Analysis of breakdown data from Xbox-1

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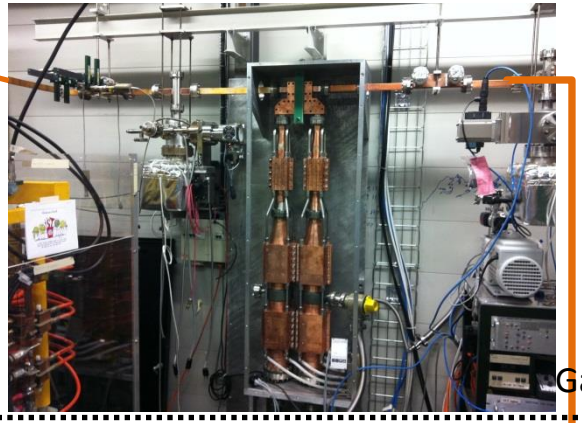
TD26R05 CC under test in Xbox-1

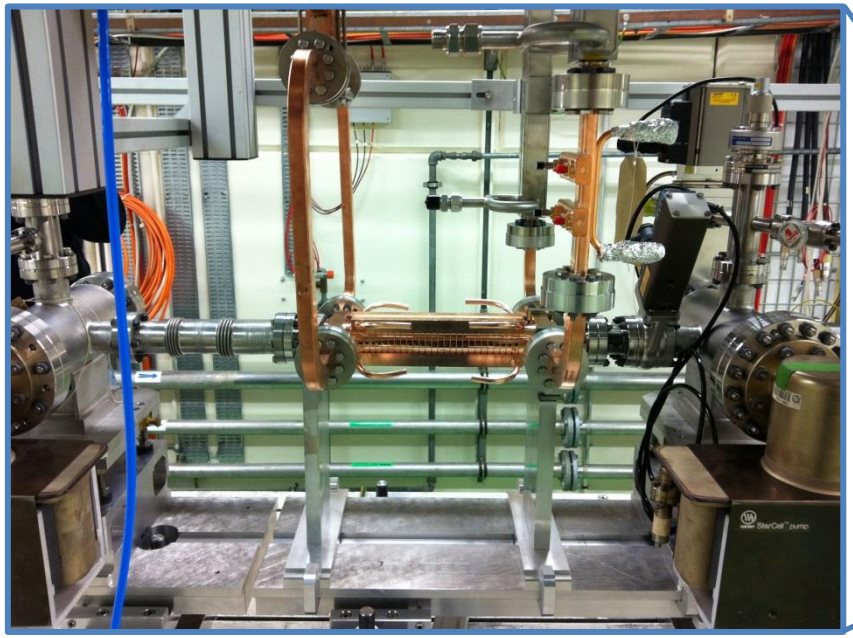
Clockwise from top-left:

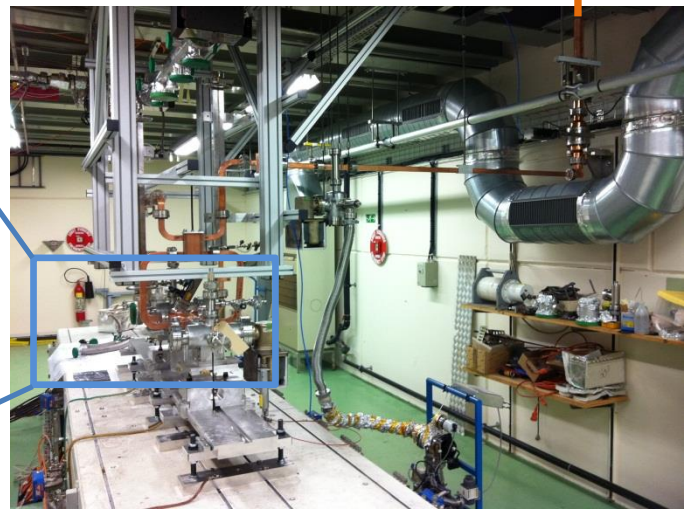
- Modulator/klystron (50MW, 1.5us pulse)
- Pulse compressor (250ns, ratio 2.8)
- DUT + connections
- Acc. structure (TD26CC)



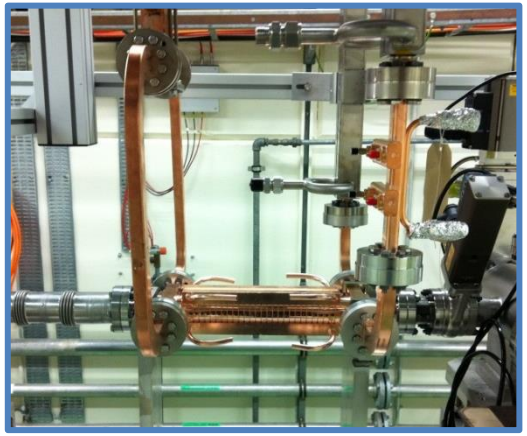
Gallery

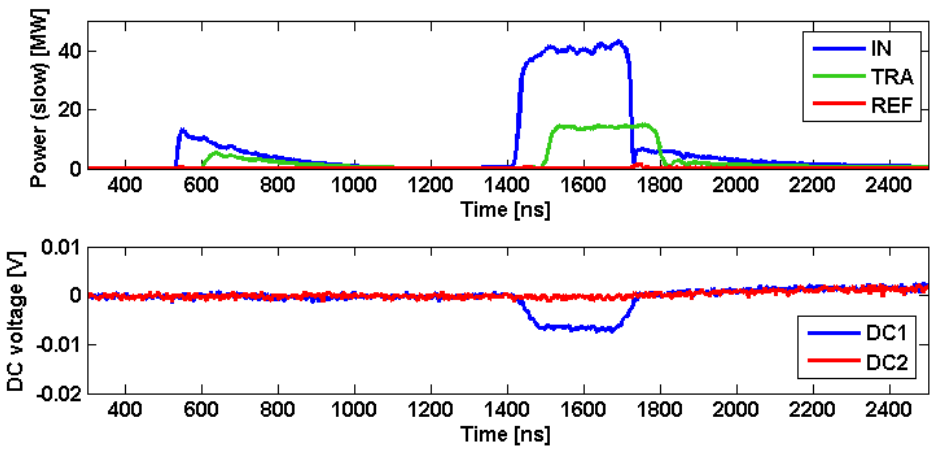
Bunker





Recorded signals

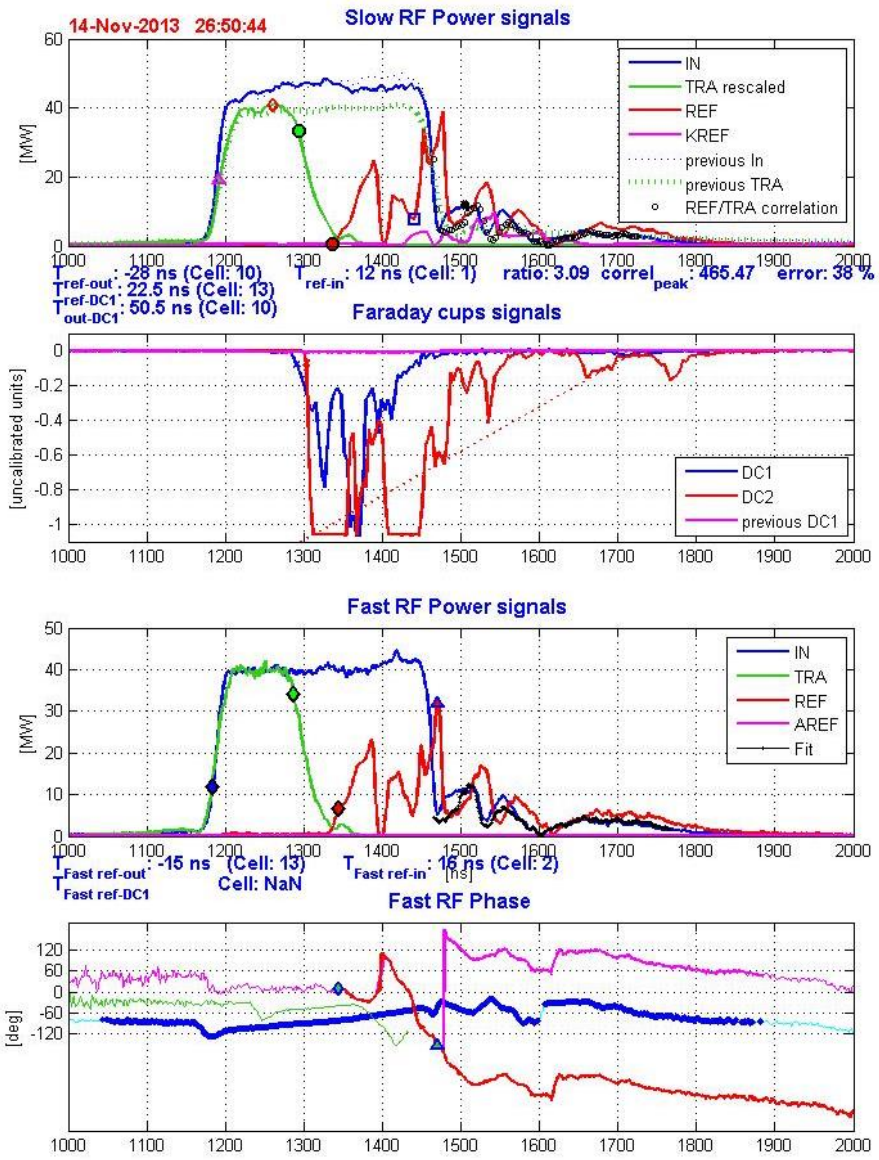




The TRA signal is attenuated and delayed

The REF signal comes directly from the bidirectional coupler, not from the ACS input

Example of signals – BD detection

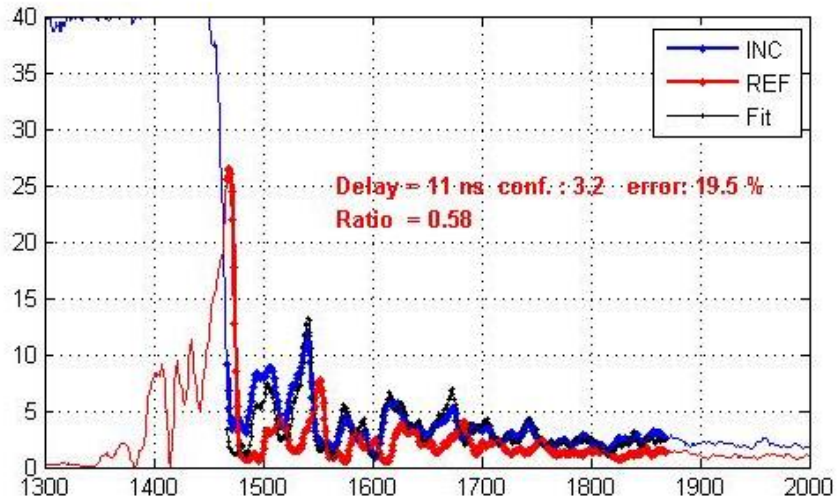


- **Transmitted power drops**
- **Reflected power increases**

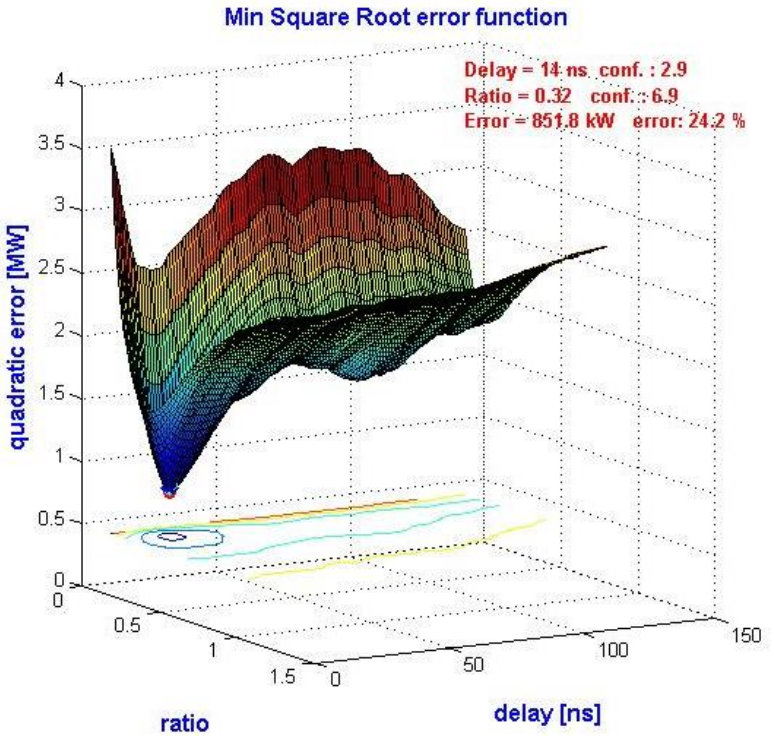
- **Faraday cup voltages are saturated**
  - typical dark current ~ mA (on FC1 at 0.4m from output coupler)
  - during BD 100-1000x increase in charge emitted

- **To find the BD cell location**
  - We can use the **difference in time** between the TRA power drop and the REF power increase;
  - **the phase information** is used to pinpoint cell location.

