VUV-sensitive SiPMs for light detection in the nEXO experiment

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Michael Wagenpfeil
SAT‘17, 7.10.2017

Enriched Xenon Observatory for double beta decay

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FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

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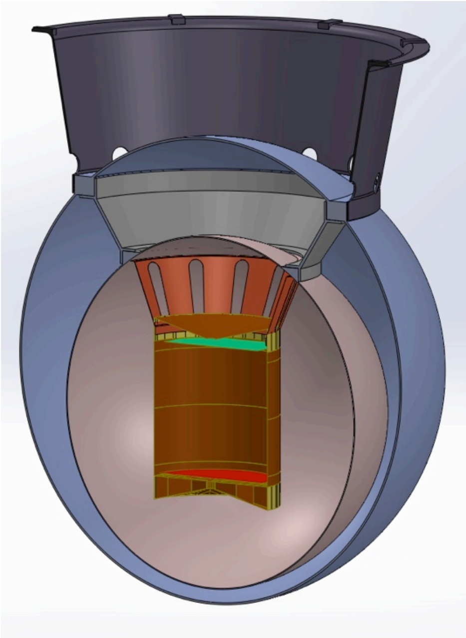
- Planned low-background experiment
- Location: Sudbury mine, Ontario (6000 m.w.e.)
- High material radiopurity
- TPC filled with 5 tonnes LXe
- Diameter & height ~ 1.3 meters



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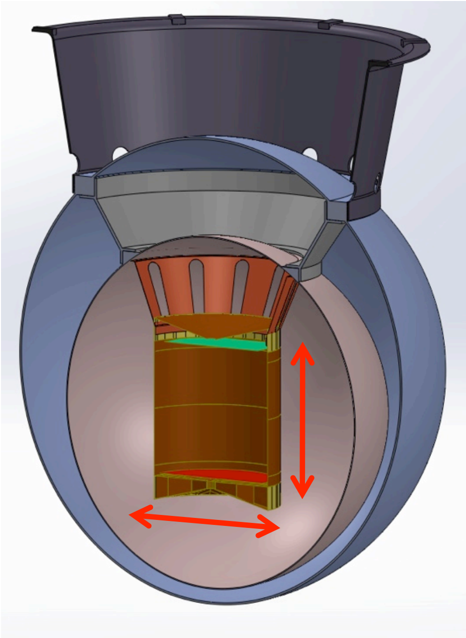

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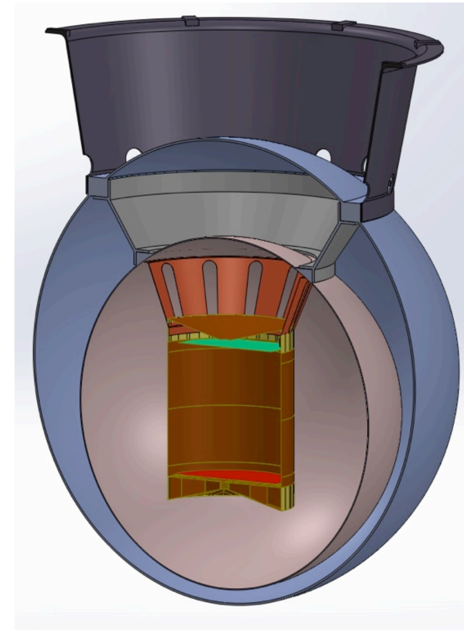

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Released charge carriers   Scintillation light

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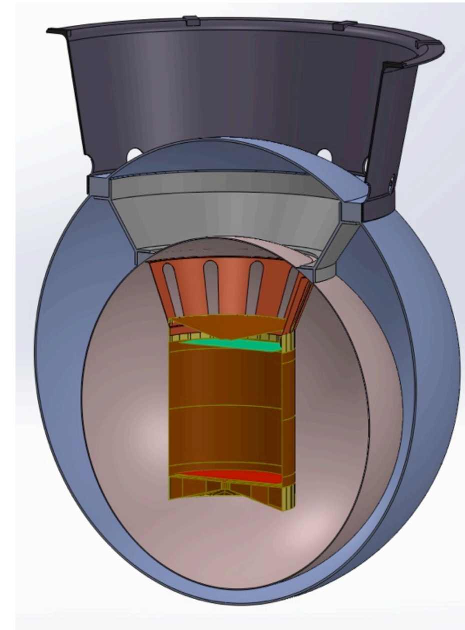


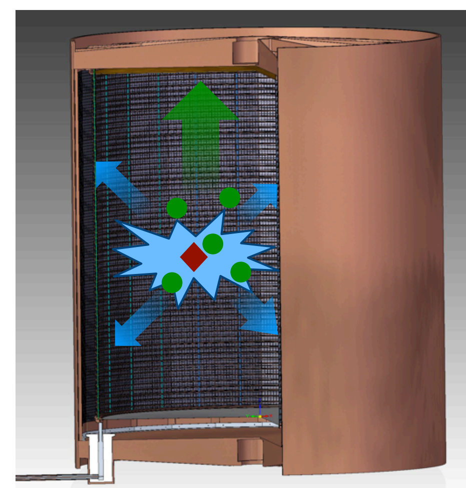
Event

Released charge carriers

Drifted to the top
- High electric drift field
- Cathode on bottom
- Anode tiles for charge det.

Scintillation light

Detected at inner wall
- 4 m^2 photo-detectors
- VUV-sensitivity (178 nm)
- High reflectivity coating



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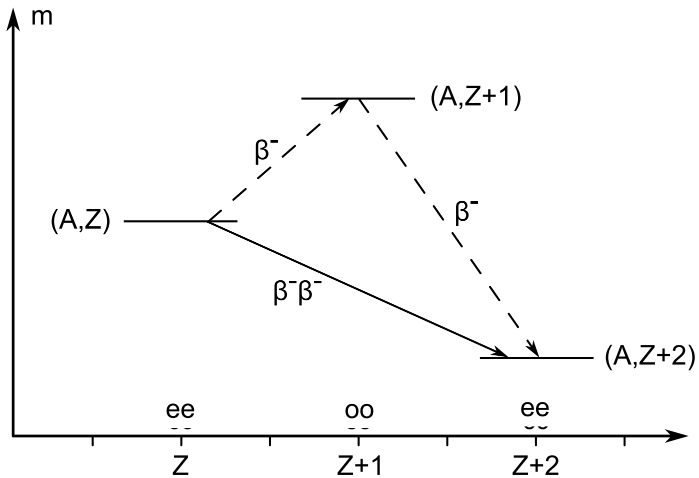
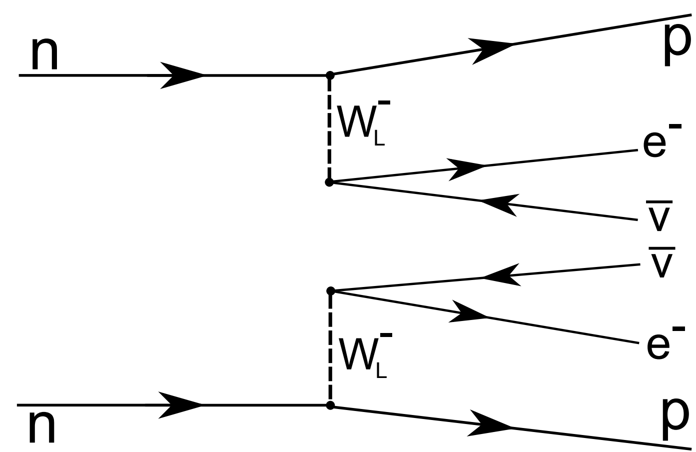
~~Neutrinoless~~ double beta decay

- Possible if single beta channel energetically forbidden
- Only ee-nuclei (^{76}Ge, ^{116}Cd, ^{136}Xe,...)
- Second order weak process
- Half-lives of 10^{18} – 10^{21} years





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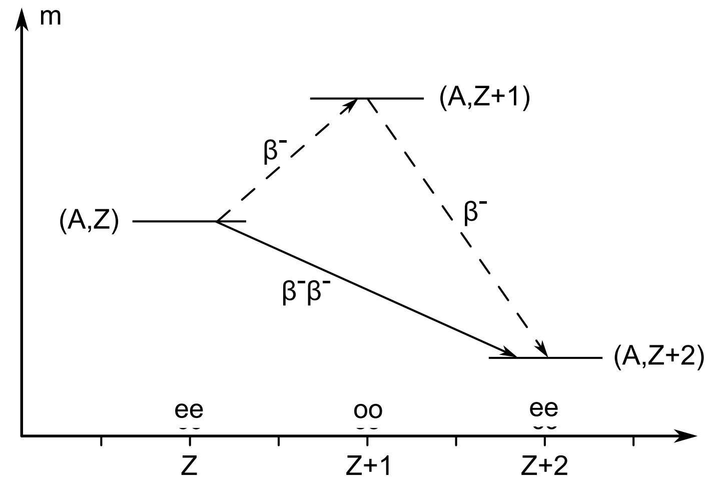

