ETH Institute for
Particle Physics

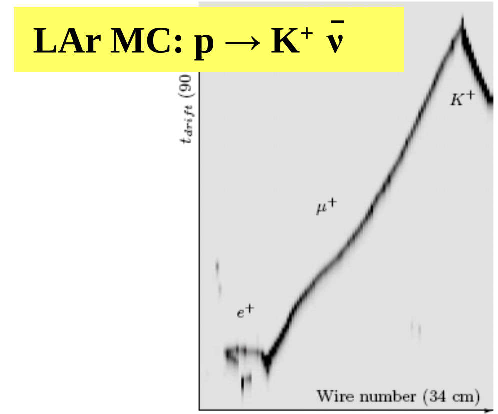
GLACIER

A. Marchionni, ETHZ

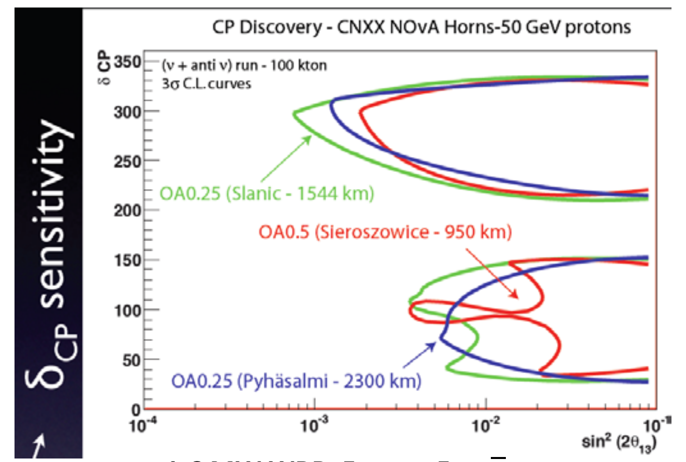
CHIPP Annual Plenary Meeting, Aug. 23-24, 2010

- **GLACIER: a 100 kton LAr detector for proton decay searches, long baseline neutrino oscillation experiments, astrophysical neutrinos observatory**
- **Recent studies and R&D towards GLACIER**
  - **LAGUNA: European design study for Large Apparatus for Grand Unification and Neutrino Astrophysics**
  - **Test setups for detailed investigation of double-phase operation of LAr TPCs, calibration and monitoring of LAr purity and drift, argon purification**
  - **Larger scale setups: ArDM (CERN RE18), ArgonTube**
  - **Test experiment T32 on a beam @ J-PARC**
- **GLACIER roadmap and next steps**
- **Conclusions**

Why a 100 kton scale LAr detector?



- **Is baryonic number conserved?**
  - **Proton decay searches**
  - **10x efficient than WC for $p \rightarrow K^+ \bar{\nu}$**

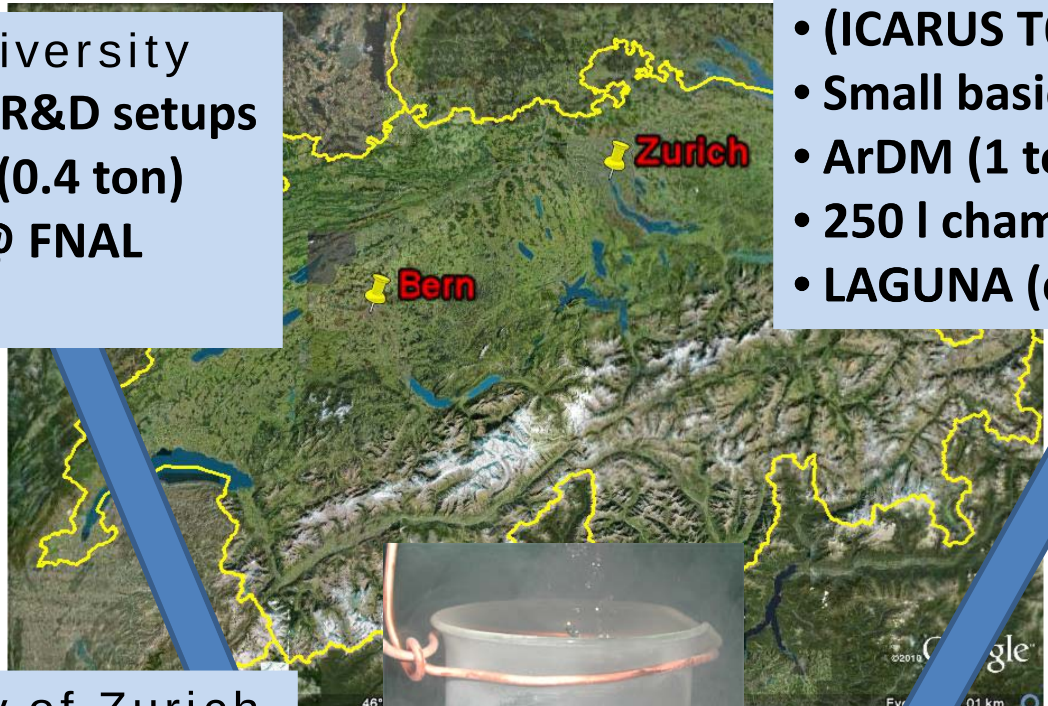


1.6 MW WBB, 5 yr ν + 5 yr ν̄

- **Any CP violation in the leptonic sector?**
  - **Long baseline neutrino oscillation experiment**
  - **better efficiency and background rejection for electron neutrinos than WC**

- **A new observatory**
  - **Supernova core collapse neutrinos**
  - **Diffuse supernova neutrino background**
  - **Atmospheric neutrinos ⟹ detection of ν_τ (not possible for WC)**

LAr activities in Switzerland



Bern University

- **Small basic R&D setups**
- **ArgonTube (0.4 ton)**
- **ArgoNeut @ FNAL**
- **LAGUNA**

A. Ereditato
F. Juget
I. Kreslo
M. Messina
U. Moser
B. Rossi
L. Scotto (ArDM)

University of Zurich

- **DARWIN**

C. Amsler
W. Creus
C. Regenfus

ETHZ

- **(ICARUS T600 @LNGS up to 2006)**
- **Small basic R&D setups**
- **ArDM (1 ton)/DARWIN**
- **250 l chamber @ JPARC**
- **LAGUNA (coordinator)**

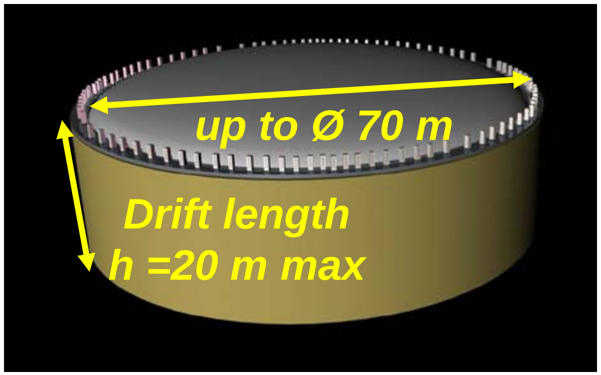
A. Rubbia
A. Badertscher
A. Curioni
U. Degunda
L. Epprecht
L. Esposito
A. Gendotti
S. Horikawa
L. Knecht
C. Lazzaro
S. di Luise
D. Lussi
A. Marchionni
G. Natterer
F. Resnati
C. Strabel
T. Viant

Giant Liquid Argon experiment (GLACIER)

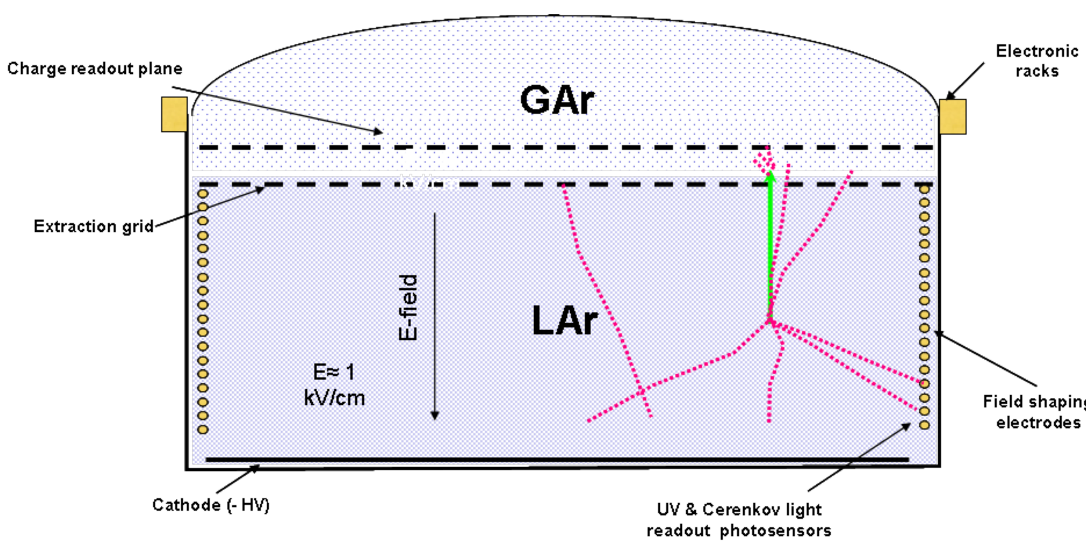
GLACIER

Giant Liquid Argon Charge Imaging ExpeRiment up to 100 kton

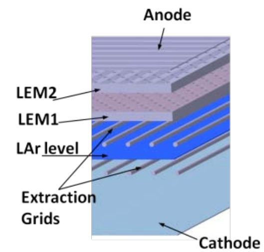
A. Rubbia hep-ph/0402110
Venice, Nov 2003

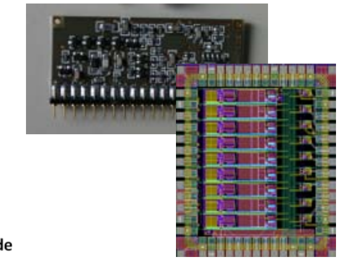


- Single module cryo-tank based on industrial LNG technology
- Simple, scalable detector design, possibly up to 100 kton
- Single very long vertical drift with full active mass
- Charge readout in double-phase LAr with amplification (LEM-TPC) for long drift paths
- Immersed HV Cockcroft-Walton for drift field (1 kV/cm)
- Light readout on surface of tank
- Possibly immersed (high Tc) superconducting solenoid to obtain magnetized detector



