HIGH RF POWER TESTING FOR THE CLIC PETS - 2010

International Workshop on Linear Colliders

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with great support from the SLAC klystrons lab team:
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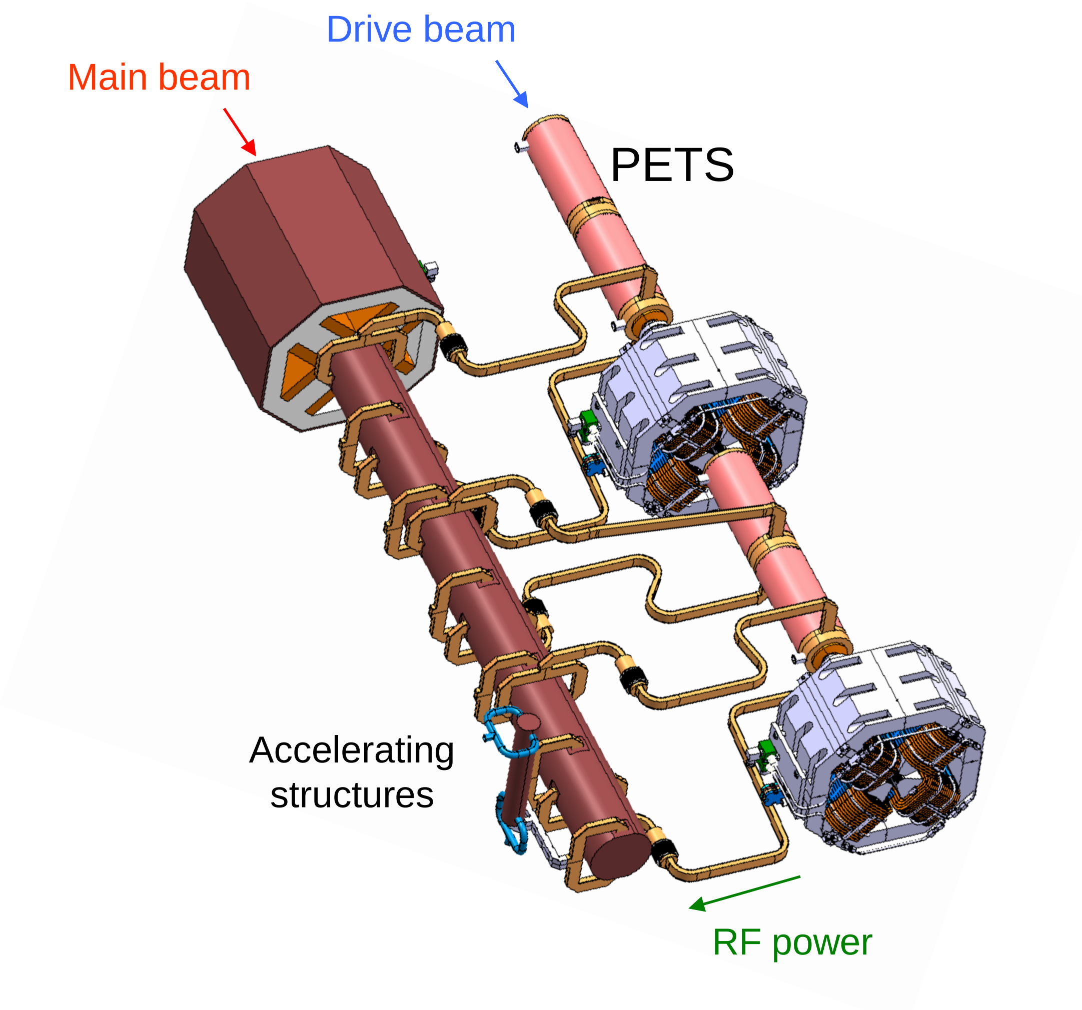
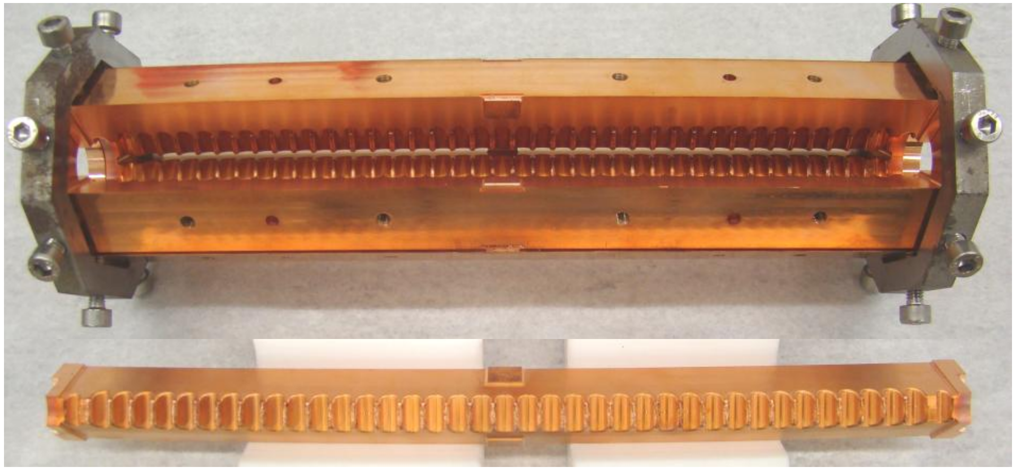
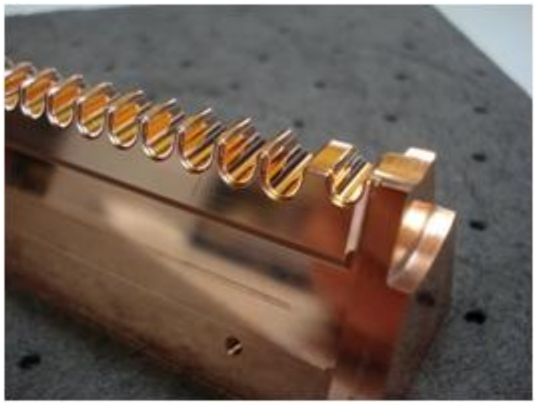
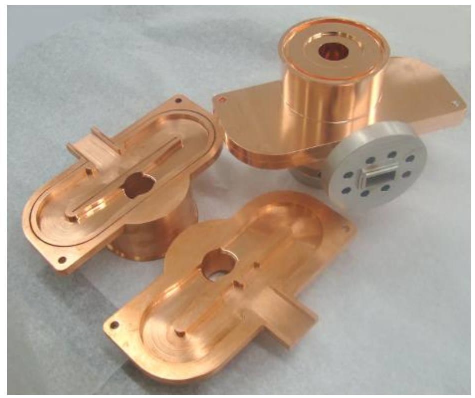
A fundamental element of the CLIC concept is two-beam acceleration, where RF power is extracted from a high-current and low-energy beam in order to accelerate the low-current main beam to high energy.