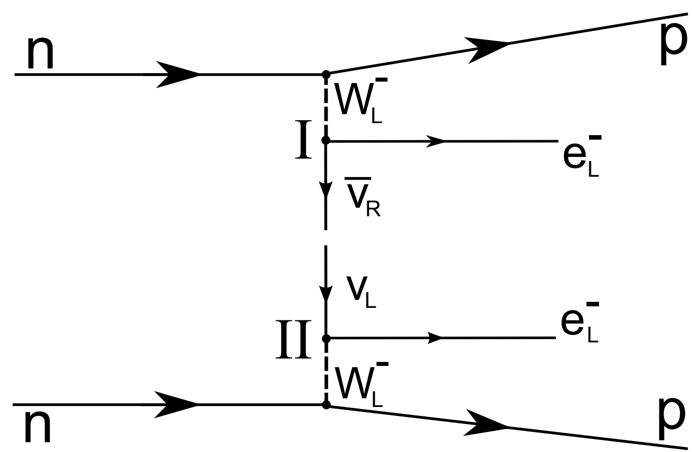

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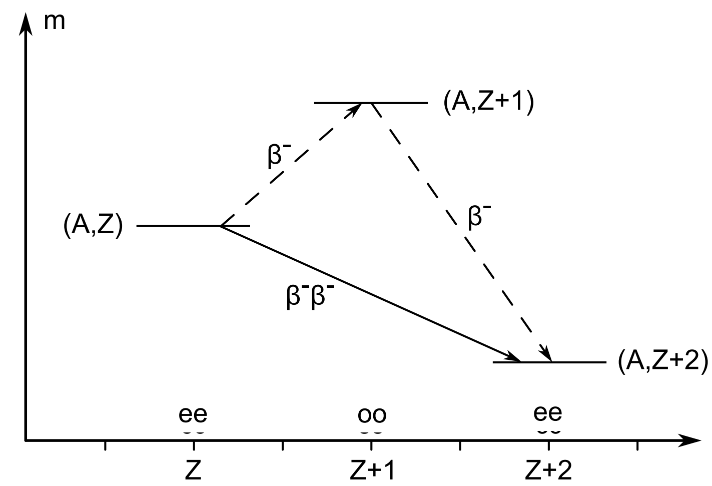


Necessary:

- Neutrino has mass
- Neutrino is its own anti-particle ($\nu = \bar{\nu}$)

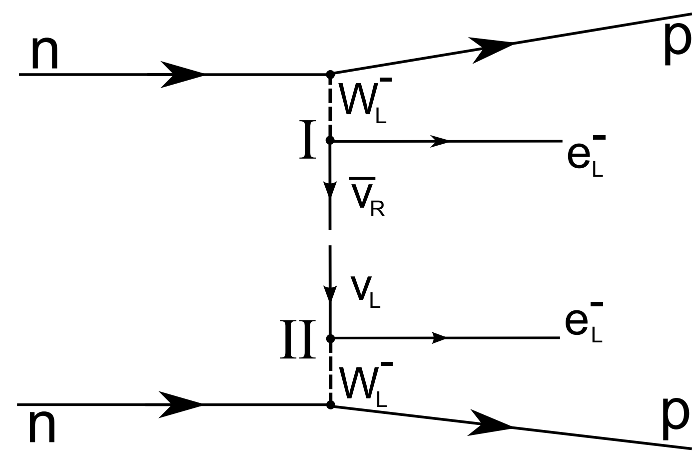
➢ SM-violation

➢ Hypothetical

➢ Enormous half-life

e.g. $T^{0\nu}_{1/2} > 1.1 \times 10^{26}$ yr; ^{136}Xe [A.Gando *PRL* (2016)]

➢ Good energy discrimination crucial



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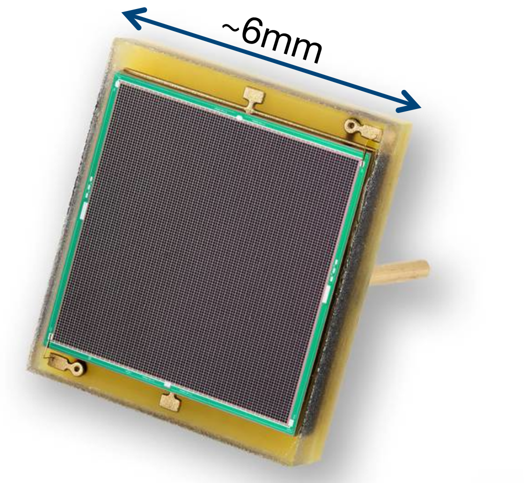
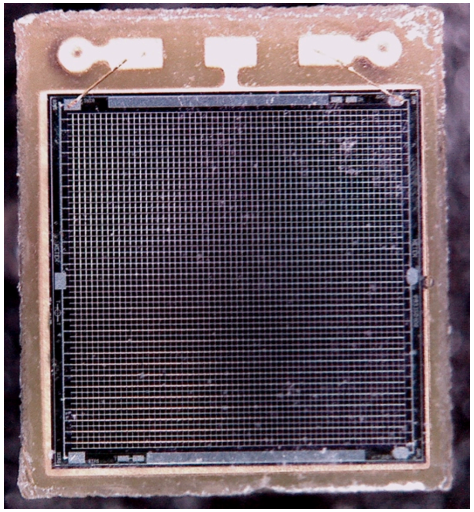
- Reverse bias (~30-60V)
- Geiger-mode (avalanche breakdown)
- High gain, radiopurity, pixel homogeneity; Low noise @ LXe temperature





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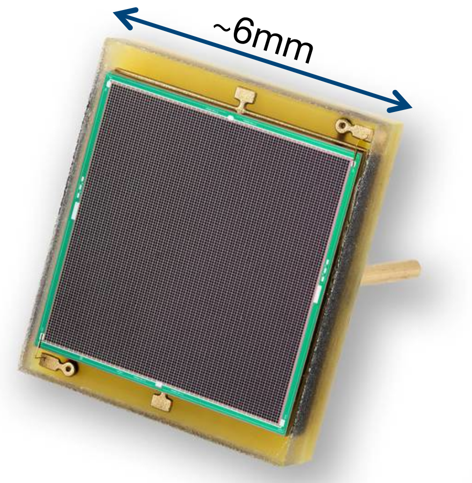

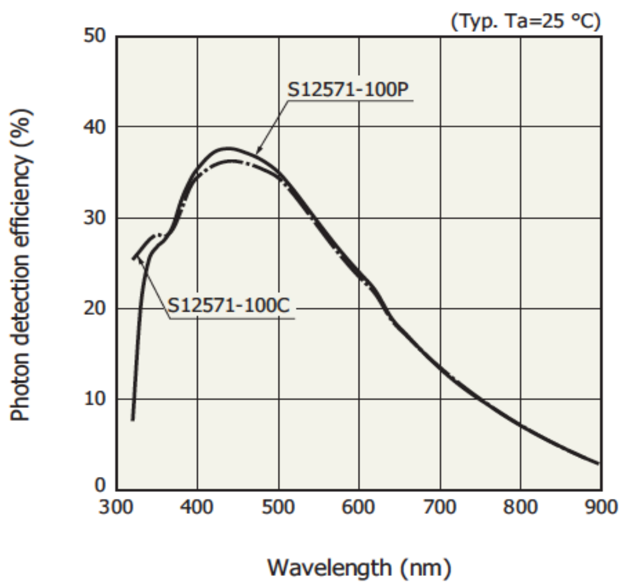

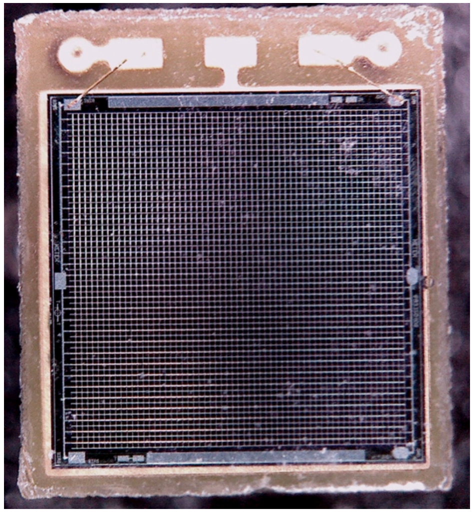

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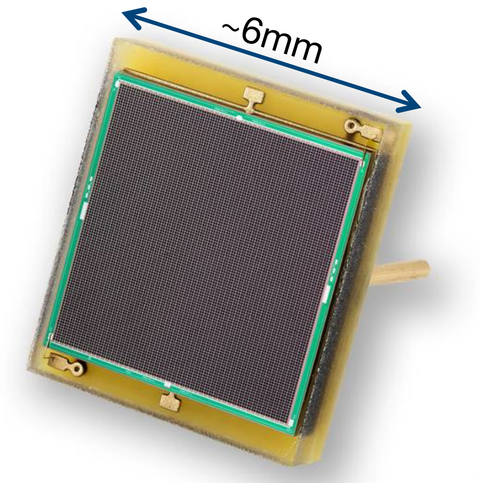

