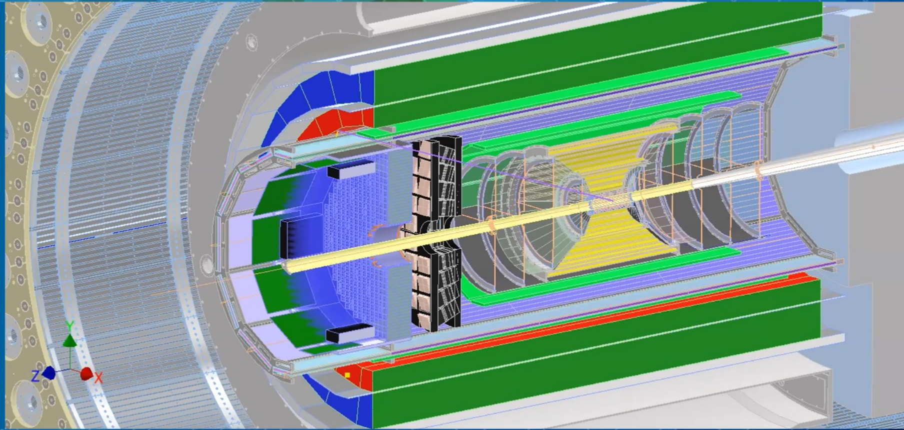
Barrel Imaging Calorimeter
SiPM Simulations



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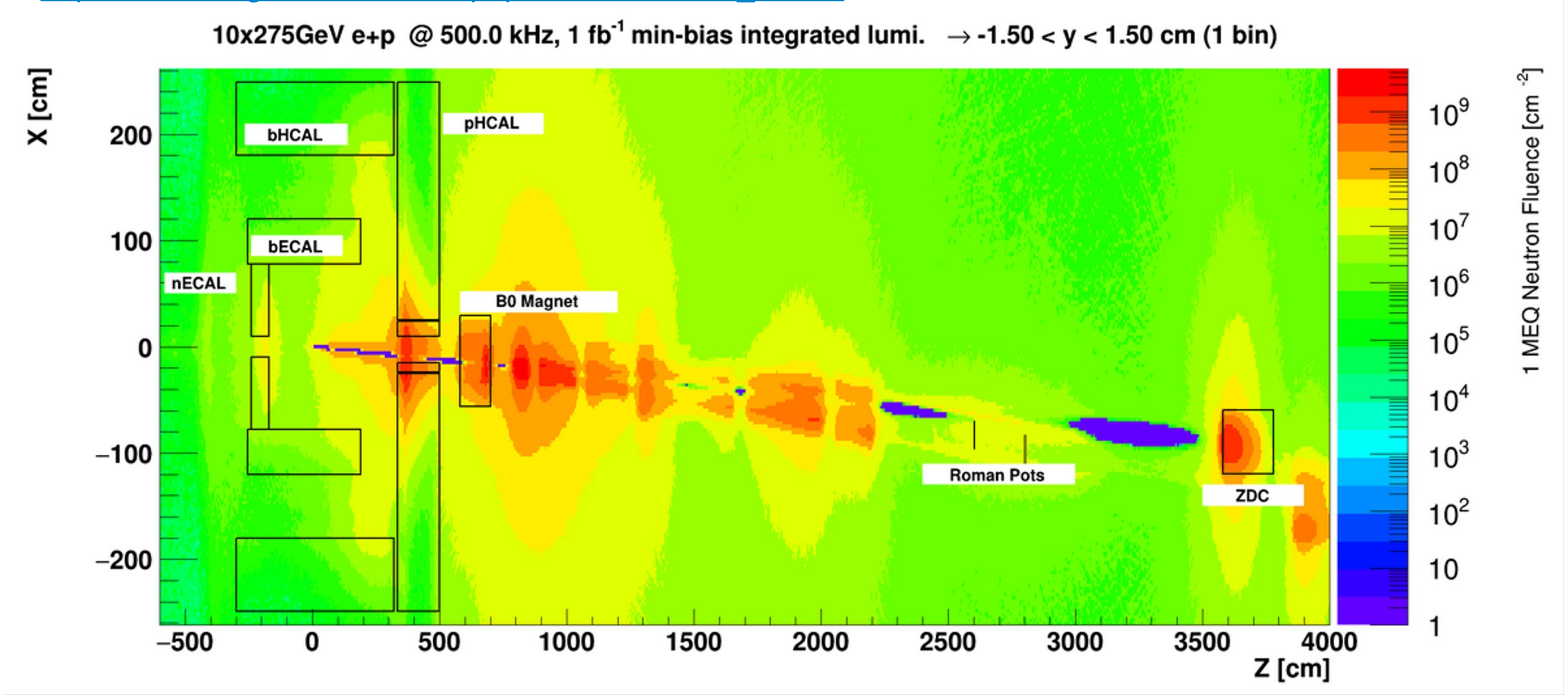
ANL
06/04/2025

