Overview of Readout Techniques for Cryogenic SiPMs

- Introduction
- Readout techniques for major projects
- Summary

W. Ootani

ICEPP, University of Tokyo

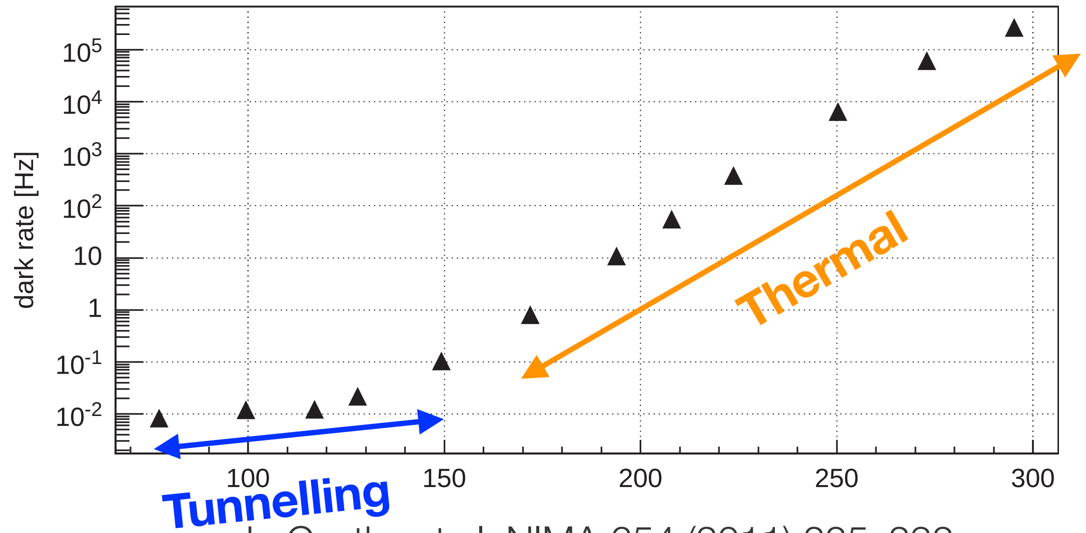
International Conference on the Advancement of Silicon Photomultipliers
Jun. 11th-15th, 2018, Schwetzingen, Germany

Core-to-Core Program

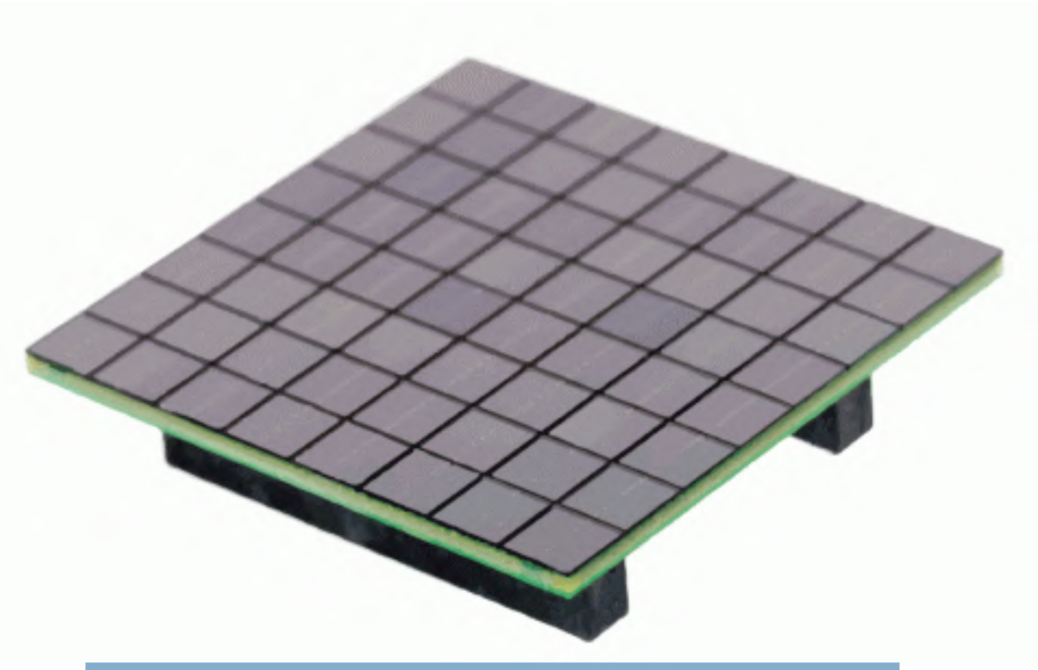
Cryogenic SiPM

- **Cryogenic experiment = best place for SiPM application**
    - Greatly suppressed DCR (ex. five orders of magnitude at LXe temperature) allows us
        - Large area application
        - Higher dose application
    - Per-area cost of SiPM already (almost) comparable to PMT
    - Even higher density array with minimum dead space possible with TSV technology
- **Large area application ≳O(1m²) already starting for cryogenic experiments**
    - MEG II LXe 0.93m² (commissioning)
    - Much larger area for (near) future projects
- **How to readout (large-area) cryogenic SiPM?**
    - Ganging scheme for large area
        - Passive or active?
    - Pre-amplification
        - Cryogenic or room temp?
    - Signal transmission
        - Cable, feedthrough

Dark count rate at low temperature



J. Csathy et al. NIMA 654 (2011) 225–232



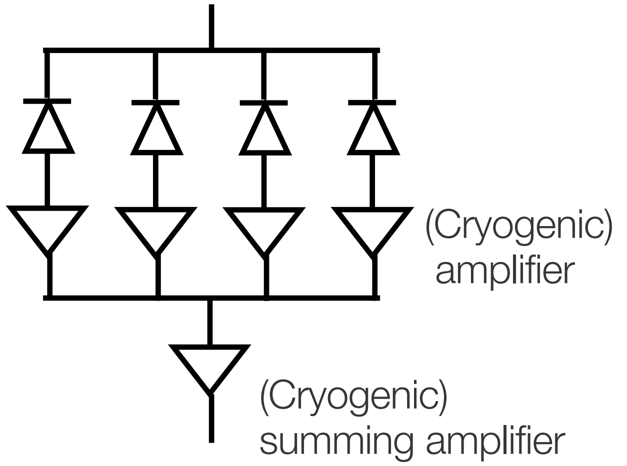
sensL ArrayJ-60035-64P-PCB
64 pcs of 6×6mm²

→$3,456

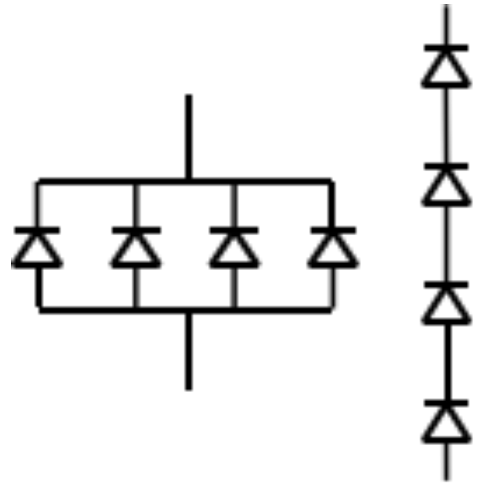
Ganging

- **Several choices depending on requirements and constraints**
  - Speed, S/N, granularity, # of readout cables, cost, …
- **Active ganging**
  - Better S/N and timing
  - Need cryogenic compatible amplifier
    - Power consumption
      - Cooling
      - Bubbling due to local heat
    - Additional radioactivity near active detector volume
    - Influence on purity of liquid
- **Passive ganging**
  - Simpler
  - Need signal transmission over long cable
  - Parallel or series?
- **Combination of active and passive ganging**

Active ganging



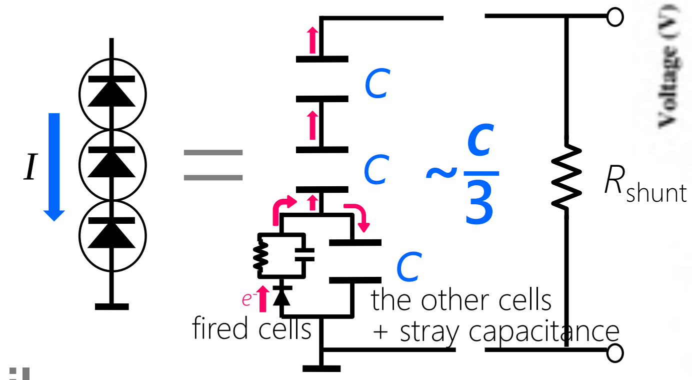
Passive ganging



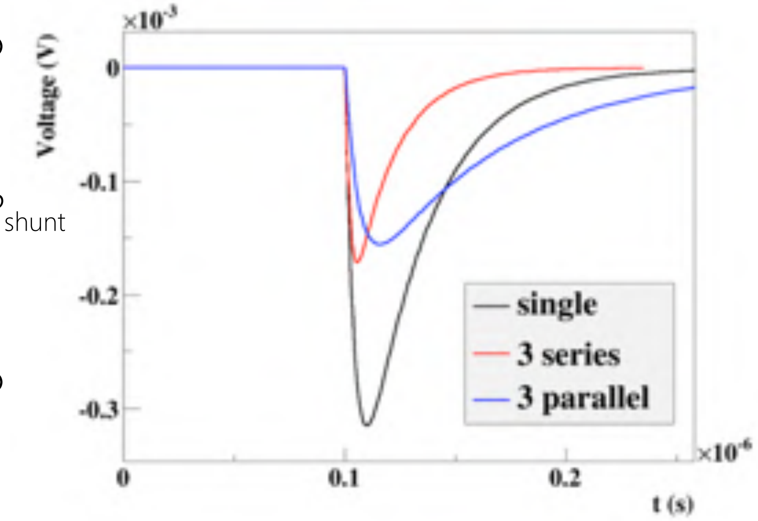
Parallel or Series?

- **Parallel**
  - Charge preserved, but amplitude reduced
  - Better S/N
  - Increasing capacitance→slow rise and long tail
    - Not optimal for timing and high rate
  - Need to group SiPMs with same breakdown voltage
- **Series**
  - Both charge and amplitude reduced (signal gain reduced)
  - Reduced capacitance→fast signal
    - Better for timing
  - Automatic over-voltage adjustment even with different breakdown voltages
  - Need higher bias voltage (× *N*)
- **Hybrid**
  - Connected in series, but with decoupling capacitor in between
  - Series connection for signal and parallel connection for bias
  - Common bias voltage
- **Combination**

