DEEP UNDERGROUND NEUTRINO EXPERIMENT

PROTO DUNE SP

Status of the Performance Paper

Performance of the Photon Detector

Flavio Cavanna for the **ProtoDUNE/DUNE PDS Group**

Collaboration Call

FNAL - Nov. 8, 2019

Fermilab DUNE

PREPARED FOR SUBMISSION TO JINST

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

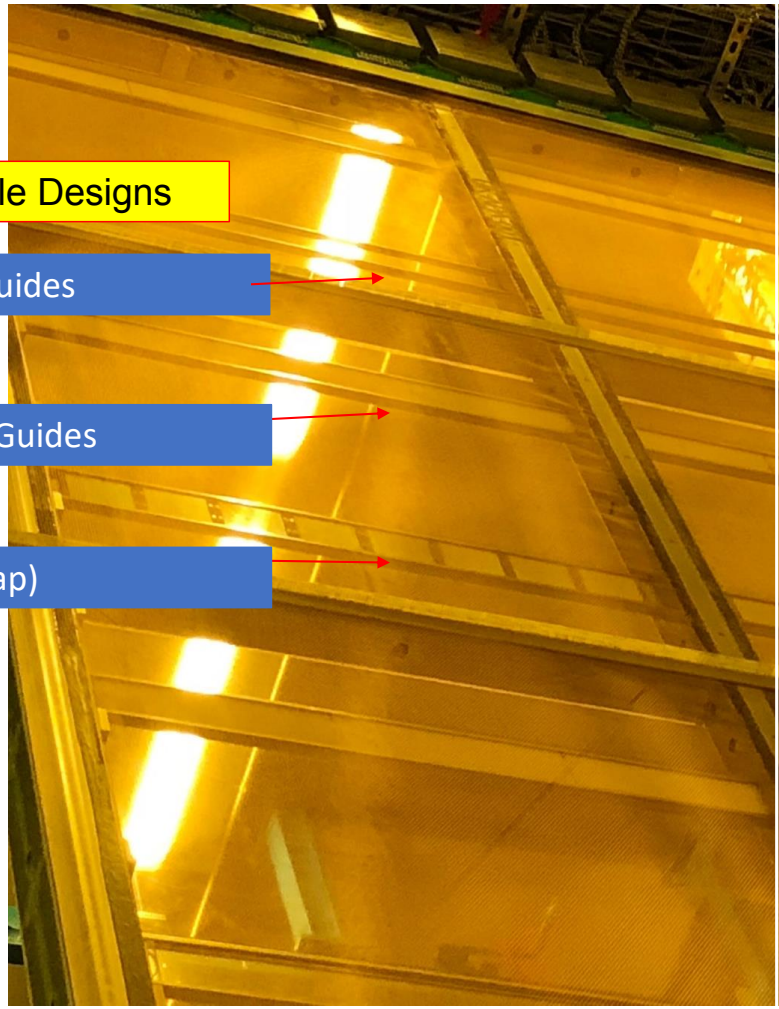
Contents

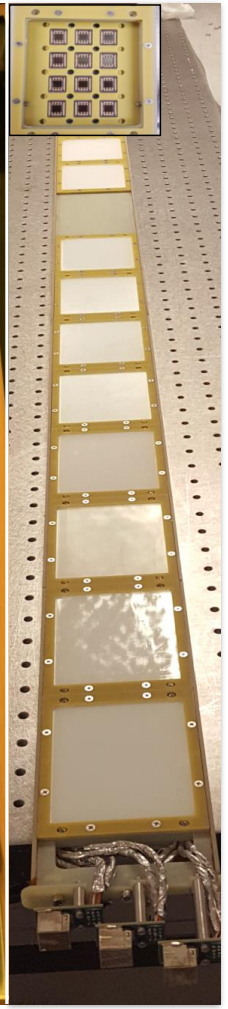
PD Module Designs

Dip-Coated Light Guides

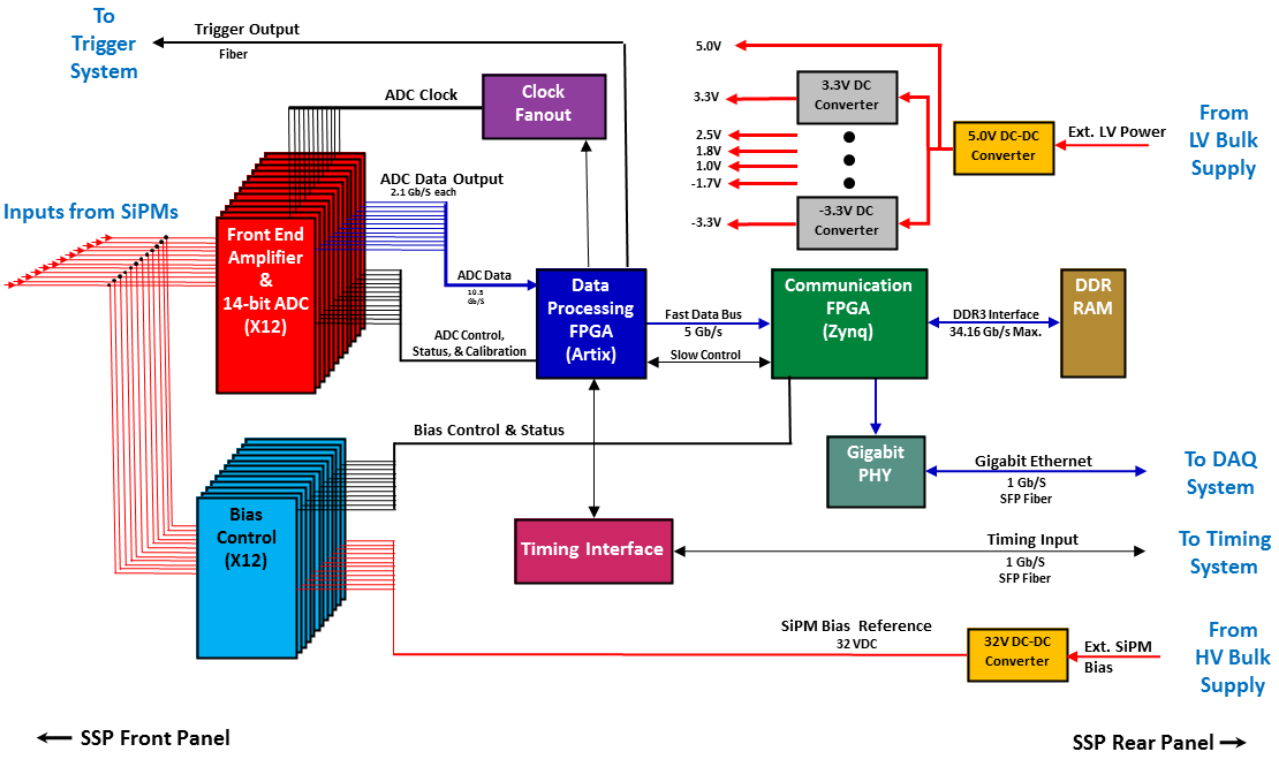
Double-Shift Light Guides

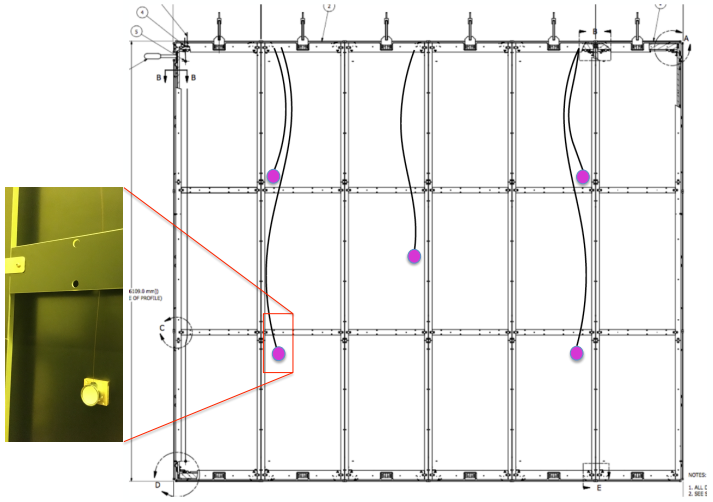
ARAPUCA (Light Trap)

