Pions, Protons & Gadolinium

Patrick Huber

Virginia Tech

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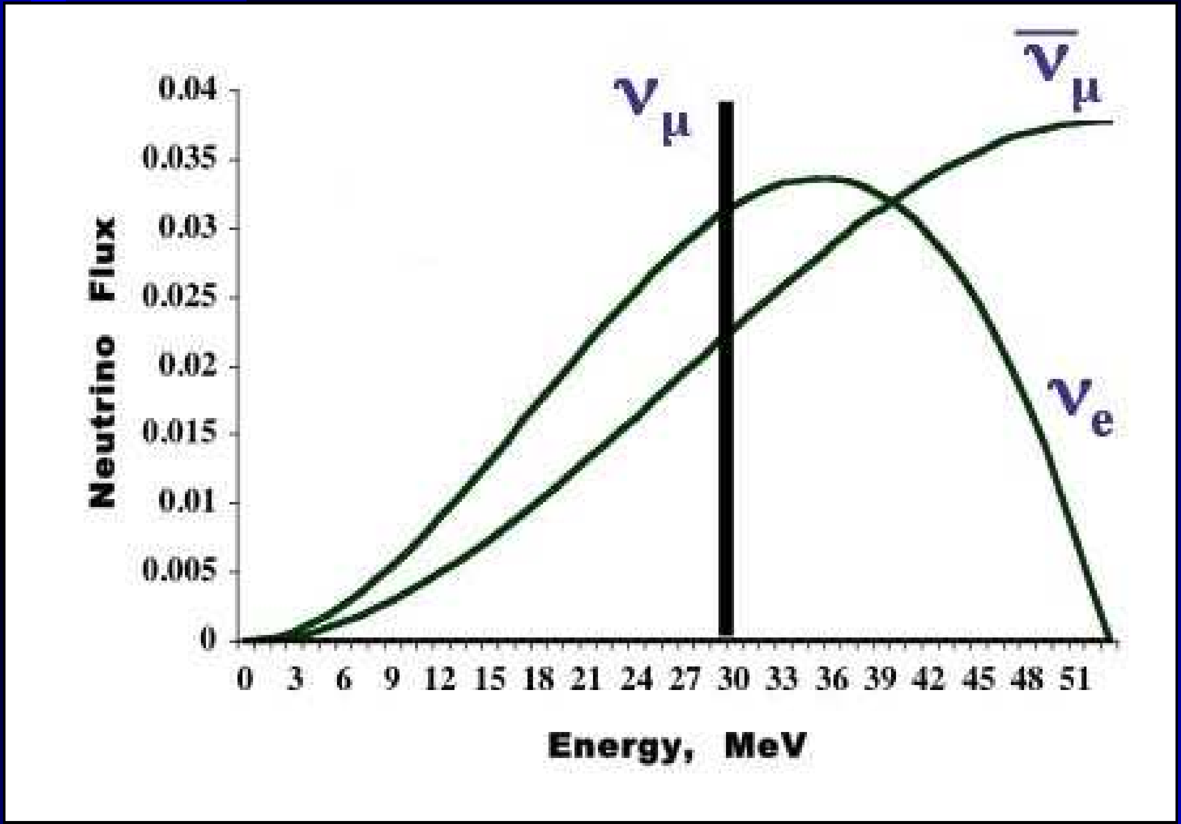
In this talk I will use Pions, Protons & Gadolinium to

- Test LSND, finally
- Study CP violation in active neutrinos

Stopped pion neutrino source



$p + X \rightarrow \pi^\pm + X'$

π^- absorbed in thick, high-Z target

$\pi^+ \rightarrow \mu^+ + \nu_\mu$
mono-energetic ν_μ

$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$
Michel spectrum

With proper target design $\bar{\nu}_e$ contamination can be kept below 10^{-3}, we will use 4×10^{-4} (LSND value).

