XENON Dark Matter Project

Photomultiplier Tubes for XENON1T

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UZH/ETH Physics PhD seminar
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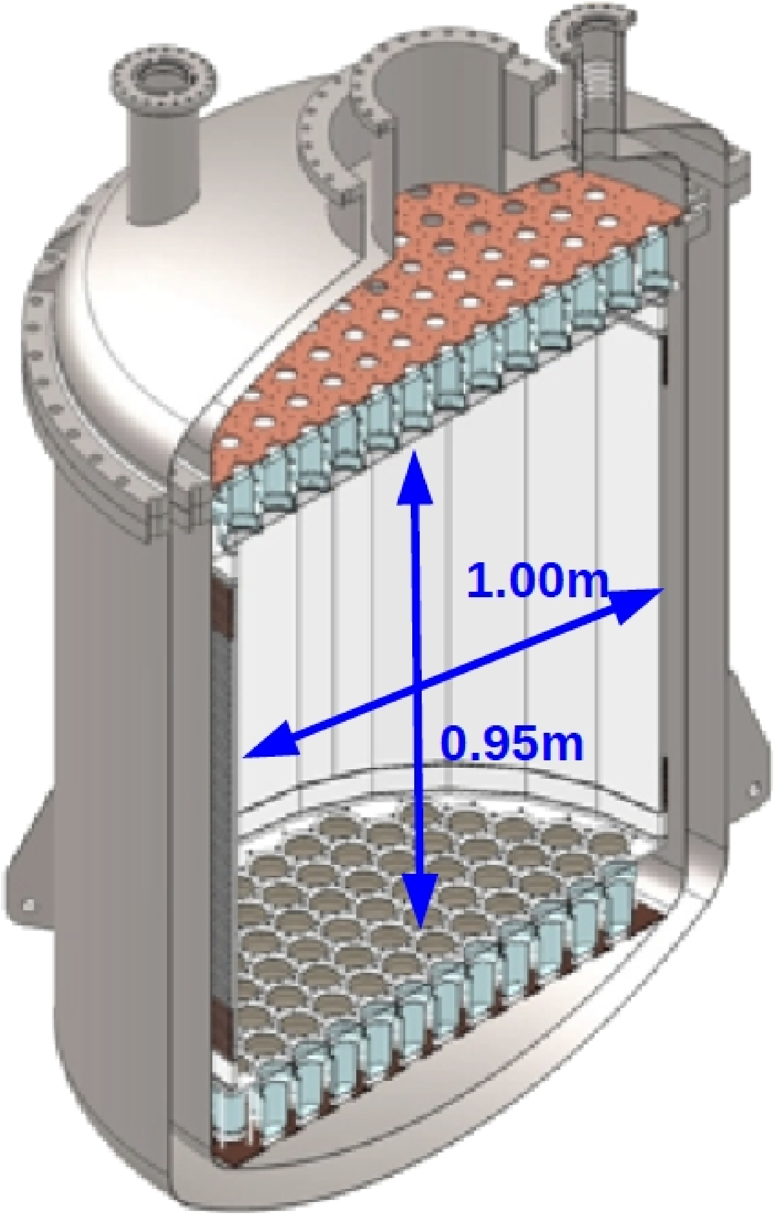
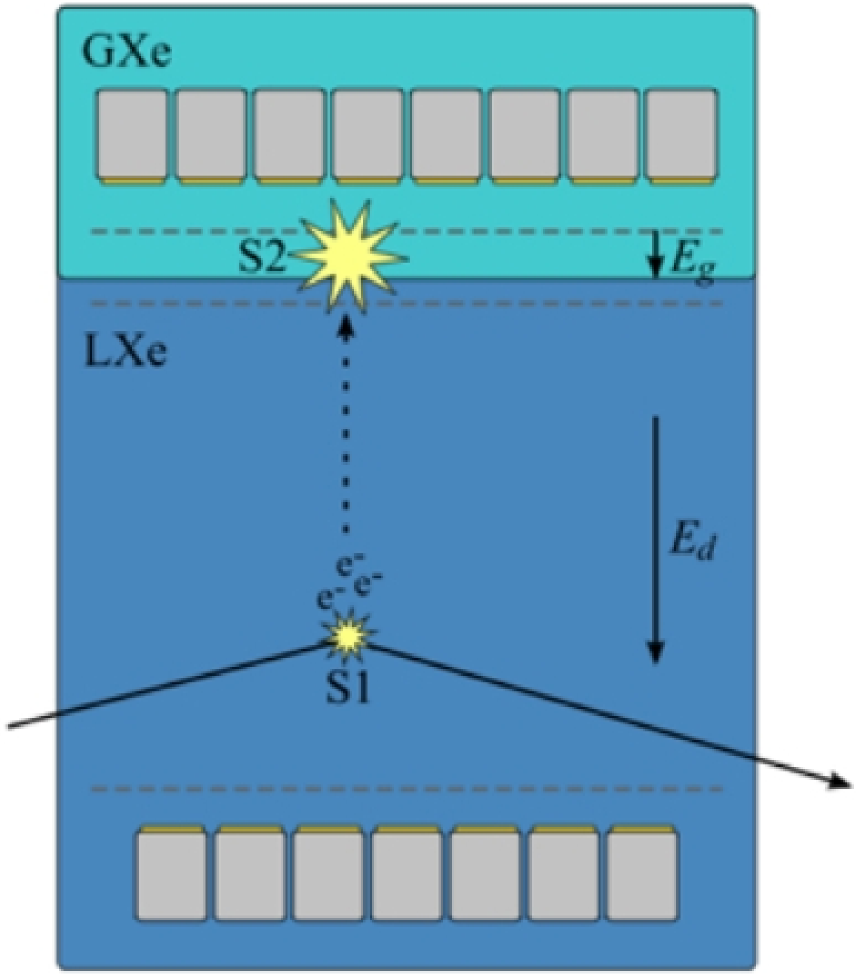
XENON1T



- ~3 t of xenon (1 t fiducial)
- 3" PMTs
- Water Cherenkov muon veto
- The detector will be placed in LNGS hall B
- Construction will start end of this year
- Measurements will start in 2015
- Sensitivity goal: 10^{-47} cm^2 at 50 GeV

It's hard to be a PMT in a TPC...



- PMTs need to work in liquid xenon (and survive the cool-down)...
- … and in presence of electric fields from the TPC grids and the surrounding PMTs
- PMTs need to be stable over long time periods
- S1 signals are small
- But S2 signals can become quite big
- Radioactivity, dark current and heat load need to be low

