

# **The Sudbury Neutrino Observatory**

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**June 2nd, 2001**

# SNO



## SNO Collaboration



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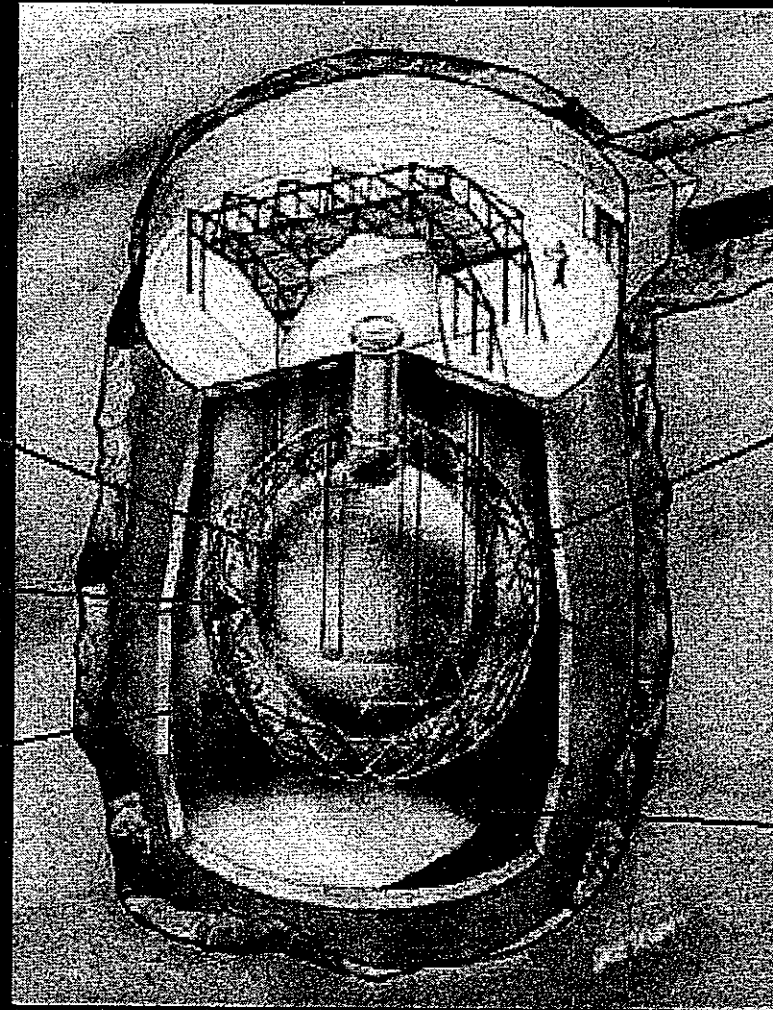
### University of Washington

R.G. Allen, G. Bahler, H.H. Chen\*

### University of California, Irvine

\* Deceased

# The SNO Detector



1000-ton D<sub>2</sub>O

Acrylic Vessel

PSUP

Concrete Skin

Phototube Support  
Structure (PSUP)

Concrete D.O.

# $\nu$ Reactions in SNO



- Measure total  $\nu$  flux from the sun.



- Low Statistics

- Strong directional sensitivity

# SNO run sequence

## The Three Phases

## Neutron Detection Method

- Pure  $D_2O$ 
  - Good CC sensitivity

- Capture on  $D$   
 $n + D \rightarrow t + p \rightarrow \gamma$  ( $E_\gamma = 4.03 \text{ MeV}$ )

- $D_2O$  with  $NaCl$ 
  - Enhanced CC sensitivity

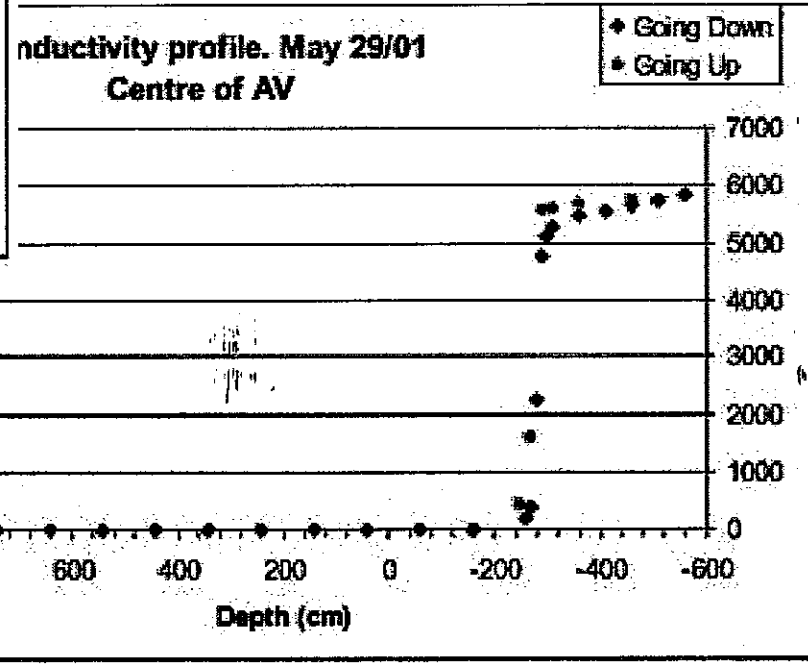
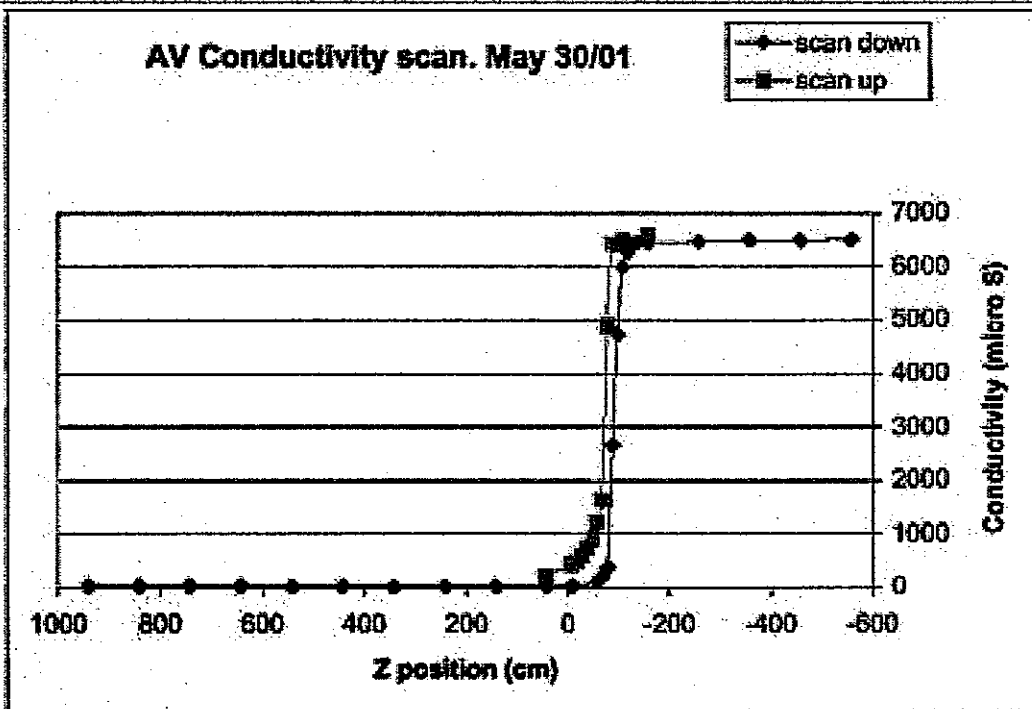
- Capture on  $^3He$   
 $n + ^3He \rightarrow t + p$

- Neutral Current Detectors
  - $^3He$  proportional counters in the  $D_2O$

- Capture on  $^3He$   
 $n + ^3He \rightarrow t + p$   
Event by event separation of CC and NC events

# Conductivity Measurements of Salt Addition

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# SNO run sequence

## The Three Phases

## Neutron Detection Method

- Pure D<sub>2</sub>O
  - Good CC sensitivity

- Capture on D
  - $n + d \rightarrow t + \gamma \dots \rightarrow e^-$  ( $E_{\gamma} = 0.3$  MeV)

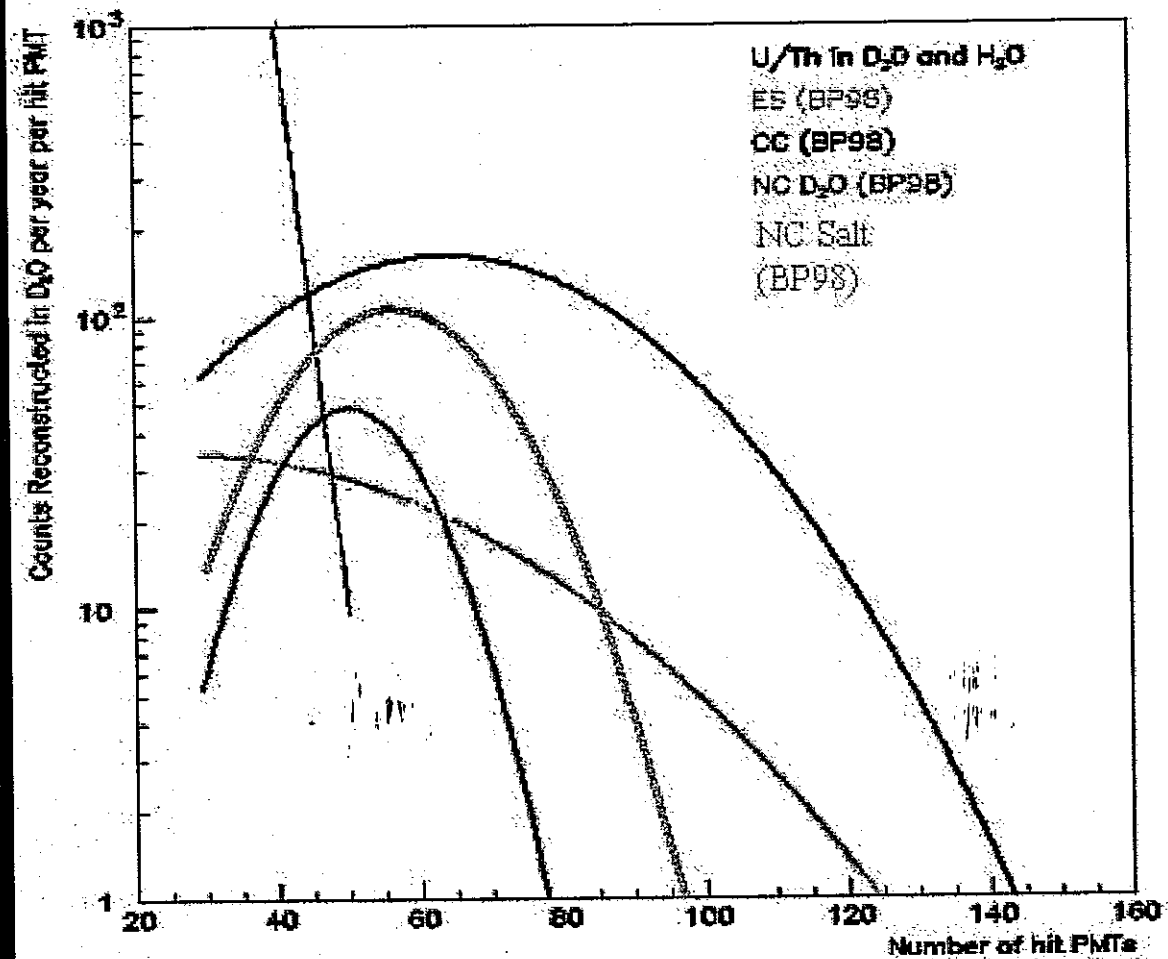
- Pure D<sub>2</sub>O
  - Enhanced NC sensitivity

- Capture on D
  - $n + d \rightarrow t + p$

- Neutral Current Detectors
  - <sup>3</sup>He proportional counters in the D<sub>2</sub>O

- Capture on <sup>3</sup>He
  - $n + {}^3\text{He} \rightarrow p + t$
  - Event by event separation of CC and NC events

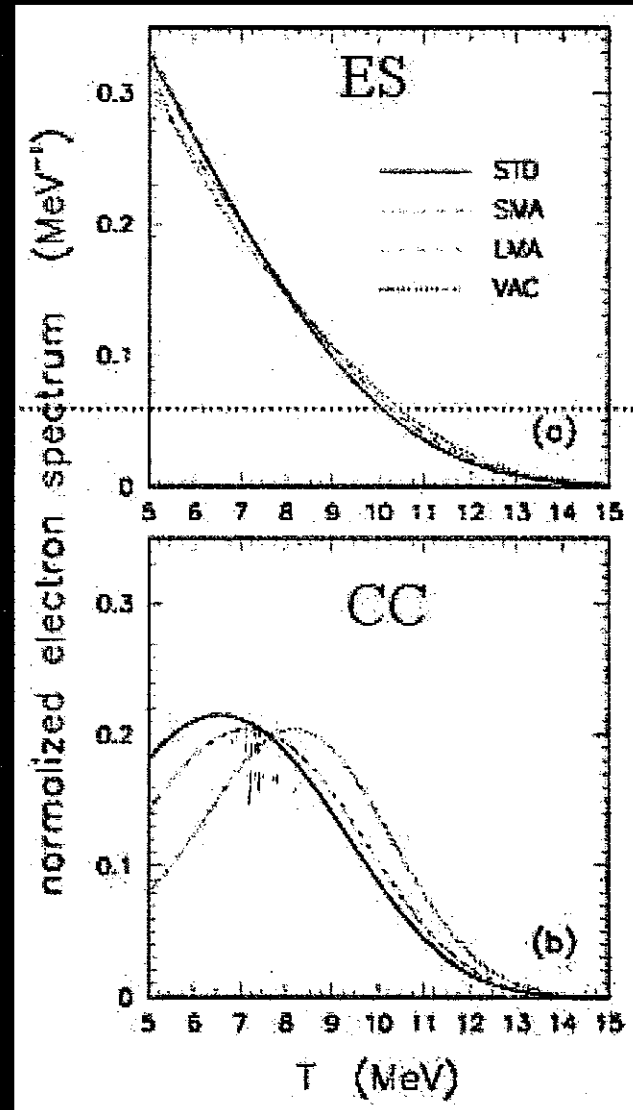
# Signals in SNO





# Smoking Guns in SNO - 1

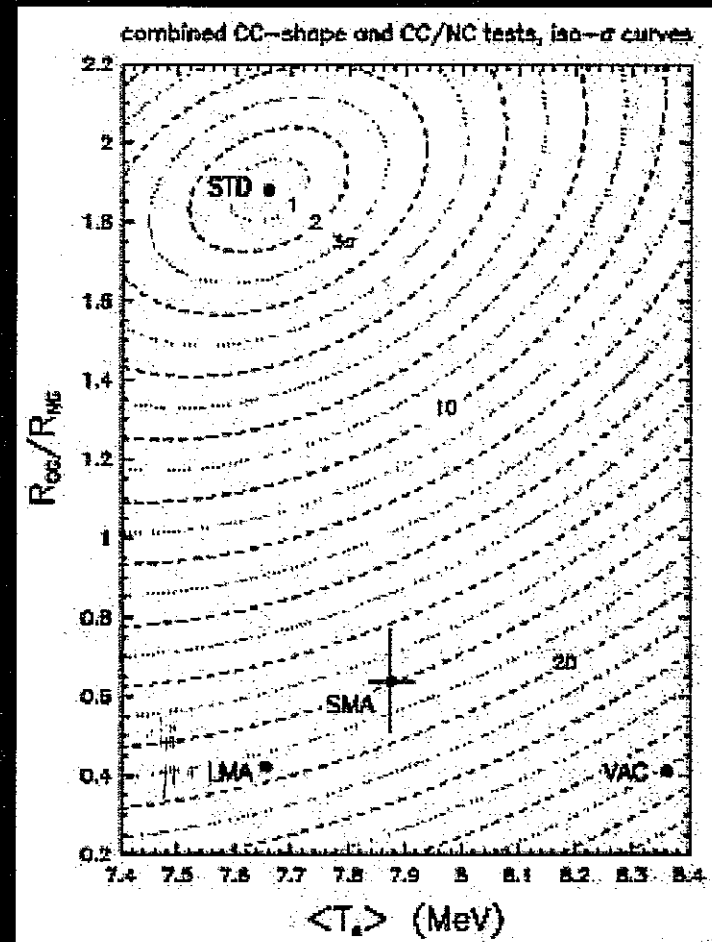
Charged-current spectrum  
is more sensitive to shape  
distortions!



