first results with new Bunch-by-Bunch acquisition system

1) motivation and purpose of this new B-b-B instrument

2) description of the **Digit-500 AC**

3) verifications on 2 units with real beam (button) signals :
   - **linearity issues due to high peaked signals**
   - **finding and keeping the right phase**
   - **long-term gain stability**

4) some **promising results**

5) preliminary **conclusions** & some **recommendations**

1) motivation and purpose of this new B-b-B instrument

we have already a B-b-B system (copy of the DLS system) but :

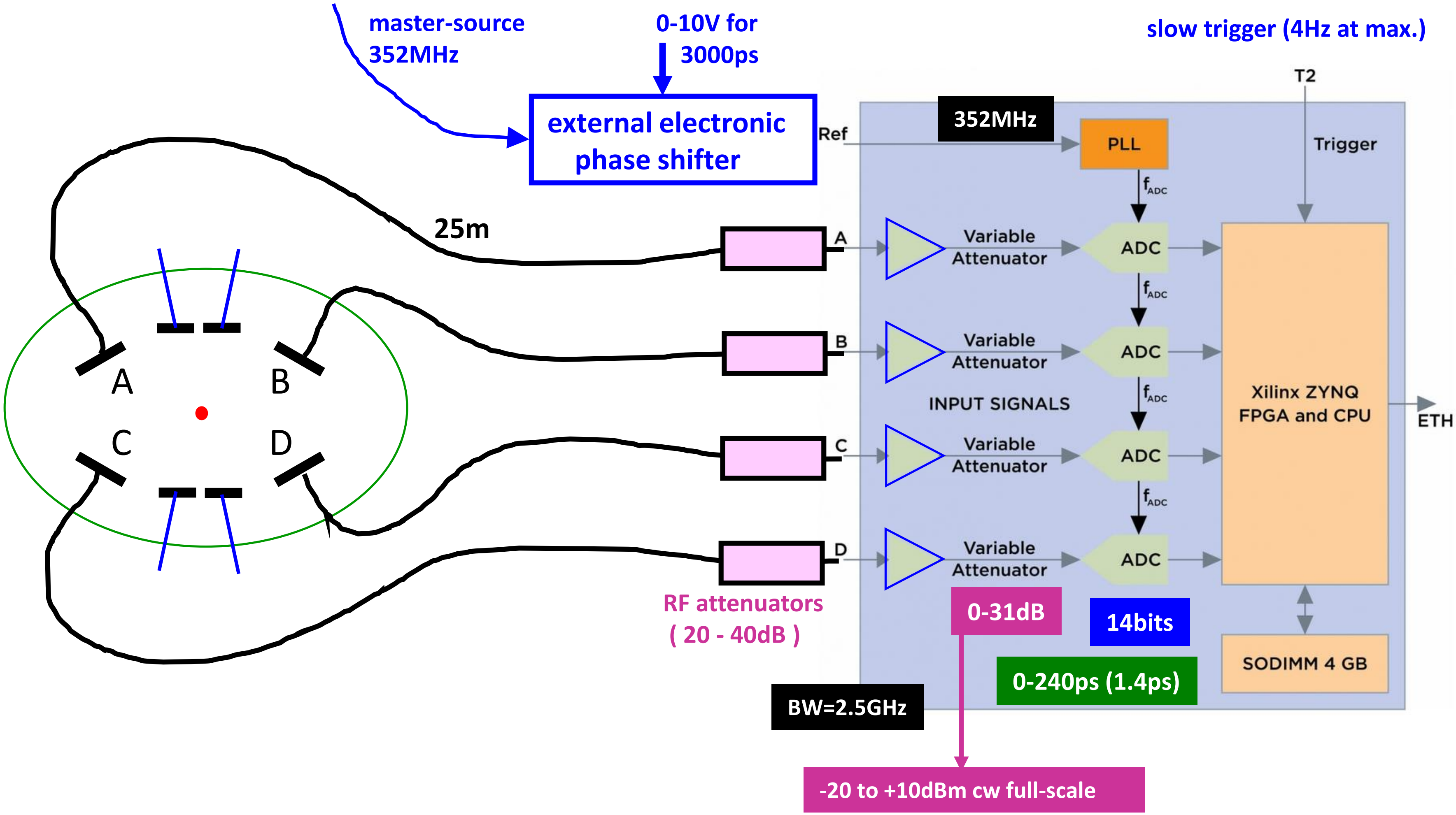
- used for other means
- only has 2 channels
- more expensive than Digit-500

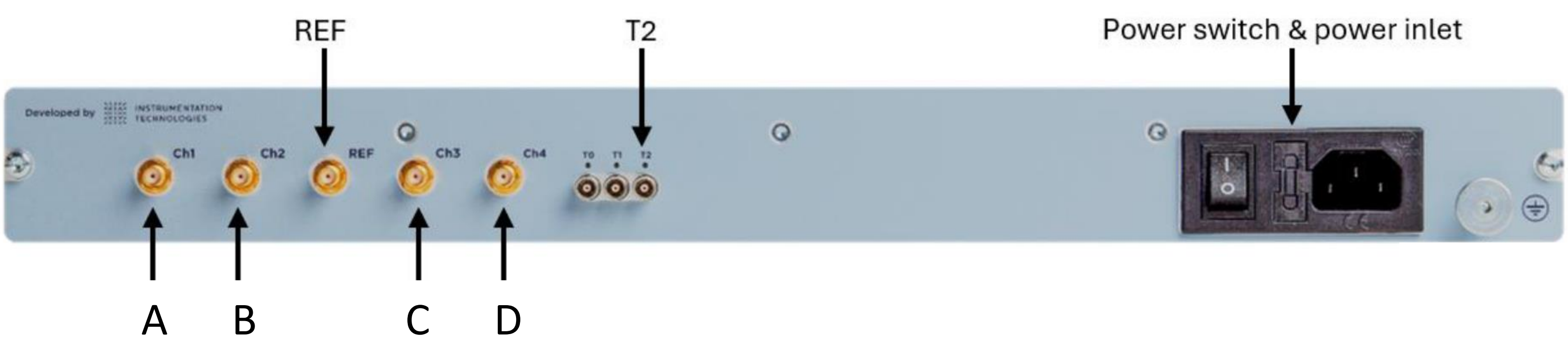
both in our **Booster** and in the **Storage Ring** many beam features, that go presently un-noticed

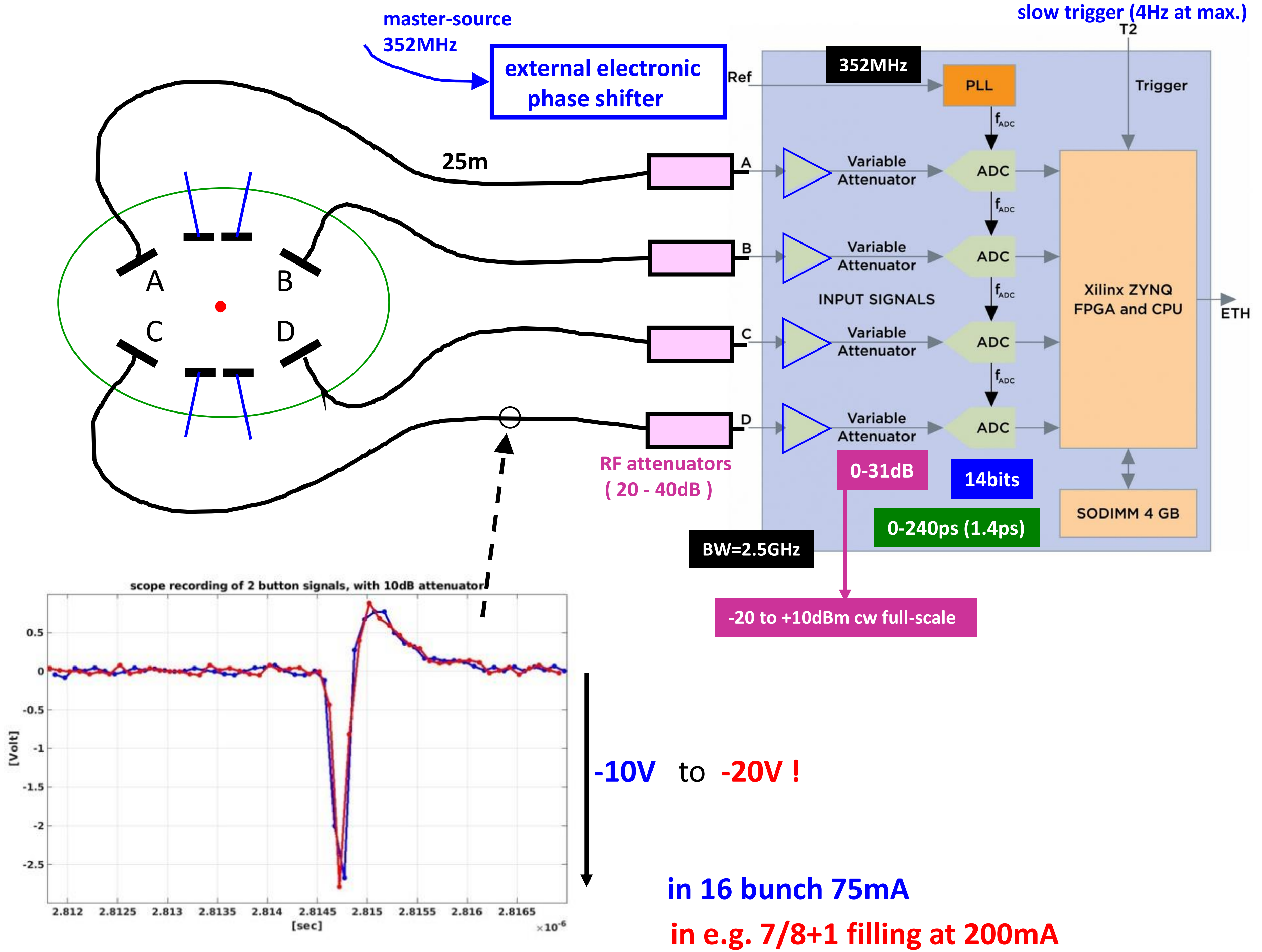
- at this fast **B-b-B time scale**
- on the **beam position**, but
- and also on the **beam-charge** → 100% of this presentation

we had (end of 2023) a financial possibility to buy **4** units
plus some special firmware

the devices comes with Tango control interface


master-source
352MHz
0-10V for
3000ps
slow trigger (4Hz at max.)
external electronic
phase shifter
T2
Ref
352MHz
PLL
Trigger
f_{ADC}
25m
A
B
C
D
A
B
C
D
Variable
Attenuator
ADC
INPUT SIGNALS
Xilinx ZYNQ
FPGA and CPU
ETH
RF attenuators
(20 - 40dB)
0-31dB
14bits
0-240ps (1.4ps)
SODIMM 4 GB
BW=2.5GHz
-20 to +10dBm cw full-scale


REF
T2
Power switch & power inlet
Ch1
Ch2
REF
Ch3
Ch4
T0
T1
T2
A
B
C
D



master-source
352MHz
external electronic phase shifter
slow trigger (4Hz at max.)
T2
352MHz
Ref
PLL
Trigger
25m
A
B
C
D
Variable Attenuator
ADC
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Xilinx ZYNQ FPGA and CPU
ETH
SODIMM 4 GB
RF attenuators
(20 - 40dB)
0-31dB
14bits
0-240ps (1.4ps)
BW=2.5GHz
-20 to +10dBm cw full-scale
scope recording of 2 button signals, with 10dB attenuator
[Volt]
[sec]
-10V to -20V !
in 16 bunch 75mA
in e.g. 7/8+1 filling at 200mA

main fill patterns at the ESRF Storage Ring :

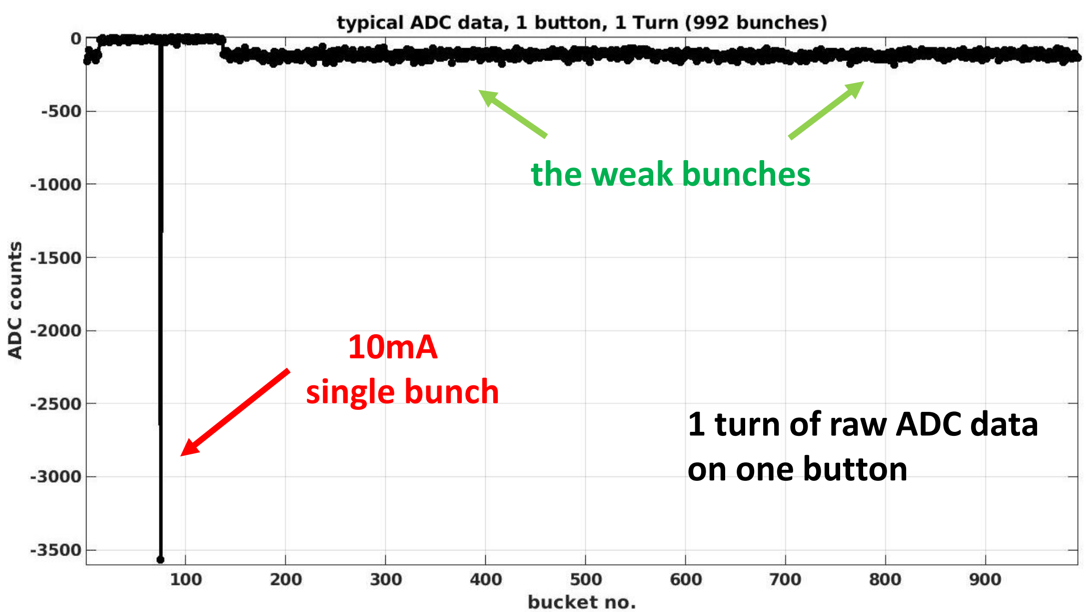
Harmonic number = 992 (RF-freq. = 352.3MHz, 2.8ns bucket separation)

1) **Uniform** → all **992** buckets filled, 200mA, 0.2mA/bunch

2) **16 bunches** → **16** buckets **5.6mA** equally spaced (16 empty spaces of 122 buckets) , 90mA

3) 4 bunches → **4** buckets **10mA** equally spaced (4 empty spaces of 247 buckets) , 40mA

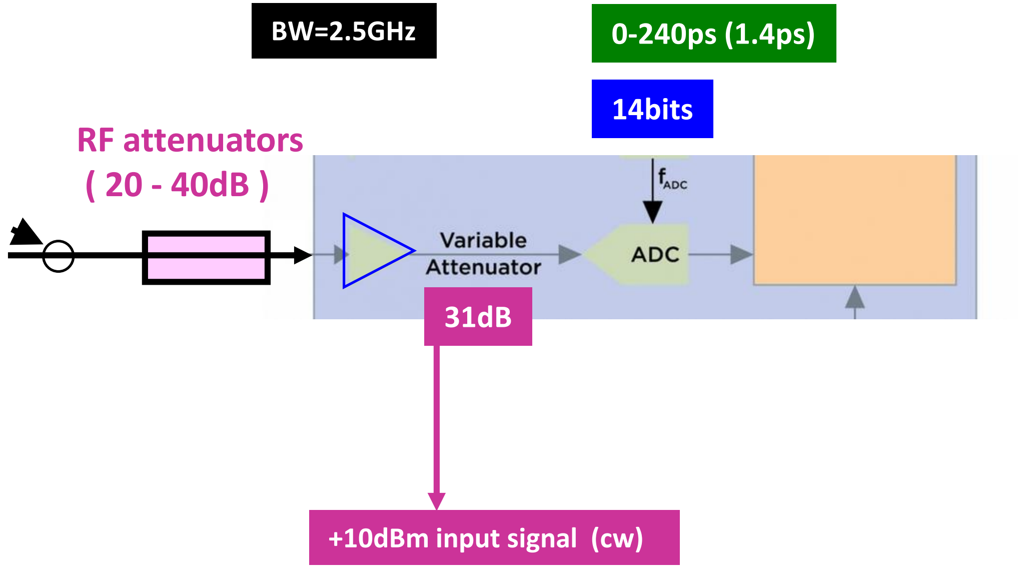
4) **7/8 + 1** → **868** buckets filled - 62 empty buckets - **1 big bunch** - **10mA** 62 empty , 200mA



-10V to -20V !

in 16 bunch 75mA

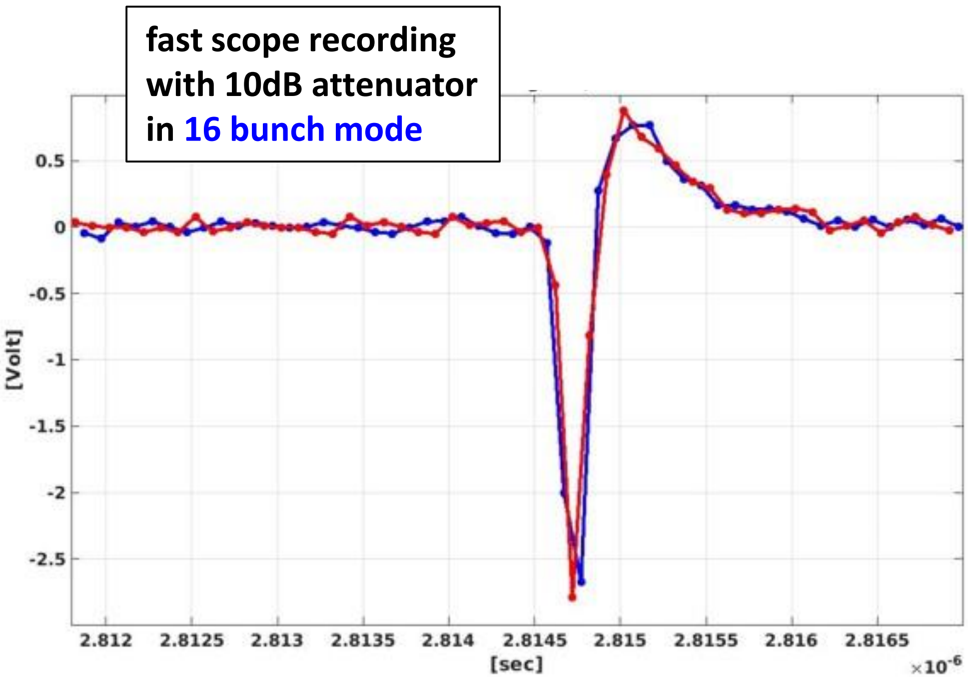
in 7/8+1 filling at 200mA



10dBm = 0.7V rms = 1V pk

10V / 1V = 10 = 20dB → 30dBm !

