

# Barrel Imaging Calorimeter SiPM Simulations

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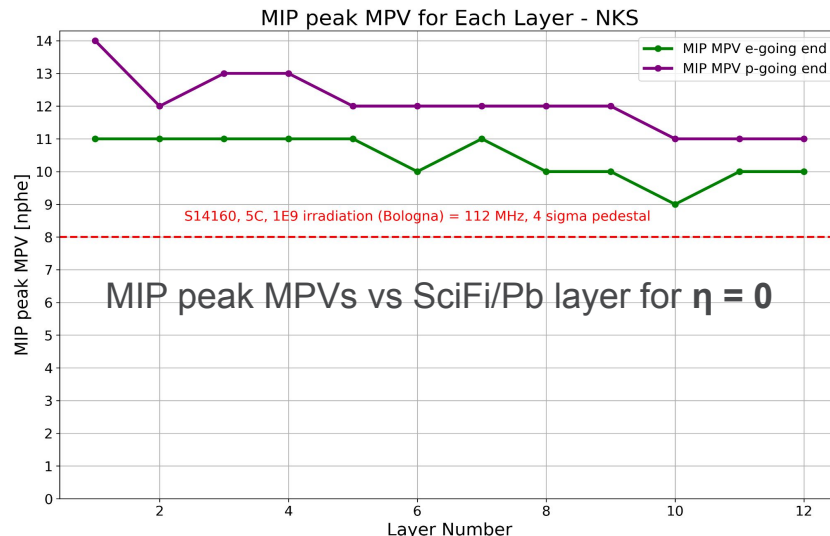
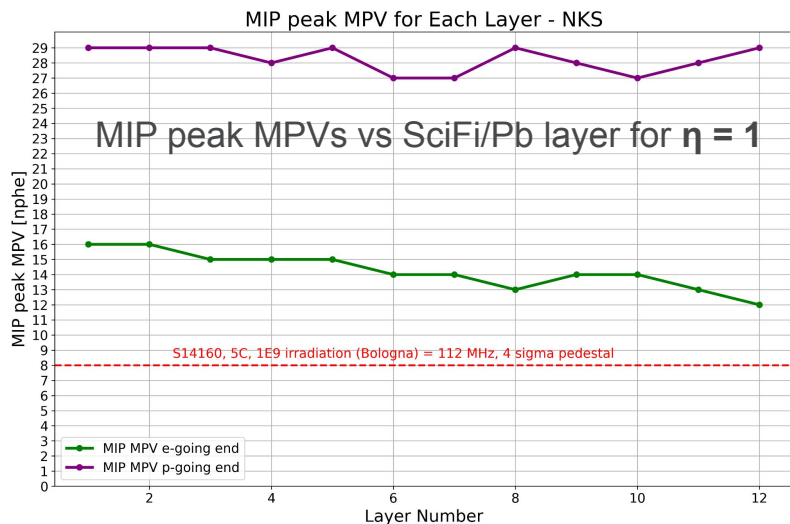


# Radiation doses

	Forward SiPMs (+z)	Backward SiPMs (-z)
Dose from physics/1 fb <sup>-1</sup>	$< 2 \times 10^7 / \text{cm}^2$	$< 5 \times 10^6 / \text{cm}^2$
Dose from hadron beam/1 fb <sup>-1</sup>	$< 3 \times 10^6 / \text{cm}^2$	$< 5 \times 10^6 / \text{cm}^2$
<b>Sum for 1 fb<sup>-1</sup></b>	<b><math>2.3 \times 10^7 / \text{cm}^2</math></b>	<b><math>1 \times 10^7 / \text{cm}^2</math></b>
<b>Sum for 100 fb<sup>-1</sup></b>	<b><math>2.3 \times 10^9 / \text{cm}^2</math></b>	<b><math>1 \times 10^9 / \text{cm}^2</math></b>
<b>Sum for 140 fb<sup>-1</sup></b>	<b><math>3.2 \times 10^9 / \text{cm}^2</math></b>	<b><math>1.4 \times 10^9 / \text{cm}^2</math></b>

Based on: [https://wiki.bnl.gov/EPIC/index.php?title=Radiation\\_Doses](https://wiki.bnl.gov/EPIC/index.php?title=Radiation_Doses)

# Readout threshold in pixels - MIPs



- Threshold determined by desire to see MIP peak for calibration
- MIP response simulated with 5 GeV muons at different eta

eta	nphe (p-going)	nphe (e-going)
0	11-14	9-11
1	27-29	12-16

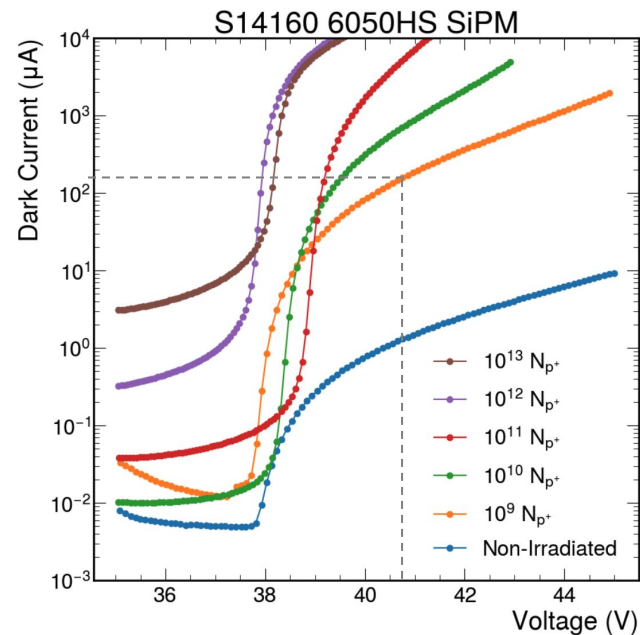
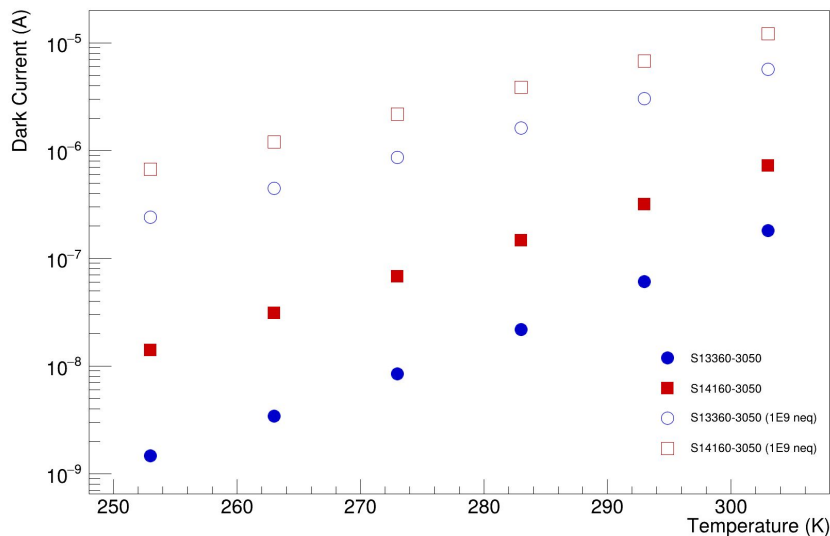
# Expected dark current levels

**INFN Bologna Irradiations:** ~5 microamps for 3x3 mm at 1E9 neq at room temp

**For 1.2 x 1.2 cm ~ 112.97 MHz of DCR for BIC at 5C (4x4 array)**

**UC Davis Irradiations:** ~100 microamps for 6x6 mm at 1E9 p+ at room temp, 1E10 factor 5-ish higher.

**For 1.2 x 1.2 cm ~350 MHz of DCR for 1E9, 1.2 GHz for 1E10 neq dose, scaling to 5C & factor 1.5 difference in damage for p dose vs. 1 MeV neutrons**



# Expected dark current levels

**UC Davis Irradiations:** ~100 microamps for 6x6 mm at 1E9 p+ at room temp, 1E10 factor 5-ish higher.  
**For 1.2 x 1.2 cm ~350 MHz of DCR** for 1E9, 1.2 GHz for 1E10 neq dose, scaling to 5C & factor 1.5  
difference in damage for p dose vs. 1 MeV neutrons

Vop (V)	Current (A)	Sample
41	1.564694E-04	6050A09.UTC_20240827__17_49
41	7.224781E-05	6050B9.UTC_20240827__21_03
41	7.526675E-05	6050C9.UTC_20240827__21_54
41	7.256339E-05	6050D9.UTC_20240827__22_35

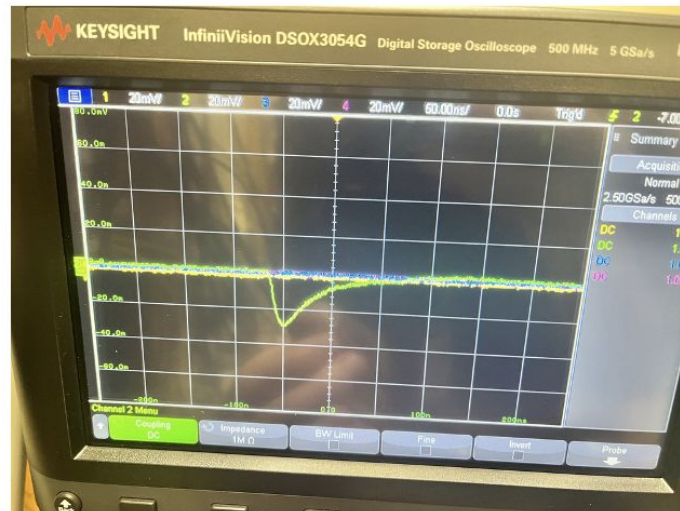
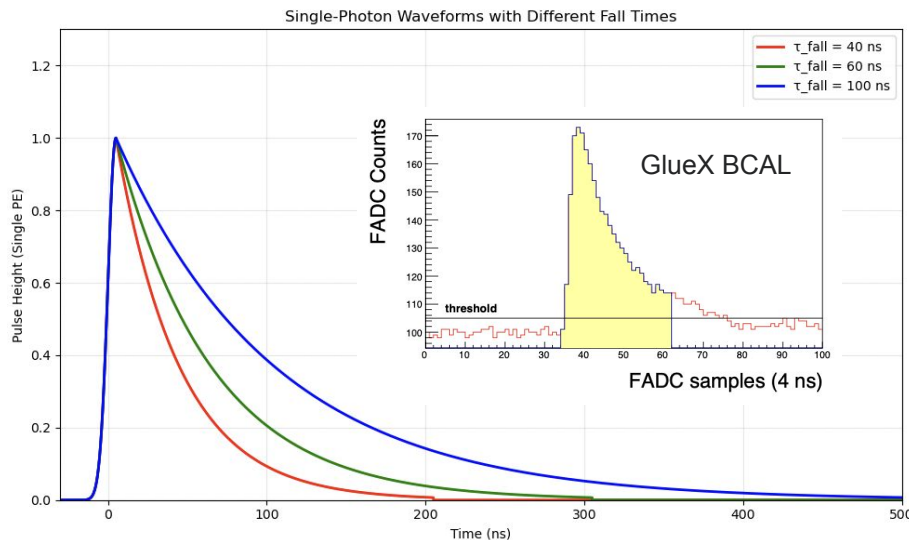
We took this number,  
and it gives us ~350  
MHz DCR

