

# ProtoDUNE PDS Calibration

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on behalf of the PDS WG

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# Introduction

- Most things we want to know concerning the PDS flow outward from calibration
  - PDS performance for t0 (ie flash matching to TPC)
  - Technology comparisons
  - Evaluation of anomalous (MicroBooNe-like) background

# Strategy

- Attempted to split task into 3 distinct groups based on photon sensor type and collector technology
  - All SensLs (A and C type) regardless of collector technology
  - MPPCs + Dip-Coated and MPPCs + Double Shift
  - MPPCs + ARAPUCA
- Used PeakFinder on DCM Runs 5927 (DaS) and 5912 (RaS)
  - Find peaks based on 5 standard deviation difference from baseline
  - 40 Sample (.266  $\mu$ s) baseline calculation
  - 20 Sample (.133  $\mu$ s) “D-Window” baseline and peak separation
  - 250 Sample (1.6  $\mu$ s) charge integration (baseline subtracted)
  - Multi-peak situations are superseded by higher peaks

# Strategy

- Attempted to split task into 3 distinct groups based on photon sensor type and collector technology

- All S

- MPP

- MPP

- Used PeakF

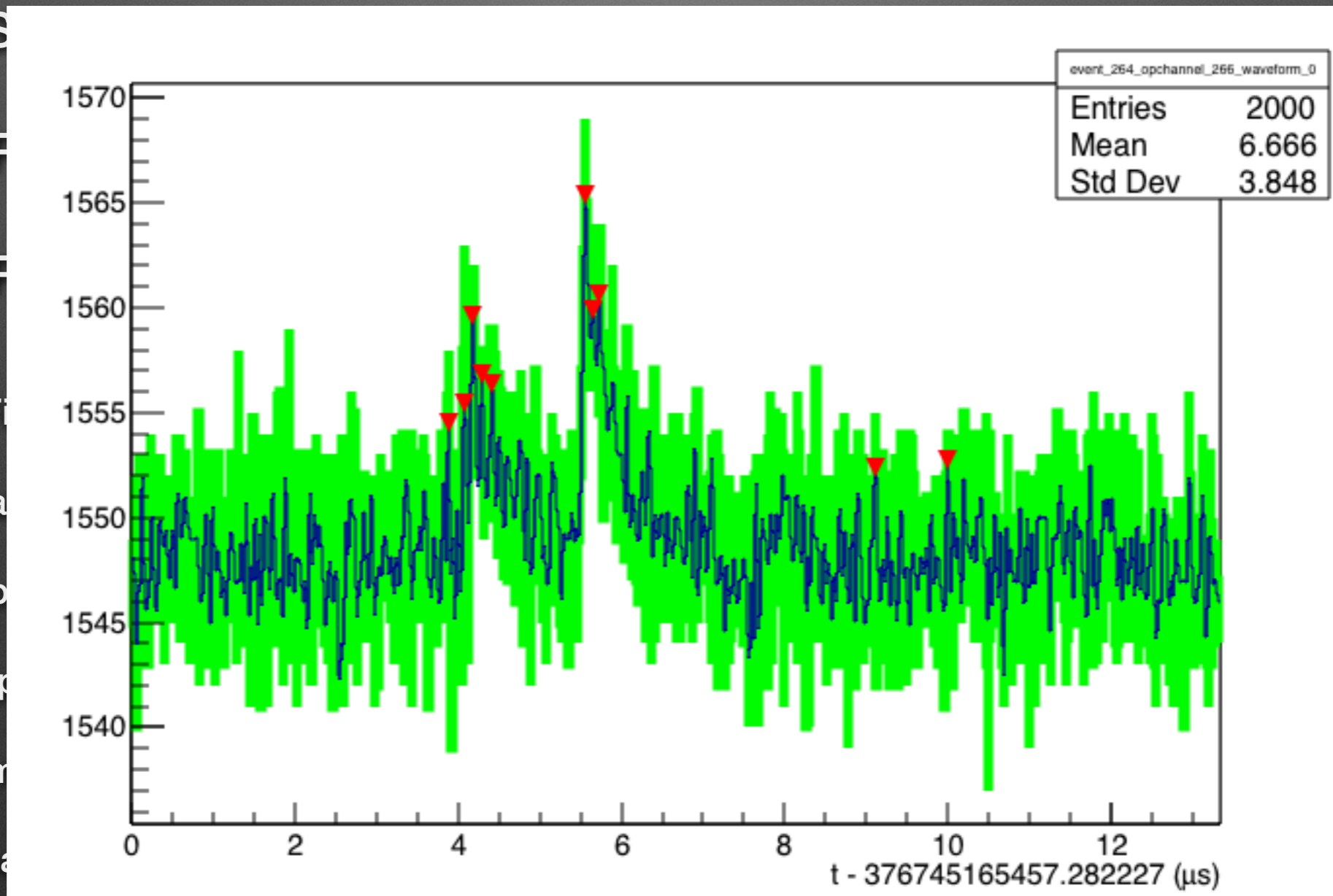
- Find pea

- 40 Samp

- 20 Samp

- 250 Sam

- Multi-pea

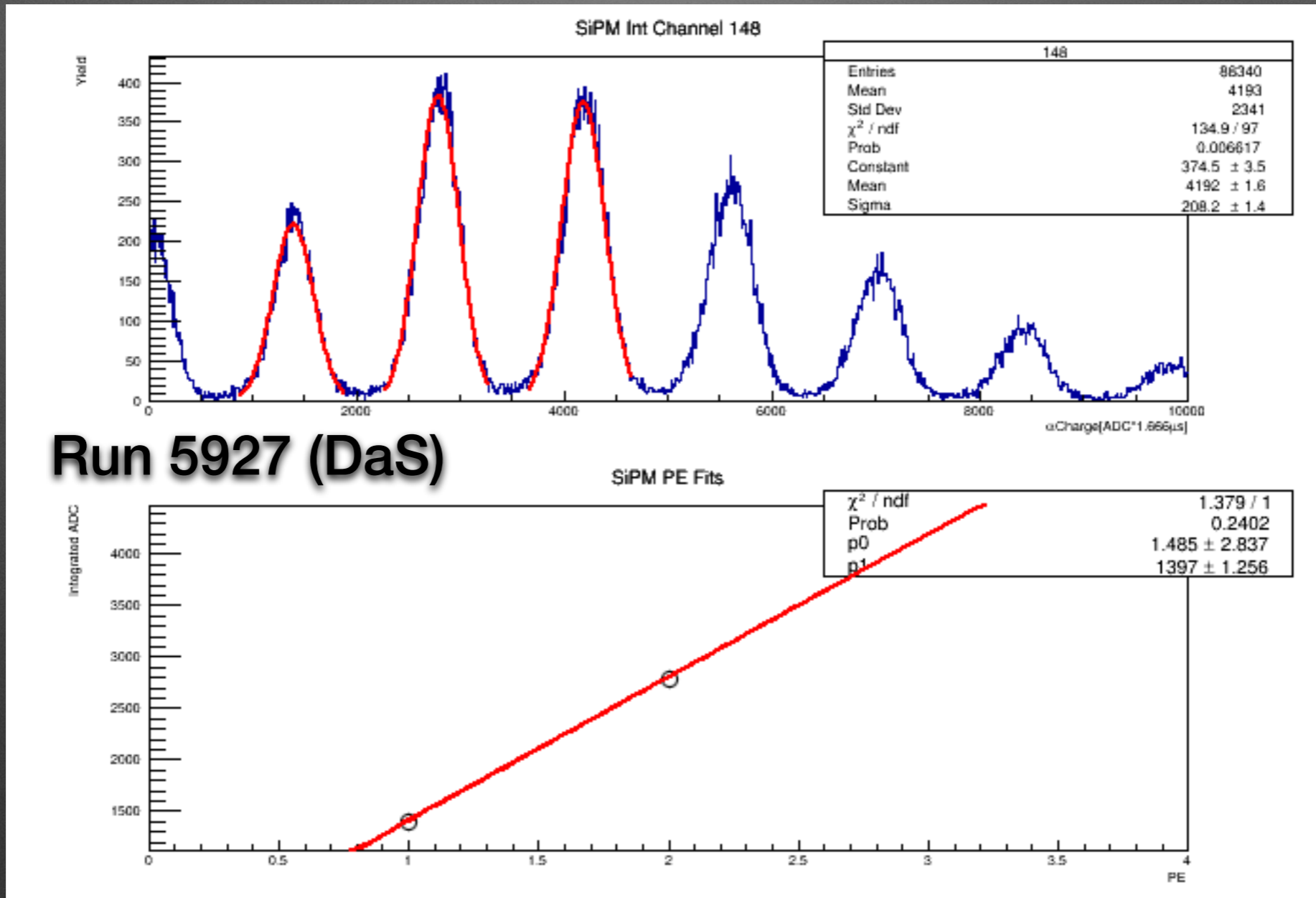


# Strategy (Cont.)

For actual calibration procedure, integer photon peaks from charge calculation were fit by gaussian and the means were fit linearly

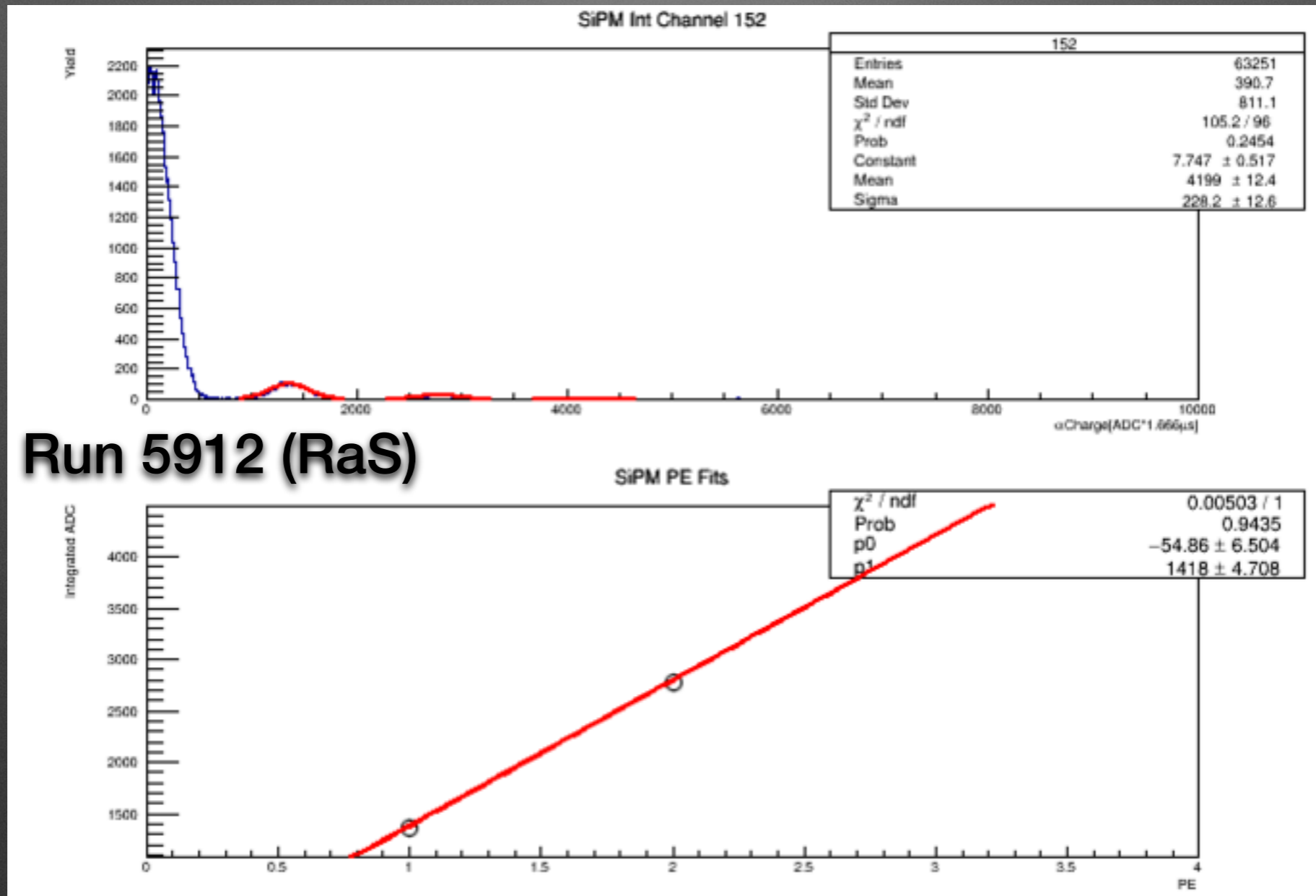
- All accepted fits have a  $\text{Chi}^2/\text{N.D.F.} < 2$
- Slope of the line should be within ballpark of the first PE peak
- The intercept is divided by the slope giving a fraction of PE
- ARAPUCA fits skip the first PE peak

# SensL + Dip-Coated



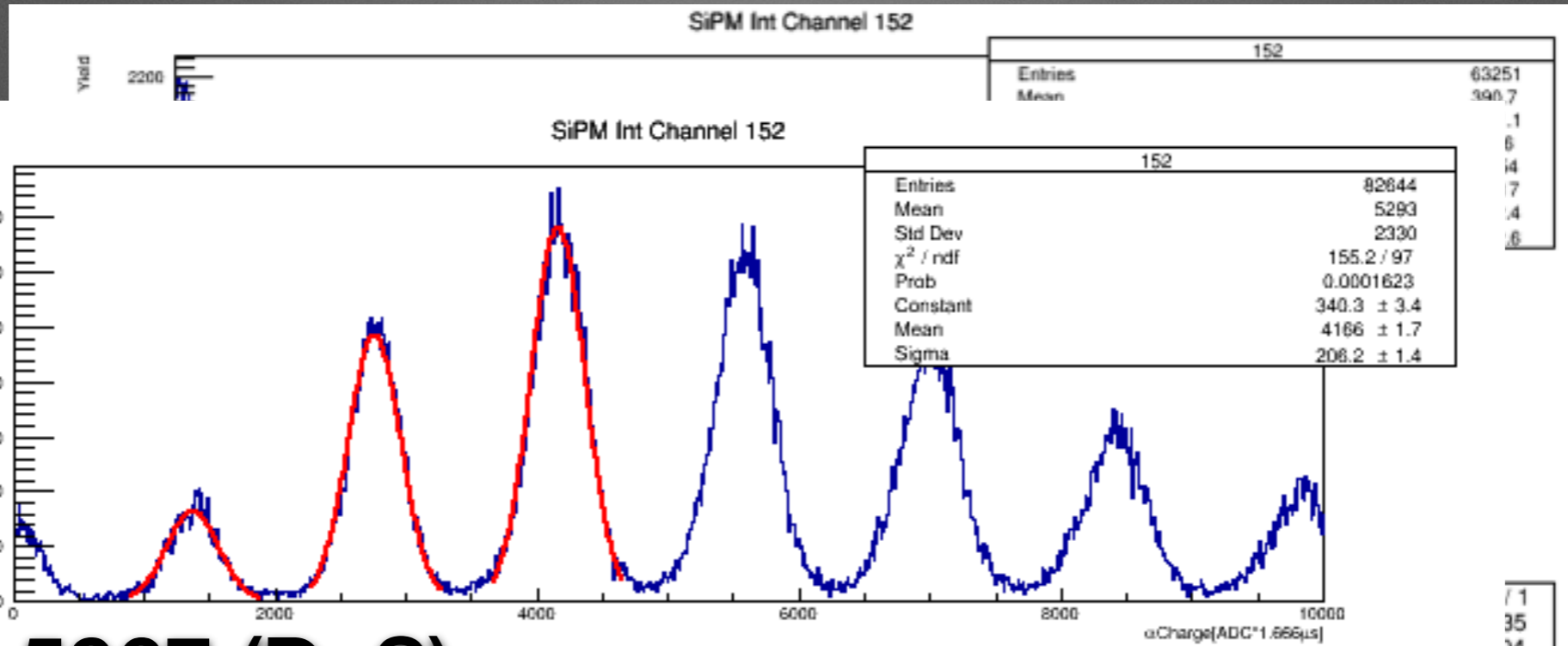
146	SensL-C1	Dip-Coated	$1424 \pm 3$	$2846 \pm 2$	$4258 \pm 2$		$1416 \pm 2$	$0.01 \pm 0.00$
147	SensL-C1	Dip-Coated	$1399 \pm 2$	$2793 \pm 2$	$4192 \pm 2$		$1397 \pm 1$	$0.00 \pm 0.00$
148	SensL-C1	Dip-Coated	$1373 \pm 2$	$2775 \pm 6$	$4187 \pm 14$		$1404 \pm 6$	$0.00 \pm 0.00$

# SensL + Double-Shift

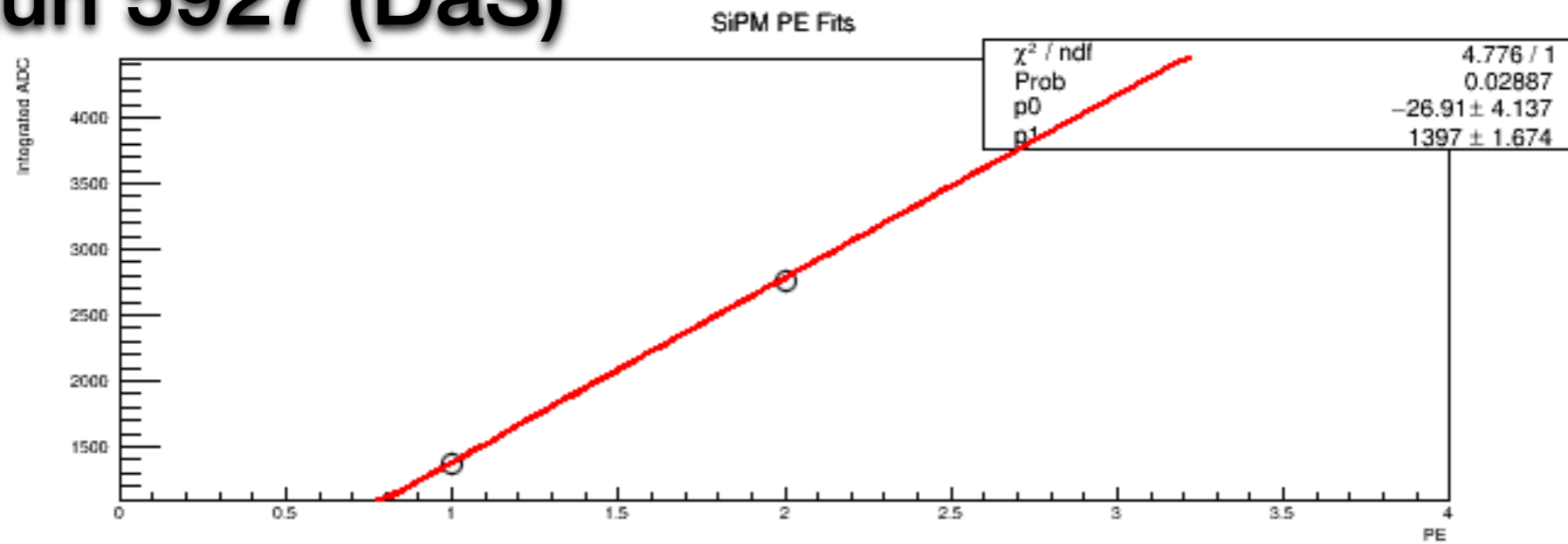


150	SensL-C1	Double-Shift	$1420 \pm 4$	$2849 \pm 5$	$4278 \pm 12$		$1428 \pm 5$	$-0.01 \pm 0.00$
151	SensL-C1	Double-Shift	$1363 \pm 3$	$2782 \pm 6$	$4199 \pm 12$		$1418 \pm 5$	$-0.04 \pm 0.00$
152	SensL-C1	Double-Shift	$1399 \pm 3$	$2891 \pm 6$	$4191 \pm 6$		$1409 \pm 3$	$-0.01 \pm 0.00$

# SensL + Double-Shift



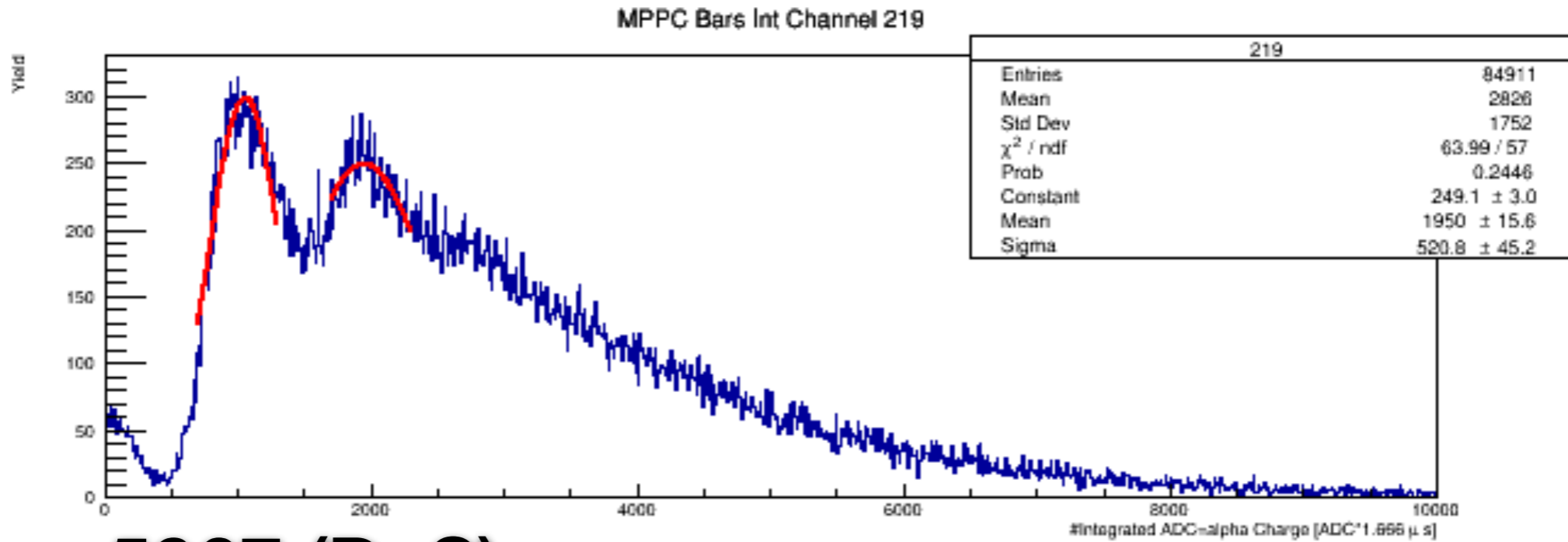
Run 5927 (DaS)



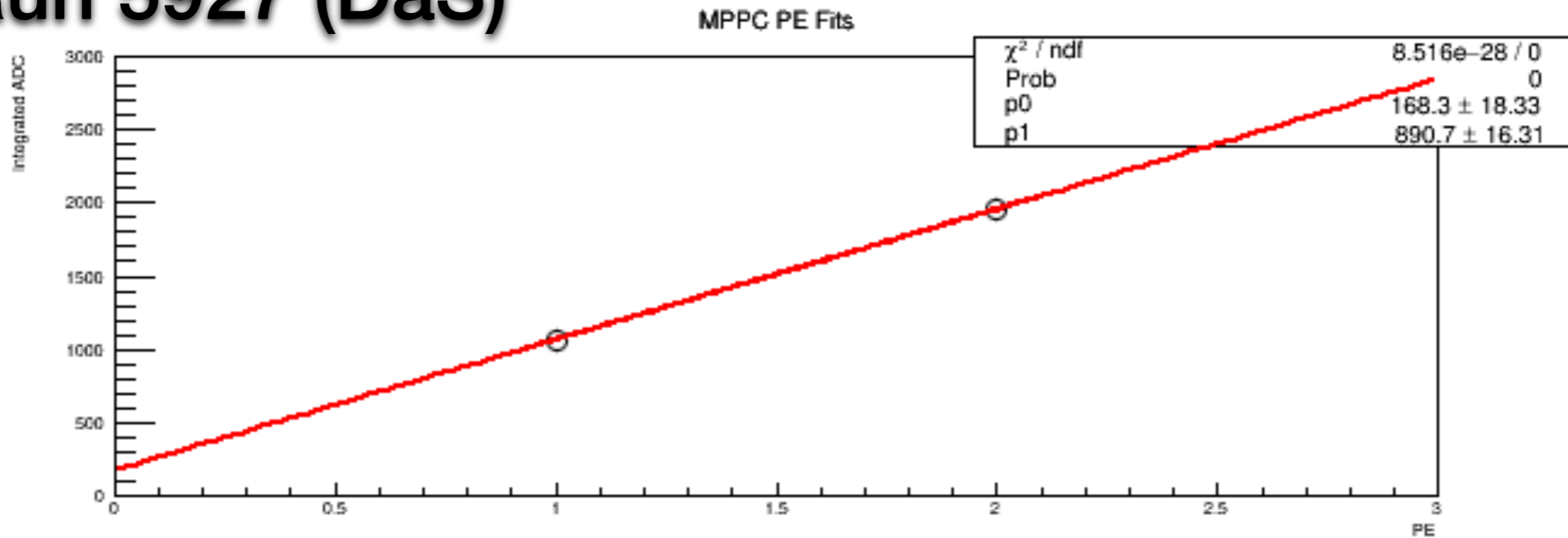
5	-0.01 ± 0.00
5	-0.04 ± 0.00



# MPPC + Dip-Coated

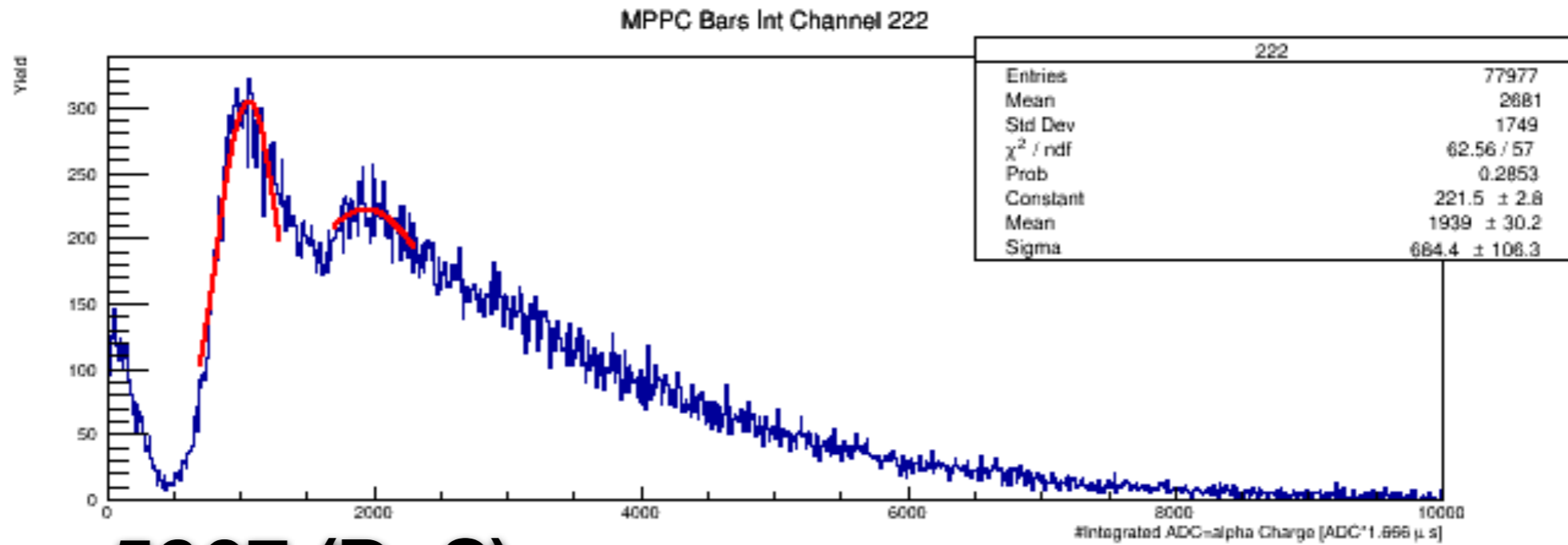


**Run 5927 (DaS)**

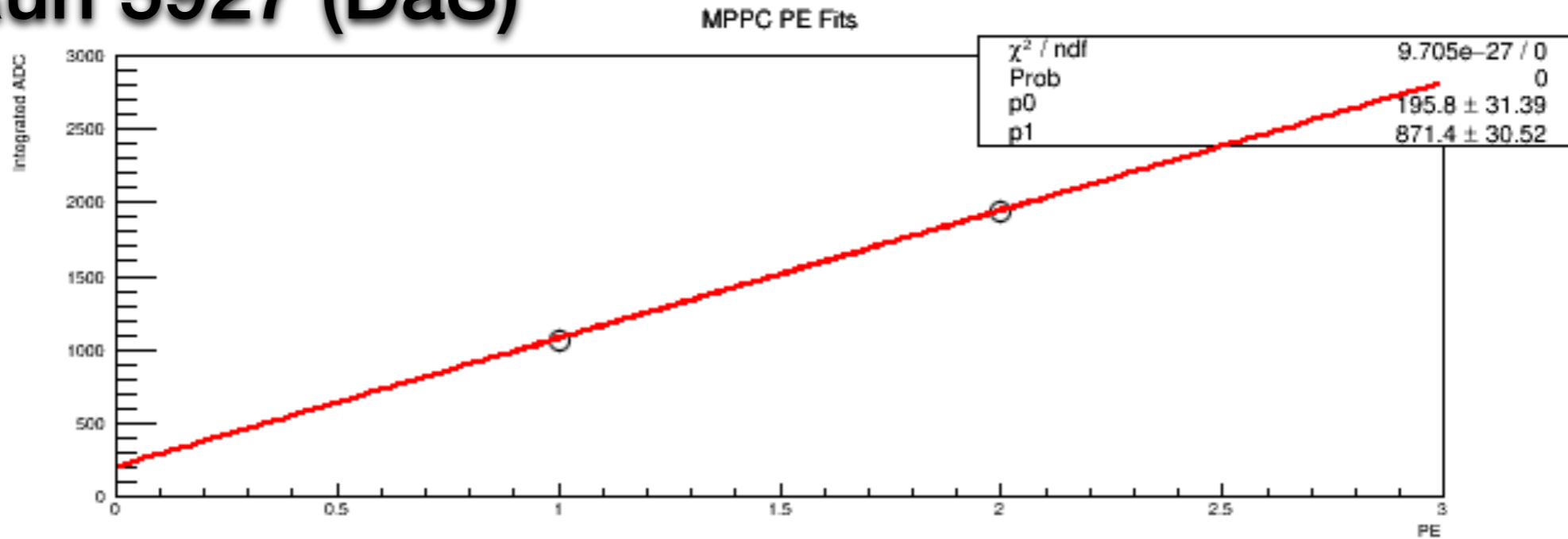


218	Hamamatsu	Dip-Coated	$1059 \pm 5$	$1950 \pm 16$		$891 \pm 16$	$0.19 \pm 0.02$
219	Hamamatsu	Dip-Coated	$1027 \pm 3$	$1912 \pm 22$		$876 \pm 22$	$0.19 \pm 0.04$

# MPPC + Double-Shift



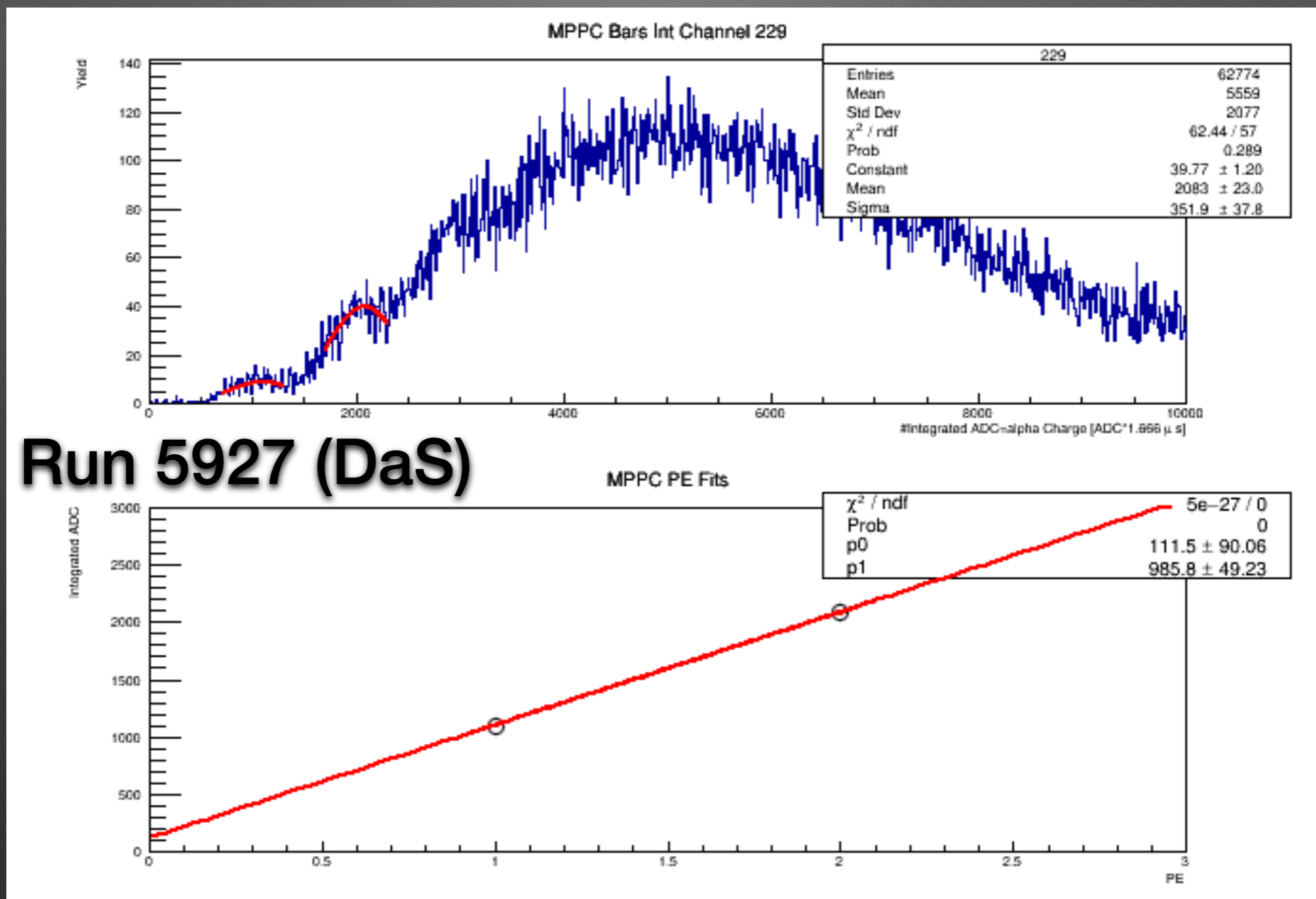
Run 5927 (DaS)



221	Hamamatsu	Double-Shift	1067 $\pm$ 4	1939 $\pm$ 30			871 $\pm$ 31	0.22 $\pm$ 0.04
222	Hamamatsu	Double-Shift	1048 $\pm$ 4	1924 $\pm$ 20			876 $\pm$ 20	0.20 $\pm$ 0.02

# MPPC + Bars

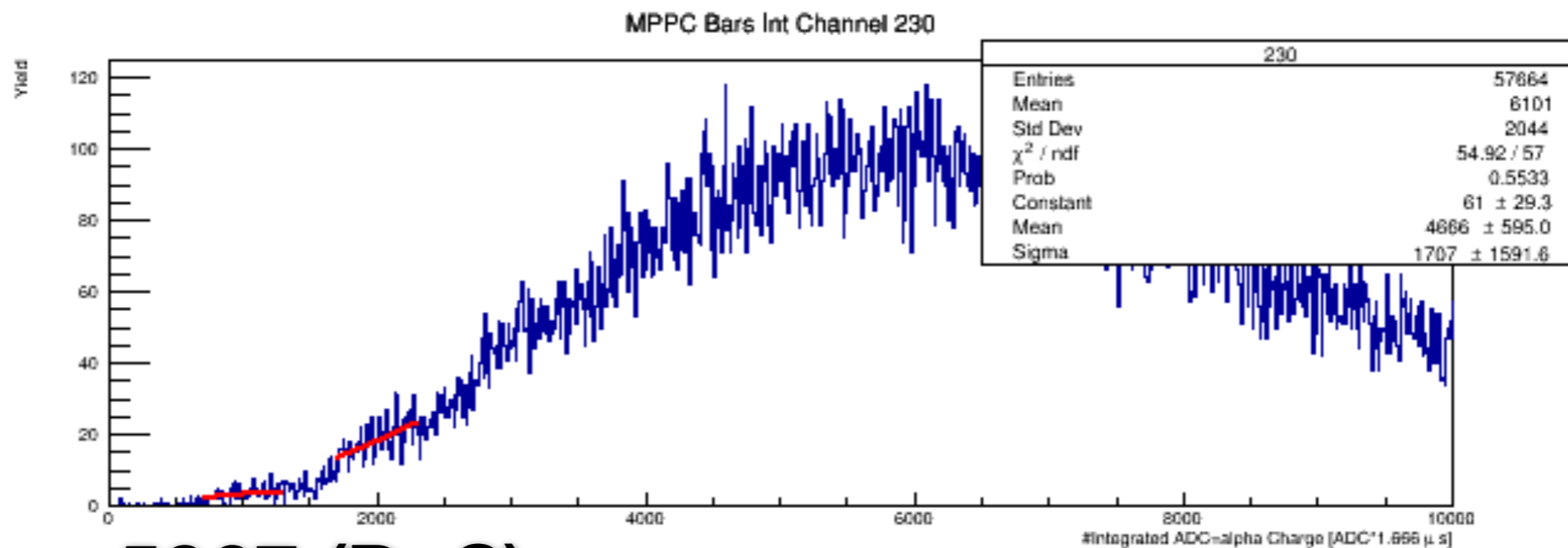
Some MPPC bar fits barely make quality cuts...



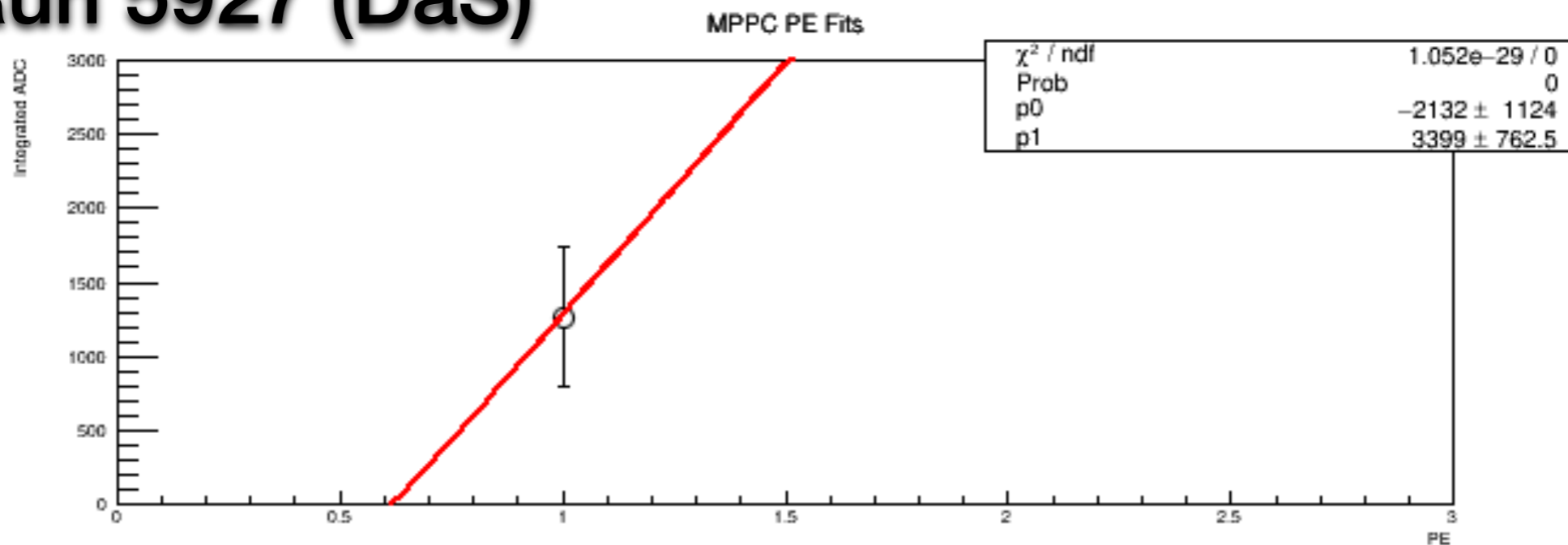
228	Hamamatsu	Double-Shift	$1097 \pm 44$	$2083 \pm 23$		$986 \pm 49$	$0.11 \pm 0.09$
229	Hamamatsu	Double-Shift	$1267 \pm 477$			$1267 \pm 477$	

# MPPC + Bars

...and some fail completely...

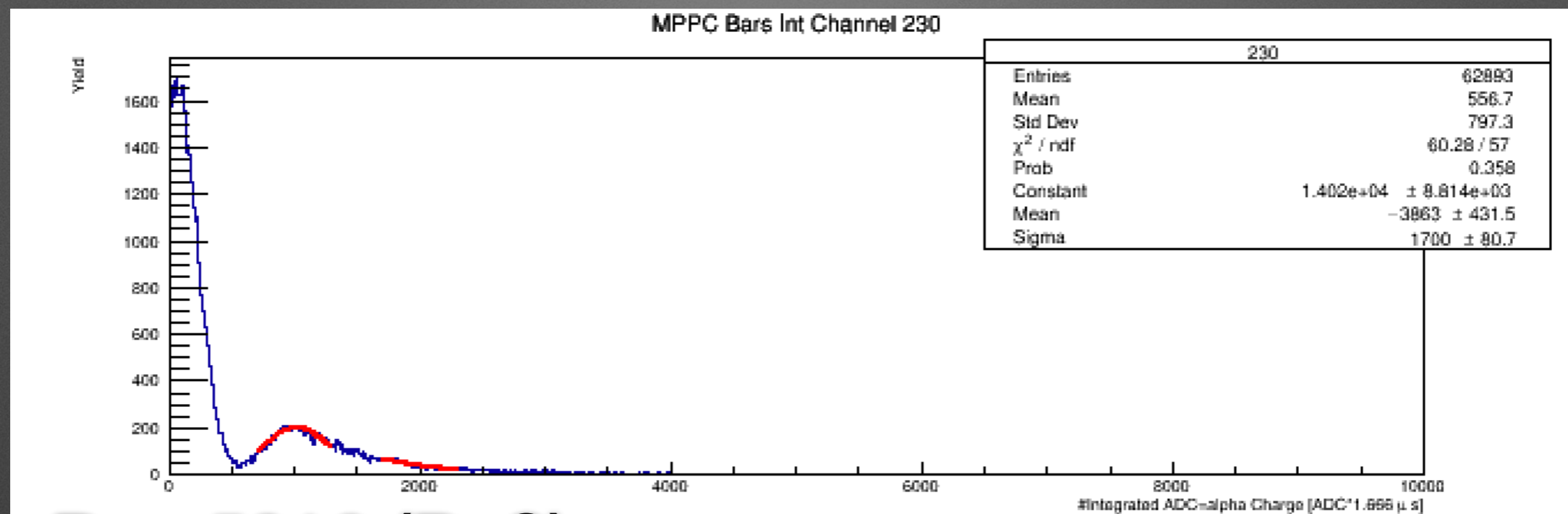


Run 5927 (DaS)

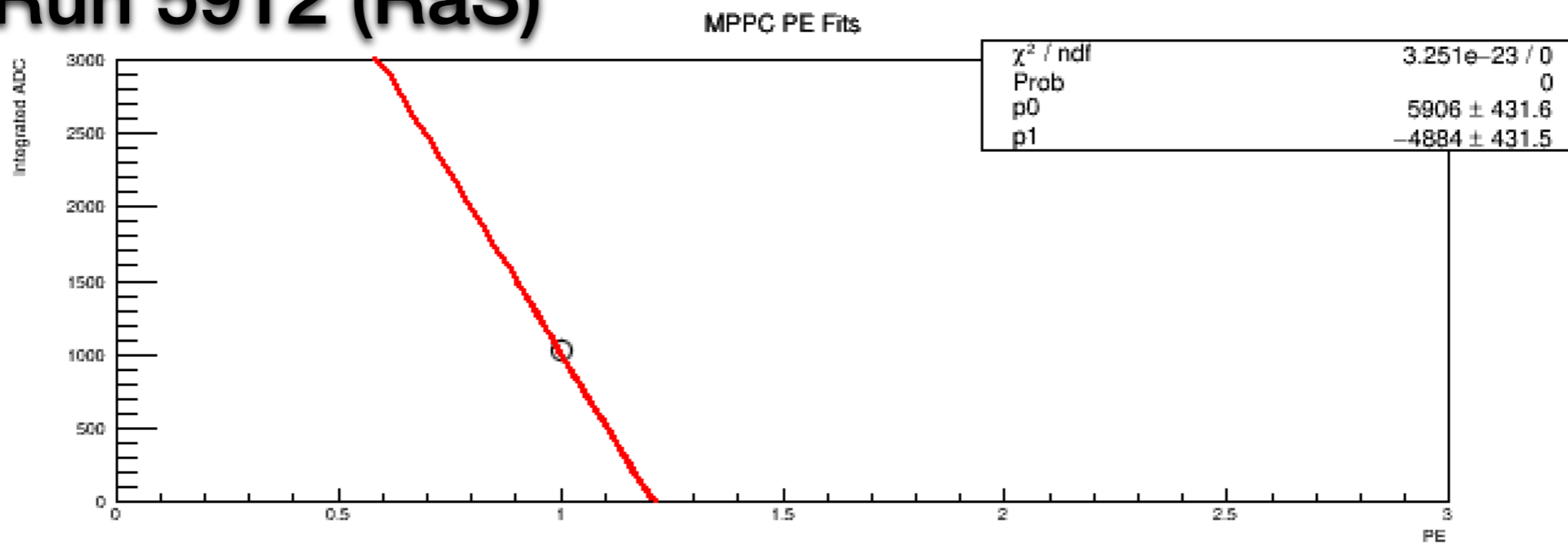


# MPPC + Bars

...in those cases I use the first peak if available.

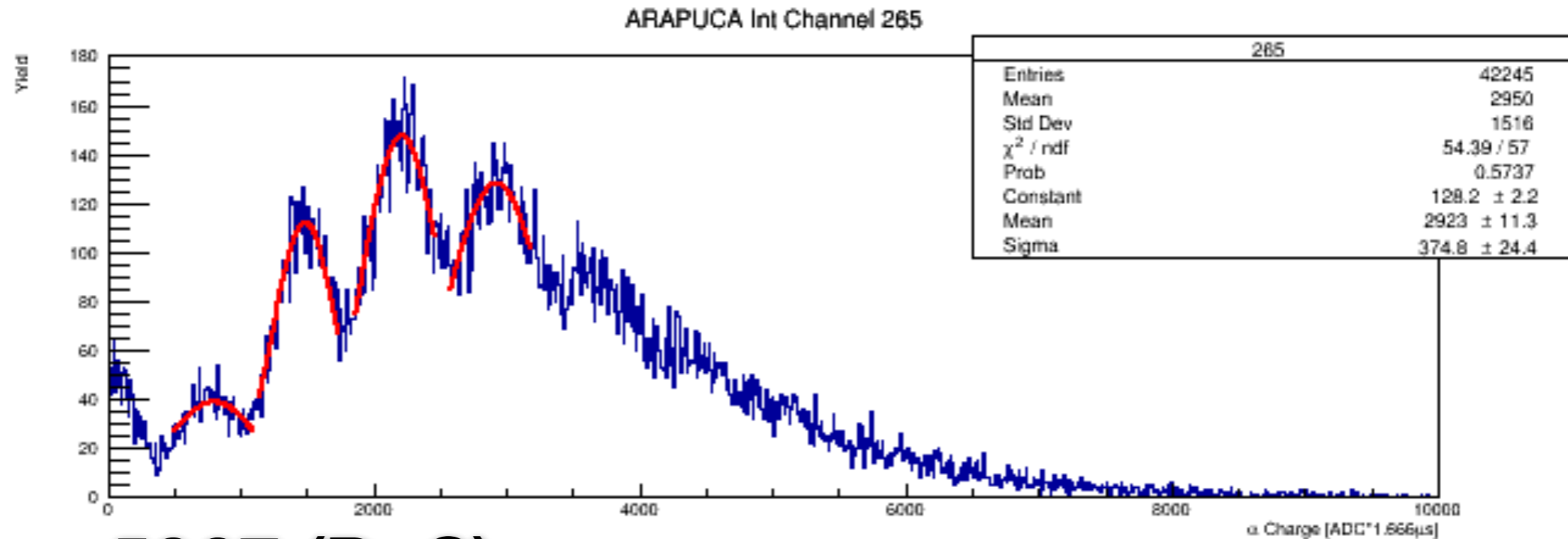


## Run 5912 (RaS)

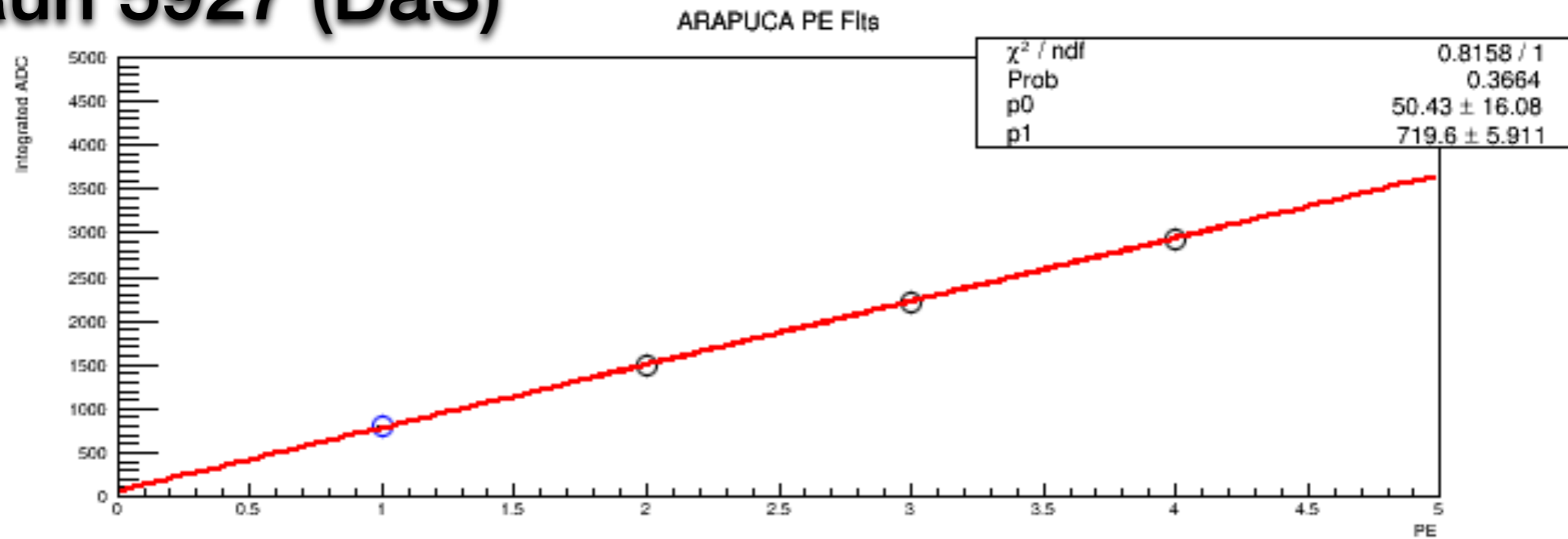


229	Hamamatsu	Double-Shift	$1267 \pm 477$				$1267 \pm 477$	
230	Hamamatsu	Double-Shift	$1000 \pm 39$	$2007 \pm 95$			$1017 \pm 39$	$0.96 \pm 0.06$

# MPPC + ARAPUCA

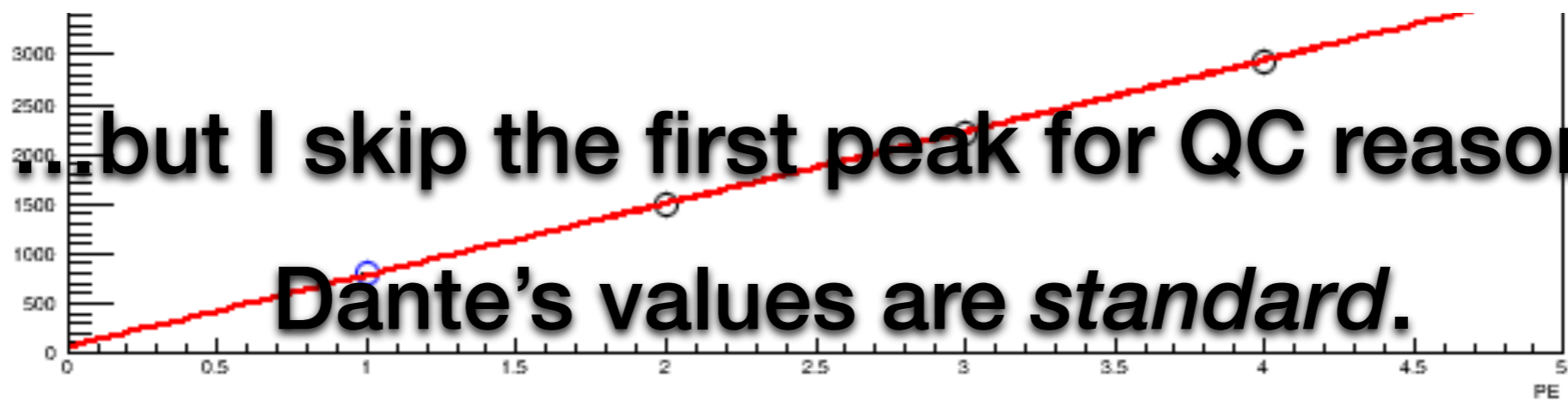
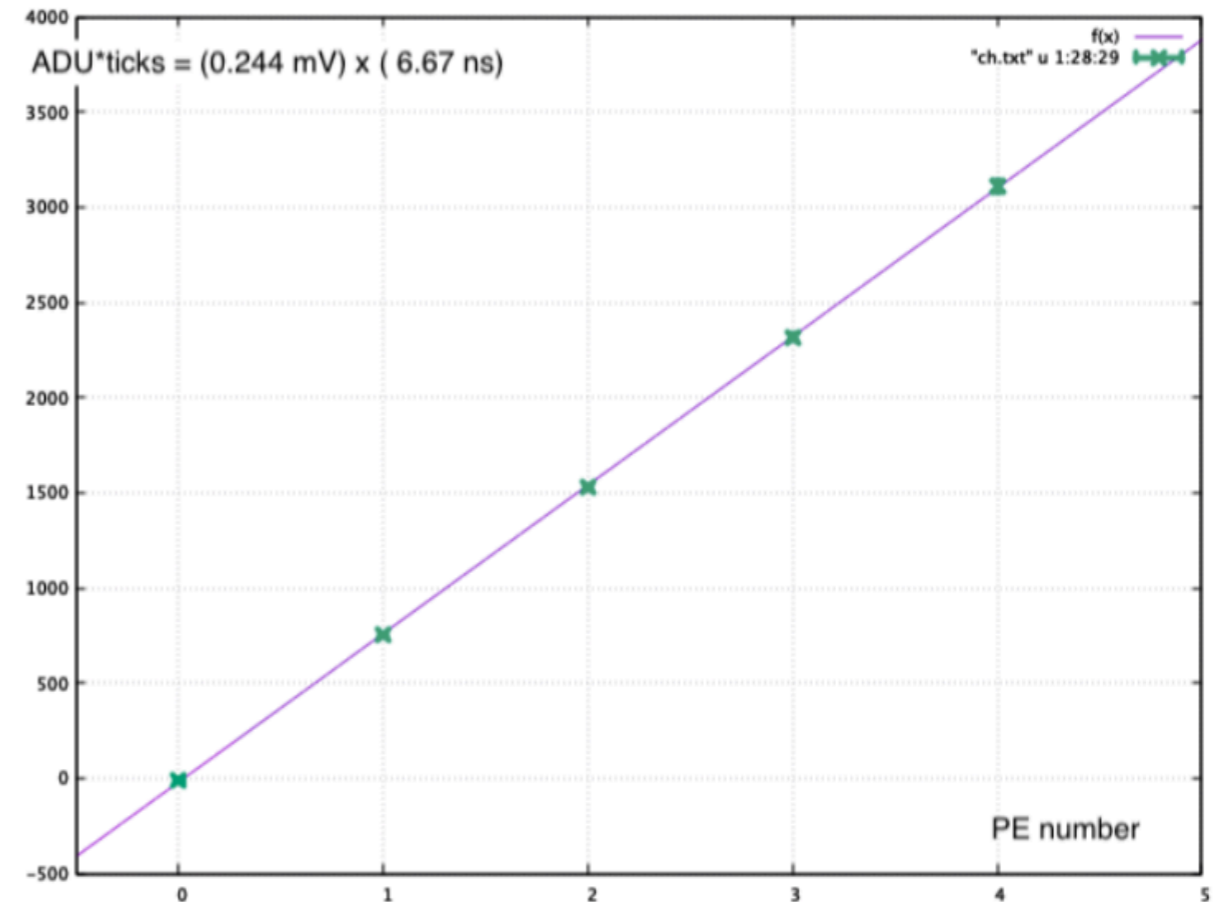
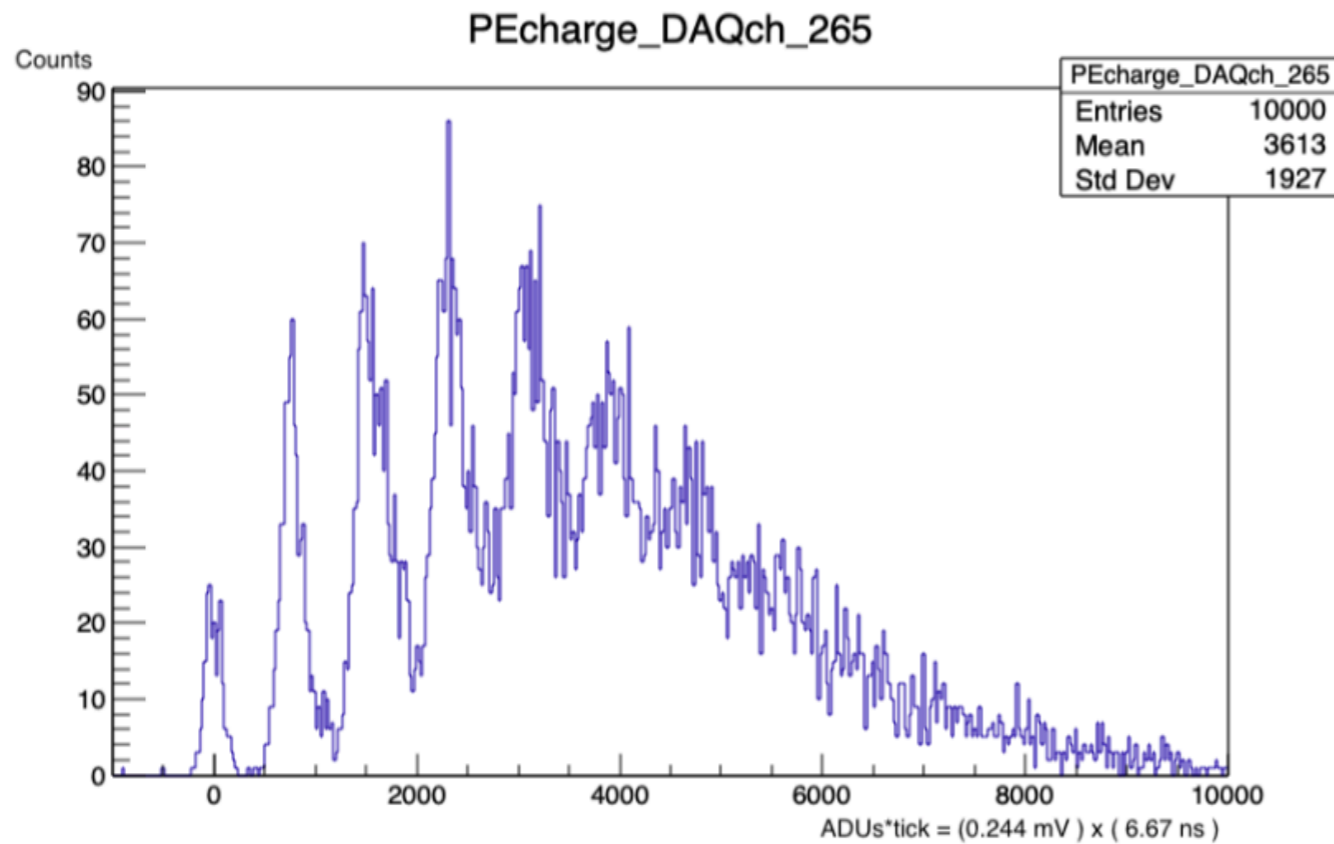


Run 5927 (DaS)



Characteristic ARAPUCA fit

# MPPC + ARAPUCA



Characteristic ARAPUCA fit

# All Calibrations (APA 1)

APA 1 Photon Sensor Calibration Values								
DAQ Channel	Sensor Type	Collector Type	1st Peak	2nd Peak	3rd Peak	4th Peak	Slope	Intercept
0	SensL-A1	Double-Shift	1418 ± 4	2856 ± 7	4232 ± 8		1411 ± 4	0.01 ± 0.00
1	SensL-A1	Double-Shift	1418 ± 4	2852 ± 7	4242 ± 8		1416 ± 4	0.00 ± 0.00
2	SensL-A1	Double-Shift	1421 ± 4	2853 ± 6	4215 ± 9		1405 ± 4	0.01 ± 0.00
3	SensL-A1	Double-Shift	1437 ± 4	2900 ± 8	4303 ± 8		1436 ± 4	0.00 ± 0.01
4	SensL-A1	Dip-Coated	1431 ± 3	2881 ± 5	4287 ± 10		1437 ± 4	0.00 ± 0.00
5	SensL-A1	Dip-Coated	1416 ± 3	2861 ± 5	4289 ± 12		1442 ± 4	-0.02 ± 0.00
6	SensL-A1	Dip-Coated	1418 ± 2	2842 ± 4	4297 ± 10		1432 ± 4	-0.01 ± 0.00
7	SensL-A1	Dip-Coated	1419 ± 3	2859 ± 5	4285 ± 10		1436 ± 4	-0.01 ± 0.00
8	SensL-A1	Double-Shift	1379 ± 4	2793 ± 8	4172 ± 25		1409 ± 7	-0.02 ± 0.01
9	SensL-A1	Double-Shift	1400 ± 4	2821 ± 7	4241 ± 23		1421 ± 7	0.00 ± 0.01
10	SensL-A1	Double-Shift	1392 ± 4	2821 ± 7	4222 ± 19		1423 ± 7	0.01 ± 0.01
11	SensL-A1	Double-Shift	1412 ± 4	2860 ± 8	4269 ± 41		1445 ± 8	0.00 ± 0.01
12	SensL-A1	Dip-Coated	1398 ± 2	2827 ± 4	4245 ± 10		1427 ± 4	-0.02 ± 0.00
13	SensL-A1	Dip-Coated	1369 ± 2	2777 ± 5	4155 ± 10		1400 ± 4	-0.02 ± 0.00
14	SensL-A1	Dip-Coated	1397 ± 2	2826 ± 4	4215 ± 10		1419 ± 4	-0.02 ± 0.00
15	SensL-A1	Dip-Coated	1398 ± 2	2833 ± 5	4216 ± 10		1421 ± 4	-0.02 ± 0.00
16	SensL-A1	Double-Shift	1387 ± 4	2798 ± 11	4205 ± 24		1410 ± 9	-0.02 ± 0.01
17	SensL-A1	Double-Shift	1402 ± 4	2807 ± 9	4193 ± 31		1402 ± 9	0.00 ± 0.01
18	SensL-A1	Double-Shift	1413 ± 4	2879 ± 9	4234 ± 32		1451 ± 9	-0.03 ± 0.01
19	SensL-A1	Double-Shift	1626 ± 4	3265 ± 8	4883 ± 36		1637 ± 8	-0.01 ± 0.01
20	SensL-A1	Dip-Coated	1361 ± 2	2790 ± 5	4182 ± 9		1418 ± 4	-0.04 ± 0.00
21	SensL-A1	Dip-Coated	1414 ± 2	2832 ± 4	4253 ± 12		1419 ± 4	0.00 ± 0.00
22	SensL-A1	Dip-Coated	1394 ± 2	2812 ± 4	4210 ± 9		1412 ± 4	-0.01 ± 0.00
23	SensL-A1	Dip-Coated	1389 ± 3	2810 ± 5	4177 ± 10		1406 ± 4	-0.01 ± 0.00
24	SensL-A1	Double-Shift	1387 ± 4	2818 ± 8	4191 ± 24		1421 ± 7	-0.02 ± 0.01
25	SensL-A1	Double-Shift	Dead Channel					
26	SensL-A1	Double-Shift	1394 ± 4	2811 ± 8	4169 ± 24		1407 ± 8	-0.03 ± 0.01
27	SensL-A1	Double-Shift	1375 ± 4	2768 ± 8	4125 ± 24		1387 ± 7	-0.01 ± 0.01
28	SensL-A1	Dip-Coated	1432 ± 3	2878 ± 5	4297 ± 11		1439 ± 4	0.00 ± 0.00
29	SensL-A1	Dip-Coated	1391 ± 3	2834 ± 5	4243 ± 10		1434 ± 4	-0.03 ± 0.00
30	SensL-A1	Dip-Coated	1391 ± 2	2822 ± 5	4224 ± 10		1423 ± 4	-0.02 ± 0.00
31	SensL-A1	Dip-Coated	1443 ± 3	2927 ± 5	4332 ± 11		1463 ± 4	-0.01 ± 0.00
32	SensL-A1	Double-Shift	1411 ± 4	2856 ± 9	4239 ± 26		1434 ± 8	-0.01 ± 0.01
33	SensL-A1	Double-Shift	1610 ± 4	3231 ± 8	4813 ± 7		1604 ± 4	0.01 ± 0.00
34	SensL-A1	Double-Shift	1375 ± 4	2798 ± 9	4154 ± 20		1407 ± 8	-0.02 ± 0.01
35	SensL-A1	Double-Shift	1360 ± 4	2782 ± 9	4156 ± 35		1416 ± 9	-0.04 ± 0.01
36	SensL-A1	Dip-Coated	Dead Channel					
37	SensL-A1	Dip-Coated	1351 ± 3	2739 ± 5	4180 ± 13		1400 ± 5	-0.04 ± 0.00
38	SensL-A1	Dip-Coated	1384 ± 3	2777 ± 5	4166 ± 11		1392 ± 4	-0.01 ± 0.00
39	SensL-A1	Dip-Coated	1376 ± 3	2802 ± 5	4217 ± 13		1423 ± 5	-0.03 ± 0.00



# All Calibrations (APA 2)

APA 2 Photon Sensor Calibration Values								
DAQ Channel	Sensor Type	Collector Type	1st Peak	2nd Peak	3rd Peak	4th Peak	Slope	Intercept
48	SensL-A1	Double-Shift	1395 ± 3	2810 ± 3	4215 ± 3		1410 ± 2	-0.01 ± 0.00
49	SensL-A1	Double-Shift	1826 ± 1	3651 ± 2	5474 ± 3		1824 ± 1	0.00 ± 0.00
50	SensL-A1	Double-Shift	1390 ± 4	2767 ± 3	4161 ± 3		1386 ± 2	0.01 ± 0.00
51	SensL-A1	Double-Shift	1849 ± 1	3691 ± 2	5530 ± 3		1841 ± 1	0.00 ± 0.00
52	SensL-A1	Dip-Coated	1347 ± 3	2760 ± 5	4165 ± 10		1411 ± 4	0.00 ± 0.00
53	SensL-A1	Dip-Coated	1419 ± 3	2867 ± 5	4288 ± 9		1439 ± 4	-0.02 ± 0.00
54	SensL-A1	Dip-Coated	1420 ± 3	2830 ± 5	4236 ± 10		1408 ± 4	-0.01 ± 0.00
55	SensL-A1	Dip-Coated	1416 ± 3	2864 ± 6	4271 ± 10		1435 ± 4	-0.01 ± 0.00
56	SensL-A1	Double-Shift	1347 ± 4	2755 ± 7	4120 ± 6		1389 ± 4	-0.03 ± 0.00
57	SensL-A1	Double-Shift	1386 ± 4	2799 ± 7	4162 ± 7		1392 ± 4	-0.00 ± 0.00
58	SensL-A1	Double-Shift	Dead Channel					
59	SensL-A1	Double-Shift	1364 ± 4	2750 ± 6	4091 ± 8		1368 ± 4	-0.00 ± 0.00
60	SensL-A1	Dip-Coated	1402 ± 2	2825 ± 4	4260 ± 8		1427 ± 3	-0.02 ± 0.00
61	SensL-A1	Dip-Coated	1397 ± 2	2818 ± 5	4197 ± 10		1409 ± 4	-0.01 ± 0.00
62	SensL-A1	Dip-Coated	Dead Channel					
63	SensL-A1	Dip-Coated	1410 ± 2	2880 ± 5	4306 ± 10		1459 ± 4	-0.03 ± 0.00
64	SensL-A1	Double-Shift	1401 ± 4	2841 ± 8	4221 ± 24		1430 ± 8	-0.02 ± 0.01
65	SensL-A1	Double-Shift	Dead Channel					
66	SensL-A1	Double-Shift	1395 ± 4	2804 ± 7	4156 ± 27		1401 ± 7	0.00 ± 0.01
67	SensL-A1	Double-Shift	1413 ± 4	2881 ± 7	4280 ± 21		1456 ± 6	-0.03 ± 0.01
68	SensL-A1	Dip-Coated	1451 ± 2	2876 ± 5	4280 ± 10		1419 ± 4	0.02 ± 0.00
69	SensL-A1	Dip-Coated	1409 ± 2	2844 ± 4	4266 ± 8		1431 ± 3	-0.02 ± 0.00
70	SensL-A1	Dip-Coated	1369 ± 2	2777 ± 4	4174 ± 8		1405 ± 3	-0.03 ± 0.00
71	SensL-A1	Dip-Coated	1422 ± 3	2857 ± 5	4300 ± 9		1437 ± 4	-0.01 ± 0.00
72	SensL-A1	Double-Shift	1389 ± 4	2824 ± 7	4244 ± 29		1433 ± 7	-0.03 ± 0.01
73	SensL-A1	Double-Shift	Dead Channel					
74	SensL-A1	Double-Shift	1382 ± 4	2811 ± 9	4206 ± 20		1421 ± 7	-0.03 ± 0.01
75	SensL-A1	Double-Shift	Dead Channel					
76	SensL-A1	Dip-Coated	1421 ± 2	2860 ± 5	4282 ± 10		1435 ± 4	-0.01 ± 0.00
77	SensL-A1	Dip-Coated	1623 ± 2	3273 ± 5	4899 ± 10		1643 ± 4	-0.01 ± 0.00
78	SensL-A1	Dip-Coated	1412 ± 2	2844 ± 4	4249 ± 10		1425 ± 4	-0.01 ± 0.00
79	SensL-A1	Dip-Coated	1413 ± 3	2842 ± 5	4267 ± 10		1428 ± 4	-0.01 ± 0.00
80	SensL-A1	Double-Shift	1419 ± 4	2800 ± 5	4175 ± 4		1378 ± 3	0.03 ± 0.01
81	SensL-A1	Double-Shift	1382 ± 4	2772 ± 6	4125 ± 5		1372 ± 3	0.01 ± 0.00
82	SensL-A1	Double-Shift	Dead Channel					
83	SensL-A1	Double-Shift	1373 ± 4	2745 ± 5	4099 ± 5		1364 ± 3	0.01 ± 0.01
84	SensL-A1	Dip-Coated	1404 ± 3	2827 ± 5	4232 ± 9		1417 ± 4	-0.01 ± 0.01
85	SensL-A1	Dip-Coated	1406 ± 3	2842 ± 5	4253 ± 10		1430 ± 4	-0.02 ± 0.00
86	SensL-A1	Dip-Coated	1390 ± 2	2828 ± 5	4246 ± 11		1434 ± 4	-0.03 ± 0.00
87	SensL-A1	Dip-Coated	1390 ± 3	2841 ± 5	4235 ± 8		1432 ± 4	-0.03 ± 0.00

# All Calibrations (APA 3)

APA 3 Photon Sensor Calibration Values										
DAQ Channel	Sensor Type	Collector Type	1st Peak	2nd Peak	3rd Peak	4th Peak	Slope	Intercept		
96	SensL-A1	Double-Shift	1346 ± 2	2739 ± 2	4137 ± 3		1396 ± 2	-0.04 ± 0.00		
97	SensL-A1	Double-Shift	1393 ± 2	2832 ± 2	4256 ± 3		1432 ± 2	-0.03 ± 0.00		
98	SensL-A1	Double-Shift	1389 ± 2	2776 ± 2	4175 ± 3		1392 ± 2	0.00 ± 0.00		
99	SensL-A1	Double-Shift	1385 ± 2	2775 ± 2	4174 ± 3		1394 ± 2	-0.01 ± 0.00		
100	SensL-A1	Dip-Coated	1390 ± 2	2778 ± 2	4174 ± 3		1392 ± 2	0.00 ± 0.00		
101	SensL-A1	Dip-Coated	Dead Channel							
102	SensL-A1	Dip-Coated	1412 ± 2	2834 ± 2	4238 ± 3		1414 ± 2	0.00 ± 0.00		
103	SensL-A1	Dip-Coated	1405 ± 2	2817 ± 2	4230 ± 3		1413 ± 2	-0.01 ± 0.00		
104	SensL-A1	Double-Shift	1641 ± 2	3272 ± 2	4888 ± 2		1624 ± 2	0.01 ± 0.00		
105	SensL-A1	Double-Shift	1398 ± 3	2782 ± 3	4194 ± 3		1399 ± 2	0.00 ± 0.00		
106	SensL-A1	Double-Shift	1630 ± 2	3255 ± 2	4878 ± 2		1624 ± 2	0.00 ± 0.00		
107	SensL-A1	Double-Shift	1629 ± 2	3253 ± 2	4871 ± 2		1621 ± 2	0.01 ± 0.00		
132	Hamamatsu	ARAPUCA	729 ± 5	1514 ± 12	2315 ± 18		782 ± 7	-0.05 ± 0.02		
133	Hamamatsu	ARAPUCA	713 ± 4	1450 ± 10	2219 ± 46		750 ± 5	-0.05 ± 0.01		
134	Hamamatsu	ARAPUCA	738 ± 4	1505 ± 9	2310 ± 36		780 ± 6	-0.05 ± 0.01		
135	Hamamatsu	ARAPUCA	750 ± 5	1568 ± 16	2310 ± 40		783 ± 10	-0.03 ± 0.02		
136	Hamamatsu	ARAPUCA	760 ± 6	1587 ± 18	2423 ± 32	3185 ± 59	812 ± 7	-0.07 ± 0.01		
137	Hamamatsu	ARAPUCA	623 ± 4	1295 ± 6	1952 ± 12	2623 ± 19	665 ± 1	-0.06 ± 0.00		
138	Hamamatsu	ARAPUCA	668 ± 6	1380 ± 8	2124 ± 14	2914 ± 47	737 ± 10	-0.09 ± 0.03		
139	Hamamatsu	ARAPUCA	616 ± 5	1256 ± 6	1877 ± 16	2507 ± 22	631 ± 2	-0.02 ± 0.01		
140	Hamamatsu	ARAPUCA	609 ± 11	1268 ± 10	1932 ± 18	2667 ± 110	673 ± 10	-0.08 ± 0.04		
141	Hamamatsu	ARAPUCA	614 ± 56	1253 ± 23.2	1848 ± 28	2536 ± 30	628 ± 9	0.00 ± 0.03		
142	Hamamatsu	ARAPUCA	721 ± 13				721 ± 13			
143	Hamamatsu	ARAPUCA	744 ± 14				744 ± 14			
108	SensL-A1	Double-Shift	1393 ± 4	2786 ± 8	4158 ± 14		1387 ± 6	0.00 ± 0.01		
109	SensL-A1	Double-Shift	1421 ± 4	2845 ± 7	4223 ± 25		1418 ± 7	0.00 ± 0.01		
110	SensL-A1	Double-Shift	Dead Channel							
111	SensL-A1	Double-Shift	1364 ± 4	2773 ± 8	4143 ± 15		1398 ± 6	-0.02 ± 0.01		
112	SensL-A1	Dip-Coated	1392 ± 2	2815 ± 5	4248 ± 10		1425 ± 4	-0.02 ± 0.00		
113	SensL-A1	Dip-Coated	1394 ± 3	2844 ± 5	4274 ± 11		1446 ± 4	-0.04 ± 0.00		
114	SensL-A1	Dip-Coated	1395 ± 2	2822 ± 5	4228 ± 10		1421 ± 4	-0.02 ± 0.00		
115	SensL-A1	Dip-Coated	1415 ± 3	2863 ± 6	4264 ± 12		1436 ± 5	-0.01 ± 0.00		
116	SensL-A1	Double-Shift	1419 ± 8	2825 ± 12	4253 ± 59		1446 ± 13	-0.05 ± 0.01		
117	SensL-A1	Double-Shift	1382 ± 7	2841 ± 13	4247 ± 54		1470 ± 13	-0.07 ± 0.01		
118	SensL-A1	Double-Shift	1373 ± 6	2830 ± 12	4229 ± 57		1436 ± 13	-0.03 ± 0.01		
119	SensL-A1	Double-Shift	Dead Channel							
120	SensL-A1	Dip-Coated	1623 ± 2	3265 ± 5	4912 ± 12		1643 ± 4	-0.01 ± 0.00		
121	SensL-A1	Dip-Coated	1378 ± 2	2788 ± 5	4219 ± 9		1416 ± 4	-0.03 ± 0.00		
122	SensL-A1	Dip-Coated	1426 ± 3	2860 ± 5	4307 ± 10		1438 ± 4	-0.01 ± 0.00		
123	SensL-A1	Dip-Coated	1407 ± 3	2826 ± 6	4228 ± 10		1414 ± 4	0.00 ± 0.00		
124	SensL-A1	Double-Shift	1607 ± 3	3186 ± 3	4761 ± 3		1577 ± 2	0.02 ± 0.00		
125	SensL-A1	Double-Shift	1865 ± 3	3719 ± 3	5561 ± 2		1848 ± 2	0.01 ± 0.00		
126	SensL-A1	Double-Shift	1635 ± 4	3262 ± 5	4904 ± 4		1634 ± 3	0.00 ± 0.00		
127	SensL-A1	Double-Shift	1612 ± 4	3233 ± 4	4819 ± 3		1603 ± 2	0.01 ± 0.00		
128	SensL-C1	Dip-Coated	1400 ± 3	2816 ± 5	4224 ± 8		1413 ± 4	-0.01 ± 0.00		
129	SensL-C1	Dip-Coated	1393 ± 3	2801 ± 5	4202 ± 9		1406 ± 4	-0.01 ± 0.00		
130	SensL-C1	Dip-Coated	1393 ± 3	2824 ± 5	4206 ± 10		1418 ± 4	-0.02 ± 0.00		
131	SensL-C1	Dip-Coated	1433 ± 3	2850 ± 5	4234 ± 8		1405 ± 4	0.02 ± 0.00		

# All Calibrations (APA 4)

APA 4 Photon Sensor Calibration Values								
DAQ Channel	Sensor Type	Collector Type	1st Peak	2nd Peak	3rd Peak	4th Peak	Slope	Intercept
144	SensL-C1	Dip-Coated	1409 ± 3	2813 ± 2	4206 ± 2		1398 ± 1	0.01 ± 0.00
145	SensL-C1	Dip-Coated	1401 ± 2	2788 ± 2	4188 ± 2		1395 ± 1	0.00 ± 0.00
146	SensL-C1	Dip-Coated	1424 ± 3	2846 ± 2	4258 ± 2		1416 ± 2	0.01 ± 0.00
147	SensL-C1	Dip-Coated	1399 ± 2	2793 ± 2	4192 ± 2		1397 ± 1	0.00 ± 0.00
148	SensL-C1	Double-Shift	1373 ± 3	2775 ± 6	4187 ± 14		1404 ± 6	-0.02 ± 0.00
149	SensL-C1	Double-Shift	1403 ± 3	2854 ± 5	4244 ± 10		1432 ± 4	-0.02 ± 0.00
150	SensL-C1	Double-Shift	1420 ± 4	2849 ± 5	4278 ± 12		1428 ± 5	-0.01 ± 0.00
151	SensL-C1	Double-Shift	1363 ± 3	2782 ± 6	4199 ± 12		1418 ± 5	-0.04 ± 0.00
152	SensL-A1	Dip-Coated	1392 ± 2	2801 ± 3	4191 ± 6		1403 ± 3	-0.01 ± 0.00
153	SensL-A1	Dip-Coated	1416 ± 2	2854 ± 3	4279 ± 7		1434 ± 3	-0.01 ± 0.00
154	SensL-A1	Dip-Coated	1398 ± 2	2820 ± 3	4226 ± 6		1417 ± 2	-0.01 ± 0.00
155	SensL-A1	Dip-Coated	1372 ± 2	2787 ± 4	4213 ± 8		1418 ± 3	-0.03 ± 0.00
156	SensL-C1	Double-Shift	Dead Channel					
157	SensL-C1	Double-Shift	1413 ± 2	2829 ± 5	4256 ± 11		1419 ± 4	0.00 ± 0.00
158	SensL-C1	Double-Shift	1419 ± 3	2865 ± 5	4300 ± 11		1443 ± 4	-0.02 ± 0.00
159	SensL-C1	Double-Shift	1404 ± 3	2818 ± 5	4214 ± 14		1410 ± 5	0.00 ± 0.00
160	SensL-C1	Dip-Coated	Dead Channel					
161	SensL-C1	Dip-Coated	1377 ± 2	2814 ± 3	4226 ± 6		1430 ± 3	-0.04 ± 0.00
162	SensL-C1	Dip-Coated	1407 ± 2	2843 ± 3	4268 ± 7		1433 ± 3	-0.02 ± 0.00
163	SensL-C1	Dip-Coated	1389 ± 2	2815 ± 3	4219 ± 6		1419 ± 3	-0.02 ± 0.00
164	SensL-C1	Double-Shift	1451 ± 2	2876 ± 5	4280 ± 10		1419 ± 4	0.02 ± 0.00
165	SensL-C1	Double-Shift	1409 ± 2	2844 ± 4	4266 ± 8		1431 ± 3	-0.02 ± 0.00
166	SensL-C1	Double-Shift	1369 ± 2	2777 ± 4	4174 ± 8		1405 ± 3	-0.03 ± 0.00
167	SensL-C1	Double-Shift	1422 ± 3	2857 ± 5	4300 ± 9		1437 ± 4	-0.01 ± 0.00
168	SensL-C1	Dip-Coated	1381 ± 3	2813 ± 7	4201 ± 11		1417 ± 5	-0.02 ± 0.00
169	SensL-C1	Dip-Coated	1409 ± 3	2861 ± 7	4283 ± 12		1445 ± 5	-0.02 ± 0.00
170	SensL-C1	Dip-Coated	1400 ± 3	2840 ± 9	4268 ± 13		1437 ± 5	-0.03 ± 0.00
171	SensL-C1	Dip-Coated	1399 ± 3	2820 ± 7	4230 ± 11		1418 ± 5	-0.01 ± 0.00
172	SensL-C1	Double-Shift	1643 ± 3	3308 ± 6	4960 ± 14		1662 ± 5	-0.01 ± 0.00
173	SensL-C1	Double-Shift	1410 ± 3	2858 ± 6	4319 ± 16		1450 ± 5	-0.03 ± 0.00
174	SensL-C1	Double-Shift	1387 ± 3	2823 ± 6	4212 ± 13		1424 ± 5	-0.02 ± 0.00
175	SensL-C1	Double-Shift	1667 ± 3	3297 ± 6	4920 ± 18		1629 ± 6	0.02 ± 0.00
176	SensL-C1	Double-Shift	1823 ± 3	3649 ± 7	5431 ± 15		1815 ± 6	0.00 ± 0.00
177	SensL-C1	Double-Shift	1409 ± 3	2840 ± 5	4242 ± 10		1424 ± 4	-0.01 ± 0.00
178	SensL-C1	Double-Shift	1371 ± 3	2784 ± 5	4145 ± 13		1402 ± 5	-0.02 ± 0.00
179	SensL-C1	Double-Shift	1409 ± 3	2846 ± 6	4246 ± 13		1428 ± 5	-0.01 ± 0.00
180	SensL-C1	Dip-Coated	1632 ± 2	3270 ± 4	4864 ± 8		1626 ± 3	0.00 ± 0.00
181	SensL-C1	Dip-Coated	1425 ± 2	2880 ± 4	4287 ± 8		1442 ± 3	-0.01 ± 0.00
182	SensL-C1	Dip-Coated	1374 ± 2	2787 ± 4	4200 ± 6		1413 ± 3	-0.03 ± 0.00
183	SensL-C1	Dip-Coated	1412 ± 2	2837 ± 5	4232 ± 10		1417 ± 4	0.00 ± 0.00

# All Calibrations (APA 5)

APA 5 Photon Sensor Calibration Values								
DAQ Channel	Sensor Type	Collector Type	1st Peak	2nd Peak	3rd Peak	4th Peak	Slope	Intercept
216	Hamamatsu	Dip-Coated	1046 ± 3	1954 ± 14			908 ± 14	0.15 ± 0.02
217	Hamamatsu	Dip-Coated	1060 ± 4	2010 ± 11			950 ± 12	0.12 ± 0.01
218	Hamamatsu	Dip-Coated	1059 ± 5	1950 ± 16			891 ± 16	0.19 ± 0.02
219	Hamamatsu	Dip-Coated	1037 ± 3	1913 ± 33			876 ± 33	0.19 ± 0.04
220	Hamamatsu	Double-Shift	1038 ± 3	1928 ± 20			890 ± 21	0.17 ± 0.02
221	Hamamatsu	Double-Shift	1067 ± 4	1939 ± 30			871 ± 31	0.22 ± 0.04
222	Hamamatsu	Double-Shift	1048 ± 4	1924 ± 20			876 ± 20	0.20 ± 0.02
223	Hamamatsu	Double-Shift	1038 ± 3	1946 ± 20			908 ± 17	0.14 ± 0.02
224	Hamamatsu	Dip-Coated	1126 ± 29	2234 ± 92			1107 ± 97	0.02 ± 0.10
225	Hamamatsu	Dip-Coated		2196 ± 74			1098 ± 37	
226	Hamamatsu	Dip-Coated		2262 ± 248			1131 ± 124	
227	Hamamatsu	Dip-Coated	1164 ± 37	2110 ± 25			946 ± 45	0.23 ± 0.08
228	Hamamatsu	Double-Shift	1097 ± 44	2083 ± 23			986 ± 49	0.11 ± 0.09
229	Hamamatsu	Double-Shift	1267 ± 477				1267 ± 477	
230	Hamamatsu	Double-Shift	1080 ± 29	2097 ± 25			1017 ± 38	0.06 ± 0.06
231	Hamamatsu	Double-Shift	1083 ± 26	2130 ± 36			1046 ± 44	0.04 ± 0.06
192	SensL-C1	Dip-Coated	1407 ± 2	2838 ± 3	4276 ± 6		1433 ± 3	-0.02 ± 0.00
193	SensL-C1	Dip-Coated	1420 ± 2	2851 ± 3	4262 ± 7		1426 ± 3	0.00 ± 0.00
194	SensL-C1	Dip-Coated	1402 ± 2	2831 ± 3	4224 ± 6		1418 ± 3	-0.01 ± 0.00
195	SensL-C1	Dip-Coated	1382 ± 2	2804 ± 4	4215 ± 6		1418 ± 3	-0.03 ± 0.00
232	Hamamatsu	Double-Shift	1012 ± 4				1012 ± 4	
233	Hamamatsu	Double-Shift	1014 ± 4				1014 ± 4	
234	Hamamatsu	Double-Shift	997 ± 3				997 ± 3	
235	Hamamatsu	Double-Shift	1020 ± 4				1020 ± 4	
196	SensL-C1	Dip-Coated	1407 ± 2	2894 ± 4	4310 ± 8		1436 ± 3	0.01 ± 0.00
197	SensL-C1	Dip-Coated	1420 ± 2	2879 ± 4	4290 ± 9		1427 ± 3	0.01 ± 0.00
198	SensL-C1	Dip-Coated	1402 ± 2	2803 ± 3	4200 ± 7		1419 ± 3	-0.03 ± 0.00
199	SensL-C1	Dip-Coated	1382 ± 2	2853 ± 4	4257 ± 8		1430 ± 3	-0.01 ± 0.00
200	SensL-C1	Double-Shift	1417 ± 3	2866 ± 6	4281 ± 12		1440 ± 5	-0.01 ± 0.00
201	SensL-C1	Double-Shift	1639 ± 3	3277 ± 5	4894 ± 14		1634 ± 5	0.00 ± 0.00
202	SensL-C1	Double-Shift	1427 ± 3	2867 ± 6	4293 ± 13		1436 ± 5	-0.01 ± 0.00
203	SensL-C1	Double-Shift	1381 ± 3	2814 ± 6	4232 ± 18		1431 ± 6	-0.03 ± 0.00
236	Hamamatsu	Dip-Coated	1029 ± 3				1029 ± 3	
237	Hamamatsu	Dip-Coated	996 ± 3				996 ± 3	
238	Hamamatsu	Dip-Coated	992 ± 3				992 ± 3	
239	Hamamatsu	Dip-Coated	1019 ± 3				1019 ± 3	
204	SensL-C1	Double-Shift	1412 ± 3	2849 ± 6	4297 ± 22		1439 ± 6	-0.02 ± 0.01
205	SensL-C1	Double-Shift	1448 ± 3	2928 ± 6	4344 ± 19		1469 ± 6	-0.01 ± 0.01
206	SensL-C1	Double-Shift	1436 ± 3	2905 ± 7	4322 ± 13		1455 ± 5	-0.01 ± 0.00
207	SensL-C1	Double-Shift	1417 ± 3	2856 ± 7	4243 ± 19		1429 ± 6	-0.01 ± 0.01

# All Calibrations (APA 6)

APA 6 Photon Sensor Calibration Values								
DAQ Channel	Sensor Type	Collector Type	1st Peak	2nd Peak	3rd Peak	4th Peak	Slope	Intercept
240	Hamamatsu	Dip-Coated	1056 ± 7	2001 ± 18			945 ± 19	0.12 ± 0.02
241	Hamamatsu	Dip-Coated	1085 ± 10	2062 ± 20			977 ± 23	0.11 ± 0.03
242	Hamamatsu	Dip-Coated	1125 ± 15	2115 ± 33			990 ± 36	0.14 ± 0.04
243	Hamamatsu	Dip-Coated	1101 ± 11	2025 ± 12			924 ± 16	0.19 ± 0.03
244	Hamamatsu	Double-Shift	1042 ± 6	2005 ± 21			963 ± 22	0.08 ± 0.02
245	Hamamatsu	Double-Shift	1064 ± 8	2047 ± 29			983 ± 30	0.08 ± 0.03
246	Hamamatsu	Double-Shift	1107 ± 11	2087 ± 25			980 ± 27	0.13 ± 0.03
247	Hamamatsu	Double-Shift	1085 ± 213	2059 ± 27			974 ± 30	0.11 ± 0.04
248	Hamamatsu	Dip-Coated	1013 ± 3				1013 ± 3	
249	Hamamatsu	Dip-Coated	1038 ± 3				1038 ± 3	
250	Hamamatsu	Dip-Coated	1023 ± 3				1023 ± 3	
251	Hamamatsu	Dip-Coated	1083 ± 5				1083 ± 5	
252	Hamamatsu	Double-Shift	1017 ± 4				1017 ± 4	
253	Hamamatsu	Double-Shift	1023 ± 4				1023 ± 4	
254	Hamamatsu	Double-Shift	987 ± 4				987 ± 4	
255	Hamamatsu	Double-Shift	973 ± 4				973 ± 4	
256	Hamamatsu	Dip-Coated	960 ± 3				960 ± 3	
257	Hamamatsu	Dip-Coated	993 ± 3				993 ± 3	
258	Hamamatsu	Dip-Coated	1021 ± 3				1021 ± 3	
259	Hamamatsu	Dip-Coated	992 ± 3				992 ± 3	
264	Hamamatsu	ARAPUCA	724 ± 5	1478 ± 6	2231 ± 13	3013 ± 19	758 ± 4	-0.04 ± 0.01
265	Hamamatsu	ARAPUCA	753 ± 6	1530 ± 9	2317 ± 13	3108 ± 30	780 ± 3	-0.03 ± 0.01
266	Hamamatsu	ARAPUCA	721 ± 5	1488 ± 7	2298 ± 9	3048 ± 13	772 ± 6	-0.05 ± 0.02
267	Hamamatsu	ARAPUCA	618 ± 9	1242 ± 9	1882 ± 16	2507 ± 12	628 ± 2	-0.01 ± 0.01
268	Hamamatsu	ARAPUCA	729 ± 16	1576 ± 35	2368 ± 20	3171 ± 23	804 ± 7	-0.06 ± 0.02
269	Hamamatsu	ARAPUCA	587 ± 5	1237 ± 6	1890 ± 8	2495 ± 7	637 ± 5	-0.06 ± 0.02
270	Hamamatsu	ARAPUCA	649 ± 6	1307 ± 8	1966 ± 7	2653 ± 12	668 ± 3	-0.04 ± 0.01
271	Hamamatsu	ARAPUCA	735 ± 11	1461 ± 9	2211 ± 9	2944 ± 15	738 ± 2	-0.01 ± 0.01
272	Hamamatsu	ARAPUCA	623 ± 12	1248 ± 29	1870 ± 15	2486 ± 26	638 ± 10	-0.08 ± 0.04
273	Hamamatsu	ARAPUCA	709 ± 66	1463 ± 20	2265 ± 36	3079 ± 93	755 ± 22	-0.05 ± 0.04
274	Hamamatsu	ARAPUCA	709 ± 11				709 ± 11	
275	Hamamatsu	ARAPUCA	756 ± 7	1589 ± 10	2435 ± 14.2	3259 ± 13	831 ± 3	-0.08 ± 0.01
260	Hamamatsu	Dip-Coated	1038 ± 4				1038 ± 4	
261	Hamamatsu	Dip-Coated	1010 ± 3				1010 ± 3	
262	Hamamatsu	Dip-Coated	1015 ± 3				1015 ± 3	
263	Hamamatsu	Dip-Coated	1068 ± 6				1068 ± 6	
276	Hamamatsu	Double-Shift	1003 ± 4				1003 ± 4	
277	Hamamatsu	Double-Shift	987 ± 4				987 ± 4	
278	Hamamatsu	Double-Shift	1009 ± 5				1009 ± 5	
279	Hamamatsu	Double-Shift	1022 ± 6				1022 ± 6	
280	Hamamatsu	Dip-Coated	1008 ± 4				1008 ± 4	
281	Hamamatsu	Dip-Coated	1032 ± 4				1032 ± 4	
282	Hamamatsu	Dip-Coated	981 ± 3				981 ± 3	
283	Hamamatsu	Dip-Coated	1045 ± 4				1045 ± 4	
284	Hamamatsu	Double-Shift	987 ± 4				987 ± 4	
285	Hamamatsu	Double-Shift	992 ± 5				992 ± 5	
286	Hamamatsu	Double-Shift	1009 ± 5				1009 ± 5	
287	Hamamatsu	Double-Shift	989 ± 4				989 ± 4	

# Conclusions

- Calibrations are at a good stopping point however additional DCM runs might be useful for Poissonian distribution calibration method
- Improvements can be made for Hamamatsu Bars (please someone do it better)
- A version of these calibrations are in the Reco code already however another update is coming (with documentation of where and how to change things)
- Onto timing and CRT/CTB flash matching!