CESR BPM: improving signal-to-noise ratio via gain tuning

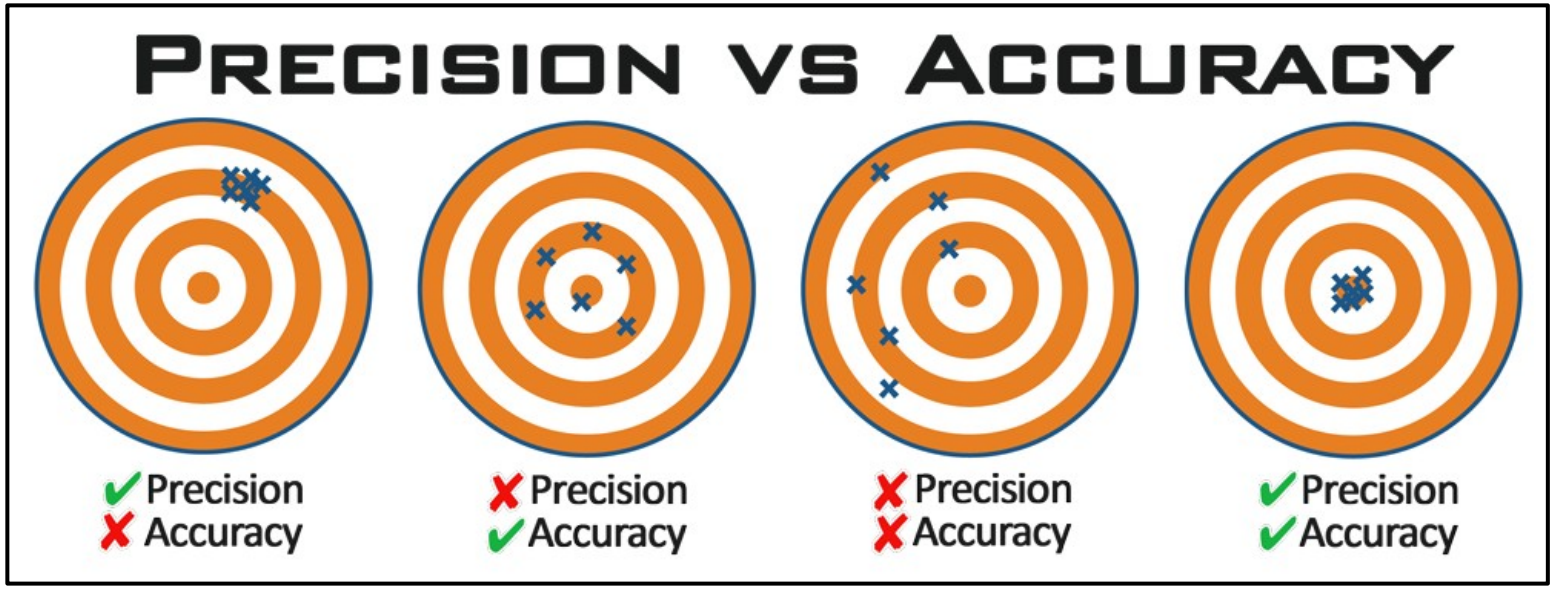
CBPM group

CBPM meeting

Feb 17, 2023

Turn-by-turn beam position precision

We care most of about the turn-by-turn beam position **precision**, i.e.: if the beam position were not to change, how **repeatable** is its measurement? We want to know well how orbits compare to each other (not as much where there are in absolute)

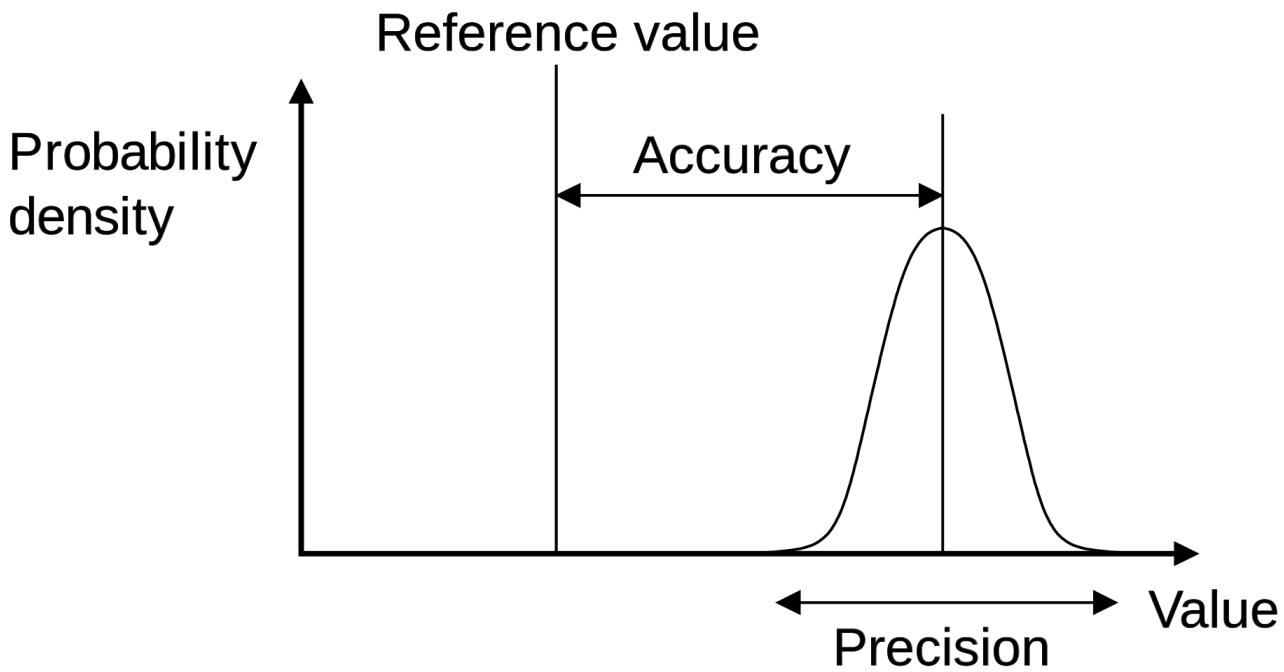


typical at CESR:

precision: $O(10)$ micron
accuracy: $O(100)$ micron

Turn-by-turn beam position precision

We care most of about the turn-by-turn beam position **precision**, i.e.: if the beam position were not to change, how **repeatable** is its measurement? We want to know well how orbits compare to each other (not as much where there are in absolute)

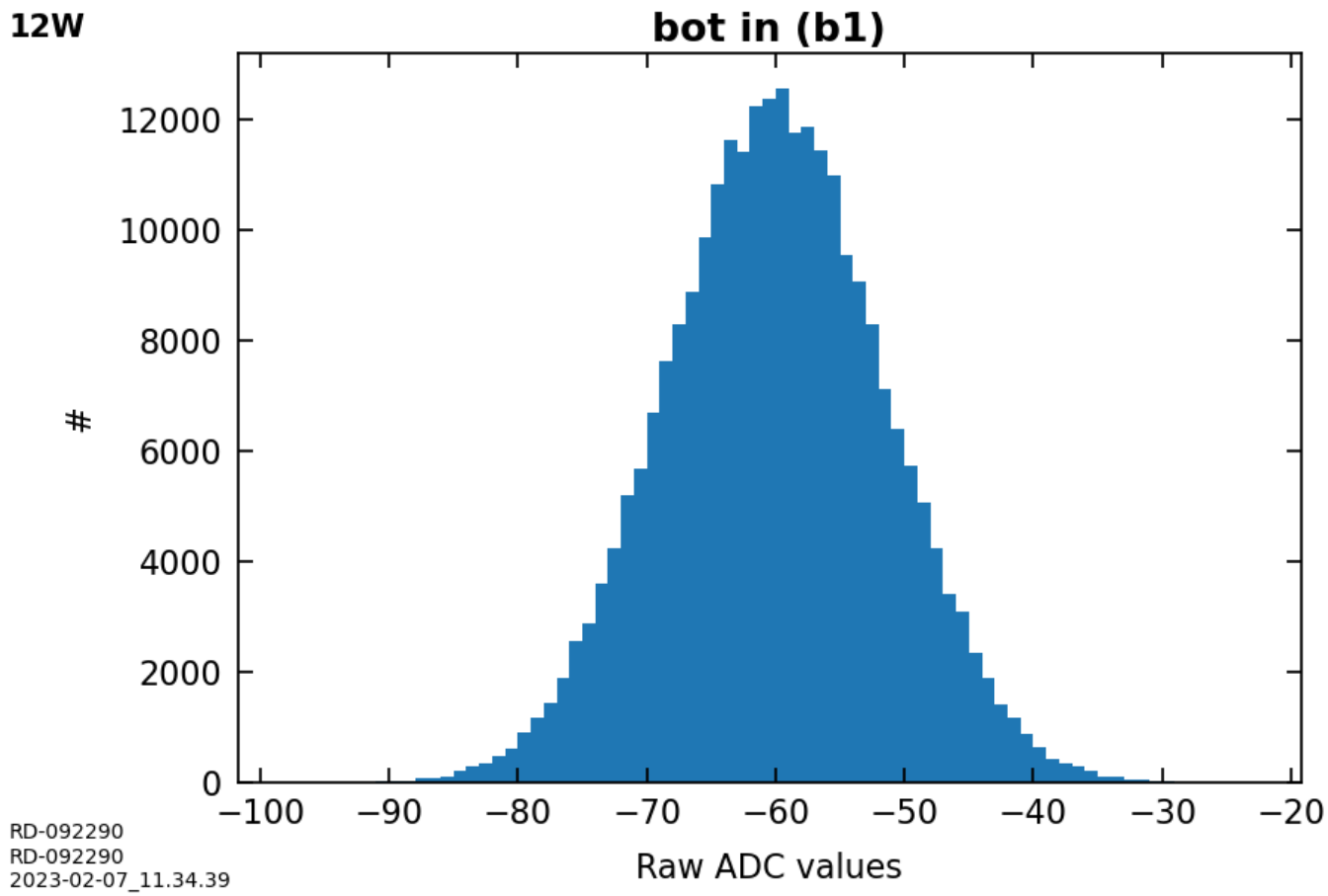


precision is defined as the **standard deviation** of a set of data points

Much of the work for CBPM3 is with respect to improving the precision. But today let's focus on CBPM2 (our current CBPM system)

Signal-to-noise ratio and precision

One of the dominant factor limiting the precision is the Signal-to-Noise ratio of the digitized CBPM button signals. Typical RMS noise is 9-18 ADU:



fixed gain mode

Signal amplitudes goes from 0 to a maximum of 32,768 ADU

Improving signal-to-noise ratio

After investigating, **Bob** found that the current CBPM setup is not maximizing the signal-to-noise ratio. He proposed to:

1) drop analog input gain by 7 via removal of a single resistor (per channel)

2) crank the current of train 1 – bunch1 from 0.7 mA to to 5 mA (7 x 0.7 mA)

This will result in reducing the input noise while preserving the same signal amplitude → better signal-to-noise ratio.

Expected improvement: factor 3

Machine study time has been allocated to demonstrate the feasibility

Two-part plan

Detailed plan available here. In a nutshell, using the CBPM triplet at 12W:

Part 1: instr elog 2060, 2061, 2064

- ✗ collect pedestal and beam data for nominal hardware configuration (0.7 mA)

Part 2: instr elog 2066, 2068

- ✗ Collect pedestal and beam data for resistor-removed configuration (5 mA)

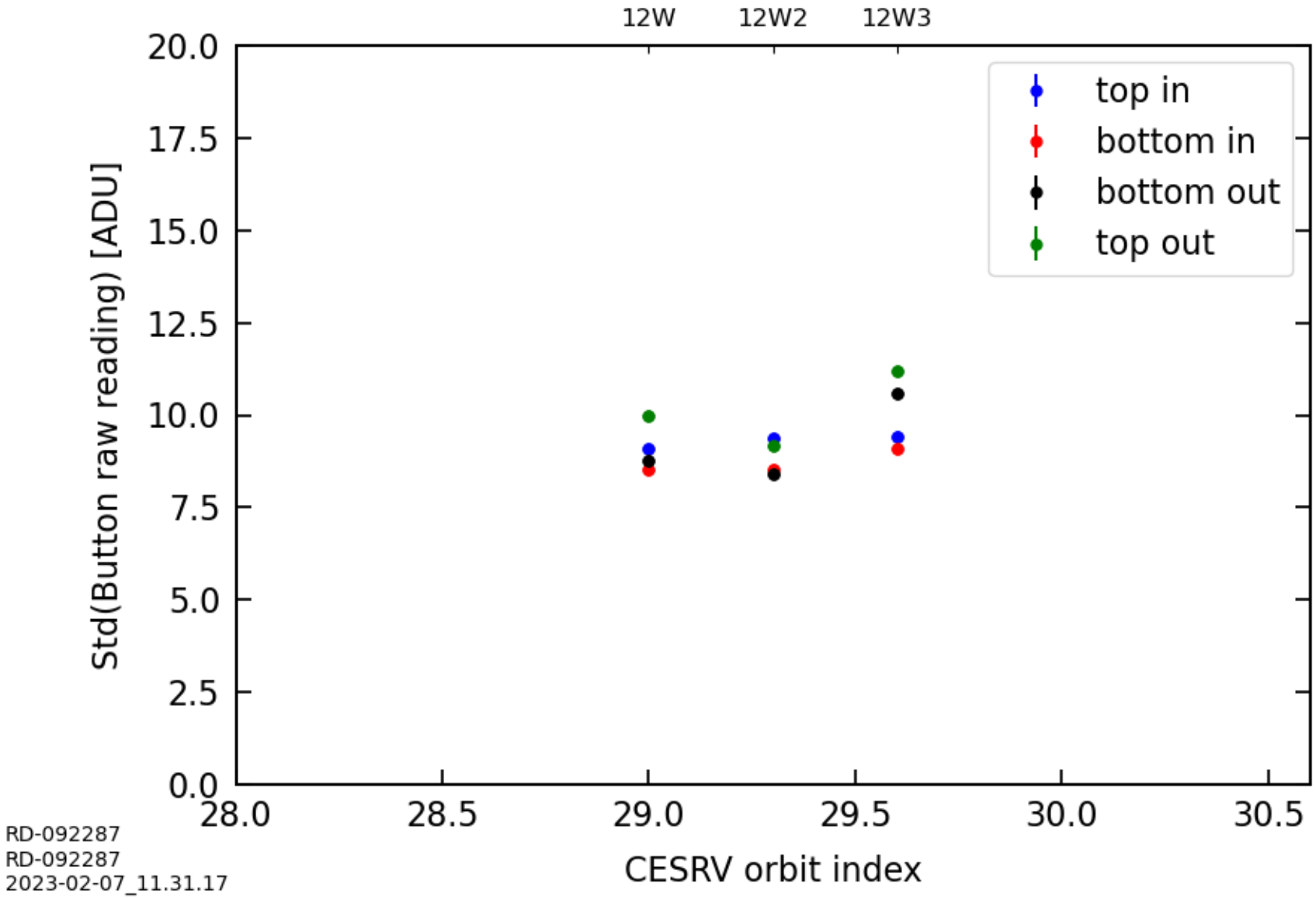
Compare following figures:

- ✗ RMS noise
- ✗ signal-to-noise ratio

RMS noise

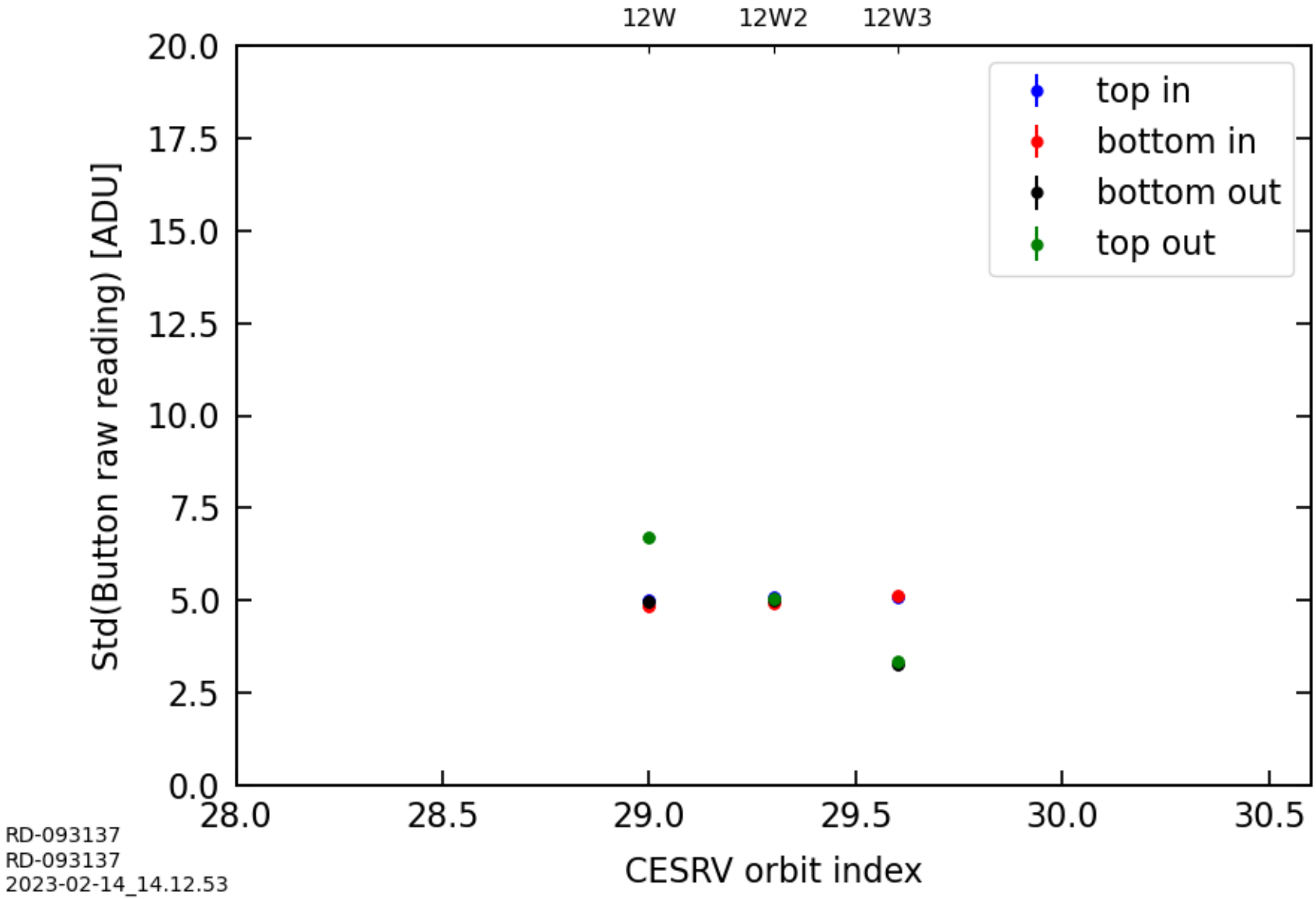
Part 1 – RMS noise

CESR cold – dataset #1



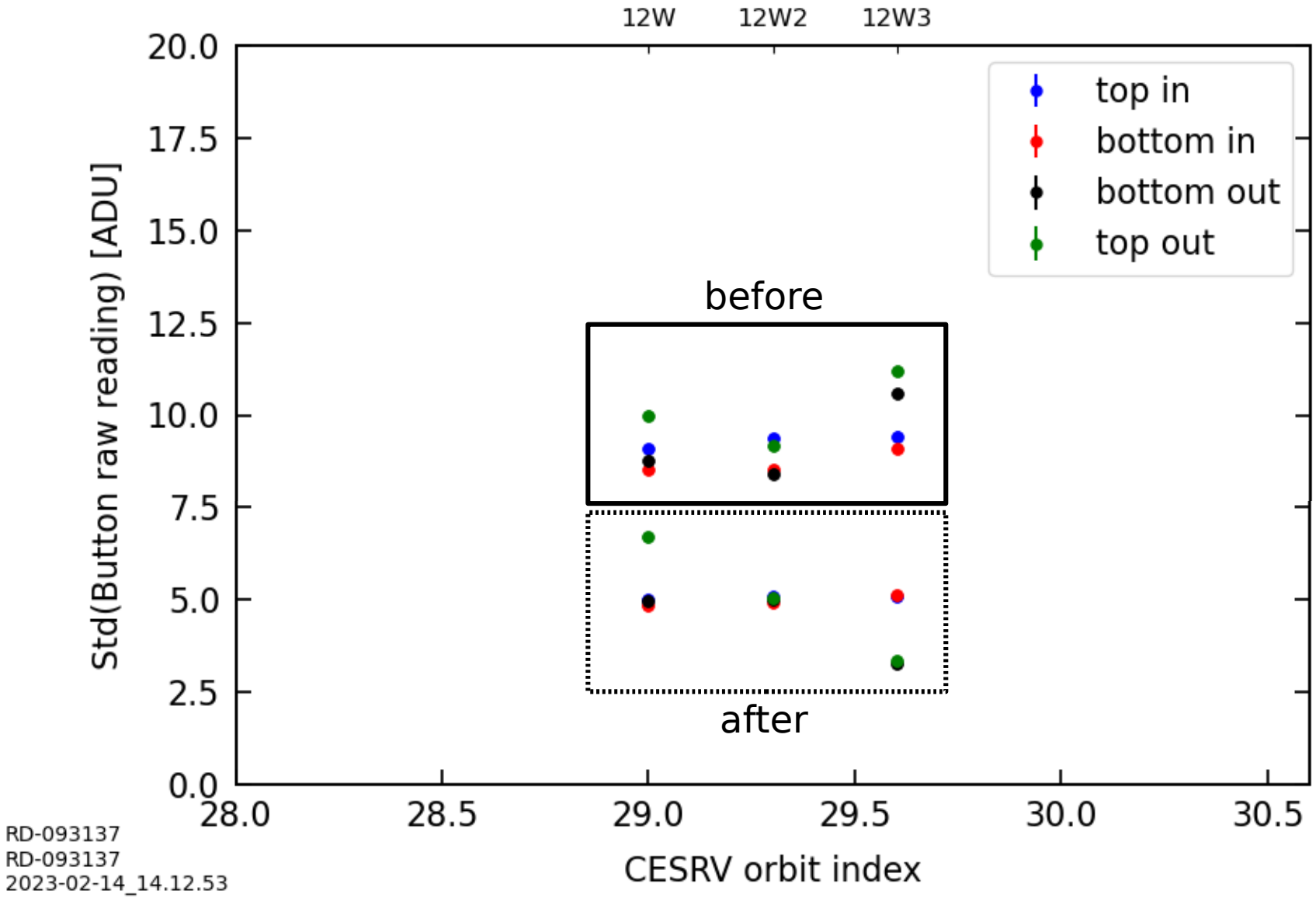
Part **2** – RMS noise

CESR cold – dataset #1



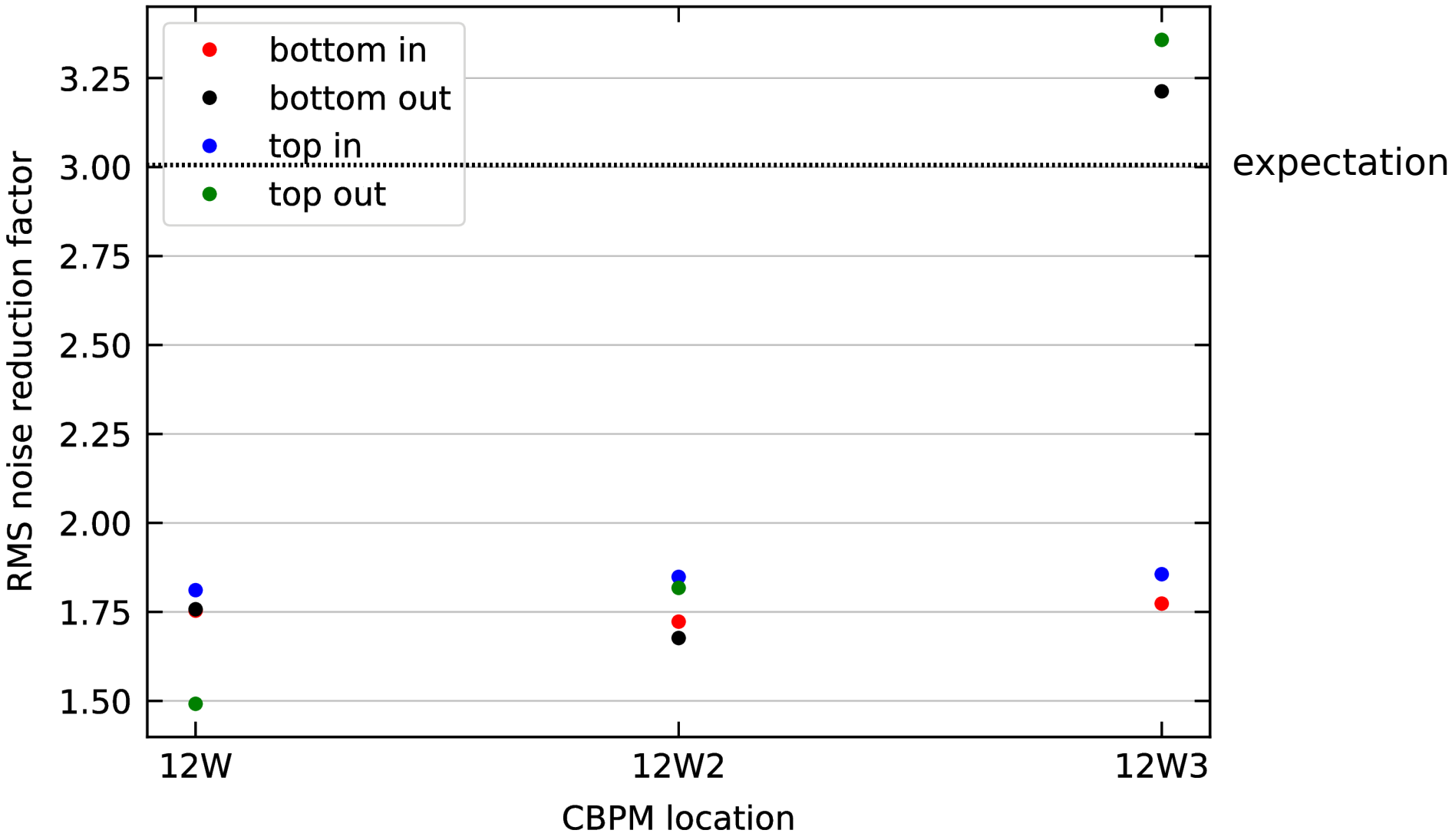
Part 1 vs Part 2: RMS noise reduction

CESR cold – dataset #1

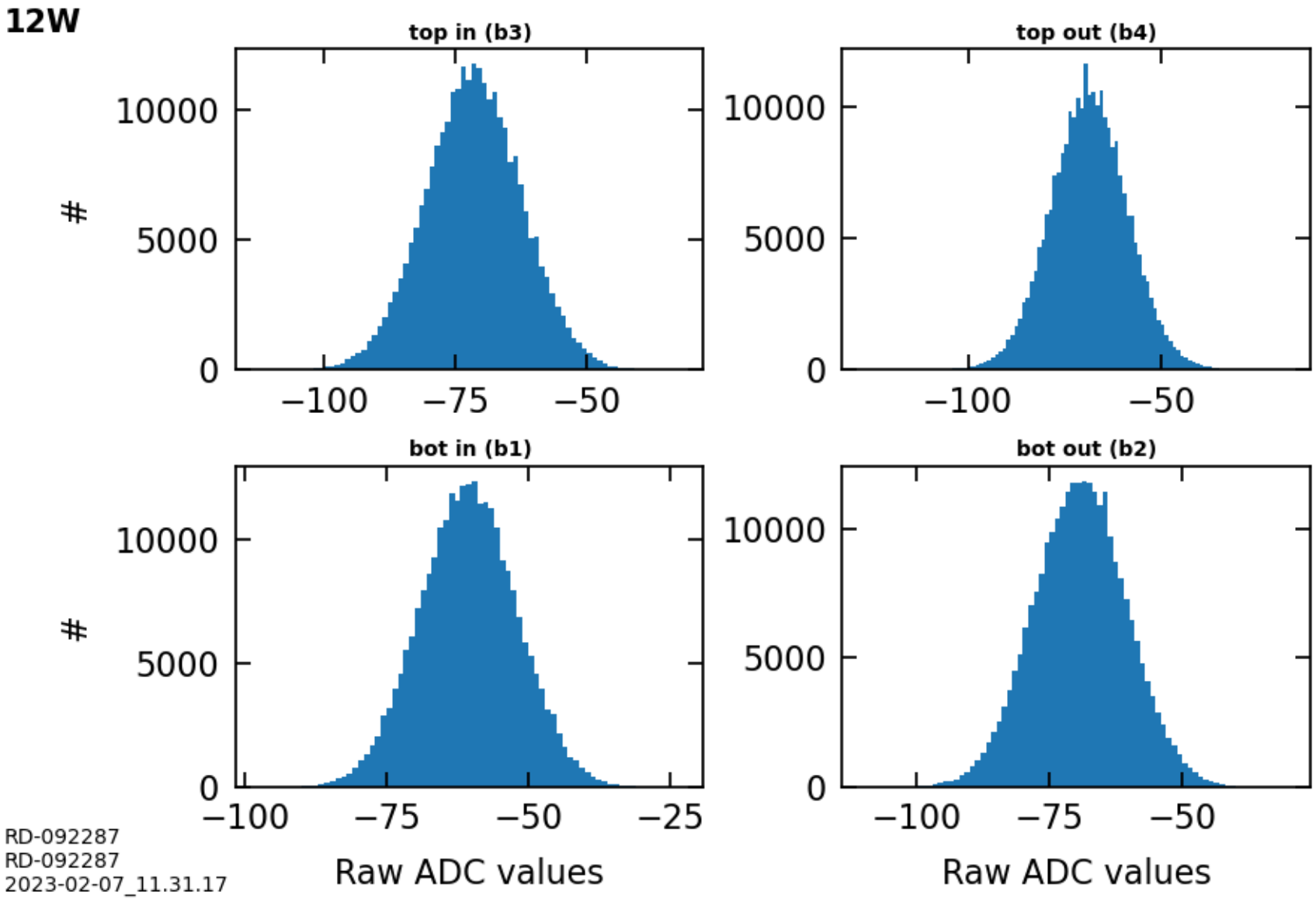


Part 1 vs Part 2: RMS noise reduction

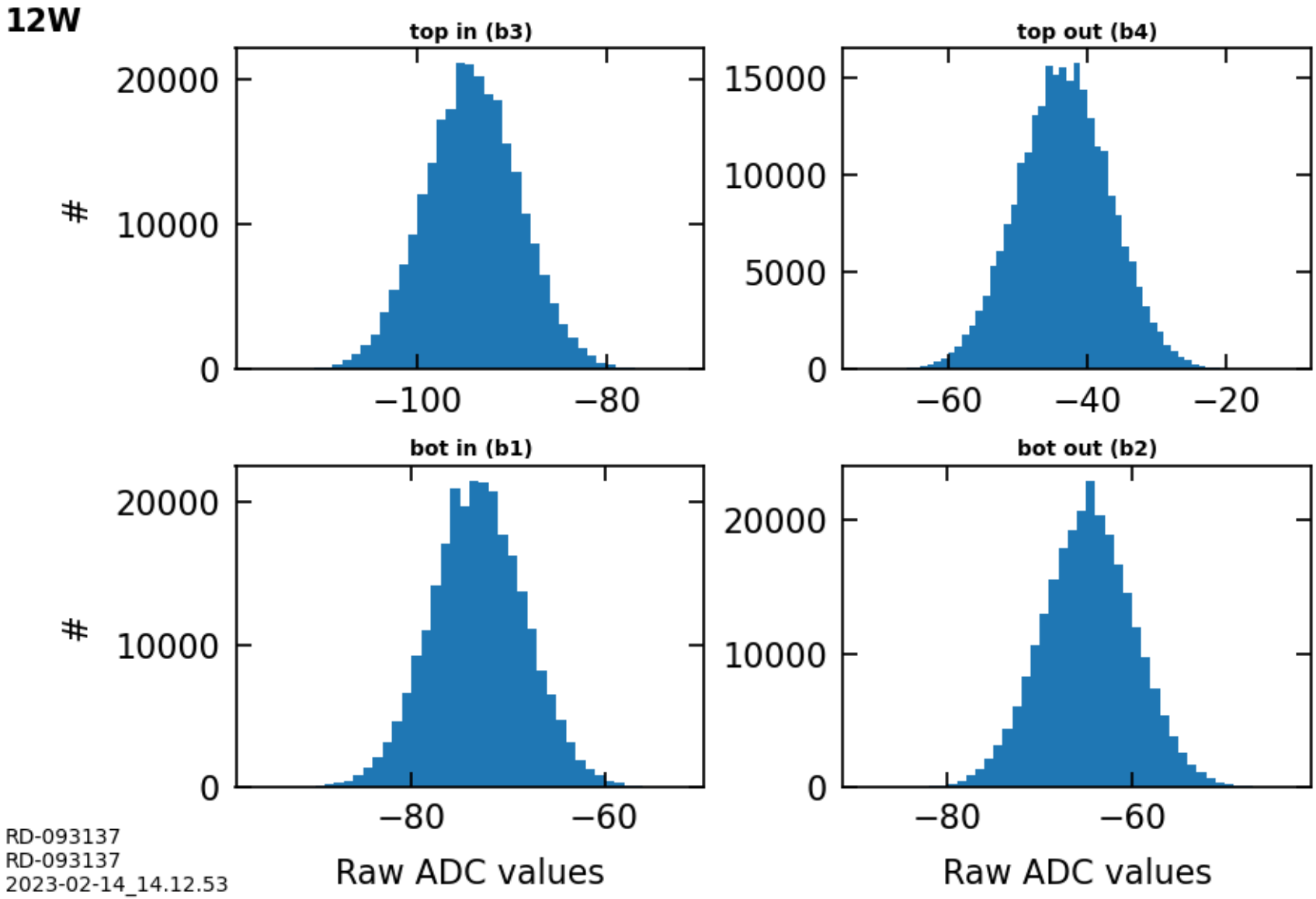
Expected noise reduction by a **factor 3**



Part 1 – Raw pedestal data



Part 2 – Raw pedestal data



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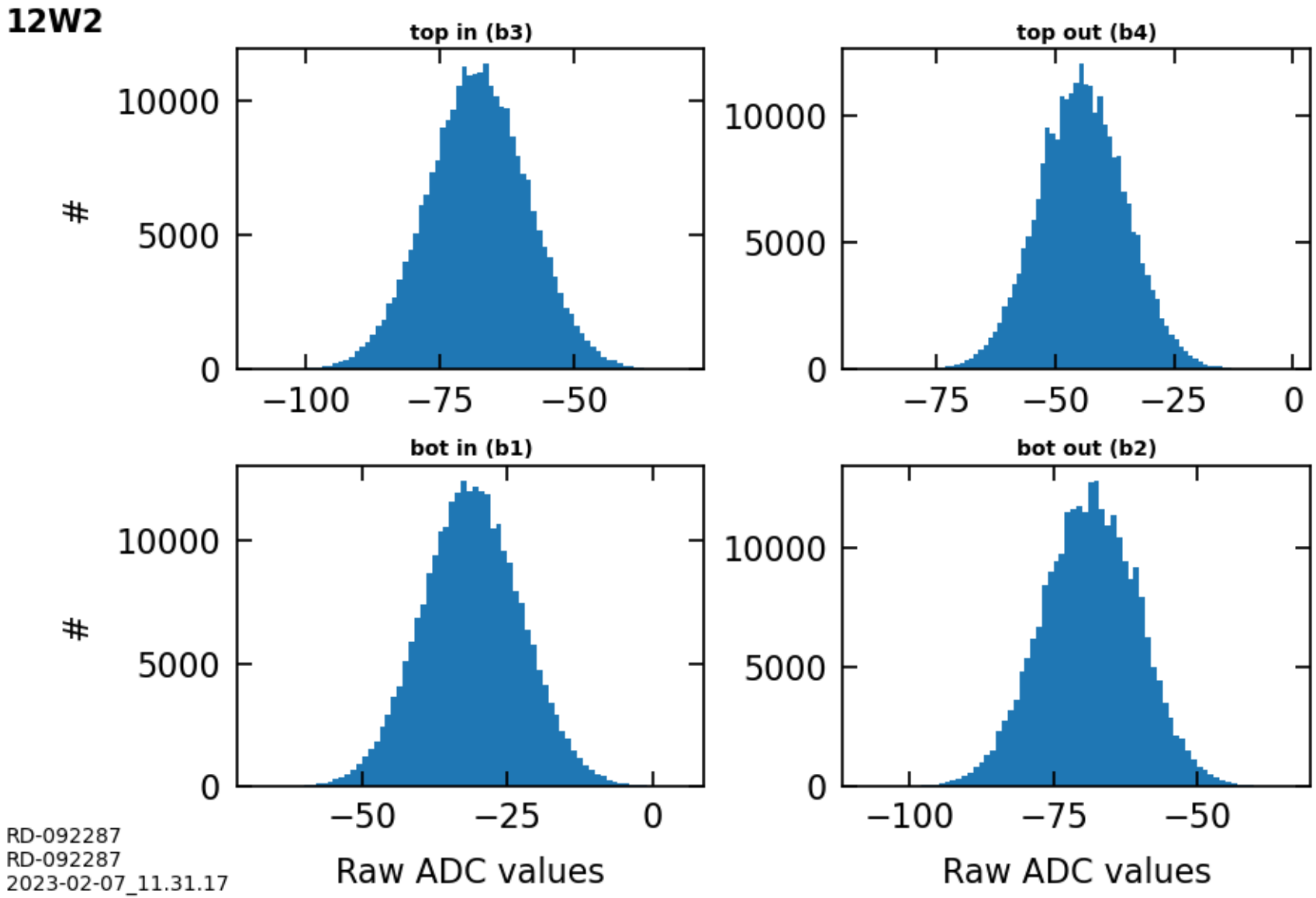
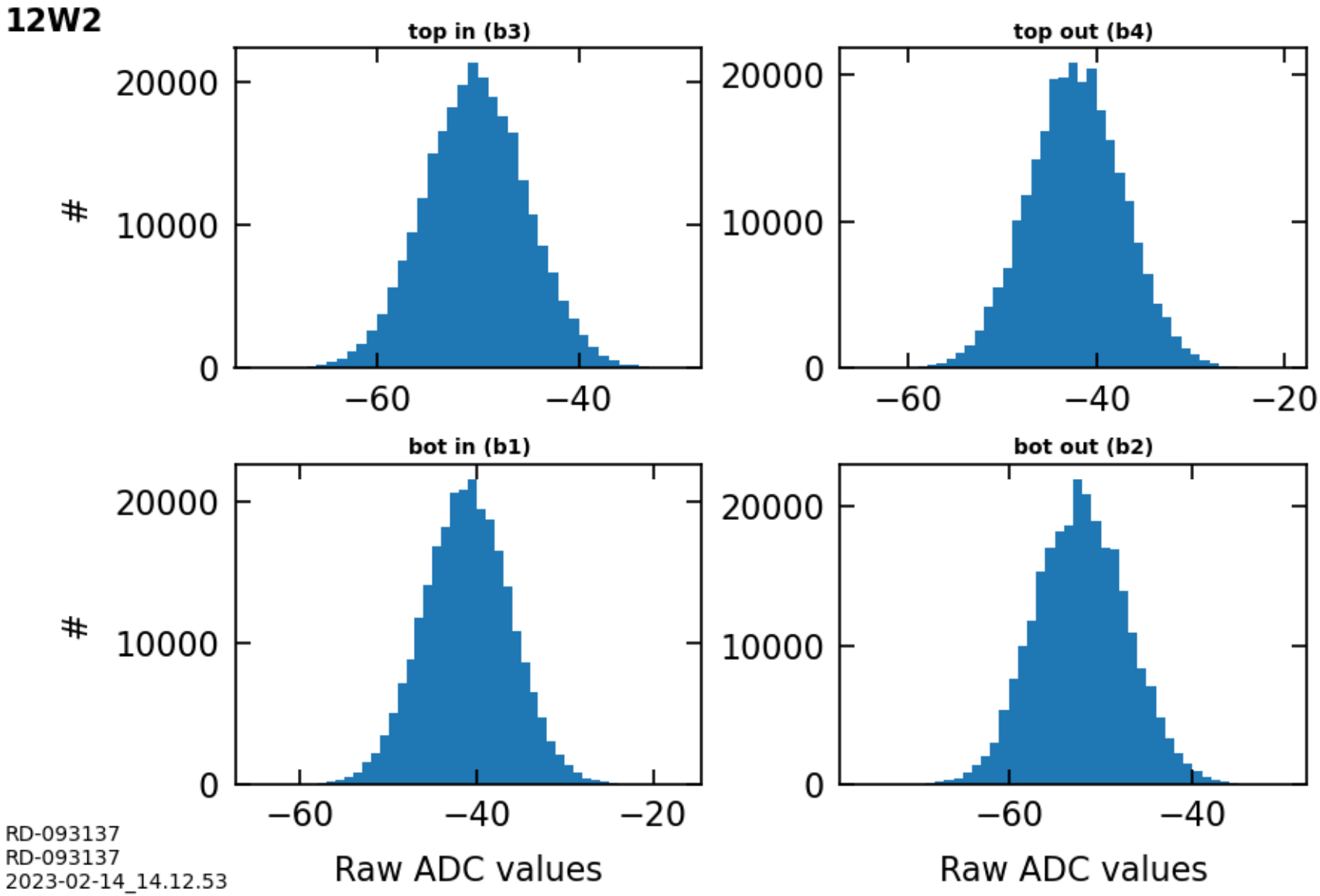


