LBNO-DEMO (WA105): A LARGE DEMONSTRATOR OF THE LIQUID ARGON DOUBLE PHASE TPC

Sebastien Murphy ETHZ on behalf of WA105

DPF 2015 Ann Arbor
✓ Measurement of CP-violating phase ($\delta_{CP}$) P5 goal of 3 sigma coverage of 75% of $\delta_{CP}$ phase space by 850-1300 kt-MW-years.

✓ 5 sigma sensitivity to mass hierarchy for all values of $\delta_{CP}$ by 400 kt-MW-years

✓ proton decay ($\sim 4 \times 10^{35}$ p $\rightarrow$ K$\nu$ $\rightarrow$ increase current limits of an order of magnitude)

✓ supernovae neutrino detection ($o(10^3)$ neutrino SN explosion @10kpc)

✓ and also: precision measurement of neutrino oscillation parameters, test of 3-neutrino paradigm, nu_tau appearance, atmospheric neutrinos, precise x-section measurements in near detector,...
DUNE double phase far detector

1.2 MW neutrino beam from FNAL to SURF underground laboratory with 40 kton Liquid Argon detector.

4 underground caverns with detector modules of 10 kton
Ionisation signals amplified and detected in gaseous argon above the liquid surface.

Allows finer readout pitch, lower energy thresholds and better pattern recognition.

A common cryostat design is being developed for both single and double phase technologies.

Will be tested by WA105 program at CERN.
Large Double phase TPCs

Concept of double-phase LAr TPC (Not to scale)

- Anode 0V
- LEM
- 2 mm
- Collection field 5kV/cm
- GAr
- Extraction field 2kV/cm
- 1 cm
- Grid
- Drift field 0.5 – 1 kV/cm
- LAr
- Drift field 0.5 – 1 kV/cm
- Cathode
- PMTs (provide t₀)

Large scale LAr TPC for LB neutrino oscillation physics, astrophysics, and nucleon decay search (GUT physics)
- Single cryo-tank based on industrial LNG solution to house O(10) kton of LAr mass
- Double-phase for charge readout with amplification:
  - Long drift distances
  - Low energy detection thresholds
  - Readouts with only collection views
  - Maximize active LAr volume whilst minimizing the number of channels.

Double phase readout: many years of R&D

O(10^6) holes!

stable operation of large area readouts

40x80cm^2

10x10cm^2

LEM/anode R&D

supporting R&D activities on smaller prototypes

ArDM 1ton
-light readout
-Operating underground

2-phase data
Double phase readout: many years of R&D

supporting R&D activities on smaller prototypes


cosmic muon

HADR shower

EM shower

2-phase data
The collaboration

WA105

22 institutes 122 physicists

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Institut de Física d’Altes Energies

IFAE

High Energy Accelerator Research Organization
KEK

Centro de Investigaciones Energéticas, Medioambientales y Sustentables

University of Glasgow

University of Jyväskylä

Institut National de Physique Nucléaire et de Physique des Particules

Univ of Zürich
The WA105 6x6x6 m³ demonstrator

Build and operate a large scale prototype to demonstrate the feasibility of DLAr TPC design for O(10kt) detectors.

Technical proof-of-principle:

✴ Purity in non-evacuated tank
✴ Large hanging field cage structure
✴ Very high voltage generation
✴ Large area charge readout
✴ Accessible cold front-end electronics
✴ Long term stability of UV scintillation light readout

On the surface in a test beam

Some detector parameters:

• Insulated membrane tank
  → inner volume 8.3x8.3x8.1 m³
• Active area 36 m²
• Drift length 6 m
• Total LAr mass 705 ton (~300 ton active)
• Hanging field cage & readout plane
• # of signal channels: 7680 in 12 signal FT
• # of PMTs: 36
test reconstruction on fully contained events from charged particle beam (well defined primary particles and energies)

- LAr TPC provide a fully active homogeneous medium
- High granularity 3x3 mm² ← two orders of magnitude better than most granular calorimeters
  - e.g., CALICE AHCAL prototype has 3x3 cm²
- Additional handle from dE/dx

Opportunity to provide unprecedented measurements of hadronic shower development to HEP community

Some goals

- Development of automatic event reconstruction
- test NC background rejection algorithms on “ν_e free” events
- Charged pions and proton cross-section on Argon nuclei.
6x6x6 m³ DLAr R&D goals: summary

