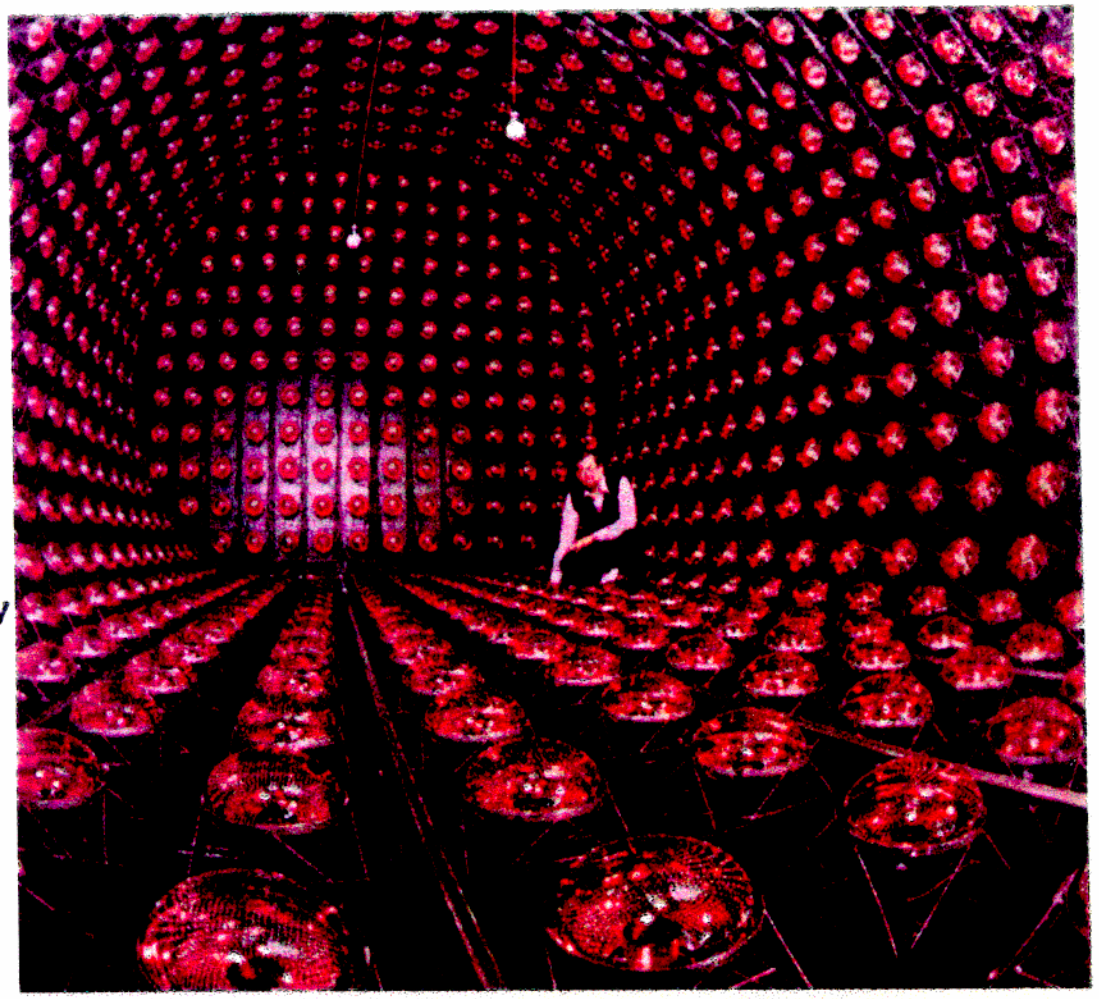
Results From LSND

- LSND results
- The BooNE proposal
- see www.neutrino.lanl.gov



G. Mills, SSI 1998

The LSND Collaboration

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G. Mills, SSI 1998

Generic Neutrino Oscillation Measurement

Step 1: Prepare a beam of neutrinos whose flavor composition is well determined

flux determination

Step 2: Measure the beam composition as a function of L (distance to the source) and neutrino energy.