Part 2 – Raw pedestal data



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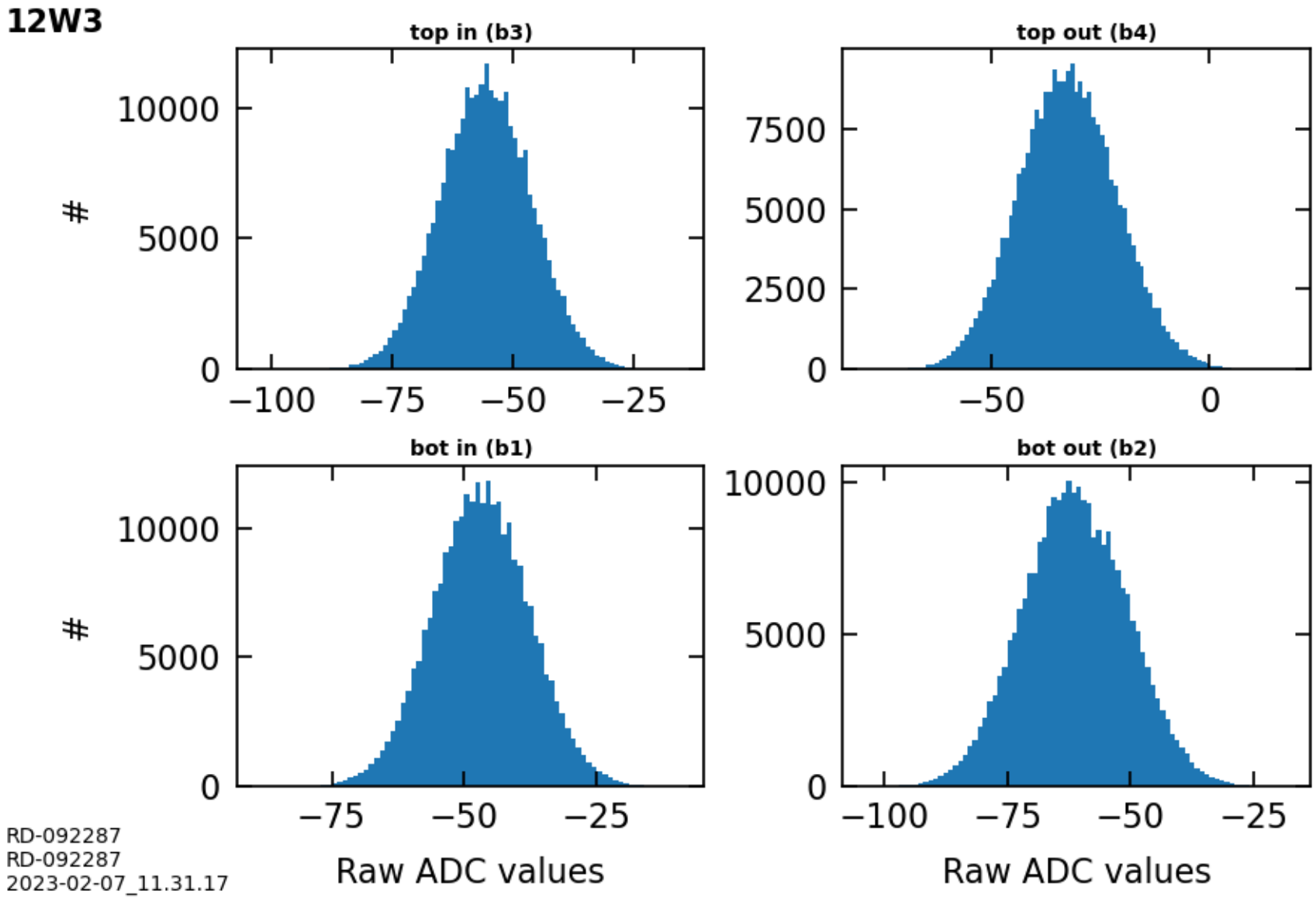
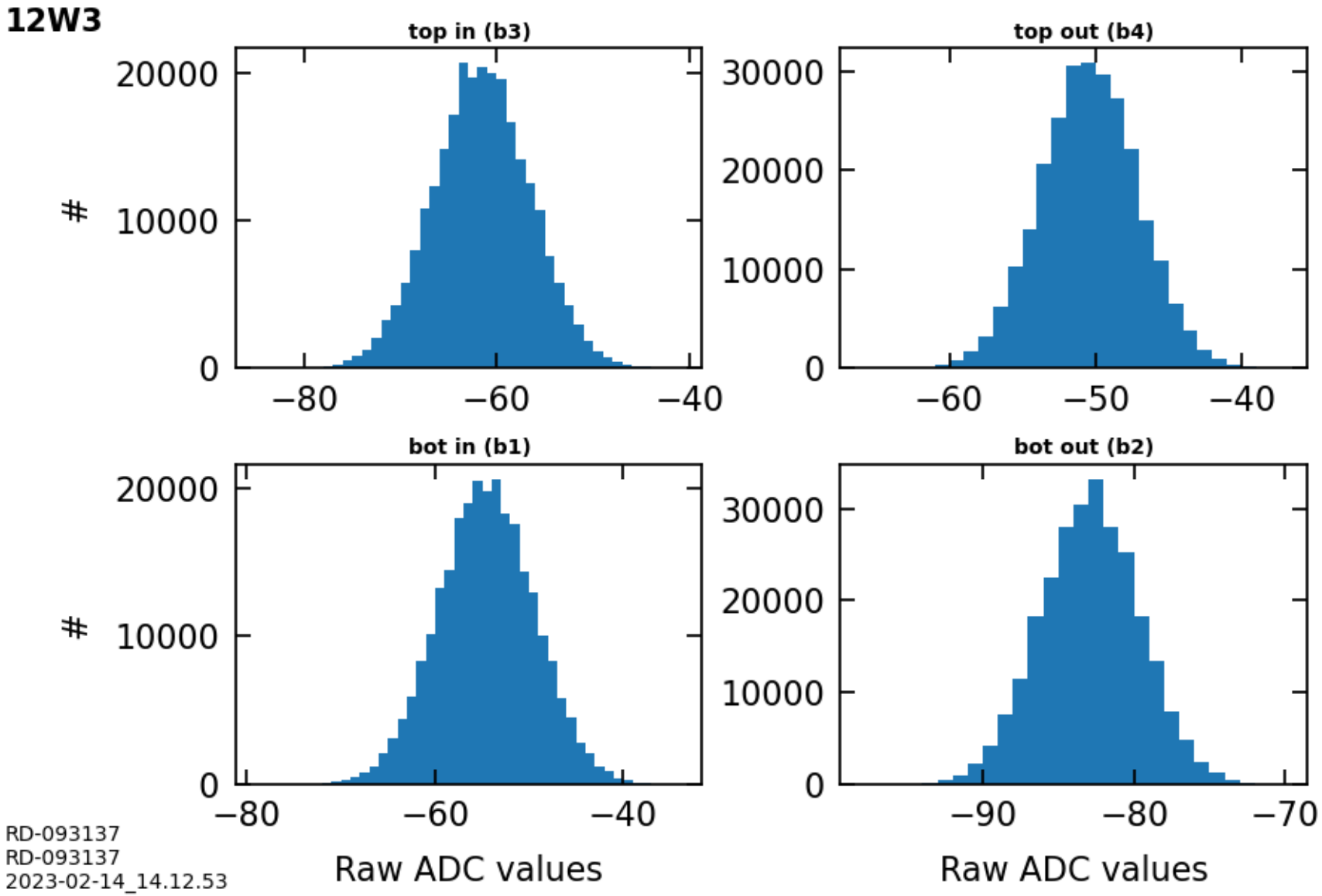


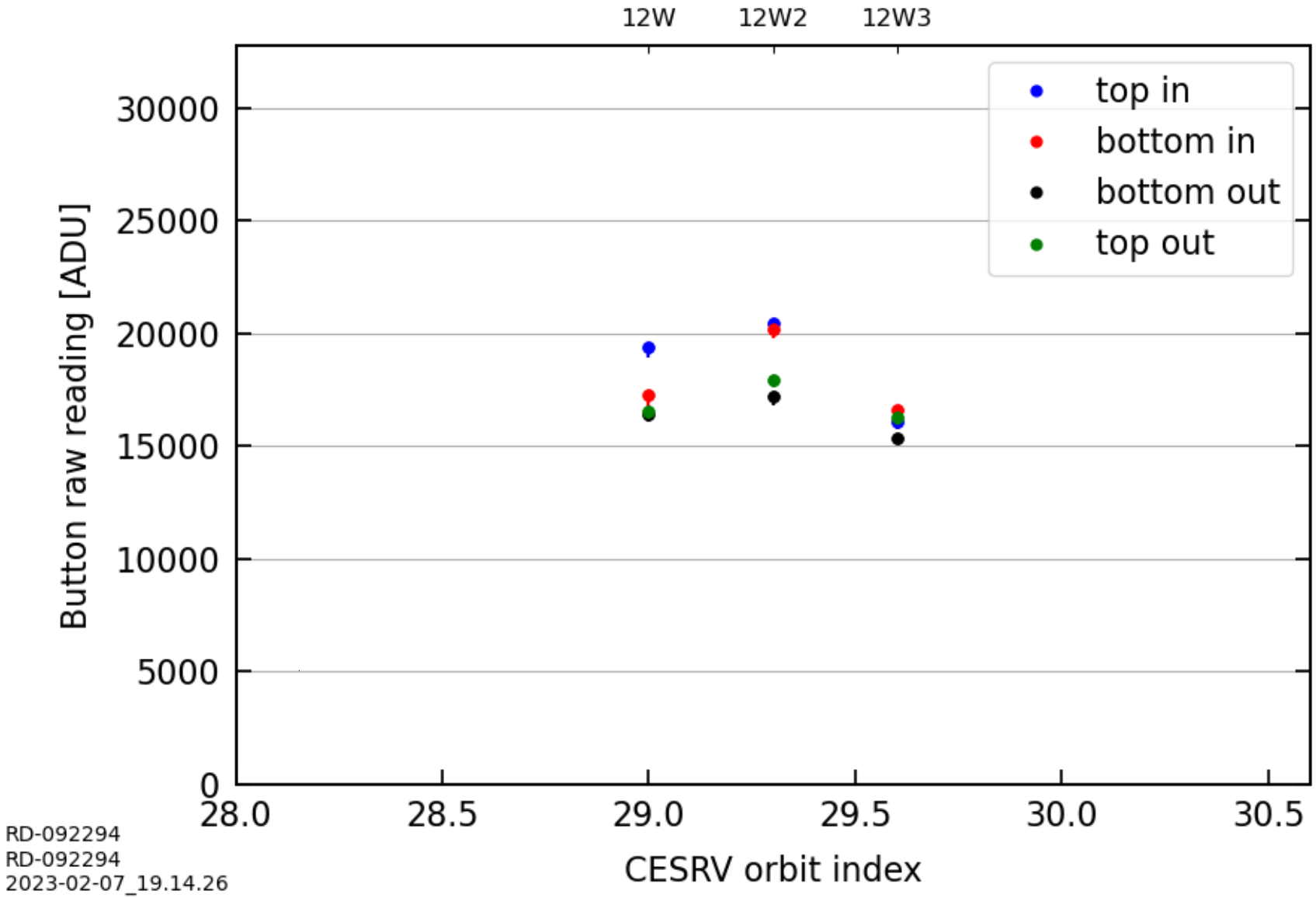
Part 2 – Raw pedestal data



Signal amplitude at 0.7 mA

Part 1 – signal amplitude

CESR current at 0.7 mA – dataset #1



Part 1 – signal amplitude

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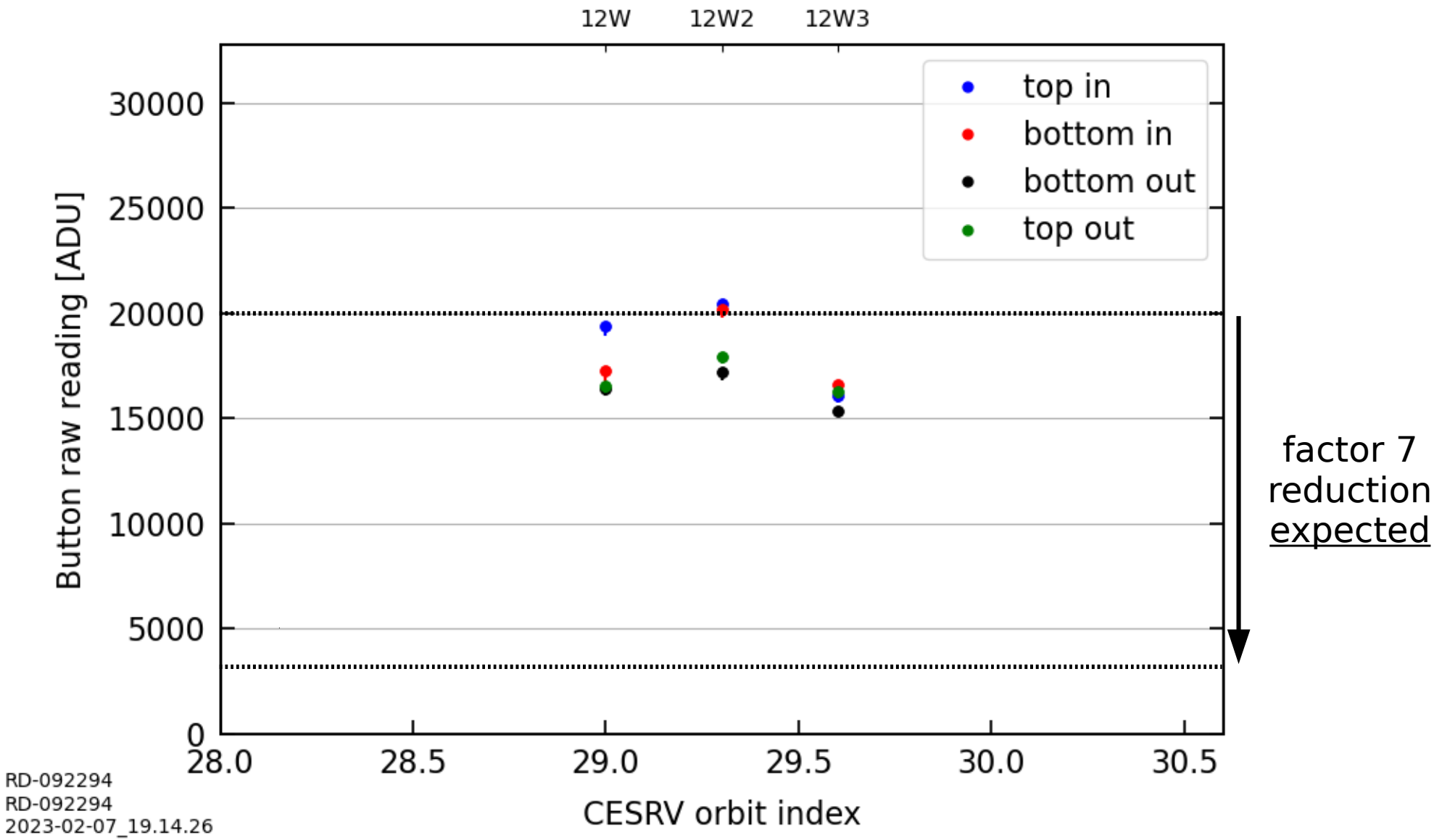
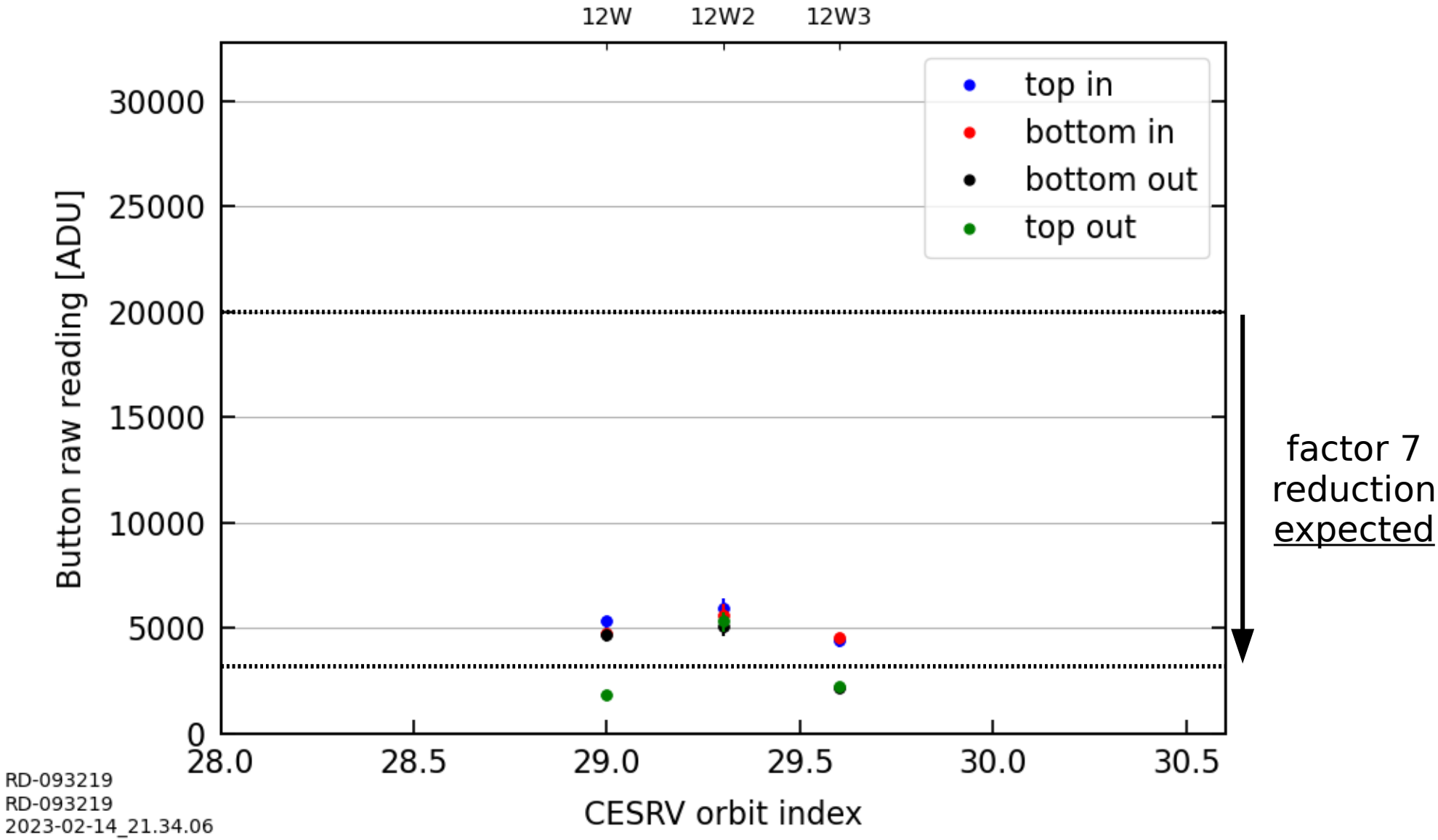


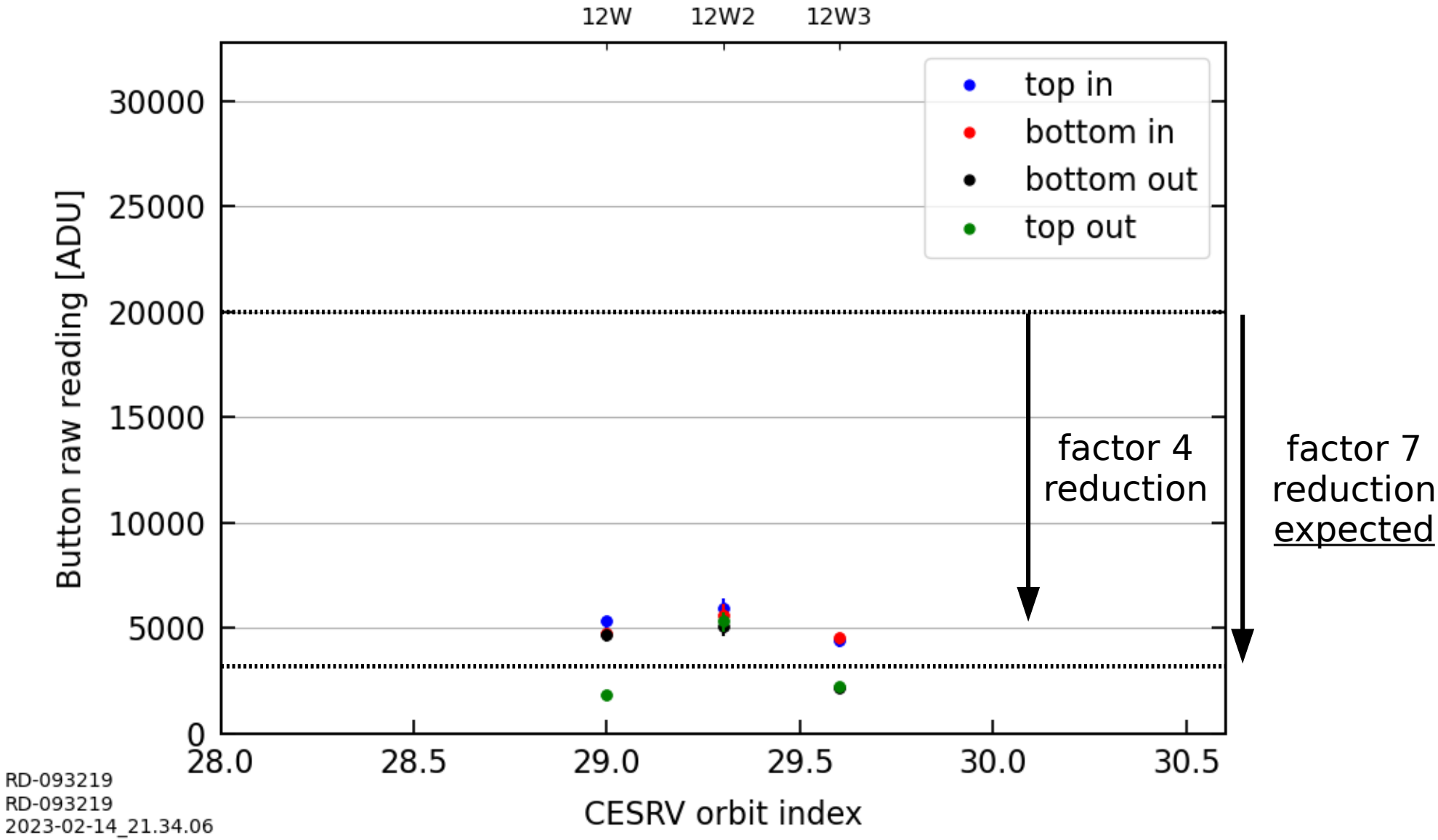
Part 2 – signal amplitude

CESR current at 0.7 mA – dataset #1



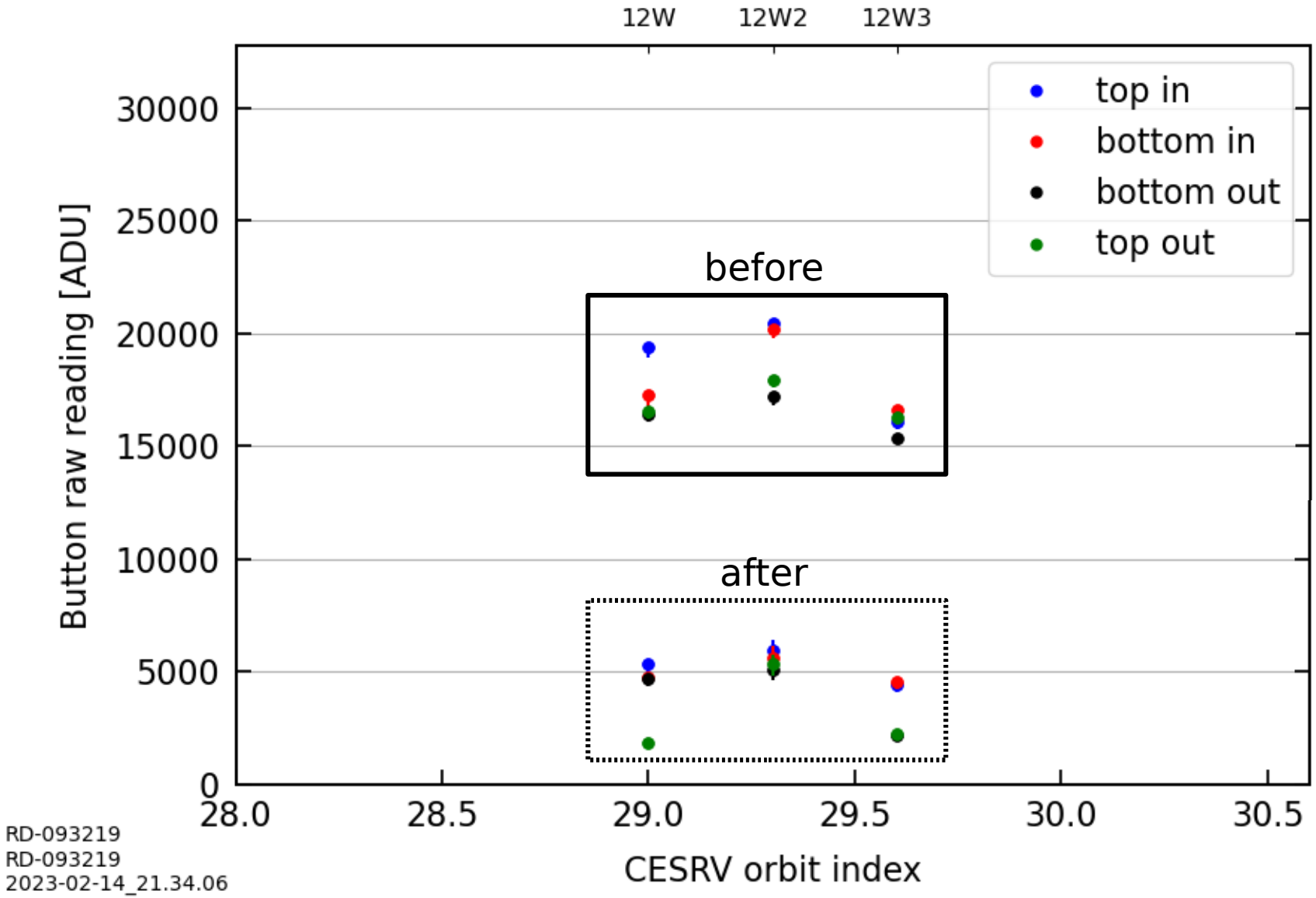
Part 2 – signal amplitude

CESR current at 0.7 mA – dataset #1



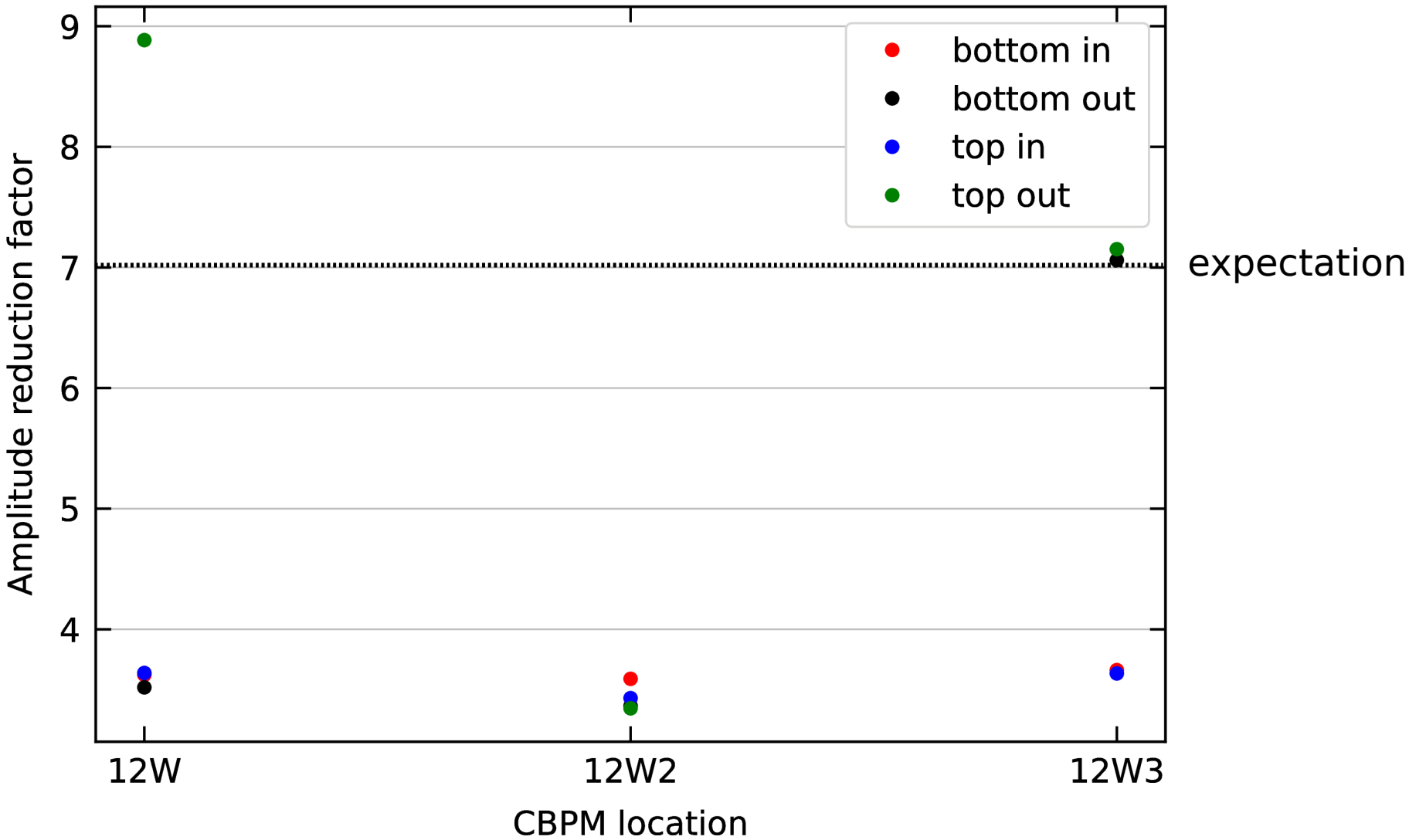
Part 1 vs Part 2: amplitude reduction

CESR current at 0.7 mA – dataset #1



Part 1 vs Part 2: amplitude reduction

Expected amplitude reduction by **factor 7**

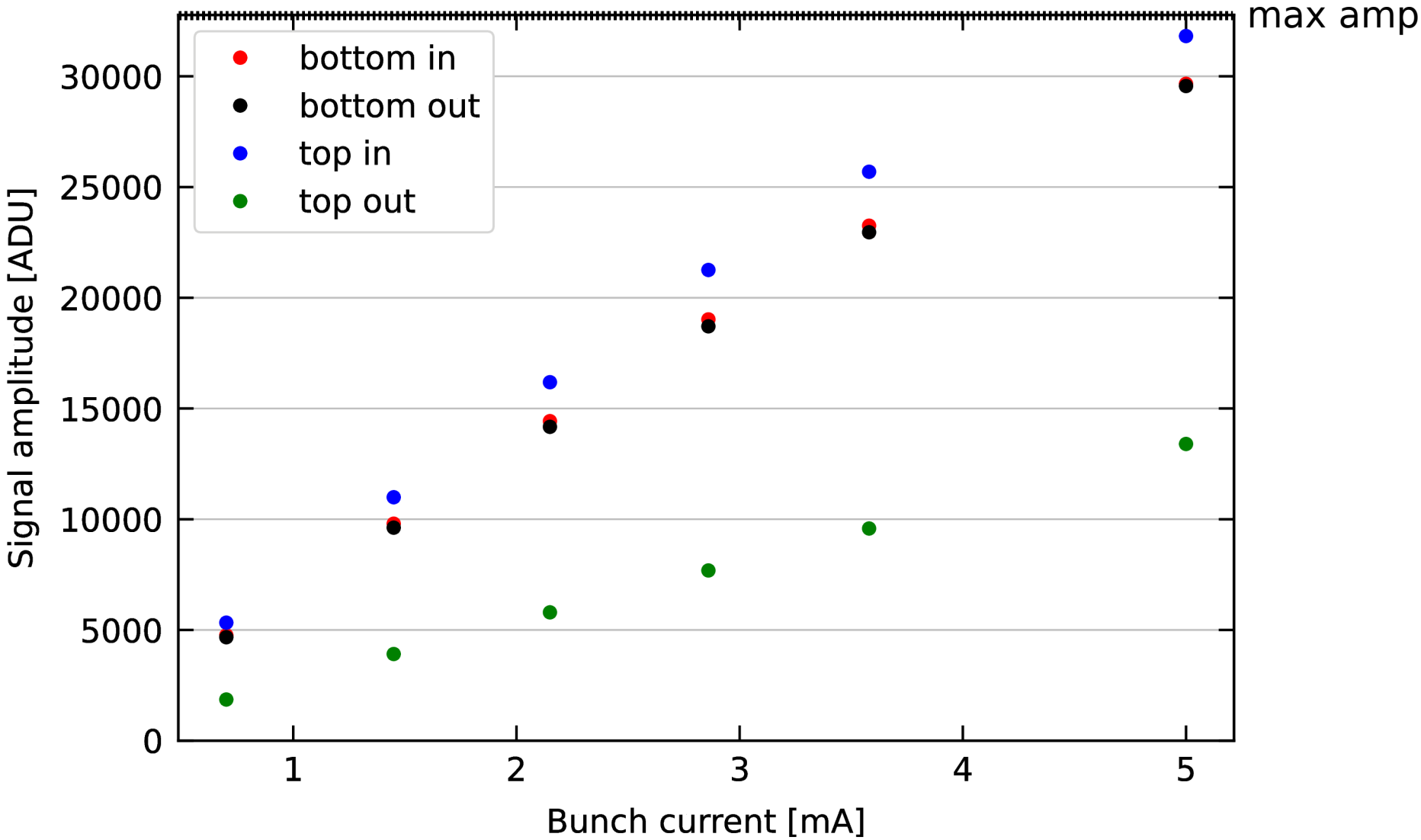


Expected button changes to track across modules since it is a straight section

Signal amplitude vs bunch current

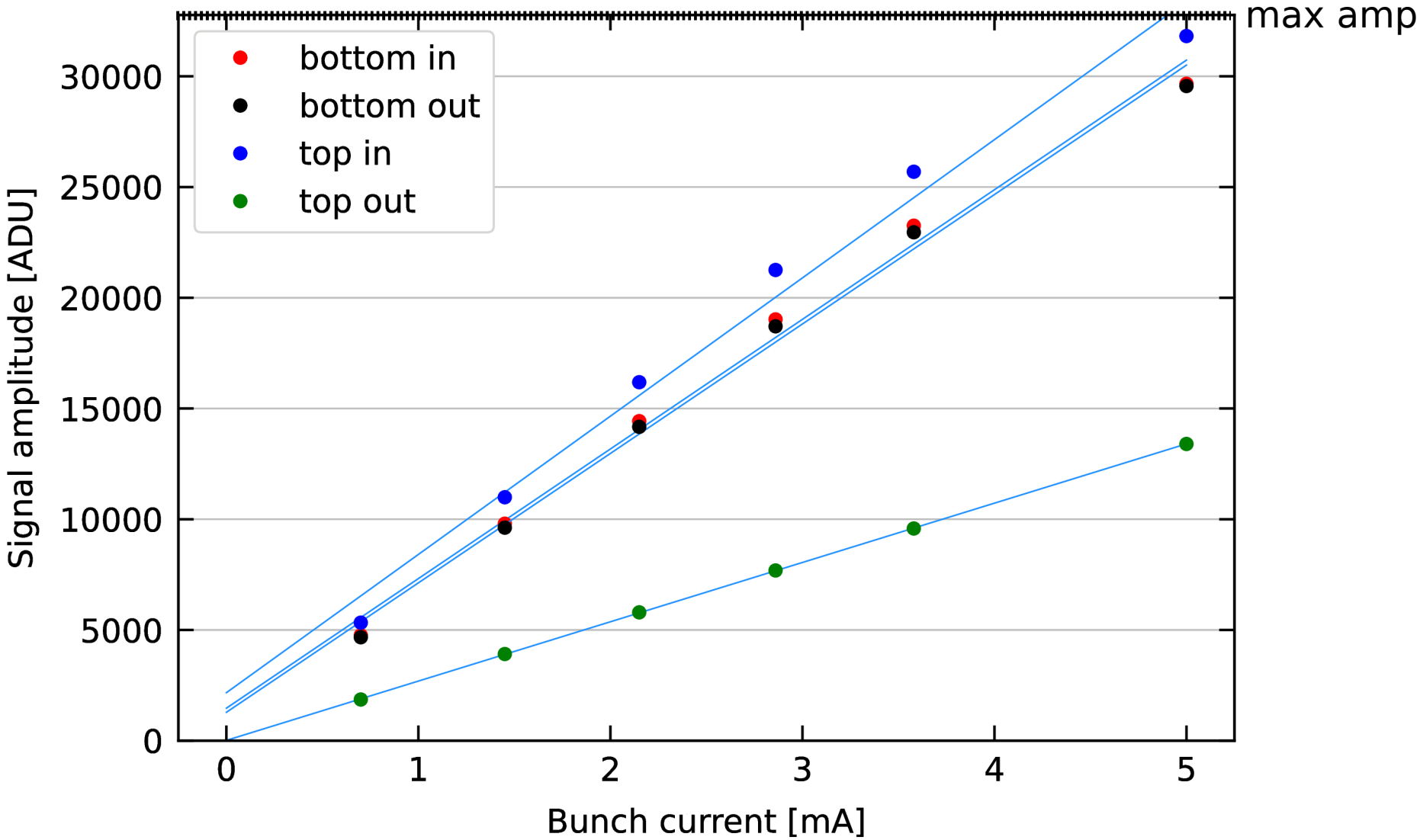
Part 2 – signal amplitude vs bunch current

12W



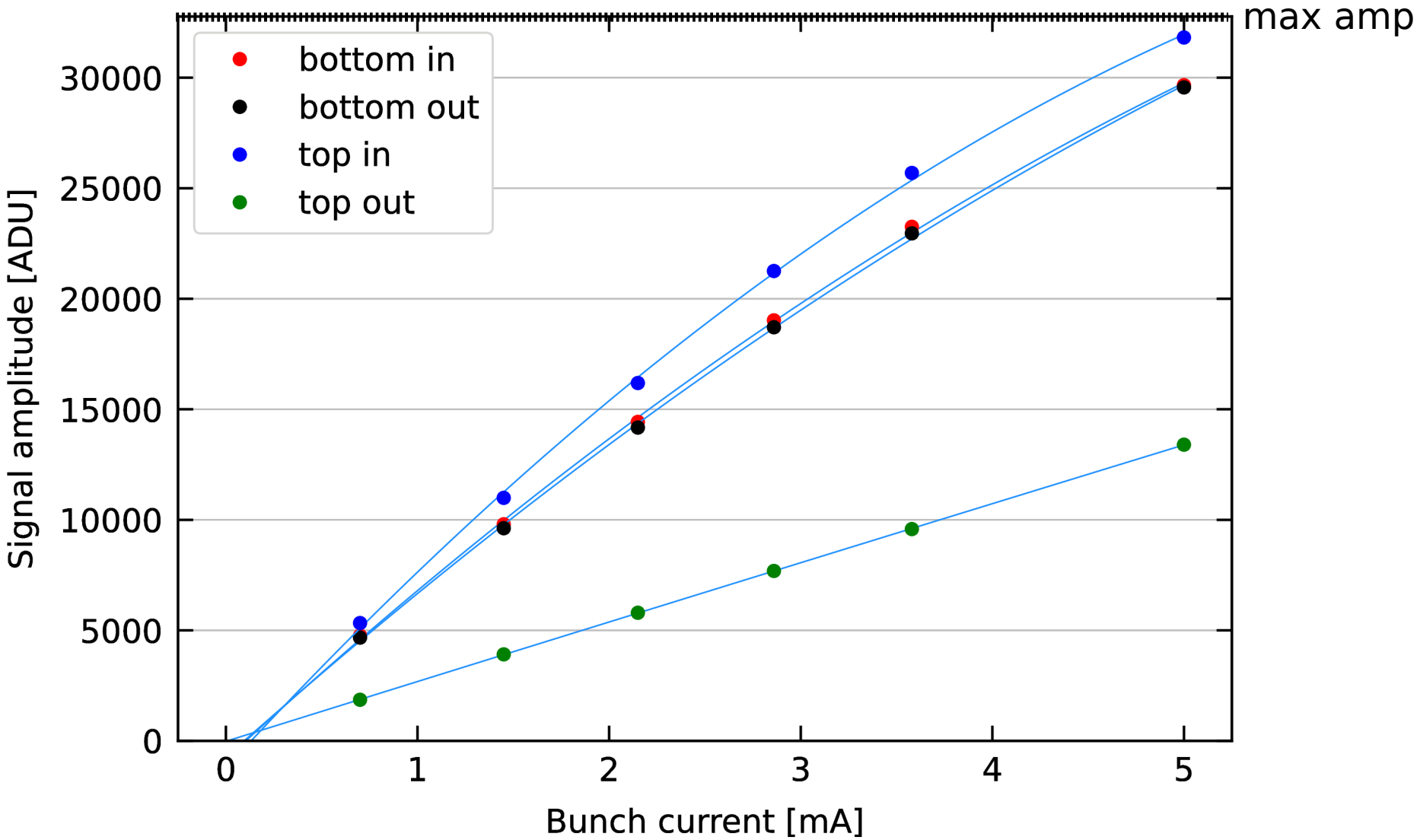
Part 2 – signal amplitude vs bunch current

12W – 1st order polynomial fit (w/o uncertainty)



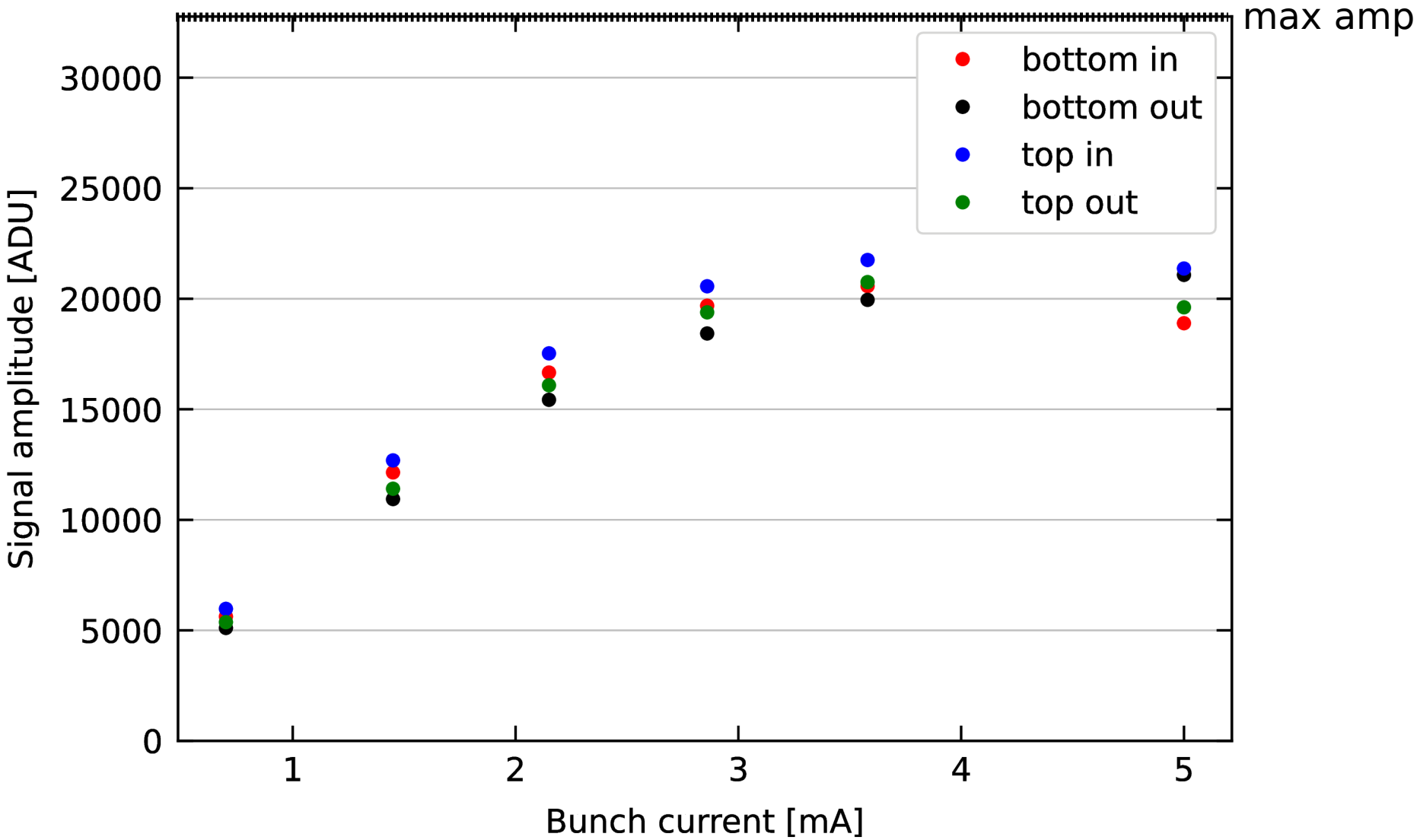
Part 2 – signal amplitude vs bunch current

12W – 2nd order polynomial fit (w/o uncertainty)



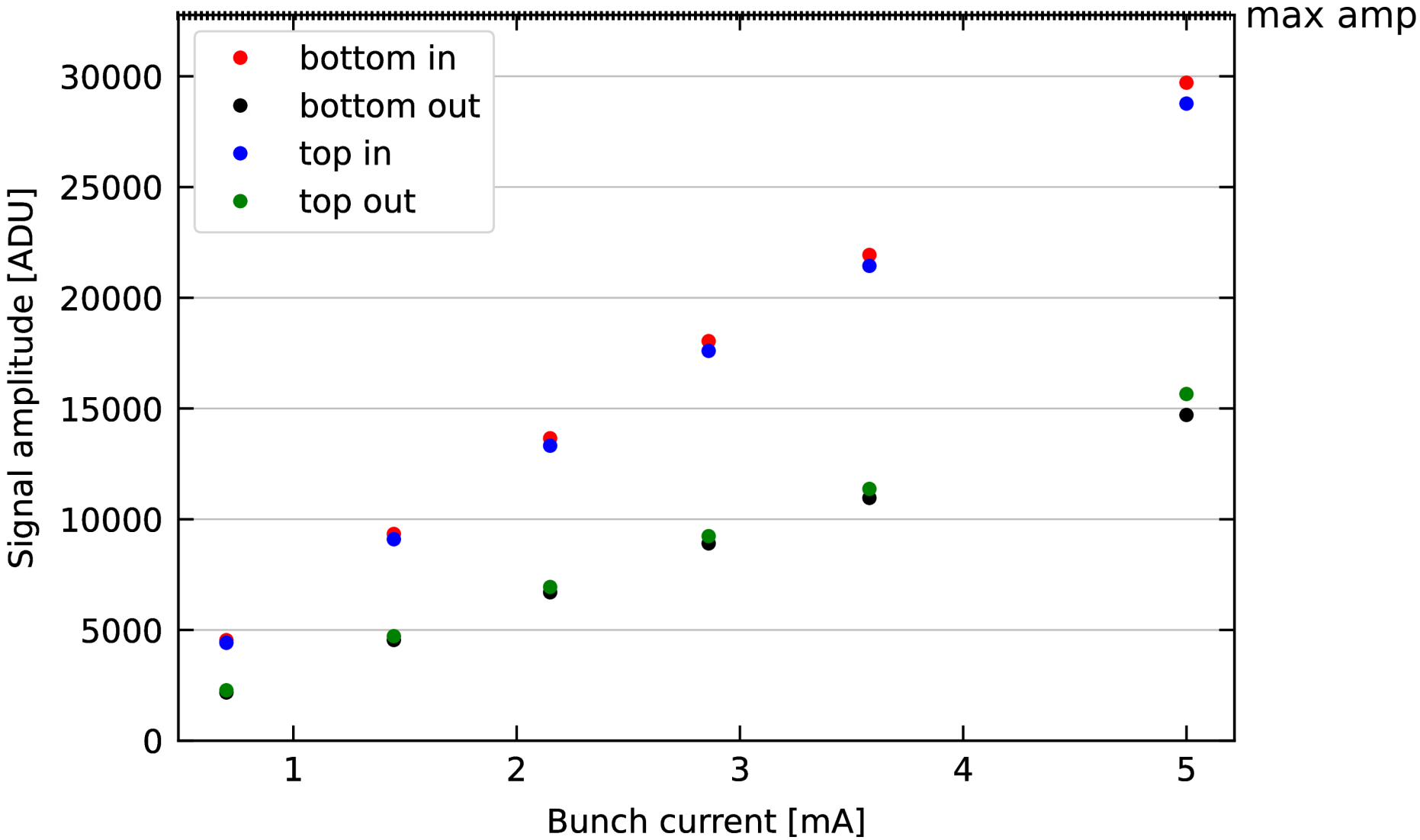
Part 2 – signal amplitude vs bunch current

12W2



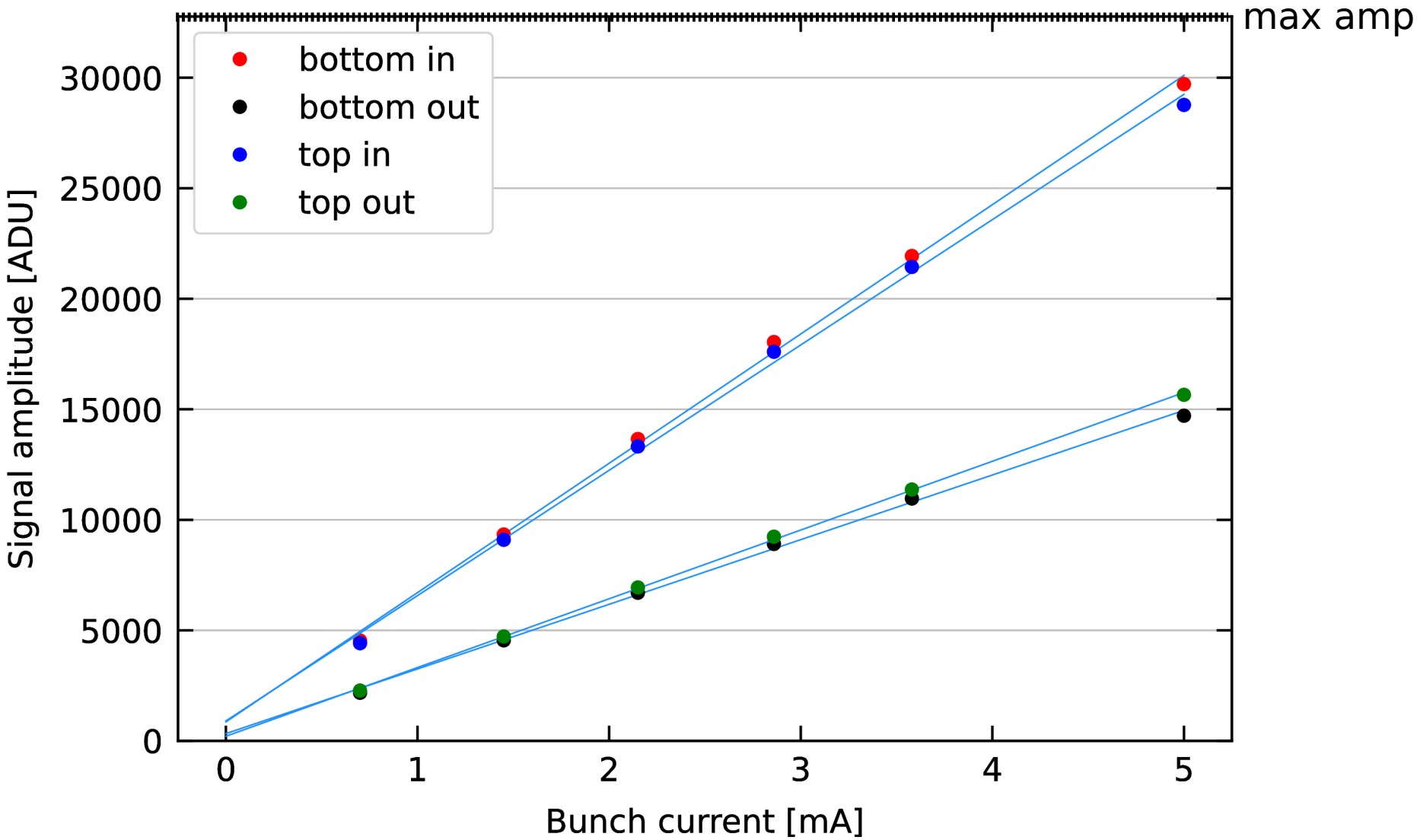
Part 2 – signal amplitude vs bunch current

12W3



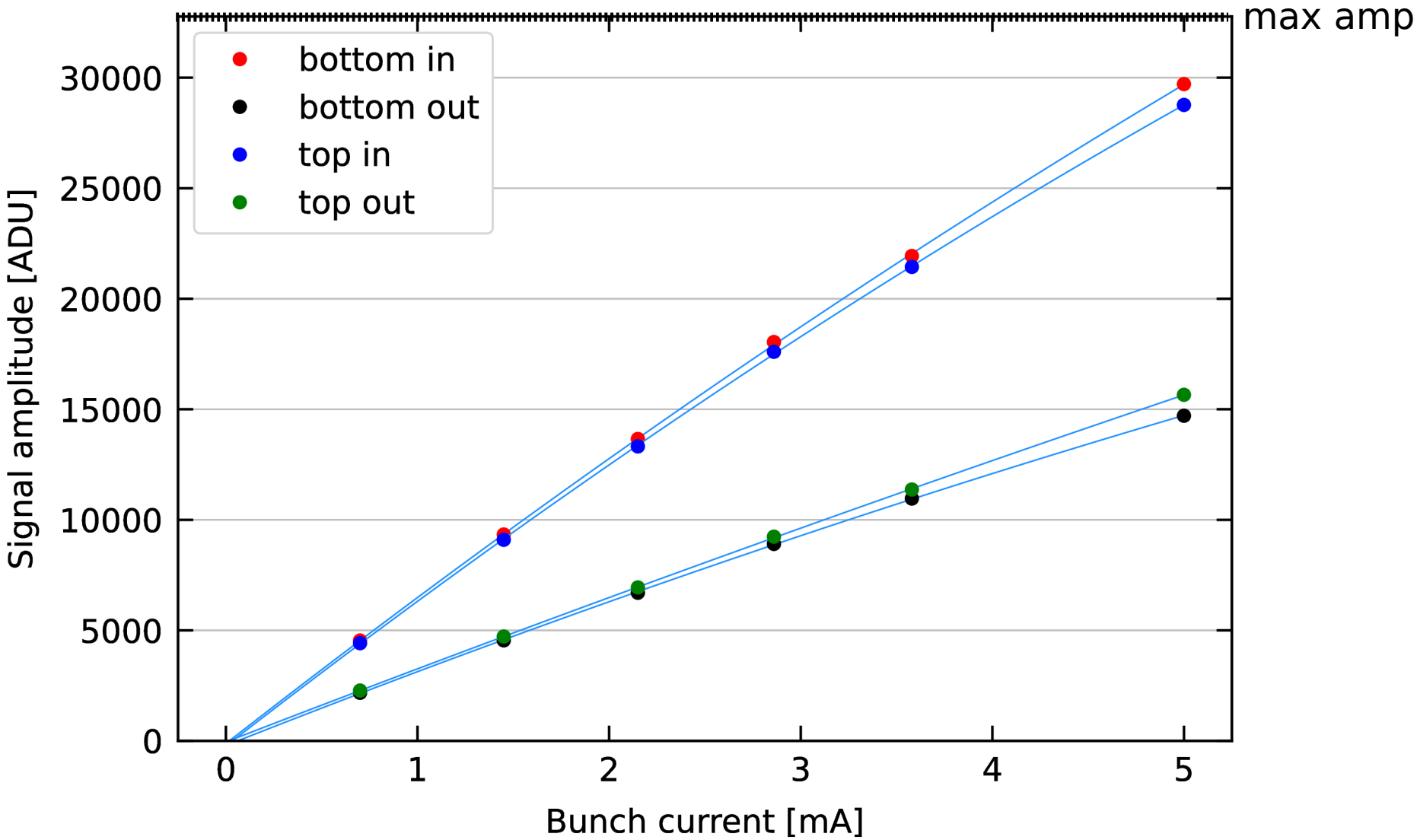
Part 2 – signal amplitude vs bunch current

12W3 – 1st order polynomial fit (w/o uncertainty)



Part 2 – signal amplitude vs bunch current

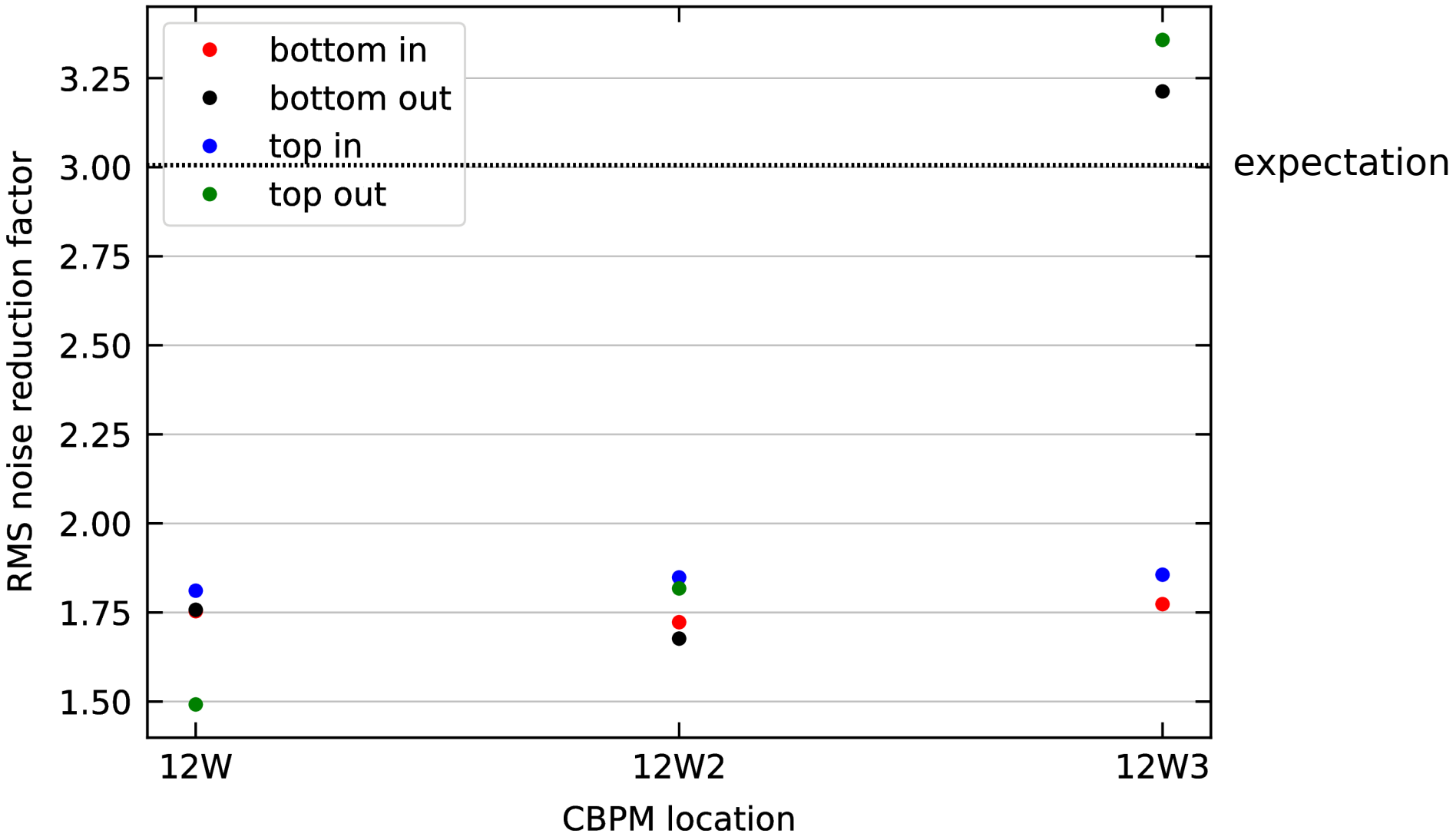
12W3 – 2nd order polynomial fit (w/o uncertainty)



To summarize

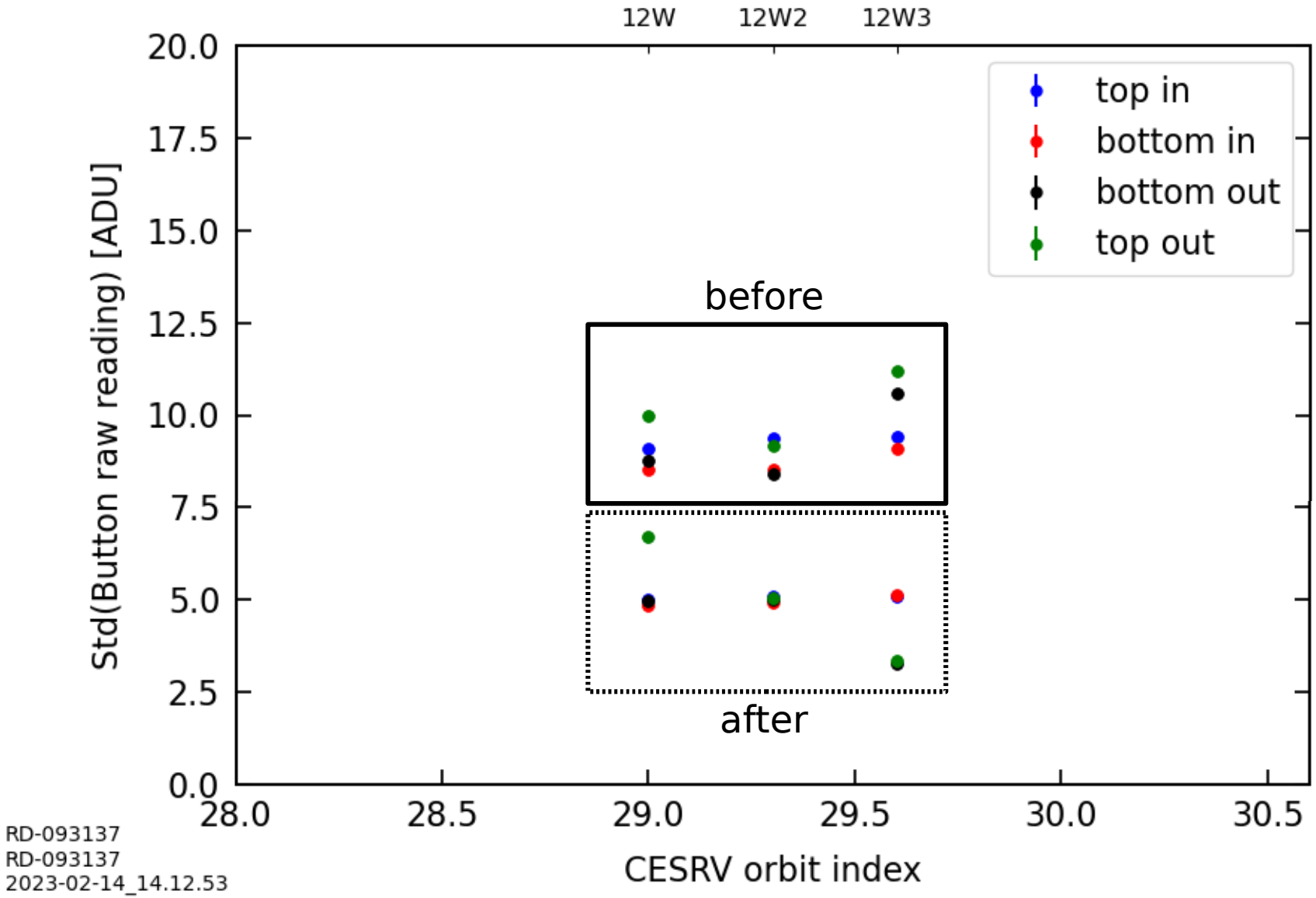
Part 1 vs Part 2: RMS noise reduction

Expected noise reduction by a **factor 3**



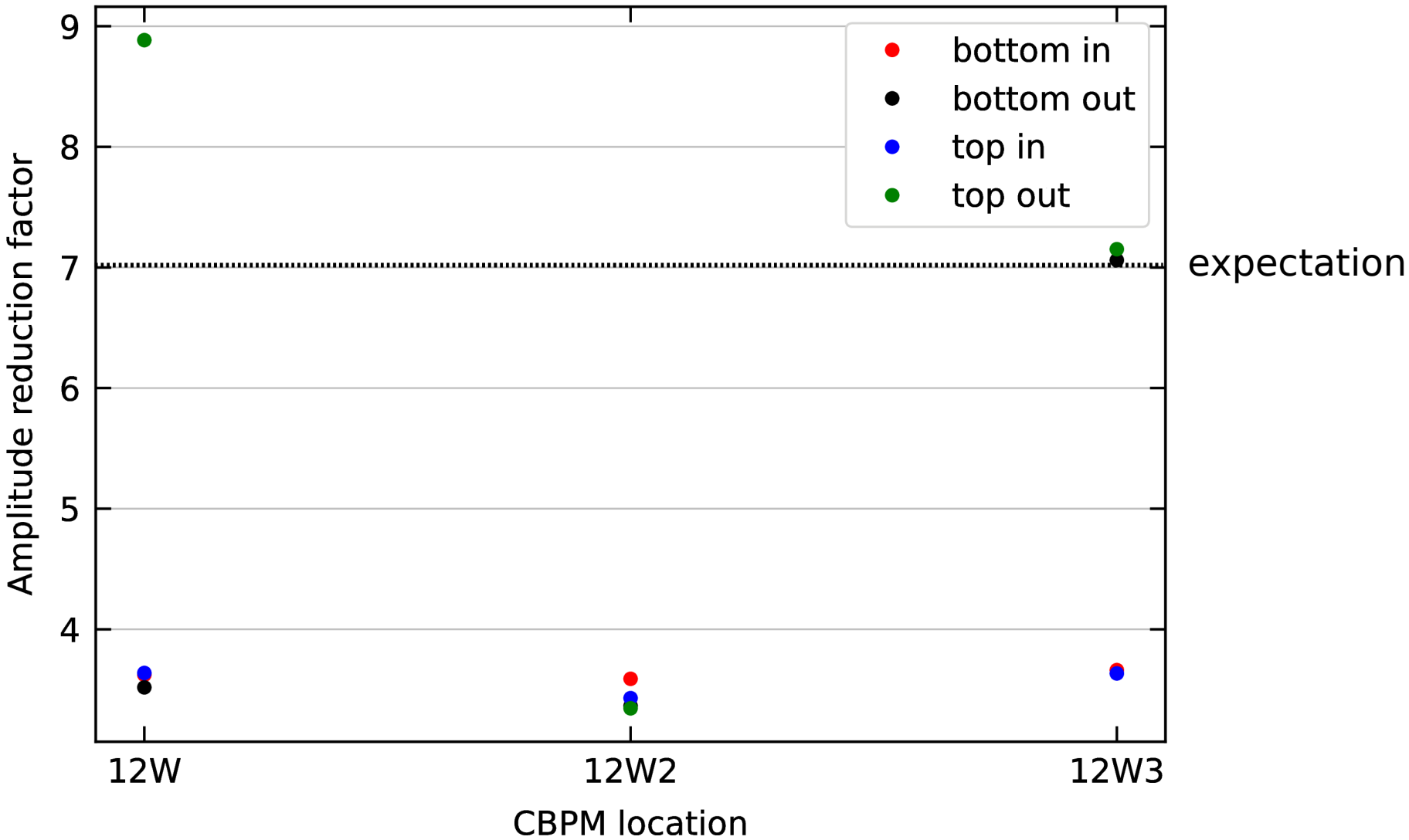
Part 1 vs Part 2: RMS noise reduction

CESR cold – dataset #1



Part 1 vs Part 2: amplitude reduction

Expected amplitude reduction by **factor 7**



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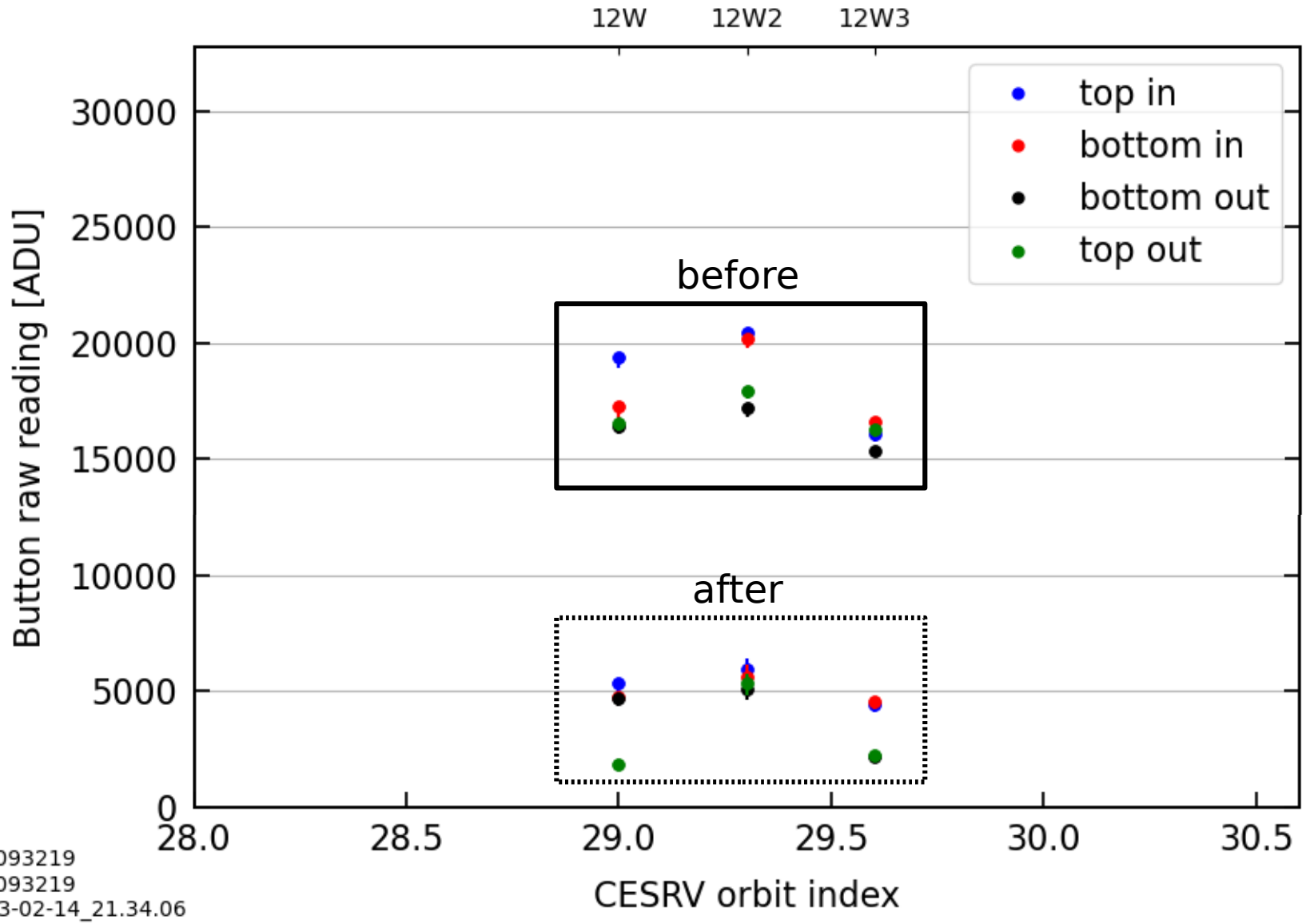
Part 1 vs Part 2: amplitude reduction

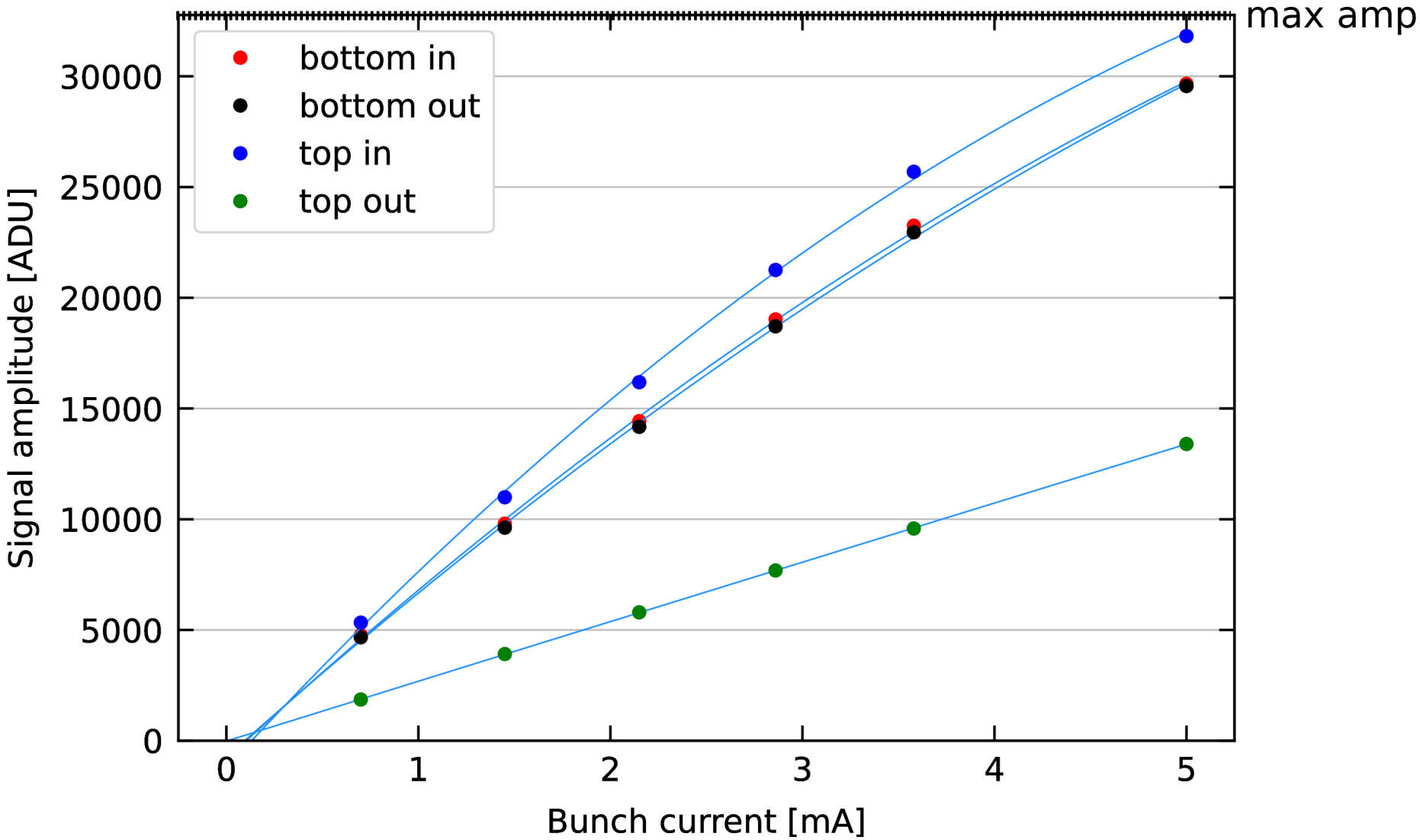
CESR current at 0.7 mA – dataset #1



RD-093219
RD-093219
2023-02-14_21.34.06

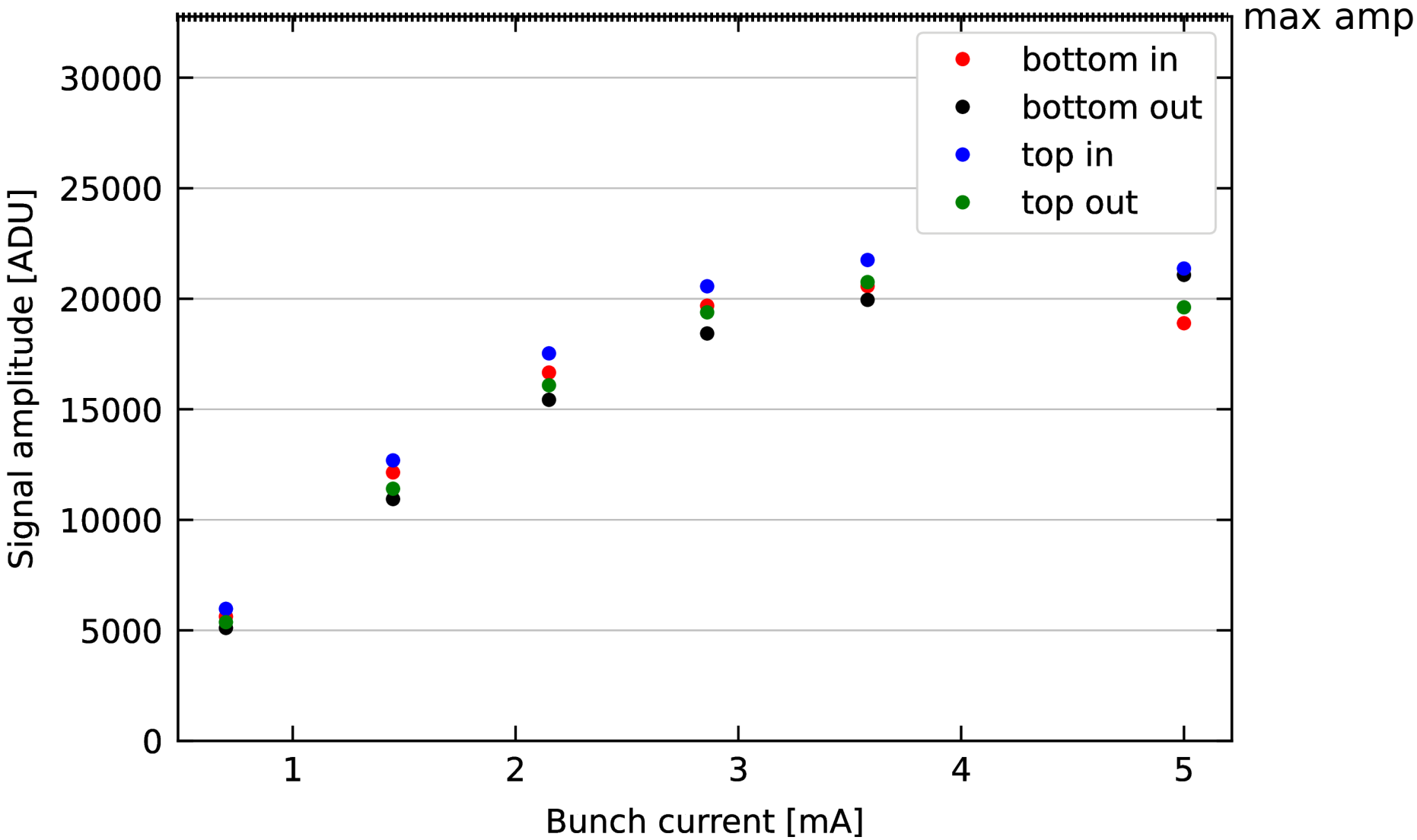
Part 2 – signal amplitude vs bunch current

12W – 2nd order polynomial fit (w/o uncertainty)



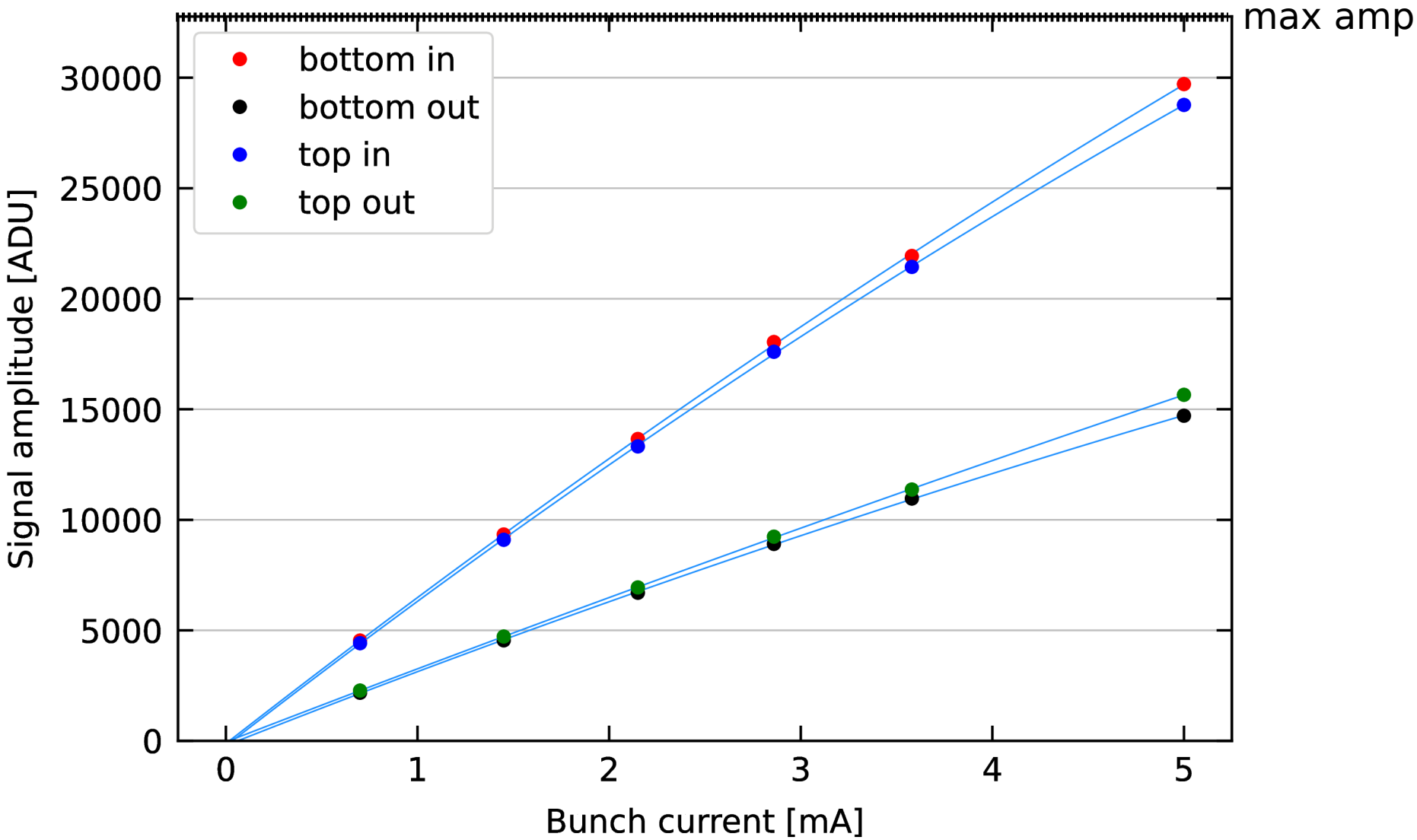
Part 2 – signal amplitude vs bunch current

12W2



Part 2 – signal amplitude vs bunch current

12W3 – 2nd order polynomial fit (w/o uncertainty)



Takeway

Non-linearities observed in module response as a function of current

Only two buttons at 12W3 (top out and bot out) are meeting expectations:

- ✗ RMS noise reduction by 3.25
- ✗ signal amplitude reduction by 7

After resistor removal and 5 mA current → **signal-to-noise ratio improved by ~3** (minus non-linearities as current increases)

Other buttons see:

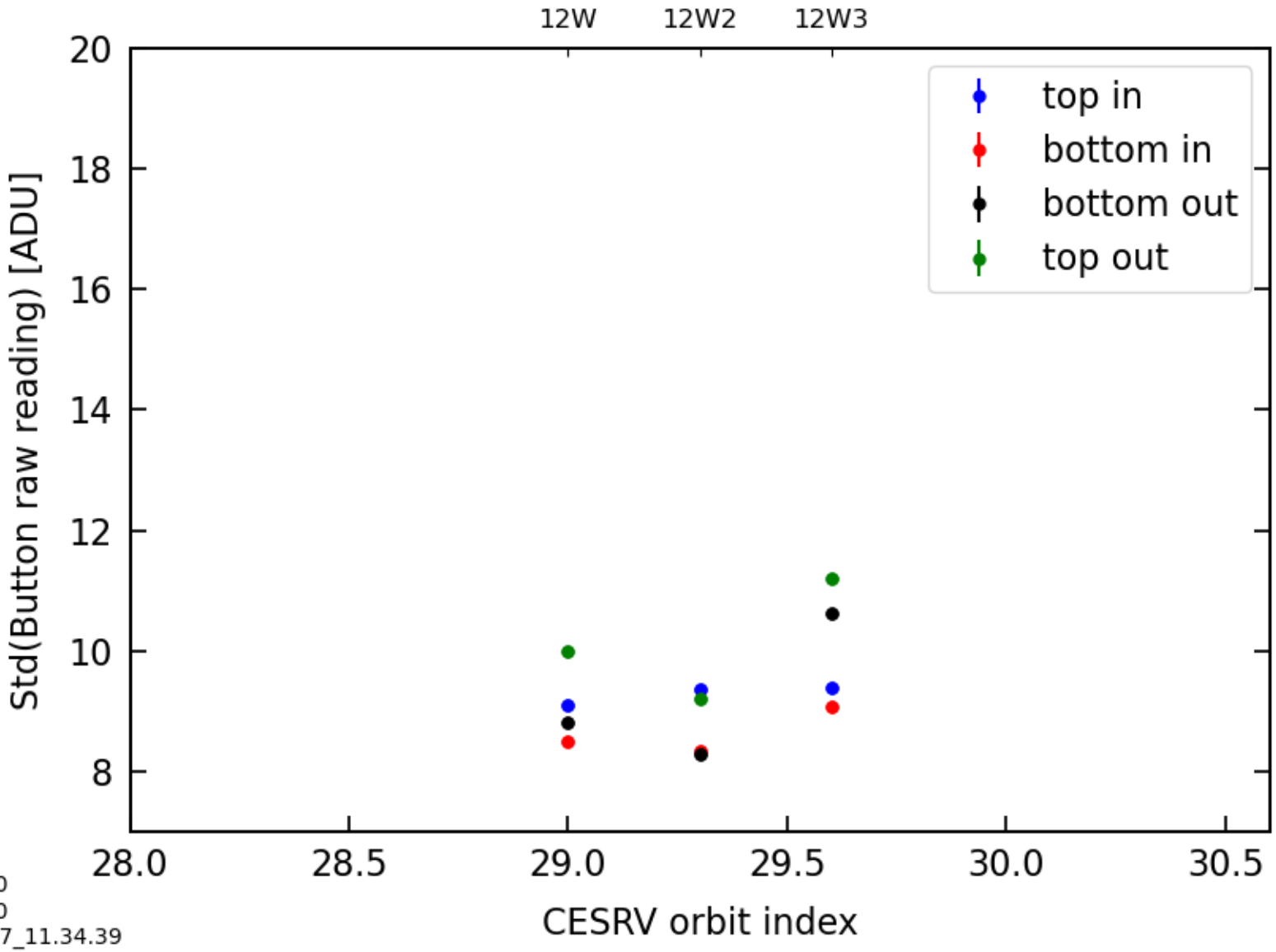
- ✗ RMS noise reduction by ~1.75
- ✗ signal amplitude reduction by ~3.6

} both are ~half of expectation

Additional materials

Part 1 – RMS noise

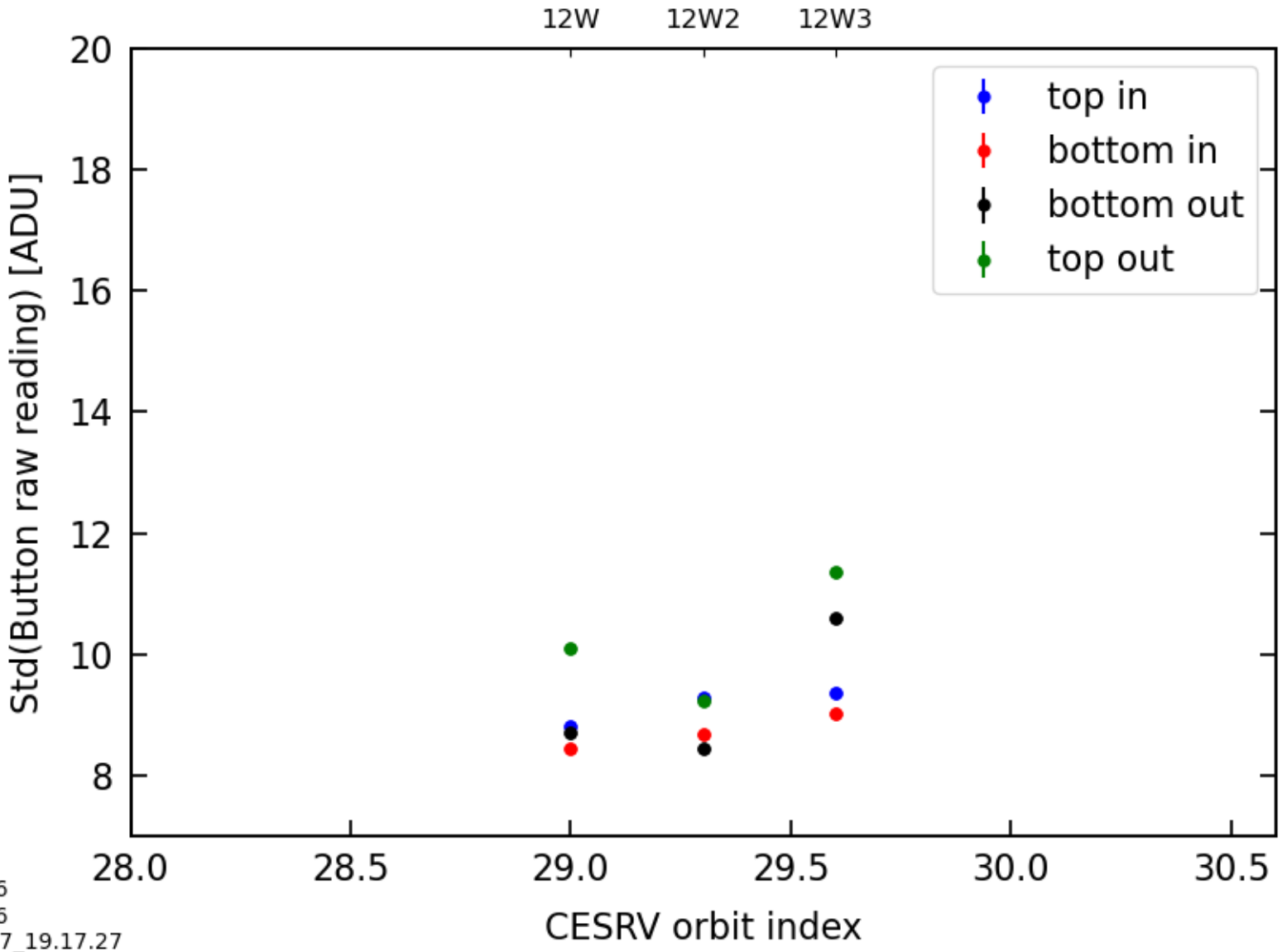
CESR cold – dataset #2



RD-092290
RD-092290
2023-02-07_11.34.39

Part 1 – RMS noise

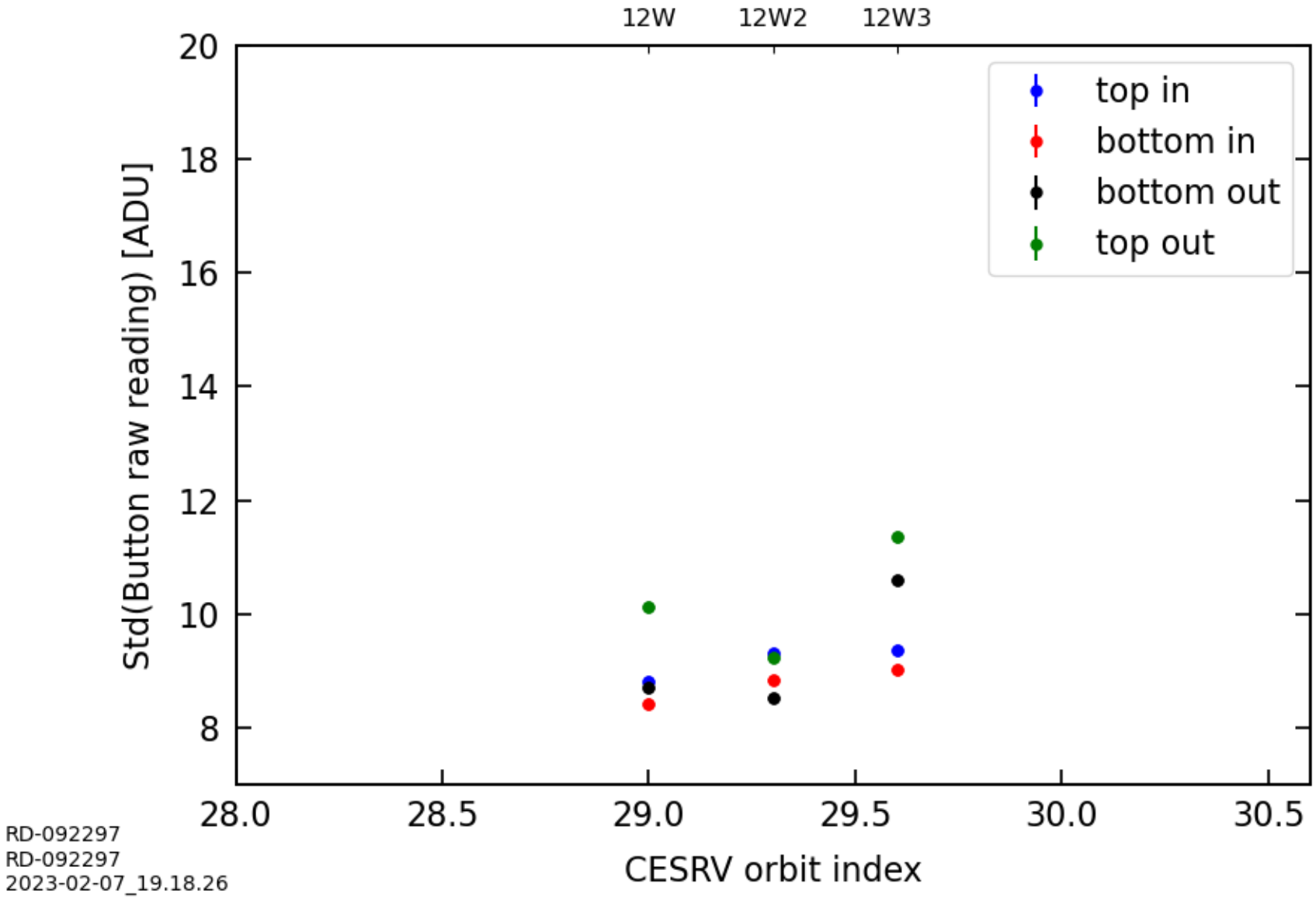
CESR hot – dataset #1



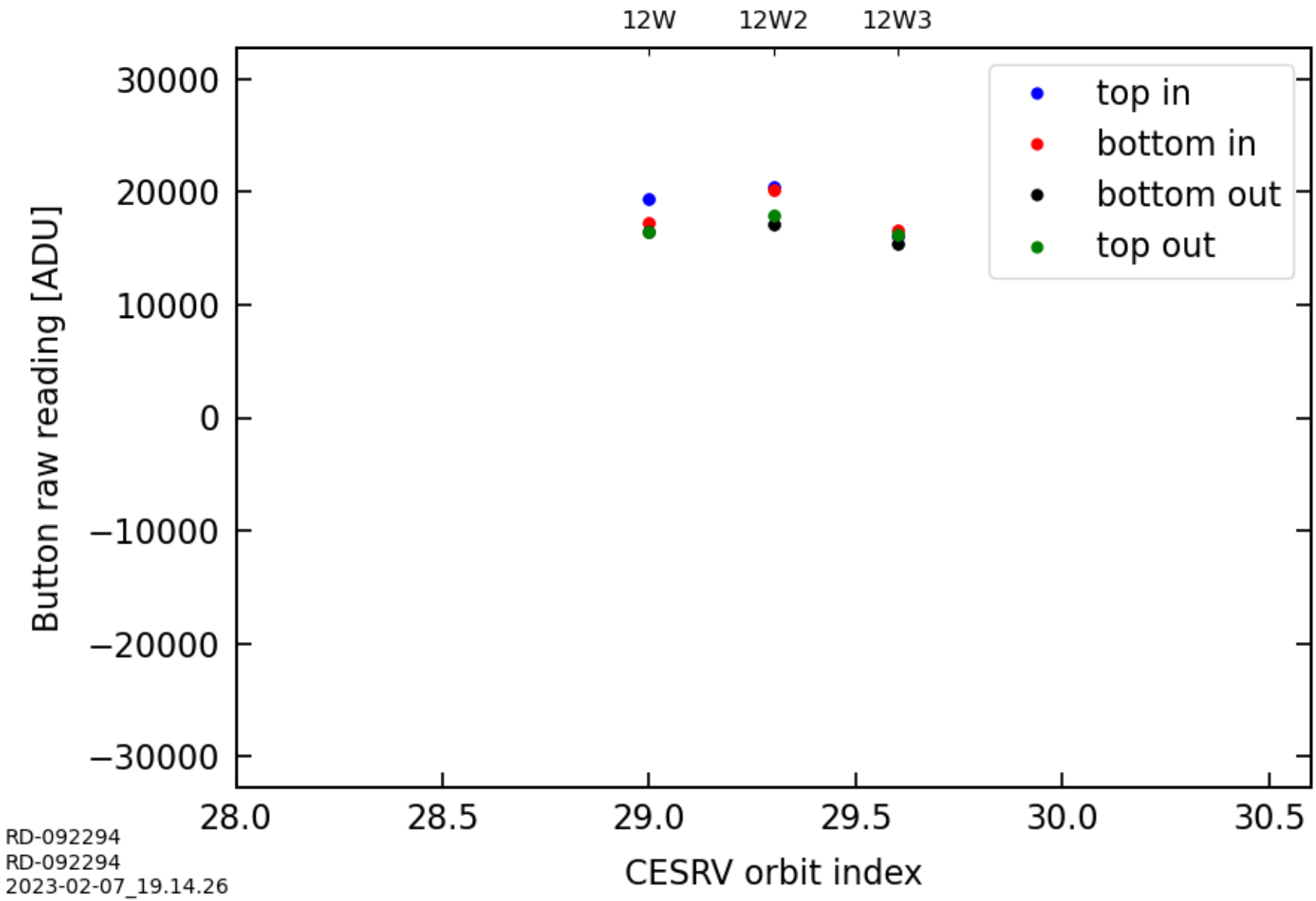
RD-092296
RD-092296
2023-02-07_19.17.27

Part 1 – RMS noise

CESR hot – dataset #2



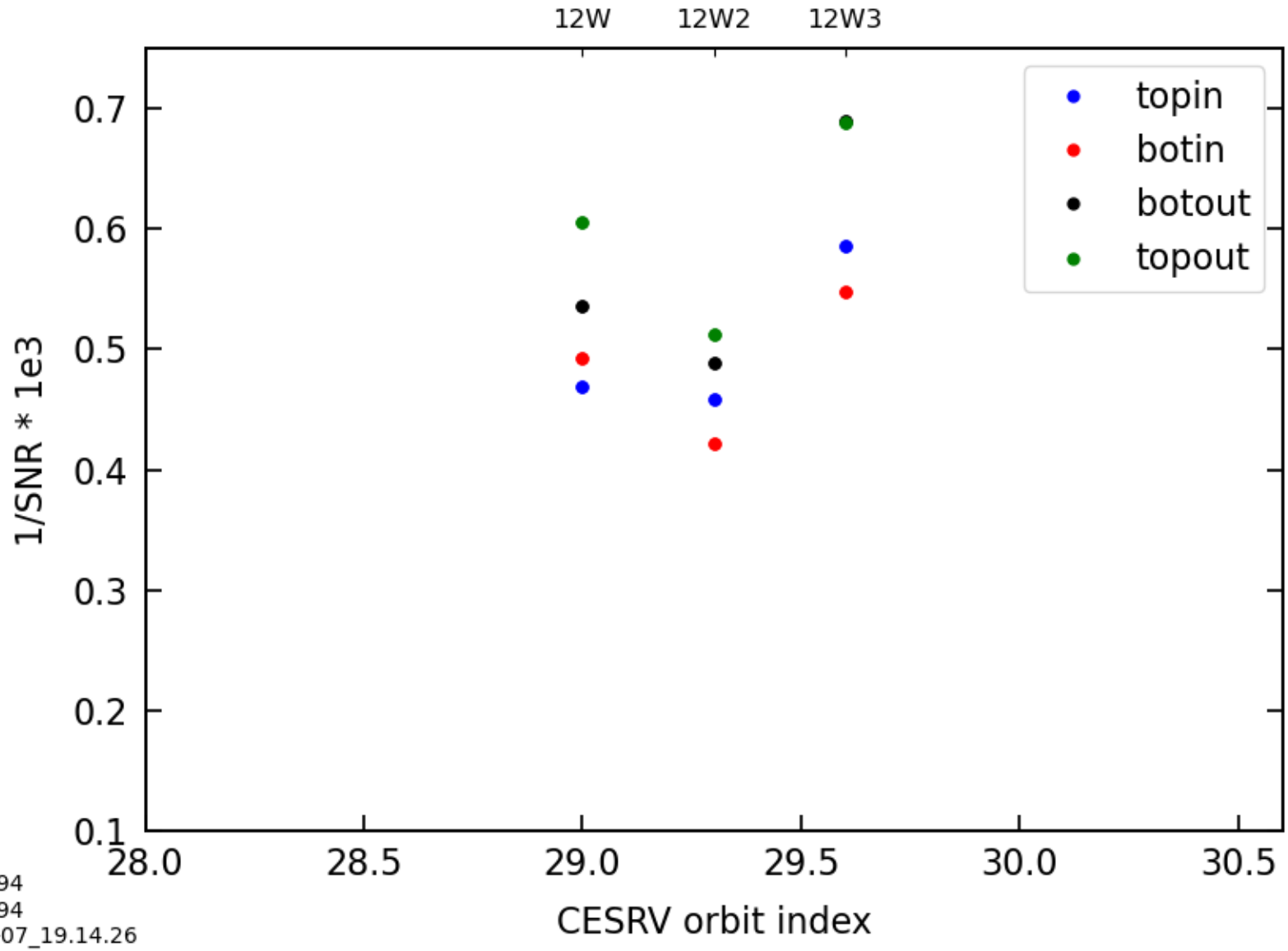
Part 1 – signal amplitude



Signal-to-noise ratio

Part 1 – signal-to-noise ratio

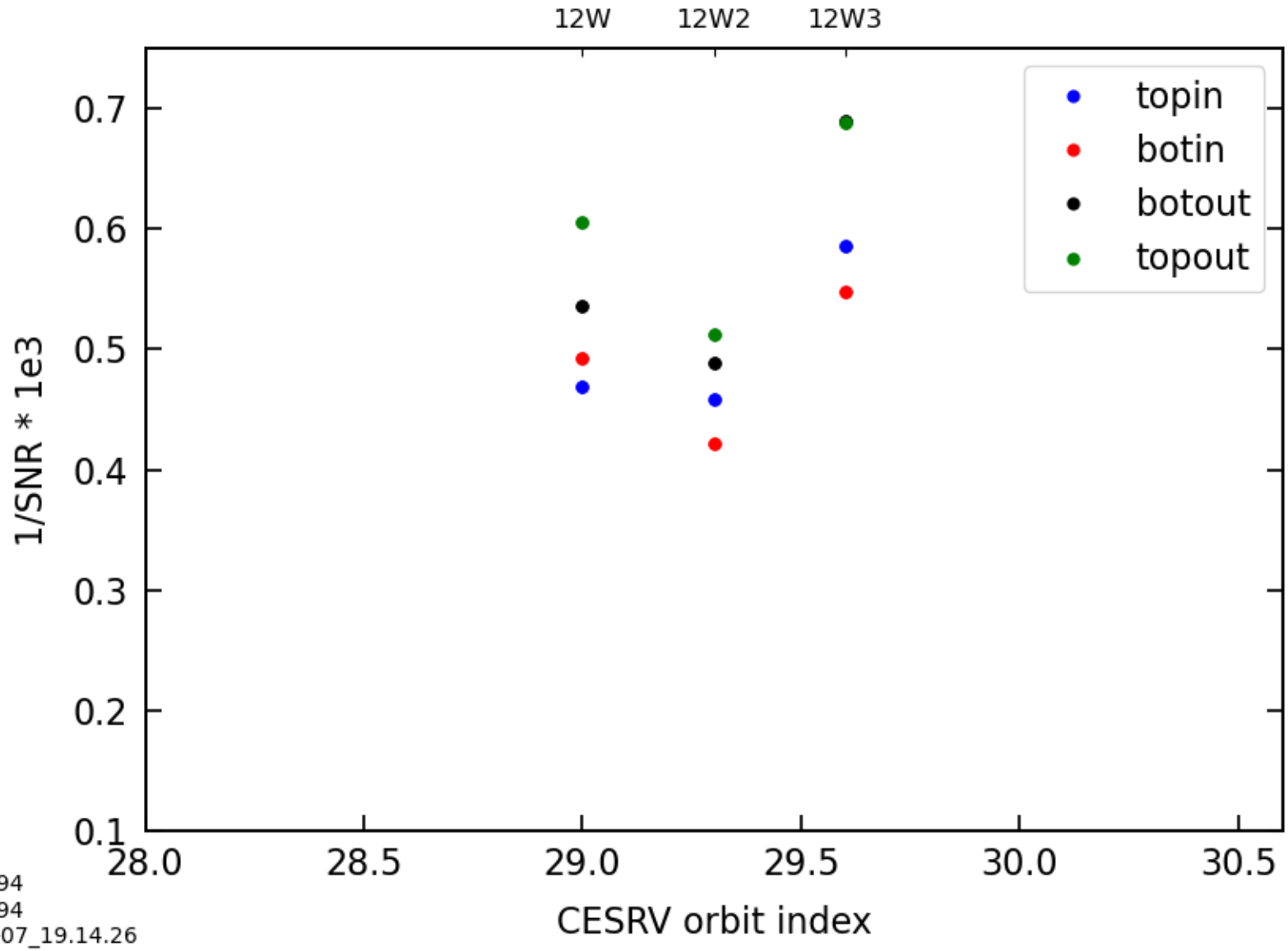
Using RD-092287 for RMS noise information



RD-092294
RD-092294
2023-02-07_19.14.26

Part 2 – signal-to-noise ratio

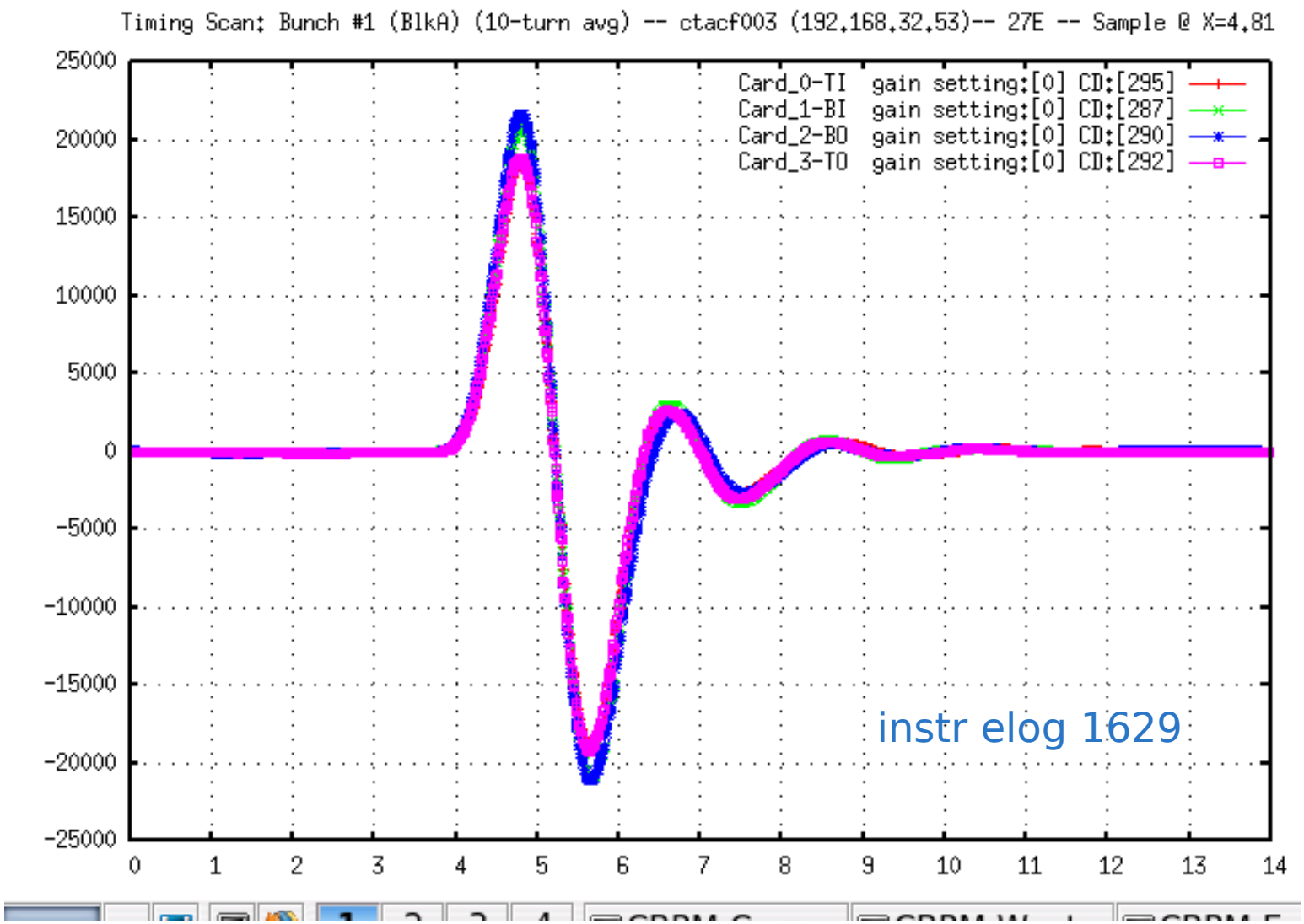
Using RD-092XXX for RMS noise information



RD-092294
RD-092294
2023-02-07_19.14.26

Button response

Beam position measurement relies on taking **one sample** of each button response to the charged bunch passing by:



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