# Sudbury Neutrino Observatory

- Physics Motivation and Experimental Approach
- Detector Specifics
- Detector Performance and Data
- Future

Main goal is to study the **Solar Neutrino Problem.**

- Independent methods of measurement of solar neutrino flux all show significant deficit relative to best solar models.
- Deficit appears to have energy dependence

  → Looks like suppression of $^7$Be $\nu$'s
- Neutrino oscillations (perhaps matter-enhanced) may be explanation

  → SuperK results on atmospheric neutrinos show strong evidence for $\nu_\mu \leftrightarrow \nu_\tau$ oscillations.

## → Sudbury Neutrino Observatory

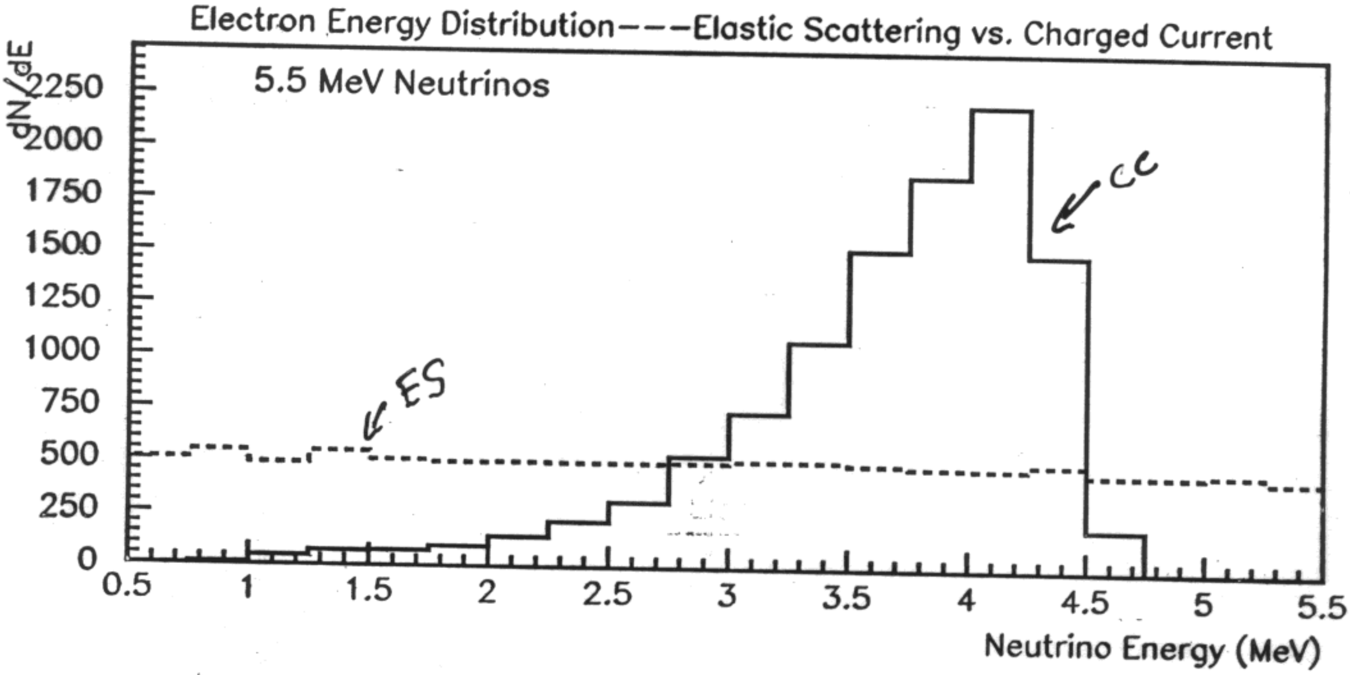
The basic idea for SNO is to use deuterium—in the form of 1000 tons of $D_2O$—as the interaction and detection medium. Solar neutrinos interact in three different ways in the $D_2O$:

- $\nu_e + d \rightarrow p + p + e^-$ (Charged Current—CC)
- $\nu_x + d \rightarrow p + n$ (Neutral Current—NC)
- $\nu_{e,(\mu,\tau)} + e \rightarrow \nu_{e,(\mu,\tau)} + e^-$ (Elastic Scattering — ES)

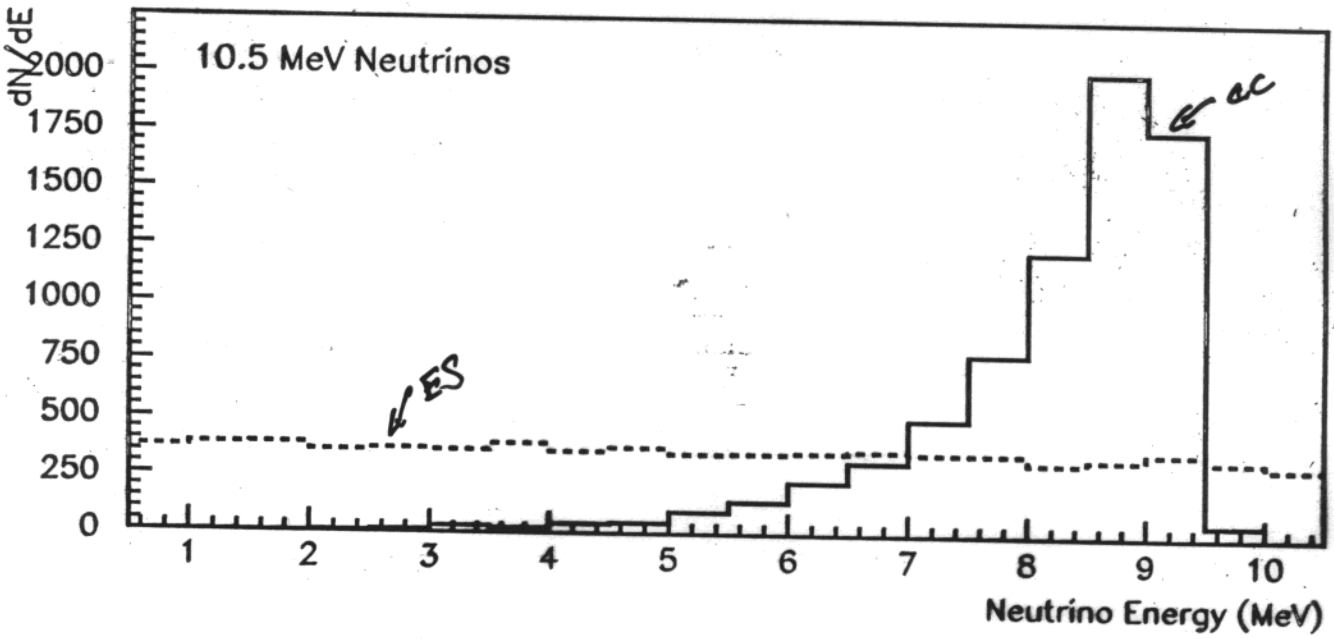
→ CC/NC ratio yields fraction of solar $\nu_e$'s

→ Even more: CC very sensitive measure of $\nu_e$ energy spectrum.

→ AND: Elastic scattering is consistency check.



Electron Energy Distribution---Elastic Scattering vs. Charged Current
dN/dE
5.5 MeV Neutrinos
CC
ES
0 250 500 750 1000 1250 1500 1750 2000 2250
0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5
Neutrino Energy (MeV)

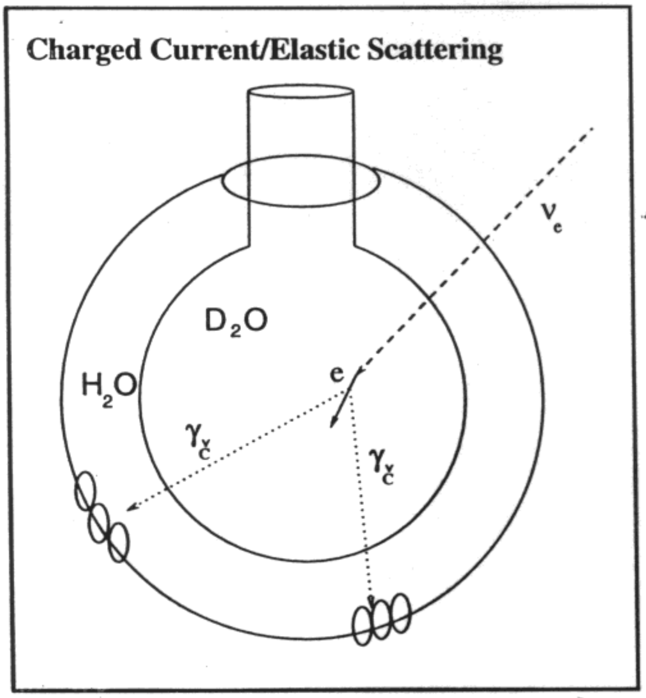
dN/dE
10.5 MeV Neutrinos
CC
ES
0 250 500 750 1000 1250 1500 1750 2000
1 2 3 4 5 6 7 8 9 10
Neutrino Energy (MeV)

