First calorimetric energy reconstruction of beam events from LAr scintillation light in protoDUNE-SP and single photon rate observation

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on behalf of the DUNE collaboration

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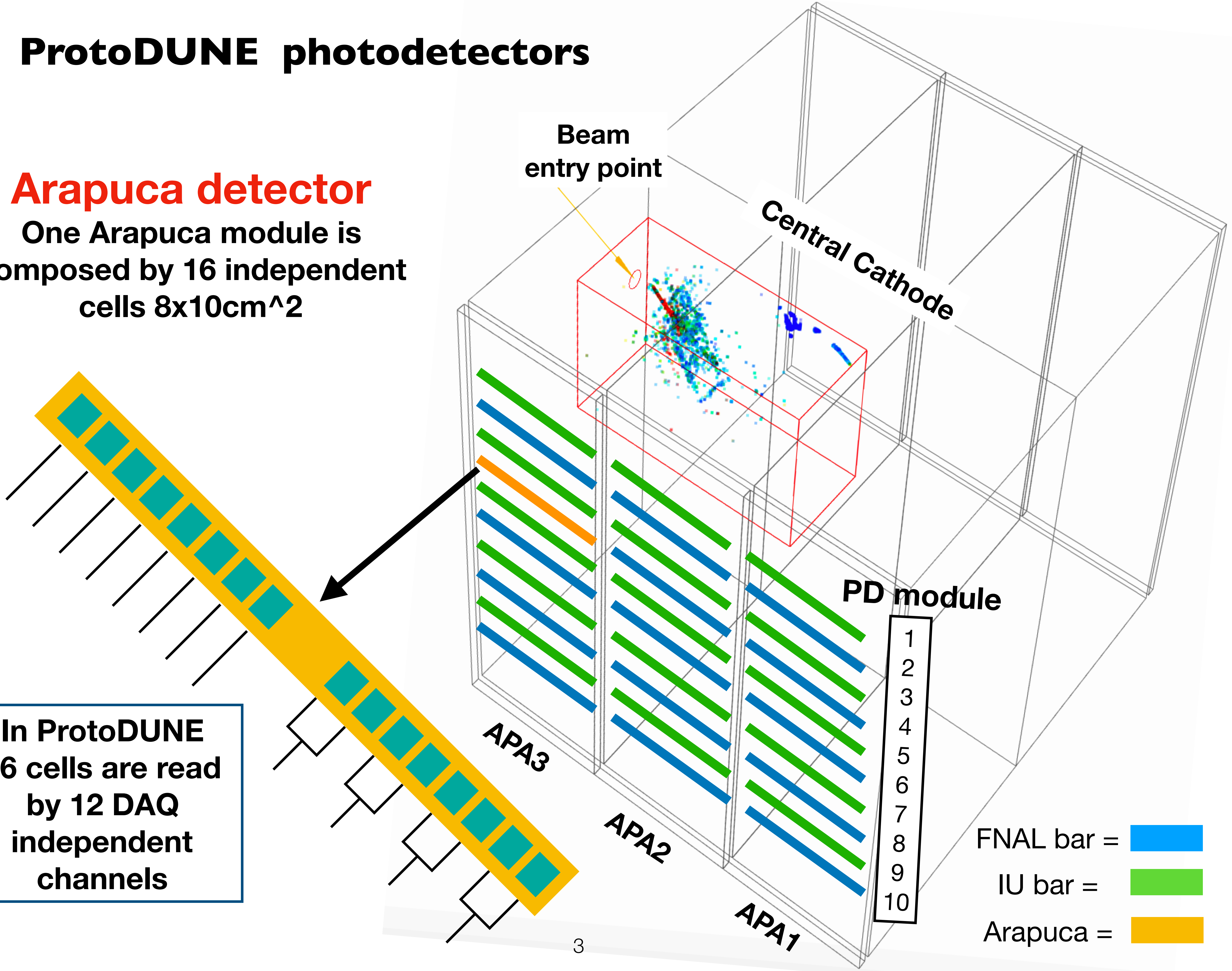
Summary

- ProtoDUNE photodetector system
- Particle identification
- Photodetector response to beam electrons
- Arapuca response to beam electrons
- Arapuca granularity
- Single photon rate from space charge

ProtoDUNE photodetectors

Arapuca detector

One Arapuca module is composed by 16 independent cells 8x10cm^2



In ProtoDUNE 16 cells are read by 12 DAQ independent channels

Particles identification

6, 7 Gev/c	HP	LP	3 GeV/c	HP	LP	2, 1, 0.5, 0.3 GeV/c	LP
Electron / Pion	1	1	Electron	1	1	Electron	1
Kaon	1	0	Pion	1	0	Pion	0
Proton	0	0	Proton	0	0	Proton	0

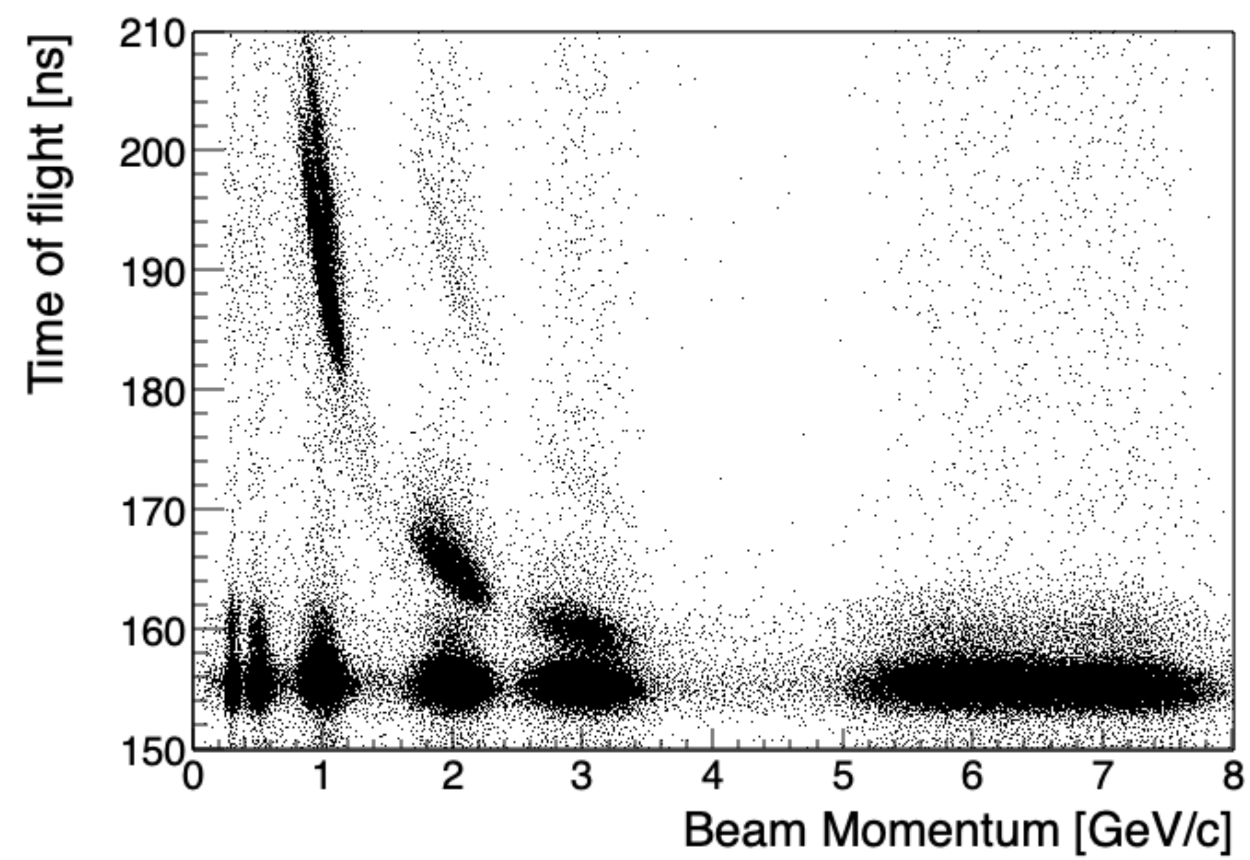
- Cherenkov PID

LP (HP)= Low (Hi) pressure

- Time of Flight

For 2 GeV/c:
TOF < 160 ns: pions
Else: protons

For 0.3/0.5/1 GeV/c:
TOF < 170 ns: pions
Else: protons



- Pandora reconstruction

For 6/7 GeV/c, pions and electrons are classified thanks the signature given by Pandora reconstruction

- Spectra analysis

Muons peak from pions and kaons spectra

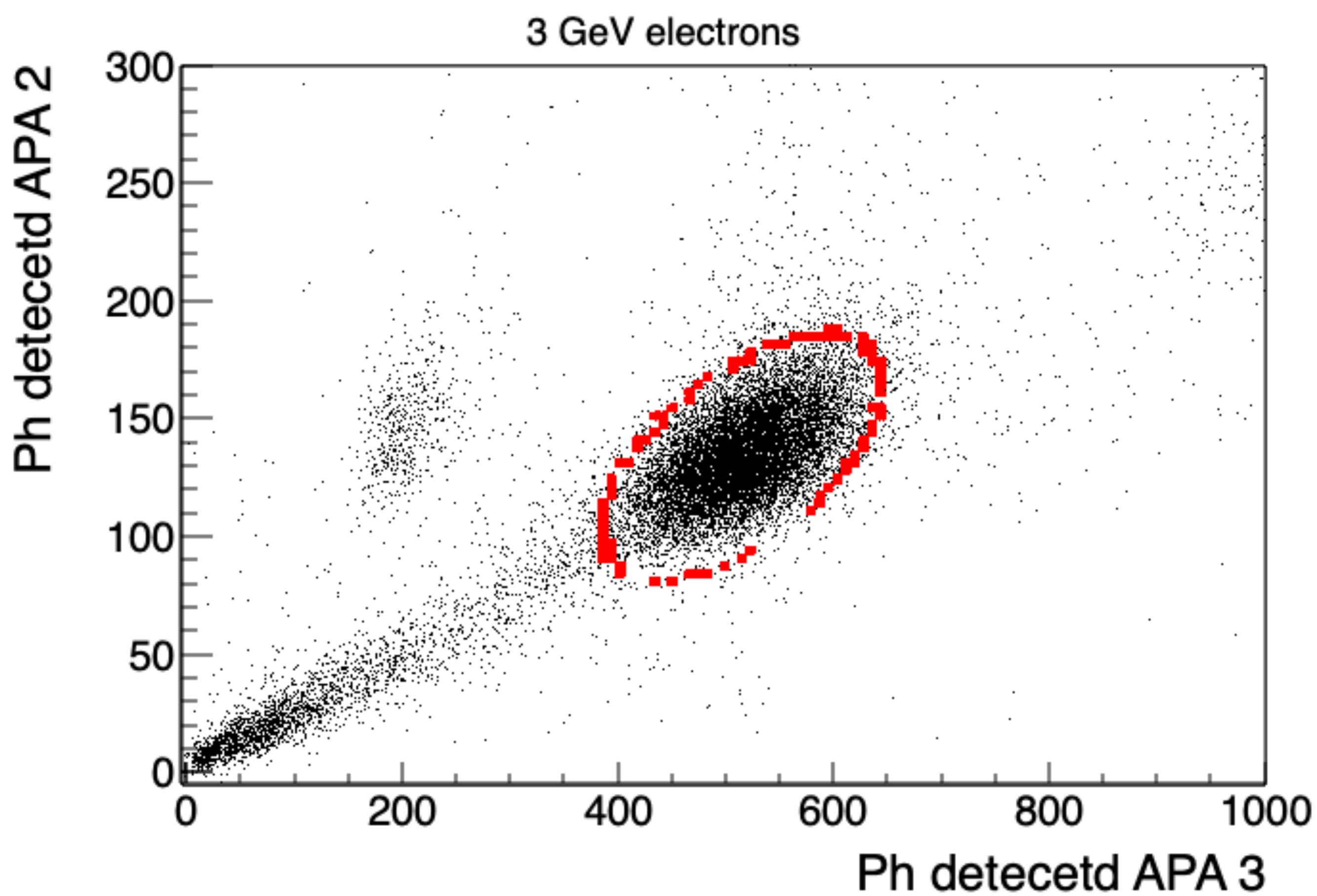
Spectra analysis

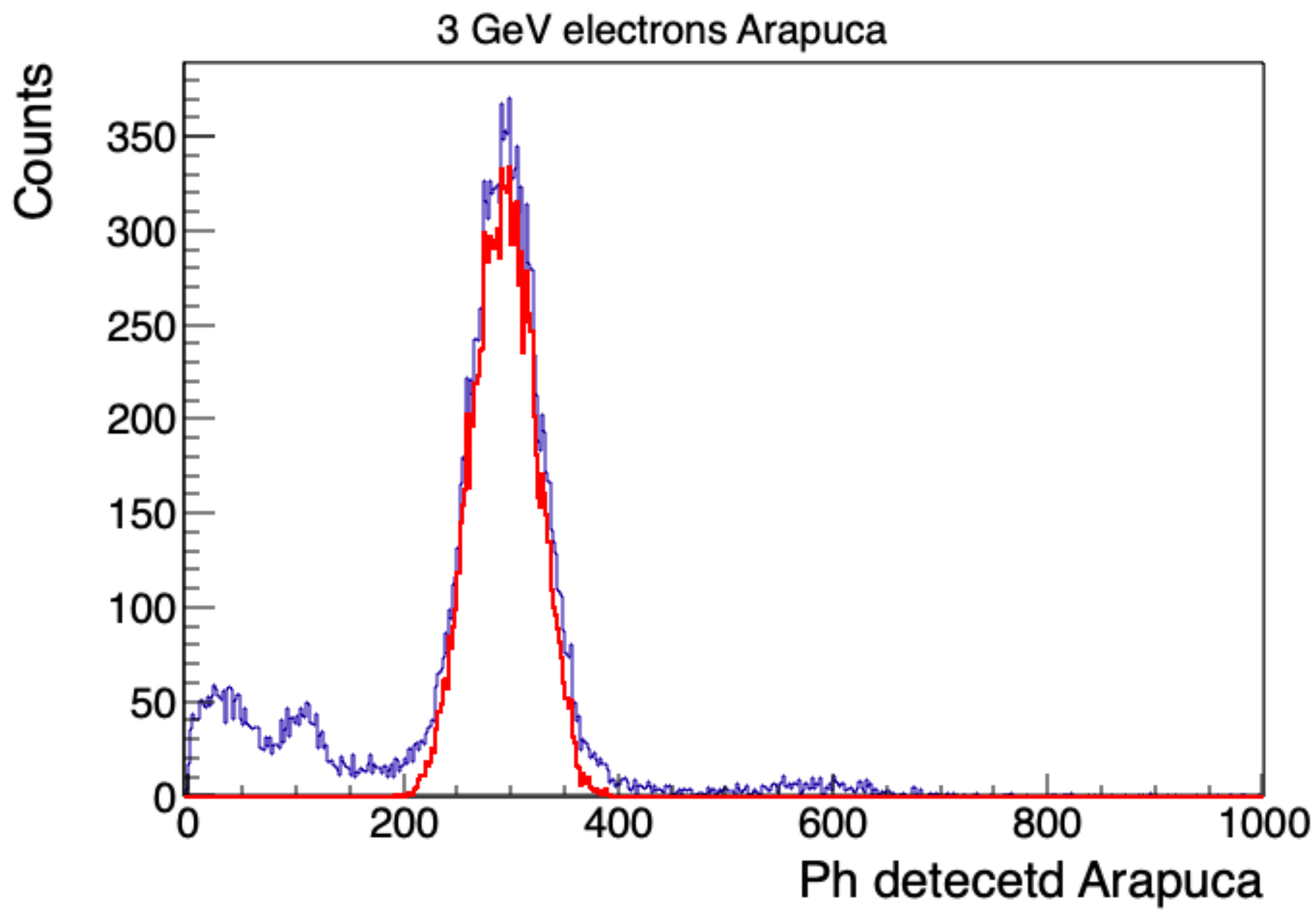
Scatter plots between the total number of photons collected from the entire APAs helps to remove extraneous events, which affect the average of photon detected.

