High-gradient test of a structure built from halves

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Outline

- **Introduction**

- **Xbox-2: T24-OPEN**
  - Conditioning
  - Performance
  - High-gradient studies

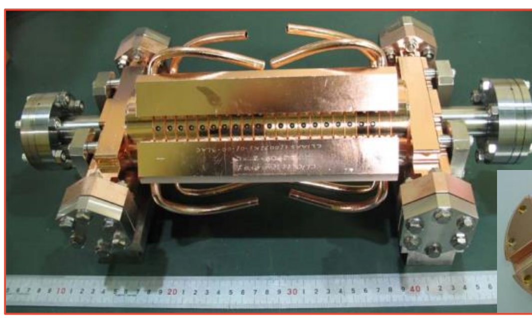
- **Summary**

Introduction

- Recent developments in design and production of normal-conducting RF structures raised the achievable accelerating gradient of 20-100 MV/m.

- High-Gradient technology could be exploited in certain applications (Linear Colliders, FEL, hadron therapy etc).

- For the Compact Linear Collider (CLIC) 10ths of thousands accelerating cavities are needed on pulse mode operation with the requirements:
  - **100 MV/m** on axis accelerating RF field (**tens of MW**) , ~**180 ns** pulse length



Main Linac Accelerating Structure: CLIC-G prototype (TD26CC), Travelling-Wave at 11.994 GHz

- High-power RF fields can lead to a **vacuum arc** formation (**Breakdown**) inside the structure → degrades beam transmission and acceleration → loss of Luminosity
  - CLIC specification on the Breakdown rate (BDR): **3×10^{-7} BD/pulse/m**

High-gradient testing

- The High-Gradient performance needs to be tested in advance at high-power test stands

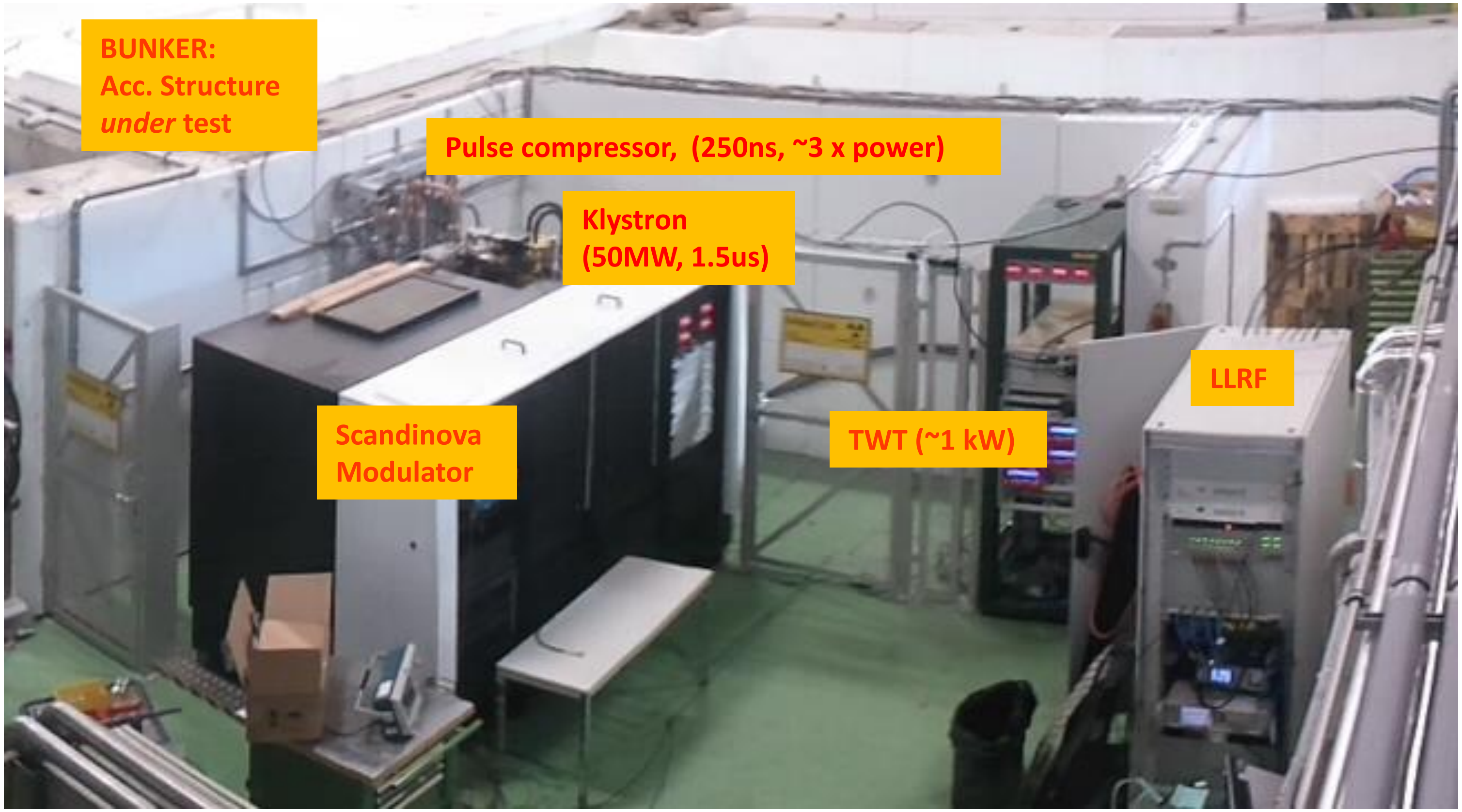
- Different CLIC prototypes of accelerating structures have been tested so far at CERN, KEK and SLAC , and high gradients above 100 MV/m have been achieved at low breakdown rate.

- At CERN: three **X-band (12 GHz) klystron-based test stands (Xboxes)** support the development of high-gradient **accelerating structures** and high-power, 50-100 MW range, and **RF components** for the CLIC project.(*N. Catalan-Lasheras et al*, IPAC14)

The Xbox-2 test stand at CERN

The Xbox-2 is the second generation of CLIC high-power klystron-based test stand at CERN.

- Same infrastructure design as Xbox-1.
- Close access to the bunker where the accelerating structure is tested.
- RF Power capabilities: up to 150 MW 250 ns



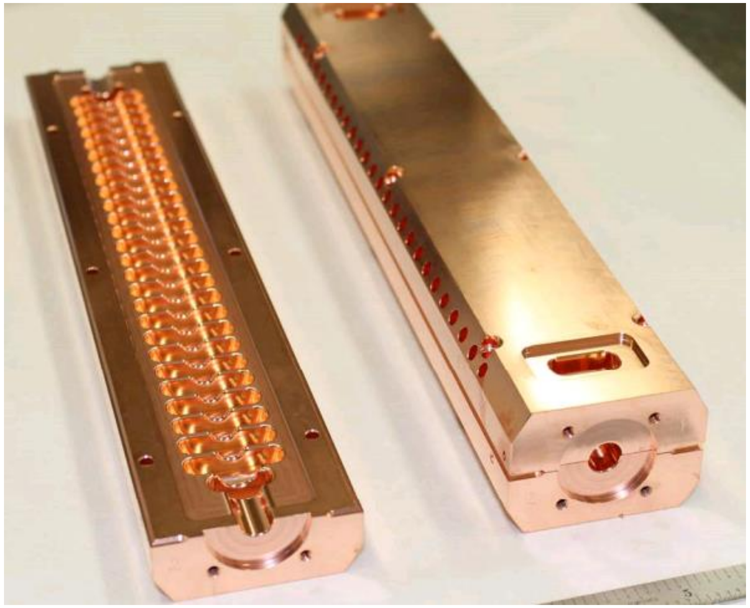
T24-OPEN

A new prototype, **CLIC-G "OPEN",** was designed and built by CERN and SLAC.

Milled structure built in **two halves** and brazed together→ potential advantages compared to traditional structures (individual cells are brazed together):

- Only two pieces per structure → significantly decrease in surface area to be machined.
- Free choice of joining since no RF currents between halves: brazing, welding…
- Overall reduction of the total fabrication cost of the structure.

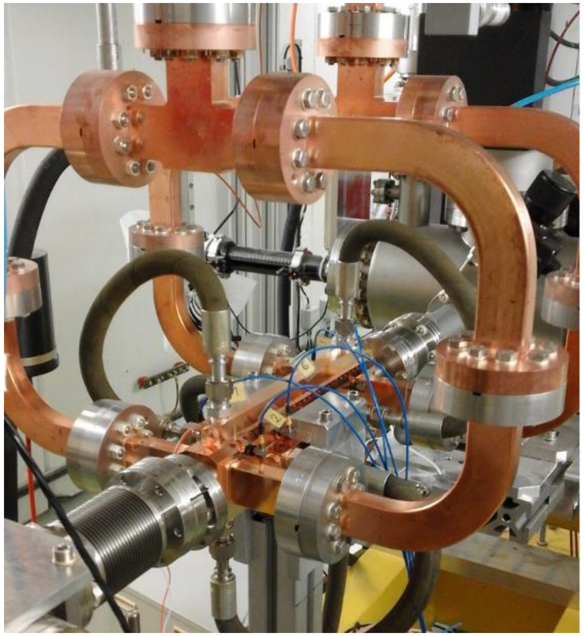
What about the structure performance?



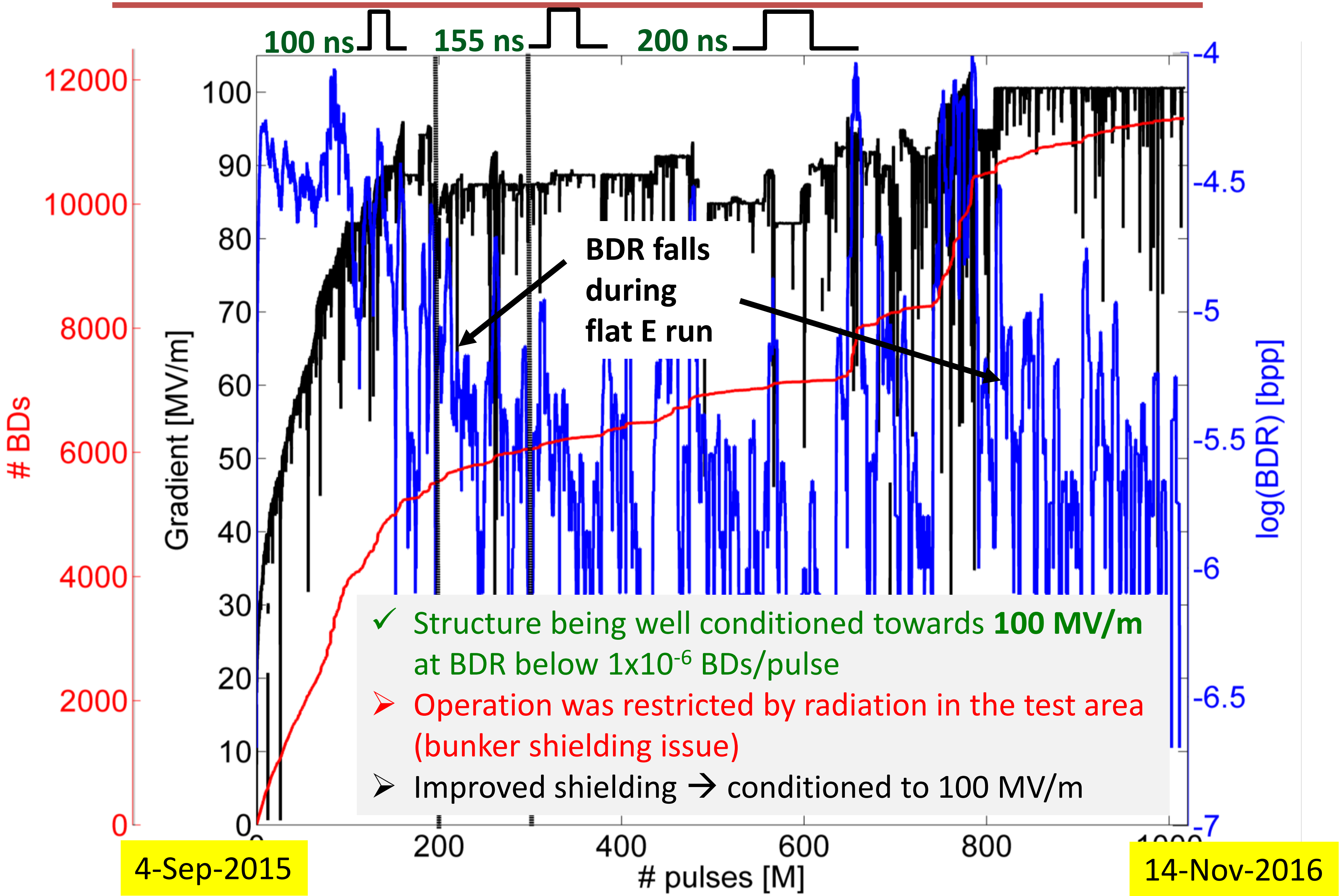
H. Zha, A. Grudiev, V. Dolgashev, IPAC2015
W. Wuensch et al., LINAC2016

- 24 regular cells (20cm-long) and two matching cells.
- Same dimensions of irises as CLIC-G
- No HOM damping

