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ArDM
a 1-ton liquid argon dark matter detector

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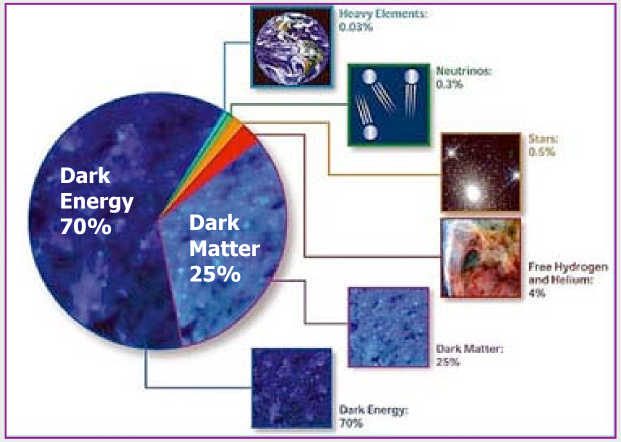
Wanted: the dark matter particle

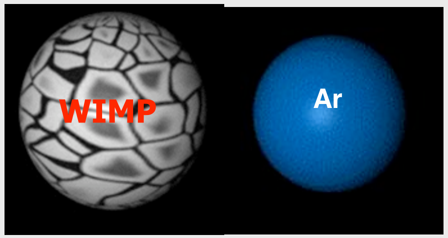


Over 80% of the matter in the universe is unknown.
It presumably consists of a sea of
Weakly Interacting Massive Particles (WIMPs).
One candidate: the Lightest Supersymmetric Particle (LSP)

How WIMPs can be measured with argon:

(Presentation of A. Rubbia this morning)

A WIMP collides with argon inside the detector…



…transmitting its kinetic energy to the nucleus…

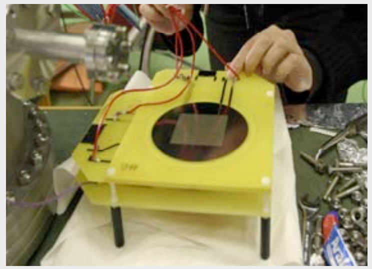
…the Argon nucleus recoils

The light is „seen" by photomultipliers

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

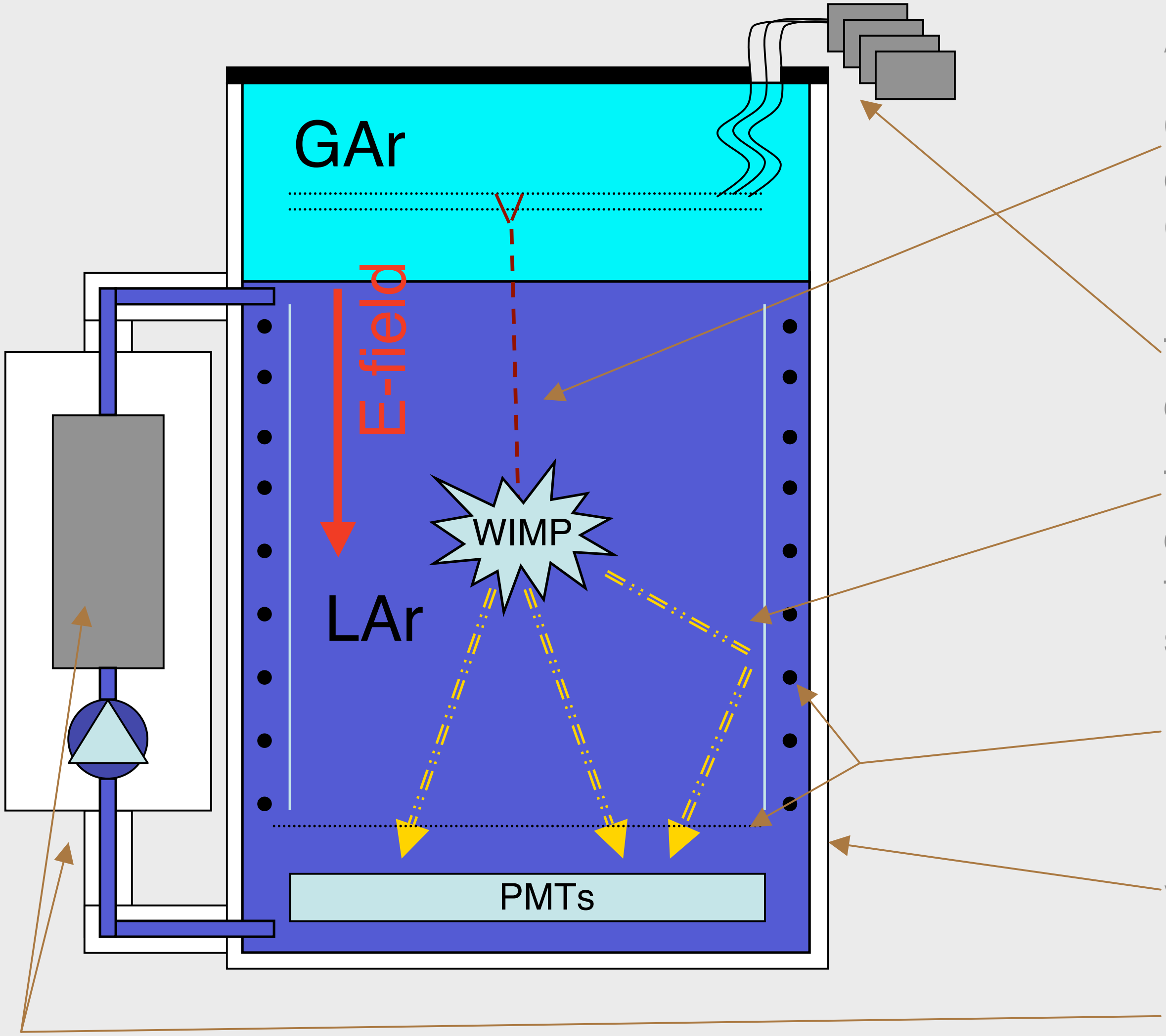
e^-

The electrons are „seen" by electron multipliers



ArDM is a one ton liquid argon detector
designed to measure ionization charge and scintillation light

ArDM 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 striped. 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.

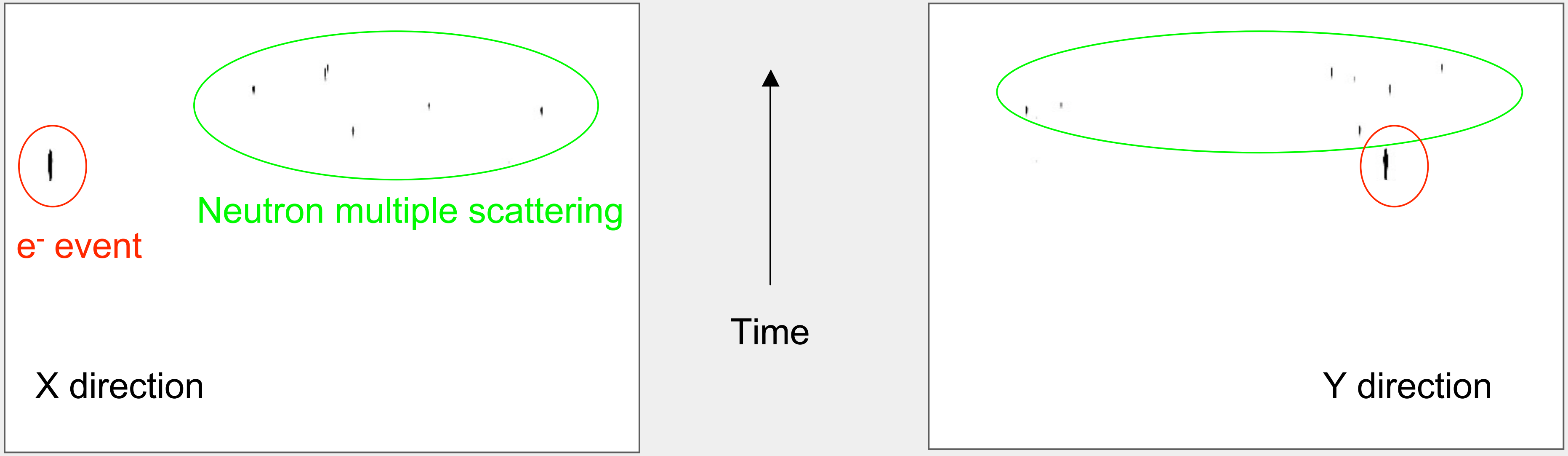
Purification: LAr pump + cartridge.

