LAGUNA-LBNO and the WA105/LBNO-DEMO

Luca Agostino
On behalf of WA105 collaboration

7th international symposium on
“Large TPCs for low-energy rare event detection”

17-12-2014
OUTLOOK

• SCIENTIFIC MOTIVATION OF NEW GENERATION NEUTRINO EXPERIMENTS

• THE LAGUNA-LBNO DESIGN STUDY RESULTS

• LBNO-DEMO MOTIVATION AND OVERVIEW

• MAIN COMPONENTS

• CONCLUSIONS
Flavour eigenstate ≠ Mass eigenstate

Mixing parameters:

• Three angles: $\theta_{12}, \theta_{23}, \theta_{13}$
• One complex phase $\delta_{CP}$
• Two squared mass differences $\Delta m_{13}^2, \Delta m_{12}^2$ HIERARCHY UNKNOWN

**Pontecorvo – Maki – Nakagawa – Sakata matrix**

\[
U = \begin{pmatrix}
1 & 0 & 0 \\
0 & \cos \theta_{23} & \sin \theta_{23} \\
0 & -\sin \theta_{23} & \cos \theta_{23}
\end{pmatrix} \times \begin{pmatrix}
\cos \theta_{13} & 0 & \sin \theta_{13} e^{-i\delta} \\
0 & 1 & 0 \\
-\sin \theta_{13} e^{i\delta} & 0 & \cos \theta_{13}
\end{pmatrix} \times \begin{pmatrix}
\cos \theta_{12} & \sin \theta_{12} & 0 \\
-\sin \theta_{12} & \cos \theta_{12} & 0 \\
0 & 0 & 1
\end{pmatrix}
\]
LAGUNA-LBNO: Large Apparatus for Grand Unification and Neutrino Astrophysics and Long Baseline Neutrino Oscillations

LAGUNA-LBNO consortium = 13 countries, 45 institutions, ~300 members
FP7 DS: 2011 - 2014

1. Accelerator based:
   - Mass Hierarchy
   - $\delta_{CP}$
   - PMNS precision
   - $3 \nu$ or $3+n$?

2. Non-Accelerator based:
   - Proton decay

3. Neutrino Astronomy:
   - Supernova neutrinos
   - Diffuse Supernova Neutrinos
   - Solar Neutrinos
   - Atmospheric Neutrinos

4. Geo-neutrinos

5. Dark Matter

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THE LAGUNA-LBNO EXPERIMENT

GLACIER (Giant Liquid Argon Charge Imaging ExpeRiment, 2003)
  • New concept of Double Phase Liquid Argon TPC for CP-violation and future deep underground detector, up to 100 kton mass (hep-ph/0402110)

LAGUNA DS (FP7 Design Study 2008-2011)
  • ~100 members; 10 countries
  • 3 detector technologies ⊗ 7 sites, different baselines (130 → 2300km)

LAGUNA-LBNO DS (FP7 DS Long Baseline Neutrino Oscillations, 2011-2014)
  • ~300 members; 14 countries + CERN
  • Fully engineered detector designs for 20/50 kt DLAr, 50 kt LSc, 540 kt WCD
  • Infrastructure design, construction scheme and full costing

LBNO (CERN SPSC Eol for a very long baseline neutrino oscillation experiment, June 2012)
  • An incremental approach with high level physics starting from phase 1 (MH + LCPV + Astro)
  • ~230 authors; 51 institutions
  • Design study is concluded and the deliverables soon on the Archive

LBNO-DEMO WA105 (@CERN first Collaboration meeting 16-17 October 2014)
  • kt-scale demonstrator for LBNO @ CERN: engineering and charged particle calibration

CERN-SPSC-2012-021, SPSC-EOI-007
CERN-SPSC-2014-013, SPSC-TDR-004
LAGUNA/LBNO CERN TO PHYÄSALMI CN2PY:

- 2300 km baseline from CERN (CN2PY) + 1160 km baseline from PROTVINO(P2P)
- SPS 400 GeV protons – 750 kW beam
- HPPS 50 GeV protons – 2 MW beam
- IHEP 70 GeV protons – 450 kW beam

Liquid Argon double phase TPC detector
GLACIER: Incremental approach
- Phase 1: LBNO20 (20kton)
- Phase 2: LBNO20+50 (70kton)

