PHOTOSENSOR TESTING IN XEBRA FOR DARWIN

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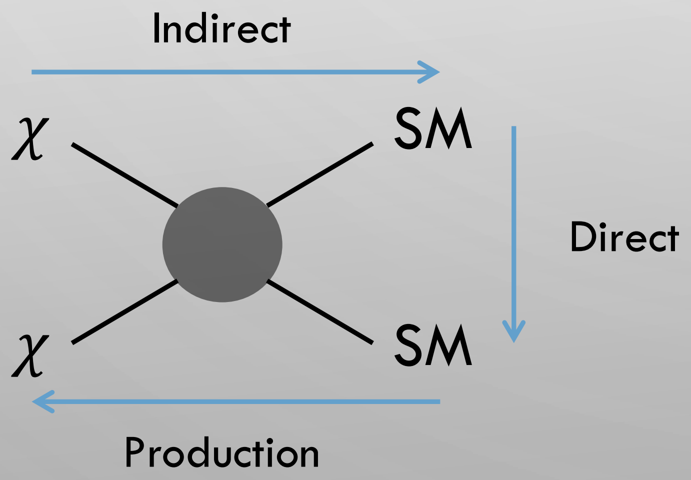
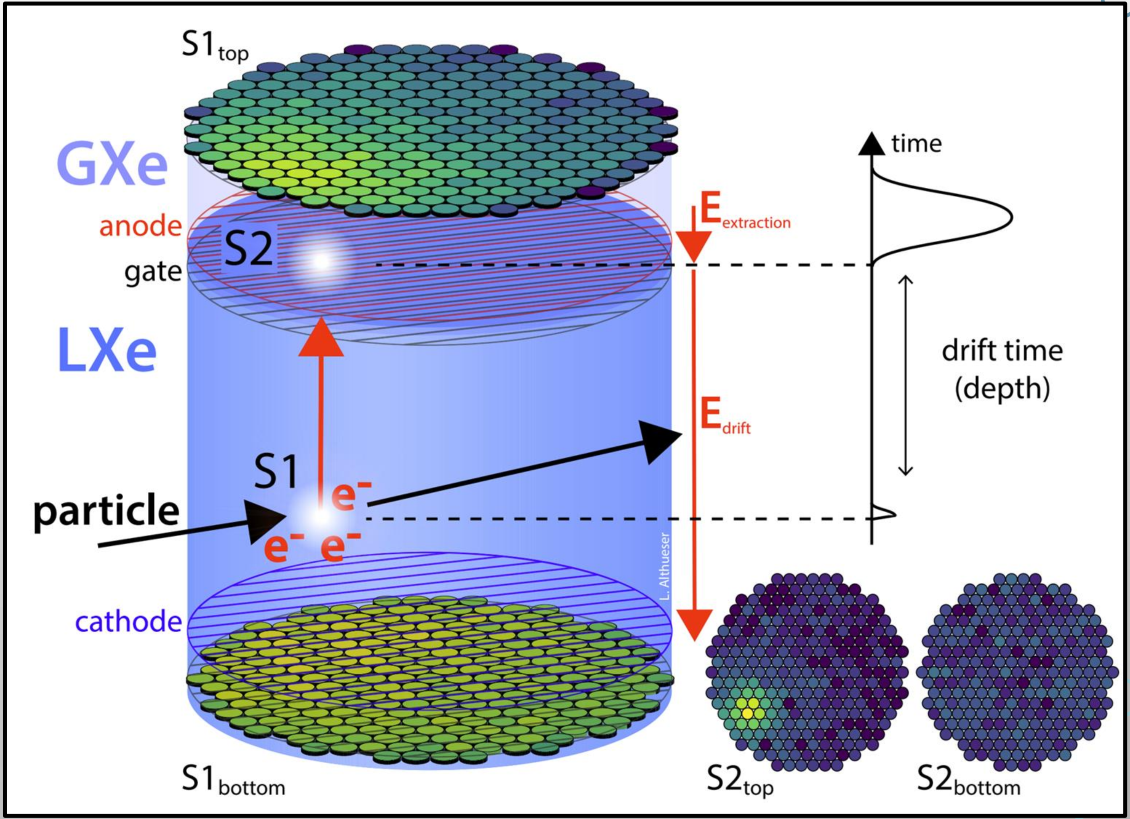
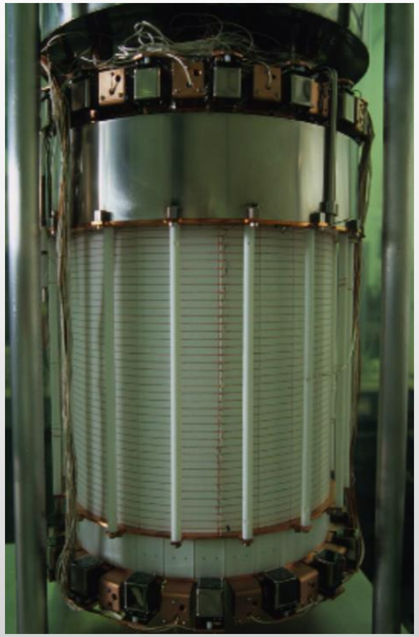
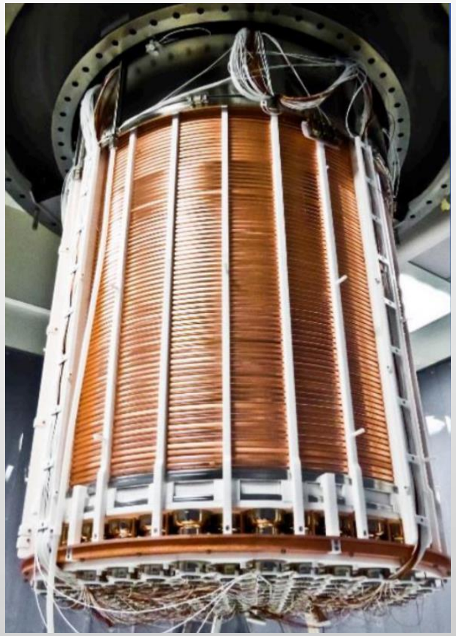
DARWIN

- Project of a next generation liquid xenon based dark matter detector
- Detects xenon scintillation light from the interaction
- Therefore needs photosensors





DARWIN

XENON10	XENON100	XENON1T	XENONnT
20 x 15 cm^2	30 x 30 cm^2	100 x 100 cm^2	130 x 150 cm^2
14kg Xe target	62kg Xe target	2t Xe target	5,9t Xe target
~ 10^{-43} cm^2	~ 10^{-45} cm^2	4 . 10^{-47} cm^2	1,4 . 10^{-48} cm^2

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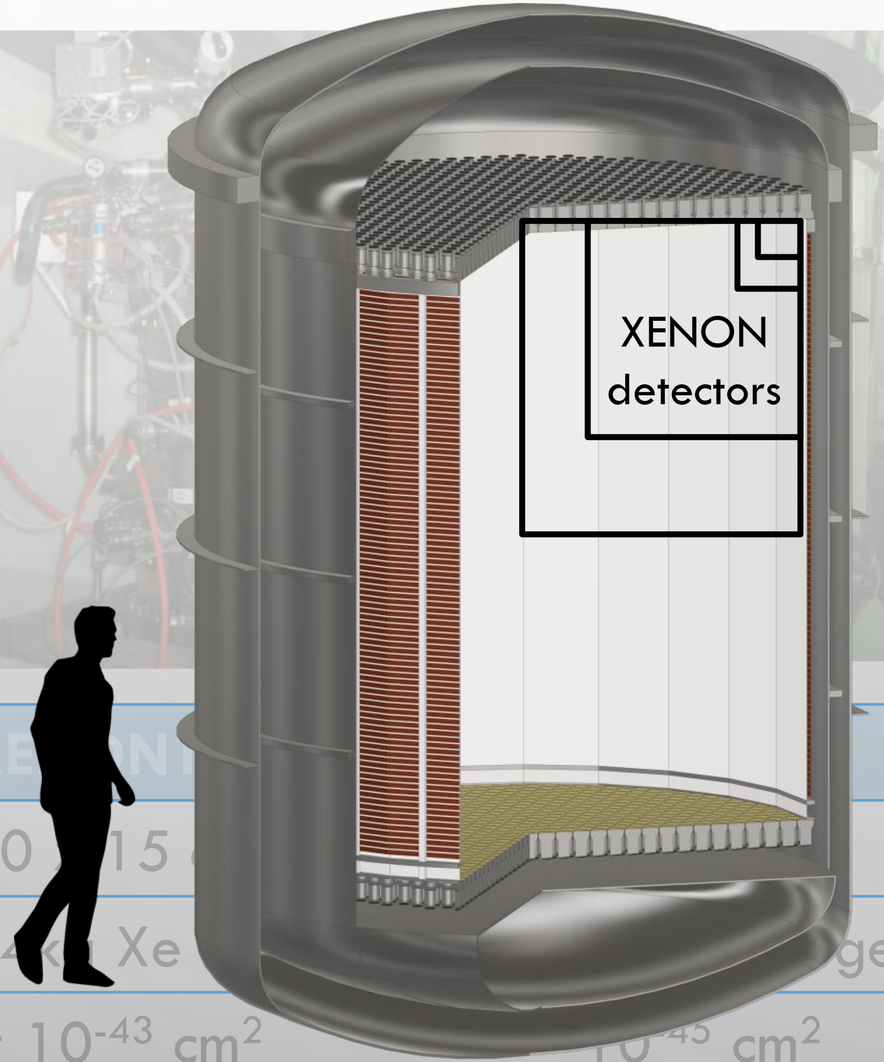
DARWIN



