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The ArDM a ton-scale liquid argon experiment for direct dark matter detection

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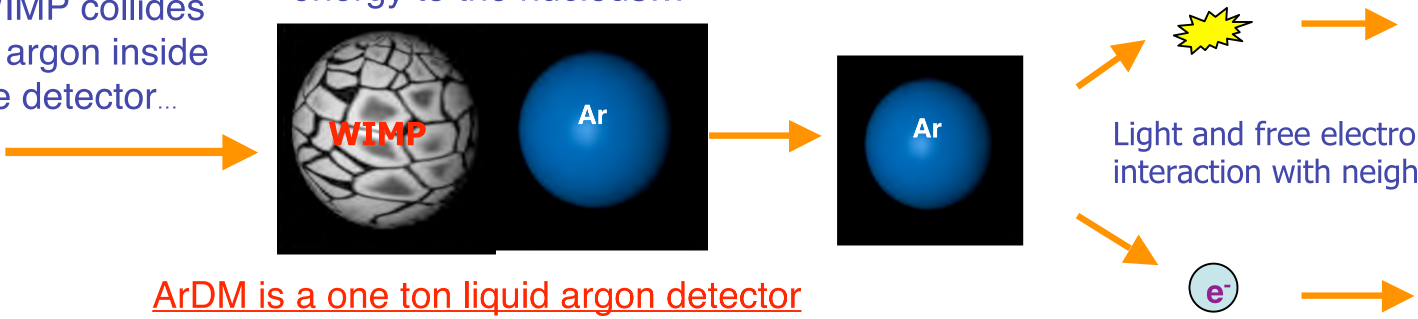
ArDM WIMP detection mechanism

WIMP-Argon elastic scattering



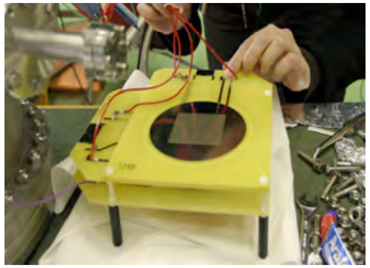
A WIMP collides with argon inside the detector…

…transmitting its kinetic energy to the nucleus…

The light is „seen" by photomultipliers

Light and free electrons are produced from interaction with neighbouring argon atoms

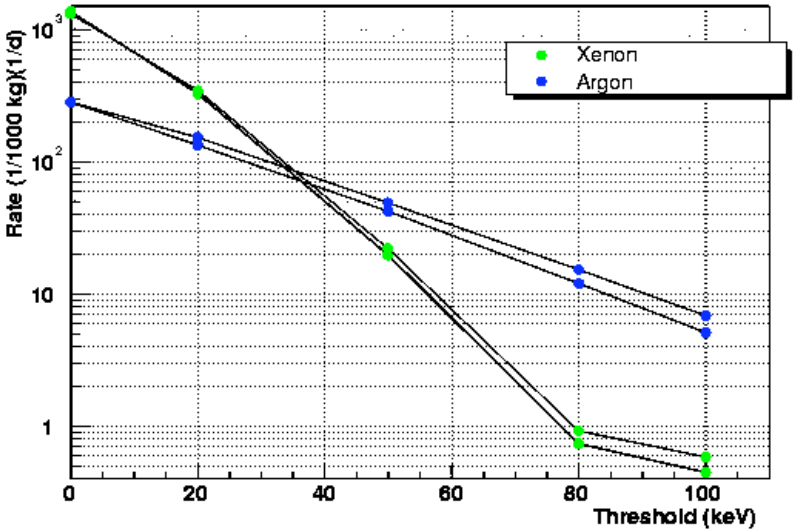
The electrons are „seen" by electron multipliers



ArDM is a one ton liquid argon detector designed to measure ionization charge with a good spacial resolution and scintillation light.

Assumptions for simulation:

- **Cross-section normalized to nucleon**
  - → $\sigma = 10^{-42}$ cm^2 $=10^{-6}$ pb
  - → M_{WIMP} = 100 GeV
- **Halo Model**
  - → WIMP Density = 0.5 GeV/cm^3
  - → v_{esc} = 600 km/s
- **Interaction**
  - → Spin independent
  - → Engel Form factor



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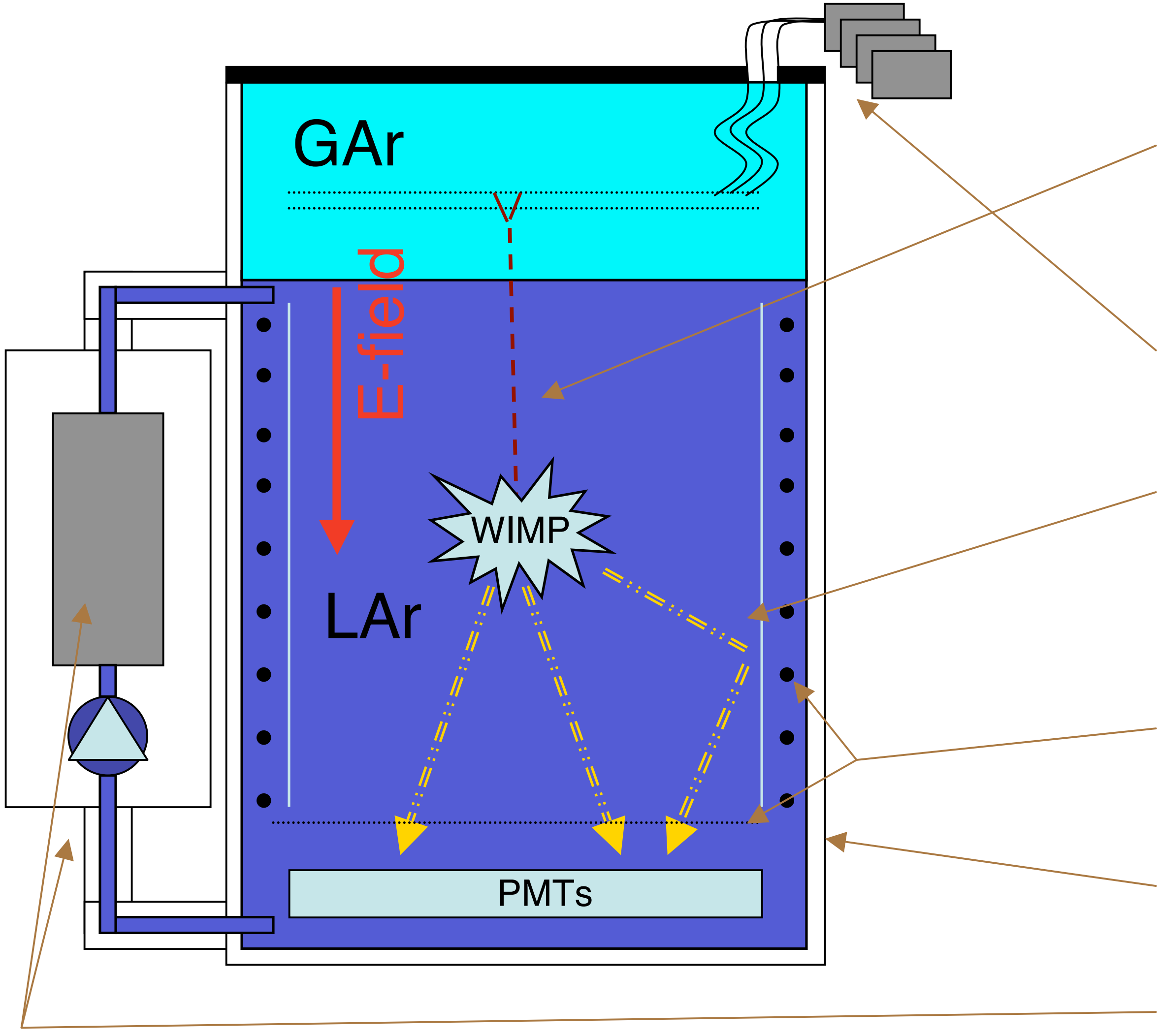
ArDM bi-phase detection principle



Ar nucleus recoils: light + charge

Charge drifts in the E-field, is extracted from the LAr surface into GAr and amplified in the Large Electron Multiplier (LEM).

The LEM is segmented. The induced charge is amplified and digitized.

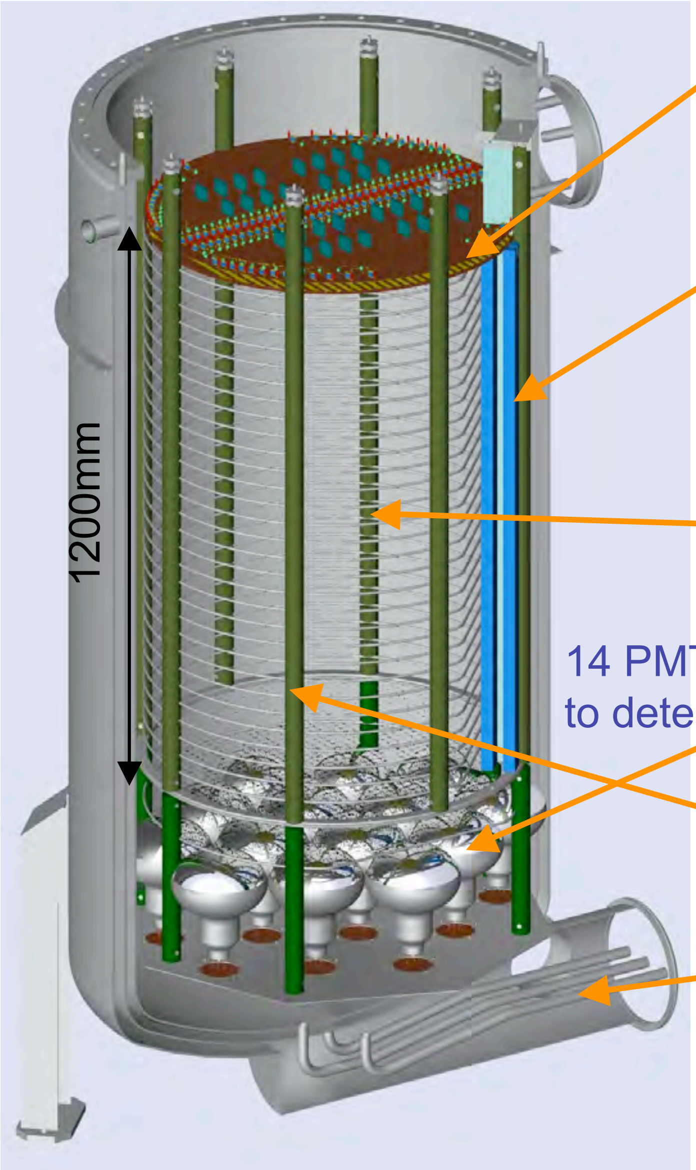
The scintillation light (128nm) is converted by a wavelength shifter on the lateral reflector and on the surface of the PMTs.

Field shaping rings, cathode and immersed HV multiplier provide a uniform E-field.

Vacuum insulated dewar.

