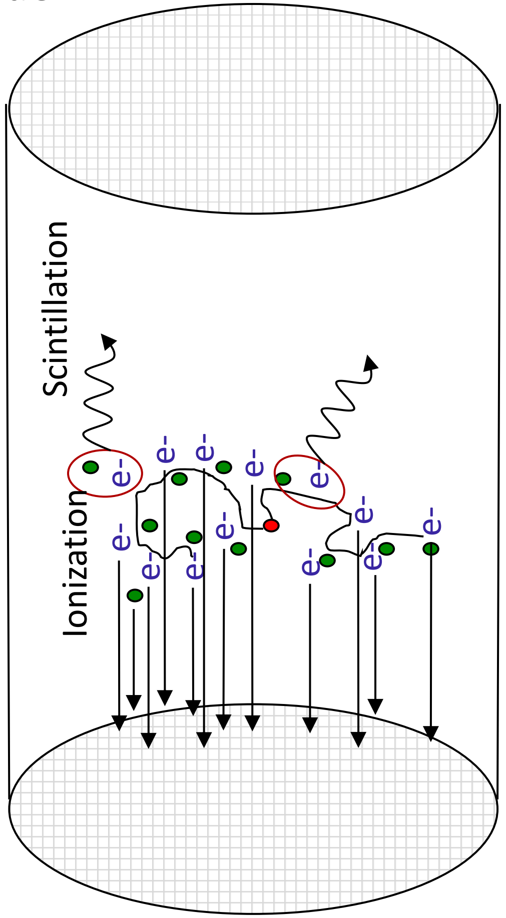
# SiPM R&D for NEXO

F. Retière on behalf of the nEXO photo-detector group

Discovery, accelerated

# Searching for $0\nu\beta\beta$ in $^{136}Xe$ with liquid Xe TPC



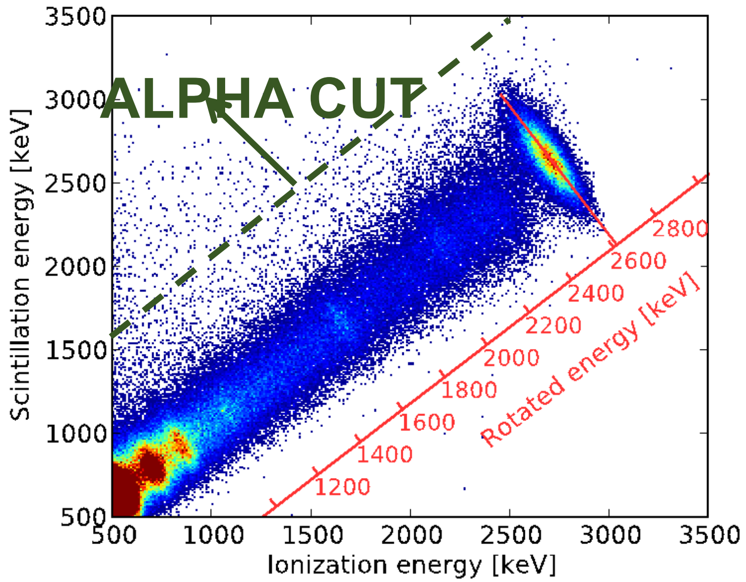



## Liquid-Xe Time Projection Chamber (TPC)

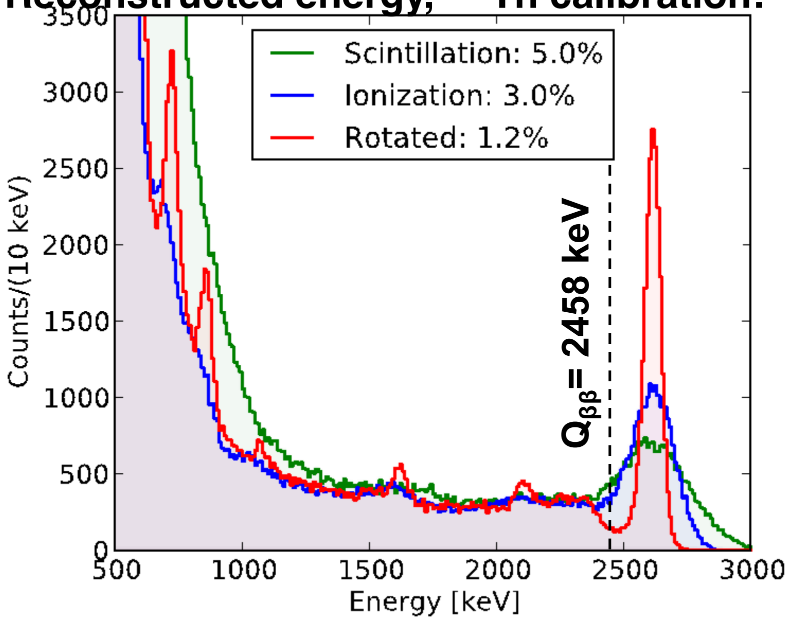
- Xe is used both as the source and detection medium.
- Monolithic detector structure, excellent background rejection capabilities.
- Cryogenic electronics in LXe.
- Detection of scintillation light and secondary charges.
  - 2D read out of secondary charges at segmented anode.
  - Full 3D event reconstruction using also scintillation light:
    1. Energy reconstruction
    2. Position reconstruction
    3. Event Multiplicity

# Light + charge for optimum energy resolution

**Scintillation vs. ionization, $^{228}$Th calibration:**



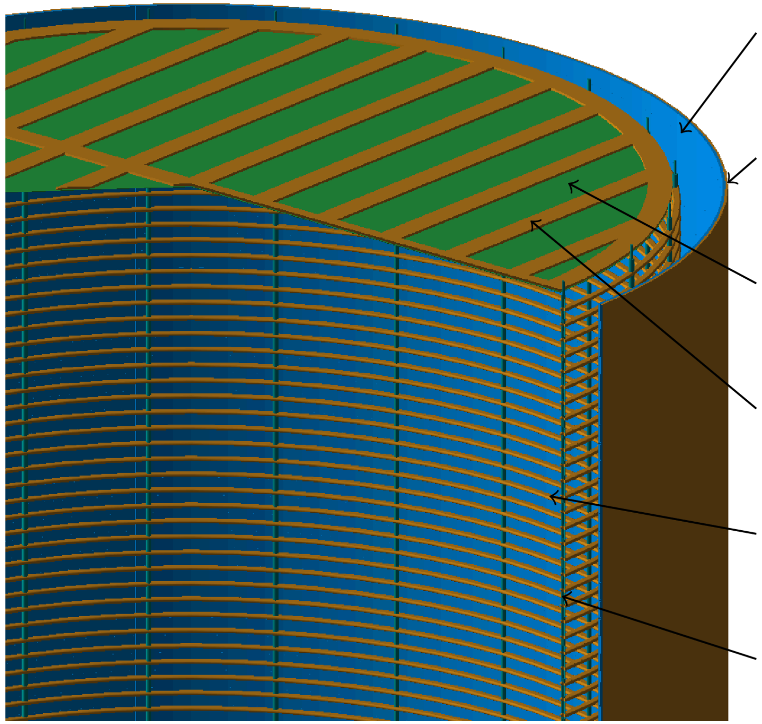

**Reconstructed energy, $^{228}$Th calibration:**




- Anticorrelation between scintillation and ionization in LXe known since early EXO R&D [E.Conti et al. Phys Rev B 68 (2003) 054201]
- Rotation angle determined weekly using $^{228}$Th source data, defined as angle which gives best rotated resolution
- EXO-200 has achieved ~ 1.23% energy resolution at the double-beta decay Q value in Phase II.

