# Barrel Imaging Calorimeter
## SiPM Simulations - Update

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08/13/2025

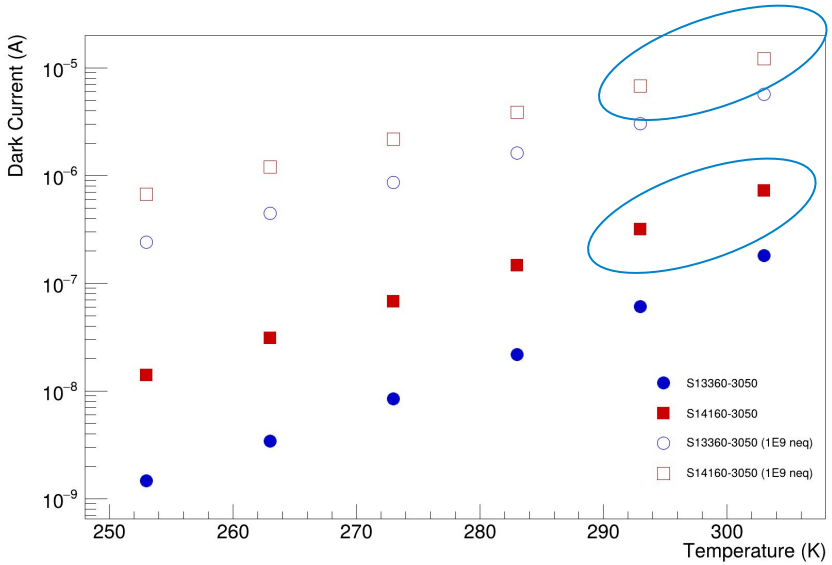
# Radiation doses

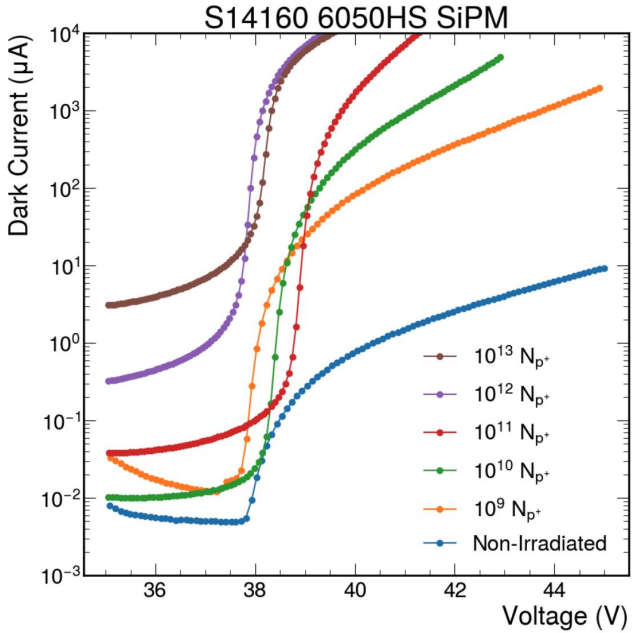
| | Forward SiPMs (+z) | Backward SiPMs (-z) |
|---|---|---|
| Dose from physics/1 $fb^{-1}$ | < 2 x $10^7$ / $cm^2$ | < 5 x $10^6$ / $cm^2$ |
| Dose from hadron beam/1 $fb^{-1}$ | < 3 x $10^6$ / $cm^2$ | < 5 x $10^6$ / $cm^2$ |
| **Sum for 1 $fb^{-1}$** | **2.3 x $10^7$ / $cm^2$** | **1 x $10^7$ / $cm^2$** |
| **Sum for 100 $fb^{-1}$** | **2.3 x $10^9$ / $cm^2$** | **1 x $10^9$ / $cm^2$** |
| **Sum for 140 $fb^{-1}$** | **3.2 x $10^9$ / $cm^2$** | **1.4 x $10^9$ / $cm^2$** |

# 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

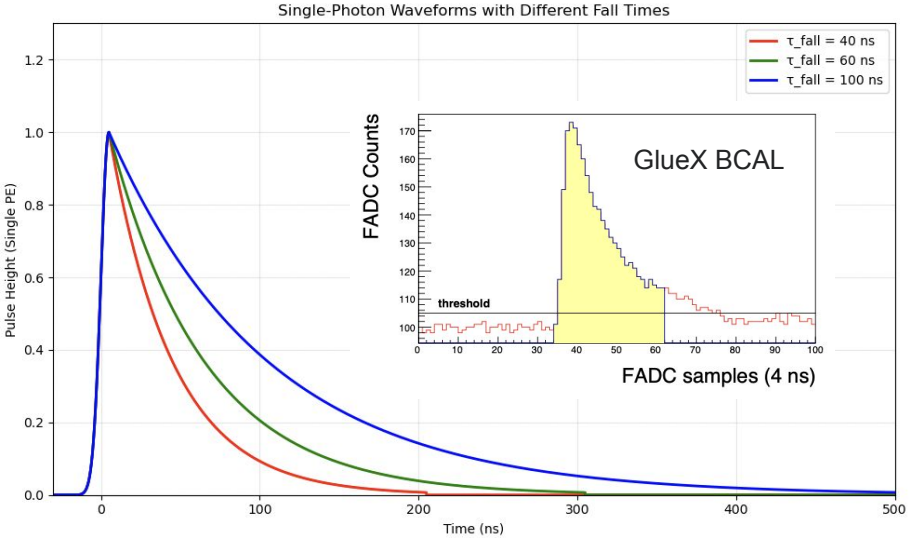
These 3 results more similar to INFN Bolognia

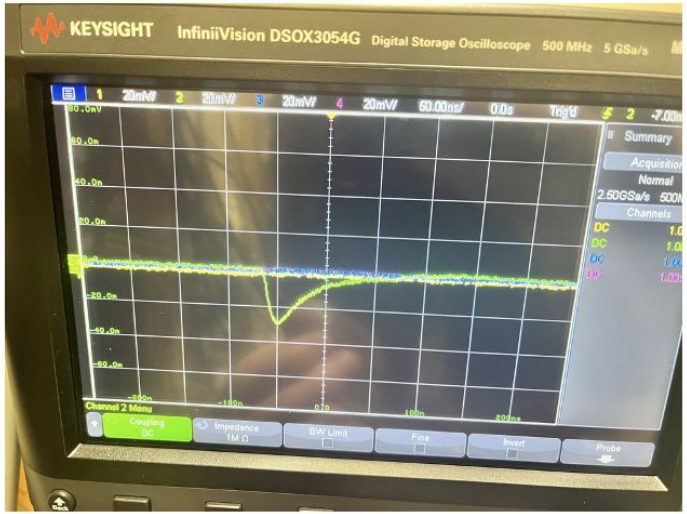
Are those 4 different SiPMs? Just to confirm.

