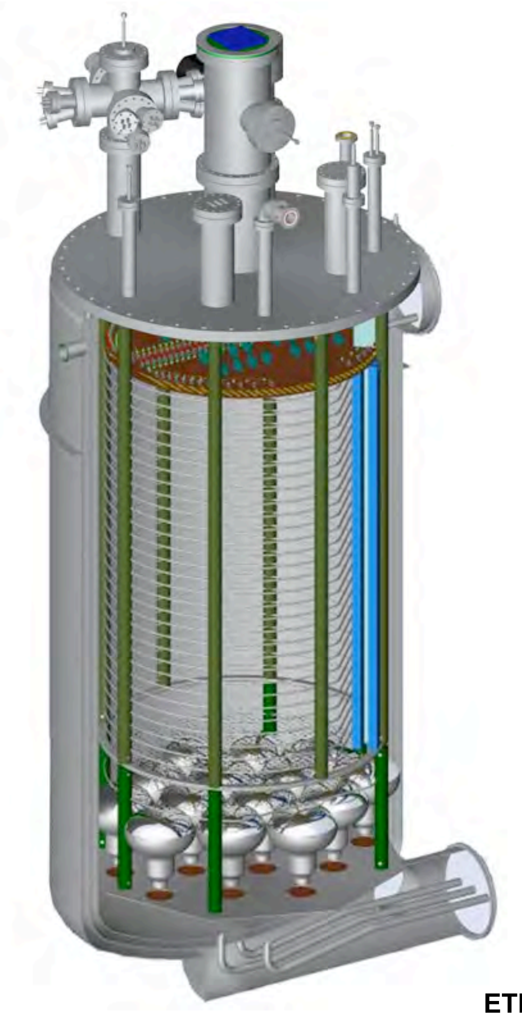
# The **Ar**gon **D**ark **M**atter experiment



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

- **Experimental outline**
- **Developments**
- **Status**
- **Outlook**


**C. Regenfus Zürich University**
**on behalf of the ArDM collaboration**

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# 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) | $10^{-42}$ ≈ 100 events/ton/day<br>$10^{-44}$ ≈ 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:**

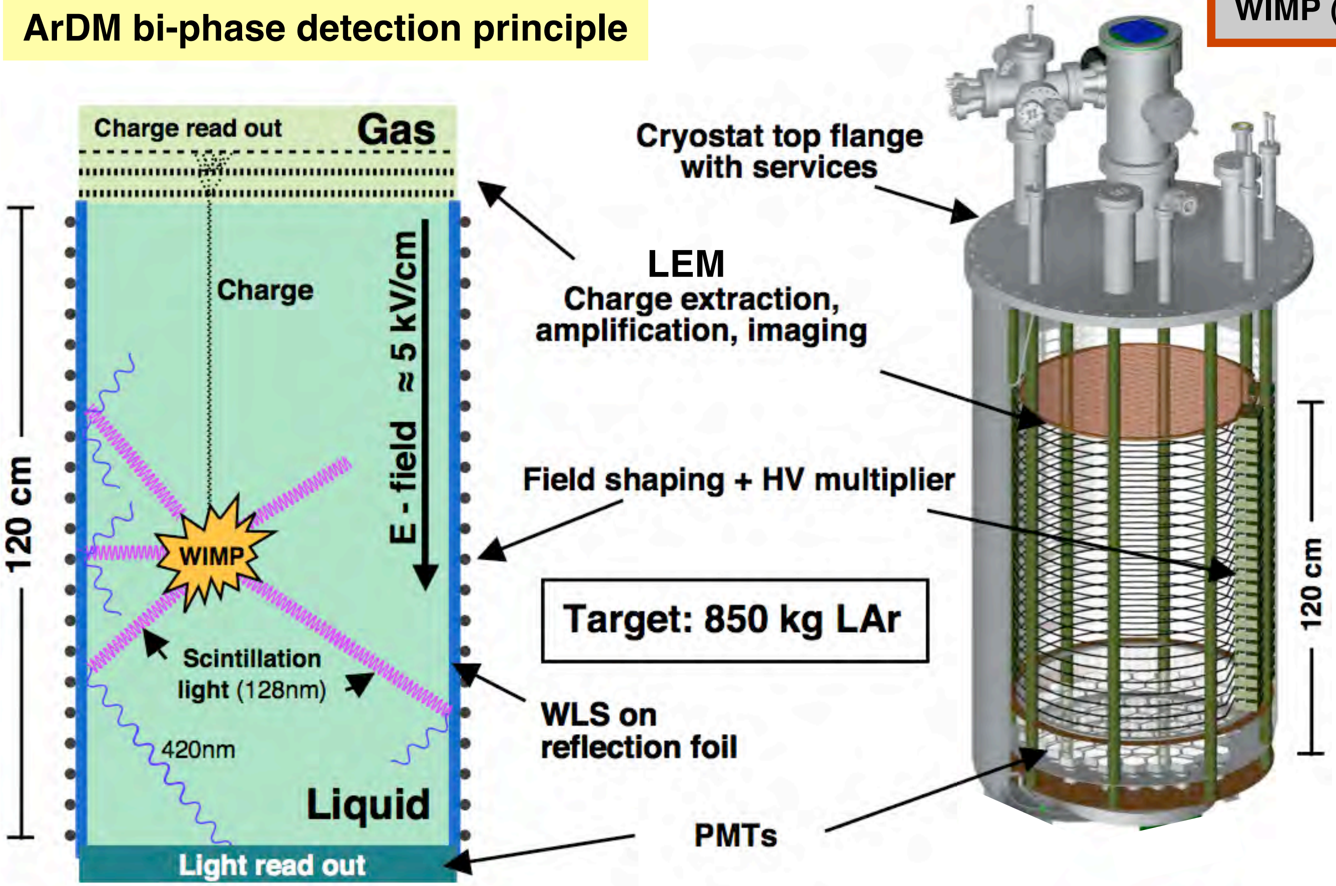
- Large volume high electric field
- Large area position sensitive charge readout (3rd-dimension from drift time)
- Large area VUV sensitive light readout with good time resolution (=> trigger)
- Efficient liquid argon purification system
- Careful choice of used (non radioactive) materials

→ TPC

# ArDM: Conceptual design

**WIMP (rc. 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: res ≈ [mm], gain ≈ $10^4$
- PMTs at bottom: eff. ≈ 2%
- Trigger rate < 1kHz
- DAQ: FADCs, buffer length ≈ 1ms

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

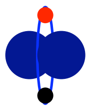
## Background rejection strategies:

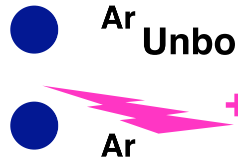
- **Topology:** (e.g. multiple elastic scatters from neutrons)
- **Localization:** (fiducial volume, 3D imaging)
- **Ionization density discrimination:**
  - **ratio of ionization to scintillation:** primary rejection against electron recoils
  - **time distribution of the scintillation light** is used to discriminate further (promising in Ar)

# Scintillation mechanism, light pulse shape

Argon eximer

$^1\Sigma_u$, $^3\Sigma_u$






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

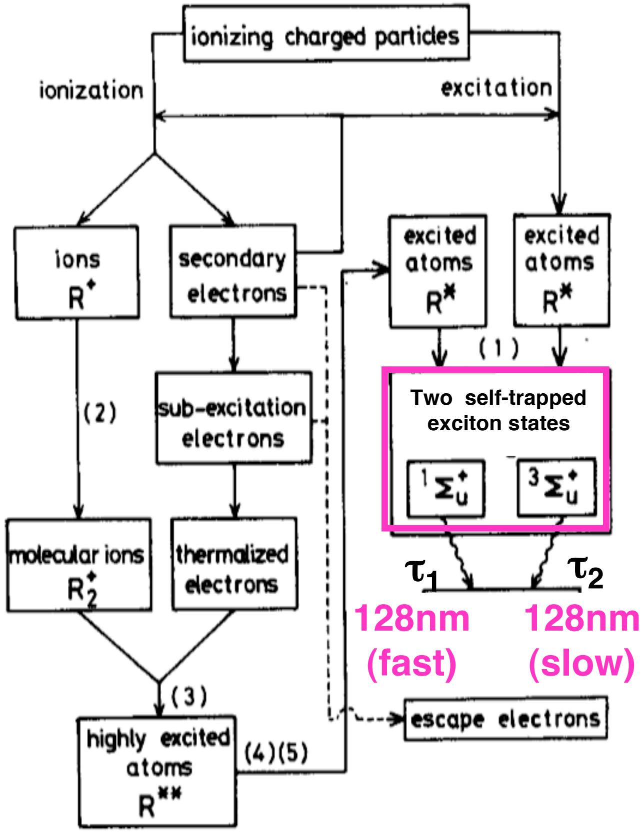
+ 128±5 nm photon

(not absorbed in mol. Ar)

