Characterization of UV-sensitive SiPM for the nEXO experiment

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

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Bärenfels, 10.10.2016

Enriched Xenon Observatory
EXO
for double beta decay

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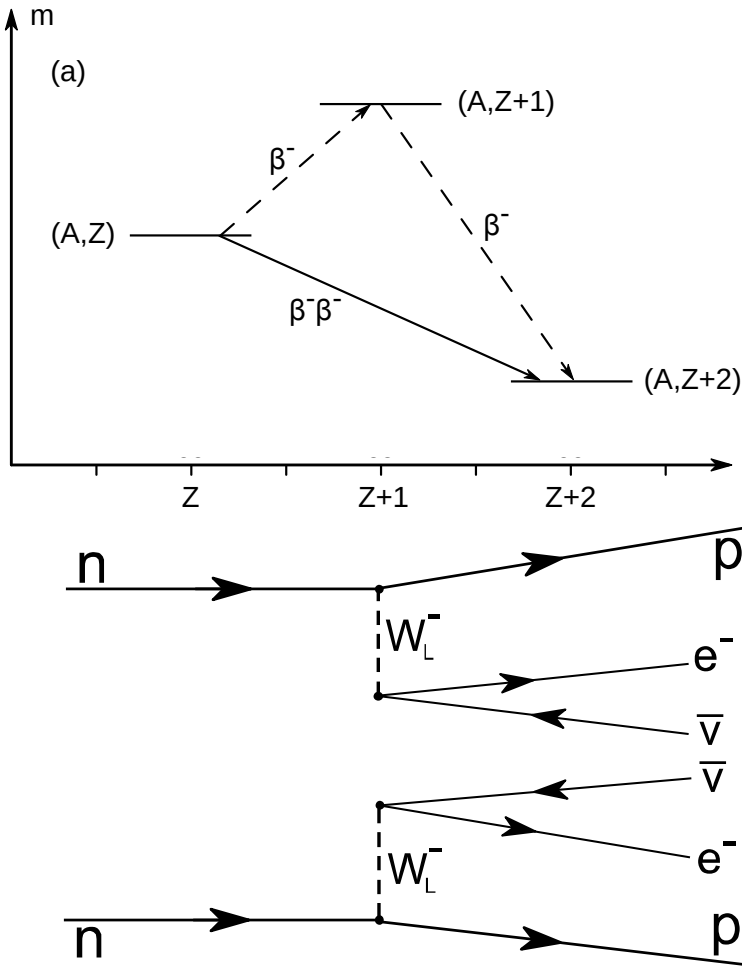
Overview

- Motivation: the neutrinoless double beta decay
- The nEXO experiment
- UV-sensitive SiPMs as photon detector
- Future plans

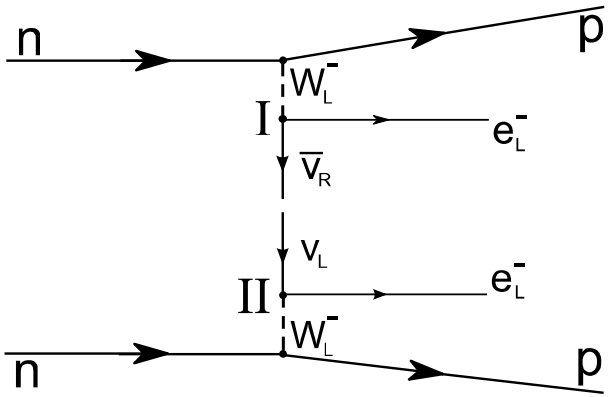
The neutrinoless double beta decay (0νββ)

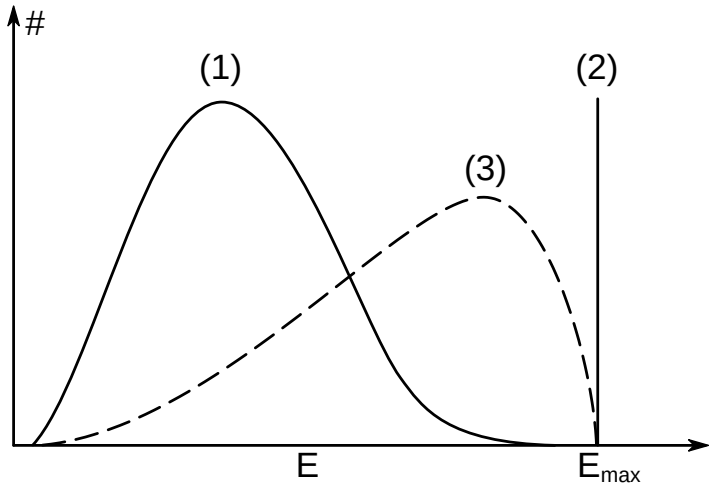
The double beta decay (2νββ)



- Possible for several ee-nuclei
- e.g. ^{76}Ge, ^{116}Cd, ^{130}Te, ^{136}Xe
- First observation in 1987
- Second order weak process
- Half lives of 10^{18} - 10^{21} years

The neutrinoless double beta decay





Necessary:

- Neutrino has mass
- Neutrino has Majorana nature (i.e. $\nu = \overline{\nu}$)

- Both violate the SM
- Never been observed
- Enormous half lives (e.g. $T^{0\nu}_{1/2} > 1.1 \times 10^{26}$ for ^{136}Xe [1])