Proton source

Obviously, the technological bottleneck is the production of a sufficiently intense proton beam with an energy of 1-2GeV.

Traditional techniques, e.g. superconducting LINACs, can provide multi-MW beams, but they are multi-G$ facilities.

Conrad & Shaevitz PRL 104:141802 (2010) pointed out that alternative accelerator technologies may exist which can deliver muli-MW beams at 1/100 of the cost.

We take this assumption at face value and assume that a multi-MW proton beam is affordable.

GADZOOKS – part A

Inverse β-decay is flavor selective reaction

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

and the positron energy is a direct measure of neutrino energy

In a water Cerenkov detector the positron is easily seen and its energy measured, but the neutron is invisible.

Adding about 0.1% in weight of Gadolinium with a neutron capture cross section of several 10,000barn will have a large fraction of neutrons capture on Gadolinium instead of capturing on protons.

GADZOOKS – part B

Why is capturing on Gd better than on p?

$$n + p \rightarrow^2 \mathrm{H} + 2.2\mathrm{MeV}\gamma$$

versus

$$n + \mathrm{Gd} \rightarrow \mathrm{Gd} + 8\mathrm{MeV}\gamma's$$

Now, if your detector happens to have a threshold around 5MeV, you see the capture on Gd but not on p.

The essential ingredient is the availability of affordable Gd salts which dissolve very well in water.

Beacom, Vagins, PRL 93:171101, (2004).

LSND reloaded

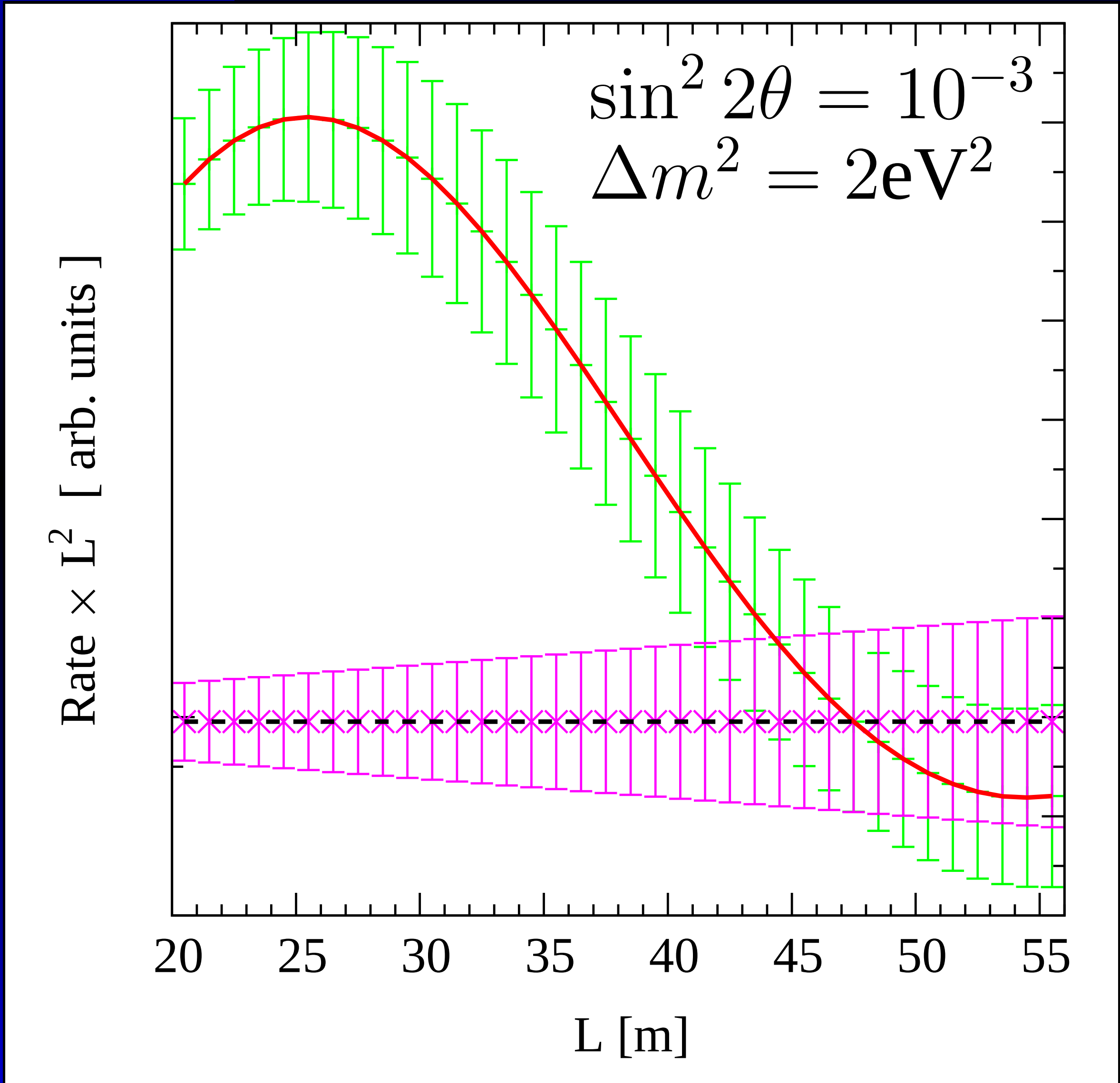
Agarwalla, PH, arXiv:1007.3228.

