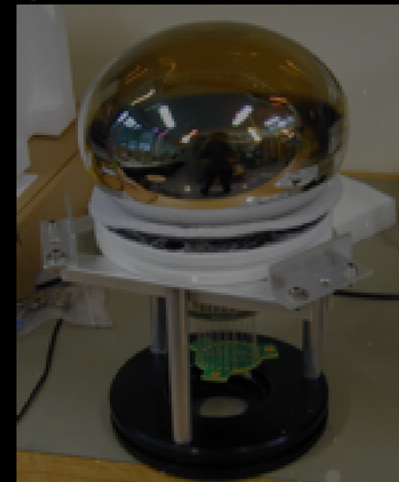
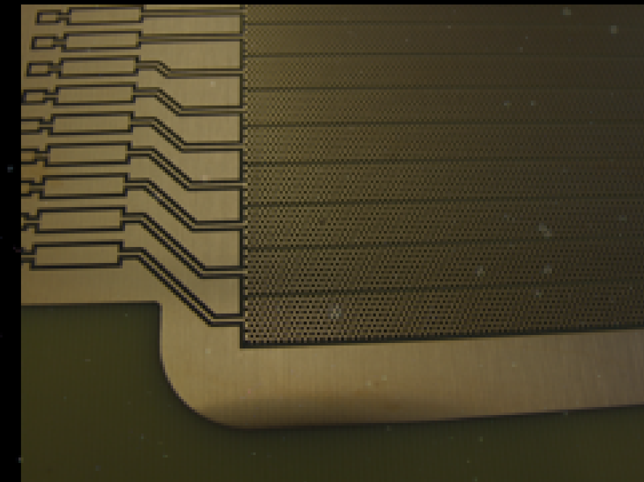
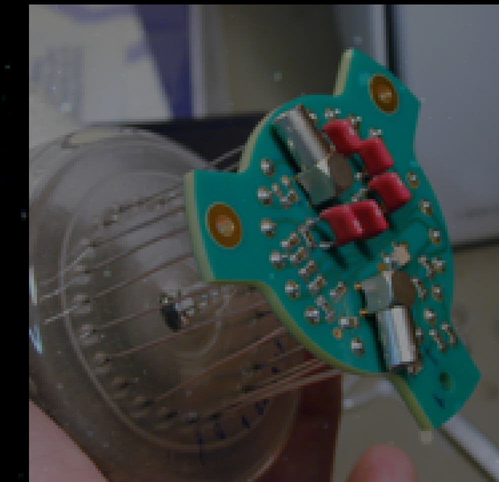
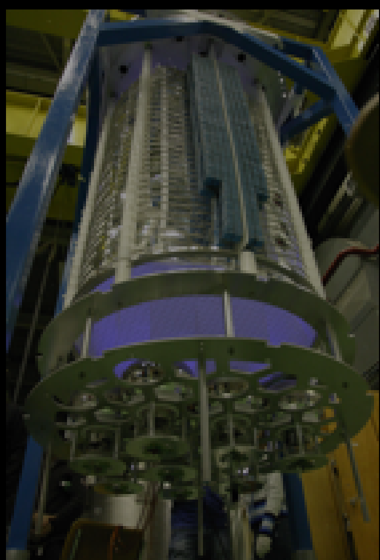
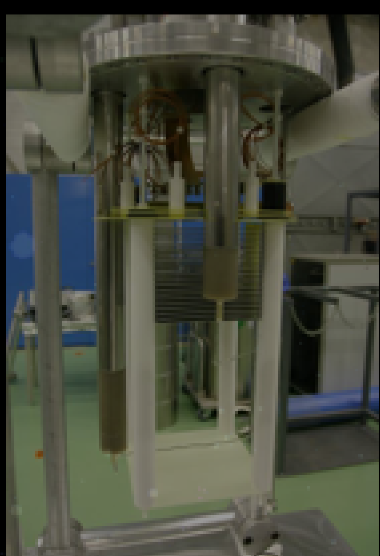
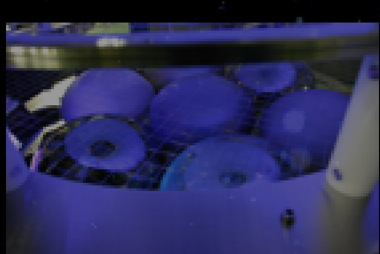








The ArDM project: A Liquid Argon TPC for Dark Matter Detection

Vittorio BOCCONE, University of ZURICH
on behalf of the ArDM collaboration

ETH Zurich, Switzerland: A. Badertscher, L. Kaufmann, L. Knecht, M. Laffranchi, C.Lazzaro, A. Marchionni, G. Natterer, P. Otiougova, F.Resnati, A. Rubbia, J. Ulbricht.
Zurich University, Switzerland: C. Amsler, V. Boccone, A. Dell'Antone S. Horikawa, C. Regenfus, J. Rochet.
University of Granada, Spain: A. Bueno, M.C. Carmona-Benitez, J. Lozano, A. Melgarejo, S. Navas-Concha.
CIEMAT, Spain: M. Daniel,M. de Prado, L. Romero.
Soltan Institute for Nuclear Studies, Poland: P. Mijakowski, P. Przewlocki, E. Rondio.
University of Sheffield, England: P.Lightfoot, K.Mavrokoridis, M. Robinson, N. Spooner.

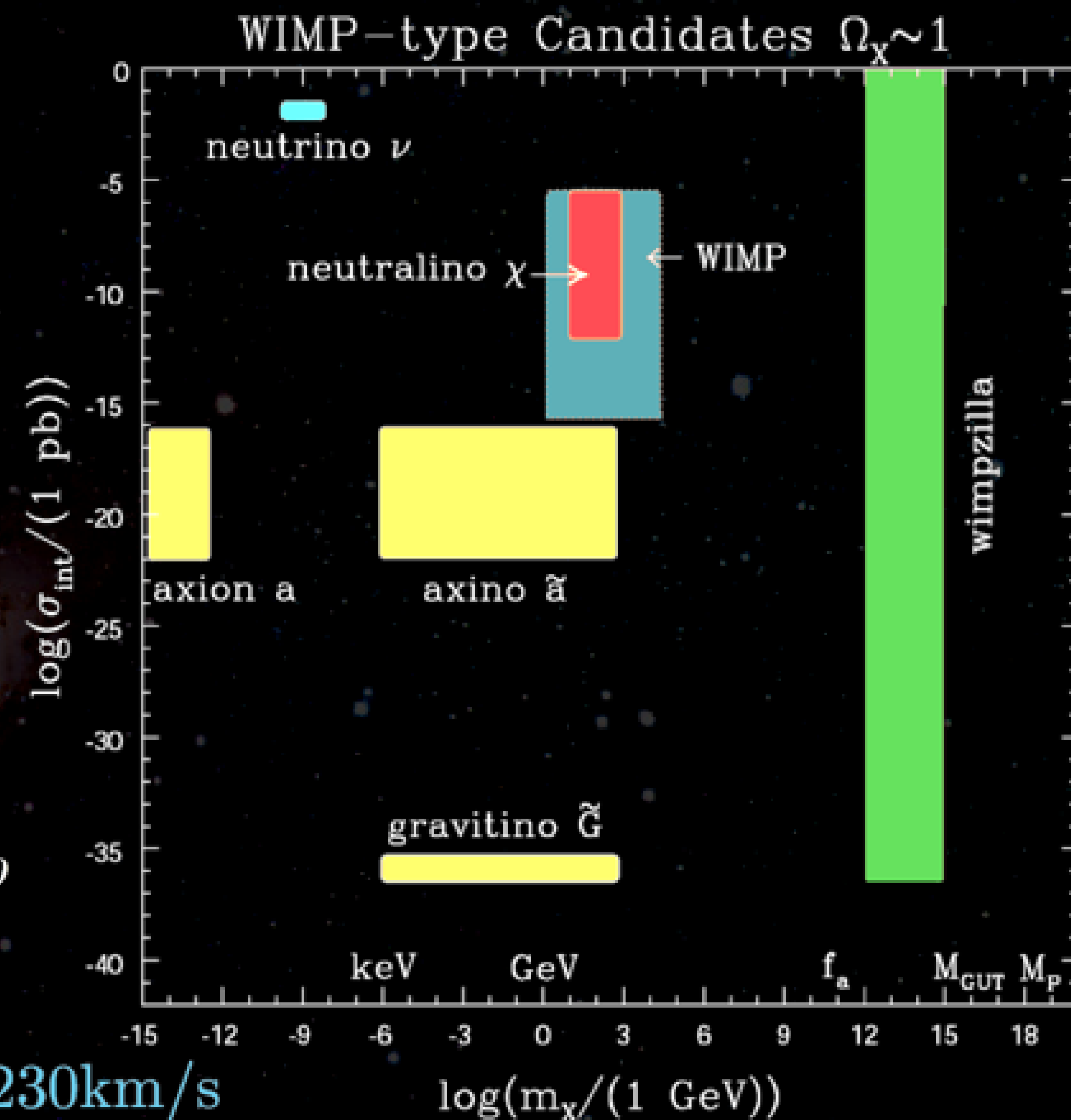
Candidates for CDM search

How can we look for candidates? They have to be stable, neutral and non relativistic.

Lightest neutralino is the best candidate because of its relic abundance in the MSSM.

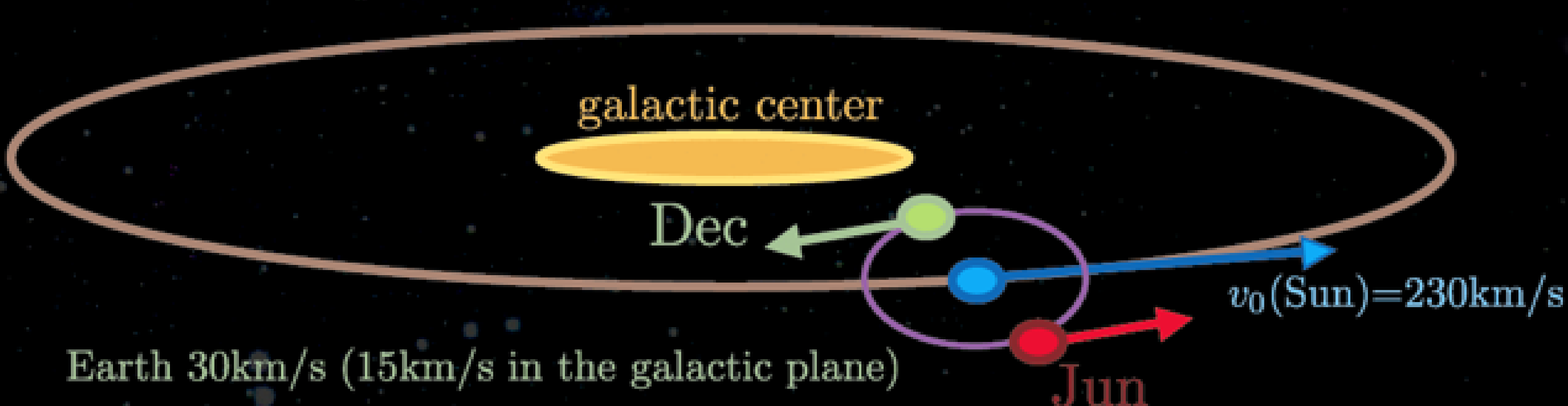
Cold, stable and heavy, there should be an halo around the galaxy center (Egret…).

$$M_W \sim (1 \div 10^4)\text{GeV} \qquad \sigma \sim (10^{-5} \div 10^{-15})pb$$

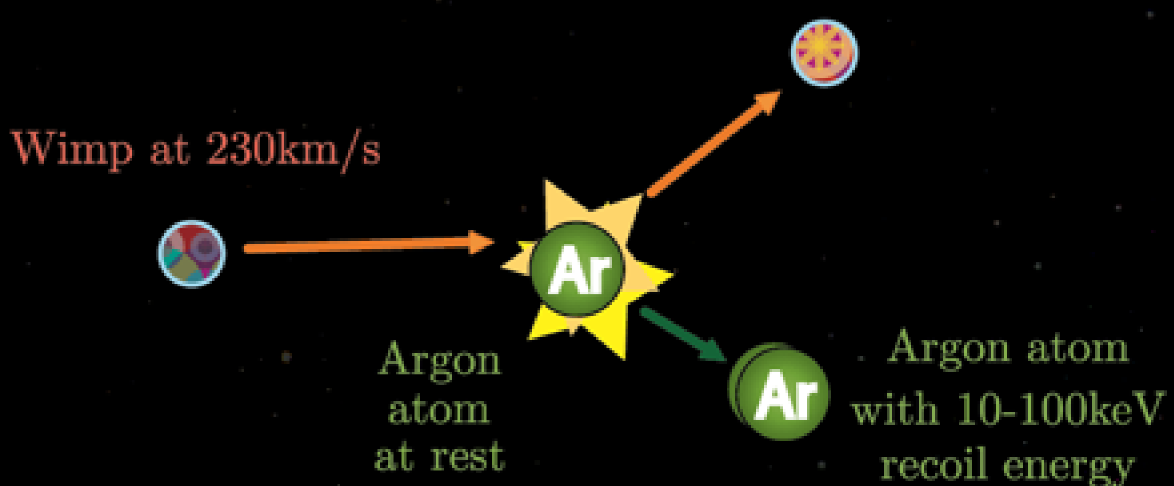


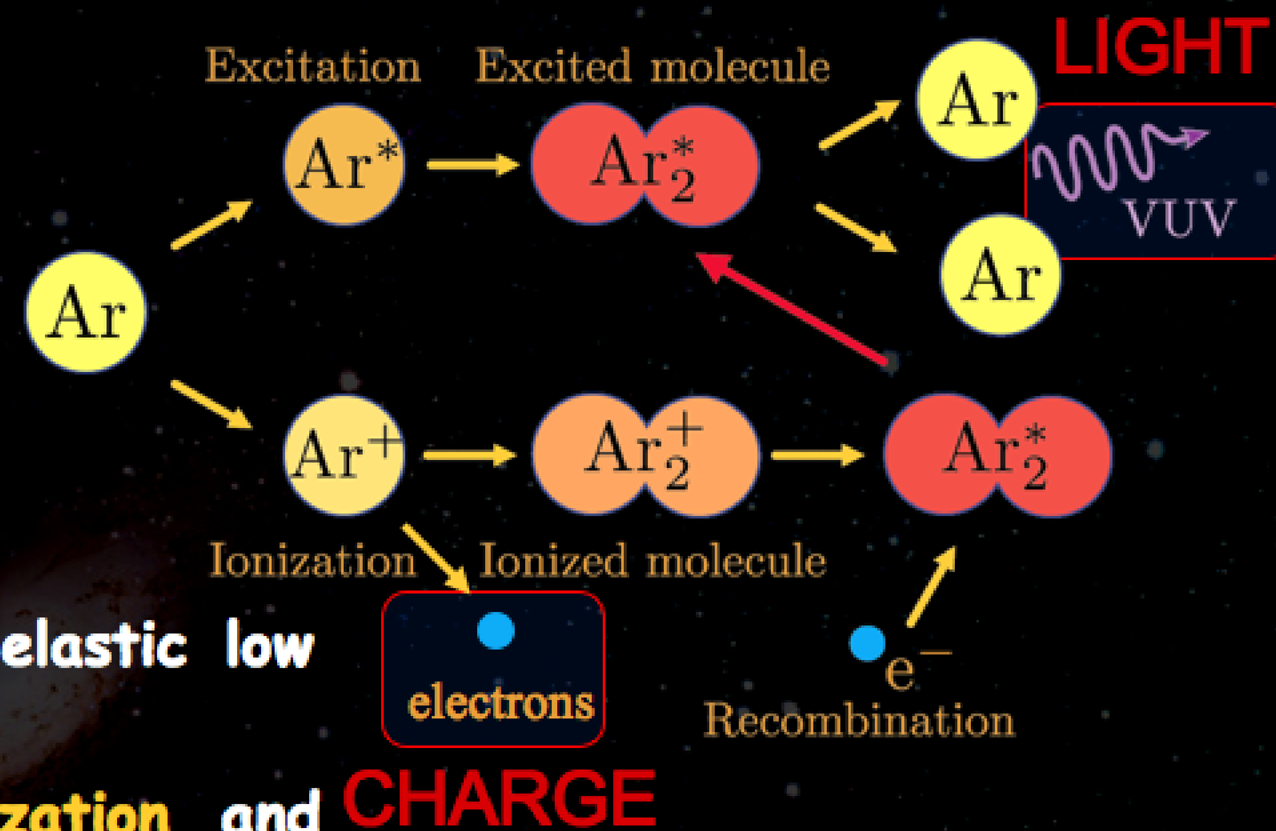
K.Choi, L.Roszkowski arXiv:hep-ph/0511003 v1

WIMP Isothermal Halo (no co-rotation) $v_0 = 230\text{km/s}$



WIMP interaction with liquid Argon



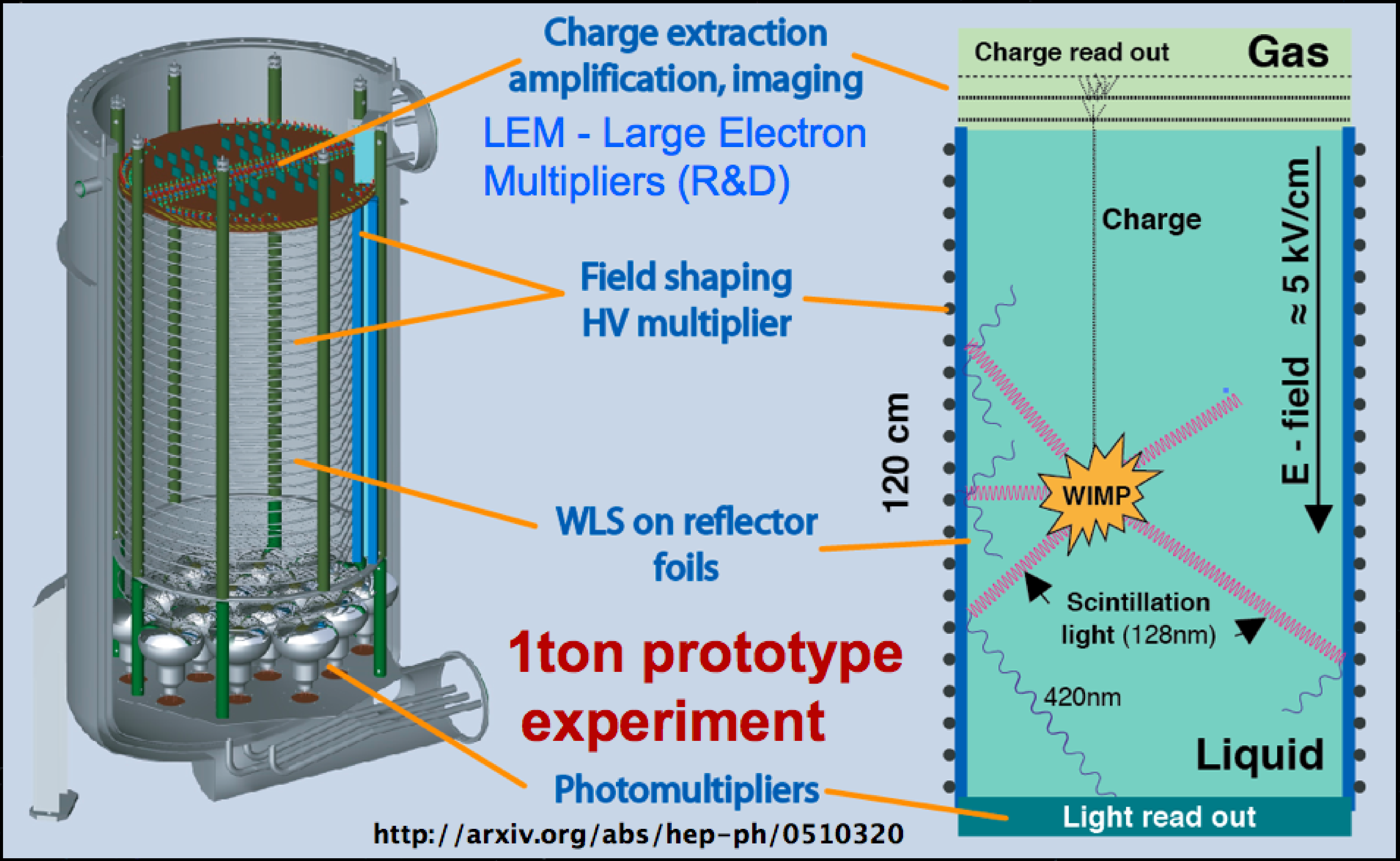


- ✓ Wimp speed **~230Km/s**, (similar to elastic low energy neutron-atom interaction);
- ✓ Recoils energy is **10-100keV**. **Ionization** and **Excitation**.
- ✓ No data for Liquid Noble Gases recoil energy spectrum.
  (except Lxe, *Aprile et al. Phys.Rev.D72 2005*)