260 x 260 cm² time projection chamber

40 tonnes of active target

Ten times improved sensitivity

XENON[illegible]			
20 [illegible] 15 [illegible]	[illegible]	100 x 100 cm	130 x 150 cm
1[illegible] Xe	[illegible]get	2t Xe target	5,9t Xe target
~ 10^{-43} cm²	[illegible] cm²	4 . 10^{-47} cm²	1,4 . 10^{-48} cm²

PHOTOSENSORS REQUIREMENTS

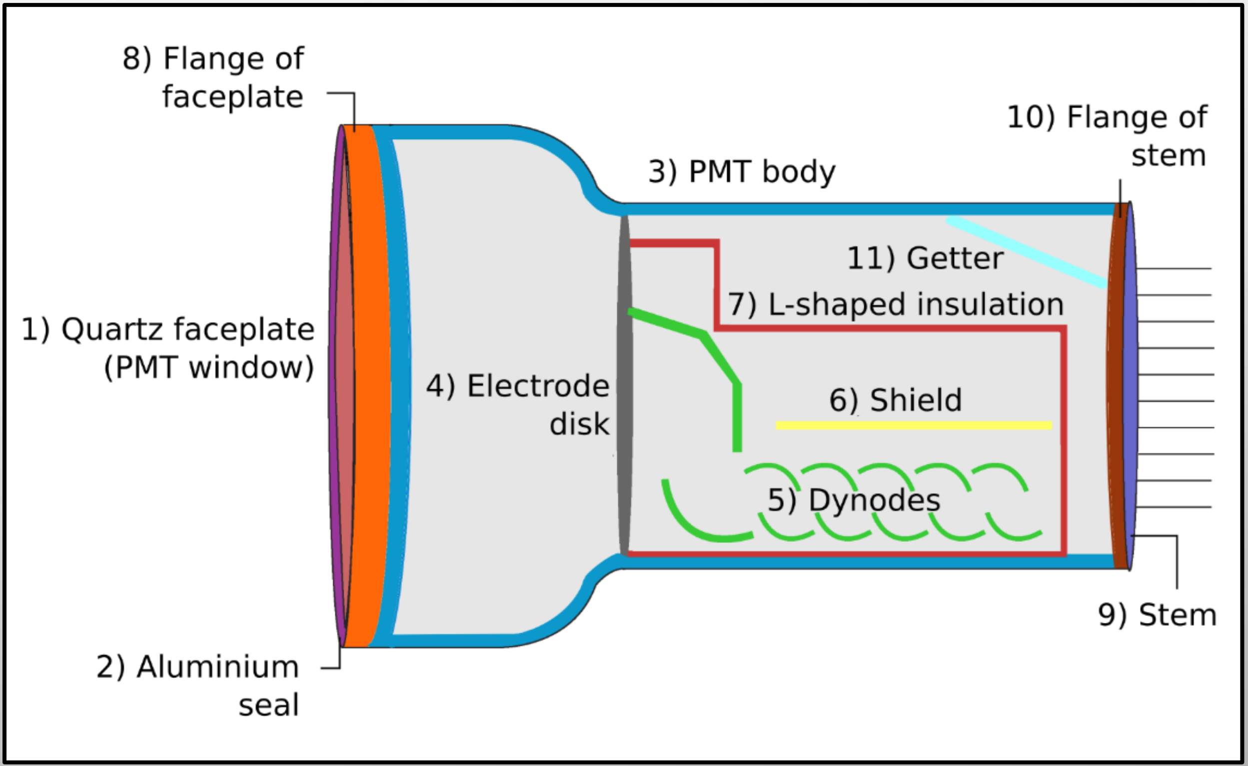
- Low radioactivity
- Vacuum ultraviolet (VUV) sensitivity and high photon detection efficiency
- Stable performance at cryogenic temperature and over time
- Low dark count rate
- Time resolution
- Low power consumption

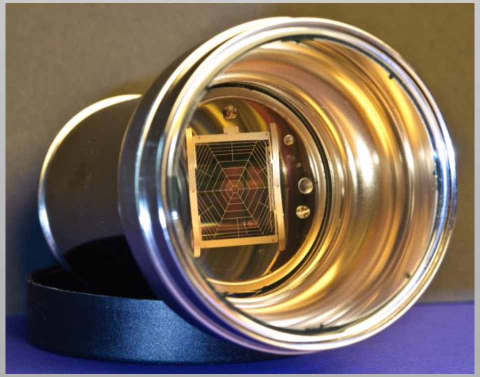
CURRENT SOLUTION IN XENON

Hamamatsu R11410-21

3 inch photomultiplier tubes (PMTs)

Optimized with the company and the collaboration **for low background**





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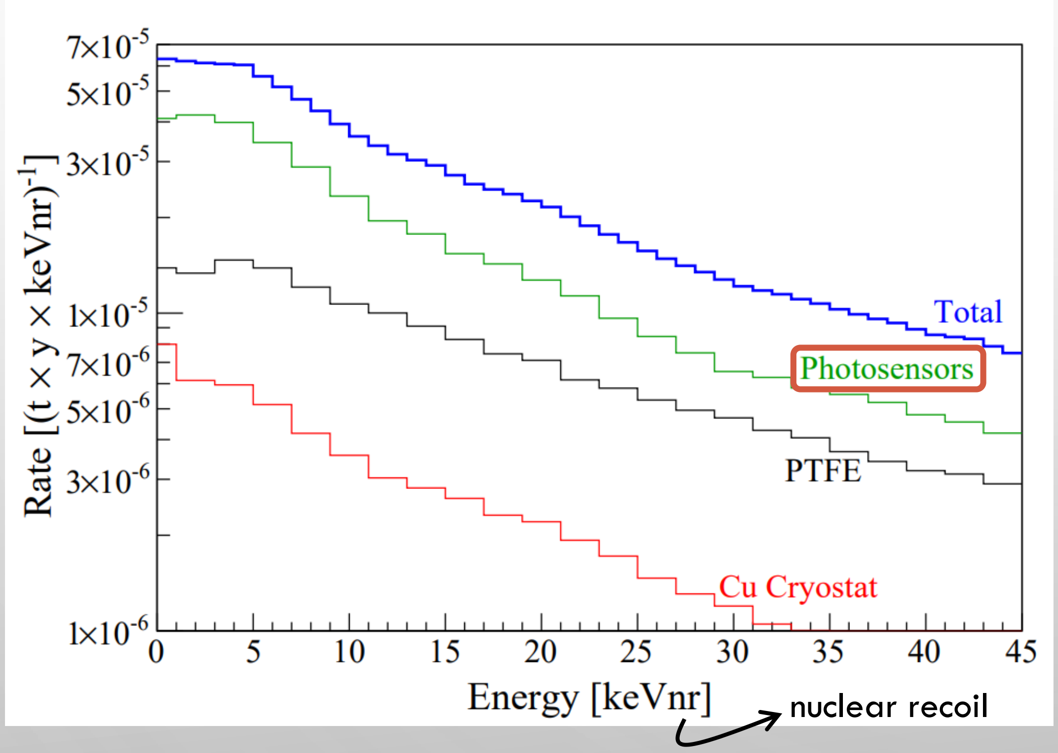
Cons of PMTs

DIRTY & EXPENSIVE



Neutron rate induced by the detector's materials

Material	Unit	^{238}U	^{226}Ra	^{232}Th	^{228}Th	^{60}Co
Titanium	mBq/kg	<1.6	<0.09	0.28	0.25	<0.02
PTFE	mBq/kg	<1.2	0.07	<0.07	0.06	0.027
Copper	mBq/kg	<1.0	<0.035	<0.033	<0.026	<0.019
PMT	mBq/unit	8.0	0.6	0.7	0.6	0.84
Electronics	mBq/unit	1.10	0.34	0.16	0.16	<0.008

Activity from the detector's materials

→ **3 to 30 times dirtier** per unit than all other materials per kilo !

