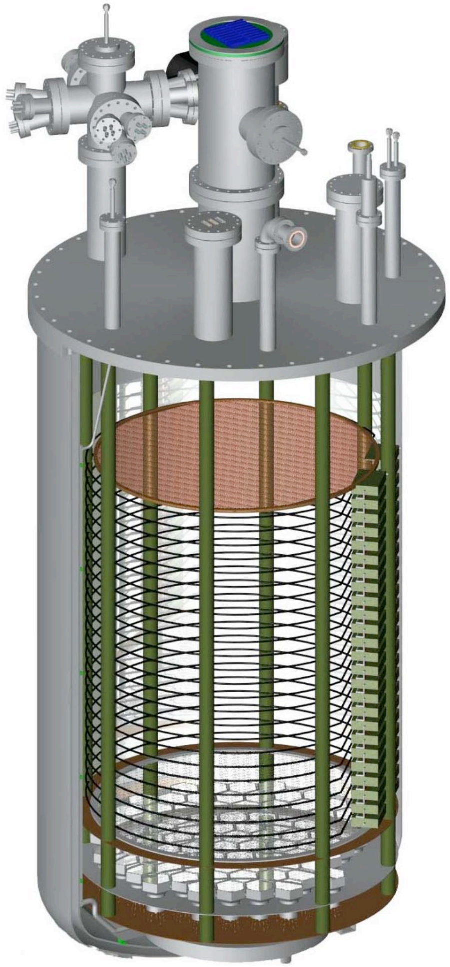
Status of the **Ar**gon **D**ark **M**atter experiment



1 ton liquid argon TPC/calorimeter for direct detection of DM

- **Motivation**
- **Experimental design**
- **Developments and status**
- **Time scale and outlook**

A.Rubbia (Zurich, ETH)
J.Phys.Conf.Ser.39:129-132,2006.

C. Regenfus
Zürich University

The ArDM group (6 institutes, 30 members)

A. Badertscher, L. Kaufmann, L. Knecht, M. Laffranchi, P. Lightfoot,
A. Marchionni, G. Natterer, P. Otiougova, A. Rubbia, J. Ulbricht
ETH Zurich, Switzerland

C. Amsler, V. Boccone, S. Horikawa, C. Regenfus, J. Rochet
Zurich University, Switzerland

A. Bueno, M.C. Carmona-Benitez, J. Lozano, A. Melgarejo, S. Navas-Concha
University of Granada, Spain

M. Daniel, P. Ladron de Guevara, L. Romero
CIEMAT, Spain

P. Mijakowski, P. Przewlocki, E. Rondio
Soltan Institute Warszawa, Poland

H. Chagani, P. Majewski, M. Robinson, N. Spooner
University of Sheffield, England

Outline

- Measure of WIMP recoil E-spectrum
- Prototype unit for large LAr detectors

- Energy threshold ~30 keV,
- 3-D imaging
- Event-by-event interaction type identification
- Trigger rate below 1 kHz

Estimated event rates on argon target (assuming recoil energy threshold ≈ 30 keV)	$10^{-42} \approx$ 100 events/ton/day $10^{-44} \approx$ 1 event/ton/day

- Development of a next generation DM detector

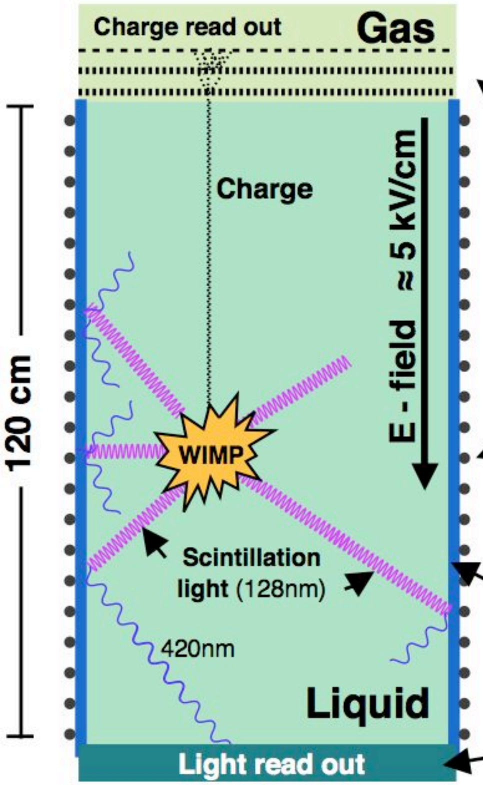
  Status: Basic R&D finished => Now in construction phase
- LAr has the potential for large and very large projects
- We try to explore the low energy frontier of this technology
- Liquid noble gas detectors still bear space for developments

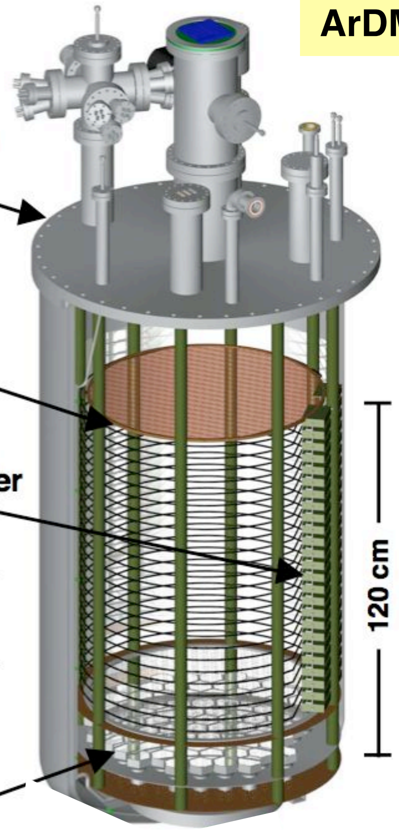
Needed:
- Large volume high electric field
- Large area position sensitive charge readout (3rd-dimension from drift time)
- Large area VUV sensitive light readout with good time resolution (=> trigger)
- Efficient liquid argon purification system
- Careful choice of used (non radioactive) materials

ArDM: Conceptual design

WIMP (rec. 30 keV) ≈ 400 VUV phot. + ≈ 3 e^-

ArDM bi-phase detection principle





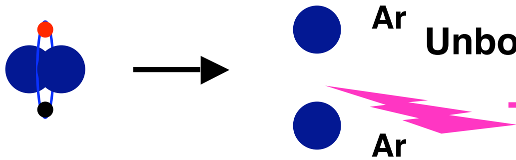
- Drift length ≈ 120 cm
- 850 kg target
- Drift field: 1..4 kV/cm
- LEM on top: gain ≈10^4
- PMTs at bottom: eff. ≈ 2%
- Trigger rate < 1kHz
- DAQ: FADCs, buffer length ≈ 1ms

Back ground rejection strategies:

- Topology: (e.g. multiple elastic scatters from neutrons)
- Localization: (fiducial volume)
- Ionization density discrimination:
    - ratio of ionization to scintillation primary rejection against electron recoils
    - time distribution of the scintillation light is used to discriminate further (promising in Ar)

Scintillation mechanism, light pulse shape

Argon eximer $^1\Sigma_u$, $^3\Sigma_u$



Unbound ground state $^1\Sigma^+_g$

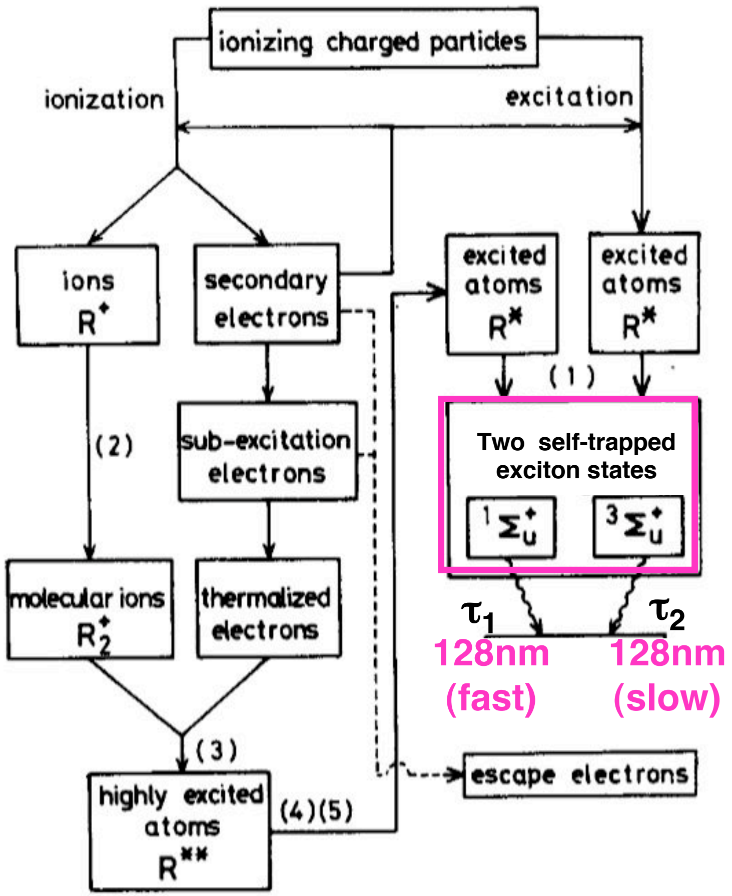
+ 128±5 nm photon

(not absorbed in mol. Ar)

Similar to alkali halide crystals (~40ph/keV)

