THE ArDM PROJECT

2nd Symposium On

Neutrinos and Dark Matter in Nuclear Physics (NDM06)

Paris September 3-9 2006

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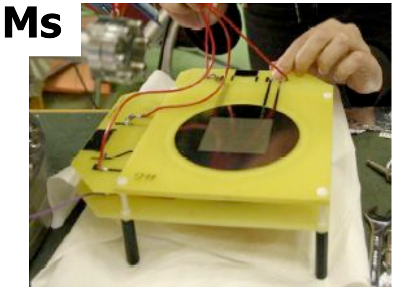
We acknowledge informal contribution from **LNF, Italy**. Interest from JINR, Russia

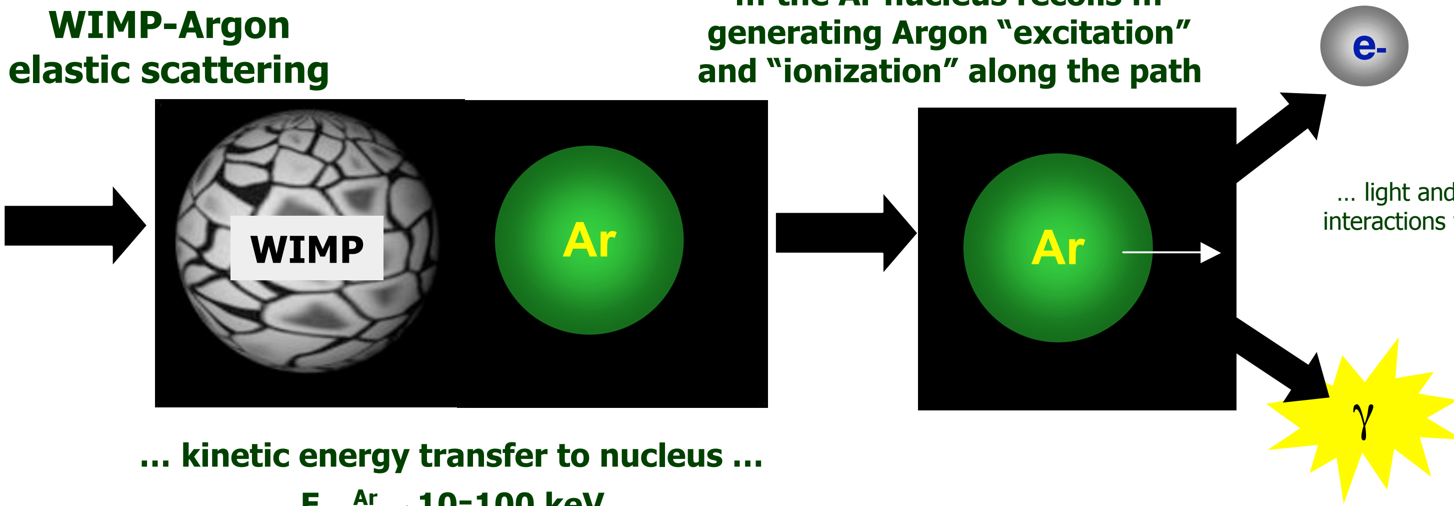
- We are constructing a 1 ton argon prototype at CERN … the goal (1st phase) is to detemonstrate the validity of the design
- It has been shown that liquid Xenon or Argon can act as a target for WIMP detection (NIM A 327 (1993) 205 & NIM A 449 (2000) 147)
- Our aim is to detect the **ionization charge** and **scintillation light** independently:

LEMs



WIMP-Argon elastic scattering

… the Ar nucleus recoils … generating Argon "excitation" and "ionization" along the path



… light and free electrons produced from interactions with neighbouring argon atoms

… kinetic energy transfer to nucleus …

E_{kin}^{Ar} ~ 10-100 keV

PMTs

→ Event vertices will be precisely localized (in space), important for γ-ray and neutron background rejection from surrounding elements

→ Event topology will be imaged and used for background rejection

→ The Ratio of ionization to scintillation used to reject β/γ -rays against nuclear recoils

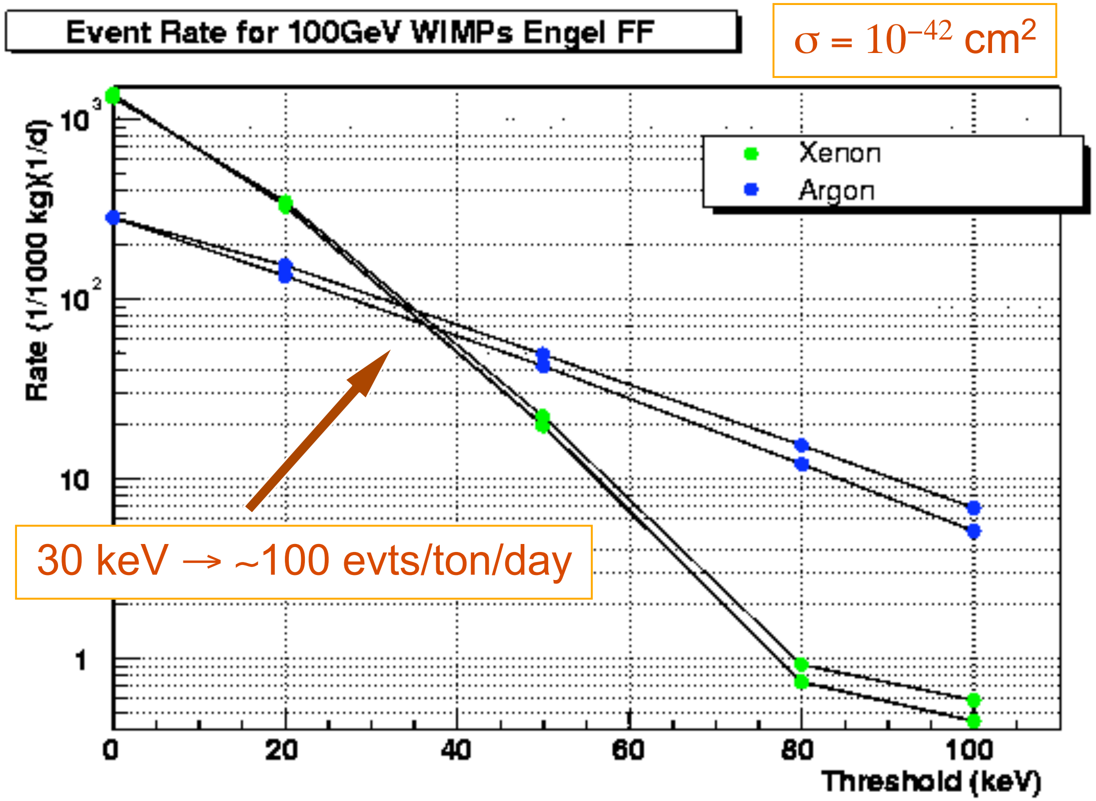
→ The time distribution of the scintillation light will be used to further discriminate between heavy recoils and other backgrounds

WIMP – Argon elastic scattering

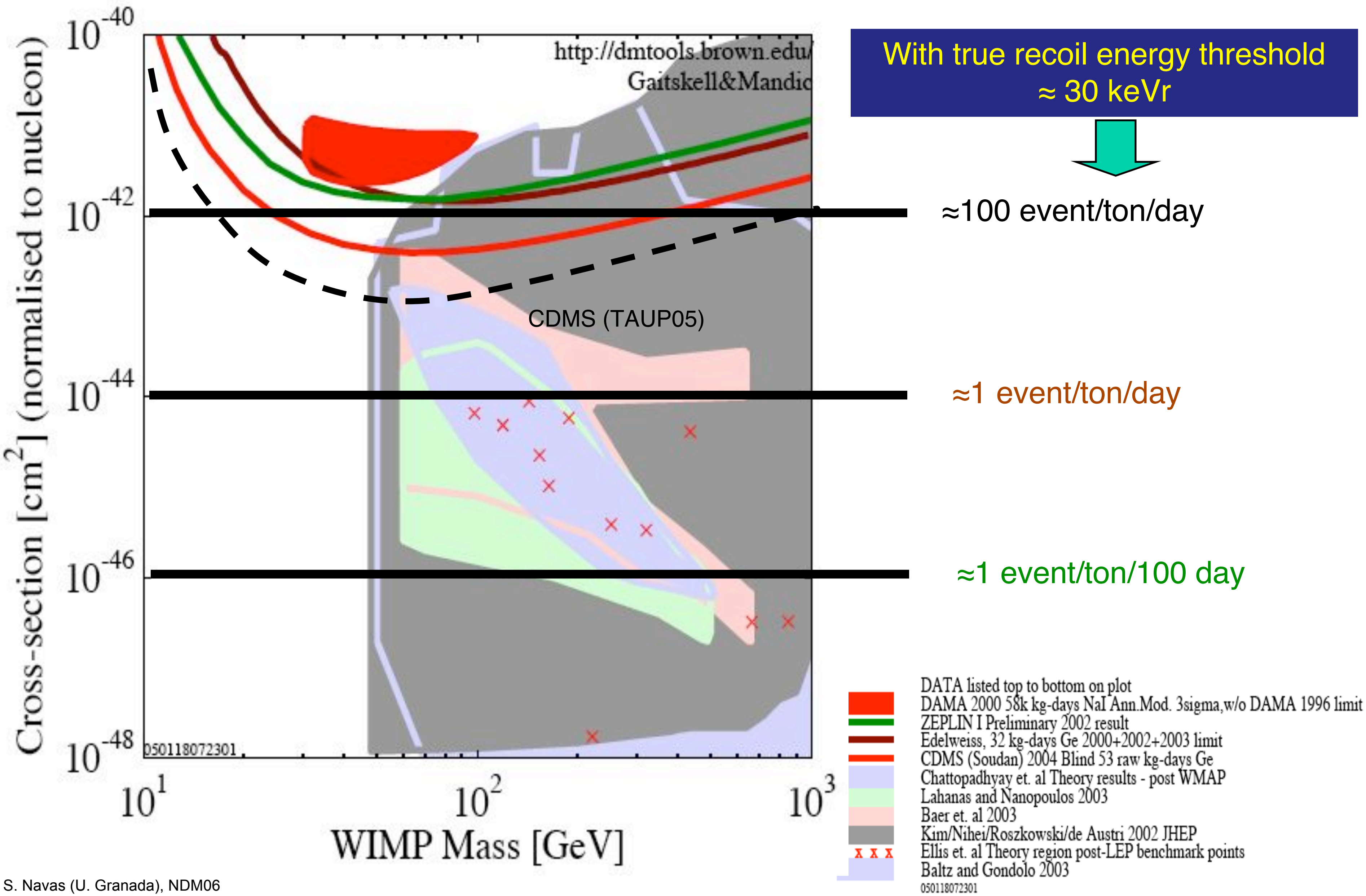
- Event rate in argon is less sensitive to threshold on recoil energy than for xenon (Form Factors)
- Recoil spectra in xenon and argon are different, providing an important cross-check in case of positive signal

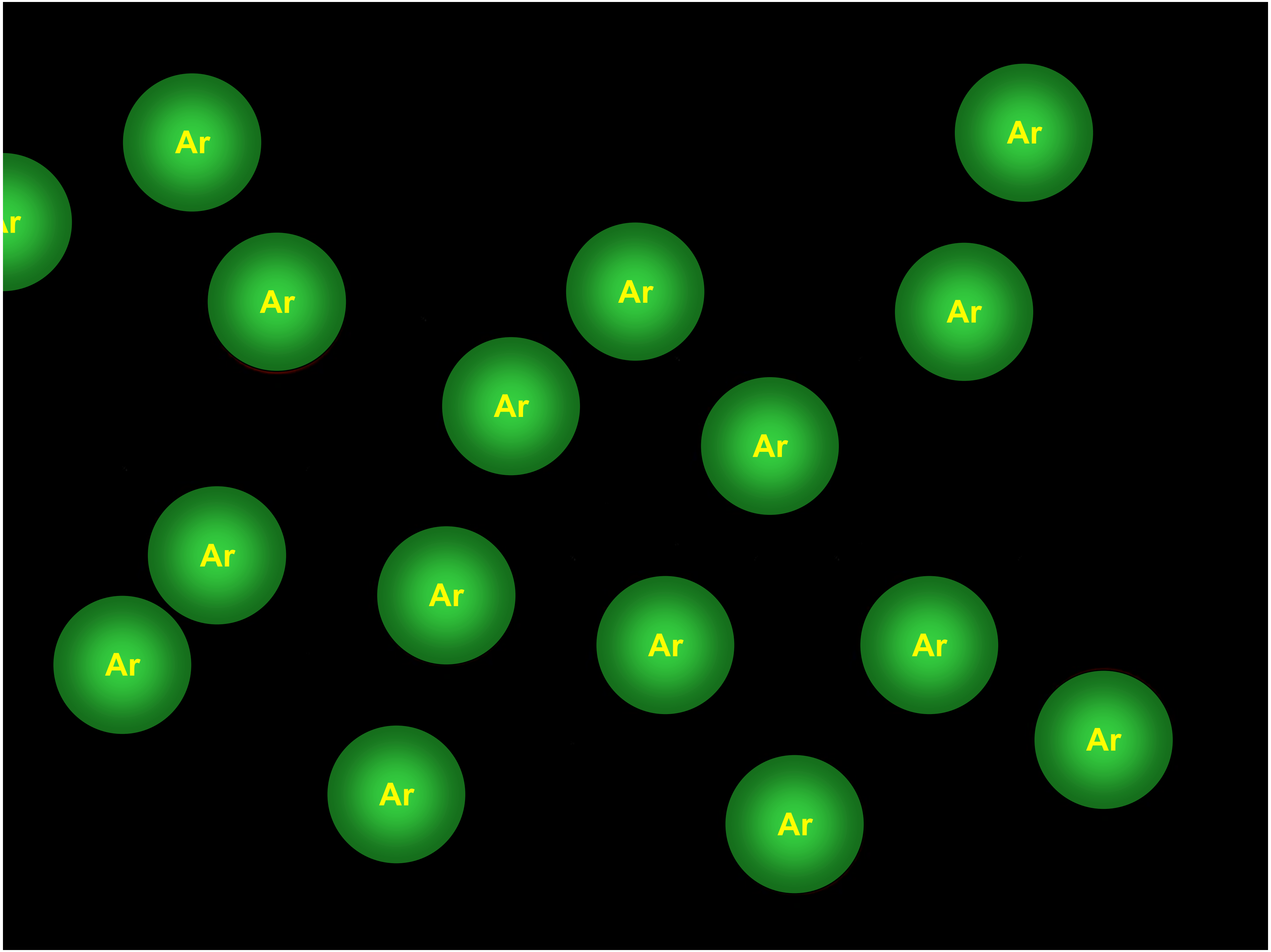
Assumptions for simulation:

- **Cross-section normalized to nucleon**
  - → $\sigma = 10^{-42}$ cm² $= 10^{-6}$ pb
  - → $M_{WIMP} = 100$ GeV
- **Halo Model**
  - → WIMP Density = 0.5 GeV/cm³
  - → $v_{esc} = 600$ km/s
- **Interaction**
  - → Spin independent
  - → Engel Form factor



Estimated event rates on Argon




Ar
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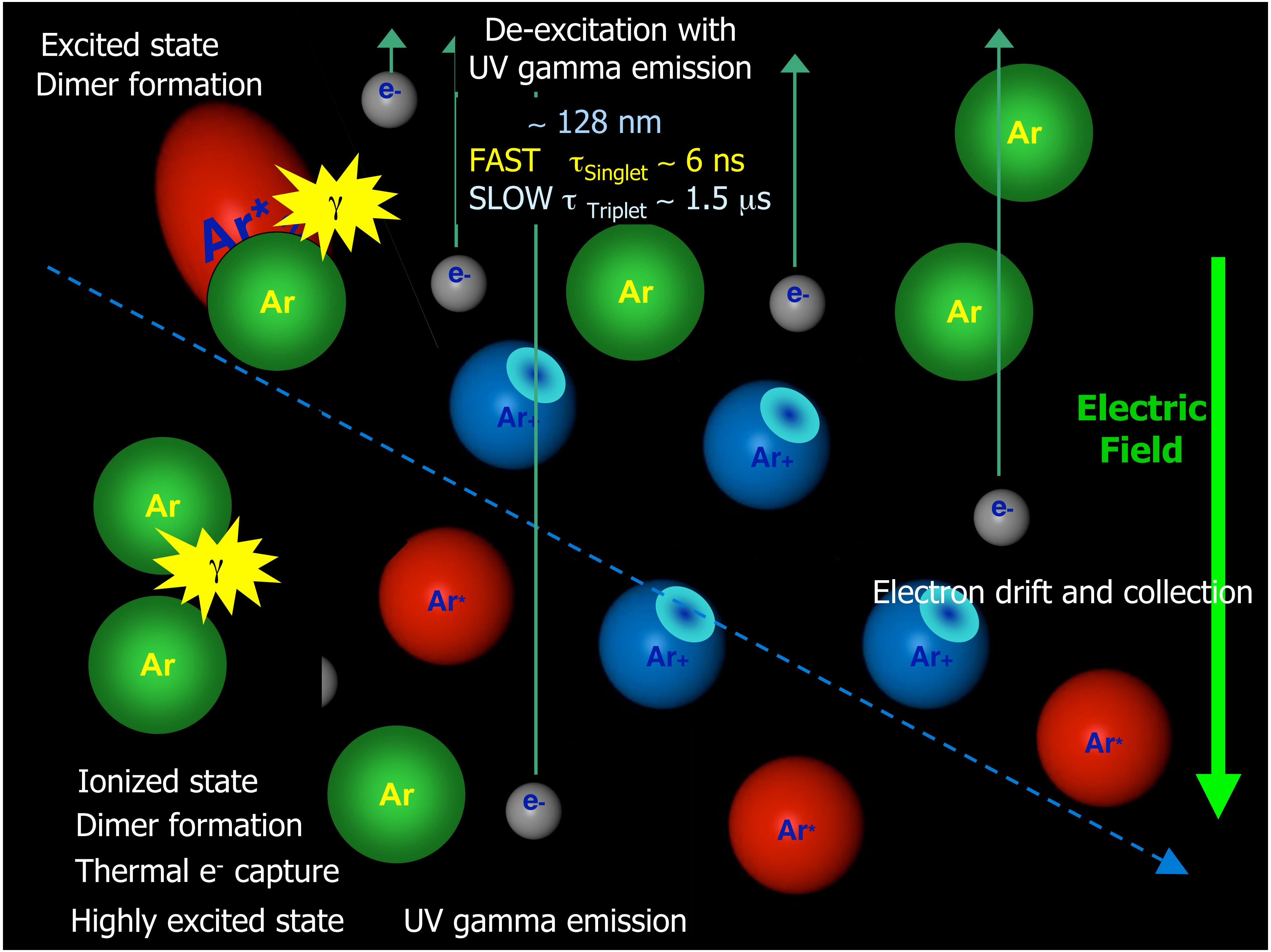
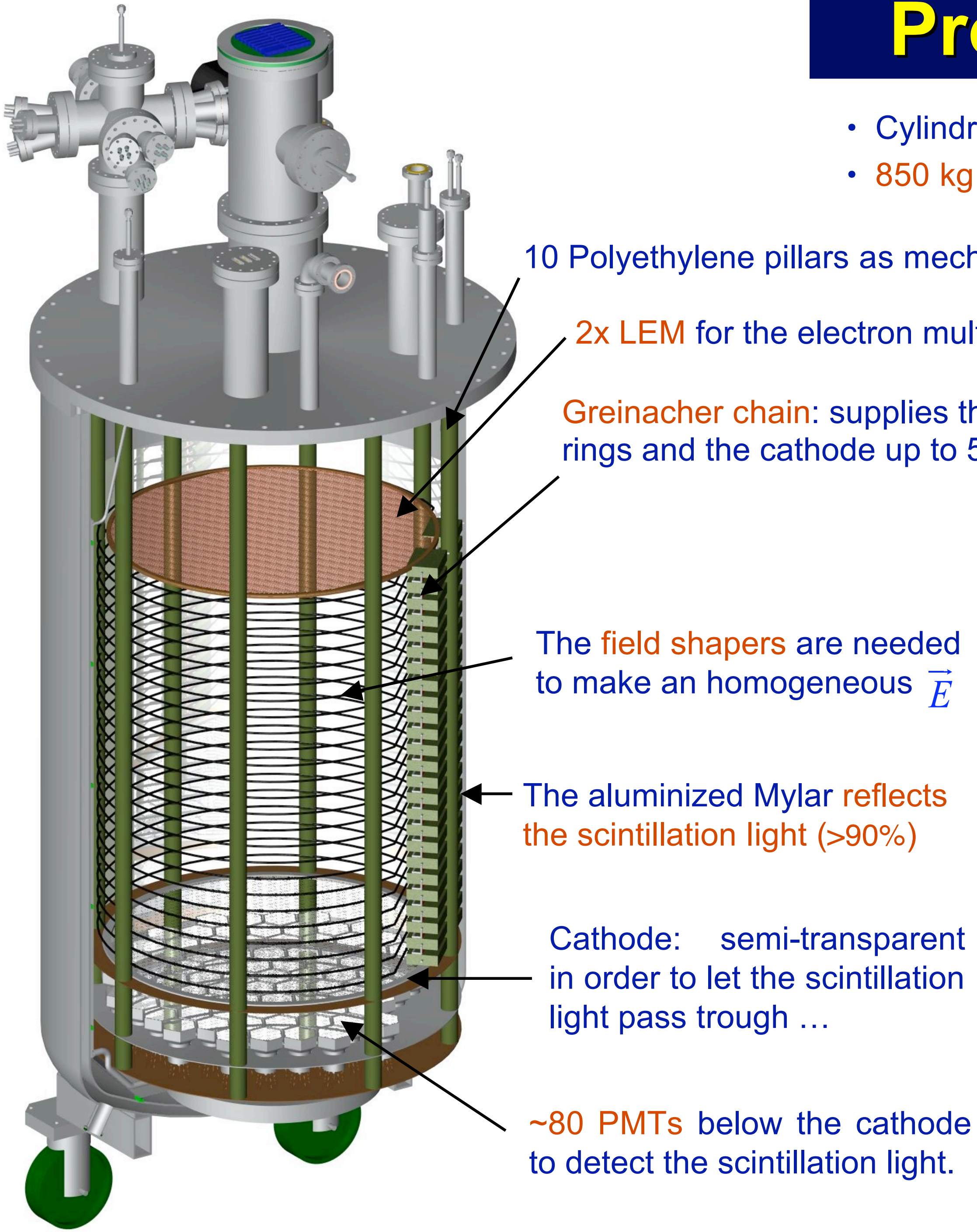
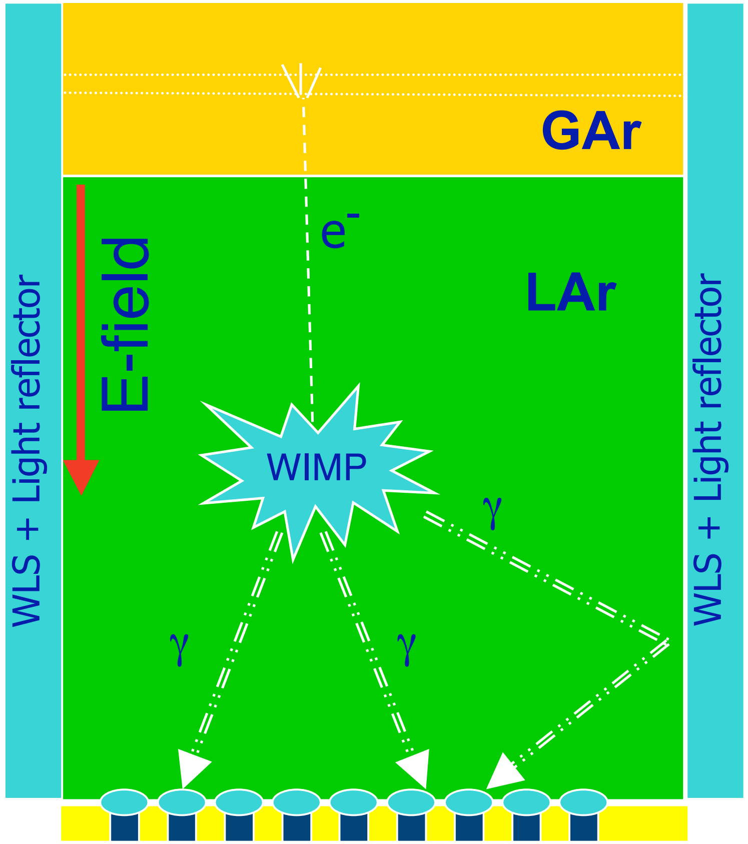

Excited state
Dimer formation
De-excitation with
UV gamma emission
~ 128 nm
FAST τSinglet ~ 6 ns
SLOW τ Triplet ~ 1.5 μs
Ar*
γ
e-
Ar
Ar+
Electric
Field
Electron drift and collection
Ionized state
Dimer formation
Thermal e- capture
Highly excited state
UV gamma emission

