

# Beam Events PD Response

## Preliminary Analysis (Focus on Arapuca)

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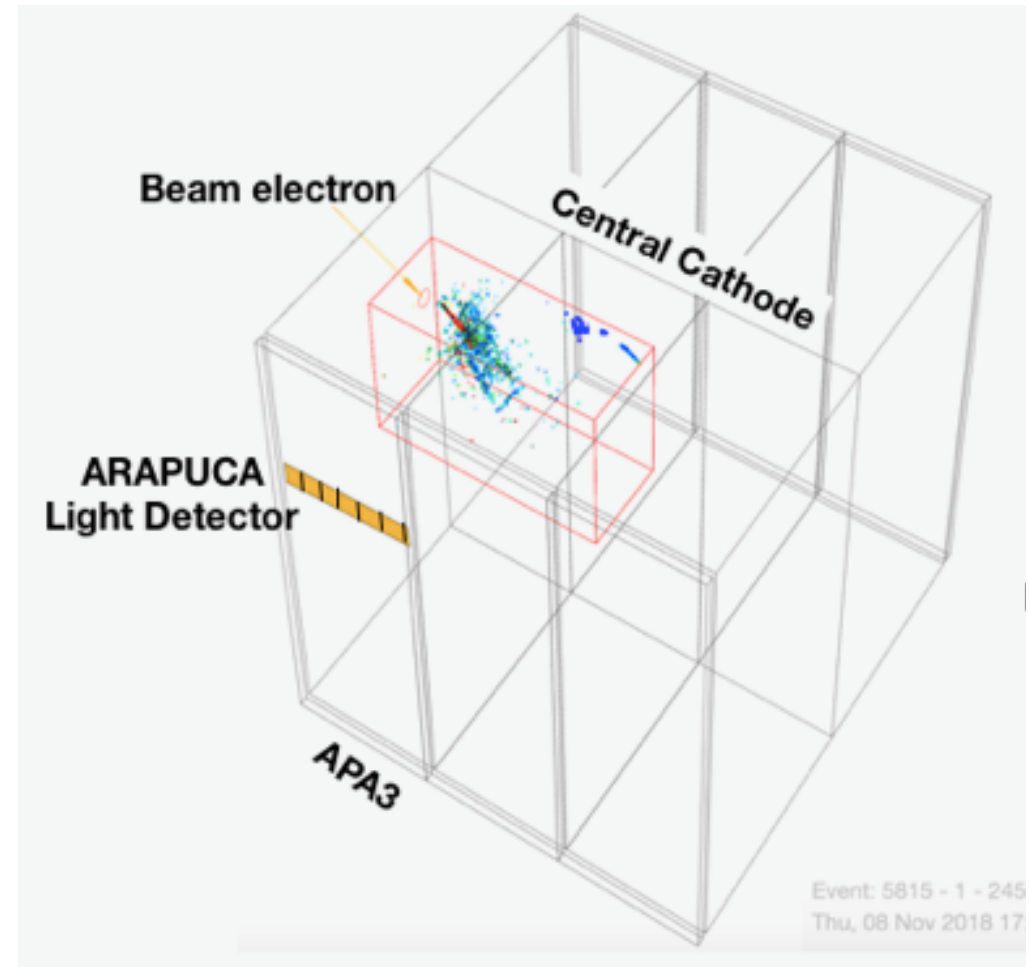
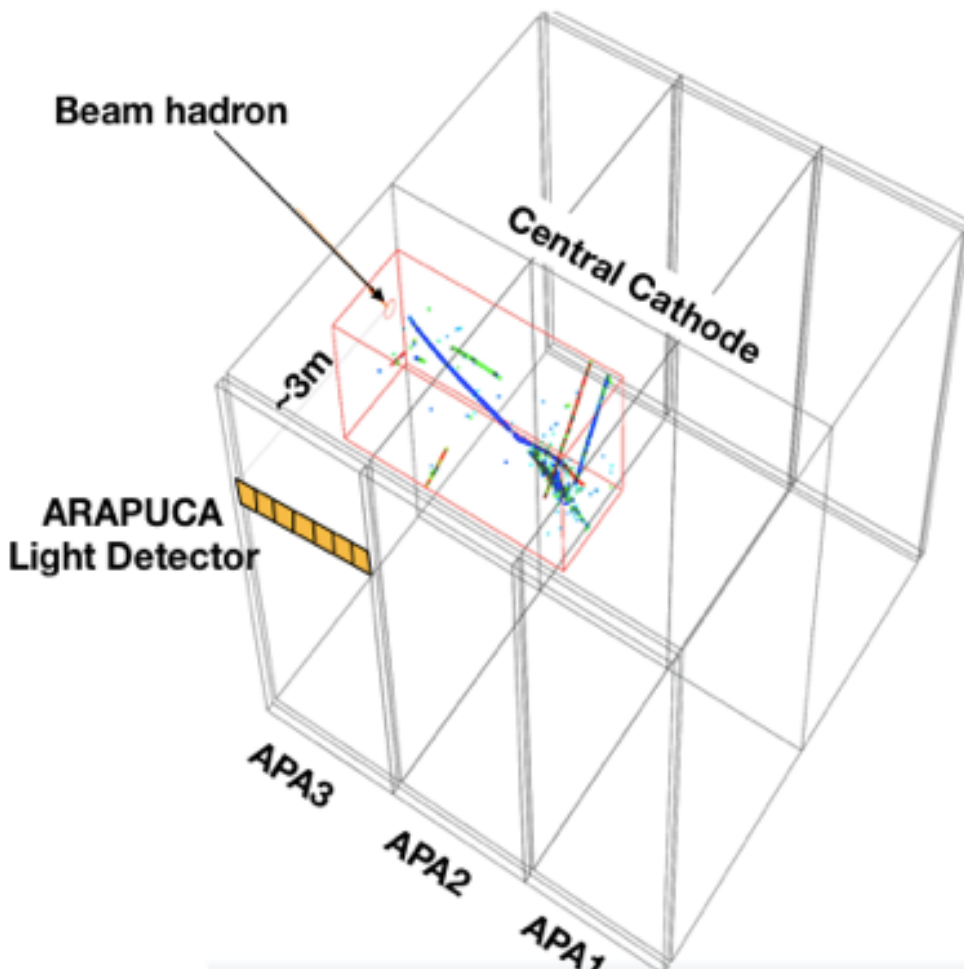
Fermilab - University of L'Aquila

DRA Mtg. - ProtoDUNE

April 17th, 2019

## PD characterization from three approaches

- Arapuca PD module for Beam momentum of 7GeV/c *(all events)*
- Arapuca PD module for all Beam momentum values *(partial events)*
- All the PD modules in the Beam-Side for Beam momentum of 7GeV/c *(all events)*



# Particle identification

Based on Justin Hugon (Louisiana State University) talk : [ProtoDUNE Sim/Reco Meeting 2018-11-28]  
 (<https://indico.fnal.gov/event/19185/contribution/2/material/slides/0.pdf>)

## - Cherenkov PID

6/7 GeV/c	High Pressure Cherenkov	Low Pressure Cherenkov	3 GeV/c	High Pressure Cherenkov	Low Pressure Cherenkov	0.3/0.5/1/2 GeV/c	Low Pressure Cherenkov
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

## - Time of Flight

For 0.3/0.5/1/2 GeV/c if not classified as electron by the Cherenkov, then TOF is used to differentiate pions and protons