The peak is fitted with a rotated 2d gaussian function.
The cut is an ellipse with diameters equal to 6 sigma.

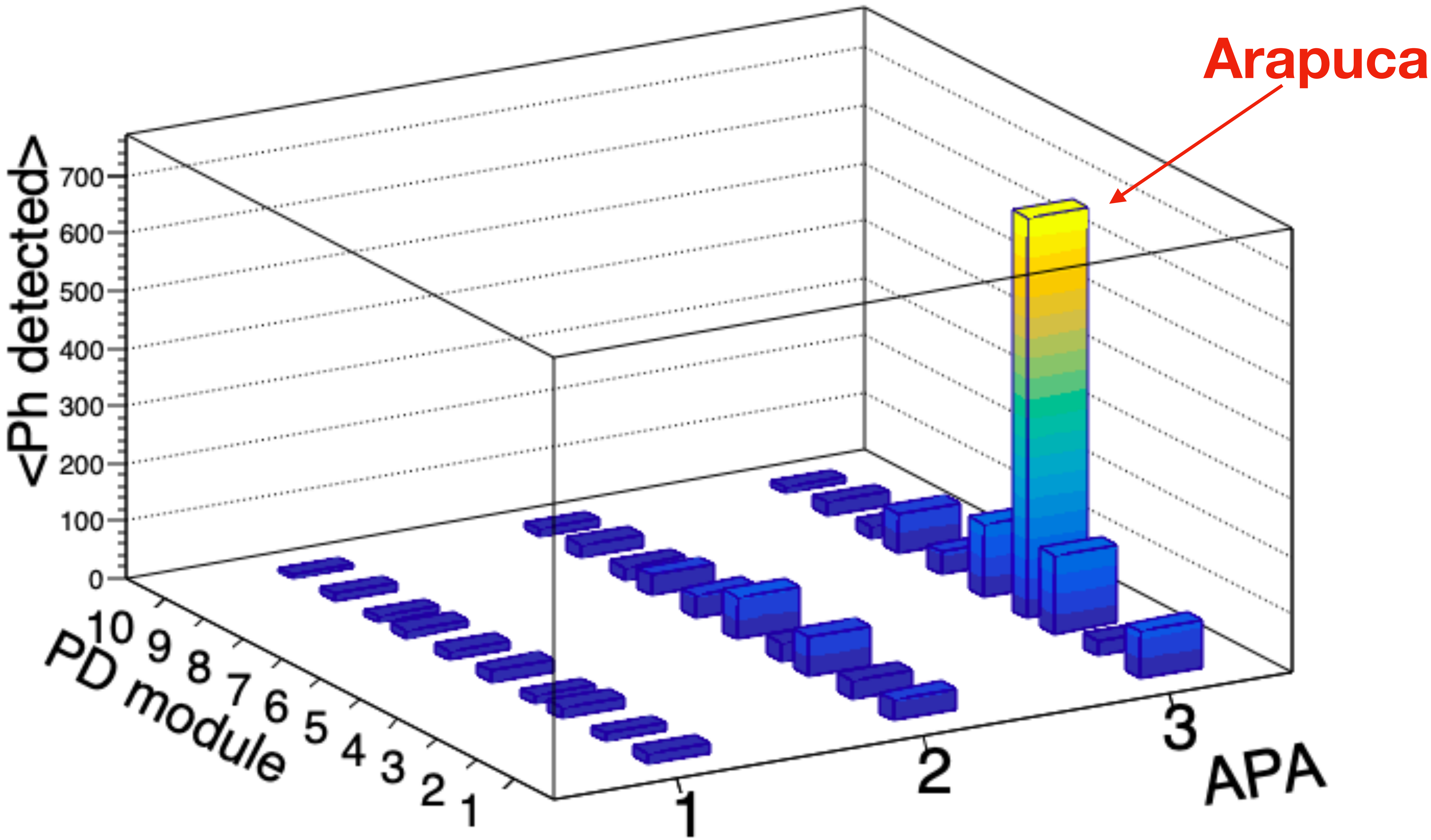
$$\begin{bmatrix} \sigma_x^2 & \rho\sigma_x\sigma_y \\ \rho\sigma_x\sigma_y & \sigma_y^2 \end{bmatrix} \rightarrow \begin{bmatrix} \sigma_\chi^2 & 0 \\ 0 & \sigma_\eta^2 \end{bmatrix}$$

On the left plot are reported the spectra for 3 GeV electrons before and after the cut



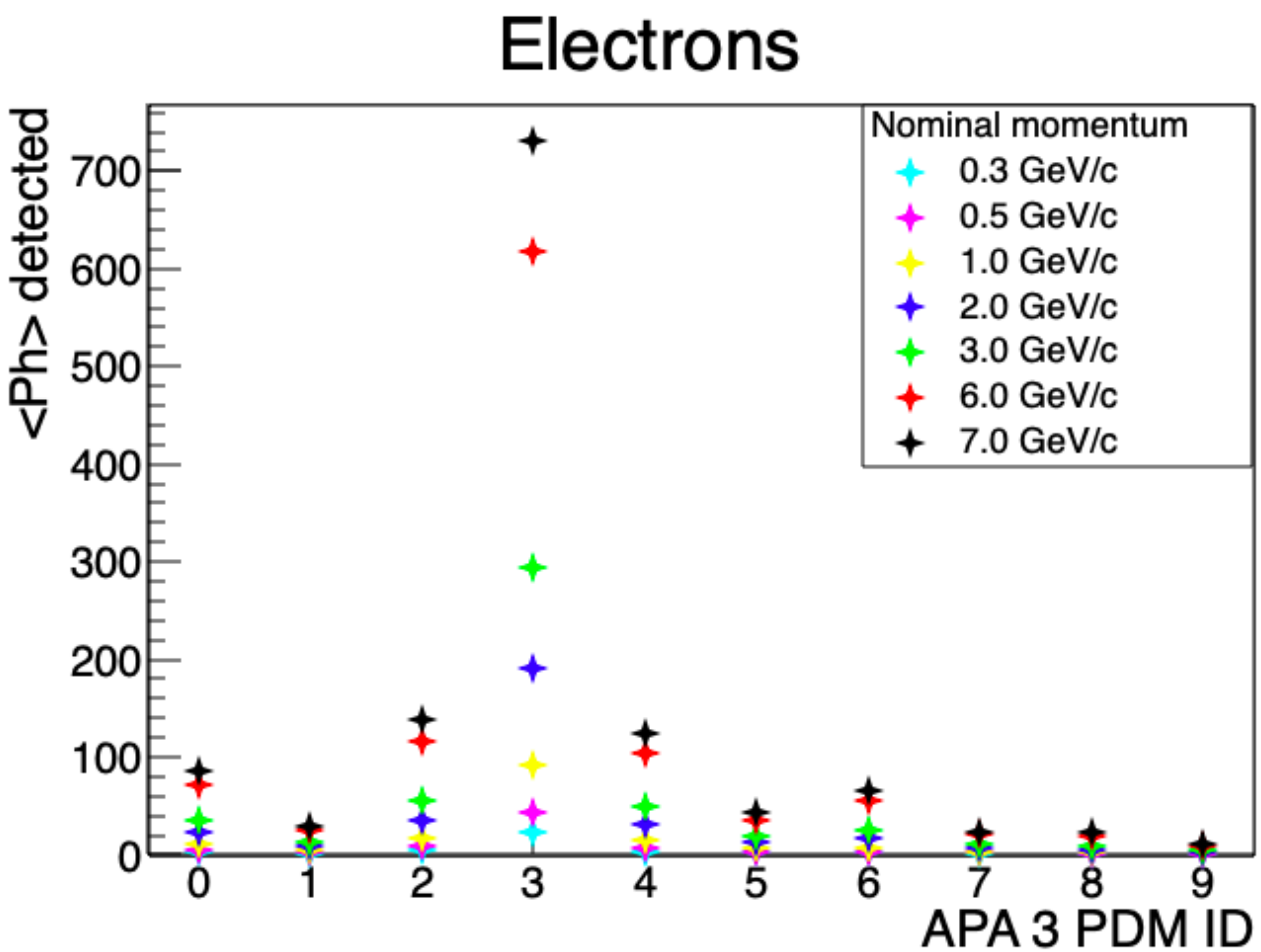


PD system response to 7 GeV beam electrons



APA 3 response to beam electrons

Electrons showers localize in front of the first APA. Here are reported the average number of photons detected by the PDMs in the APA3 for the 7 beam momentum values provided during the runs in Fall 2018



Arapuca PDM is number 3

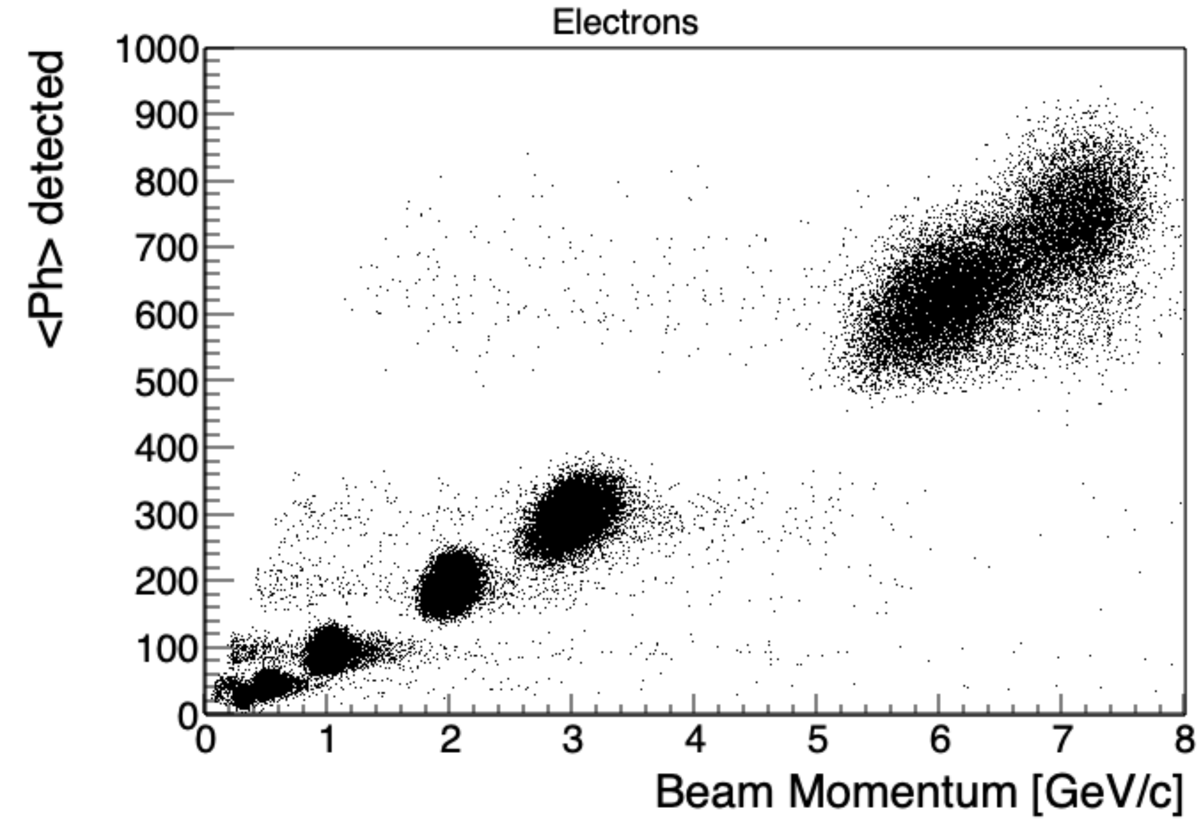
Arapuca PDM collects 5 times more photons respects the other near PD modules despite a smaller active area.

Arapuca acceptance ~ 0.5 others PDM

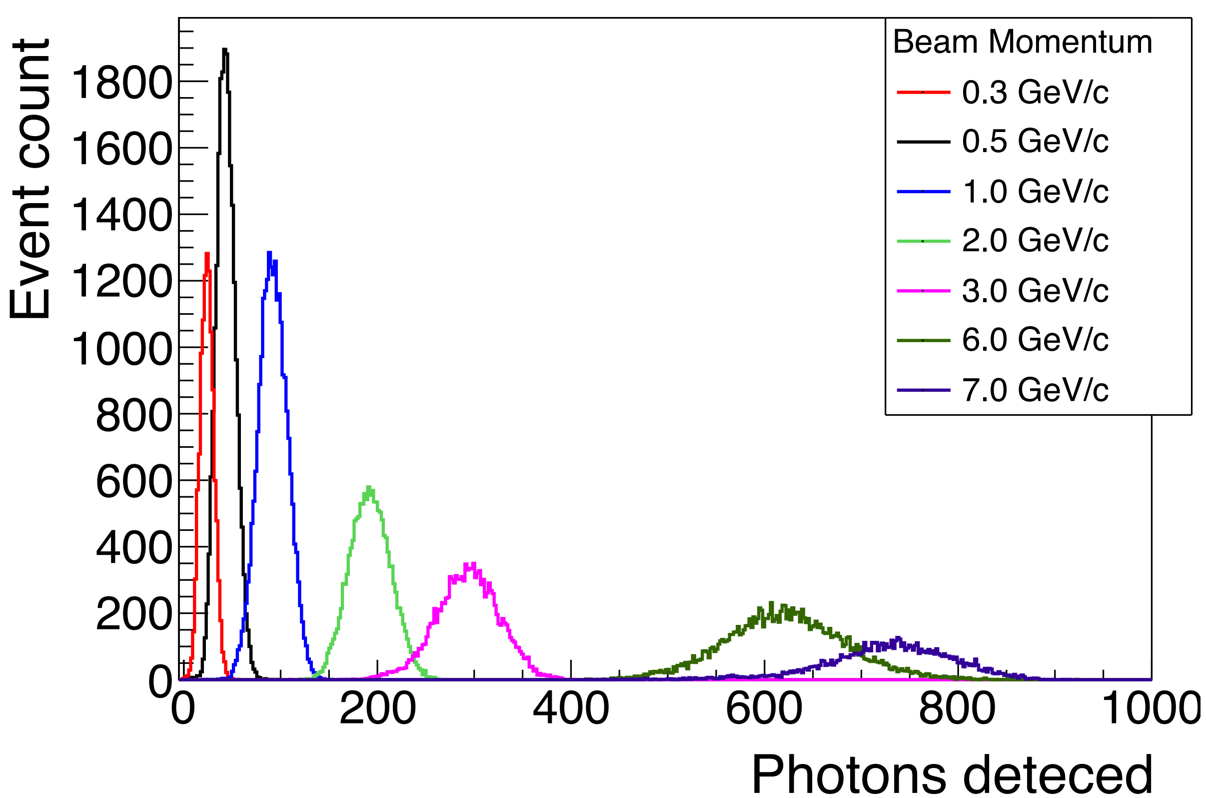
Simulation for arriving photons is not completed yet, but from first estimation we have found an efficiency between 1% and 2%