T24-OPEN installed at Xbox-2

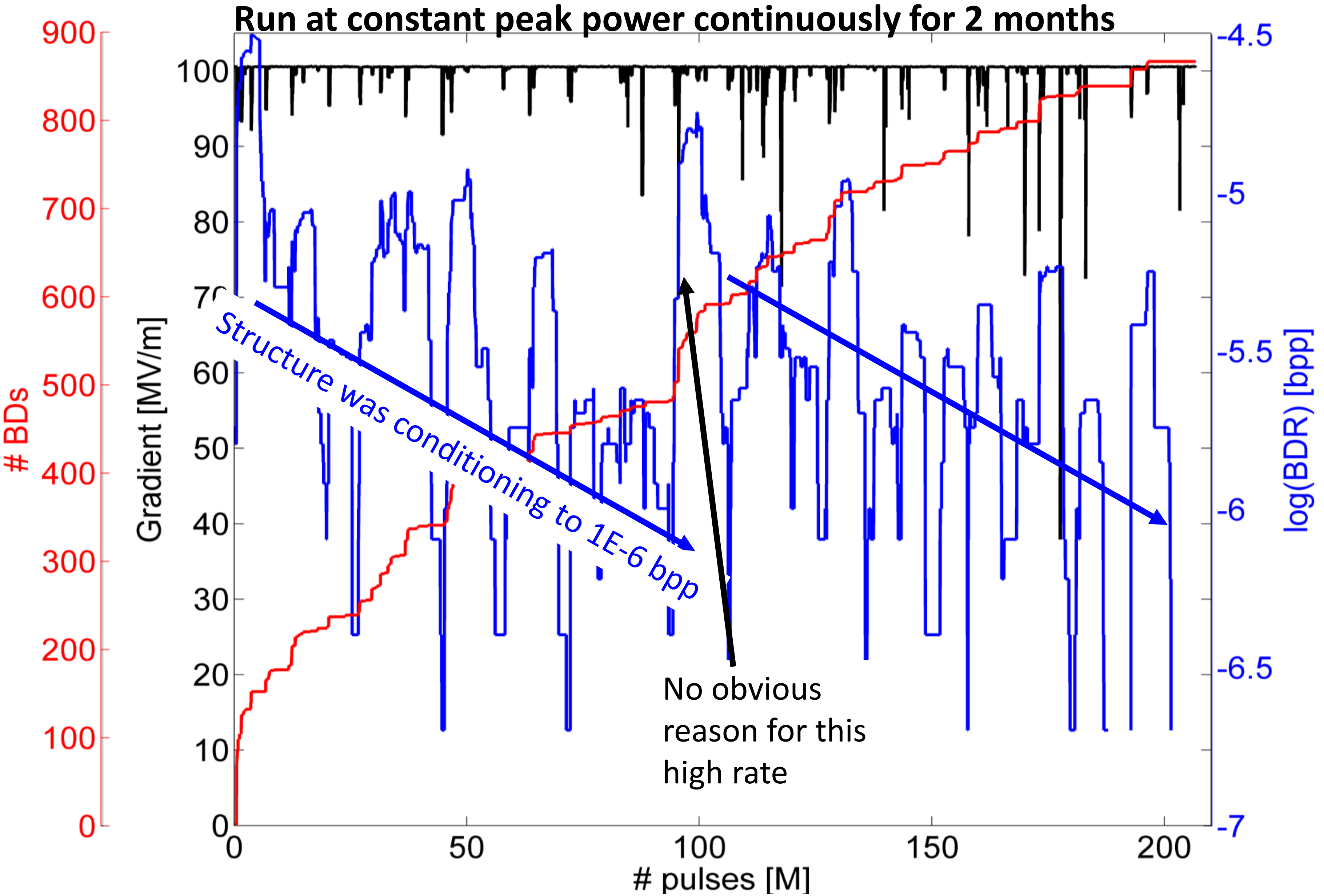


T24-OPEN Full history



- ✓ Structure being well conditioned towards **100 MV/m** at BDR below 1×10^{-6} BDs/pulse
- ➢ Operation was restricted by radiation in the test area (bunker shielding issue)
- ➢ Improved shielding → conditioned to 100 MV/m

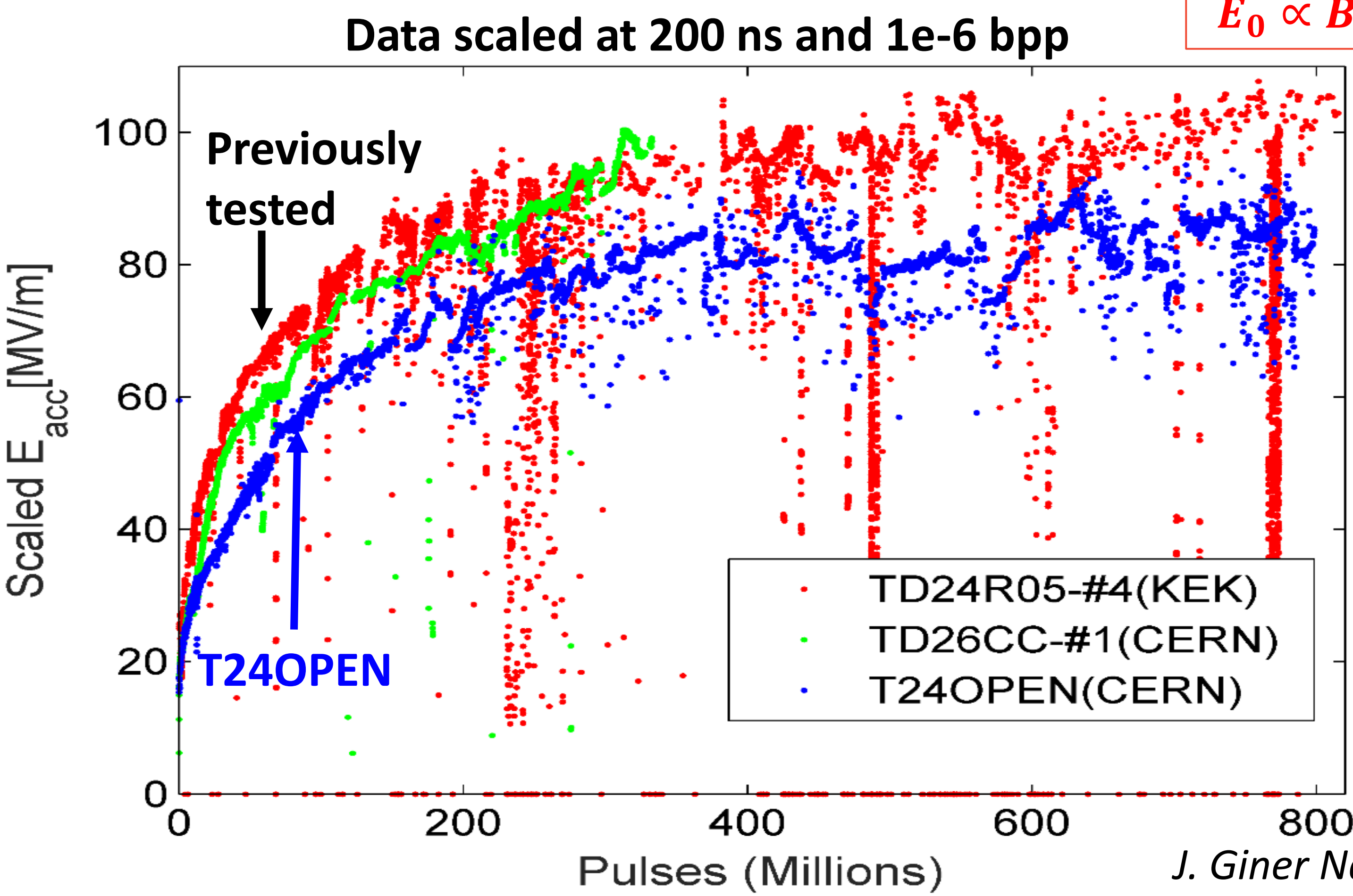
Last run @ 45 MW peak INC power



T24-OPEN Conditioning

- The T24-OPEN structure follows the **same conditioning trend** as previously tested structures with different design.