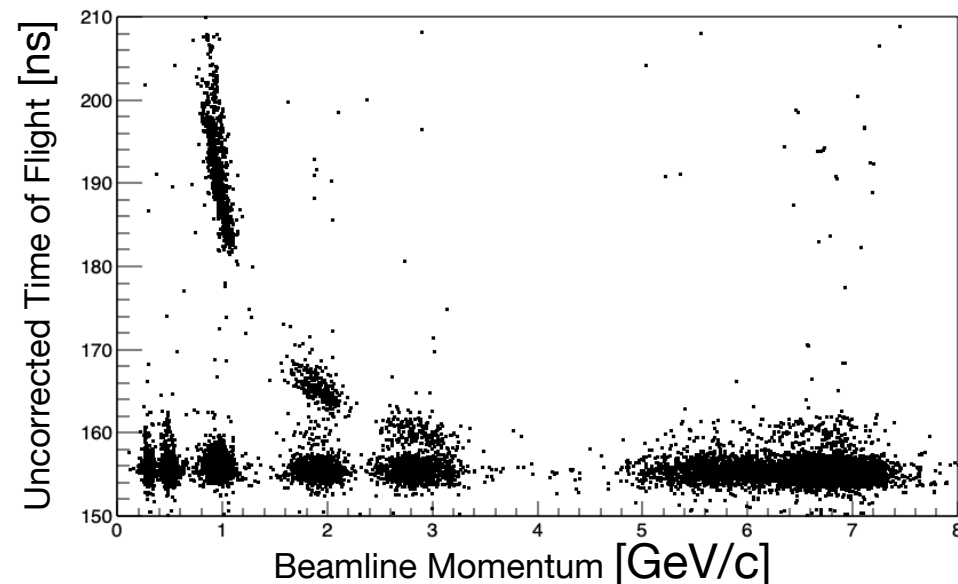
For 2 GeV/c:  
 TOF < 160 ns: pions  
 Else: protons

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

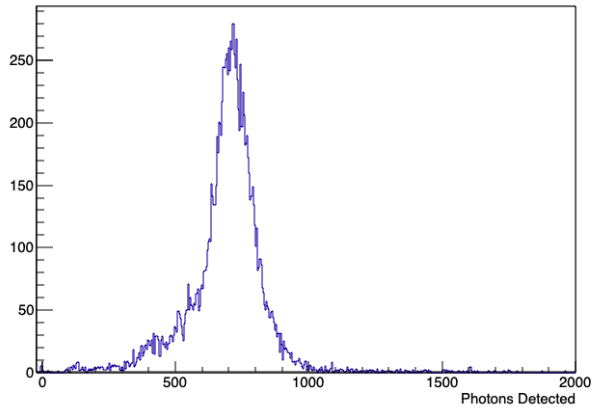
Beam Momentum vs. Time of Flight



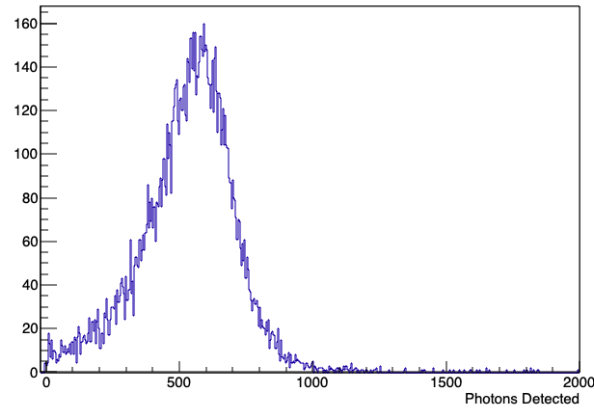
# For 7 GeV/c beam momentum, the whole amount of data is used.

Total Event	154598	Pions	85878
Electrons	13143	Kaons	7027
Muons	8941	Protons	13277

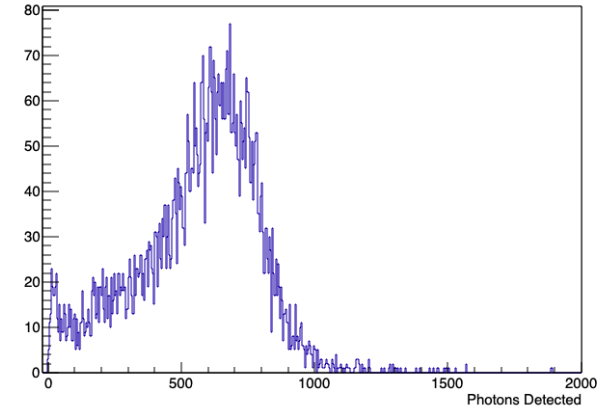
Arapuca Sum spectrum for Electrons of BM = 7 GeV/c



Arapuca Sum spectrum for Protons of BM = 7 GeV/c



Arapuca Sum spectrum for Kaons of BM = 7 GeV/c

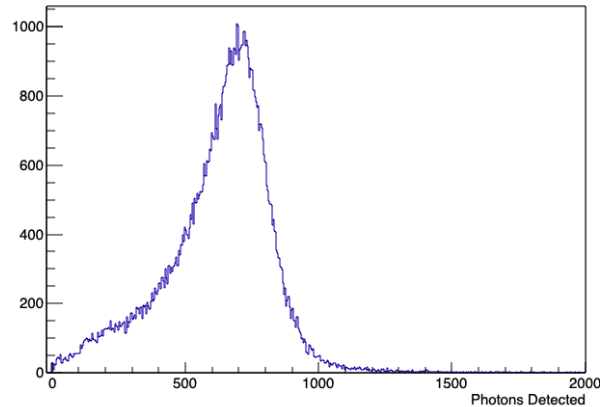


## Average number of photons per particles:

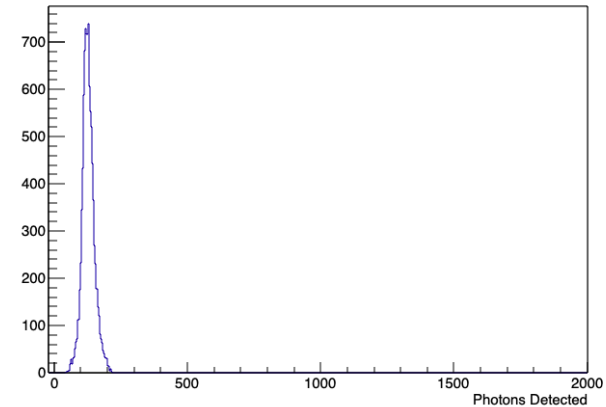
- Electros:  $\langle N_{ph} \rangle = 693$
- Muons:  $\langle N_{ph} \rangle = 128$
- Pions:  $\langle N_{ph} \rangle = 627$
- Kaons:  $\langle N_{ph} \rangle = 564$
- Protons:  $\langle N_{ph} \rangle = 534$