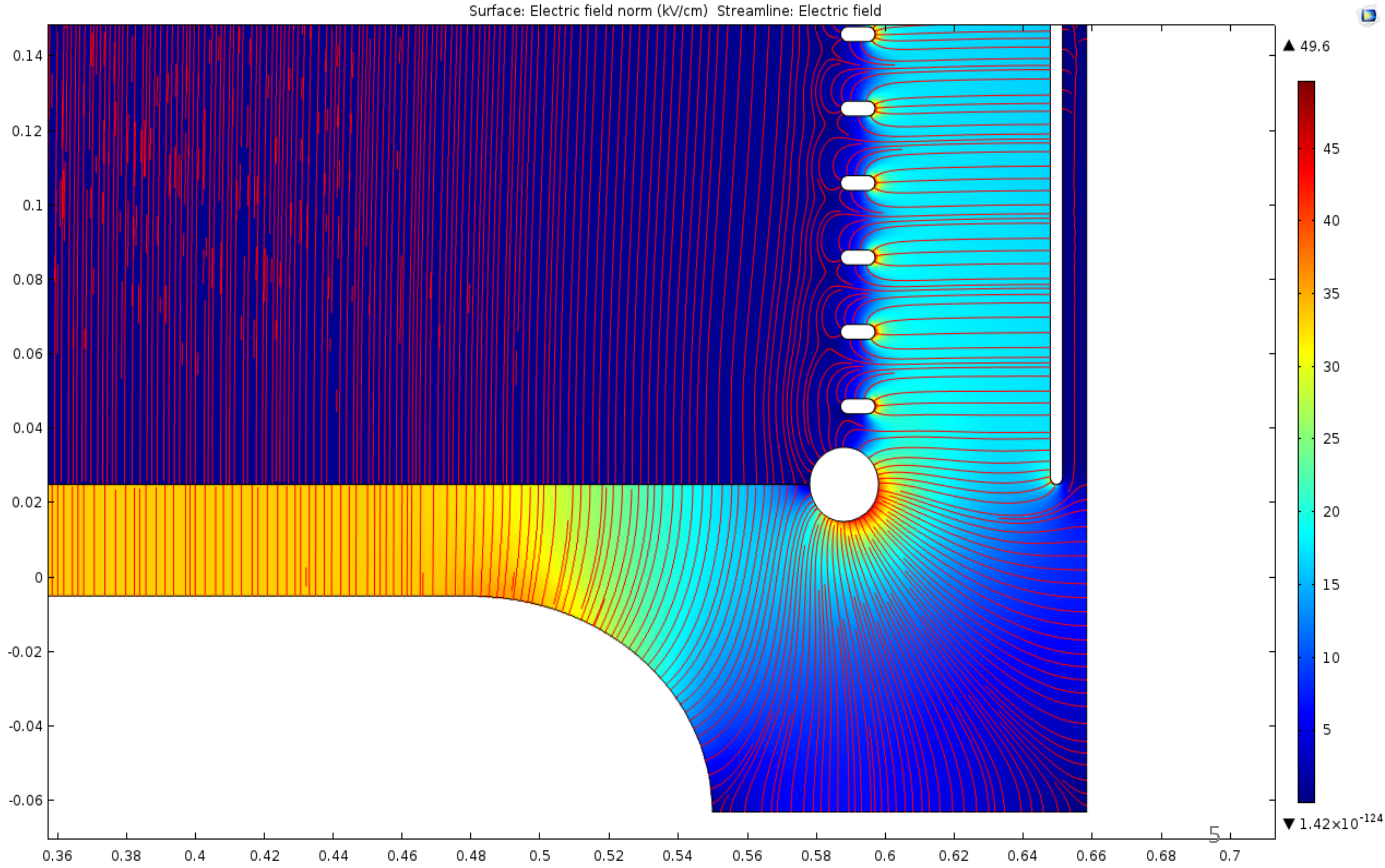
# Photon detection in nEXO

- Energy resolution dominated by light
  - Need 3% efficiency of detecting scintillation photons for 1 % energy resolution
  - With negligible noise for light detection
- Need at least 4 $m^2$ of detection area
- Need reflective electrodes

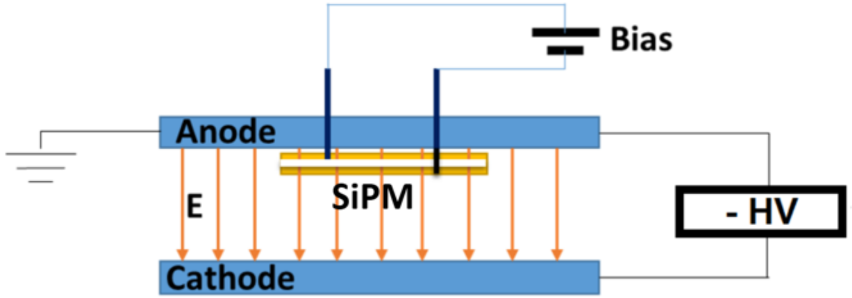


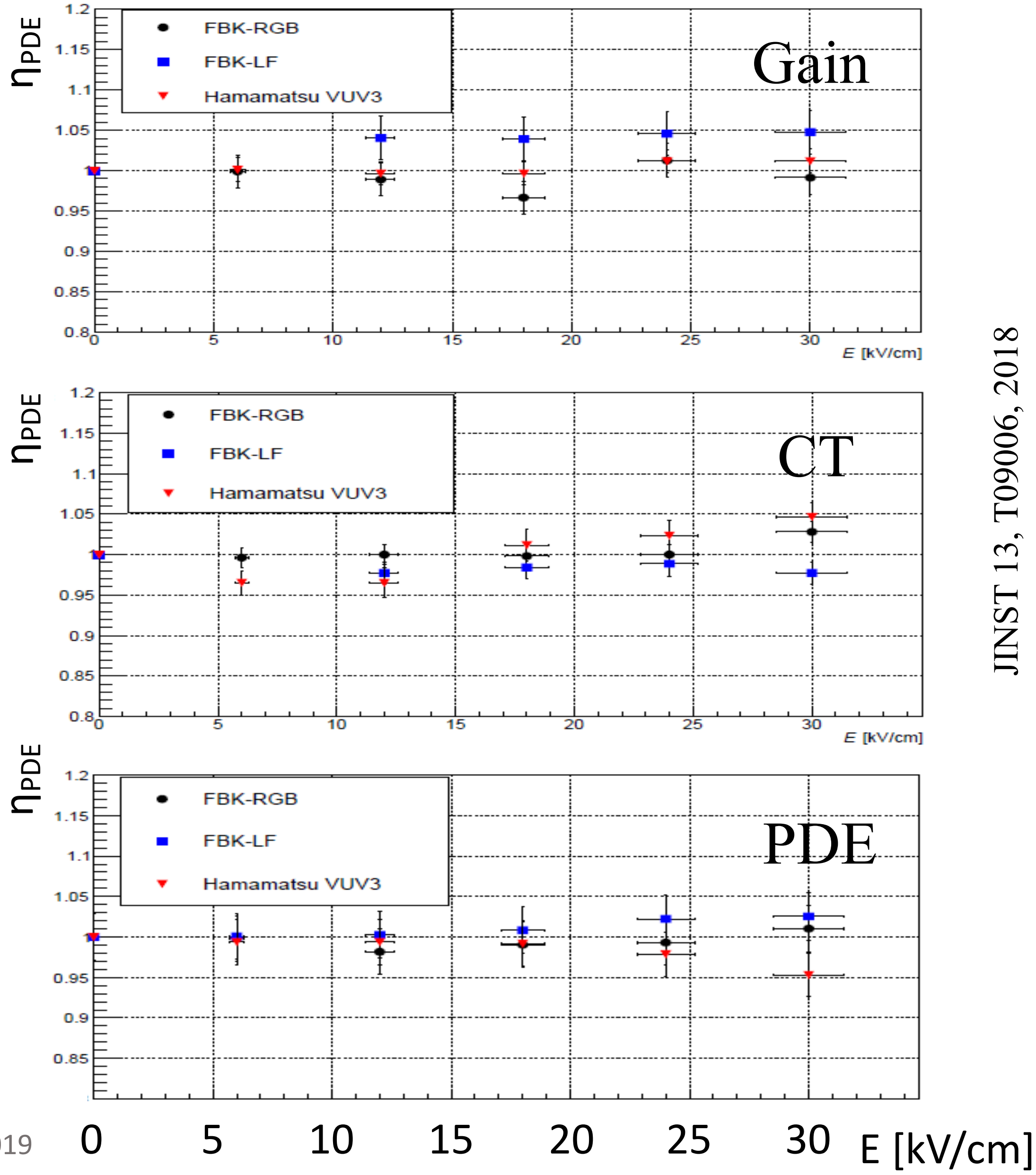
# Electric field concern?

- Static EField was found to be a non-issue
- However charge-up may still be an issue



# SiPM Performance under E-field




JINST 13, T09006, 2018

- In nEXO, SiPMs will be exposed to external E-fields up to ~20 kV/cm.
- SiPM performance in various E-fields at cryogenic temperatures (~150K) have been tested in $CF_4$.
- The tested SiPMs show good stability under the influence of different electric field strengths.
- Need to test in LXe and understand if surface charge buildup is an issue.

# SiPM for lowest radioactivity content

| | $^{238}U$ | $^{232}Th$ | $^{40}K$ |
|---|---|---|---|
| Prelim. nEXO requirements for 4m$^2$ | < 0.1 nBq/cm$^2$ | <1 nBq/cm$^2$ | < 10 nBq/cm$^2$ |
| FBK SiPM (bare wafers) A | <0.4 nBq/cm$^2$ | ~0.6 nBq/cm$^2$ | ~3 nBq/cm$^2$ |
| Hamamatsu MPPC (packaged) B | <7 μBq/cm$^2$ | <3 μBq/cm$^2$ | <3 μBq/cm$^2$ |
| SensL SiPM (packaged) C | <1.1 mBq/cm$^2$ | <33 μBq/cm$^2$ | <69 μBq/cm$^2$ |

A Counting at U.Alabama after nuclear activation at MIT shown at this meeting

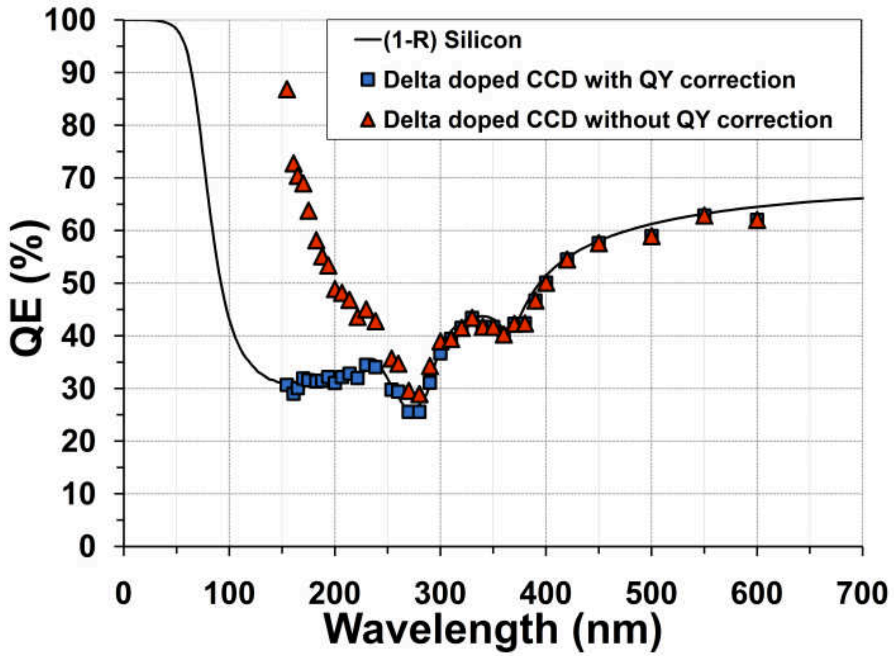
B Hamamatsu Ge counting in house. Assume 300μm SiPM thickness. Confidential

