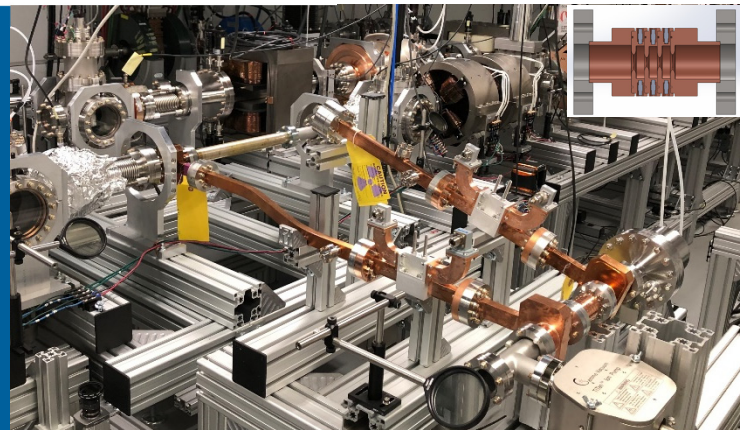


DEMONSTRATION OF GRADIENT ABOVE 300 MV/m IN SHORT PULSE REGIME USING AN X-BAND SINGLE- CELL STRUCTURE



JIAHANG SHAO*

On behalf of collaboration between Argonne National Laboratory and Tsinghua University

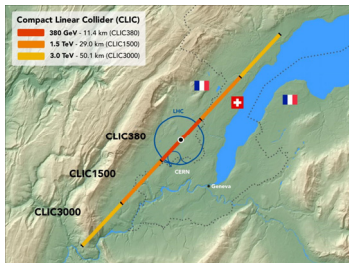
OUTLINE

- **Background and motivation**
- **X-band single-cell travelling-wave structure design**
- **Short-pulse high-power test at Argonne**
- **Long-pulse high-power test at Tsinghua**
- **Discussion**
- **Summary and future study**

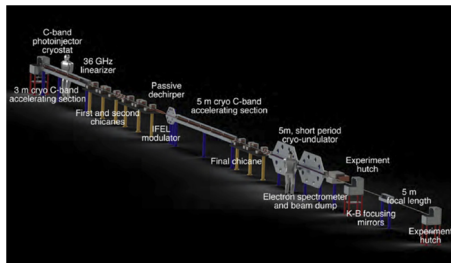
BACKGROUND AND MOTIVATION

-High gradient acceleration -

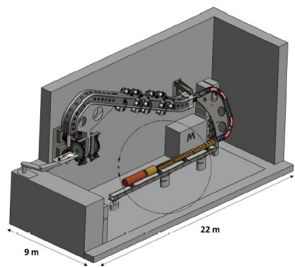
- Critical for future linear colliders and compact linac-based facilities



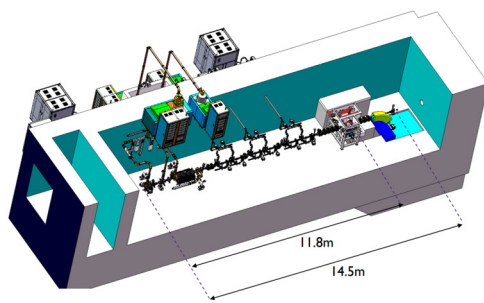
CLIC updates, CERN-2016-004 (2016)