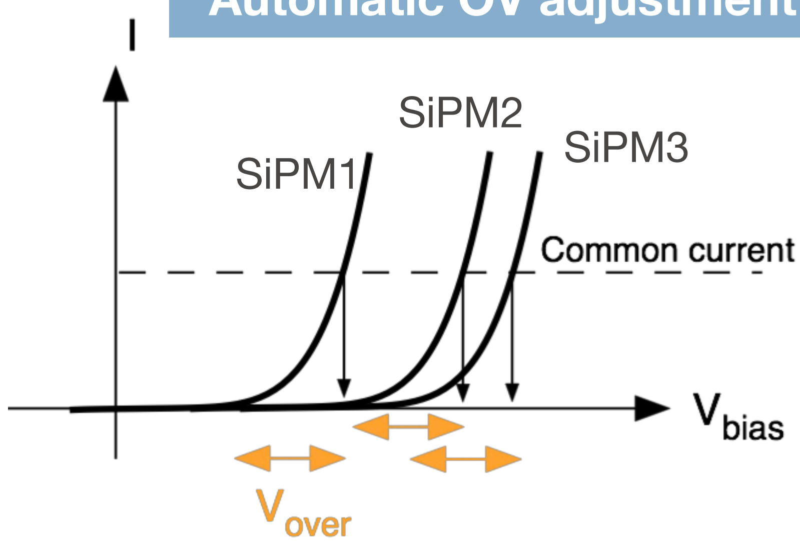
Series connection



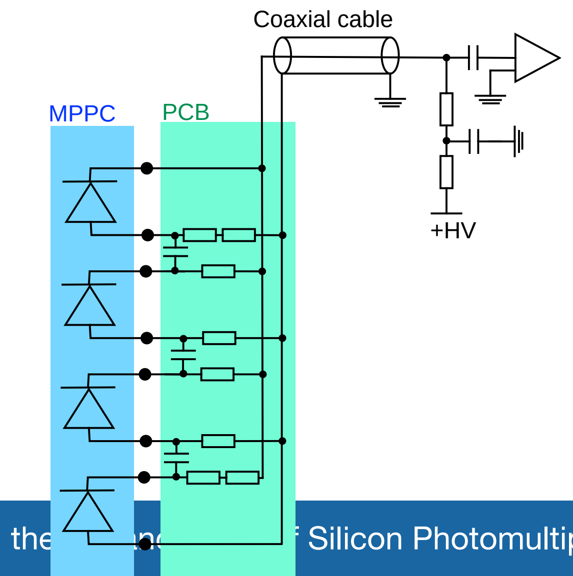
Comparison of signal shape



Automatic OV adjustment



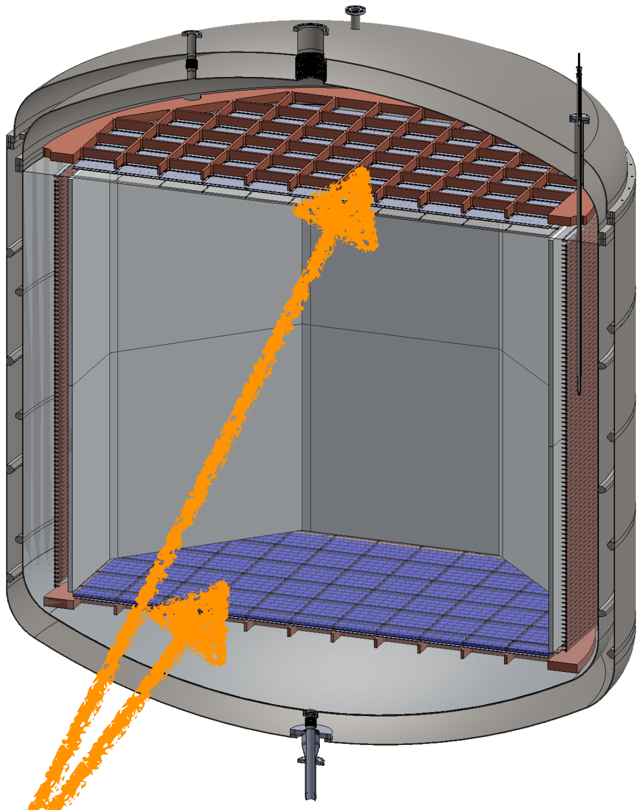
Hybrid connection



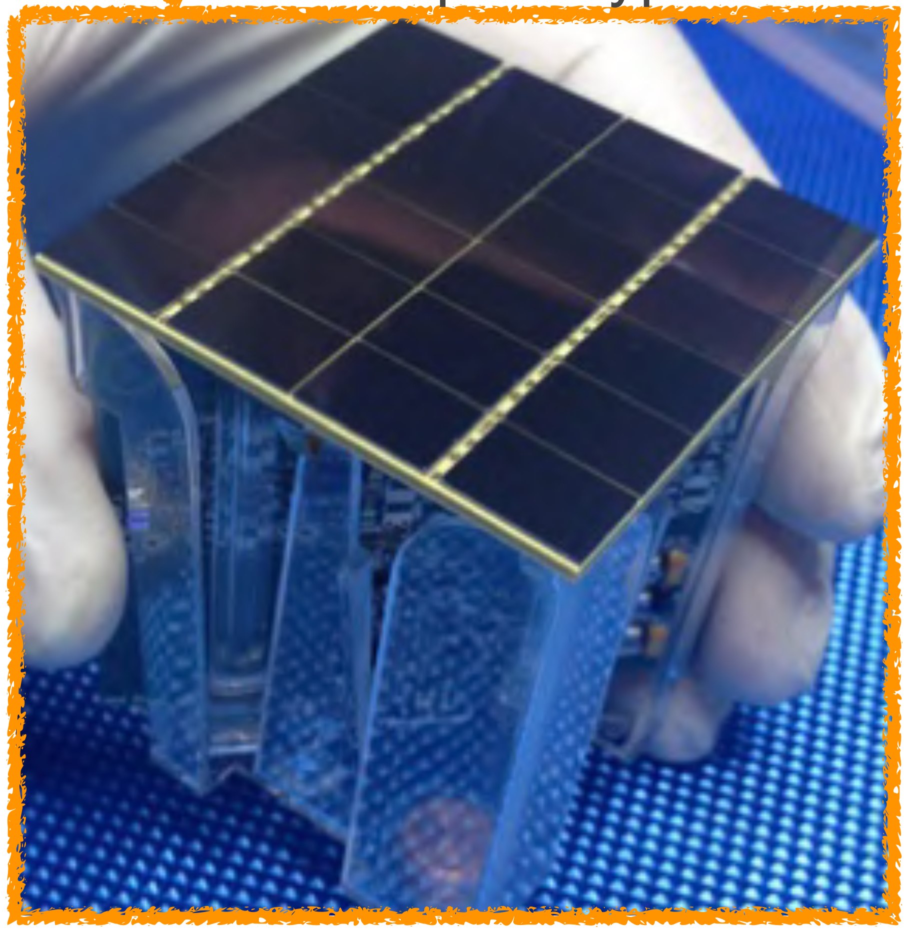
DarkSide-20k

- **DarkSide-20k**
  - Two-phase LAr TPC (20t)
  - 5210 × 25cm^2 Photon Detector Modules (PDMs)
  - Covering total area of 14m^2
  - VUV detection with WLS+TPB
- **Requirements for PDM**
  - DCR < 0.1 Hz/mm^2
  - PDE > 45%
  - SNR > 7
  - Time resolution of O(10ns)
  - Dynamic range > 50pe
  - Power consumption < 250mW
  - Radiopurity (U-238, Th-232) < mBq

DarkSide-20k



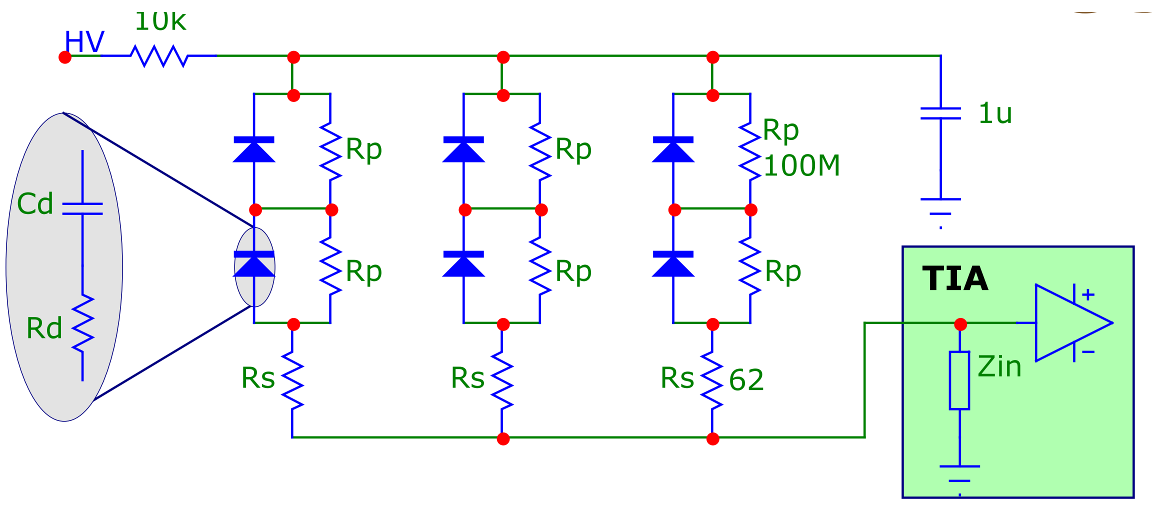
PDM prototype



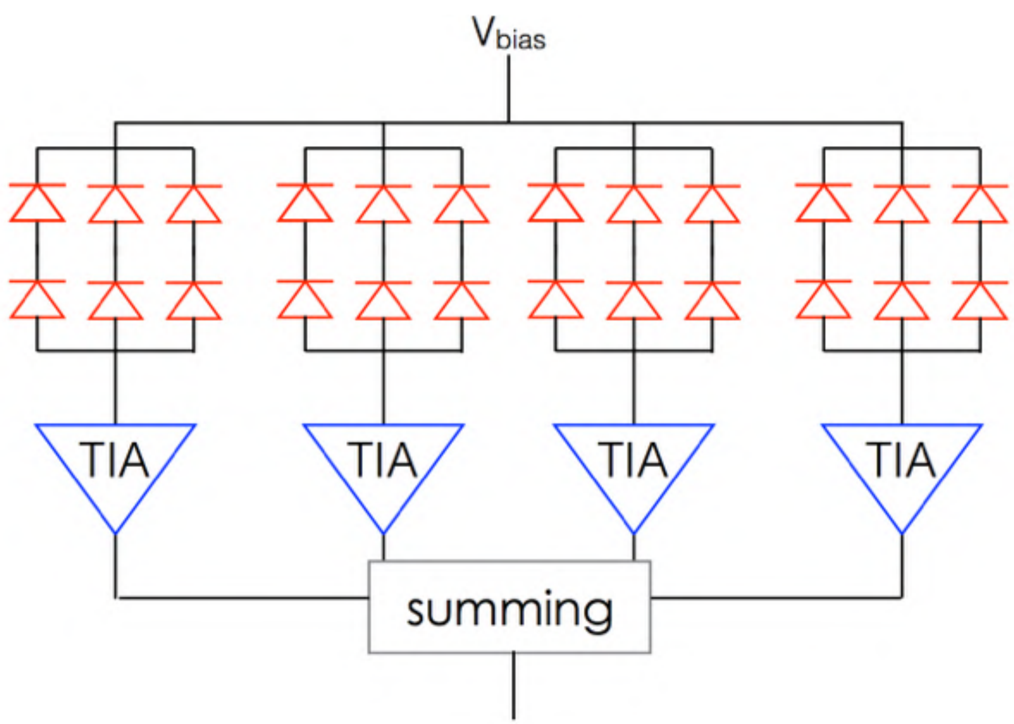
DarkSide-20k Ganging

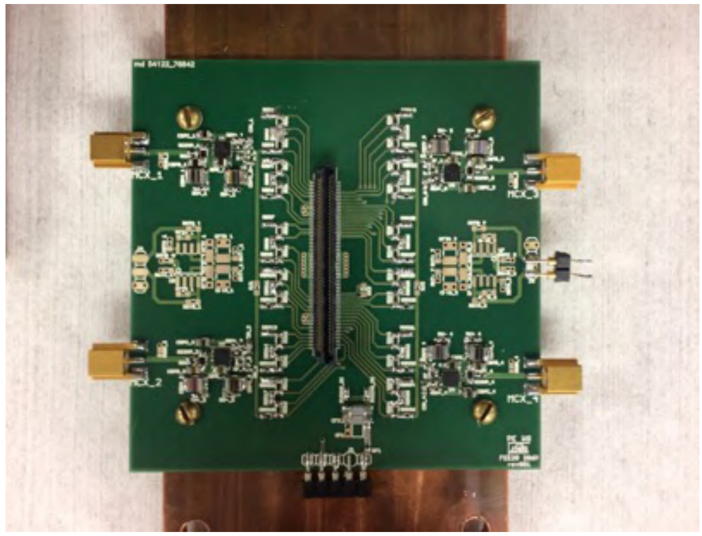
- **Ganging: passive+active**
  - **Passive**
    - $1cm^2 \rightarrow 6cm^2$
    - 3 parallel branches of 2 SiPMs in series (2s3p)
  - **Active**
    - $6cm^2 \rightarrow 24cm^2$
    - Cryogenic trans-impedance amplifier

Passive ($1cm^2 \rightarrow 6cm^2$)



Active ($6cm^2 \rightarrow 24cm^2$)



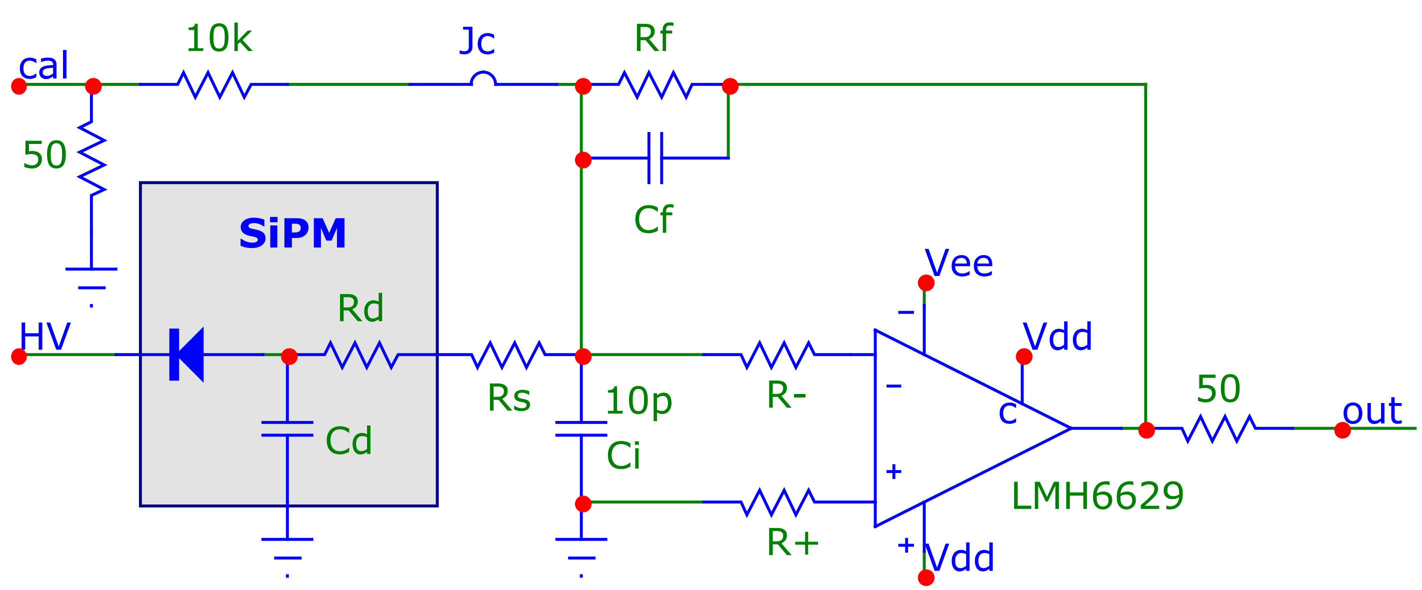


arXiv:1706:04220

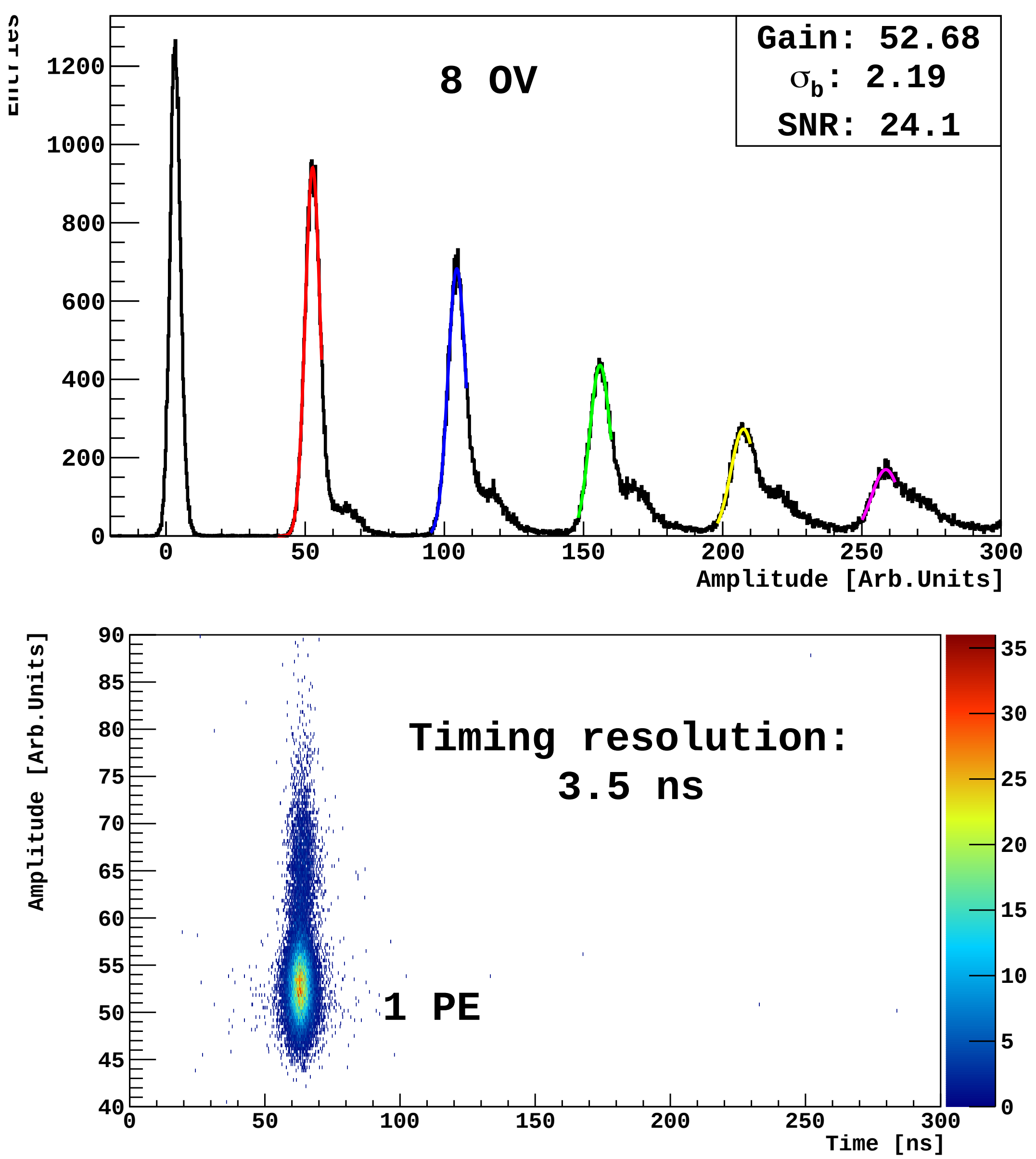
DarkSide-20k Cryogenic Amplifier

- **Cryogenic pre-amplifier**
  - Fast trans-impedance amplifier
  - High bandwidth and low noise at cryogenic temperature
  - 60 MHz at 80K with SiPM of 10×10mm²
  - Power consumption: ~40mW