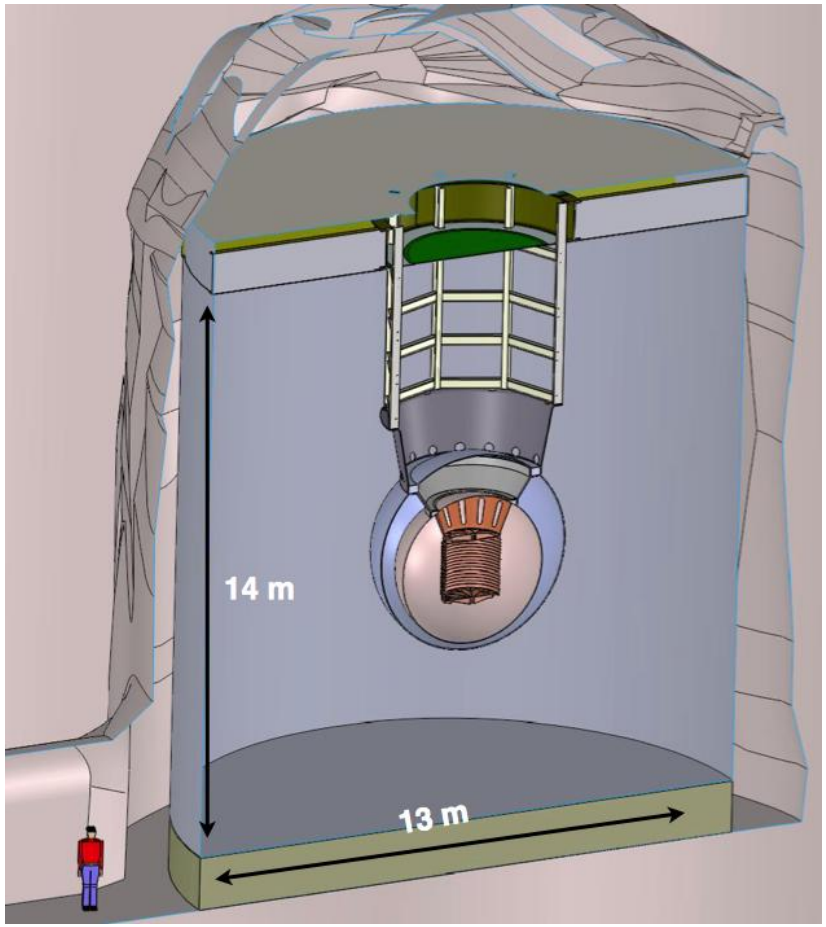
$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu}(Q,Z)\,|M^{0\nu}|^2\,m^2_{\beta\beta}$$

- Distinguish from 2νββ decay via energy

[1] A.Gando et. al. (KamLAND-Zen), *Phys. Rev. Lett*. 117.8 (2016): 082503

The *next Enriched Xenon Observatory* (nEXO)

nEXO



What we need:

- Good energy resolution ΔE
- Excellent detection efficiency ε
- Low background rate c
- Large decay material mass $M_{\beta\beta}$
- Wait a lot: t

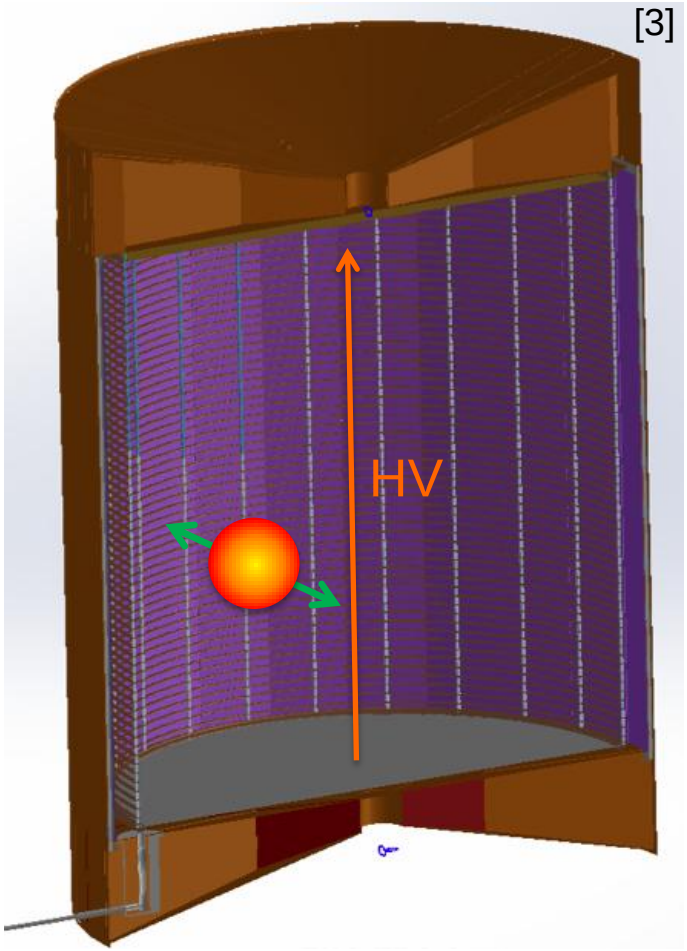
$$m_{\beta\beta} \sim \sqrt{1/\varepsilon} \left(\frac{c \cdot \Delta E}{M_{\beta\beta} \cdot t} \right)^{1/4}$$ [2]

What we plan:

- TPC with 5t of LXe
- LXe enriched to 90% in ^{136}Xe
- Low background (deep underground)
- Modern, sensitive detector systems

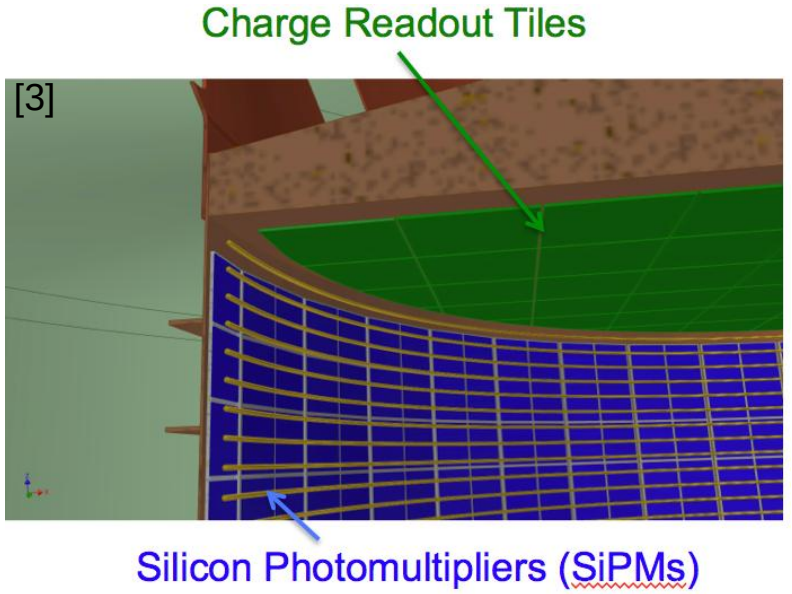
[2] J. J. Gomez-Cadenas et. al., arXiv:1109.5515 (2011)

nEXO



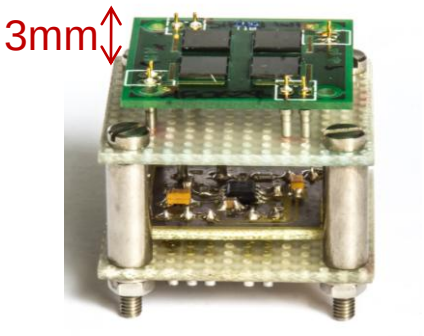
Detection systems:

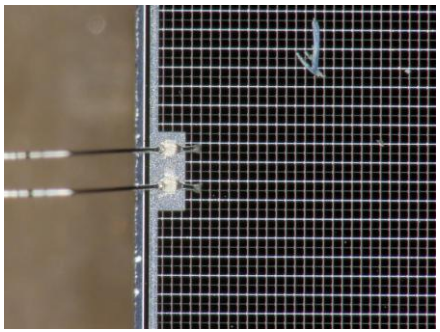
- Secondary electron drift to charge readout tiles (TPC height = 1.3 m)
- Xe-scintillation photos detected by SiPM-arrays (inner area: ~4 sqm)
- Problem: low efficiency for Xenon scintillation photons (λ = 178 nm)

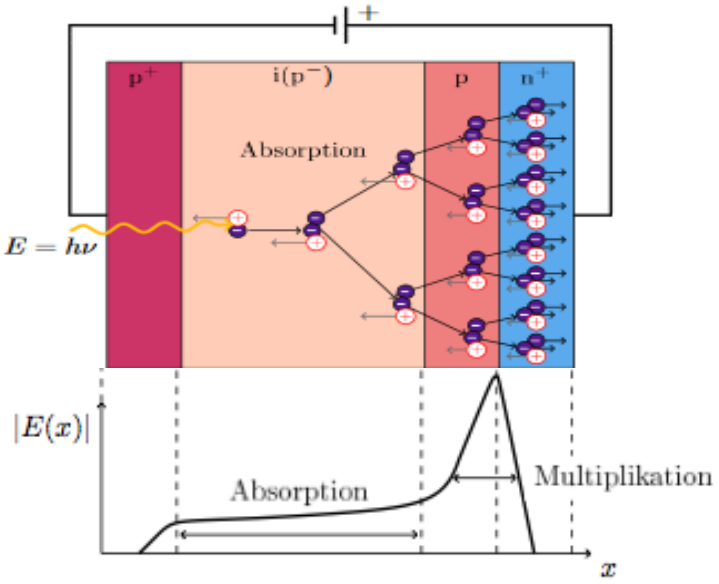


Characterization of UV-sensitive SiPMs

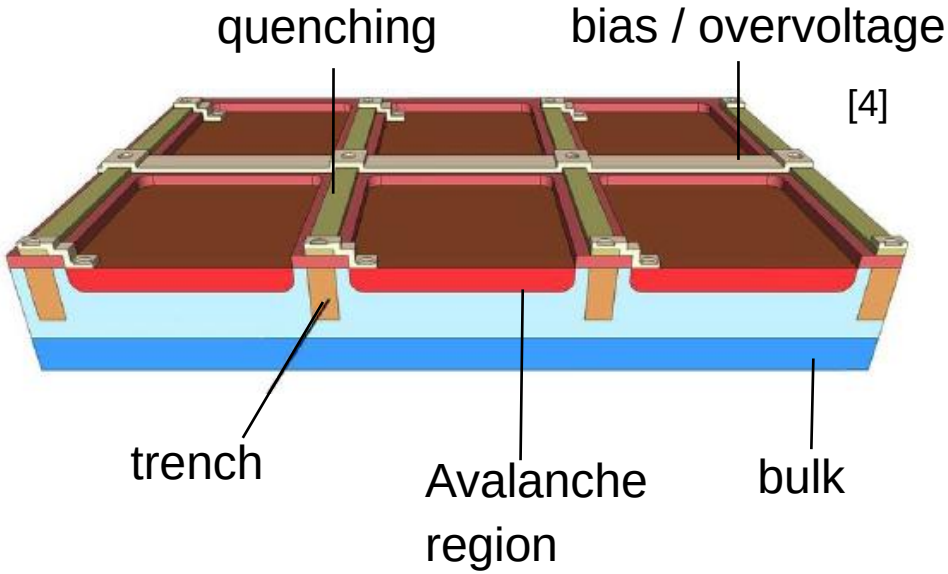
SiPM - Principle



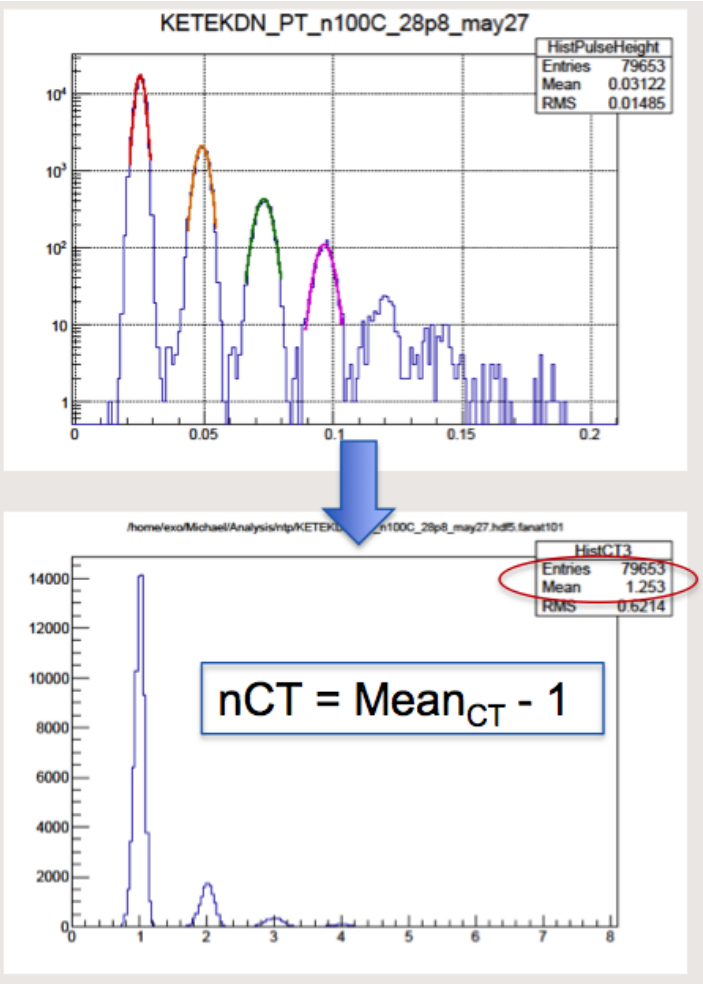




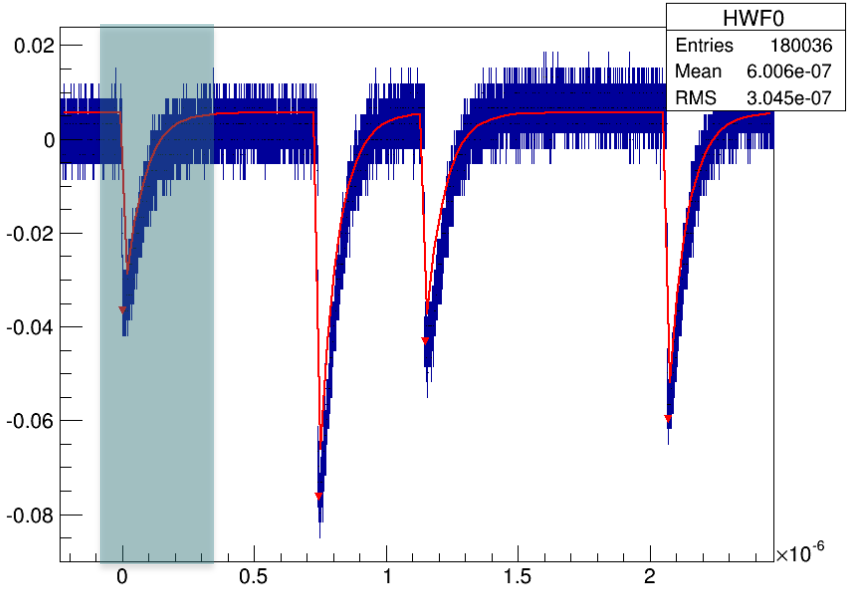
- Pixelated semiconductor detectors
- p-i-p-n doping profile
- Geiger-mode avalanche photo diodes
