Photodetectors for the XENON1T Dark Matter Experiment

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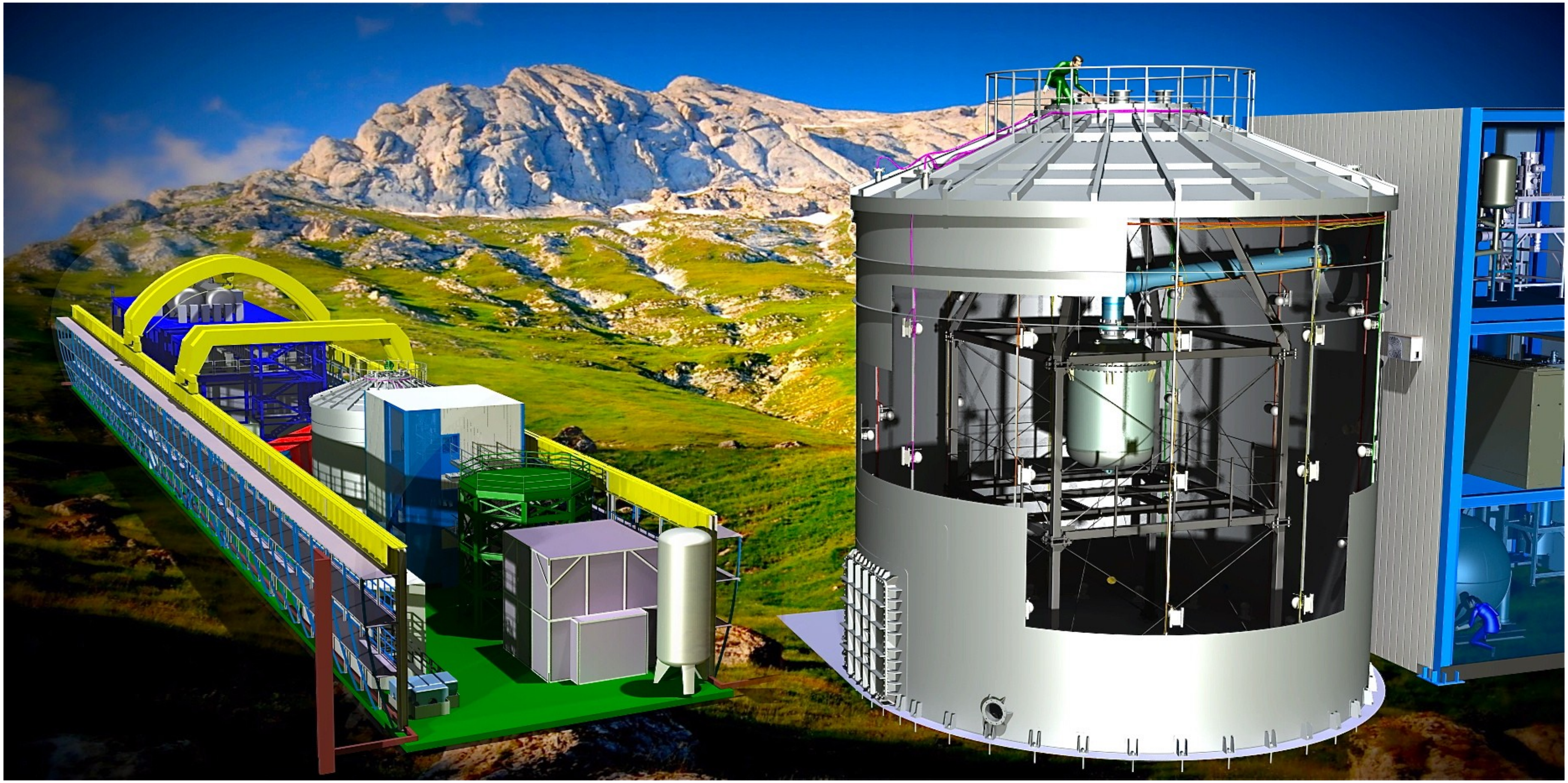
July 1st 2014, Fribourg
SPS Annual Meeting

Universität Zürich[UZH]

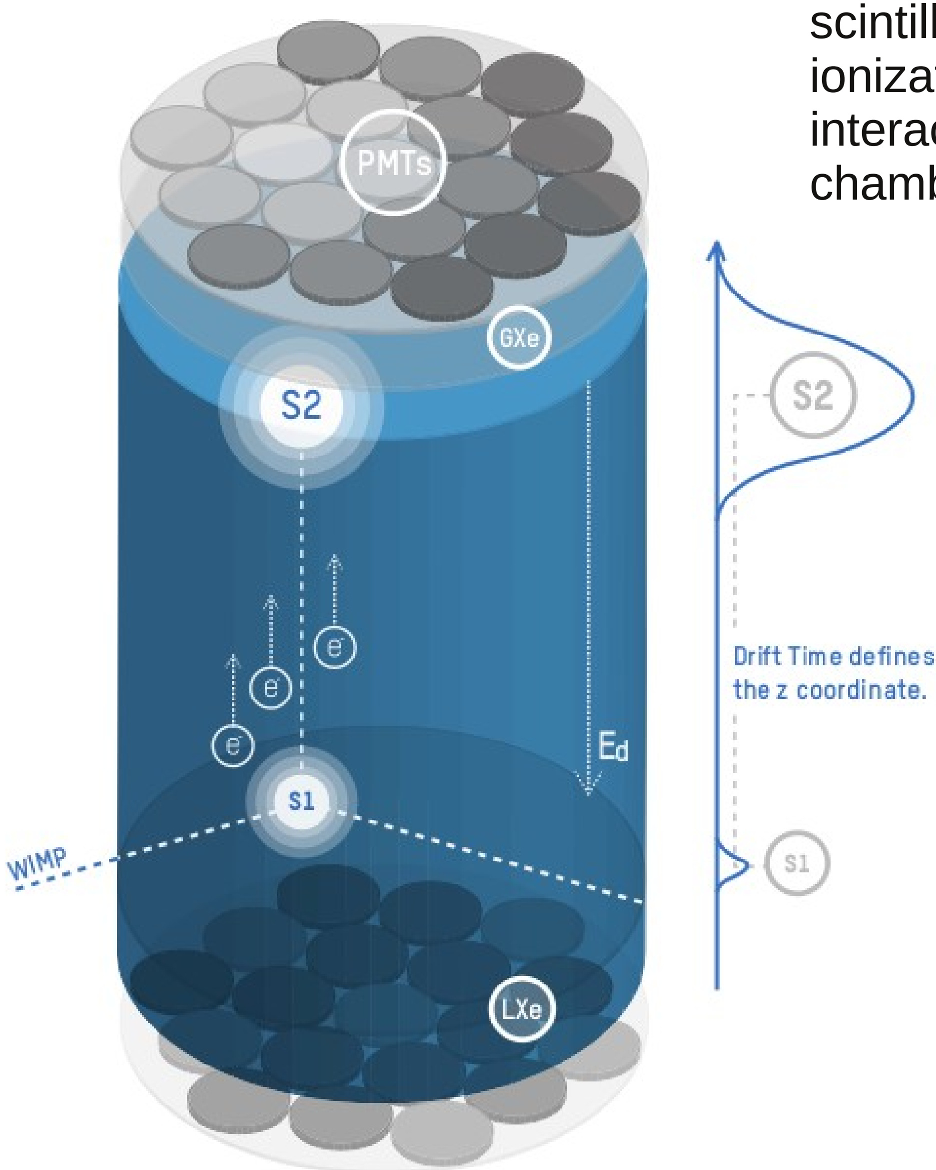
The XENON1T experiment

The XENON1T dark matter detector is currently under construction under the mountains of Gran Sasso at LNGS in Italy.



The XENON1T experiment

XENON1T is designed to search for dark matter WIMPs by measuring simultaneously the primary scintillation (**S1**) and proportional scintillation from ionization electrons (**S2**) produced by a WIMP interaction within a two phase time projection chamber (**TPC**) filled with liquid xenon (**LXe**).