# Noise studies

# SiPM Signal Template - GlueX Template

Based on GlueX BCAL (Baby BCAL) SiPM template



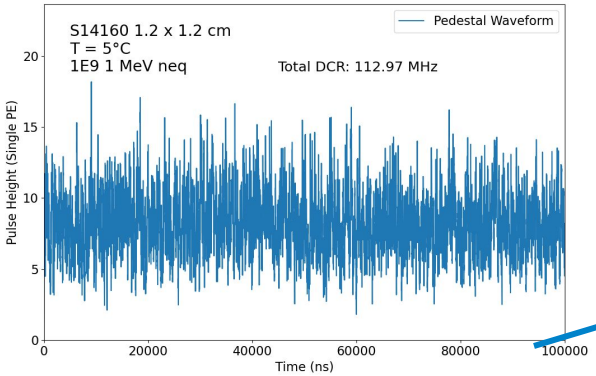



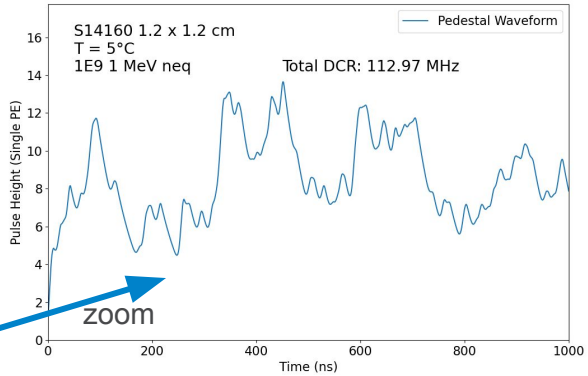

Green template taken for the studies

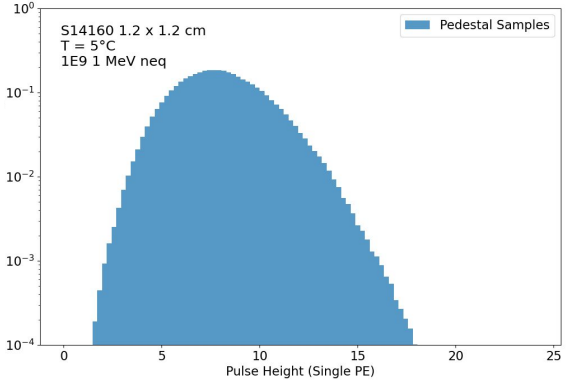
# Readout threshold and rates - GlueX template

## SiPM GlueX Template with 112.97 MHz DCR

S14160 SiPMs at 5 $^{o}$C irradiated 1e+09 1-MeV neutron equivalent dose (Bolognia)



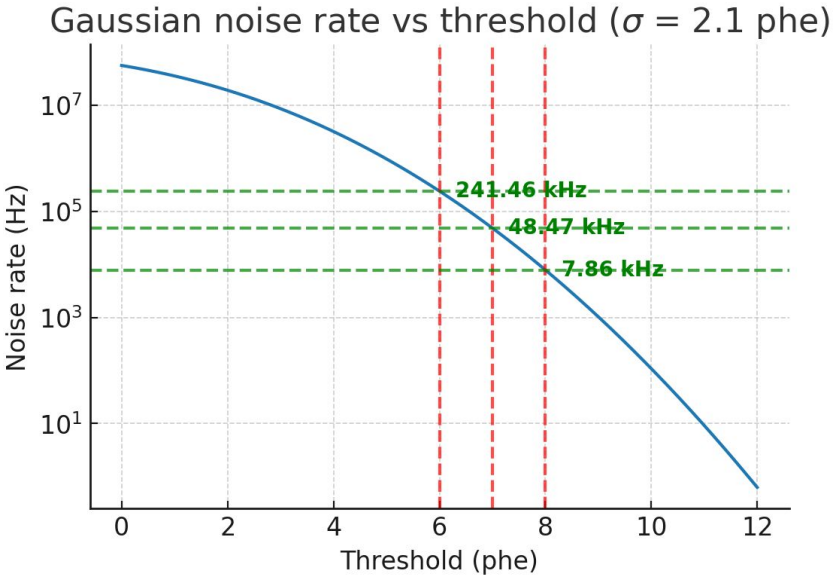



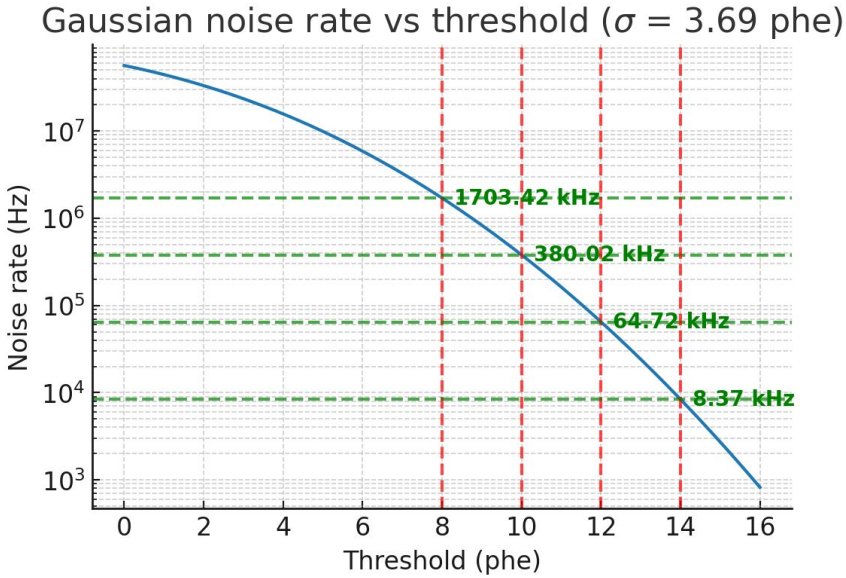

| DCR (MHz) | Noise Sigma | Rate at 3$\sigma$ (6.3 phe) | Rate at 3.5$\sigma$ (7.35 phe) | Rate at 4$\sigma$ (8.4 phe) |
|---|---|---|---|---|
| 112.97 | 2.1 phe | 152.5 Hz | 26.3 kHz | 3.58 kHz |