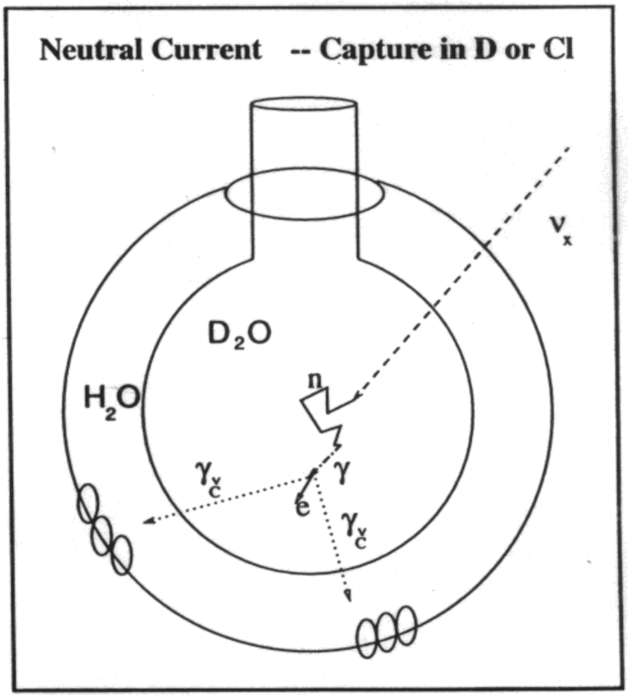
## The SNO Detector

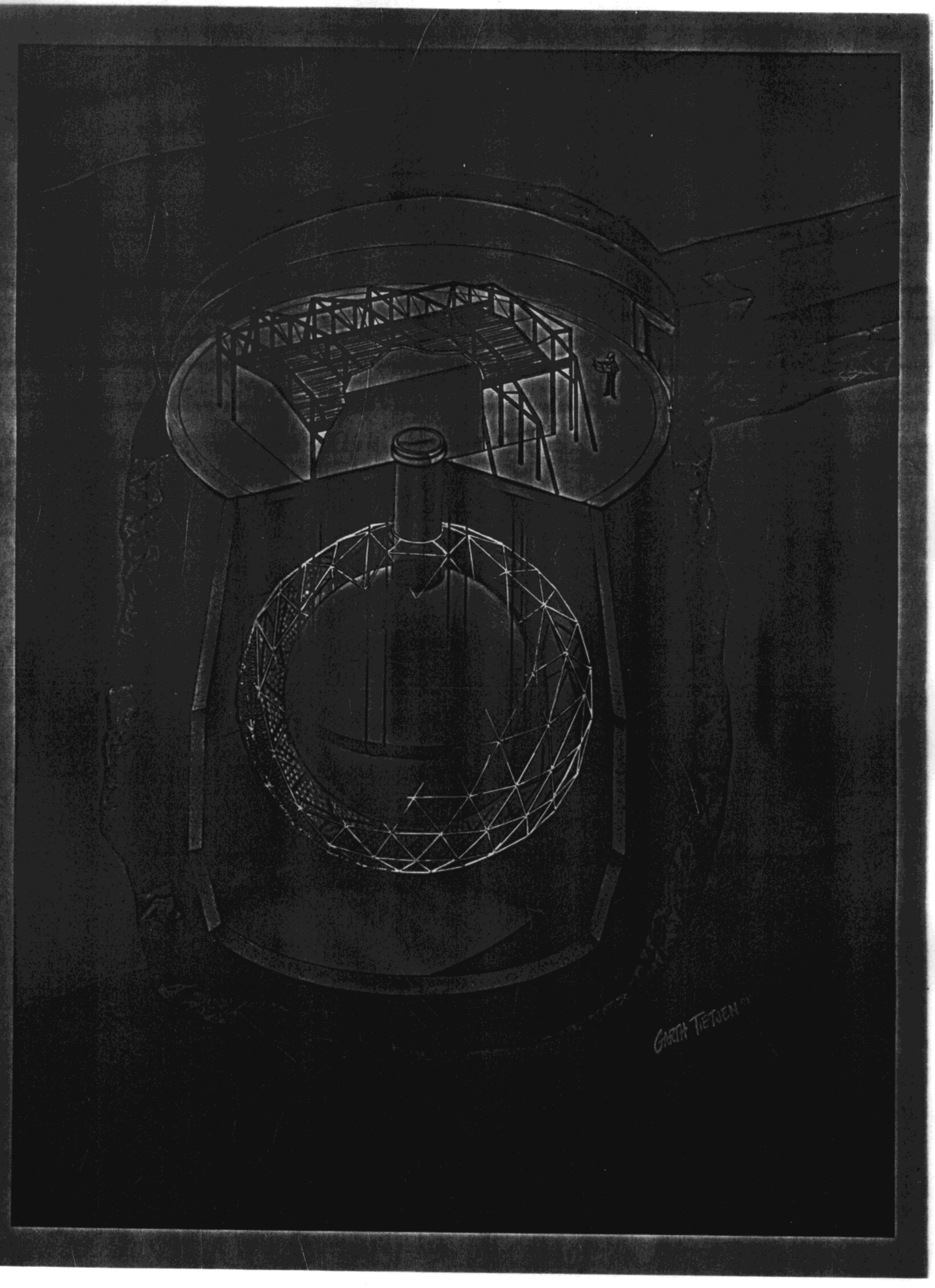
Neutrino Detection Mechanisms:

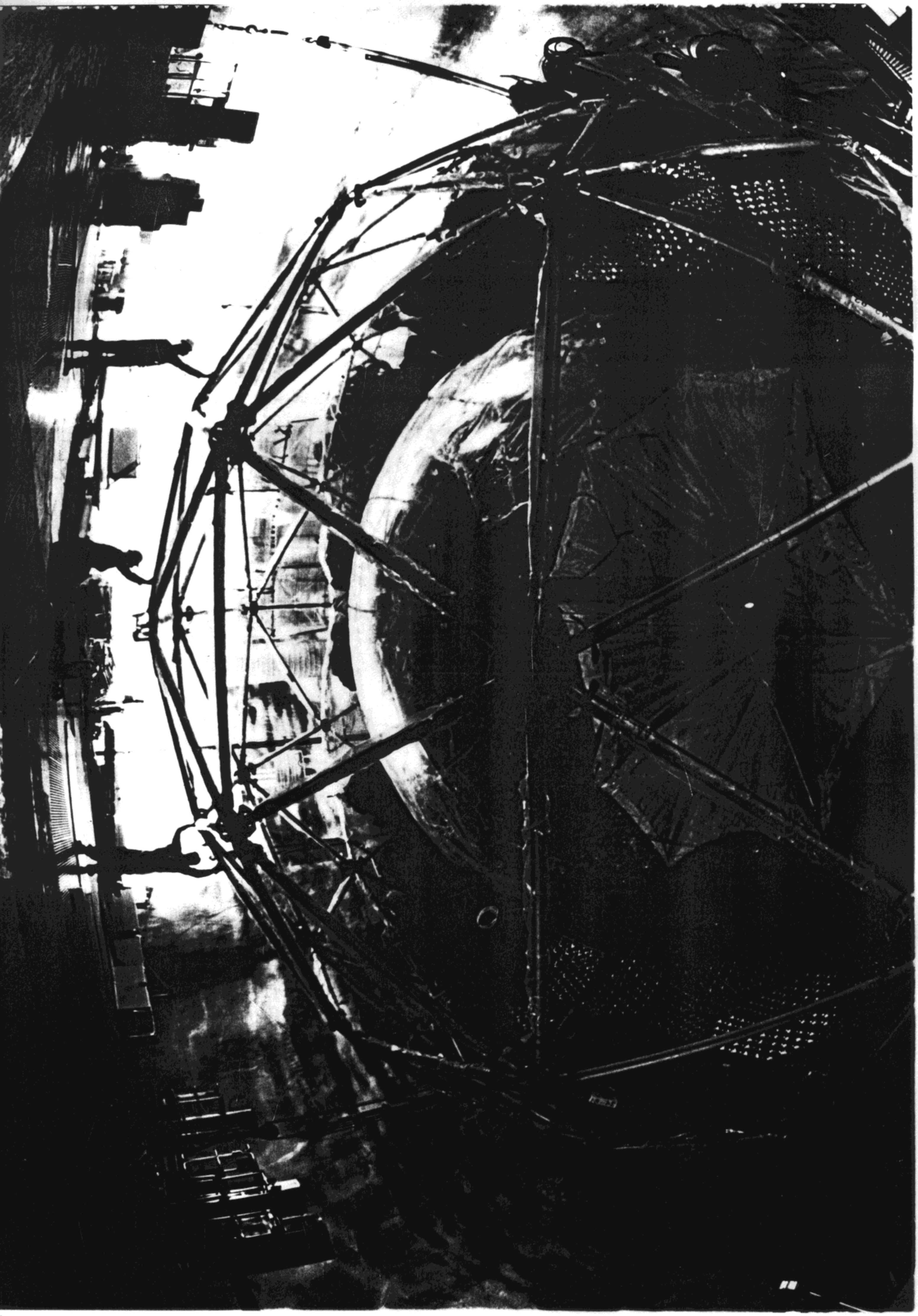
→ Charged Current/Elastic Scattering reactions produce relativistic electron directly

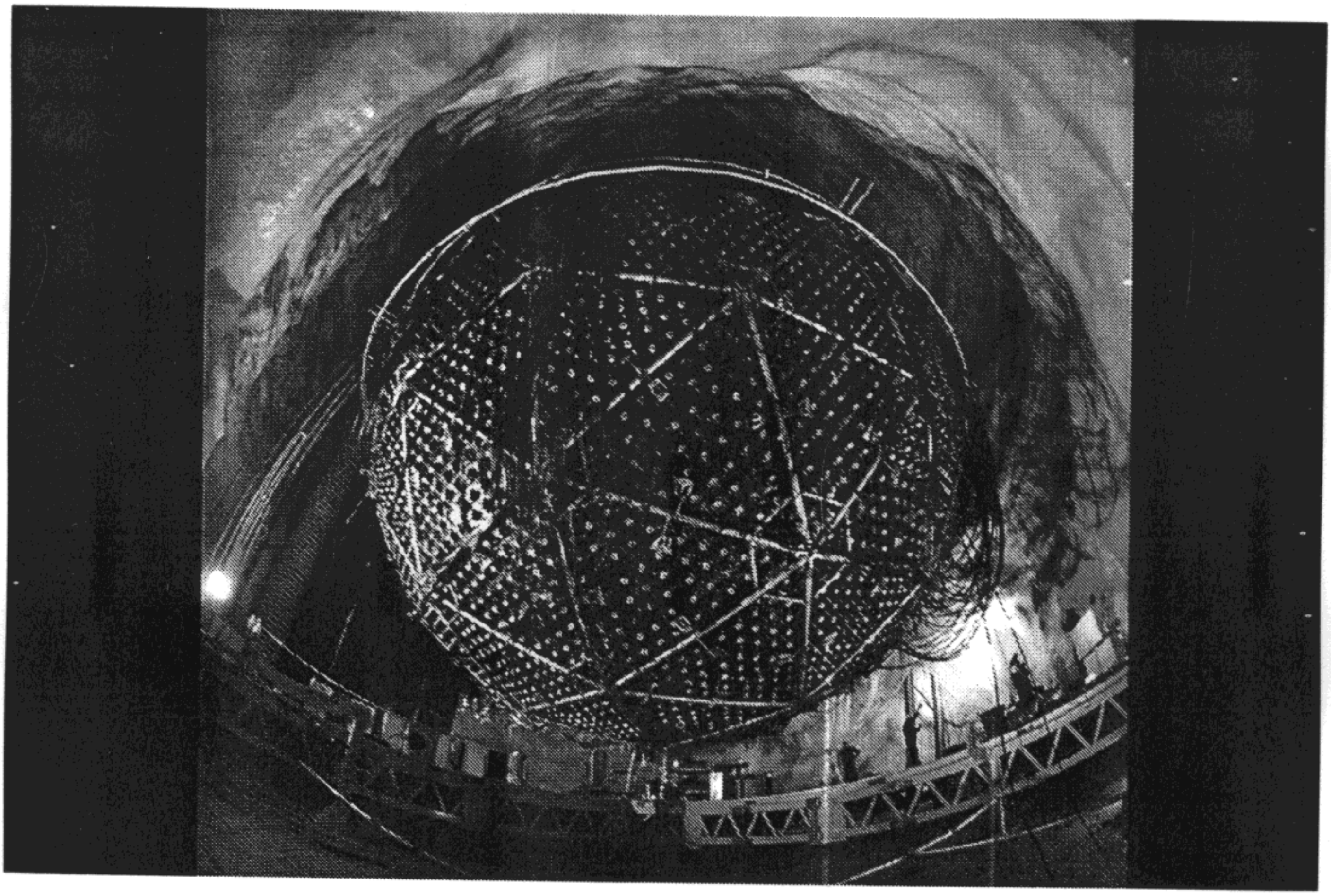
→ Neutral Current frees a neutron; detectable either with capture in $D_2O$ or Cl additive, or with $He^3$ proportional counters