$$E_0 \propto BDR^{1/30}\tau^{-1/6}$$



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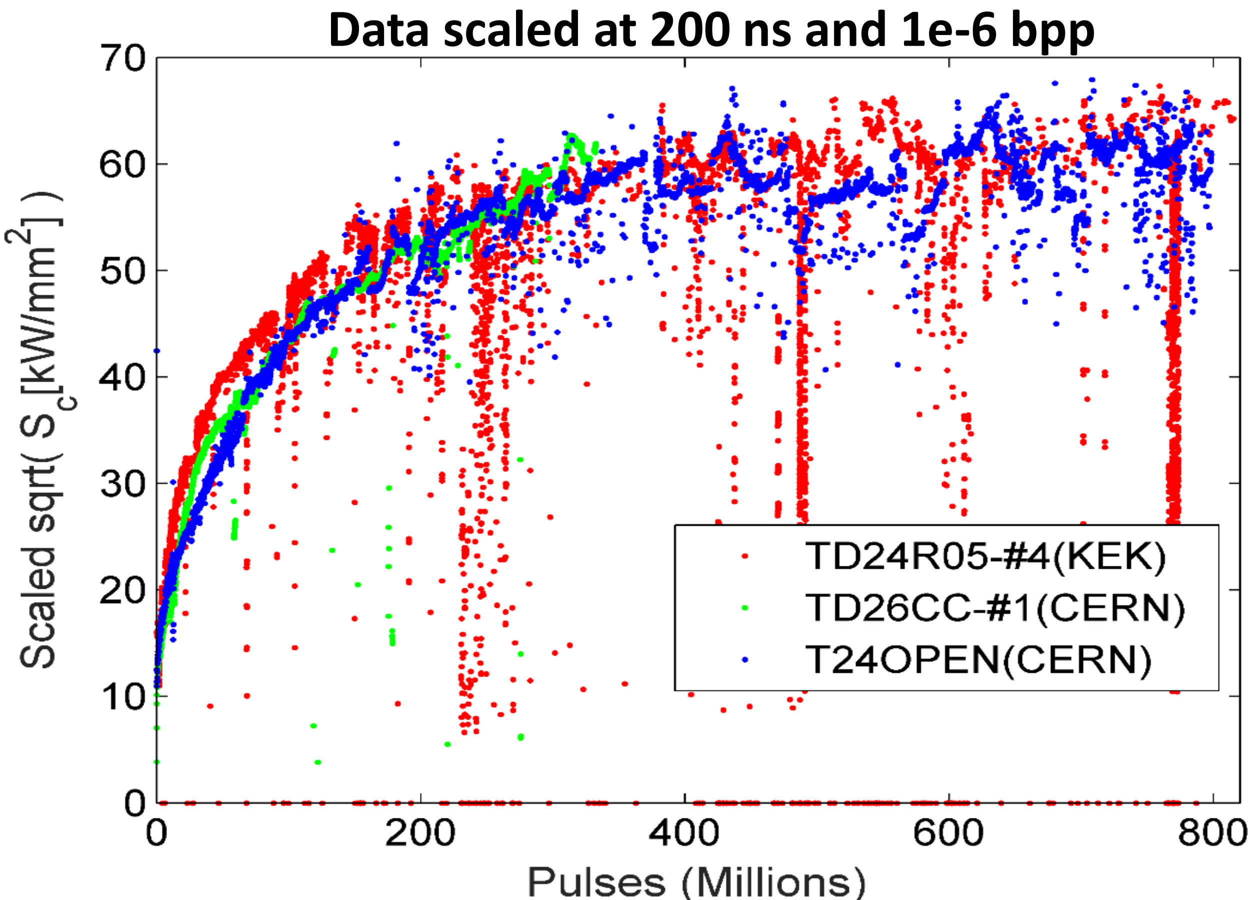
T24-OPEN Conditioning

- Unlike other CLIC designs, the **T24-OPEN** presents 20% higher surface E fields E_{surf} → E_{surf} rises faster in time
- Modified Poynting vector, **S_c fits better with conditioning curves** of previous tests in other disk-based structures. *(A. Grudiev, S. Calatroni, W. Wuensch, PRSTAB 12, 102001 (2009))*



$$S_c \propto BDR^{1/15}\tau^{-1/3}$$

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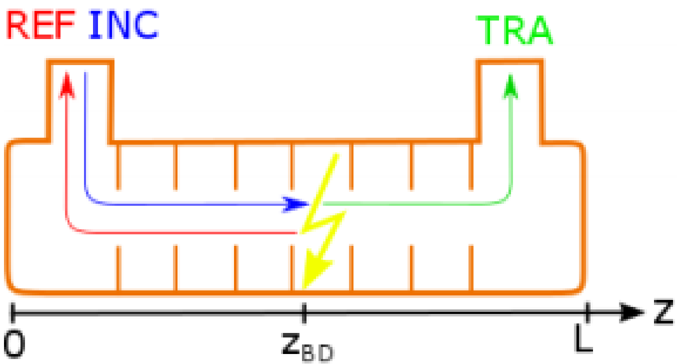
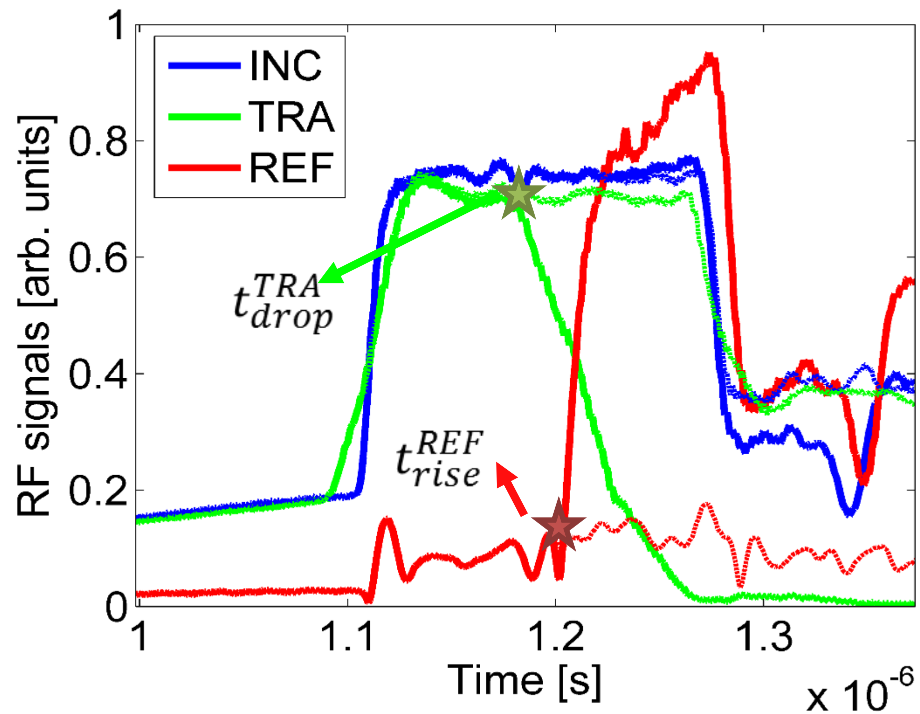
Breakdown positioning