C NEXT Ge counting. http://arxiv.org/abs/1411.1433

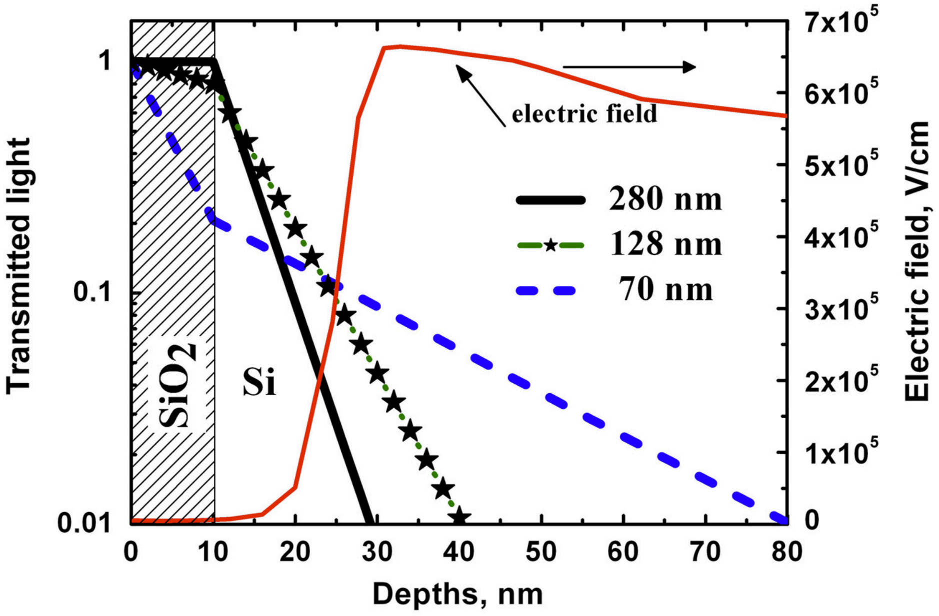
| PMT type | Normalized activity [mBq/cm$^2$] $^{238}$U | $^{226}$Ra | $^{228}$Th | $^{235}$U | $^{40}$K | $^{60}$Co | Ref. |
|---|---|---|---|---|---|---|---|
| R11410-21 | < 0.4 | 0.016(3) | 0.012(3) | 0.011(3) | 0.37(6) | 0.023(3) | this work |
| R11410-20 | < 0.56 | < 0.03 | 0.028(6) | < 0.025 | 0.37(6) | 0.040(6) | this work |
| R11410-10 | < 3.0 | < 0.075 | < 0.08 | < 0.13 | 0.4(1) | 0.11(2) | [20] |
| R11410-10 (PandaX) | – | < 0.02 | < 0.02 | 0.04(4) | 0.5(3) | 0.11(1) | [12] |
| R11410-10 (LUX) | < 0.19 | < 0.013 | < 0.009 | – | < 0.26 | 0.063(6) | [21] |
| R11410 | 1.6(6) | 0.19(2) | 0.09(2) | 0.10(2) | 1.6(3) | 0.26(2) | [20] |
| R8778 (LUX) | < 1.4 | 0.59(4) | 0.17(2) | – | 4.1(1) | 0.160(6) | [21] |
| R8520 | < 0.33 | 0.029(2) | 0.026(2) | 0.009(2) | 1.8(2) | 0.13(1) | [20] |

# VUV light detection challenges

- Reflections




- Shallow absorption depth

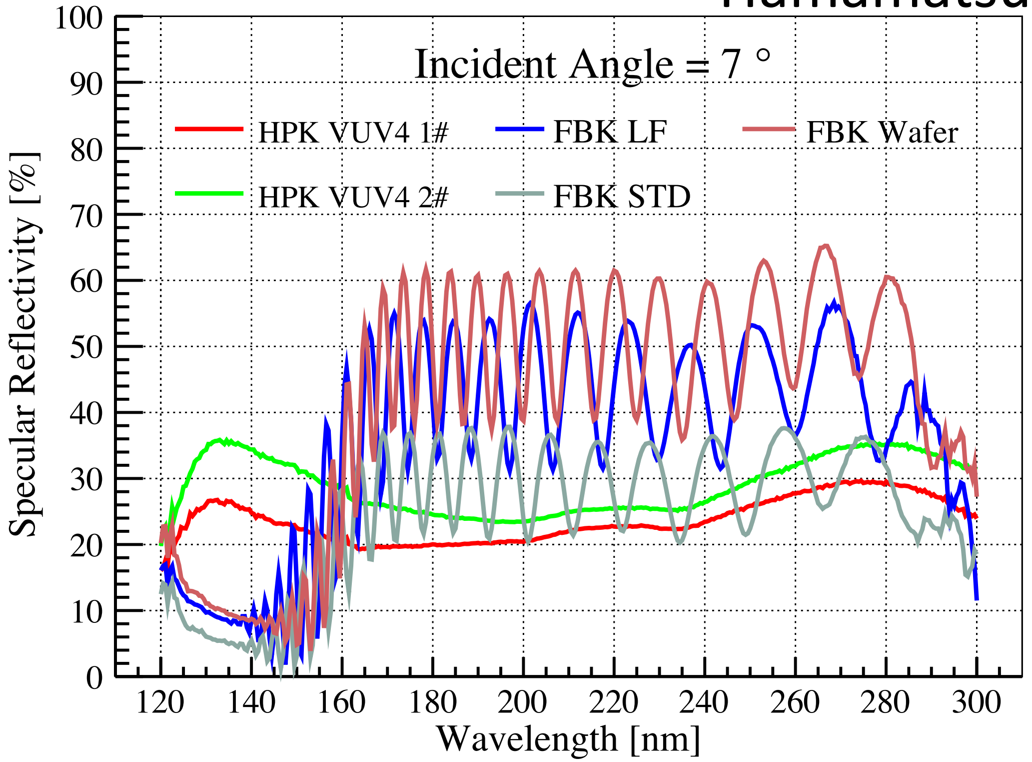


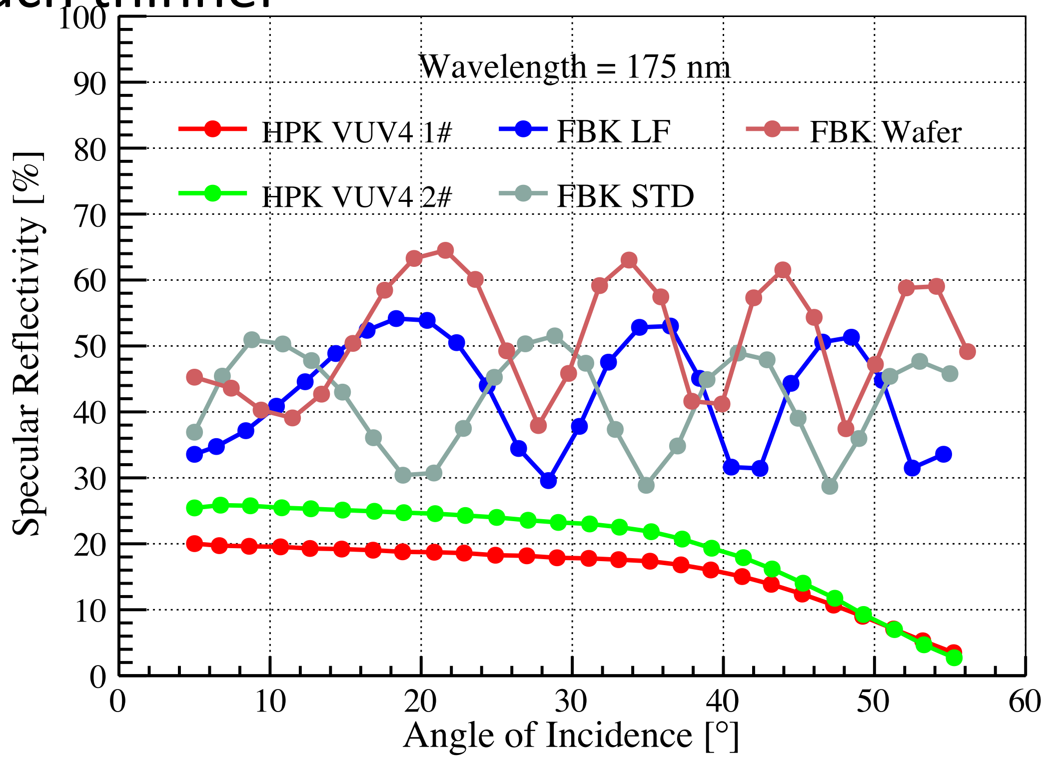
# Measuring reflections in vacuum

Measurement at IHEP and IOE (China)

