

Arapuca PD performance and calibration stability

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Arapuca performance

**The dataset used is ~ 10 % of the data acquired in the
protoDUNE beam run on Fall 2018**

Particle identification

- Cherenkov PID

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

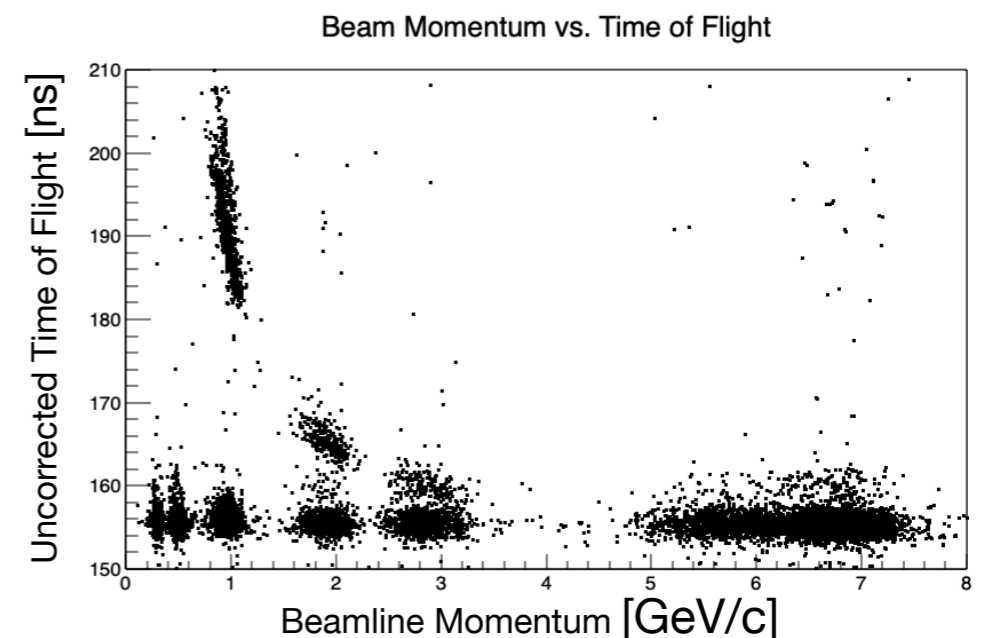
For 0.3/0.5/1 GeV/c:

TOF < 170 ns: pions

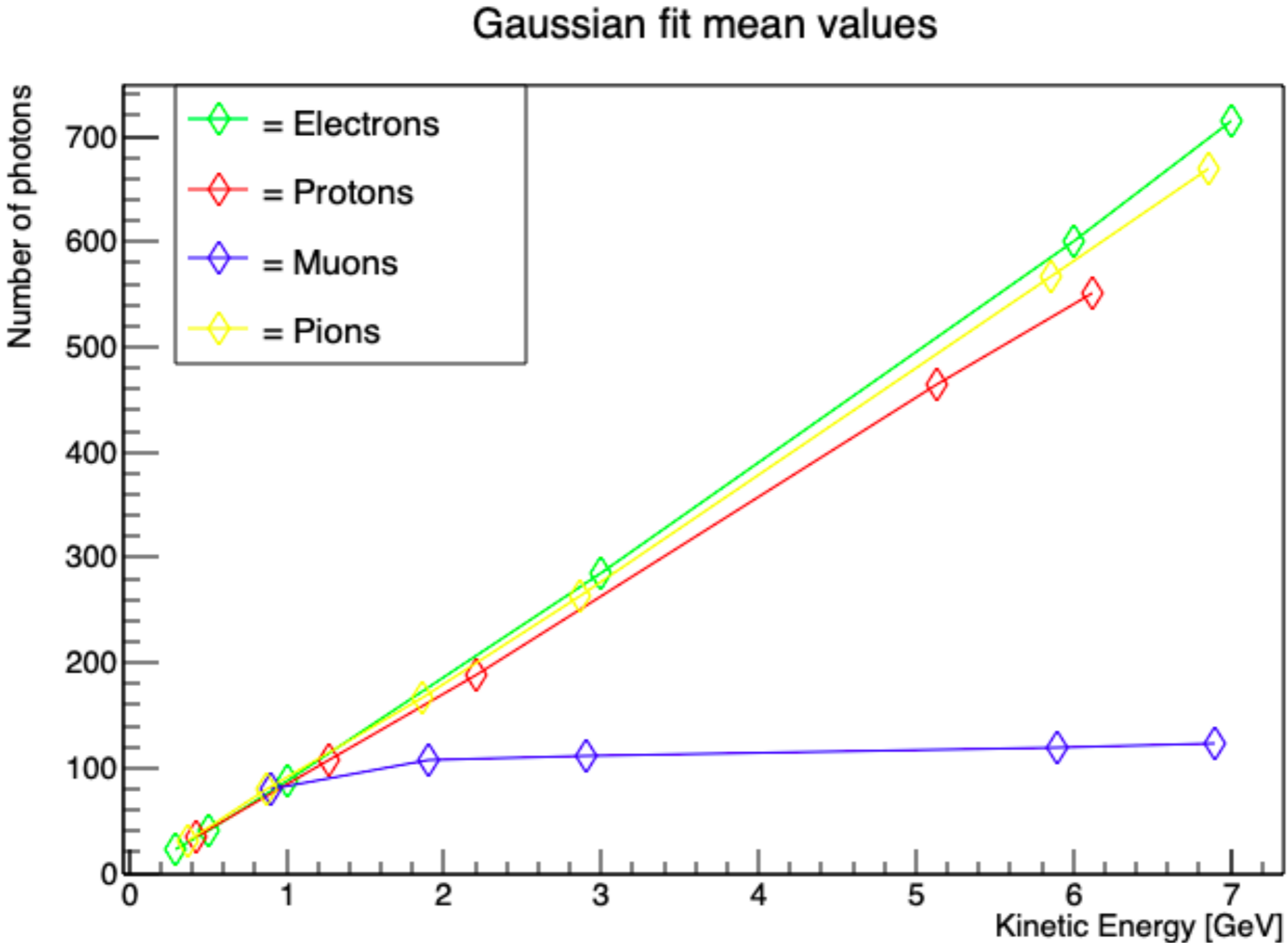
Else: protons

- Pandora reconstruction

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

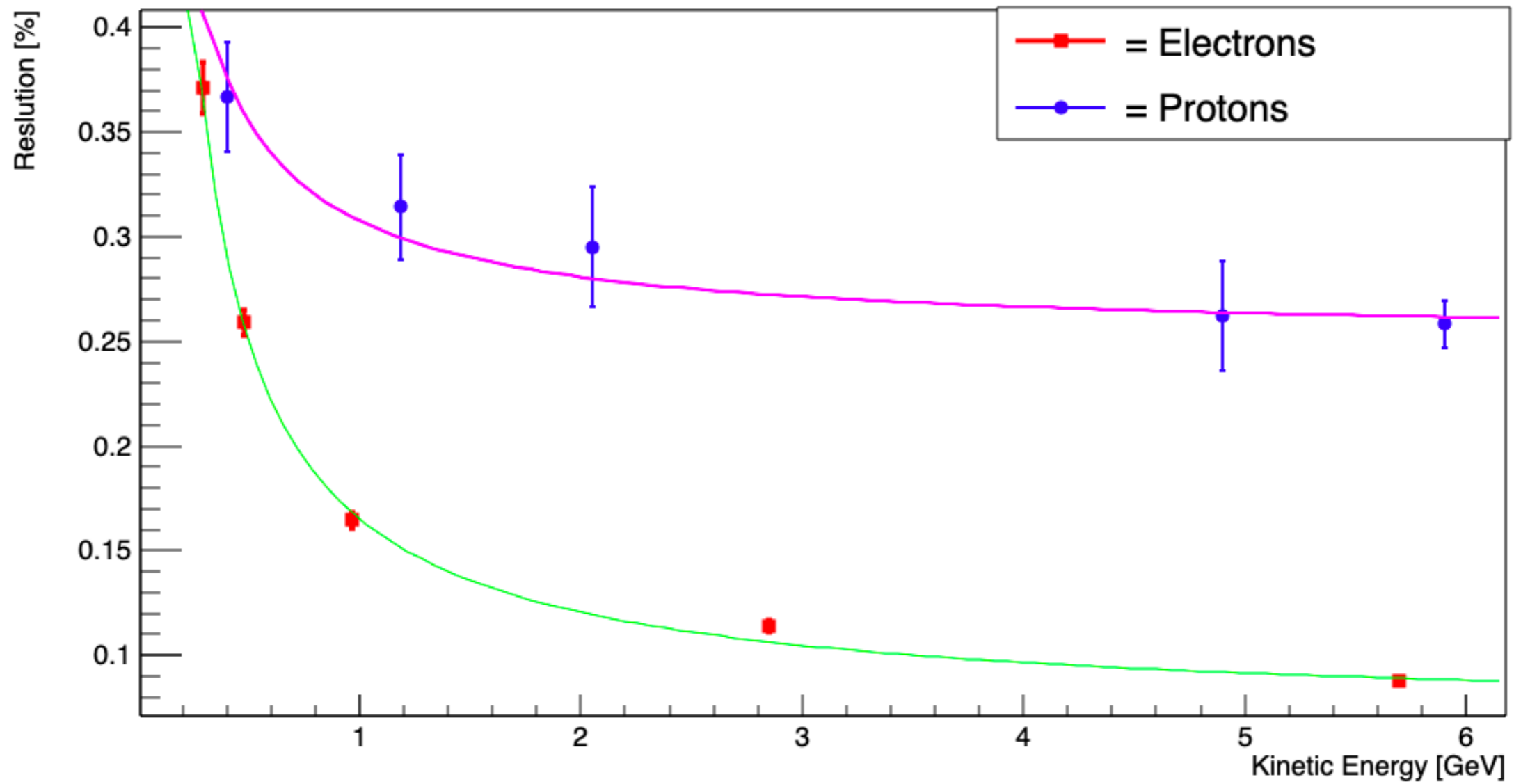


Gaussian fit mean value vs kinetic energy



Resolution: $\frac{\sigma_{N_{Ph}}}{N_{Ph}}$ vs KE

Electrons and Protons Resolution



Standard equation

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

Electrons

Parameter	Value	Error
k0	0.070	0.004
k1	0.12	0.01
k2	0.079	0.007

Protons

Paramete	Value	Error
k0	0.25	0.01
k1	0.17	0.02
k2	0.00	0.09

$$\frac{\sigma_{N_{Ph}}}{N_{Ph}} \propto \frac{1}{\sqrt{KE}}$$

$k_1 = \textit{Resolution}$

$$k_1(e) = 12\%$$

$$k_1(P) = 17\%$$

Arapuca calibration

Runs

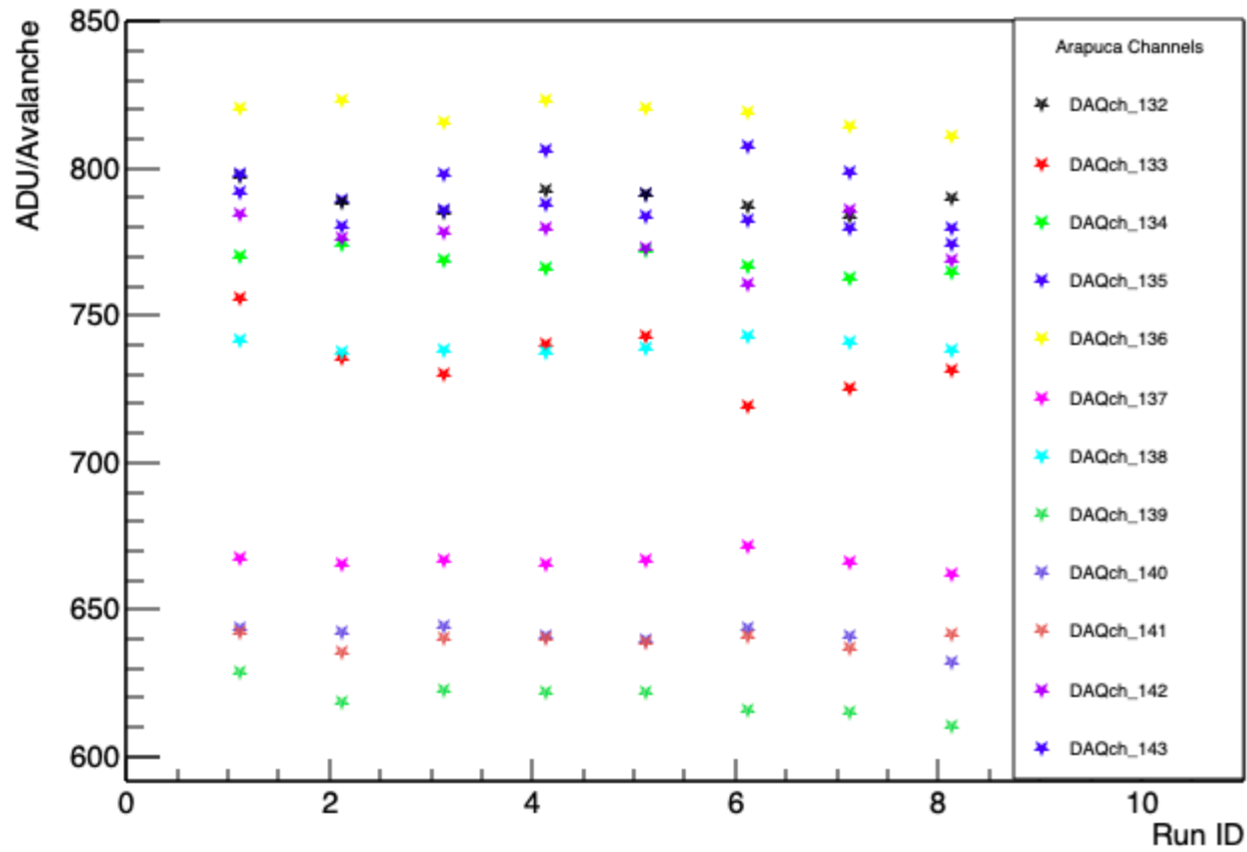
Run	Day	ID
6848	Feb 20	1
7224	Mar 19	2
7447	Mar 31	3
7461	Apr 01	4
7475	Apr 02	5
7651	Apr 24	6
7726	May 02	7
7944	May 21	8

LED config: **0x577**

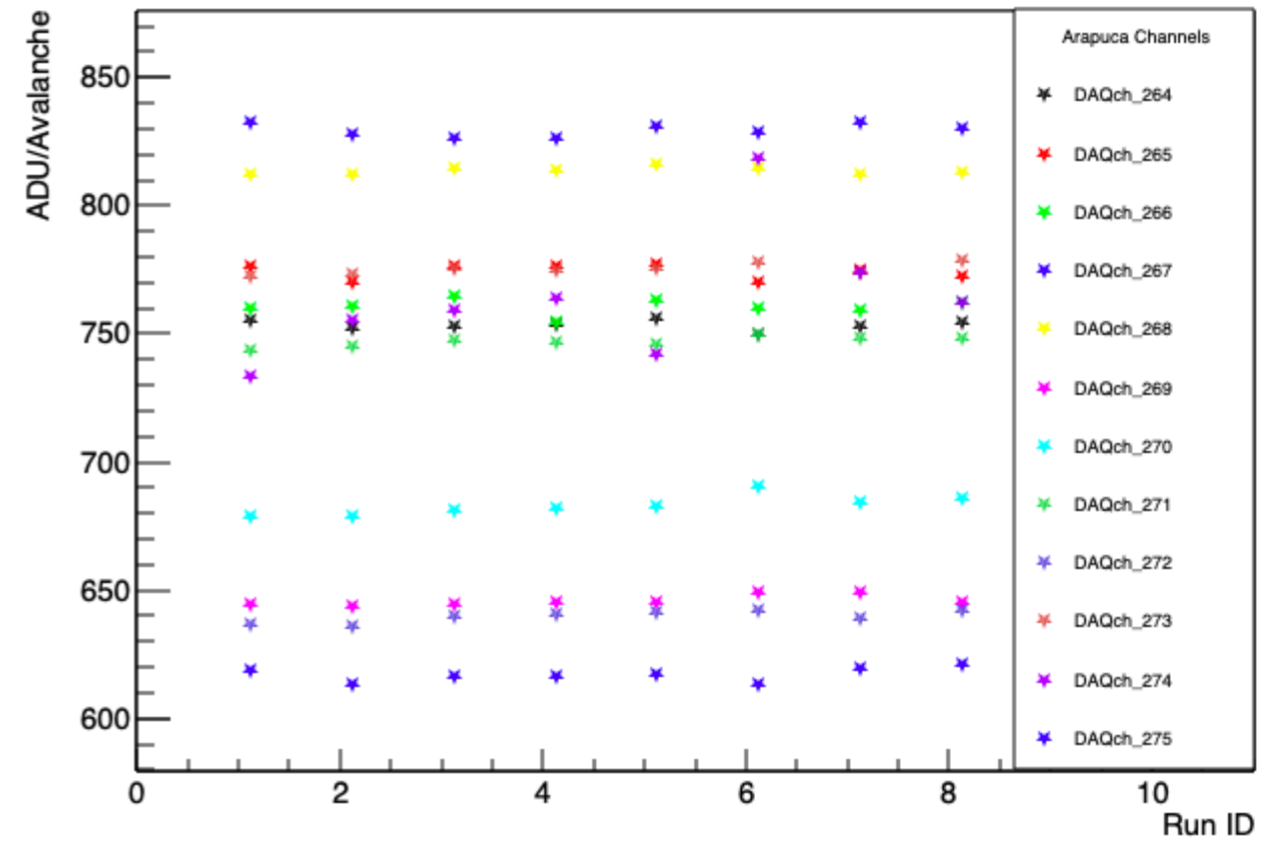
In plots runs are labeled with the ID in the table

Charge per Avalanche

PE calibration Arapuca Apa 3



PE calibration Arapuca Apa 6



Charge per Avalanche

Arapuca in APA 3

CH	Mean	STD
132	789.309	4.3429
133	734.749	11.3328
134	767.915	4.00404
135	783.961	7.07255
136	818.103	4.49692
137	666.227	2.74114
138	739.193	1.92346
139	619.16	5.60748
140	640.677	4.05732
141	639.483	2.24838
142	775.555	8.36258
143	795.083	9.1106