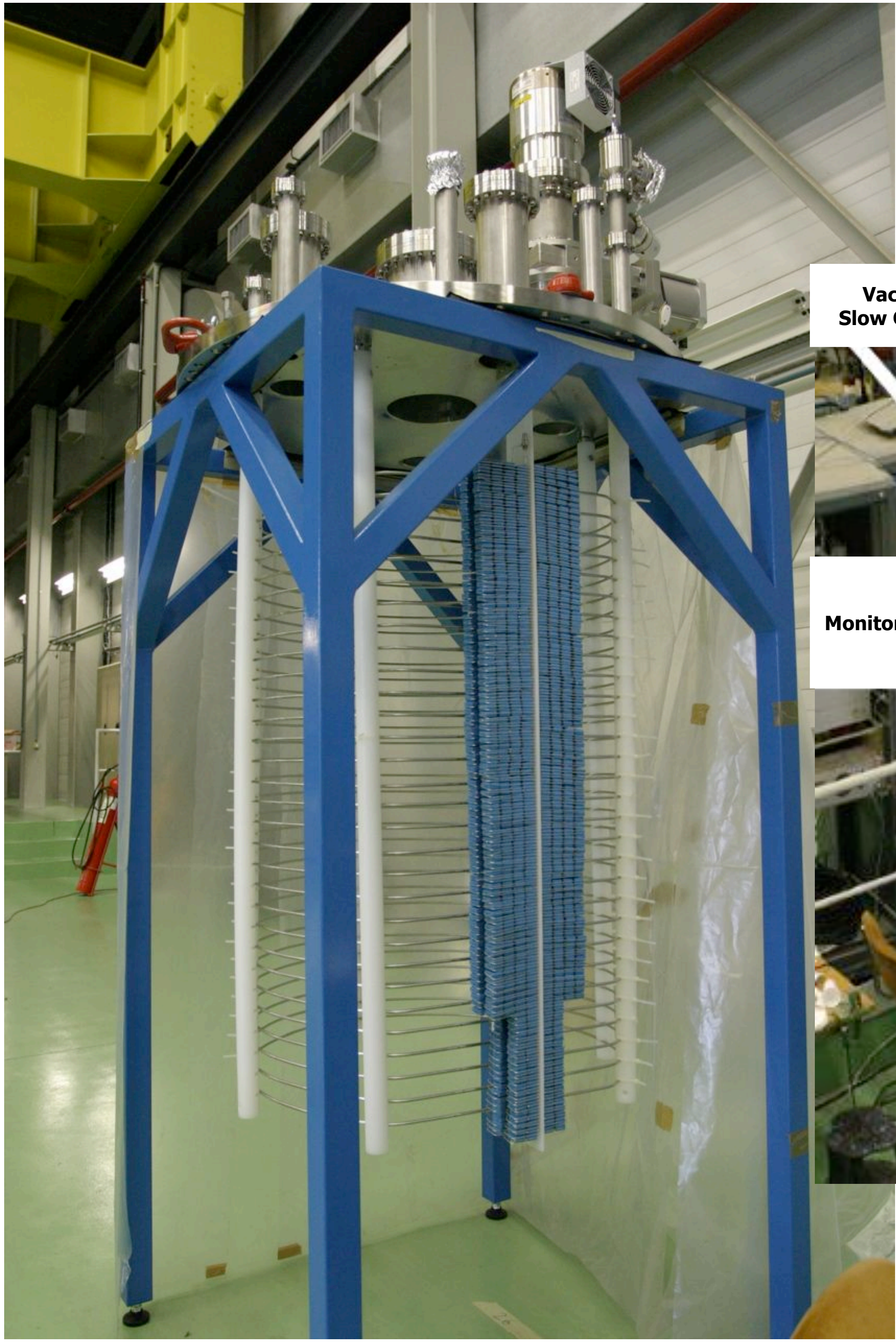
Prototype layout

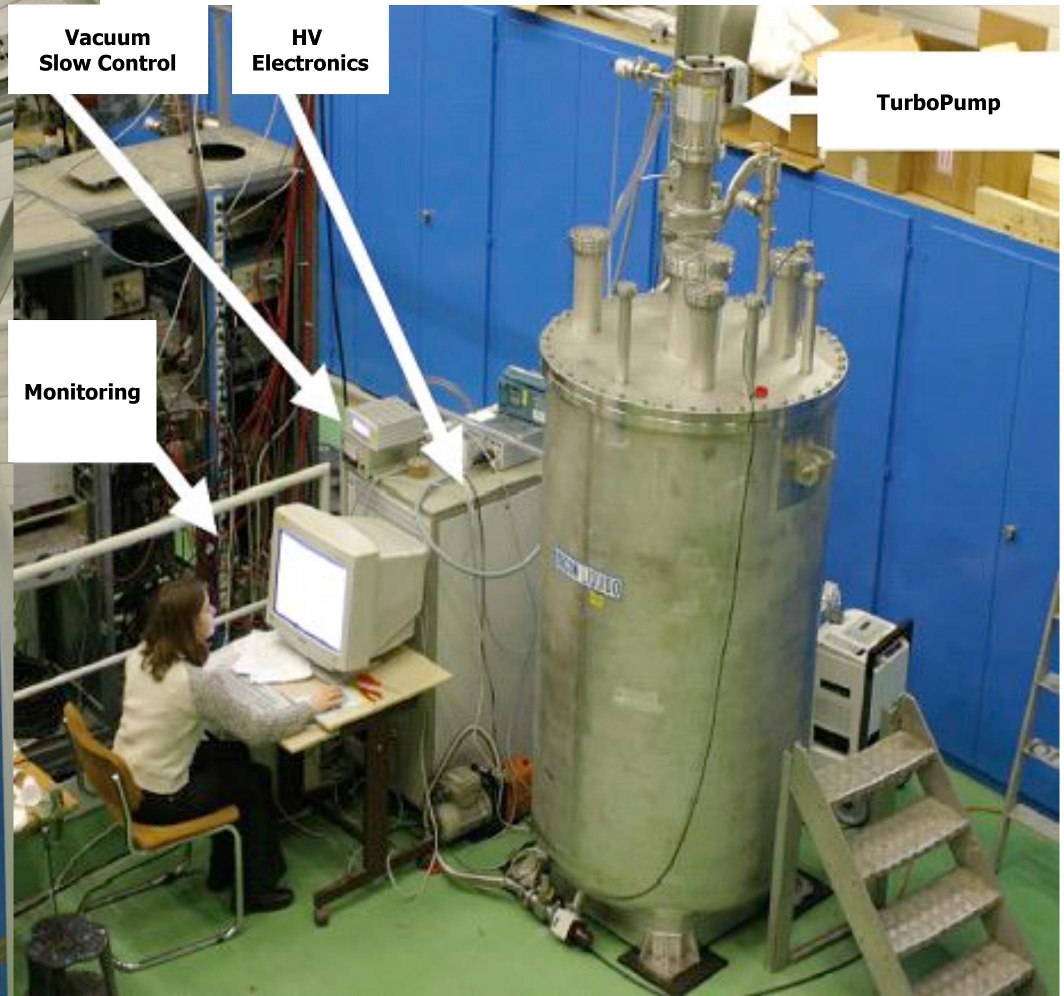
- Cylindrical volume, drift length ≈ 120 cm
- 850 kg LAr target





ArDM
1-ton prototype
@ CERN

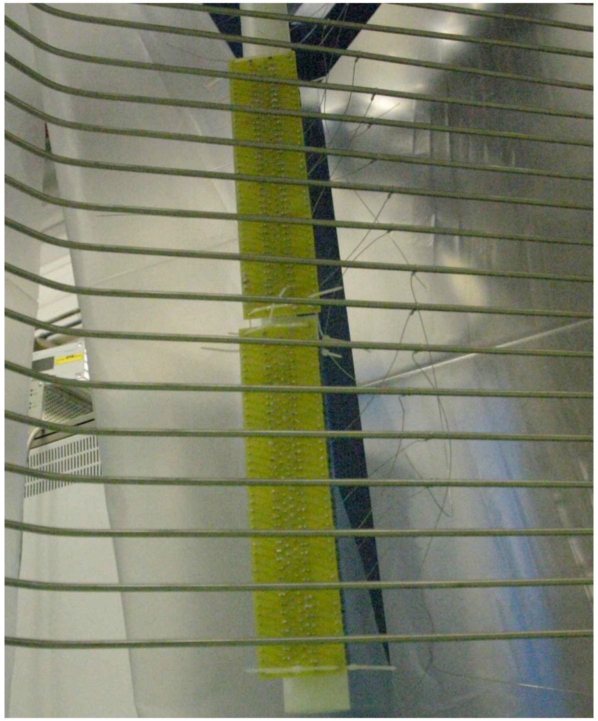


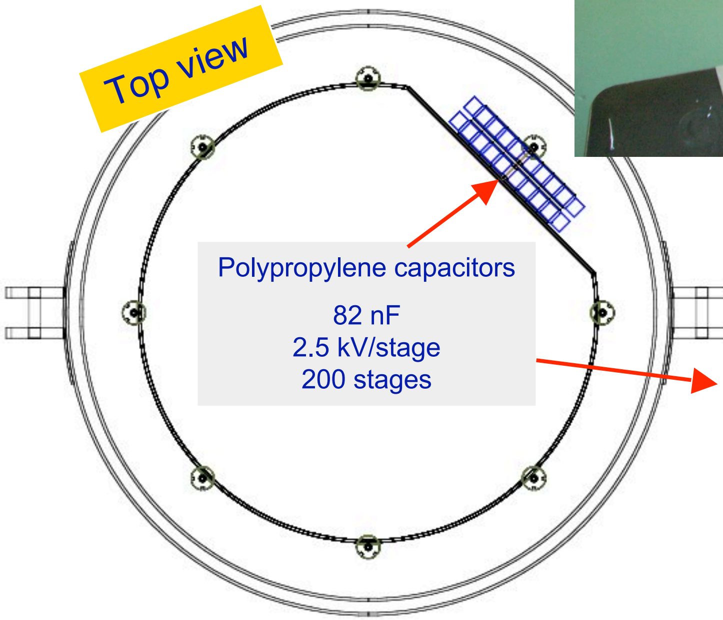


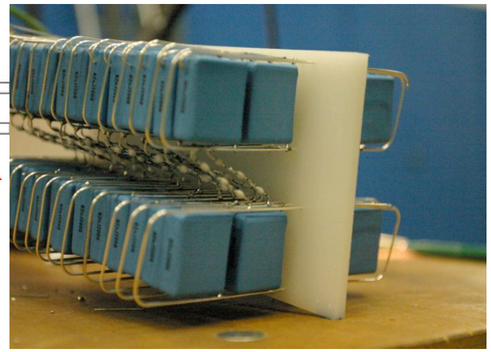
High Voltage system for drift field generation

- A cascade of rectifier cells (Greinacher/Cockroft-Walton circuit) used
- The total voltage we aim to reach is V_{tot} = 500 kV, i.e. ≈ 4 kV/cm
- Tests in liquid nitrogen have been performed
- The largest system successfully operated consists of 80 stages and reached stable operation at up to 120 kV ≈ 2 kV/cm