Diagnostics of **where the breakdown is triggered** inside the structure during the testing can be done by analysing the **RF signals** → Directional couplers to read the RF signals





When breakdown occurs:

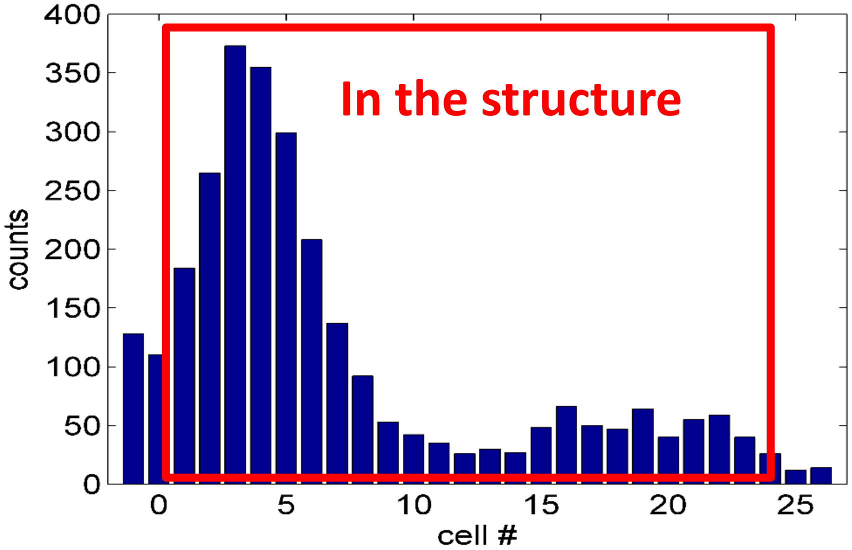
- **Transmitted power drops** t_{drop}^{TRA}
- **Reflected power rises** t_{rise}^{REF}

Trip time delay: $t_d = t_{drop}^{TRA} - t_{rise}^{REF}$

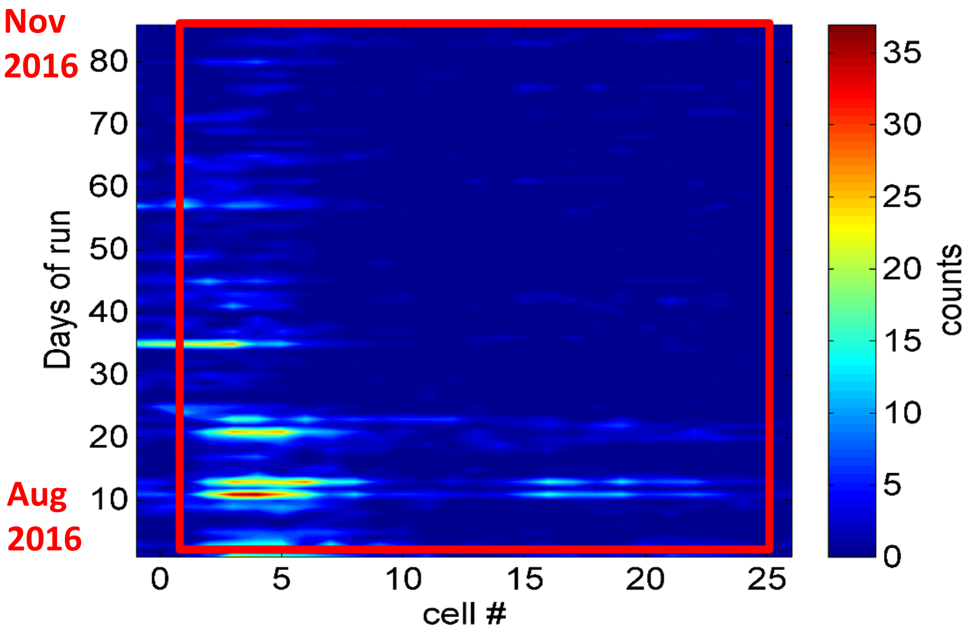
Edge method: Trip time delays, combined with RF group velocity v_g, gives the onset position of the breakdown.

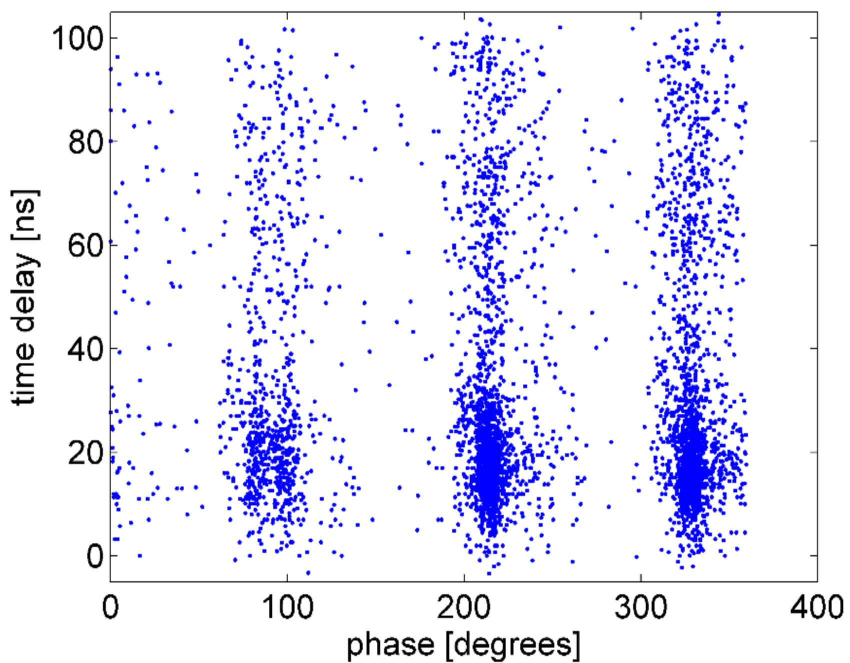
$$z_{BD} \propto v_g^{RF}(t_{drop}^{TRA} - t_{rise}^{REF})$$

