Track reconstruction in CHIPS

Maciej Pfützner and Andy Perch

Department of Physics and Astronomy, UCL

Introduction

CHerenkov detectors In Mine Pits (CHIPS) is an R&D project, which aims to develop large-scale cost-effective water Cherenkov neutrino detectors. In the first phase we propose to deploy a detector with 100 kton total mass, submerged in a flooded mine pit in Northern Minnesota [1].

- **Stage approach** – developing smaller modules while delivering physics results
  - CHIPS-M prototype (~50 ton) will be submerged this summer
- **Utilising the NuMI beam** – the most powerful neutrino beam in the world before LBNE
  - Contribute to global constraints on CP-violation and mass hierarchy (via ν_e appearance)
- **Enhancing LBNE** – can be moved to a observe the second oscillation maximum in new beam
  - Water Cherenkov detector is ideal for the low-energy neutrinos
- Leading the way to affordable Mton-scale neutrino detectors

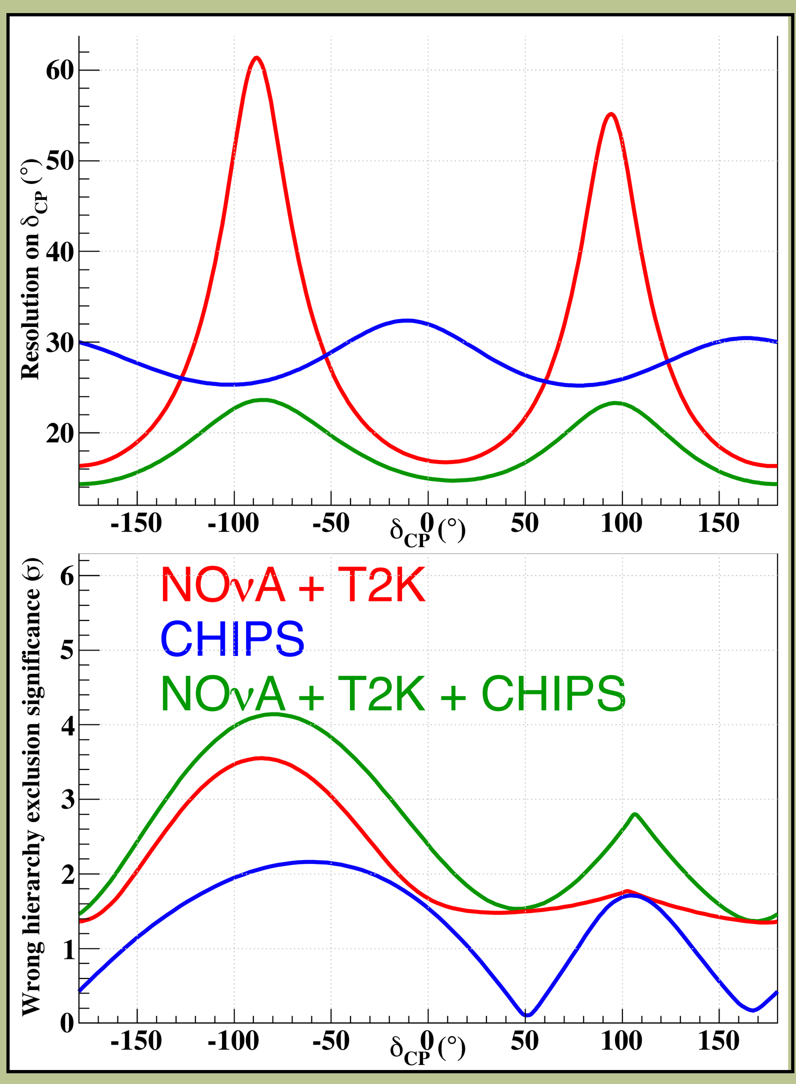
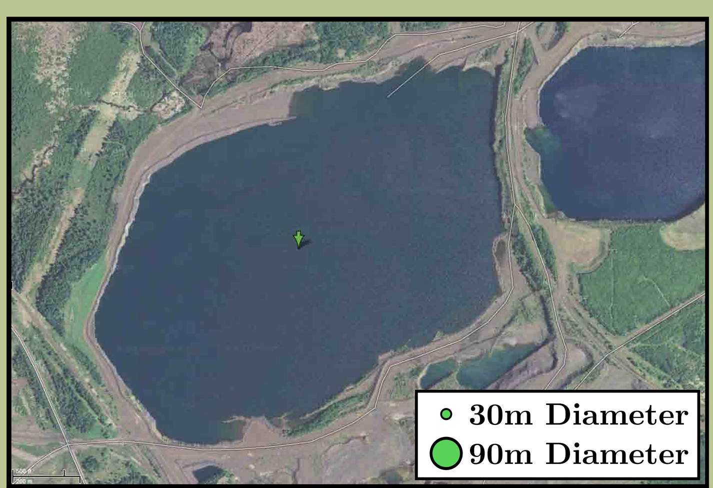
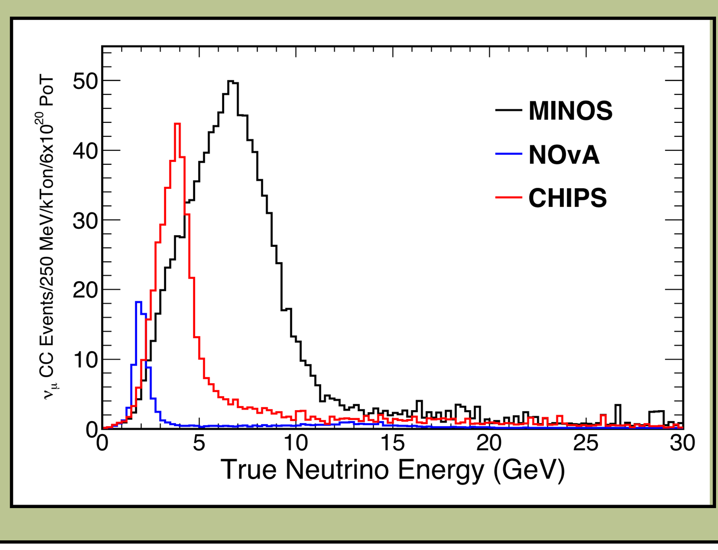


