The ArDM Experiment

A 1 Ton Liquid Argon Detector for Direct Dark Matter Search

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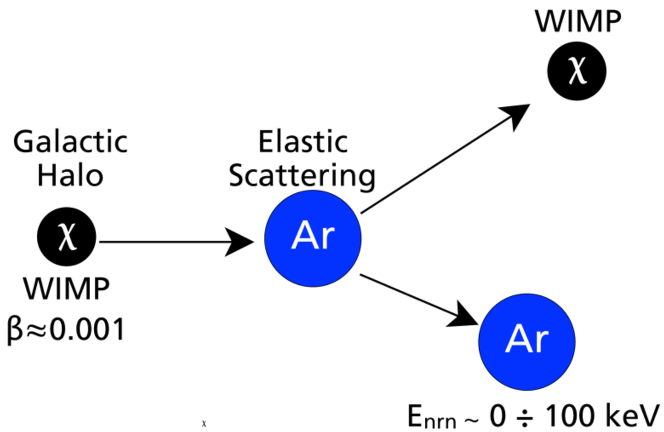
Direct WIMP Detection

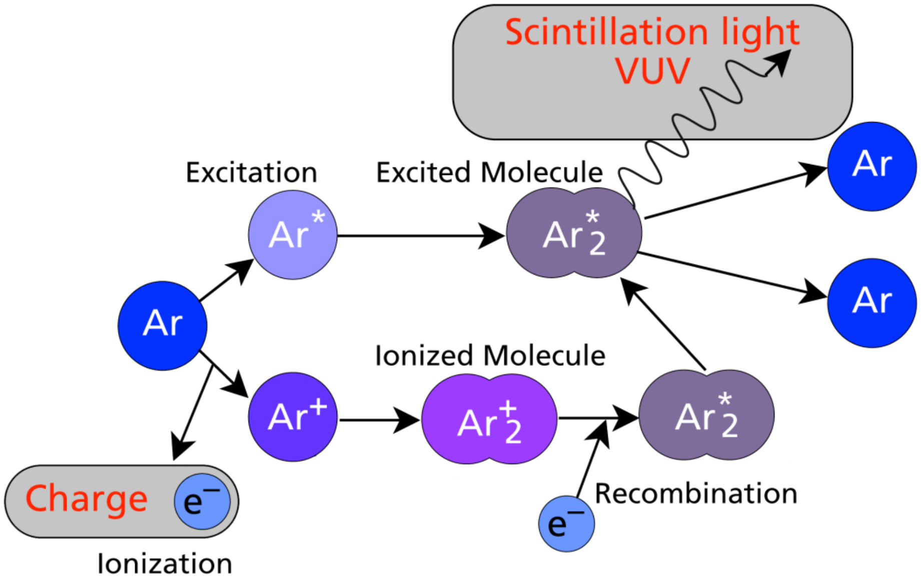
The ArDM experiment is a double phase argon calorimeter and TPC for direct detection of Dark Matter.

A leading Dark Matter candidate is the WIMP (weakly interacting massive particle): stable, neutral, non-relativistic.

The ArDM detection principle is based on elastic scattering of the WIMPs on argon nuclei.

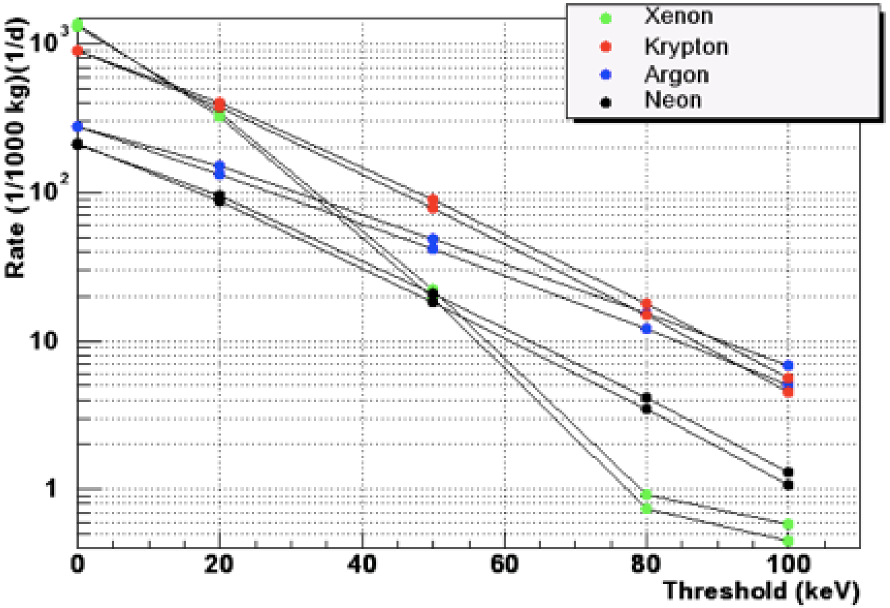
- WIMP velocity: $\beta \approx 0.001$
- Recoil energy 0 – 100 keV
- Assumed threshold for detecting a signal in ArDM: 30 keV
- Interaction similar to elastic scattering of low energetic neutrons





Both, the ionization charge and the scintillation light, are collected in the ArDM experiment.

Integrated Event Rate



Simulation of the total integrated event rate above the recoil energy threshold per day and per ton Xe/Kr/Ar/Ne

Integrated event rate for Ar assuming a recoil energy threshold of 30 keV:

Cross section per nucleon (cm^2)	**Integrated event rate** (events/ton/day)
10^{-42}	~ 100
10^{-44}	~ 1
10^{-46}	~ 0.01

Assumptions:

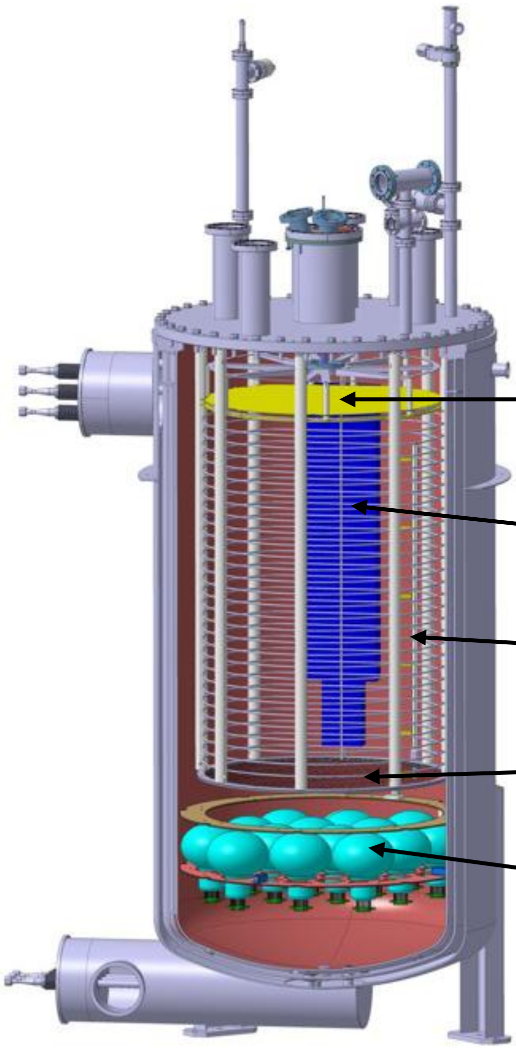
- Cross section per nucleon $\sigma = 10^{-42}$ $cm^2 = 10^{-6}$ pb
- WIMP mass M_{WIMP} = 100 GeV
- Spin independent interaction
- Engel form factor
- WIMP density = 0.5 GeV/cm^3
- Galactic escape velocity v_{esc} = 600 km/s

- The ArDM detector is under testing above ground at CERN.
- To detect this rare events the ArDM experiment will be placed in the Canfranc Underground Laboratory, a low background underground laboratory.

Conceptual Design

Cylindrical volume:	Drift length: 120 cm Diameter: 80 cm
Target:	850 kg
Drift field:	1 – 4 kV/cm

LAr cooling jacket for temperature control of the detector



Charge readout system:
LEM (Large Electron Multiplier)

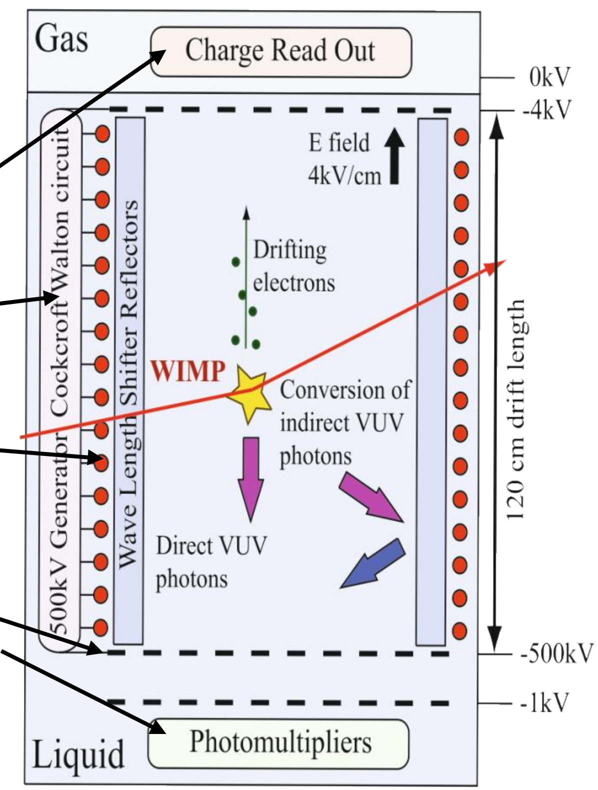
Greinacher circuit:
high voltage generator