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

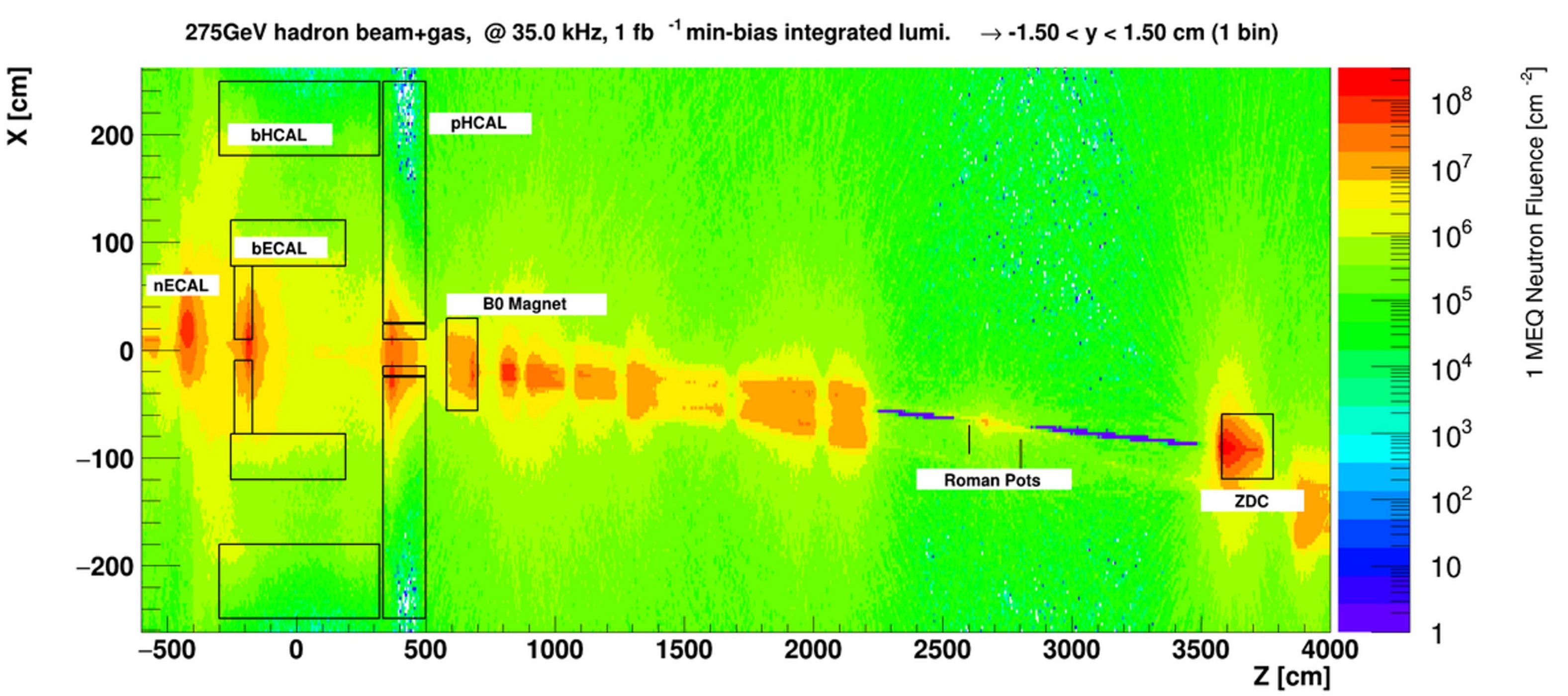
Radiation doses (results from after the 03/01/25 update)