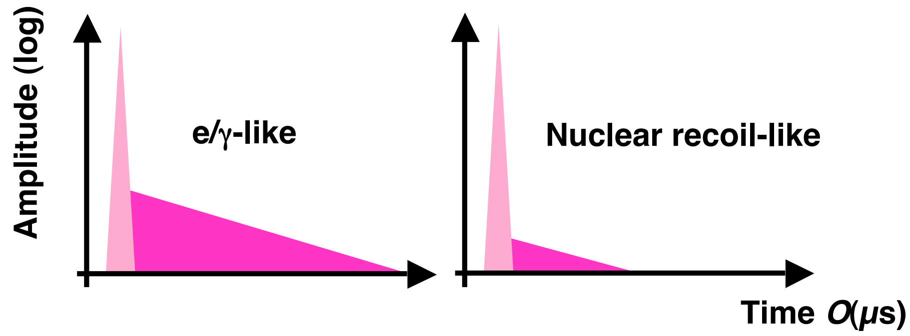
Complicate production process

Ionisation density dependent ratio (N_{trip} / N_{sing})



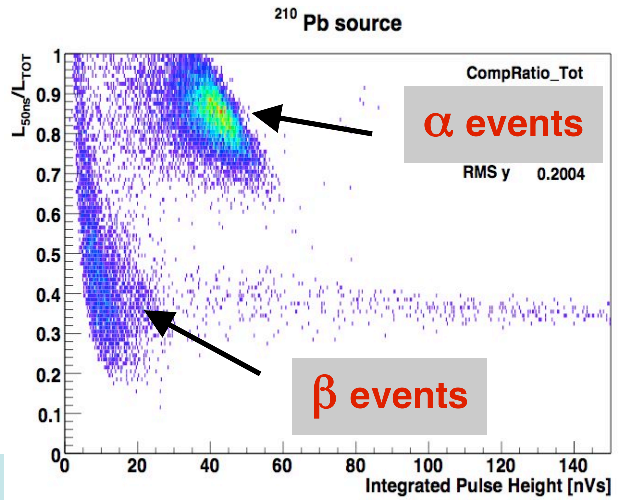
M. SUZUKI, J. RUAN and S. KUBOTA, NIM 192 (1982) 565

LAr: two characteristic decay times: 5ns, 1.6μs



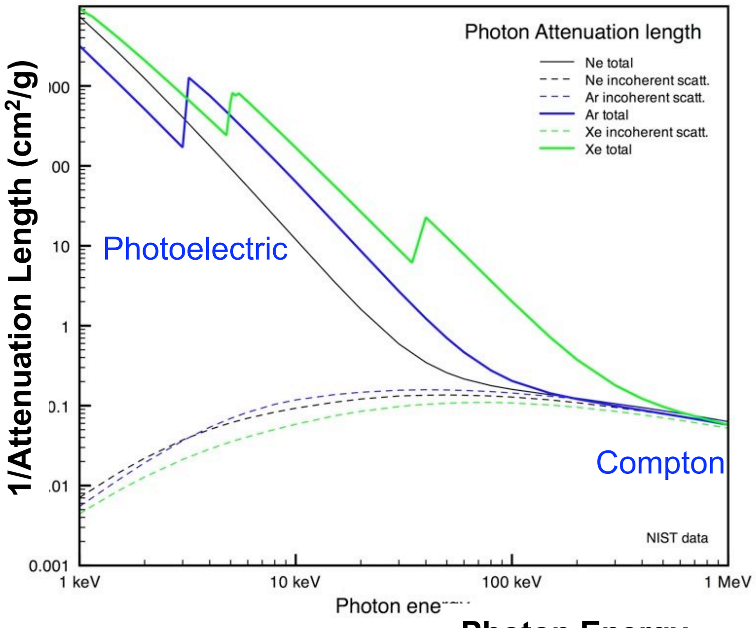
First measurements of ionization density effect

In test chamber in the lab



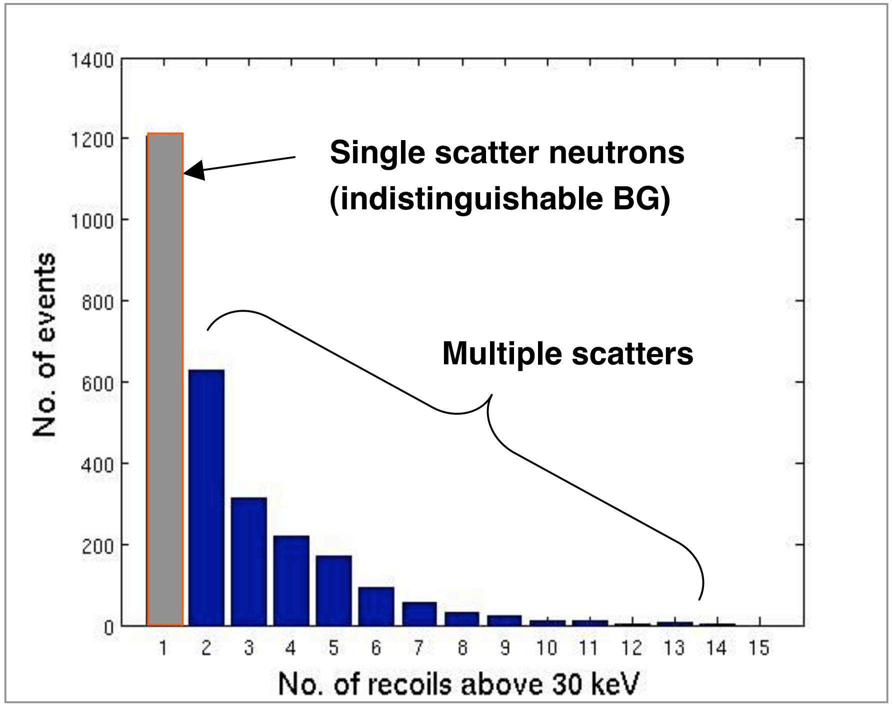
Large mass features

Good: Self shielding (external BG sources)



LAr: X_0 = 14cm

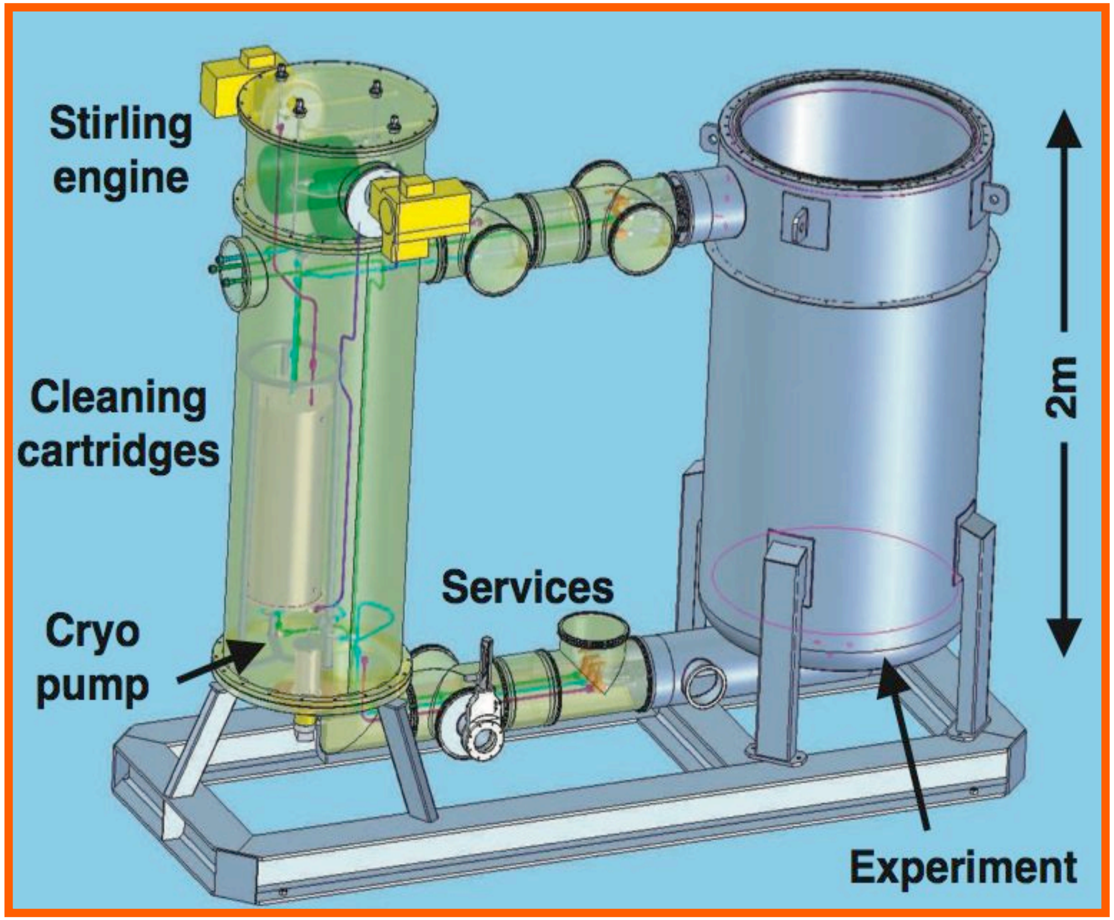
GEANT neutron MC for ArDM

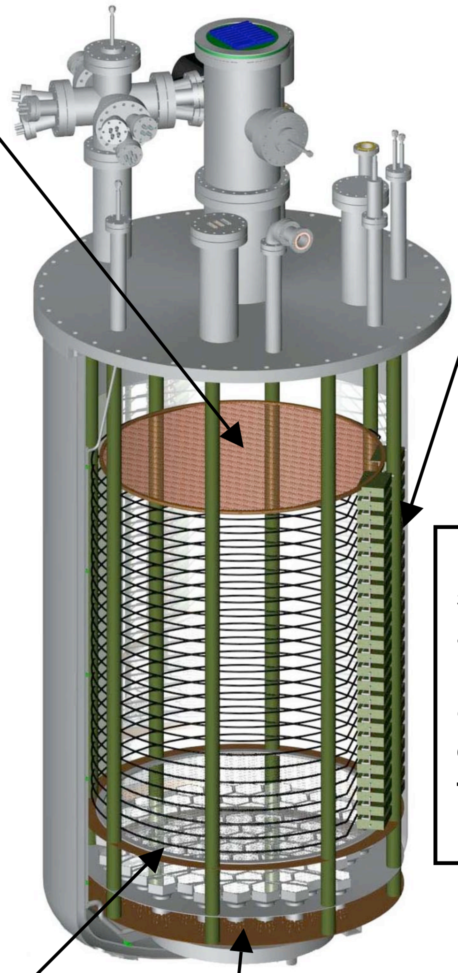


Problem: Self activity of target (e.g. ^{39}Ar, β Q=565keV)