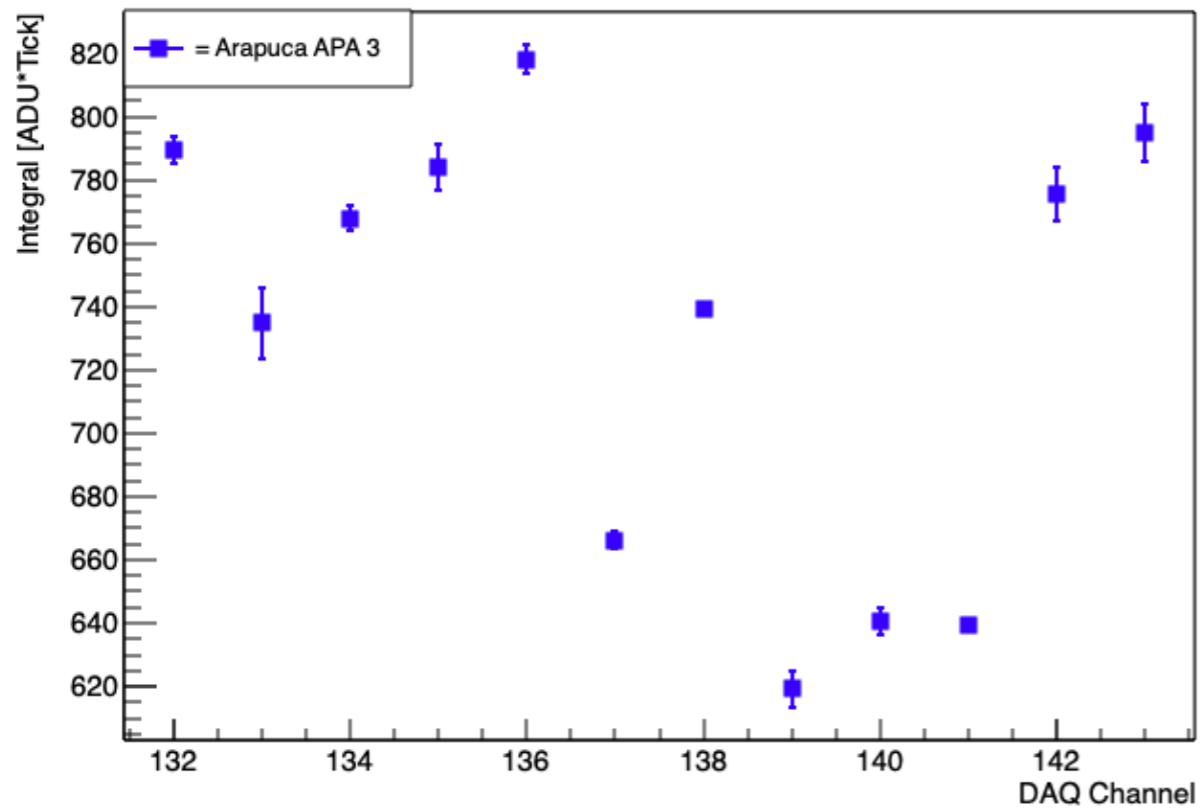
Arapuca in APA 6

CH	Mean	STD
264	753.276	1.96719
265	773.798	2.93903
266	760.289	3.00281
267	616.822	2.86628
268	813.332	1.40758
269	645.624	2.00552
270	682.685	3.78802
271	746.578	2.09169
272	639.673	2.31489
273	775.01	2.11271
274	763.351	25.5984
275	829.037	2.56327

Charge per Avalanche

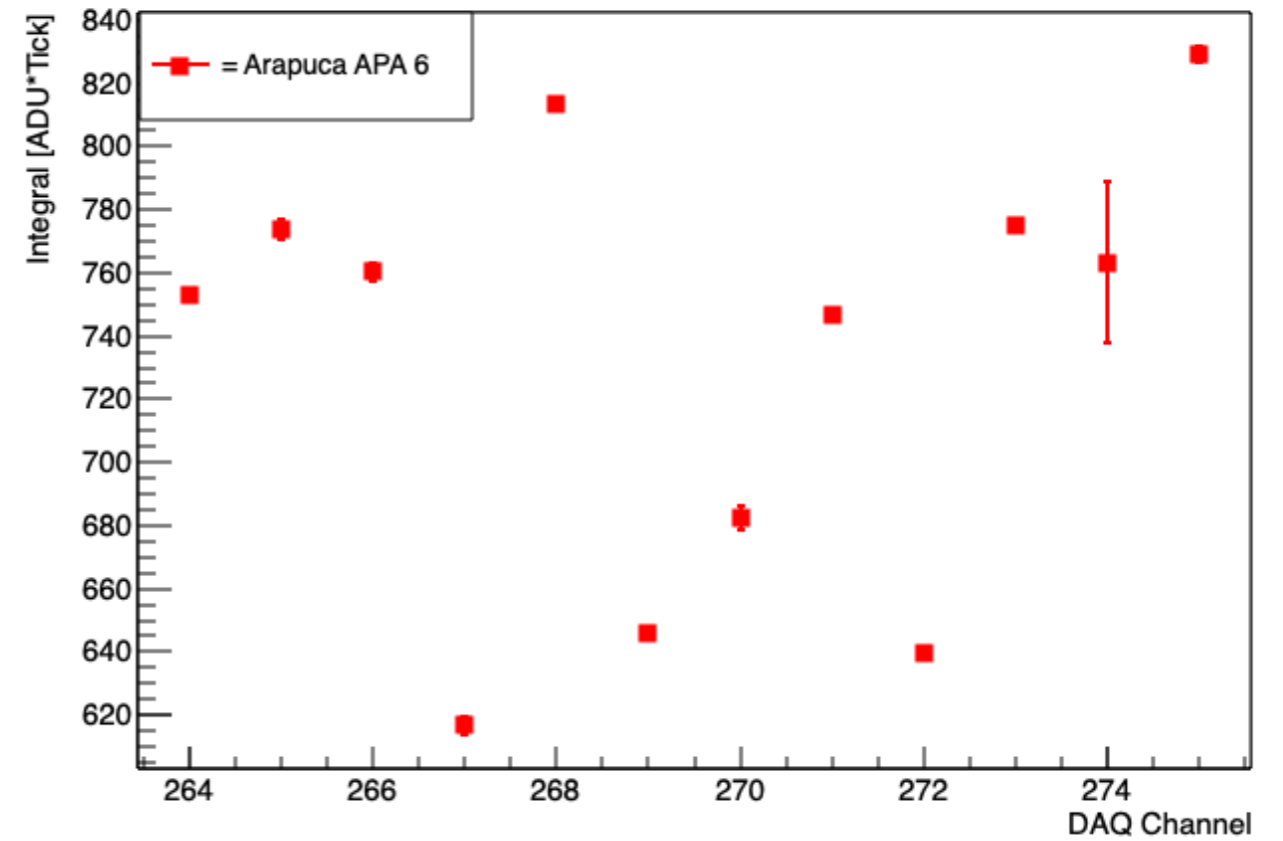
Arapuca APA 3

Charge per Avalanche



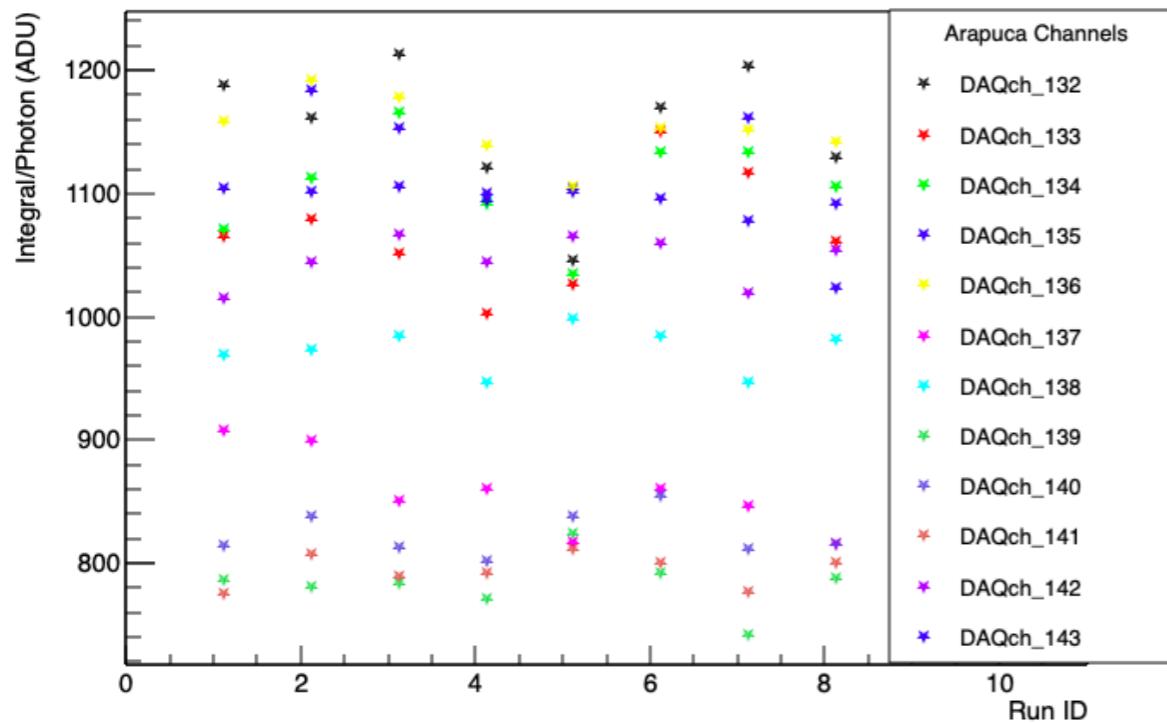
Arapuca APA 6

Charge per Avalanche

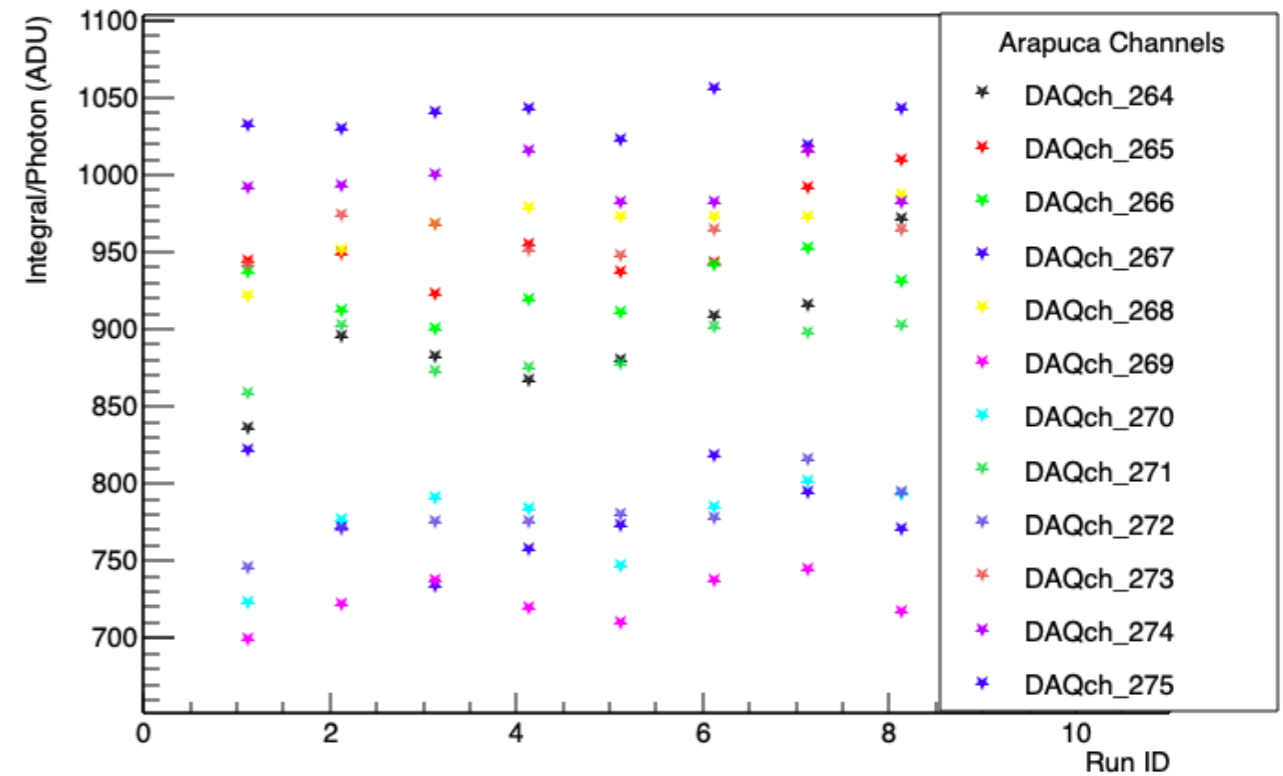


Charge per Photon Detected

Average charge per photon detected Apa 3



Average charge per photon detected Apa 6



Charge per Photon Detected

Arapuca in APA 3

CH	Mean	STD
132	1153.74	54.6542
133	1068.97	47.1005
134	1105.48	40.9215
135	1184.23	133.511
136	1152.22	26.2896
137	857.022	33.1807
138	972.503	18.2633
139	783.126	22.8989
140	822.865	17.9174
141	793.583	13.155
142	1045.95	19.7279
143	1096.94	8.87185

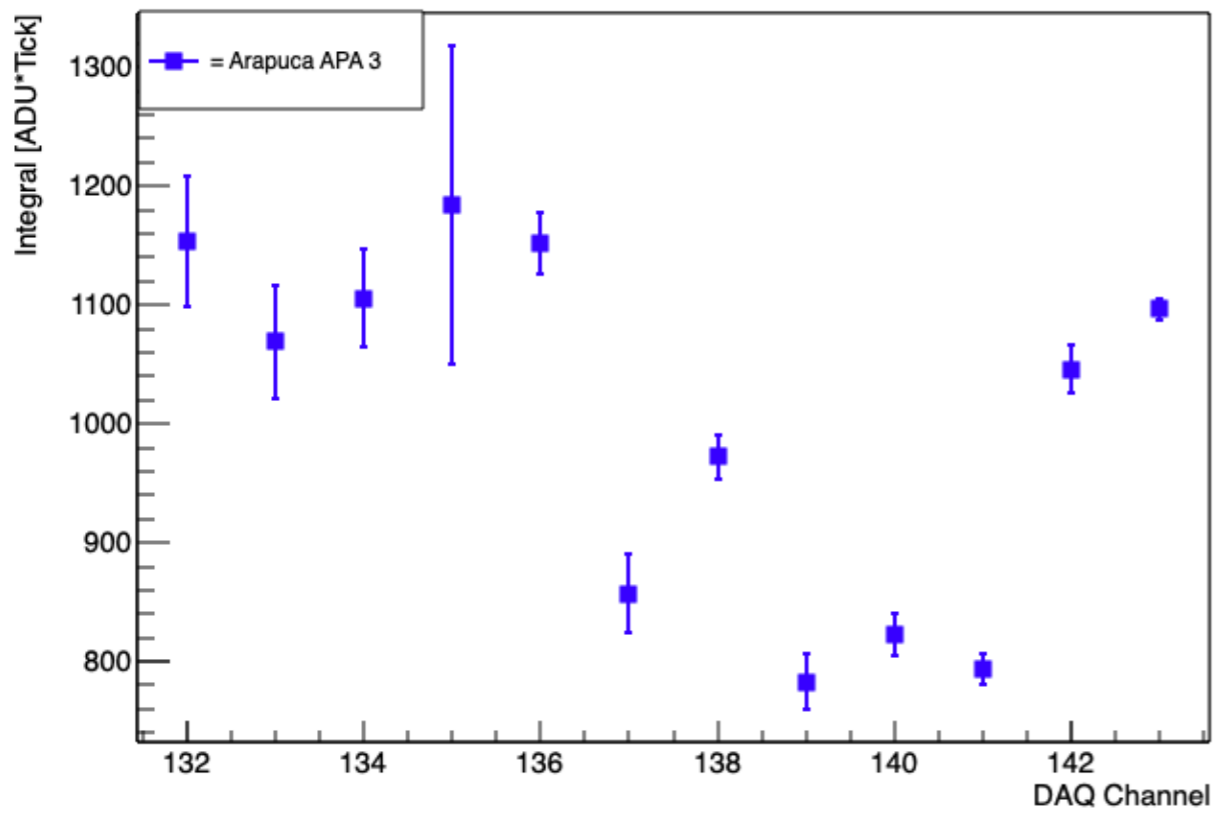
Arapuca in APA 6

CH	Mean	STD
264	894.251	40.058
265	956.366	29.3247
266	925.347	17.9829
267	779.98	29.9917
268	965.472	20.3871
269	722.984	15.2654
270	774.91	26.697
271	885.936	17.329
272	779.246	19.9705
273	965.761	22.866
274	995.246	14.0627
275	1035.56	12.0983

Charge per Photon Detected

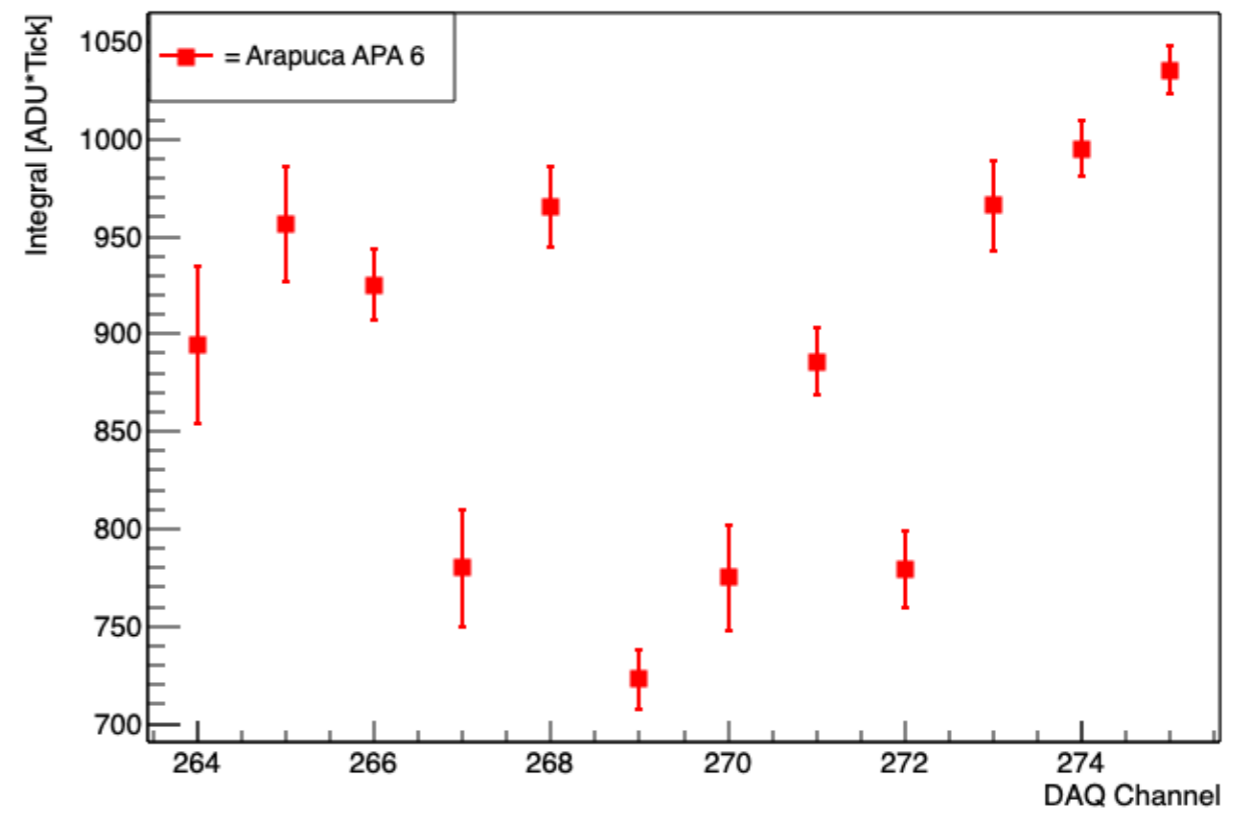
Arapuca APA 3

Charge per Photon Detected



Arapuca APA 6

Charge per Photon Detected



Avalanches per Photon Detected

$$\frac{\langle PE \rangle}{\langle PH \rangle} > 1$$

A single photon detected sometimes generates more than an avalanche (or photoelectron):

- **Cross Talks:** a single photon producing two avalanches
- **After Pulses:** a single photon producing an avalanche plus a fraction of it. The amount of extra charge depends by the delay the after pulse occurs. (If the delay is longer than the SiPM cell recovery time, the after pulse results in a PE like avalanche).
- Both extra avalanches can also be affected by after pulses and cross talks (second order noise is not negligible)

Avalanches per Photon Detected

Arapuca in APA 3

CH	Mean	Err
132	1.46171	0.0772856
133	1.45488	0.0865443
134	1.43959	0.0607954
135	1.51057	0.183931
136	1.4084	0.0398765
137	1.28638	0.0550966
138	1.31563	0.0281305
139	1.26482	0.0484388
140	1.28437	0.0361001
141	1.24098	0.0249345
142	1.34865	0.0399792
143	1.37965	0.0269674