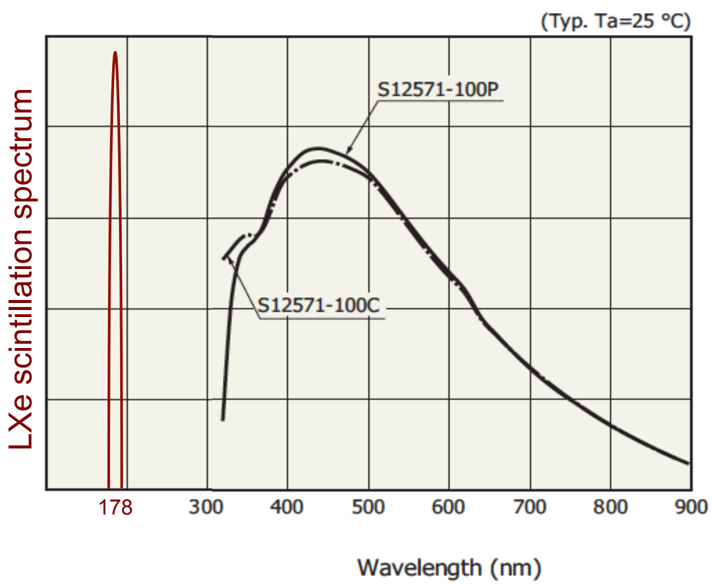

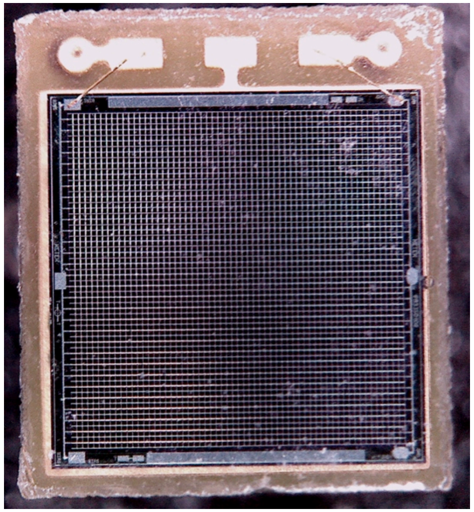

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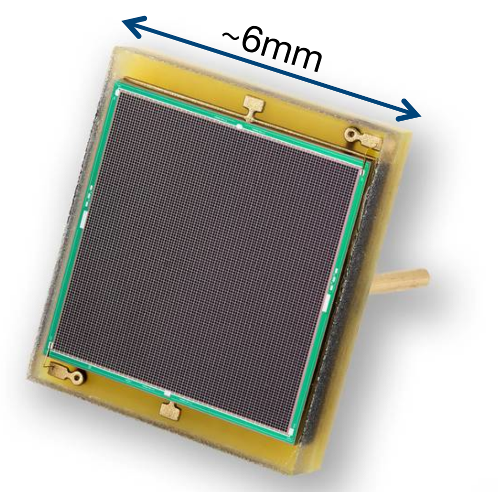
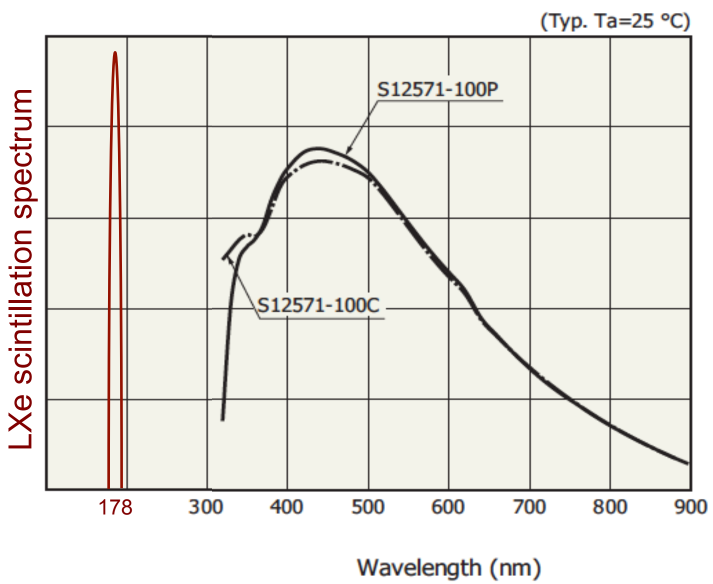
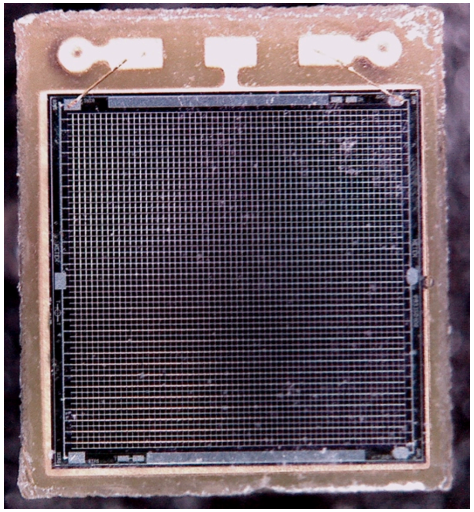
- PDE crucial detector characteristic







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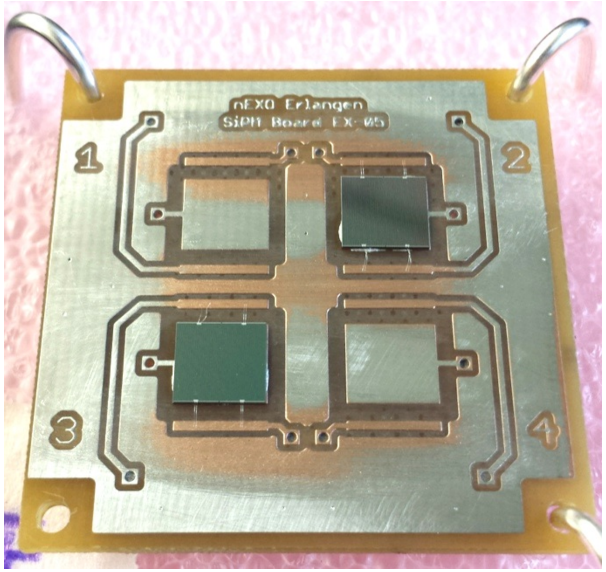
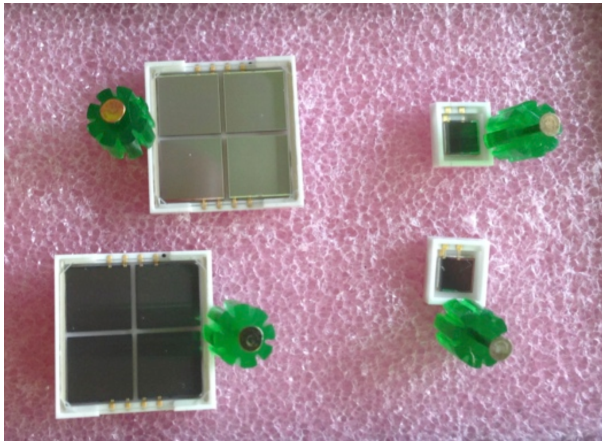
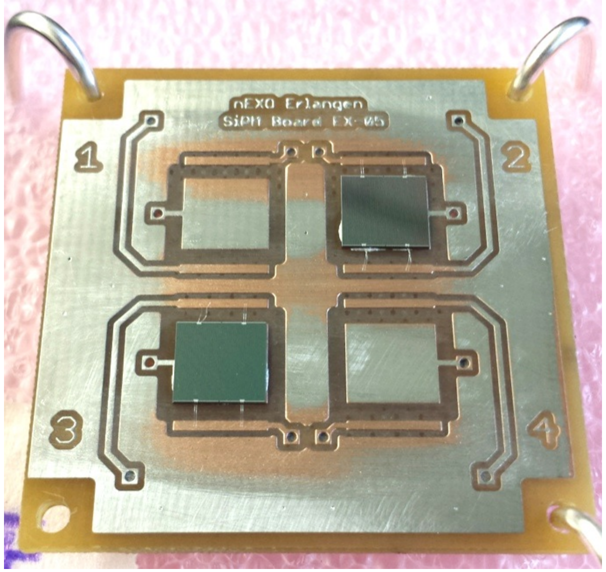


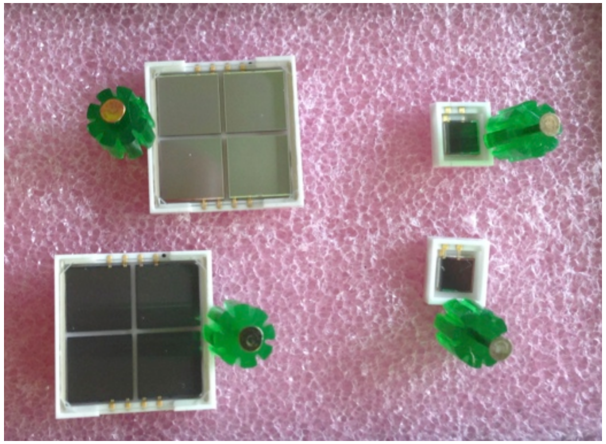


SiPM characterisation

- VUV-sensitive SiPMs from Hamamatsu and FBK

1) PDE (photon detection efficiency)
    - Measure rate from external light source
    - Compare to device with known PE