1-1.5 um of SiO2 on top of FBK SiPM

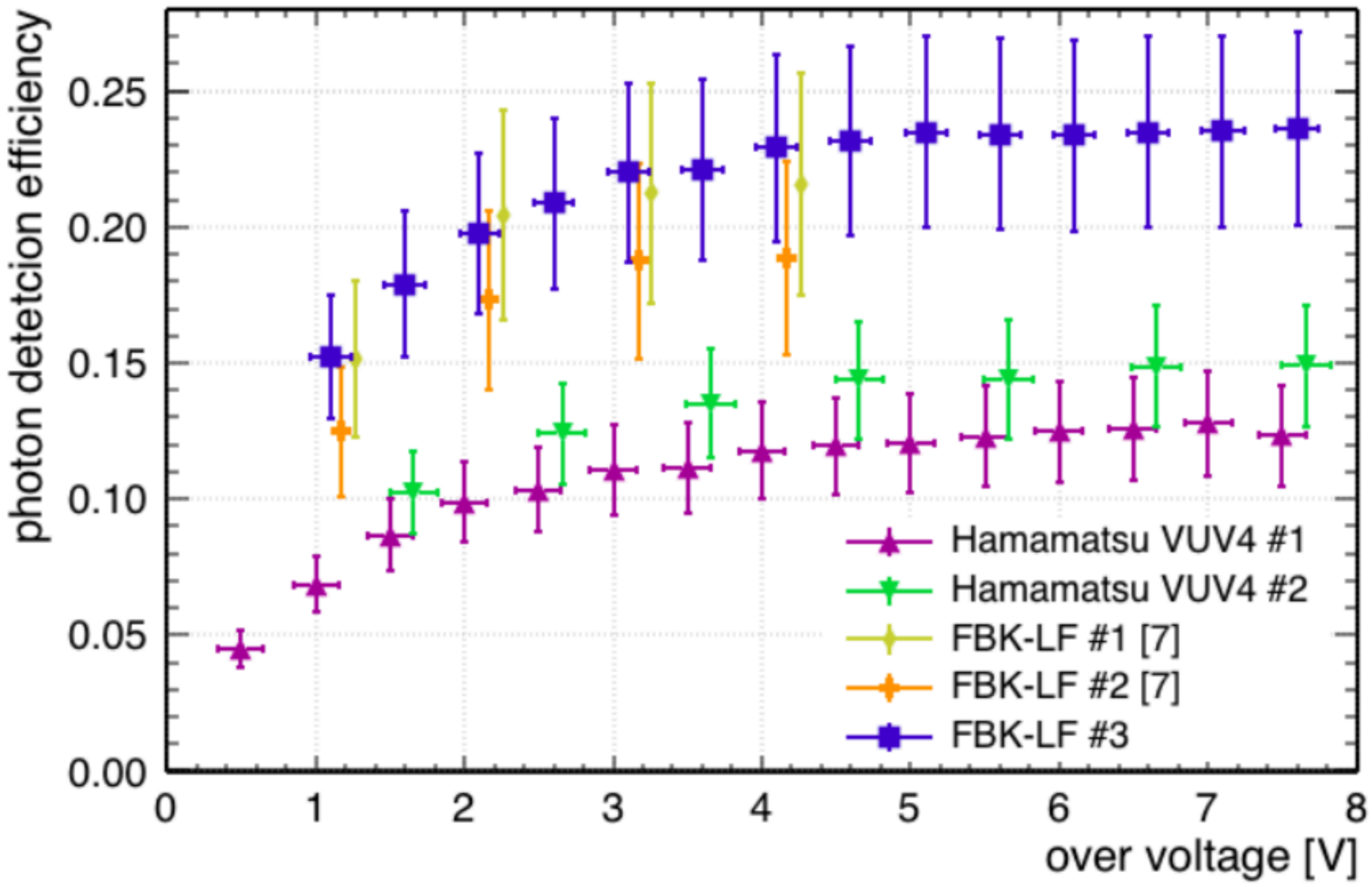
Hamamatsu much thinner



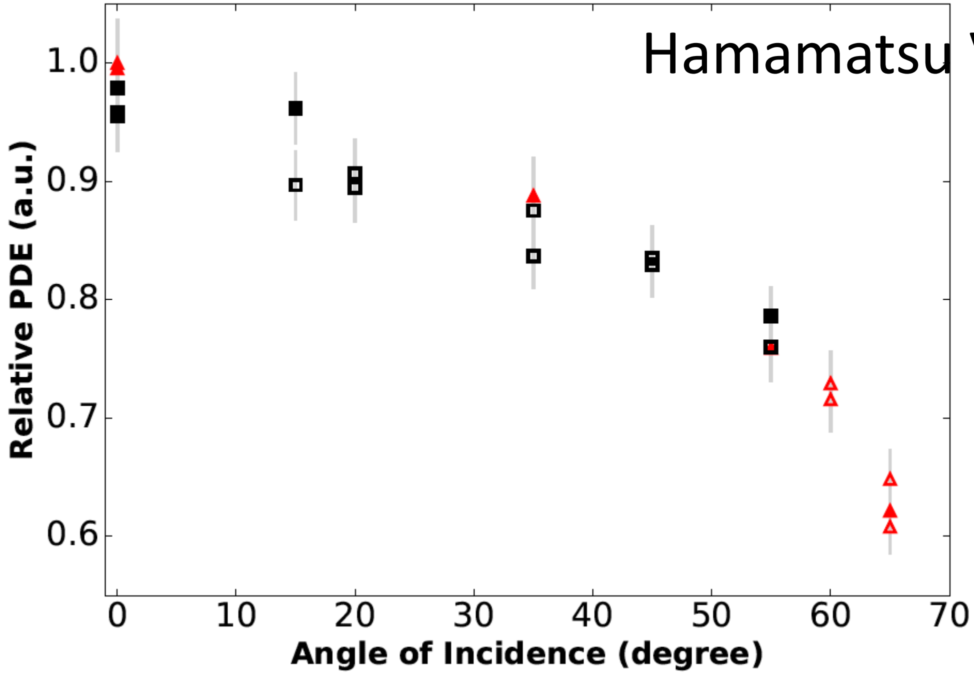
# Analog SiPMs photo-detection efficiency

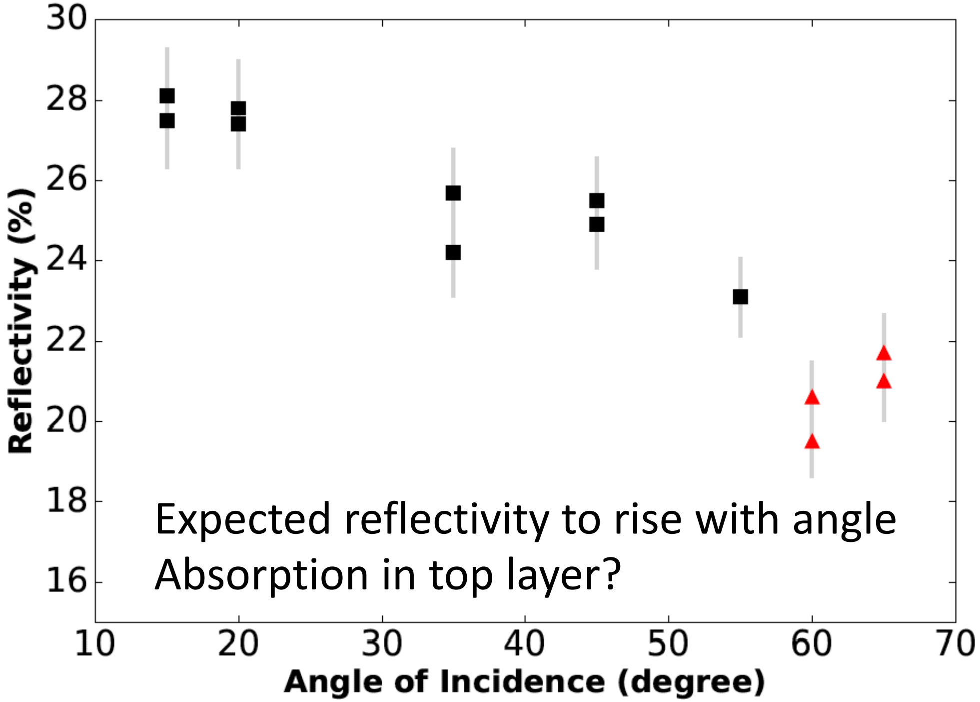
- Requirements > 15%
- Challenges
  - Reflectivity > 50%
  - Attenuation length in Si ~5.8nm
- Good progress
  - FBK meet specifications
  - Hamamatsu is close
    - We measure significantly lower PDE than HPK

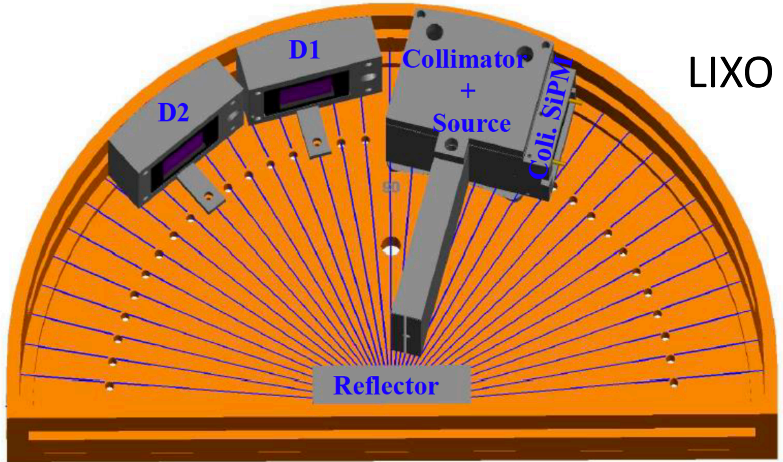



arXiv:1904.05977

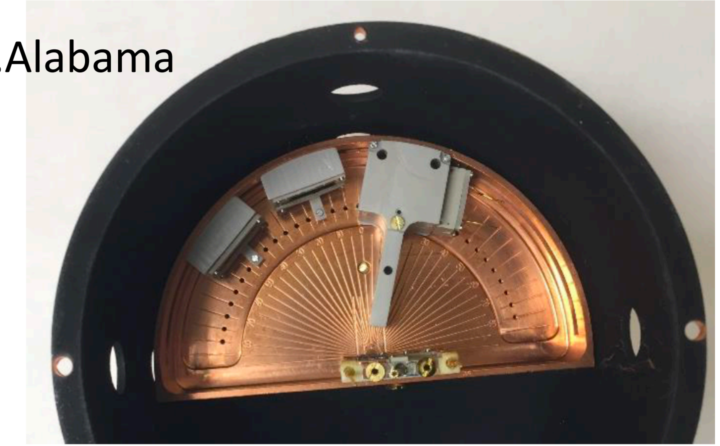
# Efficiency and reflectivity – correlation!!?




