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

$$\frac{\langle R_{obs} \rangle}{R_{pred}} \approx 0.976 \pm 0.024$$ → not significant!
→ no oscillation signal

2011 New analysis of rate predictions

- re-calculation of $\bar{\nu}_e$ spectrum by β spectrum inversion using all available data on fission products
  → shift of spectrum to higher energies (~2%)
- inclusion of long-lived fission productions
  → $\bar{\nu}_e$ flux increase (~1%)
- other effects on IBD cross-section (e.g. increase in neutron live time result)

→ new prediction for $R_{pred}^{new} \sim 1.04 \cdot R_{pred}^{old}$

⇒ larger deficit in observed rates:

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

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

$l_{osc} \lessapprox 10m$ (no spectral distortion / oscillation found)
$E(\bar{\nu}_e) = \mathcal{O}(1 MeV)$

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

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

b) Gallium anomaly

Solar neutrino experiments GALLEX & SAGE

ν_e detection: $\nu_e + {}^{71}Ga \rightarrow {}^{71}Ge + e^-$ ($E_{thr} = 233\,keV$)

→ deficit in solar ν_e rate observed

but: how accurate is calculation of cross-section?

→ independent test with ν_e source of known flux

Source calibration experiments

- strong radioactive ν_e source very close ($\ell < 1m$) from detector
- used nuclides

$${}^{51}Cr \xrightarrow{EC} {}^{51}V + \nu_e \, ; \quad E_\nu \sim 747\,keV, \; T_{1/2} = 28d$$
$${}^{37}Ar \xrightarrow{EC} {}^{37}K + \nu_e \, ; \quad E_\nu = 811\,keV, \; T_{1/2} = 35d$$

} mono-energetic neutrino sources

- source production:
  irradiation with thermal neutrons in a nuclear reactor

$$n + {}^{50}Cr \rightarrow {}^{51}Cr \, ; \qquad n + {}^{40}Ca \rightarrow {}^{37}Ar + \alpha$$

- initial activities: $\mathcal{O}(1MCi) \hat{=} 3.7 \cdot 10^{16}\,Bq$
- in total 4 measurements performed:

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

→ disappearance oscillations?

very short baselines, $E_\nu \sim 800\,keV$

→ $\Delta m^2_{41} \gtrsim 2\,eV^2$, $\sin^2 2\theta_{14} \sim 0.4$?

c) LSND anomaly

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

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

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

neutrino detector:

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

result

- excess found! $(88 \pm 22_{stat} \pm 6_{syst})$ $\bar{\nu}_e$-like events
- but: does not match known Δm^2's!
- oscillation via new Δm^2?
  $$P_{e\mu} = \sin^2\theta_{24} \sin^2 2\theta_{14} \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right) \quad ?$$
  with $\Delta m^2_{41} \sim 1\,\text{eV}^2$

d) Mini BooNE anomaly

Mini Booster Neutrino Experiment at Fermilab (~2009)

objectives: test of LSND anomaly with

→ higher ν energies (1 GeV) and longer baseline (541 m), but same L/E

→ both ν 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: 3.4σ excess observed for $E_\nu \in [300; 475]$ MeV
corresponding $\Delta m^2 \sim 1.7\,eV^2$

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