AIDA 2020

WP8/NA7 Large scale cryogenic liquid detectors

AIDA 2020 Annual Meeting
Bologna 24/4/2018

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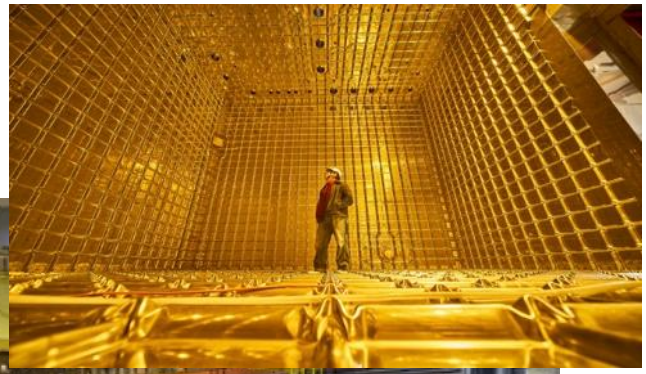
Cryogenic Detectors NA

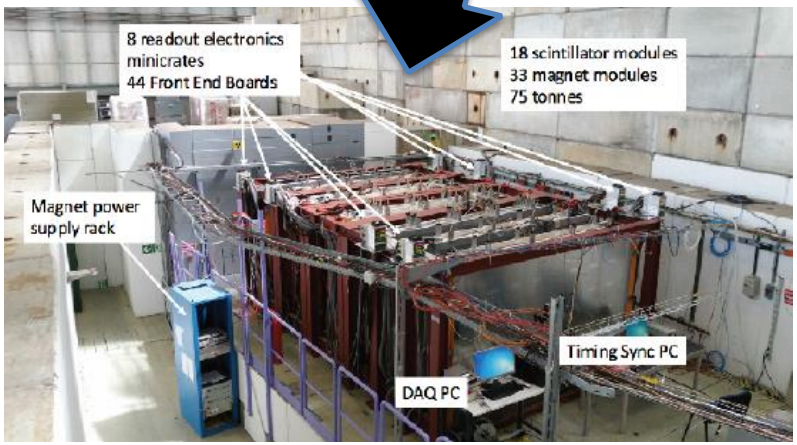
Common infrastructures of the WP8 for the R&D activities at CERN supported by the CERN Neutrino Platform

- 3x1x1 m^3 Dual-phase WA105 Pilot detector

- 6x6x6 m^3 Dual-phase Demonstrator (WA105/NP02/dual-phase ProtoDUNE)



- Baby MIND prototype (NP05)



Cryogenic Detectors NA

- **Topics and corresponding deliverables: (detector technologies)**

  - **Task 8.2 Purification and monitoring (Task leader UCL)**
  - **Task 8.3 Charge readout and double-phase (Task leader IPNL)**
  - **Task 8.4 Light readout (Task leader Ciemat)**
  - **Task 8.5 Very high voltage (Task leader ETHZ)**
  - **Task 8.6 Magnetization (Task leader Glasgow)**

- These 5 topics are identically structured in terms of goals and deliverables, following the guidelines presented above. They corresponds to the frontier developments in the field.

- Collaborating institutes: CIEMAT, CEA, LHEP Bern, ETHZ, Genève, Glasgow, IN2P3 (IPNL, APC, LPNHE, LAPP), UCL; strong connections with the US groups involved in the common project DUNE

→ Worldwide impact on the community working on large cryogenic detectors

Cryogenic detectors Networking Activity:

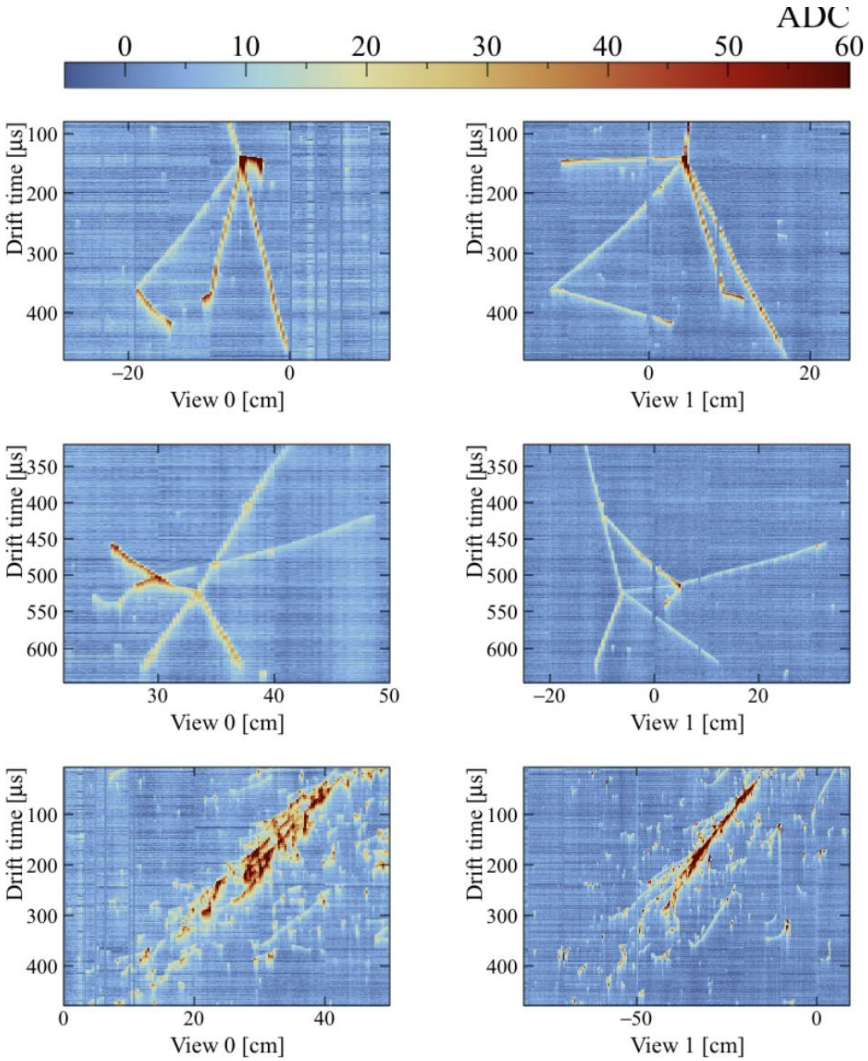
Basic concept and modus operandi:

- **Benefit from the R&D infrastructure at CERN for WA105** and of other infrastructures available in different laboratories (piggy-back)
- Integrate the hardware available in these infrastructures in a networking activity with dedicated personnel (→main requests to AIDA II in terms of manpower: postdocs contracts)
- Matching funds from other personnel involved in the activities and existing equipment

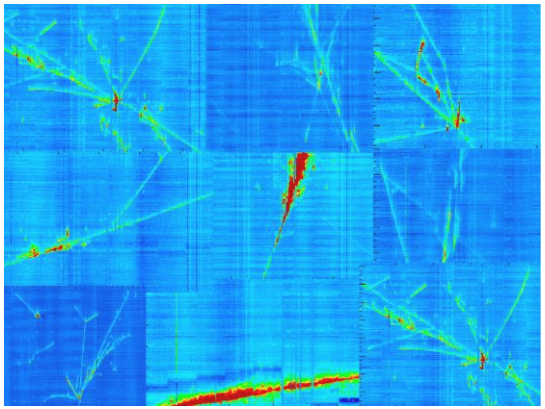
Goals:

- Networking and exchange among the existing EU expert groups involved in the development of the most innovative experimental techniques
- Reviewing and reporting on some crucial development aspects for large cryogenic detectors.
- Sharing of information and tools (dissemination) in the community and creation of a state of the art common knowledge of the field broadly applicable in future projects

Cryogenic Detectors NA



hadronic and EM showers from cosmic rays recorder in the 3x1x1



350 k cosmic events recorded with a ton scale dual phase LAr TPC.
The operation allowed for tests and results concerning the activities of task 8.2 (purification), 8.3 (charge readout) 8.4 (light readout) and 8.5 (Very high voltage). Includes interface to WP13 for the event reconstruction. publication on the performance well advanced.

Cryogenic Detectors NA

Milestones submitted around March 21st.