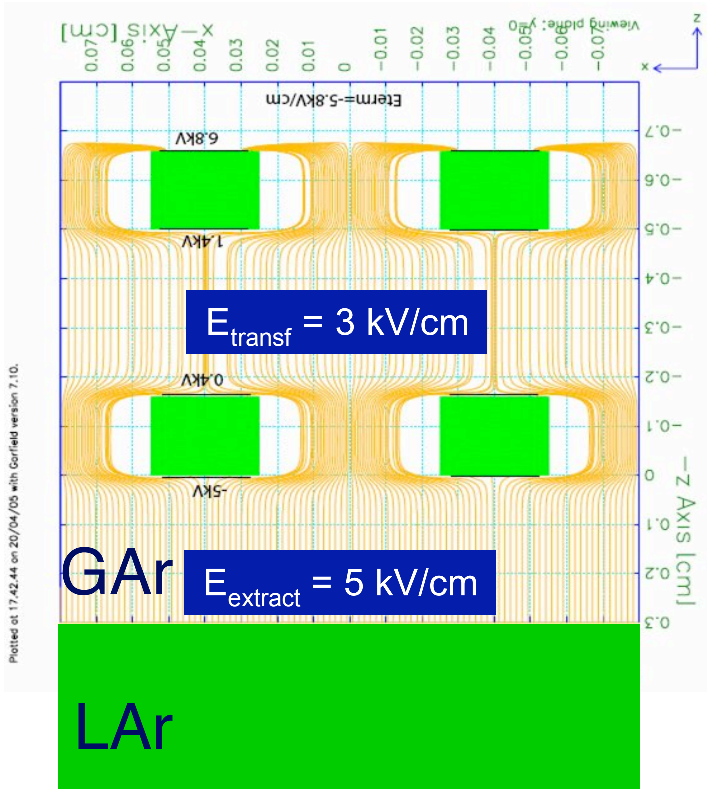
Mounted on field shaper rings

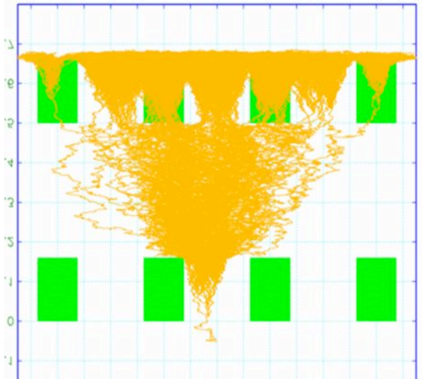




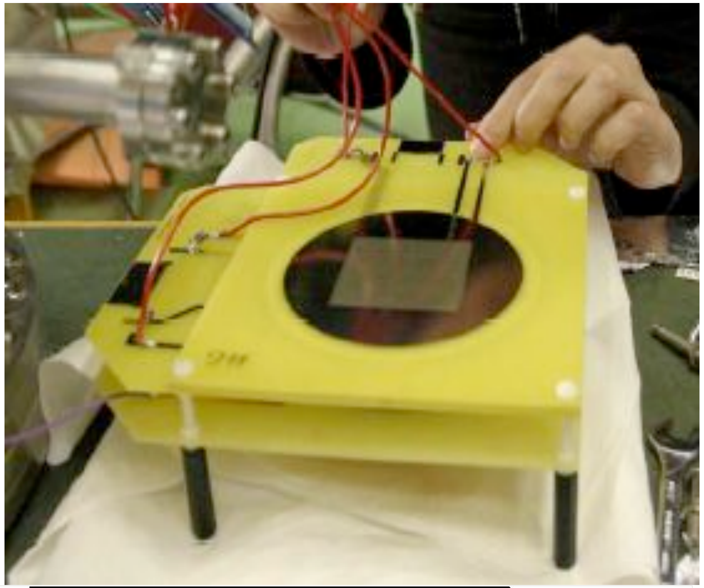


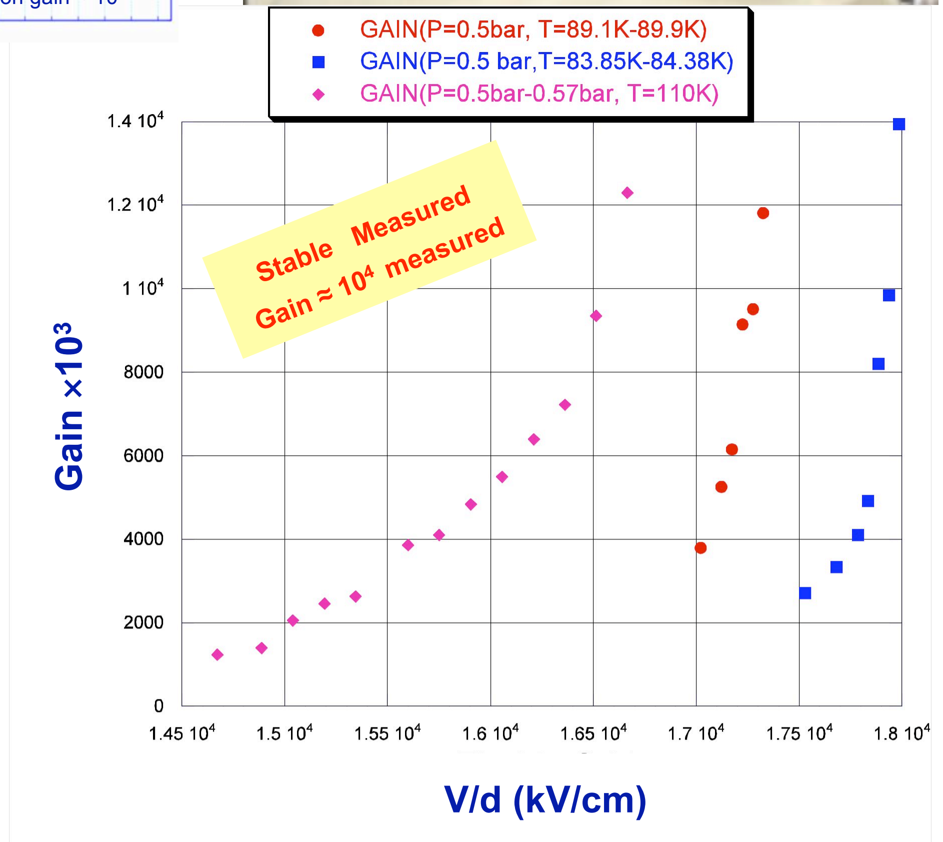
Layout of the charge readout system





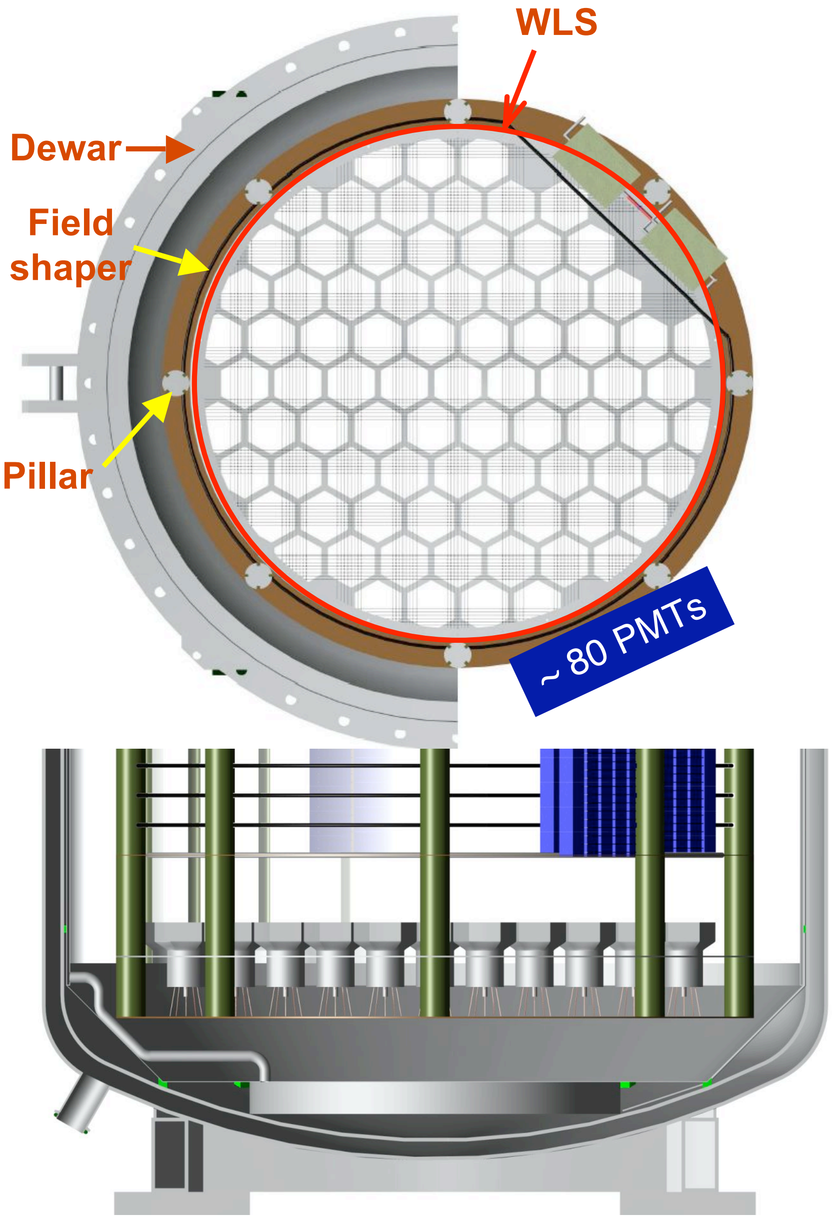
GARFIELD simulations indicate an expected single electron gain ≈ 10^4





- → Distance between stages: 3 mm
- → Avalanche spreads into several holes at second stage
- → Higher Gain reached as with one stage, with good stability
- → Hole dimension: 500 μm diameter, 800 μm distance.
- → Thickness of PCB: 1.6 mm

Layout of Light Readout system and PMT



1. Scintillation light detection via PMTs and WLS reflector in mirror walls

✓ Advantage: easier to find materials with high reflectivity for visible light than for UV light

✓ 128 nm γ produced in fiducial volume, hits the WLS mirror → diffuse reflection at 430 nm.

✓ Two layer WLS cylinder: outer to reflect visible light (99%), inner thin WLS added. Mylar foils coated with thin Al+MgF_2 layers (CERN)

2. Scintillation light detection via PMTs coated with WLS

- Polymer and Tetra-Phenyl-Butadiene (TPB) compound coated on PMT window shifts the DUV light (128 nm) to 430 nm
- Efficiency of wavelength shifting: 20% to 30%
- PMT's: array of ~80 photosensors at bottom of detector

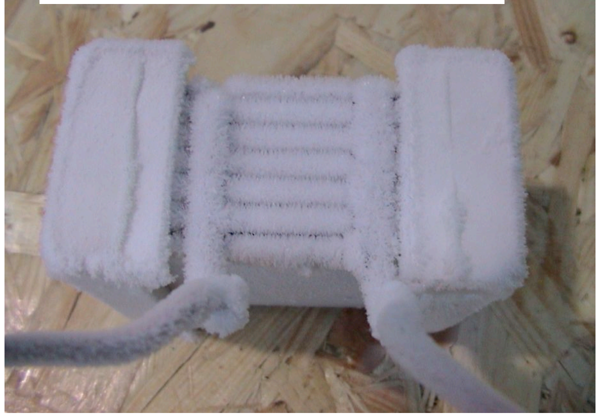
Slow Control Devices

- A series of **custom designed Slow Control devices** have been built, tested and installed to monitor temp., level, purity …

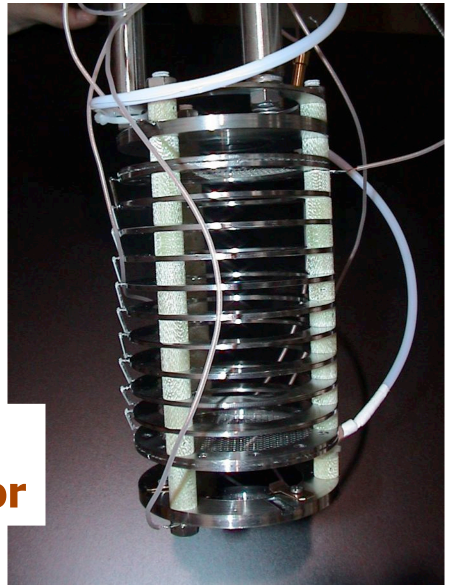
PT10K resistors

10 KΩ at 0ºC
Range: -200 to 400ºC

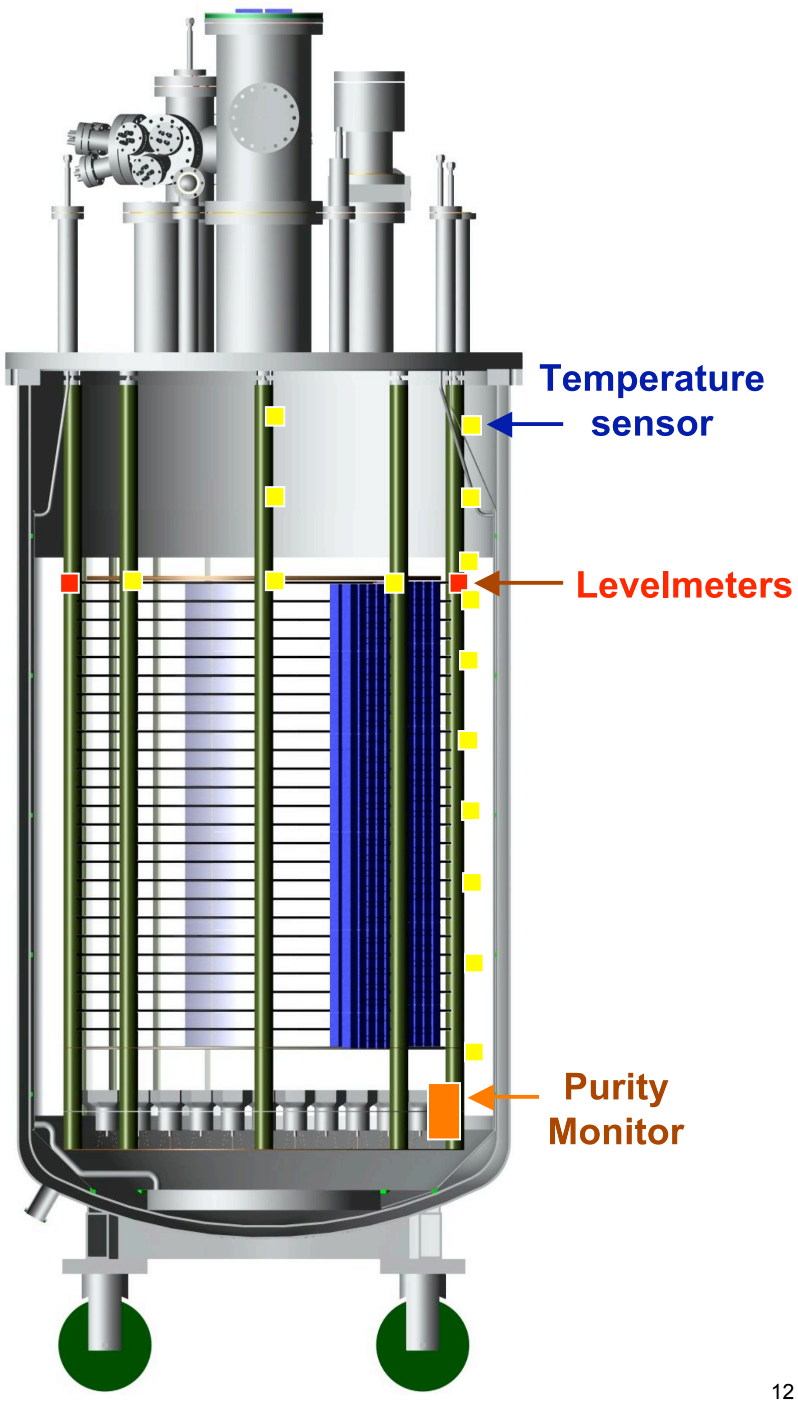
Capacity levelmeter



~ 0.7 pF/mm
precission of ~ 0.03 mm

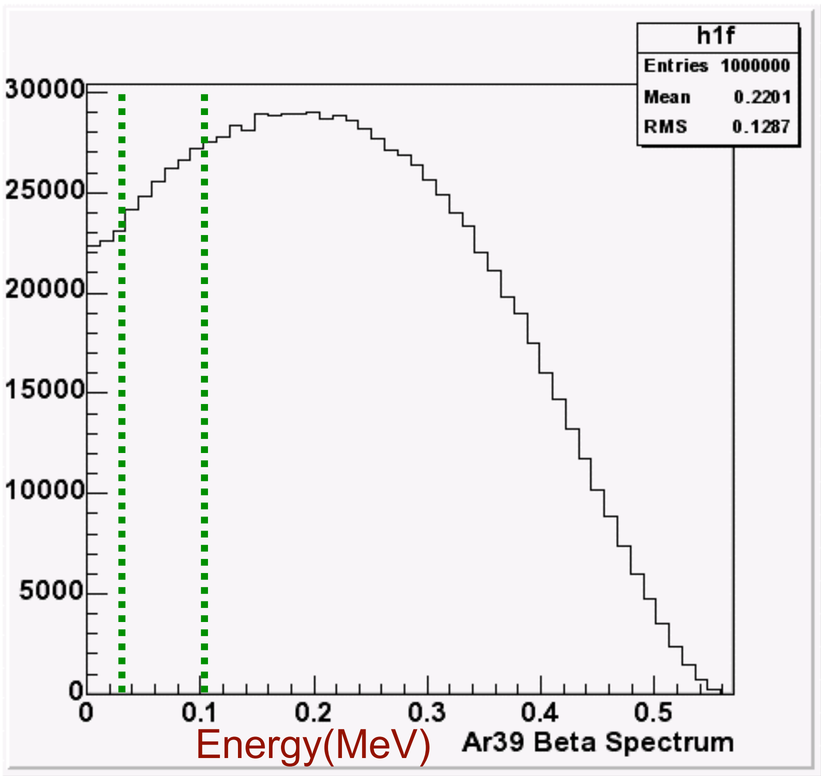


Argon Purity monitor



Intrinsic background from Argon 39 isotope

Natural argon from liquefaction of air contains small fractions of ^{39}Ar radioactive isotope (well known to geophysicists)