# Smoking Guns in SNO - 2

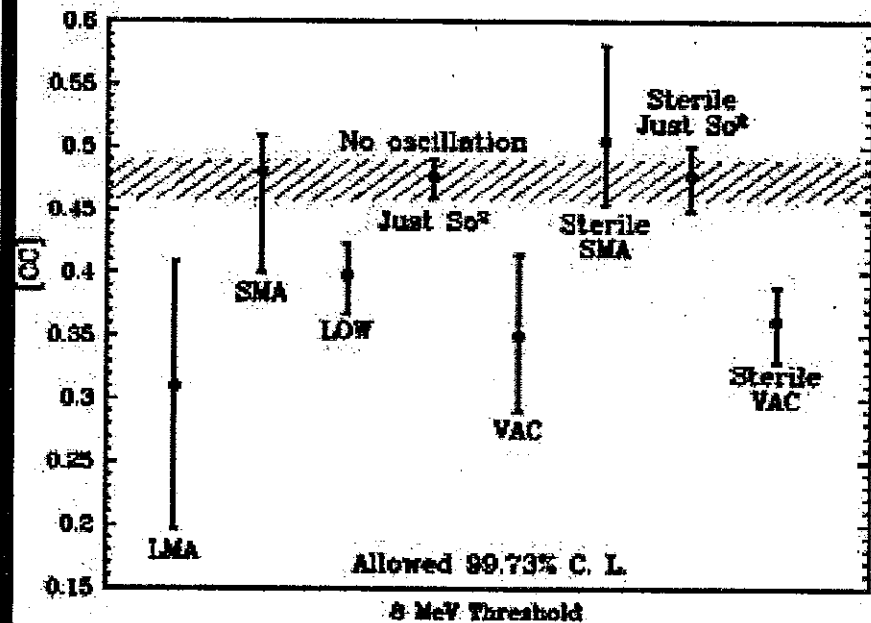
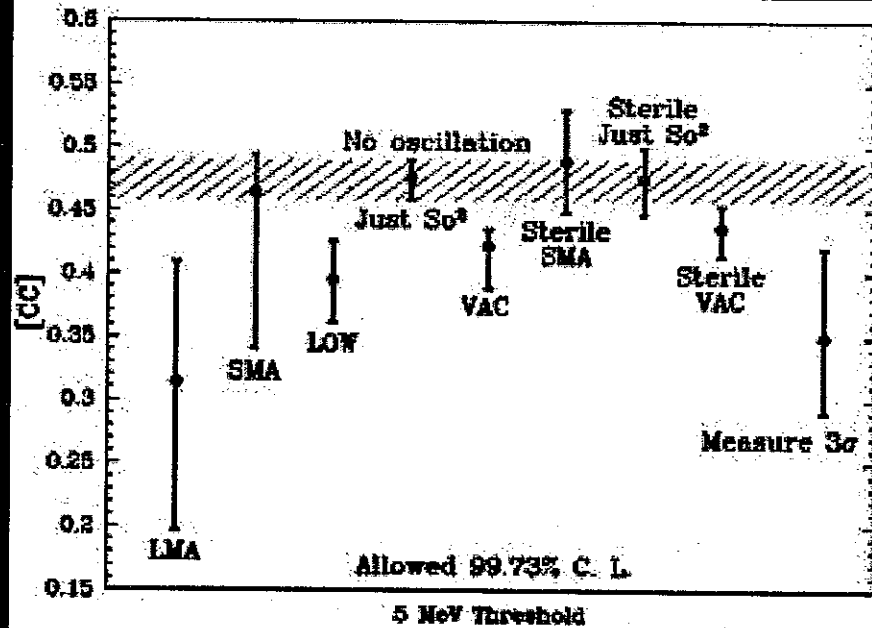
Charged-Current to Neutral Current  
 Ratio is a Great Signature  
 of Oscillations

$$\frac{CC}{NC} = \frac{V_e}{V_e + V_{\mu} + V_{\tau}}$$



Bahcall et al., Phys. Rev. D 54, 5147 (1996)

# Smoking Guns in SNO - 3



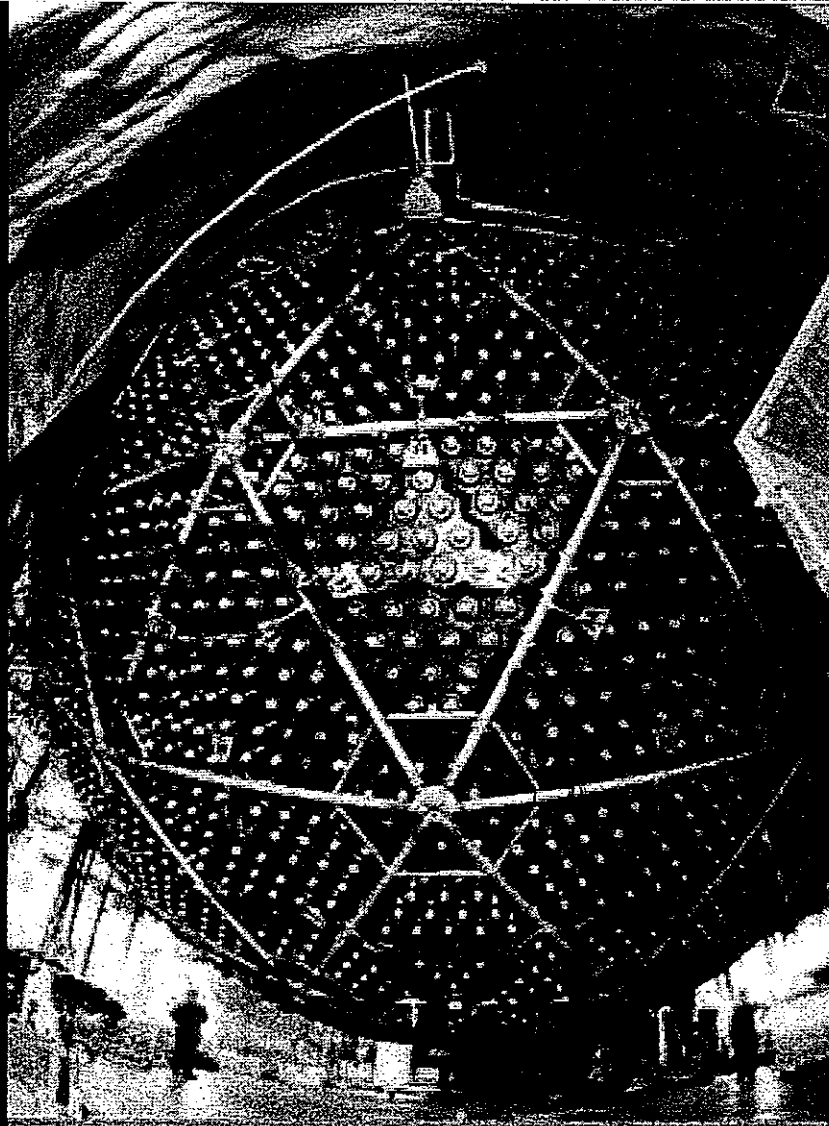
CC/ES Curve also show significant effects!

$$\frac{CC}{ES} = \frac{V_e}{V_e + 0.14(V_\mu + V_\tau)}$$

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# Construction



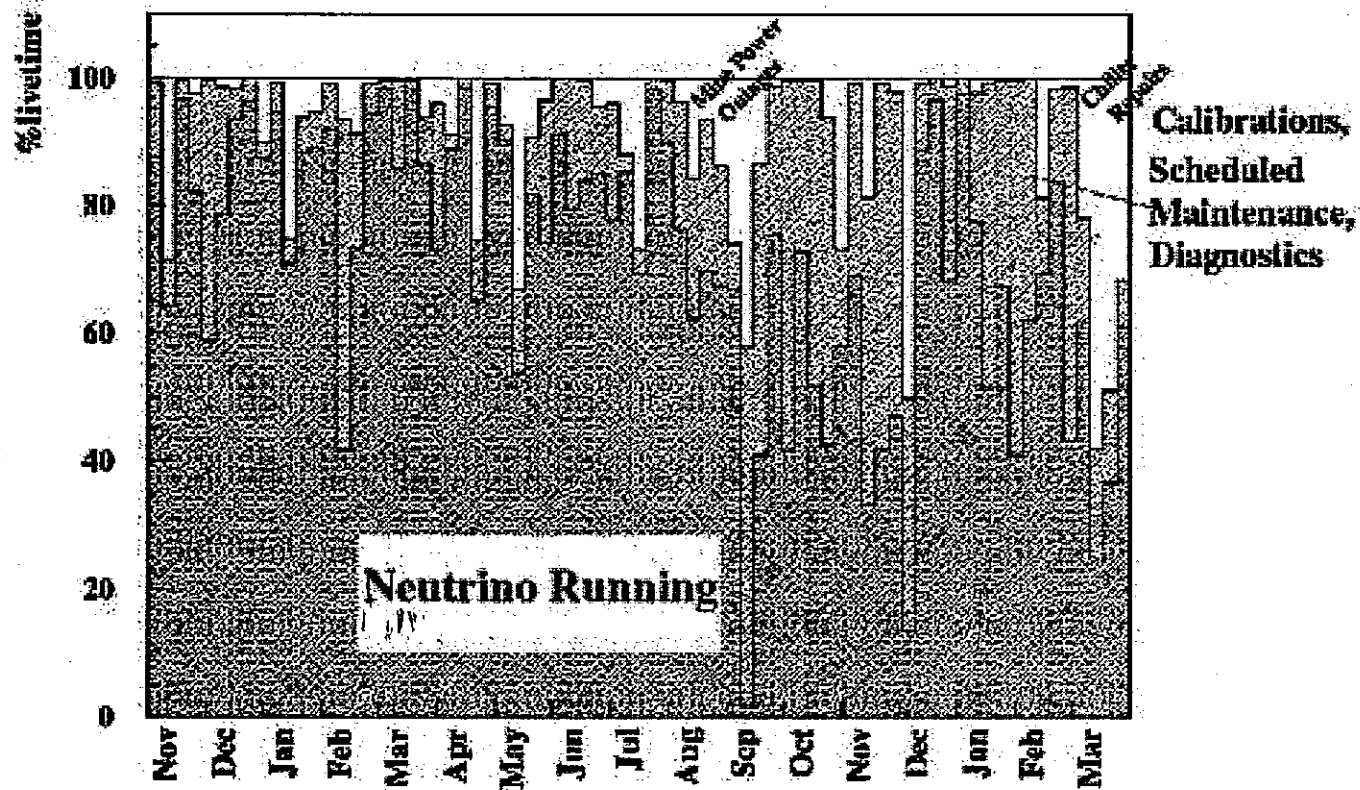
June 2nd, 2001

Dave Wark - TMU Meeting

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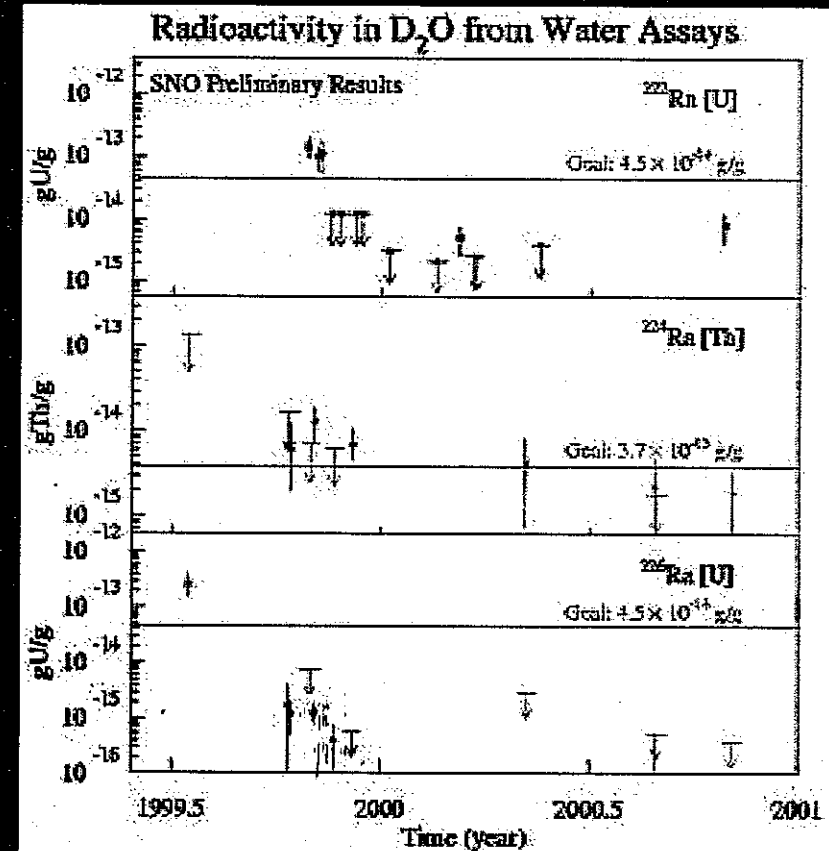
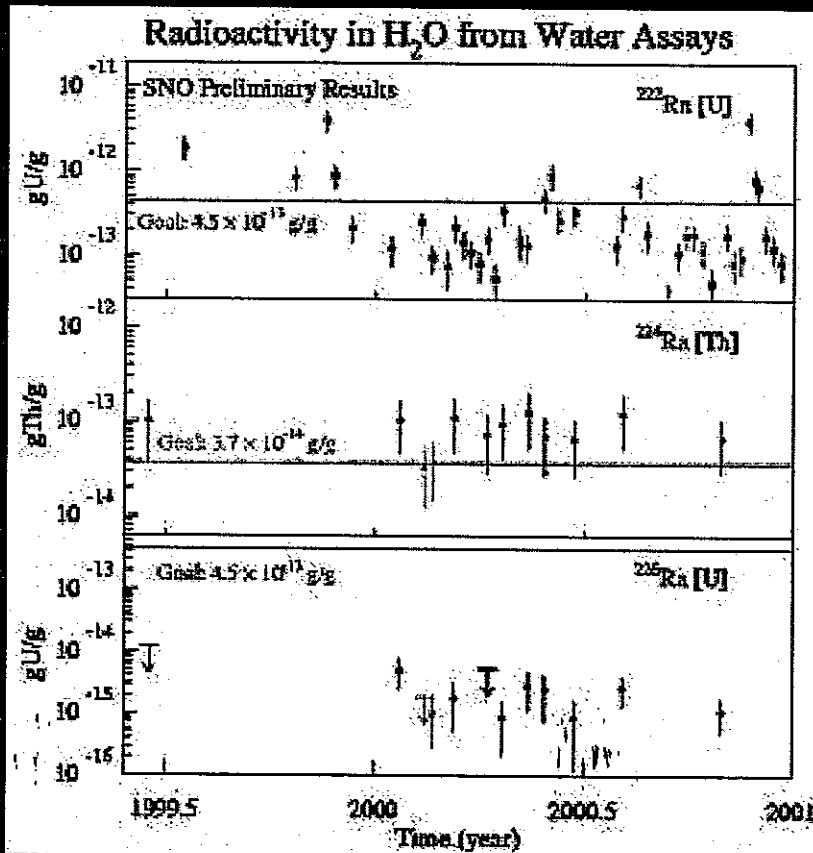
# SNO Livetime

SNO Livetime (01/11/1999 to 28/03/2001)



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# SNO Water Assays



Targets are set to reduce  $\beta$ - $\gamma$  events reconstructing inside 6m

≈ Targets for D<sub>2</sub>O represent a 5% background from  $d + \gamma \rightarrow n + p$