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

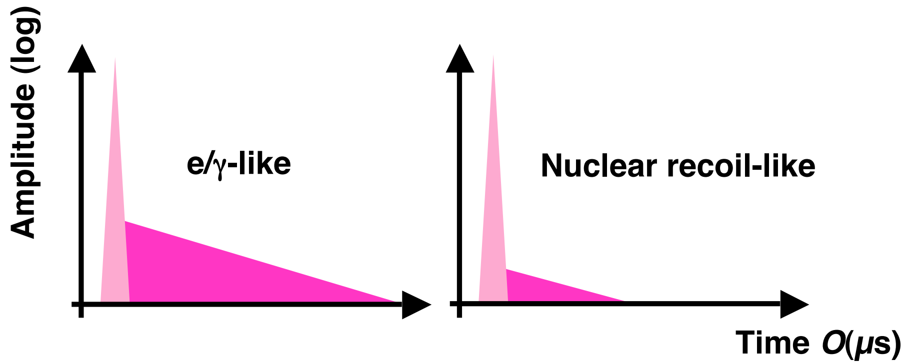
Complicate production process

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

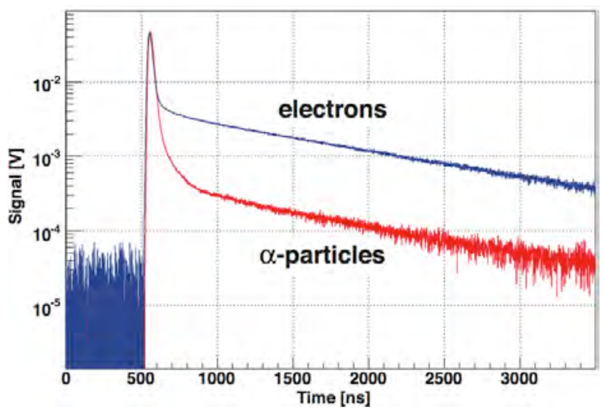


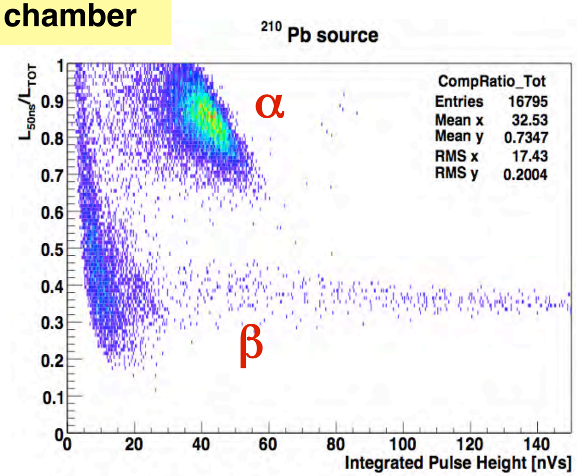

M. SUZUKI, J. RUAN and S. KUBOTA, NIM 192 (1982) 565

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



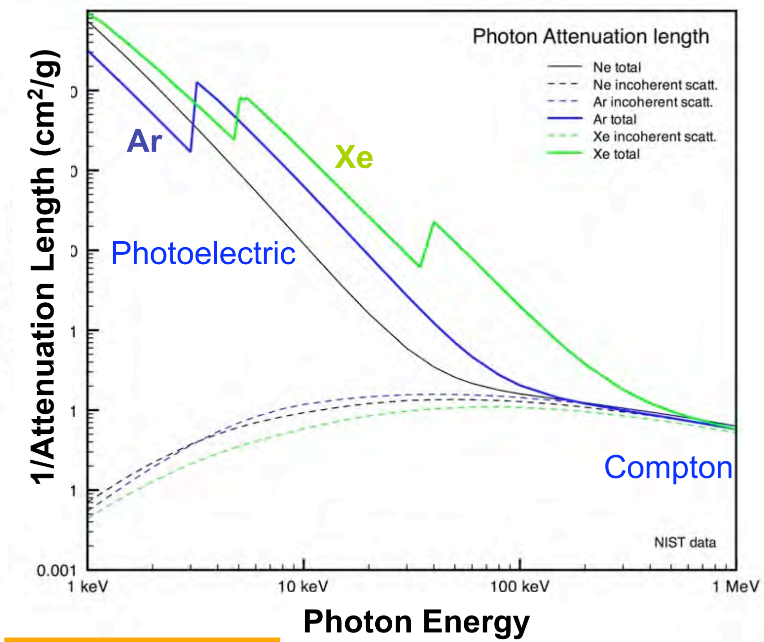

**Ionization density effect in lab test chamber**



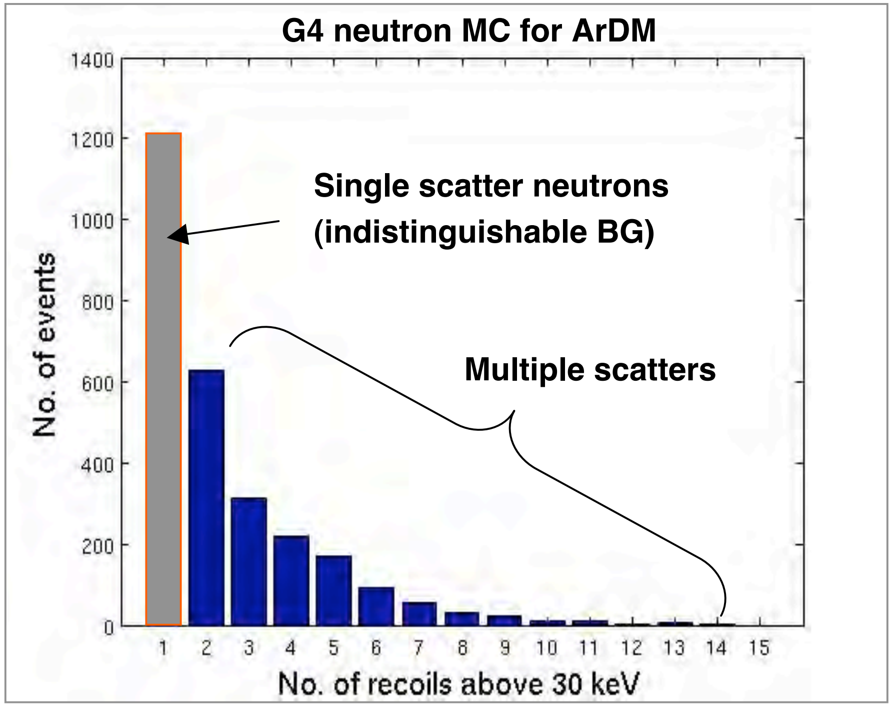



# Large mass features

**Good: Self shielding (external BG sources)**




LAr: $X_0$ = 14cm




Neutron shield is planned nevertheless

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

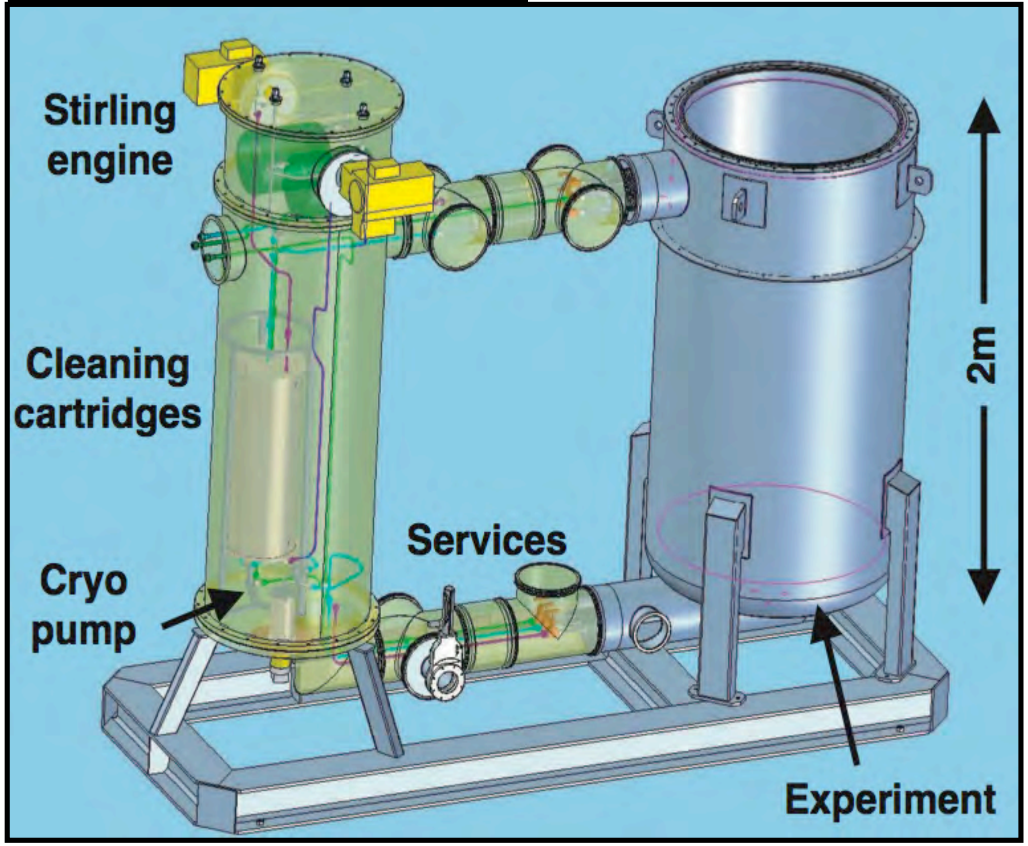
- To be suppressed (high BG suppression)
  -> Trigger rate (selective trigger)
- Deplete target (liquefy well gases)

1Bq/dm$^3$ ≈ $10^8$ /day/ton

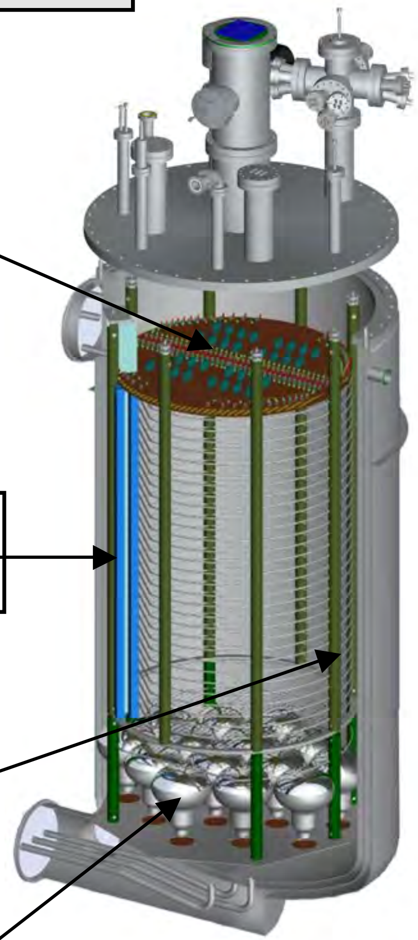
Challenge!

# Hardware and main R&D units

Cryostat and liquid purification

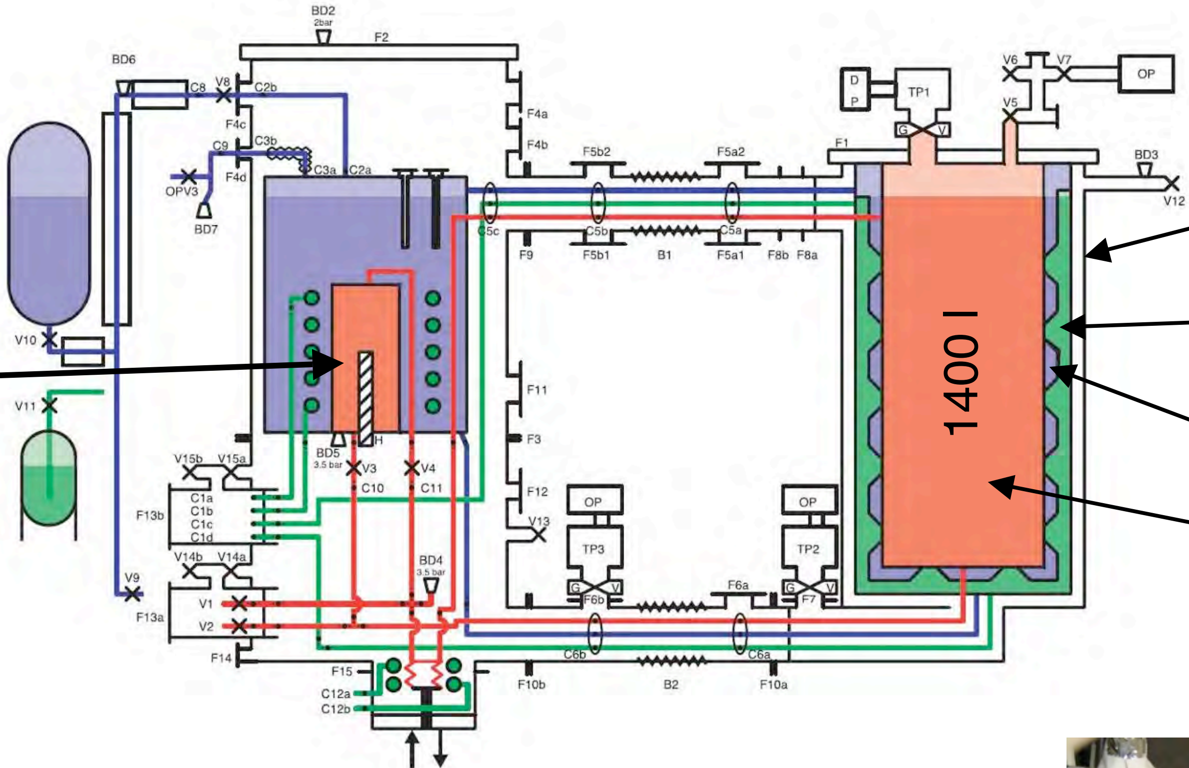



Inner detector



# Cryogenics and LAr purification

In collaboration with BIERI engineering Winterthur (CH)



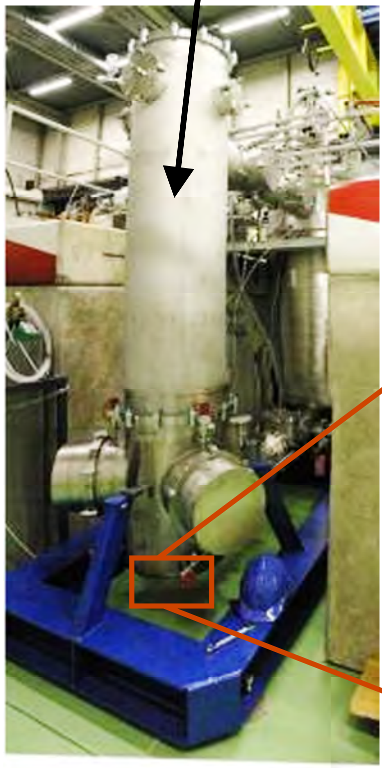

Recirculation and CuO purification cartridge

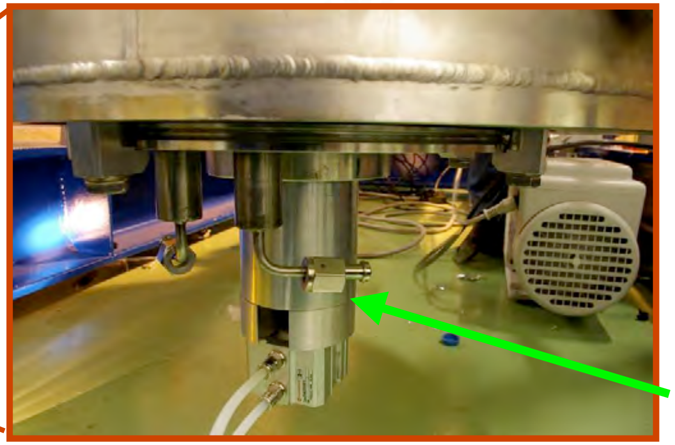
vacuum insulation

LN2 cooling jacket

'dirty' LAr cooling bath

pure LAr closed circuit



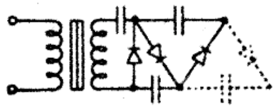


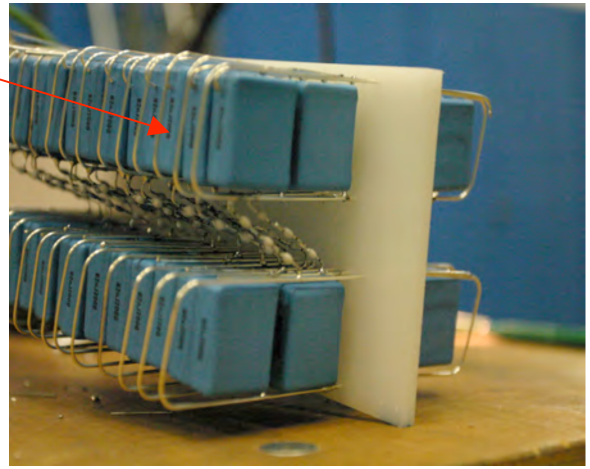
Mechanical cryo pump (bellow)