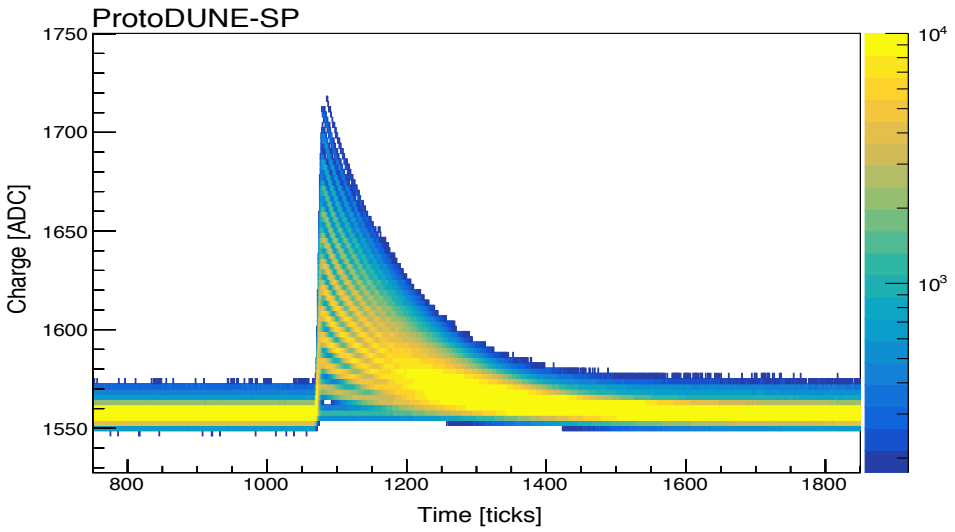


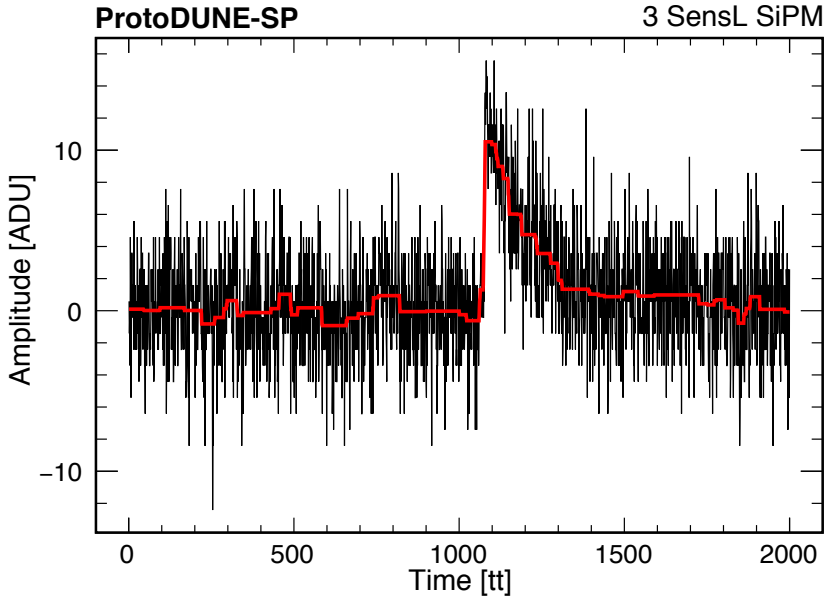


	N. of Channels	N.Channels per Module	N.Dip Coated Modules	N.DoubleShift Modules	N.ARAPUCA Modules
3-S-SiPM	172	4	21	22	-
3-H-MPPC	60	4	8	7	-
12-H-MPPC	24	12	-	-	2






ProtoDUNE-SP
Charge [ADC]
Time [ticks]
1750
1700
1650
1600
1550
800
1000
1200
1400
1600
1800
10^4
10^3


ProtoDUNE-SP
3 SensL SiPM
Amplitude [ADU]
Time [tt]
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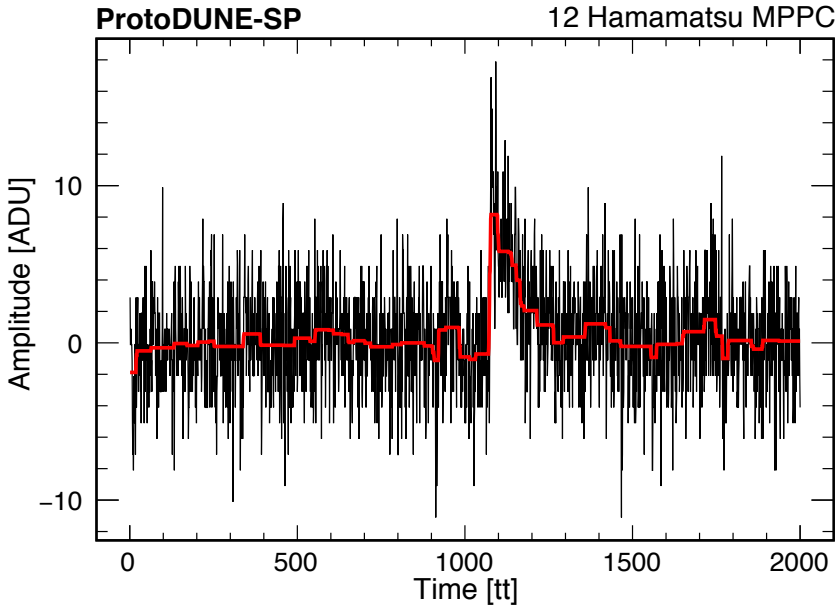
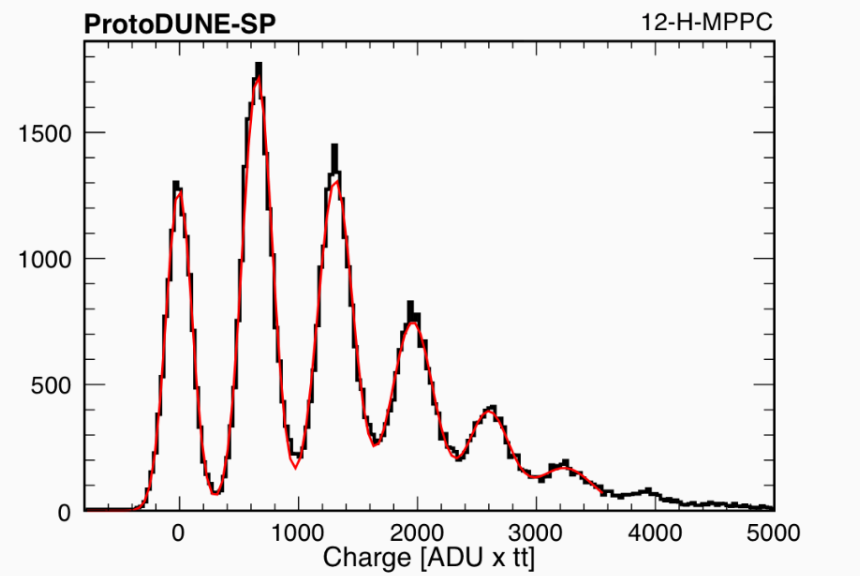
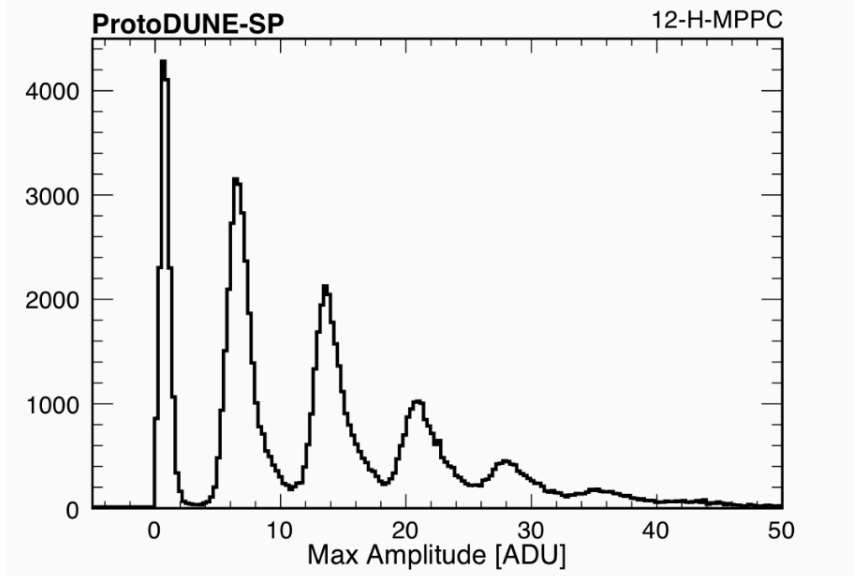
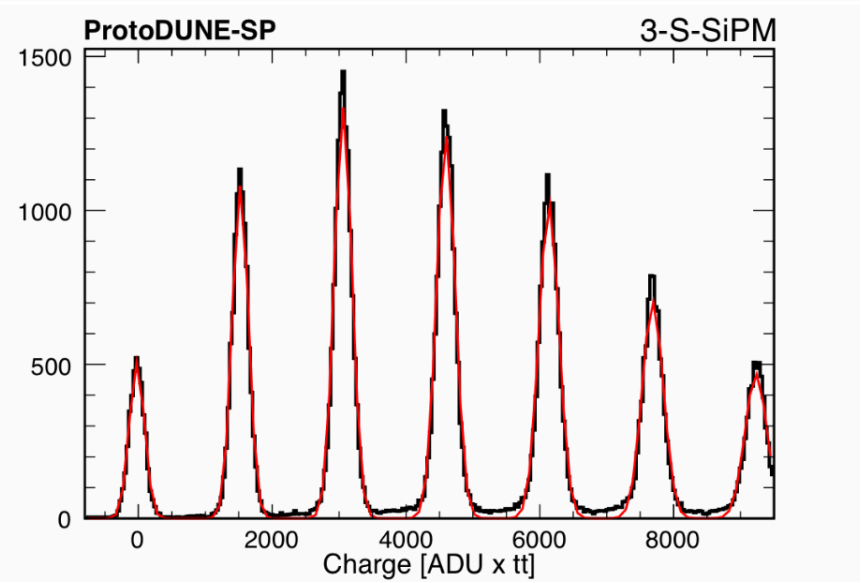
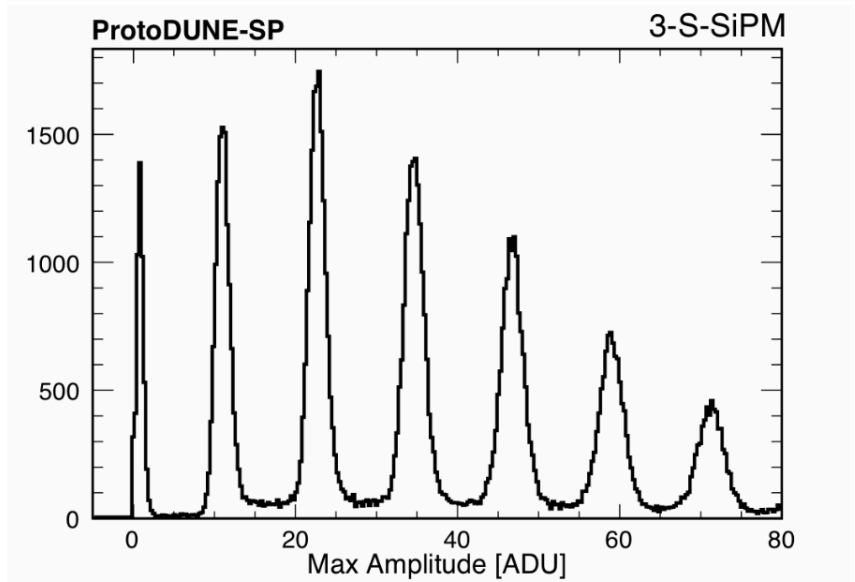
0
−10
0
500
1000
1500
2000