Remind: the momentum is fixed, the Kinetic Energy depends on the particle

Arapuca Sum spectrum for Pions of BM = 7 GeV/c

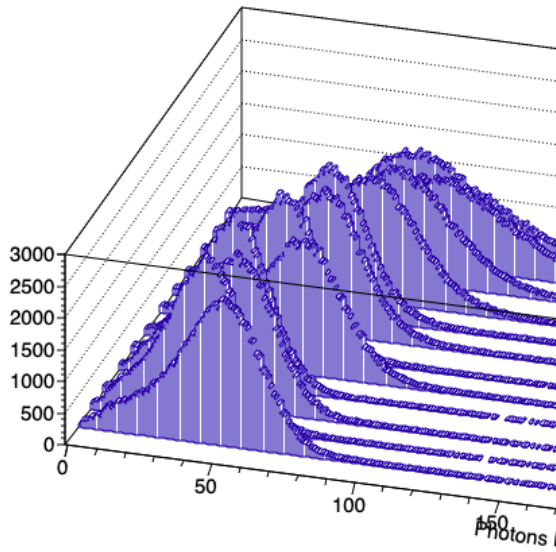


Arapuca Sum spectrum for Muons of BM = 7 GeV/c

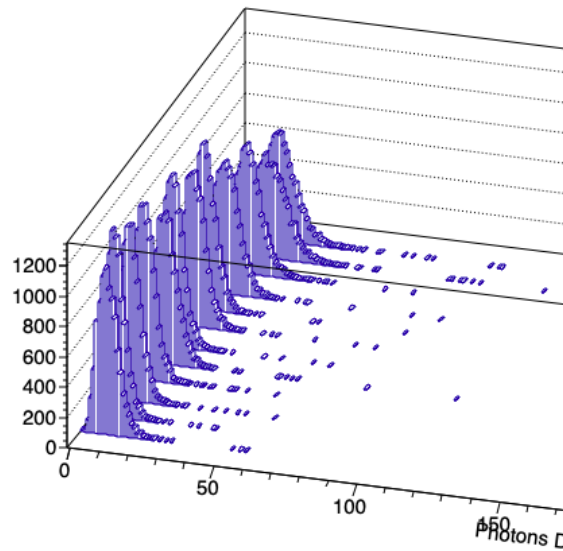


# Arapuca Spectra cell by cell for 7 GeV/c beam momentum

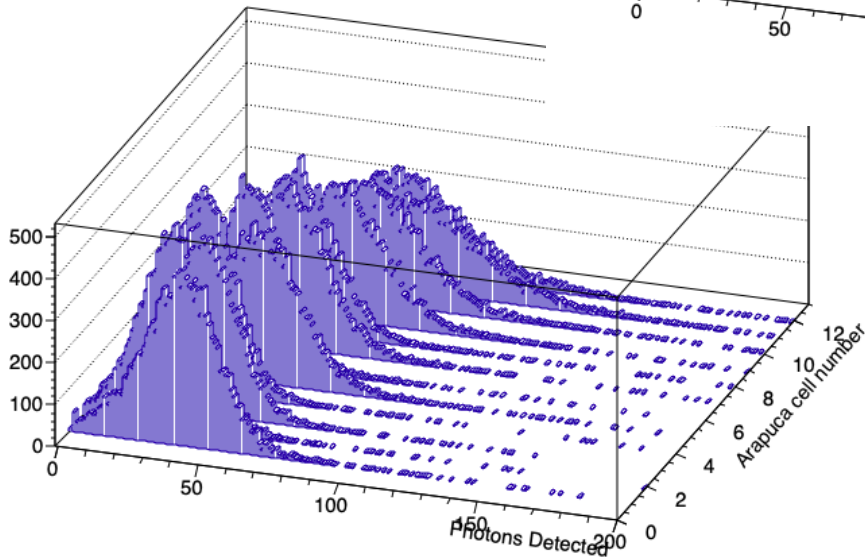
Arapuca single cell spectra for Pions of BM = 7 GeV/c