BD location: REF – INC delay



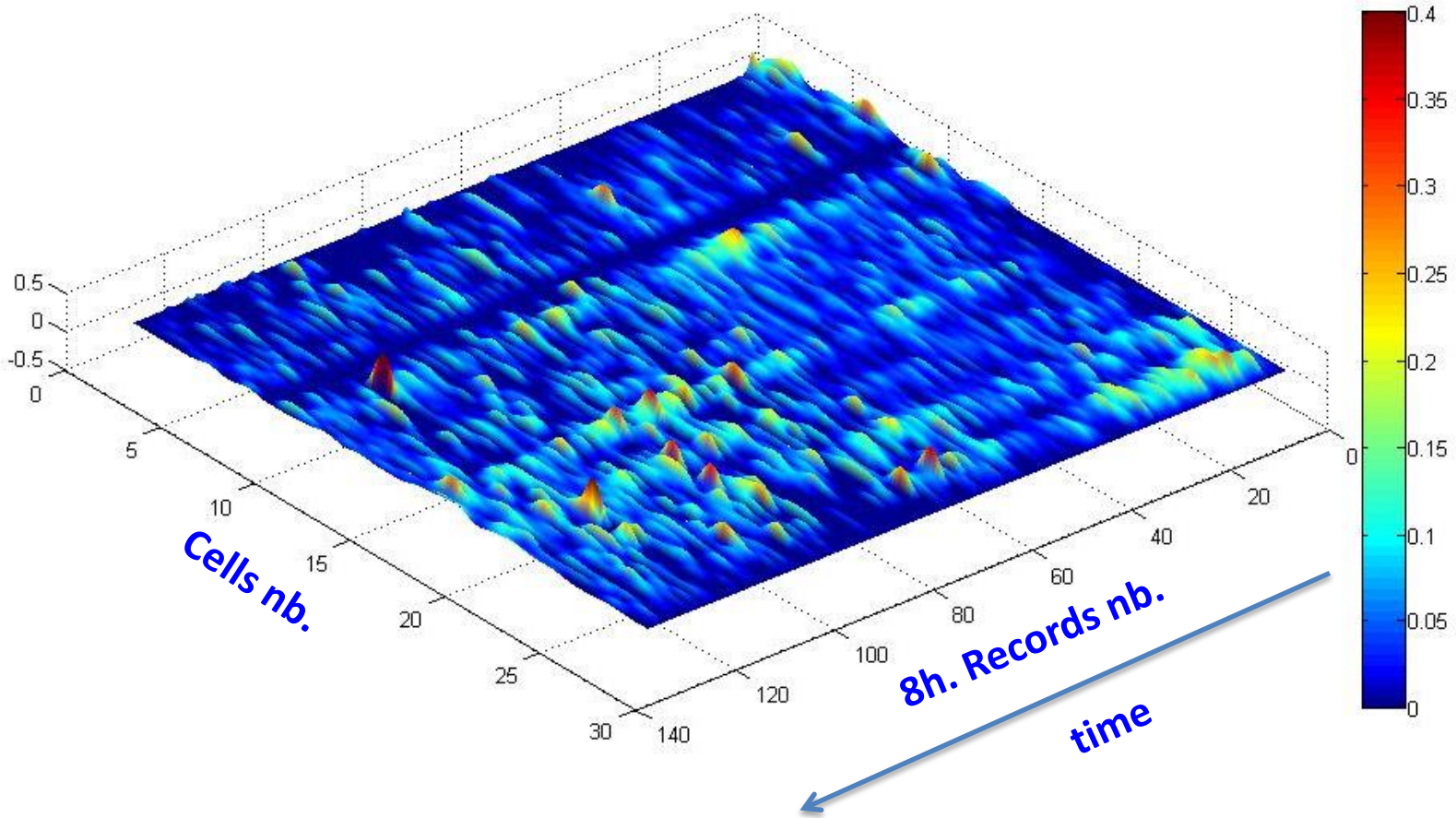
INC and REF signals and best fit of REF on INC obtained for a delay of 11 ns and a ratio of 0.58



Test method to derive best fit parameters

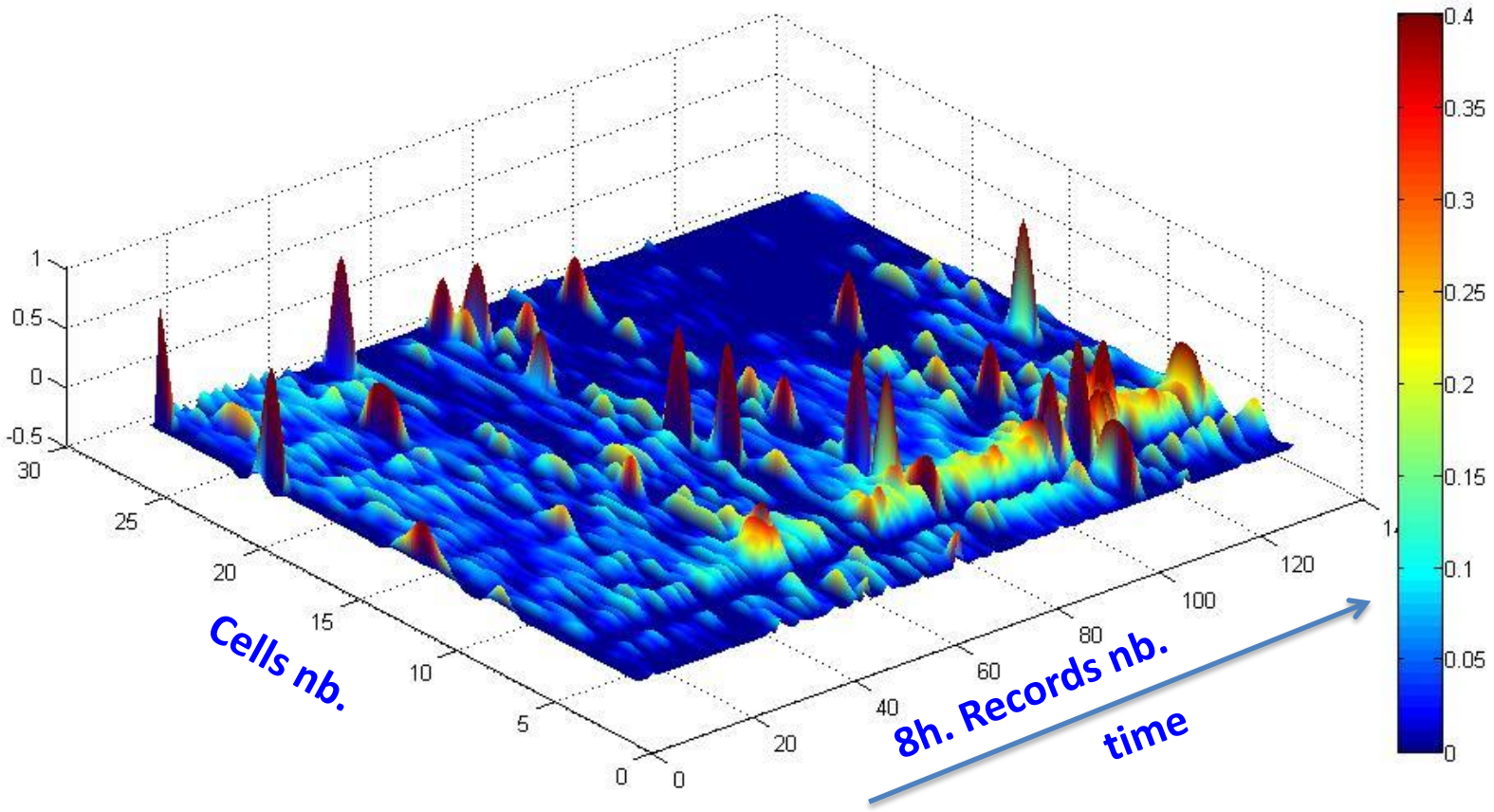
- The structure of the signal in INC power during the pulse tail allows to correlate accurately with the REF signal
- This method allows to precisely subtract the INC phase from the REF phase and also to locate the BD cell (echo method).

TD26R05CC normalized BD distribution



Corrupted files and no powered periods have been removed from the record

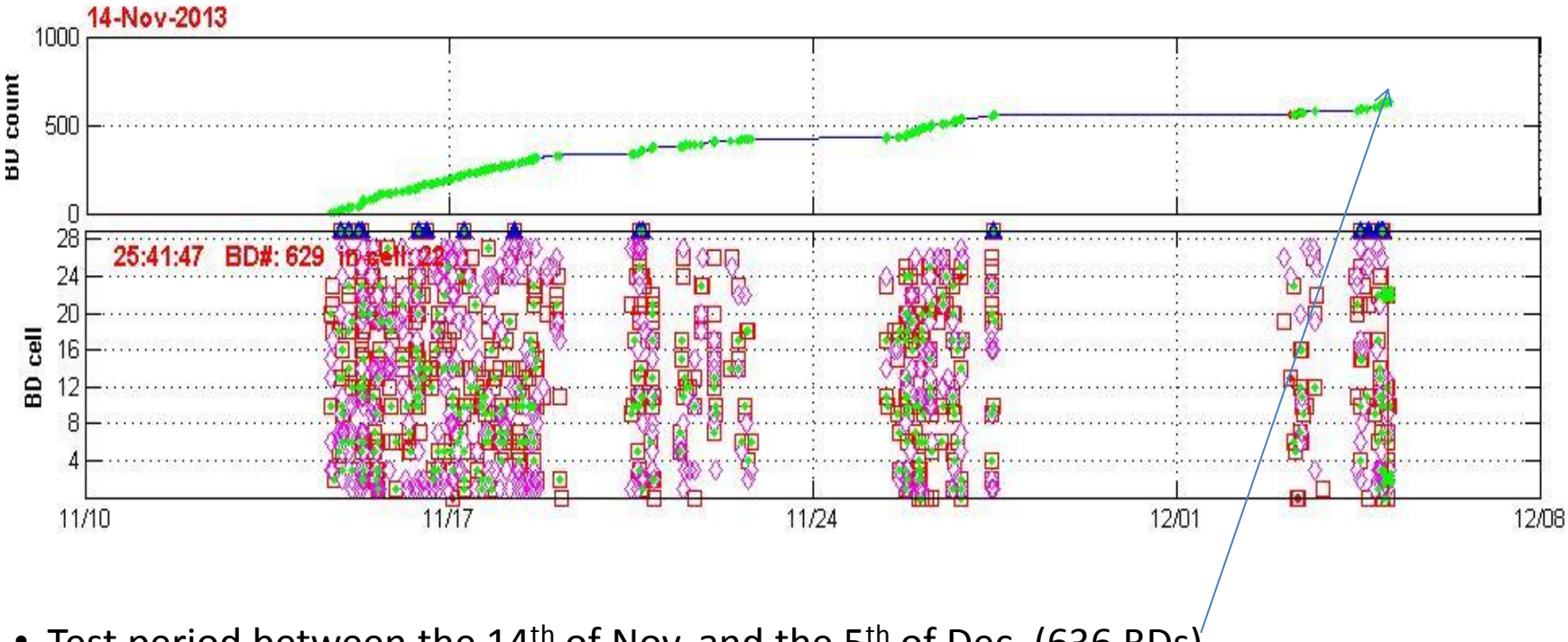
TD24R05 normalized BD distribution



Hot cells (5 and 6) have appeared from record #50

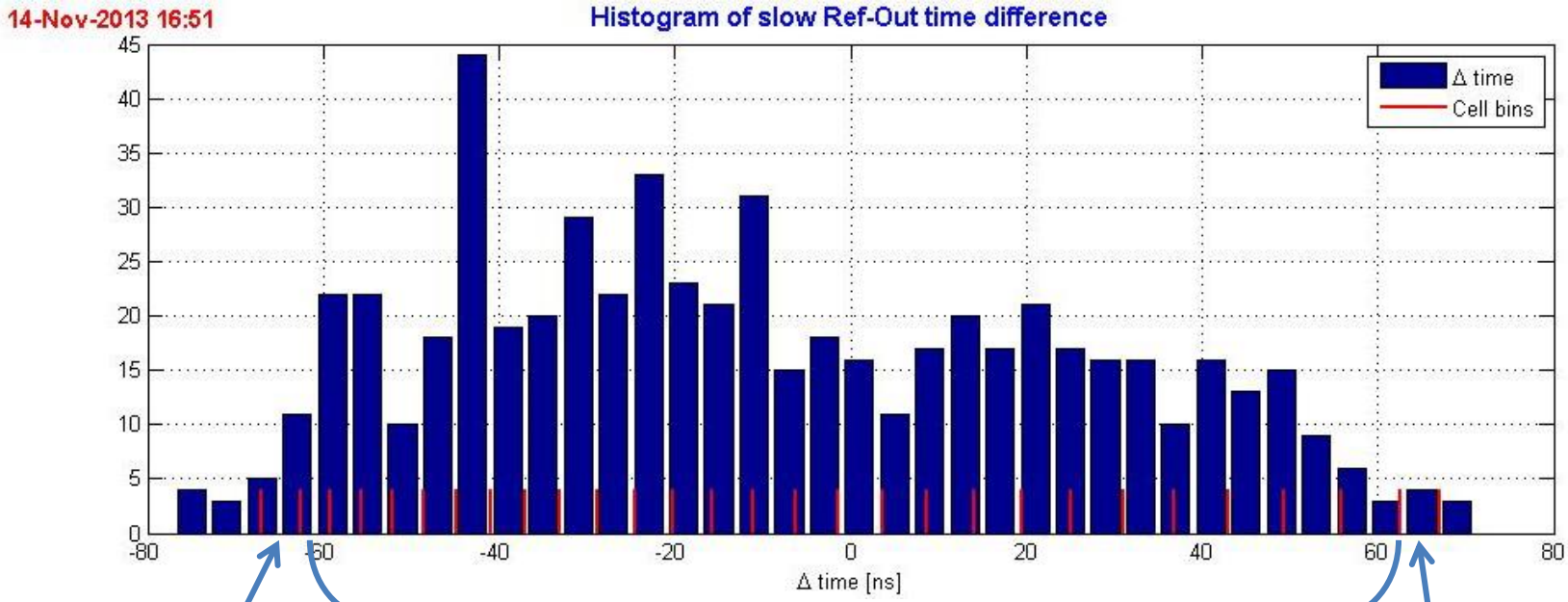
The very high peak values are an artifact of the normalization (if only 2 BDs during a record these cells will result very active)

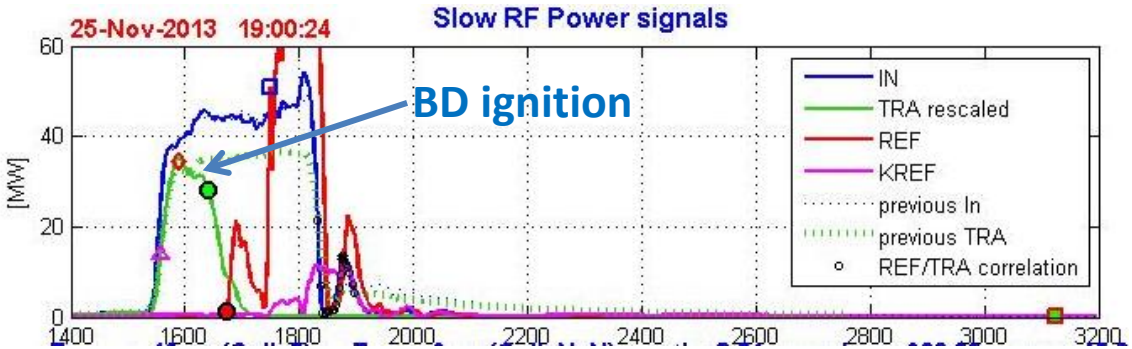
270 ns pulse length period (636 BDs)



- Test period between the 14th of Nov. and the 5th of Dec. (636 BDs)
- Pulse length 270 ns (at 90% of peak power)