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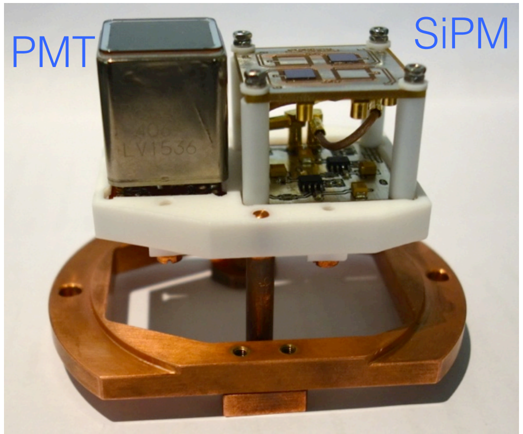

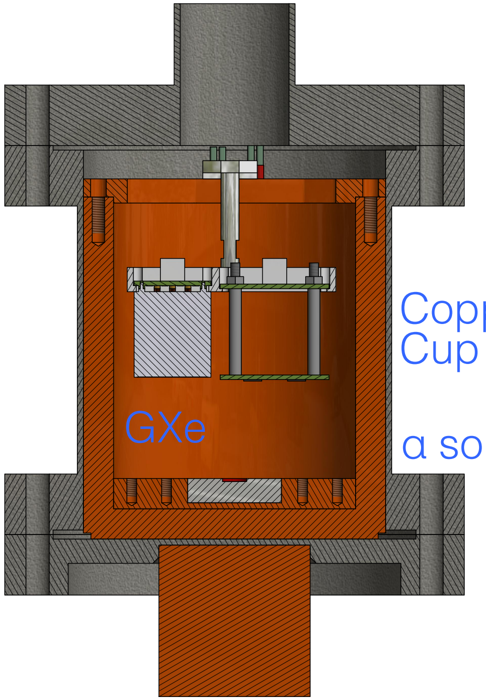

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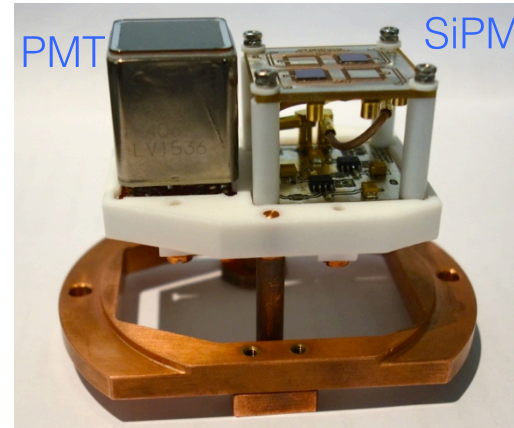

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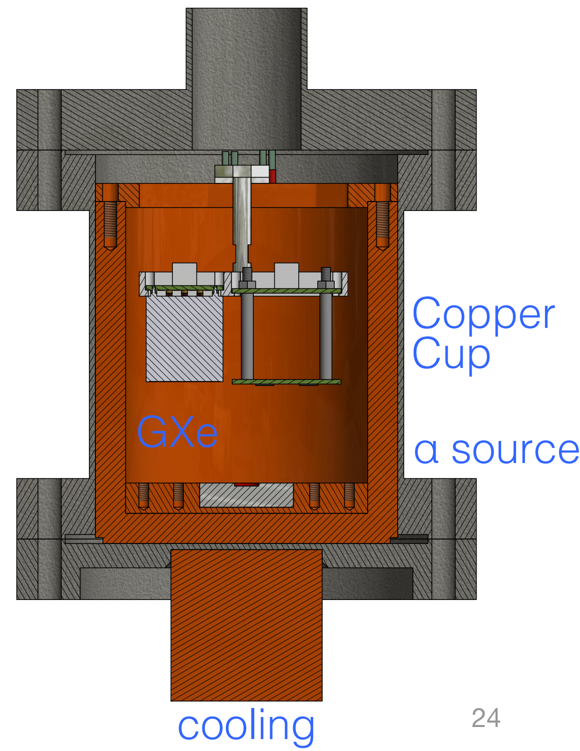

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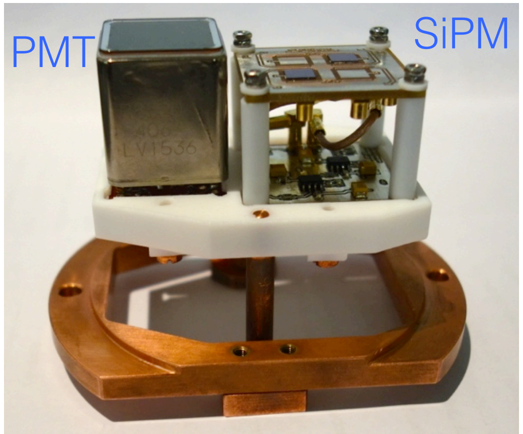
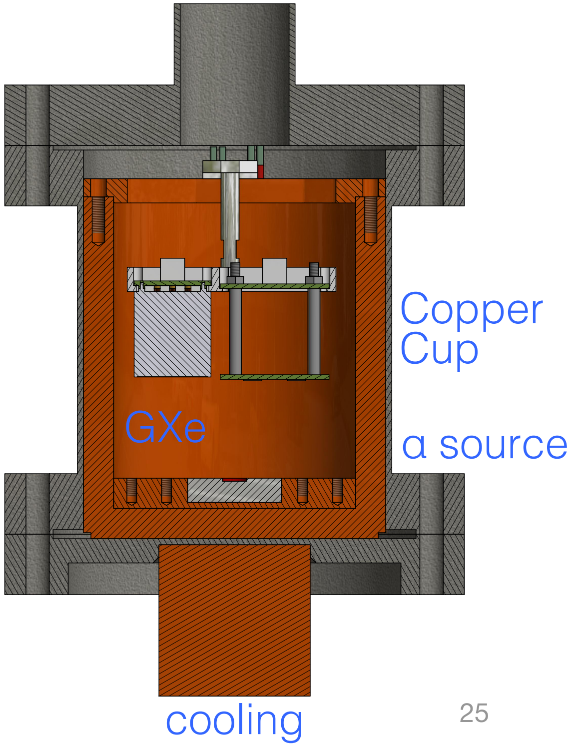
2) Dark-rate, breakthrough-voltage, gain, electronic noise, crosstalk, afterpulsing
3) Reflectivity





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- Examine reflectivity of SiPM surfaces in LXe for xenon scintillation light

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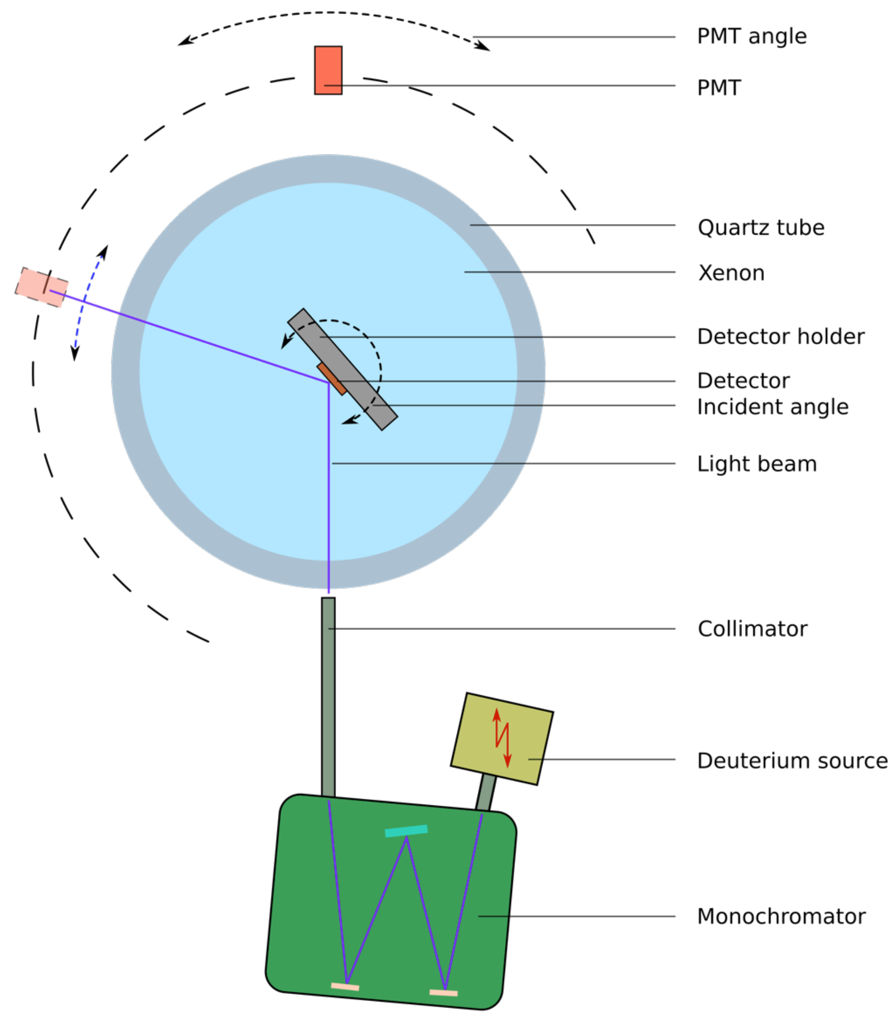