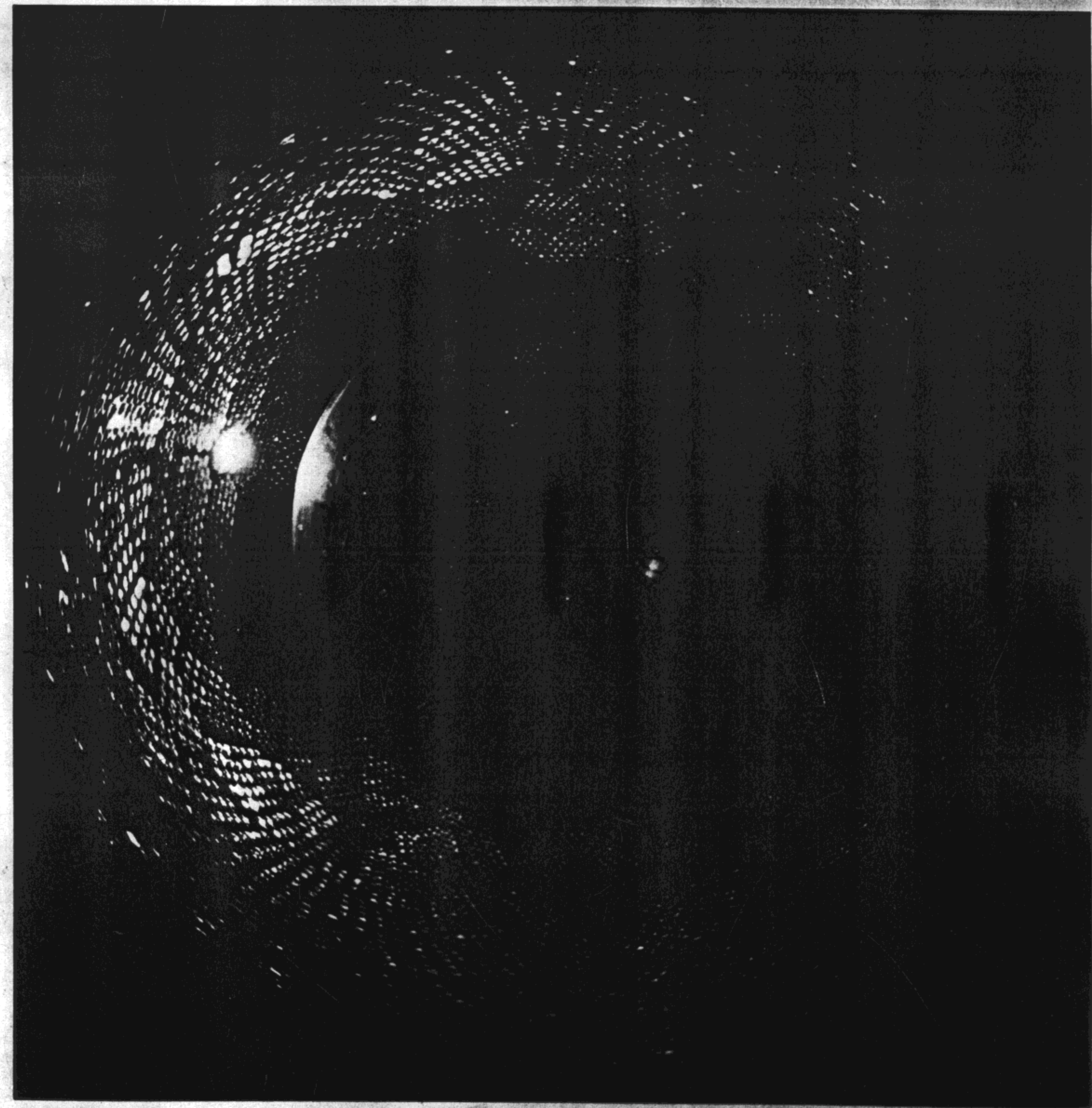



GARTH TIETJEN







# THE SNO COLLABORATION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November 30, 1998

As in any neutrino experiment, the reduction of backgrounds drives the design of the detector.

Expected signal strength for SNO (assuming flux reduced Standard Solar Model):

- Neutral Current = $\sim 3$ events/day
- Charged Current = $\sim 9$ events/day
- Elastic Scattering = $\sim 1$ event/day

→ Typical event has only 50 detected photons.

## Suppression of Physics Background

- **Cosmic Rays** — High energy events + spallation products

  → Detector is located 2 km (~ 6 km.w.e.) underground

- **Cavity wall radioactivity** Neutrons and high energy $\gamma$'s

  → Light water shields active volume

- **Phototube Radioactivity**

  → Custom made Schott glass has 5 times lower radioactivity than standard phototube glass.

  → Light water shield extends 2.5 meters between $D_2O$ and phototubes.

- $D_2O$ **Vessel**

  → Vessel (12 m diameter) constructed out of very low radioactivity acrylic and glue.

- $D_2O$ **and** $H_2O$

  → Uranium and Thorium are greatest danger (and found in mine dust).

  → Operate entire underground laboratory as a full clean room.

  → Continually purify water with hyperfiltration and reverse osmosis techniques.

## Rejection of Backgrounds

- **Energy** — Radioactive backgrounds are below energy regime where neutrinos interact.
- **Charge** — Phototube charge measurements allow identification of anomalous events.

  → In general expect only 1 photon/PMT
- **Reconstruction** — Event position and direction.

  → Requires high precision phototube timing measurements

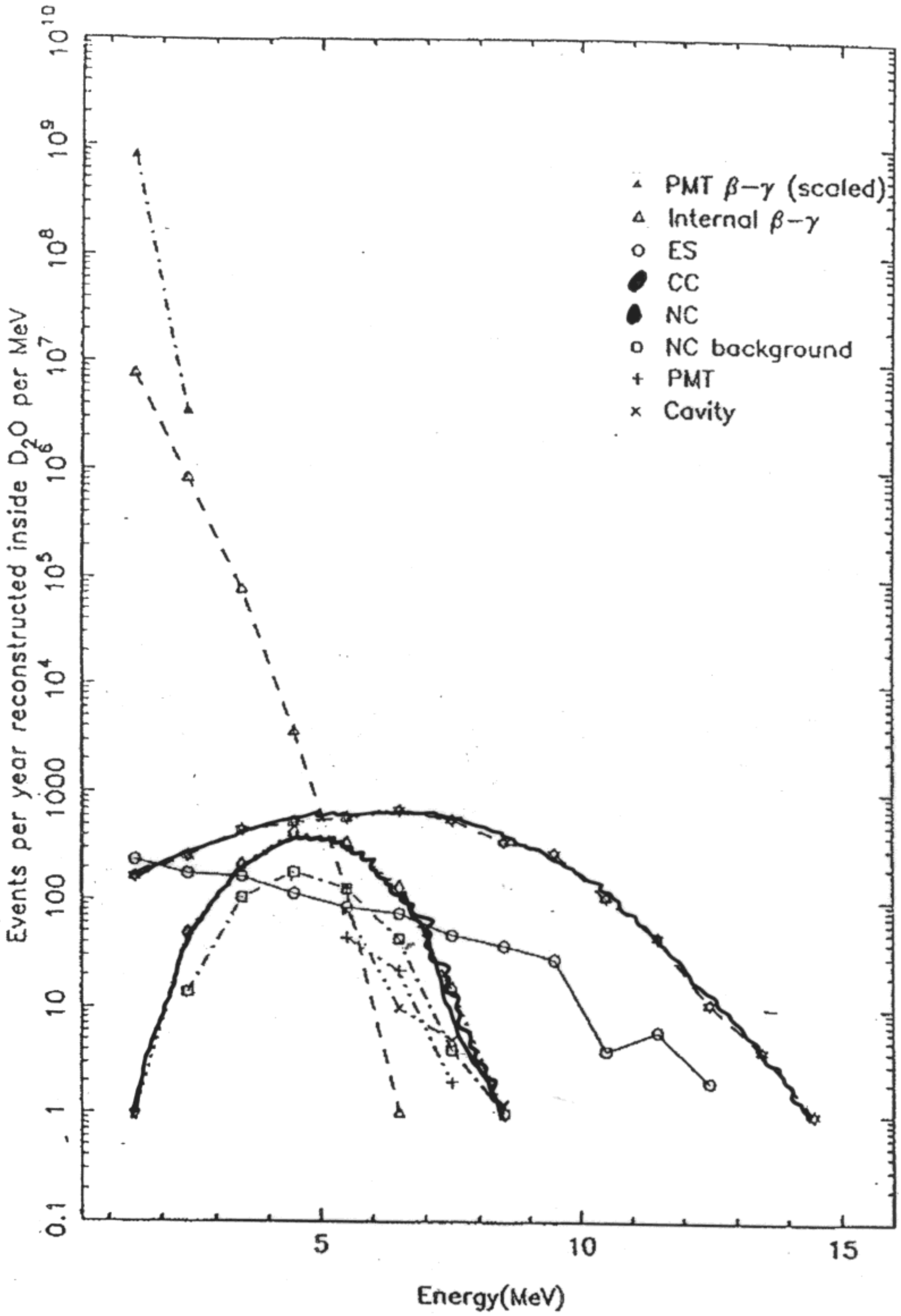
  → Charge-dependent timing correction requires high precision charge measurement ($<1$ photo-electron)

  → Elastic Scattering reaction produces forward-scattered electron

  → Charged current reaction produces angular distribution that falls as $1-\frac{1}{3}\cos\theta$.