Field shapers

Cathode

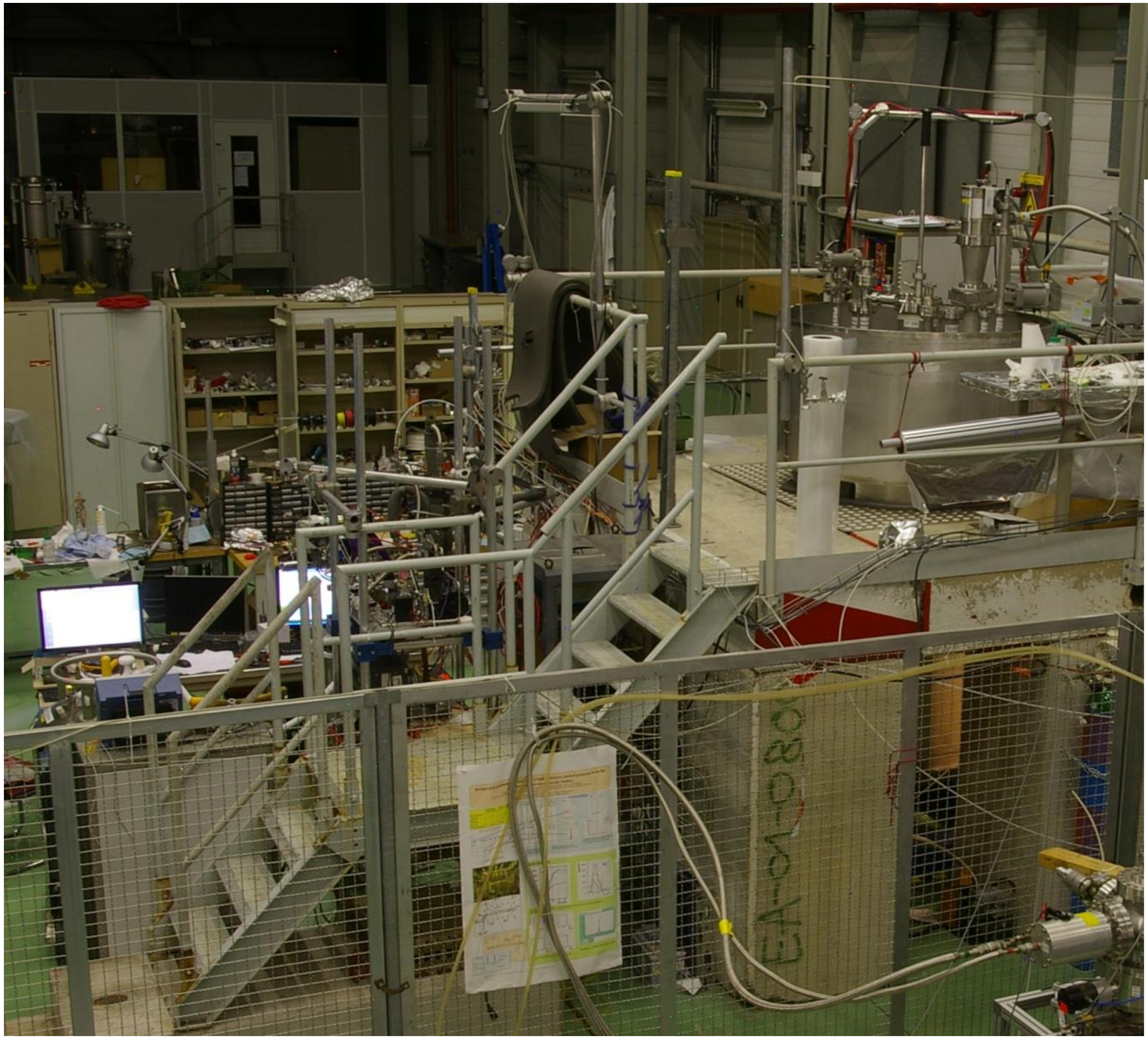
Low background photomultipliers

A. Rubbia, «ArDM: a ton-scale liquid Argon experiment for direct detection of Dark Matter in the Universe«, J. Phys.Conf.Ser.39:129-132, 2006



Detection principle

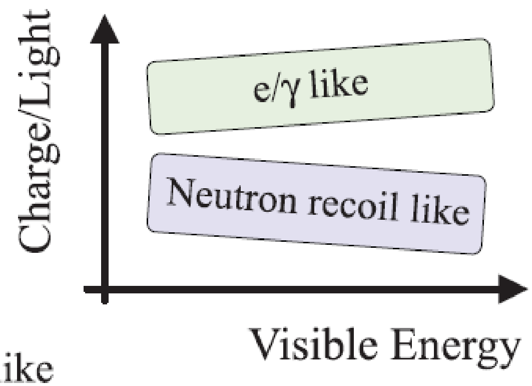
The ArDM Experiment

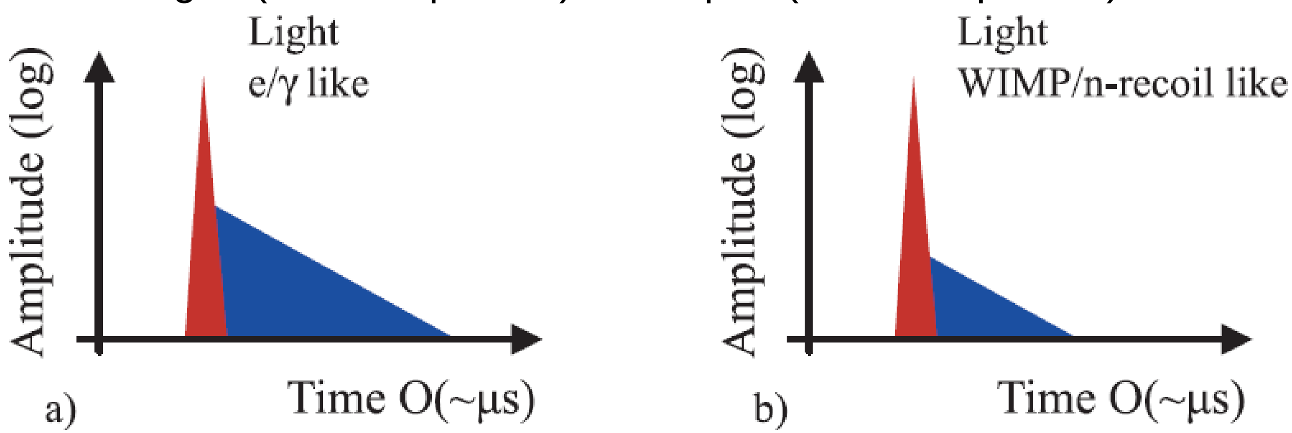


Background events

Electron and photon background:

- Originating from
  - U, Th and K contaminations of the detector material and the surrounding rock
  - Naturally occurring isotope ^{39}Ar is a β-emitter (Half-life T = 269 y; decay energy Q = 565 keV; event rate per ton Ar ~ 1 kHz)
    → Rejection of 10^8 needed for a WIMP-nucleon cross section of 10^{-44} cm^2
- Events are selected by
  - Charge/Light ratio
  - Ratio fast/slow component of the scintillation light:
    Two excited molecular levels emit scintillation light:
    singlet (fast component) and triplet (slow component)

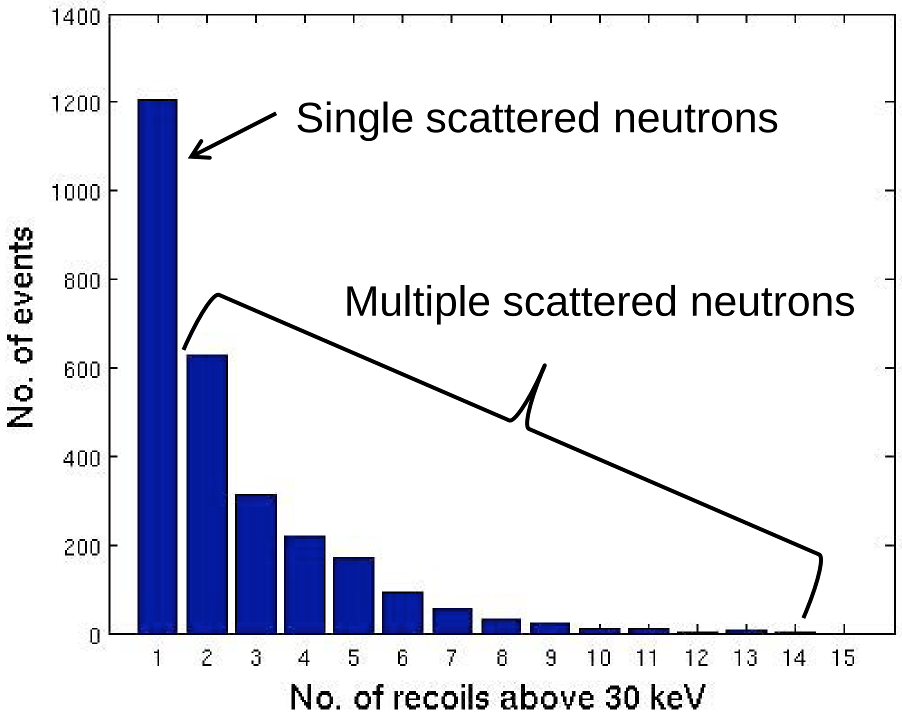




Background events

Neutron background originating from U and Th contaminations of the detector material:

- WIMP – Ar cross section is very low. → WIMP will not interact more than once. → Neutrons that scatter more than once can be rejected.
- MC studies:
  - More than 50% of the neutrons scatter more than once.
  - Less than 10% of the neutrons produce WIMP-like events. (single scattered, recoil energy ∈ [30,100] keV)



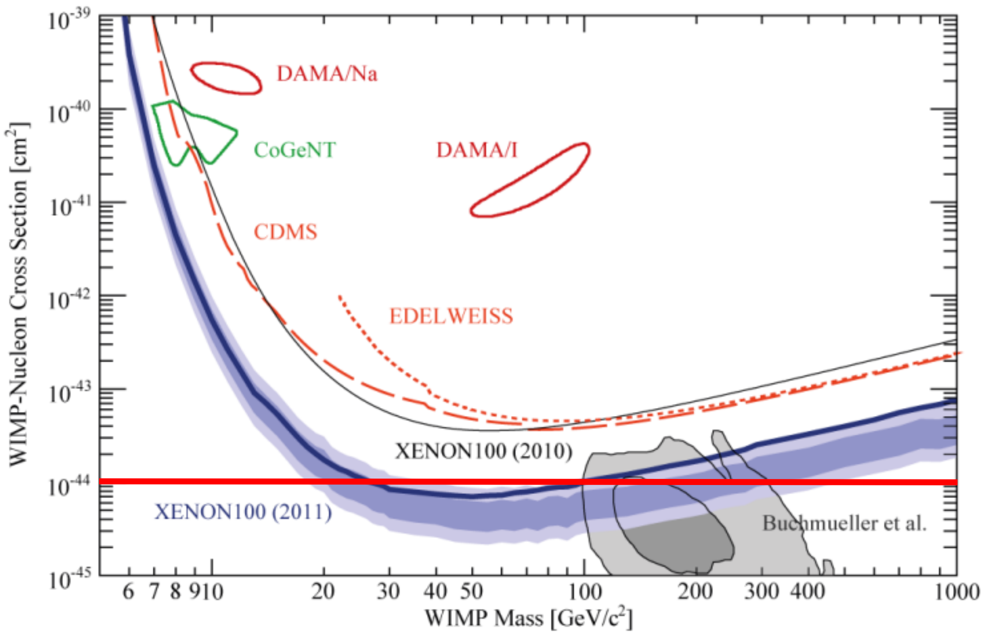
Neutrons from the surrounding rock:

- Neutron shield made of 50 cm thick PE blocks stops external neutrons

Expected background rates

Assumptions:

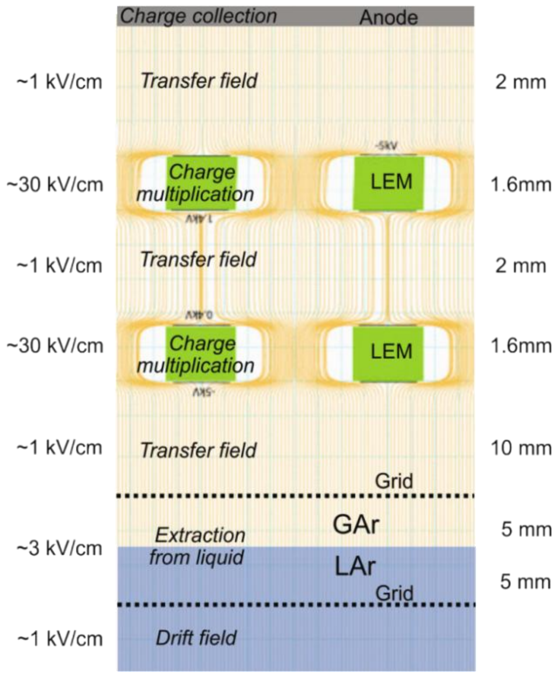
- 500 kg fiducial mass
- Background rejection for electron and photon background:
  - 10^3 from the charge/light ratio
  - 10^4 from the fast/slow component ratio (pulse shape discrimination)
- 50% efficiency of the selection of the WIMP signal
- Neutron shield is in place
- WIMP mass of 100 GeV
- WIMP-nucleon cross section of 10^{-44} cm^2
- Region of interest: Recoil energy 30 – 100 keV



E. Aprile et al. (XENON100), arXiv:1104.2549v1

^{39}Ar (evt/day)	gamma (evt/day)	neutrons (evt/day)	background (evt/day)	WIMP (evt/day)
$1.5*10^6$	47’500	0.07	0.22	0.25

Charge Readout: LEM (Large Electron Multiplier)



Principle of operation:

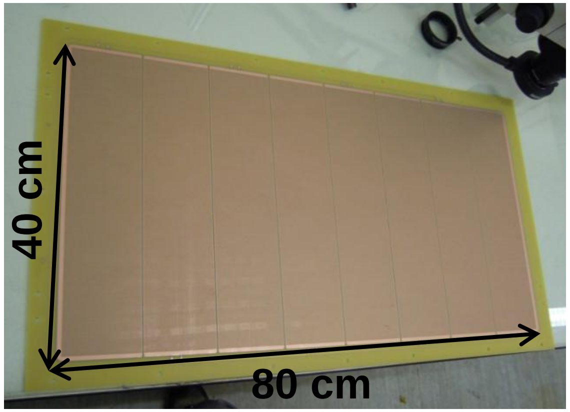
- Electrons drift up in the liquid and are extracted into the gas phase.
- Due to the high field strength in the holes of the LEM planes the electrons are multiplied. (Multiplication factor: $10^2 – 10^3$)
- The multiplied charge induces a signal in the anode.

- x- and y-position reconstruction possible due to segmentation of the anode
- z-position reconstruction using drift time of the electrons

LEM R&D has two main goals:

- Reaching high gain
- Manufacture large area LEMs (80 cm x 80 cm for ArDM)

Both goals are being addressed in parallel.