Breakdown positioning



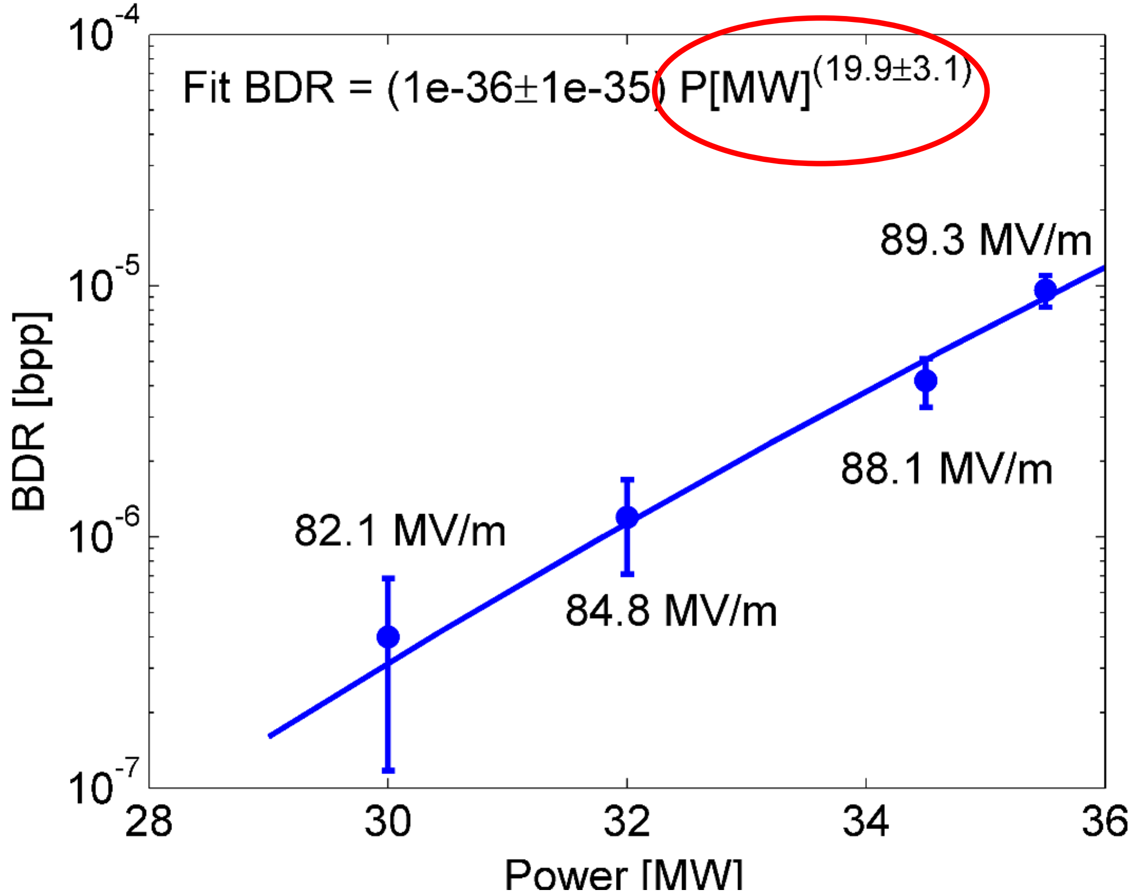
- More BDs in the beginning of the structure (started after Dec 2015)
- Not hot cell development → BDR was decreasing
- Phase distribution of the BDs spaced by ~120 degrees.
- **Combination of timing and phase information → better accuracy in breakdown localization**





BDR dependence on Power

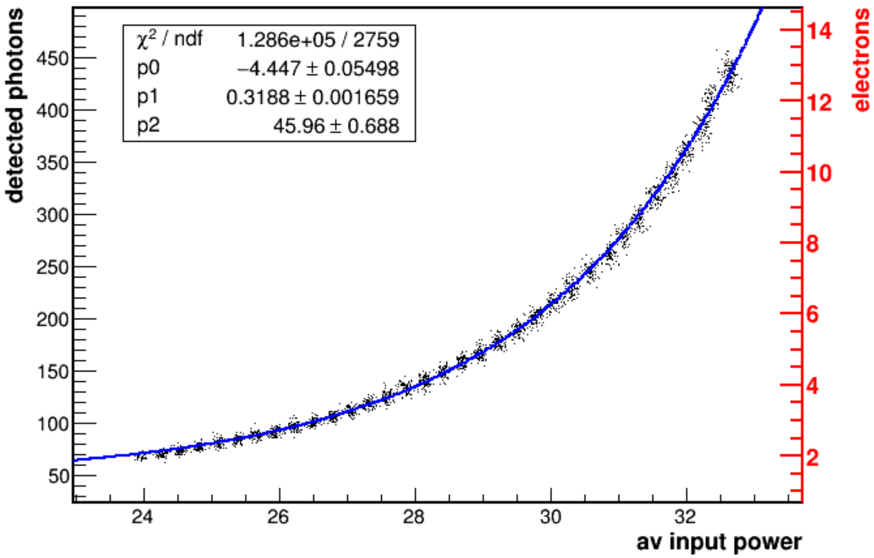
- Measurements for constant power: many interruptions due to interventions for Xbox-3 installations → idle periods in between → possible effect on the statistics.
- BDR calculated only for the last 5M pulses of each constant power run.



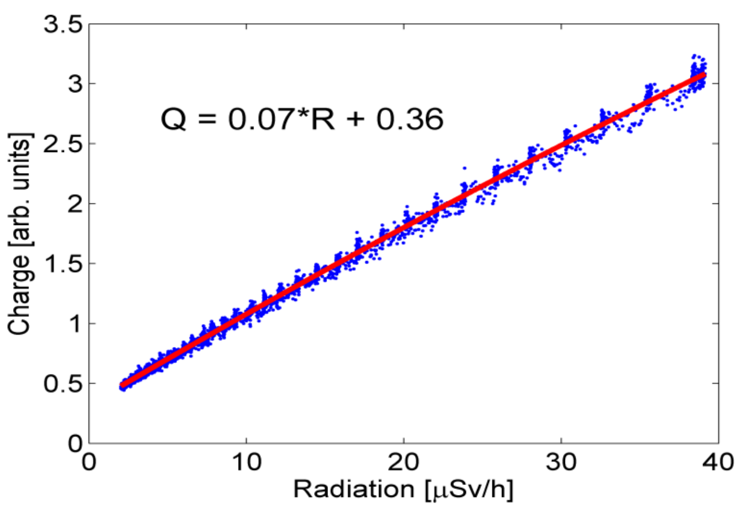
Fit follows the empirical scaling low $BDR \propto P^{15}$ for a pulse length of 200 ns.

Dark current measurements

Dark Current is measured: **Faraday Cups, Beam Loss Monitors** (BLM) (M. Kastriotou and now T. Geoffrey Lucas), **Radiation Monitors** (CERN Radioprotection group)