# Expected SNO Signals

Monte Carlo



## Detector Specifics

- $\sim$ **9500 phototubes** (PMTs) + concentrators provide $\sim$ 60% coverage
- **Electronics**:

  → Three charge measurements for dynamic range of 0.05 – 3000 photoelectrons

  → PMT timing resolution of $\sim$ 120 ps

  → Million event buffer

  → Burst capability up to $\sim$ 2 MHz (deadtime $< 10^{-6}$)

  → Absolute time (GPS) for each event good to $\sim$ 300 ns
- **Trigger**

  → Primary signal is analog sum of all 9500 channels, each tube gets the same weighting ('NHIT' trigger)

  → Analog sum of 9500 shaped PMT pulses gives greater weighting to greater PMT energy—good monitor of entire detector ('ESUM' trigger)

  → Prescaled low NHIT trigger + zero bias pulsed trigger allow continuous measurement of low energy backgrounds and noise
- **Water**

  → Recirculation/purification to maintain low backgrounds

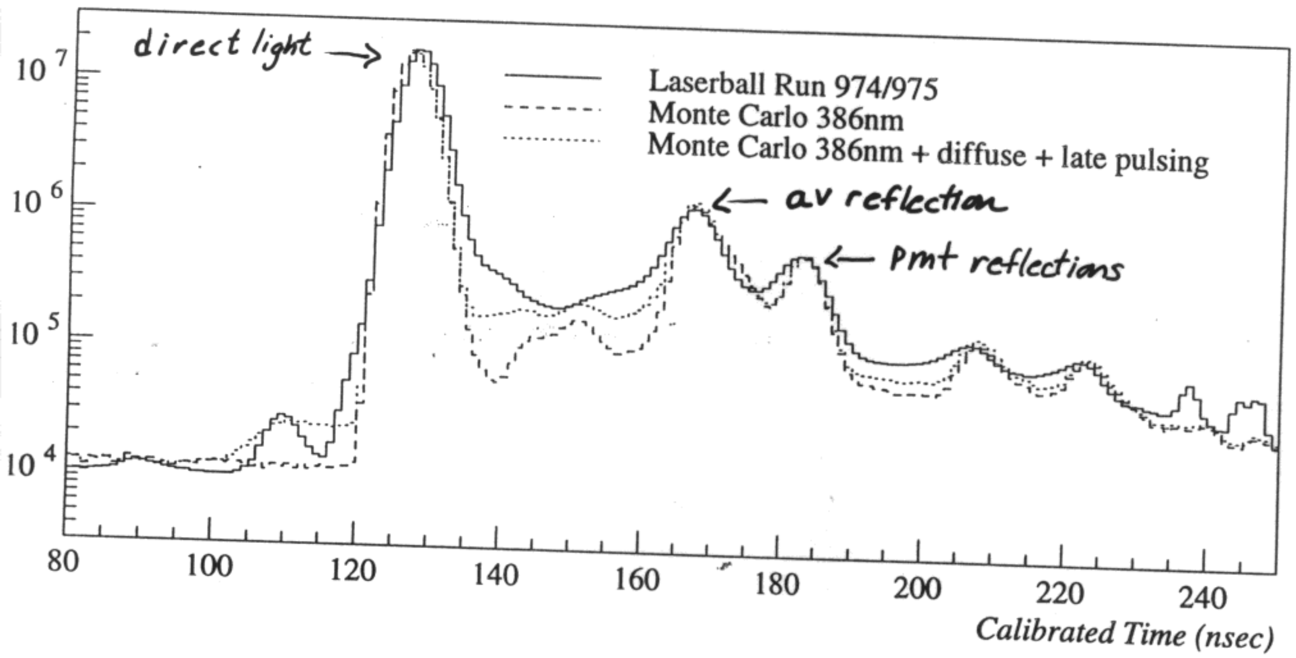
  → Periodic assays to determine radioactive contamination

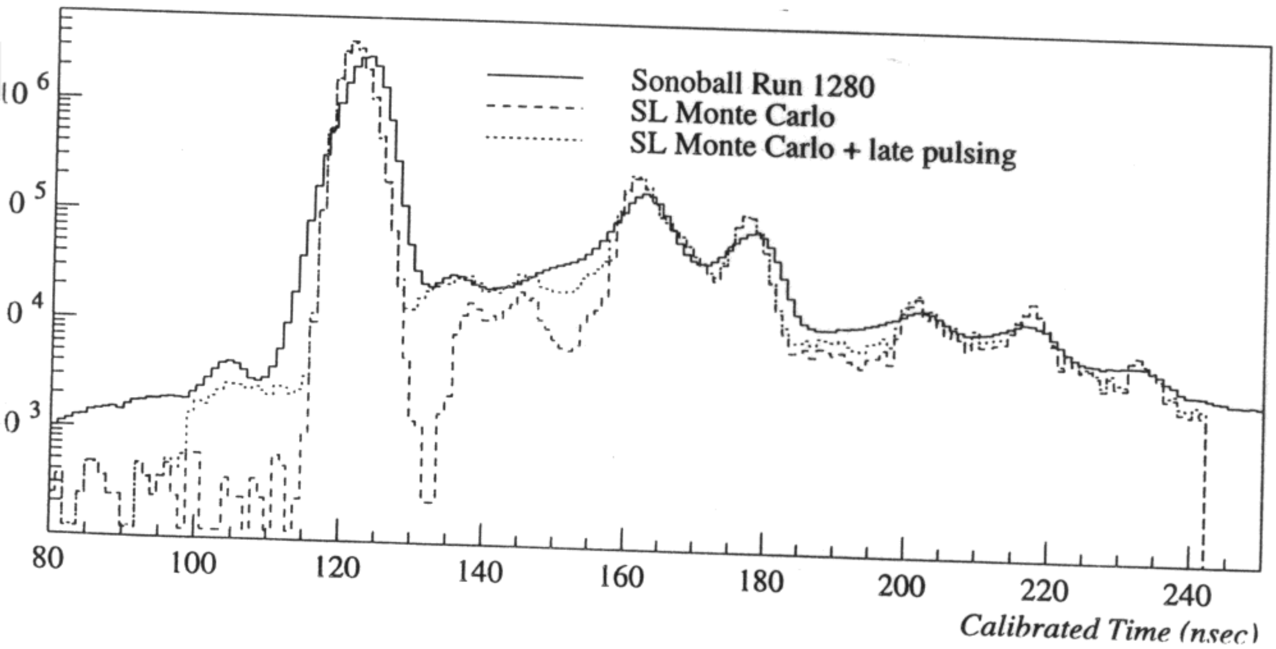
**NHIT** $\equiv$ # hit phototubes $\propto$ **Energy**

## Detector Calibrations

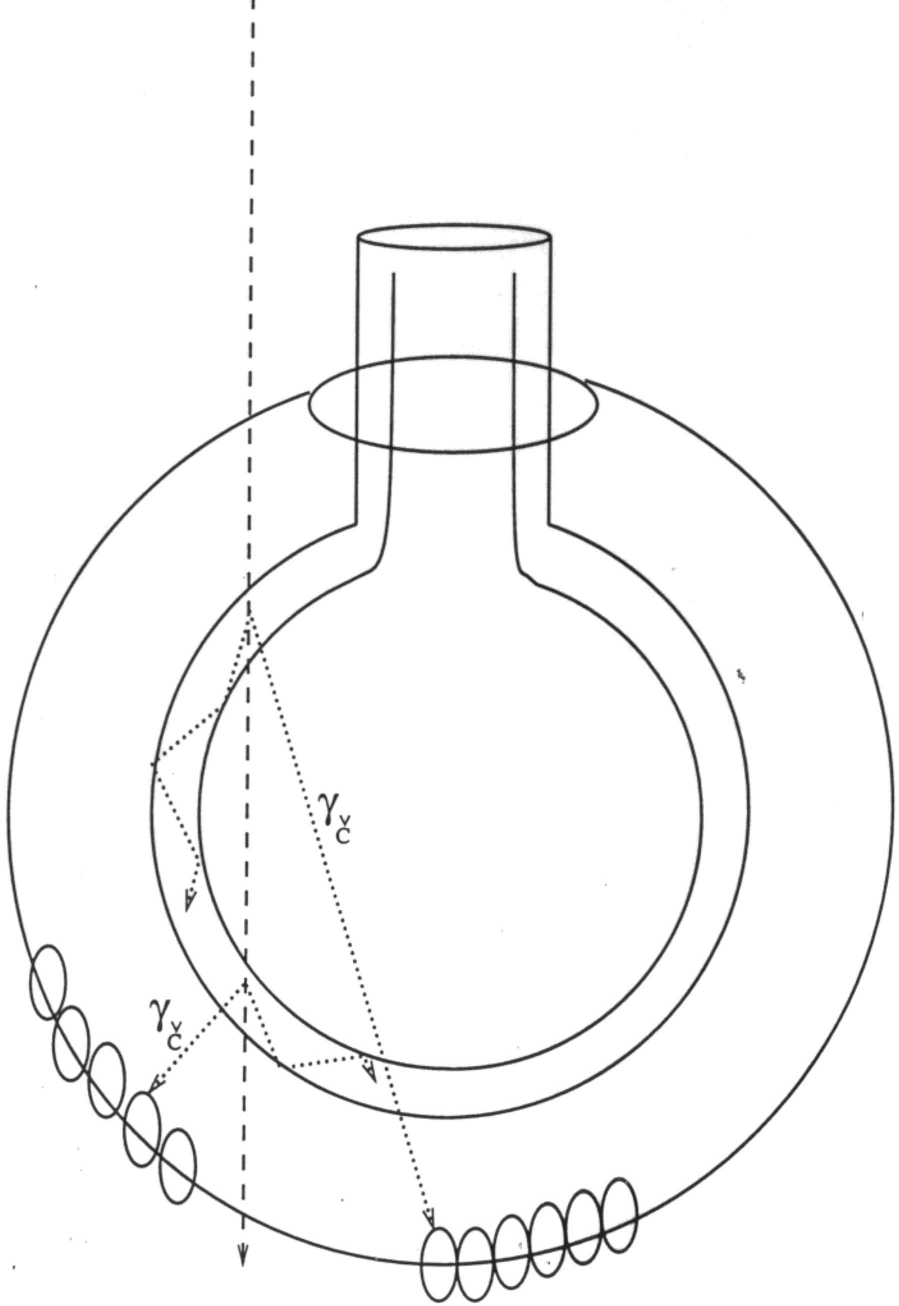
- **Optical Calibrations** — Determine reflectivity and absorption of detector components to fully model detector behavior
  - → Laser (with diffuser)
  - → LED (480 nm)
  - → *Sonoluminescent* source
- **Energy Calibrations** — Determine energy scale (tubes/MeV) and resolution
  - → $^{16}$N (6 MeV $\gamma$)
  - → pT source — $^{3}$H$(p,\gamma)^{4}$He (19.8 MeV $\gamma$)
  - → $^{8}$Li (spectrum)
- **Reconstruction** — Determine position and angular resolution and efficiency
  - → Laser, sono
  - → $^{16}$N

