High Gradient Testing of W-Band Accelerator Structures

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NORTH AMERICAN PARTICLE ACCELERATOR CONFERENCE

U.S. DEPARTMENT OF ENERGY Office of Science

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Outline

- Introduction
- Motivation and Performance of (sub-) THz Accelerators
- 110 GHz Standing-Wave Single-Cell Accelerating Structure
- Measurement of High Gradient Pulses and rf Breakdowns
- Conclusions

In Pursuit of Compactness, High Efficiency for rf Accelerators

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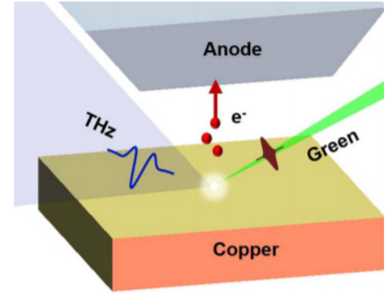
− **Accelerator Science and Technologies in the sub-Terahertz (100s GHz)regime enable**
  - Attosecond resolution
  - Ultrafast e⁻ diffraction
  - Compact X-ray sources
  - GeV Gradient, Brightness, …

− **Additional advantages**
  - Shunt impedance increases
  - RF pulse energy decreases
  - Breakdown threshold increases

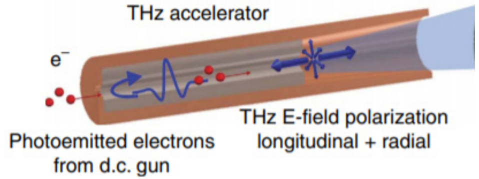
− **Contingent on rf sources development**
  - Microwave tubes, gyrotrons, ~MW, ns-μs
  - Laser generated, ~MW, ps

Photoinjectors

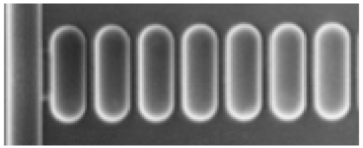


Huang et al., Scientific Rep. 5 (2015)
Huang et al., Optica (2016)

Accelerators

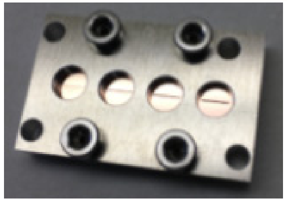


Nanni et al., Nature Comm. 6 (2015)

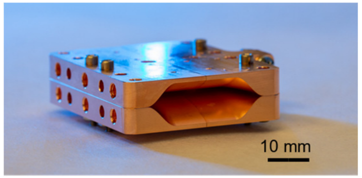


Dal Forno et al., PRAB 19 (2018)

Deflectors and Compressors

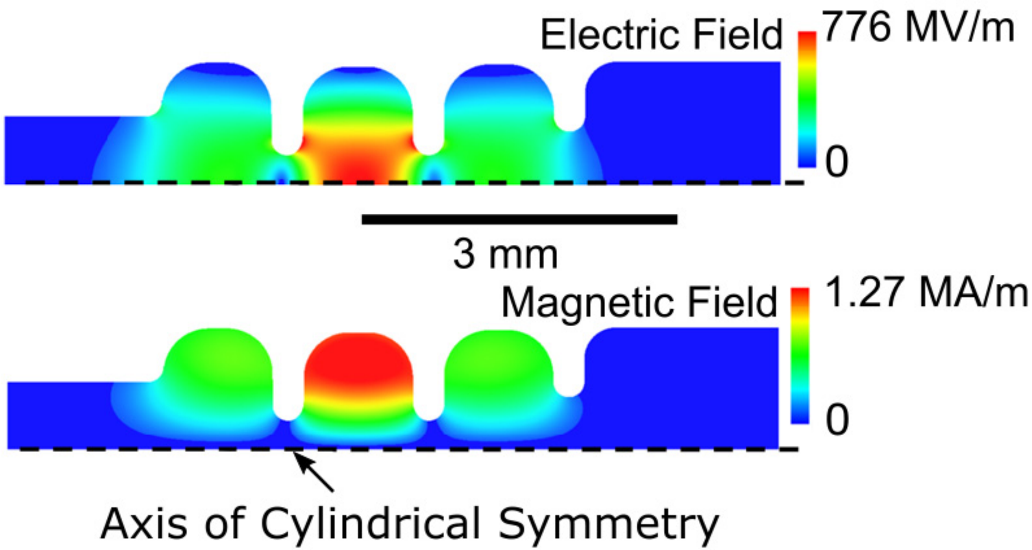


Li, et al., PRAB (2019)



Othman et al., OE (2019)
Snively et al., arXiv (2019)

Design of the First Externally Driven Single Cell W-Band Accelerator Structure



- Structure designed for comparison with X-band studies**

1 MW dissipated power ← (Accelerating gradient)

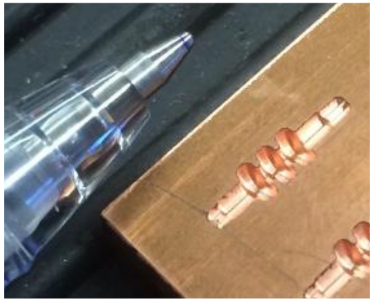
10 ns pulse ← (Pulsed heating)

Iris thickness [mm]	0.2
Quality factor Q_0	3200
Shunt impedance [MΩ/m]	360
$E_{surface}/E_{acc}$	2.27
Accelerating gradient E_{acc} [MV/m]	404
Pulsed heating [K]	70
Fill time [ns]	5

**Dolgashev et al., *Appl. Phys. Lett.* 97.17 (2010).

Coupling of High Power from External rf Source at sub-THz

Assembly of structure and impact on RF and high gradient performance is a key concern