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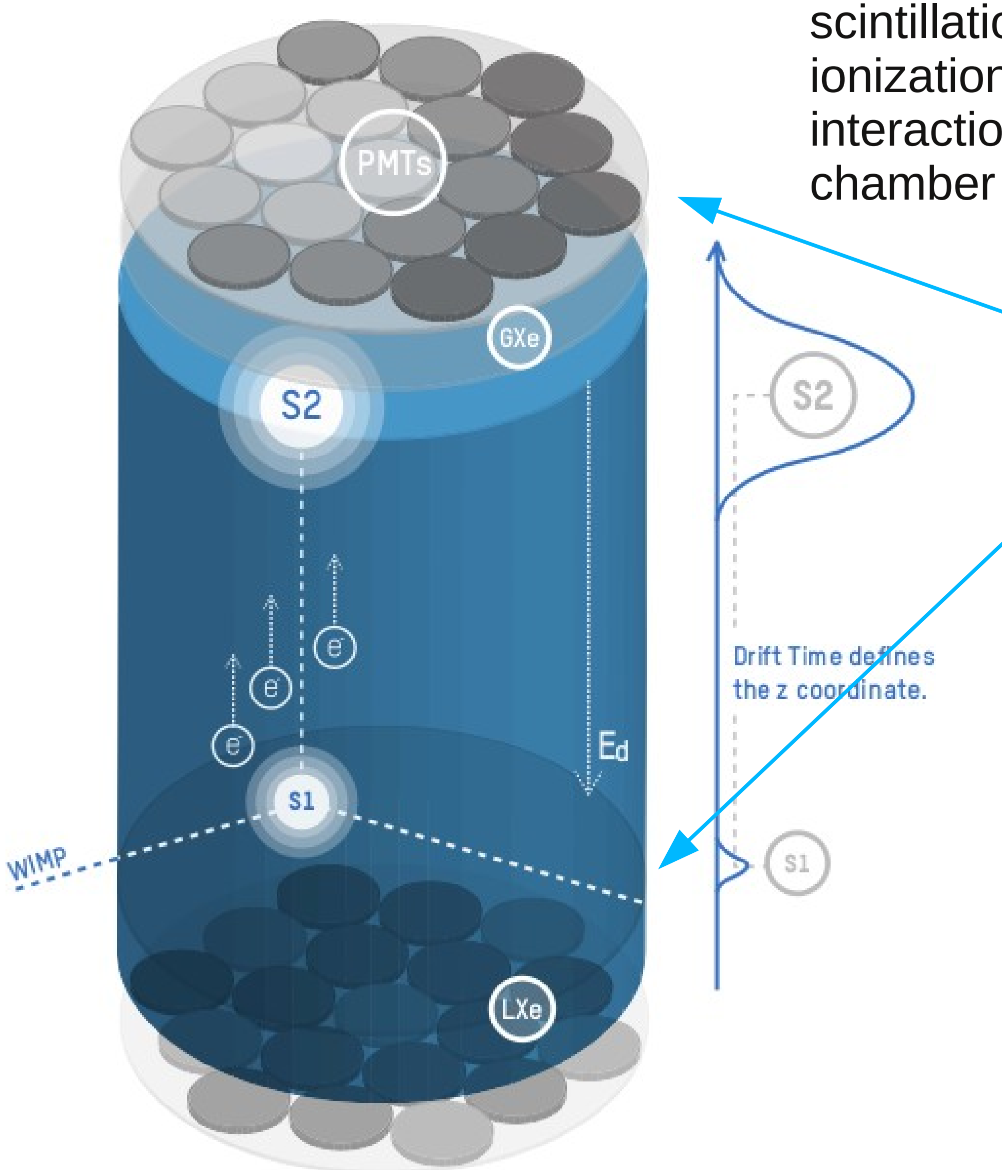

- The **top PMTs** in GXe detect S2 and give *xy* position with mm precision.
- The **bottom PMTs** are fully immersed in LXe to efficiently detect the S1 signal.

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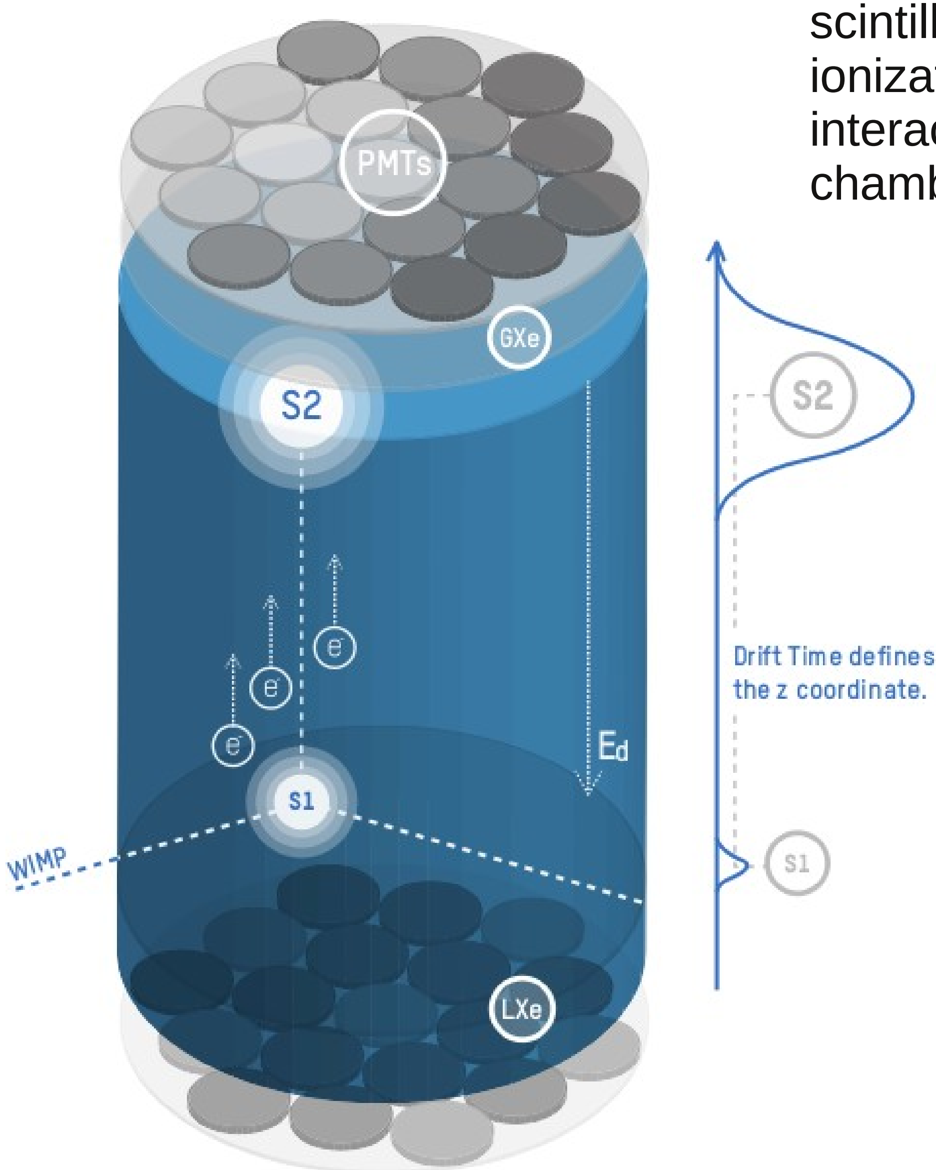

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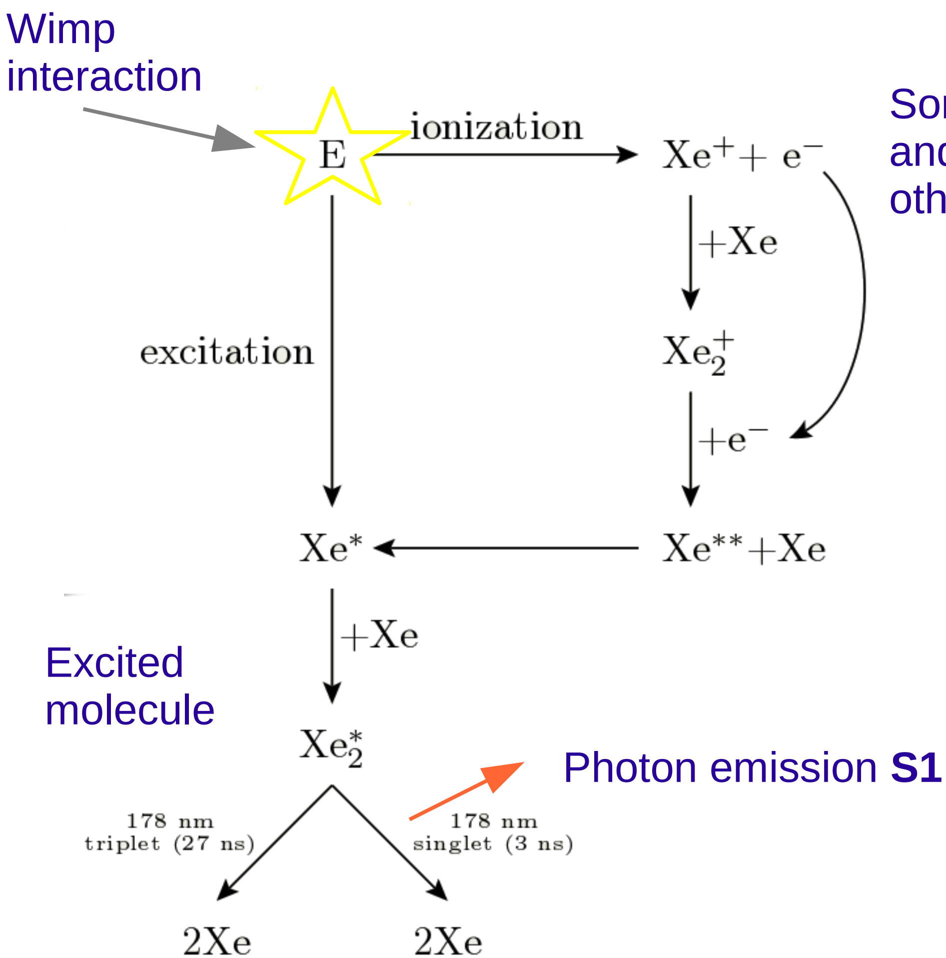
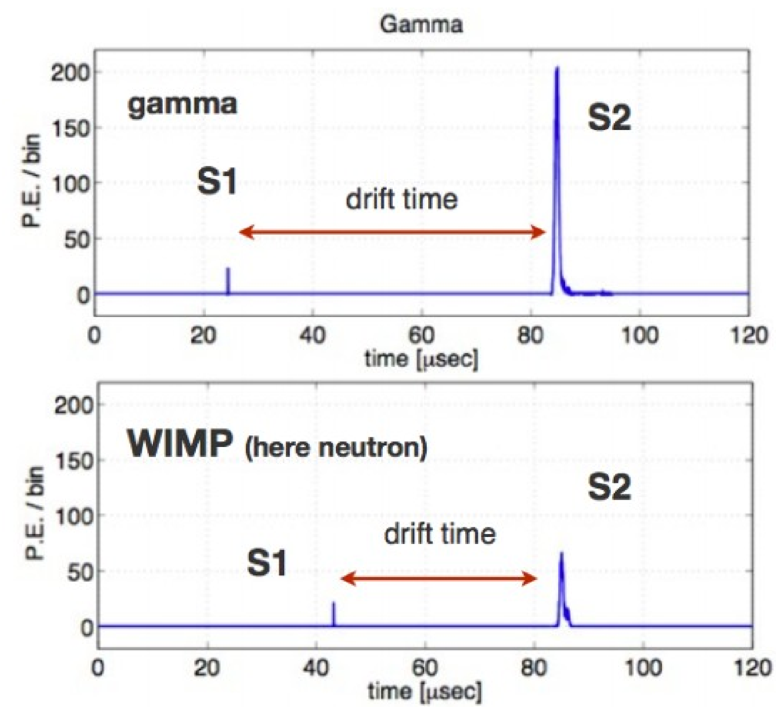
Why Xe?