- Incoming photon triggers charge avalanche discharging one pixel
- Avalanche may trigger neighbor pixel



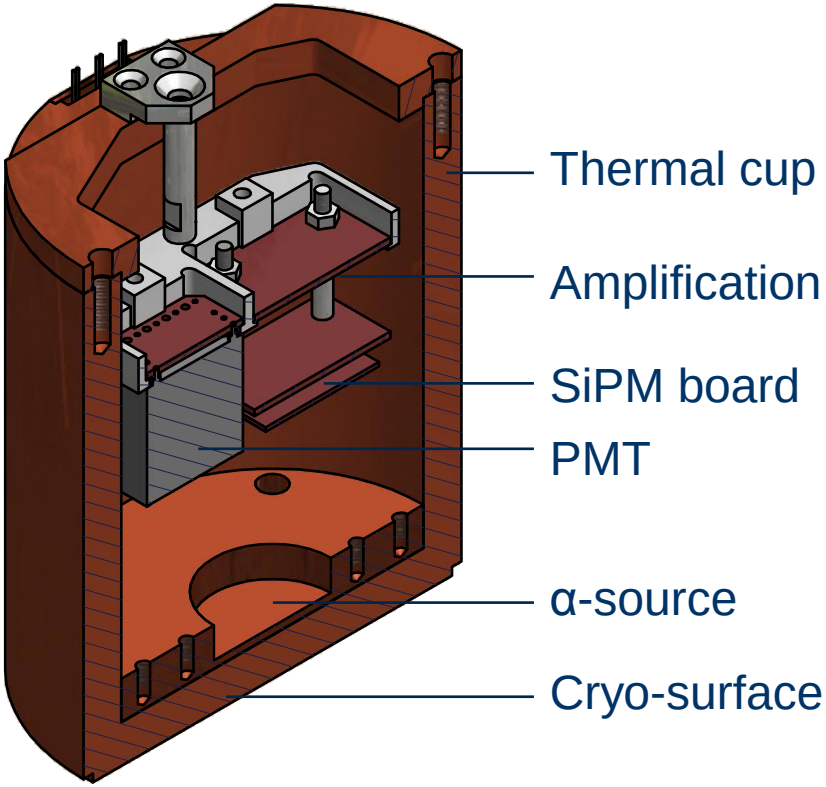
SiPM - Crosstalk



- Single photon response
- Pulse height spectrum corresponds to number of triggered pixels
- Crosstalk needs to be corrected
- Rescale spectrum with 1p.e. response



SiPM - PDE

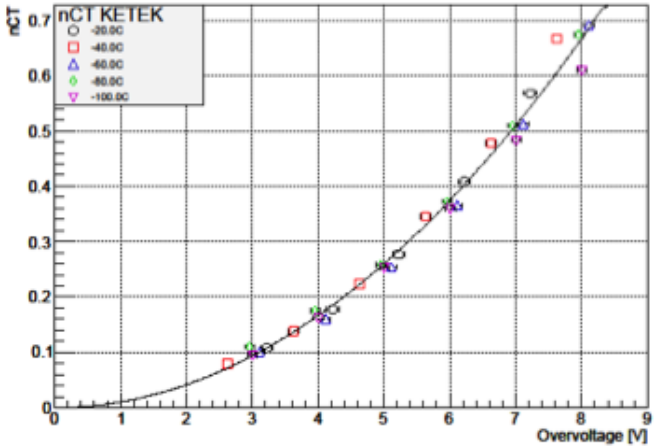


- Photon detection efficiency
- Probability for detecting impinging photons
- PDE depends on wavelength
- Reference detector necessary

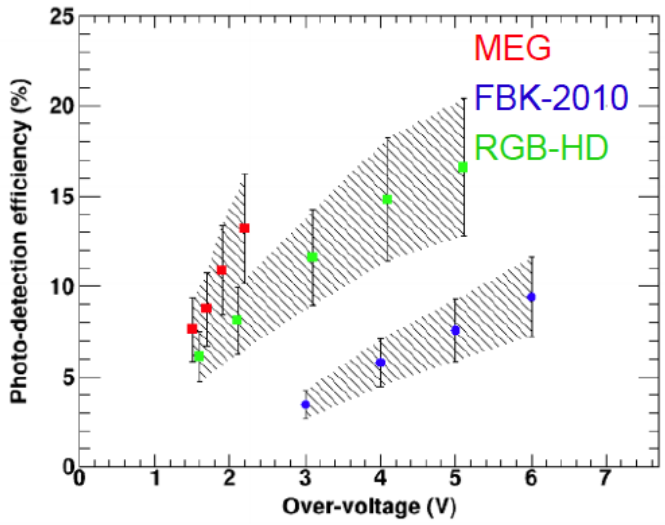
Measurement:

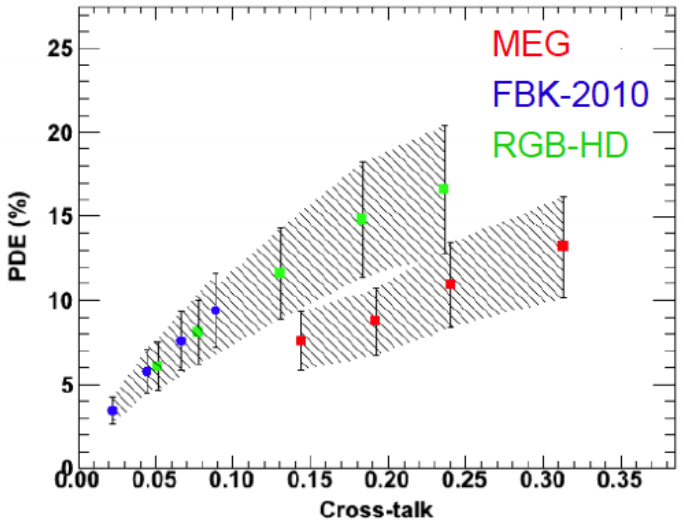
- Simulate flux within the cell
- Get detector surface areas
- Measure detection rate
- Correct for crosstalk
- Calculate PDE

SiPM - Results



- Crosstalk increases with overvoltage
- Higher bias yields higher gain and higher photon detection efficiency
- Tradeoff necessary
- nEXO requirements: >15% PDE and <20% correlated avalanches
- We are not there, yet!



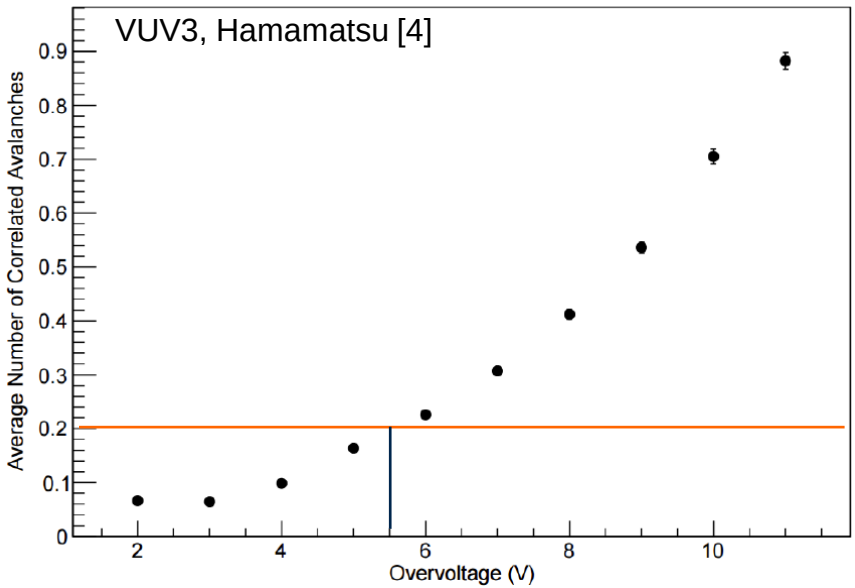


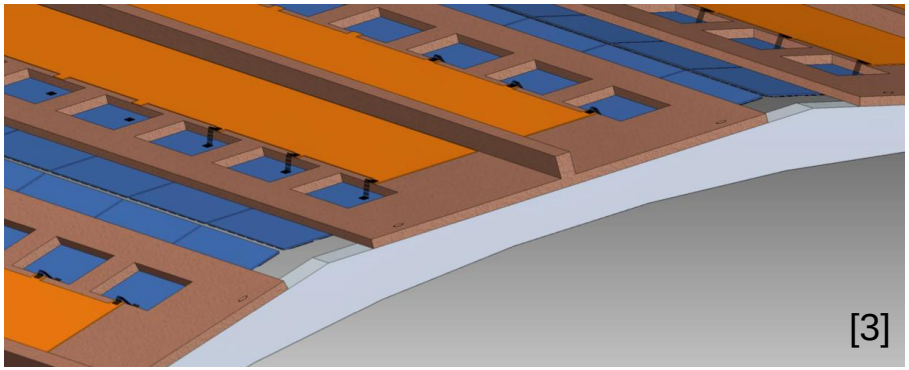
[5]

[5] Carl Rethmeier, TRIUMF; Compare to I. Ostrocskiy, arXiv:1502.07837v2

Future plans

Future plans





SiPM devices:

- Future devices need less crosstalk
- At least 15% PDE @ 178nm
- Stable amplification at high OV
- Radioactivity assay crucial

Detector system design:

- UV-sensitive SiPM-tiles (10x10cm^2)
- Reduce capacitance on channels
- Equip and operate large-area SiPM detectors
- Timeline for nEXO: construction start in 2020