Arapuca PDM response to beam electrons

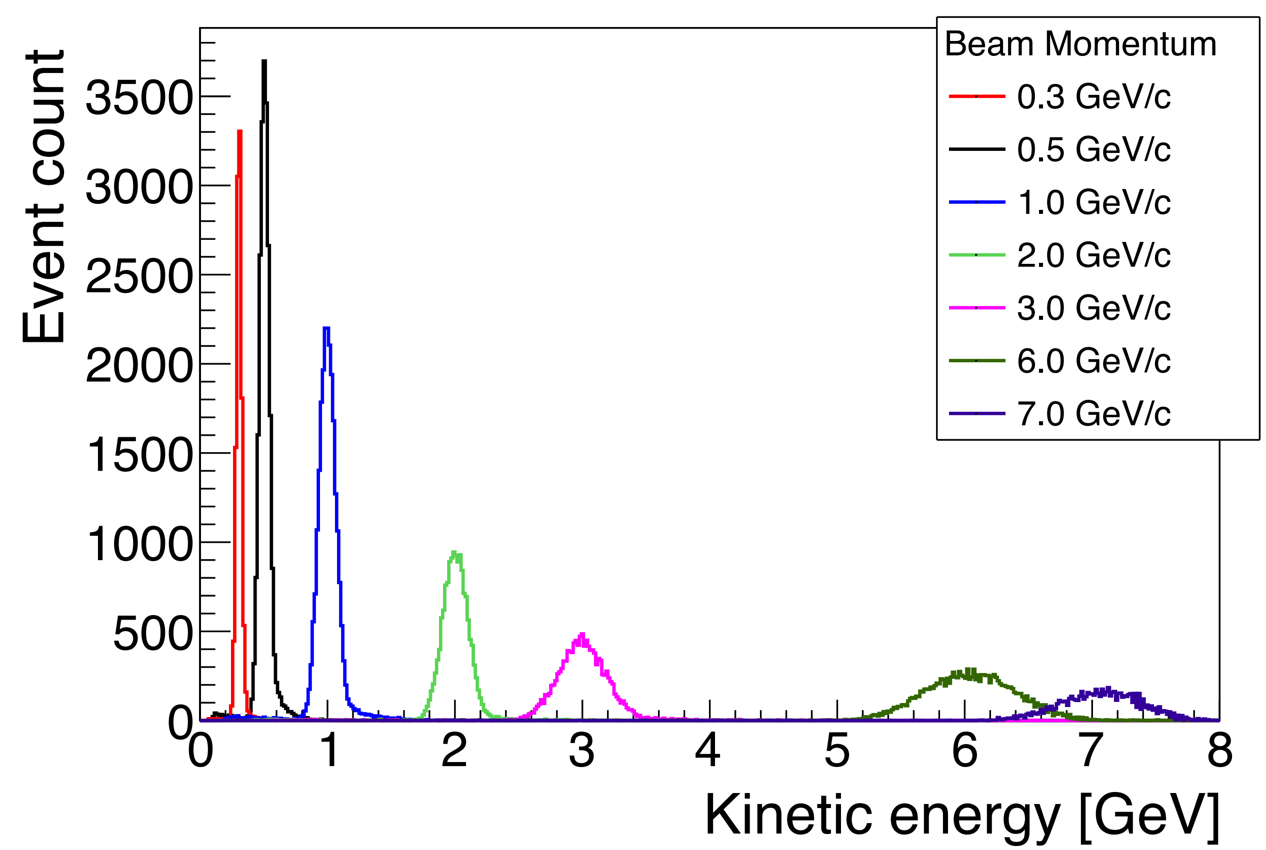
For each beam momentum nominal value photon detected spectra and kinetic energy spectra are fitted with gaussian distributions. Two quantities are then analyzed: linear response and resolution.



Ph detected



Kinetic energy



Arapuca linear response to electrons kinetic energy

Linearity between photon detected and electrons kinetic energy is checked using the mean values got from the gaussian fit for both quantities.

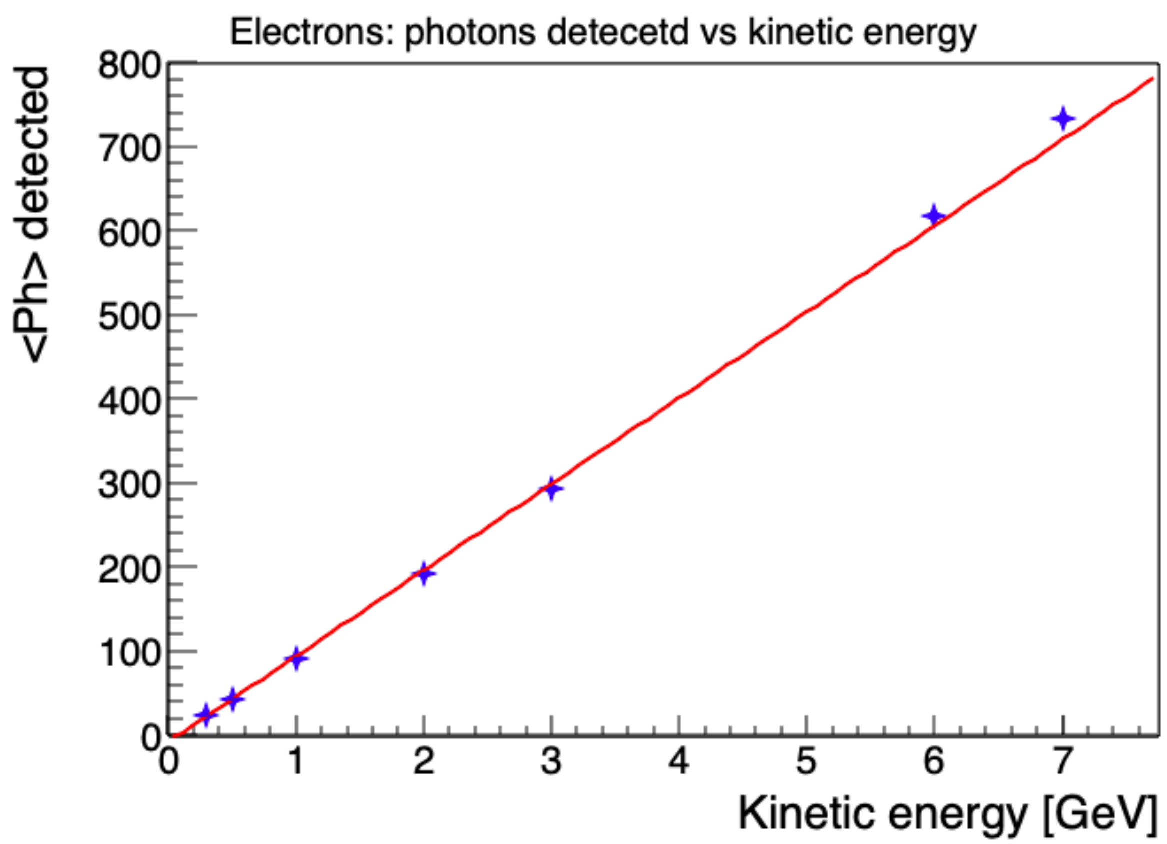
A linear fit is made using the function: $\mu_{ph} = m \cdot \mu_{KE} + q$

Getting for the parameters:

$$m = 102.44 \pm 0.05 \left[\frac{Ph}{GeV}\right]$$

$$q = -8.25 \pm 0.05\,[Ph]$$

The constant term is needed and expected negative, since there is a losing of energy before the electrons enter the TPC.



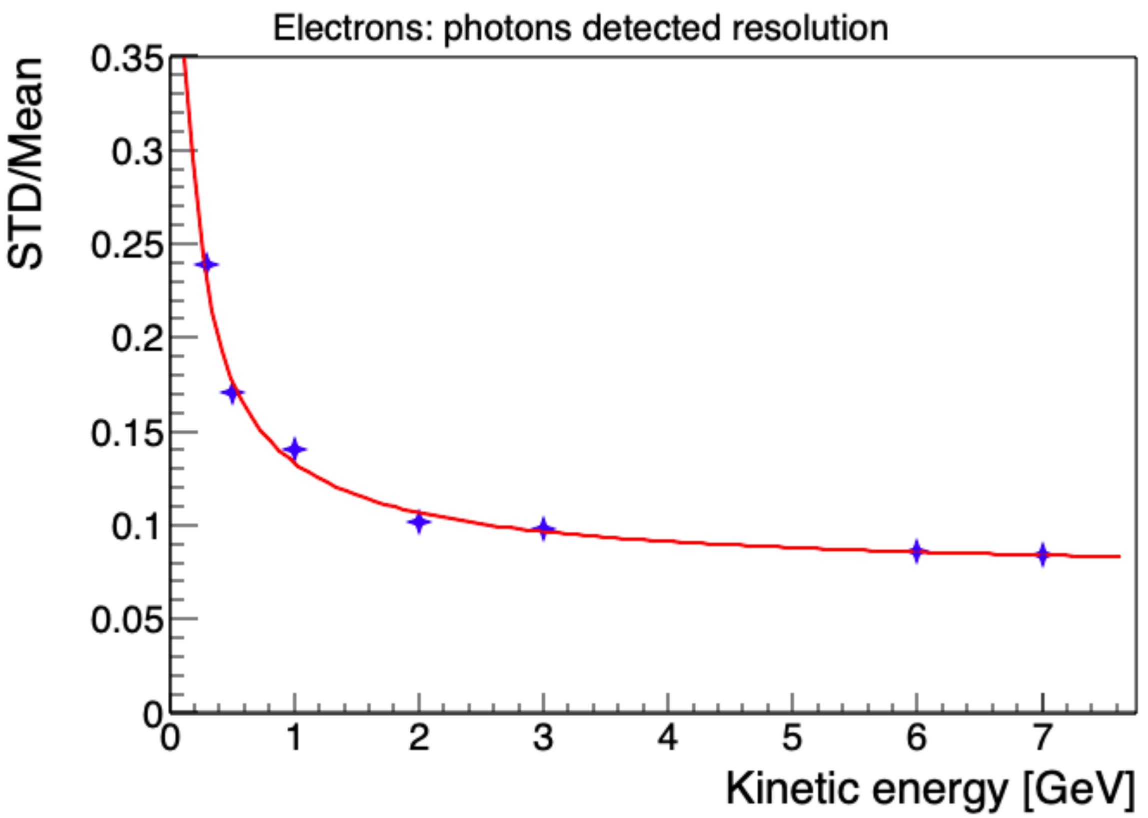
Arapuca resolution to electrons events

The detector resolution response $\frac{\sigma_{Ph}}{\mu_{Ph}}(\mu_{KE})$ can be parametrized with the

general equation: $$\frac{\sigma_{Ph}}{\mu_{Ph}} = \sqrt{k_1^2 + \left(\frac{k_2}{\sqrt{\mu_{KE}}}\right)^2 + \left(\frac{k_3}{\mu_{KE}}\right)^2}$$

Getting for the parameters:

$$k_1 = 0.073 \pm 0.001$$
$$k_2 = 0.107 \pm 0.001 \;\left[\sqrt{GeV}\right]$$
$$k_3 = 0.028 \pm 0.002 \,[GeV]$$



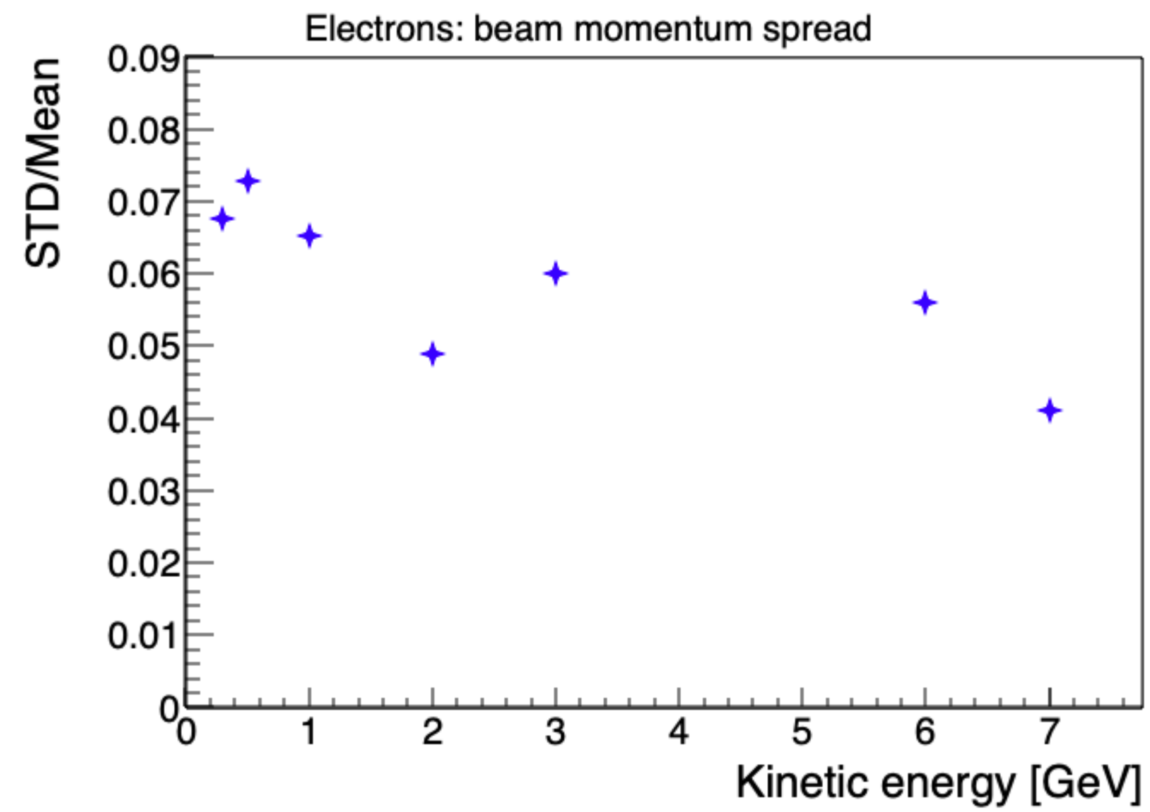
The intrinsic resolution is proportional to $\frac{1}{\sqrt{KE}}$

and it can be identified with the parameter: $k_2 \simeq 10\,\%$

Arapuca resolution corrections

The kinetic energy too has a spread around its mean values: σ_{KE}

In the upper plots is reported $\frac{\sigma_{KE}}{\mu_{KE}}(\mu_{KE})$



Replacing $\frac{\sigma_{Ph}}{\mu_{Ph}}$ with $\sqrt{\left(\frac{\sigma_{N_{ph}}}{N_{ph}}\right)^2 - \left(\frac{\sigma_{KE}}{KE}\right)^2}$