✔ Large atomic mass, high stopping power.
✔ Self shielding.
✔ No long lived radioisotopes.
✔ Efficient scintillator.
✔ Scalable.

The photon emission principle



Some electrons drift to the anode and produce the **S2** signal, while others **recombine** with Xe ions.



The **S2/S1** ratio allows to distinguish WIMPs (nuclear recoils) from the main backgrounds (electronic recoils).

The Photomultiplier Tubes

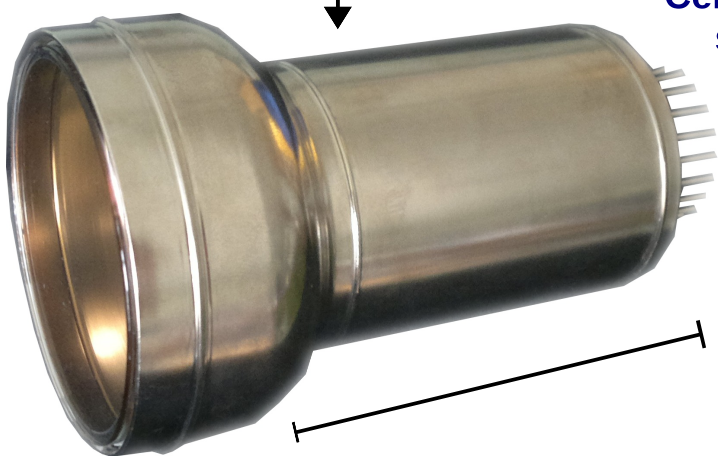
Hamamatsu R11410-21 low radioactivity **3 inch** PMTs.

Operating temperature range:
-110 to 50 deg. C

Metal casing:
Cobalt free, low radioactivity

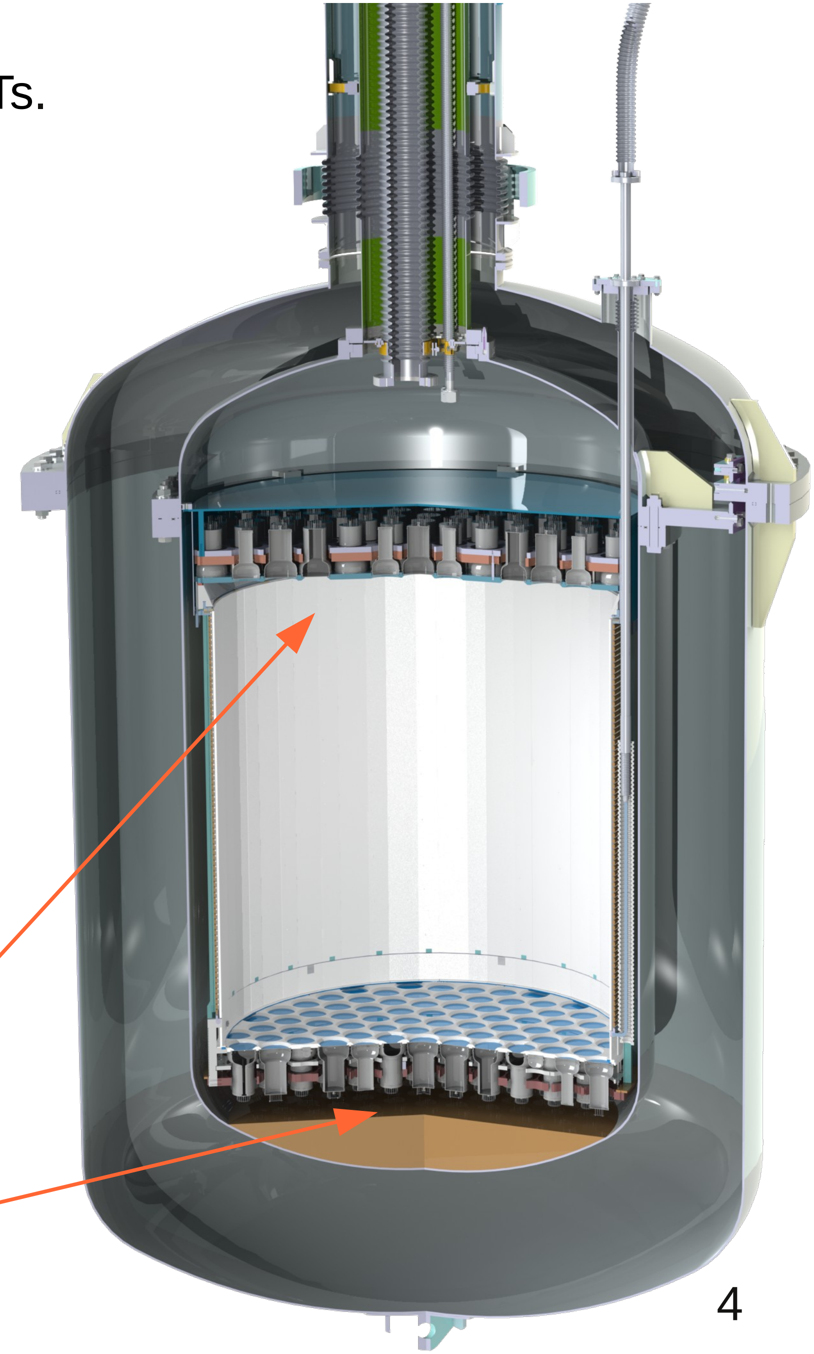
Ceramic stem.