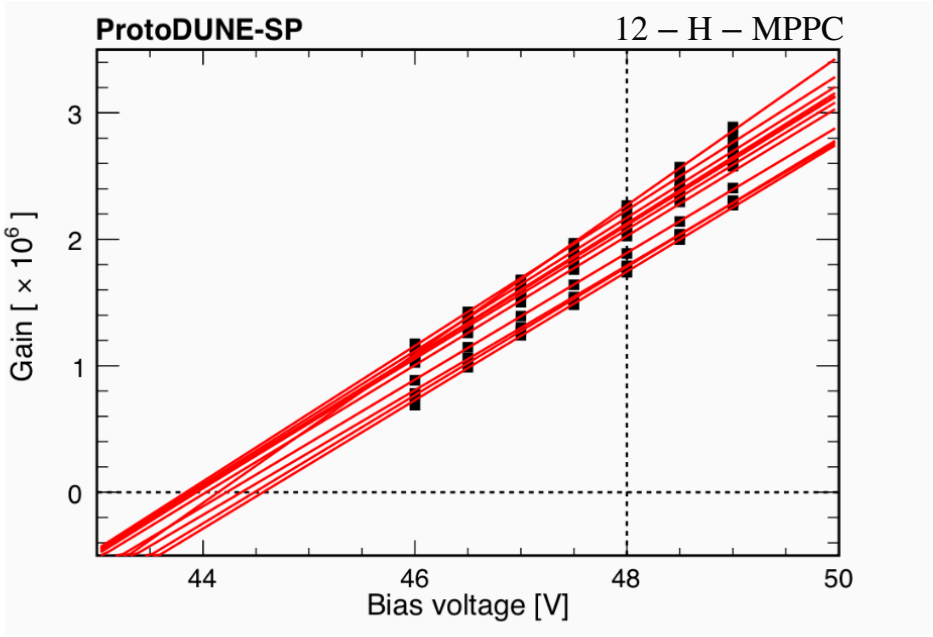

ProtoDUNE-SP
12 Hamamatsu MPPC
Amplitude [ADU]
Time [tt]
10
0
−10
0
500
1000
1500
2000

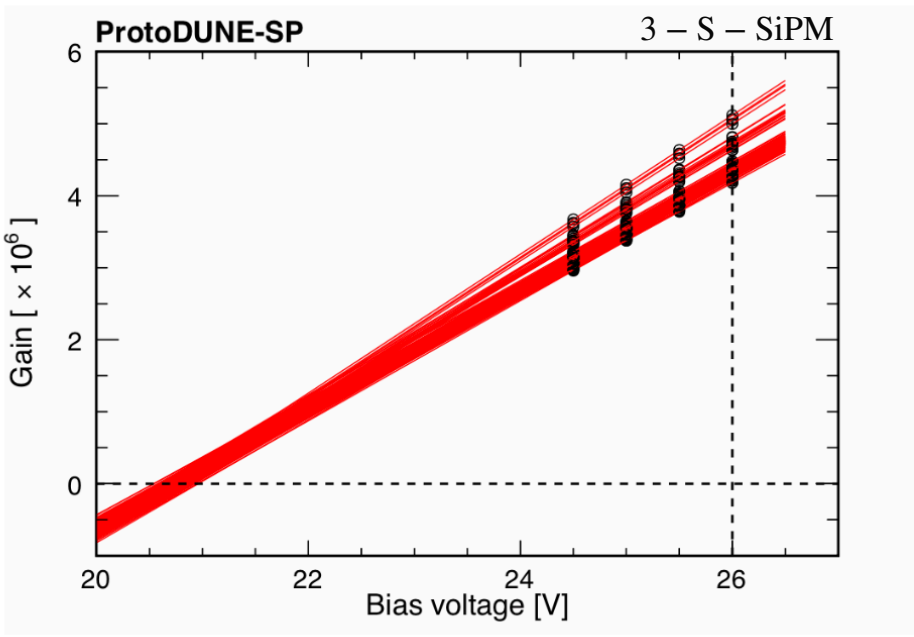


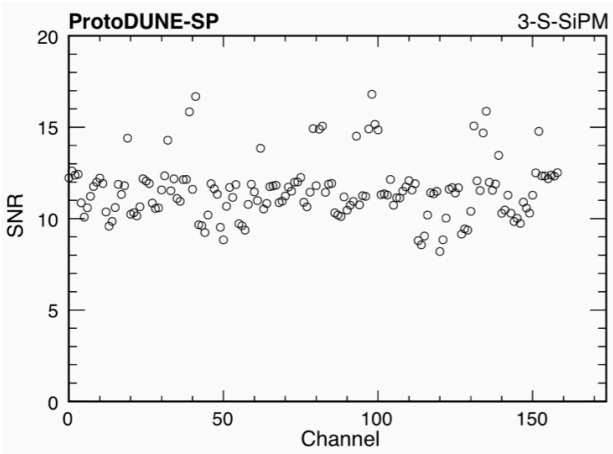


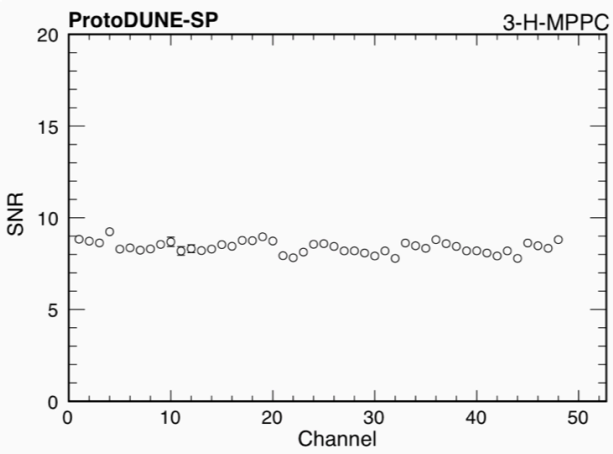


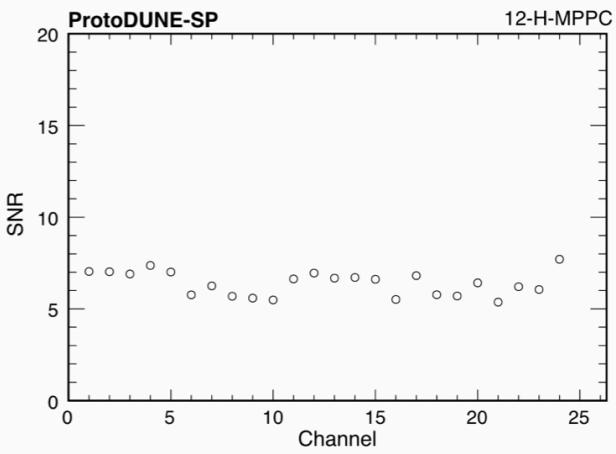






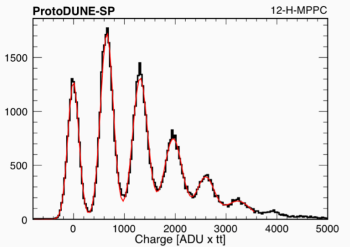






$$P(n) = \frac{\lambda^n e^{-\lambda}}{n!} \qquad \text{with} \qquad P(0) = e^{-\lambda} \qquad \rightarrow \qquad \lambda = -\ln P(0)$$

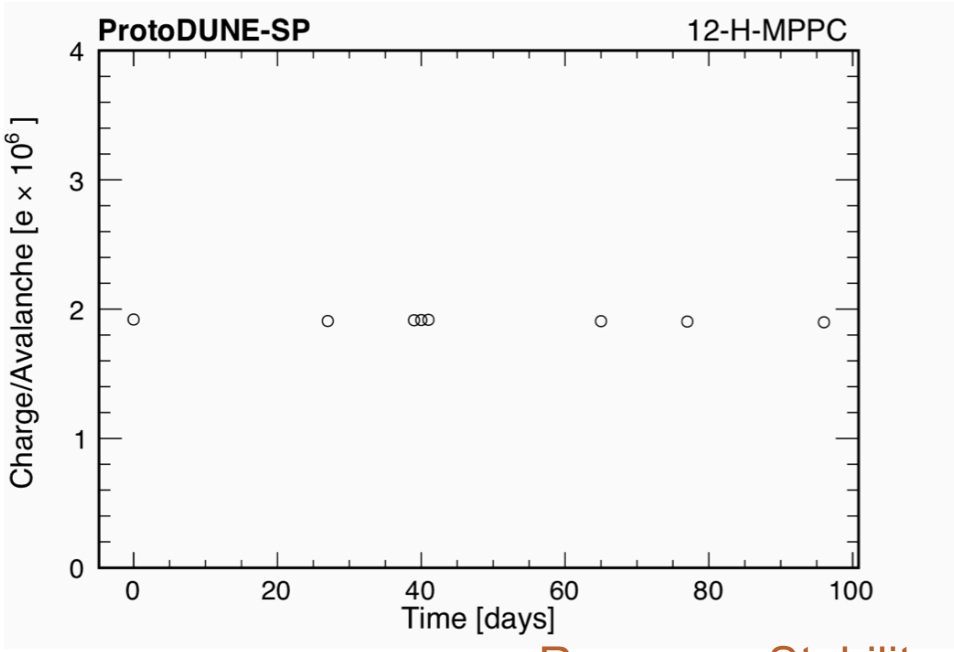
$$\lambda = -\ln\left(\frac{N_0}{N_{Tot}}\right)$$

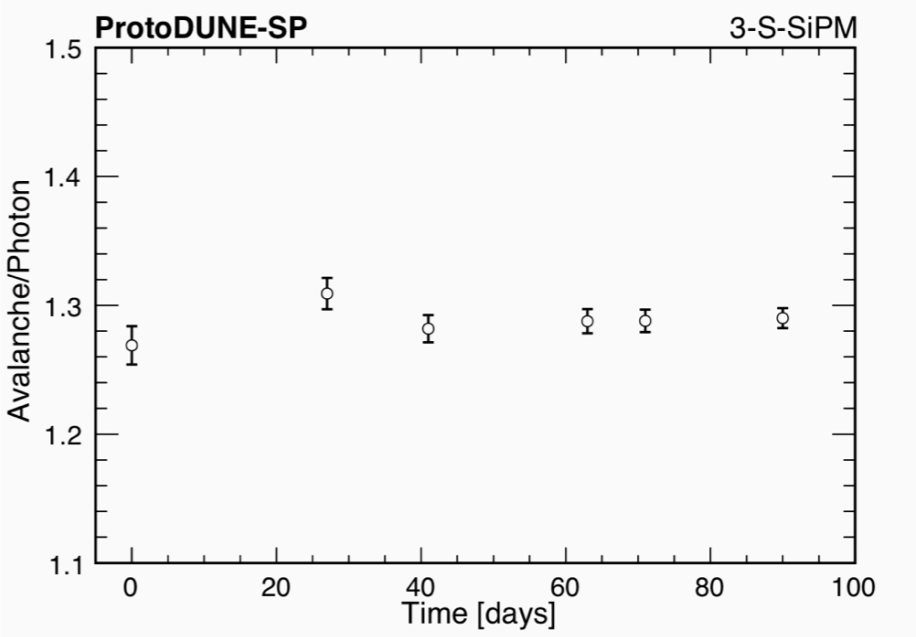


CALIBRATION

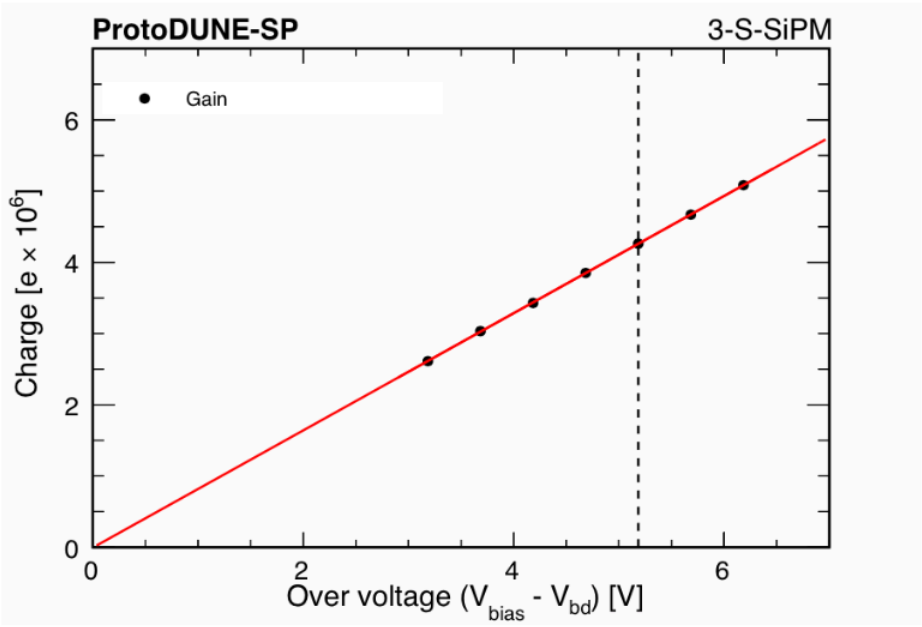
From Charge output to N. Of photons detected

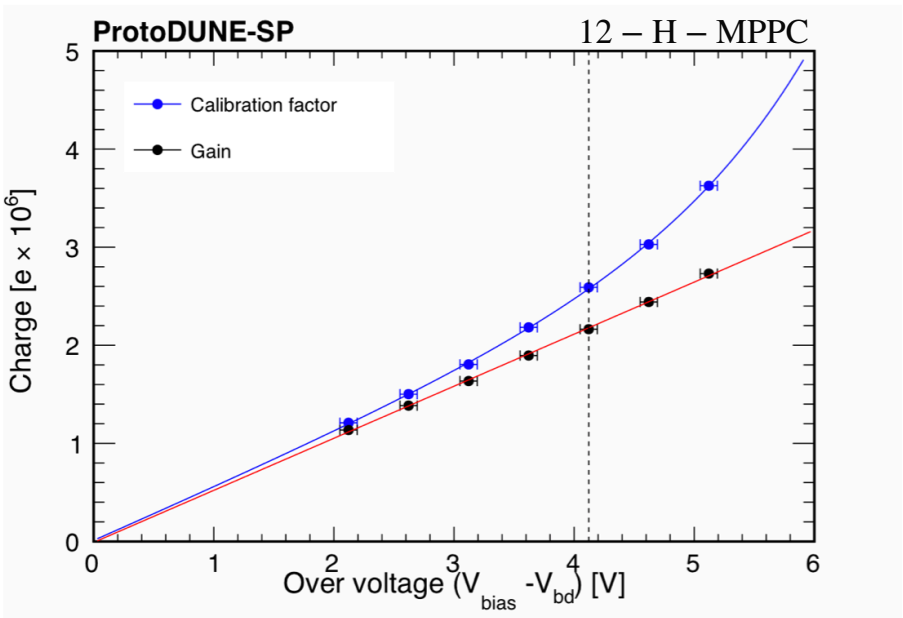
$$C = \frac{\langle Q \rangle}{\lambda}$$



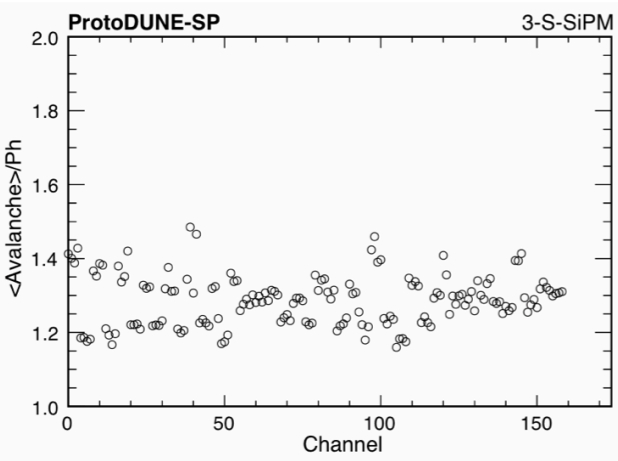


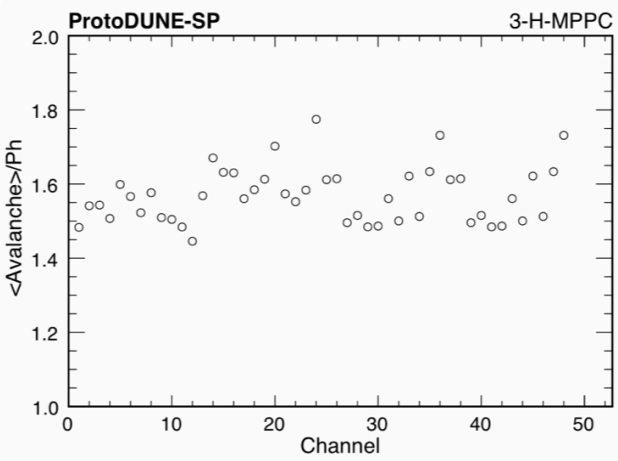
Response Stability over time (100 days)

