# Analog Electronics for Light Only Liquid Xenon experiment

**Austin de St. Croix**

MSc student, UBC

CAP Congress 2019 - SFU

*2019-06-05*

Discovery, accelerated

# What is nEXO?



**nEXO: next Enriched Xenon Observatory**

- 5 ton liquid xenon $0\nu\beta\beta$ detector to be built at SNOLAB
- Enriched with ~90% $^{136}$Xe ($2\nu\beta\beta$ source)
- See Thomas Brunner's talk on Friday (or others)

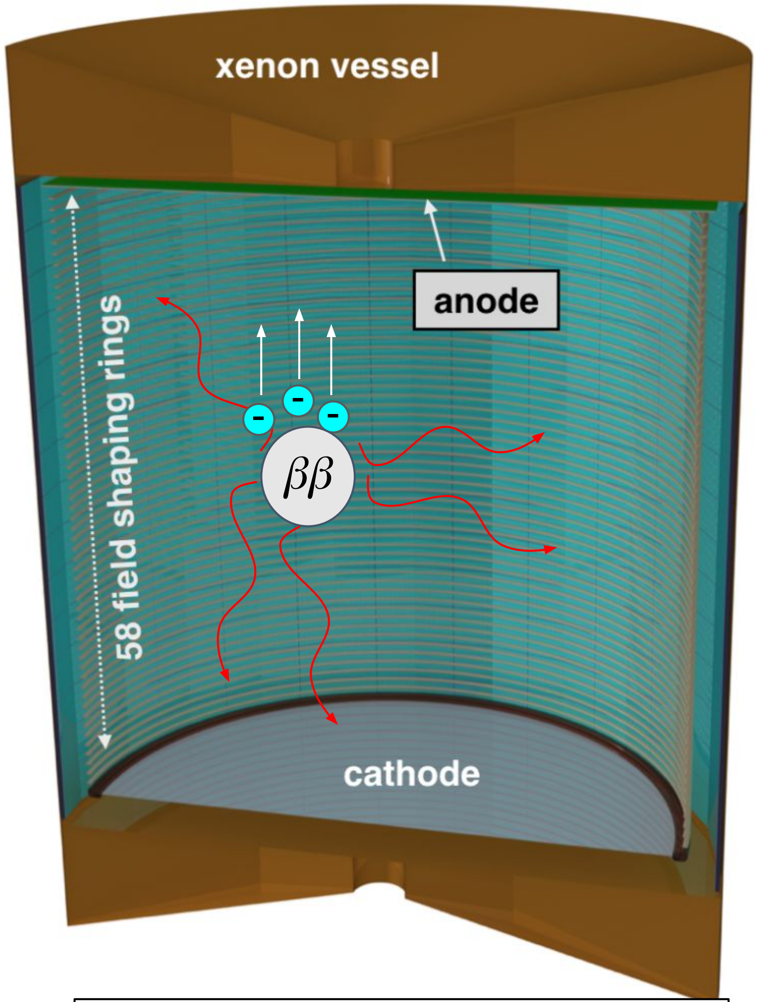


Image of nEXO TPC (from pre-CDR)
**arXiv:1805.11142**

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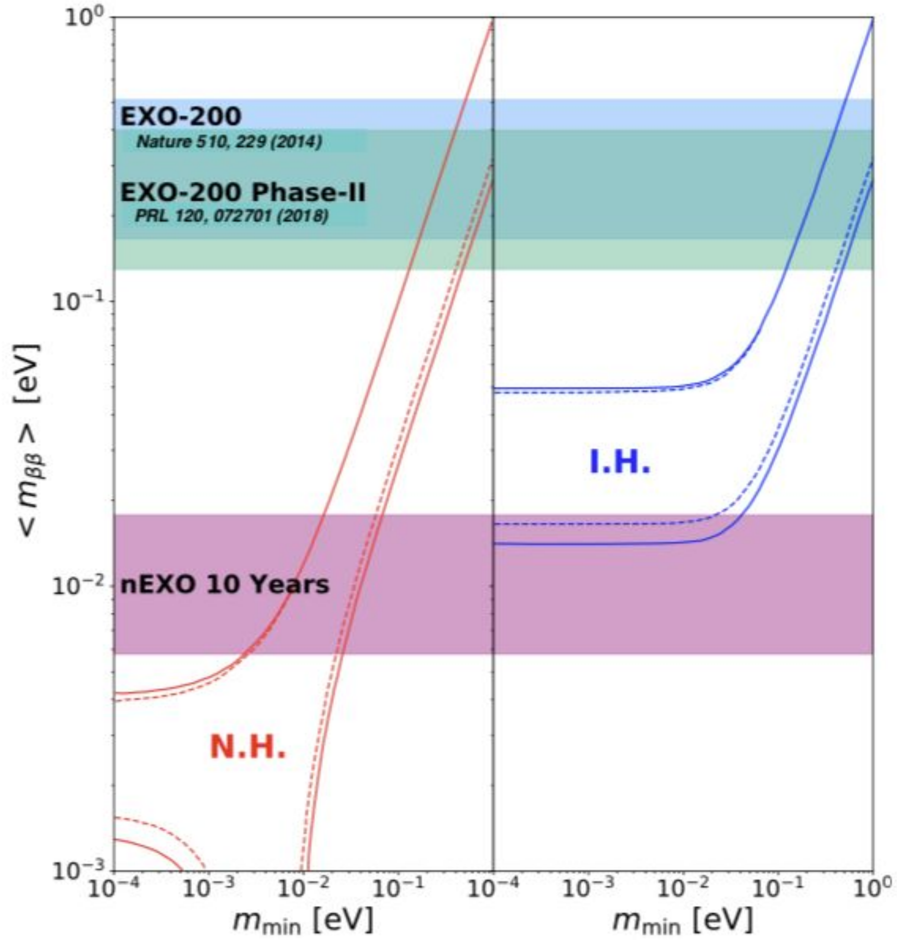


(nEXO pre-CDR) **arXiv:1805.11142**

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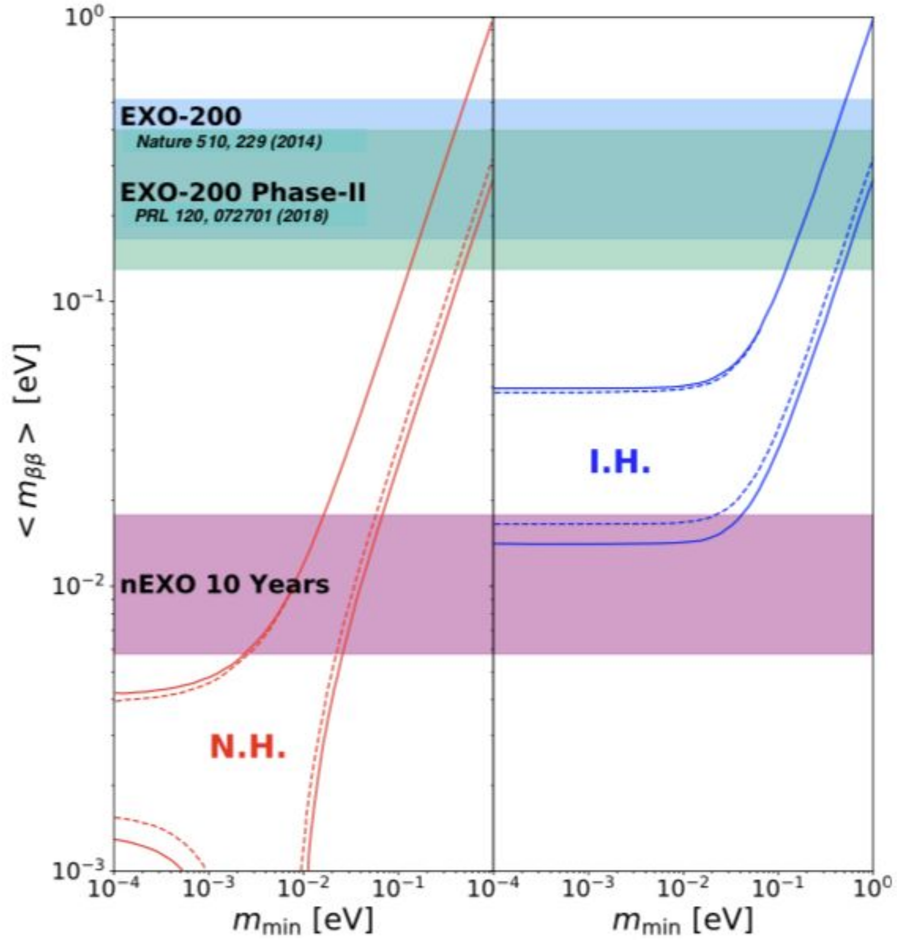
**Why LoLX?**

- nEXO requires 1% ΔE (at $\beta\beta$ endpoint 2.45MeV)

  ↳ depends on light collection efficiency
- Simple detector allows for validation of photon transport in nEXO simulations
- Cerenkov light in liquid xenon!

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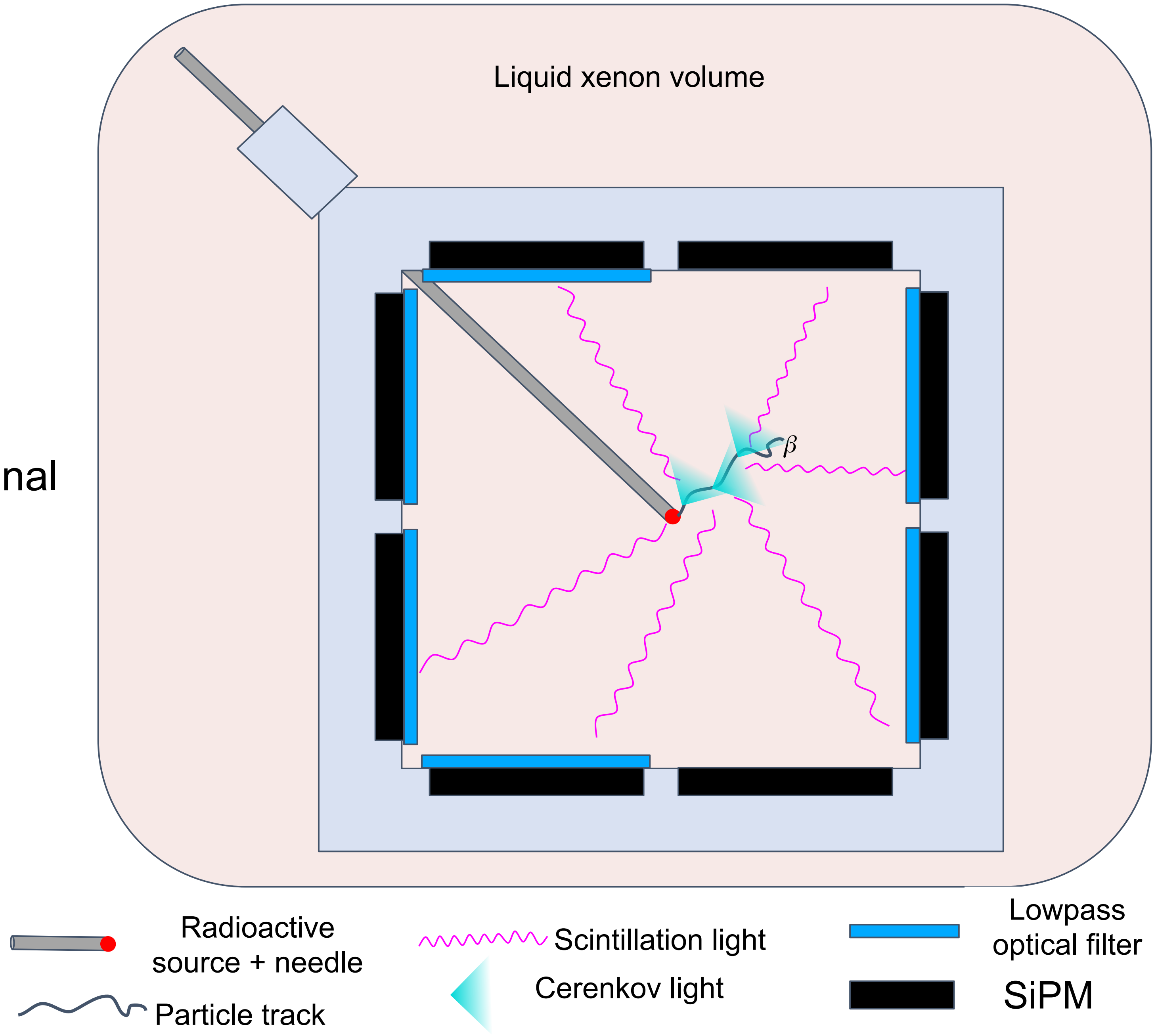
**Light Only Liquid Xenon experiment**

- single phase LXe, zero applied field
- Utilize 24 silicon photomultipliers to collect light
- push energy resolution with light signal



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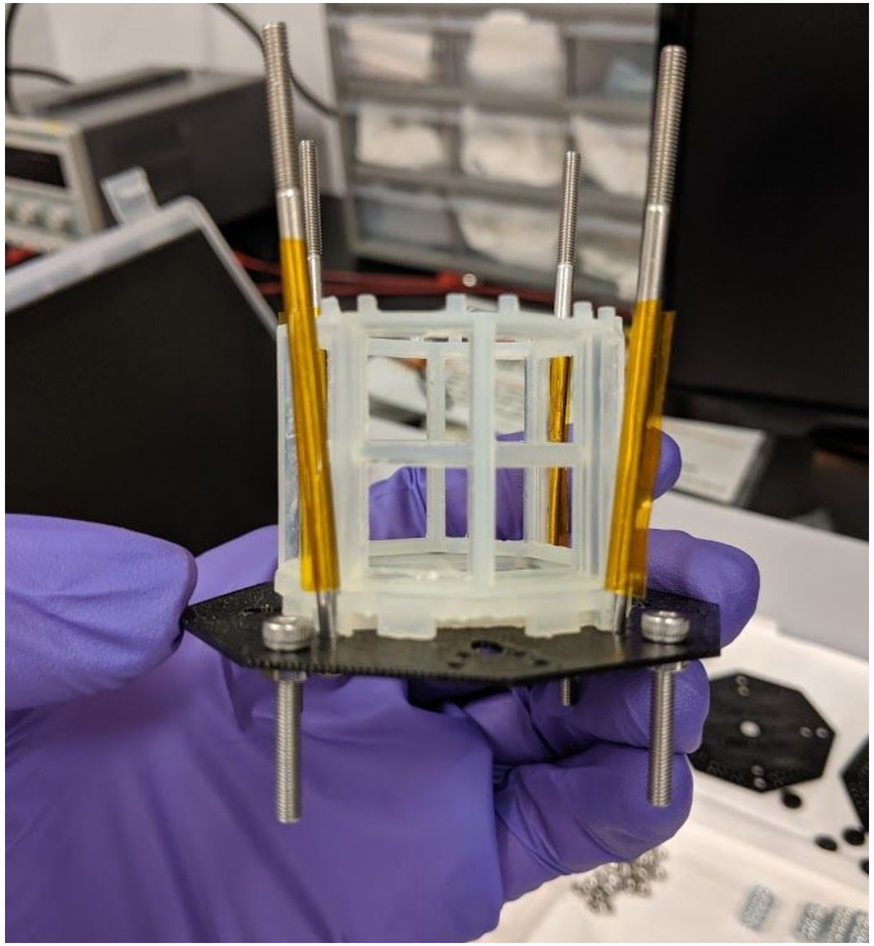
**Phase 1:** analog electronics **(this talk)**

- Single photon counting
- Use optical filters to measure **Cerenkov light** independently of scintillation



Assembled 3D printed model of detector body (McGill)

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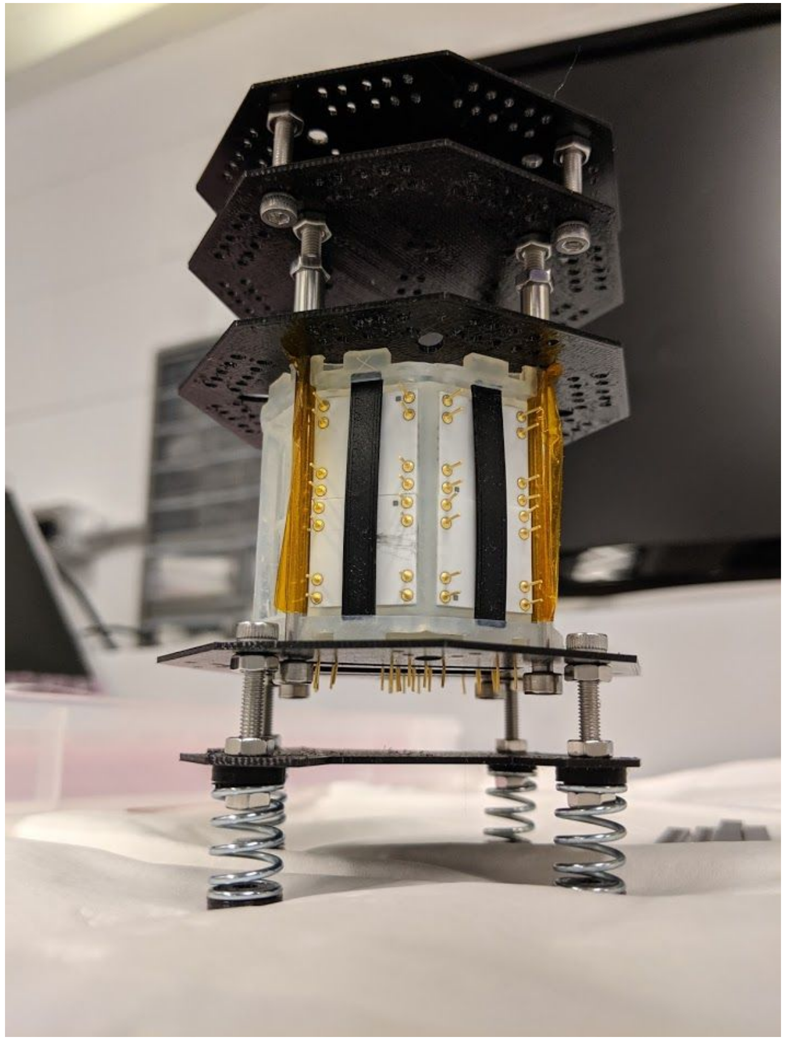
**Future:** sub nanosecond digital electronics