Quartz window:
Transparent to VUV photons



Bialkali photocathode:
Sensitive to 178 nm wavelength.
Typical QE of 32.5%

12 dynode stages:
Average gain 3.5×10^6

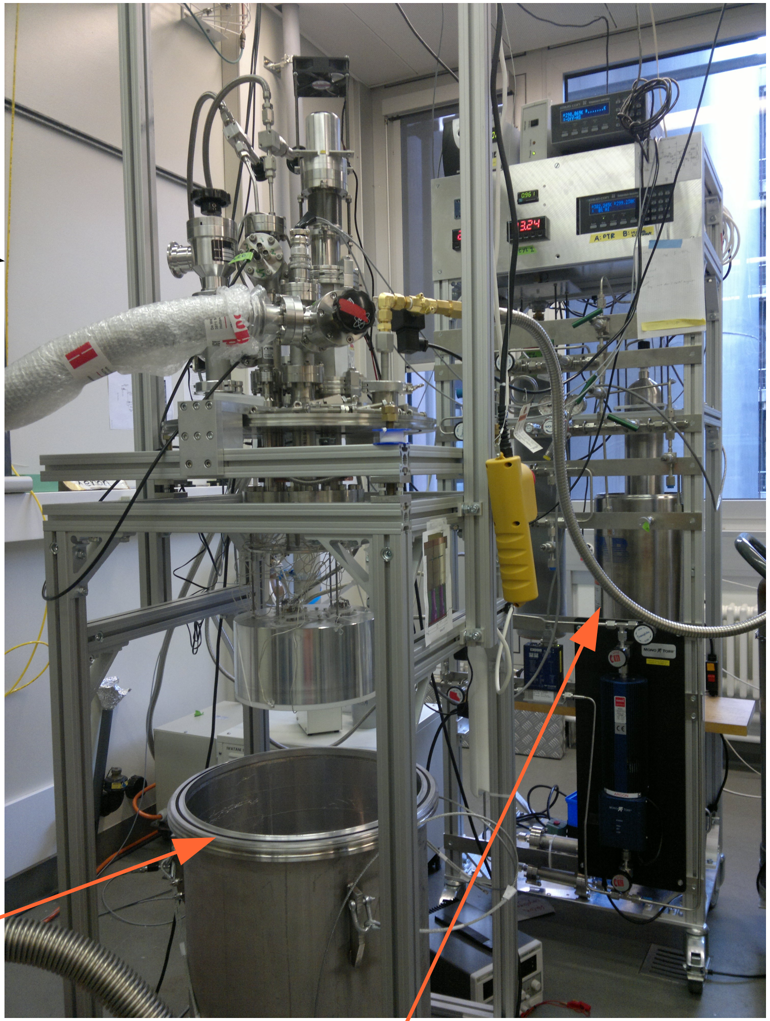


Top array: 127 PMTs.

Bottom array: 121 PMTs.

LXe chamber at UZH

The performance of the R11410 **PMTs in LXe** is tested at UZH with a dedicated experimental setup.



Double walled vacuum insulated cryostat to maintain the subzero temperatures.

Gas system to circulate the Xe from its storage bottles into the detector chamber.

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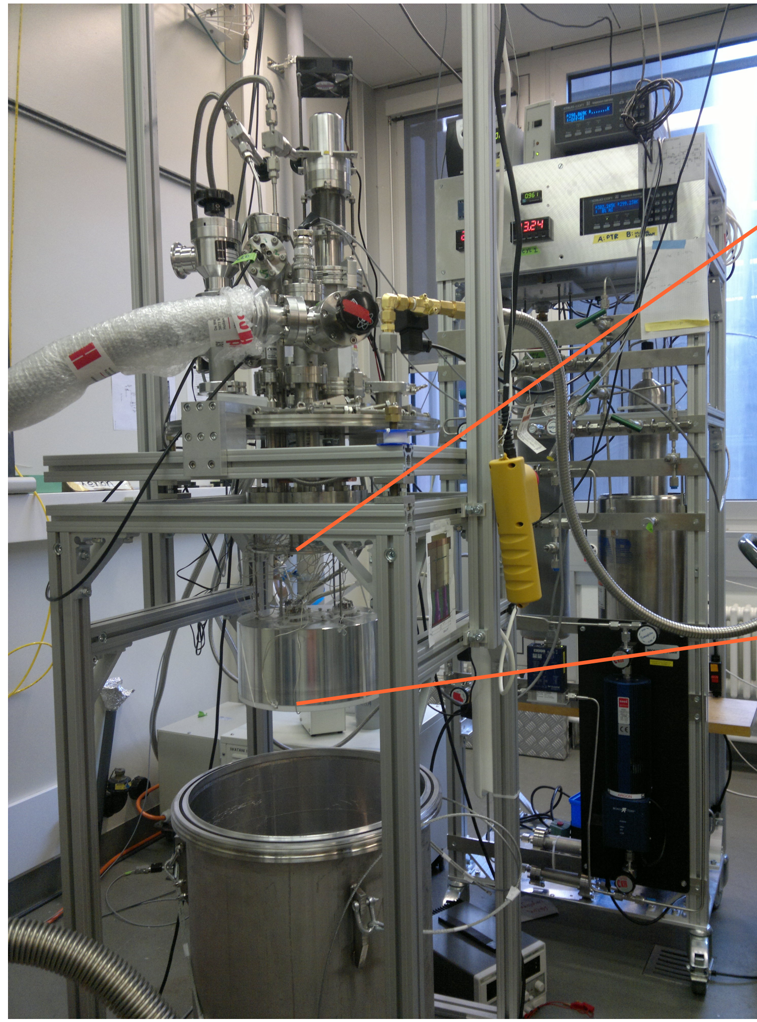