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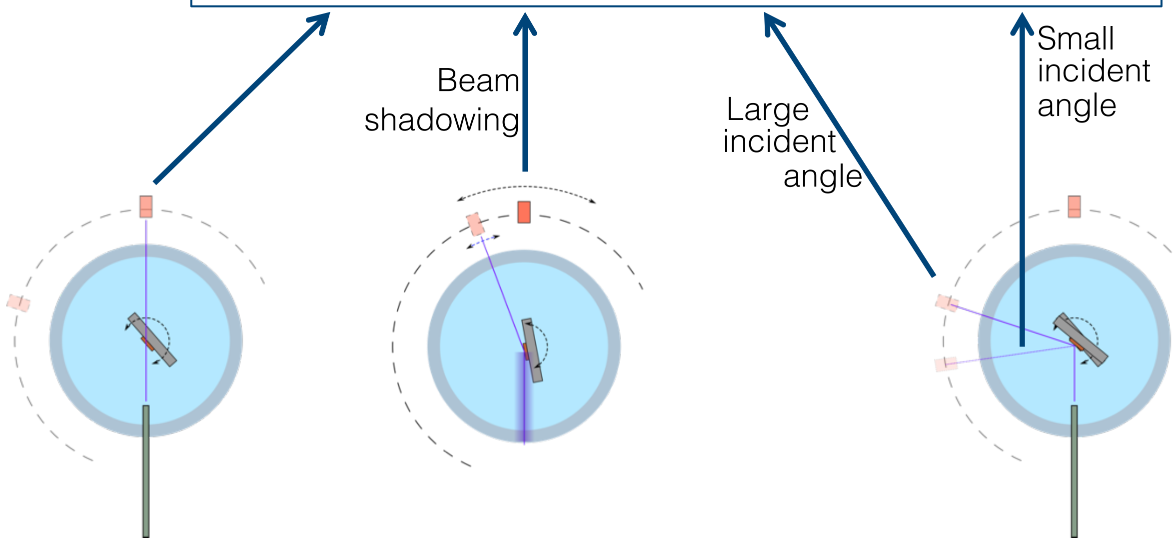

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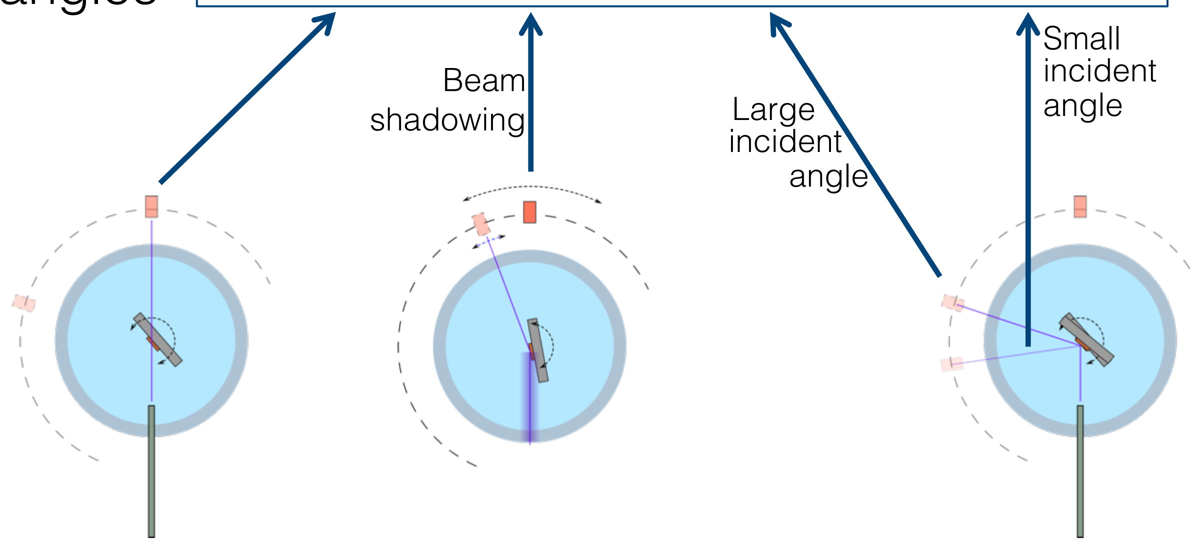

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Future

- Xenon liquefaction and recuperation system

(6) Pressure control for re-usage

(2) Pressure control

(1) Gas inlet

(3) Two step purification

(5) recuperation

(4) liquefaction

Thanks

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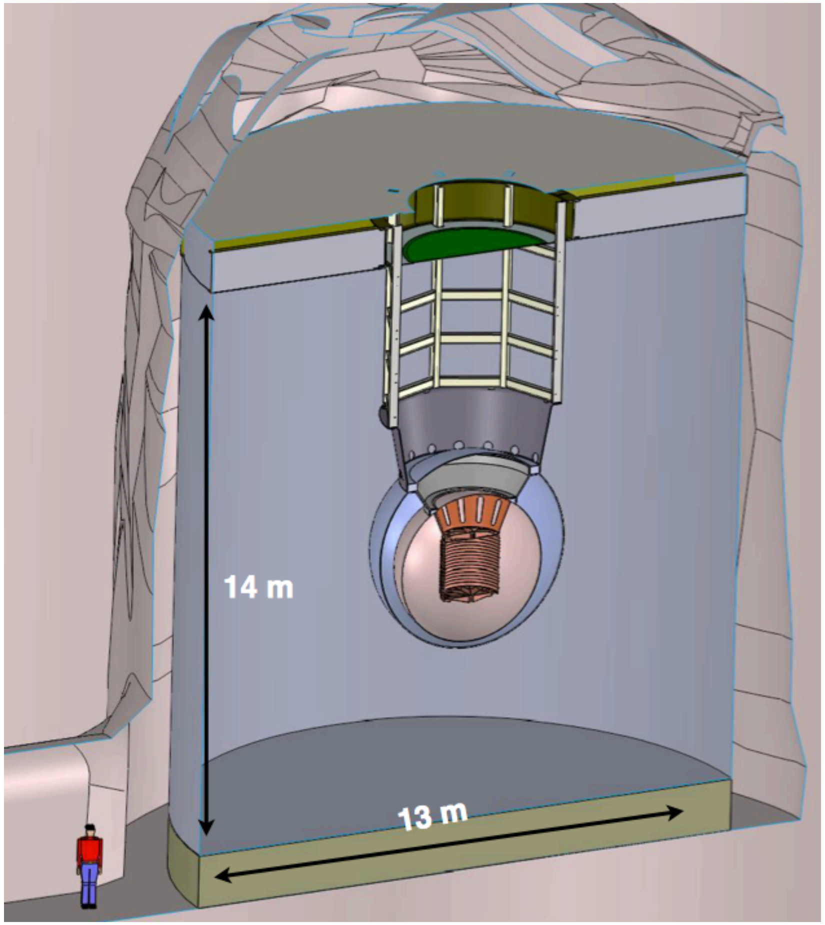
nEXO



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

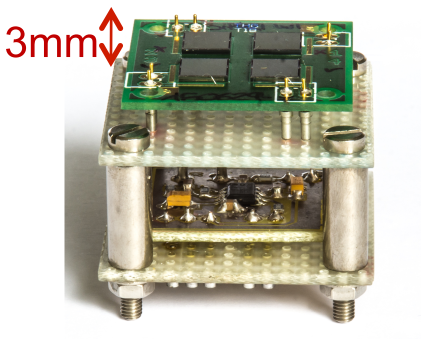
$$m_{\beta\beta} \sim \sqrt{1/\varepsilon} \left(\frac{c \cdot \Delta E}{M_{\beta\beta} \cdot t}\right)^{1/4}$$ [2]

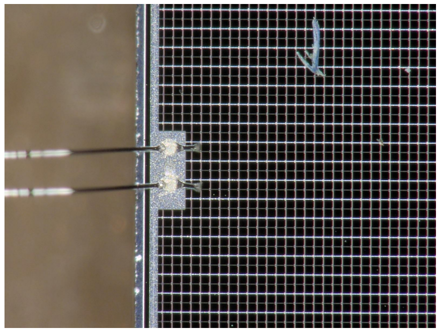
What we plan:

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

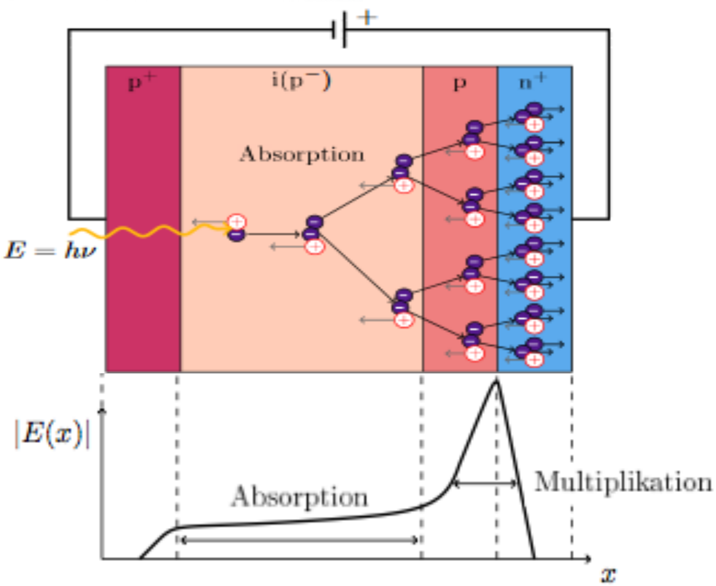
[2] J. J. Gomez-Cadenas et. al., arXiv:1109.5515 (2011)

