



Status of the Performance Paper

Performance of the Photon Detector

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Collaboration Call

PREPARED FOR SUBMISSION TO JINST

First results on ProtoDUNE-SP LArTPC performance from a test beam run at the CERN Neutrino Platform - PDS Contribution

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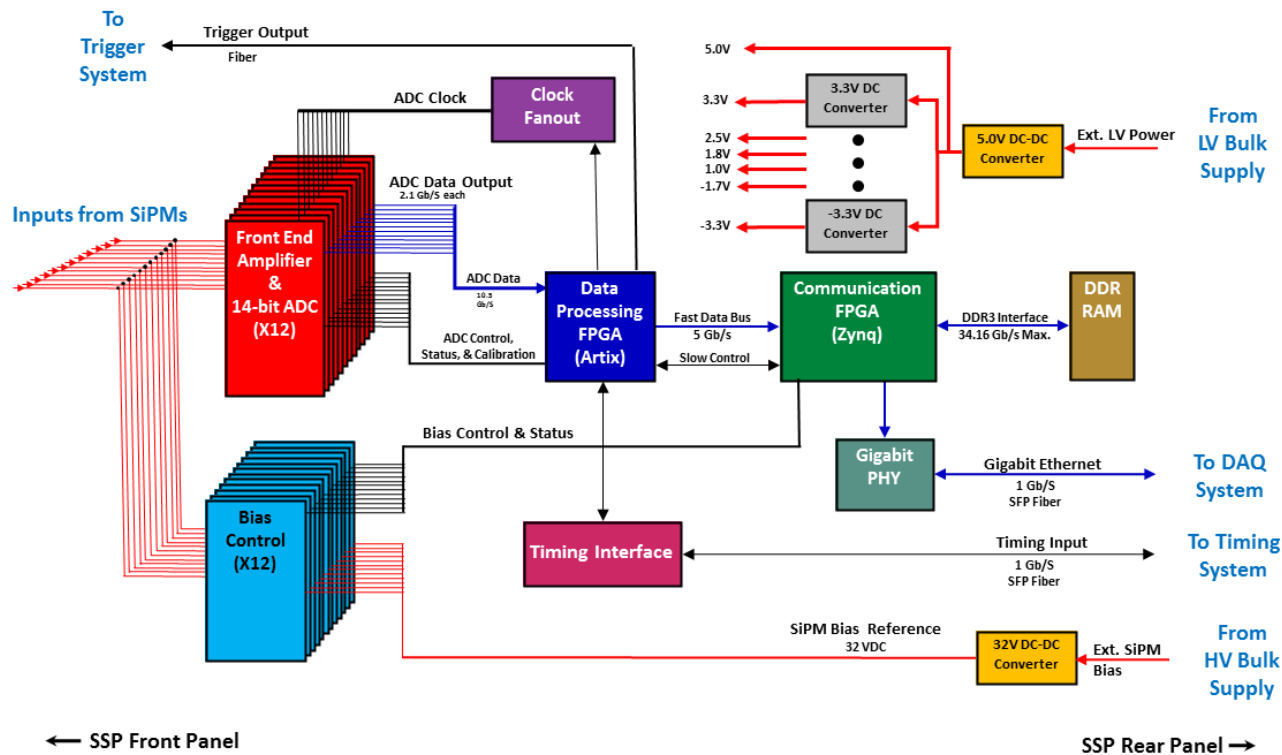
