

## Short-baseline oscillation anomalies

### a) Reactor antineutrino anomaly

1980s/90s several reactor oscillation experiments  
at 10-100m baselines

→ found slight rate deficit relative to prediction

$$\frac{\langle R_{\text{obs}} \rangle}{R_{\text{pred}}} \approx 0.976 \pm 0.024 \rightarrow \text{not significant!}$$

→ no oscillation signal

2011 New analysis of rate predictions

- re-calculation of  $\bar{\nu}_e$  spectrum by  $\beta$  spectrum inversion using all available data on fission products  
→ shift of spectrum to higher energies ( $\sim 2\%$ )
  - inclusion of long-lived fission products  
→  $\bar{\nu}_e$  flux increase ( $\sim 1\%$ )
  - other effects on IBD cross-section  
(e.g. increase in neutron live time result)
- new prediction for  $R_{\text{pred}}^{\text{new}} \sim 1.04 R_{\text{pred}}^{\text{old}}$

⇒ larger deficit in observed rates:

$$\frac{\langle R_{\text{obs}} \rangle}{R_{\text{pred}}^{\text{new}}} = 0.943 \pm 0.023 \quad (\sim 3\sigma \text{ significance})$$

Short-baseline disappearance oscillations of  $\bar{\nu}_e \rightarrow \bar{\nu}_s$ ?

$l_{\text{osc}} \lesssim 10\text{m}$  (no spectral distortion / oscillation found)

$$E(\bar{\nu}_e) = \mathcal{O}(1\text{MeV})$$

$$\hookrightarrow \Delta m_{41}^2 \gtrsim 1\text{eV}^2, \quad \sin^2 2\theta_{14} \sim 0.15$$

note: no conflict with current  $\theta_{13}$  experiments at  $\gtrsim 1\text{km}$   
→ near detectors used for normalization  
( $\sim 400\text{m}$ )

## b) Gallium anomaly

Solar neutrino experiments GALEX & SAGE



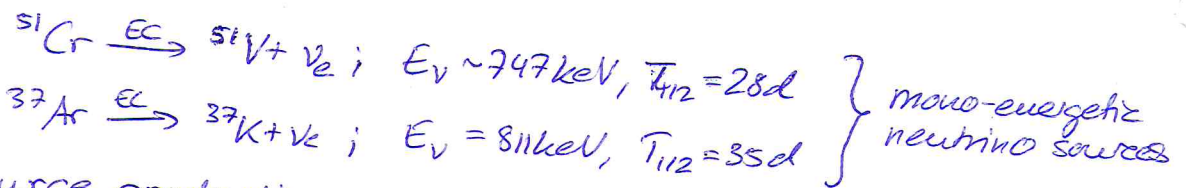
→ deficit in solar  $\nu_e$  rate observed

but: how accurate is calculation of cross-section?

→ independent test with  $\nu_e$  source of known flux

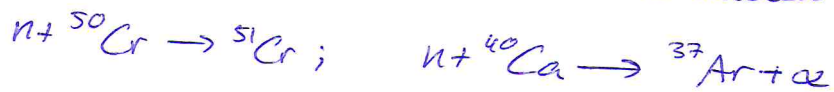
### Source calibration experiments

- Strong radioactive  $\nu_e$  source very close ( $l < 1 \text{ m}$ ) from detector
- used nuclides



- source production:

irradiation with thermal neutrons in a nuclear reactor



- initial activities:  $\mathcal{O}(1 \text{ MCi}) \hat{=} 3.7 \cdot 10^{16} \text{ Bq}$

- in total 4 measurements performed:

$$\frac{\langle R_{\text{obs}} \rangle}{R_{\text{pred}}} = 0.88 \pm 0.05 \quad (2.8\% \text{ deviation})$$

→ disappearance oscillations?

very short baselines,  $E_\nu \sim 800 \text{ keV}$

$$\rightarrow \sin^2_{41} 2\theta \sim 2 \text{ eV}^2, \quad \sin^2_{14} 2\theta \sim 0.4 ?$$

### c) LSND anomaly

Liquid Scintillator Neutrino Detector at Los Alamos (1993-98)

neutrino source: stopped pion beam  $\rightarrow \bar{\nu}_\mu \rightarrow \bar{\nu}_e$

- $\pi^\pm$  production by LE proton beam on fixed target with high-Z materials  
 $\rightarrow \pi$ 's stopped,  $\pi^-$  absorbed in nuclei ( $< 10^{-4}$ )
- $\pi^+$  decay-at-rest:  
 $\pi^+ \rightarrow \mu^+ \nu_\mu \rightarrow (e^+ \nu_e \bar{\nu}_\mu) \nu_\mu$ , no  $\bar{\nu}_e$ !
- "beam" energy: 0-55 MeV

neutrino detector:

- target: 167t of liquid scintillator
- distance to beam dump: 30m
- oscillation search: appearance  $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$

result

- excess found!  $(88 \pm 22_{\text{stat}} \pm 6_{\text{sys}}) \bar{\nu}_e$ -like events
- but: does not match known  $\Delta m^2$ 's!
- oscillation via new  $\Delta m^2$ ?

$$P_{e\mu} = \sin^2 \theta_{2\mu} \sin^2 2\theta_{14} \sin^2 \left( \frac{\Delta m_{41}^2 L}{4E} \right) ?$$

$$\text{with } \Delta m_{41}^2 \sim 1 \text{ eV}^2$$

d) MiniBooNE anomaly

Mini Booster Neutrino Experiment at Fermilab ( $\sim 2009$ )

objectives: test of LSND anomaly with

- higher  $\nu$  energies (1.6 GeV) and longer baseline (541 m), but same L/E
- both  $\nu$  and  $\bar{\nu}$  mode

neutrino source: conventional beam

detector: 800 t of mineral oil  
(Cherenkov effect + suppressed scintillation)

result: no excess observed for  $E_\nu > 475$  MeV  
(expectation for LSND anomaly)

but: 3.46 excess observed for  $E_\nu \in [300; 475]$  MeV  
corresponding  $\Delta m^2 \sim 1.7 \text{ eV}^2$

→ LSND + MiniBooNE compatible for  $\Delta m^2 < 1 \text{ eV}^2$  or  $\Delta m^2 > 3 \text{ eV}^2$ ,  
but not in between