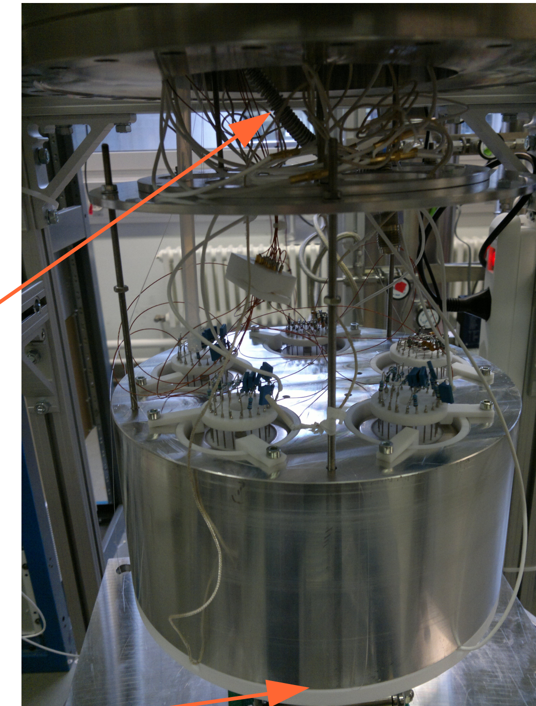

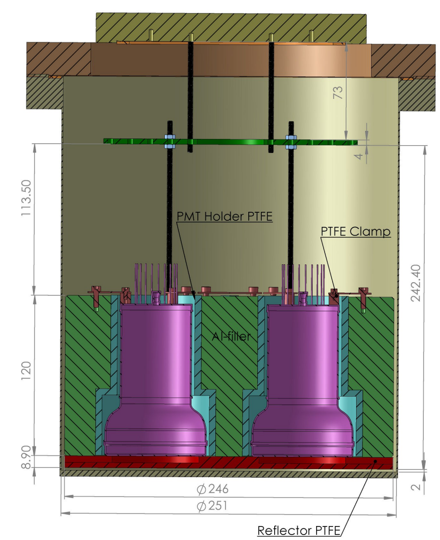

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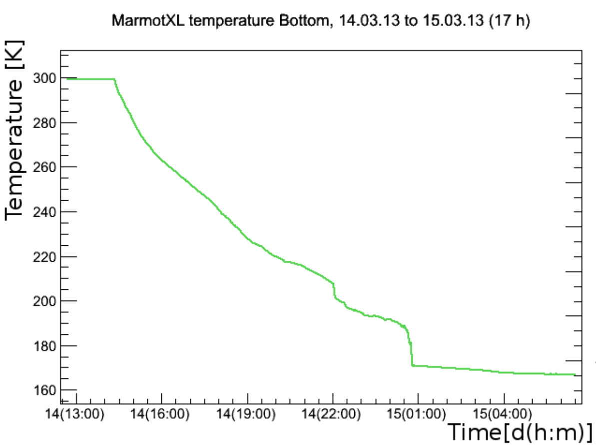
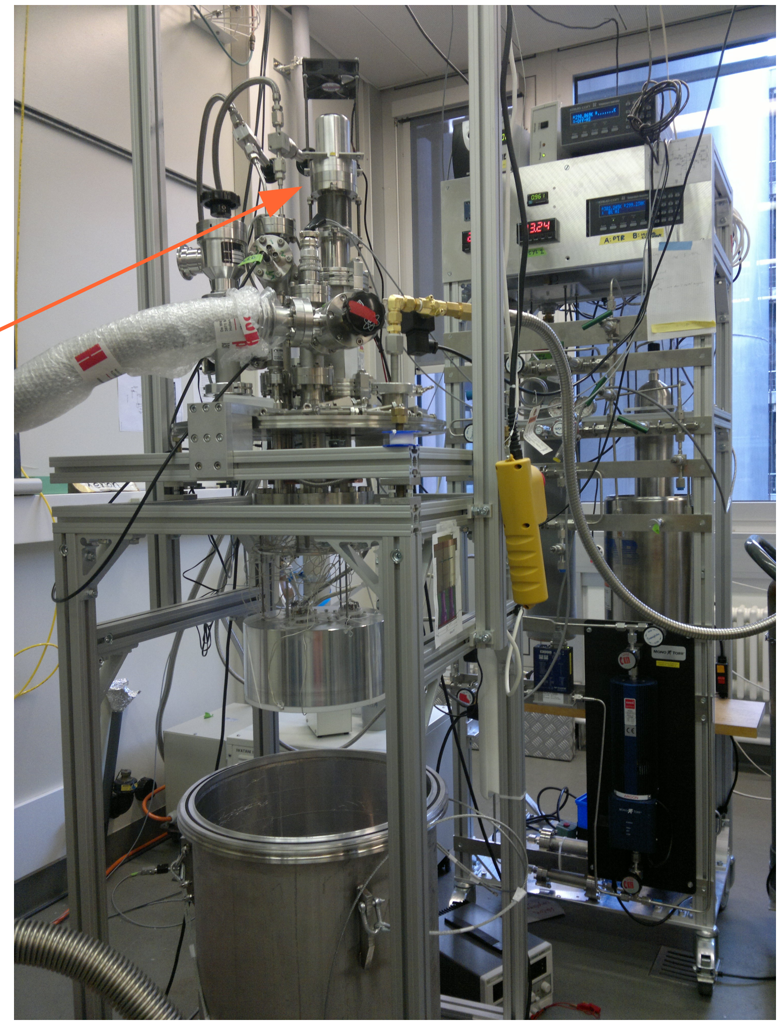
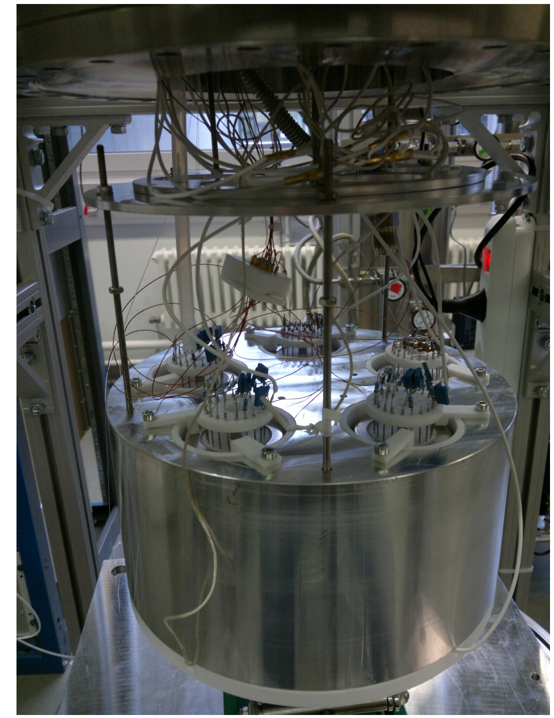
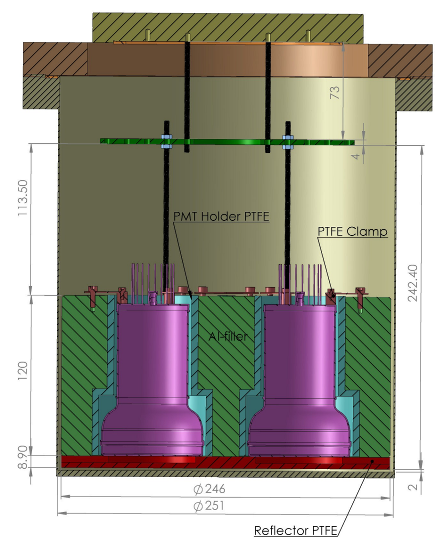
Xe liquefaction to ~170 K is achieved with a Pulse Tube Refrigerator









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Testing the performance of PMTs in LXe

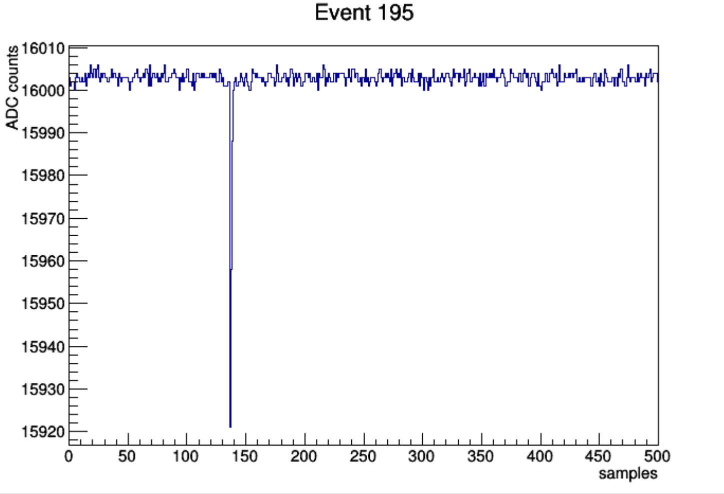
All XENON1T PMTs are characterized at room and cryogenic temperatures at **MPIK Heidelberg**.
They are also screened for radioactivity with UZH's Ge detector **Gator** at LNGS.

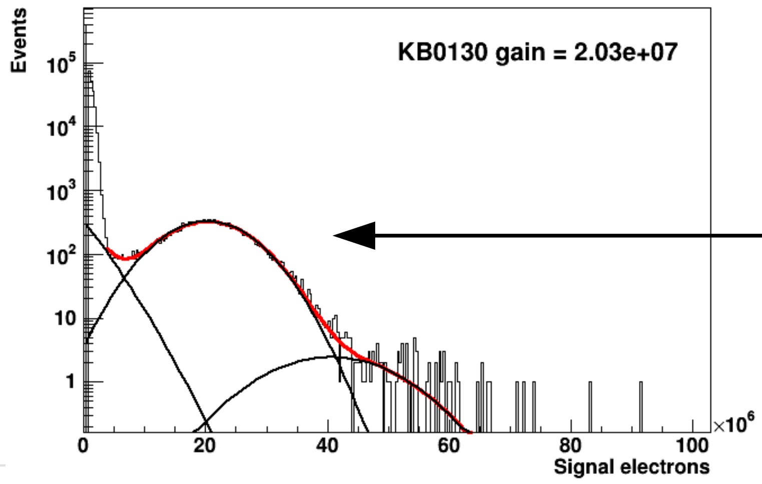
The performance of the PMTs in LXe is evaluated at UZH with different tests.

- **Gain vs HV:** Determine gain at different HV and understand how the values change in LXe.
- **Gain evolution:** Understand how the gain changes over time.
- **Thermal cycling:** How the PMTs behave during consecutive cool downs in LXe.
- **Dark Count Rate evolution:** Study the change of the DC rate over time and in LXe.
- **Afterpulse analysis:** Study the afterpulse rate and spectrum to determine the quality of the PMT vacuum.

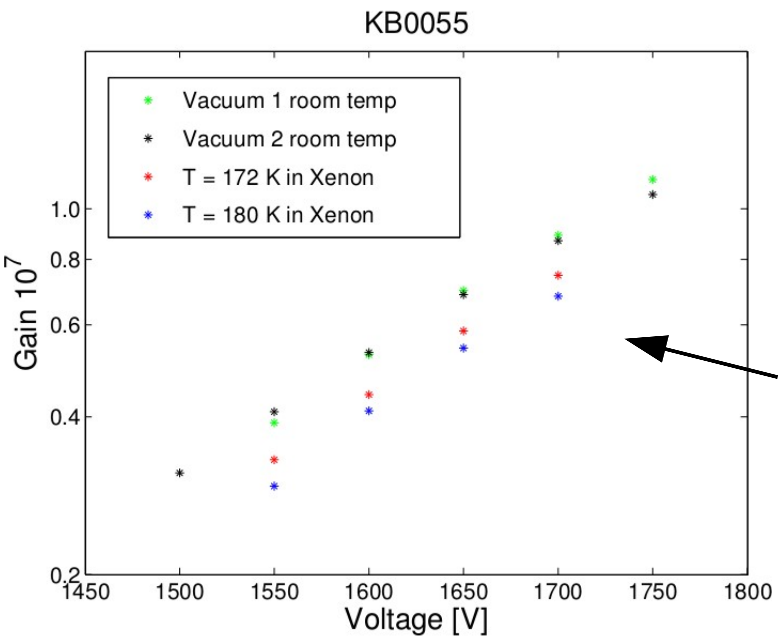
PMT Spectrum and Gain

Example event:
Photon signal from LED.



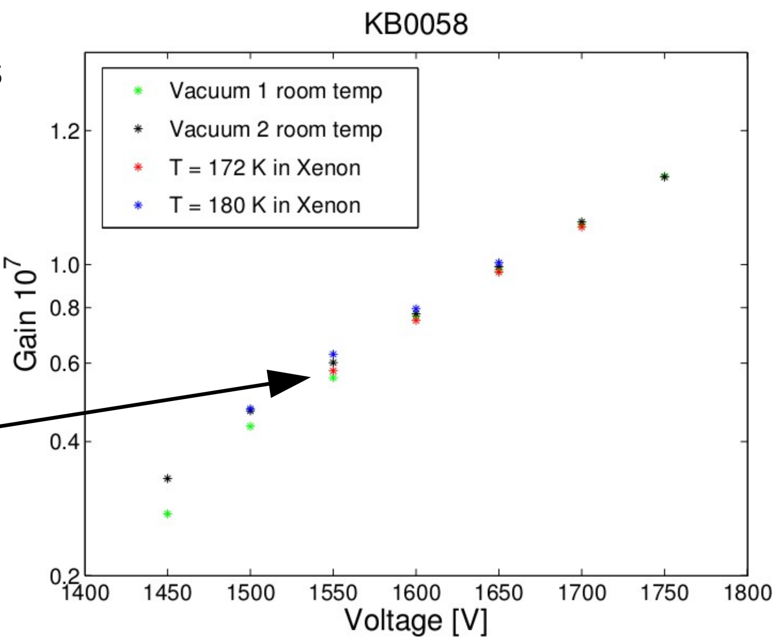


The PMT gain is estimated from the spectrum by identifying the single photo-electron peak, separated from the **noise** and double photo-electrons.