# A Neutrino Event

Event Display Parameters A 2001/11/17/20

File Move Display Data Windows View

Event Display - Parameters

Projection Move View Hits

Event Display - Map

Event Histograms

NHIT:	85
GTID:	1015749
Evt Num:	1067515
Run Num:	10001_001
Date:	01/08/2000
Time:	08:14:50.4804705
PrevNext:	103 sec / 4 min
Trigger:	20LB,20,100H,100M
PL/Int/Dif:	12 / 127 / 0
Normal:	84
Owl:	0
Low Gain:	0
Neck:	0

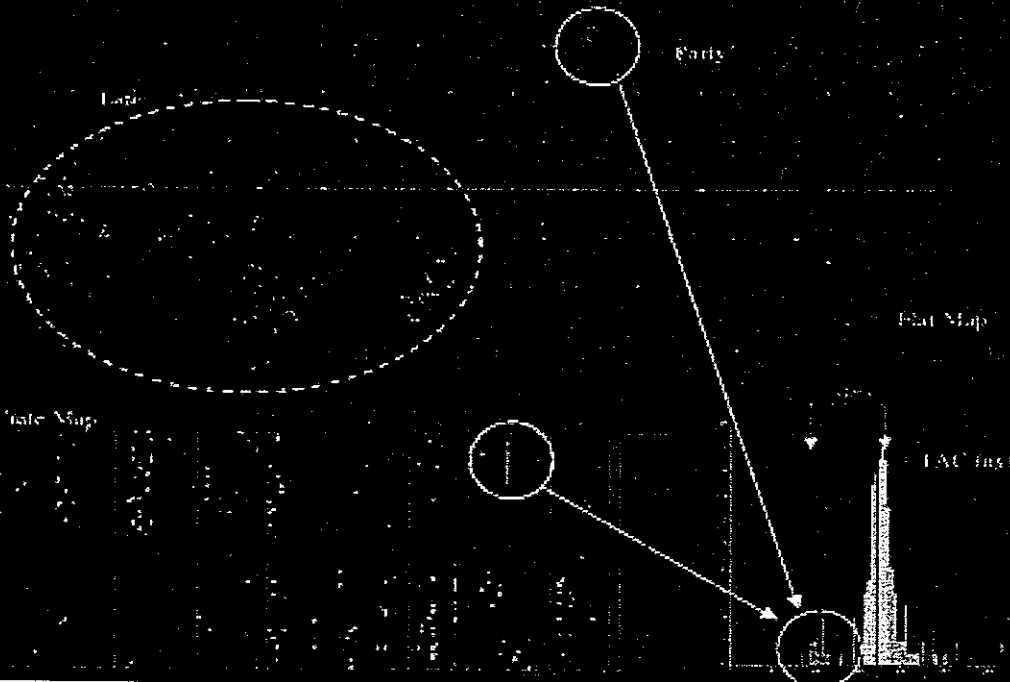
02:21 PM  
May 20

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# Instrumental Backgrounds

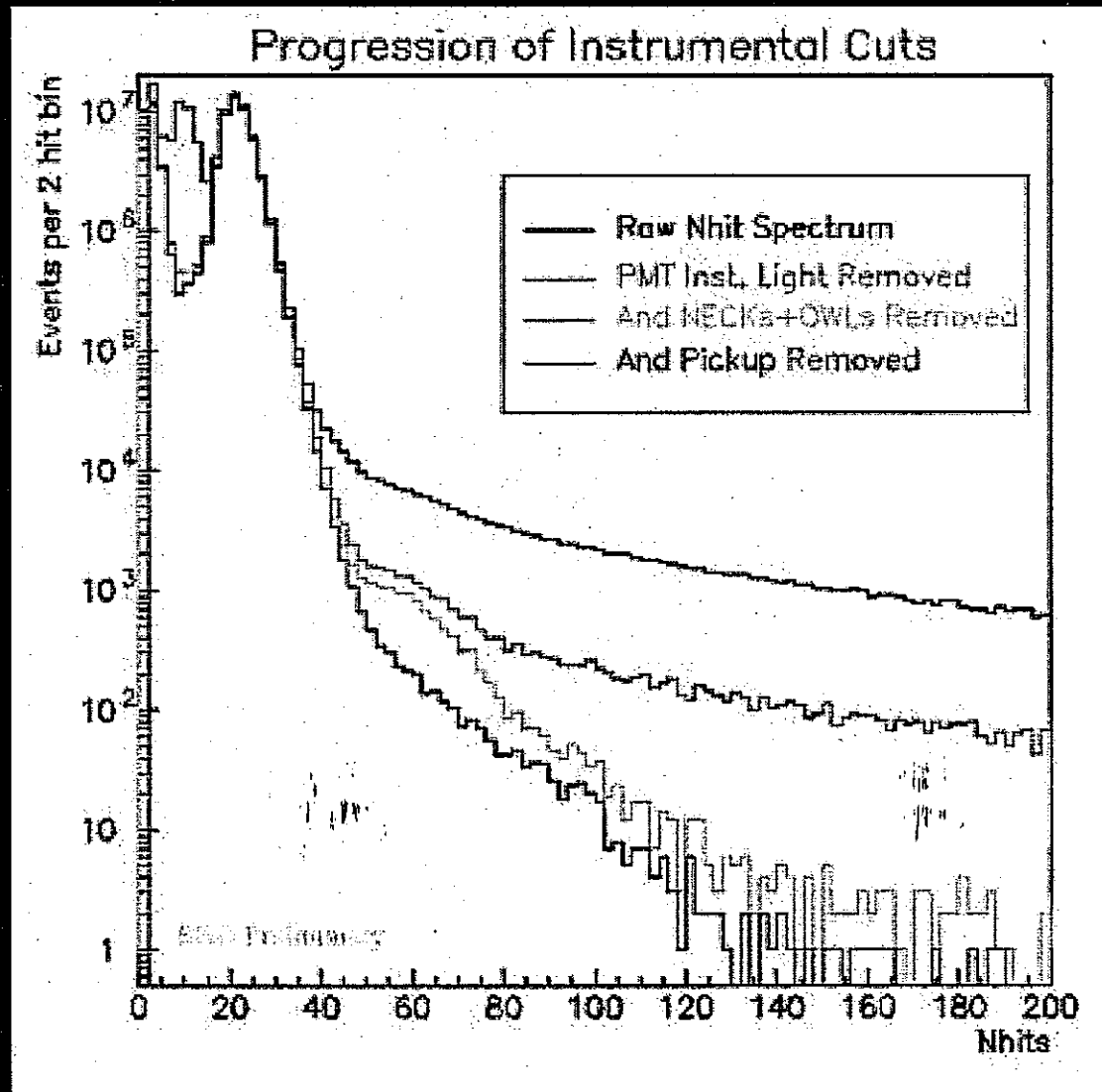
Flasher



Name	Address	City	State	Zip	Phone	Fax	E-mail	Web	URL	Notes	Comments
...	...	...	...	...	...	...	...	...	...	...	...

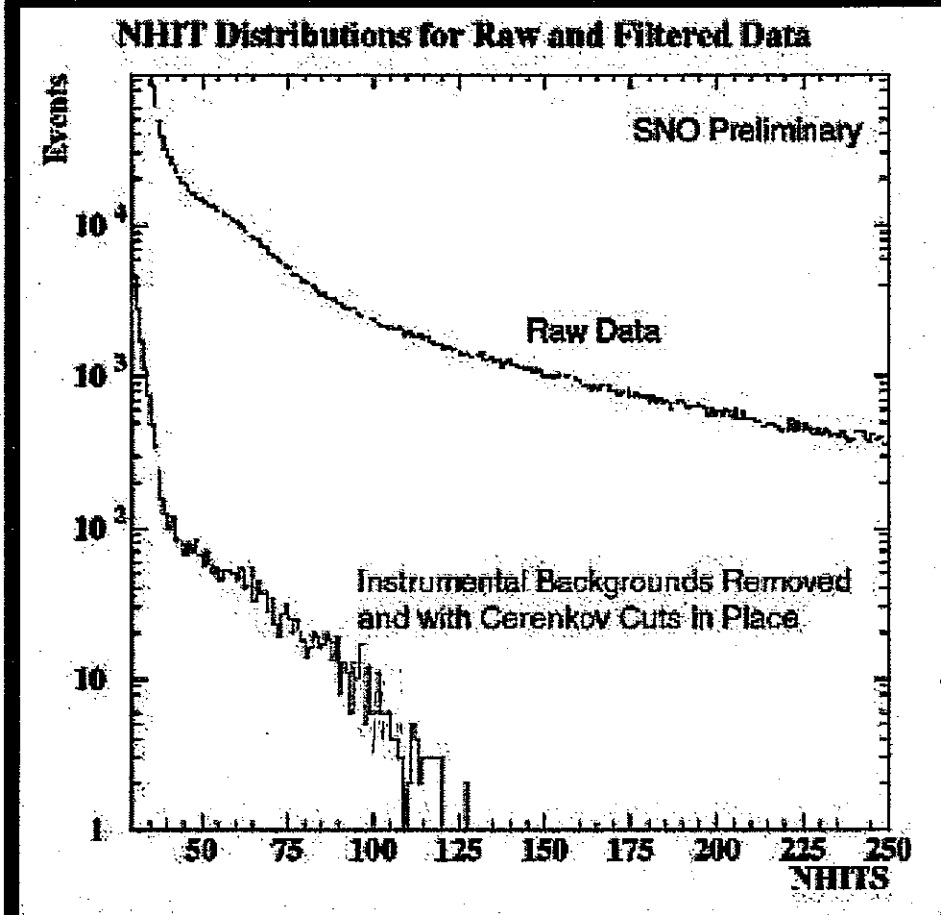
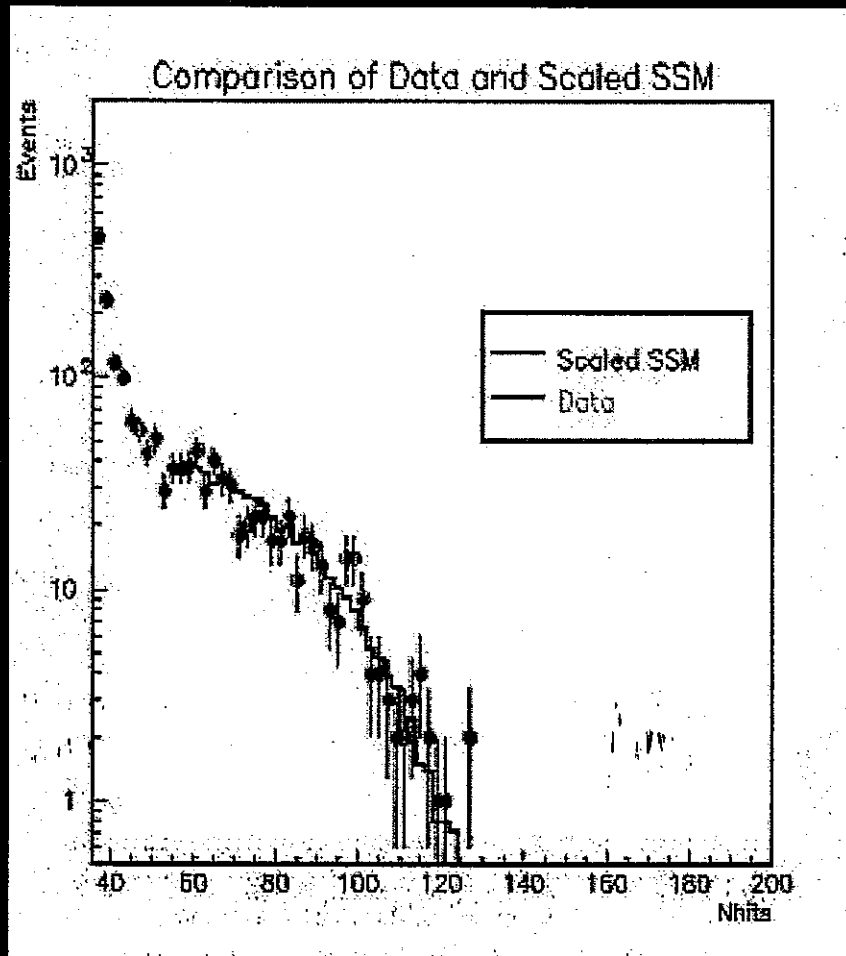
77

# Instrumental Background Cuts

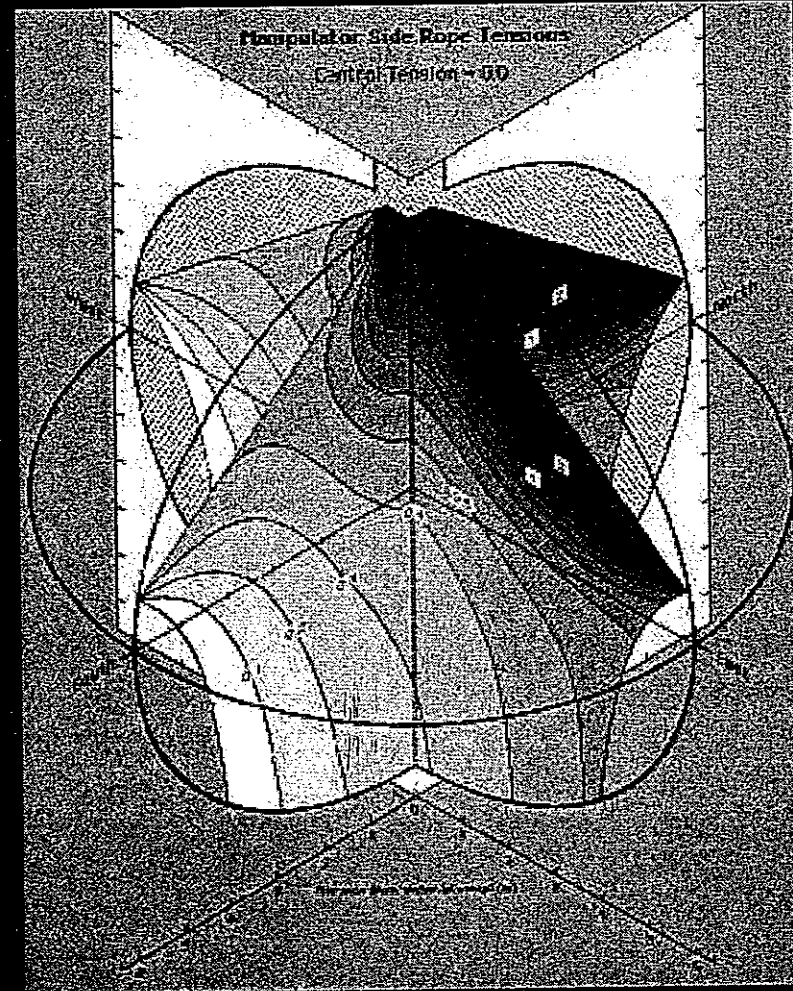
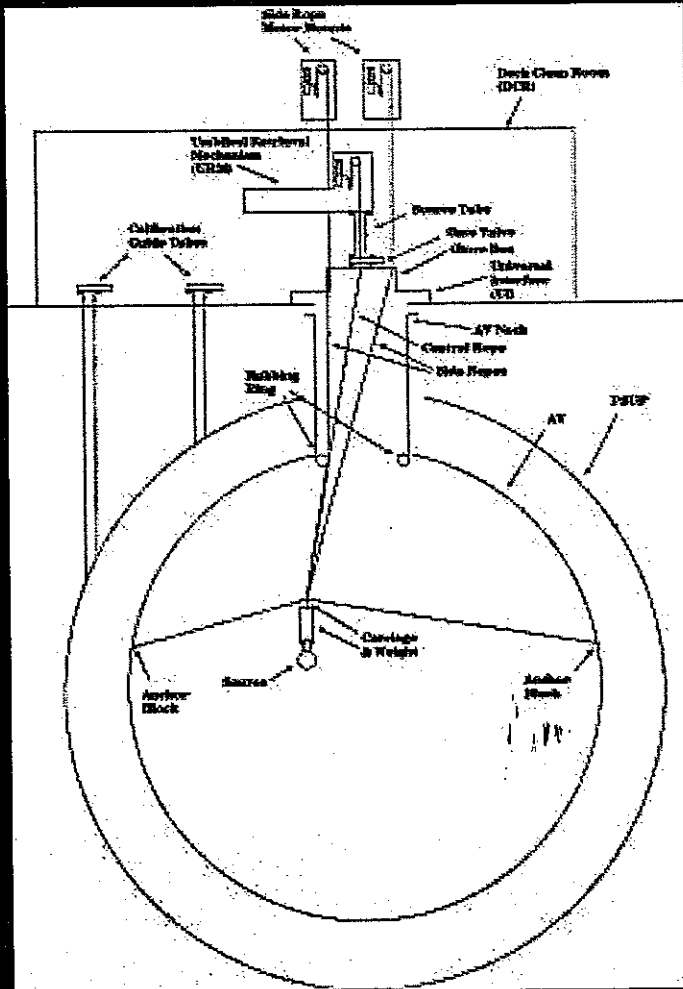