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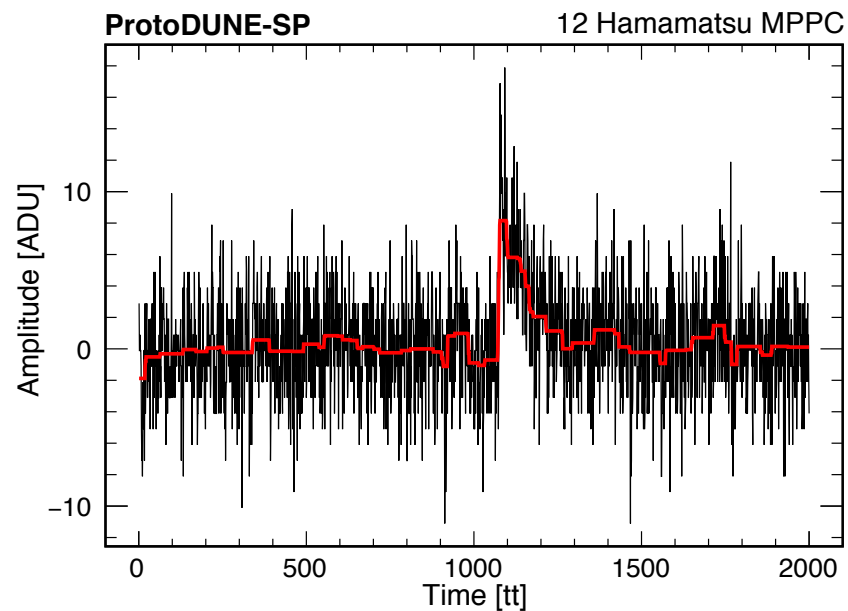
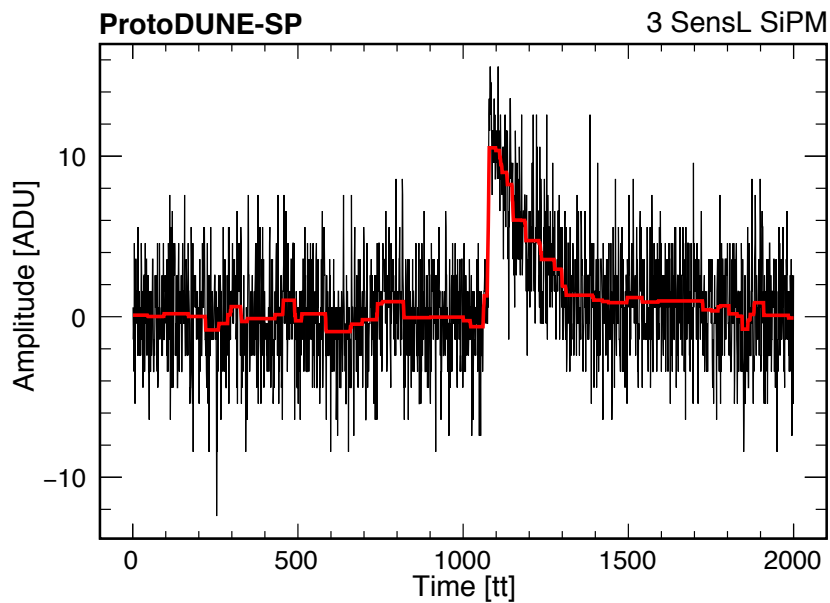
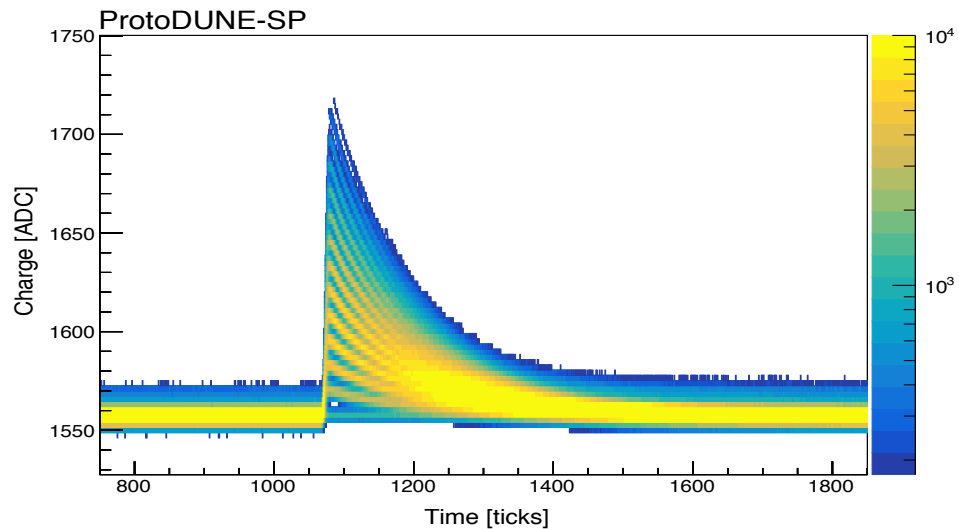
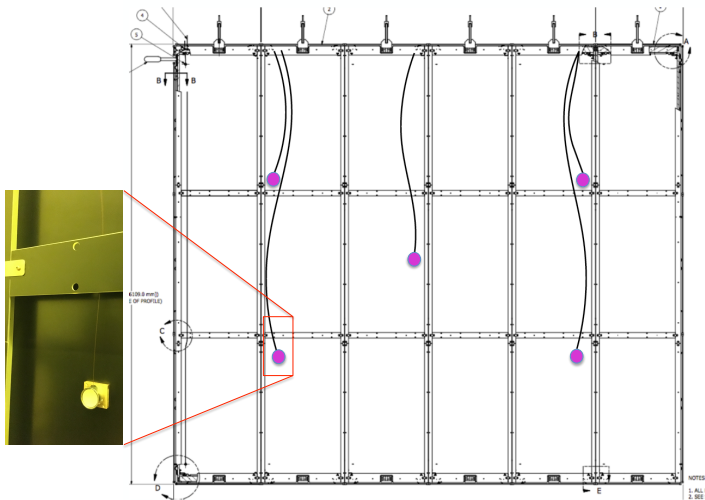
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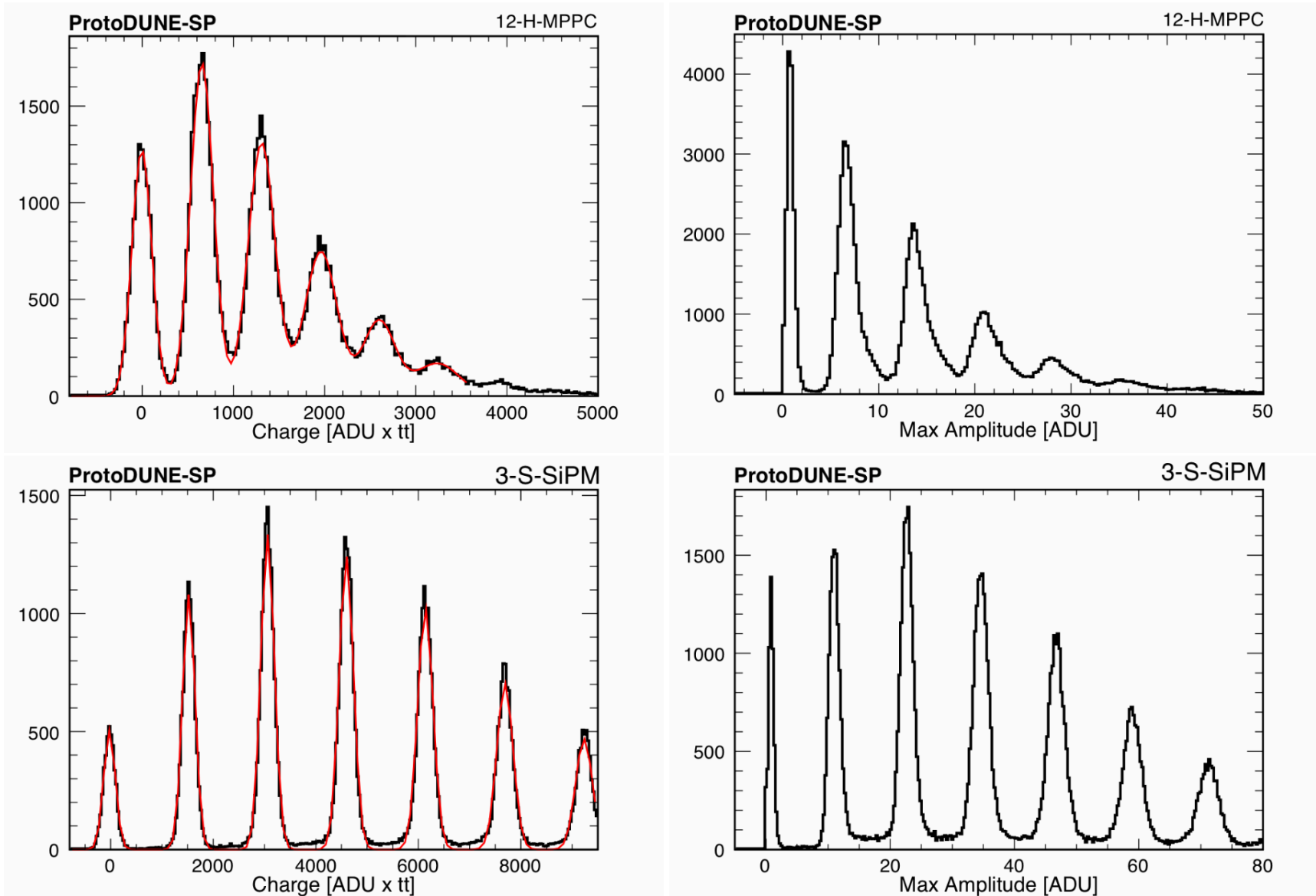
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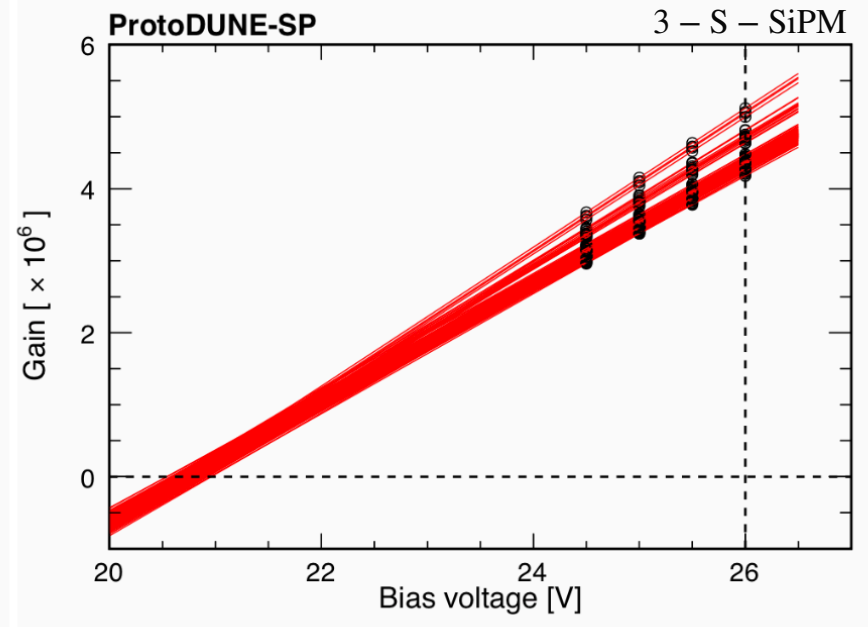
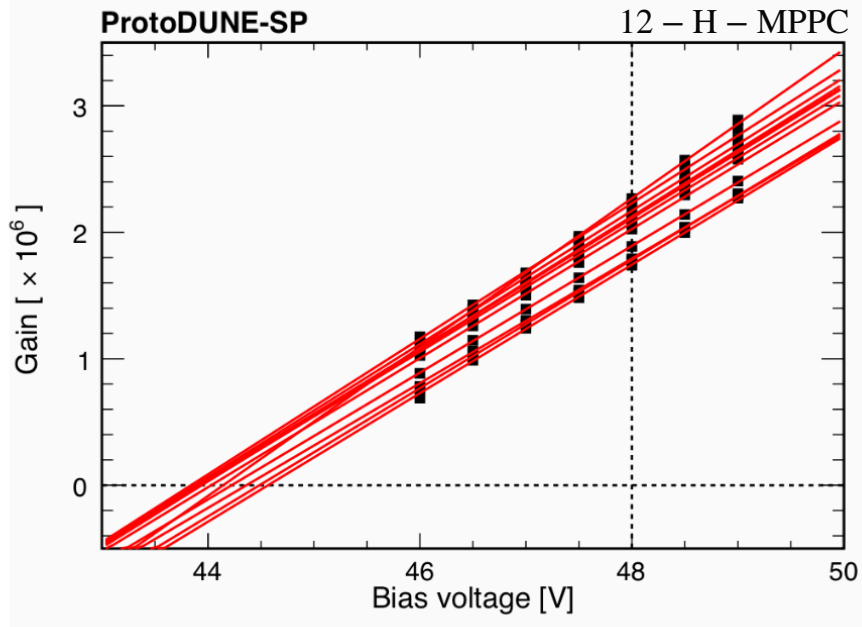