These 3 results  
more similar to  
INFN Bologna

# Noise simulations

# SiPM Signal Template - GlueX Template

Based on GlueX BCAL (Baby BCAL) SiPM template

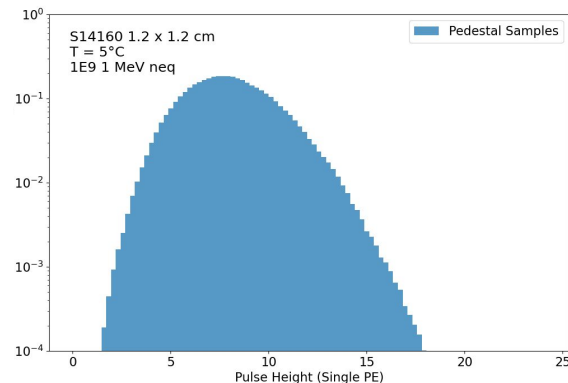
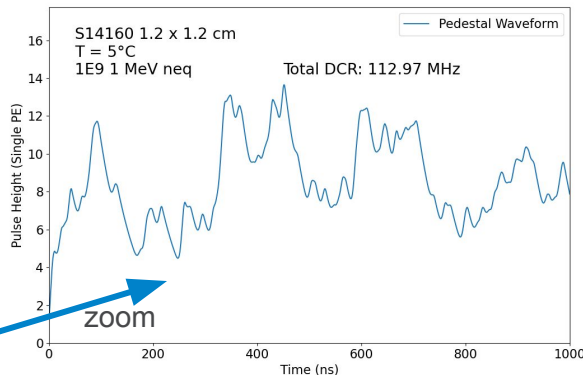
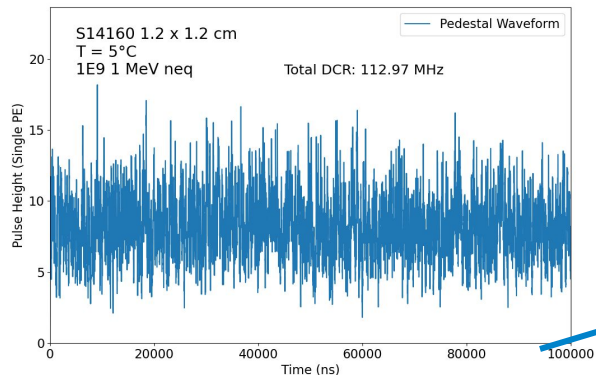


- Green template taken for the studies for an optimal scenario.
- Examples of HGCROC extracted templated (unshaped) in the backup.

# Readout threshold and rates

## SiPM GlueX Template with 112.97 MHz DCR

S14160 SiPMs at 5 °C irradiated 1e+09 1-MeV neutron equivalent dose (Bologna)



DCR (MHz)	Noise Sigma	Rate at $3\sigma$ (6.3 phe)	Rate at $4\sigma$ (8.4 phe)
112.97	2.1 phe	152.5 KHz	3.58 kHz

From **CALOROC** interfaces:

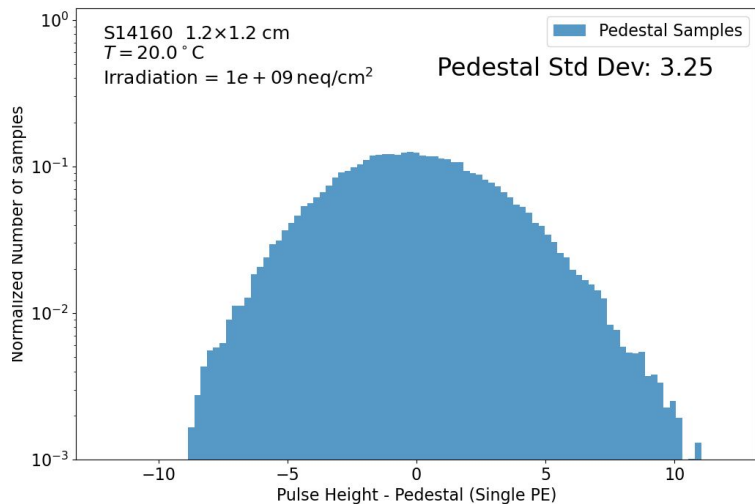
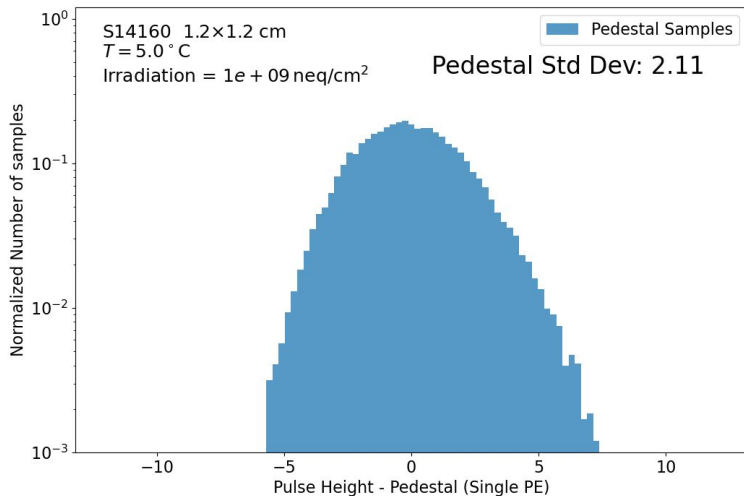
Max readout per channel with 7 samples:  
~50kHz

Max rate for SciFi/Pb channel (DIS + bckg):  
26 kHz

# Cooling of SiPMs

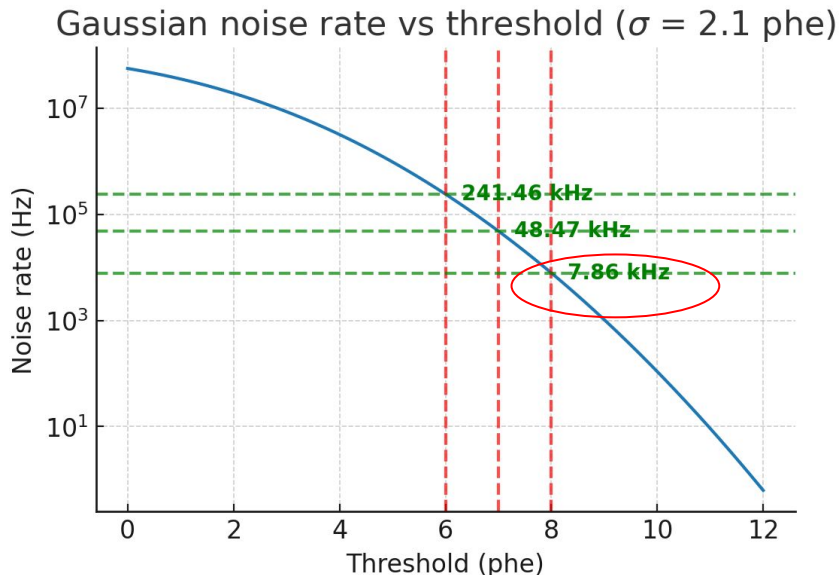
## SiPM noise is a strong function of temperature

- Factor of 2 difference in dark count rate between 5°C and 20°C
- For BIC SiPMs at 1E9 1 MeV neq dose (~1 year at max. luminosity):
  - Pedestal  $\sigma$  of **2.1 p.e. @ 5°C** vs. **3.3 p.e. @ 20°C**
- For the worst-case 9 p.e. MIP, **noise rate is too high at 20°C to readout MIPs** after a few years of running
- Operating temperature chosen to **enable MIP calibration** well into EIC



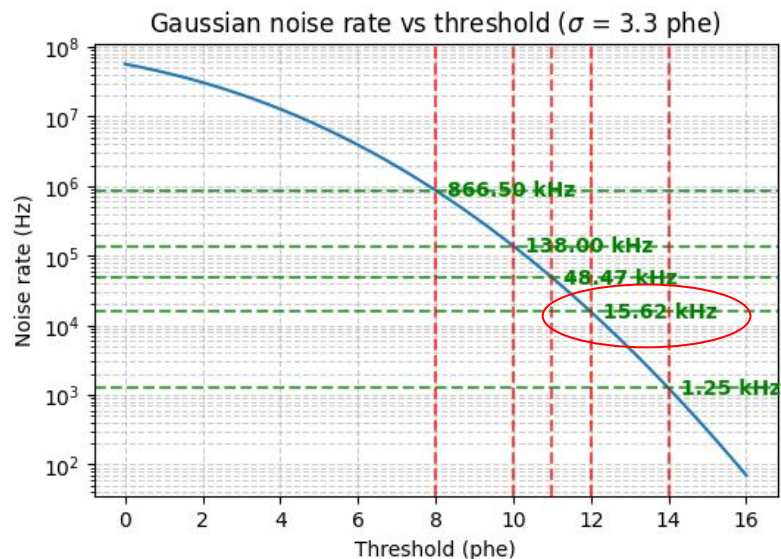
# Readout threshold and rates - GlueX template