Hamamatsu R11410

XENON100

R8520

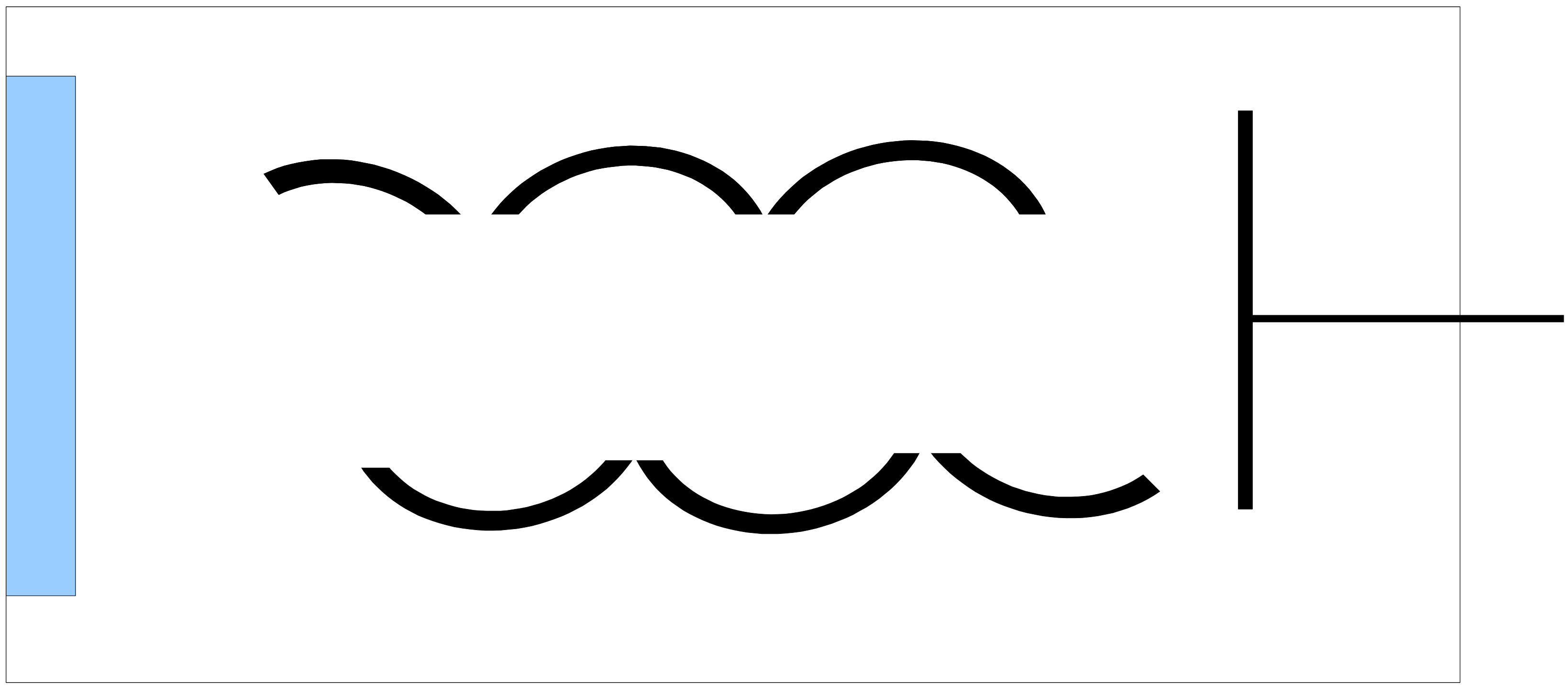
XENON1T

R11410

- 3" diameter
- Sensitive to xenon scintillation light (178 nm)
- Can be used at liquid xenon temperature (until – 110 °C)
- Very low radioactivity
  (< 15 mBq U+Th, < 30 mBq ^{40}K, < 7.5 mBq ^{60}Co)
- High quantum efficiency (> 30 %)

How does a PMT work?

Let's look inside!