# Readout threshold and rates - GlueX template

## SiPM GlueX Template with 112.97 MHz and 350 MHz DCR



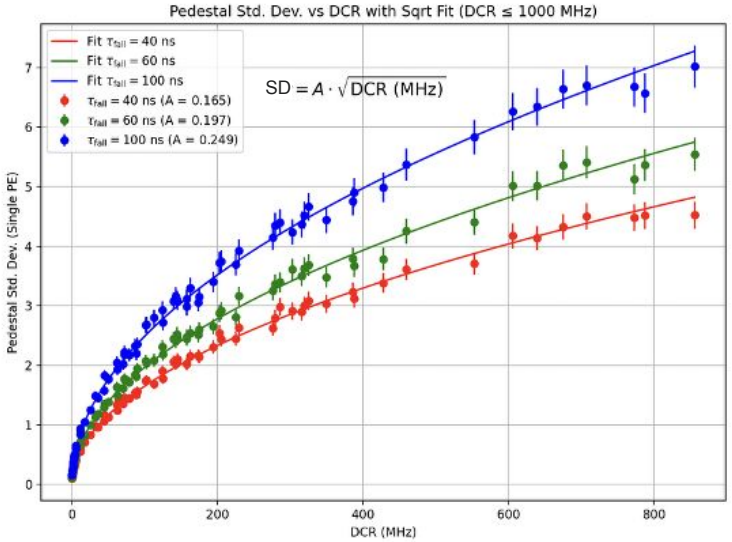

112.97 MHz

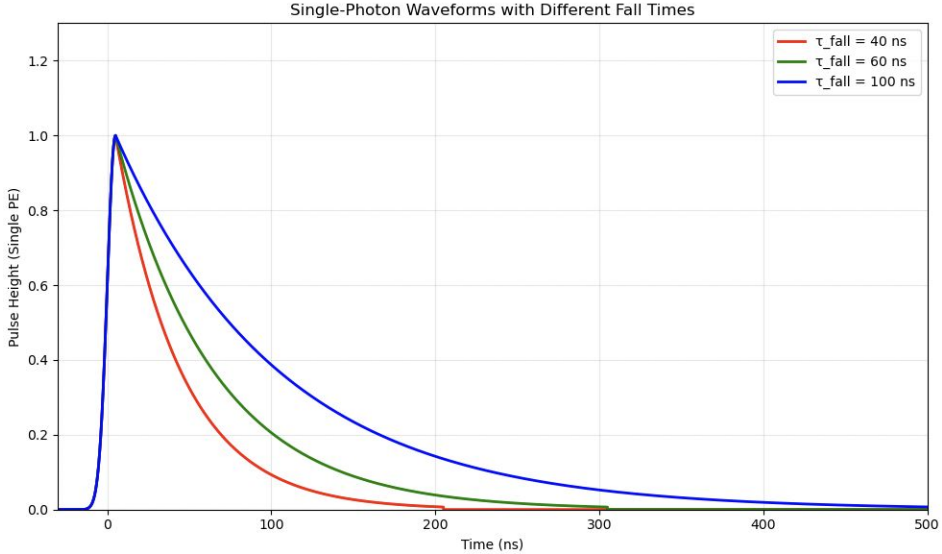



350 MHz

# Sigma pedestal vs DCR for GlueX template

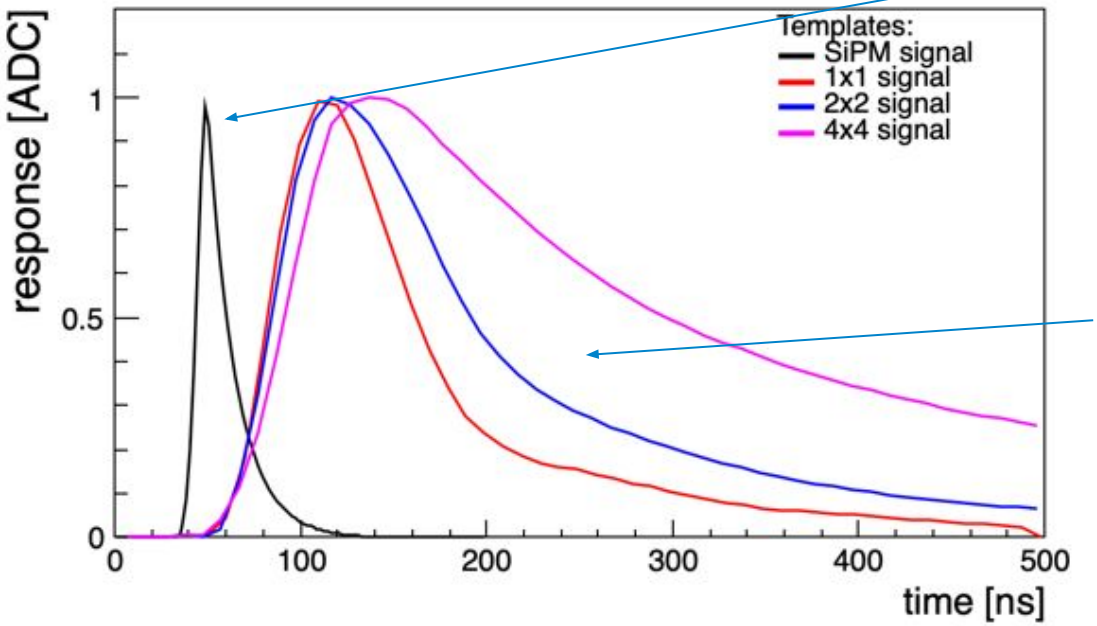
**Below the analytical formula on dependence between the noise Std. Dev. vs DCR has been extracted for different tail sizes in the GlueX template**