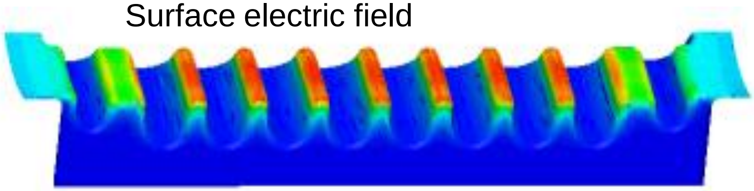




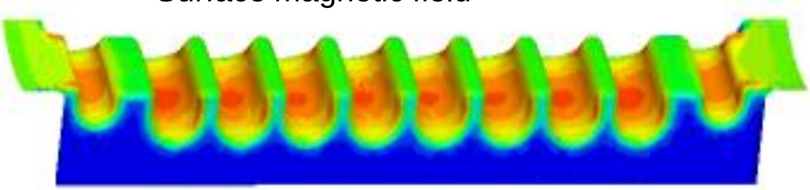




Surface electric field



Surface magnetic field



PETS specific features:

1. Big aperture, high V_g, low surface E-field
2. High peak RF power (135 MW)
3. High current (100 A)
4. HOM damping through 8 slots
5. Special coupler with choke
6. Milling technology for fabrication
7. Body assembly with clamping

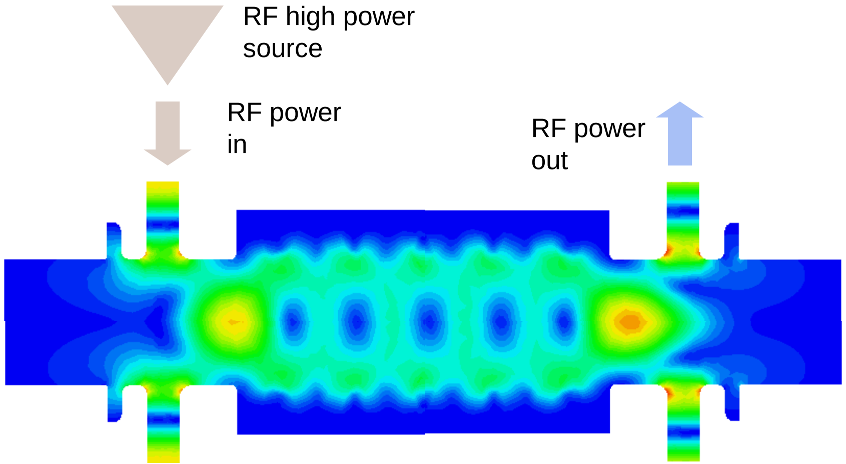
PETS parameters

- Frequency = 11.9942 GHz
- Aperture = 23 mm
- Active length = 0.213 (34 cells)
- Period = 6.253 mm (90^0/cell)
- Iris thickness = 2 mm
- Slot width = 2.2 mm
- R/Q = 2222 Ω/m
- V group= 0.459C
- Q = 7200
- E surf. (135 MW)= 56 MV/m
- H surf. (135 MW) = 0.08 MA/m (ΔT max (240 ns, Cu) = 1.8 C^0)

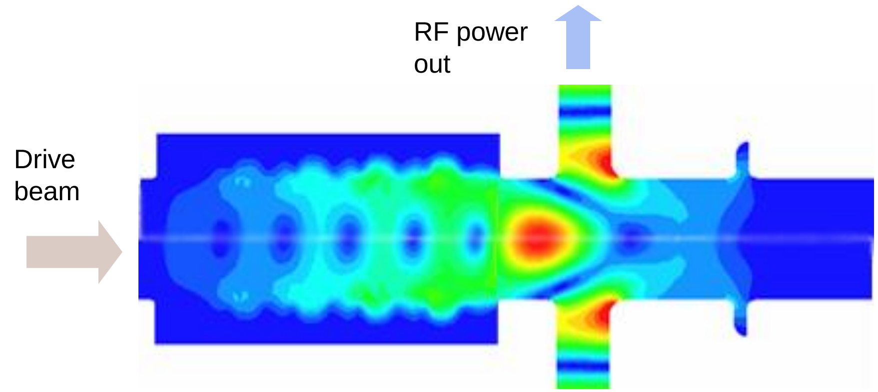
PETS testing program

RF power sources

External RF power source



Drive beam*



ASTA (SLAC)

Objective: to understand the limiting factors for the PETS ultimate performance and breakdown trip rate.

- Access to the very high power levels (300 MW) and nominal CLIC pulse length.
- High repetition rate – 60 Hz.

CTF3 (CERN + Collaborations)

Two beam test stand (CERN + Collaborations)

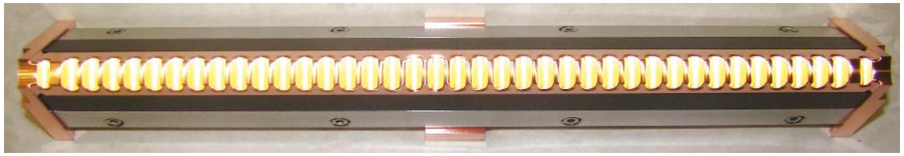
Objective: to demonstrate the reliable production of the nominal CLIC RF power level through the deceleration of the drive beam.

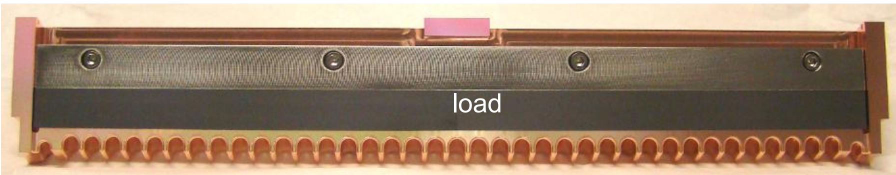
Test beam line (CERN + Collaborations)

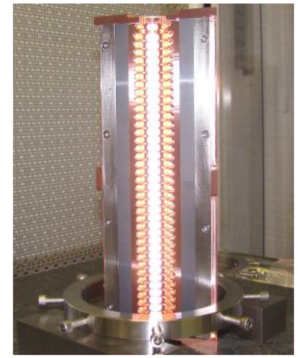
Objective: to demonstrate the stable, without losses, beam transportation in a presence of strong (50%) deceleration.

