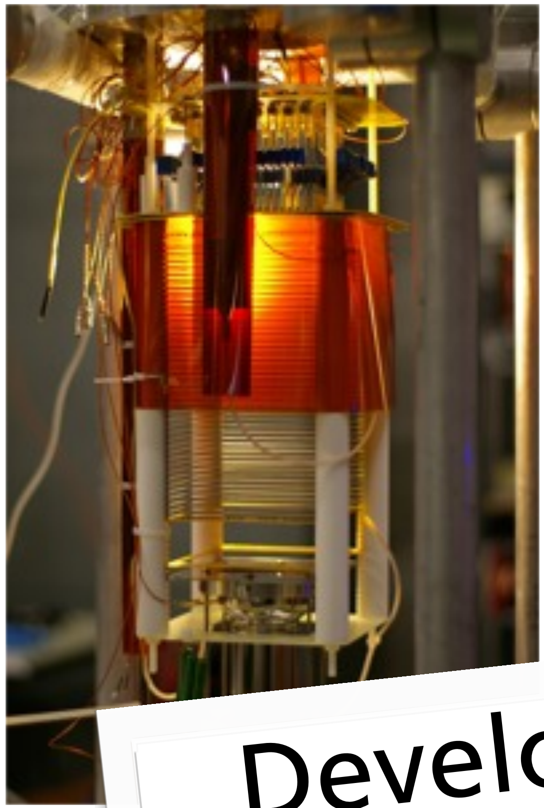
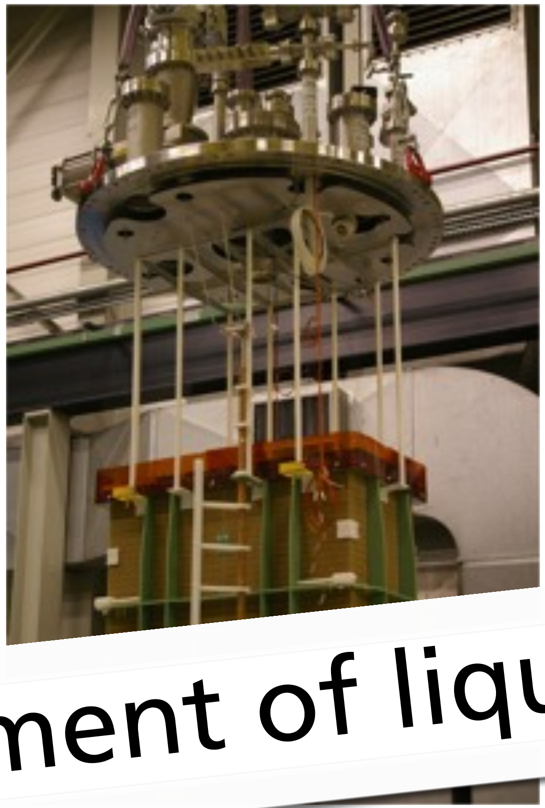




Development of liquid argon TPCs at CERN

Lukas Epprecht

PhD-Seminary 2011

Physics Motivations

What are the motivations for a next generation of detectors for rare decays?

- Neutrino physics
  - Neutrino oscillations
  - CP violation in lepton sector
  - Mass hierarchy
- Supernova studies
  - Neutrino background measurements over broad range of energy
- Proton decay
  - Charge cancellation (GUT theory)
- Dark matter search
  - WIMP search (Super symmetry?)

→ Physics beyond the standard model!

Requirements for the next generation of detectors

- Large fiducial mass
- Good energy resolution
- Good spatial resolution (in 3D)
- Good stopping abilities
- Low background

→ Detectors that fulfill this requirement are currently studied in the LAGUNA project.

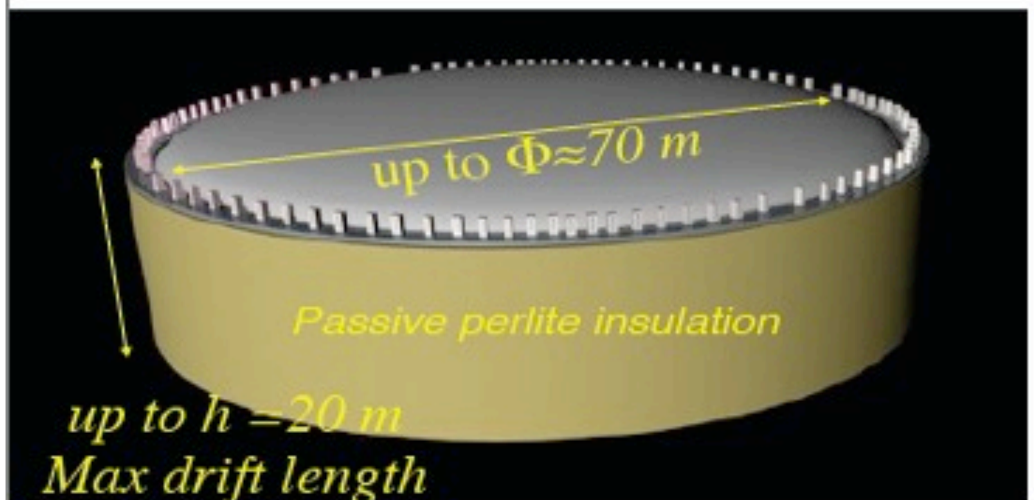
→ 3 different technologies are under investigation

- Water Cherenkov Detector (successor of SuperKamiokande)
- Liquid scintillator
- Liquid argon

A giant liquid argon detector (100 kT) is a possibility to fulfill this requirements!

Giant Liquid Argon Charge Imaging ExpeRiment (GLACIER)

AR, hep-ph/0402110 (Venice 2003)

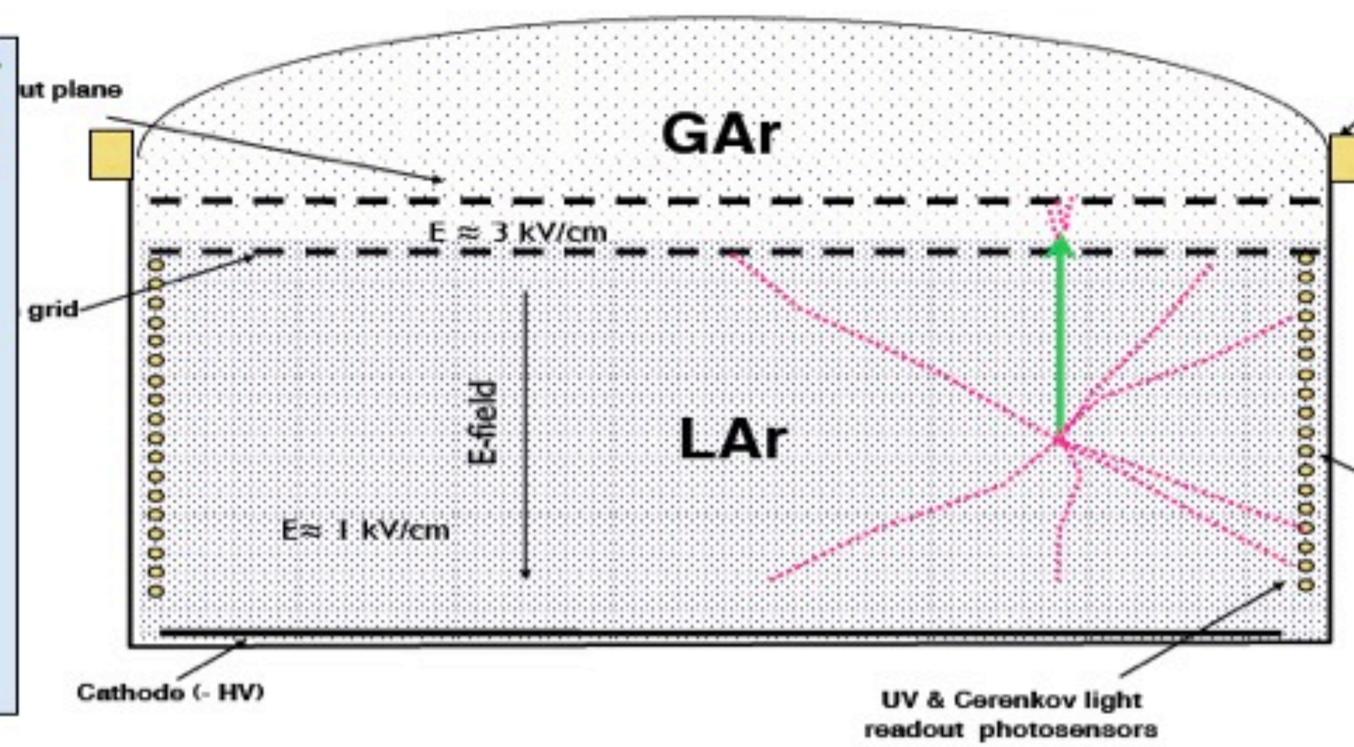


- Single module non-evacuable cryo-tank based on industrial LNG technology
- Cylindrical shape with excellent surface / volume ratio
- Simple, scalable detector design, possibly up to 100 kton
- Single very long vertical drift with full active mass
- A very large area LAr LEM-TPC for long drift paths
- Possibly immersed visible light readout for Cerenkov imaging
- Possibly immersed (high Tc) superconducting solenoid to obtain magnetized detector
- Reasonable excavation requirements (<250'000 m^3)

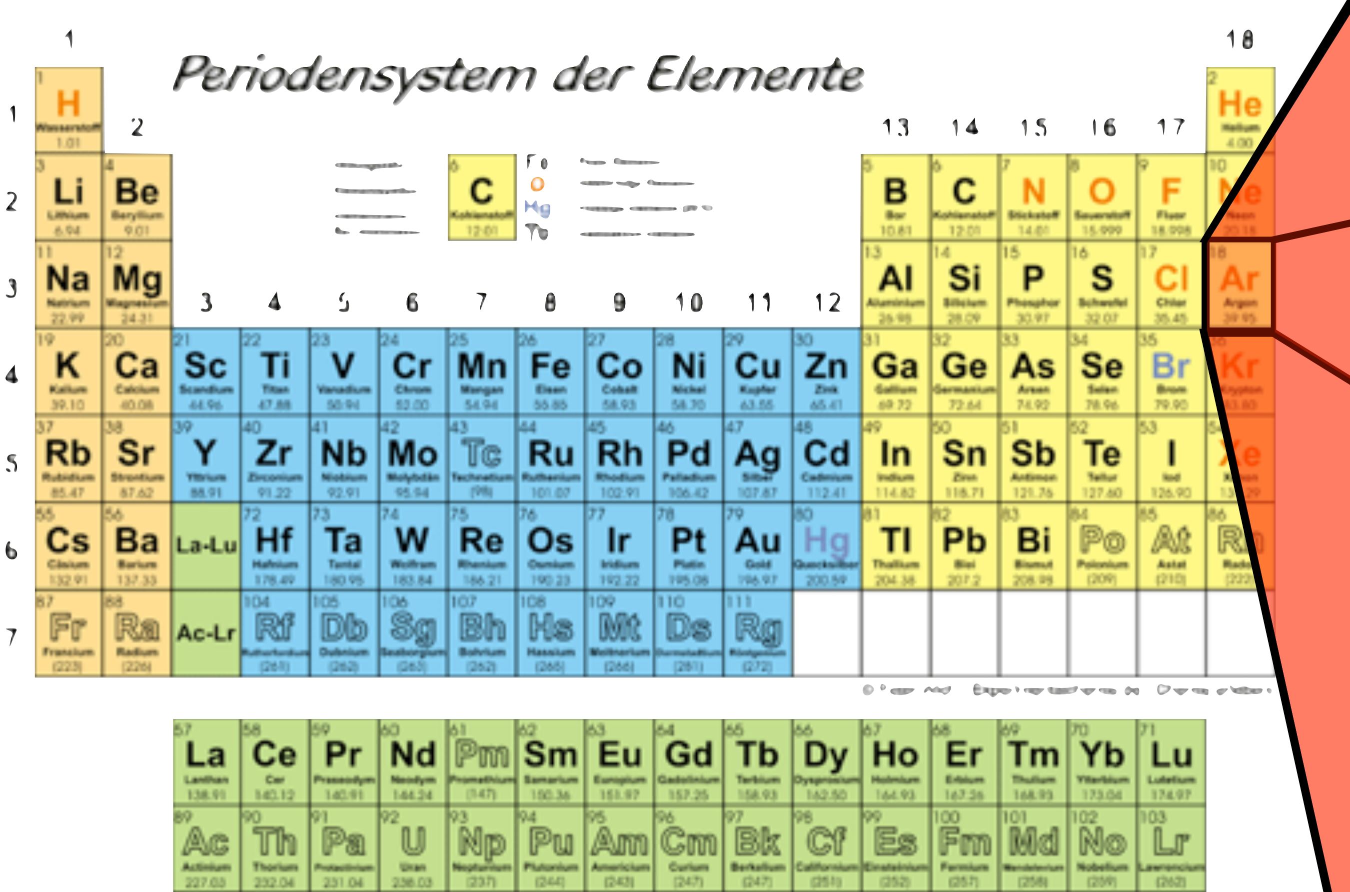
Design technical issues:

- Tank with passive insulation heat loss ≈ 80kW@LAr
- Very large area (≈3500m2) LEM/THGEM+anode with 3mm readout pitch, modular readout, strip length modulable, >=2.5x10^6 channels !
- Purification to < 10 ppt (O_2 equiv.) of bulk argon in large non-evacuable vessel, but excellent S/V ratio in vessel and time to purify before filling !
- Immersed HV Cockcroft-Walton for drift field (1 kV/cm) up to 2 MV → 10ms max drift time!
- Readout electronics (F/E; DAQ; network data flow & time stamp distrib.)
- WLS-coated 1000x 8" PMT and reflectors for DUV light detection

(Green: less challenging, Red: challenging)