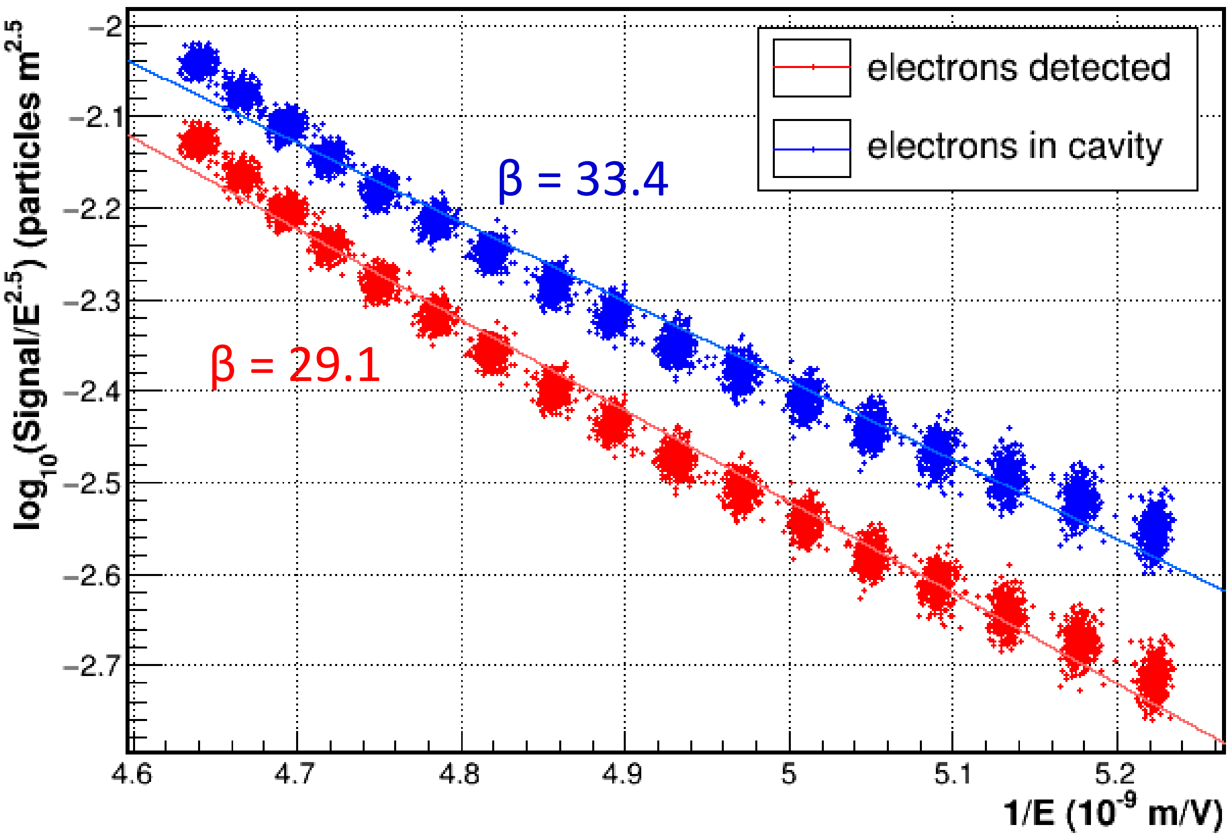
Measurements with BLM (March 2016)
Exponential fit function as in the theoretical model



Linear relation to the radiation monitor placed downstream of the structure

Field enhancement factor

Fowler-Norheim plot gives a β = 29, similar to the β for the disk-based structures. Similar values obtained also from FC and Radiation monitor.

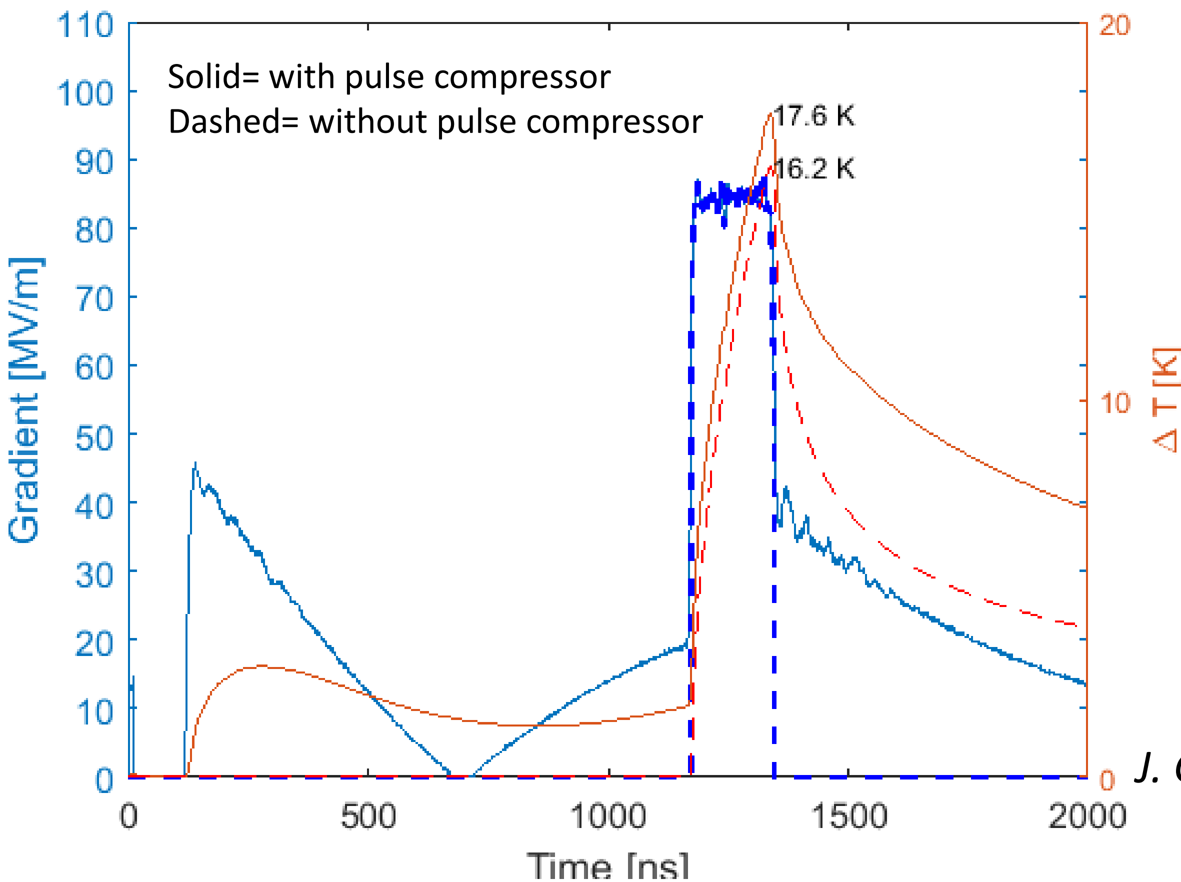


Blue points are the number of electrons inside the cavity estimated by FLUKA simulations.

M. Kastriotou ,talk at mini MeVArc 2016

Pulse shape dependence on BDR

- Two pulse shape configurations are used: with and without Pulse compressor (PC)
- Pulse surface heating increased with PC → higher effective field → higher BDR is expected *(F. Wang, C. Adolphsen, C. Nantista, PRSTAB 14, 010401 (2011))*