Figure : δ_{CP} and MH sensitivities for NOνA + T2K (5+5y + 8.8e21 PoT, red), 100 kton CHIPS (3+3y, blue) and combination (green), for normal hierarchy [1]

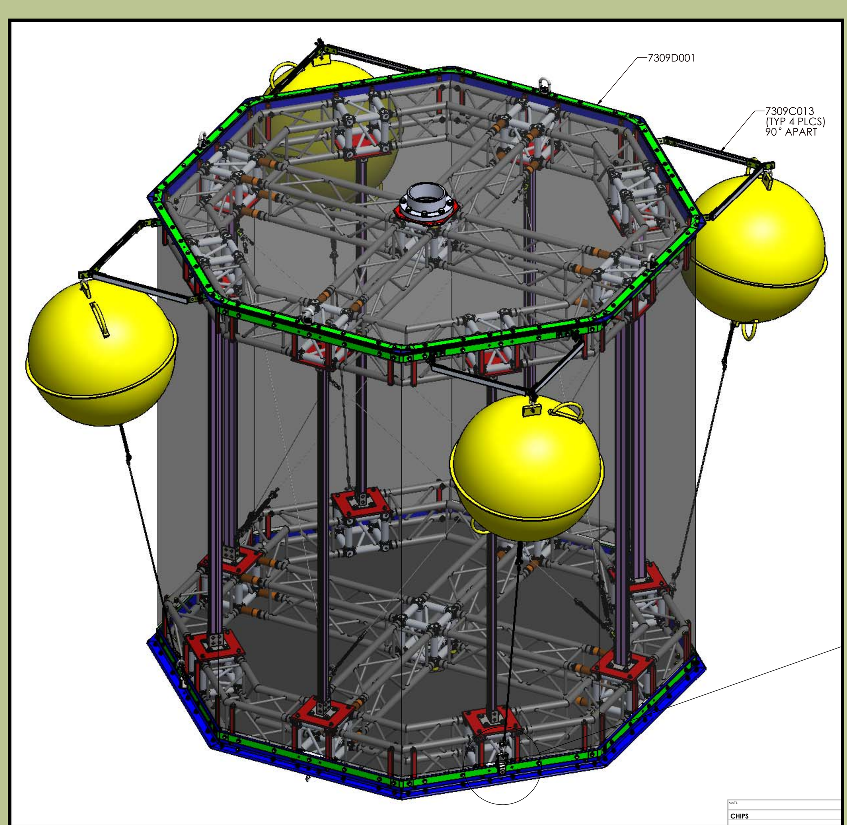
CHIPS detector

We want to deploy detector modules with a total fiducial mass of 100 kton in the Wentworth 2W pit in Minnesota – at 707 km baseline and 7mrad off-axis in NuMI beam, with flux peaking at 4 GeV.





- Existing water body provides mechanical support → decrease engineering costs
  - Structure is a light frame surrounded by a water- and light-proof liner
  - 40 m water overburden
- Using commercially available component
  - Stage stage truss for framework
  - Geomembrane for external liner
- PMT development focused on optimising light collection and timing capabilities



Reconstruction

- To measure δ_{CP} we have to observe ν_e appearance. Background from NC events with $\pi^0 \to \gamma + \gamma$: two photon rings are hard to distinguish from one electron
- Compromise between low cost and high photocathode coverage

We implement a **maximum-likelihood method** based on an algorithm developed by MiniBooNE [2]

- Calculates the likelihood of each PMT hit (charge and time) for a set of track parameters. Minimising over different tracks finds the most likely one
  - Performs better than ring-finding for multiple tracks [3]
- Preliminary reconstruction will be used to optimise design of CHIPS modules

Total likelihood separates into independent charge and time parts

Charge likelihood

- Divide charge likelihood into predicted **number of photoelectrons** (μ) and **detector response** ($f(q;\mu)$)
- μ (*predicted charge*) = integral of components parametrised with respect to distance along track (s):

$$\mu = \Phi \int_{\text{track}} \rho(s) g(\cos\theta(s); s) \epsilon(\eta(s)) \Omega(R(s)) T(R(s)) \mathrm{d}s$$

  - Light emission: absolute level (Φ), distance ($\rho(s)$) and angular profiles of Cherenkov light emission ($g(\cos\theta(s); s)$)
  - Light detection: PMT angular efficiency($\epsilon(\eta(s))$) and solid angle ($\Omega(R(s))$); absorption survival probability ($T(R(s))$)
- Tabulate the integrals to save computing time
- For multiple tracks, add predicted charges
- Distribution describing detector response = final charge likelihood function (depending only on μ)

