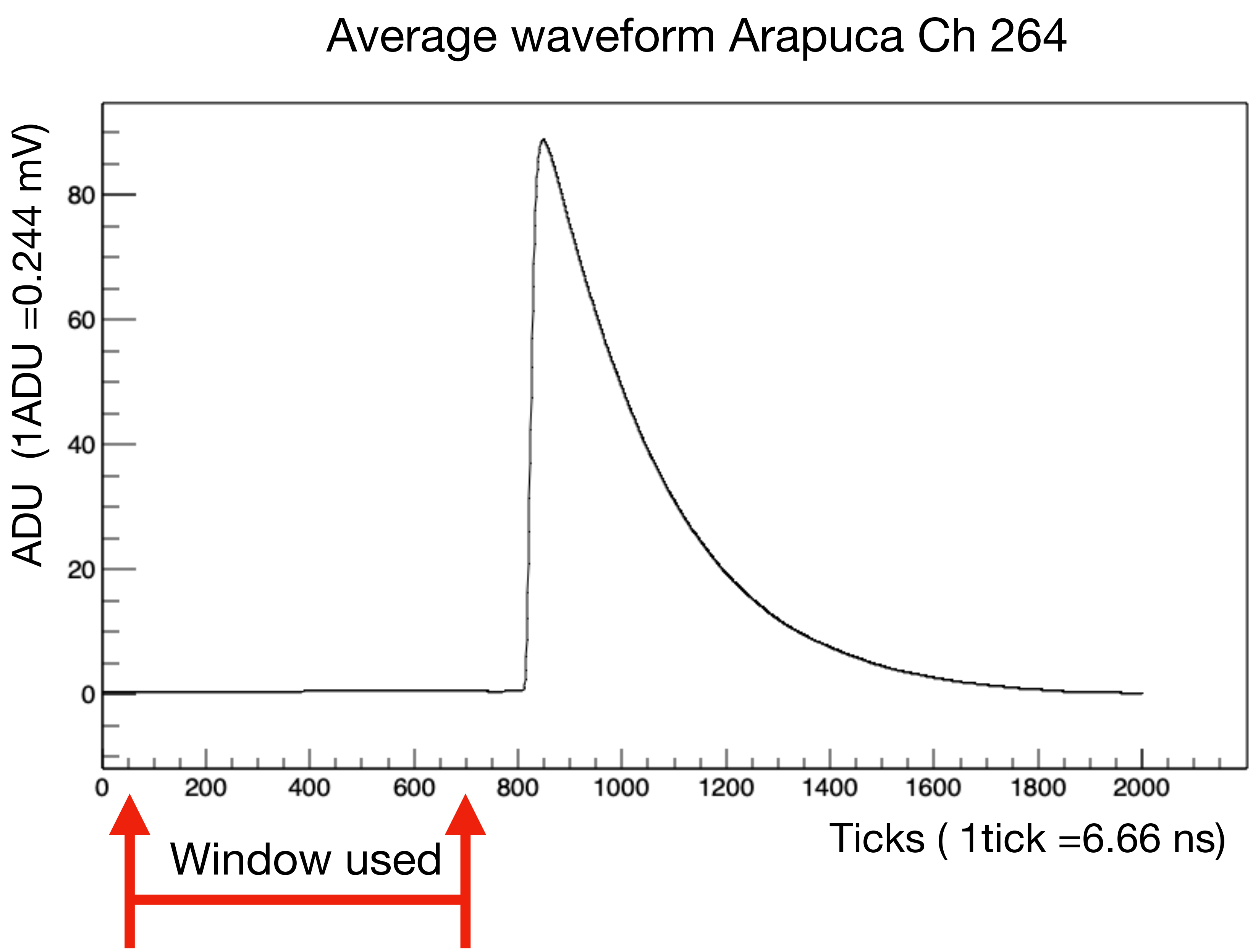
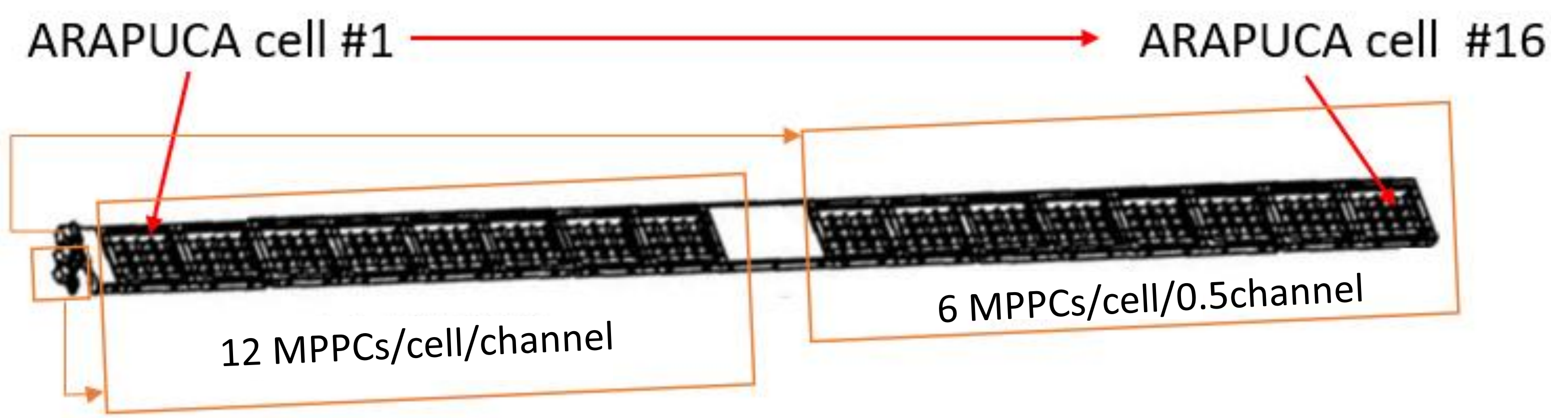
Sigle photons rate Arapuca detectors