	N. of Channels	N.Channels per Module	N.Dip Coated Modules	N.DoubleShift Modules	N.ARAPUCA Modules
3-S-SiPM	172	4	21	22	-
3-H-MPPC	60	4	8	7	-
12-H-MPPC	24	12	-	-	2

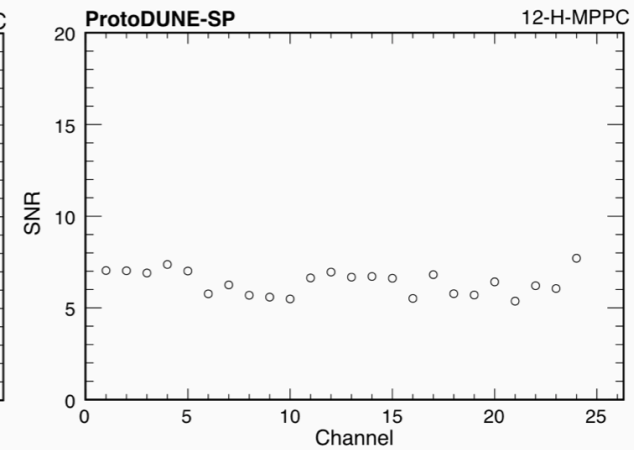
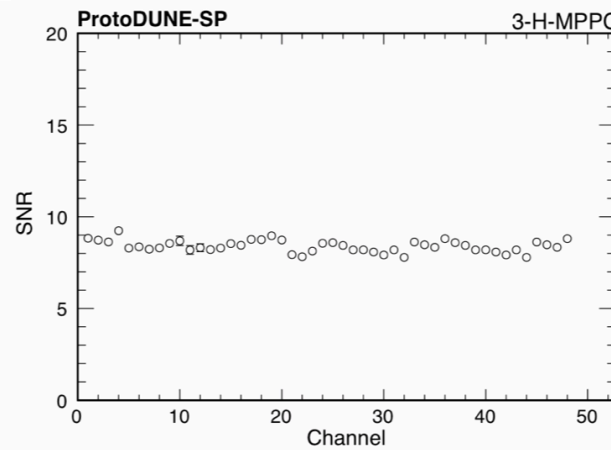
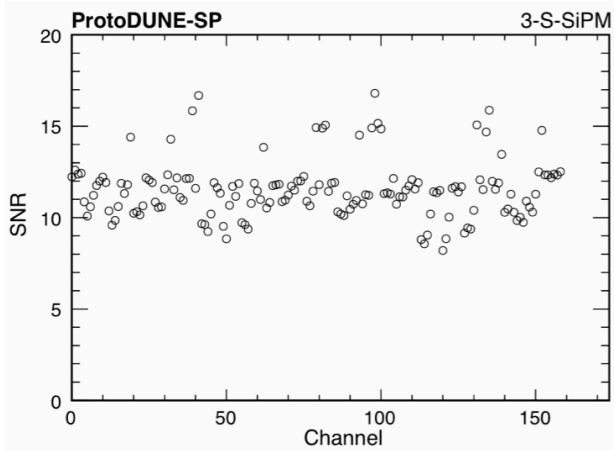






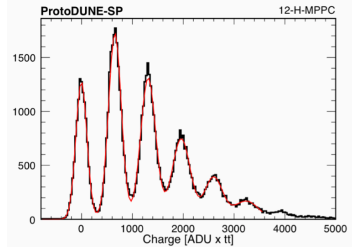


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- 5.2.3 Light Calibration [37](#)
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$$P(n) = \frac{\lambda^n e^{-\lambda}}{n!} \quad \text{with} \quad P(0) = e^{-\lambda} \quad \rightarrow \quad \lambda = -\ln P(0)$$

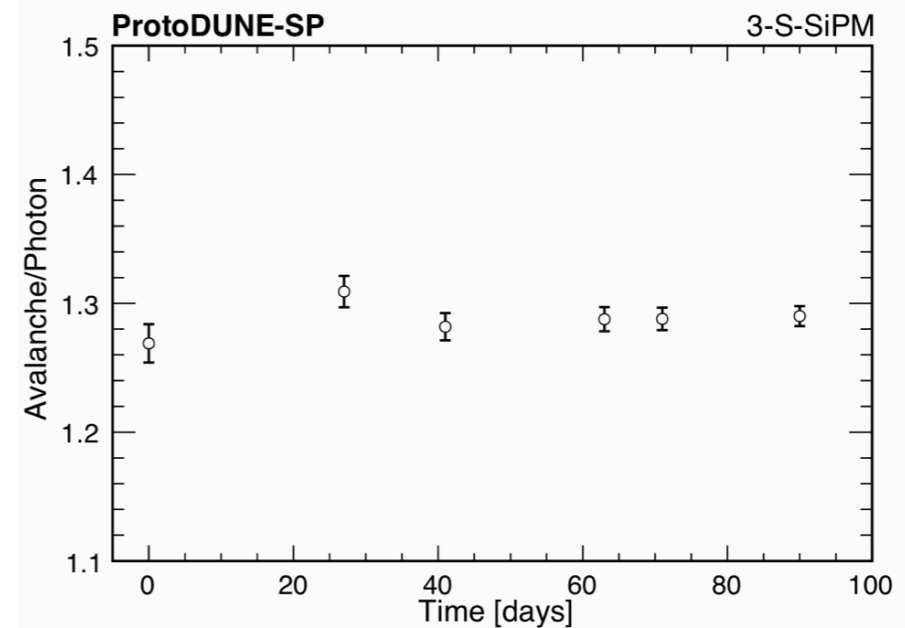
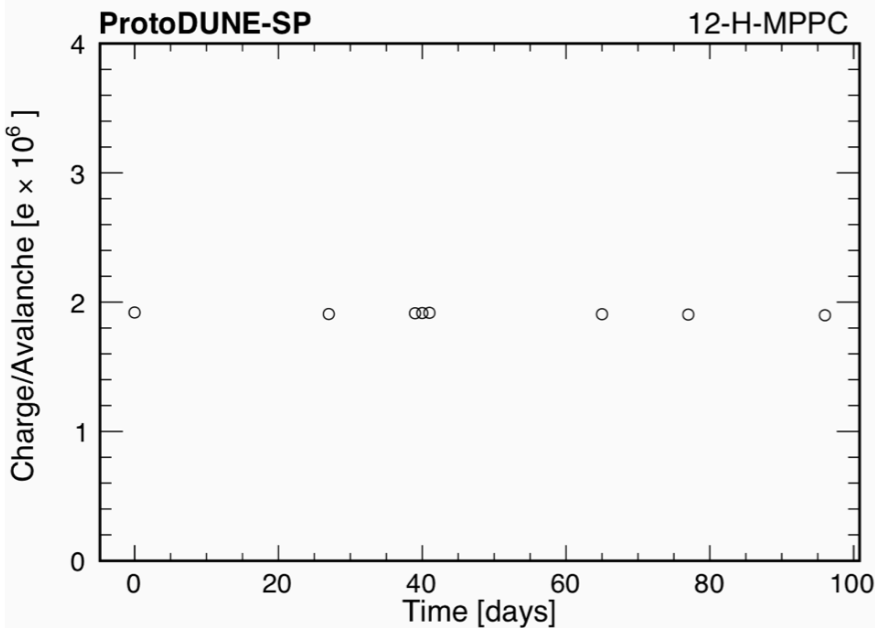
$$\lambda = -\ln \left(\frac{N_0}{N_{Tot}} \right)$$