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



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

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



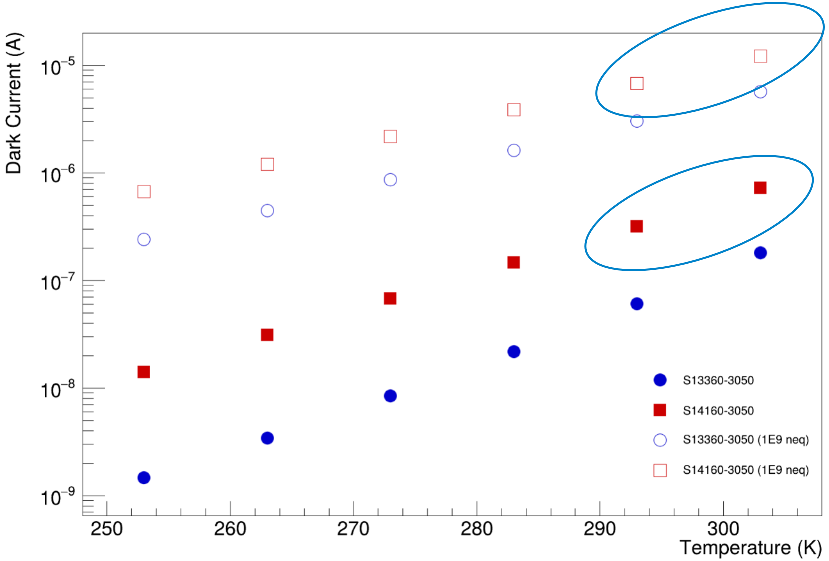
	Forward SiPMs (+z)	Backward SiPMs (-z)
Dose from hadron beam/1 fb^{-1}	$< 3 \times 10^6$ / cm^2	$< 5 \times 10^6$ / cm^2

Radiation doses

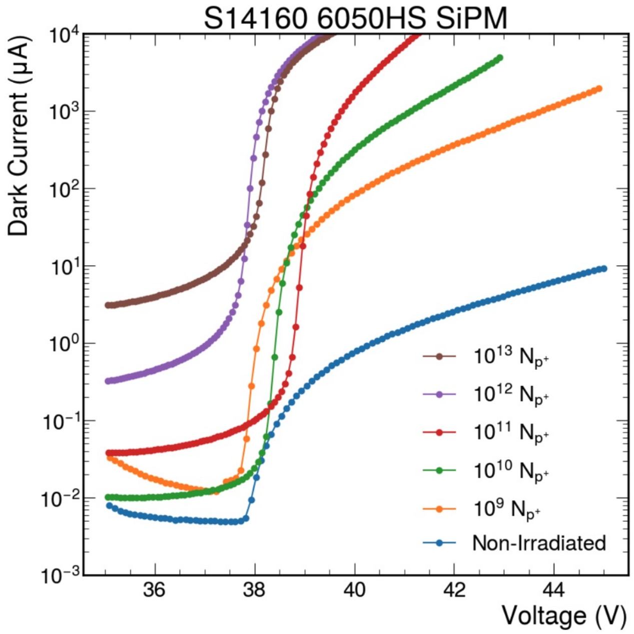
	Forward SiPMs (+z)	Backward SiPMs (-z)
Dose from physics/1 fb^{-1}	$< 2 \times 10^7$ / cm^2	$< 5 \times 10^6$ / cm^2
Dose from hadron beam/1 fb^{-1}	$< 3 \times 10^6$ / cm^2	$< 5 \times 10^6$ / cm^2
Sum for 1 fb^{-1}	**2.3×10^7 / cm^2**	**1×10^7 / cm^2**
Sum for 100 fb^{-1}	**2.3×10^9 / cm^2**	**1×10^9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