Purification: LAr pump + cartridge.

Detector Layout



Two-stage LEM.
800mm diameter

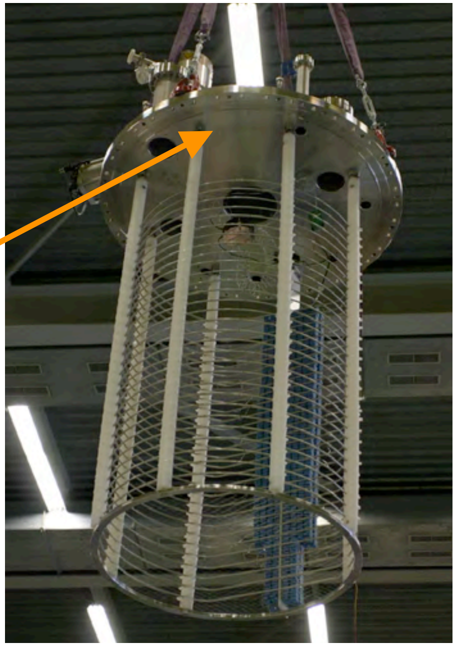
Greinacher chain:
supplies the right
voltages to
the field shaping rings
and the cathode

Field shaping
rings

14 PMTs below the cathode
to detect the scintillation light.

Support
pillars

Input/output
of the recirculation
system



Detector inner
part with the upper
flange

ArDM
Dewar

Summary of the detector parameters

Detector	
Max. drift length	120 cm
Target mass	850 kg
High voltage	
Drift field	1-5 kV/cm
Charge readout	
LEM gain	10^4 per e^-
Light readout	
Global collection efficiency	3%

Charge Read-Out System: Large Electron Multiplier (LEM)

GEM: Ref. F.Sauli, NIM A, 1997, vol. 386, p.351
THGEM: Ref. Chechik.R., Breskin,A., Shalem,C.,Mormann,D., NIM A, 2004, vol. 535, p.303

LEM is a thick macroscopic GEM

Diameter of the hole: 500 microns.

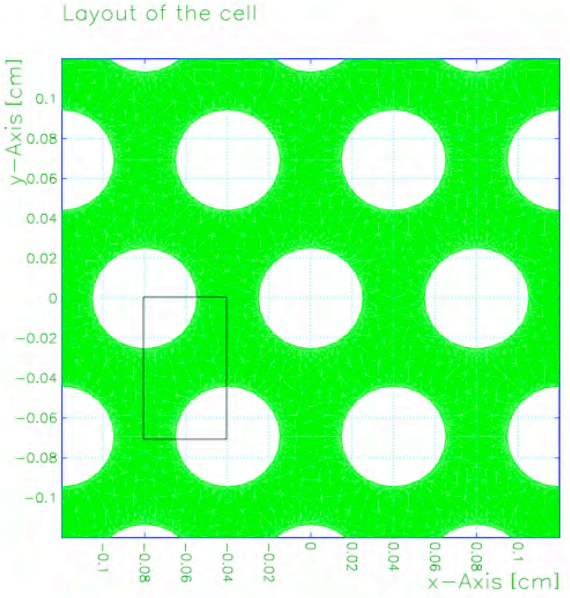
Distance between two holes: 800 microns.

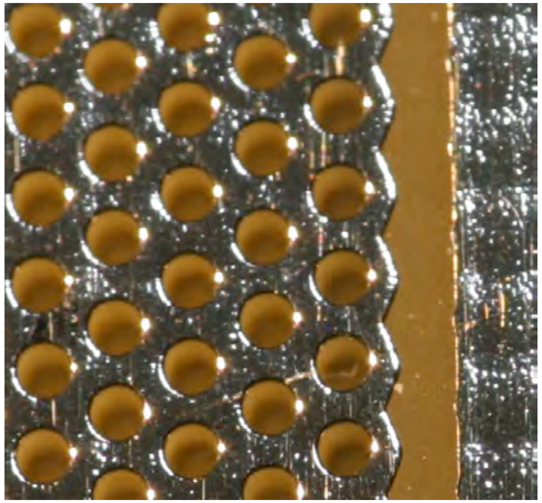
LEM thickness: 1.5mm.

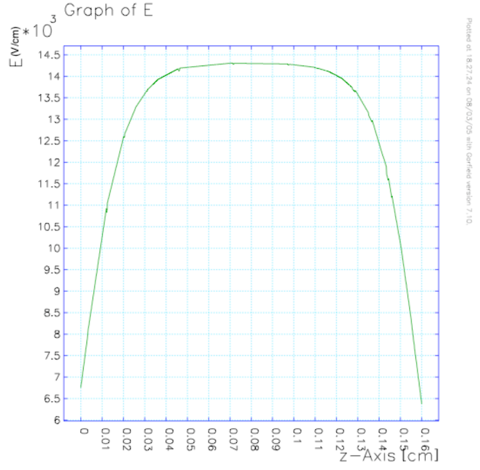
For HV supply both surfaces are covered with copper electrodes.

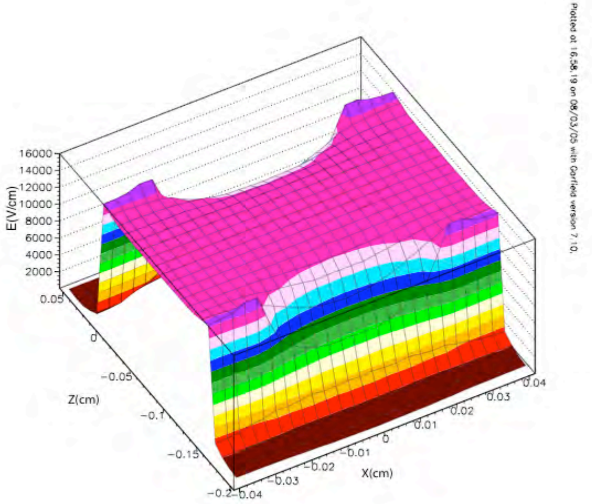
LEM is manufactured on standard PCB technique. The holes are produced by drilling.
Copper electrodes are covered with palladium layer in order to avoid oxidization.

Thickness of the electrodes is 35 microns.









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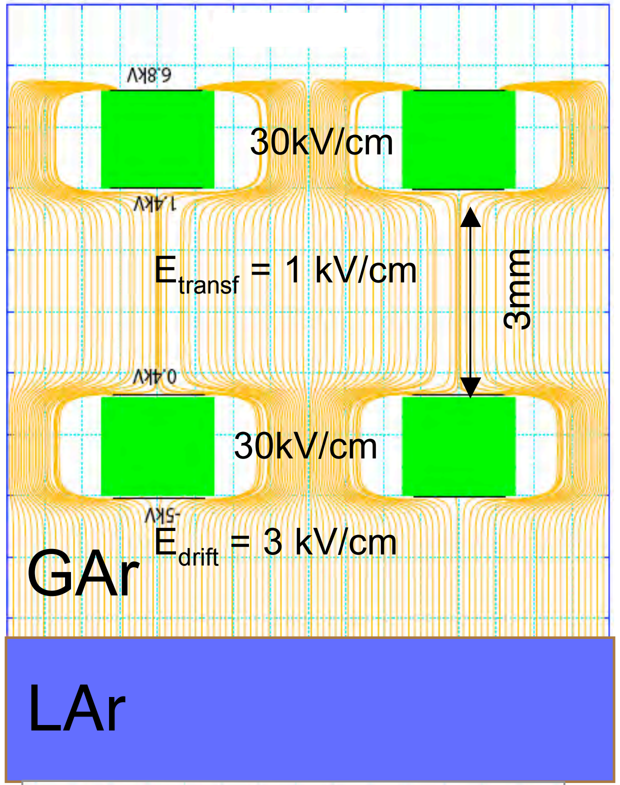
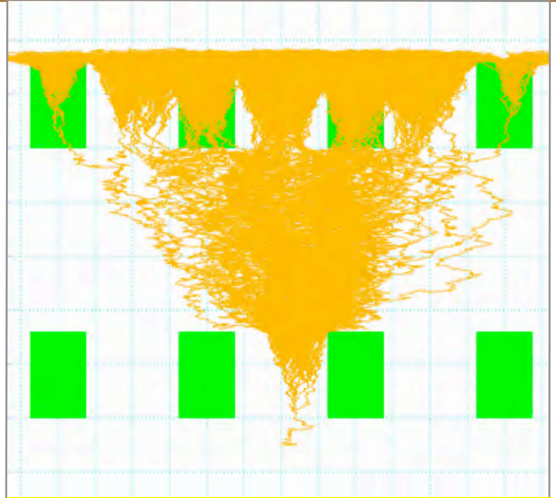
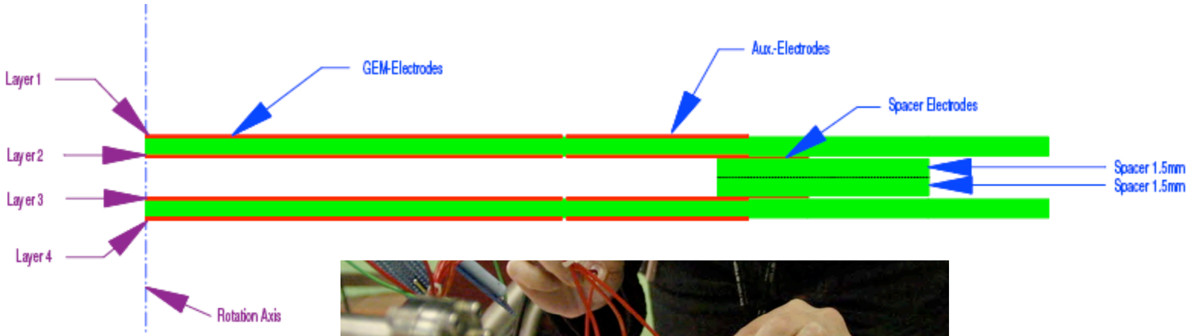
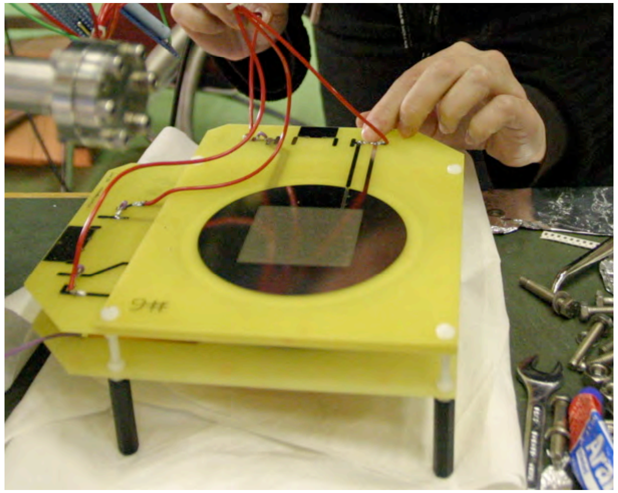
Double-stage LEM system



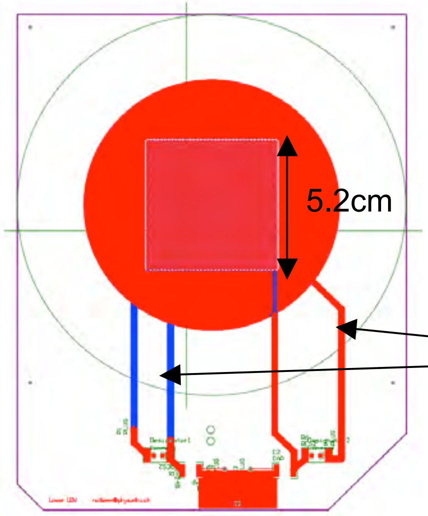


Simulation of avalanche

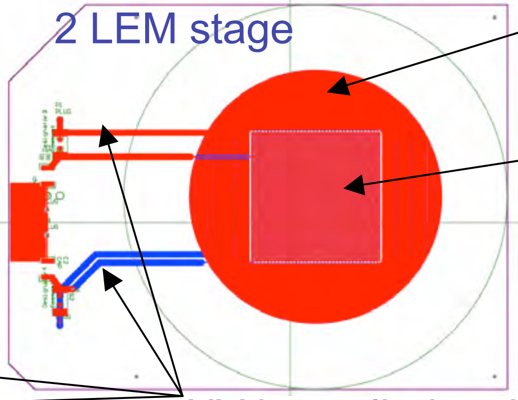




1 LEM stage



2 LEM stage



Guarding electrode.