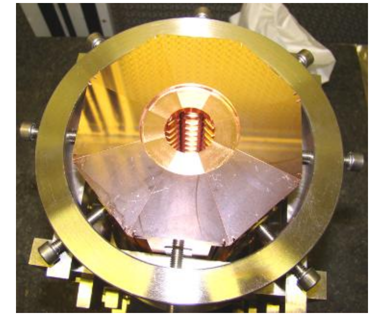
**See I. Syratchev's and E. Adli's presentations*

The first scaled (11.424 GHz) full CLIC PETS version with damping slots and damping material.

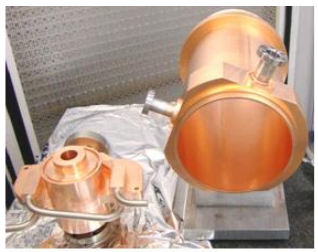


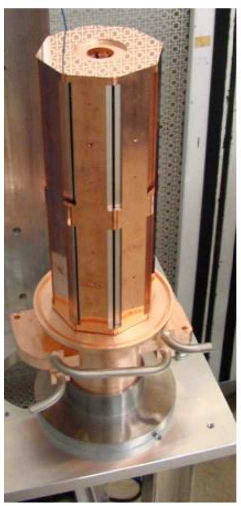




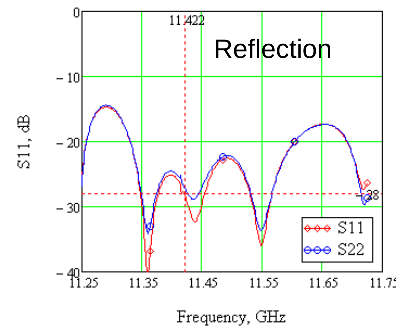


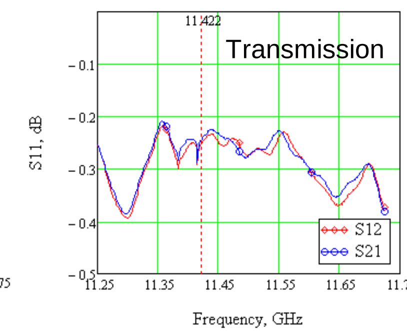
PETS preparation for the EB welding of the RF couplers and the mini-tank

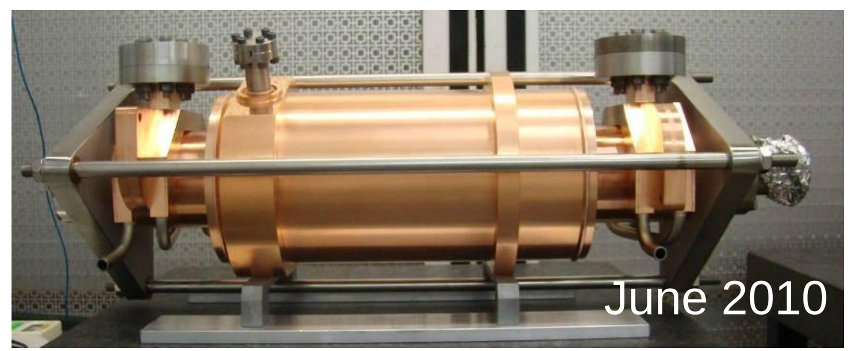




Low RF power measurements



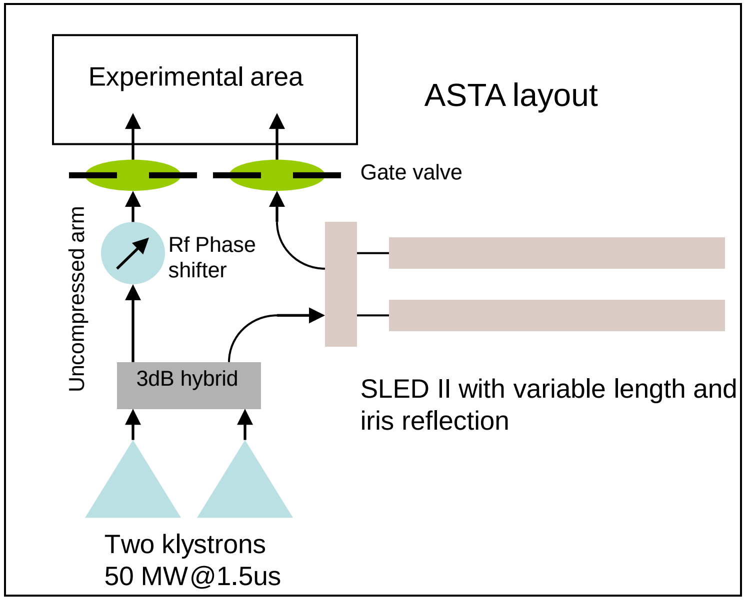




PETS testing @ ASTA, SLAC

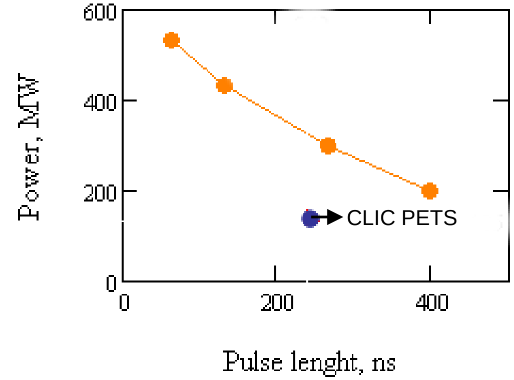
The ASTA pulse compressor with variable delay lines

The ASTA pulse compressor with variable iris



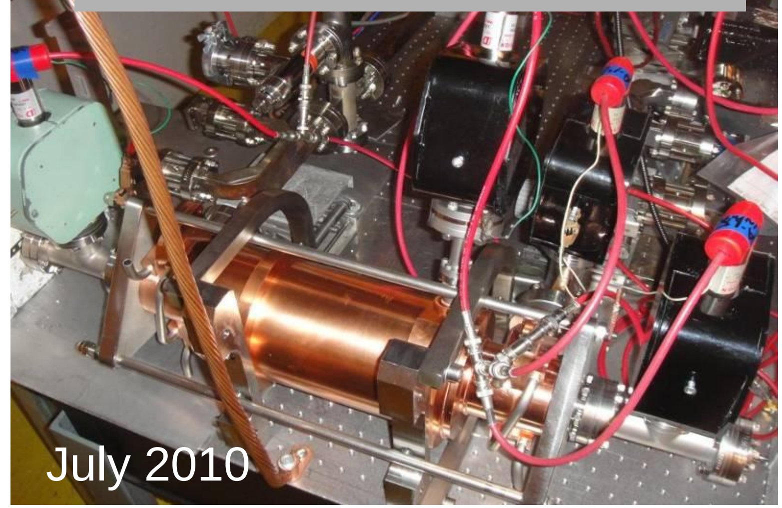
ASTA is a new generation general purpose test stand, which will allow processing the various types of the high power RF equipment at X-band. The facility can provide a very versatile pulse length and power level.