Cryogenic trans-impedance amplifier

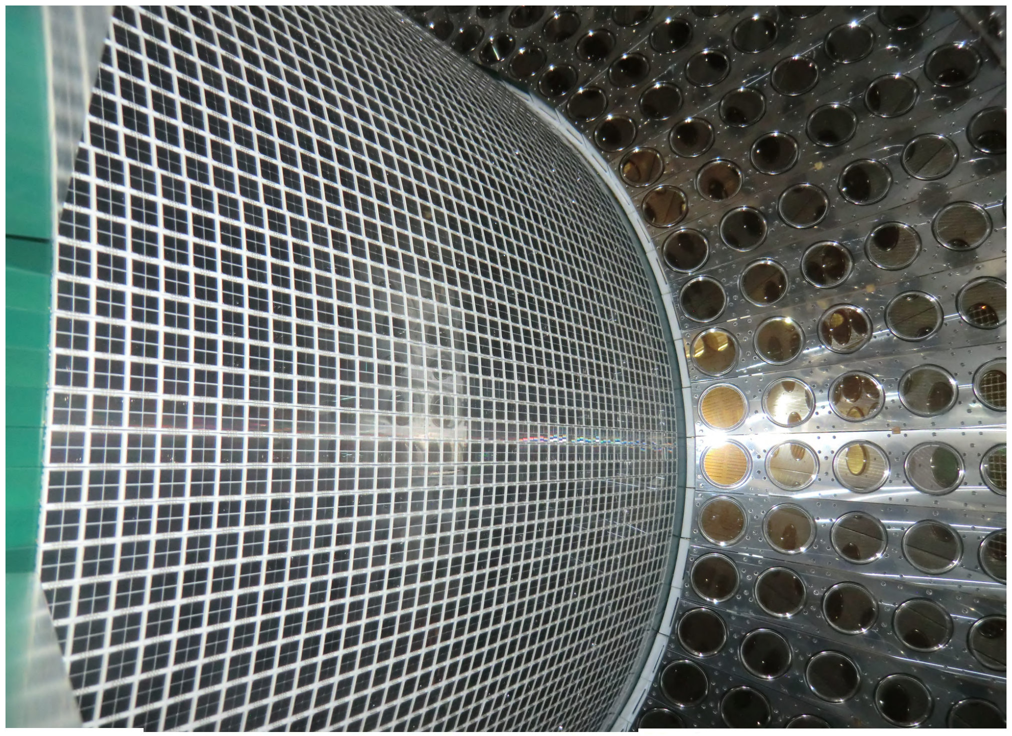


PDM performance

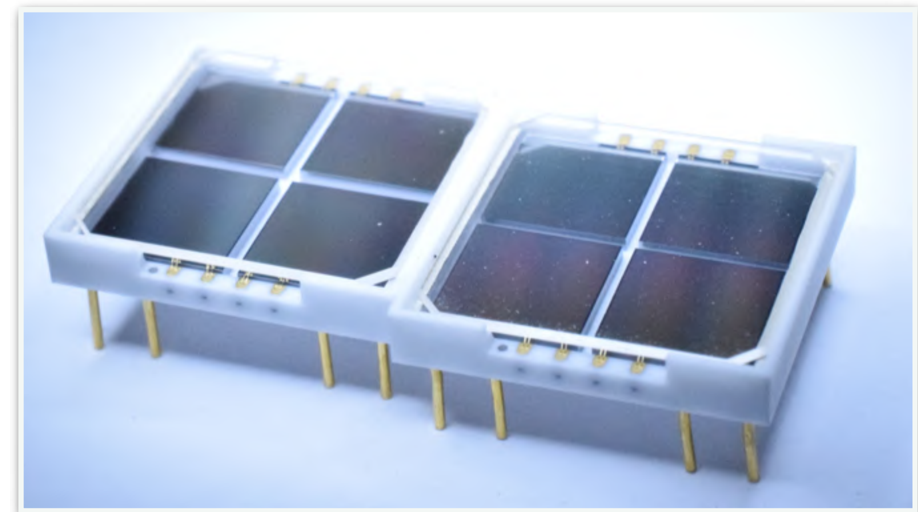


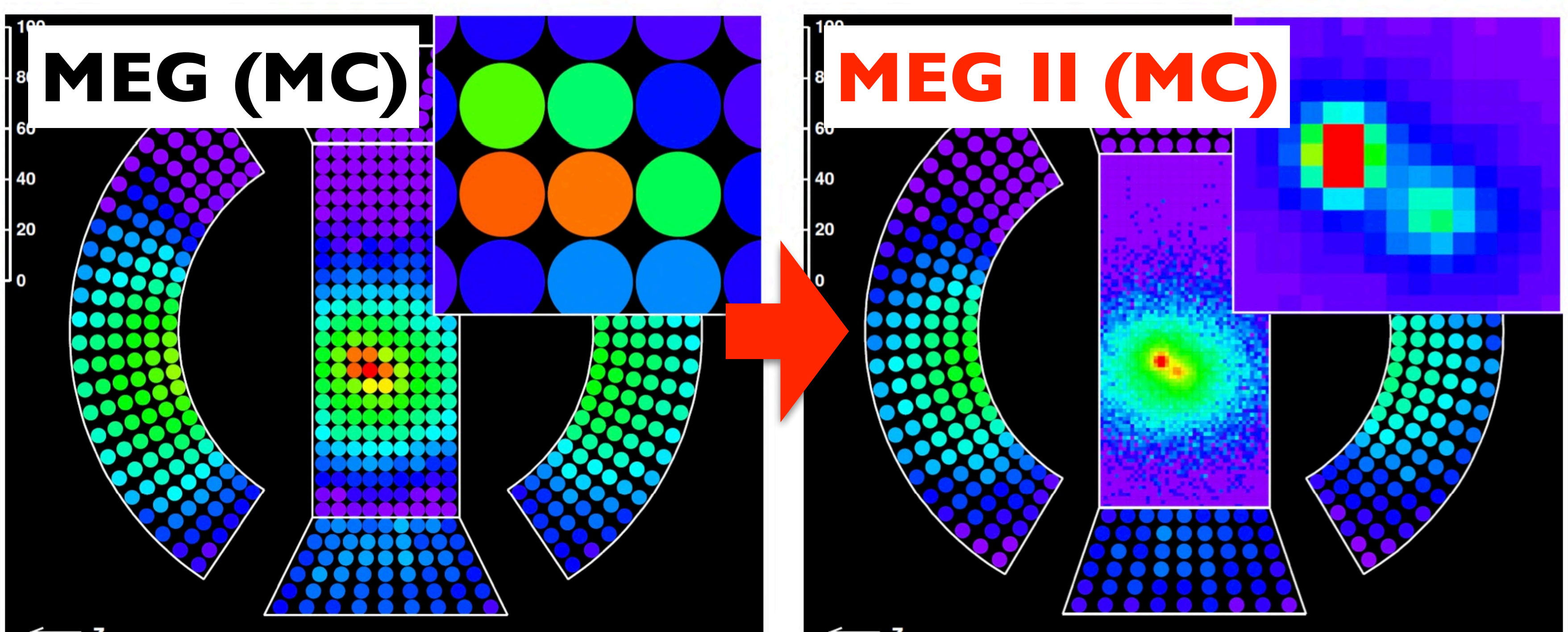
MEG II

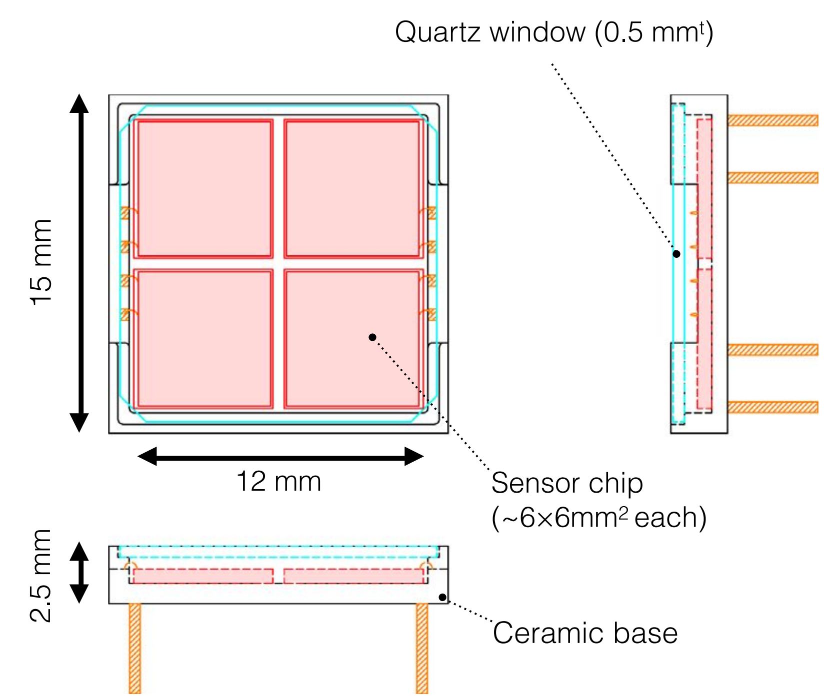
- **LXe scintillation light detection by VUV-MPPC**
  - Highly granular scintillation readout with 4092 × VUV-MPPCs (139mm² each)
  - Covering 0.92m² area with coverage of 62%