Working area

HV is applied to these strips

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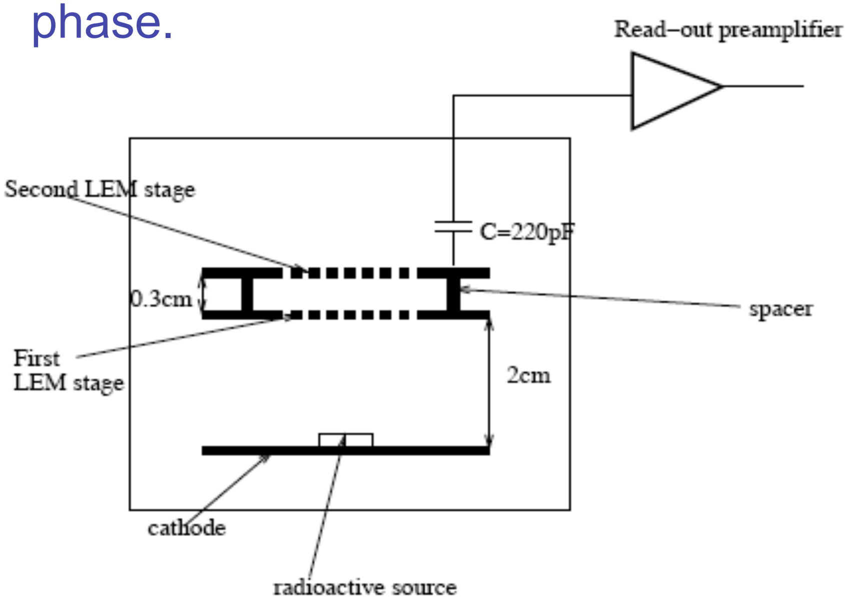
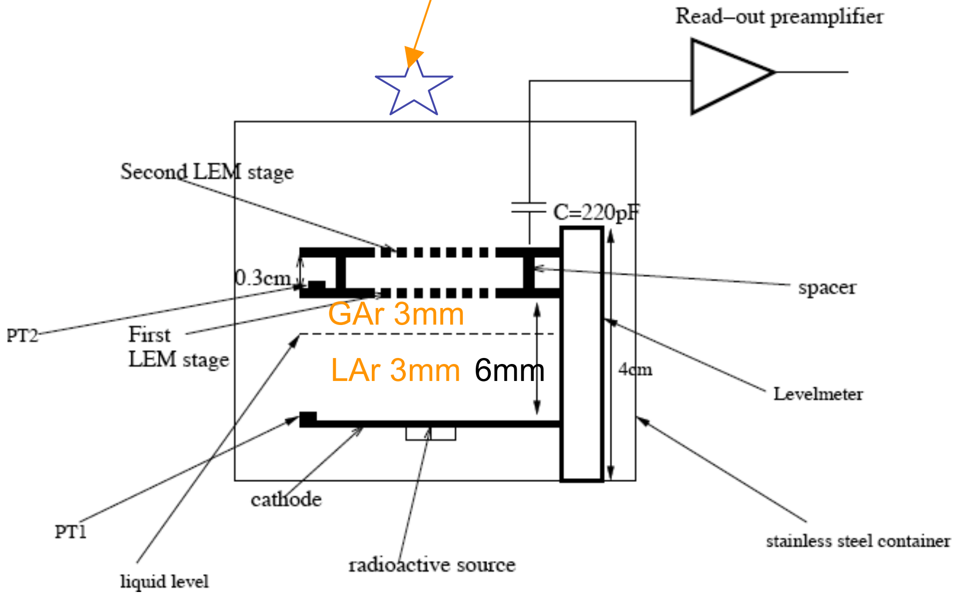
Experimental setups

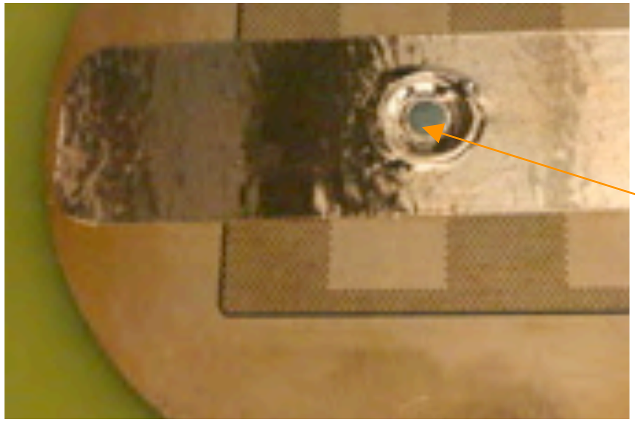
Setup for measurements in single gas phase.



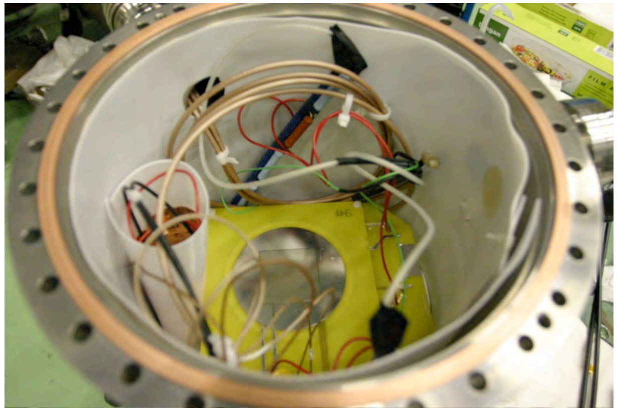
External radioactive sources,
Cs^{137} 662keV 240kBq.
Co^{60} 1.17,1.33MeV 4.85kBq



Setup for measurements in double phase

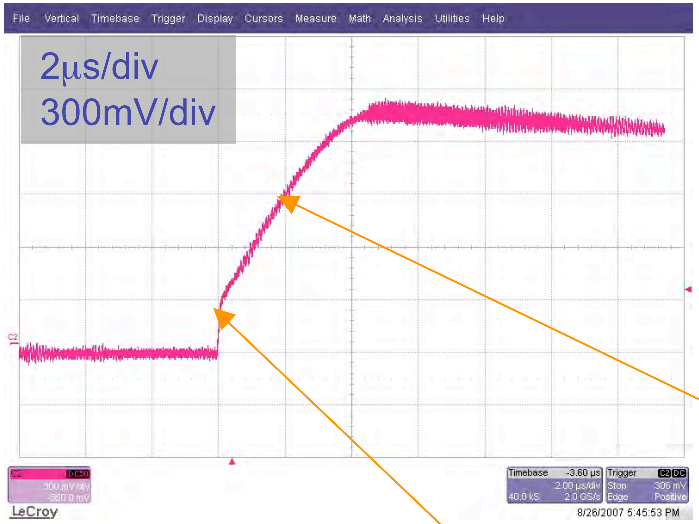


Internal r/a source
Fe^{55},5.9keV,
12kBq



Signal shapes

Signals have different shapes in pure Ar and in 90% Ar 10% CO_2 mixture. These signals were measured at room temperature and at atmospheric pressure.

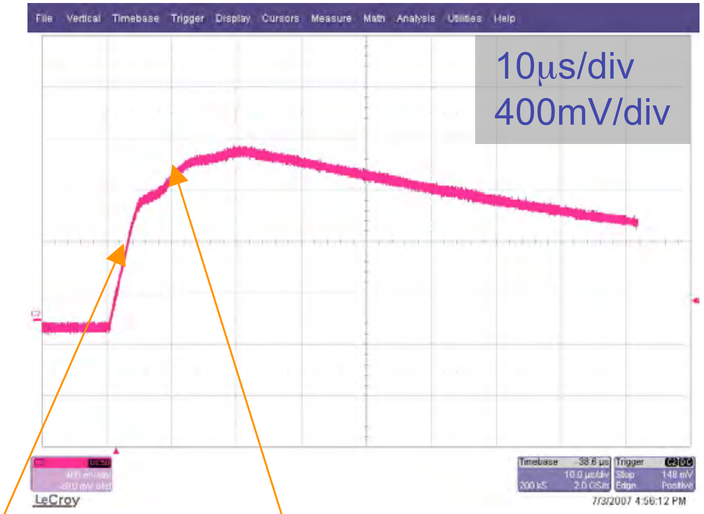


Ion- induced signal (5μs)

Electron- induced O(100ns) signal

Signal shape in $ArCO_2$ mixture
risetime is about 5μs.

The signal risetime has only one ion-induced component.
photons are absorbed by CO_2.