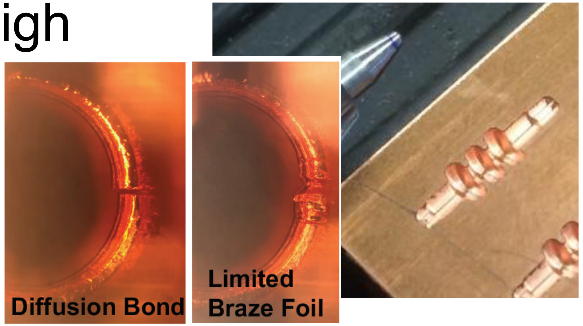


Nanni et al., *IPAC* 2016
Othman et al., *IPAC* 2019

Coupling of High Power from External rf Source at sub-THz

Assembly of structure and impact on RF and high gradient performance is a key concern

- Efficient excitation and avoid lossy metal waveguide
- 10s ns pulses to reduce pulsed heating



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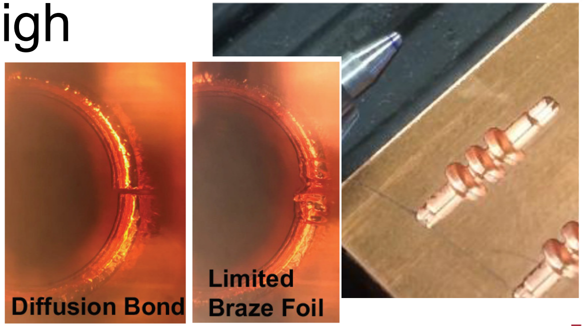
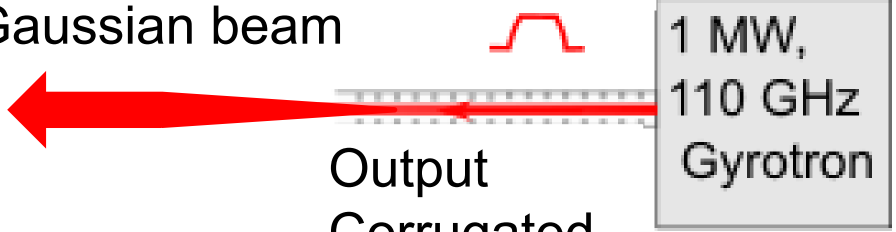
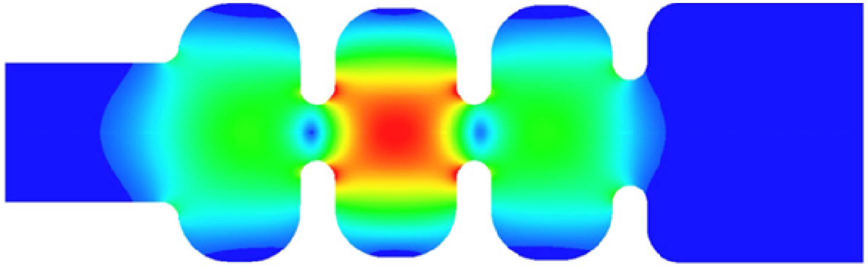


μs Pulses

Gaussian beam



Output Corrugated Waveguide



110 GHz accelerator

- ✓ Quasi optical transport
- ✓ Ultrafast rf switch

Nanni et al., *IPAC* 2016
Othman et al., *IPAC* 2019

Gaussian to TM Mode Converter for a 110 GHz Accelerator Cavity

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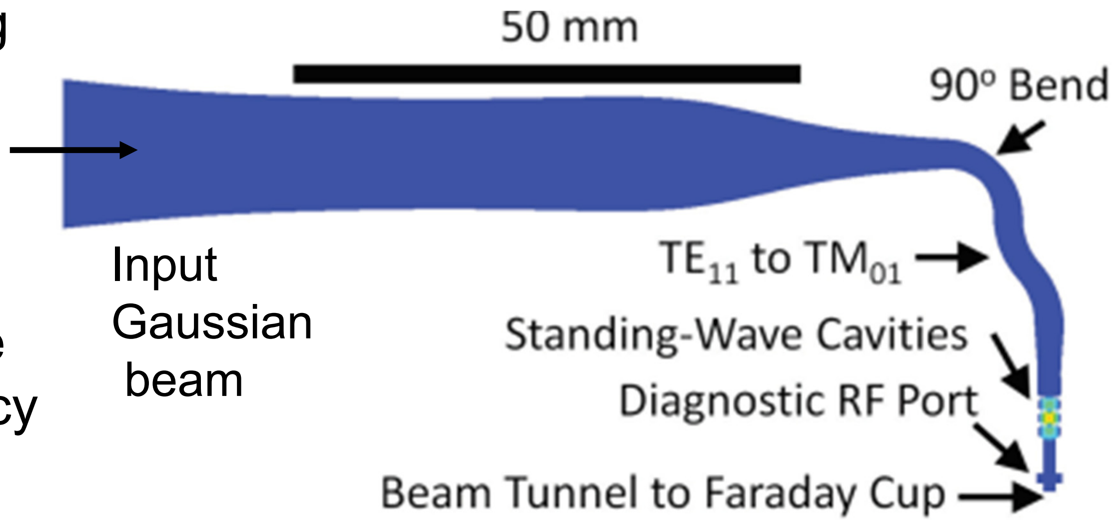
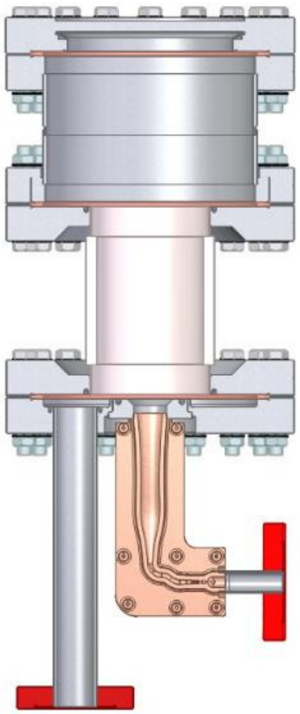
- The rf power is coupled using a tapered Gaussian horn
- The horn converts the Gaussian mode into the TE_{11} mode of a circular waveguide with 99% conversion efficiency