- **To be suppressed (high BG suppression)**
  -> Trigger rate (selective trigger)
- **Deplete target (liquefy well gases)**

Hardware

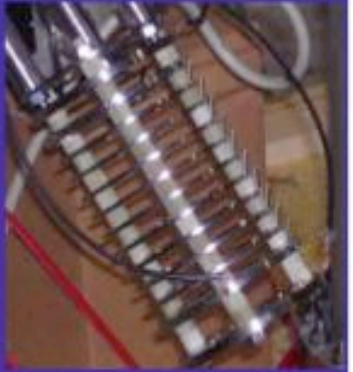

Stirling engine
Cleaning cartridges
Cryo pump
Services
Experiment
2m


Greinacher chain: voltages to the field shaper rings and the cathode (500 kV)
Two-stage LEM for electron multiplication and readout
Field shapers for a vertical homo-geneous electric field
Transparent cathode
14 8” PMTs below the cathode to detect the scintillation light

Slow control

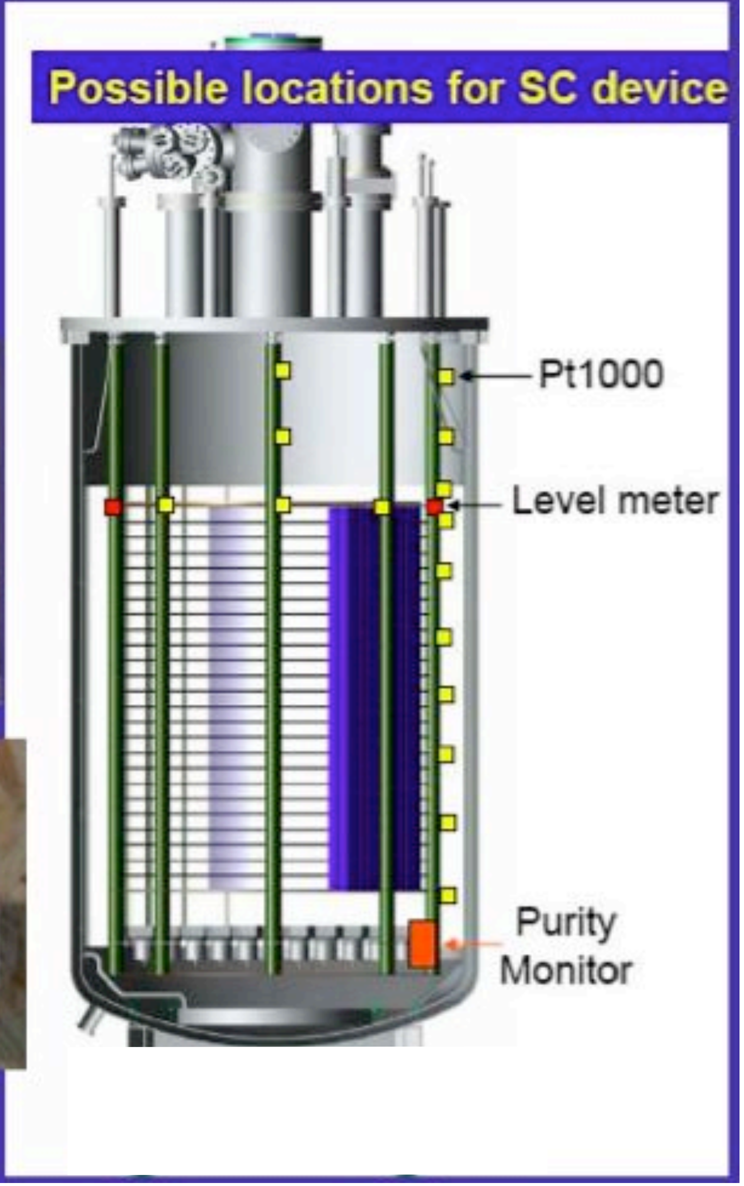
- A series of custom-designed slow control devices have been built.
- They have been installed on the detector.
- They will monitor the behavior of the detector.

Pt1K



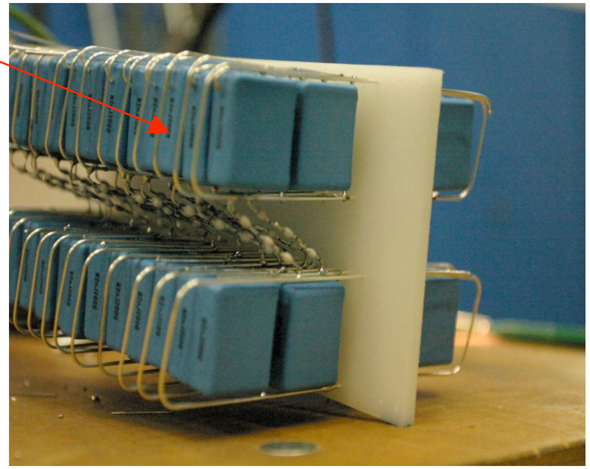
Purity monitor

Levelmeter

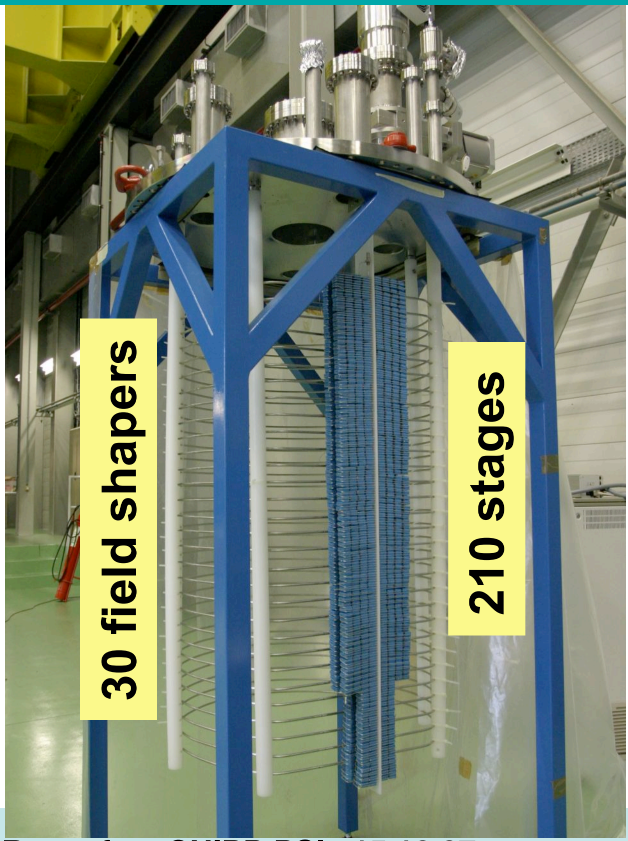


HV - generator (placed in the liquid)

- A cascade of rectifier cells (Greinacher/Cockroft-Walton circuit) is used
- Aim to reach V_{tot} = 500 kV, i.e. ≈ 4 kV/cm
- Tests in liquid nitrogen have been performed
- The largest system successfully operated consists of 210 stages (stable operation in air up to 120 kV)



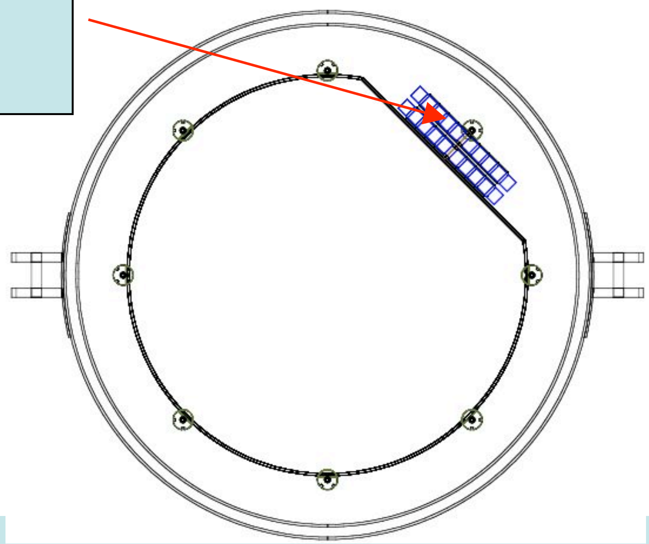
Mounted on the field shaper rings



Polypropylene capacitors

82 nF
2.5 kV/stage
200 stages

Top view

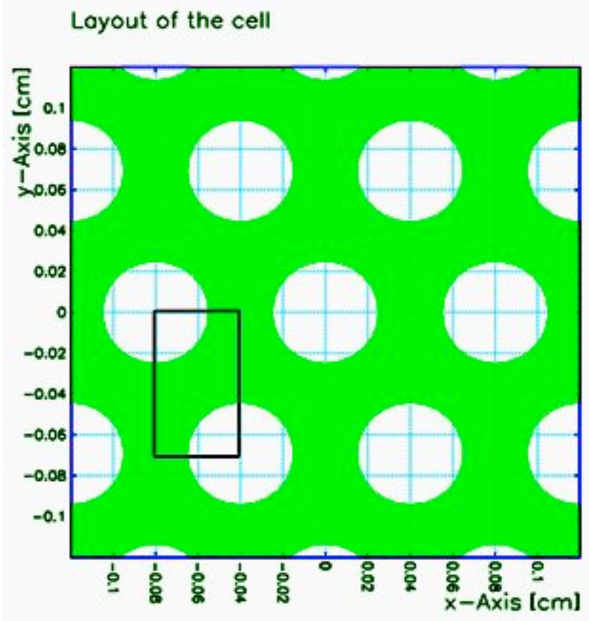


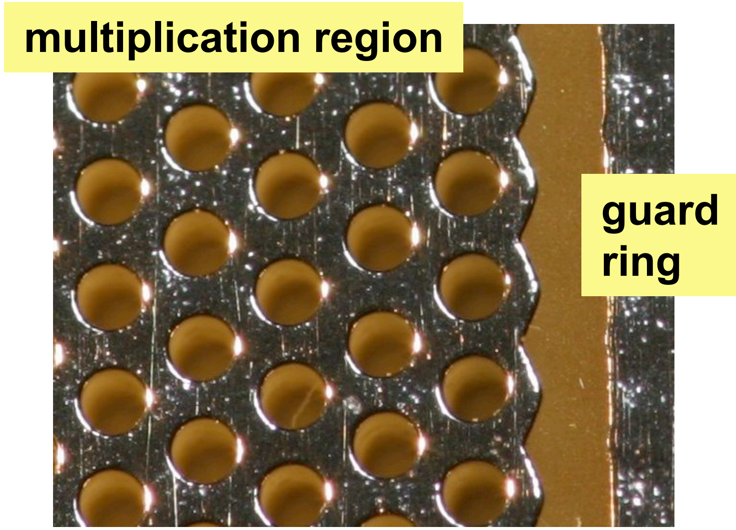
Charge read out system (LEM)