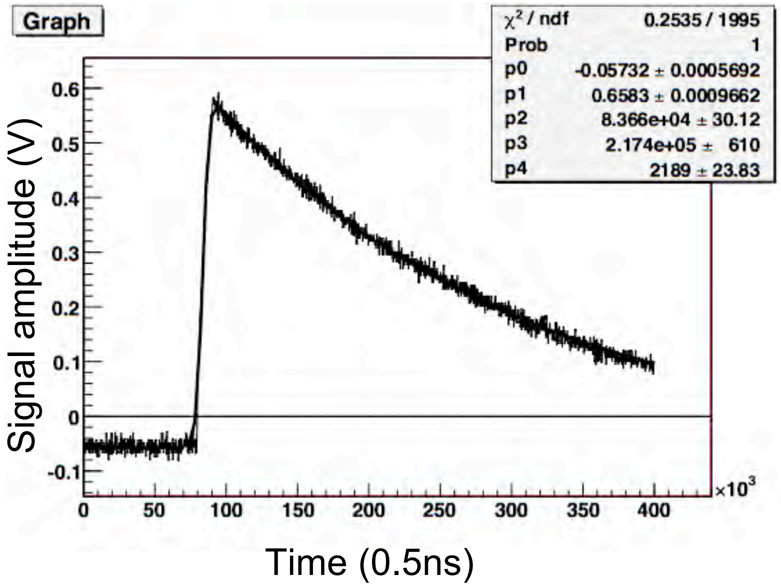


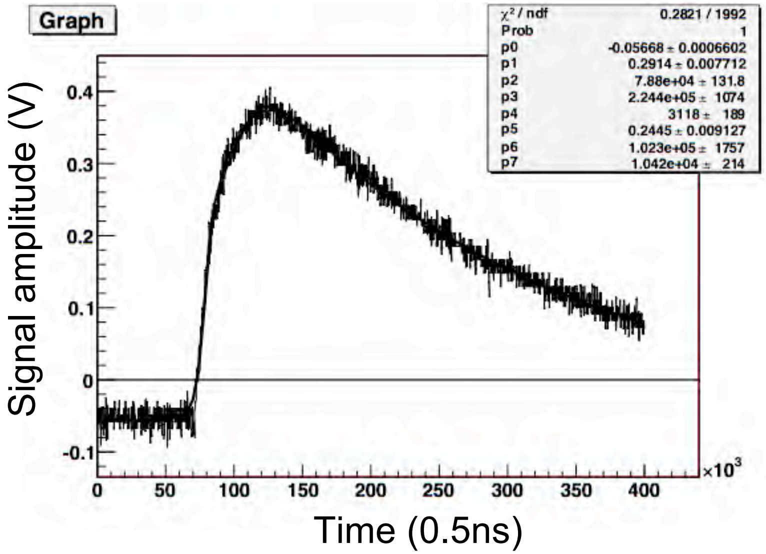
Signal shape in pure Ar.
Risetime is about 20μs.
2 components of the risetime are visible.

Fast ion-induced component, coming from development of a primary avalanche (5μs)

Slow ion-induced components, coming from development of a secondary photo-avalanche. (O(15-20μs)).

Signal fit functions.





$$f(t) = B + A\frac{e^{\frac{-(t-t_0)}{\tau_1}}}{1+e^{\frac{-(t-t_0)}{\tau_2}}}$$

$$f_1(t) = B + A\frac{e^{\frac{-(t-t_0)}{\tau_1}}}{1+e^{\frac{-(t-t_0)}{\tau_2}}} + C\frac{e^{\frac{-(t-t_0^{/})}{\tau_1}}}{1+e^{\frac{-(t-t_0^{/})}{\tau_2^{/}}}}$$

B -baseline;

t_0 -point for which the height of the function with respect to the baseline is equal to $A/2$;

A -related to the amplitude of the fast component;

τ_1 τ_2 -are related to risetime of a fast component and a falltime respectively;

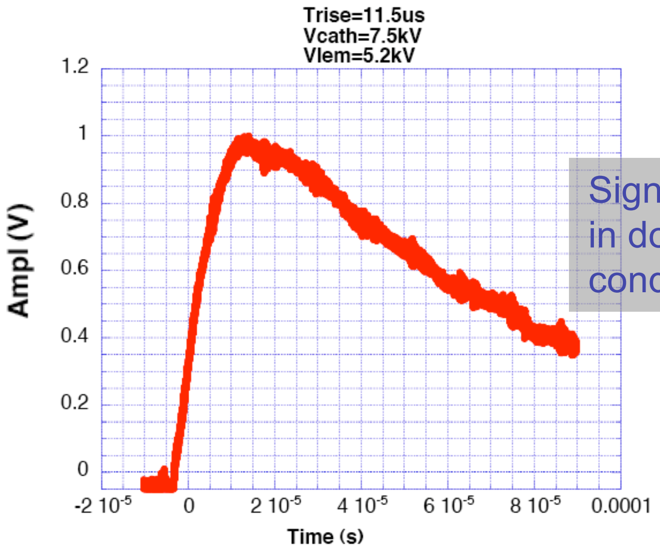
C -related to the amplitude of the slow component;

$t_0^{/}$ -point for which the height of the function with respect to the baseline is equal to $C/2$;

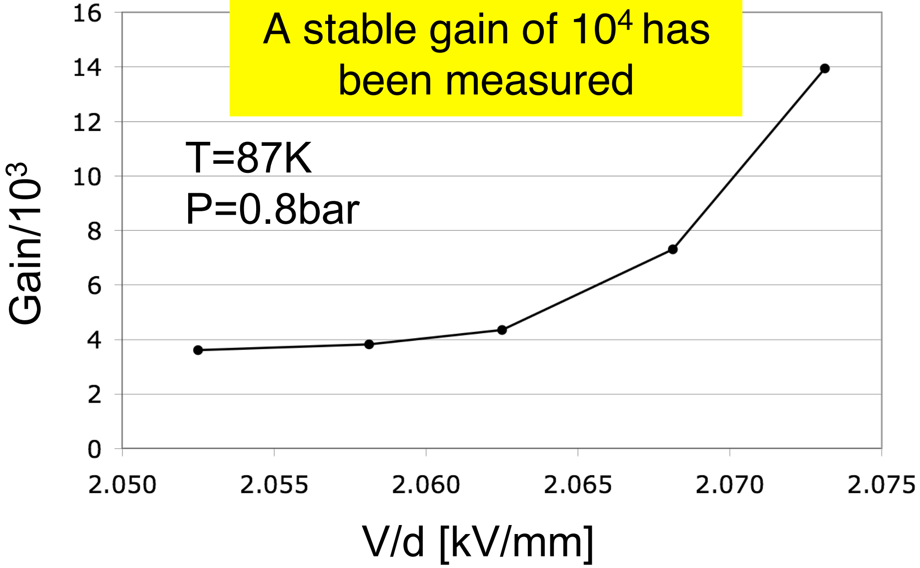
$\tau_2^{/}$ -is related to the risetime of a slow component.

Tests at cryogenic temperatures and double phase conditions.

A stable gain of 10^4 was obtained in the gas phase at cryogenic temperatures. Curve was obtained with Fe^{55} Internal r/a source.

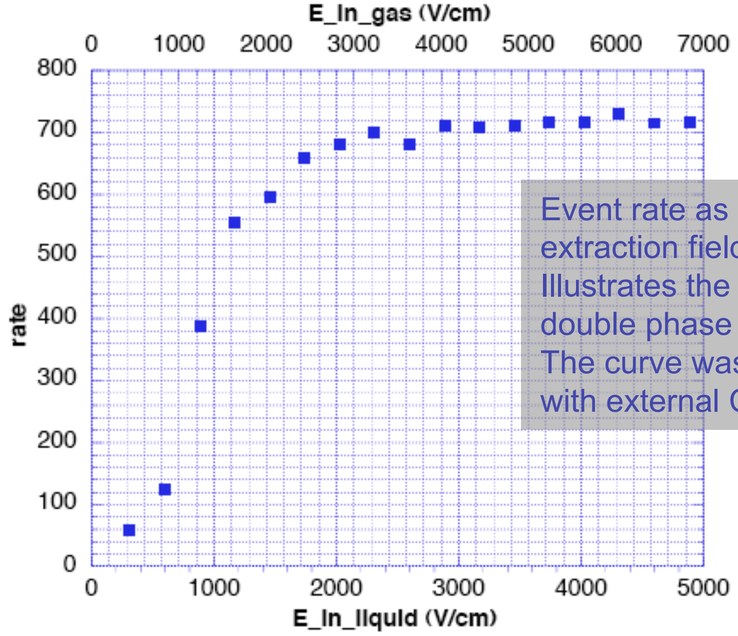


Signal shape in double phase conditions

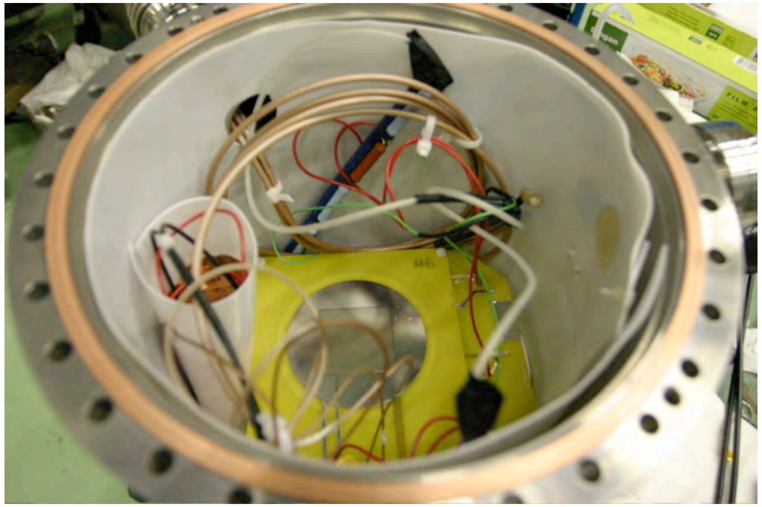


A stable gain of 10^4 has been measured

Liquid level~3mm
Vlem=5233V



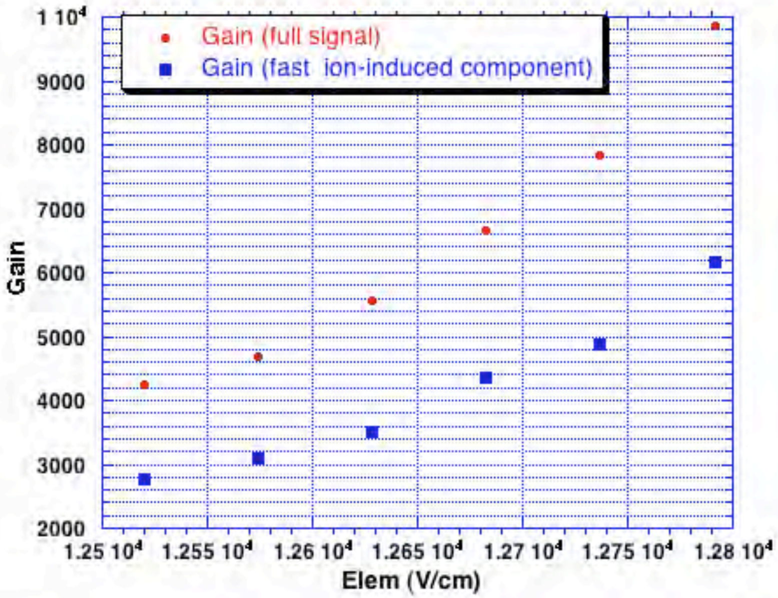
Event rate as function of extraction field.
Illustrates the operation in double phase conditions.
The curve was obtained with external Co^{60} r/a source.