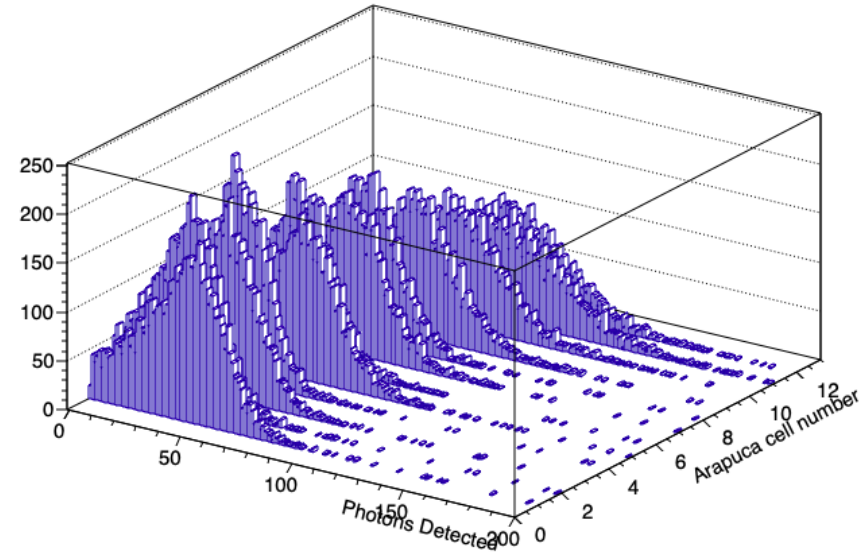
Arapuca single cell spectra for Muons



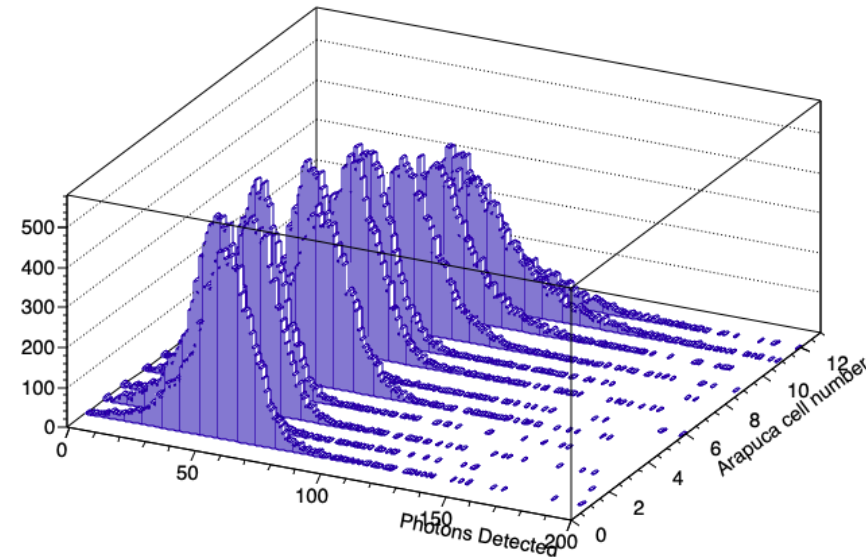
Arapuca single cell spectra for Protons



Arapuca single cell spectra for Kaons of BM = 7 GeV/c



Arapuca single cell spectra for Electrons of BM = 7 GeV/c

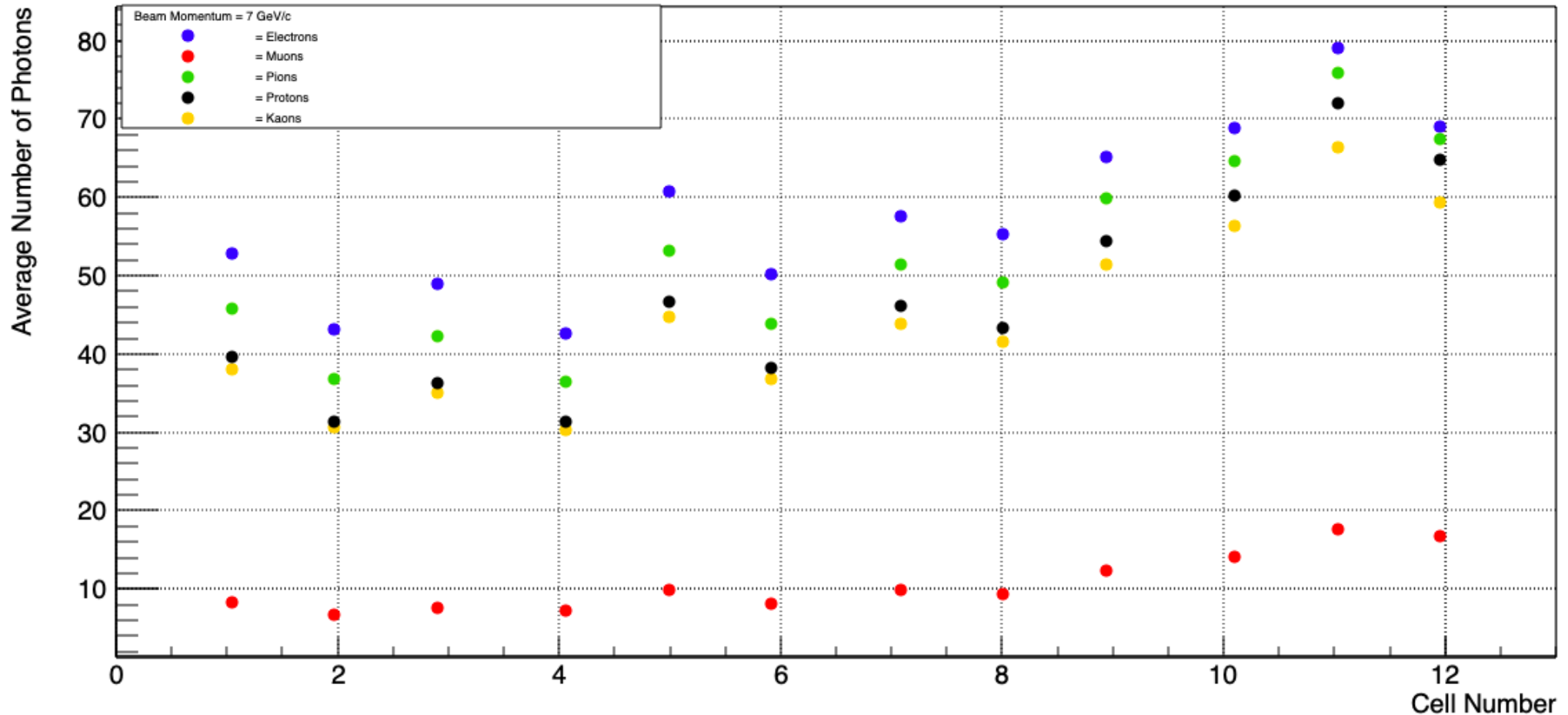


# Arapuca $\langle Ph \rangle$ Detected cell by cell

Cell 1 = DAQ channel 132 , Cell 2 = DAQ ch 133 , ....

The geometrical position have to be fixed, as well as, what are the channels with two Arapuca connected in parallele and the channels with only one Arapuca

Average number of photons detected by each Arapuca cell per particle



# Muons: data & simulation

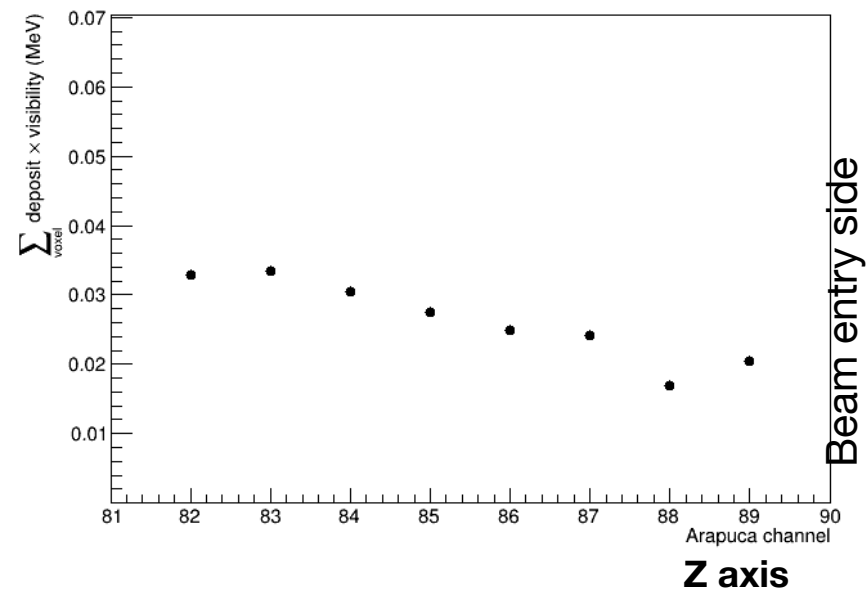
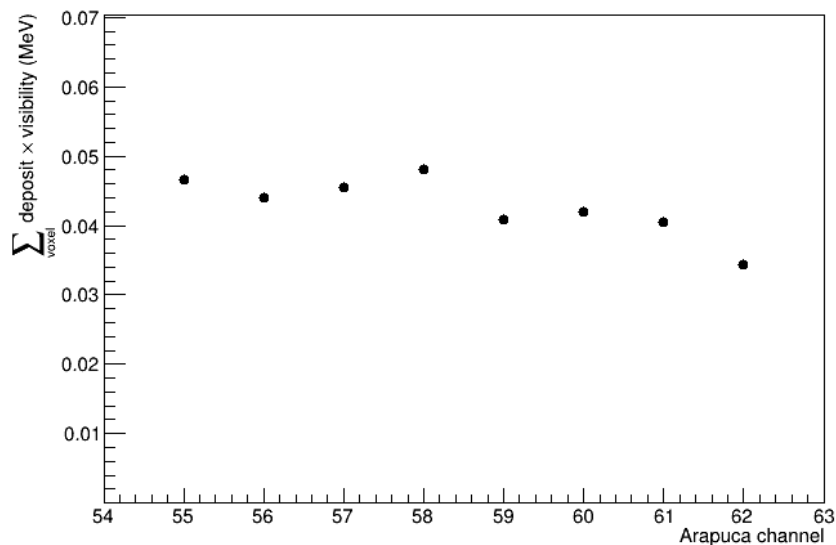
MC simulation has been made by

