Near Detector Studies in LAGUNA-LBNO

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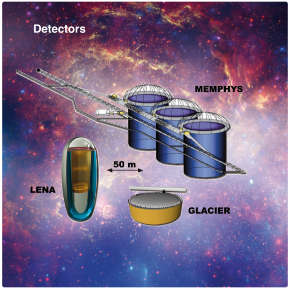
Large Apparatus studying Grand Unification and Neutrino Astrophysics - Long Baseline Neutrino Oscillations

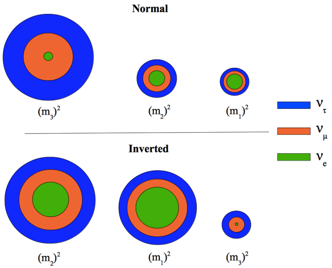
- Design feasibility study 2011 - 2014
- 7 potential sites and 3 potential detector technologies
- Unique position to host a baseline of 2300km
- Up to 100kton detectors

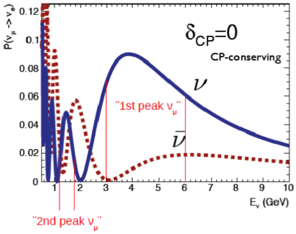


Physics

- Determine mass hierarchy $> 5\sigma$
- CP violation at 90% C.L for $\sim$60% of δ_{CP} parameter space

- Requires both Near and Far detectors
- On axis ν_μ beam - wide band beam
- Near Detector at CERN, Geneva - 800 m from the beam target
- Far Detector at Pyhäsalmi, Finland - 2300 km from CERN
  - Deepest mine in Europe at 1440m depth



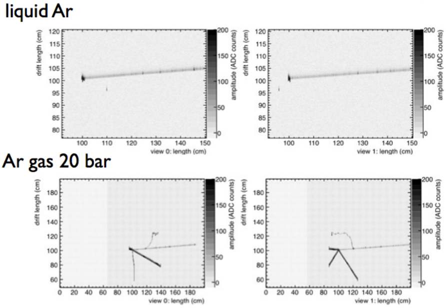


Oscillation probabilities at the LBNO far detector for ν_μ and $\overline{\nu_\mu}$.

Requirements

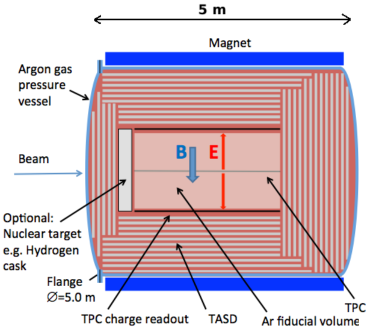
- Target to match Far detector $\rightarrow$ Liquid Argon (LAr)
- LAr neutrino rate too high for Near Detector (ND)
- Deal with high multiplicity events

- Use $\rightarrow$ Gas Argon
- Proven detector technology
- Gas at 20 bar, density 35kgm^{-3}
- Volume 2 $\times$ 2 $\times$ 2 m^3
- Mass $\sim$ 280 kg