## SiPM GlueX Template with 112.97 MHz and 270 MHz DCR



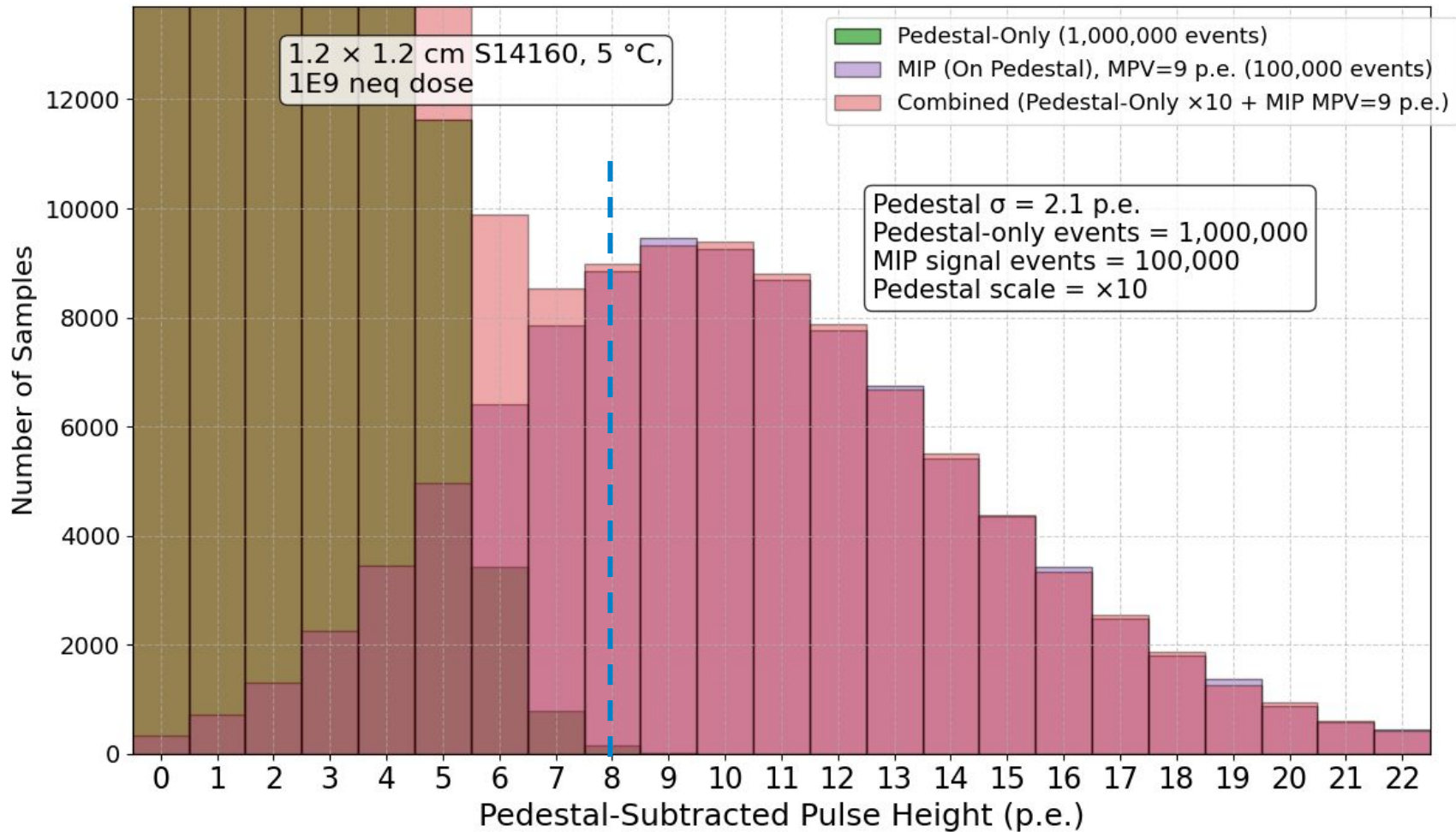
**112.97 MHz (5 deg)**

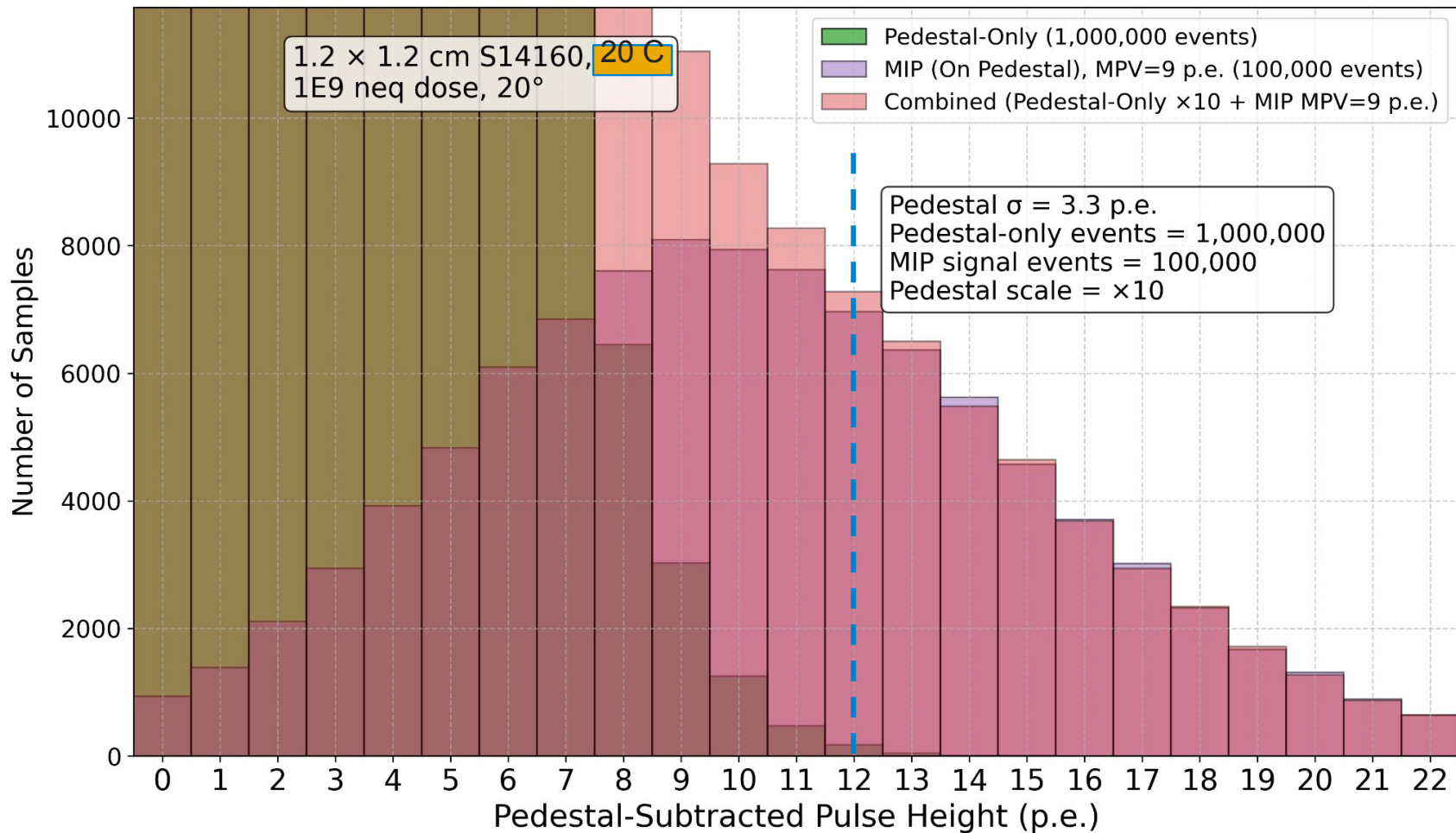
We could place the threshold at 8 phe



**280 MHz (20 deg)**

We could place the threshold at 12 phe

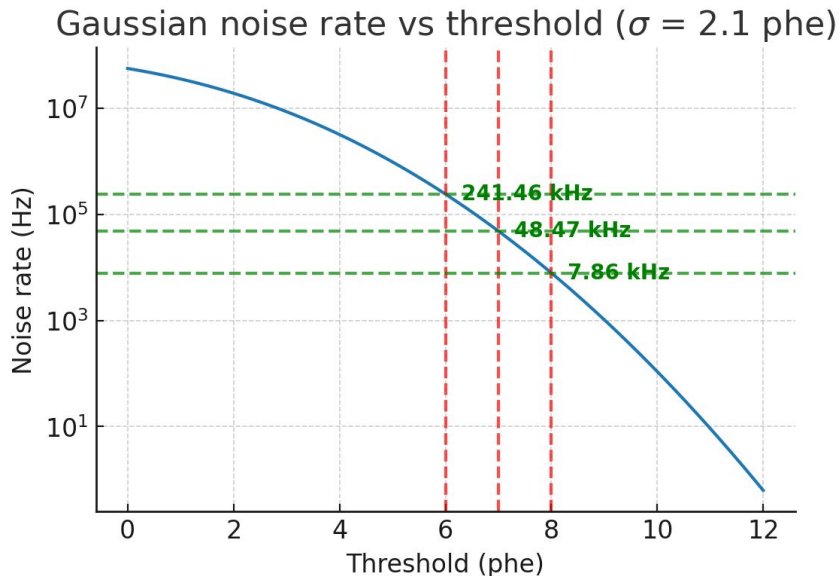




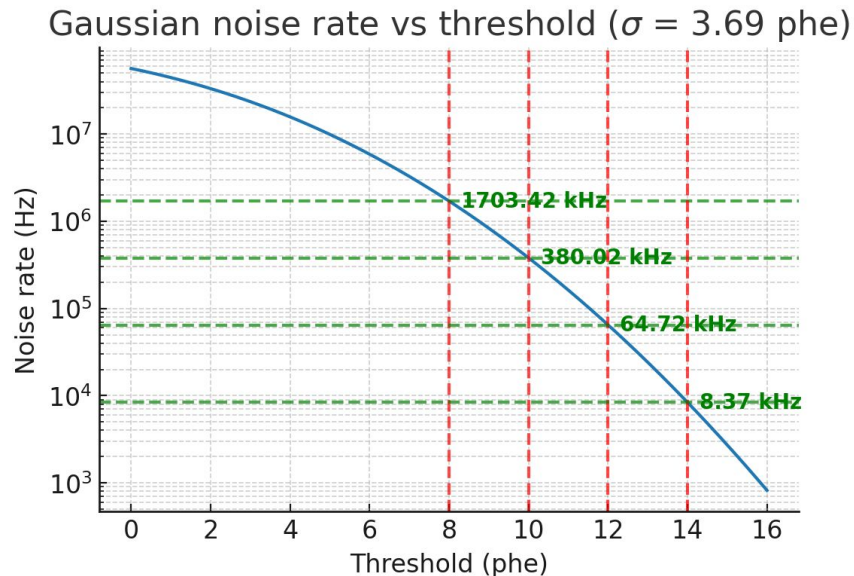
# Backup

# Readout threshold and rates - GlueX template

SiPM GlueX Template with 112.97 MHz and 350 MHz DCR



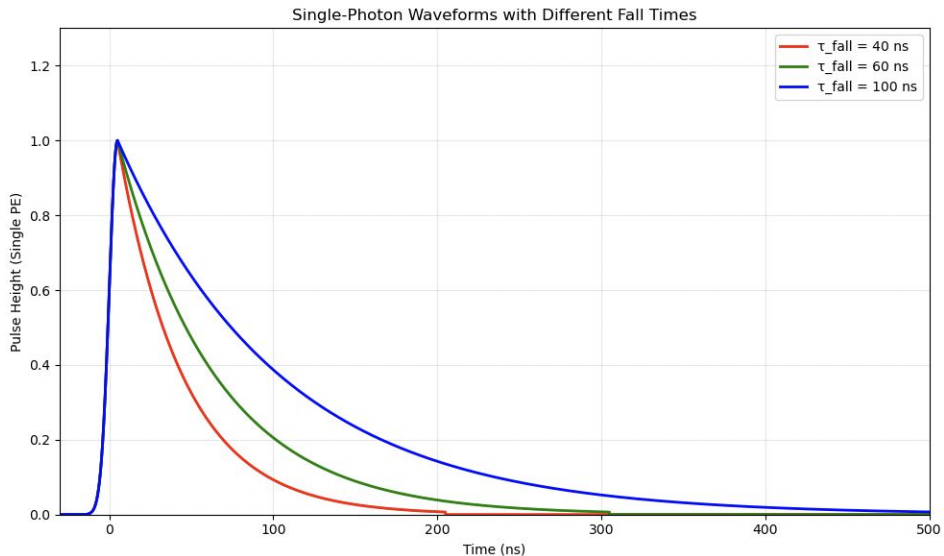
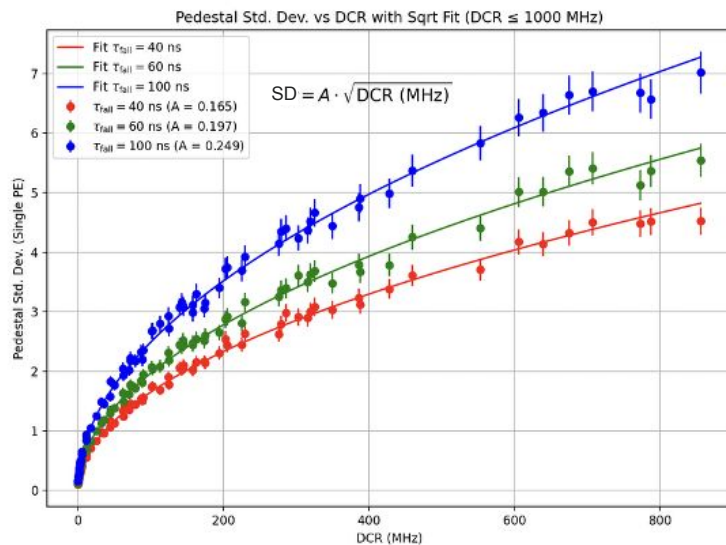
**112.97 MHz**



**350 MHz**

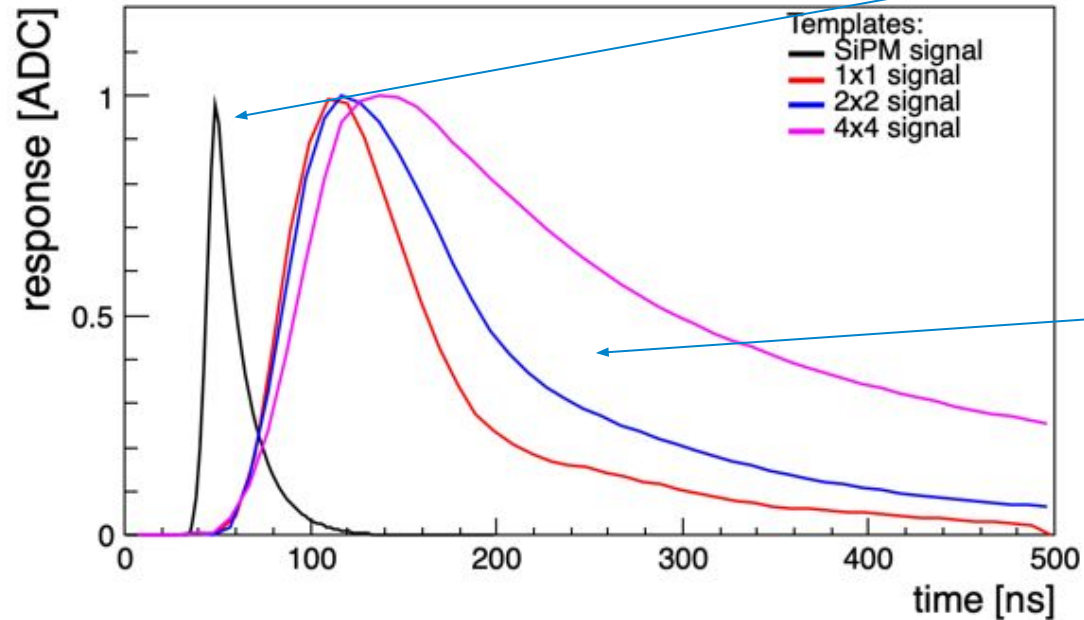
# Sigma pedestal vs DCR for GlueX template

Below the analytical formula on dependence between the noise Std. Dev. vs DCR has been extracted for different tail sizes in the GlueX template