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# Solar Neutrino Spectrum



# Manipulator



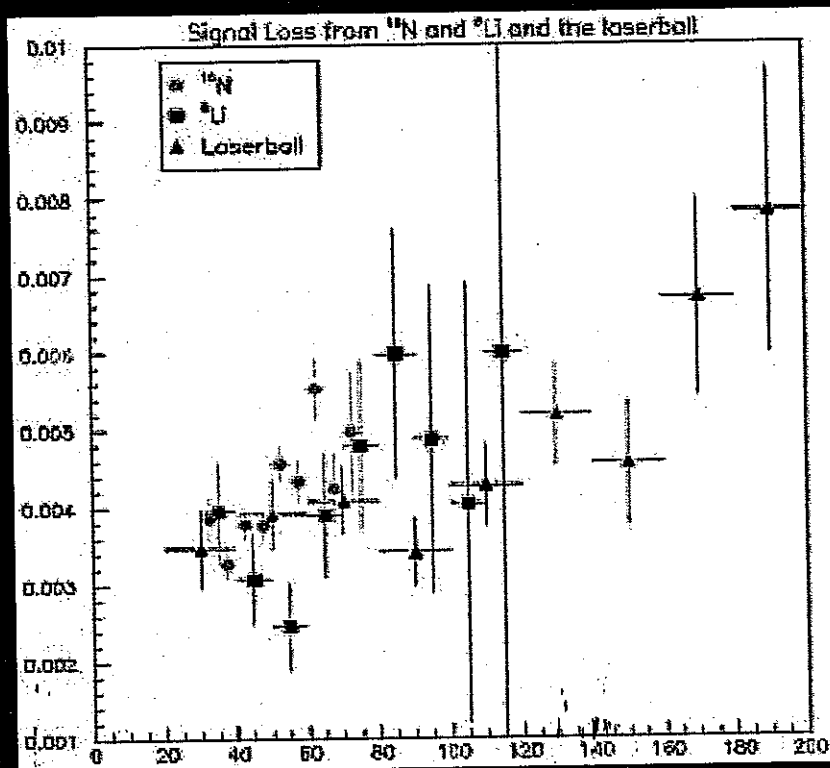
82

# How do we know this worked ?

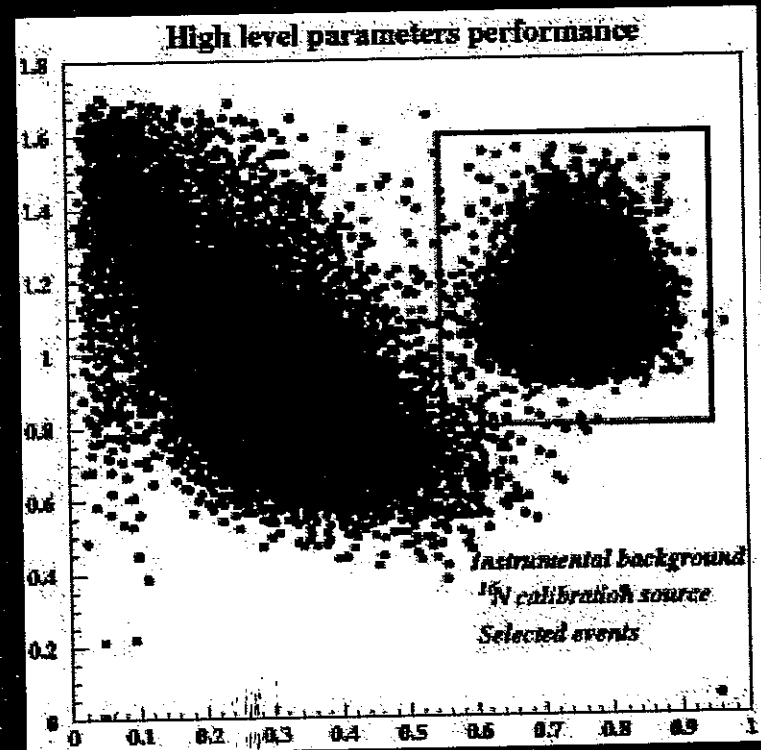
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- **We did it twice.**
- **Two different semi-independent sets of cuts were developed.**

# How do we know this worked?



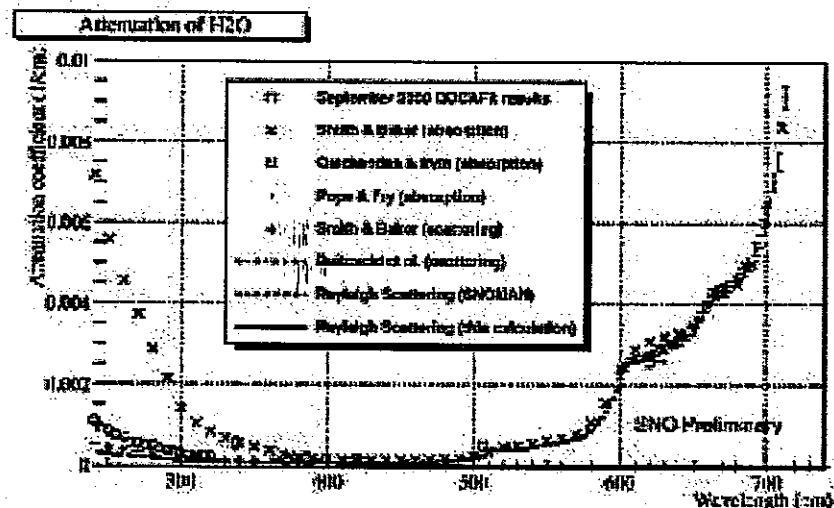
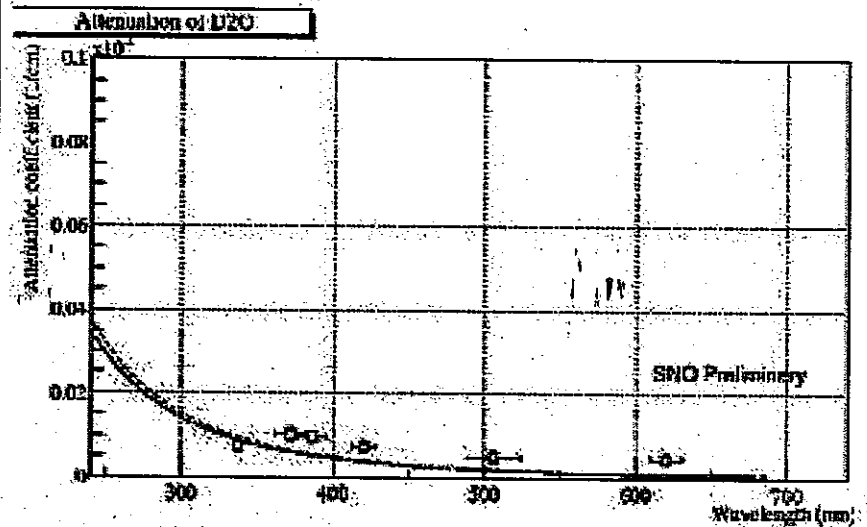
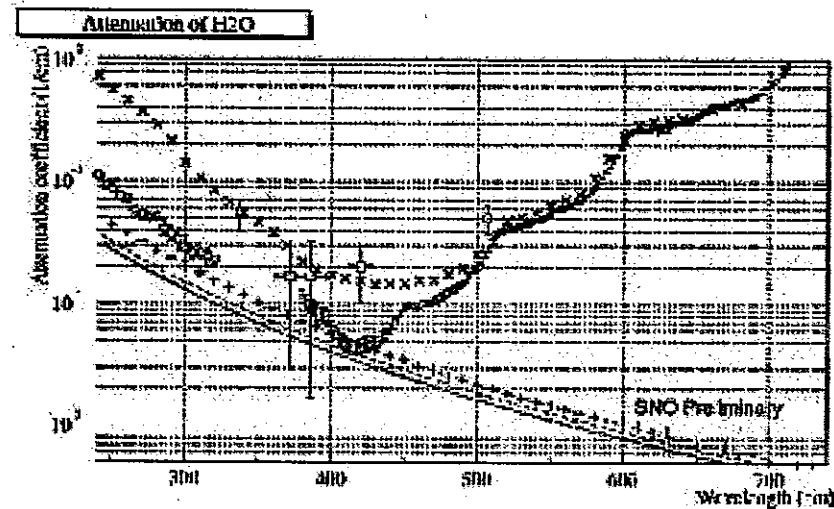
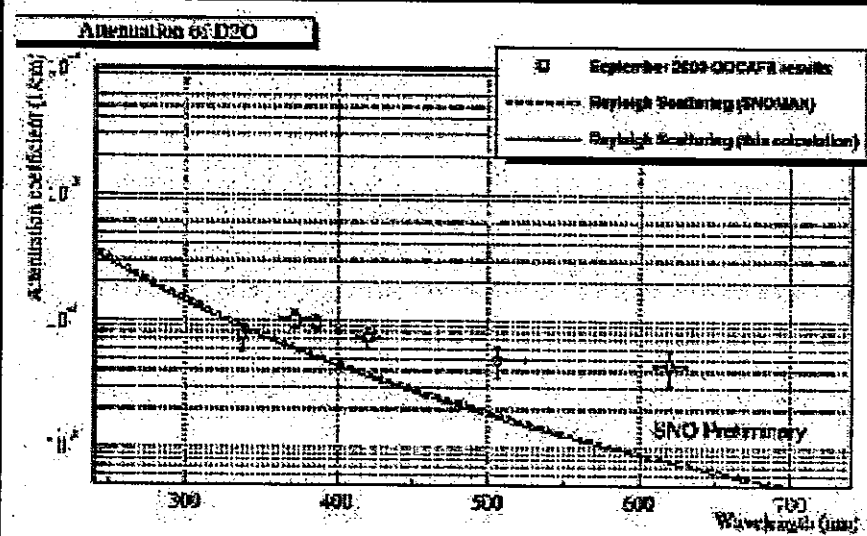
Signal loss measured with calibration sources



Contamination measured with independent cuts

# Water Clarity Results

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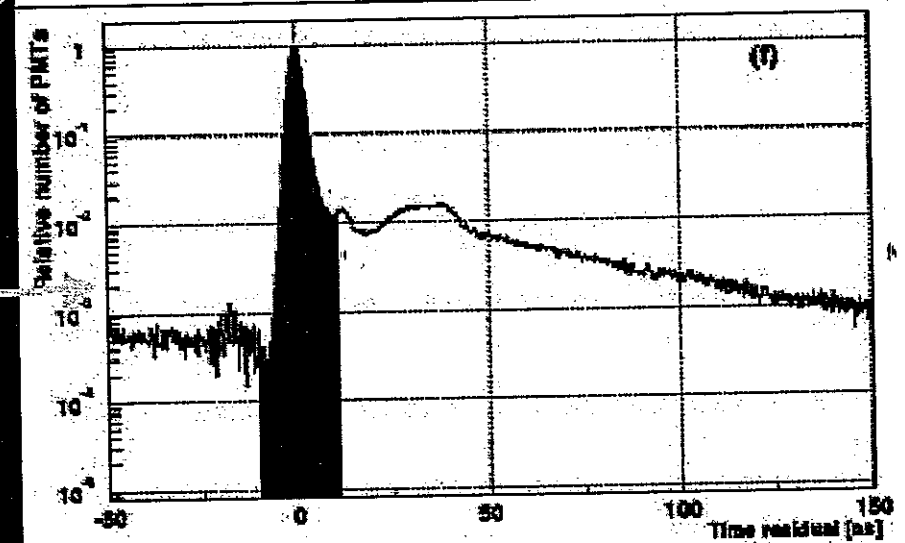
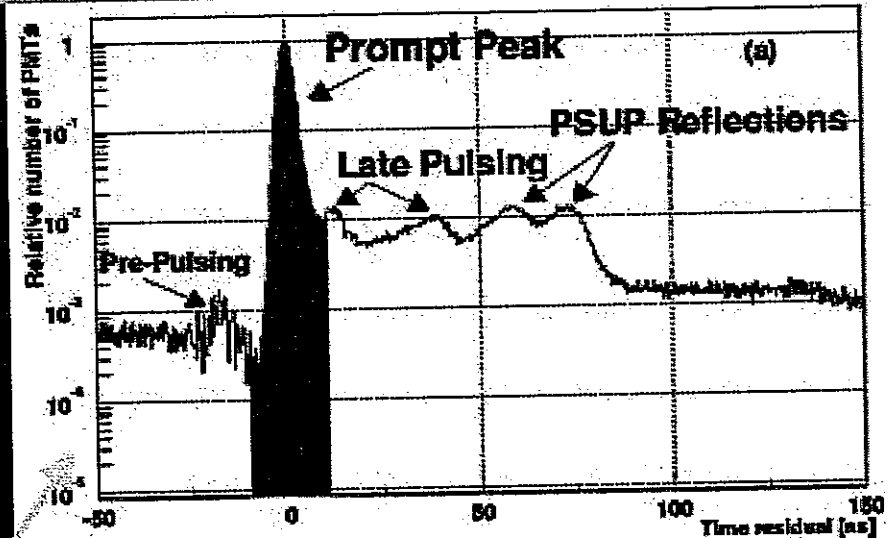


# Timing residuals in SNO

Timing Residuals – difference in time between PMT hit and direct flight time from vertex.

