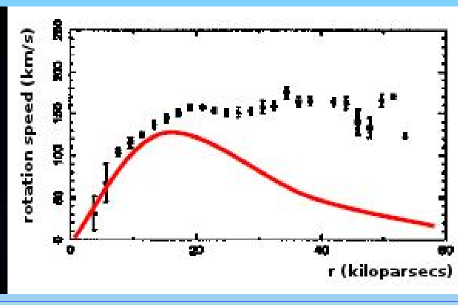
The LUX Dark Matter Detector

F. Neves on behalf of the LUX Collaboration

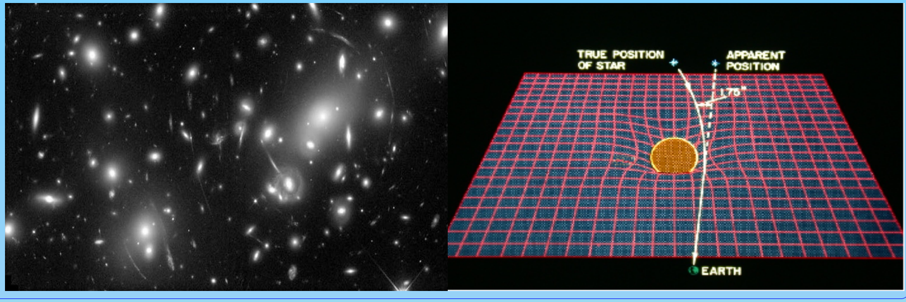
12th Pisa Meeting on Advanced Detectors

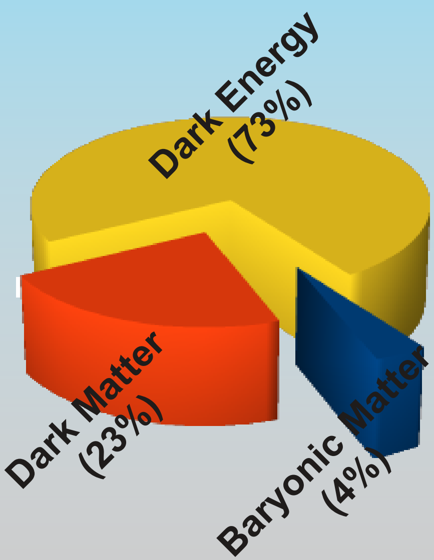
Motivation

Motion of stars, gas and galaxies
(1st reference in 1933 by Fritz Zwicky)

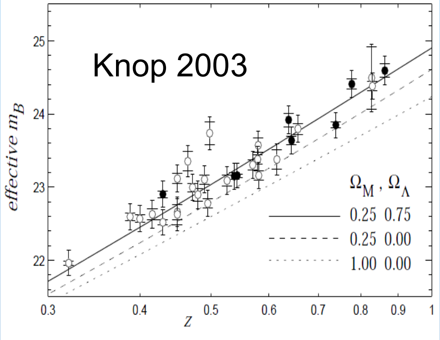


Gravitational Lensing (weak/strong)





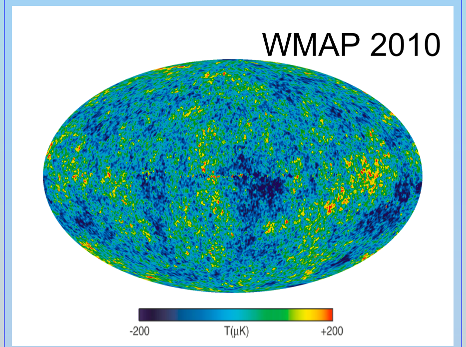
Supernovae



$\Omega_\Lambda = 0.713\,^{+0.049}_{-0.045}$

$\Omega_m = 0.287\,^{-0.045}_{+0.049}$

Cosmic microwave background

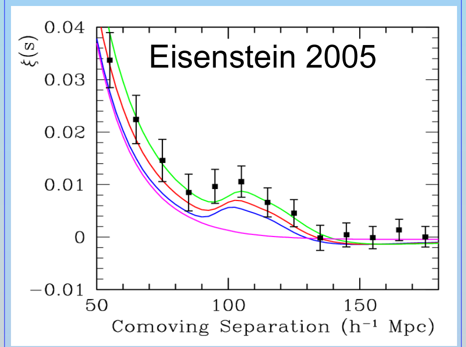


$\Omega_{total} = 1.002 \pm 0.006$

$\Omega_m = 0.273 \pm 0.015$

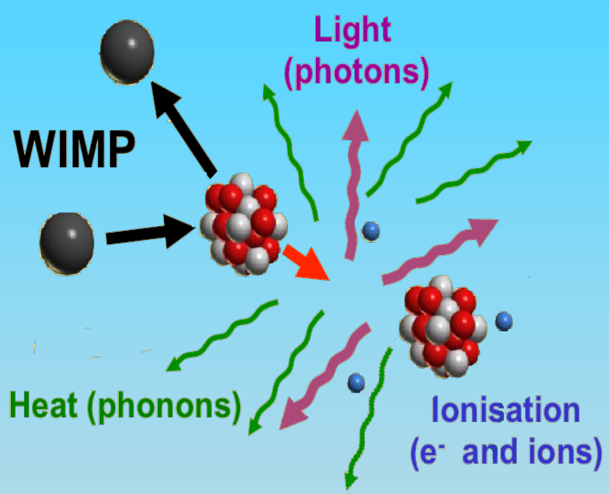
$\Omega_b = 0.0456 \pm 0.0016$

Baryonic acoustic oscillations

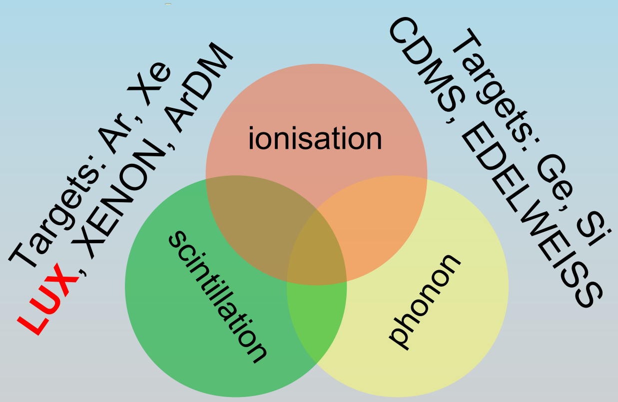


$\Omega_m = 0.273 \pm 0.025$

Dark Matter candidate: WIMPs

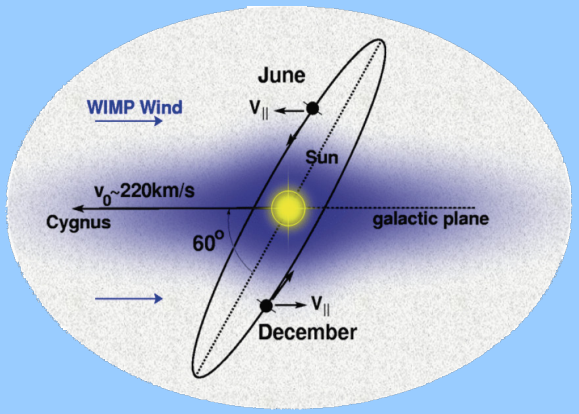


- M_{WIMP} in the *10 GeV – 1 TeV* range;
- WIMP do not interact via strong/electromagnetic forces;
- **Indirect detection**: WIMP annihilation products;
- **Direct detection**: WIMP-nucleus scattering:
  - Spin Independent: $\sigma_{SI} \sim A^2$ (dominant for A>30);
  - Spin Dependent: $\sigma_{SD} \sim J(J+1)$;



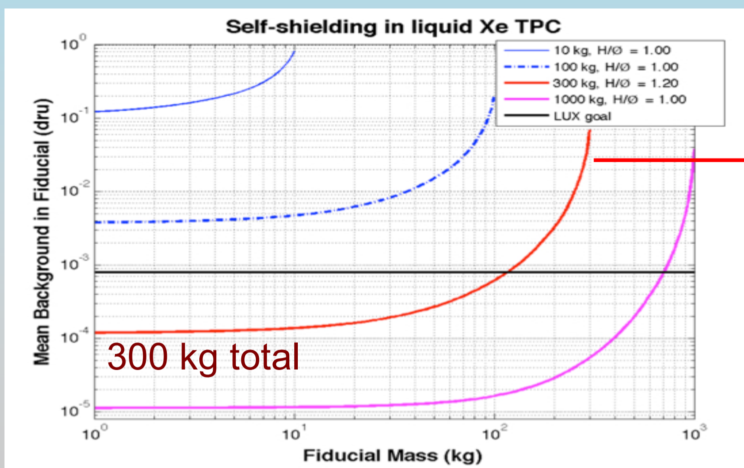
Targets: CaW_4, BGO, Al_2O_3
CRESST, ROSEBUD

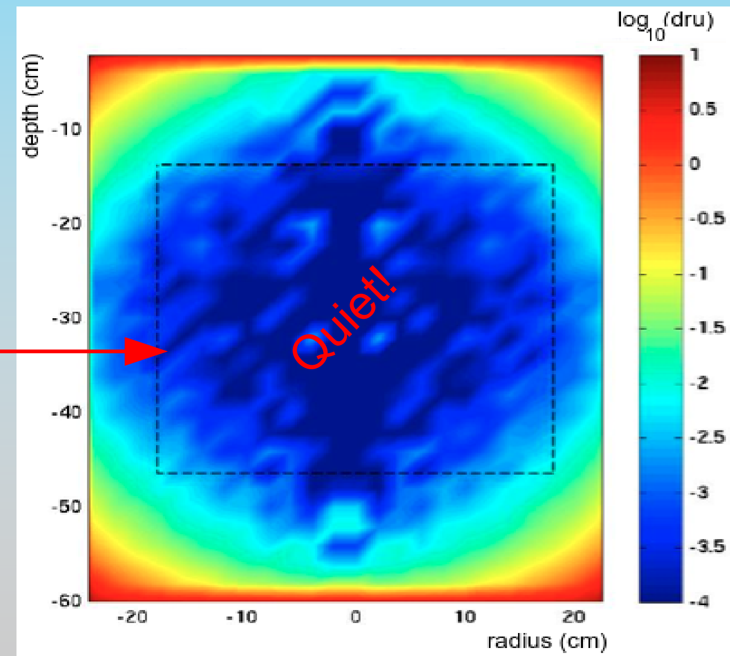
For each target both the **recoil energy** spectrum and the **interaction rate** (and its time modulation - DAMA) depend on the local **WIMP density** and **velocity distribution model.**



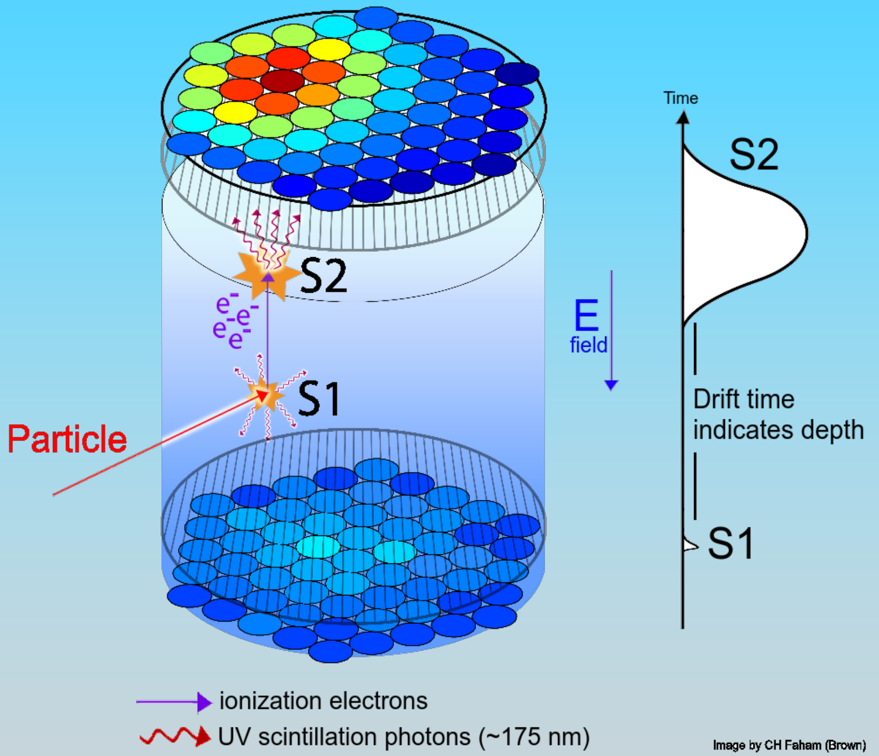
Why Liquid Xenon for direct WIMP detection?

- **High atomic number** (A~131): good for spin-independent interactions;
- ~1/2 **odd isotopes** in natural Xenon**:** spin-dependent sensitivity;
- Natural Xe has **no long-lived radioactive isotopes**: plus Kr can be reduced to ppt level;
- **High density** (≈*3 g/cm^3*): manageable detector volumes;
- Allows relatively easy **scalability to ton-level detectors**;
- **Large light output** / Sensitivity to **single ionization electrons**;
- **Nuclear recoil vs e$^-$/γ-ray discrimination**;
- Allows **self- passive shielding** by selection of an inner fiducial volume and **active- vetoing** using interactions on the outer volume;

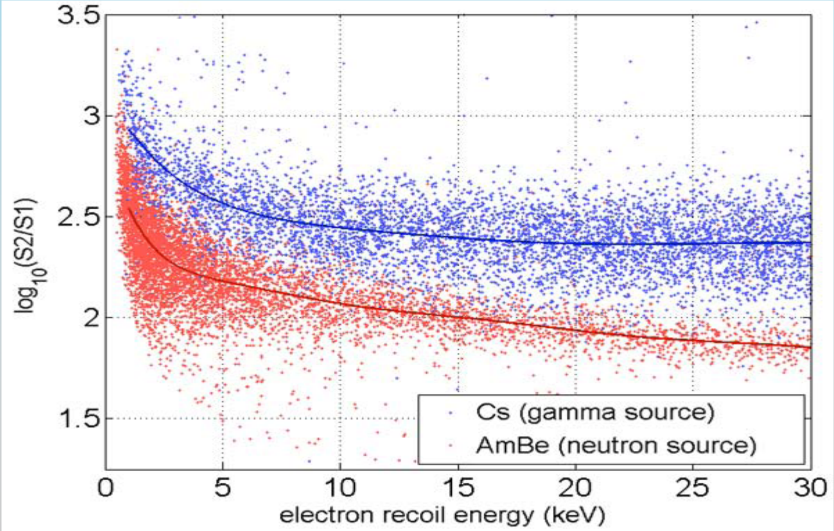




LUX is a 2-phase Xenon TPC



- **Prompt scintillation (S1)**: energy scale (keVee);
- **Proportional scintillation (S2)**: measurement of the e^- charge extracted from the liquid to the gas.
- **S2/S1** depends on the ionising particle (nuclear/electron recoil): **99.5% ER/NR rejection expected** (50% NR acceptance).

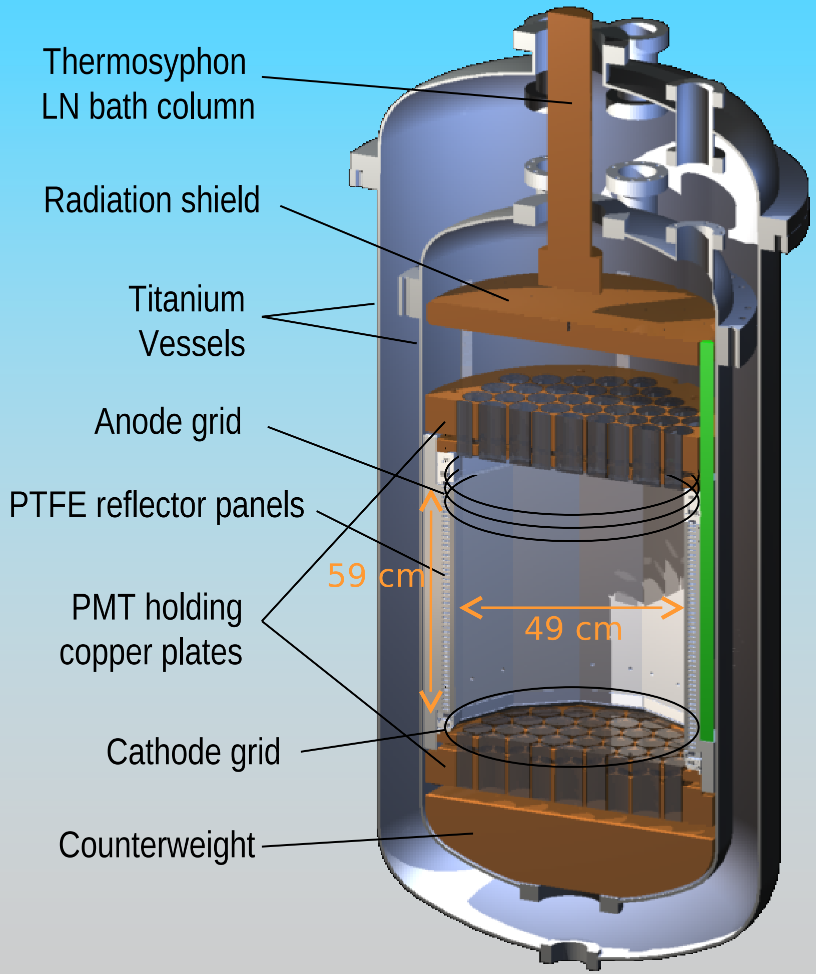


- **(x,y) position reconstruction**: from the S2 light pattern;
- **Depth of interaction (z)**: e^- drift time in the liquid (time difference between S2 and S1);

So... what's new in LUX?

- **<u>Its the bigger double-phase xenon detector (~350 kg) up to now!</u>**
  - Allows to have bigger fiducial volume;
  - Take advantage of the self-shielding properties of liquid Xenon;
- **<u>Key technologies for the next generation of tonne-scale detectors:</u>**
  - Instrumented water shielding;
  - Thermosyphon cryogenics;
  - Titanium vessel (low background);
  - Detector calibration using $^{83}Kr^{m}$ (*not covered in this talk*);

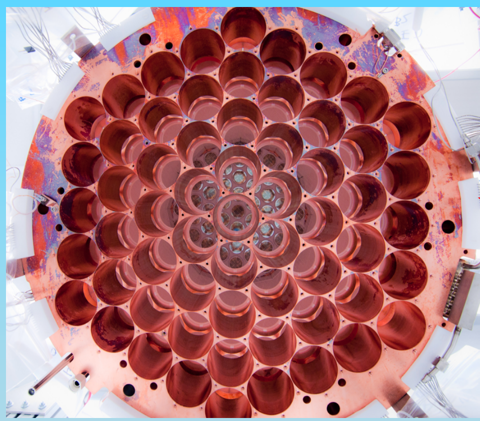
LUX detector: overview



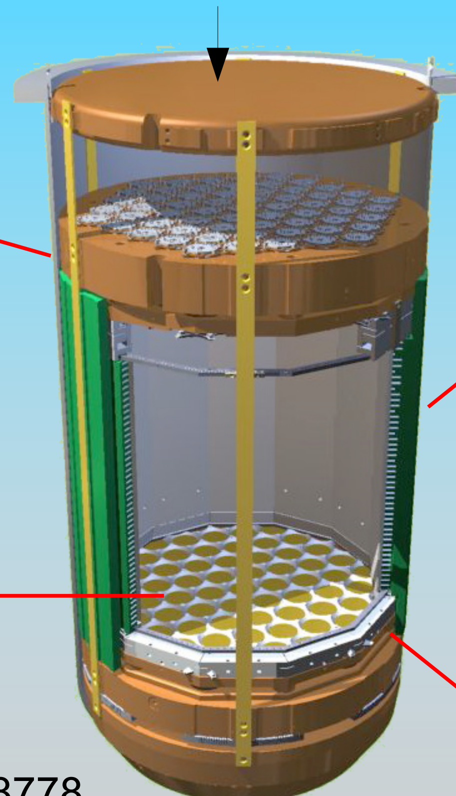
- **61 top + 61 bottom PMTs** viewing ~300 kg of xenon (expected ~100 kg fiducial);
- **Ultra low background** PMTs (12 mBq/PMT);
- Titanium cryostat (<0.2 mBq/kg);
- Internal copper shield;
- Active region defined by **PTFE** slabs (high reflectivity for xenon scintillation light);
- Maximum drift time: 50 cm;
- High flow plumbing and heat exchanger for rapid (>30 SLPM) circulation through external purifier;

LUX detector: internals

Copper PMT holding slots

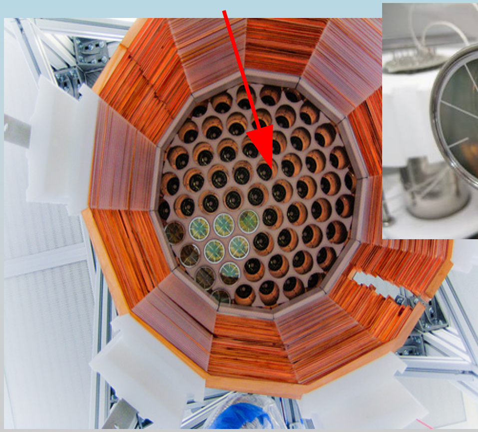


Radiation shield



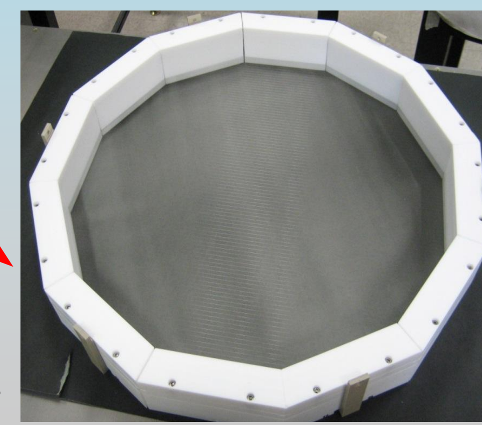
Dodecagonal field cage
+ PTFE reflector panels

PTFE “trifoils”



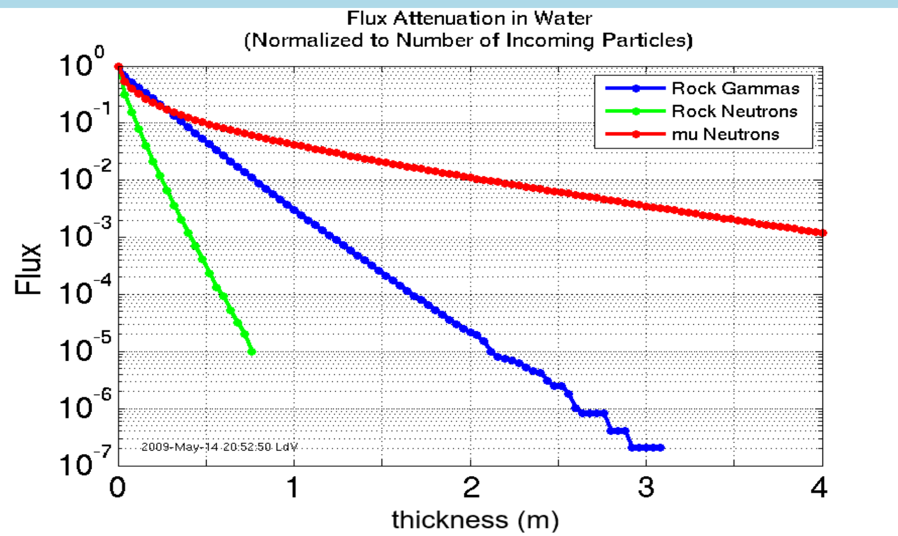
122 2" PMT R8778
QE(175 nm) ≥ 30%
U/Th ~ 9/3 mBq/PMT

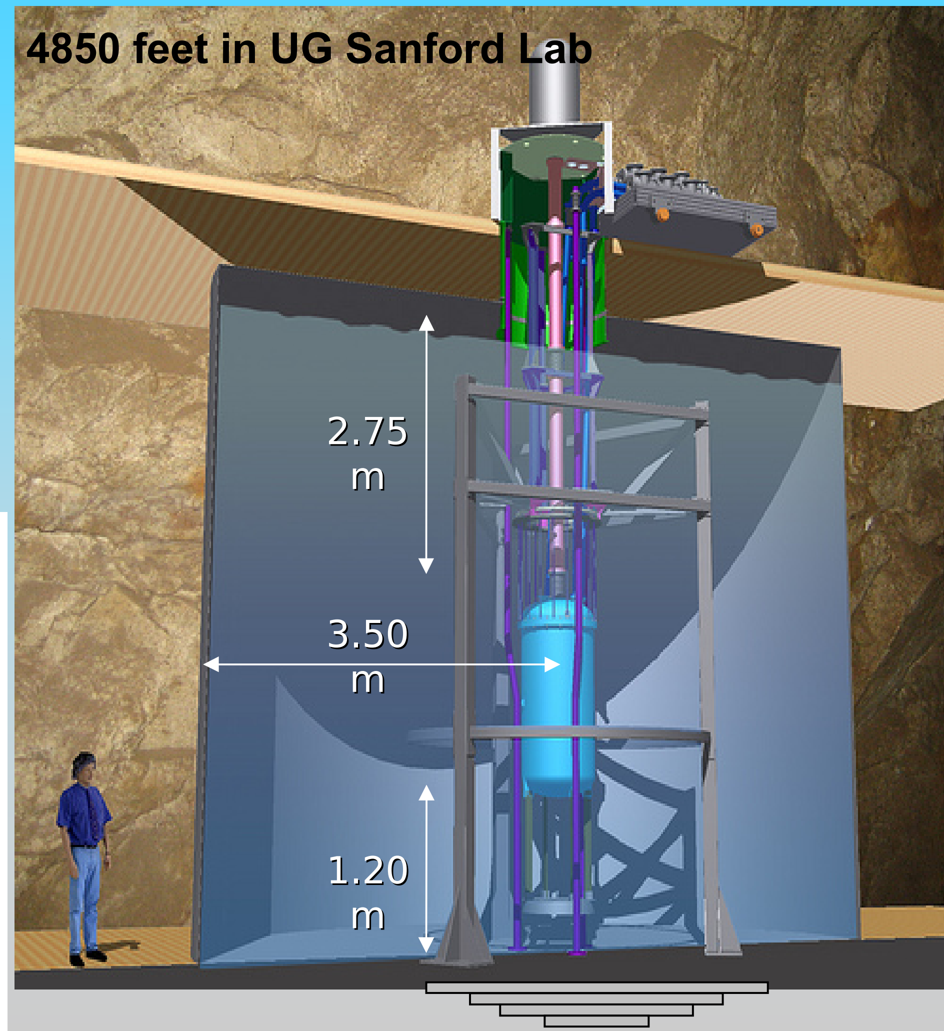
HV grids



LUX detector: water tank

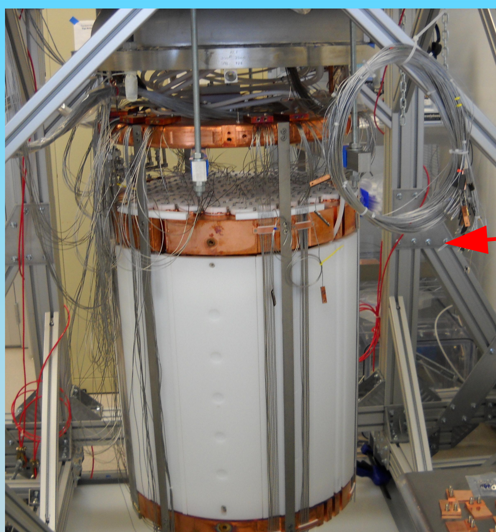
- **Ultra-low background facility:**
  - <u>all external backgrounds sub-dominant</u>;
  - γ-ray event rate reduction: $\sim 10^{-9}$;
  - n(E>10 MeV) rate reduction: $\sim 10^{-3}$;
- **Water tank**: d=8m, h=6m
  - 300 tonnes, 3.5m thickness on the sides
- **Cherenkov muon veto**:
  - 20 PMTs (10" diameter)

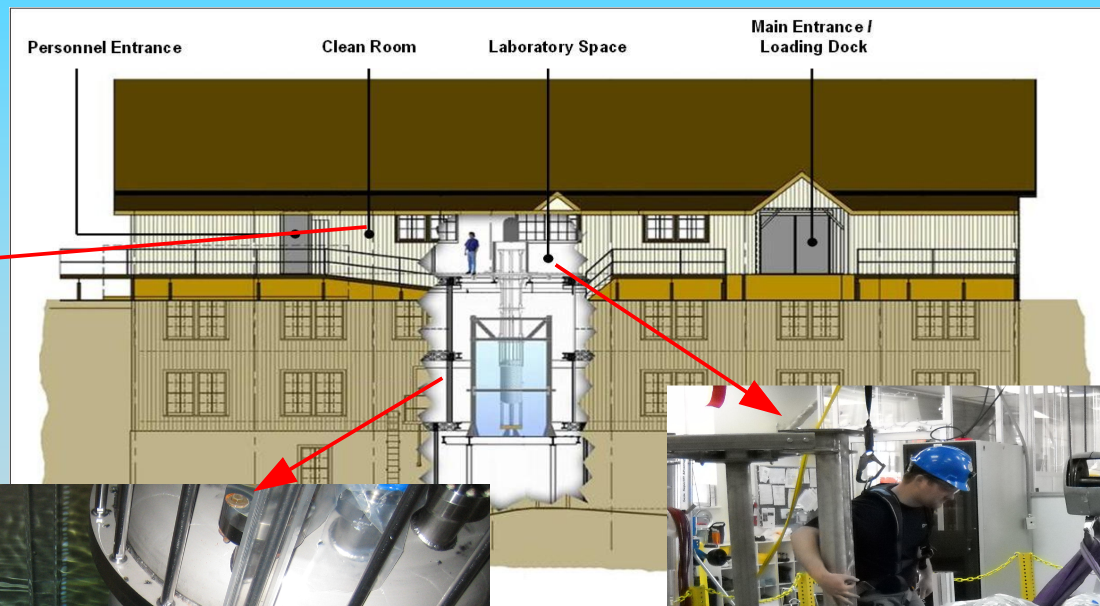


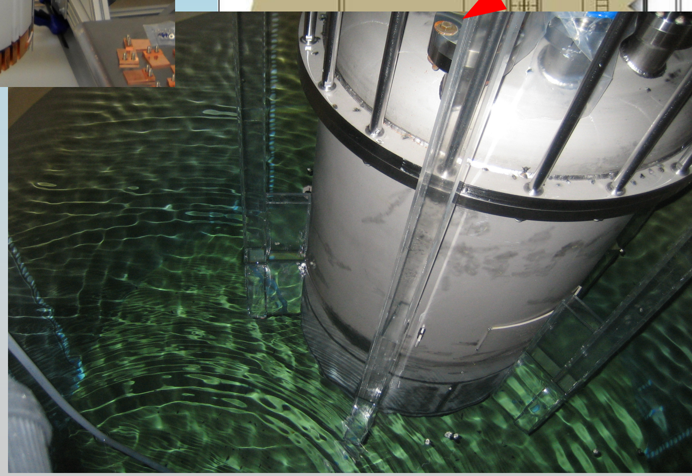


Surface detector deployment

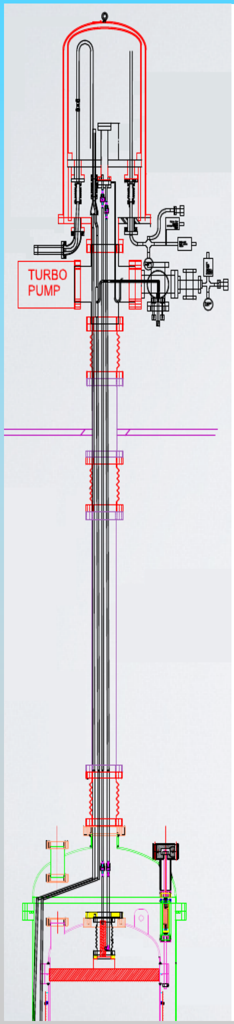
Test everything (as extensively as possible) before Underground deployment.

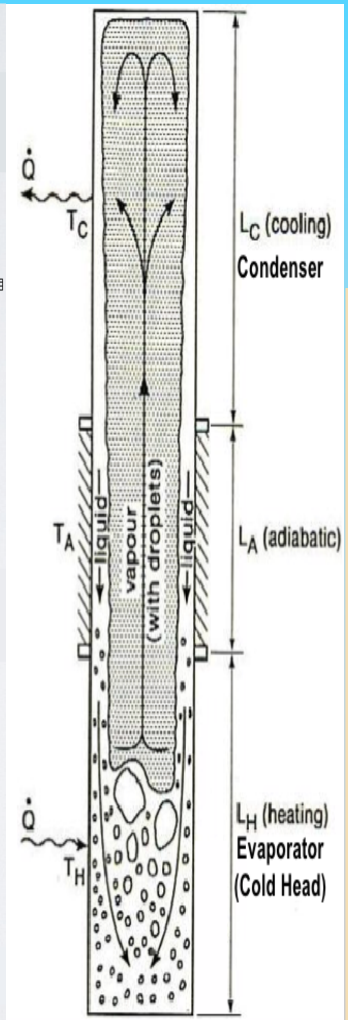




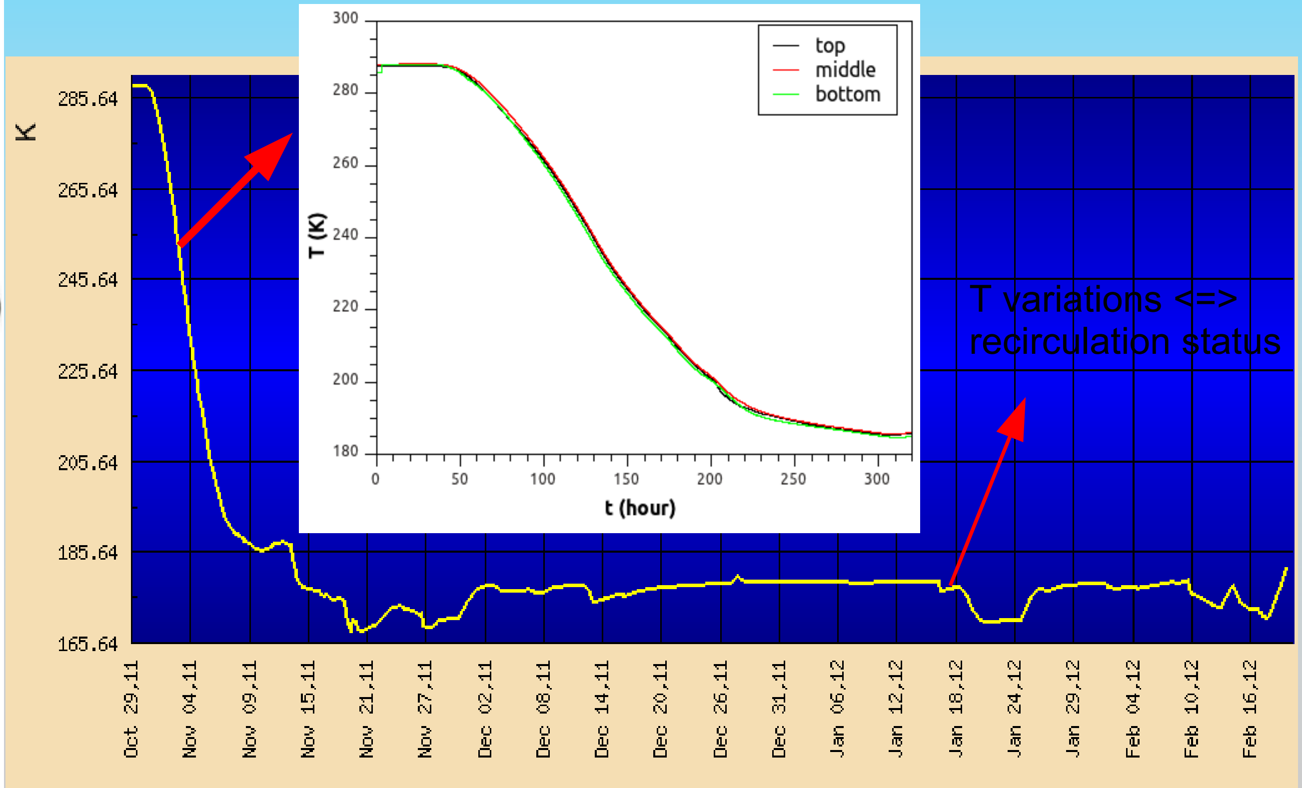


Surface run: cooling system



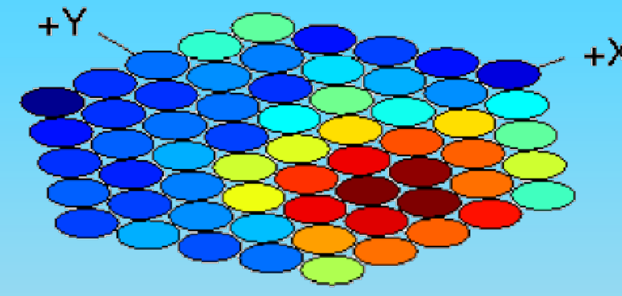


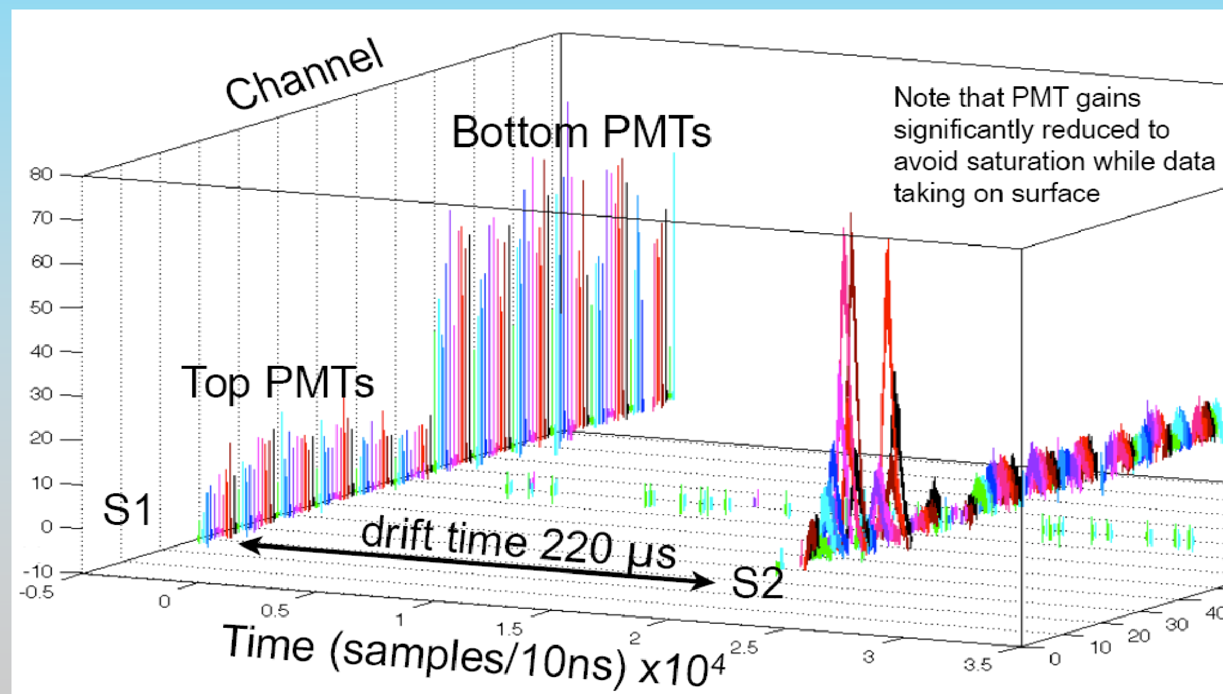
- ~kW capacity / multiple cold head deployment;
- Circulation of xenon through the purification system:
  - 0.3t Xe/day @ 35 slpm (heat load <5W);



Surface run: DAQ system

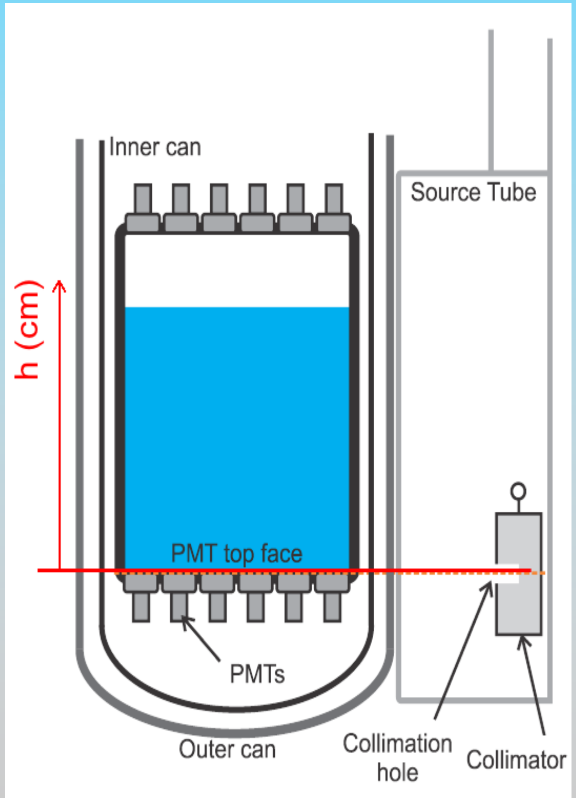
- Samples at 105 MHz with 14 bit depth;
- All acquisition channels are working:
  - surface run generated ≈3 TB of data;
- 122/122 PMTs are working:
  - one broken base in lower PMT array;

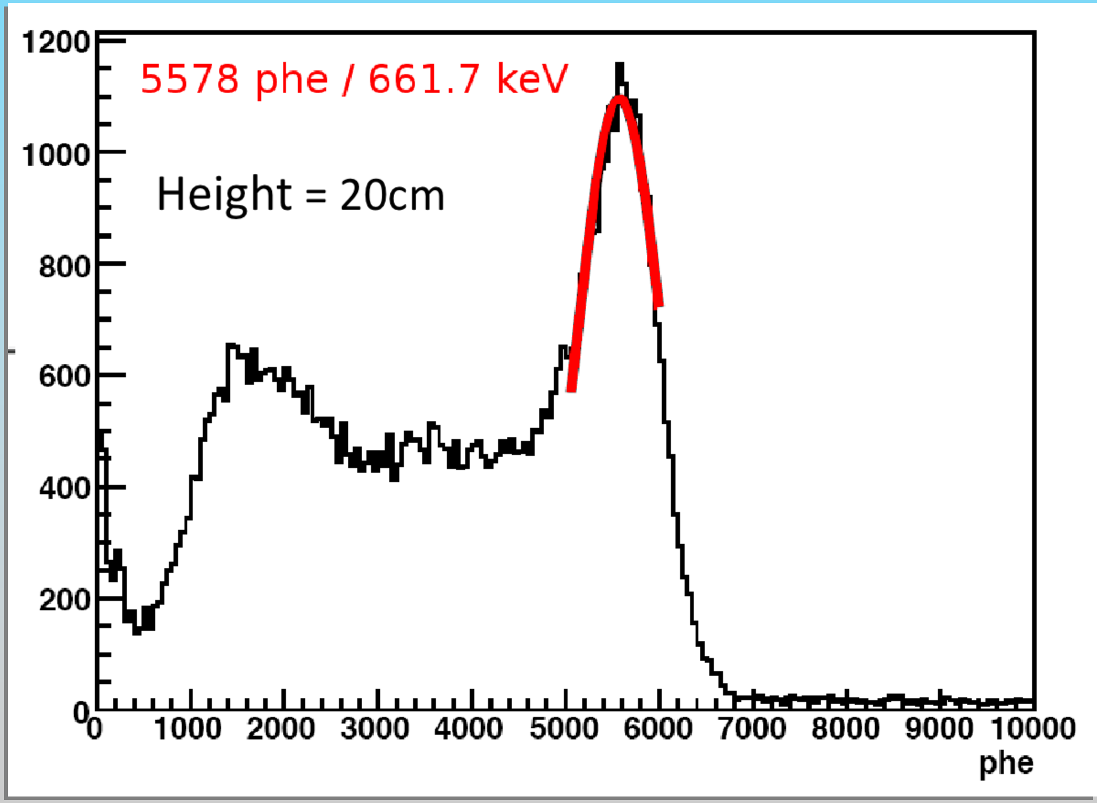




Surface run: light collection

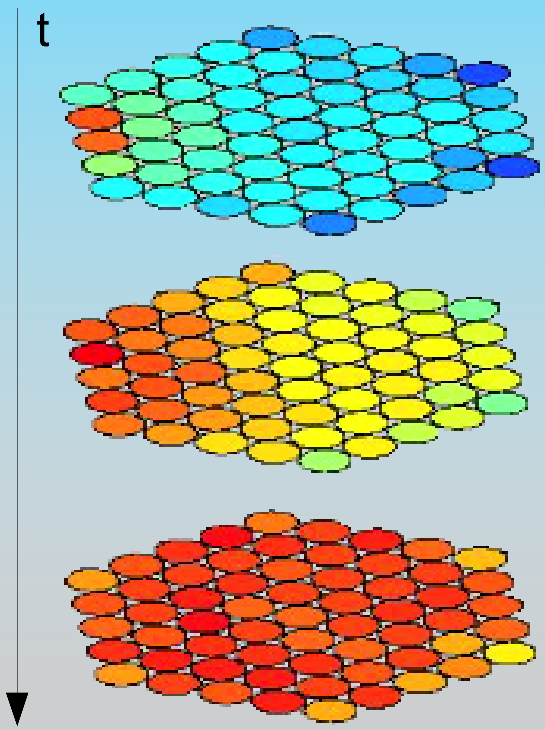
- γ-rays (662 keV) from ^{137}Cs (collimated):
  - **~8 phe/keVee** in detector center (@ zero electric field);
  - Comparison with MC simulation: $\mathbf{R_{PTFE} > 95\%}$; $\mathbf{\lambda_{abd} > 5\ m}$;



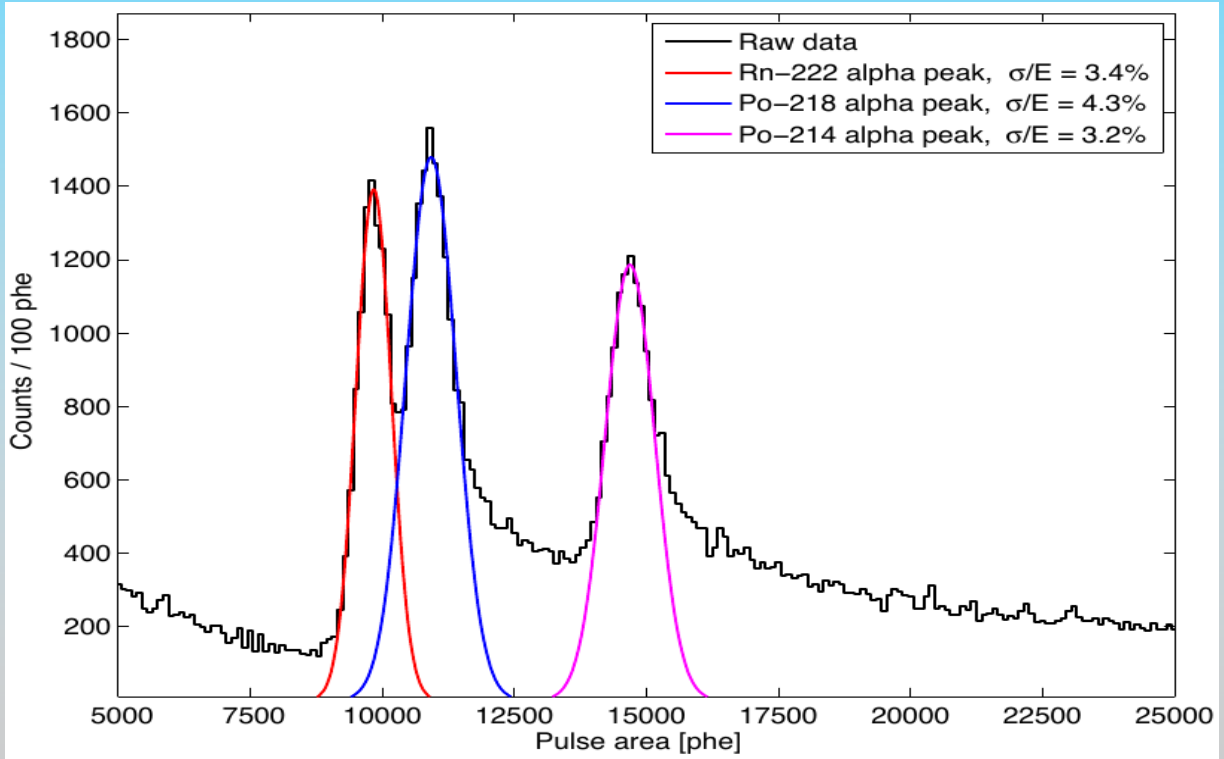


Surface run: electron life time and energy resolution

- Using alphas from ^{222}Rn injection to monitor **electron life time**: **~90 μs**
  - Failed plumbing joint limited circulation/purification performance;
- Energy resolution (Eα = 5.5 MeV) ~ 3%;

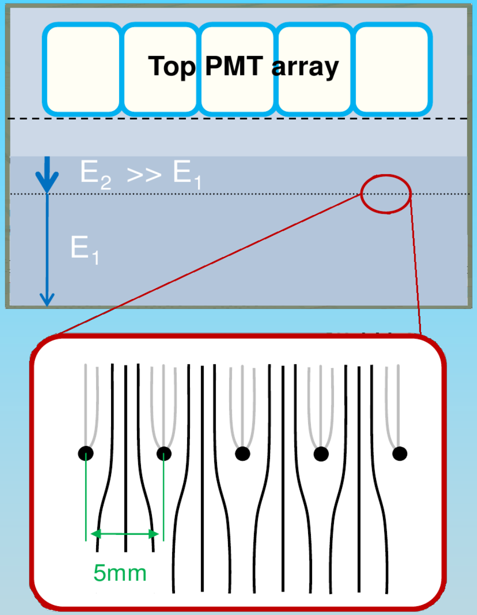


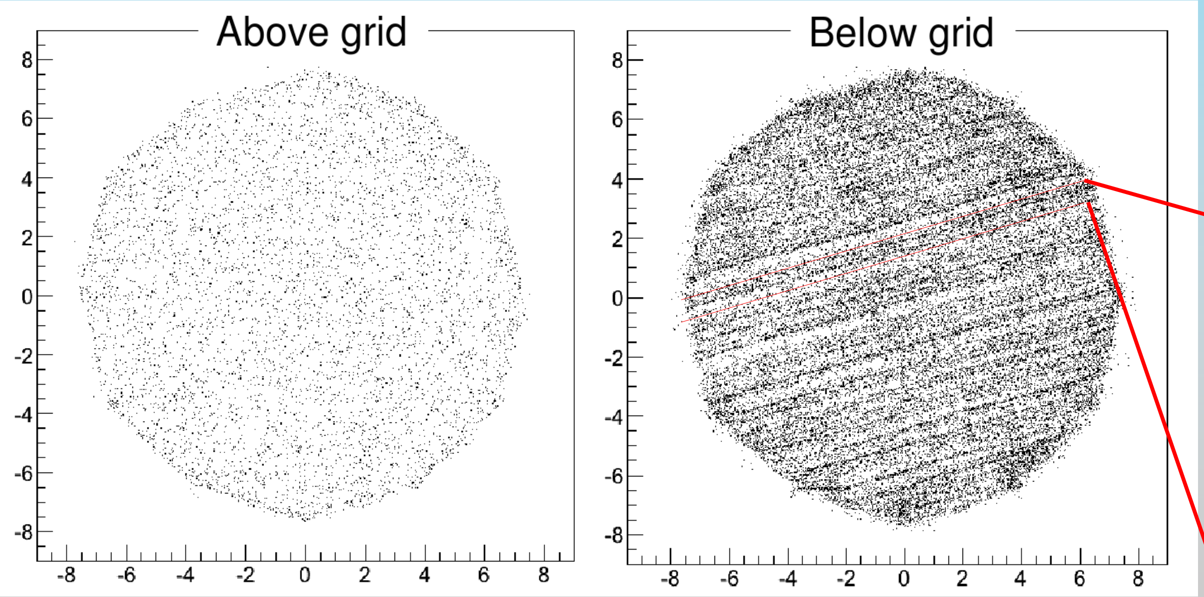
(top PMT array)

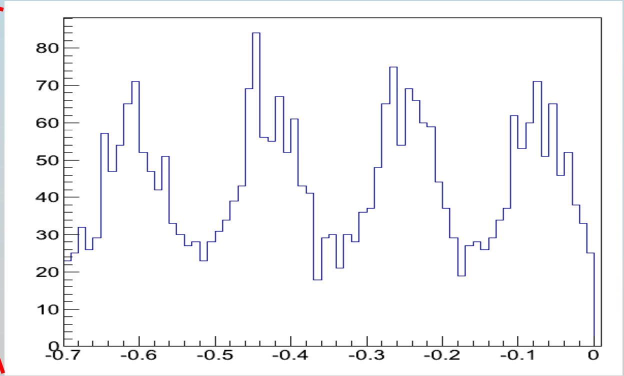


Surface run: position reconstruction

- The **light collection efficiency** ($\varepsilon(x,y,z)$) is obtained by **iteratively** fitting to each PMT channel a common cylindrical **response profile** ($R_{1..122}$) extending away from its vertical axis;
- $R_{1..122}$ adjusted using background data;
- Reconstruction of $(x,y)_{S2}$ from α interactions (E = 5.5 MeV) allows to resolve the anode grid (5 mm pitch);

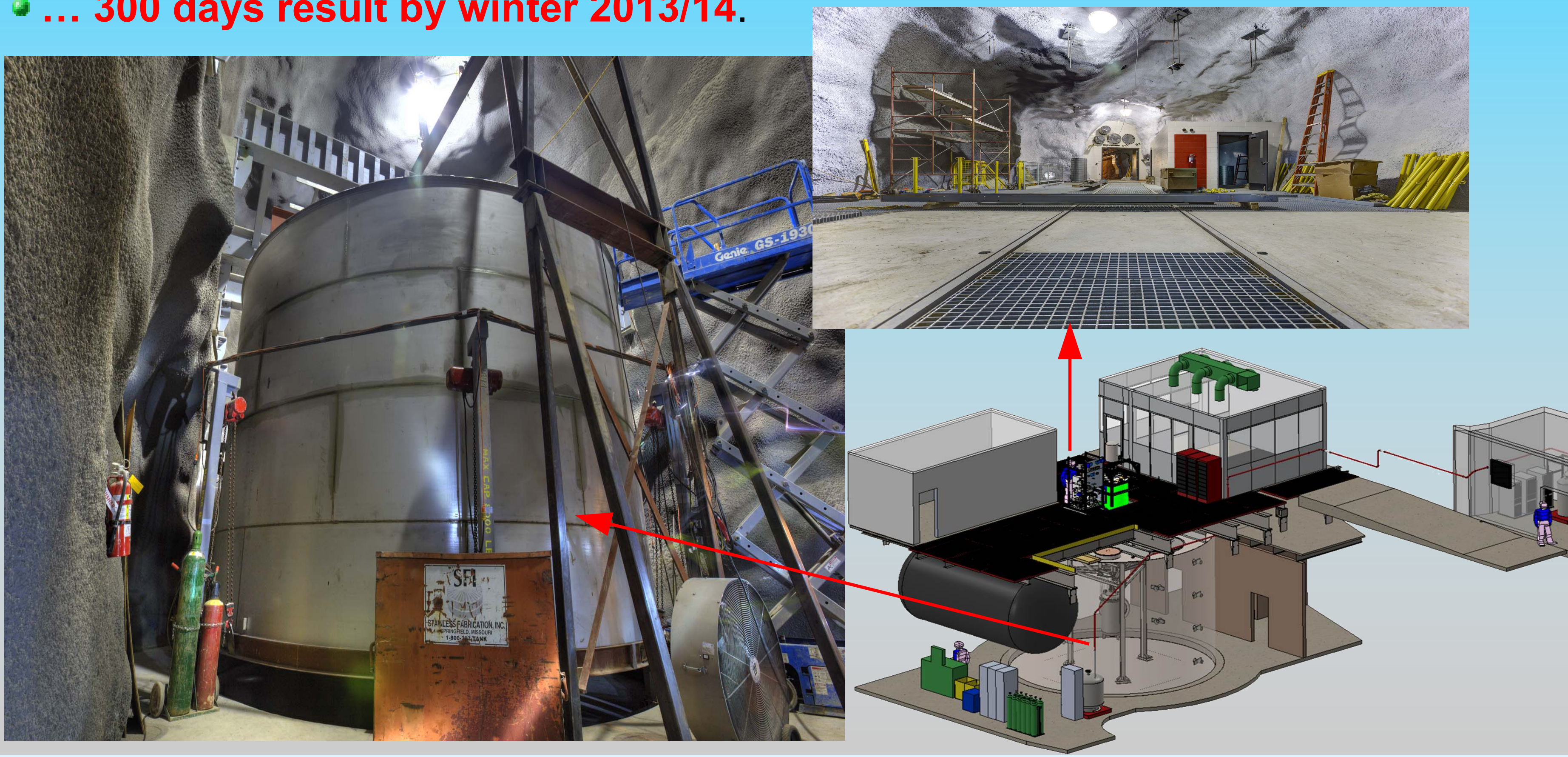






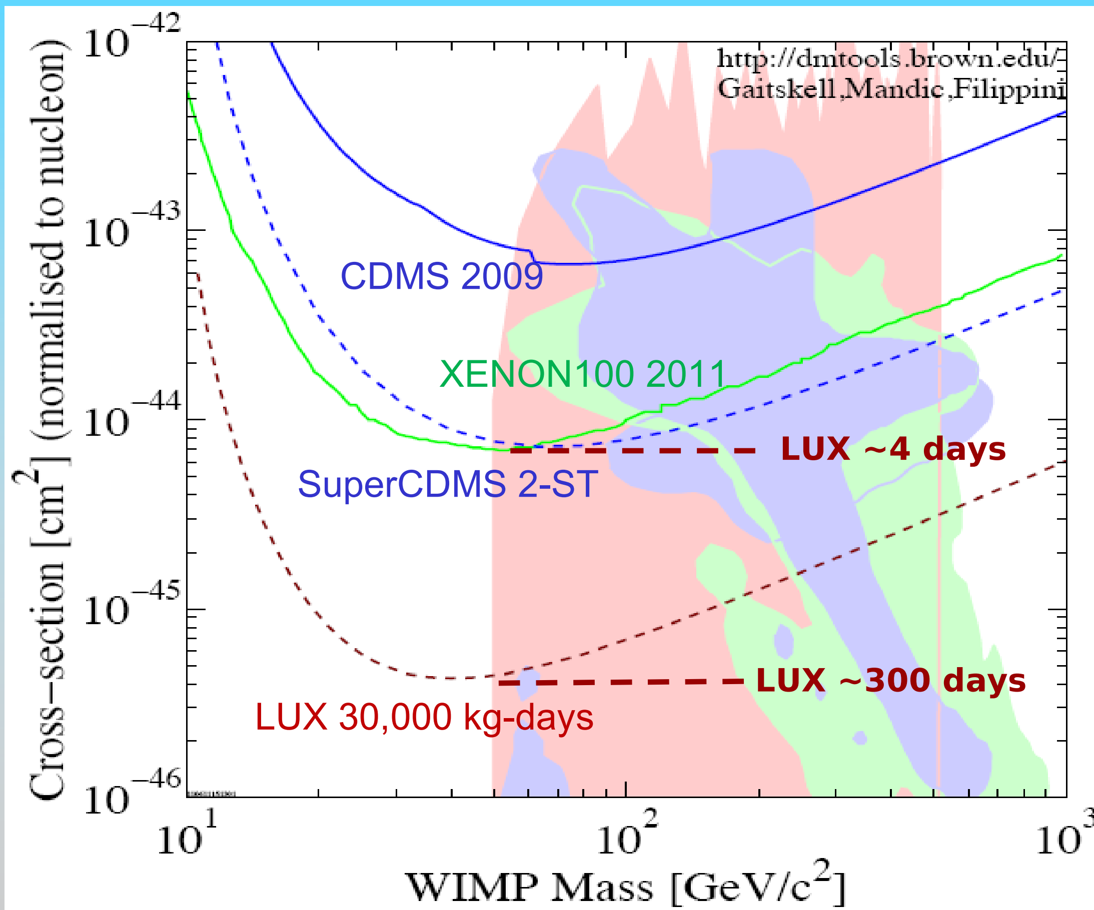
Underground detector deployment

- Underground installation <u>started at may 21</u> / Finish installation by Sep. 2012;
- Finish commissioning by Nov. 2012 / Start taking DM search data by winter 2012/13;
- **… 300 days result by winter 2013/14**.

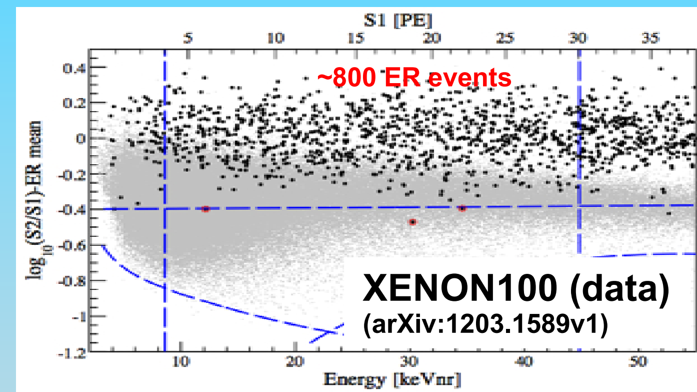


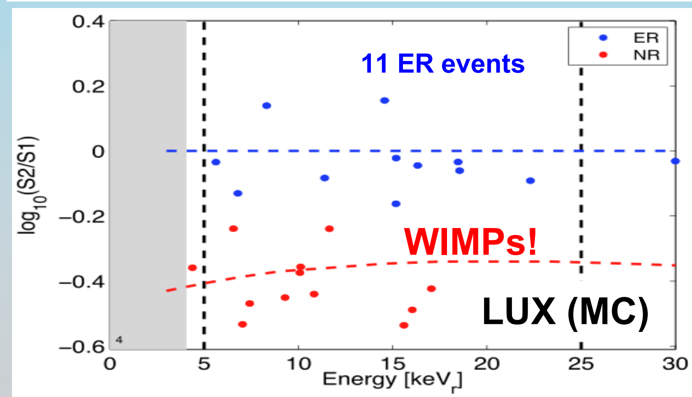
(Expected) WIMP sensitivity

<1 NR event / 300 days in 100 kg fiducial volume!



Exposures for $4x10^3$ kg.day

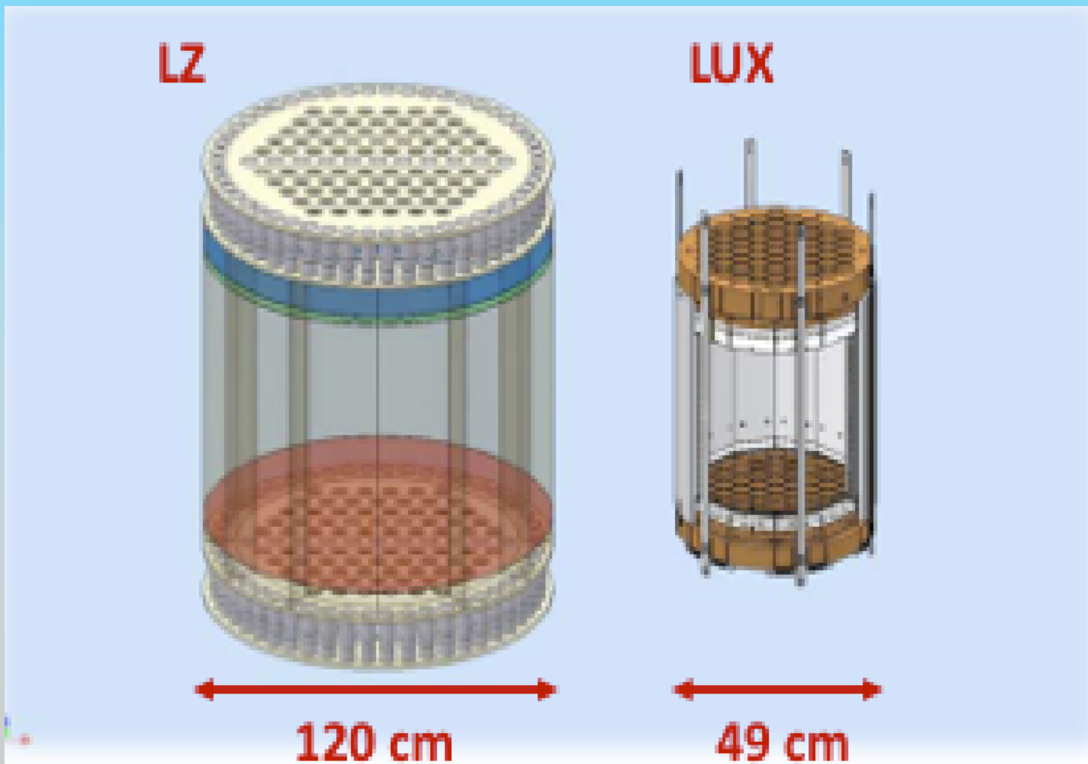


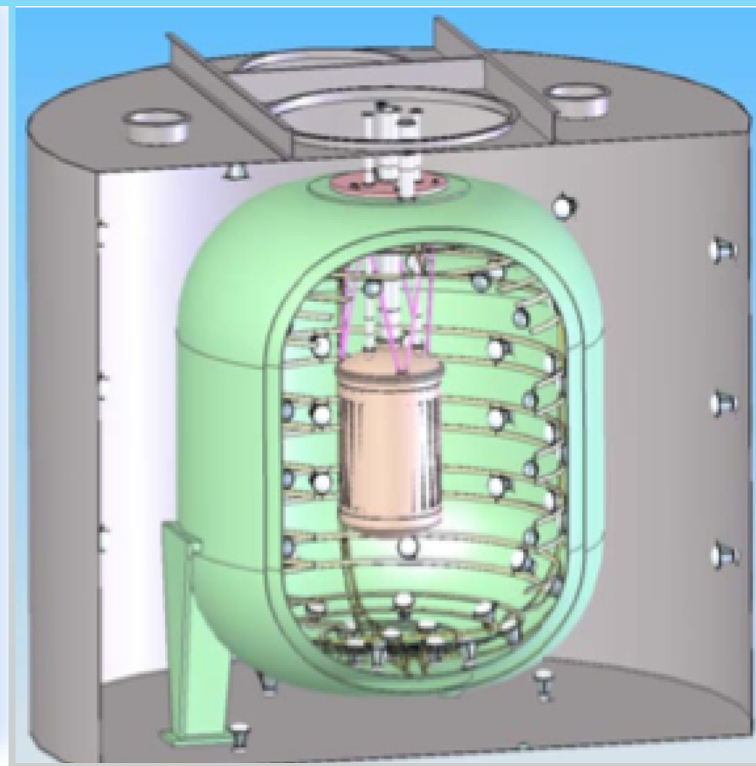


MC by D. Malling, Brown University
($M\chi$ = 100 GeV ; σ_{SI} = $1x10^{-44}$ cm^2)

Beyond LUX: LZ

- 7-tonne active TPC inside an instrumented water tank (Davis Cavern @ Sanford);
- Active shield + instrumented Xenon skin;
- Background-free run feasible (assumed 99.75% discrimination);





Summary

- Deployed into water tank shield;
- Stable cryogenic control for ~100 days of running:
    - Purification @ 35 SLPM (~0.3 ton/day);
- Working PMTs, Trigger and DAQ;
- Energy resolution: ~3% (for E_α = 5.5 MeV);
- Excellence light collection (8 phe/keVee in center @ 0-field, for E_γ=662 keV);
- Important validation of the GEANT4 simulation parameters (R_{PTFE}, λ_{abs});
- Electron life time: ~90 μs (limited by circulation failure, already solved!);
- Position reconstruction: first assessment very promising;
- Drift field limited to 120 V/cm (by electroluminescence from the cathode grid);

(cathode grid being upgraded to mitigate the electroluminescence)

The LUX Collaboration

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Kati Pech	Graduate Student

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collaboration meeting in Lead, SD in March 2011.

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Alexey Lyashenko	Postdoc
Ethan Bernard	Postdoc
Blair Edwards	Postdoc
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