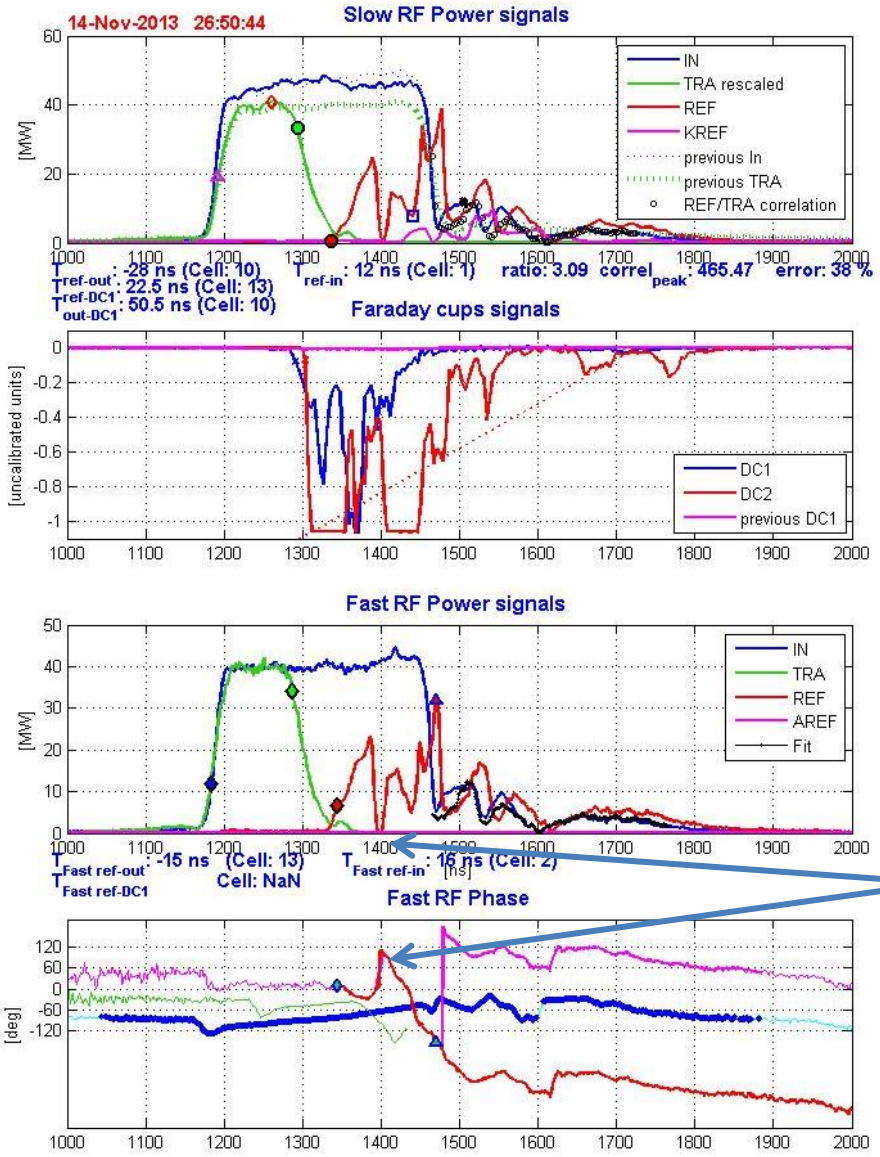
REF – TRA edges time difference

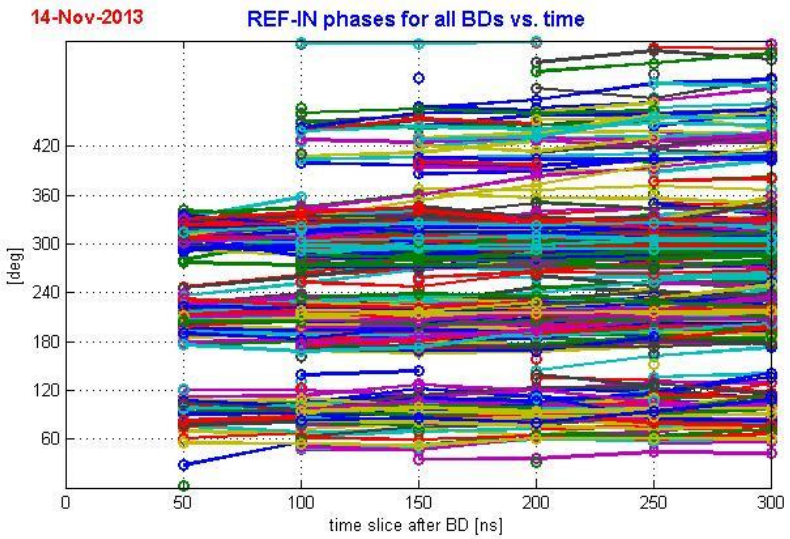




Despite difficulties to determine edges, the delays range is consistent with cell bins.

RF Phase analysis



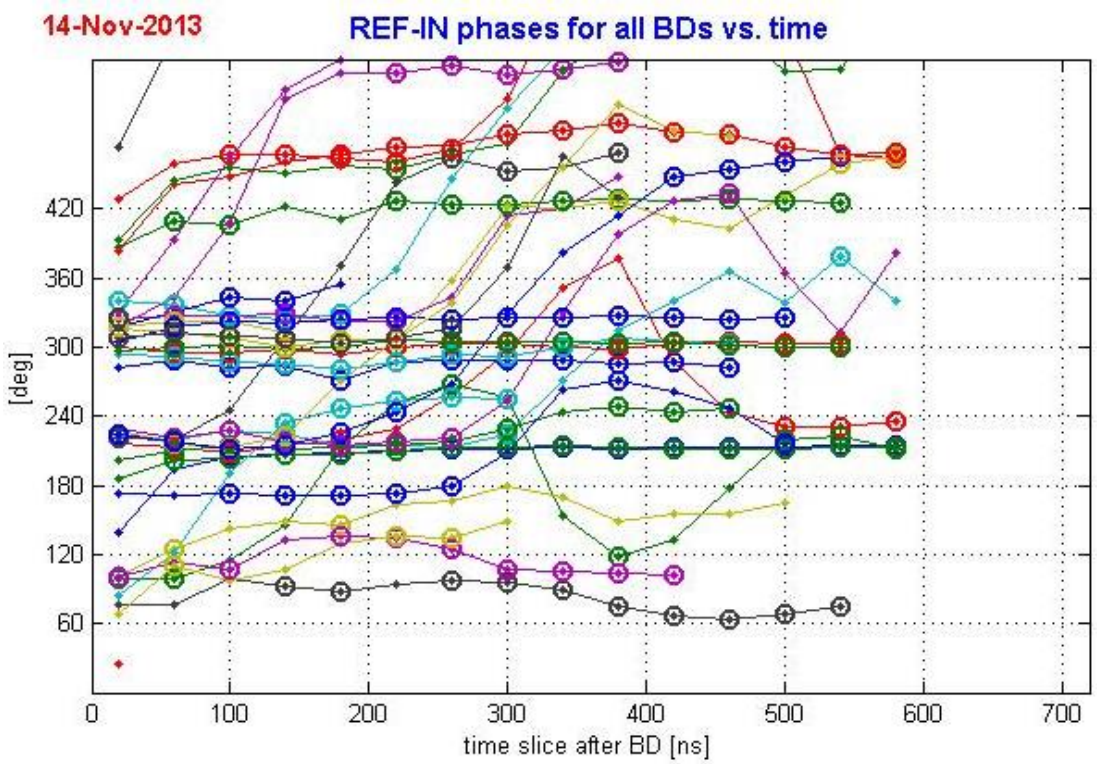


Reflected phase are grouped and separated by $2\pi/3$

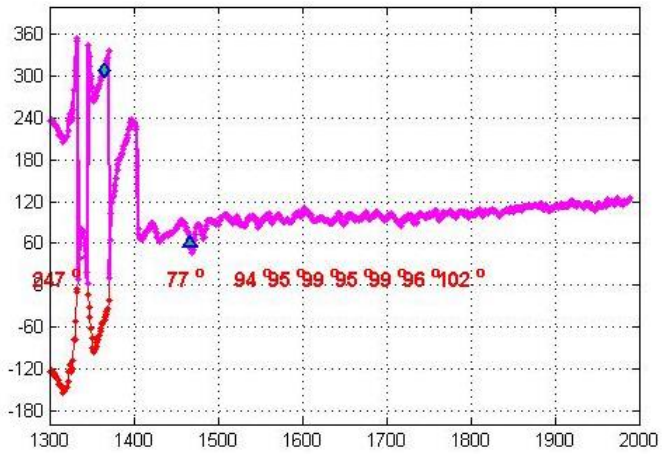
About 25% of BDs see a drift in position:

- Notch in the Reflected signals
- The overall phase change is always negative
  → BD arc is moving towards the input.

Phase evolution after INC main pulse



Phase evolution for many BDs

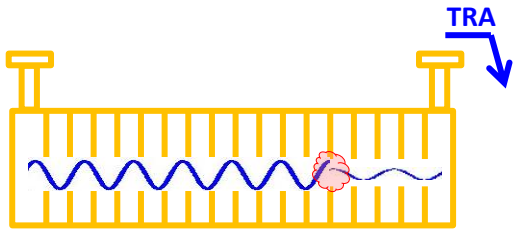


Example of phase signal after BD

- Slices of 40 ns are used to determine a series of mean phases after the INC main pulse for each BD (small dots marked curves)
- Stable phase (stand. dev. less than 7 deg) are kept (large circles)
- For each BD the median of stable phase slices is computed (this procedure permits to discard the fast phase shift periods)

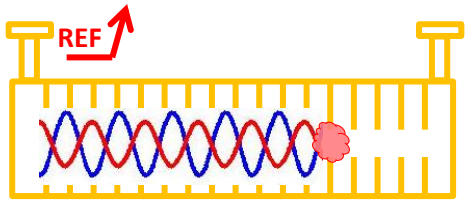
Possible explanation of the REF notches

1/



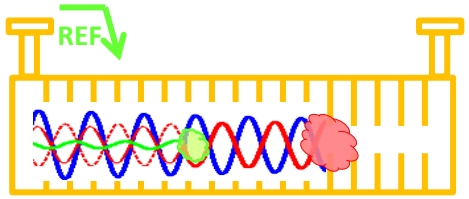
BD ignition. Plasma development. Wave absorption . TRA drops

2/



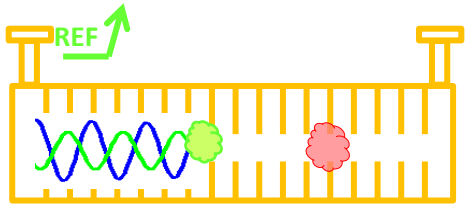
Plasma density sufficient to reflect the INC wave. REF raises

3/



Another BD appears upstream. The second reflected wave combines with the first one in power and phase and can cause destructive interference.

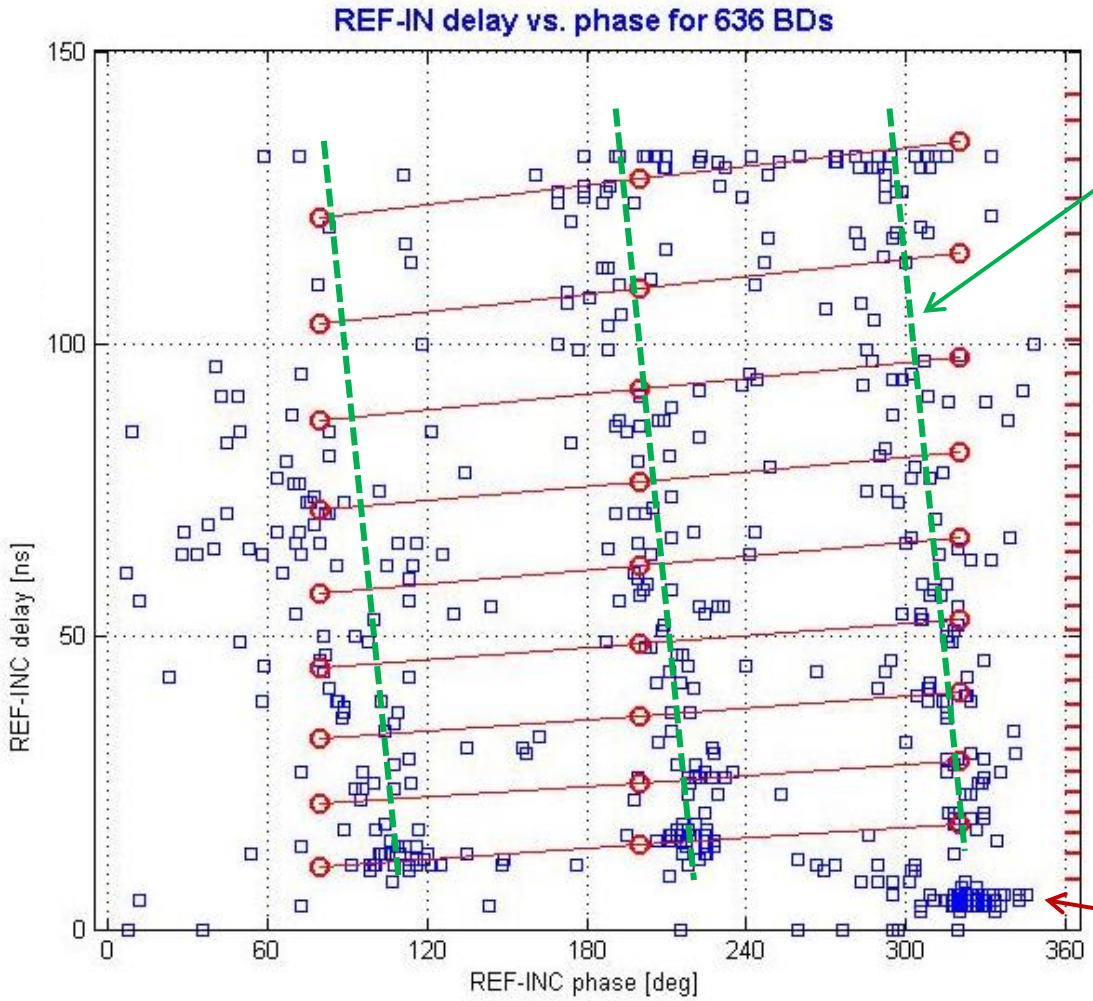
4/



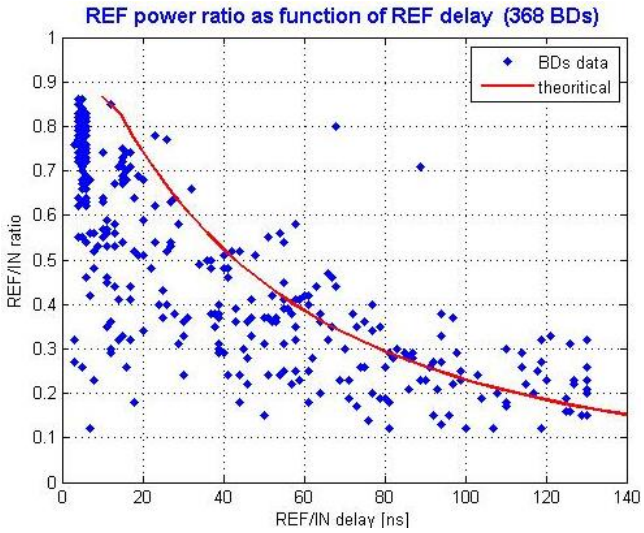
The upstream BD plasma density is sufficient to reflect the INC wave. REF raises again but with a different phase and higher amplitude.

Power is likely to be absorbed before it is reflected. This is impairing the accuracy of BD location methods based on REF_{up} – TRA_{down} thresholds

REF-INC phase vs. delay distribution

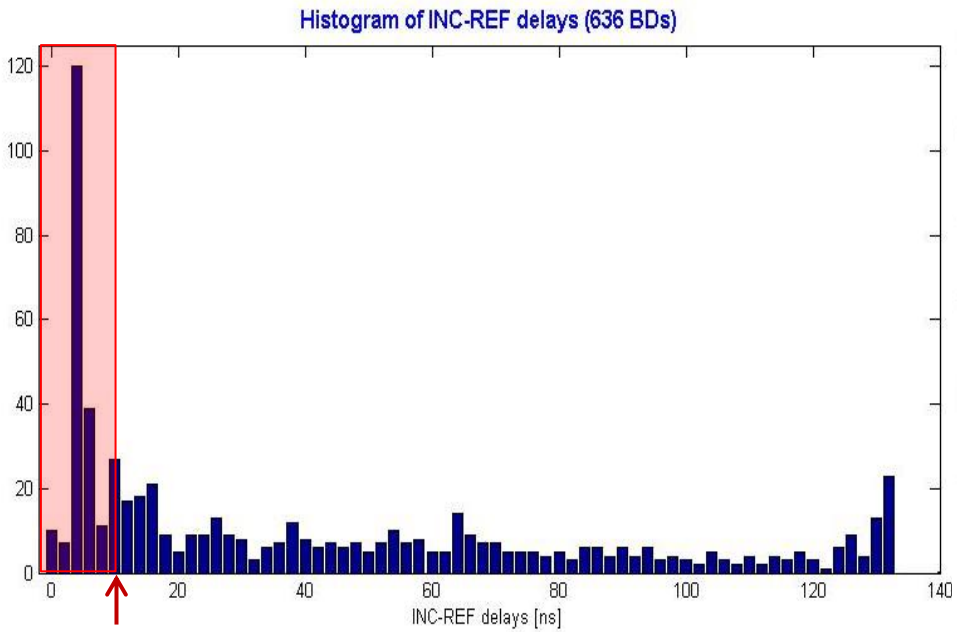


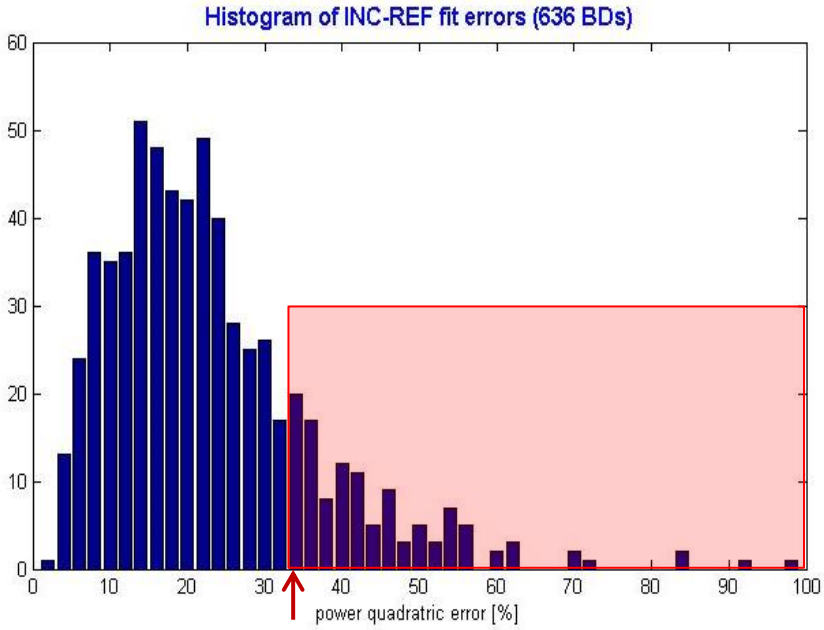
- 3 phase groups are clearly visible
- Unexplained phase drift is noticed (I/Q sensibility to signal strength ?)



- BDs outside accelerating structure

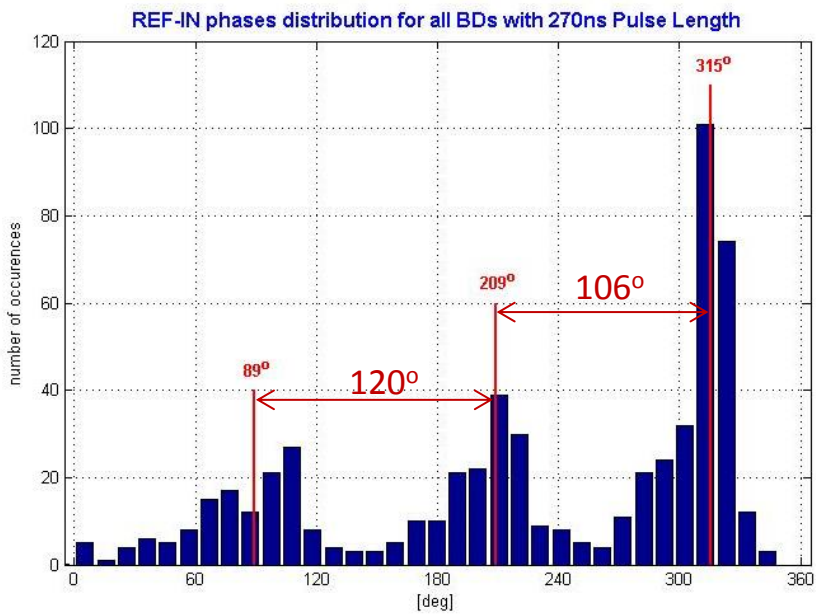
BDs screening

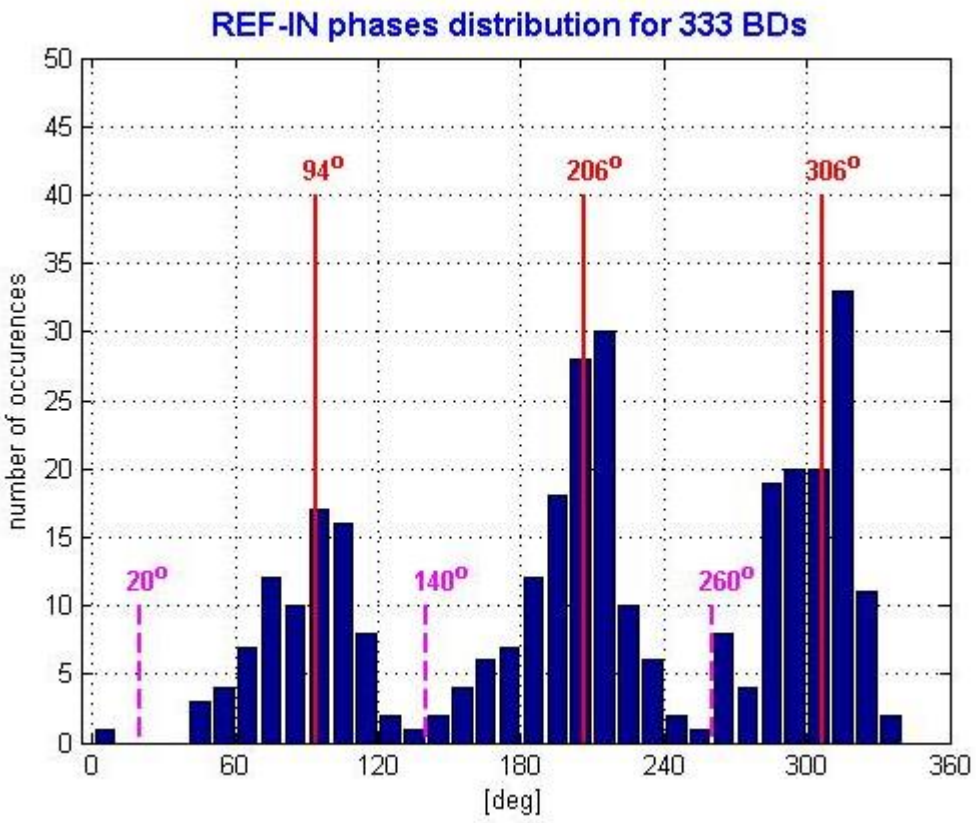




- Upon the 636 BDs
  - 183 are located in the waveguide (echo delay < 9 ns) -> discarded
  - 130 are poorly fitted (quadratic error > 33 %) -> discarded
  - 333 are kept for further analysis

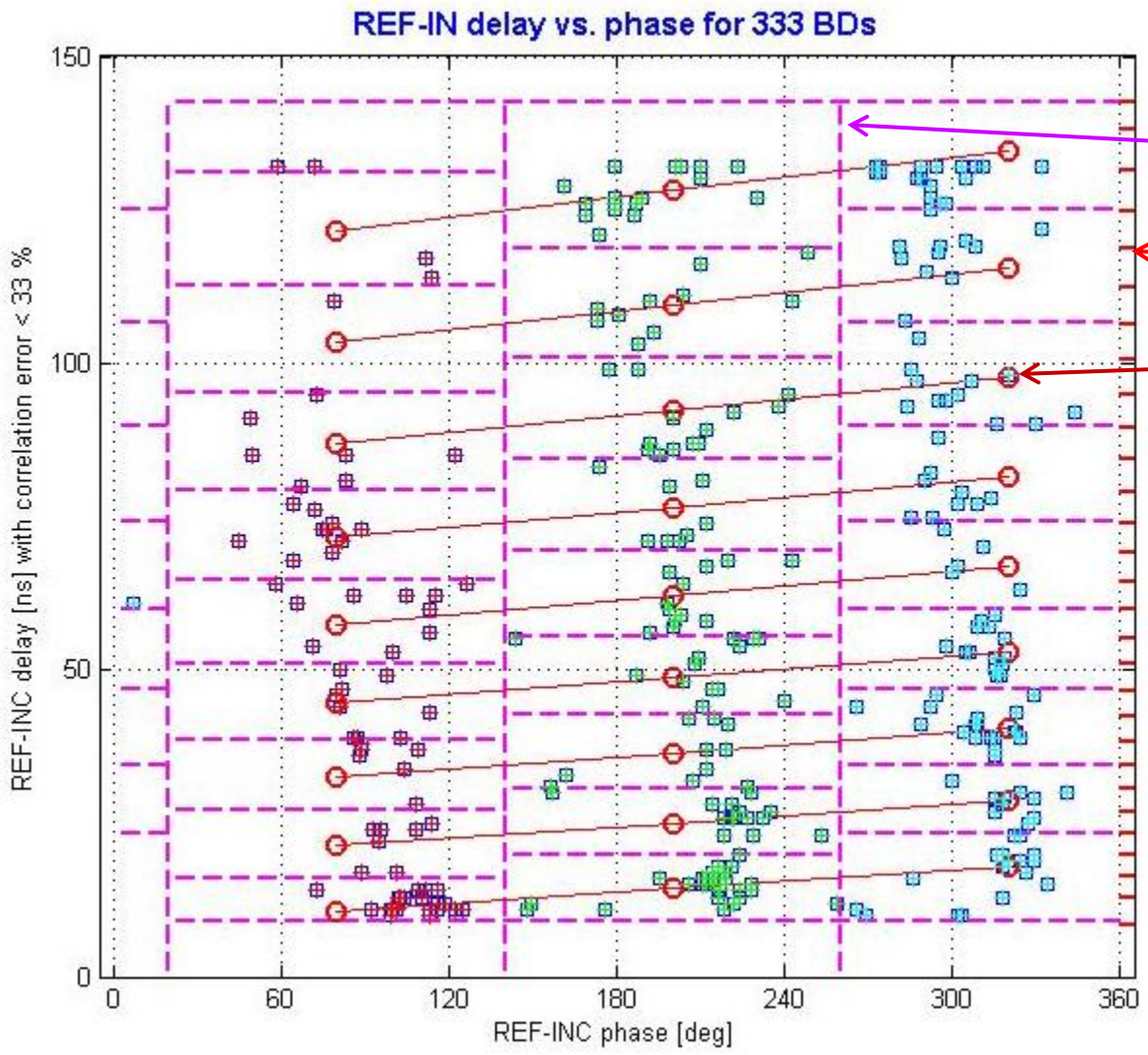
REF-INC phase distribution after screening



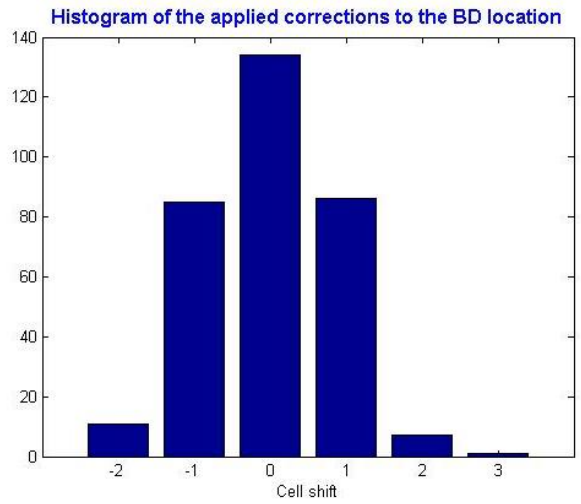


- Means are computed on each phase group delimited by minimum phase occurrence.

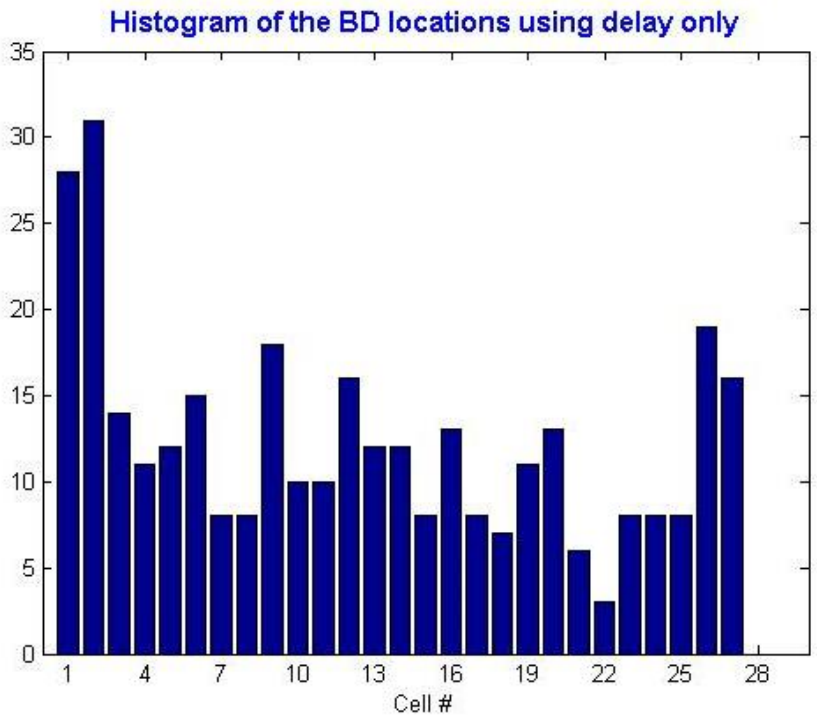
REF-INC phase vs. delay after screening



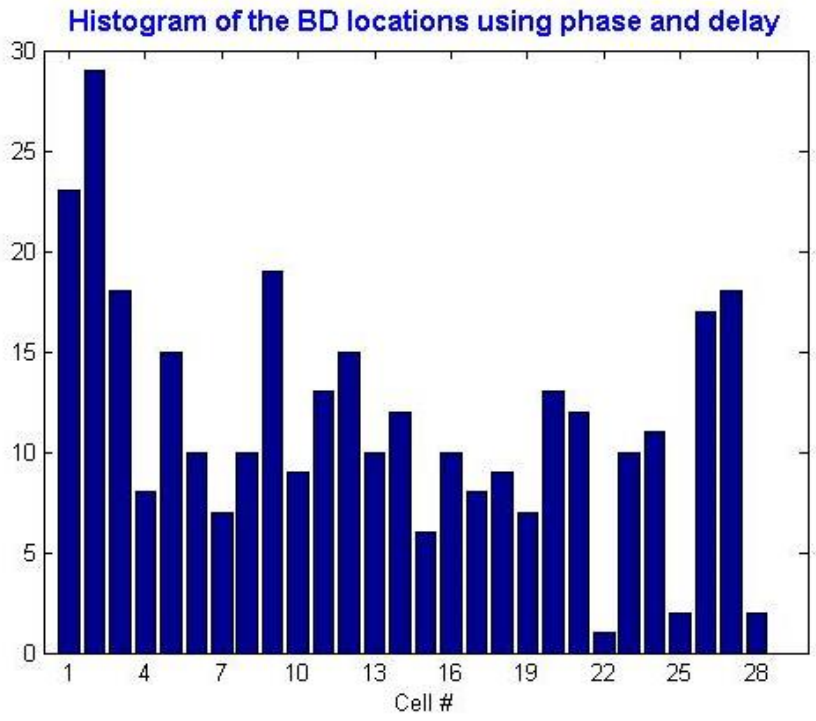
- Bins for BD location with delay and phase.
- Bins for BD location with delay only
- Cell centers delay and phase positions



Effect on BD location histogram

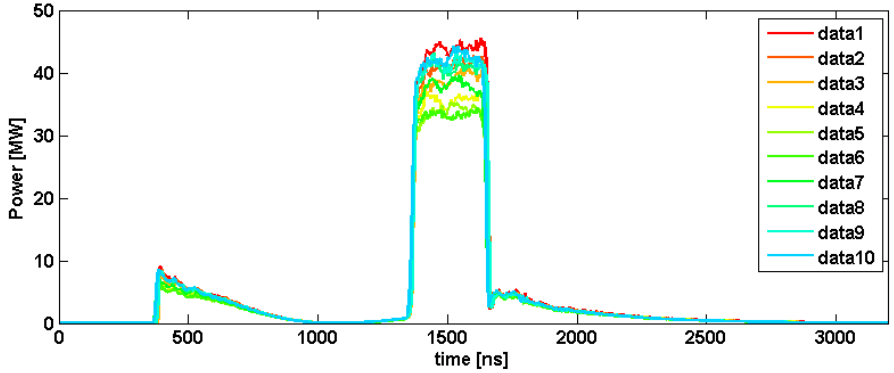


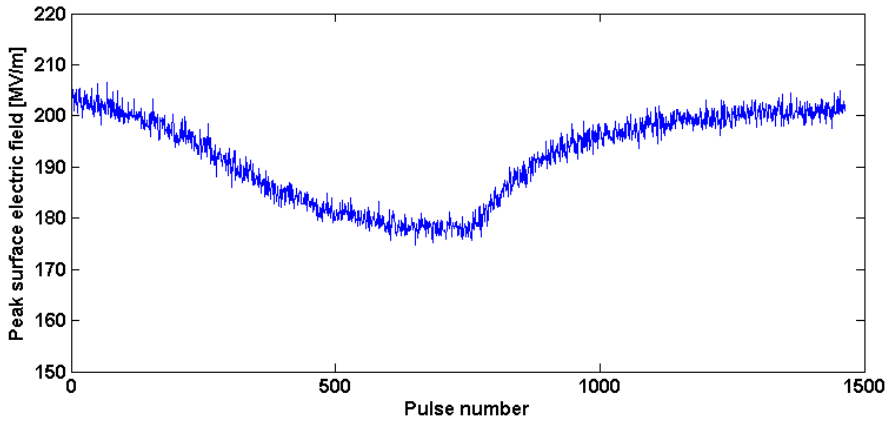
BD location histogram using delay only

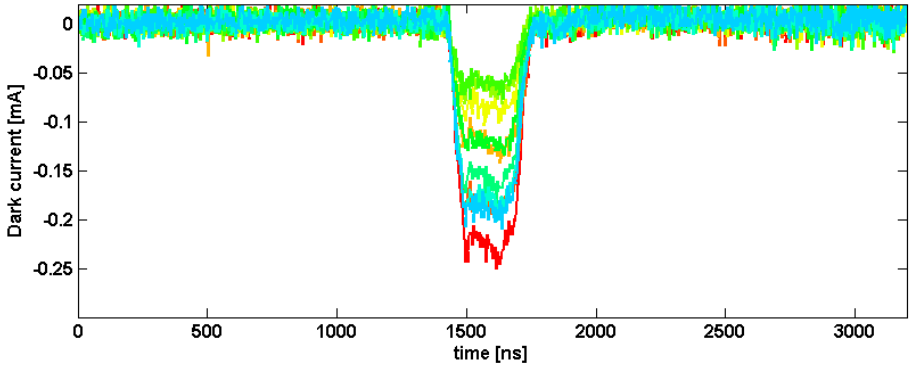


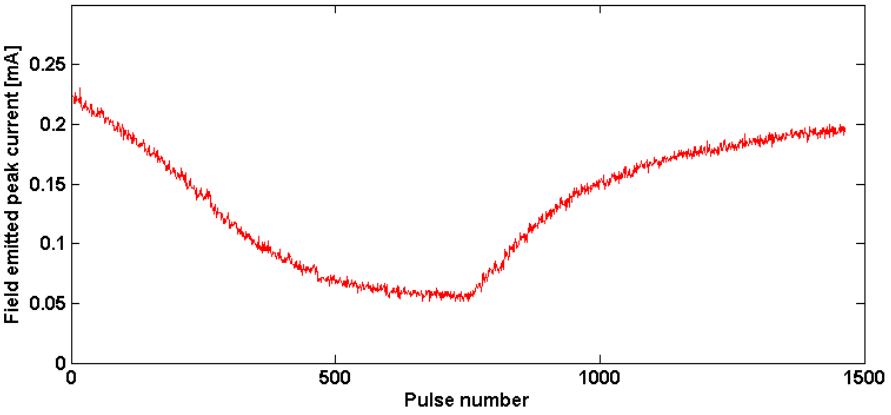
BD location histogram using delay and phase (possible 3 cells period)

Field scan every 30 minutes









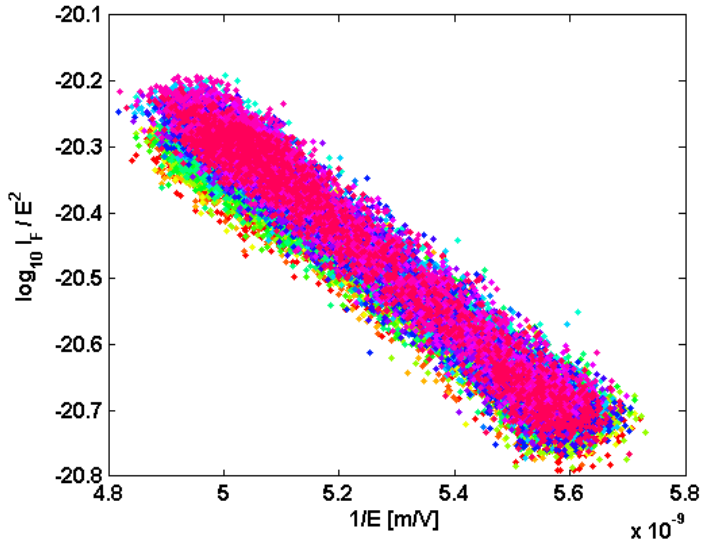
- Example of pulse shapes
- Ramp down-ramp up

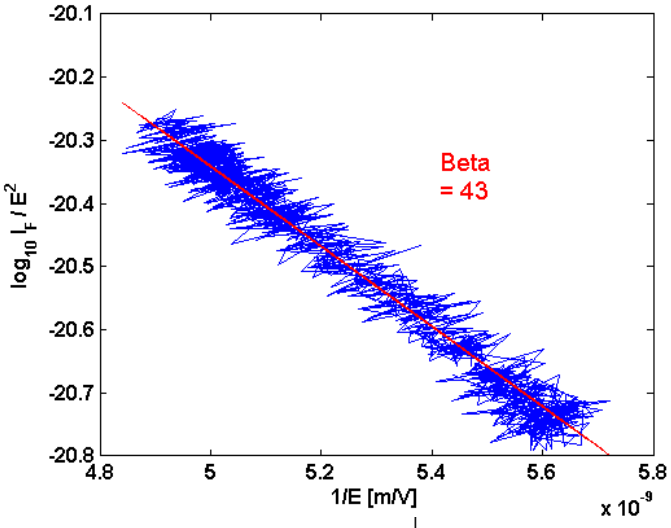
  15 s, 100% - 75% of maximum power

Peak value during flat-top as average over 20 samples

Beta monitoring during operations

- Fowler-Nordheim plots for each scan



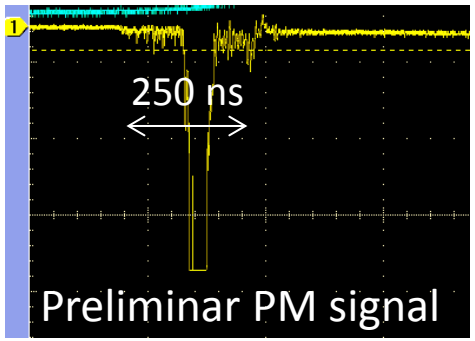


Evolution of beta value in time

beta enhancement factor ~ 40

Conclusion and further studies

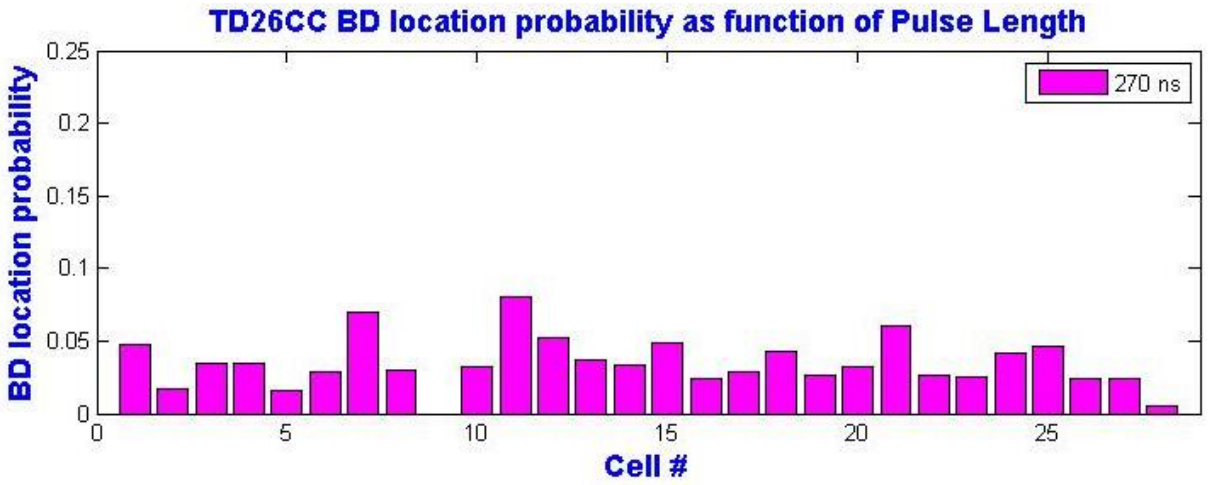
- ✓ Analysis of **BD location** by time delay and RF phase
  - TD26R05CC structure conditioned very well, no hot spot detected
  - Ref phases are grouped and separated by $2\pi/3$
- ✓ Evaluation of **Beta enhancement factor** by periodic ramping
- ✓ **New diagnostics** (and data)
  - Fast acquisition ADC for DC autocorrelation studies
  - PM for X-rays detection
  - Spectrometer for dark current energy study
- **Further studies**
  - BD ignition timing and RF phase
  - Re-calibrate powers for missing energy studies
  - Compare timings of FCU and PM
  - Study FCU upstream and downstream complete signals
  - Post-mortem analysis



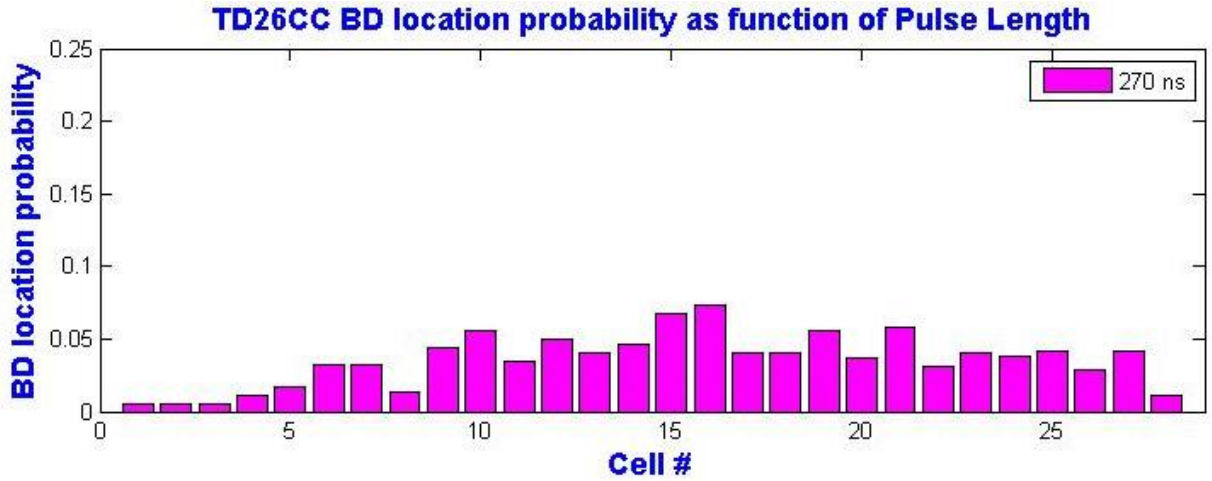
Hamamatsu R9880U-01

THANK YOU FOR YOUR ATTENTION

BD cells distribution for the 270 ns pulse

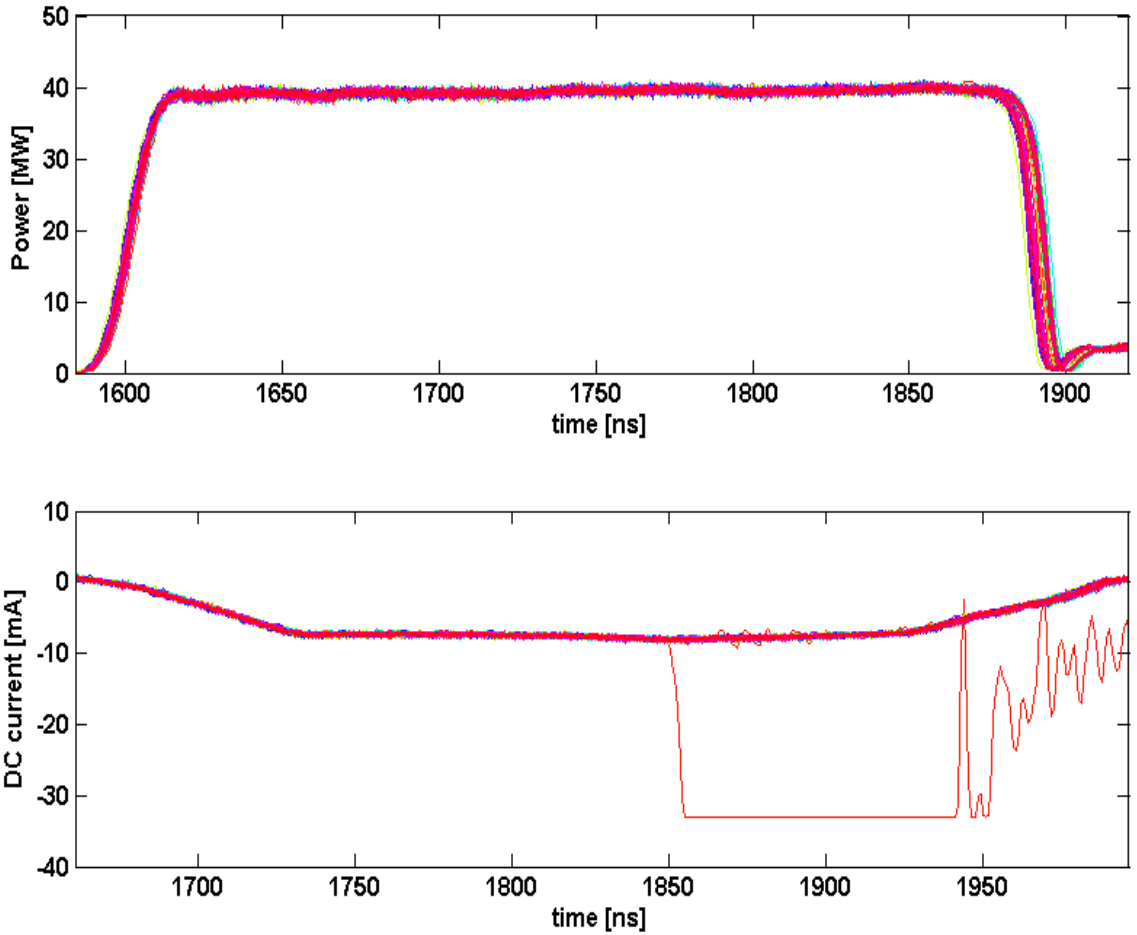


With slow signal (4 ns sampling rate)



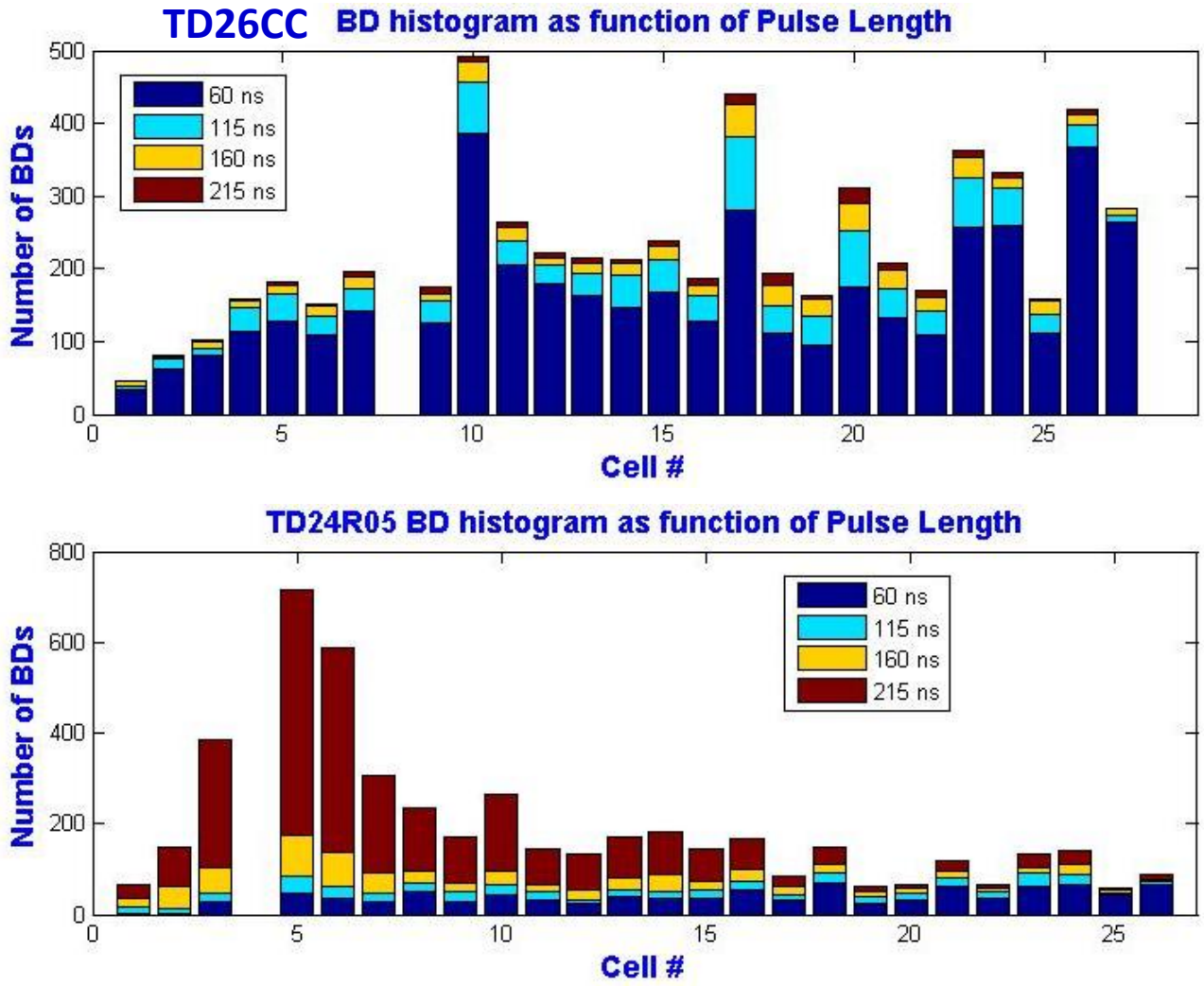
With fast signal (1 ns sampling rate)

Fast data for DC autocorrelation studies



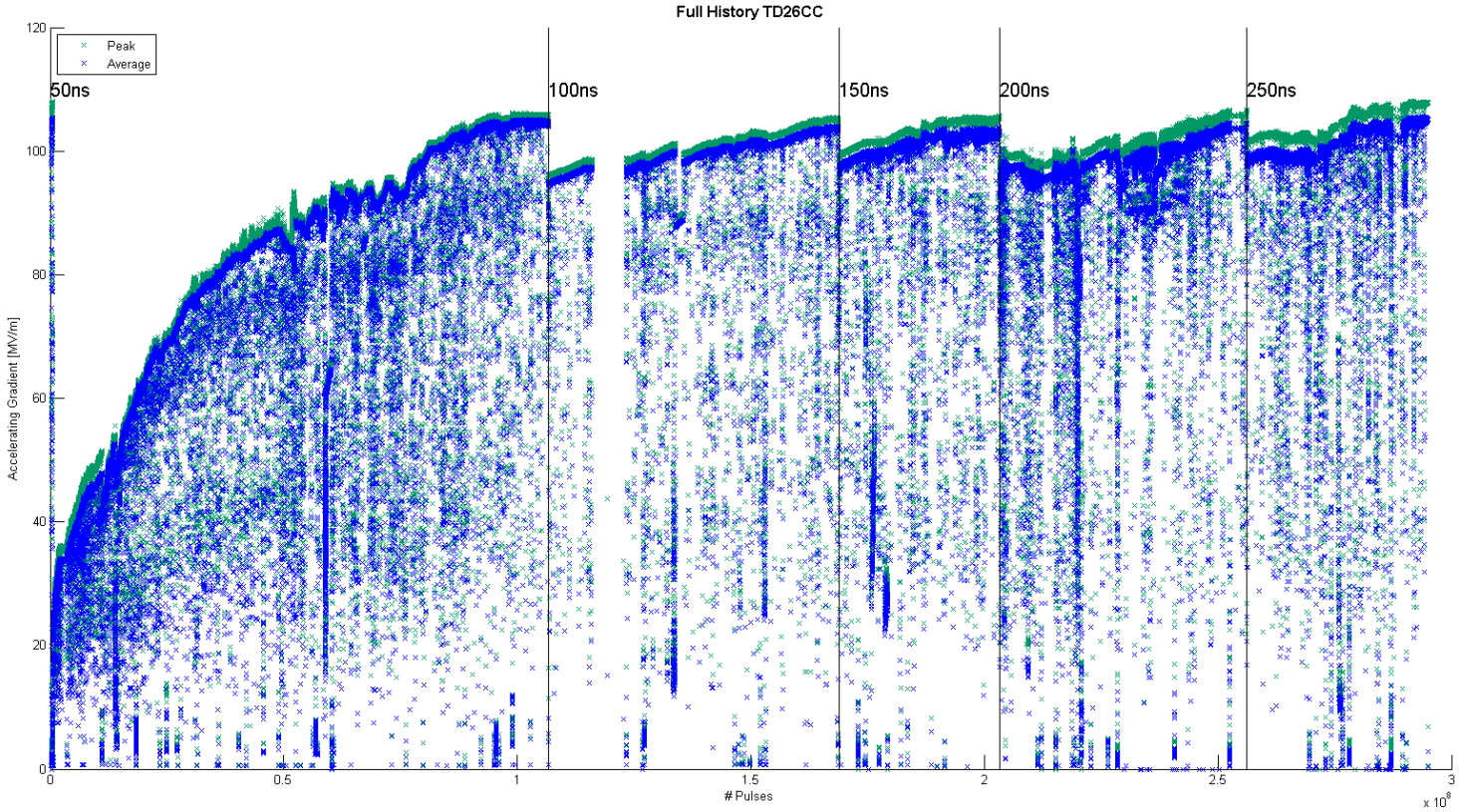
sampling rate:
1.25 Gs/s

Histogram of the BD vs. Cells

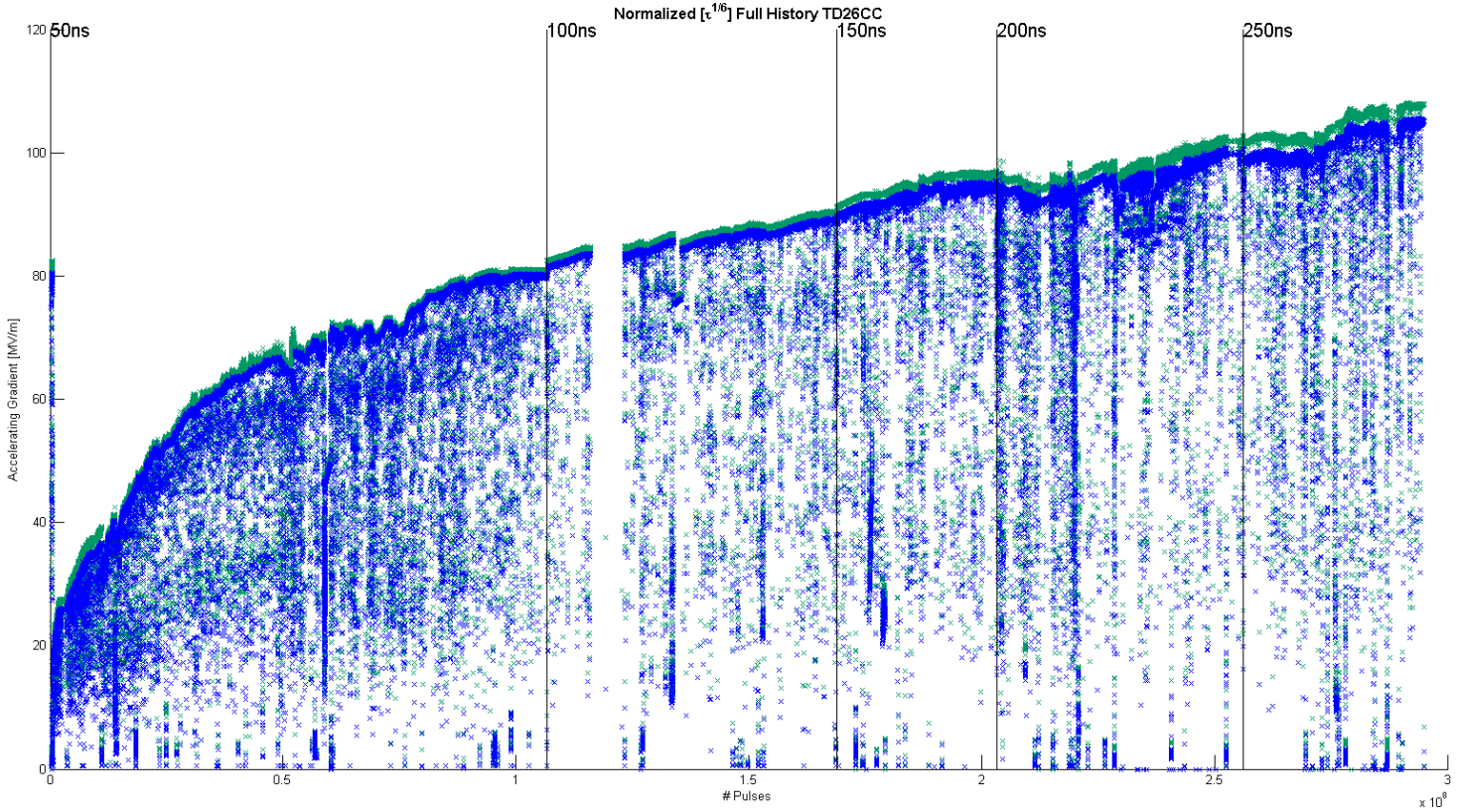


For TD24R05, BDs in Cells 5 and 6 have raised from the 160 ns pulse length test period and continue to show excess of BDs at 215 ns

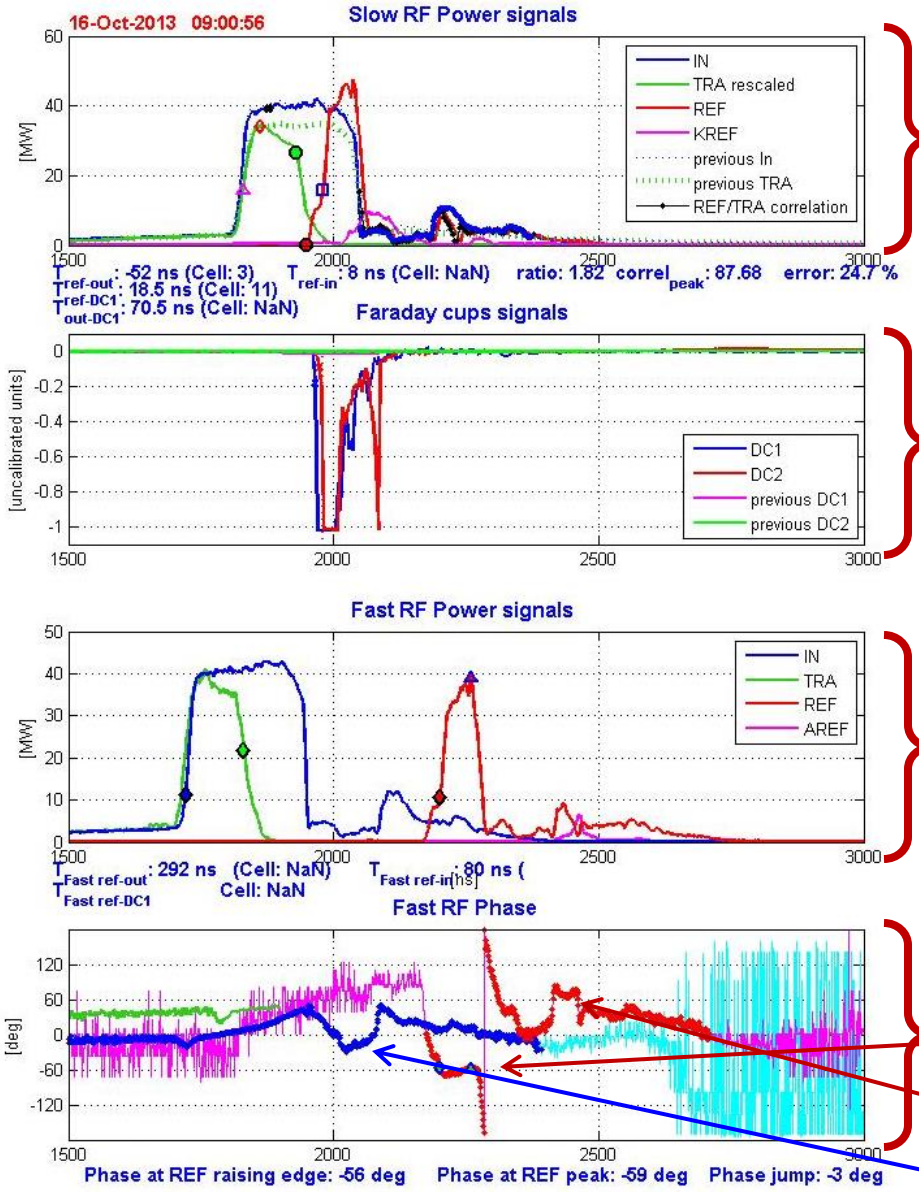
Conditioning history plot



Conditioning history plot – normalized t^1/6



RF signals BD# 01



Slow signals (4 ns on Log detectors) provide the BD location according to 4 various methods: (Ref/Out, Ref/FCU, Out/FCU and Ref/In)

FCU signals are saturated during real BDs, but still provide a rather accurate BD time (flying time to the FCU is small for relativistic electrons compared to RF group delay in the structure)

Fast signals (1ns on I/Q) are still not usable for BD location due to a trigger problem (under investigation)

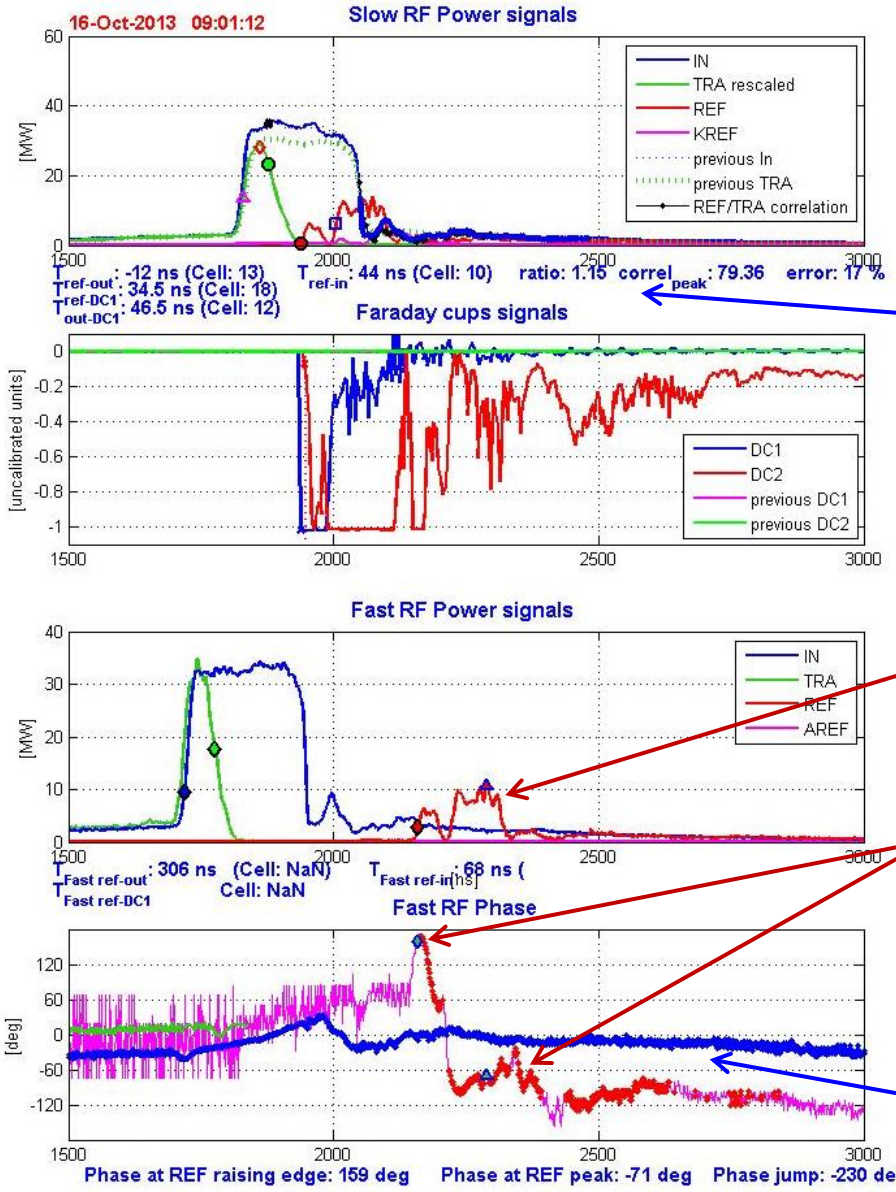
Fast signals provide phase information

REF phase: -60° from raising edge to peak

REF phase: ~ +60° on the trailing tail

INC phase: slowly raising during the pulse, than fluctuating during the trailing tail

RF signals BD# 02



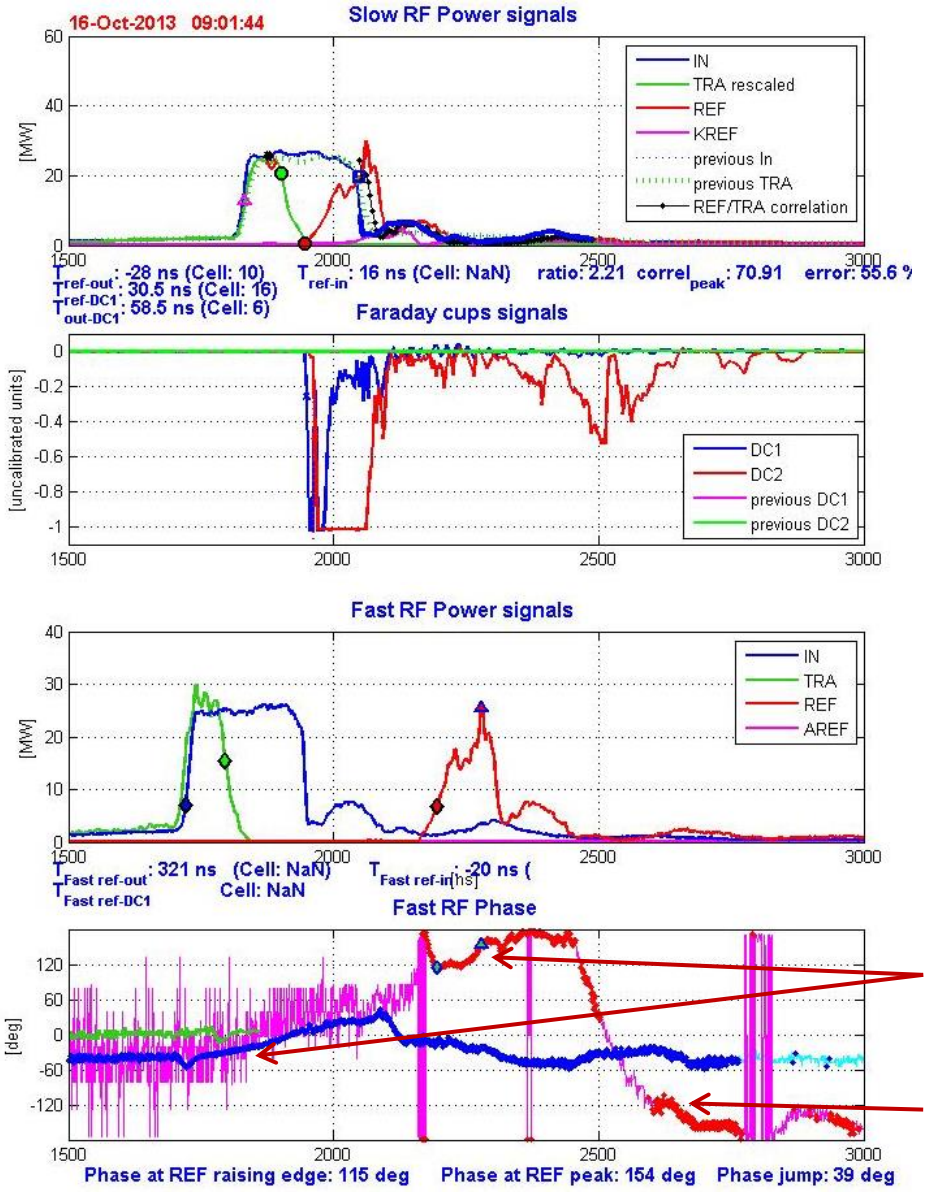
REF/Out and REF/IN methods seems to indicate a BD location drift from BD burst to BD end

REF pulse is split in 2 parts that shows 2 different phases

Phase drifts about 240^{o} from raising edge to peak REF (1st and 2nd REF pulses).

Accurate REF phase measurement should take into account the INC phase fluctuation, but delay to be determined according to BD location

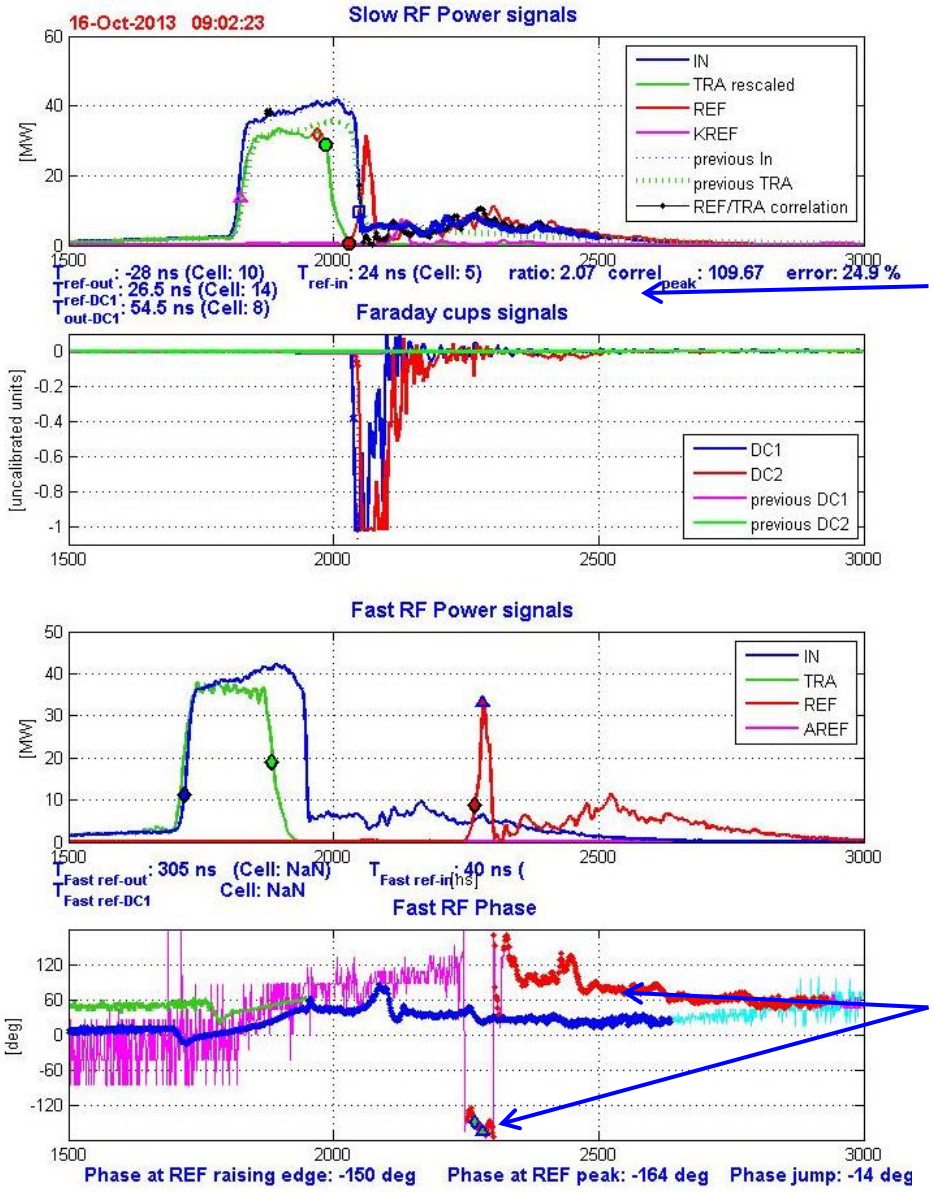
RF signals BD# 04



Stable RF phase if we consider the INC phase drift.

Then phase jumps about 300°

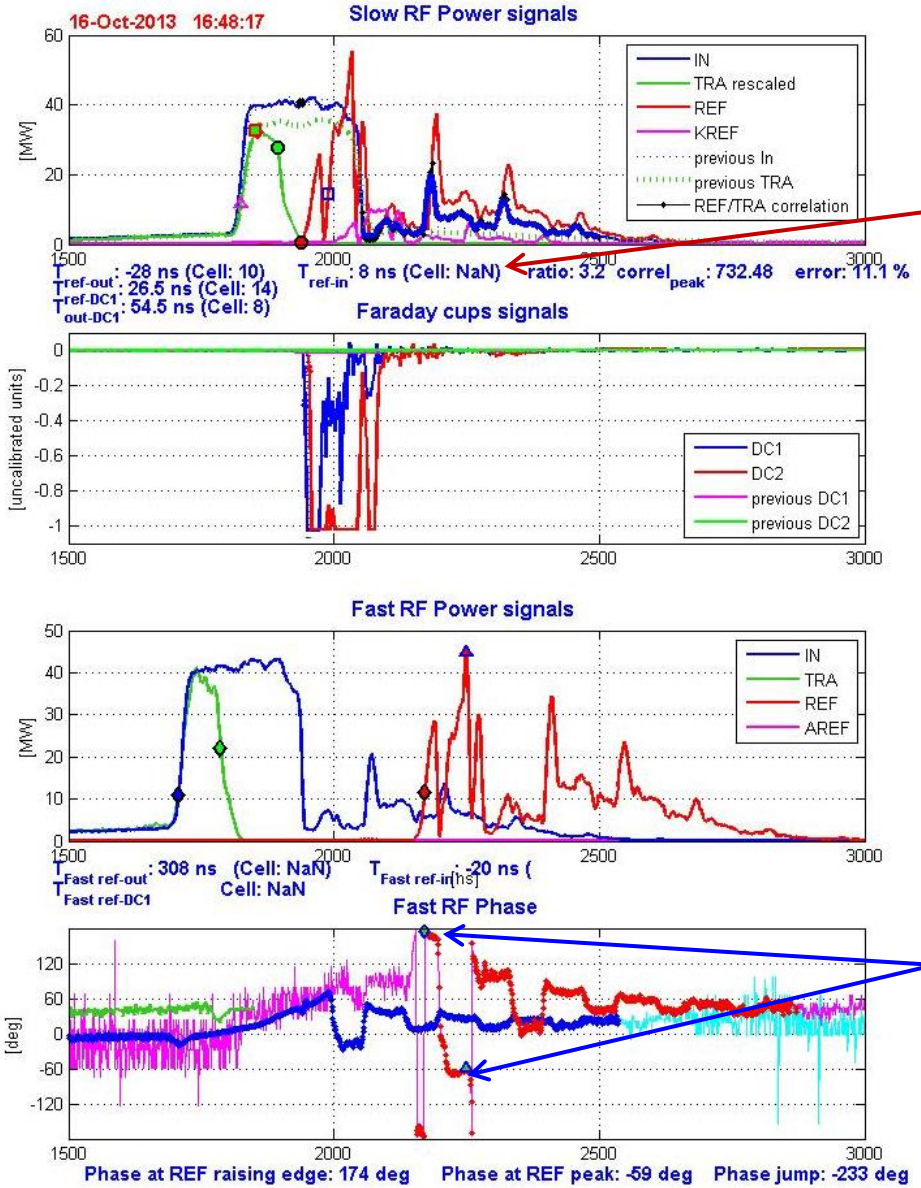
RF signals BD# 05



REF/Out and REF/IN methods : BD location drifts

REF phase jumps about 240°

RF signals BD# 35

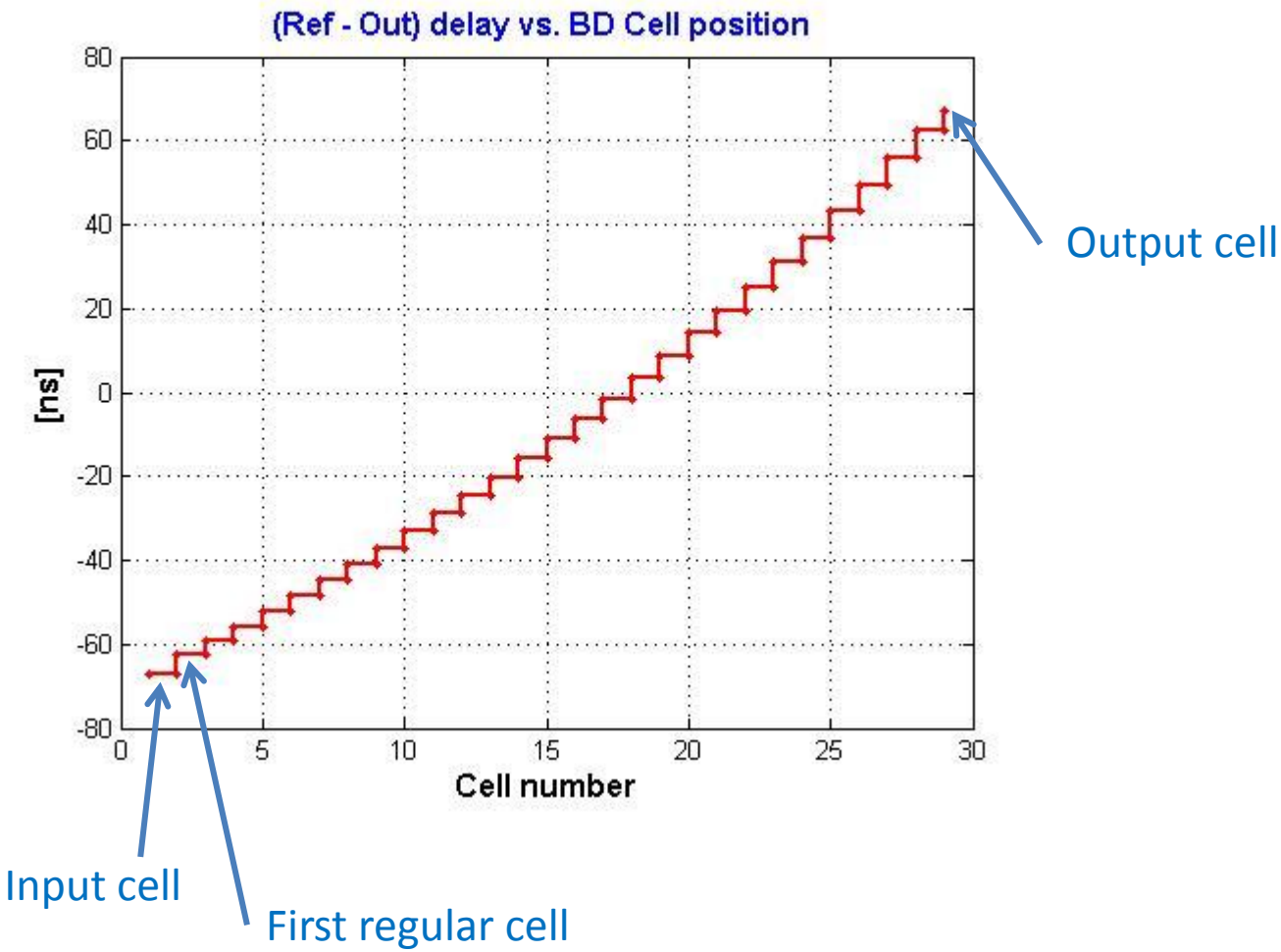


BD location drifts

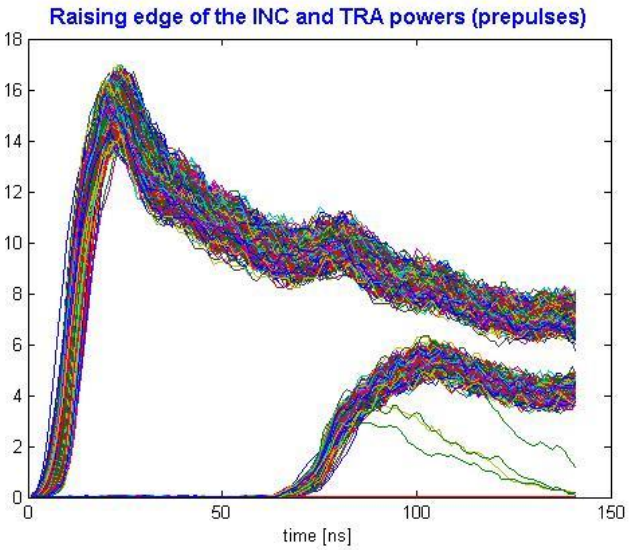
REF phase jump of 240°

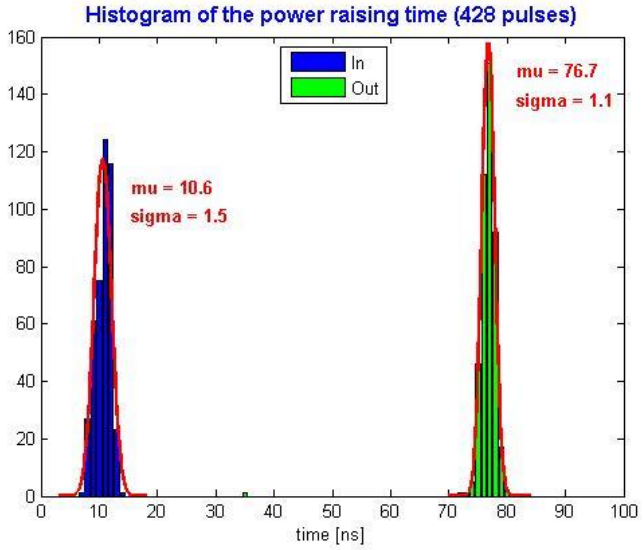
Followed by many other REF jumps probably linked to INC phase and amplitude jumps

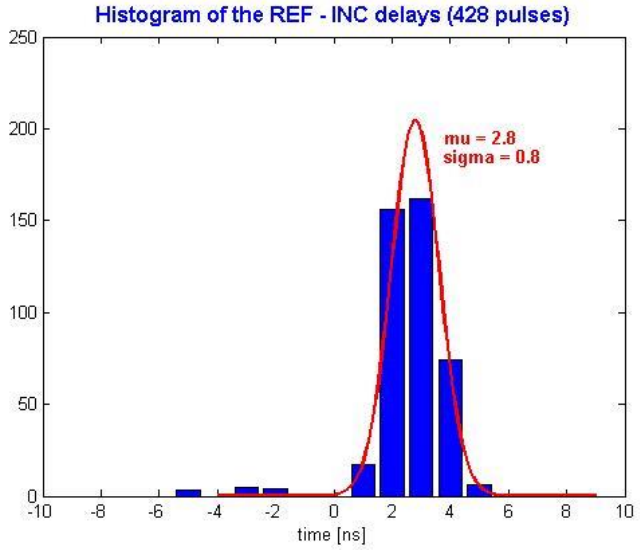
REF – TRA BDs edges delays for TD26CC

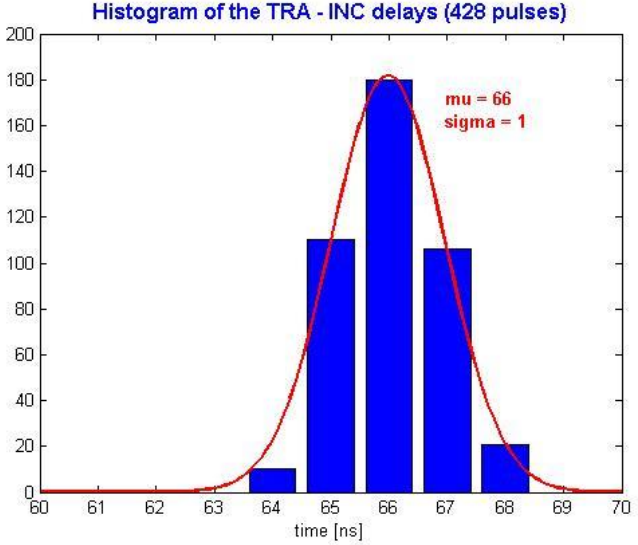


Accuracy of the delay measurement





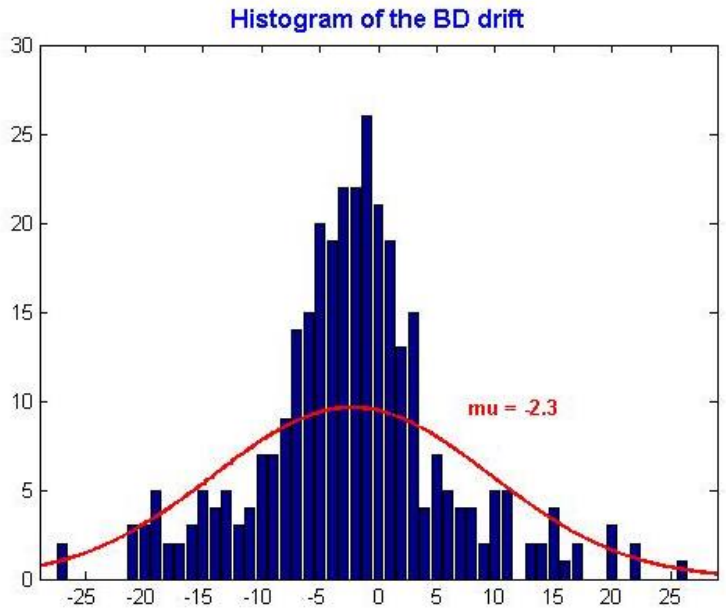


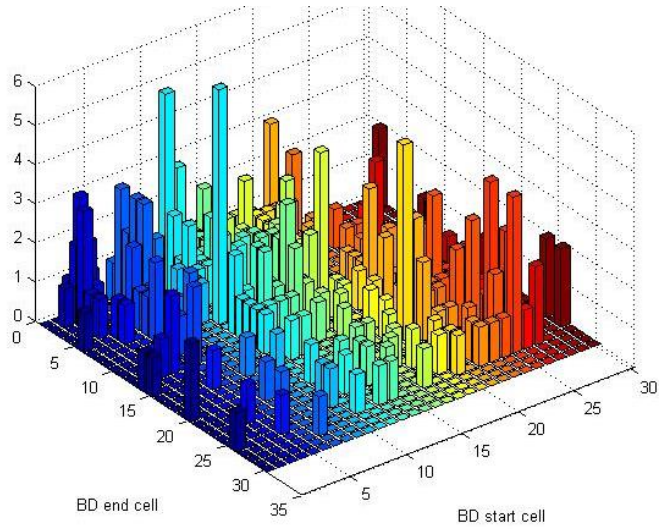


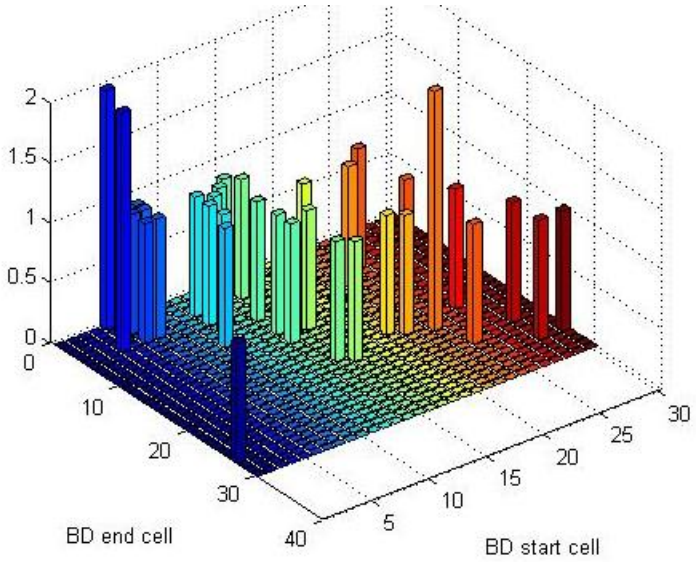
Very low sampling jitter (σ = 1 ns)

Measured filling time 66 ns (but waveguides length is included)

Drift of the BDs







To be continued….