Thanks a lot

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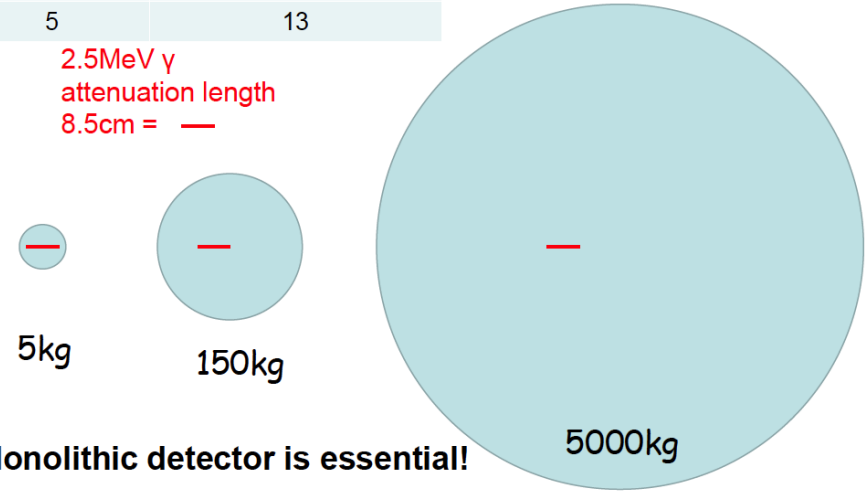
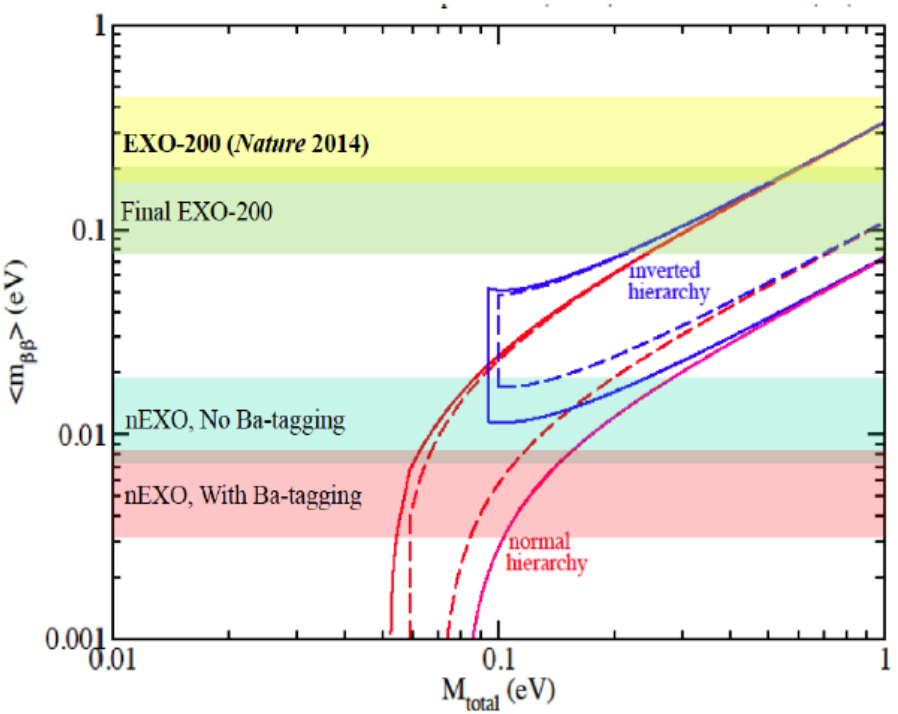
Backup

LXe mass (kg)	Diameter or length (cm)
5000	130
150	40
5	13

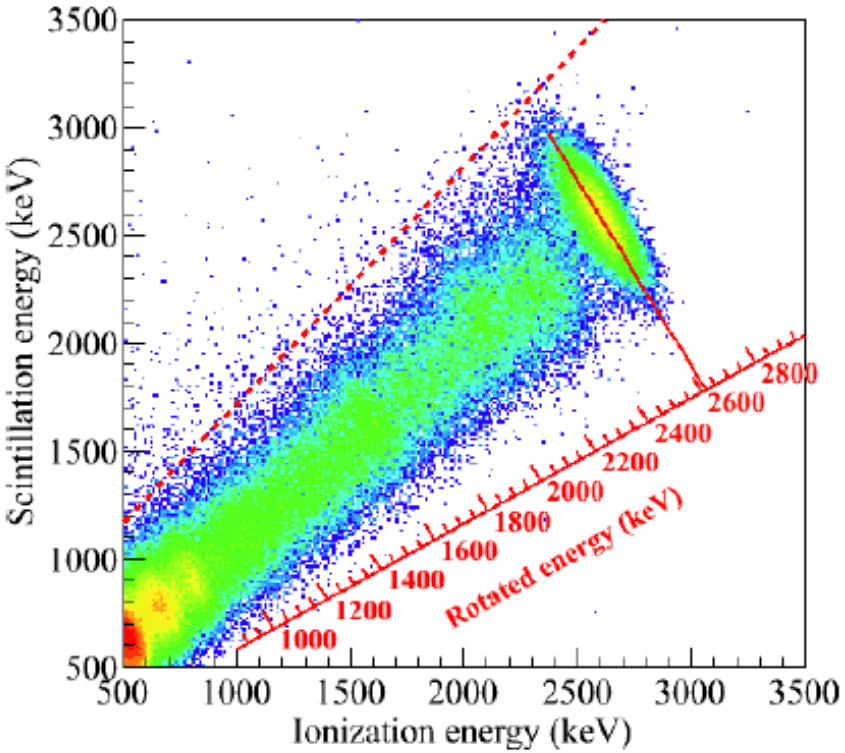
2.5MeV γ attenuation length 8.5cm =

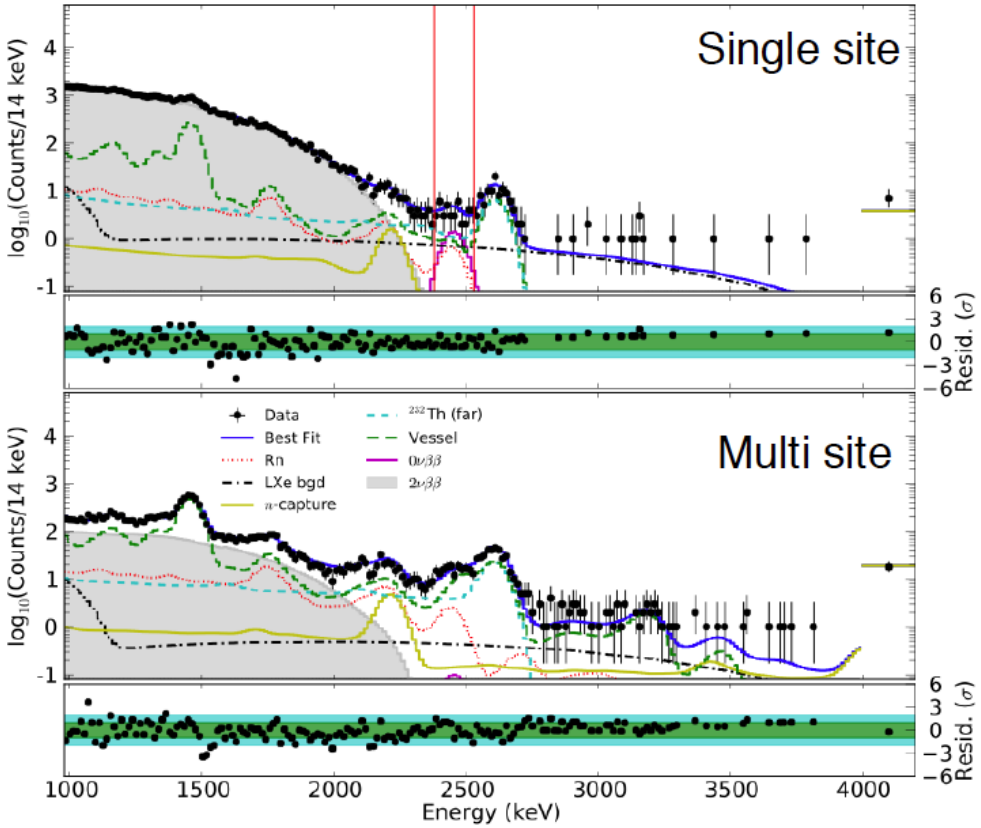


Monolithic detector is essential!