• GEM: F. Sauli, NIM A386 (1997) 531
• Optimized GEM: V. Peskov *et al.*, NIM A433 (1999) 492
• THGEM: R. Chechik *et al.,* NIM A535 (2004) 303

LEM (Large Electron Multiplier) is a thick macroscopic GEM

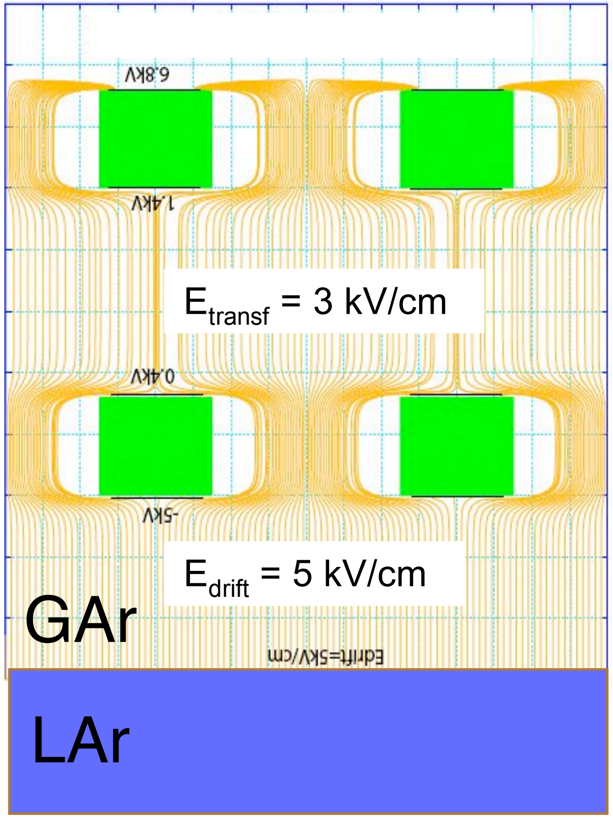
Produced by standard Printed Circuit Board methods





- Double-sided copper-clad (35 µm layer) G-10 plates
- Precision holes by drilling
- Palladium deposition on Cu (<~ 1 µm layer) to avoid oxidization
- Single LEM Thickness: 1.5 mm
- Amplification hole diameter = 500 µm
- Distance between centers of neighboring holes = 800 µm

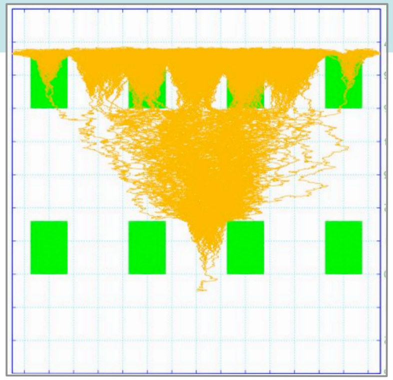
Double stage LEM



→ Distance between stages: 3mm

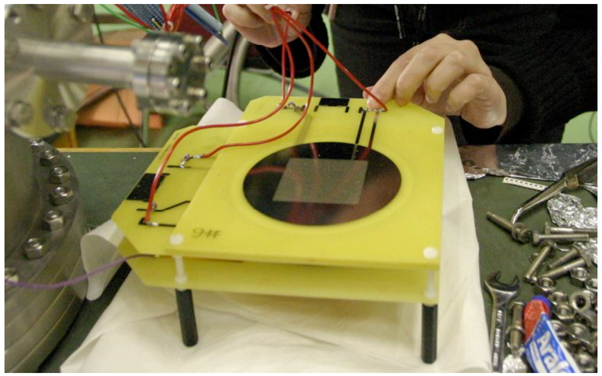
→ Avalanche spreads into several holes at second stage

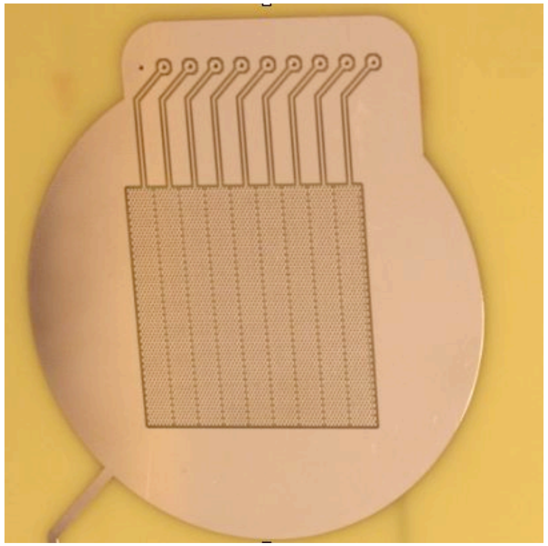
→ Higher gain reached as with one stage, with good stability



Simulation of avalanche

- **A stable gain of 10^4 has been measured**
- **Successful operation in double phase LAr mode**



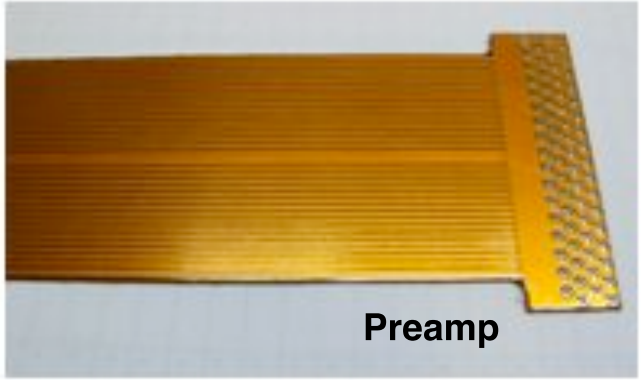


Prototype of a segmented LEM. Strip width: 6mm

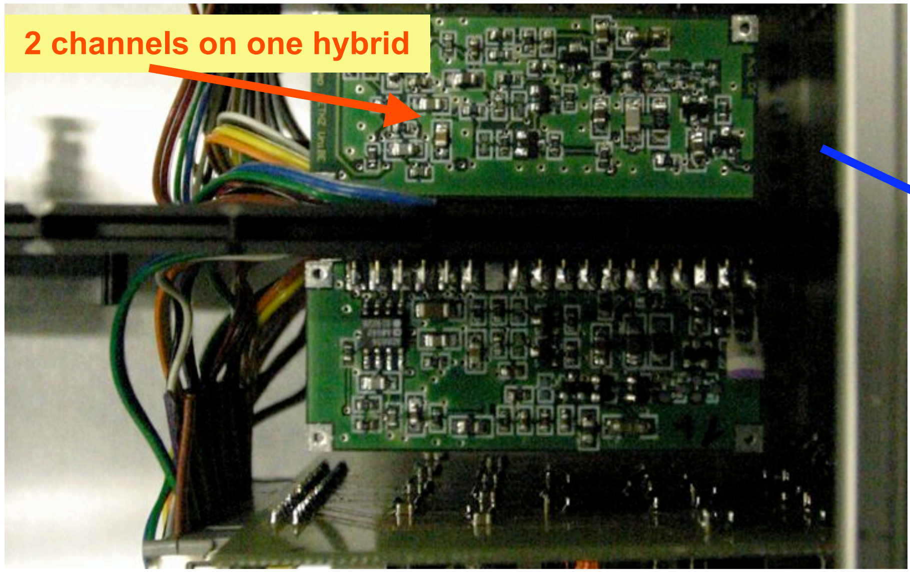
- **Final LEM charge readout system will be segmented**
- **Orthogonal strips for x-y**
- **Number of channels: 1024**
- **Strip width: 1.5mm**

LEM: Kapton Flex-Prints and read out electronics

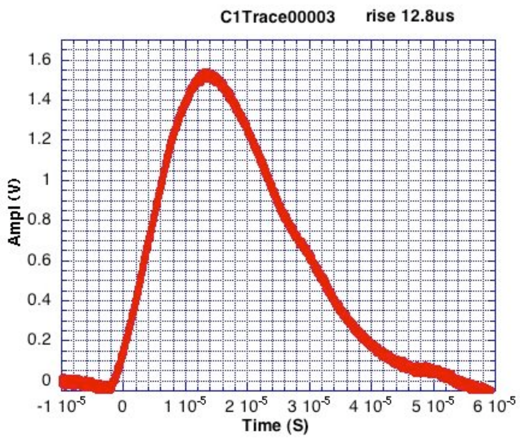
- Used for signal transfers to the readout electronics
- Sealed with epoxy-resin in a vacuum tight feed-through flange



