# ADC performance in bench tests

## BNL DUNE

David Adams
BNL
February 1, 2017

# Introduction

I continue looking at ADC data taken at BNL

- ADC samples are read out for input voltage steps
  - Using sawtooth envelope
  - 20M samples for each ADC channel
    - approximately 4k samples for each ADC bin
- New (Jan 2017) data is all P1
  - 35-ton used an earlier version
  - Expect this chip will be used for protoDUNE
- Data taken under different conditions
  - Warm (room temp) and cold (LN2)
  - Different sampling rates (1 and 2 MHz)
  - I show results for 2 MHz cold
  - All data taken with external clock
  - Different chip placements (mostly in socket)

# Data taking

Data taken by the following team

- Hucheng Chen, Shanshan Gao, Jack Fried (BNL)
- Damian Goeldi (Univ. of Bern)

Thanks to them to making this data available to me

Data format

- ADC samples
- Input voltage ramp from –300 to 2000 in 10 s

Data taken for 25 ADC chips

- 16 channels each
- I.e. a total of 400 ADC channels ➔ 1.6M ADC bins
- Chip placements
  - Chip 0 is bare
  - Chips 2 and 4 are in board
  - Remainder are in a socket

# Response

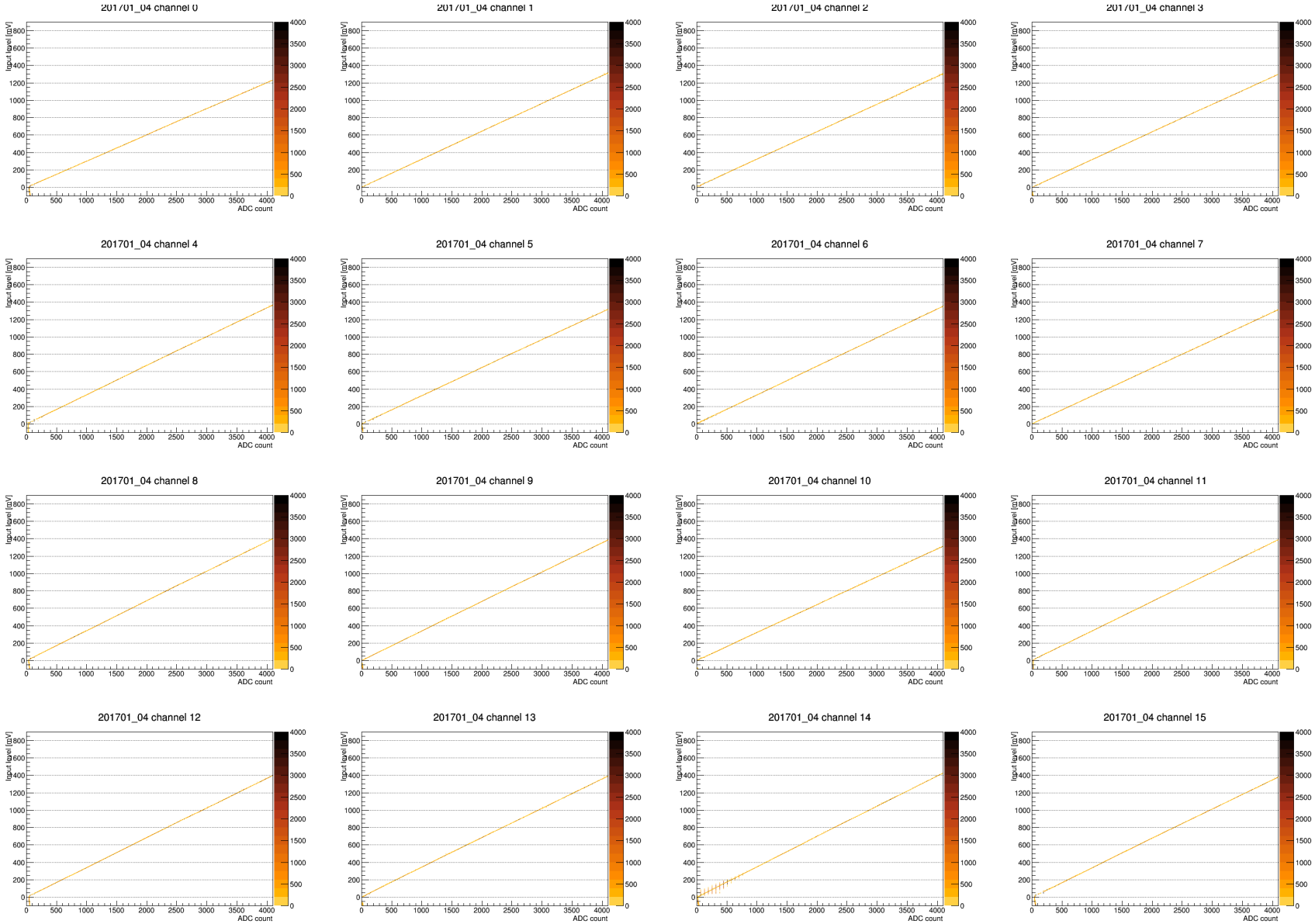
Following slides have response plots

- Input signal vs. ADC signal
- For all samples
- Followed by the same zooming in on the low end

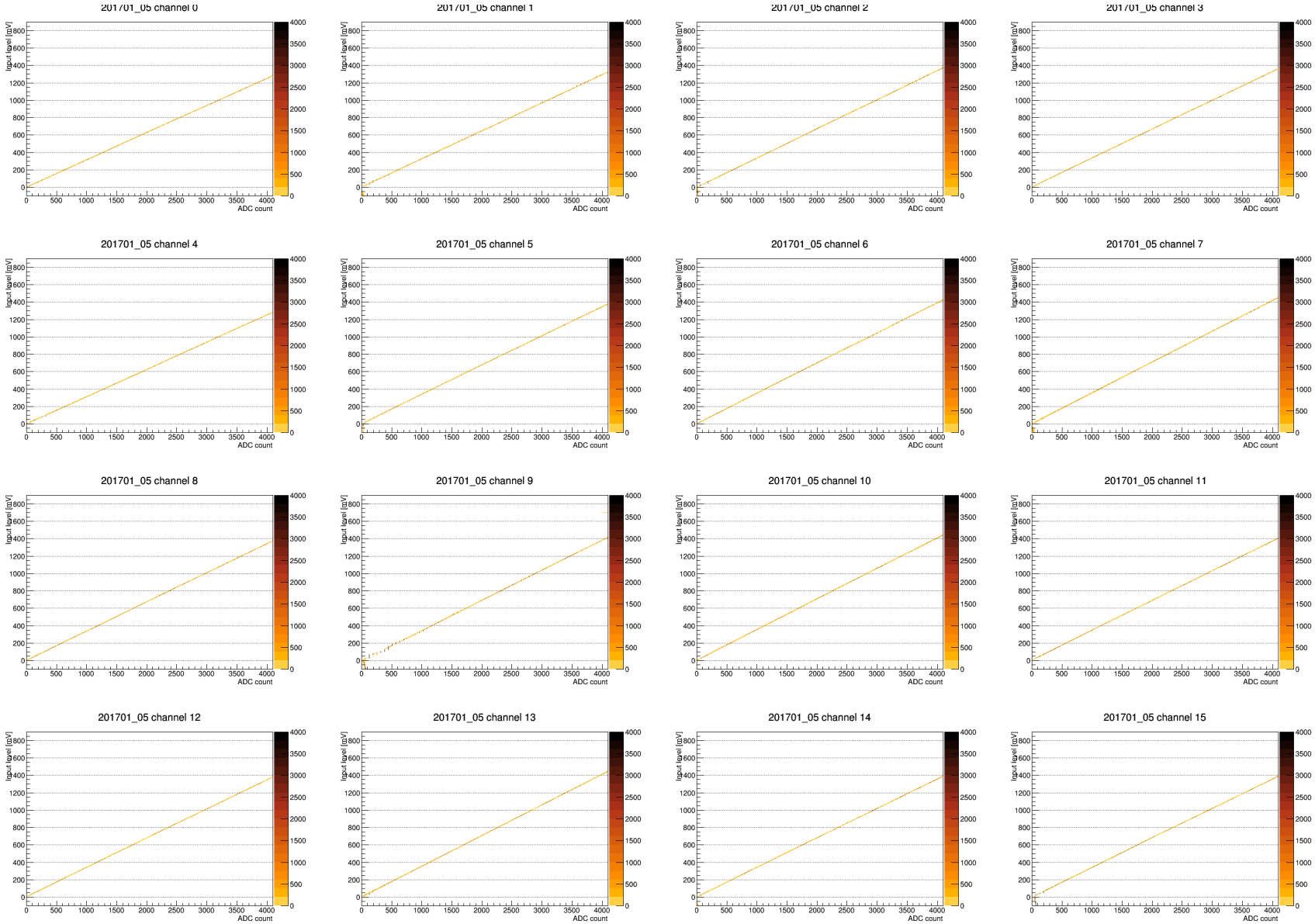
Comments

- Plots look linear by eye (fits coming later)
- Often problems in lower ADC codes
  - Below 64 or 200 or 500+

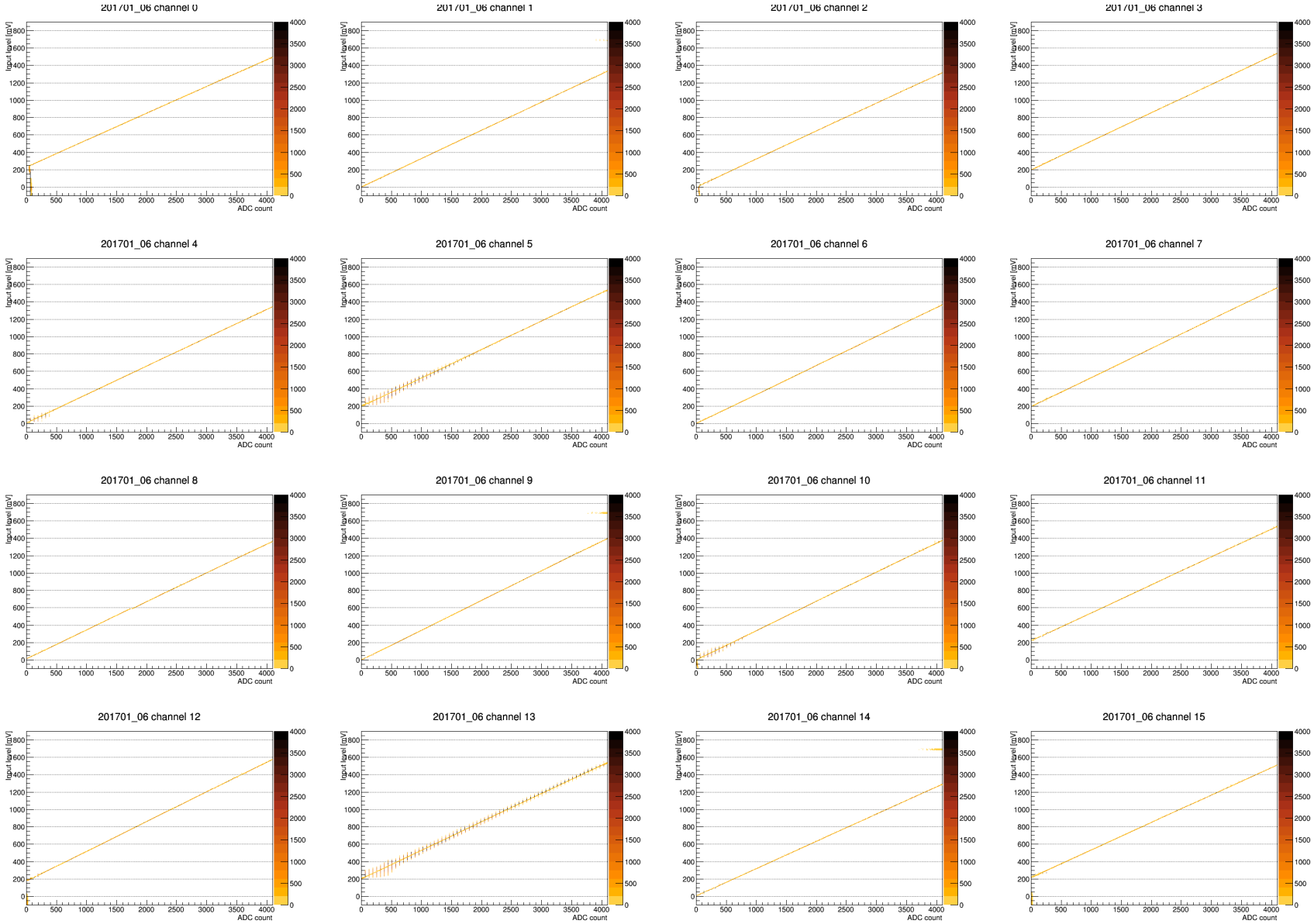
# ADC 4


201701_04 channel 0
201701_04 channel 1
201701_04 channel 2
201701_04 channel 3
201701_04 channel 4
201701_04 channel 5
201701_04 channel 6
201701_04 channel 7
201701_04 channel 8
201701_04 channel 9
201701_04 channel 10
201701_04 channel 11
201701_04 channel 12
201701_04 channel 13
201701_04 channel 14
201701_04 channel 15
Input level [mV]
ADC count

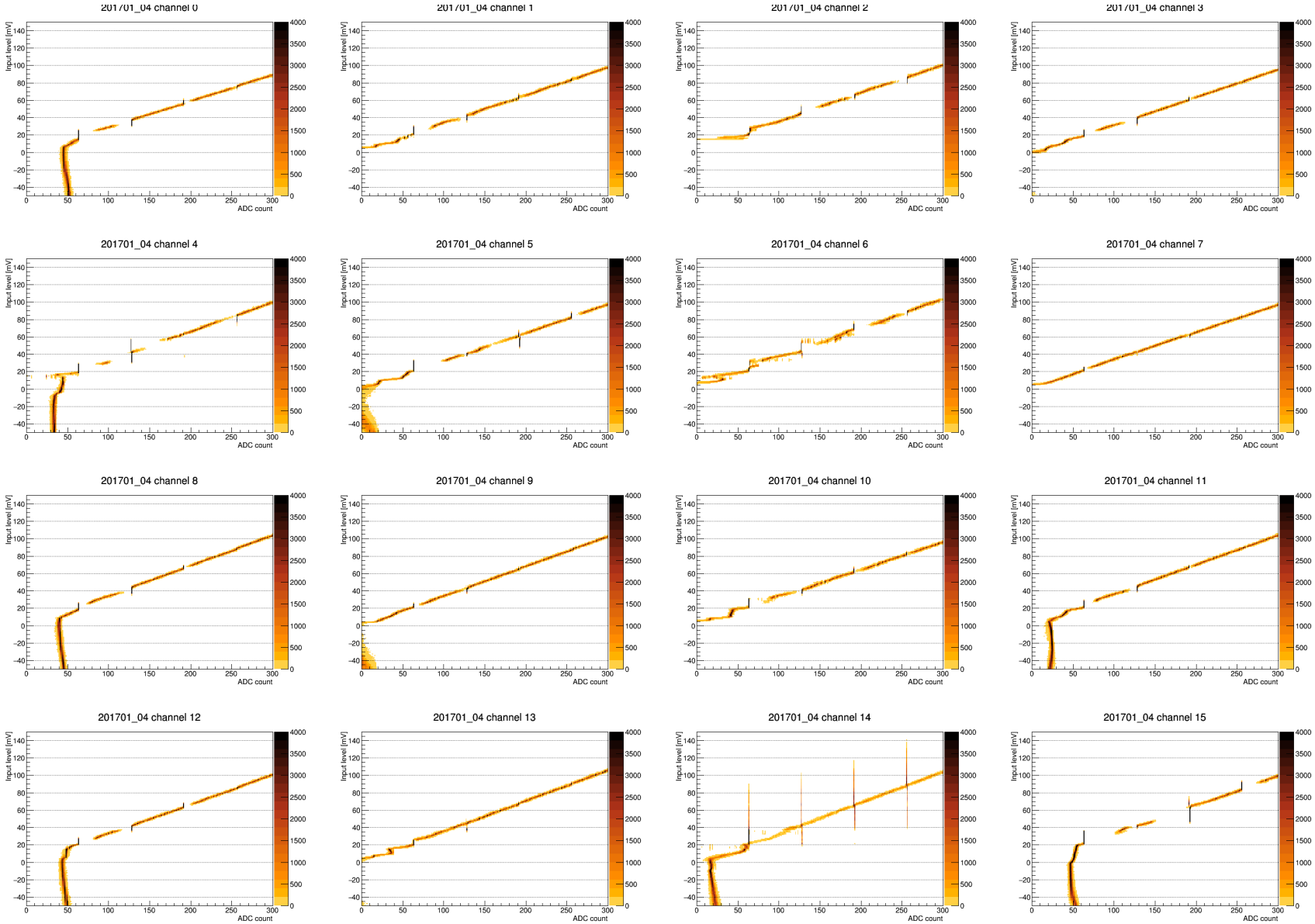
# ADC 5


201701_05 channel 0
201701_05 channel 1
201701_05 channel 2
201701_05 channel 3
201701_05 channel 4
201701_05 channel 5
201701_05 channel 6
201701_05 channel 7
201701_05 channel 8
201701_05 channel 9
201701_05 channel 10
201701_05 channel 11
201701_05 channel 12
201701_05 channel 13
201701_05 channel 14
201701_05 channel 15
Input level [mV]
ADC count

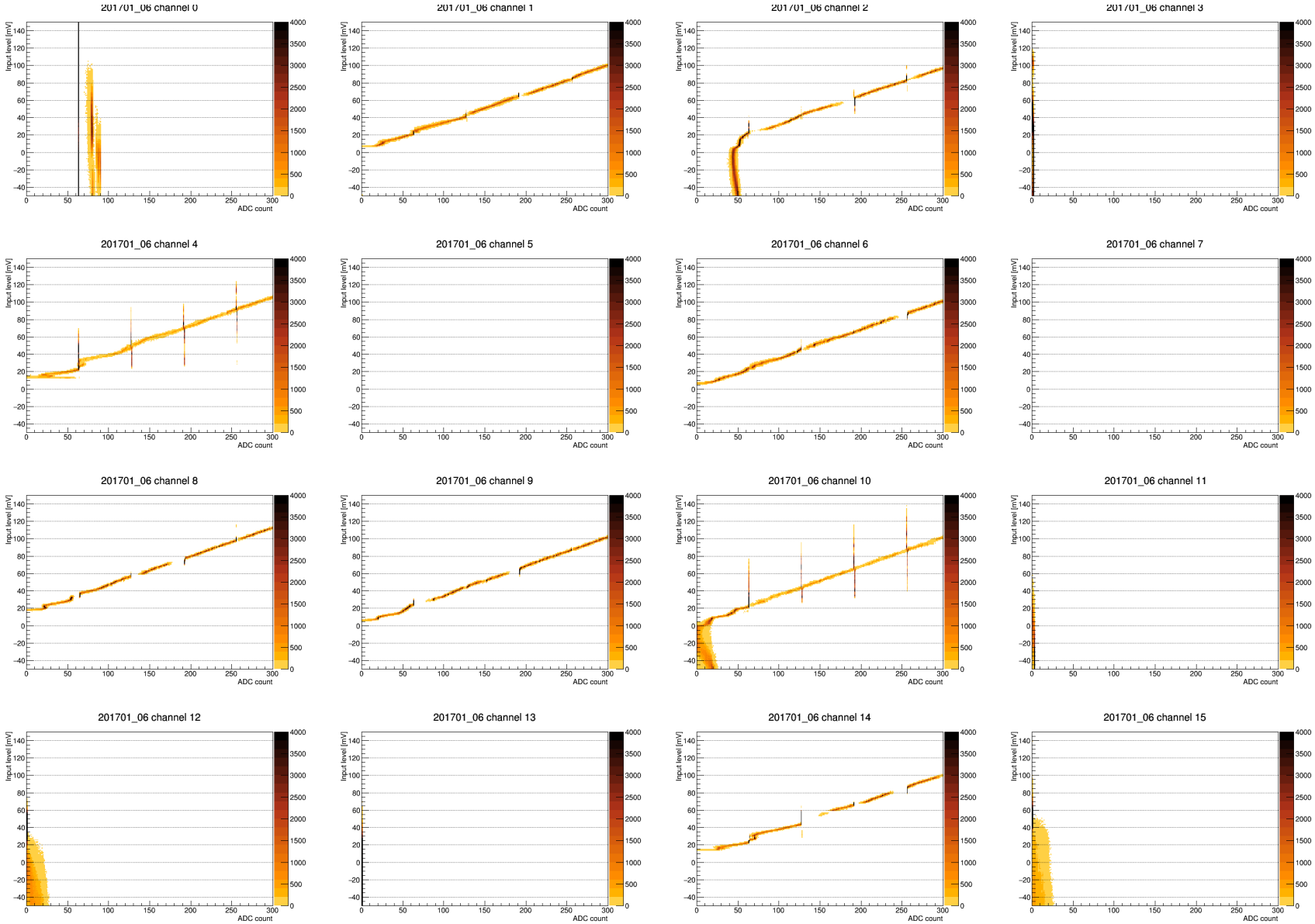
# ADC 6


201701_06 channel 0
201701_06 channel 1
201701_06 channel 2
201701_06 channel 3
201701_06 channel 4
201701_06 channel 5
201701_06 channel 6
201701_06 channel 7
201701_06 channel 8
201701_06 channel 9
201701_06 channel 10
201701_06 channel 11
201701_06 channel 12
201701_06 channel 13
201701_06 channel 14
201701_06 channel 15
Input level [mV]
ADC count

# ADC 4 zoomed


201701_04 channel 0
201701_04 channel 1
201701_04 channel 2
201701_04 channel 3
201701_04 channel 4
201701_04 channel 5
201701_04 channel 6
201701_04 channel 7
201701_04 channel 8
201701_04 channel 9
201701_04 channel 10
201701_04 channel 11
201701_04 channel 12
201701_04 channel 13
201701_04 channel 14
201701_04 channel 15
Input level [mV]
ADC count

# ADC 6 zoomed

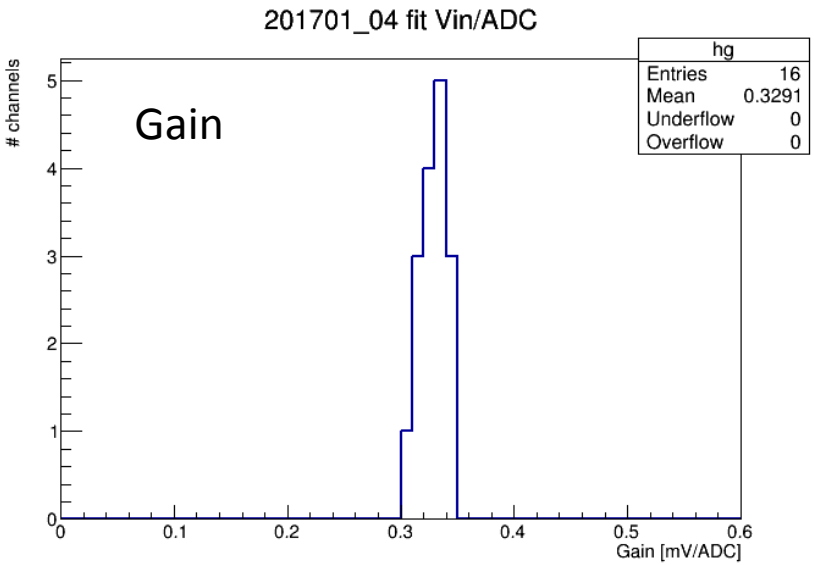

201701_06 channel 0
201701_06 channel 1
201701_06 channel 2
201701_06 channel 3
201701_06 channel 4
201701_06 channel 5
201701_06 channel 6
201701_06 channel 7
201701_06 channel 8
201701_06 channel 9
201701_06 channel 10
201701_06 channel 11
201701_06 channel 12
201701_06 channel 13
201701_06 channel 14
201701_06 channel 15
Input level [mV]
ADC count

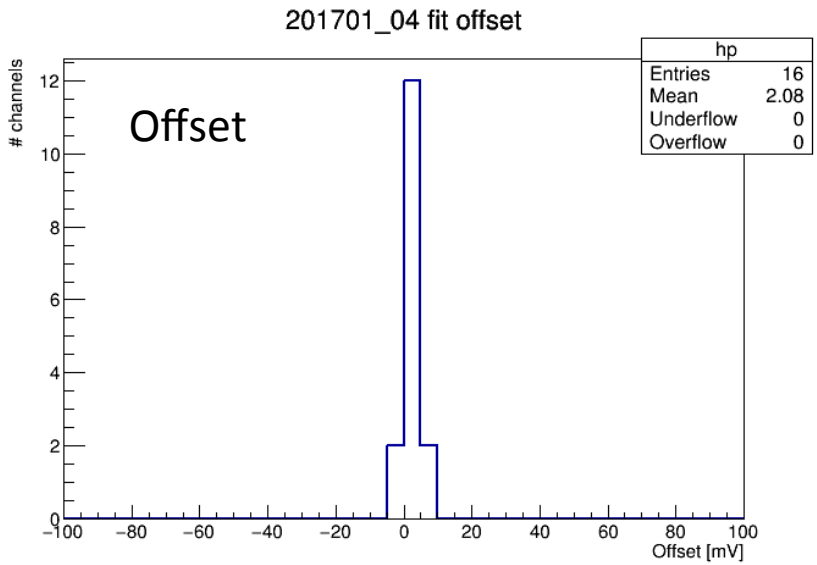
# Fits and residuals

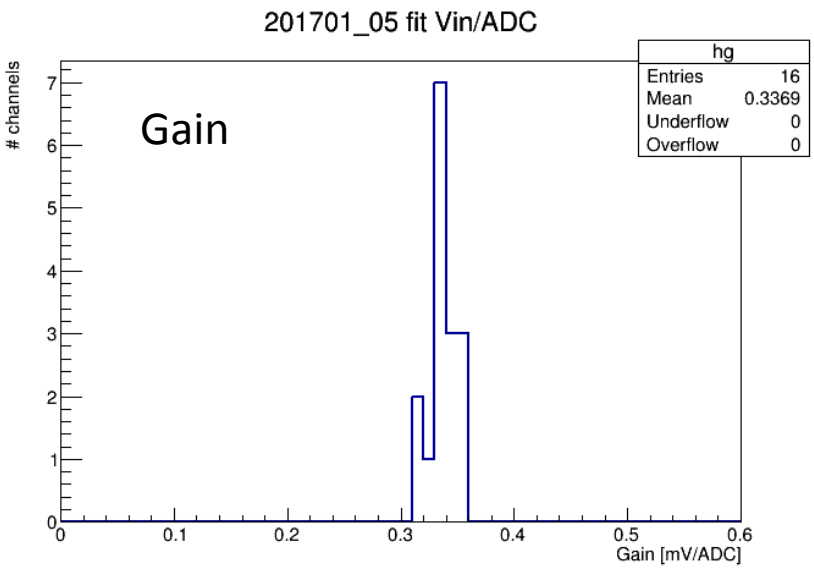
Use residuals to look at resolution and linearity

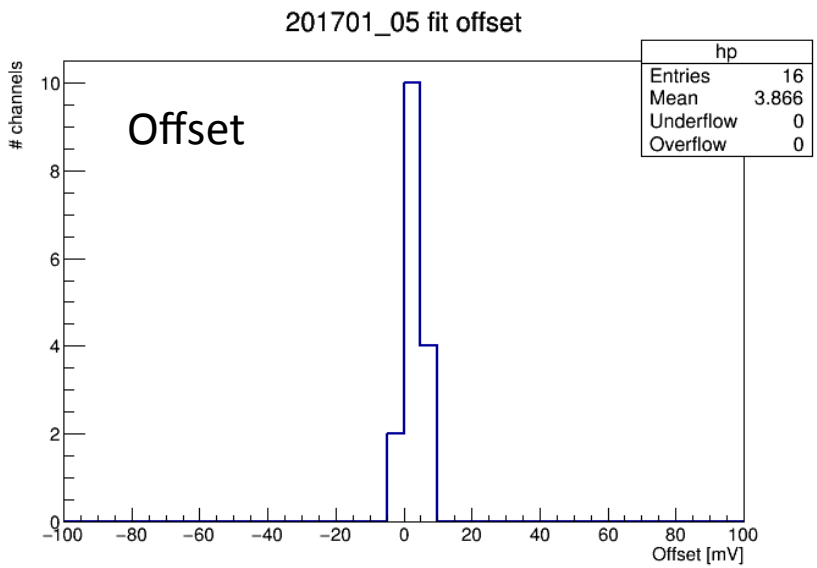
- Fit response ($V_{in}$ vs. ADC) to a line over the range (128, 4094)
  - Stuck codes (low bits all 0 or 1) are excluded in fit (but are shown in plots)
  - $V_{in}$ > 1700 mV is excluded (?)
- First plots show the distributions of fit parameters
  - Parameters are the gain (slope) and pedestal (ADC offset)
  - For two chips
- Next plots show the diff between ADC count and this fit vs. ADC count
  - For all 25 chips (16 channels/page)

# ADC 4

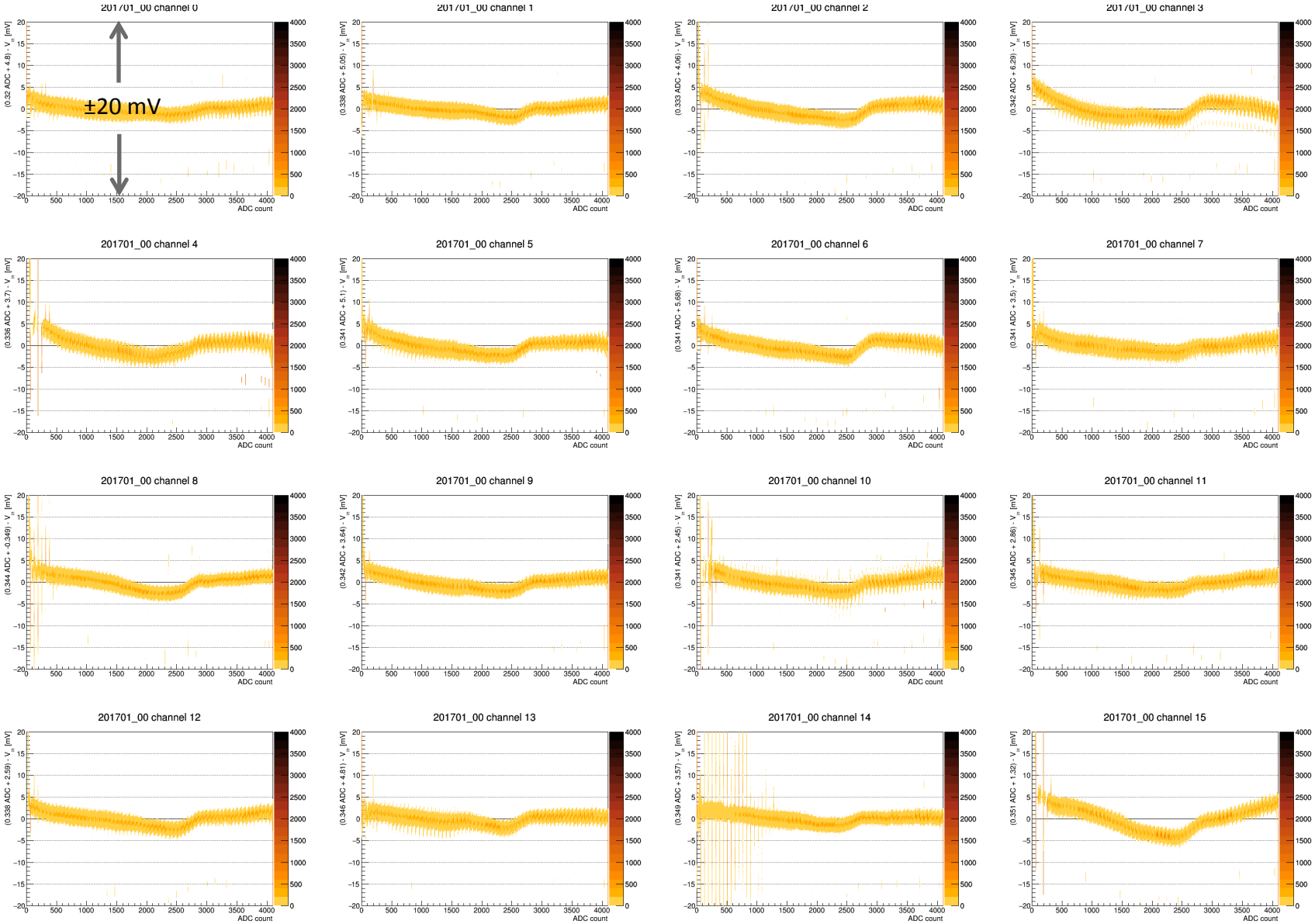

201701_04 fit Vin/ADC
Gain
hg
Entries 16
Mean 0.3291
Underflow 0
Overflow 0
# channels
Gain [mV/ADC]


201701_04 fit offset
Offset
hp
Entries 16
Mean 2.08
Underflow 0
Overflow 0
# channels
Offset [mV]

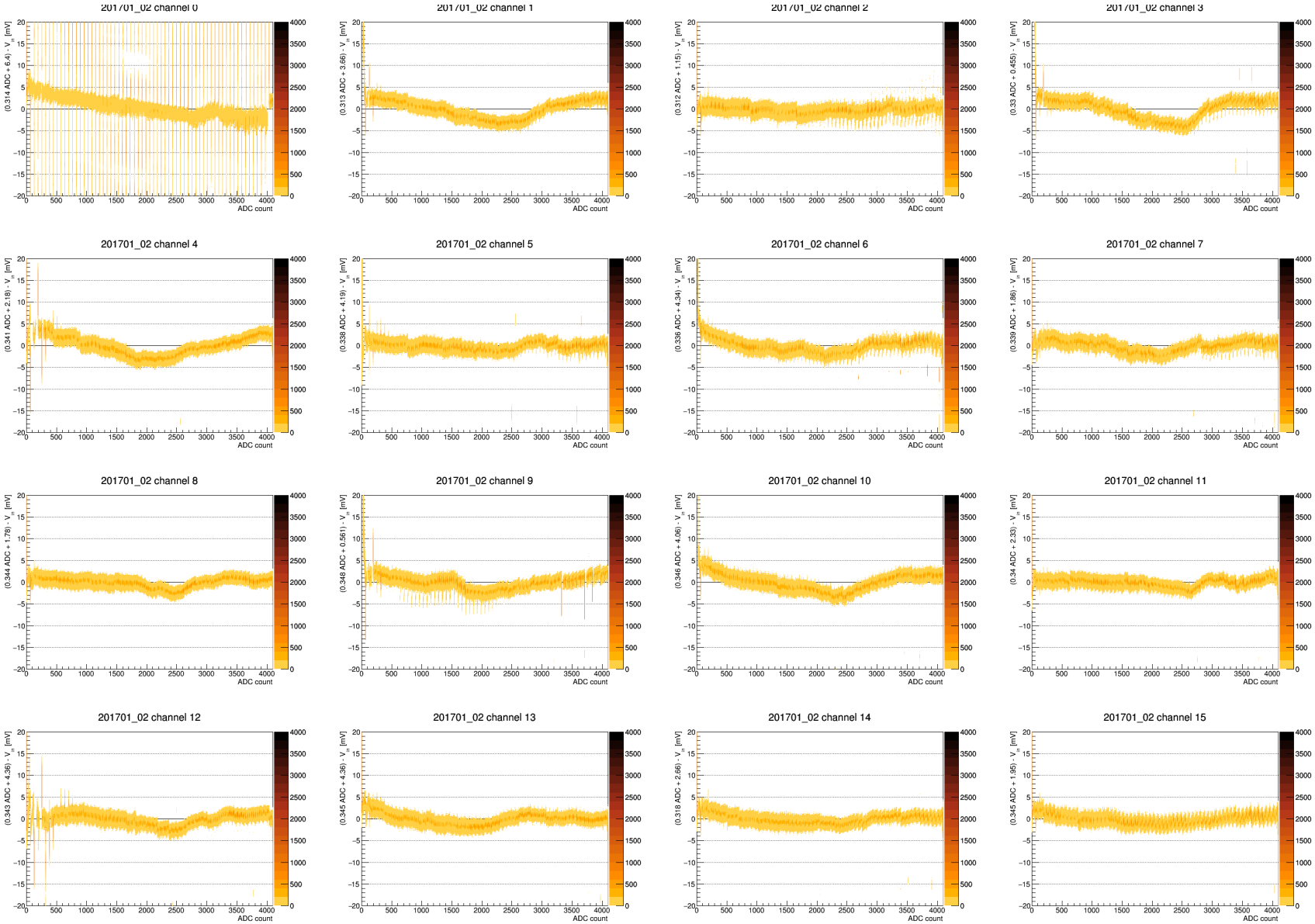

201701_05 fit Vin/ADC
Gain
hg
Entries 16
Mean 0.3369
Underflow 0
Overflow 0
# channels
Gain [mV/ADC]


201701_05 fit offset
Offset
hp
Entries 16
Mean 3.866
Underflow 0
Overflow 0
# channels
Offset [mV]

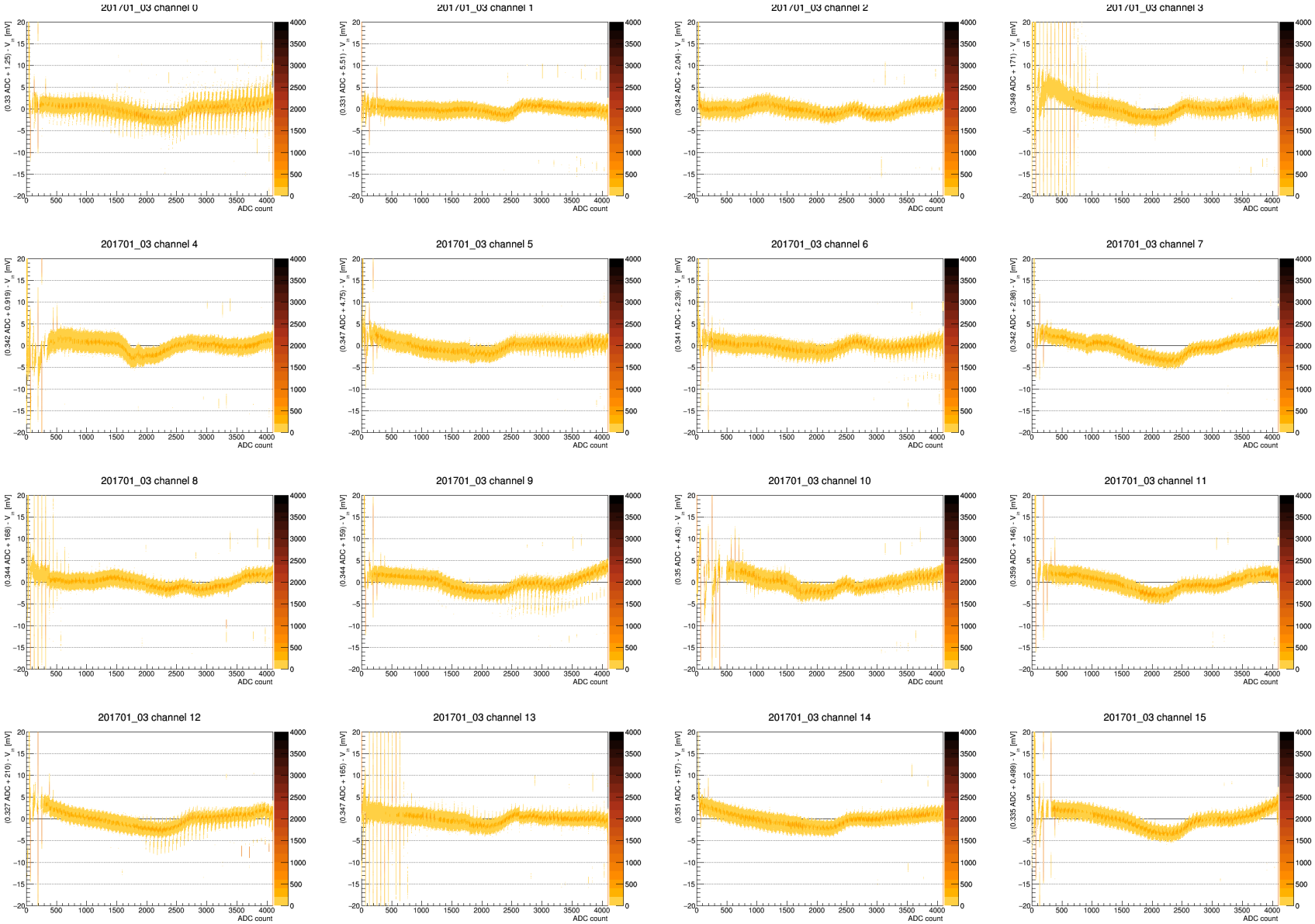
# ADC 0 (bare)


201701_00 channel 0
201701_00 channel 1
201701_00 channel 2
201701_00 channel 3
201701_00 channel 4
201701_00 channel 5
201701_00 channel 6
201701_00 channel 7
201701_00 channel 8
201701_00 channel 9
201701_00 channel 10
201701_00 channel 11
201701_00 channel 12
201701_00 channel 13
201701_00 channel 14
201701_00 channel 15
ADC count
±20 mV

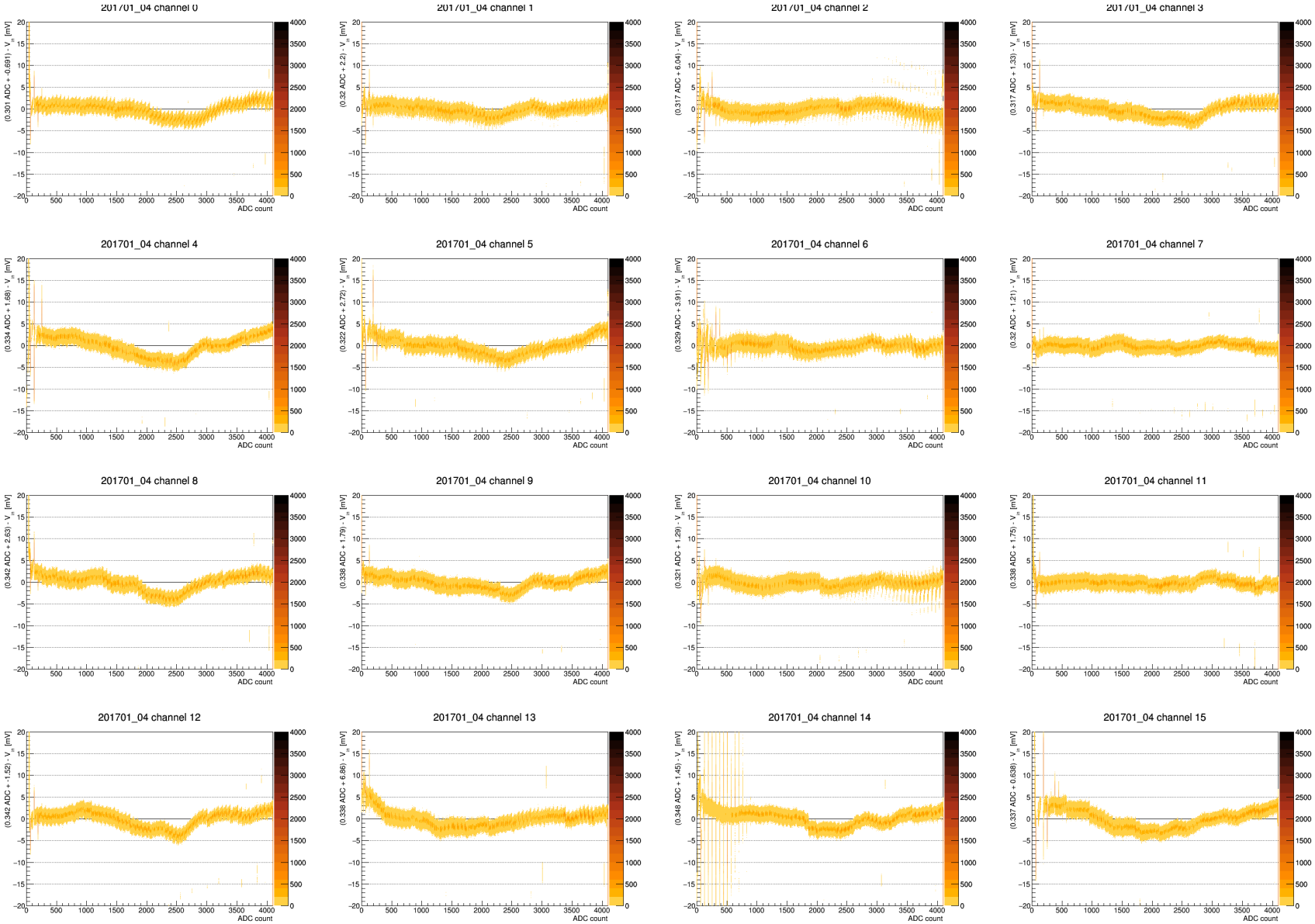
# ADC 2 (board)


201701_02 channel 0
201701_02 channel 1
201701_02 channel 2
201701_02 channel 3
201701_02 channel 4
201701_02 channel 5
201701_02 channel 6
201701_02 channel 7
201701_02 channel 8
201701_02 channel 9
201701_02 channel 10
201701_02 channel 11
201701_02 channel 12
201701_02 channel 13
201701_02 channel 14
201701_02 channel 15
ADC count

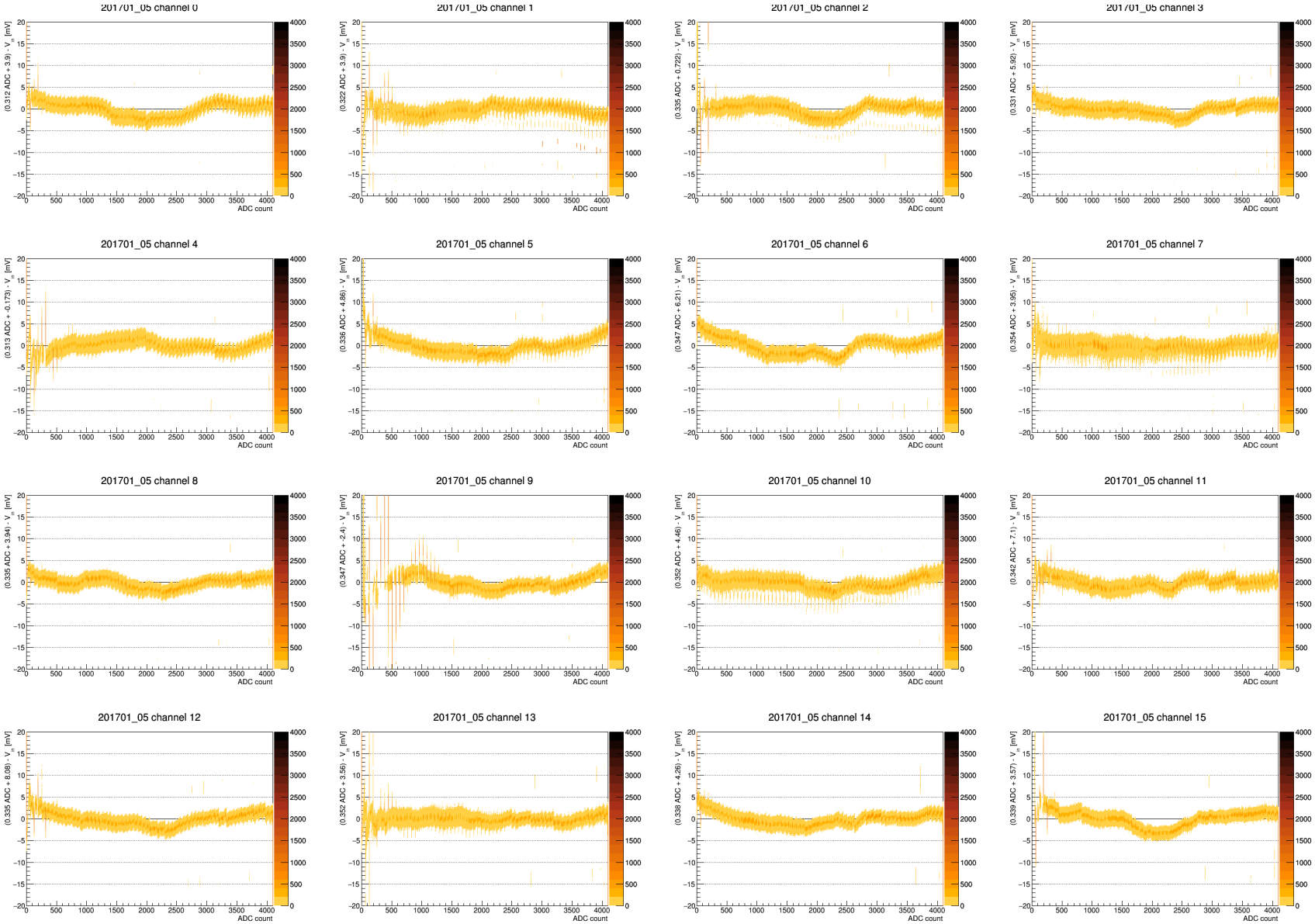
# ADC 3


201701_03 channel 0
201701_03 channel 1
201701_03 channel 2
201701_03 channel 3
201701_03 channel 4
201701_03 channel 5
201701_03 channel 6
201701_03 channel 7
201701_03 channel 8
201701_03 channel 9
201701_03 channel 10
201701_03 channel 11
201701_03 channel 12
201701_03 channel 13
201701_03 channel 14
201701_03 channel 15
ADC count

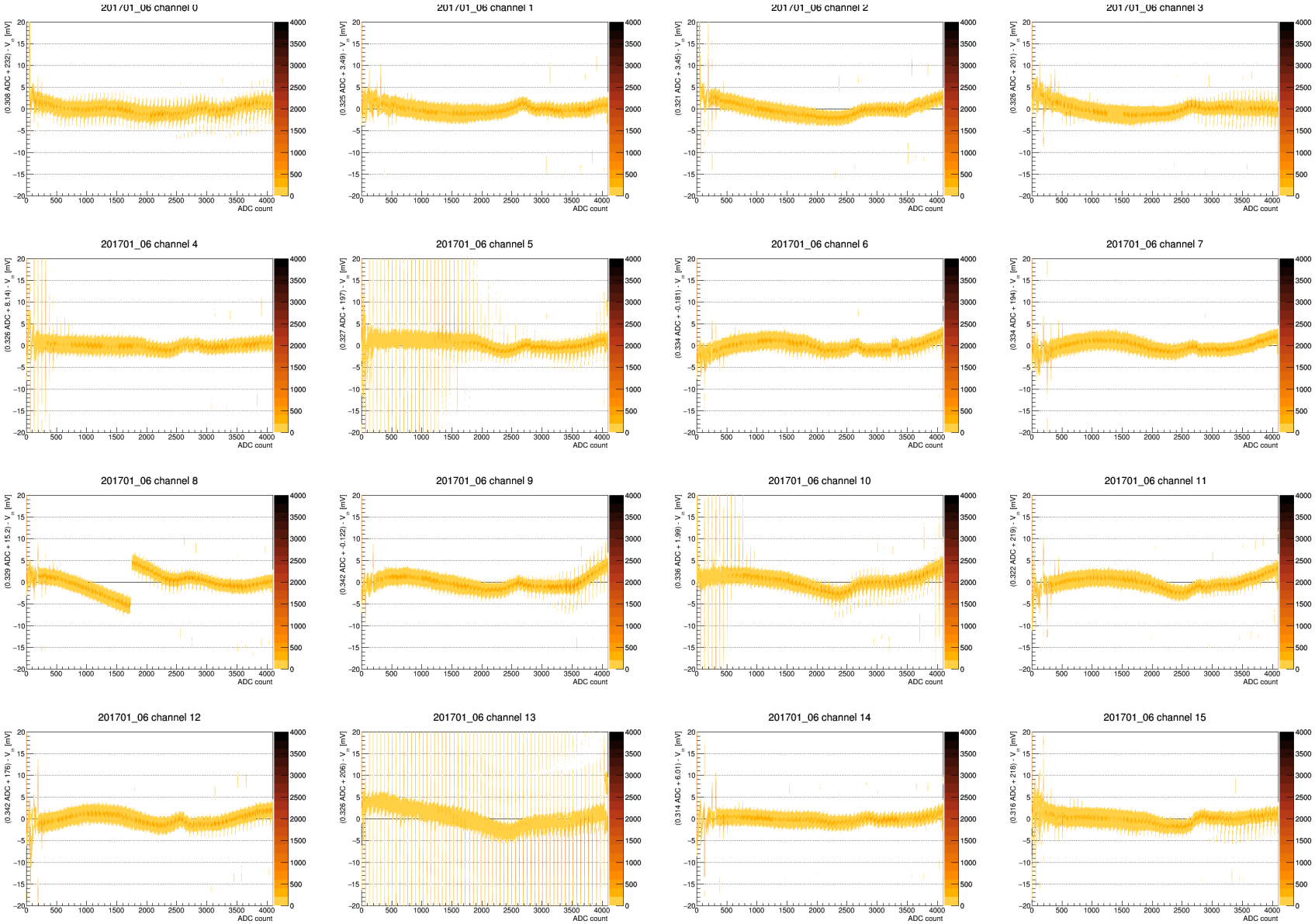
# ADC 4 (board)


201701_04 channel 0
201701_04 channel 1
201701_04 channel 2
201701_04 channel 3
201701_04 channel 4
201701_04 channel 5
201701_04 channel 6
201701_04 channel 7
201701_04 channel 8
201701_04 channel 9
201701_04 channel 10
201701_04 channel 11
201701_04 channel 12
201701_04 channel 13
201701_04 channel 14
201701_04 channel 15
ADC count

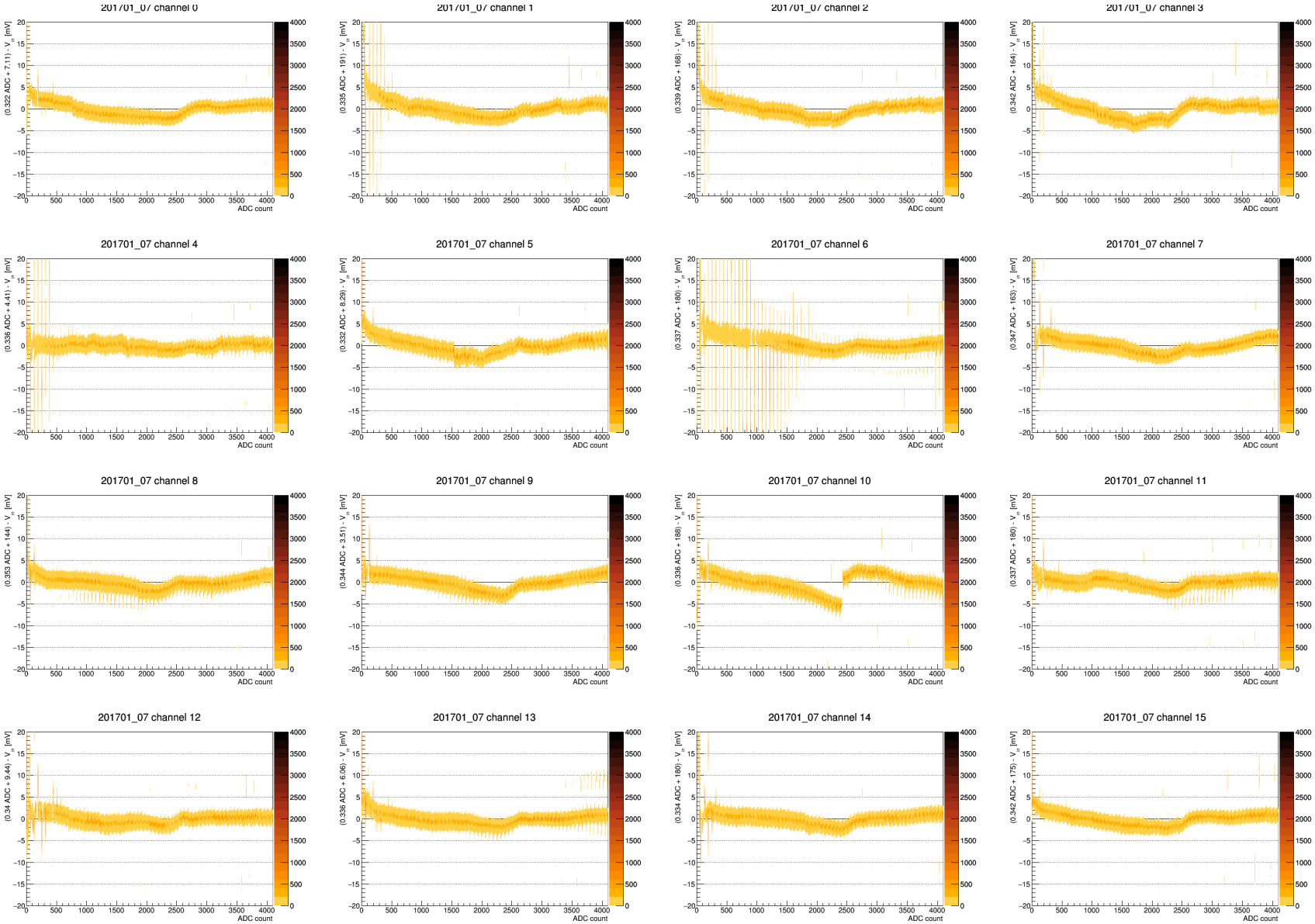
# ADC 5


201701_05 channel 0
201701_05 channel 1
201701_05 channel 2
201701_05 channel 3
201701_05 channel 4
201701_05 channel 5
201701_05 channel 6
201701_05 channel 7
201701_05 channel 8
201701_05 channel 9
201701_05 channel 10
201701_05 channel 11
201701_05 channel 12
201701_05 channel 13
201701_05 channel 14
201701_05 channel 15
ADC count

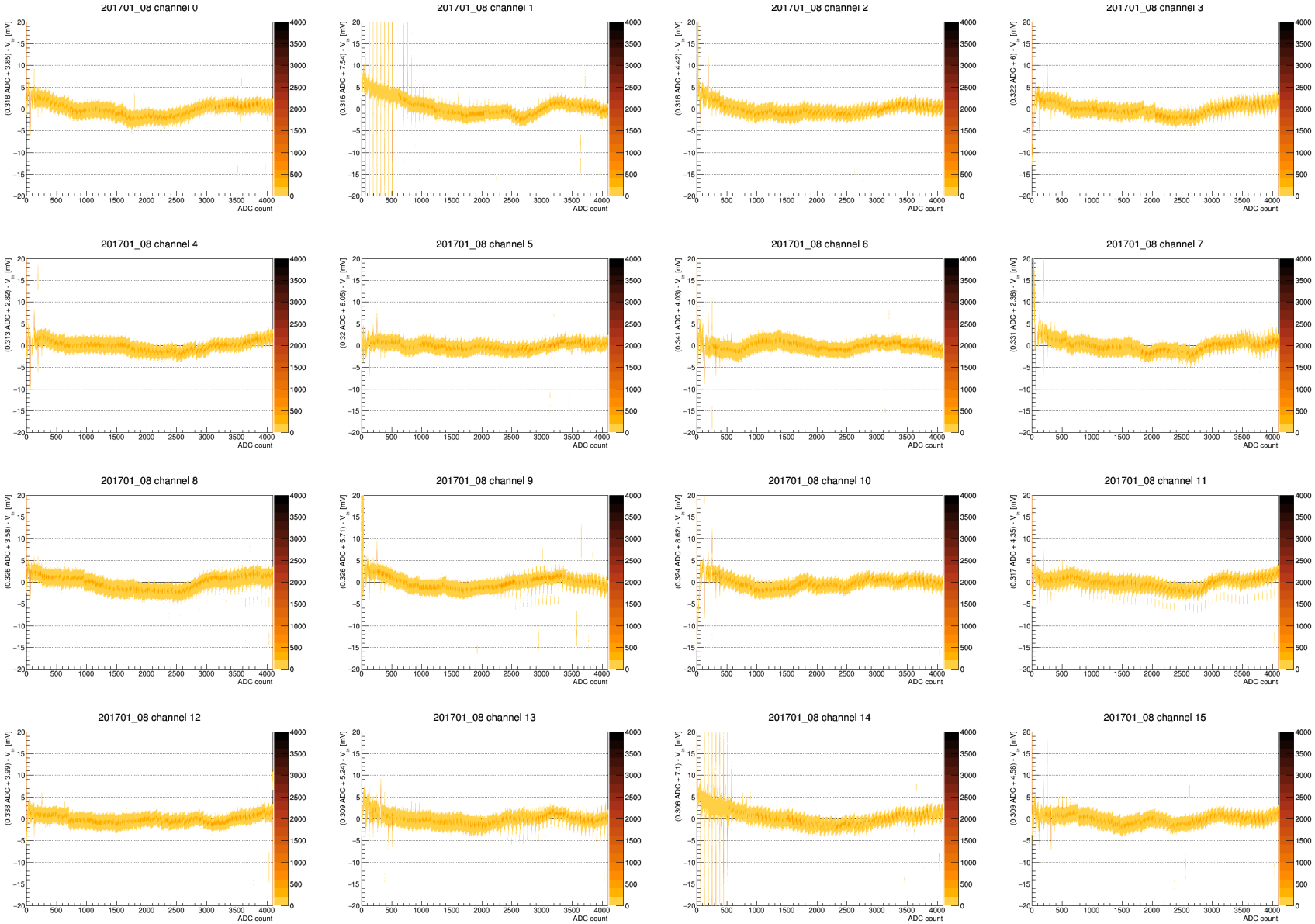
# ADC 6


201701_06 channel 0
201701_06 channel 1
201701_06 channel 2
201701_06 channel 3
201701_06 channel 4
201701_06 channel 5
201701_06 channel 6
201701_06 channel 7
201701_06 channel 8
201701_06 channel 9
201701_06 channel 10
201701_06 channel 11
201701_06 channel 12
201701_06 channel 13
201701_06 channel 14
201701_06 channel 15
ADC count

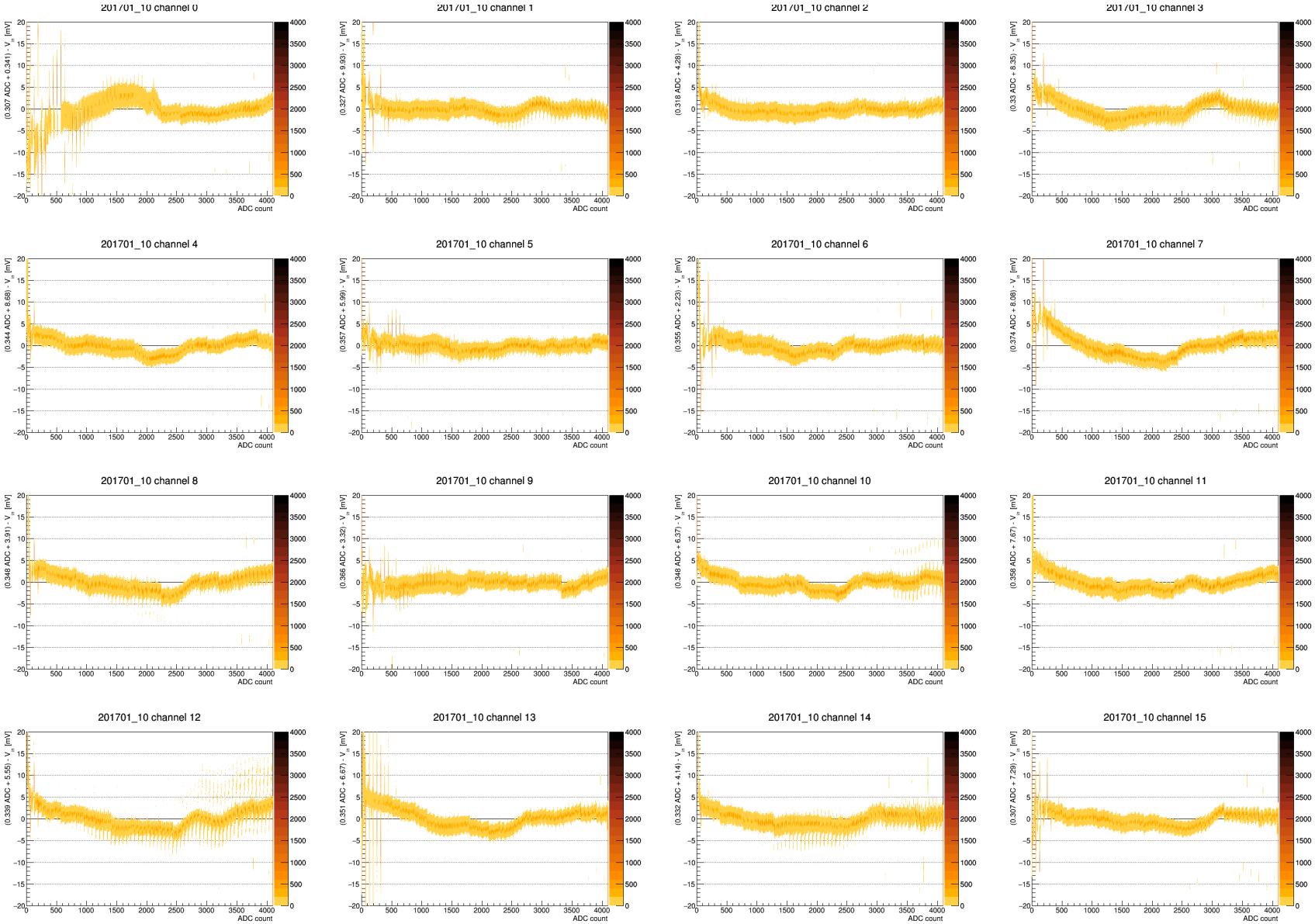
# ADC 7


201701_07 channel 0
201701_07 channel 1
201701_07 channel 2
201701_07 channel 3
201701_07 channel 4
201701_07 channel 5
201701_07 channel 6
201701_07 channel 7
201701_07 channel 8
201701_07 channel 9
201701_07 channel 10
201701_07 channel 11
201701_07 channel 12
201701_07 channel 13
201701_07 channel 14
201701_07 channel 15
ADC count

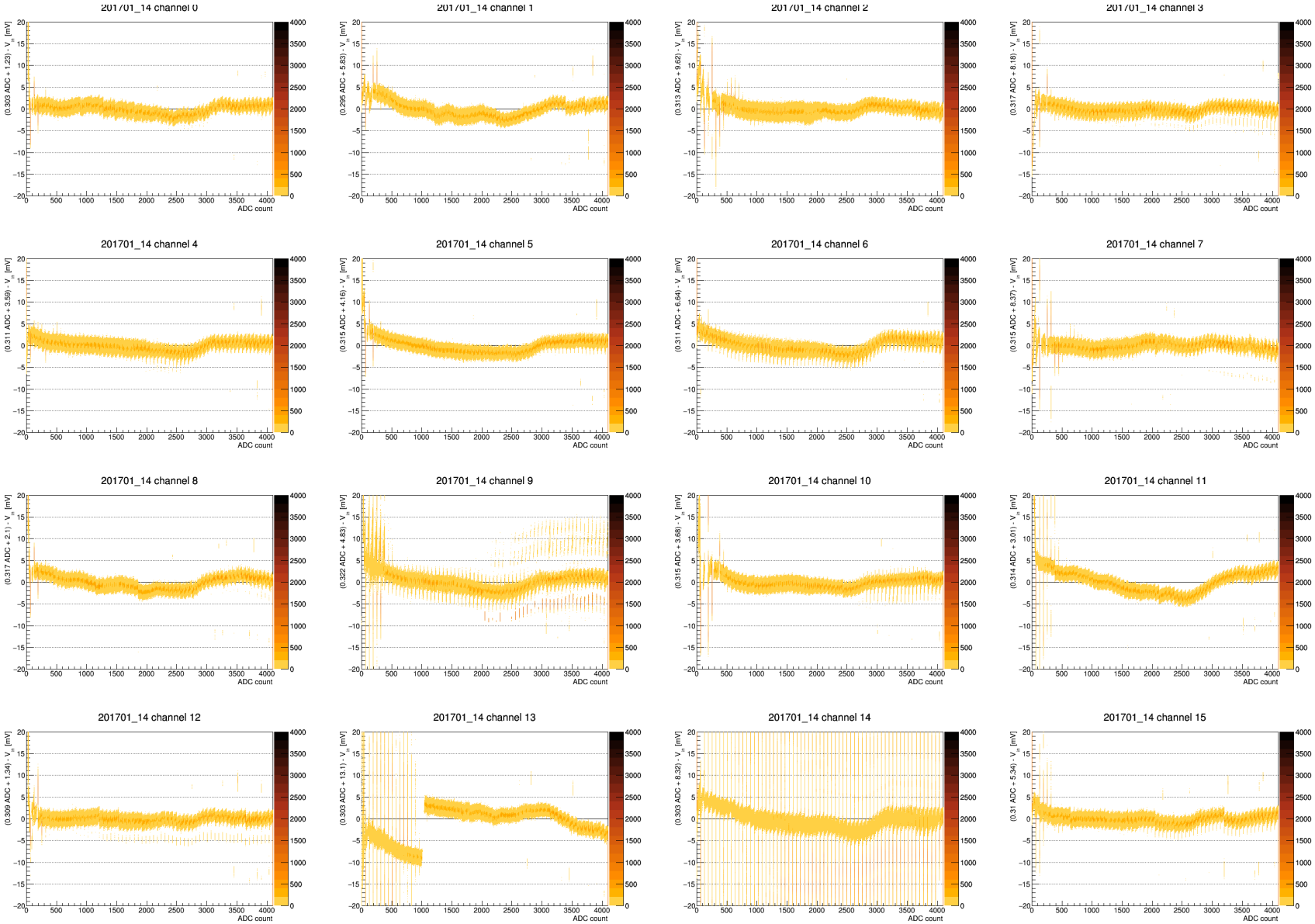
# ADC 8


201701_08 channel 0
201701_08 channel 1
201701_08 channel 2
201701_08 channel 3
201701_08 channel 4
201701_08 channel 5
201701_08 channel 6
201701_08 channel 7
201701_08 channel 8
201701_08 channel 9
201701_08 channel 10
201701_08 channel 11
201701_08 channel 12
201701_08 channel 13
201701_08 channel 14
201701_08 channel 15
ADC count

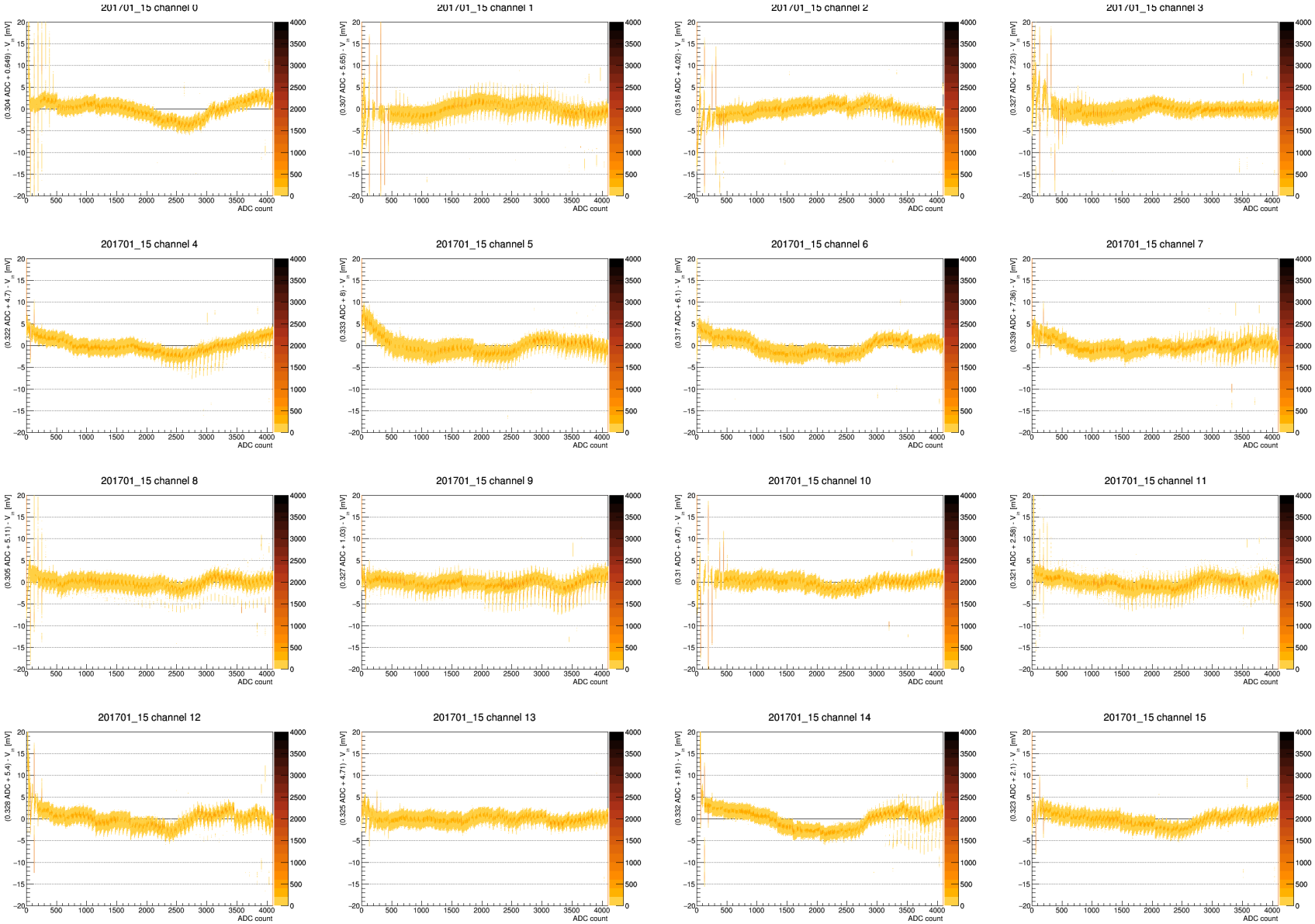
# ADC 10


201701_10 channel 0
201701_10 channel 1
201701_10 channel 2
201701_10 channel 3
201701_10 channel 4
201701_10 channel 5
201701_10 channel 6
201701_10 channel 7
201701_10 channel 8
201701_10 channel 9
201701_10 channel 10
201701_10 channel 11
201701_10 channel 12
201701_10 channel 13
201701_10 channel 14
201701_10 channel 15
ADC count

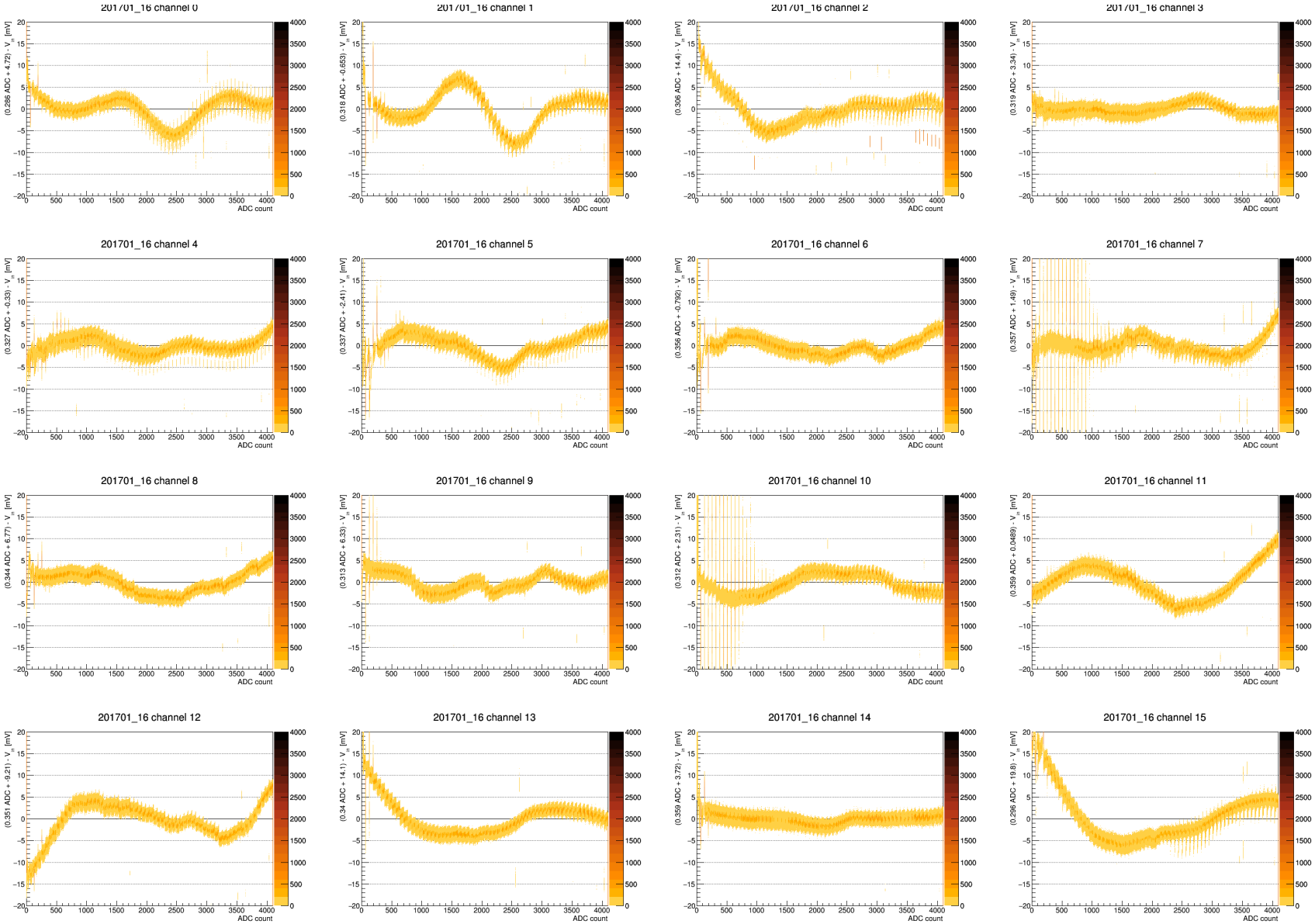
# ADC 14


201701_14 channel 0
201701_14 channel 1
201701_14 channel 2
201701_14 channel 3
201701_14 channel 4
201701_14 channel 5
201701_14 channel 6
201701_14 channel 7
201701_14 channel 8
201701_14 channel 9
201701_14 channel 10
201701_14 channel 11
201701_14 channel 12
201701_14 channel 13
201701_14 channel 14
201701_14 channel 15
ADC count

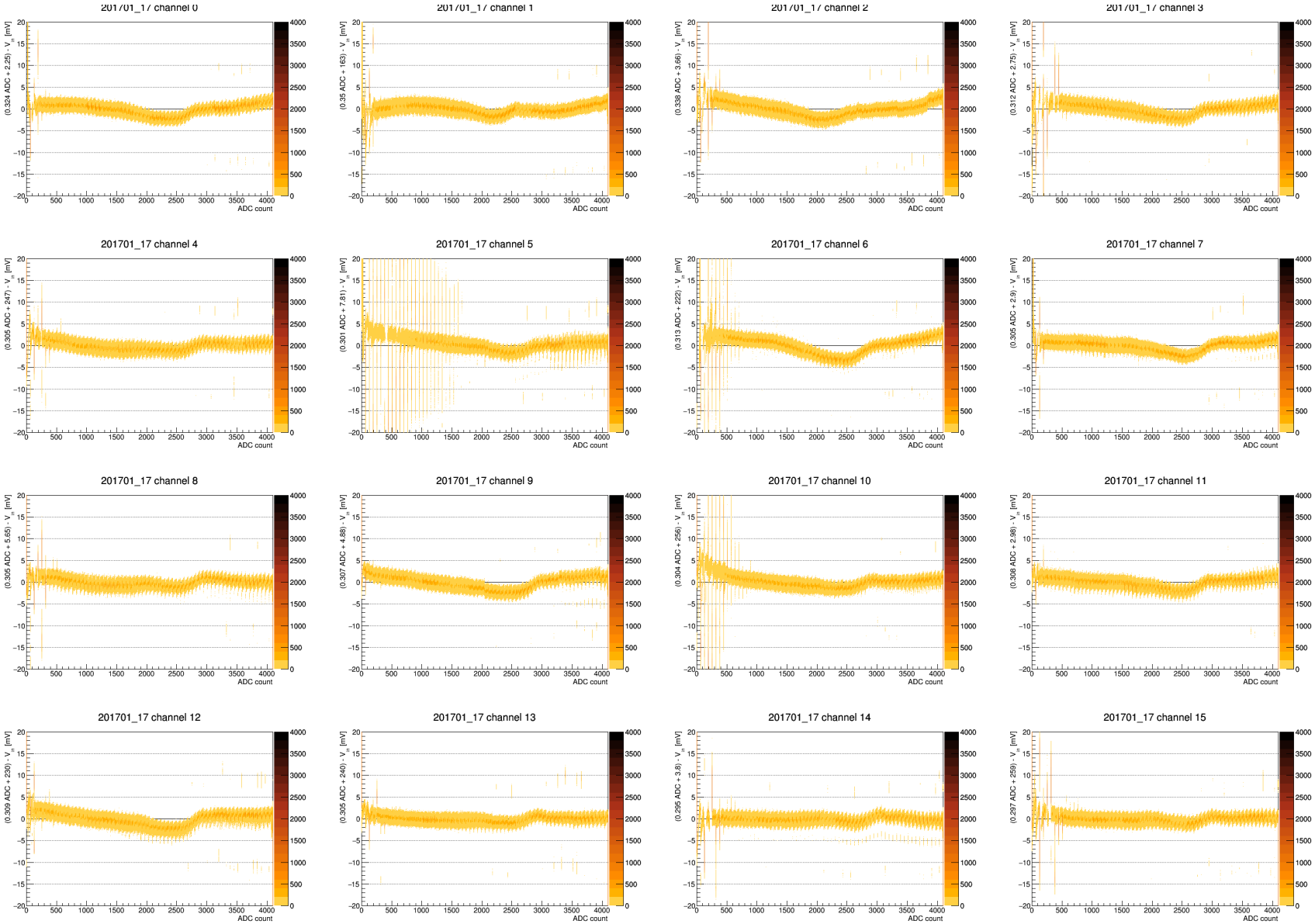
# ADC 15


201701_15 channel 0
201701_15 channel 1
201701_15 channel 2
201701_15 channel 3
201701_15 channel 4
201701_15 channel 5
201701_15 channel 6
201701_15 channel 7
201701_15 channel 8
201701_15 channel 9
201701_15 channel 10
201701_15 channel 11
201701_15 channel 12
201701_15 channel 13
201701_15 channel 14
201701_15 channel 15
ADC count

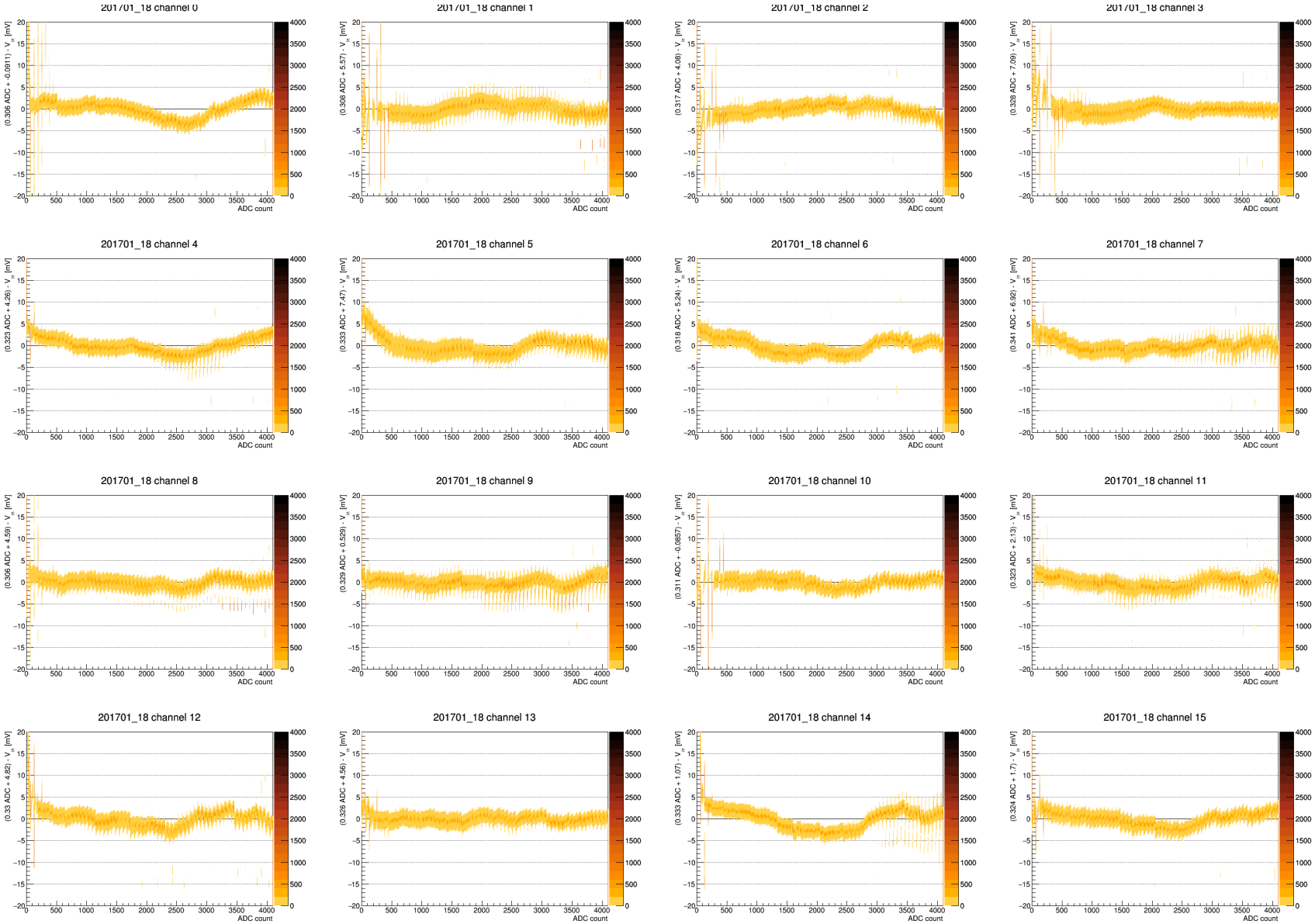
# ADC 16


201701_16 channel 0
201701_16 channel 1
201701_16 channel 2
201701_16 channel 3
201701_16 channel 4
201701_16 channel 5
201701_16 channel 6
201701_16 channel 7
201701_16 channel 8
201701_16 channel 9
201701_16 channel 10
201701_16 channel 11
201701_16 channel 12
201701_16 channel 13
201701_16 channel 14
201701_16 channel 15
ADC count

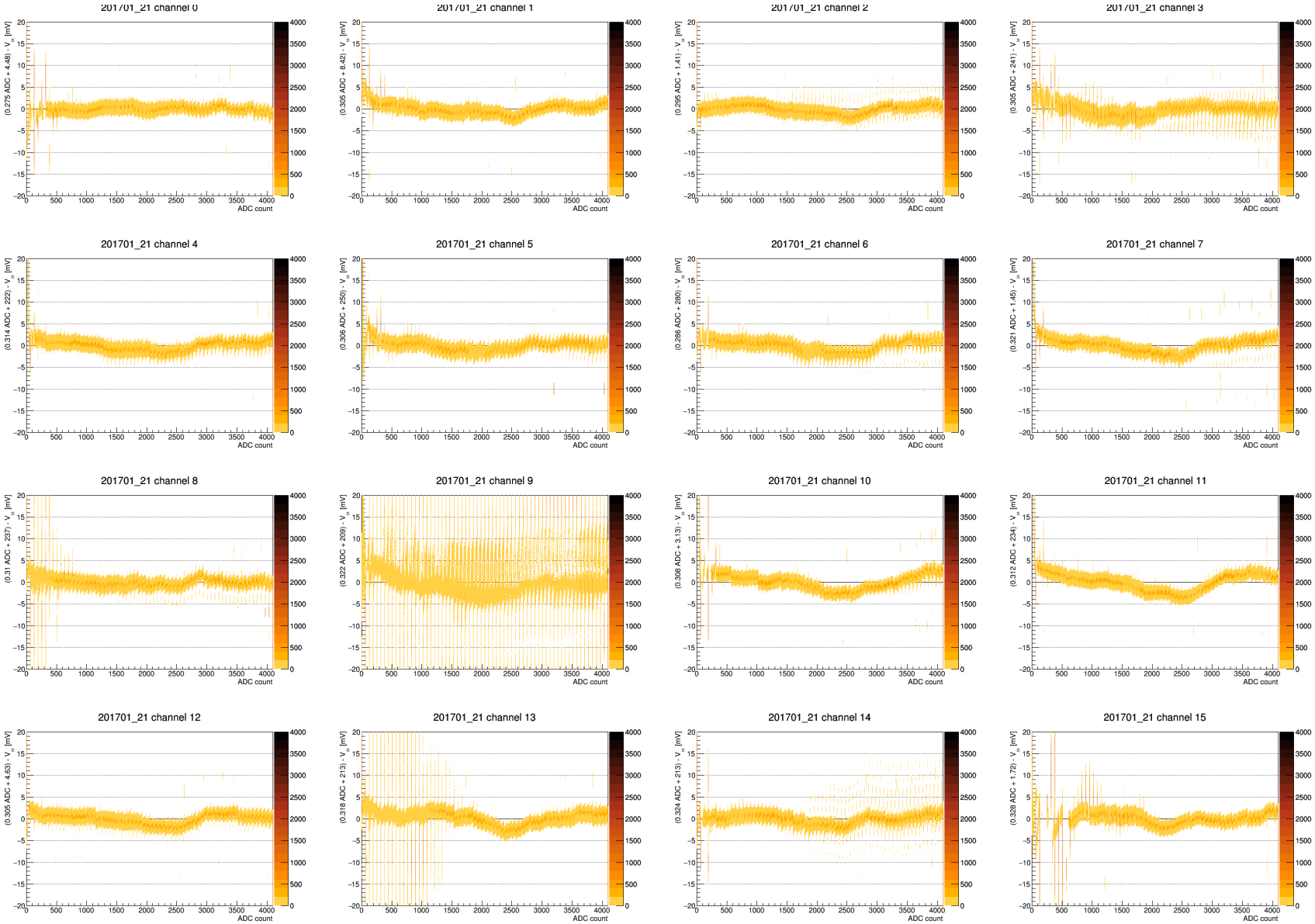
# ADC 17


201701_17 channel 0
201701_17 channel 1
201701_17 channel 2
201701_17 channel 3
201701_17 channel 4
201701_17 channel 5
201701_17 channel 6
201701_17 channel 7
201701_17 channel 8
201701_17 channel 9
201701_17 channel 10
201701_17 channel 11
201701_17 channel 12
201701_17 channel 13
201701_17 channel 14
201701_17 channel 15
ADC count

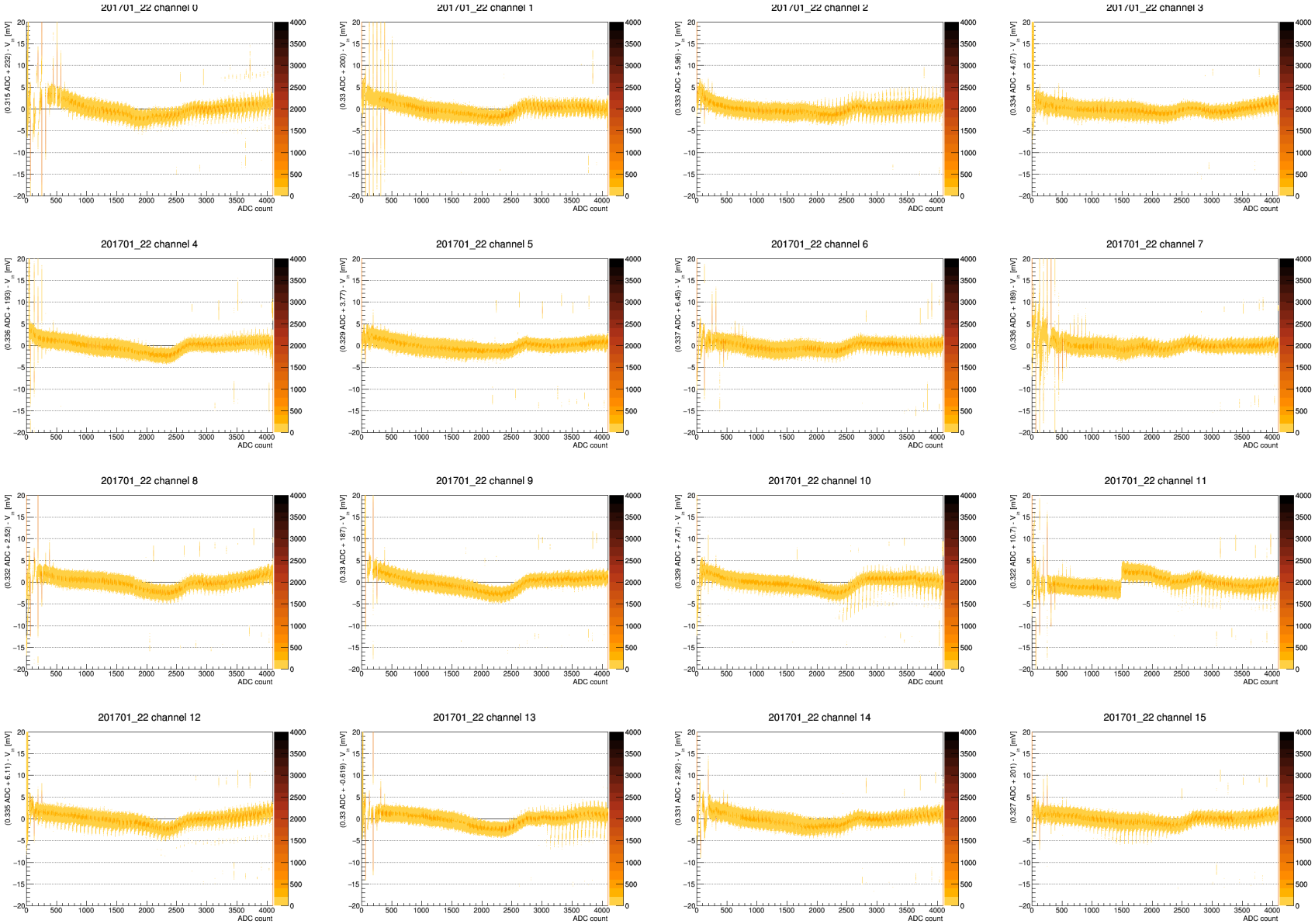
# ADC 18


201701_18 channel 0
201701_18 channel 1
201701_18 channel 2
201701_18 channel 3
201701_18 channel 4
201701_18 channel 5
201701_18 channel 6
201701_18 channel 7
201701_18 channel 8
201701_18 channel 9
201701_18 channel 10
201701_18 channel 11
201701_18 channel 12
201701_18 channel 13
201701_18 channel 14
201701_18 channel 15
ADC count

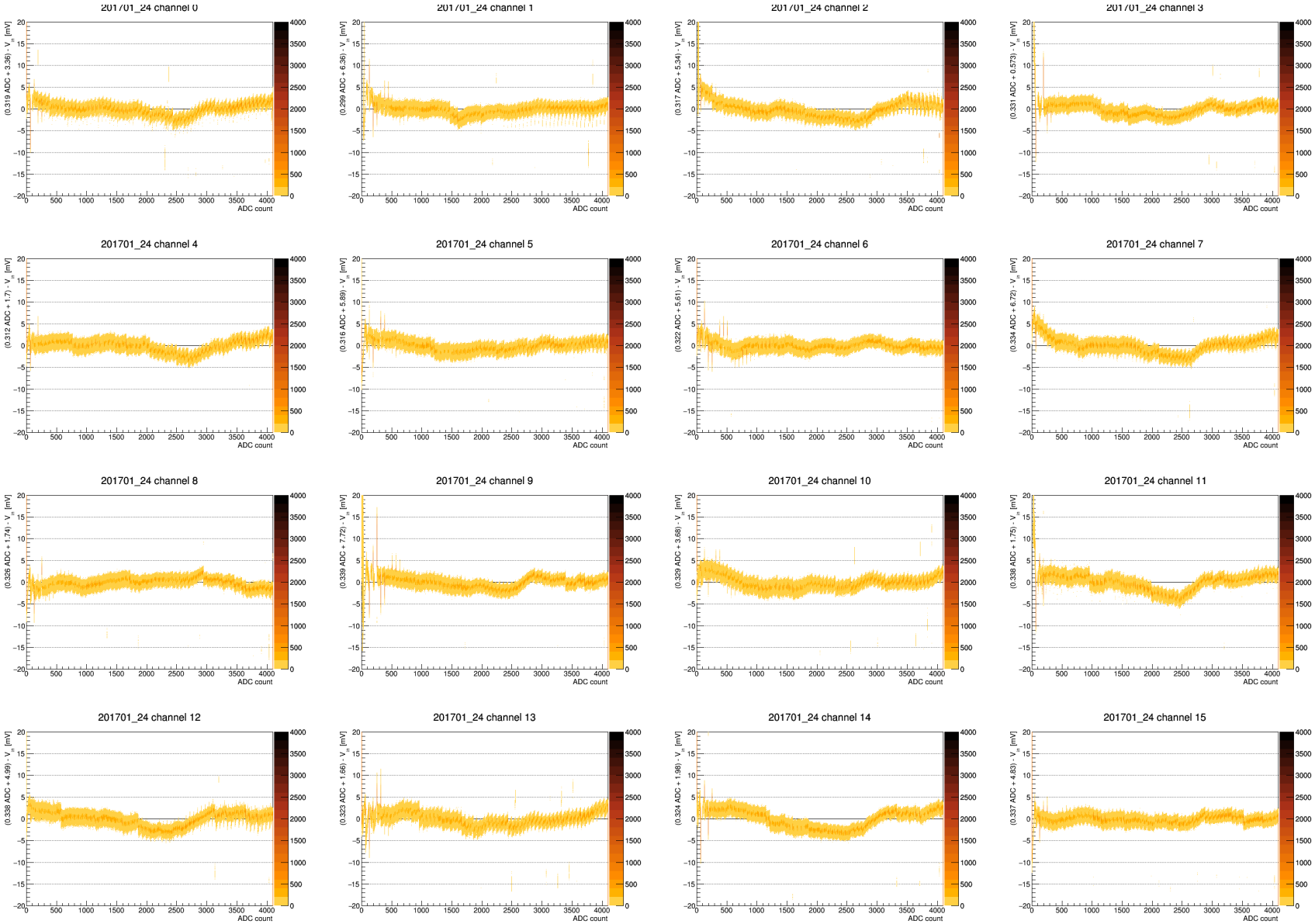
# ADC 21


201701_21 channel 0
201701_21 channel 1
201701_21 channel 2
201701_21 channel 3
201701_21 channel 4
201701_21 channel 5
201701_21 channel 6
201701_21 channel 7
201701_21 channel 8
201701_21 channel 9
201701_21 channel 10
201701_21 channel 11
201701_21 channel 12
201701_21 channel 13
201701_21 channel 14
201701_21 channel 15
ADC count

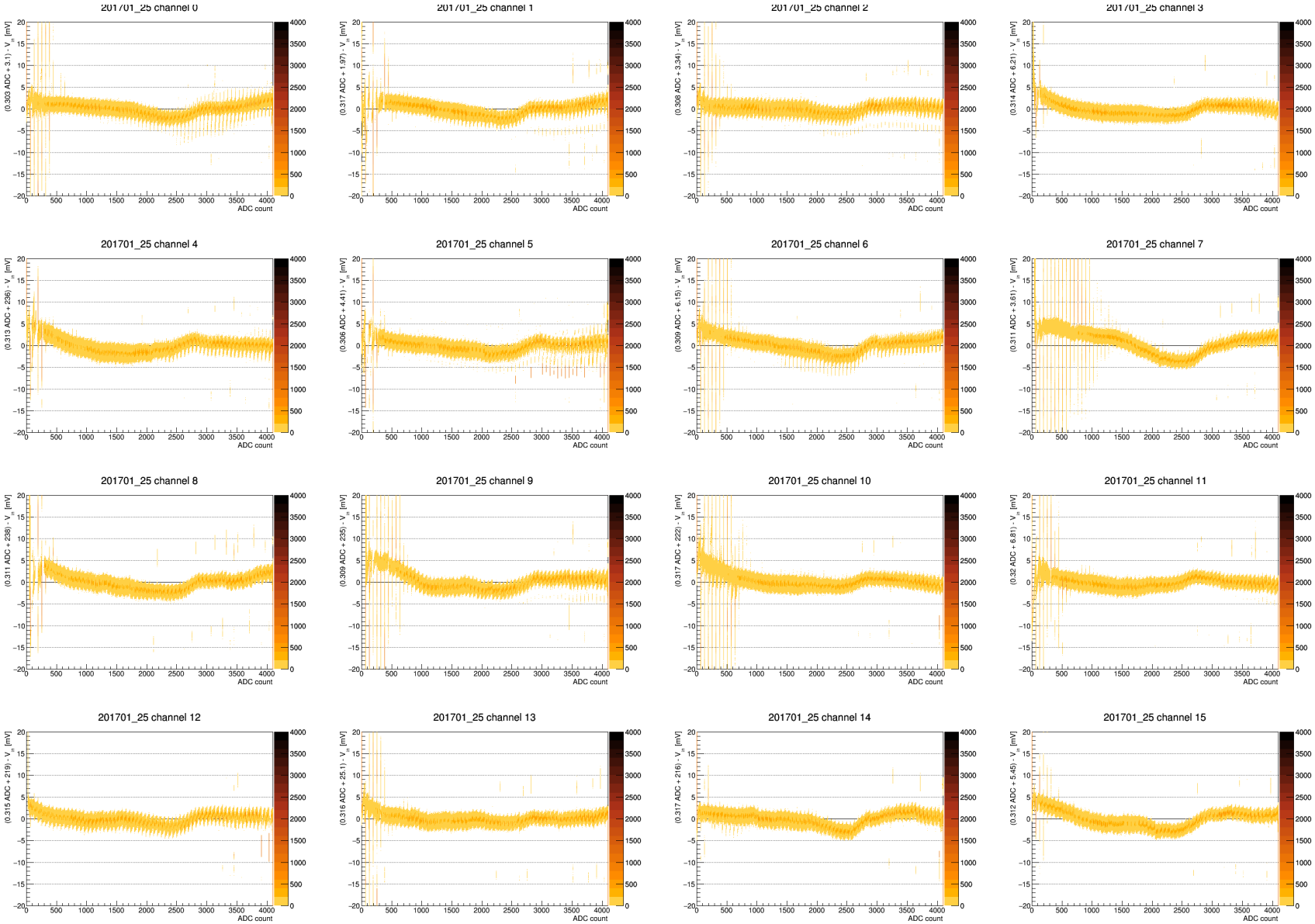
# ADC 22


201701_22 channel 0
201701_22 channel 1
201701_22 channel 2
201701_22 channel 3
201701_22 channel 4
201701_22 channel 5
201701_22 channel 6
201701_22 channel 7
201701_22 channel 8
201701_22 channel 9
201701_22 channel 10
201701_22 channel 11
201701_22 channel 12
201701_22 channel 13
201701_22 channel 14
201701_22 channel 15
ADC count

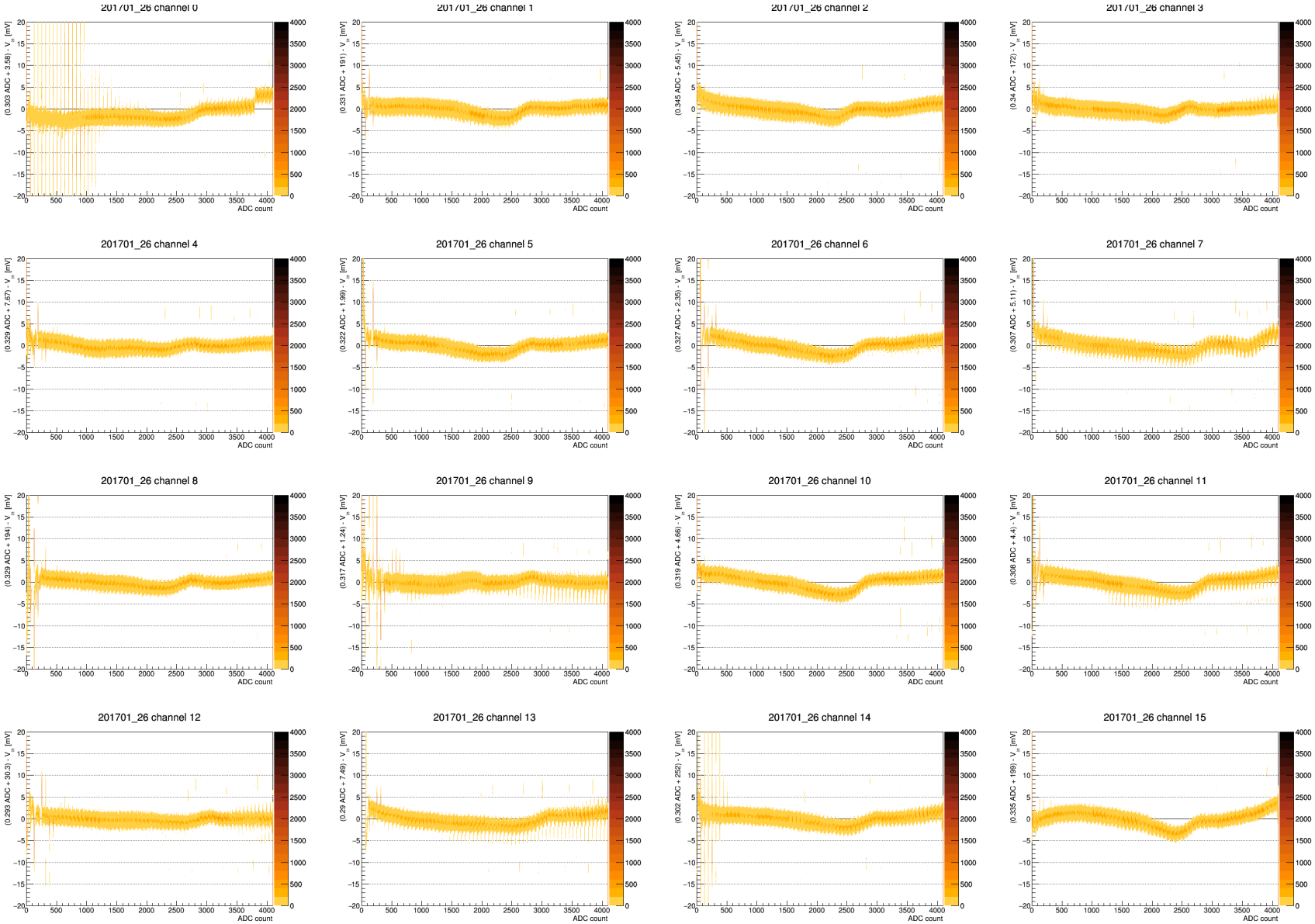
# ADC 24


201701_24 channel 0
201701_24 channel 1
201701_24 channel 2
201701_24 channel 3
201701_24 channel 4
201701_24 channel 5
201701_24 channel 6
201701_24 channel 7
201701_24 channel 8
201701_24 channel 9
201701_24 channel 10
201701_24 channel 11
201701_24 channel 12
201701_24 channel 13
201701_24 channel 14
201701_24 channel 15
ADC count

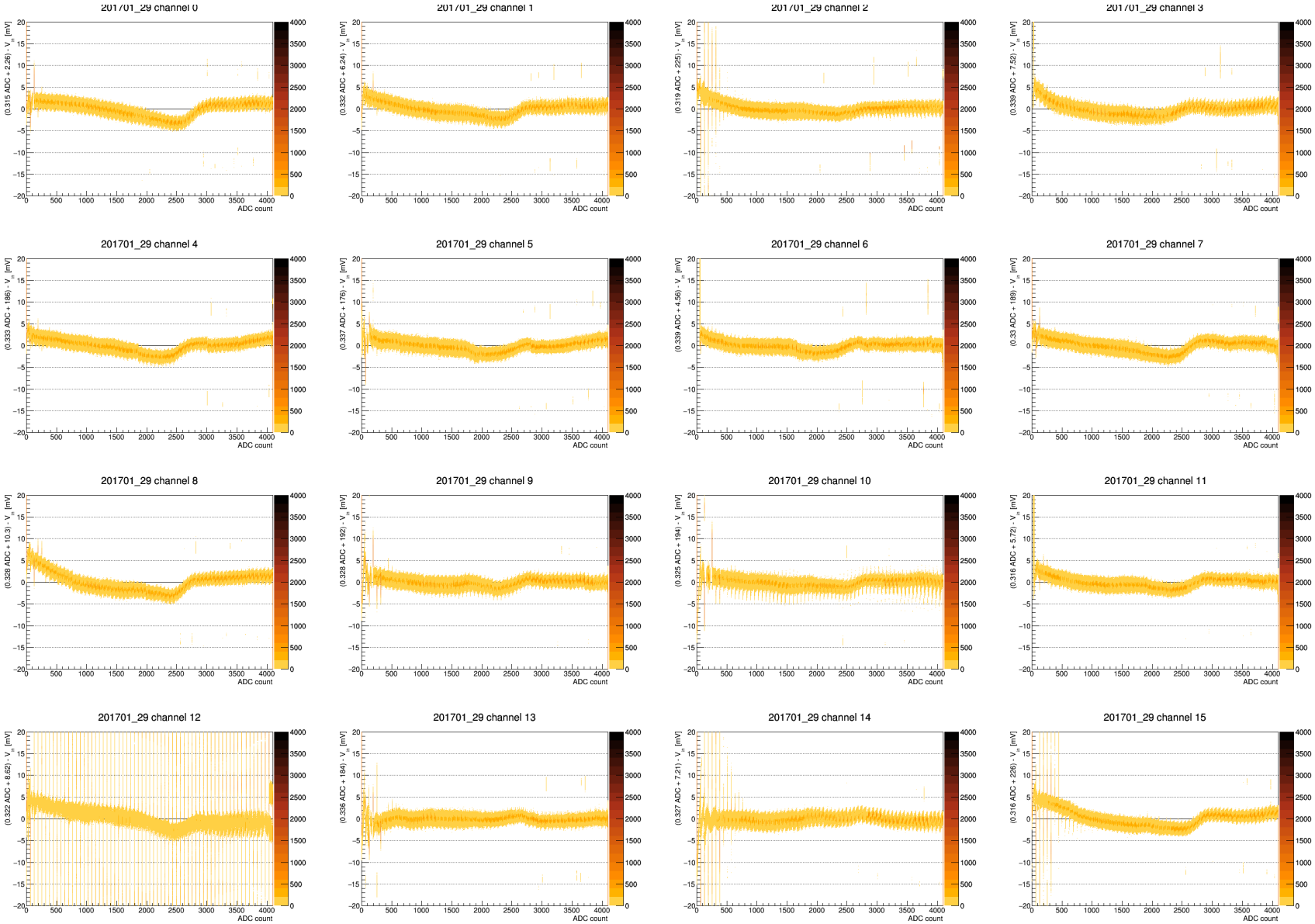
# ADC 25


201701_25 channel 0
201701_25 channel 1
201701_25 channel 2
201701_25 channel 3
201701_25 channel 4
201701_25 channel 5
201701_25 channel 6
201701_25 channel 7
201701_25 channel 8
201701_25 channel 9
201701_25 channel 10
201701_25 channel 11
201701_25 channel 12
201701_25 channel 13
201701_25 channel 14
201701_25 channel 15
ADC count

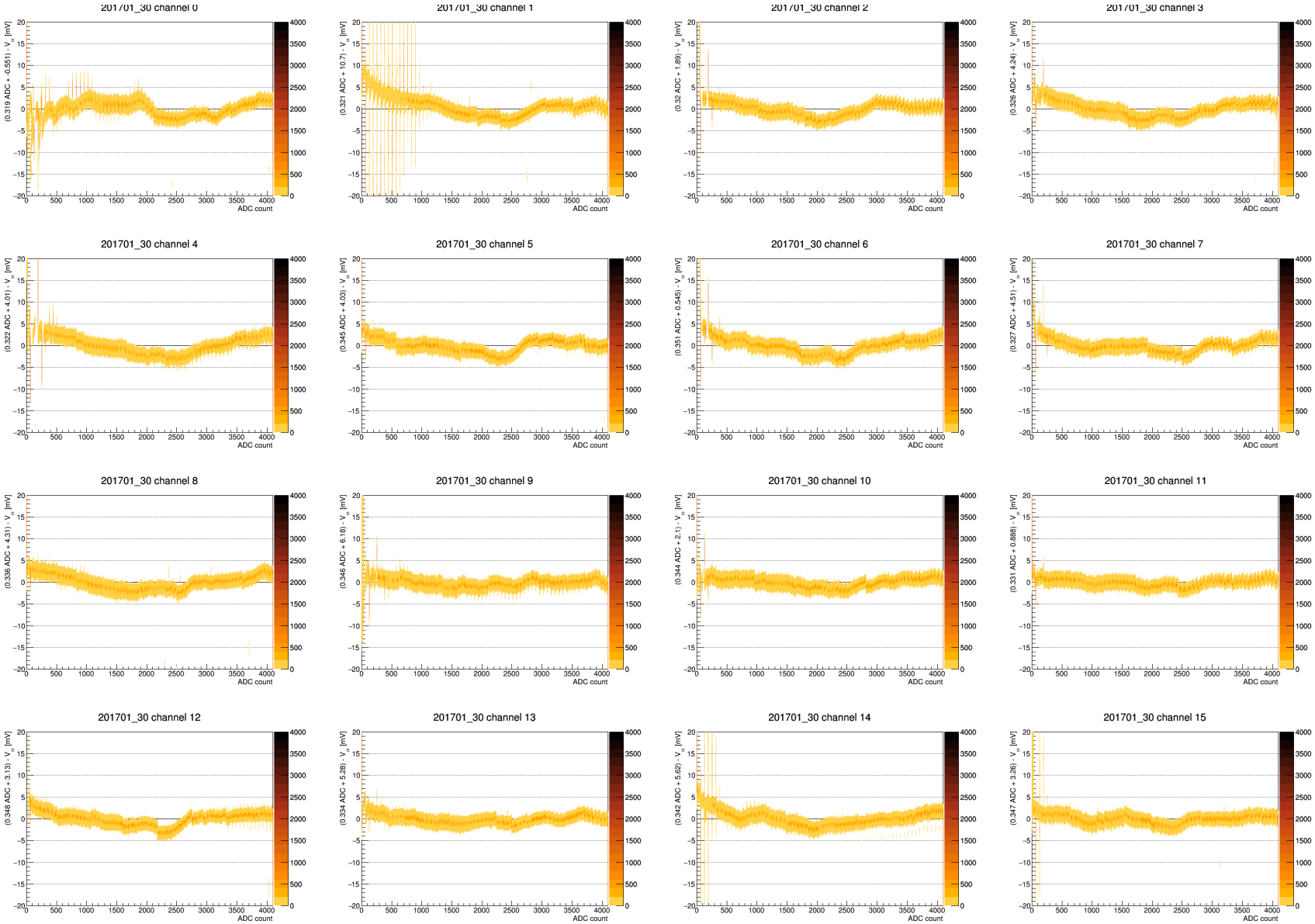
# ADC 26


201701_26 channel 0
201701_26 channel 1
201701_26 channel 2
201701_26 channel 3
201701_26 channel 4
201701_26 channel 5
201701_26 channel 6
201701_26 channel 7
201701_26 channel 8
201701_26 channel 9
201701_26 channel 10
201701_26 channel 11
201701_26 channel 12
201701_26 channel 13
201701_26 channel 14
201701_26 channel 15
ADC count

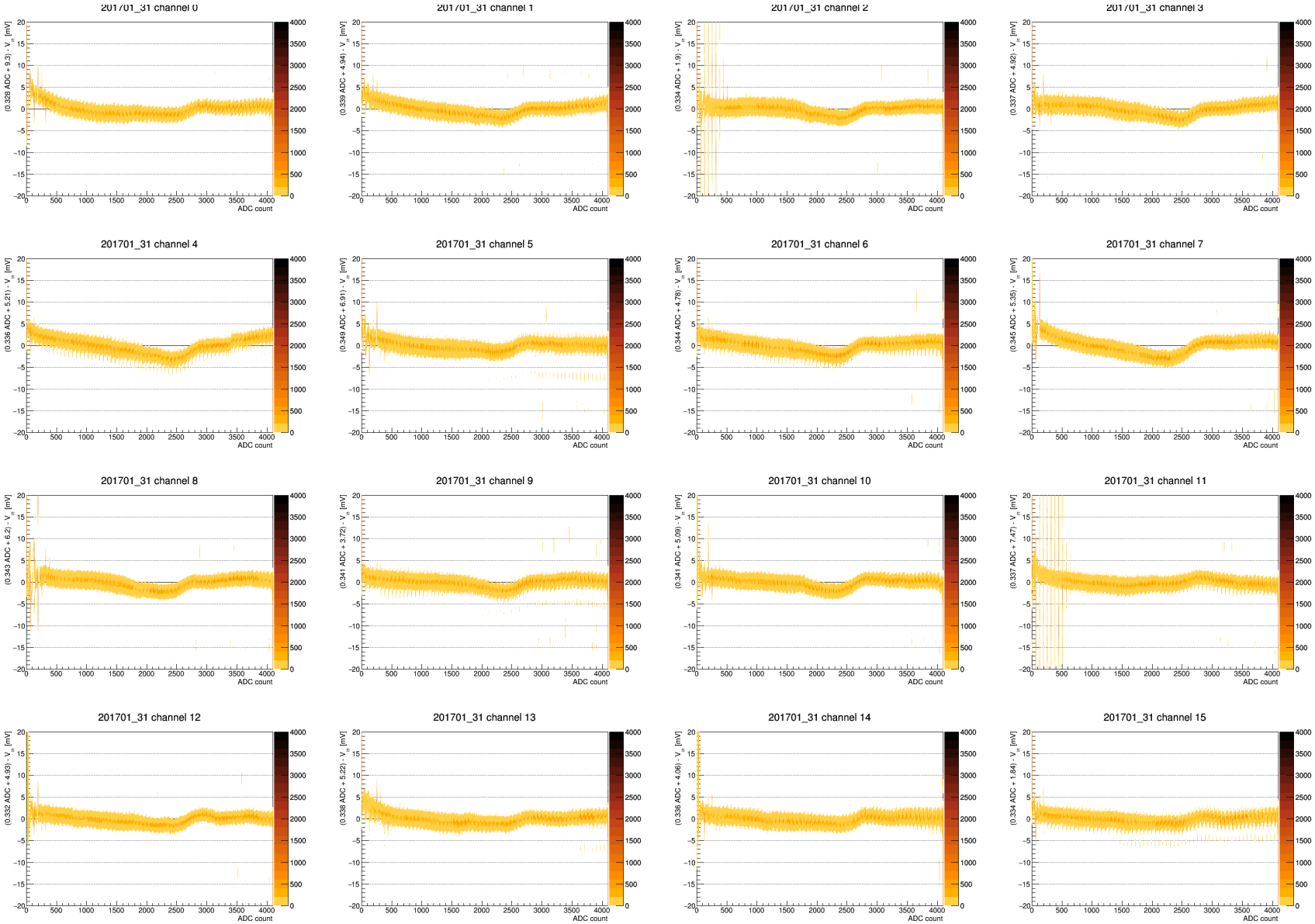
# ADC 29


201701_29 channel 0
201701_29 channel 1
201701_29 channel 2
201701_29 channel 3
201701_29 channel 4
201701_29 channel 5
201701_29 channel 6
201701_29 channel 7
201701_29 channel 8
201701_29 channel 9
201701_29 channel 10
201701_29 channel 11
201701_29 channel 12
201701_29 channel 13
201701_29 channel 14
201701_29 channel 15
ADC count

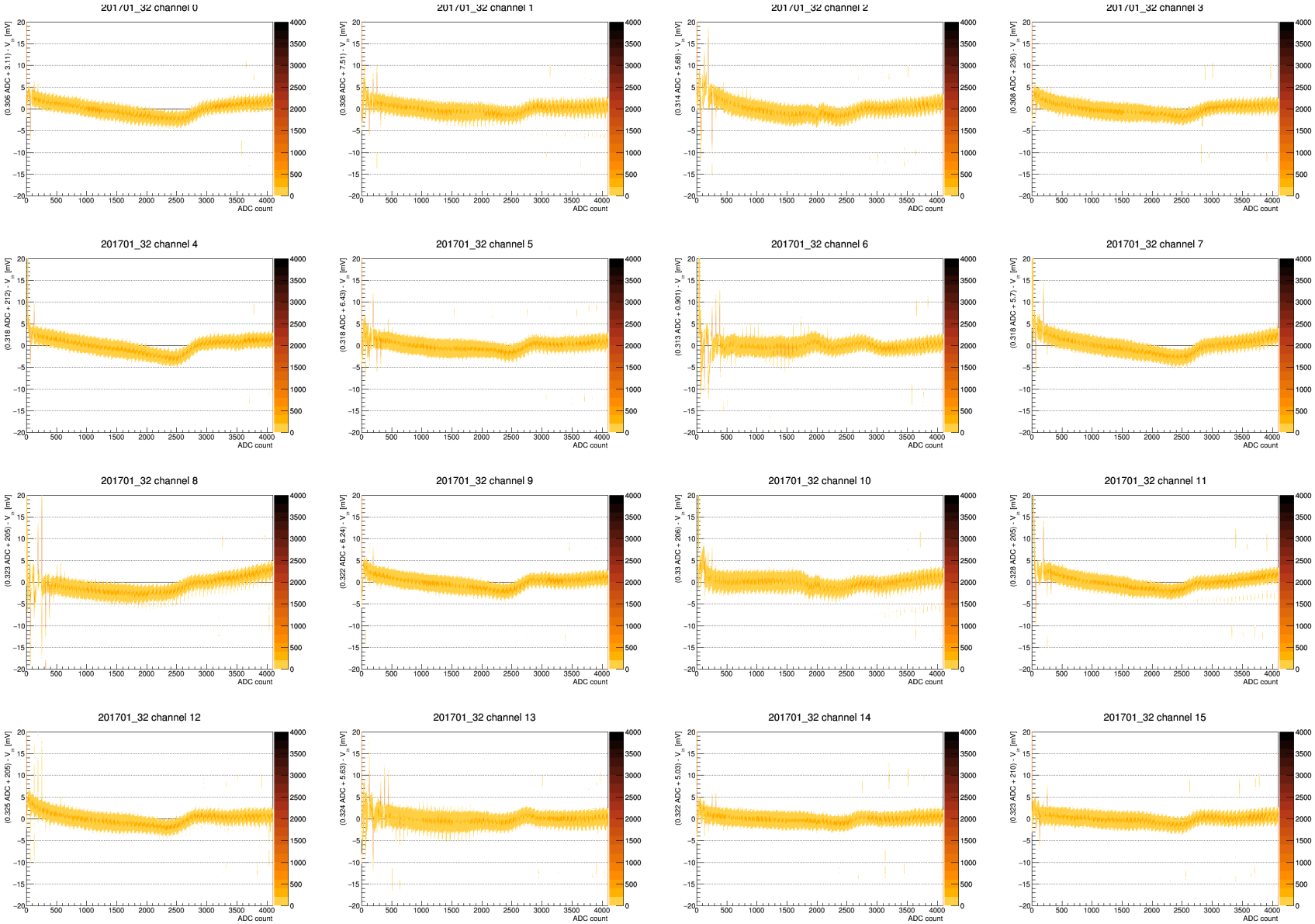
# ADC 30


201701_30 channel 0
201701_30 channel 1
201701_30 channel 2
201701_30 channel 3
201701_30 channel 4
201701_30 channel 5
201701_30 channel 6
201701_30 channel 7
201701_30 channel 8
201701_30 channel 9
201701_30 channel 10
201701_30 channel 11
201701_30 channel 12
201701_30 channel 13
201701_30 channel 14
201701_30 channel 15
ADC count

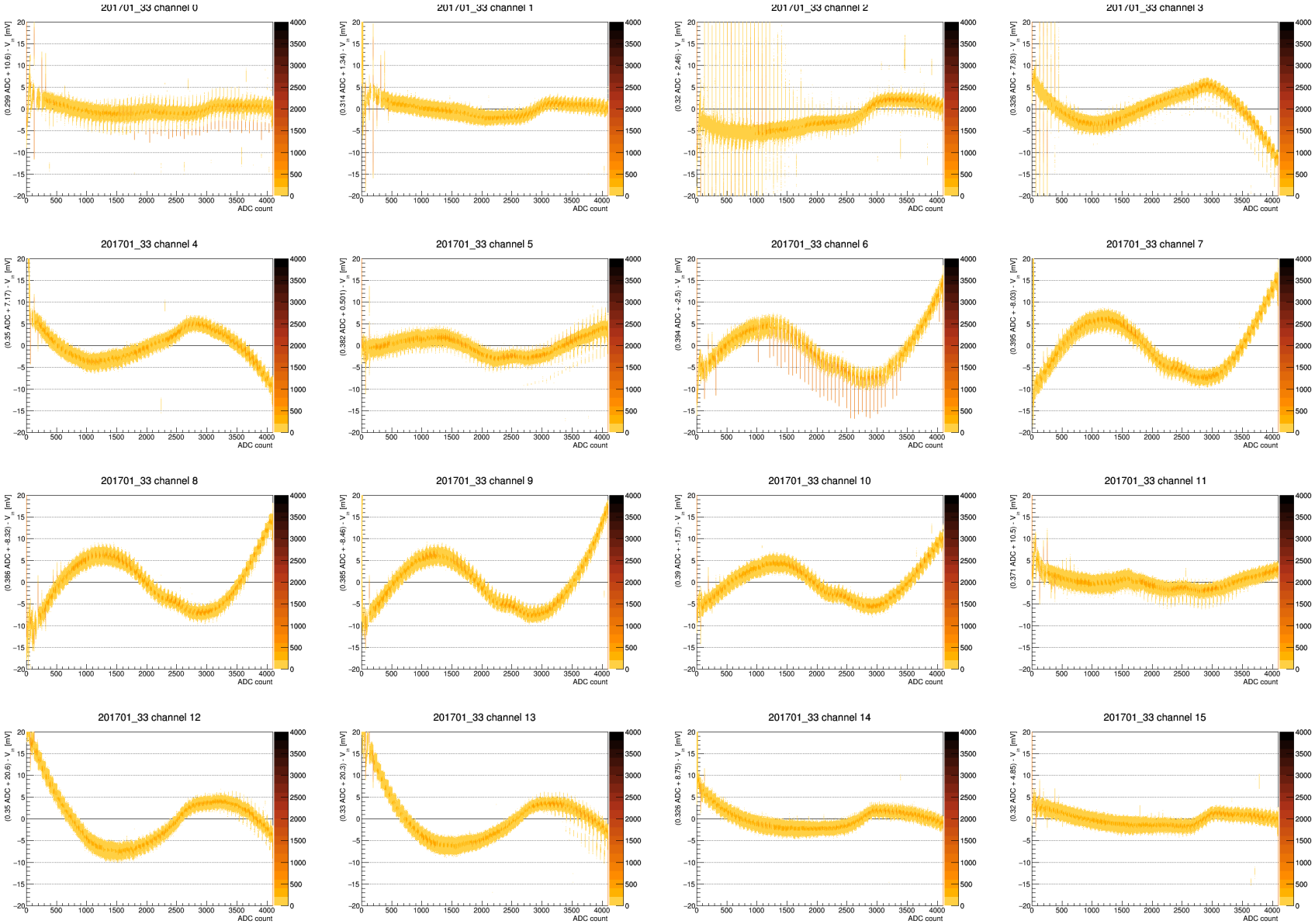
# ADC 31


201701_31 channel 0
201701_31 channel 1
201701_31 channel 2
201701_31 channel 3
201701_31 channel 4
201701_31 channel 5
201701_31 channel 6
201701_31 channel 7
201701_31 channel 8
201701_31 channel 9
201701_31 channel 10
201701_31 channel 11
201701_31 channel 12
201701_31 channel 13
201701_31 channel 14
201701_31 channel 15
ADC count

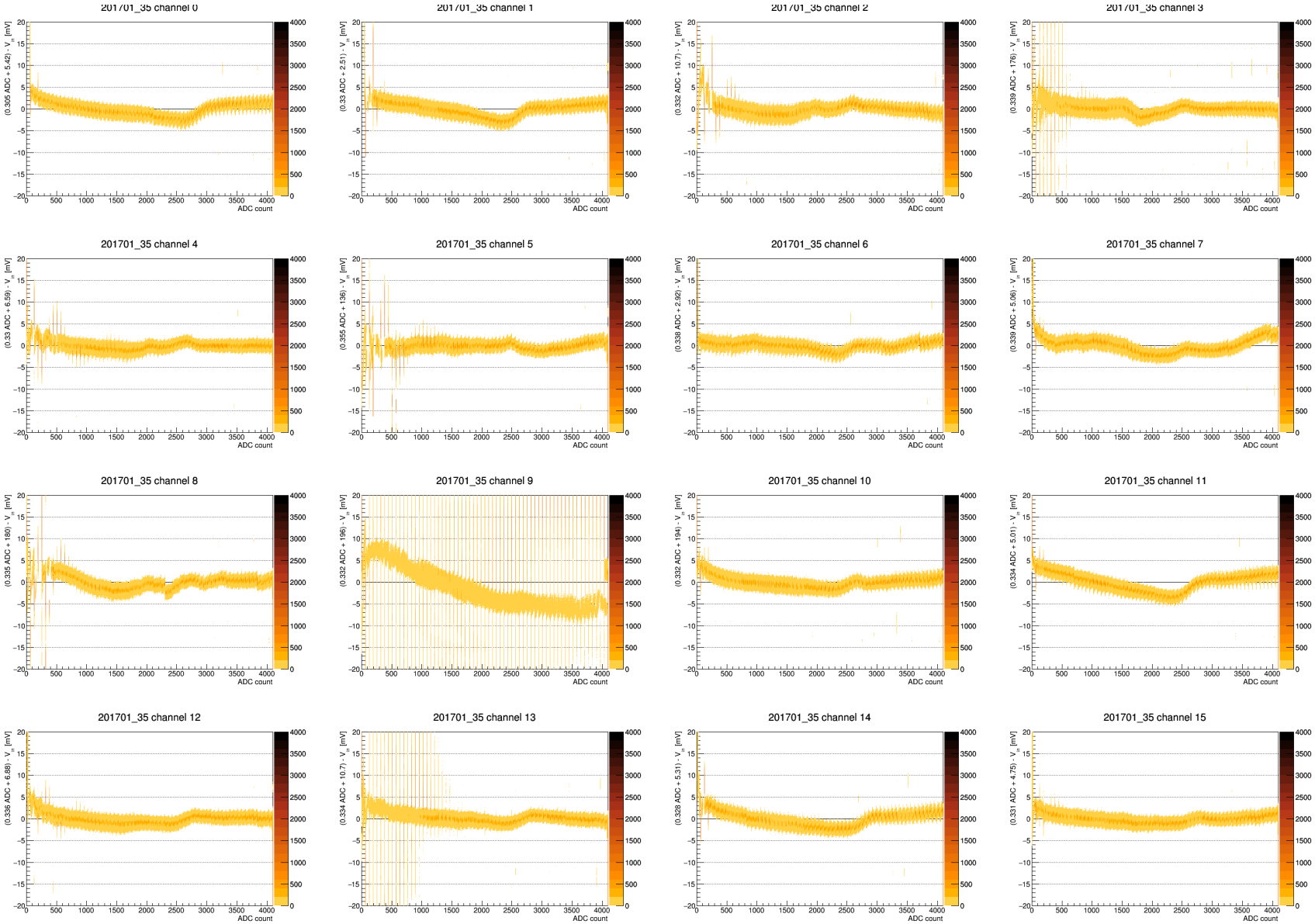
# ADC 32


201701_32 channel 0
201701_32 channel 1
201701_32 channel 2
201701_32 channel 3
201701_32 channel 4
201701_32 channel 5
201701_32 channel 6
201701_32 channel 7
201701_32 channel 8
201701_32 channel 9
201701_32 channel 10
201701_32 channel 11
201701_32 channel 12
201701_32 channel 13
201701_32 channel 14
201701_32 channel 15
ADC count

# ADC 33


201701_33 channel 0
201701_33 channel 1
201701_33 channel 2
201701_33 channel 3
201701_33 channel 4
201701_33 channel 5
201701_33 channel 6
201701_33 channel 7
201701_33 channel 8
201701_33 channel 9
201701_33 channel 10
201701_33 channel 11
201701_33 channel 12
201701_33 channel 13
201701_33 channel 14
201701_33 channel 15
ADC count

# ADC 35


201701_35 channel 0
201701_35 channel 1
201701_35 channel 2
201701_35 channel 3
201701_35 channel 4
201701_35 channel 5
201701_35 channel 6
201701_35 channel 7
201701_35 channel 8
201701_35 channel 9
201701_35 channel 10
201701_35 channel 11
201701_35 channel 12
201701_35 channel 13
201701_35 channel 14
201701_35 channel 15
ADC count

# Resolution summary

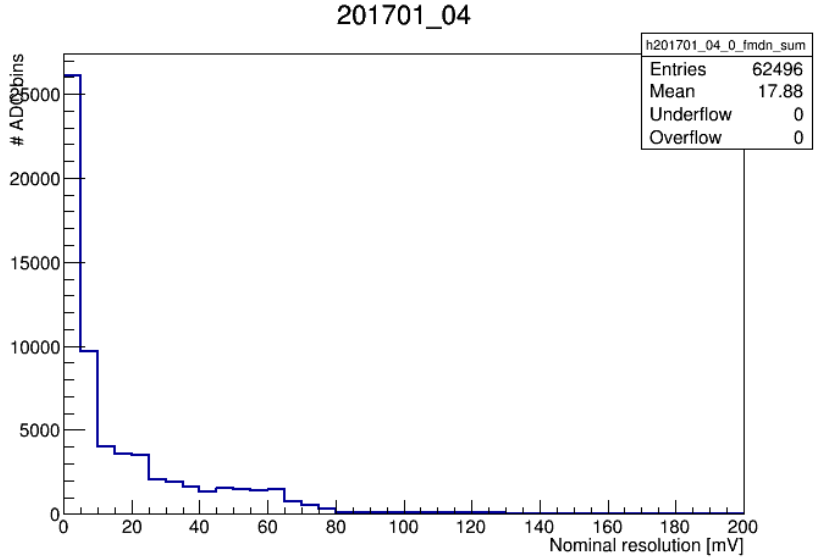
Resolution summary plots follow

- Plots have all bins for all channels for one ADC chip
- For three scenarios
  - Linear calibration with a common gain correction
  - Linear calibration with separate gain for each channel
  - Ultimate resolution uses separate mean for each ADC bin
    - I.e. 4096 parameters for each ADC channel
- ADC < 64 are excluded
- With and without stuck bits are shown separately for the ultimate resolution

# P1 nominal resolution

Nominal resolutions

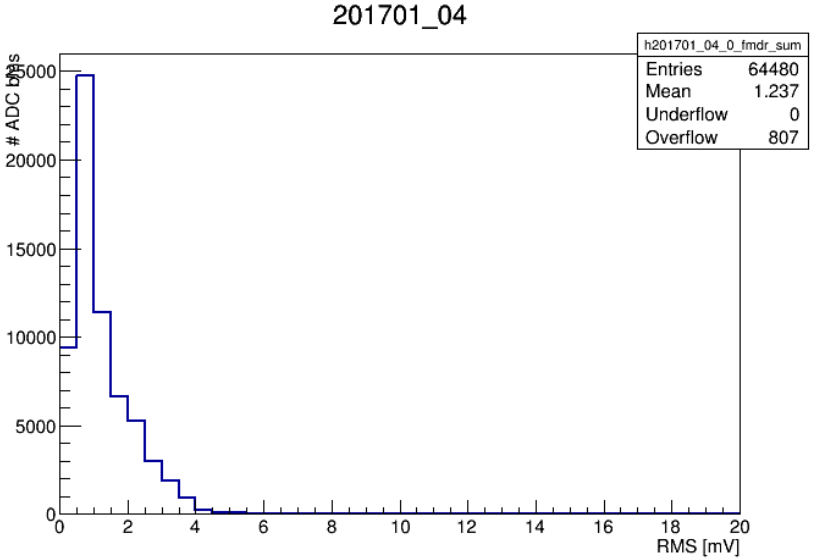
- Dominated by channel-to-channel gain variations
- Mean is 18 mV (8 fC)



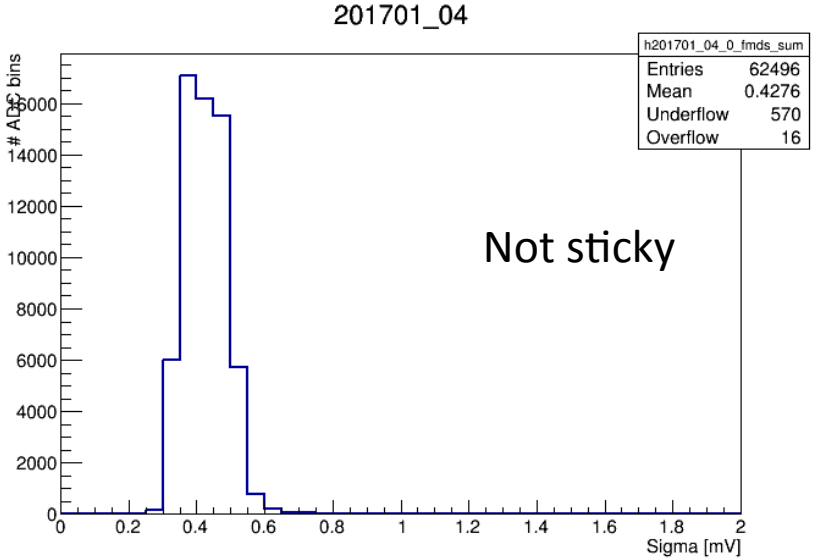
# P1 fit resolution

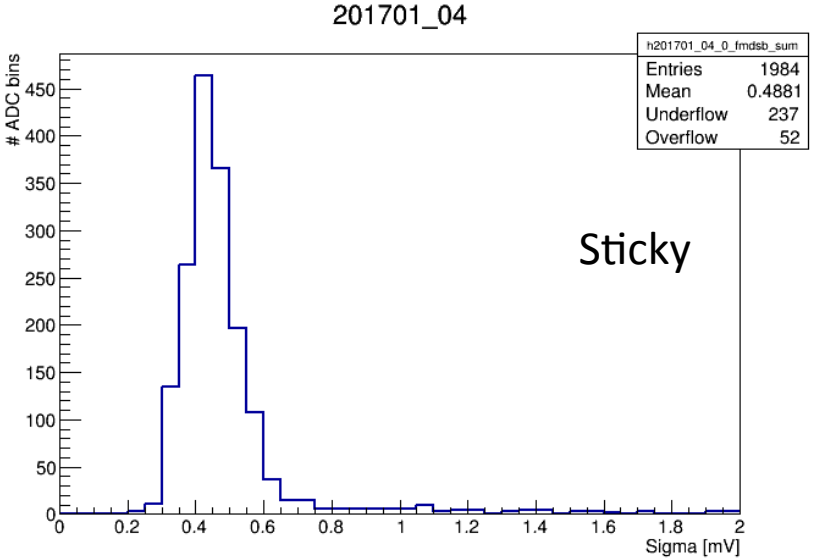
Fit resolutions

- Independent linear fit for each channel
- Dominated by nonlinearity in ADC response
- Mean is 1.2 mV (500 e)



# P1 ultimate resolution (sigma)




## Not sticky fit resolution

- Mean is 0.43 mV (180 e)

# Comments and conclusions

## Work in progress

- Showed linear-fit residuals for all 25 ADCs
- 10 additional ADCs could not be run at LN temperature

## Quality

- We can (and probably have to) use these chips for protoDUNE
- Linear calibration leaves resolution of 1.2 mV (500 e)
  - For one chip but most are similar
  - This is one tick—I plan to look at correlations (frequency dependence) to understand total contribution to a signal
- There are bad bins (codes)
  - Often (not always) sticky codes
  - We need to identify those and mitigate
    - E.g. interpolate between neighboring ticks

## Yield

- Need to keep 1000 of 3000 chips
- Won't get perfection but existing sample suggests we can manage with the above calibration and mitigation