Source at detector centre

Source at 500 cm





# Time Since Last Hit Drift

## ➤ We noted:

- Fit  $\chi^2$  a function of rate
- Timing residuals a function of rate

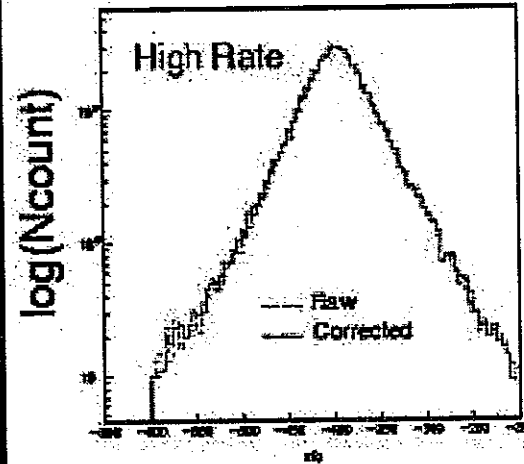
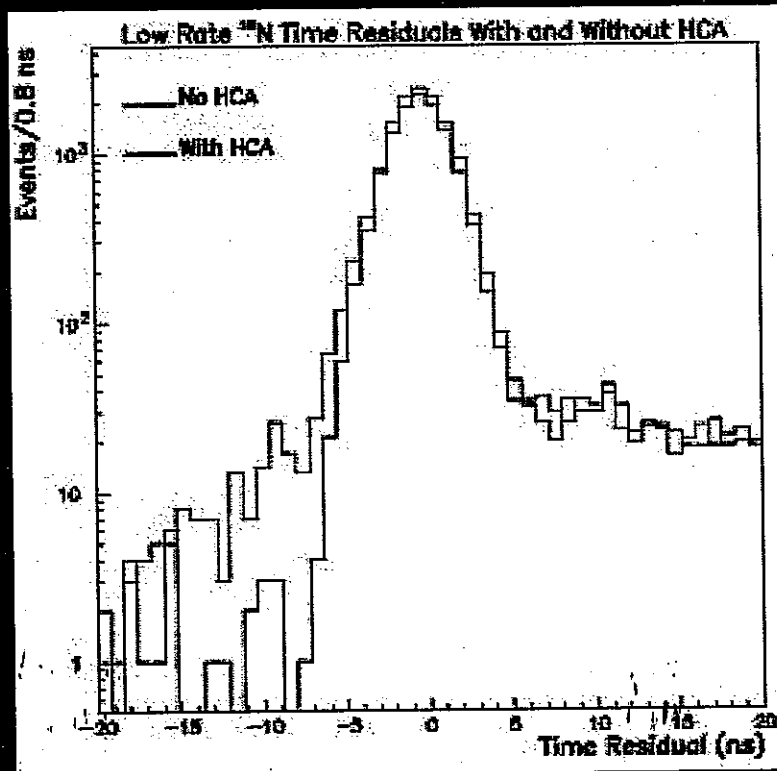
## ➤ Traced to:

- Variation in ADC pedestal with time since last hit (TSLH)
- Variation in ADC slope with time since last hit (TSLH)

## ➤ Calibrated out in HCA processor

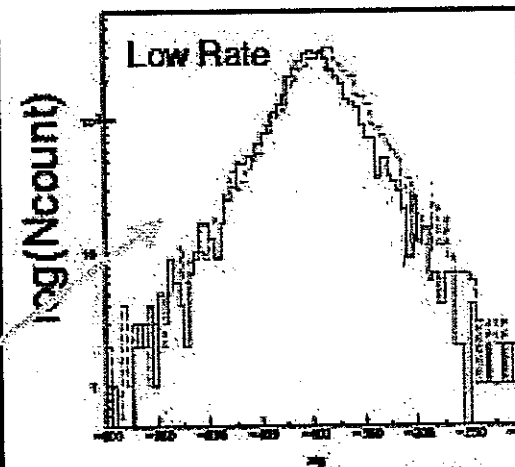
# Time Since Last Hit Correction

## Effects on Residuals



-395.9 (0.5) w/o correction  
-395.5 (0.5) w correction  
source at -400 cm

Reconstructed Z (cm)

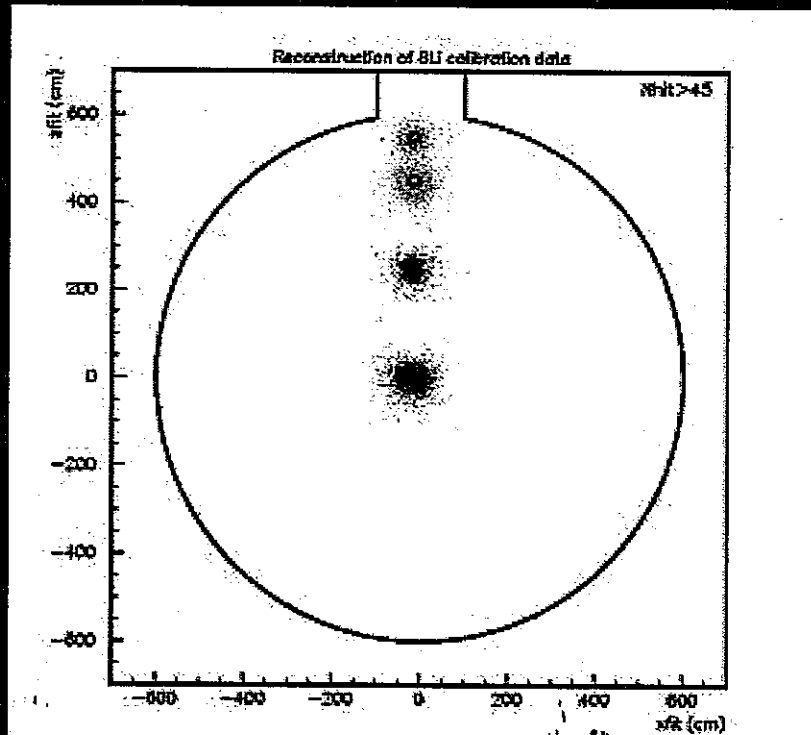


-389.7 (0.5) w/o correction  
-398.5 (0.5) w/ correction  
Source at -400 cm

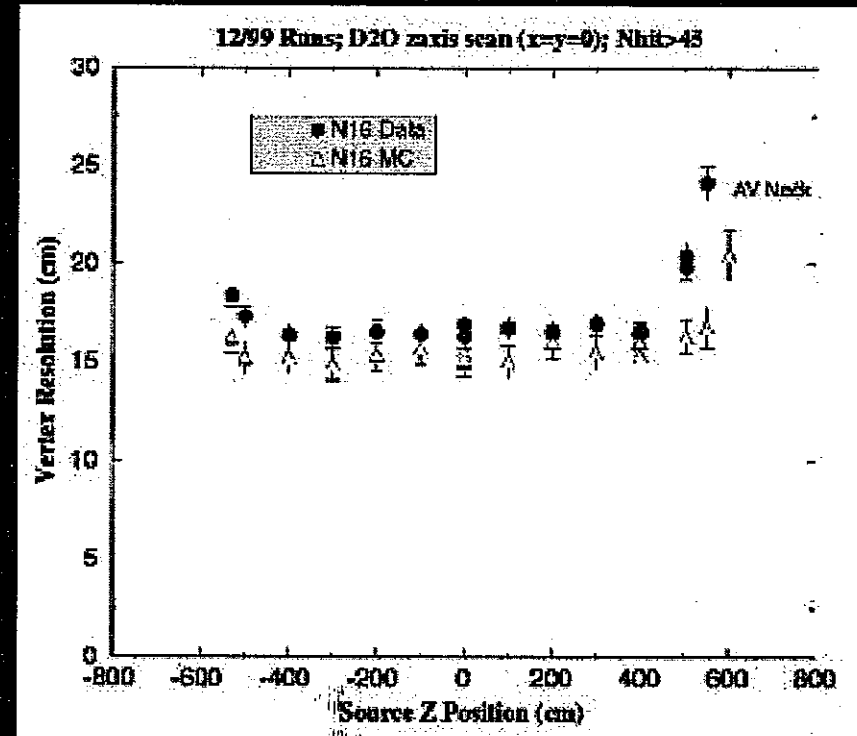
Reconstructed Z (cm)

## Effects on Fits

# SNO Event Reconstruction



Reconstruction position  
of  $^8\text{Li}$  events



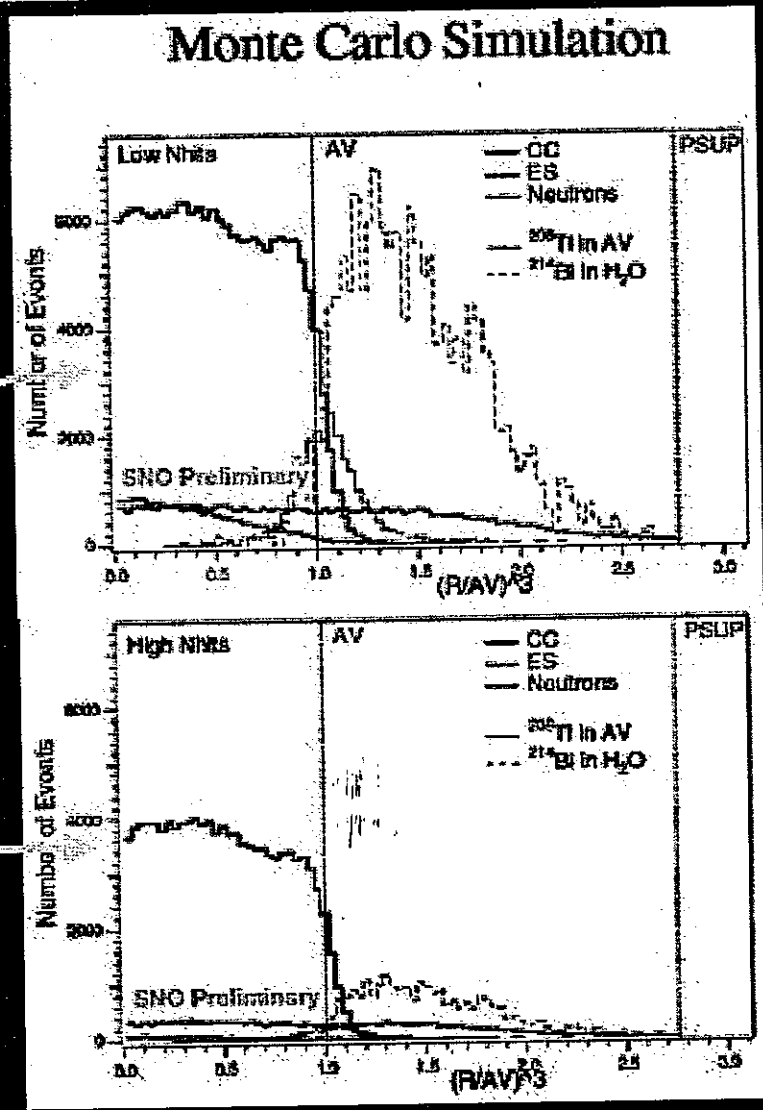
Reconstruction Resolution

# Radial profiles

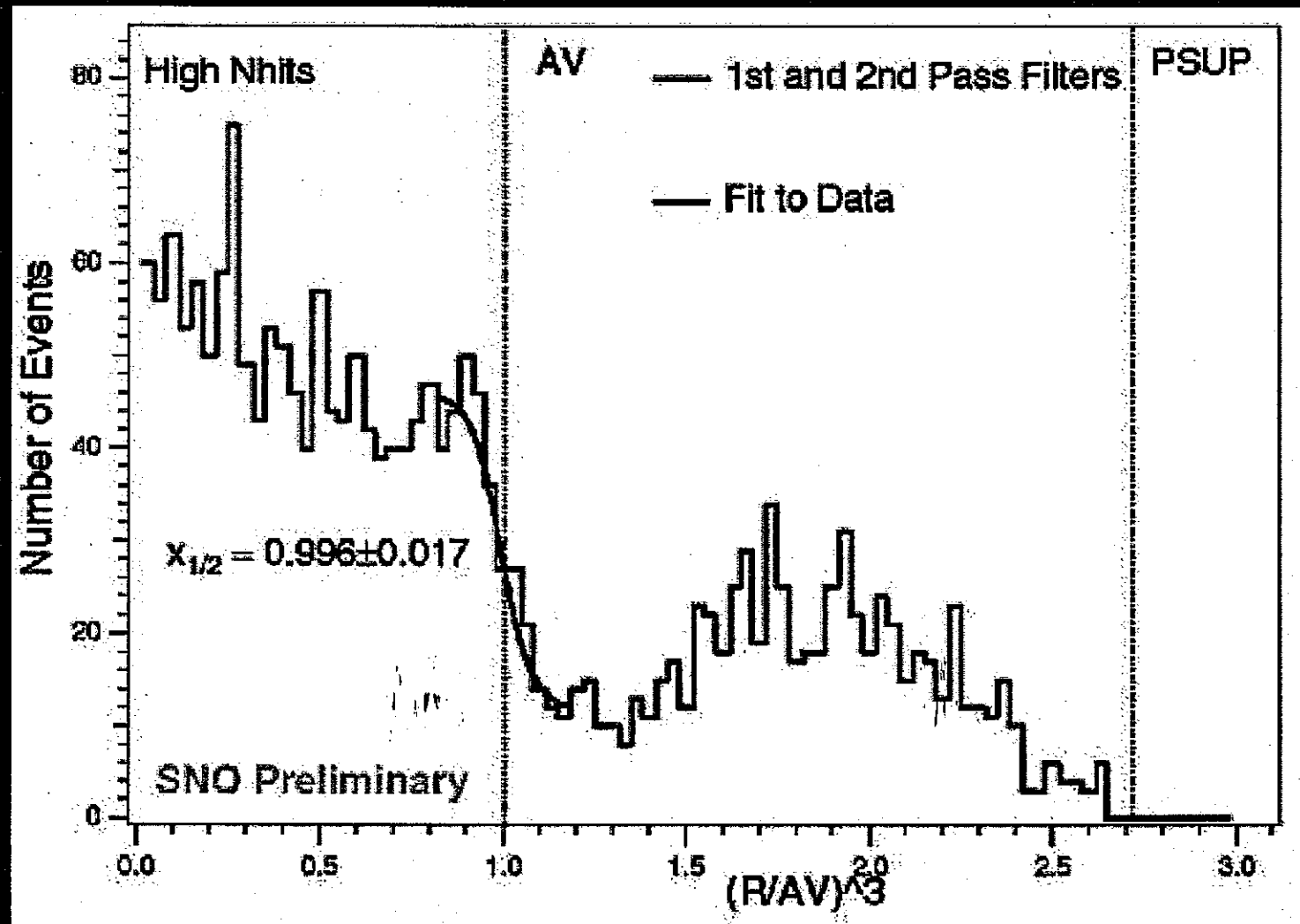
Signals and backgrounds as a function of  $r^3$