Expected dark current levels

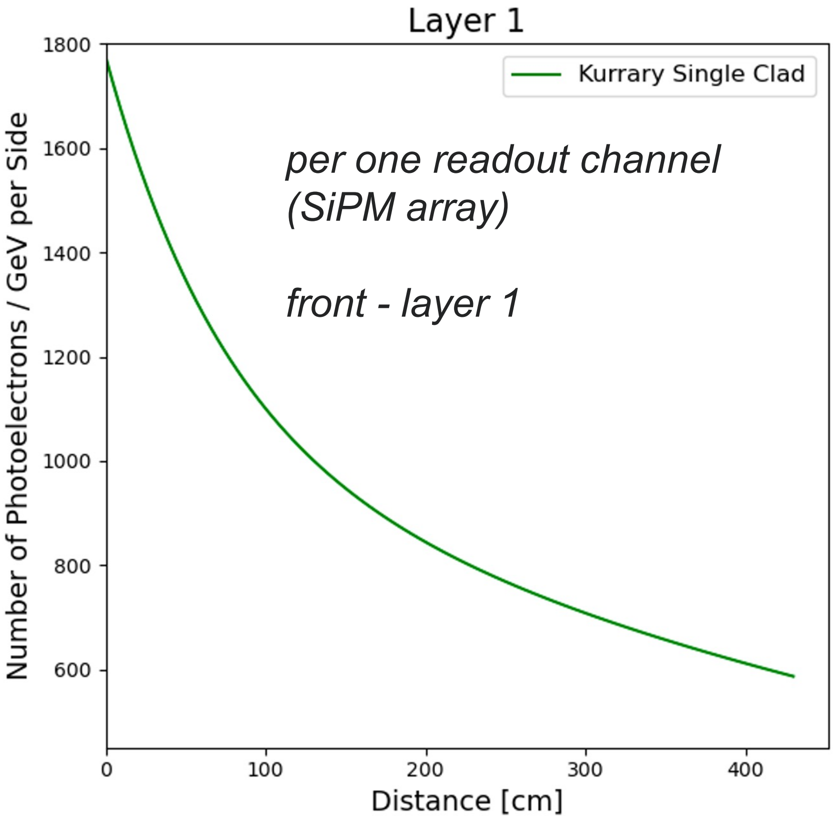
INFN Bologna Irradiations: ~5 microamps for 3x3 mm at 1E9 neq at room temp
For 1.2 x 1.2 cm ~ 100 MHz of DCR for BIC at 5C (4x4 array)

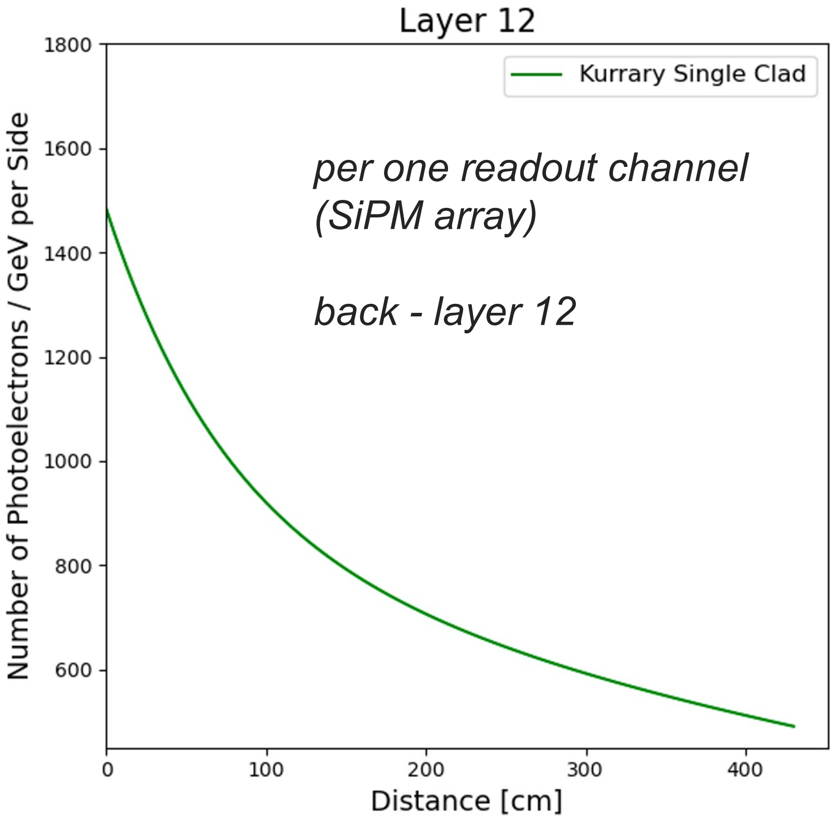


UC Davis Irradiations: ~100 microamps for 6x6 mm at 1E9 p+ at room temp, 1E10 factor 5-ish higher.
For 1.2 x 1.2 cm ~350 MHz of DCR for 1E9, 1.2 GHz for 1E10 neq dose, scaling to 5C & factor 1.5 difference in damage for p dose vs. 1 MeV neutrons