R&D towards GLACIER



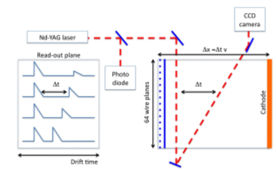


Readout devices and electronics

Diffusion

High Voltage systems

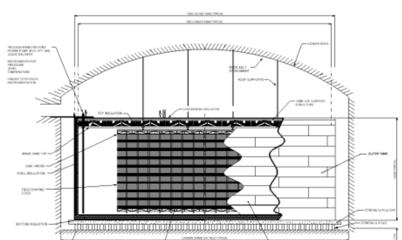
Long Drift



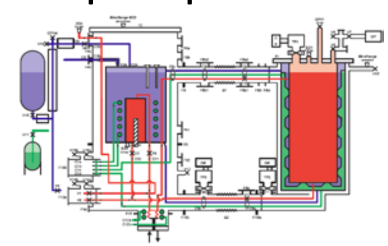
Argon Purity

Detector engineering, safety, underground construction

LAr vessel



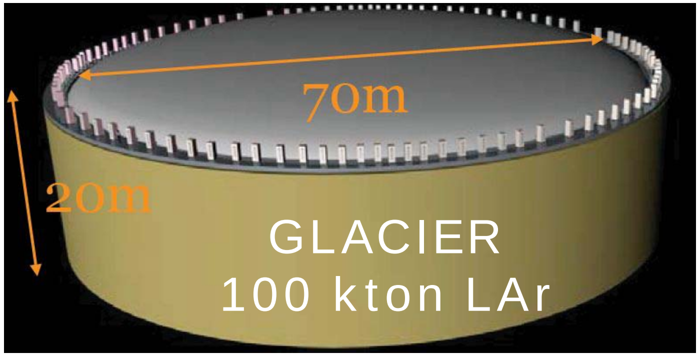
Argon Purification
Cryogenic pumps

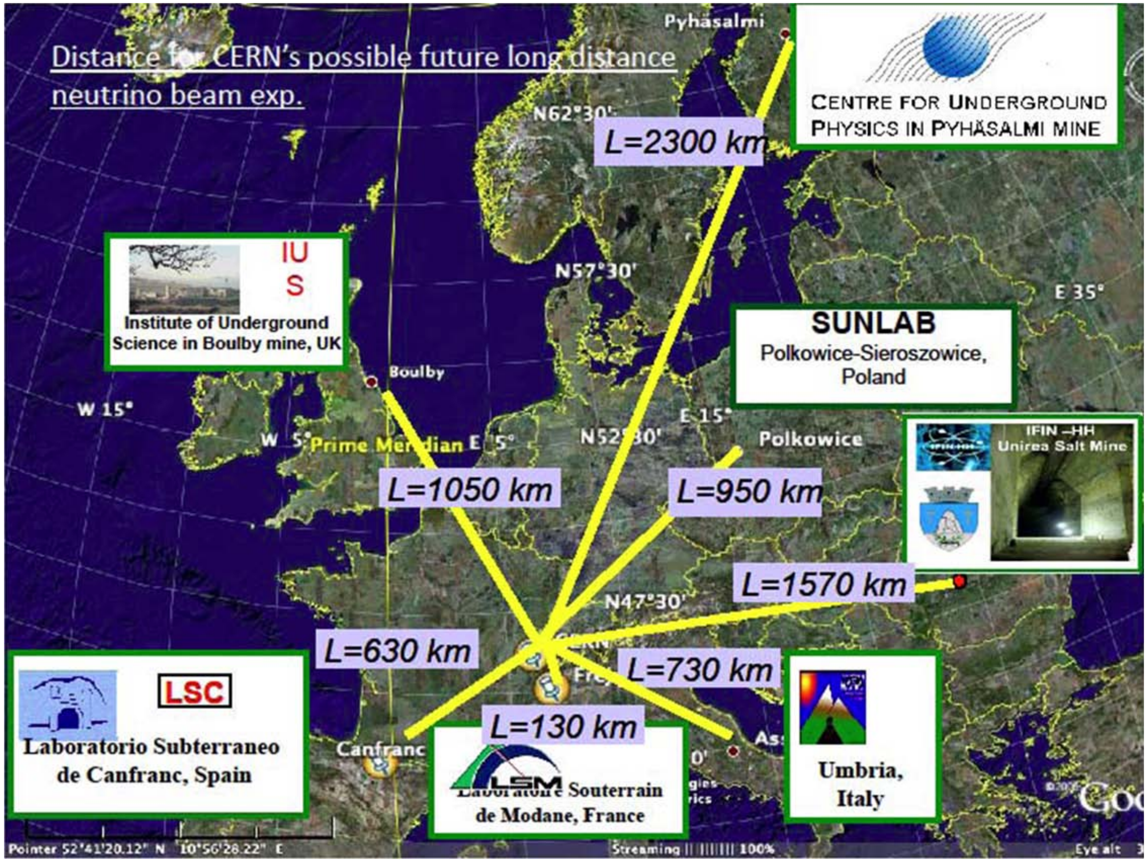


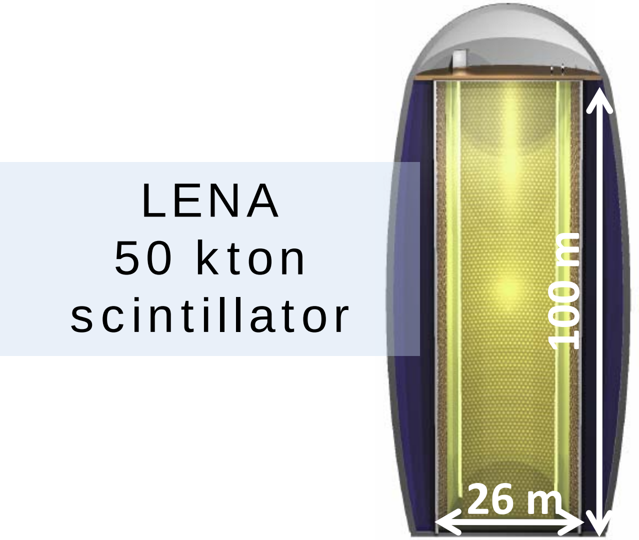
LAGUNA

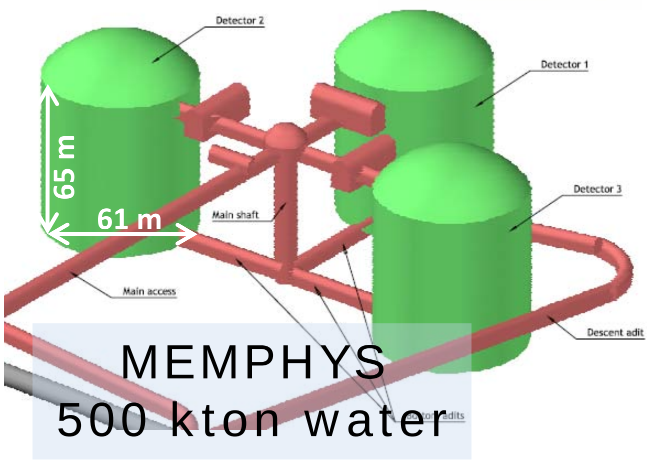
European design study for Large Apparatus for Grand Unification and Neutrino Astrophysics

- **FP7 “Design Studies” Research Infrastructures LAGUNA Grant Agreement No. 212343, P.I. A. Rubbia**
- **1.7 M € EC contribution, beneficiaries in 9 countries**
- **started in 2007, ending summer 2011**
- **planned to apply for continuation**

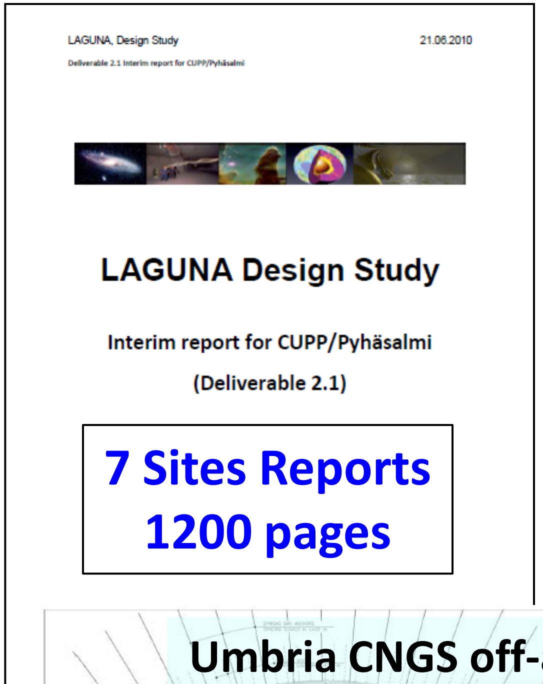








GLACIER Underground Layout Studies



LAGUNA, Design Study 21.06.2010

Deliverable 2.1 Interim report for CUPP/Pyhäsalmi

LAGUNA Design Study

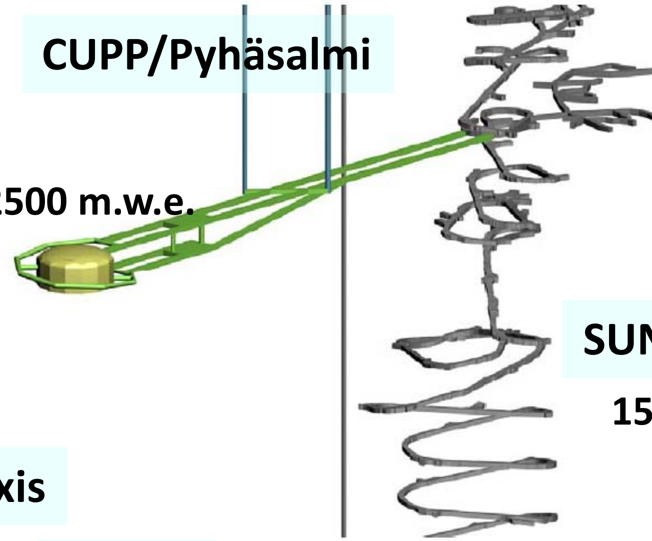
Interim report for CUPP/Pyhäsalmi

(Deliverable 2.1)

7 Sites Reports
1200 pages

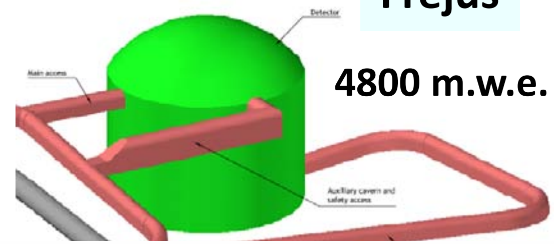
CUPP/Pyhäsalmi

2500 m.w.e.



Fréjus

4800 m.w.e.

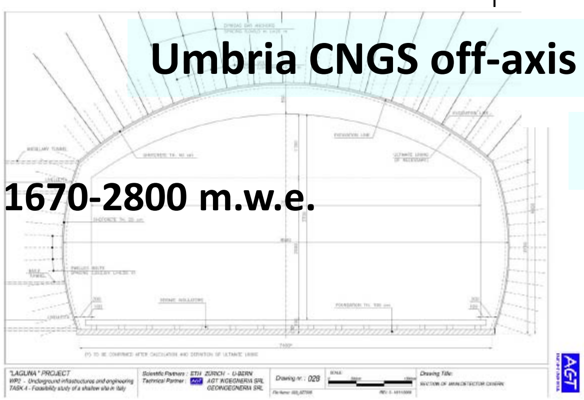


SUNLAB Sieroszowice

1500 m.w.e.

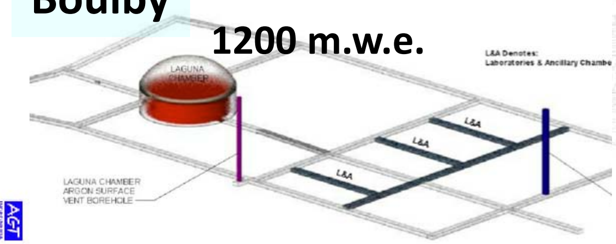
Umbria CNGS off-axis

1670-2800 m.w.e.



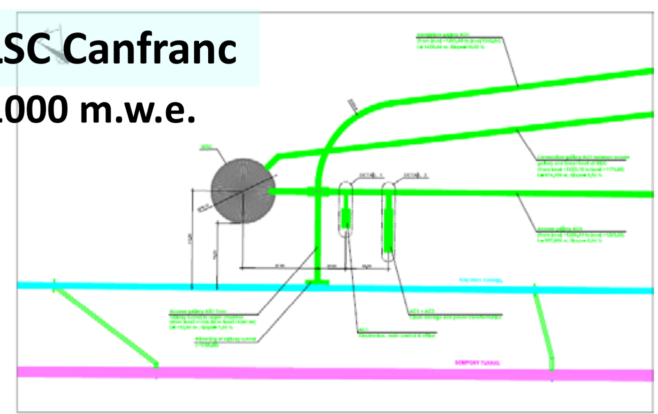
Boulby

1200 m.w.e.



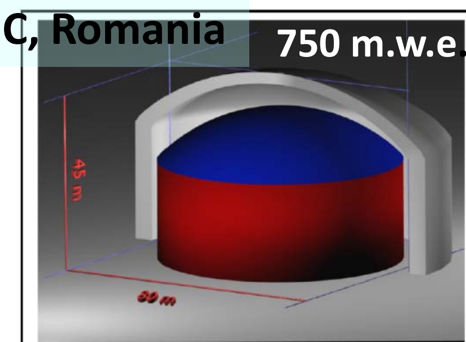
LSC Canfranc

1000 m.w.e.



SLANIC, Romania

750 m.w.e.

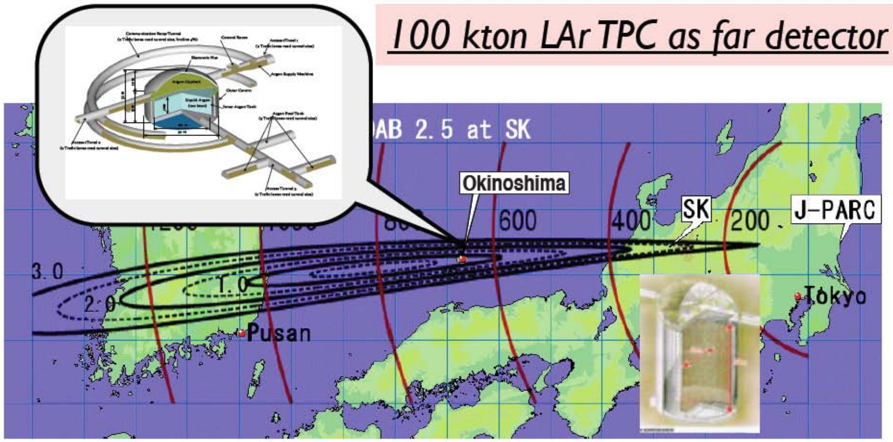


All 7 sites have considered the GLACIER option

Large LAr detectors being considered worldwide for next generation LBL experiment