Double phase LAr TPC validation:

1. Longest drift in LAr (up to 6m)
2. Ionisation e- transverse and longitudinal diffusion
3. e- attenuation and its compensation by charge multiplication with LEM operating in gas phase (LEM gain uniformity/stability/calibration)
4. HV operation in the range 300kV-600kV (or 0.5-1 kV/cm over 6m)
5. Validation of the corrugated membrane cryostat with passive insulation
6. ≤100ppt O₂-equivalent impurities in LAr in such a tank
7. Low-noise accessible ionisation charge signal readout electronics operating at low temperature (≈110K)
8. Reachable and optimisation of S/N ratio
9. Verification of possible effects of positive ions (surface! - n/a underground)
10. Robust light readout (UV aging resistant), immersed electronics
11. First calibration of a LAr TPC with beam e-/µ/hadrons
On a shorter time scale we are constructing a 3x1x1 m³ LAr TPC

- **Fully engineered versions of many detector components** with pre-production and direct implementation (installation details and ancillary services)
- **First overview of the complete system integration**: set up full chains for Quality Assessment, construction, installation and commissioning
- **Anticipate legal and practical aspects** related to procurement, costs and schedule verification
WA105 prototypes - status

LAr-Proto (3x1x1 m³)

Tank insulation and membrane being installed

DLAr (6x6x6 m³)

EHN1 extension civil engineering

Detector installation end 2015

Detector installation 2017

Detector installation 2017
WA105 prototypes - status

LAr-Proto (3x1x1 m³)

Tank outer structure

Detector installation end 2015

DLAr (6x6x6 m³)

Assembly + installation clean

Detector installation 2017
Membrane tank

outer-structure-construction-time-lapse

insulation and corrugated membrane panels being installed
How to build a membrane tank

1. Clear the lab
2. Start by assembling the outer structure
3. Weld the 6 mm thick steel plates
How to build a membrane tank

4. Trust the experts: Licensed outfitters under GTT supervision

5. Make sure you have enough storage space (~100 boxes for insulation + membrane panels)

6. check the welds (here DPT test)

7. fix the anchoring rods and start installing the insulation panels
8. Install all layers of insulation panels and sensors. (45 Pts are interleaved to monitor temperature gradient of insulation during operation)

How to build a membrane tank

8. Install all layers of insulation panels and sensors. (45 Pts are interleaved to monitor temperature gradient of insulation during operation)


Ongoing work WA105 311 and 666

accessible cold front-end electronics

feedthroughs and top-cap

light readout

automatic levelling of CRP

see poster session
Ongoing work WA105 311 and 666

- High voltage (100-600 kV)
- Cryogenic installation & high purity
- Submerged pump
- Slow control & monitoring
- Cryo-camera
- Software (simulations, DAQ, storage)
Amplification of charges in pure argon vapor

(1) charges extracted to vapor phase E field of $\sim 2\ kV/cm$

(2) charges amplified in Large Electron Multiplier (LEM) E field of $\sim 30\ kV/cm$

(3) charges collected on specially designed two view anode. Both views see the same amount of charge and have identical signals.
The Charge Readout

The extraction grid LEM and anodes are all combined in **independent modules of square meter scale** adjustable to the LAr level: **the charge readout plane (CRP)**

**extraction grid-LEM and anode all in one single module**

**example of a 3x3 m² CRP**

- **3 m × 3 m**
- **50x50 cm² LEM+anodes**
- **50 cm × 50 cm**

- Multilayer PCB anode
- Vapor
- Extraction grid
- Liquid
The detector: Charge Readout Plane

The extraction grid LEM and anodes are all combined in independent modules of square meter scale adjustable to the LAr level: the charge readout plane (CRP)

extraction grid-LEM and anode all in one single module

example of a 3x3 m² CRP

12 kt proposal
CRP - R&D towards increasing sizes

10x10 cm²

40x80 cm²

1x1 m²

3x1 m² (WA105)

3x3 m² (WA105 & DUNE)

WA105 and DUNE CRPs are all composed of modules 50x50 cm² LEMs and anodes
Assembly sequence on the CRP (3x1 m² CRP)

- placing G10 frames and extr. grid support
- screw the G10 modules on the main frame
- position the LEM/anode sandwich
- CRP frame with one LEM/anode module
- close up of the LEM/anode module
- tensioning the wires of the extraction grid
Tests in cold

strain gauges

deformations in cold

temp. monitoring
in the scope of the WA105 prototyping activities we have ordered and are testing 20 LEMs and 15 anodes from ELTOS.

Their design are the fruit of extensive R&D on smaller scale prototypes (10x10 cm$^2$ and 40x80 cm$^2$)

50x50 cm$^2$ LEM
- std PCB with o(150) holes/cm$^2$
- 1 mm thick, 500 um ø holes, 40 um dielectric rim

50x50 cm$^2$ Anode
- optimised for long readout strip
- equal charge sharing on both views

dC/dl $\sim$ 120 pF/m
**LEM characterisation**

Effect of:
- Rim size
- Hole diameter
- Hole layout
- PCB thickness

Fitting function:

$$G_{eff}(E, \rho, t) \equiv \mathcal{G} e^{\alpha(\rho, E)x} \times \mathcal{C}(t)$$

$$\alpha(\rho, E) = A\rho e^{-B\rho/E}$$

C. Cantini et al 2015 JINST 10 P03017

Max Gain 180 = MIP S/N ~800!
the LEMs have different charging up characteristics but all could be operated stably at gains of at least 20.
LEM gain stability

This is a MIP (data) event at gain of ~20 S/N

(LEM: 31 kV/cm, induction: 5 kV/cm, extraction: 2 kV/cm, drift: 0.5 kV/cm)
Large area LEMs

In the context of the WA105 3x1x1 m3 activities, we have developed the complete chain for LEM validation from construction to installation. This includes shipping, cleaning, testing, QA, storage, etc...

- Each LEM has its handling plate
- 1) Lessive (soap + water 65 °C) 8 mins
- 2) High pressure water DI water 3 mins
- 3) Rinse DI water ~1 min
- 4) Ultrasonic bath DI water 10 mins
- 5) HV test in a closed box with transparent window. CAEN N1471H PSU with 50 pA resolution
- 6) Storage in custom made box designed to hold 20 LEMs with their handling plates.
WA105 is an approved CERN R&D program which will provide vital input for DUNE. We have a set of well defined technical and physics goals to deliver which will have implications for the long baseline neutrino program.

The double phase readout is an extensively tested and proven technology that is now being scaled to the multi-square-meter area. It provides excellent S/N performance, hence low energy threshold, cost-effective etc..

In the context of WA105 an intense effort is now been deployed to scale the double phase technology to relevant scales. This includes the operation in the very near future of a 5 ton and 300 ton active volume demonstrators on the surface. Significant progress recently on the 5 ton prototype with the installation of the first GTT membrane tank for LAr TPCs.

A full Conceptual Design Report is available for a multi-10kt underground double phase LAr TPC, developed in collaboration with Industrial Partners illustrating the construction sequences, cryogenic installation, safety issues, … all with a well defined costing.
Thank you!

Extra slides
Developing square meter readout

From the point of view of the readout the goals can be largely summarised as:

• we want to **amplify** the drifting charges by operating **50x50 cm² LEMs** in pure Argon vapor at 87K with the largest possible stable gain
• we want to readout the amplified charges on **meter long strips** with the lowest possible electronic noise.

**a) LEM optimisation**

**C. Cantini et al 2015 JINST 10 P03017**

**b) Anode optimisation**

**C Cantini et al 2014 JINST 9 P03017**

\[
\begin{align*}
\frac{dC}{dl} & \sim 120 \text{ pF/m} \\
\end{align*}
\]
Developing square meter readout

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A. Badertscher et al. JINST 8 (2013)P04012,
10x10 readouts
many test of
different LEMs
and anodes.
Gain stability
etc..

40x80 readout
gain behaviour on
large areas.
reconstruction of
more complex
events (d-rays
e tc..)
50x50 cm² LEM & ANODE

detailed investigation of the LEM surface and holes

- ø 500 µm
- rim 40 µm
- pitch 800 µm
Detailed investigation of the LEM surface and holes.

- ø 500 μm
- Rim 40 μm
- Pitch 800 μm
Charges need to be extracted from the liquid to the Ar vapour. Requires 2 kV/cm in the liquid, larger than the drift field of 500 V/cm.

design 100 micron stainless wire with 3 mm pitch in x and y directions with dedicated tensioning system.
LEM + anode sandwich distance

distance between LEM & anode should be kept constant since it affects the gain. Here we had one module surveyed at the metrology lab. Planarity is within ~100 microns which is very acceptable in terms of gain variation (< 5 %).

nominal ~ 2 (LEM-anode) + 1 (LEM thickness) + ~.05 mm ≈ 3.05 mm

camera through LEM hole

![Histogram of LEM-anode distance](image)
DUNE double phase far detector

Neutrino beam from FNAL to SURF underground laboratory with 40 kton Liquid Argon detector.

4 underground caverns with detector modules of 10 kton

<table>
<thead>
<tr>
<th>Active volume sizes</th>
<th>W = 12m</th>
<th>L = 60m</th>
<th>H = 12m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active volume / LAr mass</td>
<td>8'640m³</td>
<td>12'096Ton</td>
<td></td>
</tr>
<tr>
<td>Number of field rings</td>
<td>60</td>
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1.2 MW neutrino beam from FNAL to SURF underground laboratory with 40 kton Liquid Argon detector.
DUNE schedule

LBNF/ DUNE Schedule Summary Overview

SCHEDULE CONTINGENCY:
24 months on CD-4a
31 months on CD-4b

- Jul-15 CD-1 Refresh Review
- Jan-16 CD-3a
- May-18 CD-3b
- Dec-19 CD-2/3c Project Baseline/ Construction Approval
- Feb-23 CD-4a (early completion) 24 months DOE CD-4a
- Feb-25 CD-4b (early completion) 33 months DOE CD-4b
- Sep-27 CD-4b (early completion) Apr-30
- Feb-25 DOE CD-4a

FY15 FY16 FY17 FY18 FY19 FY20 FY21 FY22 FY23 FY24 FY25 FY26 FY27
- Beamline Installation
- Near Detector Installation
- NSCF Installation
- LBNF at the Far Site Complete Detector #1 Commissioned
- LBNF at the Near Site Complete – Beamline Components Installed

06.02-04.15 N S Lockyer LBNF/DUNE Overview

35
Many aspects have already been studied with industrial partners in the scope of LAGUNA.

- Cathode design & assembly
- HV at cathode
- Drift cage design & assembly
- PMT holding
Lar Proto layout in building 182 at CERN
All Work Packages are decomposed in a one year WBS which is constantly checked and updated.

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<table>
<thead>
<tr>
<th>3x1x1 LA double phase TPC PROTO at Bld 182 CERN</th>
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<tbody>
<tr>
<td>FINAL ASSEMBLY</td>
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<tr>
<td>1.0</td>
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<td>1.6</td>
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<td>1.7</td>
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</tbody>
</table>

2 | TASK | CERN / ETH |                  |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 2.1 | Construction of outer structure of crystal | Romanika contractor | X |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 2.2 | Delivery of outer construction in 182 by truck | Romanika contractor | X |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 2.3 | Milestone: order crystal | CERN / ETH |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 2.4 | Construction of outer planes (1mm thick) inside outer structure | CERN technicians / Nexia |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 2.5 | Design for realization / welding work (includes bending, cutting, bending etc) | Galati (Span) + GTT (France) |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 2.6 | Procurement and production of materials | Galati (Span) + GTT (France) |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 2.7 | Shipment of materials and delivery to CERN | Galati (Span) |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 2.8 | Bottom construction (sidings, anchoring, panels) | Galati (Span) |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 2.9 | Installation of wall panels and corners | Galati (Span) |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 2.10 | Fitting and welding of membrane sheets | Galati (Span) |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 2.11 | Installation and welding of single pieces and and tank | Galati (Span) |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 2.12 | Testing of Crystaline (argon-eneutucium testing on hitches etc) / shaking | Galati (Span) |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 2.13 | Acceptance / reception of work | CERN / ETH |        |        |        |        |        |        |        |        |        |        |        |        |        |        |

3 | LIQUID INFRASTRUCTURE | ETH |                  |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 3.1 | Design of Liquid Infrastructure (Storage or CERN) | ETH / Wu / French designer |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 3.2 | Milestone: liquid lines outside dimensions in top cap | |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 3.3 | Contract preparation (tender + contracts) |         |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 3.4 | Ordering |         |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 3.5 | Construction of Liquid Infrastructure |         |        |        |        |        |        |        |        |        |        |        |        |        |        |        |

```

full WBS available on WA105 plone. This link: [3x1x1-construction-plan](#)
Work packages LAr Proto

All activities decomposed in well identified Work Packages.

- Chimneys
  - 6 SGFT
  - 3 SCFT
  - 3 SSFT
  - 1 HVFT
  - 1 LHFT
  - crossing pipes
  - manhole
  - deck plate
  - insulation
  - invar

- Top Cap
  - Mech frame
  - LEM+ anode
  - HV connectors
  - SG connectors
  - extraction grid
  - assembly: in clean room

- CRP
  - PTs
  - strain gauges
  - pressure monitors
  - level-meters (coax+ plate)
  - cryo-cam
  - HV + current monitoring
  - CRP level adjustment
  - Readouts and interfaces (PLC)
  - cabling (to CRP and cryostat)

- Slow control
  - 3 coated PMTs
  - GND grid
  - cathode
  - 20 field shapers
  - voltage divider
  - 8 G10 pillars
  - PMT supporting frame

- Drift Cage
  - SS outer structure
  - insulation
  - membrane

- Tank
  - cryo pump
  - piping
  - LAr storage
  - trace analysers
  - cartridge (+ regeneration)

- LAr handling
  - R&D on Asic in cold
  - DAQ scheme
  - infrastructure computers etc..
  - location of "counting house" on site?

- FE & DAQ

Assembly time
- 2 weeks
- 1 week
- 4 weeks
- 2 weeks

X-mas 2015 - detector installed in cryostat

- 182 (CR?)
- off-site (TBD)
- 182-2-001-A
- 182-2-001-B
- off-site (TBD)
- 182-2-001-C
- 182-2-005
- 182-2-004

- Essentials:
  - nomenclature of locations
  - not shown as a package but equally important "on site infrastructure" (mainly safety and clean room) runs in parallel to all the work

Abbreviations:
- SGFT: signal feedthrough
- SCFT: slow control feedthrough (includes low-voltage)
- HVFT: high-voltage feedthrough
- LHFT: liquid handling feedthrough

NB: nomenclature of locations in bd 182 are on the plane under this link

Sebastien Murphy ETHZ

DPF 2015        Ann Arbor 3-8 August 2015
Clean room in b. 182

Fully operational with measured better than ISO 8 class.
LEM procedure

- CNC drilling
- mechanical polishing
- permanganate bath +rinse
- Rims by global etching
- passivation (Chromic acid)
- Ni/Au plating

- Lessive (soap) bath at 68°C
- Ultrasonic bath DM water
- High pressure DM water
- Baking 4h 180°C (only once) or 1hr at 80°C (2nd, … iterations)
- HV test

- Cleaning is done at CERN. Procedure takes about 6hrs per LEM (mainly due to baking time)
- at ELTOS: one machine with 6 independent drills each capable of ~7 holes per second. They can drill 6 50x50 LEM in 24 hours. The timescale for the rest of the procedure depends on the organisation of production line.

- Removes glass fibber from holes
- Acide sulphuric bath
- Removes grease
- Removes dust/dirt in holes
- Polymerisation of the glass fibber (only 1st iteration) or drying
- Goal no discharges at 3.5 kV

HV test not ok  ➔  HV test ok  ➔  Storage + test
Gain characterisation of a 50x50 LEM

- Test Chamber ready to be delivered to CERN on April 7th.
- Electronic noise: $\sim 0.2 \text{ fC} / \text{channel}$ (T2K FEC).
- 0-suppression: $\times 70$ reduction in data volume.
- All tests with 10x10 prototypes in $\text{Ar}(95\%)-\text{iC}_4\text{H}_{10}$ (5%) indicate that gains of $\sim 10^3$ can be reached allowing detectors to be calibrated with a $^{55}\text{Fe}$ source.

1mm LEM (ELTOS)
500 $\mu$m holes
80 $\mu$m rim
800 $\mu$m pitch
square

-E$_i$ = 5 kV/cm

1mm LEM (ELTOS)
500 $\mu$m holes
40 $\mu$m rim
800 $\mu$m pitch
hexagonal

-E$_i$ = 5 kV/cm

Ar(95%)-iC$_4$H$_{10}$(5%)

$E_{\text{LEM}} = 14.5$ kV/cm
Drift Cage

Drift Cage

Extraction grid

25.95mm
50mm
50mm
5 Hamamatsu 8” R5912 PMTs.

3 with same installation as ArDM.

2 with “Spanish installation”. acrylic window and single cable.