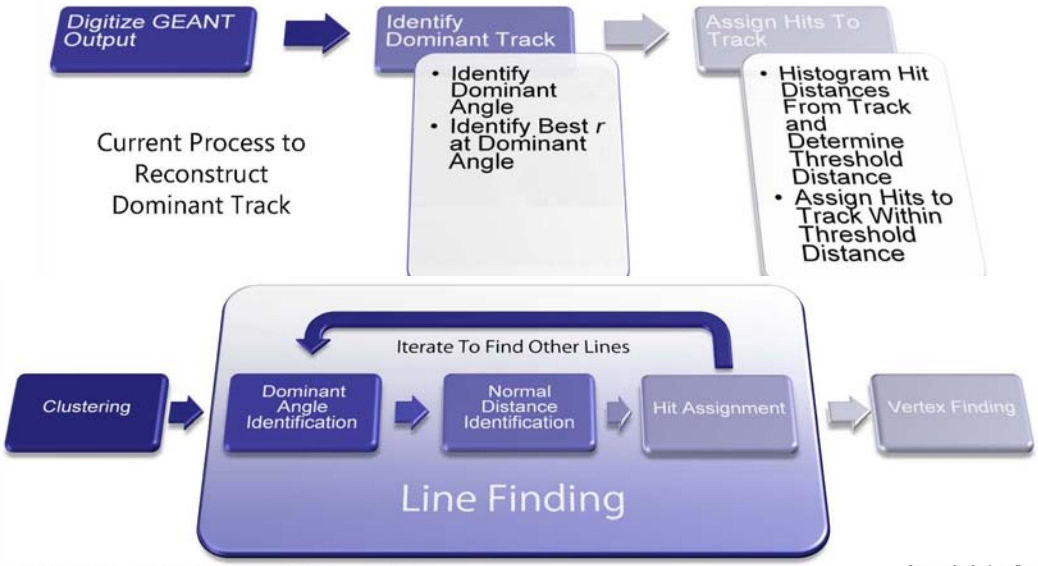


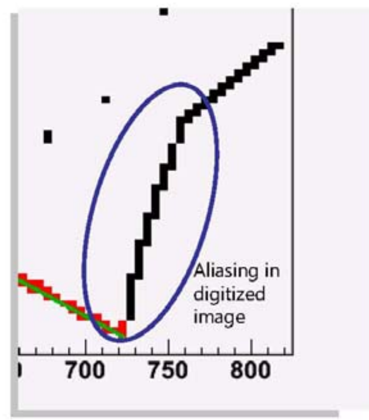
Figure 13: NC event called signal in the scan.

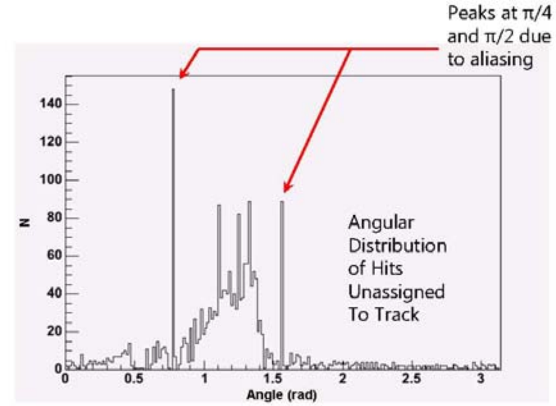
Can Computers Do Better than People?