J. Rosenzweig et al., NJP 22, 093067 (2020)



S. Benedetti et al., PRAB 20, 040101 (2020)



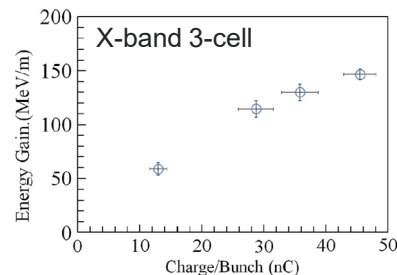
Q. Gao, HG2022

-Short-pulse acceleration -

- Promising approach to further improve gradient

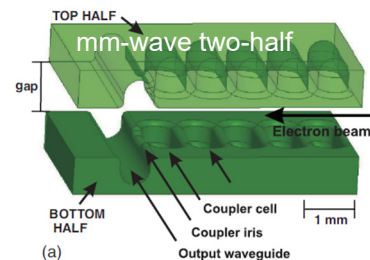
$$BDR \propto E^{30} \tau^5$$

A. Grudiev et al., PRSTAB 12, 102001 (2009)



TBA 6 ns 150 MV/m

C. Jing et al., NIMA 898, 72-76 (2018)



CWA 2.4 ns 300 MV/m

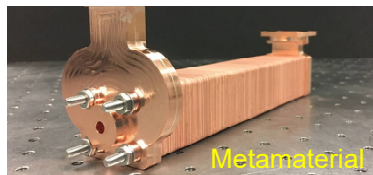
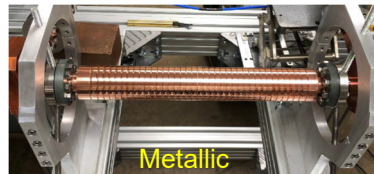
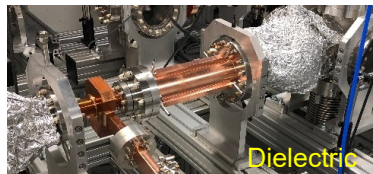
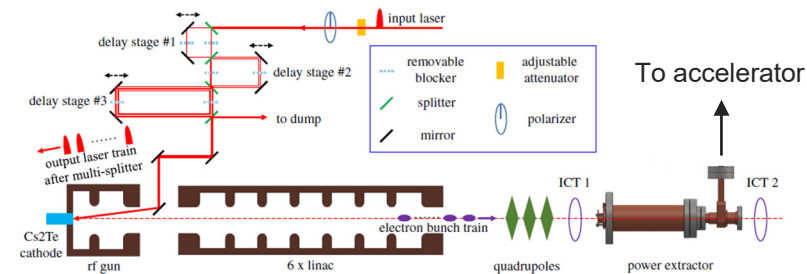
M. Forno et al., PRAB 19, 011301 (2016)

- Direct comparison of gradient between short and long pulse is yet to be performed

X-BAND SINGLE-CELL TRAVELLING-WAVE STRUCTURE

Short-pulse power source

- Power extractors driven by high charge at AWA

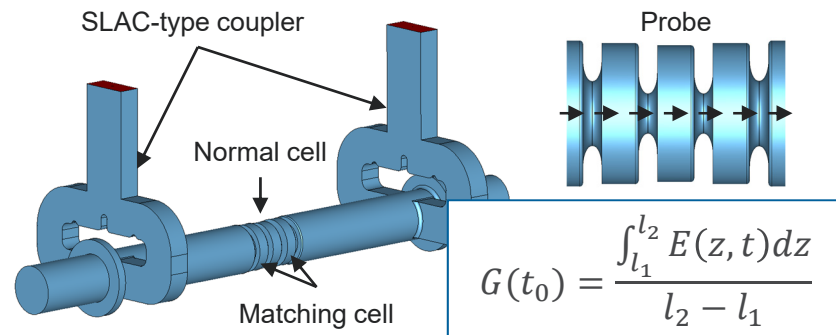


6 ns FWHM, 3 ns flat-top, 400 MW

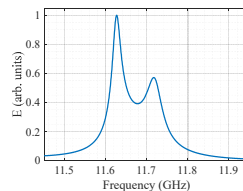
C. Jing et al., NIMA 898, 72-76 (2018)