LIXO U.Alabama







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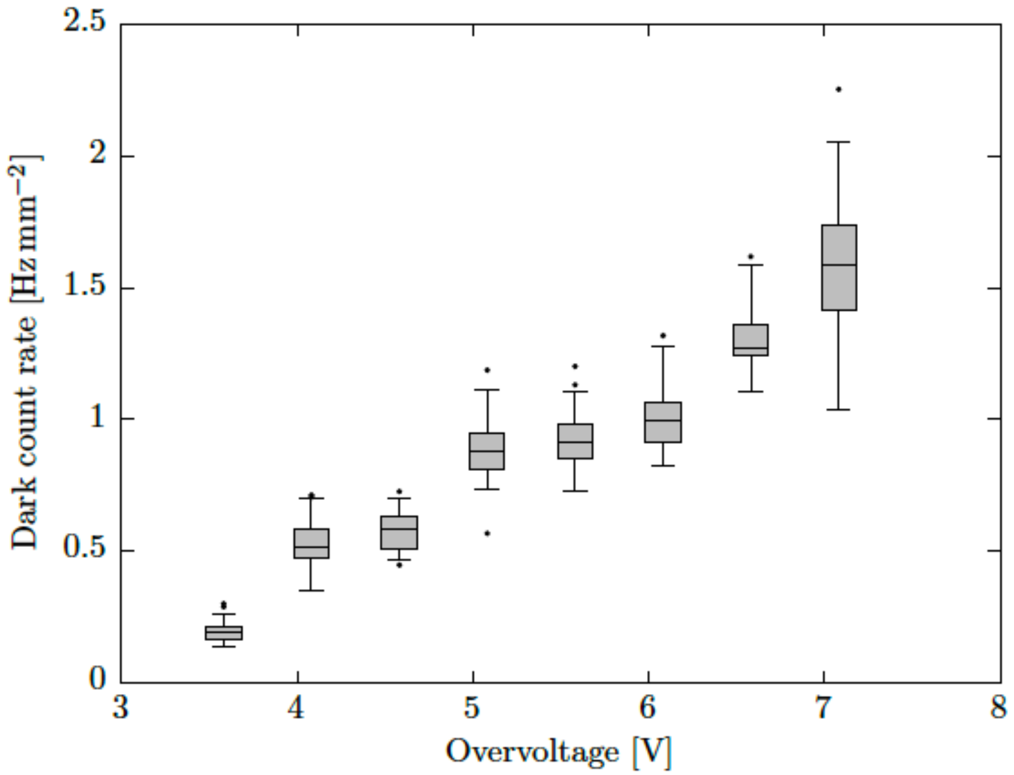
# Analog SiPM nuisance – dark noise

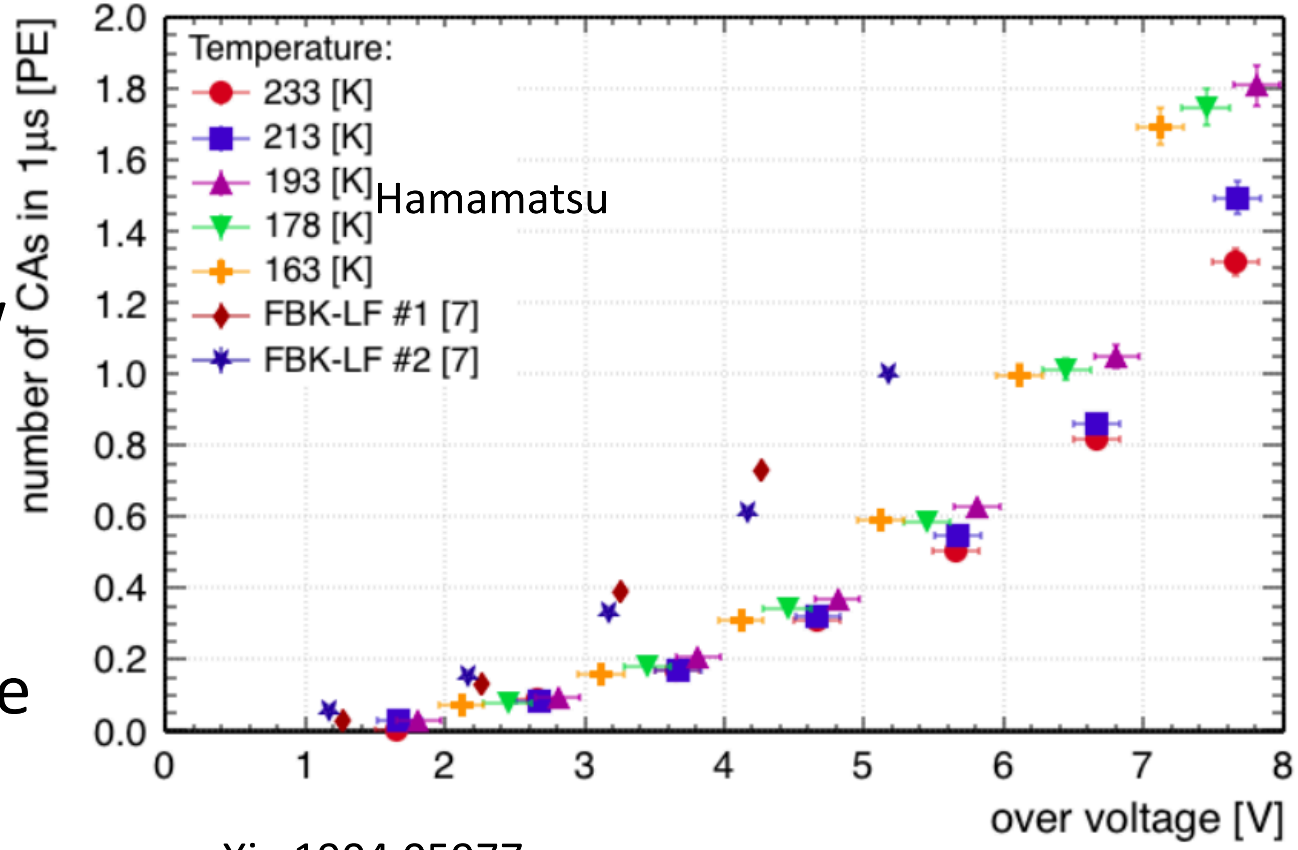
- Specification is < 50Hz/mm2 which is easily met




arXiv:1806.02220v3

# Analog SiPMs nuisance – correlated avalanches

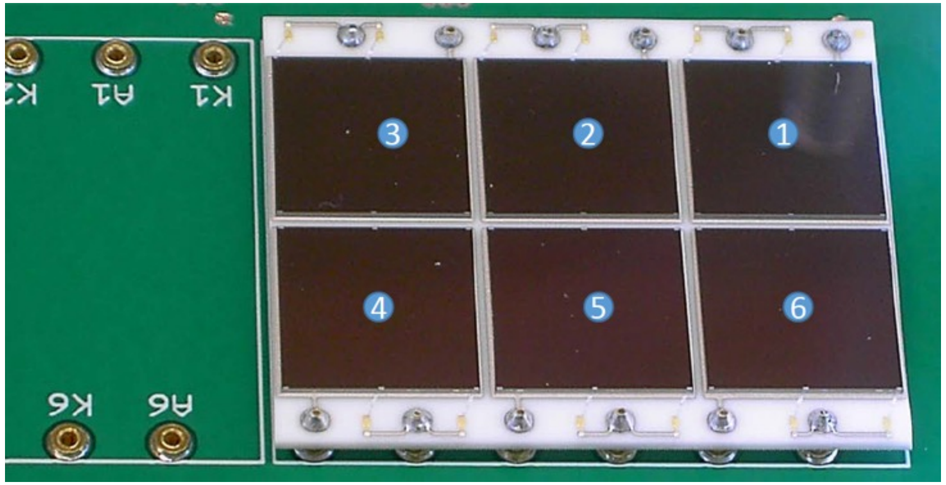
- Specification < 0.2
- FBK need to stay below 2.5V
- Hamamatsu need to stay below 3.5V
- Correlated avalanche directly worsen energy resolution
- Some cross-talk photons may be emitted in the liquid and fire other SiPMs