- perform PSD, precision scintillation measurements,
- Repeat with Argon (LoLA)



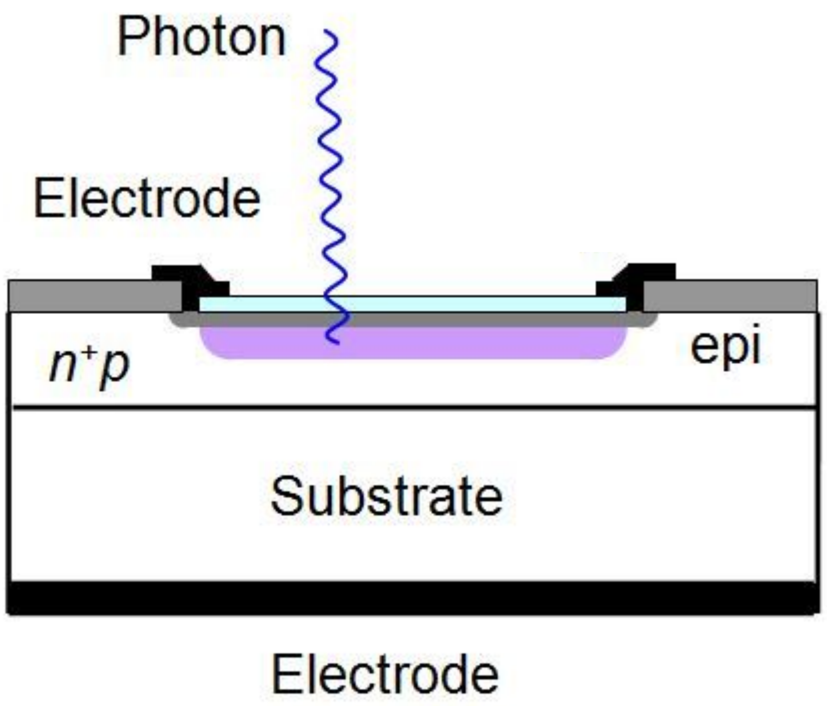
Assembled 3D printed model of detector body (McGill)

See Thomas McElroy's LOLX talk, thursday & friday

# Silicon Photomultipliers (SiPM)

**Solid state silicon device**

- Operated in reverse bias, above breakdown voltage
- Photoelectric effect generates free electron, initiates charge avalanche (**Geiger mode**)
- Gain of ~$10^6$ allows for **single photon counting**




SiPM layout

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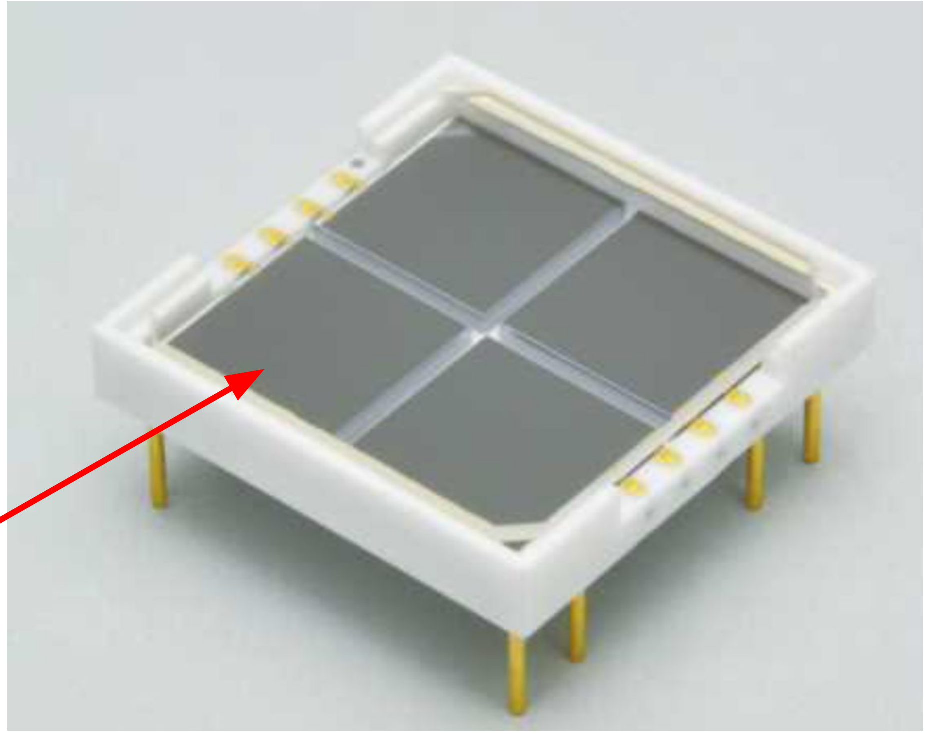
- Pixelated device (14 000 mini single PE detectors)
- see Giacomo Gallina’s talk for more info



Hamamatsu VUV4 SiPM
To be used for LOLX phase 1

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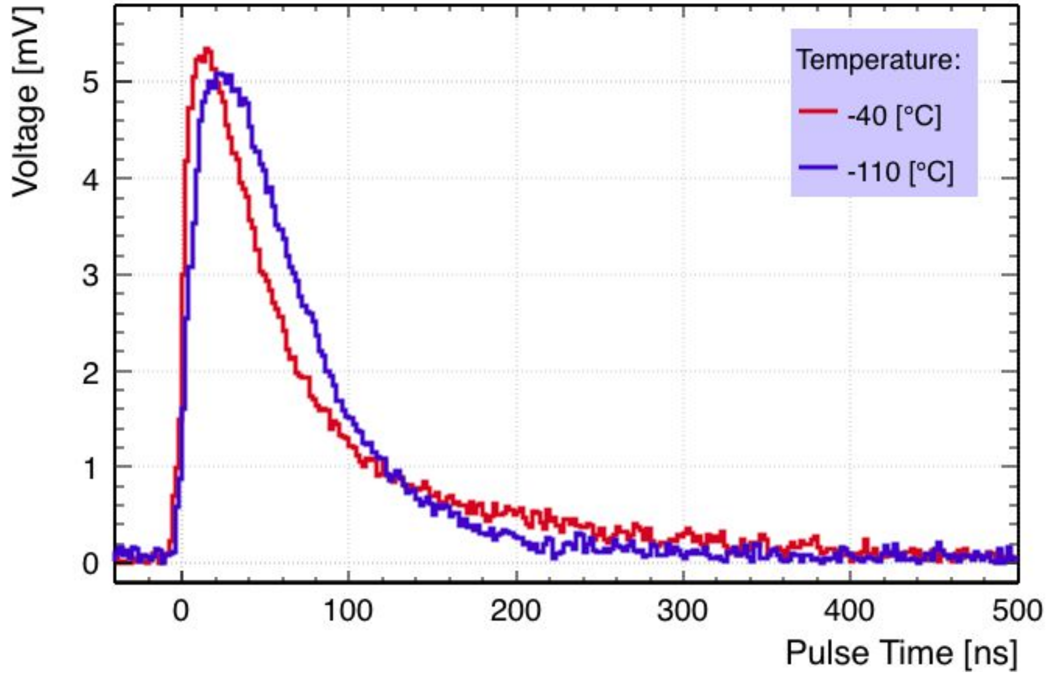


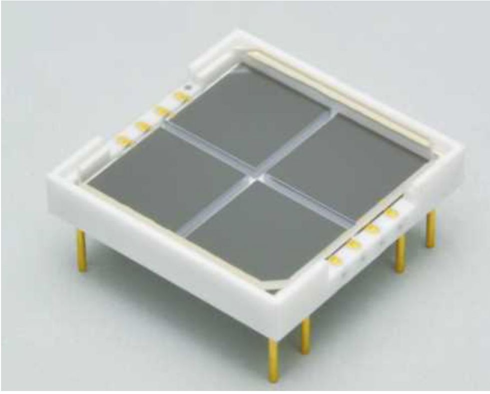

Example of raw 1 PE pulse from VUV4 SiPM

# LoLX SiPM Layout



**24 Silicon Photomultipliers**

- Each quadrant has 4 readouts → 96 outputs



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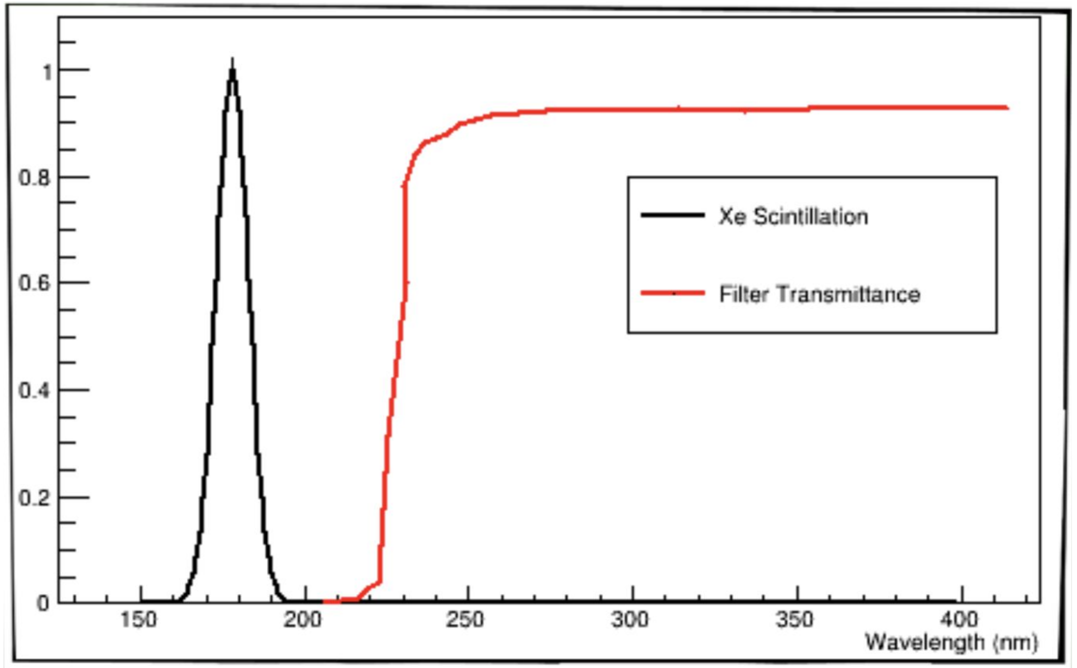
Phase 1

**22 SiPMs**: lowpass optical filter

↳ blocks scintillation light, passes Cerenkov light




Filter transmittance and xenon scintillation

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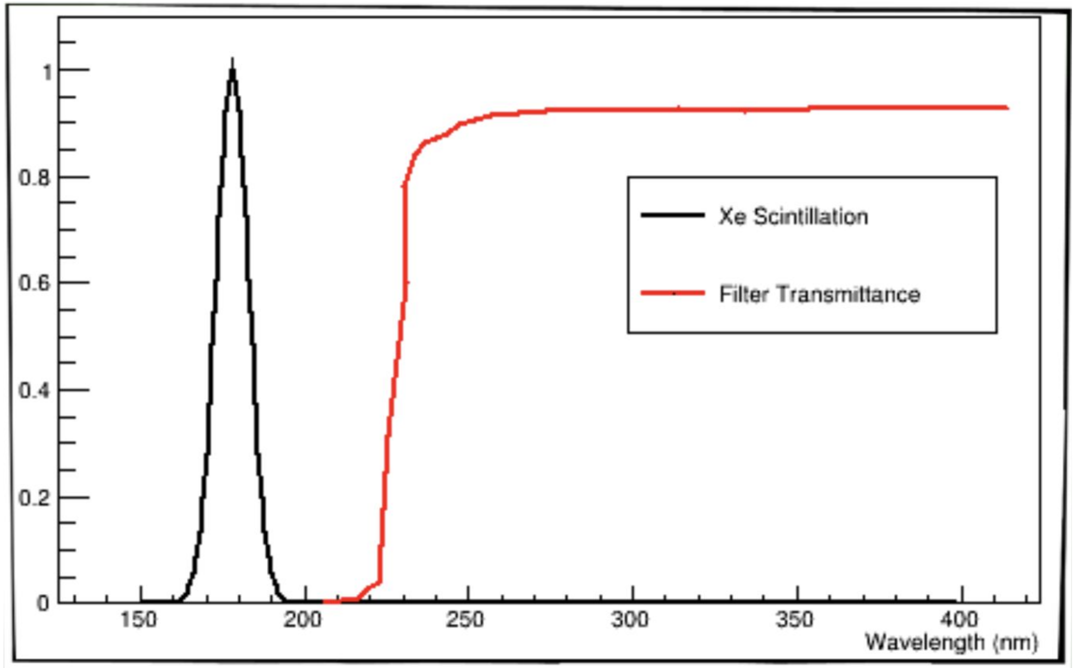
**1 SiPM:** naked

↳ views scintillation and Cerenkov light

↳ Sensitive to cross-talk photons

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**1 SiPM:** naked

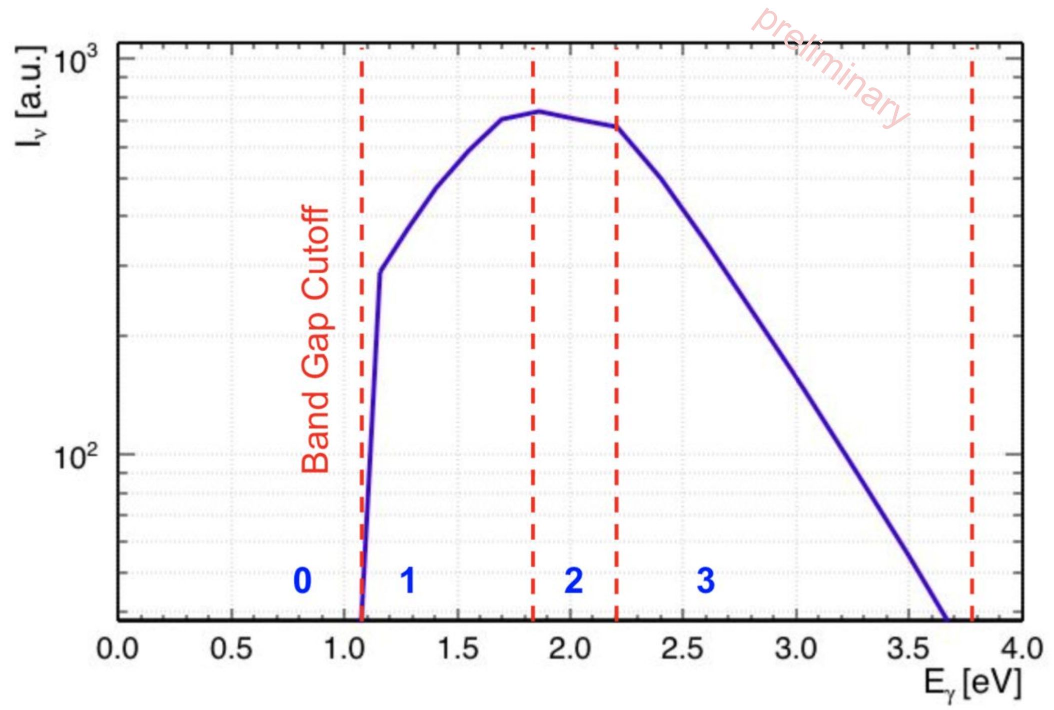
↳ views scintillation and Cerenkov light

↳ Sensitive to cross-talk photons

**1 SiPM:** UV bandpass filter

↳ allows only scintillation light

↳ blocks cross-talk photons




Cross-talk photon spectrum

# LoLX Electronics: Goals and constraints



**Nanosecond timing resolution**

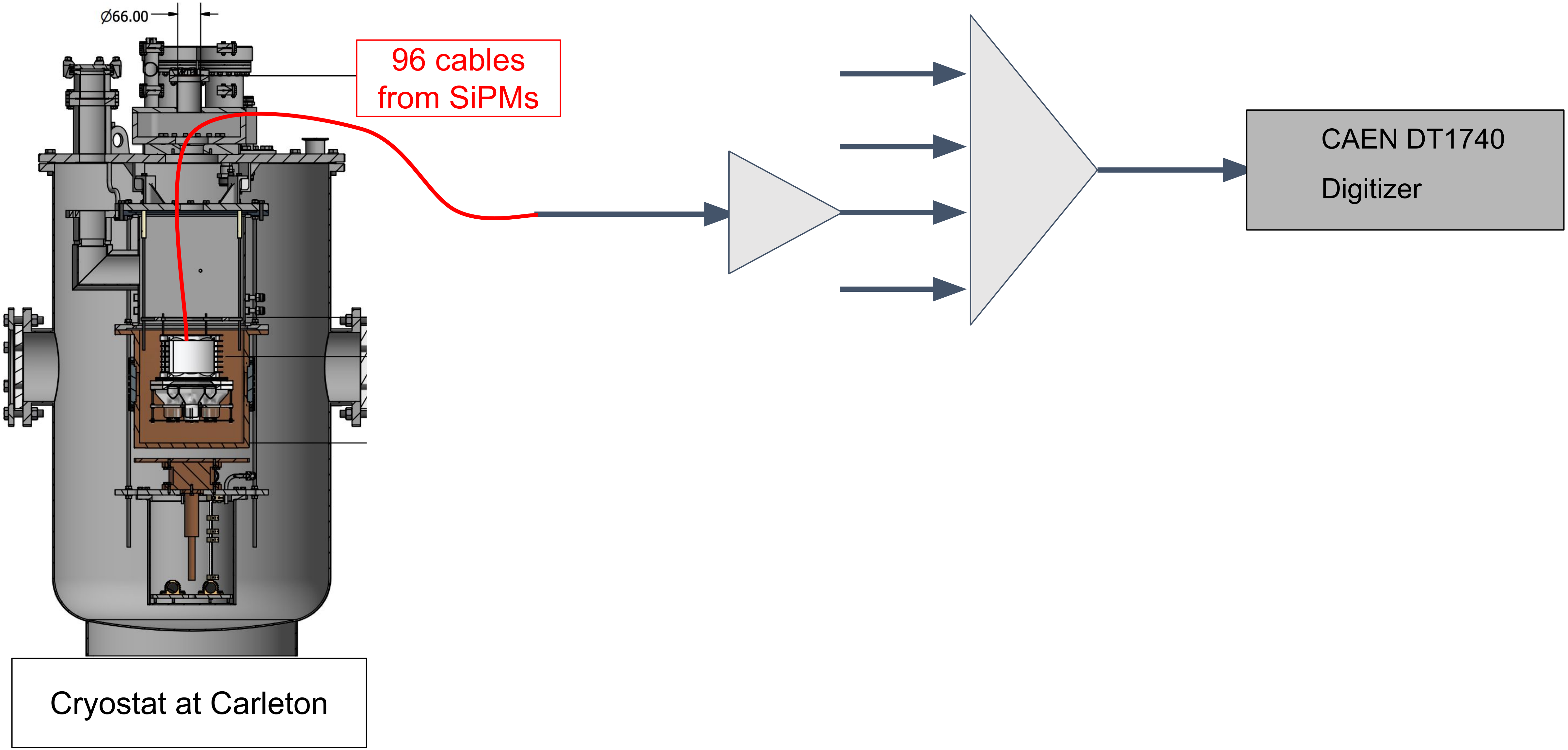
- Low jitter (sub ns)
- Equal time delay across channels

**Single photon counting**

- Requires good single PE charge/noise ratio
- Still retain full dynamic range for ‘bright’ events

# LoLX: Electronics Layout





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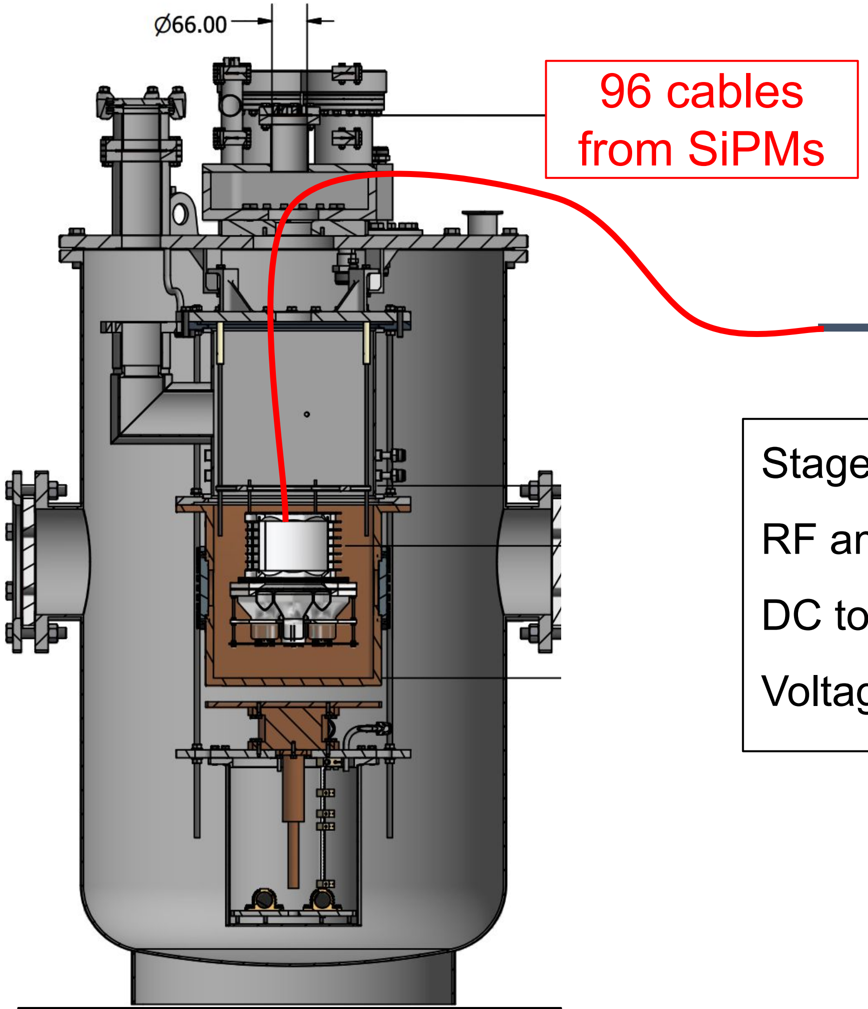
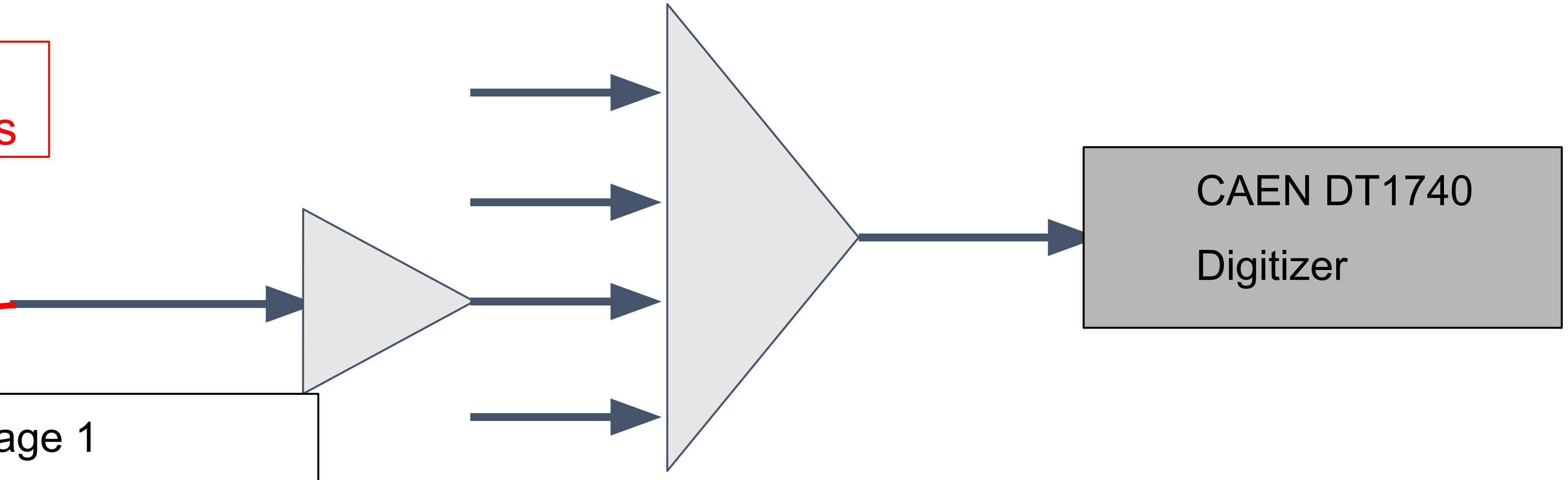
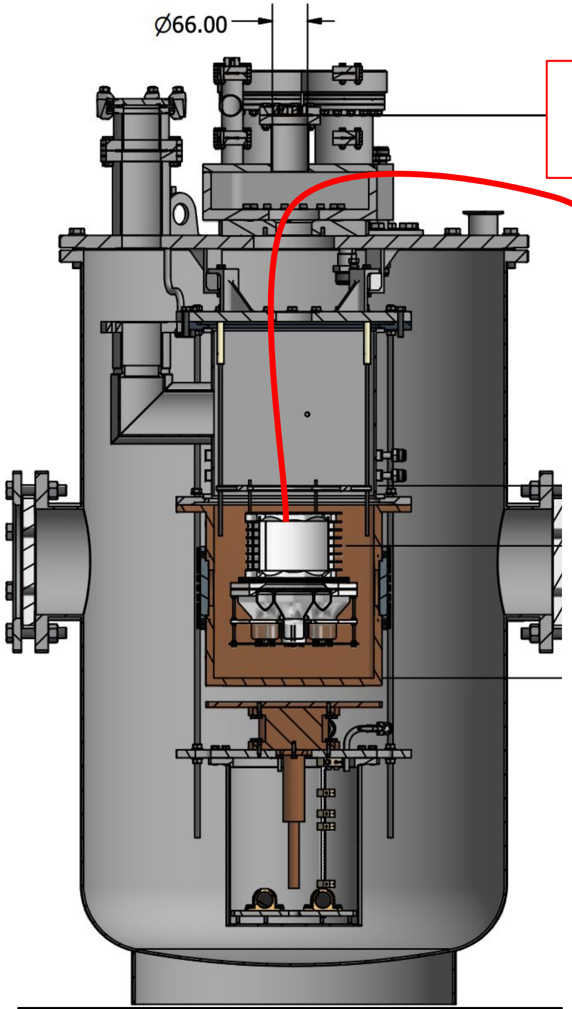



Cryostat at Carleton



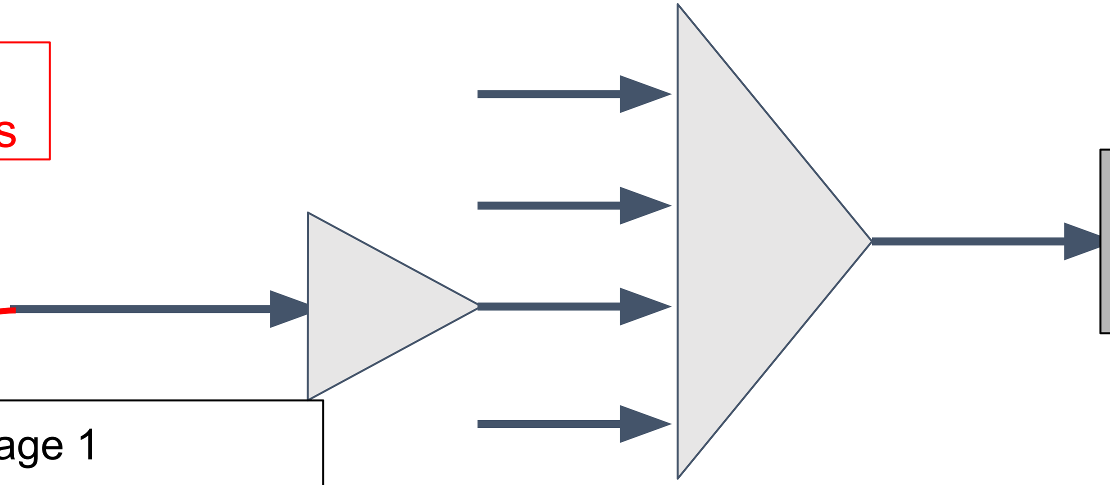

Stage 1
RF amp
DC to 2GHz BW
Voltage gain ~12

# LoLX: Electronics Layout




Cryostat at Carleton

96 cables from SiPMs



Stage 1

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DC to 2GHz BW

Voltage gain ~12

Stage 2

4ch summing

Operation amp

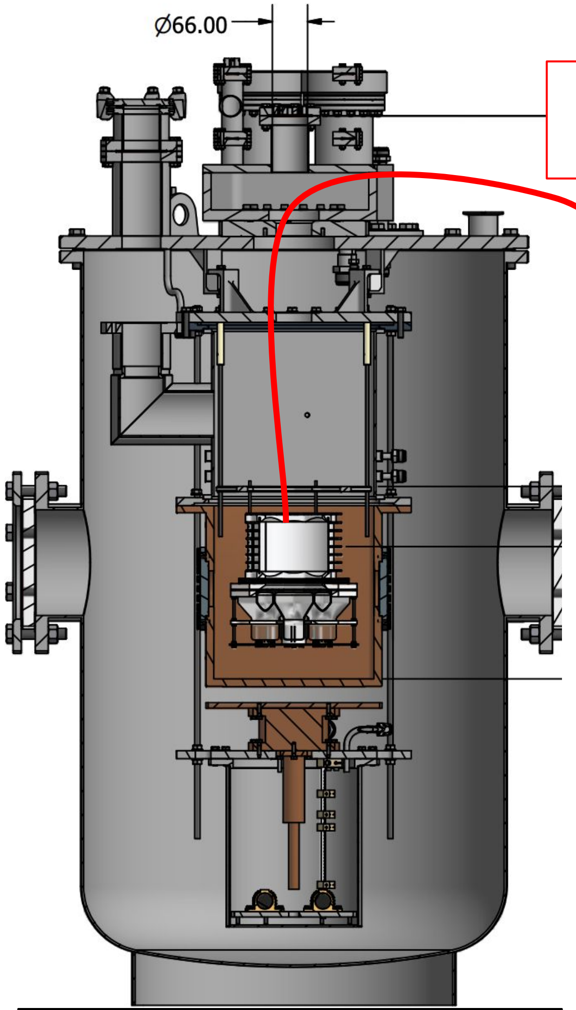
Voltage gain ~10

CAEN DT1740

Digitizer

Cerenkov SiPMs are summed → 22 channels

# LoLX: Electronics Layout

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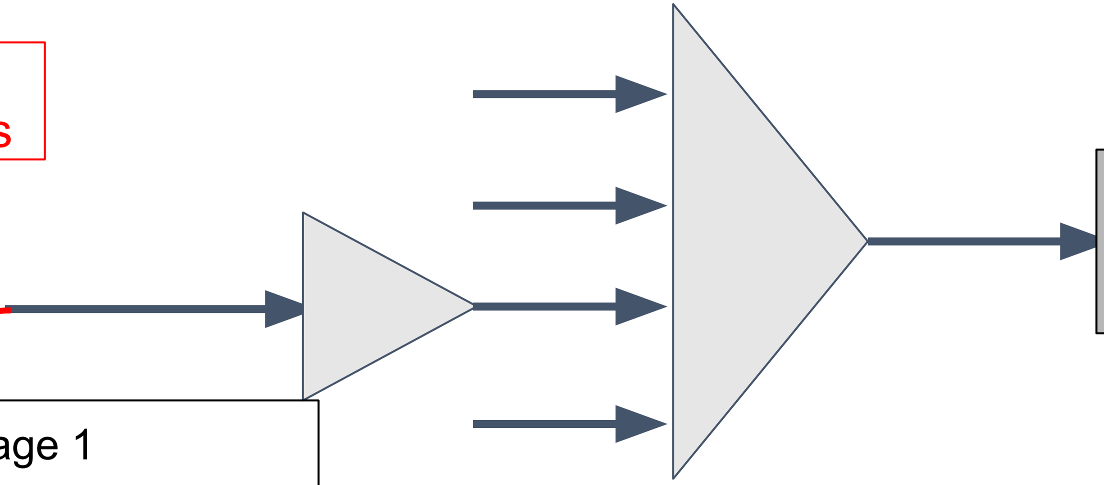

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CAEN DT1740
Digitizer

2Vpp dynamic range
12 bits
65MHz sampling (slow)

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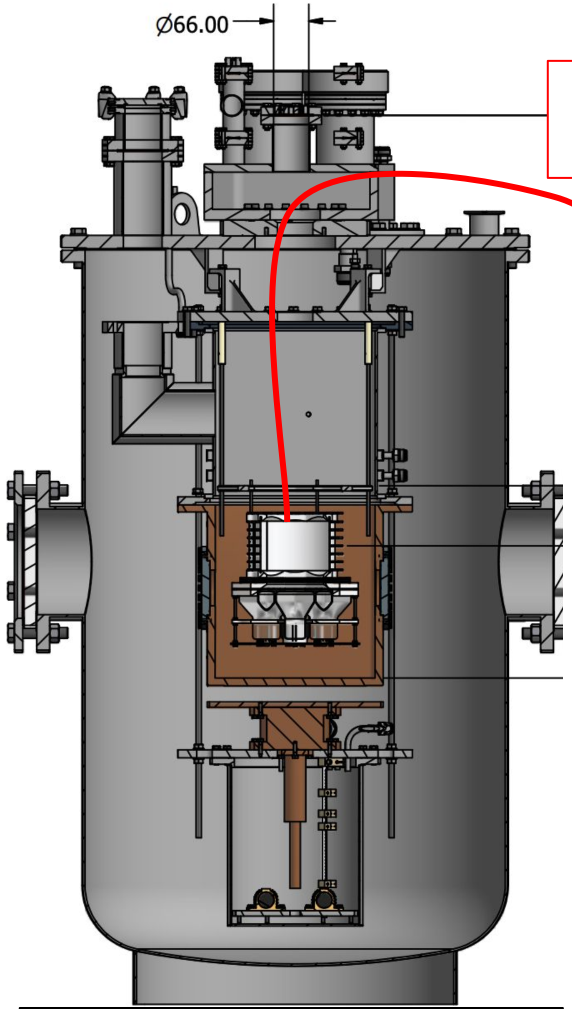


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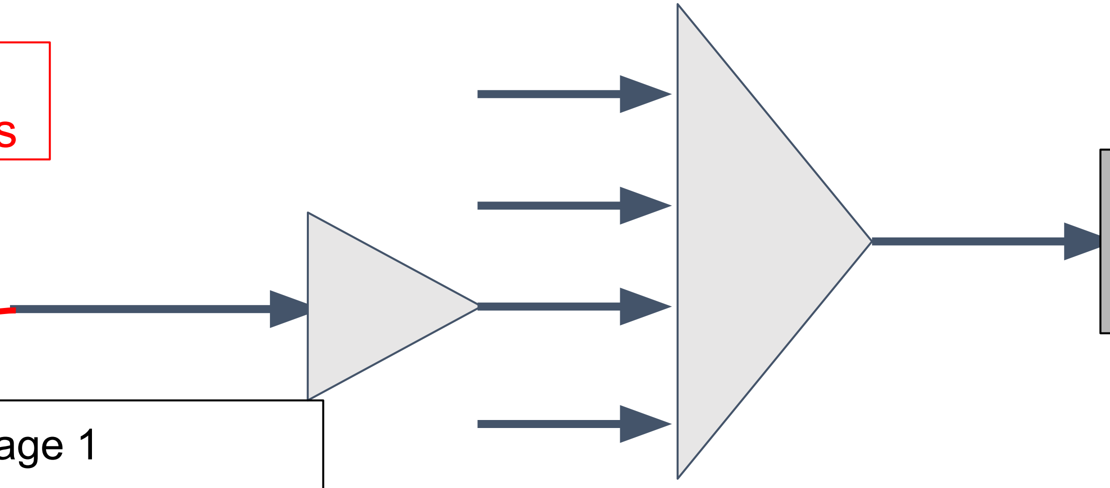

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2Vpp dynamic range
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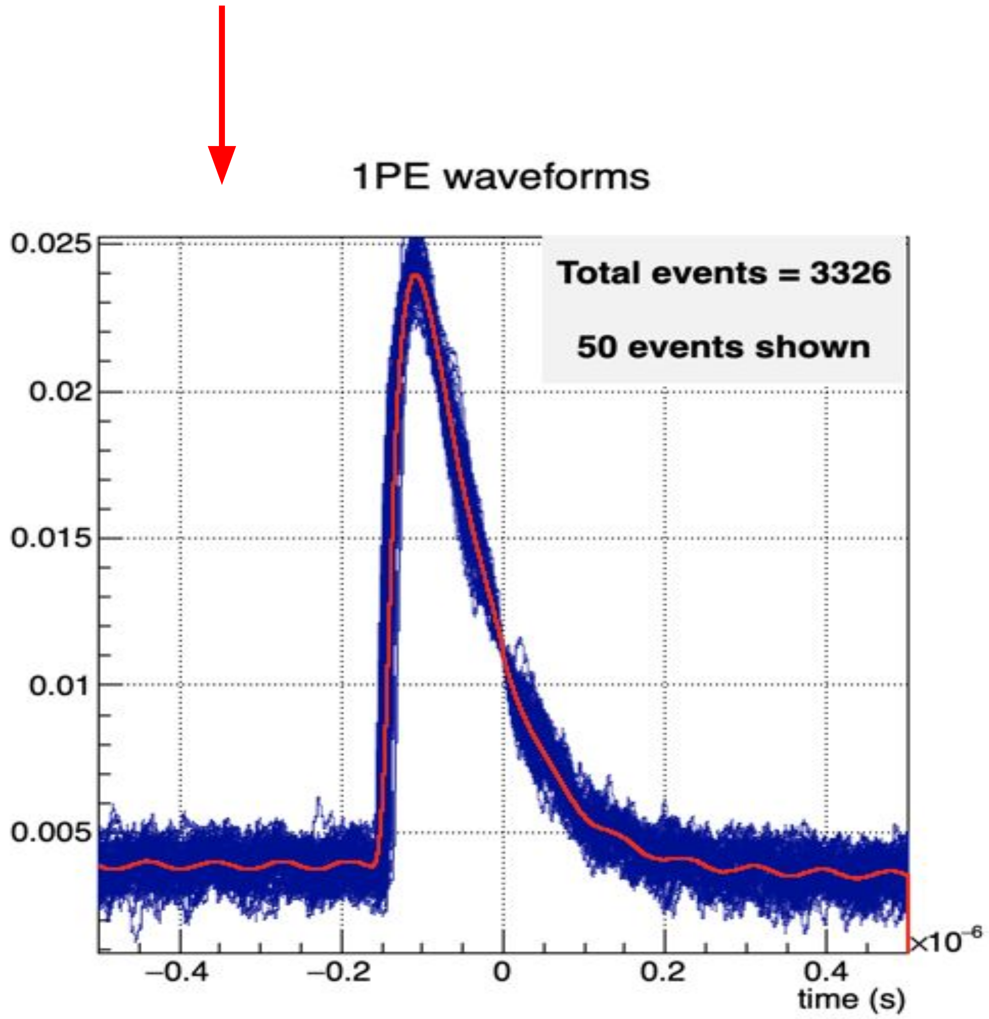
Cryostat at Carleton

Scintillation SiPMs are **not** summed → 22 + 8 = 30 channels

# Single PE resolution



Histogram charge from many waveforms



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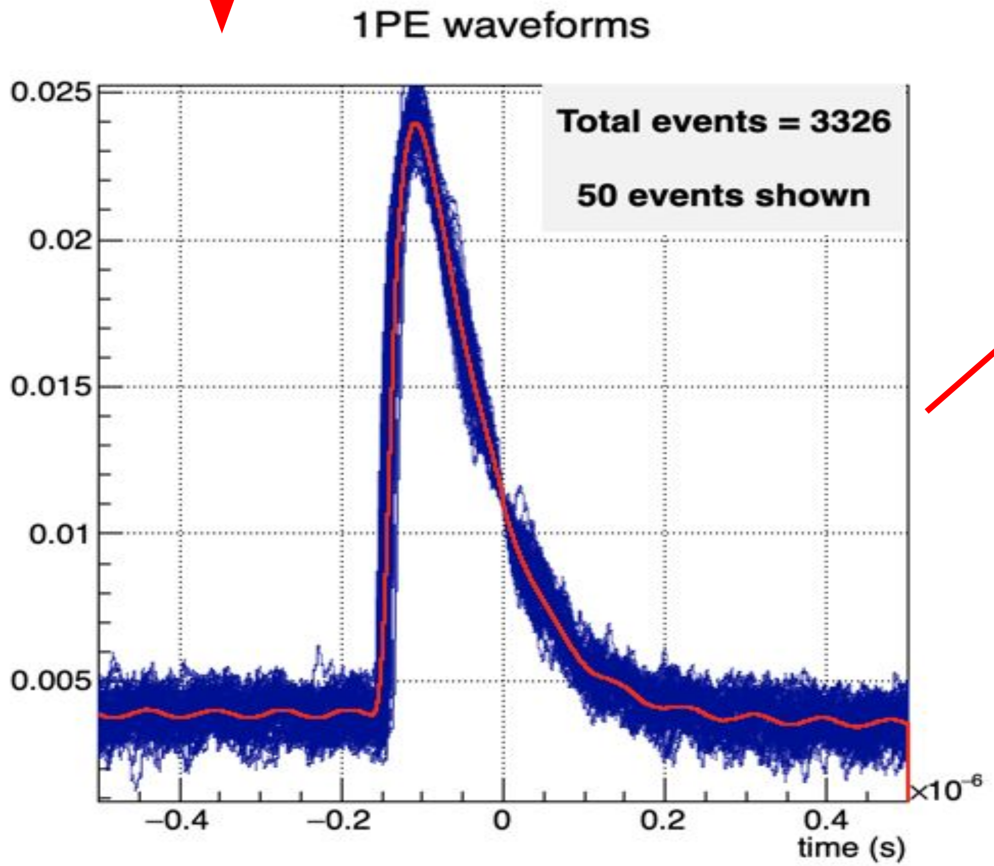
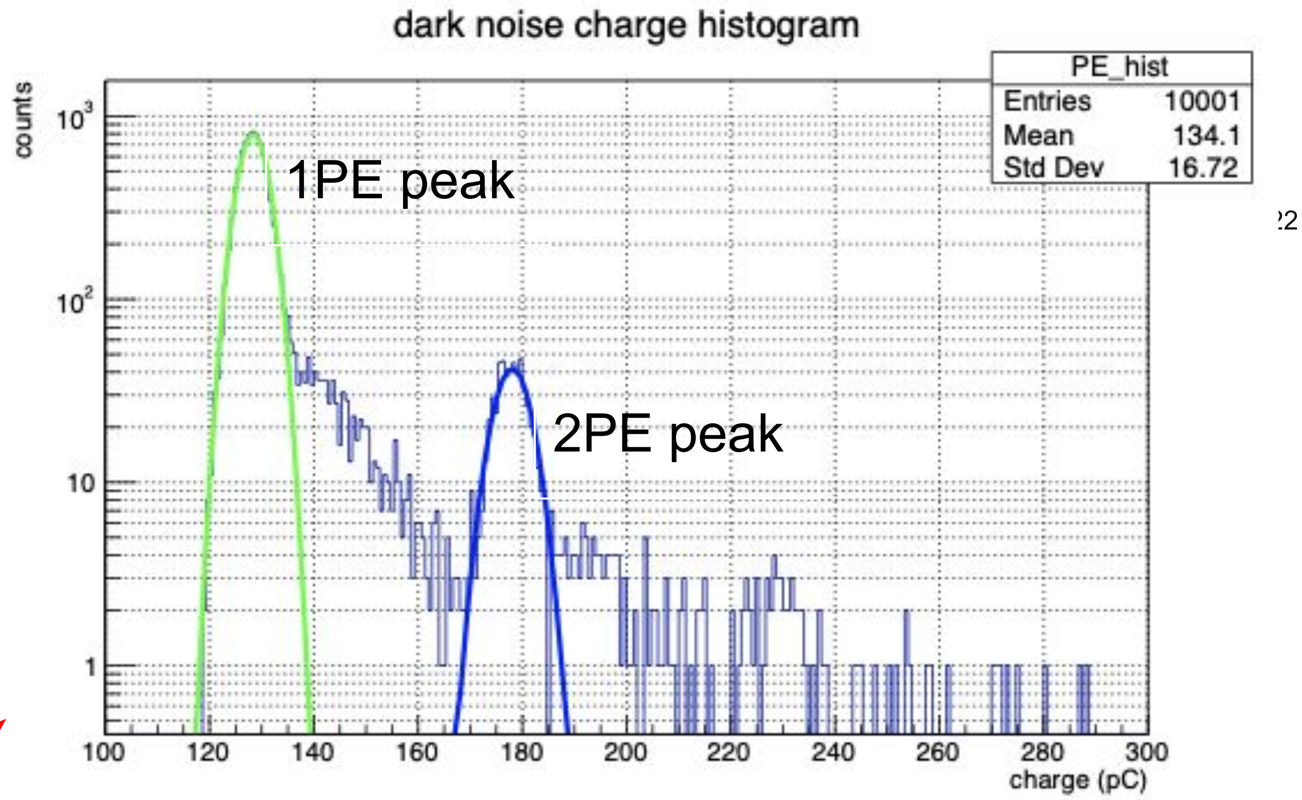



Single PE resolution is given by

1PE charge vs gaussian width

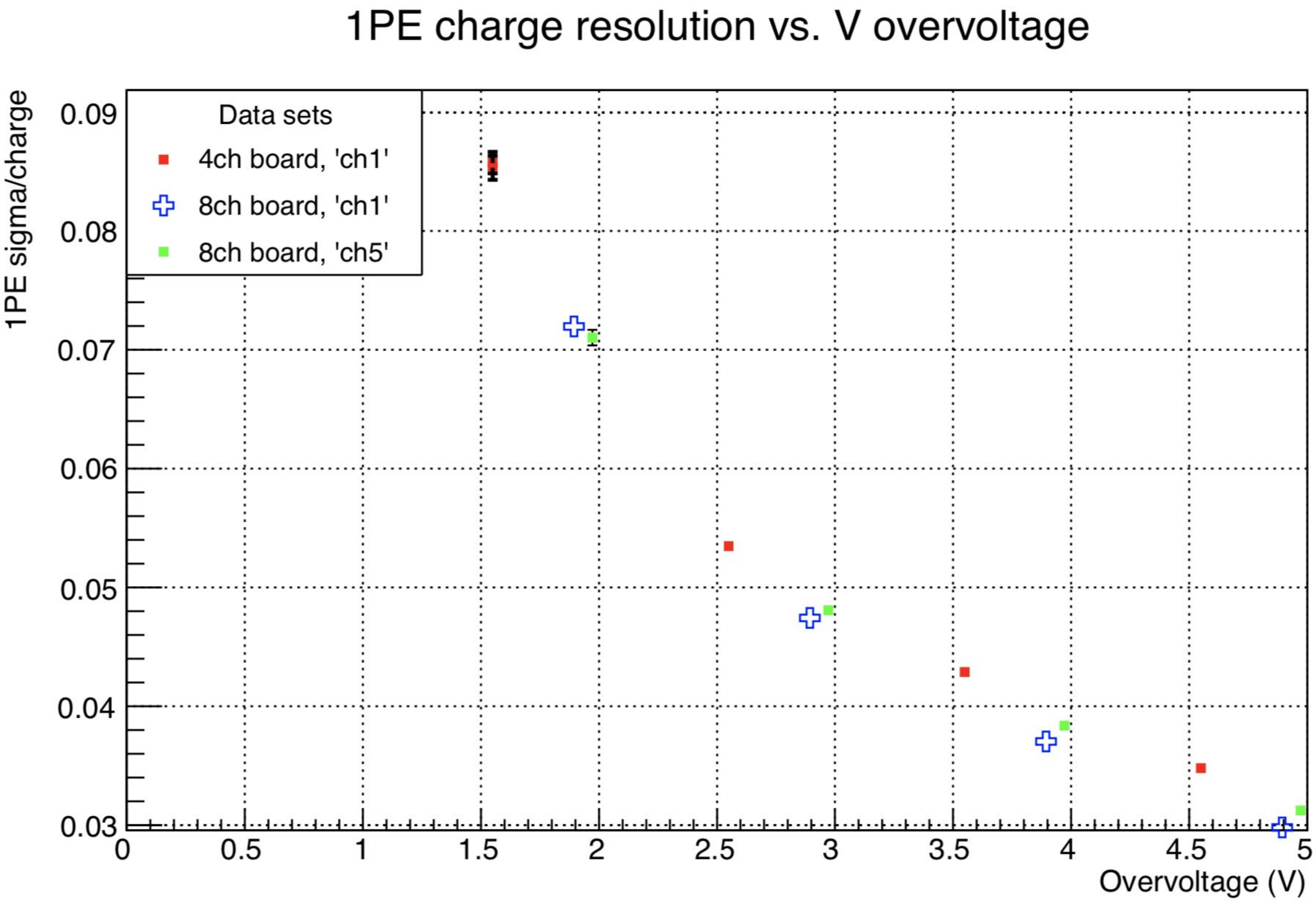
# Single PE resolution



Charge resolution is good (with scope)

Must check with digitizer

*no horizontal error bars, which represent uncertainty in breakdown voltage due to temperature uncertainty



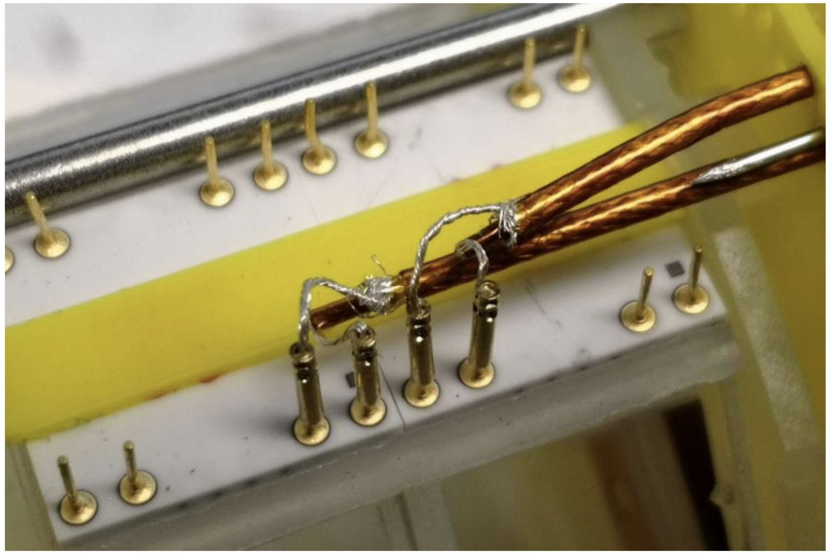
# Cable Testing



**Check for unwanted timing effects or signal attenuation**

Tested Cables

- MCX terminated coaxial cable (reference)
- MCX with vacuum feedthrough junction
- Kapton insulated coax



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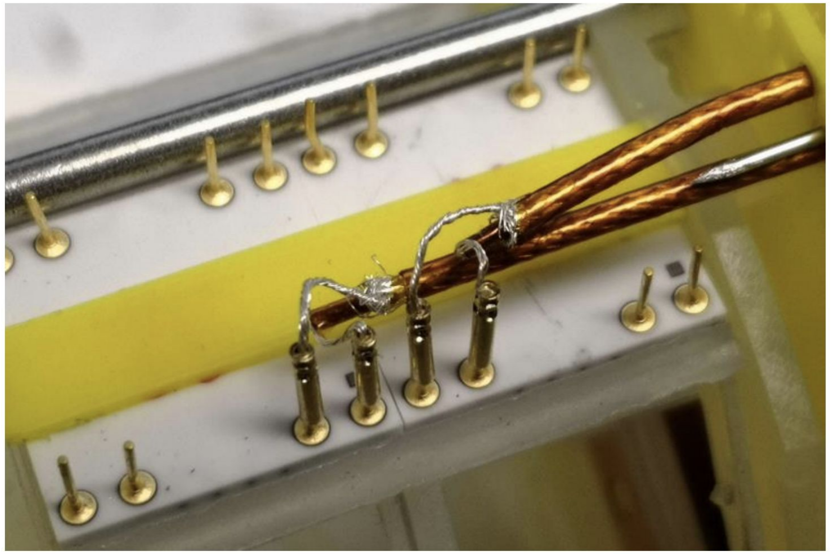

Kapton coated coaxial cable

Tested with RC circuit pulser and waveform generator

| | Cable type | Jitter (ps) | amplitude (mV) | | rise time (ns) | |
|---|---|---|---|---|---|---|
| | | | mean | std dev | mean | std dev |
| small signal (2mV VPP) | ref cable (mcx) | 178 | 63 | 3.7 | 3.2 | 0.5 |
| | kapton | 185 | 60.2 | 3.4 | 3.3 | 0.7 |
| | mcx + FT + mcx | 200 | 61.6 | 4.3 | 3.5 | 0.7 |
| large signal (50mV VPP) | ref cable (mcx) | 24.5 | 3133 | 56.5 | 2.62 | 0.067 |
| | kapton | 24.4 | 2998.7 | 53 | 2.63 | 0.064 |
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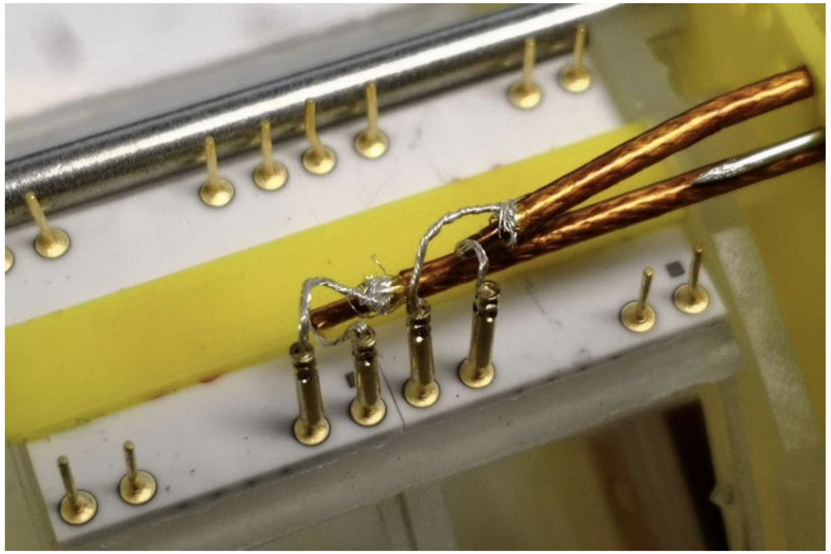


Kapton coated coaxial cable

Constrained by waveform generator rise time

# Expected Number of Photons

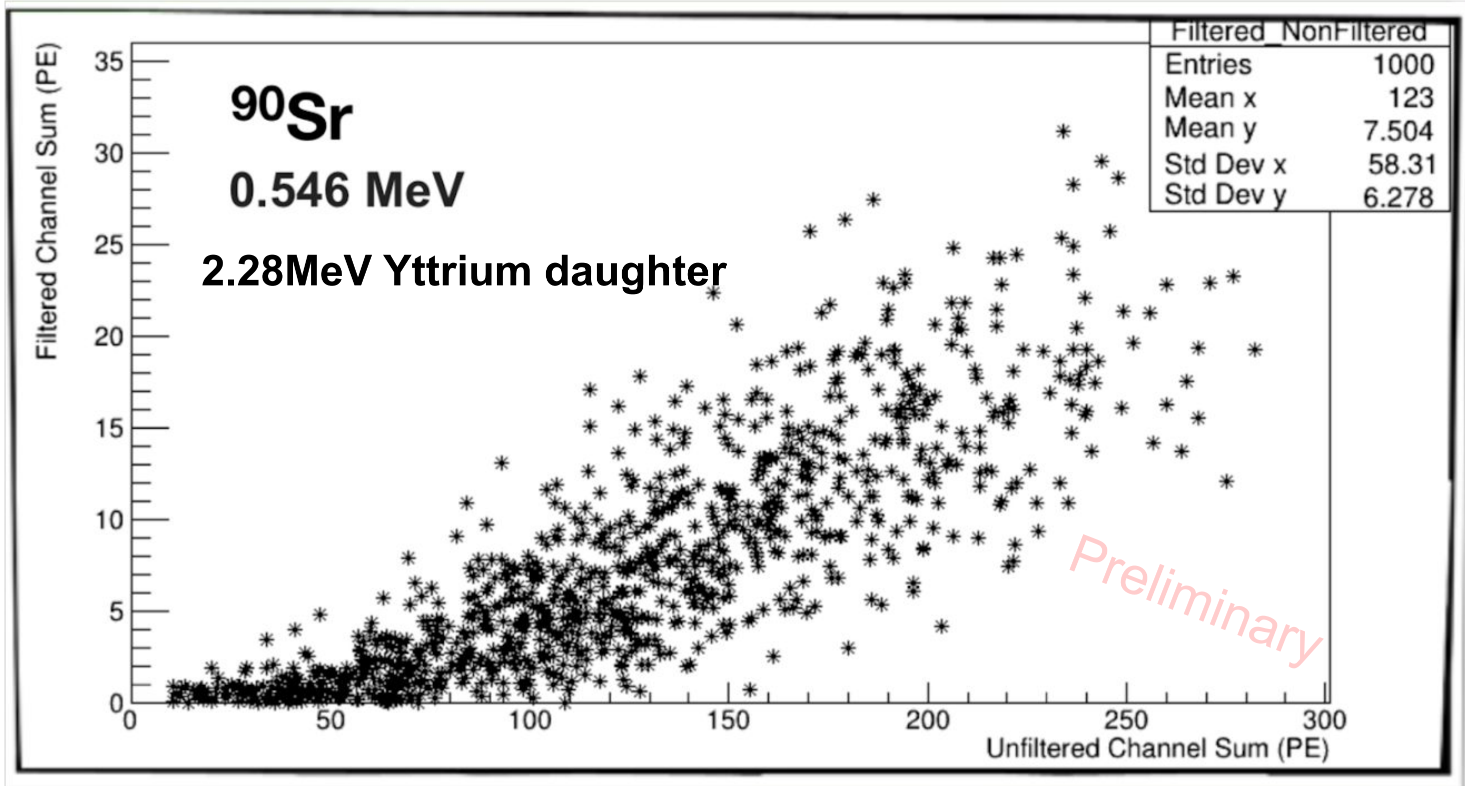


First simulation results

- Beta (below)

Y-axis: cherenkov channels

X-axis: 1 scintillation SiPM



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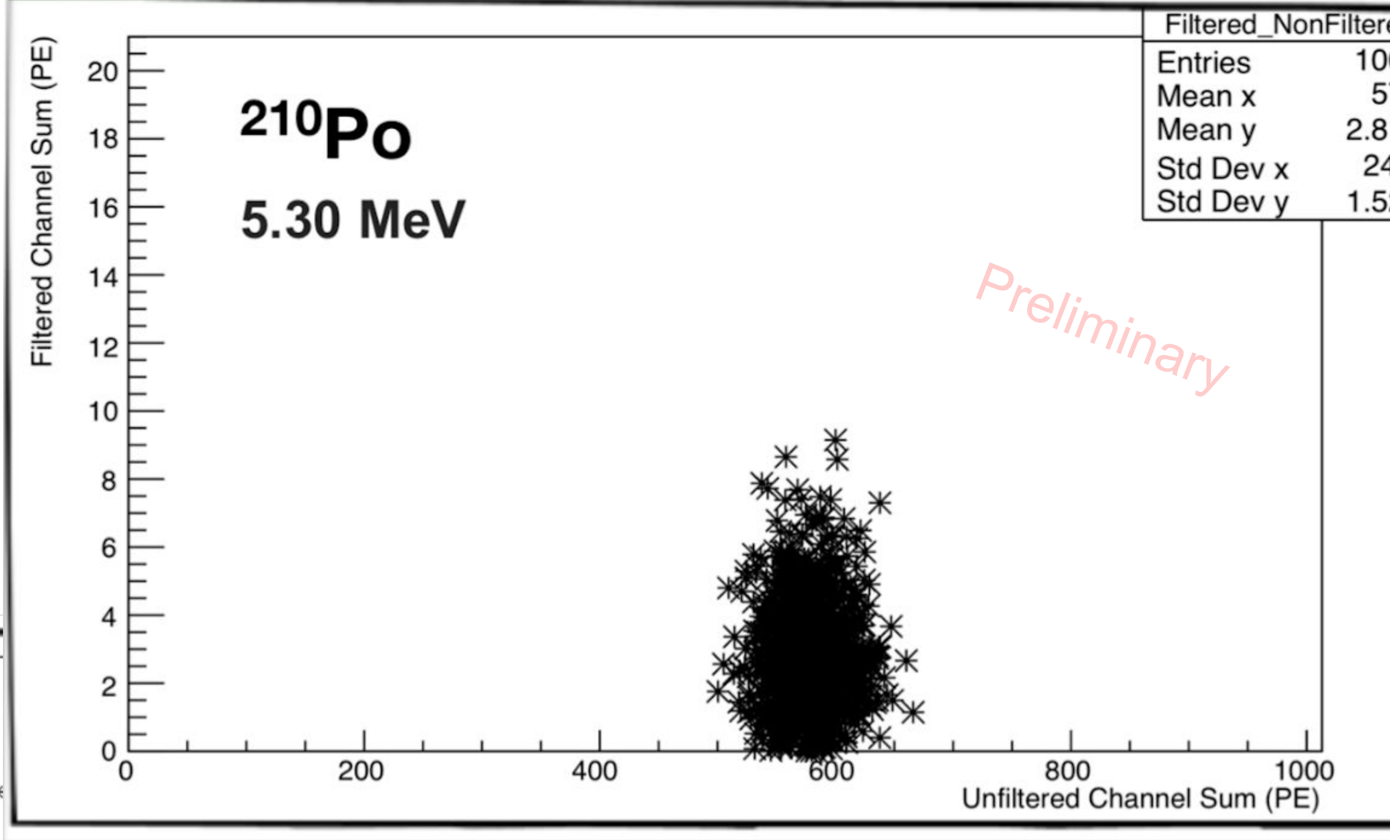


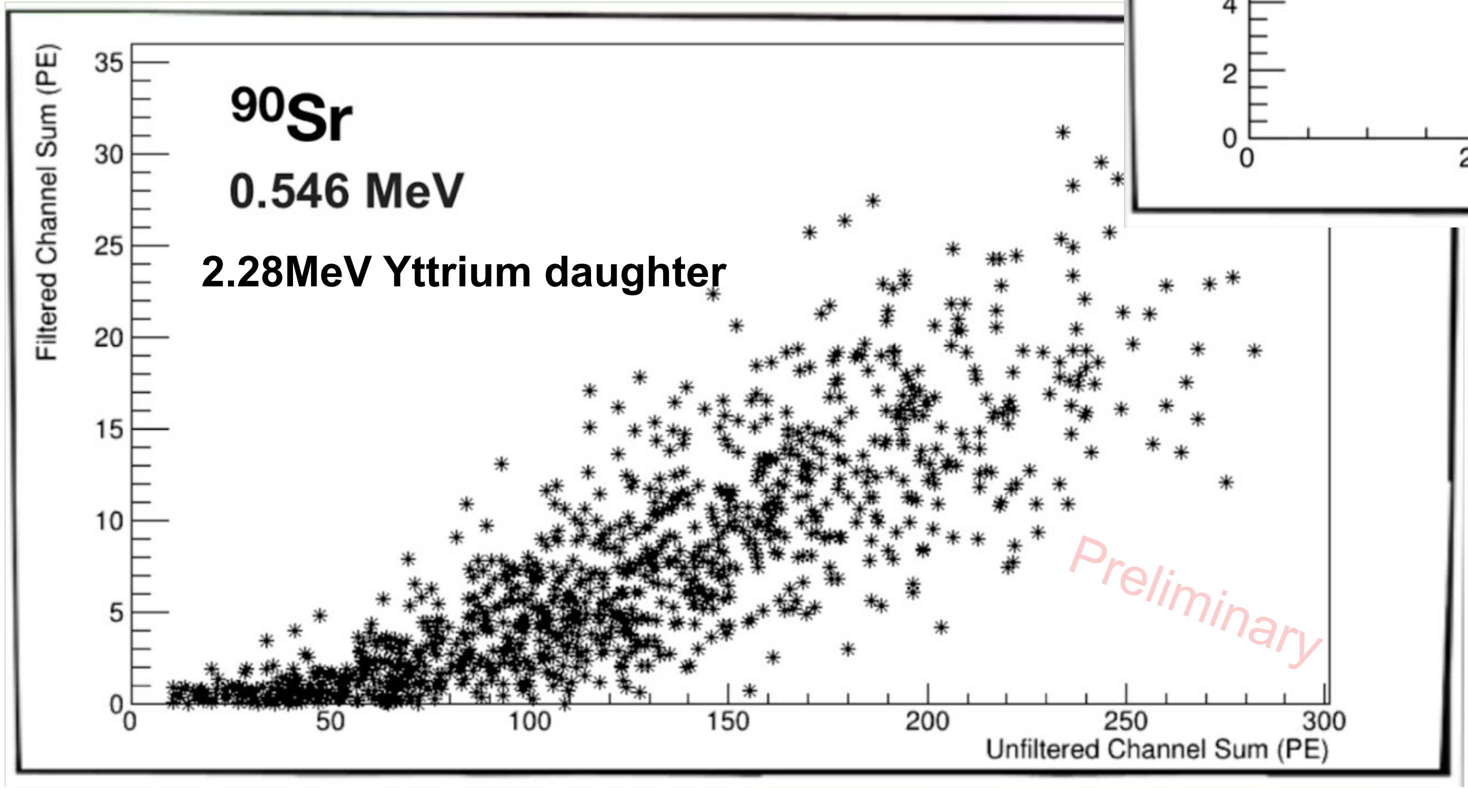

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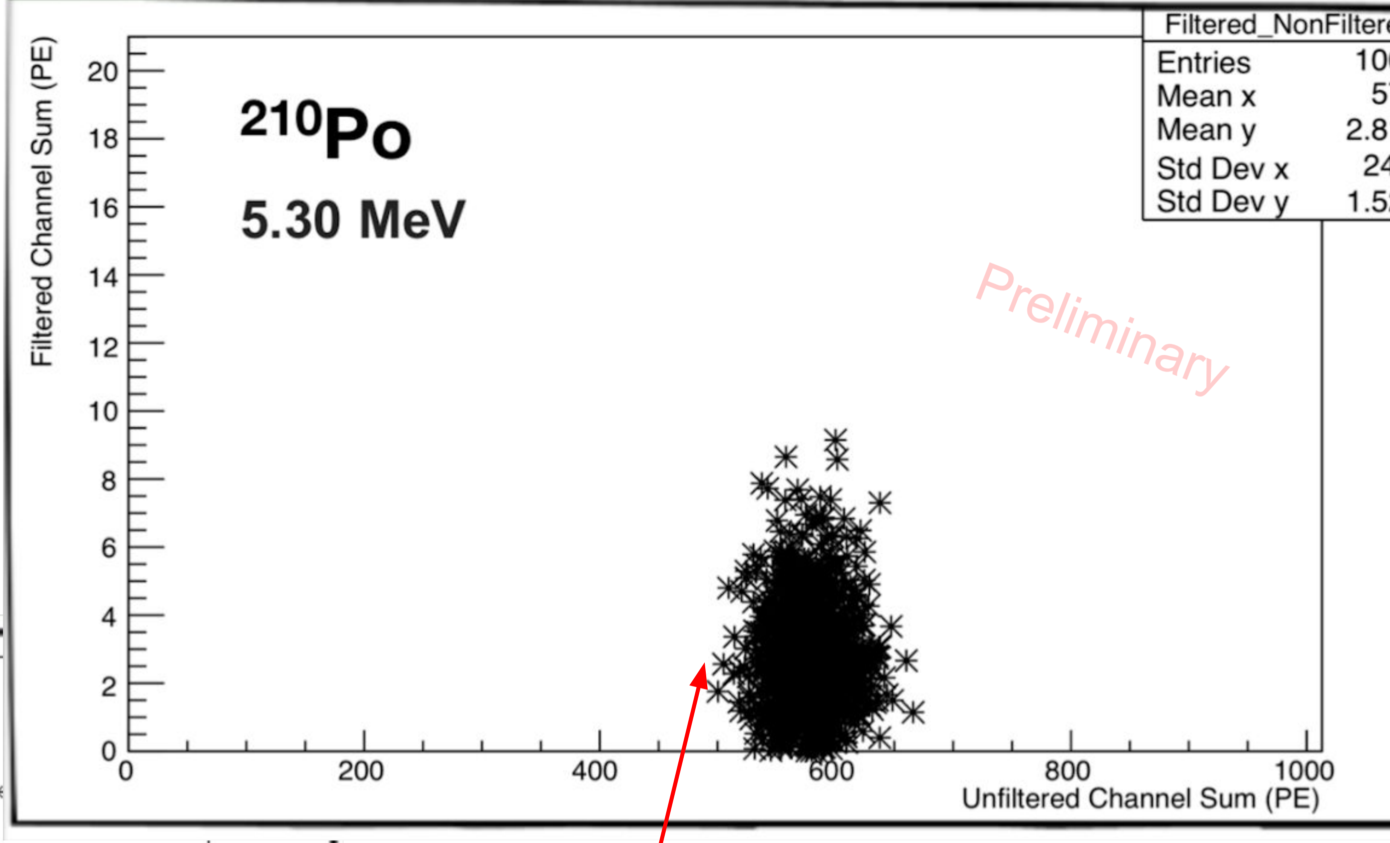
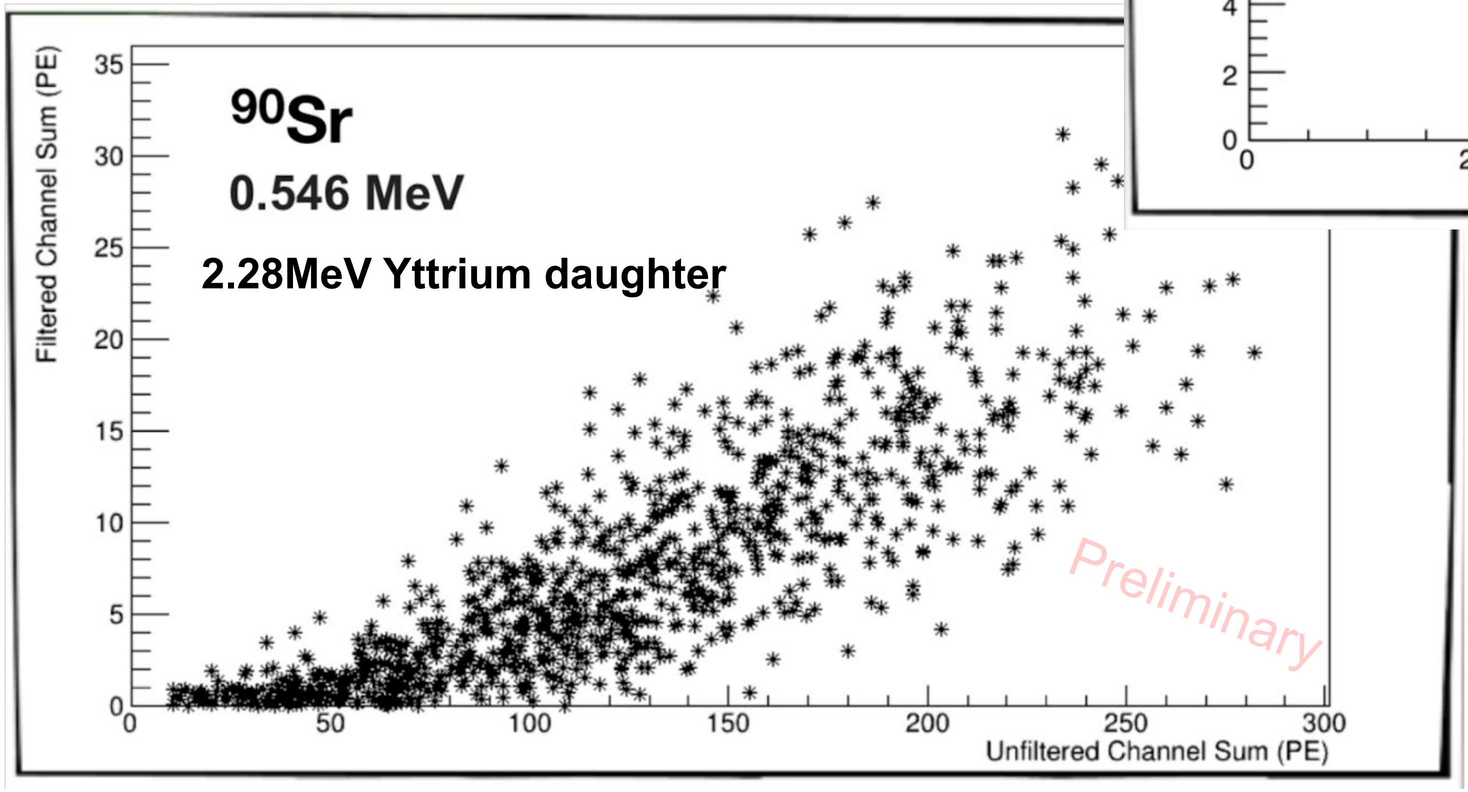



Some leakage 'cerenkov' photons for alpha event



# Digitizer: Dynamic Range



**5.3 MeV Alphas are brightest**

$$N = \frac{E \times Yield \times A_{SiPM} \times PDE}{24 \times W_{photon} \times A_{tot}}$$

| | alpha |
|---|---|
| W_ph_max (eV) = | 13.8 |
| Relative Scint. Yield = | 0.77 |
| Photo coverage(old geo) = | 0.5 |
| Photo detection efficiency = | 0.13 |
| UV filter transmittance = | 0.35 |

# Digitizer: Dynamic Range

**5.3 MeV Alphas are brightest**

- Summing scintillation channel misses dynamic range (at least 6V signal)
- Naked SiPM detects ~150 photons in each quadrant

| | 210 Po alpha |
|---|---|
| E (MeV) = | 5.3 |
| $N_{1SiPM}$ = | 617 |
| $N_{1channel}$ = | ~150 |
| Filter $N_{1channel}$ = | ~50 |

$$N = \frac{E \times Yield \times A_{SiPM} \times PDE}{24 \times W_{photon} \times A_{tot}}$$

| | alpha |
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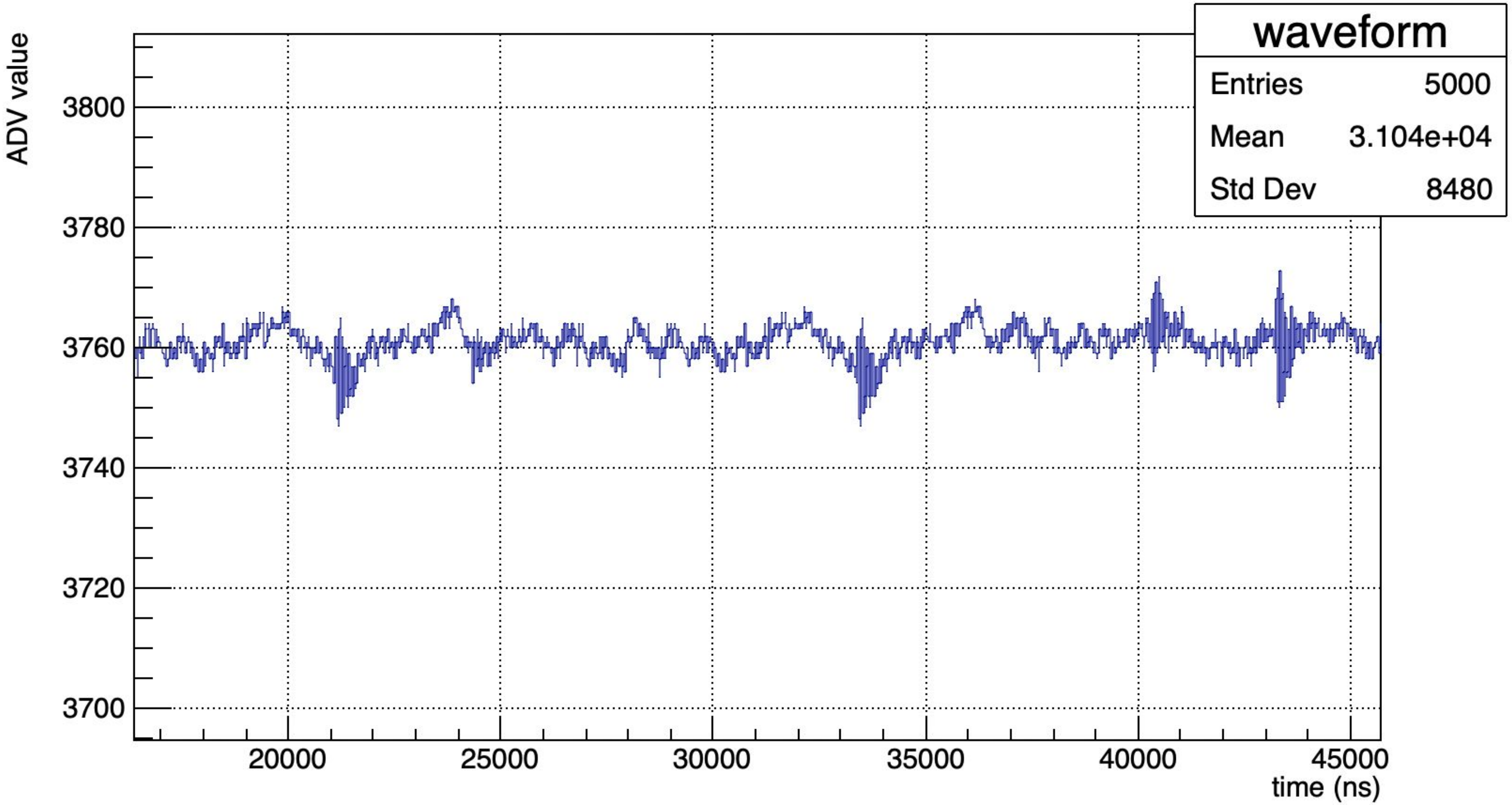
# Digitizer: Single PE resolution

Two distinct sources of noise

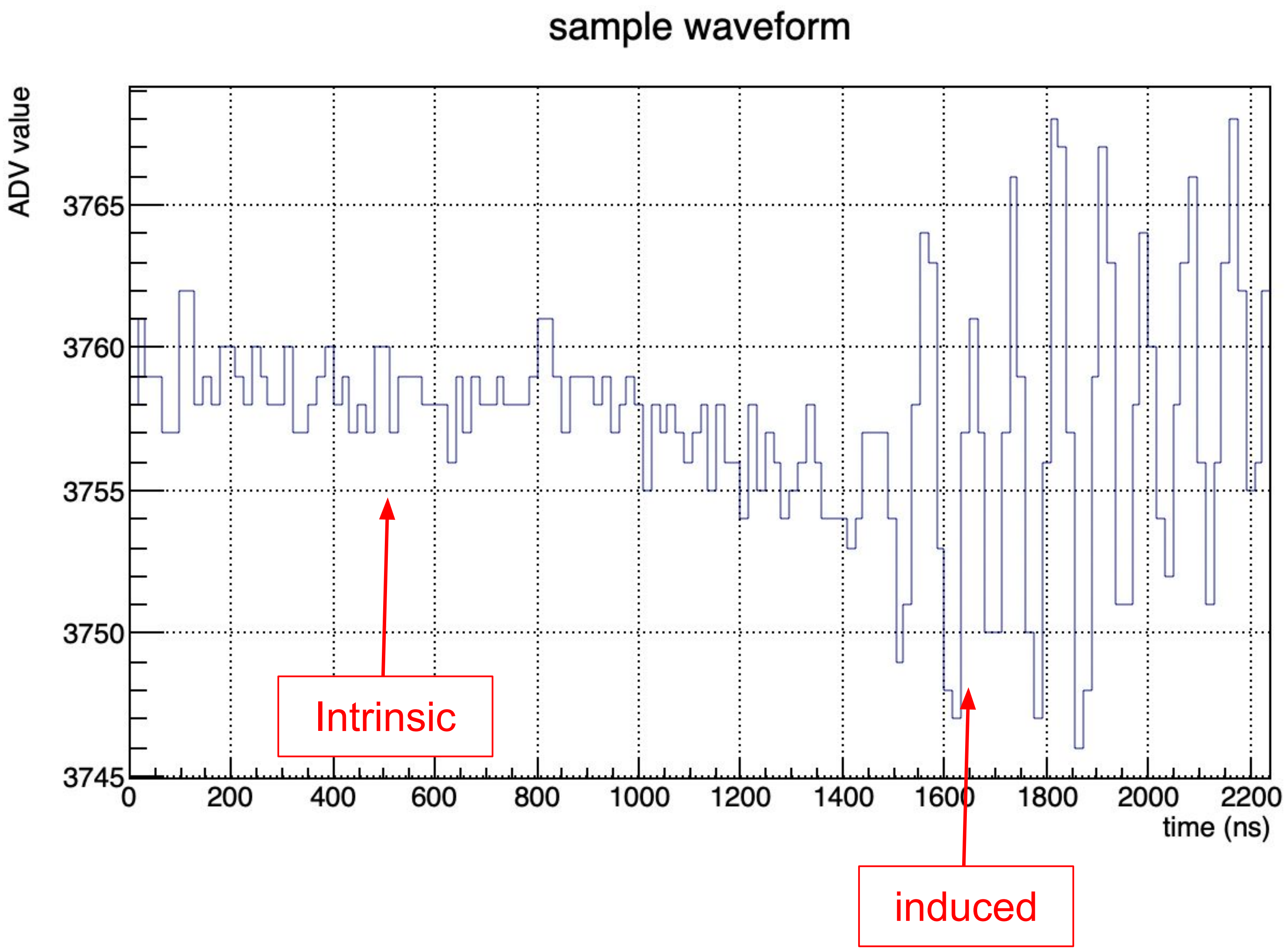


# Digitizer: Single PE resolution



Two distinct sources of noise

- Intrinsic
- induced
  (local electronics or cyclotron)



# Digitizer: Single PE resolution



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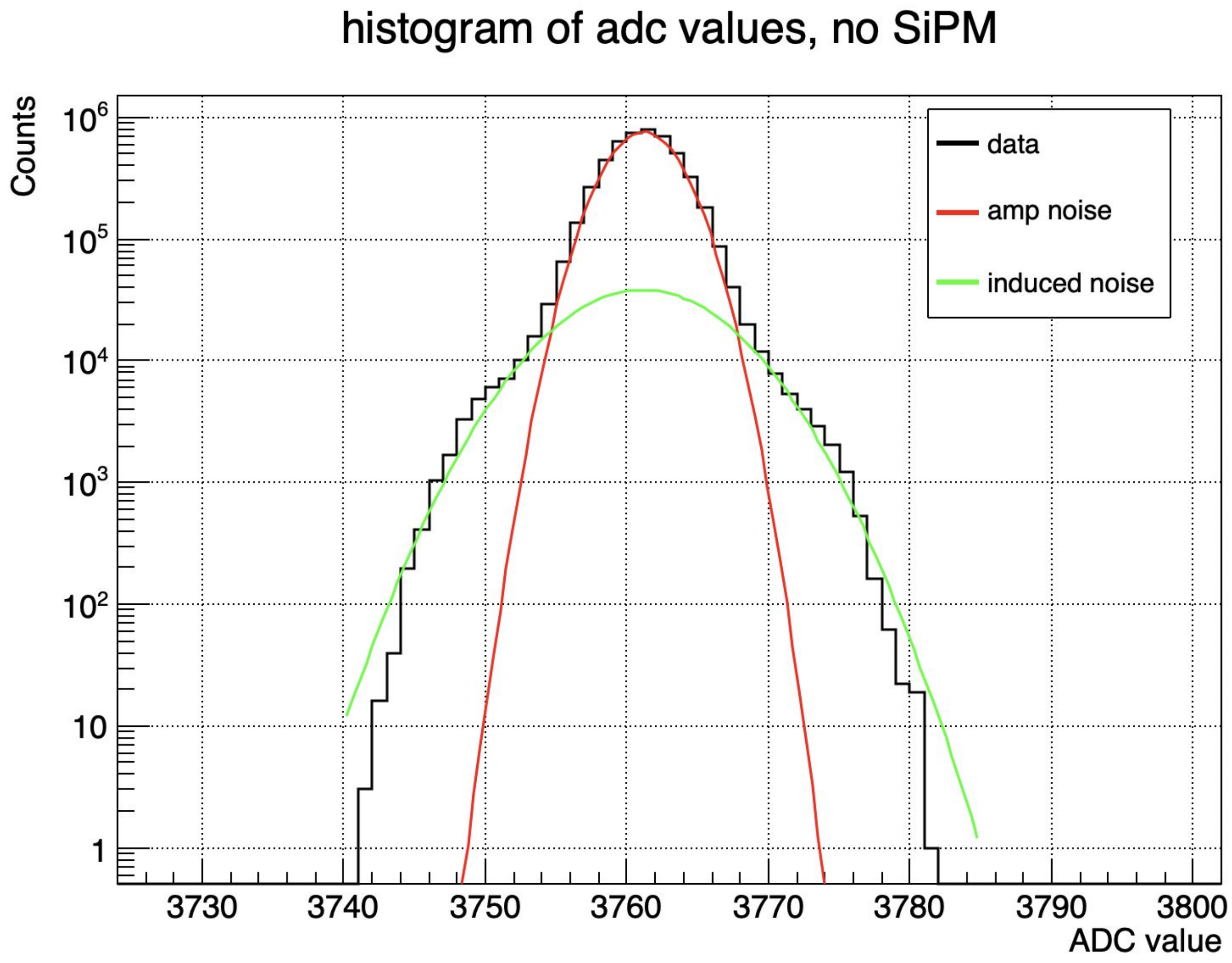
Can see clearly in histogram of ADC values

Amp noise, FWHM = 5.63 adc
Induced noise, FWHM = 12.24 adc



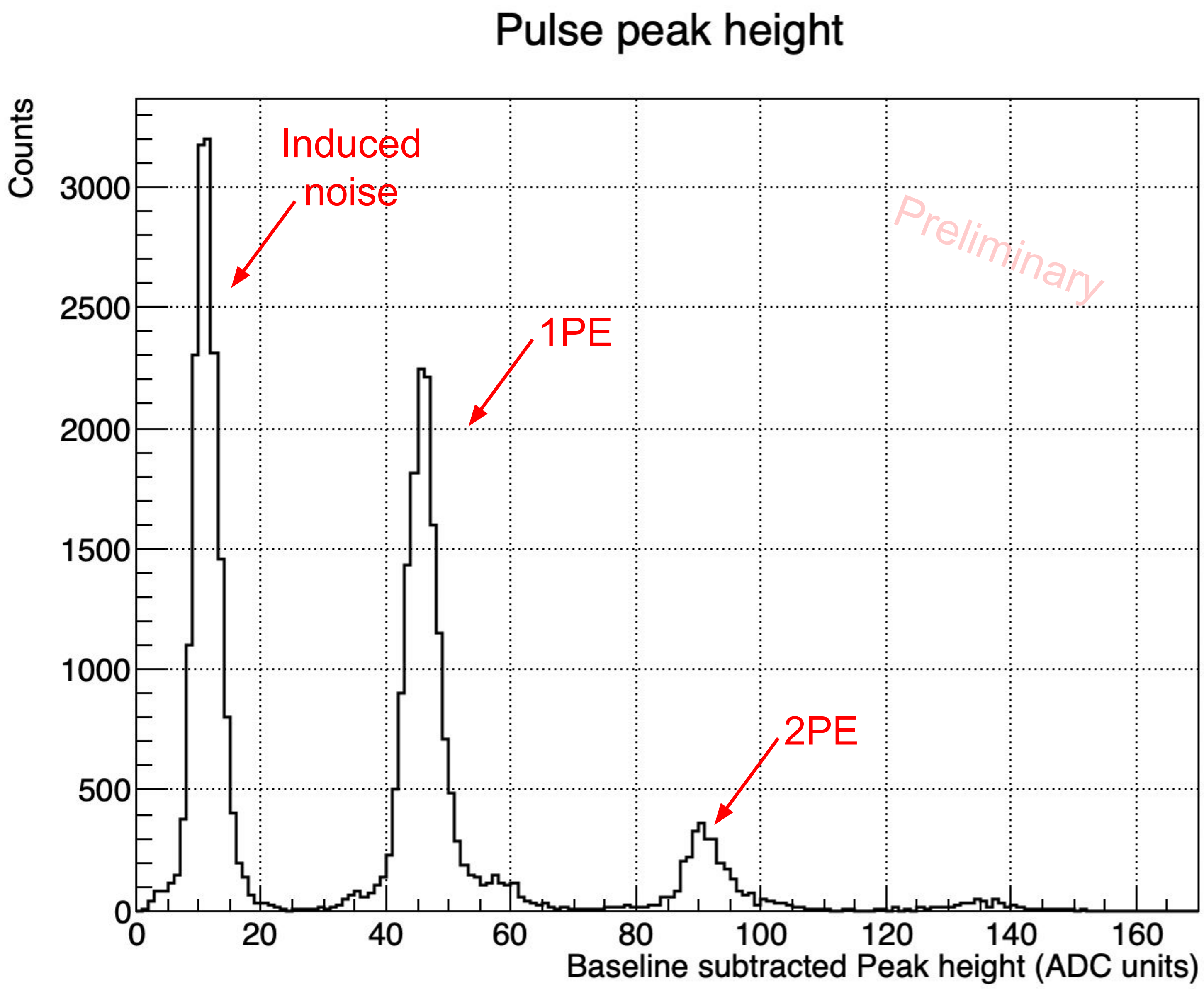
# Digitizer: Single PE resolution



Single photon counting still possible!

With SiPM attached:
T = -40C
$V_{over}$ ~ 4V

1PE peak height much higher than induced noise



# Digitizer: Single PE resolution



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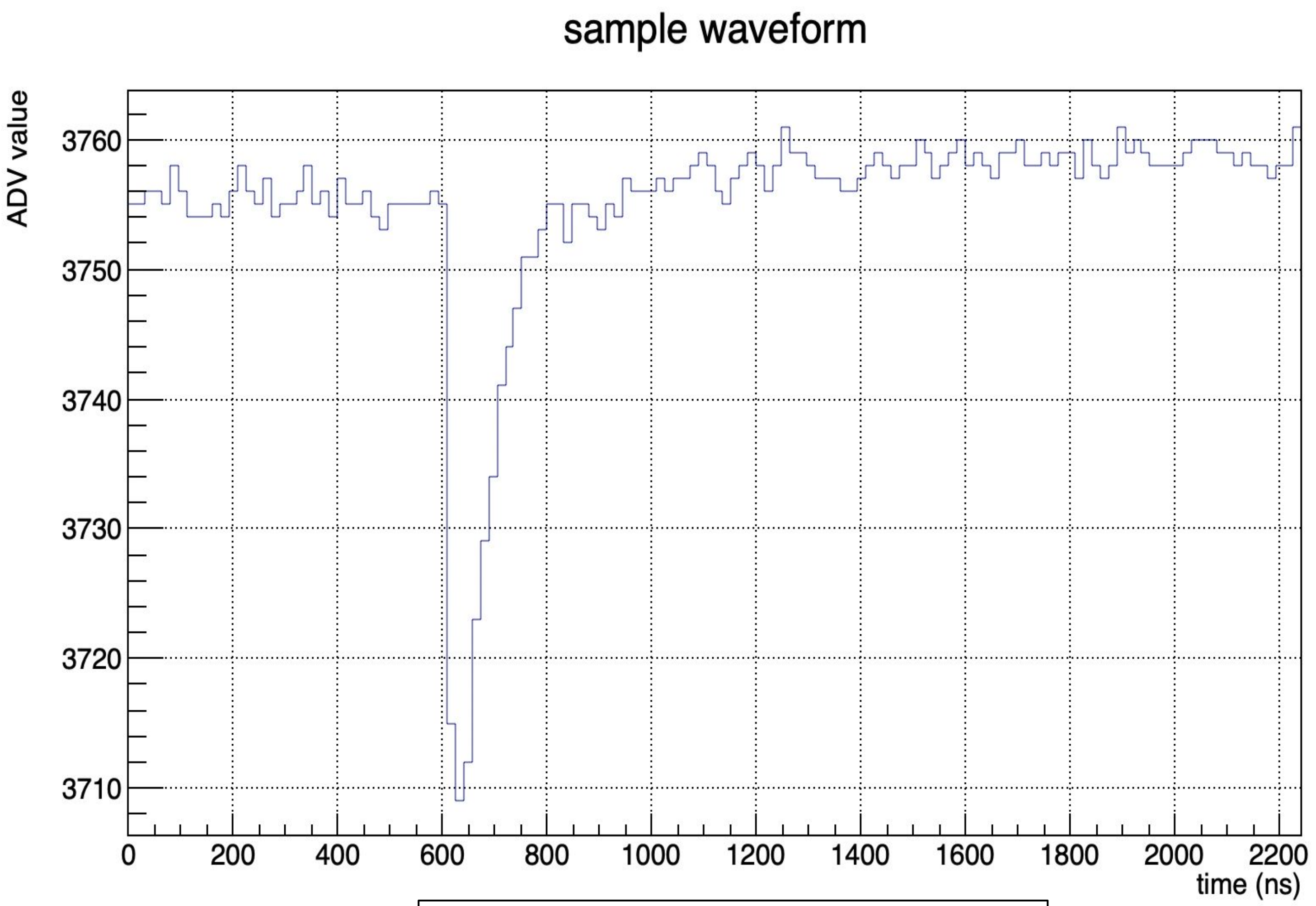
1PE peak height much higher than induced noise

All this to say: **can discriminate 1PE events from baseline**




Single PE digitized waveform

# LoLX Electronics: Conclusions



With slower electronics any cables will suffice

- cables may affect rise time at sub ns scale, must check effects with faster scope

Currently amp+digitizer gives excellend 1PE resolution

- reduce amp gain to retain full dynamic range for brightest events

LOLX is on schedule to take data by September 2019!

- Cerenkov light in LXe!

McGill: Thomas Brunner, Thomas McElroy, Tsvetelin Totev

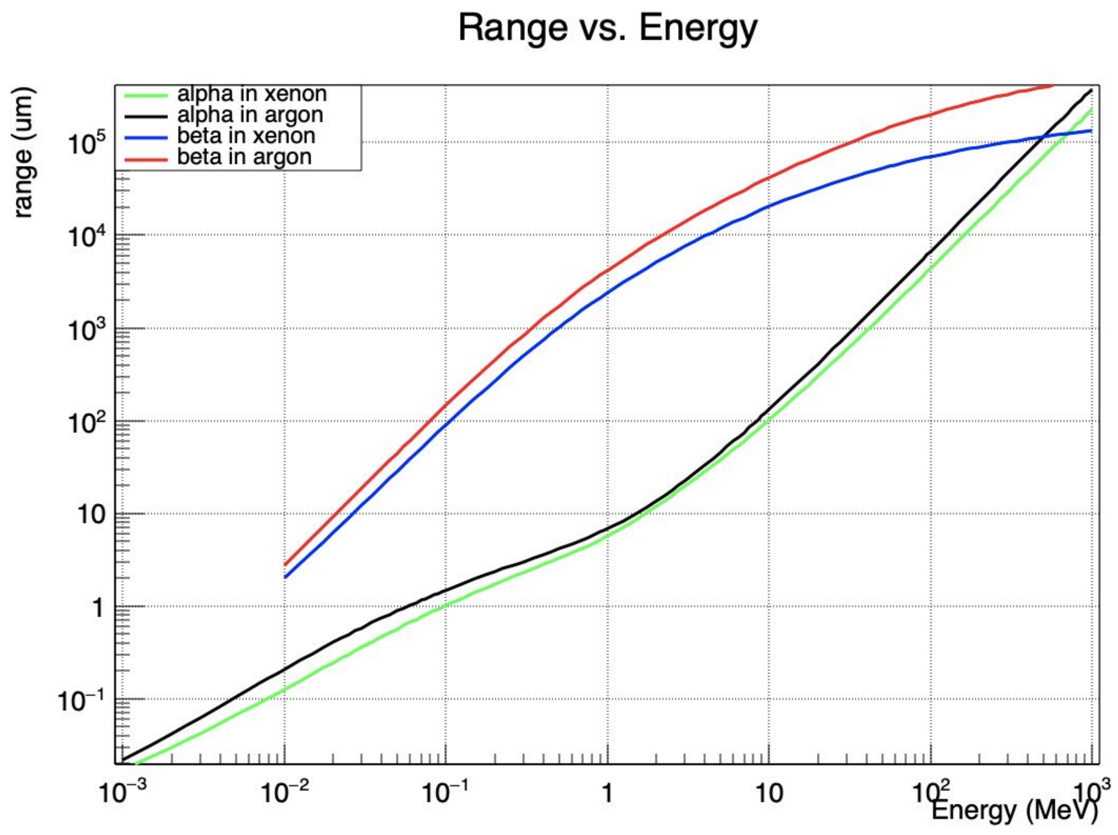
Carleton University: Razvan Gornea, Simon Viel, Damian Goeldi

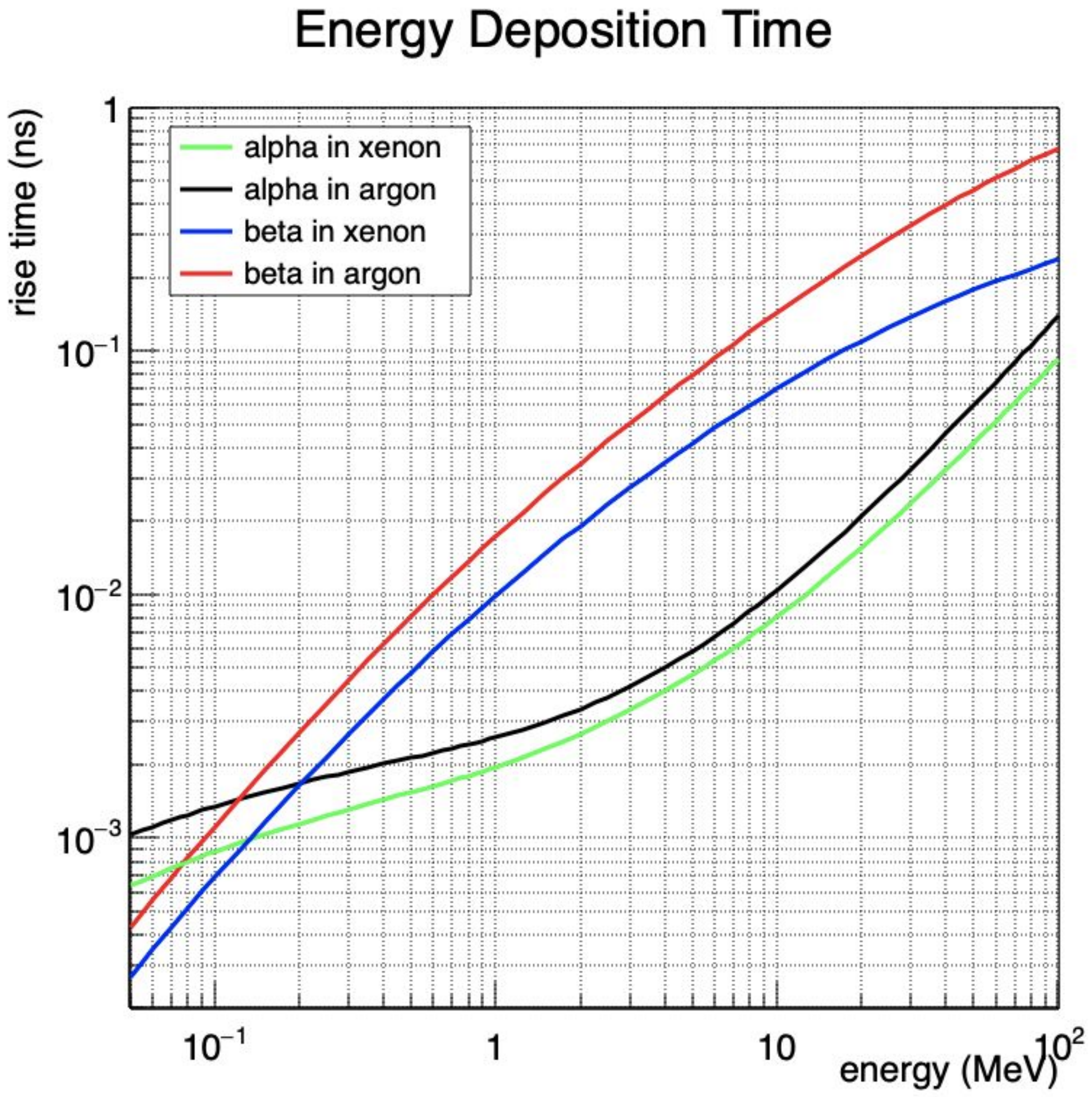
TRIUMF: Fabrice Retière, Pietro Giampa, Peter Margetak, Austin de St. Croix

INFN LNL — Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Legnaro: (Pisa): Luca Galli, Giovanni Signorelli, Simone Stracka

# Backup: Deposition time

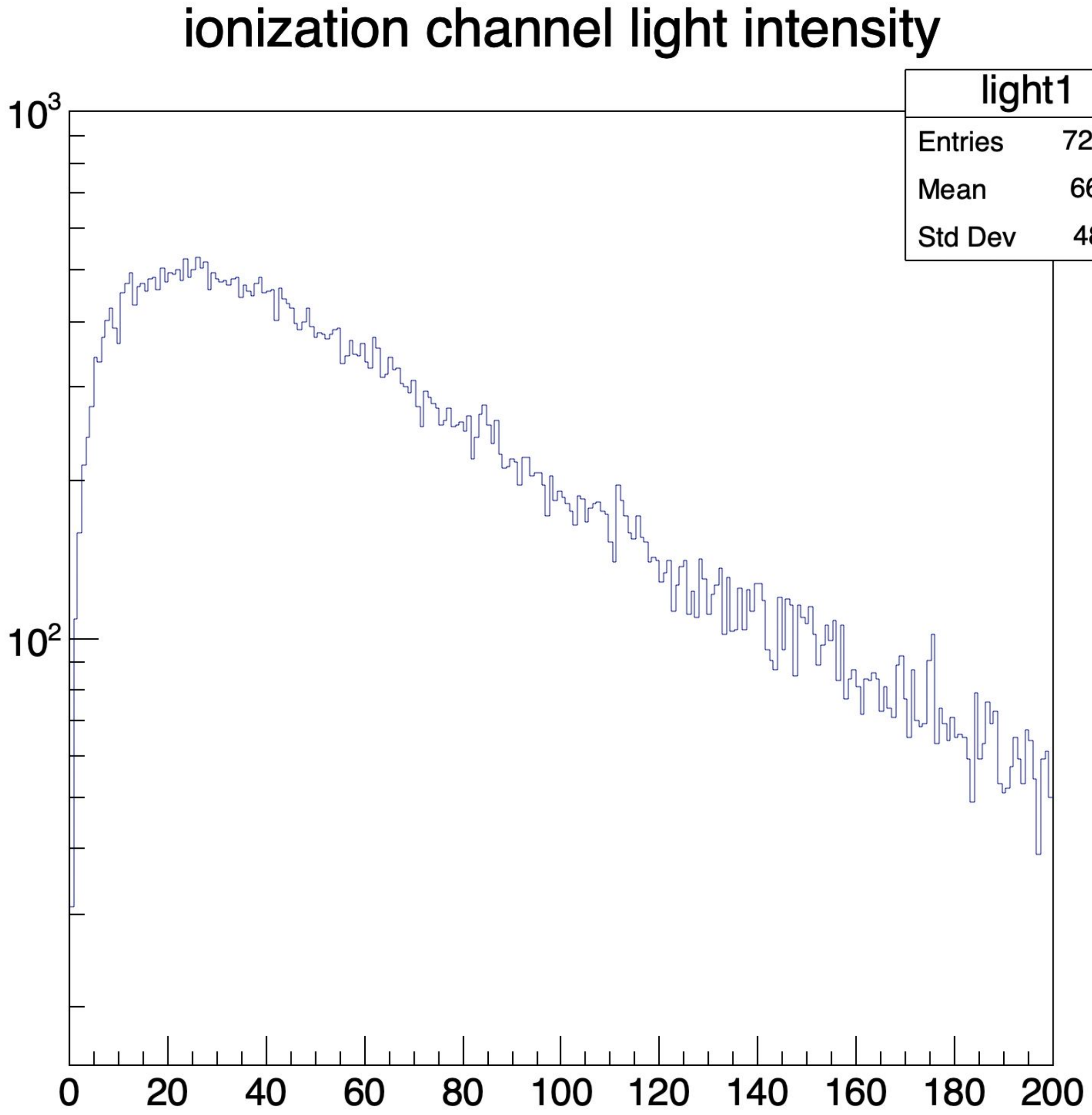




# Backup: Expected scintillation signal






$$I_N(t)_{\eta=0} = \frac{N_o}{\tau_r(1+t/\tau_r)^2}$$

$$M_s(t) = M_s e^{-t/\tau_s}$$

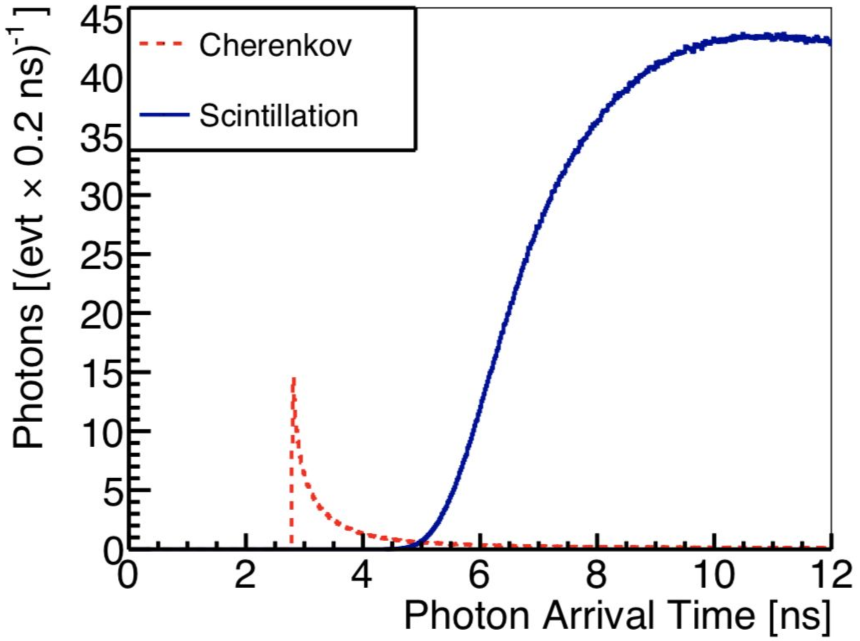
$$M_t(t) = M_t e^{-t/\tau_t}$$

# Backup: Cerenkov helping nEXO

Background Discrimination for Neutrinoless Double Beta Decay in Liquid Xenon Using Cherenkov Light

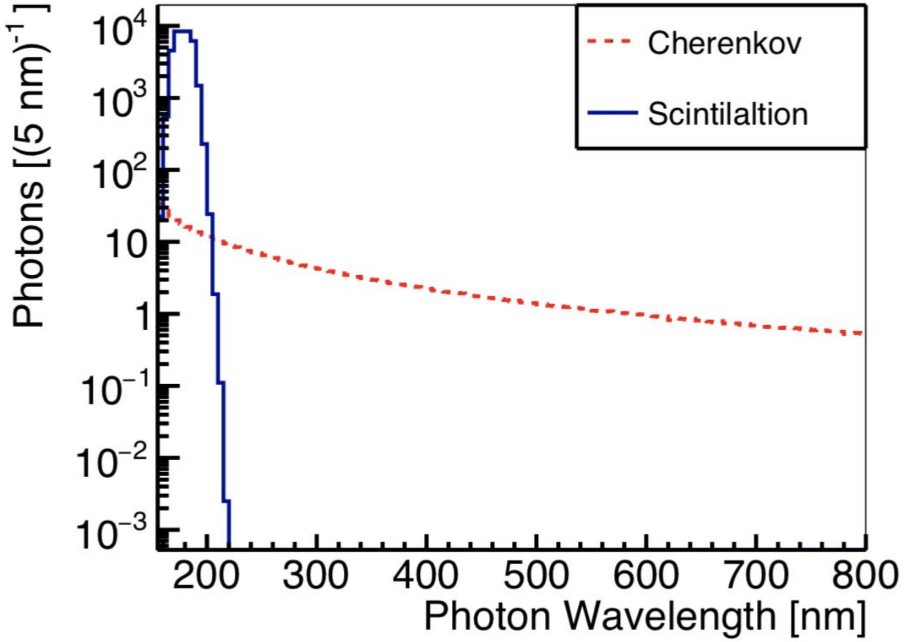
Jason Philip Brodsky[a], Samuele Sangiorgio[a], Michael Heffner[a], Tyana Stiegler[a]

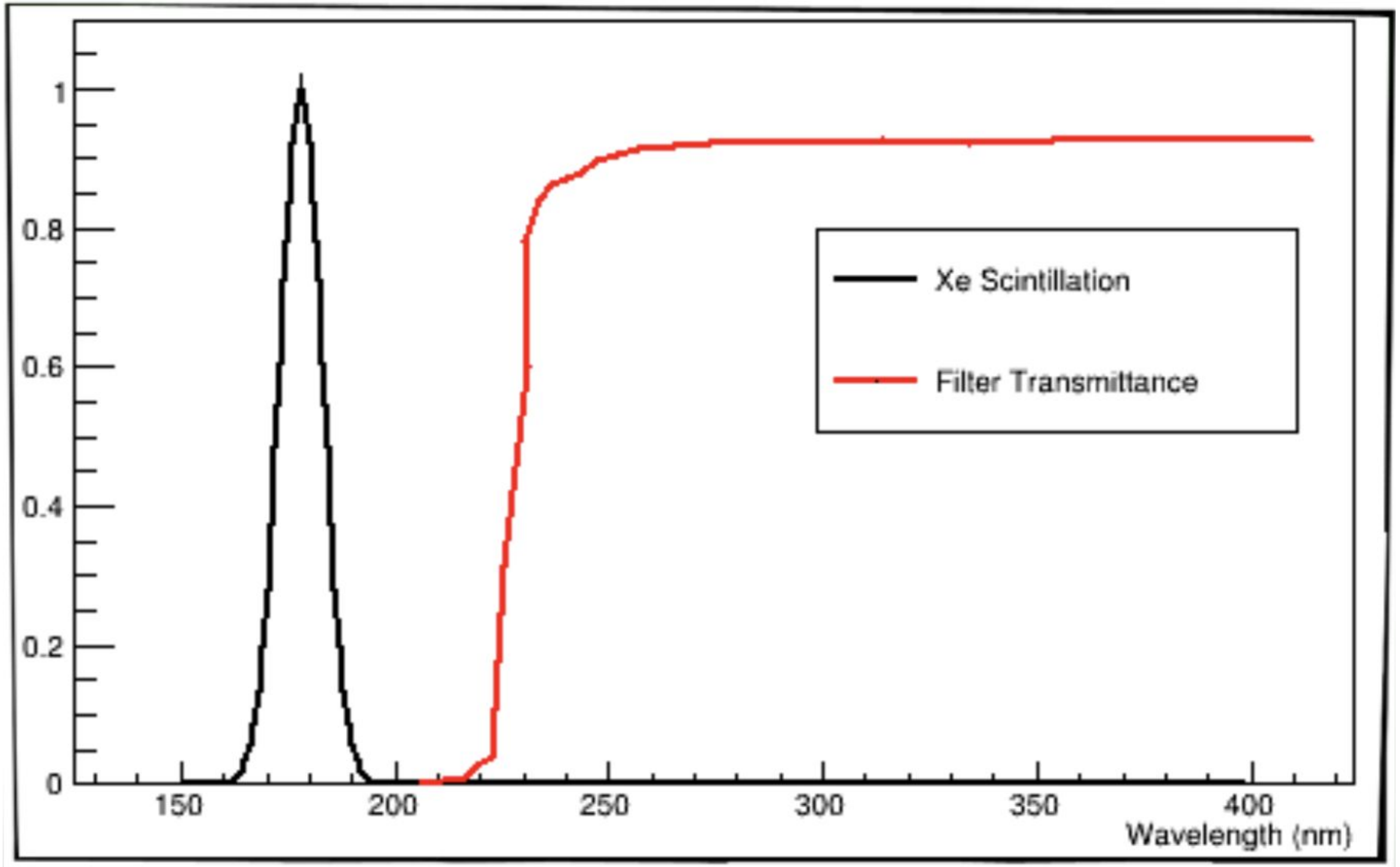
[a]*Lawrence Livermore National Laboratory*




| Case | Description | Sensitivity improvement |
|---|---|---|
| 1 | Baseline | 1.43 |
| 2 | Compton Scatters included | 1.11 |
| 3 | Perfect background rejection | 7.61 |
| 4 | Back-to-back evenly-split $0\nu\beta\beta$ | 1.96 |
| 5 | Back-to-back, even split $0\nu\beta\beta$ and straighter tracks | 5.53 |
| 6 | Truth-value Cherenkov ID | 1.40 |
| 7 | 100% detection efficiency | 1.59 |
| 8 | 10% detection efficiency | 1.20 |
| 9 | No directional information | 1.34 |

# Backup: Filter data




Transmittance spectrum of lowpass optical filters,
Covering 22/24 SiPMs

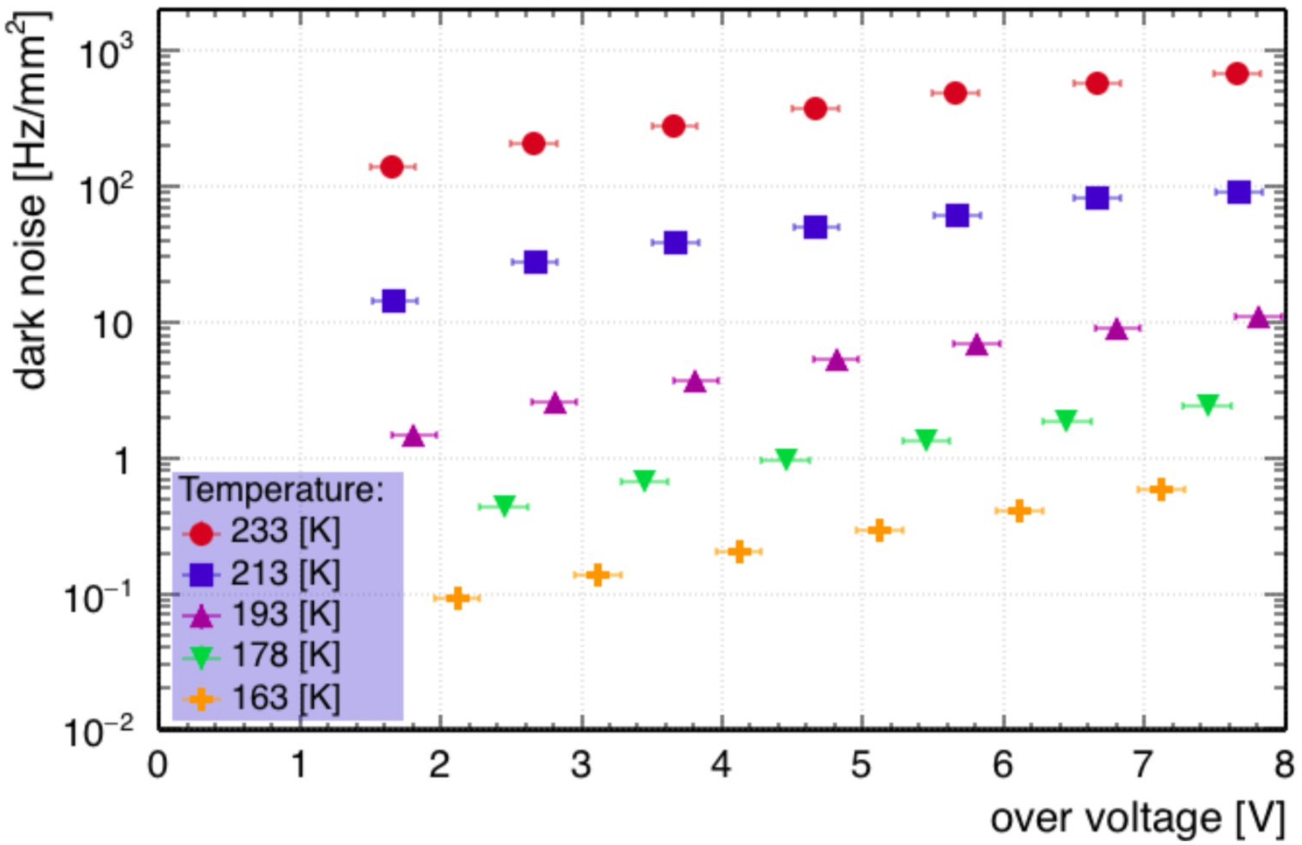
# Silicon Photomultipliers (SiPM)

Challenges for detectors

**Dark noise**

thermally excited electrons initiate

avalanche: false 1 photon signal




Dark noise results from latest VUV4 paper: **arXiv:1903.03663**

# Silicon Photomultipliers (SiPM)



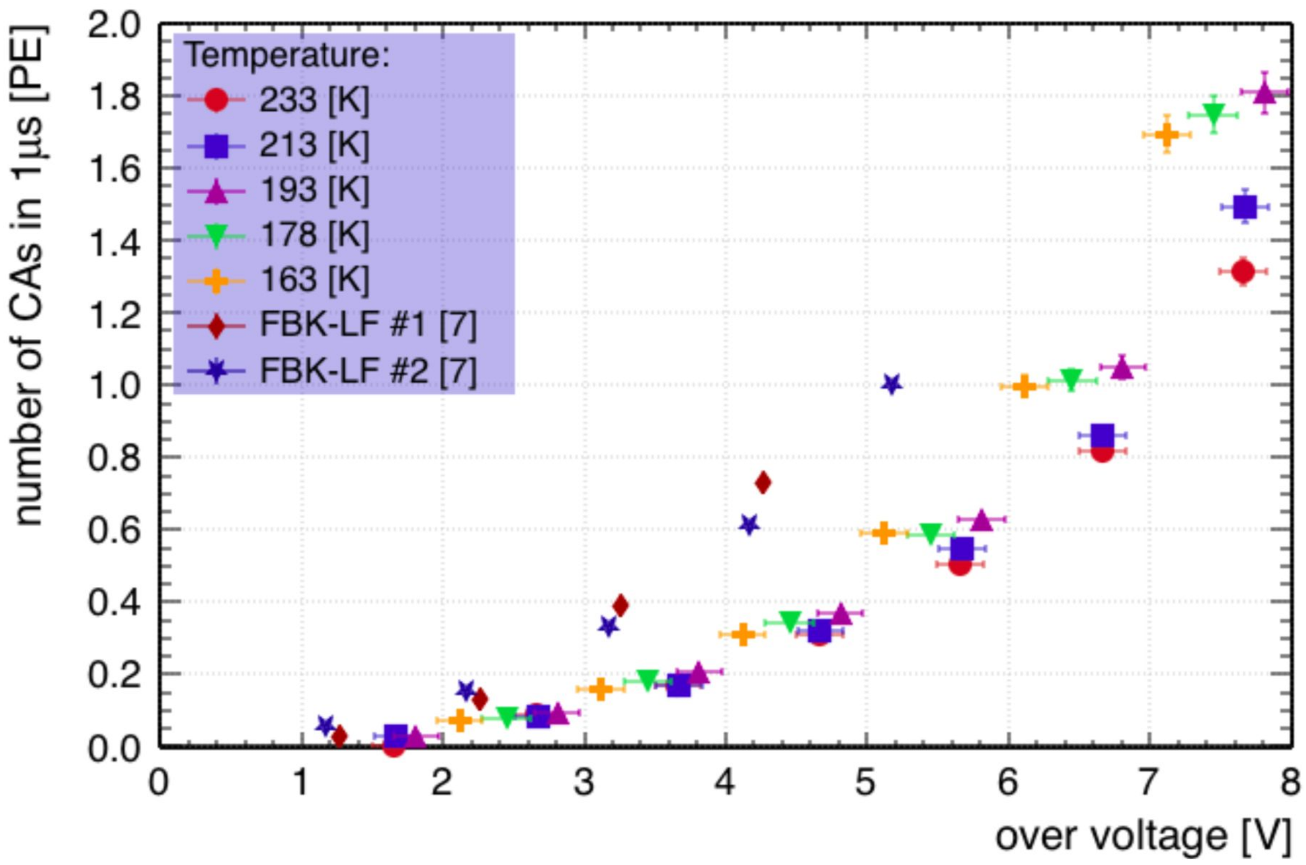
Challenges for detectors

**Cross talk**

one avalanche creates photons which triggers another pixel (1 photon → 2 )

**After pulsing**

Initially trapped charge carriers cause second avalanche after time delay




After pulsing and crosstalk results from latest VUV4 paper: **arXiv:1903.03663**