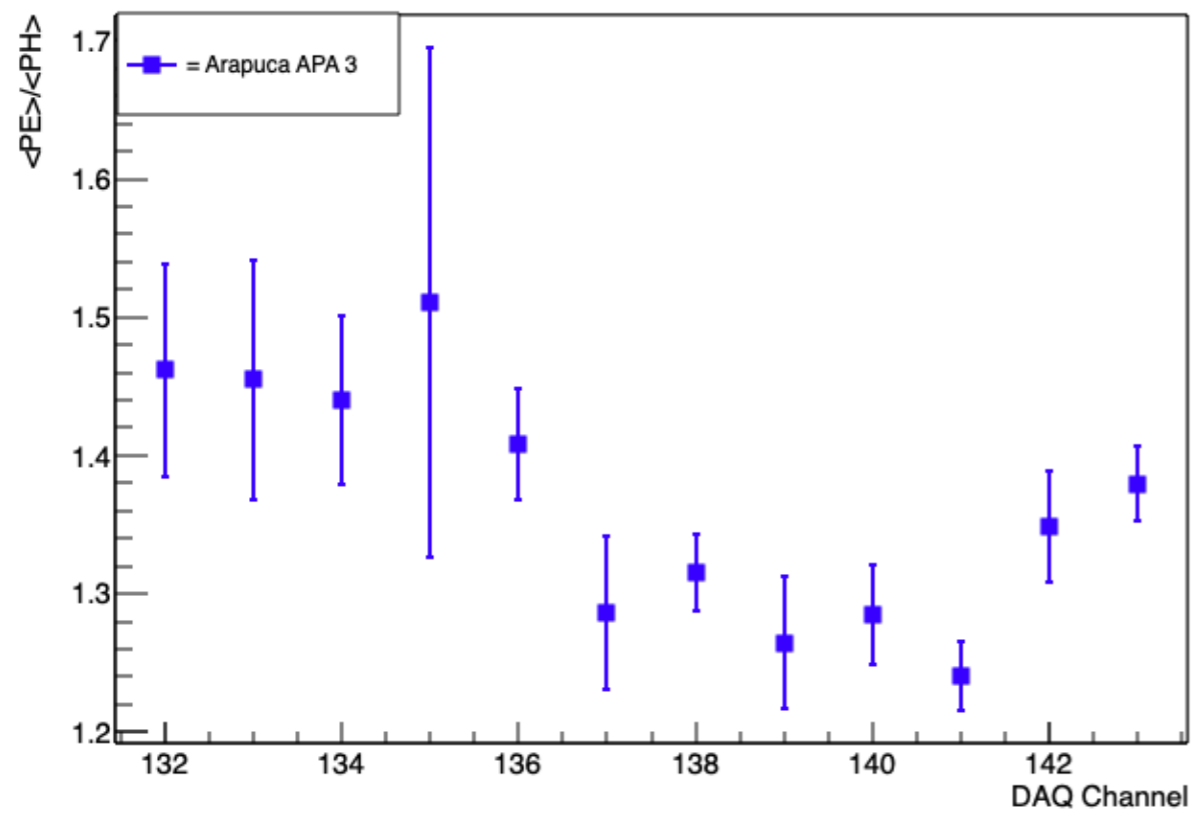
Arapuca in APA 6

CH	Mean	Err
264	1.18715	0.0562786
265	1.23594	0.0425914
266	1.2171	0.0284597
267	1.26451	0.0544989
268	1.1876	0.0271205
269	1.11982	0.0271229
270	1.1359	0.0454042
271	1.18666	0.0265359
272	1.21819	0.0356283
273	1.24613	0.0329011
274	1.30379	0.0621438
275	1.24911	0.0184553

Avalanches per Photon Detected

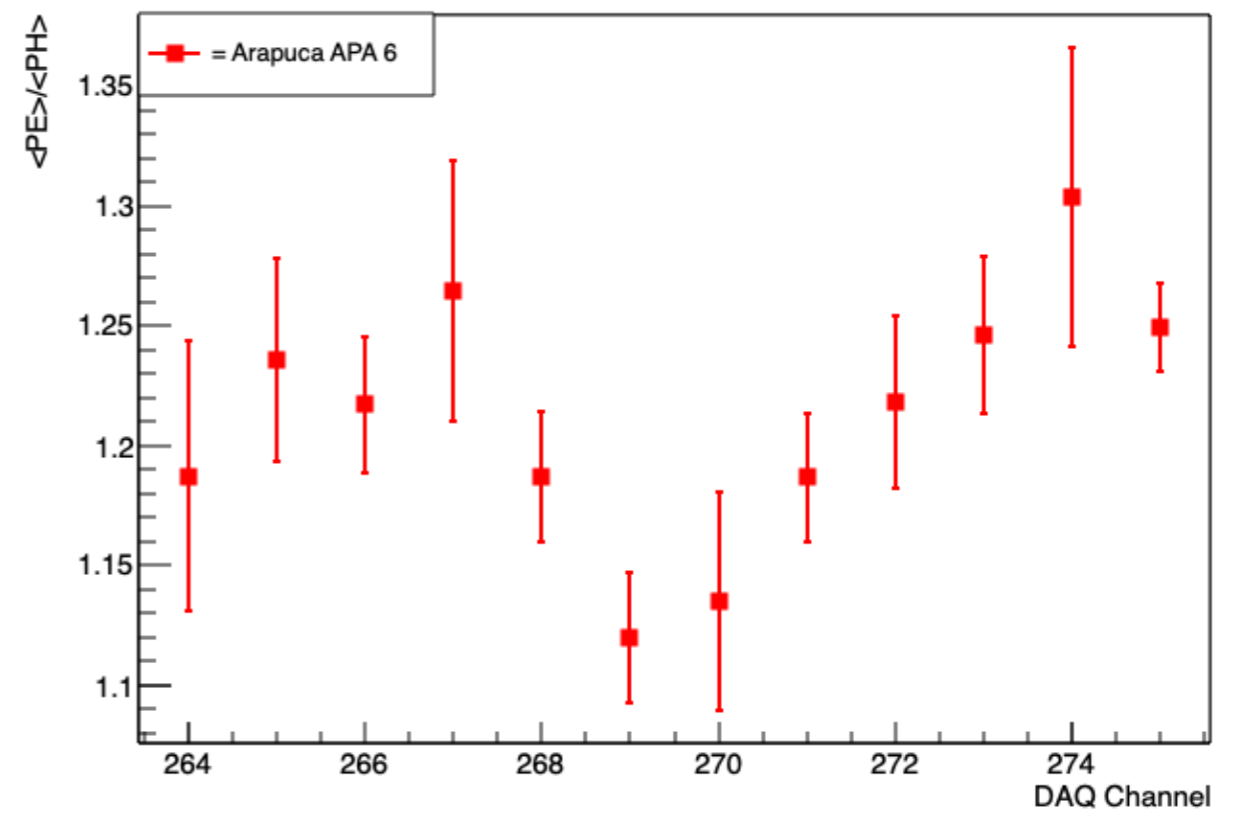
Arapuca APA 3

Avalanches per photon detected



Arapuca APA 6

Avalanches per photon detected



Avalanches per Photon Detected

Average of all Arapuca in a PD module:

Arapuca PD module in APA 3 shows a higher contribute from After Pulses and Cross Talks. This is probably due to different breakdown voltage values for the MPPCs in that PD modules.