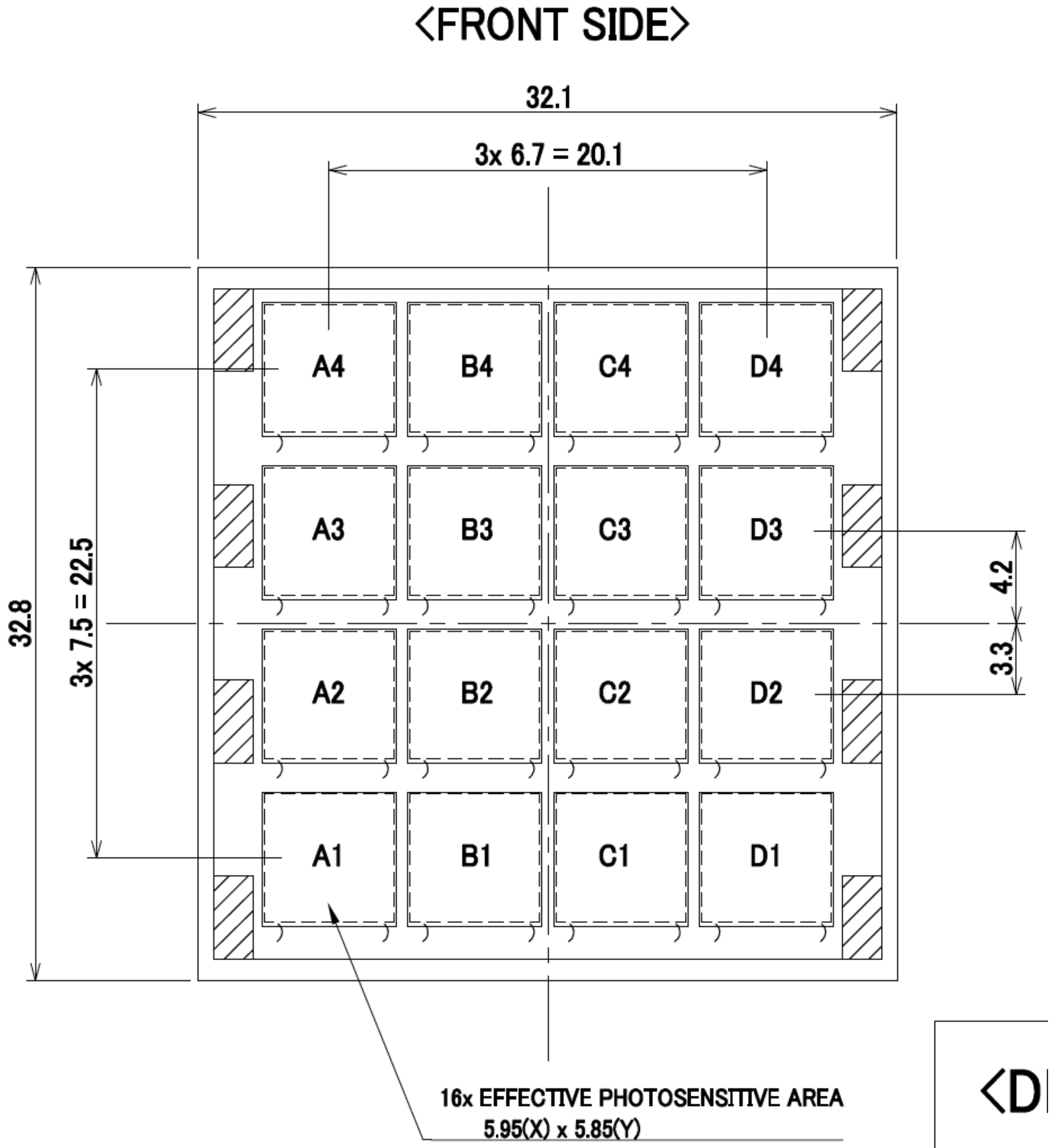

arXiv:1904.05977

# Large scale integration

- Test PCB for FBK 1x1cm$^2$ SiPMs
- ASIC developed by BNL



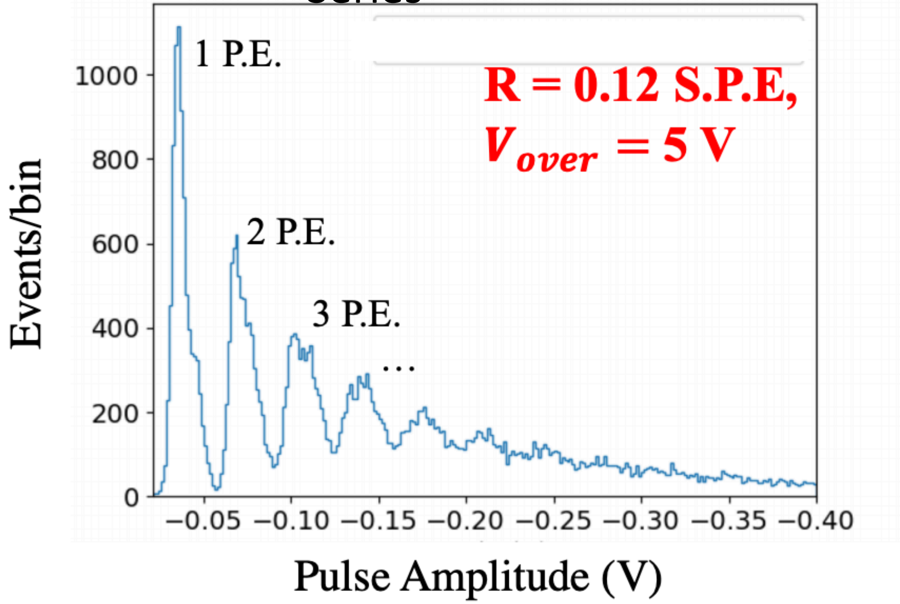
## Hamamatsu all silicon package



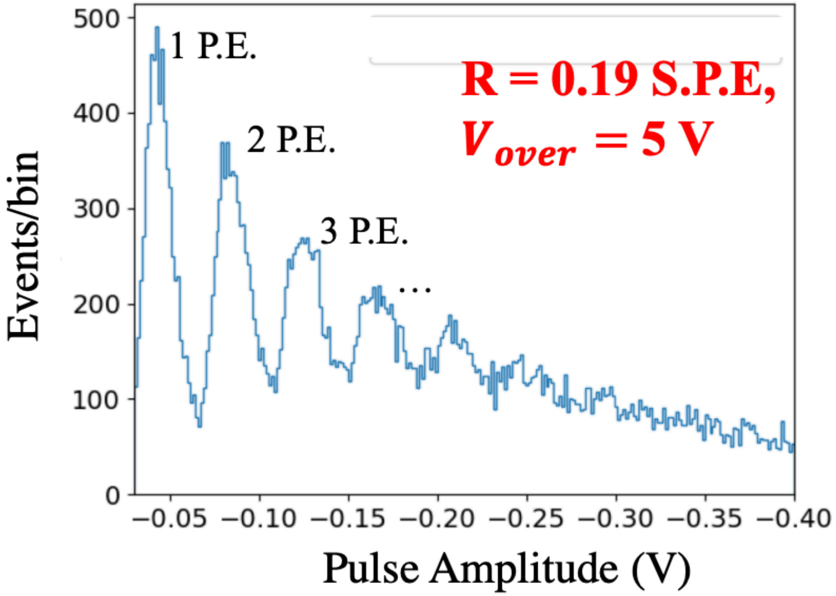
# SiPM analog electronics – a challenge

- Requirements
  - <10mW/cm2 dissipated
  - Single photon charge resolution < 0.2
- In parallel configuration may require too high over-voltage