LAr technology is maturing and it is becoming a credible alternative to WC

100 kton LAr TPC as far detector

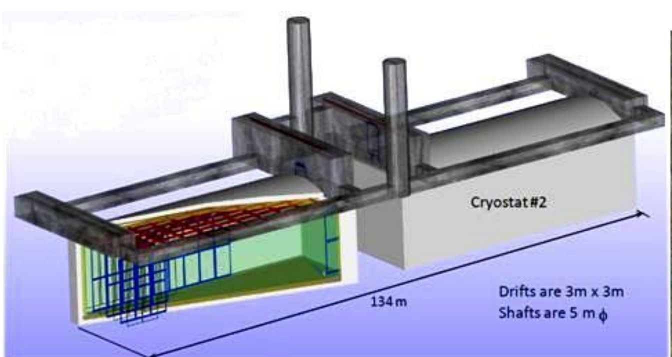


J-PARC to Okinoshima

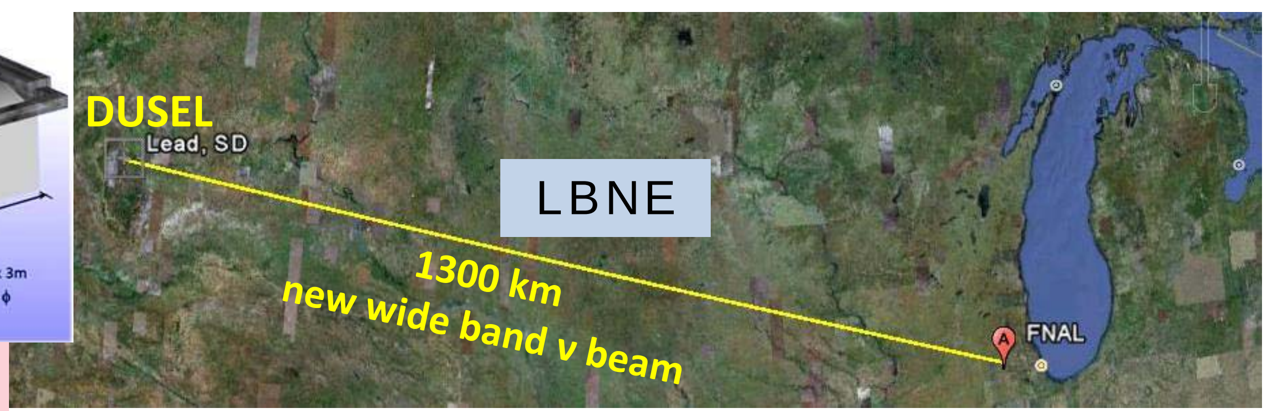
arXiv:0804.2111 [hep-ph] 2008

658 km from J-PARC to Okinoshima, with an existing 0.76° off-axis angle ν beam

ETHZ/KEK MoU for collaboration on LAr R&D



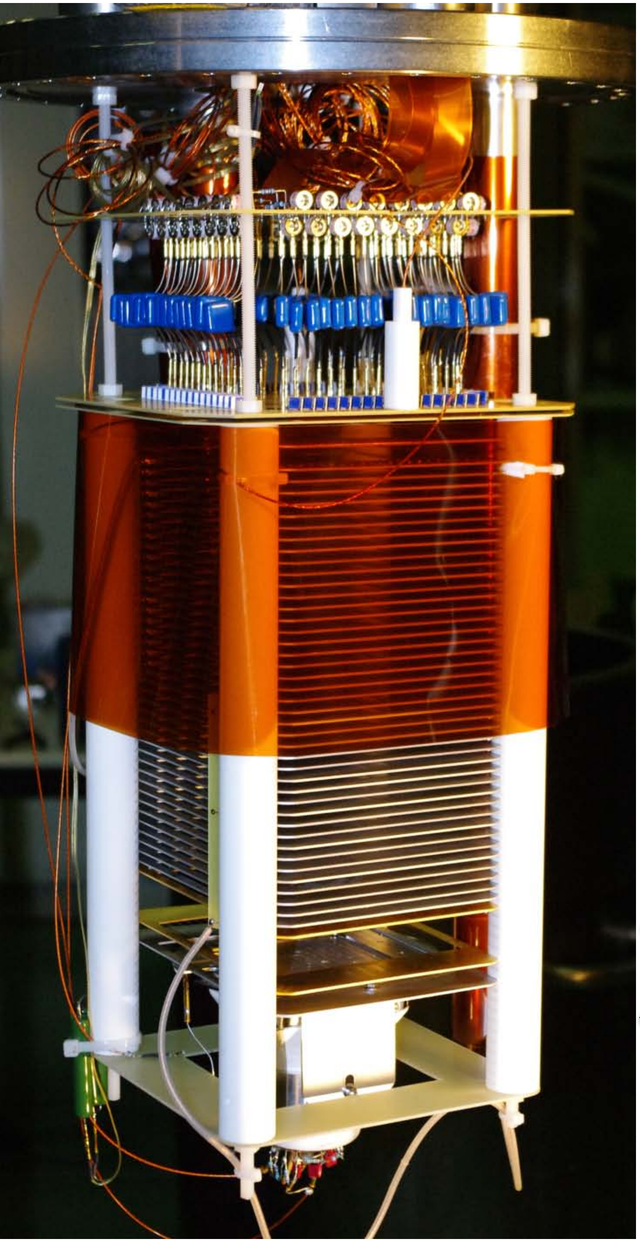
20 kton LAr TPC as far detector

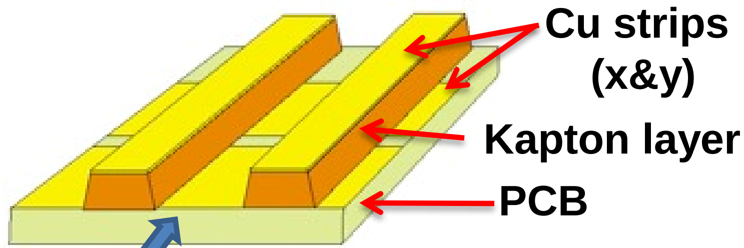


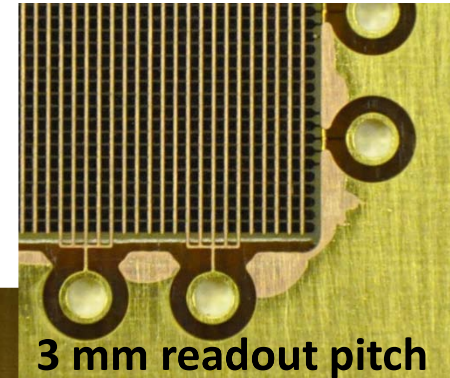
LBNE

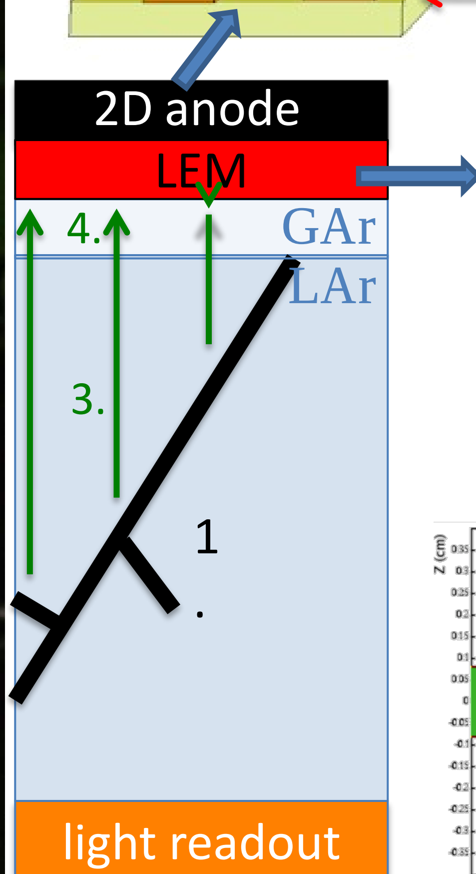
Charge readout in double phase

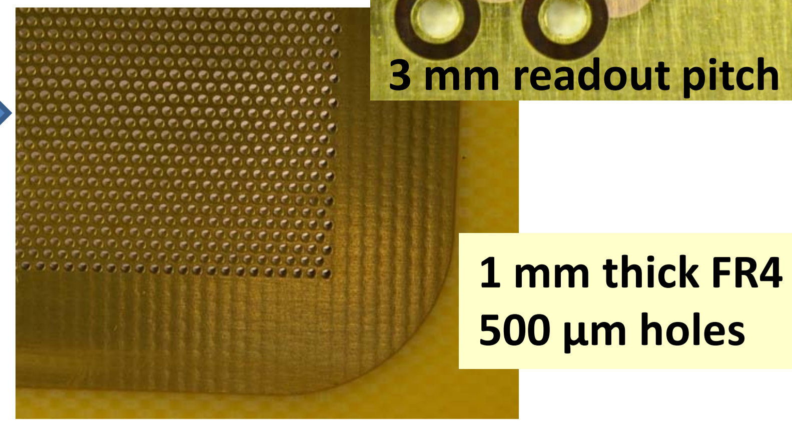
D. Lussi, A. Badertscher, A. Curioni, L. Epprecht, L. Knecht,
A. Marchionni, G. Natterer, F. Resnati, A. Rubbia, T. Viant

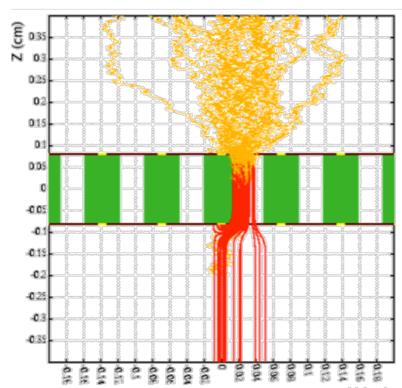










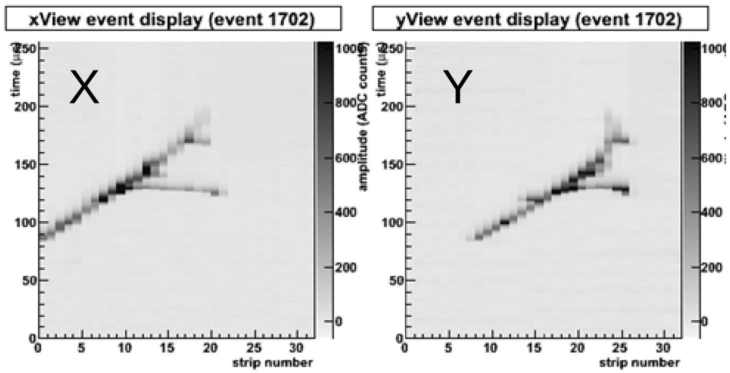


A LEM is a macroscopic hole multiplier

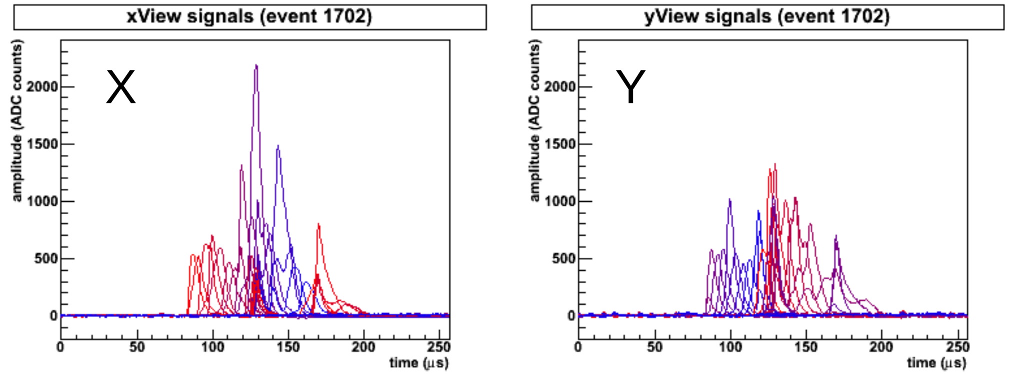
Test of Micromegas in Collaboration with Saclay

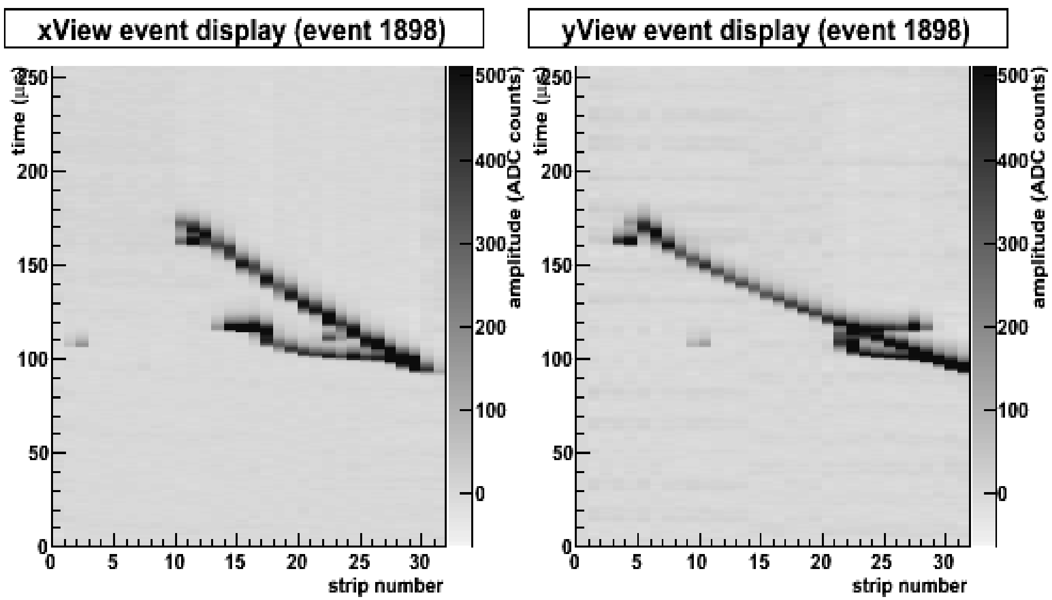
Observation of cosmic rays with a LEM-TPC