For the nominal GlueX template:  $\sigma$  of pedestal =  $0.197 \cdot \sqrt{\text{DCR in MHz}}$

# SiPM Signal Template - HGCRROC Template

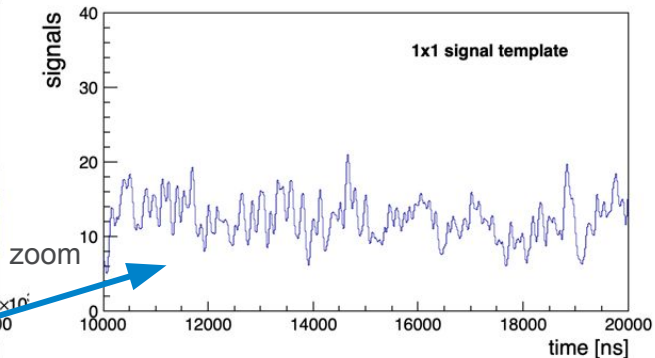
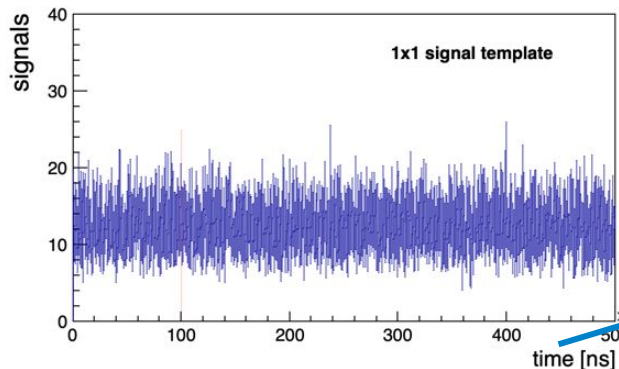
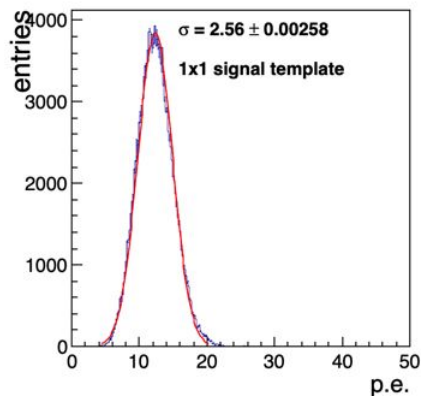


SiPM signal template tested by Norbert in his last presentation

Compared with the “HGCRROC” templates, however, we know that this is a non optimal summing scheme for us.

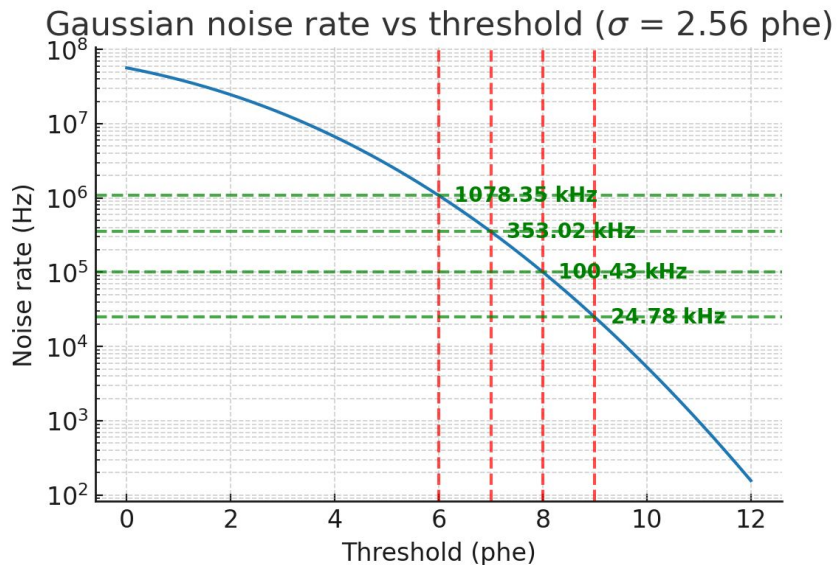
# Readout threshold and rates - 1x1 template

## 1x1 Template with 112.97 MHz DCR

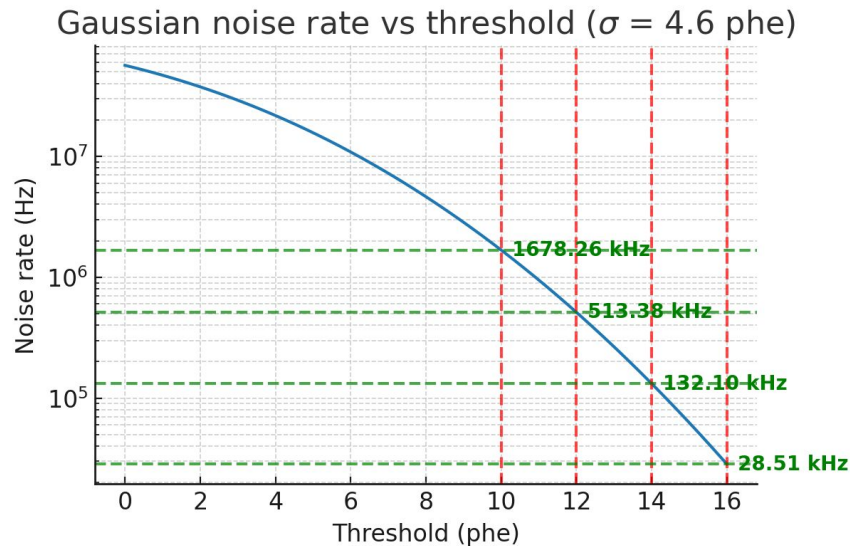


DCR (MHz)	Noise Sigma	Rate at $3\sigma$ (7.7 phe)	Rate at $3.5\sigma$ (9 phe)	Rate at $4\sigma$ (10.2 phe)
112.97	2.56 phe	152.5 kHz	26.3 kHz	3.58 kHz