Single-cell structure

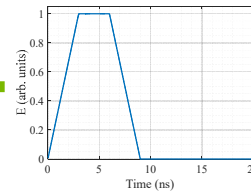
- Transient gradient calculation



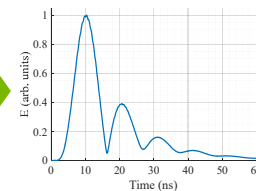
Frequency response



Input signal



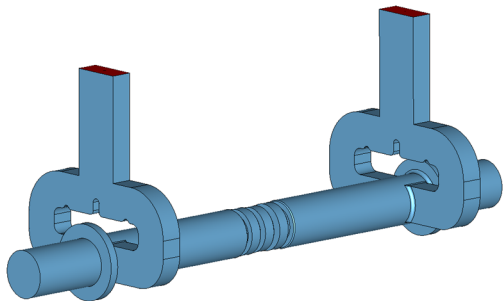
Transient field



X-BAND SINGLE-CELL TRAVELLING-WAVE STRUCTURE

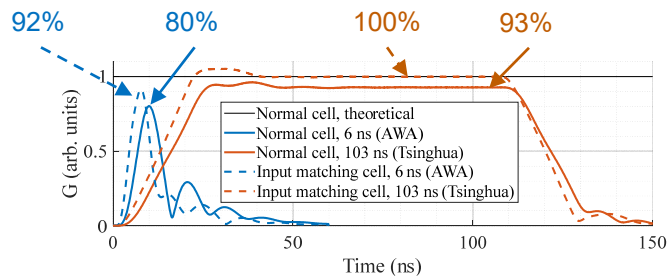
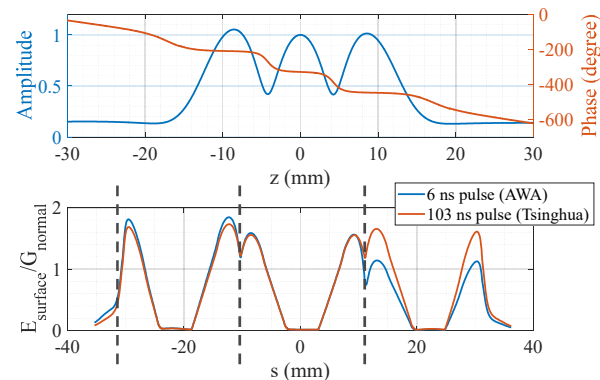
Single-cell structure

- Optimized for maximum transient gradient



Normal cell properties (11.7 GHz)

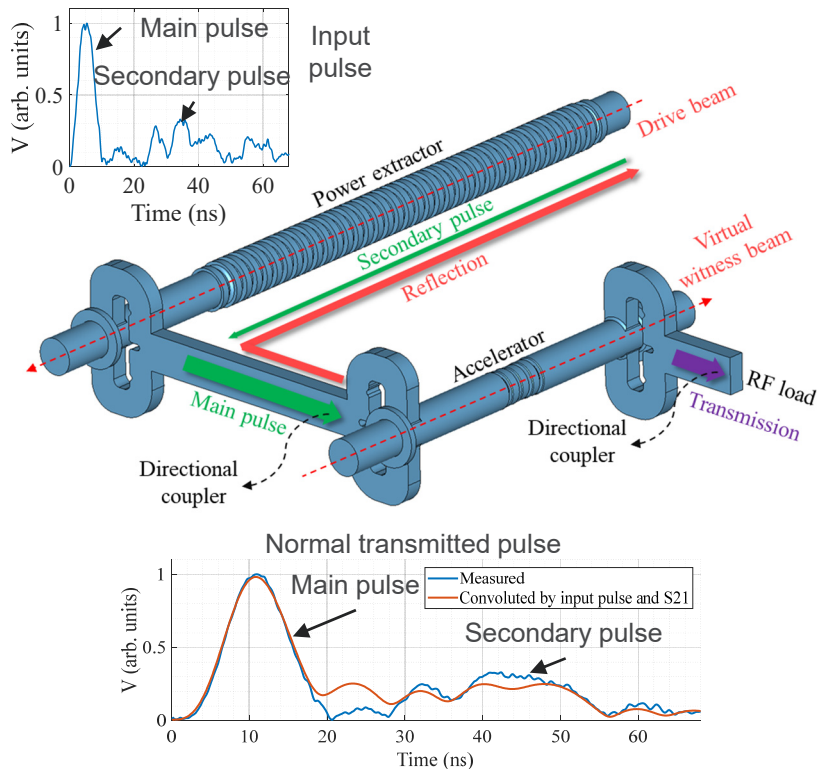
Iris diameter	6.1 mm
Iris thickness	2.9 mm
Phase advance	120 degree
Quality factor	6070
Shunt impedance r/Q	$1.4 \times 10^4 \Omega/m$
Group velocity	$0.0114c$