**Laura Paulucci** and **Franciole Marinho**

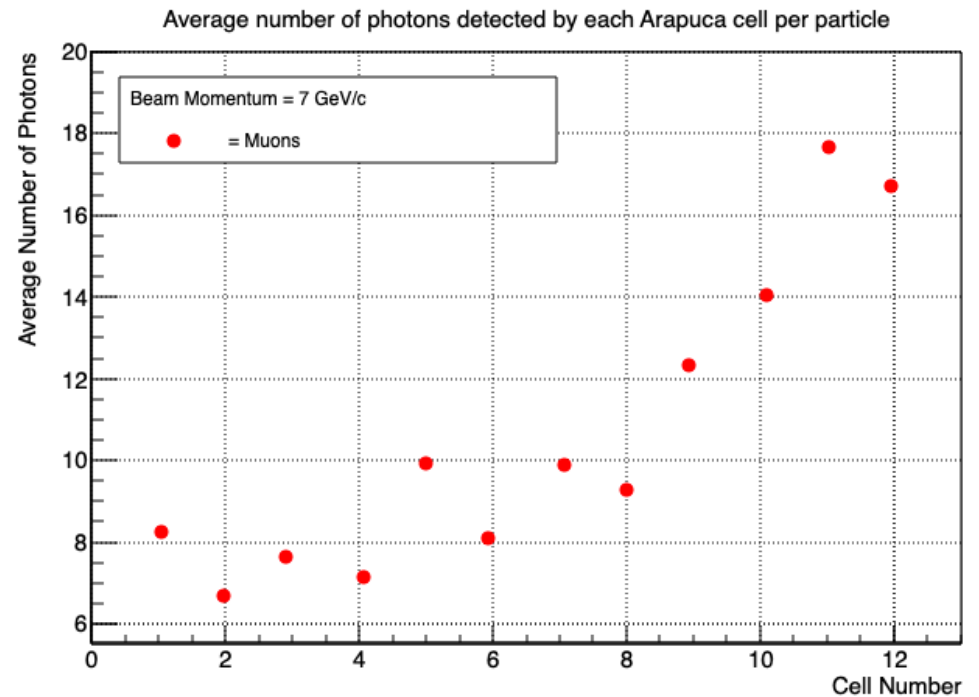
The plots below show the fraction of energy deposited normalized the acceptance of each cell.

The channel in MC have another labeling and the points are relatives to the Arapuca cells and not to the channels (12 channels for 16 Arapuca).

# Simulation

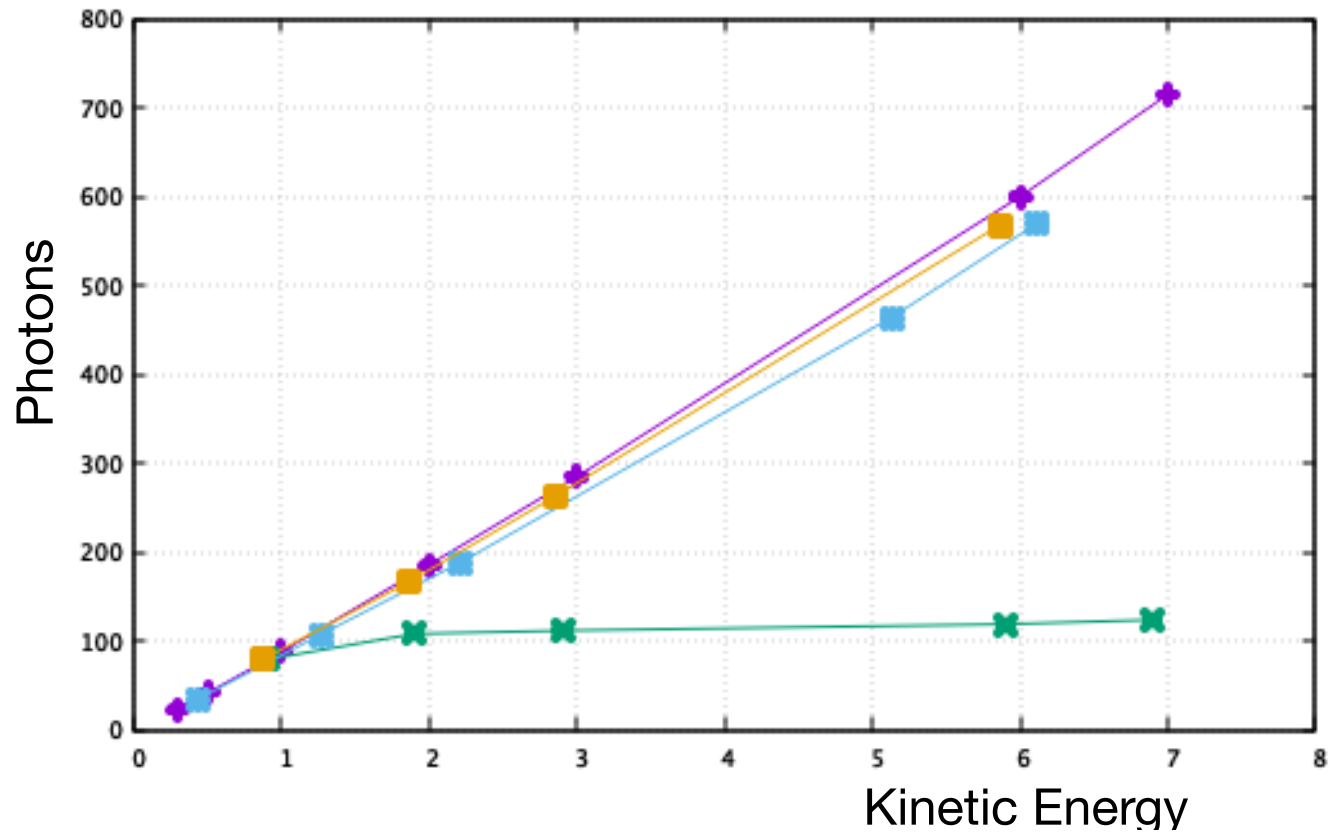


# Data



## Beam Momentum Scan

Same analysis for all the beam momentum values (for a fraction of events)



