DAEδALUS: using multiple accelerators to determine CP violation in the neutrino sector

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J. Alonso et al, *Expression of Interest for a Novel Search for CP violation in the Neutrino sector*,arXiv:1006.0260v1

Measurement of δ, the CP violating phase in the neutrino mixing matrix, is a crucial next step in our understanding of the universe. It appears as a ± sinδ term in the expression for the rate of oscillation from ν_μ to ν_e : CP violation makes the rate for ν_μ to ν_e transitions different from $\bar{\nu}_\mu$ to $\bar{\nu}_e$. δ can be determined by measuring either of these rates: DAEδALUS (Decay At rest Experiment for δ_{CP} studies At the Laboratory for Underground Science) proposes to use the second. The oscillation depends on L/E, and we maintain strict control of E by using decay-at-rest π^+ mesons which provide a source of muon antineutrinos up to 53 MeV, with very low electron antineutrino contamination.

For a good measurement one needs three values of L corresponding to 0, π/4 and π/2 of an oscillation. The near measurement establishes the total rate; the medium one the oscillation wavelength, and the far one, at the oscillation peak, the amplitude.

Rather than building a source and three detectors, we propose a single detector, shared with LBNE, a large Gadolinium loaded water Cerenkov at the underground DUSEL facility, and, at different distances, three sources from different accelerators. These machines need to deliver protons with an energy of order 1 GeV, and to run at several Megawatts. The requirements are similar to those of proposed ADSR systems, and there are opportunities for synergies in their development. We outline the technical challenges of producing such high currents, with the proposed possible solutions. These include stacked cyclotrons, the MultiMegawatt cyclotron, the Compact Superconducting Cyclotron, and the FFAG. We discuss the timescale for possible results, and how they would complement those of LBNE.

The CP violating phase δ in the neutrino sector could be the key to the matter/antimatter asymmetry of the universe. Now that measurements indicate that θ_{13} is 'large', it is sensible to consider measuring δ through muon-electron neutrino mixing: a muon neutrino beam giving an electron in the detector.

$$
\begin{aligned}
P_{\mu\to e} = &\sin^2\theta_{23}\sin^2 2\theta_{13}\sin^2\Delta_{31}\\
&\mp \sin\delta\sin 2\theta_{13}\sin 2\theta_{23}\sin 2\theta_{12}\sin^2\Delta_{31}\sin\Delta_{21}\\
&+\cos\delta\sin 2\theta_{13}\sin 2\theta_{23}\sin 2\theta_{12}\sin\Delta_{31}\cos\Delta_{31}\sin\Delta_{21}\\
&+\cos^2\theta_{23}\sin^2 2\theta_{12}\sin^2\Delta_{21}
\end{aligned}
$$

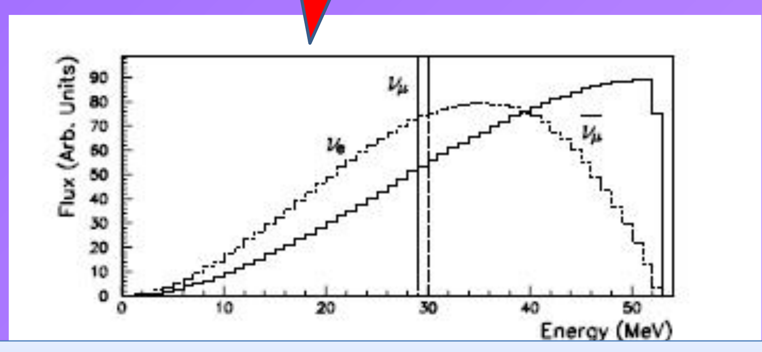
Δ_{ij} terms are $\Delta m_{ij}^2 L/4E_\nu$

-/+ sign for neutrino/antineutrino beam

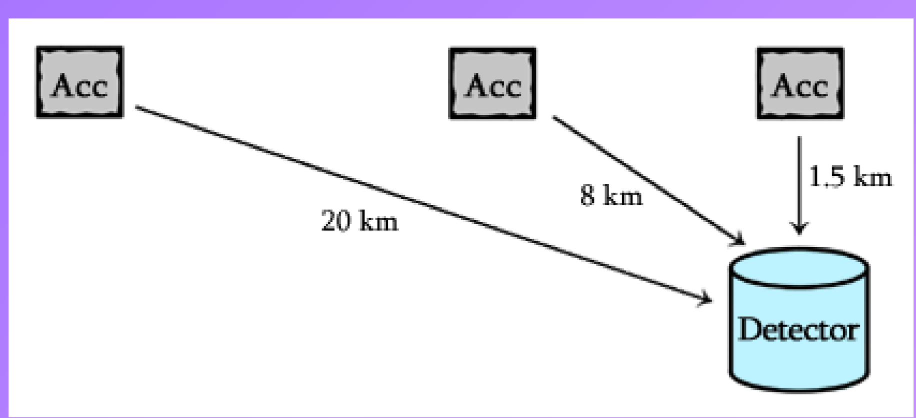
Instead of measurng neutrino/antineutrino difference, measure antineutrino rate accurately. All other quantitites are established.