For the nominal GlueX template: **σ of pedestal = 0.197*sqrt(DCR in MHz)**

# SiPM Signal Template - HGCROC Template

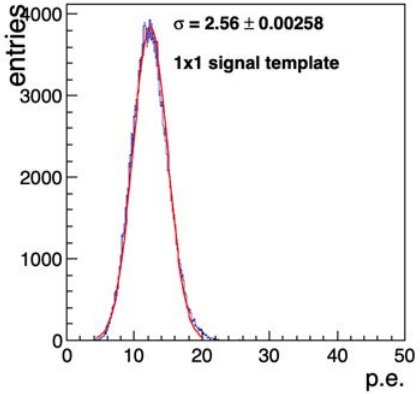


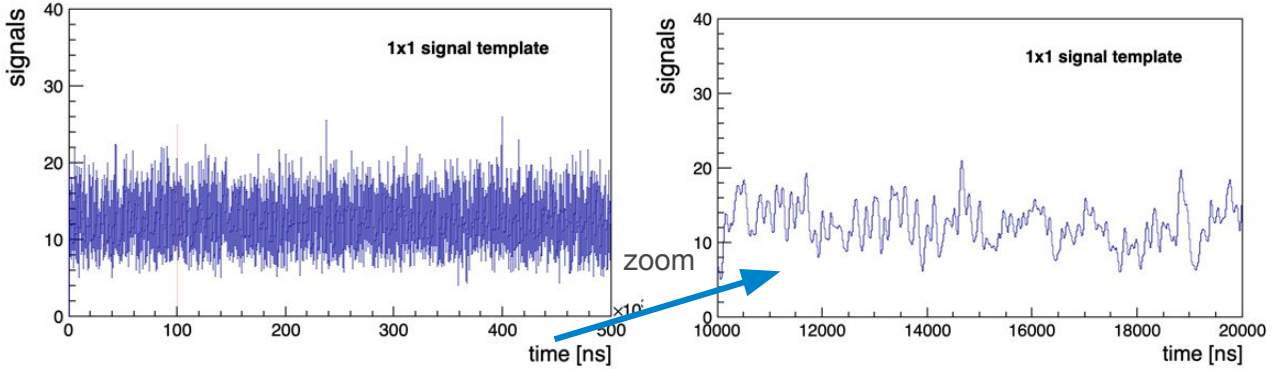

SiPM signal template tested by Norbert in his last presentation

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

# Readout threshold and rates - 1x1 template

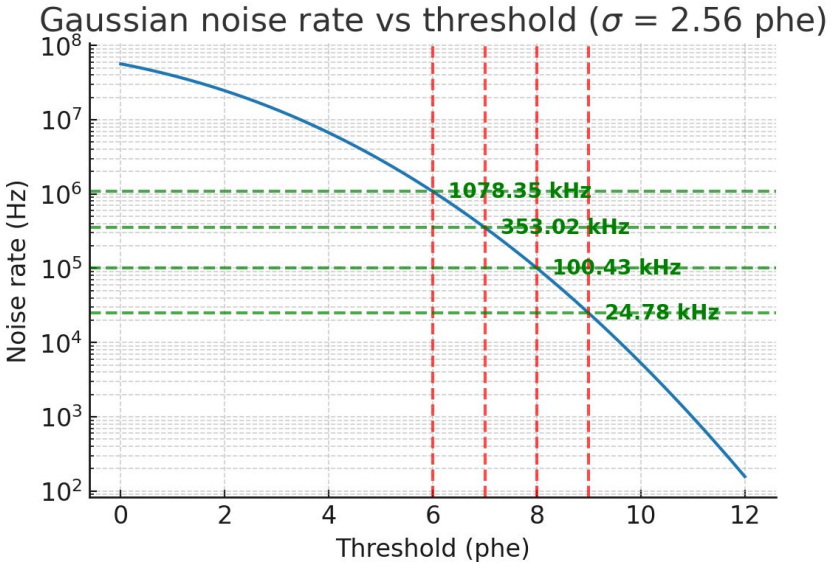
## 1x1 Template with 112.97 MHz DCR



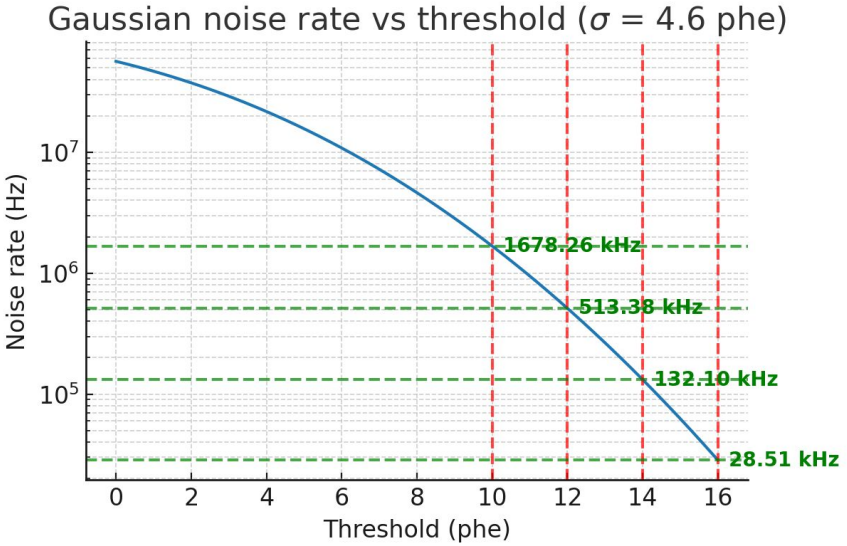




| DCR (MHz) | Noise Sigma | Rate at 3$\sigma$ (7.7 phe) | Rate at 3.5$\sigma$ (9 phe) | Rate at 4$\sigma$ (10.2 phe) |
|---|---|---|---|---|
| 112.97 | 2.56 phe | 152.5 Hz | 26.3 kHz | 3.58 kHz |

# Readout threshold and rates - 1x1 template



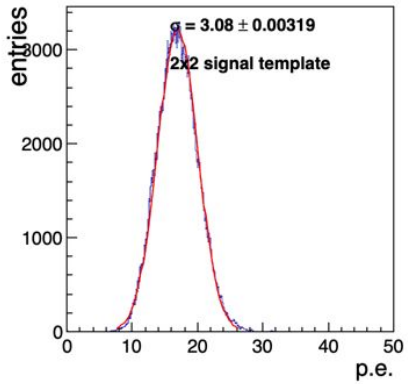

112.97 MHz

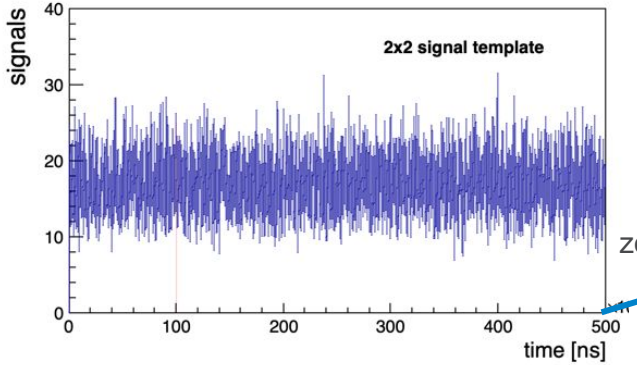


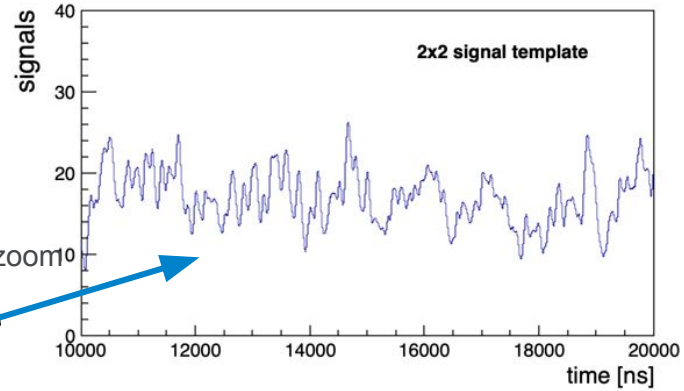

350 MHz

# Readout threshold and rates - 2x2 template

## 2x2 Template with 112.97 MHz DCR

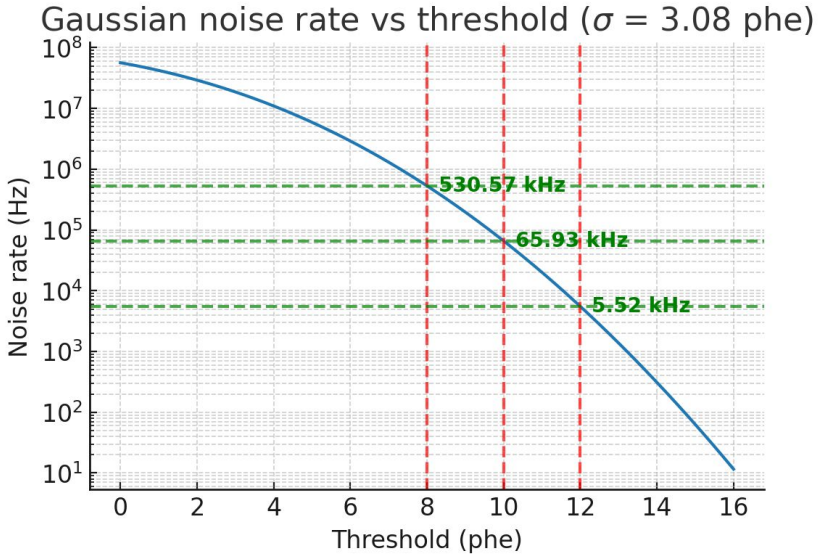


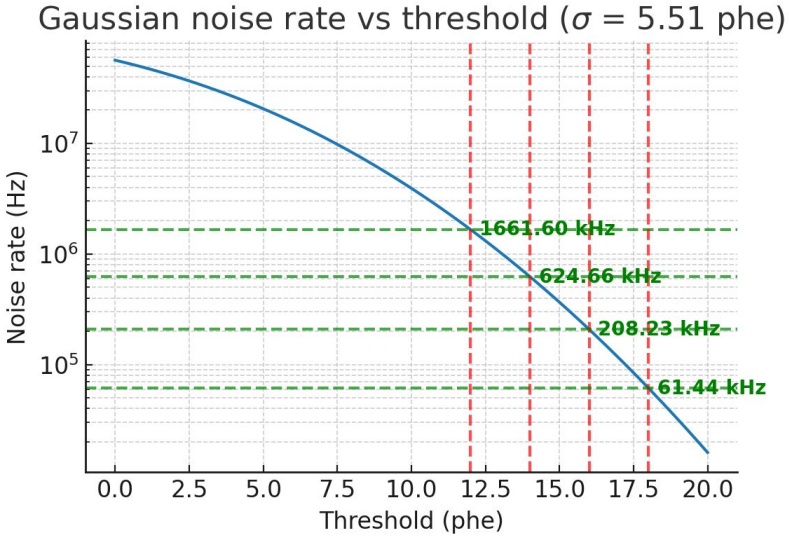




| DCR (MHz) | Noise Sigma | Rate at 3$\sigma$ **(9.24 phe)** | Rate at 3.5$\sigma$ **(10.78 phe)** | Rate at 4$\sigma$ **(12.32 phe)** |
|---|---|---|---|---|
| 112.97 | 3.08 phe | 152.5 Hz | 26.3 kHz | 3.58 kHz |