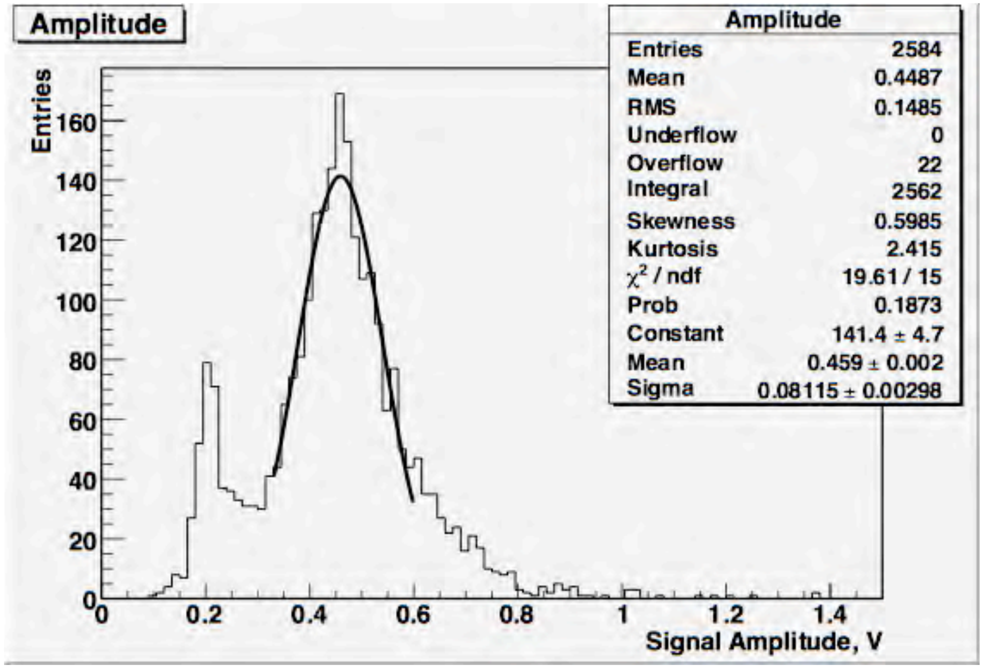


Gain estimation and signal amplitude distribution.

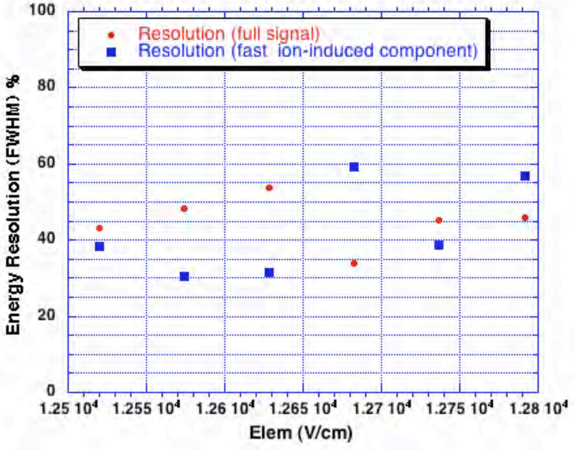
Resolution (FWHM)=42.5%

Gain





Resolution



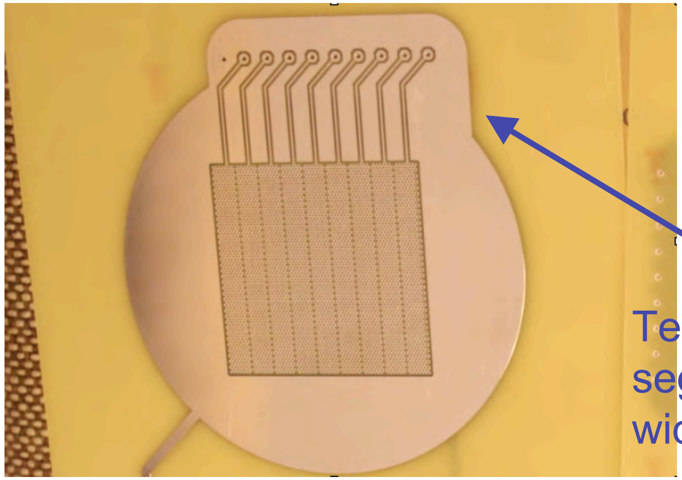
Conditions:

V_{lem} =1.9kV
V_{cath}=2.5kV
Electric field:
E=12.6kV/cm
Drift field:
E_d=0.53kV/cm

Amplitude distribution was obtained with pure Ar gas at atmospheric pressure and room temperature.
R/a source:Fe^{55}, 5.9keV.The source was collimated to the diameter of 1mm In order to decrease the event rate.

Source Rate: 240Hz.

Segmented LEM

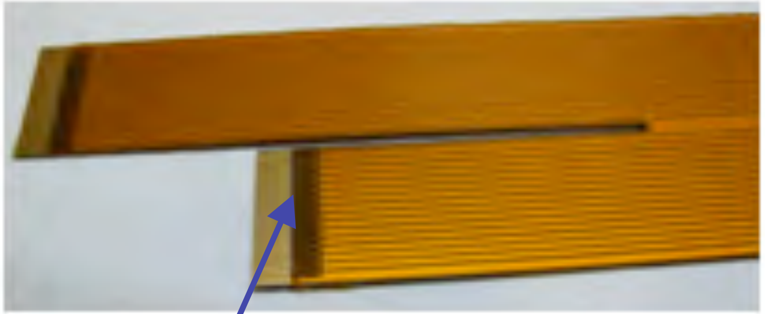


Test prototype of a segmented LEM. Strip width: 6mm

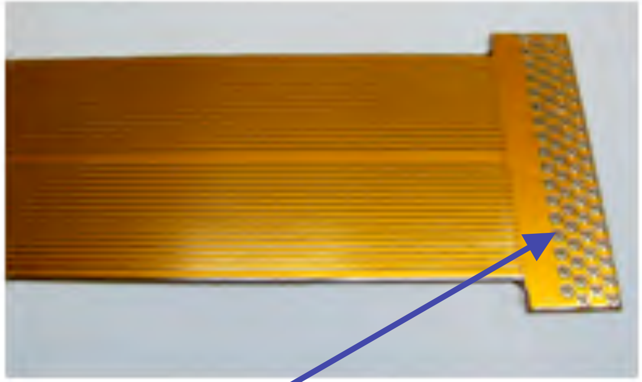
Final LEM charge readout system will be segmented.

Electrodes on both sides are striped.
Strips are perpendicular to each other.

Final number of channels: 1024
Strip width: 1.5mm



to ZIF connector on the LEM board

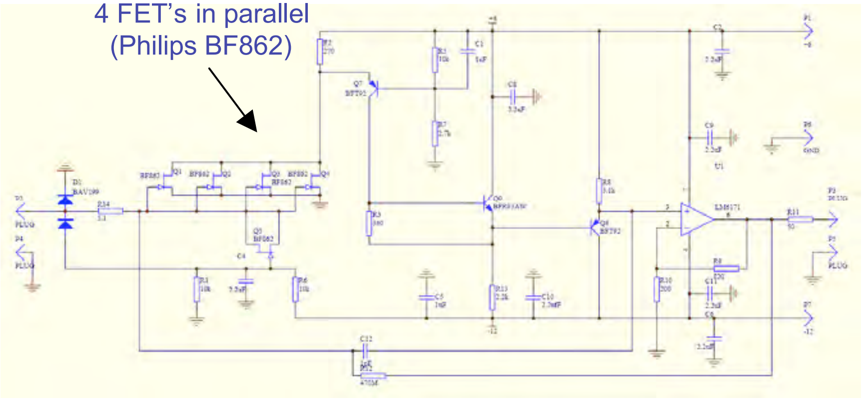


To the preamplifiers

Cables are going through a slot in a UHV flange. The slot is sealed with epoxy resin.

Readout Electronics

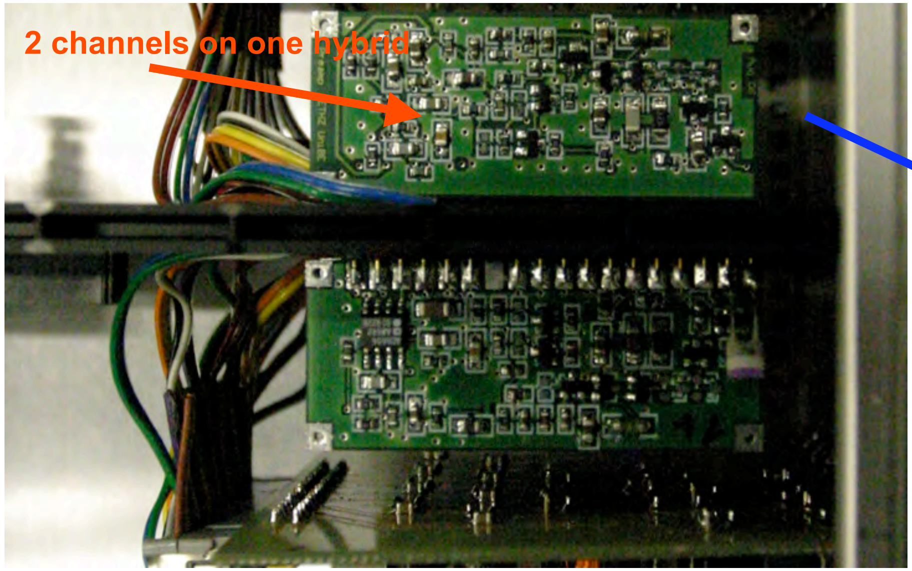
Low noise charge preamp inspired from C. Boiano et al. IEEE Trans. Nucl. Sci. 52(2004)1931

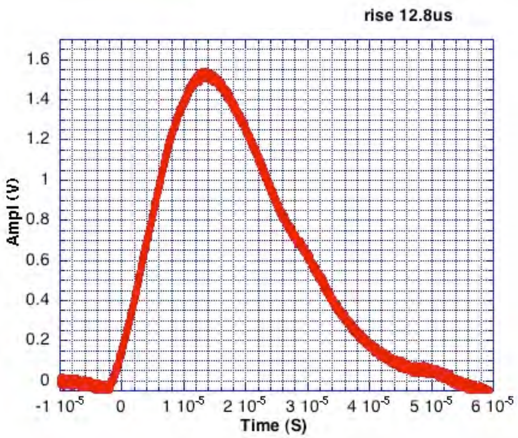


Developing A/D conversion and DAQ system:
MHz serial ADC + FPGA + dual memory buffer + ARM microprocessor

Industrial version being developed with CAEN

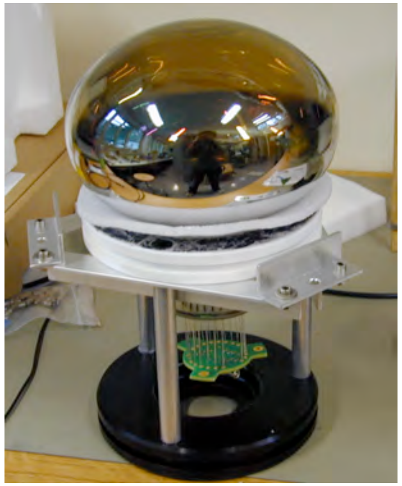
Custom-made front-end charge preamp + shaper
G~ 15mV/fC





Signal from double-phase setup

Light readout

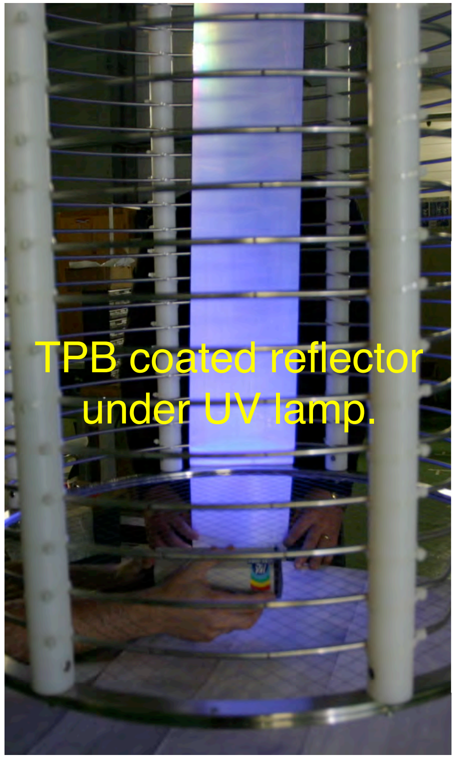


14 low background
photomultiplier tubes
cover the bottom of the detector

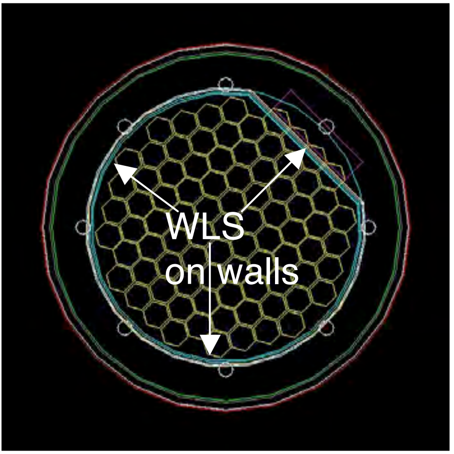
Photomultiplier tube:
Hamamatsu R5912-02MOD
20.2 cm diameter

Wavelength shifter (WLS):
Tetra-Phenyl-Butadiene (TPB)
evaporated on reflector

Reflectivity	@430nm ~97%
Shifting eff.	128→430nm >97%

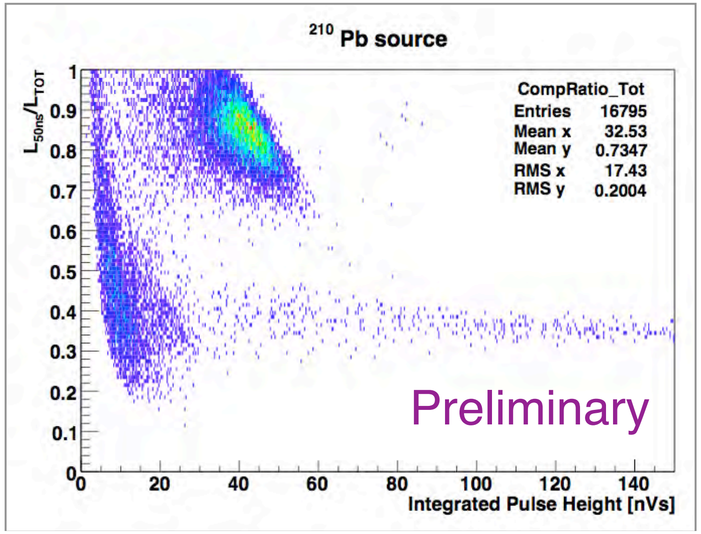


TPB coated reflector under UV lamp.



Small test setup

Radioactive source: ^{210}Pb,
α 5.3 MeV, β 1.16 MeV
α and β events are clearly separated.



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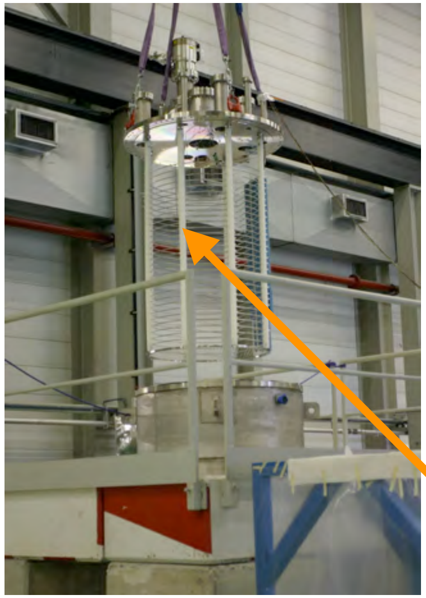
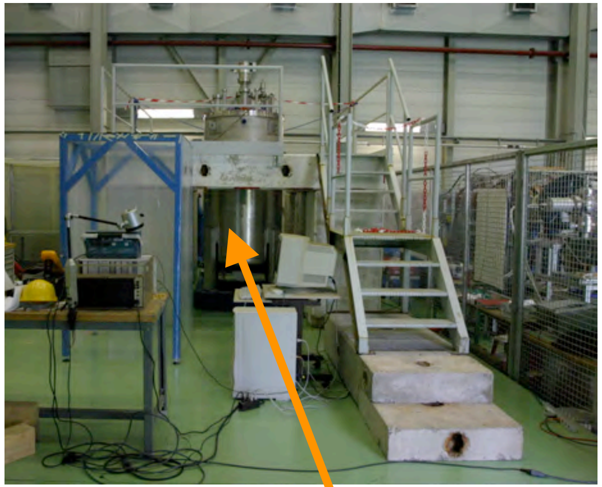
Detector assembly at CERN



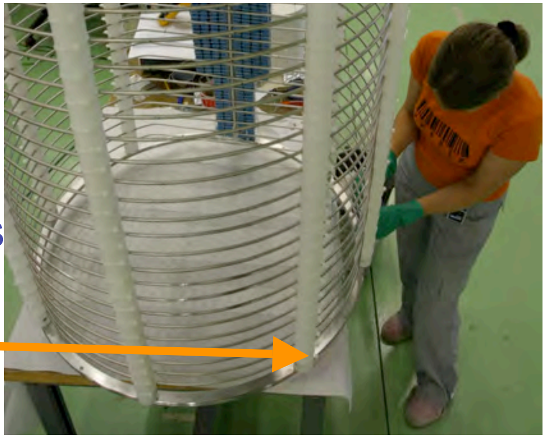


Upper flange

Detector inner part

Side view of the setup

Greinacher HV system. 210 stages
It has been completed and connected to shaping rings



Cathode mounted on the bottom of the support pillars

Concrete platform

Background studies

Background sources:

Neutrons:

From U/Th contaminations of the detector components, muon induced neutrons.

Neutron events look like WIMP-events

Electrons/Gammas:

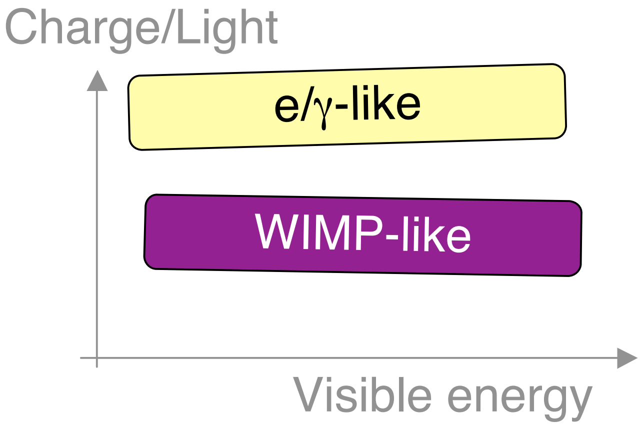
From U, Th, K contaminations of detector and surrounding rock.

Electron/Gamma events look different from WIMP-events

How can we reject the e/γ background:

–Different light/charge ratios

–Different shape of the scintillation light
(ratio fast/slow components).

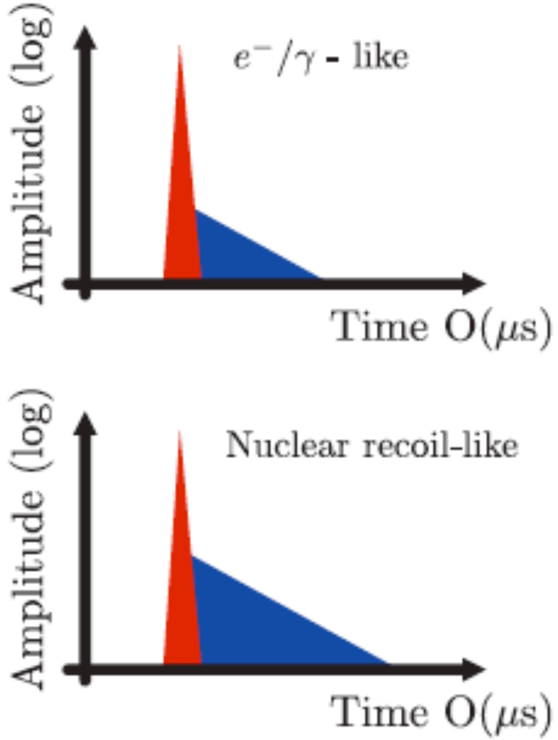

Charge/Light

e/γ-like

WIMP-like

Visible energy

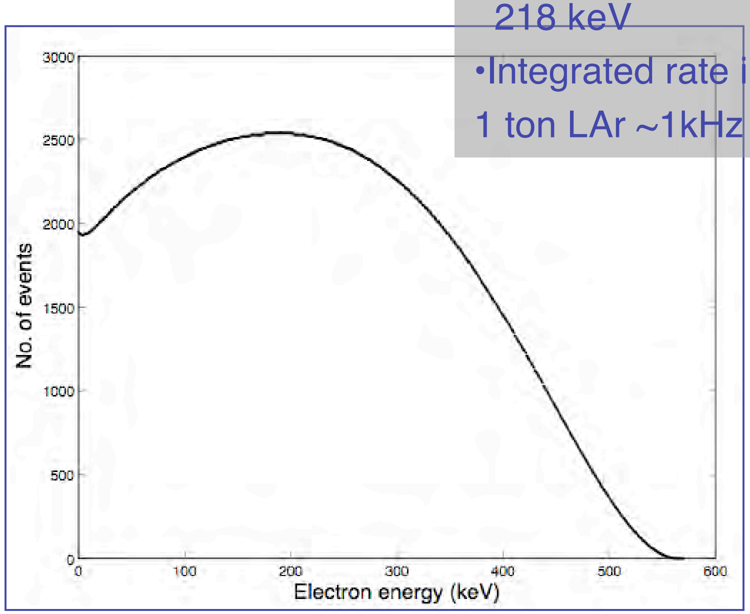
Light:



Ar^{39} and neutrons backgrounds

Natural argon from liquefaction of air contains small fractions of ^{39}Ar radioactive isotope.

- β -radioactive isotope
- Half life: 269 years
  Q=565 keV
- Mean Energy:
  218 keV
- Integrated rate in
  1 ton LAr ~1kHz

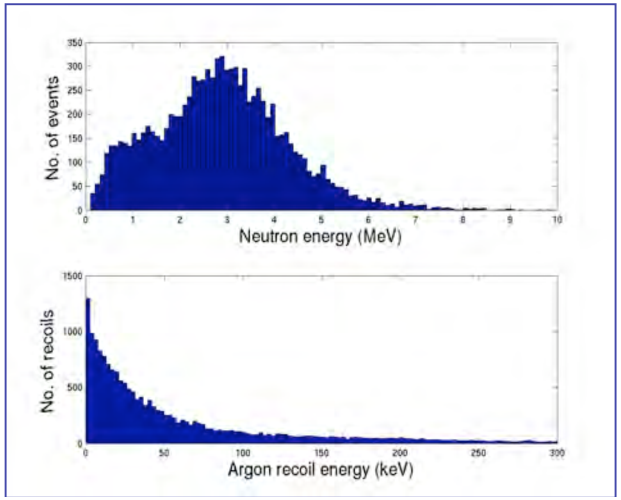


Component	n per year	WIMP-like recoils per year
Container	~ 400	~ 30
LEM (std. mat.)	~ 10000	~ 900
LEM (low bg. mat.)	< 20	< 2
14 PMTs (std. mat.)	~ 12000	~ 1000
14 PMTs (low bg. mat.)	~ 600	~ 50

About 55% of the interacting neutrons scatter more than once at the threshold of 30keV.

Less than 10% of the emitted neutrons produce WIMP-like events single recoils, energy $\in$ [30,100] keV).

The WIMP cross-section is very low, and it will scatter at most once.



We need:
Rejection power of 10^8
OR
use of ^{39}Ar-depleted argon

ArDM schedule for the near future

- Test of detector in vacuum, at CERN:
  High voltage system, purity
  Currently in preparation

- Test with gaseous argon, at CERN:
  PMTs, high voltage system and small version of LEM plates
  Next month

- Test in liquid argon, at CERN:
  Recirculation and purification system
  Before end of 2007

- Test underground at shallow depth
  2008?

Summary

1. A 1-ton prototype is being assembled at CERN to be run in a first phase above ground (2007).

2. First detector test at CERN are ongoing.

3. Key components:
   - → high drift field device
   - → LEM-based charge readout
   - → argon scintillation light detection system

4. After tests at CERN and at shallow depth will be completed, the detector will be moved to the underground laboratory (presumably to the Canfranc underground laboratory in Spain)

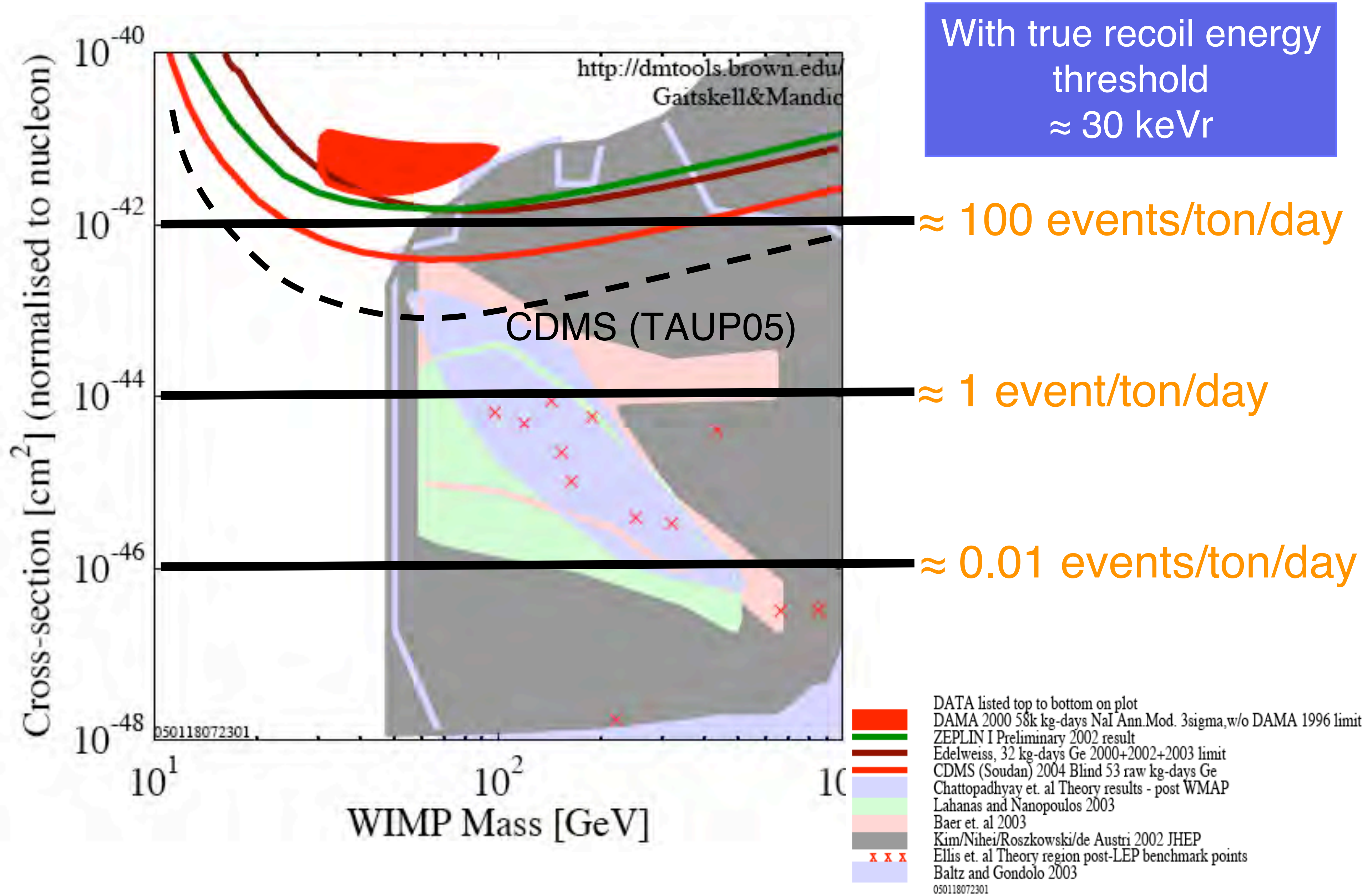
5. The expected sensitivity of the detector will be of the order of 10^{-44} cm^2 (10^{-8}pb), depending on the background rejection power.

6. This technology could be scaled. Detectors of 10 tons and more based on the same technology can be constructed.

Backup slides

Estimated event rates on argon

With true recoil energy threshold
≈ 30 keVr



CDMS (TAUP05)

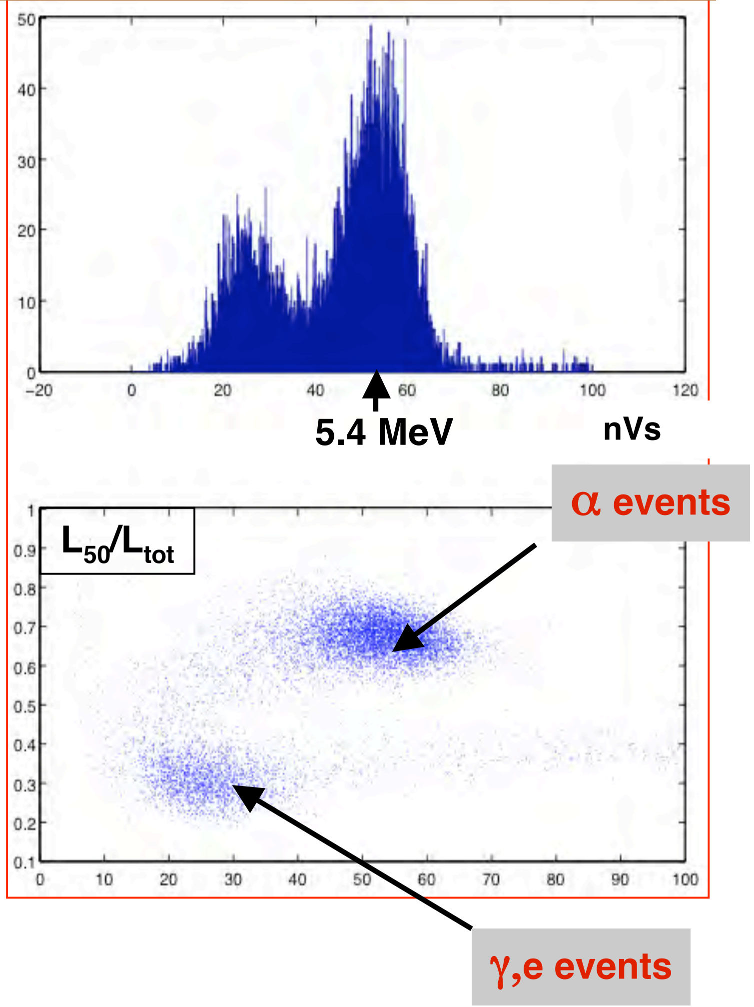
≈ 100 events/ton/day

≈ 1 event/ton/day

≈ 0.01 events/ton/day

Light measurements in liquid argon

Event separation in liquid argon

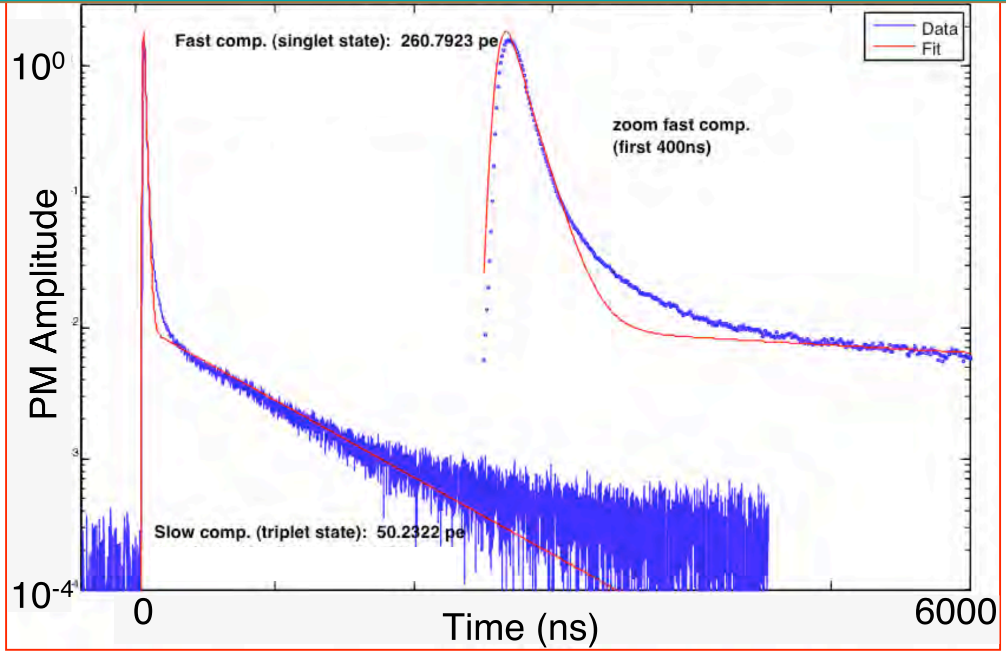


α events

γ,e events

Radioactive source: α (5.4 MeV) + β (Q = 1.163 MeV)