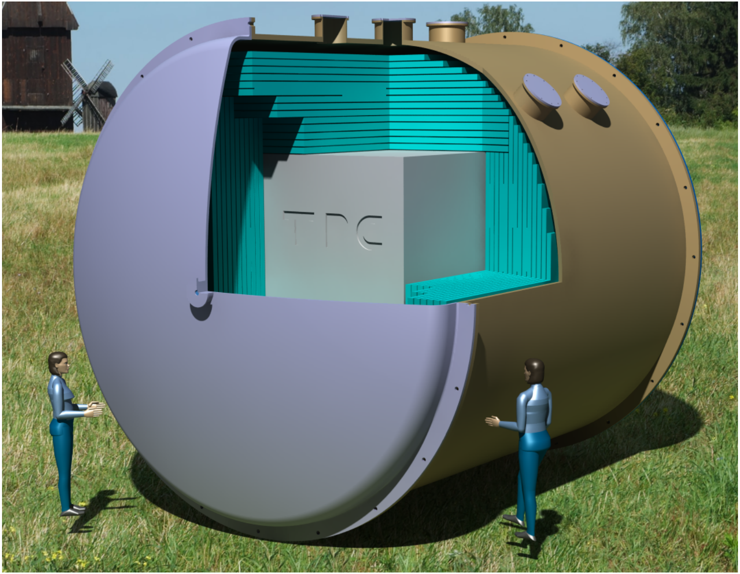


The Near Detector Concept

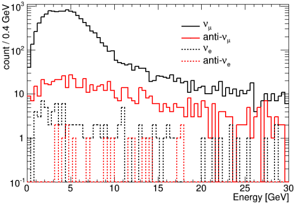
- Time Projection Chamber (TPC) → 0.3 tons
  - Primary detector target
  - Momentum measurements
  - Vertex location and tracking
- Totally Active Scintillator (TAS) → 30.0 tons
  - Fully surrounding TPC
  - Neutral particle identification
  - Muon/Pion seperation
  - Carbon target for cross sectional measurements
- Pressure Vessel → 5 m diameter, 5 m length
- Magnet → 0.5 T dipole



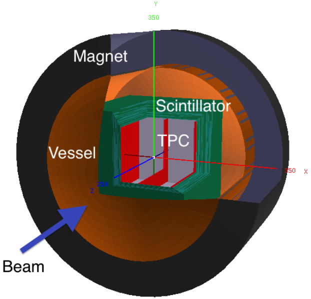
The Near Detector Design



- Geometry implemented in ROOT
- Required bespoke software
- Designed software package of GENIE (Neutrino Generator), GEANT and others
    - Read in neutrino primary vertices from flux file
    - Project to ND
    - Neutrino interactions generated
    - Secondaries tracked and recorded
    - Reconstruction and analysis