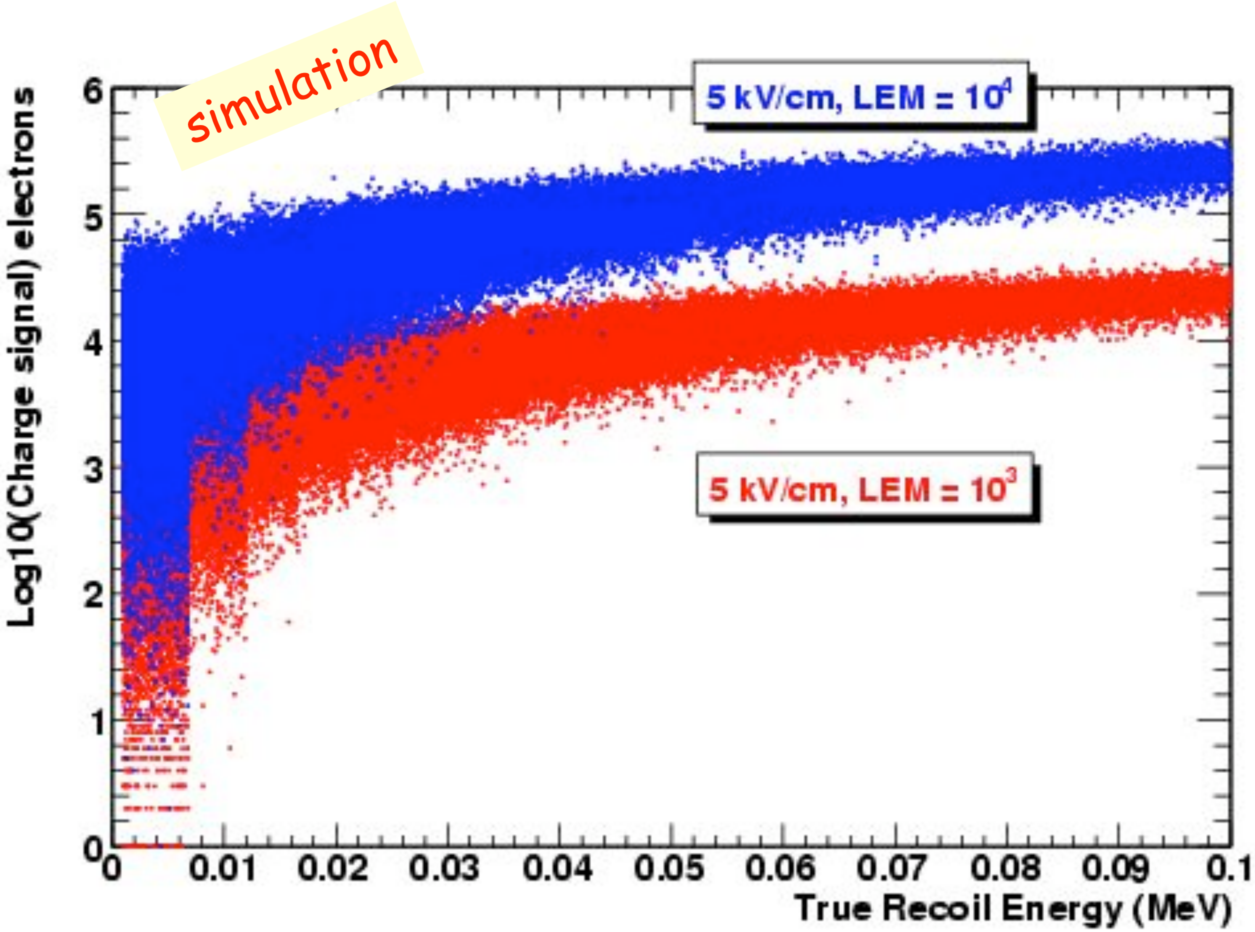


- Induced in atmospheric argon by cosmic rays
- Concentration in natural Ar: 8.1×10^{-16} $^{39}Ar/Ar$ [H.H. Loosli, Earth and Planetary Science Letters, 63 (1983) 51 and "Nachweis von ^{39}Ar in atmosphärischem Argon" PhD thesis University Bern 1968]
- Half life: 269 years, Q=565 KeV
- Mean Energy: 218 keV
- Integrated rate in 1 ton LAr ~ 1kHz

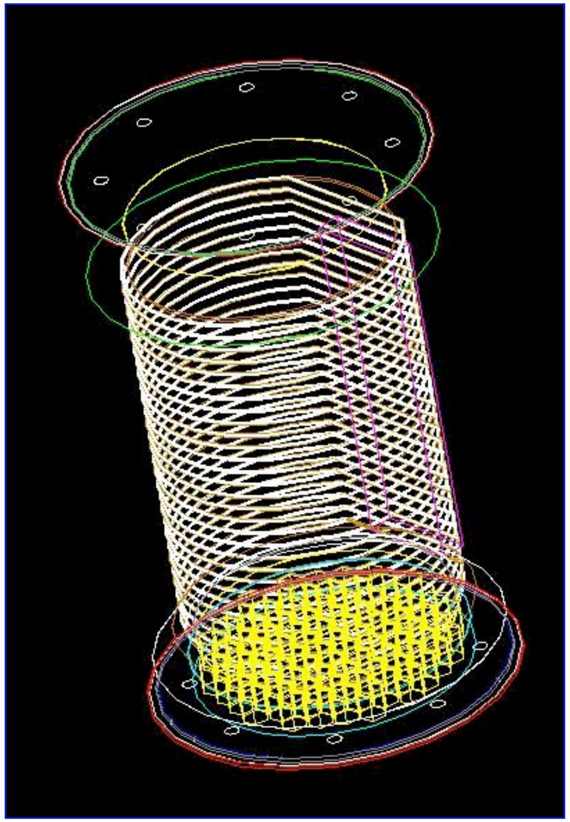
[WARP Coll.] astro-ph/0603131

To suppress ^{39}Ar fraction we consider using Ar extracted from well gases (extracted from underground natural gas). On the other hand, this source, evenly distributed in the target, provides precise calibration and monitoring of the detector response.

Charged (WIMP) signal readout



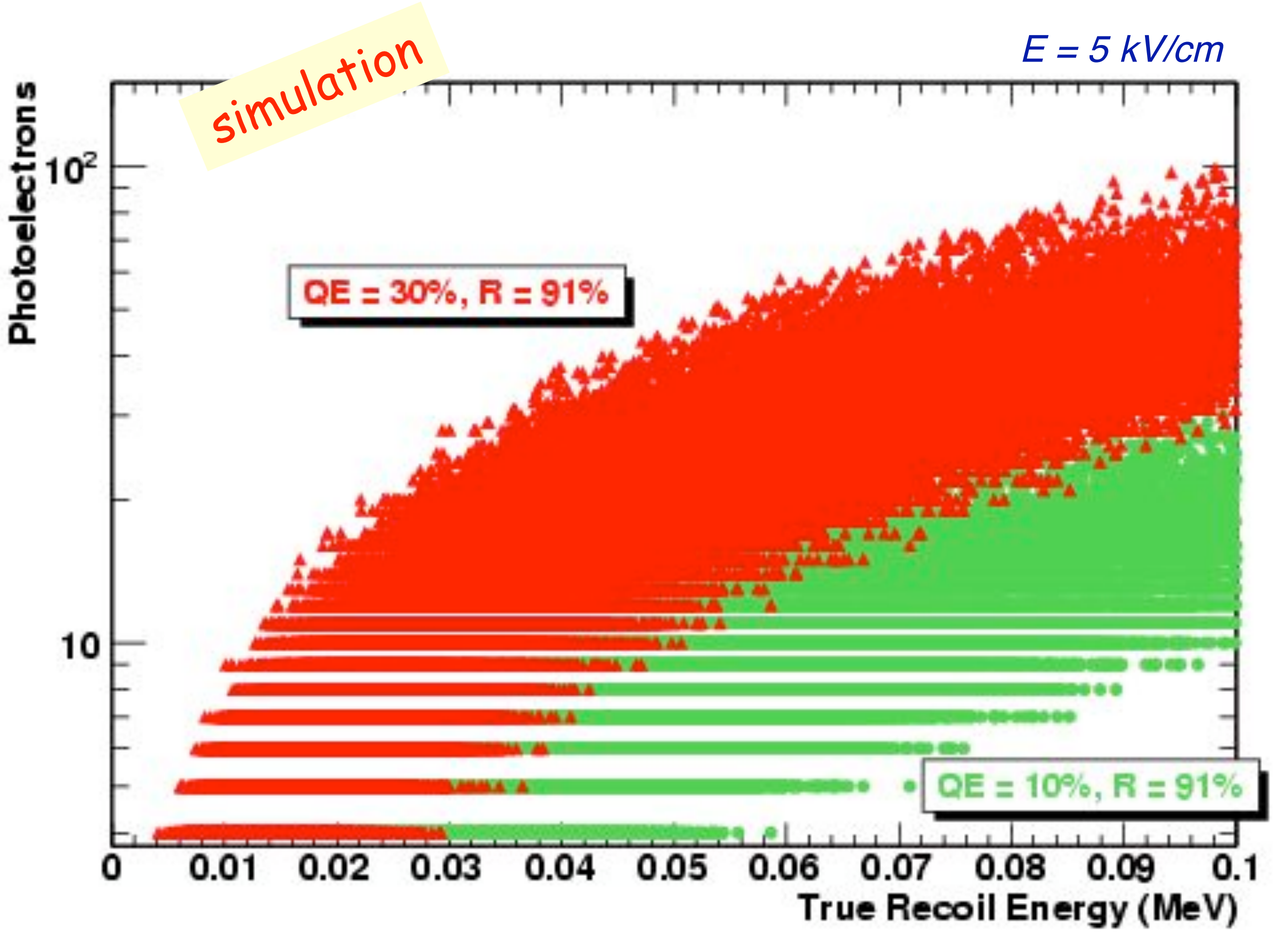
Detailed GEANT4 simulation of charge readout for various configurations



- Drift field ≈ 5 kV/cm
- Charge LEM readout: Single electron gain ≈ $10^3 \div 10^4$
- Electron lifetime included (1.4 ms ~ 0.2 ppb O_2 eq.)

Light (WIMP) signal readout

Detailed simulation of charge readout for various configurations



- Surface wall reflectivity R ≈ 90%
- Cathode transparency = 80%
- PMT coverage = 70%
- PMT quantum efficiency QE ≈ 10% ÷ 30%

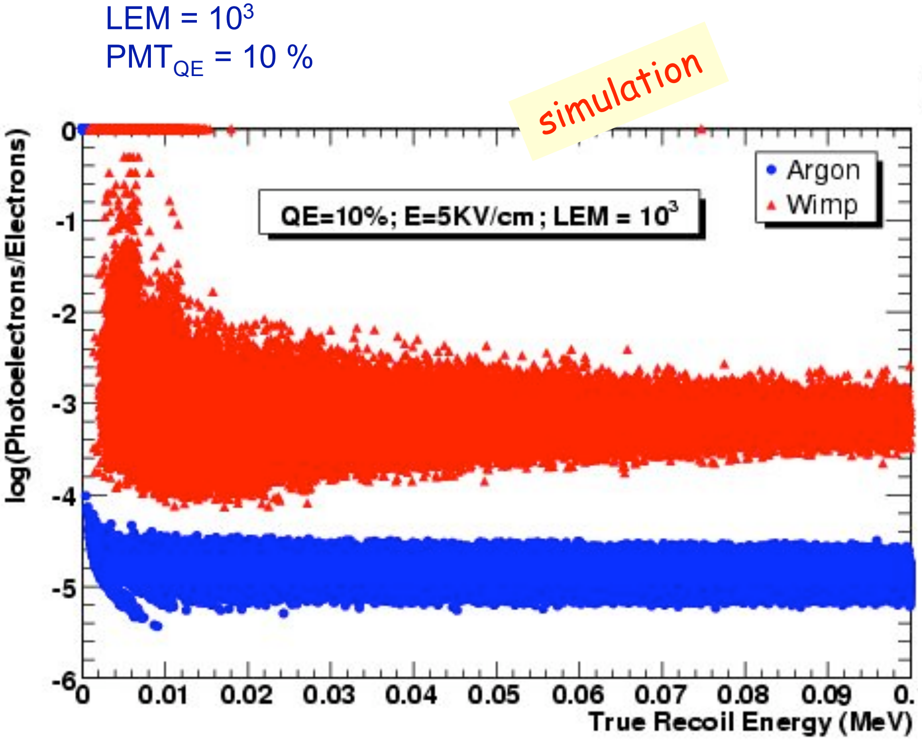
Average light yield

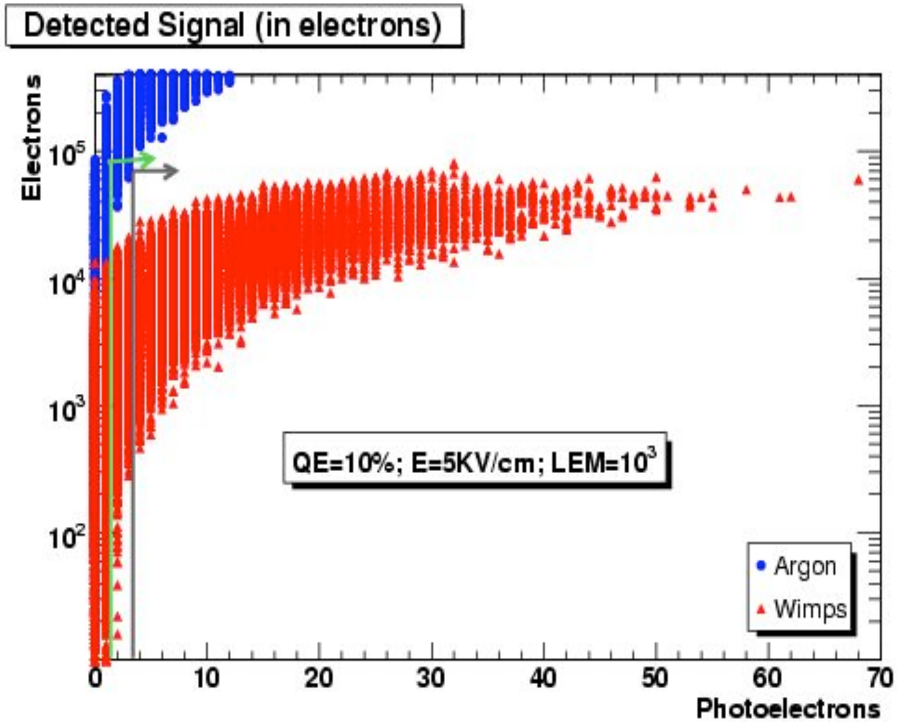
0.15 ÷ 0.43 phe/keV

WIMPs vs. ^{39}Ar background discrimination

This is MONTE CARLO, thisrelies heavily on MC, there is no reason to belive this is OK, this is exactly what the 1 ton test at CERN should prove.

Drift field E = 5 kv/cm
LEM = 10^3
PMT_{QE} = 10 %





CUTS:
True recoil energy > 30 keV
Q > 2000 electrons
light ≥ phe

phe = 2 : ~91 WIMP evts/day
phe = 4 : ~85 WIMP evts/day

(If Quenching = 0.28)

phe = 2 : ~39 WIMP evts/day
phe = 4 : ~9 WIMP evts/day

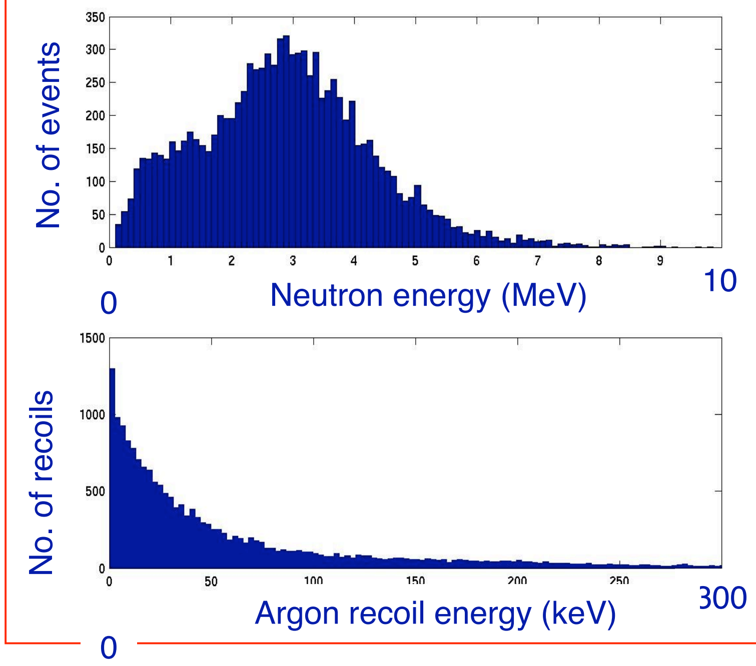
Neutron Background from detector components

Neutron sources:

- Uranium and Thorium contamination (spontaneous fission) of the detector components and the surrounding rock:
  - flux about 3.8×10^{-6} cm^{-2} s^{-1} (at 2450 m.w.e.)
  - can be shielded, e.g. by a hydrocarbon shield
- Muon-induced neutrons from surrounding rock, shielding and detector components

High energy neutrons penetrate shielding, are thereby moderated and can cause WIMP-like events.

Geant4 simulation



Event numbers per year

Component	n per year	WIMP-like recoils
Container	~ 400	~ 50
LEM (std. materials)	~ 10000	~ 1300
LEM (PEEK)	< 18	< 1
81 PMTs (std. materials)	~ 12000	~ 1350
81 PMTs (screened)	~ 600	~ 70

Compared with ~ 3500 WIMP events at $\sigma = 10^{-43}$ cm^{-2}

Nuclear recoils:

→ 70% scatter more than once within the fiducial volume → advantage of large detectors

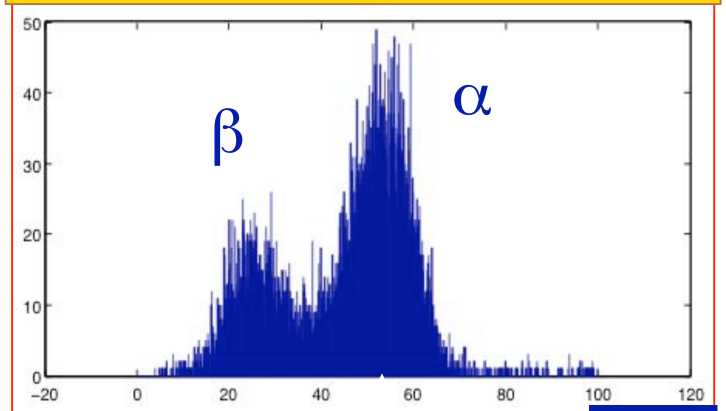
→ 10% produce a WIMP-like event (single scattering, recoil energy $\in$ [30,100] keV)

Light measurements in Liquid Argon (preliminary)

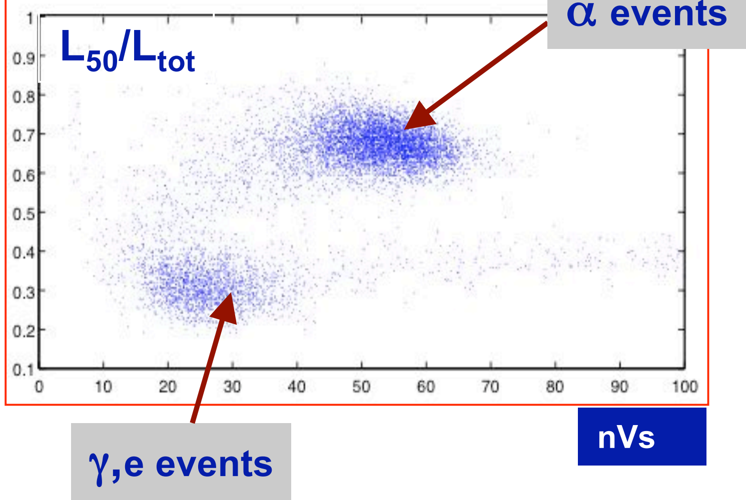
real data

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

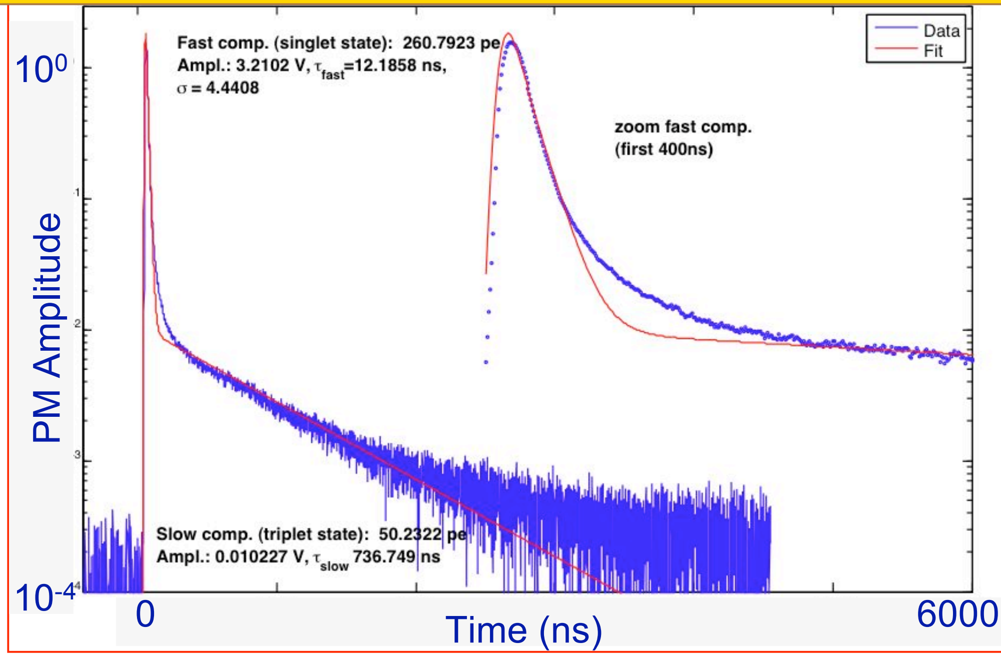
Event separation in liquid argon



Por un lado hay más luz de centelleo DETECTADA de alphas que de betas



Scintillation light from α in 1200 mbar liquid argon



→ α events separate well from γ,e events

→ Fast and slow light components distinguishable

$$\frac{I_S}{I_T} =$$

~ 0.3 for β particles

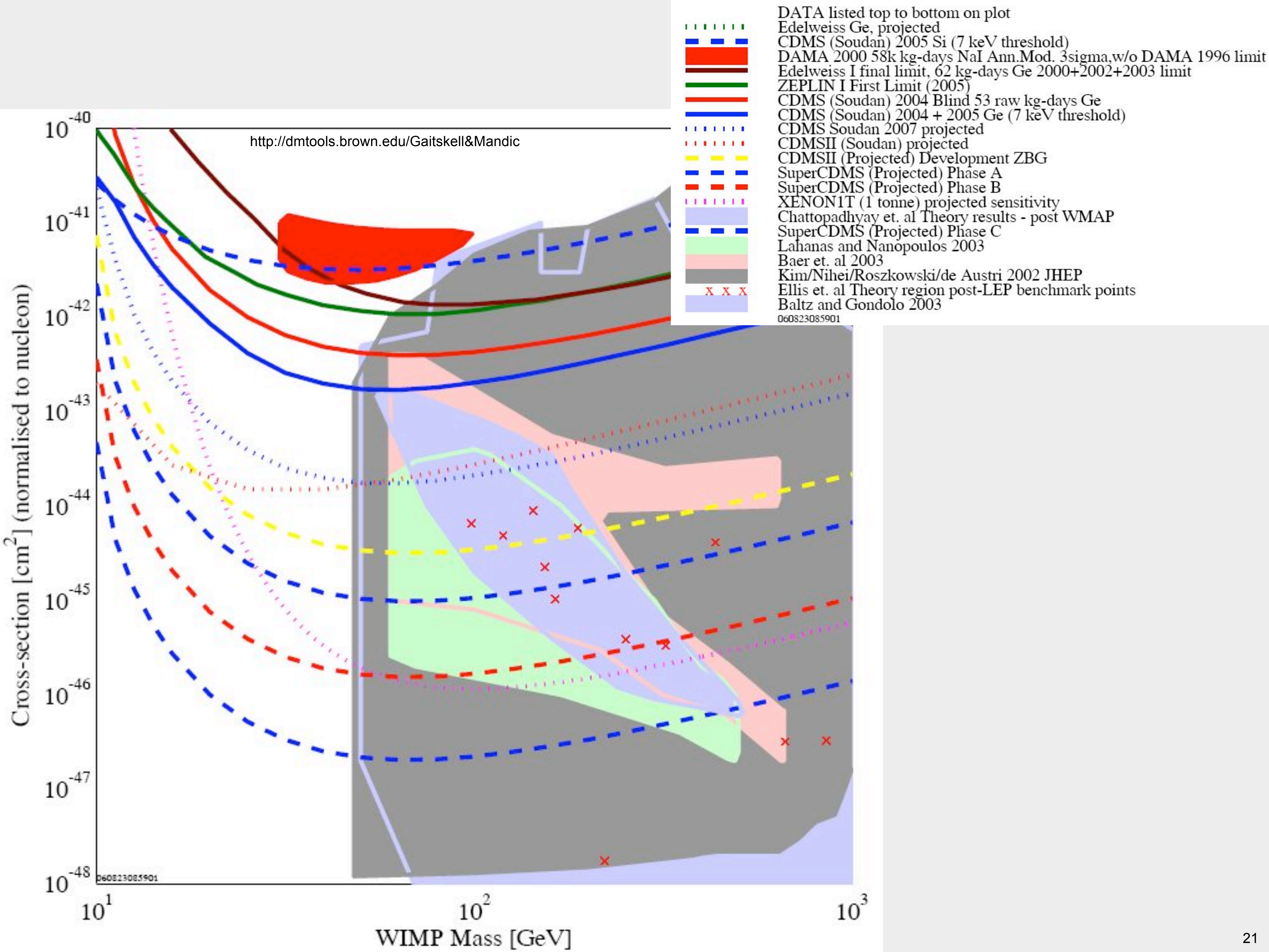
~ 1.3 for α particles

~ 3 for fission fragments

#photo-electrons	Rejection (@E=0V/cm)
>10	> 10^2
>20	> 5×10^3
>30	> 10^5

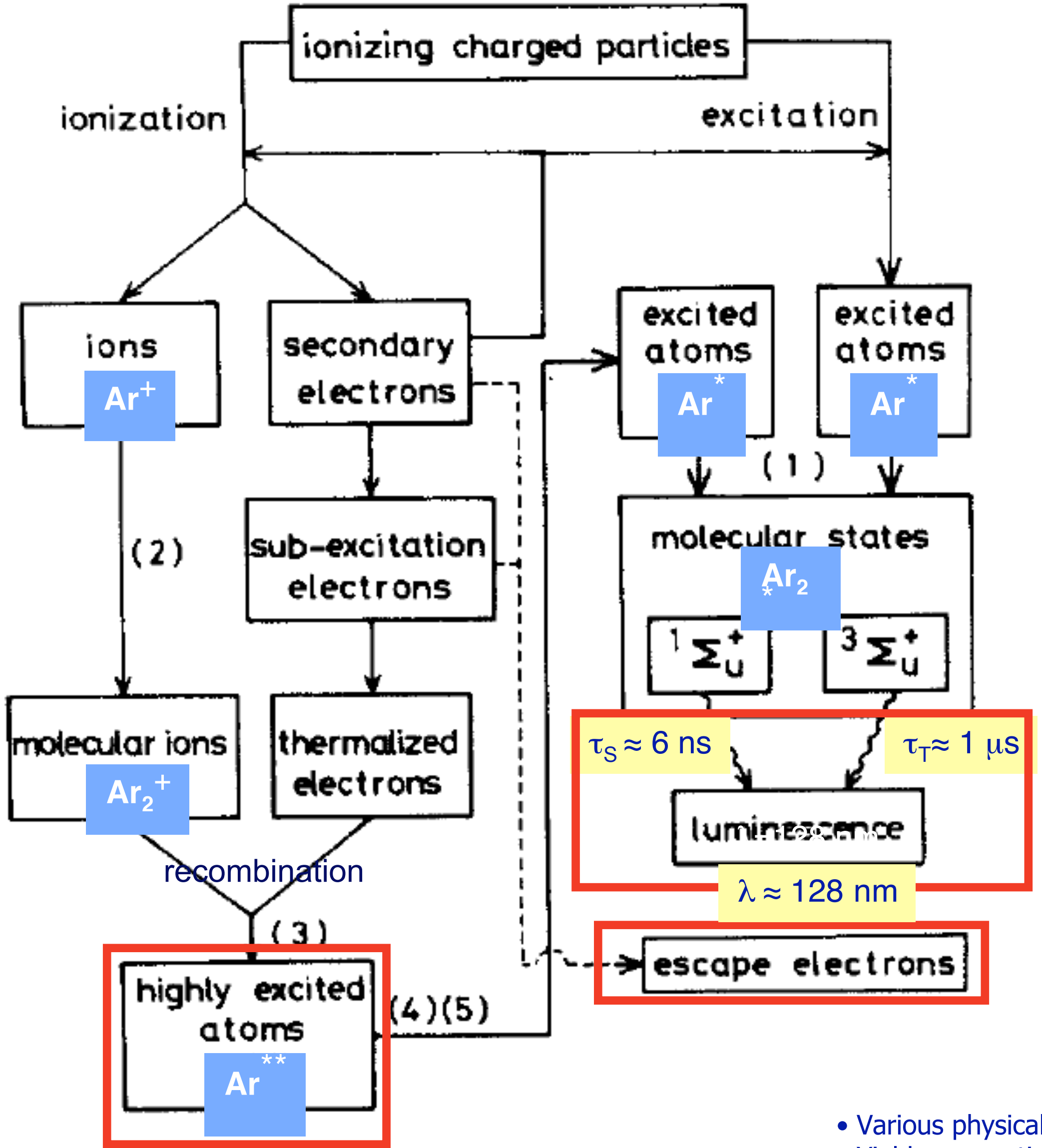
Outlook

- We are constructing a 1 ton prototype at CERN whose goal is to detemonstrate the validity of the design.
- Our first milestone is a proof of principle on γ-rays and beta electron (^{39}Ar) rejection vs nuclear recoils above ground (1st phase, 2006-2007) .
- The goal requires a successful implementation and operation of:
  - Purified Liquid Argon target
  - High drift field
  - Independent charge (LEM-based charge readout) and
  - Scintillation light (PMTs) detection systems
- Following its successful operation, we will consider a deep underground operation (2st phase, 2007?). An EOI to the Canfranc Laboratory has been submitted.
- The expected exclusion sensitivity of the prototype is 10^{-42} - 10^{-44} cm^2 SI (10^{-6} - 10^{-8} pb) depending on the background rejection power.
- This tecnology could provide the means to develop larger detectors to reach sensitivities below 10^{-44} cm^2 SI cross section.


