ECAL results from November 2015 test beam

PADME ECAL meeting

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14 Jan 2016

Test beam summary

Date: 16-30 November 2015

To test

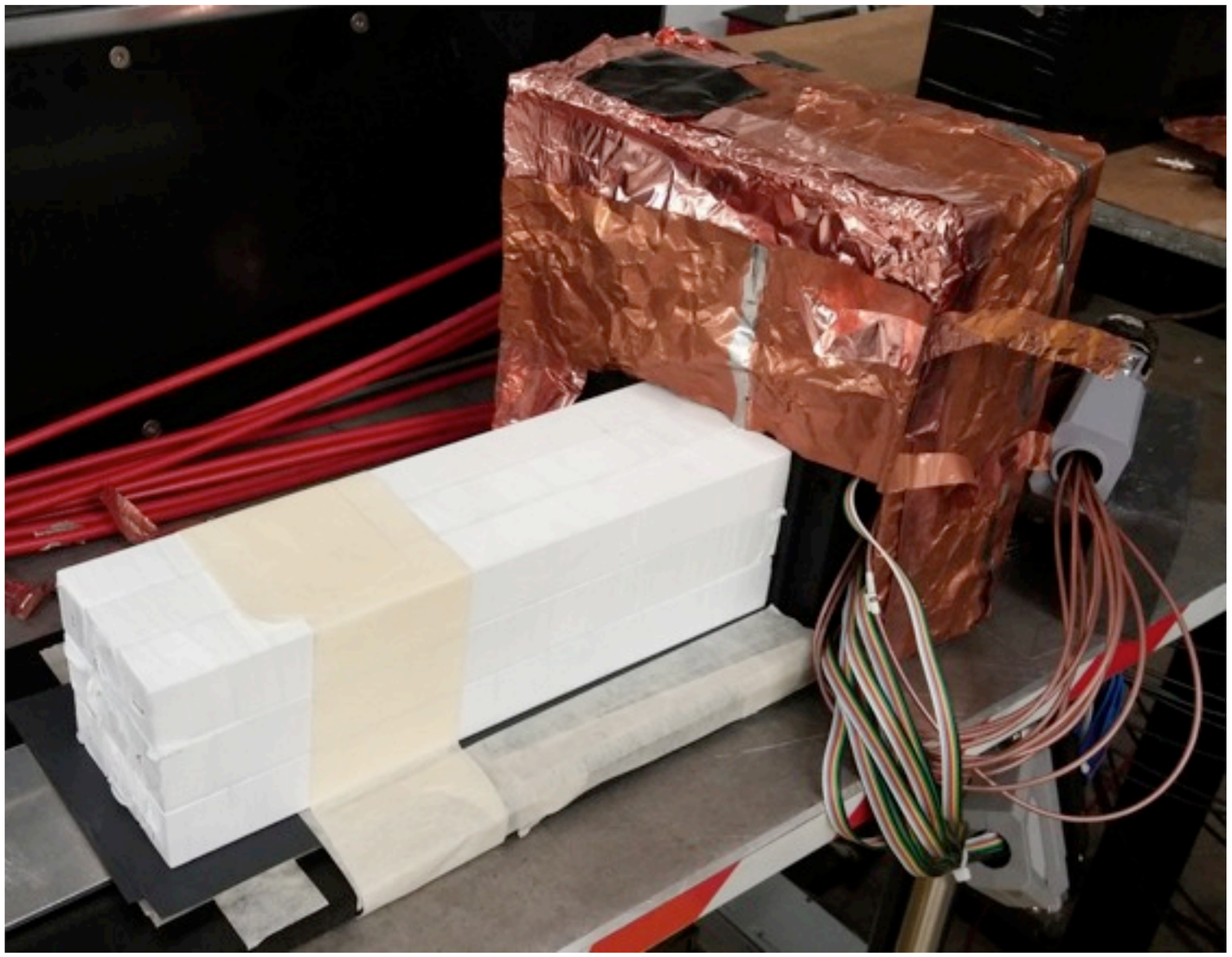
- Calorimeter: 2x 9 BGO crystals (APD and PMT)
- Active target: 2x2cm 50µm thick diamond with 19 1mm horizontal and vertical "sensitive" strips

Study performed with e^+ produced by e^+ or e^- impinging on a target. Depending on the primary beam, secondary e^+ shows a little different behavior.

Runs summary

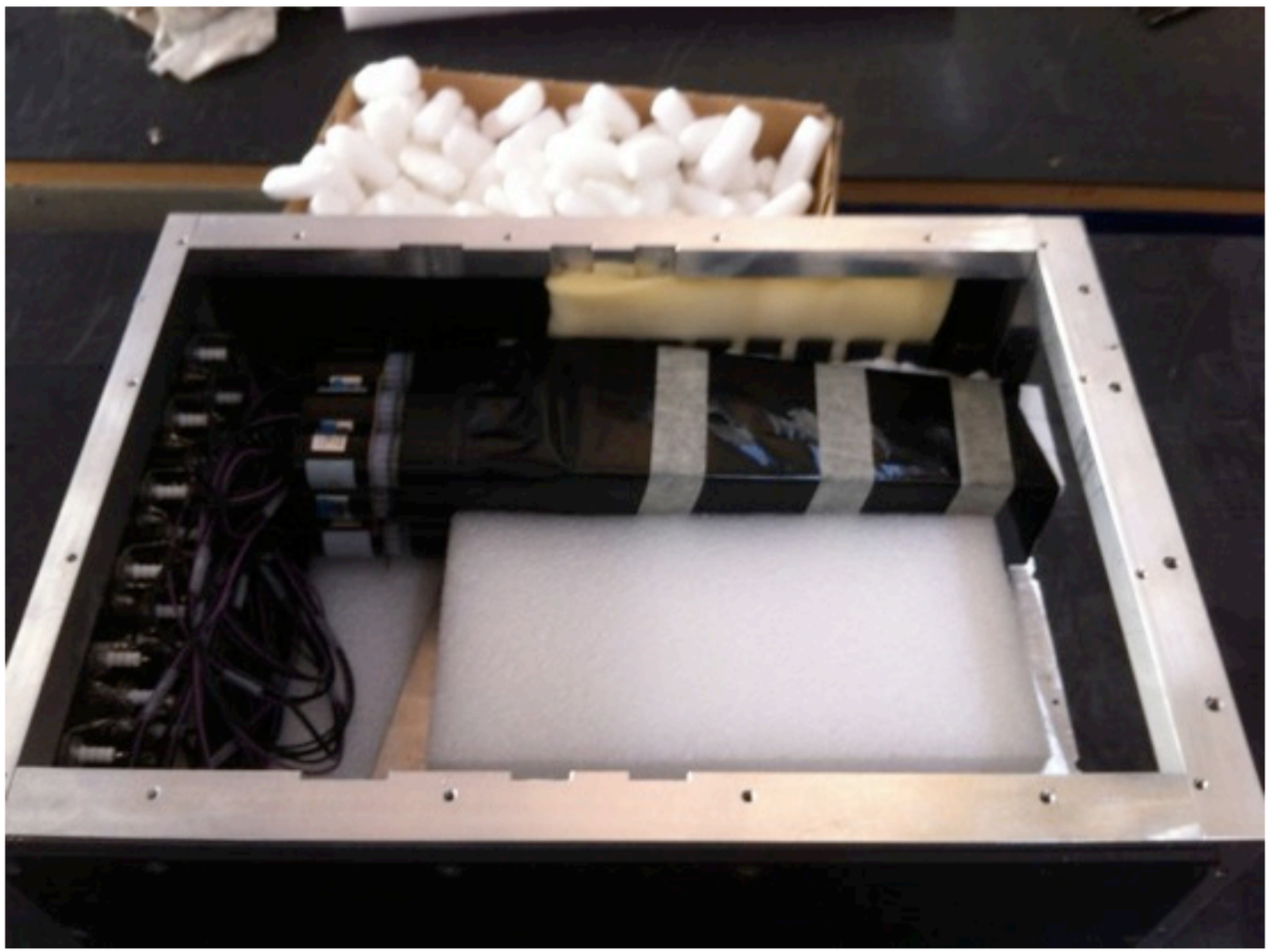
PMT		APD	
E [MeV]	# run	E [MeV]	# run
150	304	150	313
297	305	295.6	311
431	302	448	312
range [V] [-1,0]		range [V] [0,1]	
channels [0,9]		channels [16,25]	
board 0		board 0	

APD setup



- $1\times1 cm^2$ Hamamatsu S8664-1010 Si APD
- 9 $2\times2\times22 cm^3$ L3 BGO crystals (cut and polished)
- teflon wrapping
- not stable and very homemade structure (e.g. BGO are leaning against the APD faces)
- APD equalized gains =200

PMT setup

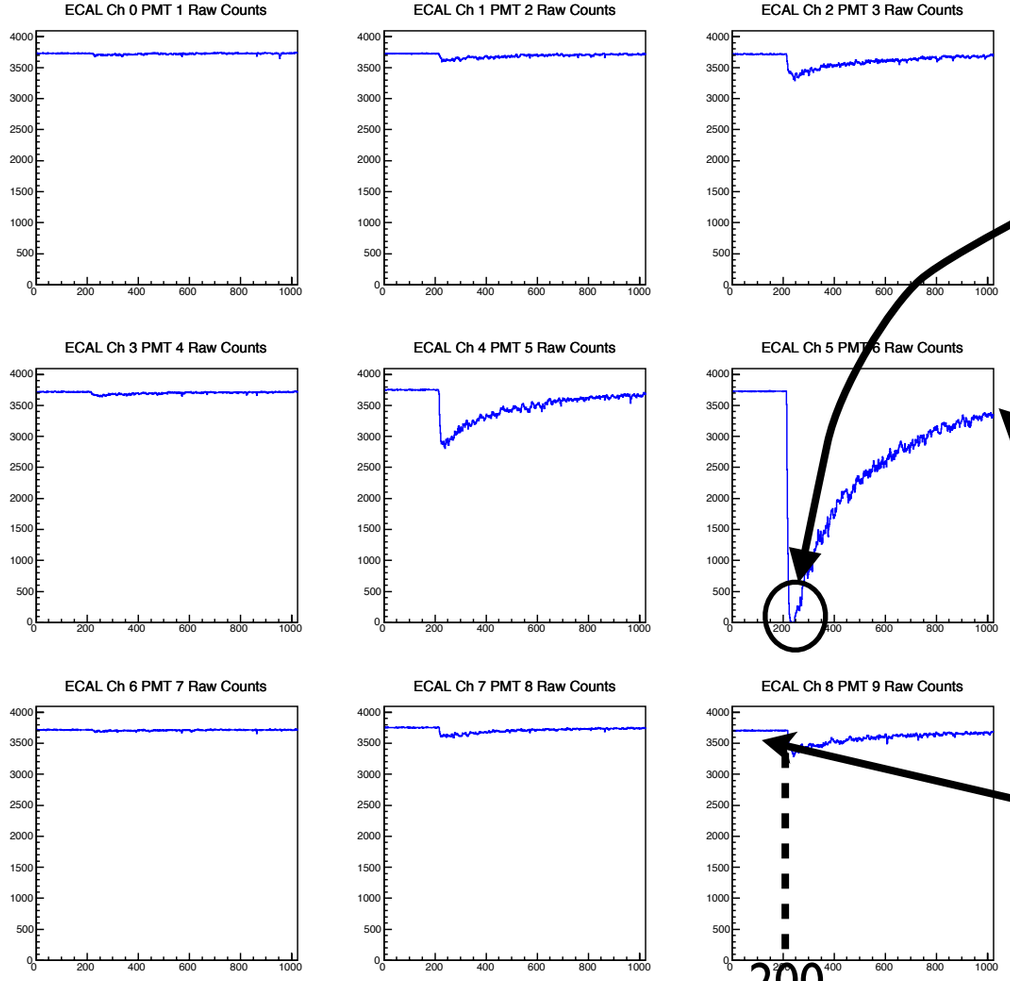


- 1” Hamamatsu R22-38 PMT
- 9 truncated pyramid original L3 BGO crystals (24cm length, 2.2×2.2cm^2 small face, 3×3cm^2 large face)
- teflon painting
- stable structure (BGO held to PMT with scotch tape, all in a solid box)
- PMT gains ≃10^5 (central one ≃20% smaller)

Raw signals

Signals registered with a V1742 CAEN board:

- 1024 samples
- 1GHz sampling frequency (1ms window)
- 1V full scale (PMT ↘: [-1,0]V, APD ↗: [-0.5,0.5]V)
- 12-bit resolution (4096 counts, 0.24mV/count)



Example of a non-centered and saturated event (PMT 431MeV)

y-scale: [0,4096]counts

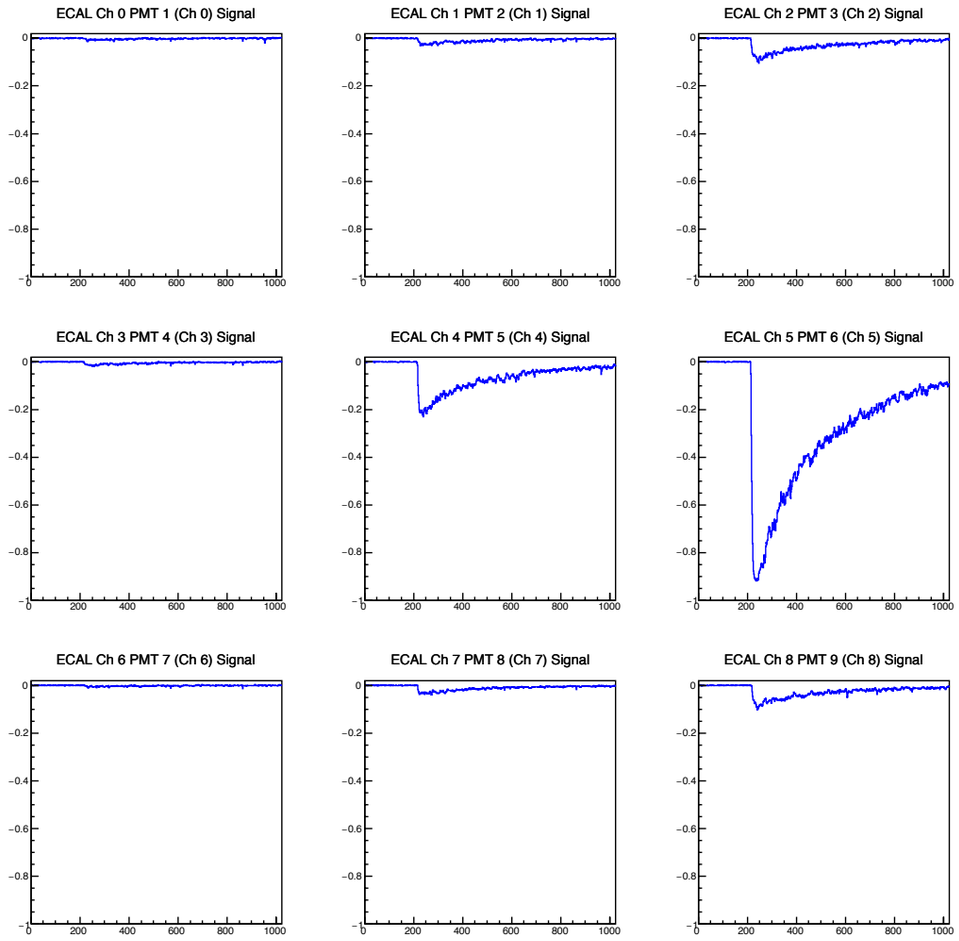
Not complete recover (theoretically visible starting from 8MeV)

average baseline (avg) evaluated w/ the firsts 70 samples

mV signals

Counts to mV:

signal(mV) = (signal(counts)-avg)/4096



Same event of previous slide

y-scale: [-1,0.02]V

(to accommodate the baseline oscillations around 0)

mV signal to charge:

To pass from C to pC ↓

$$Q(pC) = \sum weight \times signal(mV) \times 50(Ohm) \times 10^{-9}(s)/10^{-12}$$