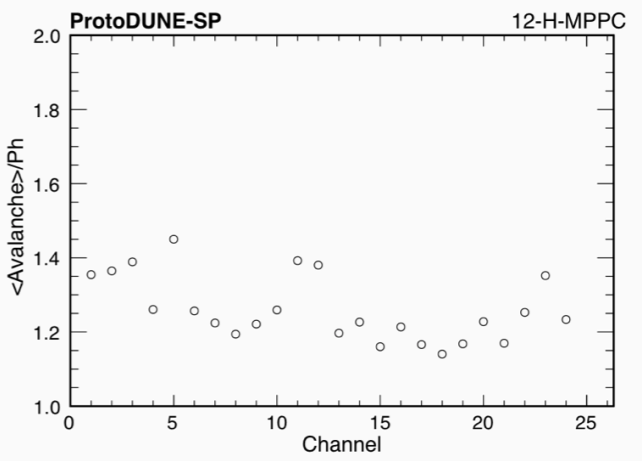




After Pulses and Cross Talk



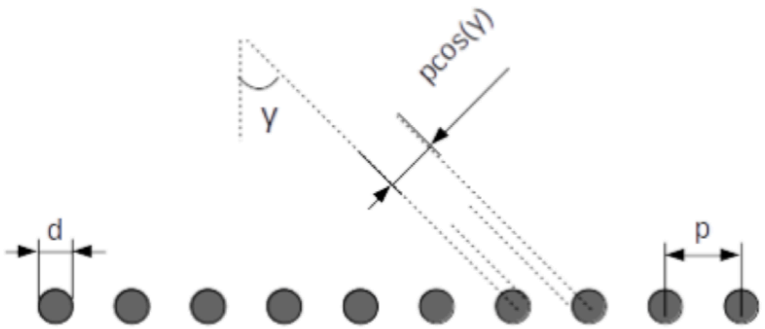


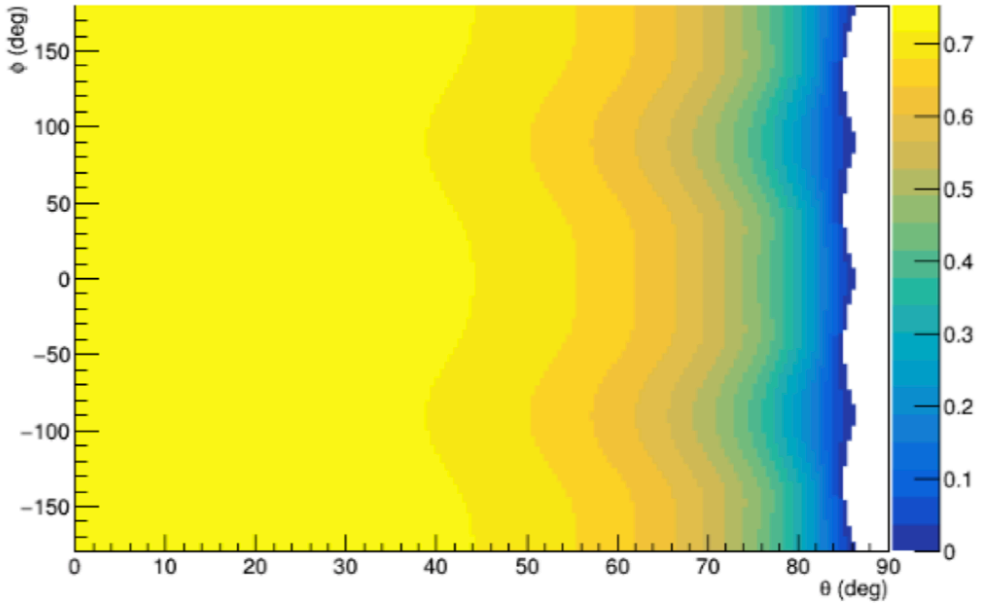


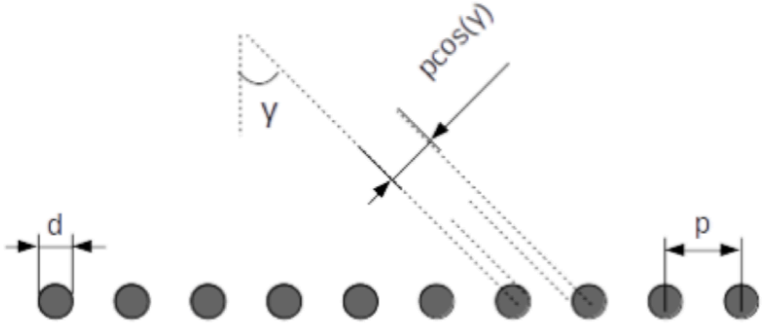
$\langle N_j^D \rangle$ Photons landing on detector optical surface [MC: LArG4+PhotonLibrary+Transmission]

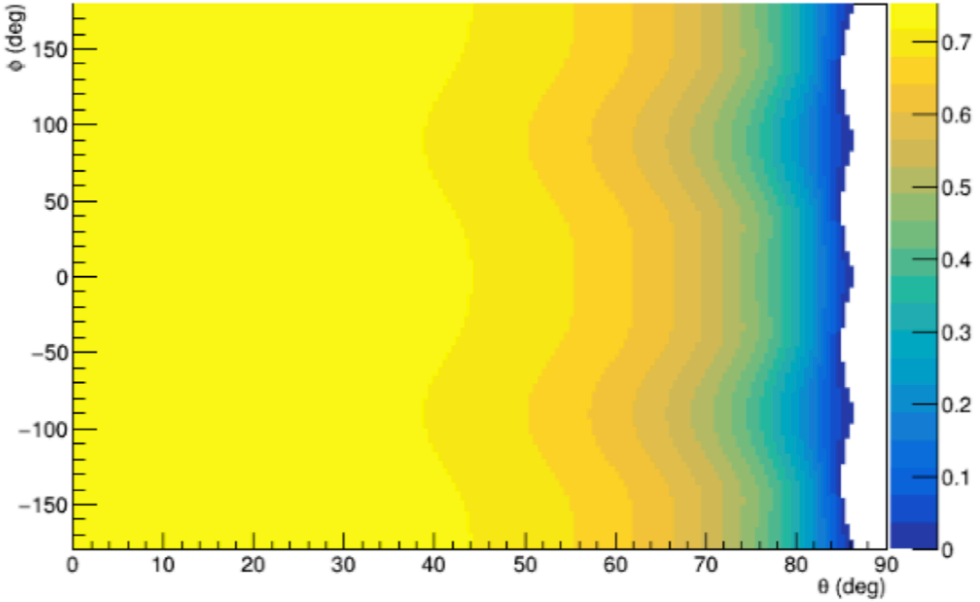
$\langle N_j^L \rangle$ Photons detected [DATA: calibrated signals]

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

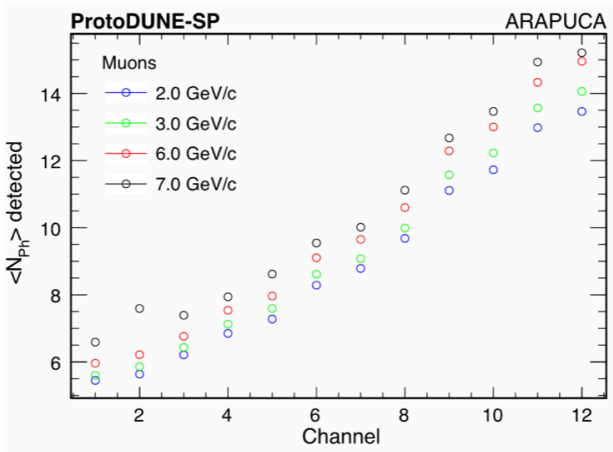


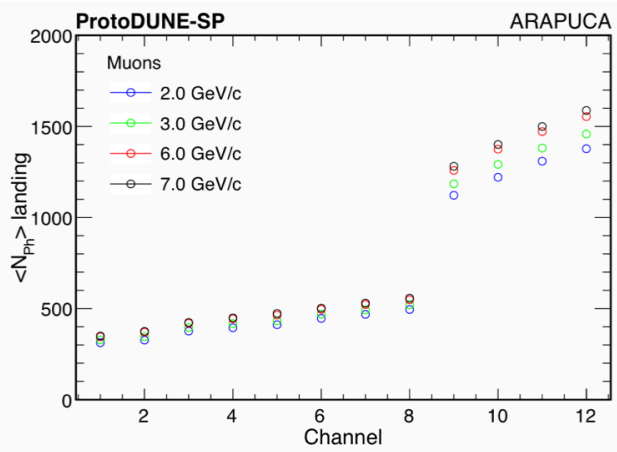


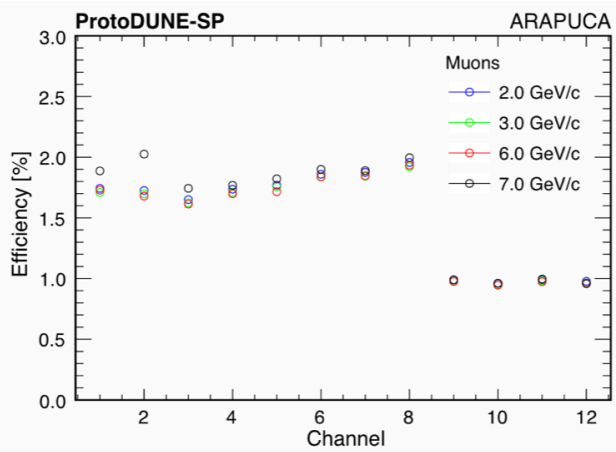

pcos(γ)
γ
d
p

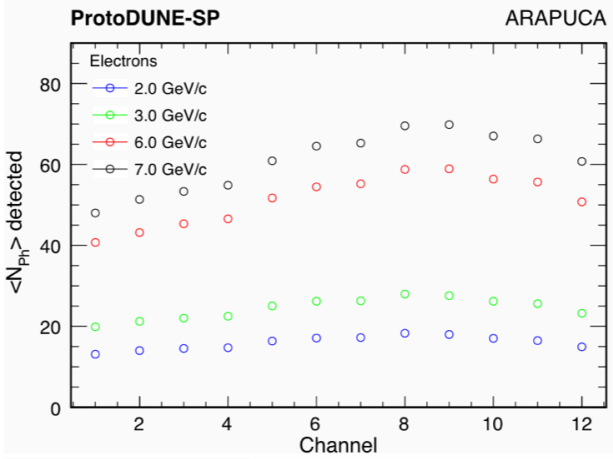

ϕ (deg)
150
100
50
0
−50
−100
−150
0
10
20
30
40
50
60
70
80
90
θ (deg)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

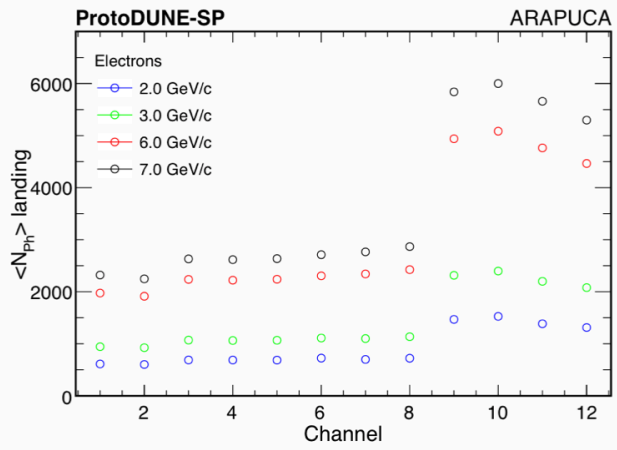
Detection efficiency of the **ARAPUCA** Bar (in APA3) - [**12 cells**]