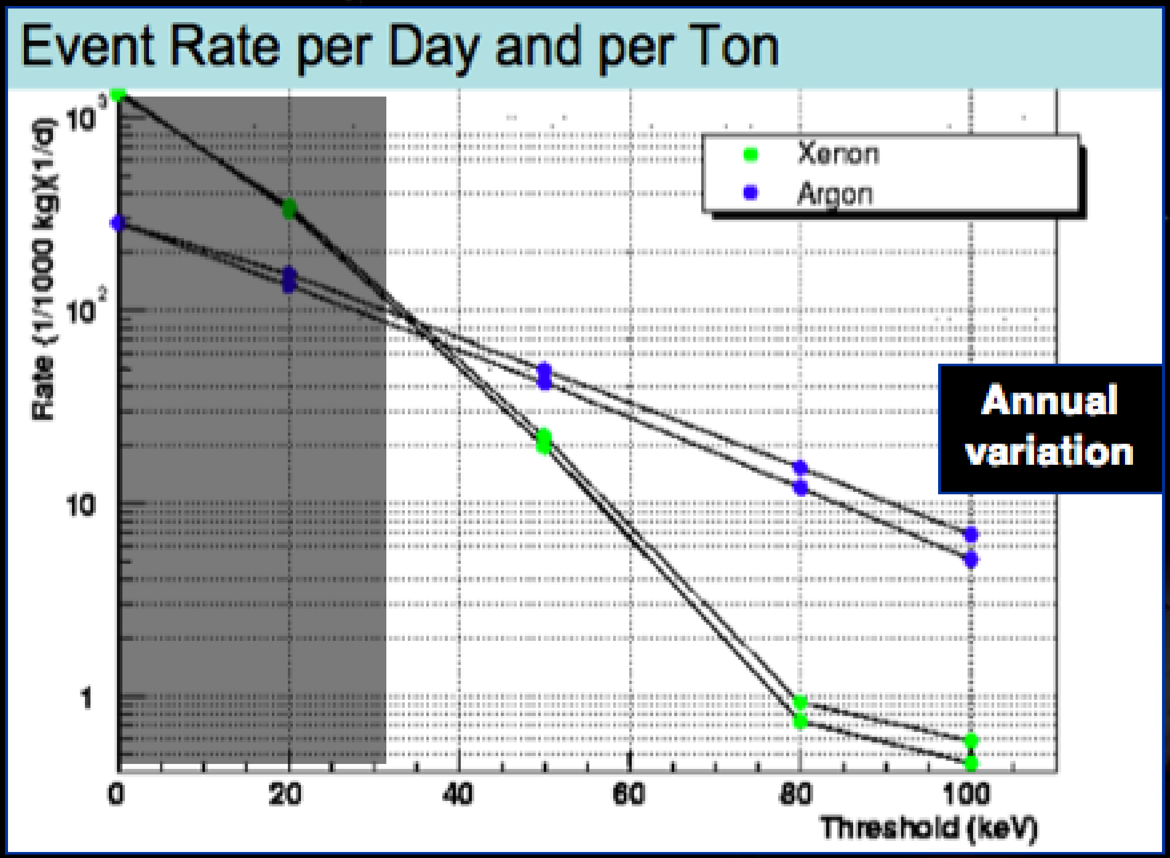
Strategies:

- ✓ **Charge**: Drift, extract to the gas phase, multiply and detect (in GAr);
- ✓ **Light**: Shift from VUV to blue, reflect and detect (in LAr).

The ArDM experiment



ArDM - Design parameters



- ✓ Cylindrical volume, drift length ≈ 120 cm
- ✓ 850 kg target (Self Shielding)
- ✓ Drift field ≈ 4 kV/cm (500KV over 1.2m)
- ✓ Charge readout at top: LEM gain ≈10000
- ✓ Light readout collection efficiency ≈ 2%
- ✓ Energy threshold ~30 keV

→ 100GeV Wimp, 10^{-6} pb

- **Event Topology:** Reject backgrounds;
- **Localization of the event:** 3D TPC imaging, granular 2D charge R/O, charge-light time difference; Vertex localized (x-ray and slow neutrons rejection);
- **Ionization Density Discrimination:** the ratio of ionization to scintillation is used to reject x-rays against nuclear recoils;
- **Pulse Shape Discrimination:** time distribution of scintillation light used for particle identification (neutron-like/electron-like).

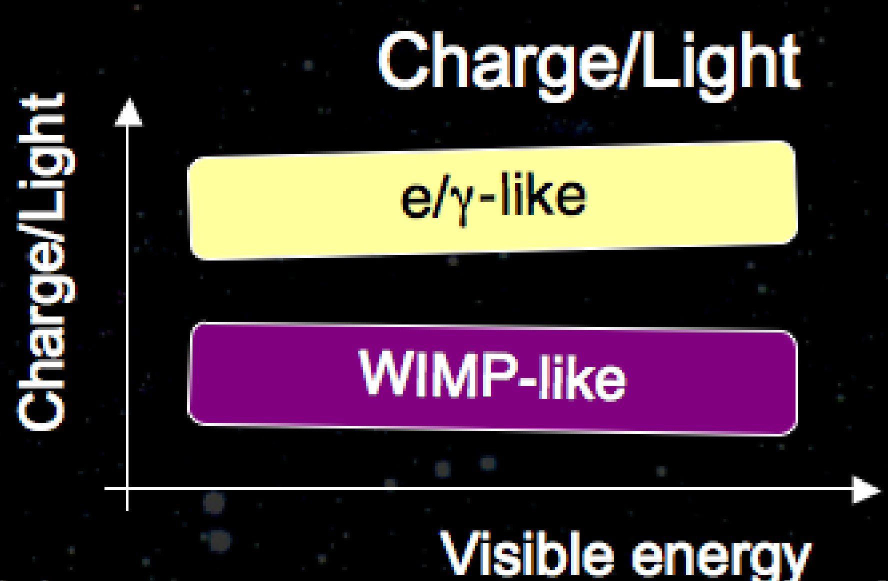
http://arxiv.org/abs/hep-ph/0510320

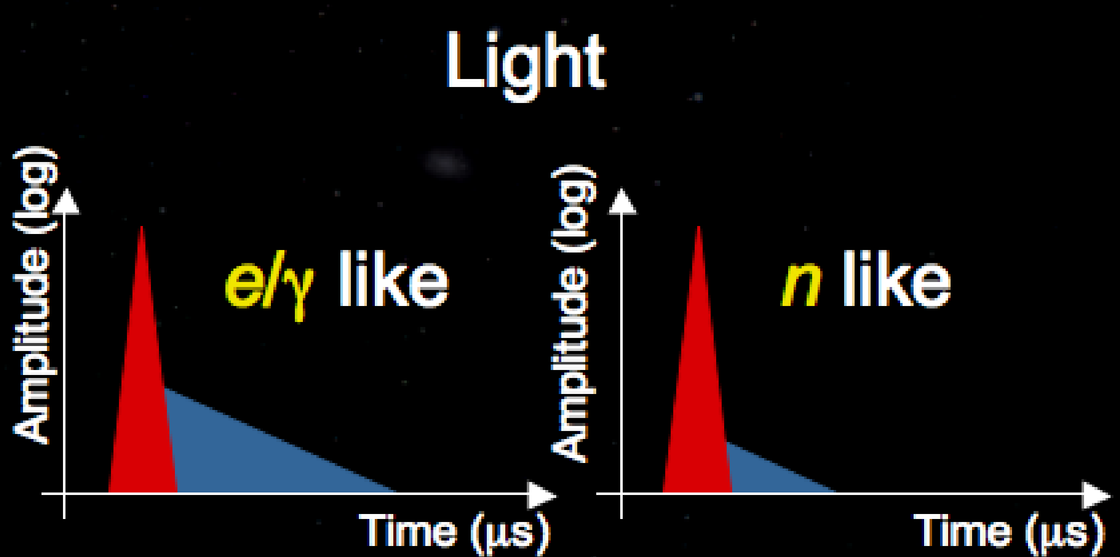
Background Studies

Neutrons (events look like WIMP-events):
- ✓ U/Th contaminations of the detector componets;
- ✓ Muon induced neutrons.

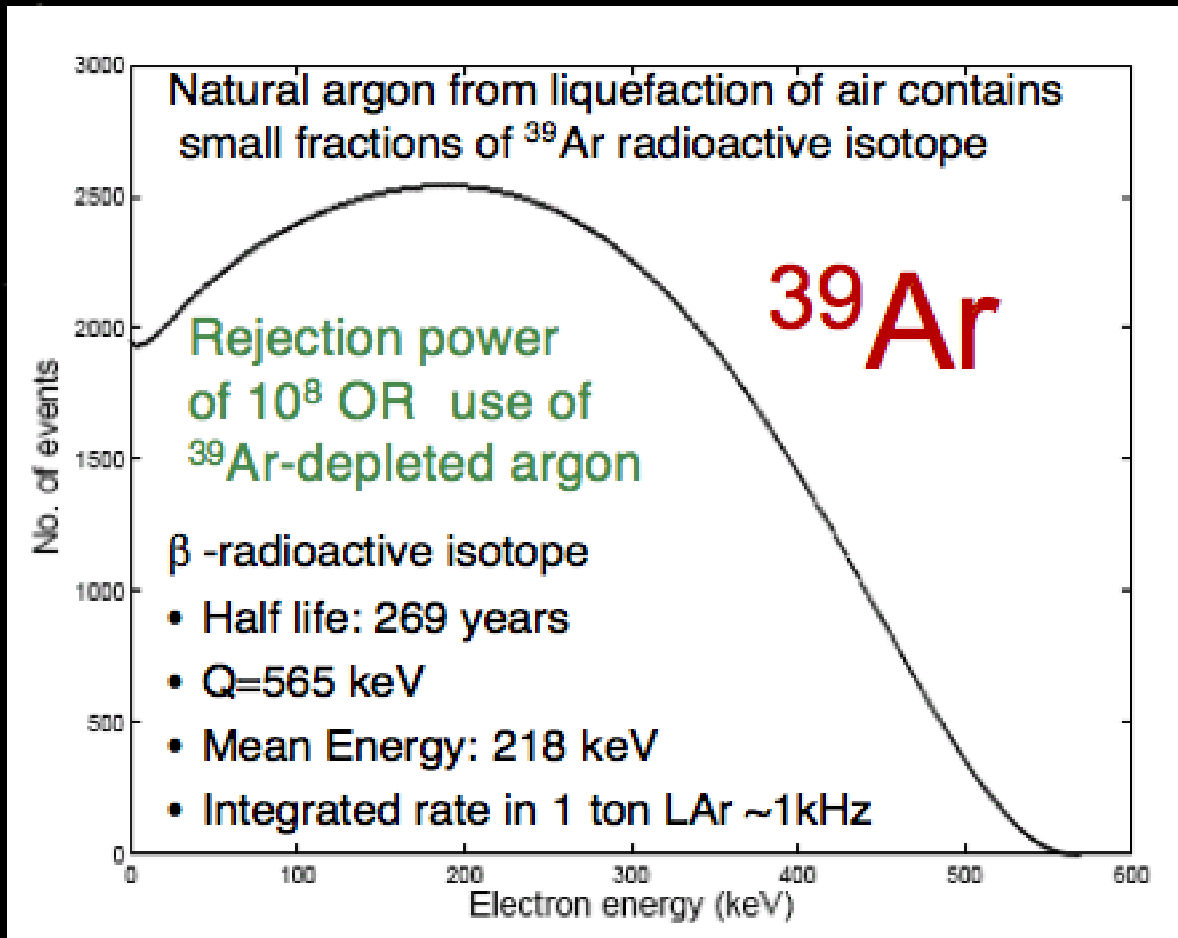
Electrons/Gammas (different from WIMP-events):
- ✓ From U, Th, P contaminations of detector and surrounding rock.

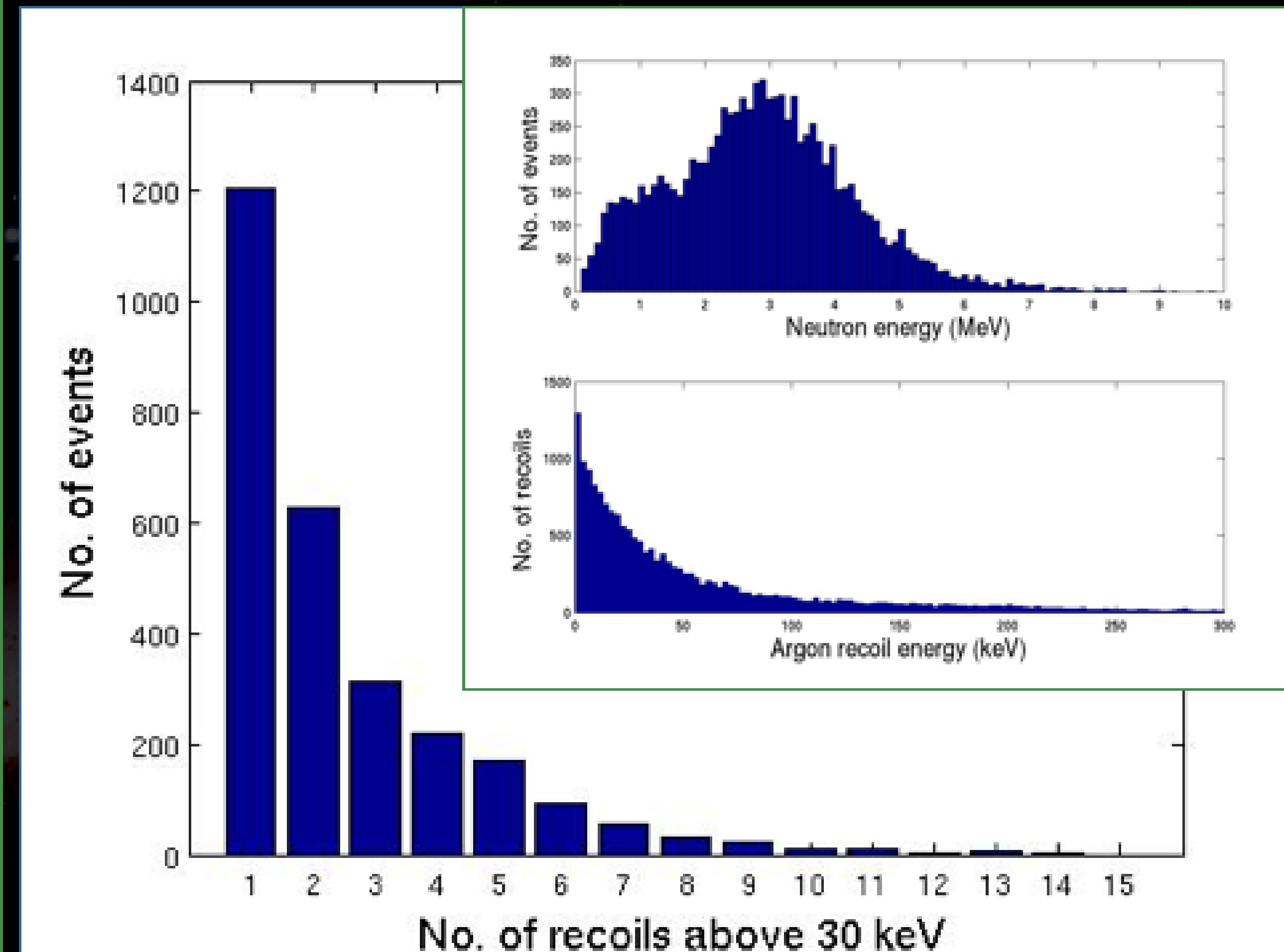
How can we reject the background:
- ✓ Different light/charge ratios
- ✓ Different shape of the scintillation light(ratio fast/slow components);





^{39}Ar and neutron background



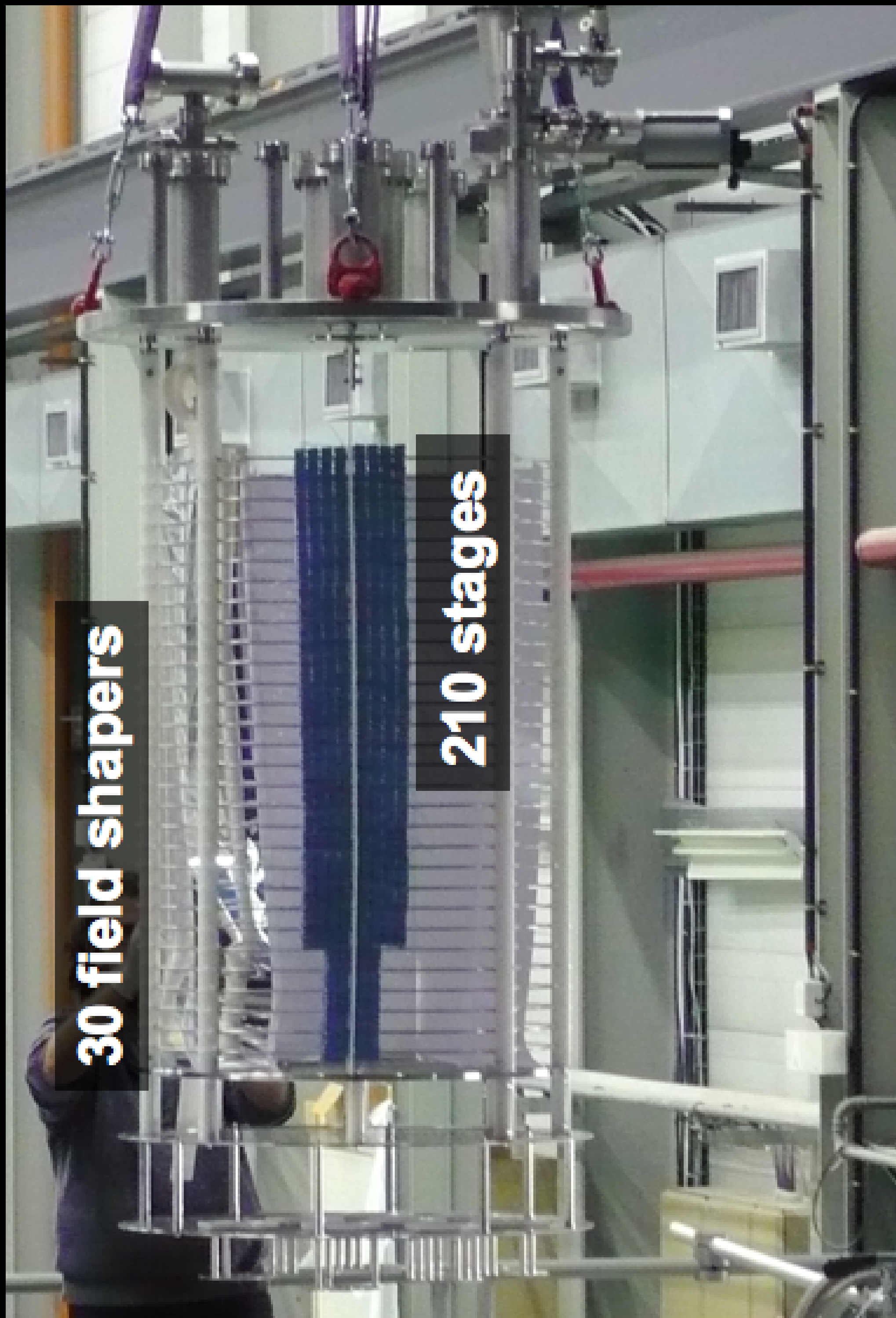


Neutrons

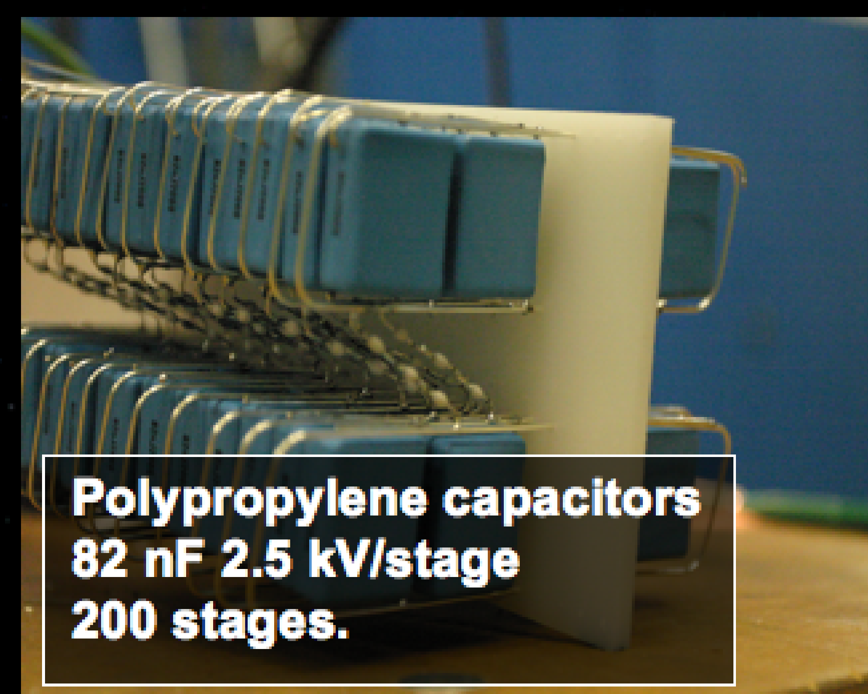
- > 50% of the neutrons scatter more than once.
- < 10% of the neutrons produce WIMP-like events single recoils (energy 30-100keV);
- Multiple scattering background can be rejected. The WIMP crossection is very low, and it will scatter only once.