S10943-4372

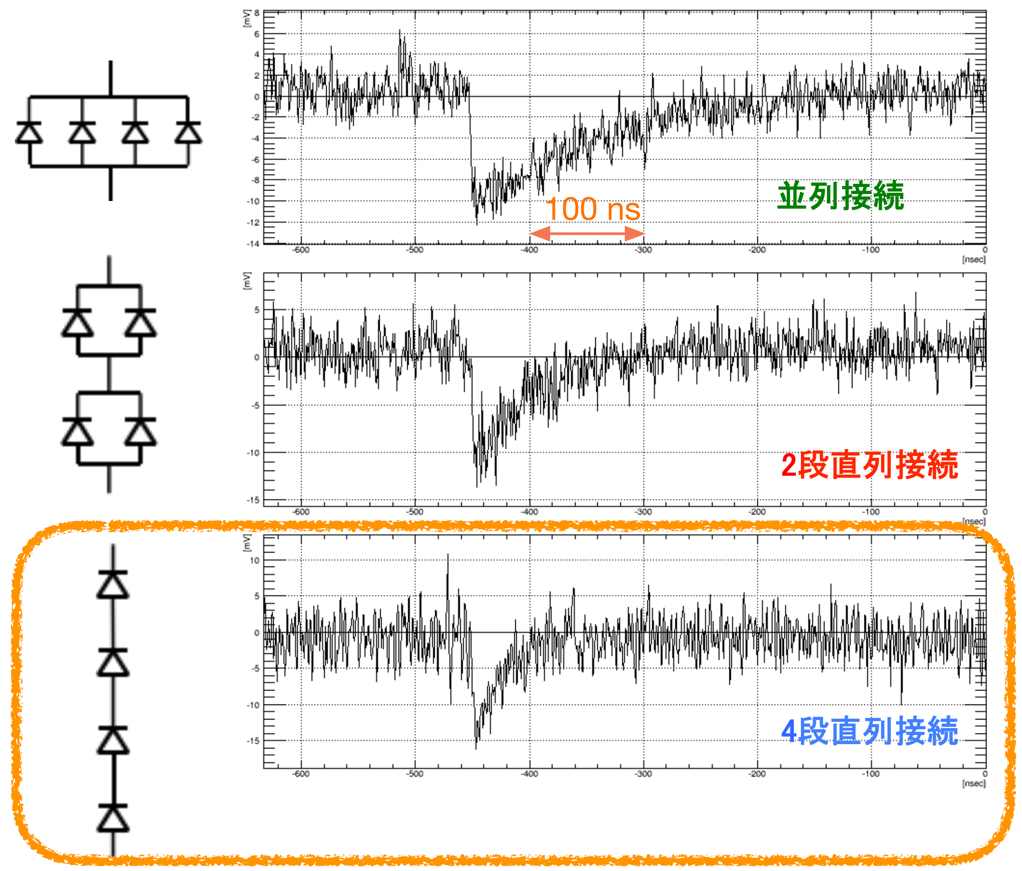


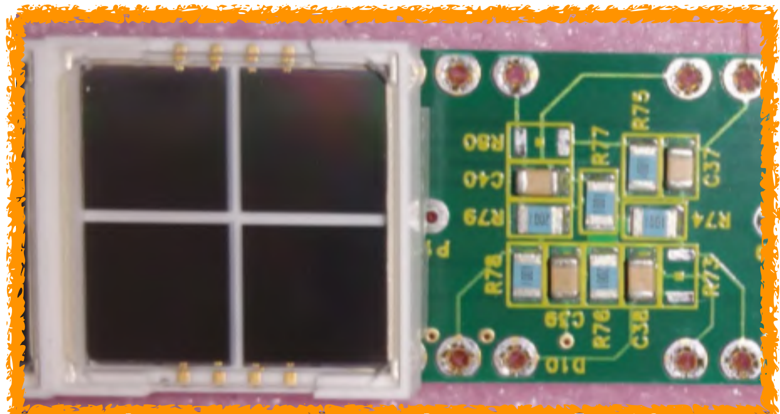


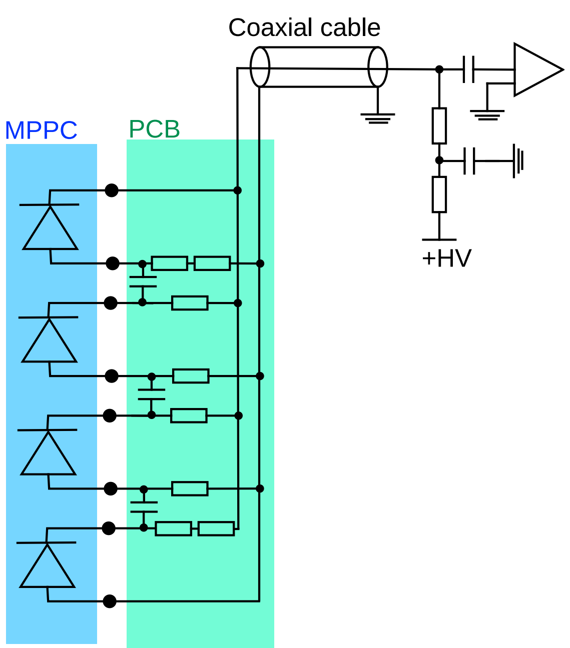


MEG II Ganging

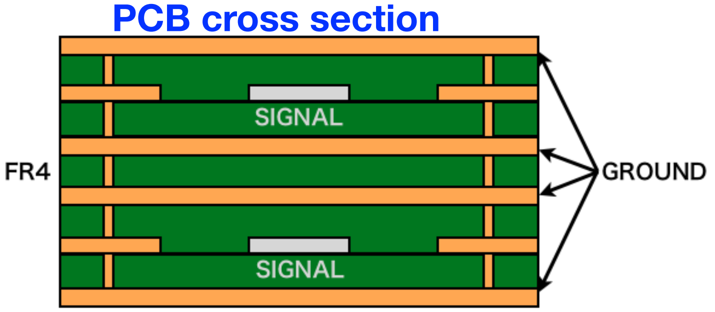
- **Requirements and constraints**
  - High granularity
  - Need both good S/N (energy) and high speed (timing)
  - No amplification at cryo temp
- **Passive ganging of 4 sensor segments (6×6mm² each)**
  - Series connection employed (timing ↔ S/N)
  - “Hybrid” connection
    - Series connection for signal
    - Parallel connection for biasing
- **PCB slab to assemble VUV-MPPCs**
  - 22 sensors mounted on each PCB
  - Series connections
  - High bandwidth signal transmission in coaxial-like signal line (50Ω)
  - Precise sensor alignment

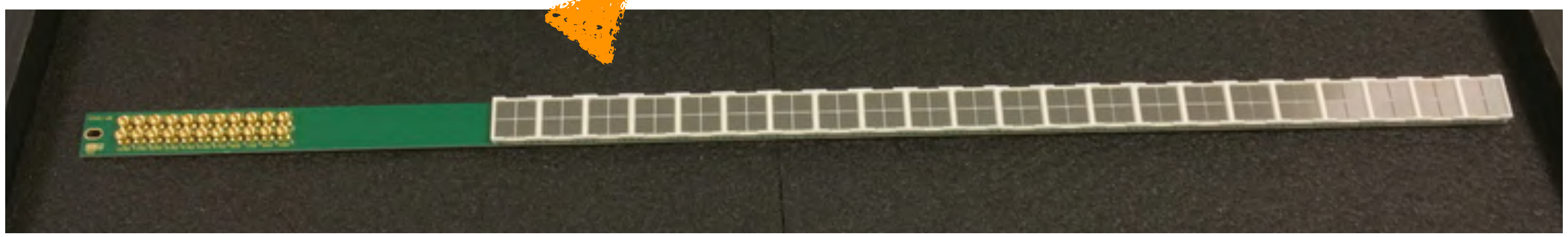






PCB cross section

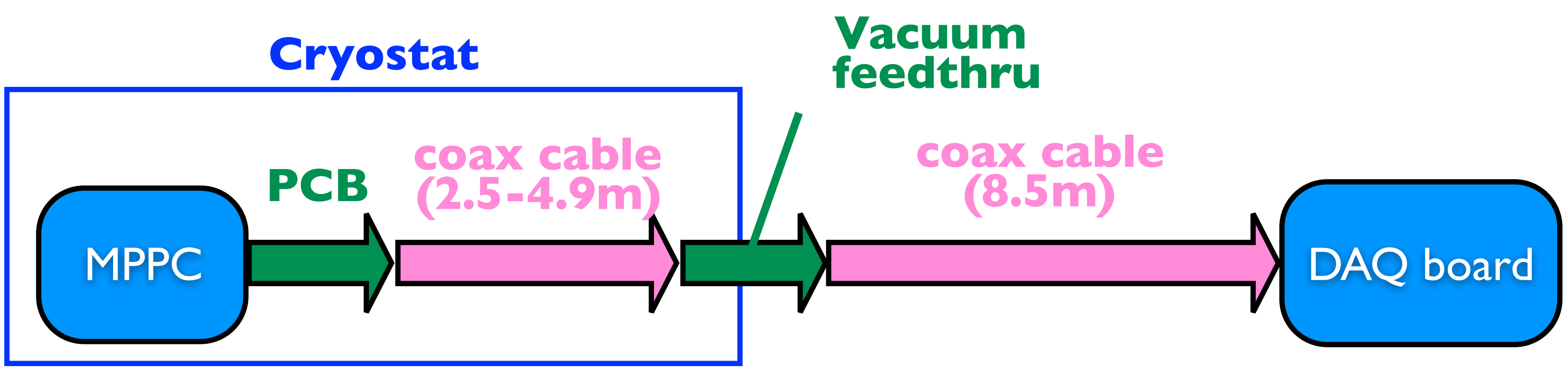


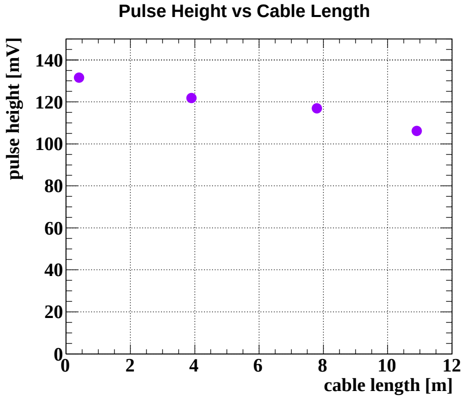


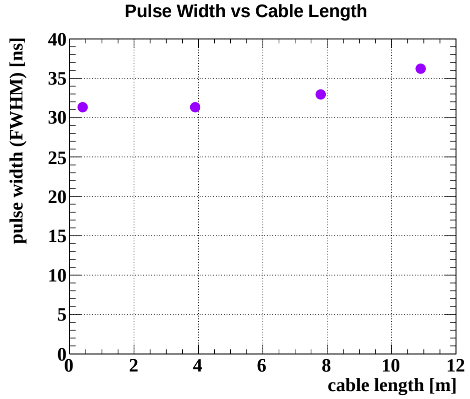
MEG II Signal Transmission

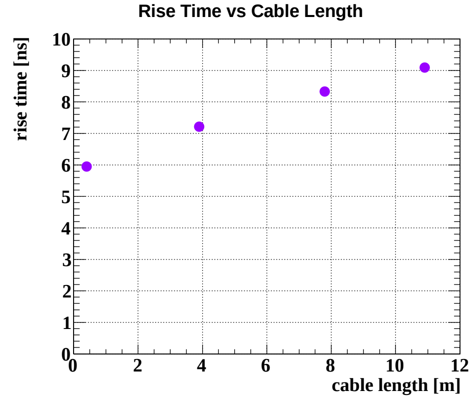
- **No amplification in LXe**
  - Signal transmission to readout electronics at room temp. via ~13m-long coaxial cable
  - Single cable for both biasing and signal transmission
- **High density PCB-based vacuum feedthrough**
  - PCB with coaxial-like signal line
    - 50Ω impedance, high noise immunity, high bandwidth, small cross-talk (<0.3%)
  - High density
    - 72ch/PCB, 6×PCBs on vacuum flange (DN160)

Readout chain

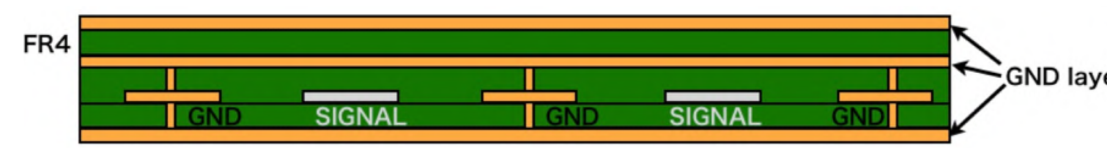


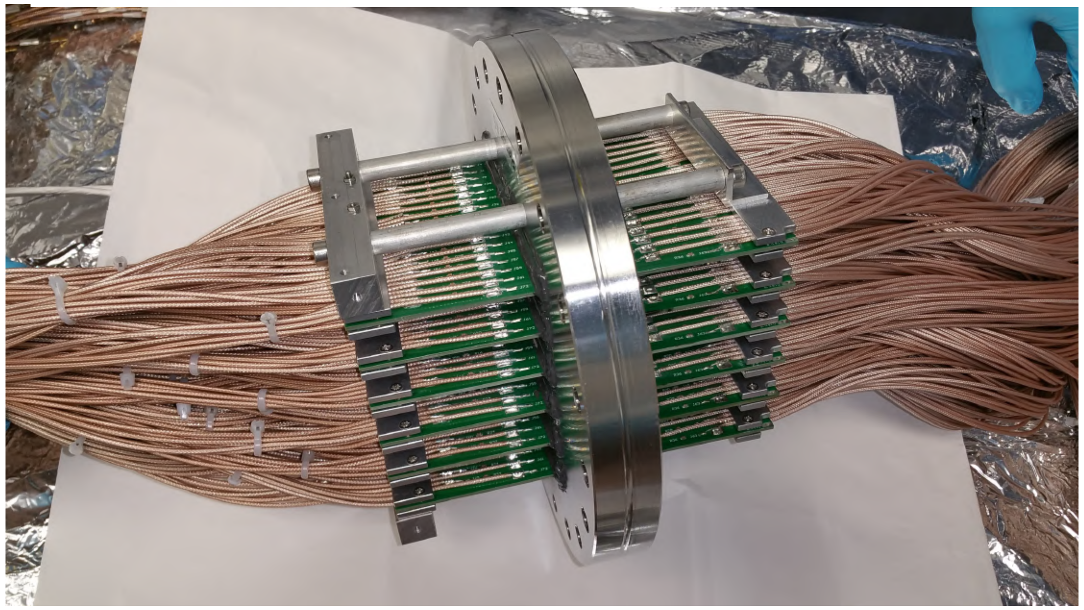






PCB-based vacuum feedthrough

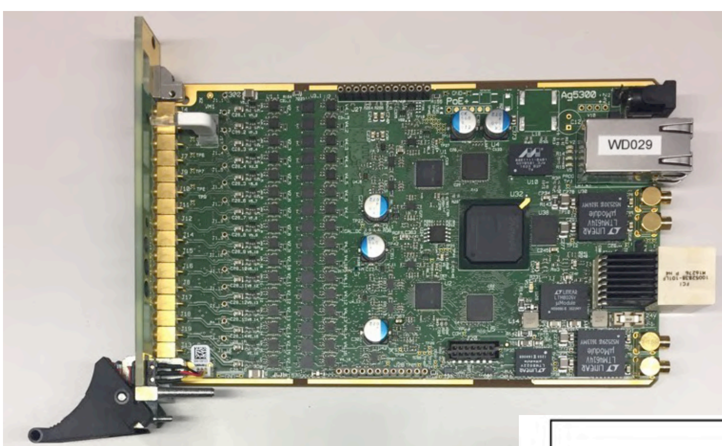




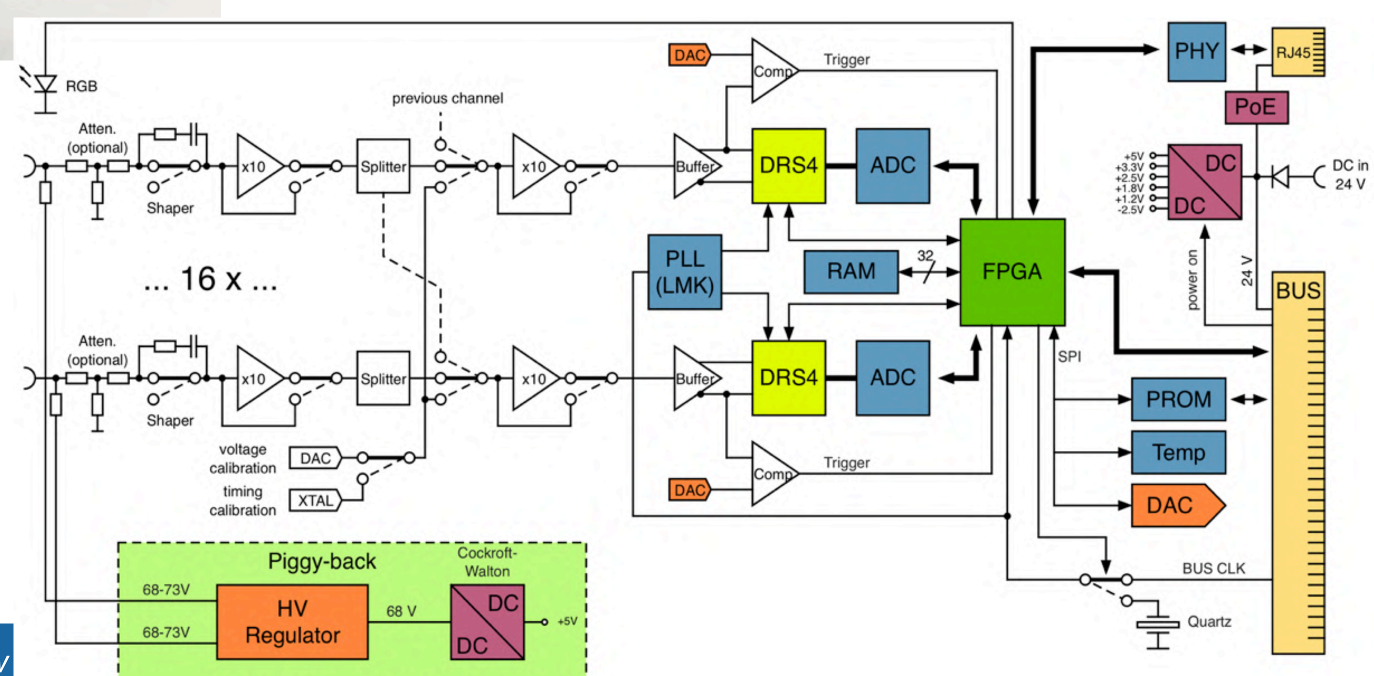
MEG II Readout Electronics

- **Combined DAQ-trigger system: WaveDAQ**
  - # of readout channels: 3000(MEG) → 9000(MEG II)
  - WaveDREAM
    - Waveform digitiser (DRS4)
    - Programmable FPGA-based trigger system
    - Bias circuit for SiPM

WaveDREAM board (16ch)



256 readout channel per crate



GERDA Phase II

- **LAr veto system in GERDA Phase II**
  - 405 fibers readout at both ends by 90 SiPMs

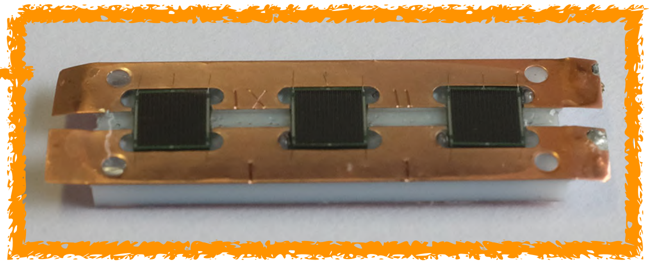
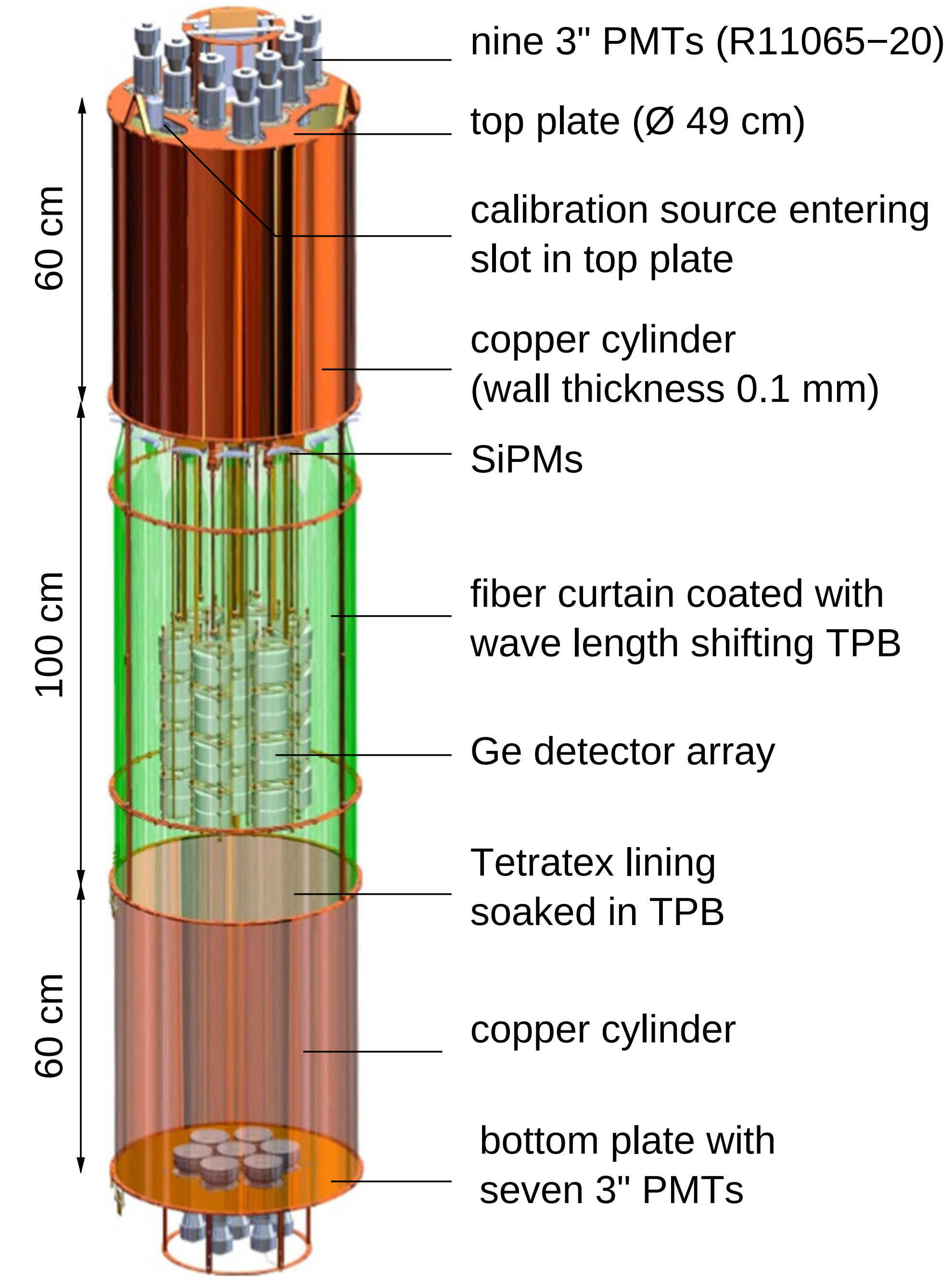
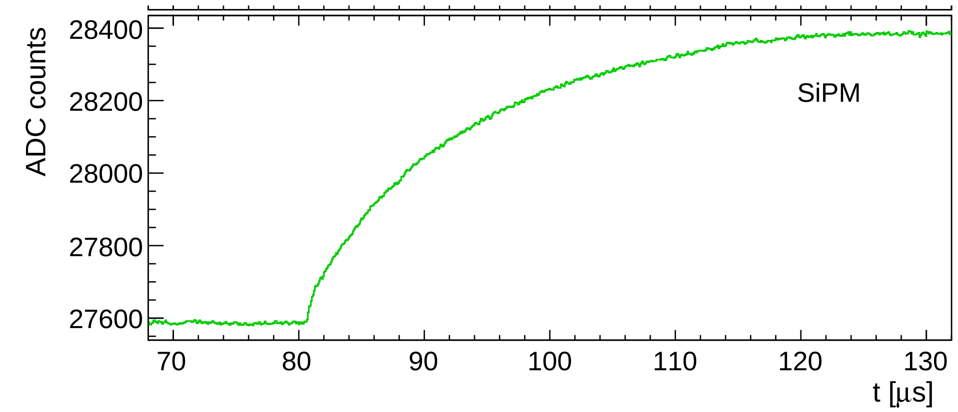


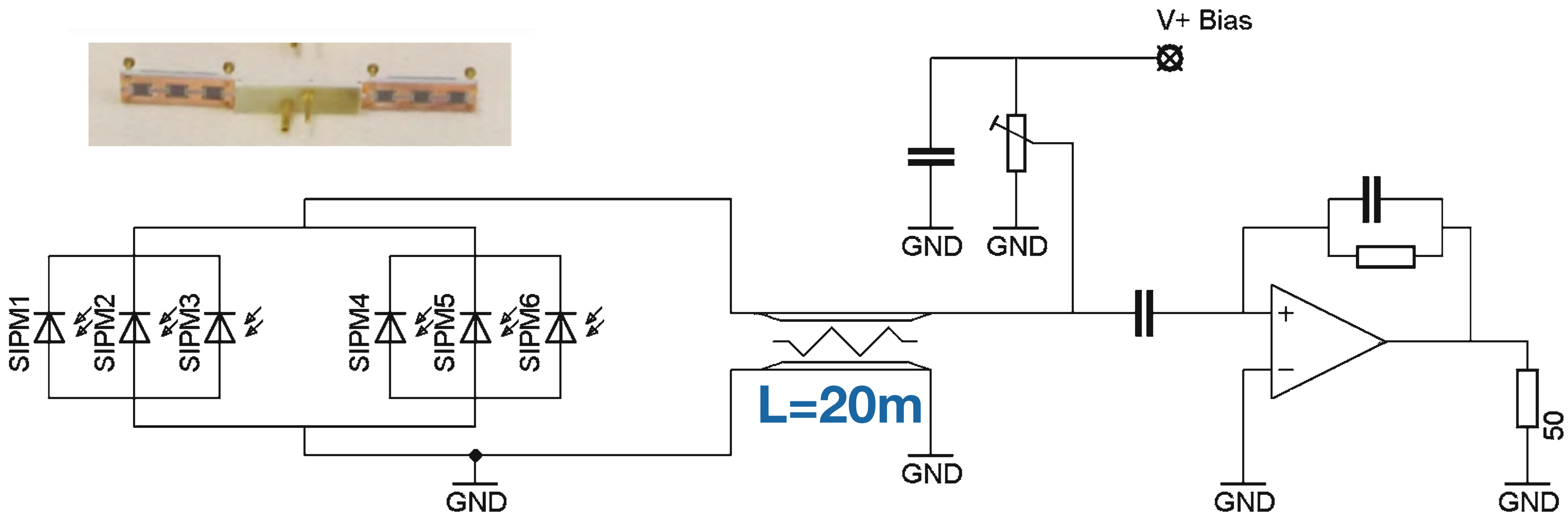
Fig. 14 The fiber curtain: height ~ 1 m, diameter ~ 0.5 m; 405 fibers read out on both ends by 90 SiPMs



GERDA Phase II SiPM readout

- **6 × SiPMs (3×3mm²) connected in parallel**
  - No amplification in LAr
  - 20m-long 50Ω cable to amplifier at room temp.
    - Slow signal
    - Signal and bias share the same cable





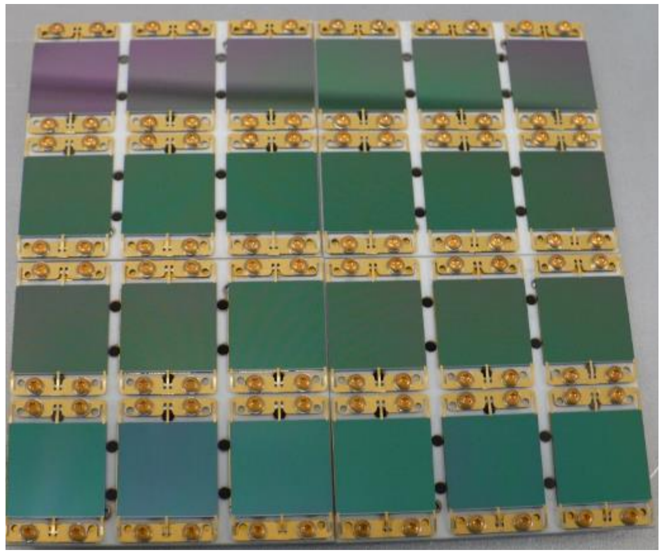
T~90K

Room temp.

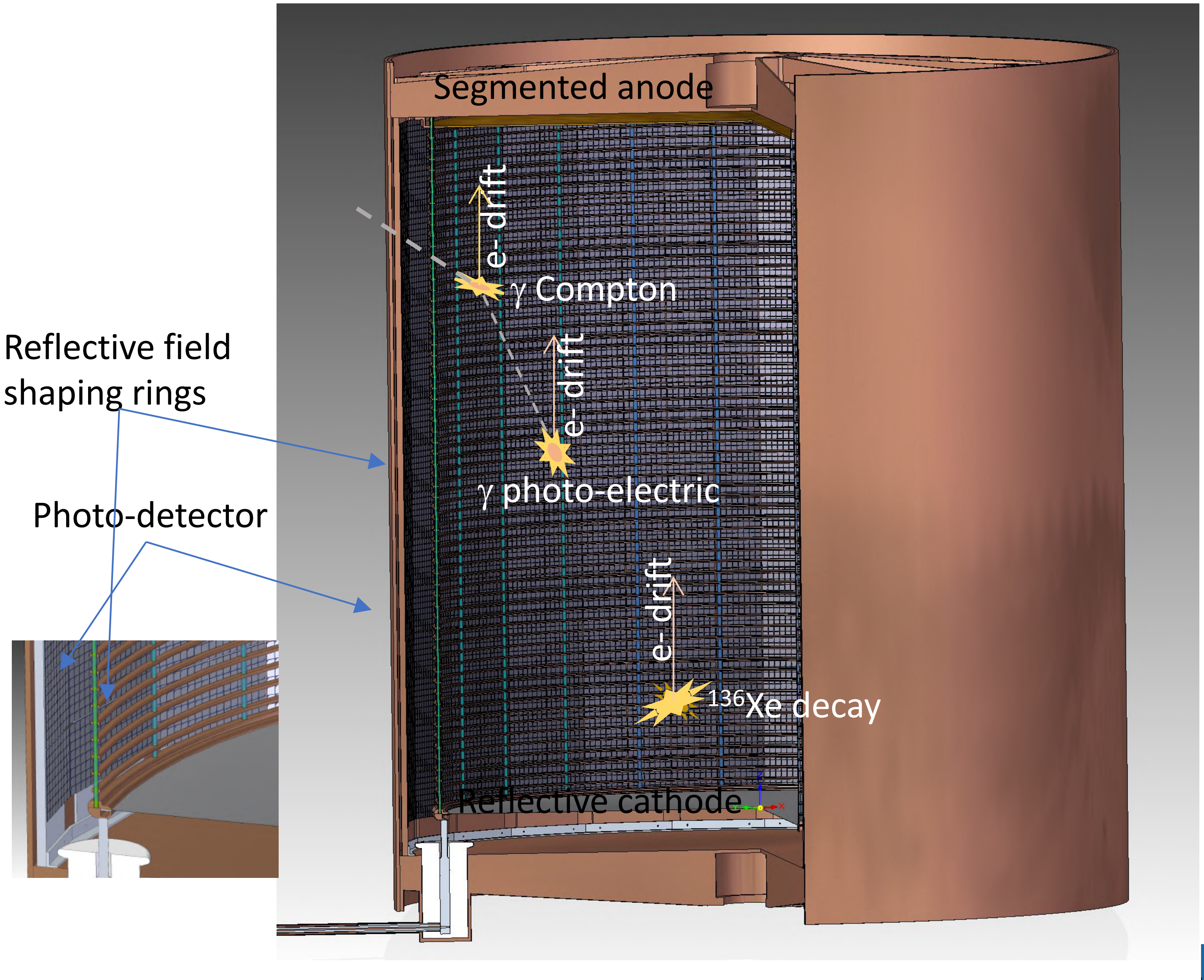
nEXO

- **SiPM light detection at barrel of nEXO**
  - VUV-SiPMs covering 4-5m^2
  - Single photodetector active area >1cm^2
  - Power dissipation < 100W
  - Noise < 0.1pe per channel
- **Two options under study for SiPM readout**
  - Cryogenic analogue readout
  - Cryogenic digital readout
    - Very low power consumption <1W