Green = Muons

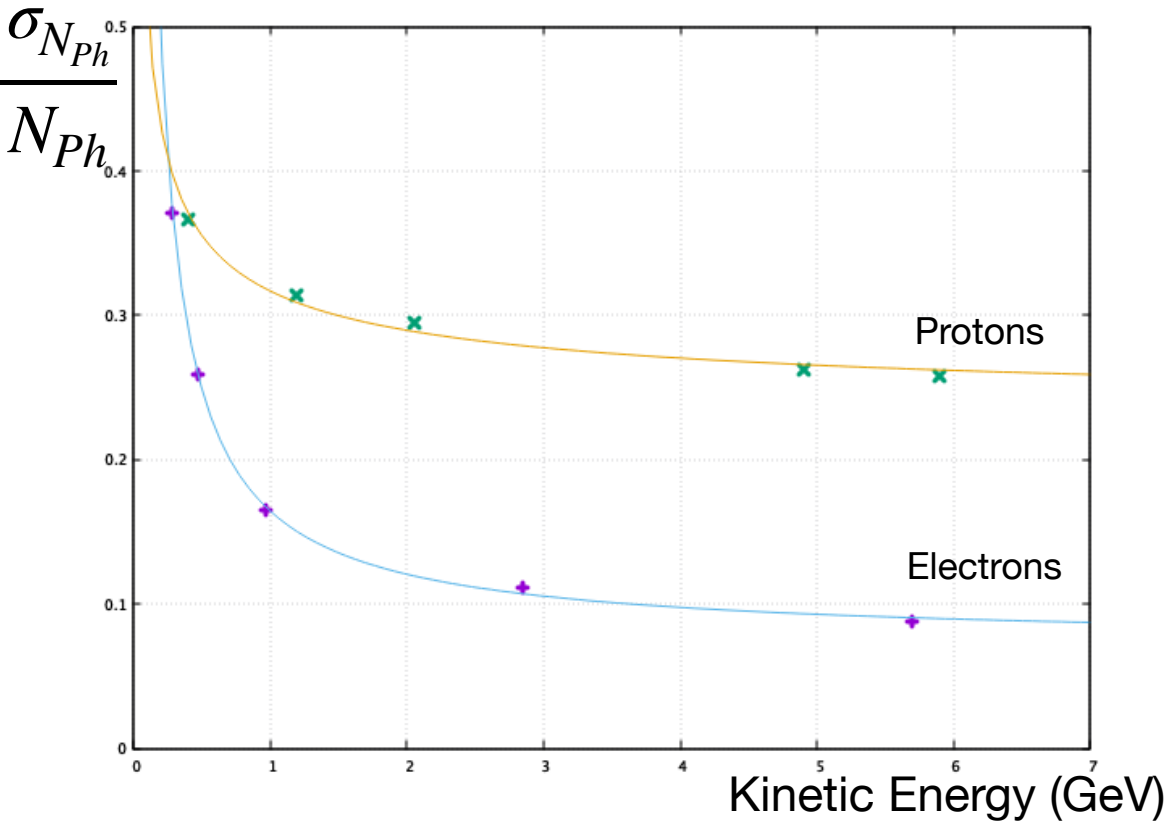
Purple = Electrons

Blue = Protons

Yellow = Pions



## Electrons and Protons Resolution



$\frac{\sigma_{N_{Ph}}}{N_{Ph}}$  is the ratio between the STD and the mean got from the spectra Gaussian fit

### Data Fitting

Protons:

$$k_1 = 0.26 \pm 0.02$$

$$k_2 = 0.17 \pm 0.07$$

$$k_3 = 0.0004 \pm 9$$

Electrons:

$$k_1 = 0.073 \pm 0.006$$

$$k_2 = 0.12 \pm 0.01$$

$$k_3 = 0.082 \pm 0.004$$

Standard fit equation :

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

## All PD modules - Beam Side response

Preliminary measurement of all PD response in the Beam-Side

**All the numbers are Photo Electrons measured (PE) and not Photons Detected (Ph).  
(For MPPCs in Arapuca : PE=1.3 Ph. SensL should have less AP and CT)**

For this analysis the calibration used is the one got from the PE separation, After Pulses and Cross Talks are not take into account.

Calibration used is the one made by Chris (SensL), Bryan (all the devices) and me (MPPCs in Arapuca). The PD modules with Bars and MPPCs are located all in the No-Beam side.

**To be noted that:**

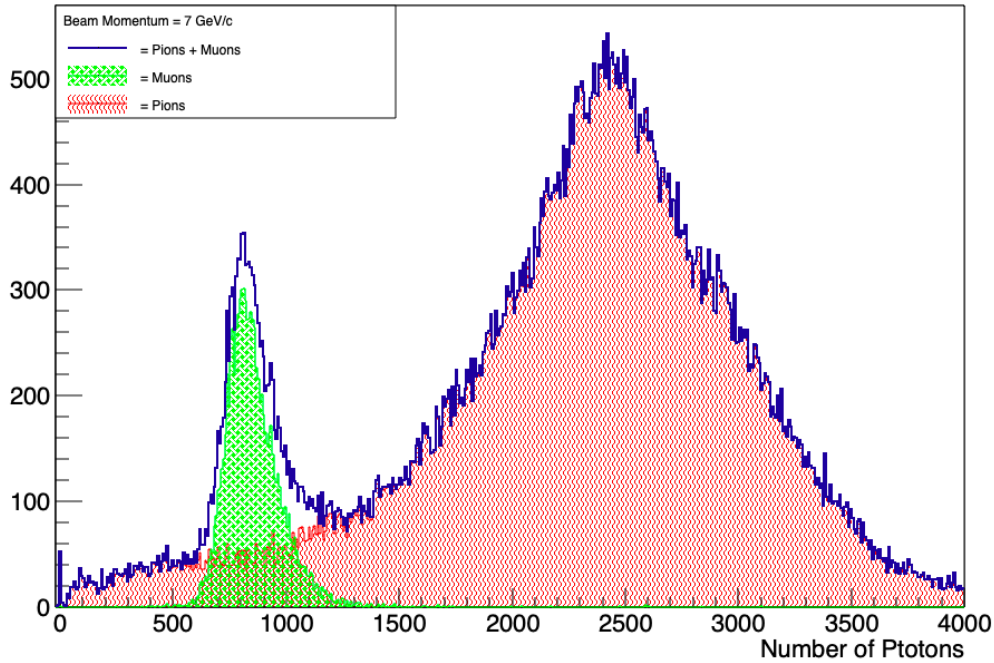
The Arapuca PD module is composed of 12 channels reading 12 MPPCs each one, in two configurations.

Each bar PD module is composed of 4 channels reading 3 SiPM each one.

# Pions and Muon

Electrons and Muons are well localized  
 Pions, Protons and Kaons shows a tail to zero.  
 We are investigating about this behavior

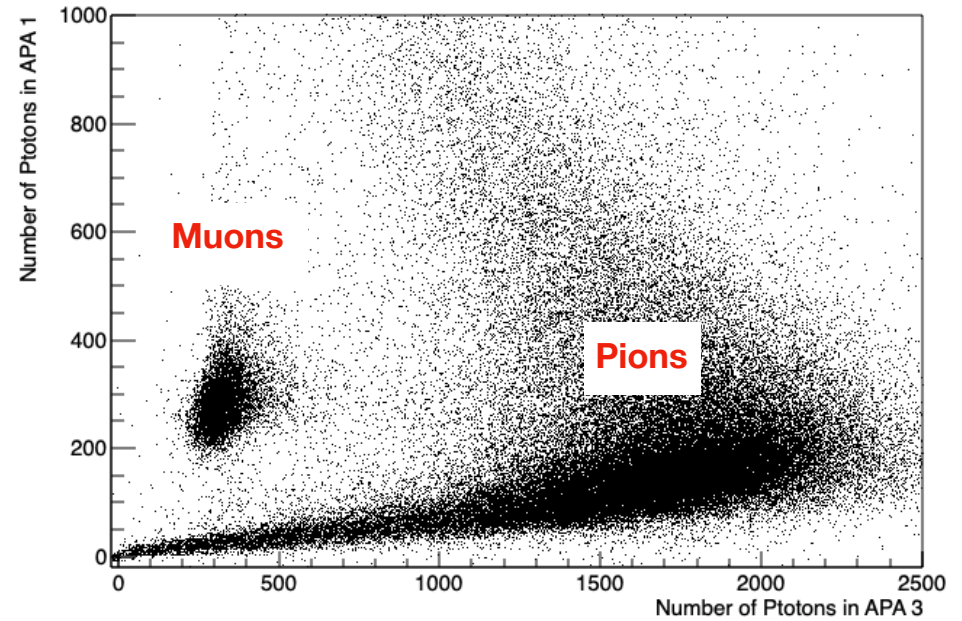
Sum of Photons from all the APAs in the beam side for Pions and Muons



Sum of Ptotons in APA 3 vs Sum of Ptotons in APA 3 for particles selected as Pions + Muons