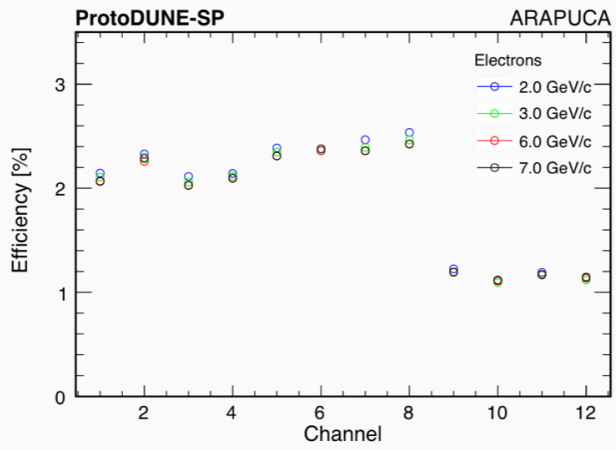












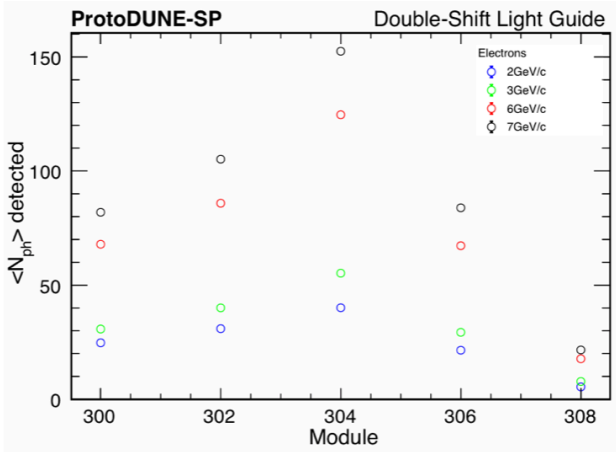
The detection efficiency of the ARAPUCA detectors in the ProtoDUNE-SP PD system is finally taken as the median value of the individual cells with its error:

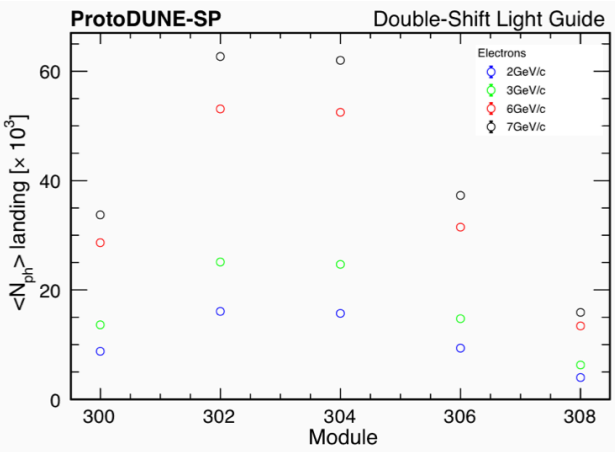
$$\text{cell type}-1 \;\; ; \;\; \tilde{\epsilon}_1 = (2.05 \pm 0.27)\%$$

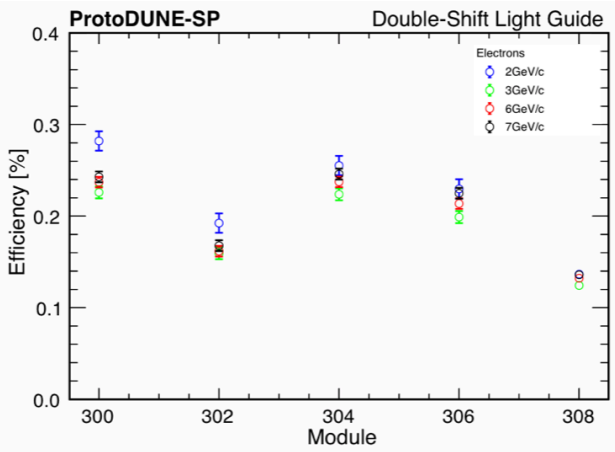
$$\text{cell type}-2 \;\; ; \;\; \tilde{\epsilon}_2 = (1.06 \pm 0.10)\%$$

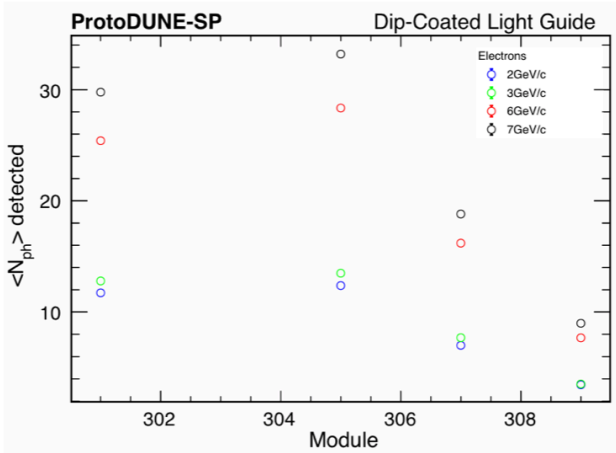
where type-1 are cells $j = 1, ..., 8$ in the ARAPUCA module and type-2 are those $j = 9, ..., 12$ with double area and same number of photosensors.

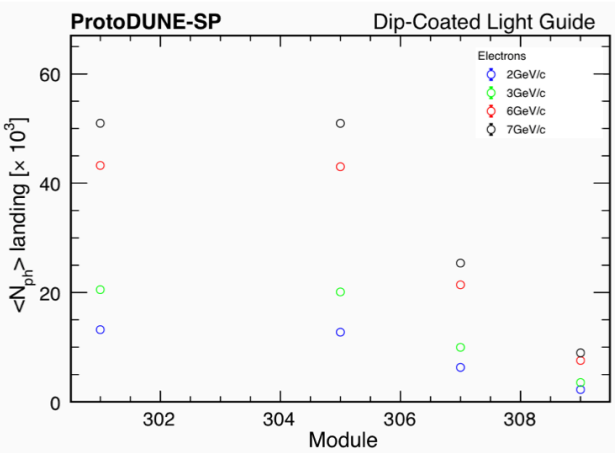
Detection efficiency of the Double-Shift Light Guide Bars (in APA3) - [5 bars]