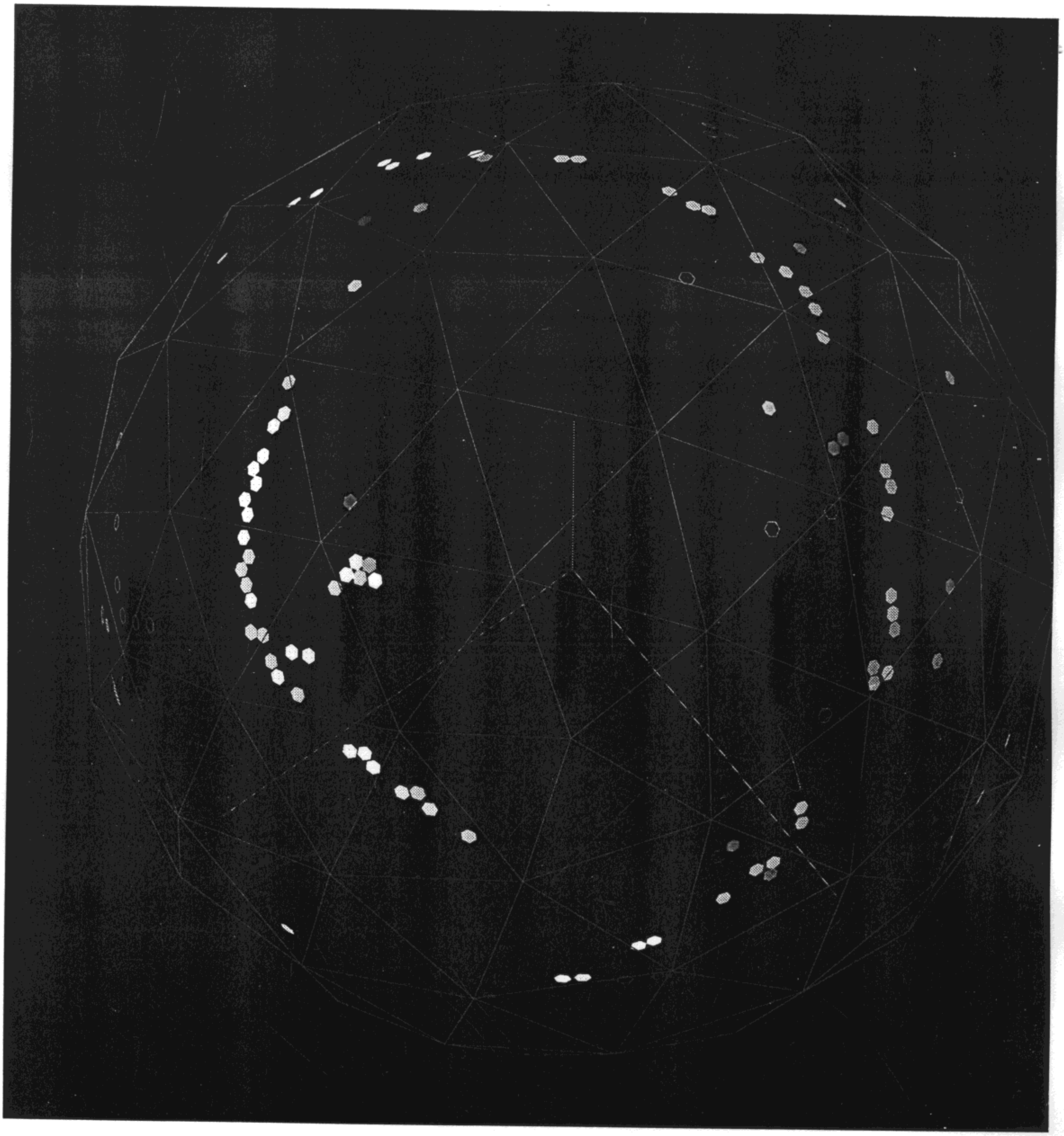
Ford / McDonald / Wark
Penn / Queens / Oxford



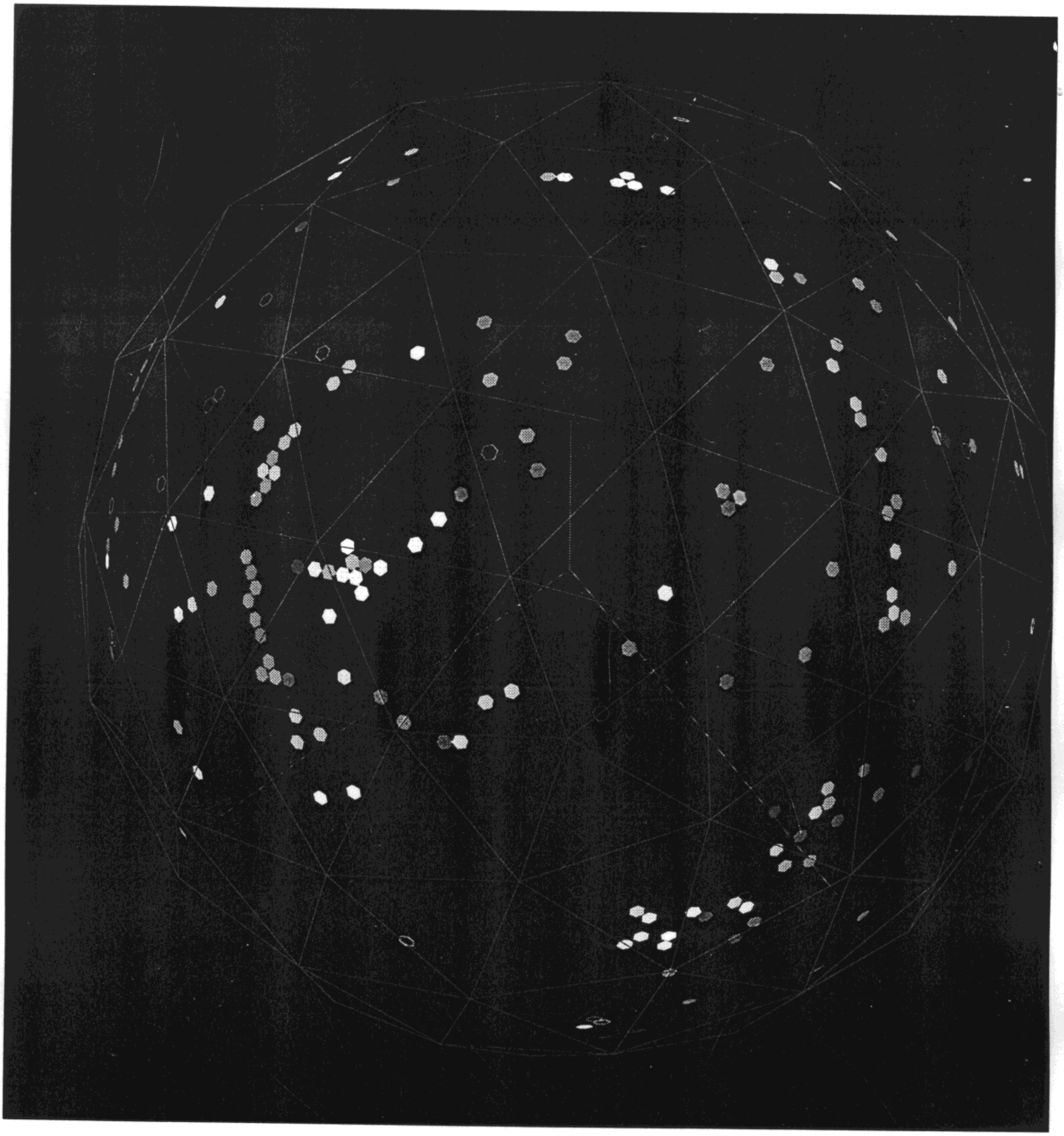
## $\mu$ Interaction (Air Fill)





Monte Carlo (air)