# Readout threshold and rates - 1x1 template



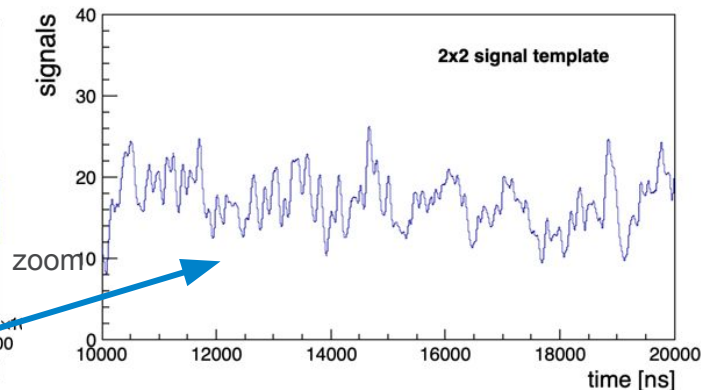
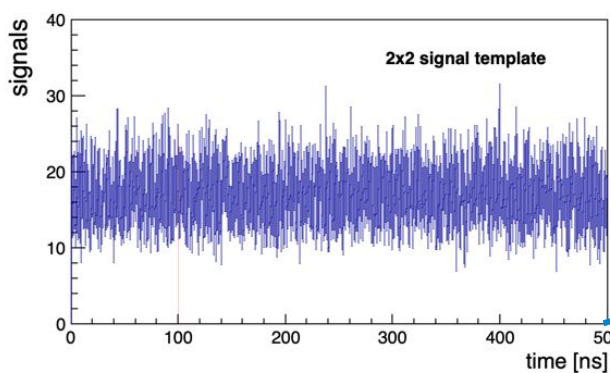
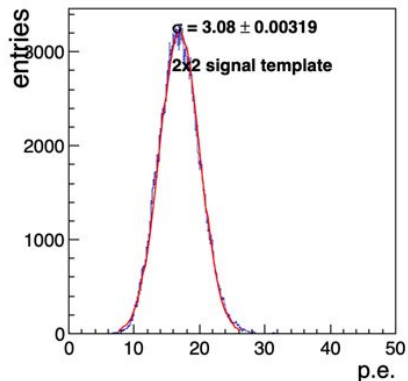
**112.97 MHz**  
threshold = 9 phe



**350 MHz**  
threshold = 16 phe

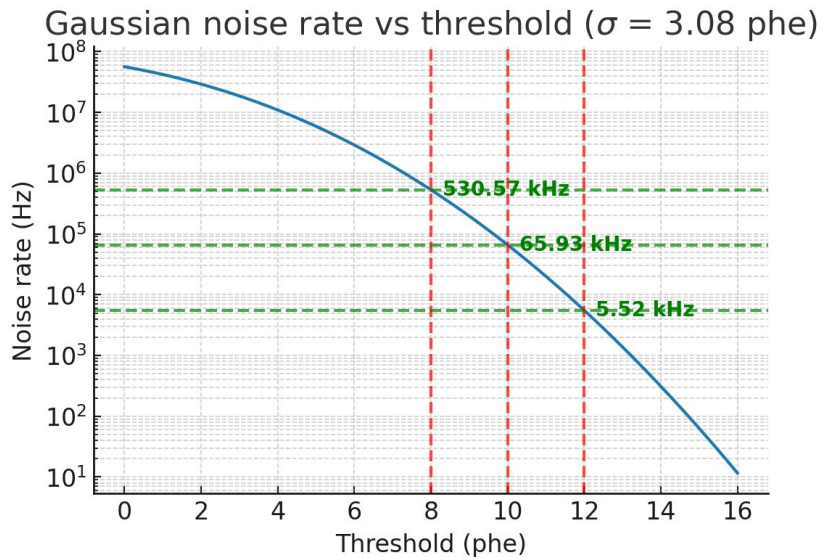
# Readout threshold and rates - 2x2 template

## 2x2 Template with 112.97 MHz DCR

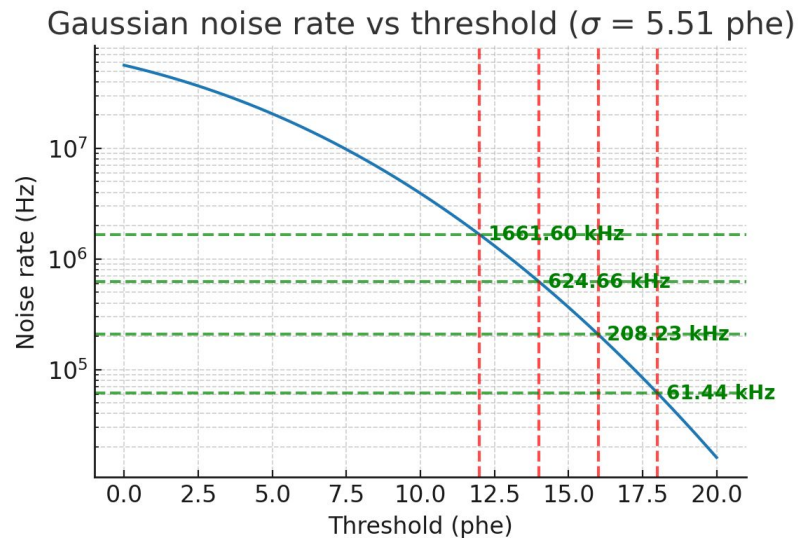


DCR (MHz)	Noise Sigma	Rate at $3\sigma$ (9.24 phe)	Rate at $3.5\sigma$ (10.78 phe)	Rate at $4\sigma$ (12.32 phe)
112.97	3.08 phe	152.5 kHz	26.3 kHz	3.58 kHz

# Readout threshold and rates - 2x2 template



**112.97 MHz**



**350 MHz**

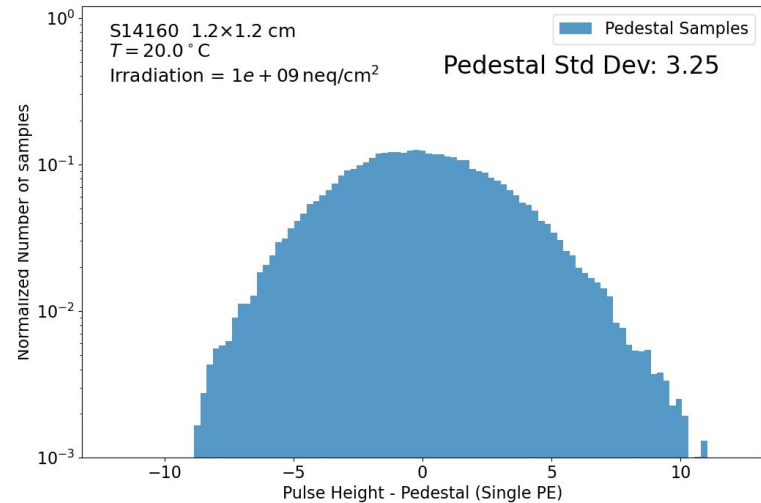
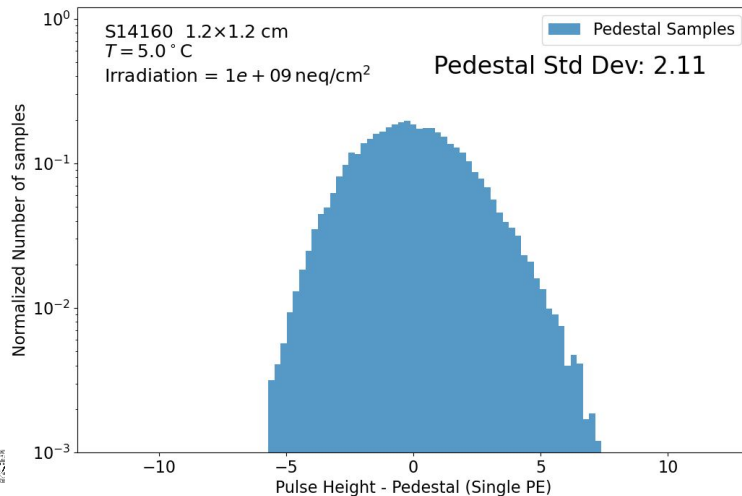
MIP signal

# Motivation of the Cooling System

## SiPM noise and gain are a strong function of temperature!

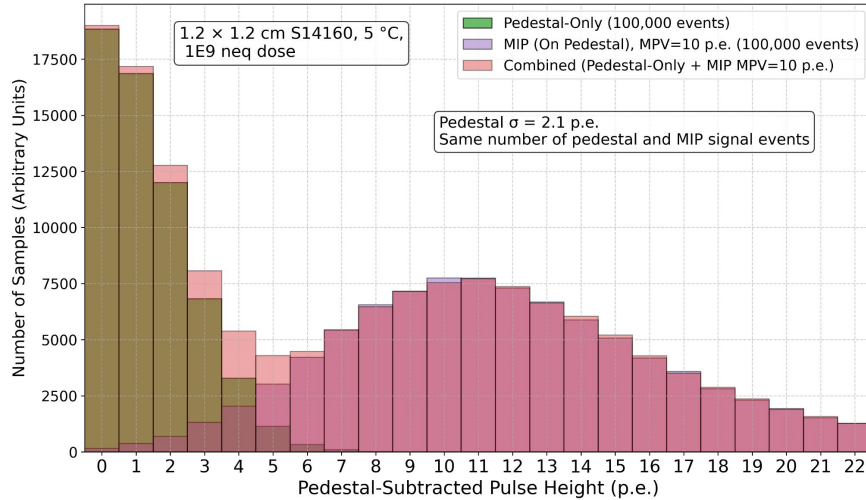
- Required temperature stability of  $7^{\circ}\text{C} \pm 1^{\circ}\text{C}$ , based on GlueX experience, to control both DCR (MIP detection) and gain (energy resolution).
- Passive Bias Temperature Compensation (GlueX: 0.1 V bin SiPMs using Hamamatsu  $V_{op}$  data, jump-trim resistors) provides  $\sim 34 \text{ mV}/^{\circ}\text{C}$  correction to maintain SiPM gain within 5%

\*Operations in GlueX at  $7^{\circ}\text{C}$  for S10931-050 SiPMs

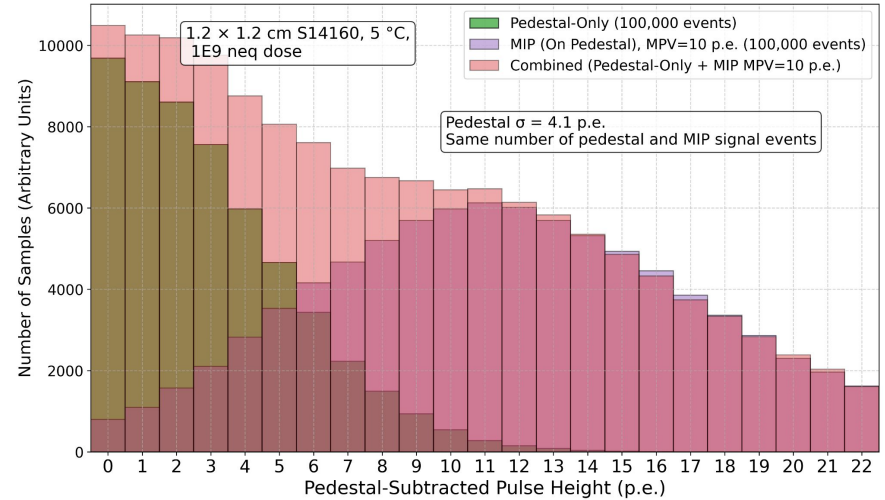


# Readout threshold in pixels - MIPs

## GlueX template



## 4x4 template



Note: same number of pedestal and signal events assumed for illustration, 112.97 MHz DCR

## Conclusions:

1. Simple 4-sigma cut would work for MIPs for initial years, but with higher irradiations coincidence condition most likely would need to be explored
2. Summing signal and shaping will play important role for BIC. Simple summing will most probably not work.