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

Drift Field



- 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)

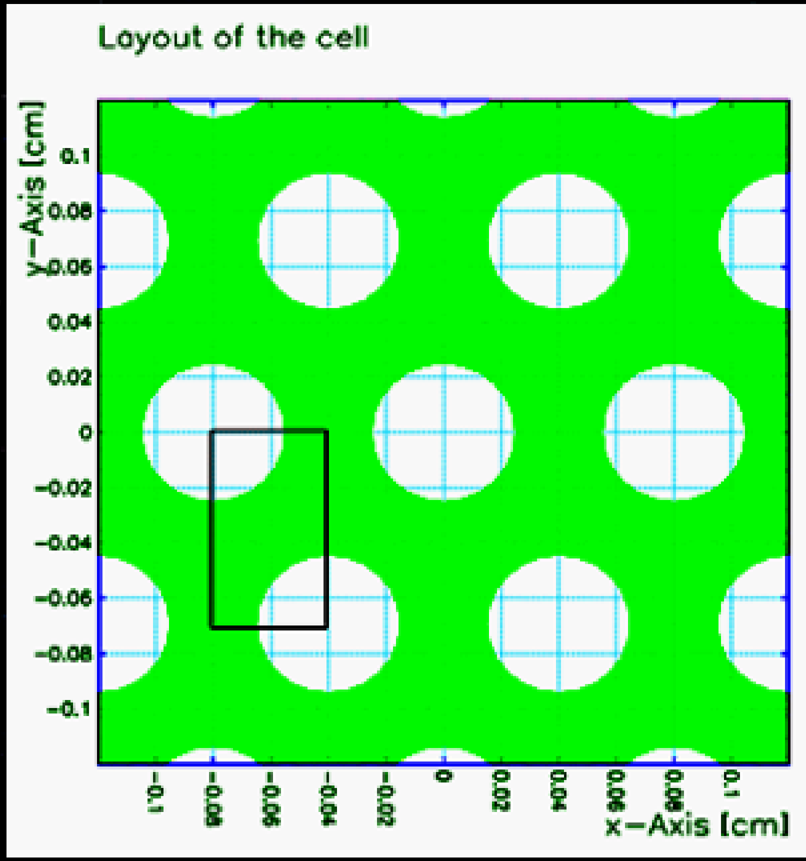


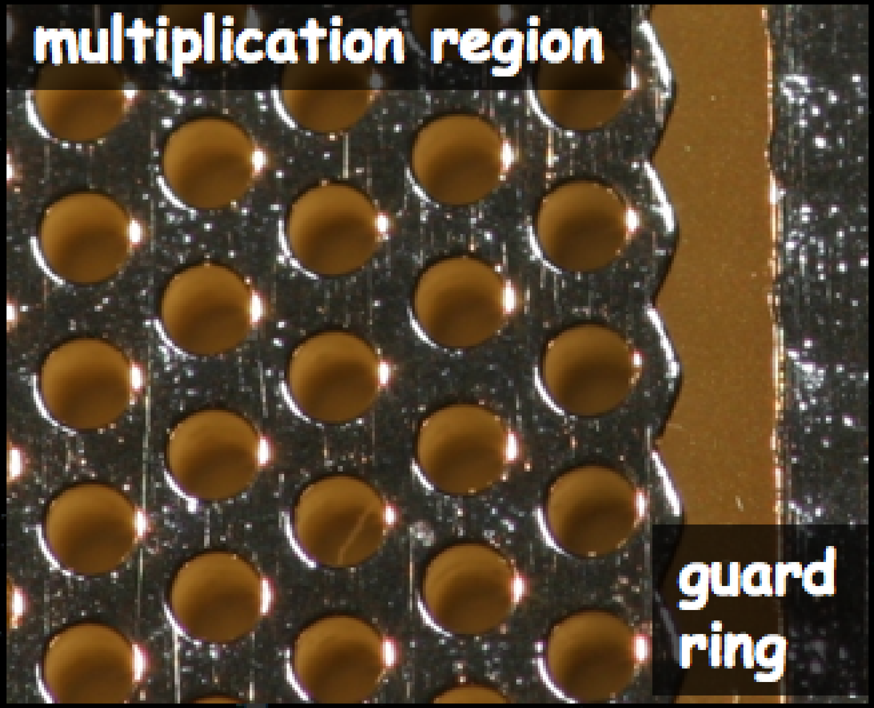
Charge Readout System

- 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

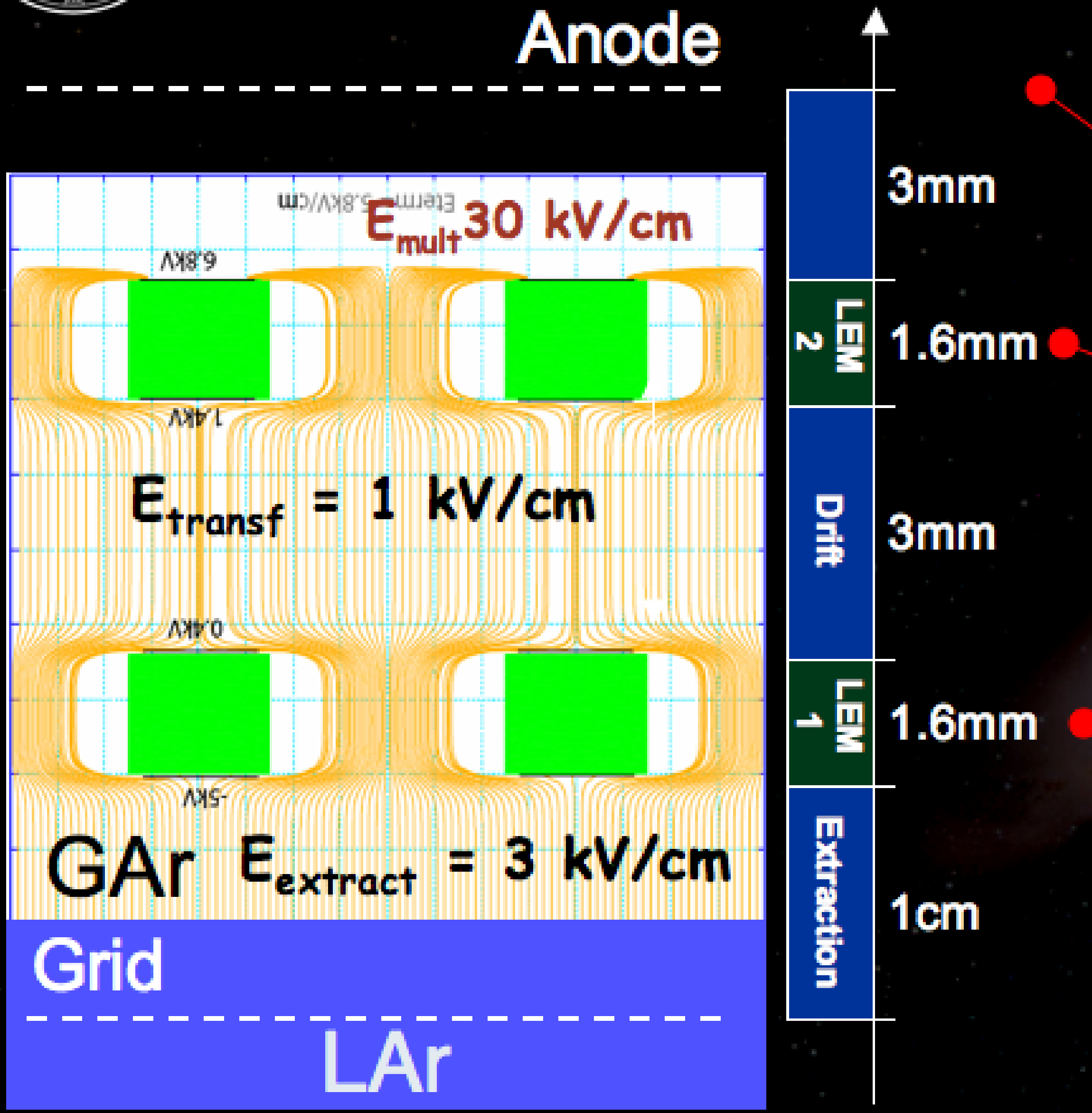
Produced by standard Printed Circuit Board methods

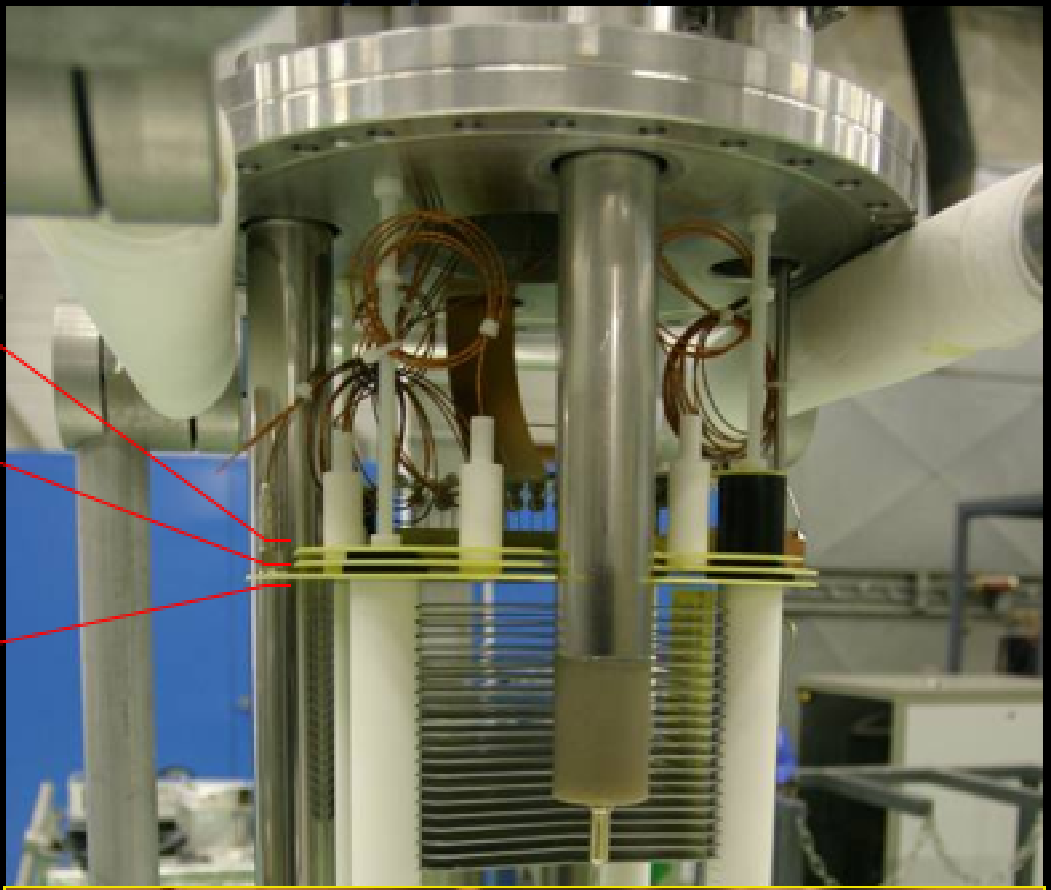


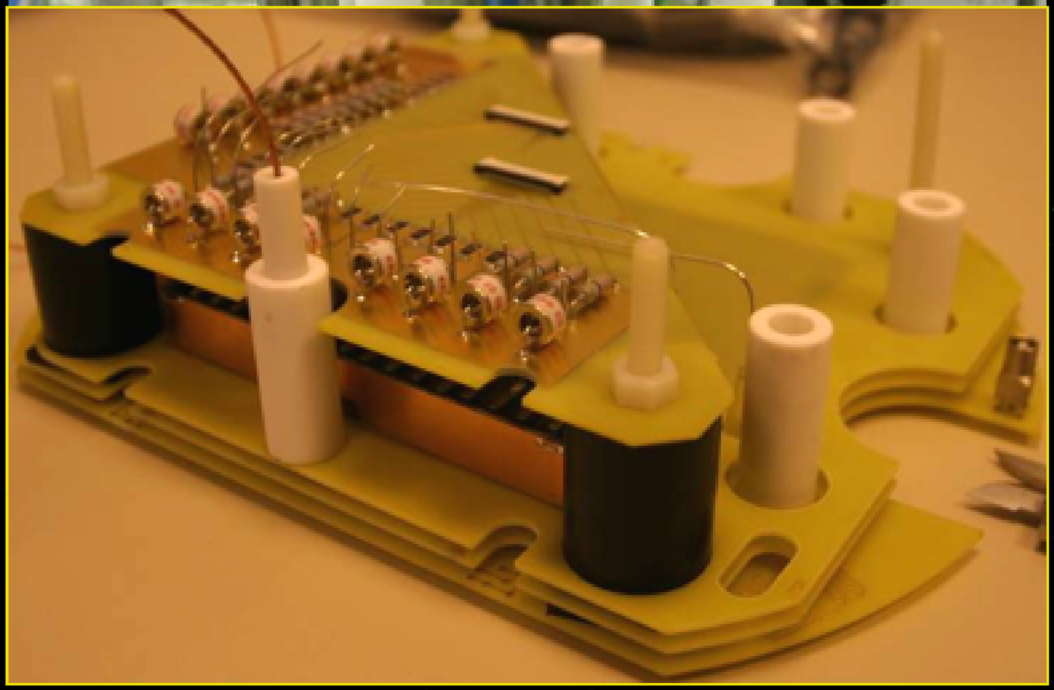


- ✓ Precision holes by drilling
- ✓ Palladium deposition on Cu (<~ 1μm layer) to avoid oxidization
- ✓ Single LEM Thickness= 1.5 mm
- ✓ Amplification hole
  - ✓ Diameter = 500 μm;
  - ✓ Pitch = 800μm

LEM R&D (1)

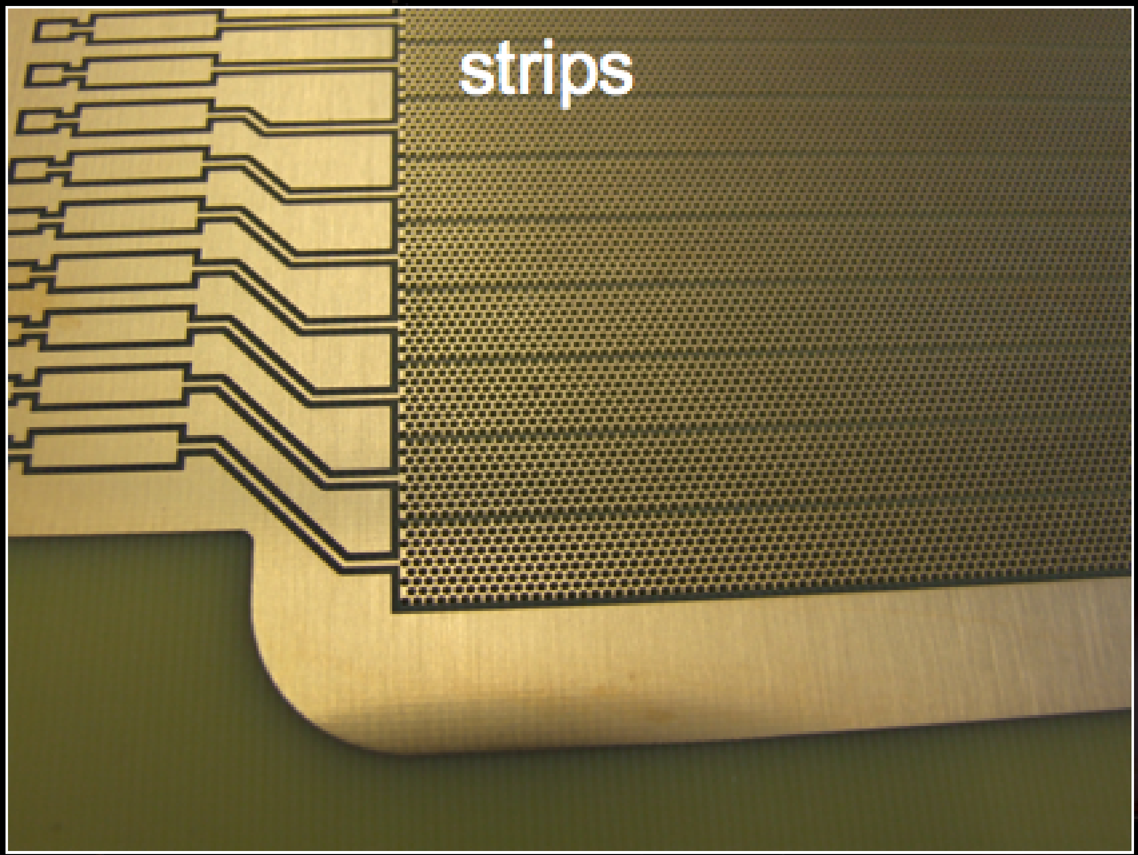


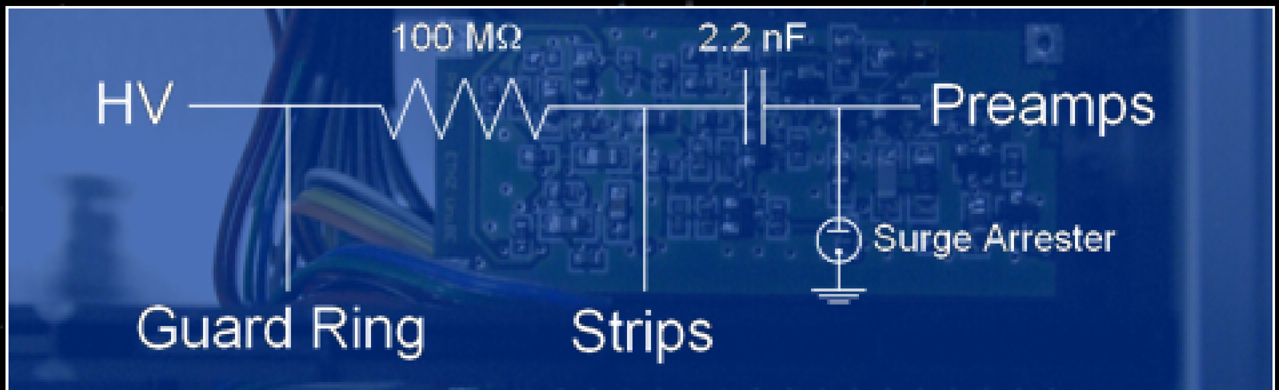




- ✓ e^- drift in LAr toward its surface (4kV/cm)
- ✓ e^- extracted to vapor phase and driven into LEM holes
- ✓ first stage multiplication in LEM 1
- ✓ e^- drift toward second LEM
- ✓ second stage multiplication LEM 2
- ✓ Induction of charge on striped anode and upper LEM2 plane