Argon Properties

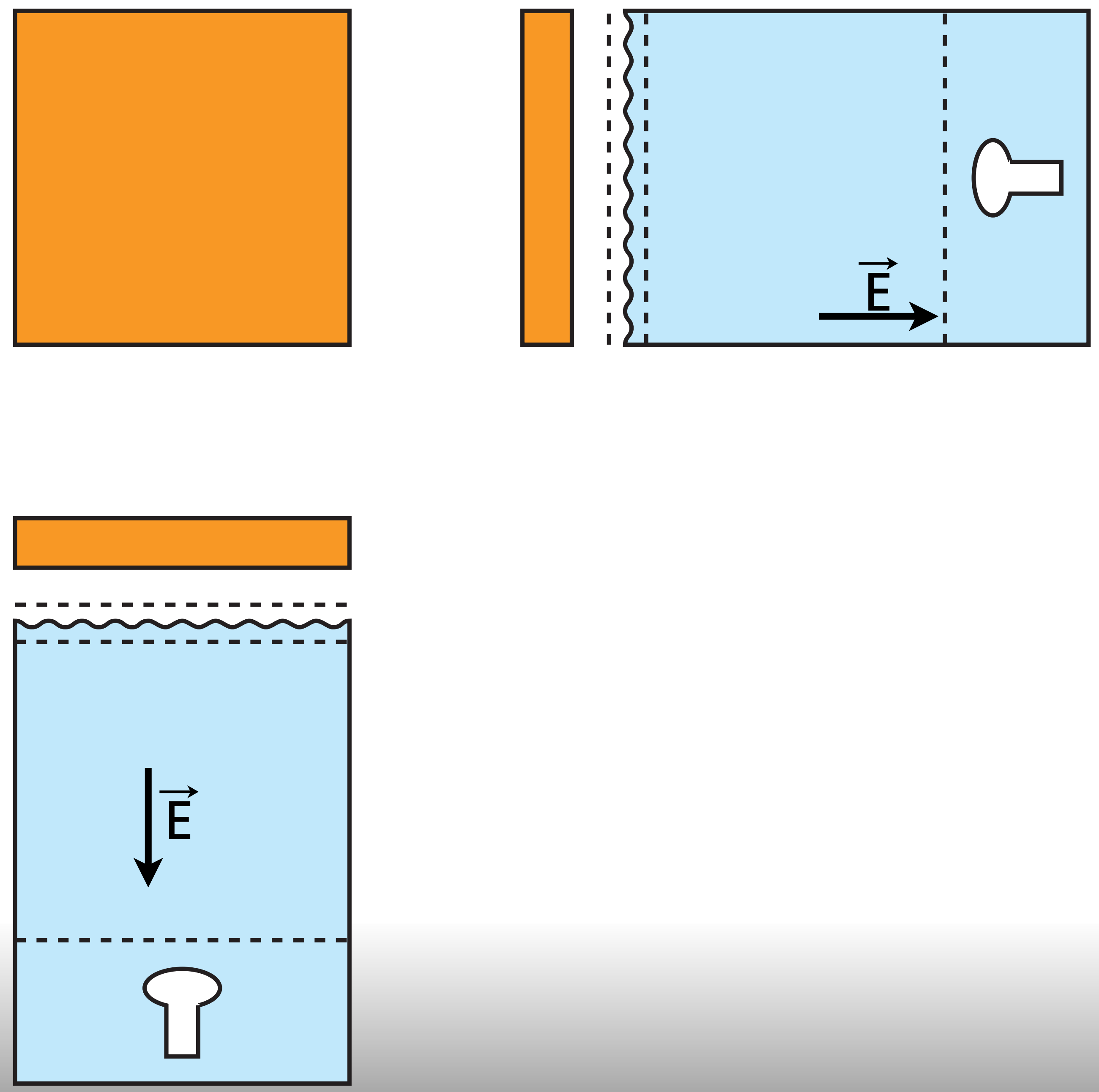


Property	Liquid Argon
Density (g/cm3)	1.4
Radiation length (cm)	14.0
Interaction length (cm)	83.6
dE/dx mip (MeV/cm)	2.1
We (eV) @ E=∞	23.6
Wγ (eV) @ E=0	20
Refractive index (visible)	1.24
Cerenkov angle	36°
Cerenkov $d^2N/dEdx$ ($\beta=1$)	≈ 130 eV^{-1} cm^{-1}
Muon Cerenkov threshold	140 MeV/c
Boiling point @ 1 bar	87 K

Why Liquid Argon for Rare-Decay-Search?

- Long experience with noble elements (Ar & Xe) as detector medium by many groups
- High scintillation (Ar: 128 nm; Xe: 175 nm) and ionization yields (Ar: 23.6 eV; Xe: 15.6 eV)
- Response to radiation understood
- Scintillation via atomic excimer states
  → good discrimination between nuclear and electron recoil by pulse shape discrimination and S1/S2
- Self shielding medium --> Reduction of external background
- Good purity can be achieved by filtering out oxygen
  → long drift of several meters possible
  → detectors are scalable
- Operation as imaging TPC
  → Particle identificatio
  → Fiducialization of volume --> Background rejection
- Argon is a byproduct from air liquification
  → Cheap ~1.5 $/l

How does a liquid argon TPC work?



1. Particle crosses detector
2. Argon atoms are excited or ionized
3. Scintillation light is detected by the pmt
   - T_0 defined
4. Electrons drift to surface
5. Charge is read out in x and y direction
   - z-direction give by the arrival time of charge
6. Track reconstruction, energy measurement, particle identification, ...

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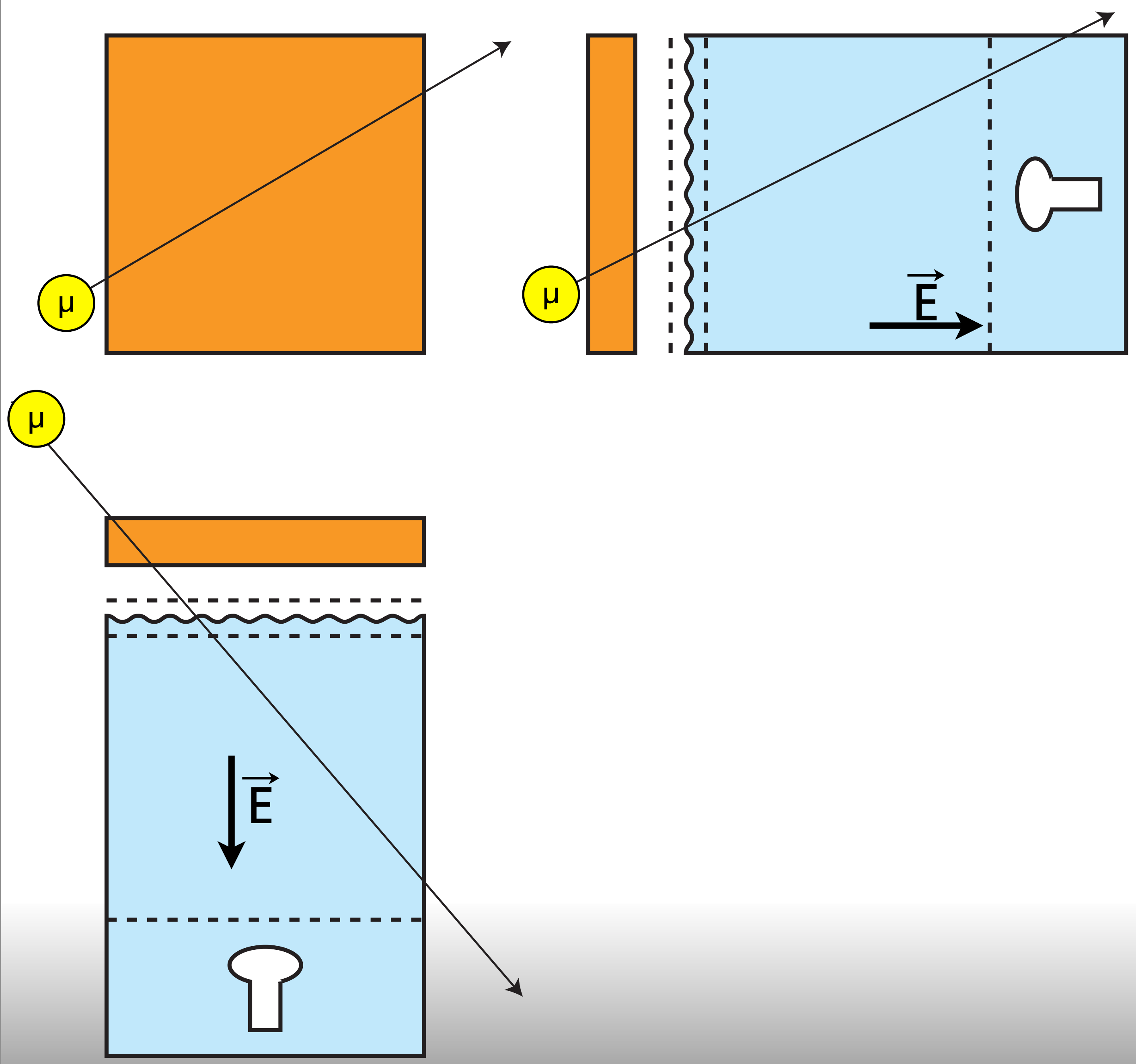

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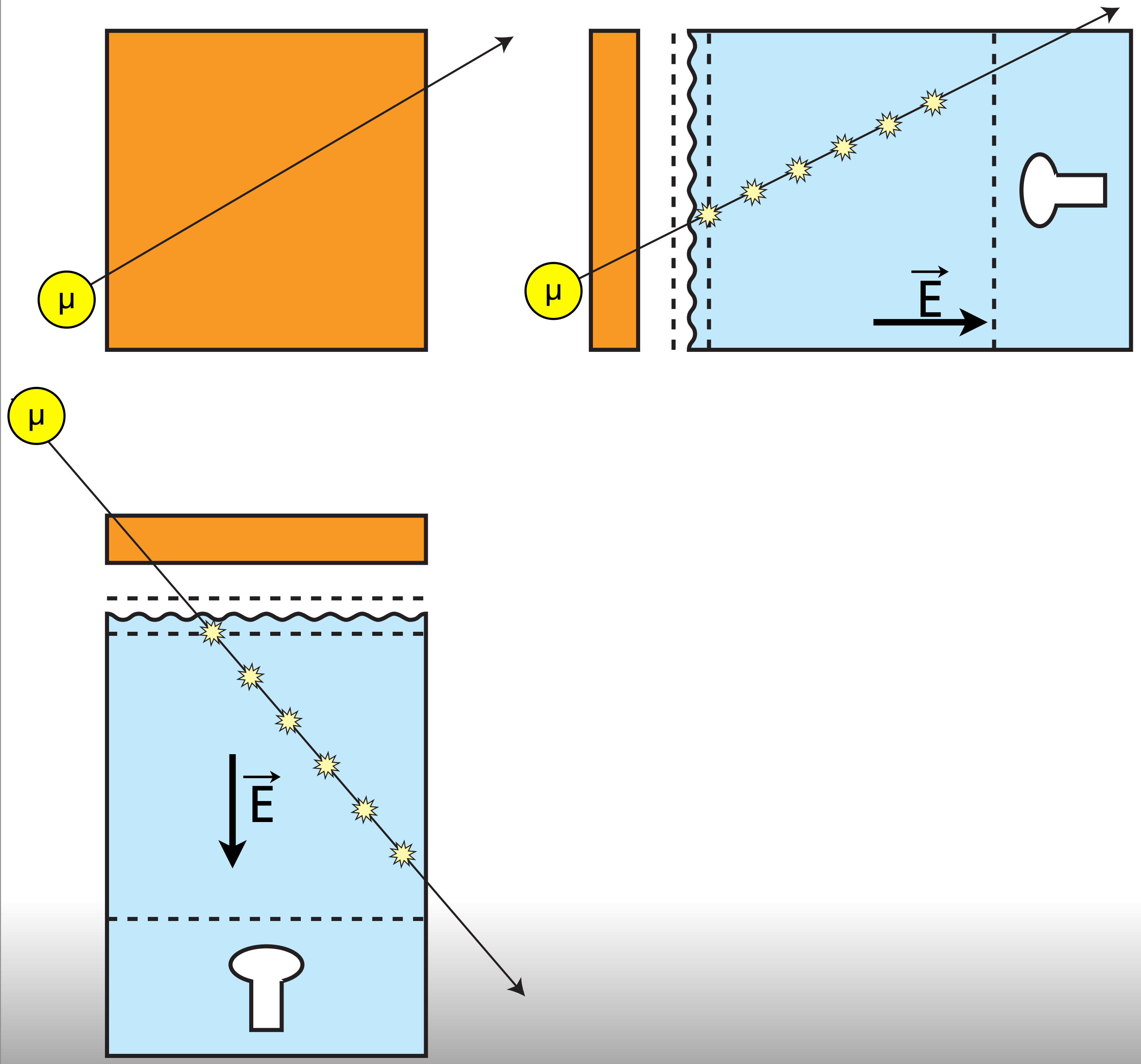