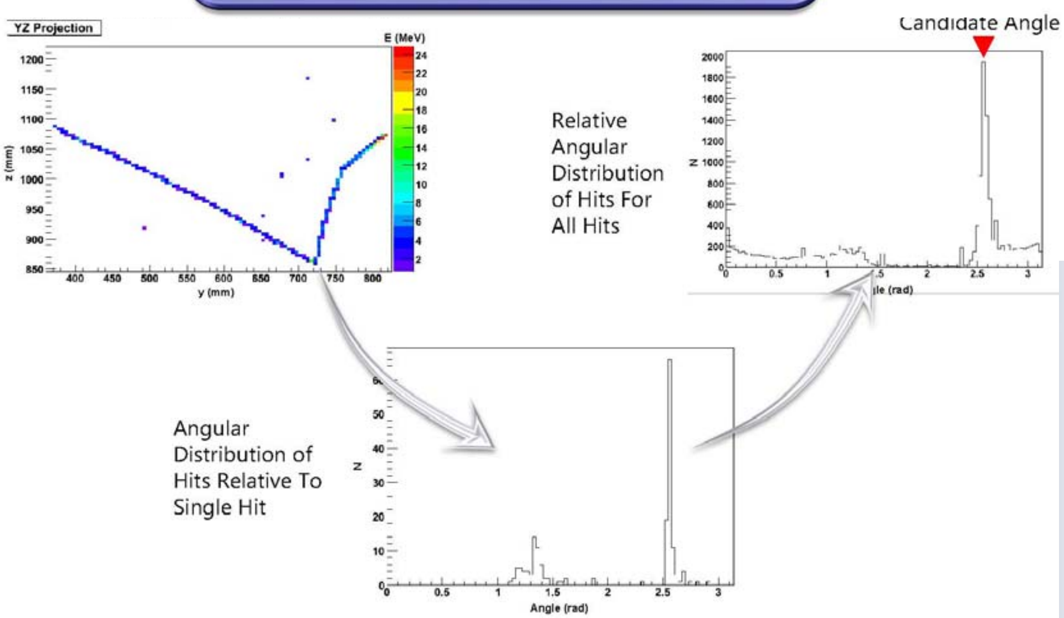
C. Anderson (2006--)



Iterating the process to find the next dominant track is difficult—digitization effects become more prominent with shorter tracks



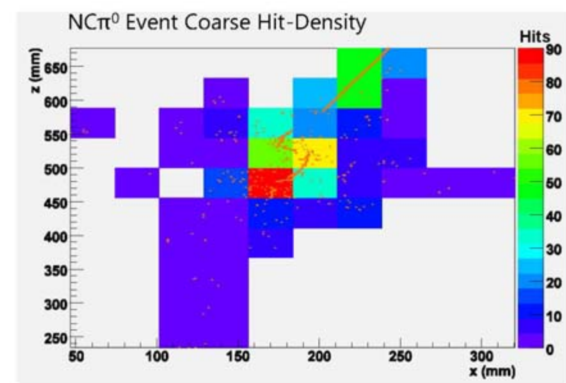




Problem at hand is identifying likely showers

Possible method of identification

- Use a coarse-to-fine grid search to map regions of high hit-density
- Tag clusters in high hit-density region as showers
- Fit clusters to a line to determine axis of shower
- Rotate into shower-axis coordinate system to determine width and length of shower
- Difficulty here is in defining "high" hit-density



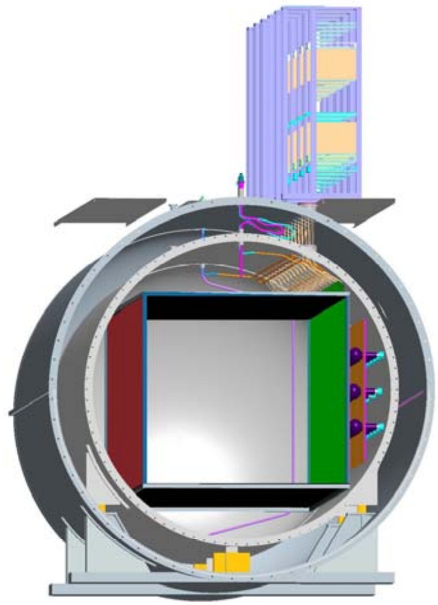
Present and Future Opportunities for Software Development

LAr TPC Hardware R&D Projects:

- Argoneut
- B0

Physics Experiments with LAr TPCs:

- ICARUS
- microBooNE
- T2K 2km Near Detector



LAr TPC event reconstruction is likely beyond the scope of an R&D project.

US effort will likely focus on the microBooNE experiment at Fermilab.

The challenge is significant: no bubble chamber event reconstruction was every fully automated.