# Readout threshold and rates - 2x2 template



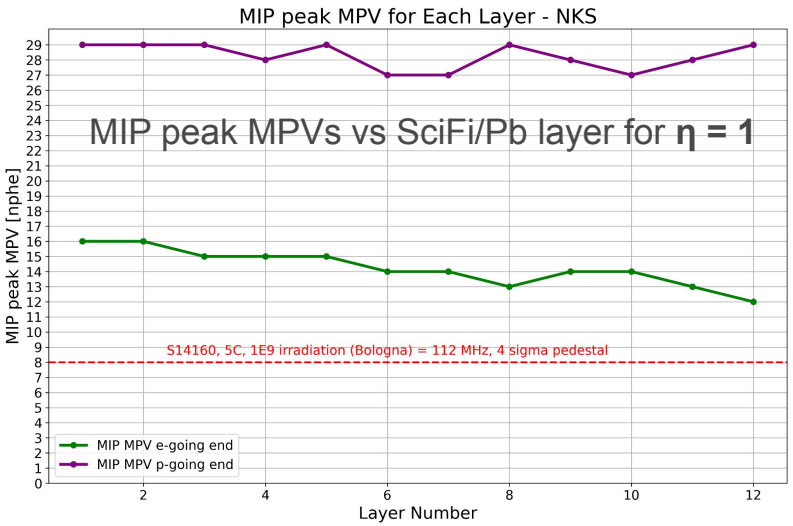

**112.97 MHz**

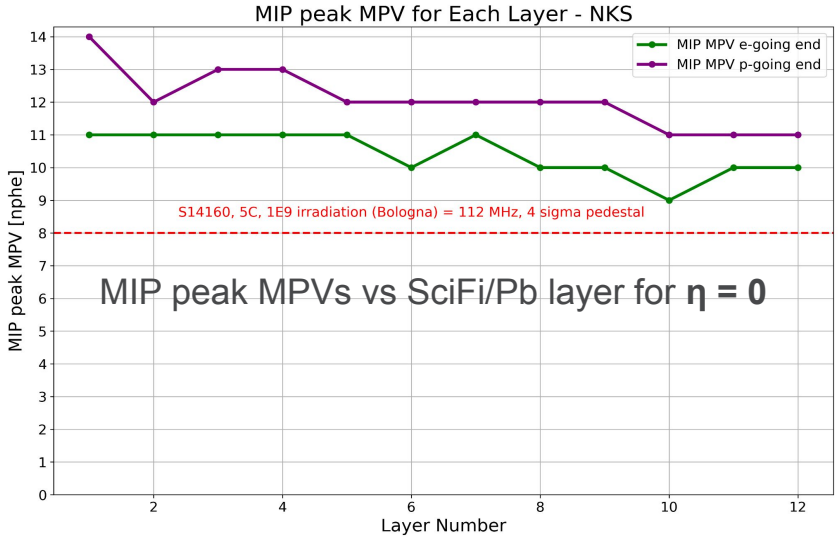



**350 MHz**

# MIP signal

# Readout threshold in pixels - MIPs



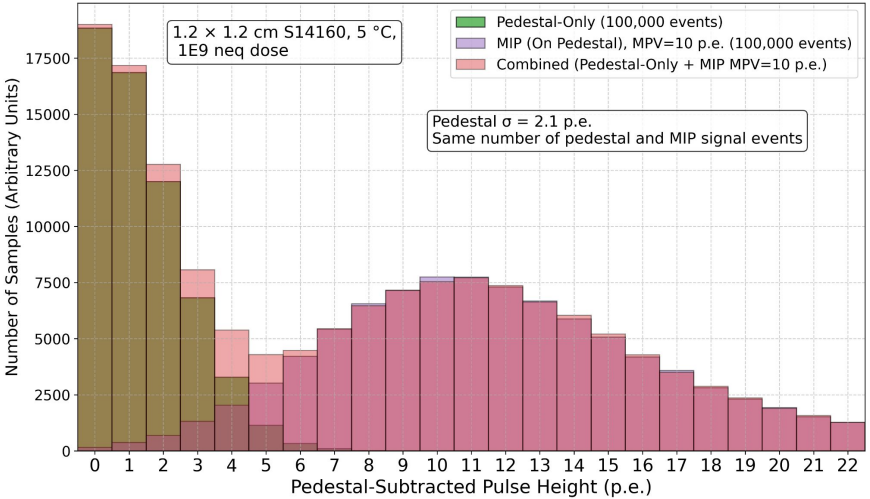




- Threshold determined by desire to see MIP peak for calibration
- MIP response simulated with 5 GeV muons at different

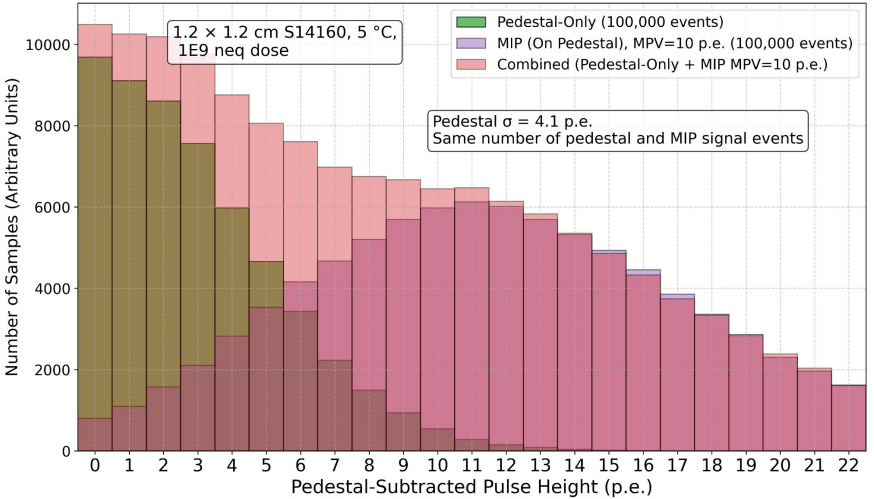
| eta | nphe (e-going) | nphe (e-going) |
|---|---|---|
| 0 (worst case scenario) | 11-14 | 9-11 |
| 1 | 27-29 | 12-16 |

# 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

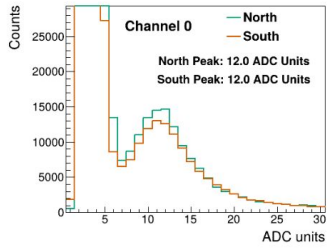
Single-channel ADC amplitudes from Baby BCal test beam

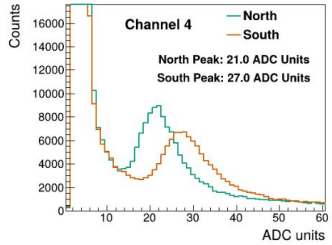
Four longitudinal readout channels

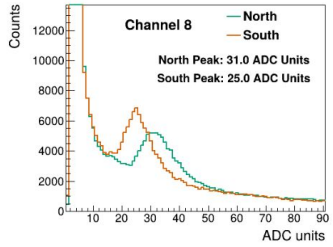
Beam was combined muons + pions

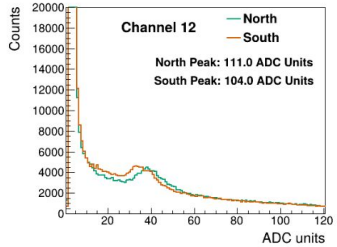
Some MIP peaks not so well resolved above pedestal + sides of showers

Beam Direction



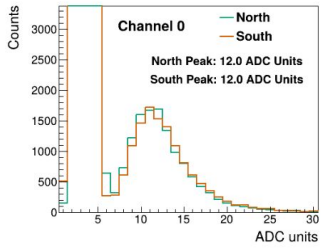



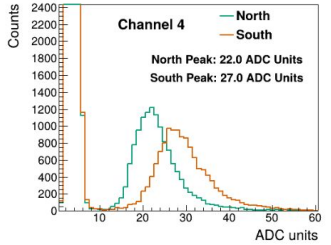



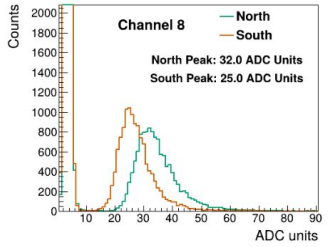

Impose requirement on event topology, MIPs leave hits in only straight lines!