Prototype large area SiPM array (24SiPMs, 24cm^2)

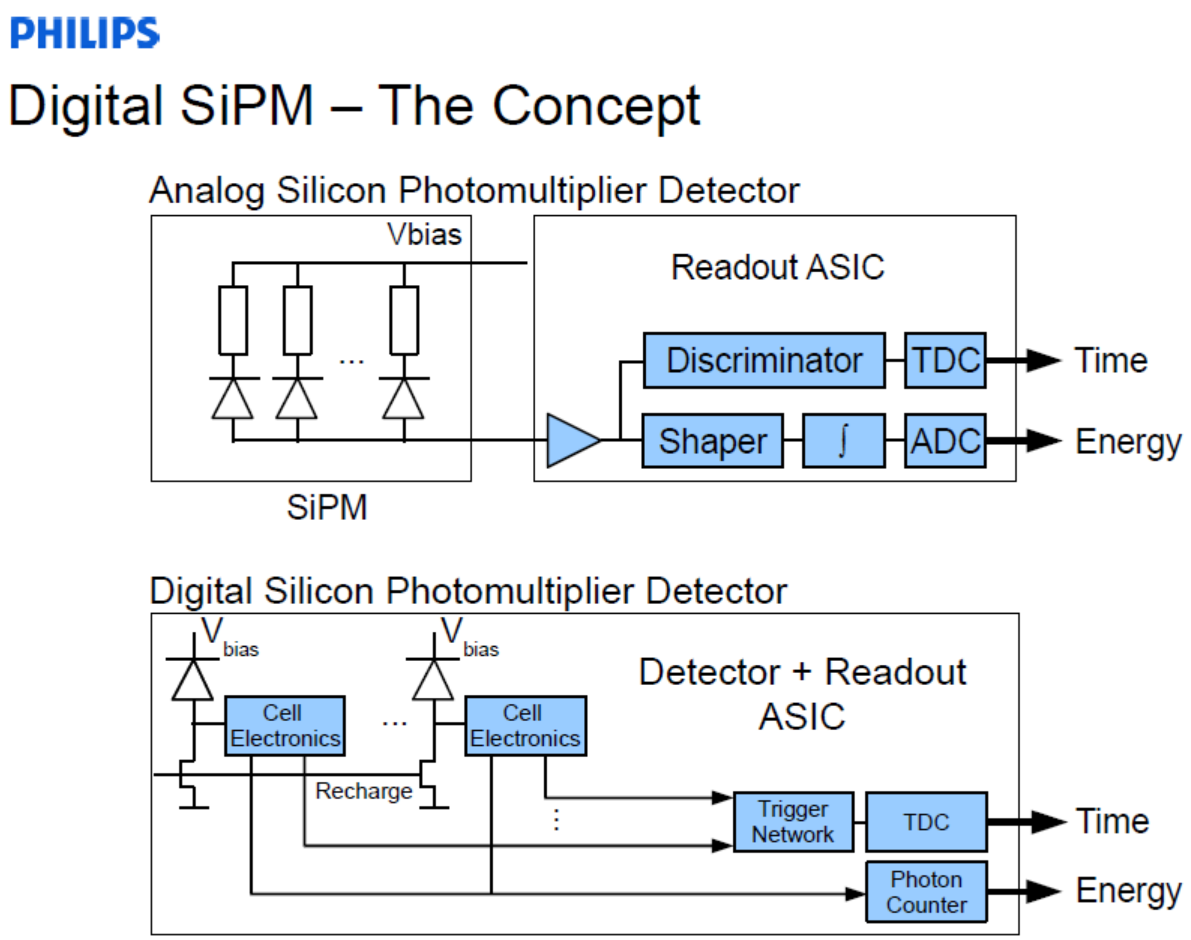


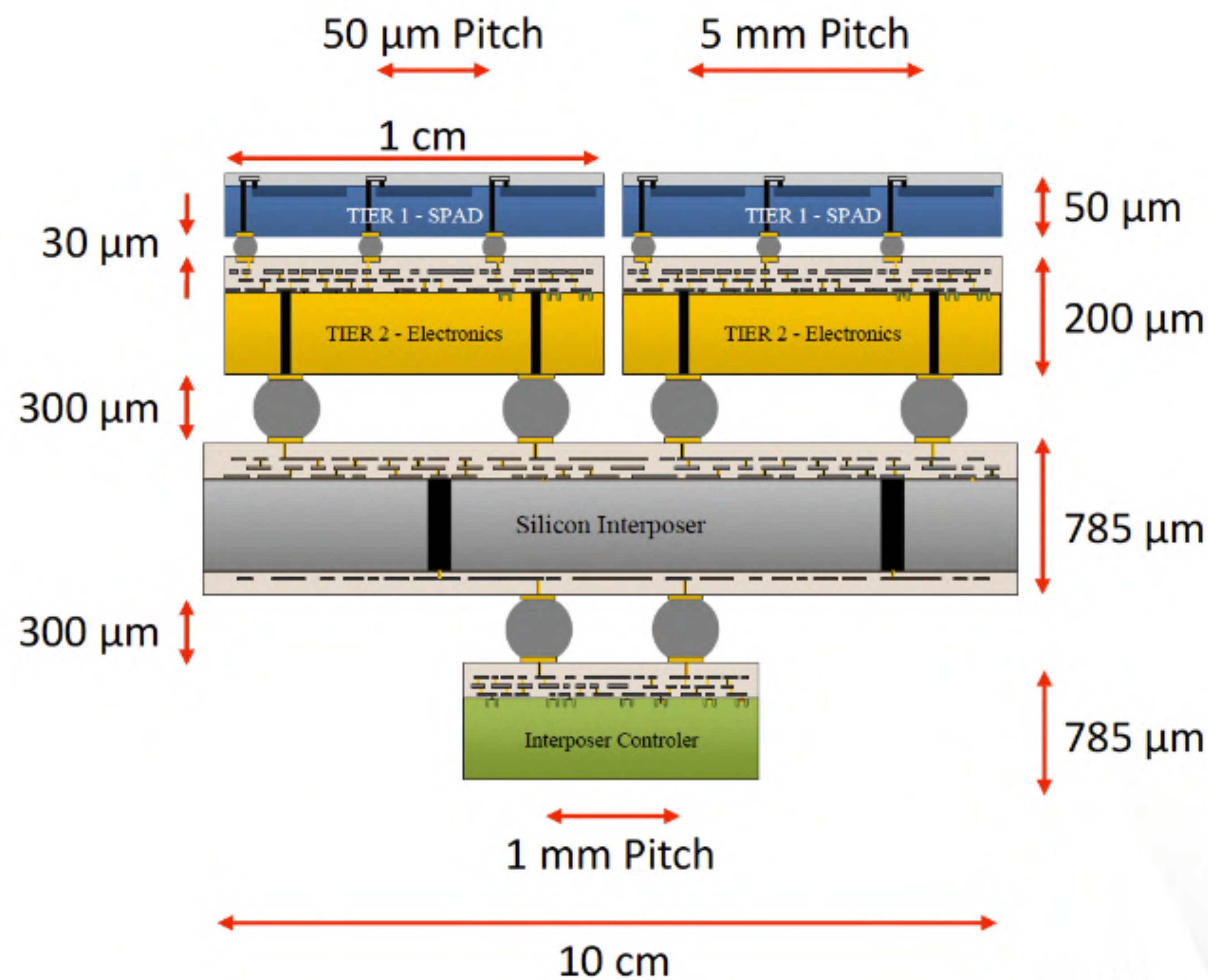
nEXO



nEXO 3D Integrated Digital SiPM

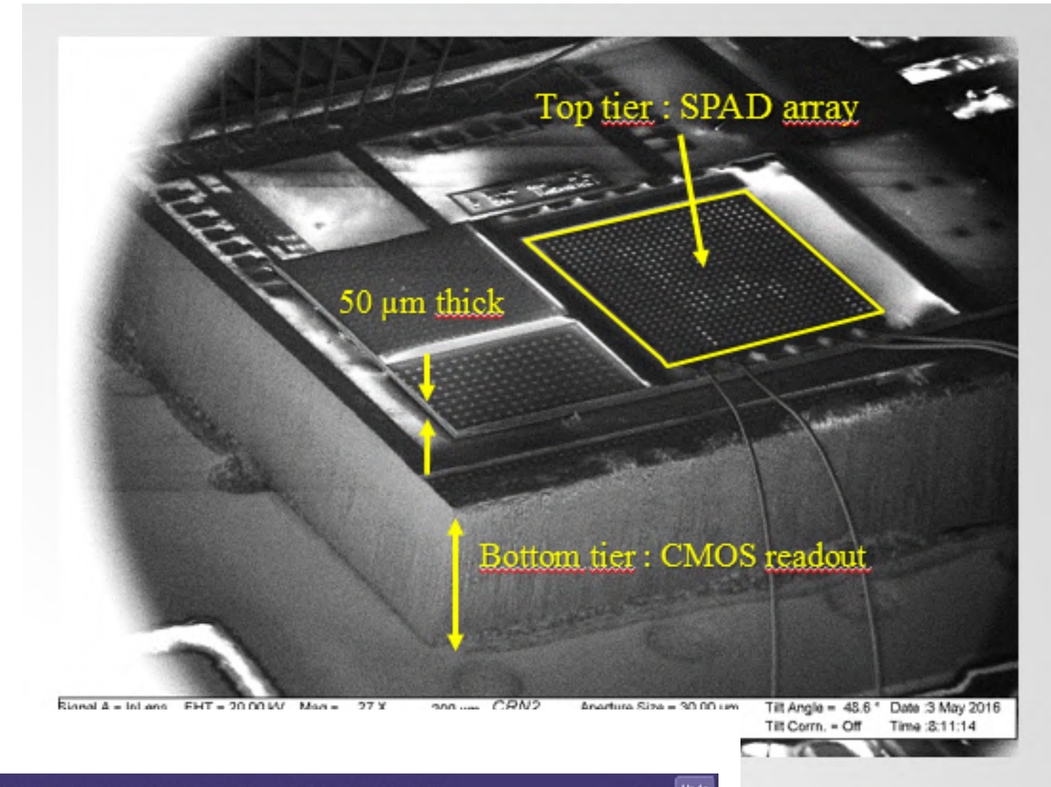
- **Digital SiPM**
  - On-cell digitisation
  - Low power consumption
  - Easier for large scale integration
- **3D-dSiPM: 3D integration to minimise dead area**
  - Tier1: SPAD
  - Tier2: electronics
  - Tier3: Data aggregator and trigger circuit