LEM R&D (2)



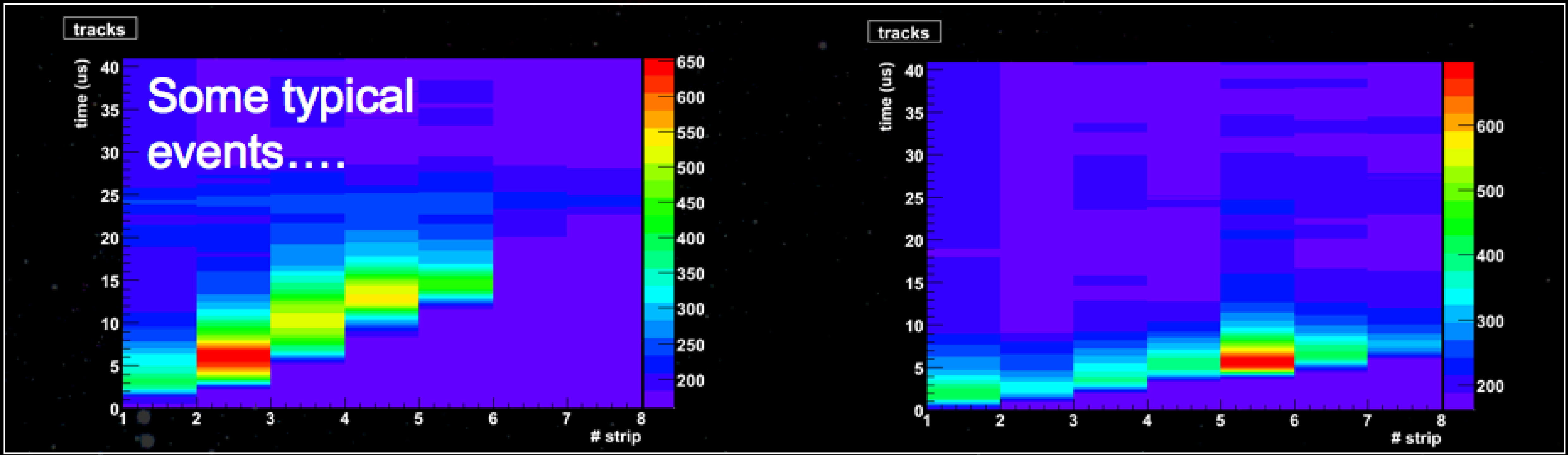


Preamps

- Gain: 10-15 mV/fC
- Rise time: ~ 1.5 μs
- Fall time: ~ 8 μs

Digitizer

- Resolution: 14 bits
- Sampling rate: 100 MHz



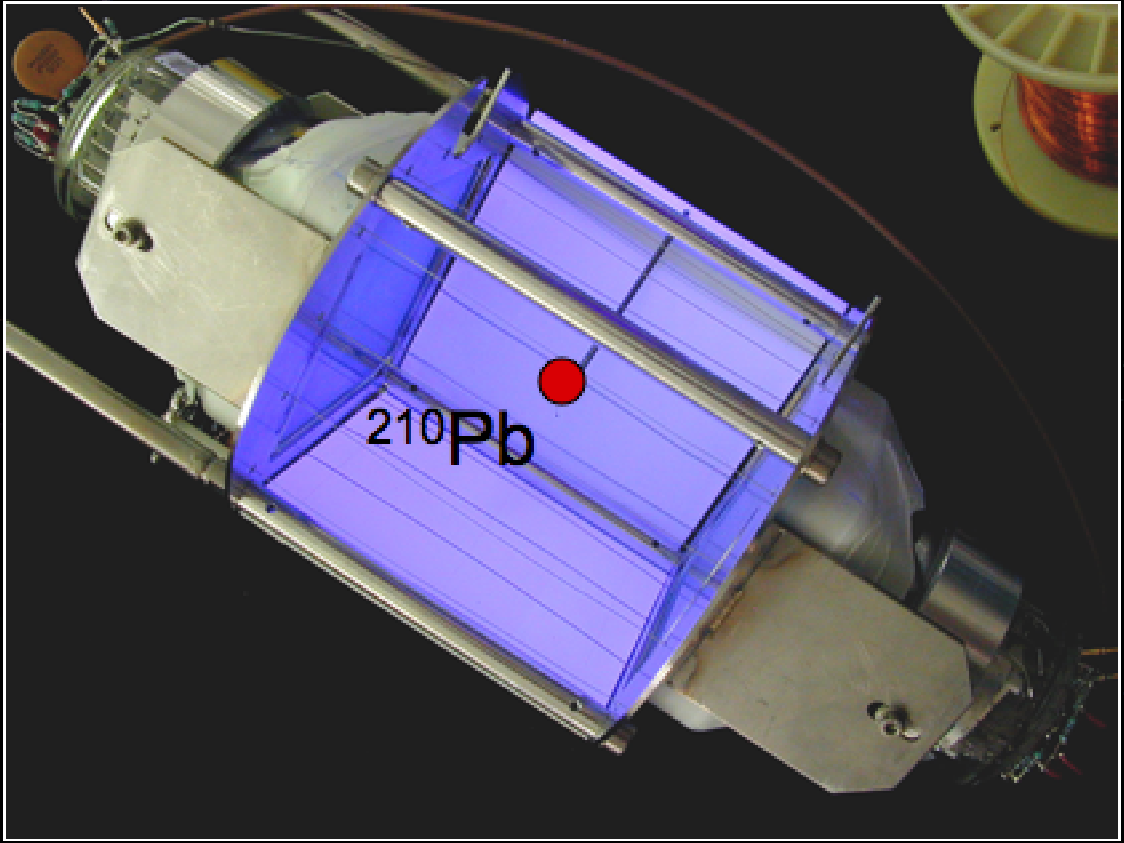
Light Readout R&D

- Decay in a narrow band =128 nm;
- Two excited molecular levels, Singlet and Triplet state with two characteristic decay times: Fast O(ns), Slow O(μs);
- Siglet decay strongly allowed;
- Triplet decay only strong spin-orbit coupling in Ar_2, impurities suppress its radiative triplet decay;
- Excitation Ratio of the two levels depend on ionization density.
- Liquid and Gas have different decay times;

Event Topologies (light)

DETECT VUV light! Need R&D on WLS and cryogenic PMTs!

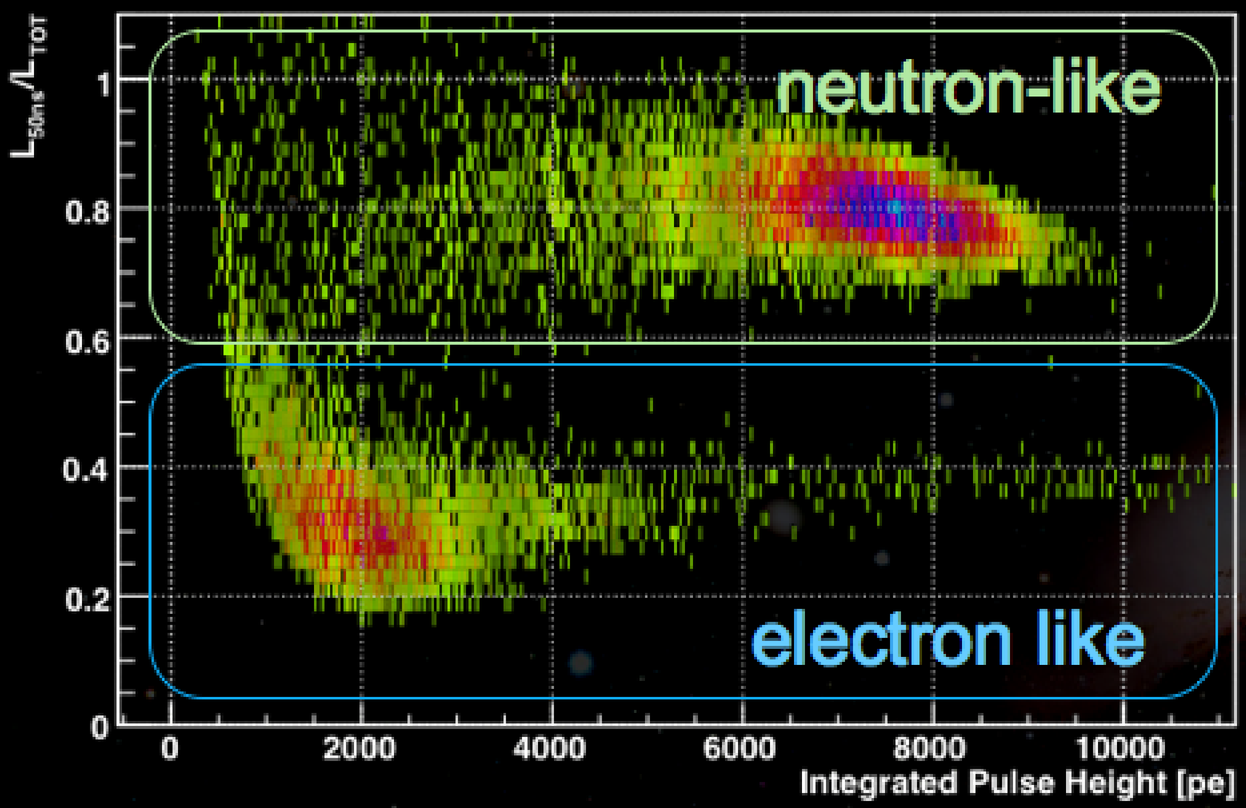
Built a 1lt/6lt test LAr cell with cryogenic photomultipliers and WLS reflectors on the side.



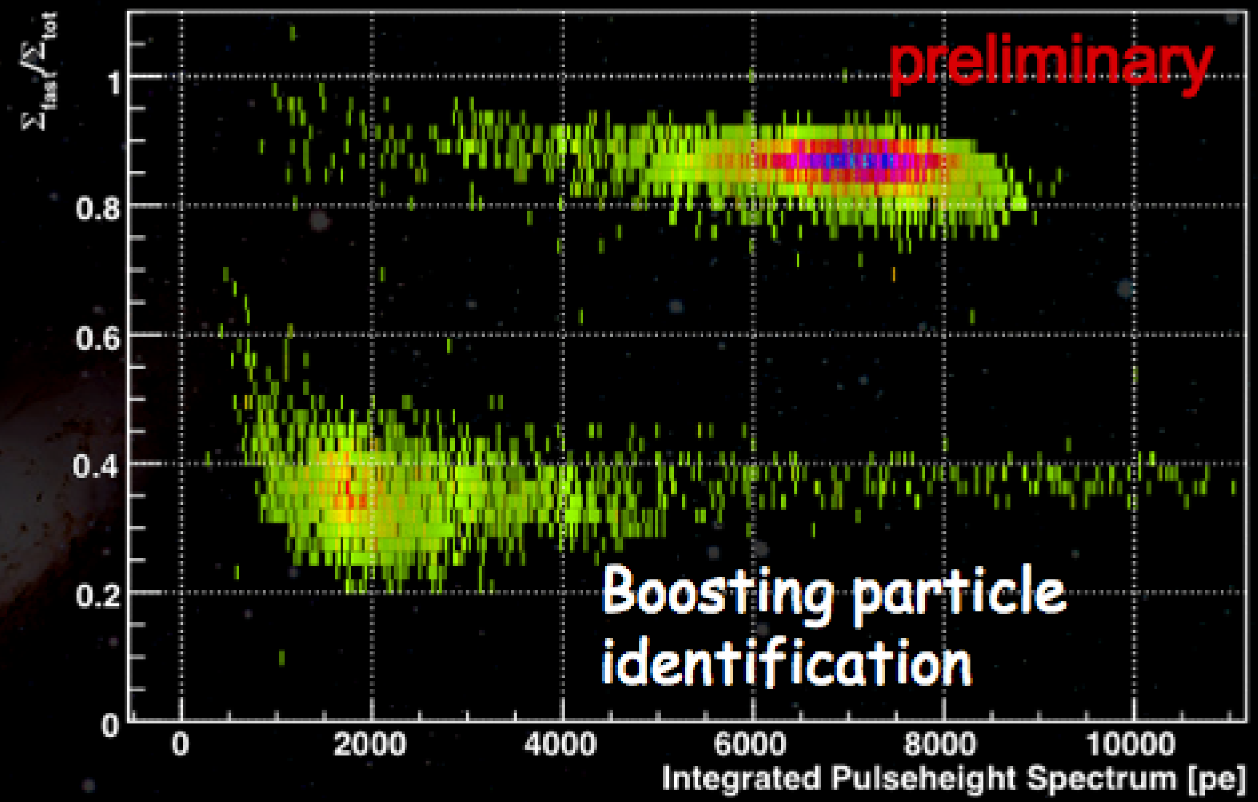
Improving Data Analysis

LAr - Dual PMT Cell

L_{50ns}/L_{tot} Component Ratio Discrimination

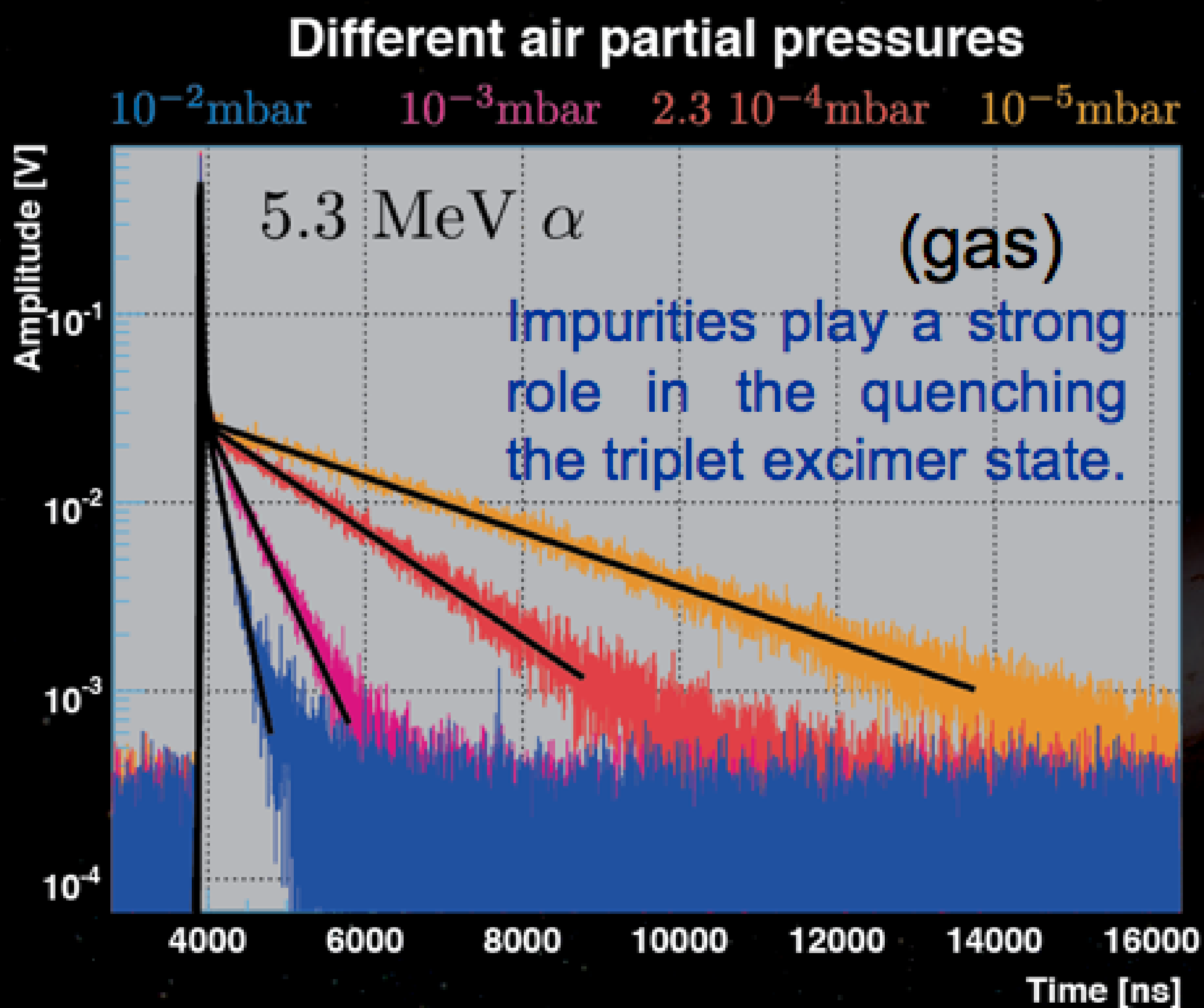


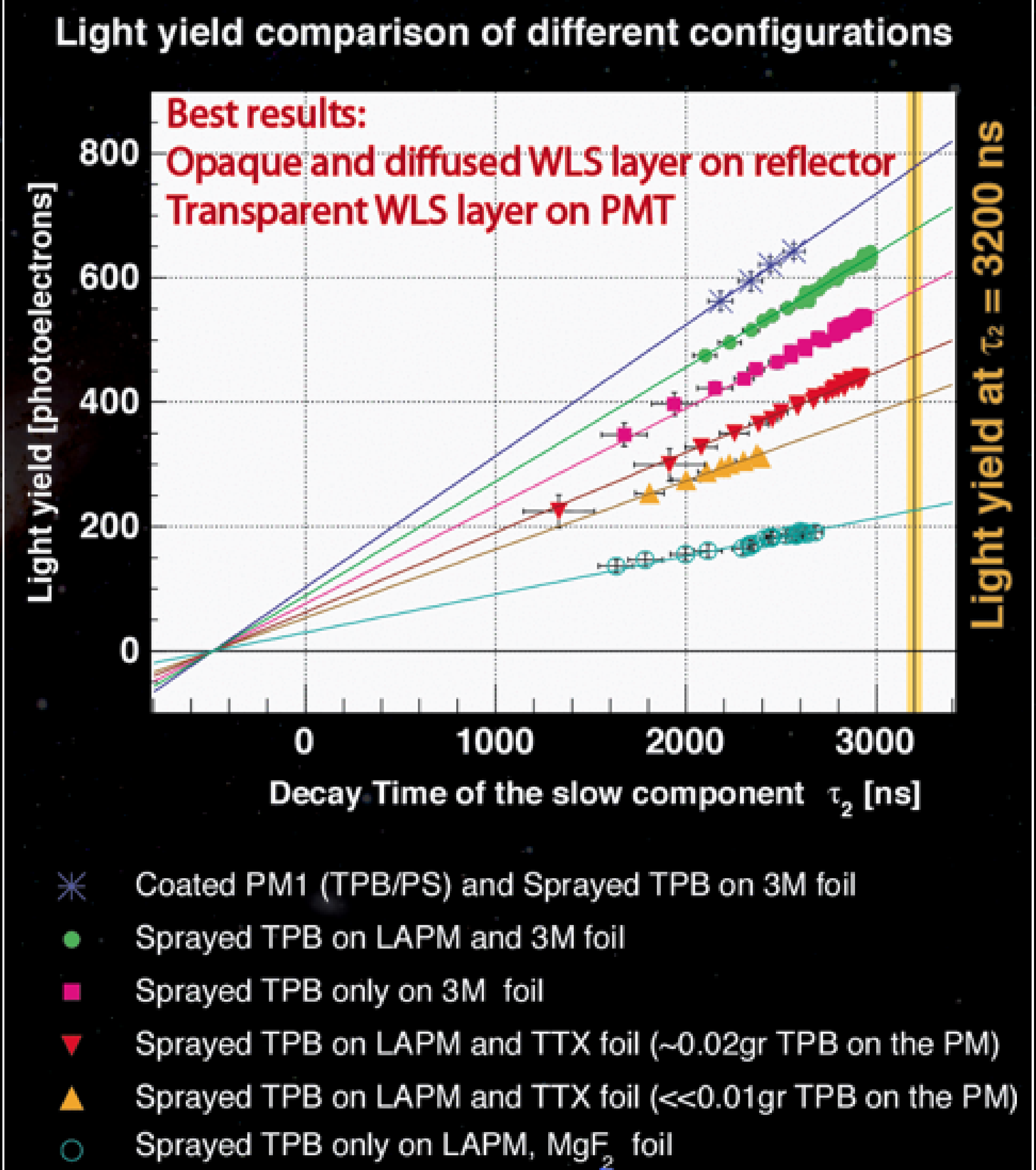
New Topology Discrimination



- ✓ Boosting particle identification with light detection to enhance background discrimination (investigating algorithms based on NN, topology fit or decision tree);
- ✓ Calibration with a neutron generator in the next future;

Quenching of the triplet state

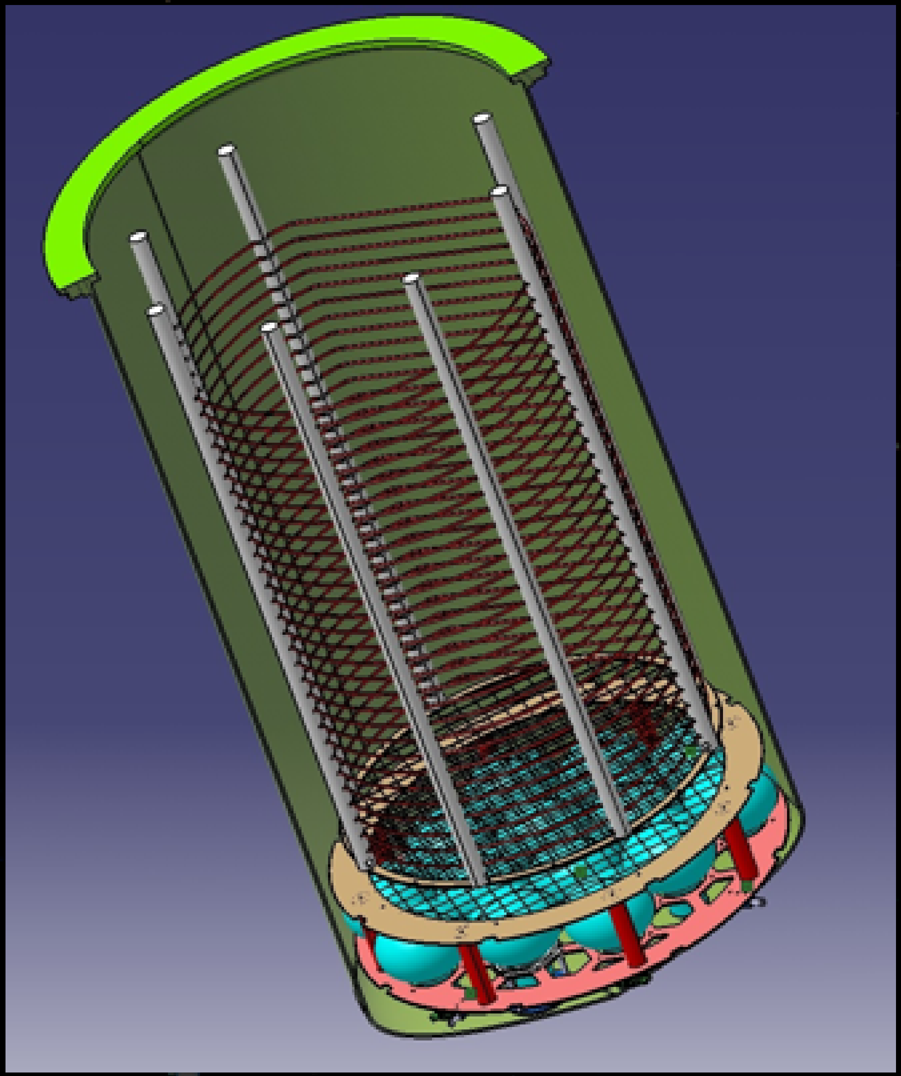


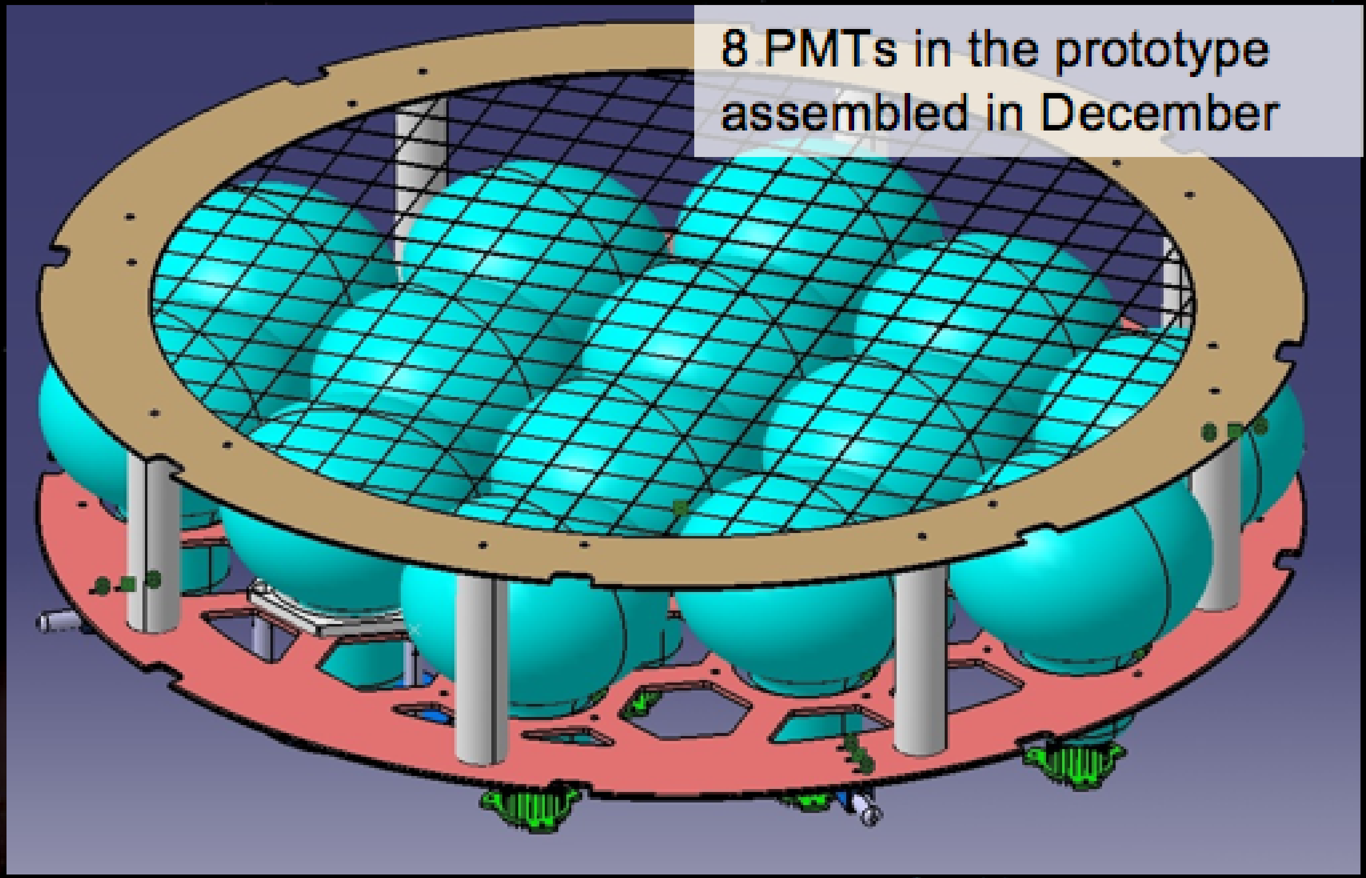


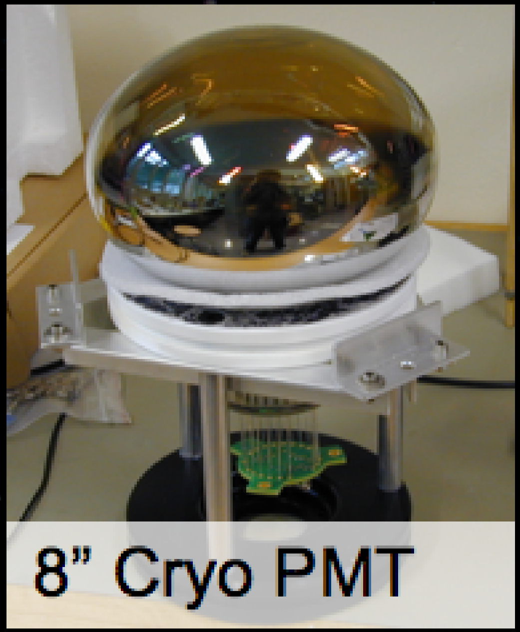
C.Amsler et al *"Luminescence quenching of the triplet excimer state by air traces in gaseous argon"* (2008) JINST 3 P02001

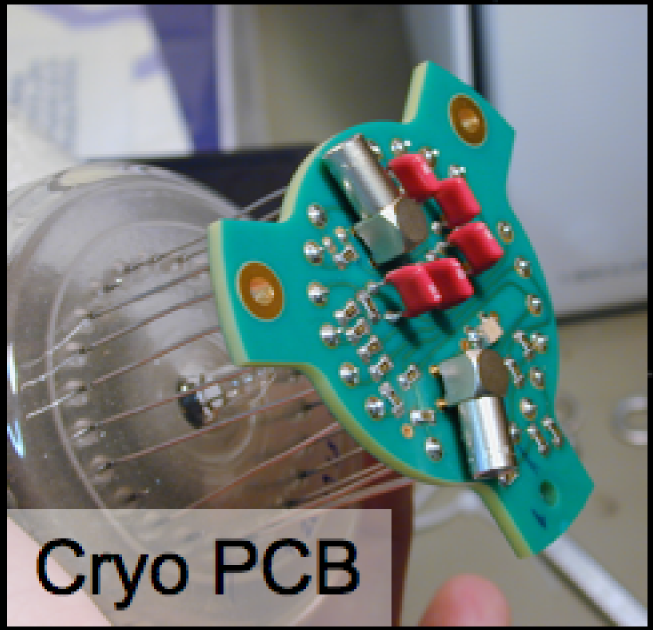
Design of the light readout

14 Photomultipliers are mounted below a metallic grid shielded from the 500kV of the cathode. Cryogenic PCBs with the voltage divider are directly mounted on the PMT.



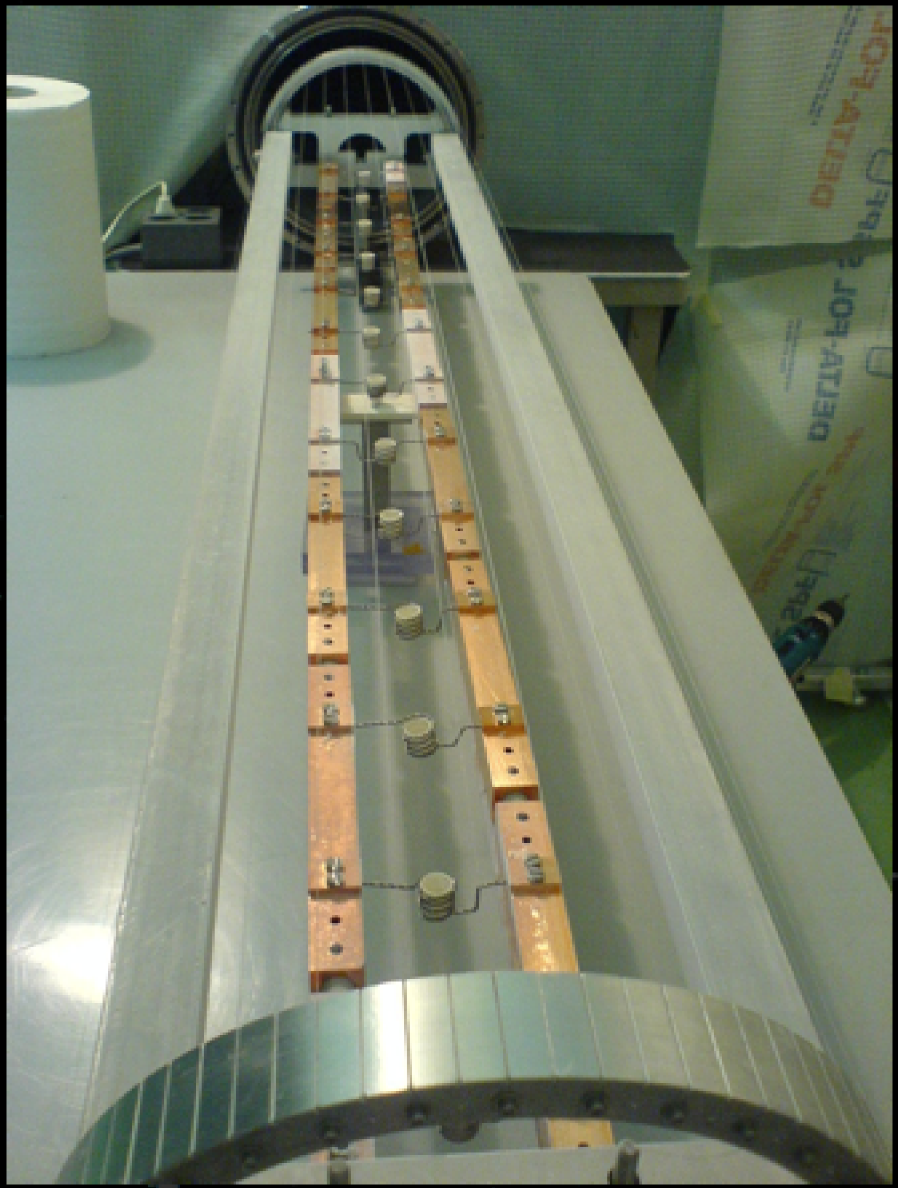


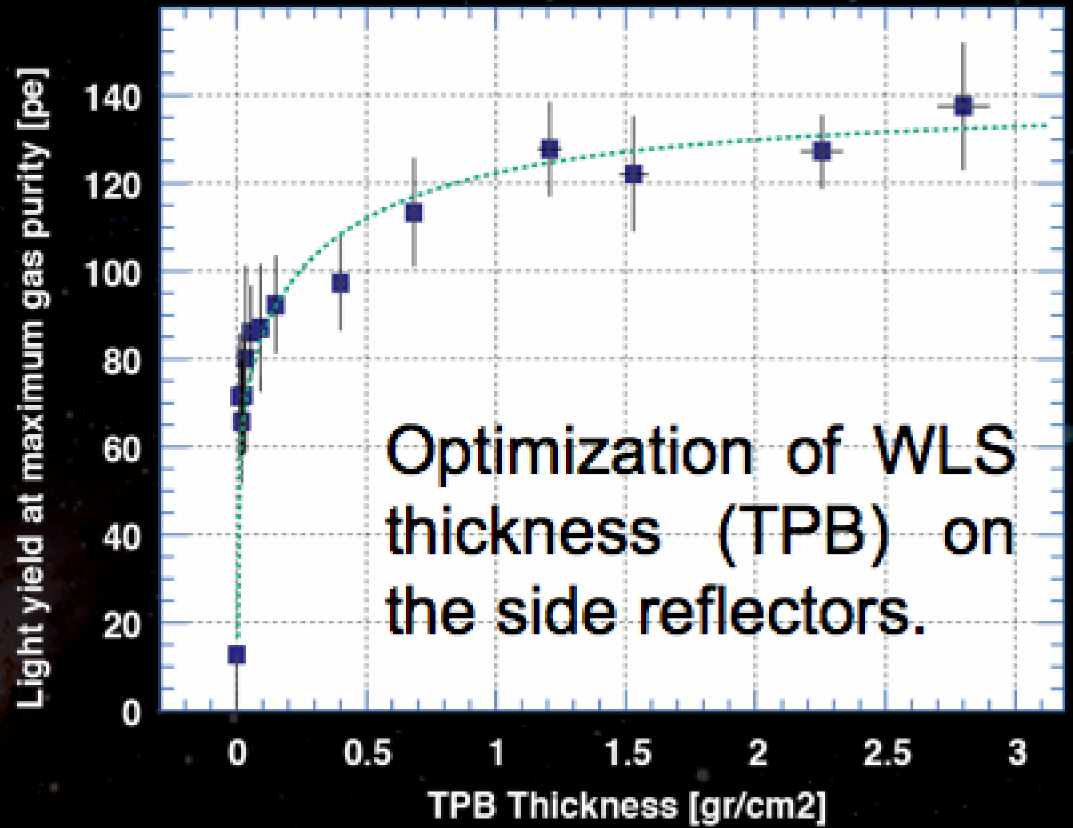




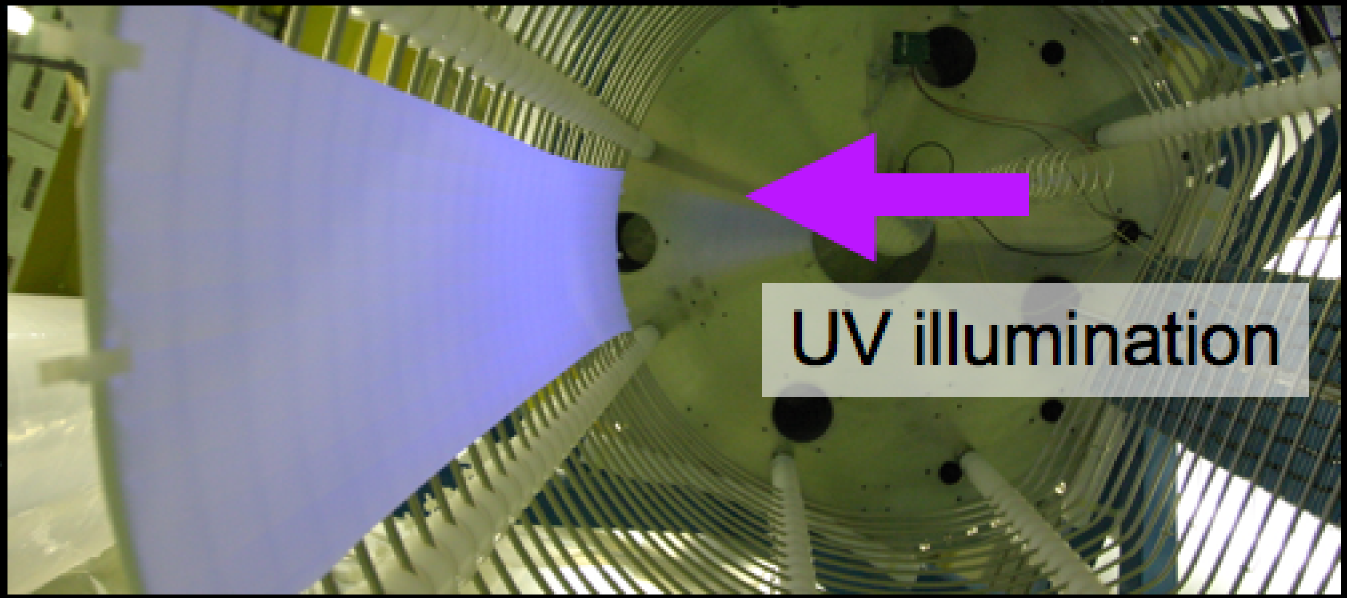
Side reflector preparation

- Sides are covered with reflectors coated with a Wave Length Shifter material (TPB).
- A large evaporator has been build to evaporate the reflectors foils.





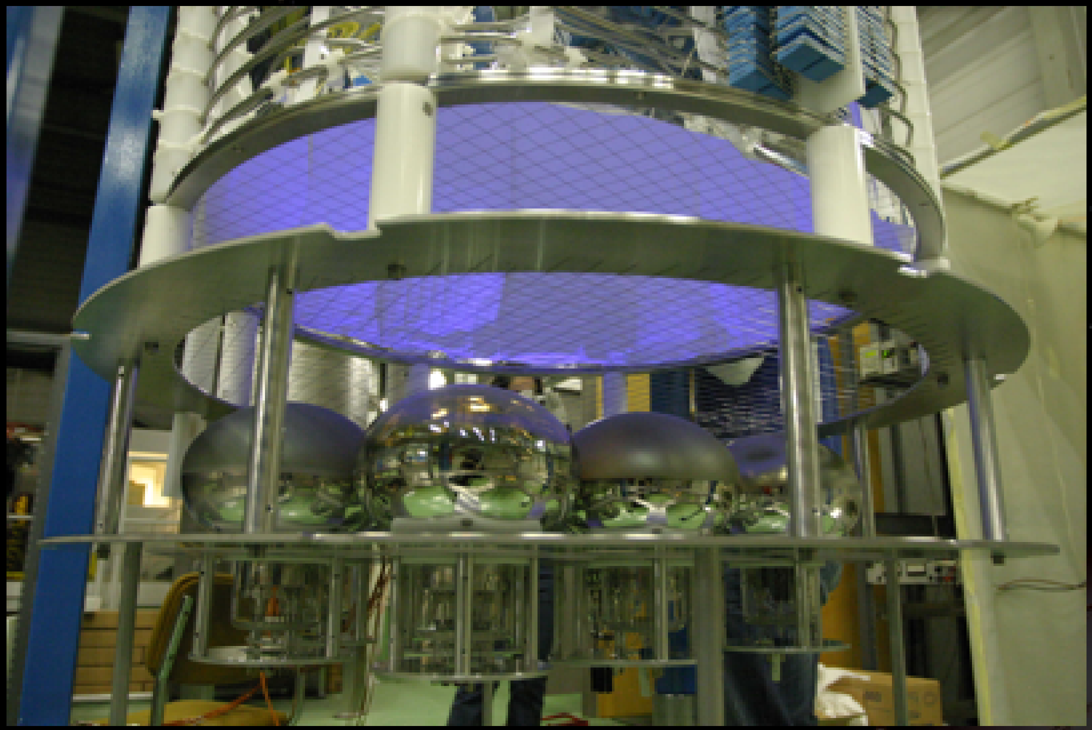
15 Reflector/shifter foils produced and installed

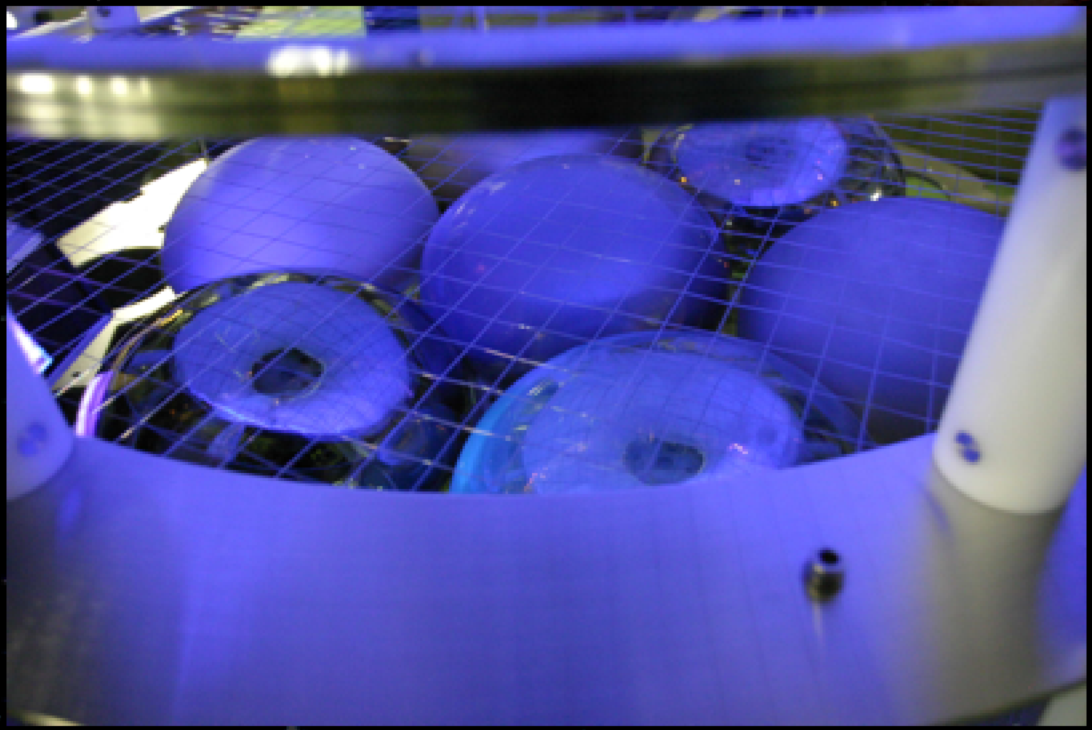


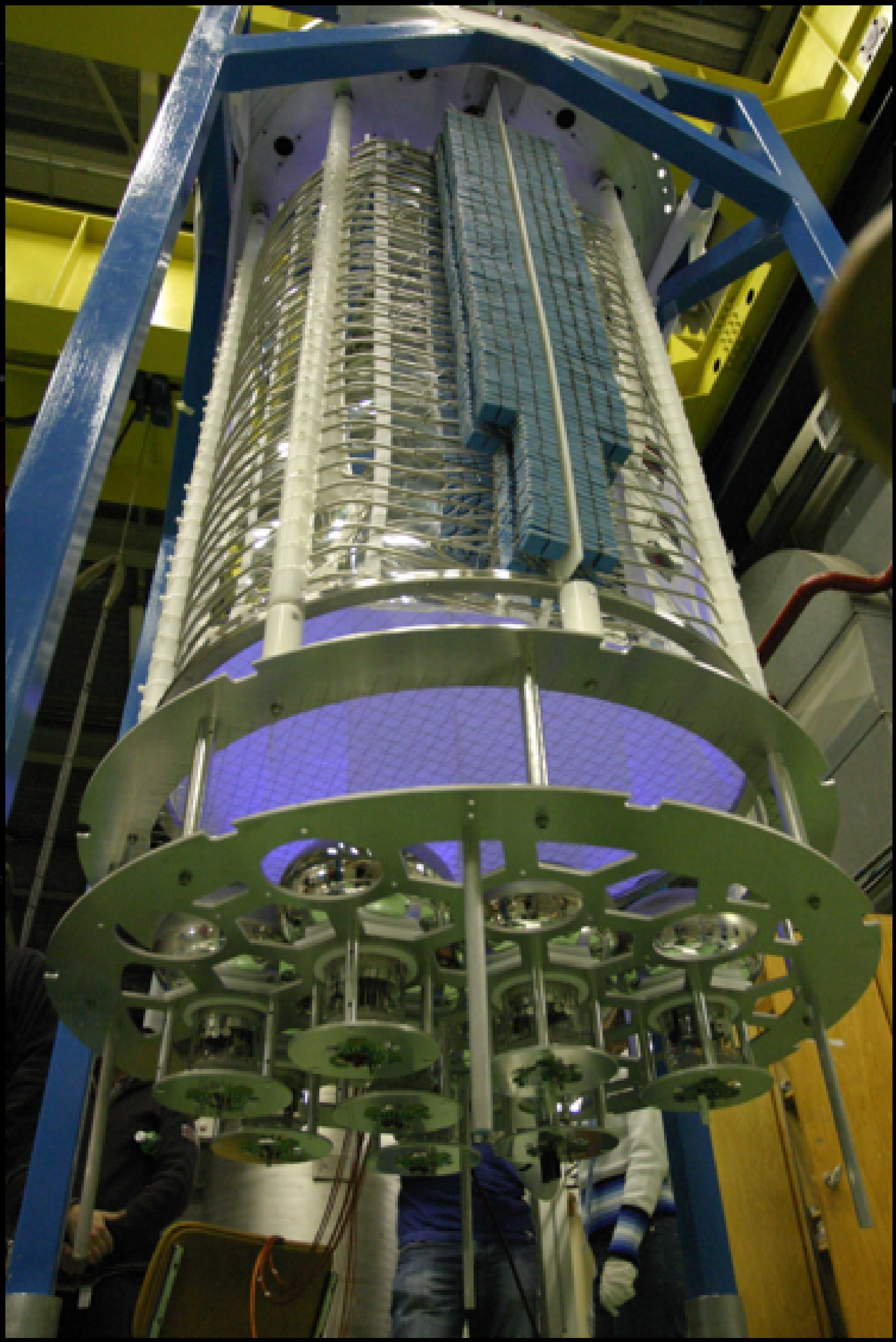
Photomultiplier configuration

Producer	Model	tubes	Source	Typ. Gain (1500V)
Hamamatsu	R5912/02mod	x5	UniZH	$\approx 1 \cdot 10^9$
Hamamatsu	R5912/01mod	x2	Granada	$\approx 1 \cdot 10^7$
ETL	ETL9357	x1	Granada	$\approx 1 \cdot 10^7$

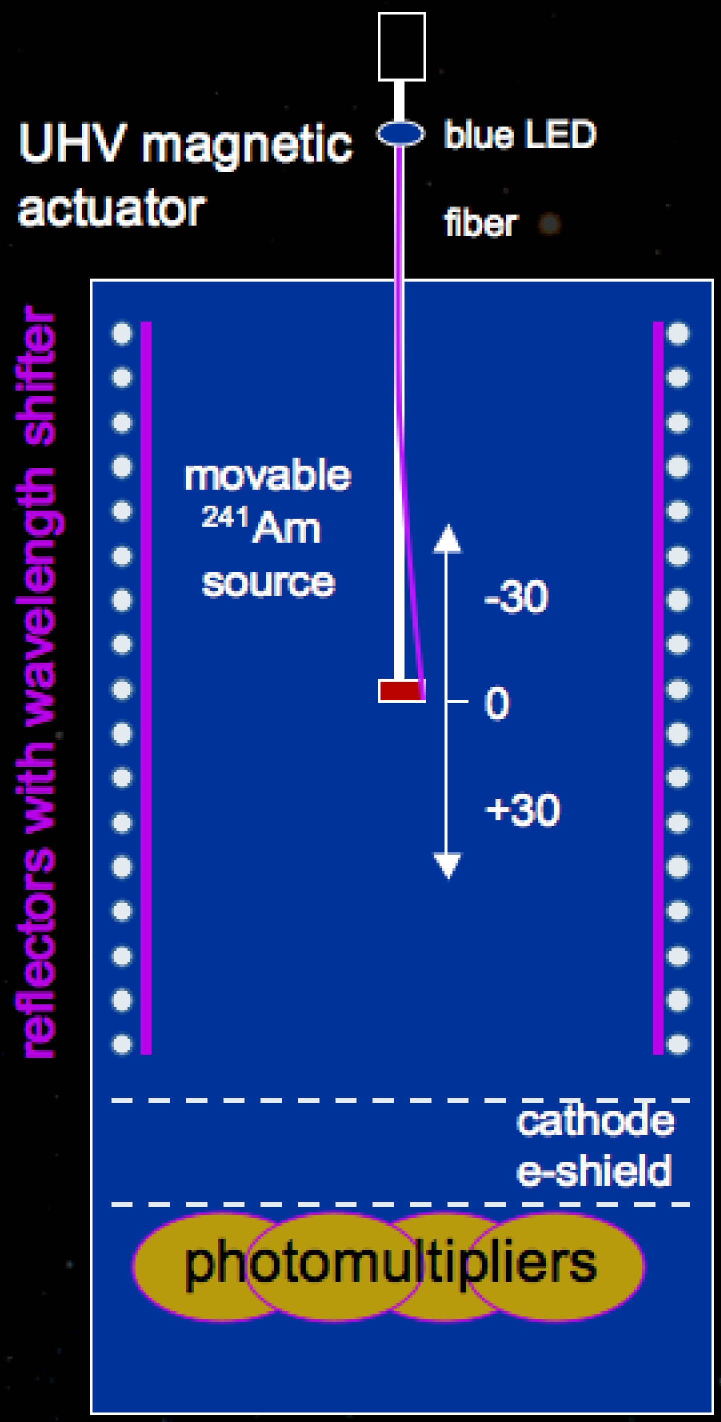
Assembled!

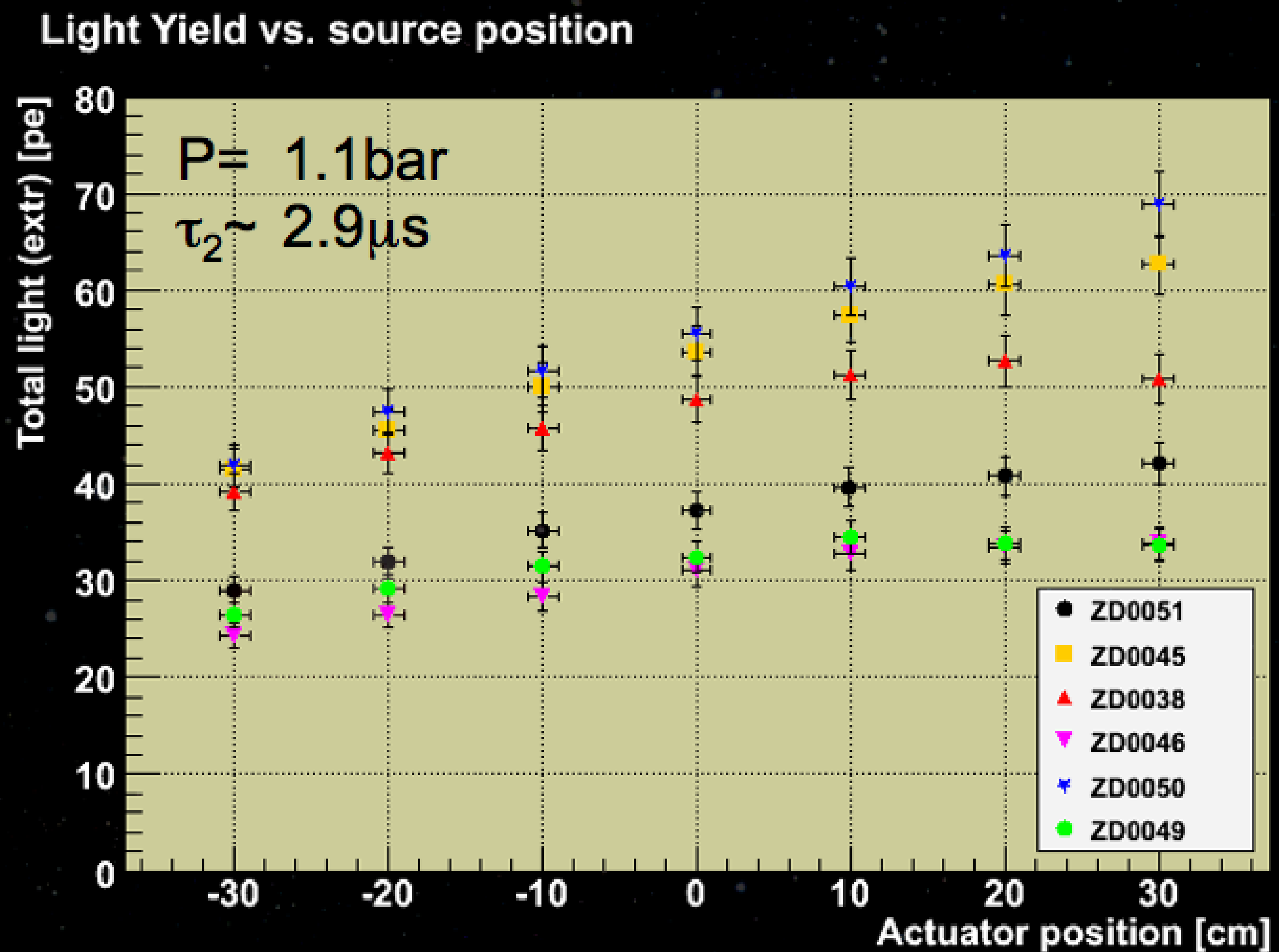






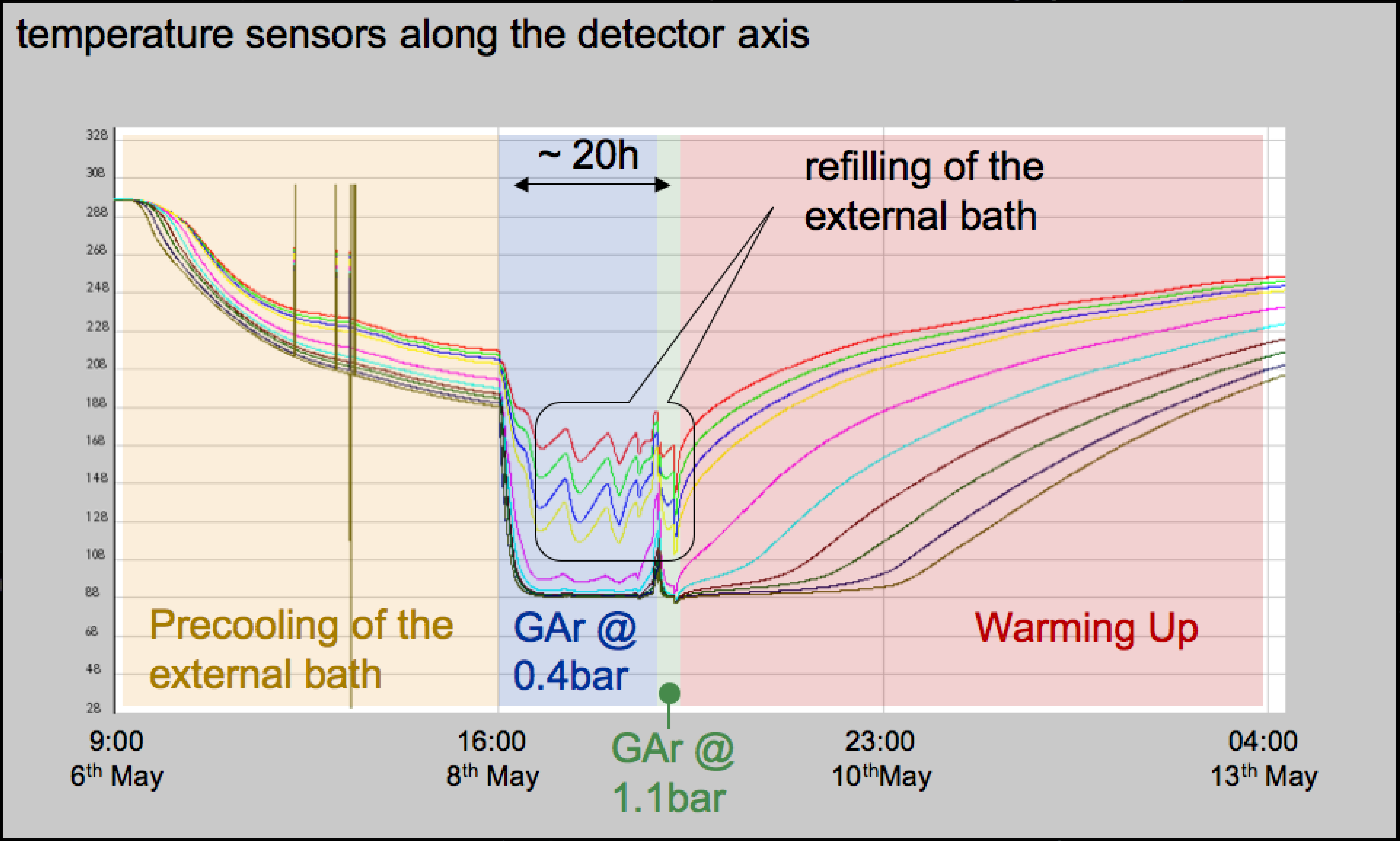
Measurement in Gas @ 300K





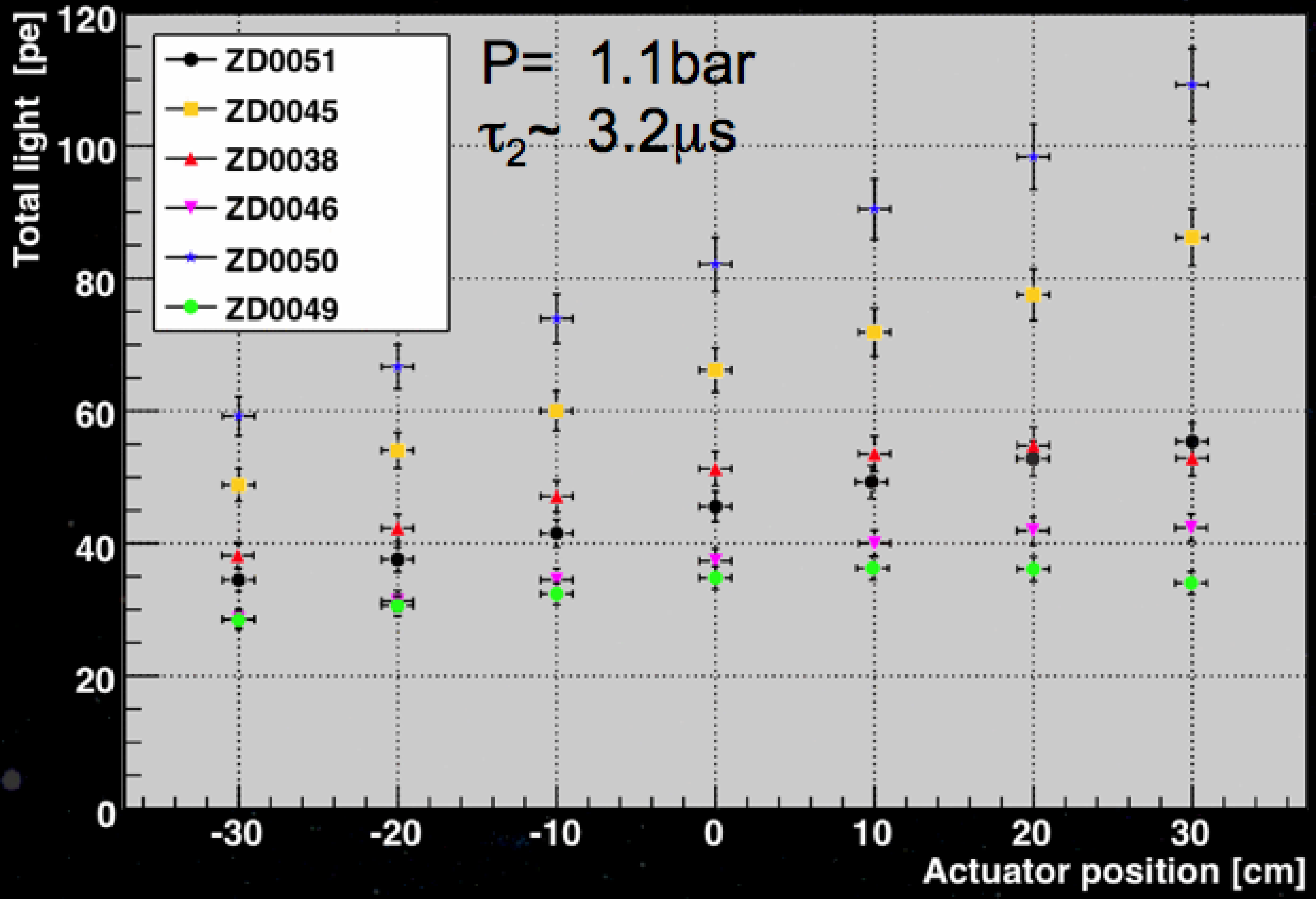
- ✓ Only 6 PMTs working in GAr, (2 sparking);
- ✓ Verified a Light Yield dependence on the position of the event;
- ✓ Preparing a measurement in liquid argon (1ton);
- ✓ Data now to be compared with MC.

Cool Down Test

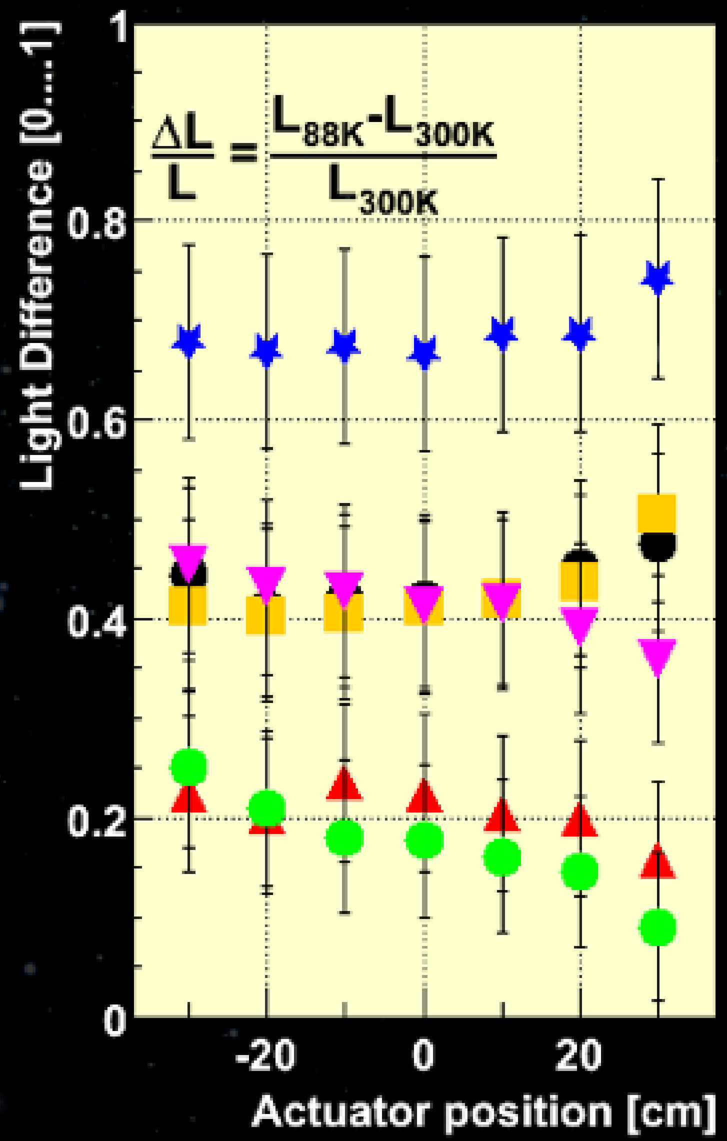


Measurement in GAr @ 88K

Light Vs. Position of the source



Light Difference



- ✓Verified a change of light yield (different effects)
  - ✓Argon emission spectrum is not only 128nm @ NPT;
  - ✓In cold gas @ 1.1bar the density is ~3 time higher;
- ✓Light difference ~ constant with position.

Prediction for the 1 ton LAr

We can try to predict (without Monte Carlo readjustment) using the experience of the 6l cell.
Extrapolation to the full coverage (14 PMTs)

	Gaseous Argon	Liquid Argon
6lt.Test Cell (only 1 PMT)	~800pe/5.3MeV α ~0.150pe/keVα measured	~4500pe/5.3MeV α ~0.8pe/keVα measured
1ton ArDM	~550pe/4.4MeVα ~0.125pe/keVα measured	~3000pe/4.4MeV α ~0.7pe/keVα expected

Expectations of Light R/O fulfills ArDM requirements

Conclusions

- ✓ R&D are in the final state;
  - ✓LEM: full size prototype in the summer;
  - ✓PMTs: 14 low background PMTS in September;
- ✓ Mechanics and cryogenic ready (minor details to be commissioned), fulfilled CERN safety requirements;
- ✓ Prototype experiment with light readout ready (8 PMTs);
  - ✓Reflectors produced and installed;
  - ✓DAQ ready, can be scaled to 14PMTs;

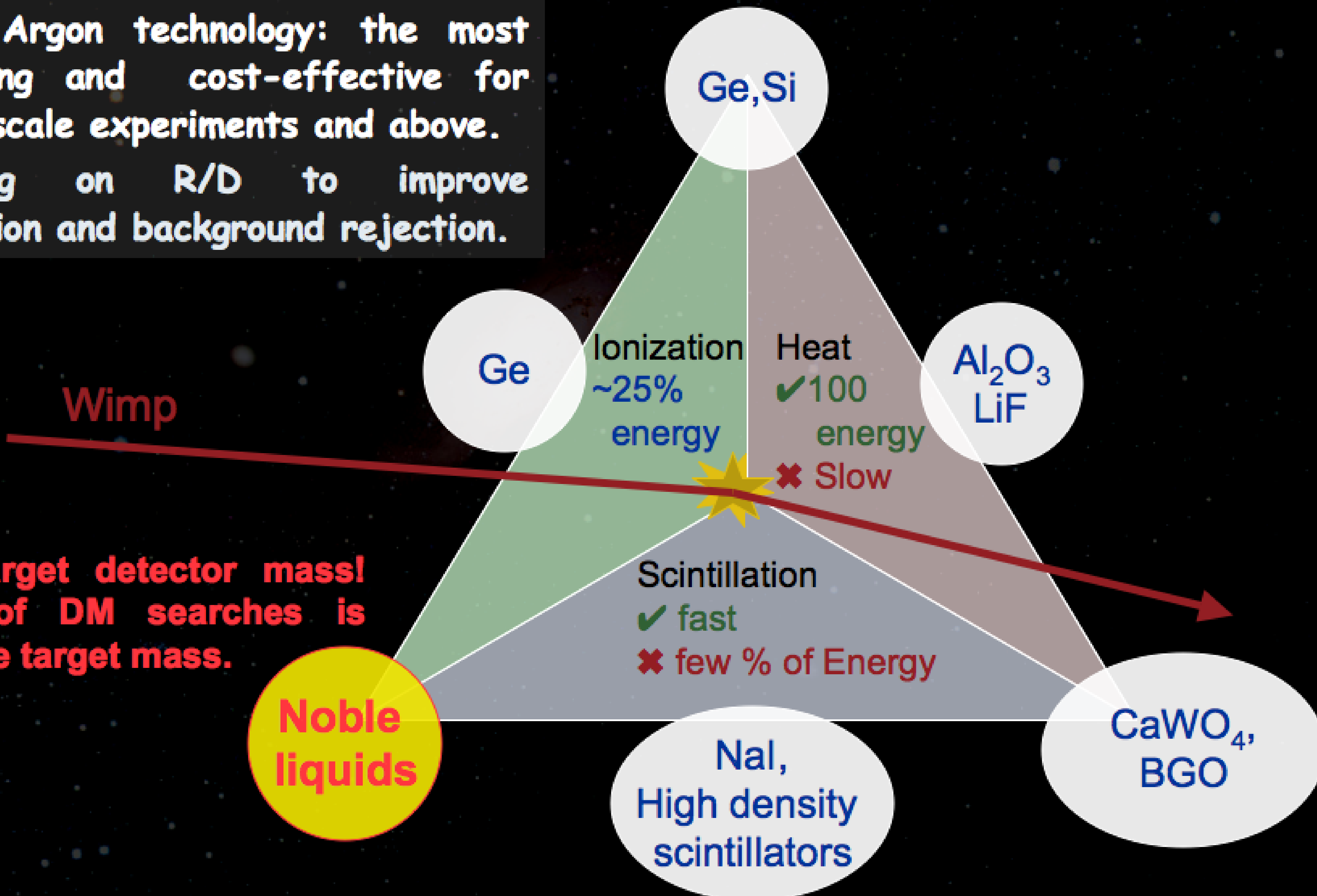
- ✓ First Cool down to 88K of the setup successful, ready for the liquid.

Backup Slides

How to detect dark matter in the lab

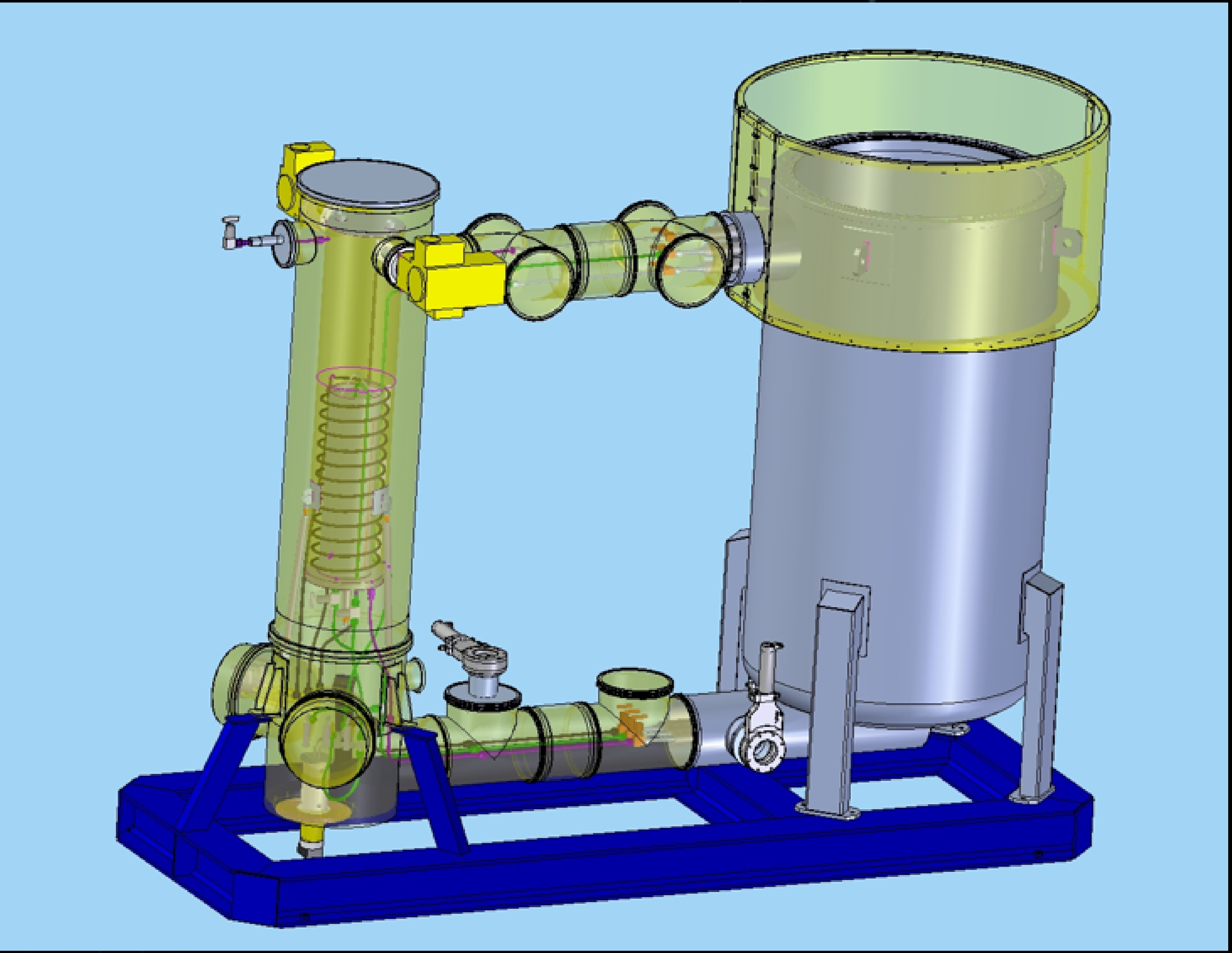
Condensed noble gases;

- ✓ Liquid Argon technology: the most promising and cost-effective for ton(s) scale experiments and above.
- ✓ Working on R/D to improve resolution and background rejection.

