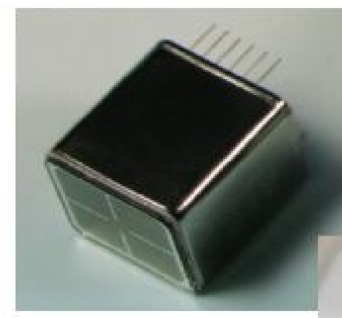
The Photomultiplier Tubes in the XENON Dark Matter Experiment



Annika Behrens
Physik-Institut Universität Zürich

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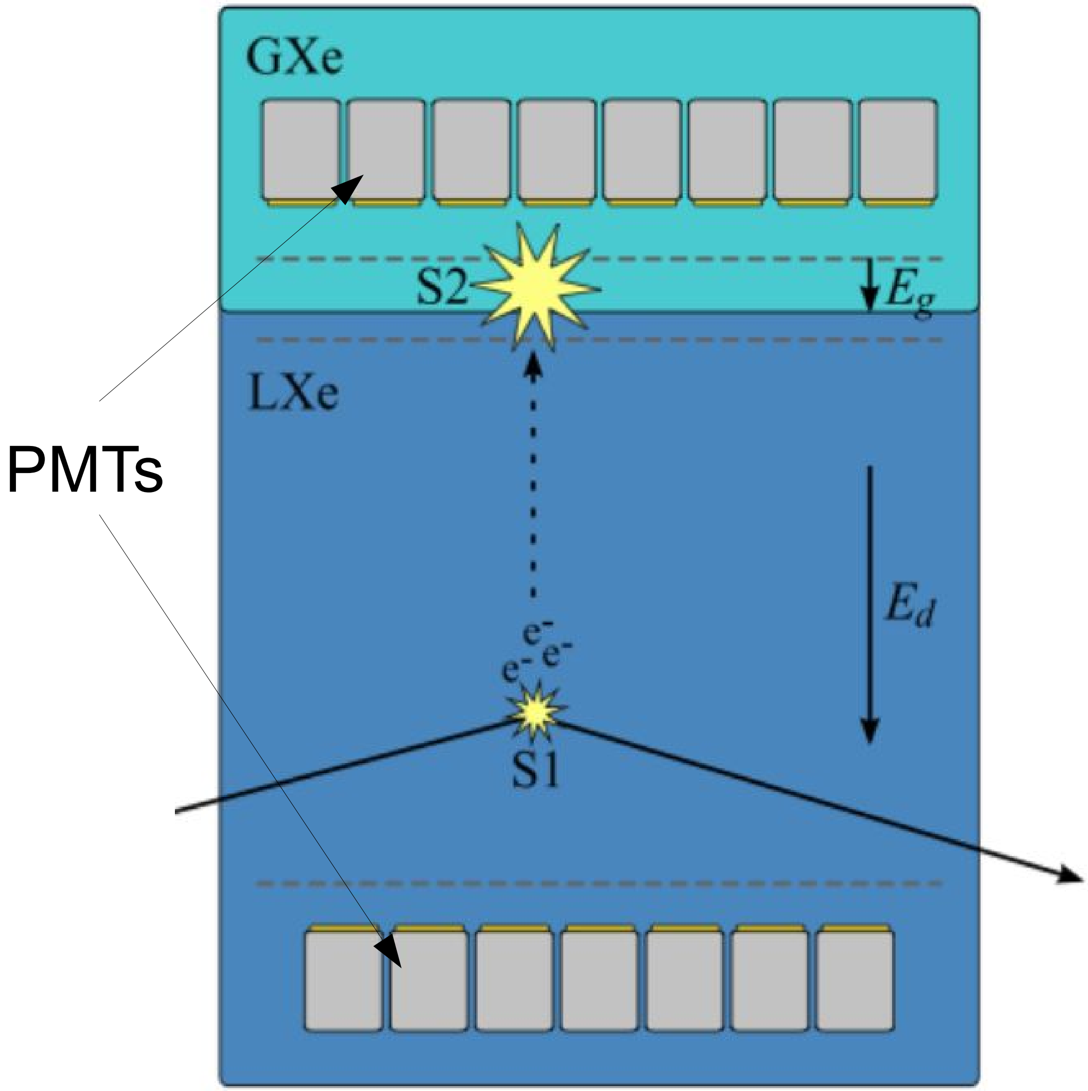
Doktorandenseminar Universität Zürich

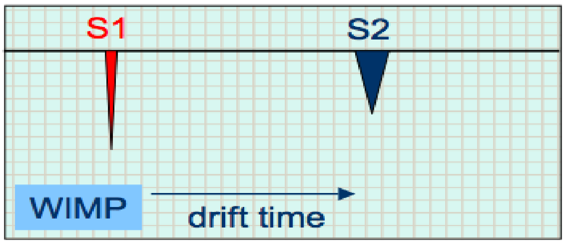
Outline

- PMTs in the XENON dark matter experiment
- XENON100 and the weekly gain calibration
- XENON1T and candidates for the light sensors
- Tests of Hamamatsu R11410

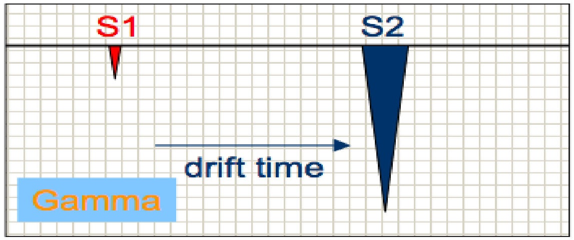
Direct WIMP Detection in Double-Phase Xenon TPCs



- Scintillation (S1)
- Charge drifts to surface, proportional scintillation signal in gas phase (S2)
- Background rejection: $(S2/S1)_{WIMP} << (S2/S1)_{Gamma}$