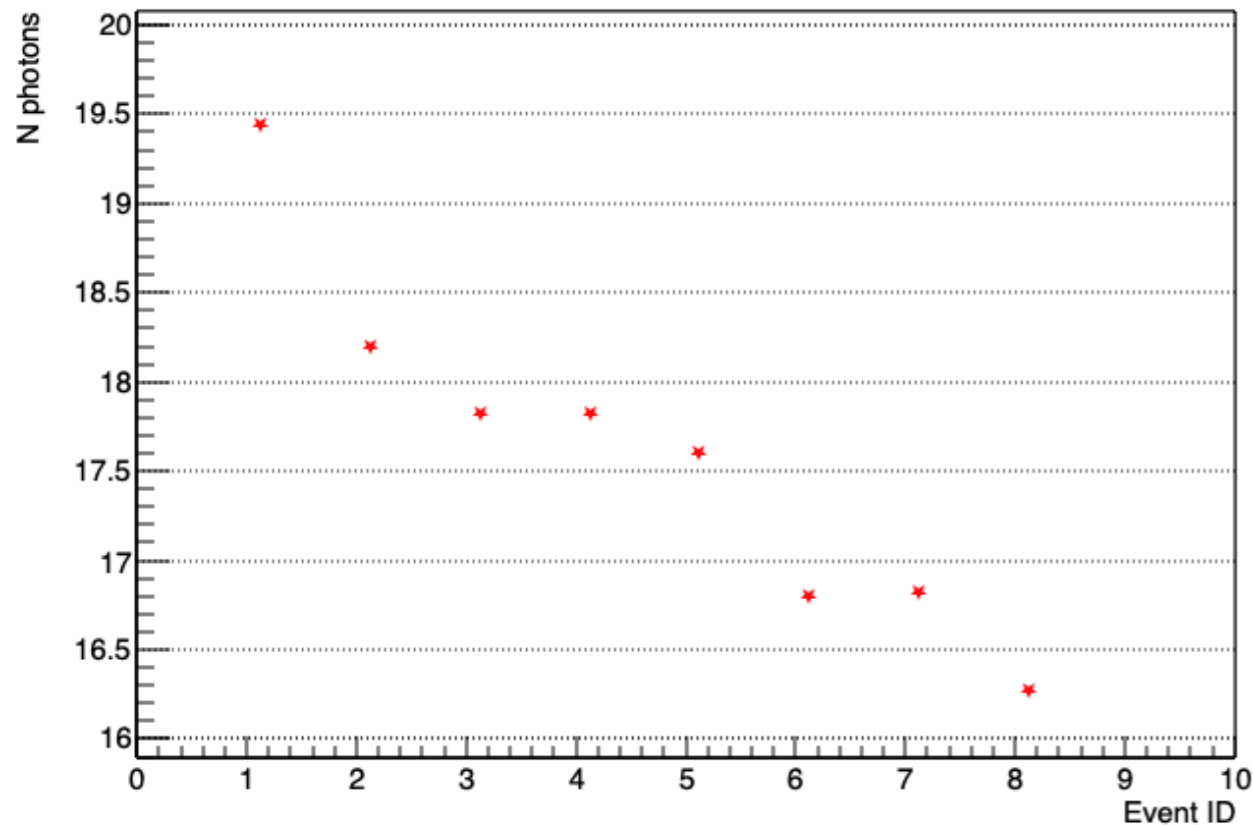
Average PE/PH per Arapuca PD module

Arapuca PD Module	$\langle \text{PE/PH} \rangle$	Err
APA 3	1.37	0.09
APA 6	1.21	0.06

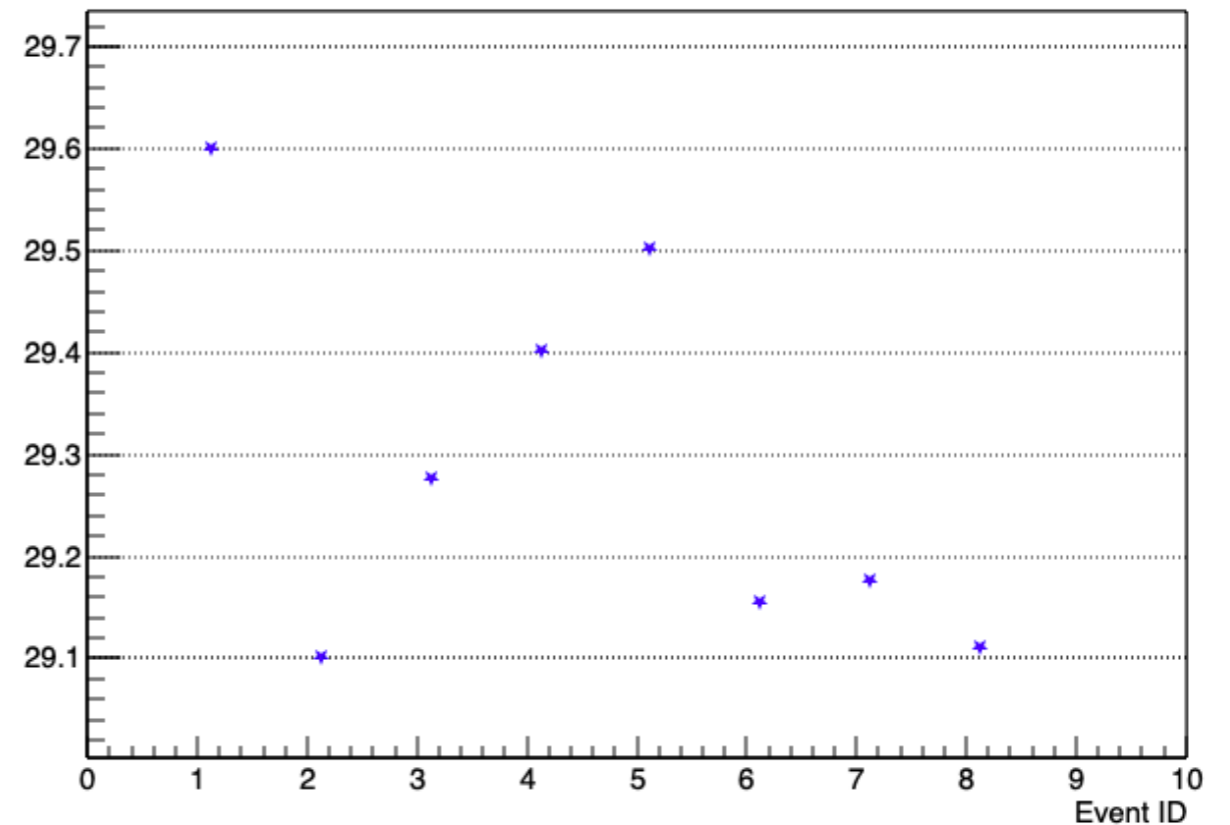
Average number of photons detected summing all channels per

Arapuca PD module $\langle N_{ph_{tot}} \rangle = \sum \langle N_{ph} \rangle_i$

Total number of photons detected from Arapuca module in APA 3



Total number of photons detected from Arapuca module in APA 6



$\langle N_{ph_{tot}} \rangle$ in APA 3 decreases from 19.5 to 16.3

$\Delta \sim 18\%$

$\langle N_{ph_{tot}} \rangle$ in APA 6 is in a range between 29.1 and 29.6

$\Delta \sim 1.6\%$