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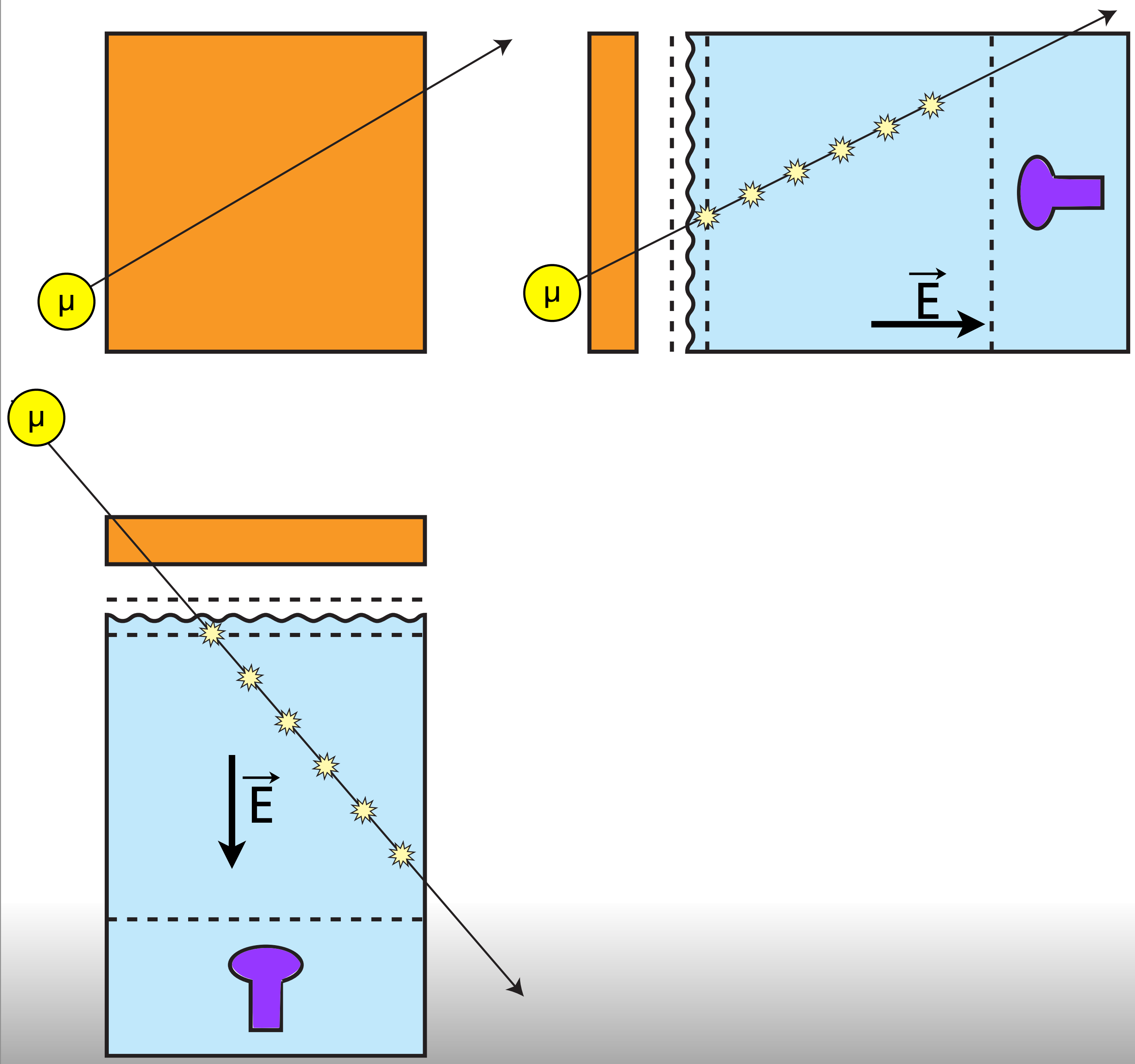

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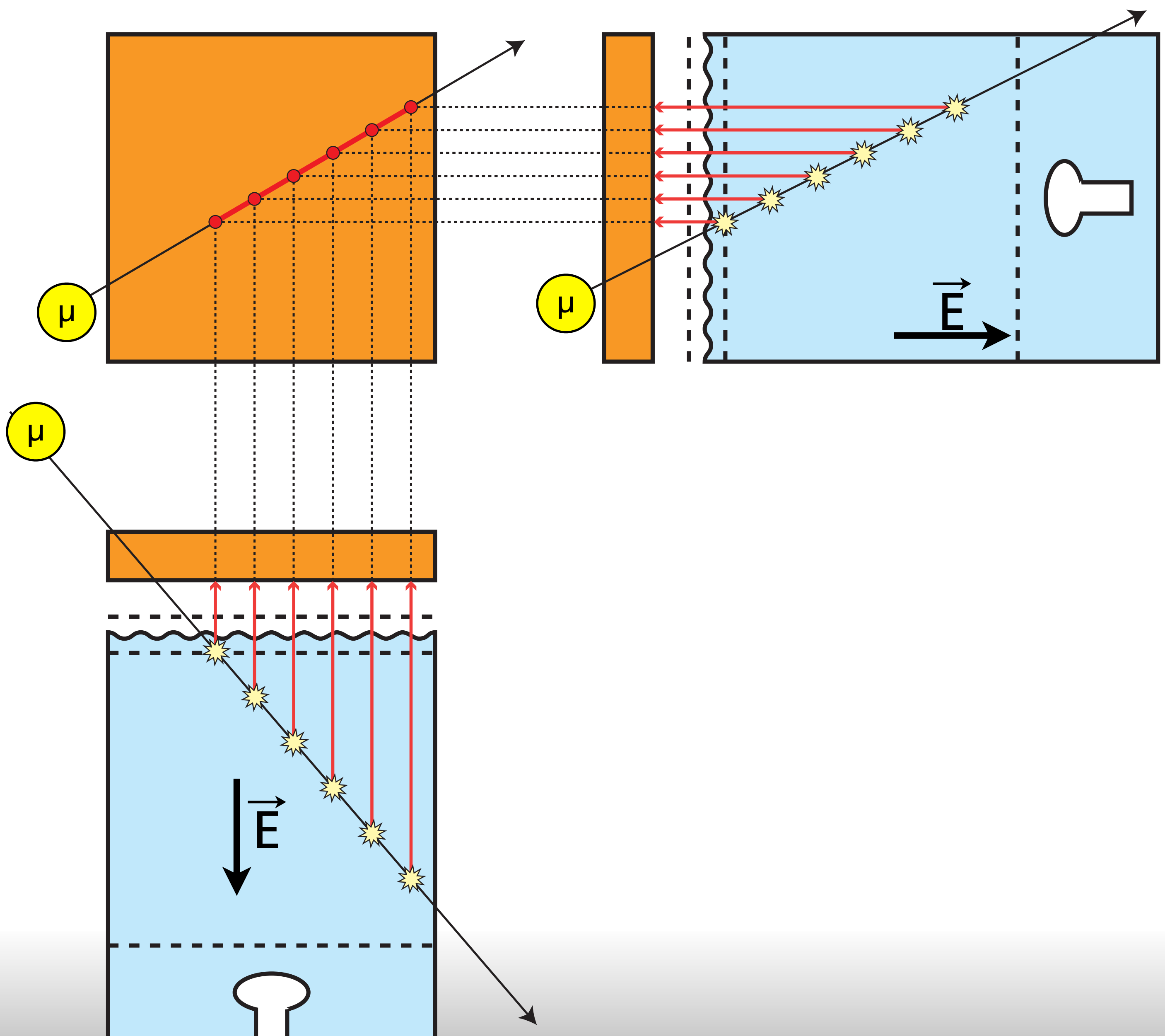

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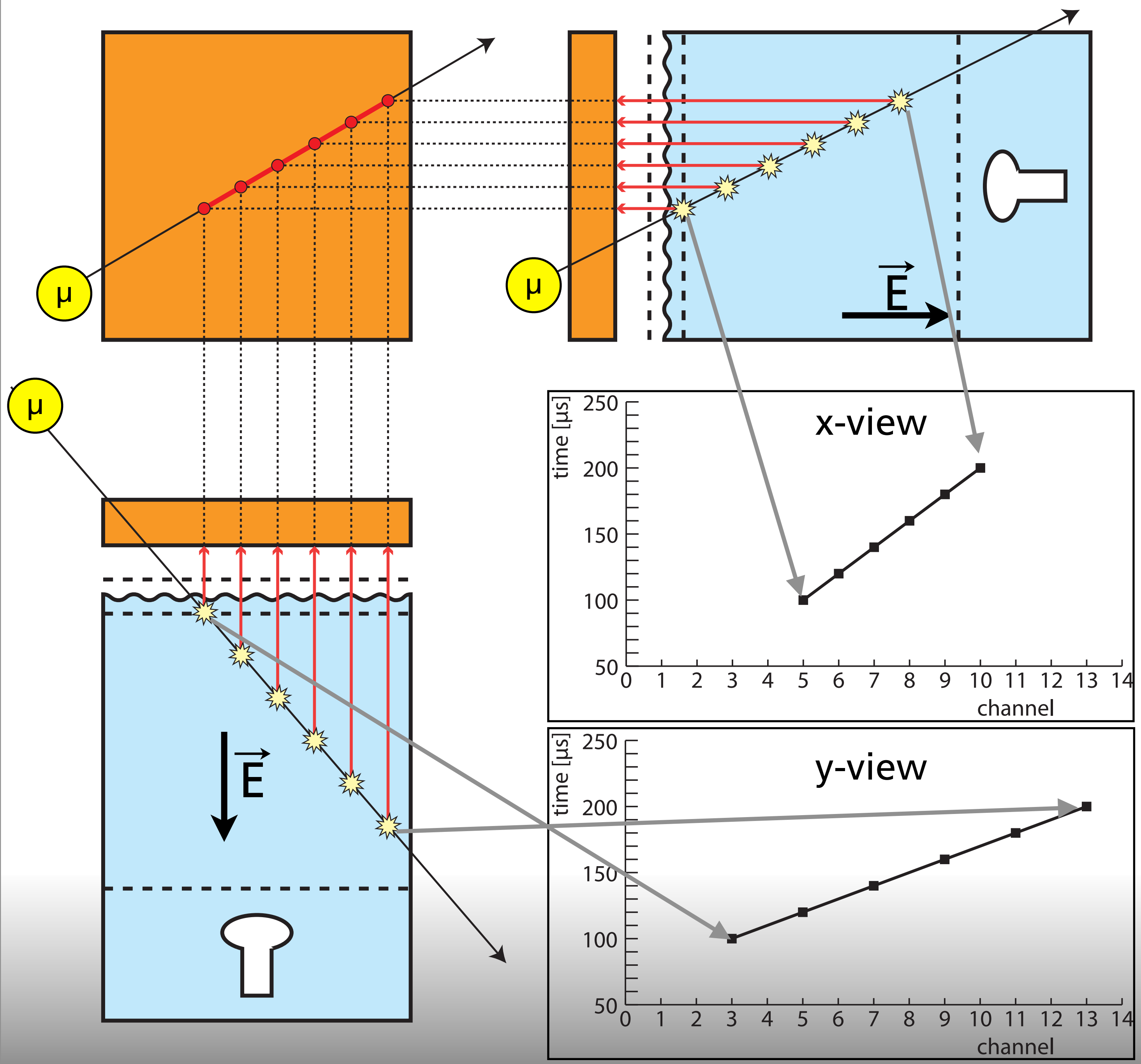

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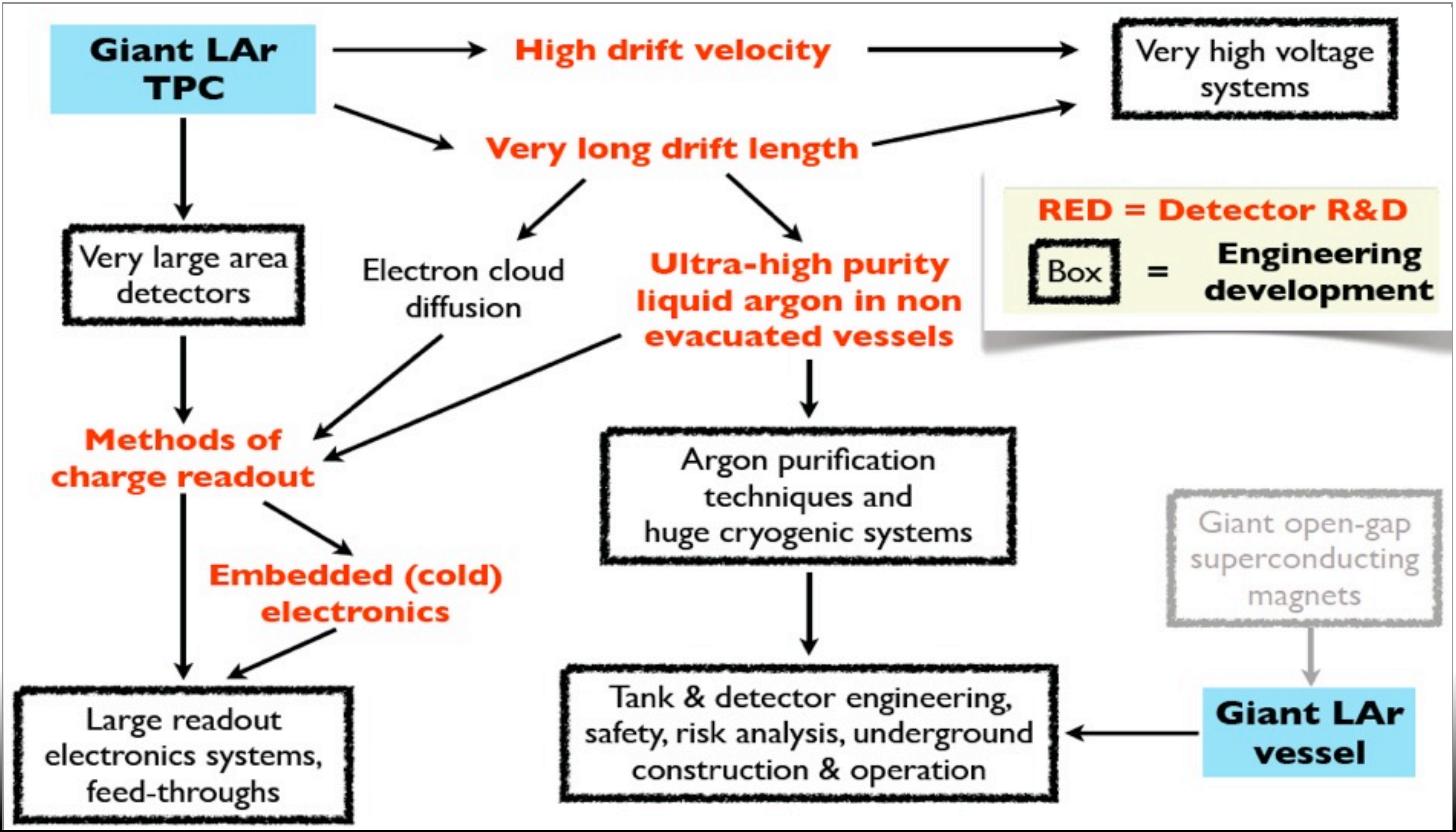
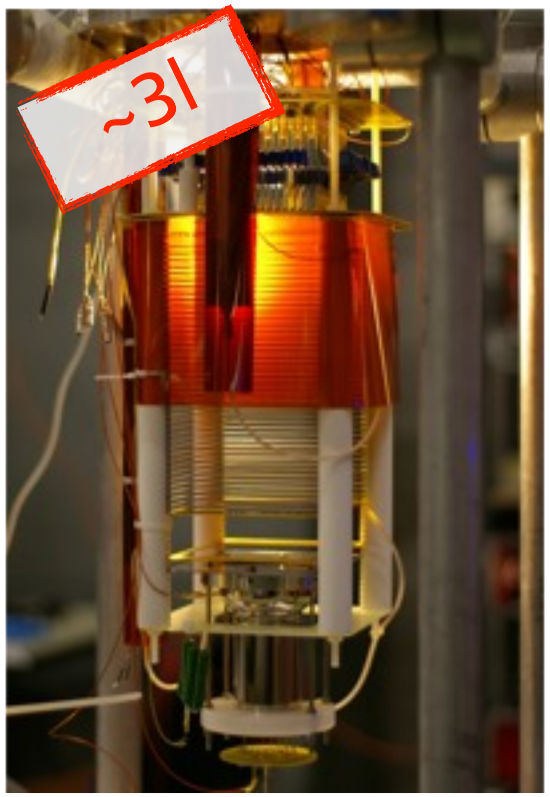
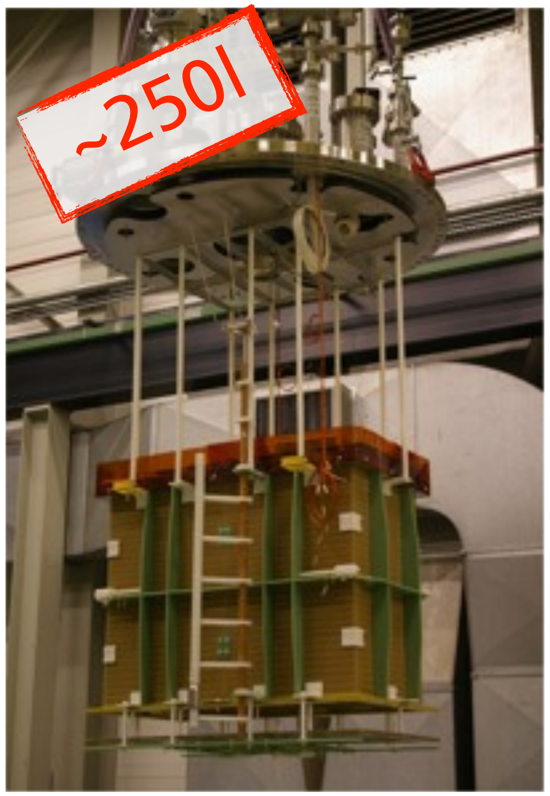
Is it feasible to build such a detector?



LAr Detectors @ CERN



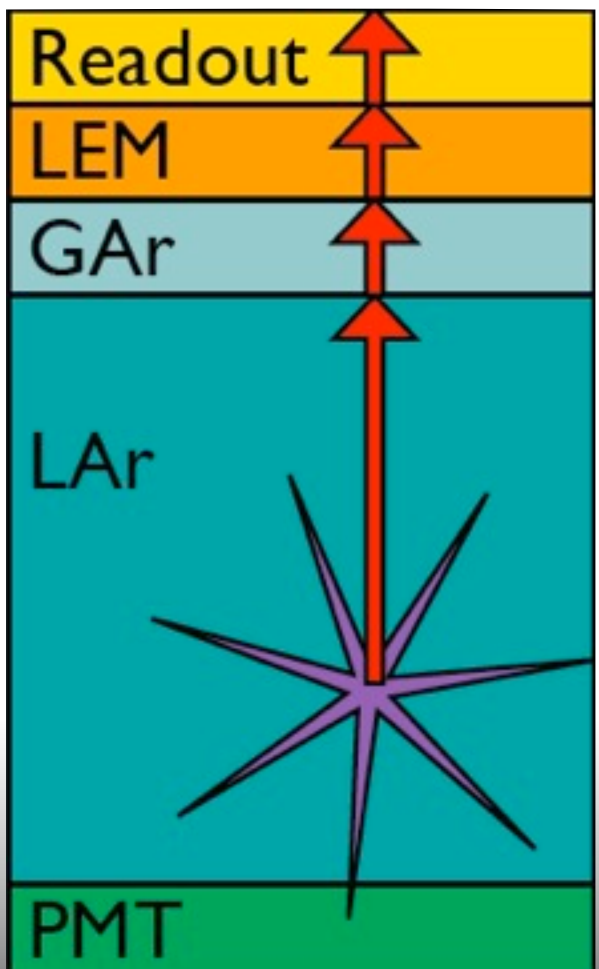


- Several setups of different size (scale-up towards larger chambers)
- Basic working principle is conserved and adjusted to the physics focus of each individual detector
- Different key aspects are studied in the different detectors
- Different physics programs

Development of a novel charge readout system

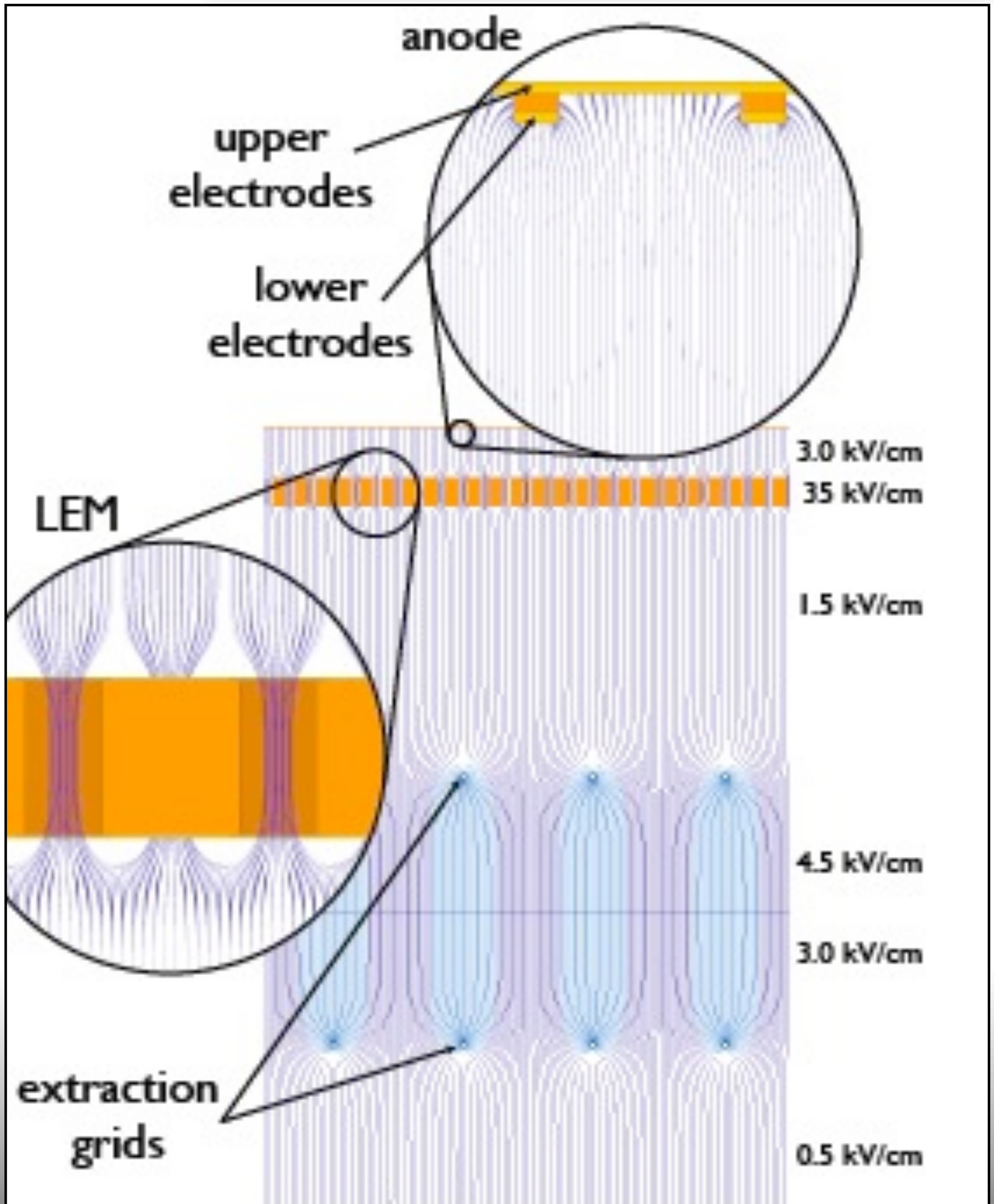
Badertscher et al., NIM A617 (2010) 188-192
Badertscher et al: NIM A 641 (2011) 48–57

Goal of this R&D is to build large, **mechanically robust** charge multipliers in order to get an amplification of about a **factor 1000**, working in cold pure argon gas. (no quencher)

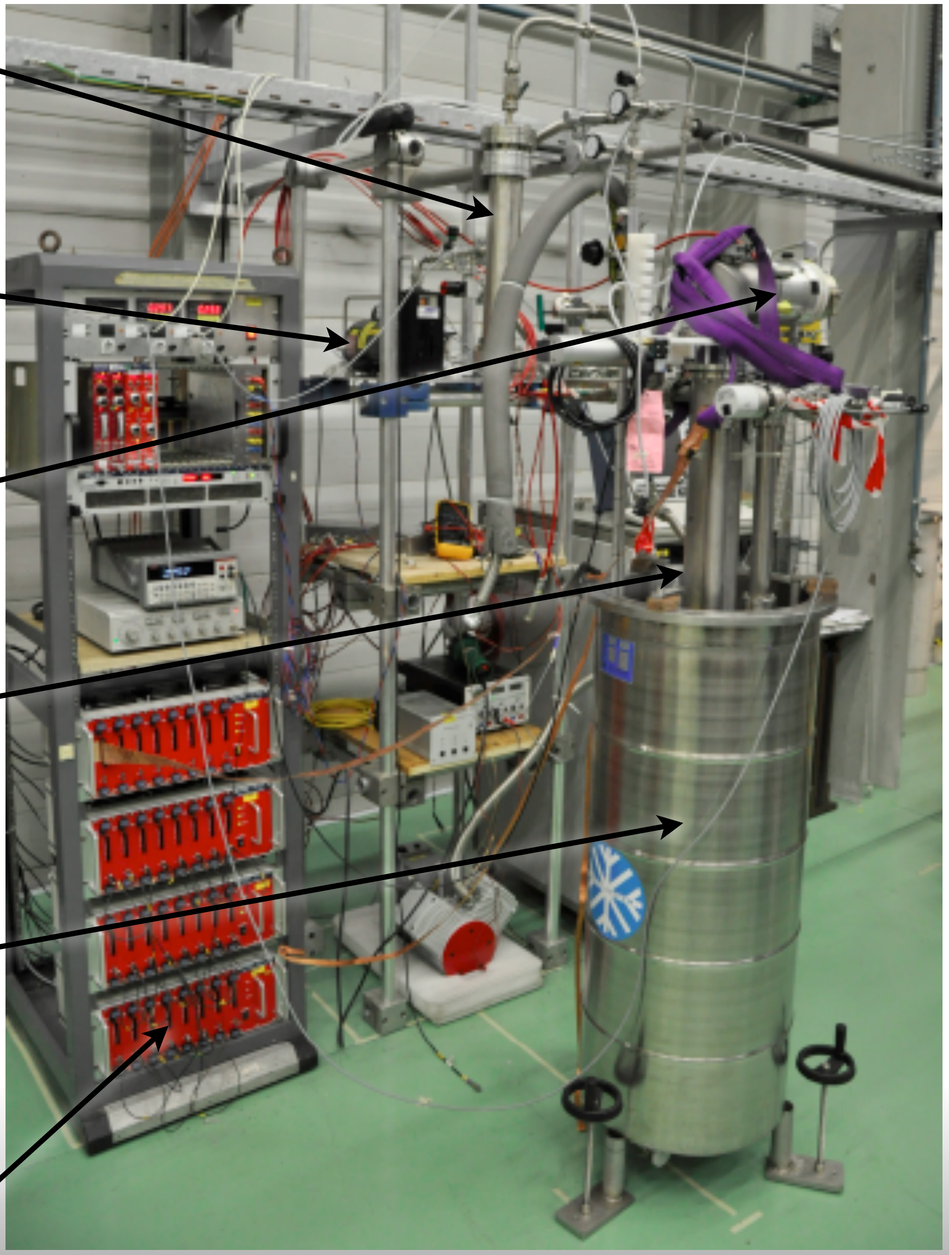


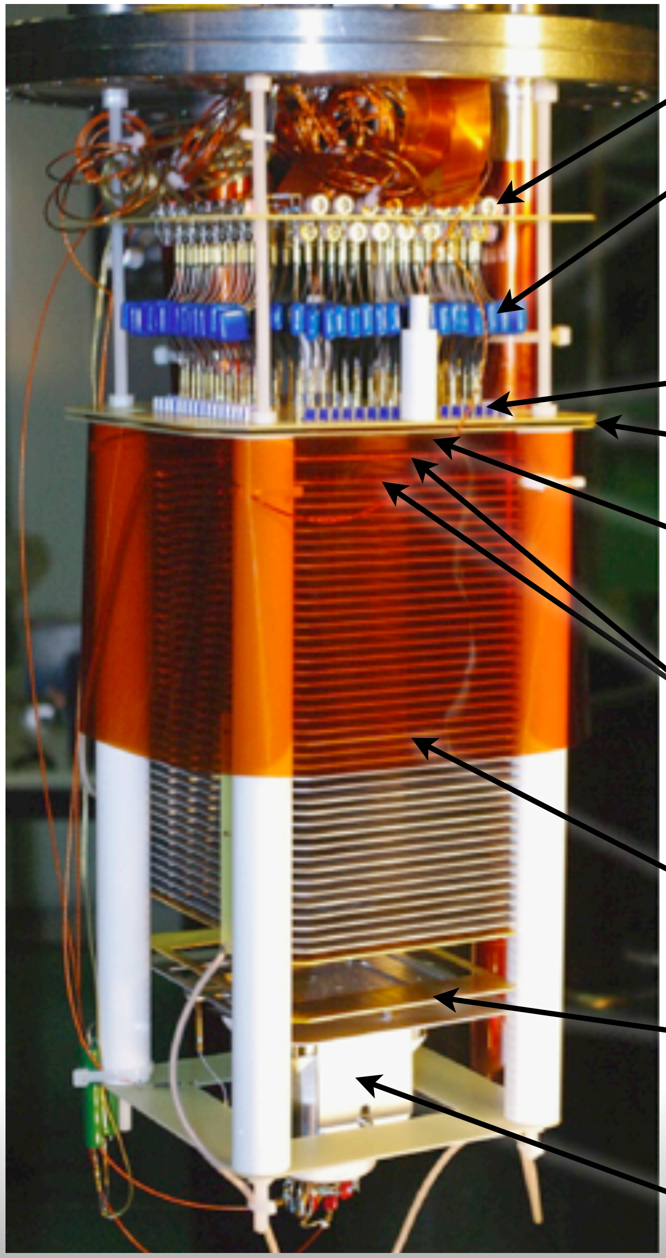
Principle of operation

- Electrons drift up in liquid
- 2 grids squeeze the field lines and electrons can pass the surface potential of the liquid
- In the high field of the LEM planes, an electron avalanche occurs. (multiplication factor: 10^2–10^3)
- Multiplied charge induces a signal in the anode
- Anode is read out in x and y direction



The 3l-Setup @ CERN

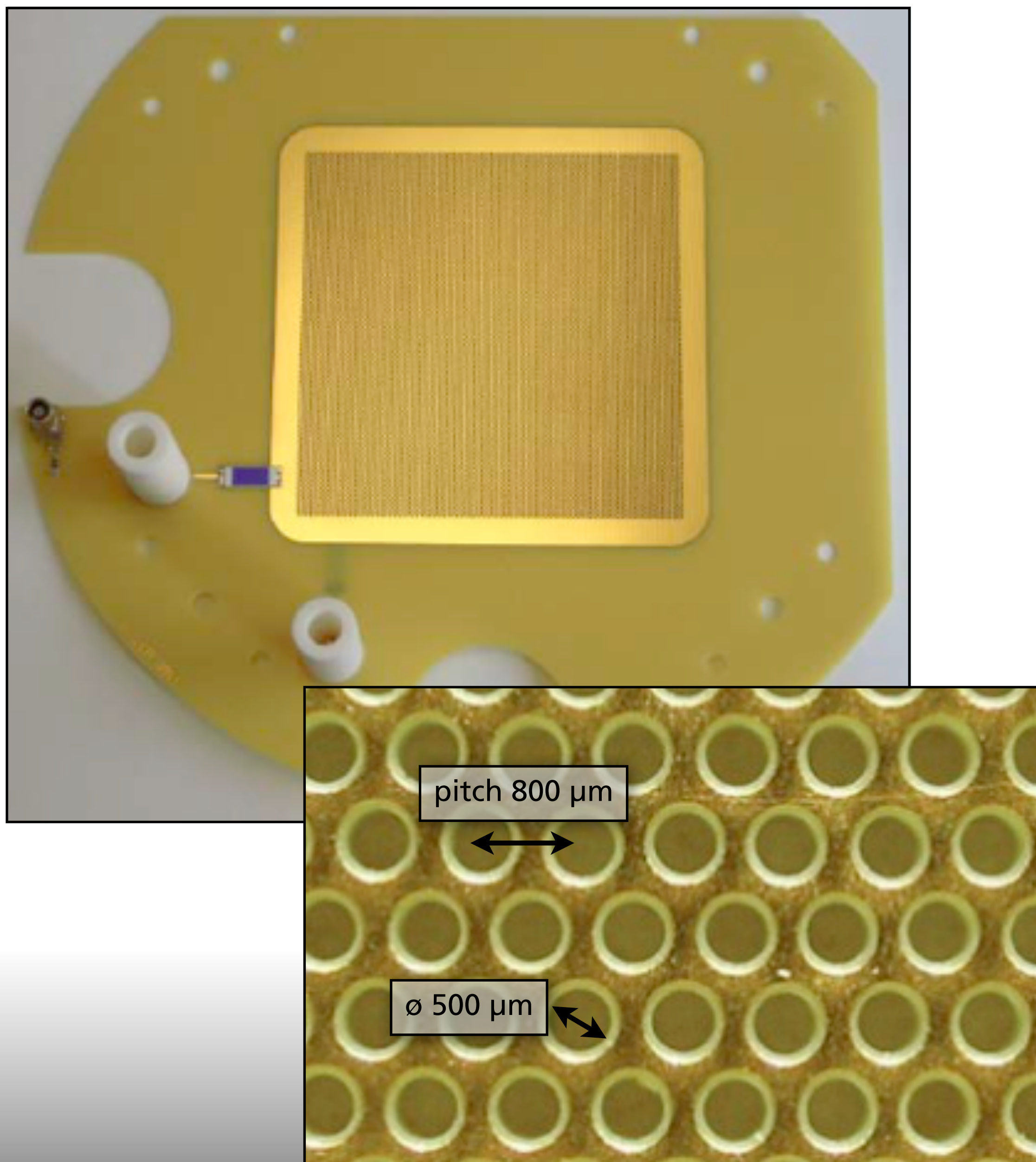




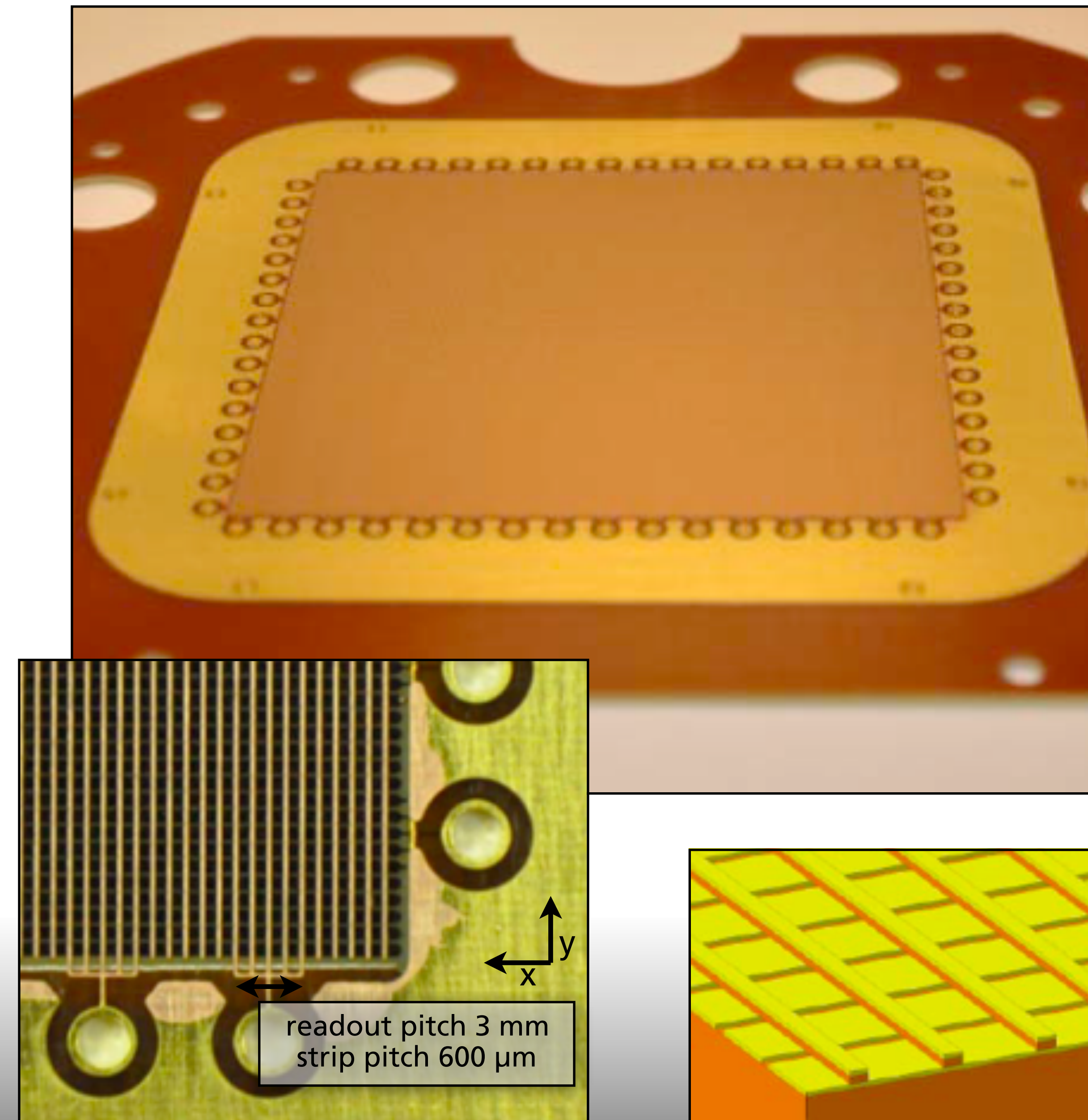
Details Charge Readout

Manufacturer: CERN TS/DEM group

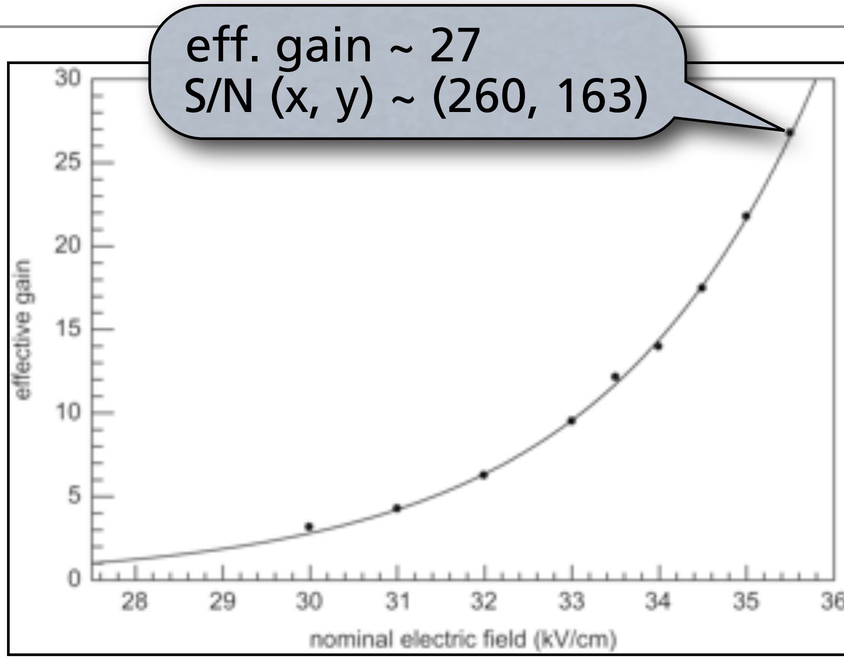
LEM
(10 x 10 x1 mm)



2D-Anode

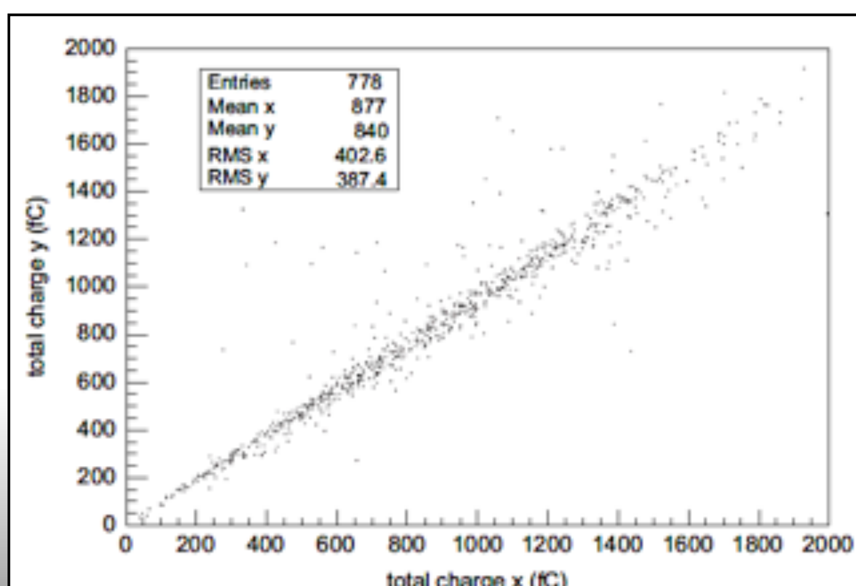


Performance of LEM



Effective gain vs electric field over single LEM

Calculated as the ratio of the total charge collected on x & y strips and the ionizisation charge deposited in the vessel (deposited charge by a MIP (electric field 500 V/cm) ~10 fC/cm)

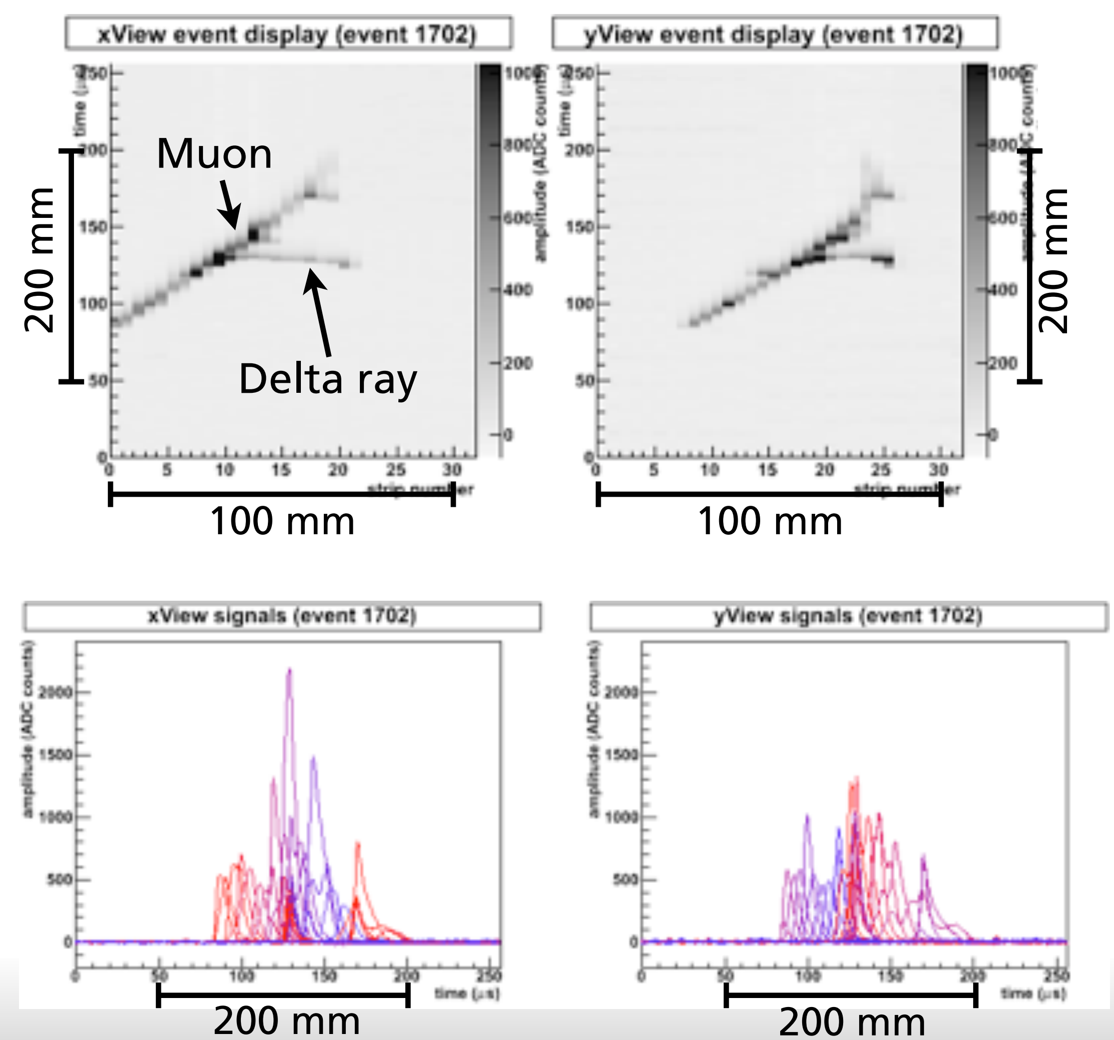


x-y charge sharing

geometry of anode strips is designed to distribute the charge equally on both strips

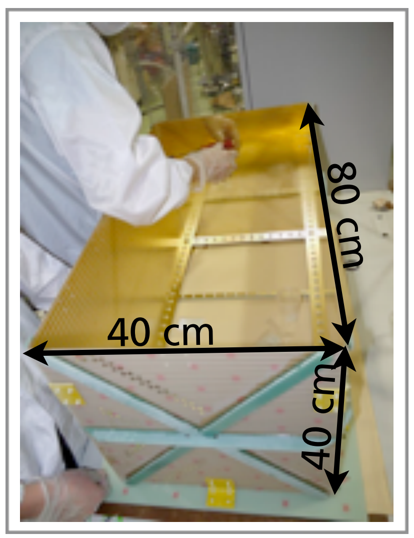
Crossing of a muon

Effective gain ~ 27



Badertscher et al: NIM A 641 (2011) 48–57

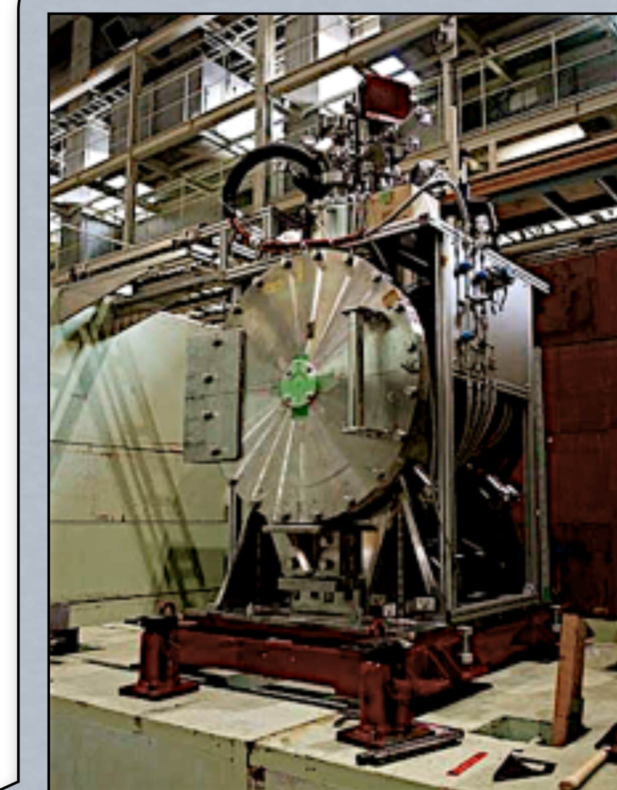
Particle identification / Exposer to beam



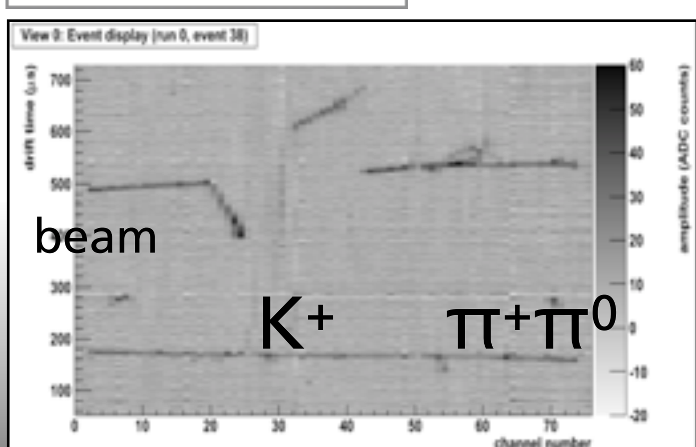
T32 Experiment @ KEK (Japan)

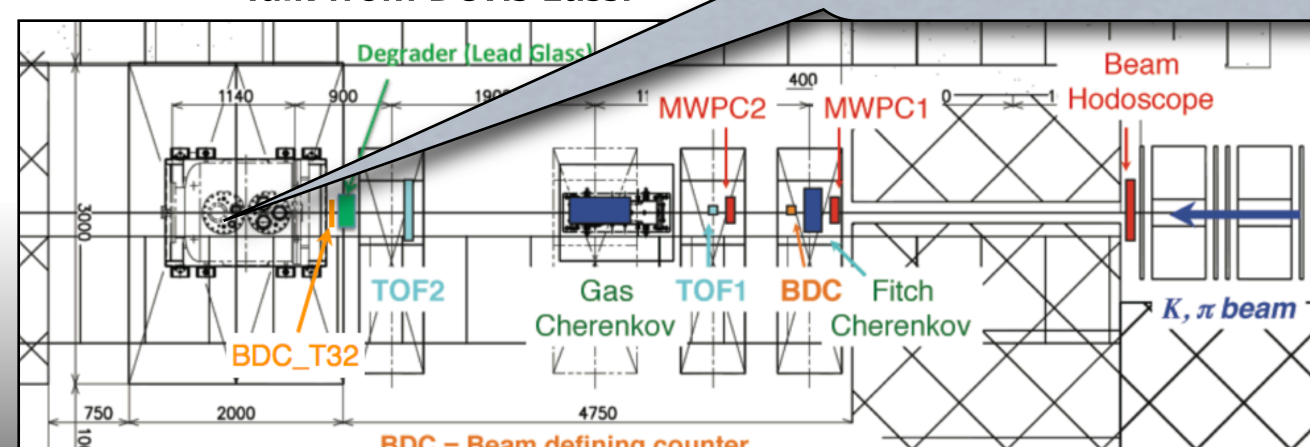
In collaboration with KEK, Waseda Univeristy & Iwate University

- First exposure of a LAr chamber (40x40x80 cm³) to a charged particle beam
- Measurements with well defined charged particle beam (e/π/K/p) at J-PARC hadron facility
- Benchmark the performance of the LAr TPC in particle identification and energy resolution (π/K separation is relevant for proton decay searches)
- Single phase detector (no multiplication)



→ Talk from Devis Lussi

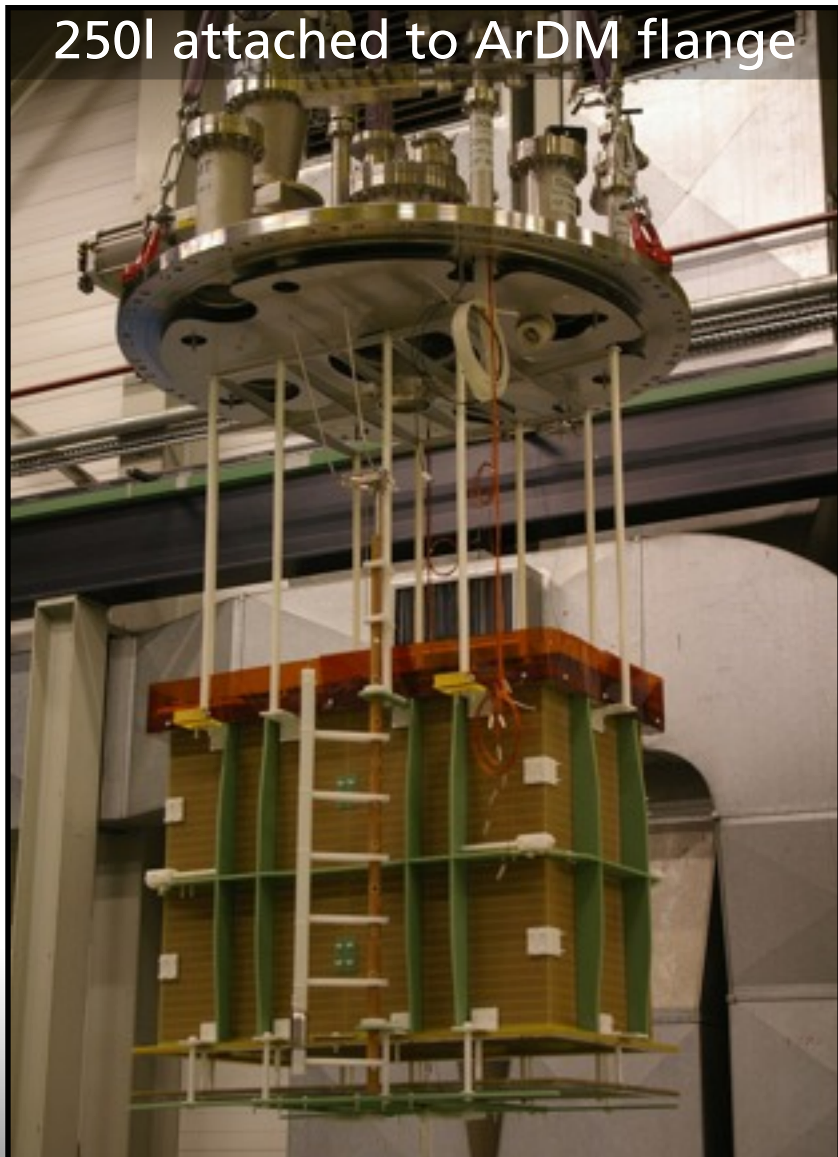


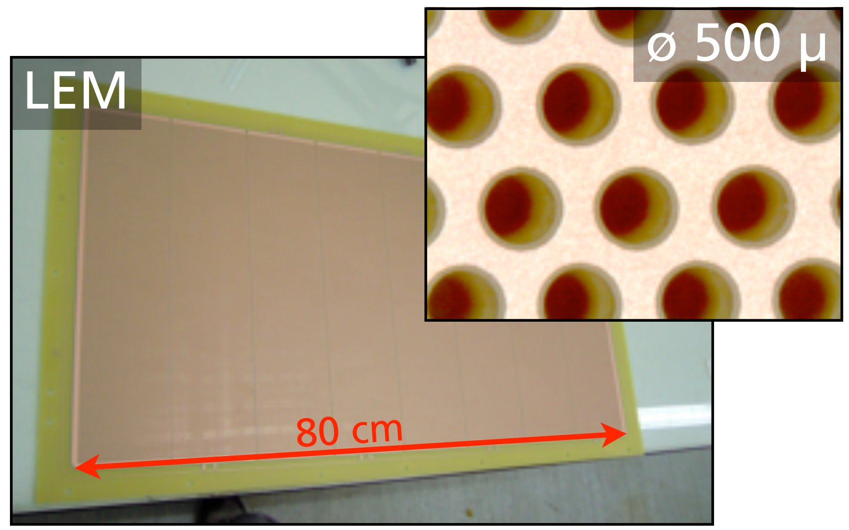


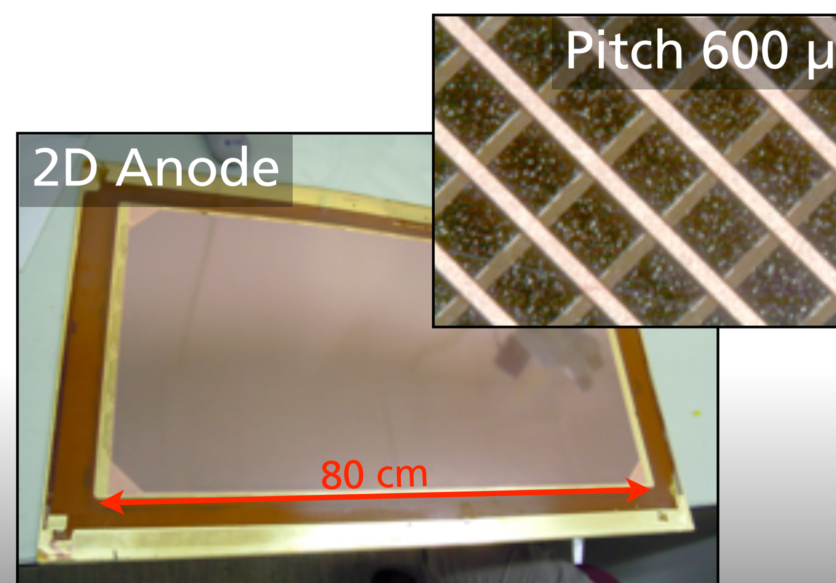
Test of largest LEM ever built @ CERN

Because of the earthquake J-PARC is at the moment not providing any beam

→ A new chamber was built and is currently tested @ CERN







- Biggest LEM and 2D anode ever built (80 x 40 cm)
  - ~ half the size of final ArDM charge readout
- LEM segmented in 8 parts to decrease capacitance
- Anode views 45° to incoming beam
- 512 channels
- Current test is performed in the ArDM vessel
- Beside the actual detector, new cryogenics and electronics are tested

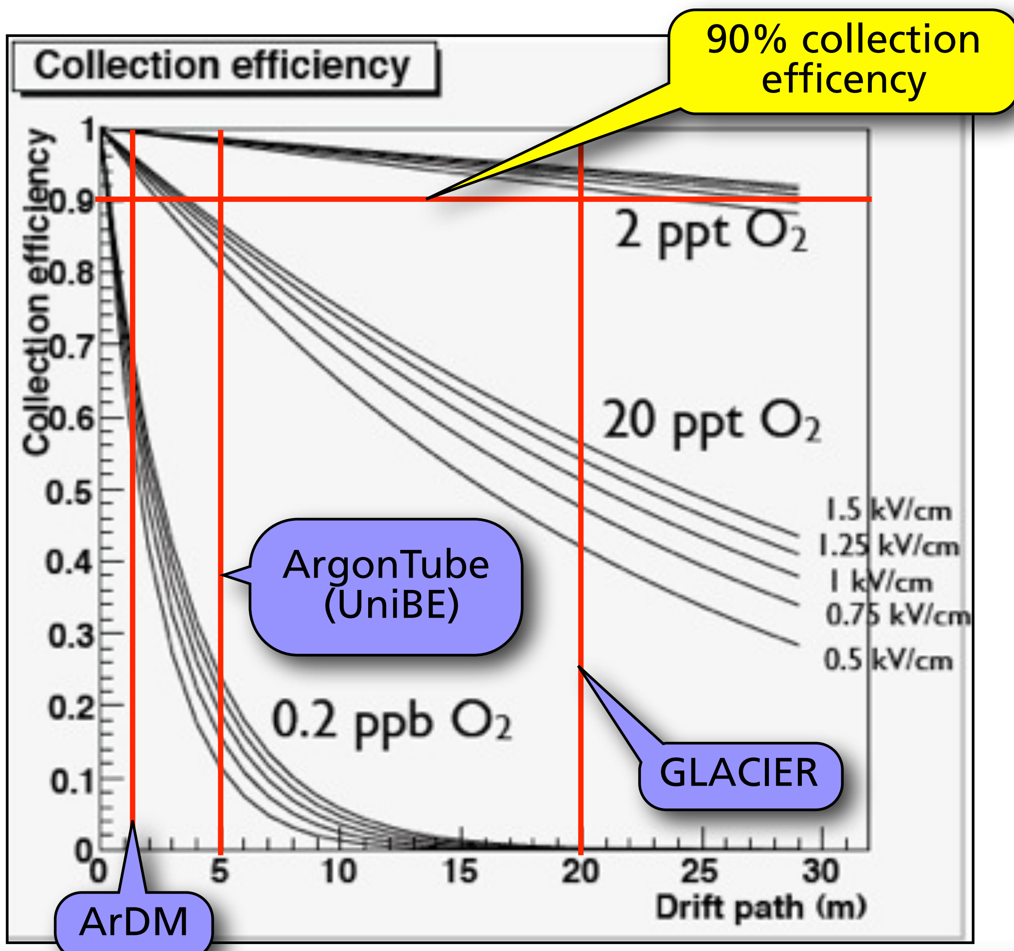
ArDM: Dark Matter Search

- ArDM is a fully functional experiment
  → Biggest dark matter detector currently under construction
- For dark matter search a main focus of the detector is to reduce background events as drastic as possible
  → Big shielding needed
  → Radio pure materials in detector
- Very good energy resolution at low energies is required
  → High efficiency on pmt's and charge readout
- Light readout is important sub detector, not only trigger

→ Talk from Ursina Degunda

Purity, a big issue for noble gas TPCs!

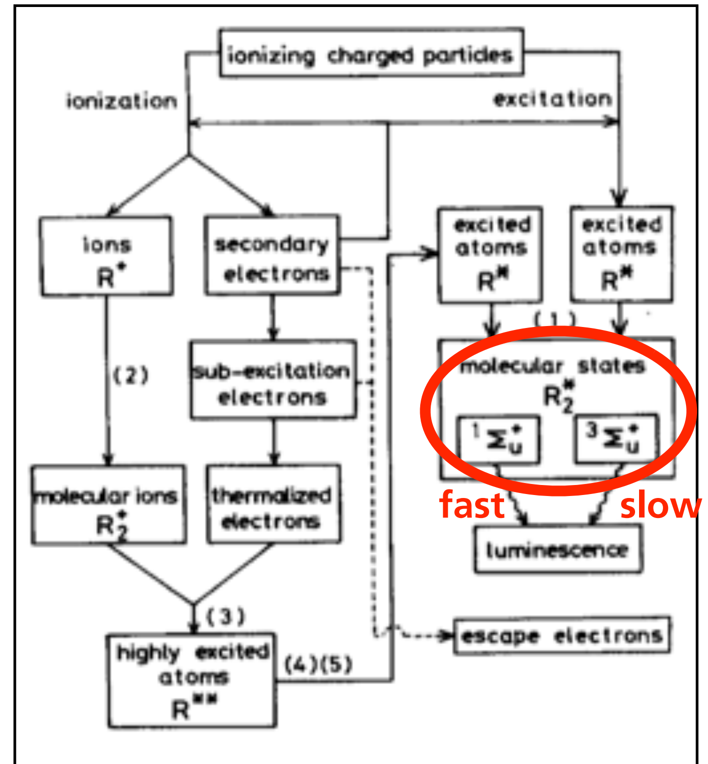
Drift of charge, as also the lifetime of excited states in argon, are strongly dependent on the amount of electro negative impurities in the noble gas.



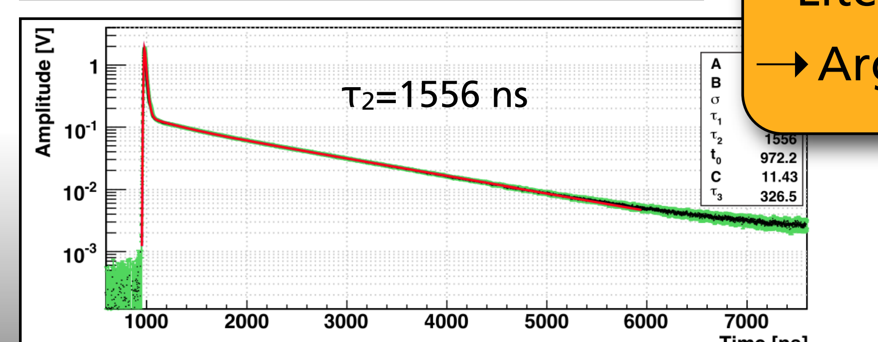
Lifetime of free charge in liquid argon:

$$\tau \approx \frac{300\mu s}{O_2(ppb)}$$

Measurement of purity down to ~100 ppb can be done by looking at the decay time of the excimer states of the scintillation.



M. SUZUKI, J. RUAN and S. KUBOTA, NIM 192 (1982) 565

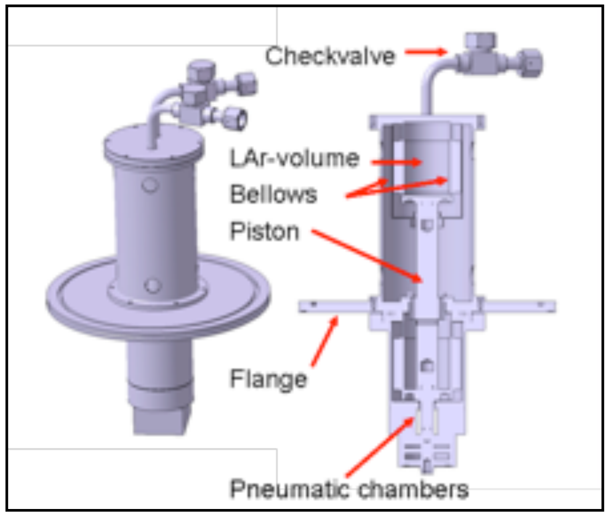


Amsler et al. 2010 JINST 5 P11003

- Excited argon has two decay channels. A fast one and slow one, depending on if the excited atom was in a singlet or a triplet state.
- The lifetime of the slow component depends on the purity of the argon.
- Lifetime measured in ArDM for the slow component: 1.56 µs. Literature: 1.2 – 1.6 µs

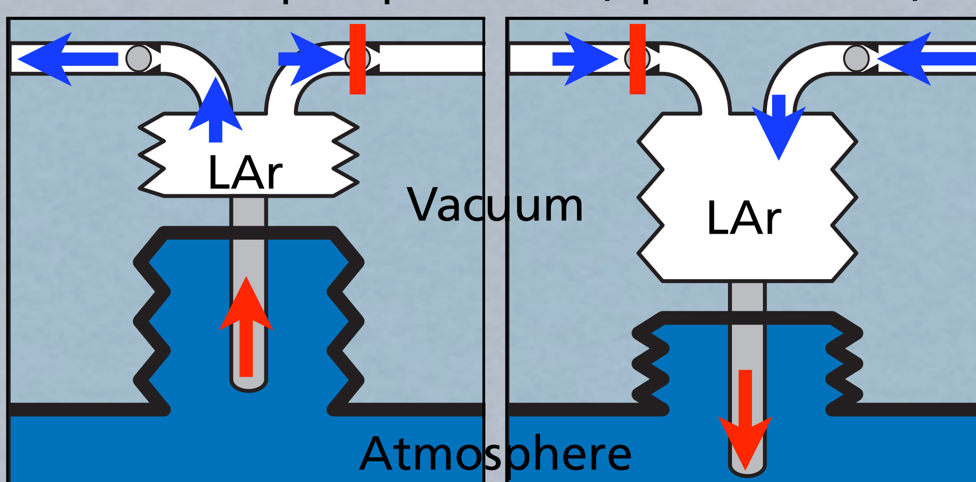
→ Argon is very pure!

Liquid Gas Purification



More powerful pump under construction
(increase of flux more than factor 2)

Bellow pump for LAr (up to 20 l / hr)

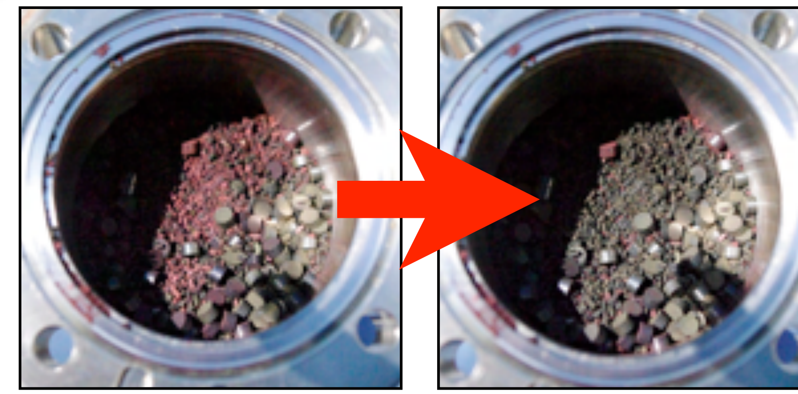


- Up to 20 l / hr
- Pneumatic actuation
- No abrasion
- No recirculation of GAr
- Limited lifetime due to membrane bellow

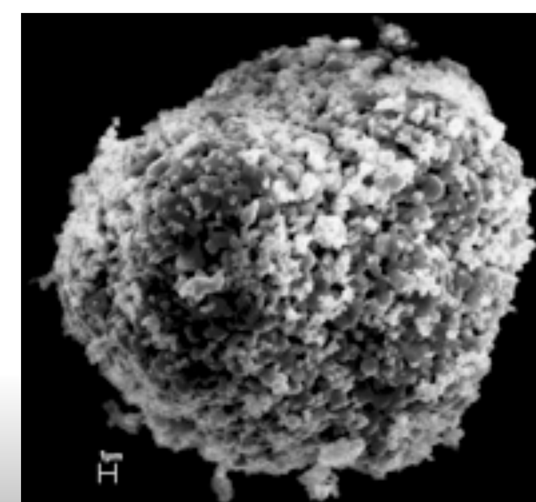
LAr cylinder containing copper cartridge (vacuum insulation removed)

Purification process:

- LAr floats through reduced copper oxide.
- Oxygen impurities oxidize copper and stay in the cartridge