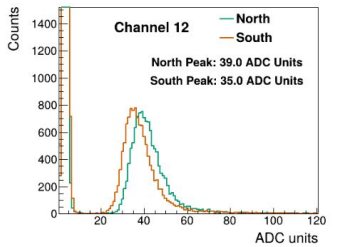
Cleans up peaks significantly

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



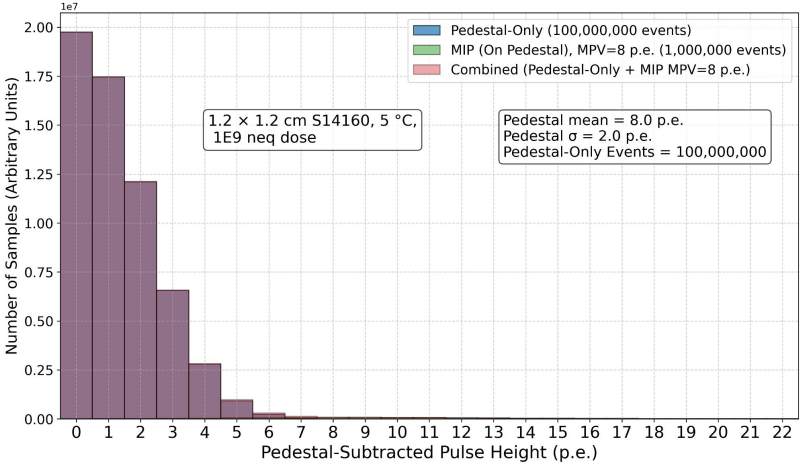



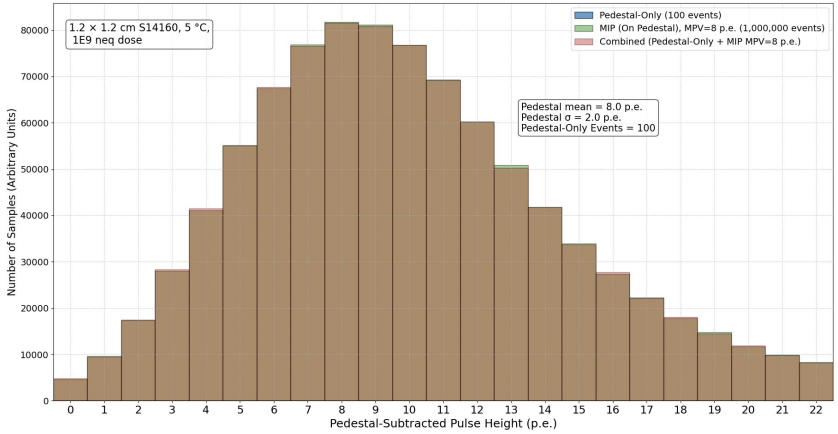
# Power of Topology

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 ~ 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

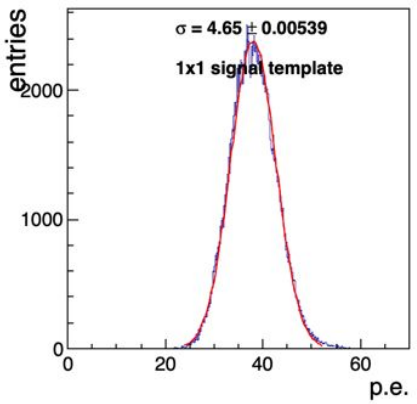
2. Simple 4-sigma cut would work for initial years for MIPs, but with higher irradiations coincidence condition would need to be explored

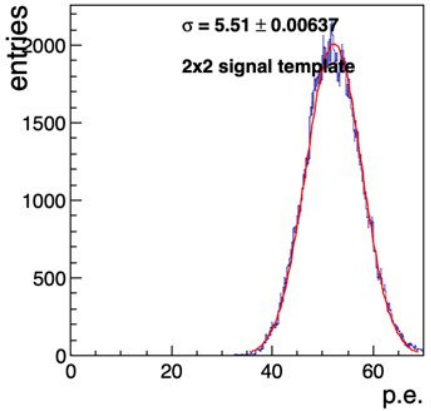
   a. MIPs are needed for calibrations. Special calibration runs with implemented dead time, lower threshold and e.g. 2 samples could be used.

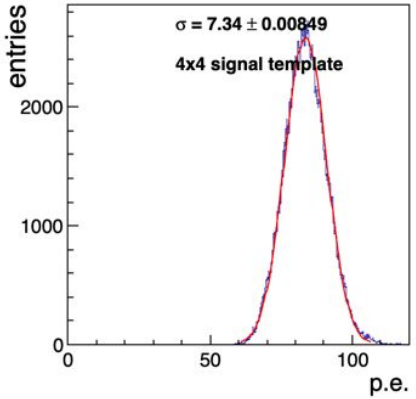
   b. Physics runs to run with the nominal threshold cut, 7 samples