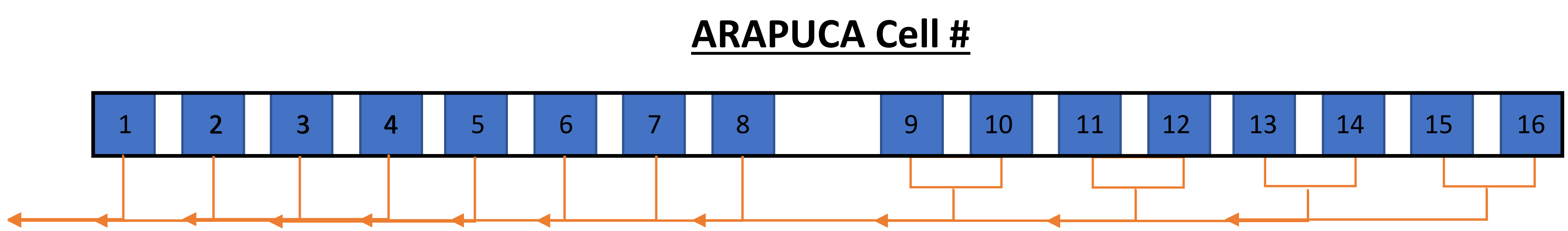
Dante Totani
Fermilab, University of L'Aquila
June 6th, 2019

•Run 7307: E filed = 500 kV/cm (standard).
•External trigger driven by CRT.
•Window before the trigger point: first 700 ticks (4.66 μs).



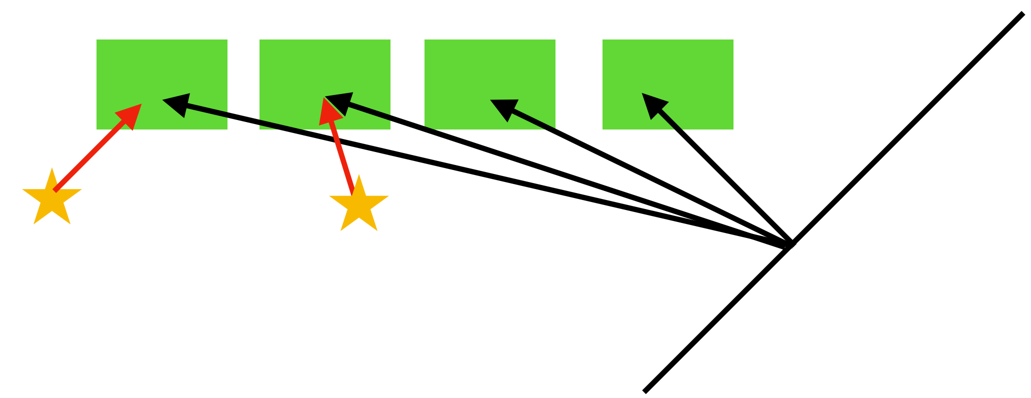
Arapuca module in protoDUNE





Correlated vs uncorrelated photons

Thanks to their granularity, an Arapuca module can distinguish correlated photons from uncorrelated ones for each event (event = single trigger)



$$n_{sum} = n_{tot}$$

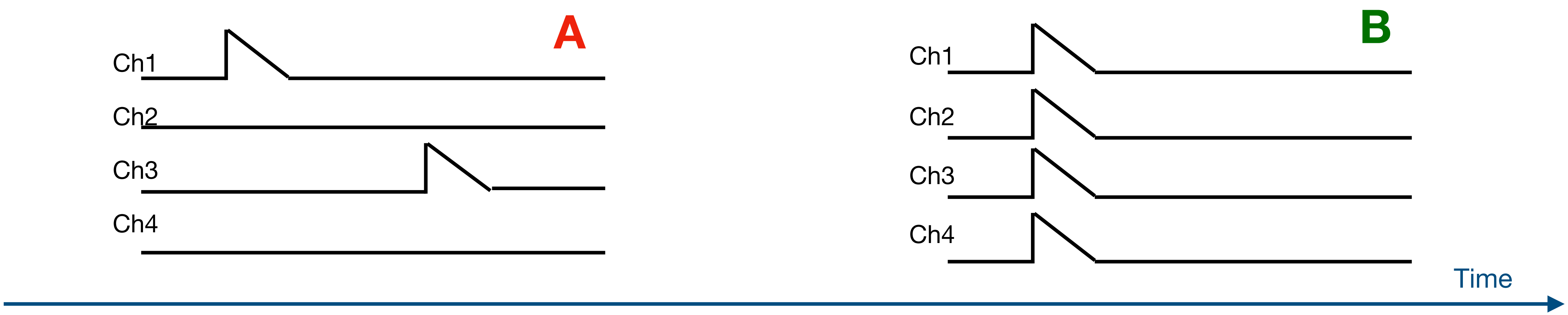
$n_{tot} = 2$ $\quad n_{sum} = \sum n_i = 2$

$n_{2,4} = 0$ $\quad n_{1,3} = 1$

$$n_{sum} = N \cdot n_{tot}$$

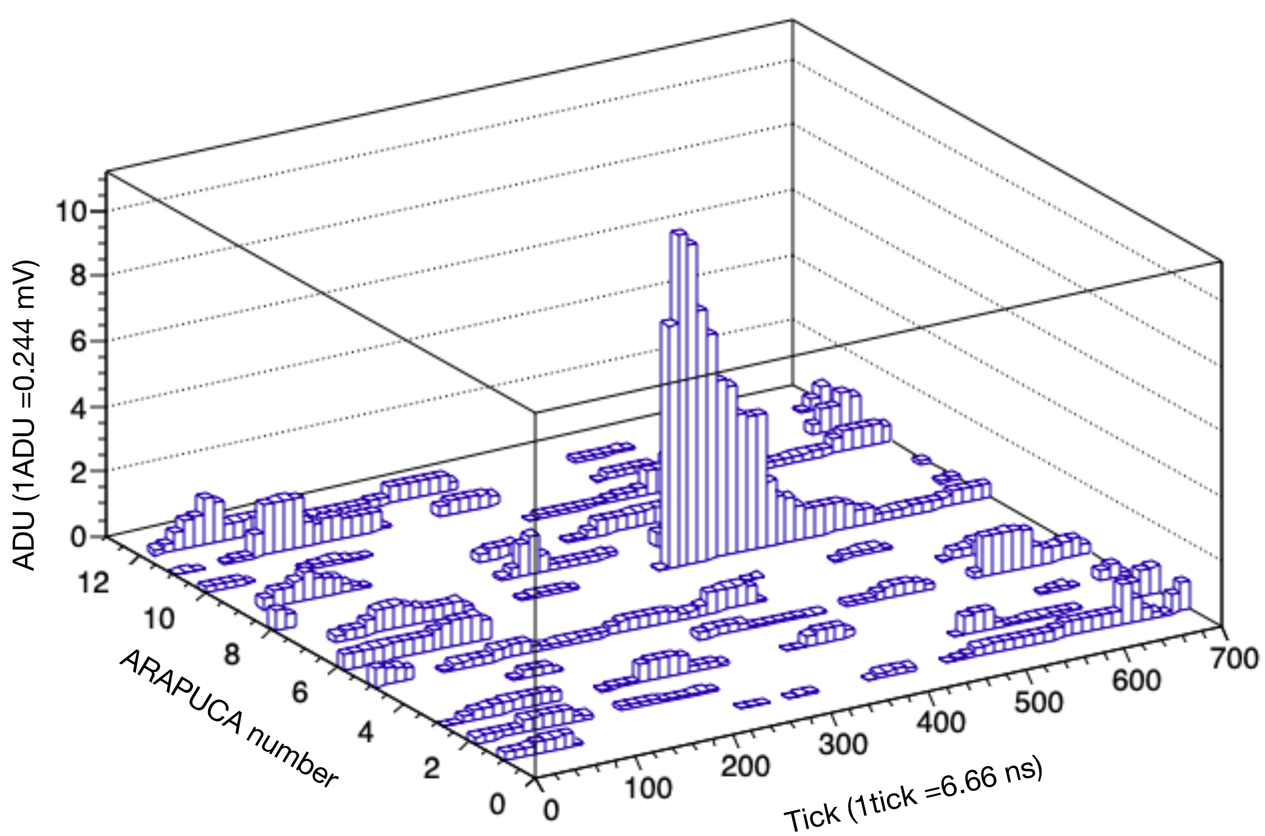
$n_{tot} = 1$ $\quad n_{sum} = \sum n_i = 4$

$n_{1,2,3,4} = 1$

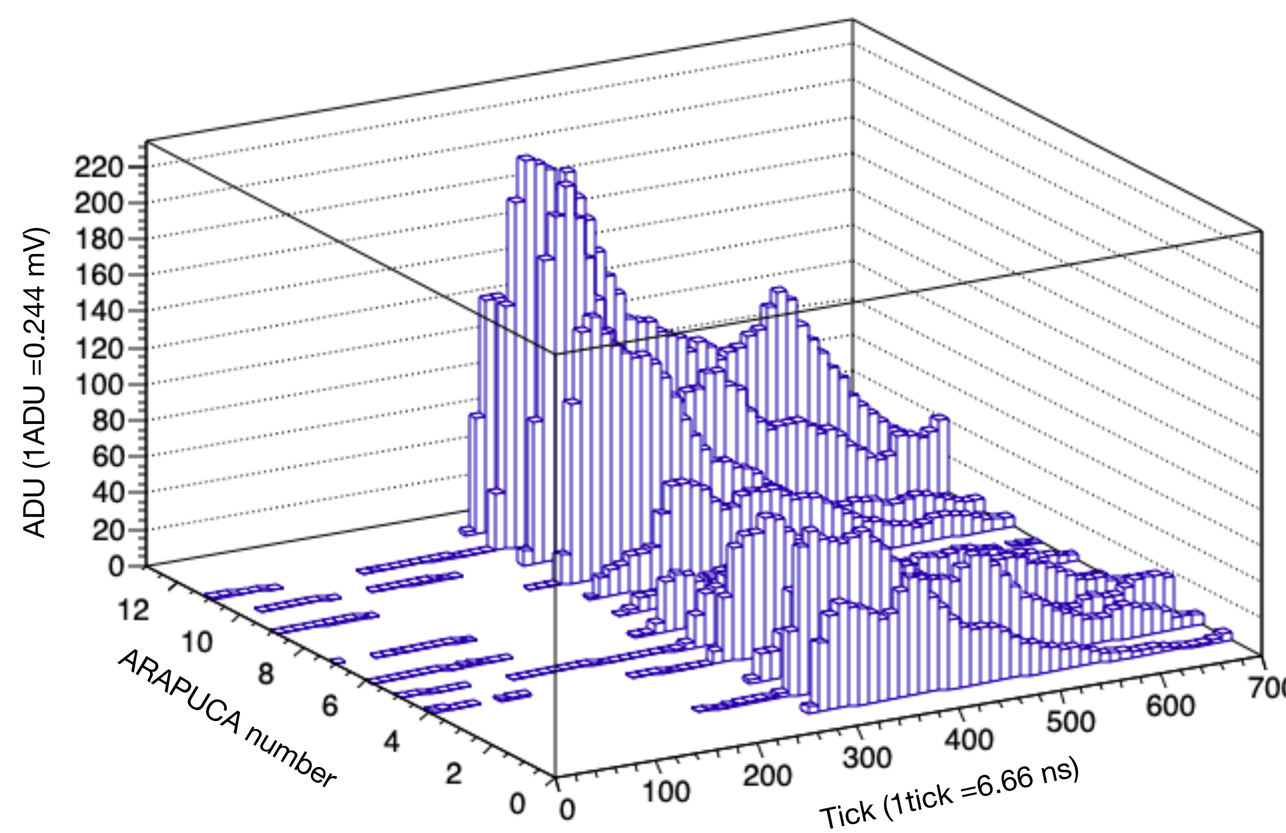


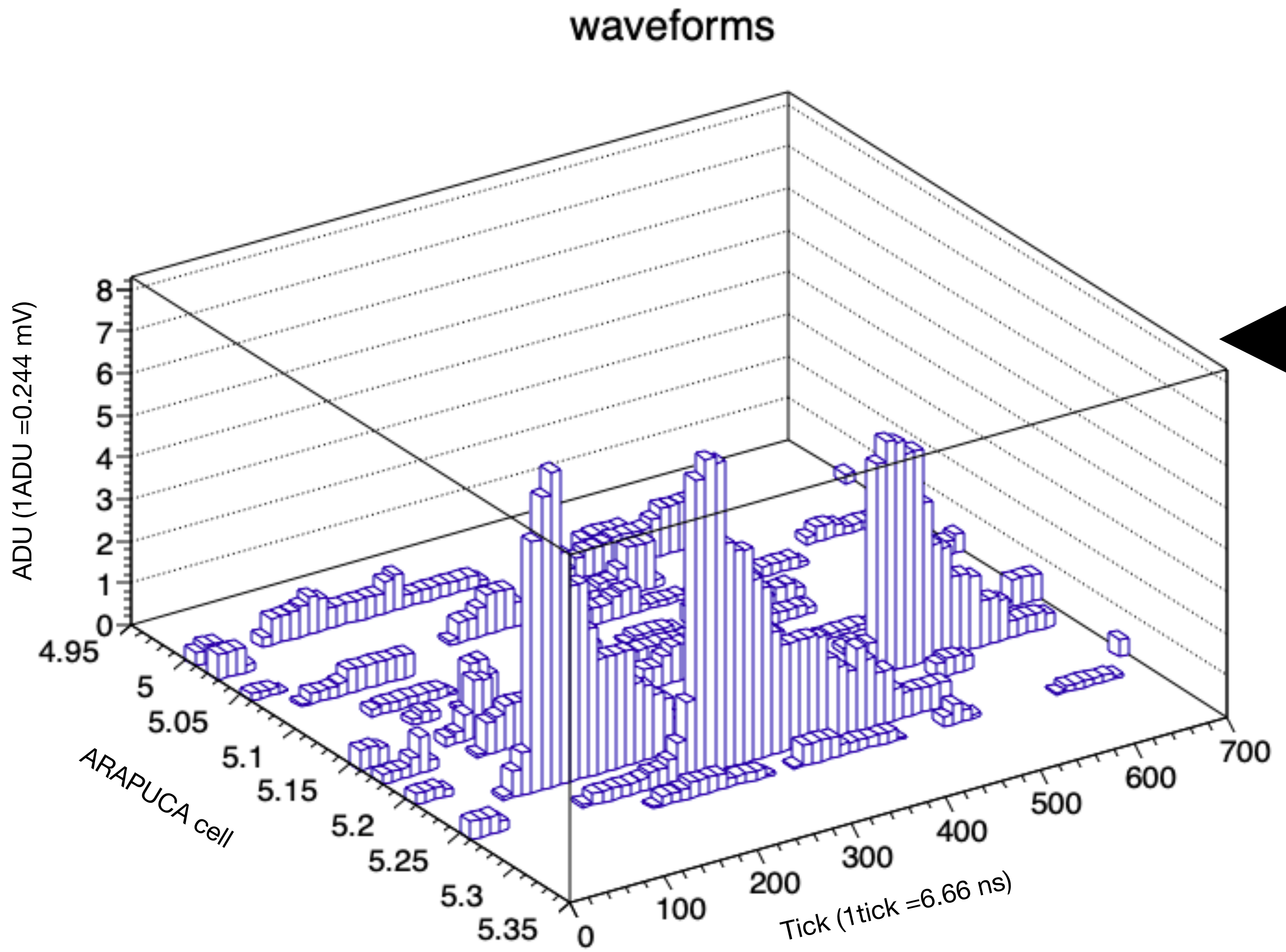
Example of events

Single photon



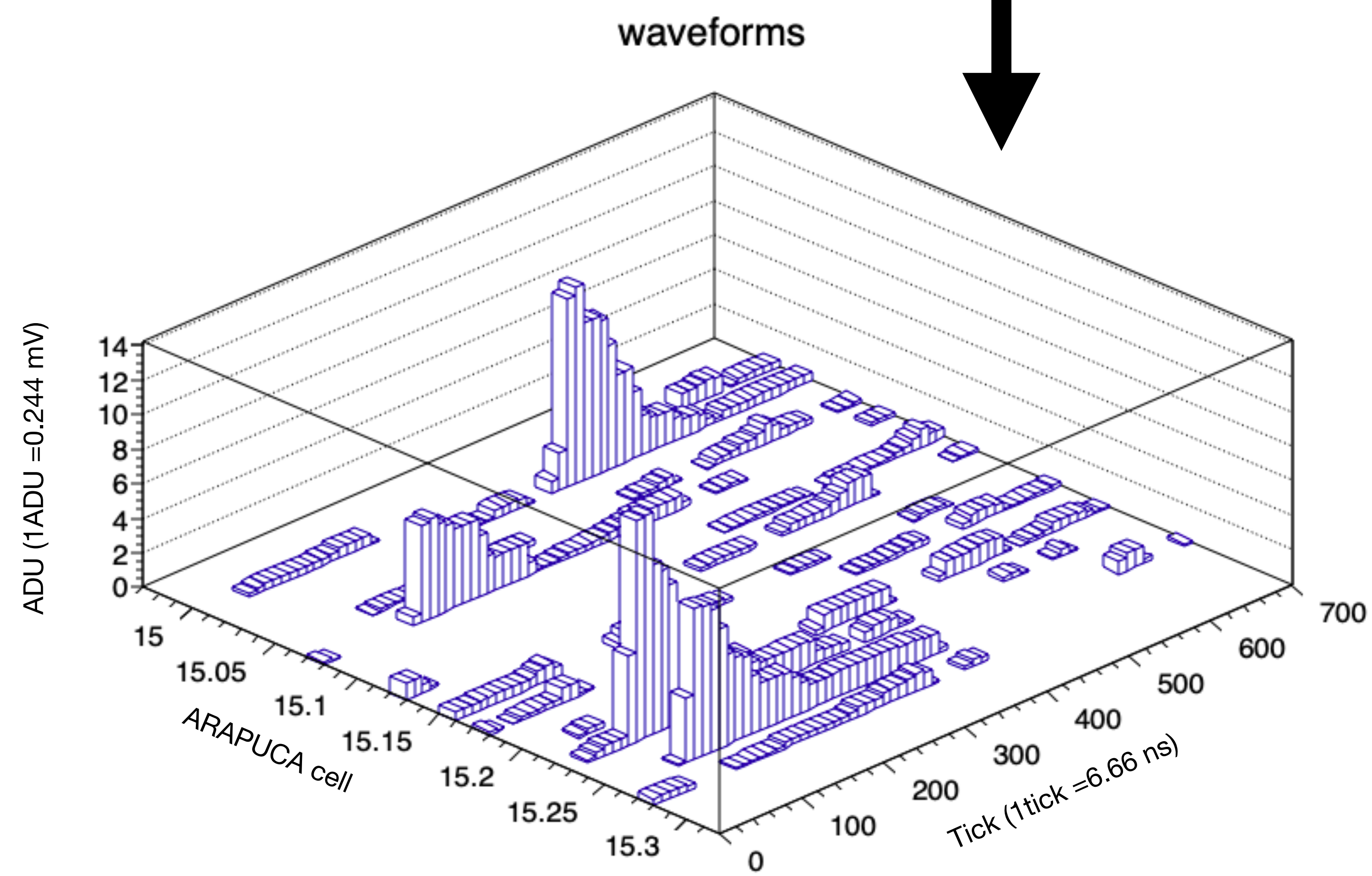
Big event: (cosmic ray)





Three single photons in three Arapuca, all uncorrelated

Three signals (probably on due to 1 Ph and two due to2Ph) in three Arapuca correlated, plus one unrelated



The time window used to assume two peak correlated is about 50 ns. (Actually it is 7 ADU = 7x6.66 ns)

NB: In order to manage the pictures, the waveforms in this plots have 10 times less timing resolution of the ones used in the analysis

Coincidence window width

The coincidence window width is determinate taking into account two points:

- **Total rate vs $\sum$ (single cell rate)**
- **Single photon poisson distribution**

For the run used we have:

- $\sum$ single cell rate before cut = **597** kHz
- Rate tot before cut = **509** kHz

Δ ~91 kHz

- $\sum$ single cell rate after cut = **486** kHz
- Rate tot after cut = **488** kHz

Δ ~2 kHz

Passing from a total of 23103 event, to 20949 event after the cut.
(Δ= 2154 -> 9% of correlated events)

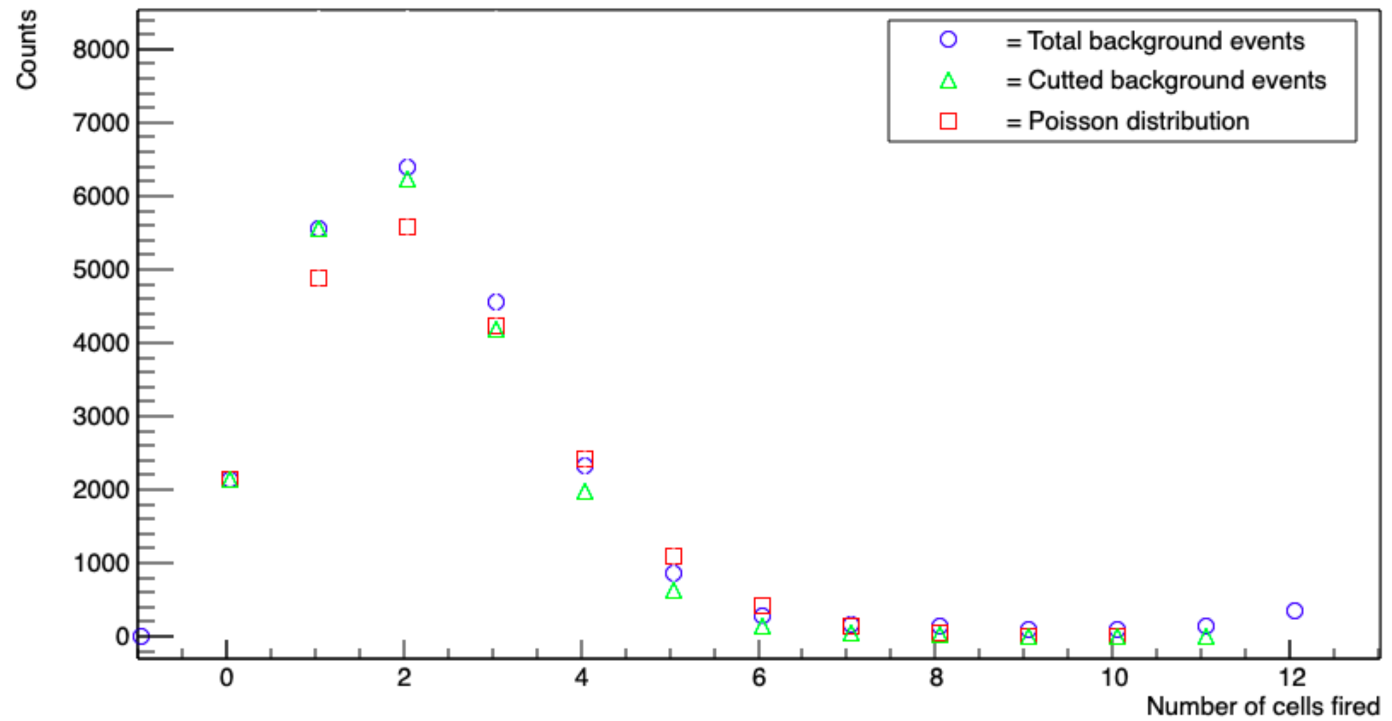
Single cell rate after cut:

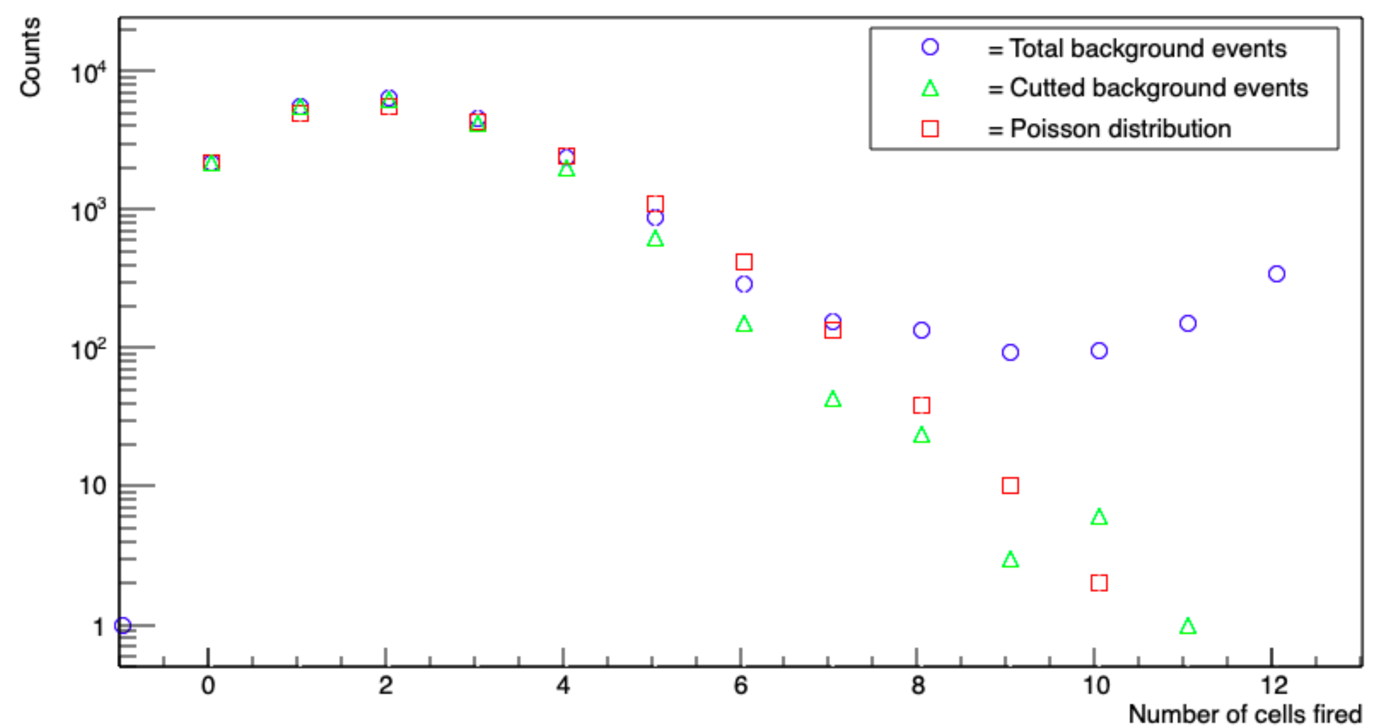
Cell n 0	Rate: 37.7 kHz
Cell n 1	Rate: 42.4 kHz
Cell n 2	Rate: 42.1 kHz
Cell n 3	Rate: 40.2 kHz
Cell n 4	Rate: 32.2 kHz
Cell n 5	Rate: 29.4 kHz
Cell n 6	Rate: 32.4 kHz
Cell n 7	Rate: 37.2 kHz
Cell n 8	Rate: 50.2 kHz
Cell n 9	Rate: 58.0 kHz
Cell n 10	Rate: 57.5 kHz
Cell n 11	Rate: 26.8 kHz

Poisson distribution vs photons distribution

The second way to estimate the goodness of the window width is to compare the distribution of the numbers of cells fired in each event before and after the cut with a Poisson distribution.

In the lower plot a log(y) scale is used to show better what happens for the correlated events.

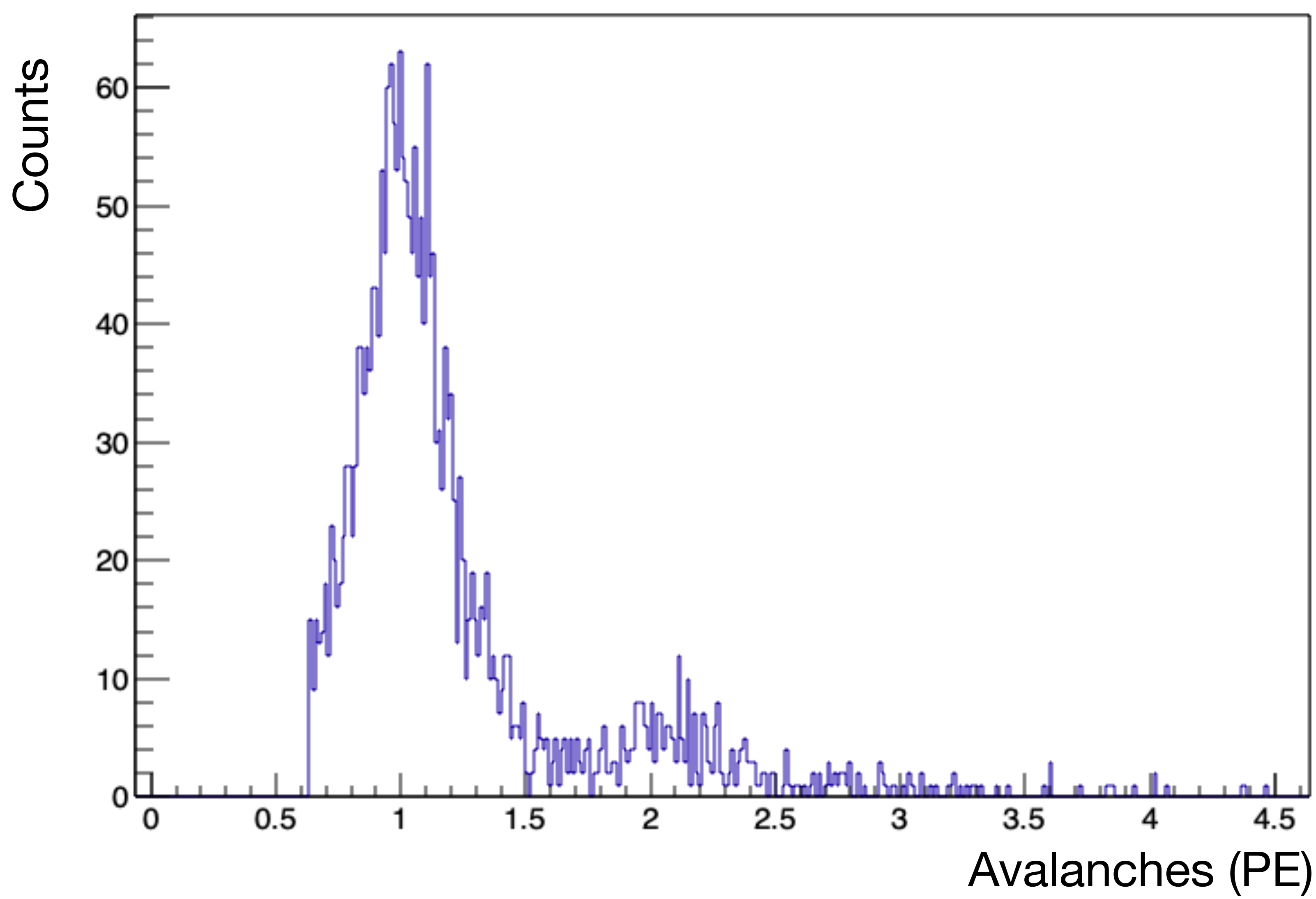




Single photons distribution: after pulses and cross talks

The two avalanches peak is expected since after pulses and cross talks.

The average number of avalanches is compatible with a single photon detected using the after pulses and cross talks estimation made in the LED test.



Ch	<N ph>
0	0.98
1	0.99
2	1.02
3	1.00
4	0.99
5	1.03
6	0.96
7	0.94
8	1.10
9	1.02
10	1.03
11	1.06

$$\frac{< Q >}{Q_{ph}} \simeq 1$$

Two independent single photons fire the same cell

$$P(n) = \frac{\lambda^n e^{-\lambda}}{n!}$$

$$\lambda = Rate \cdot \Delta T$$

There is a probability that a cell is fired in the same event by two or more single photons, but with the rate we have, that probability is very low

Cell n 0	Prop 2 couts: 1.2 %	Prop 3 couts: 0.07 %
Cell n 1	Prop 2 couts: 1.6 %	Prop 3 couts: 0.10%
Cell n 2	Prop 2 couts: 1.5 %	Prop 3 couts: 0.10 %
Cell n 3	Prop 2 couts: 1.4 %	Prop 3 couts: 0.09 %
Cell n 4	Prop 2 couts: 0.9 %	Prop 3 couts: 0.04 %
Cell n 5	Prop 2 couts: 0.8 %	Prop 3 couts: 0.03 %
Cell n 6	Prop 2 couts: 0.9 %	Prop 3 couts: 0.04 %
Cell n 7	Prop 2 couts: 1.2 %	Prop 3 couts: 0.07 %
Cell n 8	Prop 2 couts: 2.1 %	Prop 3 couts: 0.16 %
Cell n 9	Prop 2 couts: 2.7 %	Prop 3 couts: 0.25 %
Cell n 10	Prop 2 couts: 2.7 %	Prop 3 couts: 0.24 %
Cell n 11	Prop 2 couts: 0.6 %	Prop 3 couts: 0.02 %

Correction to single photons distribution considering the probability of two or more independent photons fire the same cell in a single acquisition

Average number of photons detected

Ch	Befor corrections	After corrections
0	0.98	0.97
1	0.99	0.97
2	1.02	1.00
3	1.00	0.99
4	0.99	0.98
5	1.03	1.03
6	0.96	0.95
7	0.94	0.93
8	1.10	1.08
9	1.02	0.99
10	1.03	1.00
11	1.06	1.06