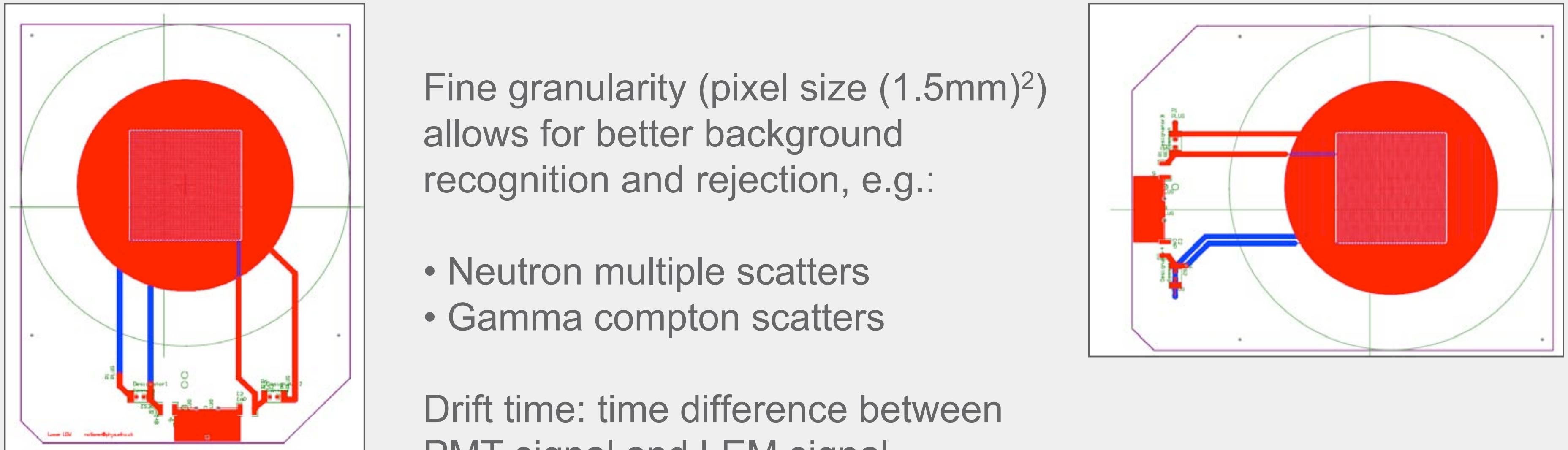
ArDM baseline parameters

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%

3D event imaging

The charge readout with two striped large electron multiplier (LEM) plates together with the light signal allows for a precise 3D reconstruction of the event





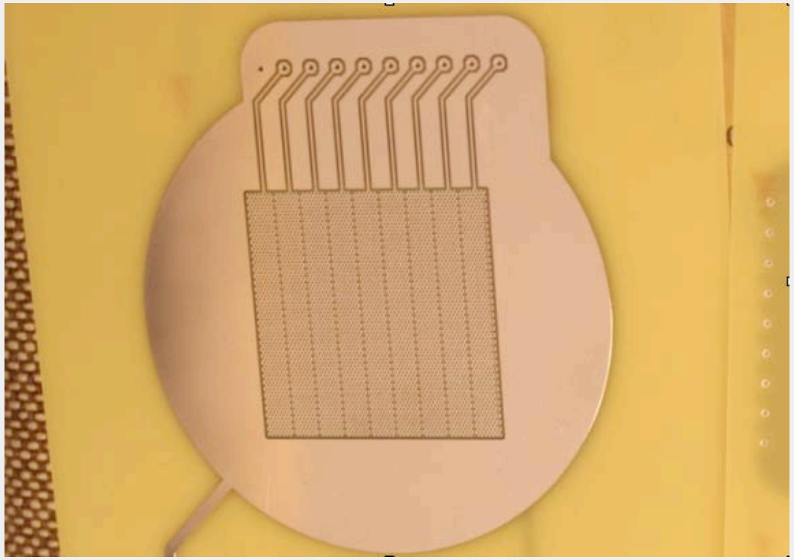
Fine granularity (pixel size (1.5mm)^2) allows for better background recognition and rejection, e.g.:

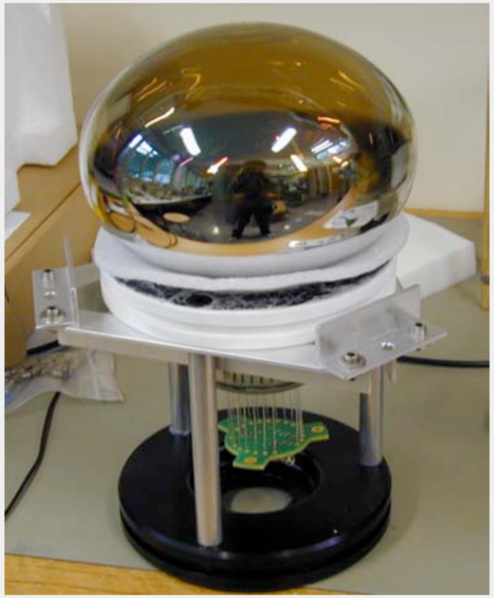
- Neutron multiple scatters
- Gamma compton scatters

Drift time: time difference between PMT signal and LEM signal

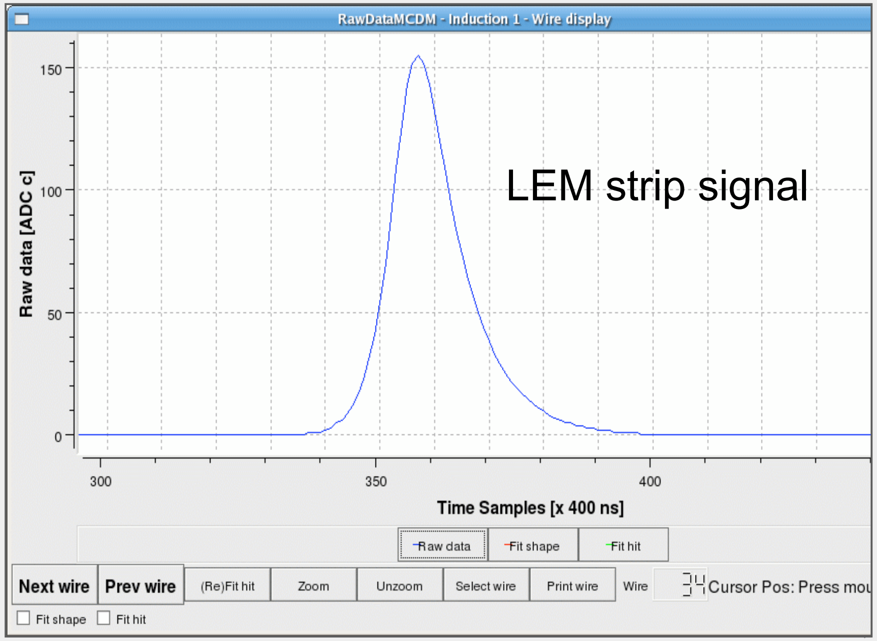
Event imaging

First version of a striped (LEM) plate, 9 strips





Photomultiplier
tube



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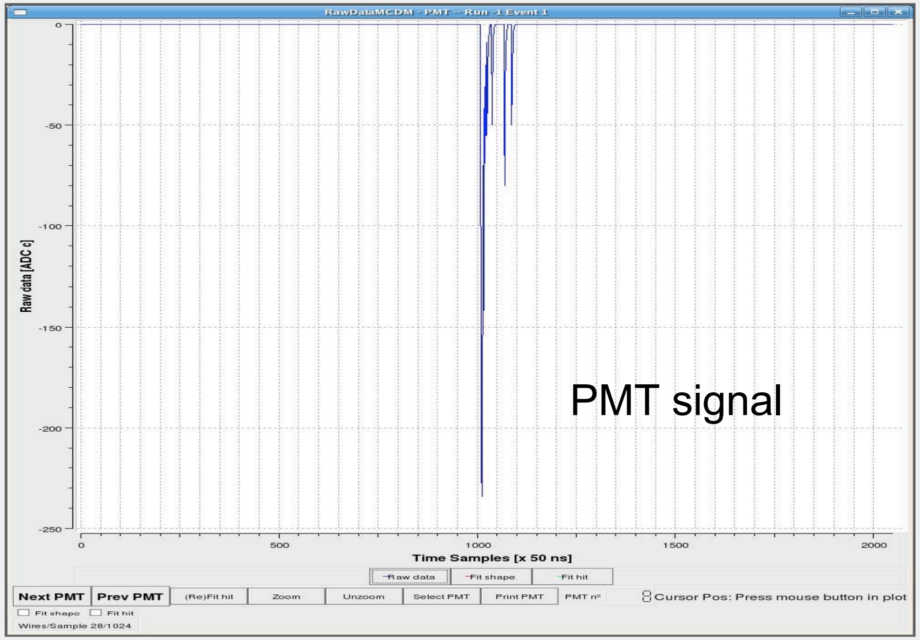
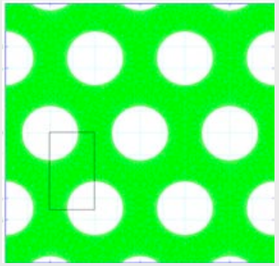


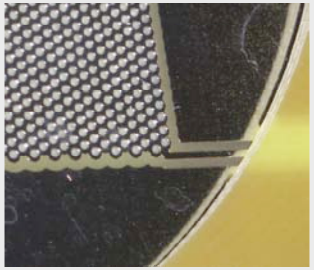
Charge readout: large electron multiplier (LEM)

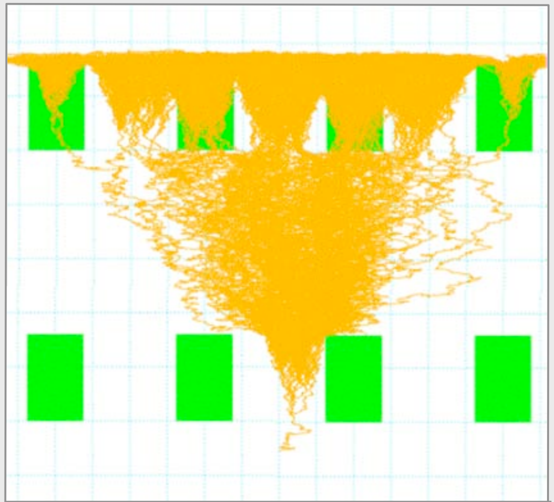
LEM is a thick macroscopic GEM

Thickness: 1.5 mm

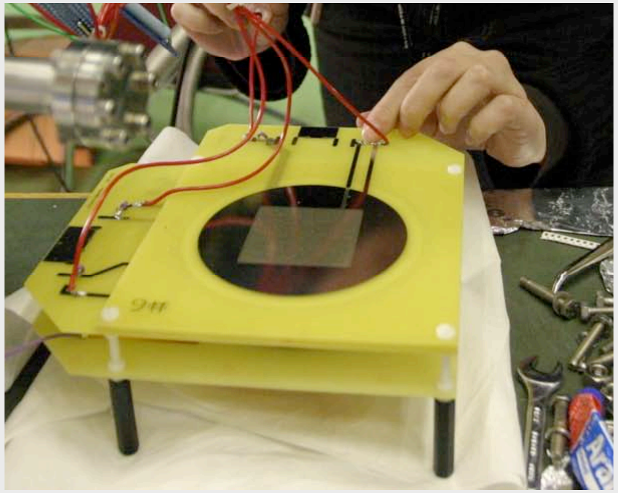
Diameter hole: 0.5 mm







Simulation of avalanche



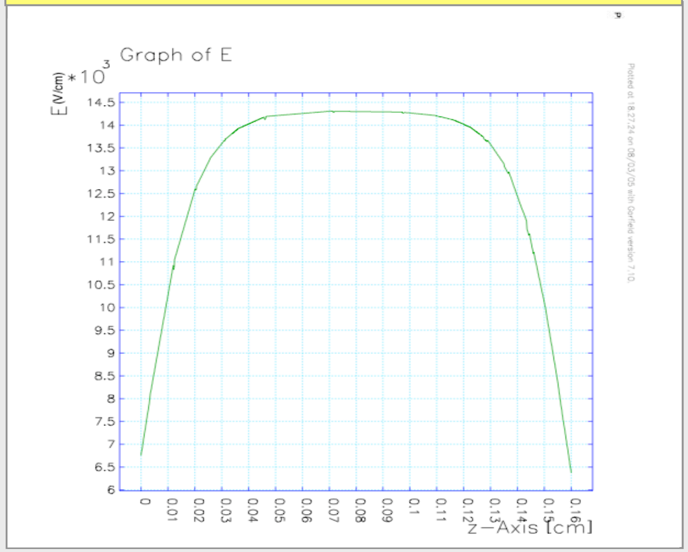
Two LEM stages setup

Distance between two holes: 0.8 mm

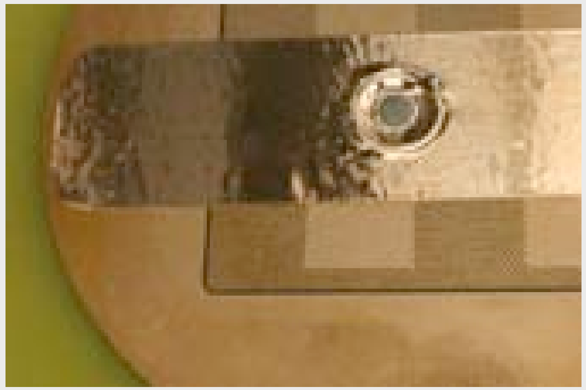
Two stages are used for ArDM to provide a high gain

Gain per stage: ~ 10^2

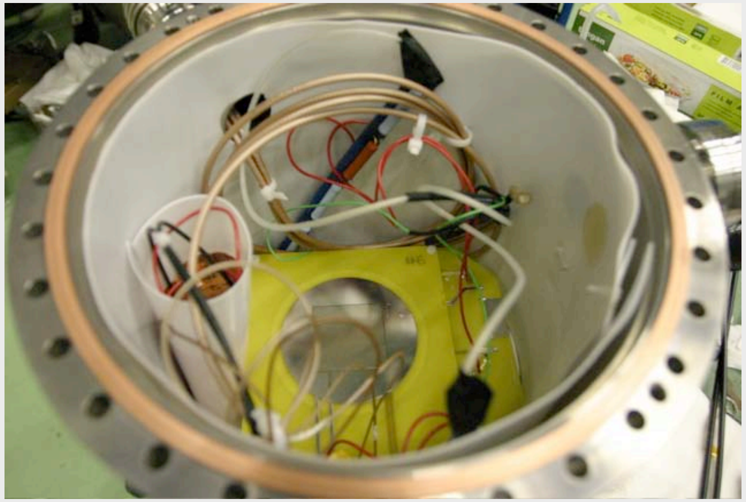
Simulation of electric field in hole



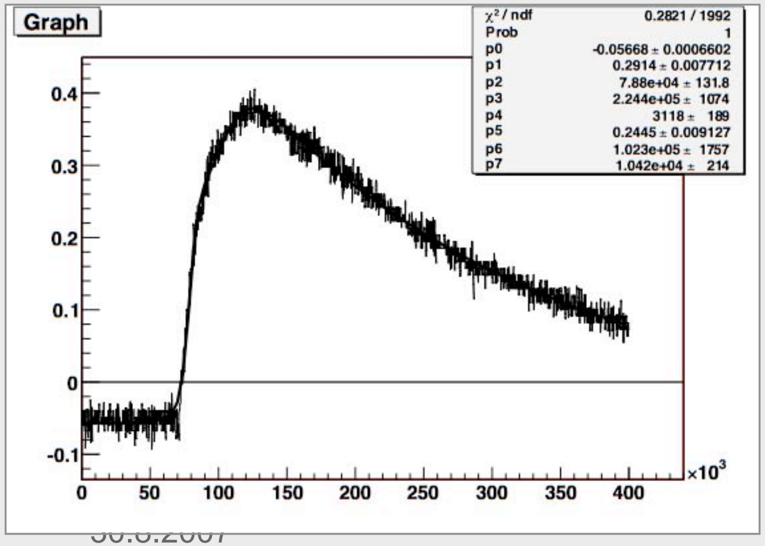
Radioactive source for tests: Fe^{55}, 5.8keV, 12kBq



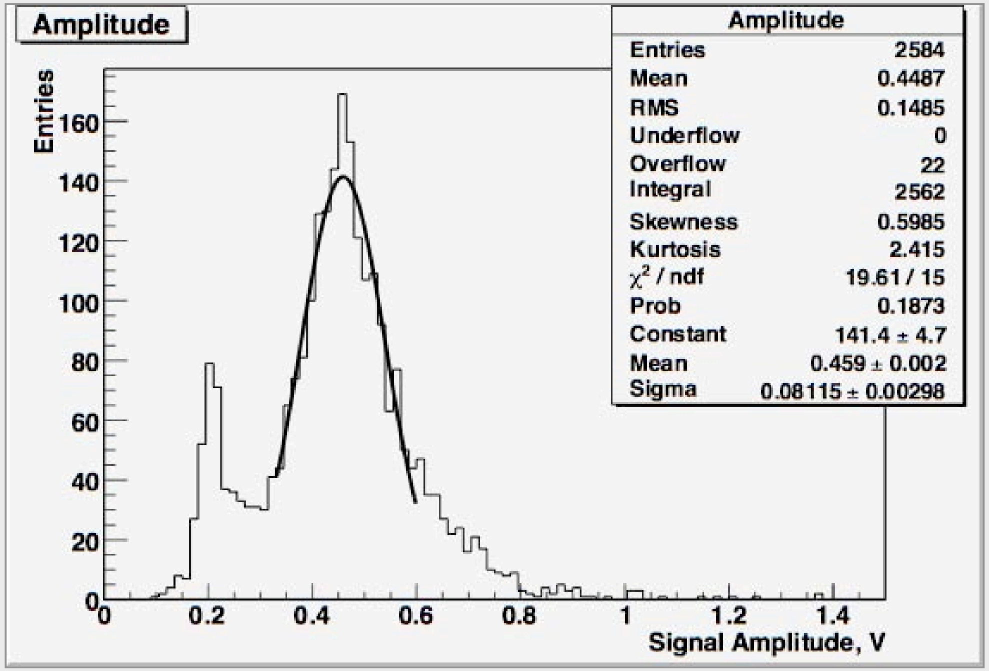
LEM signal in small R&D test setup



Signal shape in pure argon at room temperature and atmospheric pressure
Risetime is about 15μs



Resolution (FWHM)=41.5%



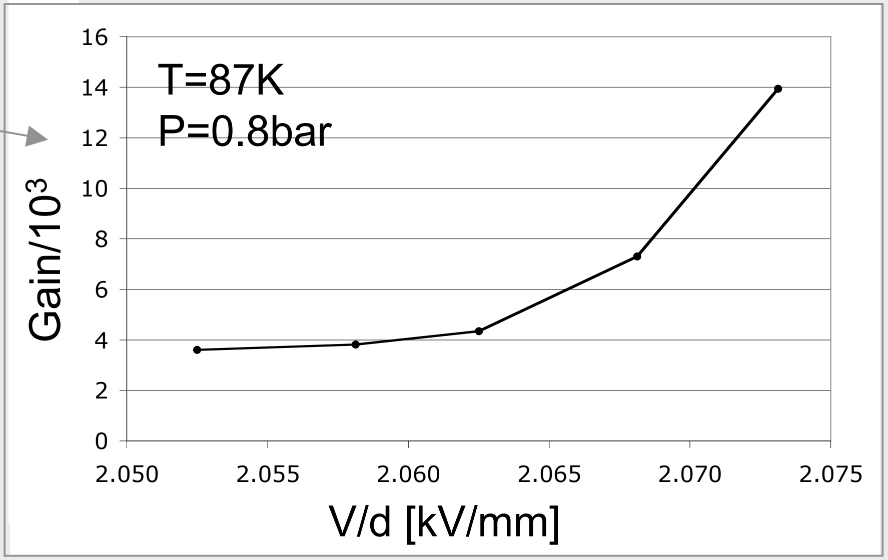
Signal amplitude distribution

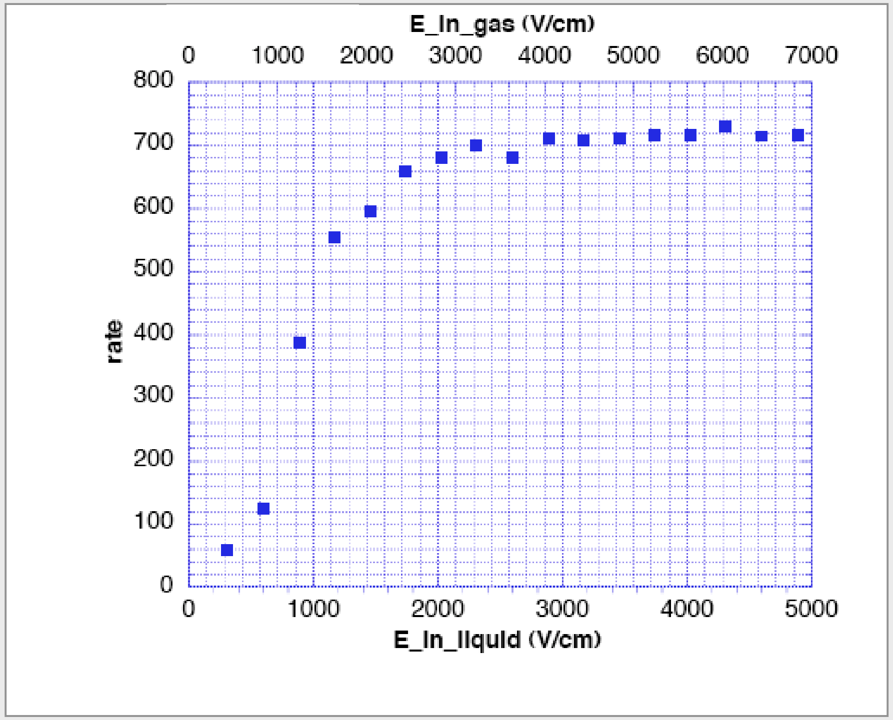
Amplitude distribution was obtained with pure argon gas at atmospheric pressure and room temperature.

R/a source: Fe^{55}, 5.8keV.
Source Rate: 240Hz.

Tests in small setup at cryogenic temperatures and double phase conditions

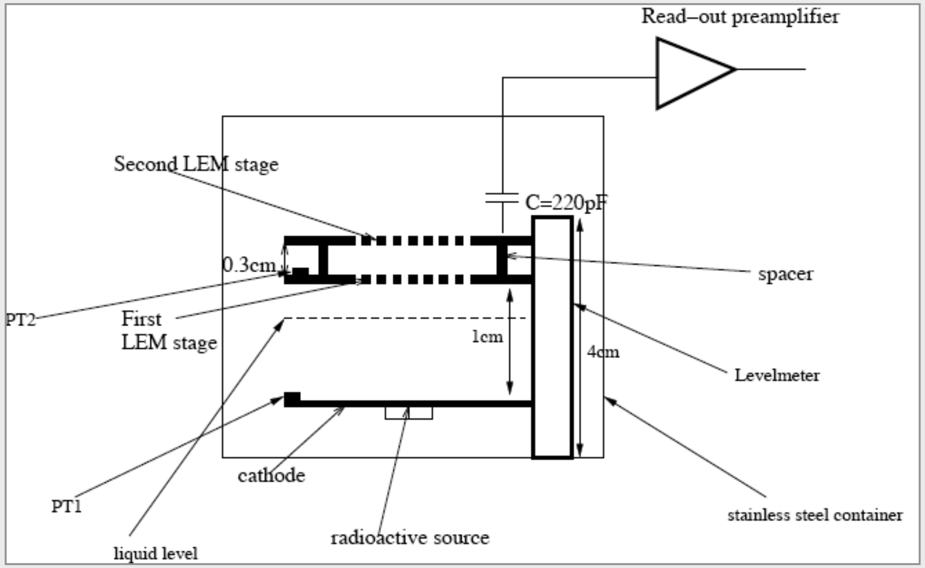
Stable gain of 10^4 measured in gas at cryogenic temperatures, Fe^{55} internal r/a source.



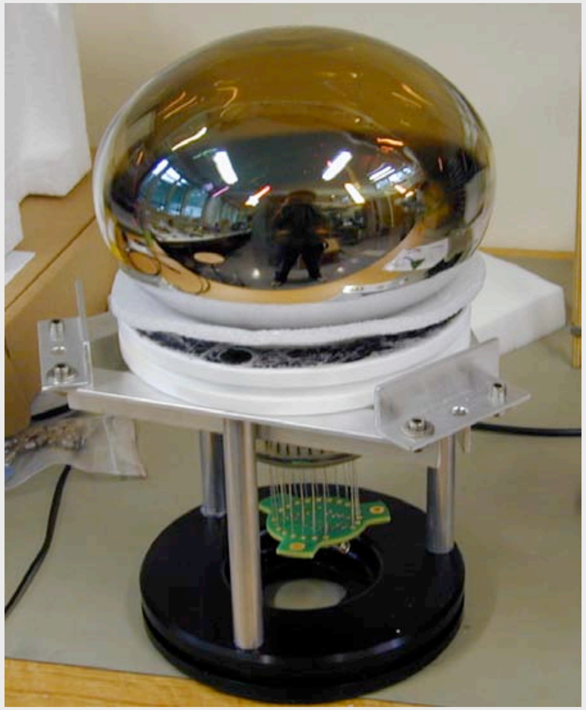


Event rate as function of extraction field.
The curve was obtained with an external Co^{60} r/a source.

Test setup with two LEM stages



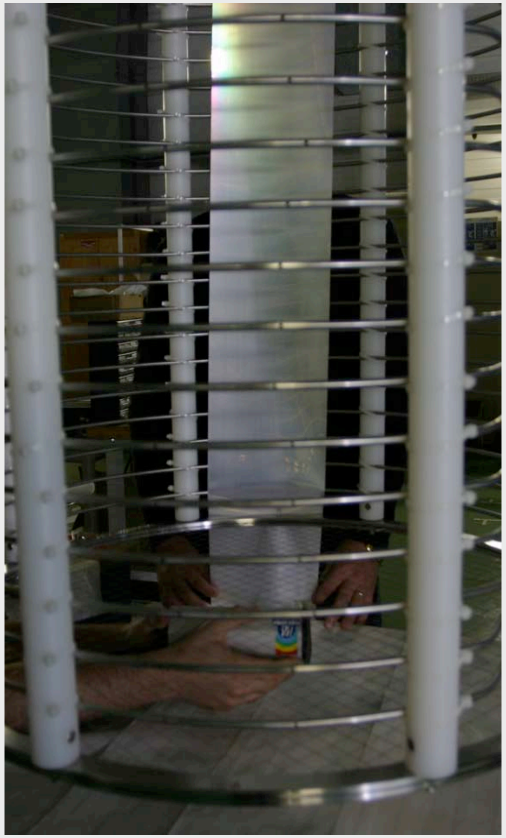
Light readout



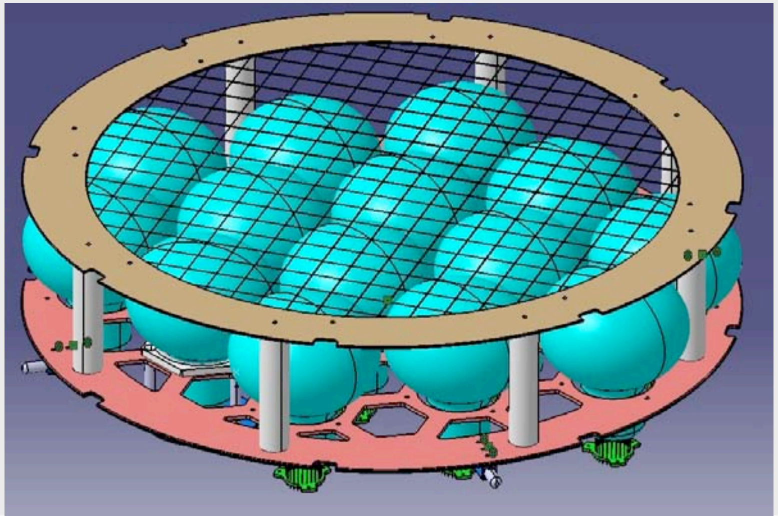
Photomultiplier tube:
Hamamatsu R5912-02MOD
20.2 cm diameter

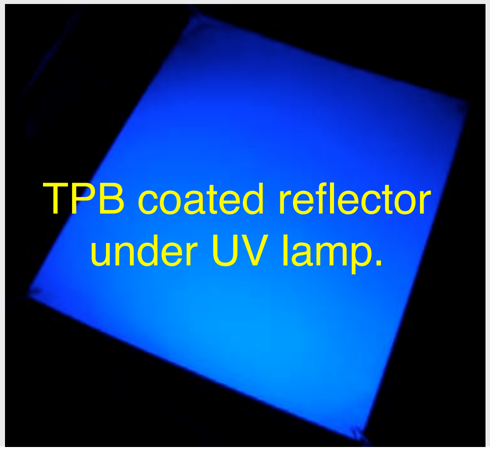
Wavelength shifter (WLS):
Tetra-Phenyl-Butadiene (TPB)
evaporated on reflector

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

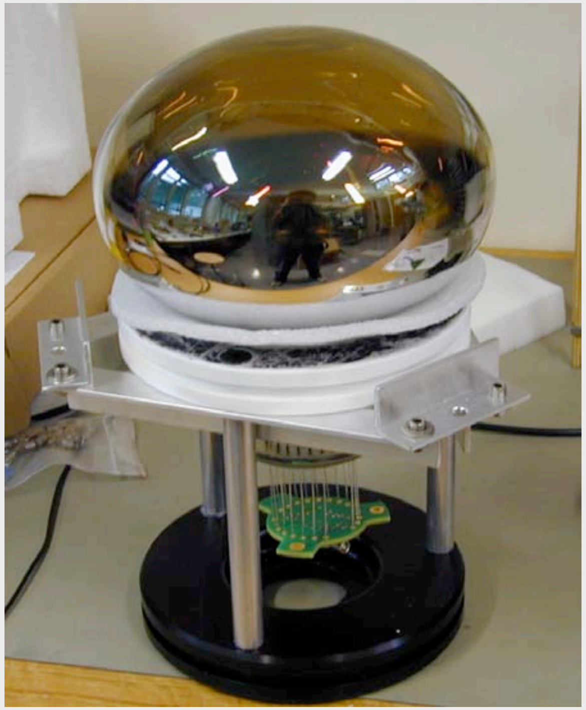


14 low background
photomultiplier tubes
cover the bottom of
the detector





Light readout



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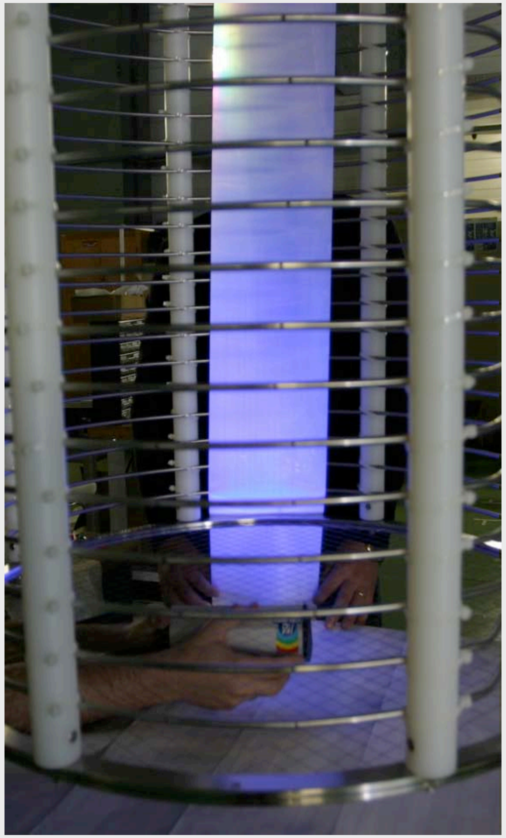

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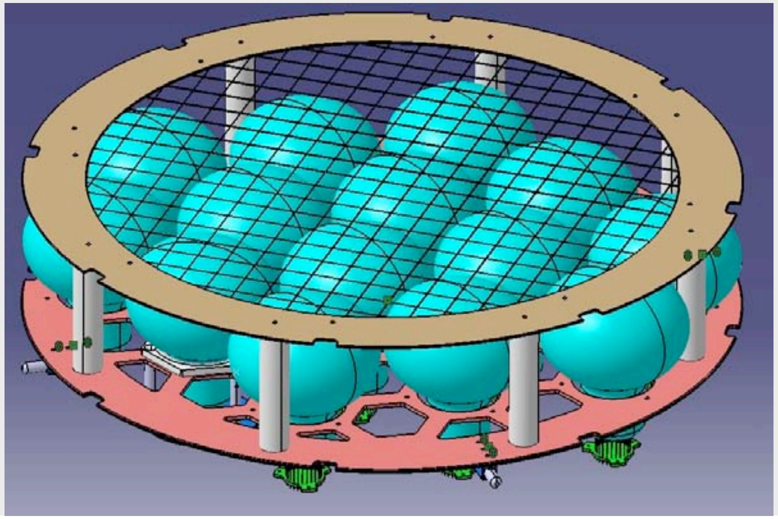
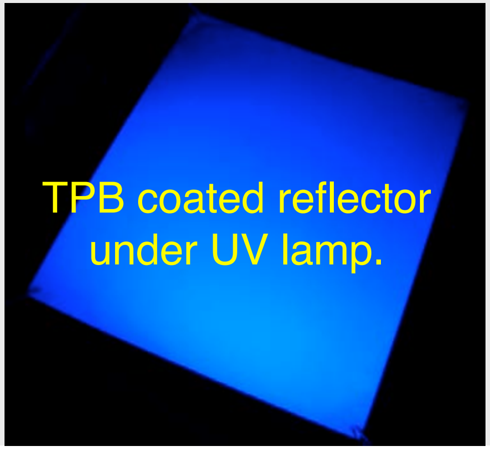


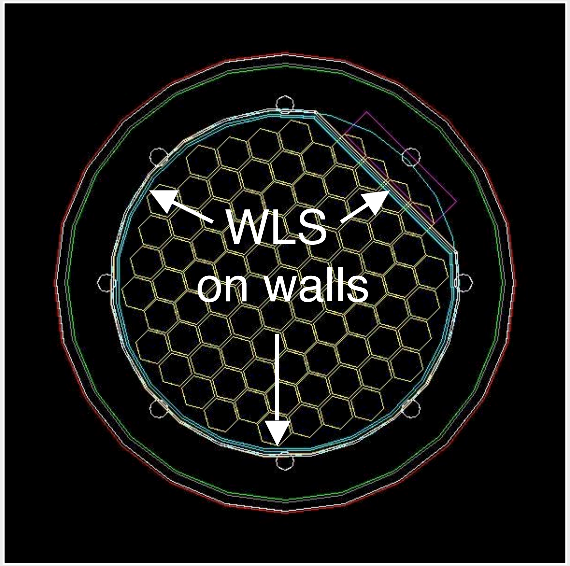


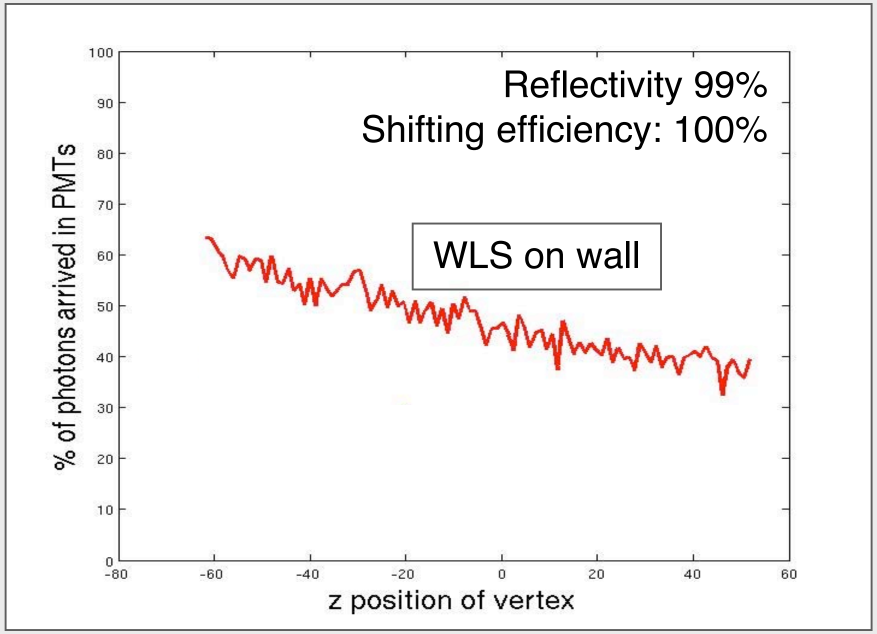
Light collection

Argon scintillation light needs to be shifted from 128 nm to visible light by a wavelength shifter

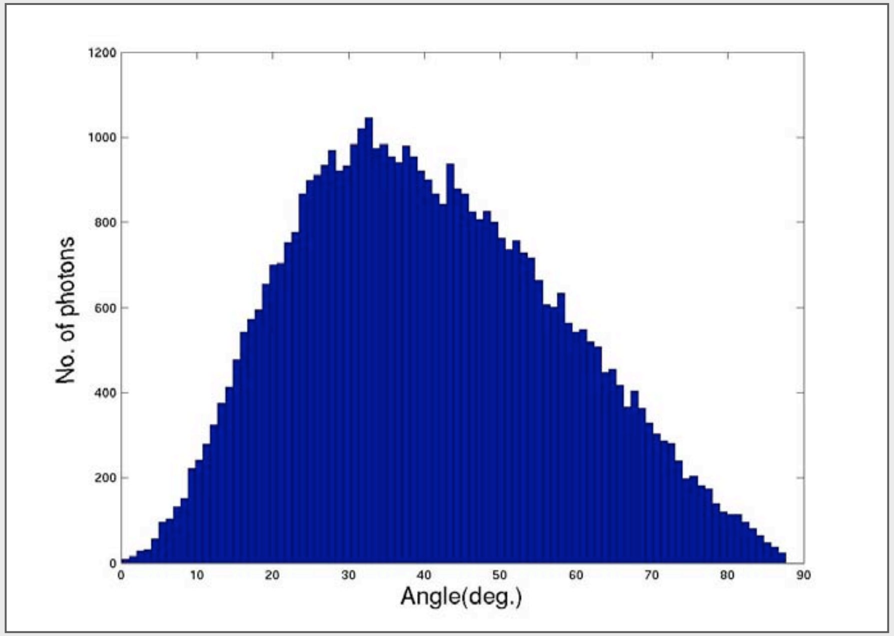
Simulations show that light collection is better if WLS is sprayed on walls instead of PMT surface

WLS on PMT





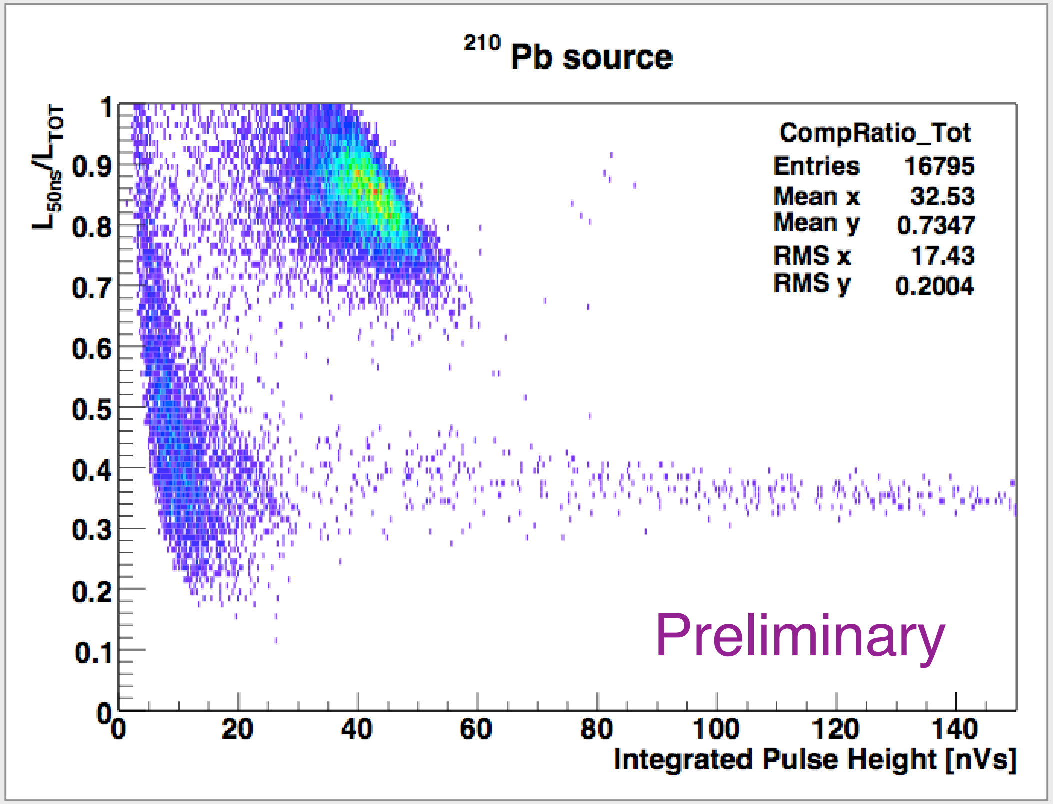
Average number of photons arrived in PMTs: 47.4%



Average incident angle of photons on PMTs: 40.6º

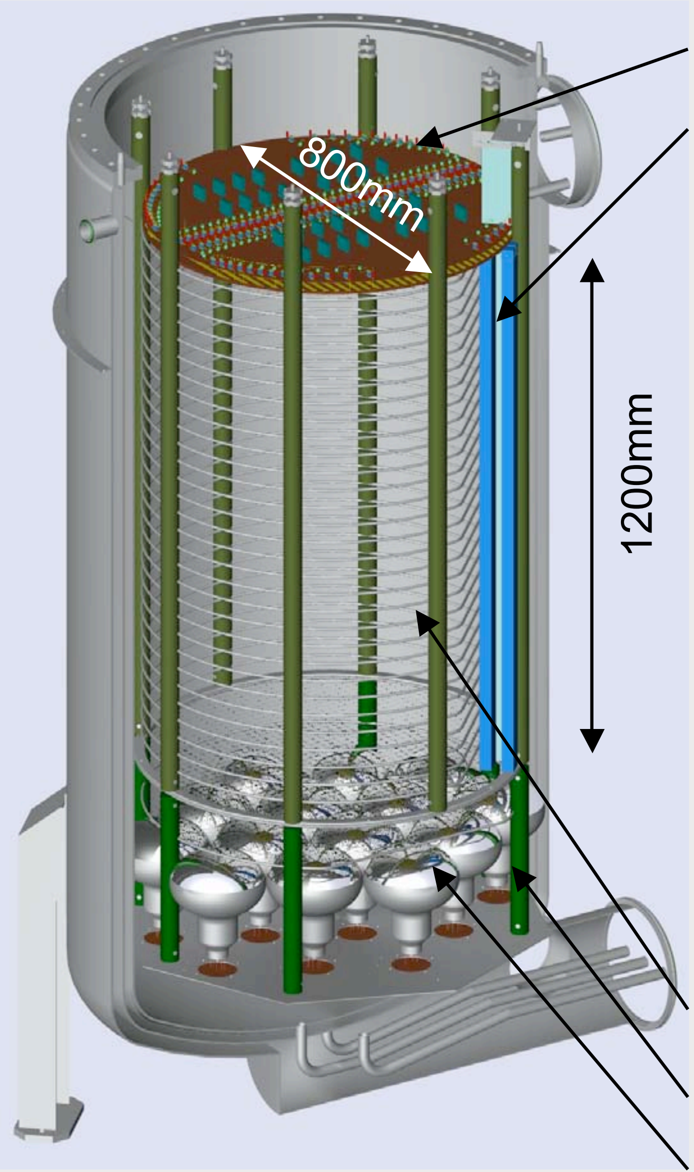
R&D: Light measurements in liquid argon with small test setup

Radioactive source: ^{210}Pb,
α 5.3 MeV, β 1.16 MeV



$\Rightarrow$ α and β events separate clearly

Construction status: Detector layout



Two-stage LEM

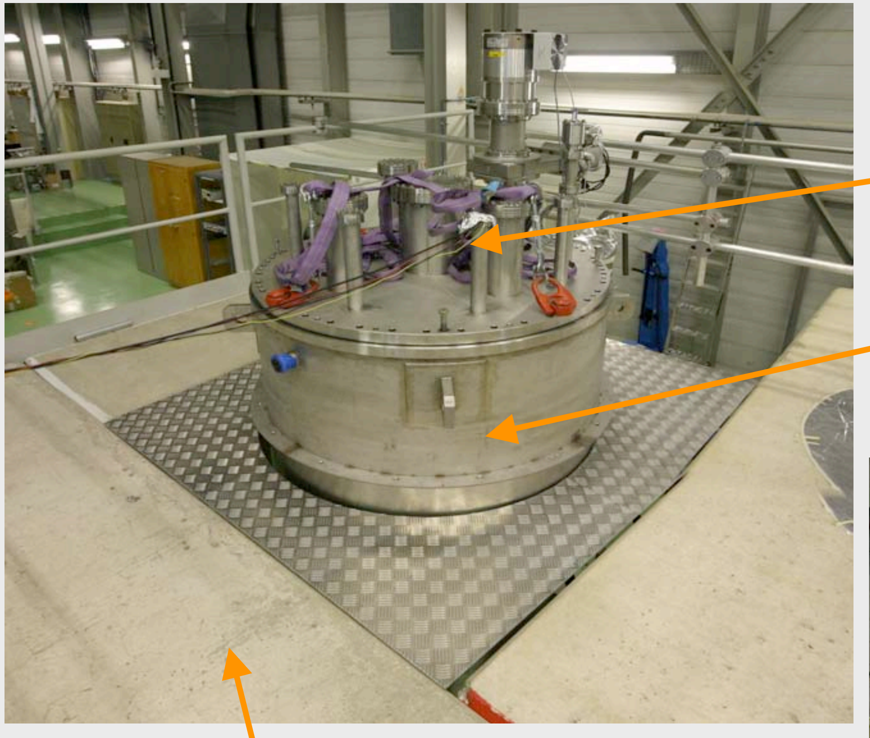
Greinacher chain: supplies the right voltages to the field shaper rings and the cathode up to 500 kV (E=1-4kV/cm)

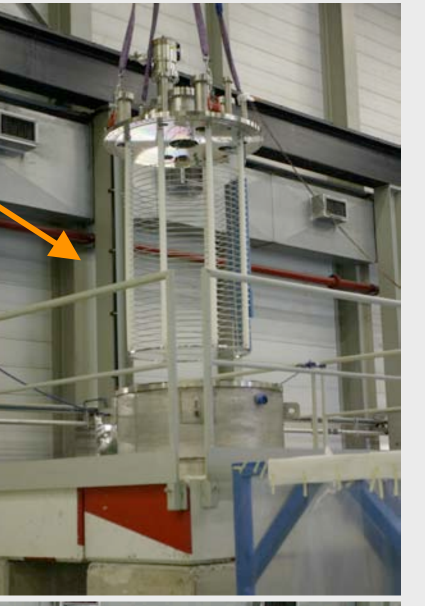
Cylindrical fiducial volume

Support pillars with field shaping rings

14 PMTs below the cathode to detect the scintillation light

Assembly at CERN





Before closing

Top flange

Dewar

Concrete access platform

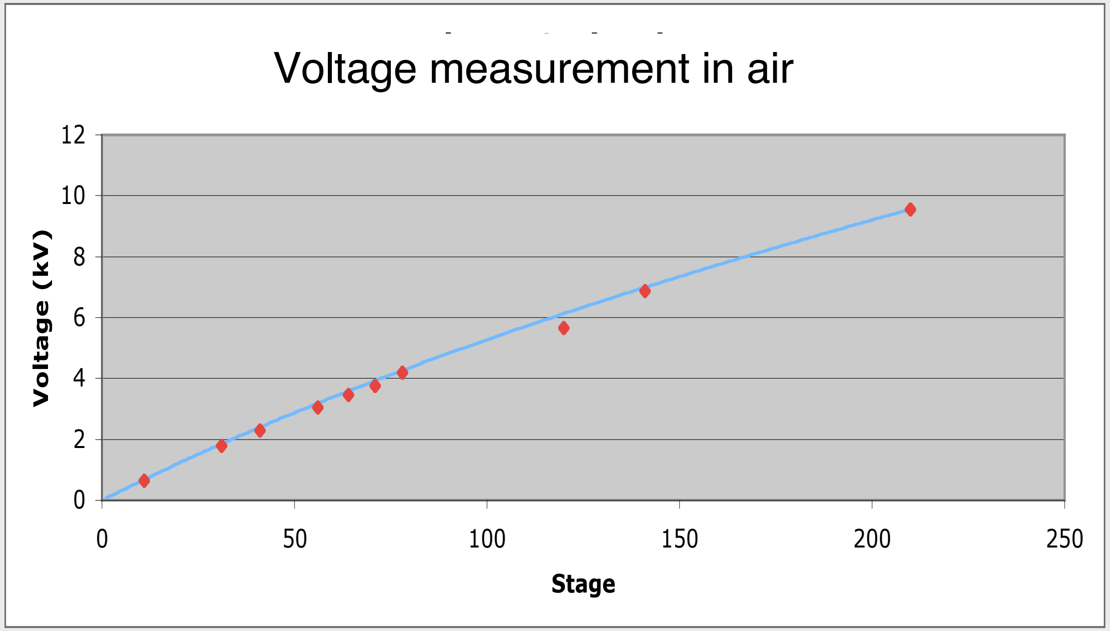
HV electronics

High voltage system

We use a cascade of HV multiplication stages (Greinacher/Cockcroft-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

Background studies

Small signal, a lot of background

⇒ Background discrimination is crucial

Background sources:

- Neutrons:

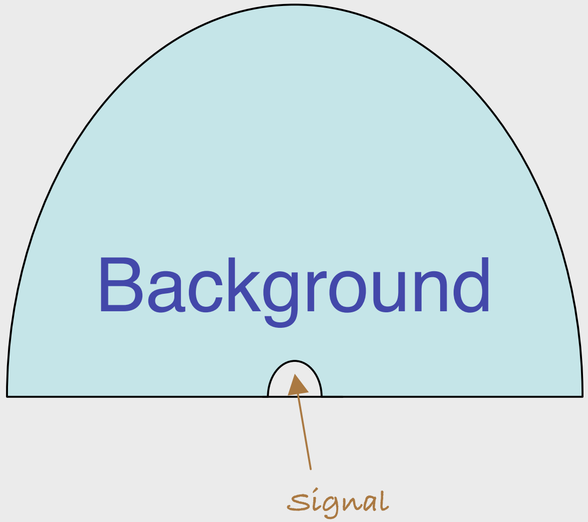
  from radioactive elements (mainly U/Th contaminations) in materials and from muons

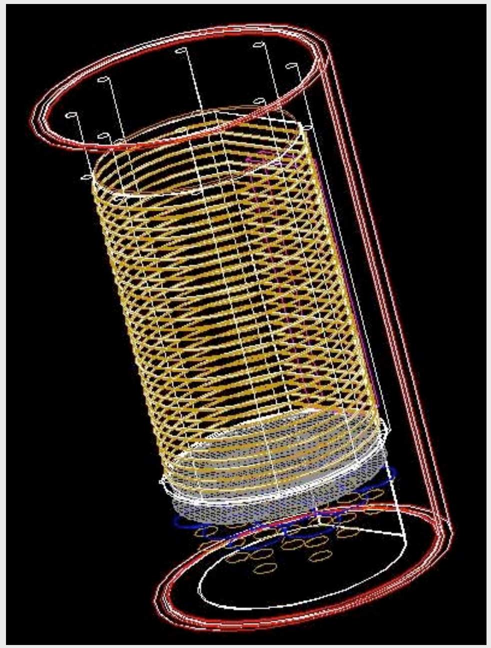
  ⇒ Neutron events look like WIMP-events

- Electrons/Gammas:

  from radioactive elements

  ⇒ Electron/Gamma events look different from WIMP-events



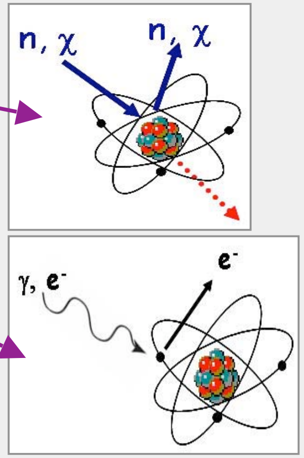


Full Geant4 detector simulation

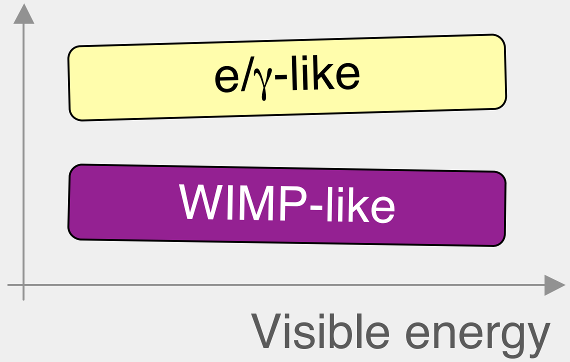
Background rejection

Neutrons and WIMPs interact with the argon nucleus

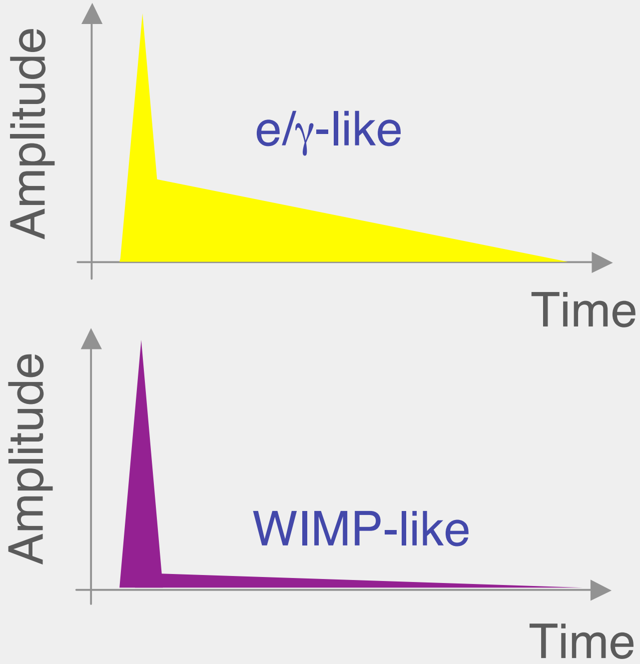
e$^-$/γ interact with shell electrons



Charge/Light:



Light shape:



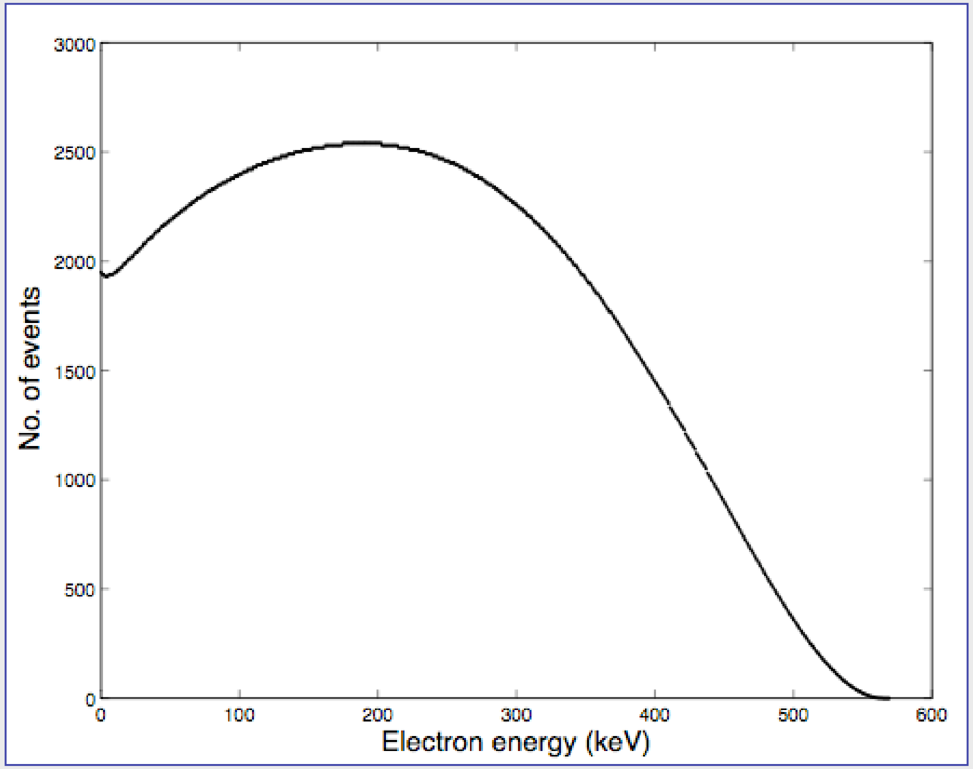
Background rejection possibilities:

- Different light/charge ratios
- Different shape of the scintillation light (ratio fast/slow components)

Needs to be confirmed in realistic conditions

An internal electron bg. source: ^{39}Ar

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



- Decays via β-disintegration
- Half life: 269 years, Q=565 keV
- Mean Energy: 218 keV
- Integrated rate in 1 ton LAr ~1kHz

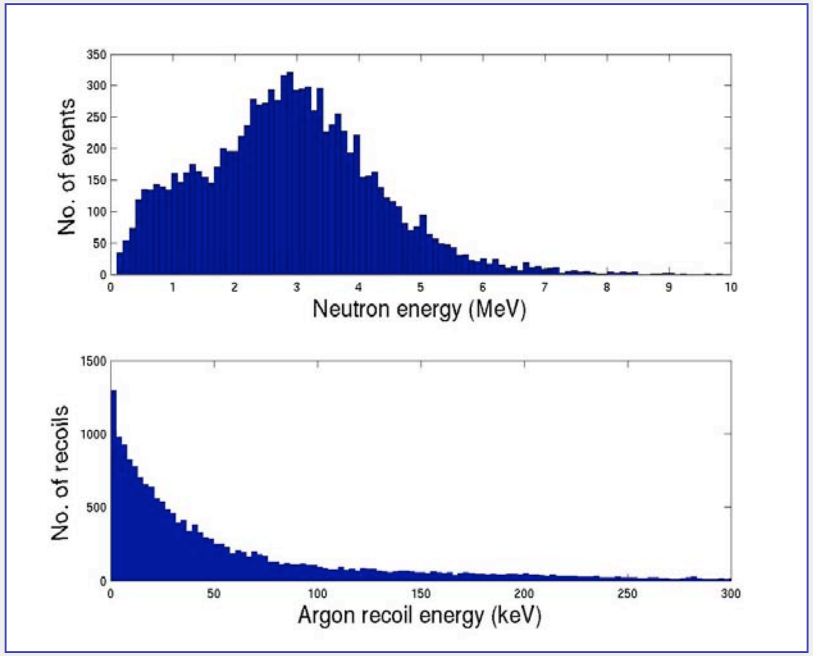
⇒ Rejection power of 10^8

OR

⇒ Use of ^{39}Ar-depleted argon

Neutron background

Similarity of neutron events with WIMP events ⇒ neutron background carefully investigated



$$E_R \simeq 2E_n \frac{m_n M_{Ar}}{(M_{Ar} + m_n)^2}(1 - \cos\theta)$$

Event numbers per year

Component	n per year	WIMP-like recoils
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

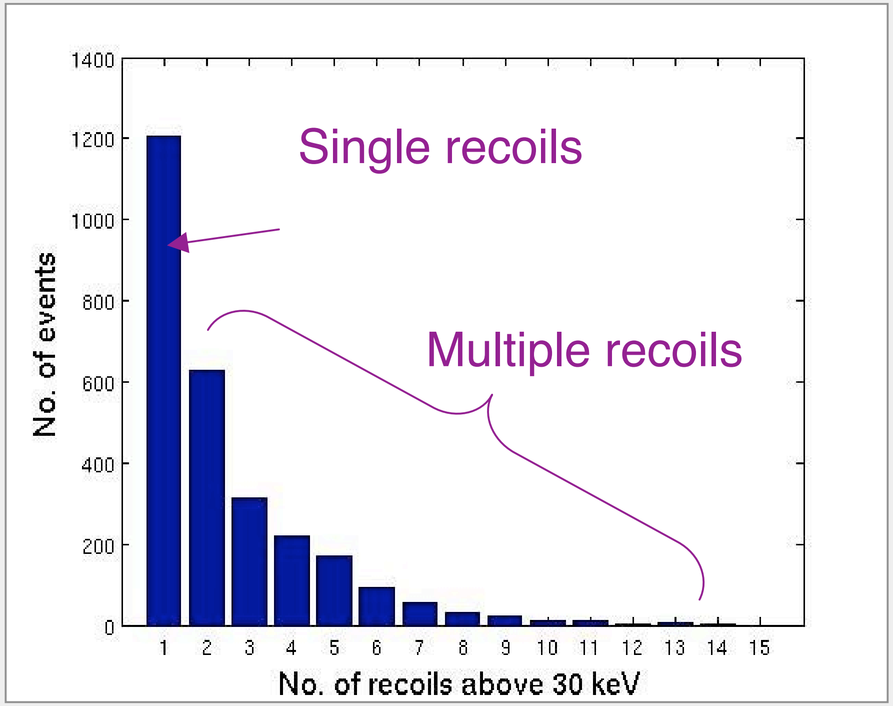
Compared with ~ 3500 WIMP events at $\sigma = 10^{-43}$ cm^2
→ low background materials important

Multiple and single neutron recoils

WIMP-argon cross section is very low ⇒ WIMP will not interact more than once
⇒ Neutron multiple scatters can be rejected

Geant4 simulation results:

Component	Multiple recoil percentage	WIMP-like events
Dewar	53 %	3 %
LEM	54 %	8 %
PMTs	56 %	4 %
Pillars	53 %	6 %



→ More than half of the neutrons scatter more than once
→ Less than 10% of the neutrons produce WIMP-like events
(single recoils, energy ∈ [30,100] keV)

Results depend strongly on the lower threshold energy!

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?

Conclusion

- Construction and first tests of the ArDM detector are ongoing
- Three technical keypoints:
  - High drift field
  - Charge readout with LEM
  - Light readout with PMTs
- After tests at CERN and presumably at shallow depth, the detector will be moved underground (presumably to the Canfranc underground laboratory in Spain)
- Depending on the rejection power, the ArDM detector reaches a sensitivity of the order of 10^{-8} pb
- The technique of ArDM is scalable. Larger detectors of 10 tons or more are a realistic perspective