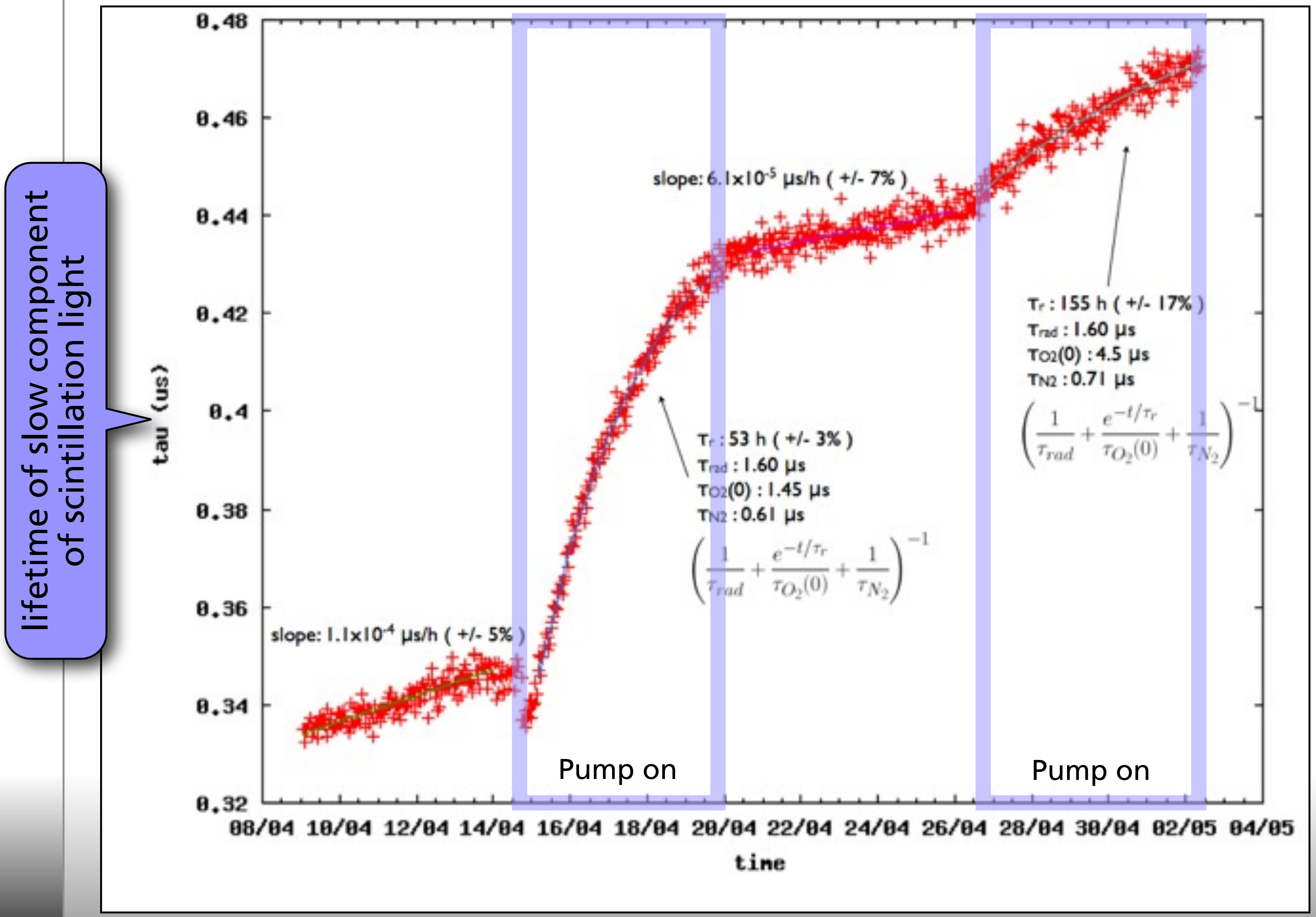


activated copper (reddish) | after a few seconds exposed to air



Sintered copper "pellet"

Results of liquid recirculation



Purification of the LAr in ArDM

- For the first time the liquid recirculation of ArDM has been tested.
- Pump was running for several days with a constant flux of ~ 15 l/hr.
- Purity is measured by looking at decay of triplet state of scintillation light.
- This was done in a cryogenic test and the initial purity of the liquid was bad.
- Increase in purity without the pump running is coming from freezing out impurities on the cold dewar wall

Next steps for purification

After good experiences with gas purification in the 3l setup, we decided to install a similar system on ArDM.

– Independent system from liquid recirculation

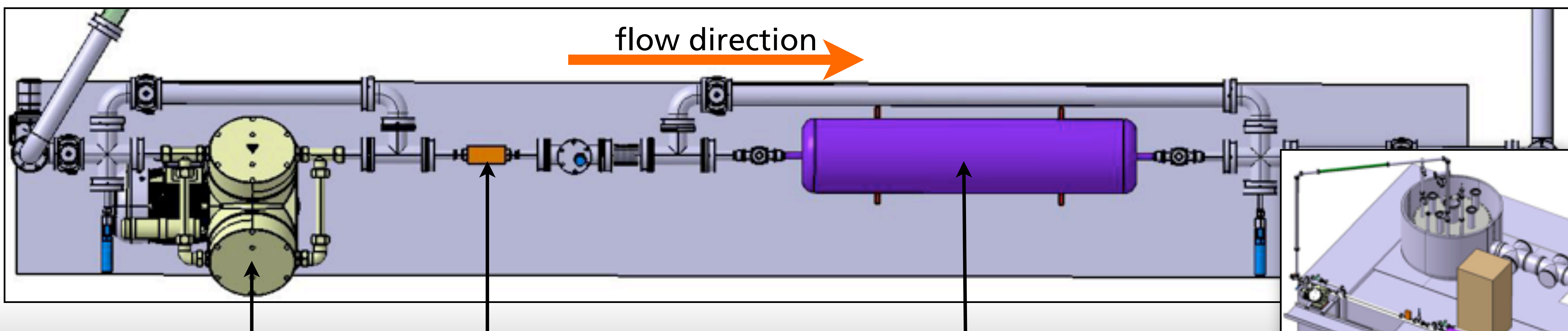
– ~ 150 l/min of GAr @ 300 K --> ~10 l LAr

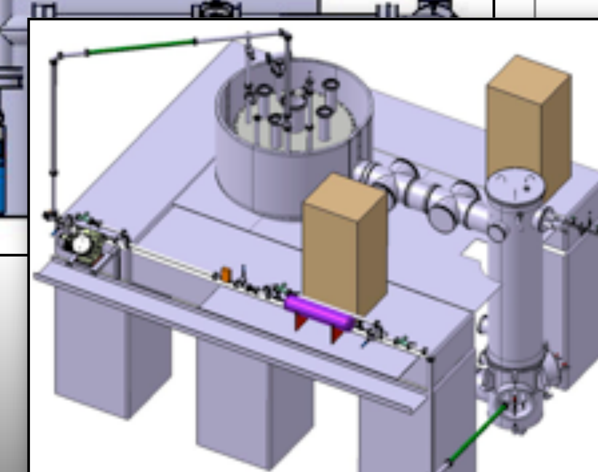
<u>Advantages</u>:

- Purification during cool down possible
- "Boil off" from argon doesn't only get recondensed but also purified
- Commercial SAES purification cartridge
- Possibility to attach gas analysis instruments
- Well known and less challenging technology

<u>Disadvantages</u>:

- Additional cooling power needed to cool down gas from room temperature to 80 K
- Much higher flux needed (1 l LAr ≈ 800 l GAr)





Purity measurements with non evacuated vessel

6m^3 @ CERN

In collaboration with Liverpool University

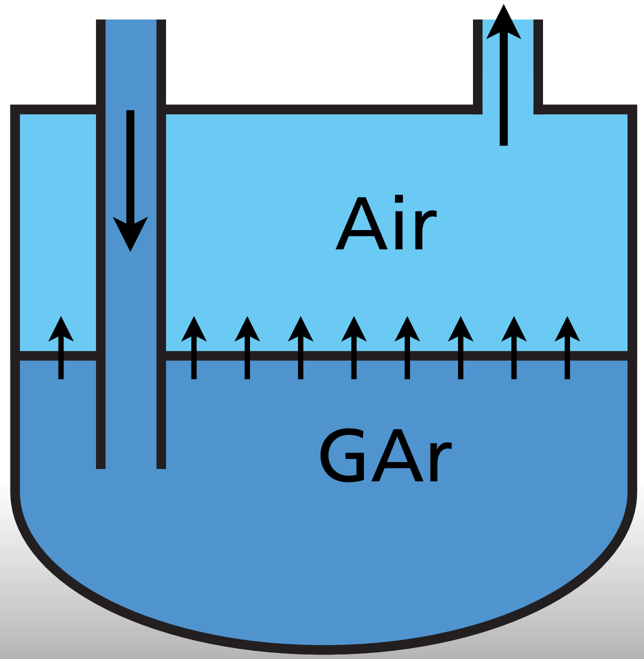
Huge volumes have the disadvantage that they can't be evacuated.

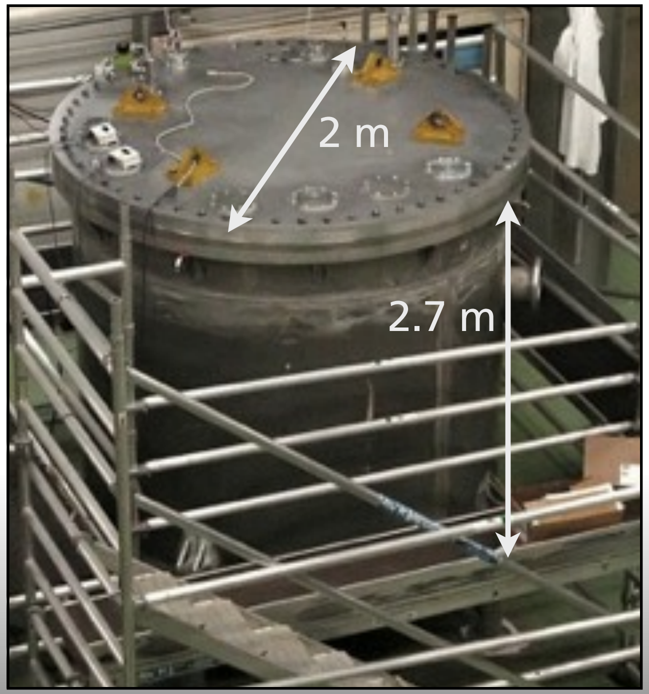
→**New concept for cleaning them is needed**

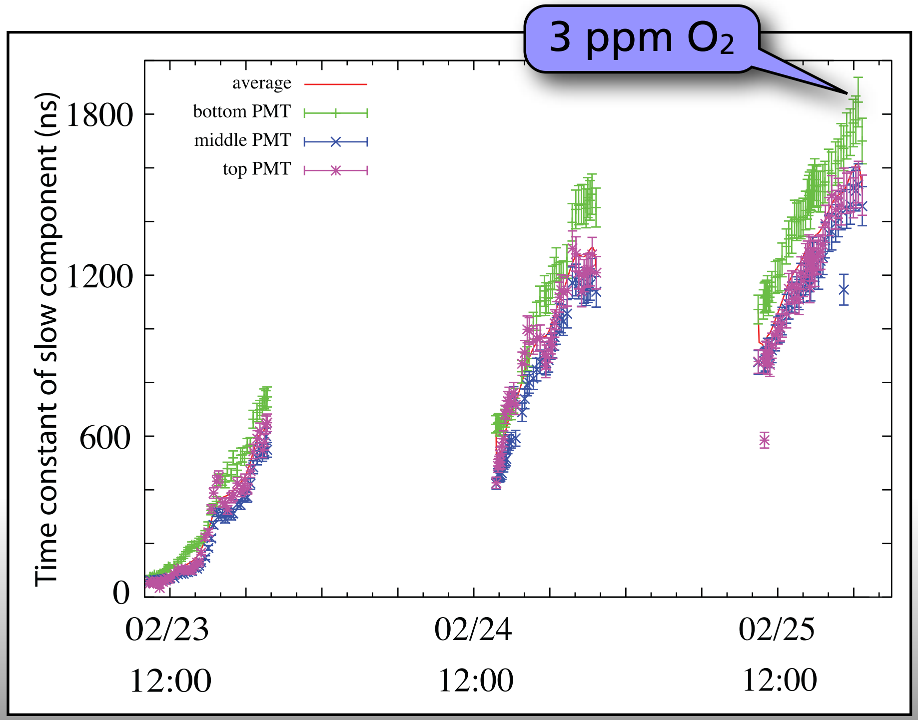
Idea is to purge the vessel. i.e. the heavy argon gas is filled in the vessel and presses out the air (piston effect)

Experiment was done, using a 8 m³ dewar

The purity was measured with oxygen monitors and by the lifetime of the slow component of the scintillation light



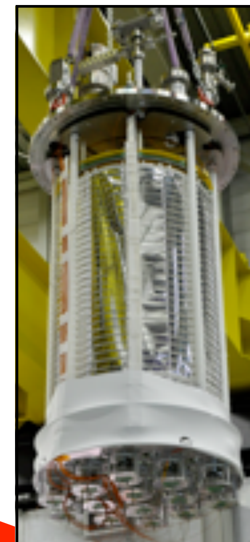




Roadmap

3l Setup @ CERN

(R&D charge readout)

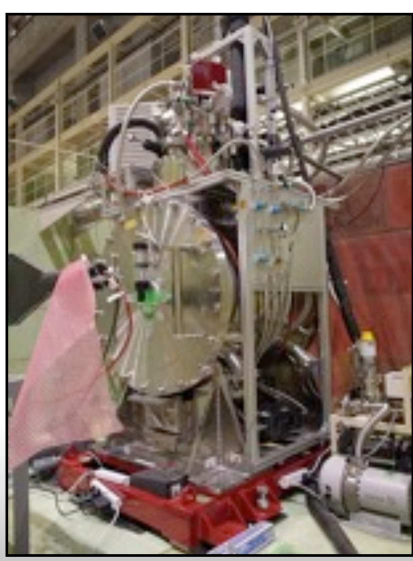


ArDM @ CERN --> LSC

(~1t LAr; Greinacher HV-Devise, large area readout, purification, ...)

$6m^3$ @ CERN

(R&D toward non evacuated vessels, charged particle test beam exposure in 2012)



P32 @ JParc

(~0.4 t LAr; π-K test beam)

ArgonTube @ Bern

(long drift up to 5 m, HV-system, purity)

1 kton @ CERN

(full engineering demonstrator towards very large LAr-detectors with stand alone short baseline physics program)

Conclusion

- Several different R&D projects are ongoing
- The upcoming milestones in the near future will be:
  - First test with large charge readout system (250l-detector)
  - Double stage charge readout with gain up to 1000 in cold, pure argon gas (3l-test setup)
  - Underground installation and operation of a 1t detector (ArDM)
  - Progress in purification

➡ Different key aspects and technologies for large liquid argon detectors are studied and developed

We are looking forward to combine the different efforts in a next prototype detector for neutrino physics!