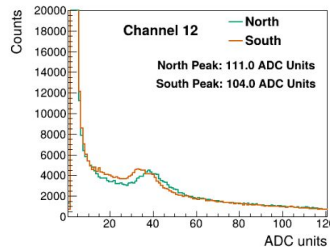
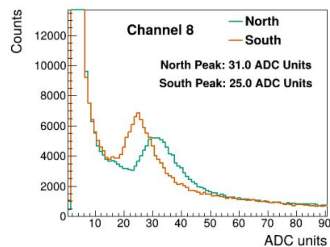
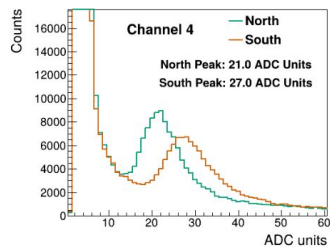
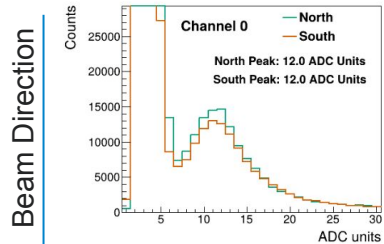
# Power of Topology

Single-channel ADC amplitudes from Baby BCal test beam

Four longitudinal readout channels

Beam was combined muons + pions

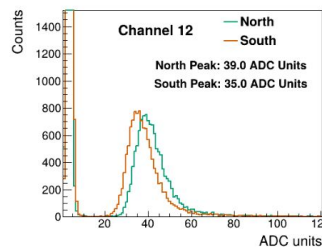
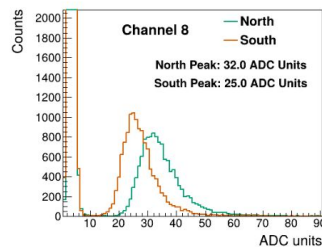
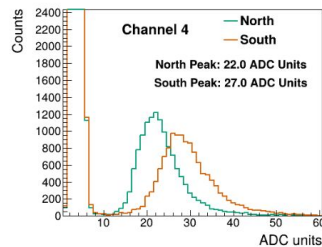
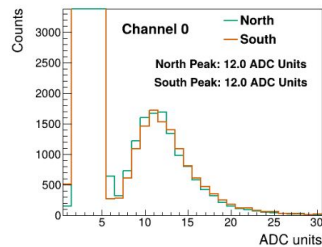
Some MIP peaks not so well resolved above pedestal + sides of showers



Impose requirement on event topology, MIPs leave hits in only straight lines!

Cleans up peaks significantly

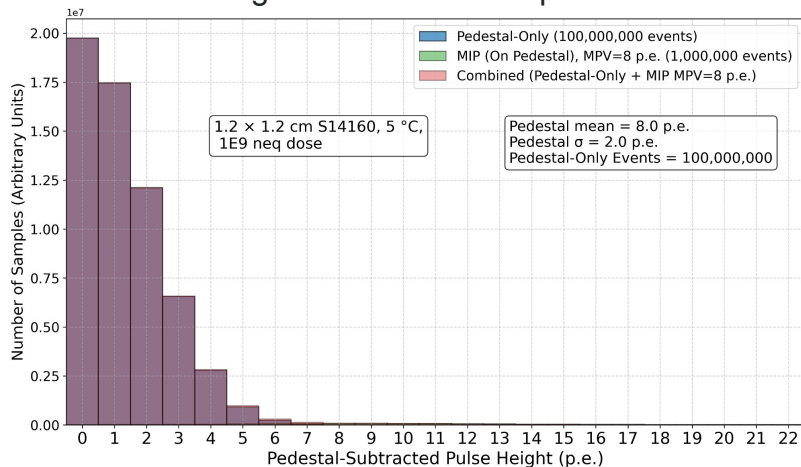
Probability of an upward pedestal fluctuation in a single channel can be large, but fluctuations in multiple channels becomes rare!



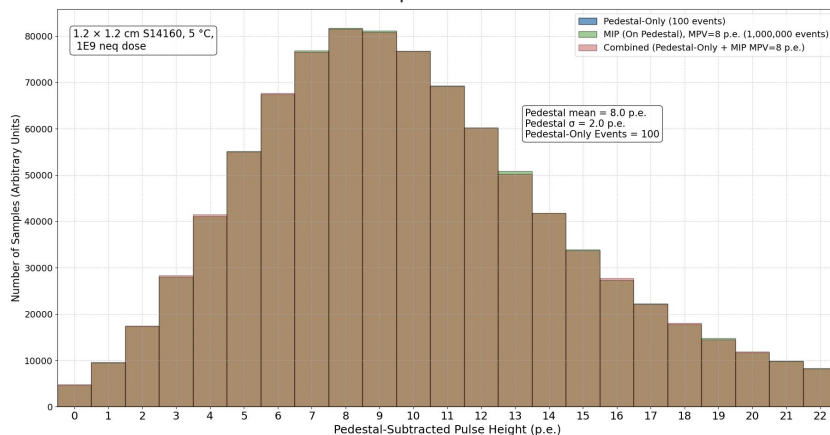
# Power of Topology

In BIC where a MIP should fire all 12 longitudinal channels, a threshold of even just 0.5 sigma of the pedestal corresponds to a  $\sim 1e6$  suppression of noise events

Raw pedestal + MIP for a single channel assuming no coincidence requirement



Pedestal + MIP for a single channel assuming 12-fold coincidence  $> 0.5\sigma_{ped.}$  requirement



A reasonable event selection (which can be done offline) that leverages the longitudinal segmentation dramatically enhances our ability to use the MIP peak for calibration!

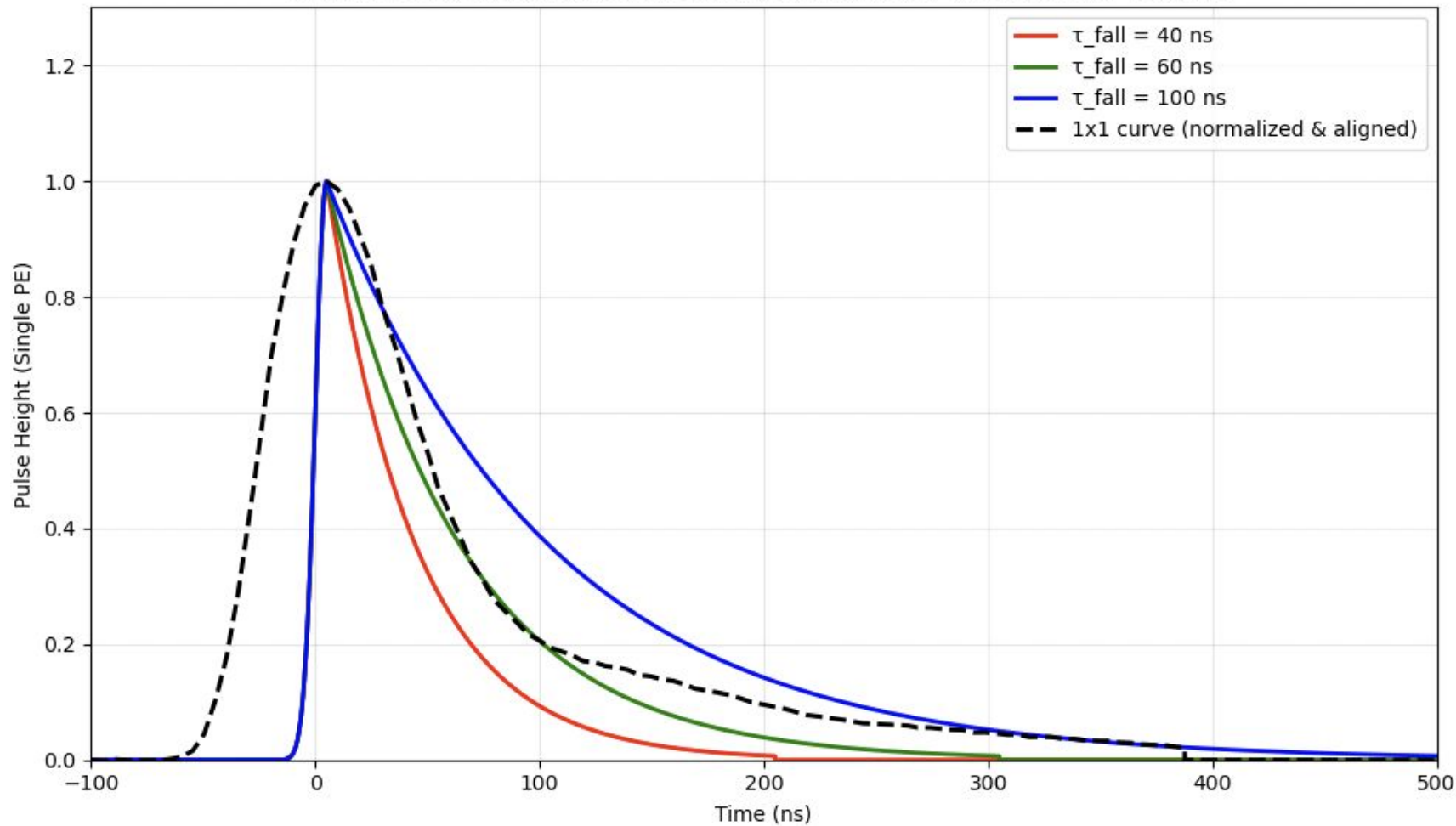
Higher pedestal sigma increases width of MIP peak but doesn't "occlude" it (at the cost of needing to read out more data). Dedicated MIP runs with lower thresholds?