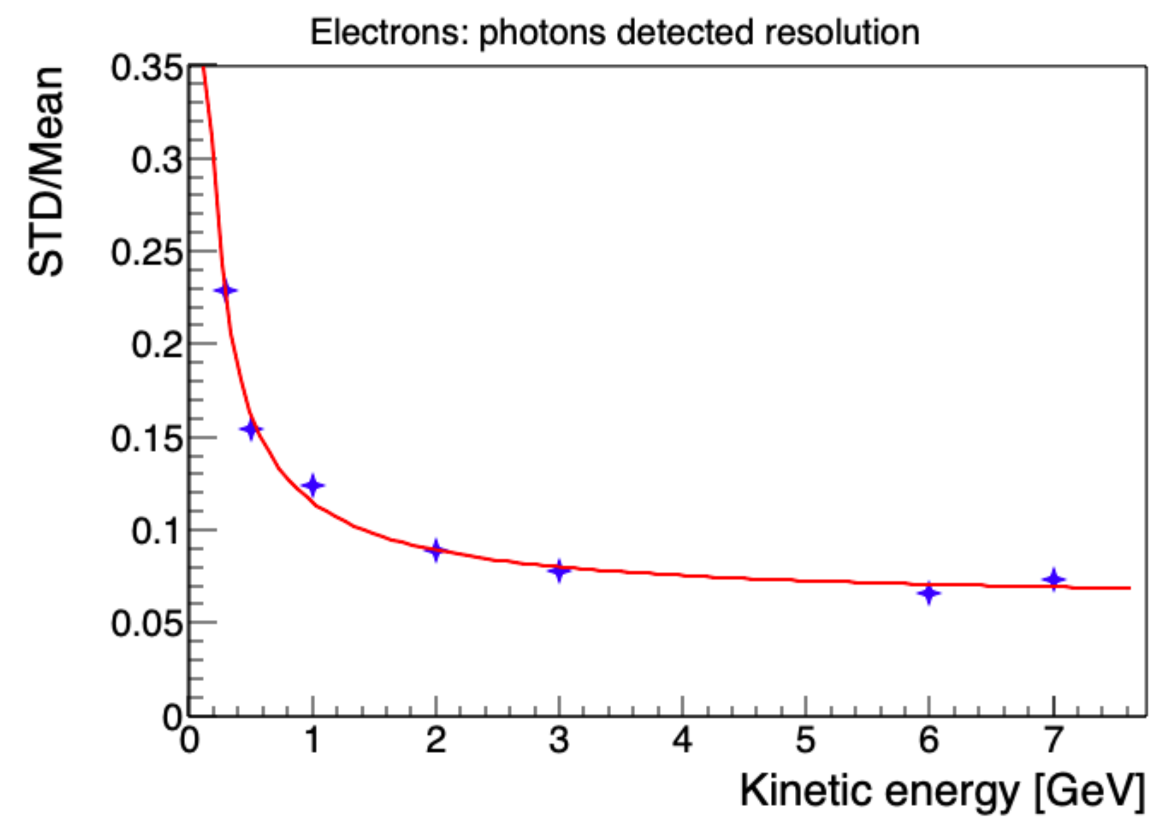
using the general equation for the fit we have:

$k_1 = 0.060 \pm 0.007$

$k_2 = 0.08 \pm 0.01 \ [\sqrt{GeV}]$

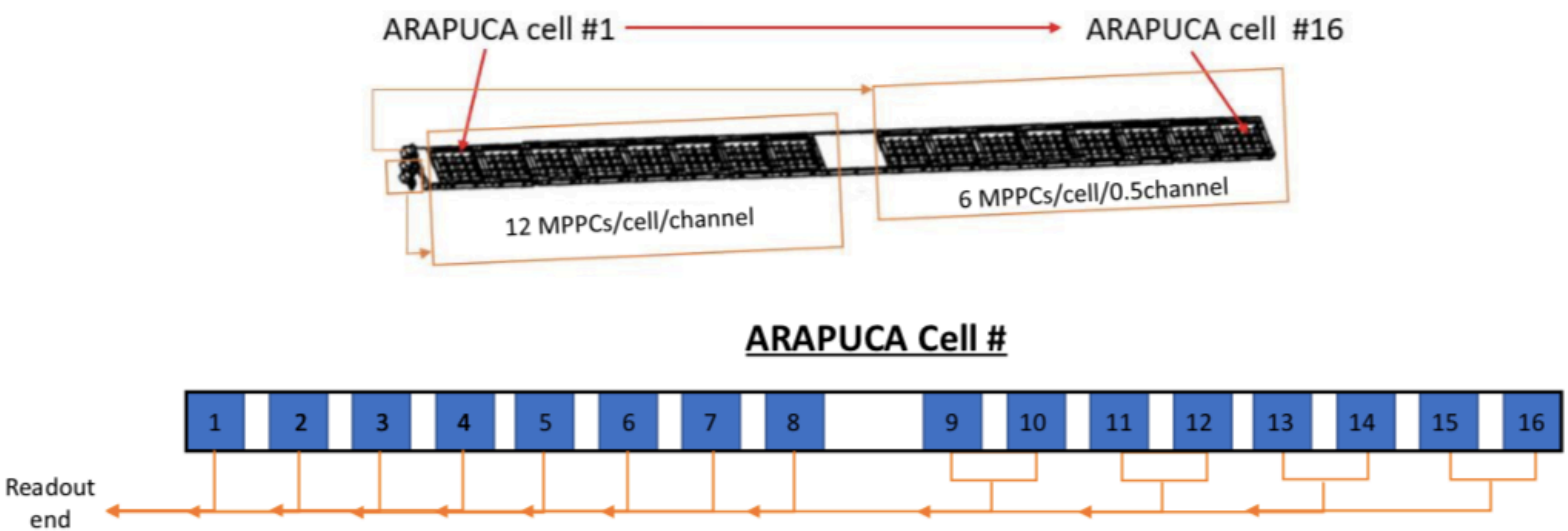
$k_3 = 0.04 \pm 0.01 \ [GeV]$

The intrinsic resolution = $k_2 \simeq 8\ \%$



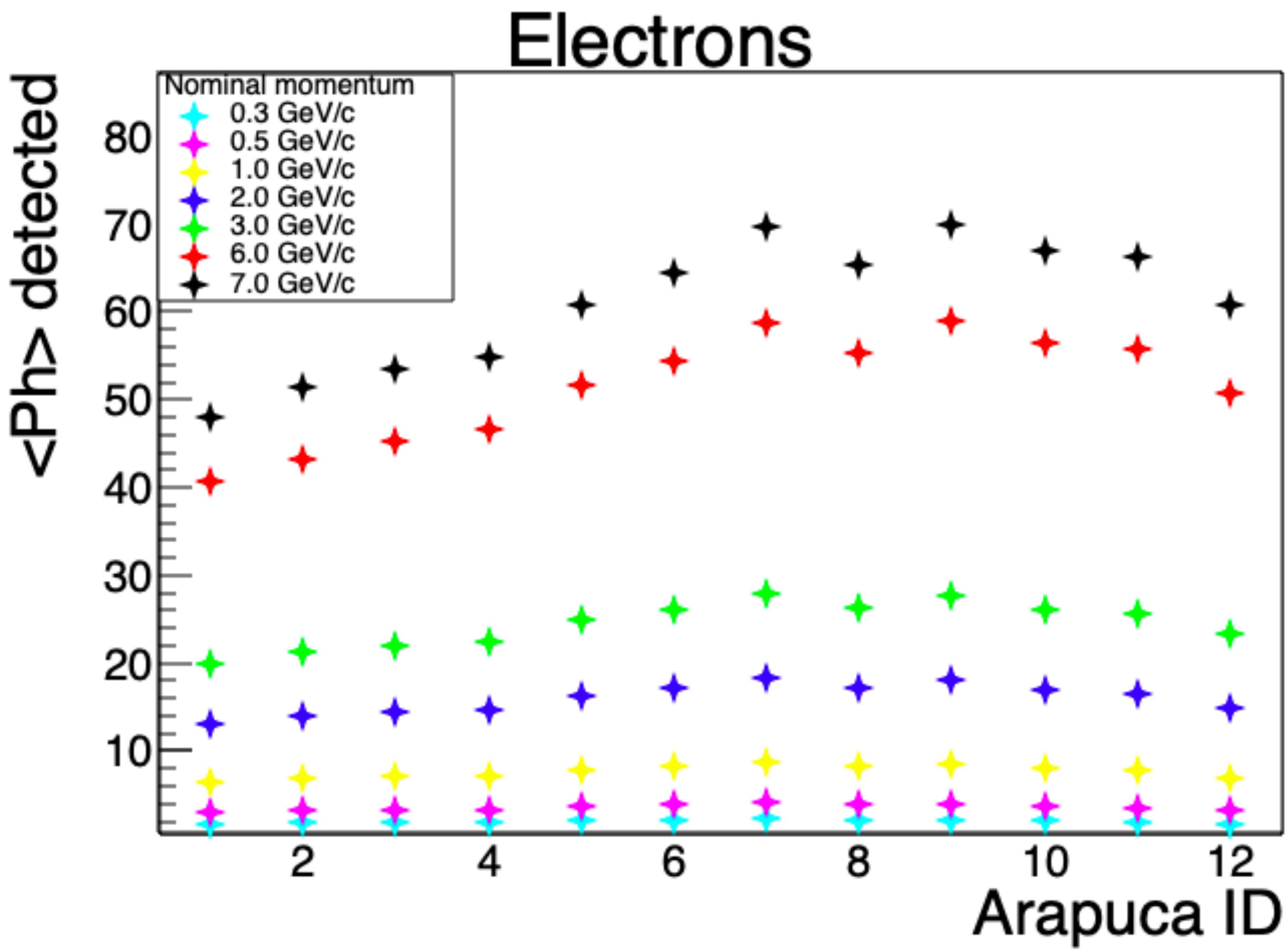
The Arapuca detector granularity

Until now we have looked at the Arapuca as a unique detector, but it is segmented and each cell can be read by an independent channel.



In protoDUNE the 2 Arapuca installed consist in 16 cells 8 read by a single channel and 8 read in couples

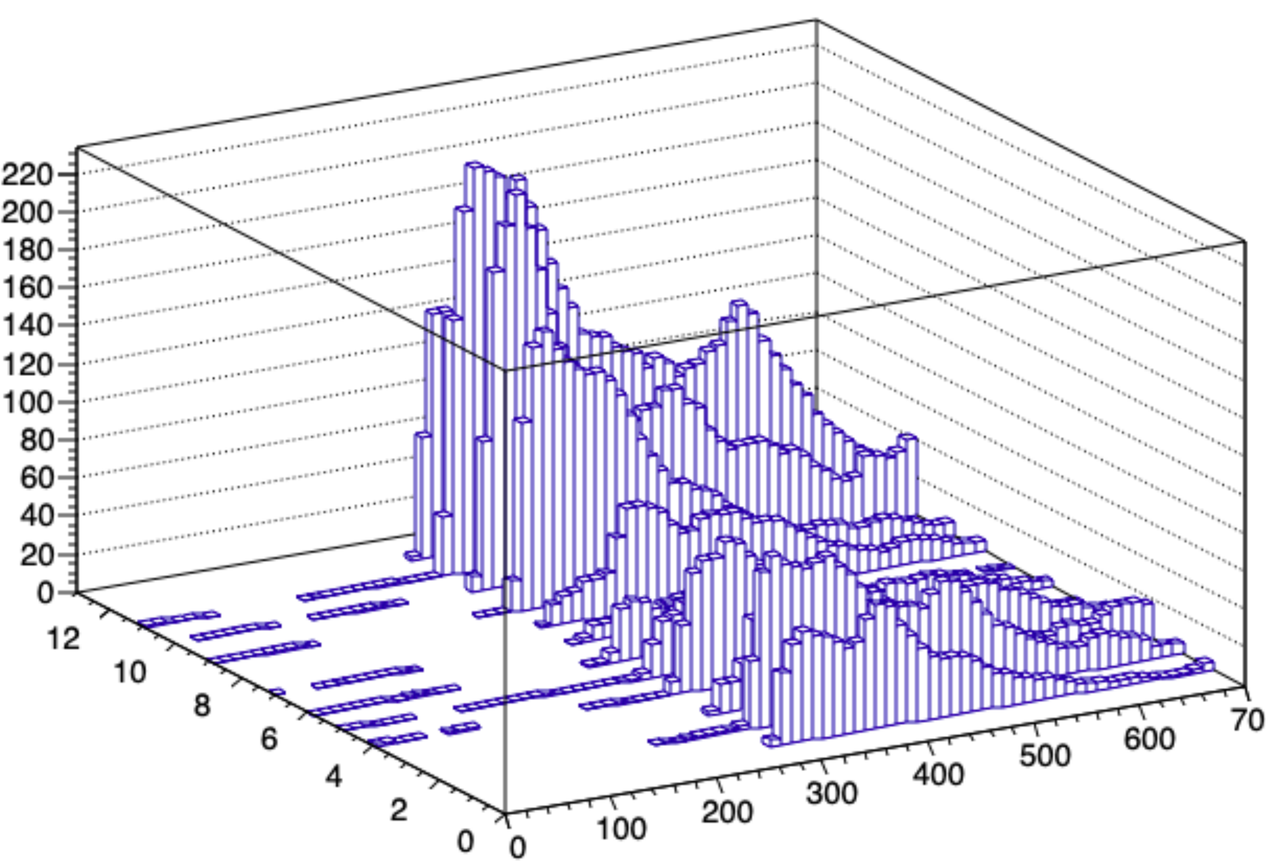
Arapuca cells response to beam electrons