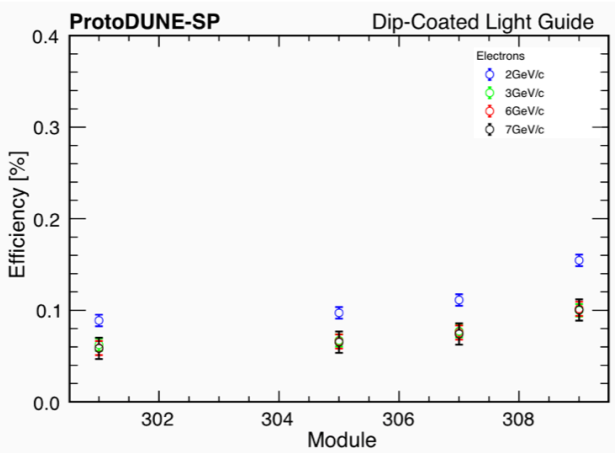




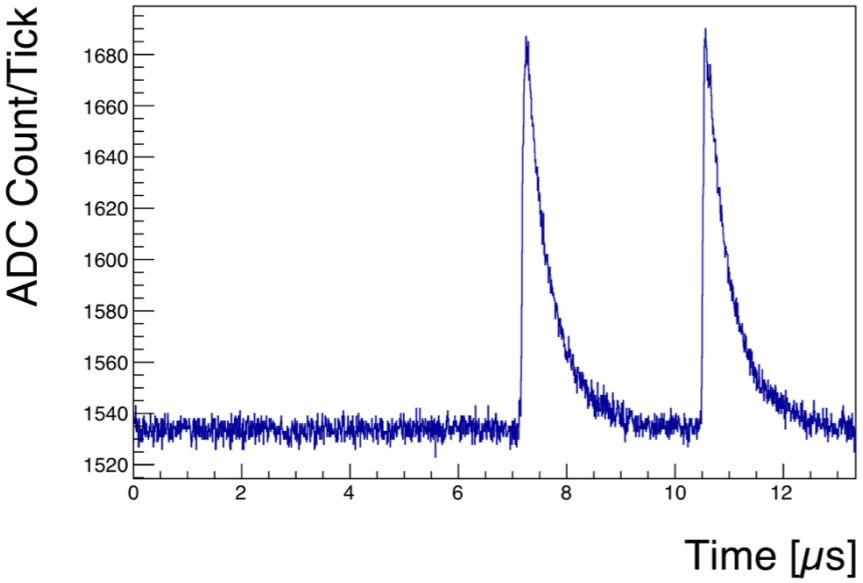


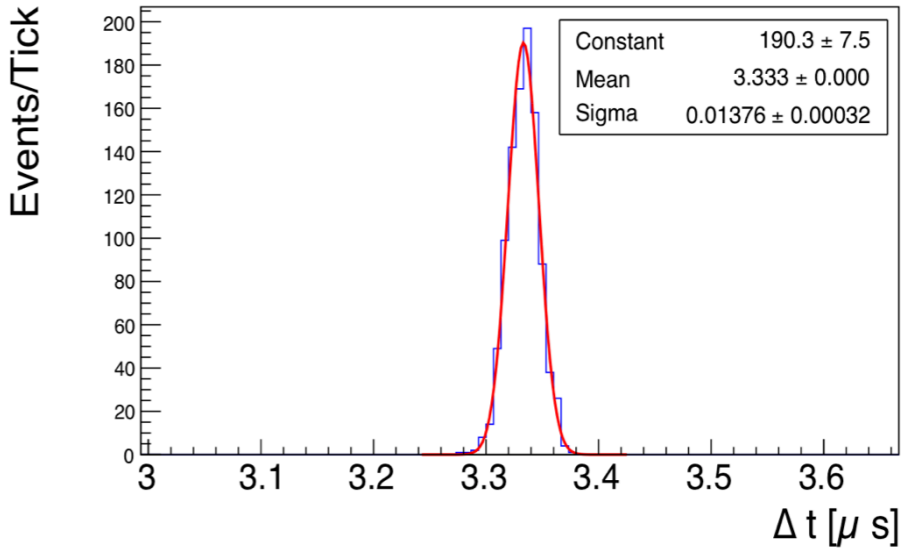




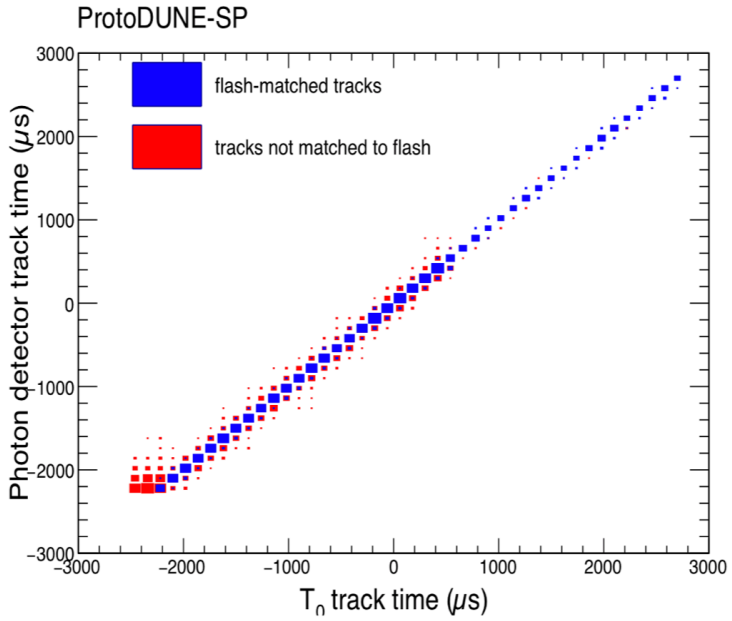


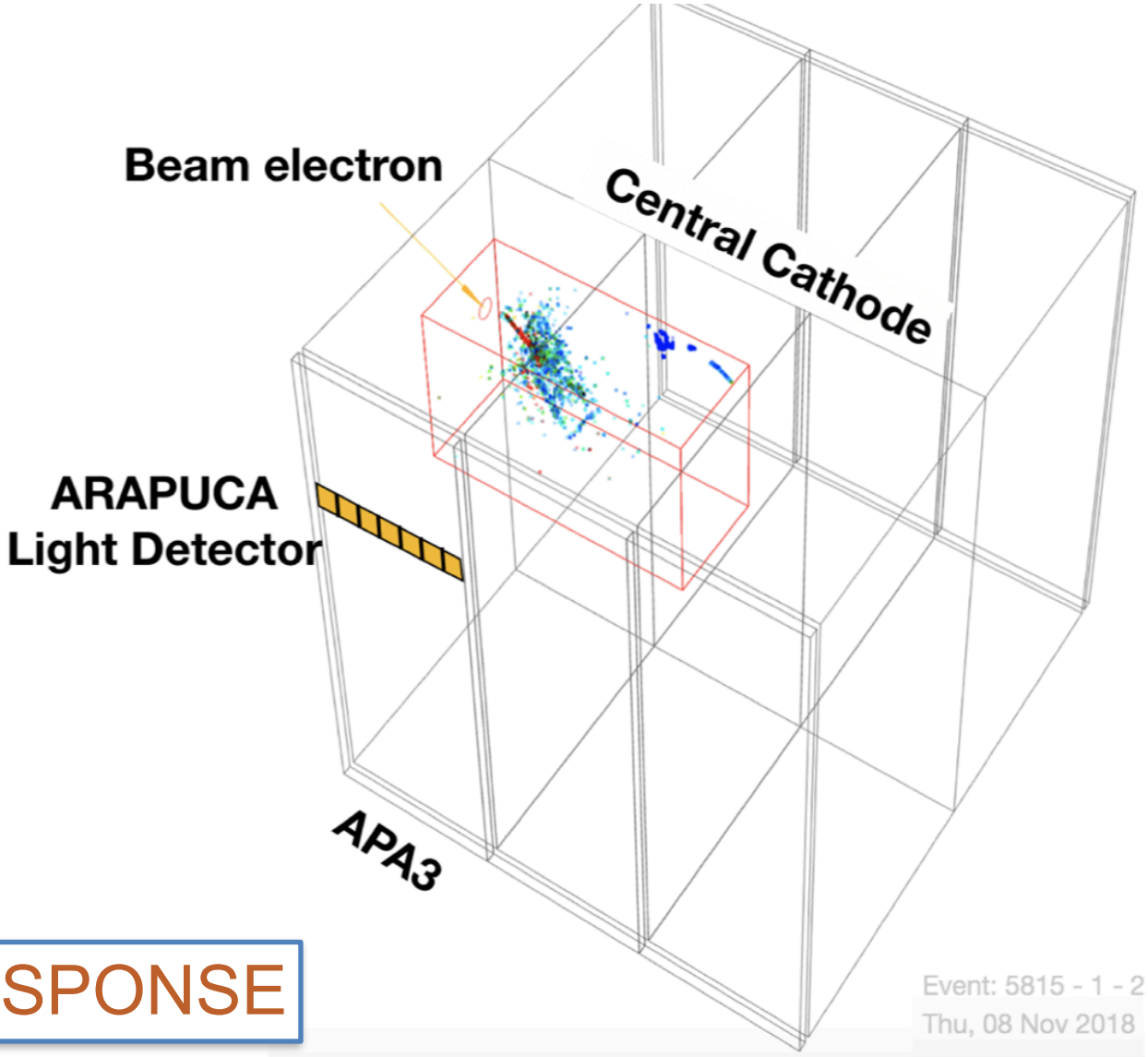
Detection efficiency of the Dip-Coated Light Guide Bars (in APA3) - [4 bars]



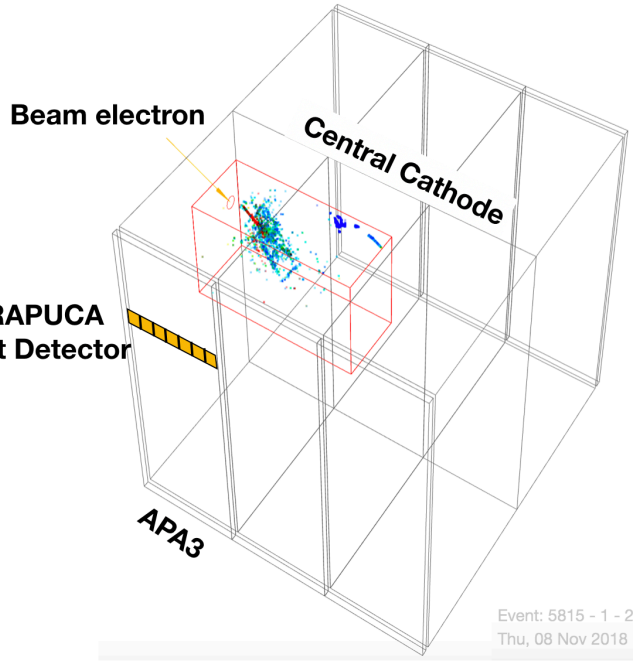


Time Resolution





PDS RESPONSE



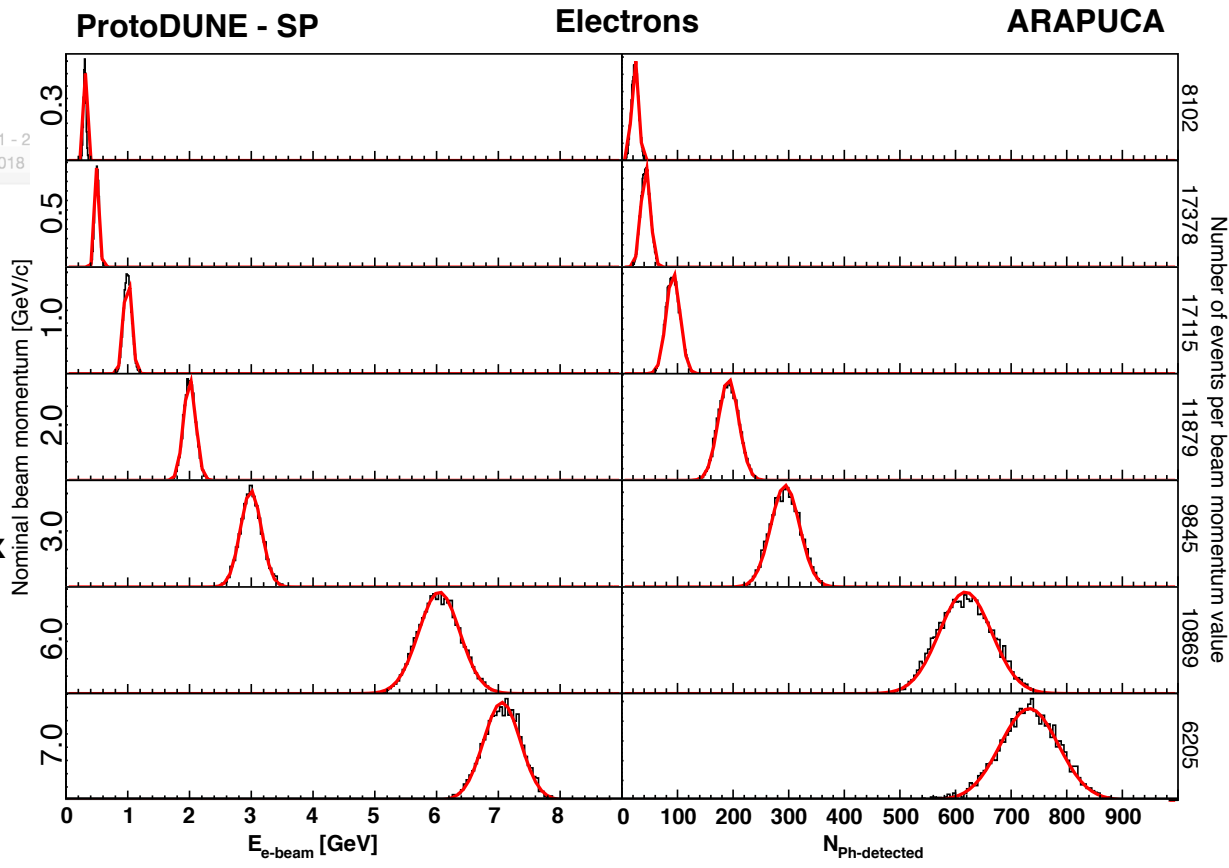
Large LAr detector operating at the CERN Neutrino Platform