# Backup

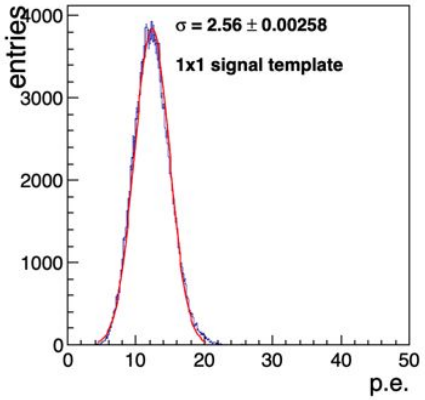
# Noise Pedestal for Simple Templates

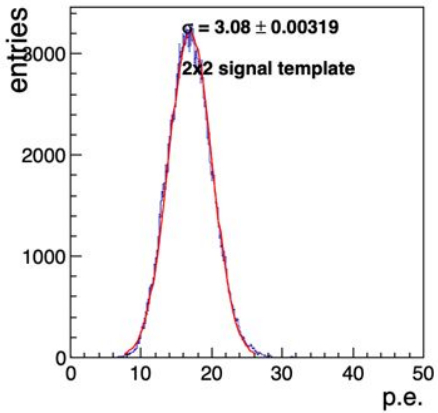


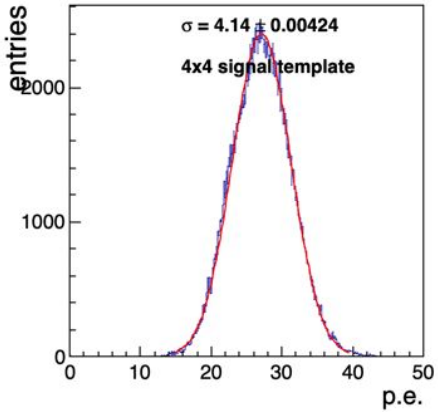




350 MHz



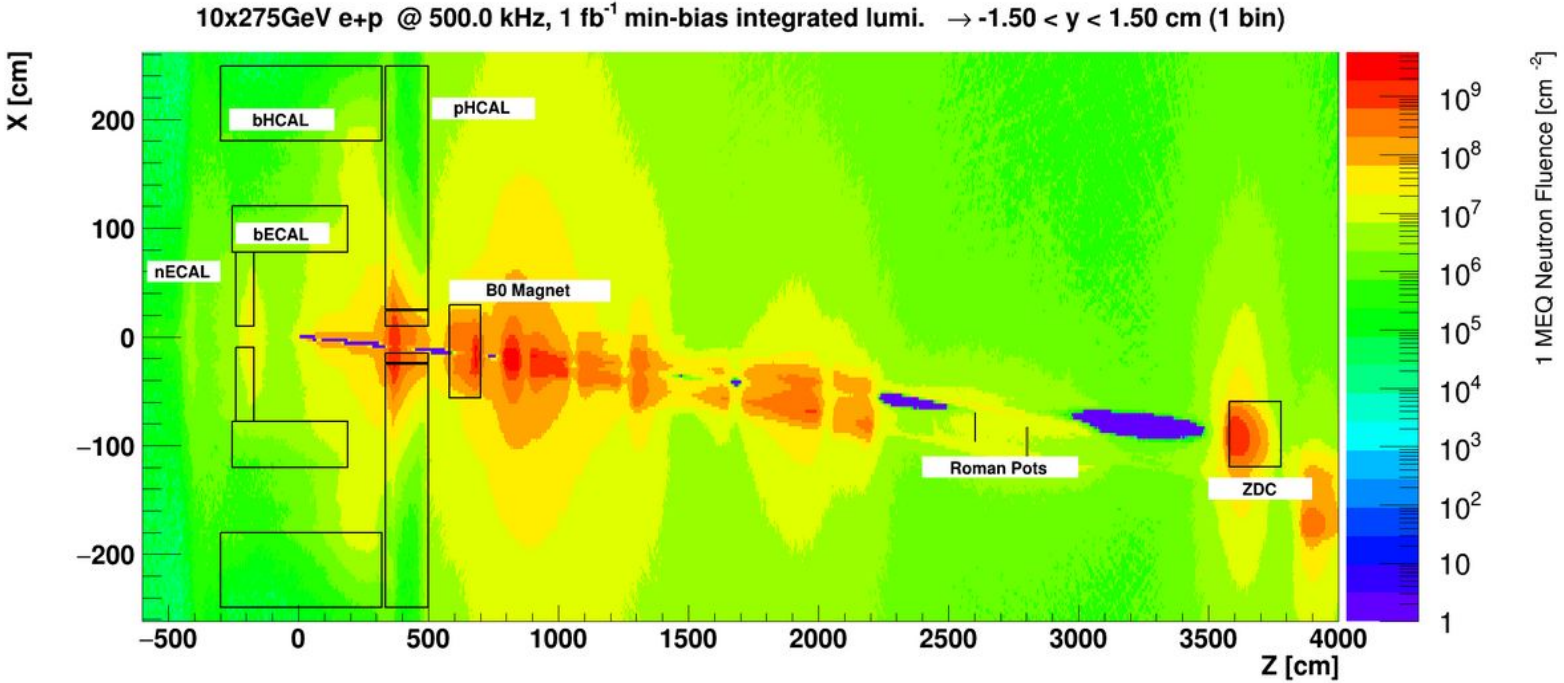

112.97 MHz

# Charge

1. Expected neutron fluxes for an integrated luminosity of 100 $fb^{-1}$
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

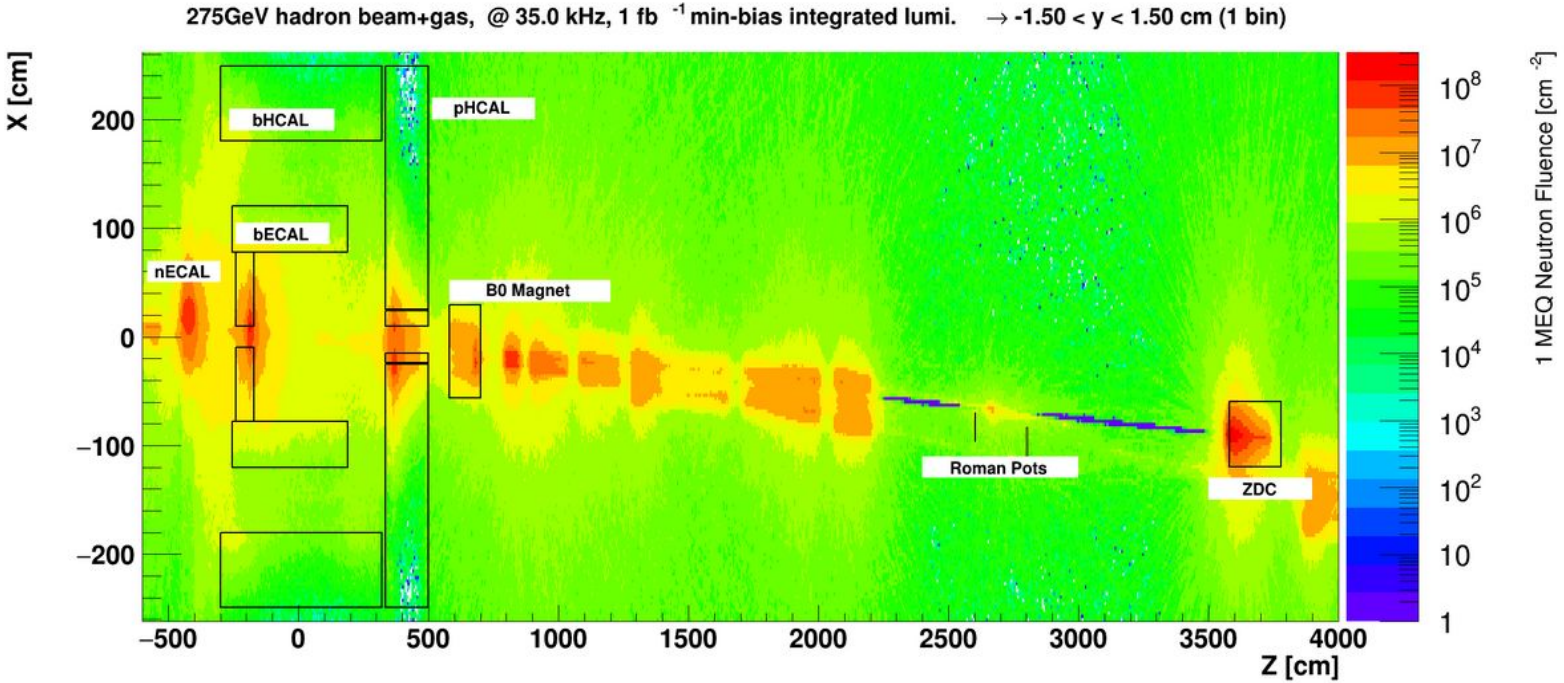
# Radiation doses (results from after the 03/01/25 update)

https://wiki.bnl.gov/EPIC/index.php?title=Radiation_Doses




| | Forward SiPMs (+z) | Backward SiPMs (-z) |
|---|---|---|
| Dose from physics/1 fb$^{-1}$ | < 2 x $10^7$ / cm$^2$ | < 5 x $10^6$ / cm$^2$ |