Event display: drift time vs position

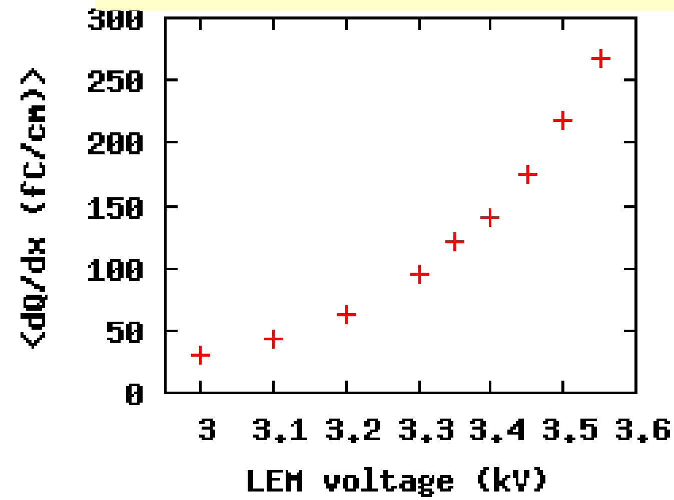


Corresponding digitized signals





Sum of collected charge in X and Y views

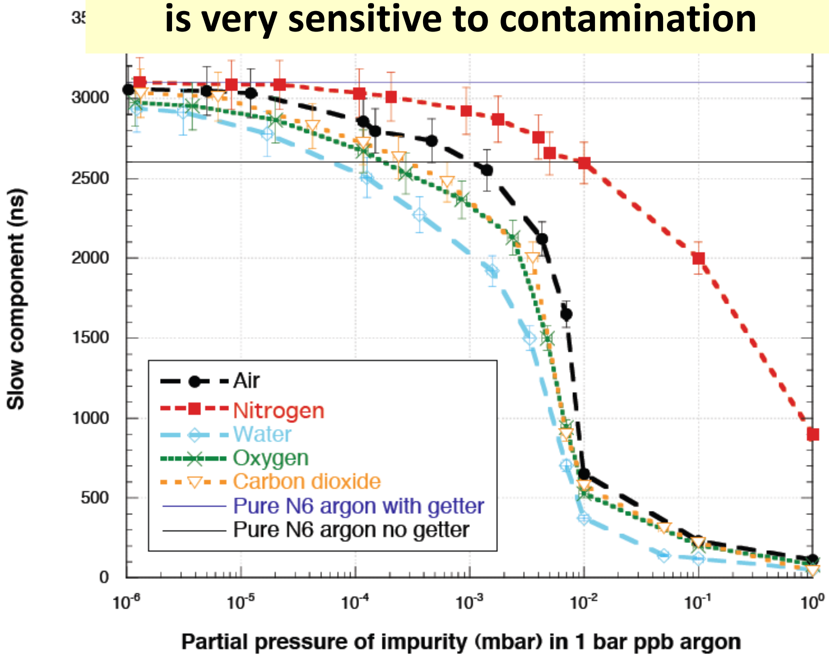


Much improved S/N (>100) compared to single-phase LAr operation (≈15)

Reached an effective charge gain of ≈27

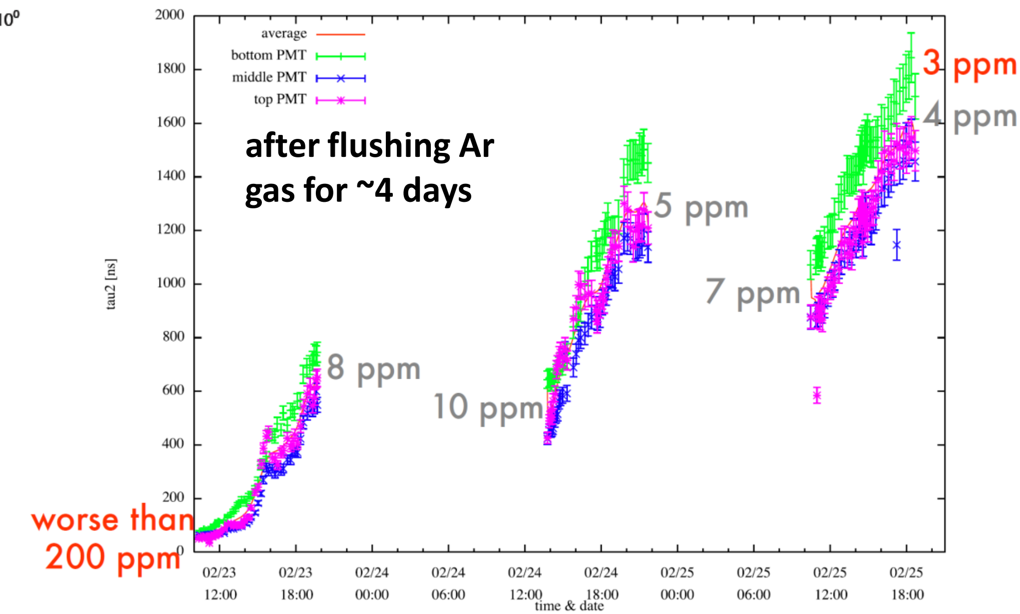
Purity in a non-evacuable 6m^3 dewar

Slow component of Ar scintillation light is very sensitive to contamination



ETHZ: **A. Badertscher, A. Curioni, U. Degunda, L. Epprecht, A. Gendotti, L. Knecht, C. Lazzaro, D. Lussi, A. Marchionni, G. Natterer, F. Resnati, A. Rubbia, C. Strabel, T. Viant**
Liverpool U.: **J. Coleman, M. Lewis, K. Mavrokoridis, C. Touramanis**

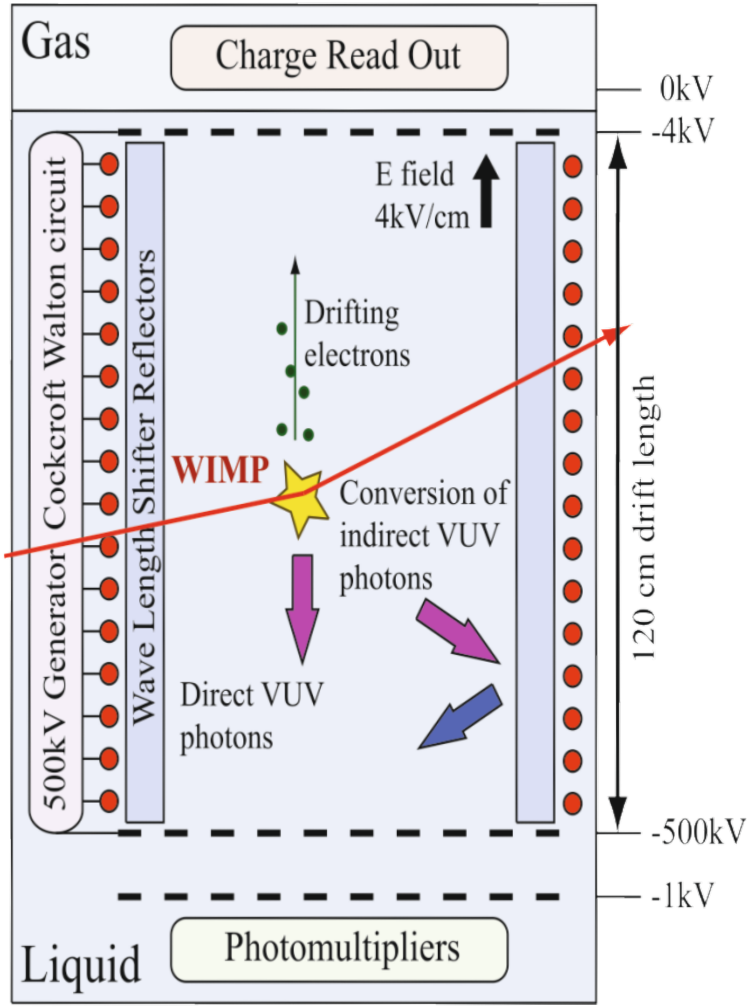
- purging air with Ar gas (piston effect)
- % level O_2 monitors + 3 PMTs each with a 40 kBq Am source to monitor Ar scintillation light
- Reached **3 ppm** O_2 equivalent via flushing
- Closed gas recirculation and purification under construction → **< 1 ppm** O_2 equivalent
- Then test in LAr phase

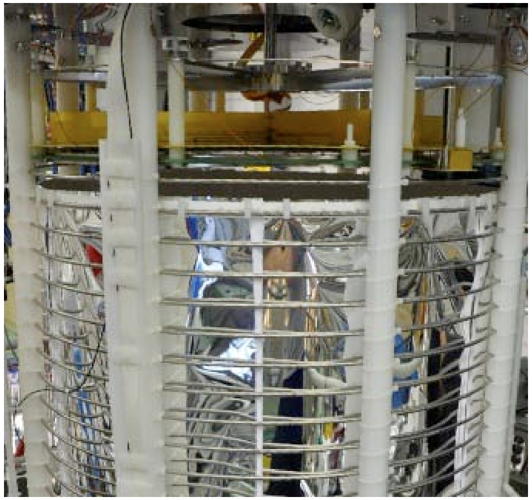


The ArDM Experiment (CERN RE18)

a 1 ton double-phase LAr TPC for direct searches of dark matter particles

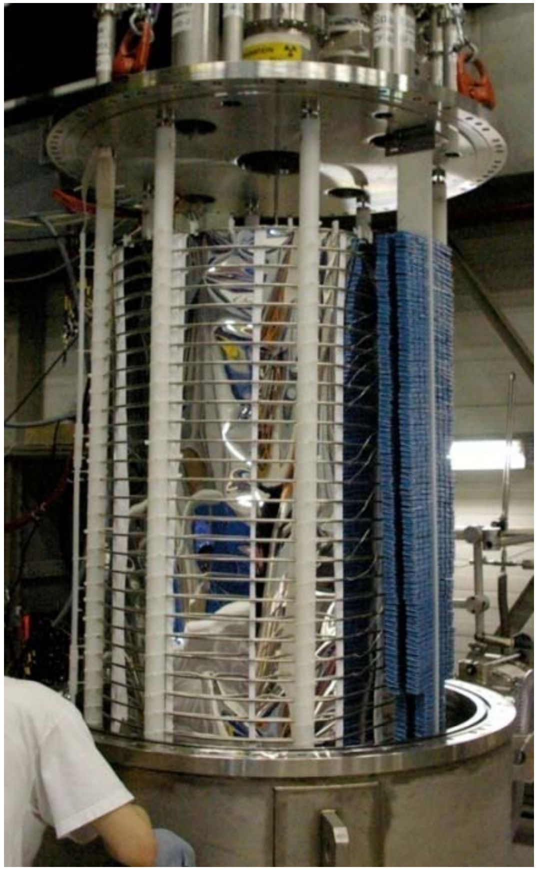
ETHZ, Zurich U., U. Granada, CIEMAT, Soltan INS, U. Sheffield, Warsaw U., INP Krakow, U. Silesia, CERN



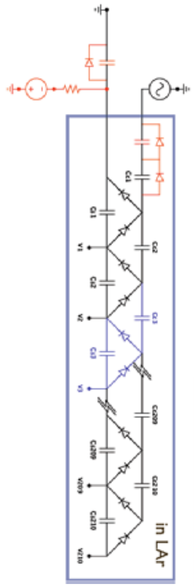


- presently installed on surface at CERN to fully tests all functionalities
- to be moved underground to LSC (Canfranc, Spain) in 2011

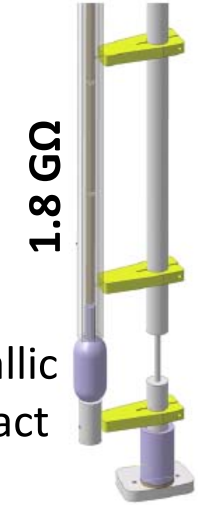
ArDM High Voltage system



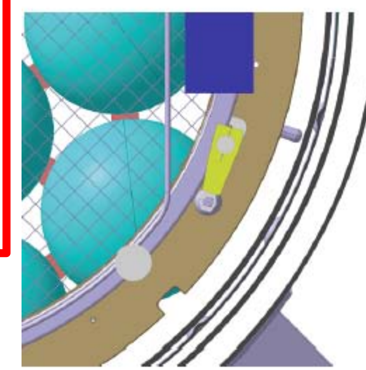
210 stages Cockcroft-Walton circuit



- 2.5 kV, 82 nF metallized film polypropylene capacitors
- 2 kV diodes (3 in series)
- 50 Hz AC voltage source