Instead of fixed L and using different E, control E and vary L

Instead of varying L through having source+several detectors, use detector+several sources



π^+ stop and decay to muons, which decay to electrons
(π^- are absorbed by nuclei).
Produce muon antineutrinos but NO electron antineutrinos



Detector

Very large – 300 kton – water Cherenkov
Detect electron antineutrinos by Inverse Beta Decay
$\bar{\nu}p \to e^+ n$
Detect coincidence between positron and neutron though Gadolinium absorption and photon
^{157}Gd(n,γ) has kilobarn cross section
Signal has very small background – measurable from 'beam-off' data.
Run each accelerator with 20% duty cycle, staggered.

Possible Timescale

Phase 0
2015 Start near accelerator, to gain experience, building up to 1MW. Detector under construction
2018 Start construction of mid- and far- accelerators, 2MW and 3MW

Phase 1
2021-2026 Run with 3 cyclotrons: 'discover' δ
2024 upgrade and possibly reposition mid and far cyclotrons

Phase 2
2026-2031 Full running. Precise measurement of δ

COMPLEMENTARITY TO LBNE

	DAEδALUS	LBNE
Measures	antineutrinos	Neutrinos (mostly)
Baseline	Short	Long
Matter effects	No	Yes
Energy	Low, narrow band: 20-53 MeV	High, wide band 300 MeV-10 GeV
Background	Very low	significant

The two experiments combine to give much improved sensitivities on δ and θ_{13}

Need several Megawatts of protons at ~1 GeV
Carbon target : pions and muons created
Aim: use technology being developed for ADSR reactors

The Baseline

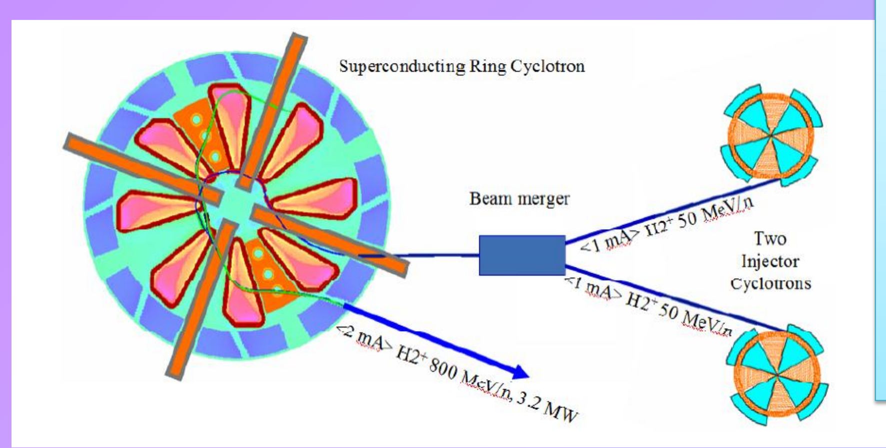
Isochronous Proton Synchrotron at PSI
590 MeV, 2.6 mA
Well understood and very successful machine
Not quite powerful enough – but not far off

Stacked Cyclotrons

Clone the PSI cyclotron several times (maybe 5) and stack them one above the other.
Same magnetic field runs through all of them.

P. McIntyre, Texas A&M
IEEE Trans on Applied Superconductivity Vol 13, p1358 (2003)

The MultiMegawatt Cyclotron



Use H_2^+ and stripping extraction
H_2^+ binding energy 2.75 eV >> H^- which is only 0.75 eV, so much more stable and easier to handle

1.6 GeV,2 mA → 800 MeV, 4mA

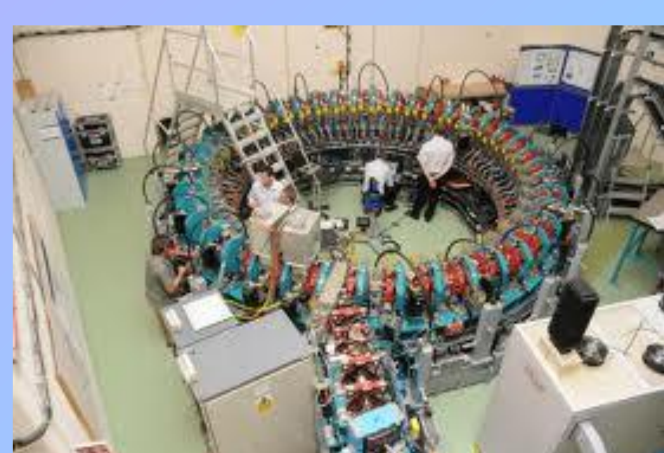
L. Calabretta et al, Proc Cyclotron '10 arXiv 1010.1493

The Compact Superconducting Cyclotron

Example: Still River Monarch[250]

Developed for proton therapy: 10T Superconducting coil. Only 250 MeV - can we run at higher currents and energies?

The FFAG



nsFFAG principle now proven.

Can we use it for high power proton machines?