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



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



Signal from double-phase setup

- Primary challenge is the short wavelength (128nm)
- VUV 9.7eV; needed MgF_2 window PMT or WLS
- Use WLS (TPB 420nm 2.9eV) + reflectors
- 14 Bialkali 8" PMTs on the bottom (sngl. photon)
- Projected light yield 2%

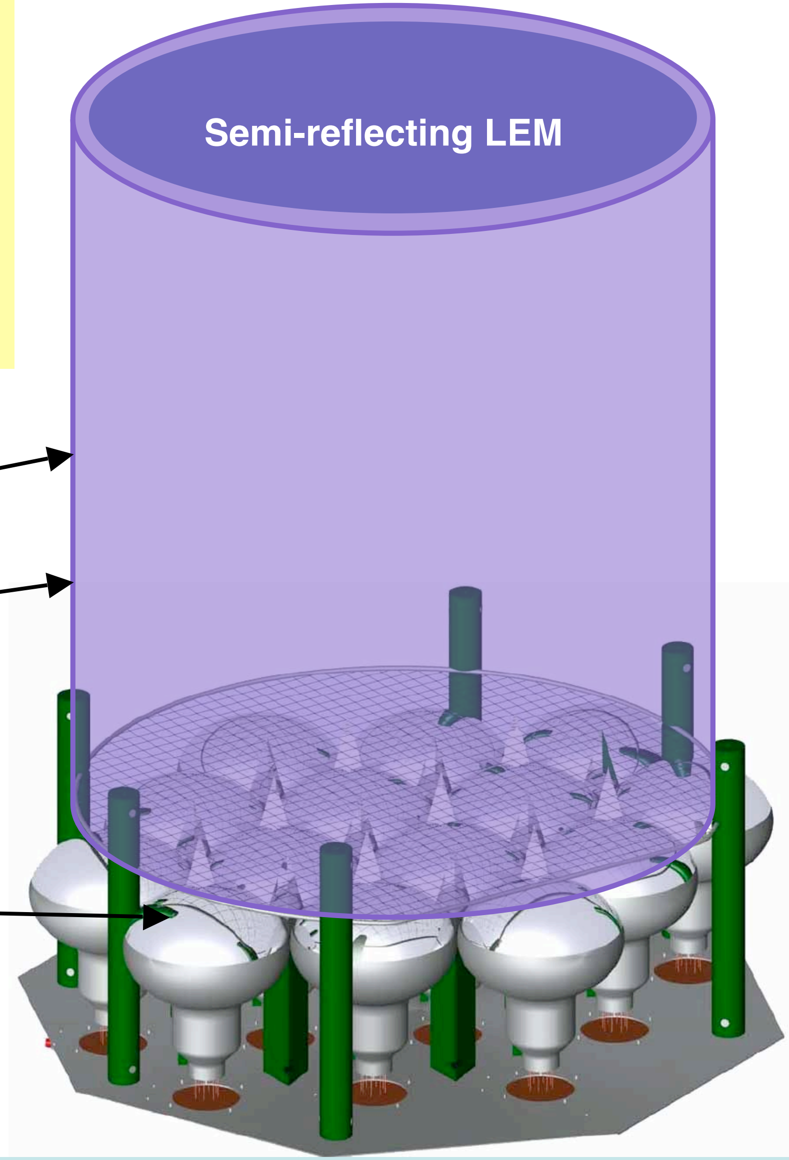
Prototype :Hamamatsu R5912-02MOD

Wavelength shifter (evaporated onto inner surface)
- TPB (Tetra-phenyl-butadien)

Reflector materials:
- Tetratex
- 3M foil

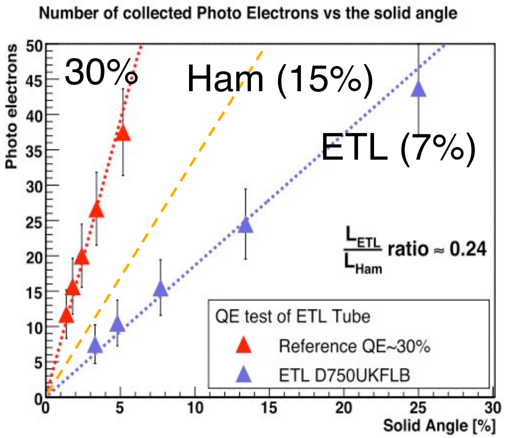
PM coatings:
- opaque TPB only
- transparent TPB/PS

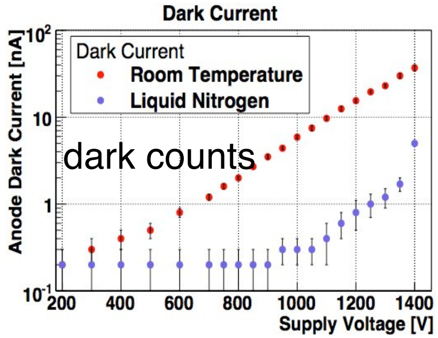
Arrangement

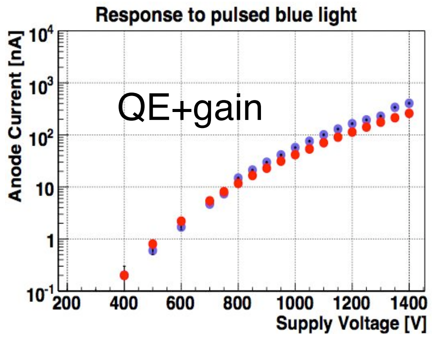


8” cryogenic PMTs

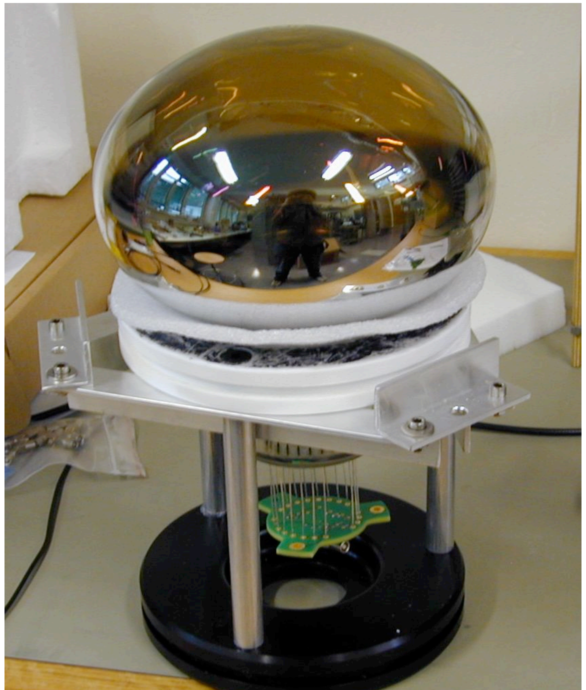
3”





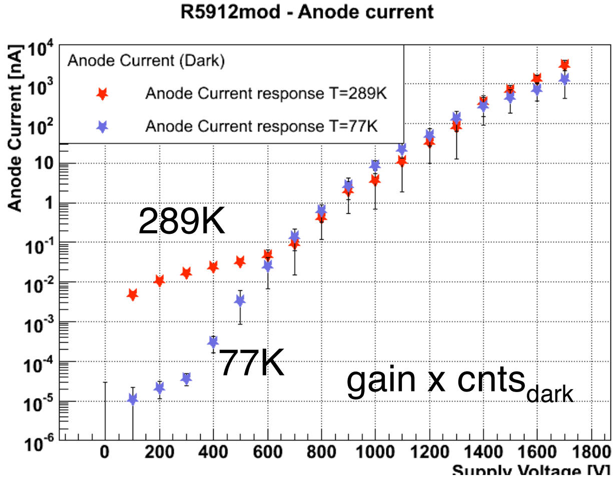


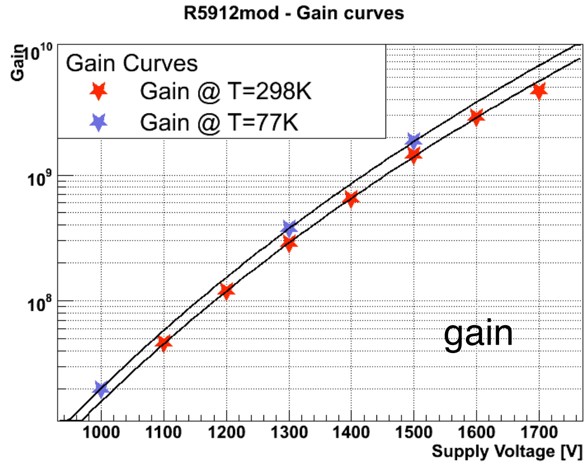
8” hemispherical
Pt underlay
14 dynodes
QE > 15%
4000 CHF/PMT



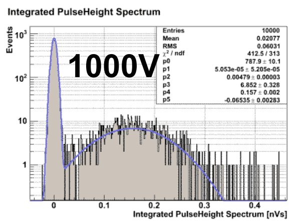
Prototype: Hamamatsu R5912-02MOD

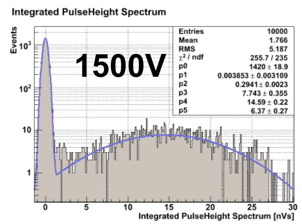
8”