- **possibility of HV measurement by the measurement of discharging current**
- **monitoring of HV through measurement of drift velocity**



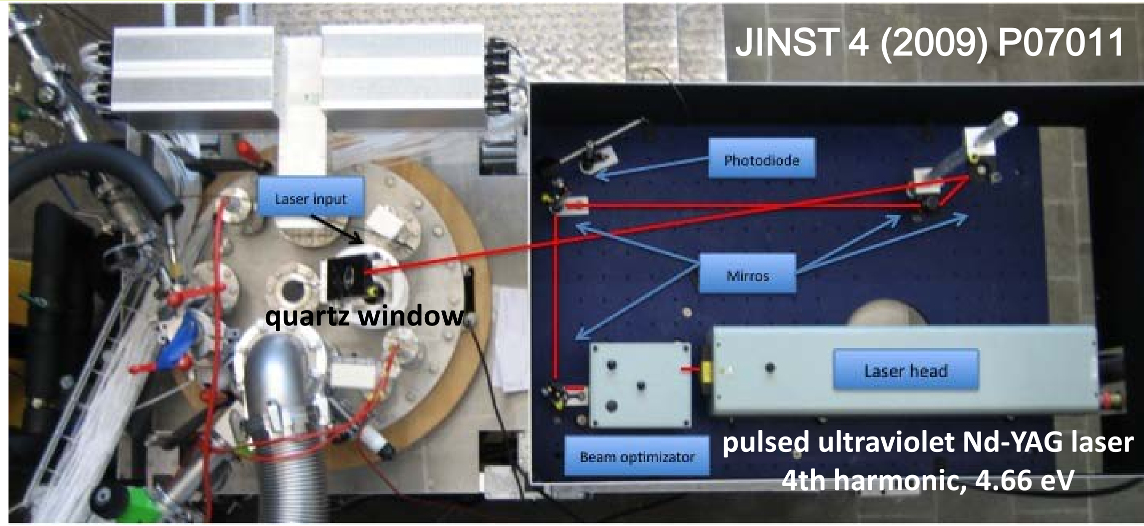
Rotary system with UHV feedthrough for discharging

- **30 field shapers with 4 cm spacing**
- **400 kV at cathode → ~3 kV/cm**
- good linearity of drift field by properly choosing the connection of one of the Cockcroft-Walton stages to each field shaper

ArgonTube @ Bern University

Full scale measurement of 5 m drift
- **signal attenuation, charge diffusion**

multi-photon LAr ionization by UV laser light

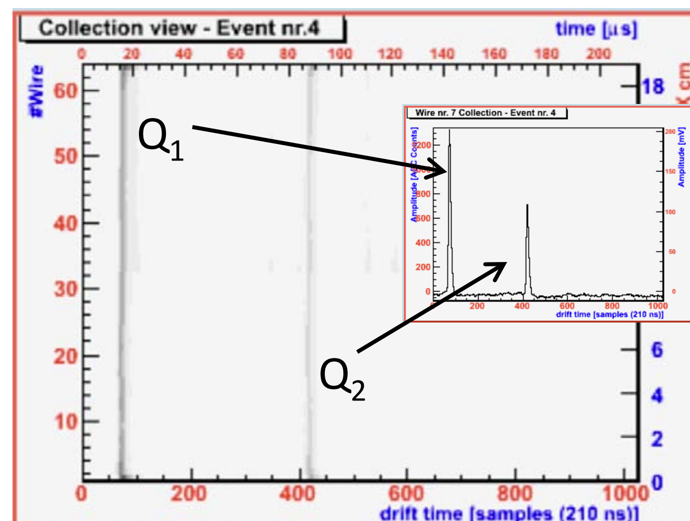


- **Infrastructure ready**
- **External dewar delivered**
- **Detector vessel, inner detector in procurement phase**

Calibration and monitoring of large LAr masses

- uniformity of drift field and drift velocity
- lifetime determination

$$\tau = \frac{\Delta t}{\ln \frac{Q_1}{Q_2}}$$

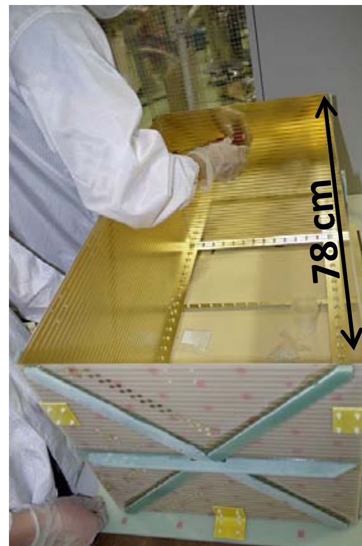


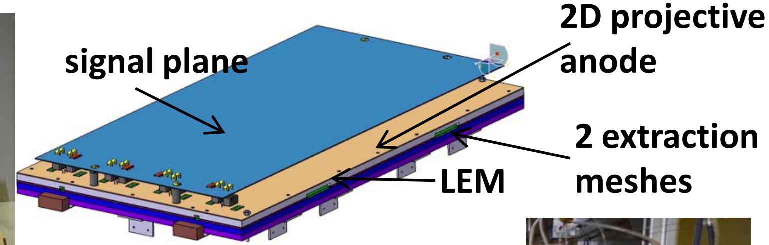
Experiment T32 @ J-PARC

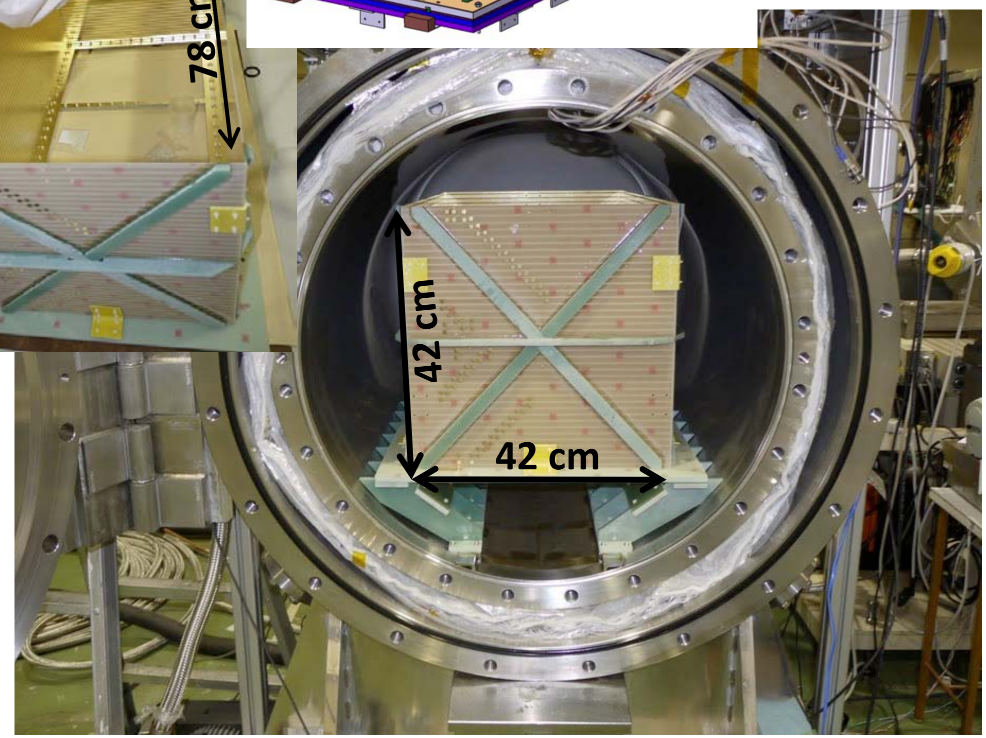
T32 approved in January 2010

ETHZ, KEK, Iwate U., Waseda U.

- develop a scalable Liquid Argon TPC detector as R&D for giant LAr TPCs
- specifically, set up and test a 250 Liter double-phase LAr LEM-TPC
- expose the chamber to K1.1BR charged particle beam, in particular K $(p \rightarrow \bar{\nu} K)$

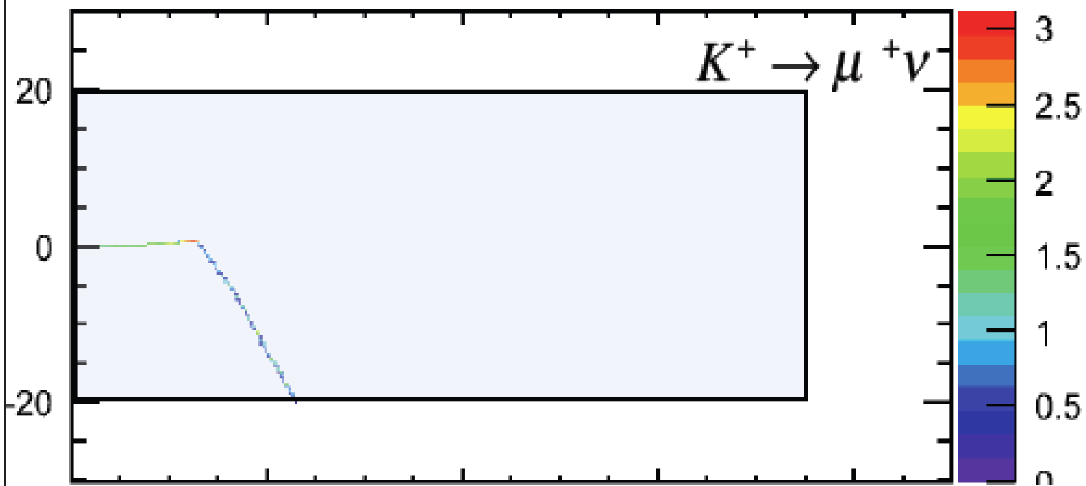


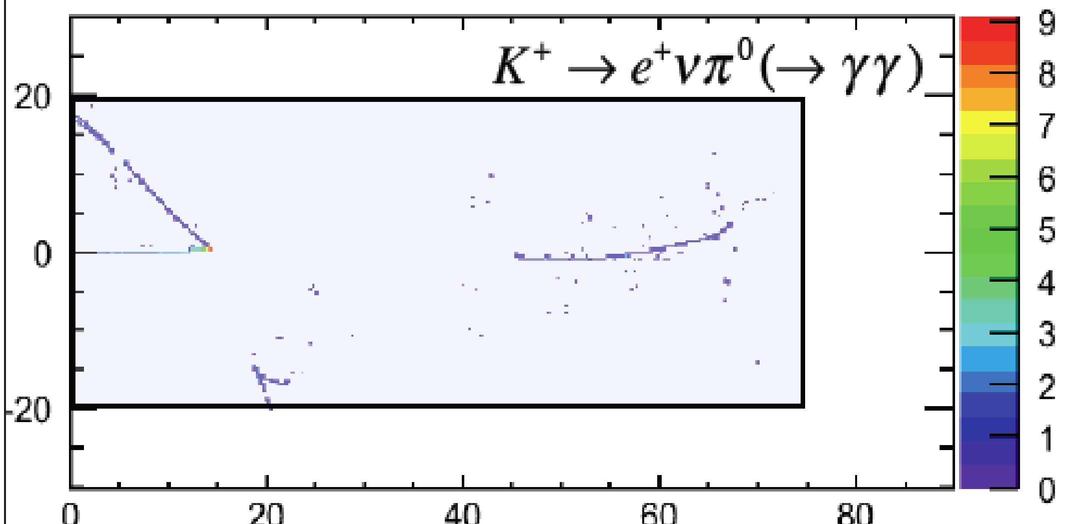




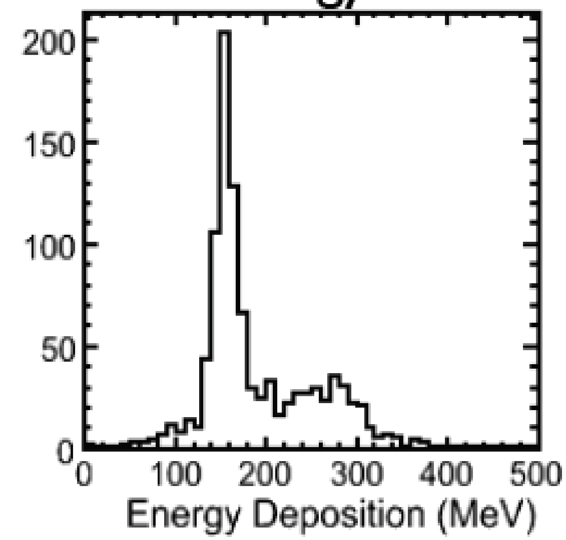
340 MeV/c K+ in 250L

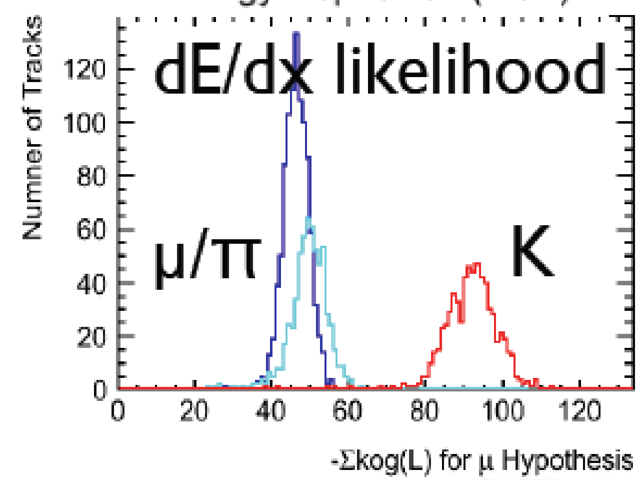
- >90% of slow kaons stop in detector with range ≈10cm (others decay in-flight)
- Many soft decay products are contained
- dE/dx analysis can be performed for particle ID