20V / 1V = 20 = 26dB → 36dBm !!

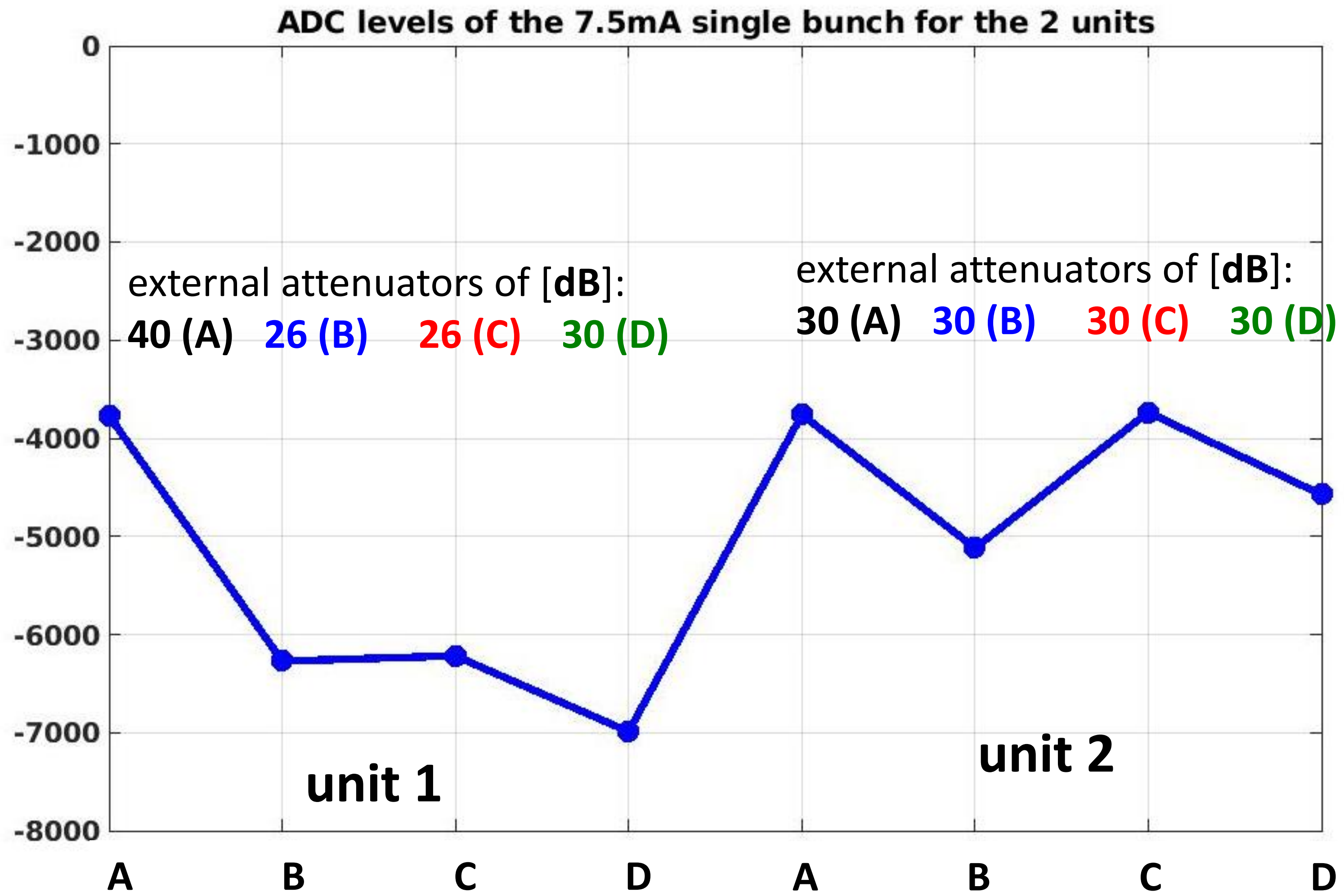


so external attenuator of 20dB or 26dB is needed …

however, tests so far show (next slides) that about <u>10dB more</u> is needed to avoid dis-linearity issues

3) verifications on 2 units with real beam (button) signals :

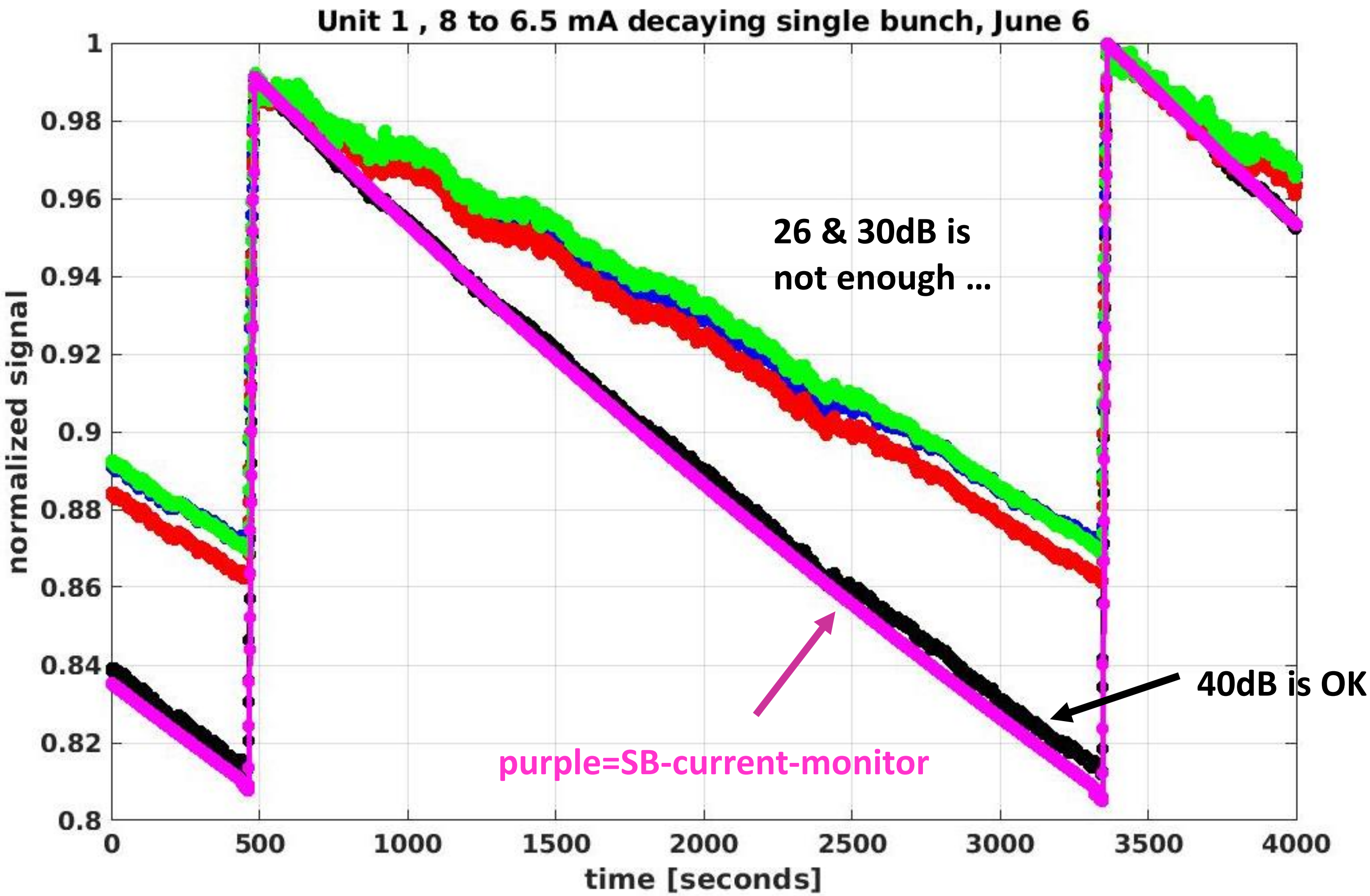
- linearity issues due to high peaked signals



- linearity issues due to high peaked signals

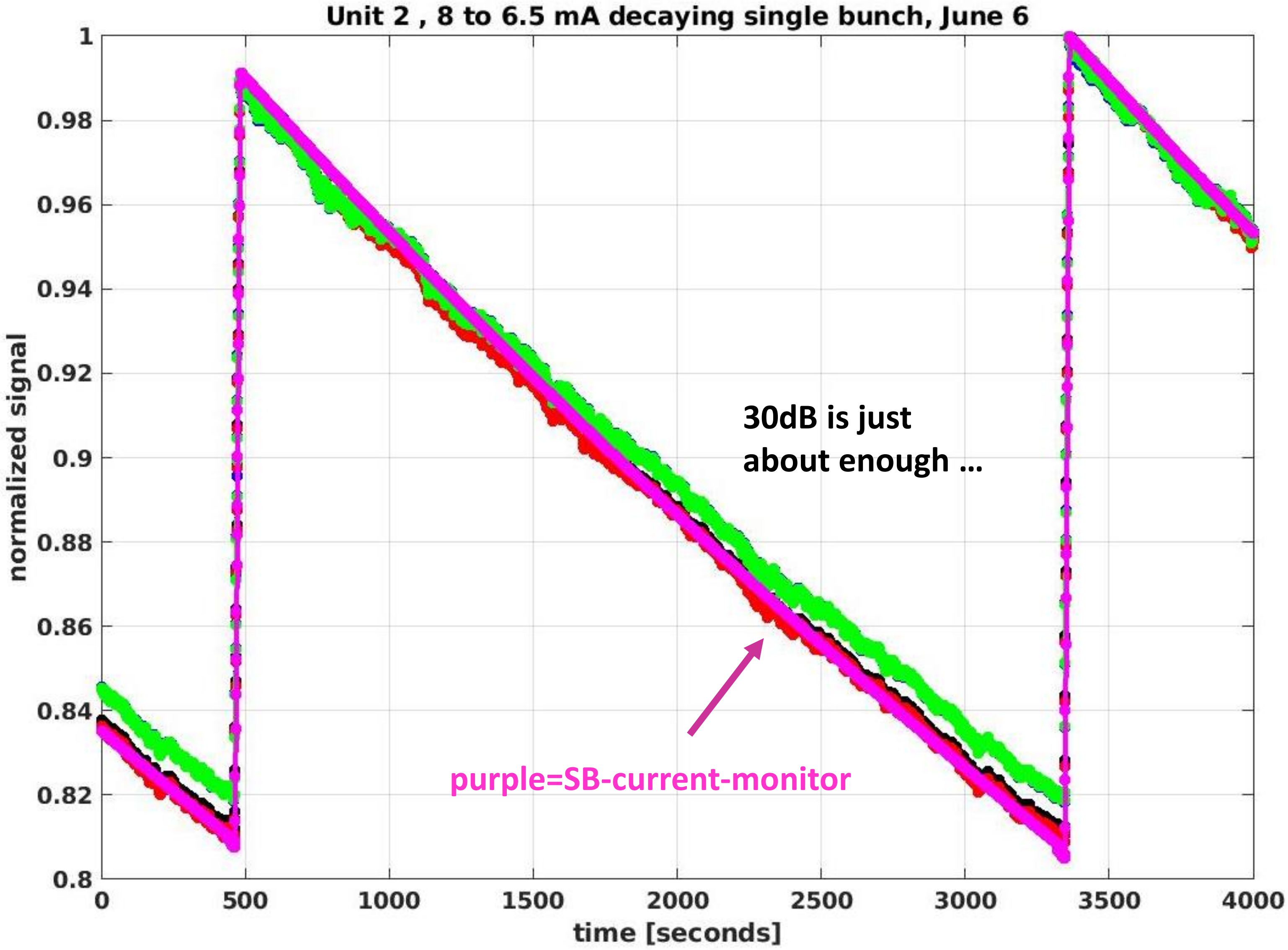
unit 1 with **external** attenuators of [**dB**]:

40 (A) , 26 (B) , 26 (C) and 30 (D)



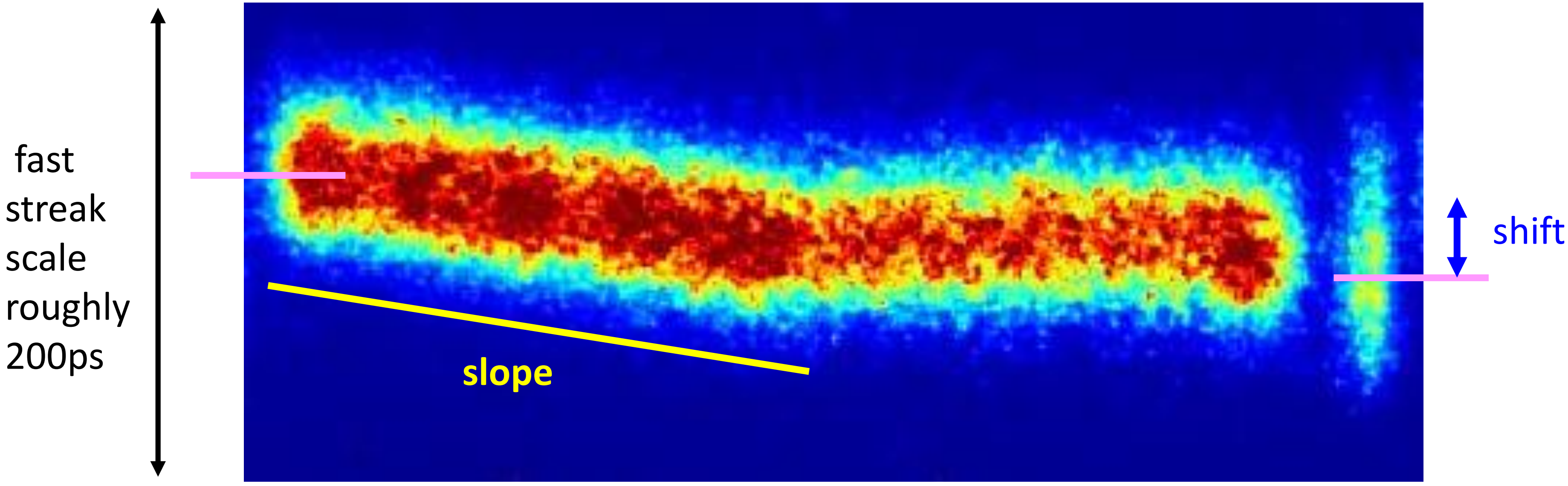
- linearity issues due to high peaked signals

unit 2 with all **external** attenuators at **30 dB**

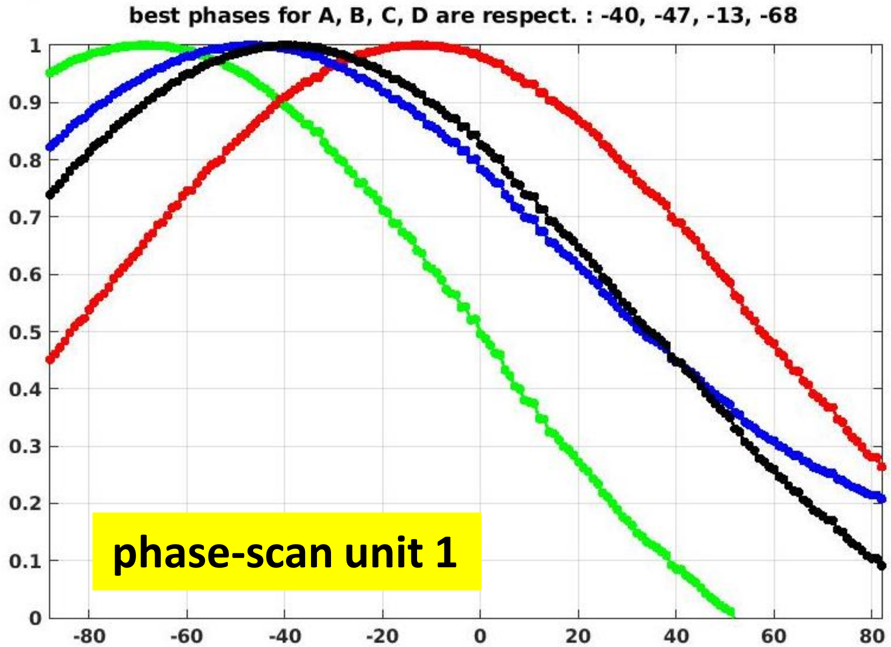


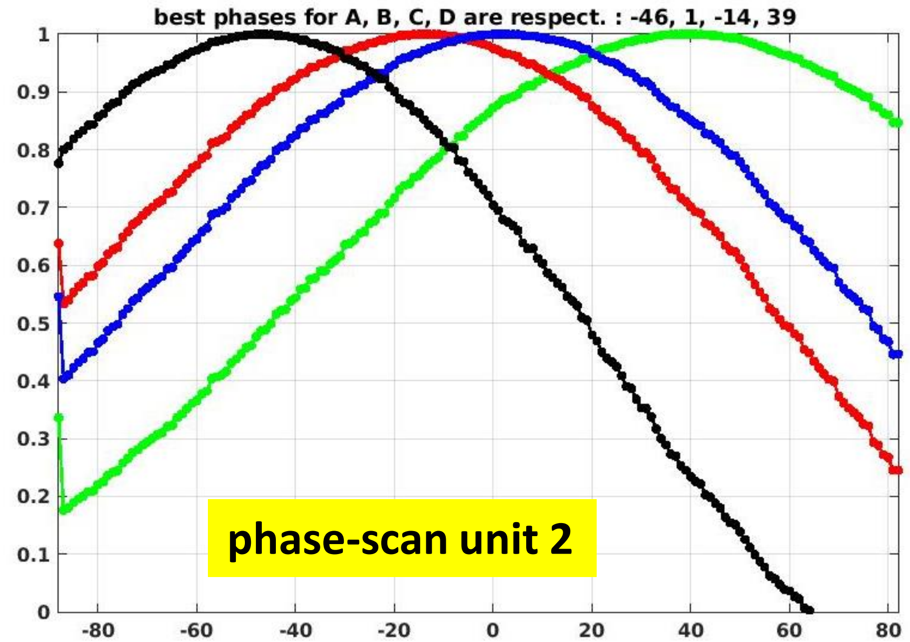
finding and keeping the right phase ....

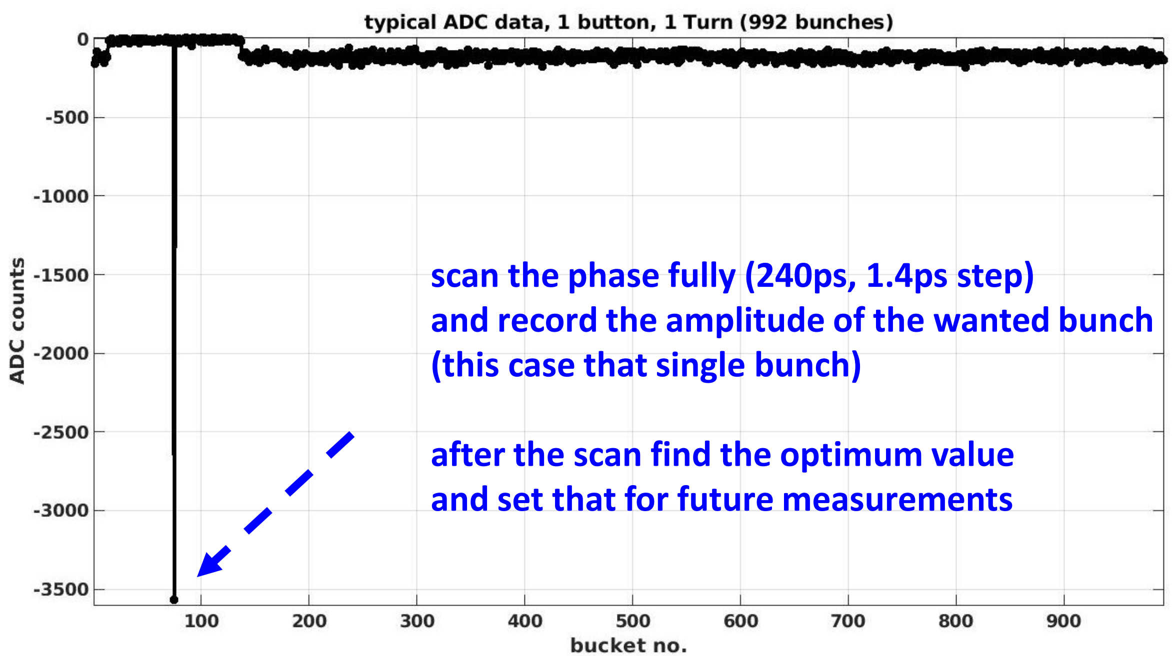
7/8 + 1 fill



the bunches do not have the same phase w.r.t. the RF-clock
an un-avoidable & intrinsic consequence of the RF-system ....


best phases for A, B, C, D are respect. : -40, -47, -13, -68
phase-scan unit 1


best phases for A, B, C, D are respect. : -46, 1, -14, 39
phase-scan unit 2

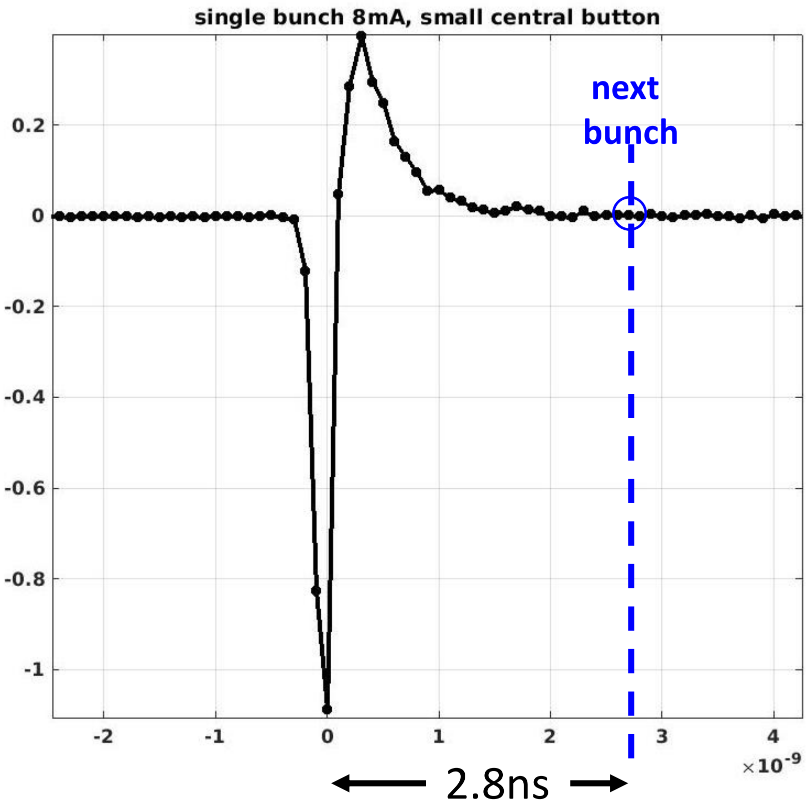

typical ADC data, 1 button, 1 Turn (992 bunches)
ADC counts
bucket no.
scan the phase fully (240ps, 1.4ps step)
and record the amplitude of the wanted bunch
(this case that single bunch)
after the scan find the optimum value
and set that for future measurements

remarks on this issue of both **linearity** & **sensitive phase** tuning :

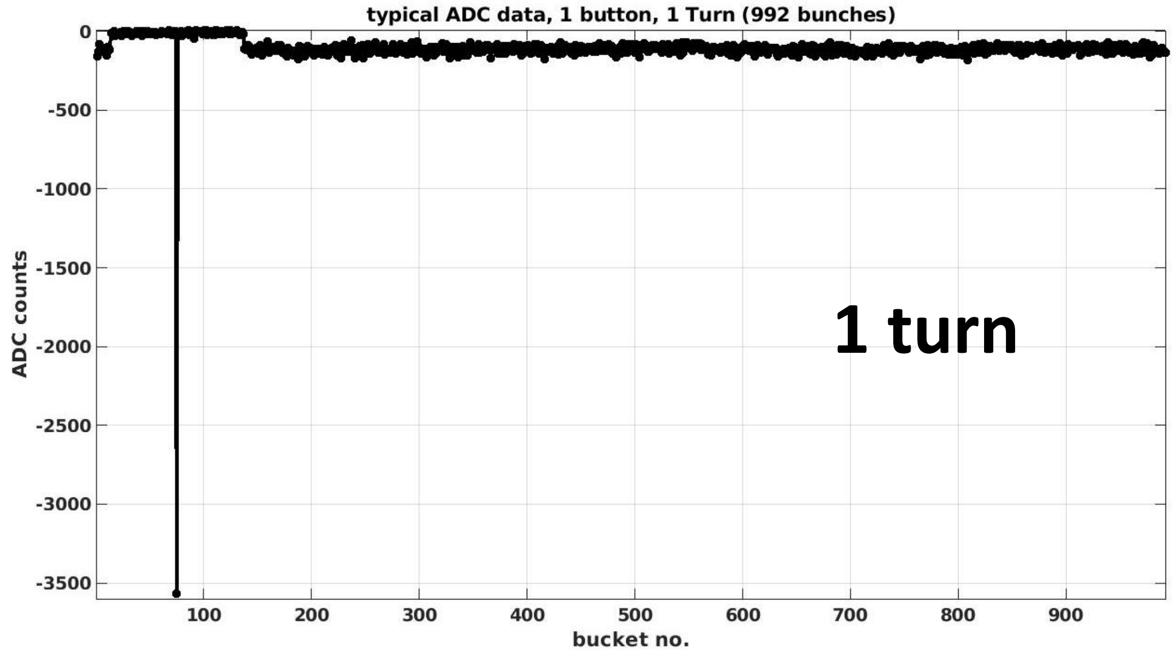
till now we used the full **2.5GHz** bandwidth of the device

to separate clearly the individual bunches separated at 2.8ns (353 MHz)

the introduction of low-pass filters (e.g. **1GHz**) would alleviate
both the issues of peak-voltage and the sensitive phase



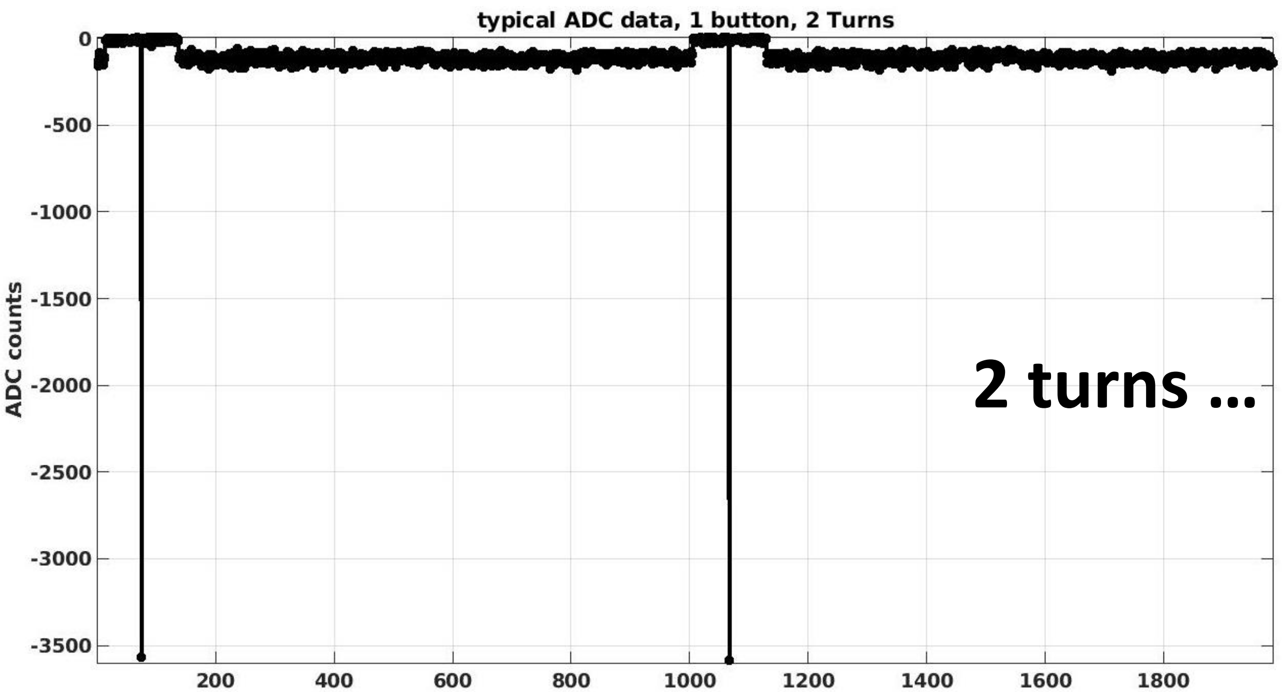
scope recording with BW
about the same
as that of the Digit-500



what to do with all that raw data ??

Digit-500 simply spits out ADC data, that is a lot ....

internal signal treatment can be added



additional firmware provided in this Digit-500 :

- the summing-up of the **ADC** buffers (at T-b-T rate) into **SUM** buffers

- keeping a history of these consecutive **SUM** buffers

<u>2 examples :</u>

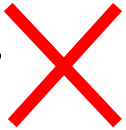
a) we can SUM-up 3500 ADC buffers → 10ms resolution
and read-out a history of 100 of these SUM buffers → 1 sec record

the noise of the B-b-B data should be improved by **60** w.r.t. to ADC data

b) we can SUM-up 350 000 ADC buffers → 1s resolution
and read-out a history of 60 of these SUM buffers → 1 min record

the noise of the B-b-B data should be improved by **600** w.r.t. to ADC data

the above has NO interest for typical fast applications of a B-b-B system,
e.g. measuring the Turn-by-Turn oscillations of all bunches



but be very powerful in **precise & high resolution charge measurements**
(of all bunches !)

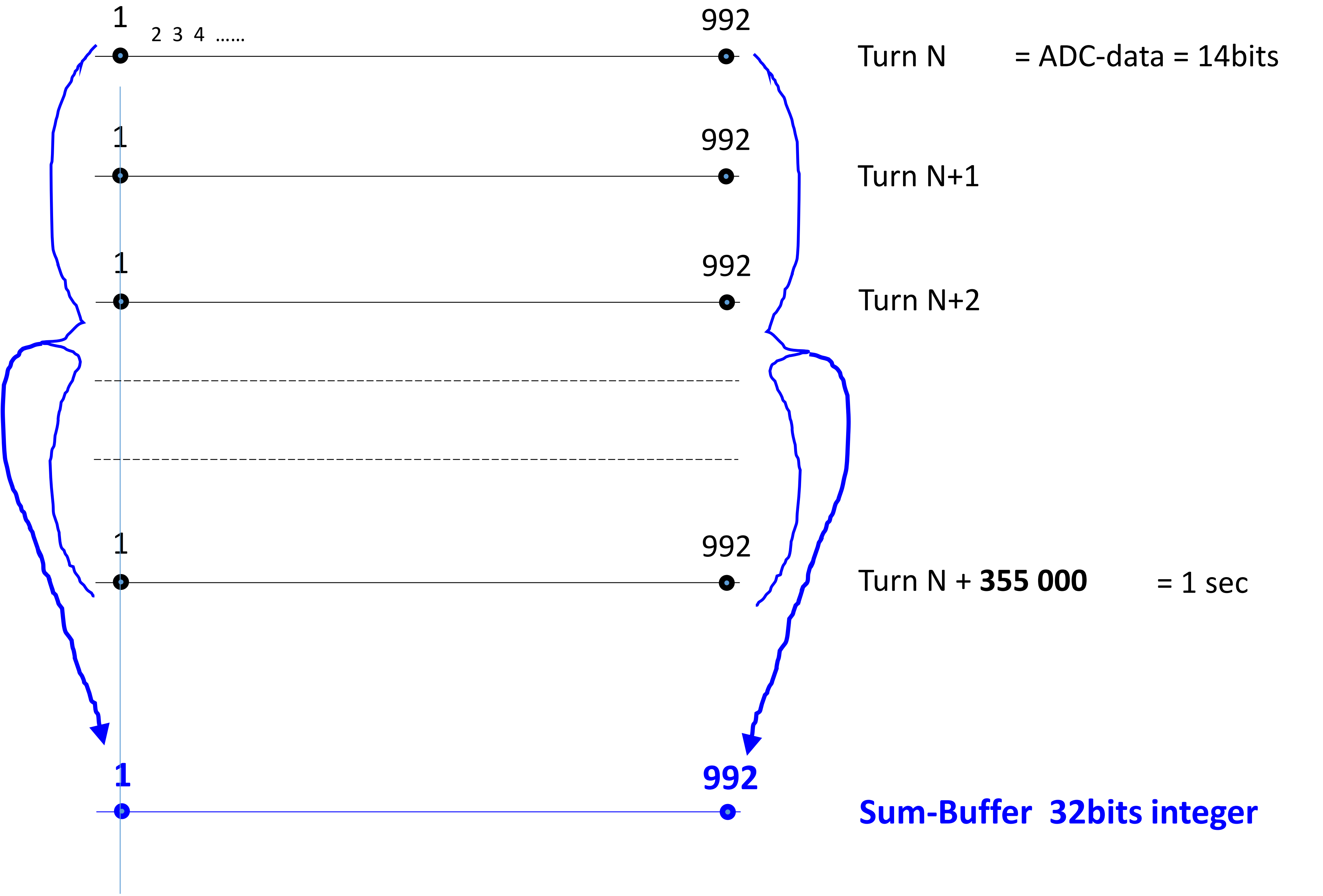
motivation for high-quality B-b-B **charge** measurements :

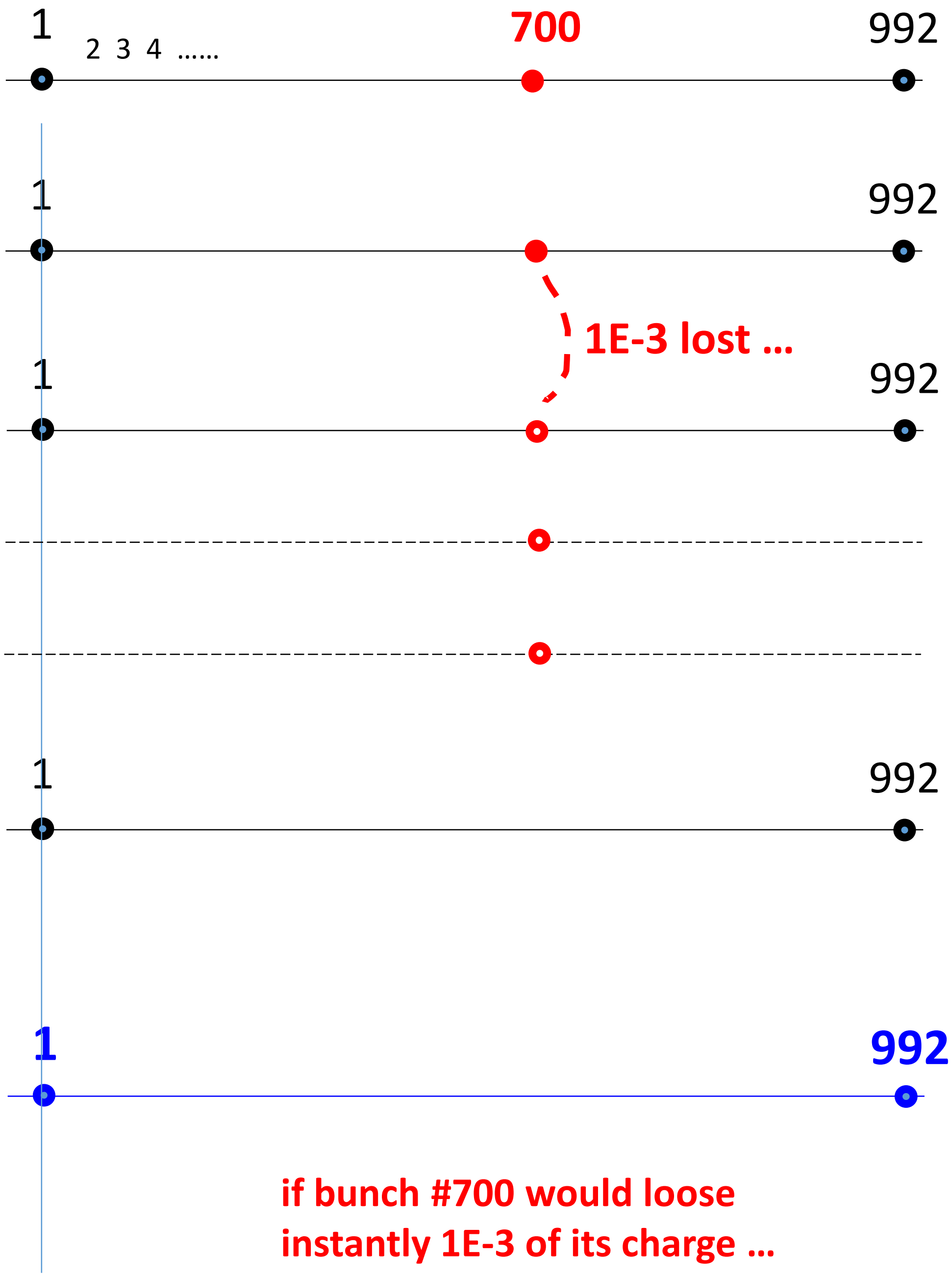
1) **measure which bunch(es) are affected by a sudden (small) fractional loss**

2) **measure the lifetime of each bunch, and their (small) relative differences**

3) measure quickly and precisely any errors / aberrations in the real filling pattern

3b) even measure any undesired bunches (supposedly empty) → *"purity measurement"*
by applying further signal treatment (anti-reflection filtering)
and/or external gating


1
2 3 4 ......
992
Turn N
= ADC-data = 14bits
1
992
Turn N+1
1
992
Turn N+2
1
992
Turn N + 355 000
= 1 sec
1
992
Sum-Buffer 32bits integer



SUM N covers 1 sec, 32 bits

SUM N+1 same next second

SUM N+2 etc.

etc.

SUM N + **60** = 1 sec

Sum-History-Buffer
32bits integer, covers 1 minute
1 sec resolution
moderate size (240Kbytes)

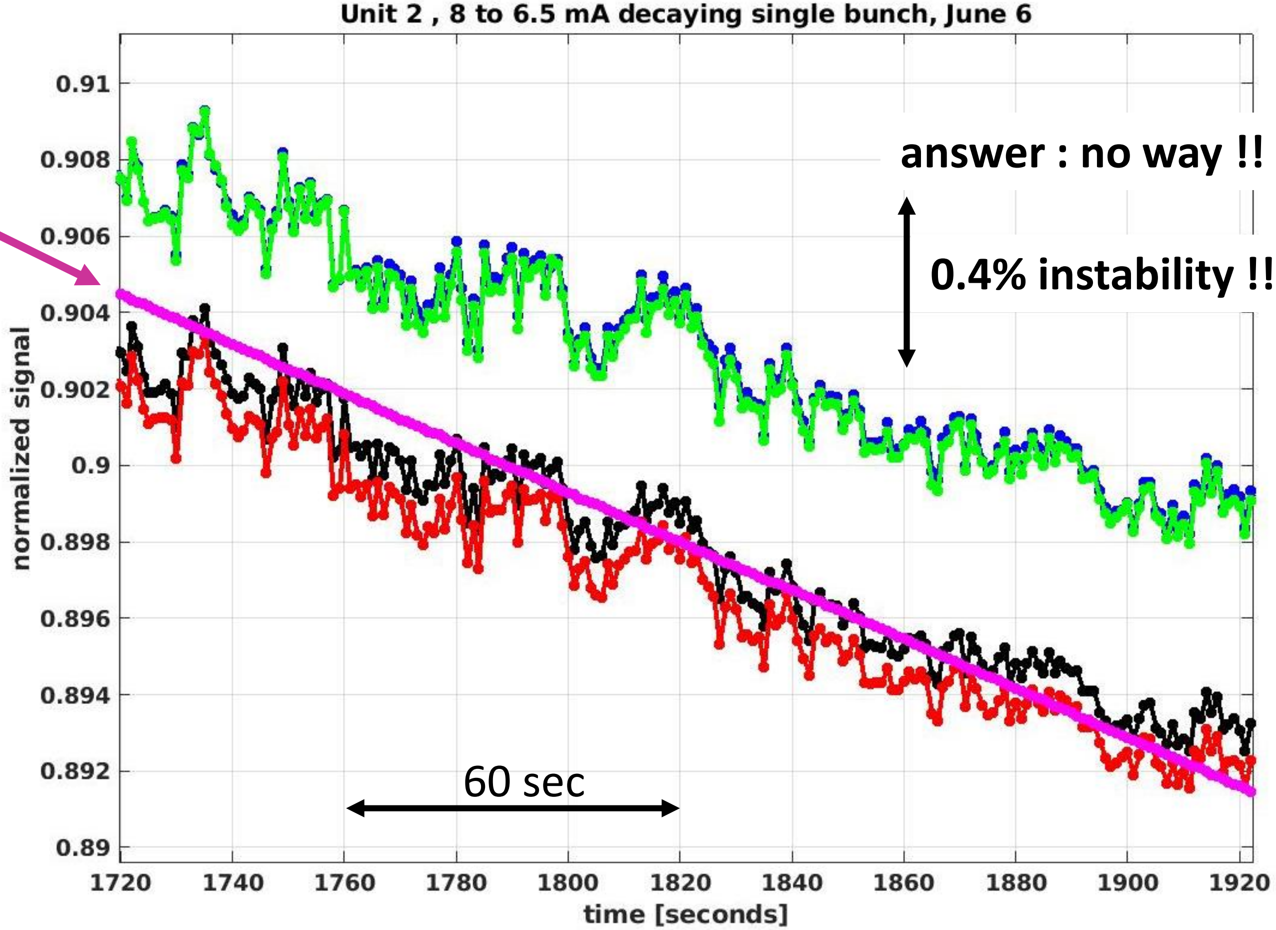
if bunch #700 would loose instantly 1E-3 of its charge … can we now detect that in the Sum-History-Buffer ?

the issue of long-term gain stability

any bunch loosing instantly 1E-3 of its charge …
can we detect that in the Sum-History-Buffer ??

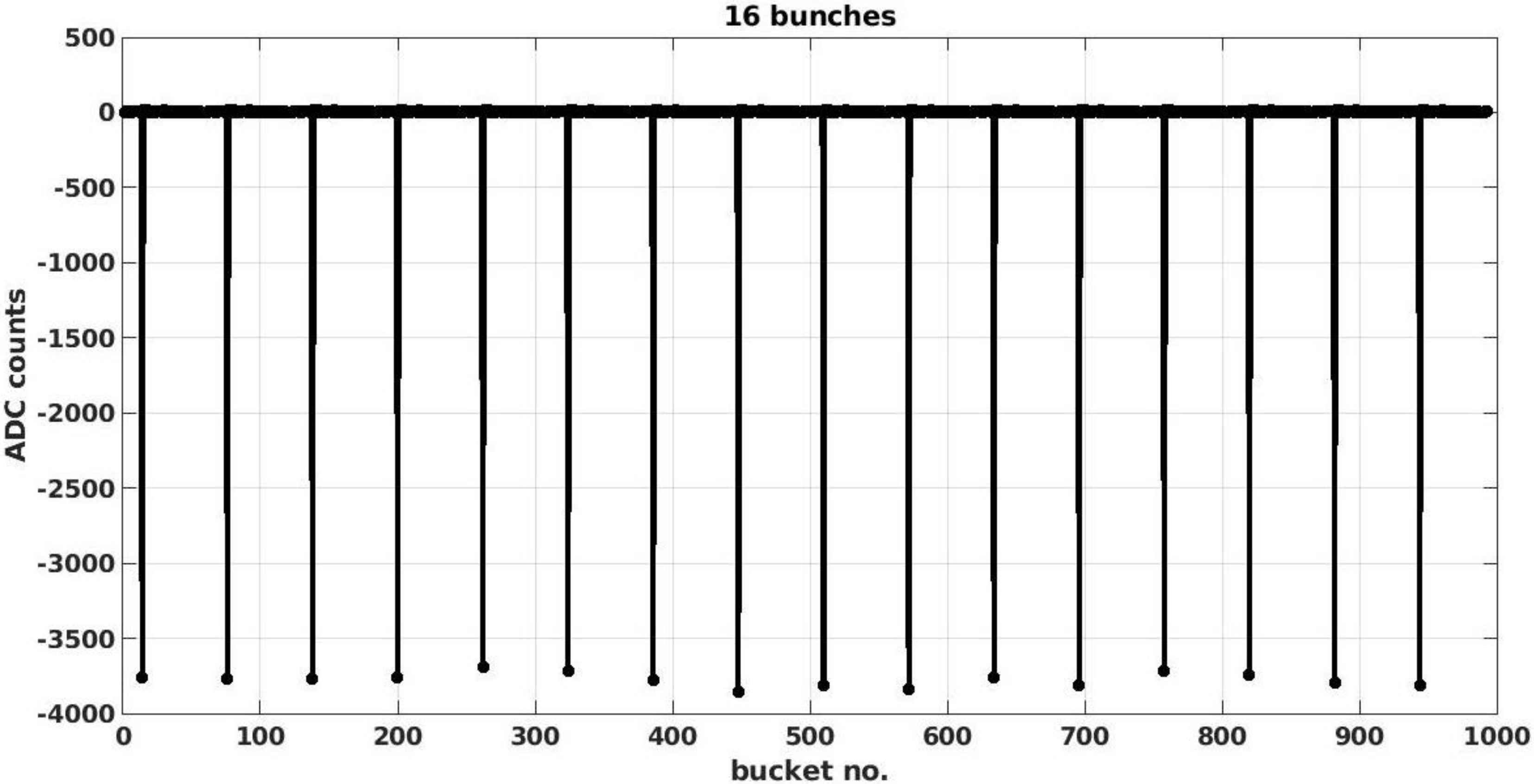
each point is a sum
of 250 000 turns

purple=
current-monitor



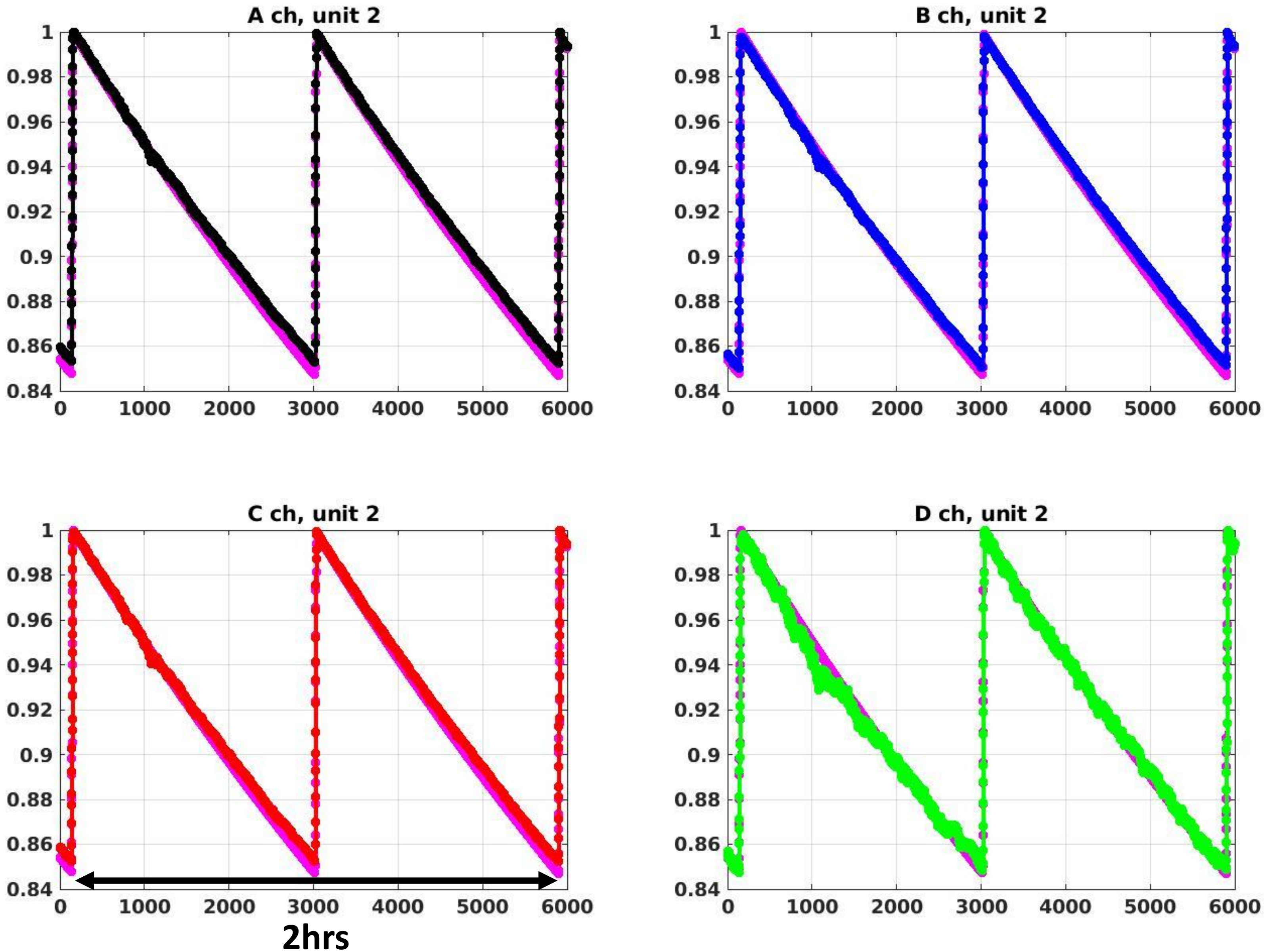
more detailed analysis in 16 bunch mode :

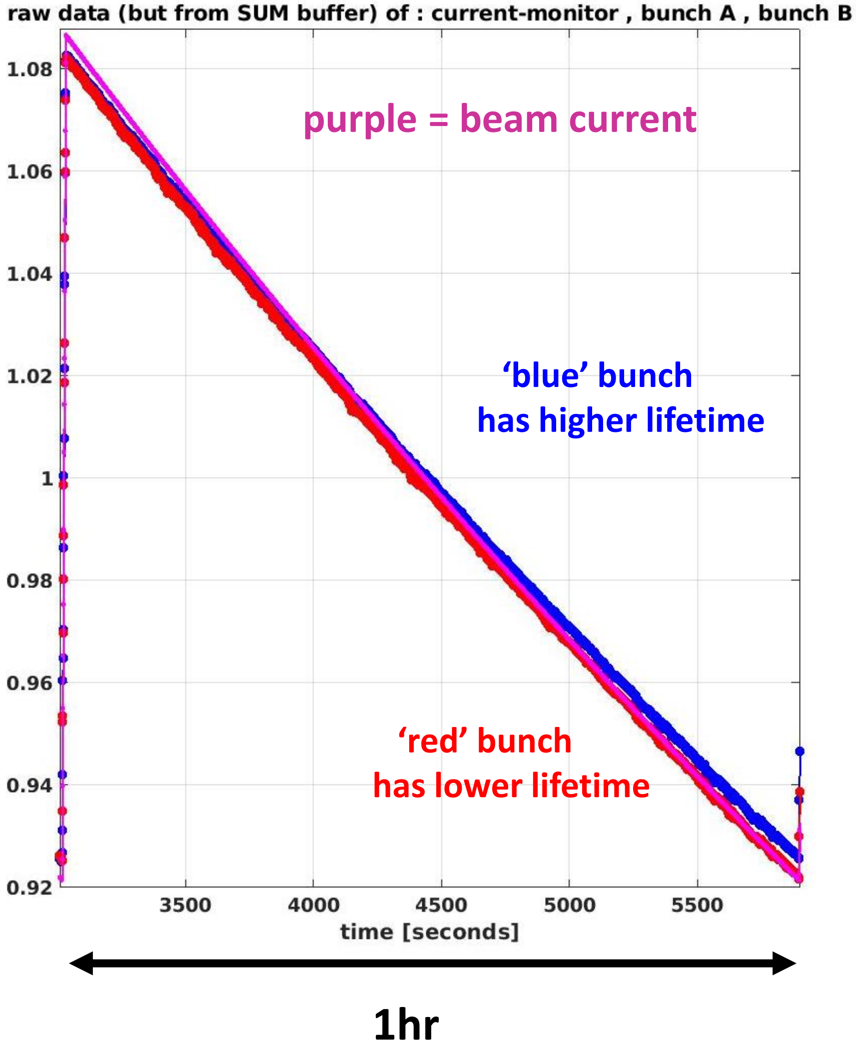
are tiny RELATIVE differences in lifetime evolution BETWEEN these bunches detectable ?

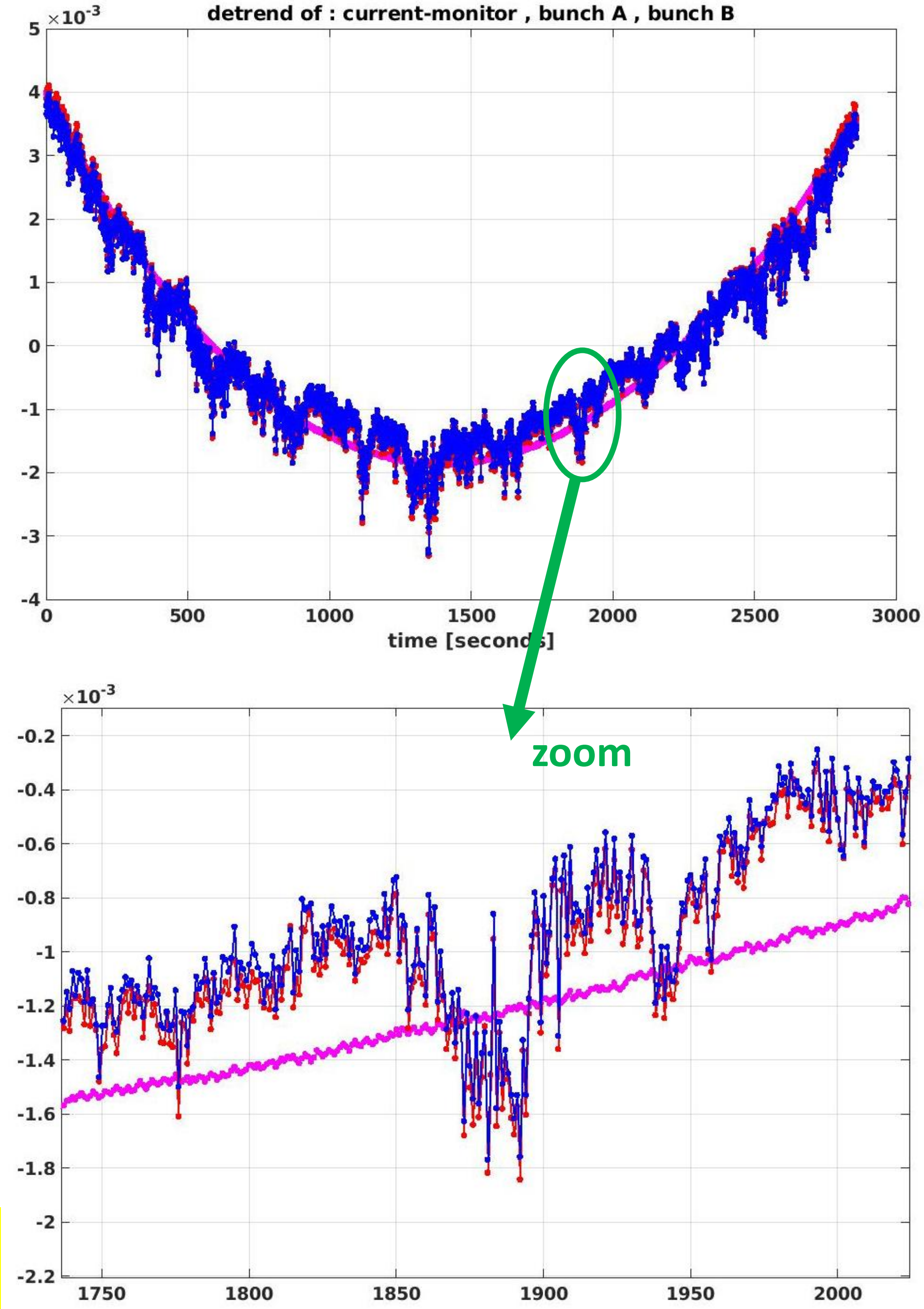


purple=single-bunch current (from CT)

other 4 colors are the sum of the 16 bunches

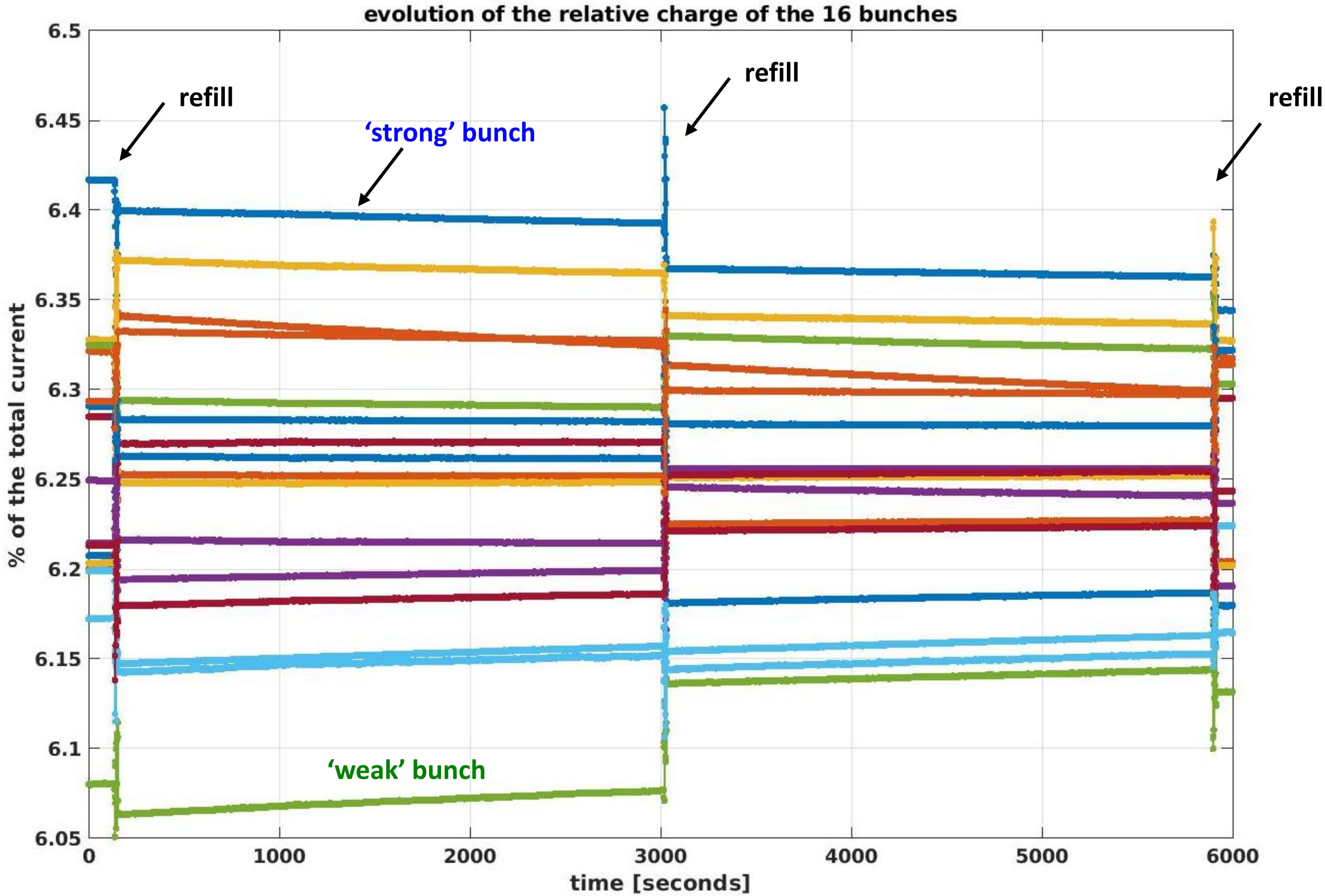




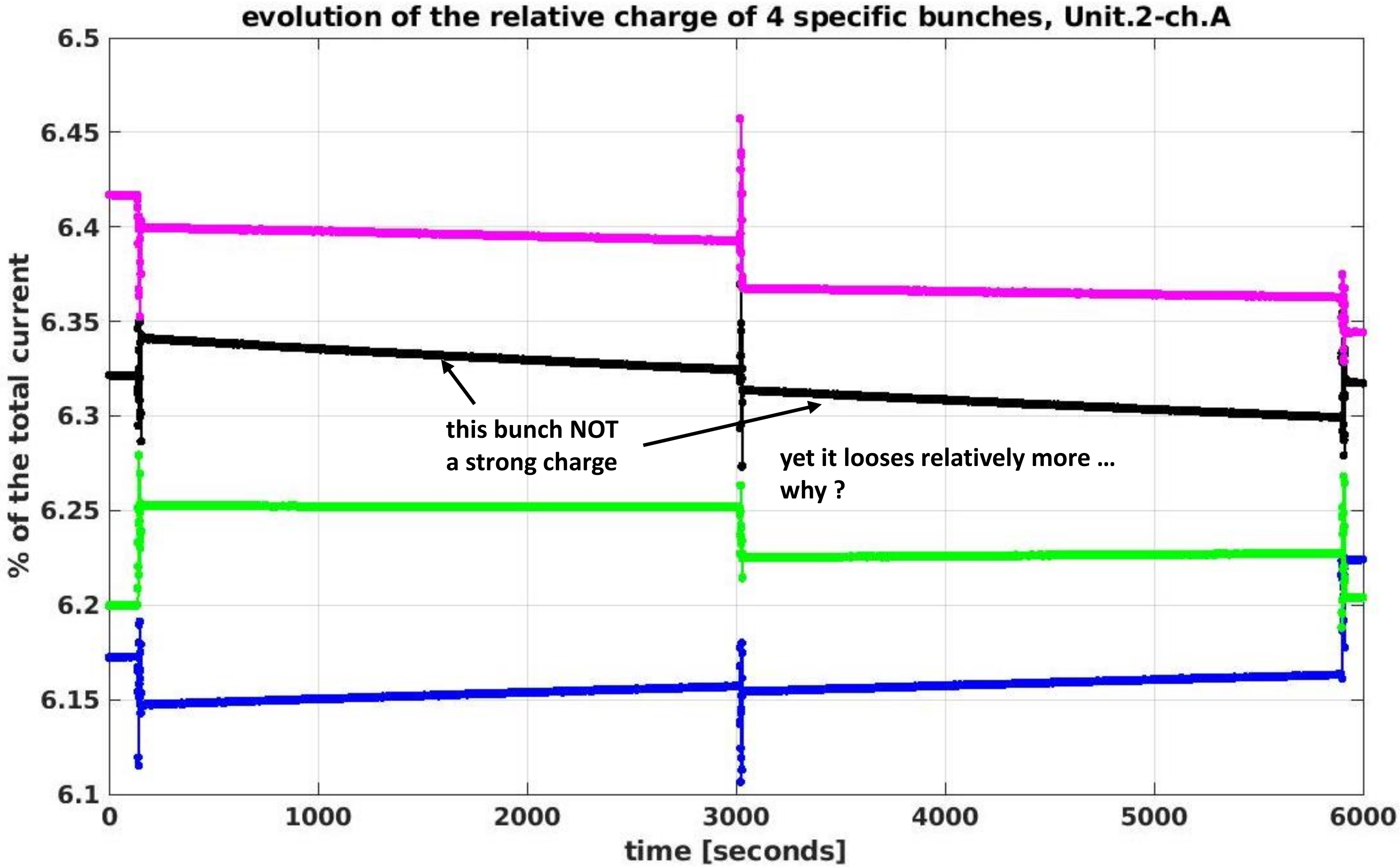


conclusion : the individual noise/fluctuation is high
however: the relative noise/fluctuations much better

→ assessing the **relative** charges of these 16 bunches → much of the noise/fluctuations is removed

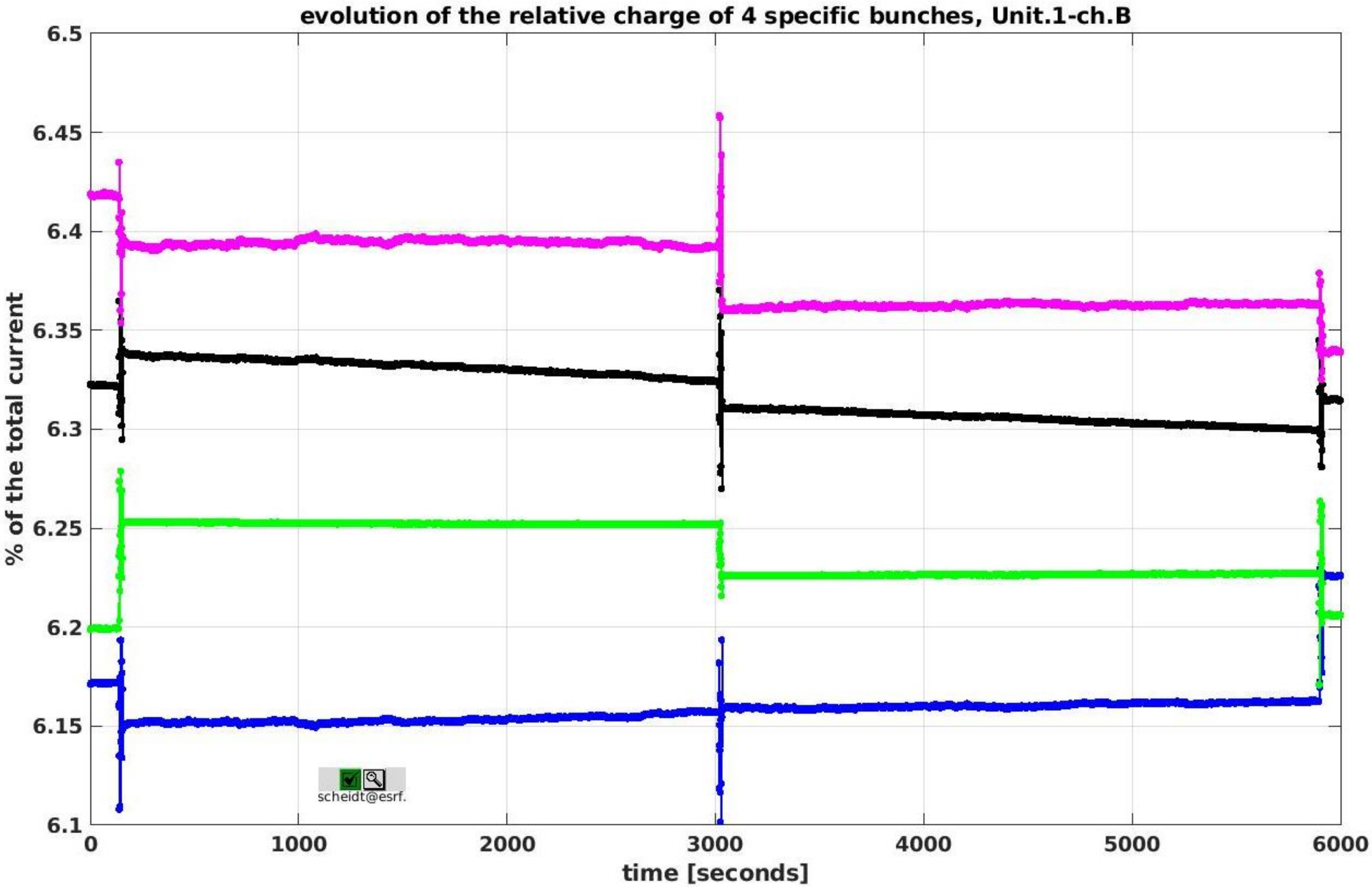


Unit-2, channel A

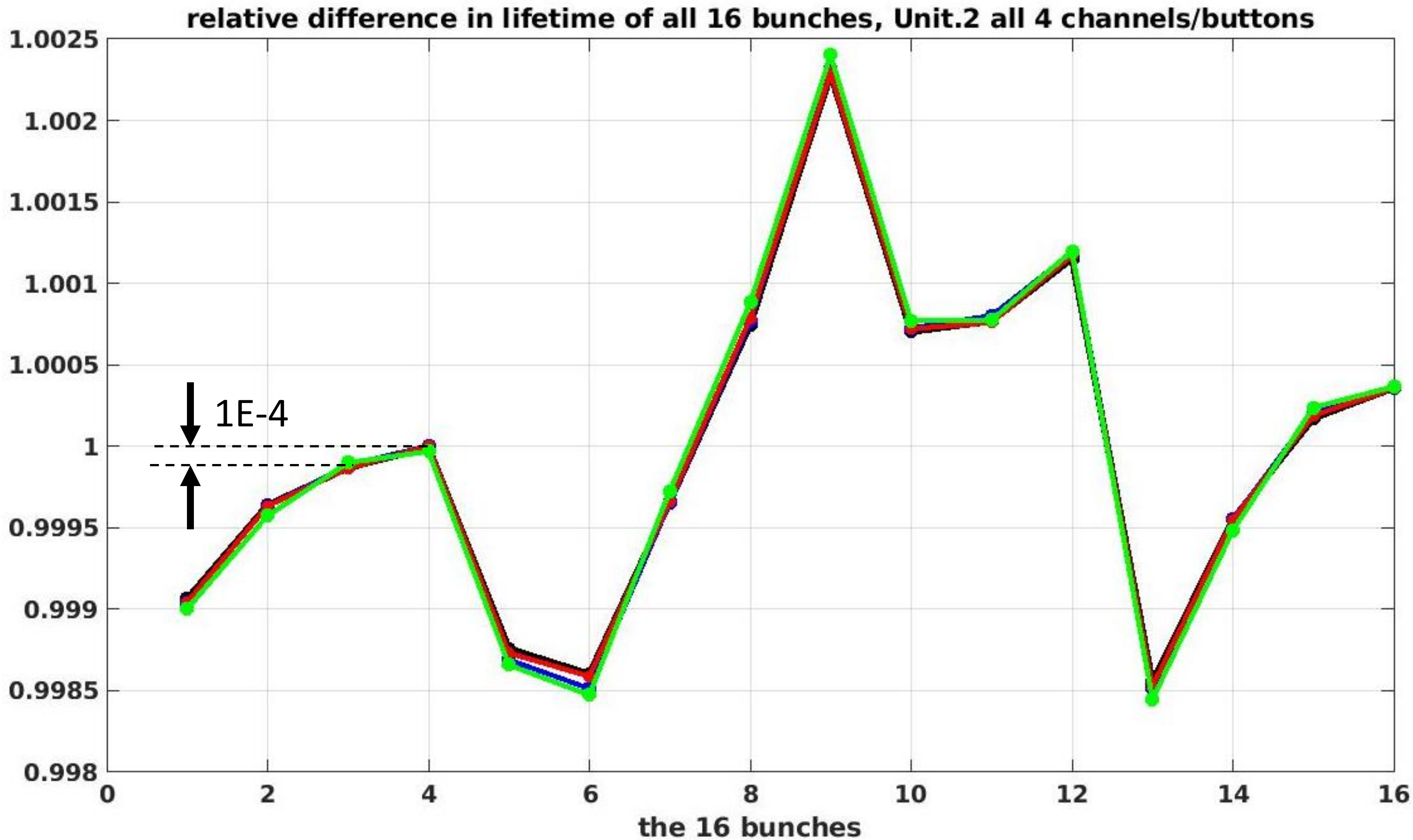


same info from **other** unit & **other** button (channel)

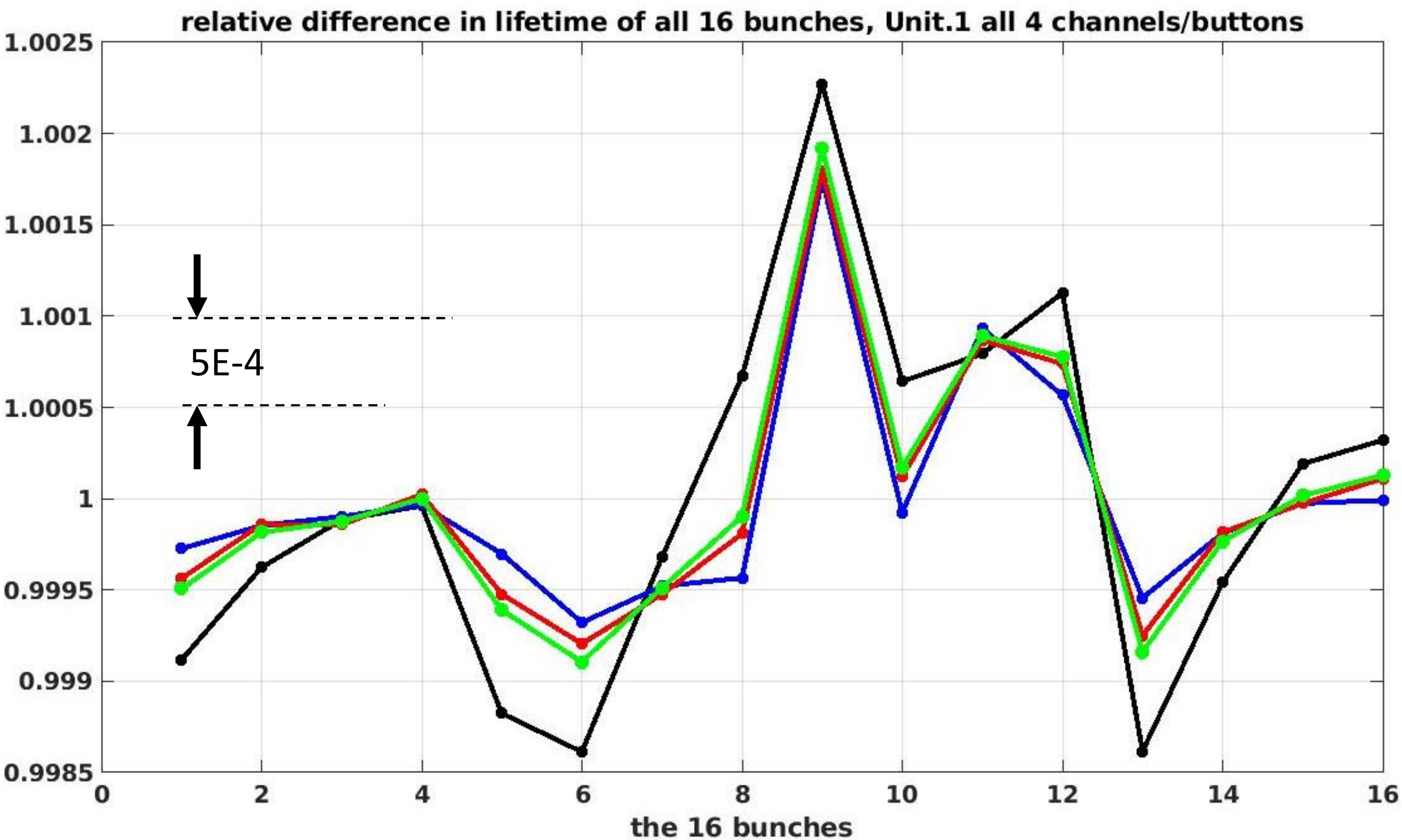
Unit-1, channel B



the average lifetime in 16 bunch is about 6hrs (21600 seconds)
tiny differences in lifetime between the 16 bunches of 1E-4 → is 2secs !
are detectable, and seen consistently by all channels

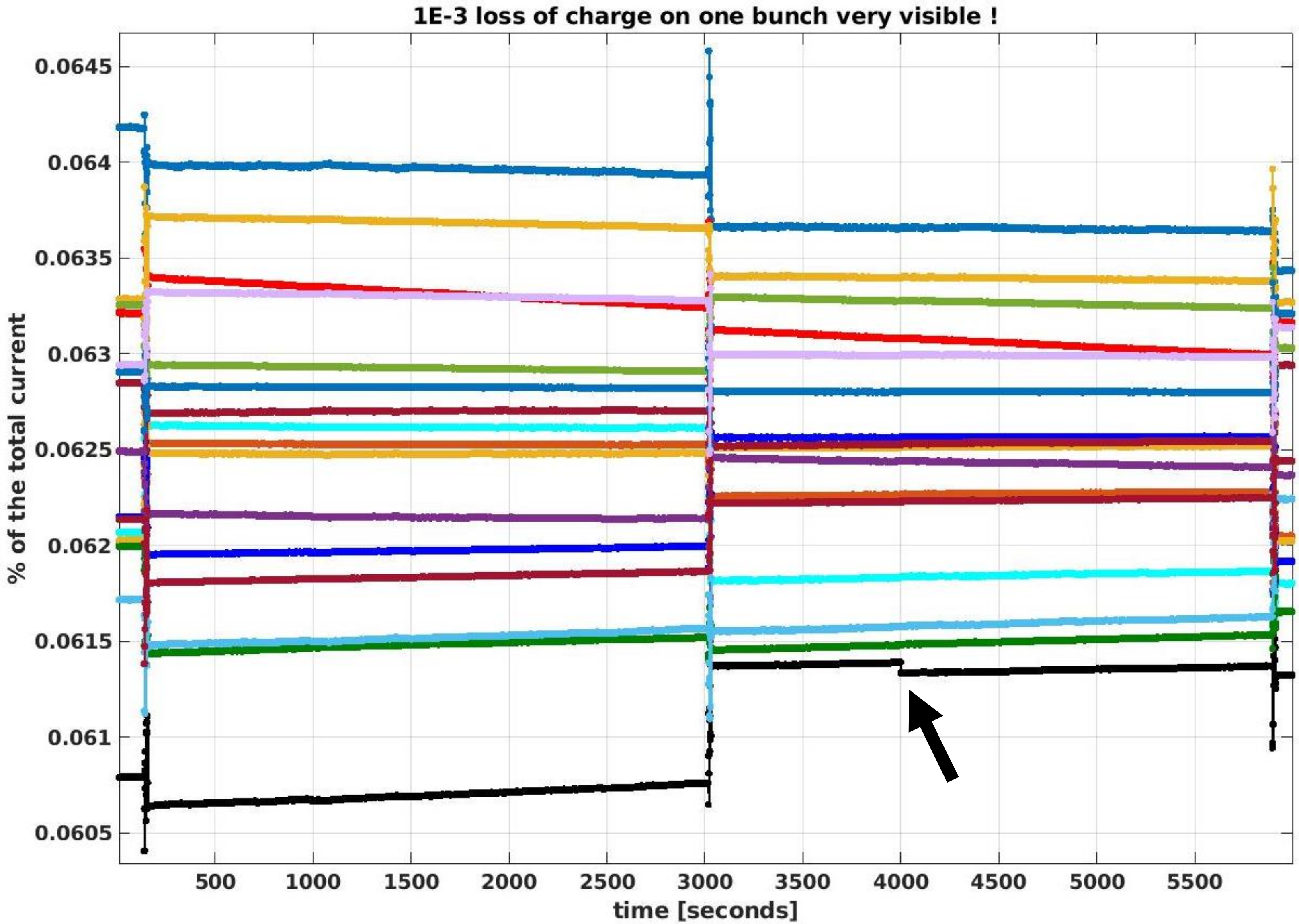


same results on same data, but other unit are slightly less consistent ….



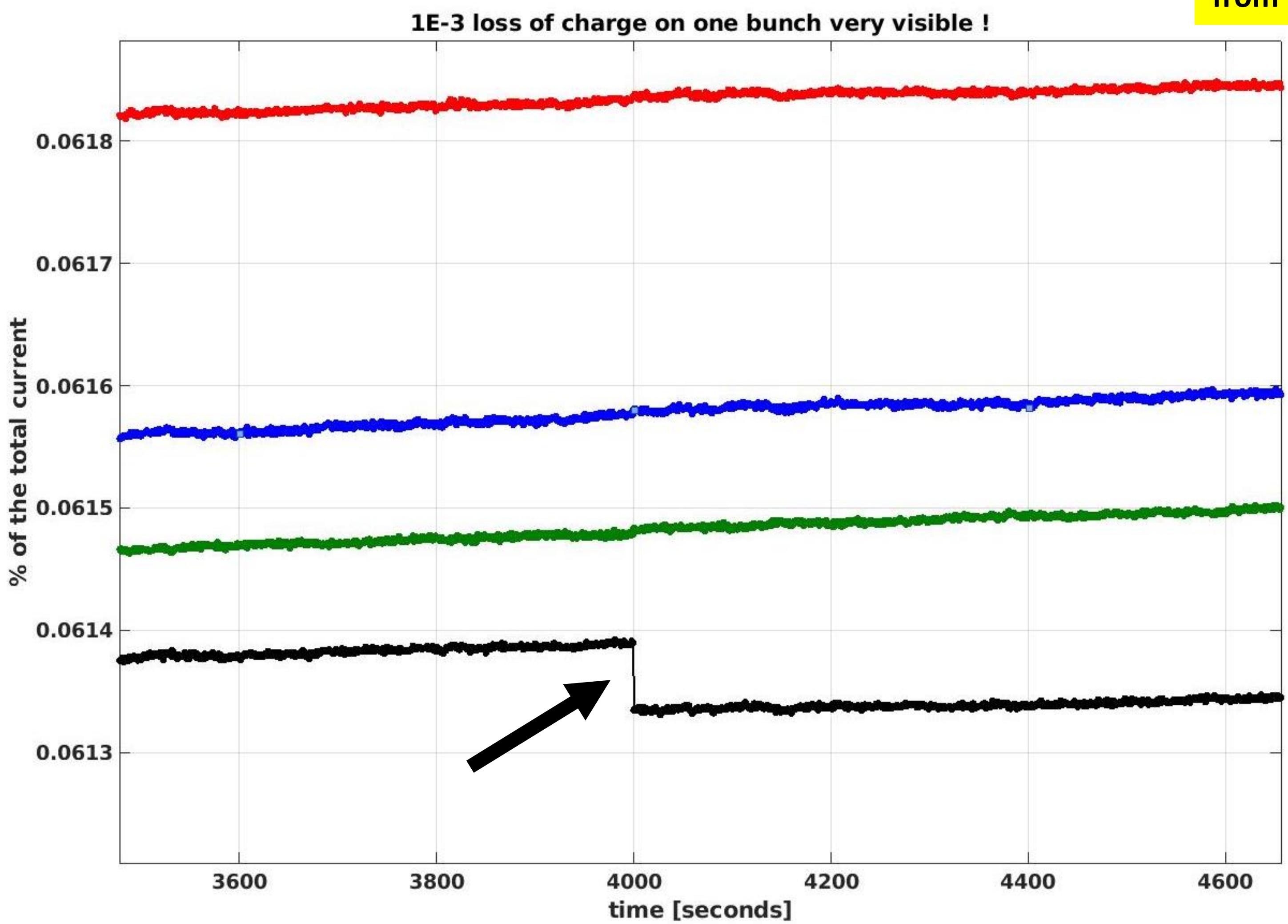
any bunch loosing instantly 1E-3 of its charge …
can we detect that in the Sum-History-Buffer ??

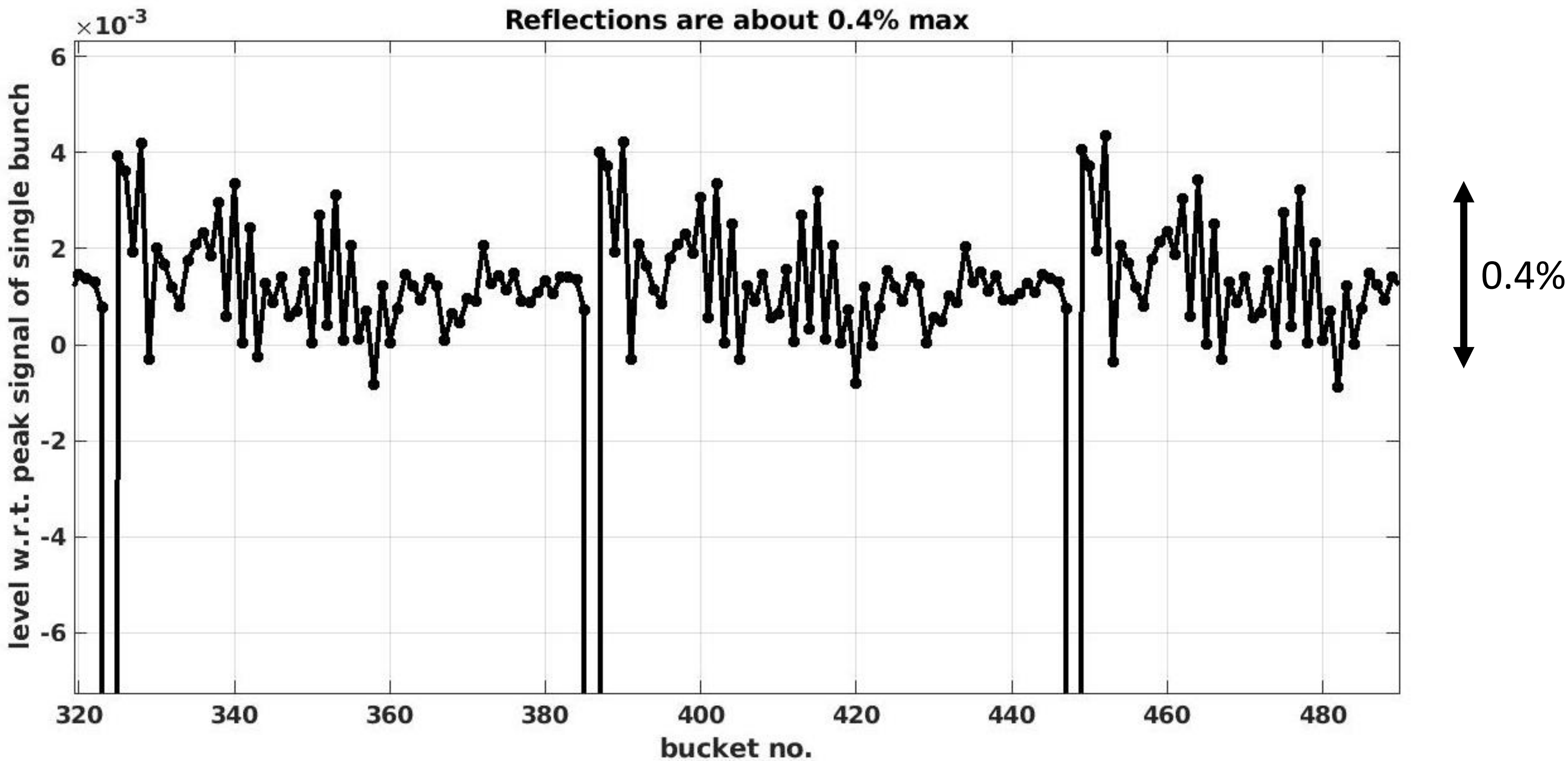
trick : 1E-3 is removed from the raw data



conclusion : on the raw data itself such tiny drop can NOT be detected
but by examining the relative charges (and thus removing global noise/fluctuations)
such tiny drops (close to 1E-4) are easily detectable

trick : 1E-3 is removed from the raw data





these reflections are :

1) very reproducible
2) measurable with high resolution thanks to this Summing function

→ an ***anti-reflection filter*** can be calculated from this
and then applied on all newly acquired data
to push the "impurity level" down to …. <1E-4 ? → **looks good so far,**
no time to show results …

preliminary conclusions & recommendations

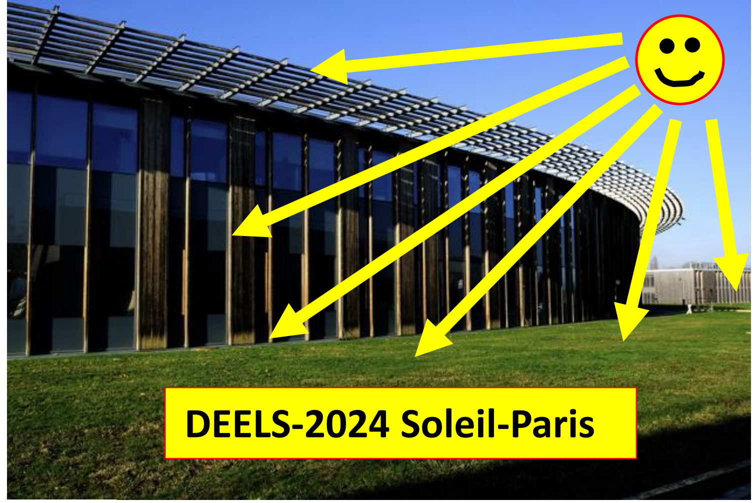
these units are good and will certainly find very useful
applications in both the Booster & SR
both for charge and for position diagnostics

the issue of (de-)phasing and peaked input signals are
not to be blamed to the instrument,
but need to be known & shared by the community and the I-Tech company

the mid-term stability (of gain or sensitivity) is not very good (but no specs defined)
but can be investigated by I-Tech experts, and perhaps be improved ?

if feasible the phase adjustment per channel should be enlarged (from only 240ps)
and a global phase adjustment (on the RF synchro) of 3000ps would be very welcome !

the implementation of adjustable attenuators directly after the input
(and NOT only after the amplifier) are also highly recommended !



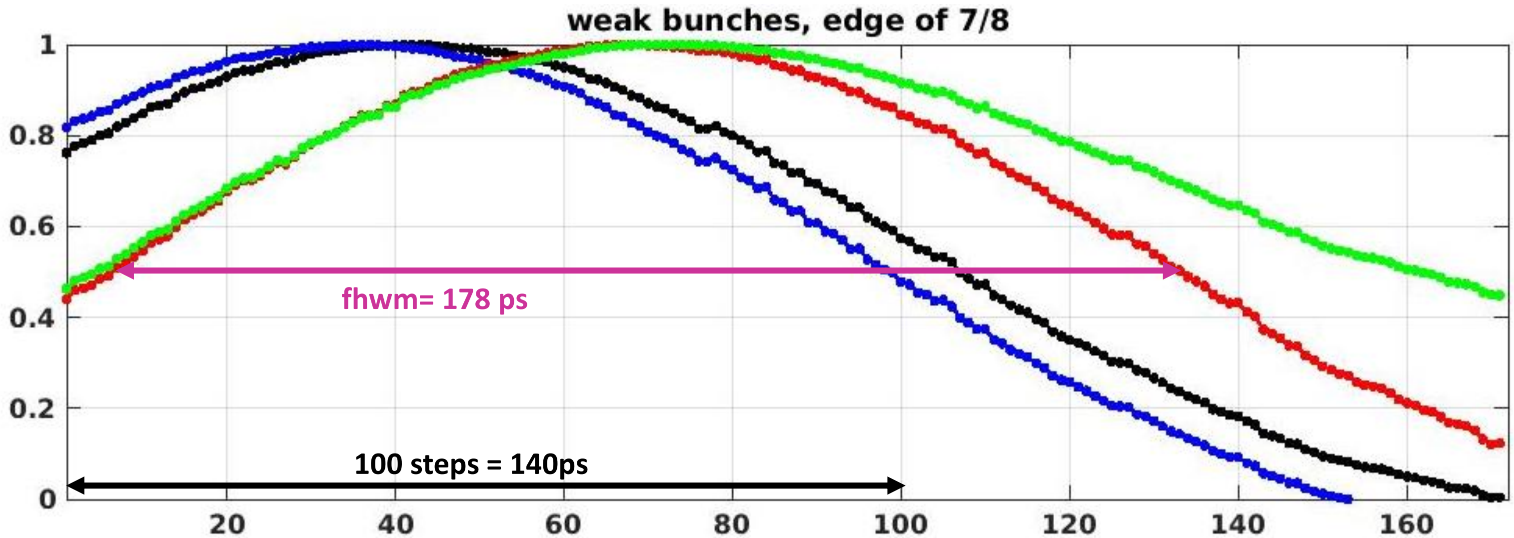
Thank you for your attention !

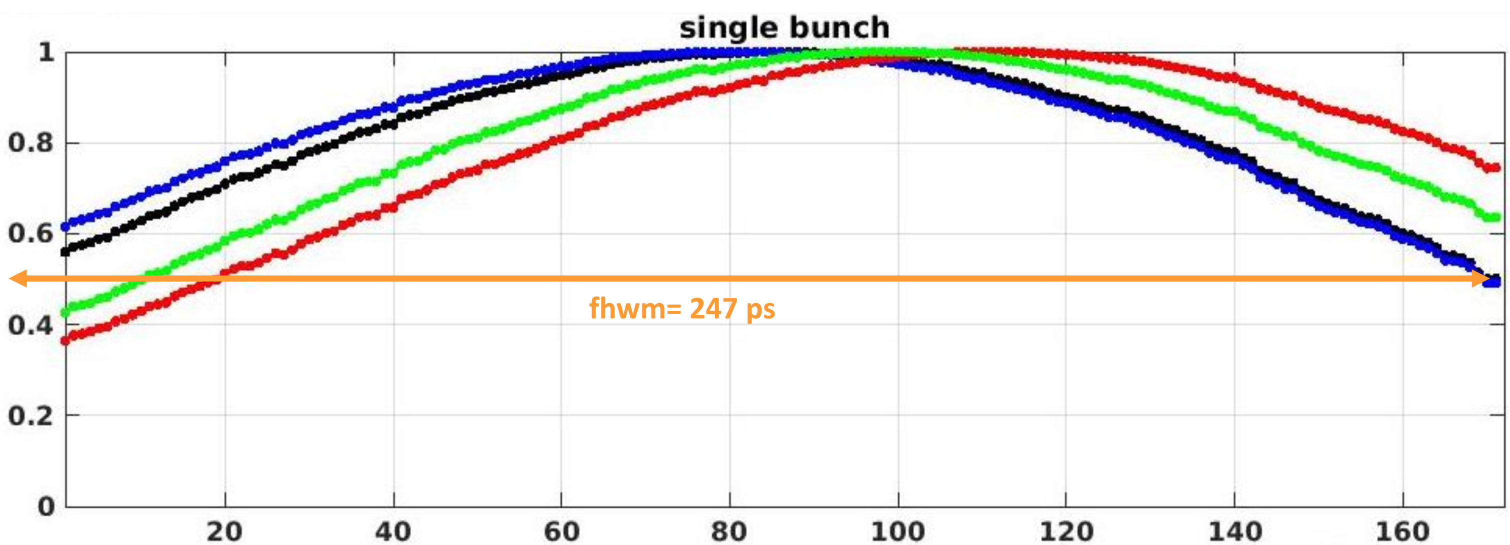
Diagnostics is *fun* !

Paris, la Seine, June 10

Grenoble

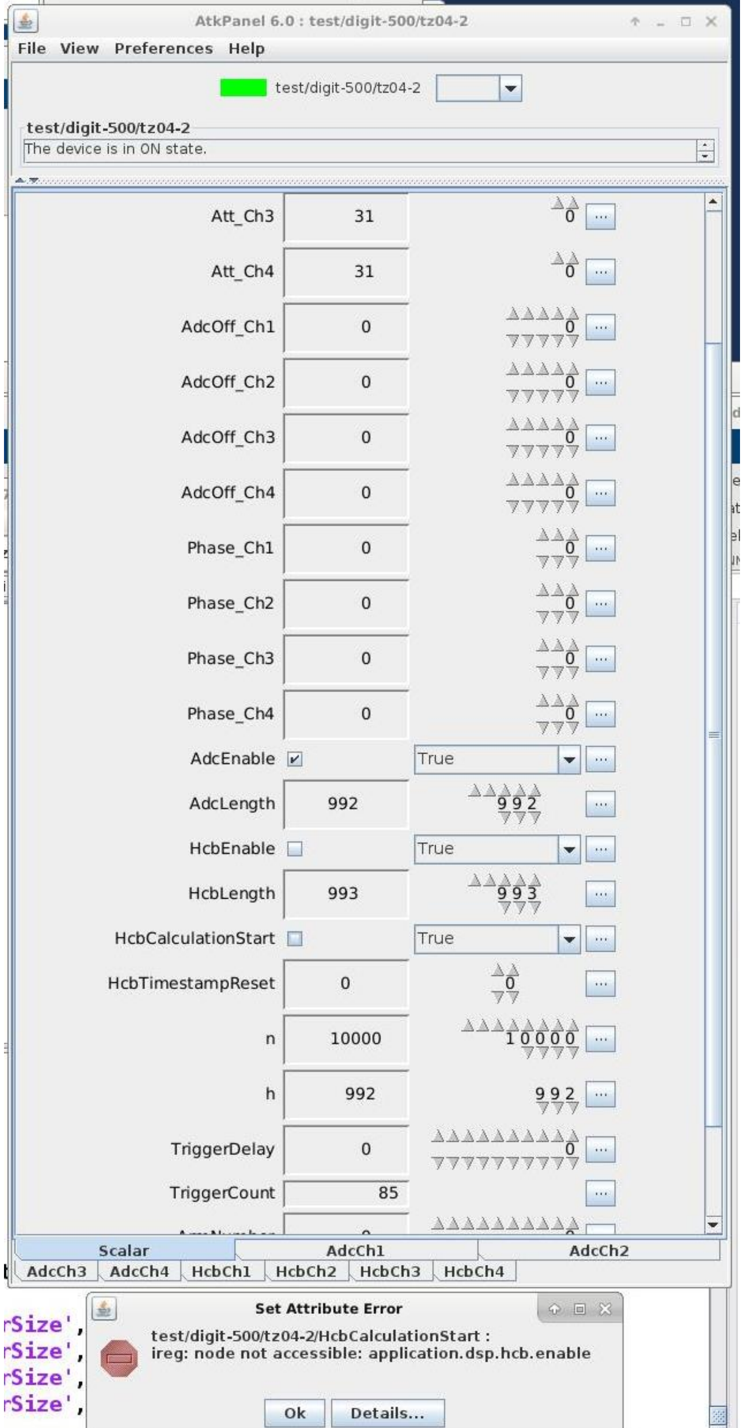
Back-up slides

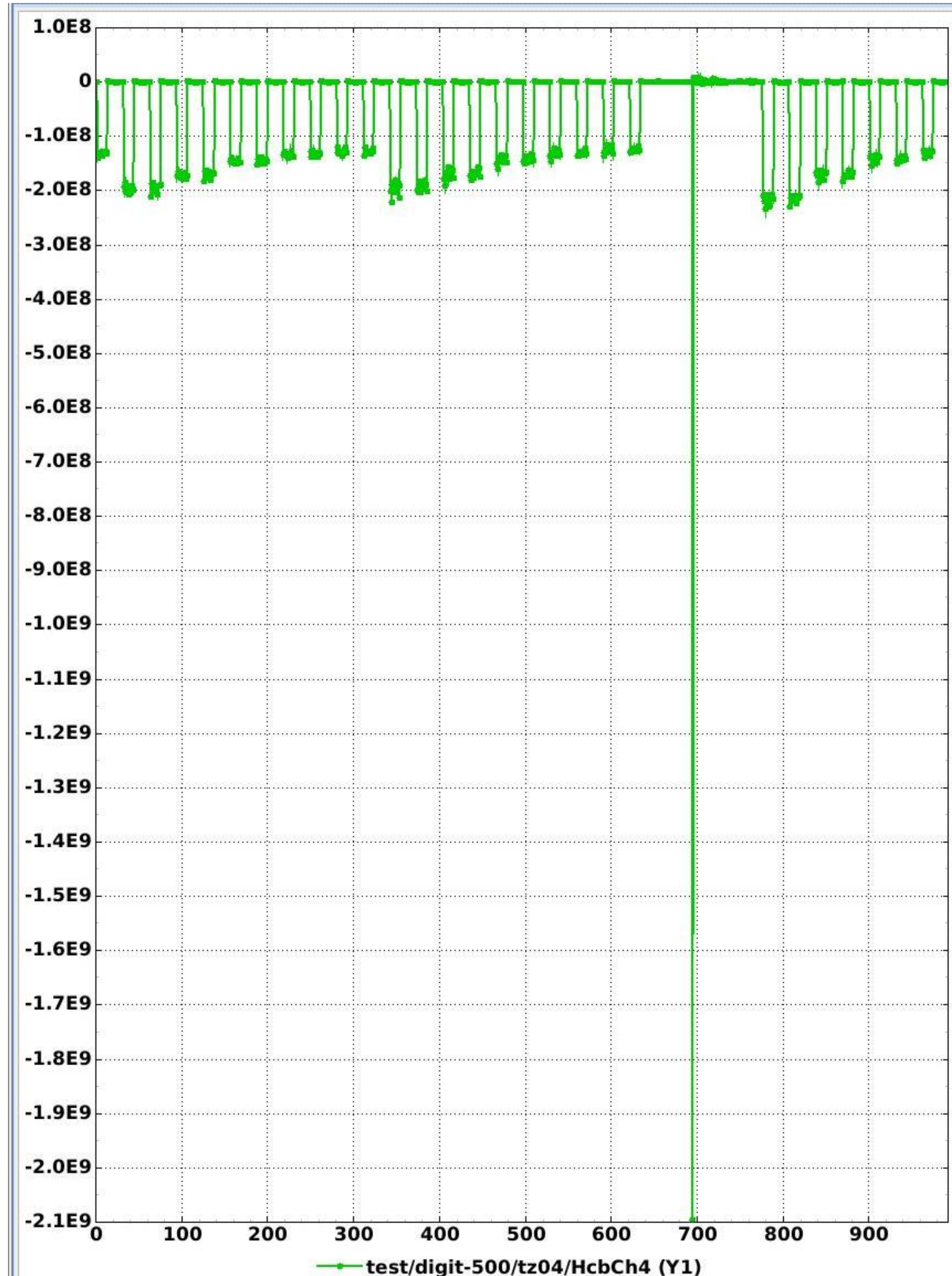


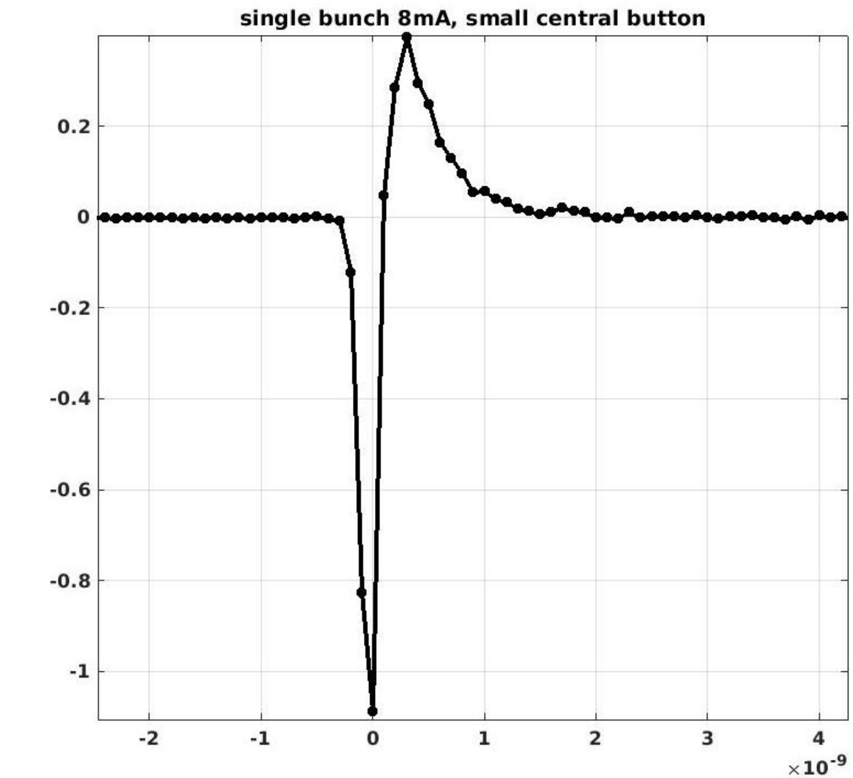


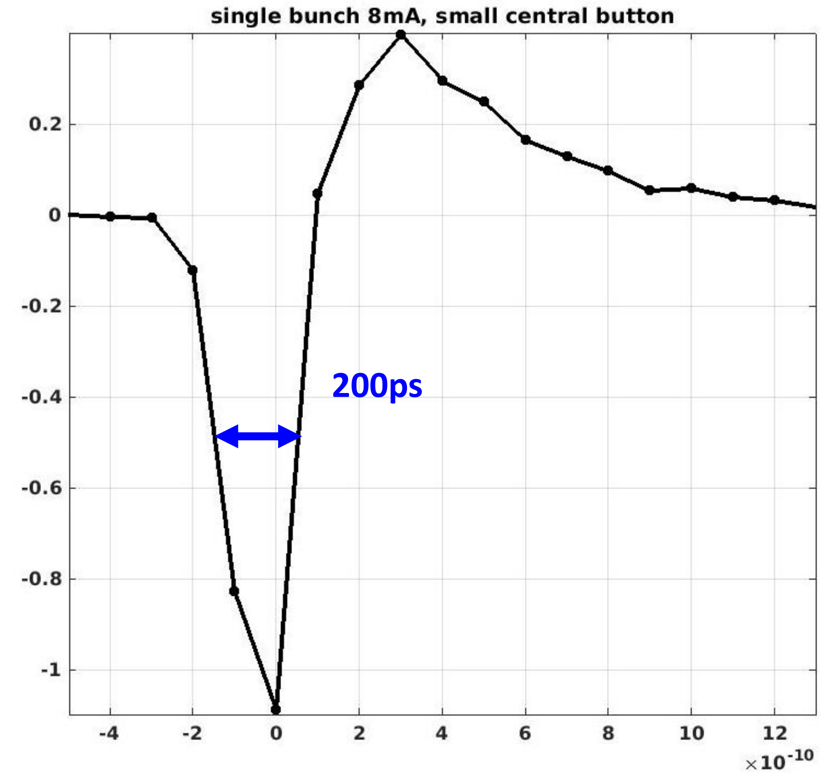
10-90% risetime of 2GHz BW is 175ps
single-bunch length [fwhm] = 120ps
weak bunch length [fwhm] = 35ps

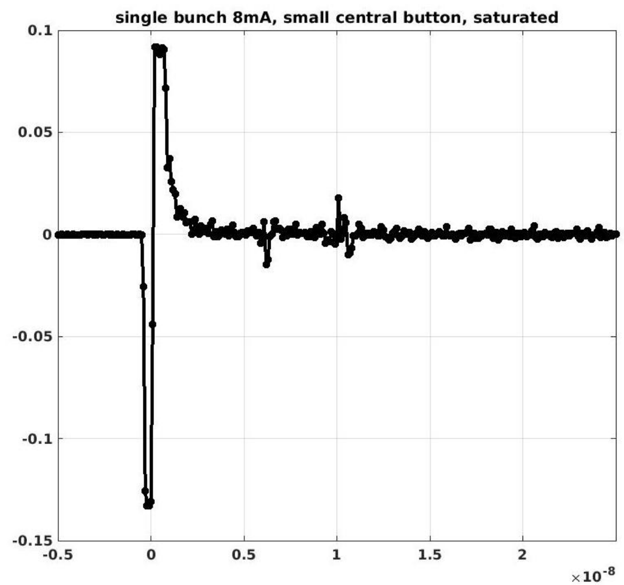
scanning the internal phase-shifters
171x1.4ps , total range = 239ps

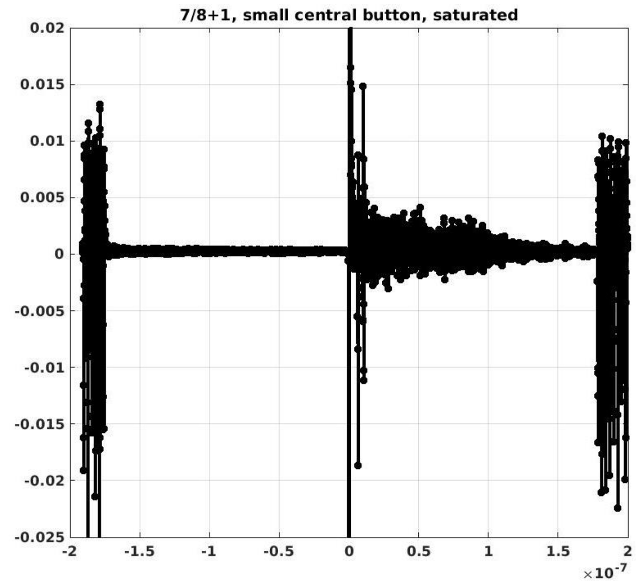

AtkPanel 6.0 : test/digit-500/tz04-2
File View Preferences Help
test/digit-500/tz04-2
test/digit-500/tz04-2
The device is in ON state.
Att_Ch3 31
Att_Ch4 31
AdcOff_Ch1 0
AdcOff_Ch2 0
AdcOff_Ch3 0
AdcOff_Ch4 0
Phase_Ch1 0
Phase_Ch2 0
Phase_Ch3 0
Phase_Ch4 0
AdcEnable True
AdcLength 992
HcbEnable True
HcbLength 993
HcbCalculationStart True
HcbTimestampReset 0
n 10000
h 992
TriggerDelay 0
TriggerCount 85
Scalar AdcCh1 AdcCh2
AdcCh3 AdcCh4 HcbCh1 HcbCh2 HcbCh3 HcbCh4
Set Attribute Error
test/digit-500/tz04-2/HcbCalculationStart :
ireg: node not accessible: application.dsp.hcb.enable
Ok Details...

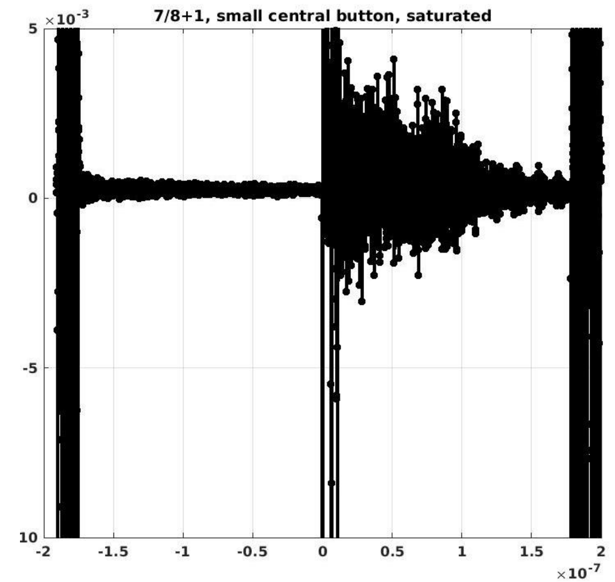

1.0E8
0
-1.0E8
-2.0E8
-3.0E8
-4.0E8
-5.0E8
-6.0E8
-7.0E8
-8.0E8
-9.0E8
-1.0E9
-1.1E9
-1.2E9
-1.3E9
-1.4E9
-1.5E9
-1.6E9
-1.7E9
-1.8E9
-1.9E9
-2.0E9
-2.1E9
0 100 200 300 400 500 600 700 800 900
test/digit-500/tz04/HcbCh4 (Y1)


single bunch 8mA, small central button
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-2 -1 0 1 2 3 4
×10^-9


single bunch 8mA, small central button
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
200ps
-4 -2 0 2 4 6 8 10 12
×10^-10


single bunch 8mA, small central button, saturated
0.1
0.05
0
-0.05
-0.1
-0.15
-0.5 0 0.5 1 1.5 2
×10^-8


7/8+1, small central button, saturated
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-2 -1.5 -1 -0.5 0 0.5 1 1.5 2
×10^-7


7/8+1, small central button, saturated
×10^-3
5
0
-5
10
-2 -1.5 -1 -0.5 0 0.5 1 1.5 2
×10^-7