Series




Parallel



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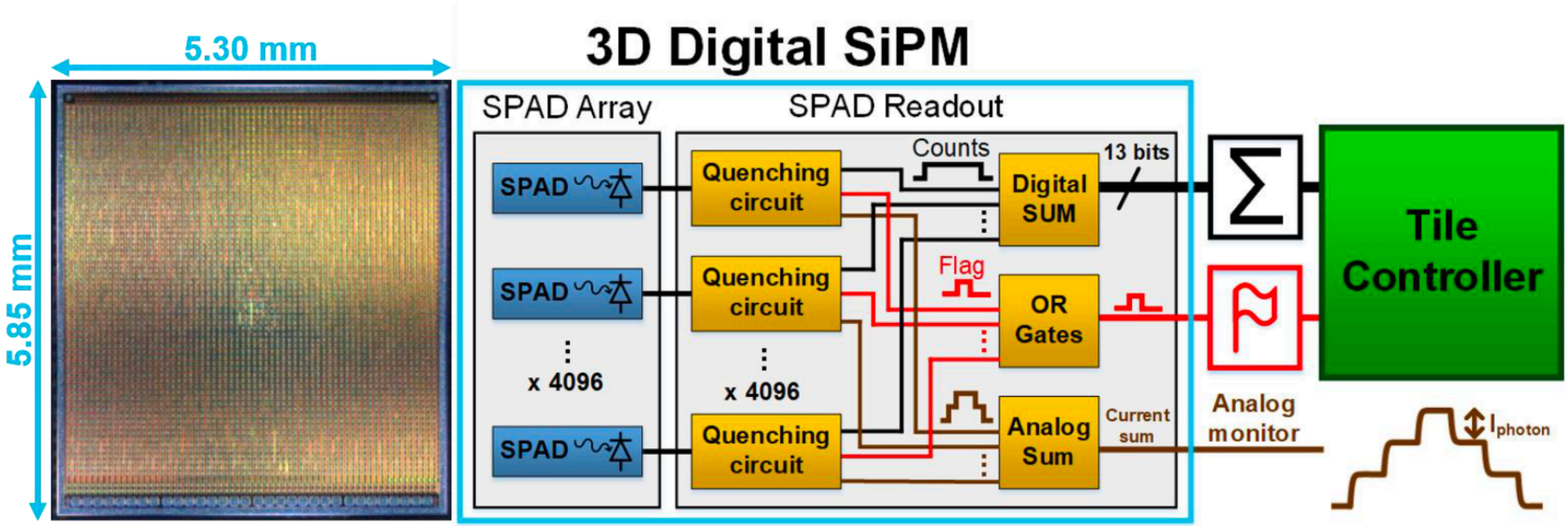
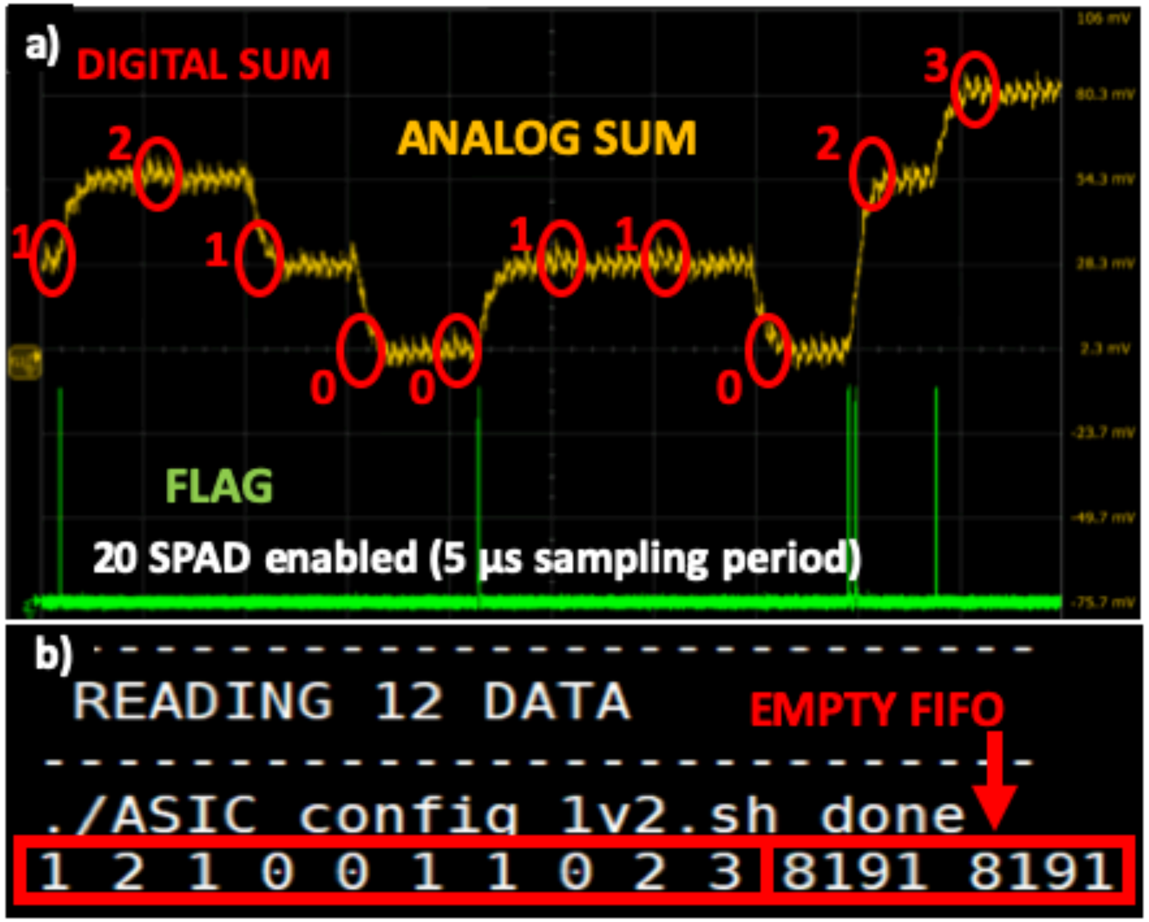
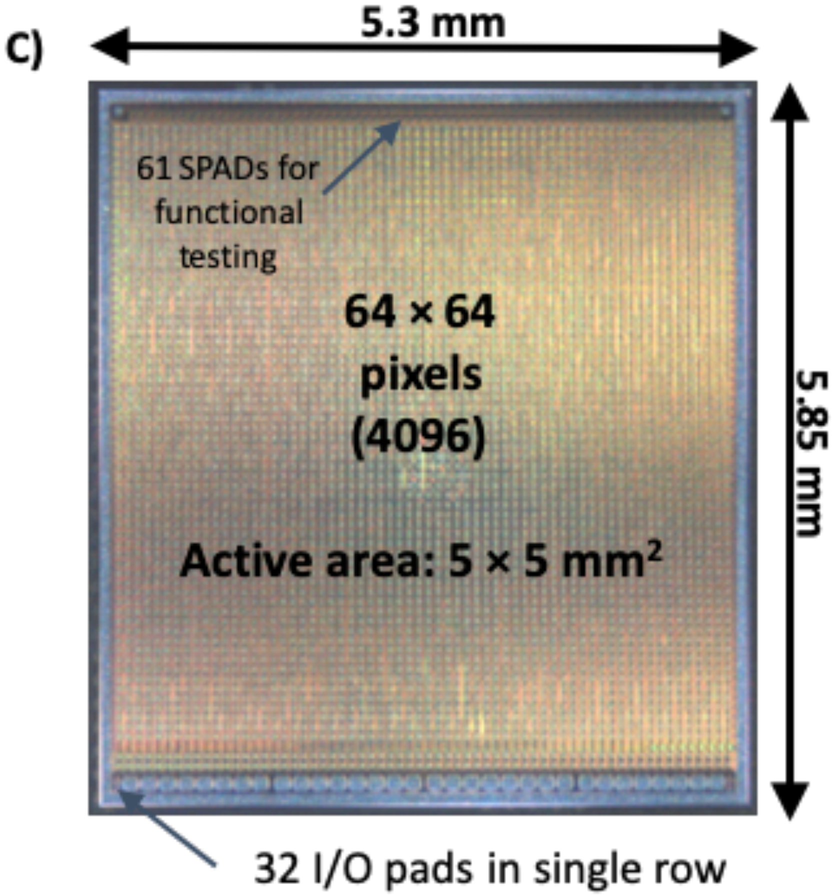
# 3DdSiPMs electronics layer for nEXO