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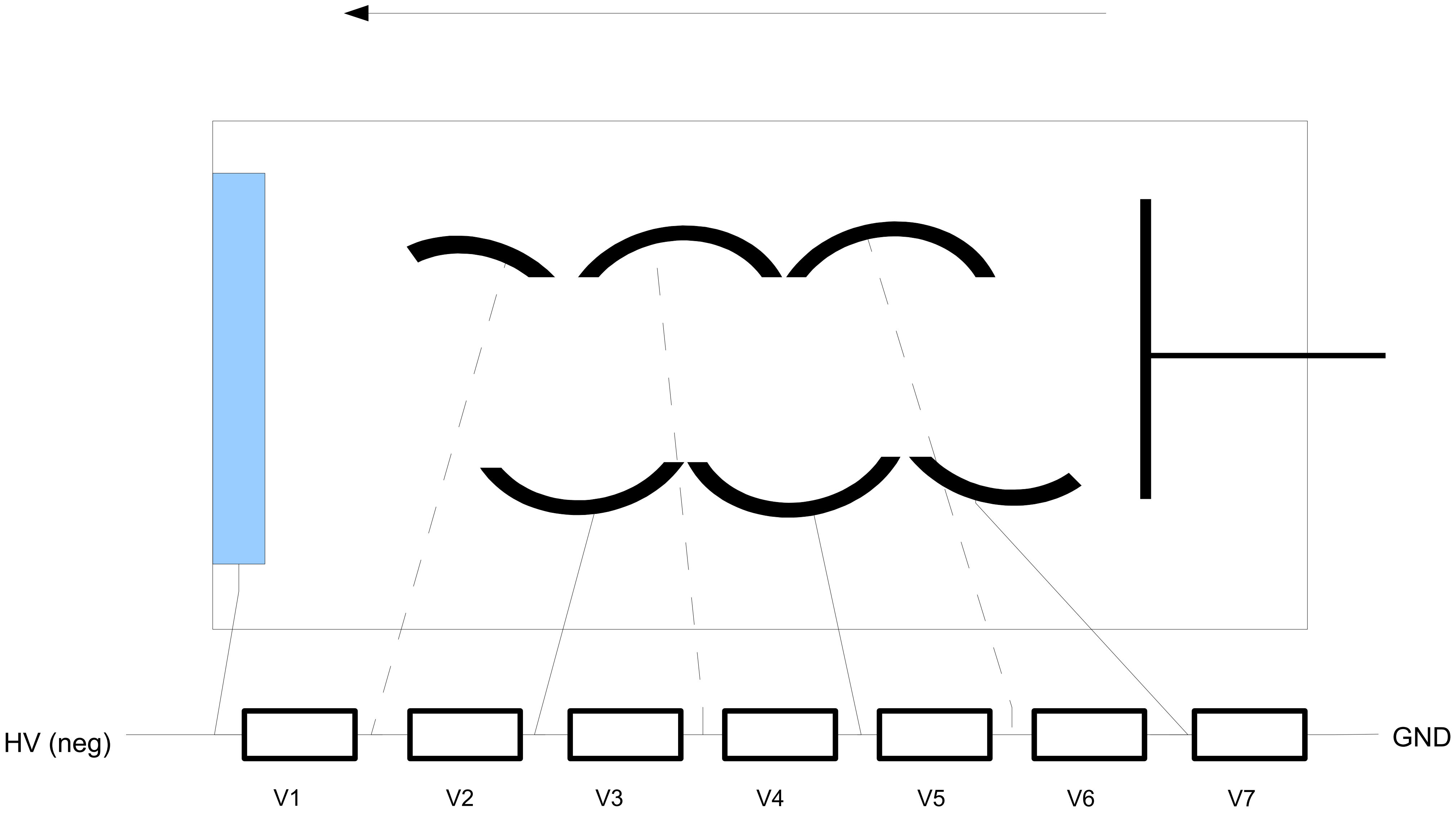
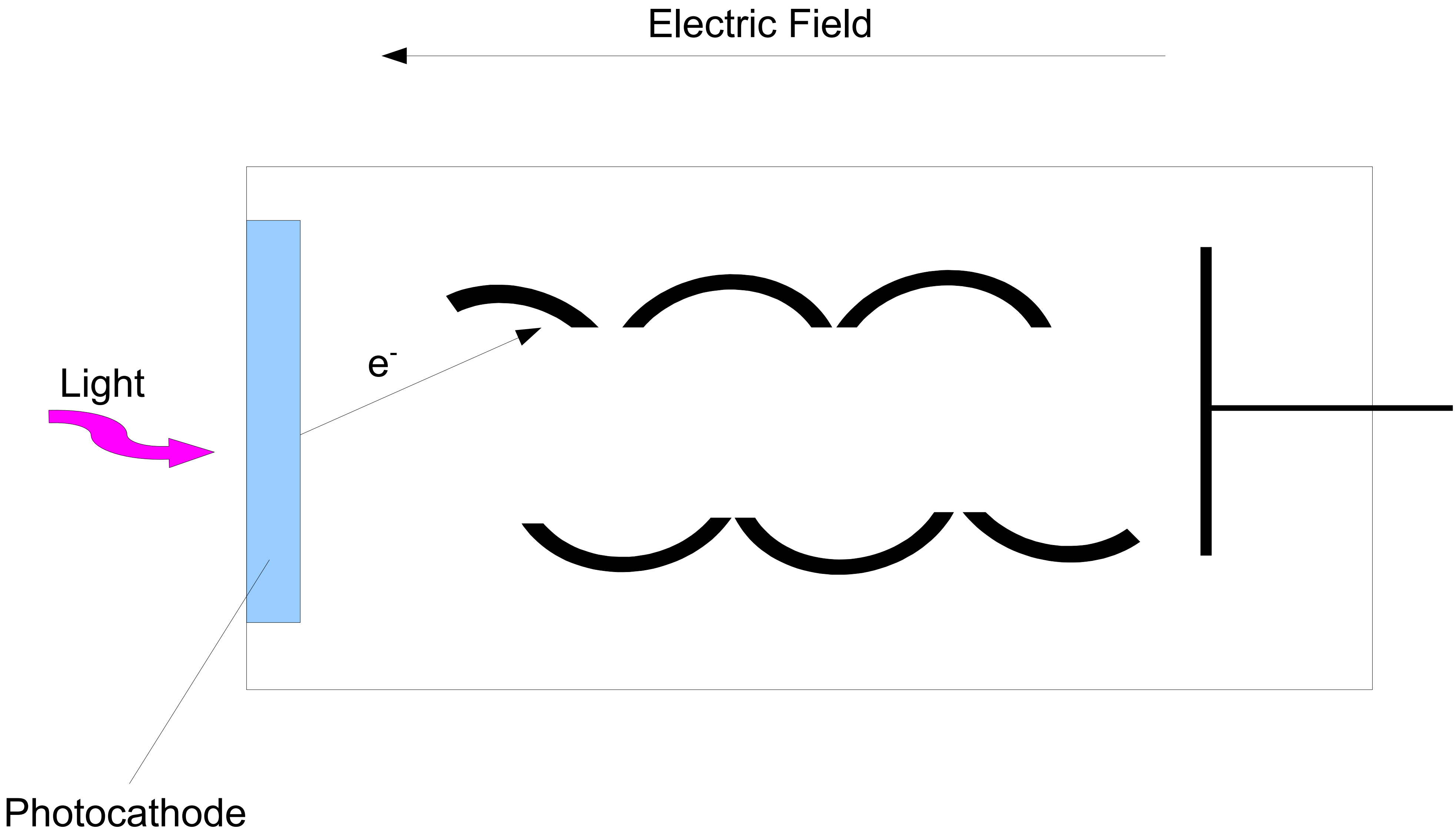