# Some conclusions

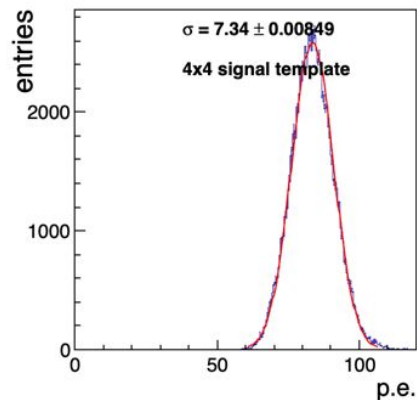
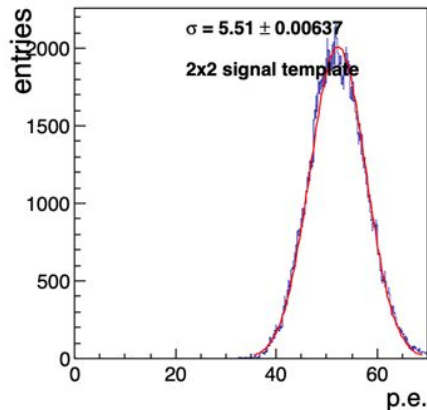
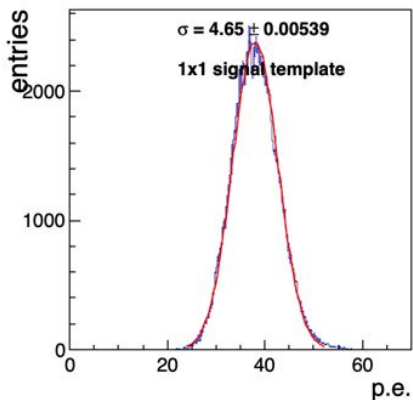
1. Summing SiPM signals and shaping will play important role for BIC. Simple summing as in the currently tested templates will most probably not work.
  - a. Noise sigma strongly depend on the template shape/length
2. Simple 4-sigma cut would work for initial years for MIPs, but with higher irradiations coincidence condition would need to be explored
  - a. MIPs are needed for calibrations. Special calibration runs with implemented dead time, lower threshold and e.g. 2 samples could be used.
  - b. Physics runs to run with the nominal threshold cut, 7 samples

Backup

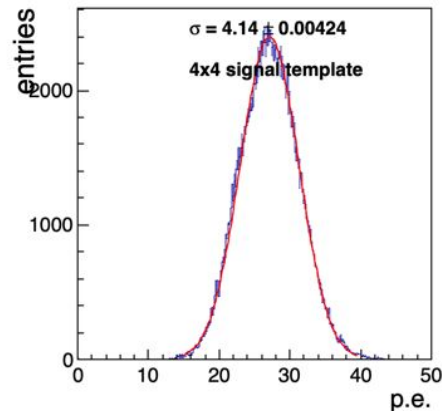
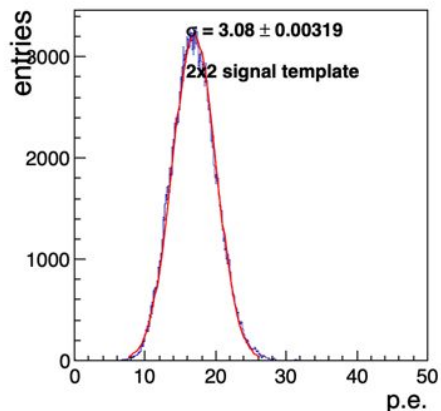
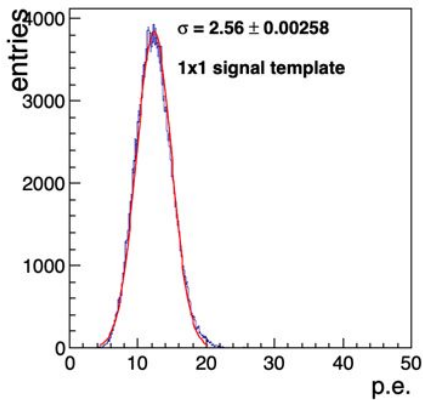
Single-Photon Waveforms with Different Fall Times + HGCROC 1x1 Template



# Noise Pedestal for Simple Templates



350 MHz



112.97 MHz

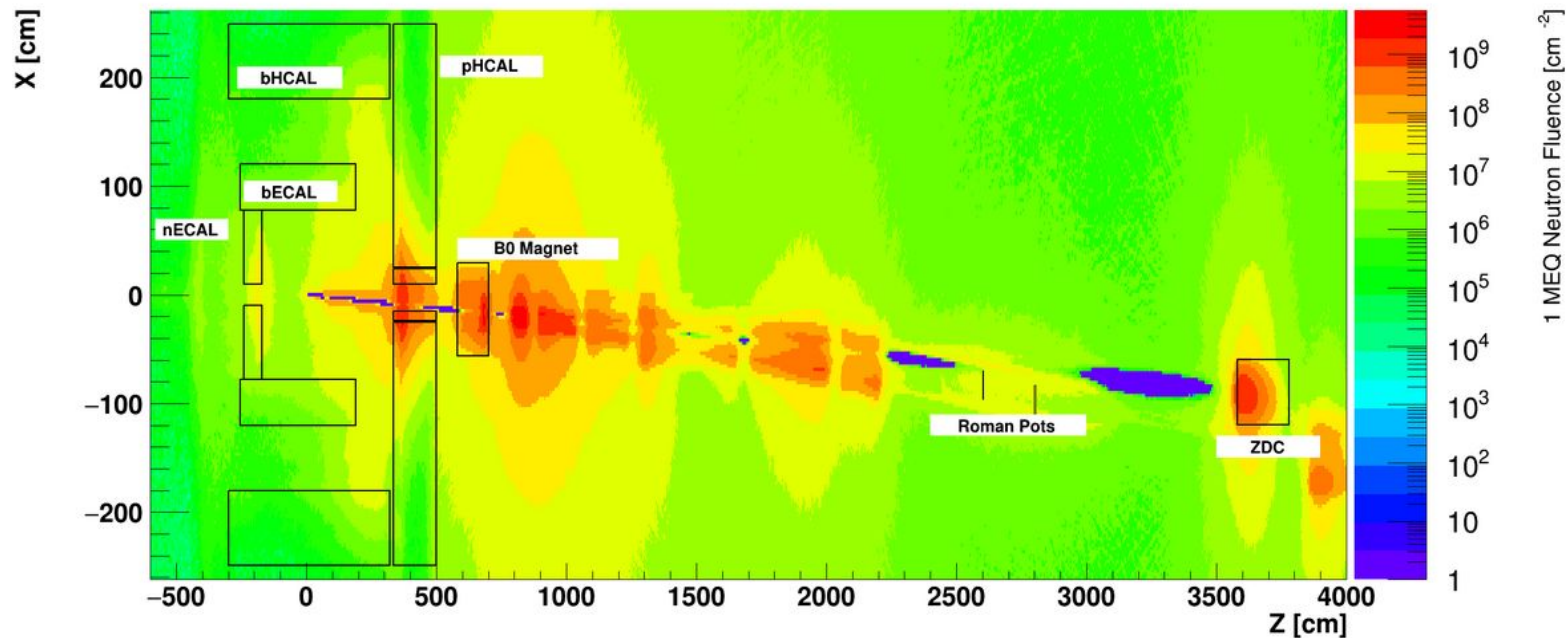
# Charge

1. Expected neutron fluxes for an integrated luminosity of  $100 \text{ fb}^{-1}$
2. Expected dark current levels
3. Light yield (LY) per GeV in pixels
4. Readout threshold in pixels
5. Noise contribution to energy resolution
6. Rates of hits above threshold caused by SiPM noise
7. Planned measurements and/or additional measurements you believe are necessary
8. Potential impact on readout electronics
9. Any other relevant information or concerns

# Radiation doses (results from after the 03/01/25 update)

[https://wiki.bnl.gov/EPIC/index.php?title=Radiation\\_Doses](https://wiki.bnl.gov/EPIC/index.php?title=Radiation_Doses)

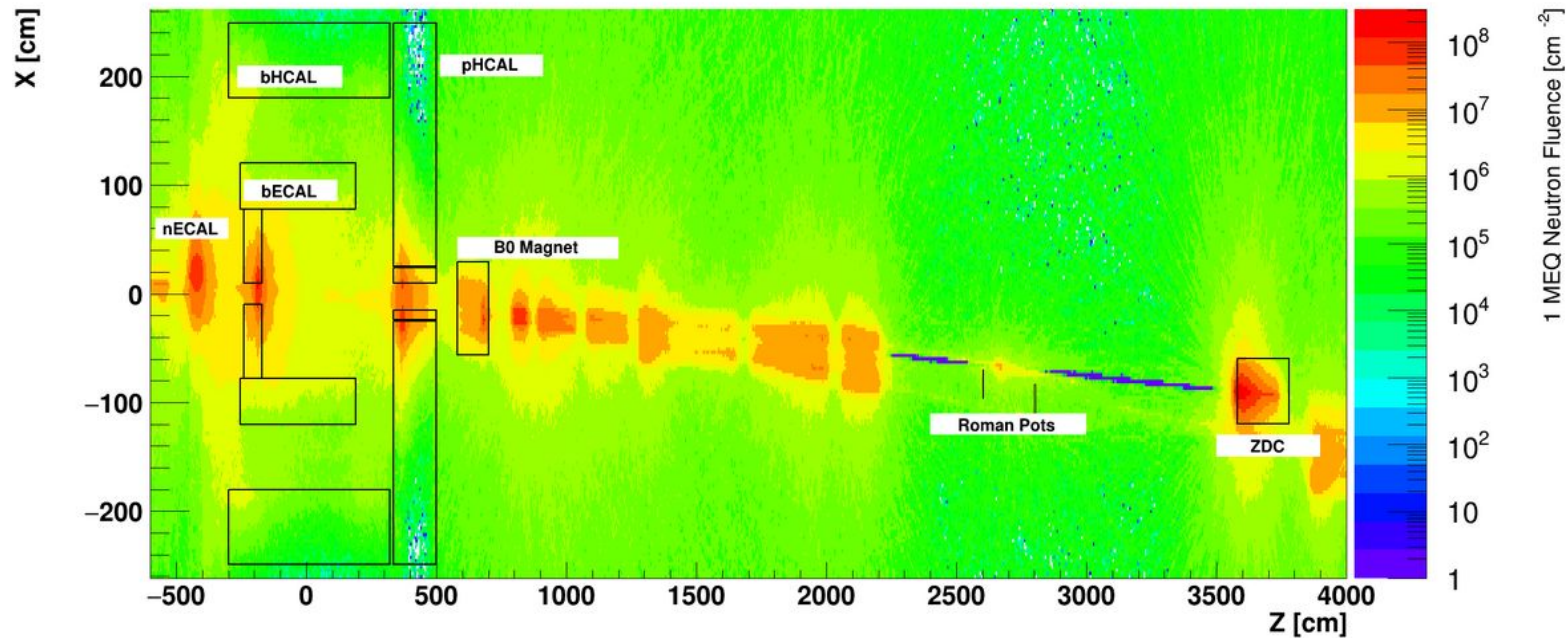
10x275GeV e+p @ 500.0 kHz, 1 fb<sup>-1</sup> min-bias integrated lumi. → -1.50 < y < 1.50 cm (1 bin)