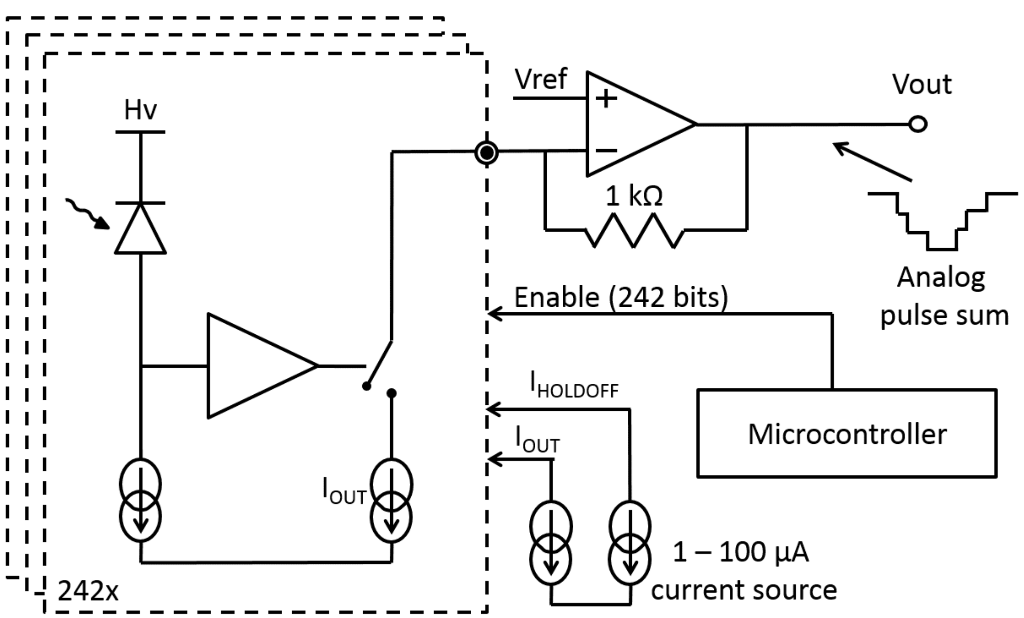


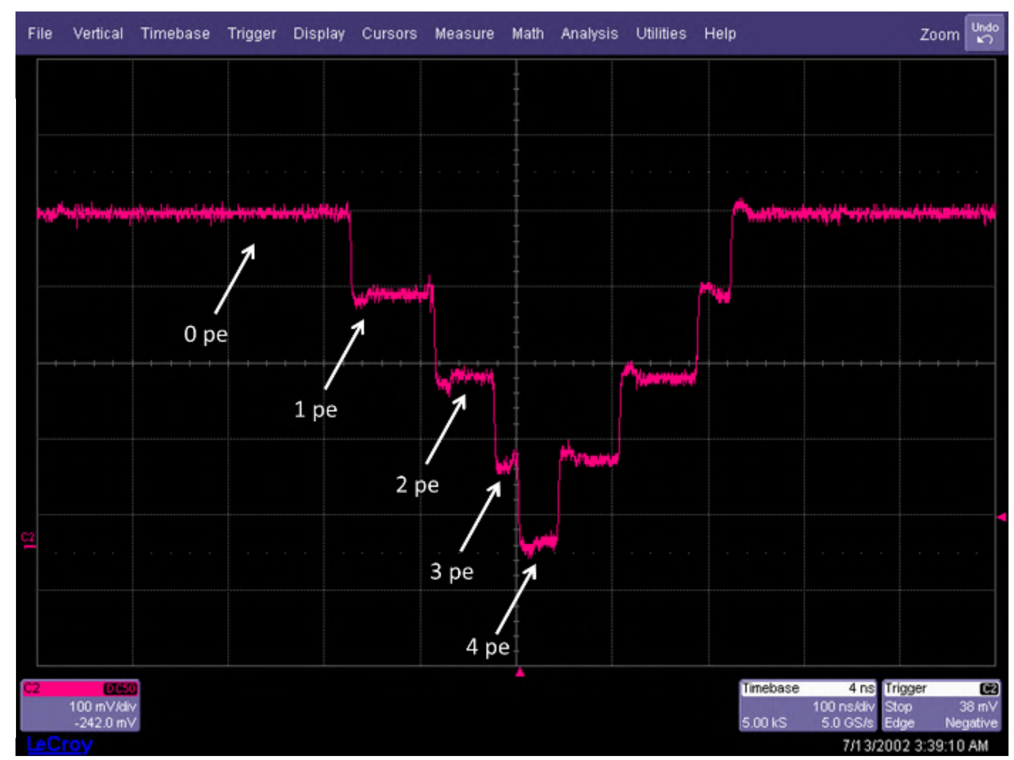


nEXO 3D Integrated Digital SiPM

- **Prototype for proof-of-principle works**

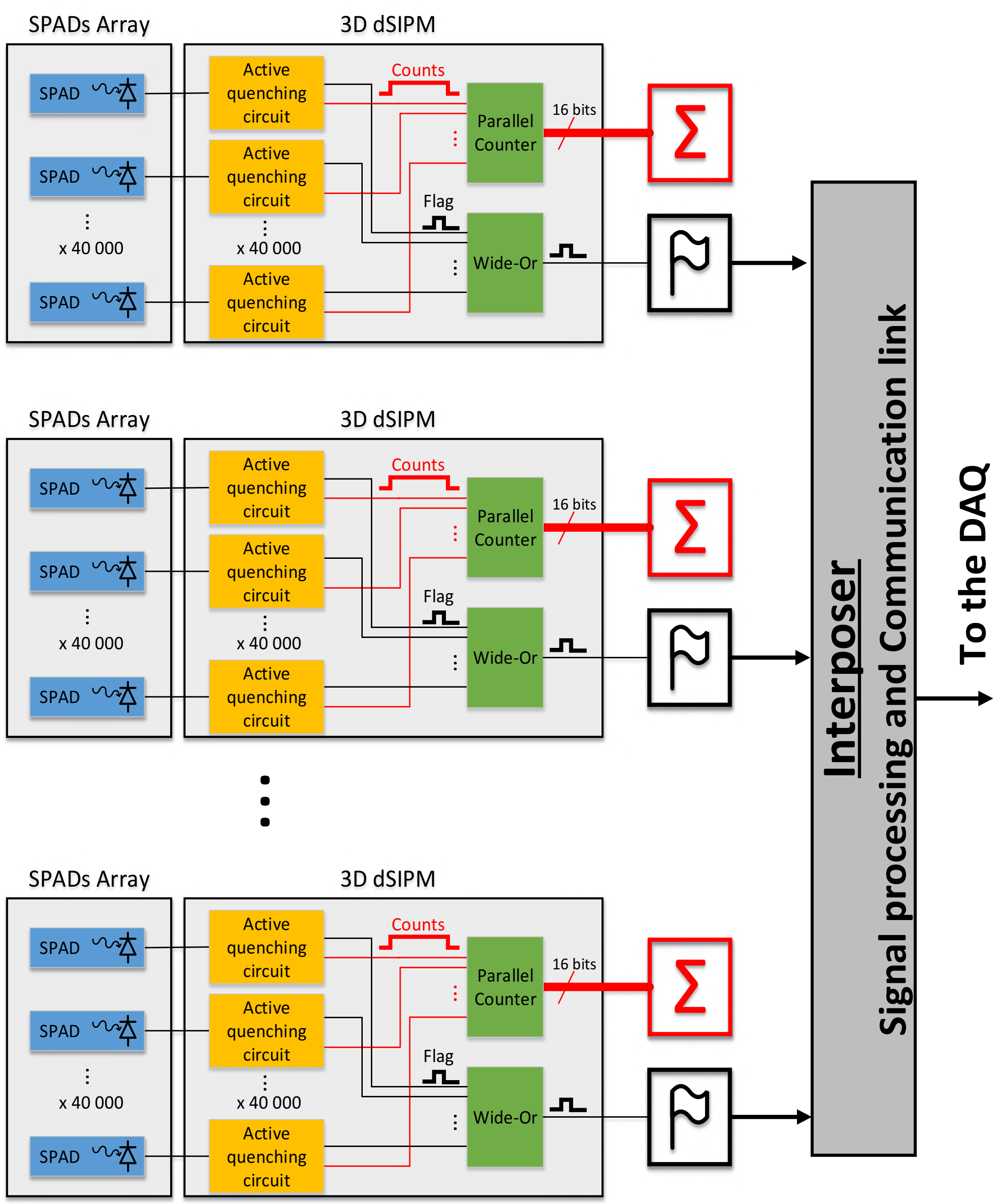






nEXO 3D Integrated Digital SiPM

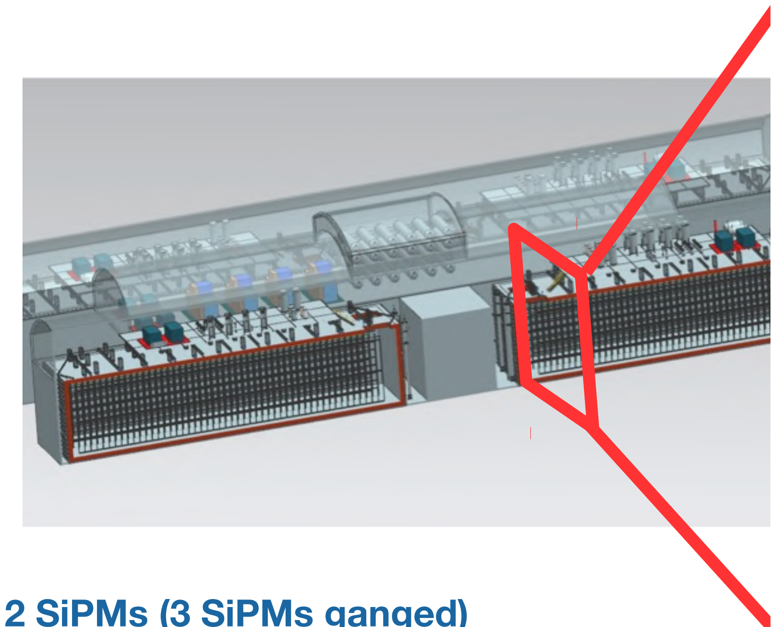
- **Operation scheme of 3D integrated digital SiPM**
  - Each tile of ~1×1cm²
  - Wired-OR over SPADs in each tile
  - Parallel adder to count # of fired SPAD
  - Coincidence over tiles
  - Trigger is generated depending on
    - Flag count
    - Coincidence

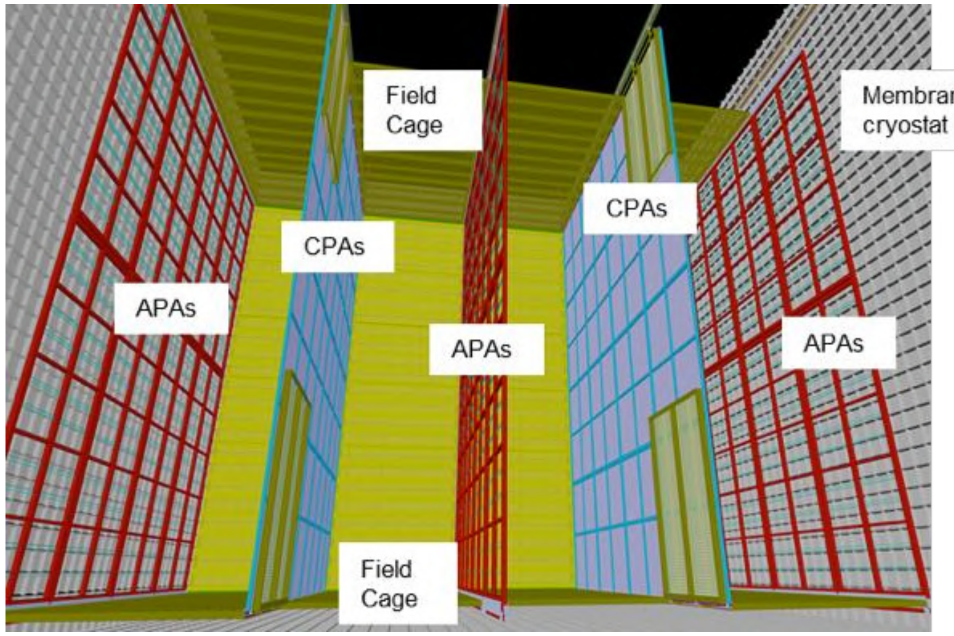


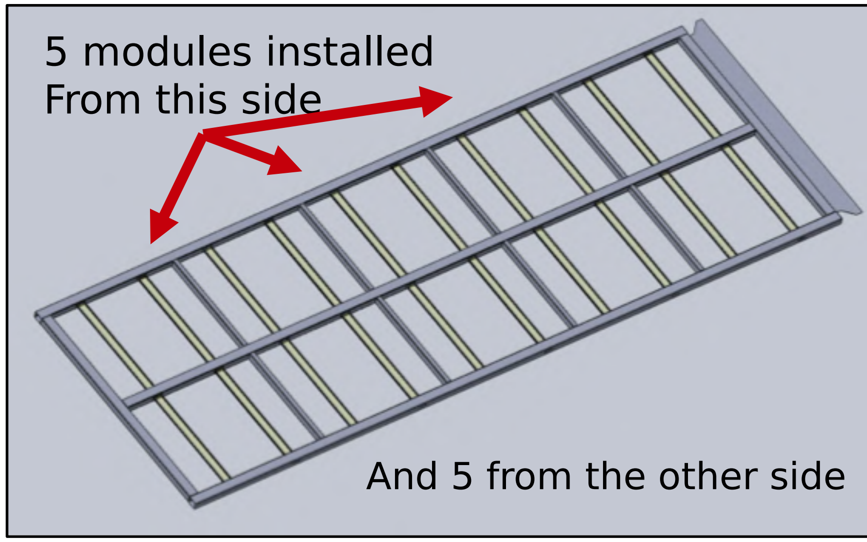
DUNE Single Phase (SP)

- **LAr scintillation light detection at DUNE SP/ProtoDUNE SP**
  - Timing and trigger purpose
- **10 Photon Detection modules (PDs) per Anode Plane Assemblies (APAs)**
  - APA frame area: 6060mm × 2300mm
  - PD active area: 2076mm × 84mm
- **A few options for PD**
  - Light guide with double WLS
  - ARAPUCA

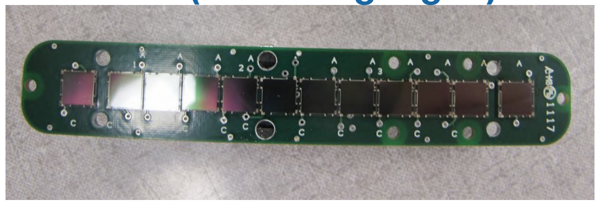
DUNE Far Detector Conceptual Design



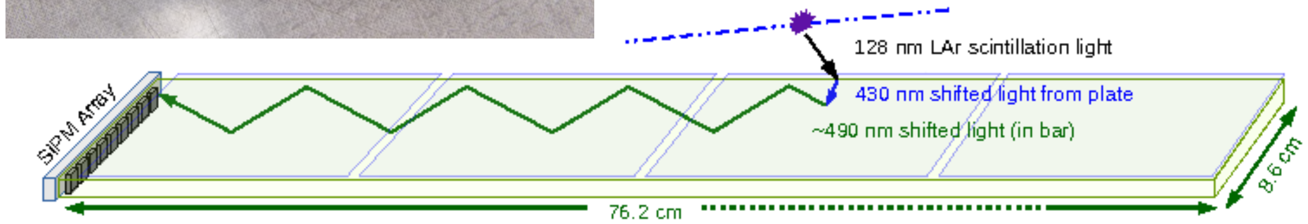




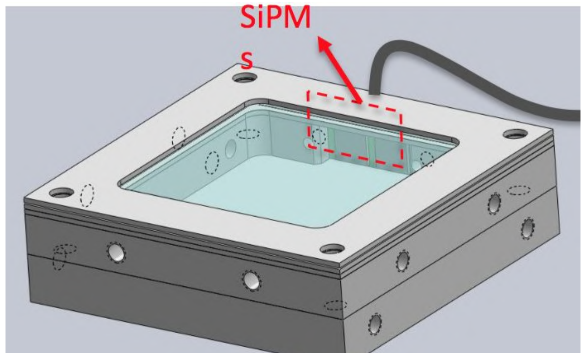
12 SiPMs (3 SiPMs ganged)