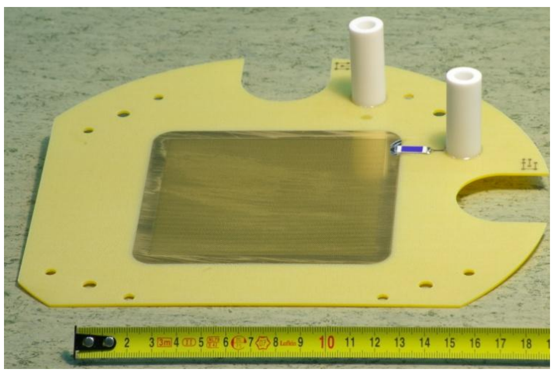


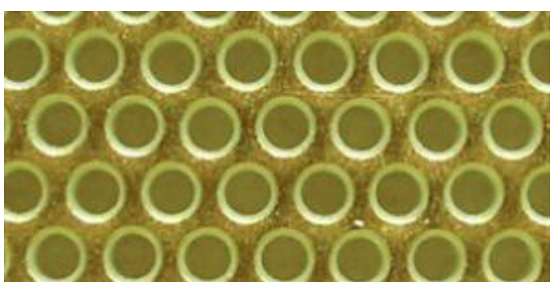
LEM of 40 cm x 80 cm produced by ELTOS S.p.A.

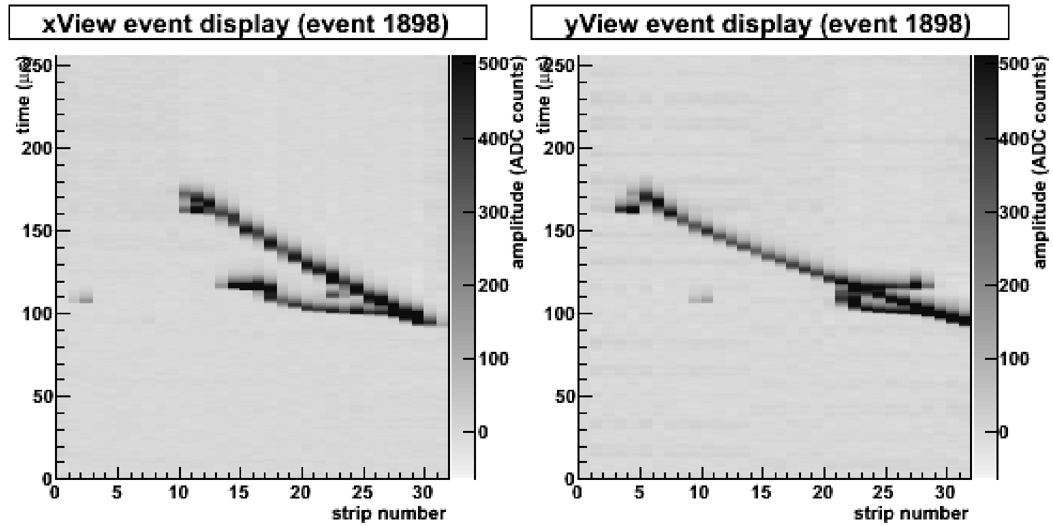
Charge Readout: LEM (Large Electron Multiplier)

Test setup 10 cm x 10 cm:

- Produced by standard PCB technique
- Hole diameter: 500 µm
- Hole pitch: 800 µm





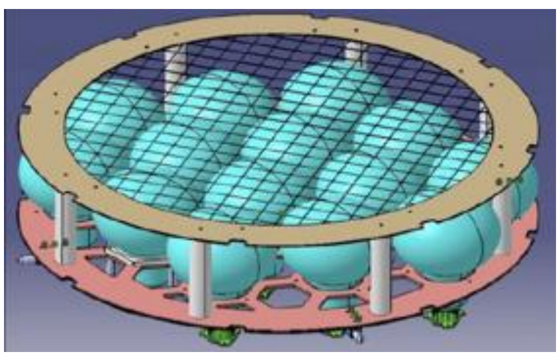


Track of a cosmic muon producing delta electrons in the test setup

Effective gain (collected charge/ionisation charge produced in LAr) **in the test setup**:

- Effective gain of ~ 30 has been reached with one LEM stage of 1 mm thickness.
- Double stage (2 x 1 mm LEM) will be tested soon. Effective gain of ~ $30^2 = 900$ is expected.

Light Readout



- Wavelength of the scintillation light: 128 nm
- PMTs are not sensitive in the VUV range

→ Wavelength shifter needed: TPB (Tetraphenyl butadiene): 128 nm → 430 nm

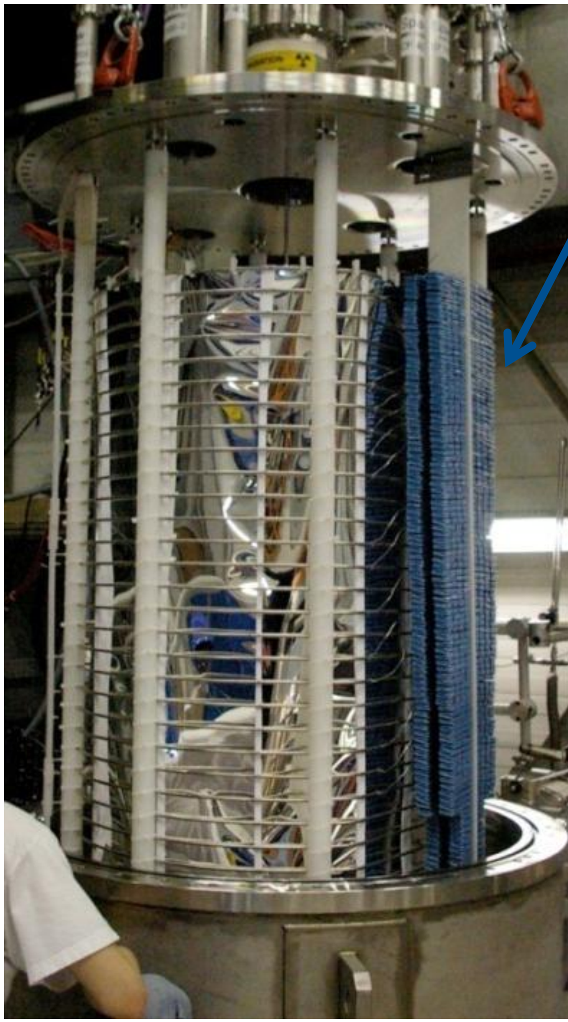
- PMTs coated with TPB in order to detect the direct light
- Reflector foil around the fiducial volume coated with TPB in order to shift indirect light