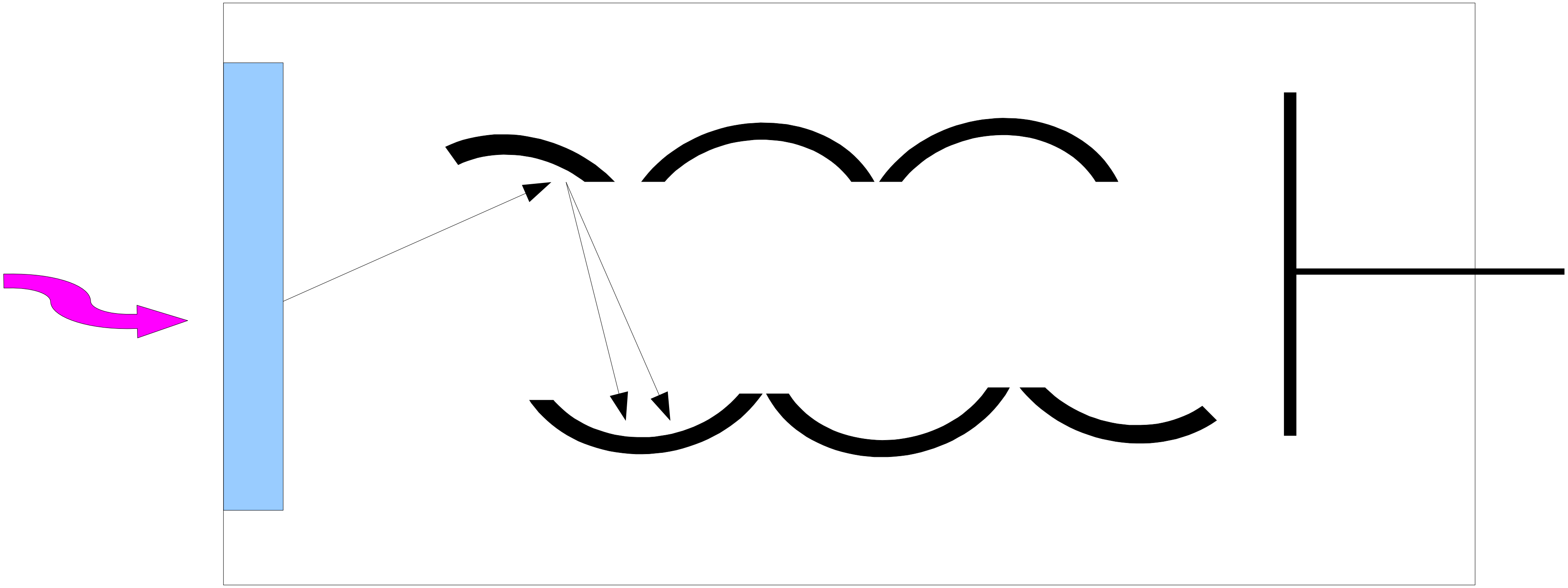
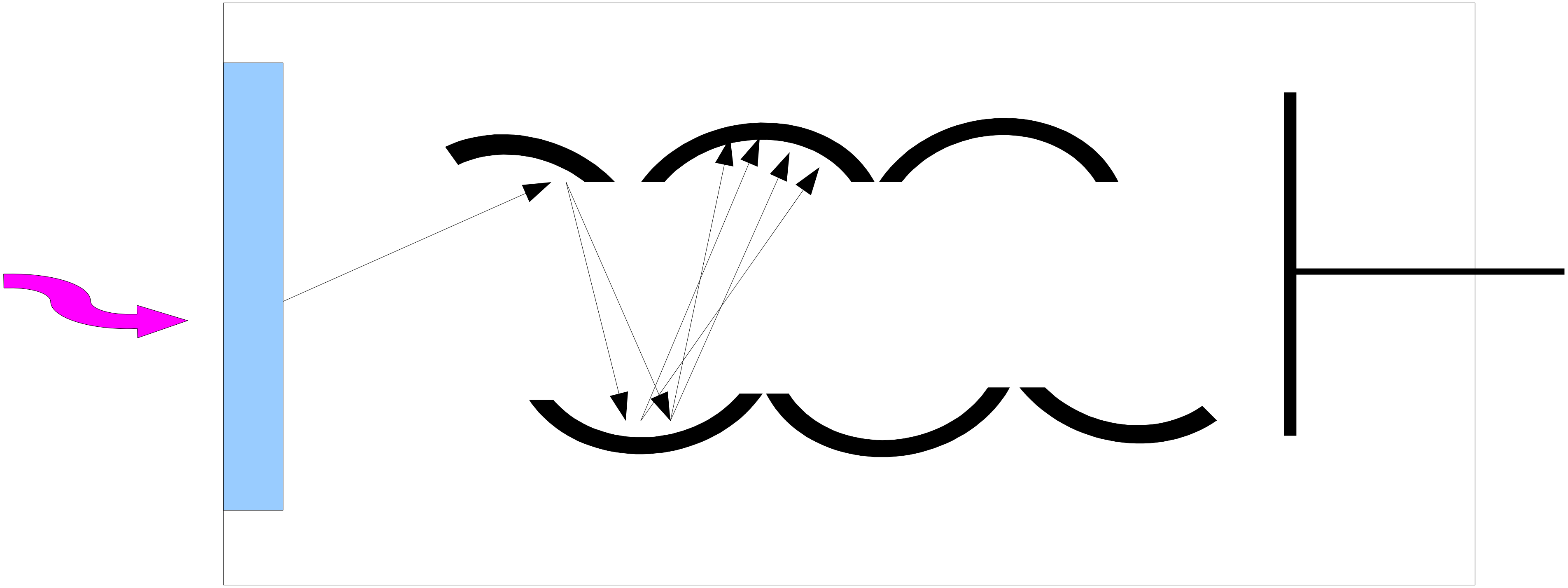
Electric Field

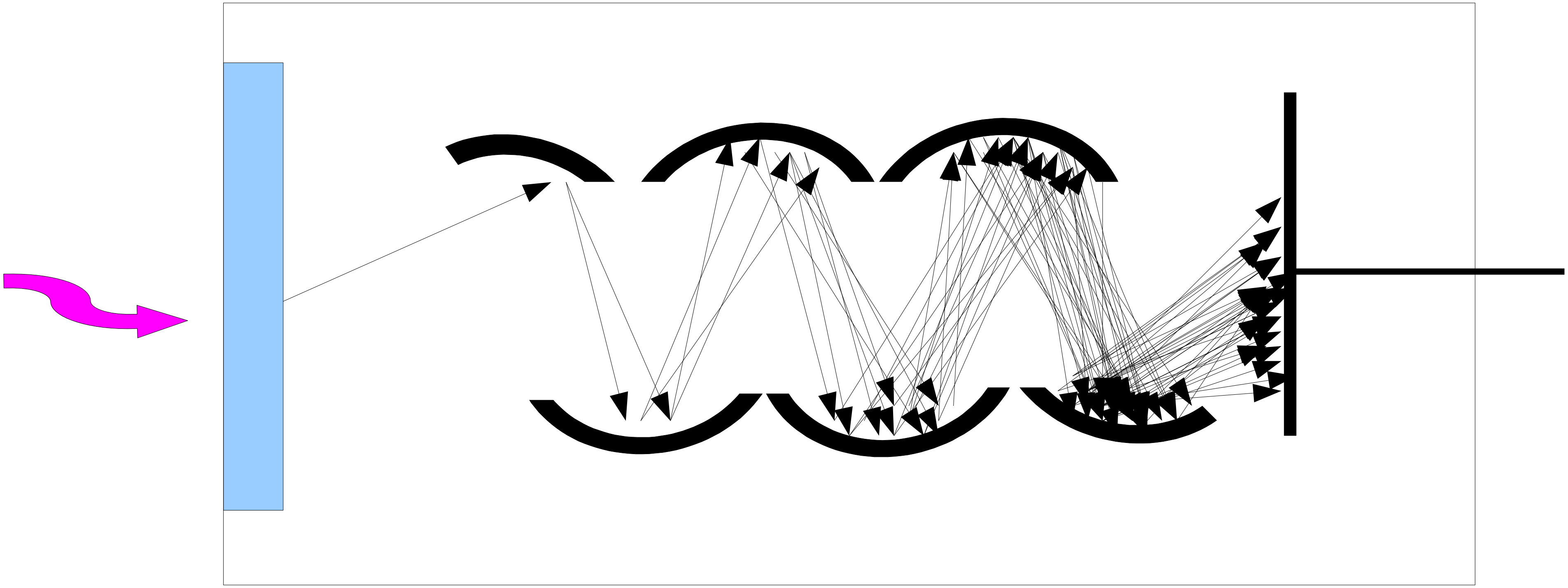



Electric Field
e-
Light
Photocathode

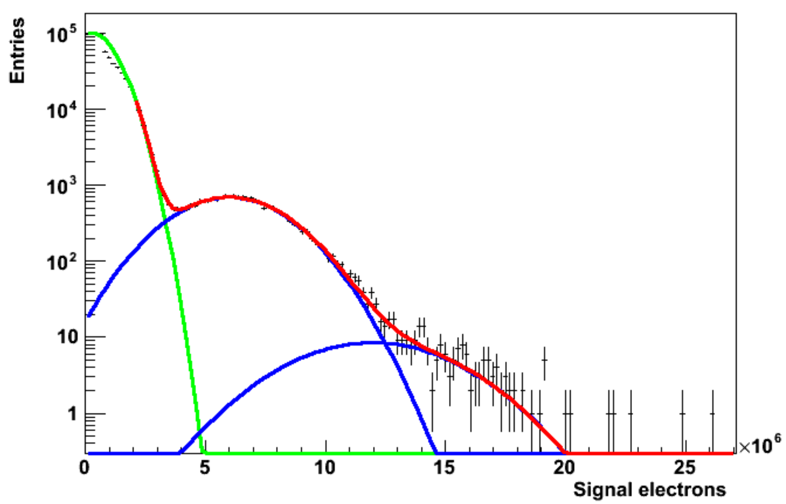
Xe
XENON
Dark Matter Project

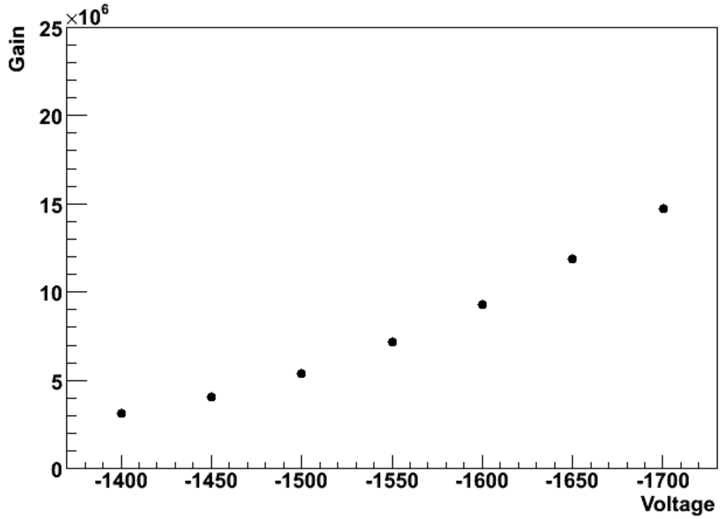






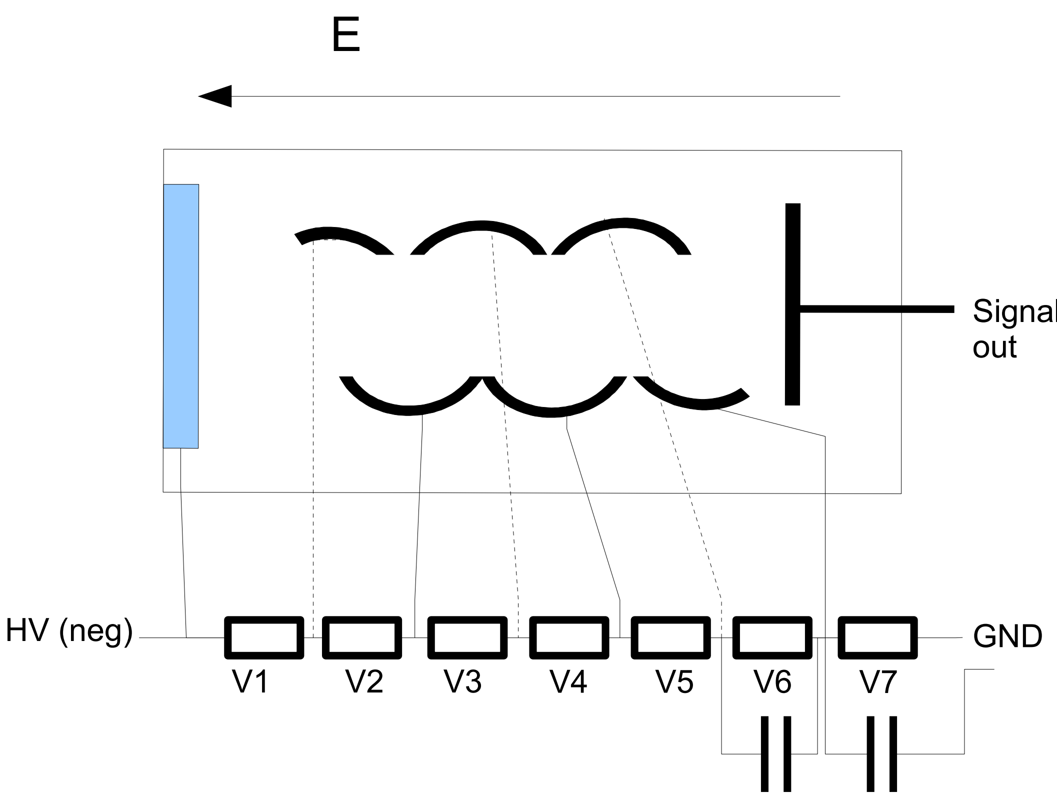
PMT gain

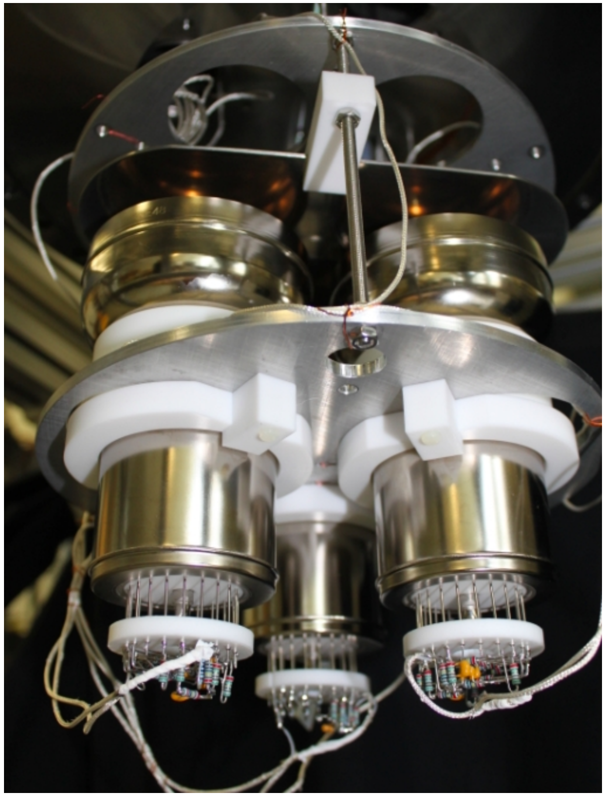




- Single photoelectron emission from low-intensity LED light
- Noise peak is fitted with gaussian function (green), single and double photoelectron peaks are fitted with two coupled gaussian functions
- The mean of the single photoelectron gaussian is the gain of the PMT
- The gain depends on the individual PMT and the bias voltage (typical: 5e6 at –1500 V)

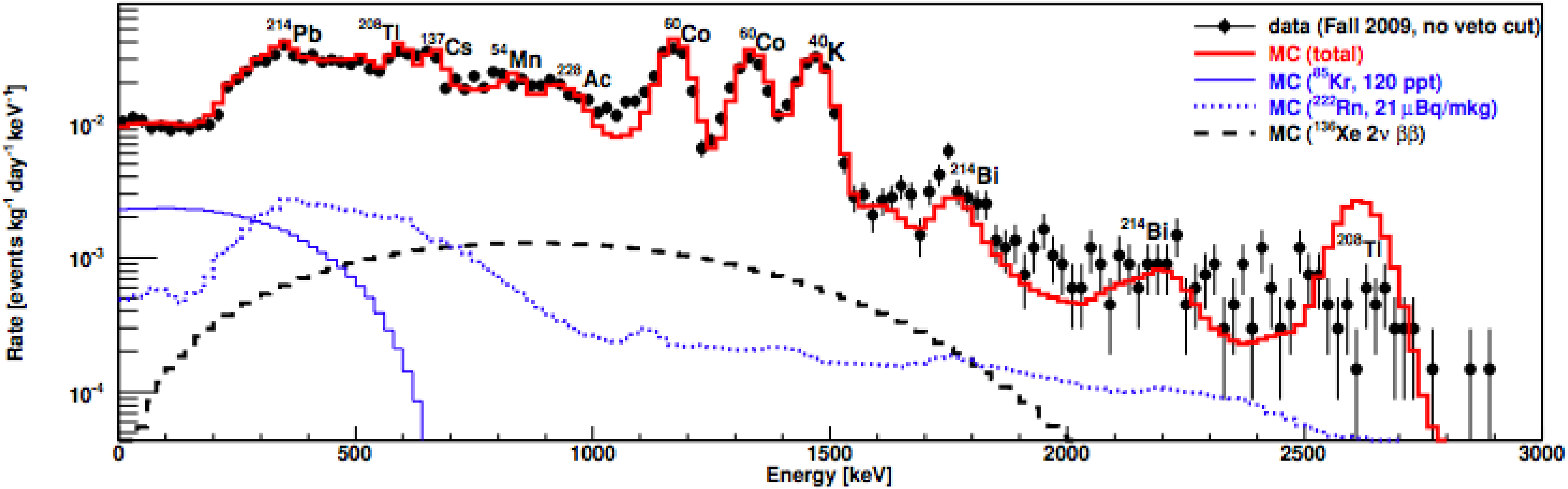
Base design





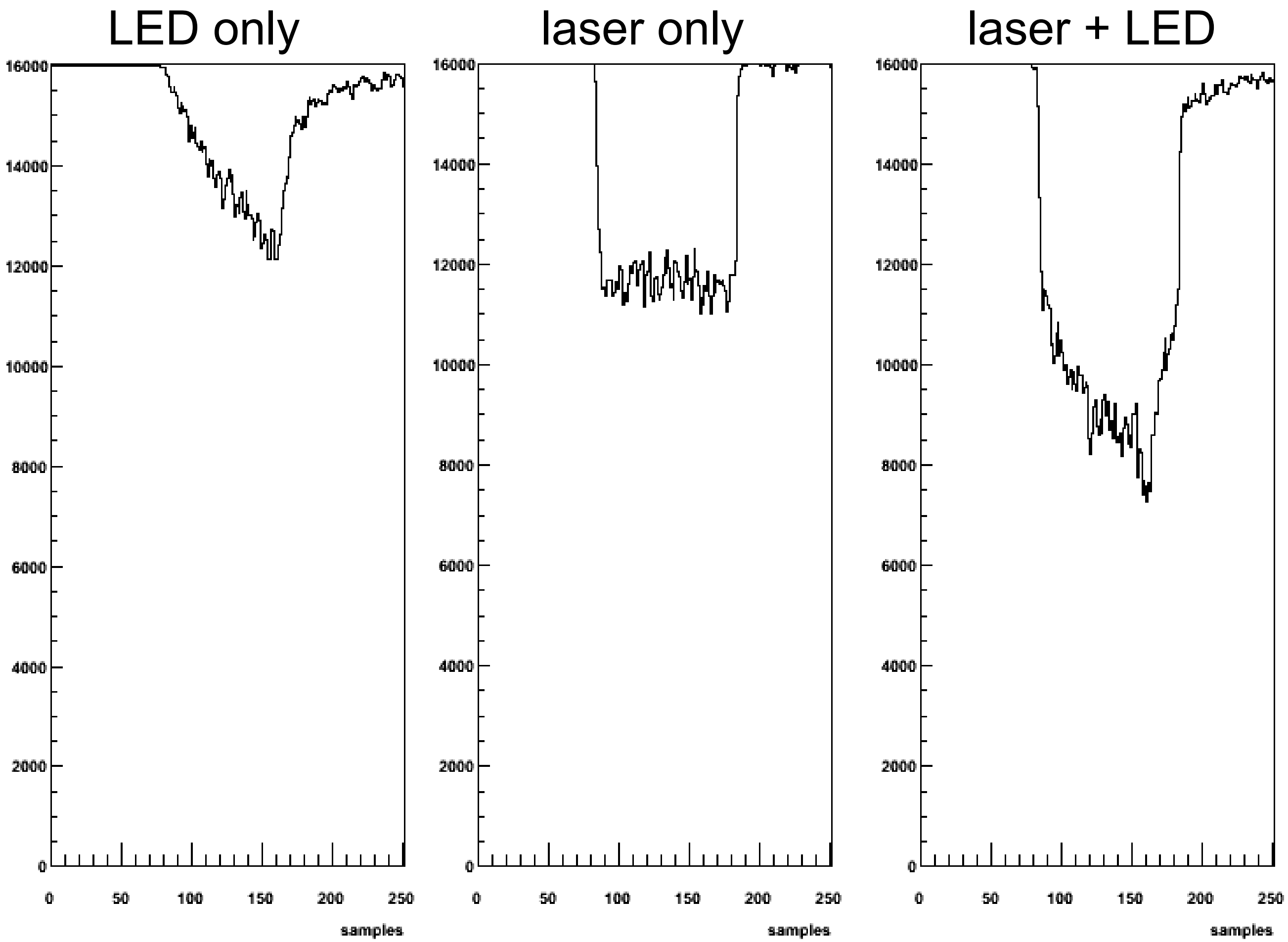
- PMT base distributes voltage to the dynodes
- Capacitors can be used to improve linearity
- But: Ceramics in capacitors increase neutron background

Why do we need good linearity?



E. Aprile et al.: Study of the electromagnetic background in the XENON100 experiment, Phys. Rev. D 83 (2011) 082001

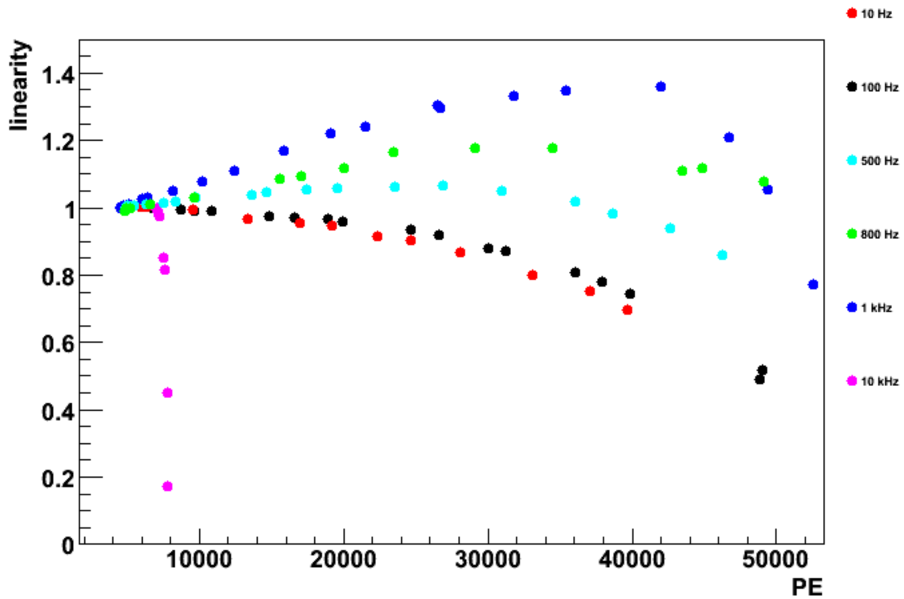
Testing linearity

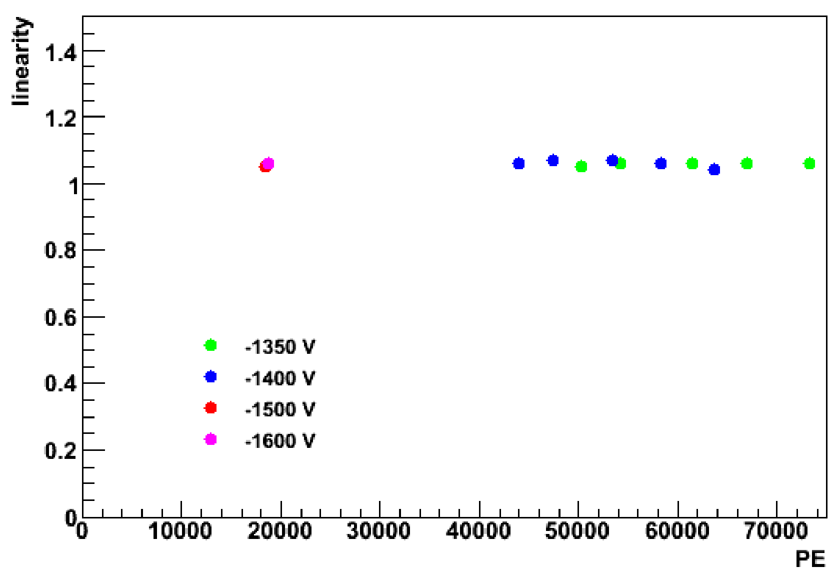


$$\text{Linearity} = \frac{(\text{Laser + LED}) - (\text{Laser only})}{(\text{LED only})}$$

- Linearity can be tested with laser and LED
- LED signal is always the same size
- Laser intensity is varied
- As long as the PMT is linear, a signal of laser and LED at the same time should be the same size as the sum of the laser and the LED signal measured separately

Linearity test results





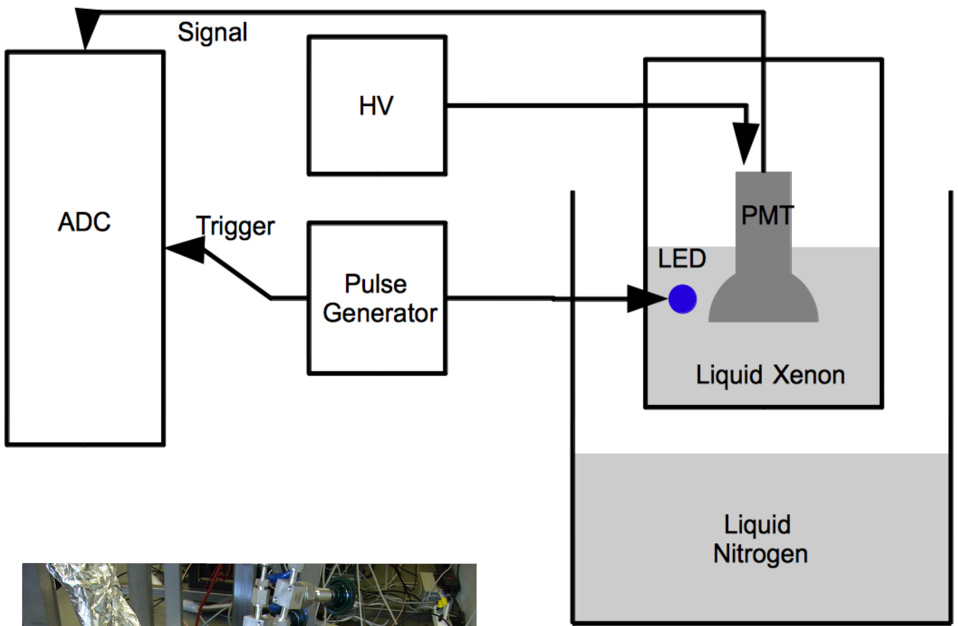
Linearity depends on:

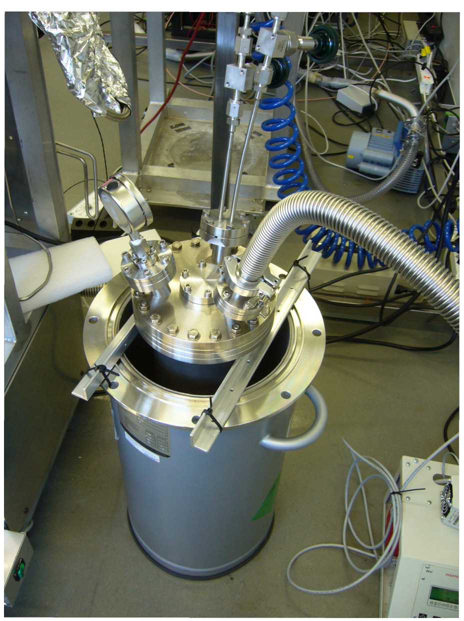
- Base design
- Voltage applied to PMT
- Signal rate

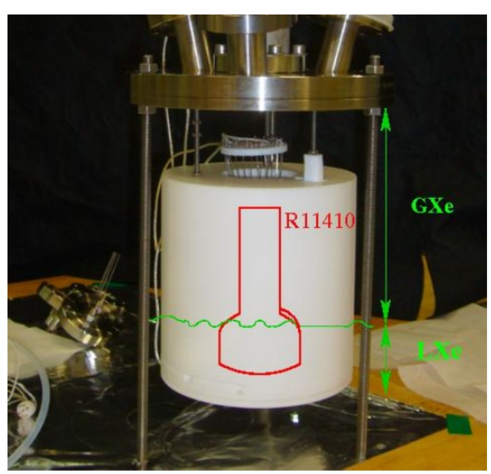
Need 5 capacitors in order to reach desired linearity!

→ Now it's the DAQ that saturates before the PMT does...

Long time stability in liquid xenon

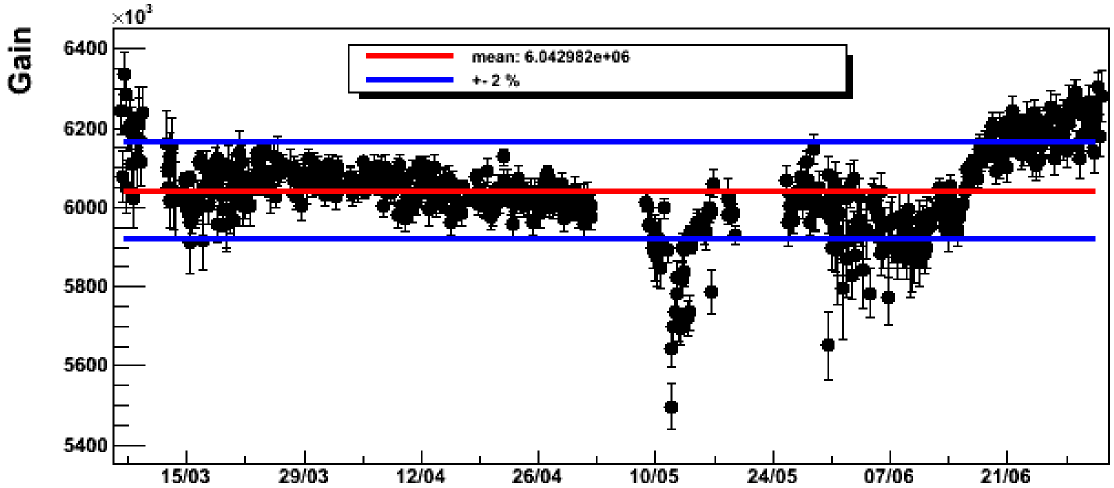


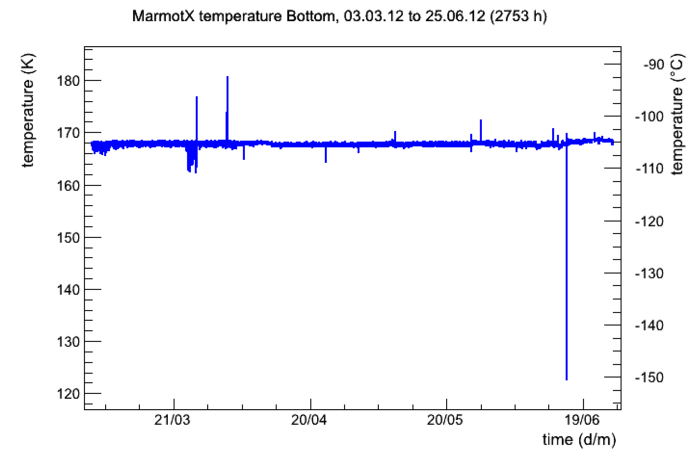


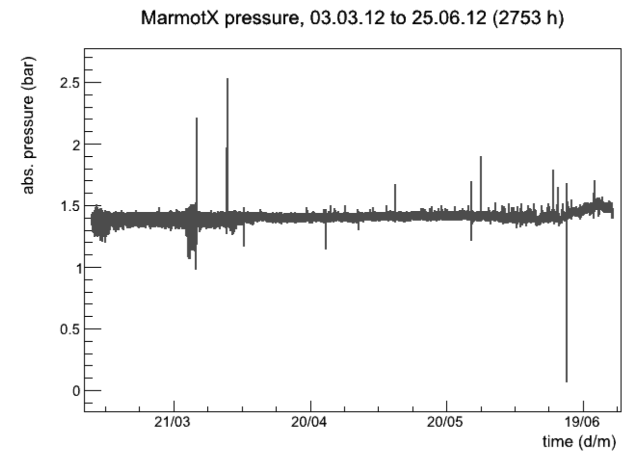


- One R11410-MOD PMT running constantly at – 1600 V for 5 months
- Photocathode submerged in liquid xenon, looking onto a small liquid xenon volume, while the pins and base are in cold xenon gas
- Cooling with liquid nitrogen vapour, automatic nitrogen refilling system coupled to temperature sensors
- Gain calibration with blue LED light every 4 hours

Long time stability in liquid xenon

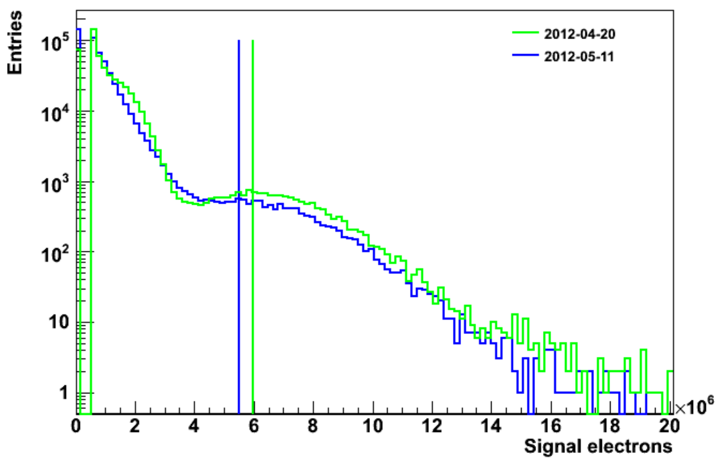




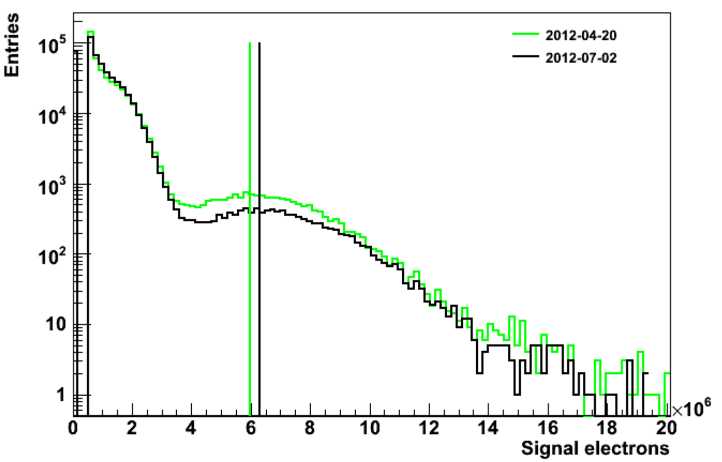


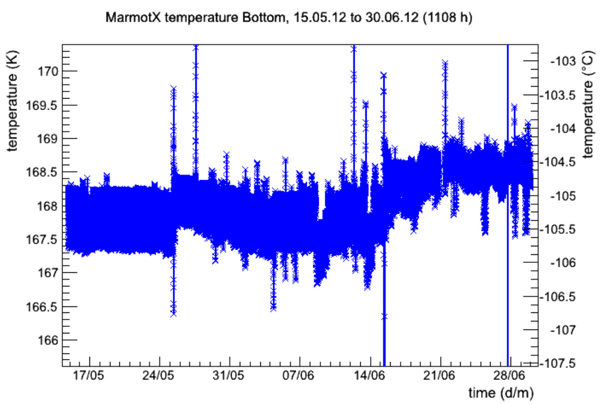
- Stable operation at 171 K and 1.4 bar
- PMT stable within 2% most of the time
- Spikes are correlated with increased electronic noise → Fitting
- Increase in gain, but also in temperature and pressure after accidentally filling too much nitrogen
- Additionally tried 5 cooling cycles. PMT was stable.

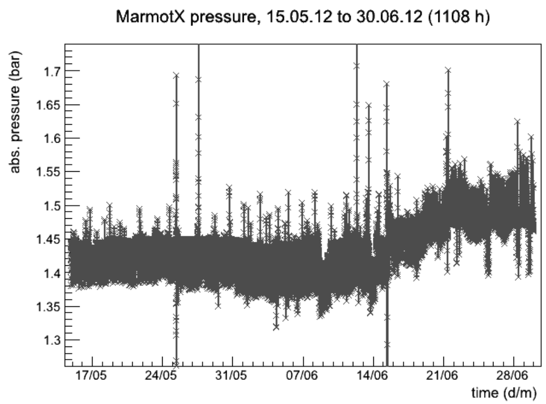
Gain instabilities



- Most spikes in the gain evolution plot seem to be related to increased electronic noise – probably no actual gain change, but change in the fit
- The increased gain observed in the end seems to be real and is related to a change in temperature and pressure







PMT stability in electric fields

- Metal plate set at HV mimics the grids in the TPC
- Variable distance between PMTs and between photocathodes and metal plate allows testing various configurations
- Chamber filled with gaseous xenon, 28 °C, 2.1 bar

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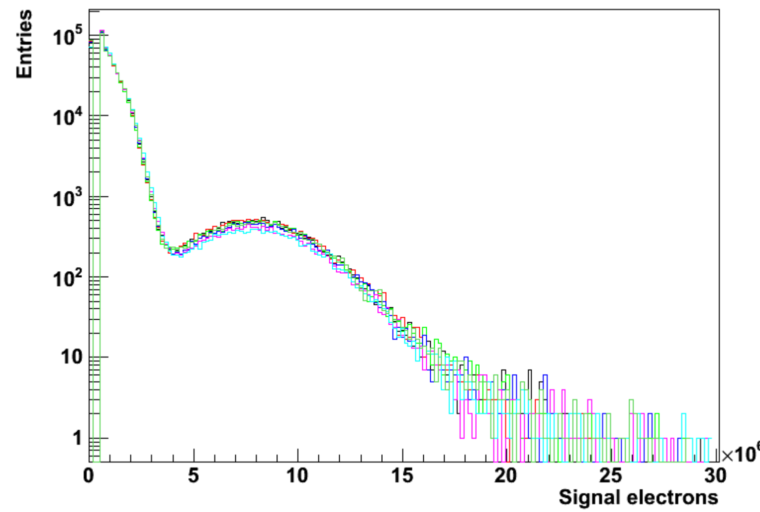
PMT stability in electric fields

PMT 1	PMT 2	PMT 3	Plate
– 1750 V	– 1600 V	– 100 V	0 V
0 V	– 1750 V	– 1750 V	0 V
– 1750 V	– 1750 V	– 1750 V	– 1500 V
0 V	– 1750 V	0 V	– 1500 V
– 1750 V	0 V	0 V	0 V
– 1500 V	0 V	0 V	– 1500 V
– 1500 V	0 V	0 V	0 V
– 1500 V	0 V	0 V	750 V
– 1500 V	0 V	0 V	1500 V
– 1500 V	0 V	0 V	1800 V



- Distance between PMTs center-to-center: 80 mm → 4 mm gap between PMTs
- Distance between plate and photocathode: 14 mm and 3 mm
- Each test over several days, gain calibration once a day
- No problems (sparks/trips/change in gain) observed in any configuration
- Also done: One high pressure test (2.5 bar). No problems.

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Summary

- The Hamamatsu R11410 is the PMT to be used in XENON1T
- A PMT base can be designed that is linear up to 90 000 photoelectrons (1.5 MeV signals in the XENON 1T detector, saturation point of the DAQ)
- One PMT was successfully tested over 5 months in liquid xenon
- Tests with three PMTs in gaseous xenon with different electric field configurations showed no problems
- Next steps:
  - The base design will be finalised (material selection, determination of minimum required capacitance)
  - The dark current will be studied
  - Cool-down tests are ongoing with a second PMT