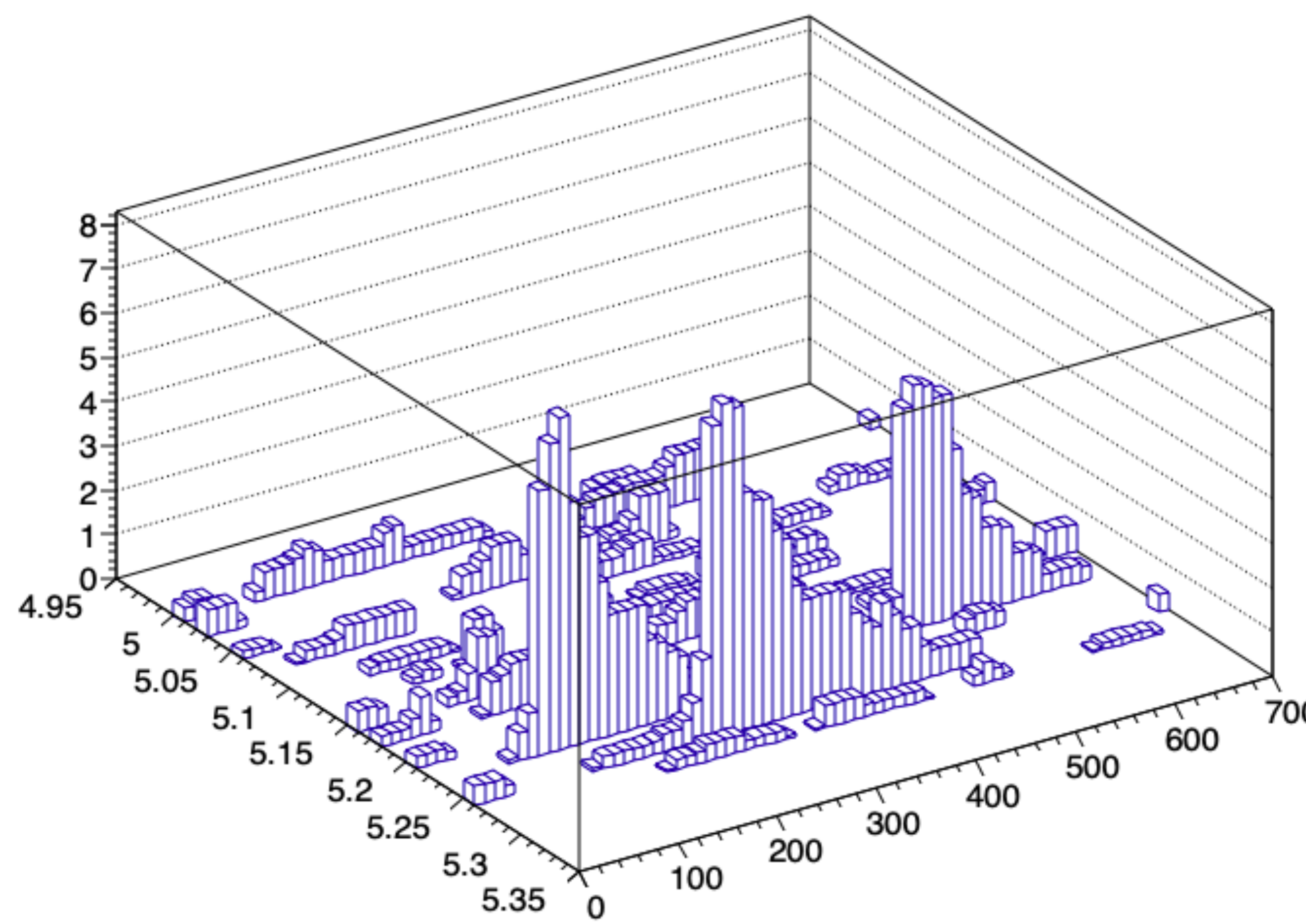


Single photon rate from space charge

Thanks Arapuca granularity is possible to distinguish events produced by ionizing events from single photons uncorrelated arriving on the PD module.

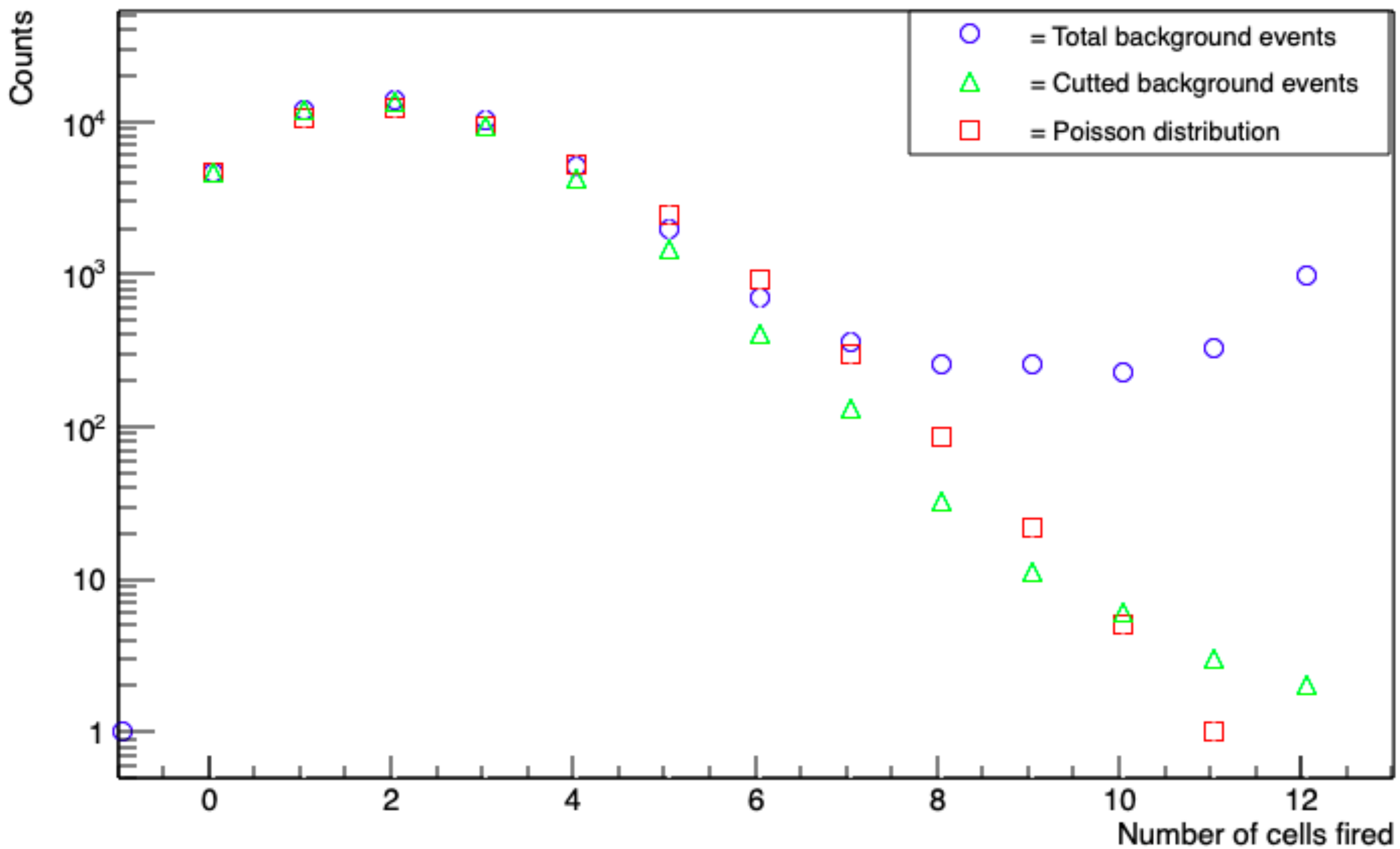
Opening a time window per each signal it is possible to determinate if they are correlated or single photons.





Single photons will fire each single cell which a probability given by Poisson distribution.

Plot shows the numbers of Arapuca cells fired per each event.
The blu points are all the events.
The green point are the events after the ionizing events removal
The red points is the Poisson distribution



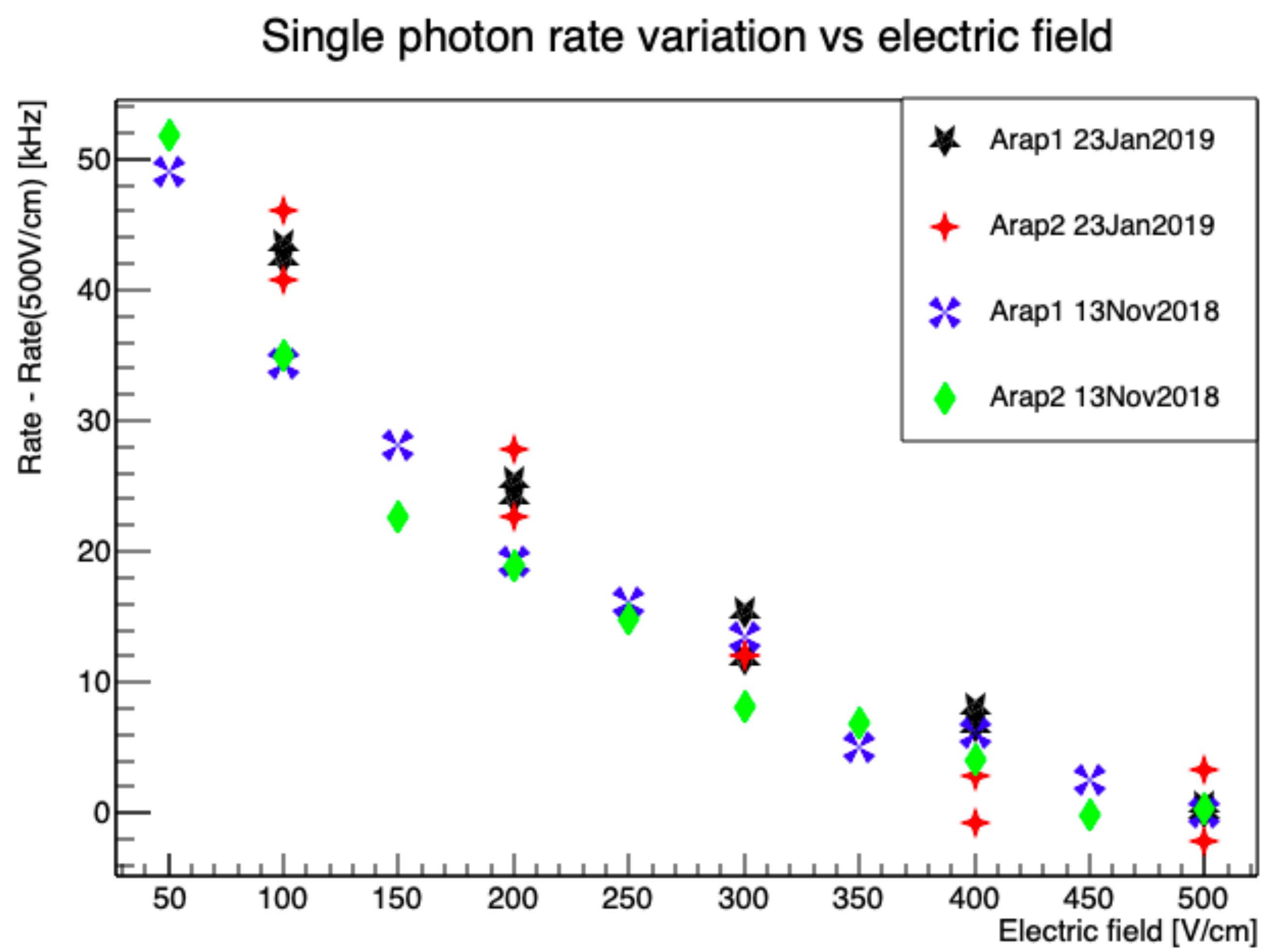
Single photon rate vs electric field

During the protoDUNE operation period two “ramps” in electric field values were performed to study the space charge effects.

In the plot are reported the two ramps for the two Arapuca PD modules installed in protoDUNE

The rate is normalized subtracting the rate at 500 V/cm.

There is an offset in the single photon rate which has to be investigated but it seems to be independent from the electric field, and does not affect the SP rate variation vs electric field