Super-Kamiokande + Gd

- The dimensions of SK's fiducial volume are so large, that LSND's whole source detector system would fit inside!
- SK is deep and thus has only very small cosmic background rate
- Event rates will be very large due large fiducial mass of 22.5kt vs 120t in LSND
- 300kW proton beam power are sufficient
- We assume the beam stop to be 20m away from the surface of SK, which should provide sufficient shielding against neutrons
- Can one put Gd into SK? – subject of ongoing study

. . .

L pattern in SK

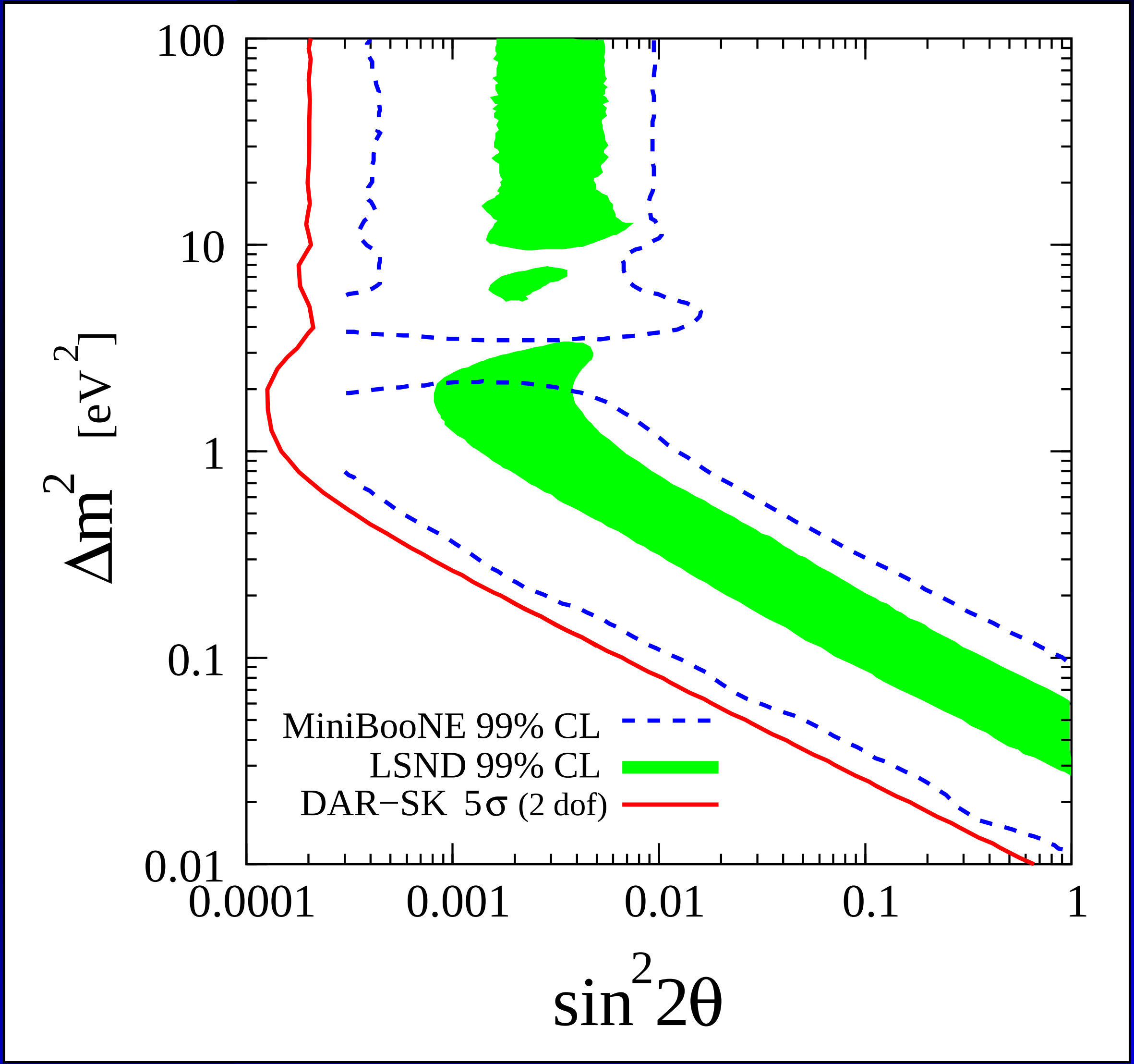


Beam stop size 0.5m & vertex resolution in SK 0.75m added in quadrature yields $\Delta x = 0.9$m. We use 1m bins.

Includes integration over the full beam spectrum from 20MeV upwards

Black: background
Red: oscillation signal

Sensitivity to sterile neutrinos



We cover the whole 99% CL region from both MiniBooNE and LSND at more than 5σ CL in one year

If a signal is seen, we know whether is oscillation or something else from L-dependence

LBNE & stopped pion beams

Agarwalla, PH, Link, Mohapatra, arXiv:1005.4055

Why?

- LBNE has to run neutrinos and anti-neutrinos in order to disentangle CP and matter effects
- LBNE may use a 200kt water Cerenkov detector, which could/should be doped with Gd
- Anti-neutrino run in a superbeam is difficult due to lower anti-neutrino production, lower detection cross sections and large neutrino contamination in the anti-neutrino beam
- Inverse beta decay paired with a stopped pion source at the a distance of 20km provides excellent event rates