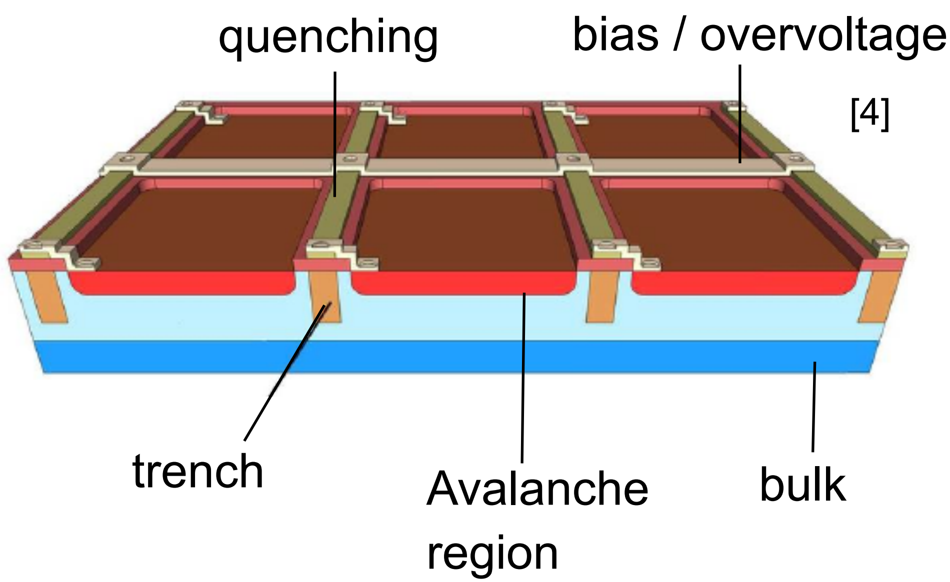
SiPM - Principle



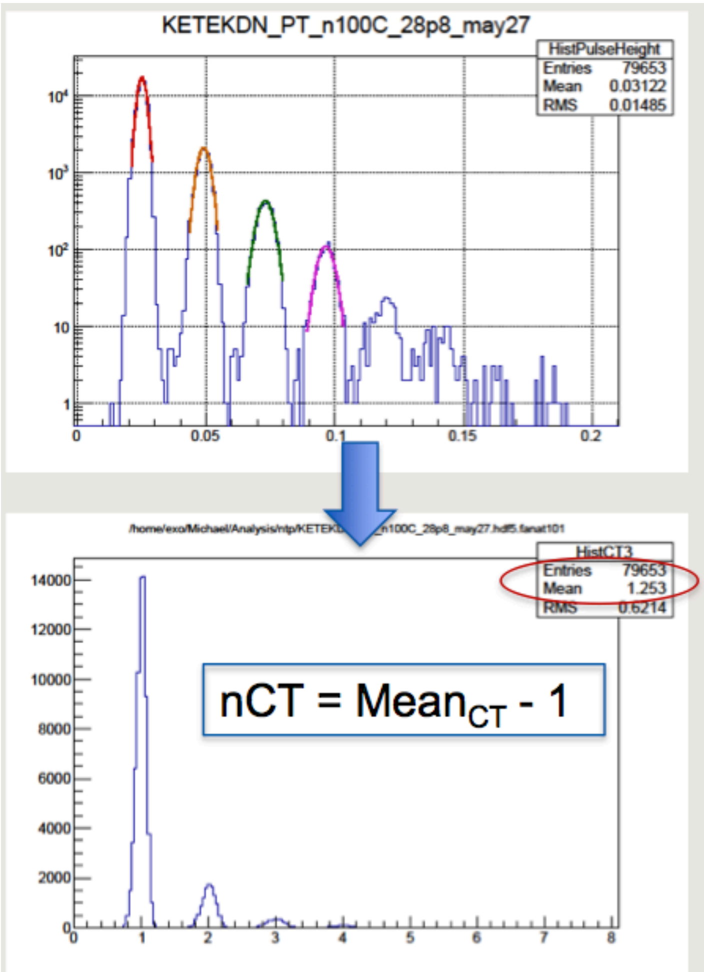


- Pixelated semiconductor detectors
- p-i-p-n doping profile
- Geiger-mode avalanche photo diodes
- Incoming photon triggers charge avalanche discharging one pixel
- Avalanche may trigger neighbor pixel

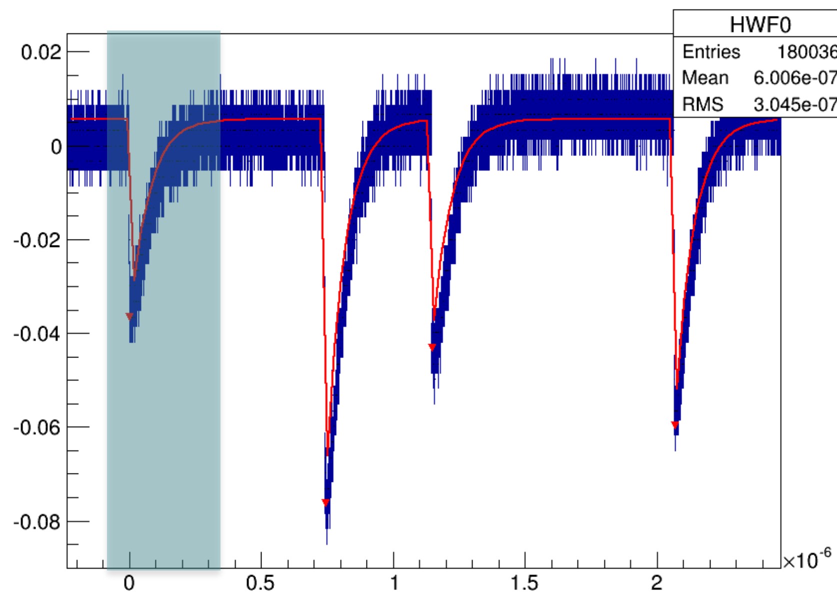




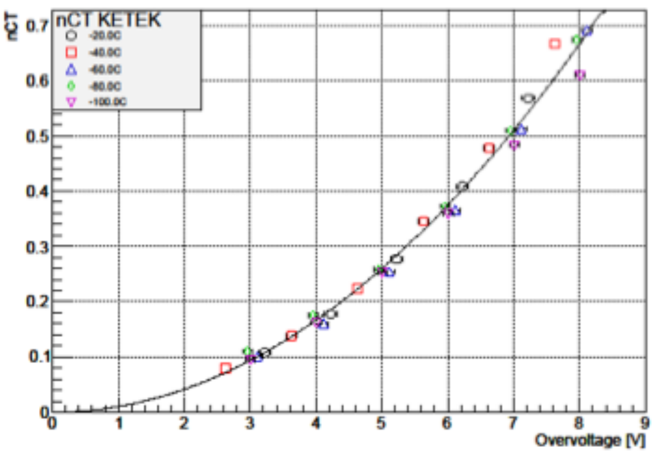
SiPM - Crosstalk



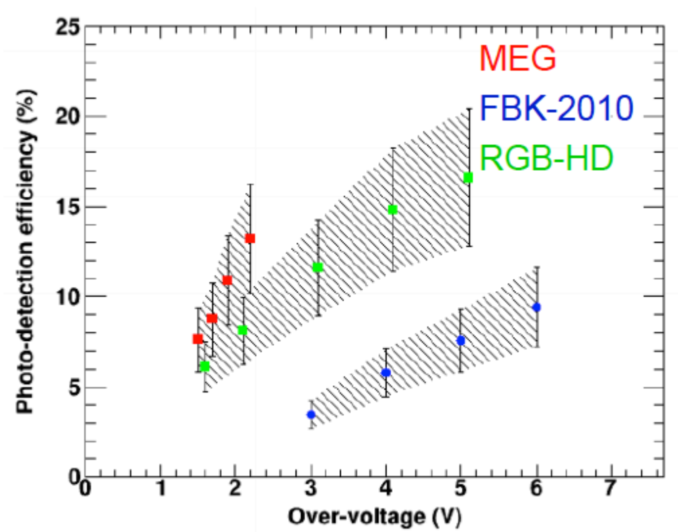
- Single photon response
- Pulse height spectrum corresponds to number of triggered pixels
- Crosstalk needs to be corrected
- Rescale spectrum with 1p.e. response