LBNO20 20 kton full cost = 226 M€
AN INCREMENTAL APPROACH

- **5 kton PILOT:**
  
  5kt DLAr detector
  - First kton scale installation of Double Phase Liquid Argon underground
  - Astrophysics and underground neutrino detection without beam
  - Proton decay

- **Phase I (LBNO20):**
  
  24kt DLAr detector + beam from CERN SPS (750kW, Ep=400GeV)
  - Guaranteed 5 σ MH determination + 46 % δ_{CP} coverage at 3 σ
  - *p-decay sensitivity from p→Kν improved by 1 order of magnitude w.r.t. current limit*

- **Phase II (LBNO70):**
  
  70 kt DLAr detector + HPPS beam (2 MW, Ep = 50 GeV) or Protvino beam
  - δ_{CP} coverage at 5 σ
  - *sensitivity to MH effect on SuperNovae neutronization burst*

- **LBNO-DEMO:**
  
  6X6X6 m^3 DLArgon at CERN ➔ Exposure to charged hadron beam (0.5-20 GeV/c)
  - Demonstrate the operation of double phase LAr detectors at the multi-100-ton scale
  - Test and extrapolate technical solutions to large scale in an “affordable” way
  - LBNO-DEMO provides precise calibration of energy response as a function of E ➔ very important for neutrino oscillation systematics
MASS HIERARCHY AND CP COVERAGE

MH
Power vs exposure for all values of $\delta_{CP}$ (shaded bands)

LBNO20 + SPS

CP

$\chi^2$ (rad)

$3\sigma$

$5\sigma$

JHEP05(2014)094

arXiv:1412.0593v1

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WHY A PROTOTYPE FOR LBNO?

LBNO-DEMO IS THE LAST STEP BEFORE THE LARGE-SCALE EXTRAPOLATION TO MULTI-KTON UNDERGROUND DETECTORS

• Liquid Argon purity under control
• Large hanging structure
• Long term stability of light readout
• Large area read-out
• Very high voltage generation
• Cold end warm electronics

A LARGE SCALE PROTOTYPE TO DEMONSTRATE THE FEASIBILITY OF THE LBNO GLACIER DETECTOR
MAIN TPC PARAMETERS

- Inner vessel size: 8.3×8.3×8.1 m³
- Active LAr area: 36 m²
- Total LAr mass: 705 t
- Drift field: 0.5 – 1.0 kV/cm
- # of charge readout modules: 36
- # signal feedthrough: 12
WA105 GOALS

• Calorimeter in charge particle beams, energy reconstruction

• Automatic event reconstruction

• Particle identification efficiency from track signature

• Measure of charged pion cross sections on Argon nuclei

• Development and proof-check of industrial solutions

Data-taking performed by using a well known charged particles beam
WA105 COLLABORATION

- University of Glasgow
- University College London
- University of Jyväskylä
- University of Oulu
- Rockplan Ltd
- Horia Hulubei National Institute (IFIN-HH)
- University of Bucharest
- University of Geneva, Section de Physique,
- ETH Zürich
- INFN-Sezione di Pisa
- CERN
- High Energy Accelerator Research Organization (KEK)

10 countries
22 institutes
>100 physicists
DOUBLE PHASE LAR TPC PRINCIPLE

1) Scintillation
2) Charge drift
3) E amplification

PMTs (trigger and t0)

Liquid

Gas
e- multiplier
collection anode
cathode
**WA105**

**CHARGE READOUT (1)**

36 m² active surface equivalent to 1:20 of 20 kton GLACIER.

12 signal feed-through chimneys

F/E + Cold/warm signal feed-through + Micro TCS Crate
AMPLIFICATION SECTION:
EXTRACTION GRID - > LEM - > ANODE

See talk by Wu Shouxing

2 mm Collection 5 kV/cm
GAS Extraction 2 kV/cm
LIQUID 1 cm

(1) Large Electron Multiplier (LEM)
25-35 kV/cm

(2) Anode
Drift cage of scaled design developed in LAGUNA-LBNO for 20/50 kton.