DATA listed top to bottom on plot
Edelweiss Ge, projected
CDMS (Soudan) 2005 Si (7 keV threshold)
DAMA 2000 58k kg-days NaI Ann.Mod. 3sigma,w/o DAMA 1996 limit
Edelweiss I final limit, 62 kg-days Ge 2000+2002+2003 limit
ZEPLIN I First Limit (2005)
CDMS (Soudan) 2004 Blind 53 raw kg-days Ge
CDMS (Soudan) 2004 + 2005 Ge (7 keV threshold)
CDMS Soudan 2007 projected
CDMSII (Soudan) projected
CDMSII (Projected) Development ZBG
SuperCDMS (Projected) Phase A
SuperCDMS (Projected) Phase B
XENON1T (1 tonne) projected sensitivity
Chattopadhyay et. al Theory results - post WMAP
SuperCDMS (Projected) Phase C
Lahanas and Nanopoulos 2003
Baer et. al 2003
Kim/Nihei/Roszkowski/de Austri 2002 JHEP
Ellis et. al Theory region post-LEP benchmark points
Baltz and Gondolo 2003
060823085901
http://dmtools.brown.edu/Gaitskell&Mandic
Cross-section [cm²] (normalised to nucleon)
WIMP Mass [GeV]
060823085901

Processes induced by charged particles in Argon

M. Suzuki et al. NIM 192 (1982) 565



The electron-ion density is so high in the ionization track produced by alpha particles that the recombination process proceeds much faster than the electron drift, an produces "singlet" excitons abundantly, resulting in the fast recombination luminiscence.
Since **the specific ionization density** significantly **affects the time dependence** of the scintillation light of liquid Argon, it is possible to distinguish different ionizing particles by using a pulse shape discriminator. This will provide an effective background rejection mechanism.

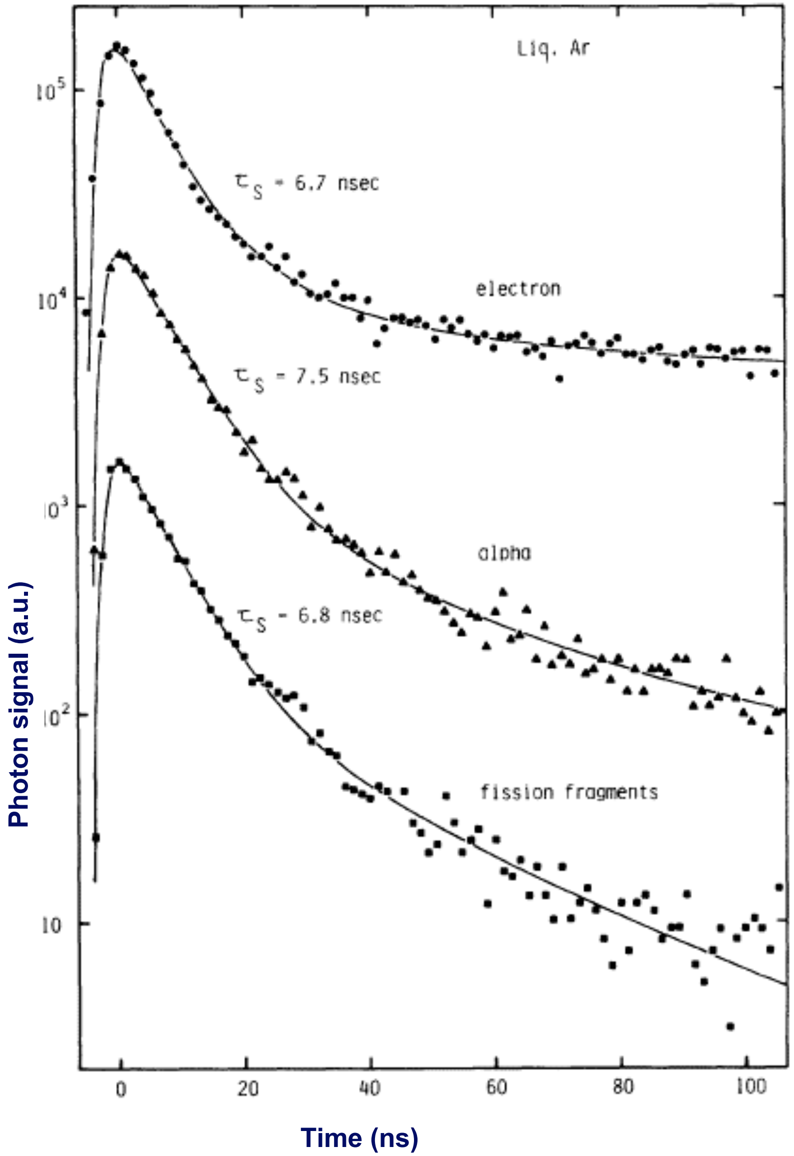
En Xenon líquido la emisión de centelleo tiene:
$\lambda \approx 170$ nm $\tau_S \approx 5$ ns $\tau_T \approx 30$ ns

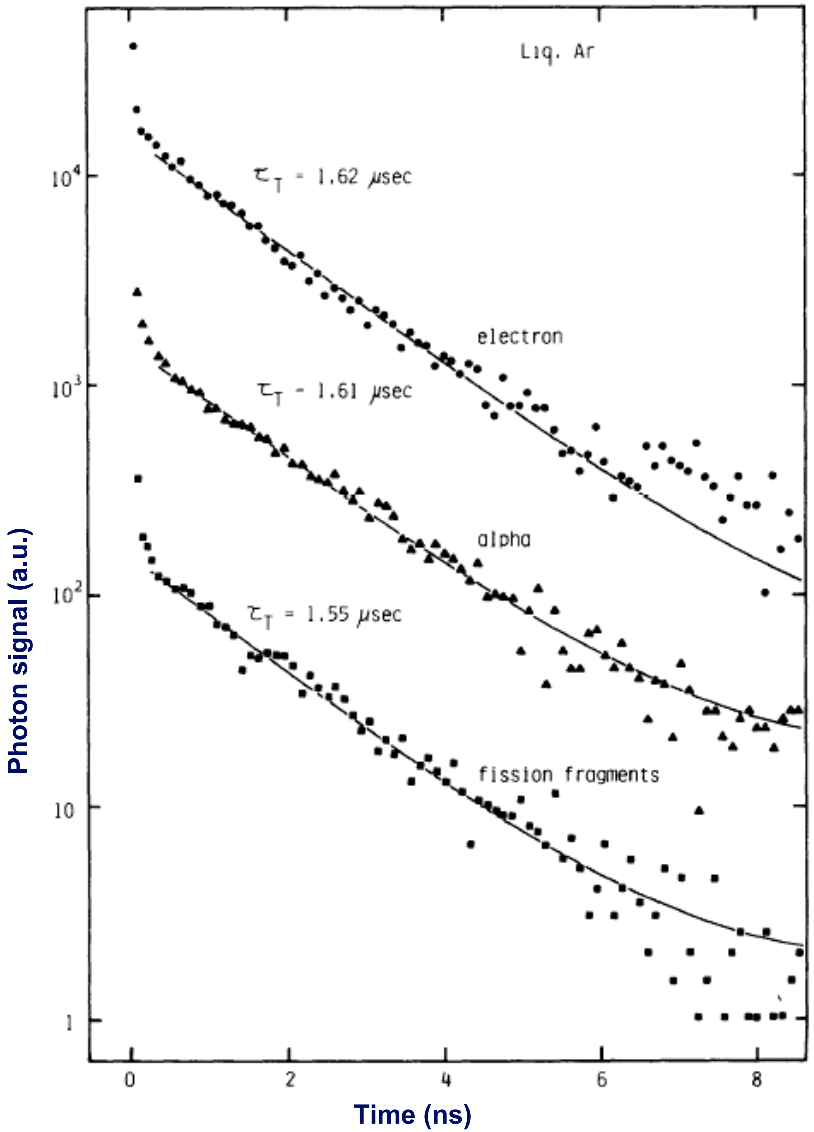
UV Light (two components)
+
Charge

- Various physical processes leading to scintillation & ionization
- Yields are particle, energy and drift field dependent
- Simulation describes different response to WIMP and MIPs

Time dependence of scintillation light

A. Hitachi et al., Phys. Rev. B 27 (1983) 5279



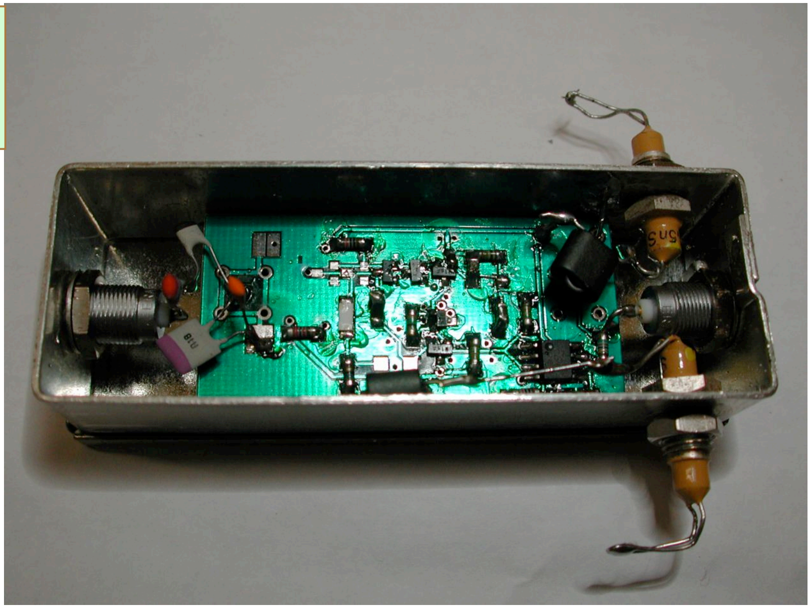


Effect of ionization density on the time dependence of luminescence !

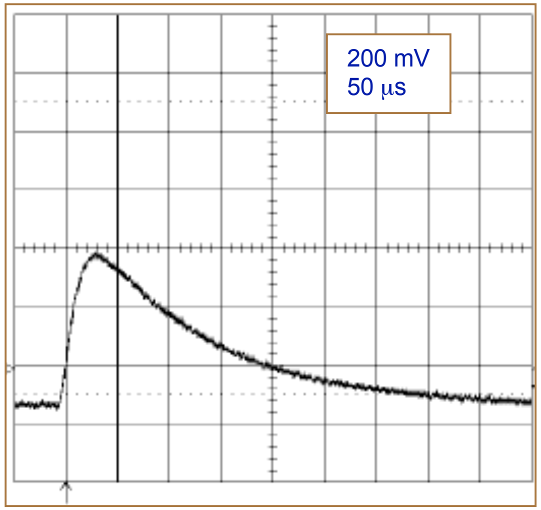
Two-stage LEM: measurements (preliminary)

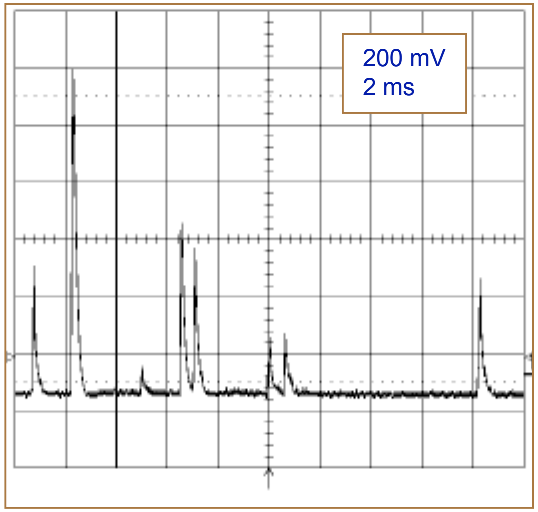
Custom-made front-end charge preamplifier (3.3 mV/fC)

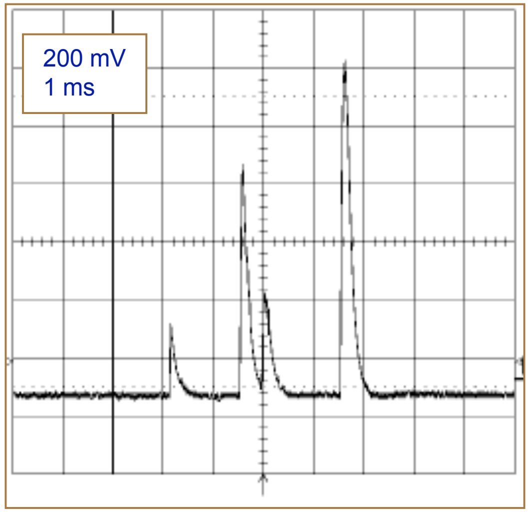
inspired from C.Boiano et al. IEEE Transact. on Nucl. Science, Vol. 51 Nº5 2004