Light yield (LY) per GeV in pixels



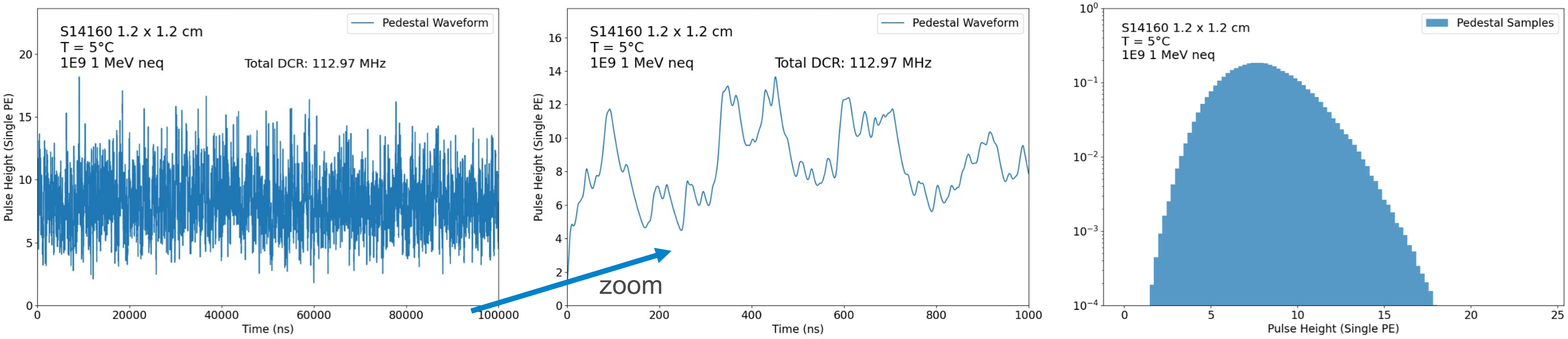


Readout threshold in pixels - Simulations

Simulation Inputs: SiPM readout

Simulations of the expected pedestal position and sigma realistic SiPM DCR and signal shape

Scenarios for different SiPM families, irradiations and operating temperatures tested



Example simulated baseline and pedestal for S14160 SiPMs at 5 ^{o}C irradiated 1e+09 1-MeV neutron equivalent dose

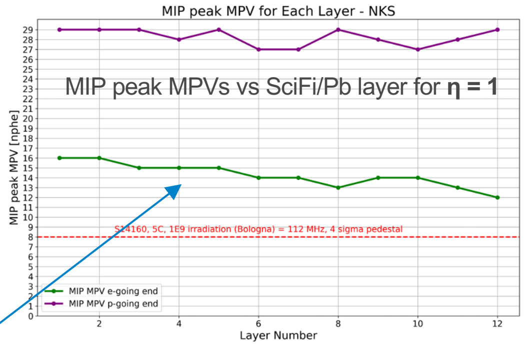
Readout threshold in pixels - MIPs

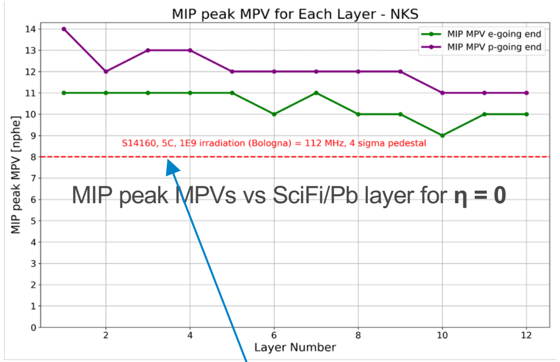
Threshold determined by desire to see MIP peak for calibration

MIP response simulated with 5 GeV muons at different rapidities ~ 9 p.e. at worst

Deposited energy per readout cell (MIP peak most probable value) with Single-Clad Kuraray fiber (fulfilling FDR fiber specs) compared with 4 sigma pedestal peak from SiPM (FDR specs) simulations

MIP signal well separated for 1E9 1-MeV neq/cm^2 irradiation

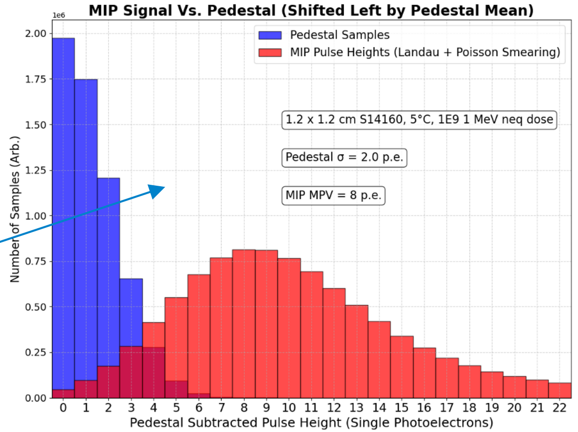




8 phe taken for illustration of the worst case scenario (4σ of pedestal)