RF pulse @ power in the ASTA compressed arm



PETS ready for shipping to SLAC

PETS installed into the ASTA bunker at SLAC



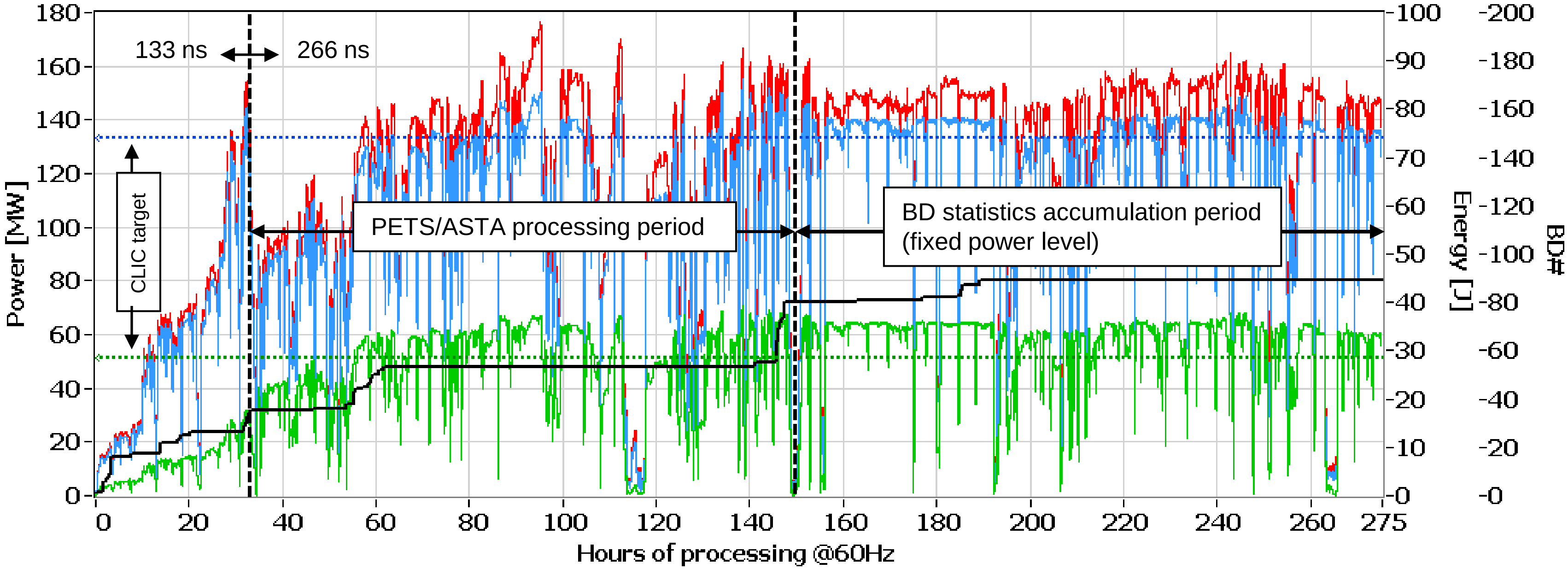
General remarks

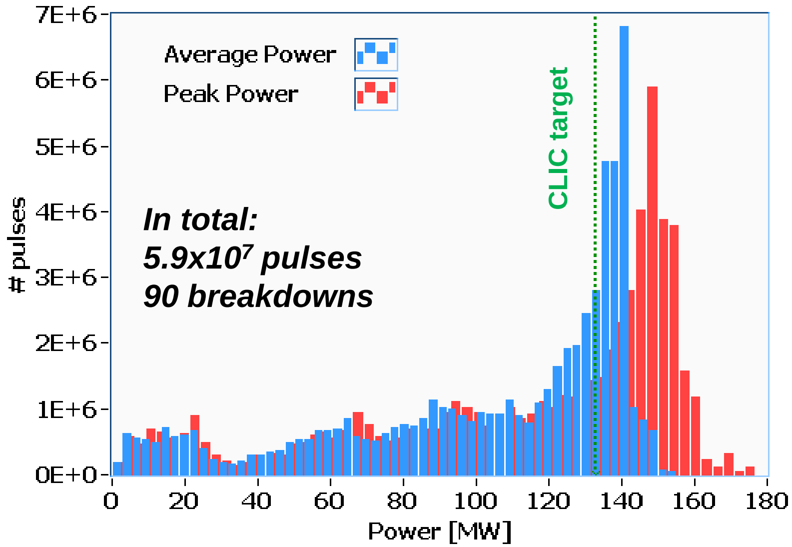
- **275 hours** of PETS high power testing were overall accumulated.

- In order to obtain breakdown statistics, the PETS was running at a fixed power level of 142 MW and pulse length 266 ns (18% higher pulse energy than in CLIC) for **125 hours**.

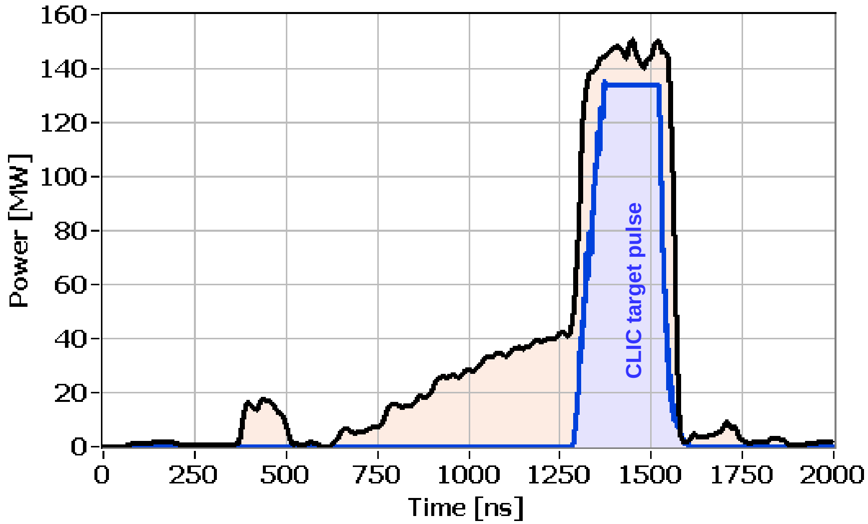
- The whole RF network system in ASTA was also being conditioned at the same time, which somewhat limited the power production stability at high power levels due to the **vacuum interlocks trips** in the waveguide circuit.