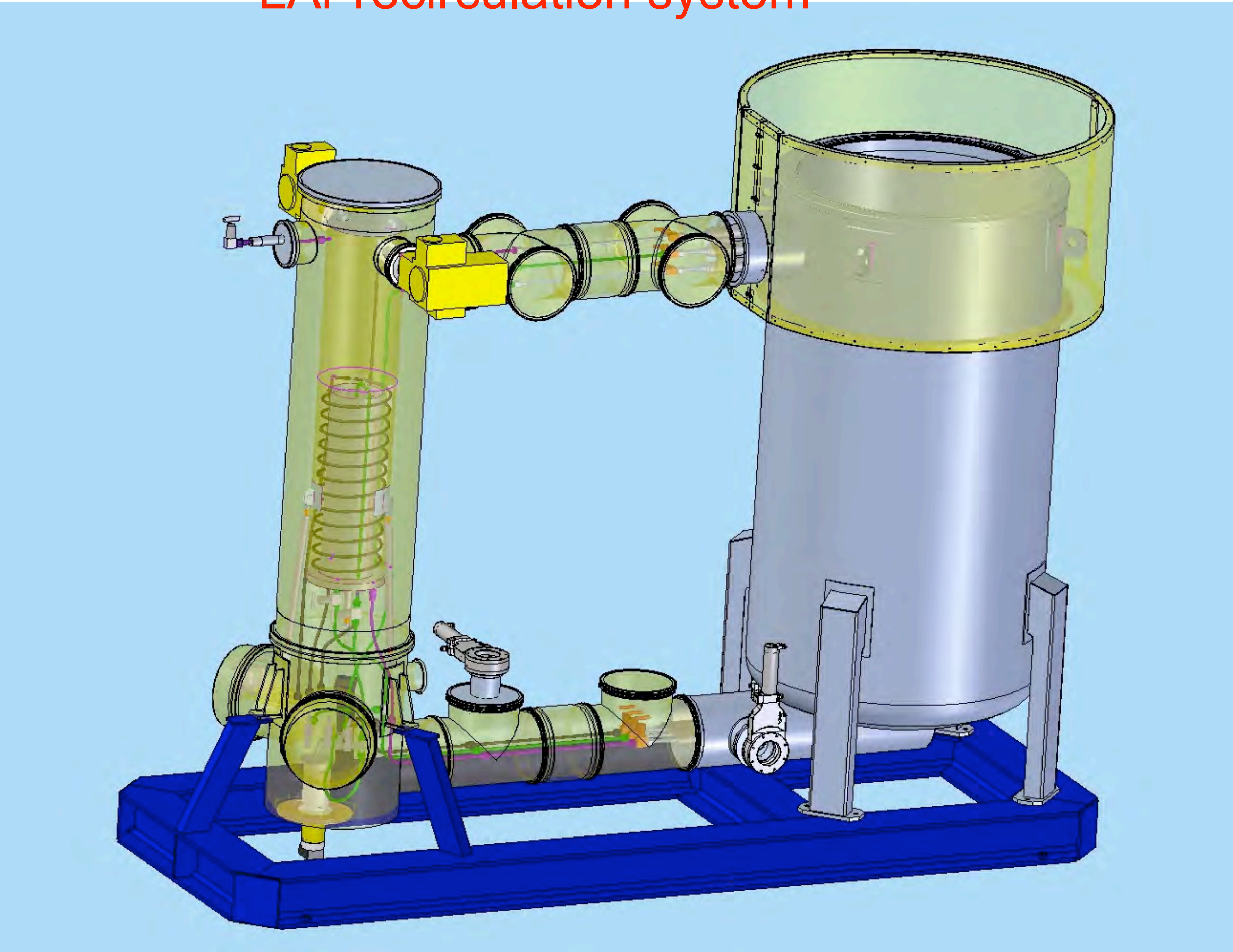
Scintillation light from α in 1200mbar liquid argon



→ α events separate well from γ,e events

→ Fast and slow light components distinguishable

LAr recirculation system

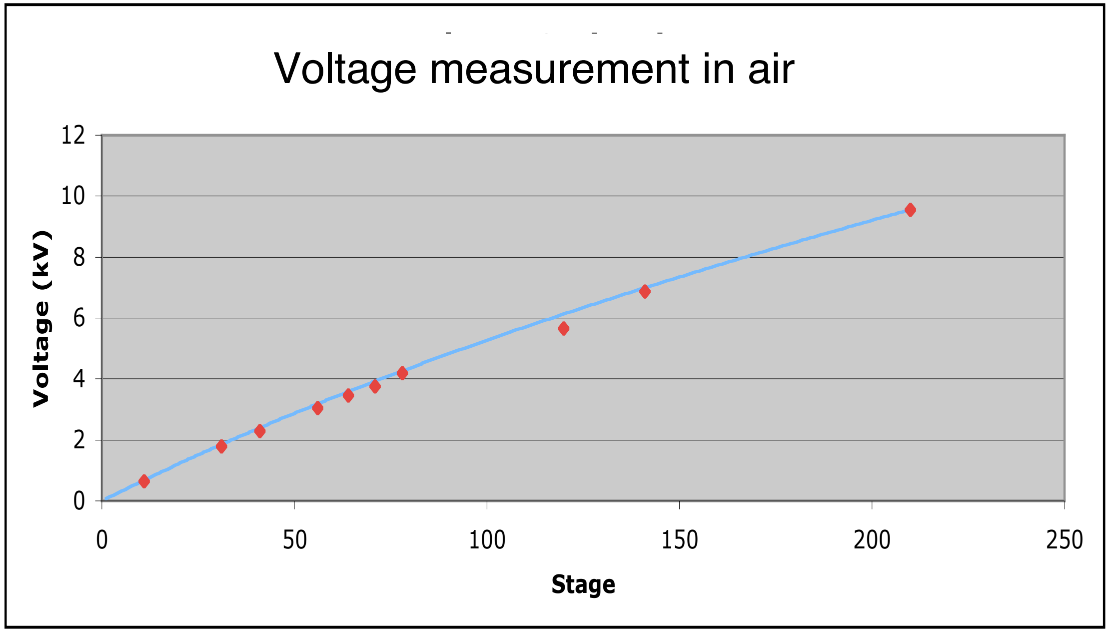


High voltage system

We use a cascade of HV multiplication stages (Greinacher/Cockroft-Walton circuit) directly connected to the field shaping rings

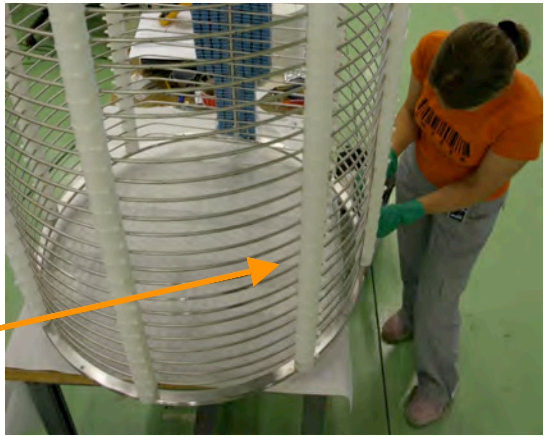
The voltage at the last stage is designed to reach 500 kV, i.e. ≈ 4.17 kV/cm

The Greinacher circuit has been completed and connected to the field shaping rings



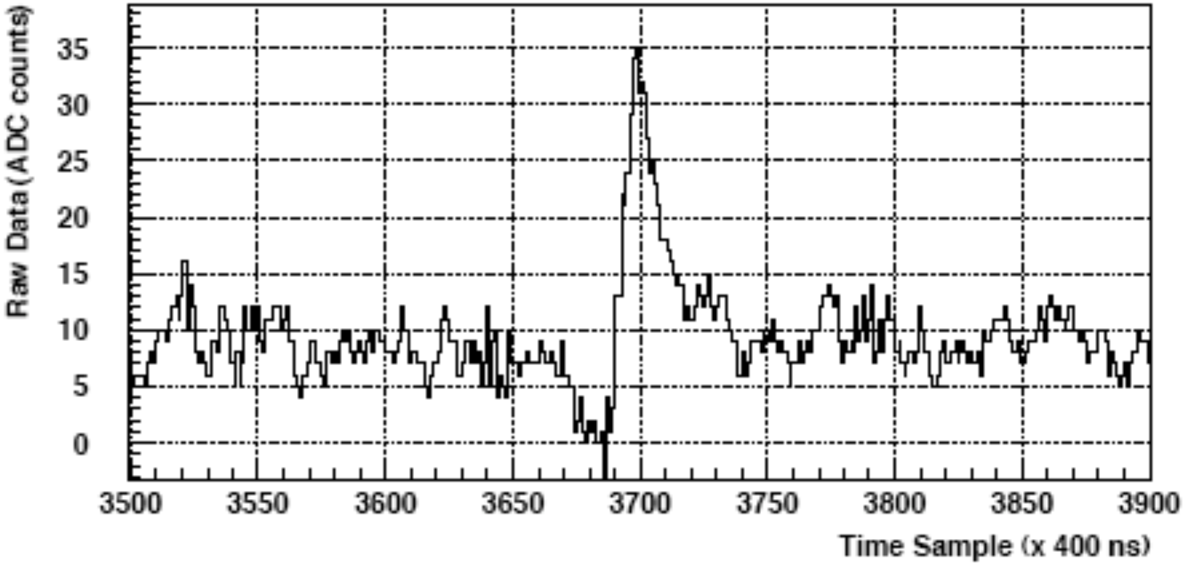
Small nonlinearity of the voltage distribution can be corrected with attachments to field shapers

Cathode mounted on the bottom of the support pillars



Liquid Argon TPCs detect the ionization charge to create the image of the event and the scintillation light can be used for triggering or T_0 definition.

To detect the ionization charge in a large noble liquid detector very low noise charge preamplifier is required (challenging, costly).
For example: in ICARUS detector the signal is only 15000 electrons for a minimum ionizing particle track with 3mm wire pitch. In this case to obtain a high signal to noise ratio the equivalent noise charge has to be less then 1000 electrons.



Signal from a MIP recorded
In the Induction plane of T600
ICARUS detector.

In 100 kton detector with 20 m drift In a field 1kV/cm the drift time is about 10 ms.
With a 2 ms electron lifetime , the 6000 electron/mm signal is attenuated by:

$$e^{-t/\tau} \approx 1/150$$

It is too low for a readout as in ICARUS

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