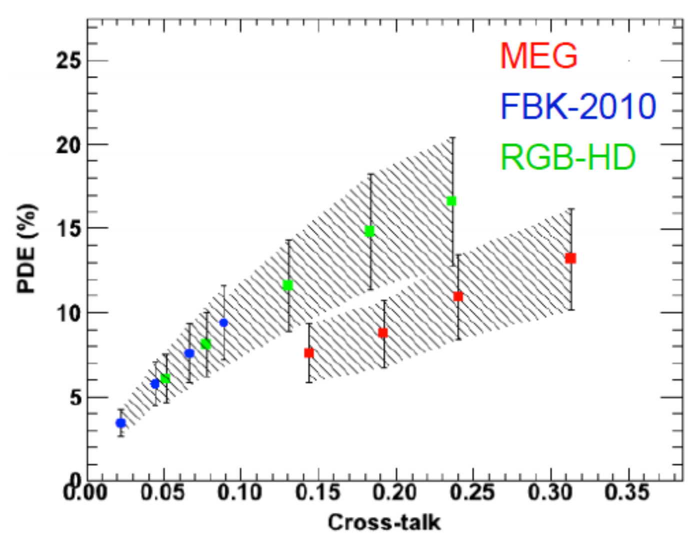


SiPM - Results



- 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]

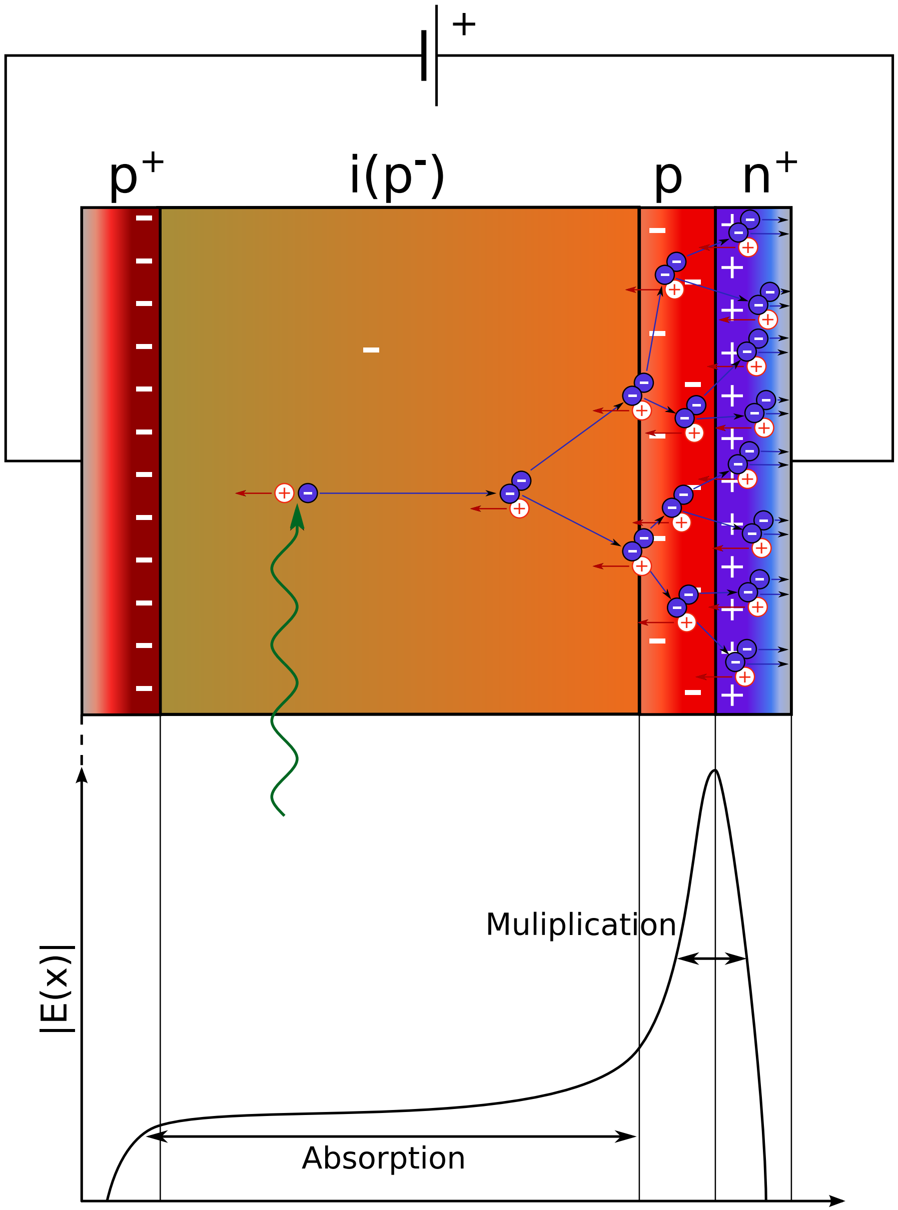
[5] Carl Rethmeier, TRIUMF; Compare to I. Ostrocskiy, arXiv:1502.07837v2

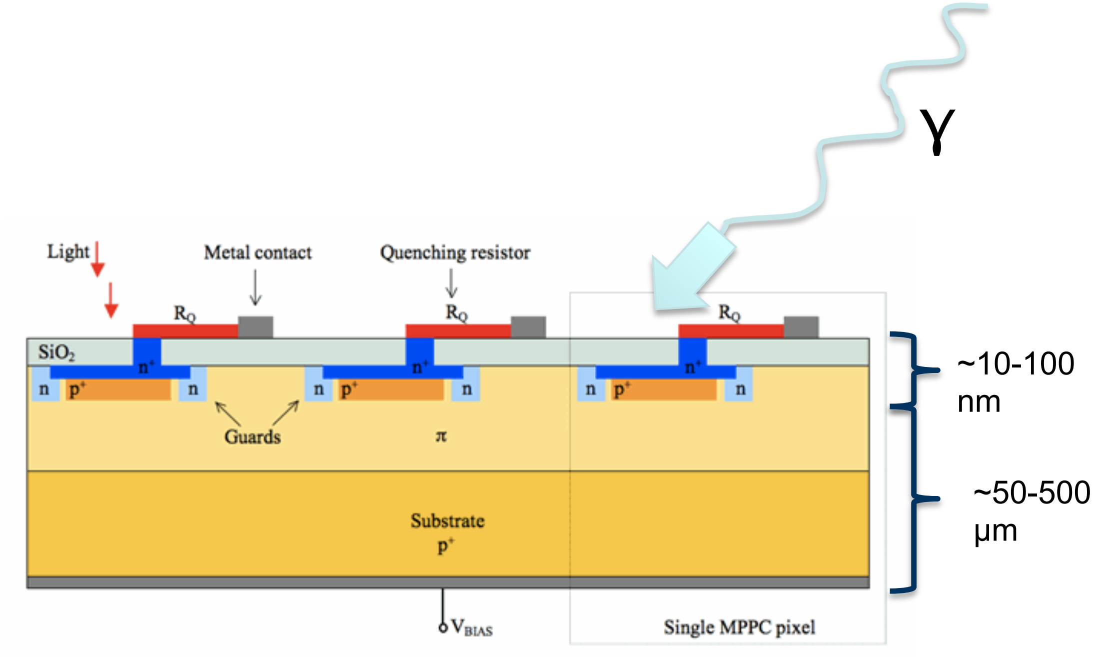
Bonus

- Large thickness Geiger-mode detectors difficult
- Split absorption and multiplication domain
- Add additional p-layer

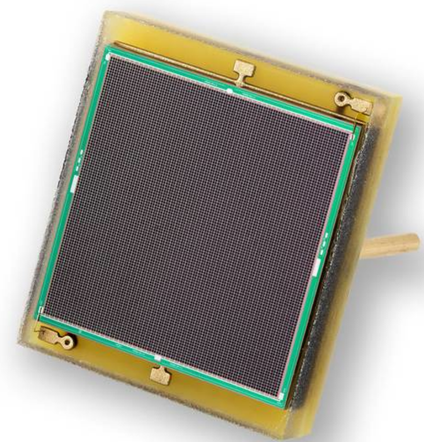
- Photos is absorbed via photo-effect
- Photoelectron follows E-field to multipl. domain
- charge carrier avalanche forms

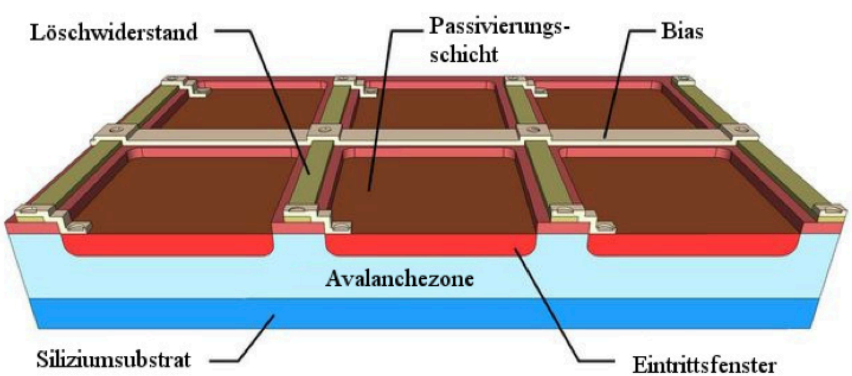
- Problem: large dead time or low rate limit
- Solution: pixelize device



