LBNO-DEMO (WA105): a large demonstrator of the Liquid Argon double phase TPC

Sebastien Murphy ETHZ on behalf of WA105

WIN2015 Heidelberg
✓ 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(10’000) 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
DUNE double phase far detector

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
- Grid
- Cathode
- Collection field 5kV/cm
- Extraction field 2kV/cm
- Drift field 0.5 – 1 kV/cm

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
  - Maximise active LAr volume whilst minimising the number of channels.

Double phase readout: many years of R&D

supporting R&D activities on smaller prototypes

40x80cm²
stable operation of large area readouts

10x10cm²
LEM/anode R&D

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

1ton light readout operating underground

cosmic muon

HADR shower

EM shower

2-phase data
The collaboration

22 institutes 122 physicists
The WA105 6x6x6 m$^3$ 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
**WA105: important Physics milestones**

test reconstruction on **fully contained events** from charged particle beam (well defined primary particles and energies)

- **5 GeV** pions, electrons/positrons, protons, muons

Some goals

- Development of automatic event **reconstruction**
- **test NC background rejection** algorithms on “νe free” events
- Charged **pions** and proton **cross-section** on Argon nuclei.

- 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
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 outer structure

**DLAr (6x6x6 m³)**

- EHN1 extension civil engineering

Detector installation end 2015

Detector installation 2017
WA105 prototypes - status

LAr-Proto (3x1x1 m³)
Tank outer structure

DLAr (6x6x6 m³)

Detector installation end 2015

Detector installation 2017
Membrane tank

outer-structure-construction-time-lapse

insulation and corrugated membrane panels installation in July
Ongoing work WA105 311 and 666

- Accessible cold front-end electronics
- Feedthroughs and top-cap
- Light readout
- Automatic levelling of CRP
Ongoing work WA105 311 and 666

- high voltage (100-600 kV)
- slow control & monitoring
- cryo-camera
- cryogenic installation & high purity
- software (simulations, DAQ, storage)
- submerged pump
Amplification of charges in pure argon vapor

(1) charges extracted to vapor phase E field of ~2 kV/cm

(2) charges amplified in Large Electron Multiplier E field of ~30 kV/cm

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

Data collected on a 40x80 cm² DLaR TPC at CERN
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)

example of a 3x3 m² CRP
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)

example of a 3x3 m² CRP
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
- Screwing the G10 modules on the main frame
- Positioning 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 ~ 120 pF/m

C. Cantini et al 2015 JINST 10 P03017

C Cantini et al 2014 JINST 9 P03017
LEM characterisation

- rim size
- hole diameter
- hole layout
- PCB thickness

optimisation from 10x10 cm² LEMs in pure argon vapour

C. Cantini et al 2015 JINST 10 P03017

effect of

Max Gain 180 = MIP S/N ~800!

Fitting function:

\[ G_{\text{eff}}(E, \rho, t) \equiv \mathcal{T} e^{\alpha(\rho, E)x} \times \mathcal{C}(t) \]

\[ \alpha(\rho, E) = A \rho e^{-B \rho/E} \]
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 \( \sim 20 \) S/N

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

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View 0: Event display (run 15937, event 22)

View 1: Event display (run 15937, event 22)

View 0: Signals (run 15937, event 22)

View 1: Signals (run 15937, event 22)
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…
**Conclusion**

*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.

*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*

\[ \frac{dC}{dl} \sim 120 \text{ pF/m} \]
Developing square meter readout

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A. Badertscher et al. JINST 8 (2013)P04012,
50x50 cm² LEM & ANODE

Detailed investigation of the LEM surface and holes

ø 500 μm

Pitch 800 μm

Rim 40 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.
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 \sim 2 \text{(LEM-anode)} + 1 \text{(LEM thickness)} + \sim 0.05 \text{ mm} \approx 3.05 \text{ mm}

camera through LEM hole
DUNE double phase far detector

1.2 MW neutrino beam from FNAL to SURF underground laboratory with 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>
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<tbody>
<tr>
<td>Active volume / LAr mass</td>
<td>8'640 m³</td>
<td>12'096Ton</td>
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</tr>
<tr>
<td>Number of field rings</td>
<td>60</td>
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<tr>
<td>Field ring vertical spacing</td>
<td>200mm</td>
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<tr>
<td>Field ring tube diameter</td>
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<td>Anode deck size</td>
<td>W = 12m</td>
<td>L = 60m</td>
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<tr>
<td>Sub-Anode size</td>
<td>W = 3m</td>
<td>L = 3m</td>
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</tr>
<tr>
<td>Number of Sub-anodes</td>
<td>4 x 20 = 80</td>
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<td>Number of CRP / sub-anode</td>
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<td>Total number of CRP</td>
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<tr>
<td>Number of LEM planes / sub-anode</td>
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<tr>
<td>Total number of LEM planes</td>
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<tr>
<td>Number SFT chimneys / sub-anode</td>
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<td>Total number of SFT chimneys</td>
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<tr>
<td>Number of read-out channels / SFT chimney</td>
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<tr>
<td>Total number of read-out channels</td>
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<td>Total number of Suspension FTs</td>
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<td>Total number of Slow Control FTs</td>
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<tr>
<td>Number of HV feedthrough</td>
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<td>HV for vertical drift</td>
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<td>Number of voltage degrader resistive chains</td>
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<td>Resistor value</td>
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<tr>
<td>Total number of resistors</td>
<td>300</td>
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<tr>
<td>Total number of PMTs</td>
<td>180 (1 / 4m²)</td>
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DUNE schedule

**LBNF/ DUNE Schedule Summary Overview**

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

- **FY15**
  - Beamline Installation
  - Near Detector Installation
  - NSCF Installation

- **FY16**
  - LBNF at the Far Site Complete
  - Detector #1 Commissioned
  - LBNF at the Near Site Complete – Beamline Components Installed

- **FY17**

- **FY18**

- **FY19**

- **FY20**

- **FY21**

- **FY22**

- **FY23**

- **FY24**

- **FY25**

- **FY26**

- **FY27**

- **Sep-27**
  - CD-4b (early completion)  
  - Apr-30  
  - DOE CD-4b

- **Feb-25**
  - DOE CD-4a

- **Feb-23**
  - CD-4a (early completion)
  - 24 months

- **Dec-19**
  - CD-2/3c Project
  - Baseline/ Construction Approval

- **May-18**
  - CD-3b

- **Jan-16**
  - CD-3a

- **Jul-15**
  - CD-1 Refresh Review

**Legend**

- CFFS Preliminary & Final Design
- FSCF Excavation and Caverns
- Cryostat and Cryogenics Construction
- FD Detector Design and Prototyping
- FD Detector 1-4 Procurement: assembly, installation, filling, commissioning
- CFNS Preliminary & Final Design
- Near Detector & Beamline Design
- Near Detector Procurement and Assembly
- Beamline Conventional Facilities and Component Installation
- N.D. Hall & Install of Near Detector in Hall
- ND Commissioning

**Timeline**

- 06.02-04.15
- N S Lockyer | LBNF/DUNE Overview
Many aspects have already been studied with industrial partners in the scope of LAGUNA

- Cathode design & assembly
- Drift cage design & assembly
- HV at cathode
- 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.

full WBS available on WA105 plone. This link: 3x1x1-construction-plan
All activities decomposed in well identified Work Packages.
Clean room in b. 182

Fully operational with measured better than ISO 8 class.

the clean room inside b. 182

view of the 4x1.5 m optical table for the CRP assembly

main room with CRP assembling area

soldering station with extractors

view of the soldering room
LEM procedure

- 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.

- Cleaning is done at CERN. procedure takes about 6hrs per LEM (mainly due to baking time)
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 10 \( \times 10 \) prototypes in Ar(95\%)-iC\(_4\)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 \( \mu \text{m} \) holes
- 80 \( \mu \text{m} \) rim
- 800 \( \mu \text{m} \) pitch

**Square**
- \( E_i = 5 \text{ kV/cm} \)

**Hexagonal**
- \( E_i = 5 \text{ kV/cm} \)

Ar(95\%)-iC\(_4\)H\(_{10}\)(5\%)
- \( E_{\text{LEM}} = 14.5 \text{ kV/cm} \)
Drift Cage

Shuoxing Wu ETHZ
Sebastien Murphy ETHZ
CERN Neutrino I
Light readout

5 Hamamatsu 8” R5912 PMTs.

3 with same installation as ArDM.

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