Low  $N_{hit}$

High  $N_{hit}$

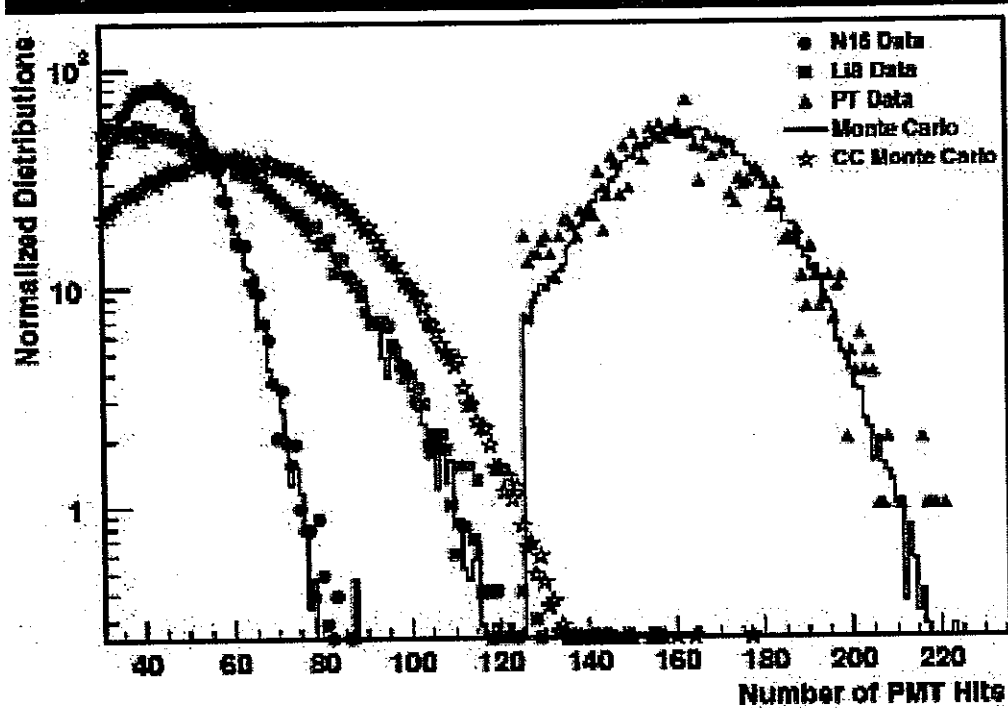


# SNO Event Reconstruction

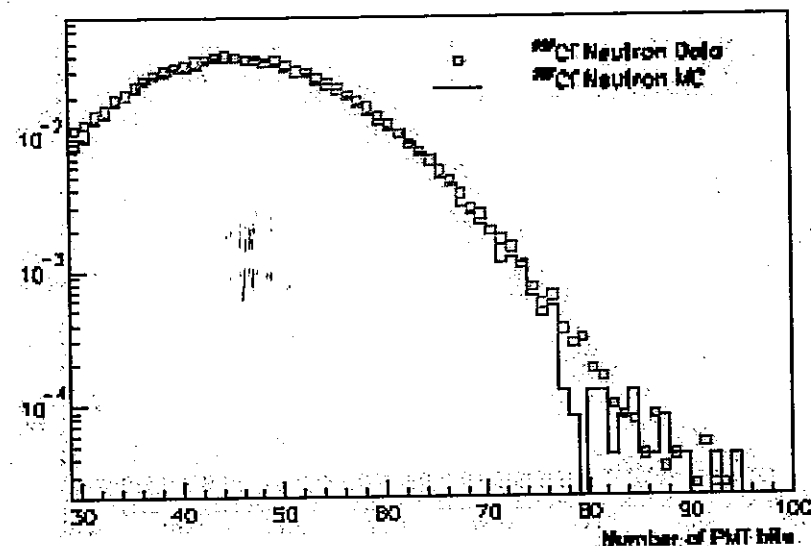


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# SNO Energy Calibrations

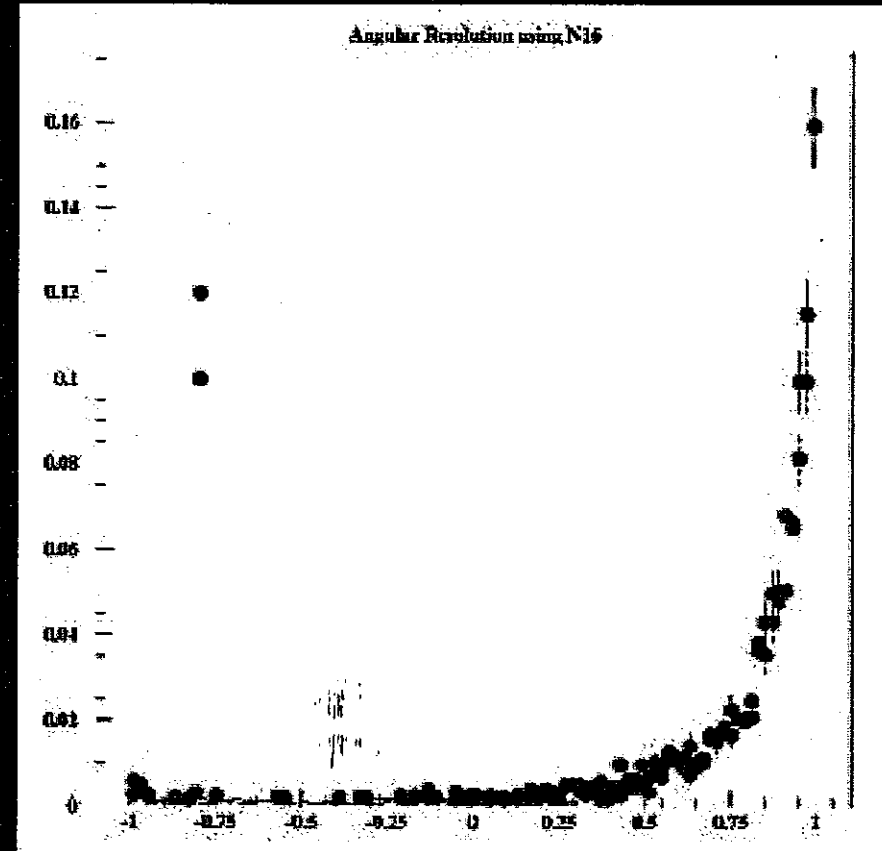
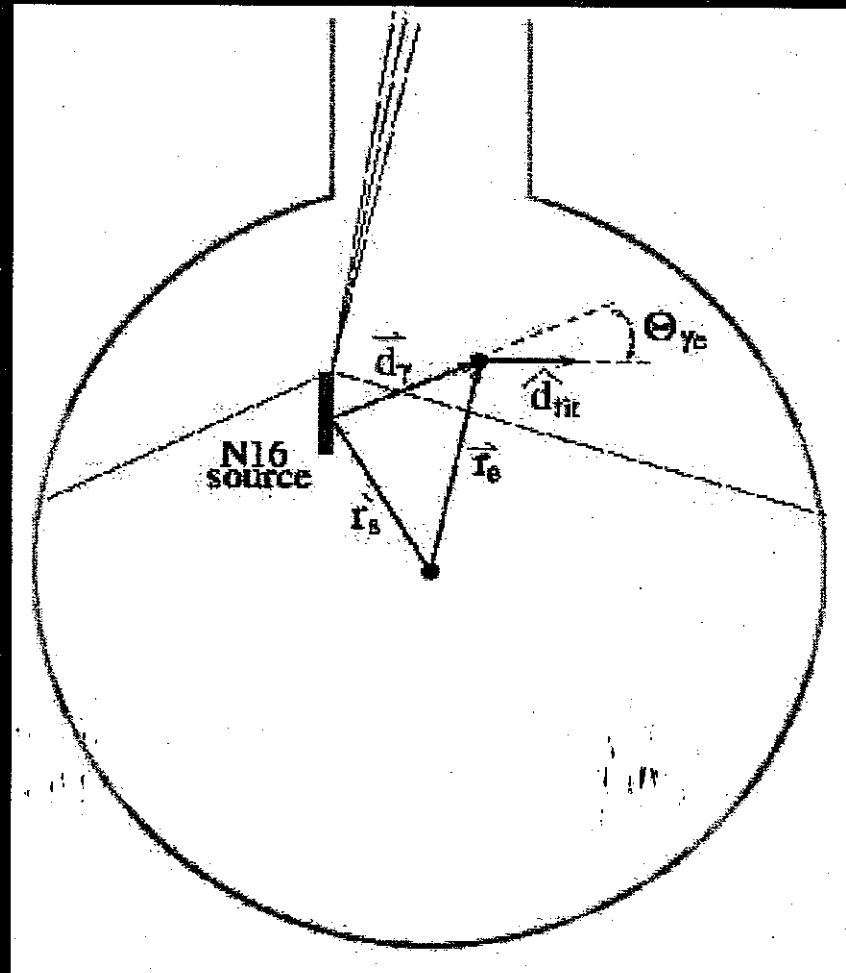


$^{252}\text{Cf}$  neutrons



$\beta$ 's from  $^8\text{Li}$   
 $\gamma$ 's from  $^{16}\text{N}$  and  $t(p,\gamma)^4\text{He}$

# Angular Resolution



# Backgrounds from the Data

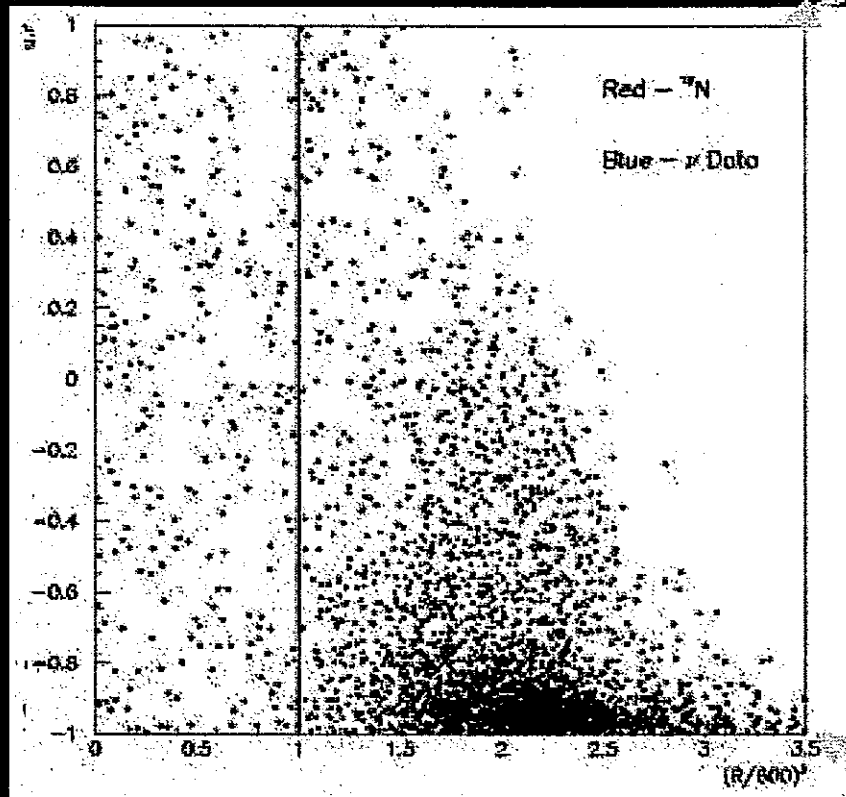
- External  $\gamma$ -ray background
- $\beta\gamma$  background from the AV
- $\beta\gamma$  background from the H<sub>2</sub>O
- $\beta\gamma$  background from the PMTs



# External $\gamma$ -ray background

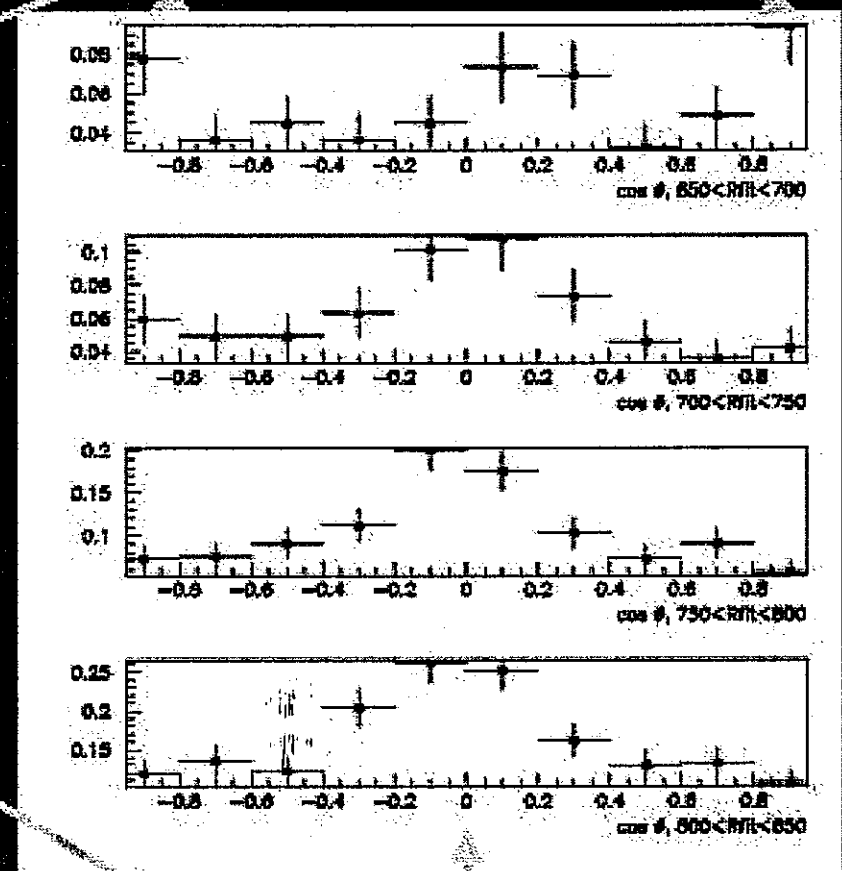
93

$\hat{u} \cdot \hat{r}$



$r^3$

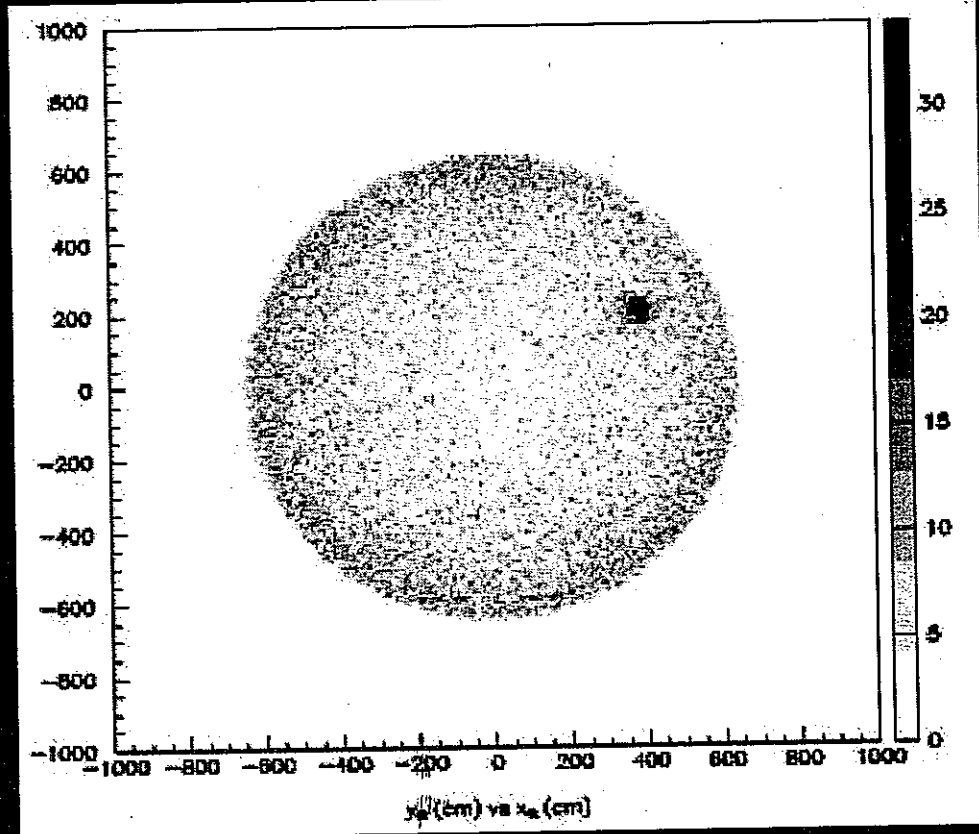
Outward going



Inward going

# Acrylic Vessel Assay

- Every piece sampled and tested
- Sample bonds tested
- Direct Assay by Cherenkov light