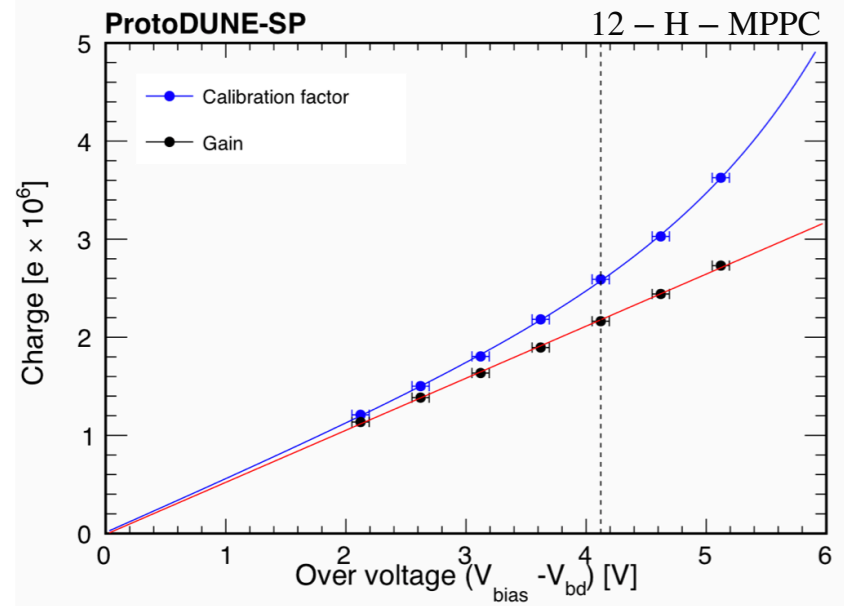
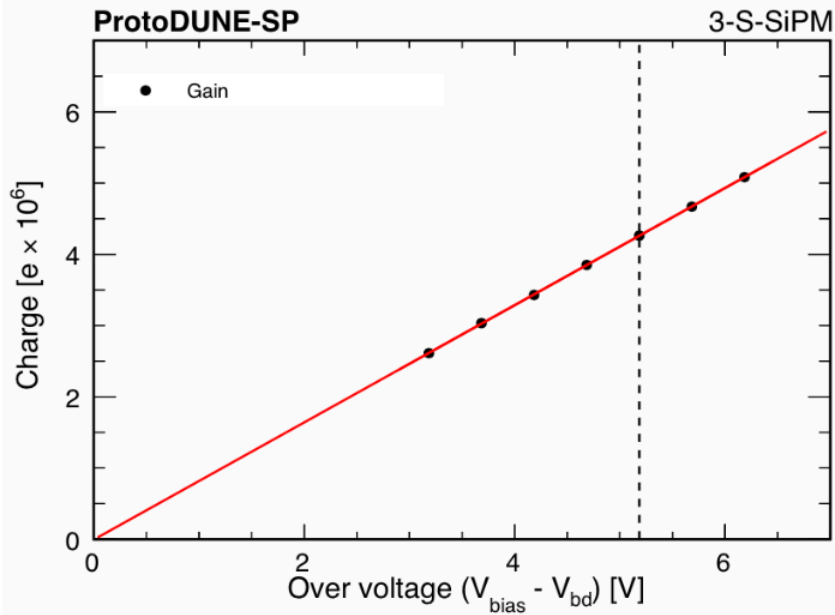
CALIBRATION

From Charge output to N. Of photons detected

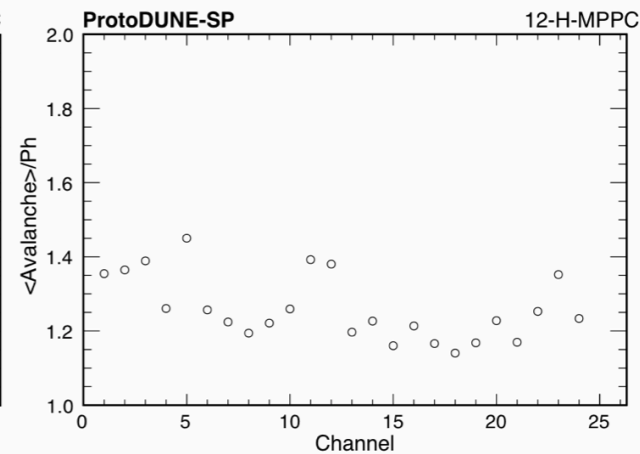
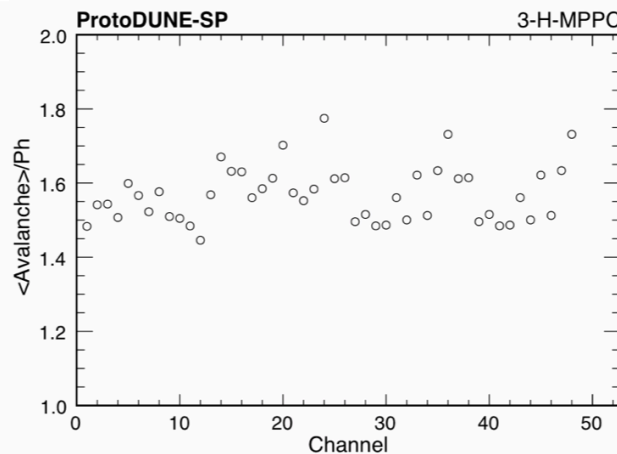
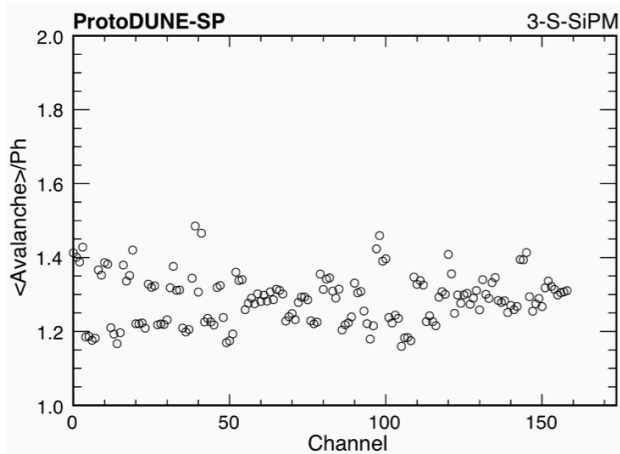
$$C = \frac{\langle Q \rangle}{\lambda}$$



Response Stability over time (100 days)



After Pulses and Cross Talk



5.3 Photo Detector Performance

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5.3.1 Efficiency

42

5.3.2 Time Resolution

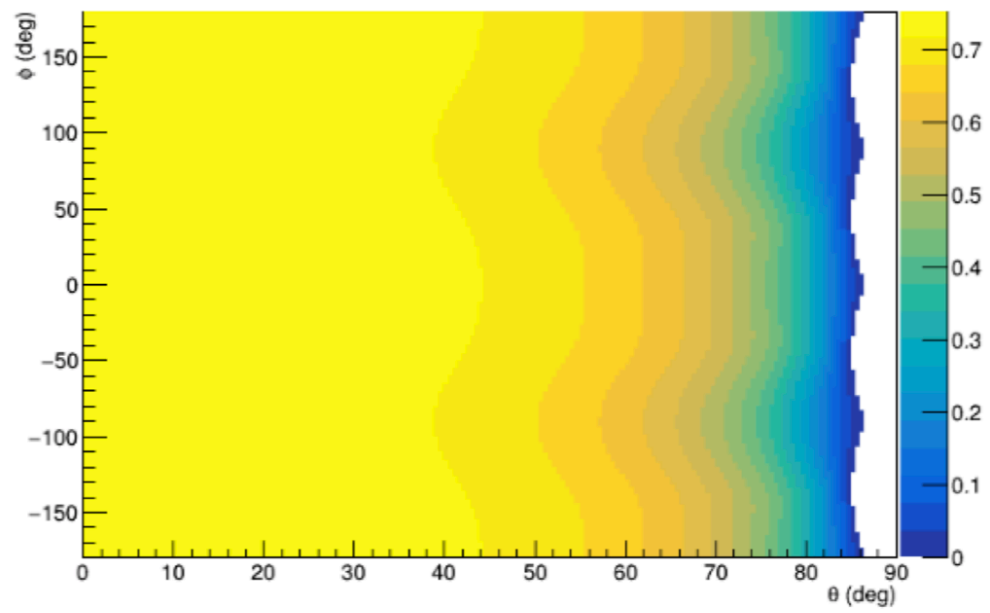
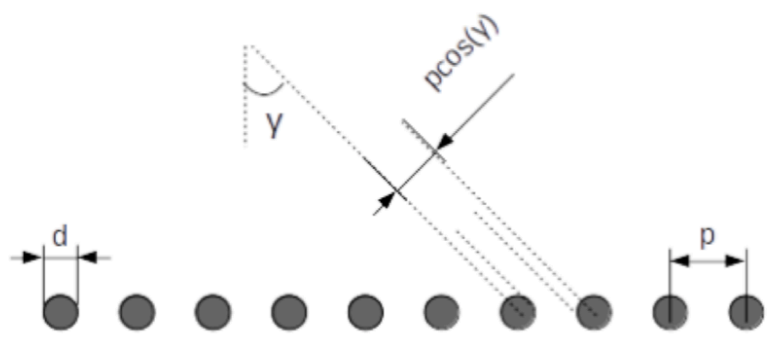
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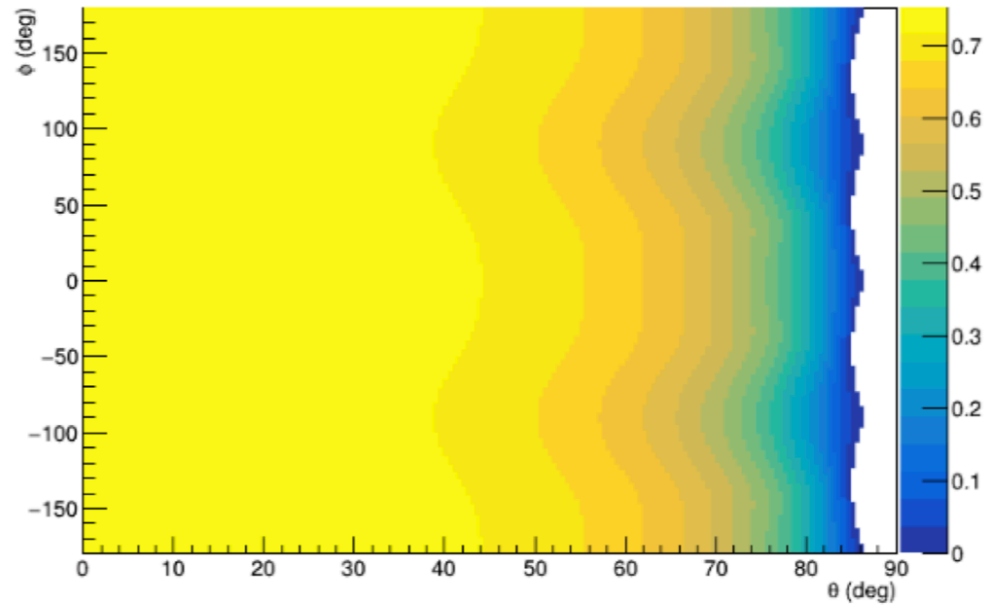
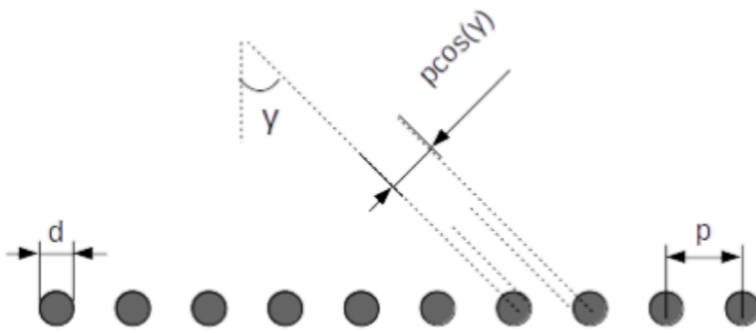
5.4 MonteCarlo Validation with Cosmics *SubSection in preparation*