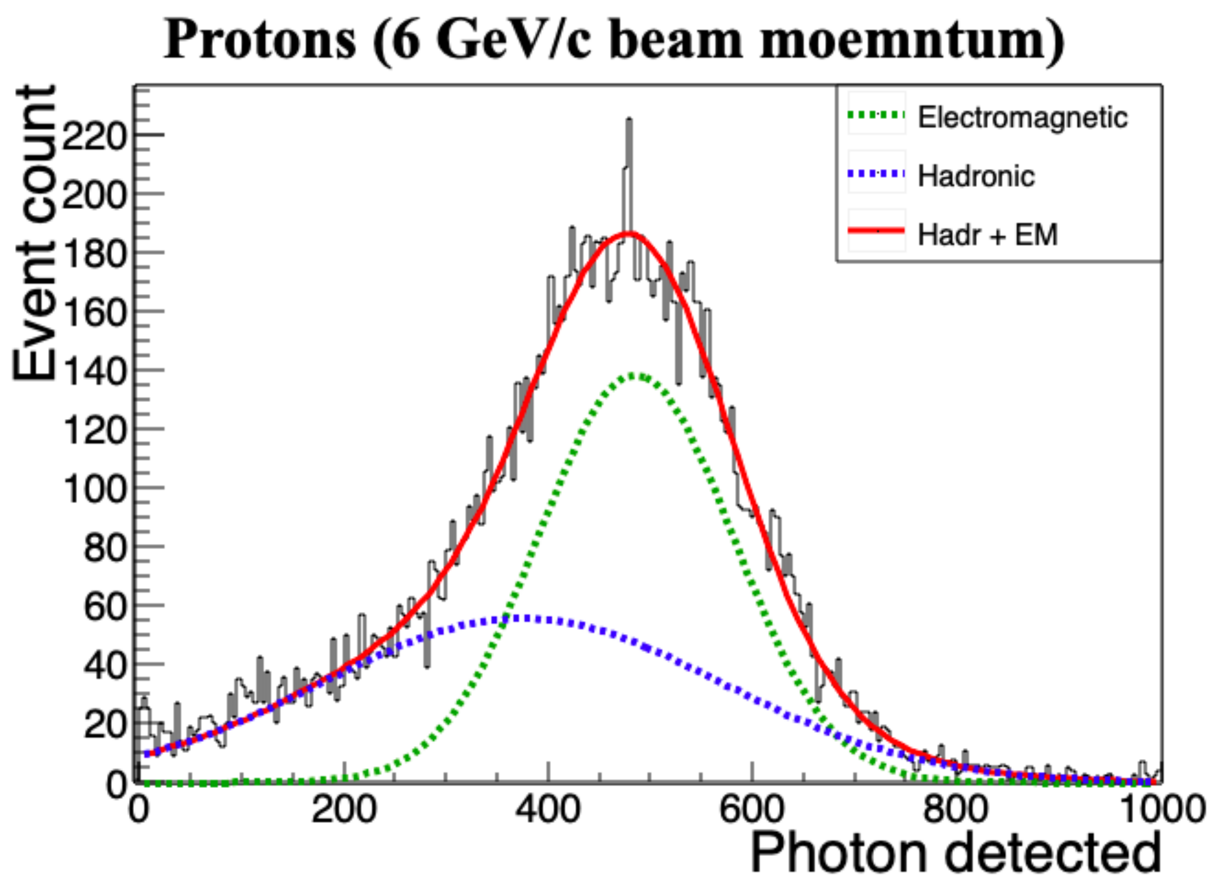


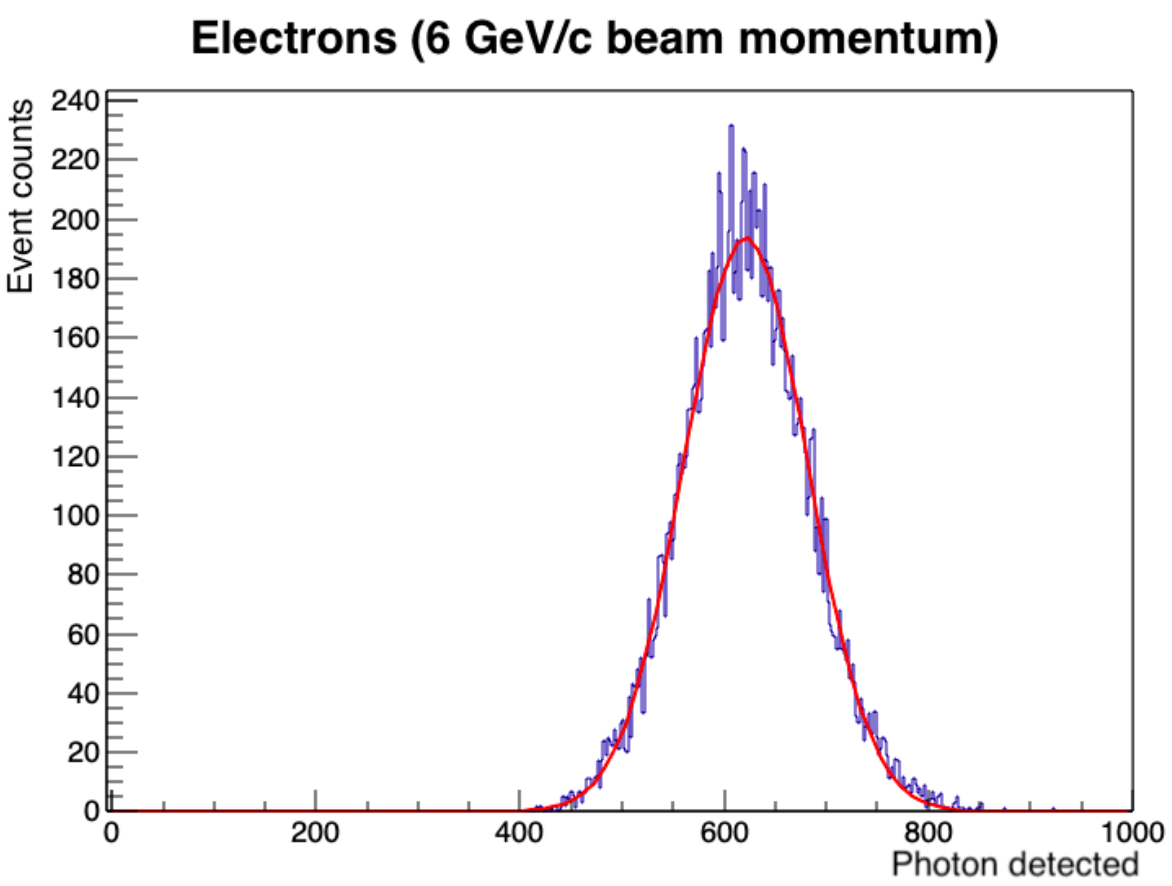
Thank you

Back up slides

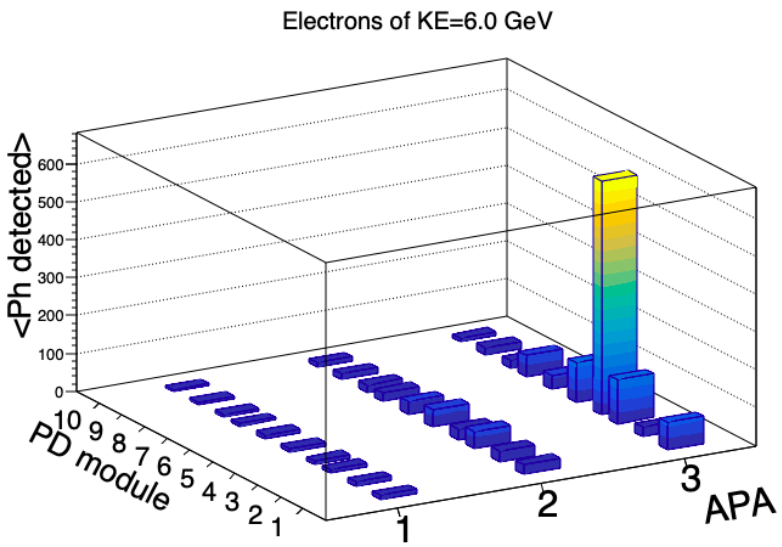
Electrons vs Protons spectra

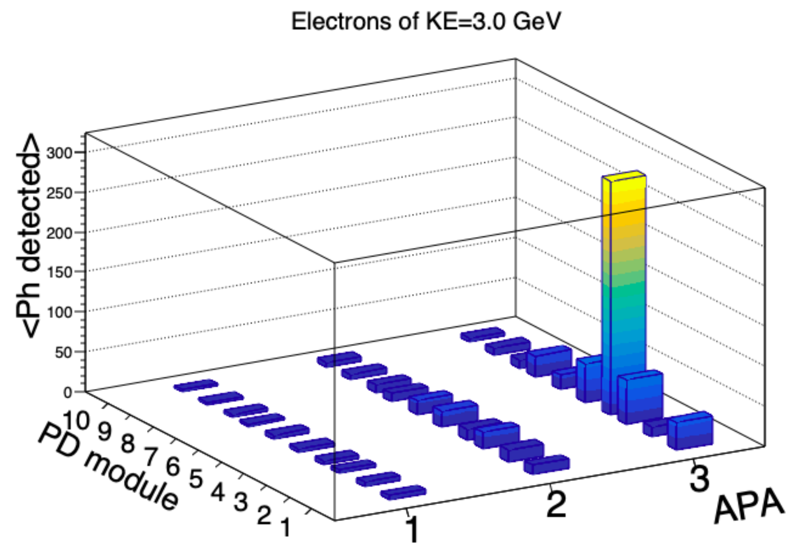
Protons produce showers where is present the hadronic component, giving a spectrum that is the sum of an hadronic and electromagnetic components. For electrons only the electromagnetic component is present

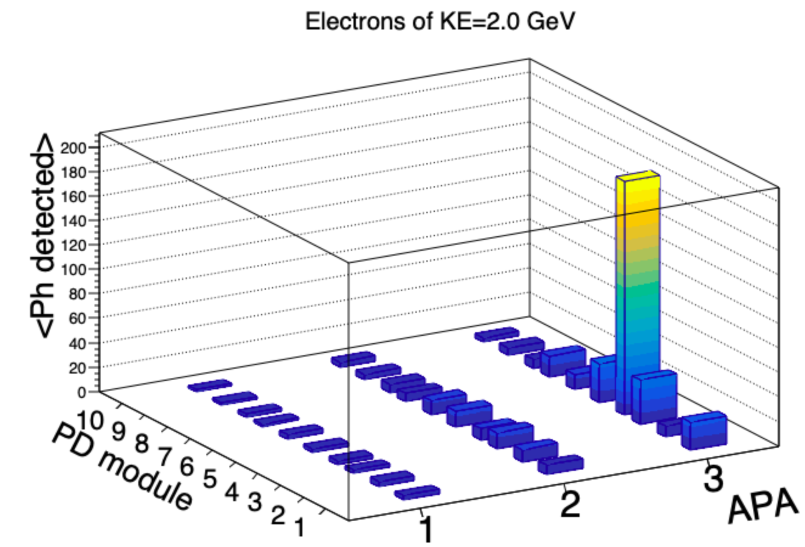


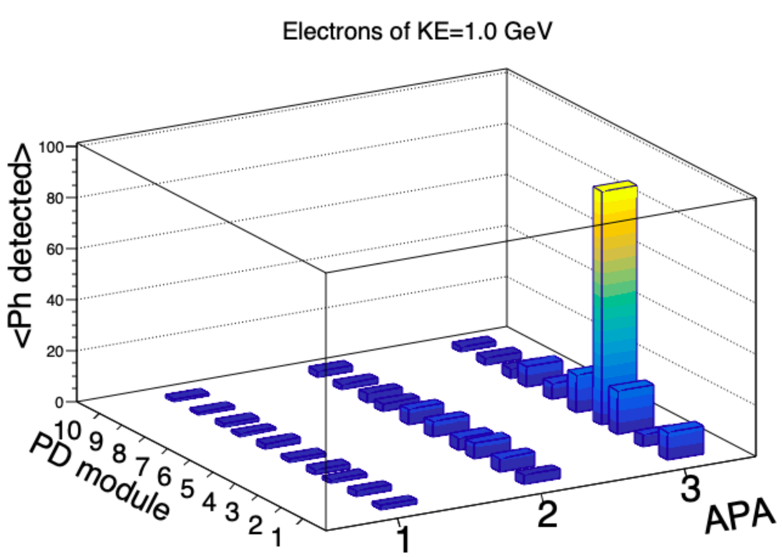


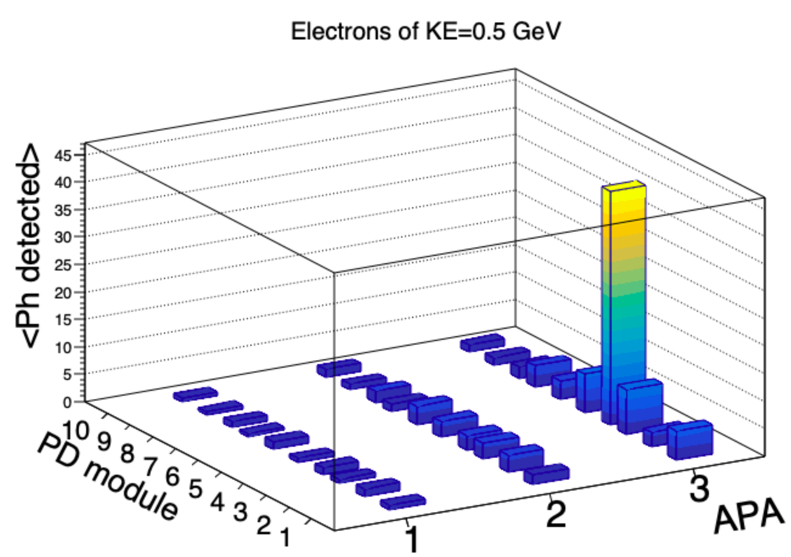
PD system response to beam electrons

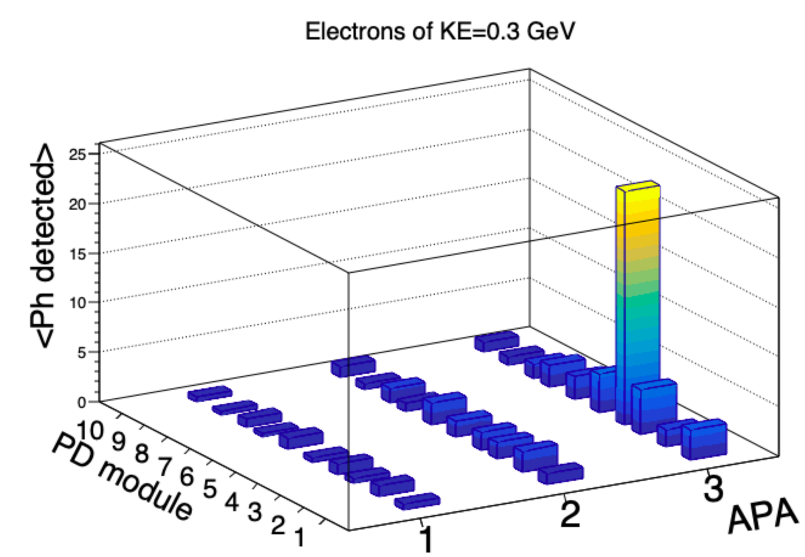












Arapuca resolution corrections

The kinetic energy too has a spread around its mean values: σ_{KE}

In the upper plots is reported $\frac{\sigma_{KE}}{\mu_{KE}}(\mu_{KE})$

Calling:

C_d : the detector response $\left(N_{ph} = C_d \cdot KE\right)$

R_d : the detector intrinsic resolution:

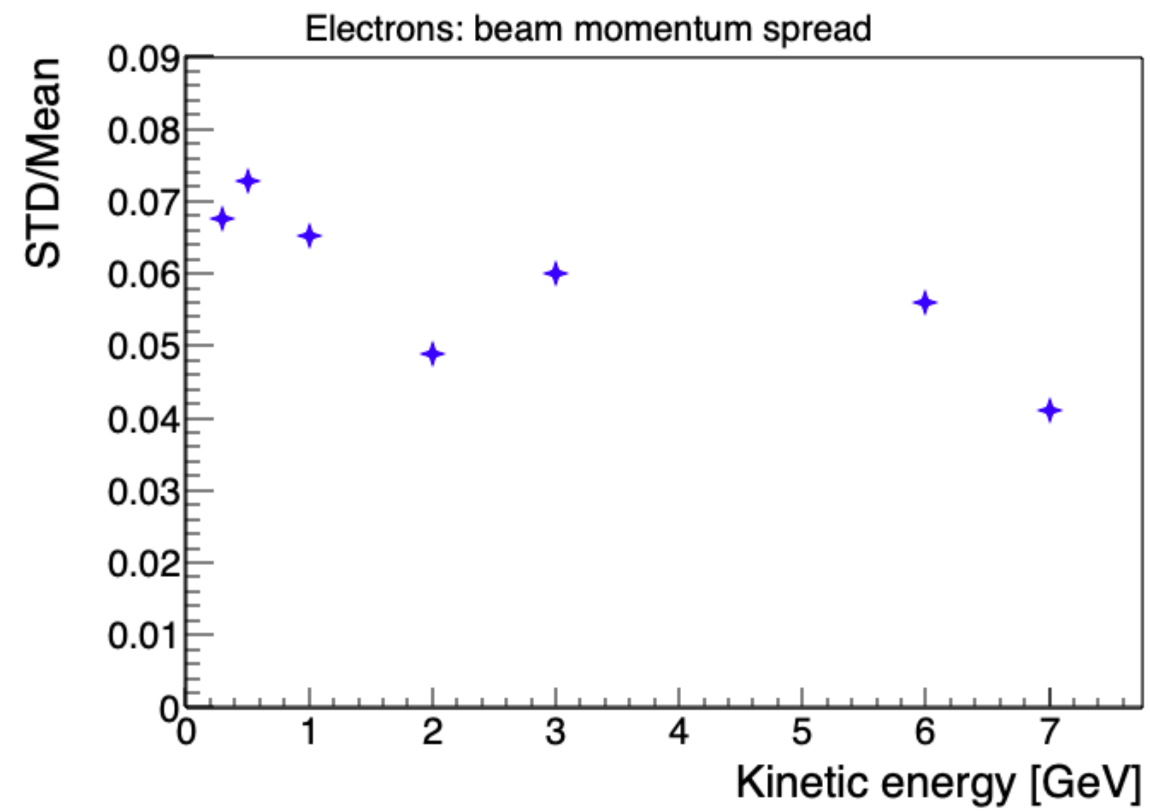
$$R_d = \sqrt{\left(\frac{\sigma_{N_{ph}}}{N_{ph}}\right)^2 - \left(\frac{\sigma_{KE}}{KE}\right)^2}$$