PETS processing history





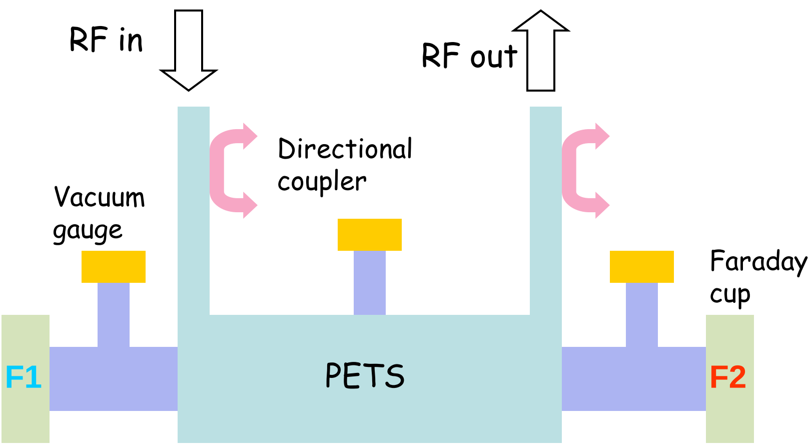
Average and peak power distributions



Typical RF pulse shape in ASTA during the last 125 hours of operation

Breakdowns in the PETS

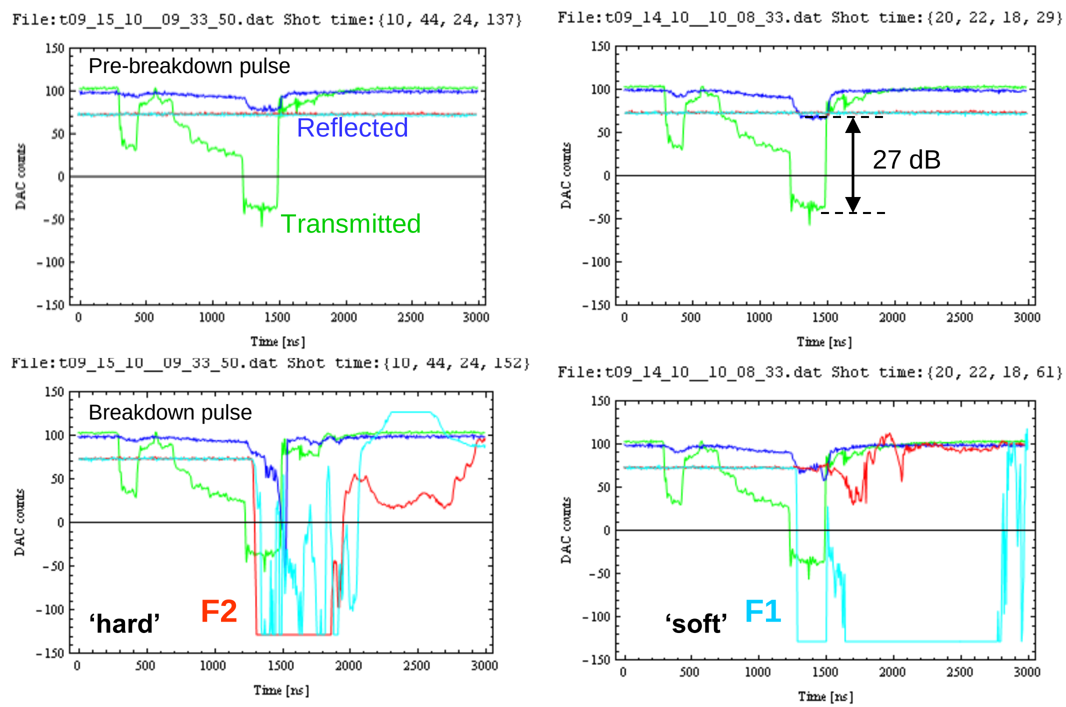
The breakdown acquisition signals:
- Reflected and transmitted power
- Vacuum controllers
- Faraday cups mounted at both PETS extremities.



Processing strategy:

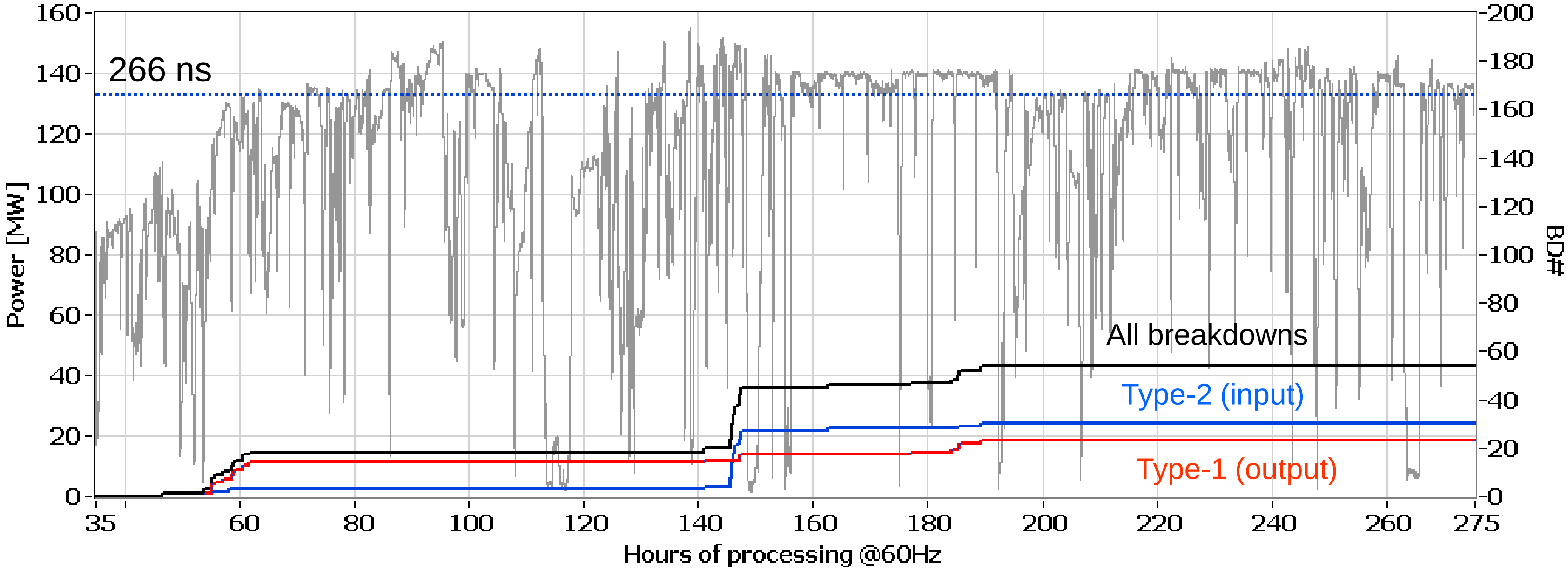
In case of breakdown, the RF power is shut down on the next pulse and restarted/ramped up after a few seconds, vacuum interlocks permitting.

Two typical breakdown events in the PETS (raw data)

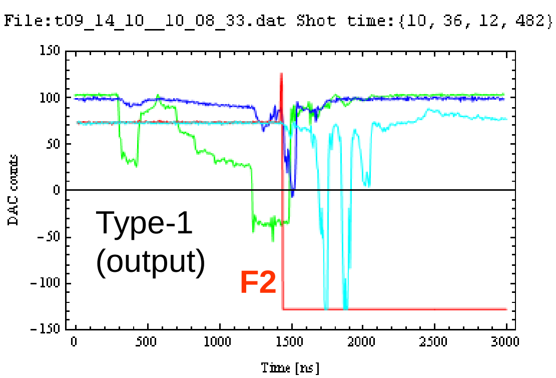


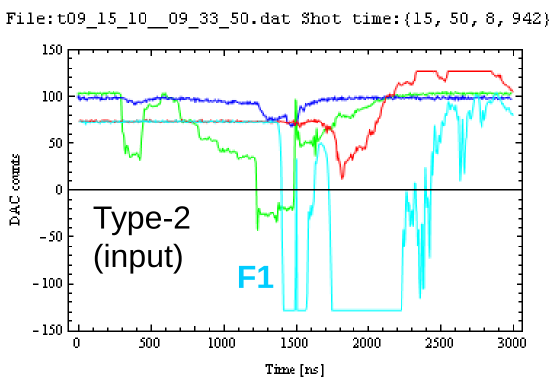
1. 'Hard' event. The variation in reflection is measurable.
2. 'Soft' event. The variation in reflection is negligible.

Breakdowns locations



1. In general, the breakdowns were grouped into two types of events with respect to the Faraday cups signals.
2. We suggested that this can help to identify the breakdown location by correlating the arrival times and amplitudes of the two. Following, “type-1” events are located close to the output coupler and “type-2” are closer to the input coupler.
3. We also observed that “hard” events are mostly associated with “type-1” events.