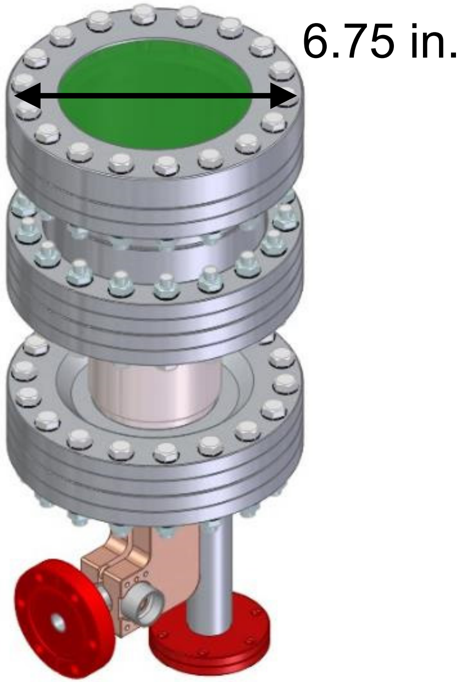


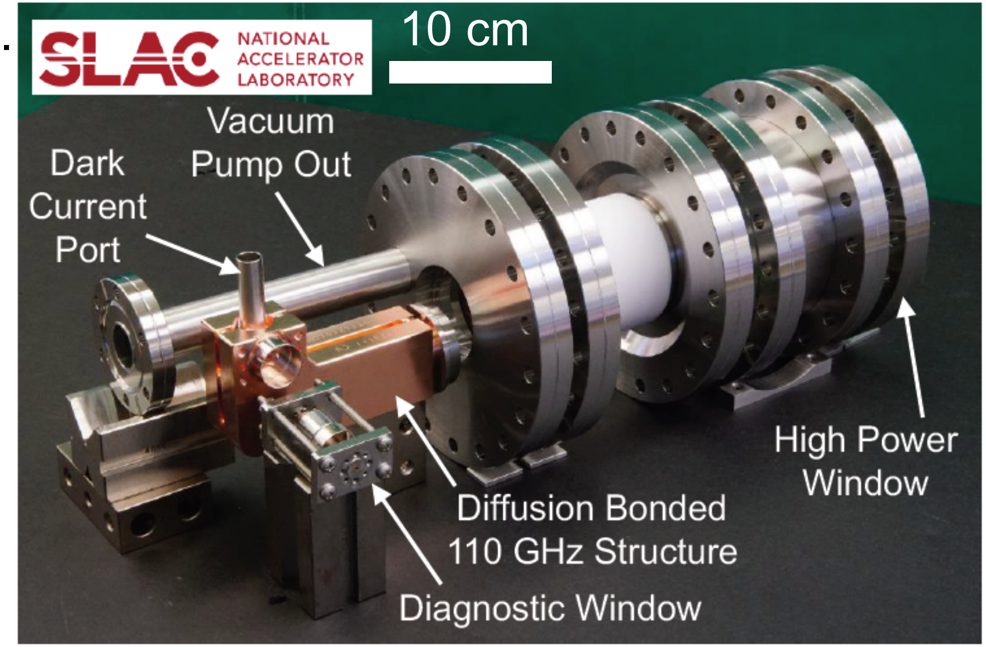
- A TE_{11} to TM_{01} mode converter includes a 90º bend with a 97% power conversion efficiency and a bandwidth exceeding 2 GHz
- A WR-10 diagnostic window is used to probe cavity fields

Nanni et al., *IPAC* 2016.

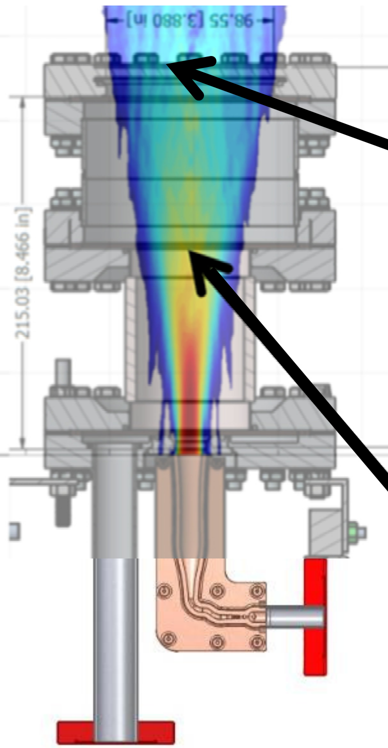
110 GHz High Gradient Structure Full Assembly



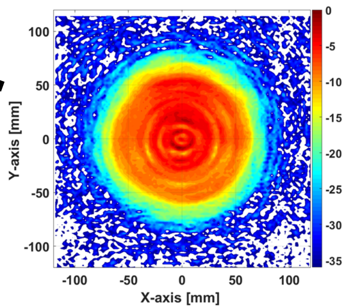




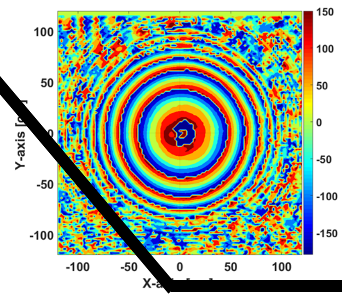
Quasi-Optical Transport Cold Test



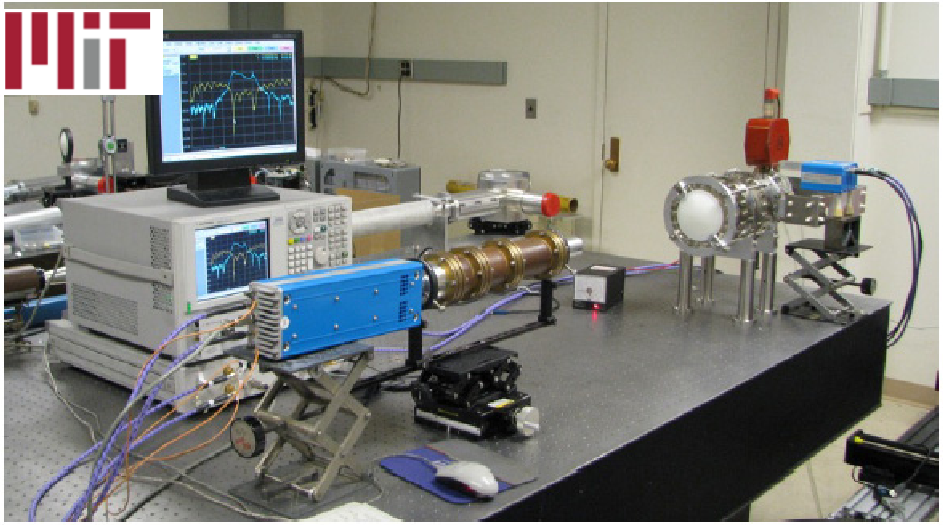
Measured Amplitude



Measured Phase



Gaussian beam launcher used to test excitation

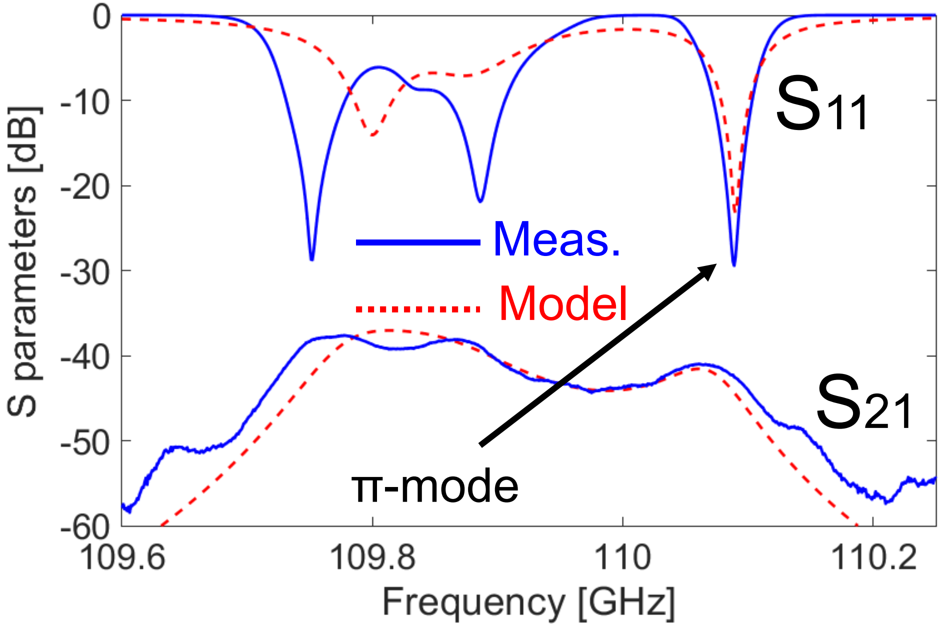


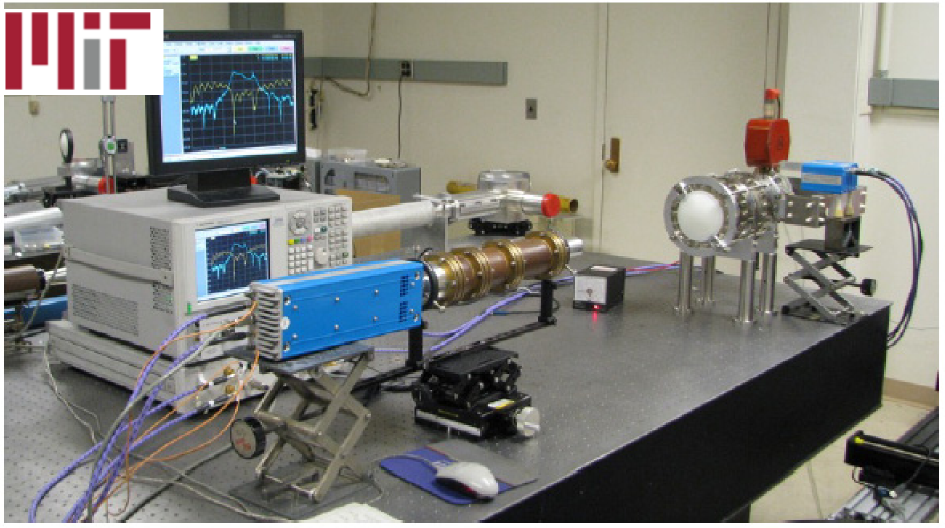
Back propagated field in the cut plane of the assembly

First Quasi-Optical Coupling into Narrow-Band Accelerating Structure

Quasi-Optical Transport Cold Test

- Good agreement in cold test - π-mode 110.1 GHz, S_{11}<−25 dB, S_{21}≈−41 dB

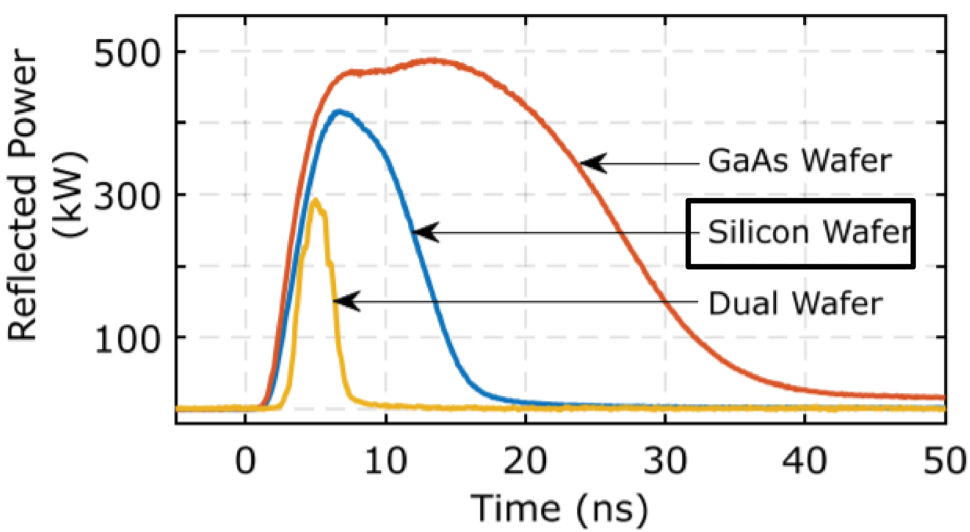


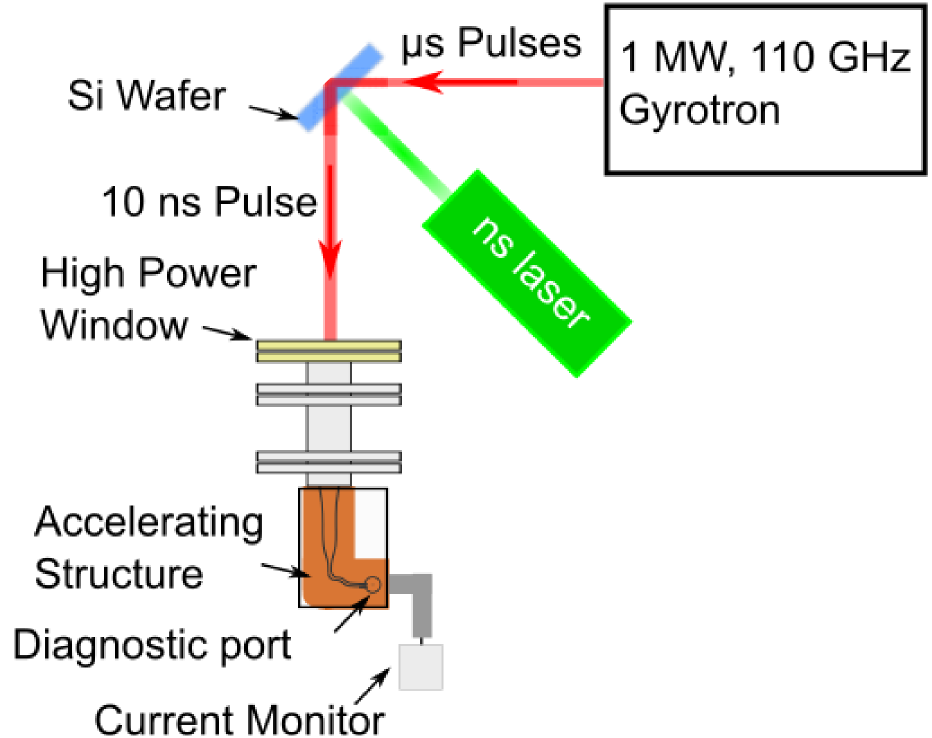


First Quasi-Optical Coupling into Narrow-Band Accelerating Structure

Laser-Based Semiconductor Switch for Pulse Shaping

- Short tunable pulse lengths 10s ns at MIT
- Quasi-optical coupling at high power up to MW





Picard et al., *App. Phys. Lett* 114.16 (2019)
Kutsaev et al., *Phys. Rev. Appl.* 11.3 (2019)

Laser-Based Semiconductor Switch for Pulse Shaping

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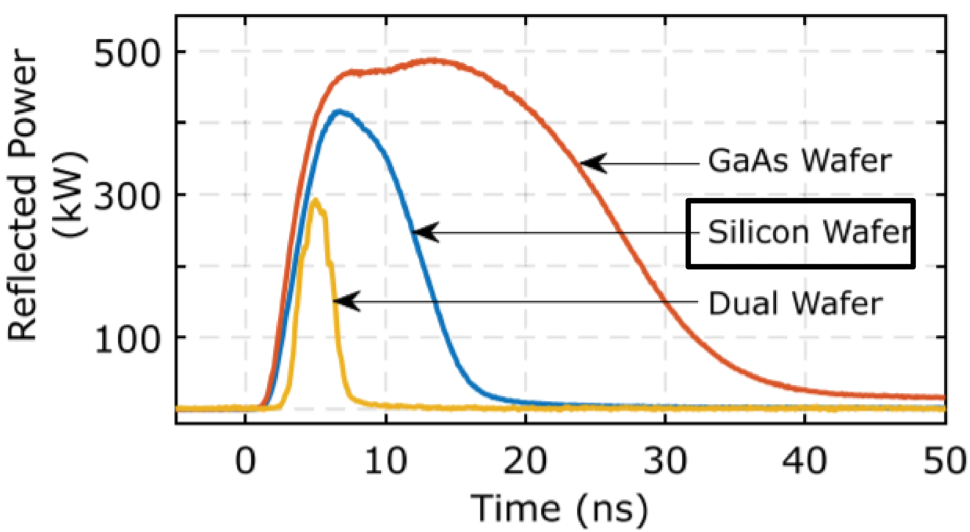

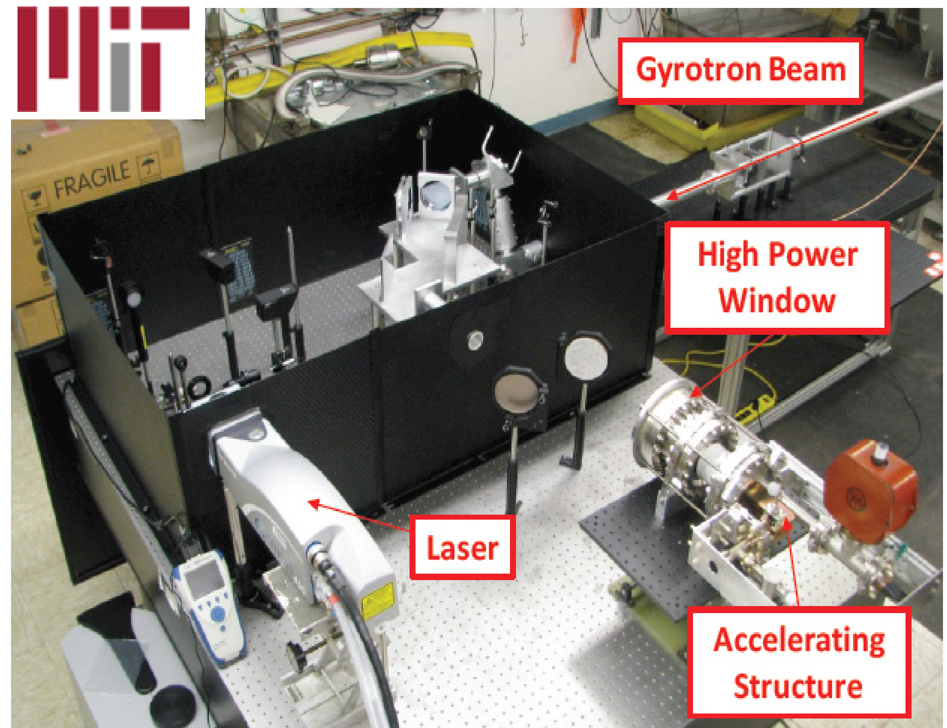

Picard et al., *App. Phys. Lett* 114.16 (2019)
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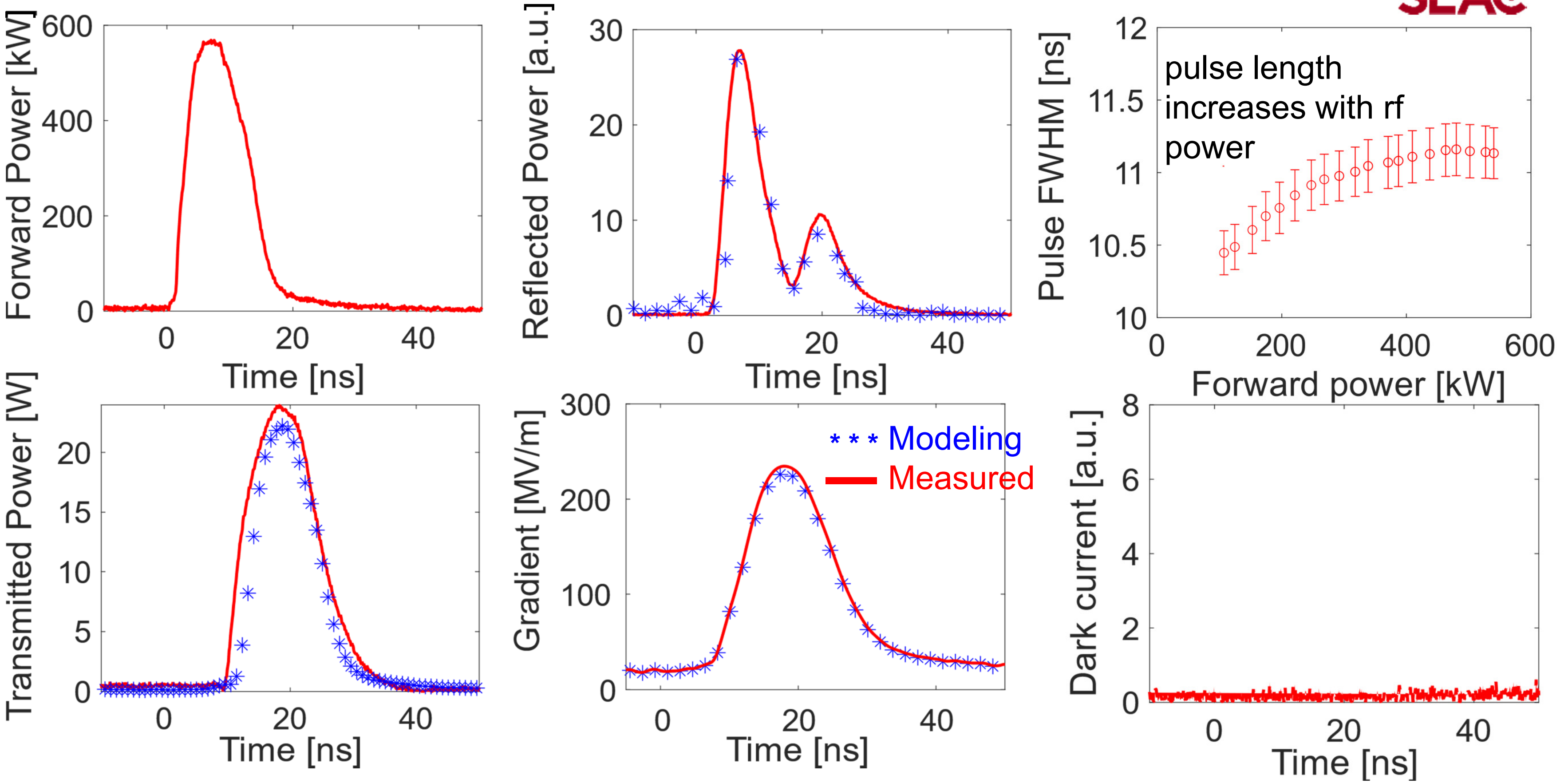
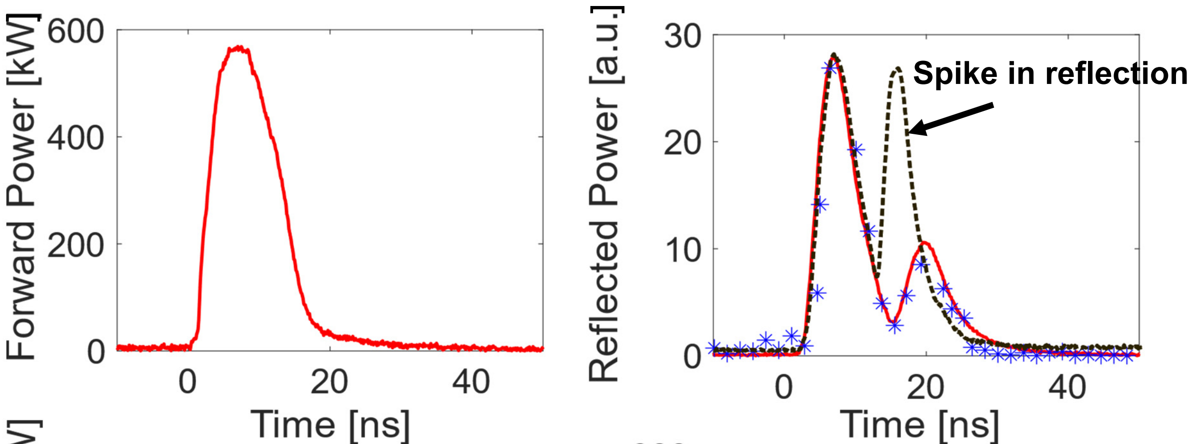
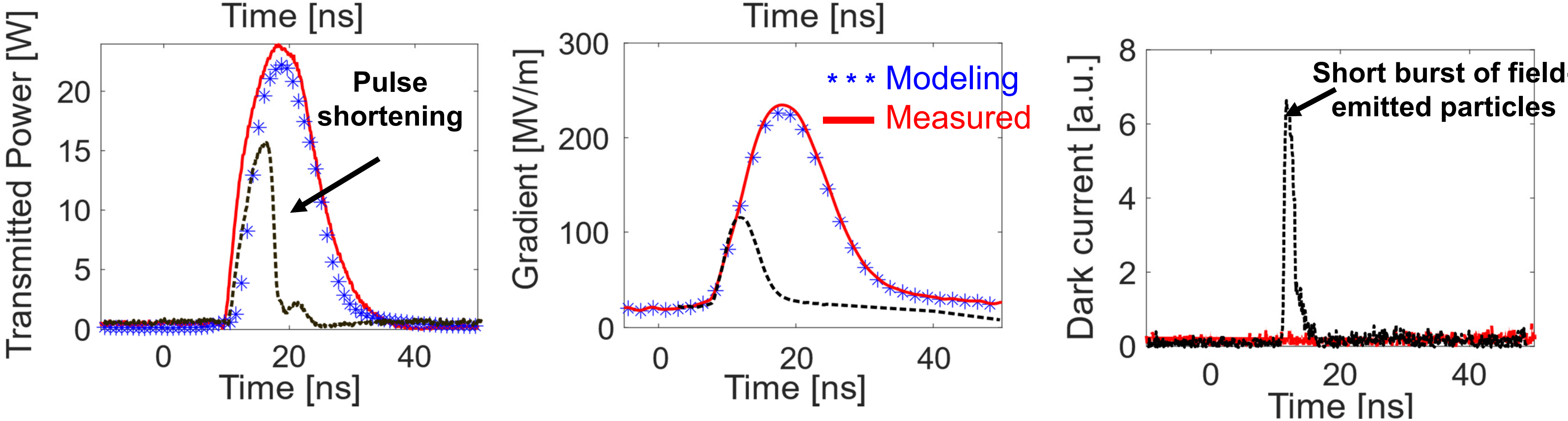
Measurement of High Power rf Pulses



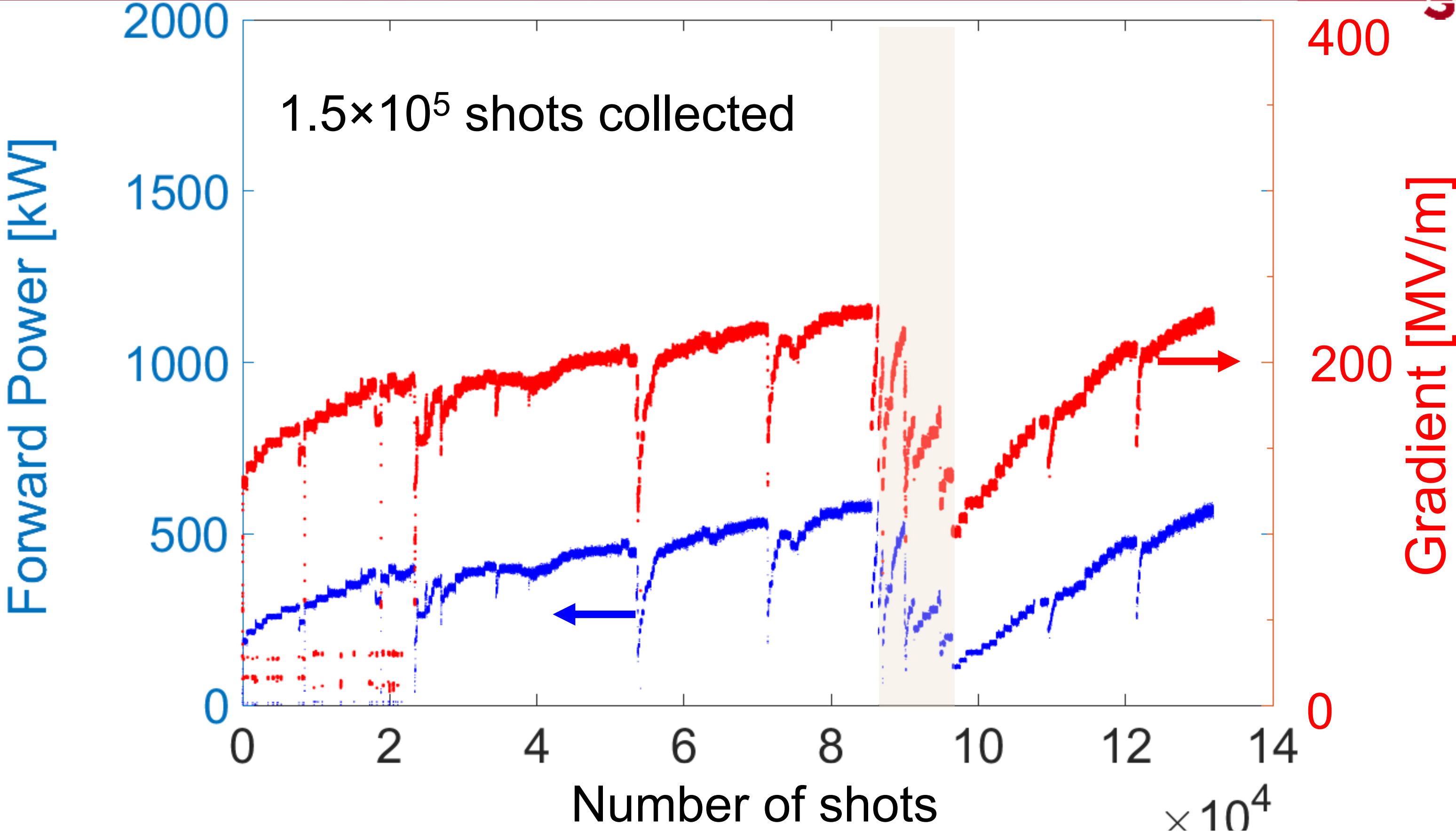
Measurement of High Power rf Pulses – rf Breakdowns