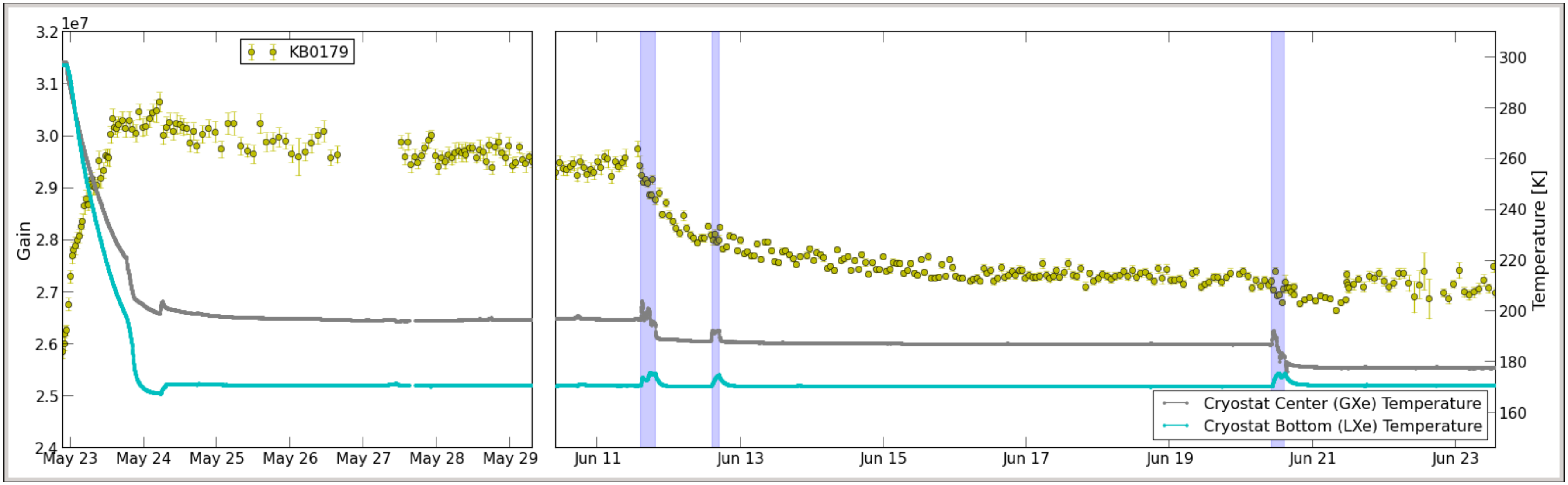
The gain of each PMT is measured at different voltages.

When operated in LXe, some PMTs show a decrease of around 10%, while in others the change is very small.



Gain Evolution

15%

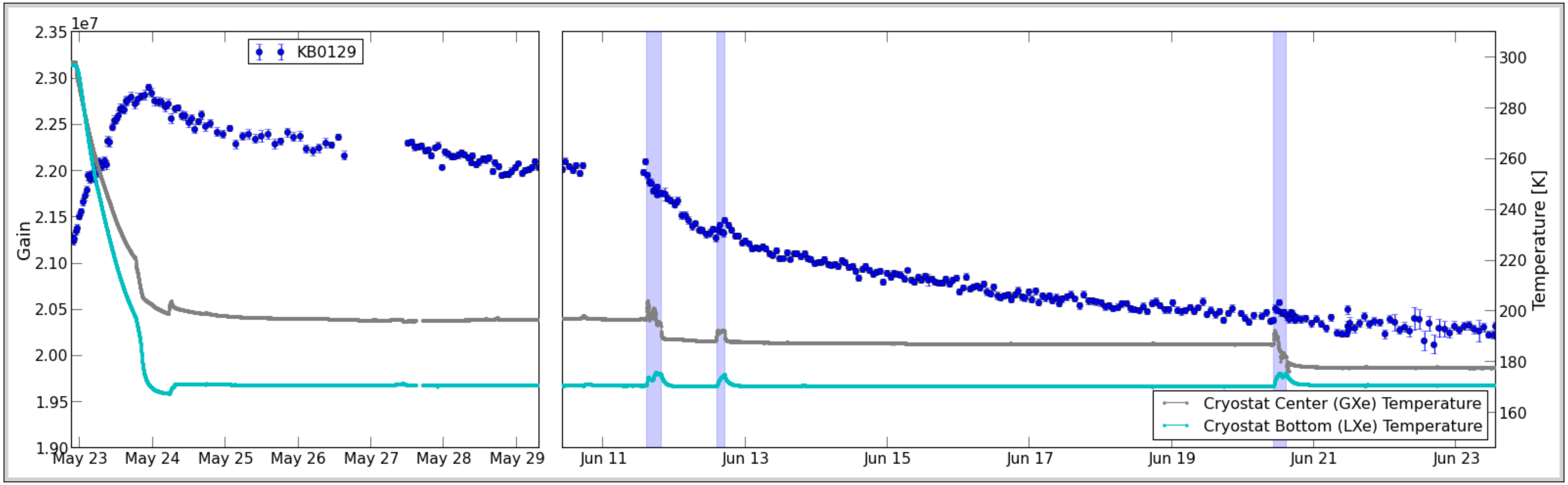


-10%

GXe only

PMTs covered in LXe

+5%



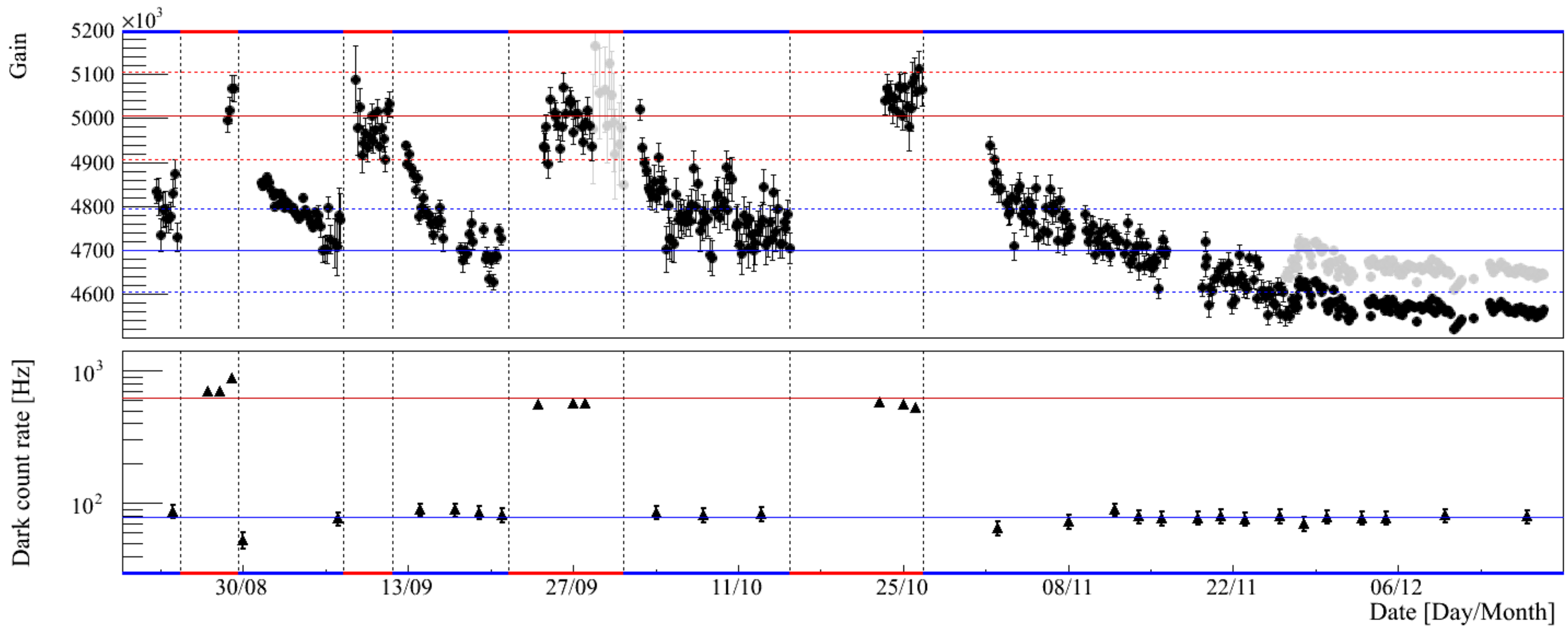
-10%

These values include a x10 amplification factor from an external amplifier.

Long term stability tests

Thermal cycling: In order to test the stability of the PMTs in LXe, the tubes are submitted to a series of cool downs (170 K) and warm ups (room temp.) where the gain and dark count rate are monitored constantly.

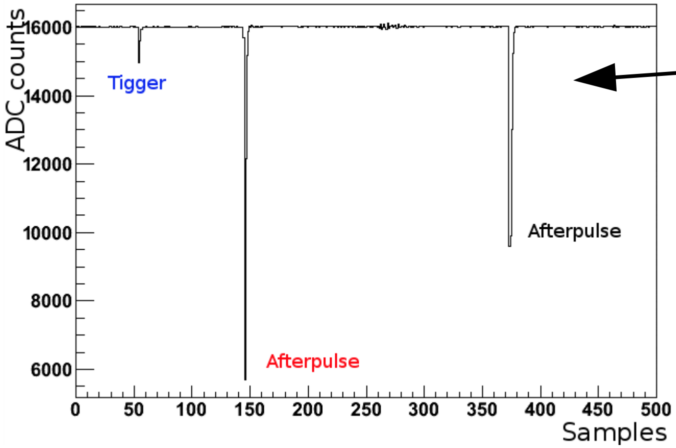
Dark Current:
Thermal emission from the photocathode produces signals in the PMT.



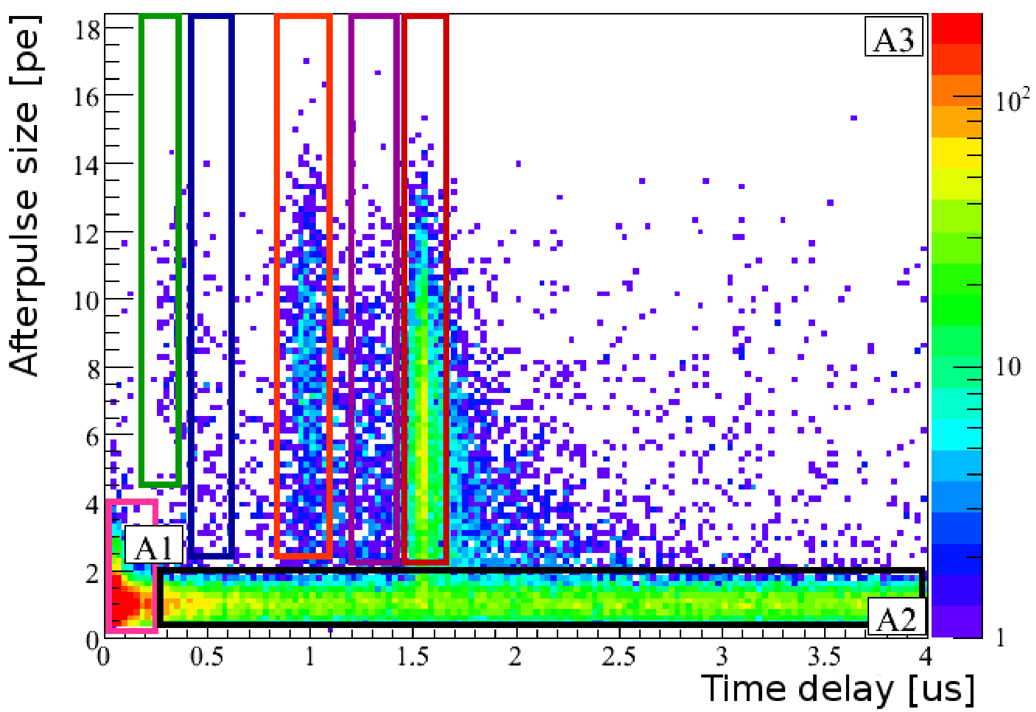
- At room temperature the gain remains constant within 2%.
- When at LXe temperature, the gain decreased around 5%.
- The DC rate decreased by a factor 10.

L. Baudis et al. JINST 8 P04026 (2013)

Study of Afterpulses



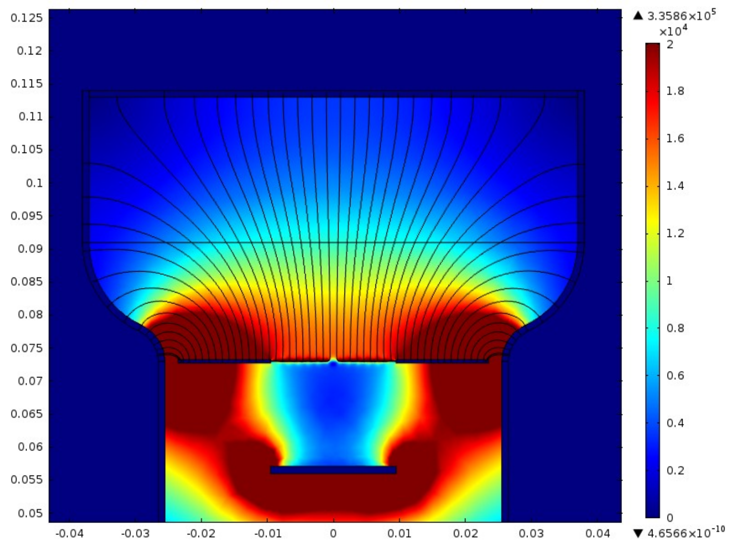
Afterpulses are signals that appear after the trigger signal.



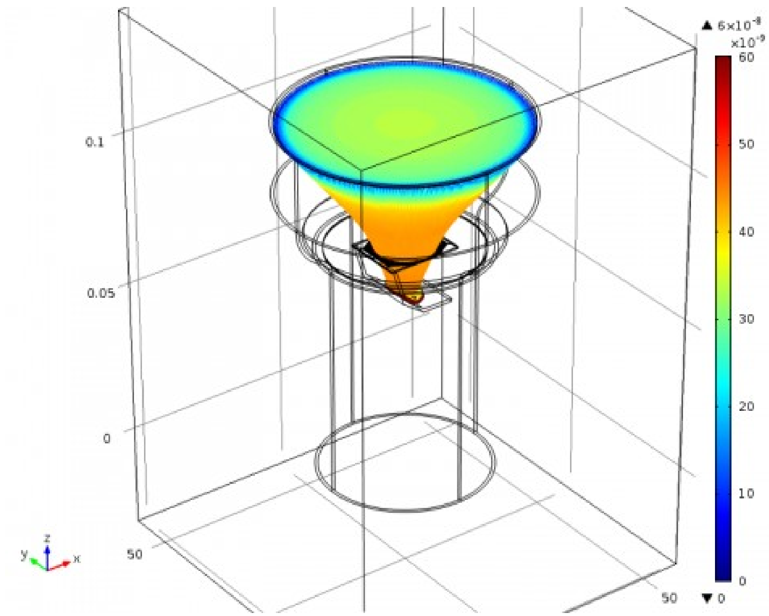
Three groups of afterpulses are observed:

- **A1:** Pulses of short delay (tens of ns), caused by elastic scattering electrons on the first dynode.
- **A2:** Populated mostly by dark pulses and single photoelectrons.
- **A3:** Pulses produced by positive ions from gas molecules within the PMT.
  These afterpulses can be used as a diagnosis of the vacuum quality and identification of contaminants (CH_4, CO_2, etc.) inside the tube.

PMT field simulations

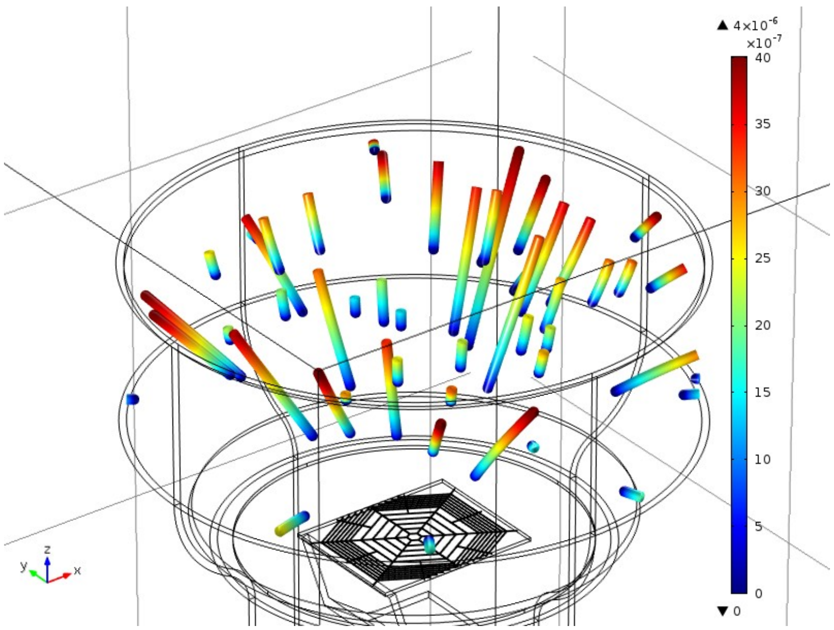


Since the field inside the PMT is very complex because of the geometry it has been simulated with COMSOL.