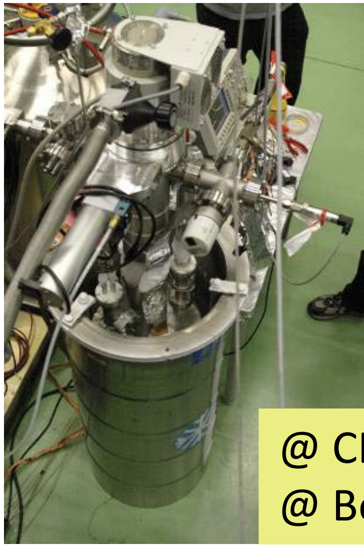


Total energy in LAr



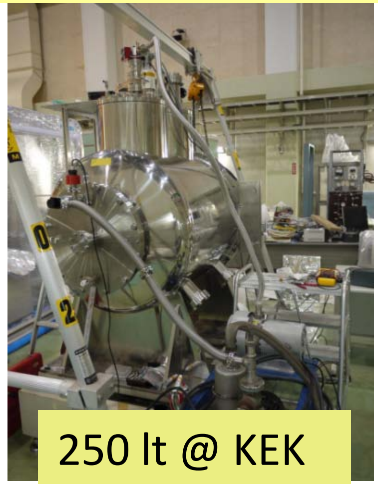


GLACIER Roadmap



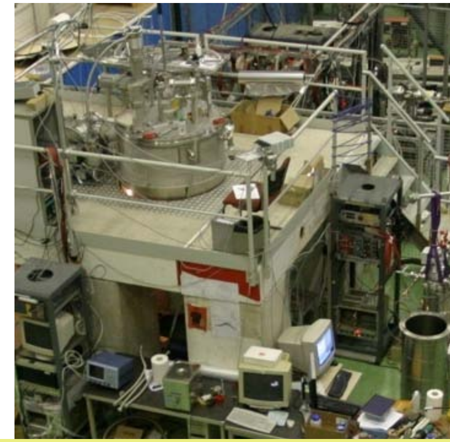
@ CERN
@ Bern

small test setups for readout devices, electronics



250 lt @ KEK

low energy K test beam @ J-PARC

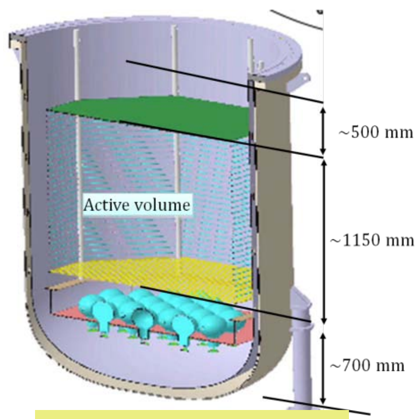


ArDM (RE18), presently @ CERN

1 ton LAr, Cockroft-Walton, LAr recirculation and purification, industrial electronics, safety, optimized for dark matter searches, in operation

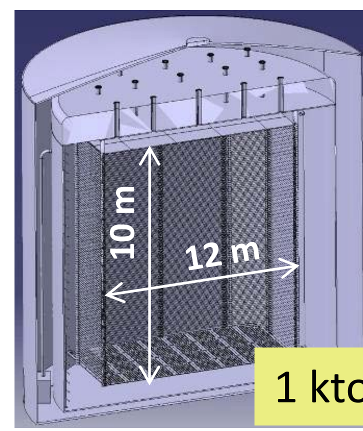
ArgonTube@ Bern

5 m drift, 0.4 ton under procurement



6 m^3 @ CERN

to be proposed for test beams in NA @ CERN



1 kton

full engineering demonstrator for larger detectors + physics

Next steps

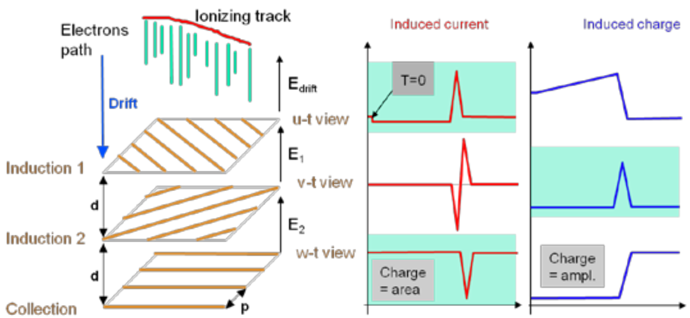
- **The LAGUNA design study is ending on July 2011**
- **A 100 kton scale LAr detector coupled to a ν super-beam is the most effective way to look for CP violation in the leptonic sector if present generation of neutrino experiments find evidence for a non-zero θ_{13} mixing angle**
- **LAGUNA-LBNO planned to be submitted by November 25, 2010**
  - 3 years study
  - study of a conventional neutrino beam from CERN to a LAGUNA site
  - investigate planned collaboration with KEK (Japan) and LBNE (US)
- **Time scale for LAGUNA/GLACIER > 2020**
- **Considering the possibility of a GLACIER-1kton detector on a short-baseline CERN ν beam (2015-2020 ?)**
  - SPS will be the highest power ν source @ CERN for at least 10-15 years
  - a West Area narrow band ν beam, coupled to a kton size bubble-chamber like detector, would allow precision measurements on ν_μ and ν_e, and in particular a new precise determination of the Weinberg angle $\sin^2\theta_W$ through CC and NC purely leptonic processes (Zνν coupling, NuTeV anomaly)

Conclusions

- A ~100 kton LAr detector for proton decay, CP violation searches in the leptonic sector and astrophysical neutrino observatory
  - First ideas for a giant LAr detector developed in Switzerland, active involvement in world-wide LAr activities
- Achieved important R&D results
  - demonstration of the operation of a LAr TPC in double-phase with charge amplification in the gas phase, opening the possibility of very long drifts
  - novel tools developed for calibration and monitoring of large LAr masses
- ArDM: ton-scale LAr detector in operation, presently at CERN, to be moved underground to LSC (Canfranc, Spain) in 2011
- ArgonTube: under procurement in Bern for a 5m drift test
- LAGUNA-LBNO: to study the possibility of a conventional neutrino beam from CERN to a LAGUNA site, with a large choice of different baselines
- A 1 kton-scale device is the appropriate choice for a full engineering prototype of a 100 kton detector
  - being considered for a short-baseline CERN ν beam experiment

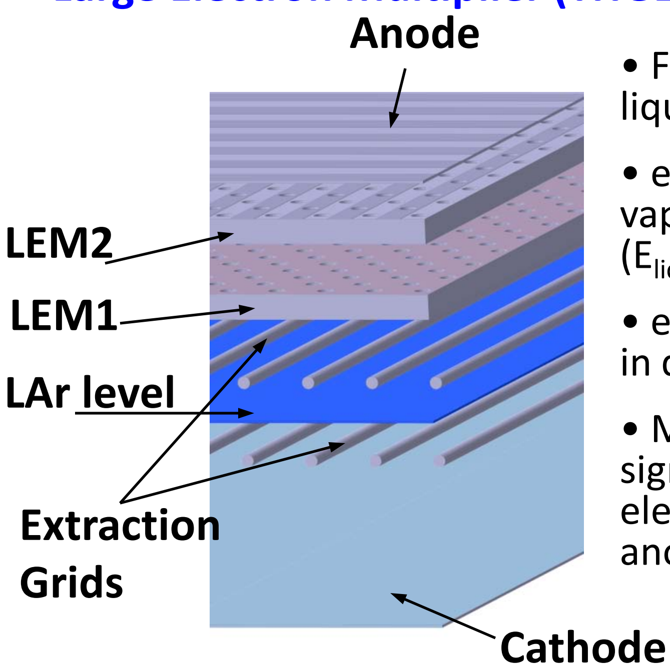
Ionization charge readout techniques in LAr

single LAr phase, wire planes



C. Rubbia, CERN Report 77-8, May 1977

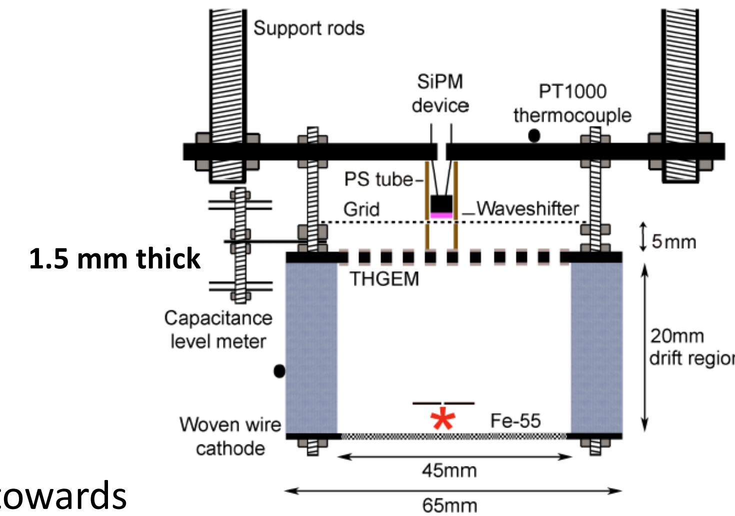
double phase Ar
Large Electron Multiplier (THGEM)

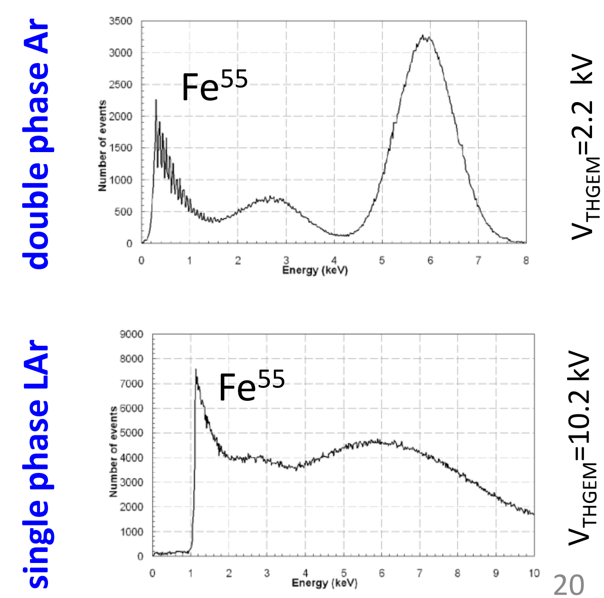


- Free e^- drift in LAr towards liquid-vapour interface.
- e^- are extracted to the vapour via extraction grids (E_{liq} > 2.5 kV/cm).
- e^- undergo multiplication in double stage LEM.
- Multiplied charge induces signals on the segmented electrodes of top LEM and anode.