Reflector foil under UV illumination

14 x 8 inch cryogenic low radioactivity PMT (Hamamatsu R5912) located at the bottom of the detector

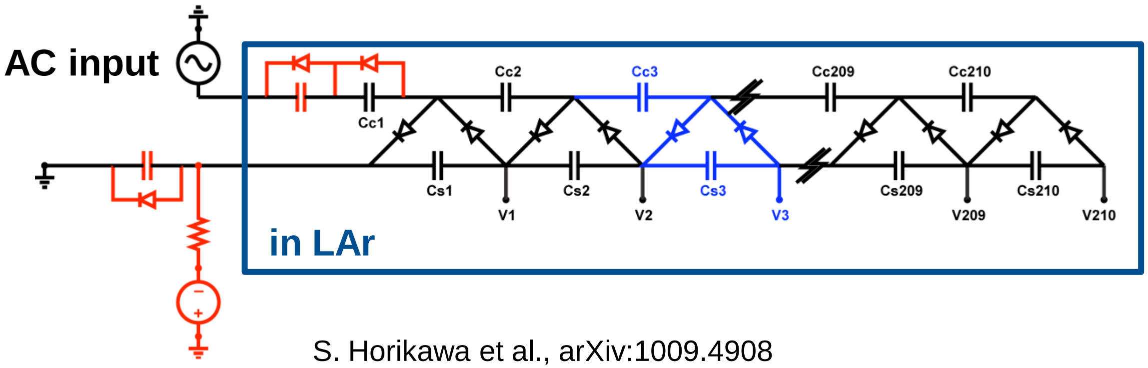
In order to improve the light yield new 3 inch high QE, low background cryogenic PMTs (Hamamatsu R11065) are currently tested at CERN.

High Voltage Generator



Greinacher (Cockcroft-Walton) circuit

- 210 stages (1520 capacitors, 1260 diodes) immersed in liquid argon
- 30 field shapers with 4 cm spacing
- Good drift field linearity
- Alternating current input (50 Hz, maximum V_{pp} ~ 2.5 kV)
- Up to 400 kV (3 kV/cm) at cathode possible
- Operated up to 70 kV (0.6 kV/cm) in stable conditions in liquid argon for the first time in September 2010



S. Horikawa et al., arXiv:1009.4908

ArDM Control System

- Control system ensures safe operation of the ArDM experiment by:
  - Monitoring the condition of the ArDM detector
  - Regulation of the vacuum system and the cryogenics system
  - Safety monitor (fire detector, oxygen monitor)

- ArDM control system is based on a PLC (Programmable Logic Controller):
  - Computer designed for process automation
  - Facility for extensive input/output arrangements for sensors and actuators
  - High reliability due to specialised hard- and software

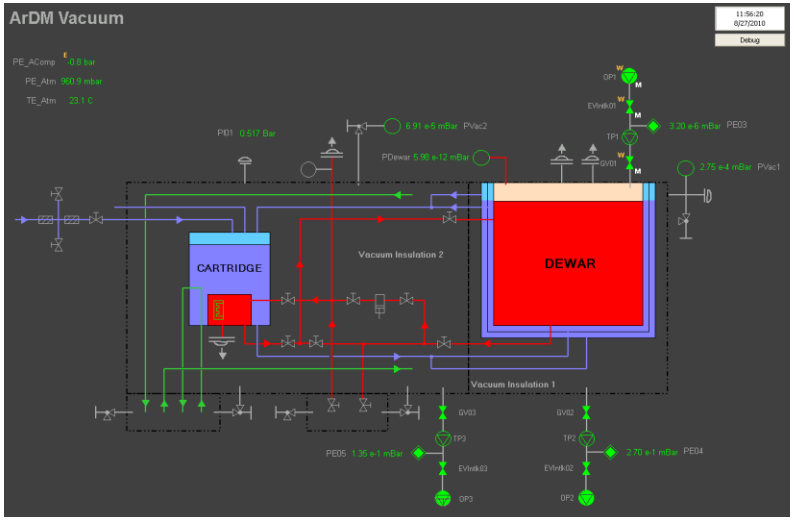
  → ArDM control system serves as a safety system

- PLC for ArDM was installed in collaboration with the CERN PH-DT-DI group

PLC modules for ArDM (Schneider Electric Modicon Premium)

ArDM Control System

- PLC communicates with a supervisory computer by Ethernet
- Process visualisation software (PVSS):
  - Human-machine interface
  - Visualisation of the vacuum and cryogenic system
  - Historical viewing of data