~ 5000 € per PMT

Would need 1700 units for DARWIN

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OTHER AVAILABLE SOLUTIONS

	3" PMT	SiPM	DSiPM
VUV sensitivity	☑	☑	☒
Low radioactivity	☒	☑	☑
Low dark count rate	☑	☒	☑
Low price	☒	☑	☑
Tested in Lxe TPCs	☑	☒	☒
Production ease	☒	☑	☑

HeiKa chip

Not yet!

Main reason why they are still used

Major drawback!

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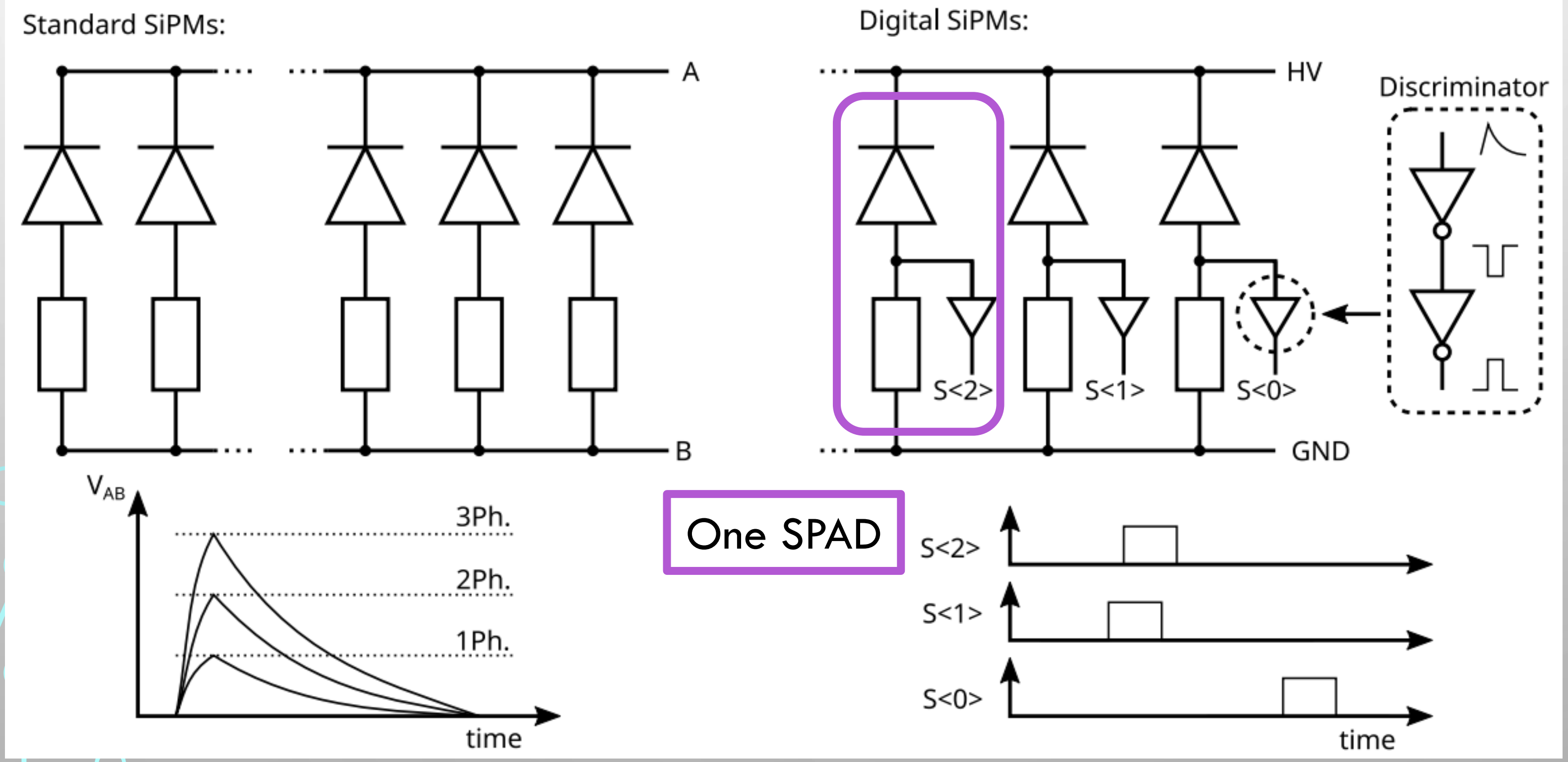
HEIKA CHIP

Digital SiPMs made of an array of single photon avalanche diodes (SPADs) read out individually



Lower power consumption

Better spatial resolution

However, less filling because of readout electronics

Each SPAD can individually be turned off

XEBRA

LN2 reservoir

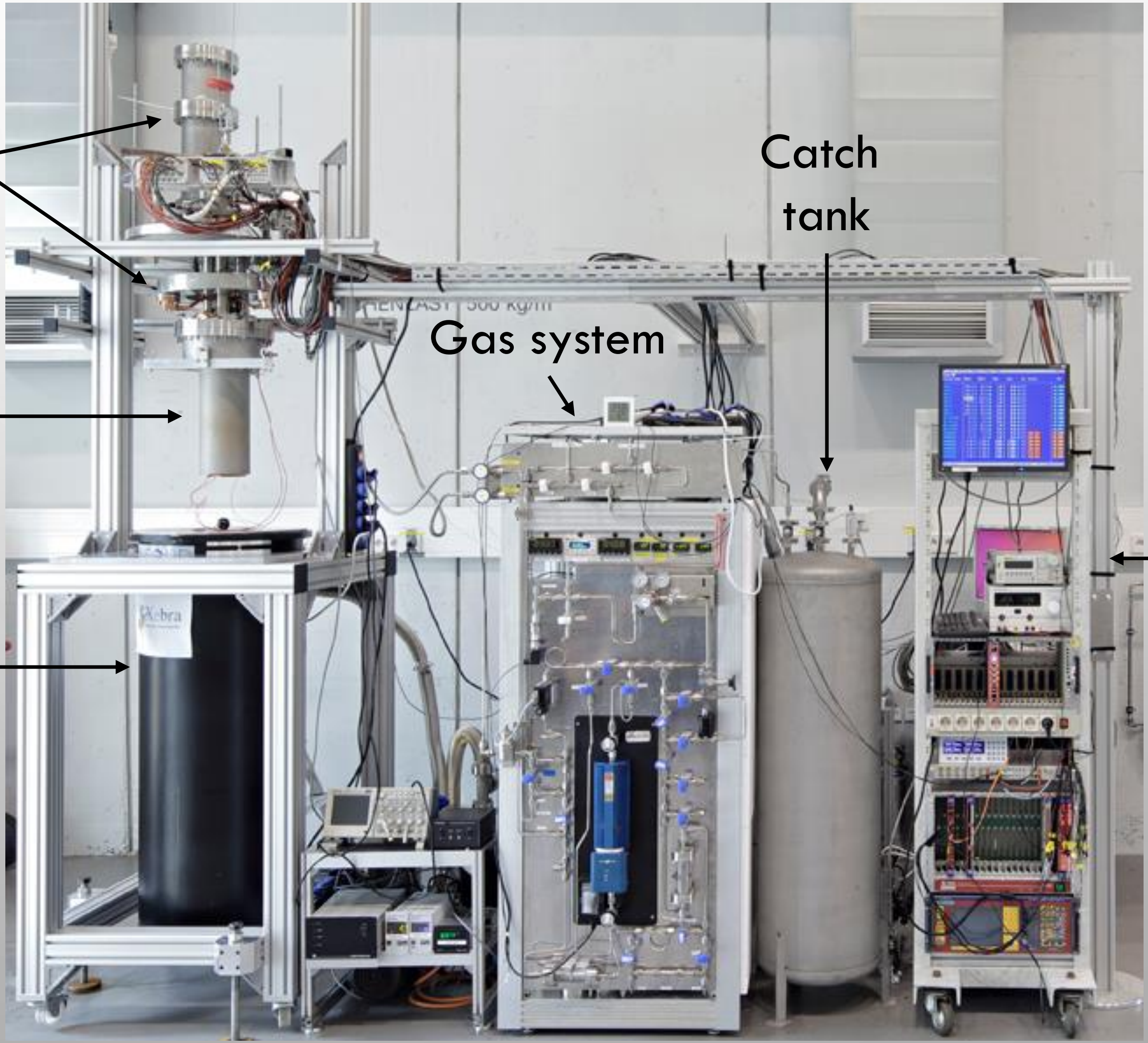
Catch tank

Gas system

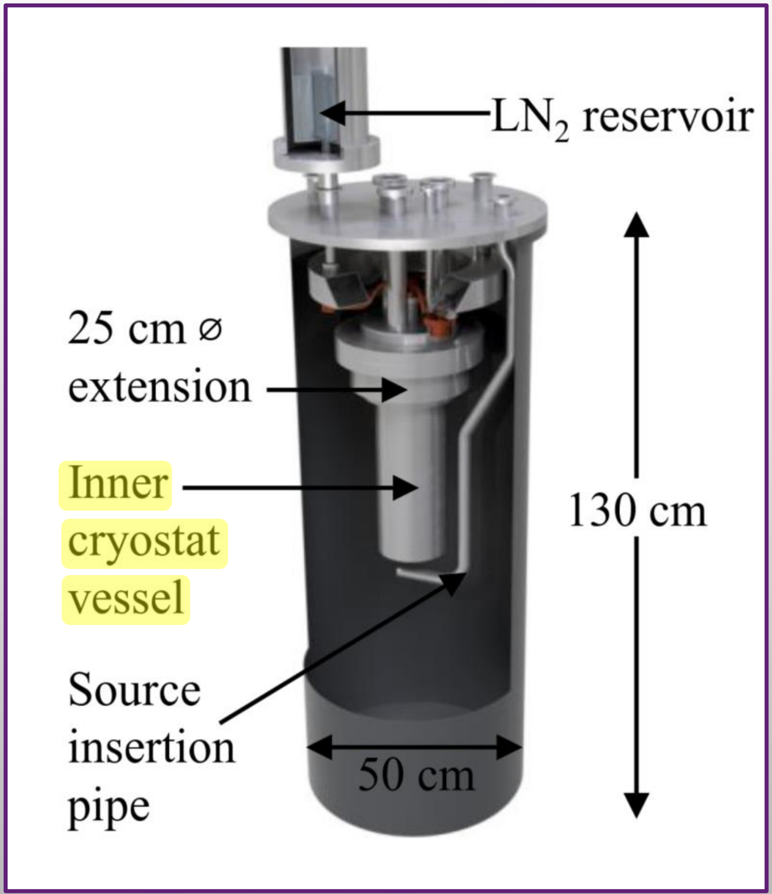
Inner vessel

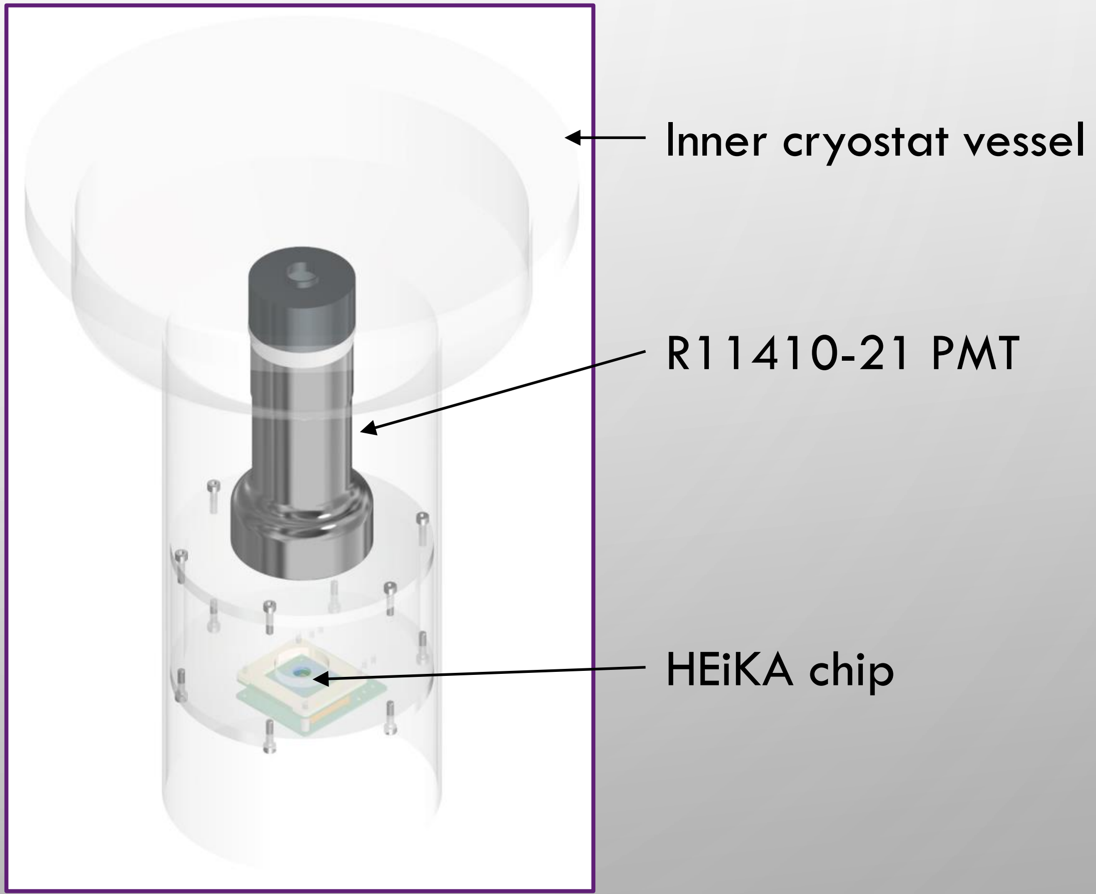
Data acquisition rack

Outer vessel

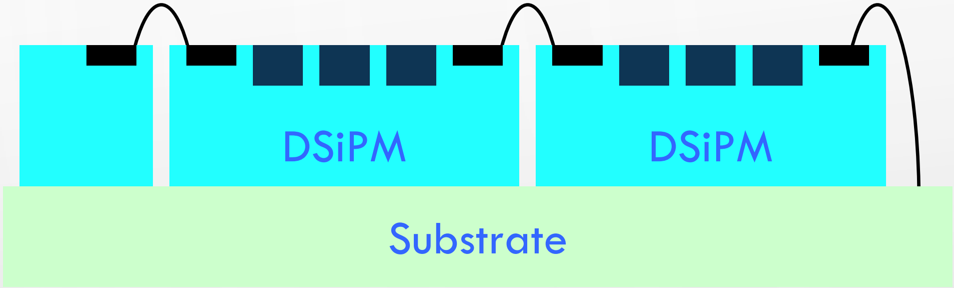


SETUP

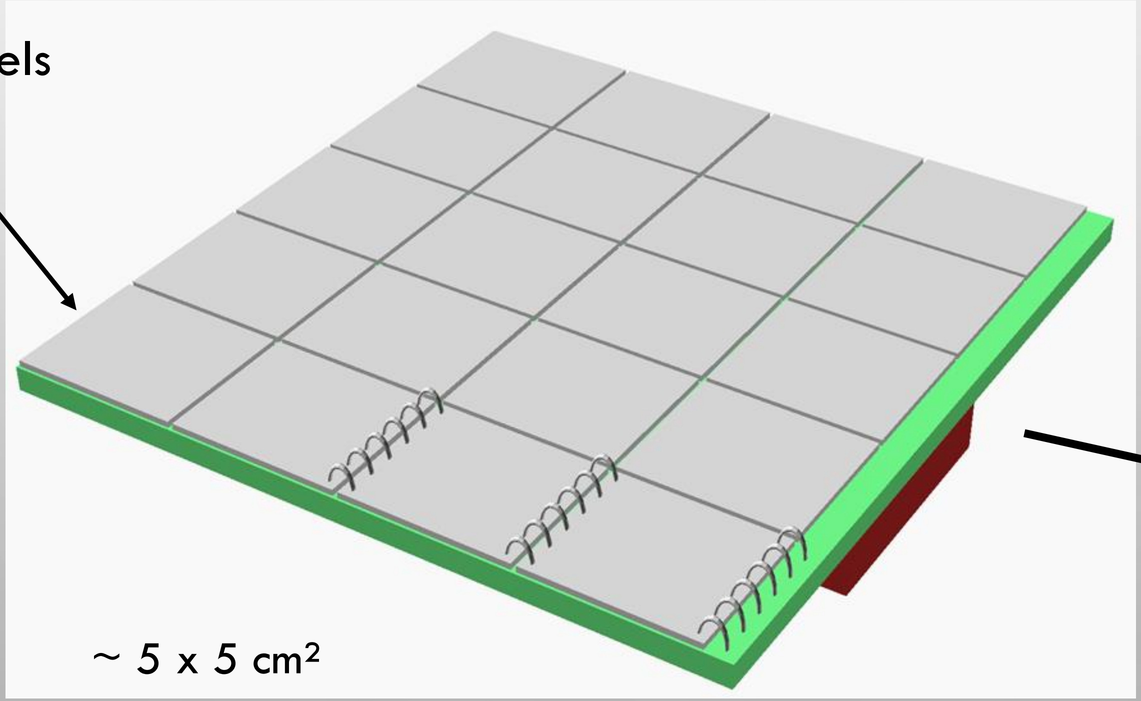

LN_2 reservoir
25 cm ⌀
extension
Inner
cryostat
vessel
130 cm
Source
insertion
pipe
50 cm


Inner cryostat vessel
R11410-21 PMT
HEiKA chip

SETUP



~1000 pixels per chip



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PMT COMPARISON

- **First ever test** of this chip in cryogenic conditions with high voltage applied
- Shine a LED through the PTFE
- Compare PMT and DSiPM
  - Quantum efficiency
  - Time resolution
  - Single photon detection
  - High # of photons saturation

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THANKS FOR YOUR ATTENTION !

Let's fill this column !

	3'' PMT	DSiPM
Dark count rate	$8x10^{-3}$ Hz	?
Quantum efficiency	35%	?
Gain	Up to 10^7 e^-	?
High # of photons detection	Yes	?

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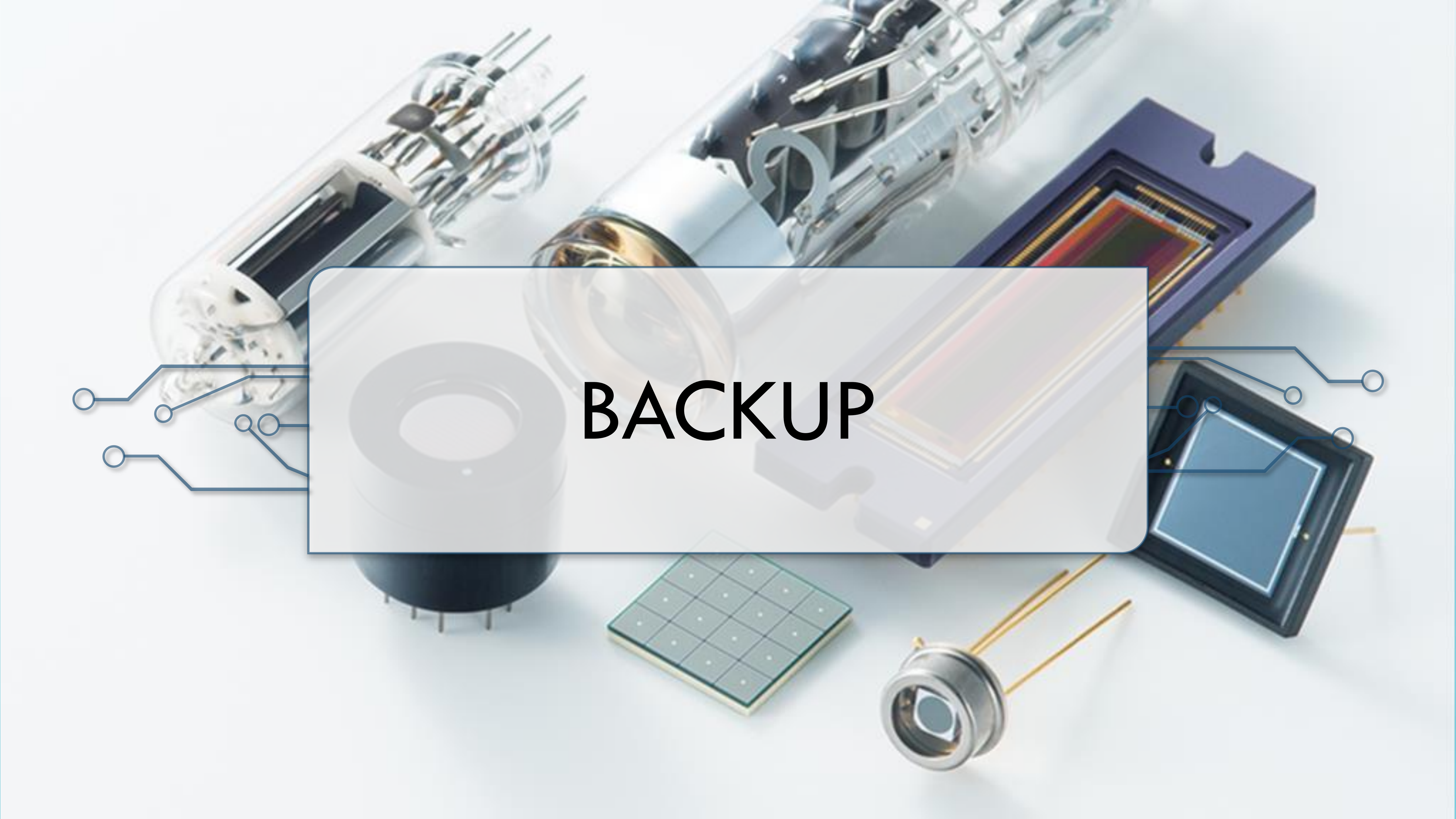
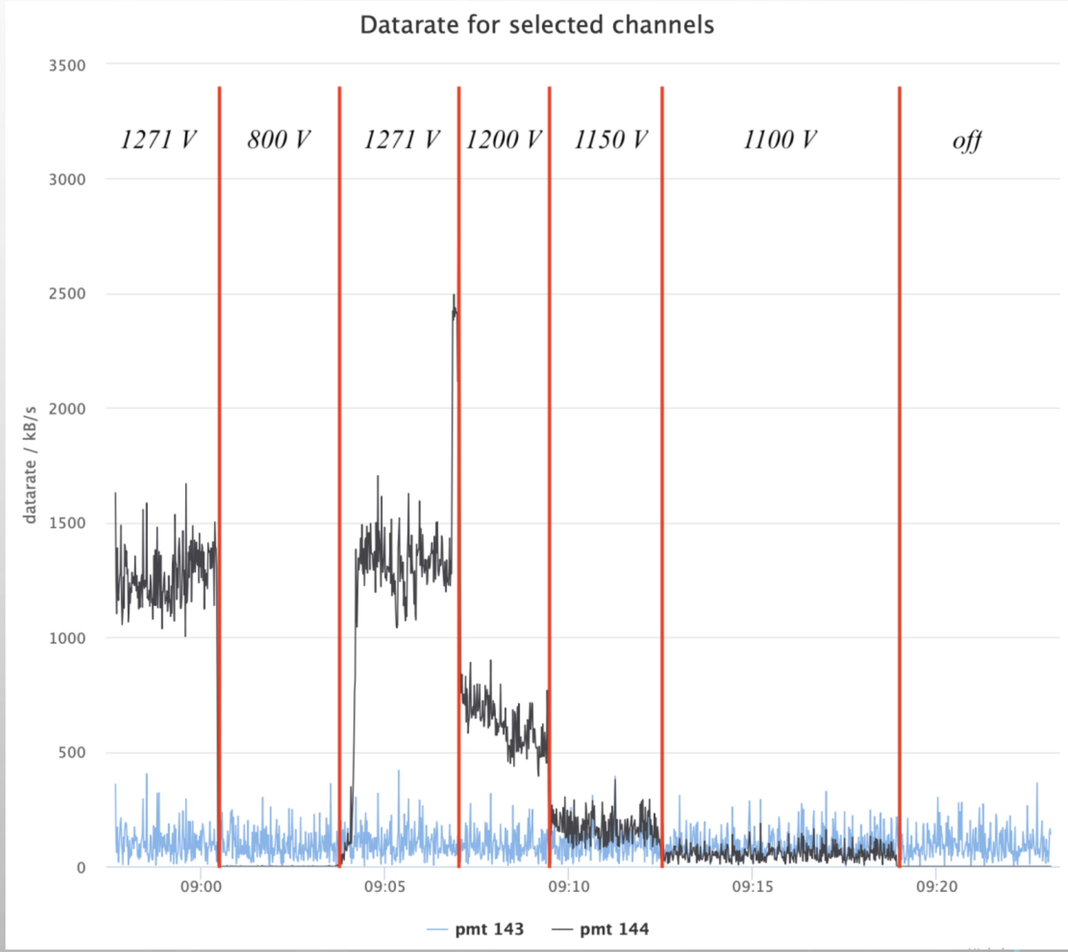
BACKUP



RELIABILITY

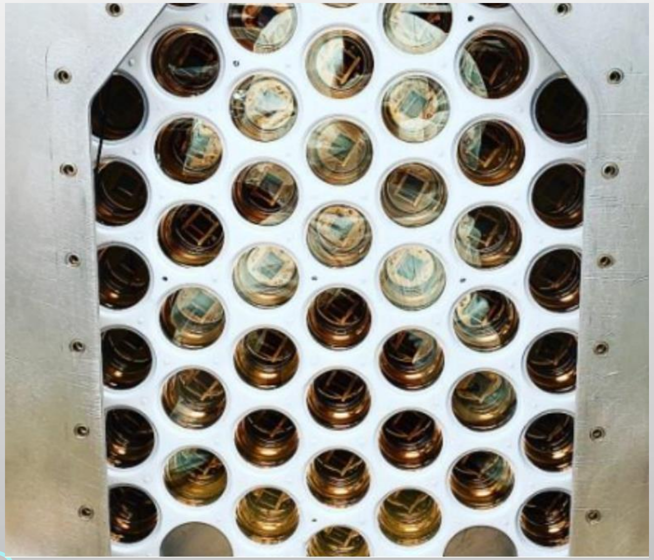
- 27 out of 494 PMTs in nT are either turned off or ignored during analysis → more than 5%
- Due to vacuum leaks, low PMT gain or electric noise



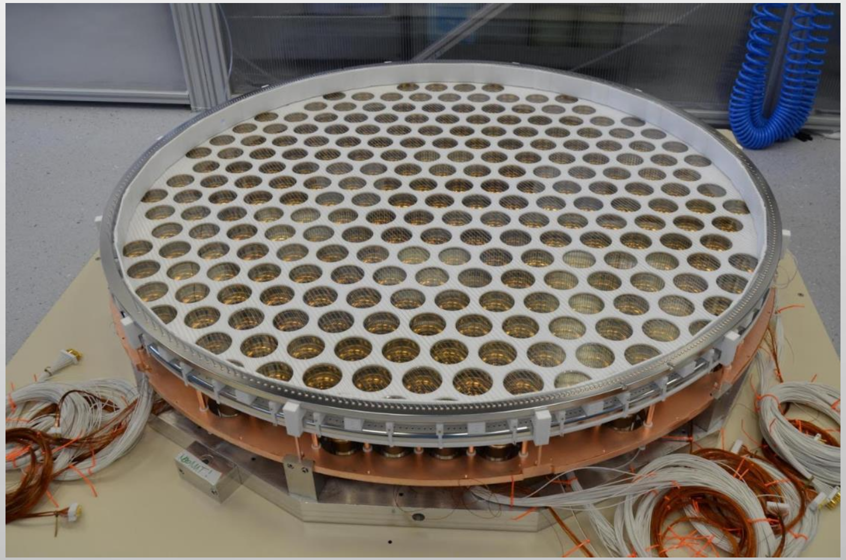
Example of a recent bad behavior of a PMT when usual HV is applied

LOW DARK COUNT RATE & TESTED

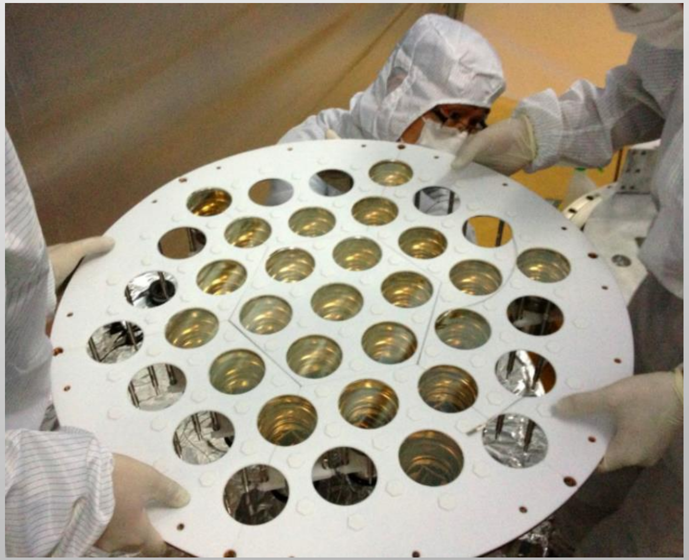
Dark count rate (DCR) of ~ 8.10^{-3} Hz/mm²



Section of LZ array



Top array of XENONnT



Bottom array of PandaX

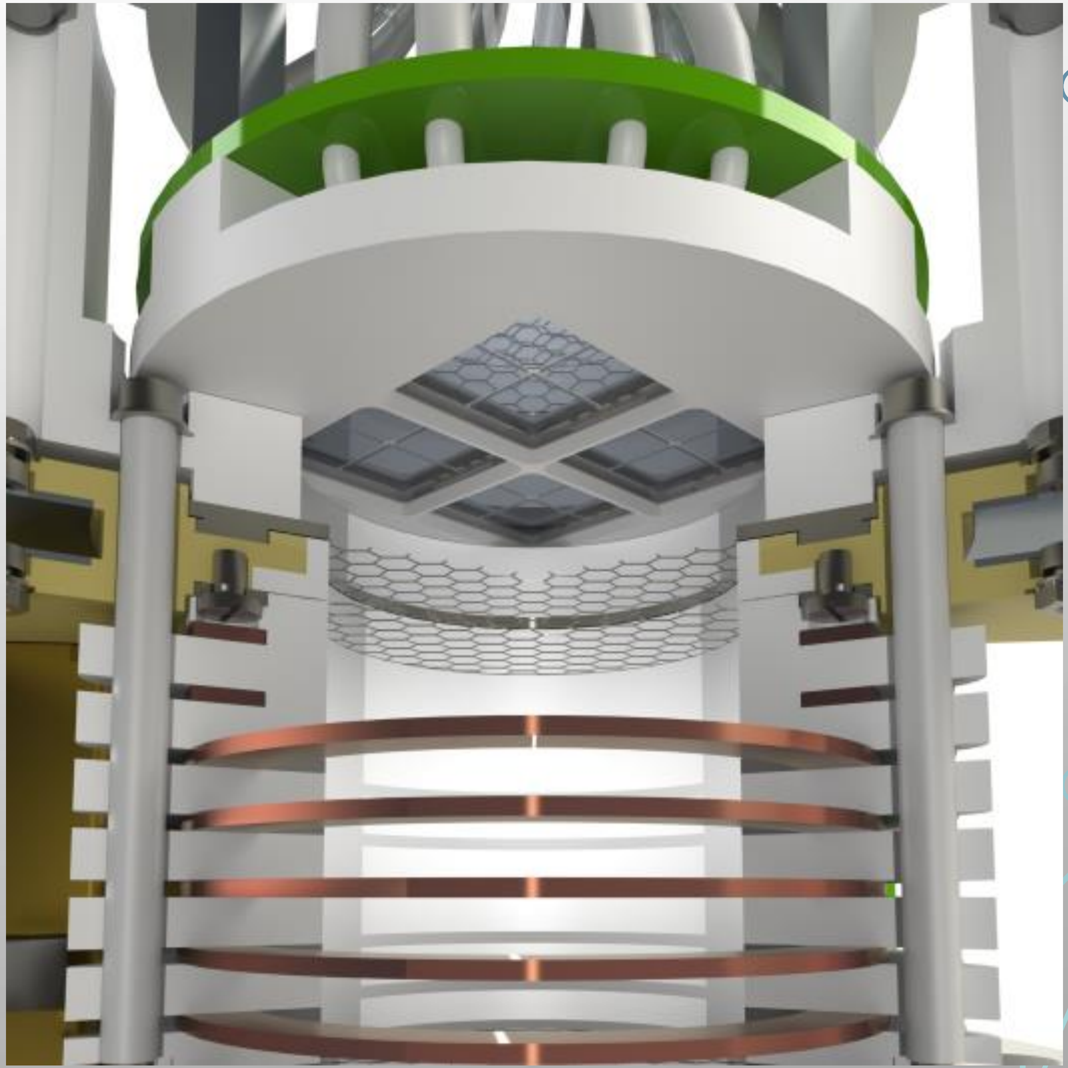
→ All R11410 Hamamatsu PMTs

LOW RADIOACTIVITY HAMAMATSU PMTS

- Photocathode and base of the PMTs with low radioactive material
- Is 20 to 50% less radioactive than R14110
- Material used show 3 times more leaks

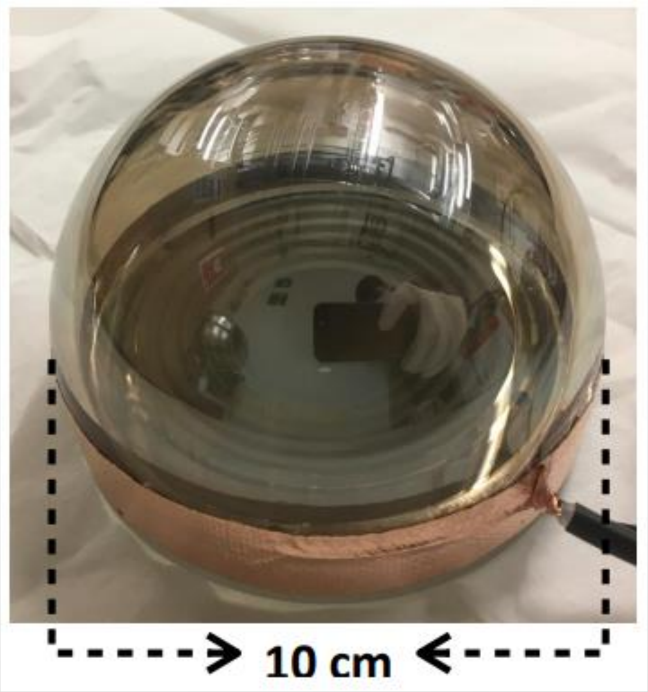
MULTI PIXEL PHOTON COUNTER

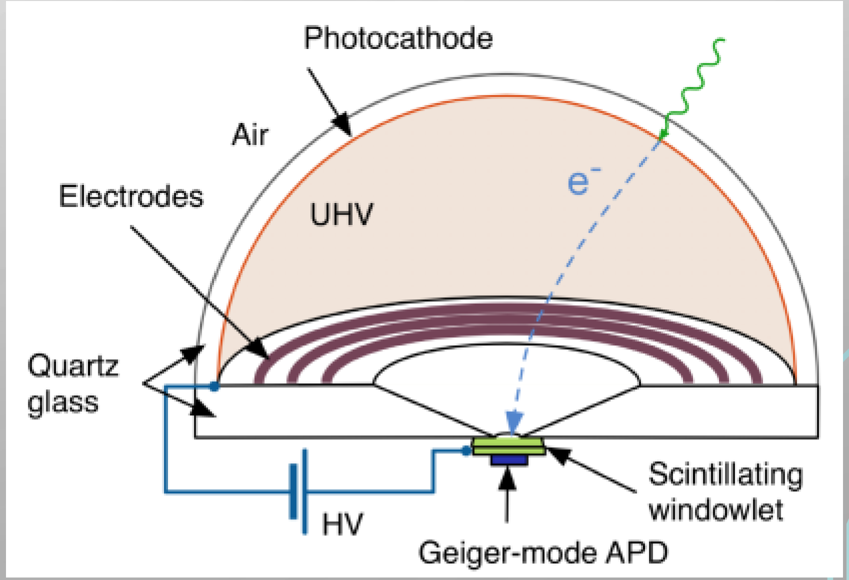
- A type of silicon photomultiplier (SiPM)
- Avalanche photodiodes connected in parallel
- Is less radioactive
- More stable over time
- Already used in other experiments
- But has 2 orders of magnitude higher dark count rates at LXe temperature



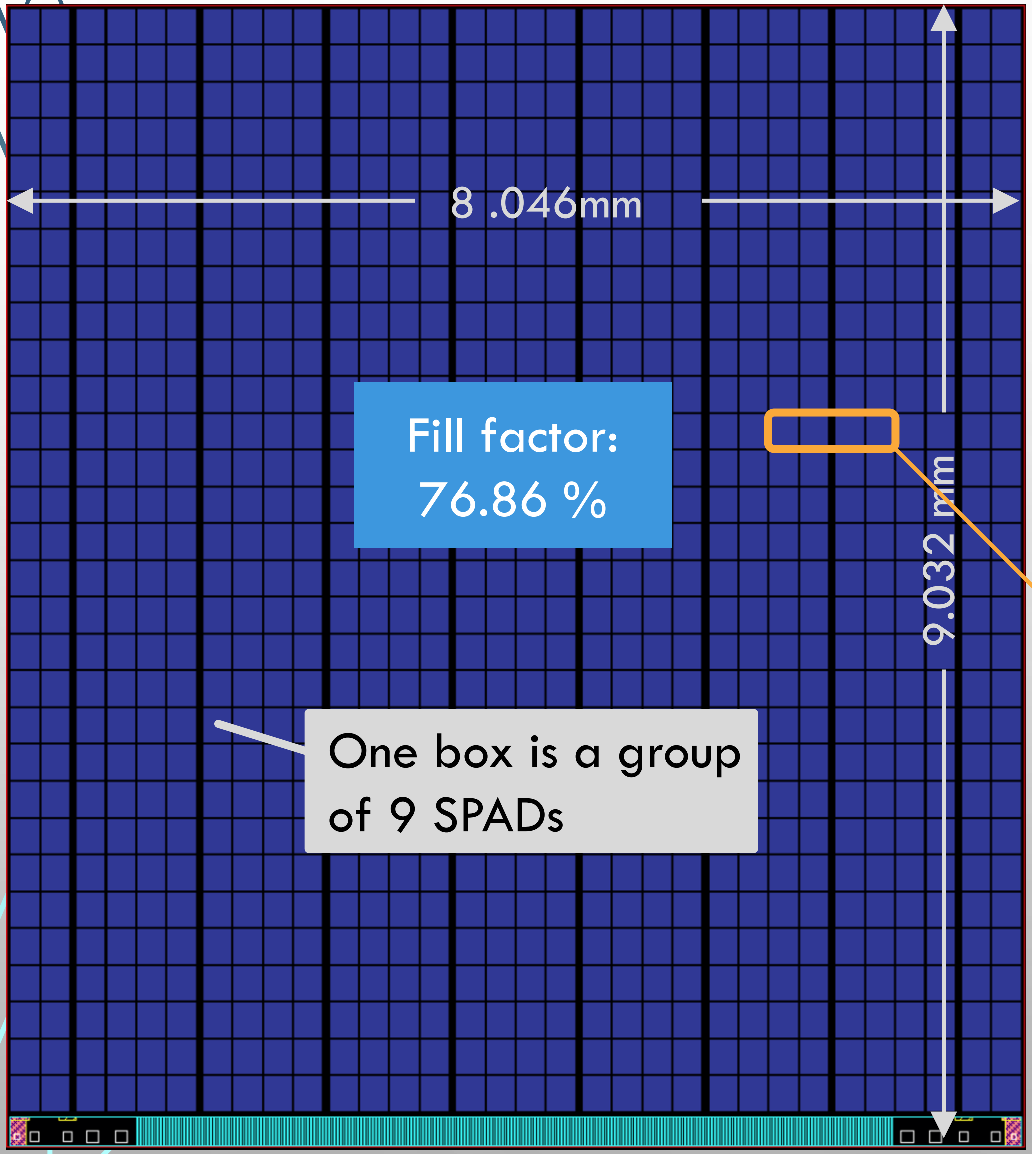
ABALONE

- Photon to photoelectron (photocathode) back to photon (scintillator) detected by SiPM
- Tested in gaseous xenon successfully
- Less material → low radioactivity
- Ten times lower DCR than traditional PMTs
- High high voltage needed (25kV)
- Not tested enough yet





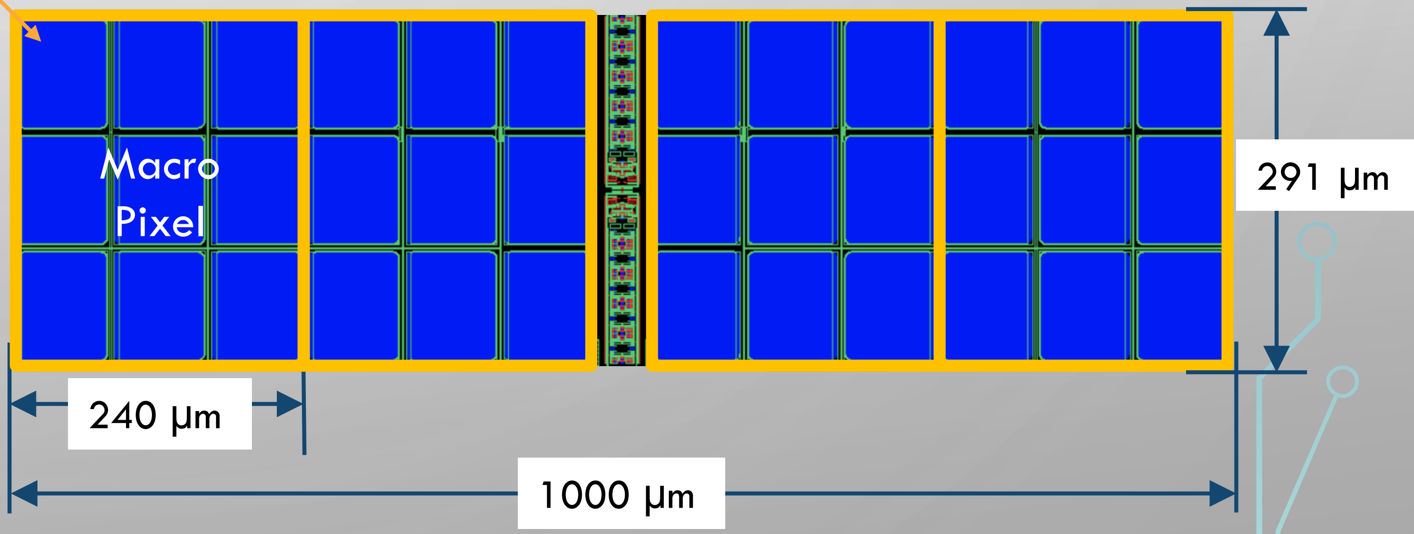
HEiKA chip



8640 SPADs grouped in "macro pixels"

→ 960 macro pixels

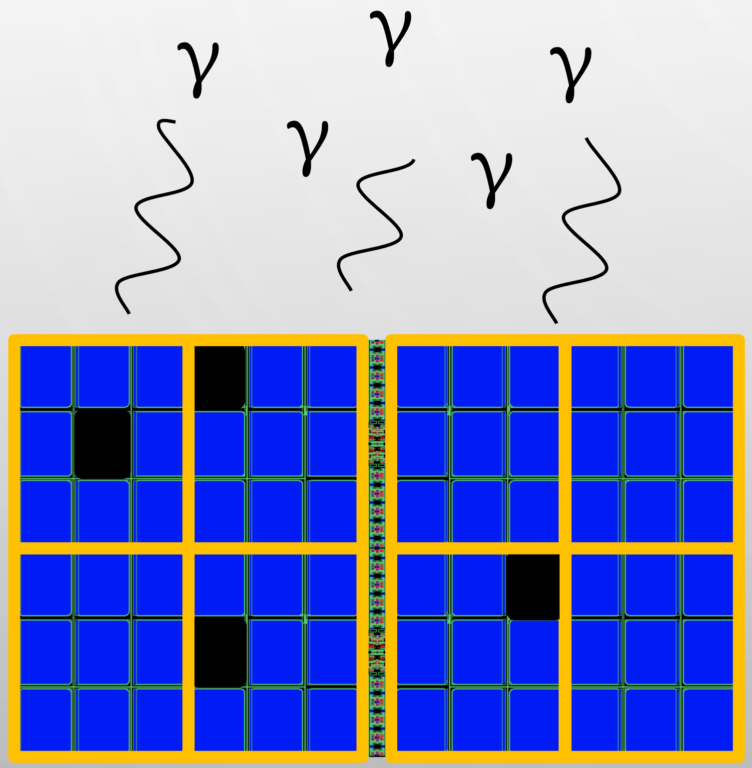
Macro pixels read out individually



HEiKA chip

Each SPAD can individually be turned off if DCR is too high

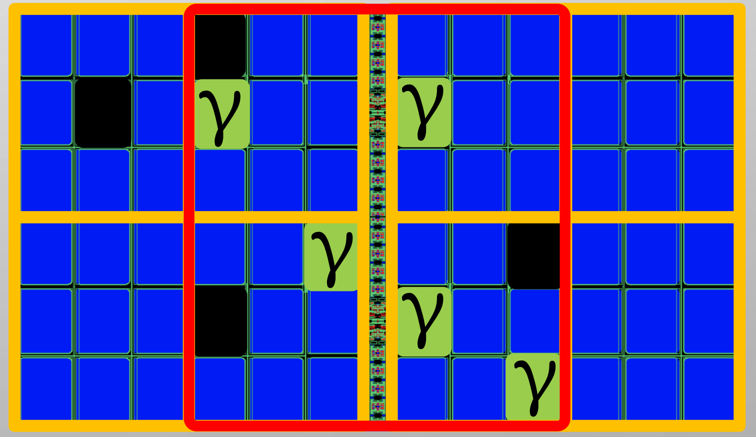
SPADs are OR-ed to a macro pixel



Turned off SPADs due to high rates

5 SPADs activated but only 4 macro pixels

Event reconstructed as 4 photons hit



Activated SPADs

Reconstructed event

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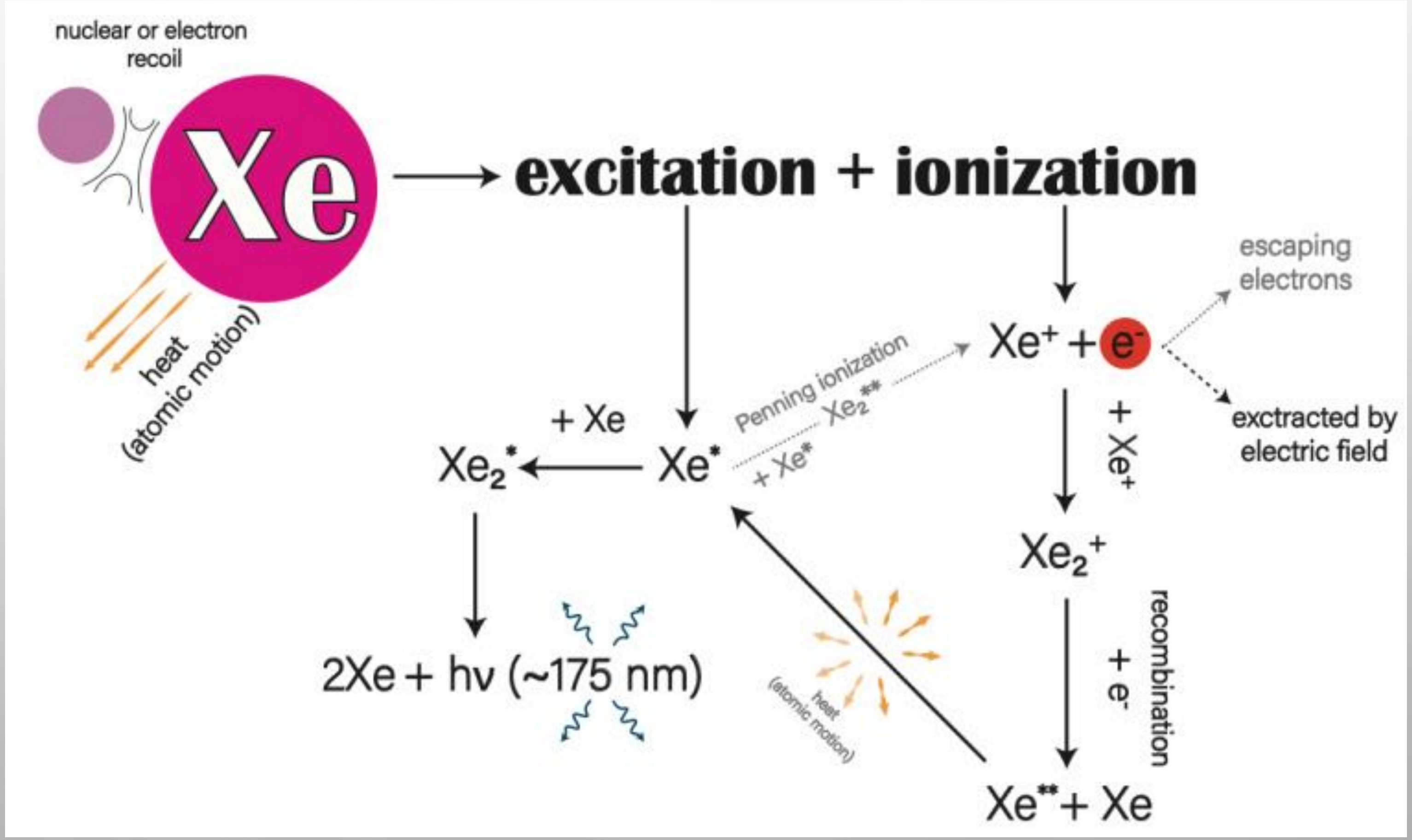
QUANTA GENERATION IN XENON TPC



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QUANTA GENERATION IN XENON TPC

- Deposited Energy

Average energy to produce a quanta

Light and Charge quanta

$$E_d = \frac{W \cdot (n_\gamma + n_e)}{L}$$

Lindhard quenching factor | ER ~ 1, NR ~ 0.2

- Interaction type

$$\left(\frac{n_e}{n_\gamma}\right)_{NR} < \left(\frac{n_e}{n_\gamma}\right)_{ER}$$

ER → stronger ionization density → More Charge quanta

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