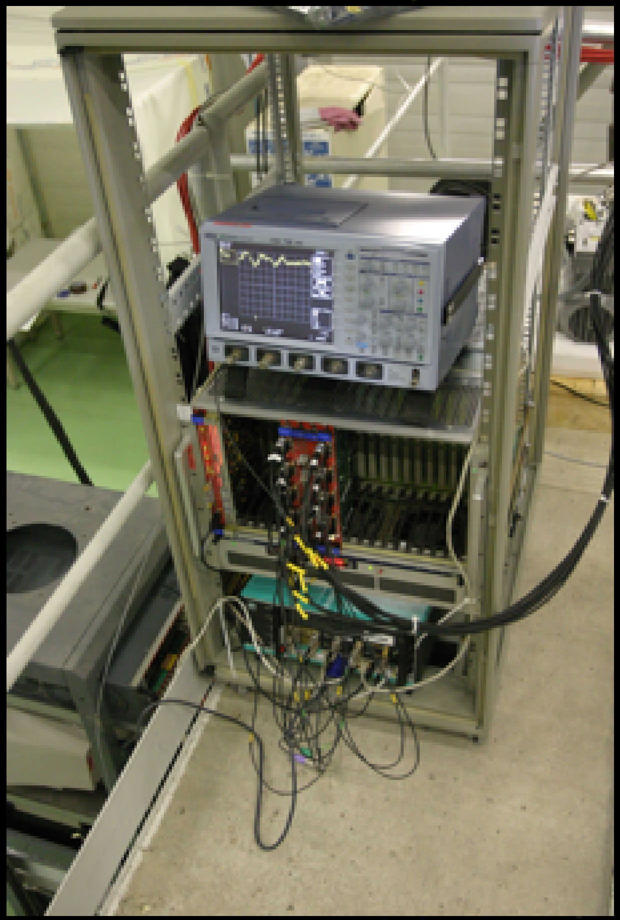


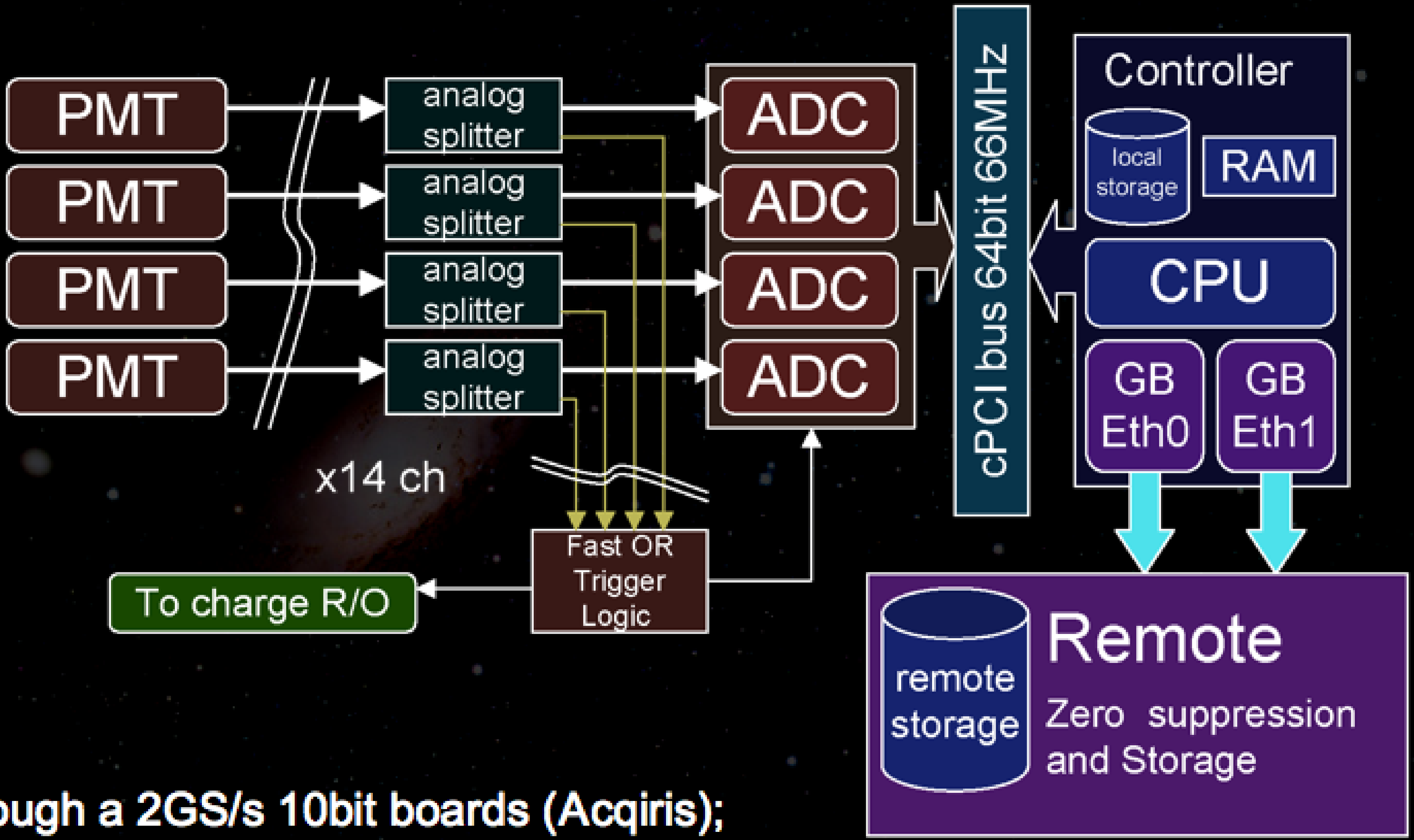
Sufficient target detector mass! Sensitivity of DM searches is limited by the target mass.

Cryogenic and purification



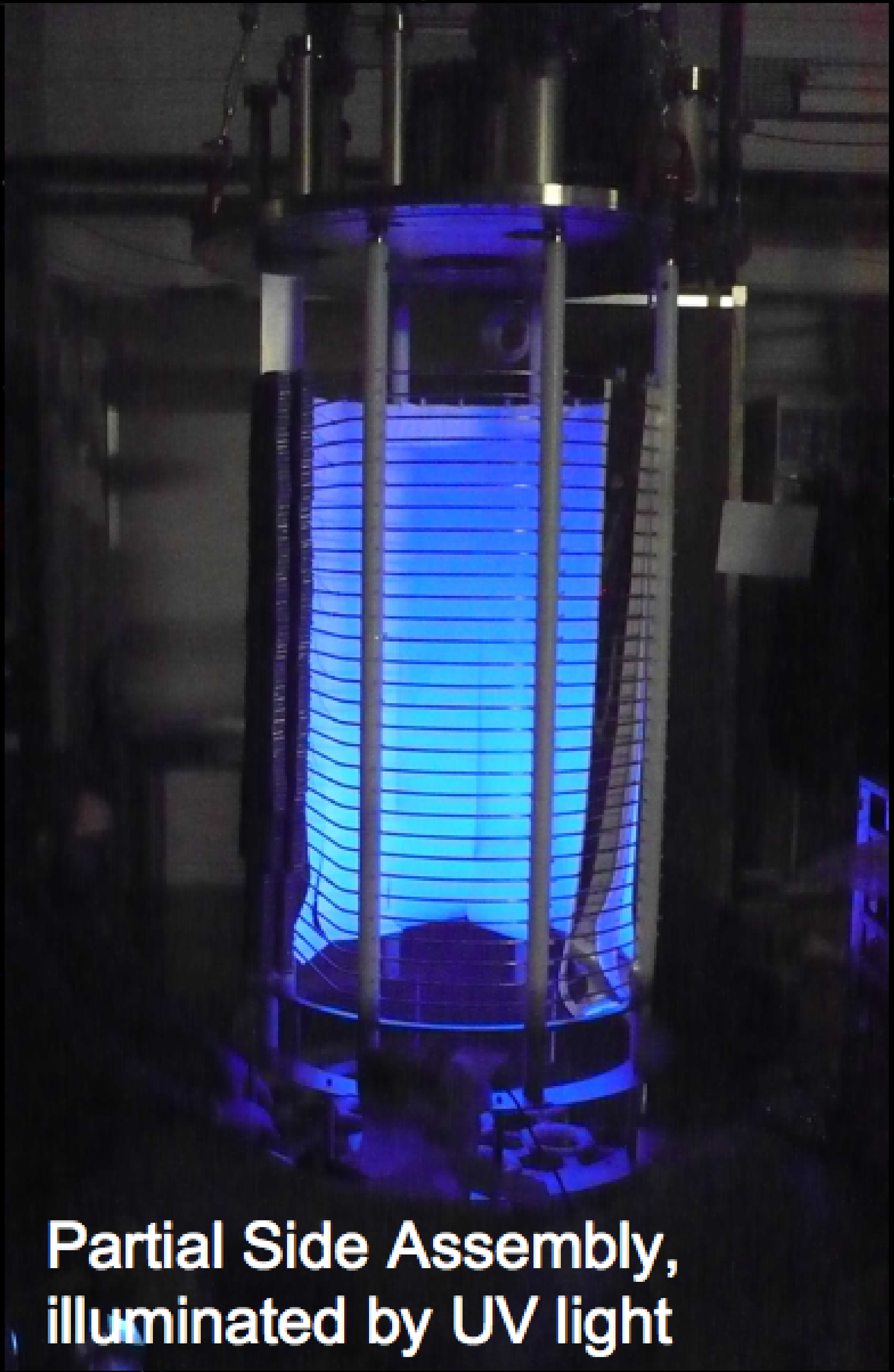
DAQ for Light Readout





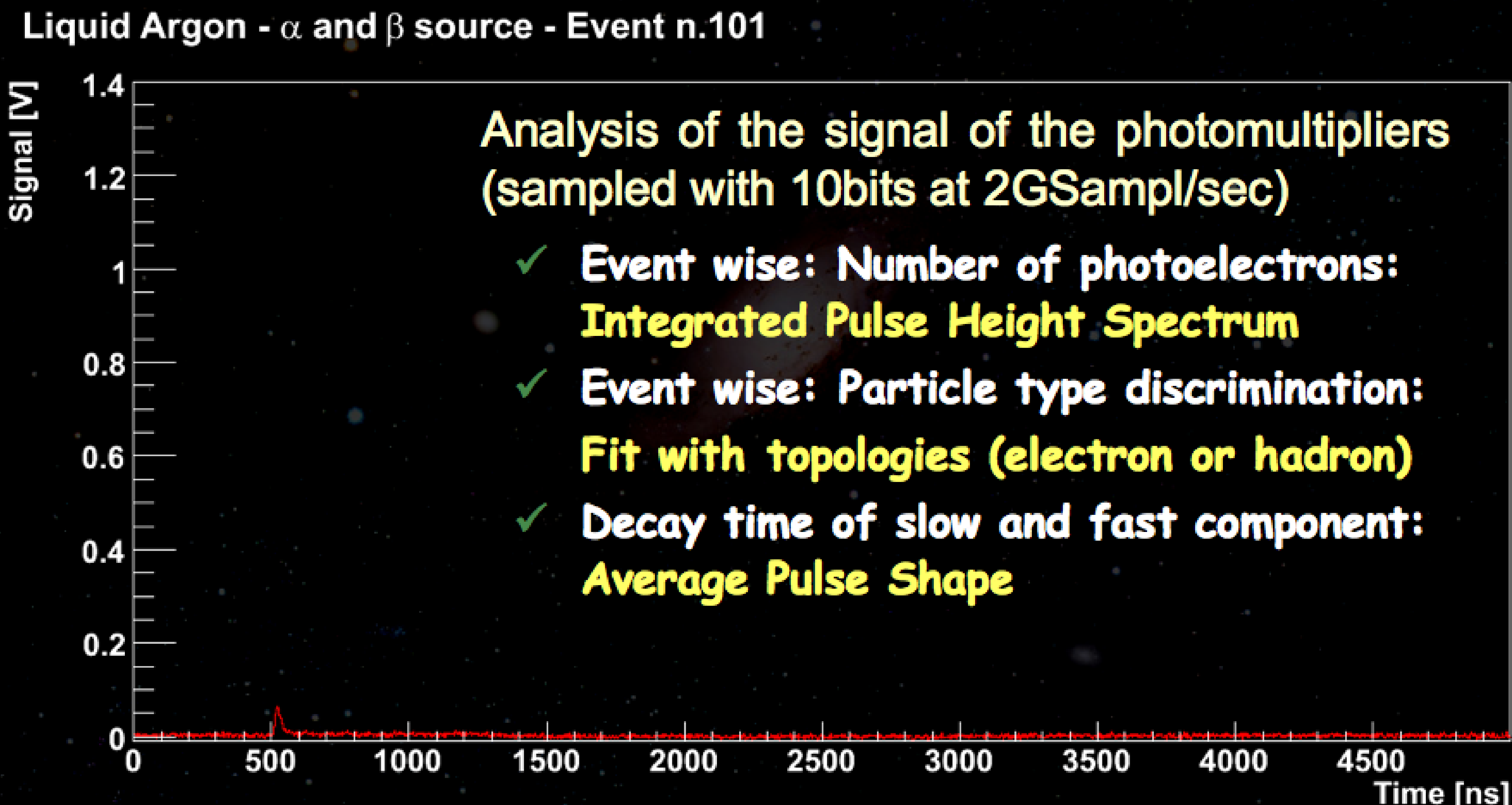
- Data are acquired through a 2GS/s 10bit boards (Acqiris);
- Waveform are digitized and stored;
- A on line monitor is present to check data quality;
- Integration with the LEM data/trigger to be done.

Assembly of Side Reflectors



Partial Side Assembly,
illuminated by UV light

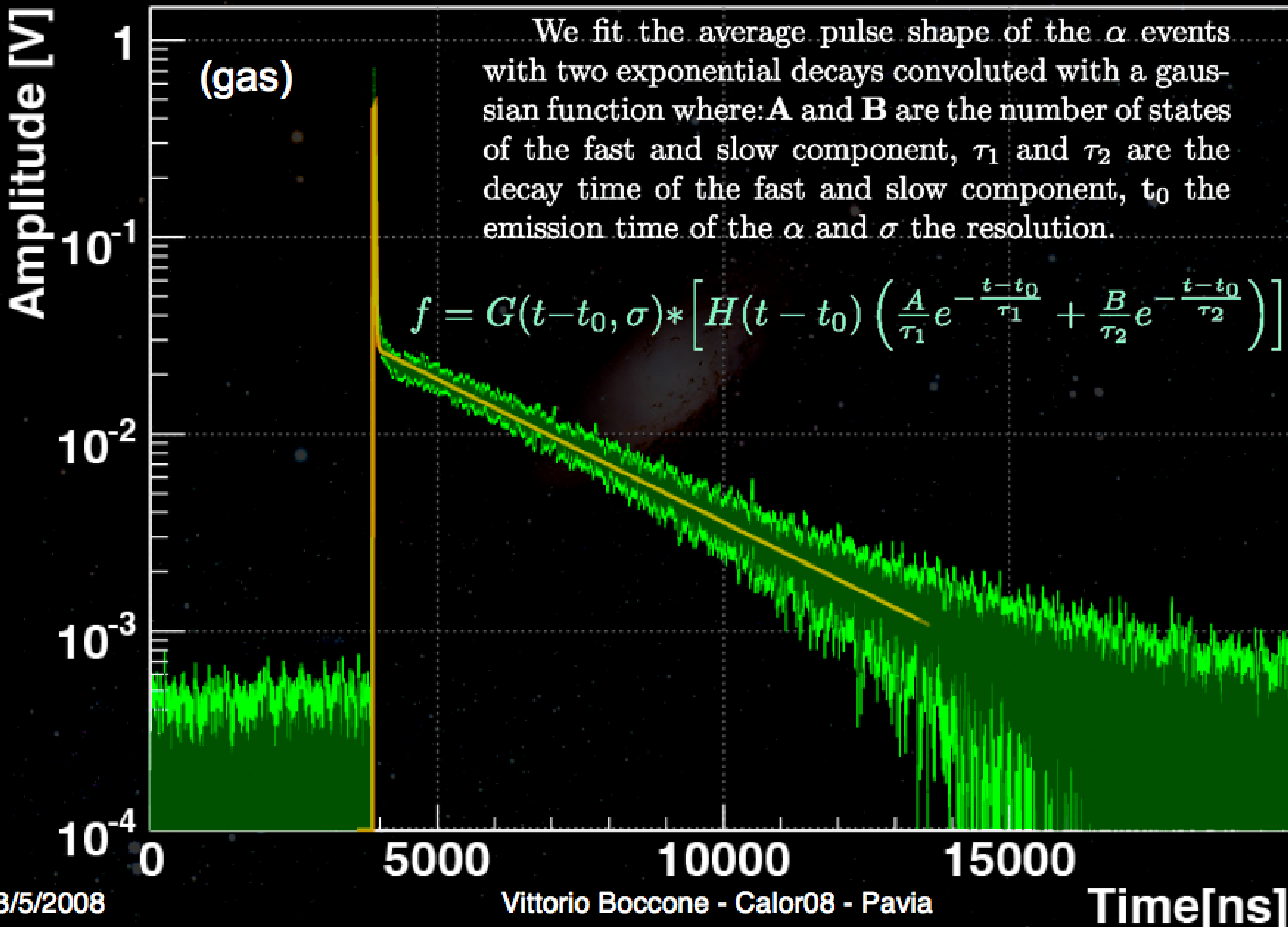
Improved Light Analysis



Analysis of the signal of the photomultipliers (sampled with 10bits at 2GSampl/sec)

- ✓ Event wise: Number of photoelectrons: **Integrated Pulse Height Spectrum**
- ✓ Event wise: Particle type discrimination: **Fit with topologies (electron or hadron)**
- ✓ Decay time of slow and fast component: **Average Pulse Shape**

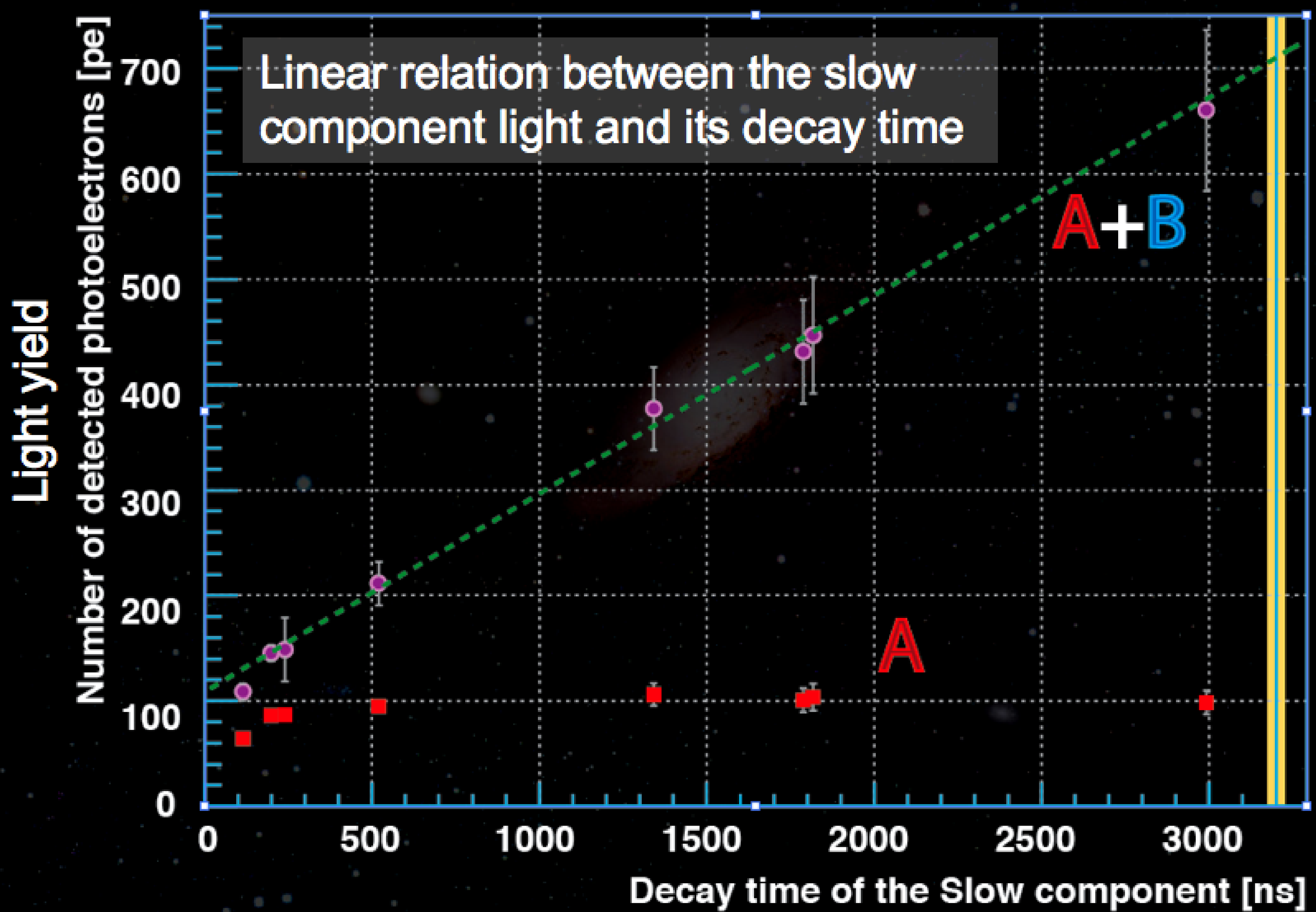
Scintillation parameters



We fit the average pulse shape of the α events with two exponential decays convoluted with a gaussian function where: **A** and **B** are the number of states of the fast and slow component, τ_1 and τ_2 are the decay time of the fast and slow component, $\mathbf{t}_0$ the emission time of the α and σ the resolution.

$$f = G(t-t_0,\sigma)*\left[H(t-t_0)\left(\frac{A}{\tau_1}e^{-\frac{t-t_0}{\tau_1}} + \frac{B}{\tau_2}e^{-\frac{t-t_0}{\tau_2}}\right)\right]$$

Light yield and slow components



END