Example pedestal + MIP signal spectrum for 8 phe MIP signal (lower limit, η = 0) after 1E9 1-MeV neq/cm^2 irradiation

Pedestal mean subtracted



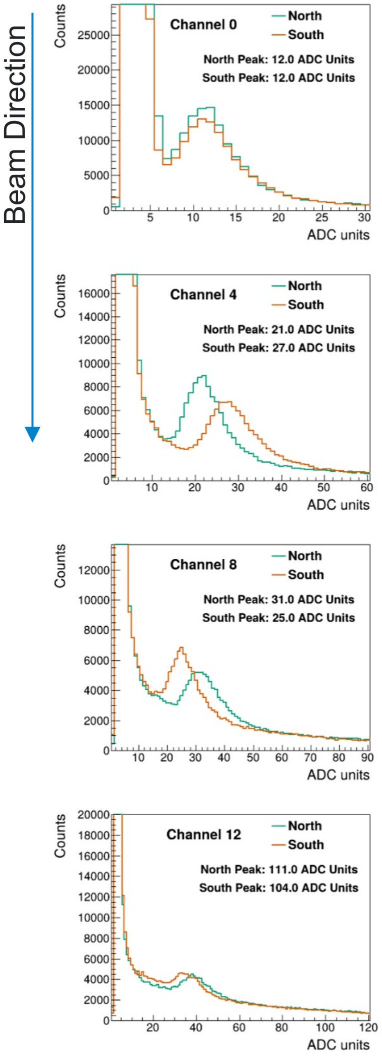
Power of Topology

Single-channel ADC amplitudes from Baby BCal test beam

Four longitudinal readout channels

Beam was combined muons + pions

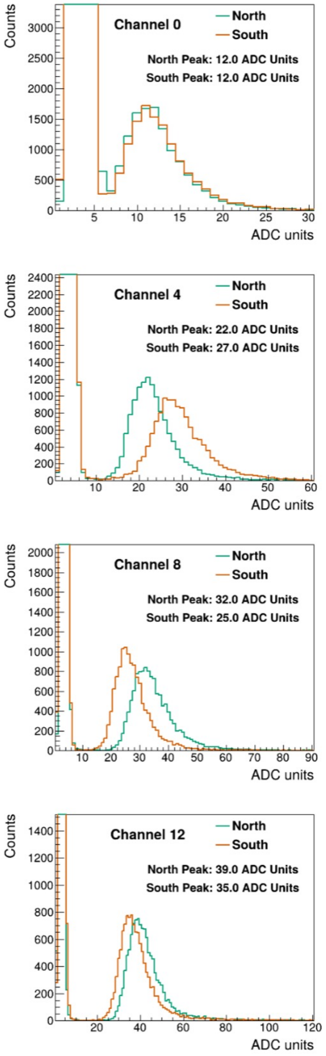
Some MIP peaks not so well resolved above pedestal + sides of showers



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

Cleans up peaks significantly

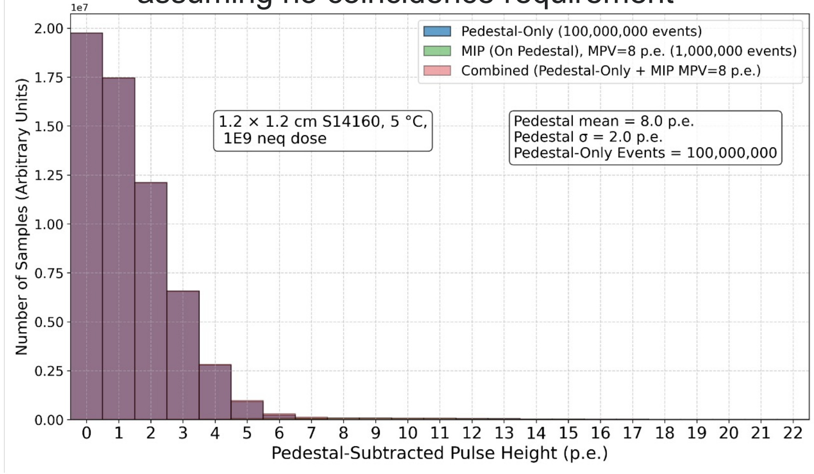
Probability of an upward pedestal fluctuation in a single channel can be large, but fluctuations in multiple channels becomes rare!