Drift time

Simulation of electrons from the photocathode to the first dynode.

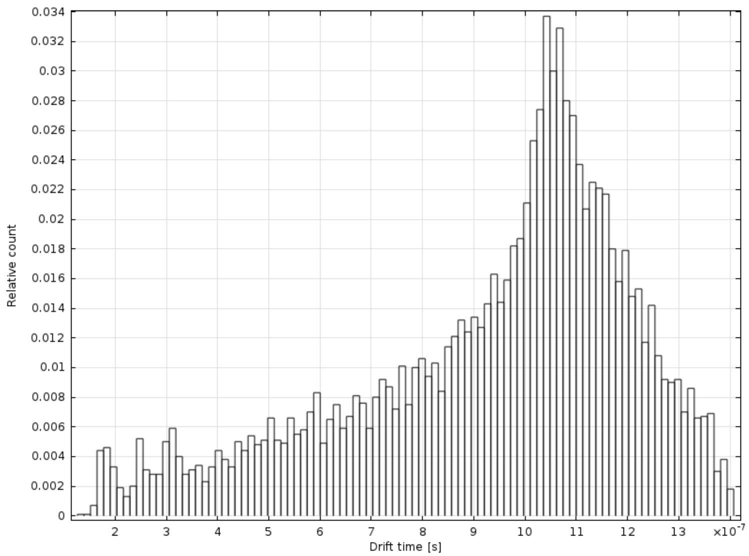


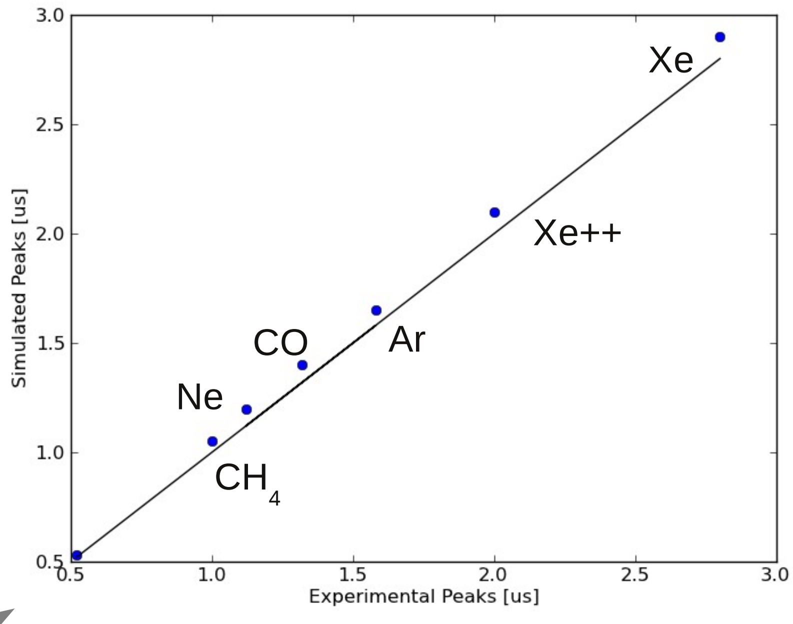
← Simulation of ions produced in the volume of the PMT

Simulations by Peter Barrow.

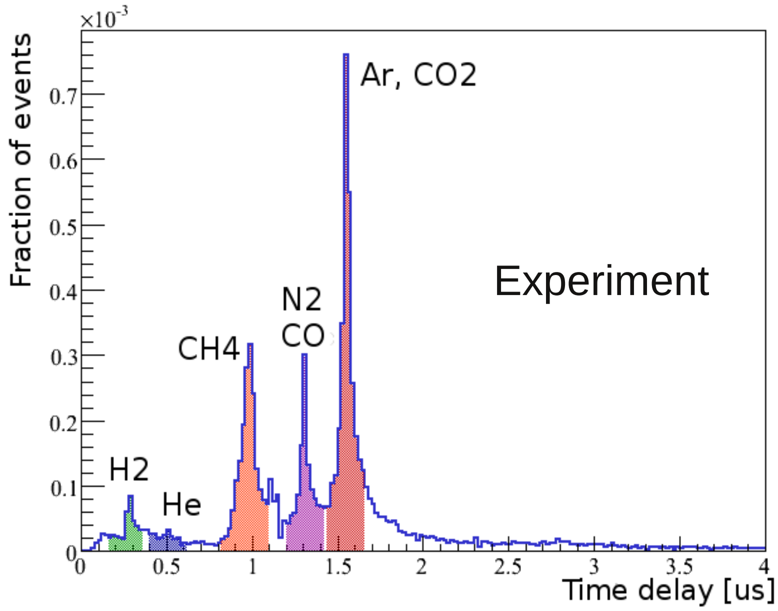
Simulation and experiment

CH_4 drift time from simulation:





The simulated drift times are in agreement with the experimental results within 5%.

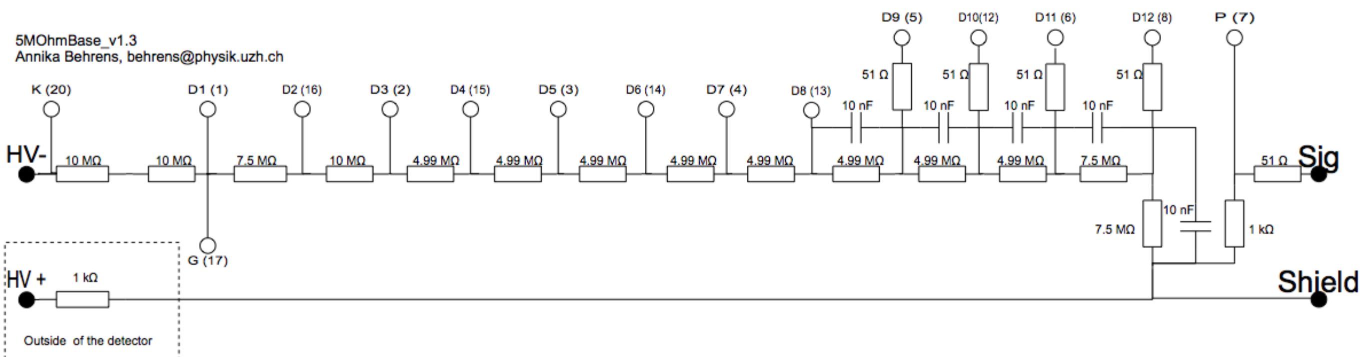


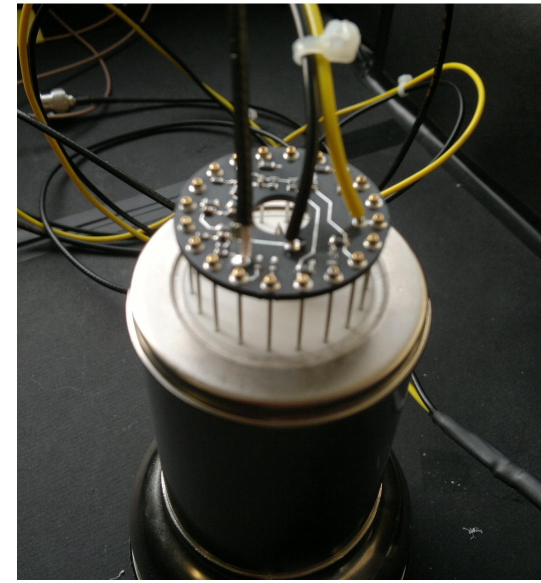
The afterpulse analysis allows to identify the gas remnants within the PMT and helps **identify leaks or impurities**.

HV divider base

Developed at UZH for optimized:

- Linearity. Up to 50k PE, approx. 1 MeV particle. Rates up to 350 Hz (required during calibrations).
- Low heat dissipation (total under 10W).
- Sub-zero temperature performance
- Good P/V ratio and high gain





Screening results: Base contribution

Units: mBq	^{238}U	^{226}Ra	^{228}Ra	^{228}Th	^{235}U	^{40}K	^{60}Co	^{137}Cs
PMT only	< 13	0.50 +- 0.10	0.50 +- 0.10	0.50 +- 0.06	0.37 +- 0.05	13 +- 2	0.71 +- 0.03	< 0.19
PMT + base	< 16	0.95 +- 0.07	0.70 +- 0.10	0.60 +- 0.06	0.43 +- 0.05	13 +- 2	0.72 +- 0.03	< 0.21

Outlook

- The construction of XENON1T has started at LNGS.
- At UZH we'll continue testing a subset of the XENON1T PMTs in LXe before their final installation in XENON1T.
- Data taking will start in 2015 in search for a sensitivity of $2x10^{-47}$ cm^2.