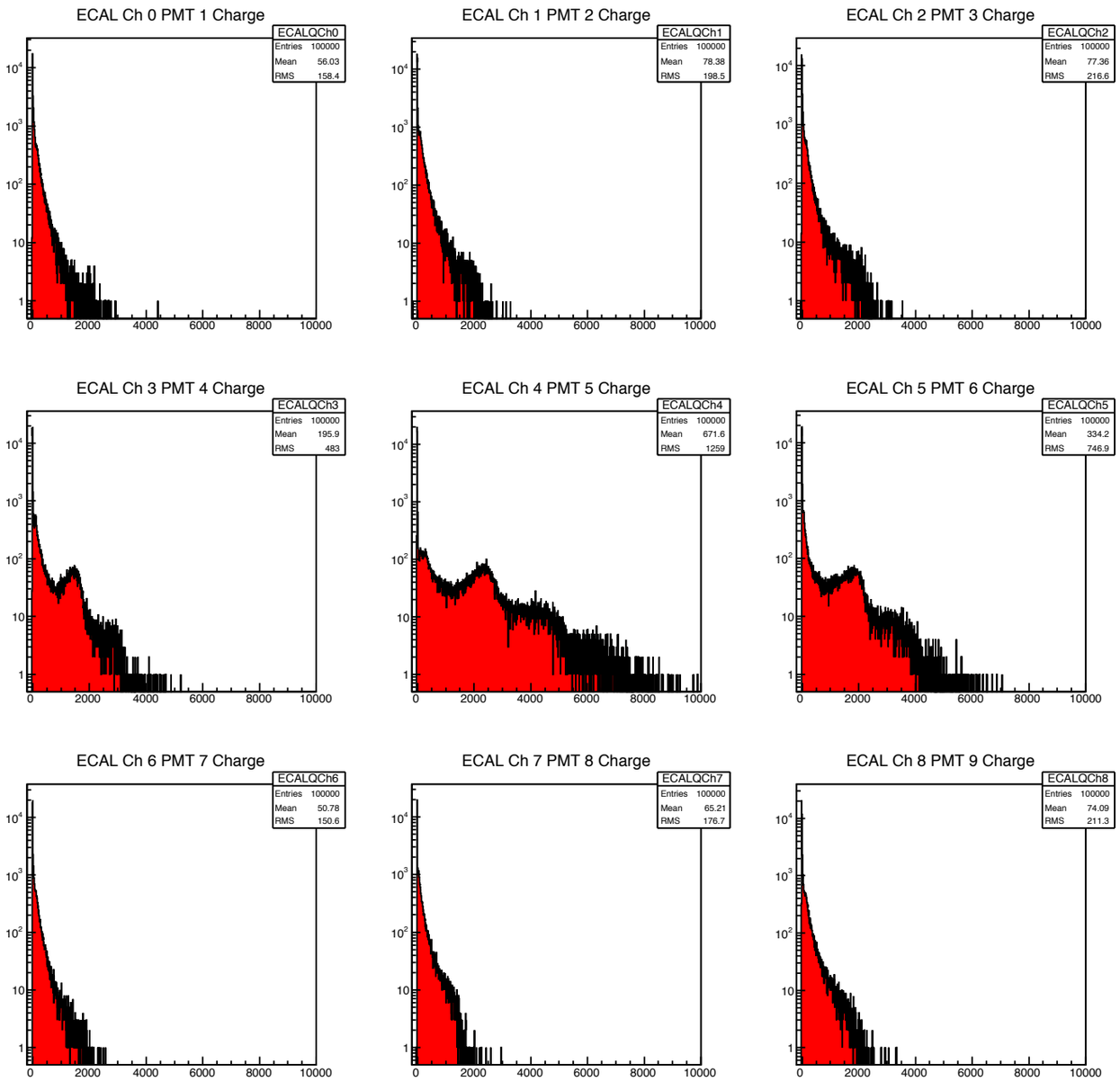
weight(Central channel PMT) = 1.21

weight(all other channels) = 1

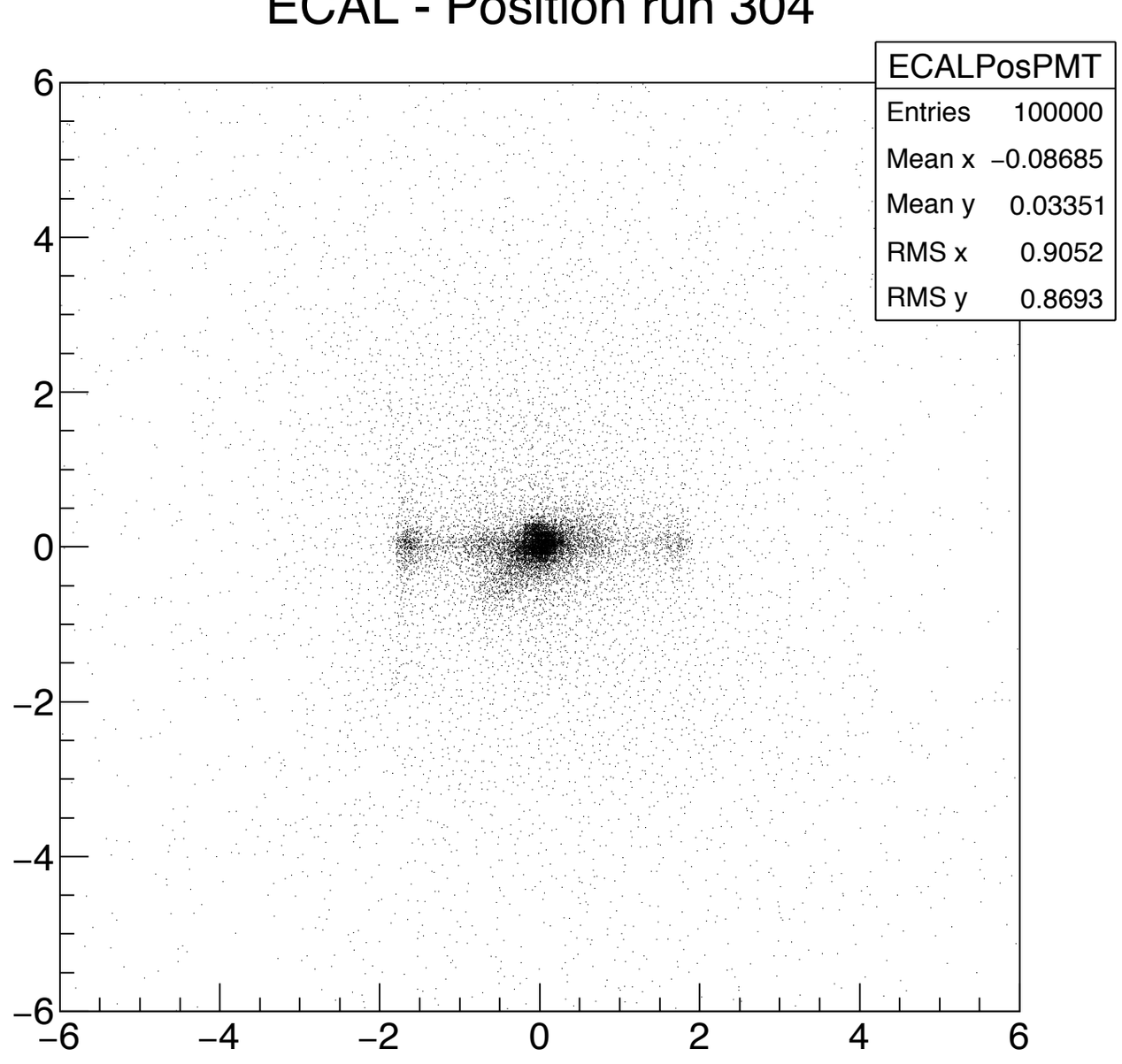
PMT run 304 (1)

E = 150MeV

Single channel spectra



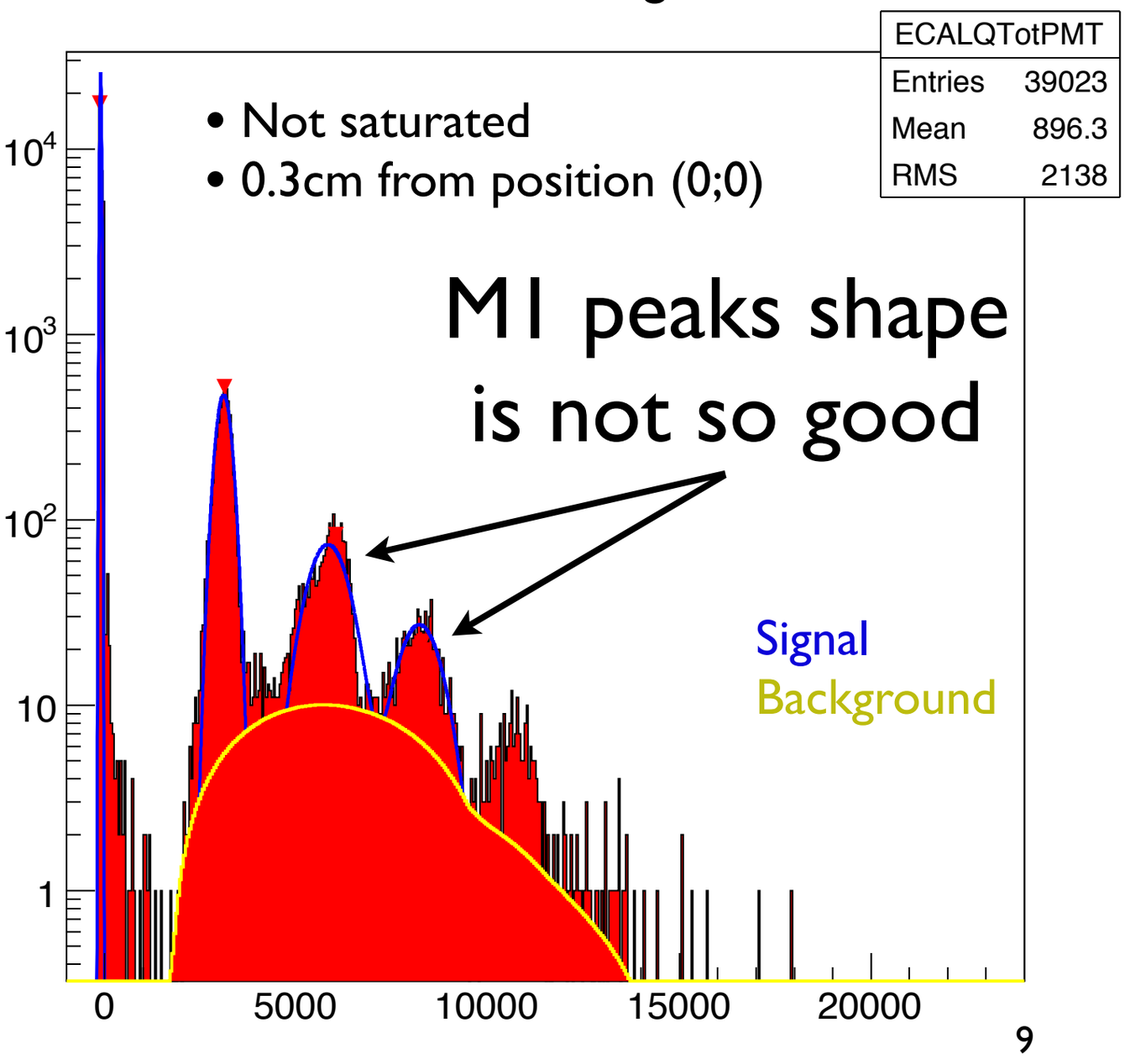
Interaction position



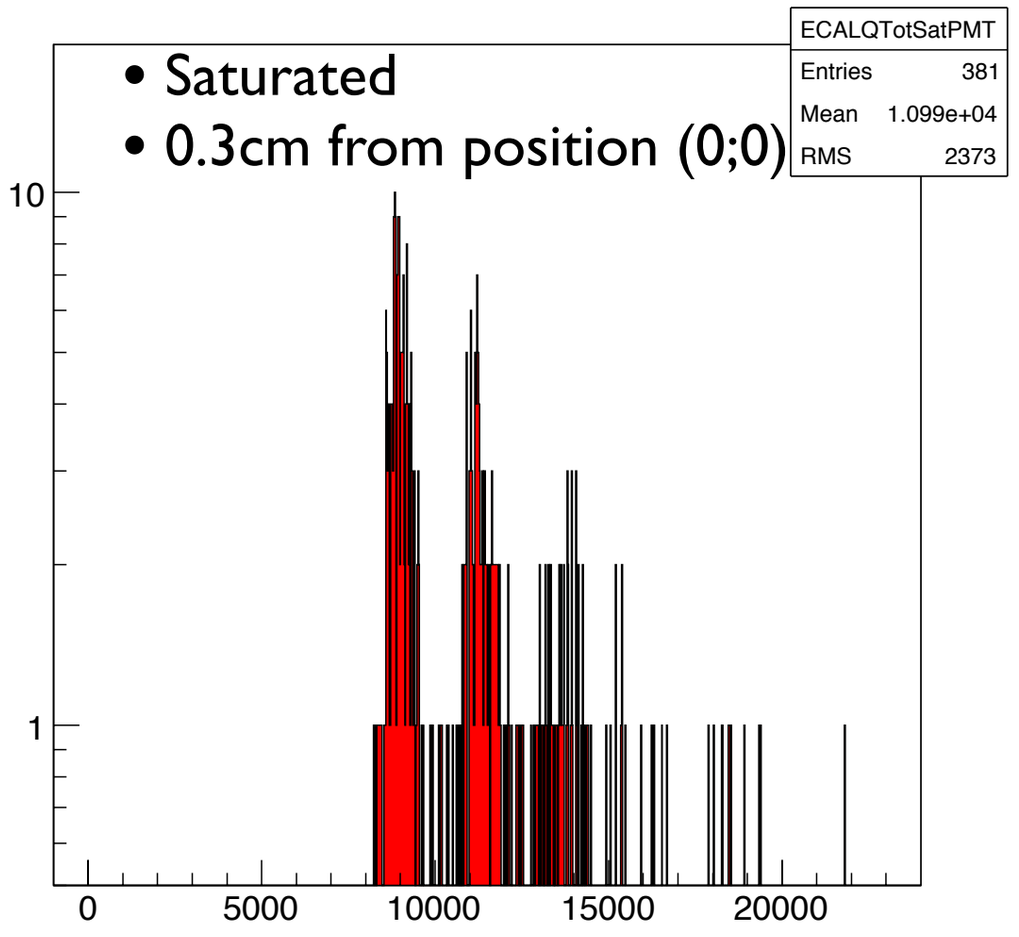
PMT run 304 (2)

E = 150MeV

Charge spectrum



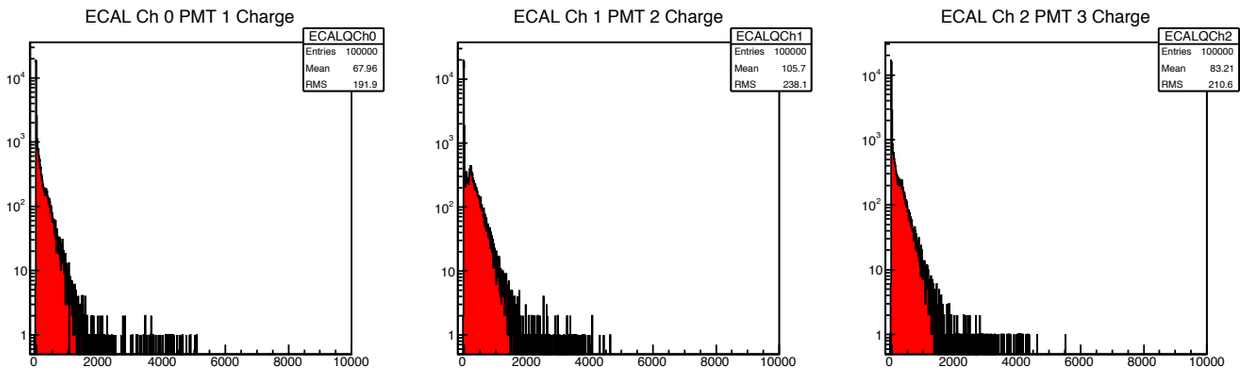
Saturated charge spectrum



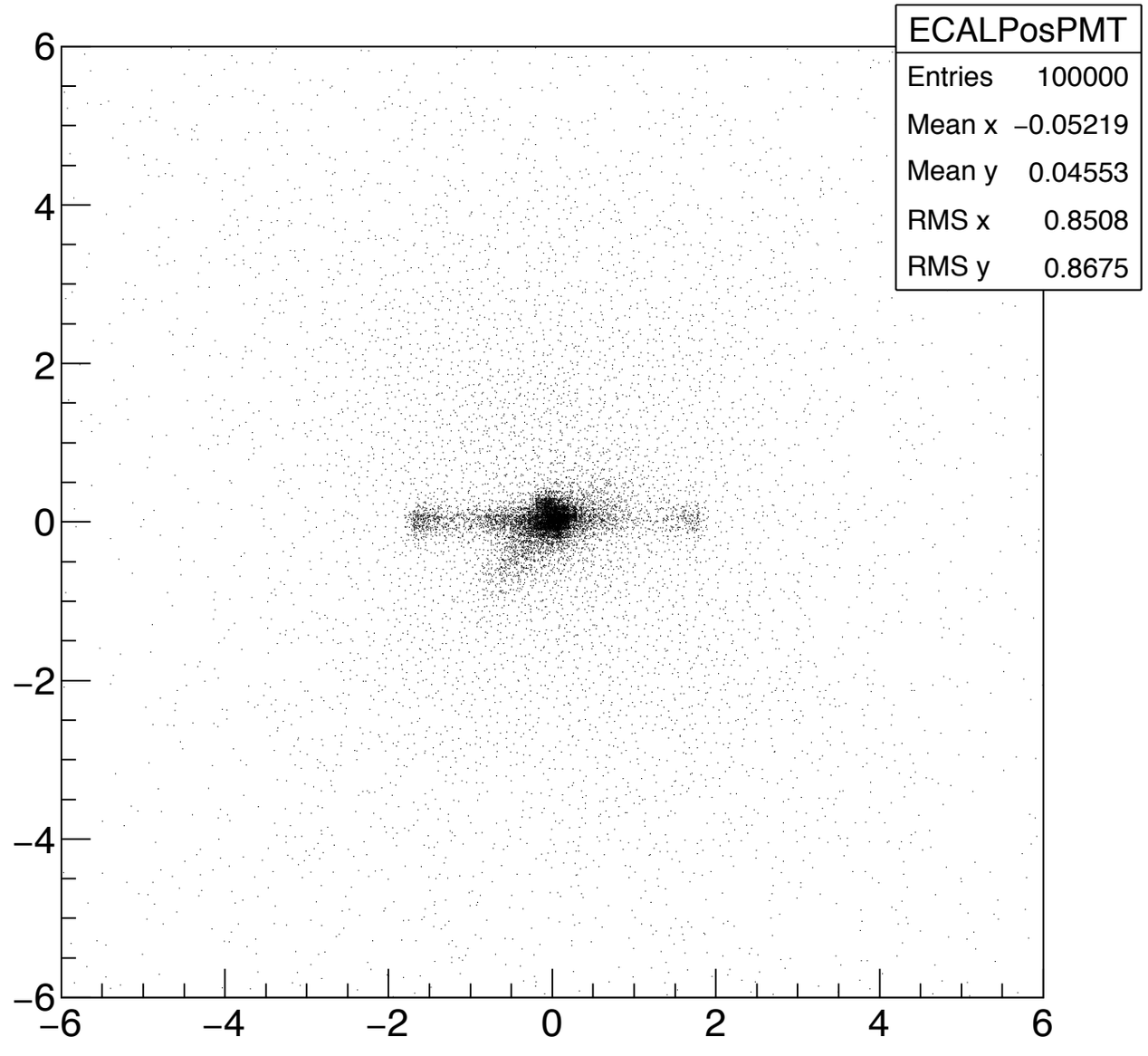
PMT run 305 (1)

E = 297MeV

Single channel spectra



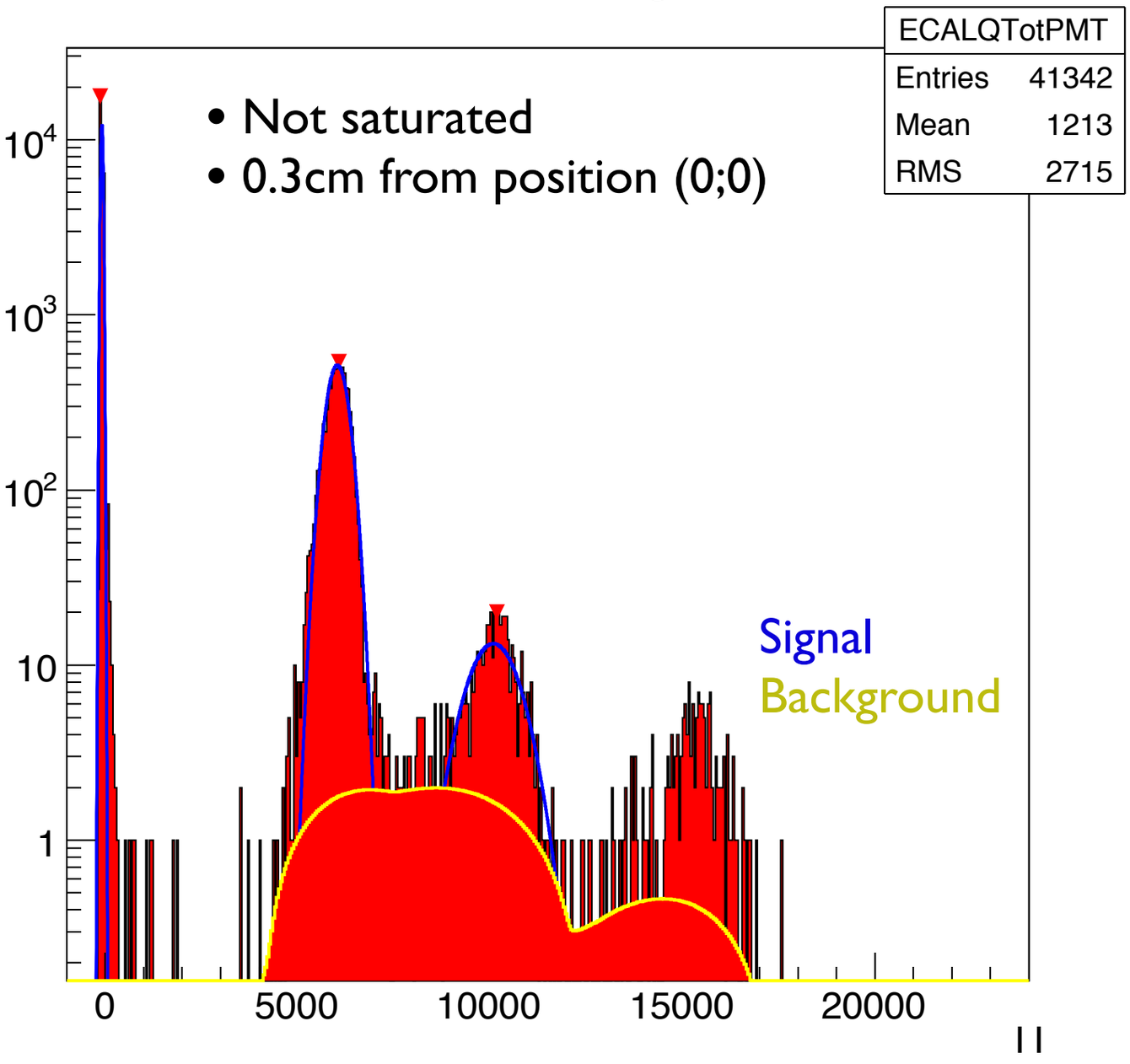
Interaction position



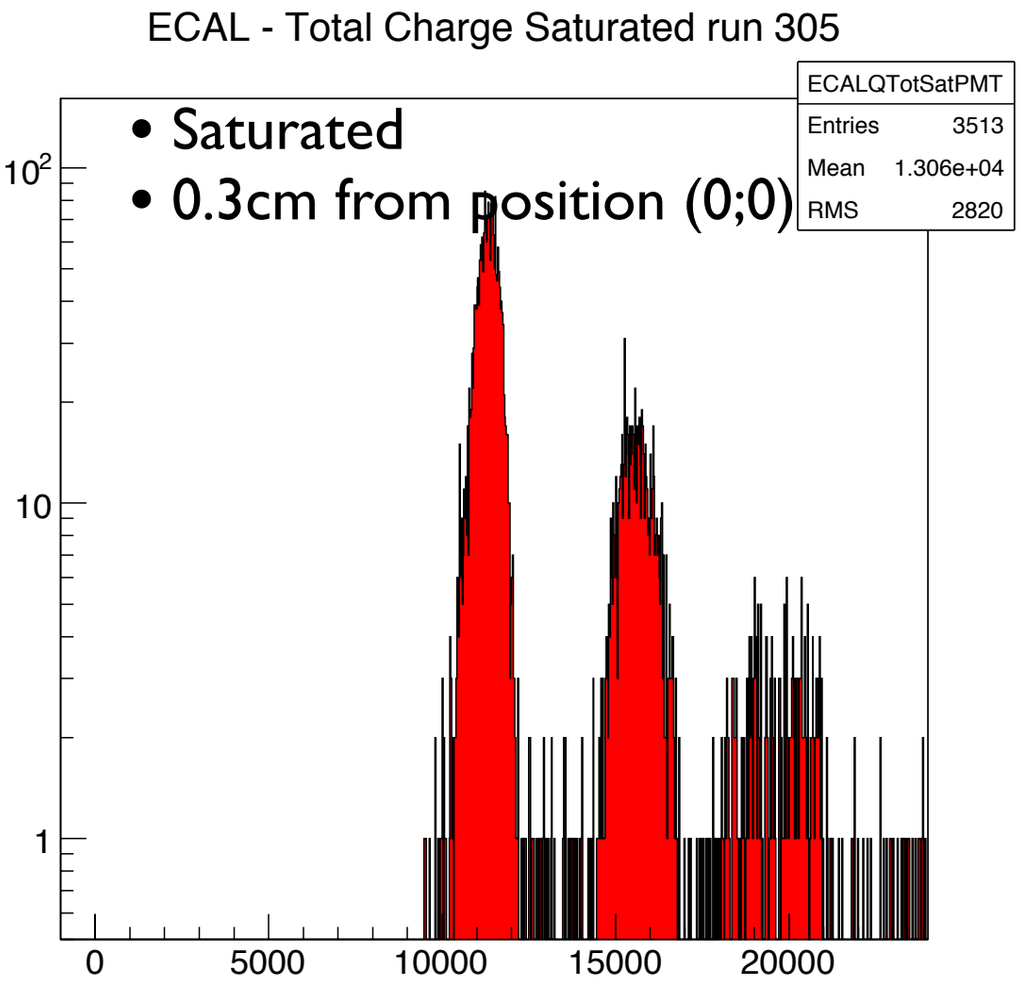
PMT run 305 (2)

E = 297MeV

Charge spectrum



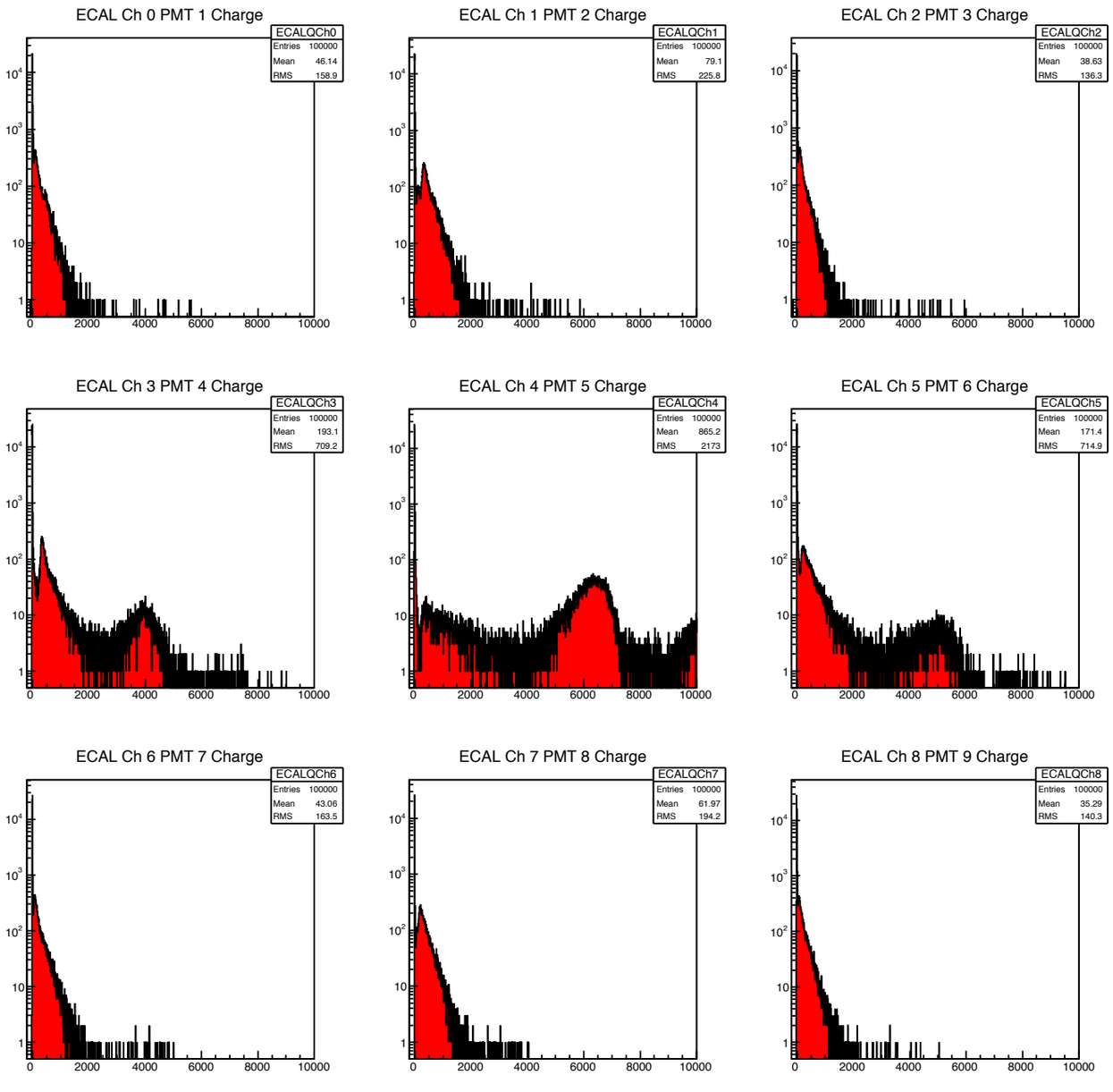
Saturated charge spectrum



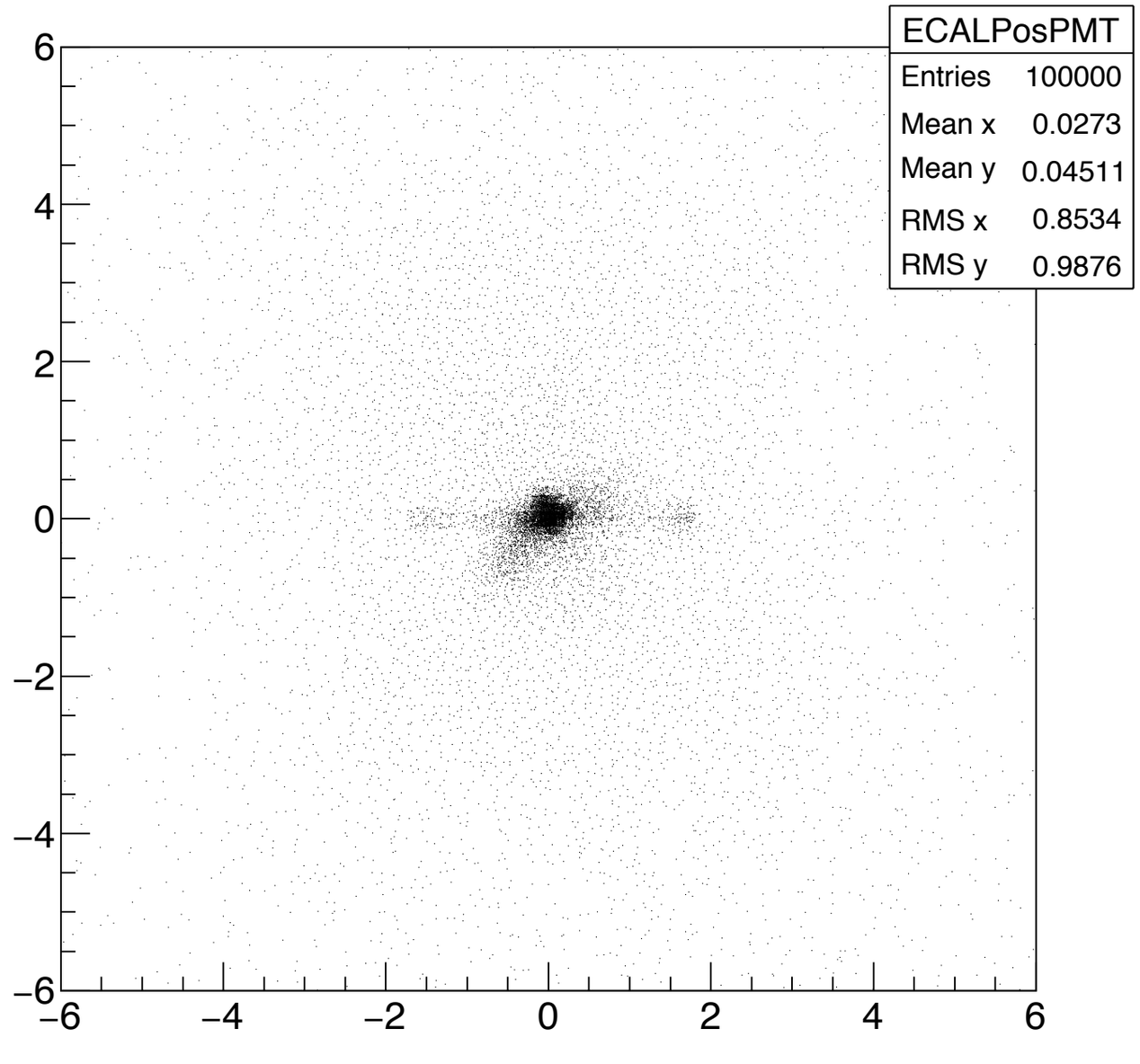
PMT run 302 (1)

E = 431MeV

Single channel spectra



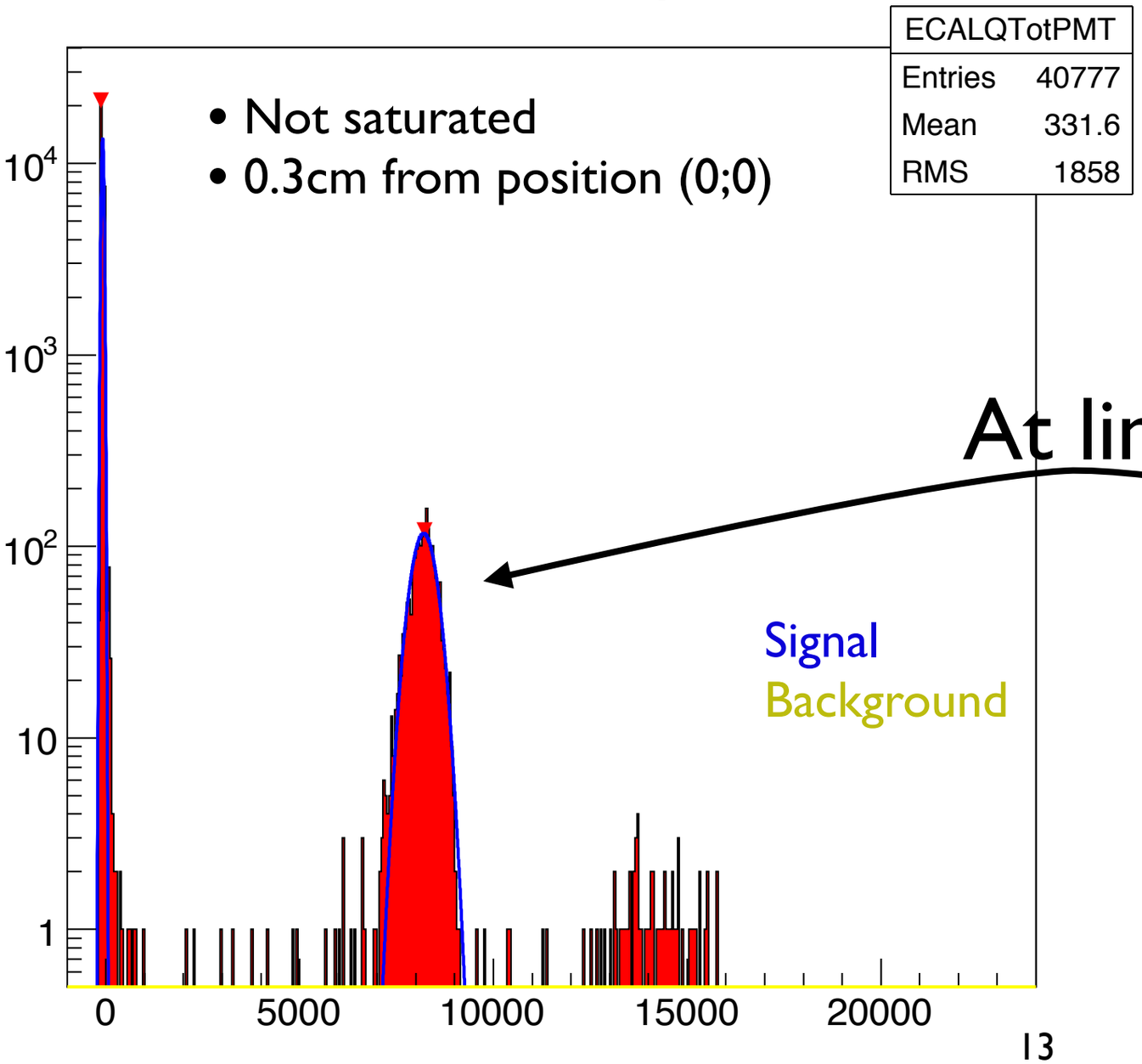
Interaction position



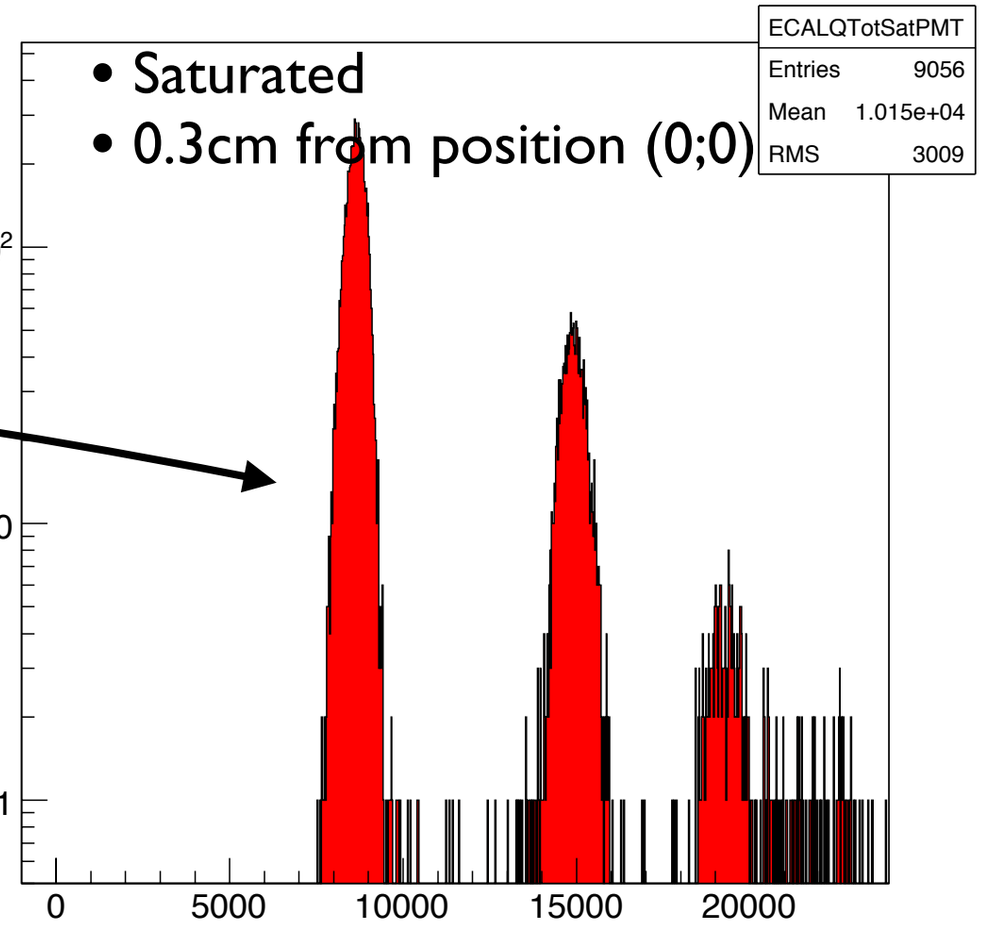
PMT run 302 (2)

E = 431MeV

Charge spectrum



Saturated charge spectrum

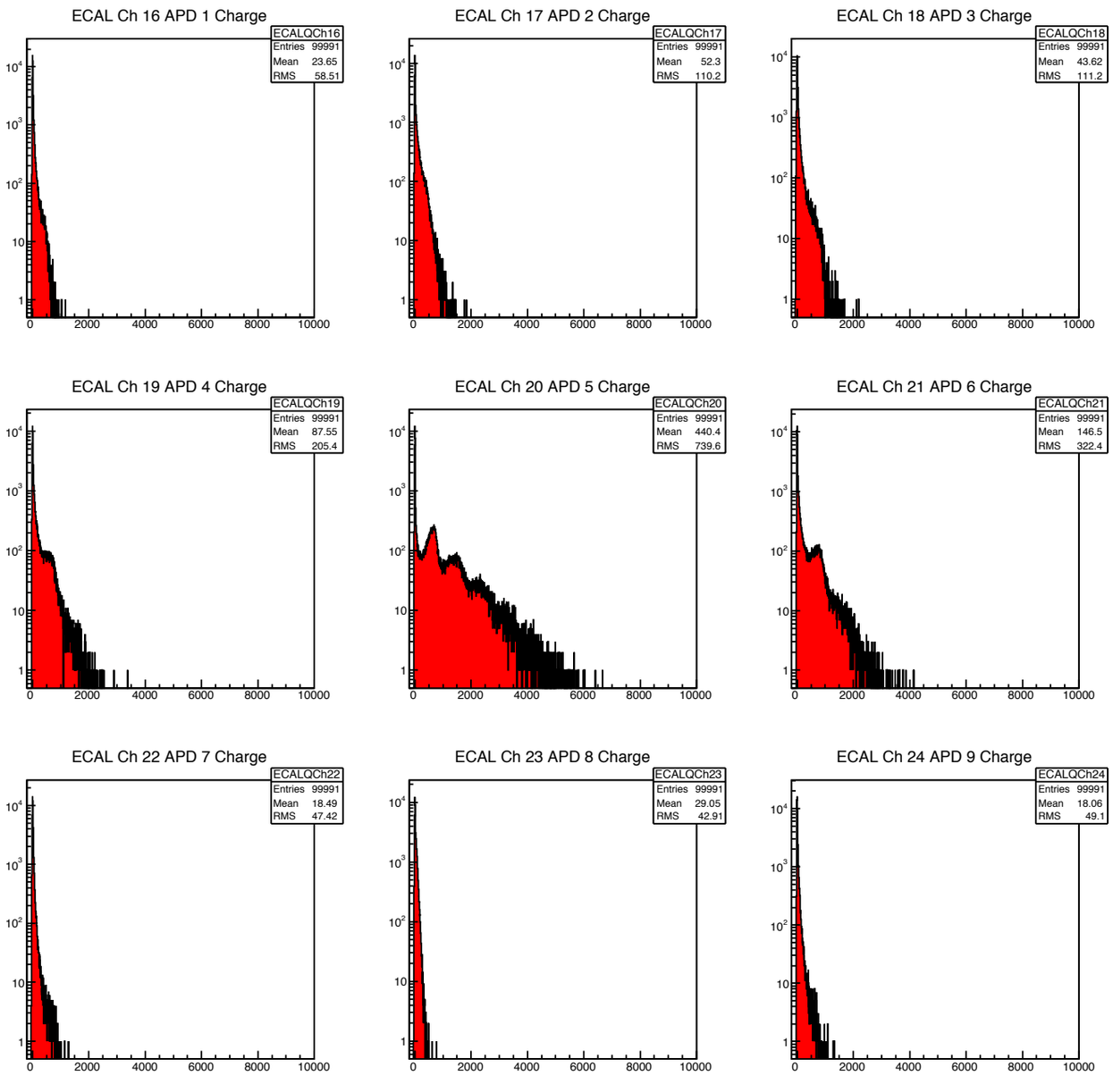


At limit!

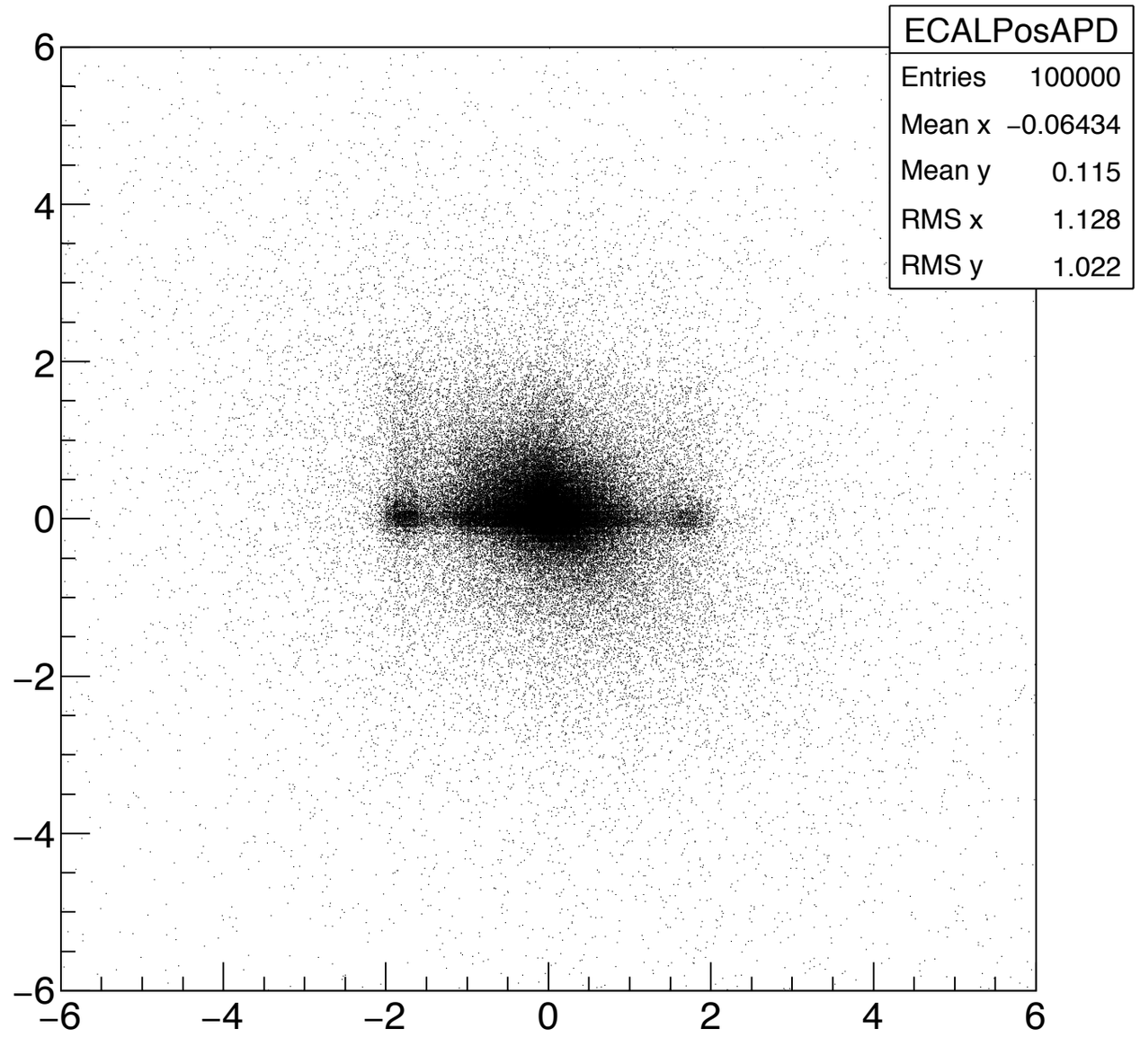
APD run 313 (1)

E = 150MeV

Single channel spectra



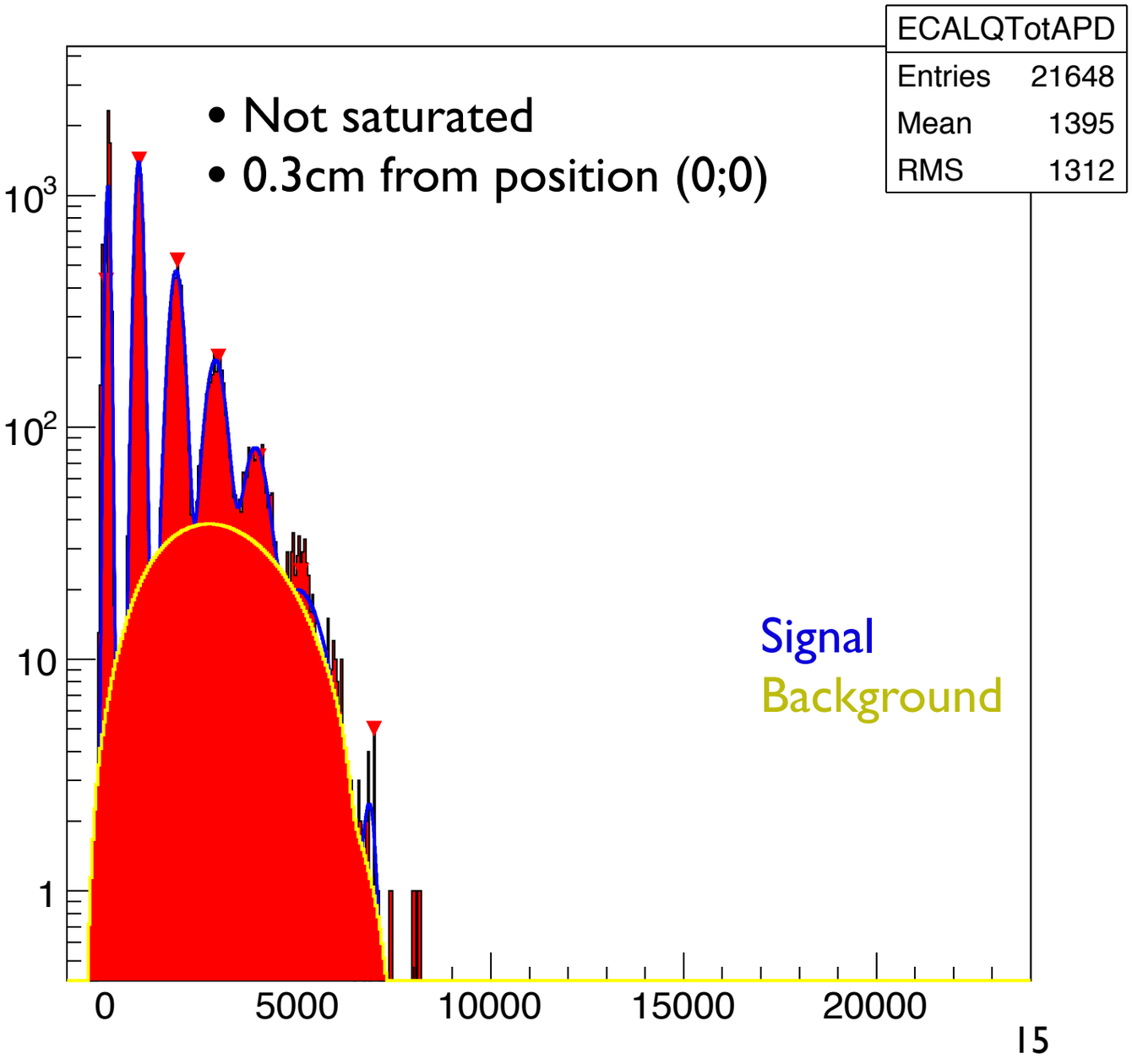
Interaction position



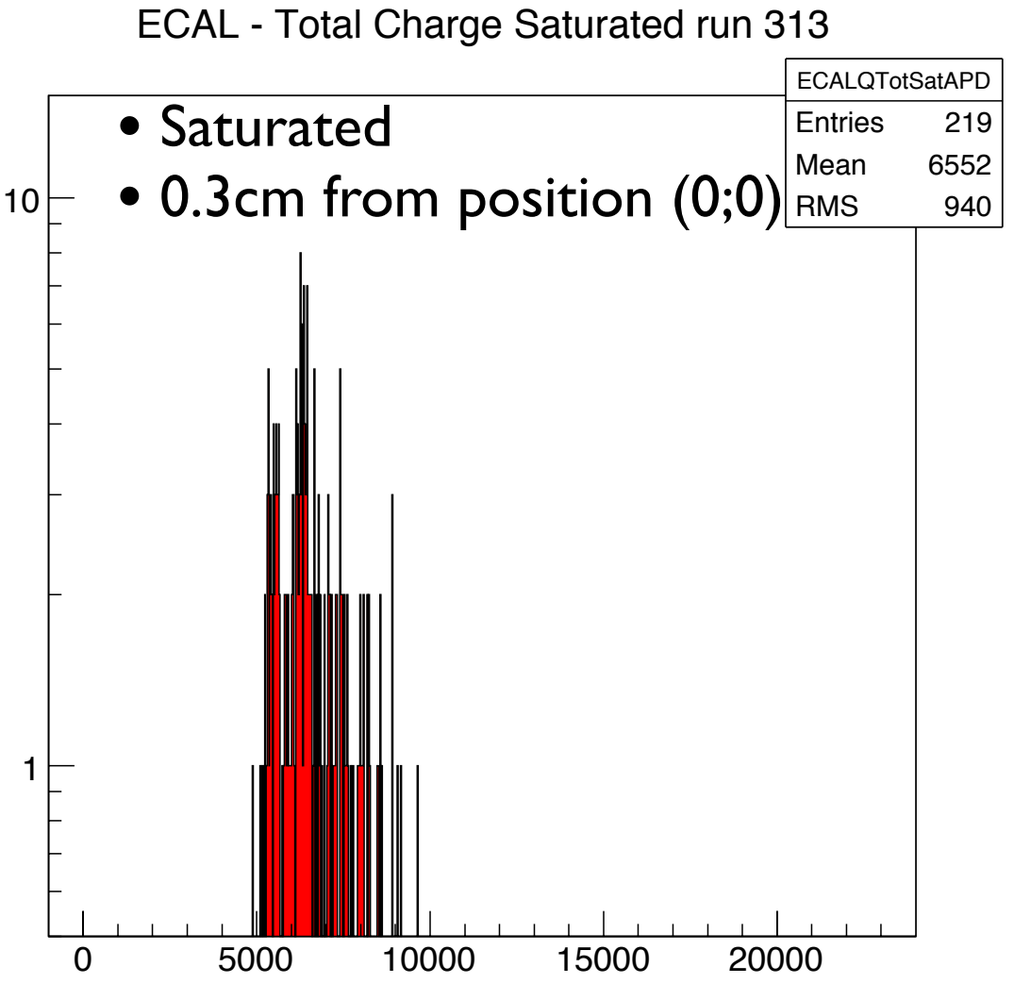
APD run 313 (2)

E = 150MeV

Charge spectrum



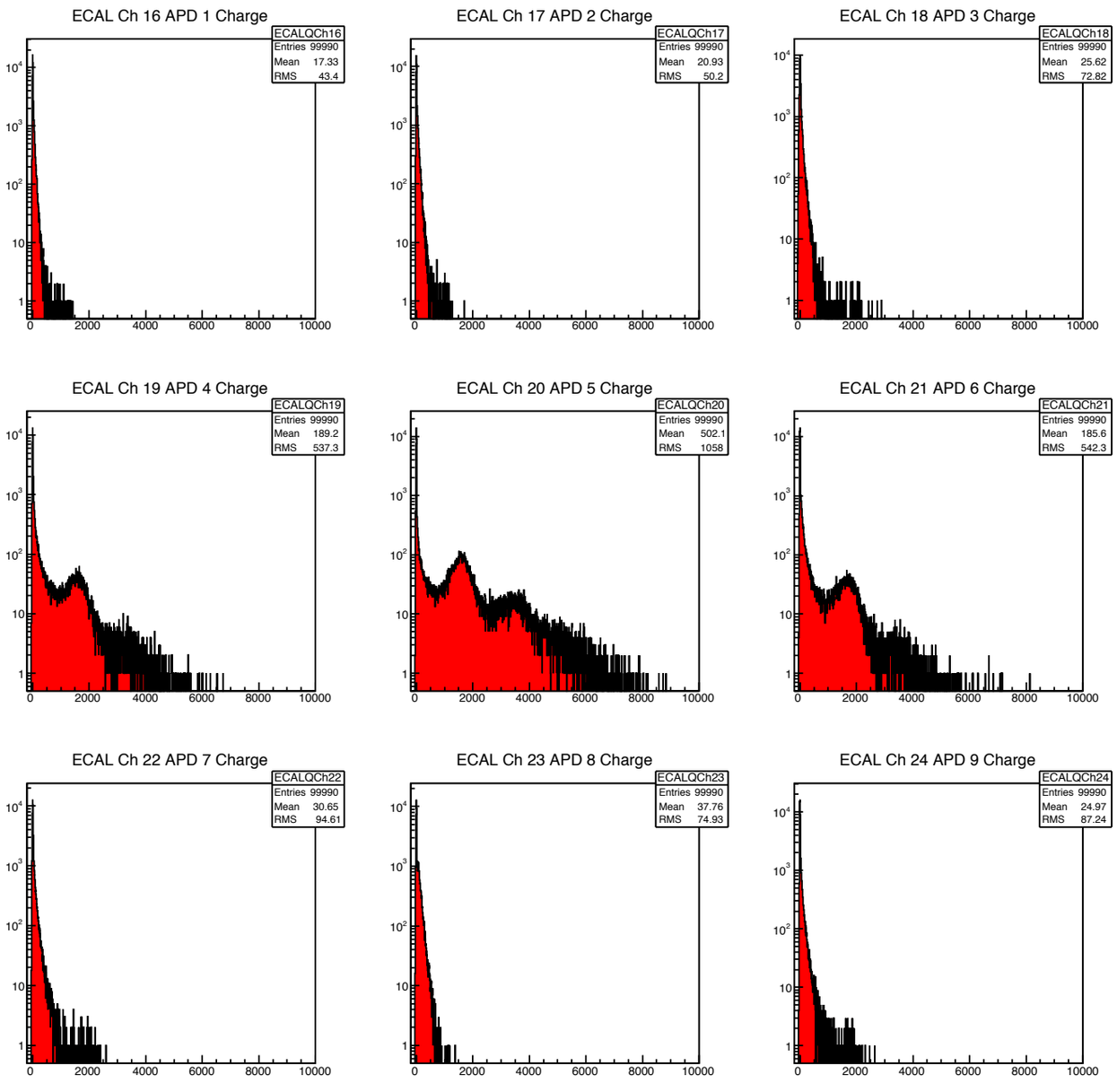
Saturated charge spectrum



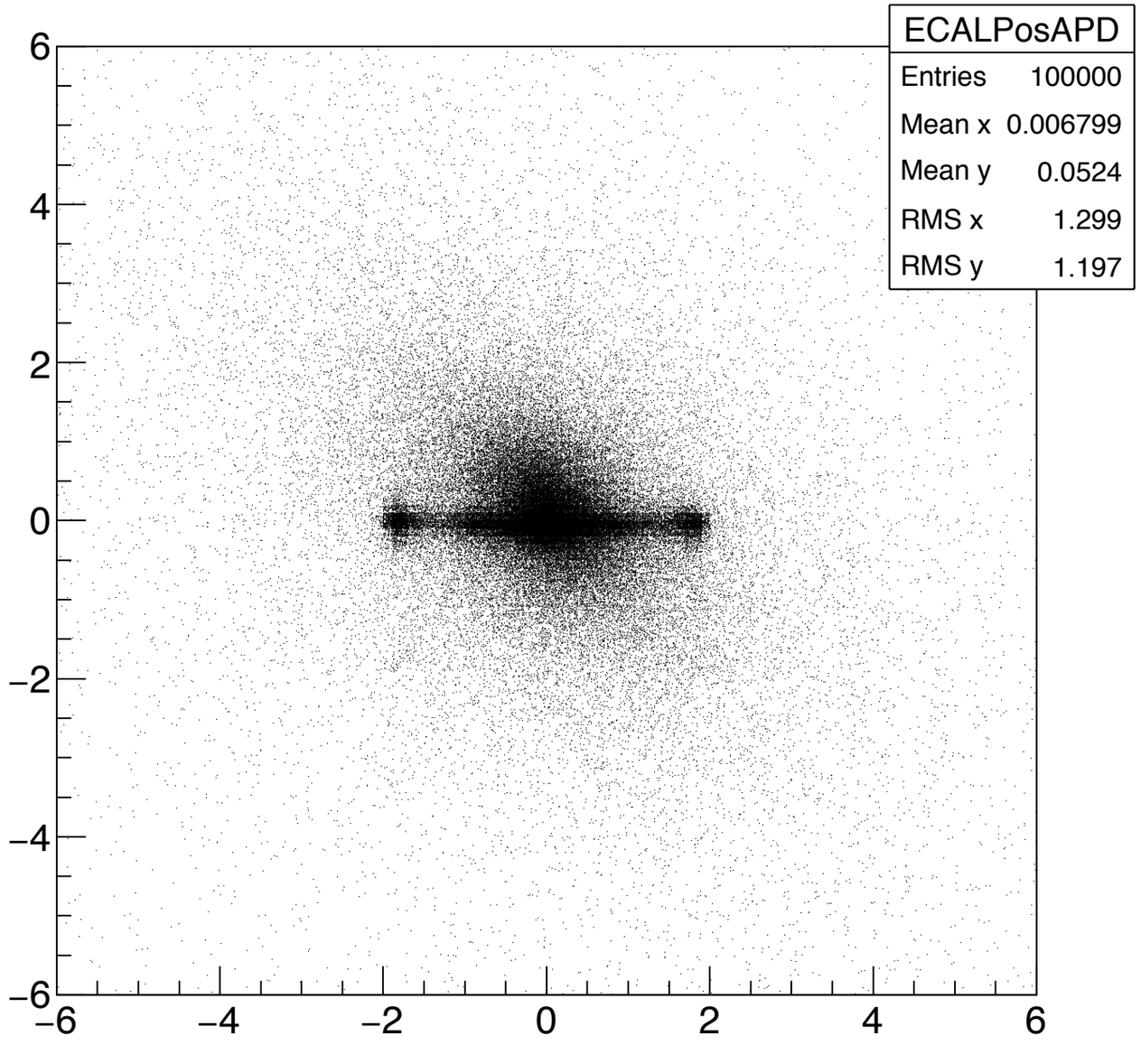
APD run 311 (1)

E = 296MeV

Single channel spectra



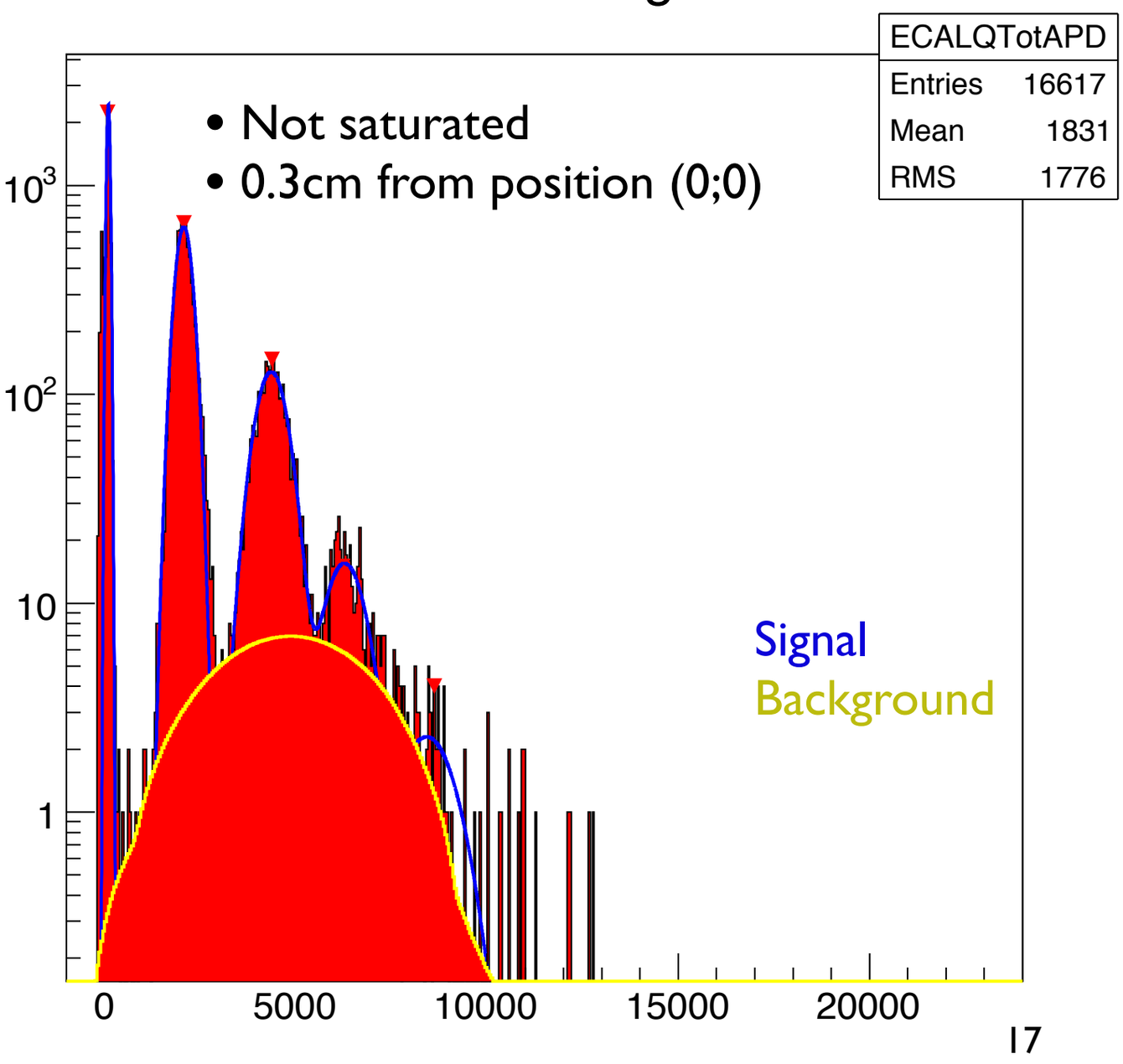
Interaction position



APD run 311 (2)

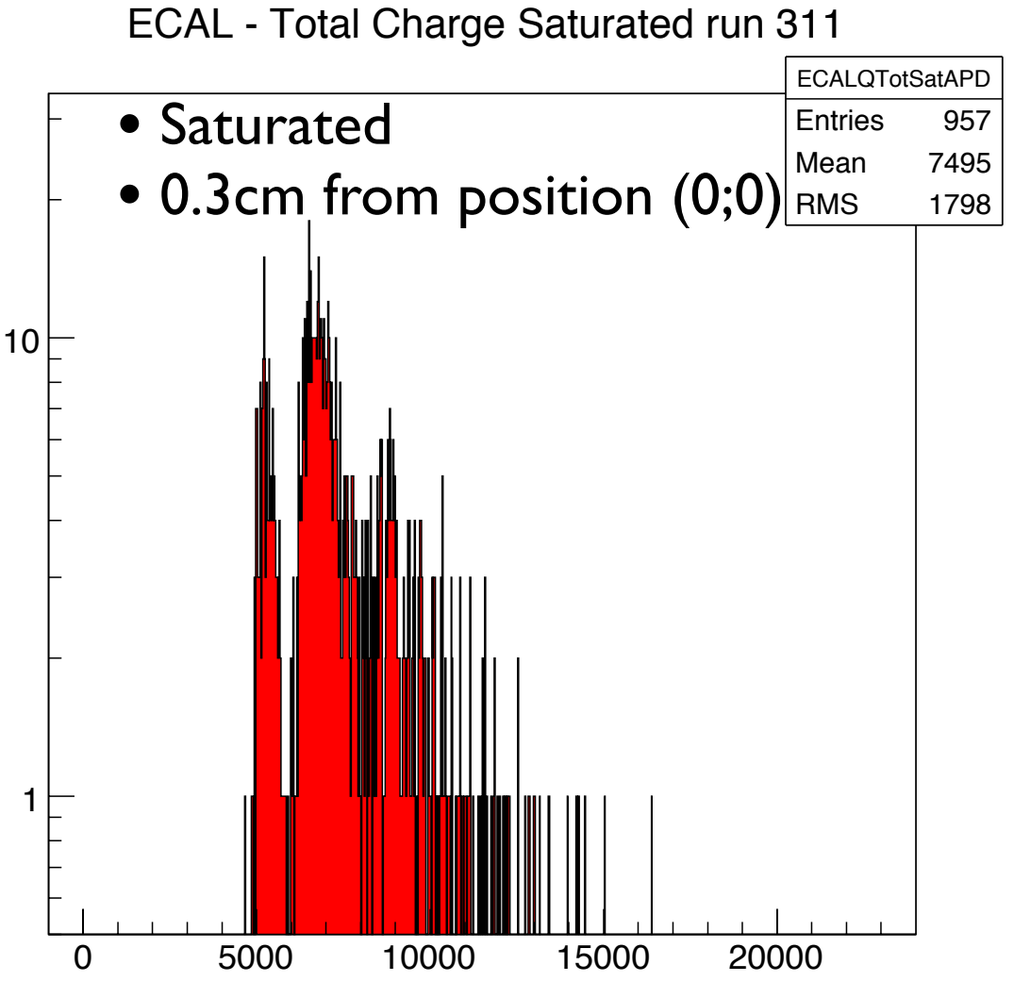
E = 296MeV

Charge spectrum



17

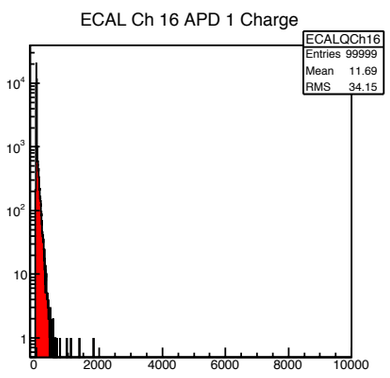
Saturated charge spectrum

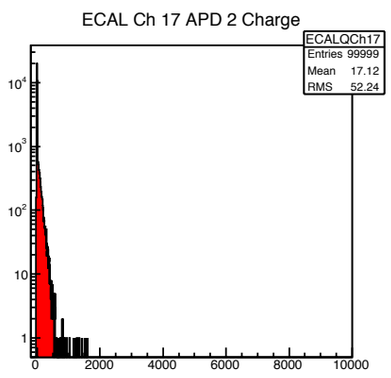


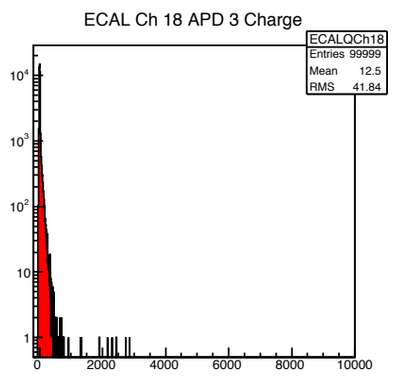
APD run 312 (1)

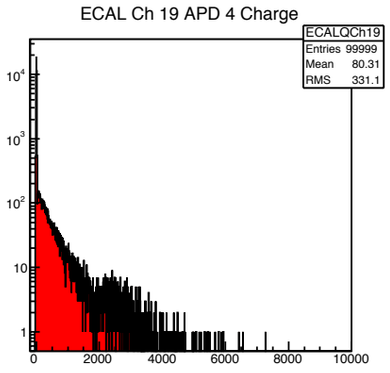
E = 448MeV

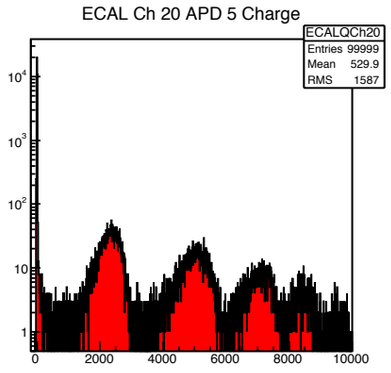
Single channel spectra

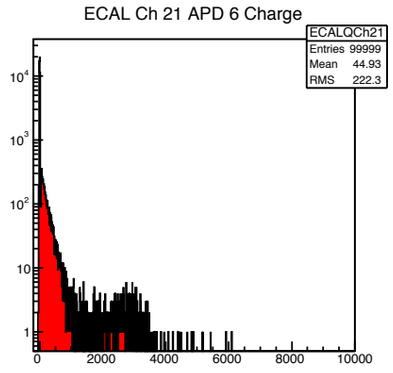


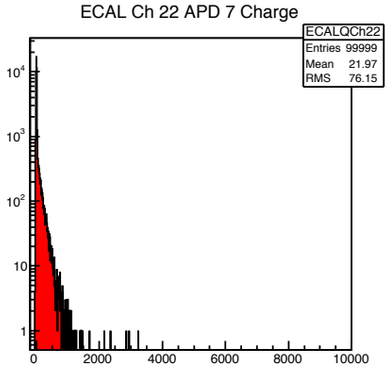


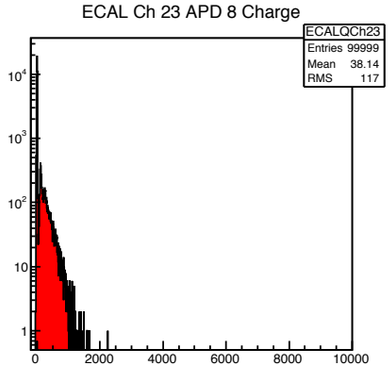


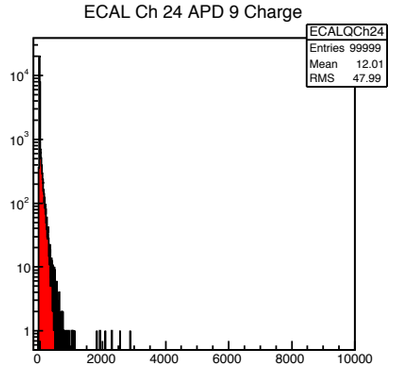




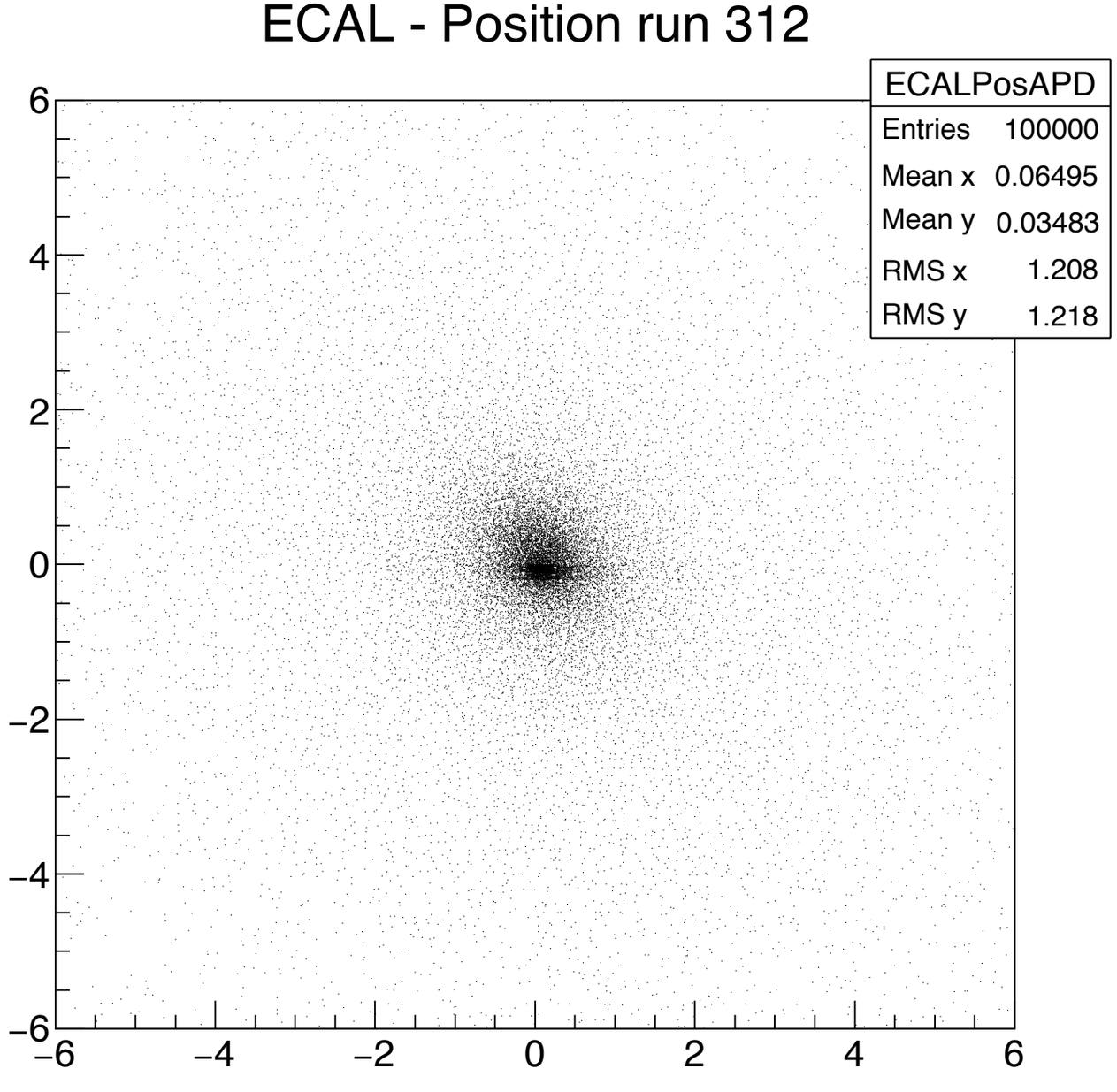








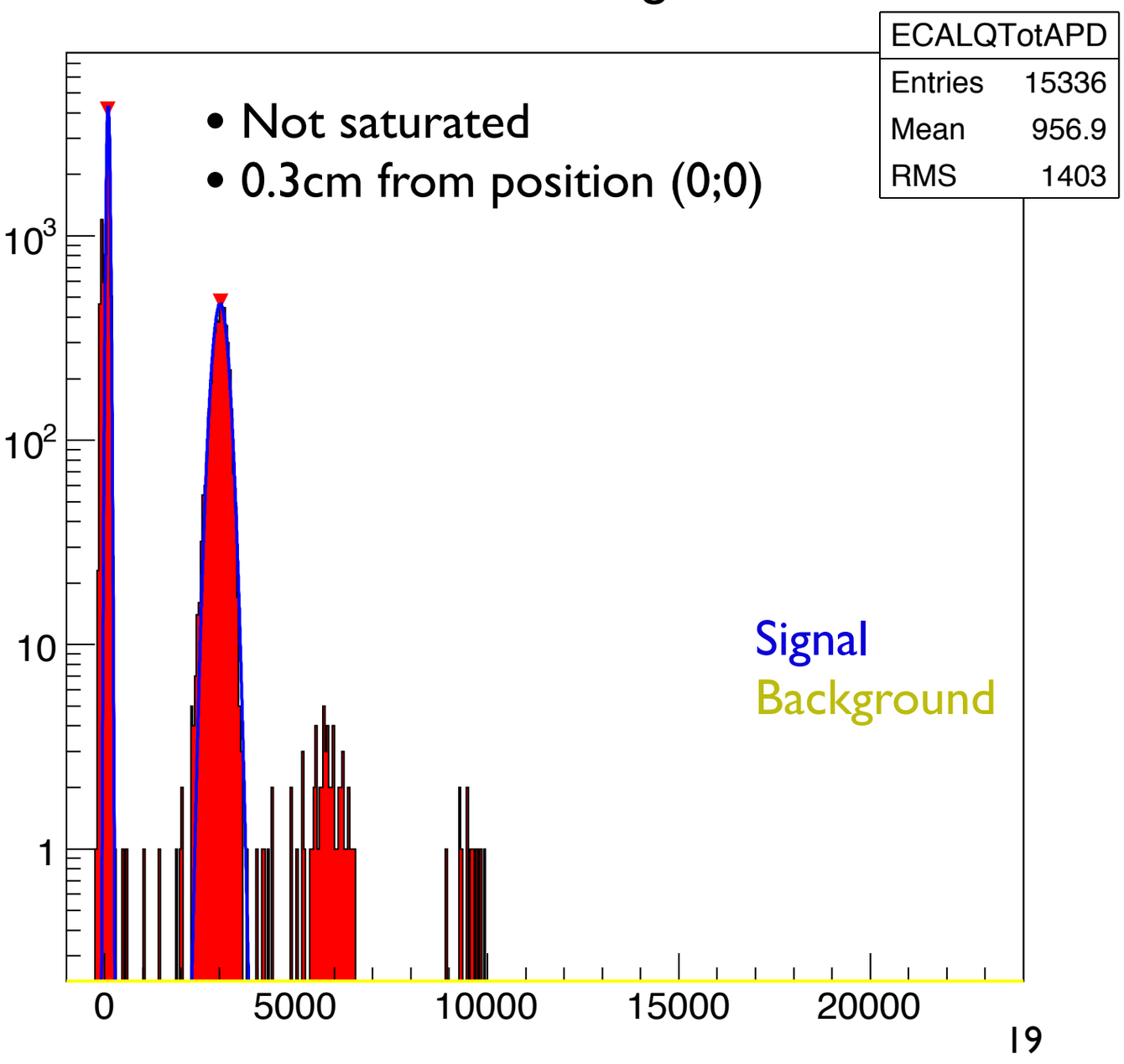
Interaction position



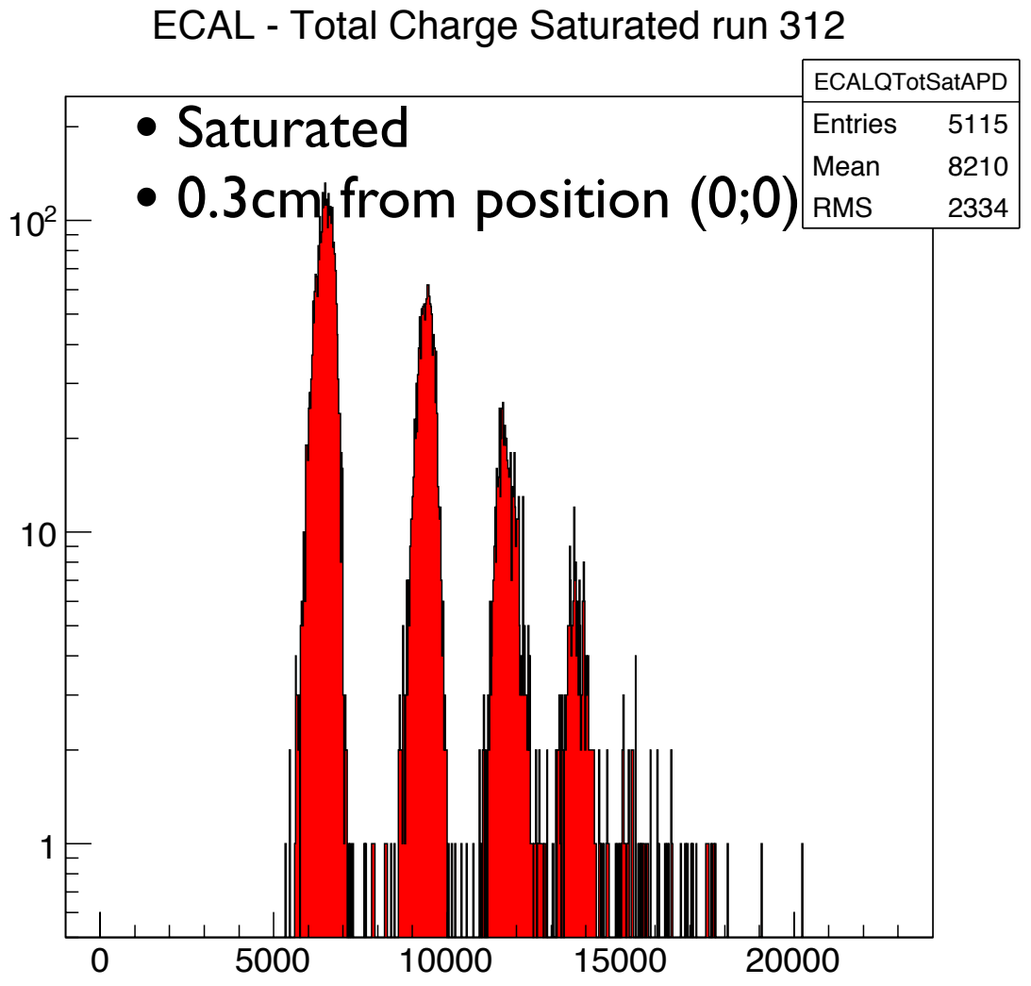
APD run 312 (2)

E = 448MeV

Charge spectrum



Saturated charge spectrum



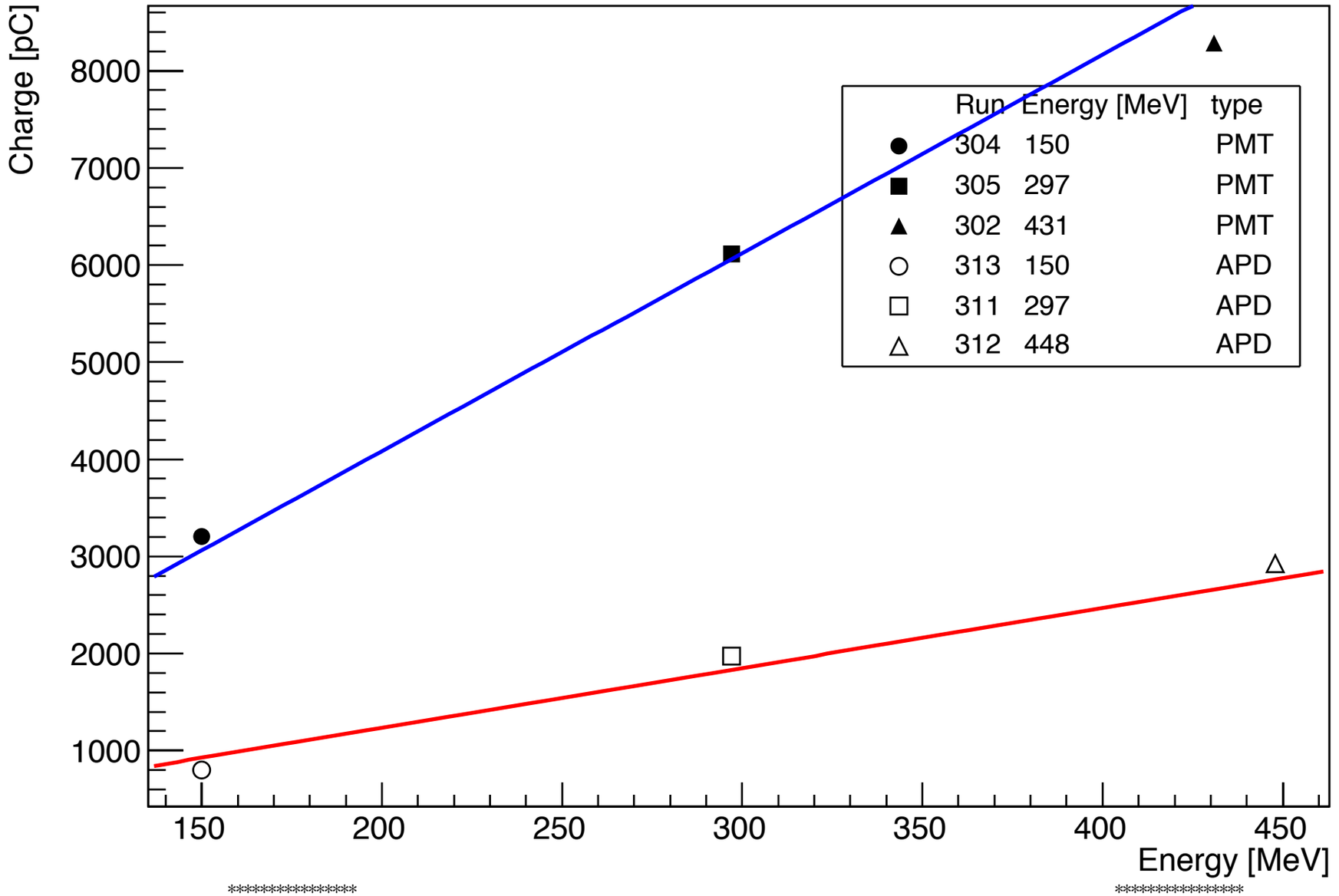
Charge linearity M1

- Charge is evaluated as the difference between the considered multiplicity peak and the pedestal peak position

- Only multiplicity 1 is considered

Charge linearity w/o intercept

Fitting function: $p0 \cdot E$



****
PMT charge fit
****

FCN=6576.36 FROM MIGRAD STATUS=CONVERGED 14 CALLS 15 TOTAL
EDM=5.66243e-14 STRATEGY= 1 ERROR MATRIX ACCURATE

EXT PARAMETER			STEP	FIRST
NO.	NAME	VALUE	ERROR	SIZE	DERIVATIVE
1	p0	2.04121e+01	9.22999e-03	3.65508e-04	3.64599e-05

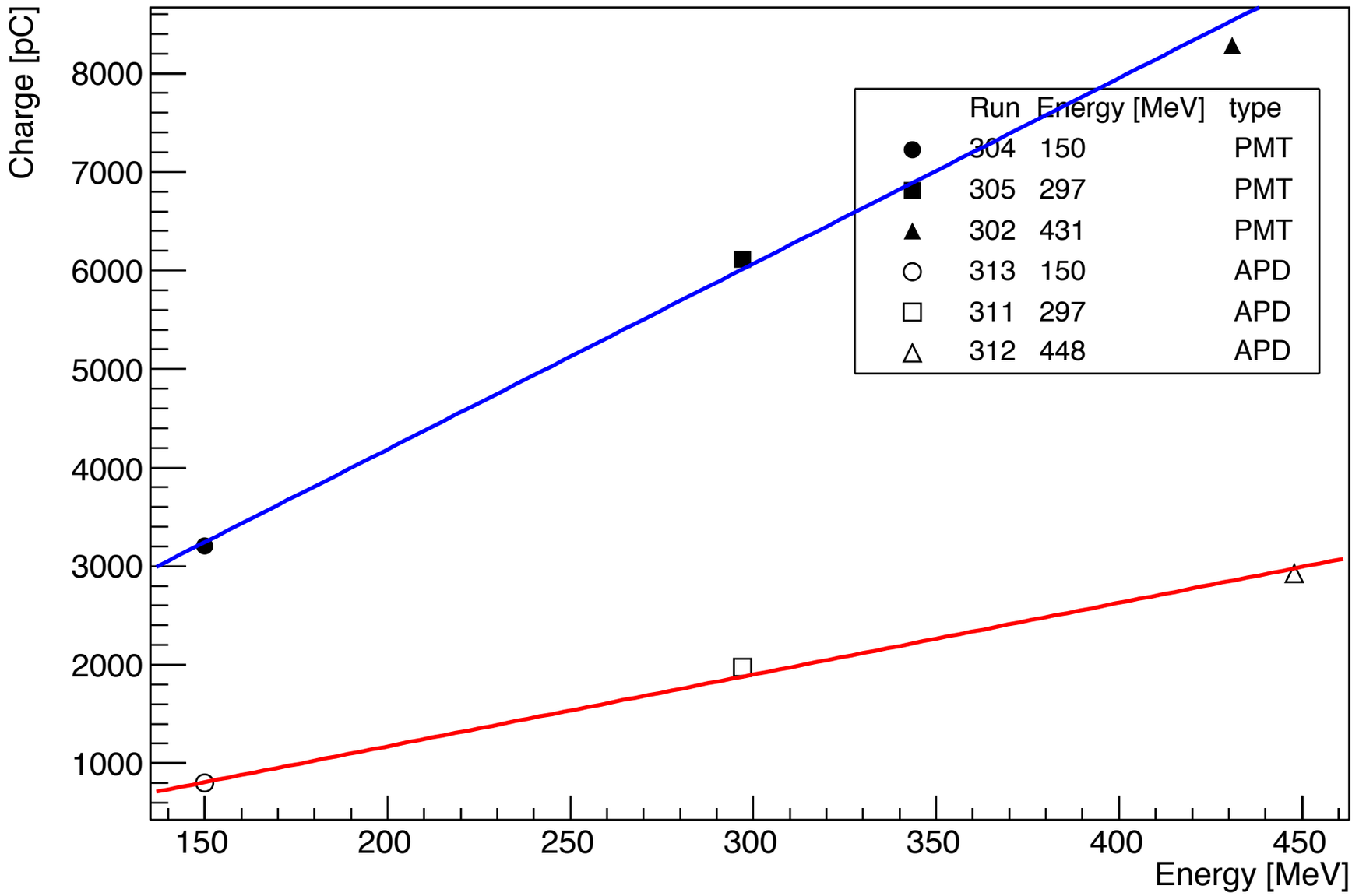
****
APD charge fit
****

FCN=16472.5 FROM MIGRAD STATUS=CONVERGED 14 CALLS 15 TOTAL
EDM=6.68722e-16 STRATEGY= 1 ERROR MATRIX ACCURATE

EXT PARAMETER			STEP	FIRST
NO.	NAME	VALUE	ERROR	SIZE	DERIVATIVE
1	p0	6.17035e+00	4.51644e-03	2.83047e-04	8.09733e-06

Charge linearity w/ intercept

Fitting function: $p0 \cdot E + p1$



****
PMT charge fit
****

FCN=1887.45 FROM MIGRAD STATUS=CONVERGED 35 CALLS 36 TOTAL
EDM=9.14444e-18 STRATEGY= 1 ERROR MATRIX ACCURATE

NO.	NAME	EXT PARAMETER VALUE	ERROR	STEP SIZE	FIRST DERIVATIVE
1	p0	1.88390e+01	2.47575e-02	1.95850e-04	-9.28767e-08
2	p1	4.17344e+02	6.09478e+00	4.82139e-02	-1.03751e-09

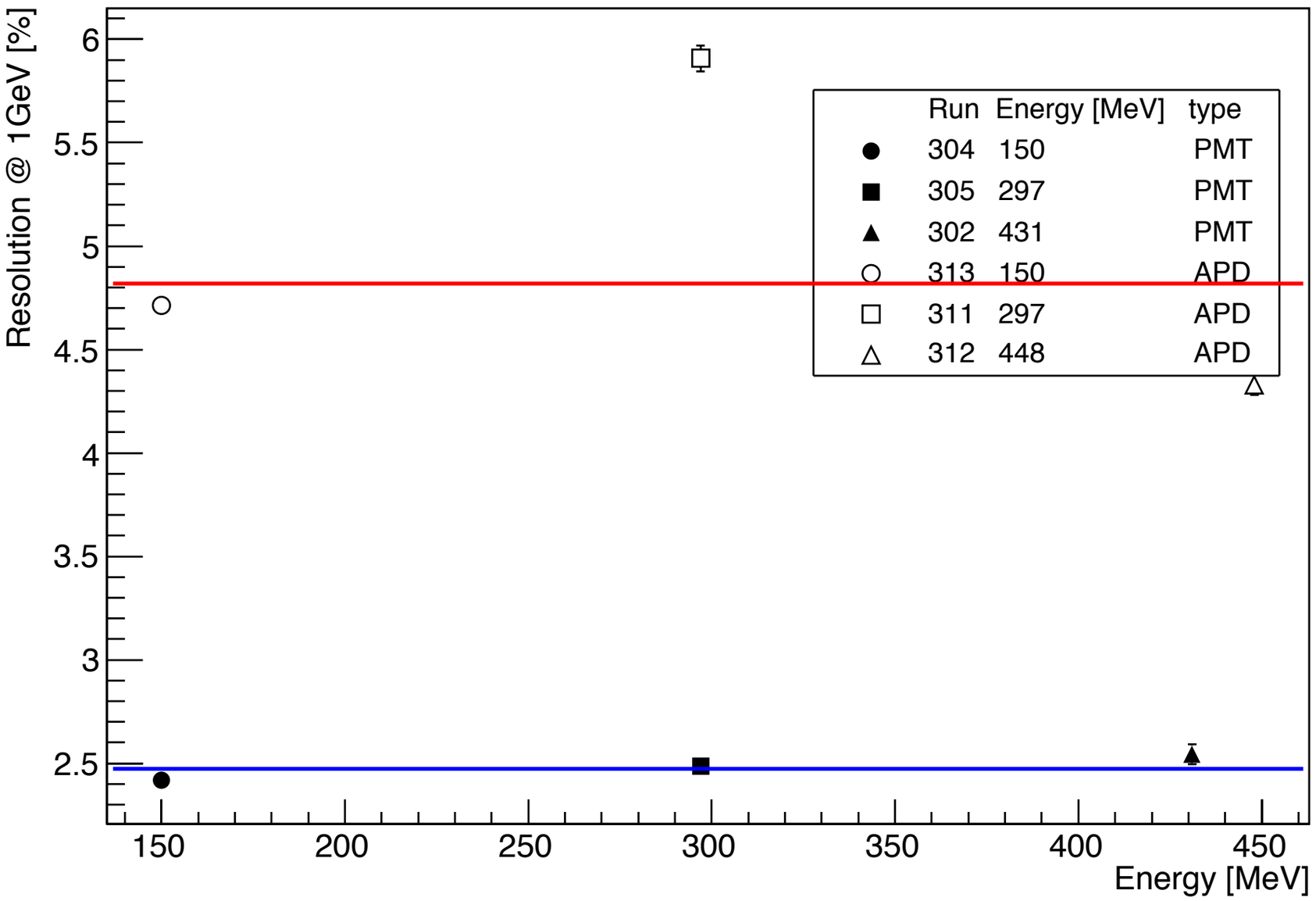
****
APD charge fit
****

FCN=1428.68 FROM MIGRAD STATUS=CONVERGED 33 CALLS 34 TOTAL
EDM=8.54114e-19 STRATEGY= 1 ERROR MATRIX ACCURATE

NO.	NAME	EXT PARAMETER VALUE	ERROR	STEP SIZE	FIRST DERIVATIVE
1	p0	7.27950e+00	1.01081e-02	9.05410e-05	3.13910e-08
2	p1	-2.83931e+02	2.31491e+00	2.07345e-02	-4.38639e-10

Resolutions

Fitting function: $p0$



Values from the gaussian fit to the peaks

$$\frac{\sigma_Q}{\mu_Q}\sqrt{E(\mathrm{GeV})}$$

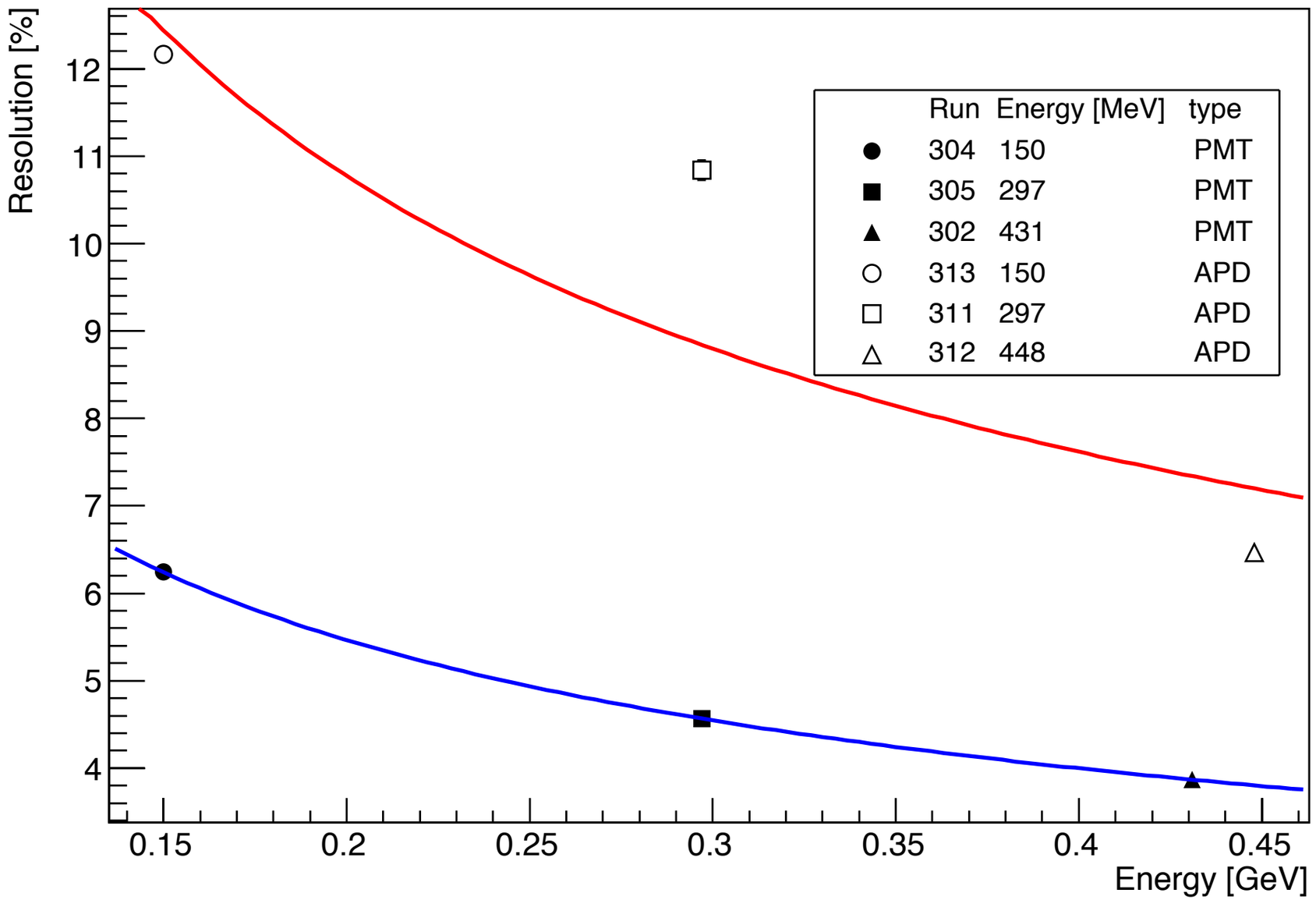
```
**********
*PMT resolution @1GeV fit*
**********
FCN=5.44002 FROM MIGRAD    STATUS=CONVERGED      14 CALLS          15 TOTAL
                     EDM=4.18141e-16    STRATEGY= 1      ERROR MATRIX ACCURATE
  EXT PARAMETER                                   STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   1  p0           2.47335e+00   1.77528e-02   2.19978e-05   1.62896e-06
```

```
**********
*APD resolution @1GeV fit*
**********
FCN=412.623 FROM MIGRAD    STATUS=CONVERGED      12 CALLS          13 TOTAL
                     EDM=2.51487e-14    STRATEGY= 1      ERROR MATRIX ACCURATE
  EXT PARAMETER                                   STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   1  p0           4.81817e+00   2.67825e-02   2.65964e-04   8.37377e-06
```

Resolutions

Fitting function: $\frac{p0}{\sqrt{E}} + p1$

Resolu



Values from the gaussian fit to the peaks

$$\frac{\sigma_Q}{\mu_Q}$$

****
PMT resolution fit
****

FCN=0.00949282 FROM MIGRAD STATUS=CONVERGED 103 CALLS 104 TOTAL
EDM=3.77436e-09 STRATEGY= 1 ERROR MATRIX ACCURATE

EXT PARAMETER NO.	NAME	VALUE	ERROR	STEP SIZE	FIRST DERIVATIVE
1	p0	2.23950e+00	1.01933e-01	8.70939e-06	5.53254e-04
2	p1	4.57354e-01	1.96021e-01	8.02534e-06	1.50966e-03

****
APD resolution fit
****

FCN=412.623 FROM MIGRAD STATUS=CONVERGED 127 CALLS 128 TOTAL
EDM=1.64191e-08 STRATEGY= 1 ERROR MATRIX ACCURATE

EXT PARAMETER NO.	NAME	VALUE	ERROR	STEP SIZE	FIRST DERIVATIVE
1	p0	4.81817e+00	2.67832e-02	2.65964e-04	-7.47966e-04
2	p1	3.04379e-10	3.75472e-02	1.21340e-03	** at limit **

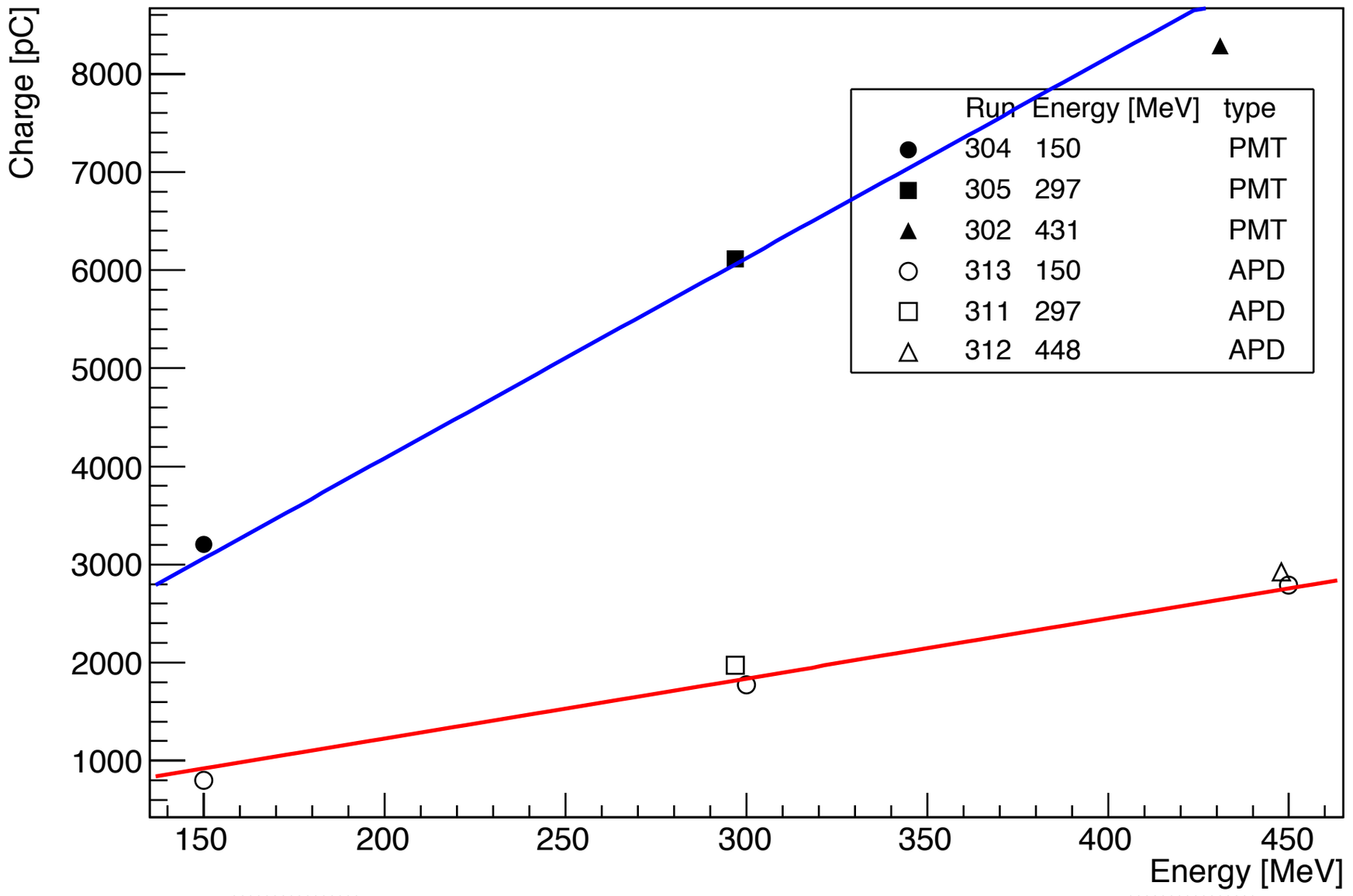
Charge linearity M optimized

- Charge is evaluated as the difference between the considered multiplicity peak and the pedestal peak position

- Optimized multiplicity is considered: up to M3 for APD @ 150MeV (other are discarded due to saturation or bad peak shape)

Charge linearity w/o intercept

Fitting function: $p0 \cdot E$



****
PMT charge fit
****

FCN=6576.36 FROM MIGRAD STATUS=CONVERGED 14 CALLS 15 TOTAL
EDM=5.66243e-14 STRATEGY= 1 ERROR MATRIX ACCURATE

EXT PARAMETER NO.	NAME	VALUE	ERROR	STEP SIZE	FIRST DERIVATIVE
1	p0	2.04121e+01	9.22999e-03	3.65508e-04	3.64599e-05

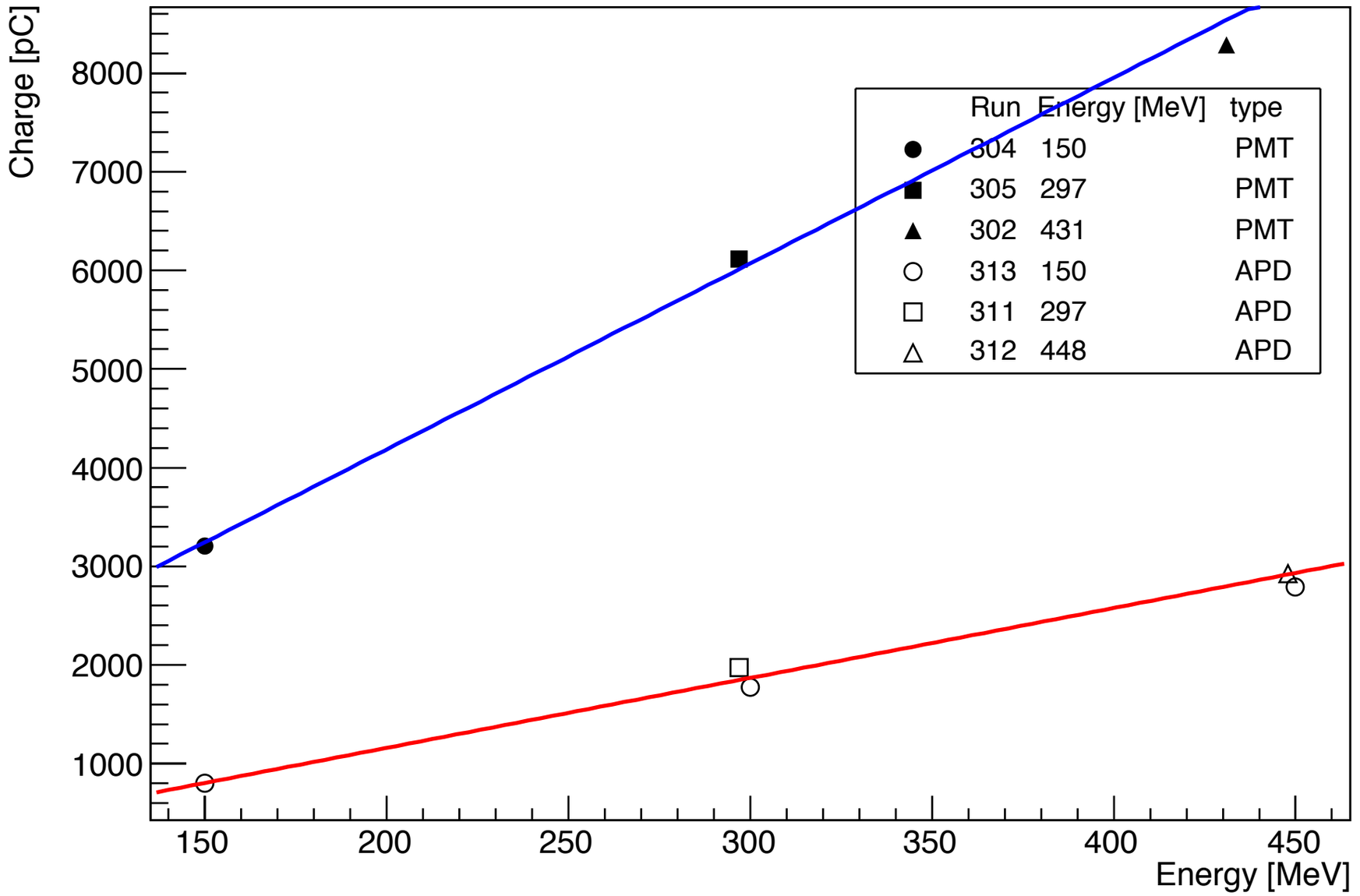
****
APD charge fit
****

FCN=17113.6 FROM MIGRAD STATUS=CONVERGED 14 CALLS 15 TOTAL
EDM=2.46668e-16 STRATEGY= 1 ERROR MATRIX ACCURATE

EXT PARAMETER NO.	NAME	VALUE	ERROR	STEP SIZE	FIRST DERIVATIVE
1	p0	6.12804e+00	3.97160e-03	2.53699e-04	-5.59250e-06

Charge linearity w/ intercept

Fitting function: $p0 \cdot E + p1$



****
PMT charge fit
****

FCN=1887.45 FROM MIGRAD STATUS=CONVERGED 35 CALLS 36 TOTAL
EDM=9.14444e-18 STRATEGY= 1 ERROR MATRIX ACCURATE

NO.	NAME	EXT PARAMETER VALUE	ERROR	STEP SIZE	FIRST DERIVATIVE
1	p0	1.88390e+01	2.47575e-02	1.95850e-04	-9.28767e-08
2	p1	4.17344e+02	6.09478e+00	4.82139e-02	-1.03751e-09

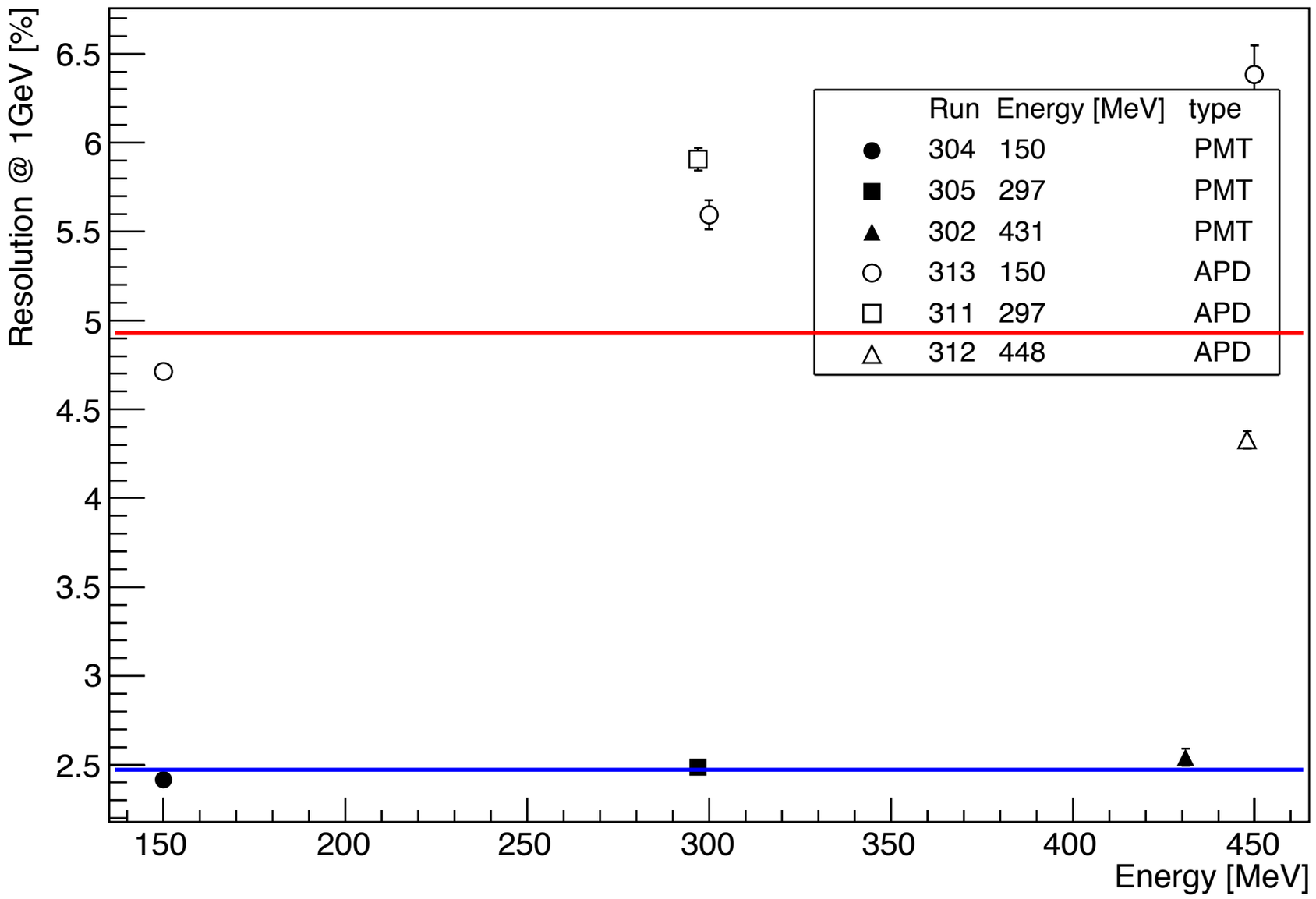
****
APD charge fit
****

FCN=3472.42 FROM MIGRAD STATUS=CONVERGED 33 CALLS 34 TOTAL
EDM=2.59272e-19 STRATEGY= 1 ERROR MATRIX ACCURATE

NO.	NAME	EXT PARAMETER VALUE	ERROR	STEP SIZE	FIRST DERIVATIVE
1	p0	7.09814e+00	9.20662e-03	1.14291e-04	-1.79048e-07
2	p1	-2.61830e+02	2.24178e+00	2.78295e-02	-6.12768e-10

Resolutions

Fitting function: p0



Values from the gaussian fit to the peaks

$$\frac{\sigma_Q}{\mu_Q}\sqrt{E(\mathrm{GeV})}$$

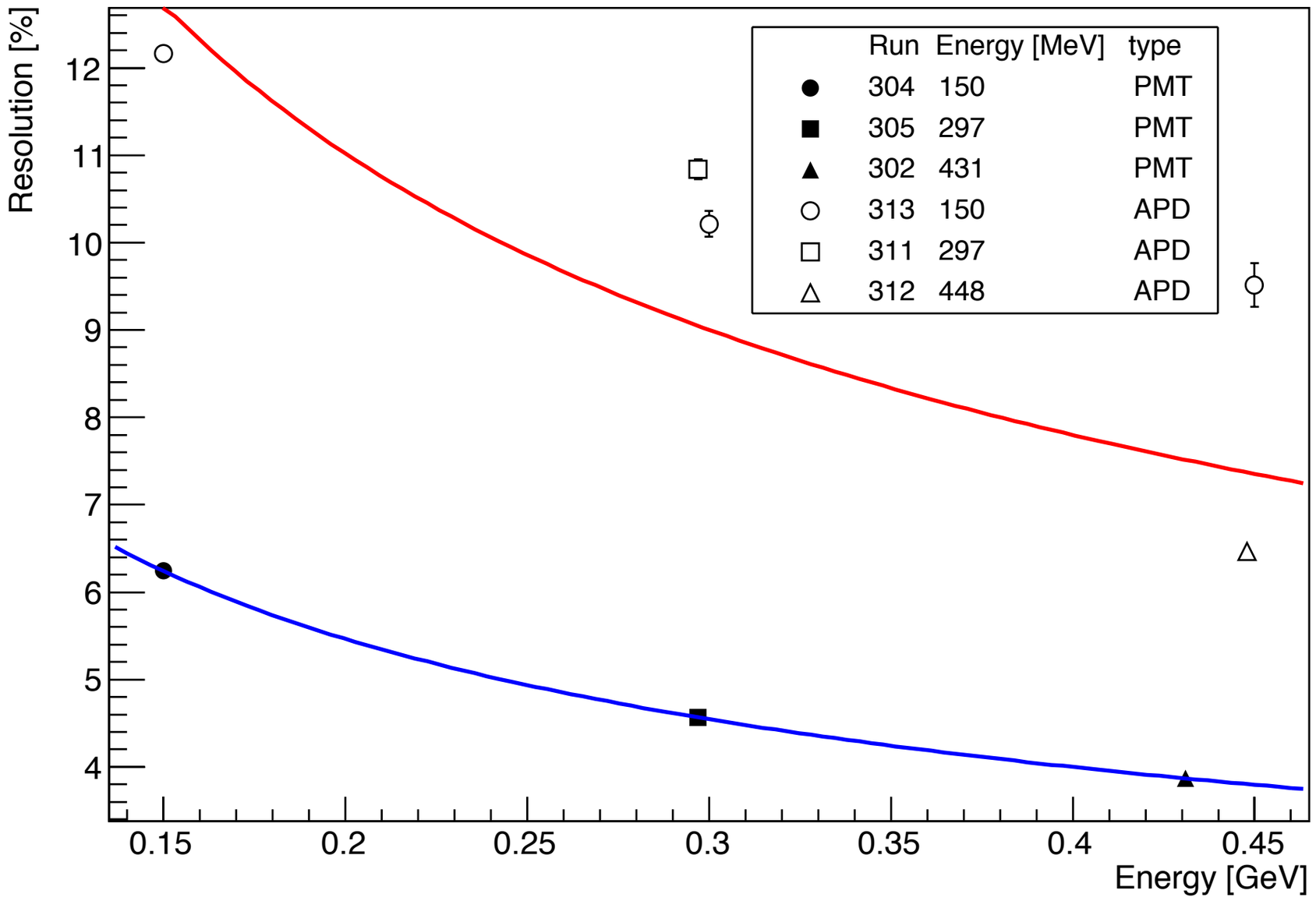
****
PMT resolution @1GeV fit
****
FCN=5.44002 FROM MIGRAD STATUS=CONVERGED 14 CALLS 15 TOTAL
EDM=4.18141e-16 STRATEGY= 1 ERROR MATRIX ACCURATE
EXT PARAMETER STEP FIRST
NO. NAME VALUE ERROR SIZE DERIVATIVE
1 p0 2.47335e+00 1.77528e-02 2.19978e-05 1.62896e-06

****
APD resolution @1GeV fit
****
FCN=575.114 FROM MIGRAD STATUS=CONVERGED 12 CALLS 13 TOTAL
EDM=4.63137e-16 STRATEGY= 1 ERROR MATRIX ACCURATE
EXT PARAMETER STEP FIRST
NO. NAME VALUE ERROR SIZE DERIVATIVE
1 p0 4.92957e+00 2.51242e-02 2.94453e-04 -1.21137e-06

Resolutions

Fitting function: $\frac{p0}{\sqrt{E}} + p1$

Resoluti



Values from the gaussian fit to the peaks

$$\frac{\sigma_Q}{\mu_Q}$$

****
PMT resolution fit
****

FCN=0.00949282 FROM MIGRAD STATUS=CONVERGED 103 CALLS 104 TOTAL
EDM=3.77436e-09 STRATEGY= 1 ERROR MATRIX ACCURATE

EXT PARAMETER NO.	NAME	VALUE	ERROR	STEP SIZE	FIRST DERIVATIVE
1	p0	2.23950e+00	1.01933e-01	8.70939e-06	5.53254e-04
2	p1	4.57354e-01	1.96021e-01	8.02534e-06	1.50966e-03

****
APD resolution fit
****

FCN=575.101 FROM MIGRAD STATUS=CONVERGED 151 CALLS 152 TOTAL
EDM=4.16025e-07 STRATEGY= 1 ERROR MATRIX ACCURATE

EXT PARAMETER NO.	NAME	VALUE	ERROR	STEP SIZE	FIRST DERIVATIVE
1	p0	4.91764e+00	1.22386e-01	2.94450e-04	3.46470e-02
2	p1	2.34355e-02	5.70671e-01	1.14012e-03	9.14528e-03

Conclusions

- M>1 saturates for PMT
- With the actual gain @ E>400MeV PMTs signals saturate
- PMT resolution (charge) is ≃2 (≃3) times better (larger) than the APD one (structure solidity, crystals dimensions and wrapping have to be considered)
- BGO+PMT resolution is compatible with the 2.5% in literature
- APD charge shows a good linearity with M>1
- APD resolution has evident problems