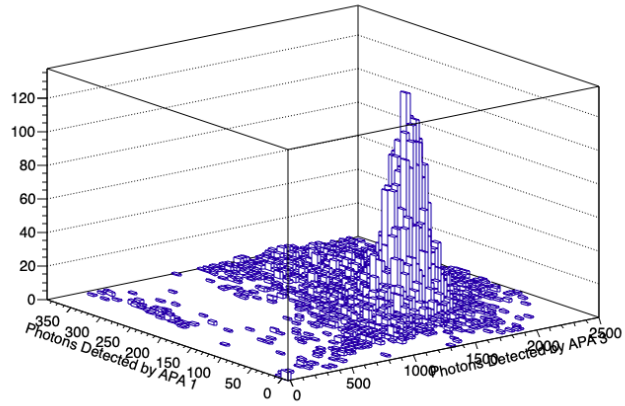


Sum of Ptotons in APA 3 vs Sum of Ptotons in APA 3 for particles selected as Pions + Muons



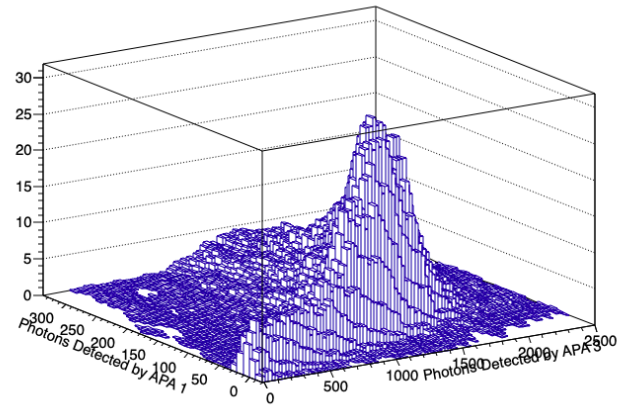
## Electrons

APA 3 vs. APA 1 spectra for Electrons of BM = 7 GeV/c



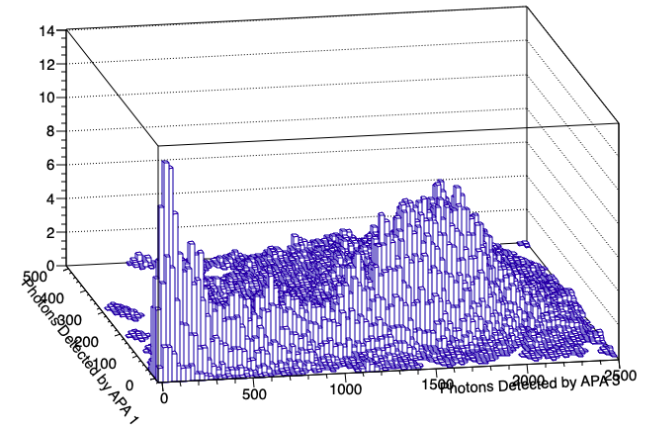
## Protons

APA 3 vs. APA 1 spectra for Protons of BM = 7 GeV/c

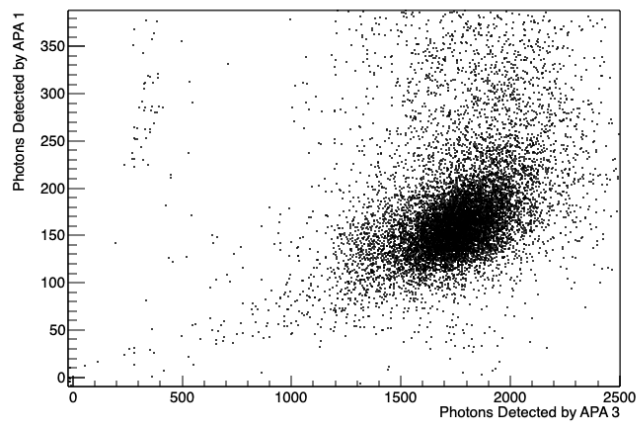


## Kaons

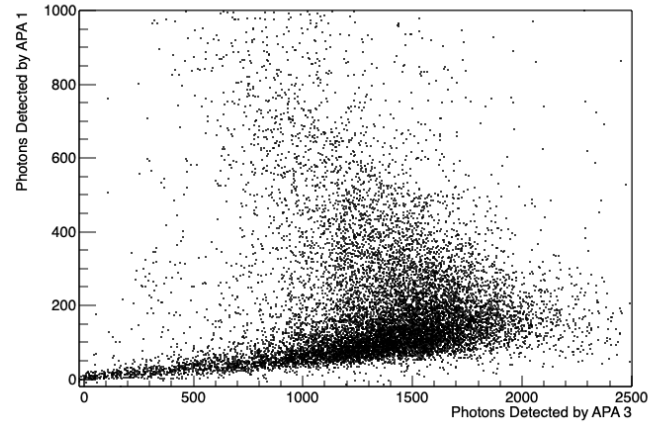
APA 3 vs. APA 1 spectra for Kaons of BM = 7 GeV/c



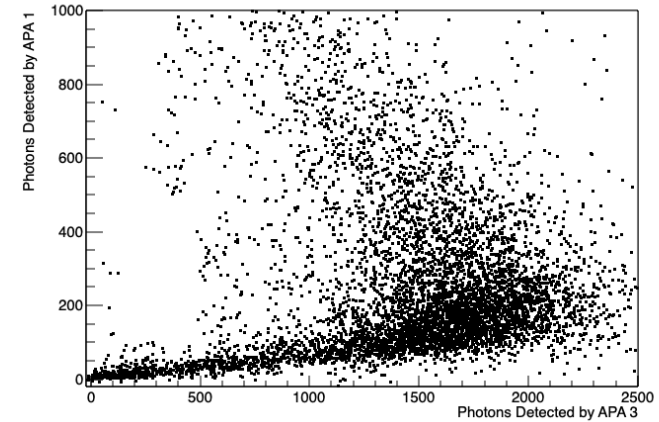
APA 3 vs. APA 1 spectra for Electrons of BM = 7 GeV/c