# CMOS chip is working

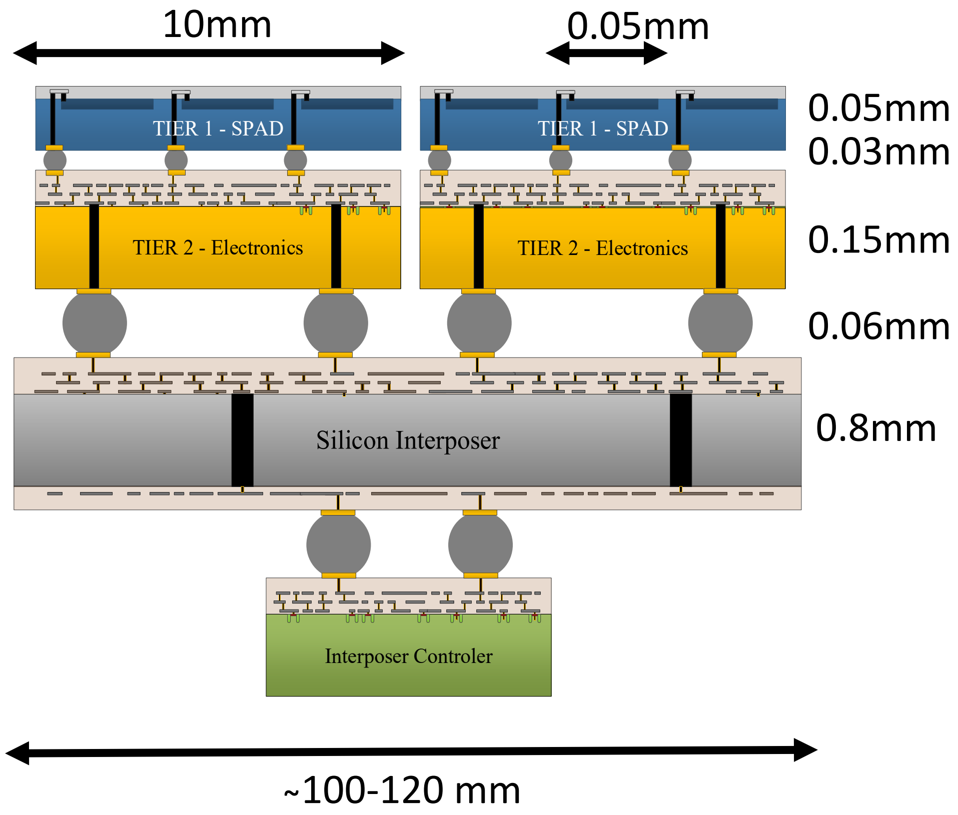


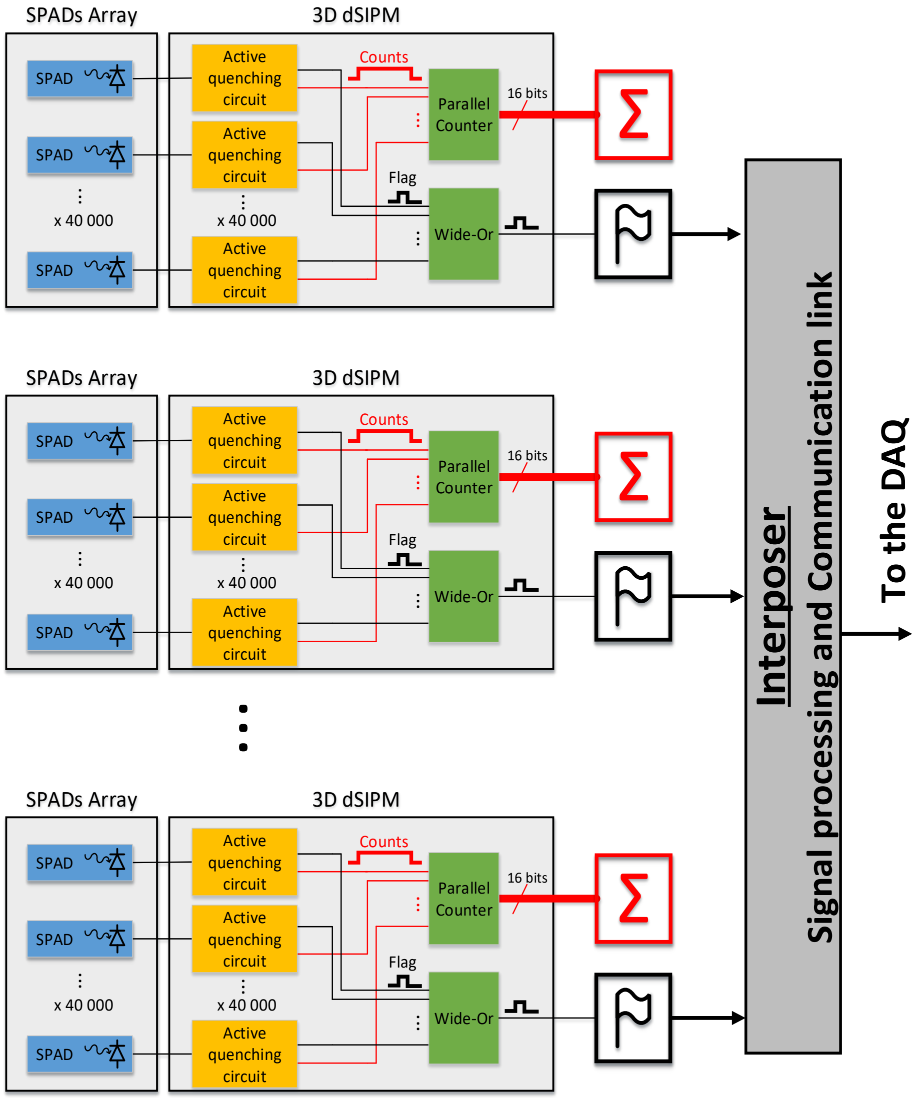



TRIUMF

# 3DdSiPM ideal architecture for nEXO

nEXO



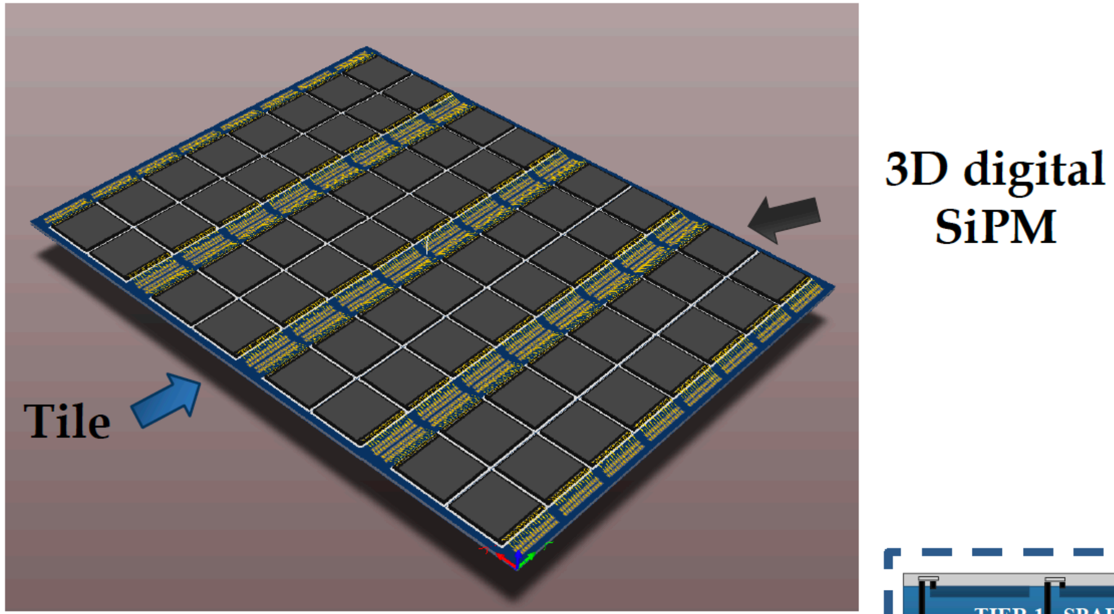



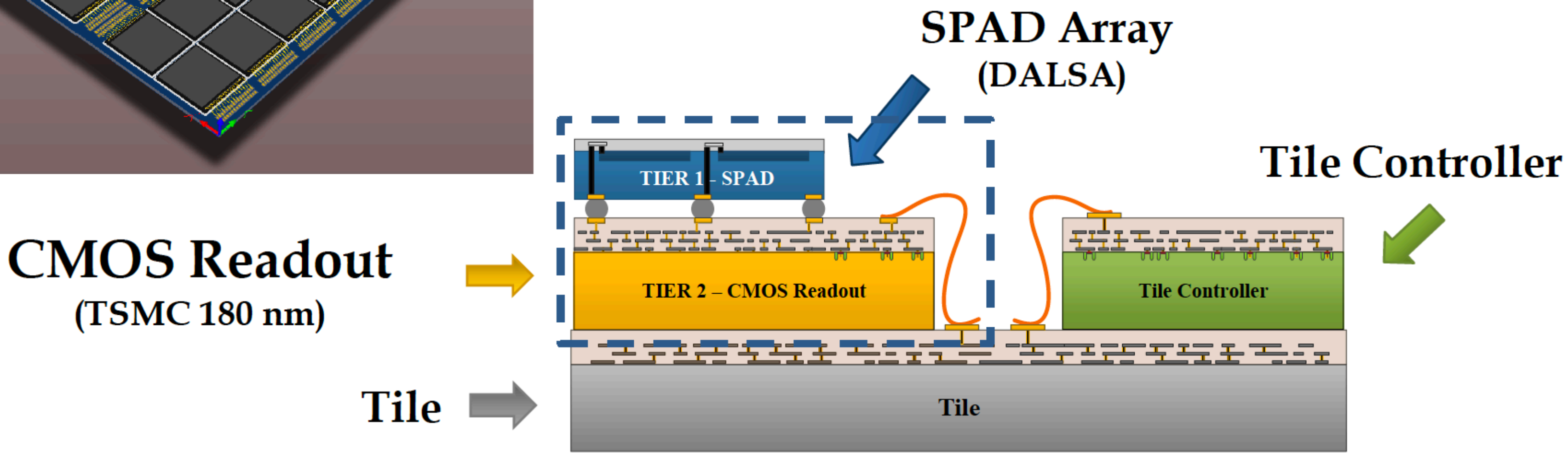

## Tile Controller

- Adjustable coincidence window
- Adjustable threshold
- A trigger is generated when:
  - Flag count > threshold
  - Inside the coincidence window
- The parallel adder of each 3DdSiPM is activated for the duration of the scintillation

# 3DdSiPMs integration

Working towards this solution by 2021



# Silicon interposer = a silicon PCB

- Motivation:
  - Very low radioactivity of silicon
  - Perfect coefficient of thermal expansion matching with SiPM
- Issue: can transmission line and via be good enough
  - Capacitance and resistance per unit length
- R&D within nEXO
  - Led by China: IHEP and Institute of micro-electronics
  - Led by Canada with a contract to Fraunhofer IZM (Berlin)

# Summary

- nEXO a liquid Xenon detector searching for neutrino less double beta decay
- Light detection is critical to nEXO's success → driving a vigorous R&D program
  - Successful development of VUV SiPM and associated electronics
- Supporting 3DdSiPM development in Canada
- Lots of detector results coming up soon
- And hopefully a ground breaking discovery in 5-10 years

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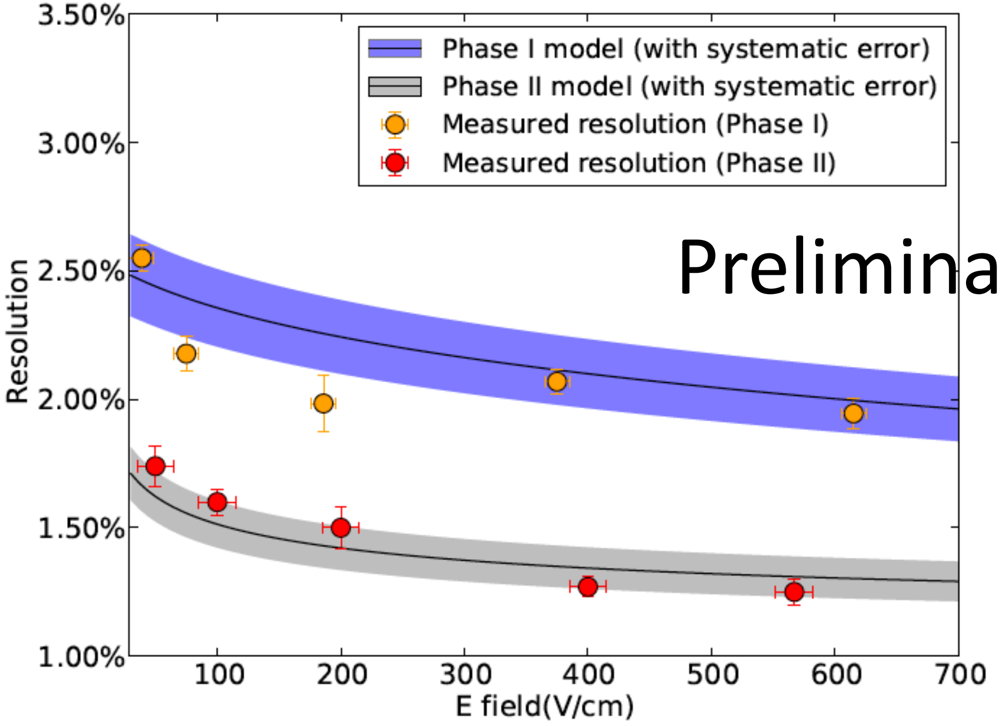
# Deep UV light detection – other applications

- Smoke analysis
  - Mie scattering of deep UV light for a portable and low power smoke detector
- Gas analysis
  - Detect fluorescence induced by deep UV light
- Developing a unified concept: Single Photon Air Analyser
- And of course PET using LXe
  - Is LXe a good scintillator for TOF PET?
- But also liquid Argon for physics and other applications

# EXO-200. Modeling energy resolution

- EXO-200 data shows very strong (98% correlation) between recombination (e- loss) and increase scintillation
- EXO-200 energy resolution dominated by APD electronics noise




Preliminary