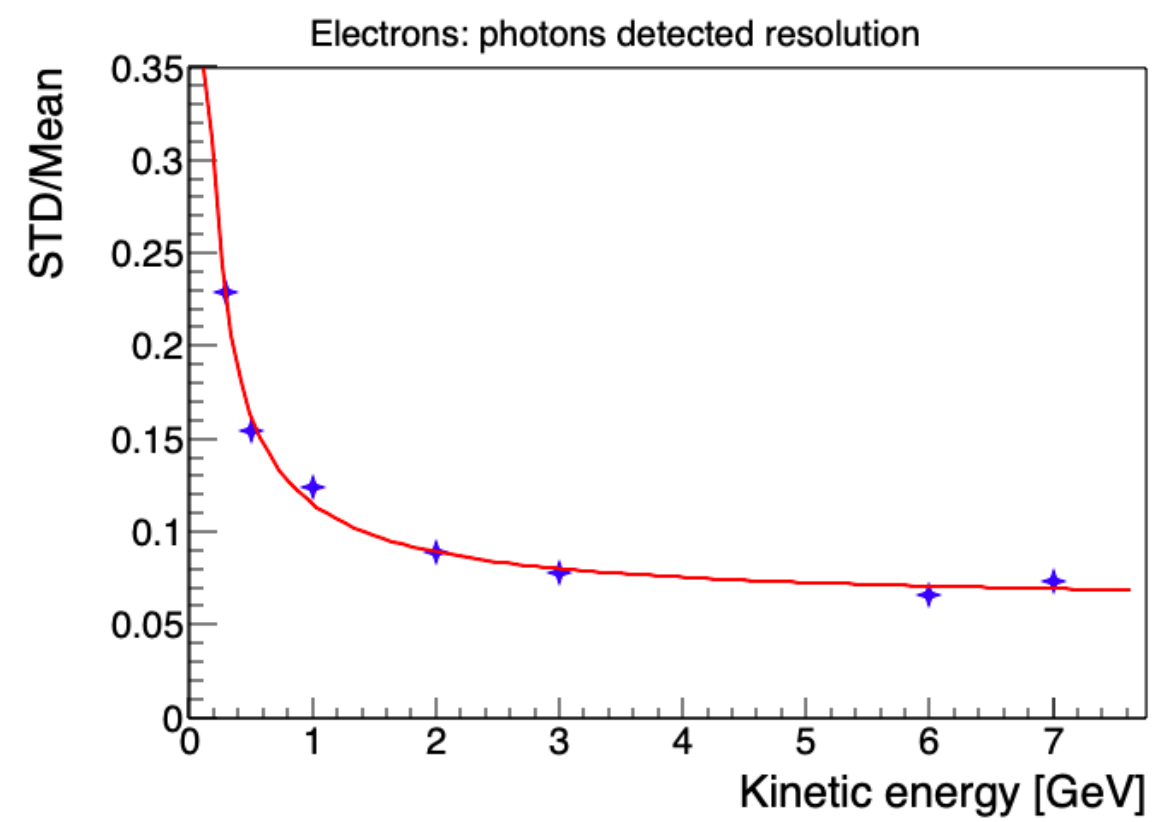
using the general equation for the fit we have:

$k_1 = 0.060 \pm 0.007$

$k_2 = 0.08 \pm 0.01 \ \left[\sqrt{GeV}\right]$

$k_3 = 0.04 \pm 0.01 \ [GeV]$



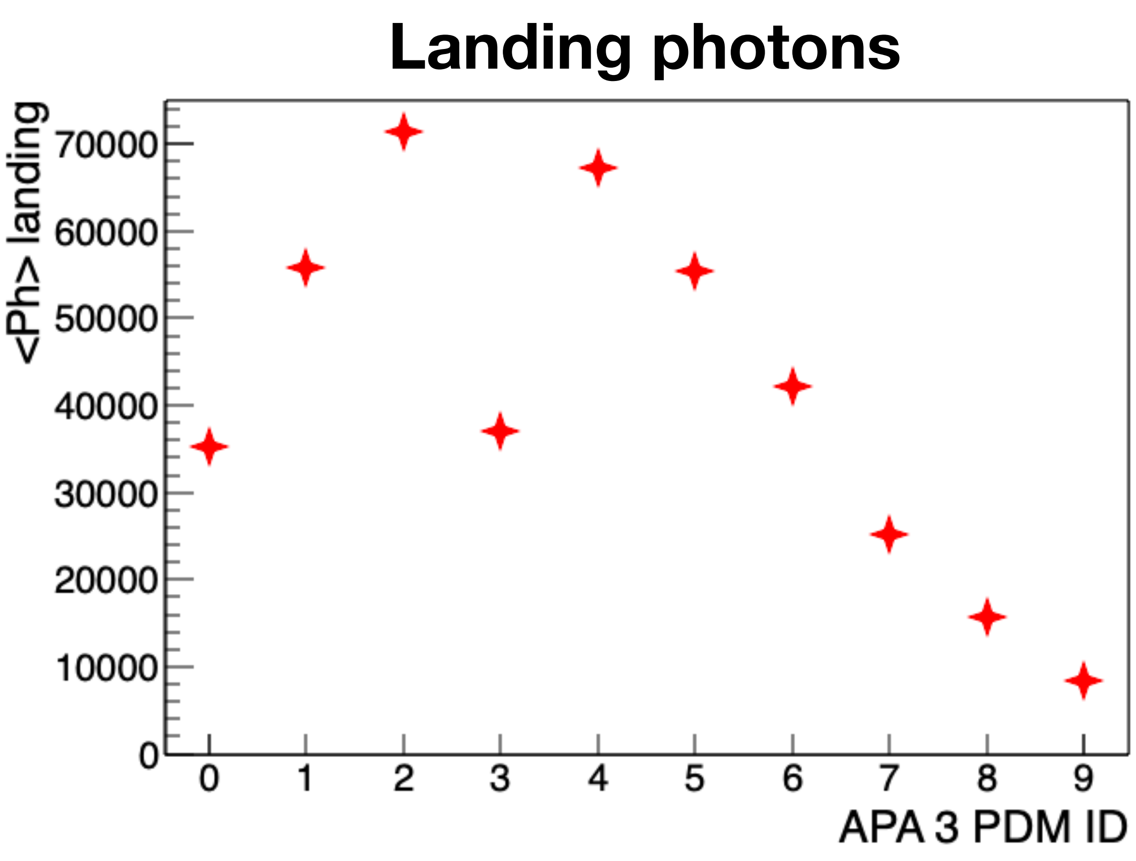


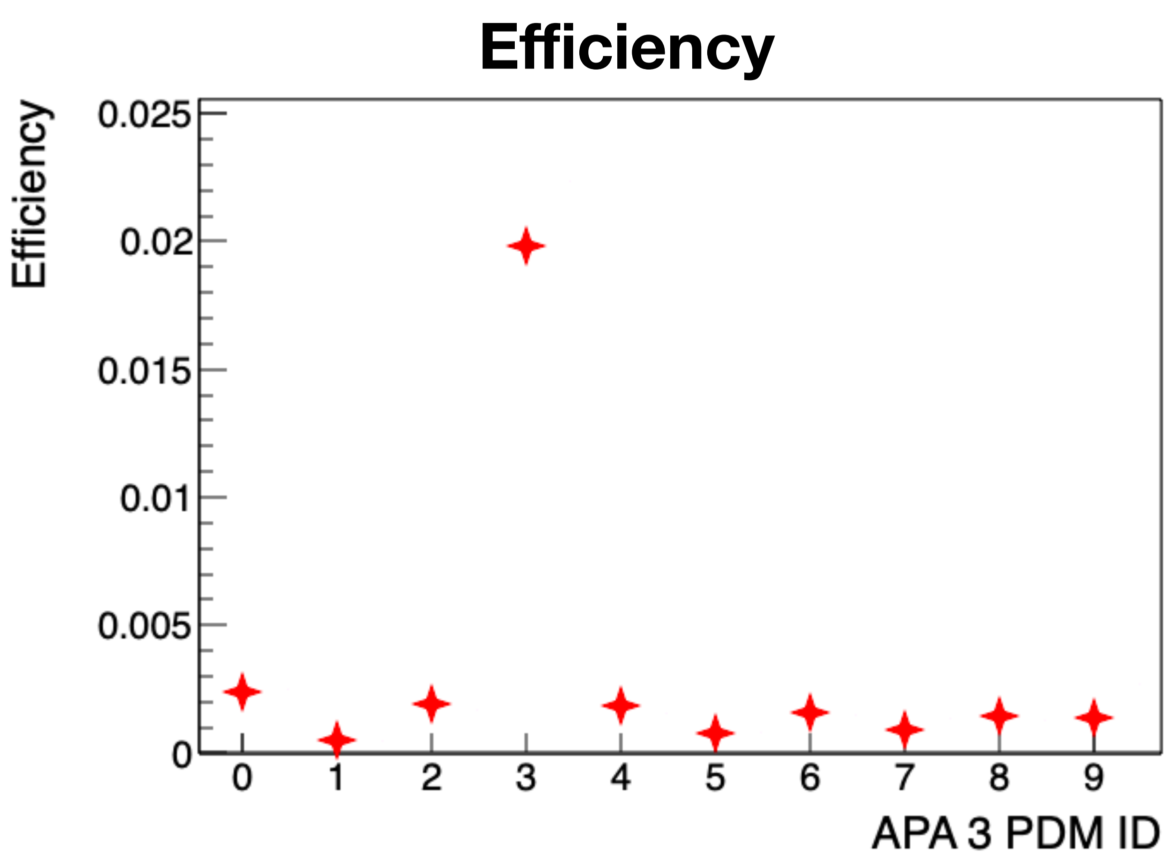
Arriving photons estimation for 7 GeV beam electrons

Arriving photons simulation is not completed yet.

- for the mash shadow is used a average value
- for some channels more statistic is needed

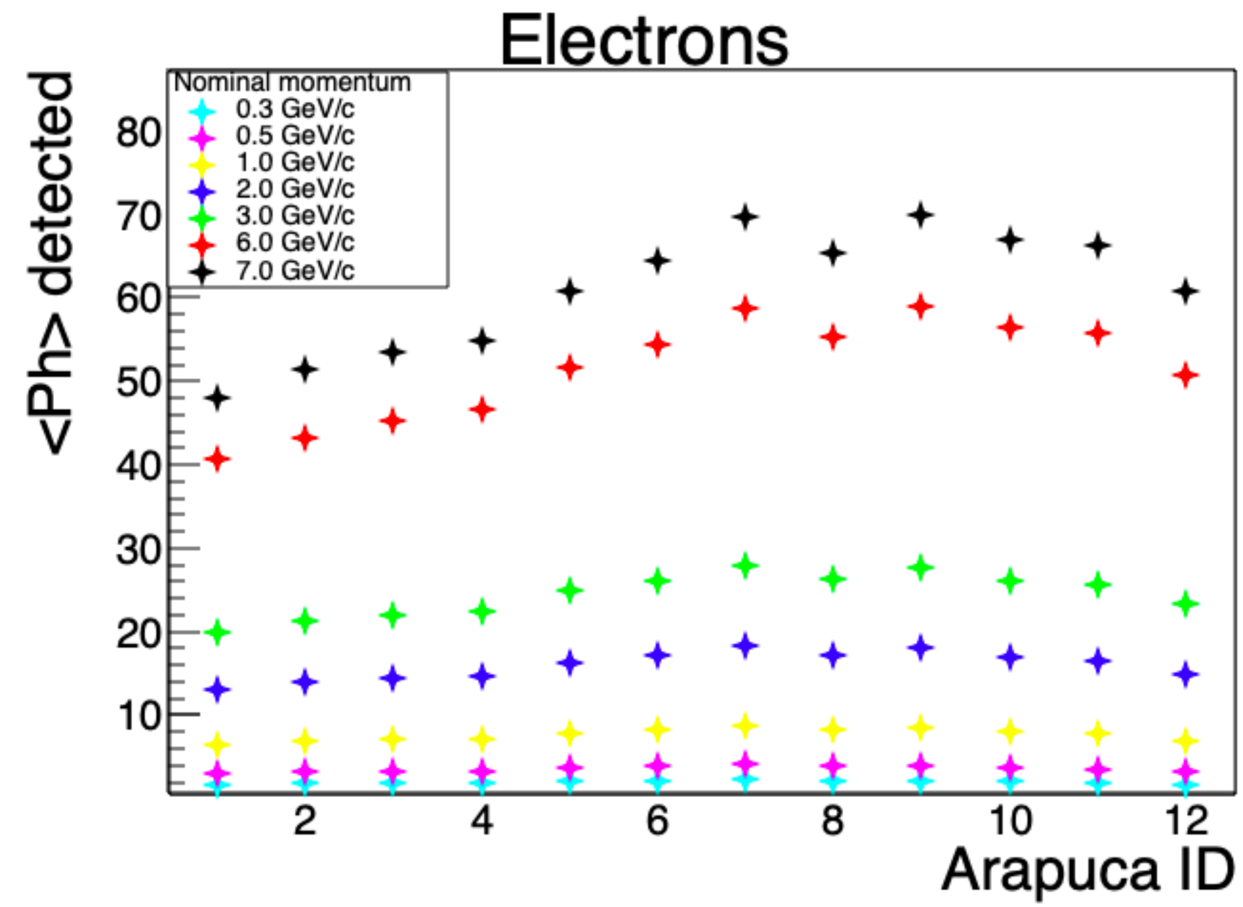
However a very preliminary result on efficiency shows a value ~ 2%

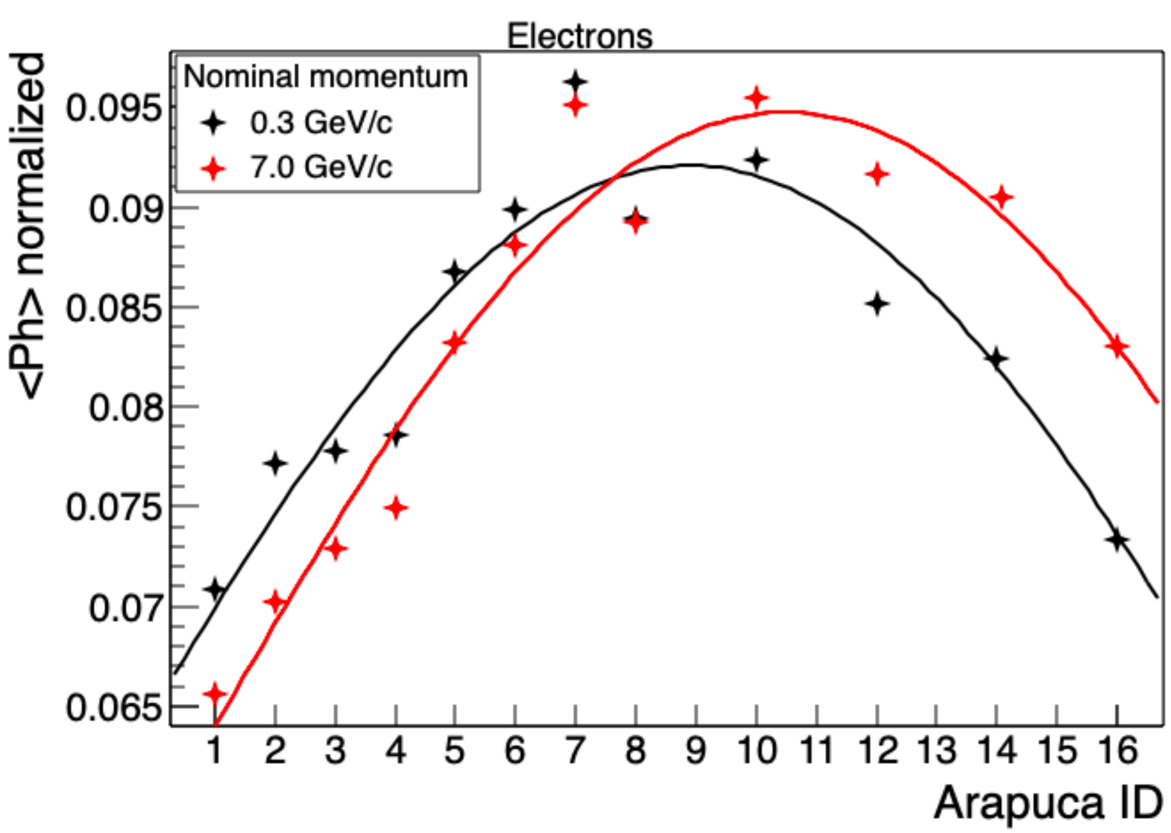




Arapuca cells response to beam electrons

The Arapuca granularity results superfluous applications for the beam events, since we know from the beam info the track geometry and the particle kind in each event.