$\langle N_j^D \rangle$ Photons landing on detector optical surface [MC: LArG4+PhotonLibrary+Transmission]

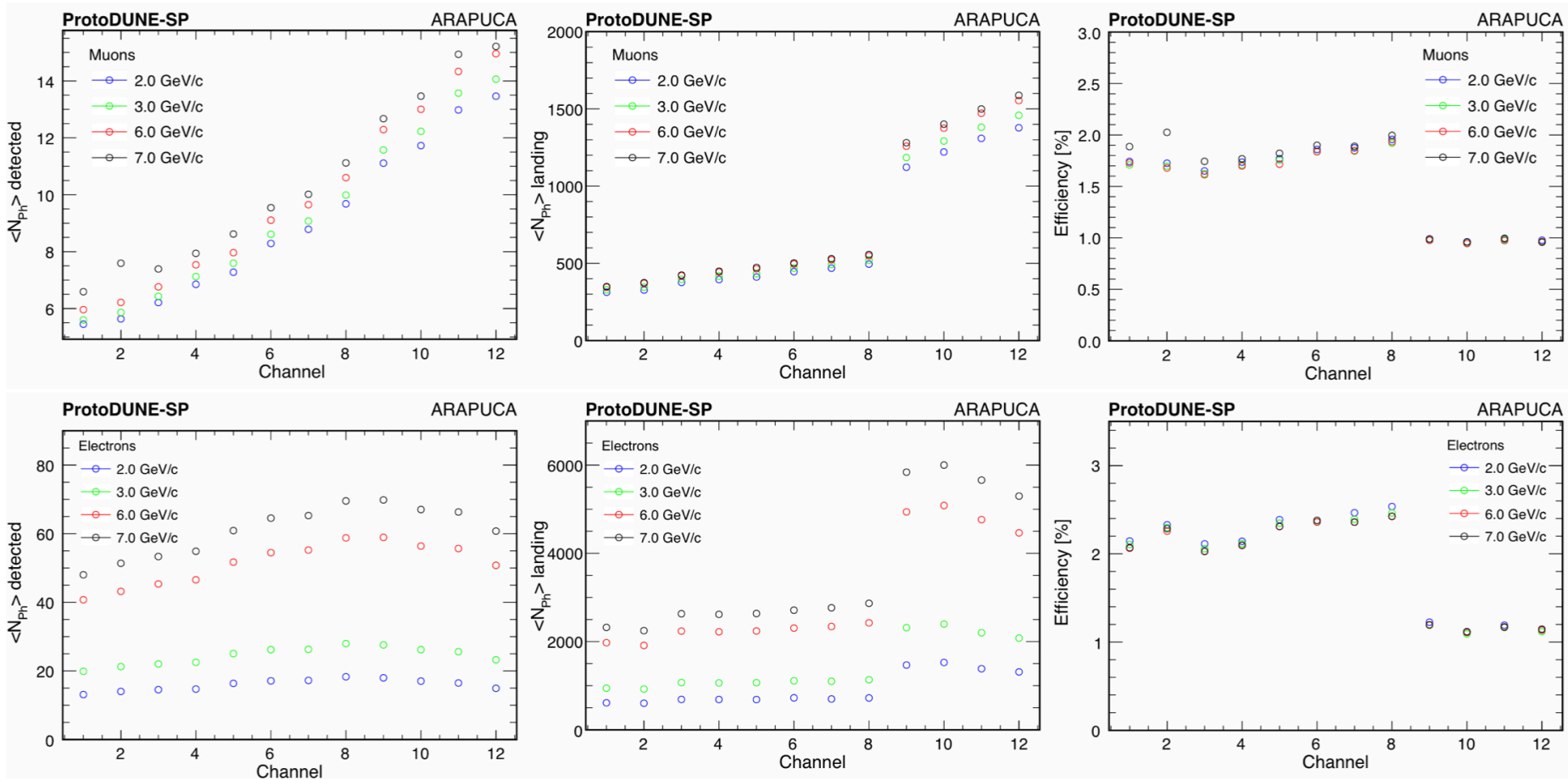
$\langle N_j^L \rangle$ Photons detected [DATA: calibrated signals]

$$\epsilon_j = \frac{\langle N_j^D \rangle}{\langle N_j^L \rangle} \text{ efficiency}$$





Detection efficiency of the ARAPUCA Bar (in APA3) - [12 cells]



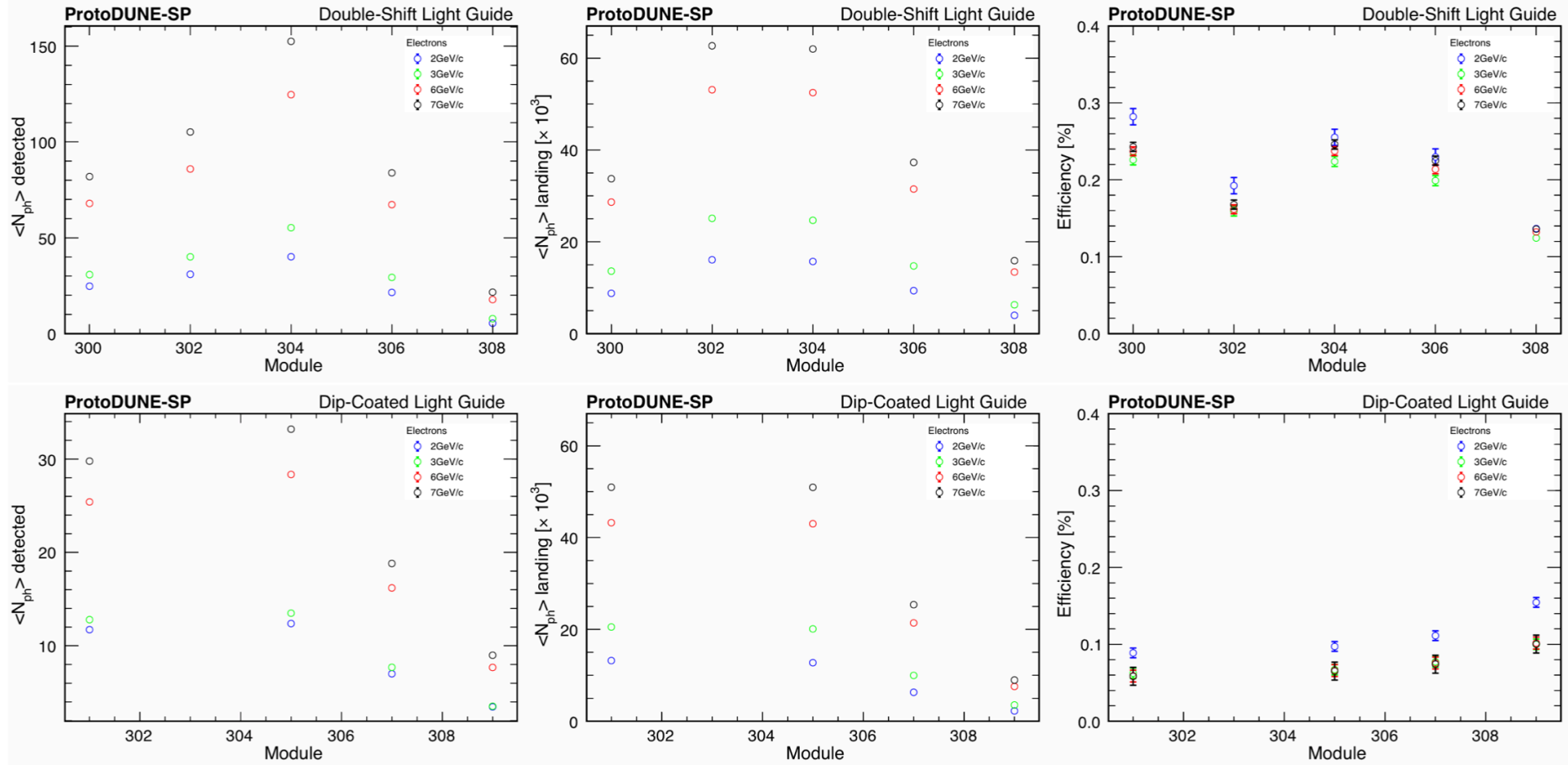
The detection efficiency of the ARAPUCA detectors in the ProtoDUNE-SP PD system is finally taken as the median value of the individual cells with its error:

$$\text{cell type-1 ; } \tilde{\epsilon}_1 = (2.05 \pm 0.27)\%$$

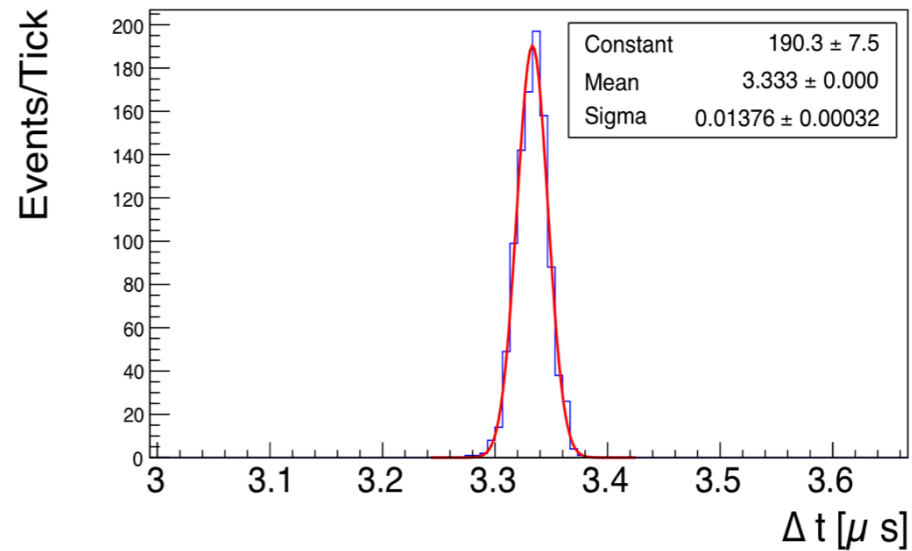
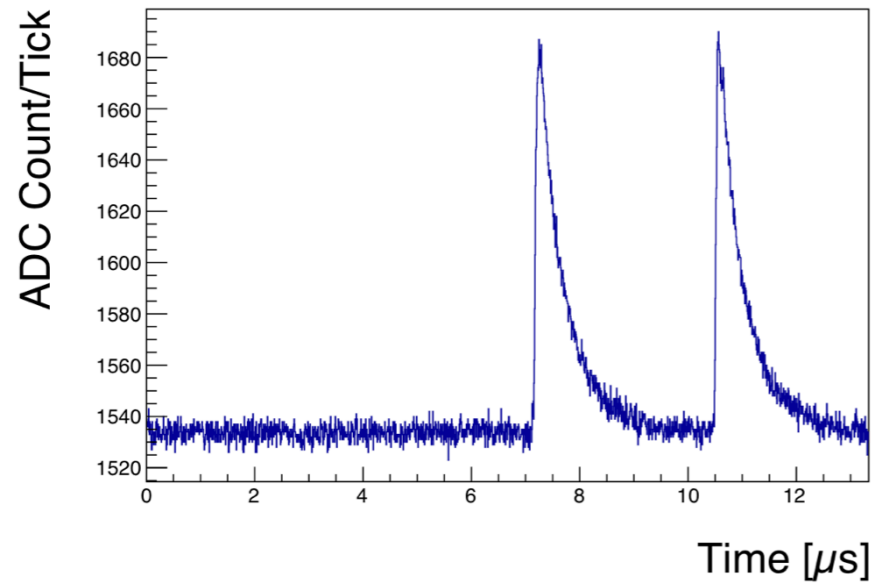
$$\text{cell type-2 ; } \tilde{\epsilon}_2 = (1.06 \pm 0.10)\%$$

where type-1 are cells $j = 1, \dots, 8$ in the ARAPUCA module and type-2 are those $j = 9, \dots, 12$ with double area and same number of photosensors.

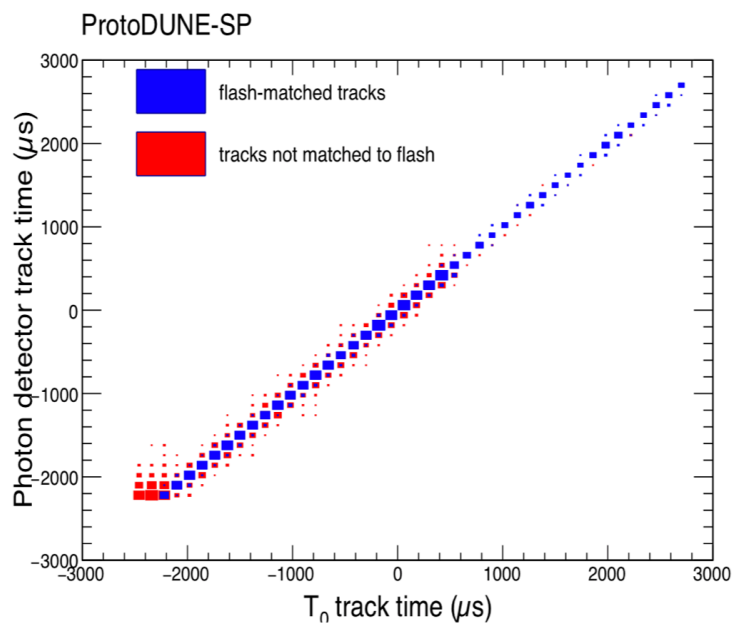
Detection efficiency of the Double-Shift Light Guide Bars (in APA3) - [5 bars]



Detection efficiency of the Dip-Coated Light Guide Bars (in APA3) - [4 bars]