A. Badertscher et al., arXiv:0811.3384

secondary scintillation from THGEM



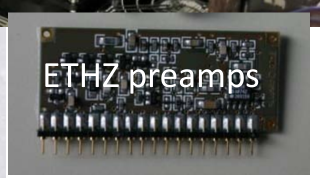


P.K. Lightfoot et al., JINST 4 (2009) P04002

Development and R&D on readout electronics

❑ Development of LAr TPC electronics for small scale devices

- CAEN, in collaboration with ETHZ, developed A/D and DAQ system
- 12 bit 2.5 MS/s flash ADCs + FPGA

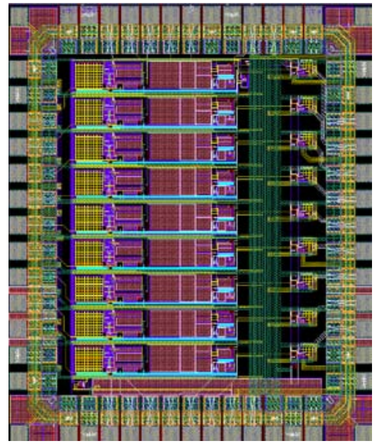


~11 mV/fC
S/N =10
@ 1 fC, C_i=200 pF

MIP ~10 fC/cm

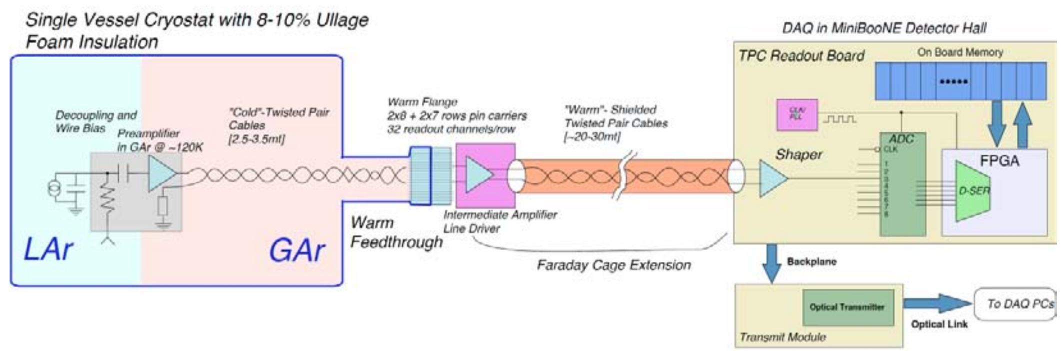
❑ R&D on electronics integrated on the detector

C. Girerd et al., poster at this workshop



- IPNL Lyon - 0.35µm CMOS charge amplifier working at cryogenic temperature
- 1st version bench-tested in 2008
- new version with shaper optimization under development
- to be tested on a LEM TPC setup

MicroBoone electronics



- 10^4 electronic channels : JFET in cold Gar
- V. Radeka group @ BNL working on 87K CMOS ASIC

Charge amplification system in ArDM

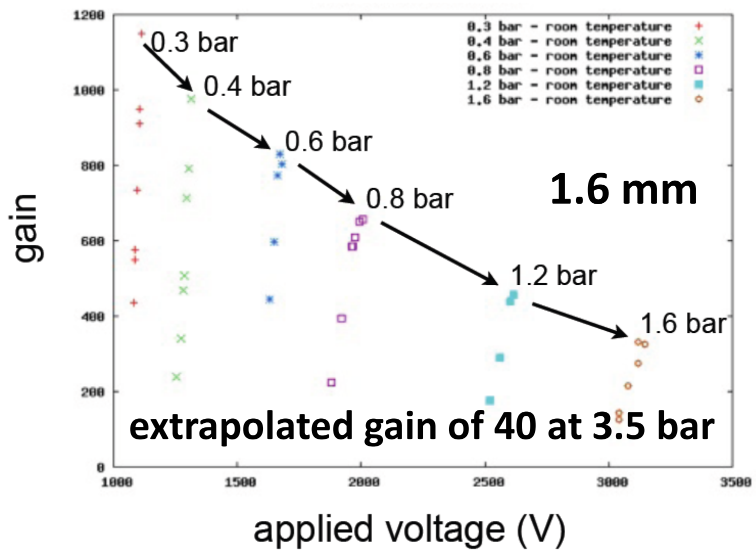
- ArDM requires fine segmentation (few mm, 1024 channels), charge gain of ~1000

$$Gain=e^{\alpha x}$$

x: effective LEM hole length

α: 1st Townsend coefficient $\approx Ape^{-B\rho x/V}$

- edge effects of the holes limit the maximum gain before discharging
- good tolerances in LEM fabrication is essential, in particular the presence of a centered rim around the hole
- new LEMs of 0.5, 1.0, 1.6 mm thickness fabricated at the CERN PCB workshop (good quality!)

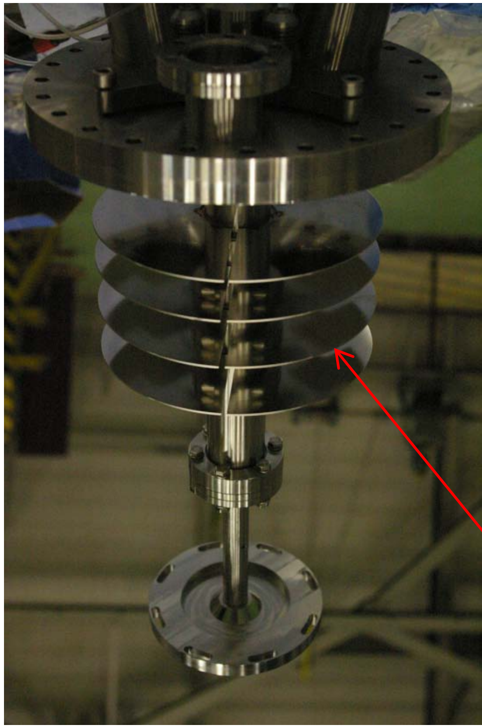


- density of LAr at 87K/1 bar is equivalent to that at 300K/3.5 bar
- use of thinner LEMs, compensating the increase in pressure by a decrease of the hole length
- also considering the possibility of working in subcooling conditions, @ 0.7 bar, 84 K

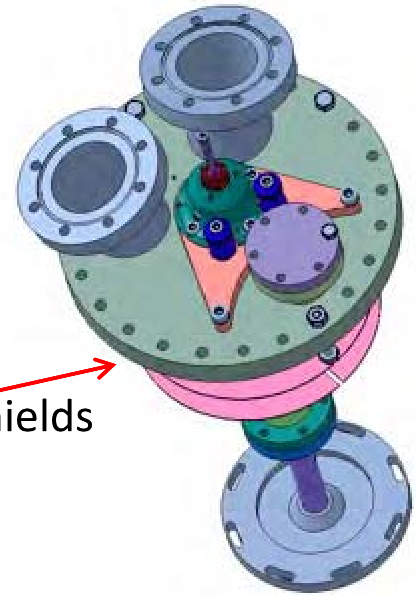
- already constructed a 60x60 cm^2 LEM for Compass, 40x80 cm^2 also possible

ETH Institute for Particle Physics

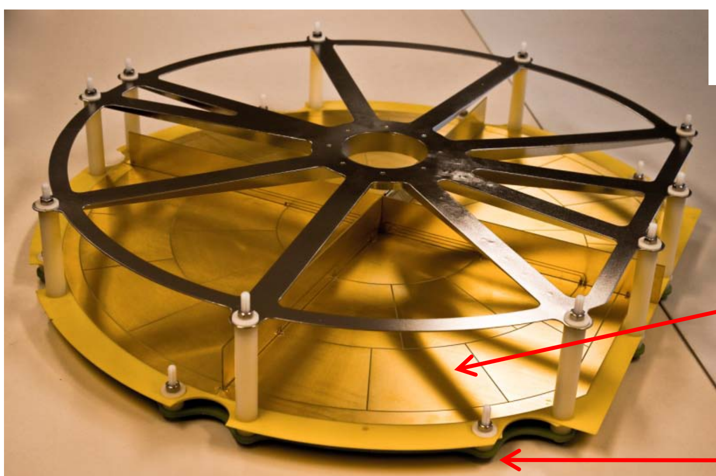
Intermediate step towards a charge readout in ArDM



adjustable hanging system with vertical and tilting movements



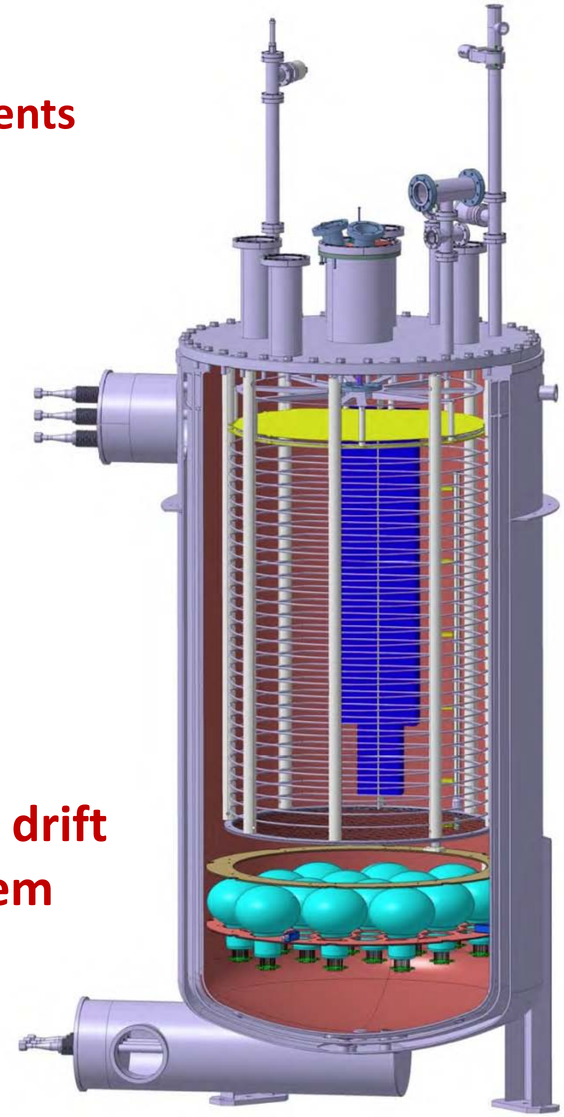
thermal shields



first test of the charge drift and extraction system

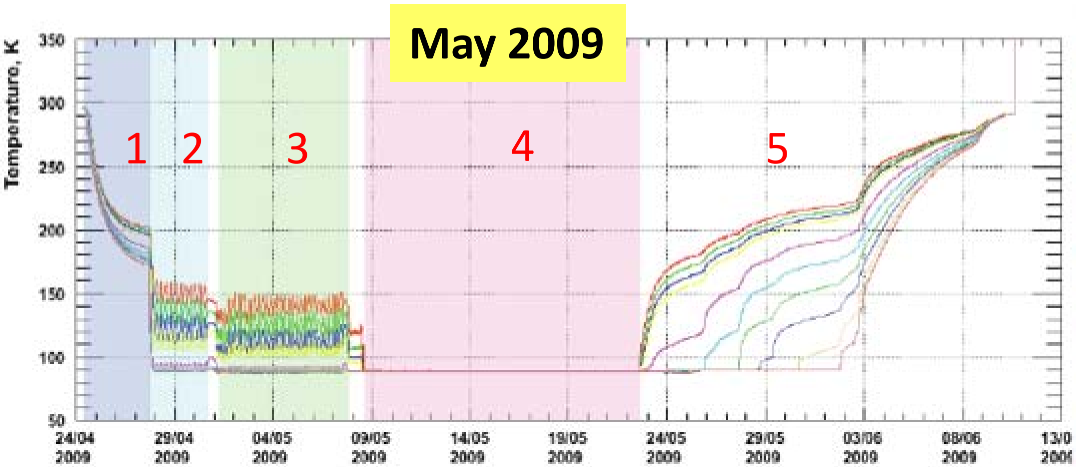
32 pads readout

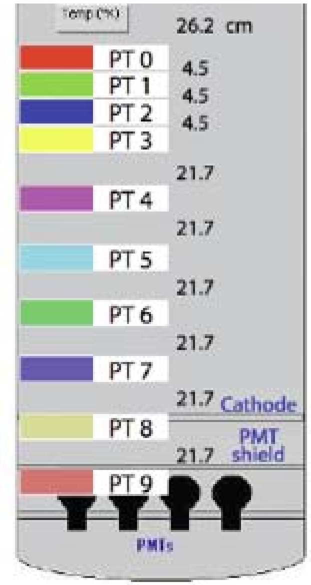
extraction grids



LAr filling of the detector

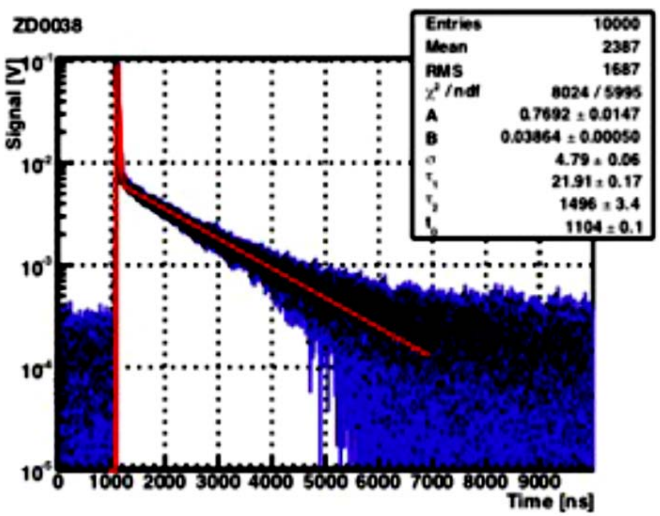
ETH Institute for Particle Physics

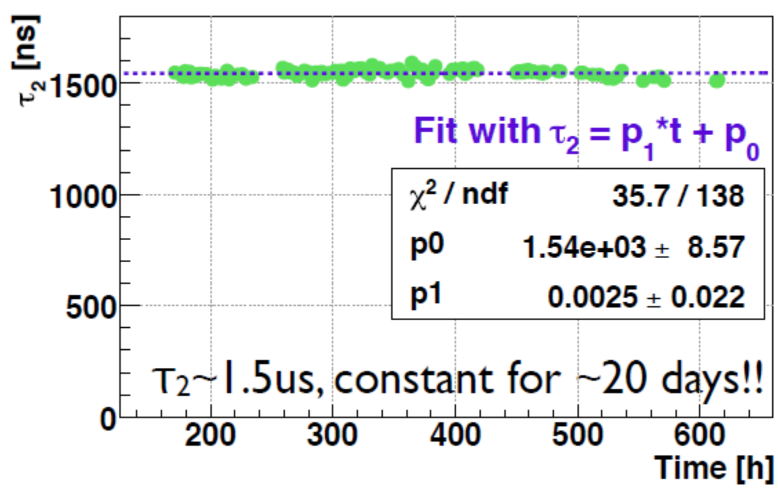




1. cool down, detector under vacuum
2. measurements in pure cold Ar gas
3. detector half filled with LAr, PMTs immersed
4. fully filled with LAr
5. warm-up phase