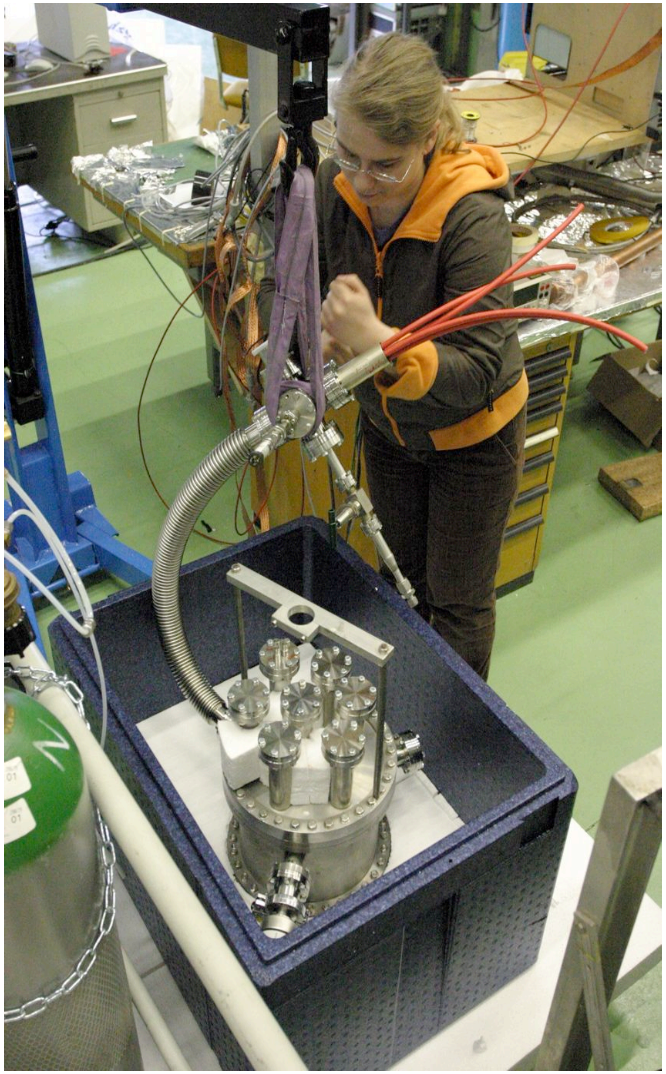
- Shapes of the signals from double-stage LEM system
- Average signal rise time: 12 μs.
- Signals from Fe^{55} radioactive source (5.8 keV), event rate about 1 kHz.

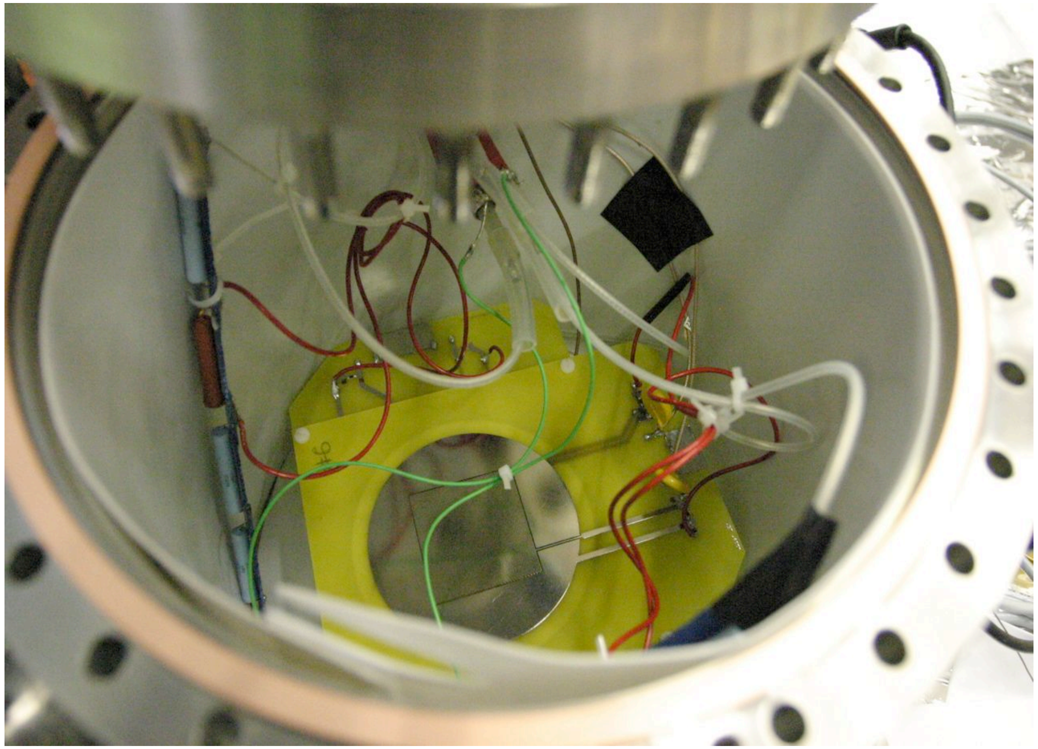




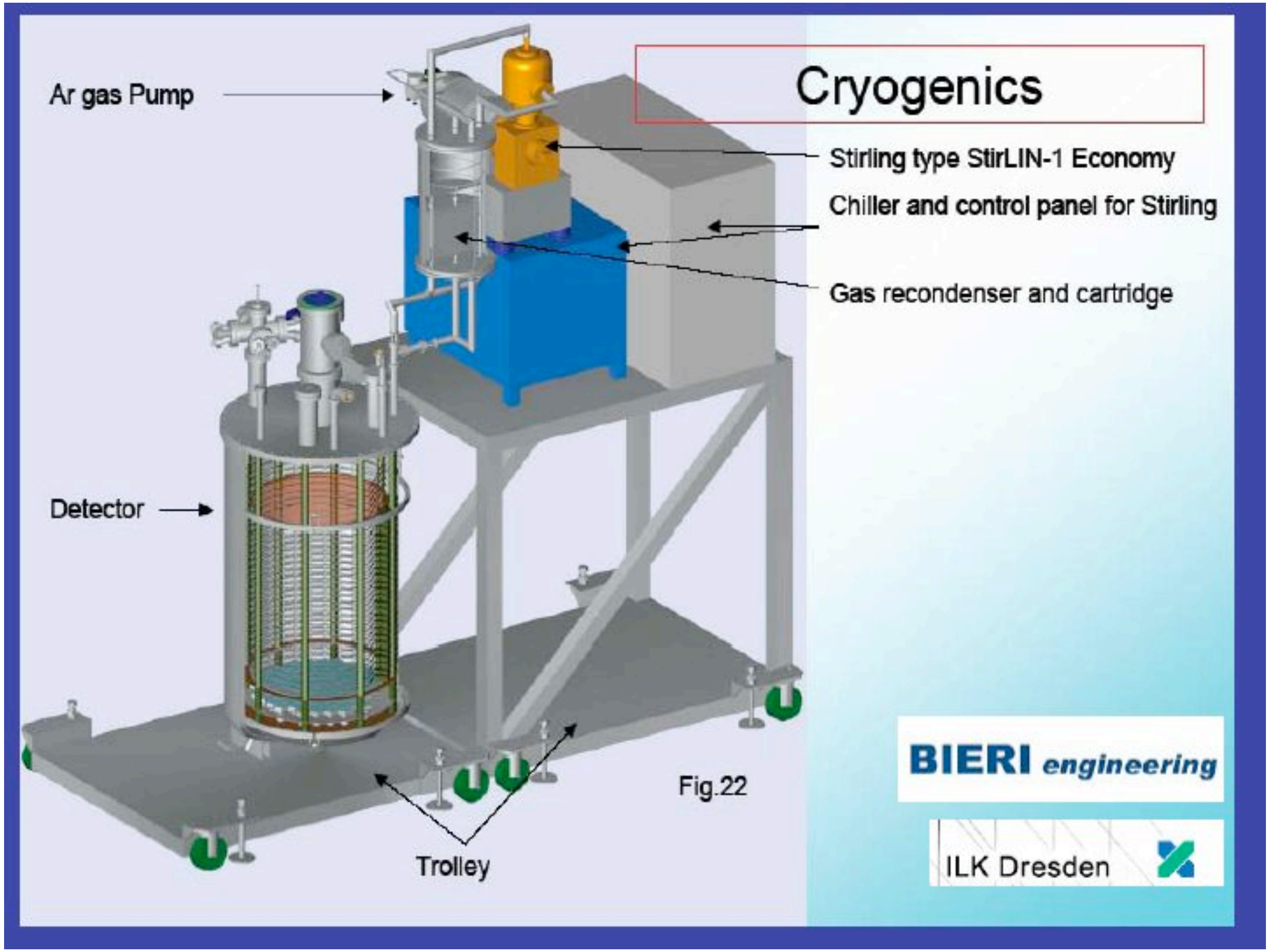


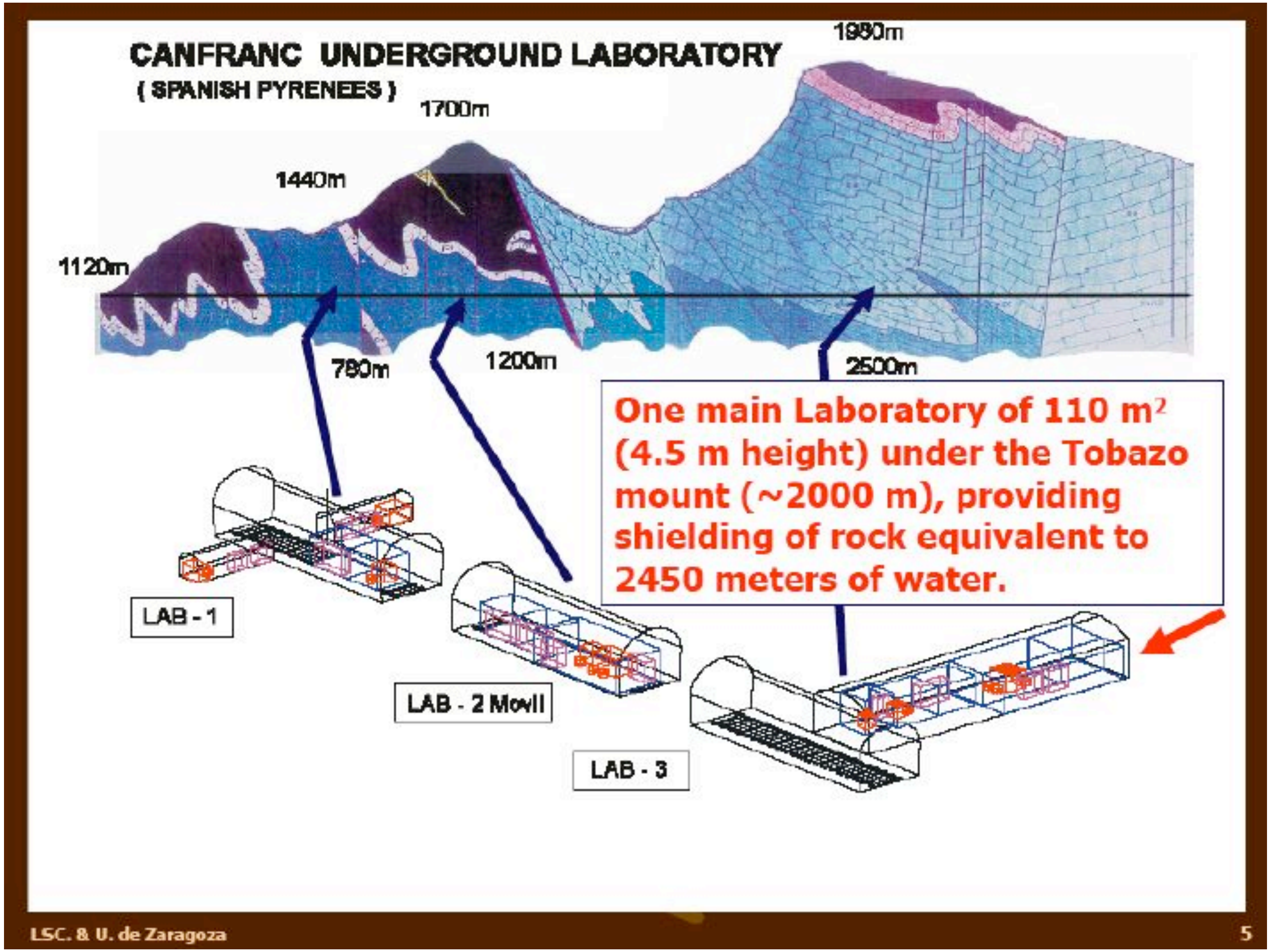
Two-stage LEM test setup





Considered PMT	Hamamatsu R6237-01MOD*
Shape	Square
Size	7.6 × 7.6 cm^2
Peak sensitivity	420 nm
Window	Borosilicate
Cathode type	Bialkali
Typ. Gain	$3x10^5$ (8 dynodes)
Quantum Eff.	~20% (430 nm)


Cryogenics
Ar gas Pump
Stirling type StirLIN-1 Economy
Chiller and control panel for Stirling
Gas recondenser and cartridge
Detector
Trolley
Fig.22
BIERI engineering
ILK Dresden


CANFRANC UNDERGROUND LABORATORY
(SPANISH PYRENEES)
1980m
1700m
1440m
1120m
780m
1200m
2500m
One main Laboratory of 110 m²
(4.5 m height) under the Tobazo
mount (~2000 m), providing
shielding of rock equivalent to
2450 meters of water.
LAB - 1
LAB - 2 Movil
LAB - 3
LSC. & U. de Zaragoza
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