APA 3 vs. APA 1 spectra for Protons of BM = 7 GeV/c



APA 3 vs. APA 1 spectra for Kaons of BM = 7 GeV/c

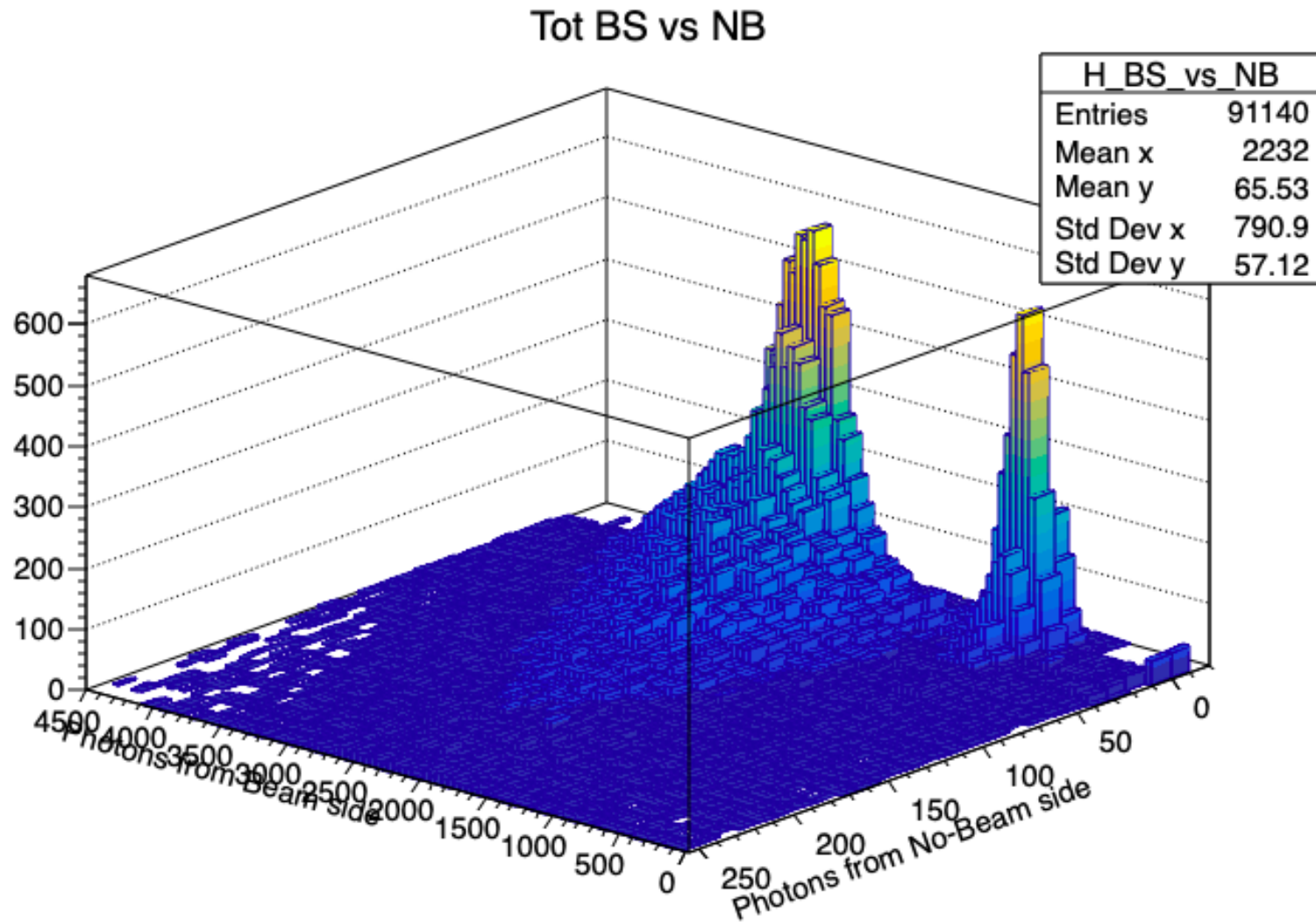


Electrons (and Muons) don't show tail to zero.

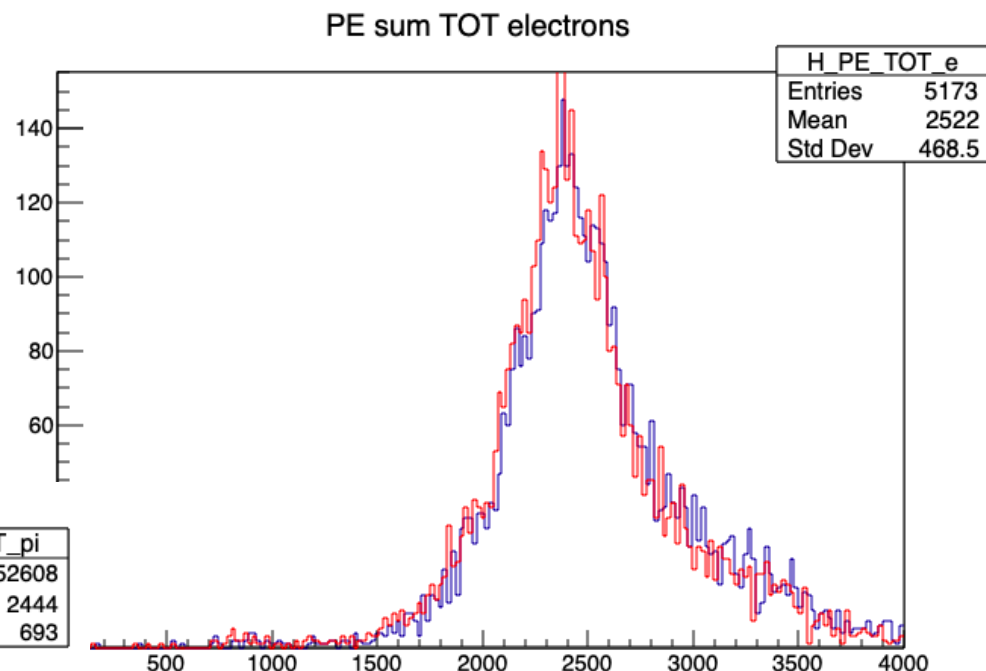
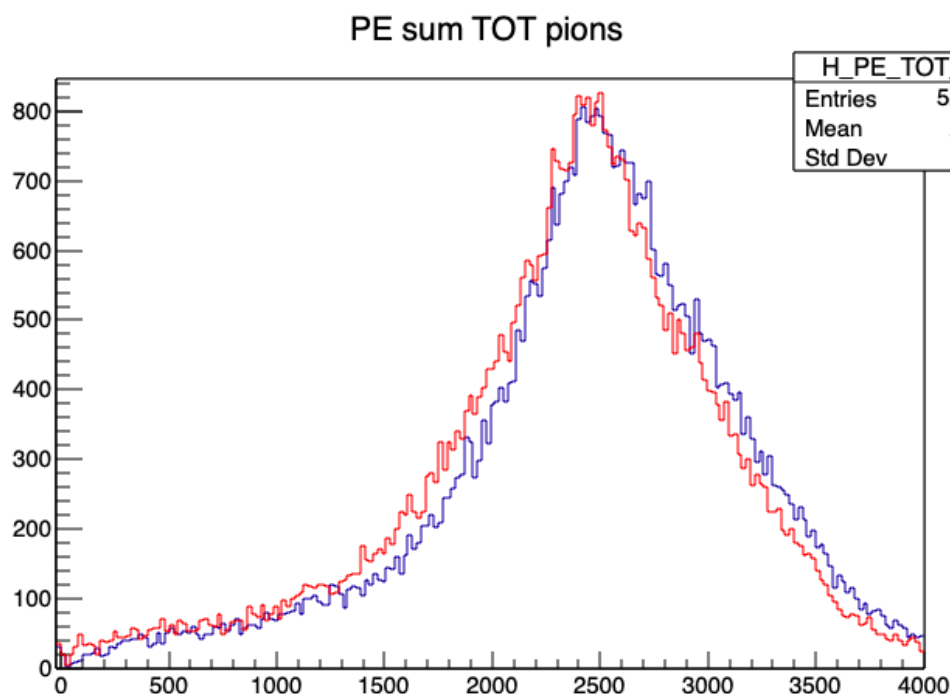
Kaons, Protons and Pions have a tail very similar each other

**Next step:**

**investigation about No-Beam side ionization particle escape**



Summing all the six APAs.  
(in this plots are missing some PD  
modules: all APA 4 and four PD  
modules in APA 5 )



In these plots are reported the  
Spectra for sum in APA 1,2,3  
And spectra for sum in APA  
1,2,3,5,6.  
When we add No-Beam side  
APAs we can see a shift in the  
Pions spectra but not in the  
Electrons spectra.

**Some ionizing particles from Hadronic shower cross the cathode,  
we are investigating about it**