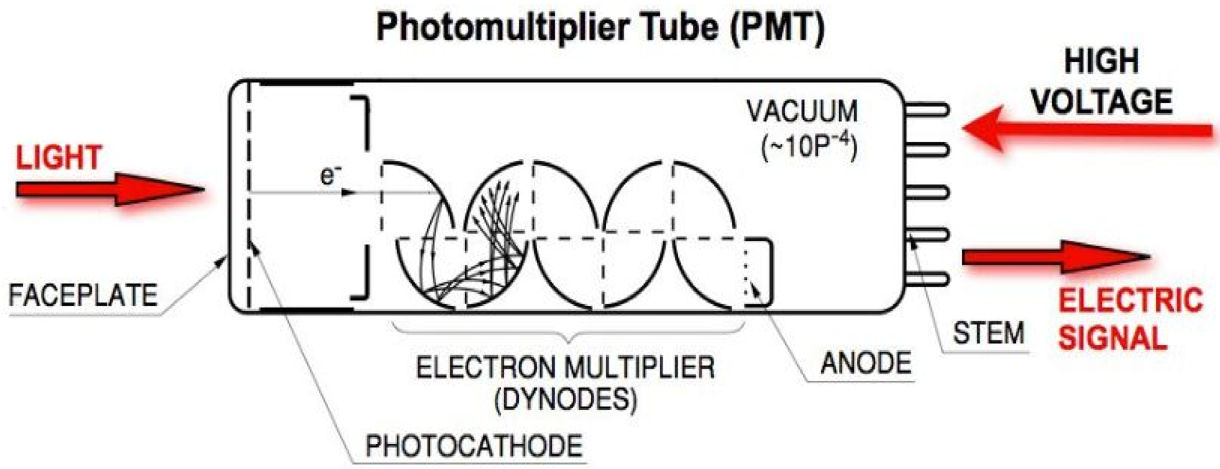


WIMP: nuclear recoil



Gamma: electron recoil

Photomultiplier Tubes

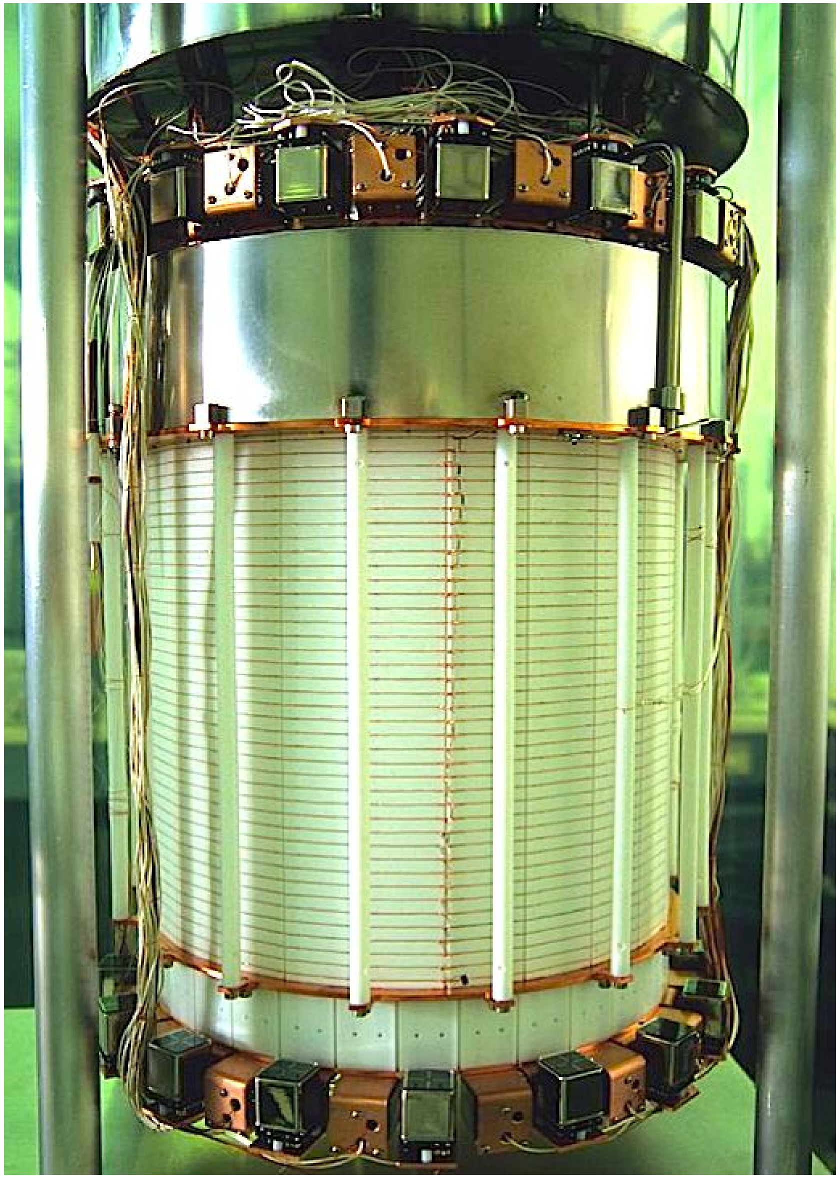


- **Quantum Efficiency (QE)**: Probability, that a photon hitting the photocathode produces a photoelectron

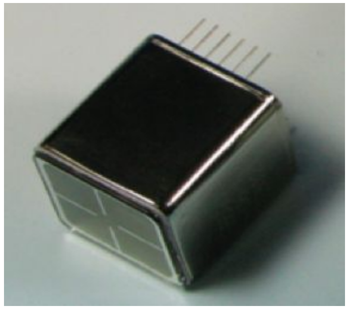
- **Collection Efficiency (CE)**: Probability, that a photoelectron reaches the first dynode

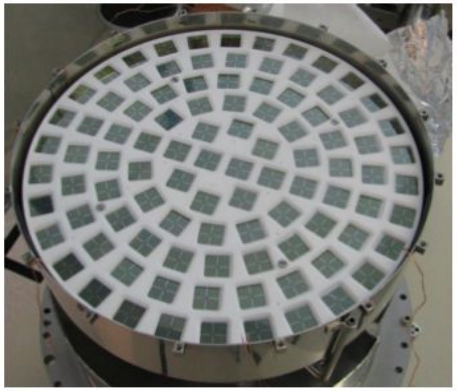
- **Gain**: Number, by which the first photoelectron has been multiplied when reaching the anode