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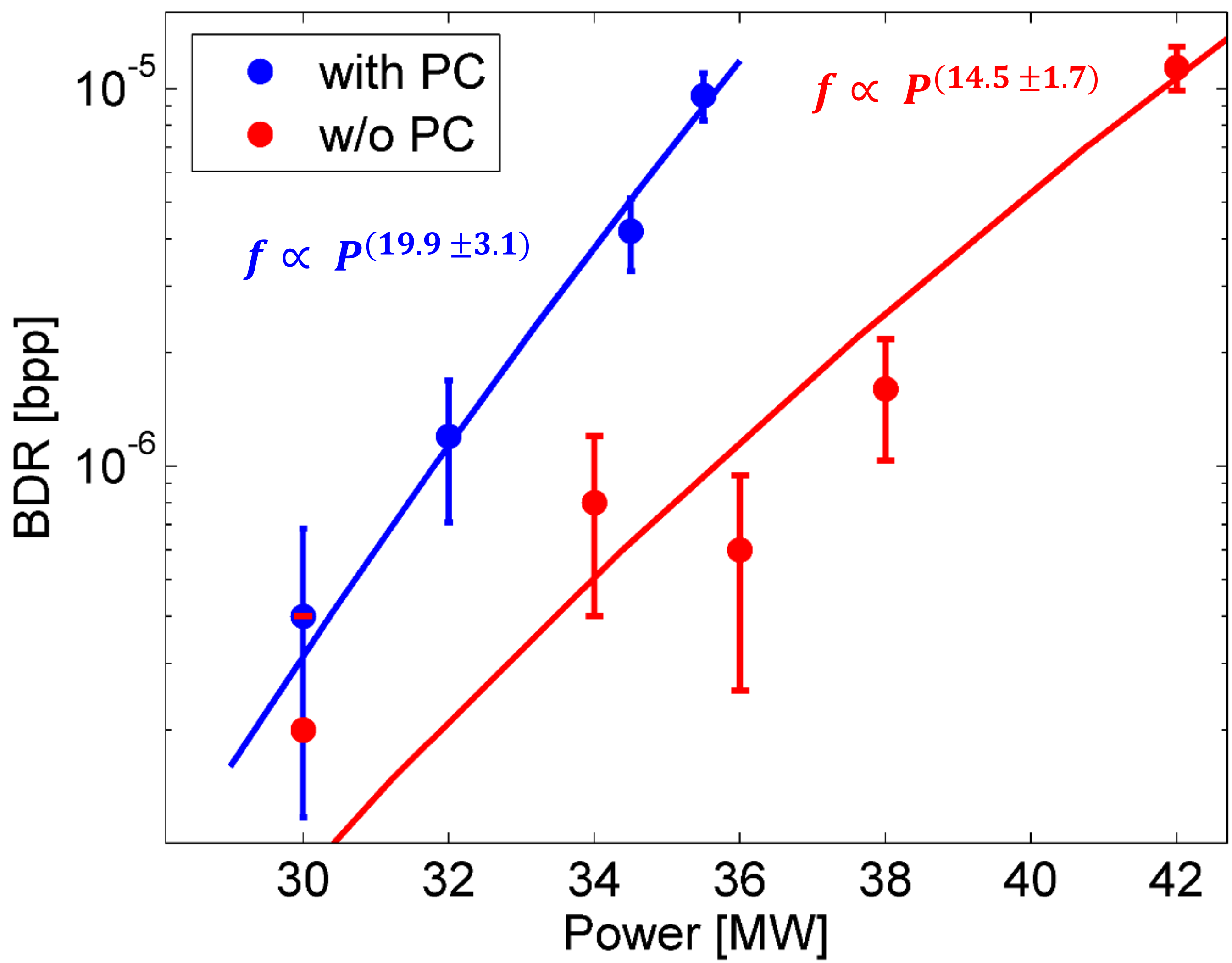
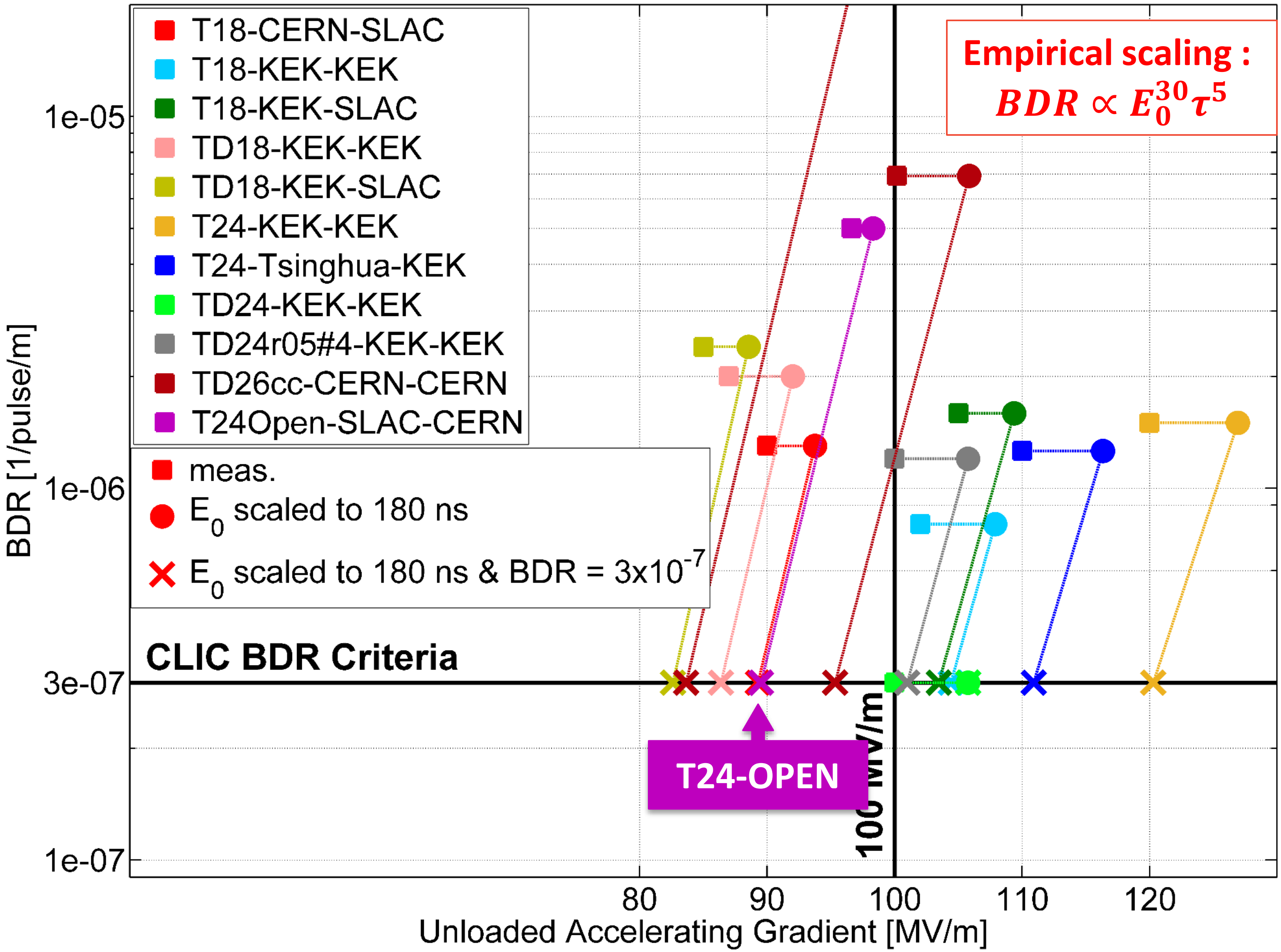
Pulse shape dependence on BDR

Measurements showed that BDR with the PC is larger than without PC



Fit follows the empirical scaling, $\boldsymbol{BDR \propto P^{15}}$ for the same pulse length (200 ns)

Conditioning summary



Summary

- Milled structures have **potential advantages - cost, treatment, materials**

- T24-OPEN built in halves was installed at Xbox-2 test stand at CERN for checking its performance with respect to the disk-based structures
  - **Structure conditioning:** similar trend as the other structures
  - **Breakdown localization:** more BDs in the beginning but not hot cell developed
  - **Field emission:** similar enhancement field factor β as the other structures

- High-gradient studies of the **pulse shape effect on the structure performance :** Pre-pulse due to the PC increased the BDR