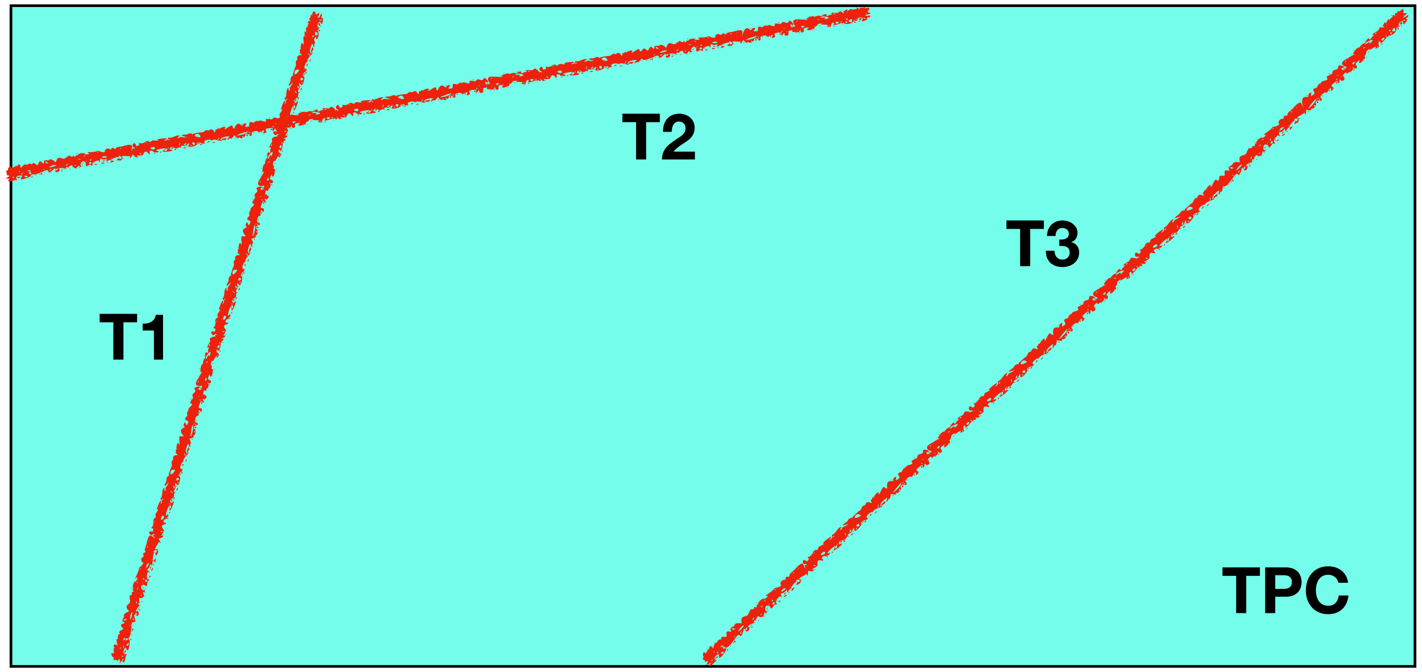




One of the possible applications could be the determination of the showers length from the light pattern detected by the cells.

Arapuca granularity power

A possible useful application for the Arapuca granularity could be the track identification in the TPC.

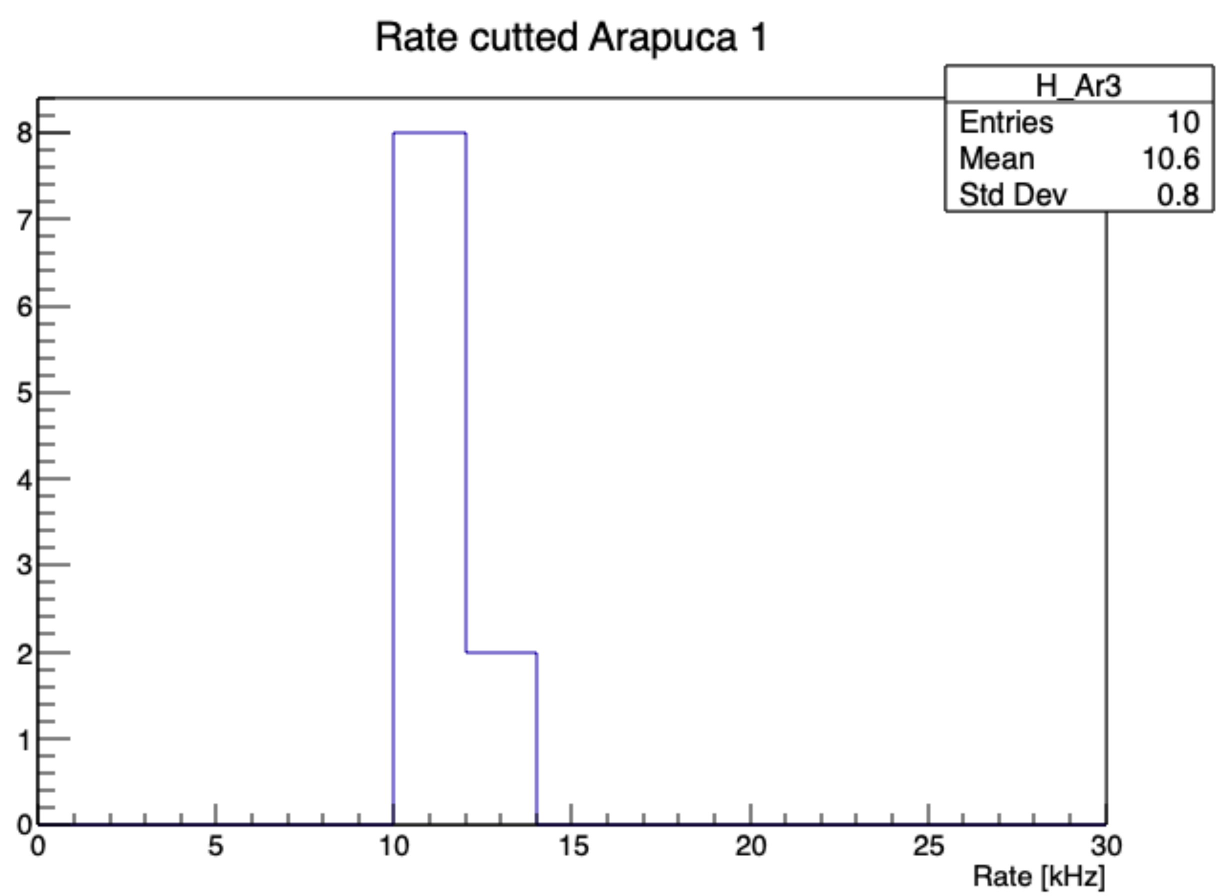


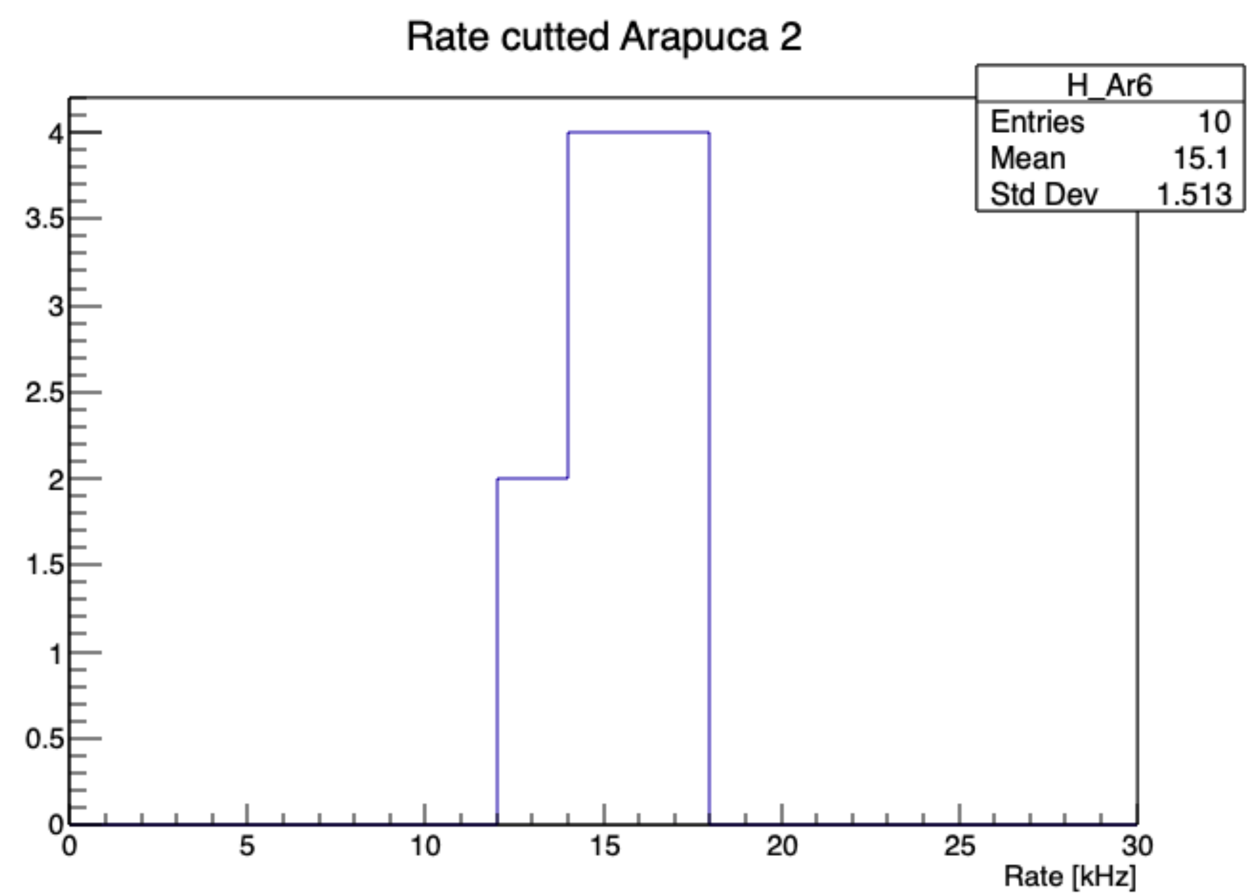
The TPC time window is $\sim 3\,ms$.
More tracks are recorded together.

The photodetectors have a much smaller window $\sim 13\,\mu s$ with resolution of $6.67\,ns$

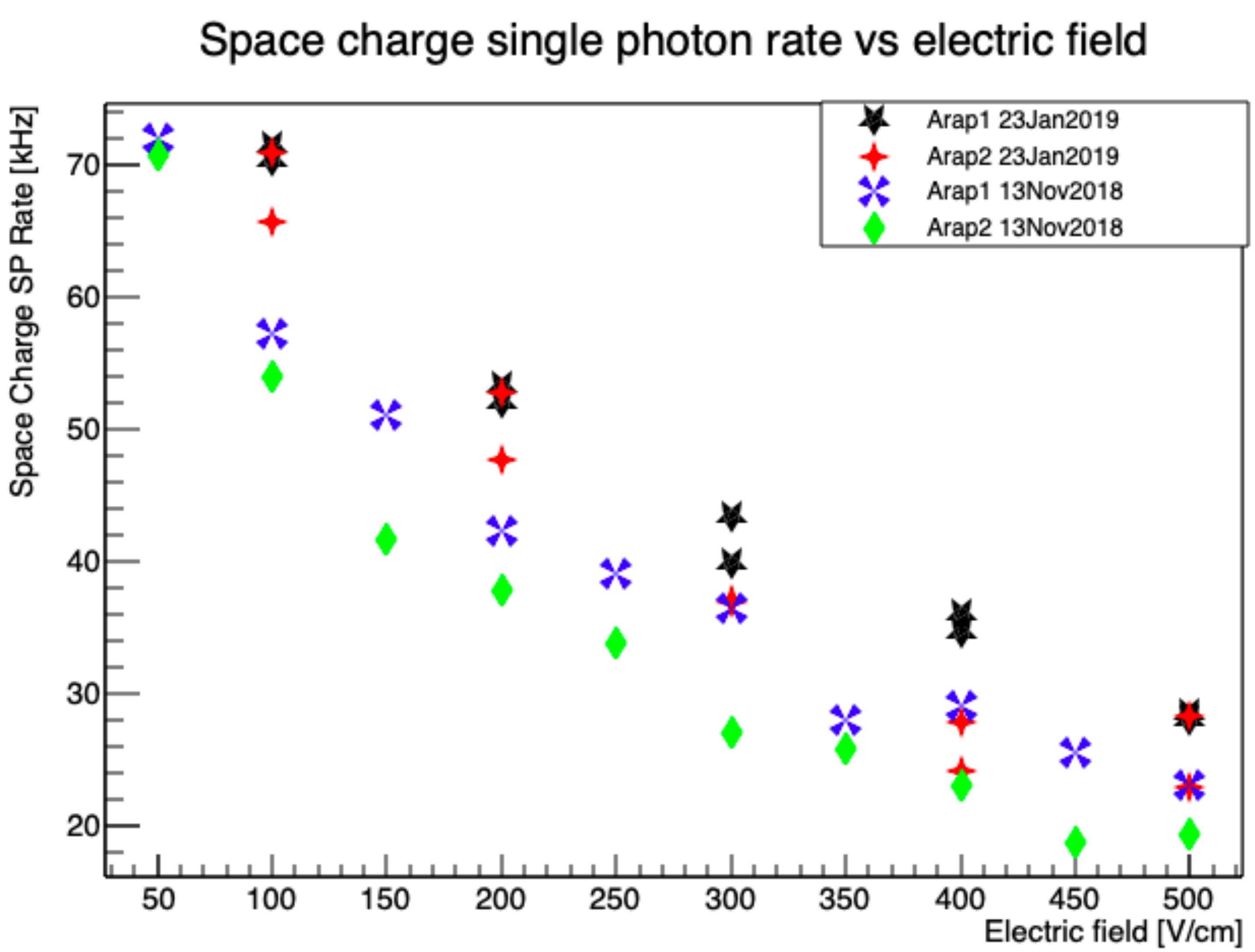
Using the tracks geometry given by the TPC we can reconstruct the light pattern produced by each track. Comparing these patterns with the light observed in the PD system it is possible associate each set of waveforms (PD event) to a given track, and hence getting its timing (t0).

Ionizing events cut rate are independent from the electric field





Offset and single photon rate from space charge absolute values



Ramp	Arapuca	OffSet
Nov 2018	1	70 kHz
Nov 2018	2	84 kHz
Jan 2019	1	154 kHz
Jan 2019	2	465 kHz

Subtracting that offset from the data measured we have: