Progress in high gradient testing the KT structure in Valencia

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On behalf of the IFIC RF team.

Outline

- ❑ The high-power RF laboratory at IFIC
- ❑ The KT S-band Backward Traveling Wave (BTW) structure under test
- ❑ Operation overview
- ❑ Preliminary analysis of BDs and dark current
- ❑ Summary

The high-power RF laboratory at IFIC

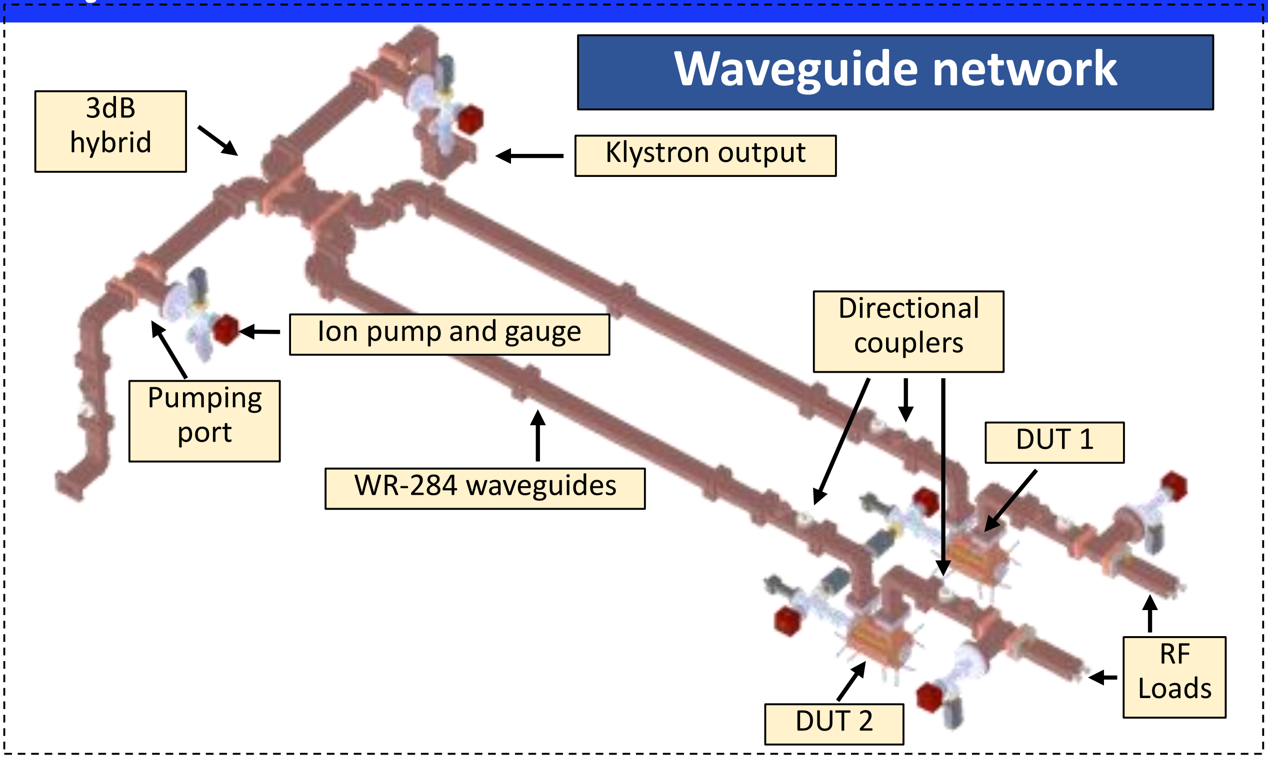
Main aim:

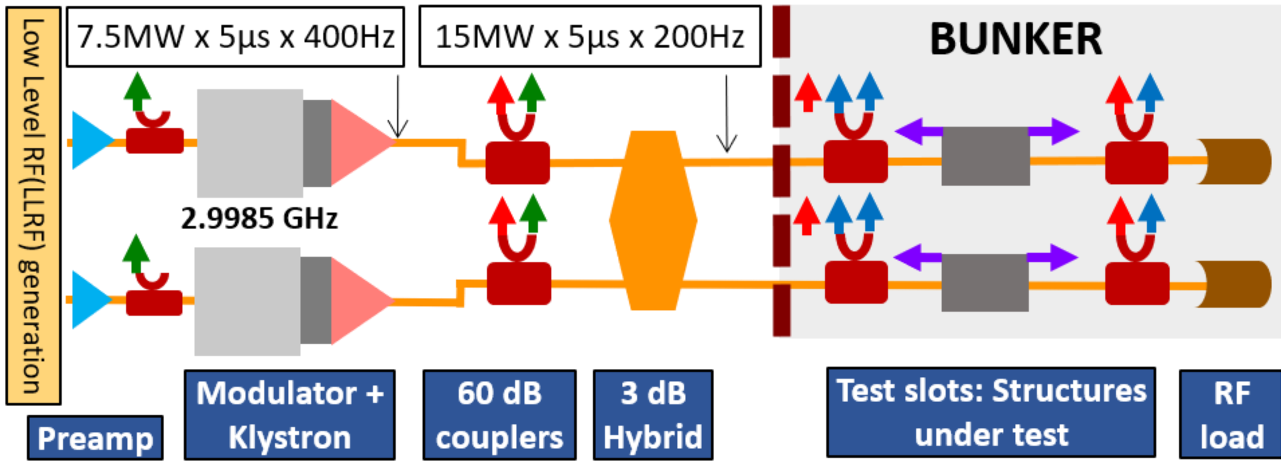
- ❑ **High-gradient normal conducting RF cavities research topics at S-Band (2.9985 GHz).**

❑Very similar to the Xbox-3 test facility at 12 GHz but for a central frequency of 2.9985 GHz.

❑ Low level RF (LLRF): real-time control system with fast system interlock based on Ni-PXI system.

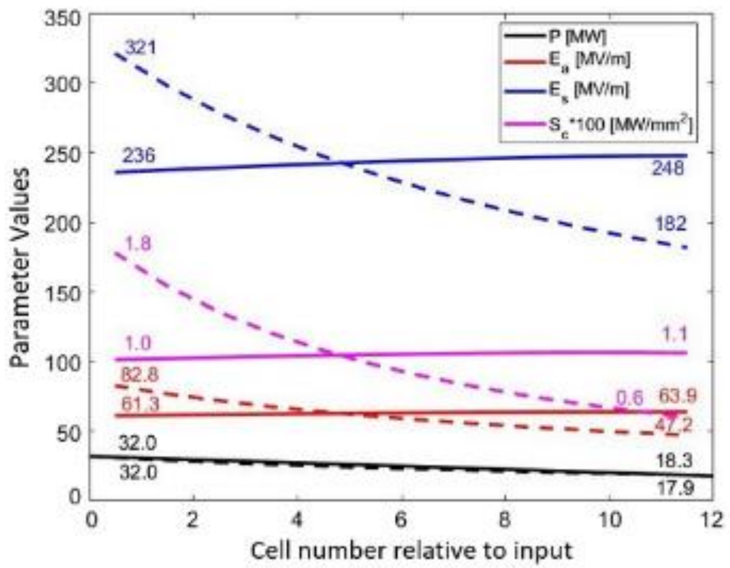
❑ HPRF manage the amplification and guiding of the RF to the DUT to test **2 structures at a time at up to 15 MW, 5 us pulse, 200 Hz repetition rate.**



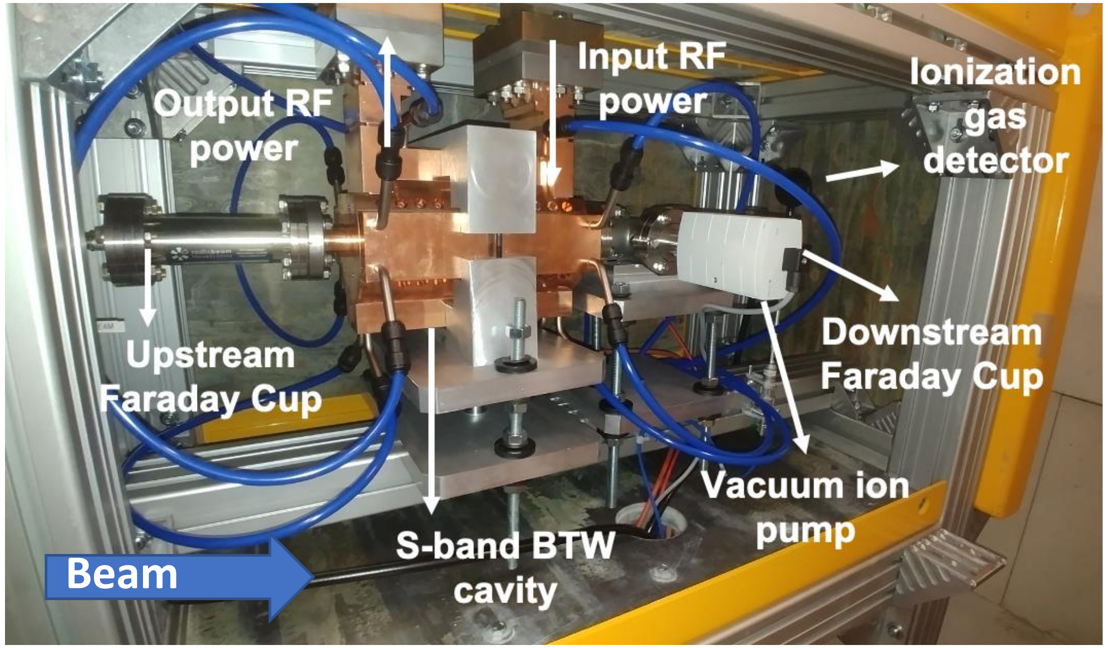


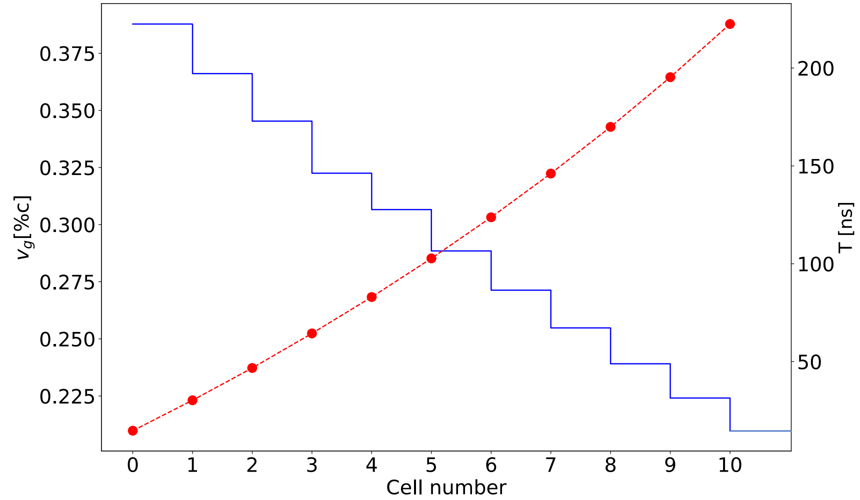
The KT S-band BTW structure

- Currently conditioning the second CERN KT funded S-band accelerating structures based on CLIC technology to accelerate protons.
  - S-band BTW structure (2.9985 GHz)
  - 12 cells with Δϕ=150°
  - Filling time: 224 ns
  - Structure length: 189.9 mm
  - Group velocity: 0.39/0.21 %c



A. Vnuchenko et al., High-gradient testing of an S-band, normal-conducting low phase velocity accelerating structure, Phys. Rev. Accel. Beams, 8 23 084801. 13 p, year = "2020", http://cds.cern.ch/record/2730215





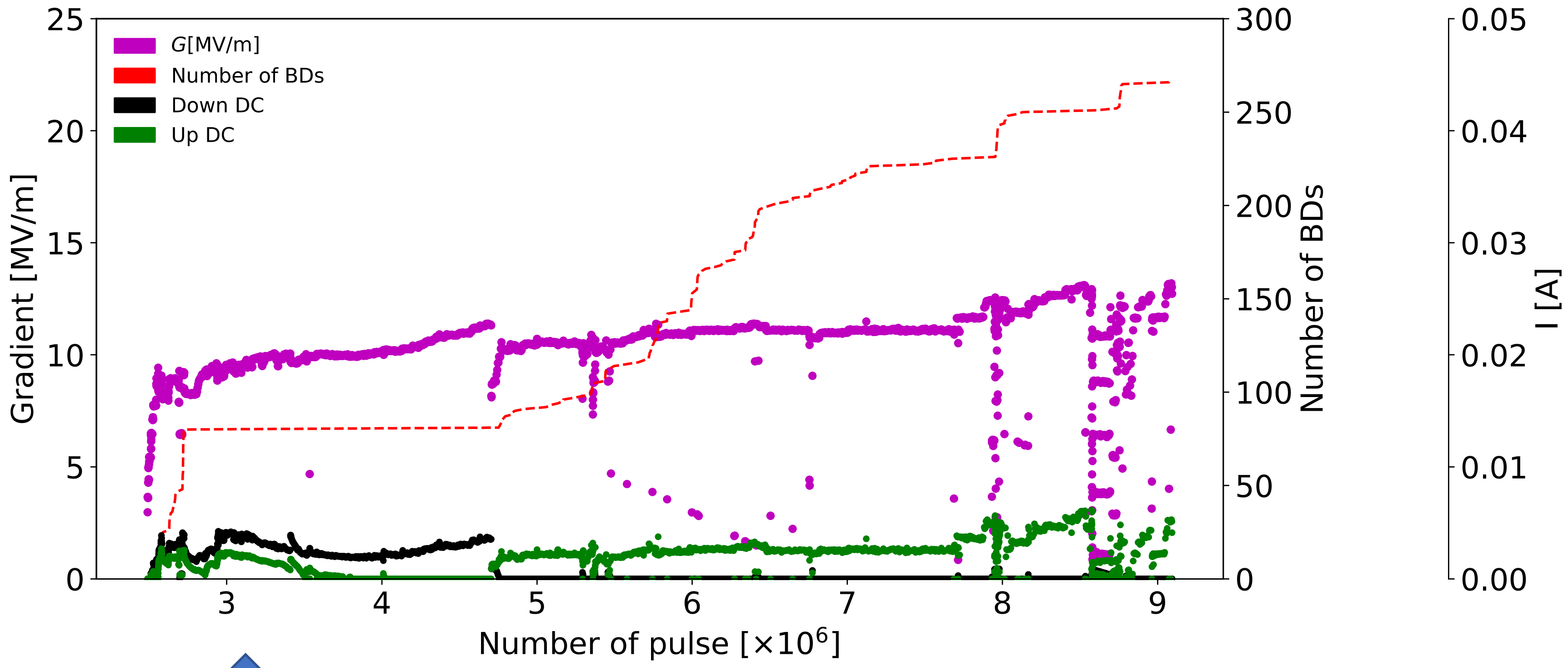
Simulated data from S. Benedetti

Operation overview 2019

- **Manual operation (October, November 2019).**
- **Operation parameters:**
  - **Repetition rate**: max. 50 Hz
  - **Pulse length** (flat top): 550 ns
  - **Input power**: 0-2.55 MW
  - **Average gradient**: 0-16.06 MV/m
  - **Vacuum** Below ~1e-8 mbar
  - **Temp. structure**: 22-23°C

$$G\left[\frac{MV}{m}\right] = 50[MV/m]\sqrt{\frac{INC\_P[MW]}{20.16[MW]}}$$

With current set-up we could go up to 43 MV/m



Dark current observed in the downstream FC only on the first days.

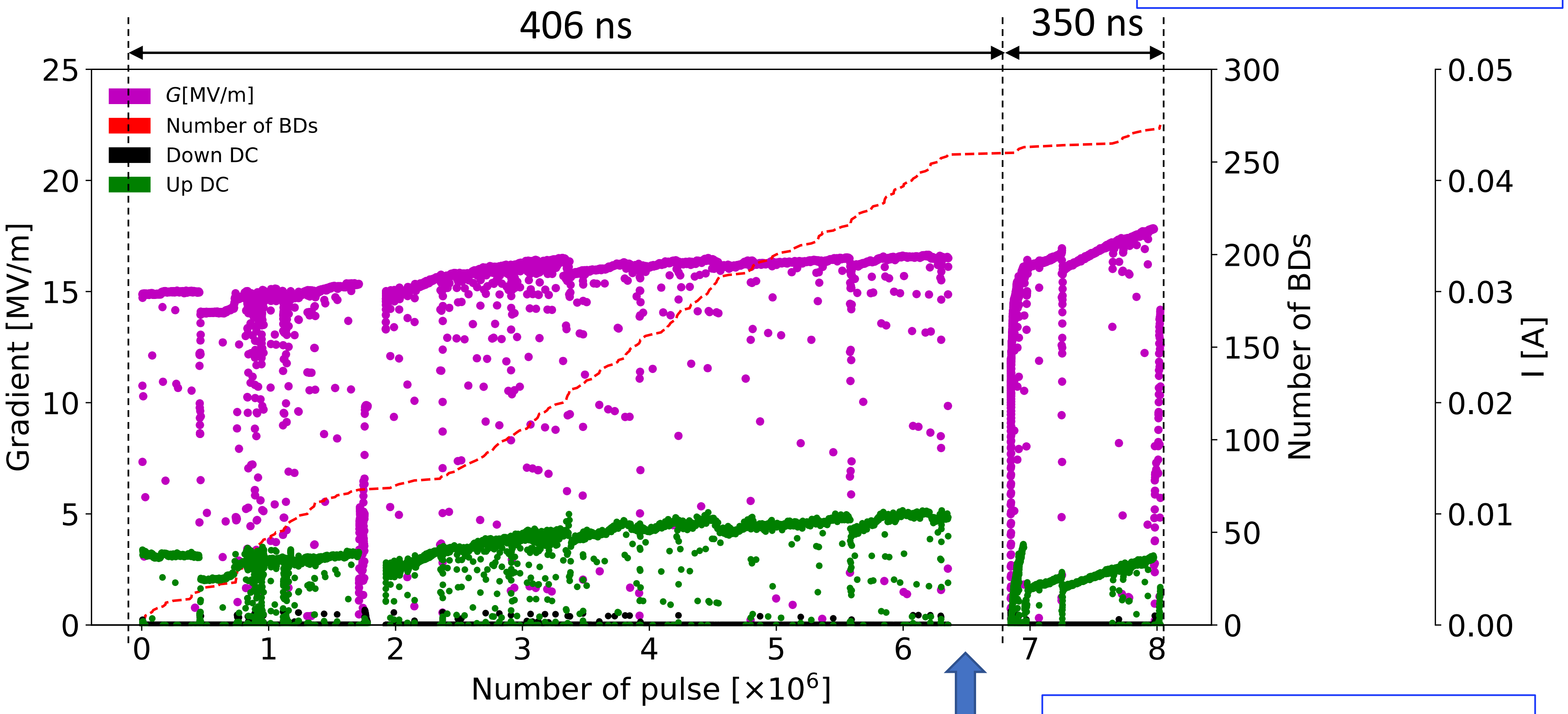
~9M pulses, 262 BDs

Operation overview 2020

- **Start of conditioning (in July 2020 set the pulse counter to 0).**
  - Delayed due to lockdown and a leak on the hybrid -> fixed using epoxy and working fine so far.
  - Operation using the conditioning algorithm with BDR limit set to 5×10^{-5}.

New operation mode tested in which all pulses are sent to the structure -> allowing to go up to 400 Hz

- **Operation parameters:**
  - **Repetition rate**: 25-200 Hz
  - **Pulse length** (FT): 406 ns -350 ns
  - **Input power**: 1.76-2.61 MW
  - **Average gradient**: 14.86-17.5MV/m
  - **Vacuum** Below ~1e-8 mbar
  - **Temp. structure**: 22-23°C

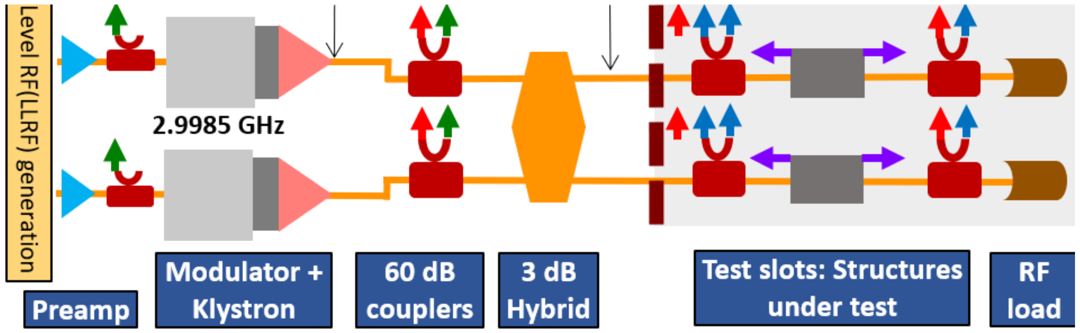


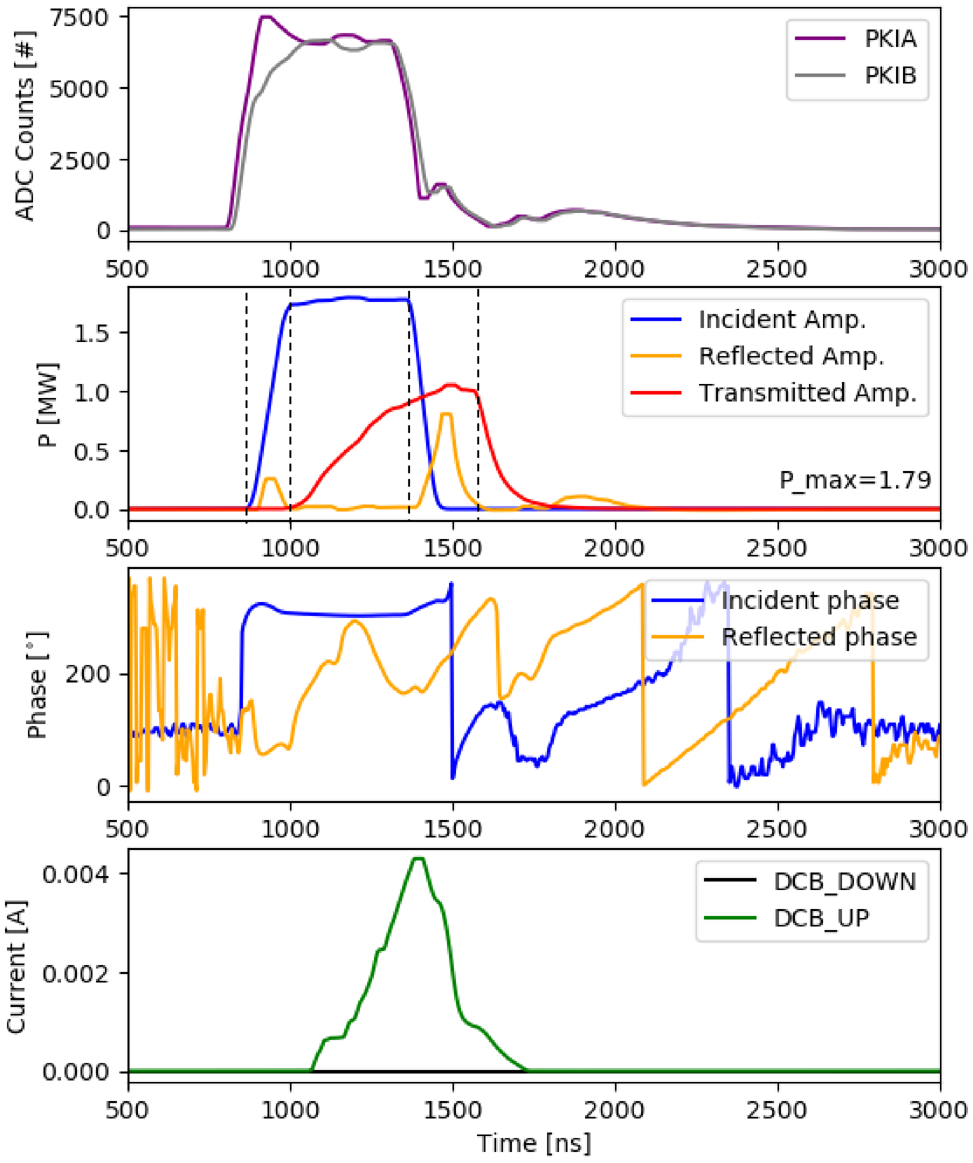
Software tests

~7.5M pulses, 271 BDs

Normal pulse main signals for BD analysis I

Data from 18/11/2020

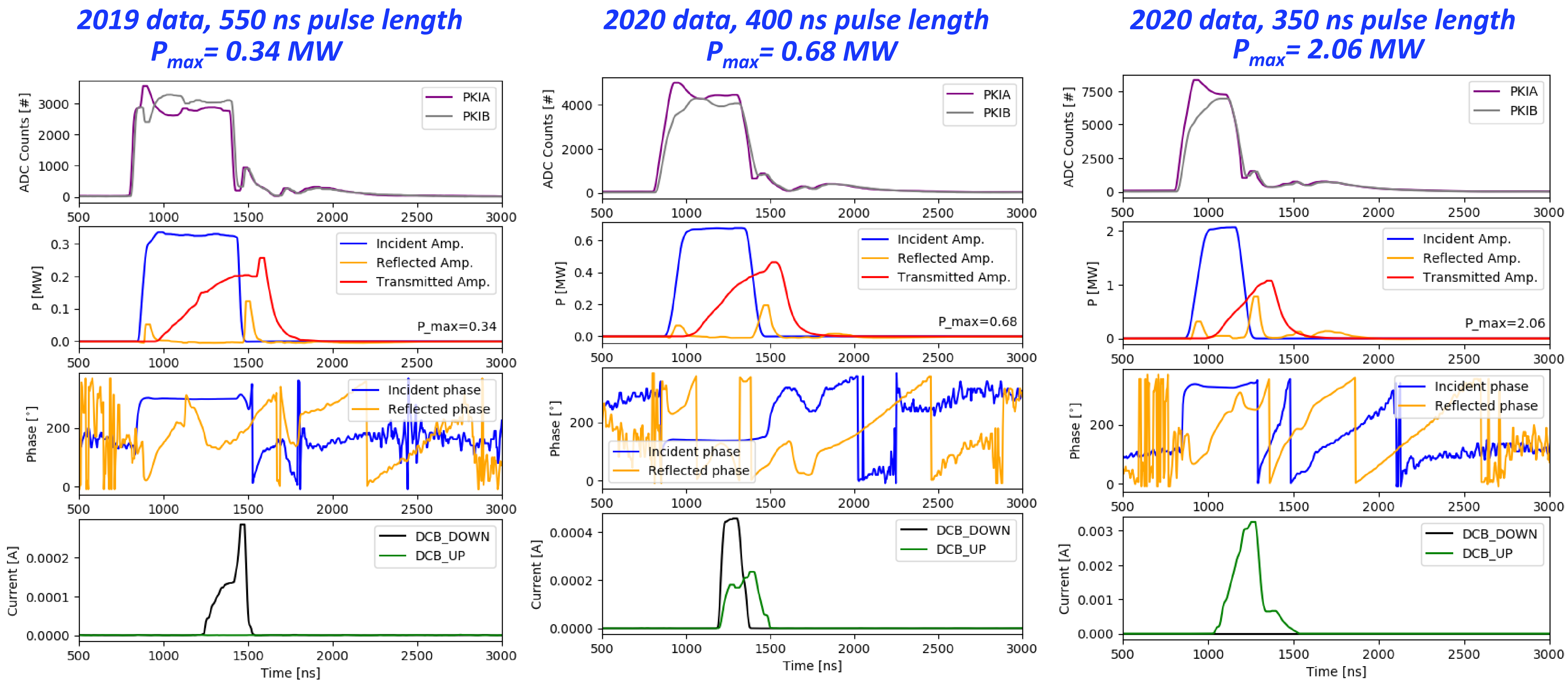




- ❑ Main signals to monitor the conditioning and BD analysis.
- ❑ **Reflected signals** calibration performed last week.
  - ❑ Plotted signal corresponds to the reflected signal reaching the klystron (PKR) and has been calibrated with the incident (PSI) calibration curve and multiplied by 4 to make it visible.
    - ❑ **Wrong cabling fixed last week.**

- ❑ **Transmitted pulse** shape is deformed.
  - ❑ Asymmetric rise and drop of the signal.
  - ❑ Delay w.r.t incident.
    - ❑ In the ramp up ~120 ns : not close to the designed filling time expected for the structure
    - ❑ In the ramp down ~195 ns.

Normal pulse main signals for BD analysis II

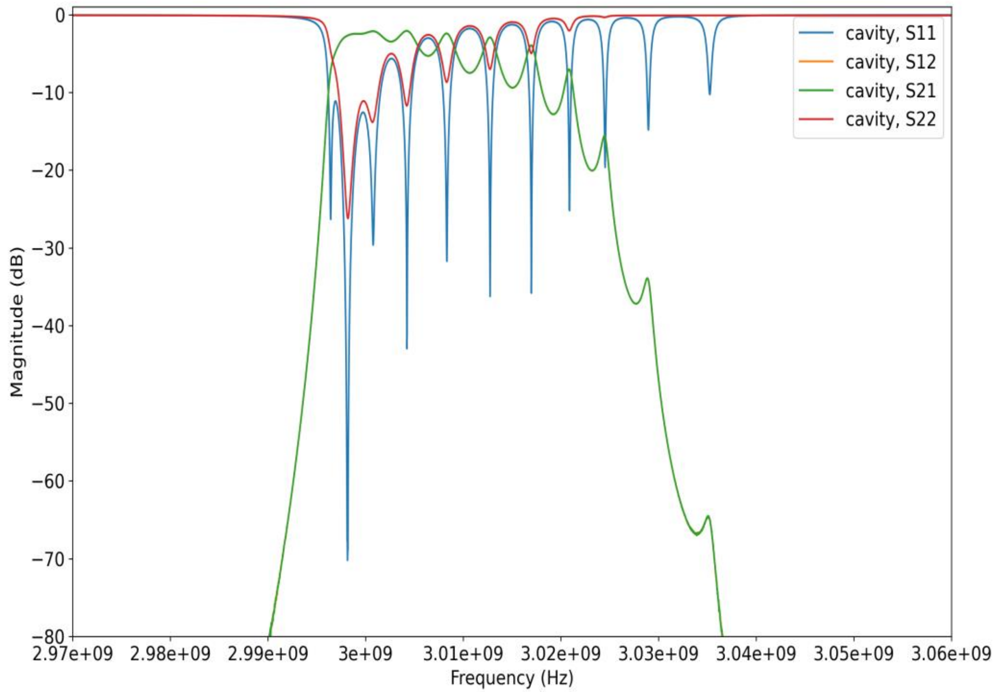


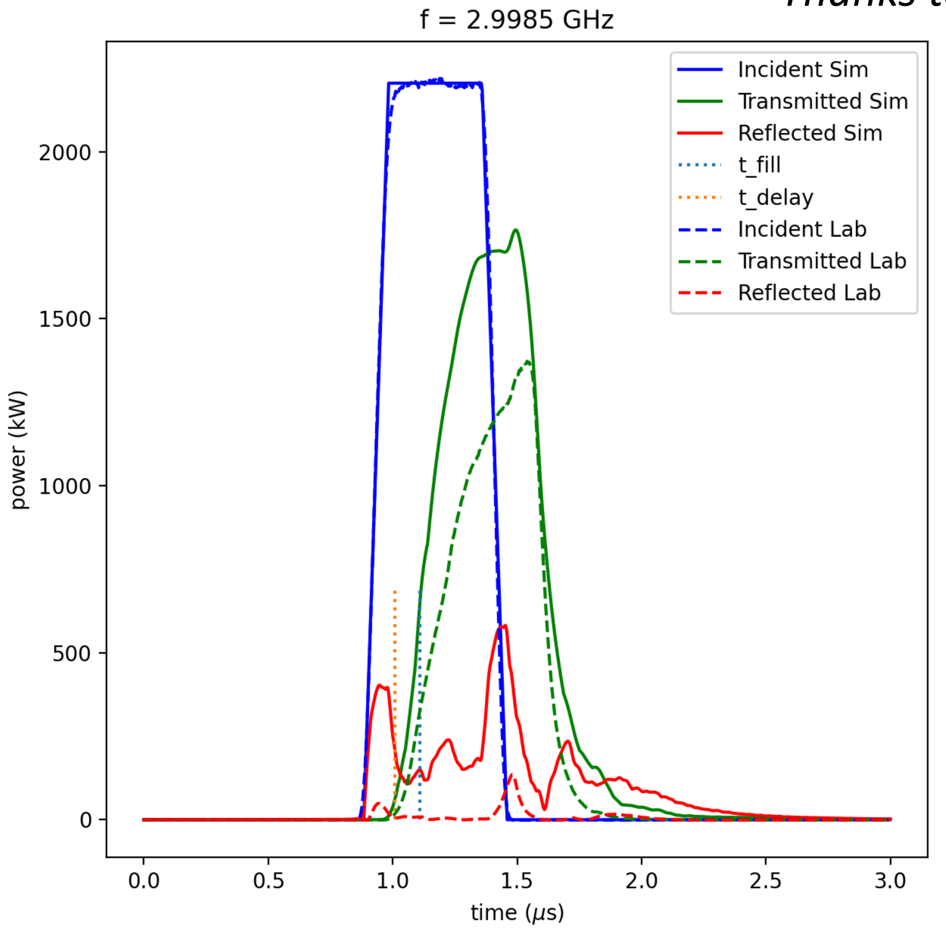
- ❑ Illustrate the effect on the shape of the signals due to the pulse length.
- ❑ Observed effect on the dark current for low input power.

Simulated vs measured pulse

Thanks to P. Martínez

- Simulation performed using measured scattering parameters.
- Incident pulse characteristics: width = 350 ns, t_up = 100 ns, f = 2.9985 GHz, P = 2.235 MW

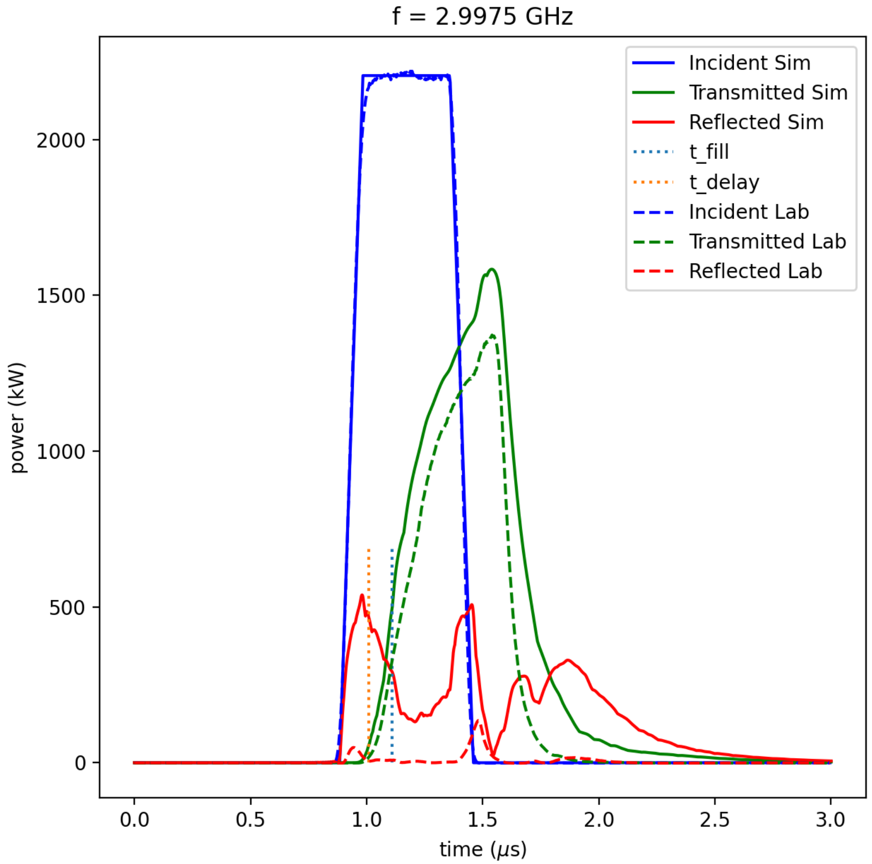




- Reflected signal in the plot is actually PKRB.
  –> wrong cabling found last week .
- Difference on transmitted signal amplitude.

Simulated vs measured pulse

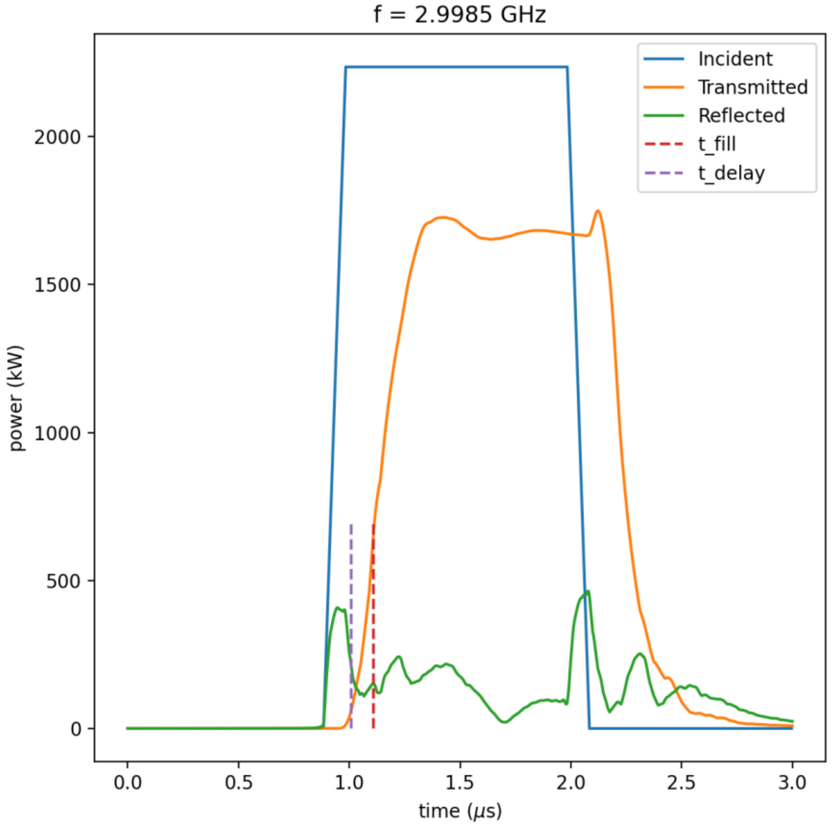
- ❑ Better agreement for a pulse with f=2.9975 GHz



- ❑ Need to check in the laboratory the real working point?
- ❑ Amplitude still different but less.

- ❑ Pulse width = 1 μs

Thanks to P. Martínez

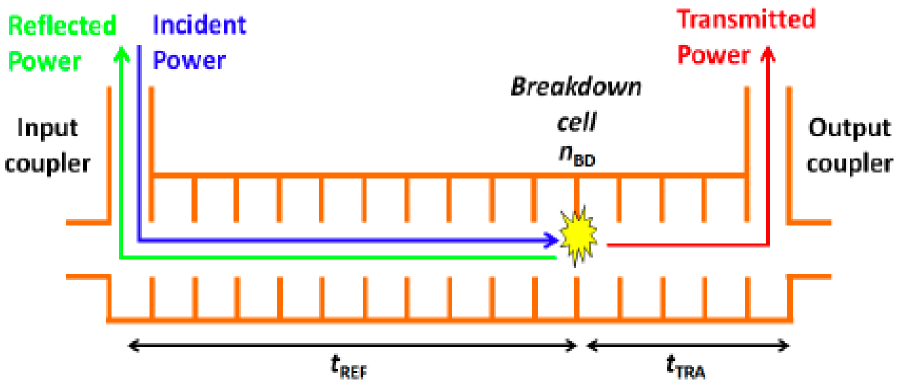


- ❑ More squared pulsed characterized by a plateau with two peaks.

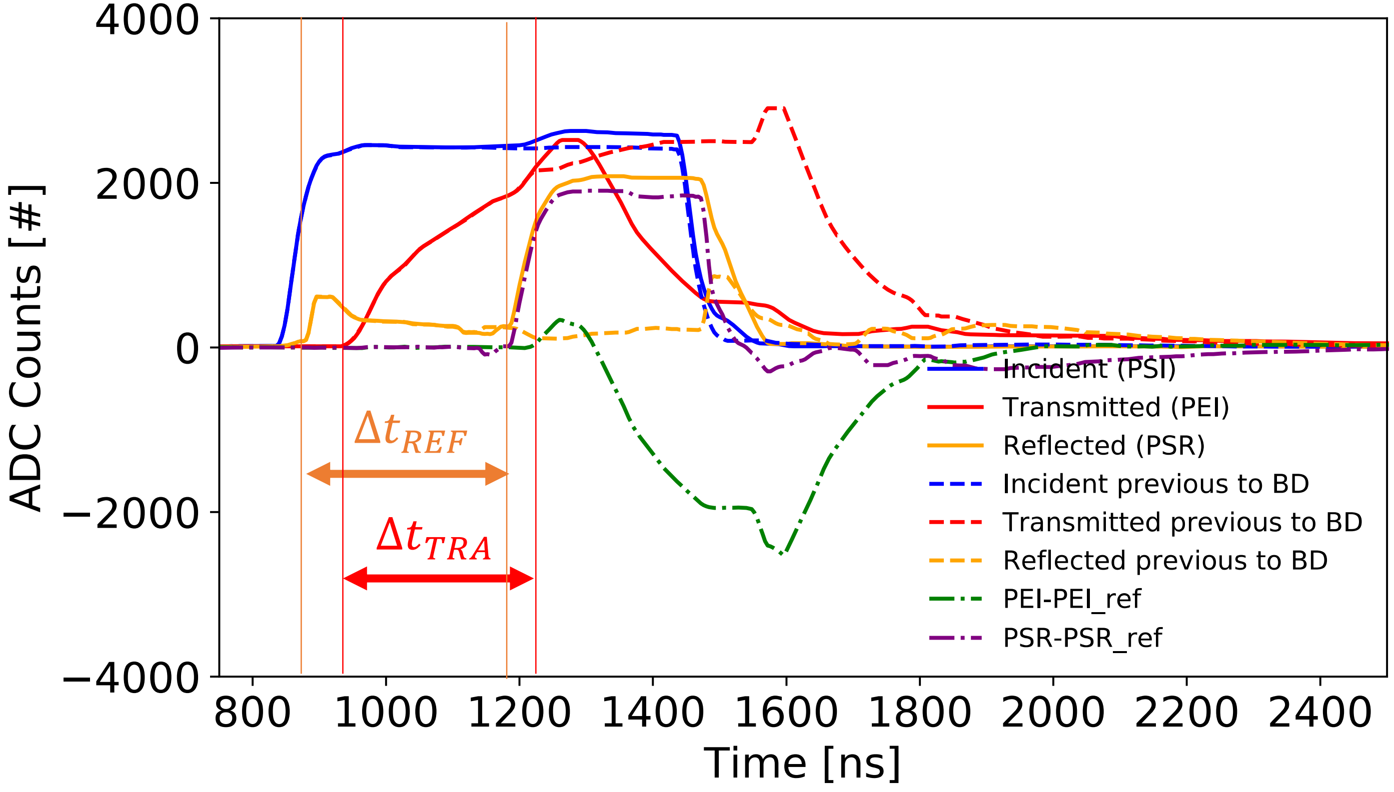
- ❑ In all studied cases the delay between incident and transmitted signals in the rise up is about 120 ns as in measurements.

BD localization analysis

- We are interested in finding the regions which limit the overall performance of the structure.



2019 data, 550 ns pulse length



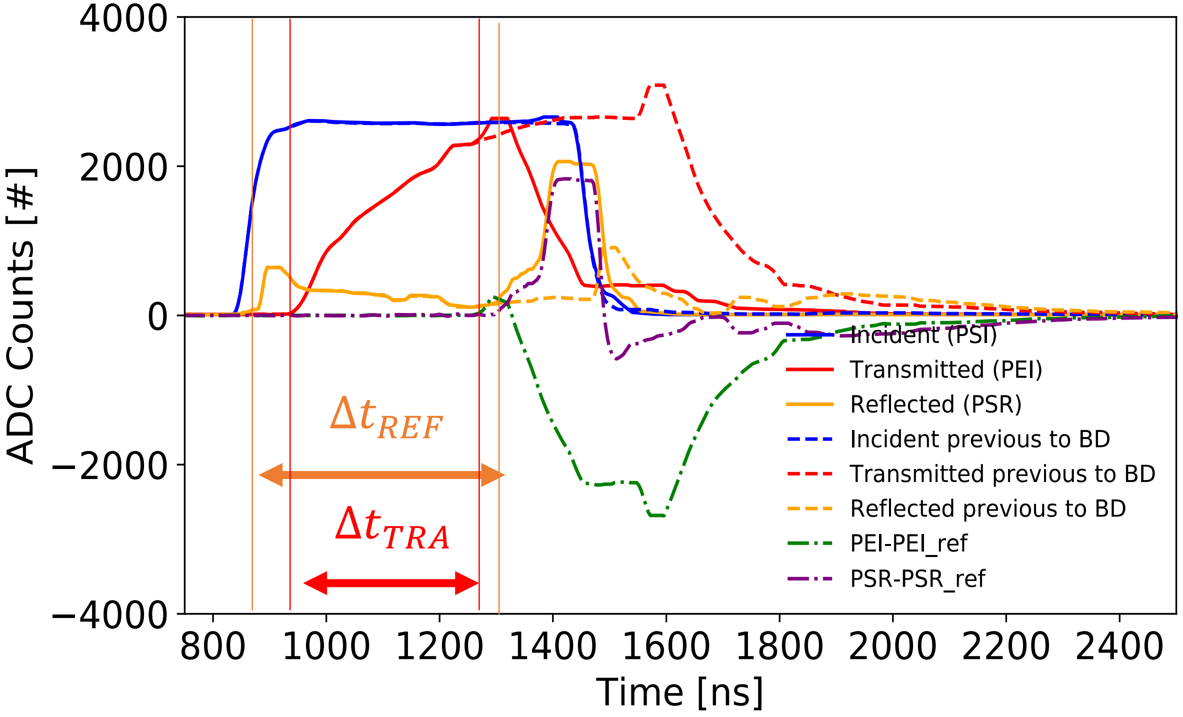
Edge method: compares the time of detection in which the reflected power rises and the transmitted drops.

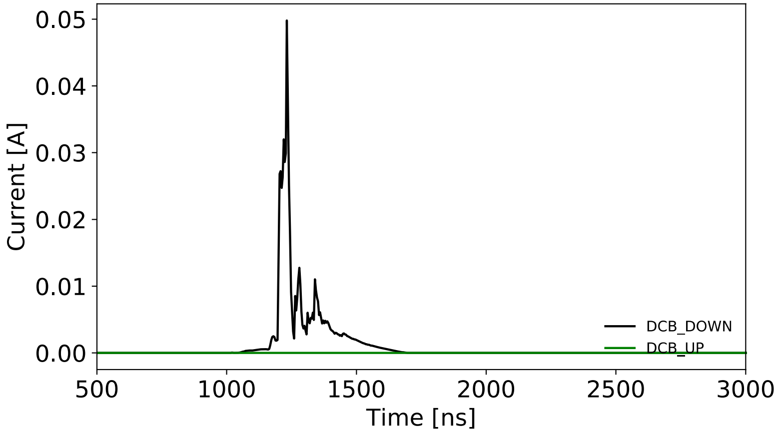
$$t_d^{edge}[ns] = \frac{\Delta t_{REF} - \Delta t_{TRA}}{2}$$

- Analysis to be updated applying the calibration of all signals.

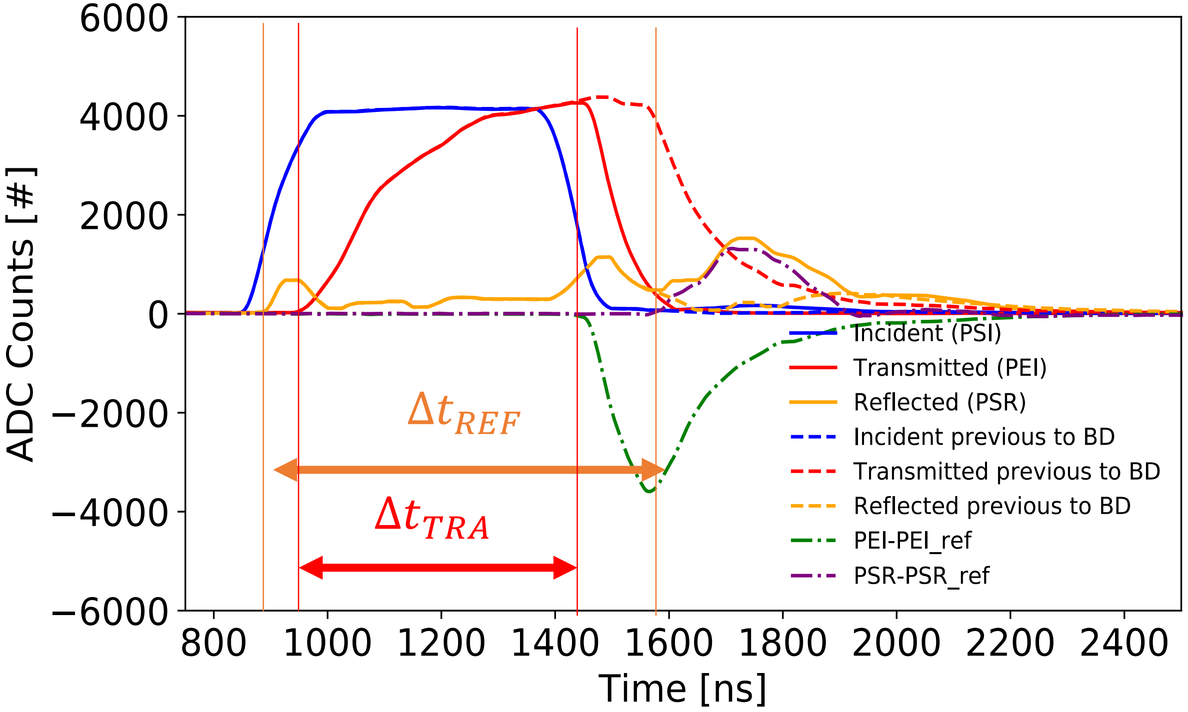
Examples of BD events

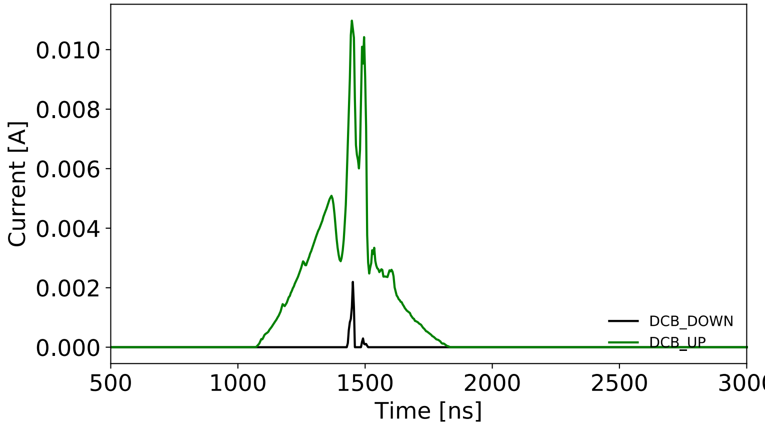
2019 data, 550 ns pulse length





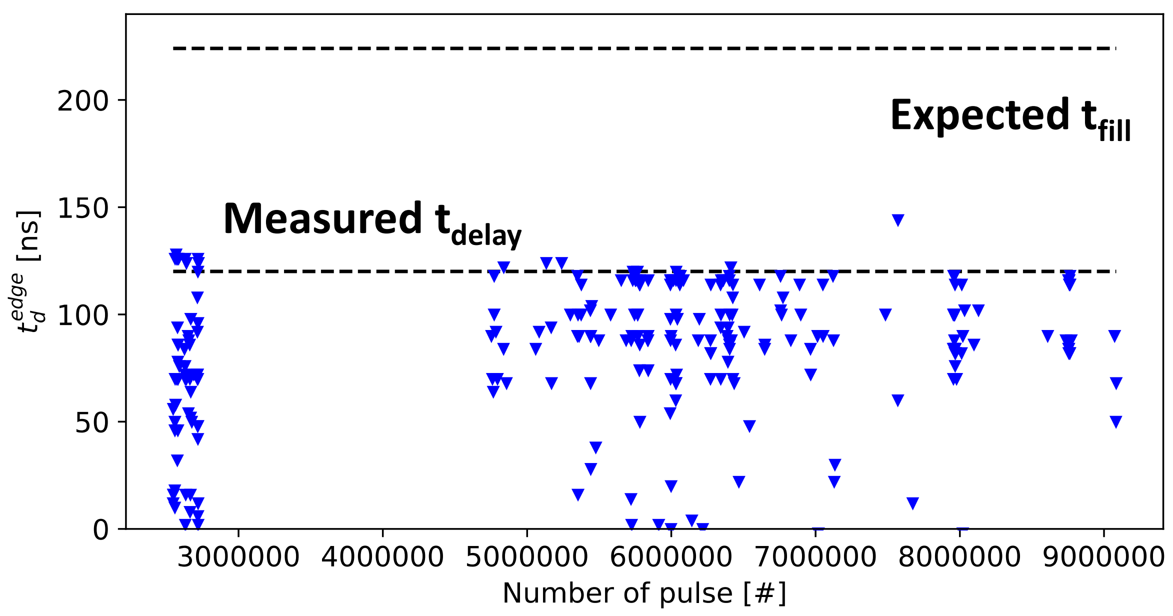
2020 data, 400 ns pulse length



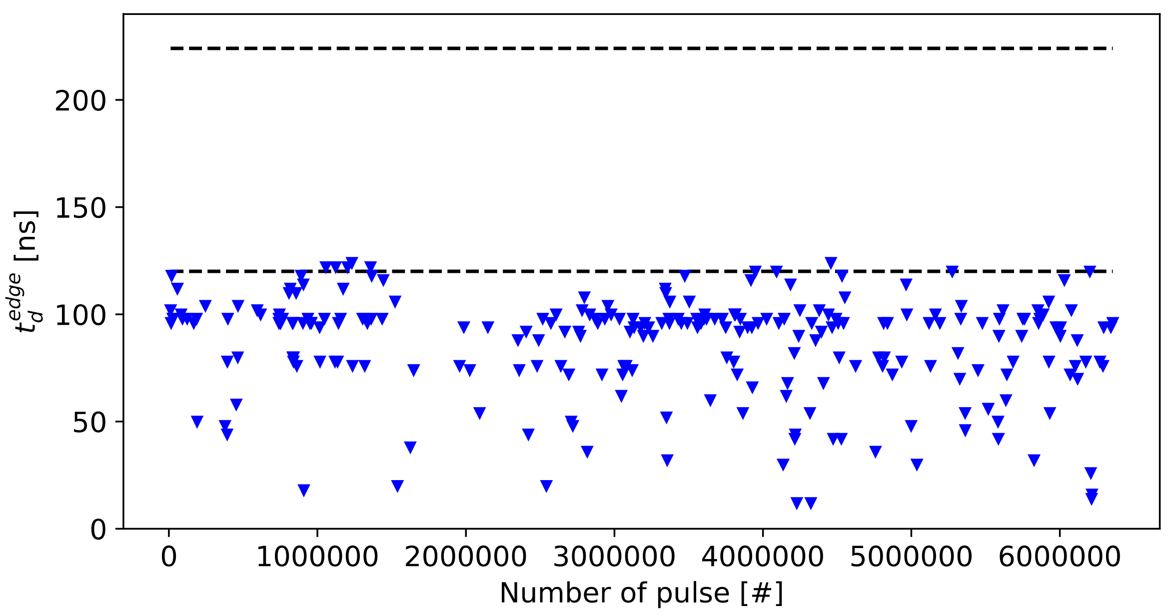


Preliminary summary of BD analysis localization

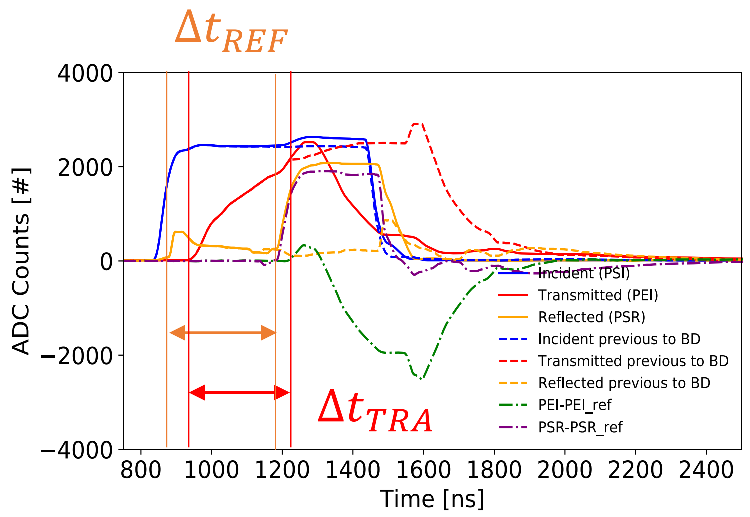
2019 data, ~262 BDs



2020 data, ~271 BDs



- Distribution of BDs delays not well understood.
  - The method seems to work well for other structures that have a t_{delay} between incident and transmitted signals closer to the t_{fill}.
  - Issues on the analysis on the definition of the rising time of the transmitted signal (Δt_{TRA})?



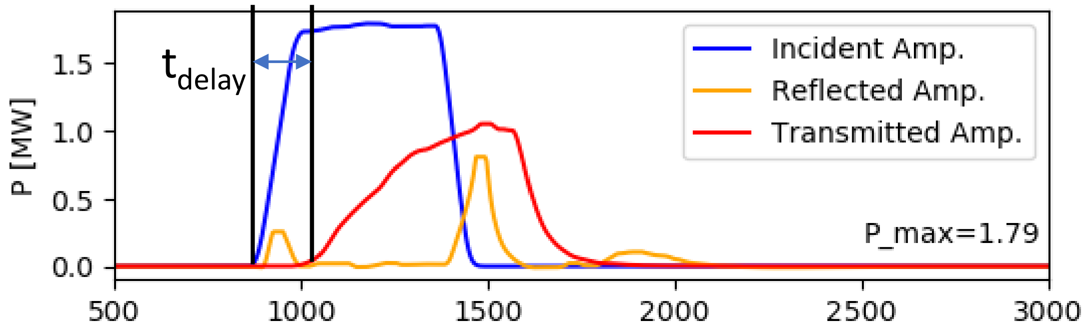
Preliminary summary of BD analysis localization

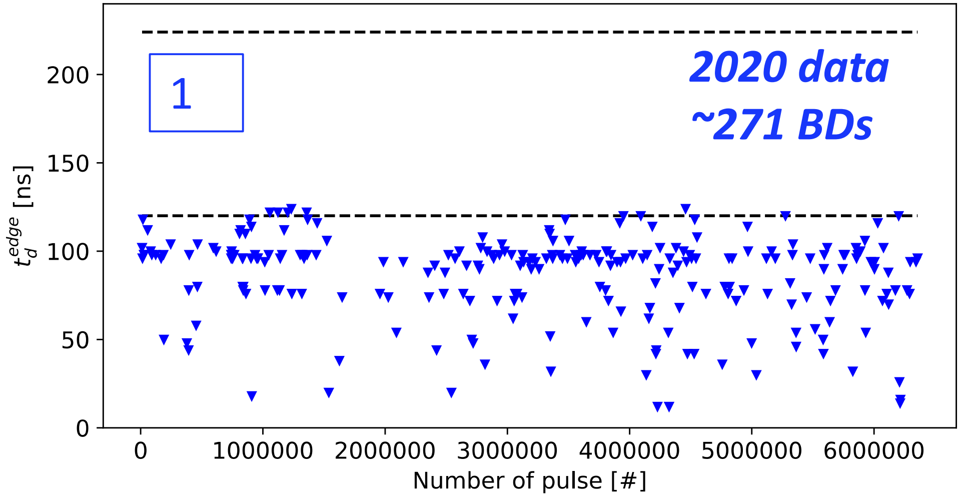
1 $$t_d^{edge}[ns] = \frac{\Delta t_{REF} - \Delta t_{TRA}}{2}$$

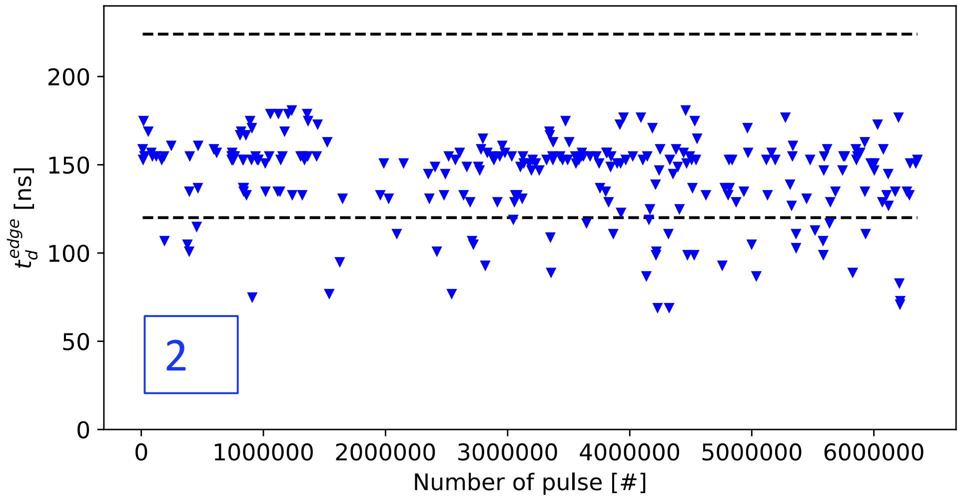
Using the typical formula with the absolute values of rising reflected signal and drop of transmitted signal.

2 $$t_d^{edge}[ns] = \frac{t_{REF} - t_{TRA} + t_{fill}}{2}$$

- Expressions 1 and 2 should be equivalent if $t_{fill} = t_{delay}$?



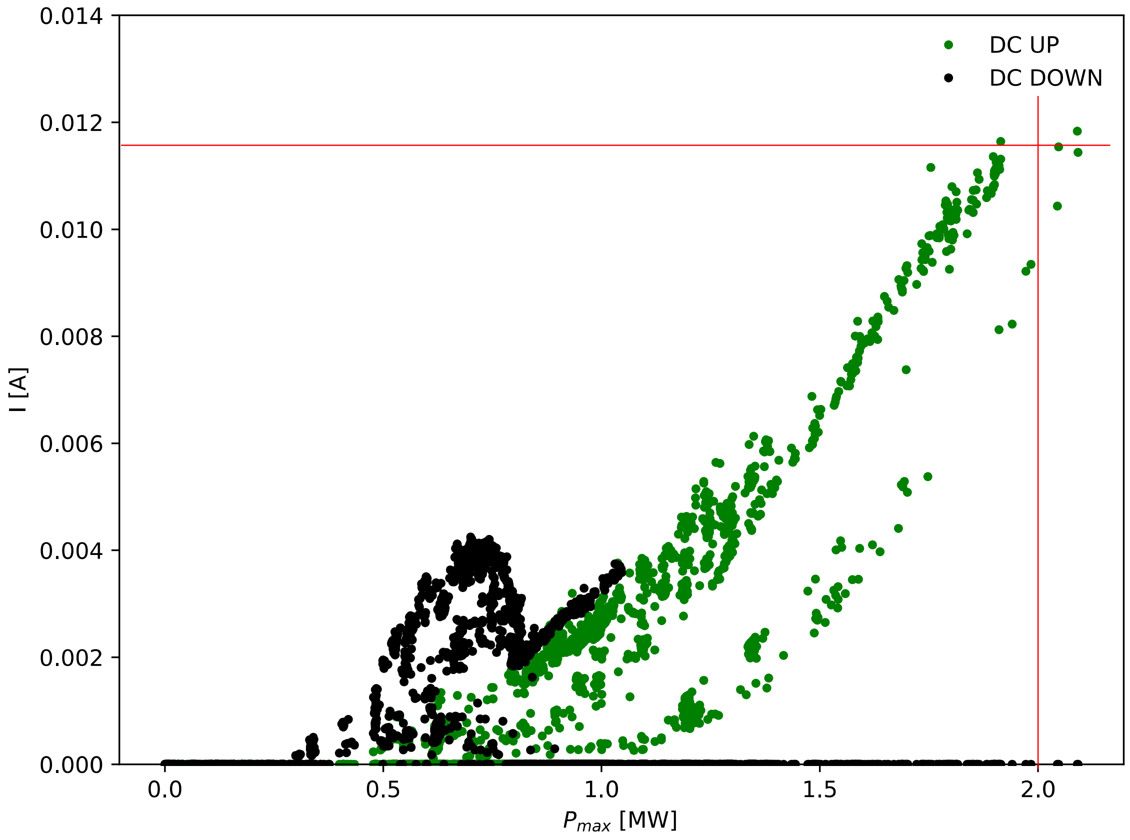




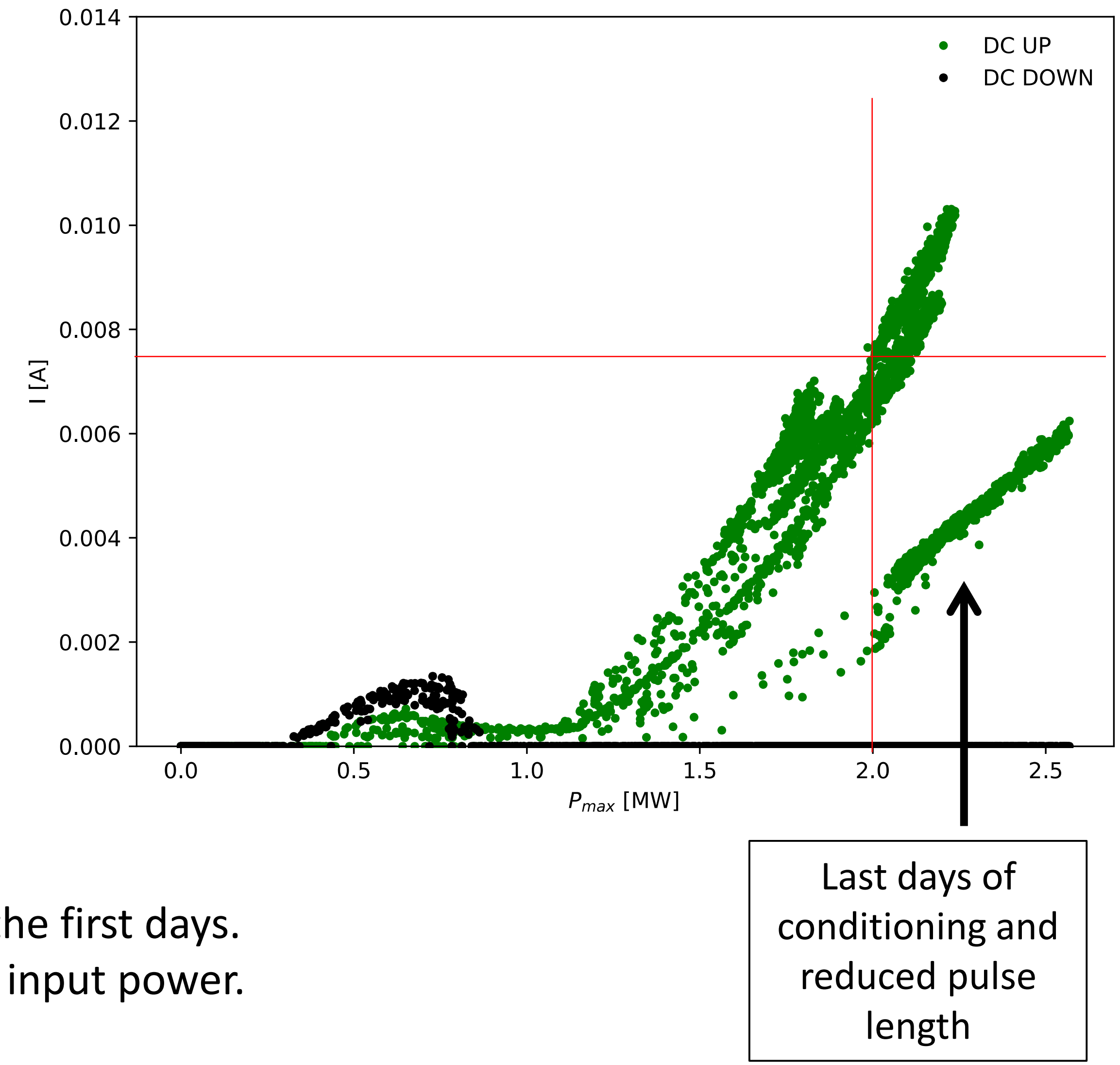
- The applicability of the method 1 and how to apply it is under investigation as well as finding a way to measure the filling time from the measured signals.

Preliminary summary of dark current vs input power

10-11/2019 data



7-8/2020 data



- ❑ In 2019 higher level of DC signals was observed in the first days.
- ❑ Reproducible pattern of dark current signals at low input power.
- ❑ We start to see an impact of the conditioning.

Summary

- The conditioning of the KT S-band BTW structure has been started in order to test its performance.
  - An accelerating gradient of ~17.5 MV/m has been reached.
  - The effect of the conditioning process is visible on the dark current data.
  - First preliminary breakdown localization analysis needs further understanding.

On going work:

- Checking attenuation measurements and repeating some calibration of the signals.
  - To be implement on the analysis.

Next:

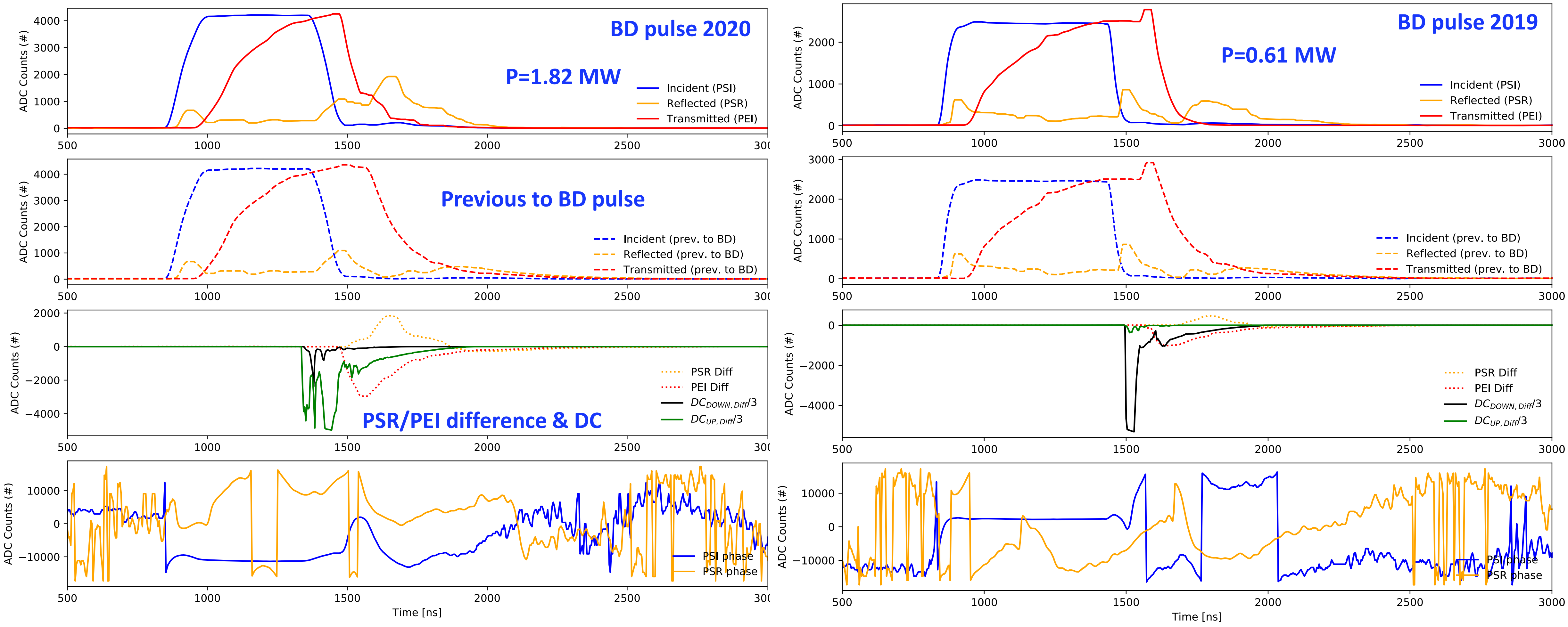
- Continue the conditioning of the KT structure.

Thank you very much for your attention!

Back up

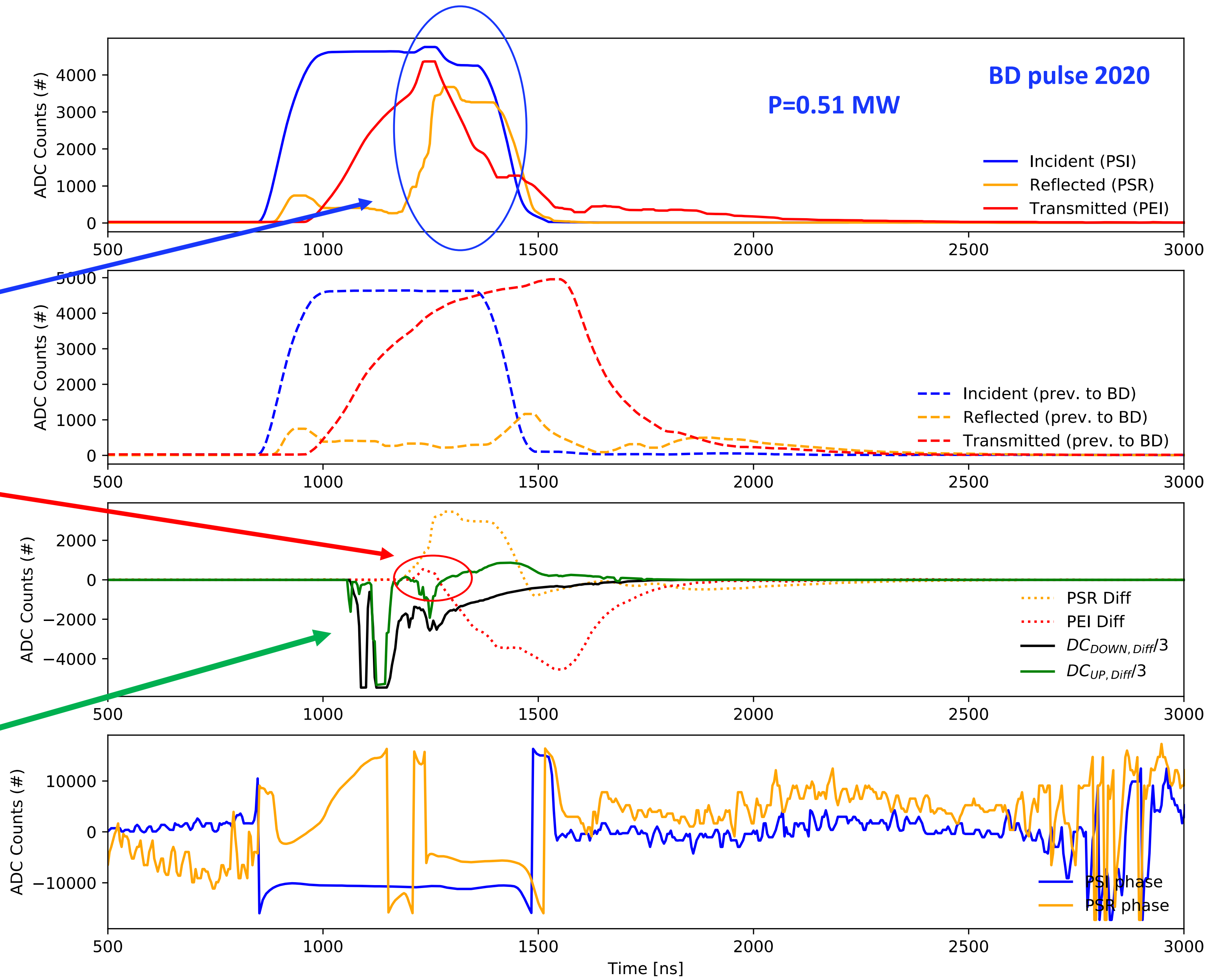
BD pulses: example I

- Most common BD event observed triggered by dark current signals.
- Reflected signal at the very end of the signal pattern.
- In some cases higher dark current observed in the upstream FC (RF input) others in the downstream FC (RF output).



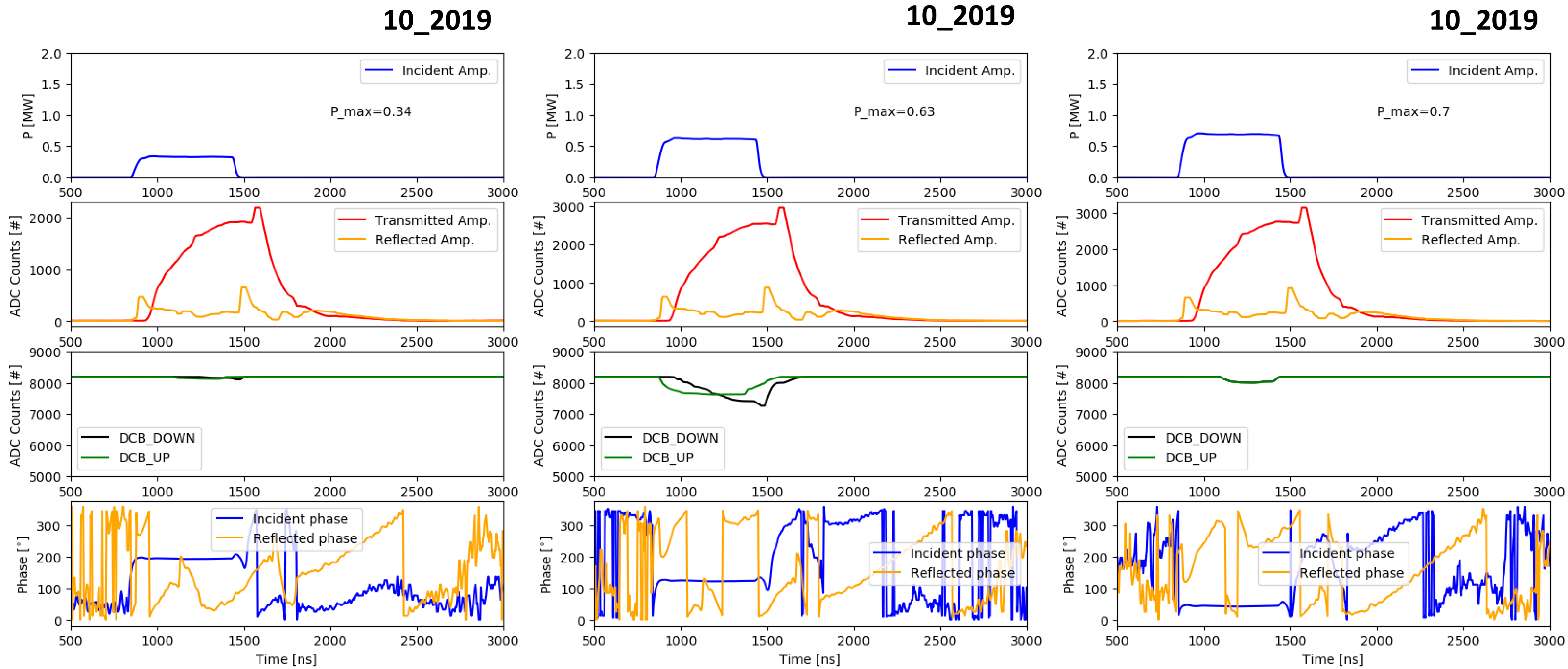
BD pulses: example II

- Higher reflected signal.
- An effect is observed in the incident signal.
- The transmitted signal slightly increase before falling.
- Note that the DC signals saturate. For making the plot more compact the DC signal has been divided by 3.



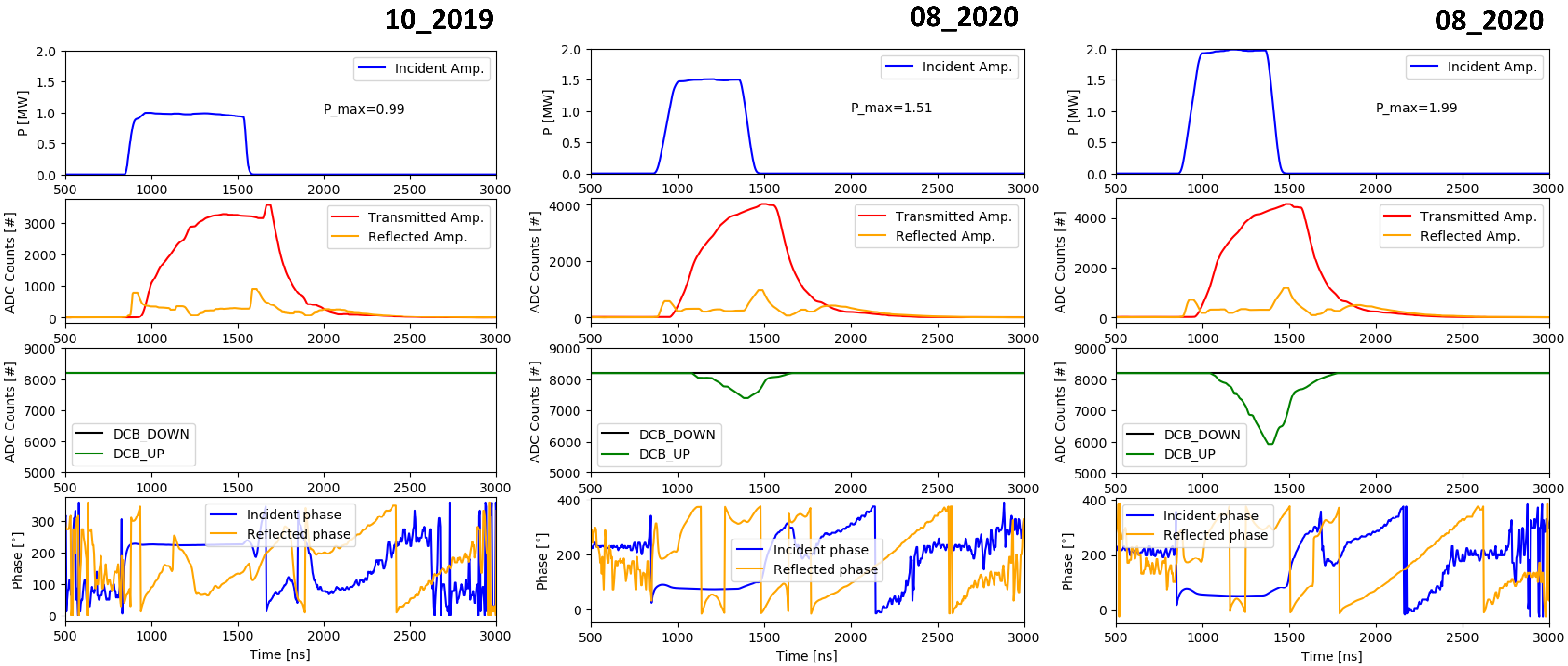
Normal pulse example

- ❑ Differences are observed on the measured dark current downstream and upstream depending on the input power.



**Calibration of the transmitted signal to be performed.

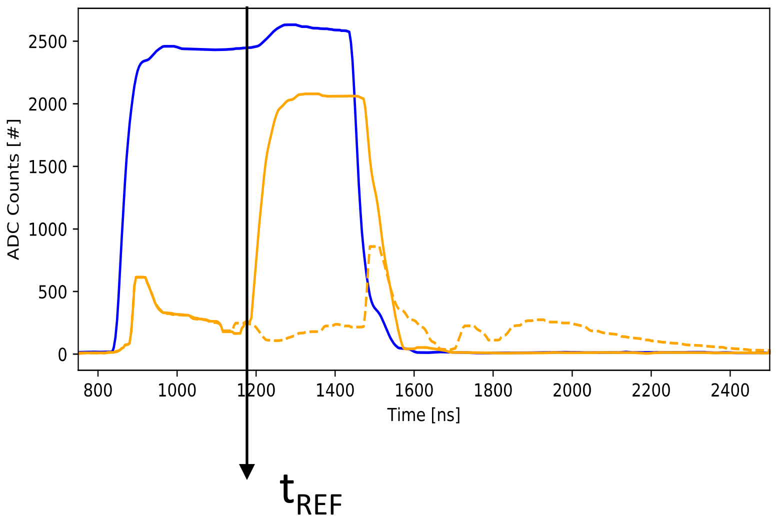
Normal pulse example

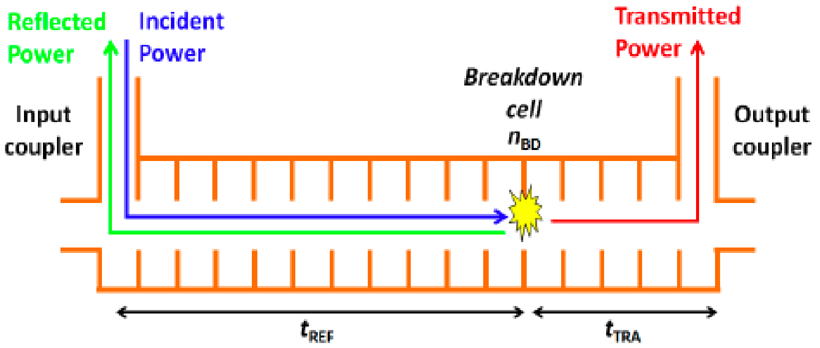


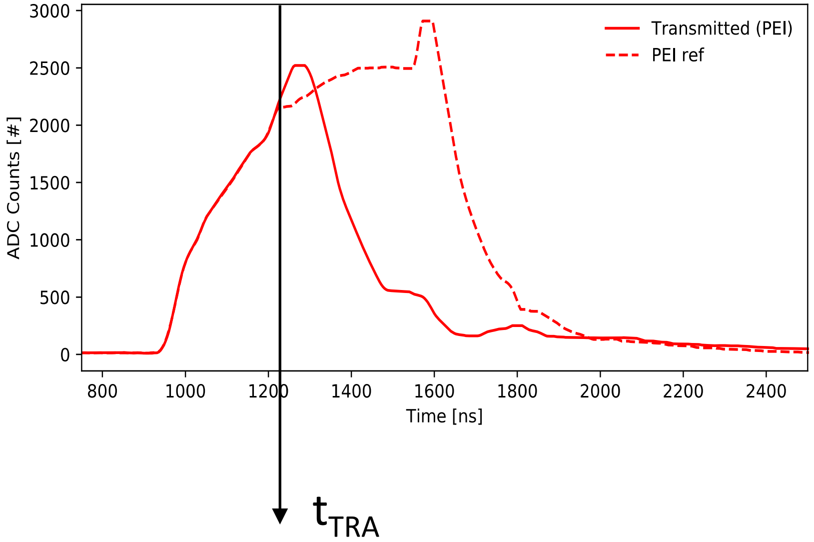
- ❑ The observed difference on the 2019 and 2020 incident pulse shape is due to a change on the slope timing.
  - ❑ Small impact on the reflected and transmitted shape signals.

BD localization: ‘Edge method’

- ❑ Assuming that the signals are temporally aligned.
- ❑ Assuming that the rise and drop of signal for the reflected and transmitted signals occur at the same time.







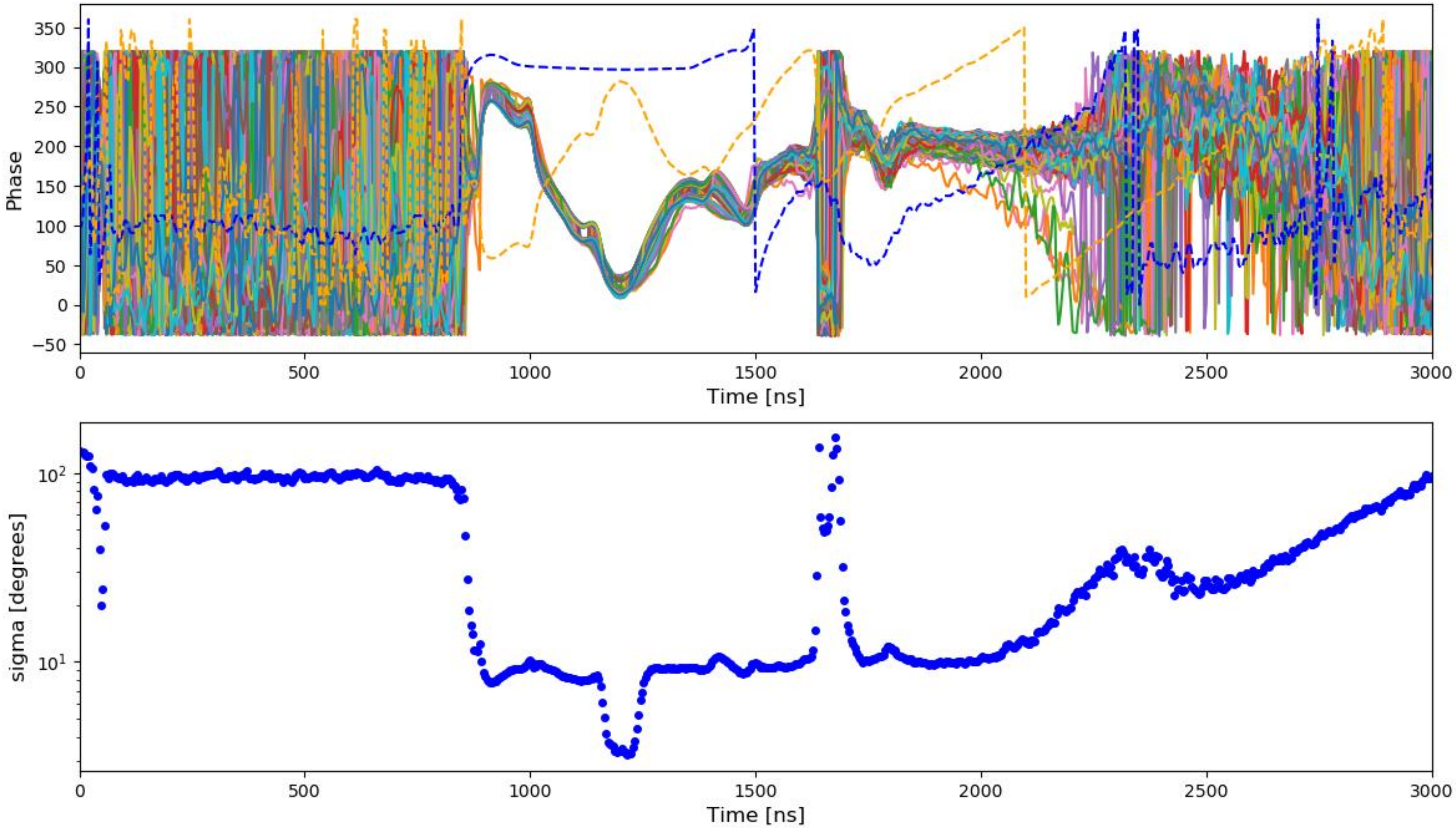
$$t_d^{edge}[ns] = t_{REF} - t_{TRA} + tfill$$

$$t_d^{edge}[ns] = \sum_{n_{cell}}^{n_{BD}} \frac{L_{cell}}{v_g(n_{cell})} - \sum_{n_{BD}}^{n_N} \frac{L_{cell}}{v_g(n_{cell})} + t_{fill}$$

- ❑ A t_{fill} has to be added in order to ensure the same time origin of the signals as one is measured at the entrance and the other at the exit of the structure.

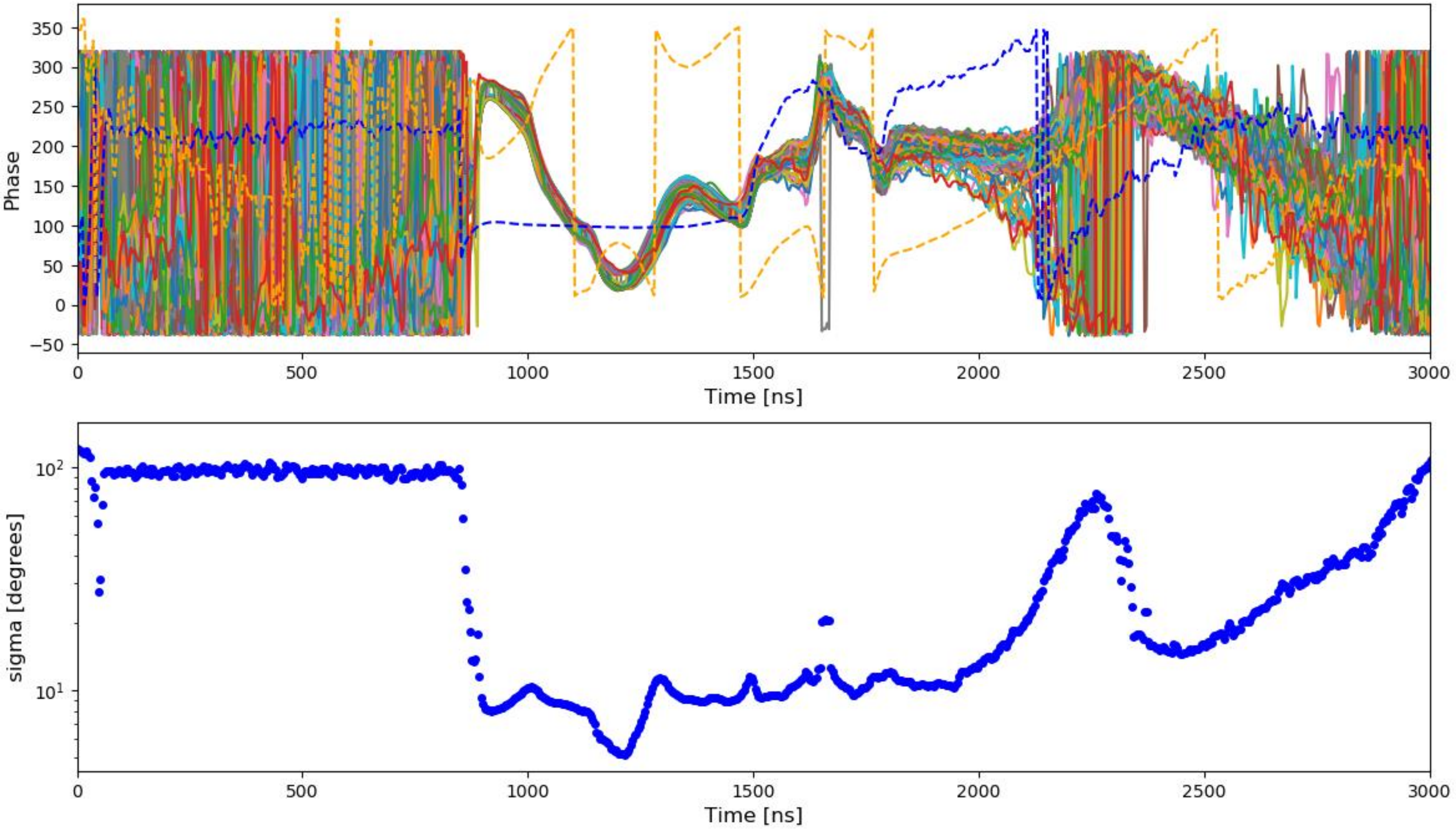
Phase signal stability check

26_08_2020



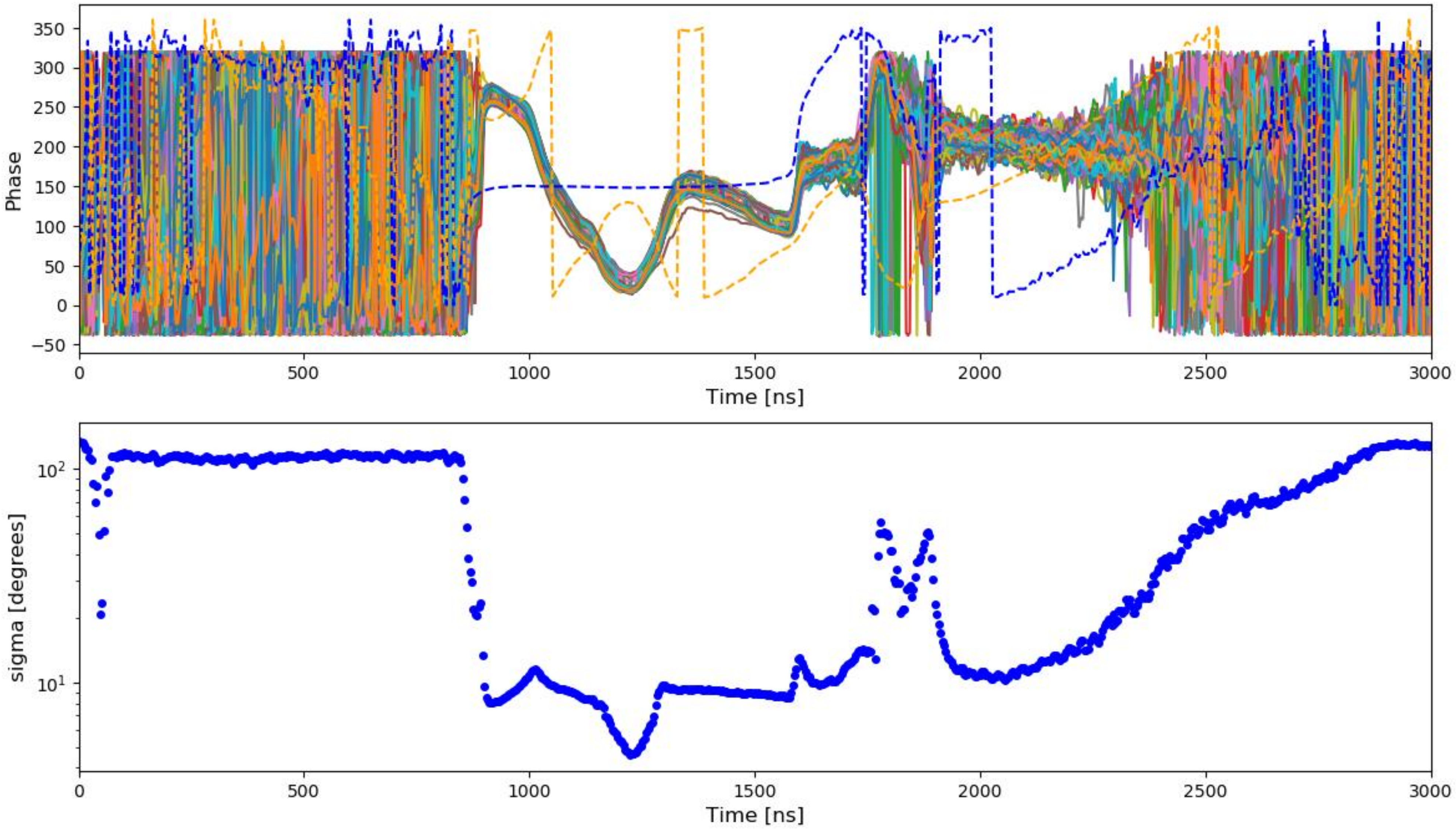
Phase signal stability check

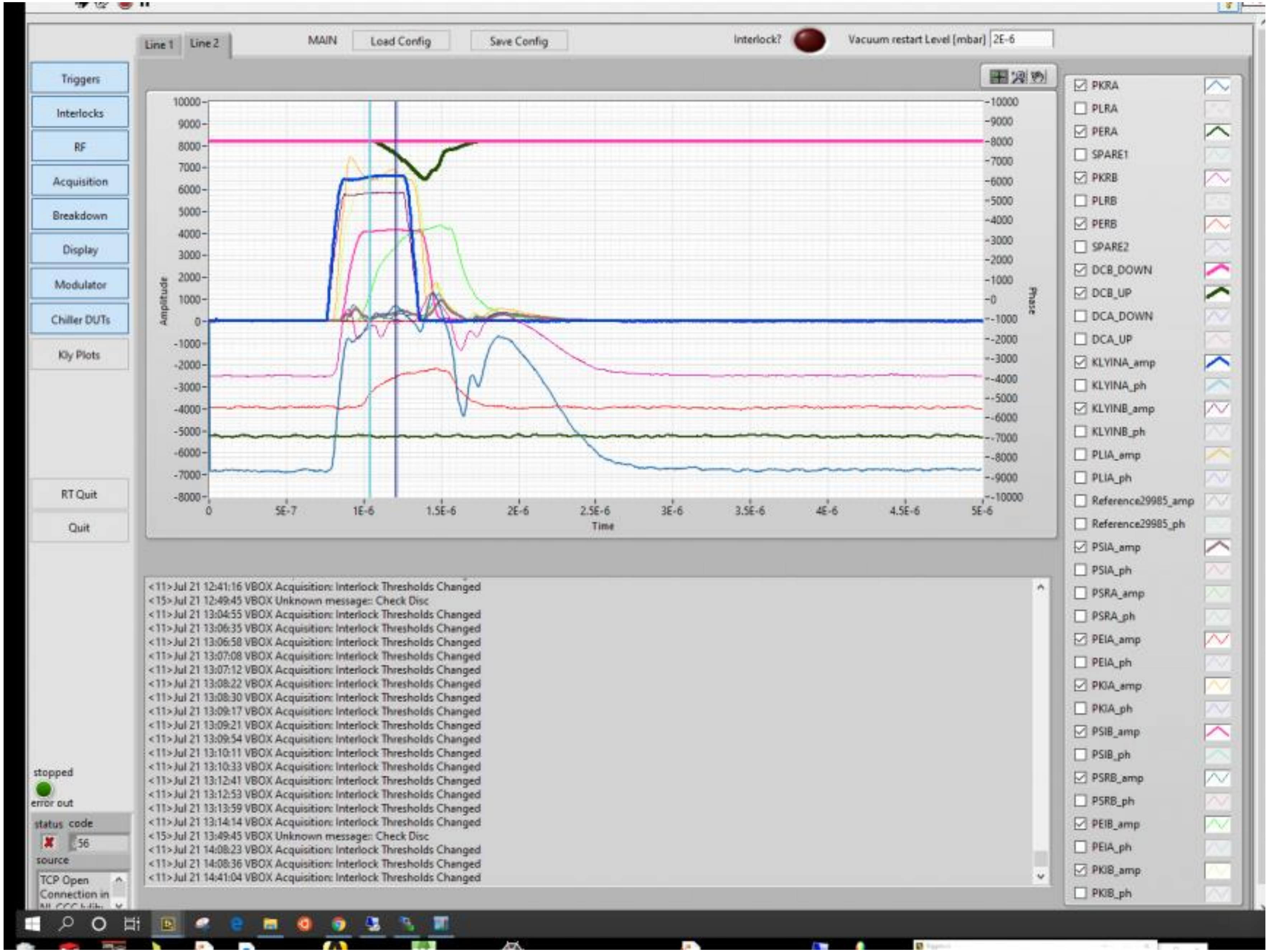
24_07_2020



Phase signal stability check

19_11_2019




Line 1
Line 2
MAIN
Load Config
Save Config
Interlock?
Vacuum restart Level [mbar]
2E-6
Triggers
Interlocks
RF
Acquisition
Breakdown
Display
Modulator
Chiller DUTs
Kly Plots
RT Quit
Quit
Amplitude
Phase
Time
PKRA
PLRA
PERA
SPARE1
PKRB
PLRB
PERB
SPARE2
DCB_DOWN
DCB_UP
DCA_DOWN
DCA_UP
KLYINA_amp
KLYINA_ph
KLYINB_amp
KLYINB_ph
PLIA_amp
PLIA_ph
Reference29985_amp
Reference29985_ph
PSIA_amp
PSIA_ph
PSRA_amp
PSRA_ph
PEIA_amp
PEIA_ph
PKIA_amp
PKIA_ph
PSIB_amp
PSIB_ph
PSRB_amp
PSRB_ph
PEIB_amp
PEIA_ph
PKIB_amp
PKIB_ph
<11>Jul 21 12:41:16 VBOX Acquisition: Interlock Thresholds Changed
<15>Jul 21 12:49:45 VBOX Unknown message: Check Disc
<11>Jul 21 13:04:55 VBOX Acquisition: Interlock Thresholds Changed
<11>Jul 21 13:06:35 VBOX Acquisition: Interlock Thresholds Changed
<11>Jul 21 13:06:58 VBOX Acquisition: Interlock Thresholds Changed
<11>Jul 21 13:07:08 VBOX Acquisition: Interlock Thresholds Changed
<11>Jul 21 13:07:12 VBOX Acquisition: Interlock Thresholds Changed
<11>Jul 21 13:08:22 VBOX Acquisition: Interlock Thresholds Changed
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<11>Jul 21 13:09:17 VBOX Acquisition: Interlock Thresholds Changed
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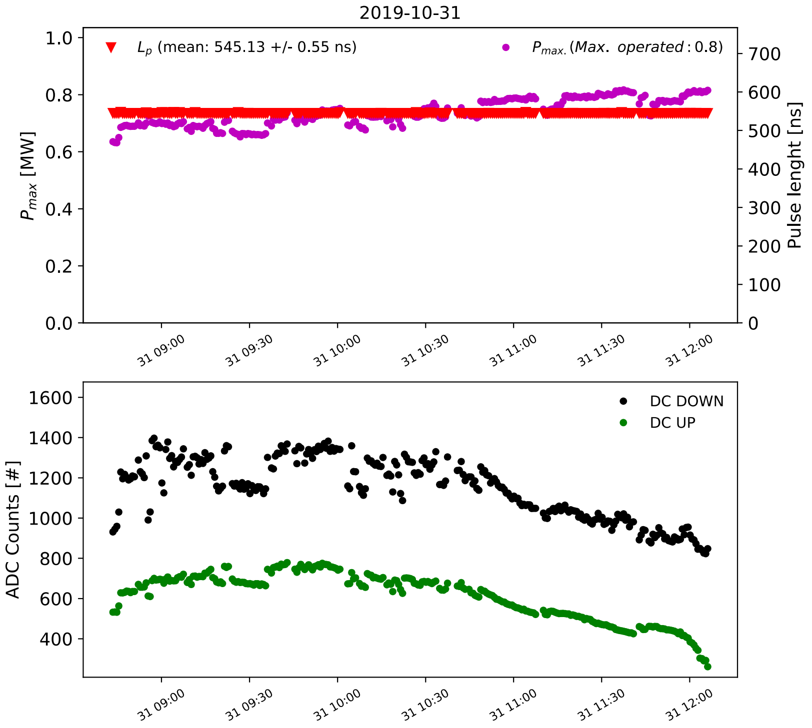
<11>Jul 21 14:08:36 VBOX Acquisition: Interlock Thresholds Changed
<11>Jul 21 14:41:04 VBOX Acquisition: Interlock Thresholds Changed
stopped
error out
status
code
56
source
TCP Open
Connection in

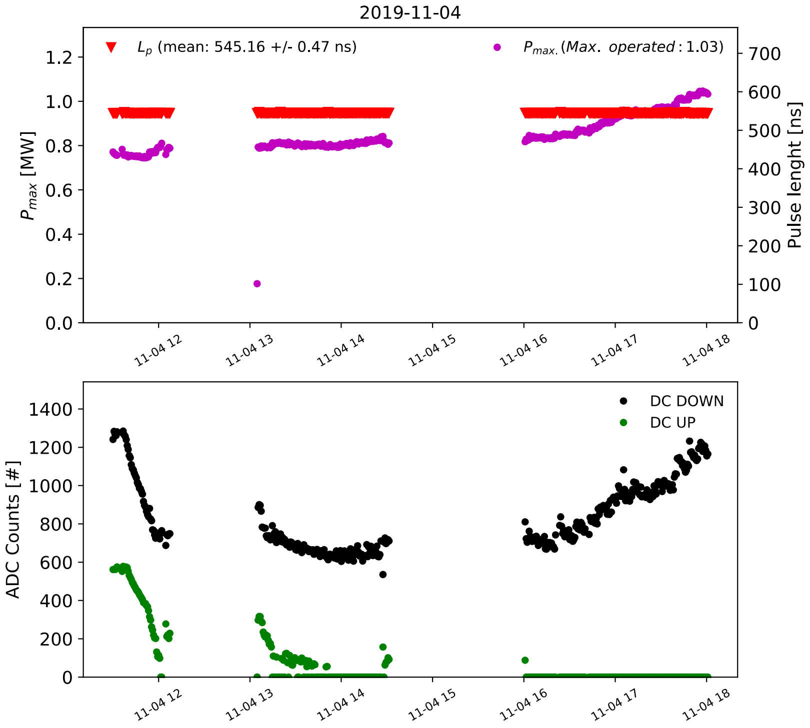

Line 1
Line 2
MAIN
Load Config
Save Config
Interlock?
Vacuum restart Level [mbar]
2E-6
Amplitude
Phase
Time
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
-8000
-9000
-10000
0
5E-7
1E-6
1.5E-6
2E-6
2.5E-6
3E-6
3.5E-6
4E-6
4.5E-6
5E-6

Downstream and upstream DC signals

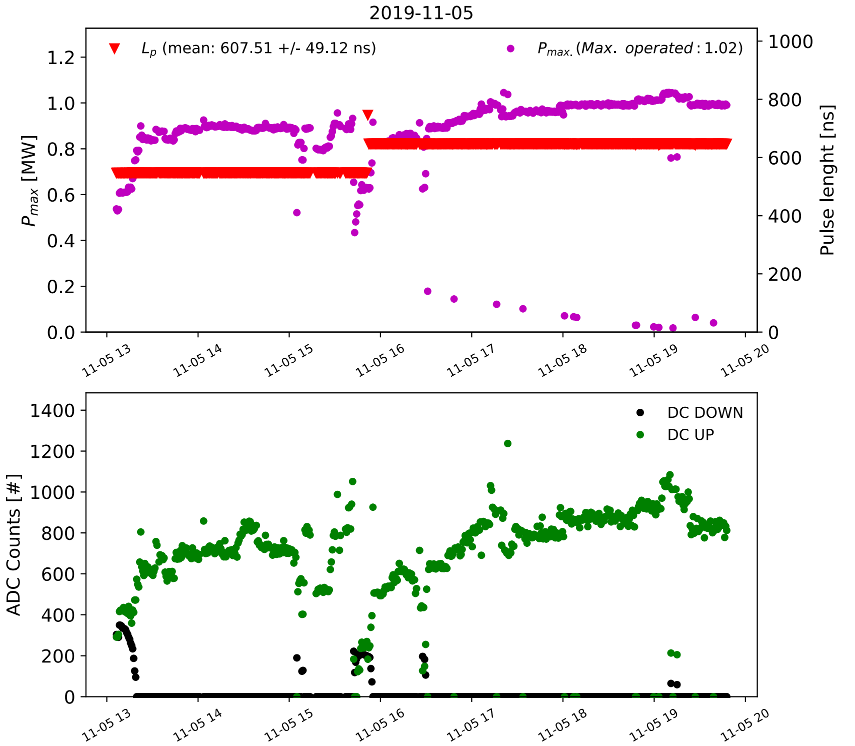
- One of the two cables for the FC data was not properly connected. The good cabling was performed on the 4-5/11/2019.



DCB_DOWN -> DCB_DOWN
DCB_UP -> DCA_DOWN



DCB_DOWN -> DCB_DOWN
DCB_UP -> DCA_DOWN



DCB_DOWN -> DCB_DOWN
DCB_UP -> DCB_UP

Filling time