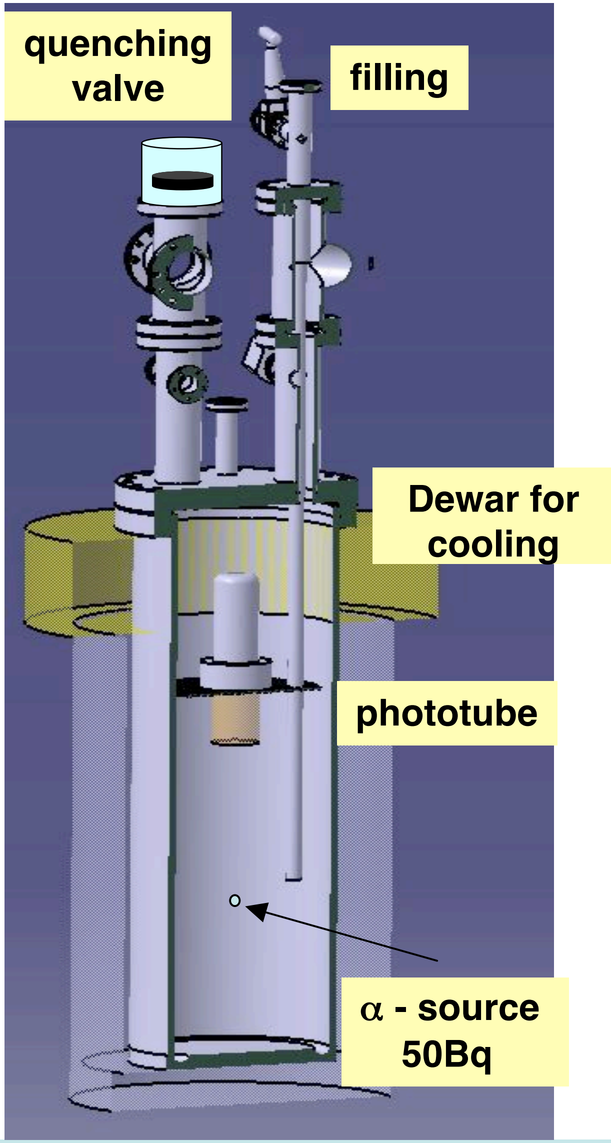
Single photon spectra





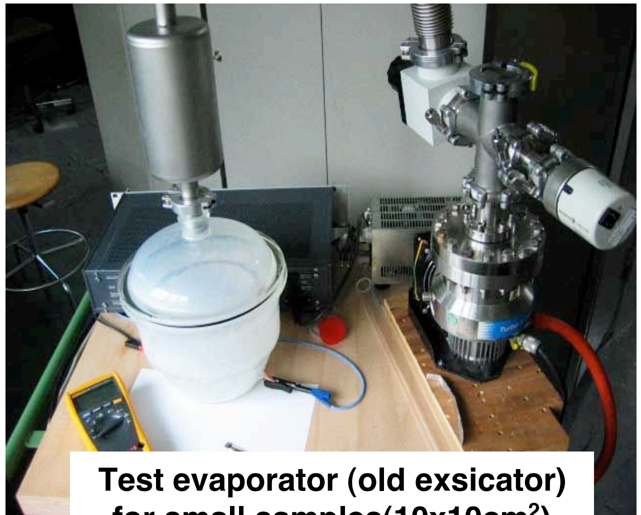
R&D efforts

5 liter test chamber



- Develop VUV read out in a test setup in the lab (light yield)
- Use radioactive sources (^{210}Pb: α 5.3 MeV, β^{-} 1.16 MeV)
- First with GAr and later with LAr
- Investigate purity effects
- Resolution, light yield, ionisation density dependence (incl. spread) at low recoil energy (neutron source)

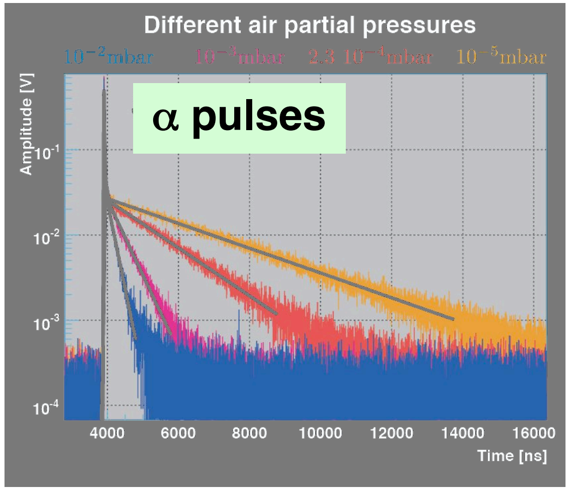
- WLS is deposited by spraying or evaporation
- Thickness determined from the weight

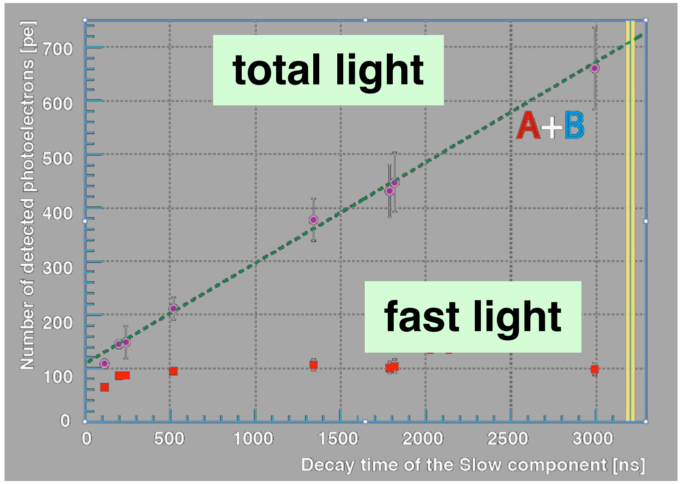


Test evaporator (old exsicator) for small samples(10x10cm^2)

Light yield measurements in argon gas

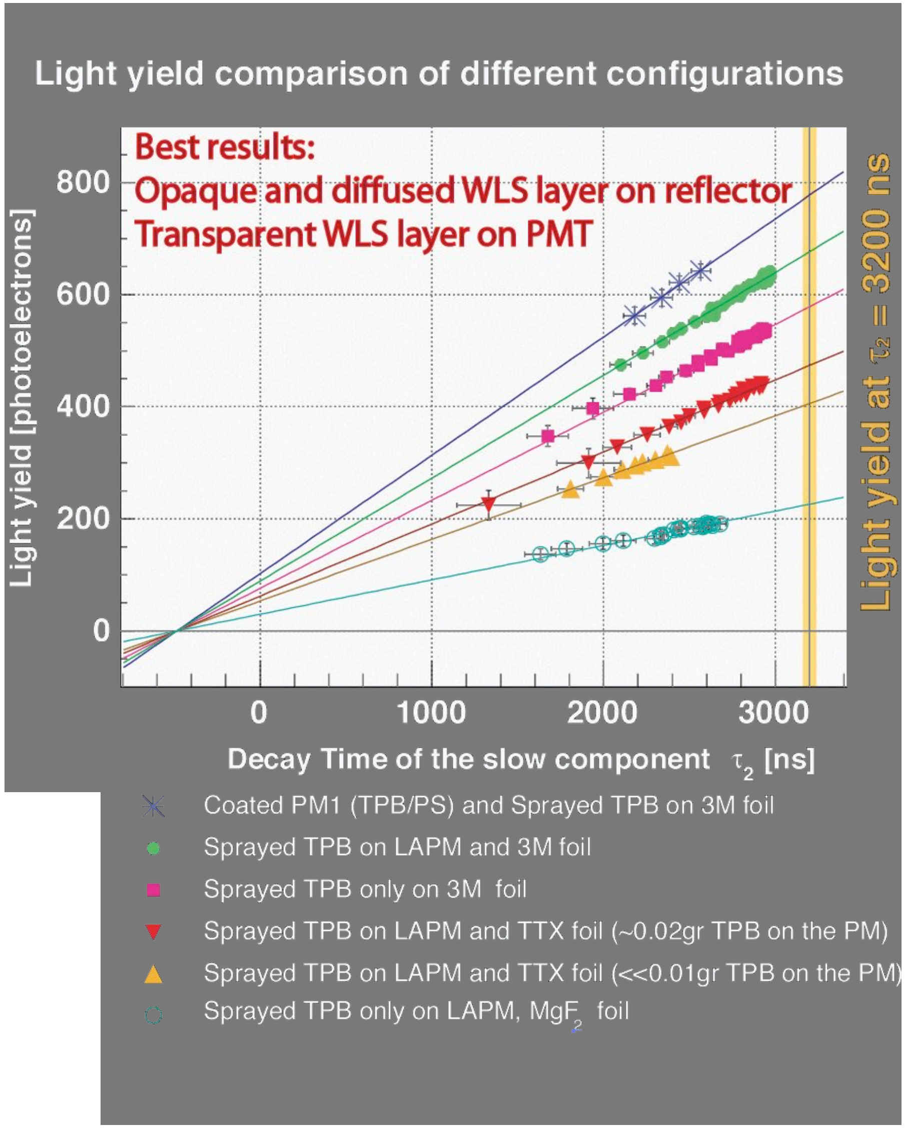
Calibration (to the purity of GAr)





C.Amsler et al., *"Luminescence quenching of the triplet excimer state by air traces in gaseous argon"* arXiv:0708.2621

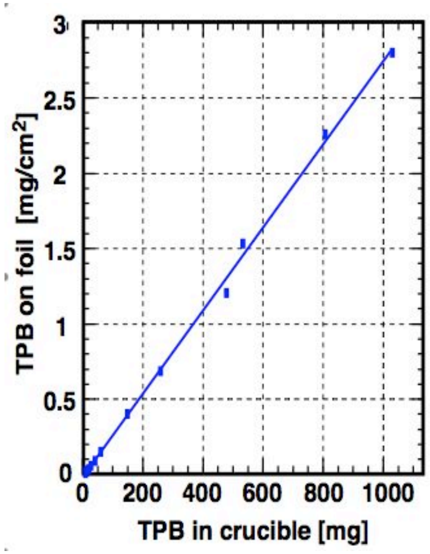
Choice of the reflector type

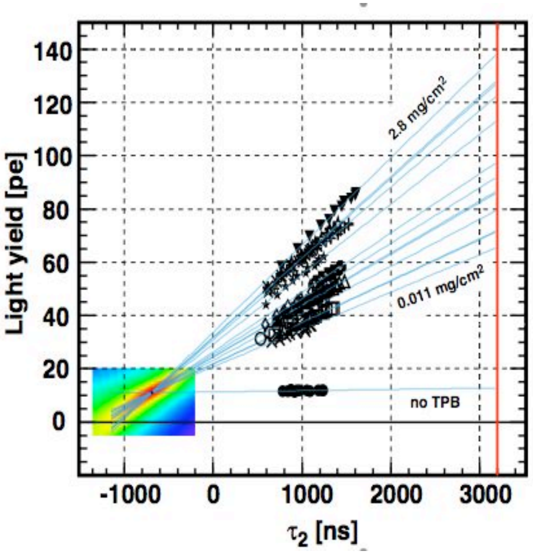


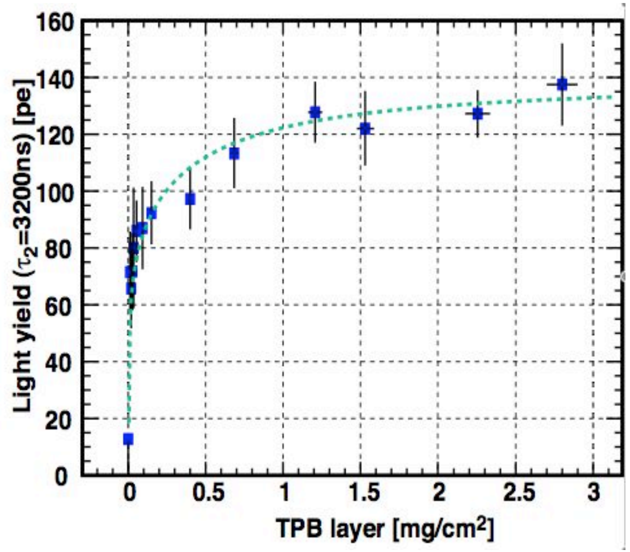
TPB VUV conversion efficiency measurement

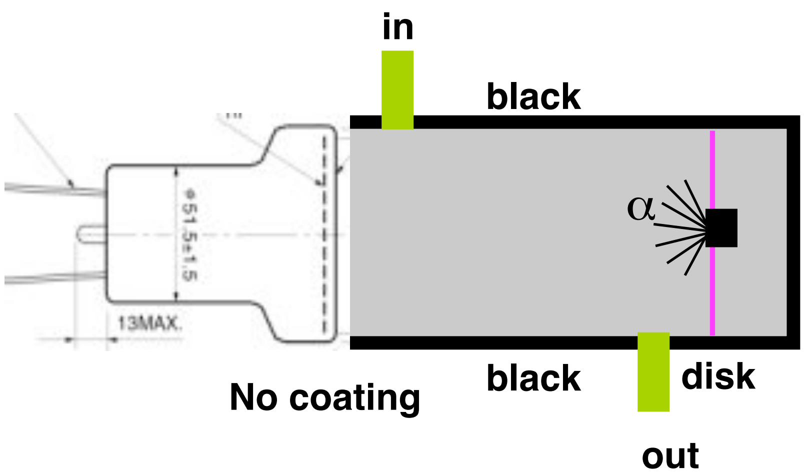
Hugo Cabrera (Master thesis)

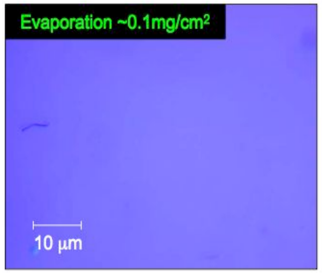
On a variety of evaporated samples, measured under flushing with GAr

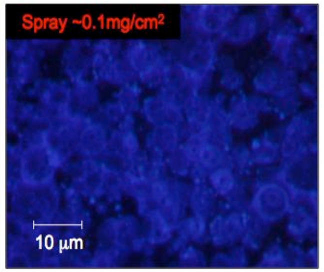












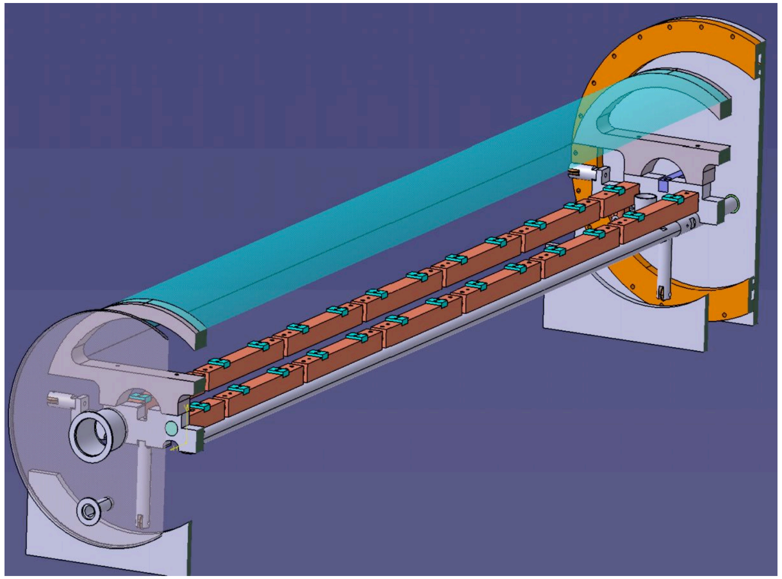
Done with 3M foil as base

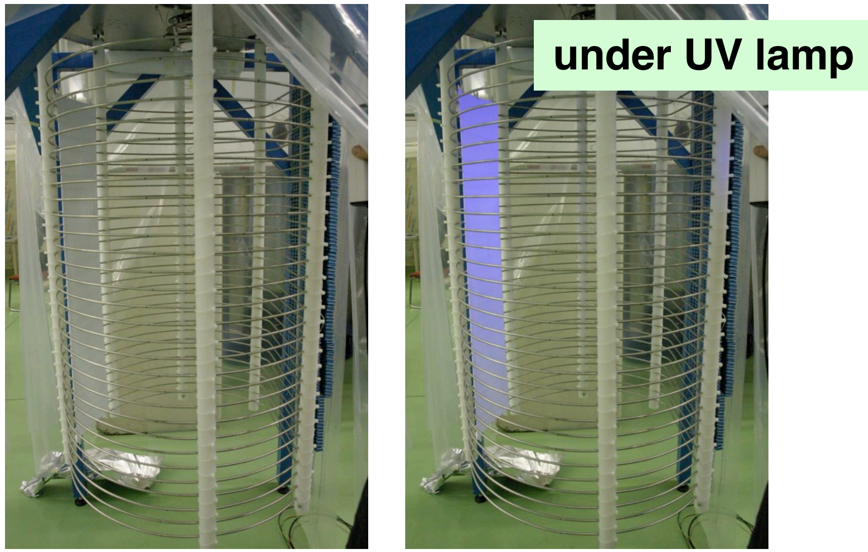
TTX seems to improve light yield (~10%?)

Reliable evaporation thickn. (~ filling of crucible)

Conclude: a layer of 1mg/cm² will do

Large scale evaporator





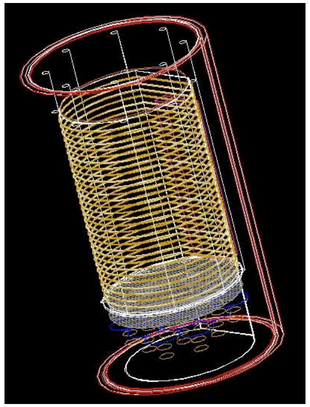
- 13 crucibles in series
- Holder for stiff and soft material
- Constant solid angle in phi
- Tested with various reflector material
- Reflectors for experiment produced

Background studies

Background sources:

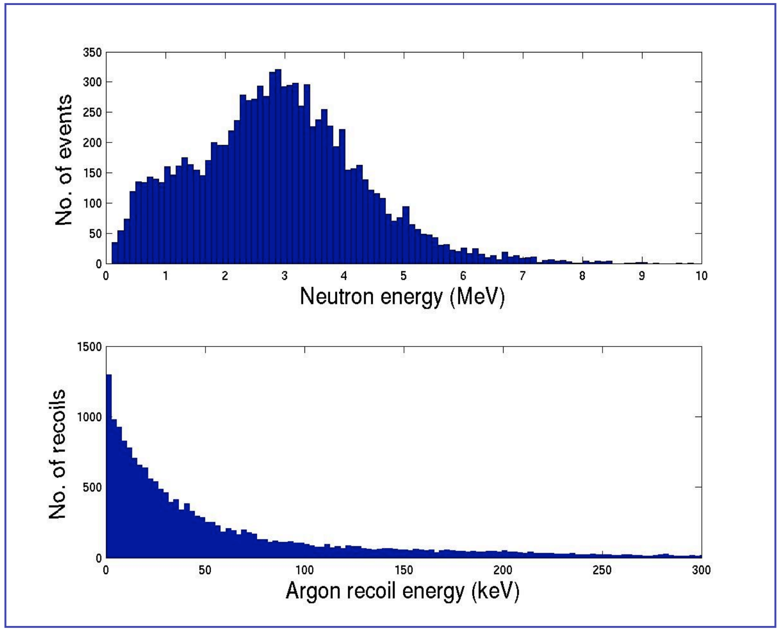
Neutrons: radioactive material (mainly U/Th contaminations) and from muons

(neutron events look like WIMP-events)



Full Geant4 detector simulation

Electrons/Gammas: from radioactive elements

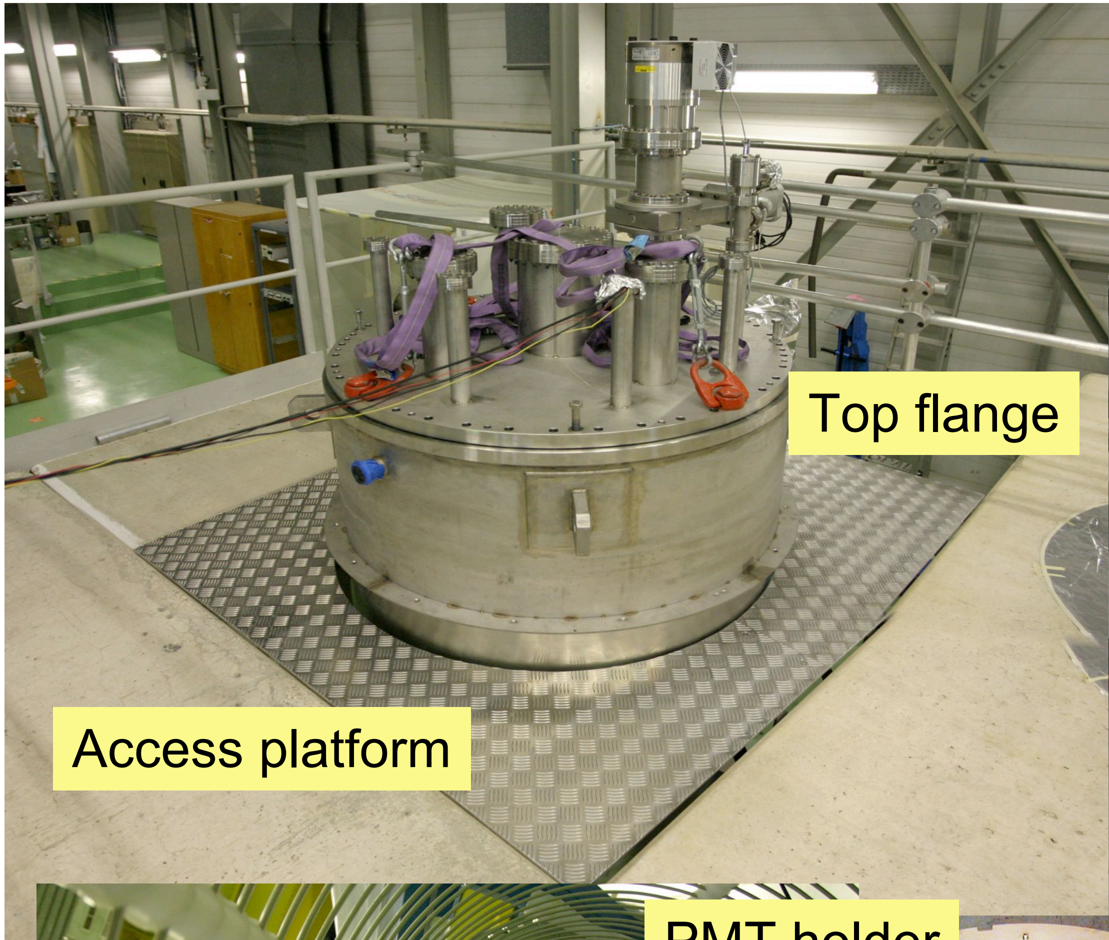


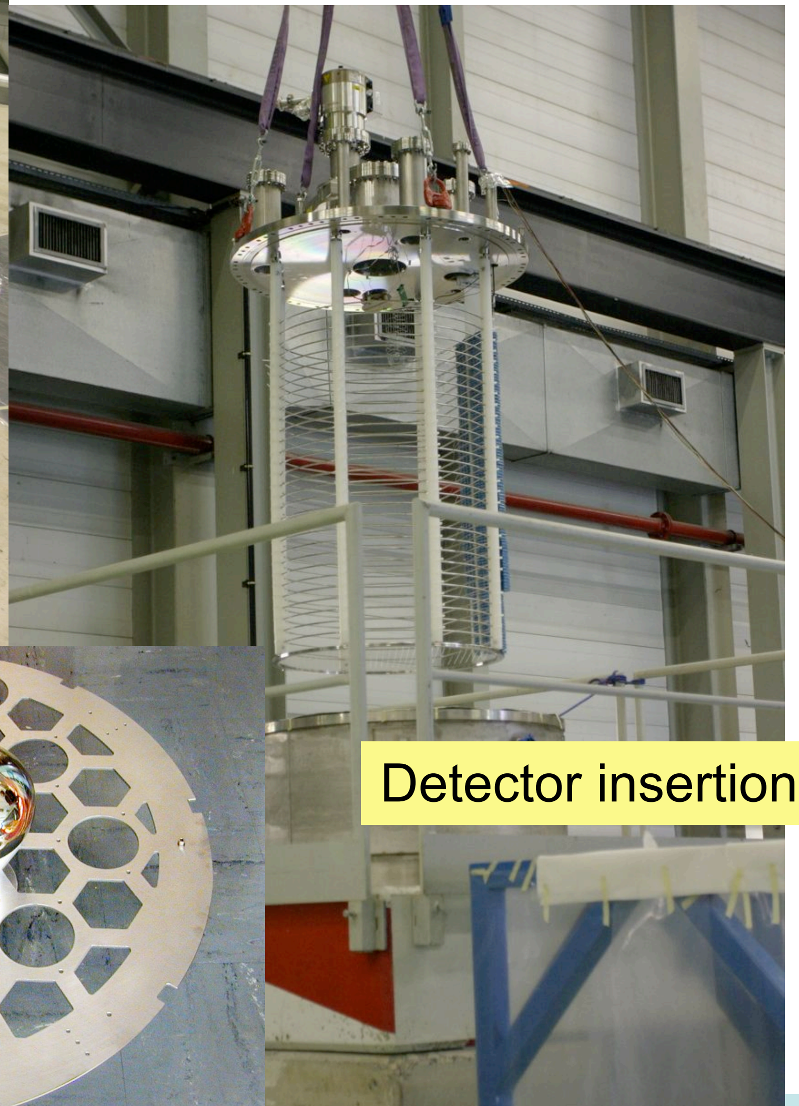
Component	n events per year	WIMP-like recoils
Container	~ 400	~ 30
LEM (std. mat.)	~ 10000	~ 900
LEM (low bg. mat.)	< 20	< 2
14 PMTs (std. mat.)	~ 12000	~ 1000
14 PMTs (low bg. mat.)	~ 600	~ 50

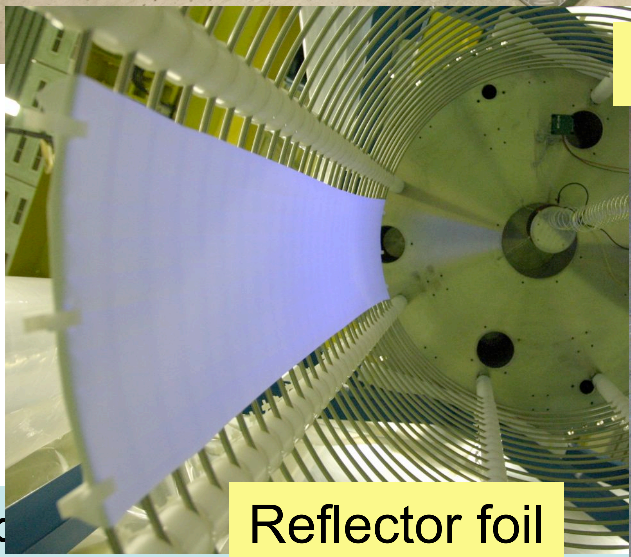
30 keV threshold

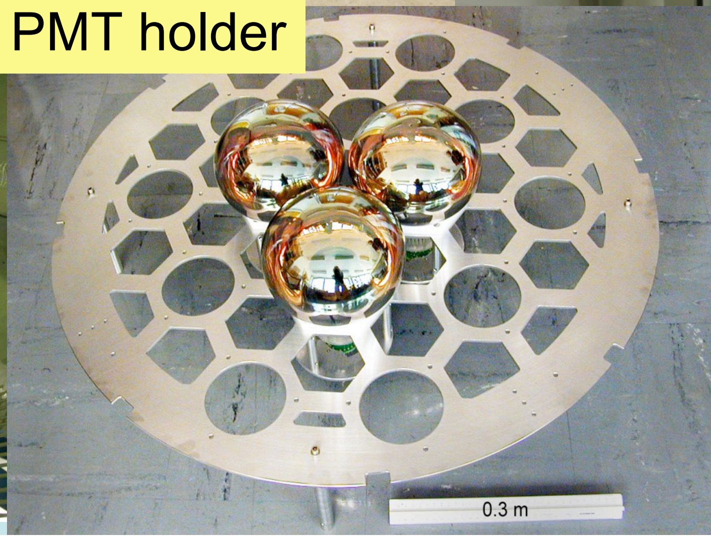
Compared to ~ 3500 WIMP events at $\sigma = 10^{-43}$ cm2 => low background materials important

Assembly at CERN









Near future strategy (2007 at surface, CERN)

- **First full assembly over the next months**
  - Full mechanics (cooling engine later)
  - Liquid recirculation and purification
  - Include 8 PMTs
  - HV system
  - LEM next year

- Verify light collection efficiency
- Test HV system at low temperature over long periods
- Commission slow control system
- Test purification technology
- Calibrate with γ and n sources
- Test light/charge ratio discrimination
- Test pulse shape discrimination
- Study cleanliness of detector

Test underground at shallow depth 2008?

We then want to take ArDM underground to fully study the performance and capabilities of the concept in realistic background conditions.

Outlook

- We confirmed the performance of individual detector components
- We should soon operate the full scale prototype
- This 1-ton prototype is being assembled at CERN to be run in a first phase above ground this year
- Following a successful operation above ground, we will consider a deep underground operation
- Our proposal to install at the Canfranc Underground Laboratory was strongly encouraged by the LSC Scientific Committee in July 2006.
- The expected sensitivity of the underground prototype should be 10^{-42} cm^2 to 10^{-44} cm^2 , depending on the background rejection power.
- This technology could provide the means to develop larger detectors to reach sensitivities below 10^{-44} cm^2 SI cross-section.