Brice, LANL



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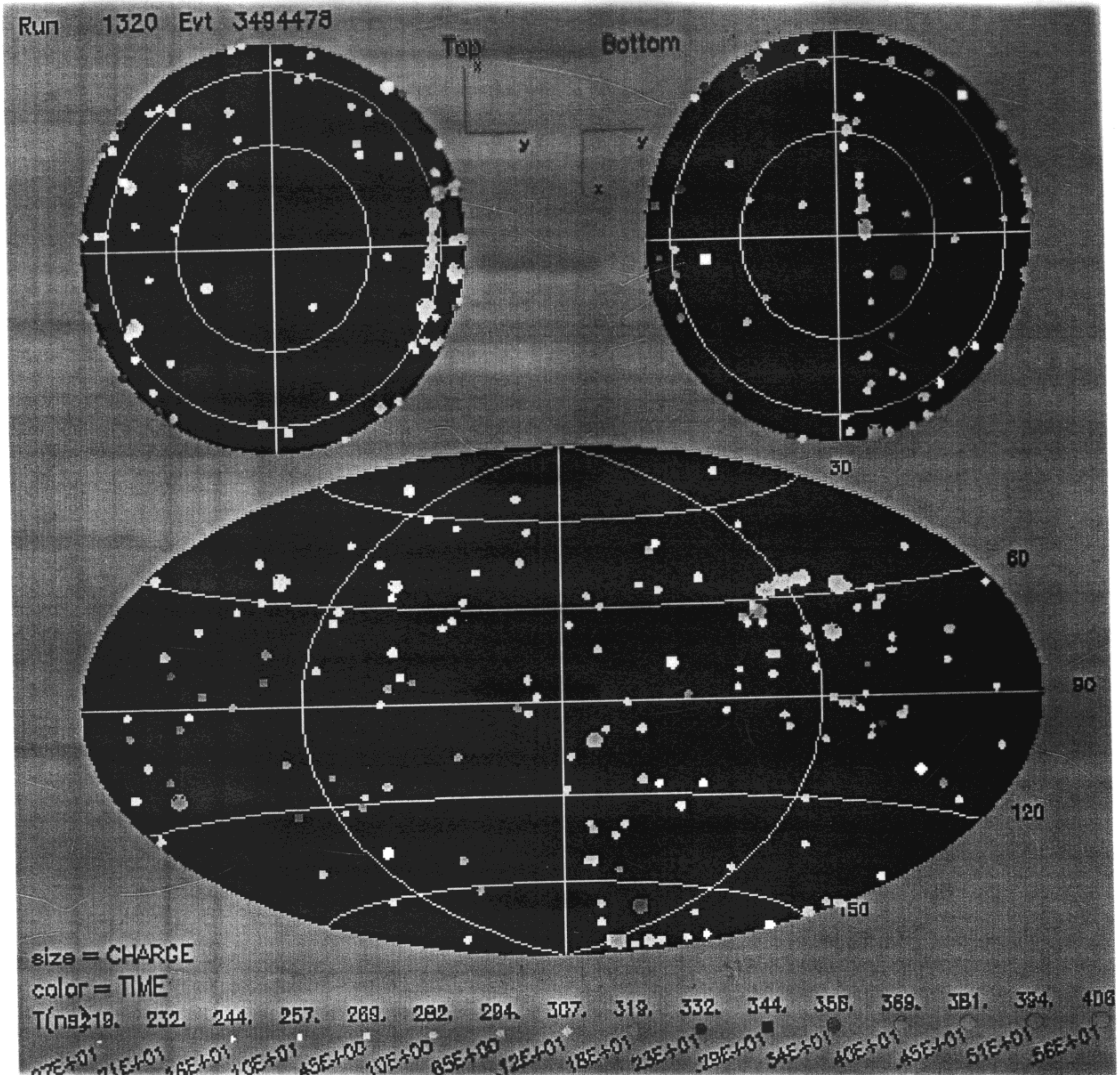
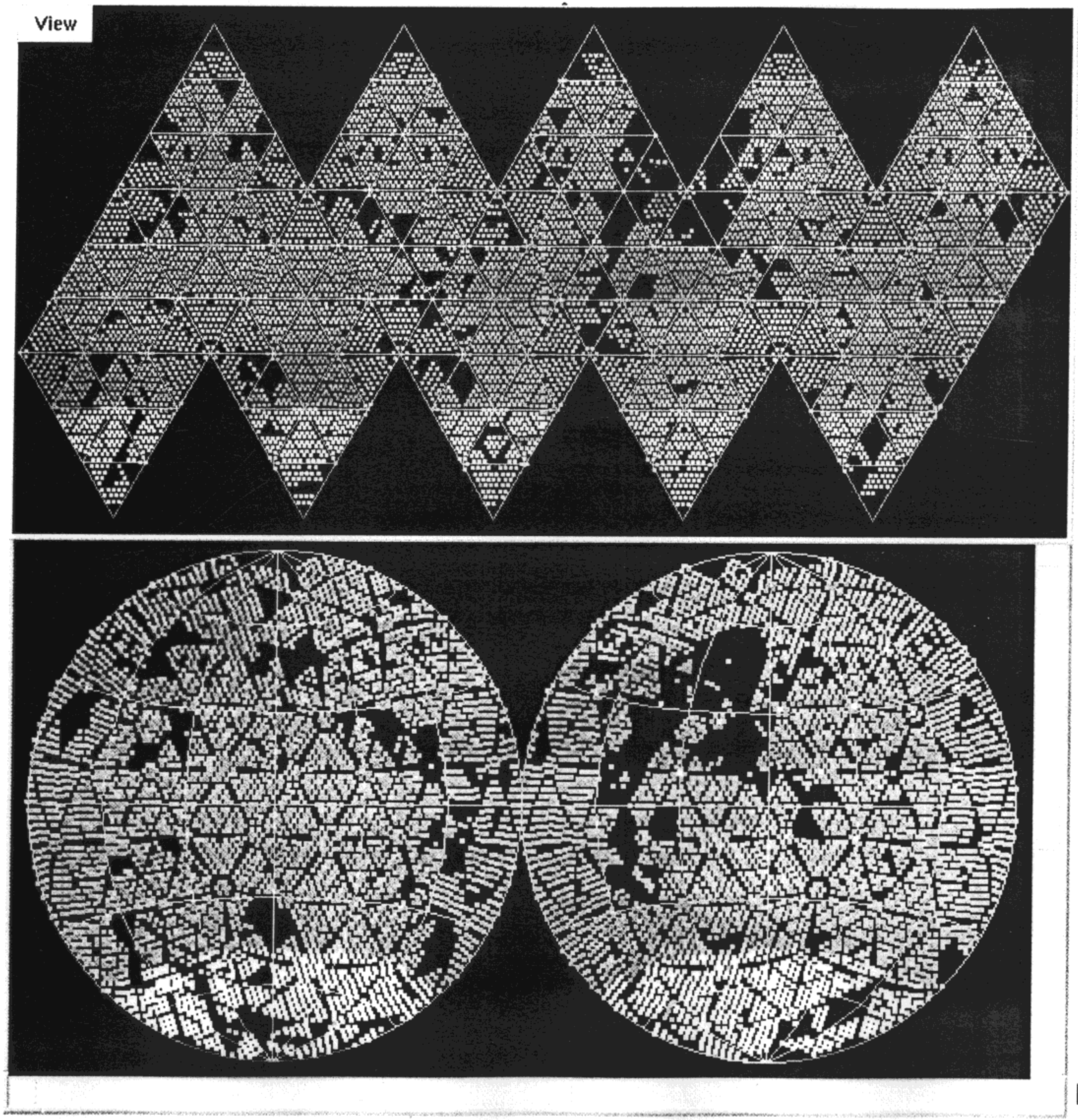
Brice WANG (air data)