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)

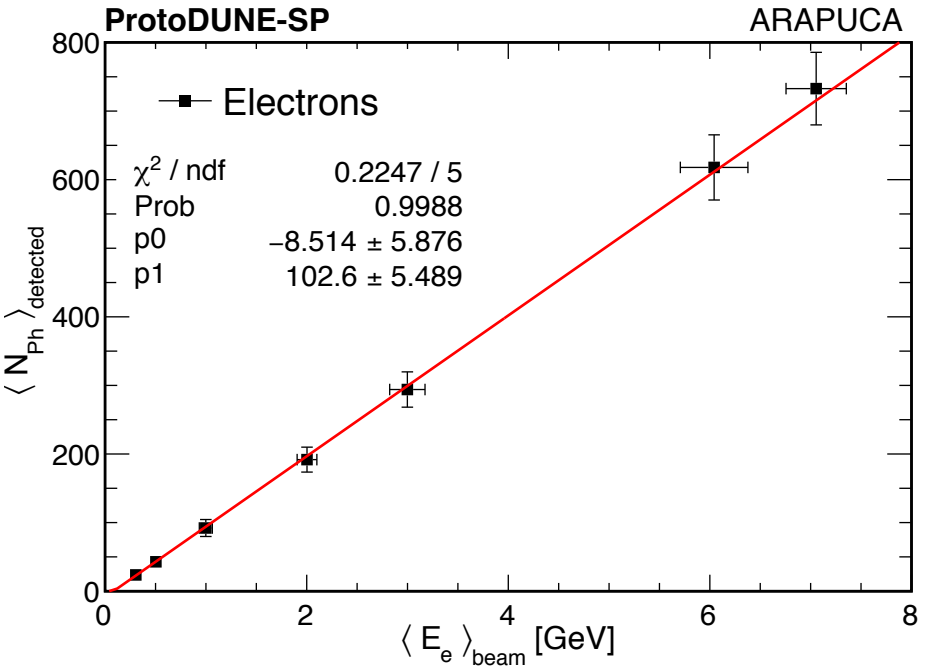
EM shower at ~3 m distance in the (drift) direction

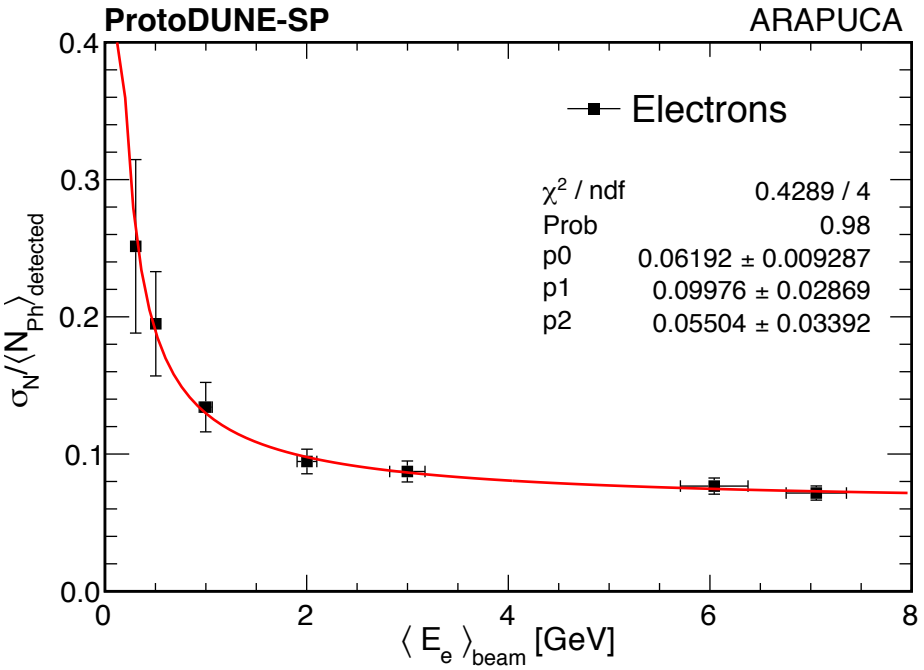
x



Incident Electron momentum distribution

detected photons spectra





Linearity

of light response over the entire range of energies.

The slope gives the light yield

$$LY = 103\ Ph/GeV$$

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:** $p_2 = 55\ MeV$
  from excellent SiPM readout S/N ratio
- **Constant term:** $p_0 = 6.2\,\%$
  from non-uniformities in light collection (from one side only)

PDS RESPONSE

Last section (in preparation)

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

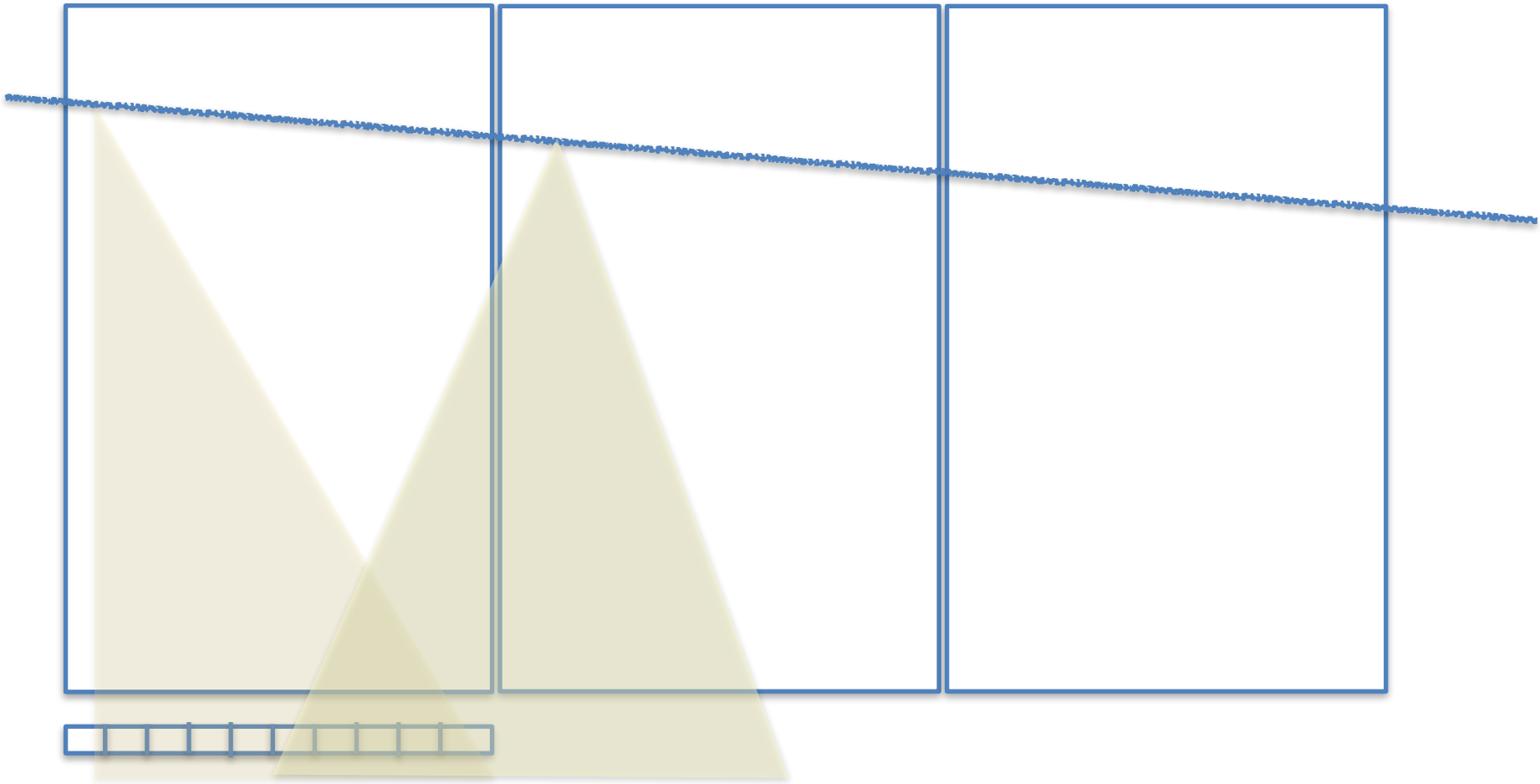
$\langle Rate \rangle = xxx \pm yy \quad \mathrm{kHz}$ and rate stability over time

Single photon rate vs electric field

BACK UP

Crossing Muon

PDS RESPONSE



EM Shower

PDS RESPONSE