RF Conditioning of a High-gradient, Normal Conducting, Next-generation L-band RF Photogun with 1% Duty Factor at PITZ

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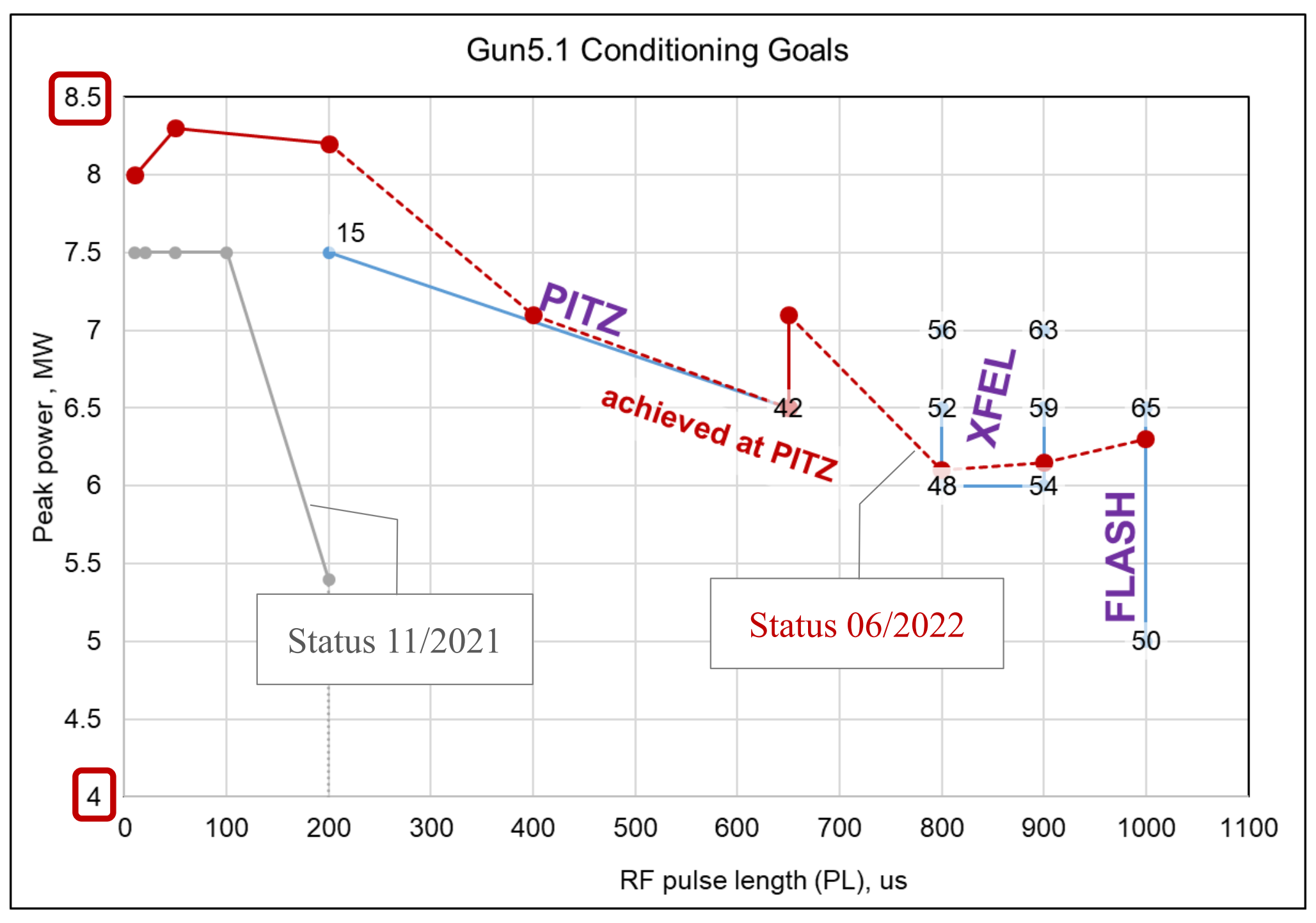
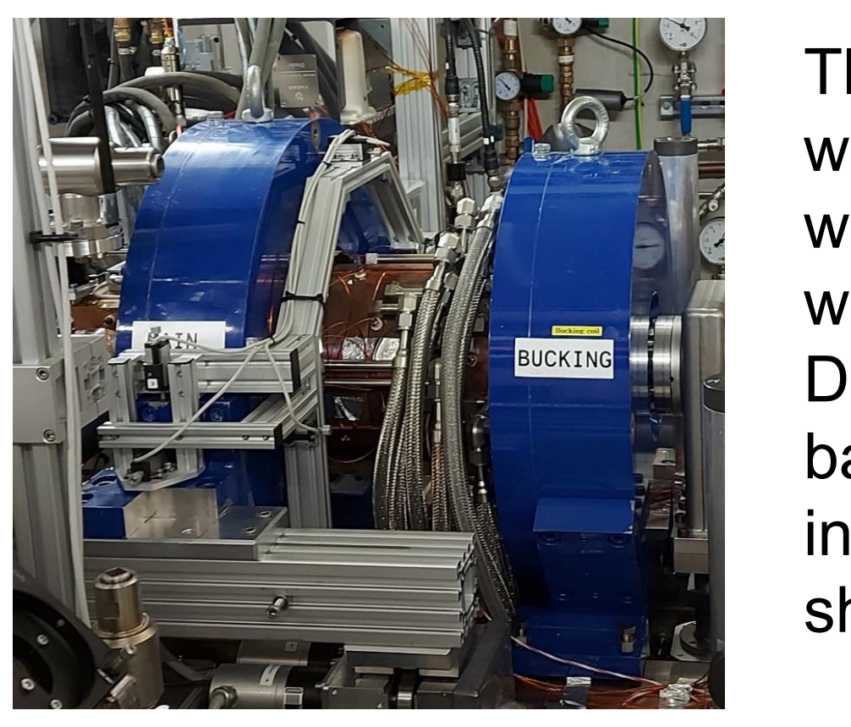
Abstract

A new generation of normal conducting 1.3GHz RF gun was developed to provide a high-quality electron source for superconducting linac driven free-electron lasers like FLASH and European XFEL. Compared to the Gun4 series, Gun5 aims for a 50% increase of the duration of the RF pulse (up to 1 ms at 10 Hz repetition rate) combined with high gradients (up to ~60 MV/m at the cathode). In addition to the improved impedance, the new cavity is equipped with an RF probe to measure and control the amplitude and phase of the RF field inside the gun. The first prototype of the new RF gun was manufactured at DESY and installed at the Photo Injector Test Facility at DESY in Zeuthen (PITZ) in October 2021. In mid-October 2021 the RF conditioning began, aiming for achieving the aforementioned RF parameters. The conditioning procedure involves a slow gradual increase in repetition rate, RF pulse duration and peak power while carefully monitoring vacuum conditions and signals from interlock sensors. The results of RF conditioning will be reported.

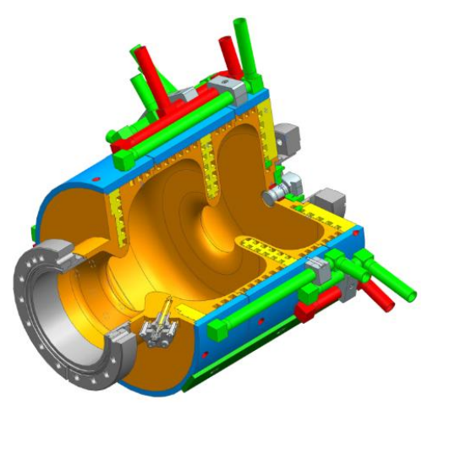


Gun5.1 Setup at PITZ



The RF gun cavity is a 1½-cell normal conducting copper cavity operating in the π-mode standing wave at 1.3 GHz. The Gun5 design includes several major improvements over the Gun4-generation, which are aimed at improving the performance of the gun. The elliptical shape of the internal geometry was applied in order to optimize the distribution of the peak electric field over the cavity surface. Detailed studies to reduce the dark current resulted in an elliptical shape of the cathode hole at the back wall of the cavity. In order to control the RF field in the cavity directly an RF probe has been integrated in the front wall of the full cell. An optimized cavity cooling system and improved rigidity should mitigate the challenges associated with the 1% duty cycle.

The Gun5.1 RF feeding setup inherited the waveguide distribution system of the previous generation of guns (Gun4.x), including two RF windows and a T-combiner in vacuum.

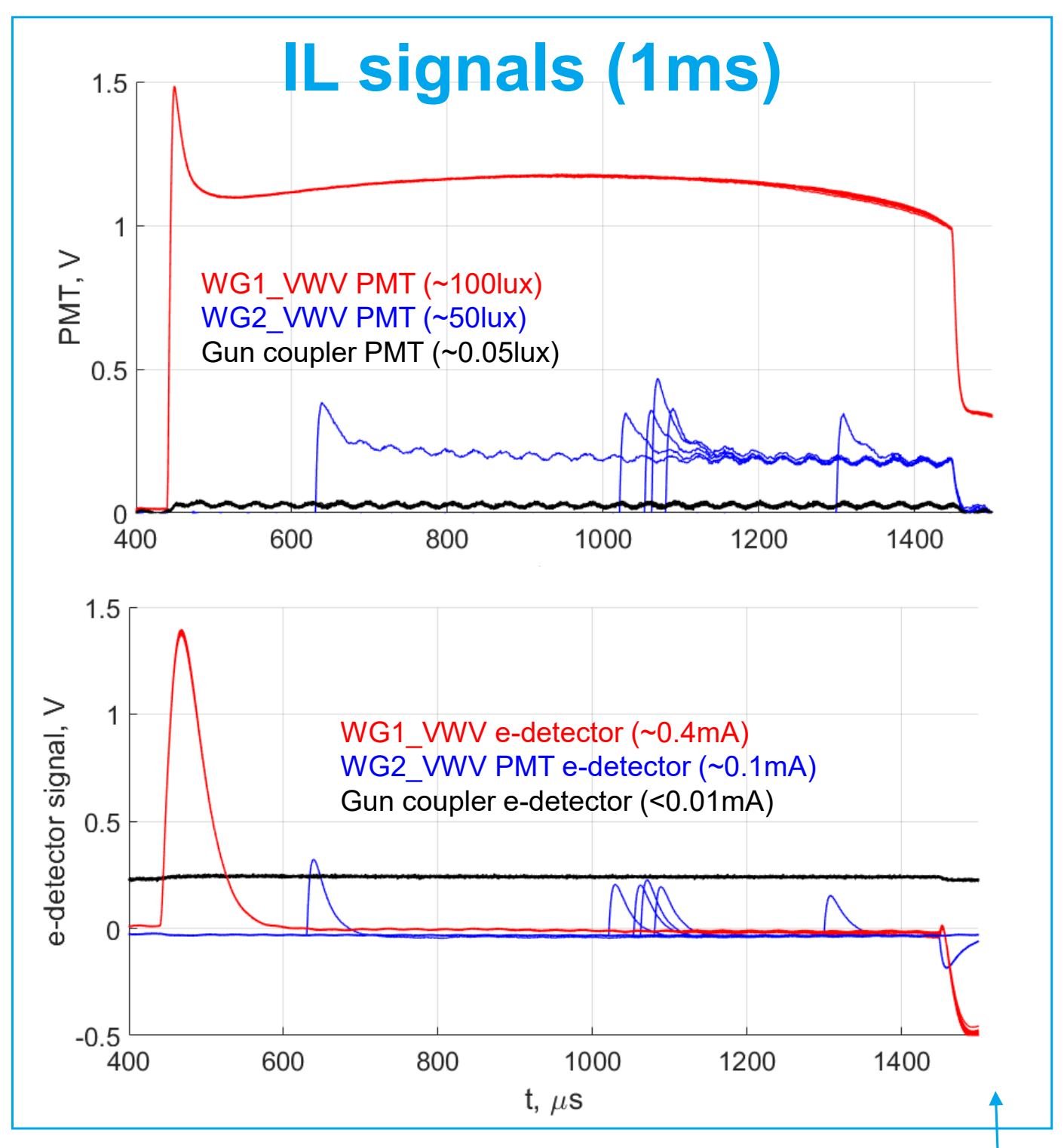


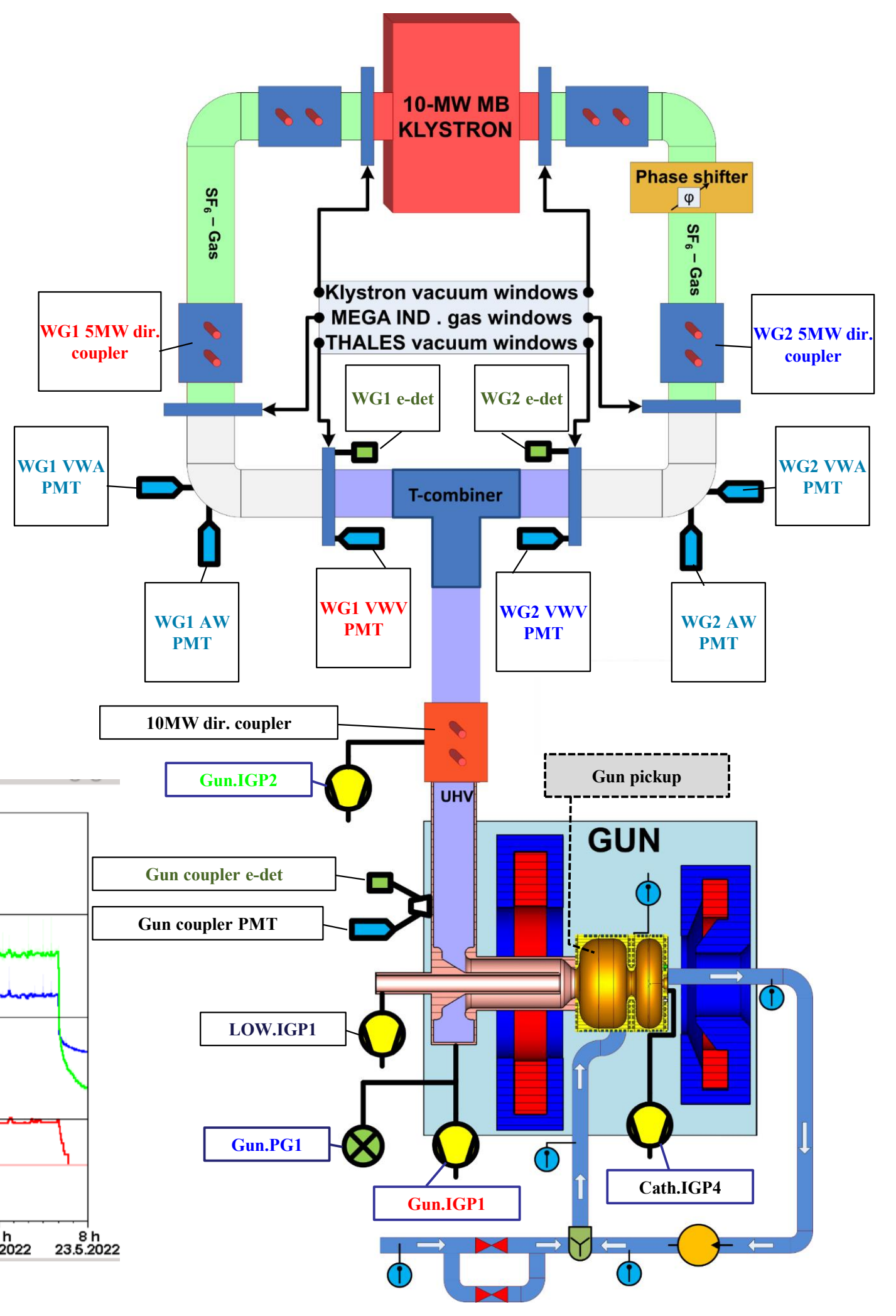
The cavity of the Gun5.1 prototype was tuned to the operation frequency and reasonable field balance of the π-mode electric field. According to these results, the axial field distribution of the π-mode has a field balance

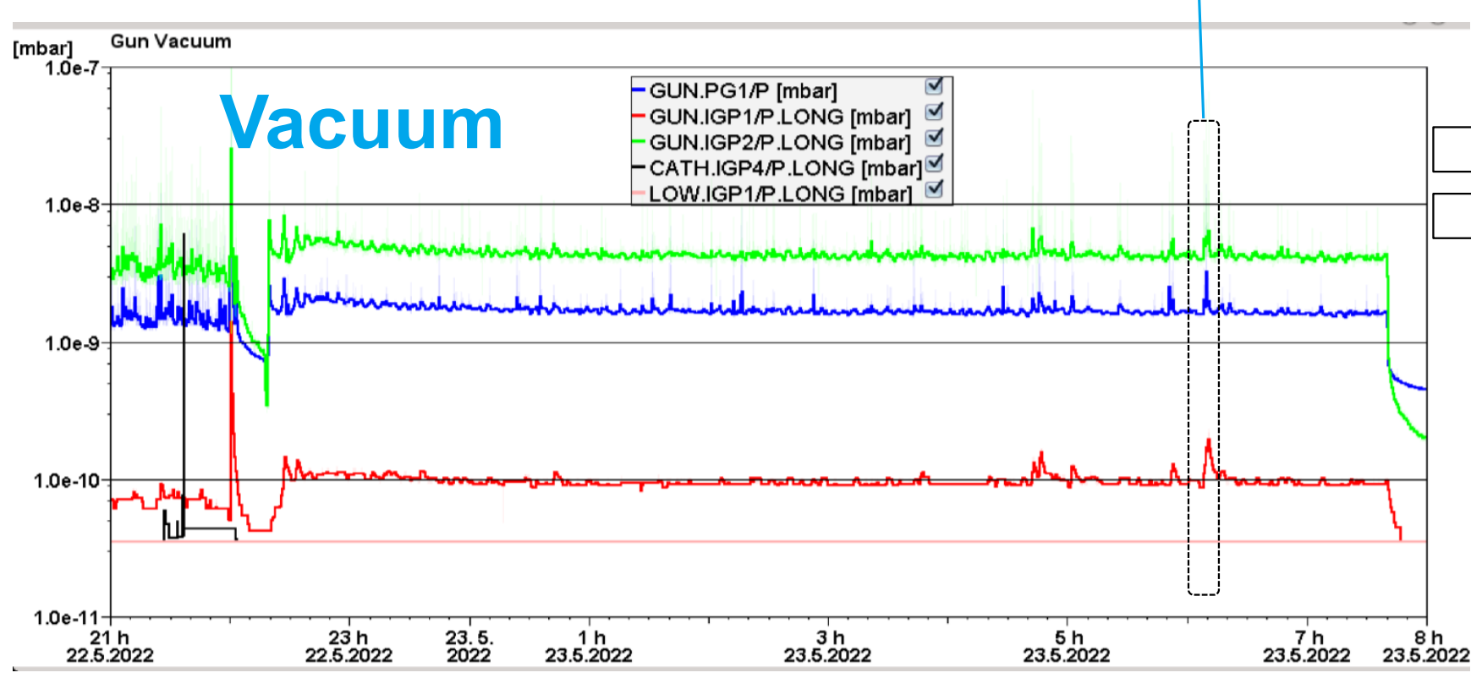
$$\left|\frac{E_{cath}}{E_{fullcell}}\right| \approx 1.097$$

$$P_{RF}[MW] \cong 0.00192 \cdot (1 \pm 0.037) \cdot (E_{cath}[MV/m])^2$$

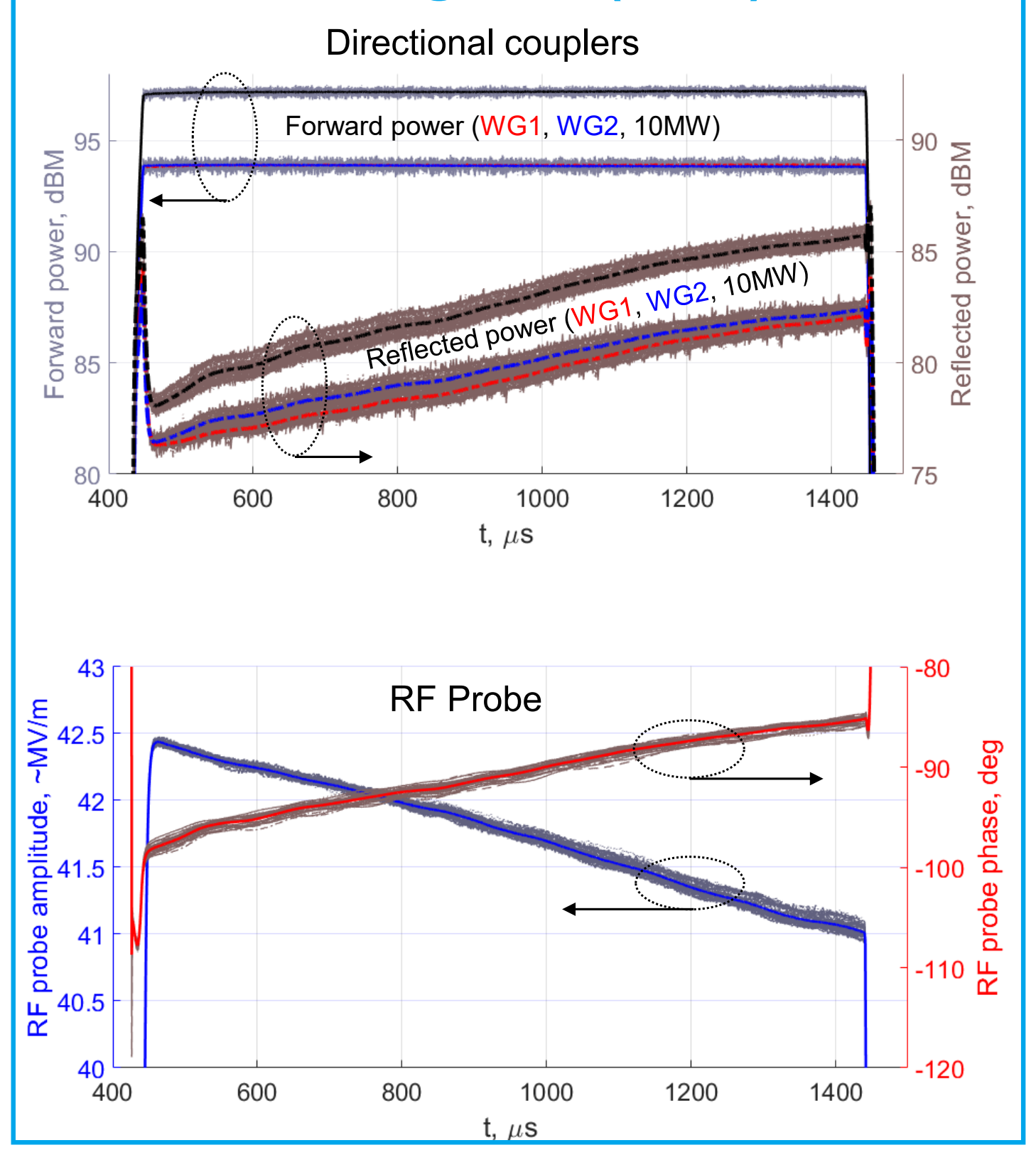
IL signals (1ms)



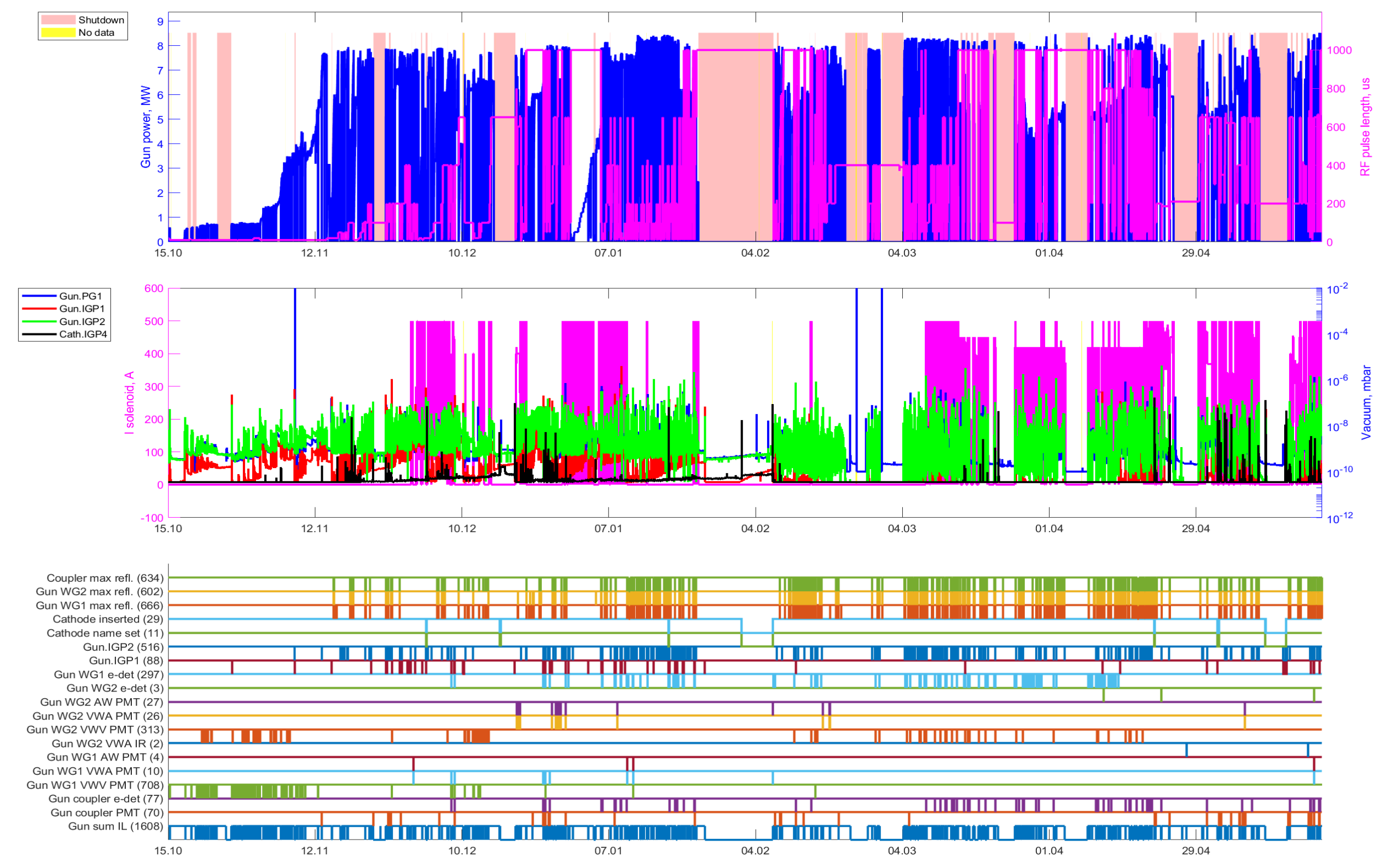




RF signals (1ms)

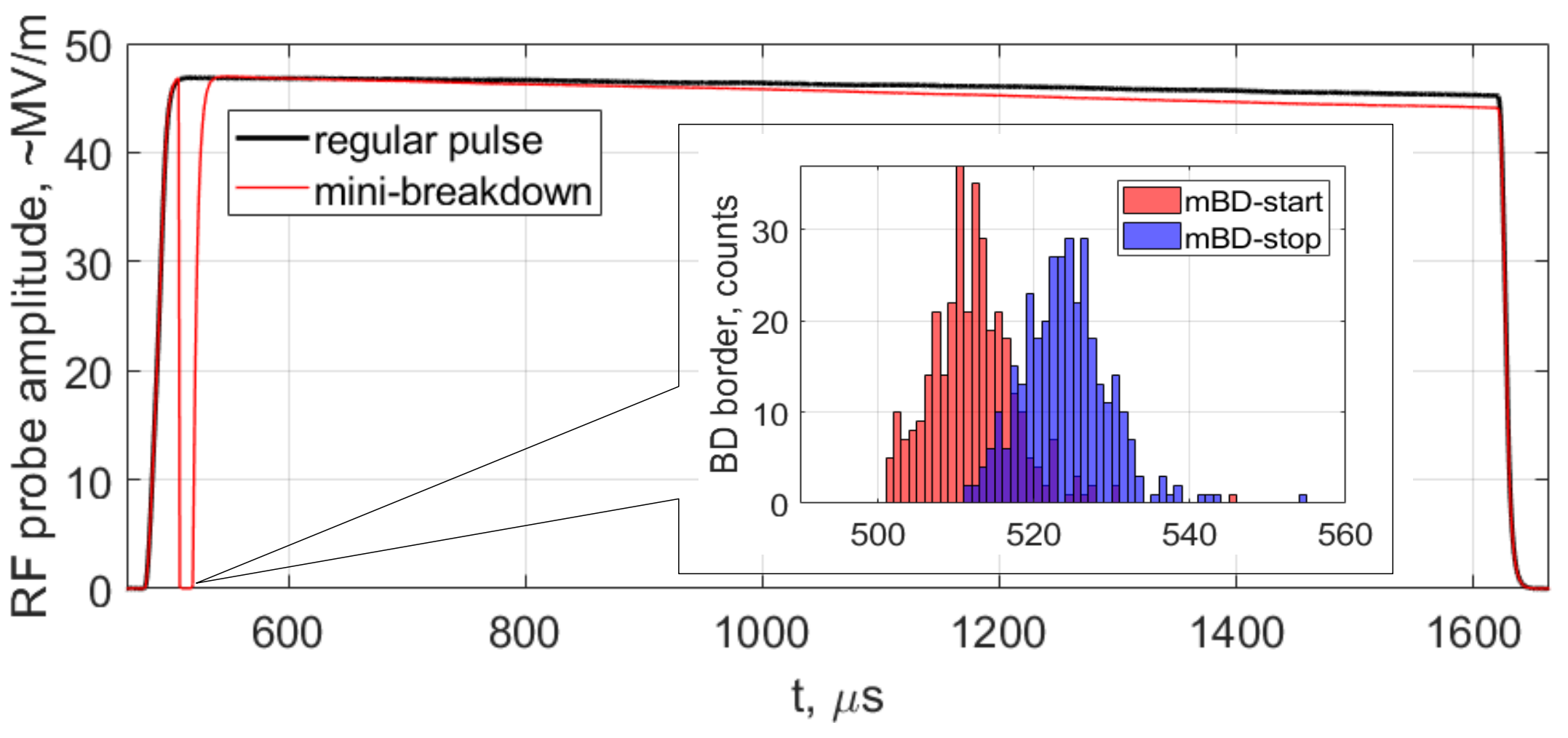


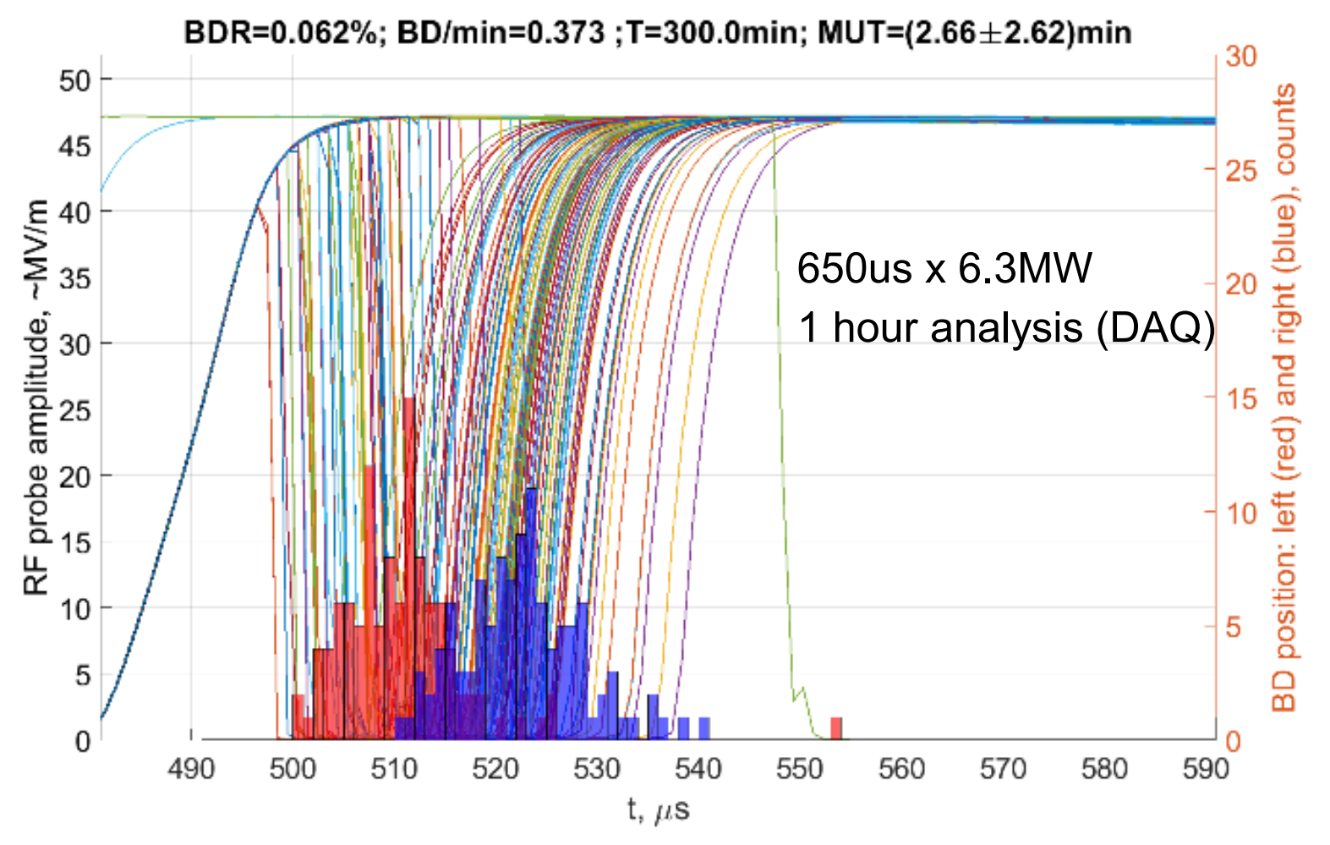
RF Gun Conditioning History

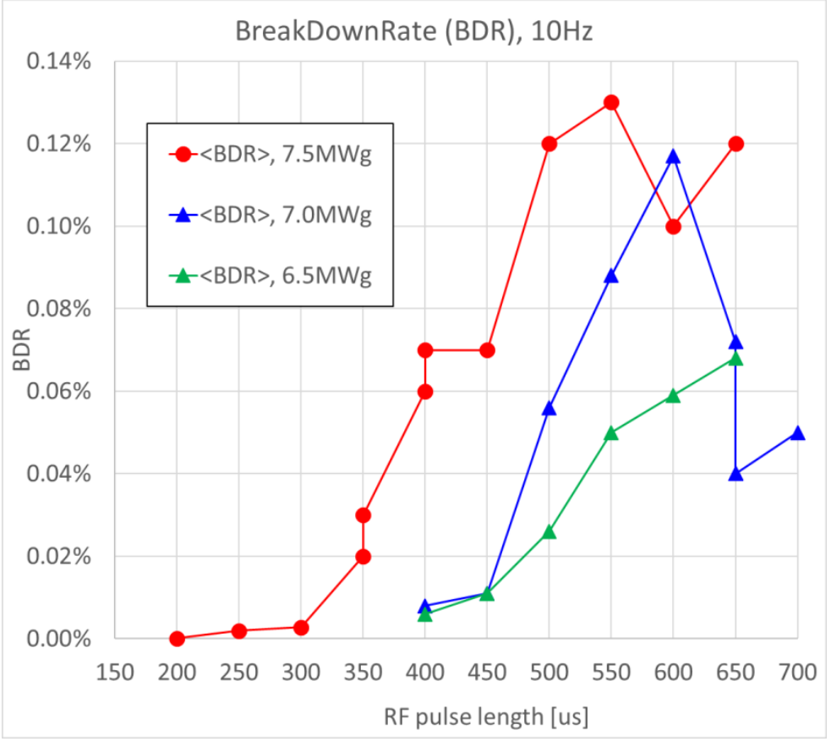


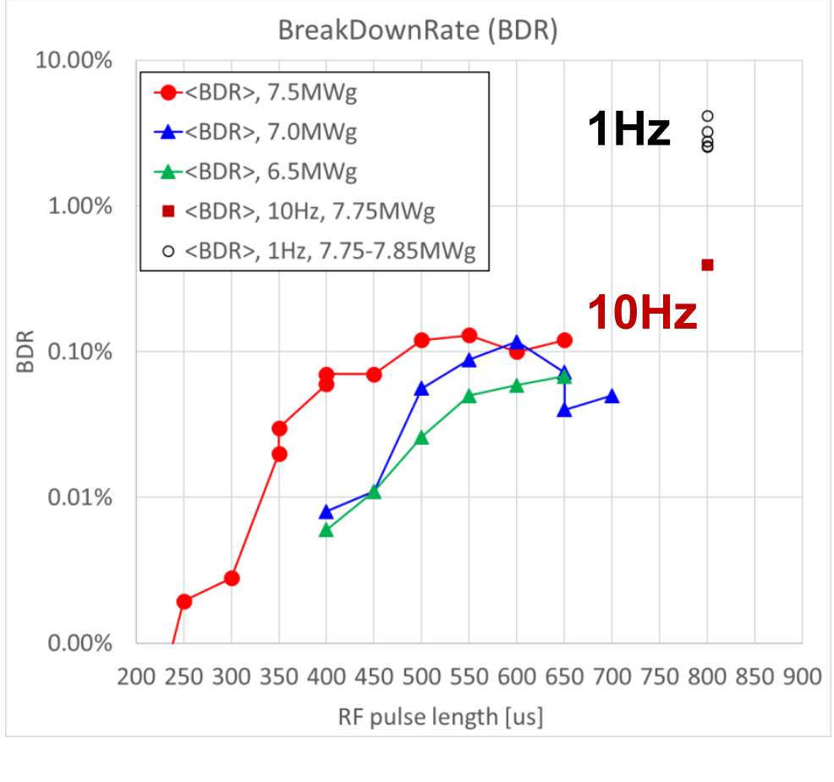
Mini-breakdown events

Currently, the RF performance of Gun5.1 is limited by what are called as mini-breakdowns within RF pulses detected by the gun cavity pickup and by all directional couplers for reflected power signals. A typical mini-breakdown (mBD) is a short (~10…15 µs) interruption within the first part of an RF pulse (usually the first 30 µs of the flattop), then the amplitude is restored within the characteristic cavity filling time to the nominal amplitude. The mini-breakdown rate (the ratio of number of "broken" pulses to the total pulse number) was measured to be ~0.05…0.2% at various RF pulse length and peak power levels. It starts to be detectable at an RF pulse length of ~350…400 µs and increases as the peak power increases. All mBD events are always accompanied by a small vacuum pressure spike (from ~2·10^{-9} mbar to 5…8·10^{-9} mbar), which is well below the vacuum interlock threshold. No correlation was found between mBD events and the static magnetic field configuration around the gun and the RF feed system. It is remarkable that the aforementioned location of a mBD within the RF pulse remains approximately the same for various pulse durations and peak power levels. The reason and nature of this distortion in the gun operation is still under investigation. Despite the rather low rate, mBD events could impact the efficiency of the LLRF feedback. This is a probable reason for irregular behavior of the rms jitter in the first part of the RF pulse measured during 1 ms LLRF tests.









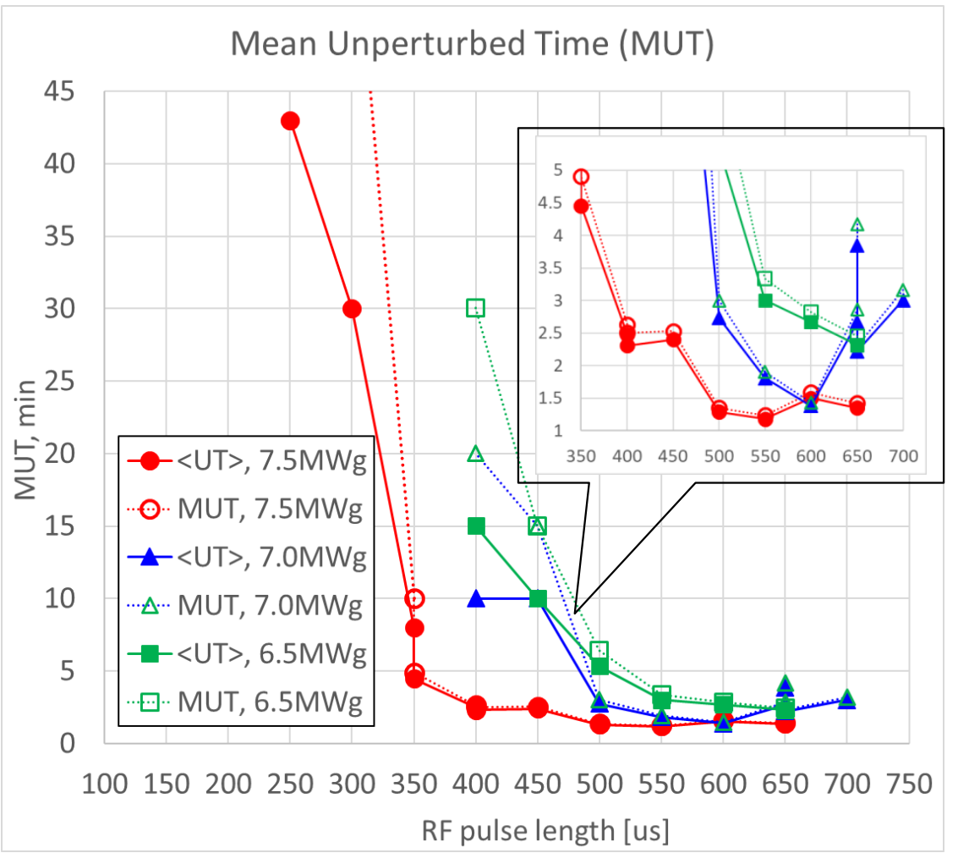
Breakdown rate (BDR):

$$BDR = \frac{\text{number of corrupted pulses}}{\text{total number of pulses}}$$

Mean Unperturbed Time:

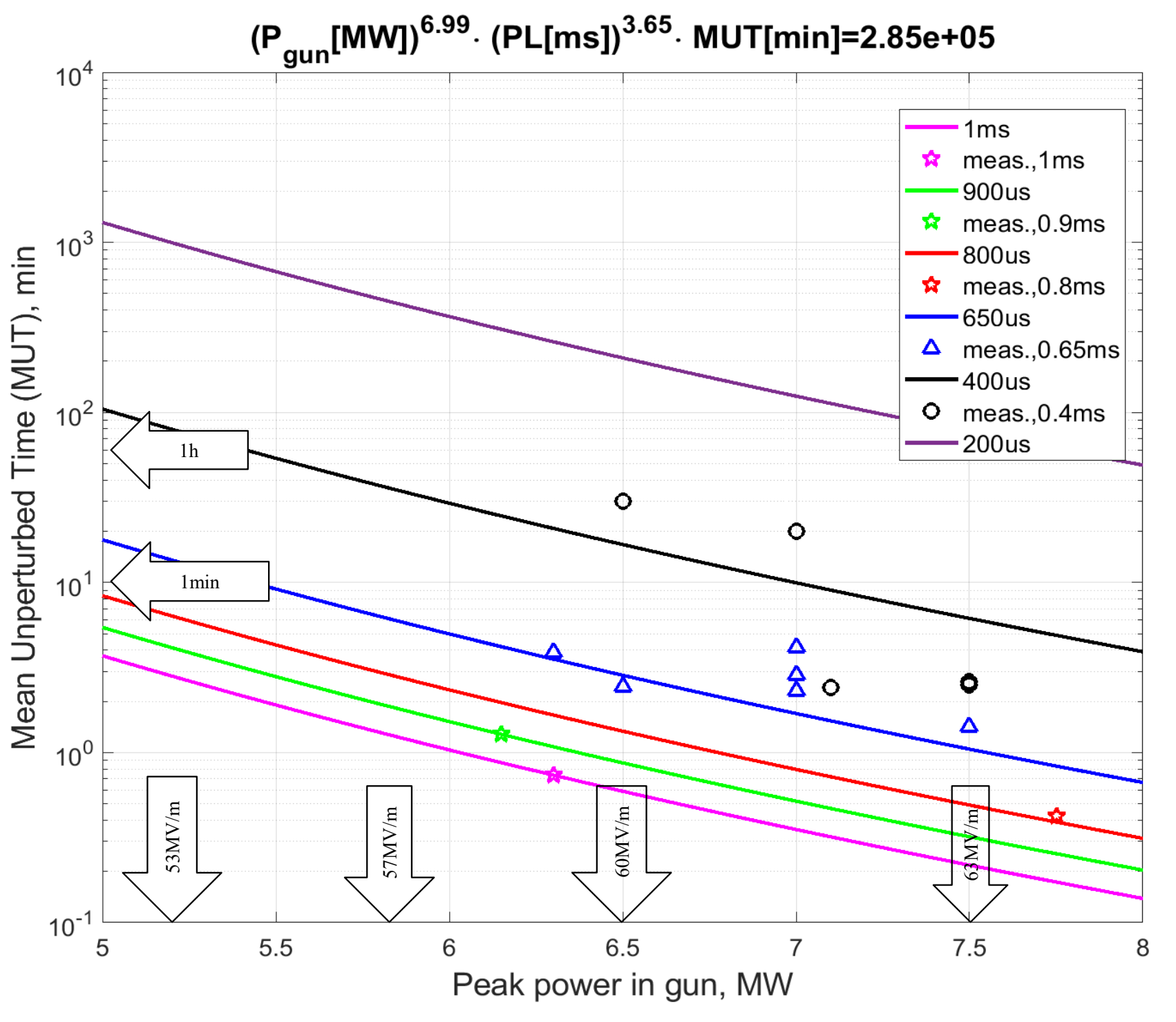
$$MUT = \frac{T_{meas}}{\text{number of corrupted pulses}}$$

$$MUT \sim \frac{1}{<BDR>}$$

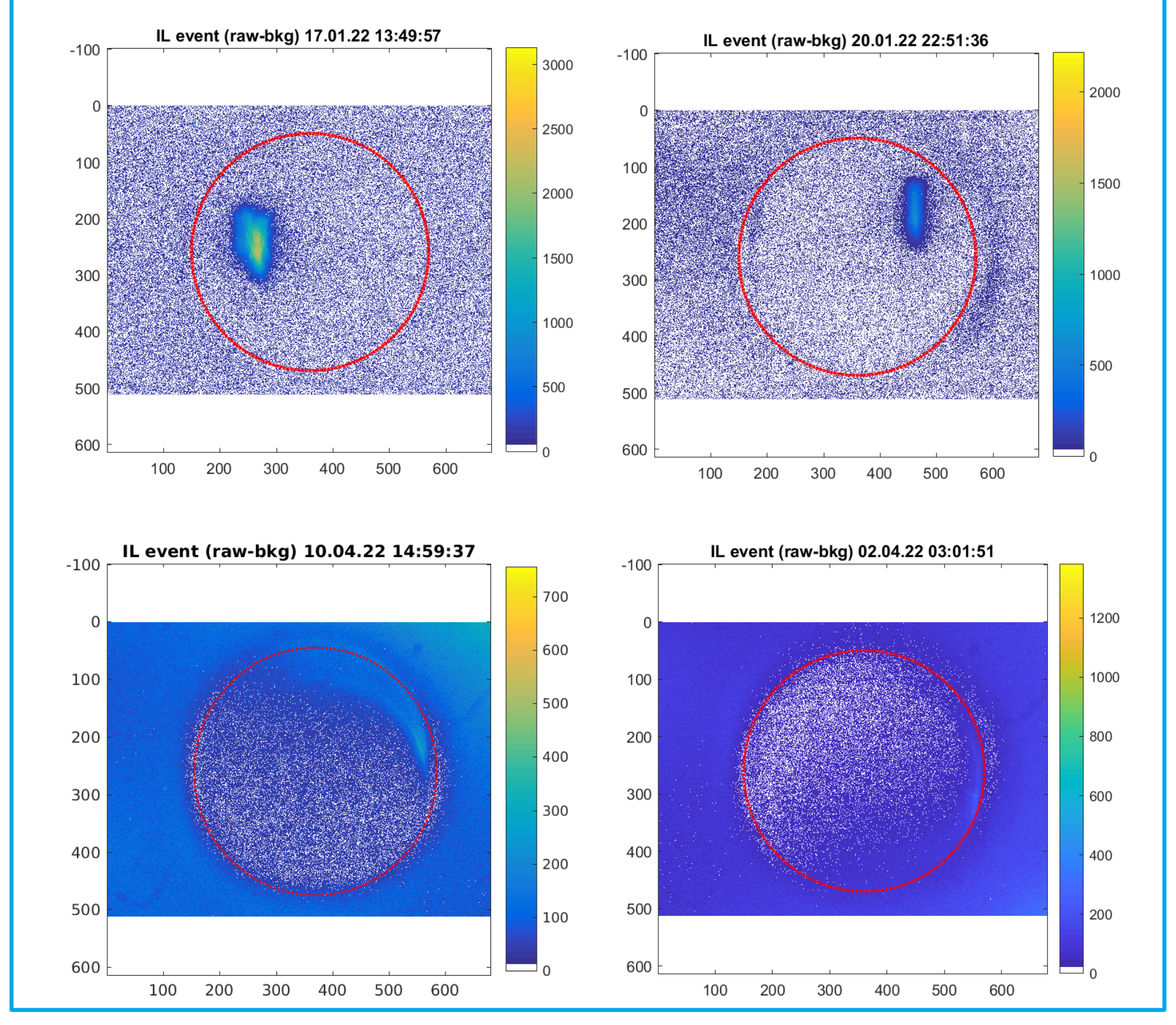


BDR (MUT) scaling* for PITZ

$$\left(P_{gun}[MW]\right)^a \cdot (PL[ms])^b \cdot MUT(min) \approx L = const$$



Gun trip imaging



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* A. Grudiev et al. "New local field quantity describing the high gradient limit of accelerating structures." *Physical Review Special Topics-accelerators and Beams* 12 (2009): 099902.

$$\frac{E_0^{30} \cdot \tau^5}{\text{BDR}} = \text{const},$$

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