Measured LAr flux ~ 20 l/hr

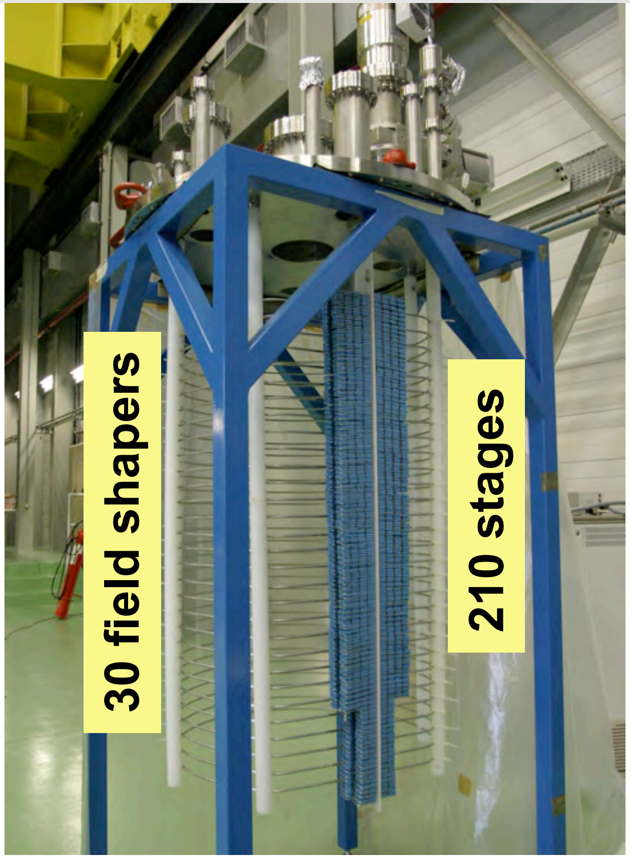
# HV - generator (placed in the liquid)

- 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)





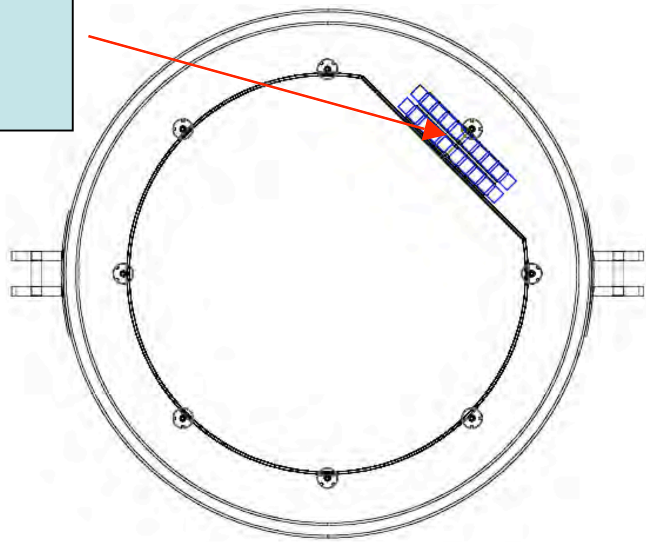
**Mounted on the field shaper rings**



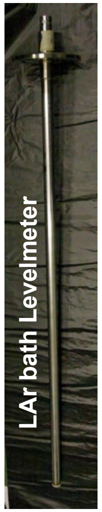

Polypropylene capacitors

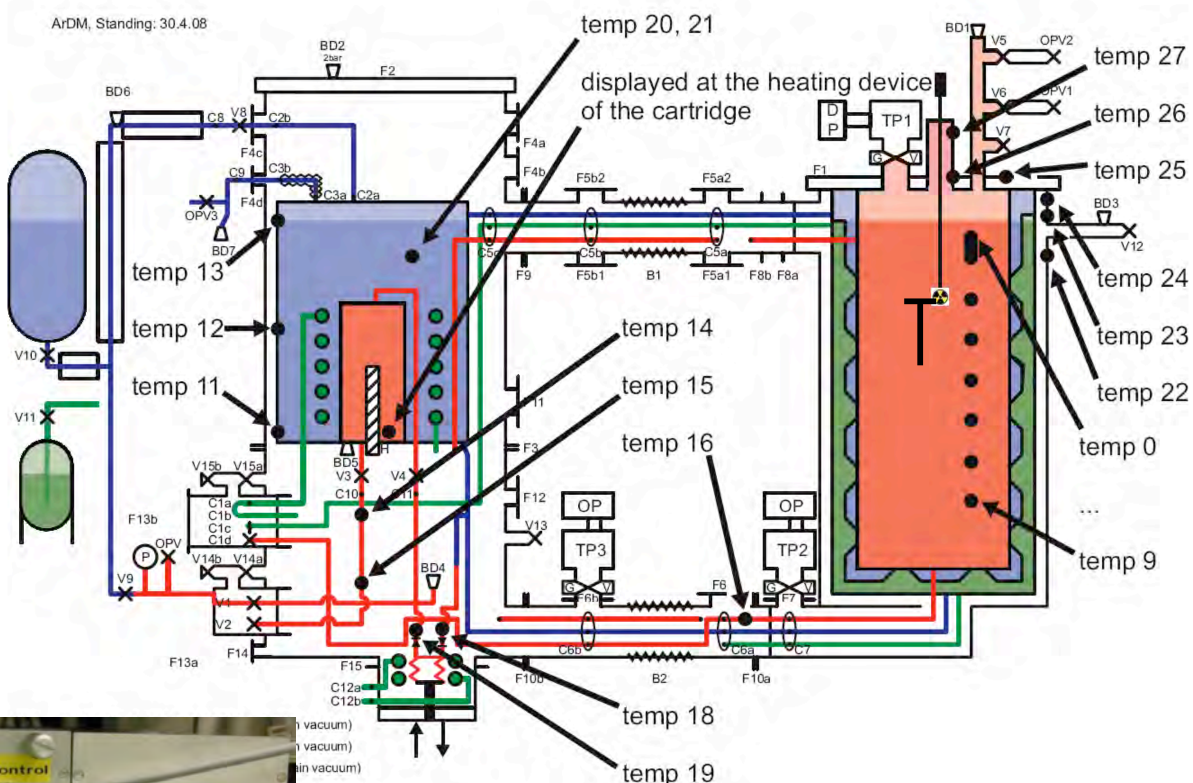
82 nF
2.5 kV/stage
200 stages

**Top view**



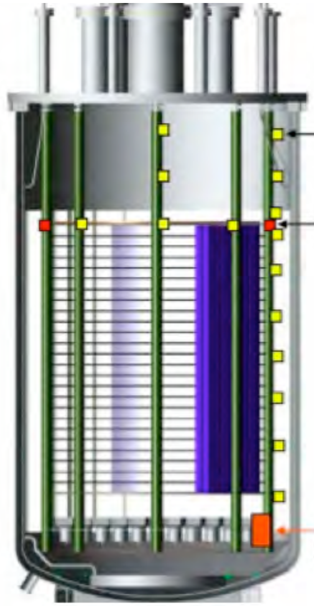
# Slow control





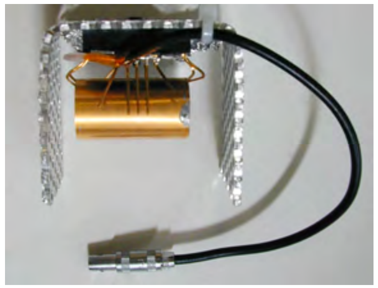
**Dual phase charge extraction**



**Precision capacitive level sensors**

**Pt 1000**


**Floaters (optional)**

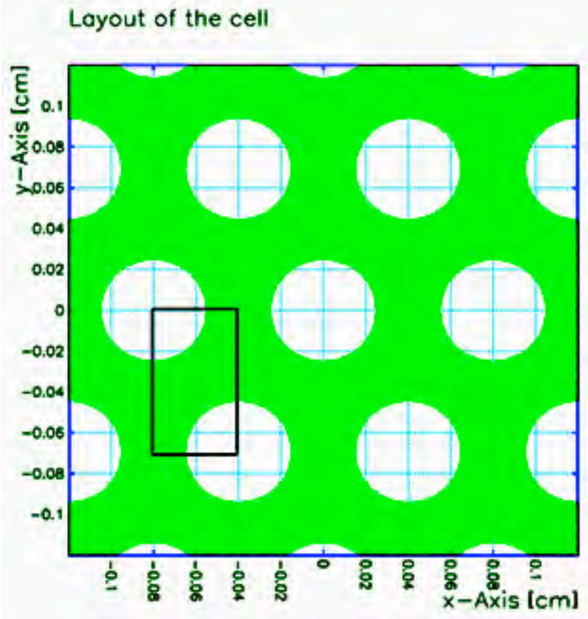


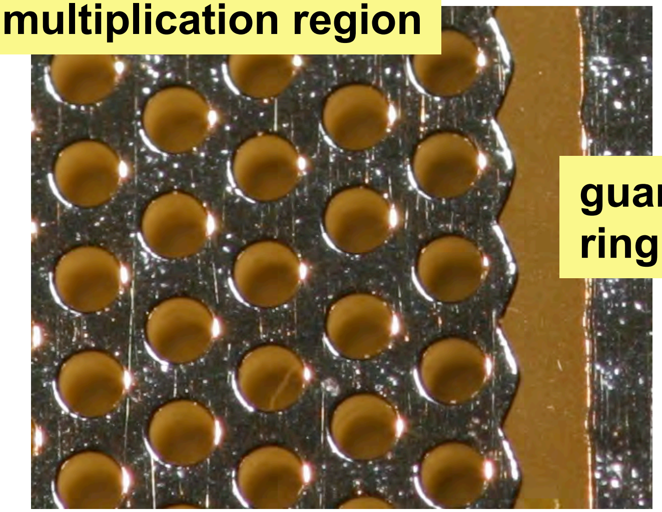
# LEM: Charge read out system (major R&D project)

- **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**

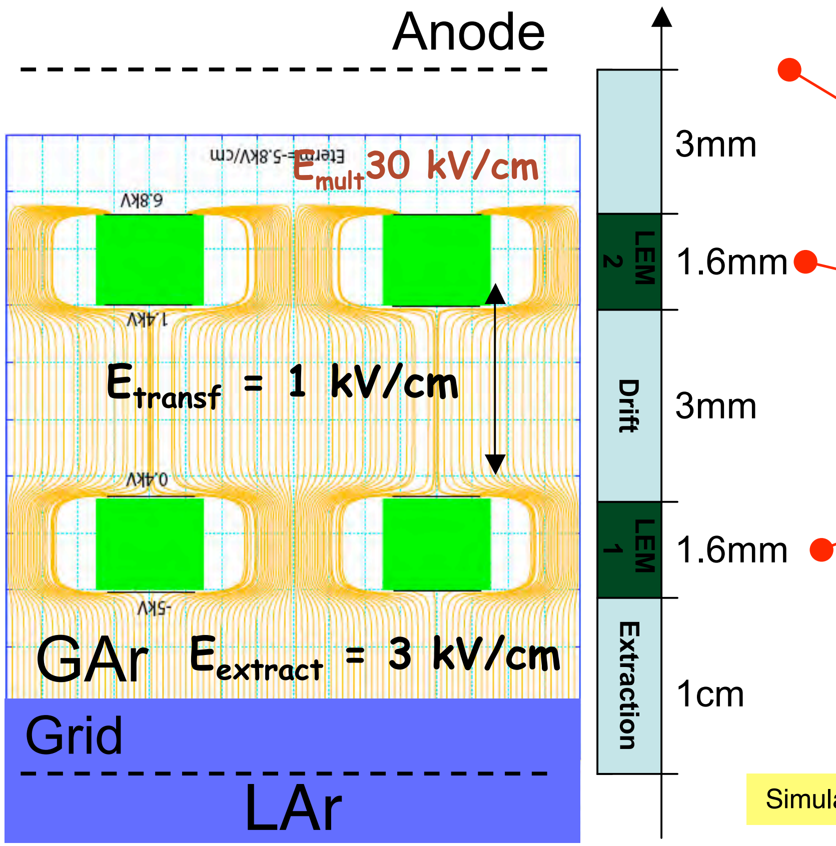
**LEM (Large Electron Multiplier) is a thick macroscopic GEM**

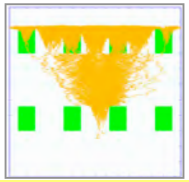
**Produced by standard Printed Circuit Board methods**



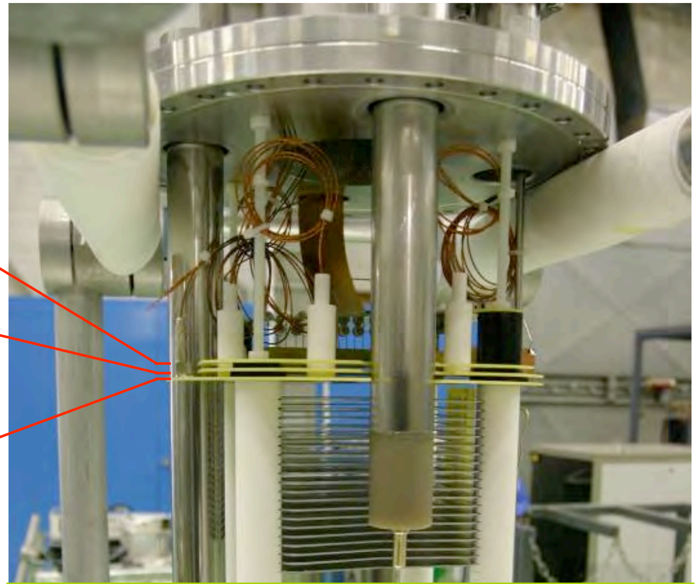



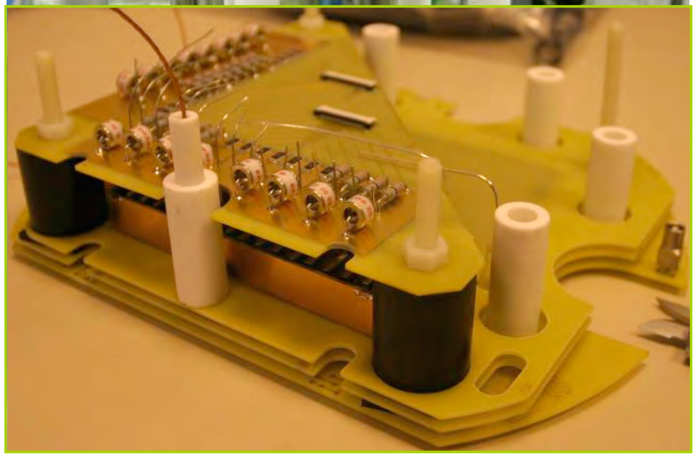

- Double-sided copper-clad (35 μm layer) G-10 plates
- Precision holes by drilling
- Palladium deposition on Cu (<~ 1 μm layer) to avoid oxidization
- Single LEM Thickness: 1.5 mm
- Amplification hole diameter = 500 μm
- Distance between centers of neighboring holes = 800 μm



Simulation of avalanche



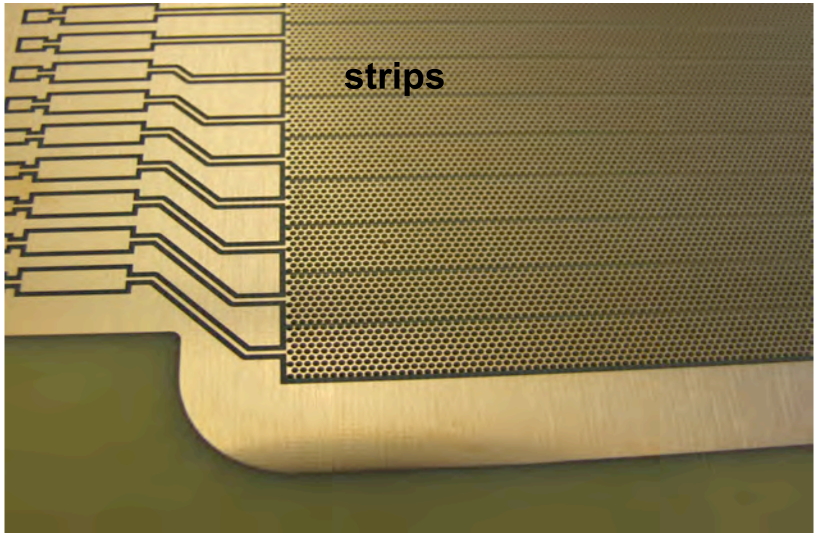


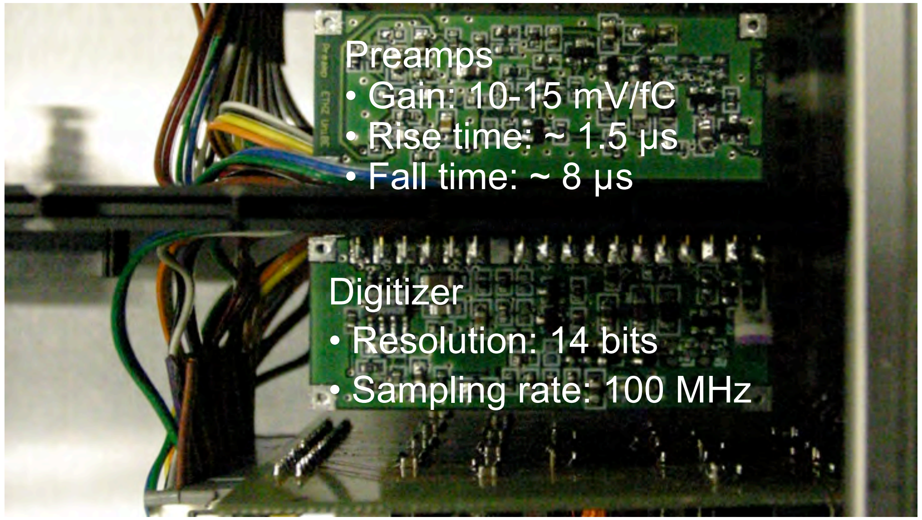
- $e^-$ drift in LAr toward its surface (4kV/cm)
- $e^-$ extracted to vapor phase and driven into LEM holes
- first stage multiplication in LEM 1
- $e^-$ drift toward second LEM
- second stage multiplication LEM 2
- Induction of charge on striped anode and upper LEM2 plane

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

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

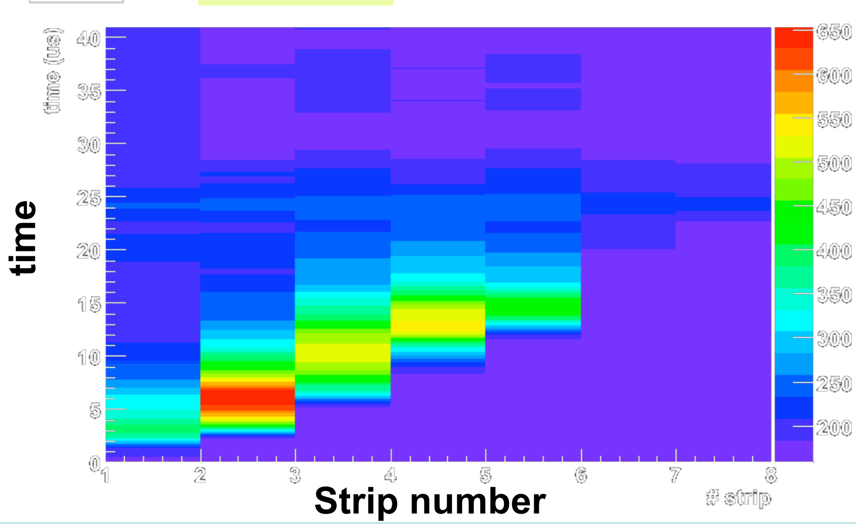
# LEM R&D (recent progress)

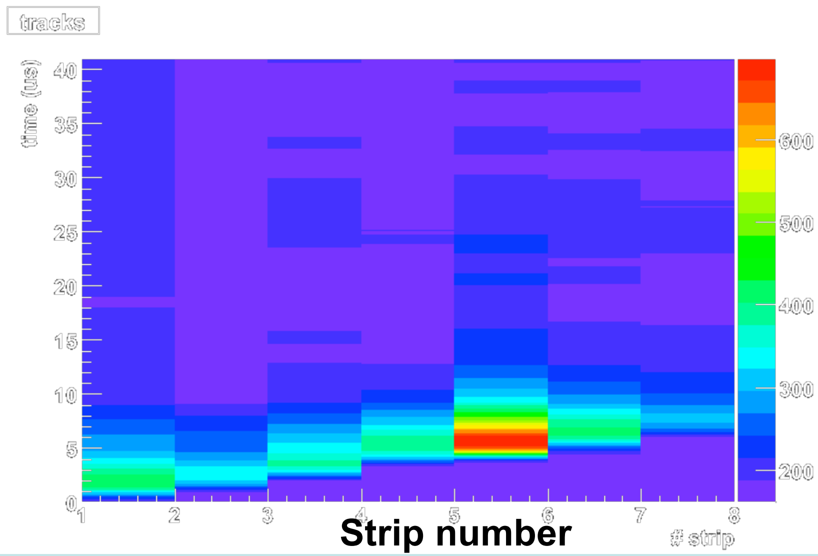



**Developing A/D conversion and DAQ system:**
**MHz serial ADC + FPGA + dual memory buffer + ARM microprocessor**

**Cosmics**

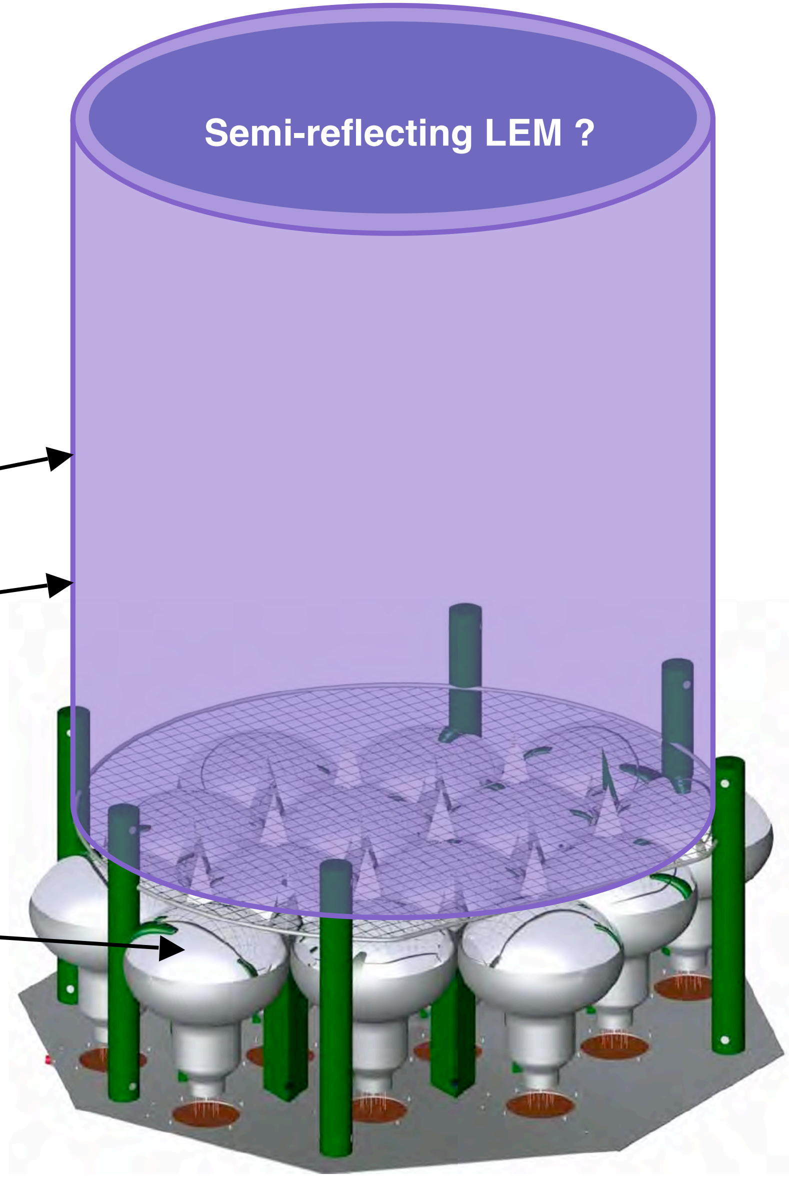


# Light read out

- 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%

Concept




PMTs Hamamatsu R5912-02MOD

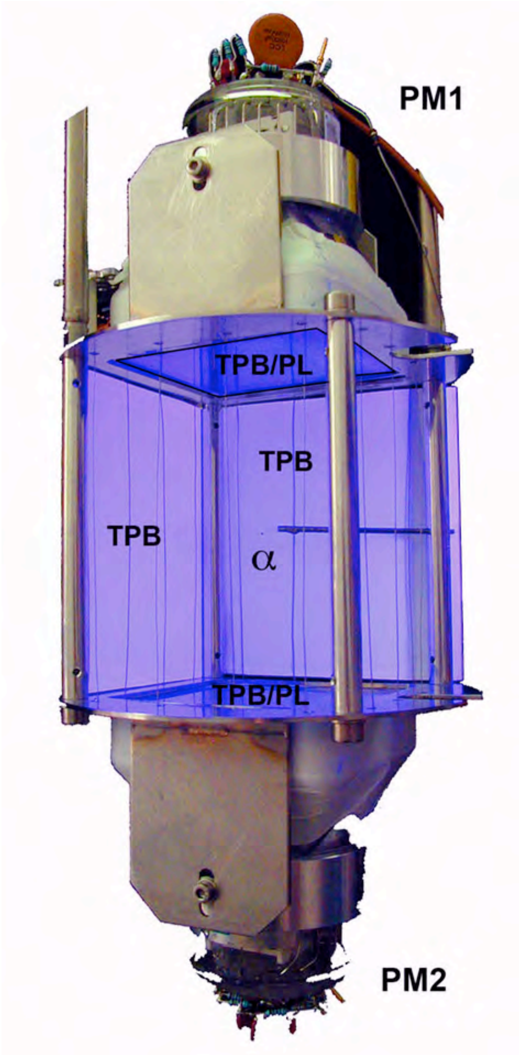
Wavelength shifter (evaporated onto inner surface)
- TPB (Tetra-phenyl-butadien)

Reflector materials:
- Tetratex
- 3M foil

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

# Light read out R&D efforts

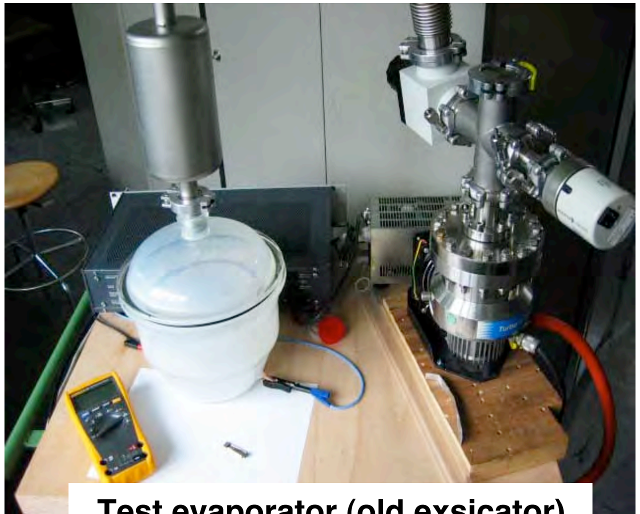
## Test unit from the lab




- Develop VUV read out in a test setup in the lab (light yield)
- Use radioactive sources ( $^{210}$Pb: α 5.3 MeV, $\beta^-$ 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)

**Example**

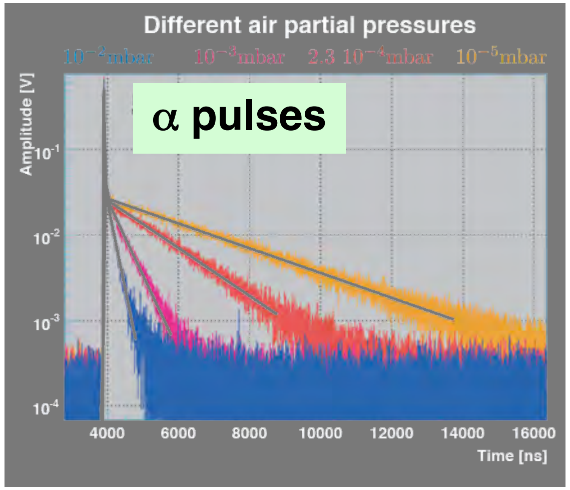
- WLS is deposited by spraying or evaporation
- Thickness determined from the weight

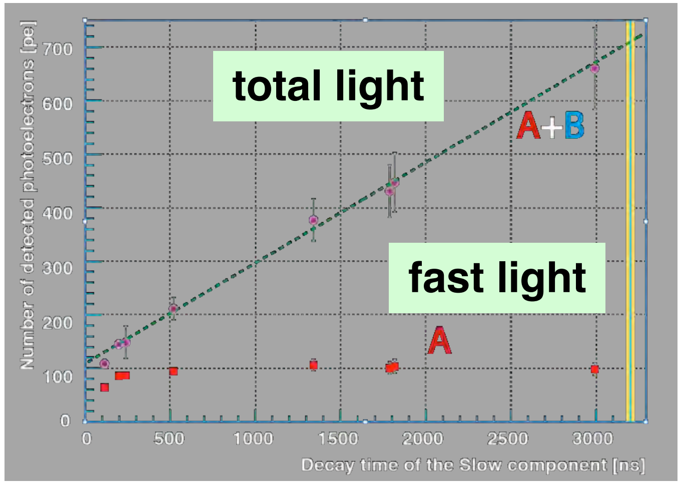


Test evaporator (old exsicator) for small samples(10x10cm$^2$)

# Light yield optimization - use GAr

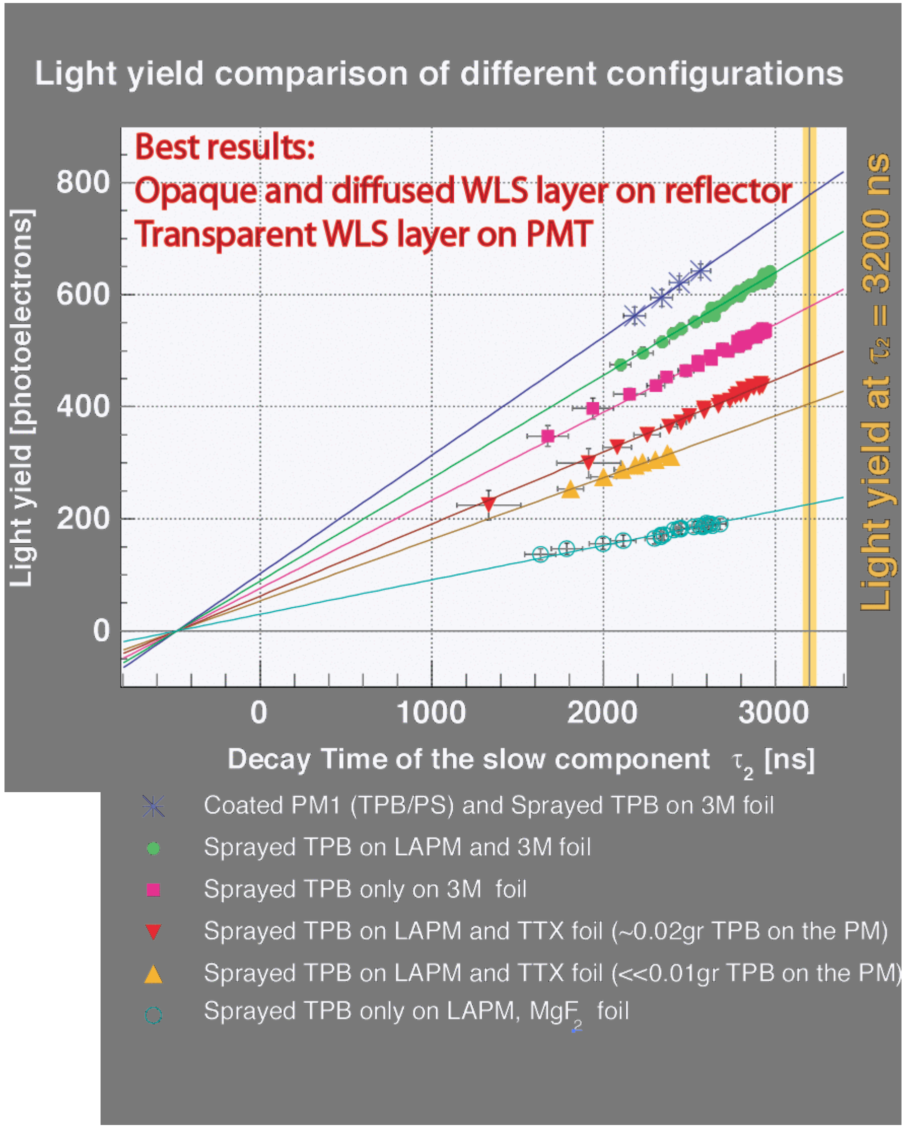
## Calibration (to the purity of GAr)



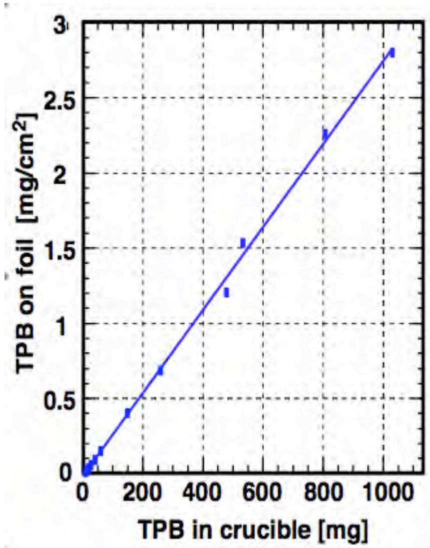

C.Amsler et al., *"Luminescence quenching of the triplet excimer state by air traces in gaseous argon"* arXiv:0708.2621

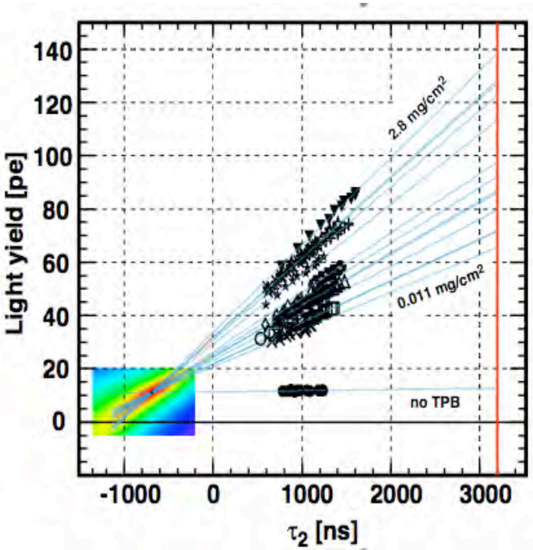
## Choice of the reflector type

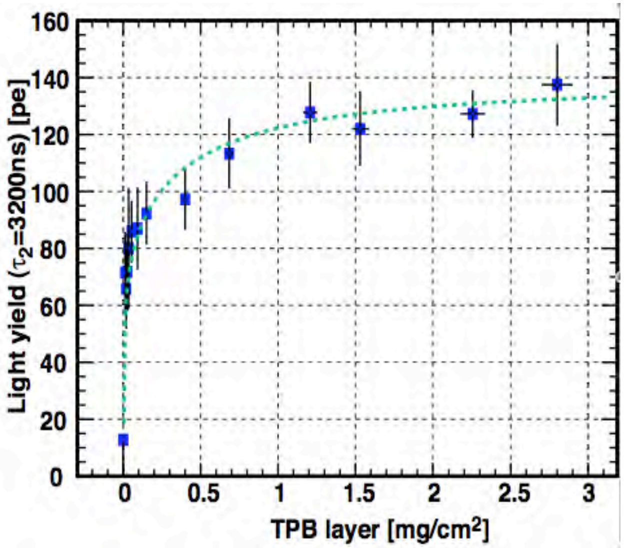


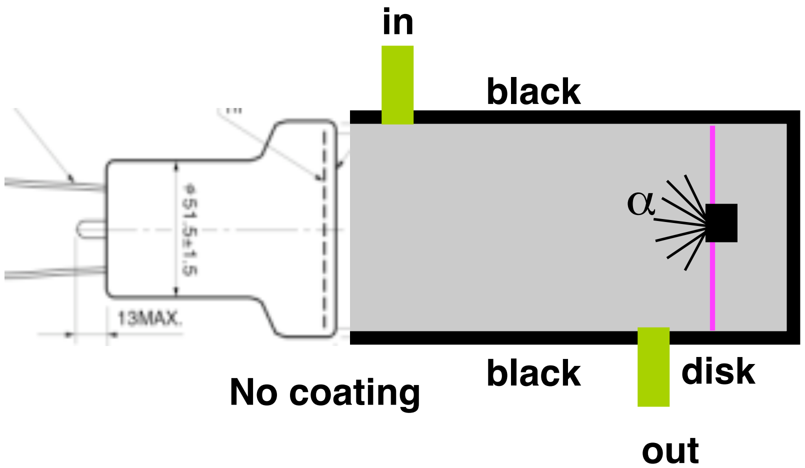
# TPB VUV conversion efficiency measurement

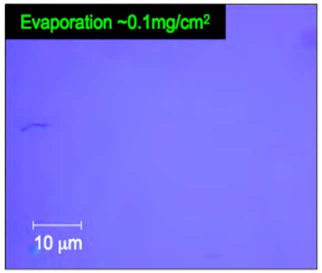
On a variety of evaporated samples, measured under flushing with GAr

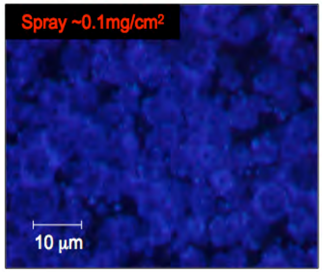



Done with 3M foil as base

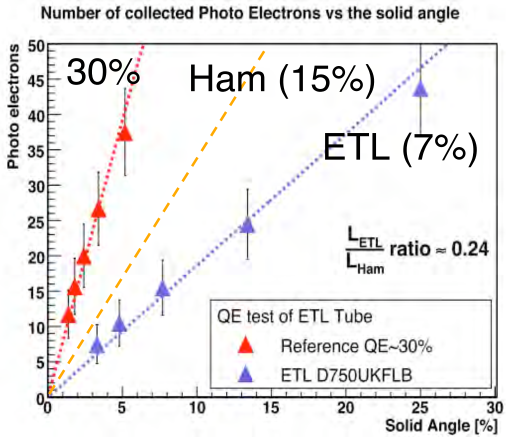
TTX seems to improve light yield (~10%?)

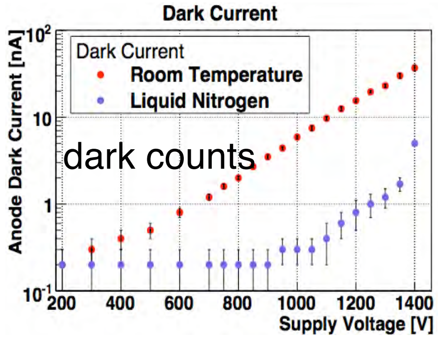
Reliable evaporation thickn. (~ filling of crucible)

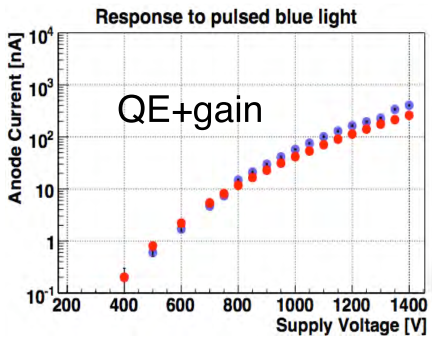
Conclude: a layer of 1mg/cm² will do

# 8” cryogenic PMTs selection

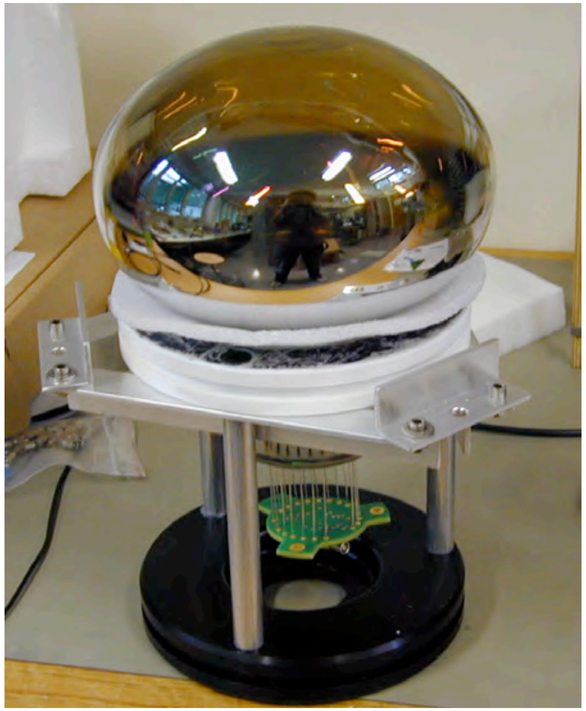
3”



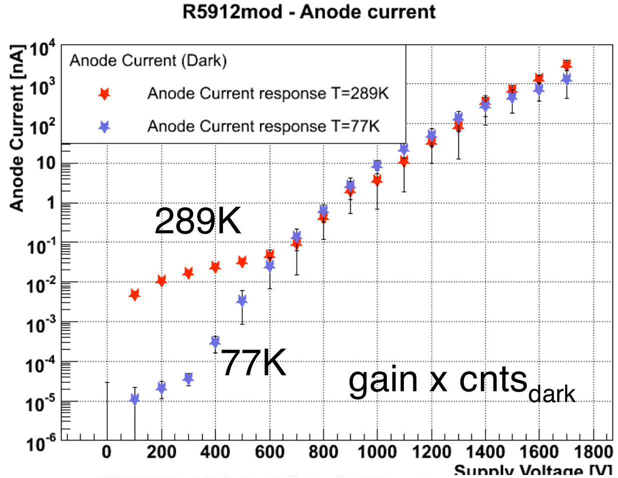

**8” hemispherical**
**Pt underlay**
**14 dynodes**
**QE > 15%**
**4000 CHF/PMT**

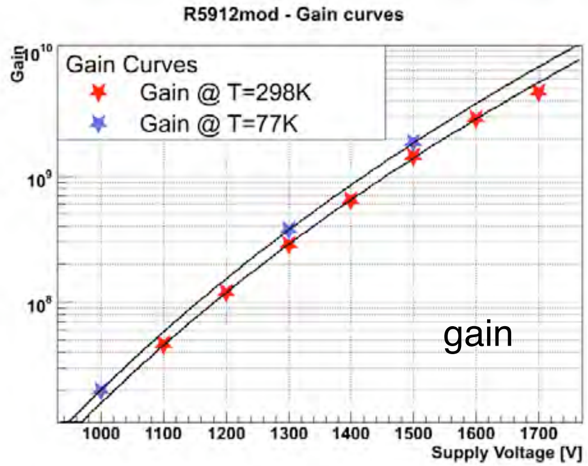


**Hamamatsu R5912-02MOD**

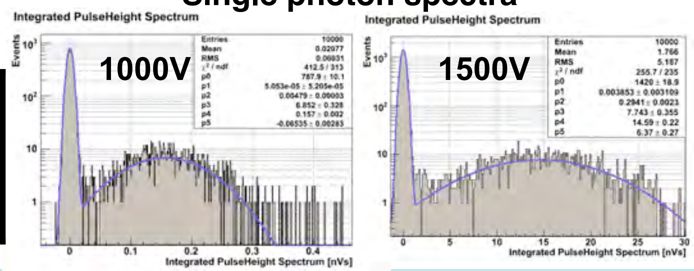
| Bq/Kg | K-40 | U | TH | Total |
|---|---|---|---|---|
| Norm.Glass | 3.20 | 0.69 | 0.52 | 4.41 |
| **LRIGlass** | **0.27** | **0.34** | **0.15** | **0.76** |

8”



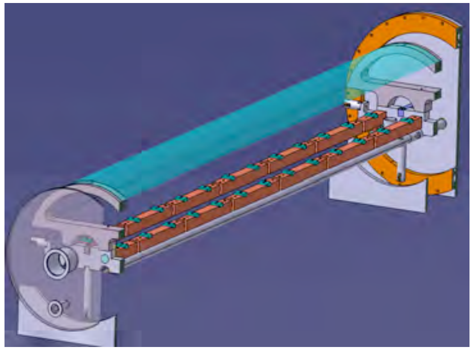



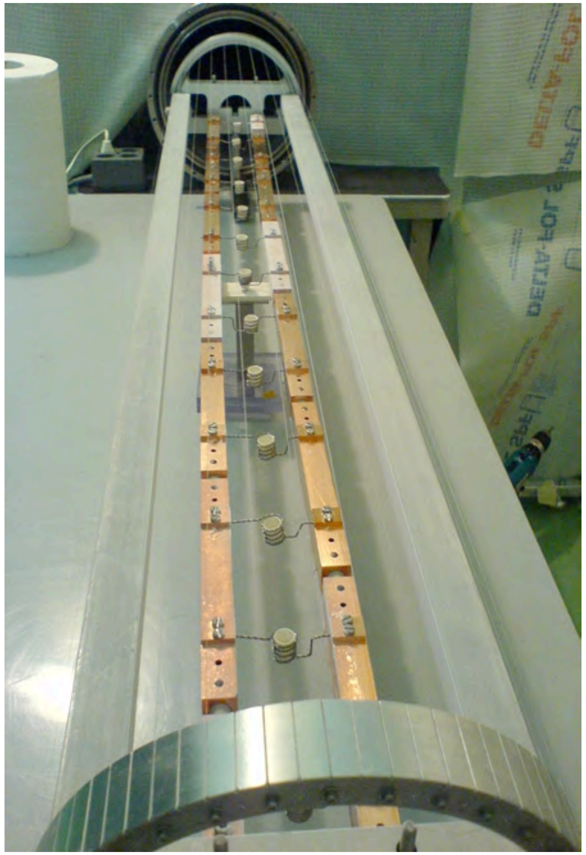

## Single photon spectra



# Large scale evaporator : WLS/reflectors

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

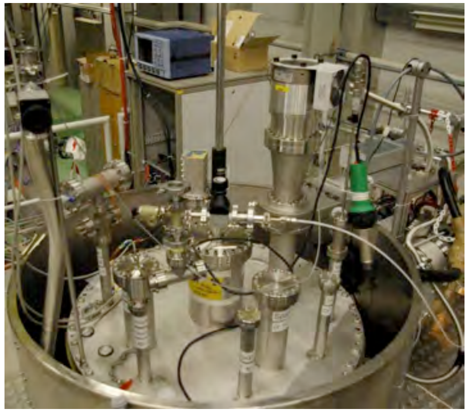




15 Reflector/shifter foils produced and installed

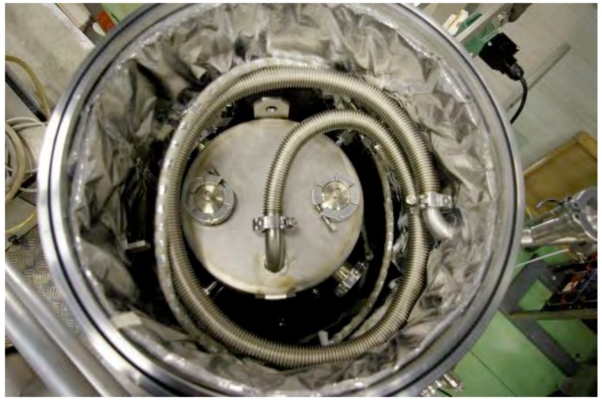
# ArDM Assembly  Sept. 2007 - May 2008

Top flange



Exp. area at CERN

LAr bath

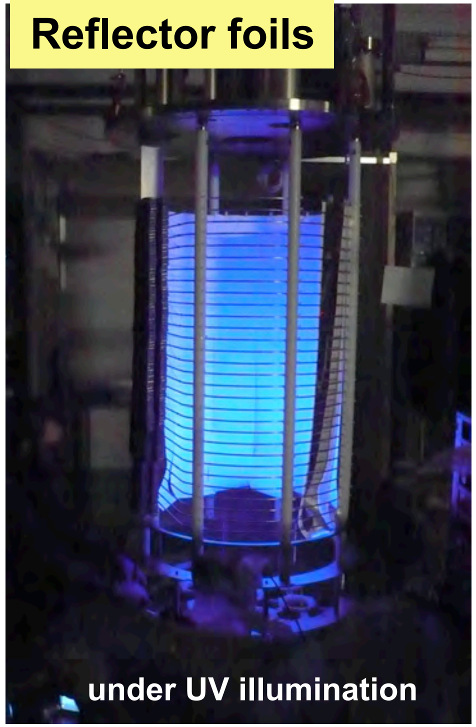


Detector insertion

PMT mechanics

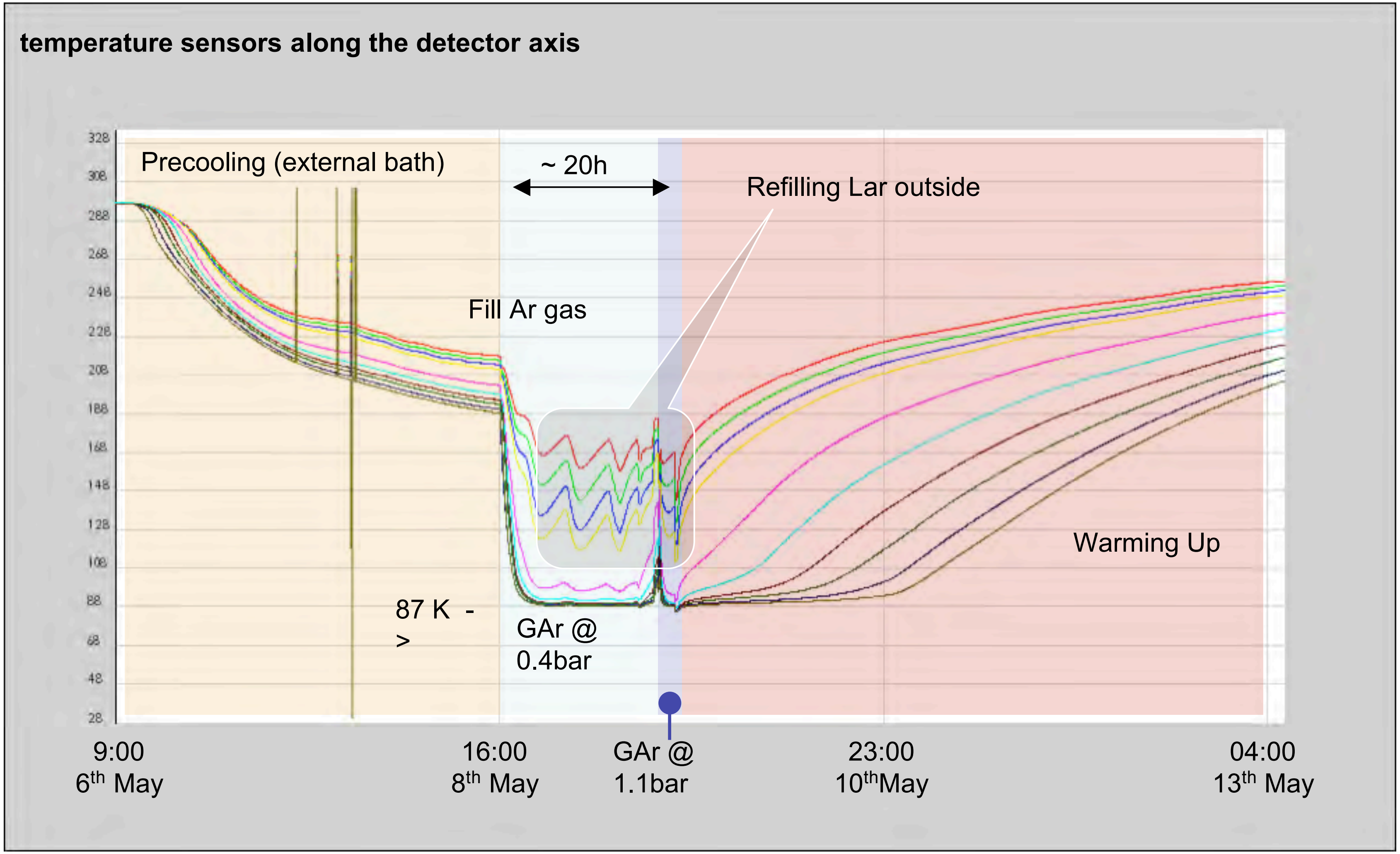
CuO cartridge

Reflector foils

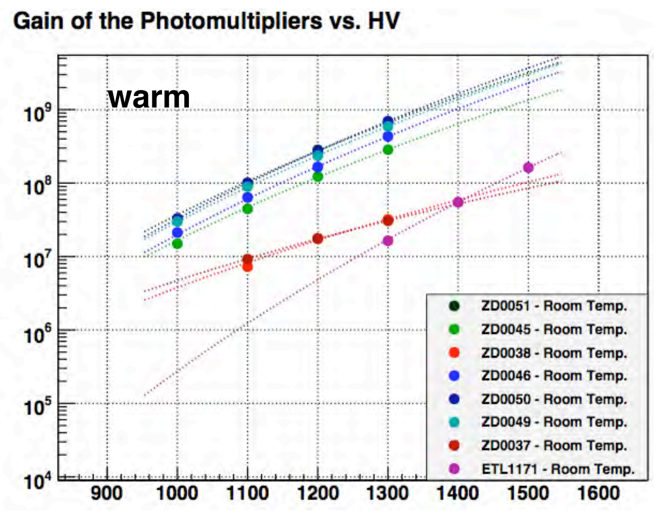


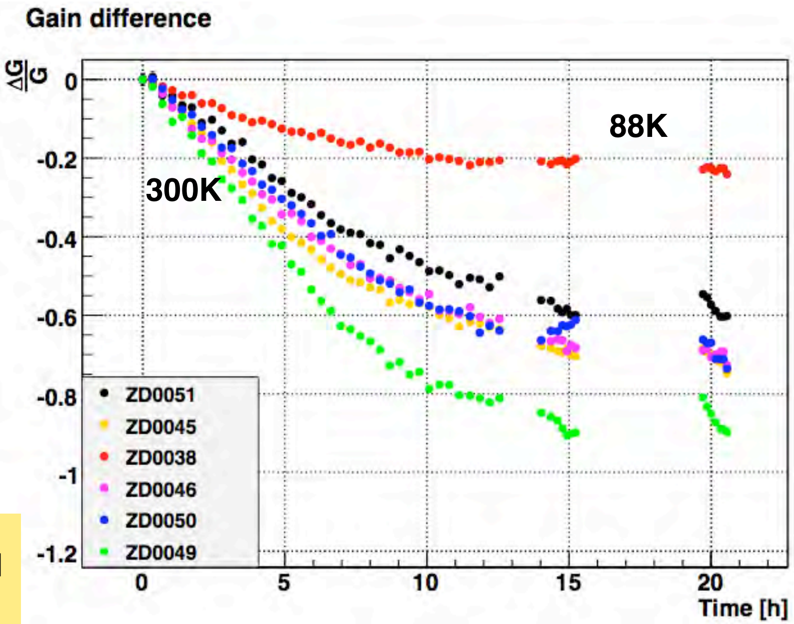
# First cool down under gaseous argon (May 08)

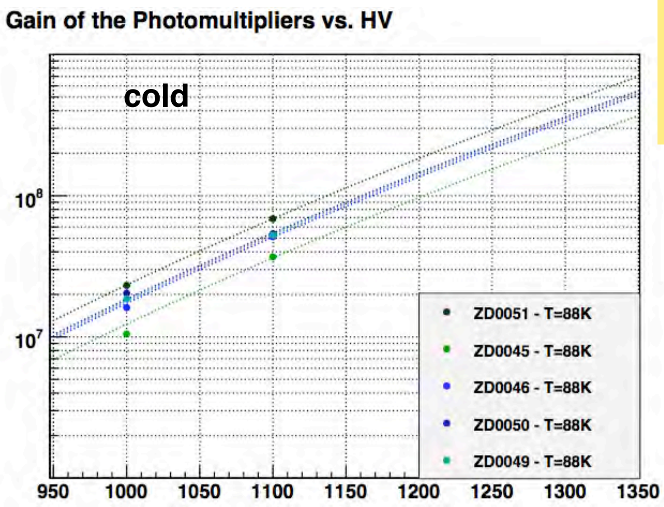
**Test cryogenic system (recirc. pump) and cryogenic behaviour of PMTs**



# PMTs @ 300K and 88K

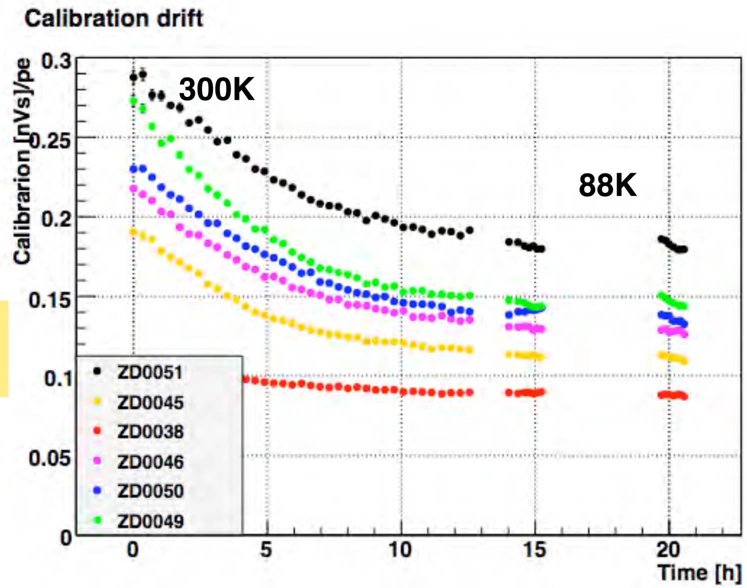


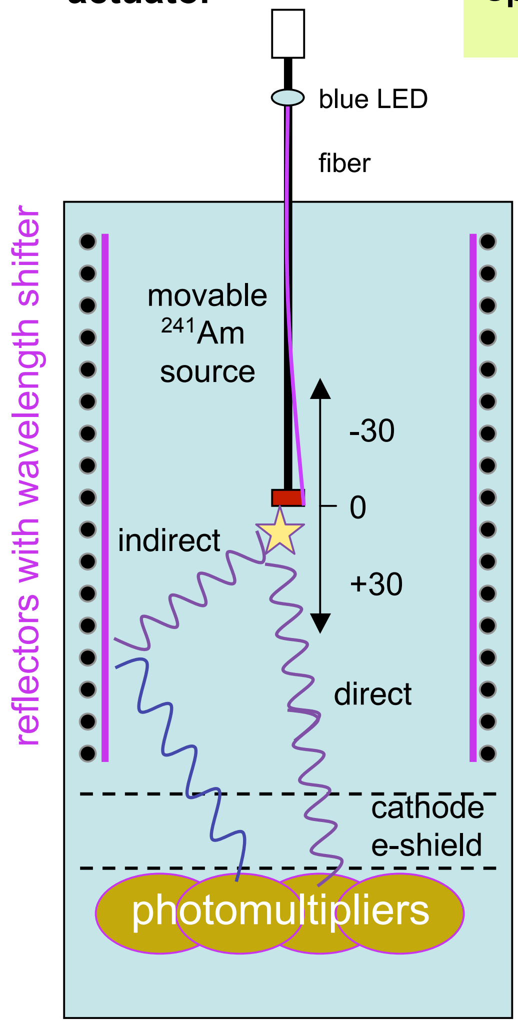

- PMTs work nicely at cold
- Dark count rate OK
- QE under investigation (no indication of drop)

**Hamamatsu R5912-02MOD confirmed and ordered**



# Understanding the light collection

**UHV magnetic actuator**




**Up to now in gas only!**
**Liquid planned**

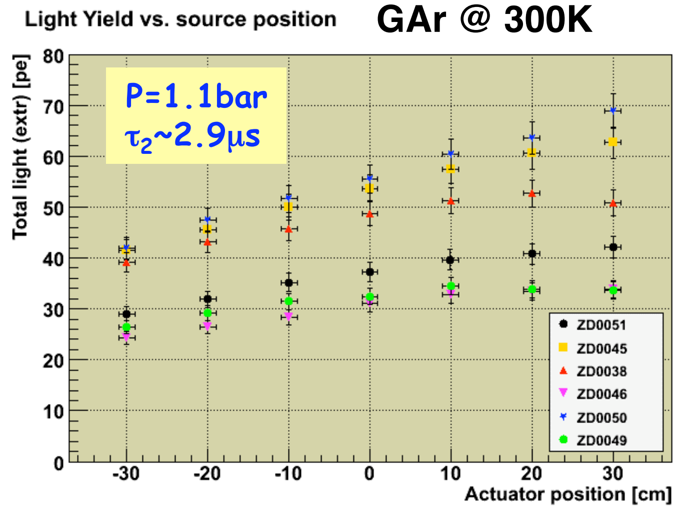
**Testing different PMTs and versions +**

- **VUV absorption**
- **solid angle**
- **diffuse reflection**
- **direct conversion**
- **impinging angle**

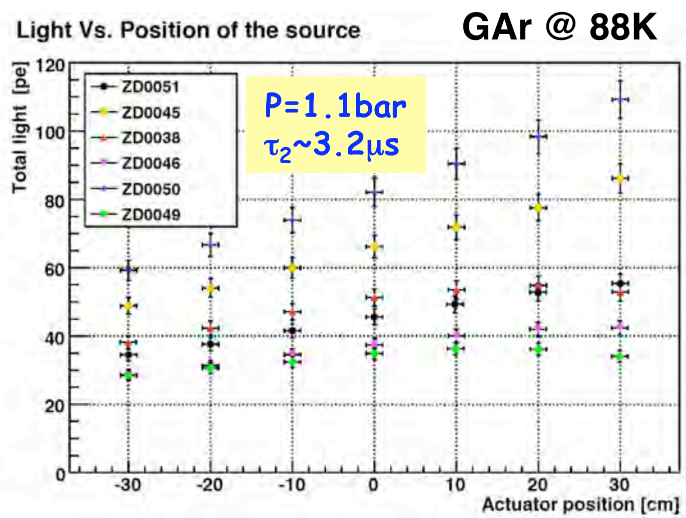
**(non trivial)**

**Hamamatsu R5912-02MOD confirmed and ordered**

**Readout plane**




**Comparison to MC is in progress**

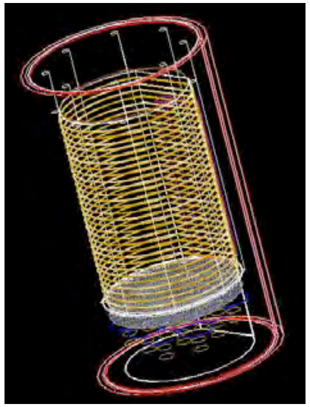


# MC background studies

**Background sources:**

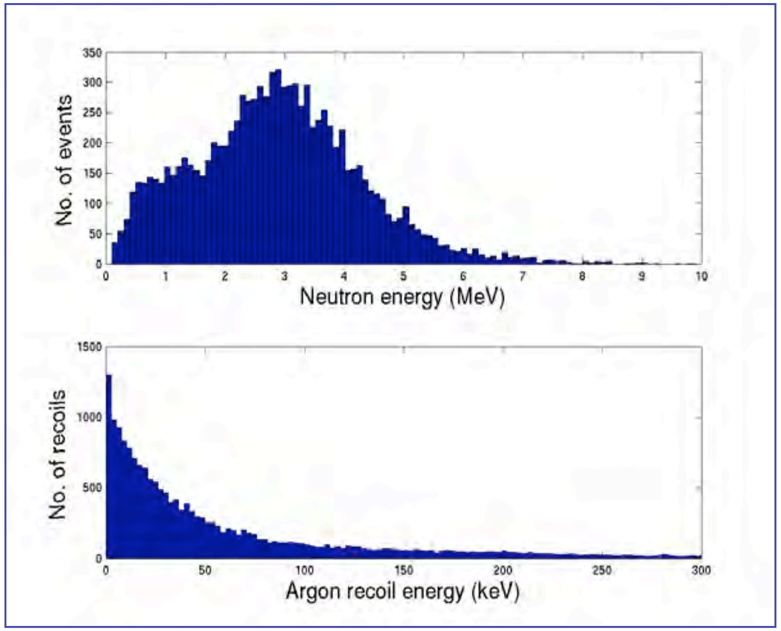
**Neutrons: radioactive material (mainly U/Th contaminations) and from muons**

**(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 |

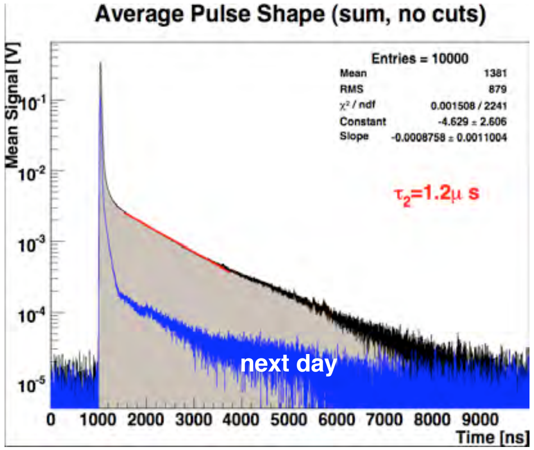
**30 keV threshold**

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

# Purity monitor cell (in preparation)

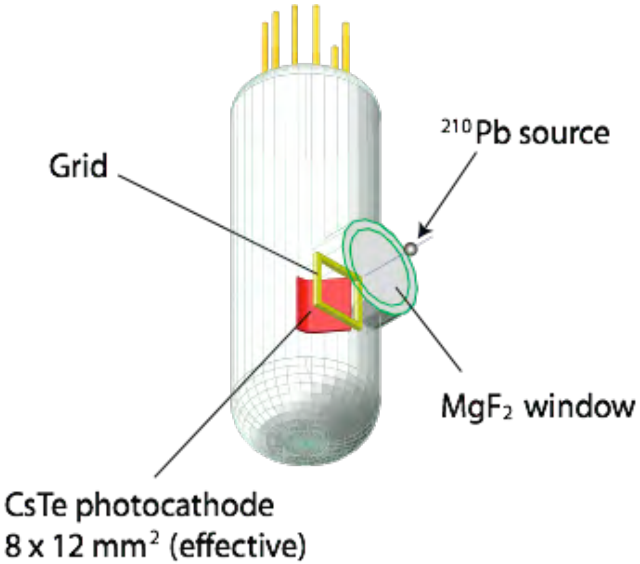
Identify additional cleanliness needs

**Purity effect on scintillation in LAr**



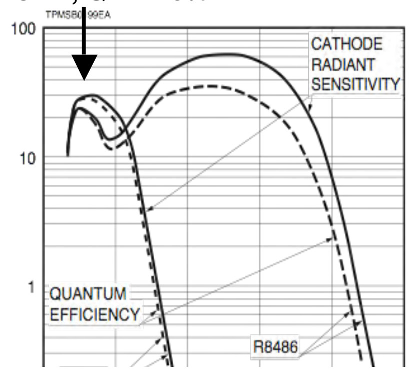

**Similar for ionisation charge (we also plan charge read out)**

**Side window PMT MgF2 window**

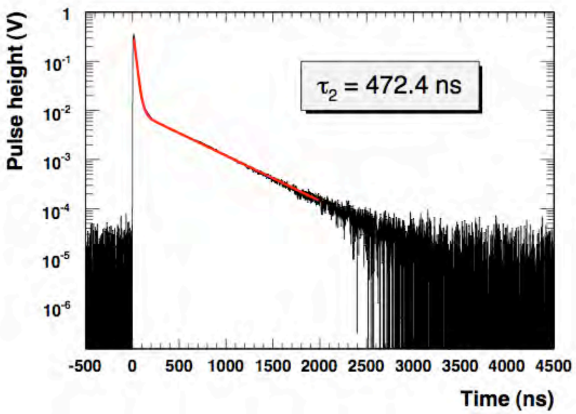


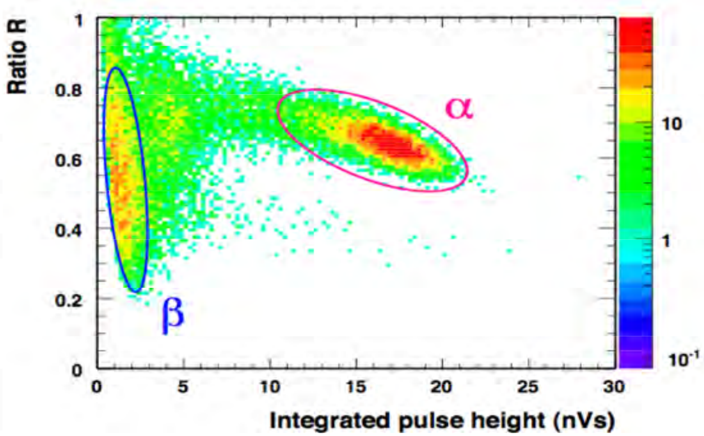

**Typ. spectral response**

**128nm, QE ~ 20%**



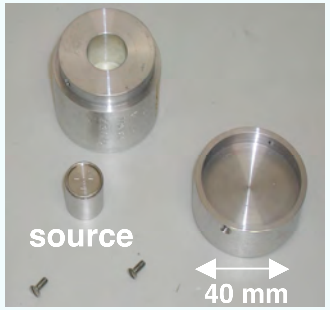

**Signals from dirty LAr (open dewar)**



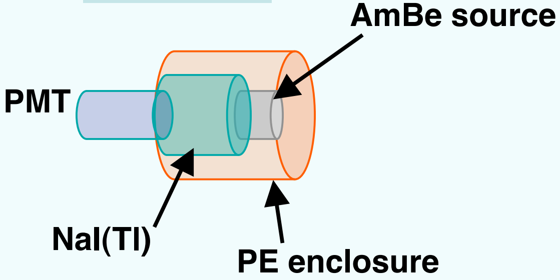




# Recoils from neutrons (in preparation)

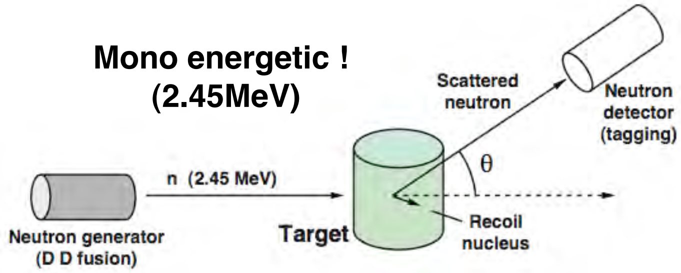
**AmBe source**




**n - trigger**

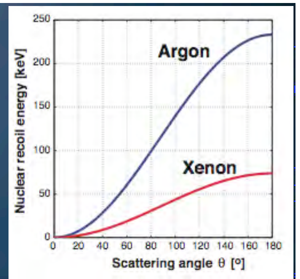



**Mono energetic !**
**(2.45MeV)**



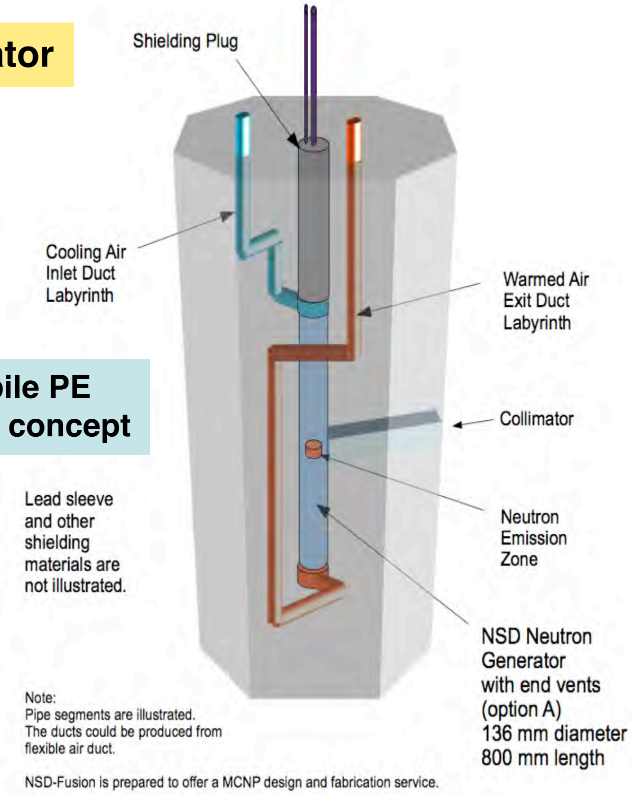

**DD fusion generator**

- $1.25 \times 10^7$ n/s 4πsr DD fusion neutrons
- $U_{max}$ = 120 kV, $I_{max}$ = 10 mA
- > 20,0000 hour lifetime
- High stability and repeatability (< 0.1%)
- Air cooled (integrated axial fan)
- Bremsstrahlung shielded with 4mm Pb





**Mobile PE shield concept**



# Near future strategy (at surface, CERN)

- Implementation of liquid recirculation circuit
- Finalize mechanics (cooling engine later)
- Address safety issues (handling of 1 ton LAr)

<u>Run setup with LAr</u>

- Operation of LAr pump and purification circuit
- Verify light collection efficiency
- Test HV system at low temperature over long periods
- Calibrate with $\gamma$ and n sources
- Test pulse shape discrimination
- Study stability and cleanliness of detector

Complete PMTs (incl. HV and FADC system) -> 14 LRI

Finalise LEM developments and design

Production and installation of full size LEM

Installation of a cryocooler

Explore additional purification necessities

Proceeding towards ‘physics’ operation of ArDM

# Outlook

- Detector component R&D is in the final stage
- We confirmed the performance of individual detector components
- We should soon operate the full scale prototype at surface/CERN
- We consider underground operation at shallow depth (CERN)
- Following successful operation, we 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.
- LAr/TPC technology could provide the means to develop very large highly sensitive multi purpose detectors