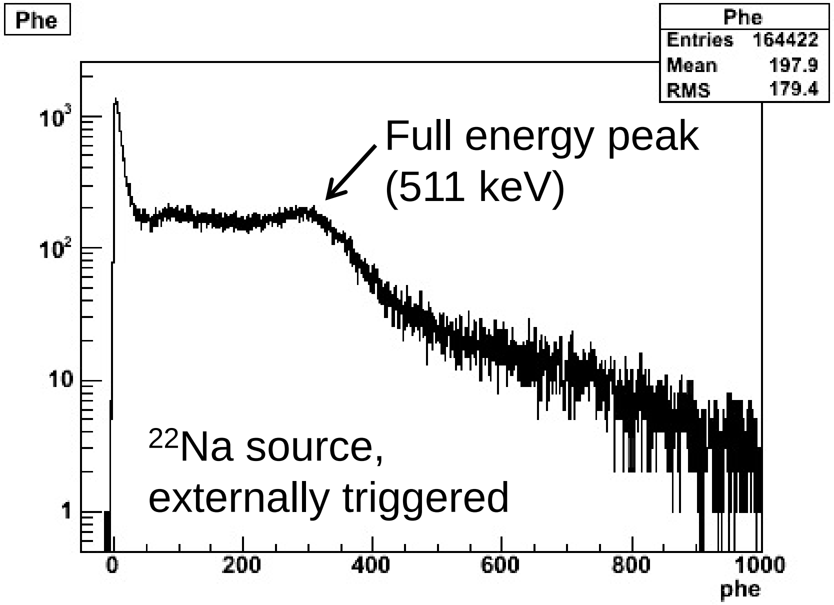


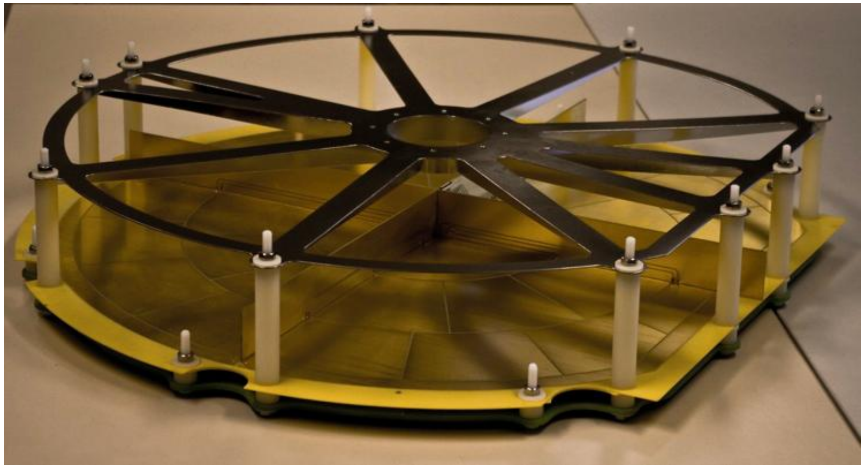
- PLC based control system is installed in 7 racks together with the DAQ and the HV supply
- Control system has been tested successfully in two runs in September 2010 and March-April 2011

Cool Down Test in September 2010

Main goals of the cool down test in September 2010:

- Operate the light readout configuration with 14 PMTs
- First test of drift and charge extraction from liquid to gas phase with a temporary charge readout system
- Run ArDM with the PLC
- Collect several TB of data with external sources (^{22}Na, AmBe)



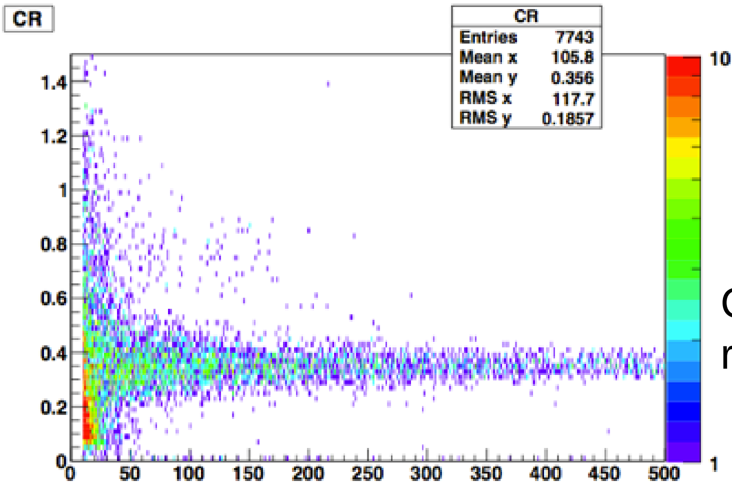


Temporary charge readout system:

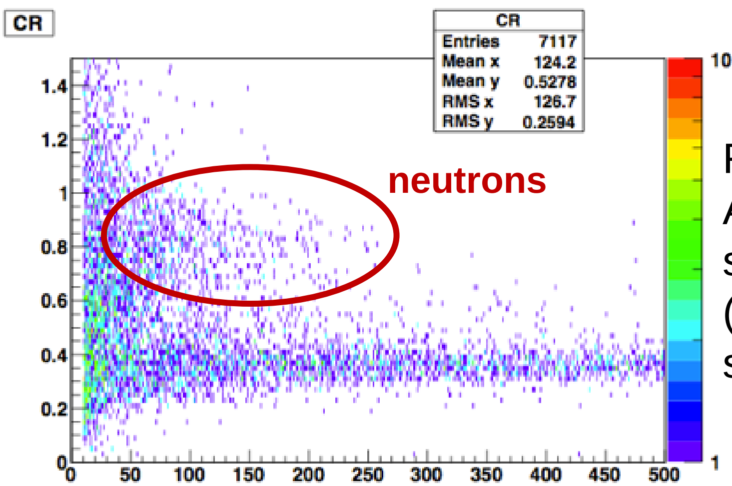
- Anode (32 channels) and 2 extraction grids
- No charge multiplication yet!
- Diameter: 80 cm
- Can be adjusted to the liquid level by 3 capacitive level meters

Cool Down Test in September 2010

Particle identification by pulse shape discrimination

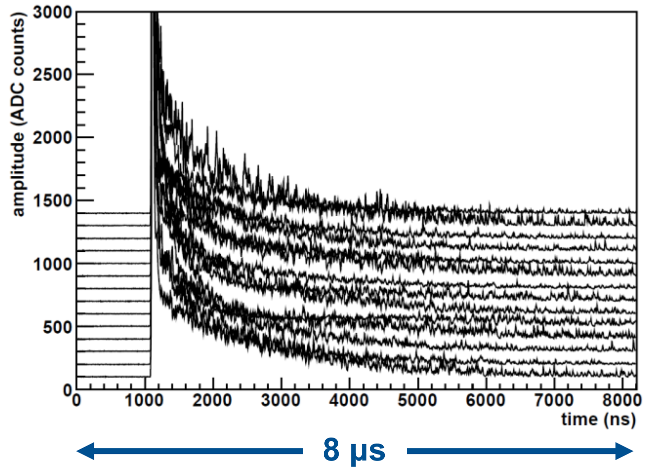


Control run

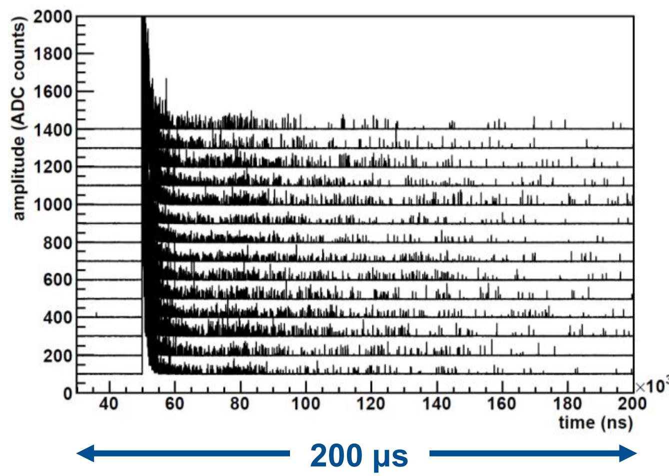


Run with AmBe source (neutron source)