cross section, detection efficiency, backgrounds

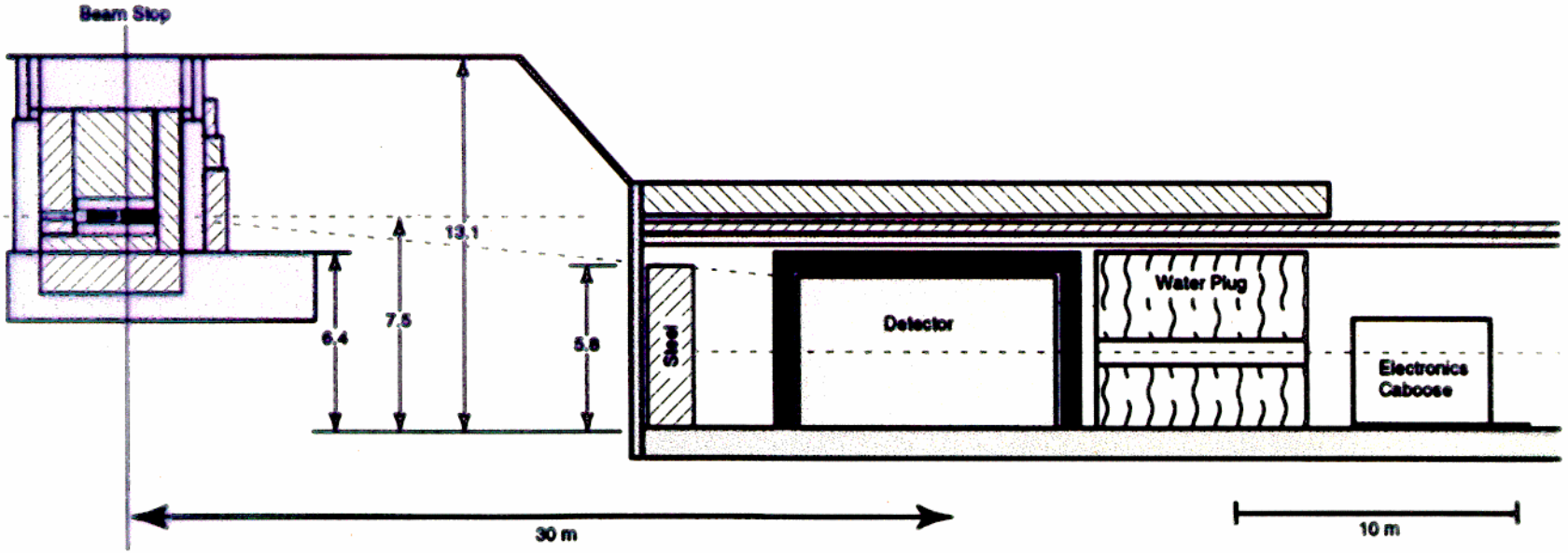
Step 3: Determine if flavor composition changes as expected for neutrino oscillations

$$P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e) = \sin^2(2\theta)\ \sin^2\left(1.27\ \Delta m^2 \frac{L}{E_\nu}\right)$$

G. Mills, SSI 1998

Neutrino production:

- Neutrino production area: 800 MeV protons @ 1mA
- ~ 0.1 pion/proton, water target, Fe sheilding
- π^+/π^- production ~ 8, π^+ decay while π^- are absorbed
- $\nu_e/\nu_\mu < 7.5 \times 10^{-3}$



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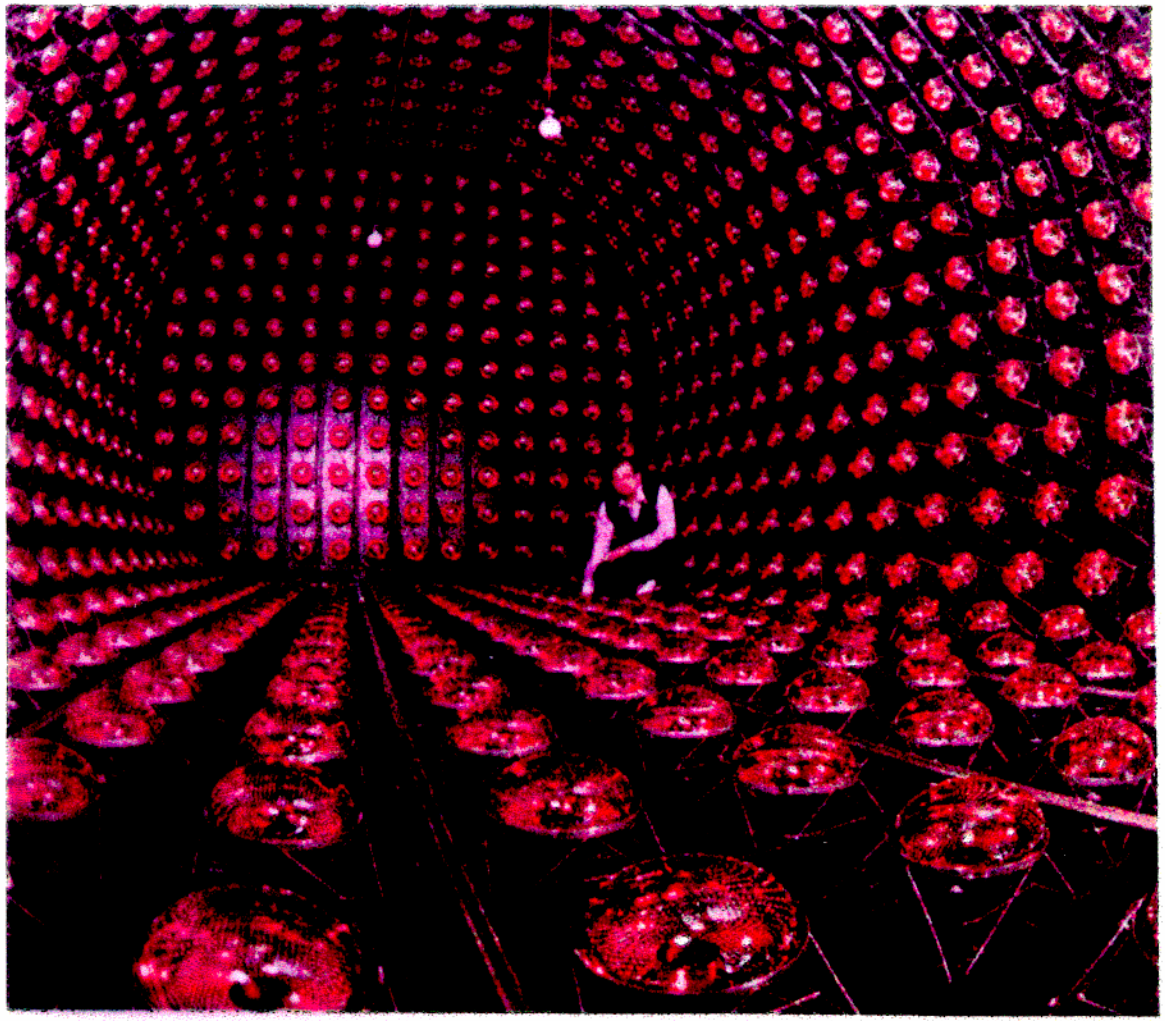
The LSND Dectector



- 167 tons of mineral oil ($n\text{-}CH_2$) as target
- Cherenkov Light + Scintillation Light
- 1220 20cm diameter PMT's
- Cosmic ray backgrounds measured in beam-off data (93%)

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Electron Neutrino Charged Current Cross Sections (DAR)

Exclusive:

$$\nu_e\ {}^{12}C \rightarrow e^-\ {}^{12}N_{G.S.}\ , \qquad {}^{12}N_{G.S.} \xrightarrow{\tau = 15.9ms} {}^{12}C\ e^+\ \nu_e$$

(515 excess events)

$$\sigma_{measured} = (9.1 \pm 0.4 \pm 0.9) \times 10^{-42}\ cm^2$$

$$\sigma_{theory} = 9.3 \times 10^{-42}\ cm^2$$

Inclusive:

$$\nu_e\ {}^{12}C \rightarrow e^-\ {}^{12}N^*\ \ and\ \ \nu e^- \rightarrow \nu e^-$$

(660 excess events)

$$\sigma_{measured} = (5.7 \pm 0.6 \pm 0.6) \times 10^{-42}\ cm^2 \qquad \sigma_{measured} = (4.2 \pm 0.6 \pm 0.4) \times 10^{-42}\ cm^2$$

$$\sigma_{theory} = 6.3 \times 10^{-42}\ cm^2 \qquad \sigma_{theory} = 3.97 \times 10^{-42}\ cm^2$$

G. Mills, SSI 1998

Muon Neutrino Charged Current Cross Sections (DIF)

Exclusive:

$$\nu_\mu \; {}^{12}C \rightarrow \mu^- \; {}^{12}N_{G.S.}$$

(56.8 excess events)

$$\sigma_{measured} = (6.6 \pm 1.0 \pm 1.0) \times 10^{-41} \, cm^2$$

$$\sigma_{theory} = 6.4 \times 10^{-41} \, cm^2$$

Inclusive:

$$\nu_\mu \; {}^{12}C \rightarrow \mu^- \; {}^{12}N^*$$

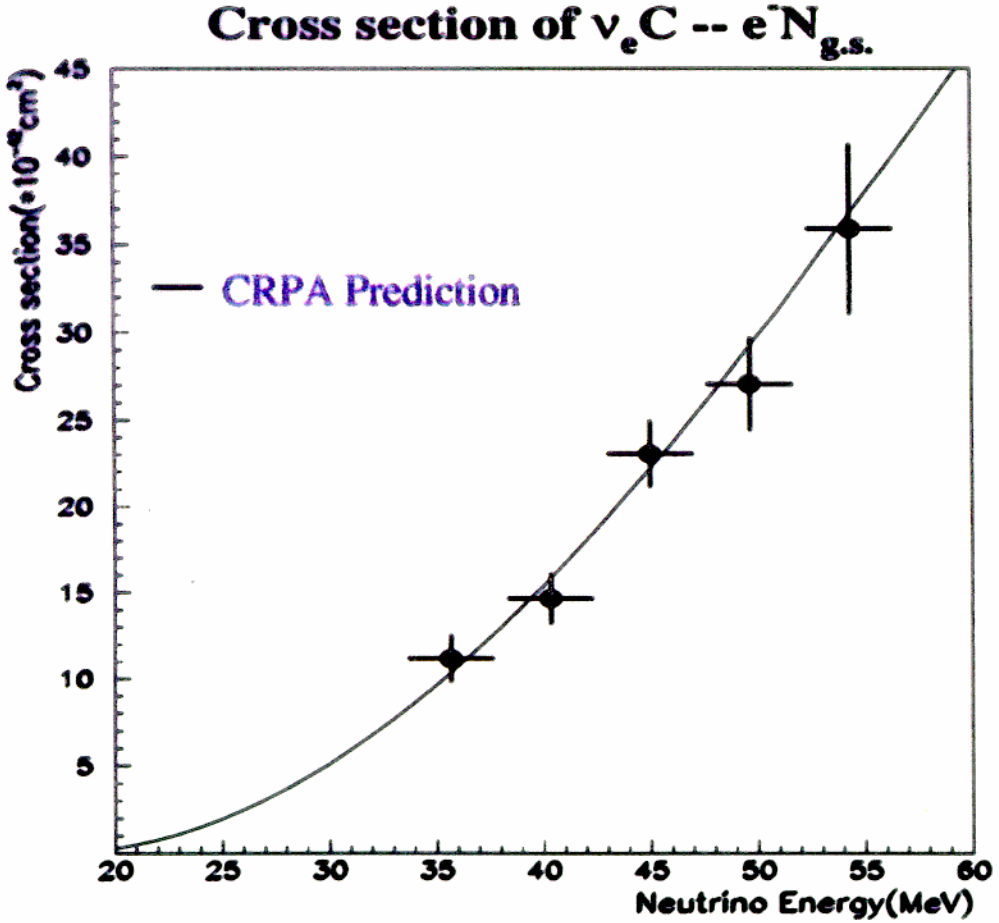
(1738 excess events)

$$\sigma_{measured} = (11.2 \pm 0.3 \pm 1.8) \times 10^{-40} \, cm^2$$

$$\sigma_{theory} = 20.5 \times 10^{-40} \, cm^2$$

G. Mills, SSI 1998

$$\nu_e \; {}^{12}C \rightarrow e^- \; {}^{12}N_{G.S.}\,, \qquad {}^{12}N_{G.S.} \xrightarrow{(\tau=15.9ms)} {}^{12}C \; e^+ \; \nu_e$$



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Decay at Rest Oscillation Search

$$\bar{\nu}_\mu \xrightarrow{\text{oscillation}} \bar{\nu}_e$$

$$(L \approx 30m)$$

$$\bar{\nu}_e \; p \rightarrow e^+ + n$$

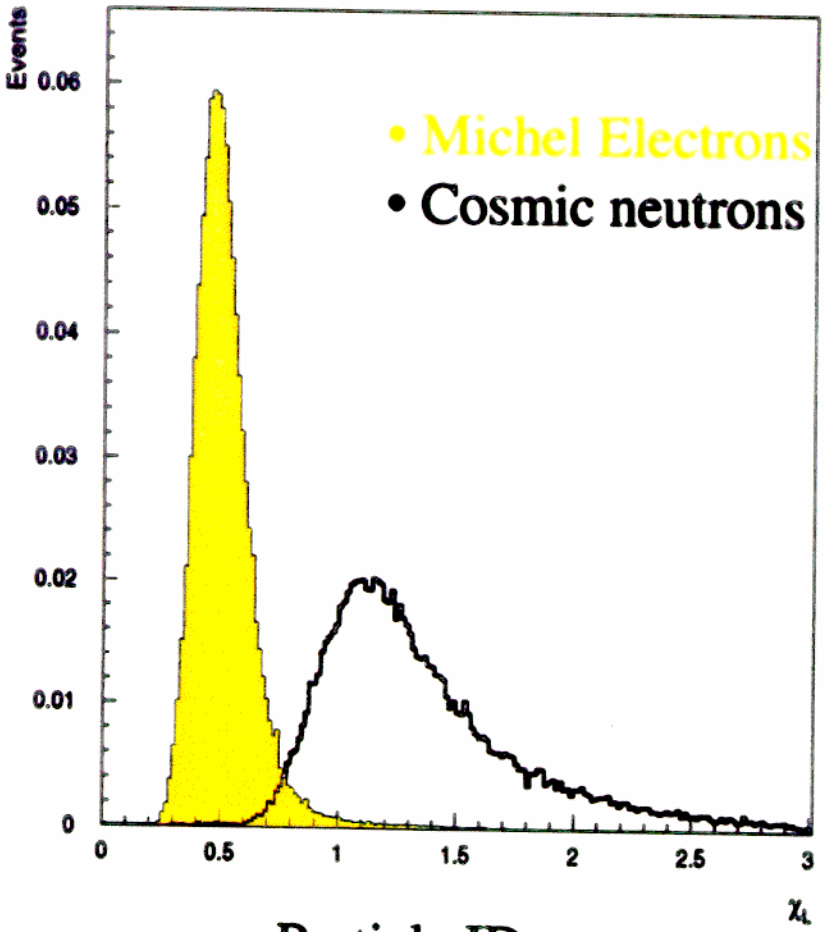
$$\downarrow \; (\tau_{capture} = 186\mu s)$$

$$n \; p \rightarrow d + \gamma \; (2.2\,MeV)$$

- **Event Selection :** (Efficiency = 37% without R cut)
  - Positron identification: χ_1
  - Correlated photon identification R
  - Positron Energy:
    - 20 MeV - 60 MeV (high acceptance)
    - 36 MeV - 60 MeV (low background)

LSND Electron/Positron Particle Identification

- Criteria:
  - Cherenkov Ring (χ_a)
  - Late Light (χ_t)
  - Vertex quality (χ_r)
  - $\chi_l = \chi_a \chi_t \chi_r$



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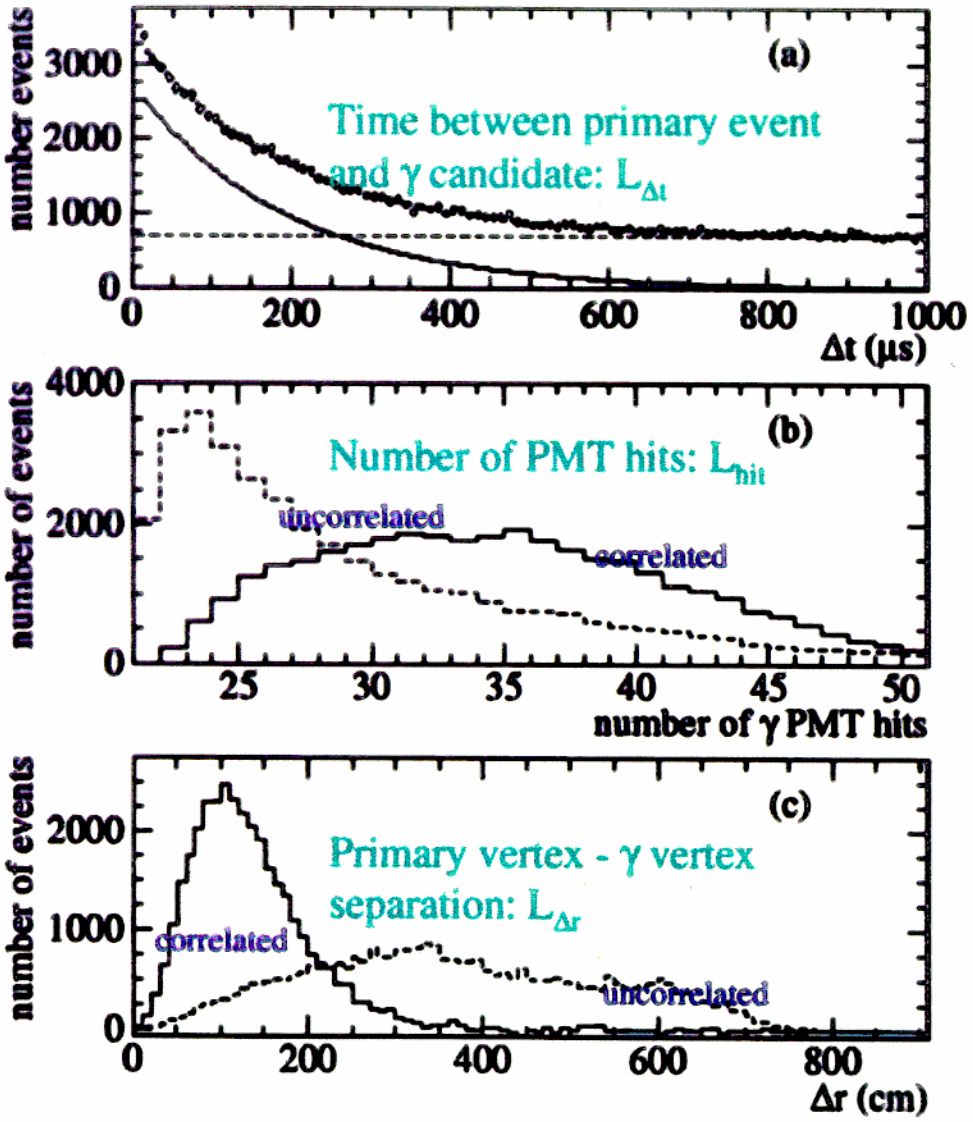
Definition of R:

(Correlated γ ID)

$$R \equiv \frac{\left[L_{\Delta t} L_{\Delta r} L_{hits}\right]_{correlated}}{\left[L_{\Delta t} L_{\Delta r} L_{hits}\right]_{uncorrelated}}$$



LSND Neutrino Physics

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Neutrino Induced Backgrounds: ($20<E_{positron}<60$ MeV)

		R ≥ 0	R > 30
With Neutrons			
$\bar{\nu}_e p \rightarrow e^+ n$	μ^- DAR	12.9 ± 2.1	3.0 ± 0.5
$\bar{\nu}_\mu p \rightarrow \mu^+ n$ and			
$\bar{\nu}_\mu {}^{12}C (\bar{\nu}_\mu {}^{12}C) \rightarrow \mu X$	π^- DIF	5.0 ±2.2	1.2 ± 0.5
Total		17.9 ± 3.5	4.2 ± 0.7
Without Neutrons			
$\nu_\mu C \rightarrow \mu^- X$	π^+ DIF	15.0 ± 6.4	0.1 ± 0.1
$\nu_e {}^{12}C \rightarrow e^- {}^{12}N$	μ^+ DAR	999 ± 162	6.0 ± 1.0
$\nu_e {}^{12}C \rightarrow e^- {}^{12}N$	μ^+ DAR	69± 11	0.5 ± 0.1
$\nu e \rightarrow \nu e$	μ^+ DAR	85 ± 7.3	0.5 ± 0.1
$\nu e \rightarrow \nu e$	π^+ DIF	11.2 ± 2.0	0.1 ± 0.1
$\nu_e C \rightarrow e^- X$	π DIF	6.8 ± 1.2	
$\nu_\mu C \rightarrow \pi^0 X$	π^- DIF	0.4 ± 0.11	
$\nu_e C \rightarrow e^- X$	π^+ DIF	1.2 ± 0.2	
Total		1188 ± 148	4.8 ± 0.8
Grand Total		1206 ± 148	11.5 ± 0.5

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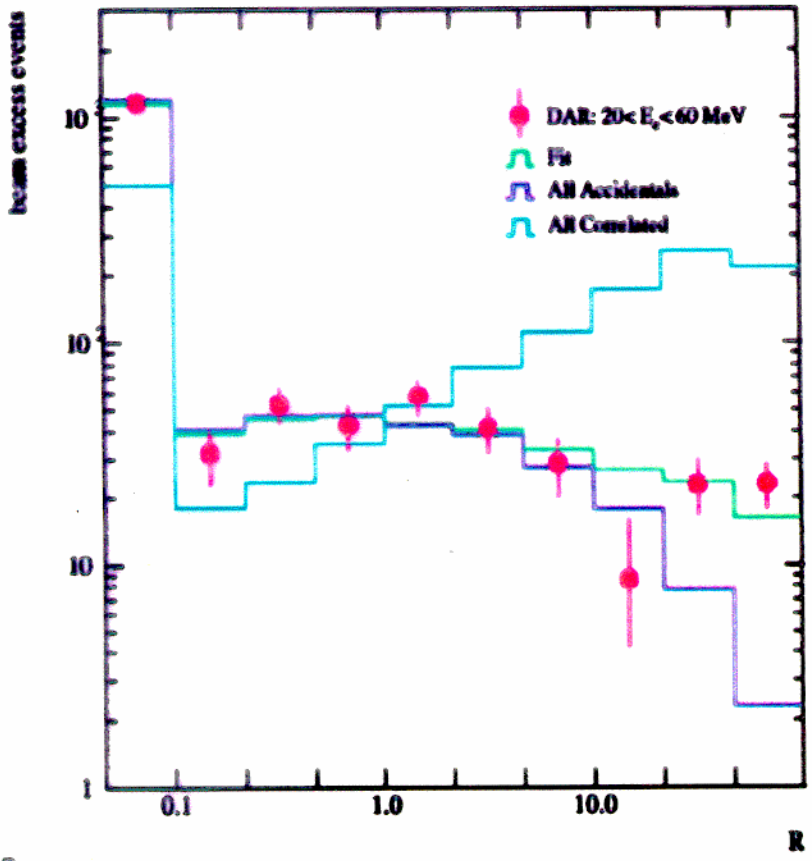
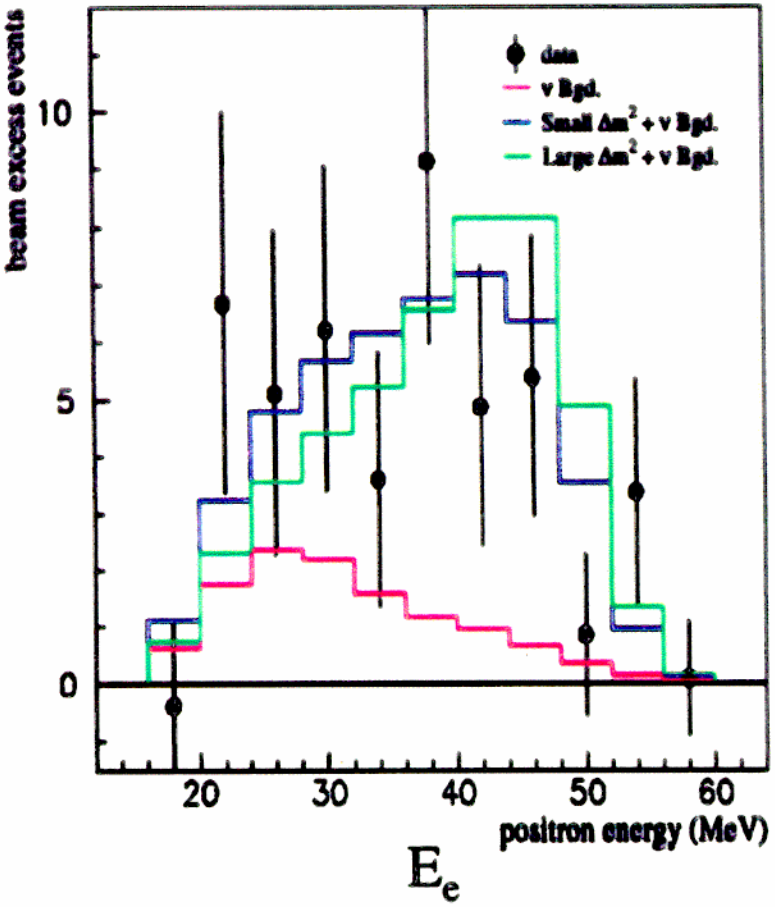
DAR R and energy distributions:

$20<E_e<60$



R

R>30



E_e

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1993-1997 DAR Preliminary Results:

Selection	Beam On	Beam Off	ν background	Excess
"Golden" E>36, R>30	29	5.2 ± 0.6	3.0 ± 0.6	20.8 ± 5.4
"Loose" E>20, R>30	61	15.6 ± 1.0	11.5 ± 1.5	33.9 ± 8.0

Fitting the R distribution:

$$P_{oscillation} = 0.31 \pm 0.09 \pm 0.05$$

G. Mills, SSI 1998

Decay-in-Flight Search

$$\pi^+ \rightarrow \nu_\mu \mu^+ : \quad \nu_\mu \xrightarrow{\text{oscillation}} \nu_e : \quad \nu_e\, {}^{12}C \rightarrow e^- X$$

- Low Backgrounds:

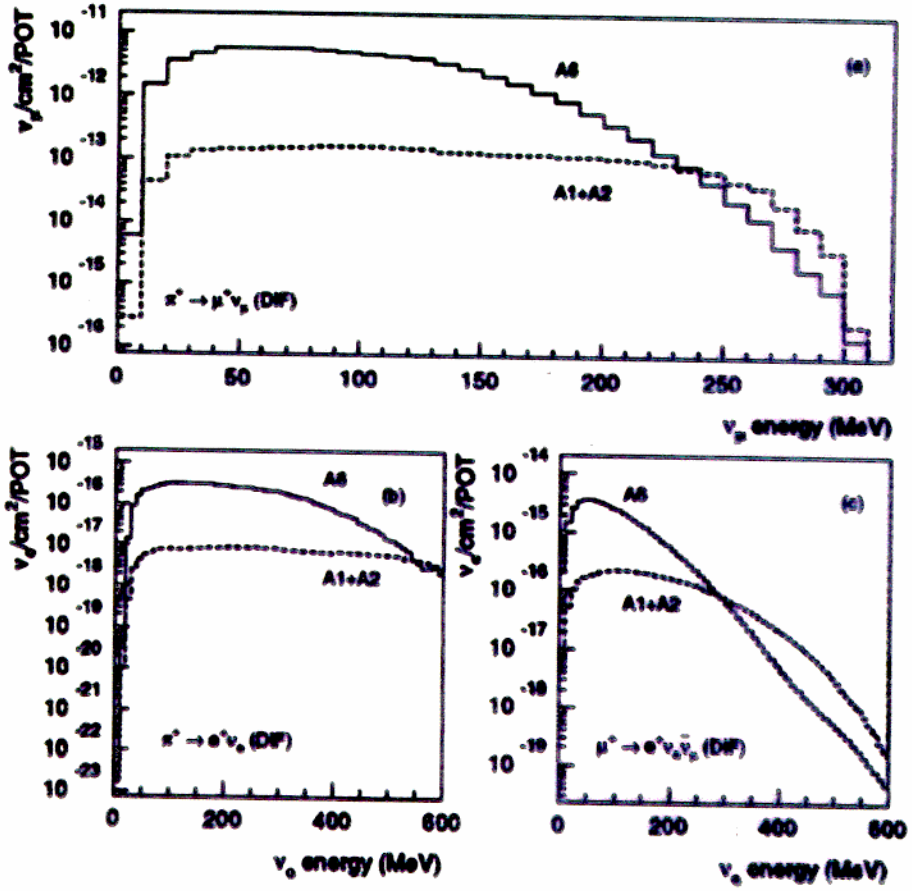
  $\pi^+ \rightarrow \nu_e e^+, \quad BR \approx 10^{-4}$

  $\mu^+ \rightarrow \nu_e e^+ \bar{\nu}_\mu: \qquad c\tau_\mu >> c\tau_\pi >> L_{Decay} \Rightarrow \dfrac{N_{\nu_e}}{N_{\nu_\mu}} \approx \dfrac{1}{2}\dfrac{L}{c\tau_\mu \gamma_\mu} \approx 10^{-3}$

- Reduce cosmic-ray backgrounds:
  - electron ID
  - fiducial volume
- Subtract cosmic-ray component of beam-on using beam-off data
- Calculate beam related backgrounds

DIF Neutrino Flux

- 3 targets:
  - A1/A2 (~100m)
  - A6 (~30m)
- π^+ chain dominates
- Backgrounds:
  - μ^+ DIF (ν_e)
  - π_{e2} (ν_e)



Event Selection

- **Final selection:**
  - **Amount of light in Cerenkov cone** — cosmic neutrons/muons
  - **Electron identification likelihood** — cosmic neutrons /muons
  - **Depth event traveled into detector volume** — cosmic γ (π^0 decay)
  - **Veto shield activity** — cosmic neutrons/ muons
  - **cos θ with respect to incident ν direction** — ν–e elastic

Results of Event Selections

Sample	On(Off)	Backgrounds (Cosmic)	Backgrounds (Neutrino)	Eff.	Osc. Prob.	Fluct. Prob
A	23(114)	8.0±0.7	4.5 ±0.9	0.084	$(2.9 \pm 1.4) \times 10^{-3}$	7.0×10^{-3}
B	25 (92)	6.4±0.7	8.5 ±1.7	0.138	$(1.7 \pm 0.9) \times 10^{-3}$	1.6×10^{-2}

Conclusion: Event excess not explained by backgrounds at >98% CL in each analysis

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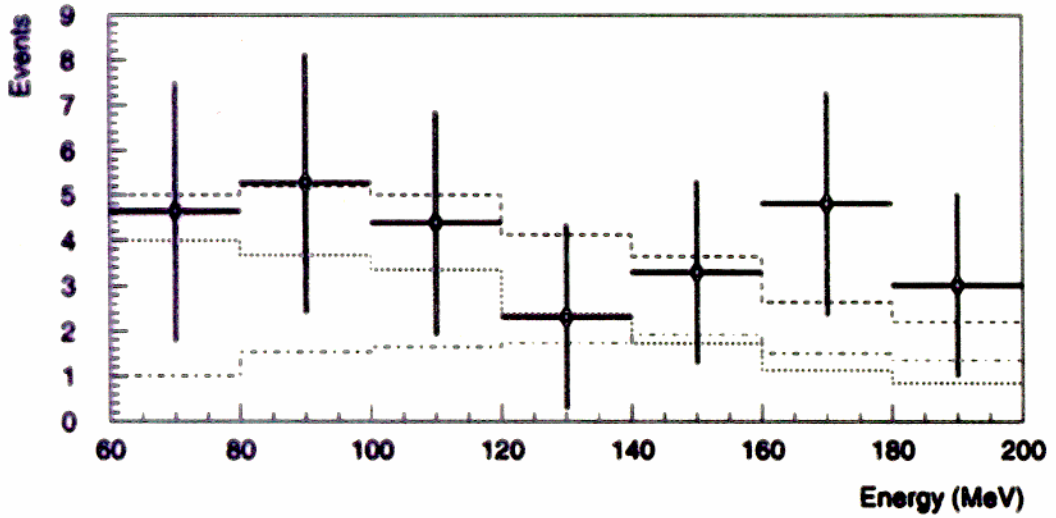
Event Electron Energy (OR)



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LSND Measurement Comparison

Process	Flux	σ_ν	efficiency	Backgrounds
$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	μ^+ DAR	inverse β decay	Michel electrons (χ_l)	small for R>30
	$\nu_e\,^{12}C$	$\nu_e p \rightarrow e^+ n$	cosmic neutrons (R)	
$\nu_\mu \rightarrow \nu_e$	π^+ DIF (MC)	$\nu_e\,^{12}C \rightarrow e^+\,^{12}N^*$	MC calculation	$\nu_e\,^{12}C \rightarrow e^+\,^{12}N^*$
	$\nu_\mu\,^{12}C \rightarrow \mu^+\,^{12}N_{GS}$		60-200 MeV electrons	

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DAR Likelihood Fit

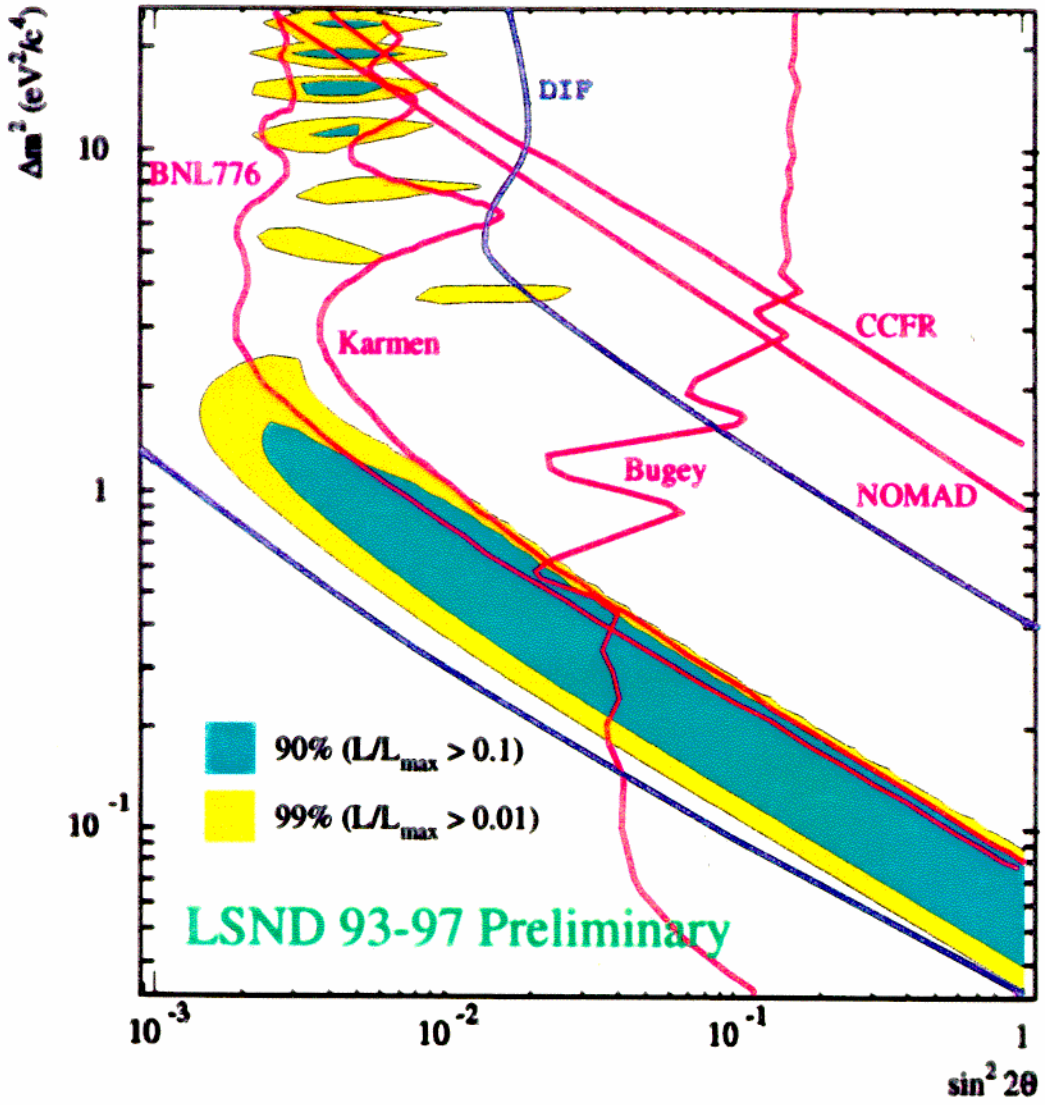
- 2 Generation Model

$$P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e) = \sin^2(2\theta)\ \sin^2\left(1.27\ \Delta m^2 \frac{L}{E_\nu}\right)$$

- Poisson likelihood region from 70000 bins in:
  - L
  - $E_{positron}$
  - R
  - $\cos(\theta_{positron})$

DIF Confidence Region

- Poisson confidence region from four bins in:
  - $E_{electron}$



G. Mills, SSI 1998

Summary of LSND Oscillation Results

- Present:
  - DAR analysis complete 1993-97
  - DIF analysis complete for 1993-95 data
  - Resulting excess events are consistent with oscillation hypothesis
- Future:
  - Global analysis of DAR/DIF/CC inclusive electron data from 18-400 MeV is underway
    - ~ 50% increase in fiducial acceptance
    - improved reconstruction/R/electron ID (x 2)
  - 3 more months of running in 1998-1999 (25% increase)
  - BooNE experiment has been approved at FNAL
    - >1000 oscillation events per year
    - definitive study of LSND region
    - precise measurement of oscillation/mixing parameters, CP violation...