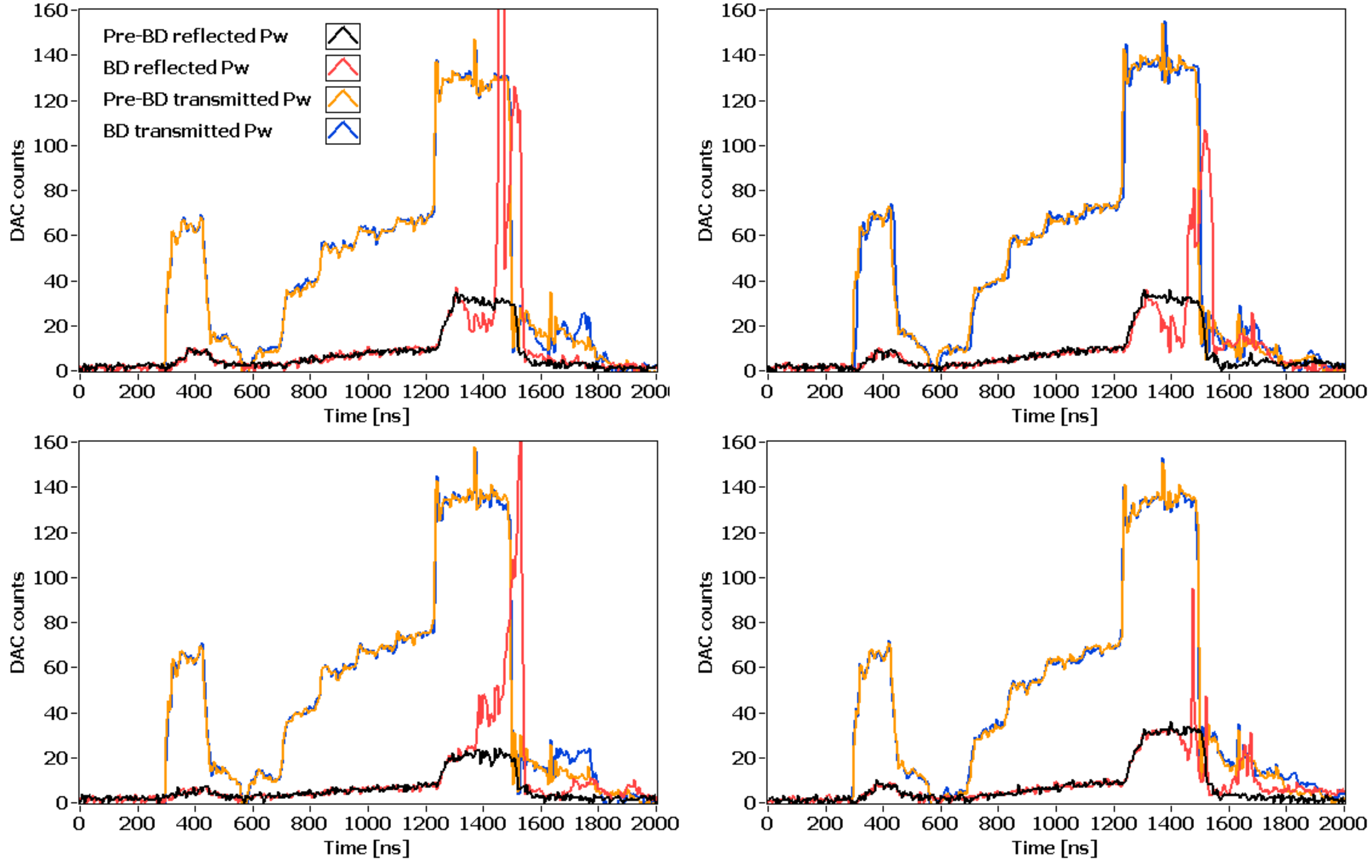


Total breakdowns	53
Type-1	23
Type-2	30

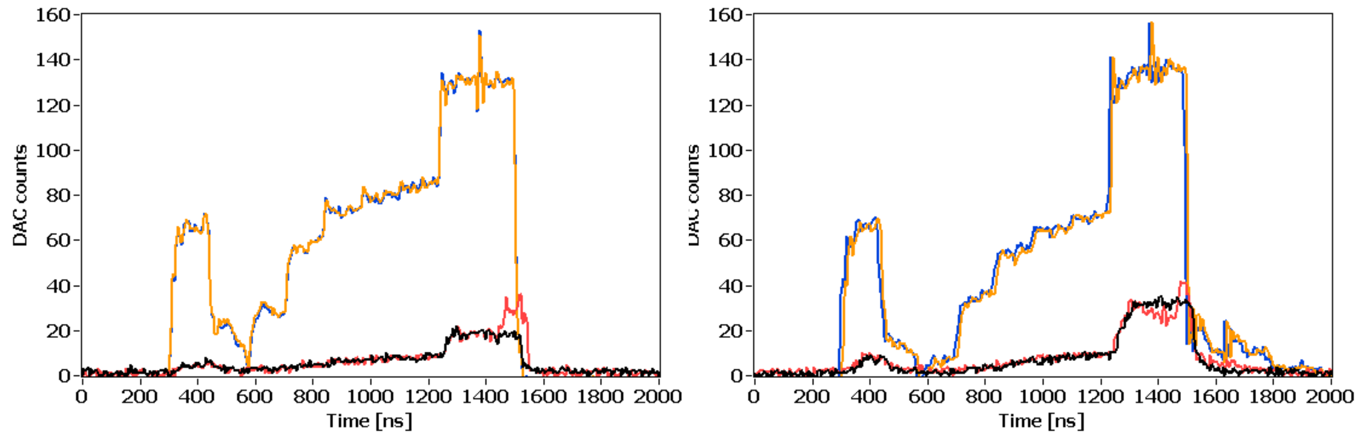
Missing Energy

None of the registered breakdowns showed traces of pulse shortening (missing energy). Any of these events will be practically undetectable in the CLIC environment.

‘hard’ events examples

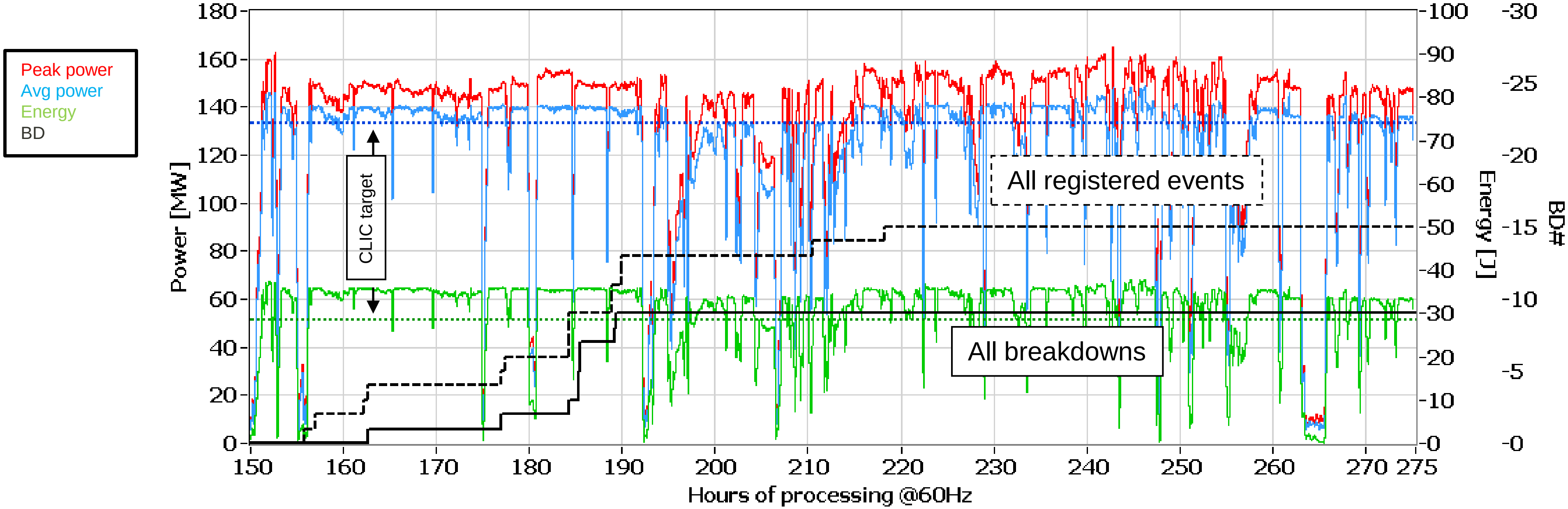


‘soft’ events examples



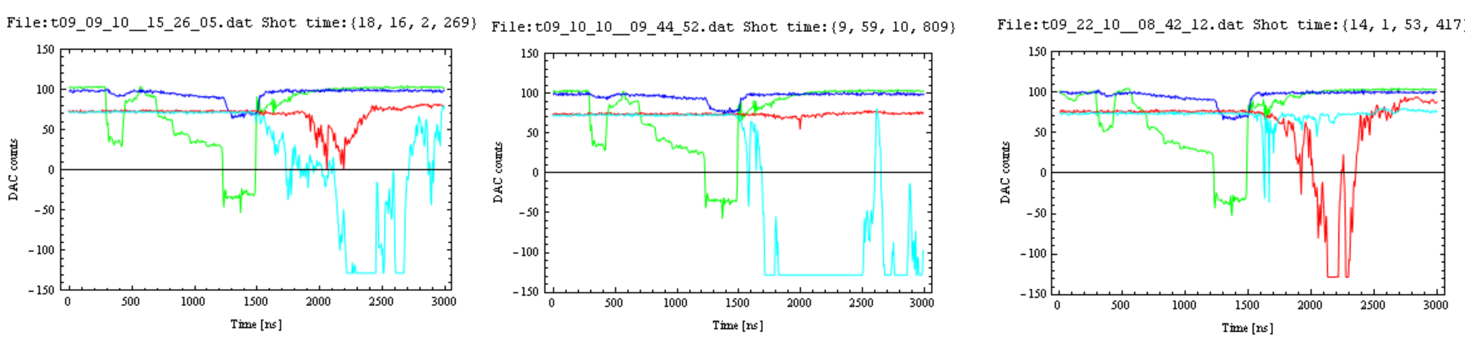
PETS breakdown trip rate

BDR statistics accumulation testing period (142 MW x 266 ns).