Must Understand BDR at this New Regime for Gradient, Pulse Length, Pulsed heating



Cavity Processing and Collecting Breakdown Statistics



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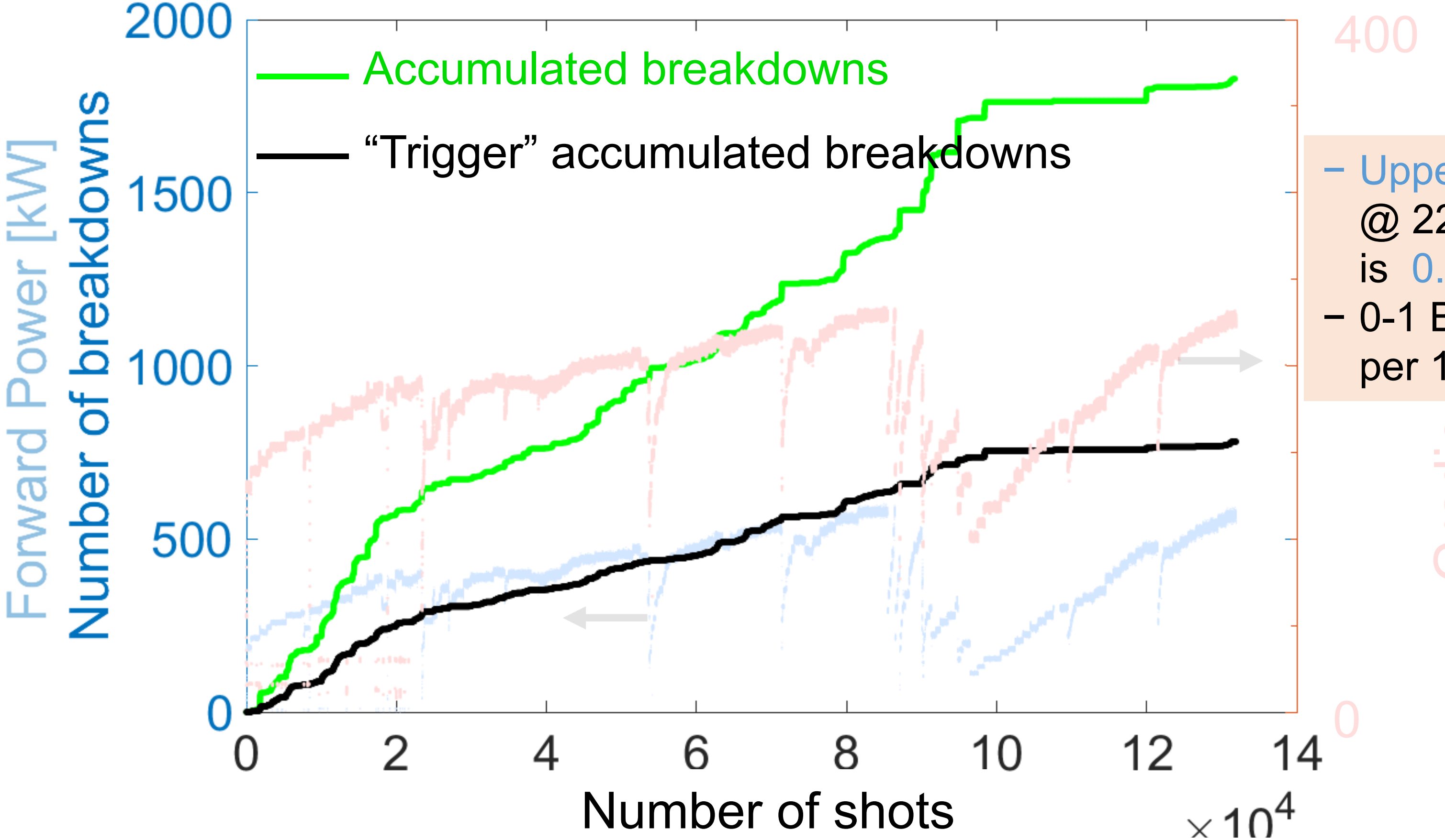
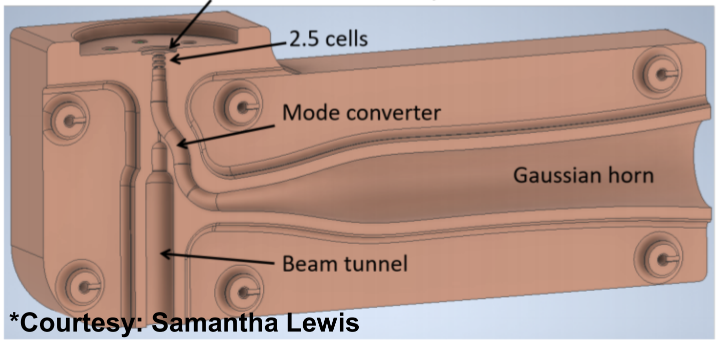


- Upper bound @ 220 MeV/m is 0.1/pulse/m
- 0-1 BD event per 1k shots

Summary and Outlook

- mm-Wave/THz accelerating structures promise high gradient achieving GeV/m
- Understanding the performance of structures at high frequency and high-field is needed
- Advanced manufacturing techniques deliver expected performance
- Record breakdown statistics at highest gradient for at least 10^6 shots – Comparison with X-band studies
- Gun type structures, field emission



*Courtesy: Samantha Lewis

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Samantha Lewis

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Thank you for your attention!

– Questions?

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