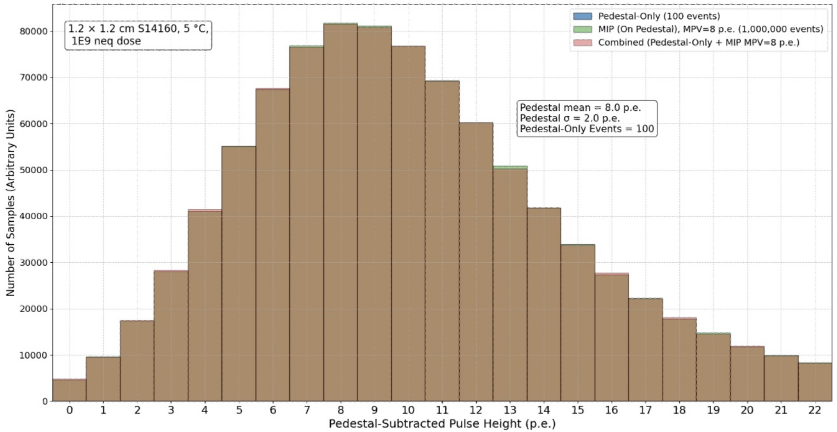
Power of Topology

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 ~ 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?

Further Questions

1. Noise contribution to energy resolution:

We simulated it and the impact is small O(few MeV).

1. Rates of hits above threshold caused by SiPM noise

Depends on threshold applied and pedestal sigma (e.g. for 100 MHz…). A 2 sigma cut assuming HGCROC would produce ~ 1 MHz per channel. At 1 GHz DCR level (1E10 neq) could run with this for dedicated MIP runs and run with 4 sigma for normal running.

1. 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

1. Potential impact on readout electronics

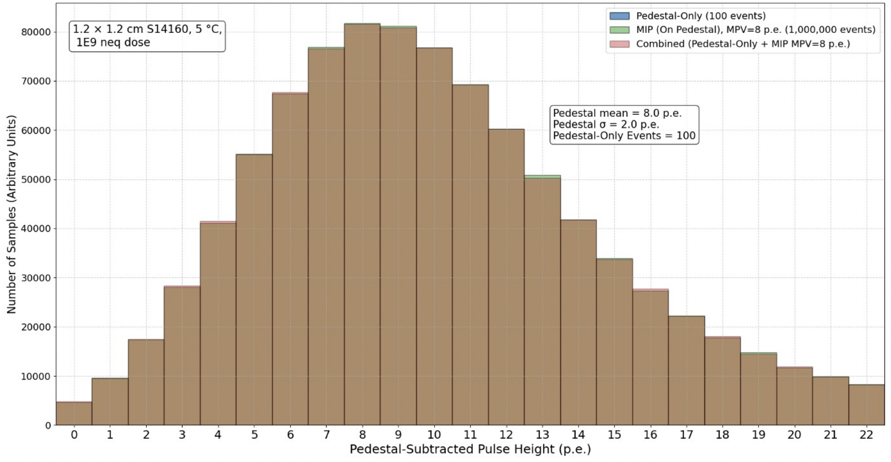
***Baseline:** We treat each channel separately in the DAQ using a threshold cut. Even in the worst case (irradiated sensor, MIP at $\eta = 0$), the MIP is well-separated*

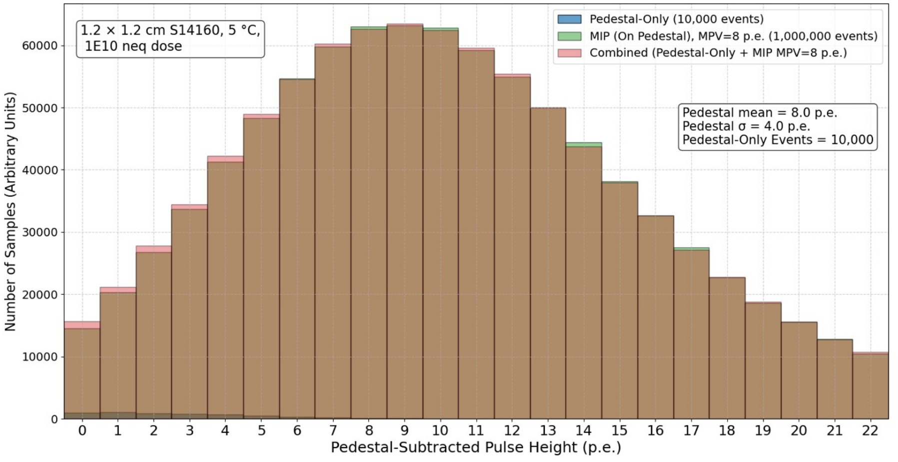
***Mitigation:** We can lower readout thresholds if desired (enough headroom in ASIC) and apply simple coincidence logic for zero suppression (e.g. in the DAM module)*

Backup

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





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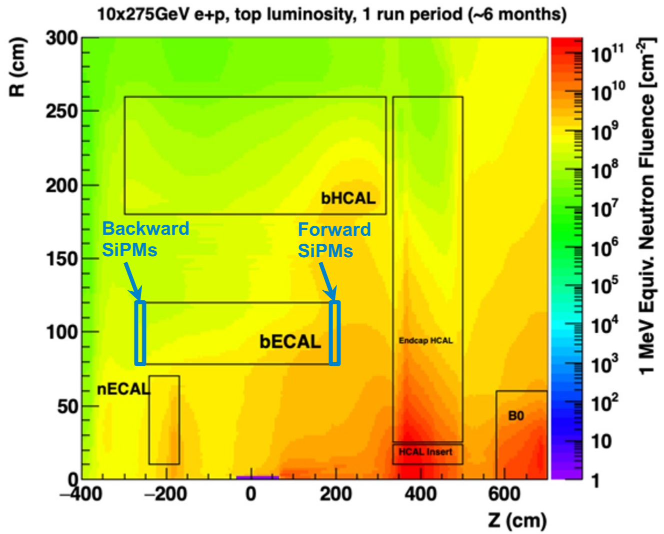
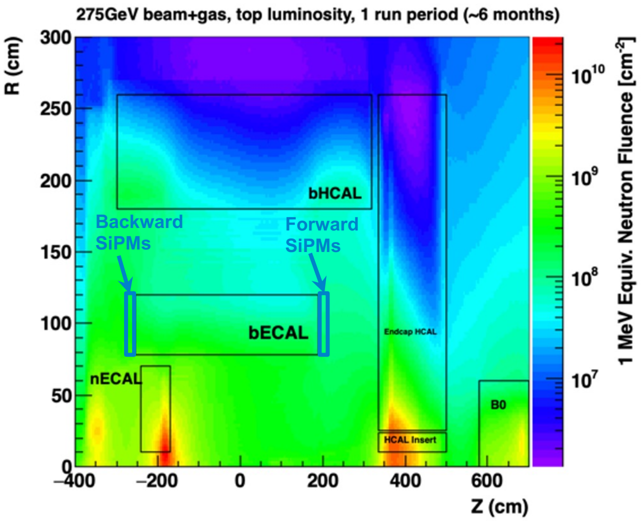




1 MeV equivalent neutron fluence ***at 10x275 GeV @ top machine luminosity for 6 months of running at 100% machine and detector efficiency***.

	Forward SiPMs (+z)	Backward SiPMs (-z)
Dose from physics*	~ 3×10^{10} / cm^2	~ 6×10^{9} / cm^2
Dose from beam + gas*	~ 9×10^{9} / cm^2	~ 5×10^{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

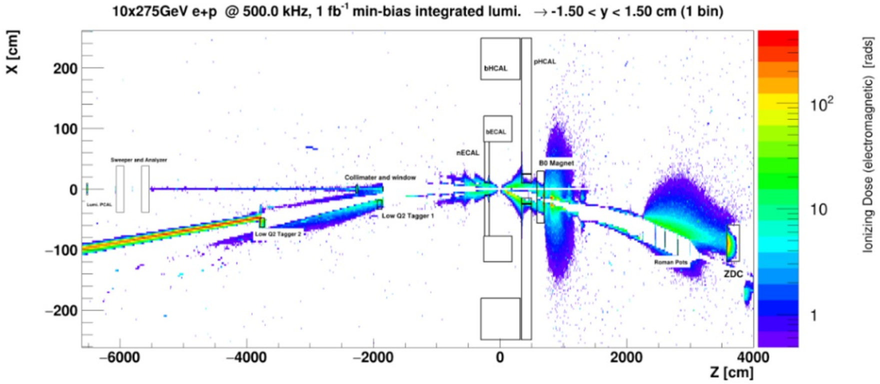
https://indico.bnl.gov/event/28073/

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