Light guide with double WLS

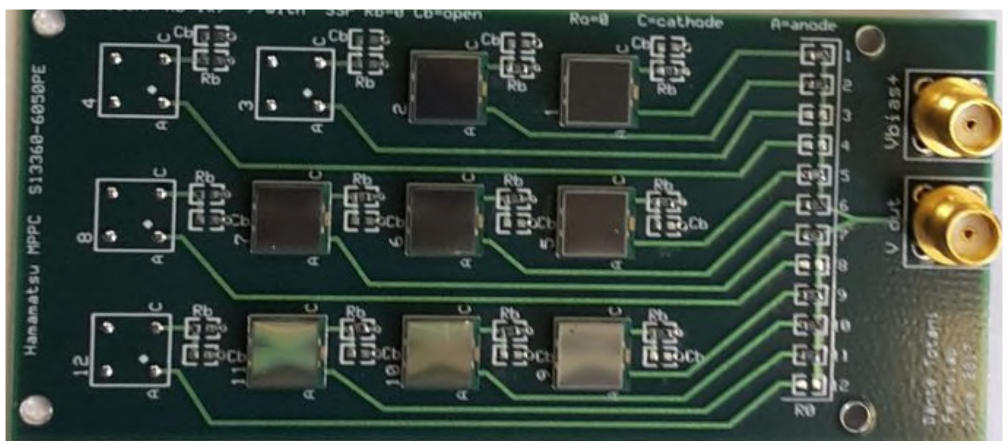


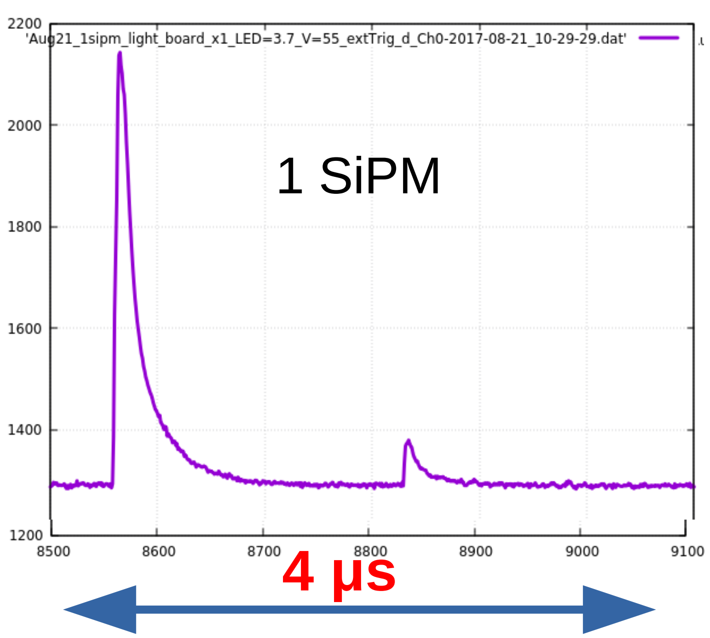
ARAPUCA

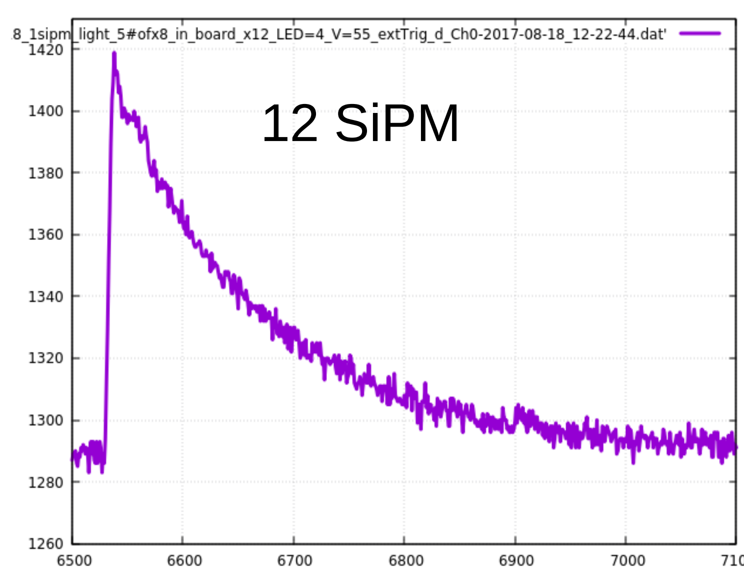


ARAPUCA (DUNE SP) Ganging

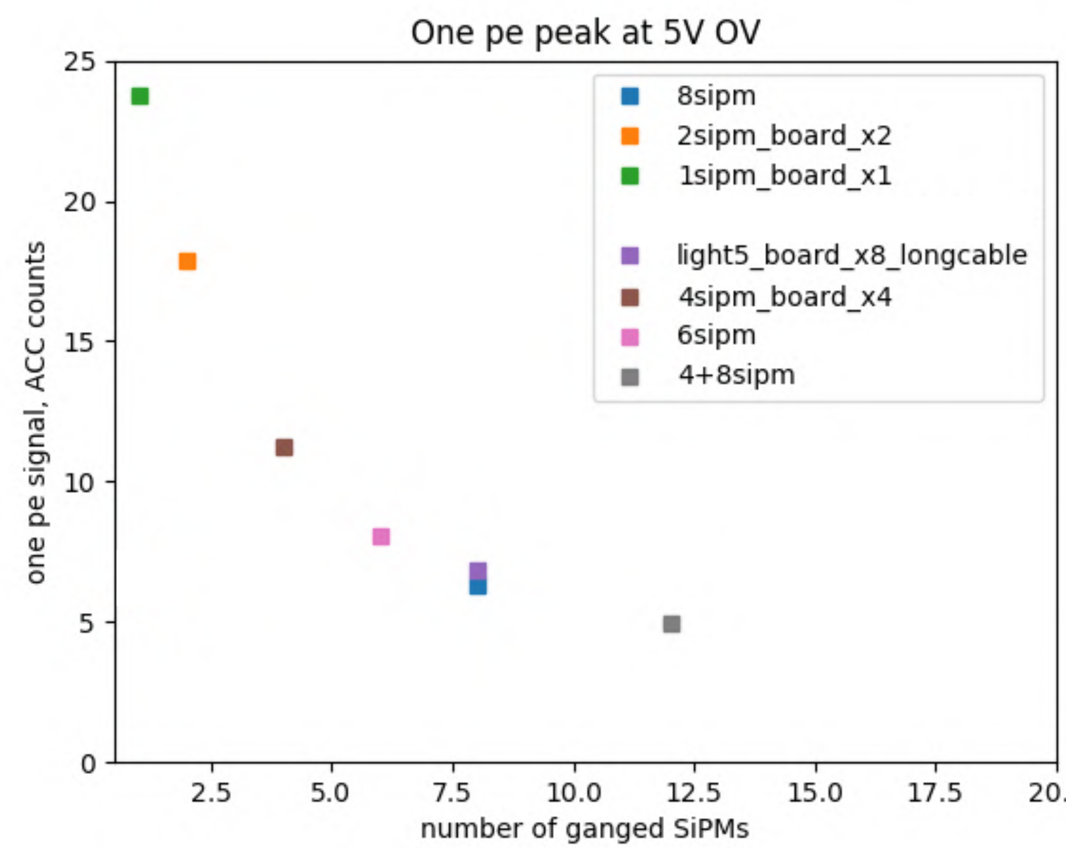
- **Two options for ganging under study**
  - Passive and active ganging
- **Passive ganging with parallel connection**





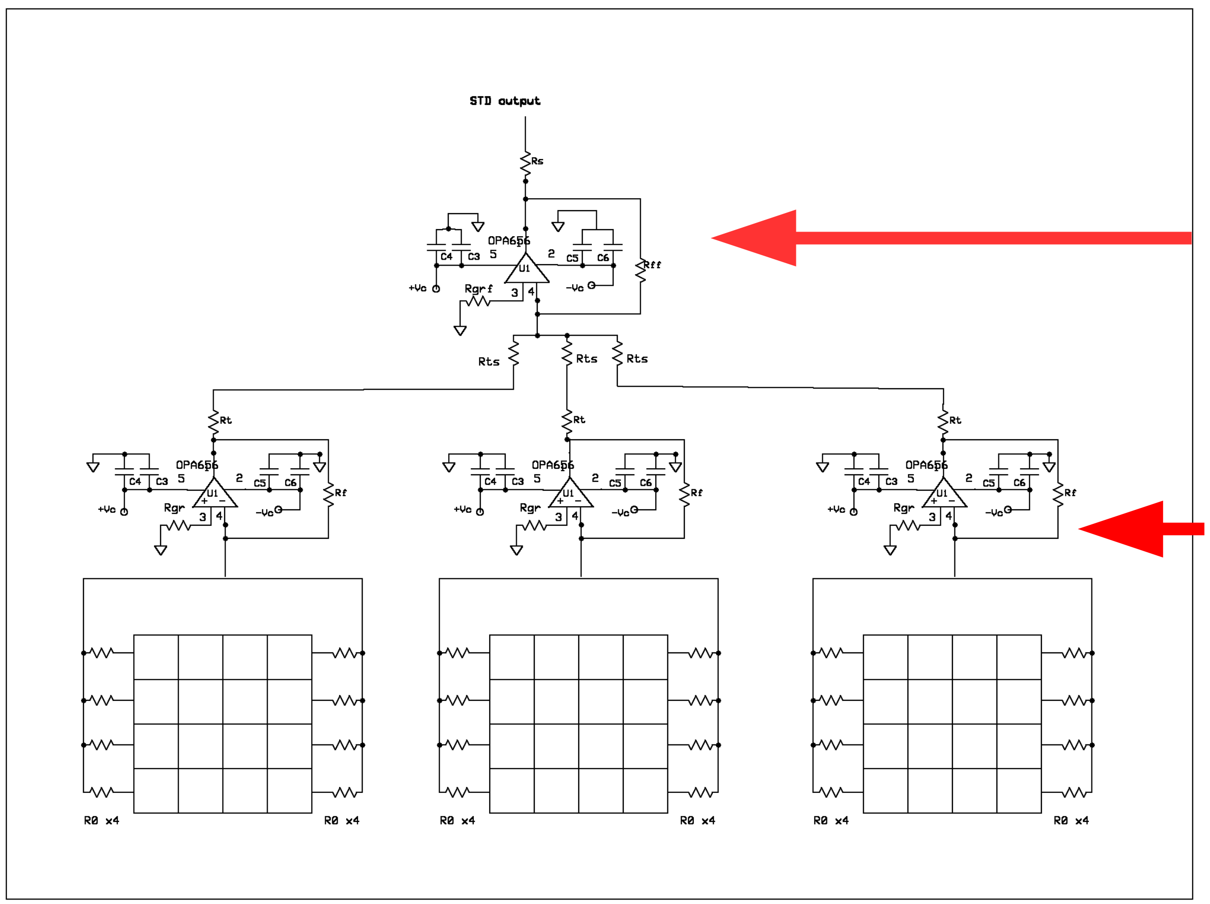


Single photon peak as a function of SiPM ganging



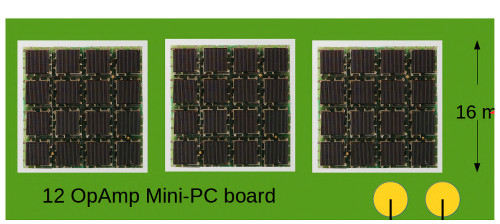
ARAPUCA (DUNE SP) Ganging

- **Active ganging**

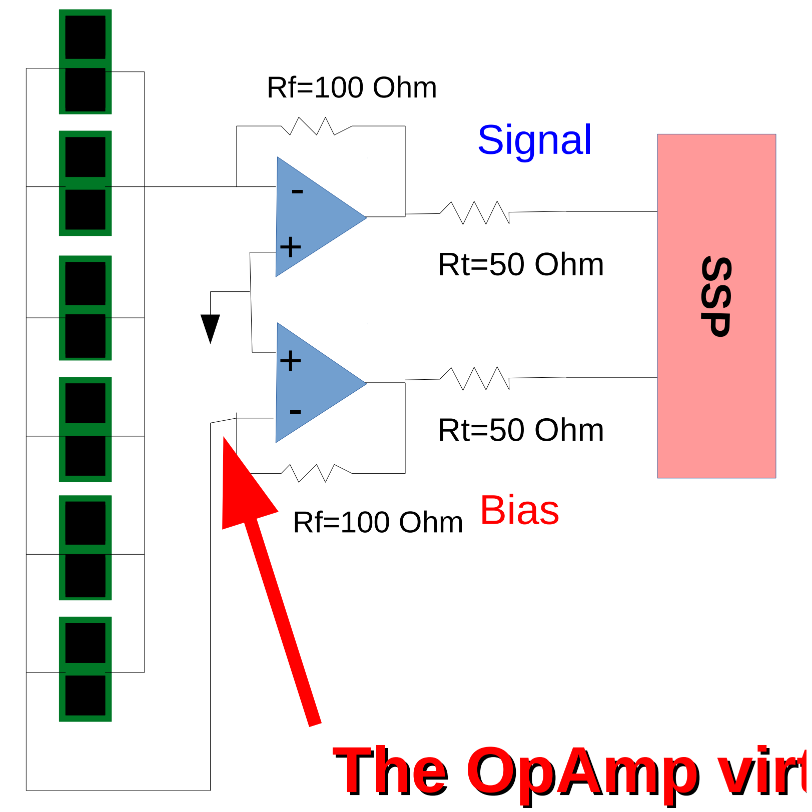


A second stage works as a buffer to sum the first stages

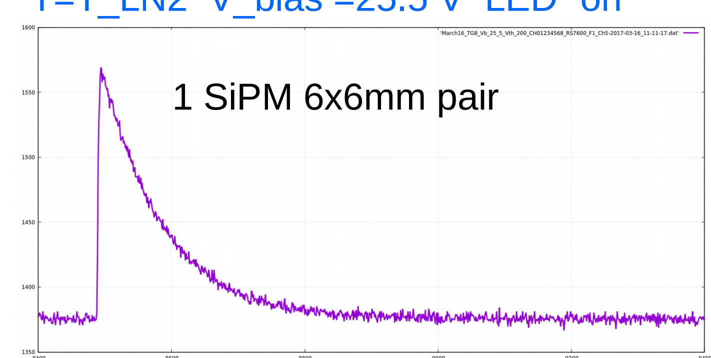
The virtual ground of the inverting imput allows to connect SiPMs decoupling the capacitance and hence preserving the signal shape.

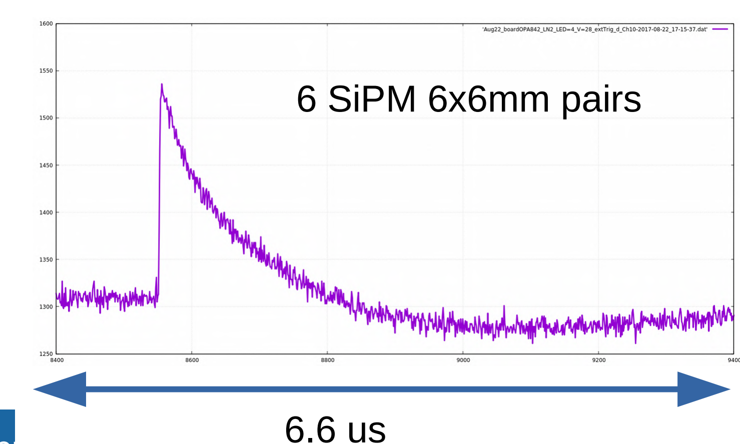


Active ganging for ProtoDUNE



T=T_LN2 V_bias =25.5 V LED "on"





Summary

- **Cryogenic experiment is an ideal place for SiPM application**
- **SiPM application to cover large area >O(m^2) starting**
  - Taking advantage of greatly suppressed DCR at cryogenic temperature
- **Different choices on readout techniques depending on requirements and constraints**
- **Experience at MEG II as a forerunner would be an important input for the forthcoming experiments**
  - See my talk on MEG II

N.B. the numbers are still unsettled for most of the projects

	DarkSide-20k	MEG II	GERDA Phase II	nEXO	DUNE SP (10kt module)
Operating temp	~90K (LAr)	~165K (LXe)	~90K (LAr)	~165K (LXe)	~90K (LAr)
Ganging	passive+active	passive	passive	passive/active/ digital	passive/active
# sensor readout	5210	4092	15	10000	6000
Sensor area per readout	25cm^2	1.4cm^2	0.54cm^2	4-5cm^2	17.3cm^2(ARAPUCA) 2.7cm^2(Bar) 5.4cm^2(Split)
Total area	14m^2	0.9m^2	8.1cm^2	4-5m^2	10.4m^2(ARAPUCA) 1.6m^2(Bar) 3.2m^2(Split)
Amplification	~90K	RT	RT	~165K	90K/RT
Status	In preparation	Commissionong	Running	In preparation	In preparation

Thank you for your attention!