$\Delta V$  well below

( $\sim 1/10$ )

the target level of

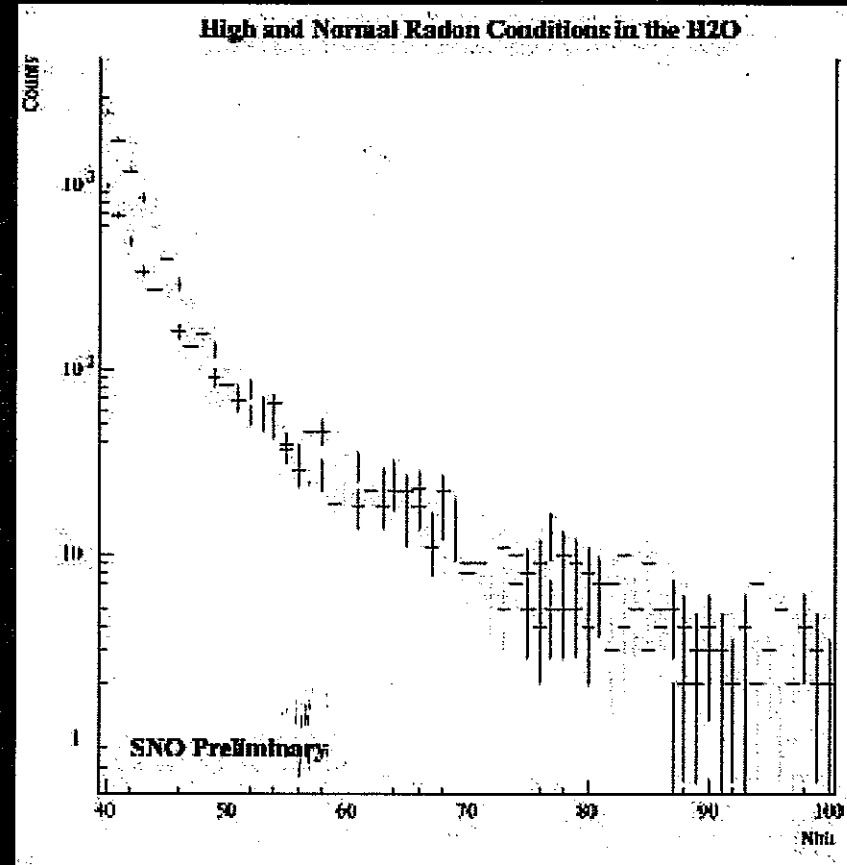
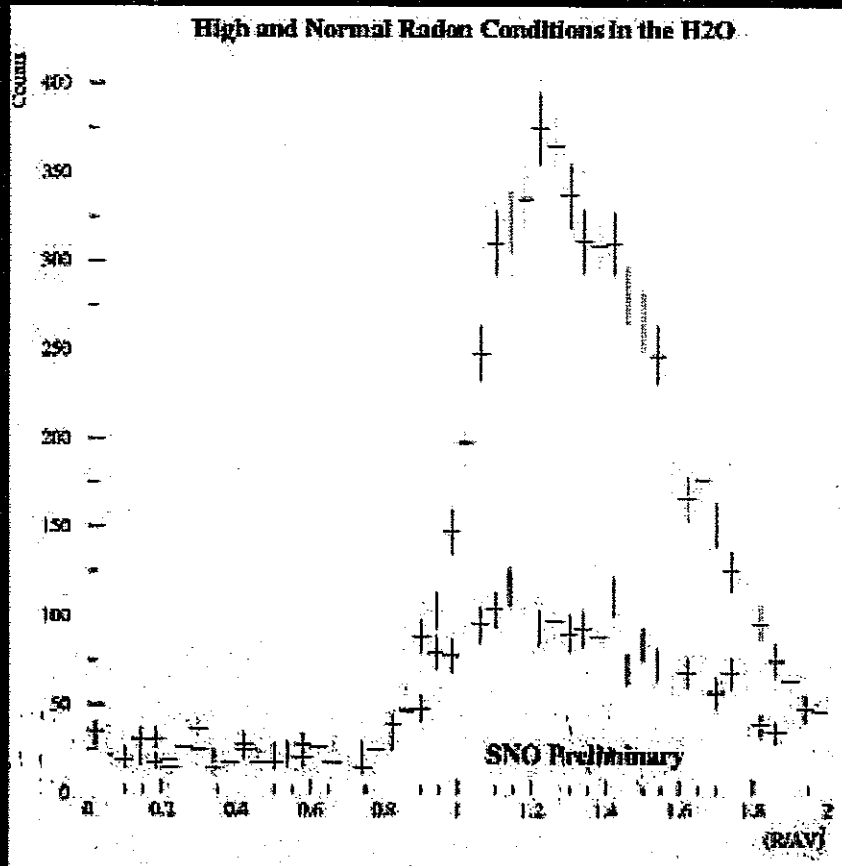
2 ppb U/Th

Berkeley Blob

$9^{+20}_{-5} \pm 3 \mu\text{g Th}$

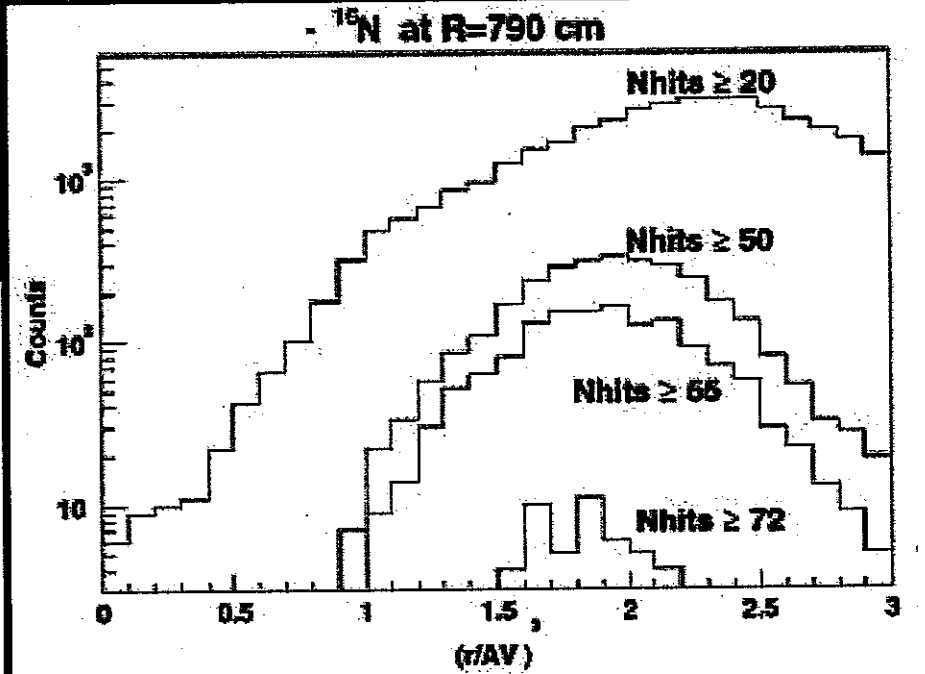
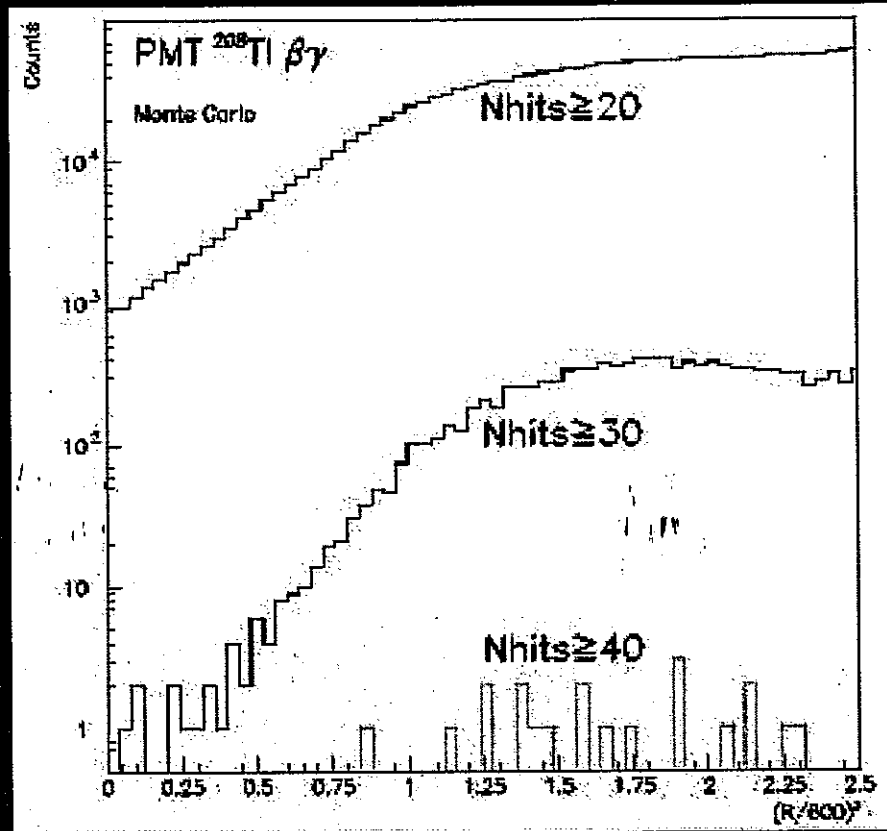
# H<sub>2</sub>O βγ background

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# PMT $\beta\gamma$ background

Expected to be small  
within D<sub>2</sub>O



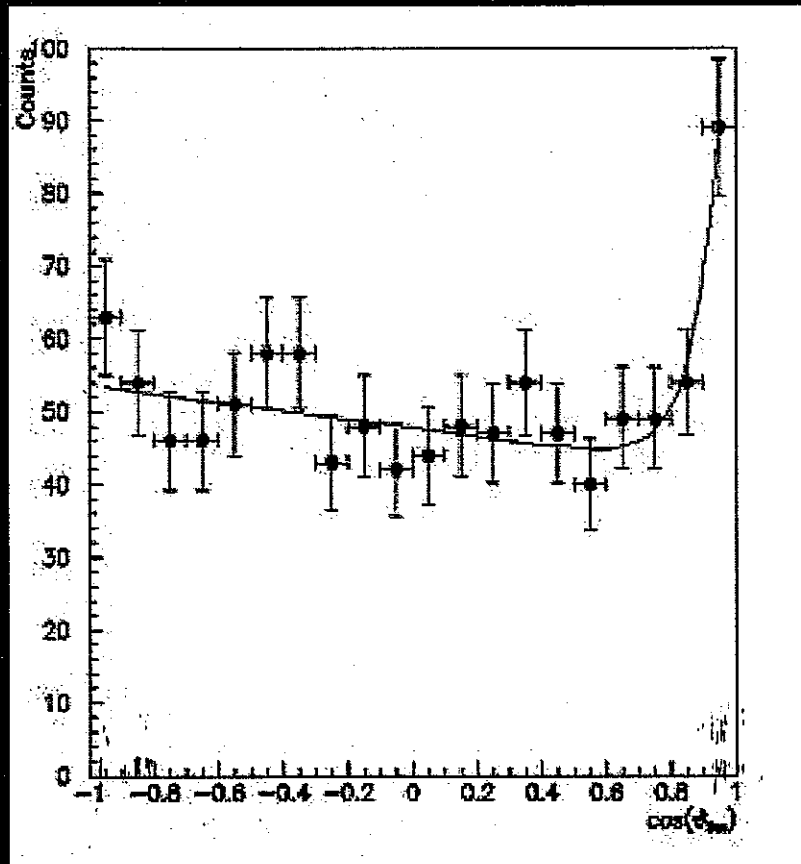
Checking with:  
 $^{16}\text{N}$   $\gamma$  tails  
Hot thorium source

# Backgrounds from the Data

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- **External  $\gamma$ -ray background**
- **$\beta\gamma$  background from the AV**
- **$\beta\gamma$  background from the H<sub>2</sub>O**
- **$\beta\gamma$  background from the PMTs**
- **$\beta\gamma$  background from the D<sub>2</sub>O.**

# SNO $\cos(\theta)_{\text{sun}}$ distribution

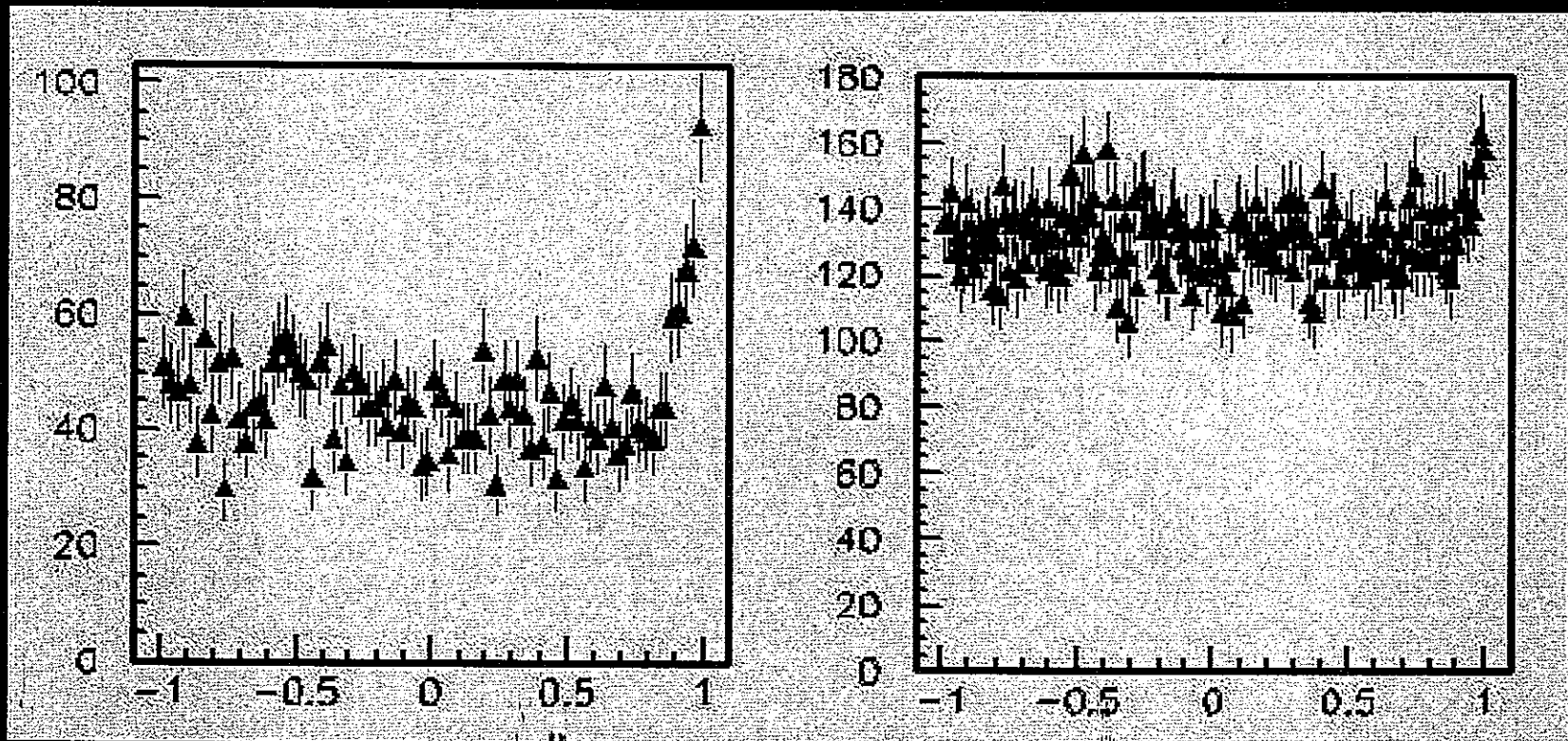


Directly towards  
the Sun

Directly away  
from the Sun

Electron Angle with respect  
to the direction from the Sun

# Low threshold $\cos(\theta)_{\text{sun}}$

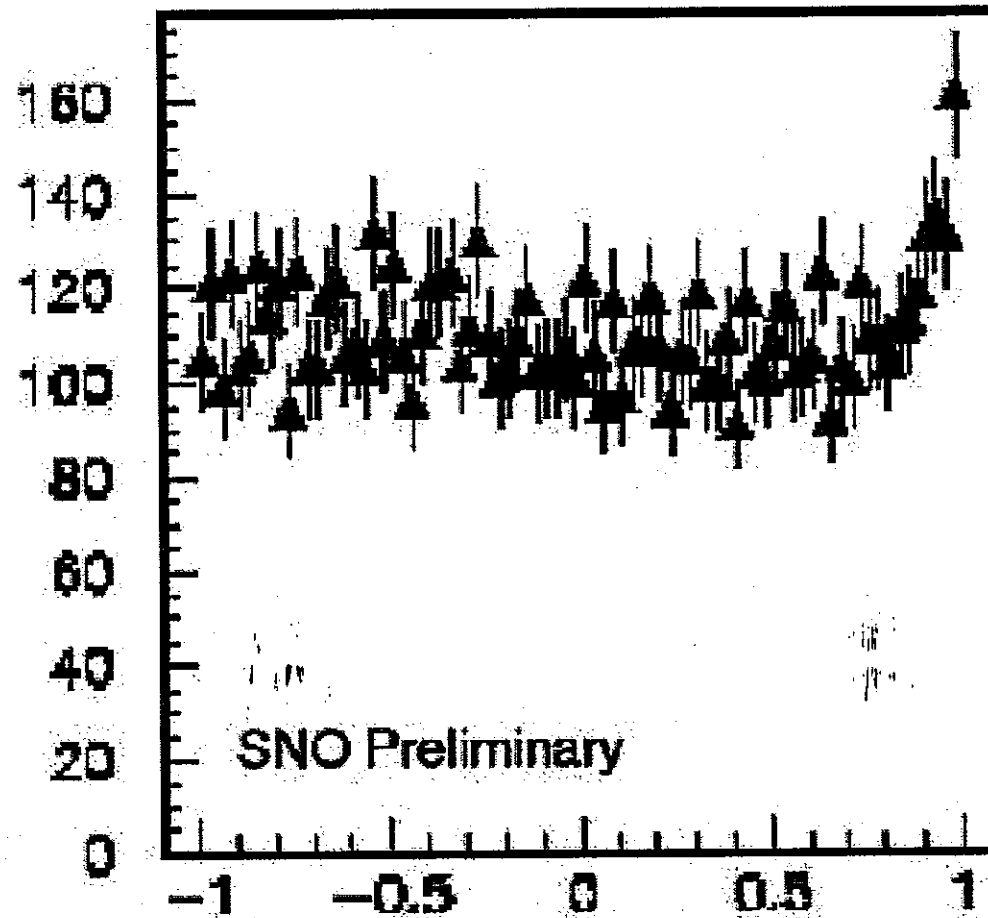


$E_{\text{thresh}} \sim 4.5 \text{ MeV}$

$E_{\text{thresh}} \sim 3.5 \text{ MeV}$

$\sim 4.0 \text{ MeV } \cos(\theta)_{\text{sun}}$

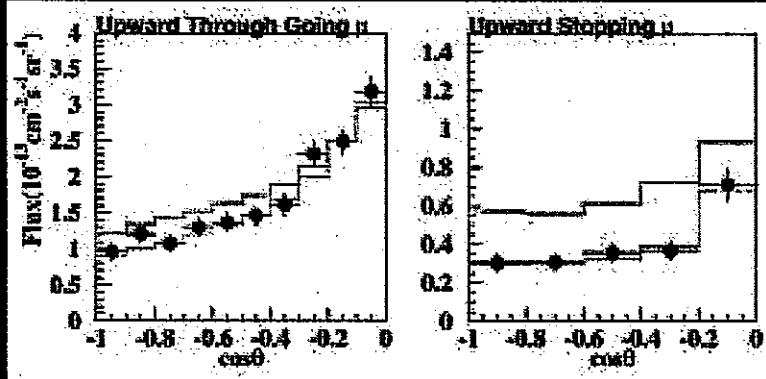
$\sim 4.0 \text{ MeV Threshold}$



100



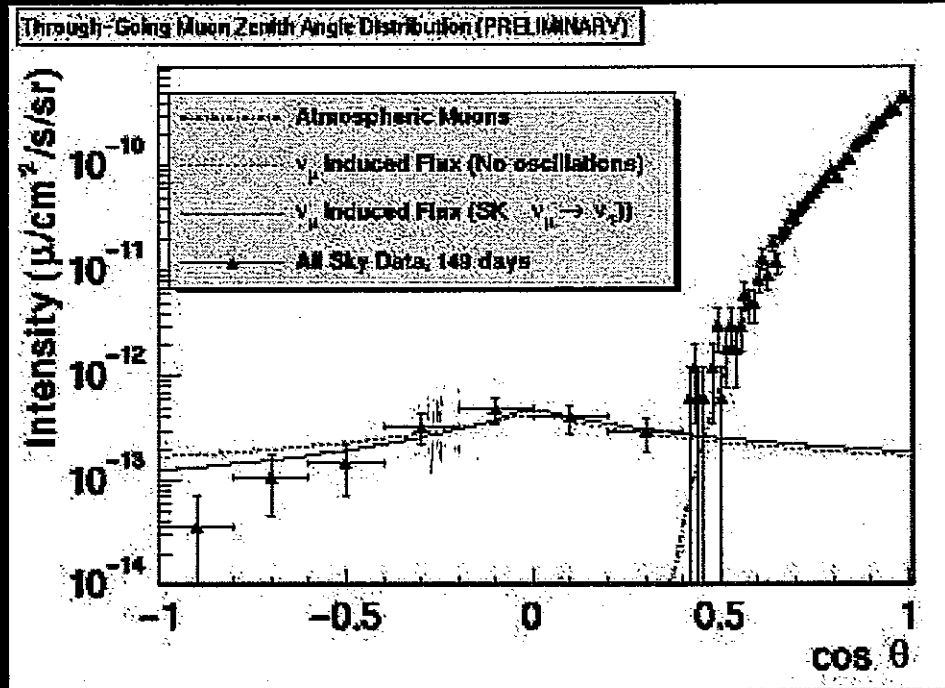
# Thru muons



← Supporting evidence from thru  $\mu$

Also seen by Soudan, Macro

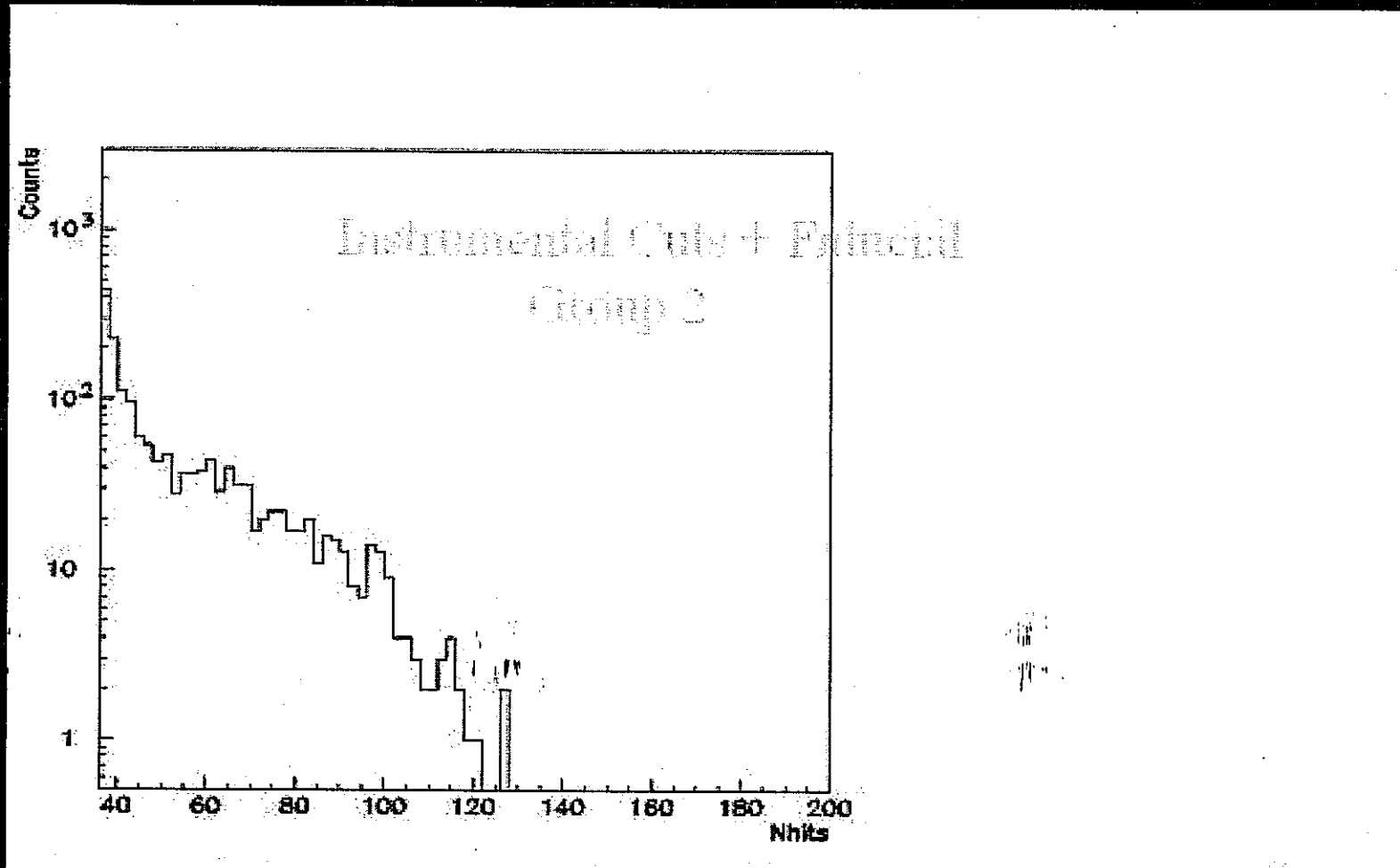
Evidence from SNO, but statistically limited →



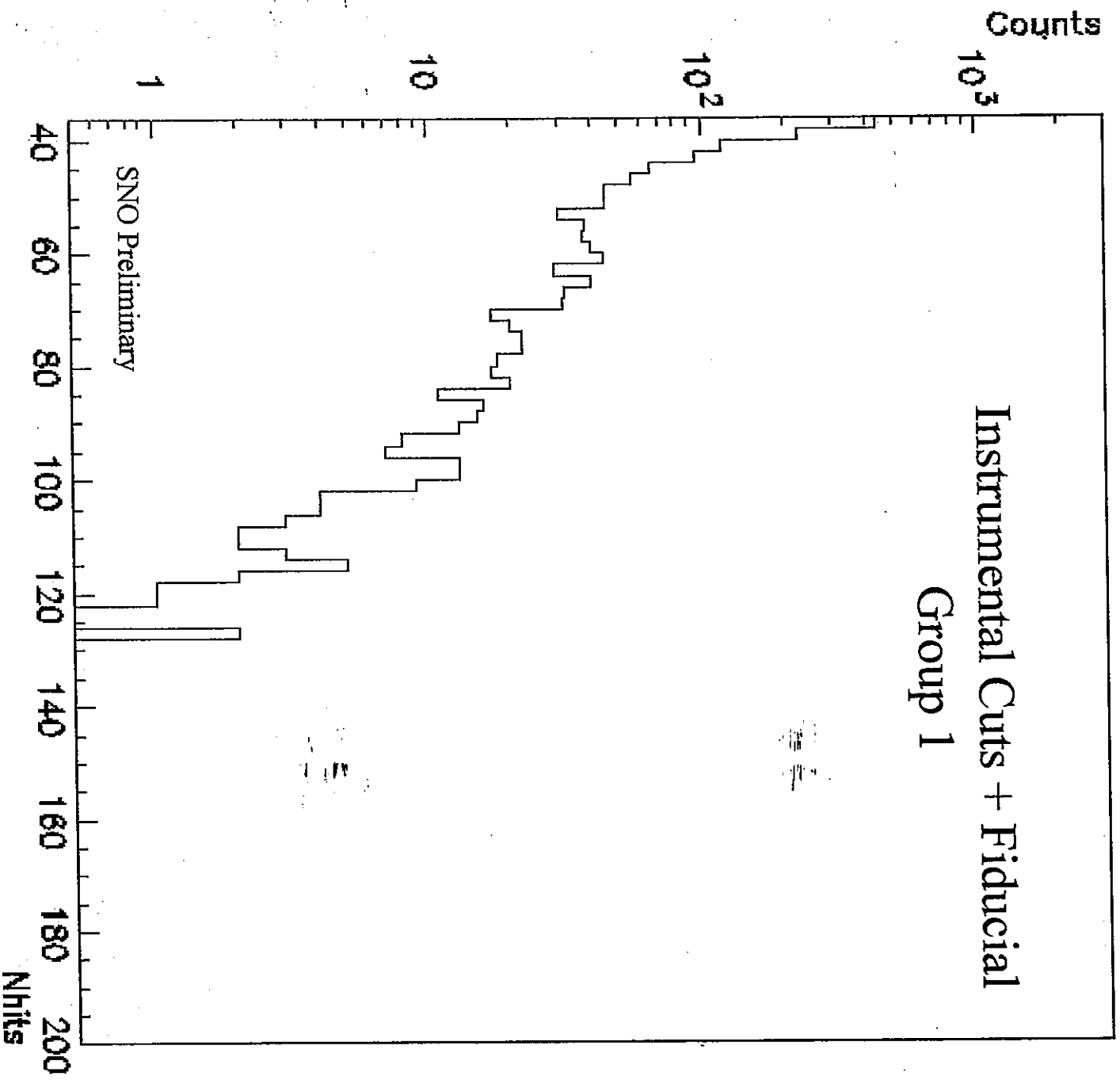
# Conclusions

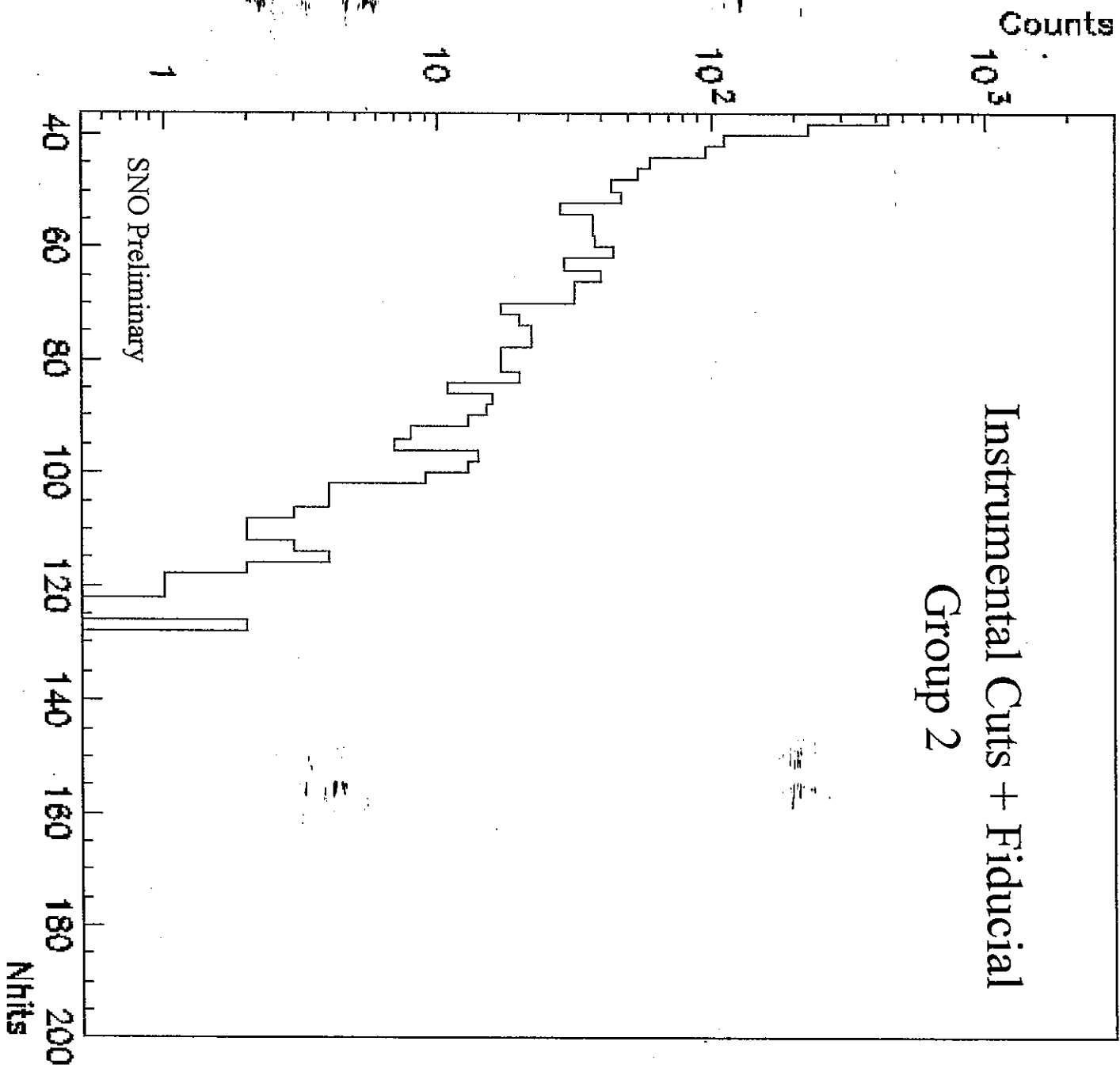
- **The SNO detector is taking beautiful data.**
- **The first phase of the experiment has been completed!**
- **Analysis is proceeding and first results should be soon.**
- **Day/Night, NC in pure  $D_2O$ , other results to follow.**
- **Stay tuned.....**

# First pass comparison



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100

100

100

100

100

100

100

100