· MS72: Bi-annual progress reports and meetings on purification and monitoring

http://cds.cern.ch/record/2310567?ln=en

· MS73: Bi-annual progress reports and meetings on ionisation charge readout

http://cds.cern.ch/record/2310430

· MS74: Bi-annual progress reports and meetings on light readout

http://cds.cern.ch/record/2310378

· MS75: Bi-annual progress reports and meetings on very high voltage

http://cds.cern.ch/record/2310575?ln=en

· MS76: Bi-annual progress reports and meetings on magnetisation

http://cds.cern.ch/record/2310592?ln=en

Cryogenic Detectors NA

- The R&D activities supported by AIDA 2020 are conducted with the support of the CERN neutrino platform which **provides several infrastructures**

- The deliverables of AIDA2020 are defined in more general terms independently on the single tests/experiments (3 x1x1, ProtoDUNE-DP, DUNE, Baby-Mind)

- The deliverables include a part related to **networking and general dissemination (Networking Reviewing and Sharing),** as described in the contractual documents, plus **some specific aspects of the R&D which have been isolated** from the context of the specific experiments

- In order to combine the general dissemination goal and the documentation of specific aspects, as foreseen since the beginning of the project the writing of the deliverables is under the form of **wiki pages**. This will make all the outcome of the R&D available to the community. Good participation and visibility of young people/postdocs. Links to other material and other AIDA2020 activities

- A summary of the information on the wiki pages can also be extracted to fill a pdf report for the deliverables of the various working groups

→ The editing of the wiki pages is in progress for the deadlines of the various deliverables

Cryogenic Detectors NA

Deliverables

https://twiki.cern.ch/twiki/bin/view/AIDA2020WP8/WebHome

Welcome to the AIDA2020 WP8 wiki pages

AIDA 2020

The Networking Activity (NA7) on Large Scale Cryogenic Liquid Detectors is a Work Package (WP8) of the AIDA2020 project. WP8 fosters knowledge sharing and common tools in the neutrino community as regards state-of-the-art in very large cryogenic liquid detectors.

The construction of liquid argon detectors at the 10 kton scale is an essential ingredient of the international long-baseline neutrino program unifying the European and USA efforts.

WP8 activities focus on some among the most challenging aspects related to this large scale detectors development:

- Task 8.2 Purification and monitoring
- Task 8.3 Charge readout and dual-phase readout technology
- Task 8.4 Light readout
- Task 8.5 Very High Voltage (VHV)
- Task 8.6 Magnetisation

The deliverables are being summarised on the Twiki, contents are taking shape

see presentation at SC 14:

https://indico.cern.ch/event/681858/contributions/2793626/attachments/1593618/2523032/AIDA_WP8_ST14.pdf

Purification/monitoring:

- Review: purity assessment and detector control methods
- Large scale monitoring systems for LAr detector *
- LAr level monitoring *
- Cryogenic cameras *
- Gas purity during purge *
- LAr purity and recirculation *
- Purity and stability of thermodynamic conditions in industrial LNG vessels *

(*) Specific aspects extracted from tests conducted on the 3x1x1

Light readout:

- Review: light readout methods SipM/PMTs etc
- Coating techniques for PMTs (direct TPB coating, plastic base coating), uniformity assessment *
- Development of QA methods for PMTs testing *
- Digitization of light signals *
- Development of HV/signal unified cabling (comparison positive and negative bases) *
- Development of transparent cathode with TPB coating *

(*) Specific aspects extracted from tests conducted on the 3x1x1 or for ProtoDUNE-DP

Charge readout:

- Review: single and dual phase charge readout
- LEM production/cleaning/tests procedures *
- LEM integration on large DP readout surfaces *
- Cryogenic DP accessible electronics *
- High bandwidth DAQ system for giant LAr detectors *
- Synchronization system for giant LAr detector *

(*) Specific aspects extracted from tests conducted on the 3x1x1 or for ProtoDUNE-DP

Very High Voltage (VHV):

- Review: very high voltage methods for large noble liquids TPCs
- Development of VHV simulations, critical aspects in detector design *
- Development of VHV feedthroughs and generators, tests *
- Construction techniques for large field cages/cathodes *

(*) Specific aspects extracted from tests conducted on the 3x1x1 or for ProtoDUNE-DP, DUNE

Magnetization:

- Review on magnetization schemes
- Results from tests of novel magnetization schemes
- How to deal with LAr magnetization, superconductive lines

Purification in LAr TPCs

LAr TPCs are able to reconstruct the tracks of particles as they traverse across the liquid argon medium by collecting the scintillation light and ionisation charge produced as they move. Ideally, all electrons should be drifted to the anode plane, but in practice, part of the ionisation charge is lost, due to the presence of electronegative impurities in the liquid. To keep such loss to a minimum, purging the cryostat with gas argon before filling and purifying the liquid argon during operation are essential.

Purging

Before filling and prior to cool down, the cryostat is purged with pure gas argon (purified by passing it through a getter) to remove air from inside the tank. The purge is first performed in open-loop and then in closed-loop at a later stage. During the purge in open-loop the gas argon injected in the cryostat is free to exhaust to air through a venting valve. When the purge in closed-loop starts, the venting valve is closed, so that the gas cannot escape to atmosphere. Instead the injected gas argon is extracted from the vessel through a double diaphragm pump and subsequently purified by a getter before going back into the cryostat. The getter (a commercial SAES MicroTorr MC4500) removes H_2O, O_2, CO, CO_2, and H_2 down to <100ppt. The concentration of impurities, namely water, oxygen, and nitrogen, is constantly monitored through Residual Gas Analysers (RGAs) at various sampling points in the cryogenic system. To compensate for the sampled gas, the system also contains a make-up gas line which injects purified gas argon. During the purge in open-loop the ratio of nitrogen to oxygen (3.7 for air) may give hints to whether or not air leaks are present in the system. Once the levels of H_2O, N_2 and O_2 are below ~50 ppm, the second purge in closed-loop may start. Cool down starts once the levels of the water, oxygen, and nitrogen impurities have fallen to a few ppm or even less.

Cool down

impurities vs time.pdf

Evolution of the impurities measured in the gas during open, closed loop piston purge and cooling down. The measured temperatures inside the gas near the bottom, middle and top of the main cryostat volume are indicated in blue.

To perform the cooling down of the cryostat, a mixture of LAr and GAr at 87 K is inserted into a system of atomising nozzles located at the corner of the cryostat. The nozzles generate a spray which allows the tank to be cooled down uniformly and slowly, thereby preventing thermal shocks to the components inside. This method was successfully tested for the first time at FNAL in the 35-ton cryostat. The cooling power provided by the nozzles must compensate for the total heat input to the cryostat via the passive insulation and other internal heat sources (e.g. internal cables, electronics, injection of warm gas, recirculation pump, etc.), as well as provide enough cooling power to reach 87 K.

While cooling down takes place, the levels of the water, oxygen, and nitrogen impurities drop even further, as impurities “freeze” and the outgassing rate decreases. Once the cool down stage has completed, the filling stage of the cryostat can begin.

Charge readout for large scale cryogenic liquid detectors

Table of Contents

Charge readout in liquid argon

Liquid argon Time Projection Chambers (LAr TPC) exploit liquid argon as interaction and detection medium. Similarly as in gas TPC, a fully homogeneous detector can be built by enclosing the active LAr volume in a field shaping cage which defines a uniform electric field of typically 0.5–1 kV/cm. This field is used in order to drift the electrons from the ionization produced by charged particles to a segmented anode. The clouds of electrons, produced by charged particles along their trajectories in LAr, keep during while drifting their original shape being affected by small diffusion effects. Two orthogonal coordinates (or more than two coordinates at different angles, typically one collection view and two induction views) can be reconstructed by reading independent views on the anode plane. The measurement of the drift time, corresponding to the travel path of the electrons at constant speed from the production point to the anode, allows for the the reconstruction of the coordinate orthogonal to the anode plane. The detector can then provide an accurate 3D imaging of the original distribution of the ionization, similarly as in bubble chambers.

The original detector concept was pioneered by C. Rubbia in 1977. LAr does not attach the electrons produced by the energy losses, however residual electronegative impurities, such as oxygen molecules, which would absorb the electrons must be removed from the liquid in order to avoid the absorption of the electrons along their drift path.

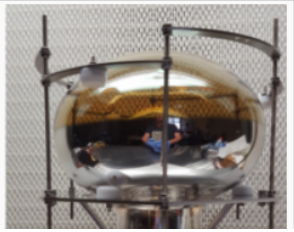
If the anode is immersed in the liquid it will just collect the electrons produced by the track ionization (typically 18000 electrons every 3 mm of path of a particle at the ionization minimum). This signal has then

Light readout for large scale cryogenic liquid detectors

Table of Contents

Light readout in liquid argon

Photomultipliers (PMTs) have been typically used as large area photodetectors in liquid argon (LAr). In particular, the 8-inch Hamamatsu R5912-20Mod cryogenic PMT [1] is a 14-stage high gain PMT with a bi-alkali photocathode, which has been adequately modified to compensate the gain diminution expected in a cryogenic environment, so 14 dynodes are used instead of 10. In addition, a thin platinum layer has been added between the photocathode and the borosilicate glass envelope to preserve the conductance of the photocathode at low temperature increasing the quantum efficiency. The photon detection system of ProtoDUNE dual phase (DP) [2] is formed by 36 of these PMTs. A PMT mount has been designed, manufactured and assembled at CIEMAT. The support frame structure has been made of 304 L Stainless steel and Nylon 6.6 pieces assembled by A4 stainless steel screws that minimize the mass while ensuring the PMT support to the cryostat membrane. The PMTs will be placed at the ProtoDUNE-DP membrane corrugation squares and the base will be glued to the membrane.



Very high voltage (VHV)

Generation and transport of very high voltage (O(100) kV) in pure cryogenic liquid and gases has always been a rich source of R&D. Indeed cryogenic detectors have the huge advantage of generating a complete 3-D image of all particles from an interaction and reconstruct the particles' energies well while sorting event from background. However, because of the dense media (compared to gas) they require high drift fields of 500 V/cm. This kind of experiments aiming at a maximum drift of several meters require bias voltages at their cathode in the hundreds of kilovolt range. The problem is to be able to generate this extremely high voltages and to get the voltage to the cathode over an unusually large distance without compromising the purity of the argon inside the detector by letting heat or air inside. Nonetheless there is a huge worldwide effort to tackle those issues.

The components

The very high voltage system consists off:

- **Generation:** The power supply should be able to provide the maximal operation high voltage (HV) and the power cable should be rated for this voltage.
- **Transmission:** The HV feedthrough (HVFT) should be designed to sustain this maximal operation HV.
- **Design:** The shape of all the elements of the TPC should be carefully designed to avoid critical field regions (maximal electric field above 40 kV/cm).
- **Electrostatic simulations:** The whole detector including the cathode, the field cage and the feedthrough has been simulated using the COMSOL multiphysics software. This work was done inside the WP8 and the results have been summarised in [refThesisPin]. We optimised the design of the feedthrough through simulations and we studied the influence of the different parameters of the HVFT design in the computed electric field along the whole TPC. The results are important also for future R&D on HVFT, cathode and field cage design.

Transmission: The high voltage feedthrough

Giant time projection chambers filled with liquid argon is the technology of choice for future neutrino experiments like DUNE. One of the biggest challenges in this kind of detectors is to be able to bring the voltage from warm temperature (outside the detector) to the LAr which is at cryogenic temperature. To deliver the voltage inside the cryostat is used a vacuum tight feedthrough. A first prototype of such a future feedthrough – a giant insulating plug – was successfully tested at CERN under AIDA-2020 WP8 and was in operation during more than four months inside a 3m3 Dual phase TPC prototype at CERN.

The feedthrough was designed by Franco Sergiampietri at CERN and its general design comes from the experience acquired during the ICARUS experiment [reflcarus] where lower high voltage feedthroughs were successfully tested up to -150 kV and operated for several years at - 75 kV. The 300 kV feedthrough is a scaled up and improved design. The scale up was essentially based on the following considerations:

Cryogenic Detectors NA

Extension:
We do not see any specific problems our drawback arising from an AIDA extension of the above cited tasks.

Extension allows for including also some results from 6x6x6 operation, postpone 8.2 deliverable

WP8 has connections with WP-13 on gaseous detector and WP-3 on the particle flow algorithms for reconstruction of LAr TPC events. We would for sure benefit from an extension of those WPs.

Felix's extension request document:

WP8 Large scale cryogenic liquid detectors
D8.2 Charge readout and double phase M42 postpone to M54
Following successful operation of a 1-ton dual phase liquid argon detector and construction of a 6x6x1m^3 structure, test results from a larger device come in reach and would significantly add to the value of the Deliverable

Cryogenic Detectors NA

Overvier WP8 scientific goals *Dario Autiero*		
Aula 6 14:30 - 15:00		
Purification and monitoring *Laura Manenti*		
Aula 6 15:00 - 15:30		
Charge Readout and dual phase *Dario Autiero*		
Aula 6 15:30 - 16:00		
Coffee Break *Aula 6* 16:00 - 16:30	**Coffee Break** *Aula 7* 16:00 - 16:30	**Coffee Break** *Salone Bolognini* 16:00 - 16:30
Light readout *Clara Cuesta*		
Aula 6 16:30 - 17:00		
Very high voltage *Sebastien Murphy*		
Aula 6 17:00 - 17:30		
Magnetistation *Etam Noah Messomo*		
Aula 6 17:30 - 18:00		

Cryogenic Detectors NA

Conclusions:

- Moving from R&D phase to documentation of the results and the editing of the deliverables

- Following the scheme already defined in the contractual documents:

Networking, Reviewing, Sharing of some specific aspects of the R&D (not a report on the infrast ructure)

- Deliverables based on wiki pages in order to combine documentation with sharing, wiki cont ent under development following the scheme defined above

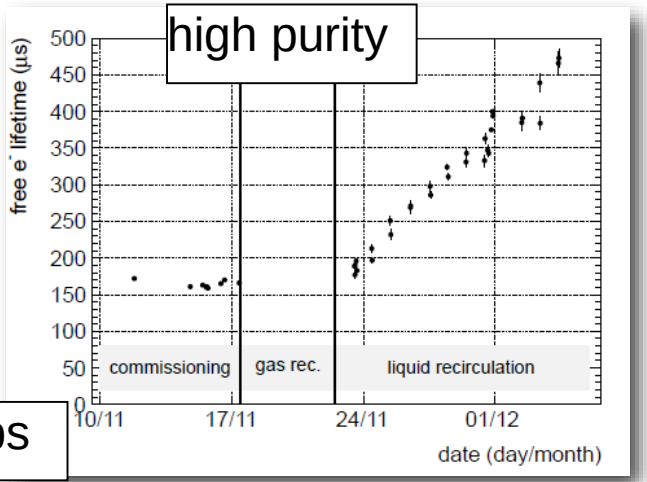
- Milestones achieved on schedule

- Synergies with WP13 and WP3 (more details in following talks)

Purification and Monitoring (Task leader UCL)

Networking, Reviewing and Sharing of infos and tools (NRS) the following points:

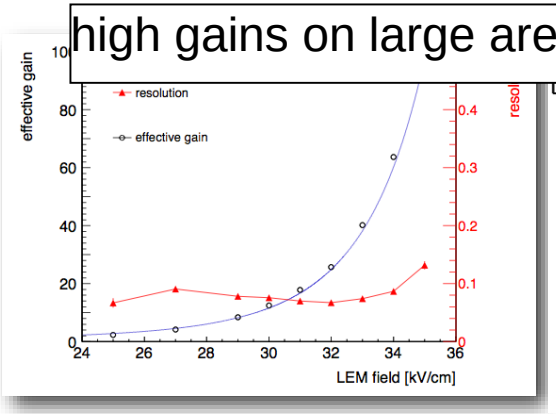
- Scaling of purification systems for massive cryogenic detectors (purification and recirculation of noble liquids and gases)
- Assessment of common measurement techniques for purity monitoring
- Techniques for levels control and measurement of thermodynamic conditions

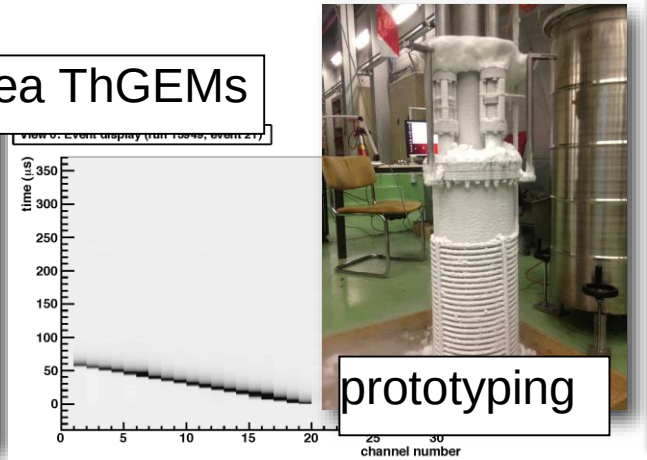


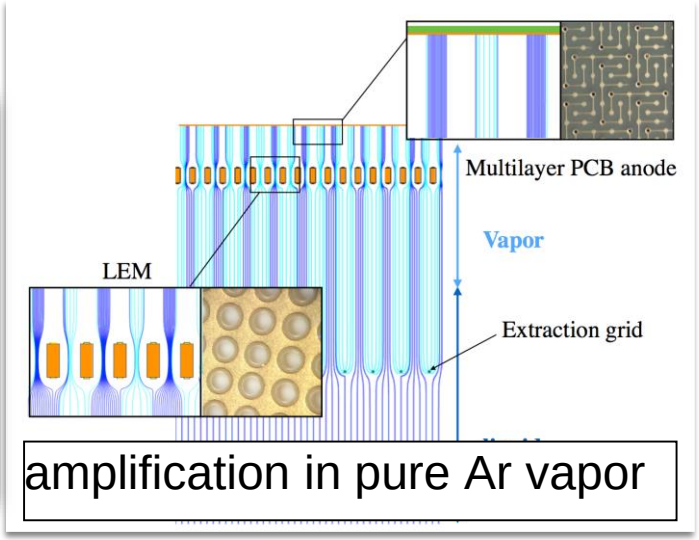
Charge readout and double phase (Task leader IPNL)

Networking, Reviewing and Sharing of infos and tools (NRS) on the following points:

- Ionization charge readout techniques in liquefied noble gases
- Double-phase techniques for charge amplification with electrons extraction from the liquid phase and amplification with micro-pattern gas detectors in absence of quenching
- Charge readout front-end cryogenic electronics and large scale digitization systems
- Definition of a basic setup detector+electronics for sharing in the community



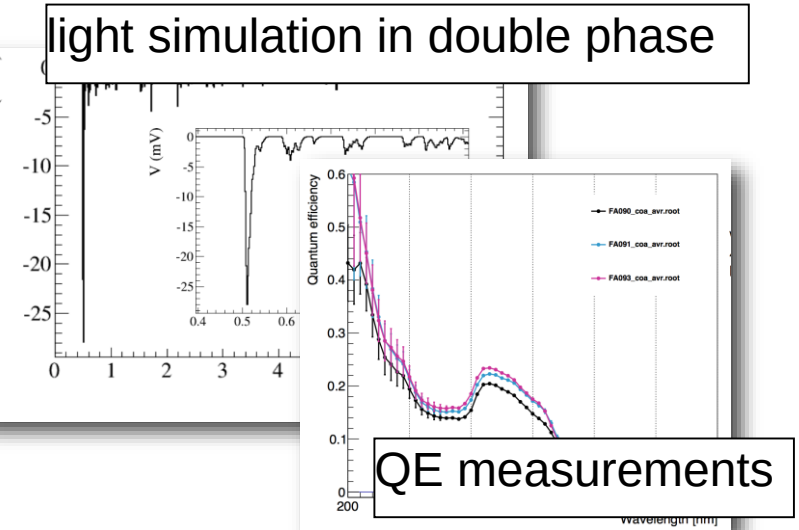


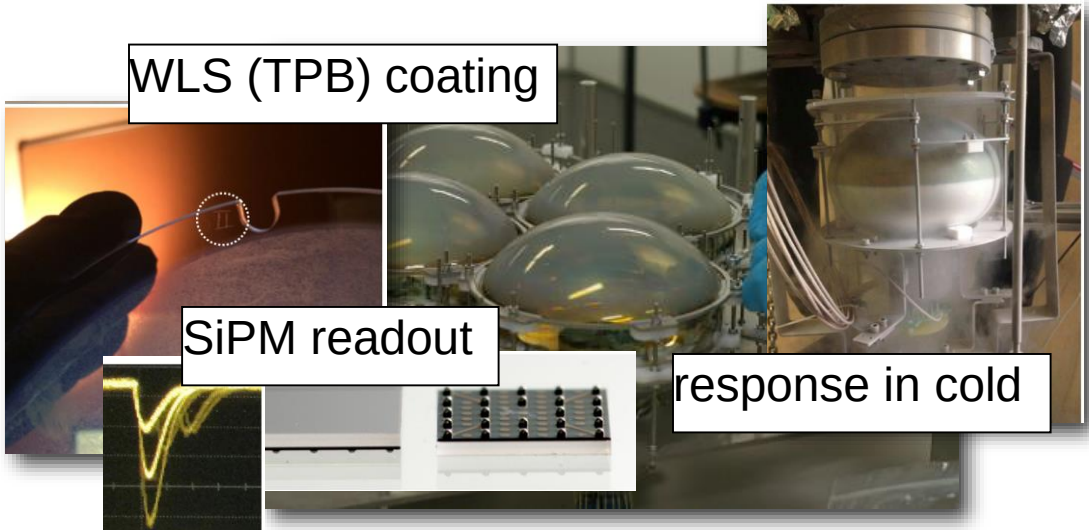


Light readout (Task leader CIEMAT)

Networking, Reviewing and Sharing of infos and tools (NRS) on the following points:

- Large photo-detectors (PMT, SiPM) for the readout of scintillation light in liquefied noble gases
- Wavelength-shifting techniques for large area readout in cryogenic detectors
- Digitization techniques of the scintillation signals in liquefied noble gases and definition of a basic setup (PD+electronics)



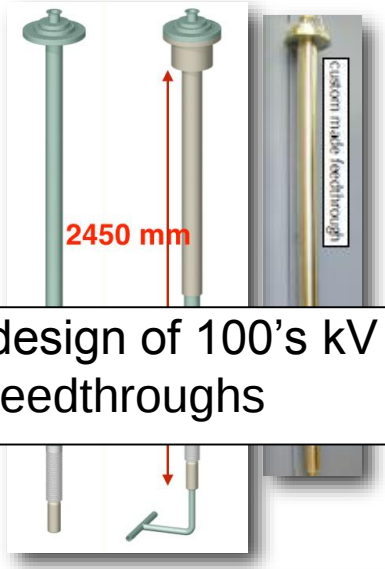


Very High Voltage (Task Leader ETHZ)

Connected to high fields, long drift paths -> V up to ~MV

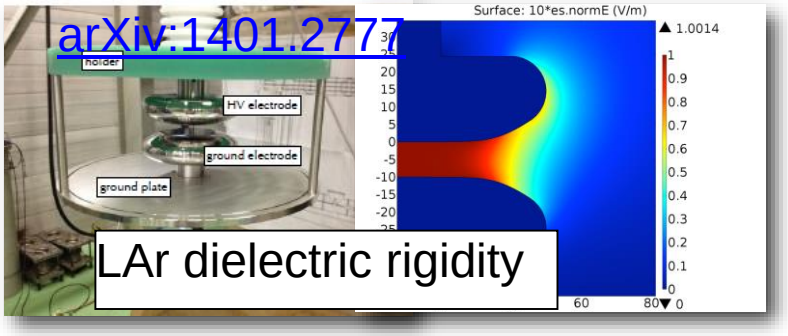
Networking, Reviewing and Sharing of infos and tools (NRS)
on the following points:

- Reviewing of VHV generation
- VHV transport: connection to VHV generators and feedthrough
- Study of phenomena related to high fields in nobles gases and liquids
- Study of cathodes and drift field cages design

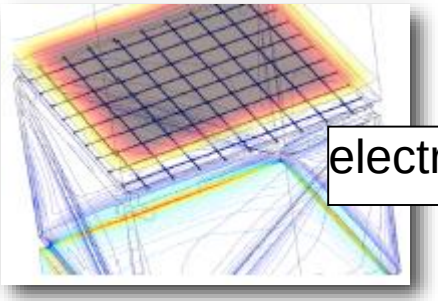


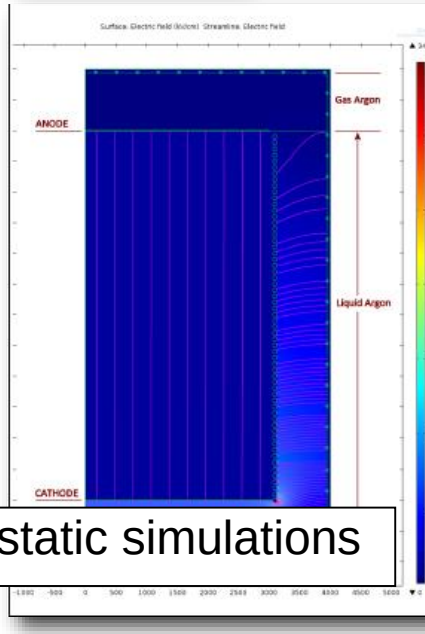
design of 100's kV feedthroughs

Example of NA in the field: « High voltage in noble liquids »
https://indico.fnal.gov/conferenceDisplay.py?confId=7394



LAr dielectric rigidity





electrostatic simulations

Magnetisation (Task Leader Glasgow)

Magnetisation of large volumes in cryogenic detectors based on testing novel superconductive magnetisation schemes: originally proposed for MIND detectors of LBNO, Neutrino Factory, nuSTORM. having great potential for other detectors based on liquefied noble gases

Networking, Reviewing and Sharing of infos and tools (NRS) on the following points:

- **Study of magnetisation based in Superconducting Transmission Line (STL)**
- **Study of magnetisation based on High Temperature Superconducting (HTS) line**
- **First tests on iron: MIND50 hardware from AIDA available at CERN**