- **Drift field:** 0.5-1kV/cm
- **Potential difference:** 300-600 kV
- **60 equally spaced electrodes**
- **Drift velocity of electrons:** 1.6-2.0 mm/s

Heinzinger power supply
SHOWERS CONTAINMENT AND RECONSTRUCTION (1)

• SHOWERS ENTIERELY CONTAINED IN THE DEMONSTRATOR

• ENERGY DISTRIBUTION CENTERED ON THE INITIAL ENERGY OF THE PARTICLE

![Graph showing energy distribution and containment]

- Glacier 20kt
- 6x6x6 m³
- 3x1x1 m³

17/12/14
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THE DEMONSTRATOR IS A COMPLETELY HOMOGENEOUS CALORIMETER WITH GRANULARITY OF $3\times3$ mm$^2$ WITH FULL CONTAINMENT

- HIGH ACCURACY IN HADRONIC SHOWER RECONSTRUCTION FOR THE VALIDATION OF SIMULATIONS

- ENERGY RECONSTRUCTION
  
  $E_{\text{reco}} = \alpha E_{\text{had}} + \beta E_{\text{em}}$

  $\sigma / E = A / E + B$

- ENERGY RESOLUTION

- AUTOMATIC RECONSTRUCTION SOFTWARE NEEDED
MIND for WA105

Magnetized Iron Neutrino Detector 500 tons of magnetize iron downstream to LBNO-DEMO

- **CHARGE ID EFFICIENCIES** FOR LOW ENERGY
- **INTERACTIONS**
- **BACKGROUND ANALYSES**
- **PARTICLE MOMENTUM** RECONSTRUCTION
Dedicated extension of the EHN1 in the Prevesin site

Requirements:

- 20x30 m
- 2m deep pool

Fitting in half of the EHN1 extension or in existing EHN1 hall (as backup solution if extension not built in timely fashion)

EHN1 Extension foreseen by CERN

Civil engineering activities started 1-20 GeV/c beam

Deviated extension of the EHN1 in the Prevessin site
The EHN1 extension - 28 October 2014

LBNO-Demo
## Construction of EHN1 extension on the critical path

### Optimization of construction schedule

Currently aim to start data taking by mid 2018

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### TIME-SCALE

**DATA TAKING EXPECTED BY MID 2018**
CONCLUSIONS

THE WA105 COLLABORATION WILL BUILD AND EXPLOIT A 700 ton DOUBLE PHASE LIQUID ARGON LBNO DEMONSTRATOR AT CERN

DEMONSTRATING THE LARGE DOUBLE PHASE DETECTOR FEASIBILITY

STUDYING THE RESPONSE OF THE DETECTOR TO A CHARGED PARTICLES BEAM

AFFORDING NEW ENGINEERING AND TECHNICAL CHALLENGES

ALLOWING THE FUTURE CONSTRUCTION OF NEW GENERATION LIQUID ARGON DETECTORS
BACKUP
LAGUNA/LBNO CERN TO PHYÄSALMI CN2PY:

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ARGON PURITY

Charge attenuation because of attachment to impurities

Collection efficiency

2 ppt O₂

20 ppt O₂

0.2 ppb O₂

Drift path (m)

1.5 kV/cm
1.25 kV/cm
1 kV/cm
0.75 kV/cm
0.5 kV/cm

T600 MicroBoone
LBNE
GLACIER
the LEMs have different charging up characteristics but all could be operated stably at gains of at least 20.

Paper in preparation
LEM gain curves

Fitting function: $G_{\text{eff}}(E, \rho, t) \equiv T e^{\alpha(E) \cdot \rho} \times \mathcal{C}(t)$

$\alpha(\rho, t) = \lambda e^{-\beta(\rho, t)}$

- Max Gain: 80
- MIP S/N: 2000!

- Hole diameter:
  - 500 $\mu$m ($\kappa=0.830$)
  - 400 $\mu$m ($\kappa=0.905$)
  - 300 $\mu$m ($\kappa=0.938$)

- Hole layout:
  - hexagonal ($\kappa=0.900$)
  - square ($\kappa=0.900$)

- Thickness:
  - 1 mm ($\kappa=0.830$)
  - 0.8 mm ($\kappa=0.739$)
  - 0.6 mm ($\kappa=0.710$)

- Rim size:
  - 80 $\mu$m ($\kappa=0.830$)
  - 40 $\mu$m ($\kappa=0.900$)
DIFFUSION IN LAR

Drift fields $E=0.5, 0.75, 1, 1.25, 1.5$ kV/cm

**Longitudinal Diffusion**
- Drift path (m)
- $\sigma$ (mm)
- $D_L=4 \text{ cm}^2/\text{s}$

**Transverse Diffusion**
- Drift fields $E=0.5, 0.75, 1, 1.25, 1.5$ kV/cm
- $D_T=13 \text{ cm}^2/\text{s}$