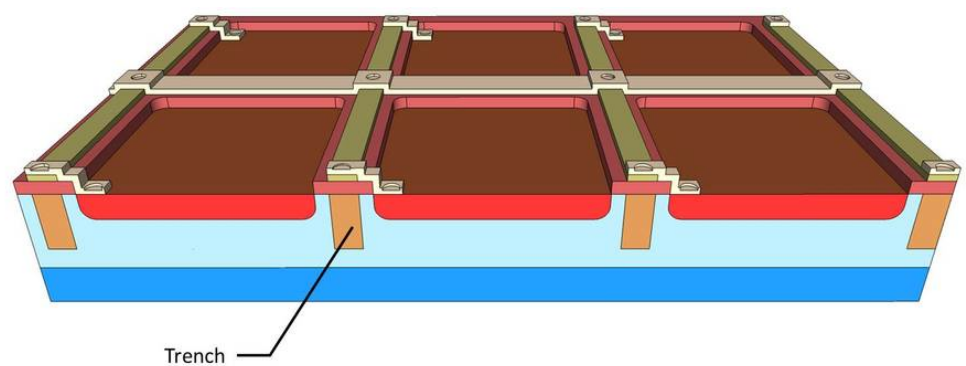


γ
Light
Metal contact
Quenching resistor
R_Q
SiO$_2$
n$^+$
n
p$^+$
Guards
π
Substrate
p$^+$
V_{BIAS}
Single MPPC pixel
~10-100 nm
~50-500 µm





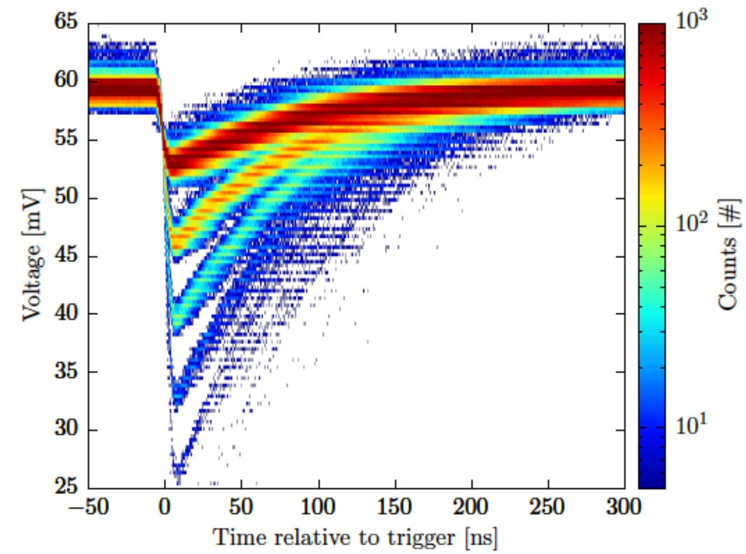
Löschwiderstand
Passivierungs-schicht
Bias
Avalanchezone
Siliziumsubstrat
Eintrittsfenster



Trench

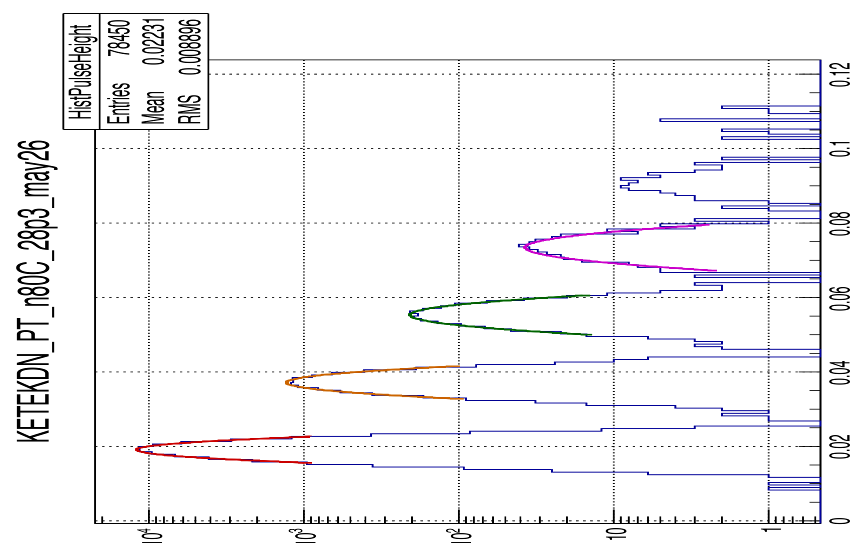
Bonus

- SiPMs detect photoelectrons NOT photons
- Can't distinguish between different effects to create free electrons within the detector
- Dark events due to thermal excitation

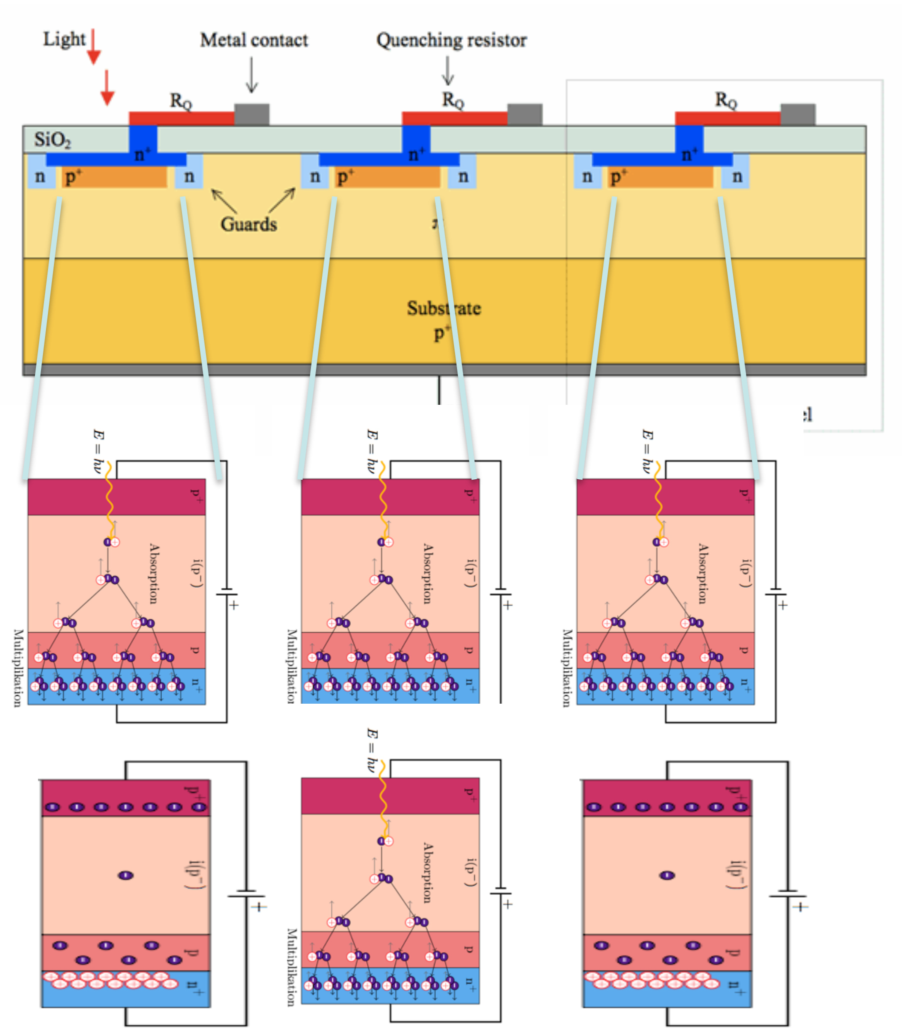


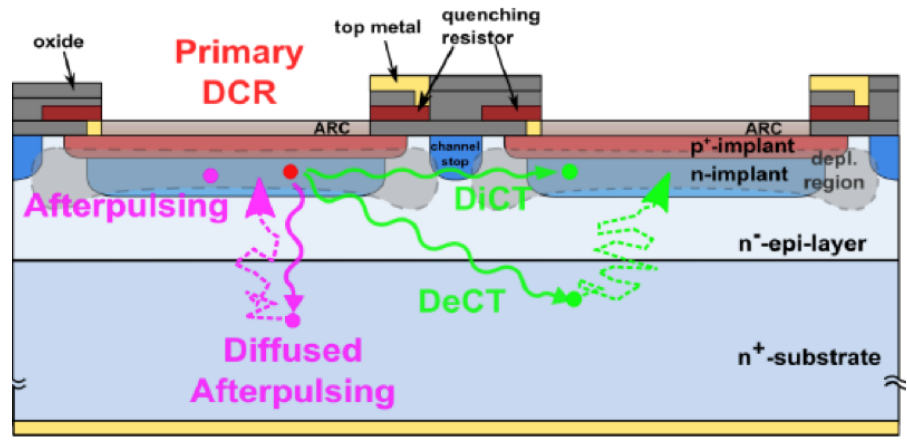
- Peaks refer to number of fired microcells = pixels
- can be identified as sum of events that equal 1 (2,3,…) photoelectrons (p.e.)
- Again: we do not count photons:

p.e. = photo<u>electron</u> equivalent



Bonus





- Direct crosstalk: second pixel triggered by diffused photons of primary avalanche
- Delayed crosstalk: same process but parasitic charge carrier generated in substrate and drifted to second pixel
- More exotic: crosstalk reflection and external crosstalk