- The input matching cell has higher gradient and surface field than the normal cell

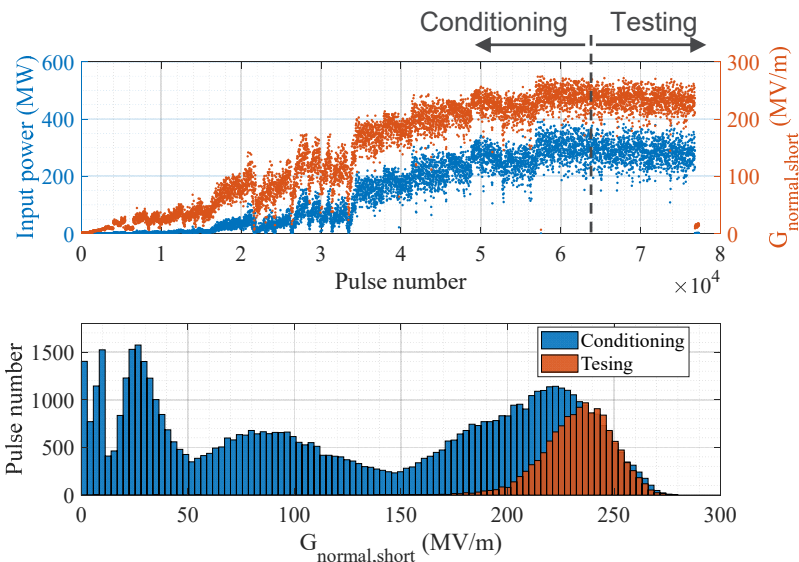
SHORT-PULSE HIGH-POWER TEST AT ARGONNE

Experimental setup



RF conditioning

- 7.7×10^4 pulses accumulated at 2 Hz repetition

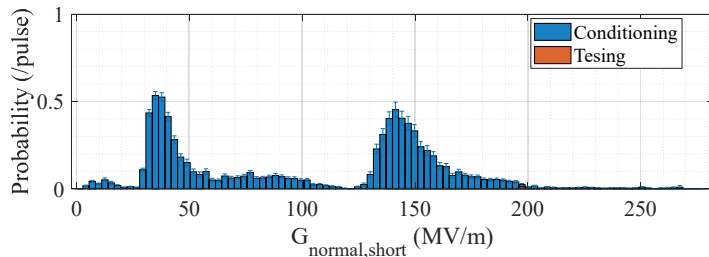
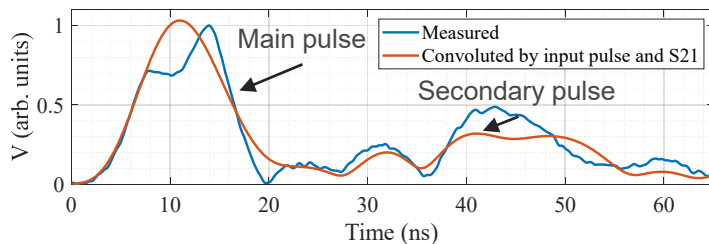


SHORT-PULSE HIGH-POWER TEST AT ARGONNE

Abnormal type I

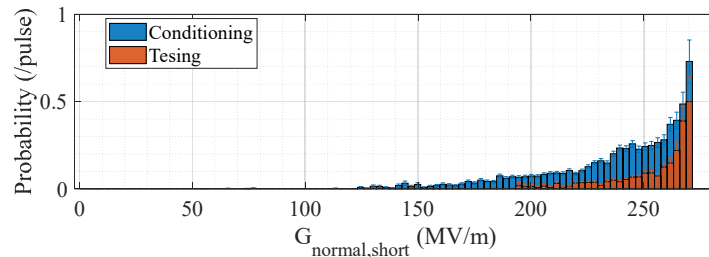
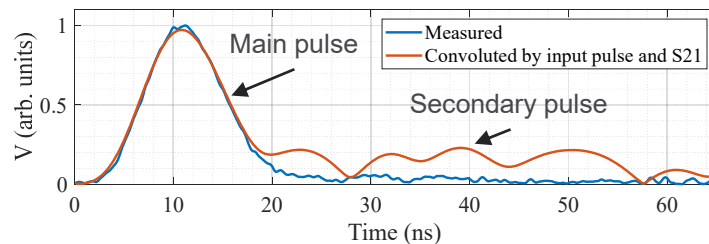
- Distorted main pulse
- Disappeared after conditioning
- Likely to be caused by multipacting