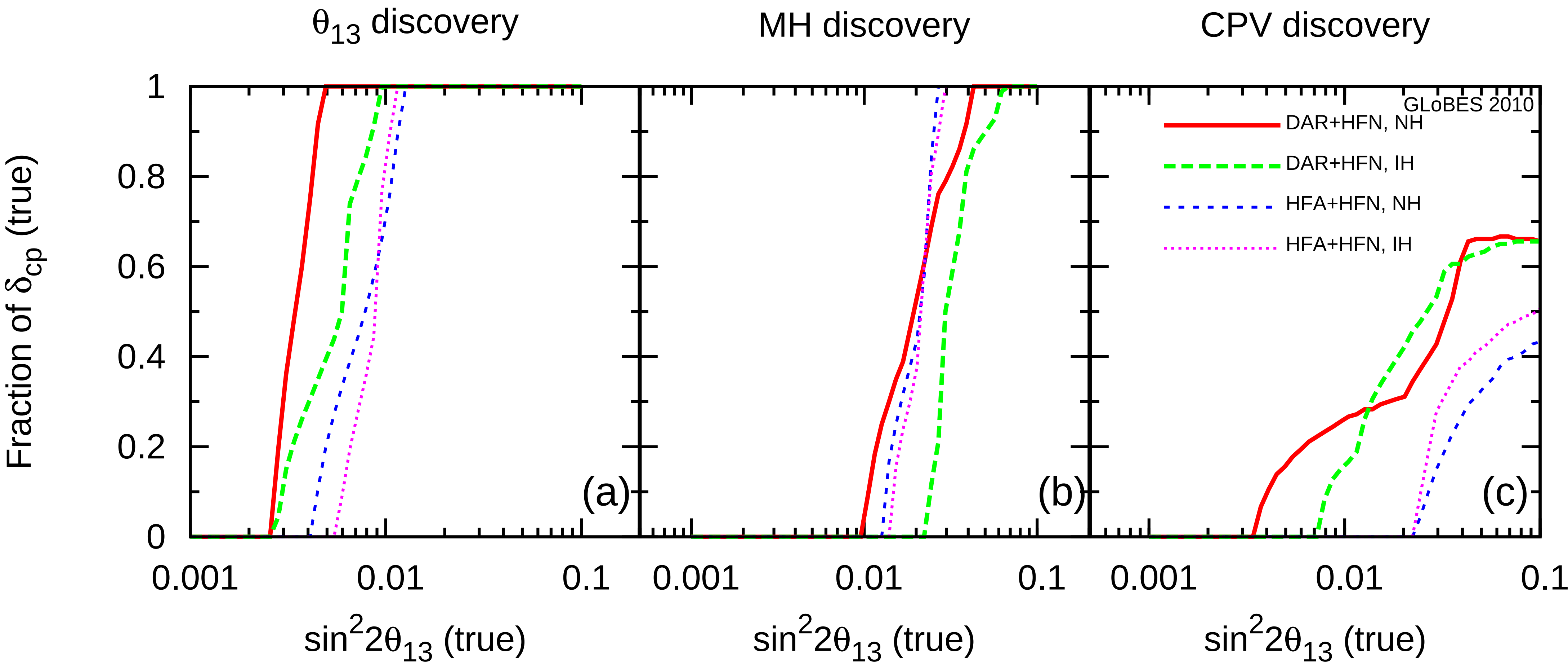
Event rates

In the following we distinguish the horn focused neutrino run (HFN) and anti-neutrino run (HFA) and the anti-neutrino run from the stopped pion source (DAR). For the HF options we assume 700kW beam power and for the DAR option 4 proton accelerators of the sort described in PRL 104:141802 (2010)

	$\bar{\nu}_\mu \to \bar{\nu}_e$	bgn	$\nu_\mu \to \nu_e$	bgn
DAR+HFN	398	73	511	143
HFA+HFN	77	53	255	71

Comparison of the signal and background event rates of 6 years running of DAR+HFN and HFA+HFN at $\sin^2 2\theta_{13} = 0.1$. Detector mass is 100kt.

Sensitivities



CP sensitivity largely improved!