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

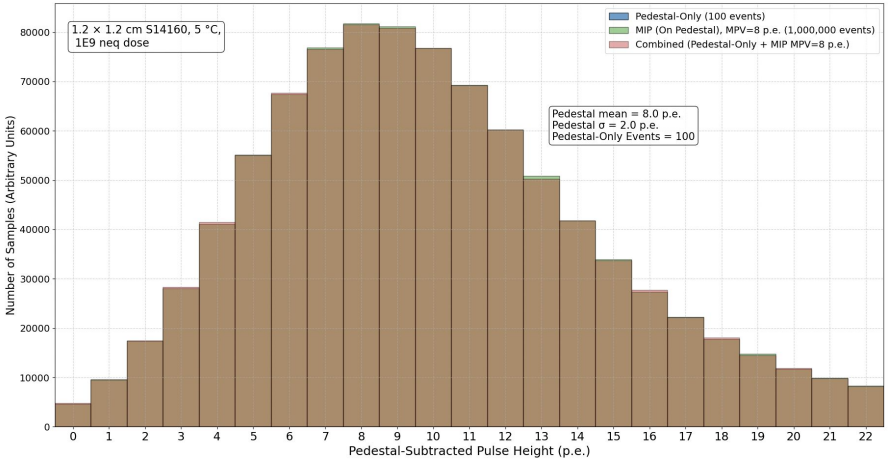


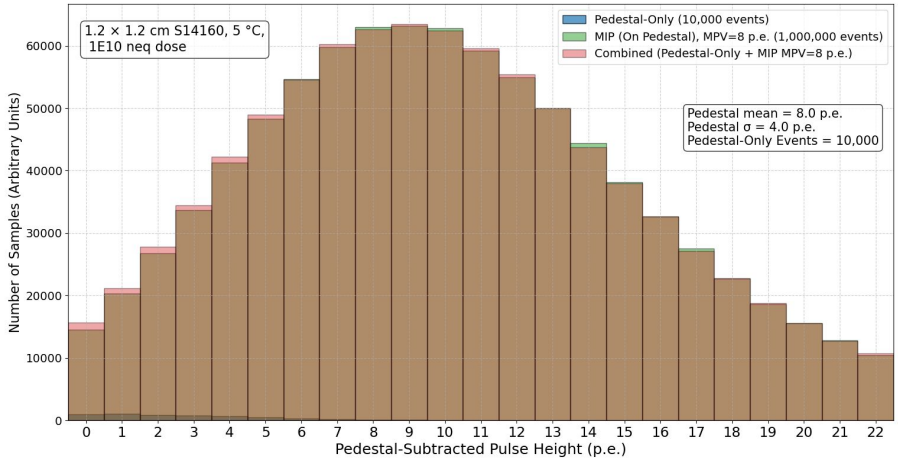

| | Forward SiPMs (+z) | Backward SiPMs (-z) |
|---|---|---|
| Dose from hadron beam/1 $fb^{-1}$ | < 3 x $10^6$ / $cm^2$ | < 5 x $10^6$ / $cm^2$ |

# Impact of DCR on MIP peak

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

Noise hits “overwhelming” the MIP is not an issue even at 1E10 neq dose



# Further Questions

1. Noise contribution to energy resolution:

*We simulated it and the impact is small O(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*

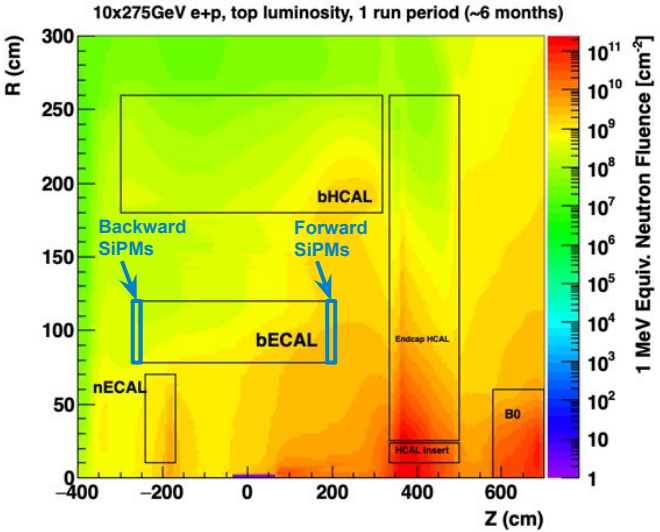
4. Potential impact on readout electronics

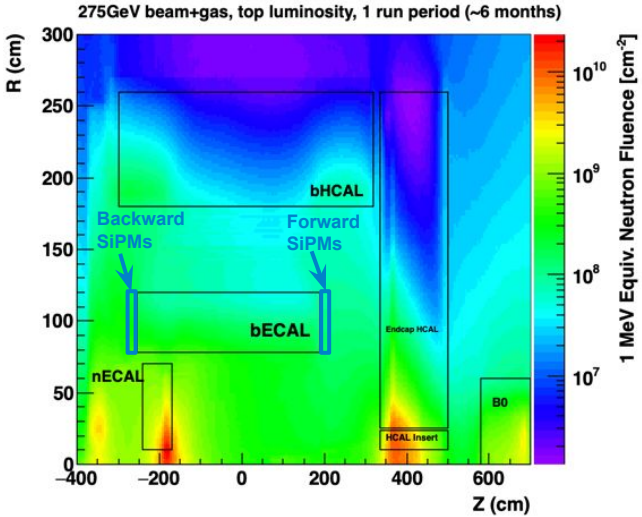
***Baseline:*** *We treat each channel separately in the DAQ using a threshold cut. Even in the worst case (irradiated sensor, MIP at $\eta = 0$), the MIP is well-separated*

***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




*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 $10^{10}$ / $cm^2$ | ~ 6 x $10^9$ / $cm^2$ |
| Dose from beam + gas* | ~ 9 x $10^9$ / $cm^2$ | ~ 5 x $10^9$ / $cm^2$ |

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

# Facility Lifetime

https://indico.bnl.gov/event/28073/

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 a the EIC commissioning and ramp up luminosities ( $\int L = 38\ fb^{-1}$) 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 |

# Radiation Doses

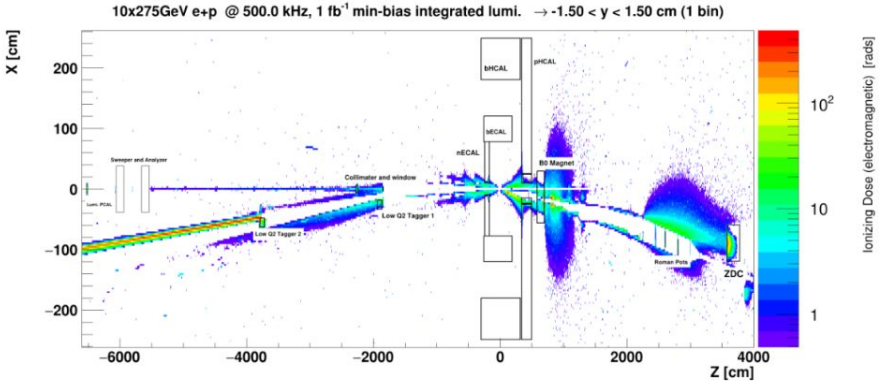
https://indico.bnl.gov/event/28073/

All the information is posted at 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 $fb^{-1}$, 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