H. Xu et al., PRAB 22, 021002 (2019)



Abnormal type II

- Blocked secondary pulse and normal main pulse
- Probability decreases after conditioning
- Likely to be caused by RF breakdown



LONG-PULSE HIGH-POWER TEST AT TSINGHUA

Experimental setup

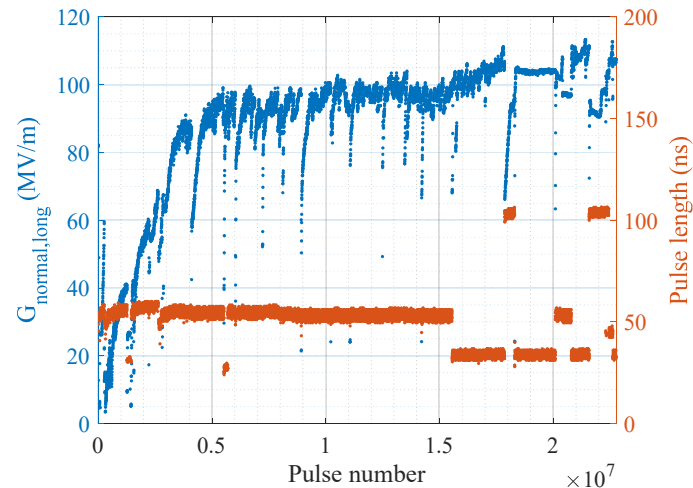
- Driven by klystron with pulse compressor