DAR alone

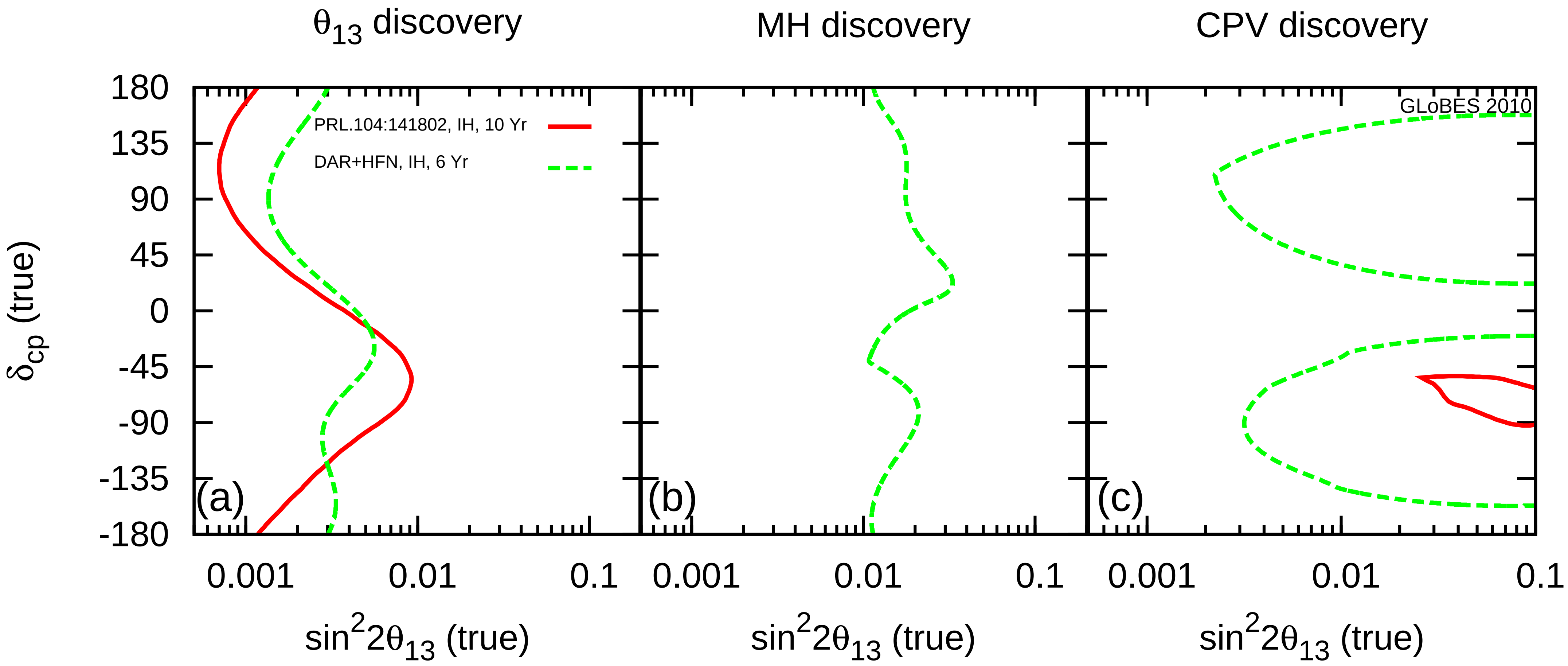
In PRL 104:141802 (2010) it was suggested to use only the DAR beam. In this case, three baselines, 1km, 8km and 20km and 6-10 proton accelerators were suggested.

Later the DAEδALUS collaboration formed around this idea arXiv:1006.0260, arXiv:1008.4967.

The main difference to our work is, that we do not assume to know the mass hierarchy *a priori* and therefore we find the DAR alone has no sensitivity to CP violation at all.

Once DAR is combined with HFN, the 1km and 8km baselines are no longer needed and a much smaller number (4) of proton accelerators is sufficient.

Comparison



Red: DAR alone, 8 years, 7 accelerators @ 20km , 2 @ 8km and 1 @ 1km
Green: DAR +HFN, 6 years, 4 accelerators @ 20km

Summary

- stopped pion sources are well know and have a lot of applications
- technology development crucial – can there be “cheap” multi-MW proton accelerators
- power consumption and intense radioactivity at the target remain a serious problem
- 300kW beam sufficient to finally settle LSND
- multi-MW beams together with LBNE can provide more physics, earlier

For applications in electroweak precision physics, see Agarwalla, PH, arXiv:1005.1254