Backup

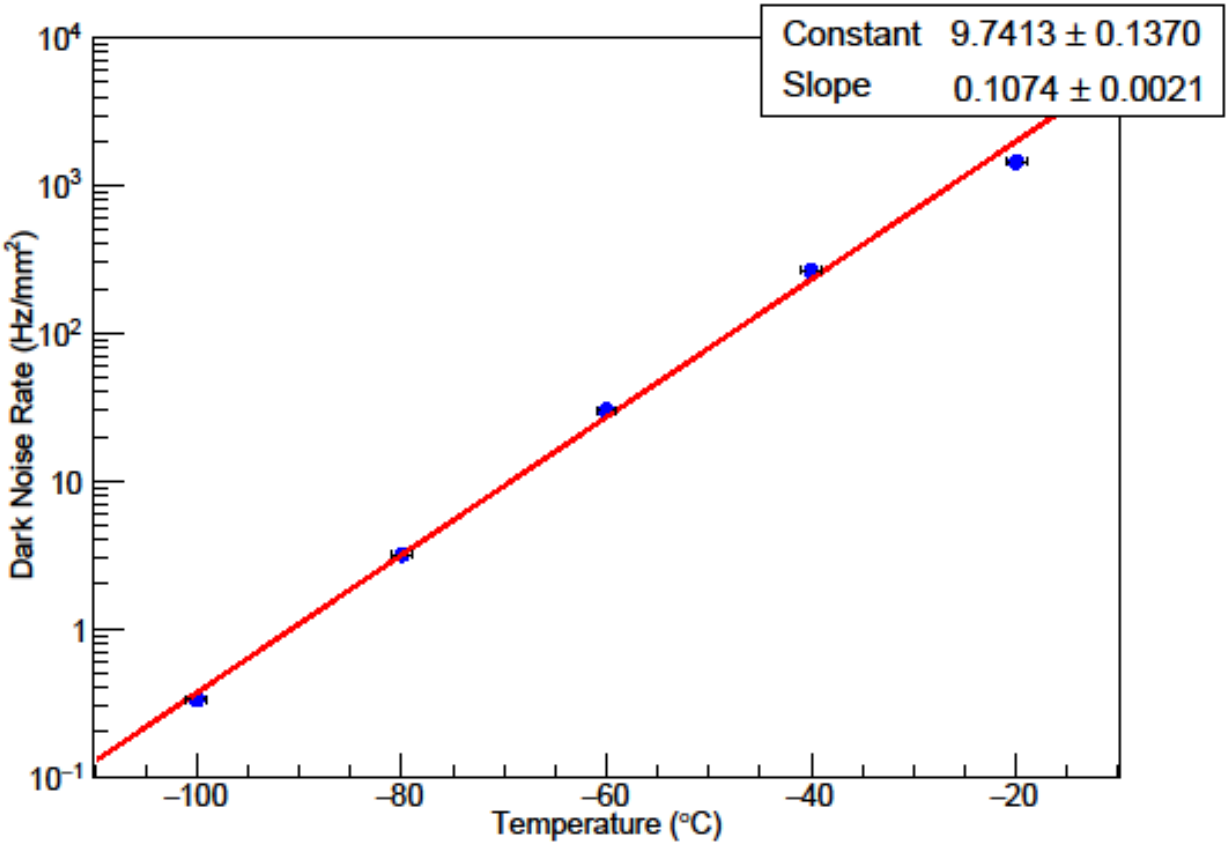

Scintillation energy (keV)
Ionization energy (keV)
Rotated energy (keV)
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800


Single site
Multi site
log10(Counts/14 keV)
Resid. (σ)
Data
Best Fit
Rn
LXe bgd
n-capture
232Th (far)
Vessel
0νββ
2νββ
Energy (keV)

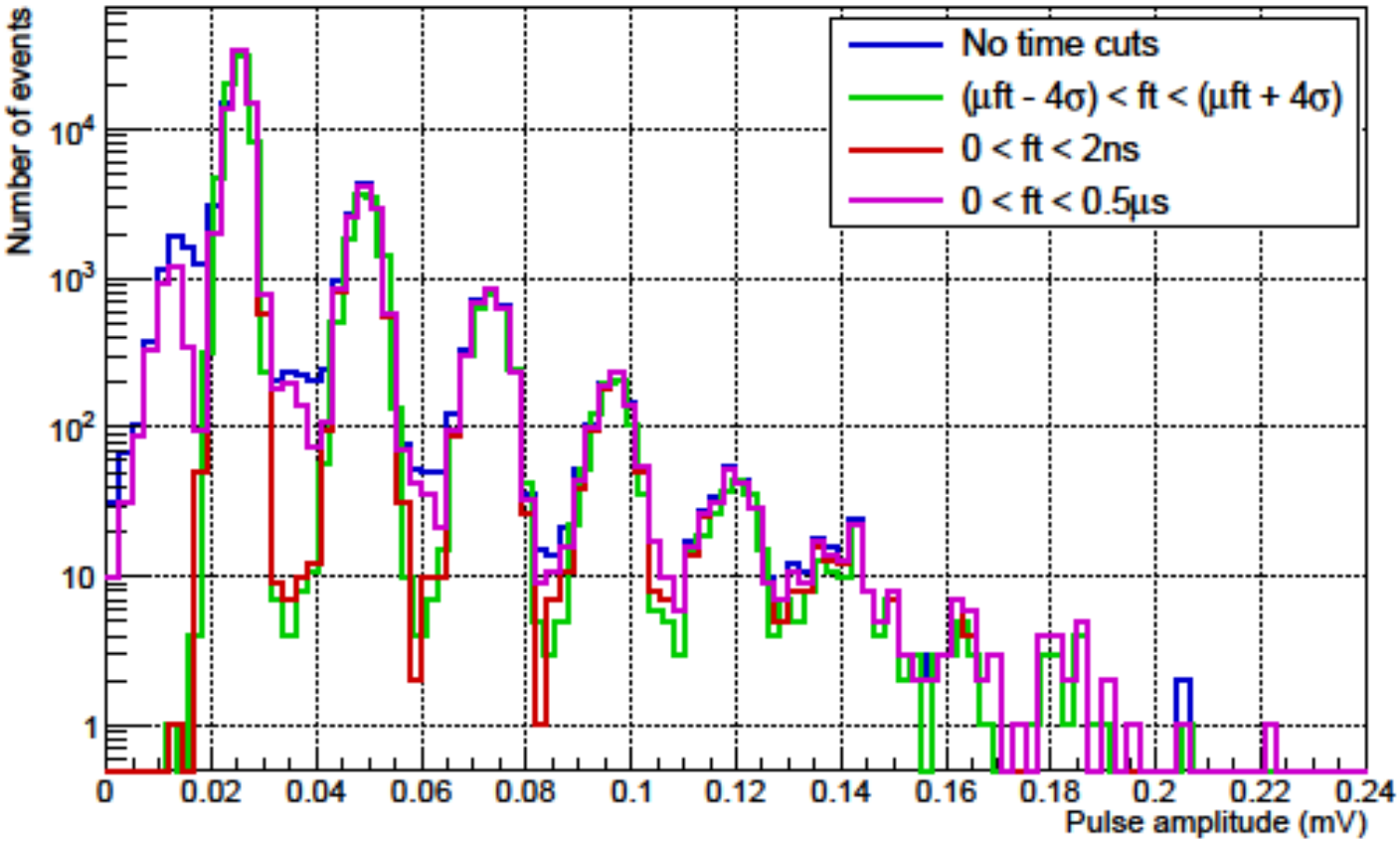
Backup

Parameters	Value
Photo-detection efficiency at 175-178nm in liquid Xenon	≥15%
Radiopurity: contribution of photo-detectors to the overall background	<1%
Dark noise rate at -100°C	≤50Hz/mm²
Average number of correlated avalanches (cross-talk and after-pulse) per parent avalanche at -100°C within 10µs	≤0.2
Single photo-detector active area	≥1cm²
Capacitance	*<50pF/mm²*
Gain fluctuations + electronics noise	<0.1PE

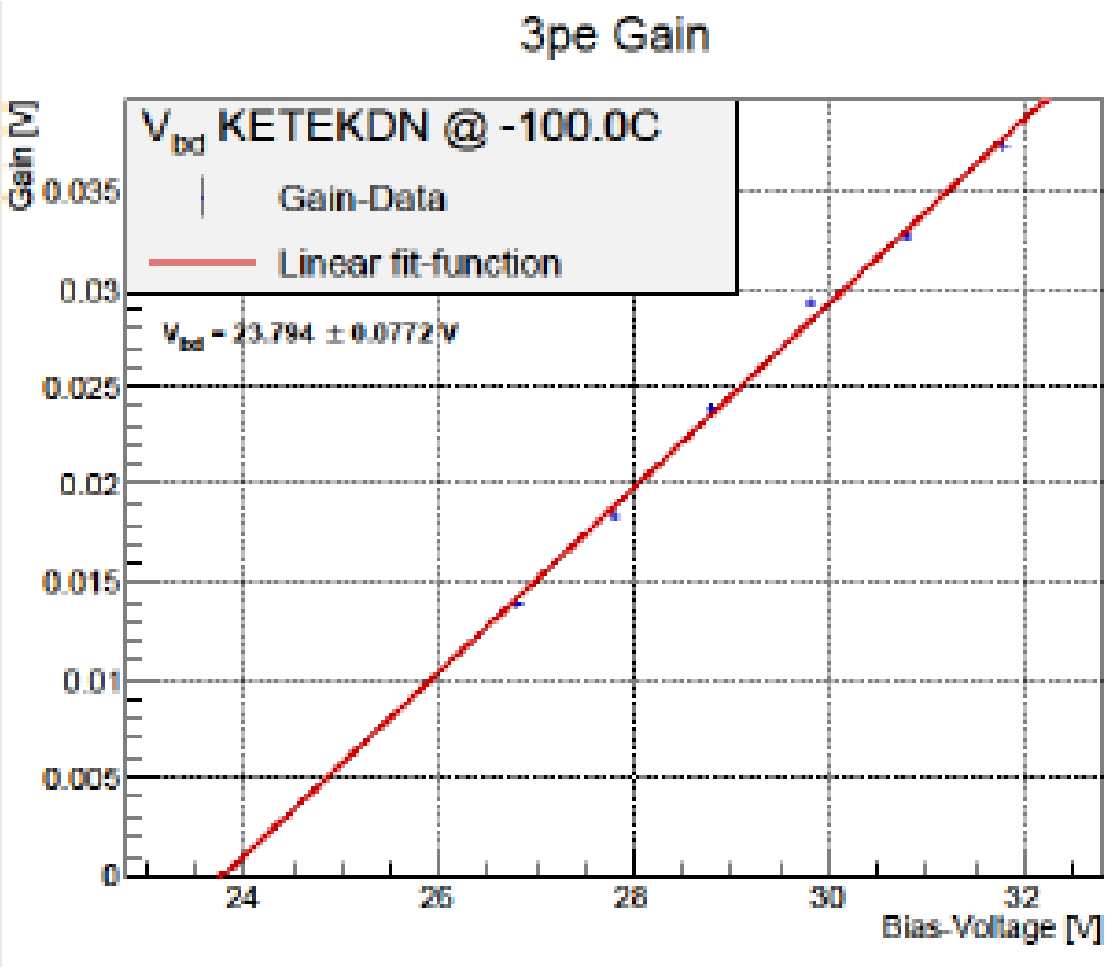
Backup


Constant 9.7413 ± 0.1370
Slope 0.1074 ± 0.0021
Dark Noise Rate (Hz/mm²)
Temperature (°C)
10⁴
10³
10²
10
1
10⁻¹
–100
–80
–60
–40
–20

Backup


No time cuts
(μft - 4σ) < ft < (μft + 4σ)
0 < ft < 2ns
0 < ft < 0.5μs
Number of events
10^4
10^3
10^2
10
1
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
Pulse amplitude (mV)

Backup


3pe Gain
V_{bd} KETEKDN @ -100.0C
Gain-Data
Linear fit-function
V_{bd} = 23.794 ± 0.0772 V
Gain [V]
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
24
26
28
30
32
Bias-Voltage [V]