Achieved a detector vacuum of 10^{-6} mbar before LAr filling





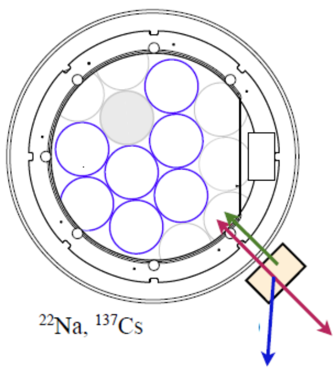
Monitored LAr purity by the measurement of the slow component of the Ar scintillation light

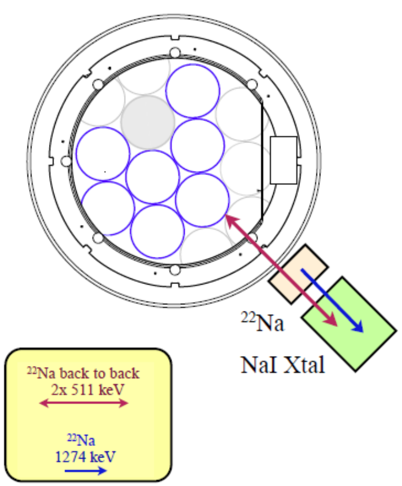
Preliminary results of measurements with a PMT test setup in ArDM

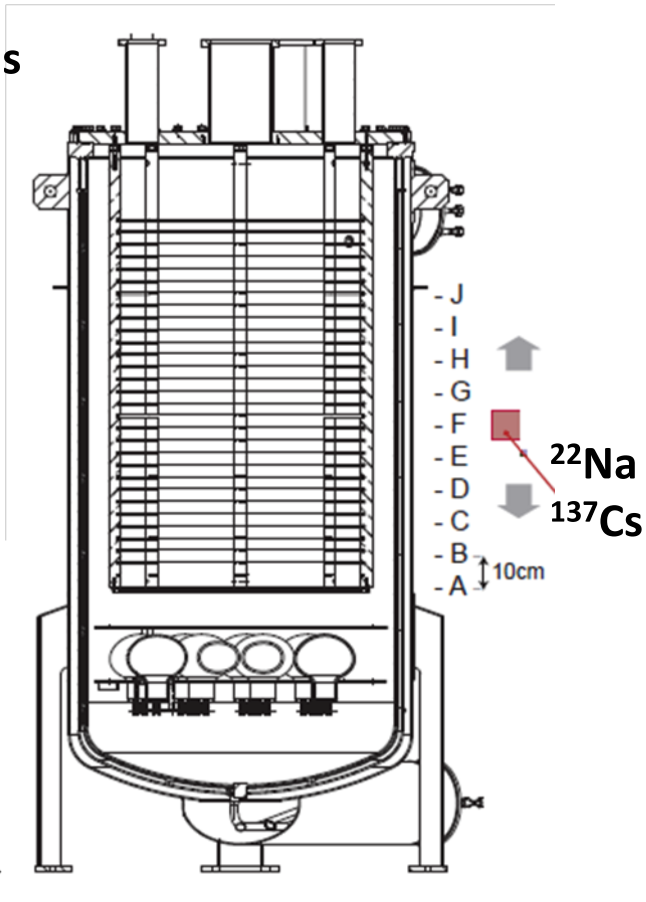
ETH Institute for Particle Physics

Test with radioactive sources: ^{22}Na, ^{137}Cs

Trigger configurations



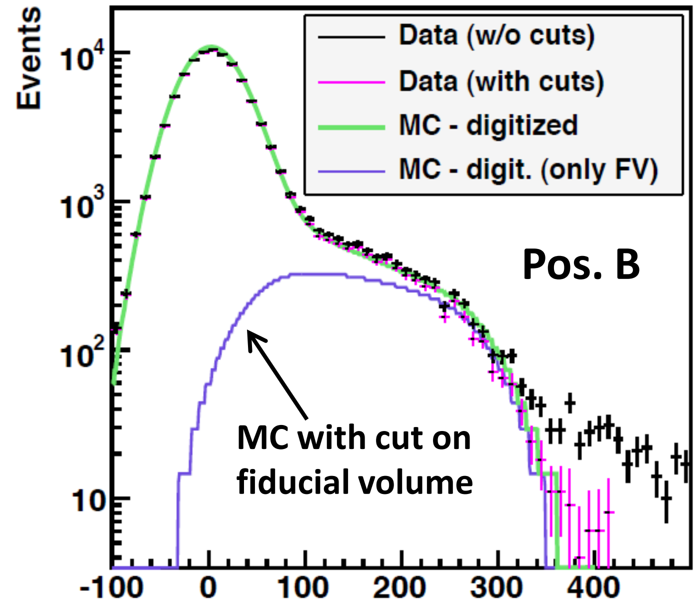




^{137}Cs: γ 662 keV

^{22}Na: β^+, γ 1275 keV

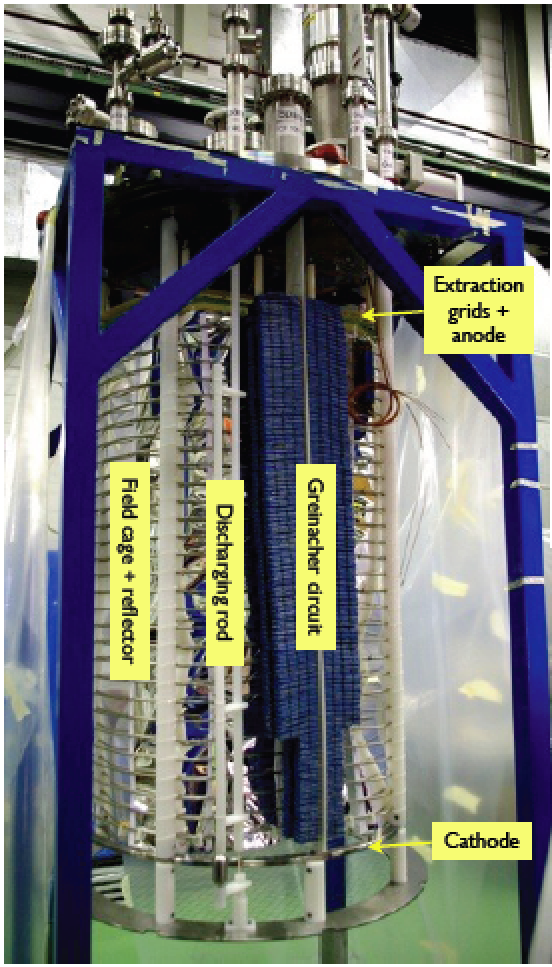
^{22}Na with NaI Xtal trigger (1.8 MeV)



Position	Distance from cathode [cm]	Light yield 7 PMTs [p.e./keVee]
B	10	0.502 ± 0.007
D	30	0.440 ± 0.005
F	50	0.370 ± 0.006
G	60	0.319 ± 0.005

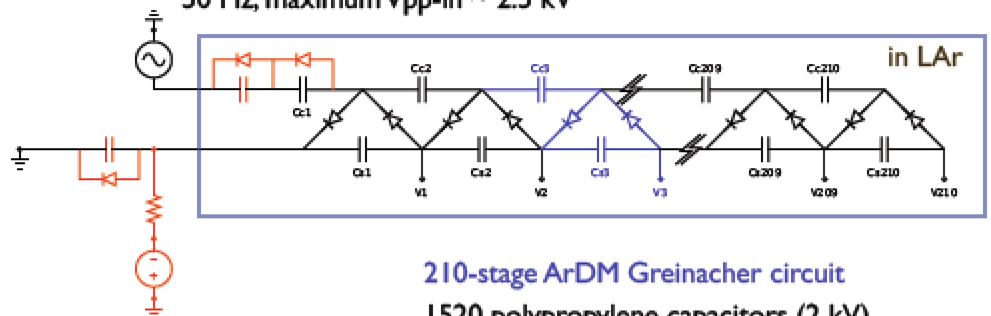
(Error only statistical)

Drift high voltage generator



Novel method of generating drift high voltage

50 Hz, maximum Vpp-in ~ 2.5 kV



DC voltage source for "offset"

maximum V_{DC} = –8 kV

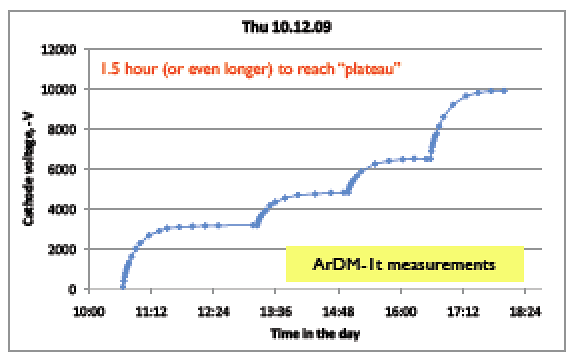
210-stage ArDM Greinacher circuit

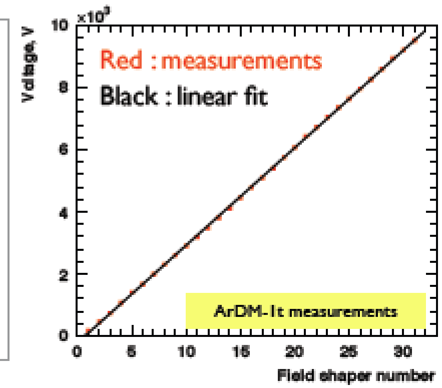
1520 polypropylene capacitors (2 kV)

St.1–170 : 4 × 82 nF ; St171–210 : 2 × 82 nF

1260 avalanche diodes

3 diodes in series at each symbol

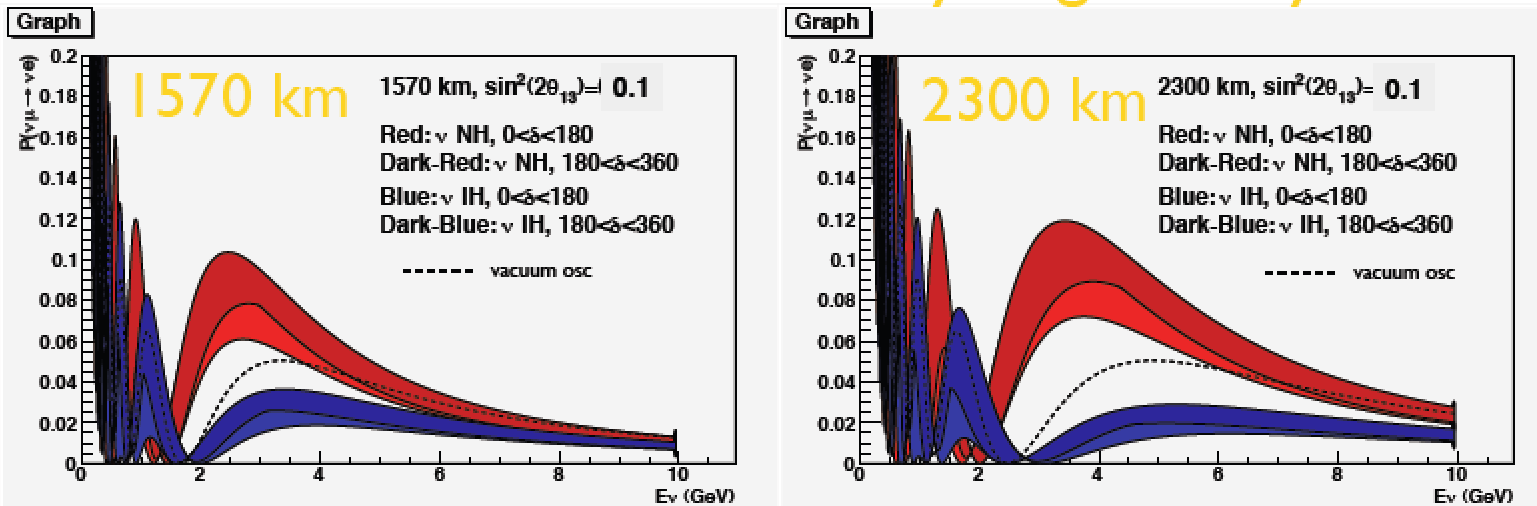




Opportunities of long baselines

CERN-Slanic & CERN-Pyhäsalmi offer very long baselines not considered elsewhere in the world ➠ unique physics opportunities in Europe

CPV and mass hierarchy degeneracy



Determine CPV and mass hierarchy and resolve degeneracies and so-called "π-transit" effect

See e.g. arXiv:0908.3741v1 for "Magic 2500 km baseline"