Time Resolution



7 Photon Detector Response

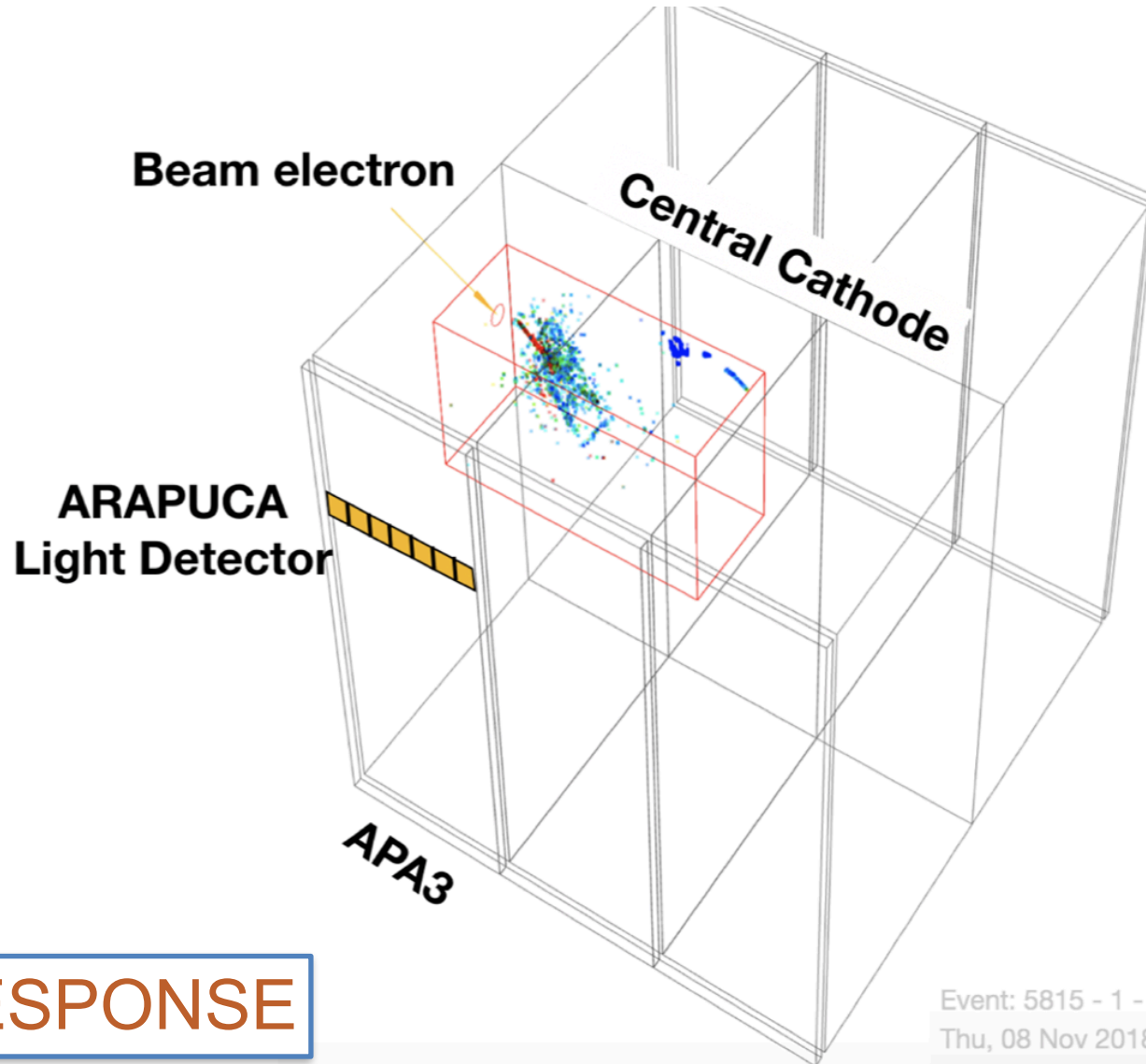
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7.1 Calorimetric Energy reconstruction from scintillation light and Energy resolution

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7.1.1 Beam electrons and EM showers

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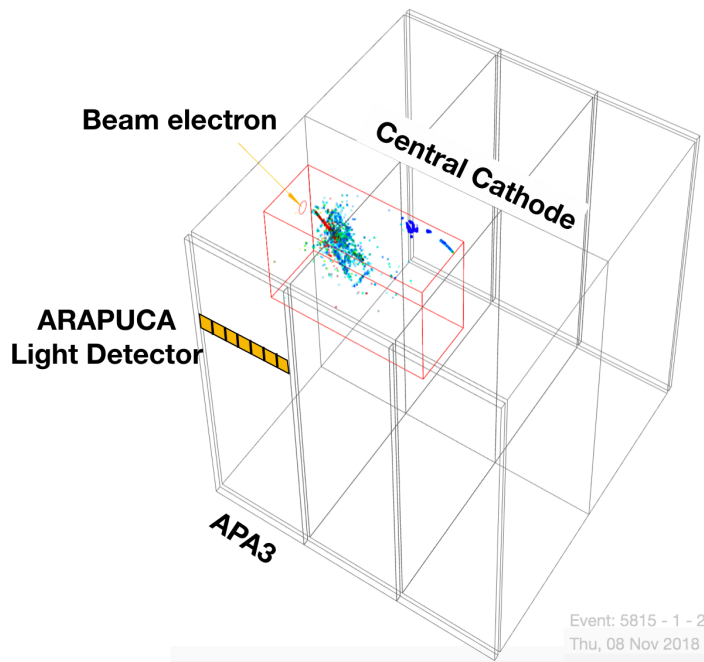


PDS RESPONSE

Event: 5815 - 1 - 2
Thu, 08 Nov 2018

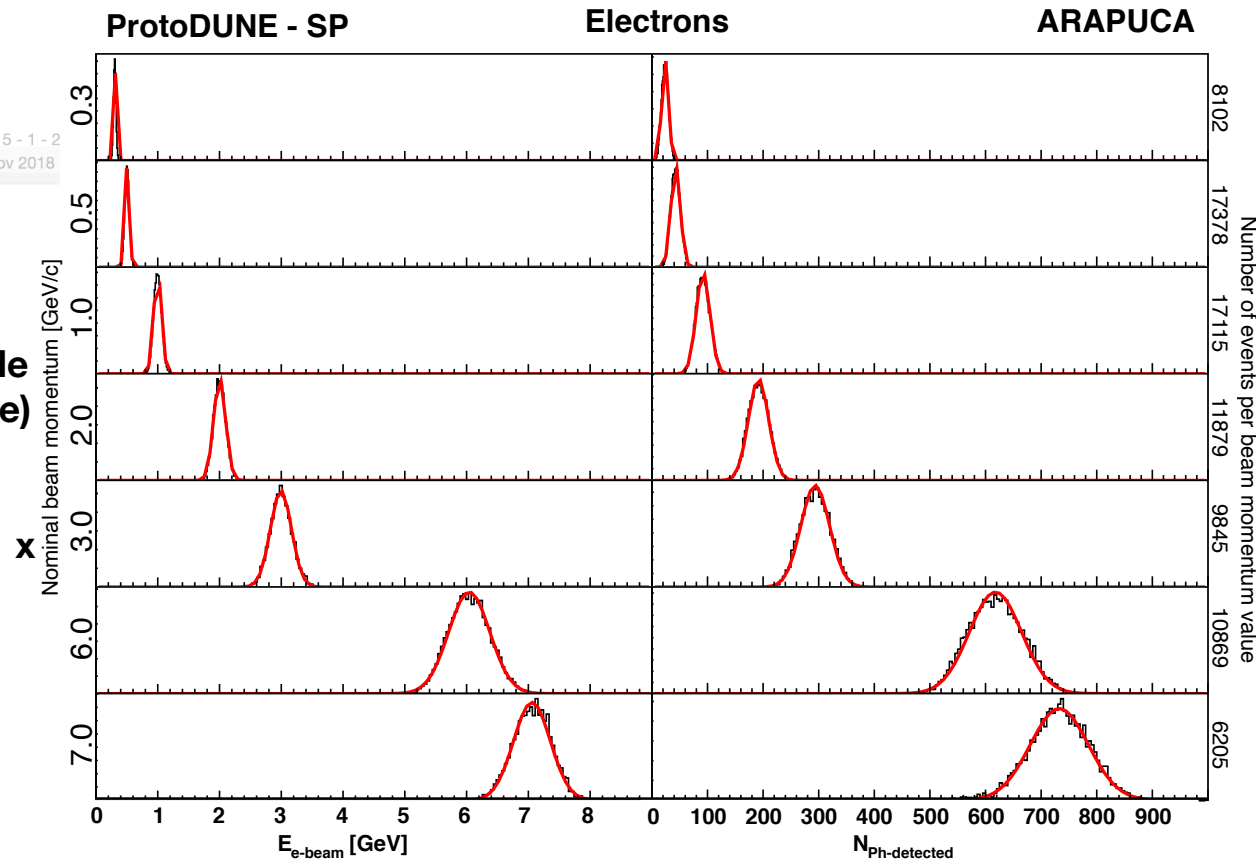
Large LAr detector operating at the CERN Neutrino Platform

Operating on the H4-VLE charged particle test beam offers a first ever opportunity to directly probe the calorimetric response *with light* to EM and hadronic showers in the sub- to few-GeV momentum range.



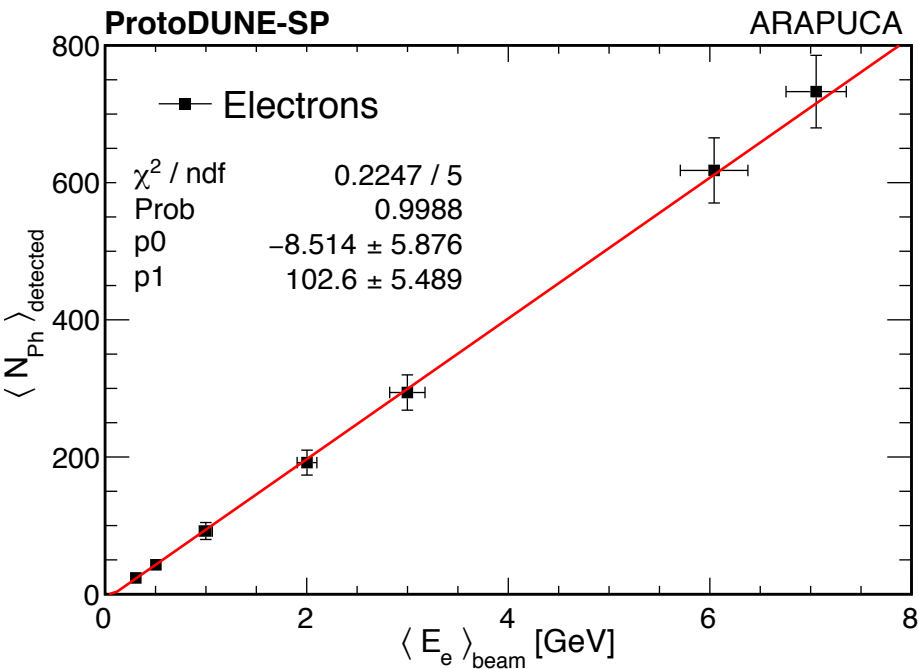
calorimetric response from Light signal from a single ARAPUCA module (~0.5‰ photo-sensitive area coverage)

EM shower at ~3 m distance in the (drift) direction



Incident Electron momentum distribution

detected photons spectra



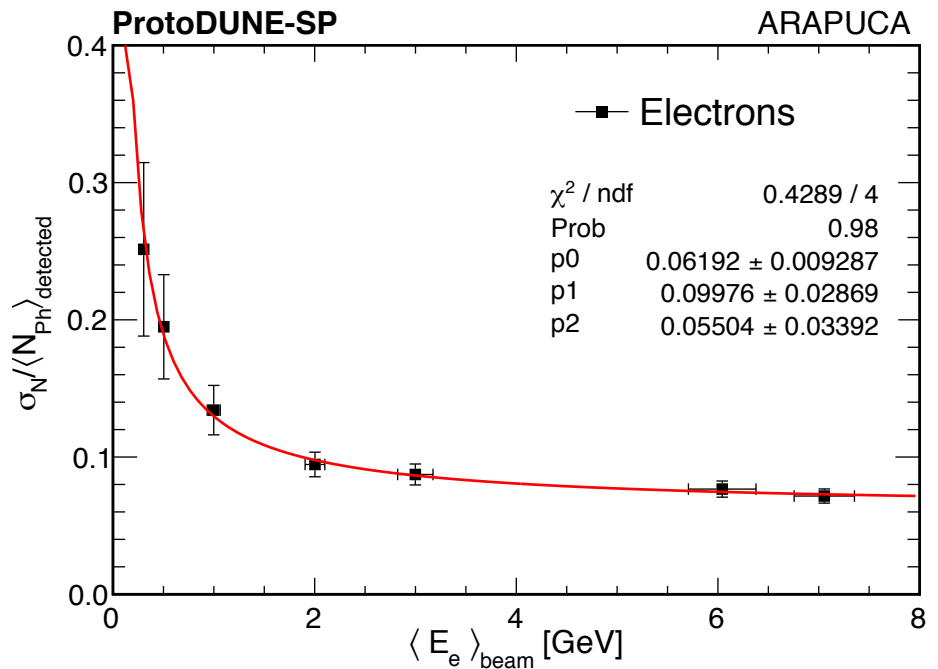
Linearity

of light response over the entire range of energies.

The slope gives the light yield

$$LY = 103 \text{ Ph/GeV}$$

from (only) one ARAPUCA module, relative to a diffused light source (EM shower) at a distance of about 3 m



Energy Resolution from light

$$\frac{\sigma_E}{E} = p_0 \oplus \frac{p_1}{\sqrt{E}} \oplus \frac{p_2}{E}$$

- Stochastic term: $p_1 = 10 \%$
from limited photo-sensitive area coverage
- Noise term: $p_2 = 55 \text{ MeV}$
from excellent SiPM readout S/N ratio
- Constant term: $p_0 = 6.2 \%$
from non-uniformities in light collection (from one side only)

7 Photon Detector Response

7.1 Calorimetric Energy reconstruction from scintillation light and Energy resolution

7.1.1 Beam electrons and EM showers

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7.2 Single Photon rate

PDS RESPONSE

Last section (in preparation)

- **Light from ionizing events**
- **Single photons from recombinations**

$\langle Rate \rangle = xxx \pm yy$ kHz and rate stability over time

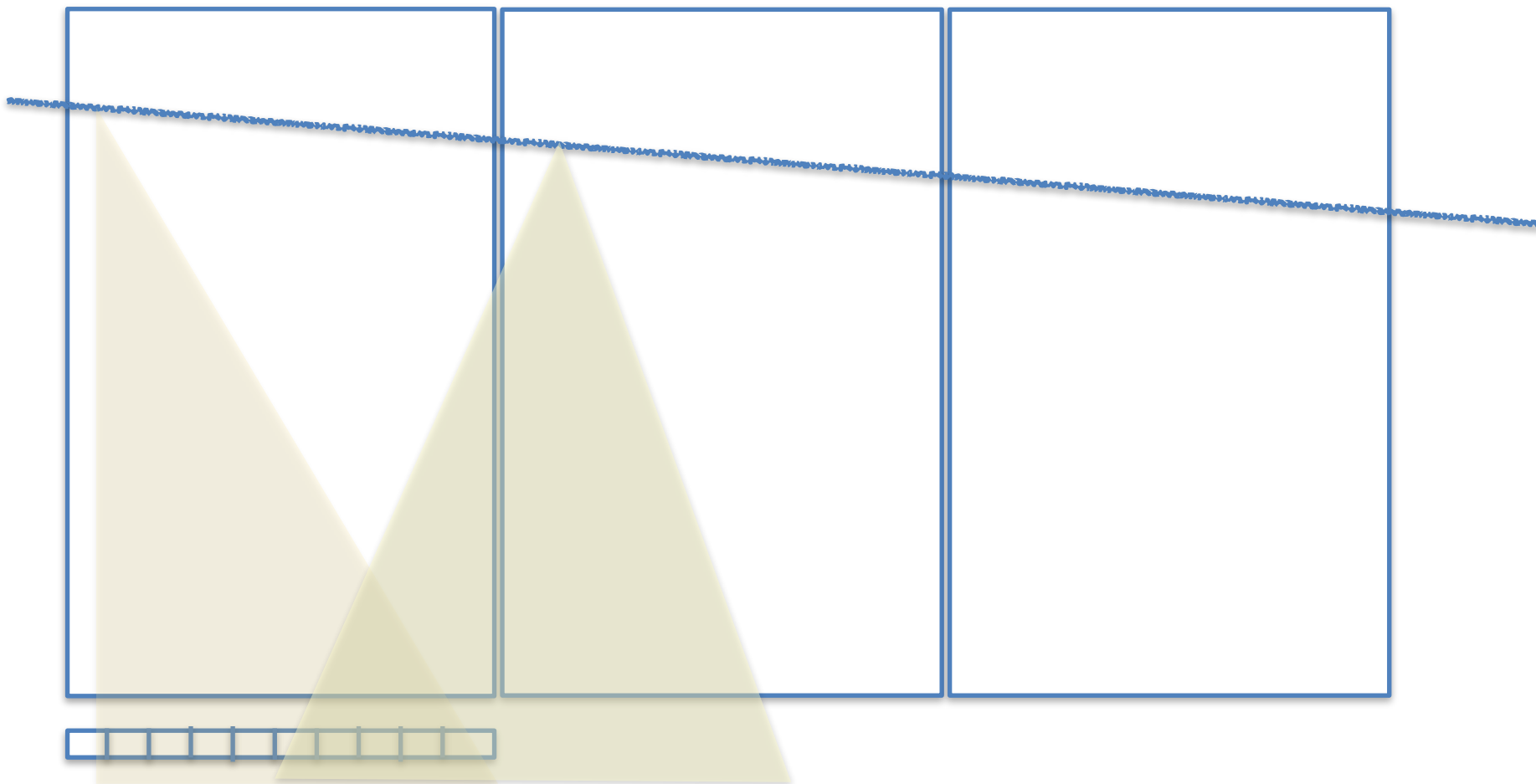
Single photon rate vs electric field



BACK UP

Crossing Muon

PDS RESPONSE



EM Shower

PDS RESPONSE