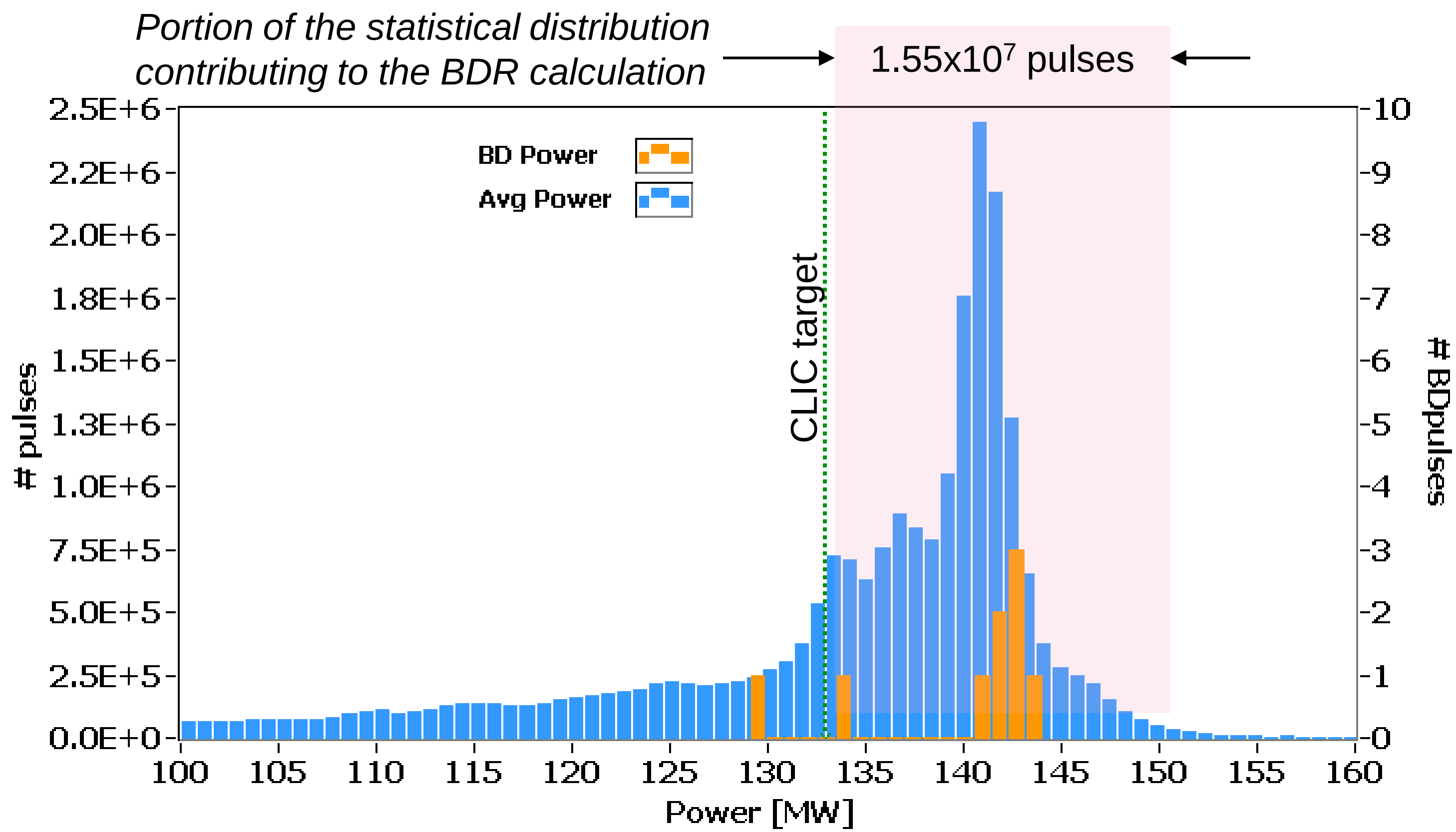


During ~125 hours of testing, 15 events were logged into breakdown counter following Faraday cups signals. Six of them were discarded from breakdown statistic due to the late (in time) appearance of the dark current and thus irrelevant for CLIC.

Examples of discarded events



PETS breakdown trip rate



1. 1.55×10^{7} pulses were accumulated in a 125 hours run with fixed peak power and pulse length.
2. 8 PETS breakdowns were identified giving a breakdown rate of **5.3×10^{-7}/pulse/PETS**.
3. Most of the breakdowns were located in the upper tail of the distribution and happened at earlier stage of the run, which makes the integrated BDR estimate rather conservative.
4. During the last 80 hours no breakdowns were registered giving a BDR **<1.2×10^{-7}/pulse/PETS** counting only the pulses with average power higher than the CLIC nominal.

Summary

1. The complete feasibility demonstration of the power production in CLIC will require PETS operation with 100 A drive beam (partially covered in CTF3 – 30 A). However these experiments will be more focused on the beam dynamics and machine protection issues (partially covered in TBL).

2. The feasibility of the PETS operation at a peak RF power level ~7% higher and with RF pulses ~10% longer compared to the CLIC requirement was successfully demonstrated in klystron driven experiments at SLAC.

3. The tests at a fixed power level were stopped, when the measured breakdown trip rate went close enough to CLIC specification: $1\text{x}10^{-7}$/pulse/PETS. In our case it was after 80 hours of operation without any breakdown (BDR $<1.2\text{x}10^{-7}$/pulse/PETS).

4. The demonstration has been done in more demanding environment then needed for CLIC - with extra input coupler and uniform RF power distribution along the structure (>50% of breakdowns happened closer to the input coupler).

Future plans

1. Further testing of the PETS at a CLIC RF power level and measured breakdown trip rate would require enormous operational time (hundreds of hours) to provide reasonable statistic in order to improve the BDR measurement accuracy. Together with tight ASTA experimental schedule this approach looks rather inefficient.

2. A more reasonable approach is moving towards even higher power levels: 180-200 MW. It will potentially allow for a shorter testing time and could result in more understanding about PETS ultimate performance. To perform these tests, ASTA itself should be processed accordingly, to able to operate stable at such high power levels.