Traces from the 14 PMTs



Without charge extraction

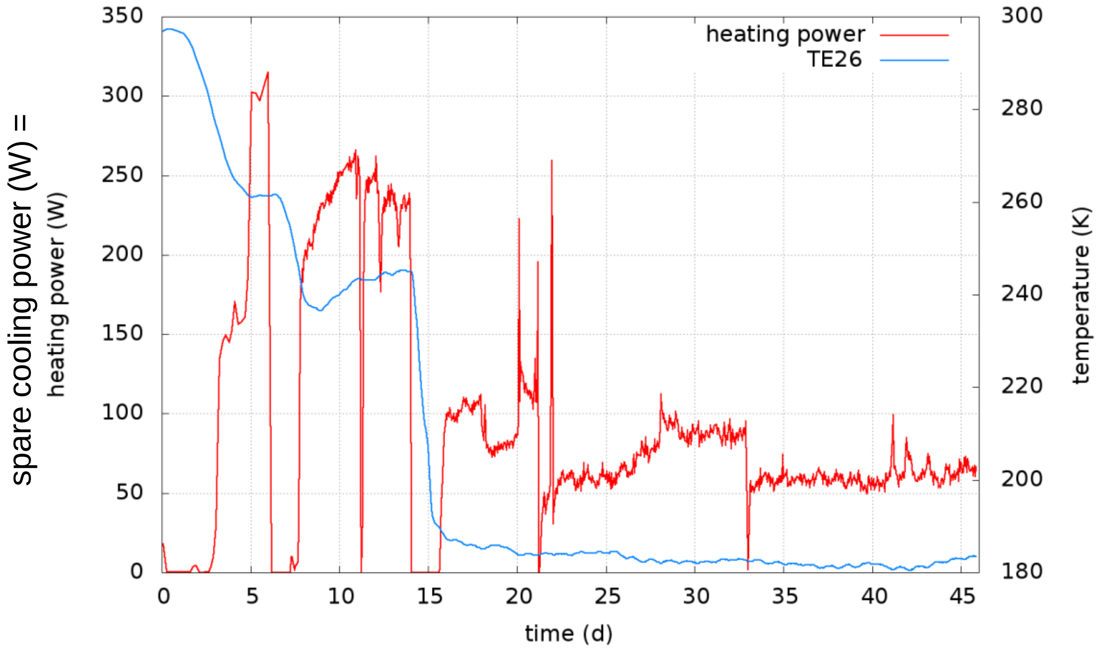


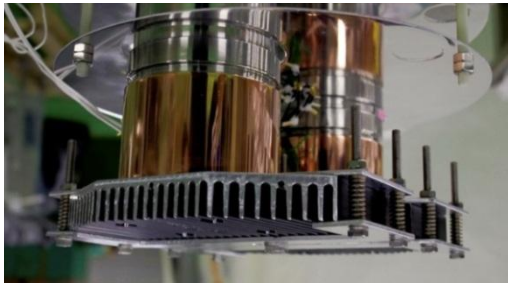
With charge extraction: S1/S2 signal (from muon crossing the detector)

Upgrade of the Cryogenic System with Cryocoolers

Upgrade of the cooling system to a zero loss system:

- 2 cryocoolers (Cryomech AL300) with totally 600 W of cooling power at LAr temperature
- Cooling power regulated by the PLC using a PID controller
- Pressure variations in the gas phase of the detector < 5 mbar
- The system has been operated successfully for more than 45 days.



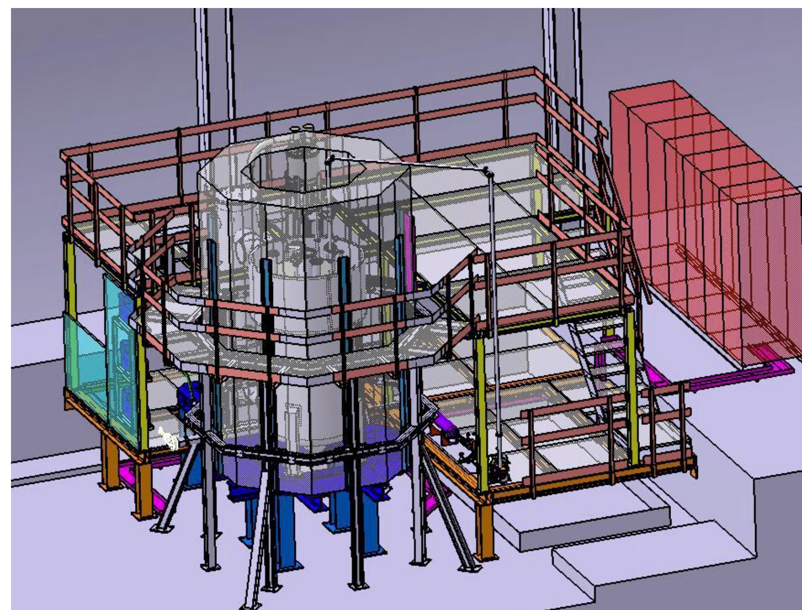


Cold heads for recondensing argon

Recondenser unit

Canfranc Underground Laboratory (LSC)

- Location: Somport tunnel in the Pyrenees
- 850 m below „El Tobazo“:
  - 2500 meters water equivalent of shielding from cosmic rays
  - μ flux ≈ $2*10^{-7}$ μ/cm^2/s
- Low background environment
- ArDM has been approved by LSC for a period of four years starting 2011.
- ArDM will be transferred to LSC by the end of 2011.



Summary & Outlook

- The ArDM experiment has been commissioned successfully at CERN.
  - The light readout configuration with 14 PMTs was operated successfully.
  - The Greinacher high voltage generator was operated up to 70 kV.
  - The charge extraction from the liquid to the gas phase was demonstrated.
  - The cooling system has been upgraded to a zero loss system.
  - The PLC has been tested successfully during two runs.

- R&D for the final charge readout is in progress and shows good results. The new 40 cm x 80 cm LEM will be tested in September 2011.

- The ArDM experiment will be transferred to the Canfranc underground laboratory by the end of 2011.

- A first run underground including a measurement of the ^{39}Ar background is planned for the beginning of 2012.