Okada event $\theta_t \simeq 85°$ $d_{\oplus} \cong 65$ km

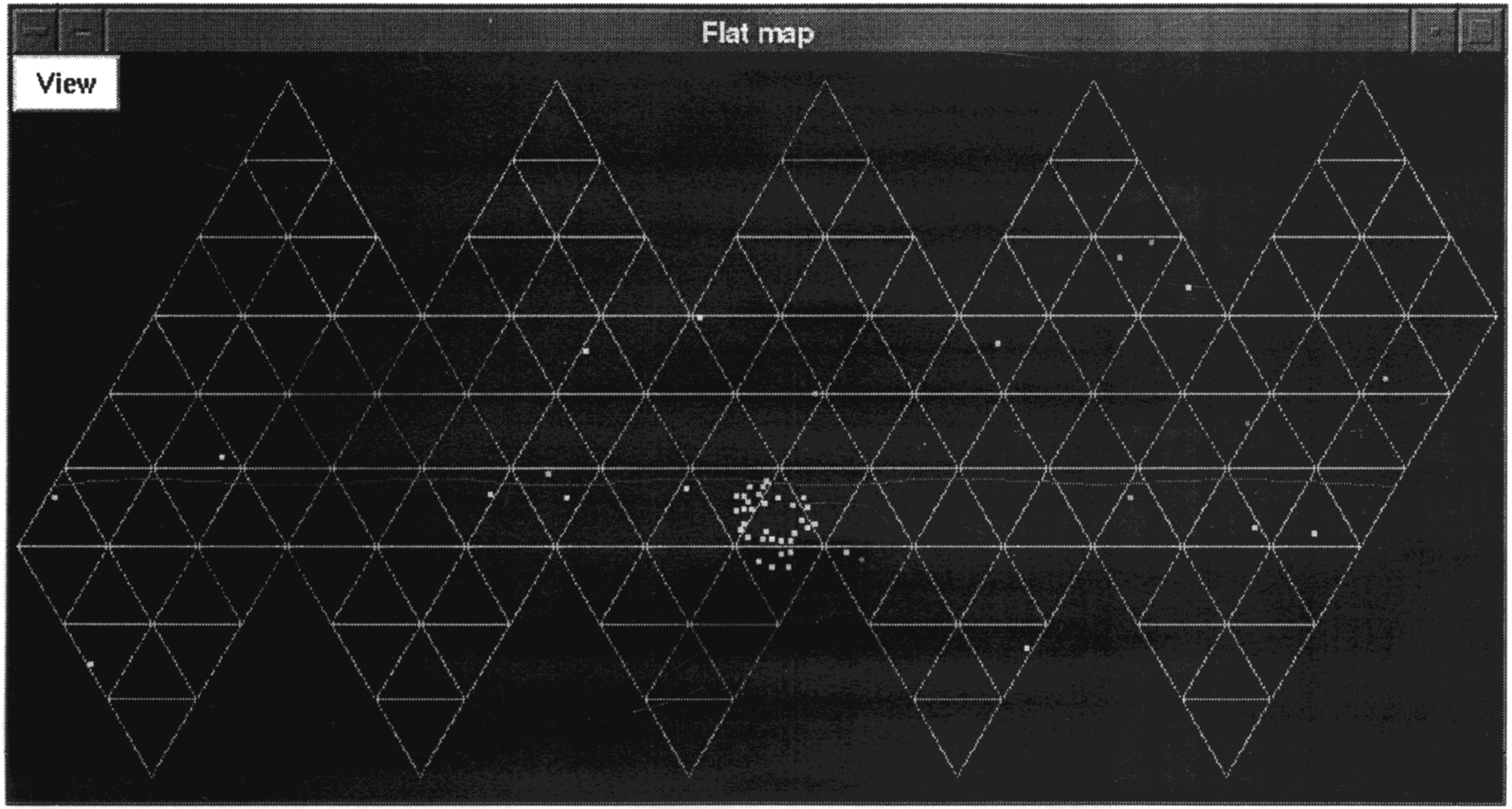



Okada, LBL




Wittich,
Seifert

Neutrino Observatory

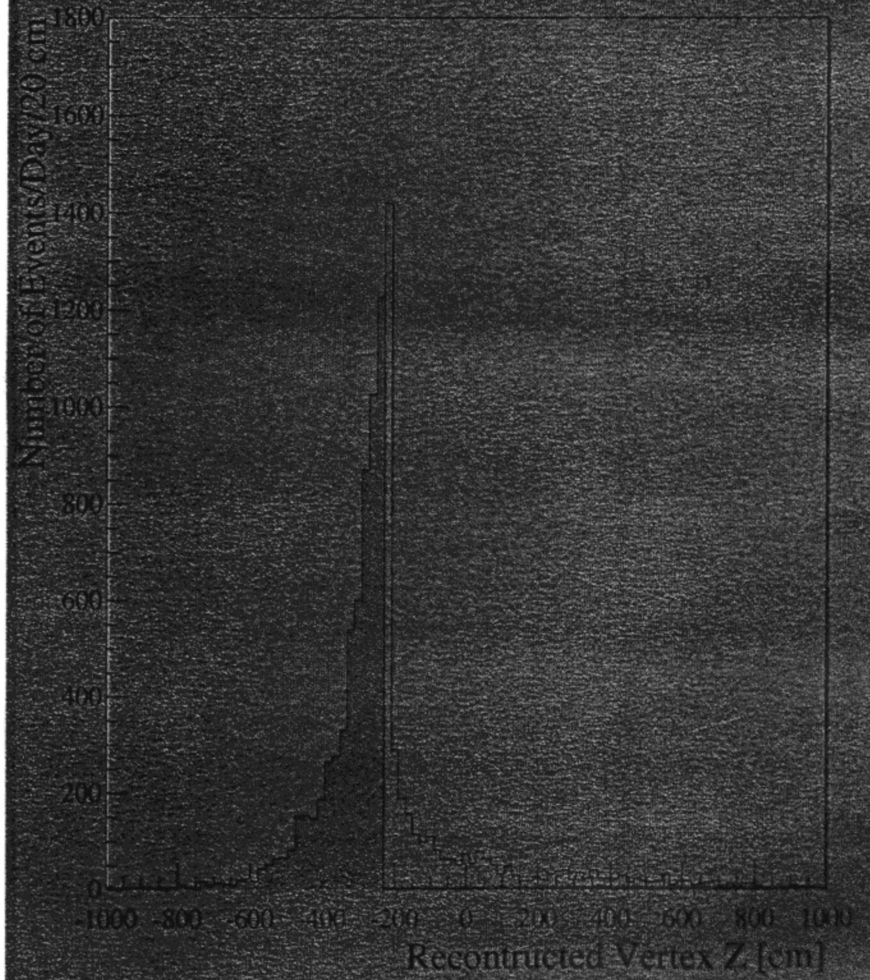


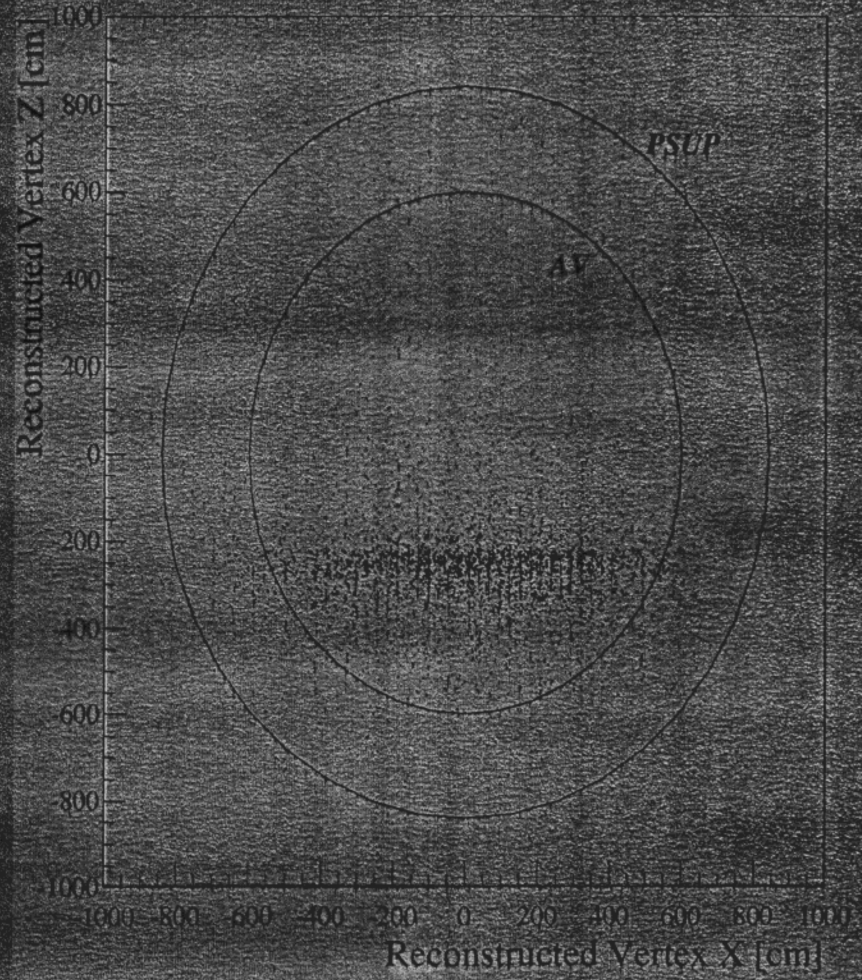

Neubauer, Penn

Poulay, Queens

# SNO Gamma-Ray Events

*Reconstructed Events from 1998/10/13, Run 1698*

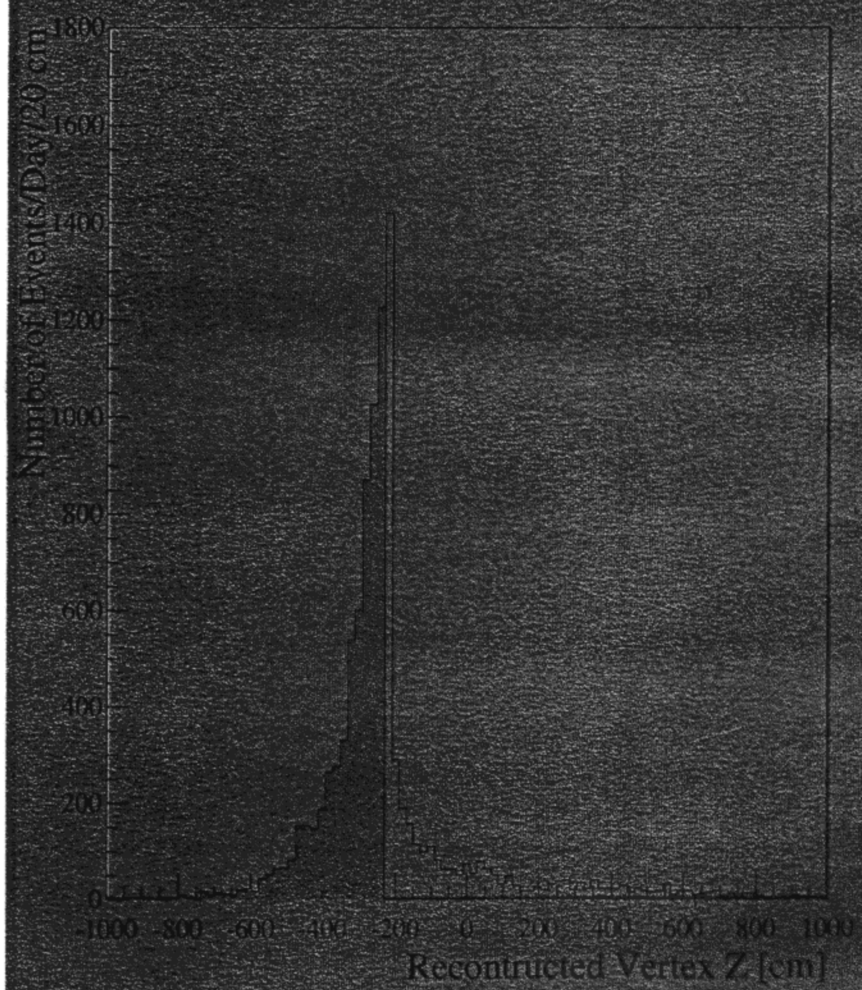


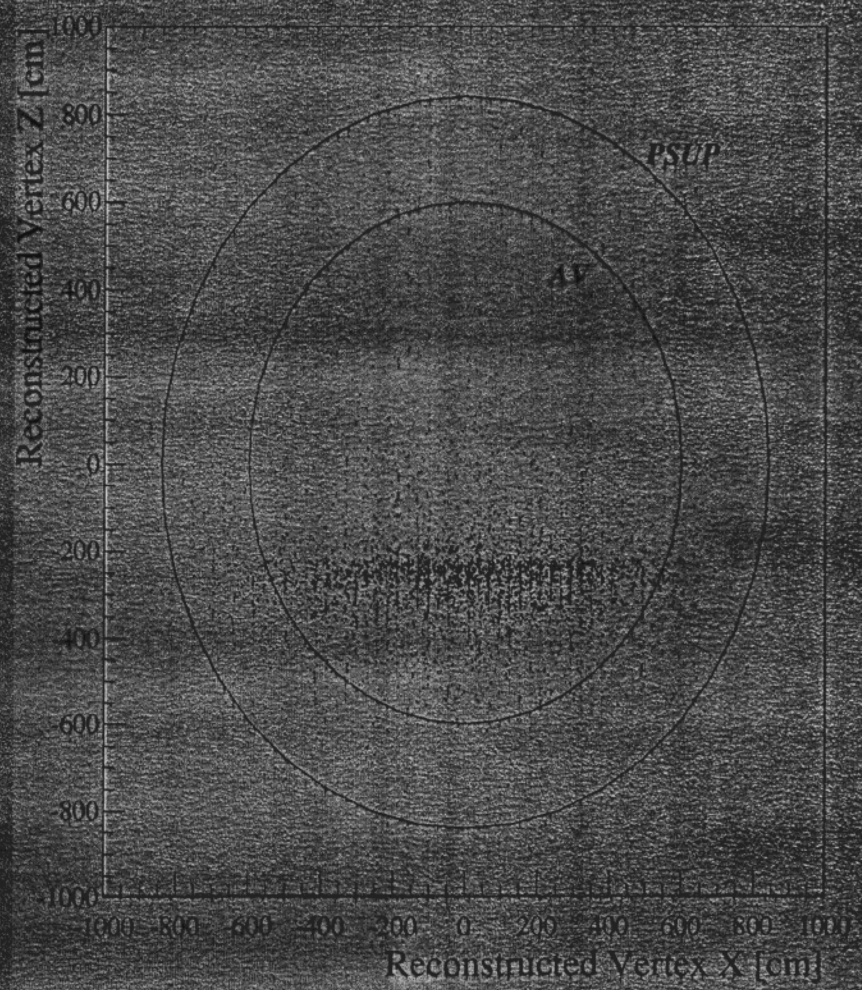



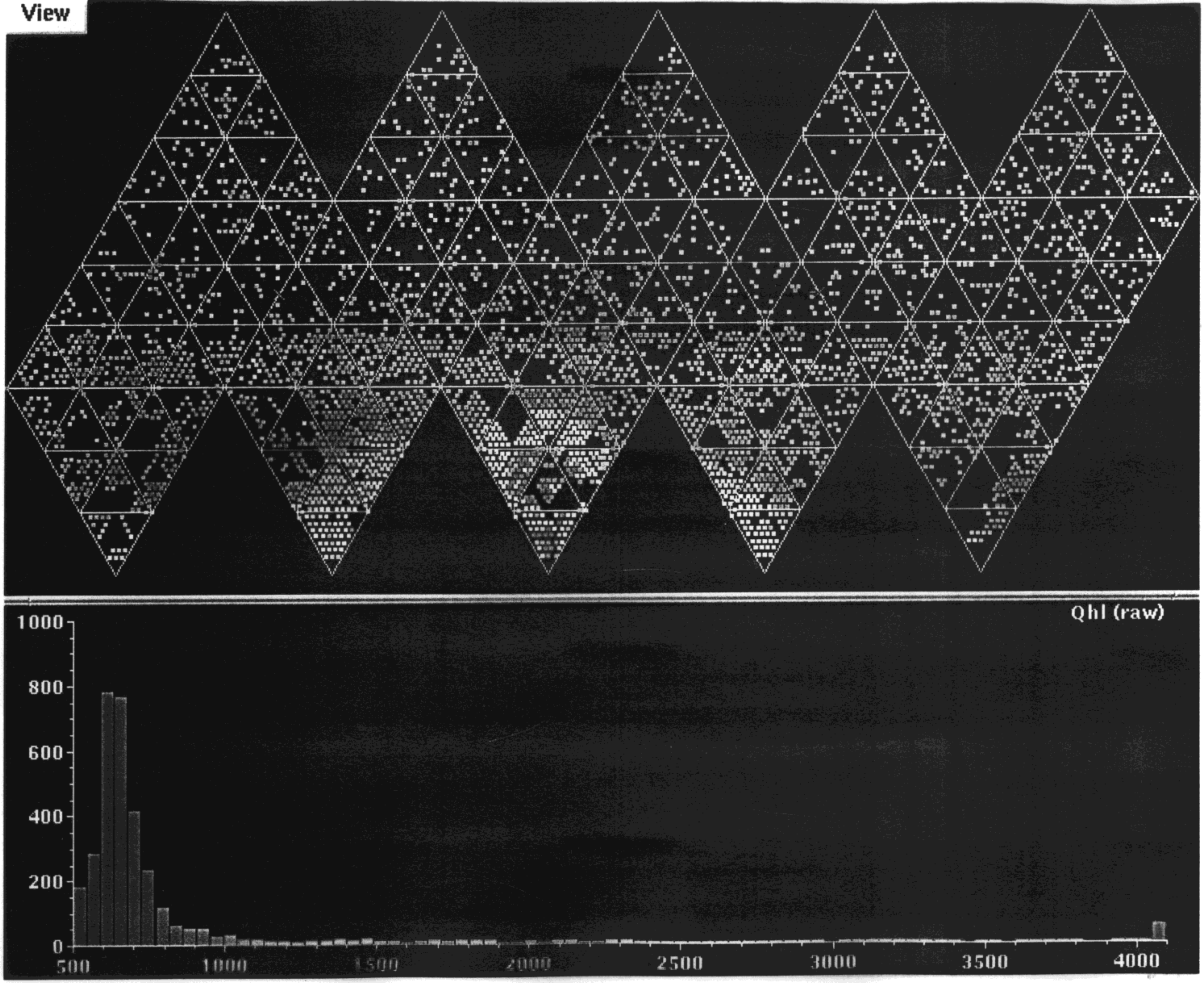
Poulay, Queens

# SNO Gamma-Ray Events

*Reconstructed Events from 1998/10/13, Run 1698*




View
Qhl (raw)
1000
800
600
400
200
0
500
1000
1500
2000
2500
3000
3500
4000

# Data History

*Focus so far has been on understanding detector*

- *February, 1998*: First Light! LED data with 32 tubes.
- *April-May*: First Air Fill data (∼ 4500 channels) "Beam off"
  - → Laser
  - → Sono
- *June-August*: Long term Air Fill Runs
  - → Muons
  - → Radon studies
  - → Cavity $\gamma$'s
  - → $^{16}$N Tests
  - → Sono,Laser
- *Sept. 14-19*: First Partial Fill runs (no $D_2O$)
- *Oct-Dec.*: Continuing Partial Fill runs
  - → Cavity $\gamma$'s
  - → Muons

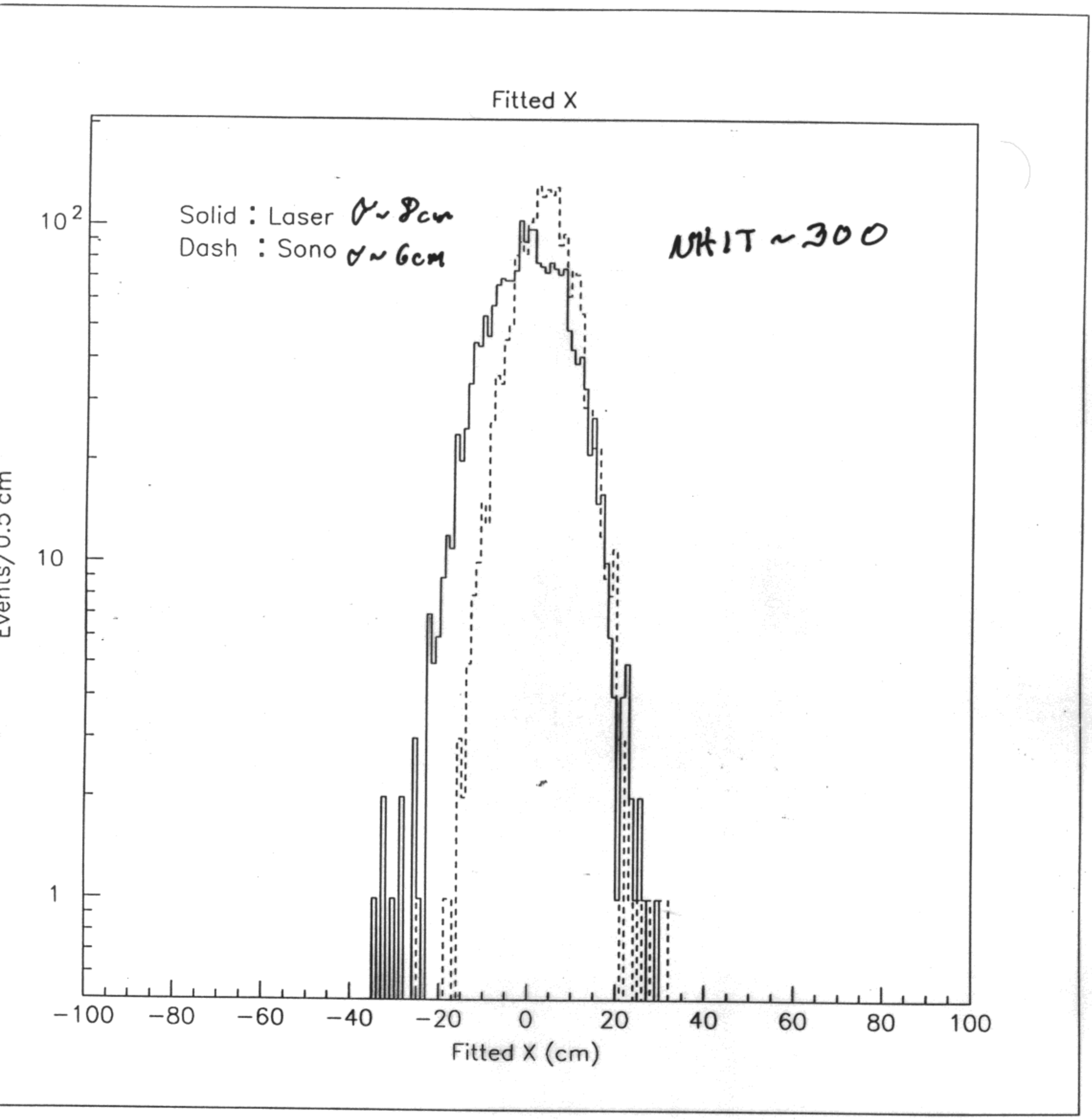
# Detector Operation and Performance

## Trigger

- **Pulsed Trigger** — Zero bias (NHIT = 0 threshold)
- **Prescaled Low NHIT** — For sampling of low energy ($\sim 1$ MeV) data
- **Long (100 ns) Coincidence NHIT** — Primary trigger for neutrino data

  → Even in partial fill (worst case), SNO runs very comfortably ($\sim 30$ Hz) at NHIT $\sim 30 =$ 3-5 (?) MeV

  → Can run at sustained rate of $\sim 700$ Hz at this threshold.
- **Short (20 ns) Coincidence NHIT** — Study of low energy backgrounds near center of detector
- **Energy Sum** — For studies of PMT radioactivity, detector anomalies


Fitted X
Solid : Laser σ ~ 8cm
Dash : Sono σ ~ 6cm
NHIT ~ 300
10^2
10
1
Events/0.5 cm
−100
−80
−60
−40
−20
0