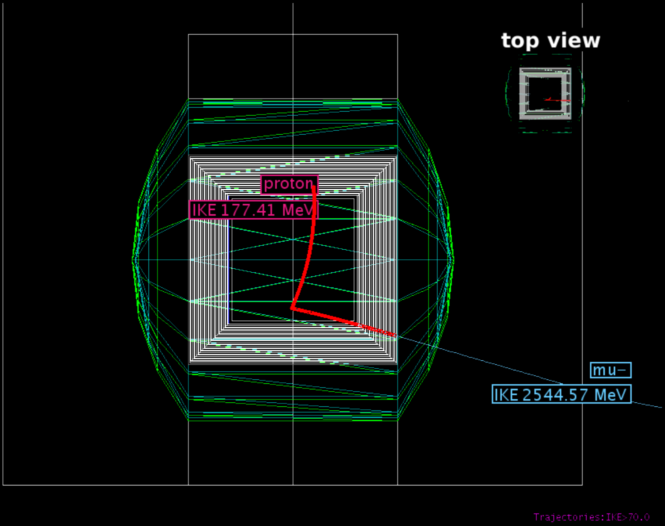


Full neutrino flavour flux at ND



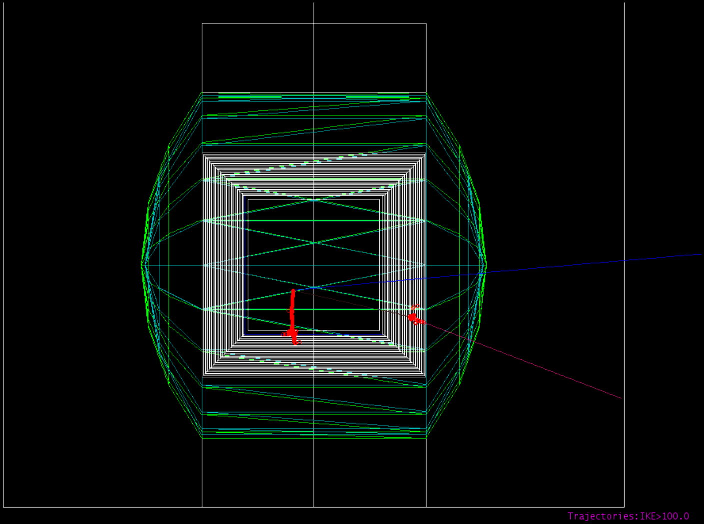
Geometry as shown in ROOT display

Event Display



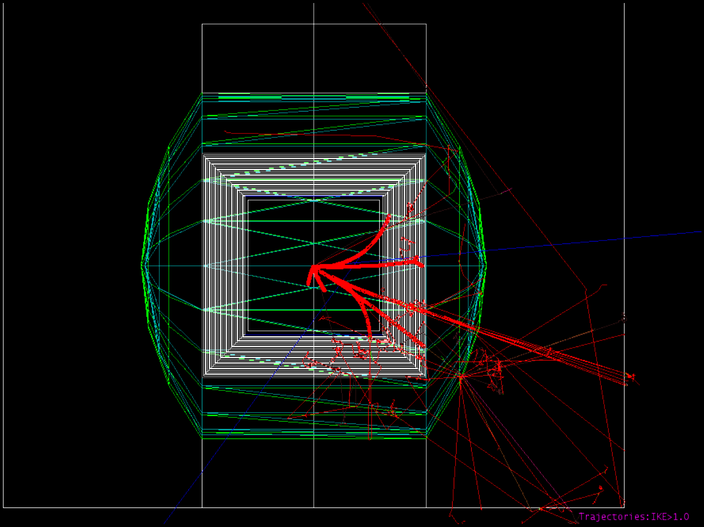
CCQE event $\mu + p$

Event Display



$$\nu + \pi^+ + n$$

Event Display



$$\nu + p + p + p + n + n + \pi^0 + \pi^+ + \pi^-$$

Particles from Neutrino Interactions in TPC

- Exposure 1.22 $\times$ 10^{20} p.o.t
- 345228 events (94% ν_μ)
- High energy beam $\rightarrow$ DIS events
- Large multiplicities $\sim$ 6.5 particles per neutrino event
- Beam spill of 3.5 $\times$ 10^{13} p.o.t

Primaries from entire gas volume

particle	count
p	647631 (28.9%)
n	533868 (23.9%)
π^+	277825 (12.4%)
π^0	265408 (11.9%)
μ^-	243577 (10.9%)
π^-	144379 (6.5%)
γ	23000 (1.0%)
μ^+	11953 (0.5%)
e^-	2981 (0.1%)
e^+	439 (<0.1%)
other	86120 (3.8%)
Total	**2237481** (excluding ν)

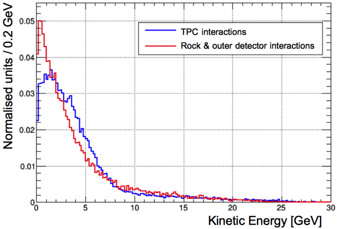
Can expect 0.0116 $\pm$ 0.0002 (stat) ν_μ events / spill / m^3

Neutrino Interactions from Rock

Neutrinos also interact outside TPC → Rock + Outer Detector

- Muons from these interactions contribute significantly to TPC rate
- Similar energy spectrum to ν TPC interactions
- Rock muons $\sim$ 2 μ / spill / m^3
- Interactions in TPC $\sim$ 0.01 μ / spill / m^3

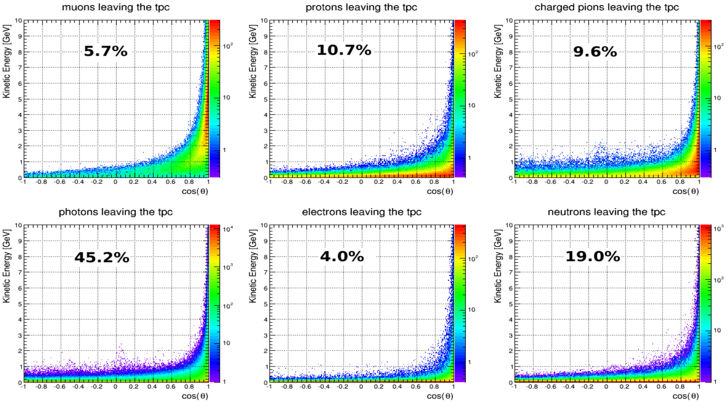
The kinetic energy spectrum for muons in the TPC for neutrino interactions in and outside the TPC.