Y. Jiang et al., IEEE Trans. Microw. Theory Tech., 69, 1586-1593, (2021)

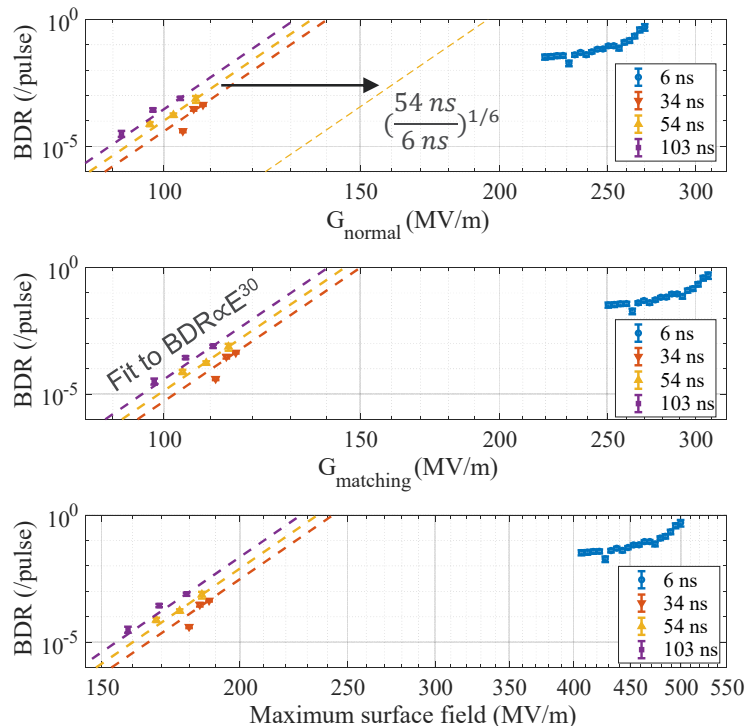
RF conditioning

- 2.3×10^7 pulses accumulated at 40 Hz repetition



DISCUSSION

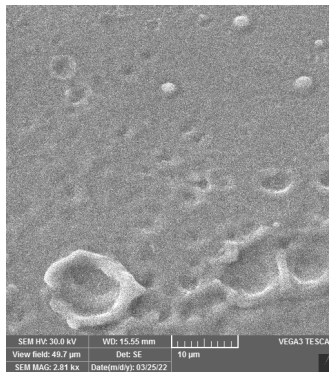
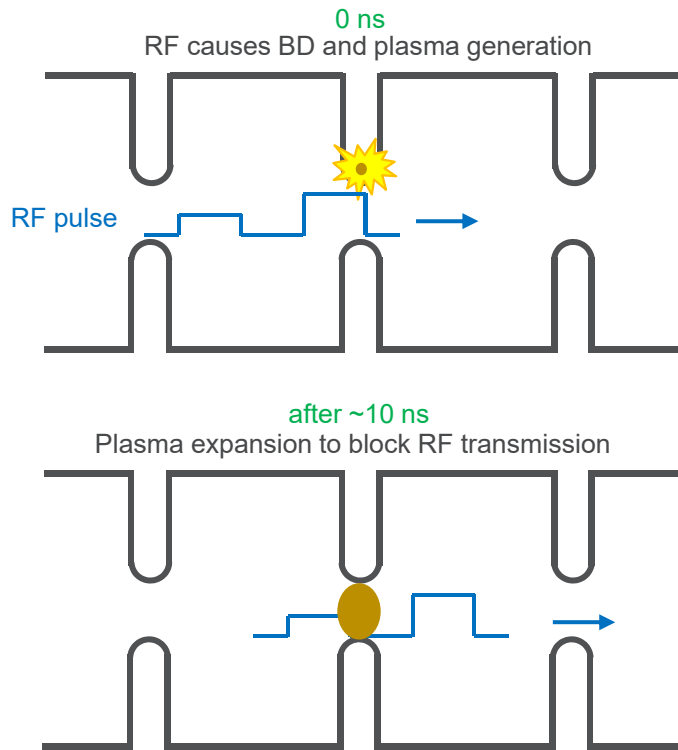
Comparison of short and long pulse results



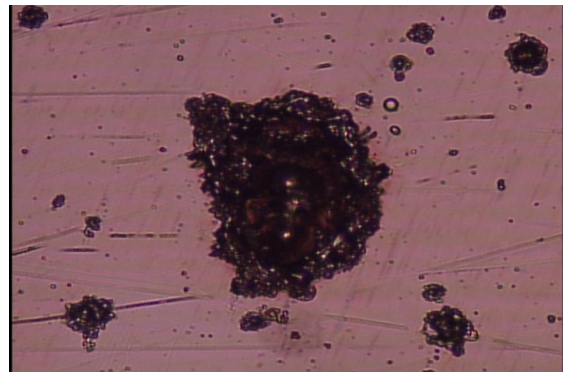
- Accelerating gradient of the normal cell and the input matching cell reaches **270 MV/m** and **310 MV/m**
 - Surface field of the input matching cell reaches **500 MV/m**
 - Gradient improved at least twofold using short pulse (limited conditioning period, only secondary pulse taken into consideration)
 - BDR vs. pulse length doesn't follow the empirical scaling law in short-pulse regime
- ↓
- **New physics of RF breakdown in short-pulse regime**

DISCUSSION

- Breakdown Insensitive Acceleration Regime (BIAR) -



ANL: $\phi 10\text{-}20\ \mu\text{m}$



- Transmitted RF pulse and accelerated beam not influenced by RF breakdown
- Reduced structure damage due to limited energy available for breakdown avalanche

SUMMARY AND FUTURE STUDY

- **First direct comparison of achievable gradient in short and long pulse TBA scheme**
 - Short-pulse gradient doubles the long-pulse one:
 - 270 MV/m and 310 MV/m accelerating gradient in the normal cell and the input matching cell
 - 500 MV/m surface gradient in the input matching cell
 - With short pulses, the main pulse shape remains intact at high field and structure surface presents reduced damage
- **Future directions**
 - Systematically investigate the dependence of BDR on pulse length and iris size in short-pulse regime
 - Expand high gradient study into multi-cell structures: DDA, MTM, parallel-coupled, ...
 - Conduct application research in BIAR regime

ACKNOWLEDGEMENT

- **Argonne Team**

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THANKS!