XENON100

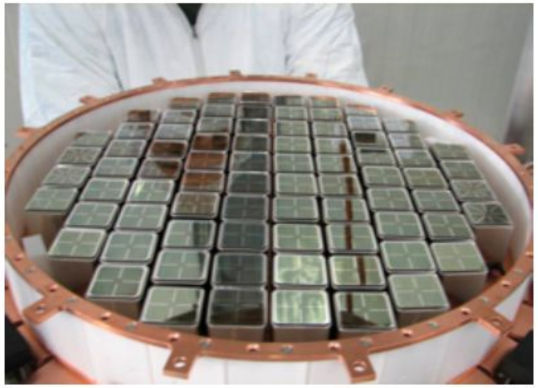


- 242 PMTs in two arrays + veto
- Hamamatsu R8520 (1"x1")
- Sensitive to xenon light (178nm)
- Low radioactivity
- QE ~23 % (top, veto) and ~33 % (bottom)
- Gain ~ $2x10^6$





Top PMT array (98 PMTs)

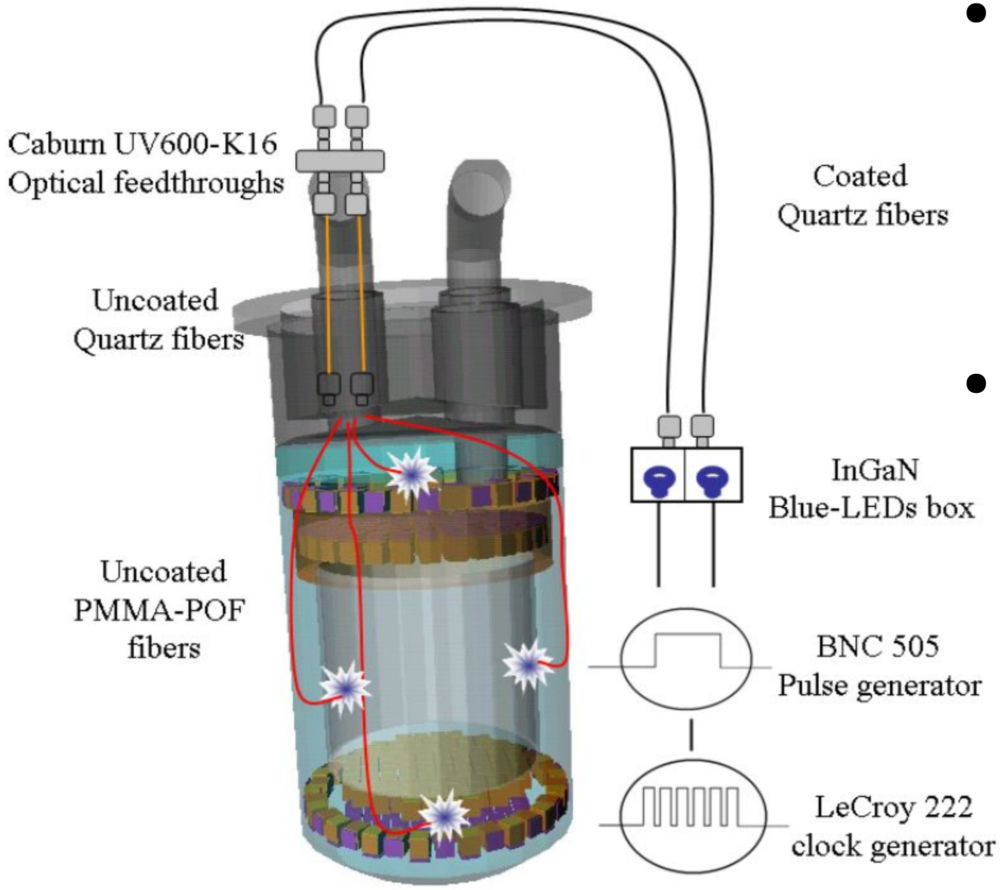


Bottom PMT array (80 PMTs)

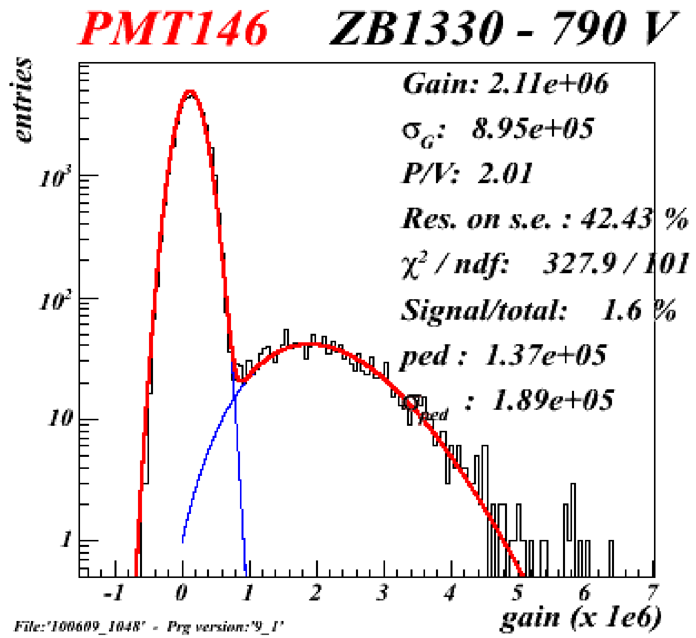
Motivation

- Quantum efficiency and collection efficiency differ for individual PMTs
- Gain depends on the supply voltage and might not be stable in time
- Gain calibration improves detector response (position reconstruction, energy resolution)