For every 1 muon track from TPC get 200 from rock!

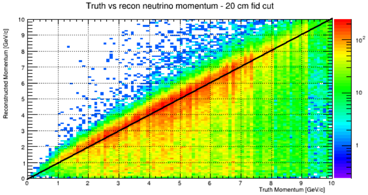
What is leaving the TPC?

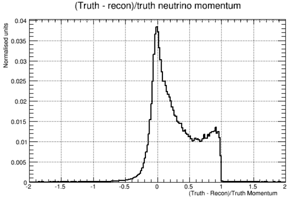
- Key for next stages of detector design
- TPC alone is not enough

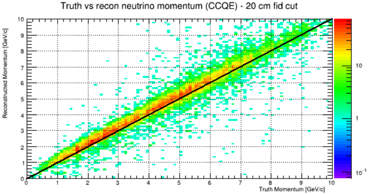


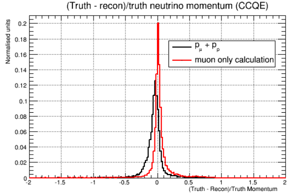
Momentum Reconstruction in the TPC

- Only tracks with hits (energy deposition points) recorded
- Calculate sagitta from truth momentum
- $s = BL^2 / 26.7\ p_{truth}$
- $ds = 300\ \mu m$ (T2K ND280)
- Smear this value and recalculate $p = BL^2 / 26.7\ s$
- Sum momentum for each track → Reconstructed neutrino momentum
- 20 cm fiducial cut applied
- **Require at least 3 hits per track**









Charged Current Quasi Elastic (CCQE) Interaction:

ν + n $\rightarrow$ l + p

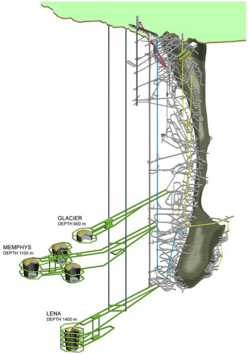
Reconstruct from muon only:

$$E_{\nu_\mu} = \frac{E_\mu m_p - m_\mu^2}{m_p - E_l + p_\mu cos\theta}$$

Status and Next Steps

Summary:

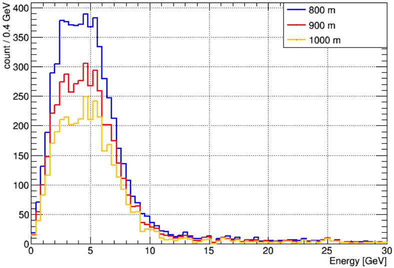
- LAGUNA-LBNO physics motivation strong
- Constructed software framework adaptable to many experiments
- Studies very relevant for other LB experiments - LBNE
- Initial studies show ND capabilities
- Design study ends Sep 2014



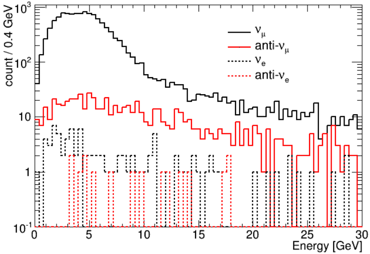
Backup Slides

ND Placement and Incident Flux

- ND placement from the beam target is limited to 800 - 1000 m
- Beam muons to much for < 800 m
- Engineering costs and restrictions for > 1000 m



Neutrino flux incident on ND at 800, 900 and 1000 m from the target



Neutrino flux incident on the ND showing flavour composition of the beam at 800 m

Further Distances for 2.4×2.4×3 m TPC

- Include distances of 900 and 1000m
- Moving to 1000m can reduce rock muons by ∼1/3
- Signal/background ratio does not change

distance [m]	800	900	1000
ν inside TPC [μ/m^2/spill]	0.0250 ± 0.0004	0.0204 ± 0.0003	0.0159 ± 0.0002
ν outside TPC [μ/m^2/spill]	6.11 ± 0.05	4.92 ± 0.04	3.98 ± 0.04
outside/inside ratio	244.4 ± 4.4	241.2 ± 3.1	250.3 ± 4.0

*All errors are statistical only