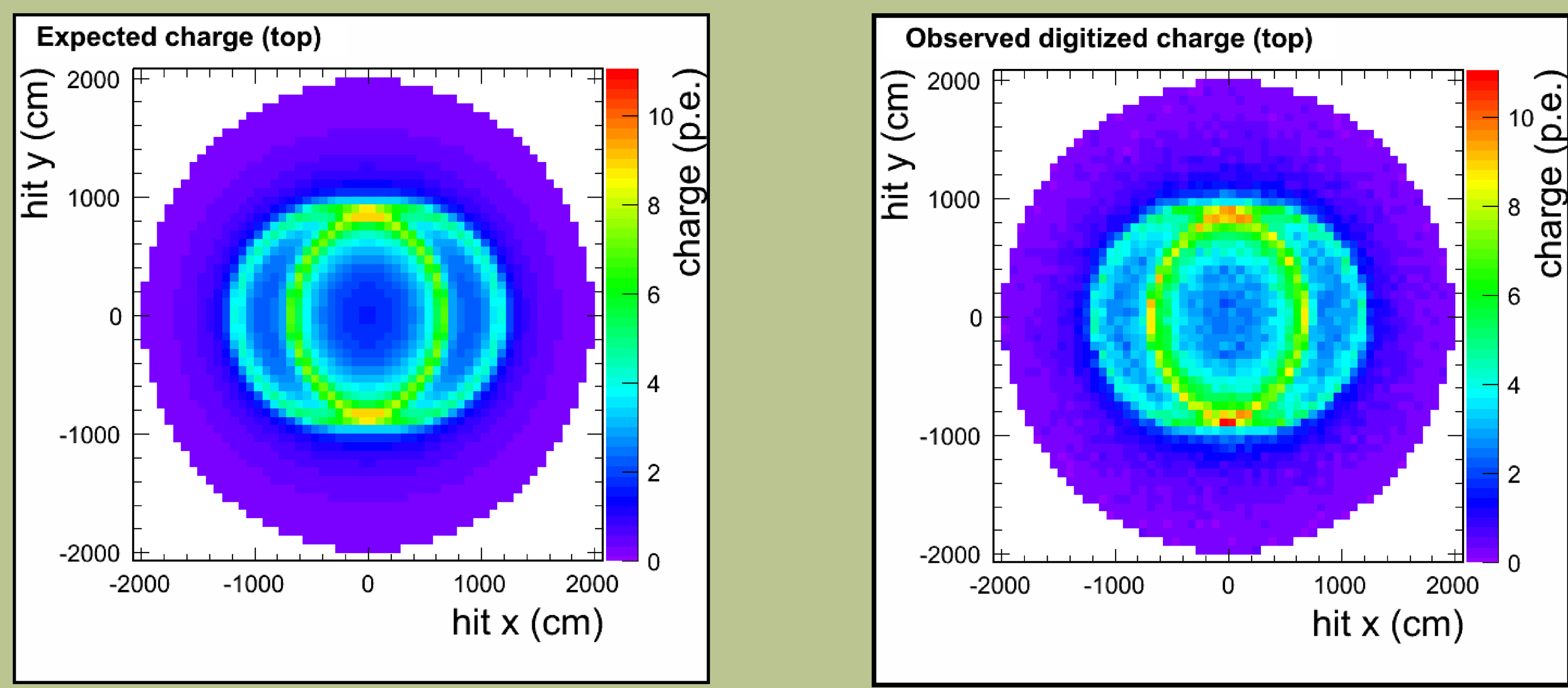


Figure : Mean observed charge compared to predicted response for two upward 500 MeV electrons (top cap only). Optic light scattering has not yet been implemented.