	Forward SiPMs (+z)	Backward SiPMs (-z)
Dose from physics/1 fb <sup>-1</sup>	< 2 x 10 <sup>7</sup> / cm <sup>2</sup>	< 5 x 10 <sup>6</sup> / cm <sup>2</sup>

# Radiation doses (results from after the 03/01/25 update)

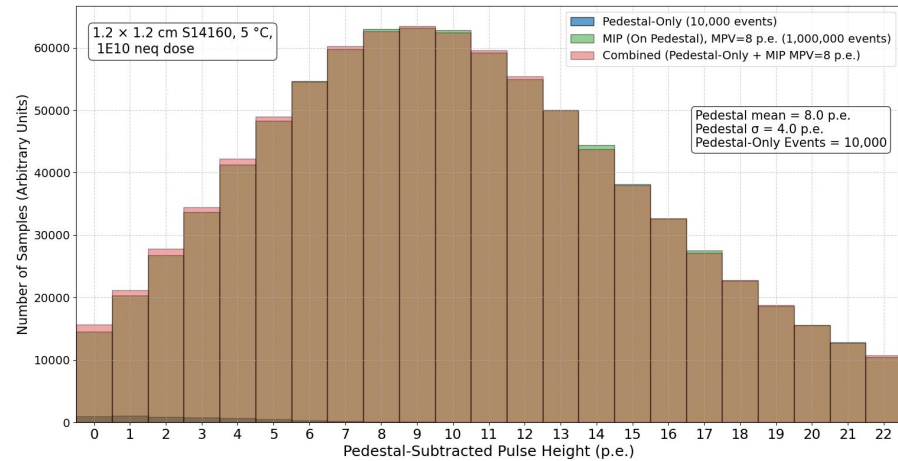
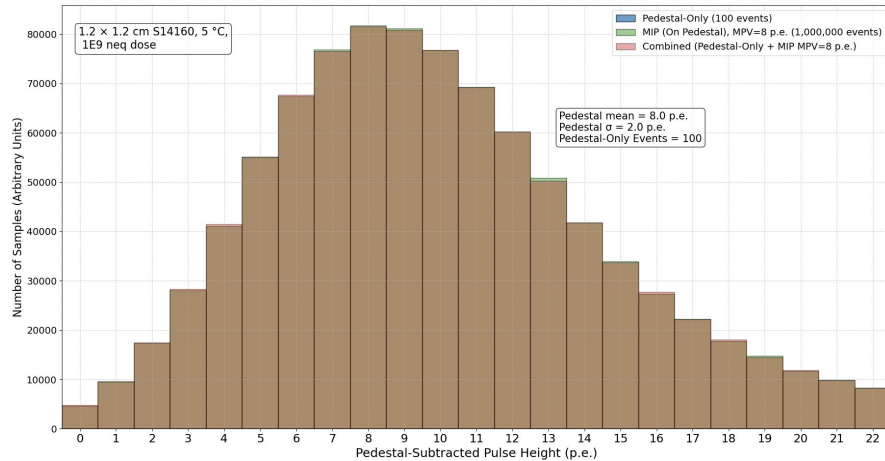
275GeV hadron beam+gas, @ 35.0 kHz,  $1 \text{ fb}^{-1}$  min-bias integrated lumi.  $\rightarrow -1.50 < y < 1.50 \text{ cm}$  (1 bin)



	Forward SiPMs (+z)	Backward SiPMs (-z)
Dose from hadron beam/ $1 \text{ fb}^{-1}$	$< 3 \times 10^6 / \text{cm}^2$	$< 5 \times 10^6 / \text{cm}^2$

# Impact of DCR on MIP peak

Primary effect of higher dark count rate (and larger pedestal sigma) is widening of the MIP peak



# Further Questions

1. Noise contribution to energy resolution:

*We simulated it and the impact is small  $O(\text{few MeV})$ .*

2. Rates of hits above threshold caused by SiPM noise

*Depends on threshold applied and pedestal sigma. Can have dedicated lower threshold runs for MIPs if necessary,*

3. Planned measurements and/or additional measurements you believe are necessary

*All simulations of DCR impact strongly depend on the SiPM analog pulse shape, need to see what shaping is possible with HGCROC*

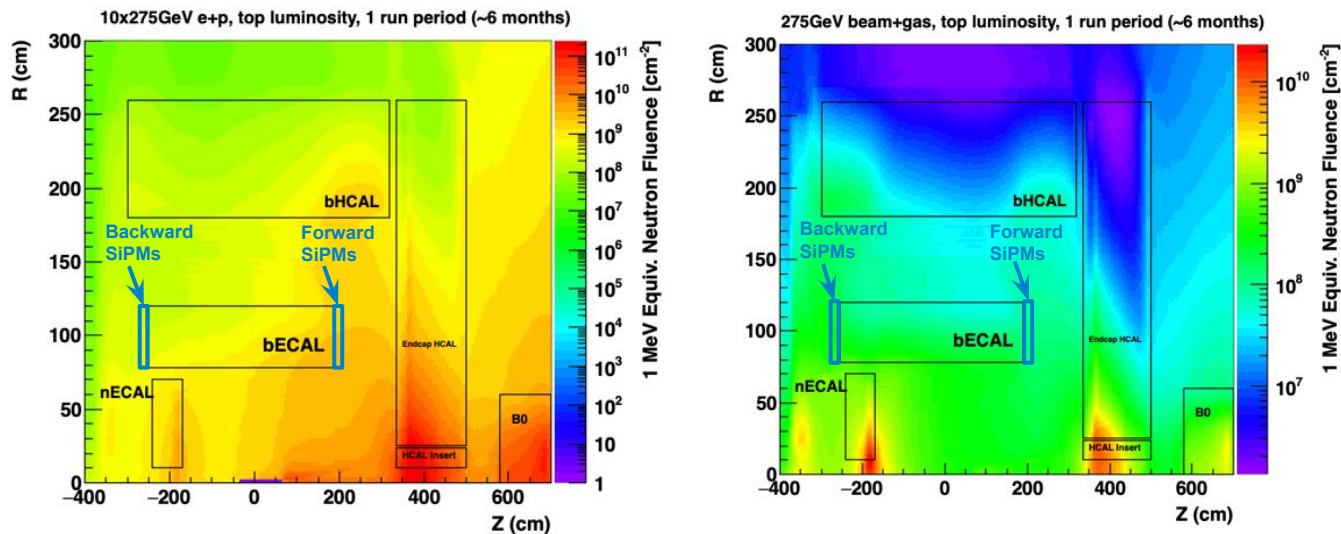
4. Potential impact on readout electronics

**Baseline:** *We treat each channel separately in the DAQ using a threshold cut. Even in the worst case (irradiated sensor, MIP at  $\eta = 0$ ), the MIP is well-separated*

**Mitigation:** *We can lower readout thresholds if desired (enough headroom in ASIC) and apply simple coincidence logic for zero suppression (e.g. in the DAM module)*

# Radiation doses (results from before 03/01/25 update)

[https://wiki.bnl.gov/EPIC/index.php?title=Radiation\\_Doses](https://wiki.bnl.gov/EPIC/index.php?title=Radiation_Doses)



← 1 MeV equivalent neutron fluence at 10x275 GeV @ top machine luminosity for 6 months of running at 100% machine and detector efficiency.

	Forward SiPMs (+z)	Backward SiPMs (-z)
Dose from physics*	~ 3 x 10 <sup>10</sup> / cm <sup>2</sup>	~ 6 x 10 <sup>9</sup> / cm <sup>2</sup>
Dose from beam + gas*	~ 9 x 10 <sup>9</sup> / cm <sup>2</sup>	~ 5 x 10 <sup>9</sup> / cm <sup>2</sup>

\*In 1 MeV equivalent neutron flux for 10 year-periods of running with top luminosity

For EIC we define a 30 y lifetime, to define radiation doses one needs to have a rough split between the beam energies over this 30 years here is assumption

EIC is built to run the following beam energy combinations:

5 GeV x 41 GeV, 5 GeV x 100 GeV, 10 GeV x 100 GeV, 10 GeV x 275 GeV and 18 GeV x 275 GeV

For simplicity all hadrons are treated as protons, which should be okay for radiation purposes.

Based on this, one gets the following:

Electron Energy			Hadron Energy		
5 GeV	10 GeV	18 GeV	41 GeV	100 GeV	275 GeV
10 years	10 years	10 years	5 years	12 years	13 years

For ePIC 30 y lifetime for radiation will be too long so my suggestion is to use 15 years with 5 years at the EIC commissioning and ramp up luminosities ( $\int L = 38 \text{ fb}^{-1}$ ) and 10 years at full EIC capabilities

Electron Energy			Hadron Energy		
5 GeV	10 GeV	18 GeV	41 GeV	100 GeV	275 GeV
3 years	3 years	4 years	2 years	4 years	4 years

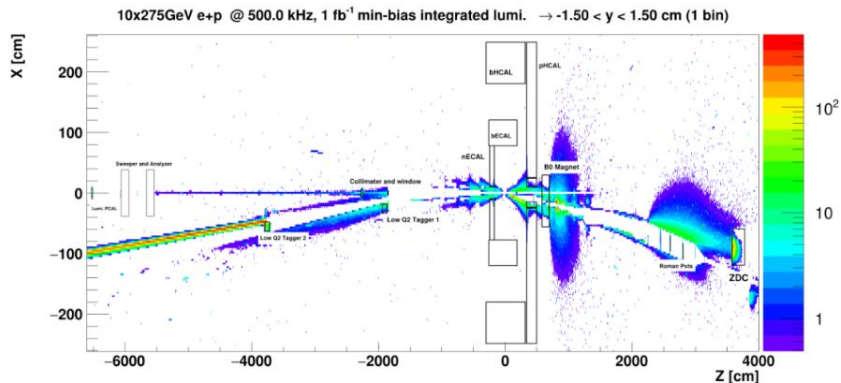
All the information is posted at [https://wiki.bnl.gov/EPIC/index.php?title=Radiation\\_Doses](https://wiki.bnl.gov/EPIC/index.php?title=Radiation_Doses)

To obtain the full radiation dose one needs to add the radiation dose due to electron-nucleon scattering + electron beam backgrounds and hadron beam backgrounds

The figures are for an integrated lumi of  $1 \text{ fb}^{-1}$ , so one needs to scale to the total integrated luminosity for the 15 years as described earlier.

It is very important to have the material budget correct also along the beam pipe, like the SC magnets

## Electromagnetic radiation doses



## Charged hadron radiation doses