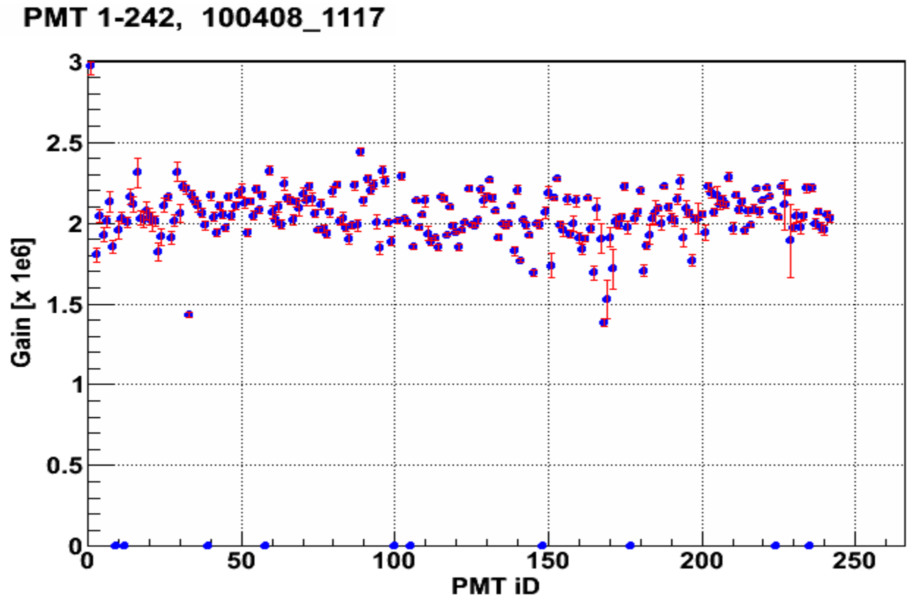
Gain Calibration of the XENON100 PMTs



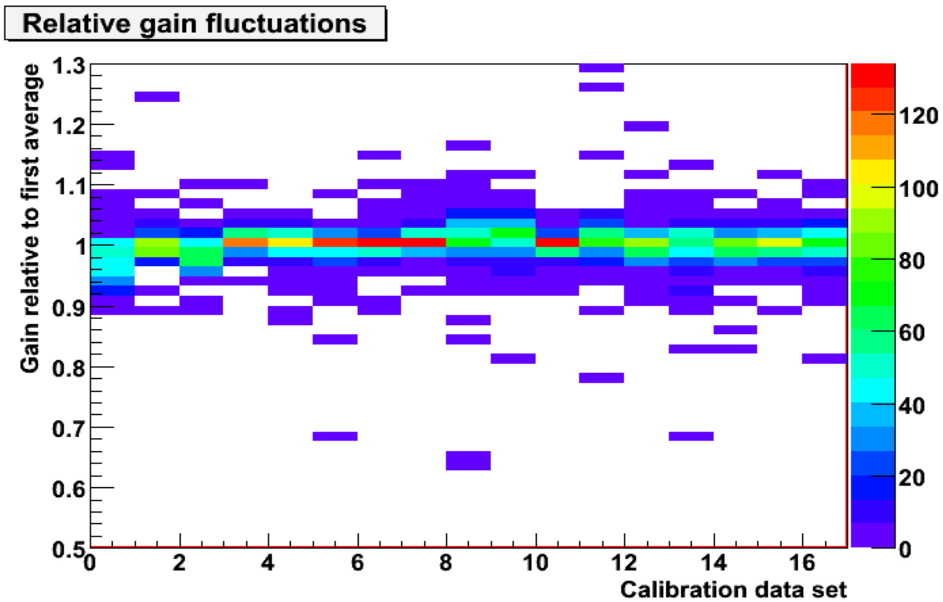
- Weekly gain calibration
- Stimulation of single photoelectron (SPE) emission of photocathode with blue LED light
- Gain from fit to spectrum

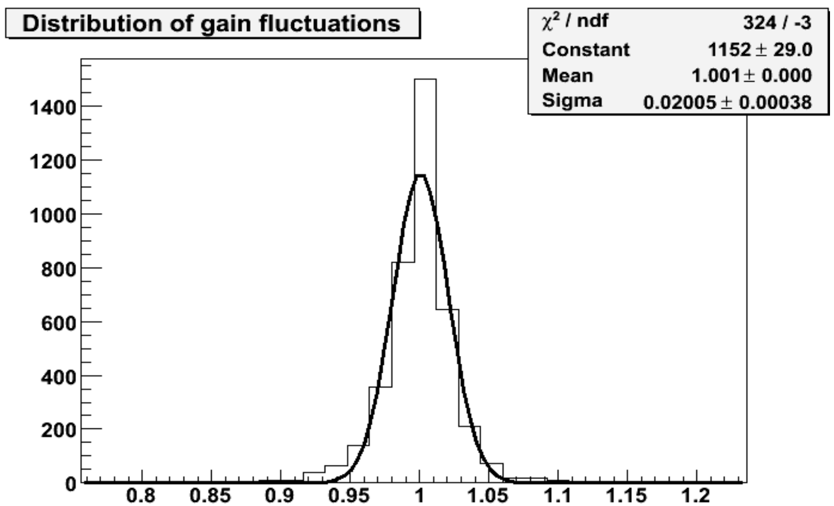


Gain Calibration of the XENON100 PMTs

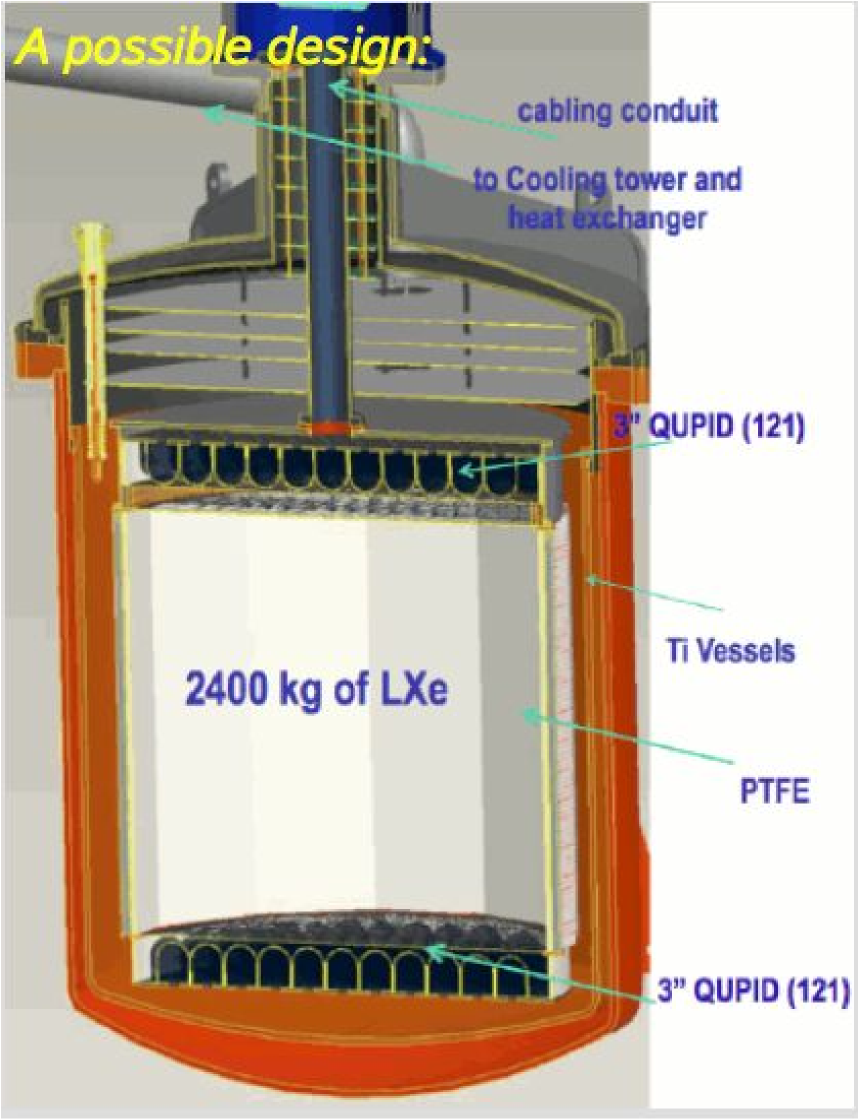


- Average gain: 2.067×10^6
- Measured gain values are stable in time within 2%





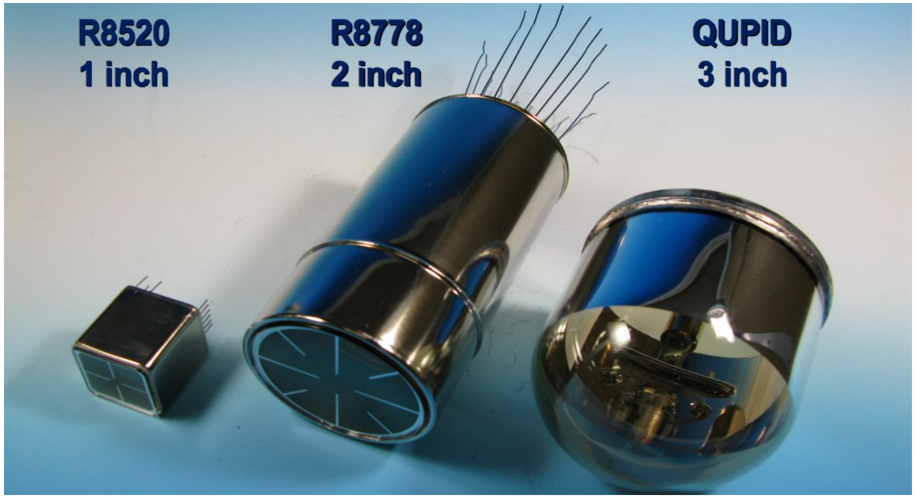
XENON1T



- Now in design phase
- Construction: 2011-2012
- Integration and commissioning: 2012-2014
- First data run: 2014
- Location: LNGS or LSM
- 1.1 t of liquid xenon in the fiducial volume (XENON100: 40 kg)
- 242 light sensors

Light Sensors in XENON1T

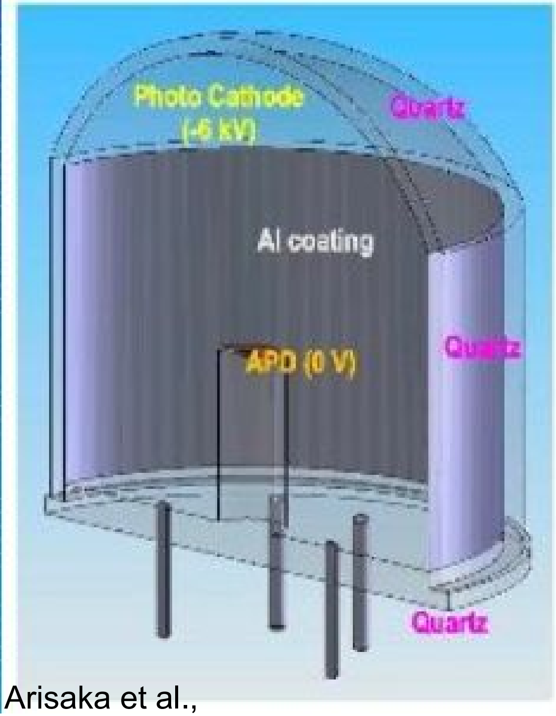
- High quantum efficiency (QE)
- Low Radioactivity
- Light sensors with larger area than in XENON100
- Candidates: QUPID, R11410, R8778, ?



QUPID

- **QU**artz **P**hoton **I**ntensifying **D**etector
- Hybrid photodetector
- Very low radioactivity

(^{238}U <0.49 mBq, ^{232}Th < 0.4 mBq, ^{40}K < 2.4 mBq, ^{60}Co < 0.21 mBq)



K. Arisaka et al.,
Astroparticle Physics 31 (2009) 63–74

- Photoelectrons from photocathode are accelerated by 6kV to the APD, producing ~2000 secondary electrons each
- Factor 30 APD gain
- => Total gain ~60 000
- QE: 30-35% at 170 to 450 nm

Currently only few prototypes exist at UCLA, further tests will be done at UZH

Hamamatsu R11410

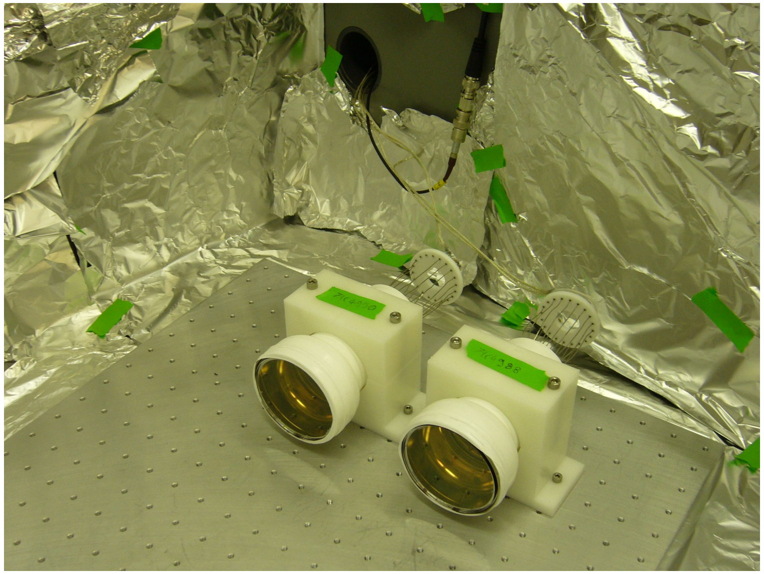
- New 3 inch low radioactivity PMT
- Bialkali photocathode (QE 26% at 175 nm)
- 12 dynode stages
- 160 – 650 nm (max at 420 nm)
- Min -110°C, max 50 °C
- Gain given by Hamamatsu: $5x10^6$

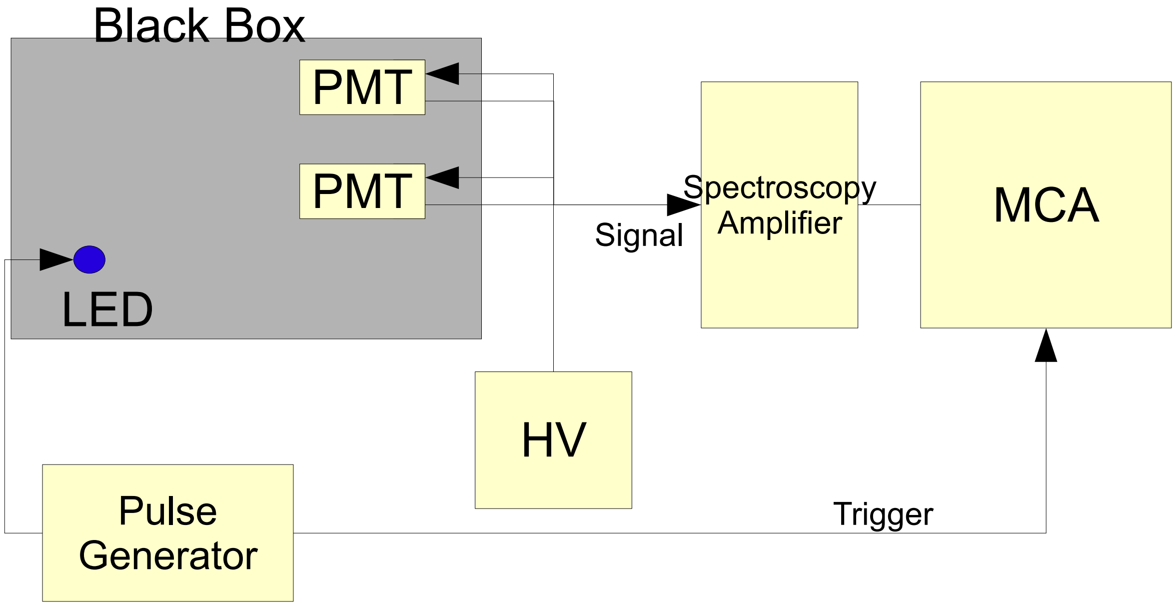
Screening with Gator

Isotope	Activity of R11410 per PMT	Activity of R11410 per area	Activity of R8520 per area
^{238}U	6.1 ± 0.7 mBq/PMT	0.13 mBq/cm^2	0.02 mBq/cm^2
^{232}Th	3.0 ± 0.6 mBq/PMT	0.07 mBq/cm^2	0.02 mBq/cm^2
^{60}Co	8.4 ± 0.8 mBq/PMT	0.18 mBq/cm^2	0.09 mBq/cm^2
^{40}K	50 ± 8 mBq/PMT	1.10 mBq/cm^2	1.7 mBq/cm^2

- Radioactivity too high (ca. factor 10) for our purpose
- Hamamatsu provided modified version (R11410-MOD) that is supposed to have lower radioactivity, will now be screened with Gator

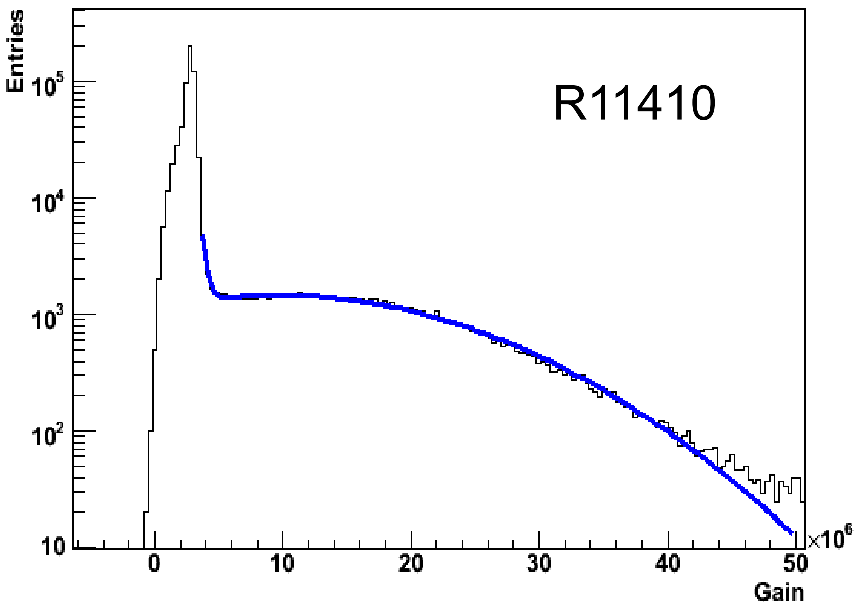
PMT Tests at Room Temperature

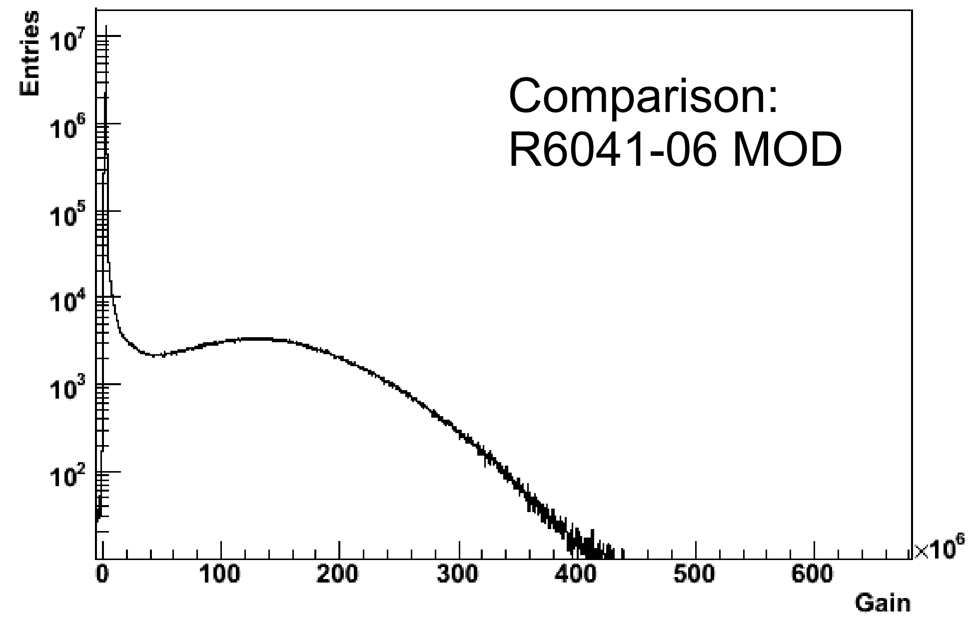




- Black box for shielding from external light
- LED for SPE spectra
- PMT signals are amplified and shaped by a spectroscopy amplifier and recorded by an MCA

SPE Spectrum of R11410

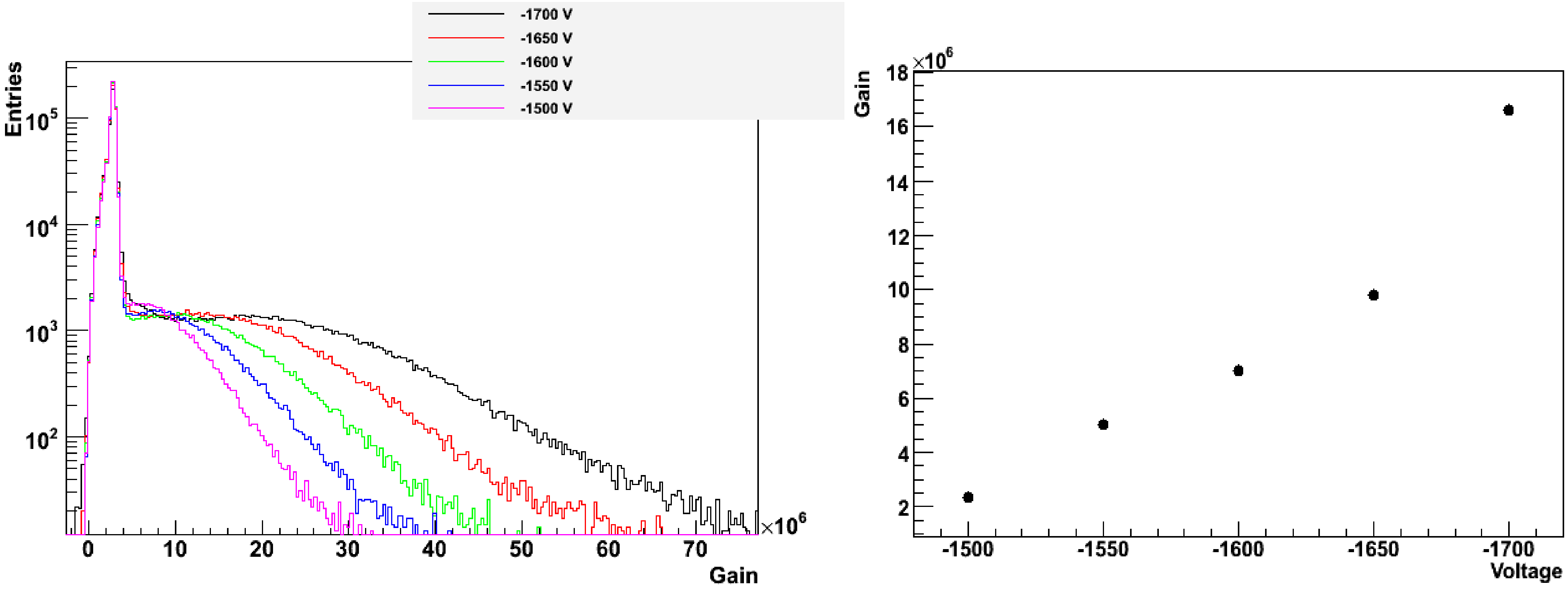




- Single photoelectron spectra taken with LED light
- Peak-to-valley ratio up to 1.12

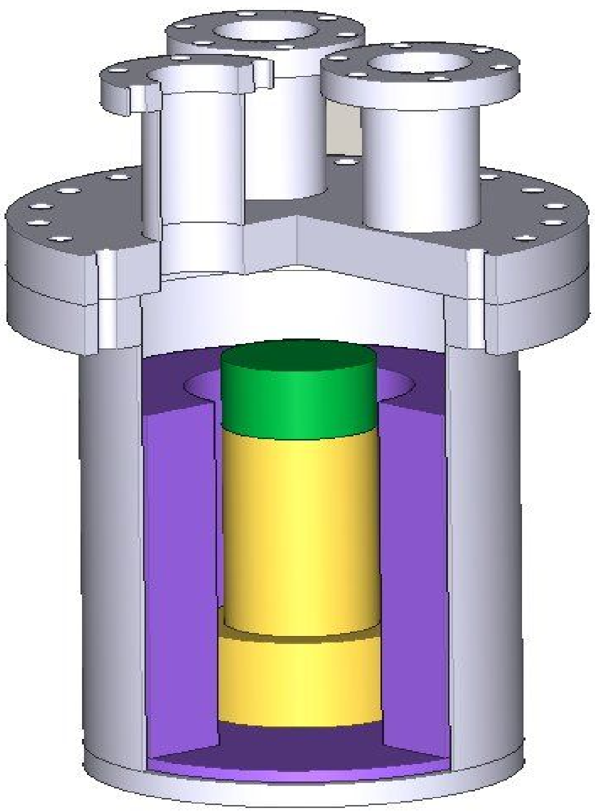
Gain of R11410

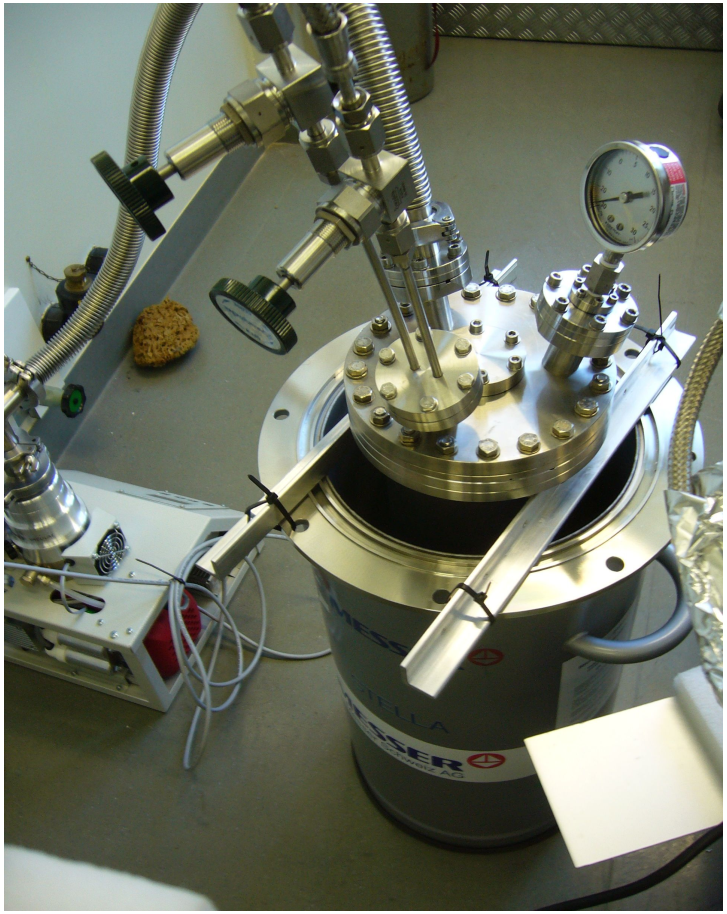
- Gain from fit to SPE spectrum
- Better Performance at higher voltages



Test Setup with Liquid Xenon

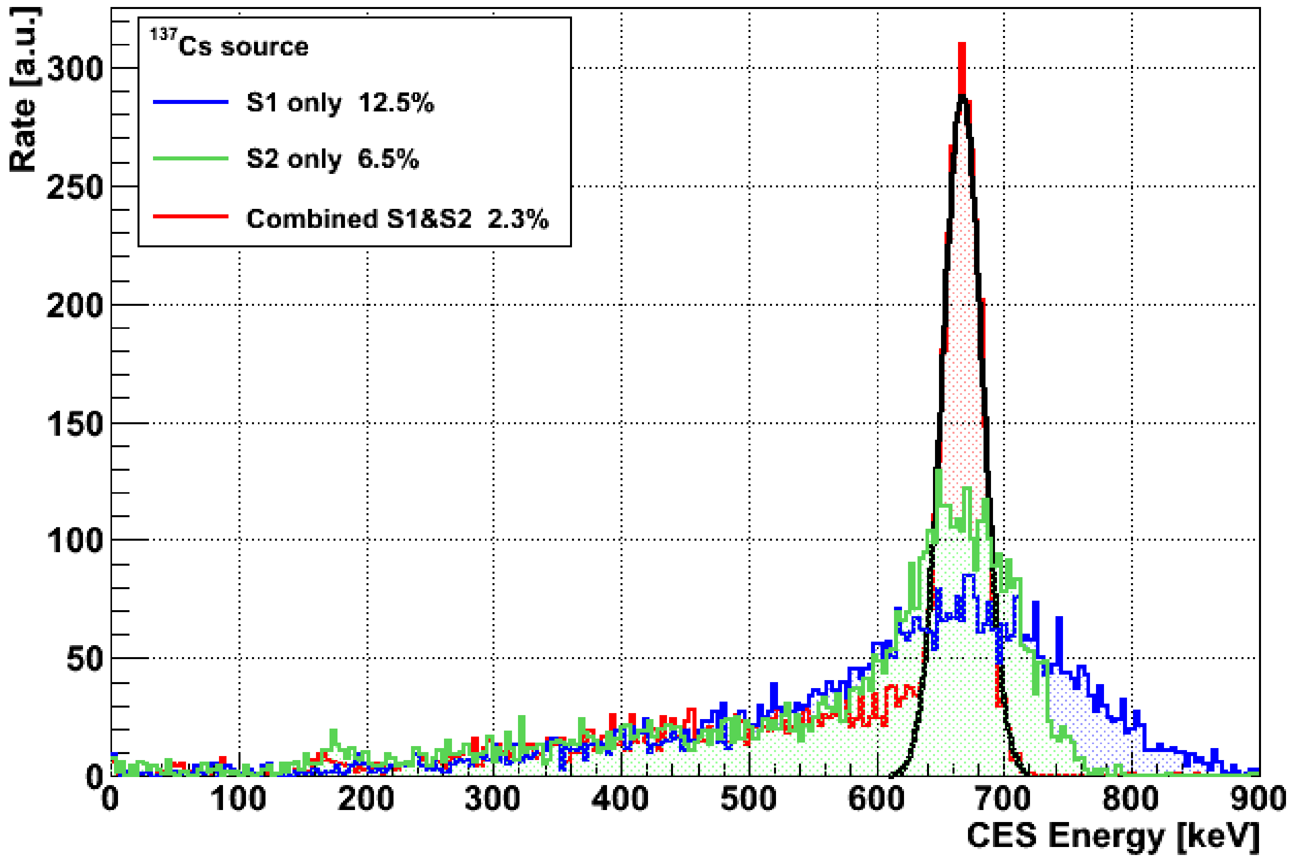
- Tests with LED and sources in small single-phase xenon chamber now in preparation





Summary

- PMT gains in XENON100 are very stable



Summary

- For XENON1T, new light sensors with larger area are necessary
- QUPIDs might be used, but are still under development
- R11410 has been tested at room temperature
  - Not suitable as it is now (radioactivity, performance)
  - Being improved by Hamamatsu
- R11410 will now be tested in liquid xenon