20
40
60
80
100
Fitted X (cm)

Frati, Penn

## Channels

- $> 99.8\%$ of 9728 electronics channels working
- Mean channel threshold about 0.4 photoelectrons
- Median threshold near 0.3 photoelectrons
- Tube timing looks good!

## Water

- Uranium levels in $D_2O$ and $H_2O$ ten times lower than design goal
- Thorium levels in $H_2O$ already at design goal
- Thorium levels in $D_2O$ few times higher than design goal

## Surprises (Some Nasty)

- *More light than expected from $\mu$s and $\gamma$s hitting acrylic vessel in Air Fill data.*
- *Light from* $D_2O$ *Fill* — Static? Cavitation?
- *Flasher PMTs* — Light emitted from phototube

  → Rate in Air Fill data much higher than anticipated (few/minute)

  → Hard to model systematics

  → Rejection through charge and reconstruction cuts at 99.8% level

  → Rate appears to be significantly smaller in tubes underwater, except during mine-related seismic events(!)

- *Wet-end high voltage breakdown*

  → Marginal design of connector means unknown number susceptible to problem.

  → High rate, large events make running difficult if tubes left on.

  → Breakdown eventually destroys base resistors in some tubes.

  → Of tubes run underwater so far, $\sim$ 15% have shown some degree of breakdown ($\sim$ 4.5% of total).

## Future Plans

- Continue filling detector beyond current 3/4.
- Start taking calibration $\sim$ 1 month after detector is full.
- Monitor HV breakdown in connectors.
- Start taking neutrino data in $\sim$ 2 months after radon has decayed away.

## Conclusions

- Majority of SNO detector is in excellent shape.
- Poised to start the physics program in $\sim$ 2 months.
- SNO will soon give us:

  → Measure of the solar $\nu_e$ flux.

  → First high-resolution measure of the solar $\nu_e$ spectrum ($^8$B).

  → First measurement of the fraction of non-electron flavor neutrinos from the Sun.