Time Likelihood

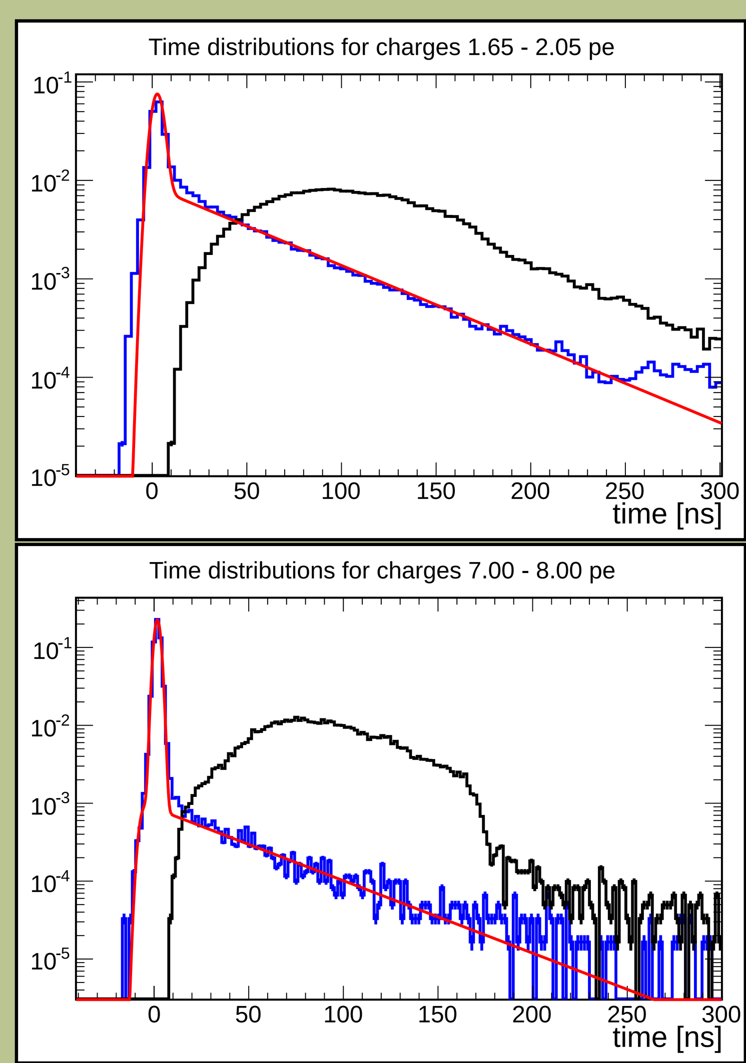


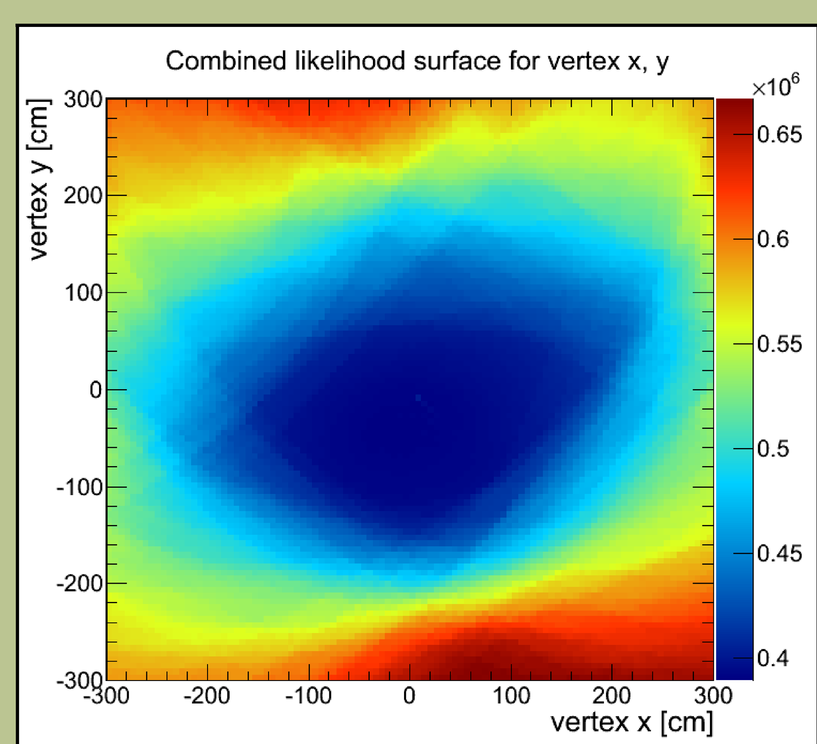
Figure : Time distributions shown for two charge bins of a 1000 MeV muon sample

- Correct registered time (**black** lines) by subtracting light's time-of-flight from track to PMT
  - This holds sensitivity to track vertex and directions
- Distributions of corrected time (t_c, **blue** lines) depend only on track energy and predicted charge (μ) at the PMT
  - Fitted with a **gaussian peak** (direct light) + **exponential decay** (scattering and reflection)
  - Parametrise charge and energy dependence in two stages of polynomial fits
- Likelihood function of t_c is recreated for given μ and energy (**red** lines)

Minimising the likelihood

The combined likelihood algorithm is now being tested and a preliminary fitter is being implemented.

Shown is a likelihood surface plotted against vertex coordinates x and y for a 1500 MeV muon originating in $(0, 0, 0)$, with other variables fixed at their true values.



References

[1] P. Adamson *et al.*, *CHerenkov detectors in Mine PitS (CHIPS) Letter of Intent to FNAL*, 2013

[2] R.B. Patterson *et al.*, *The Extended-Track Event Reconstruction for MiniBooNE*, Nucl. Instrum. Meth. A608, 206-224, 2009

[3] K. Abe *et al.* [T2K Collaboration], *Observation of Electron Neutrino Appearance in a Muon Neutrino Beam*, Phys. Rev. Lett. 112, 061802, 2014