



ACCELERATOR LABORATORY OF
TSINGHUA UNIVERSITY

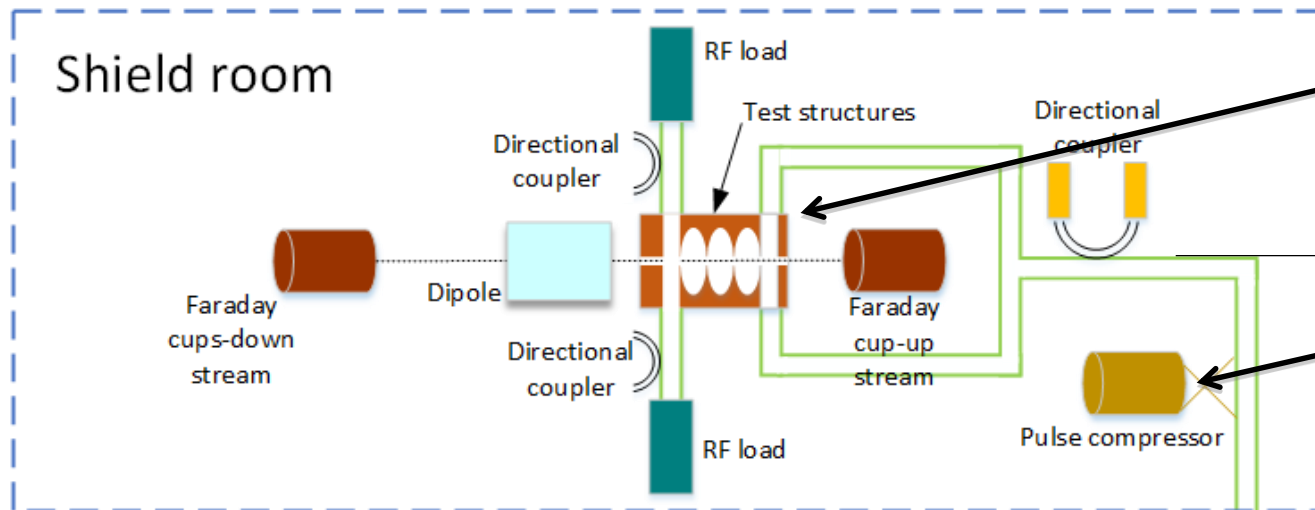


Development of Tsinghua X-band High Power Test stand (TPoT-X)

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The 12th International Workshop on Breakdown Science and
High Gradient Technology, Chamonix, France

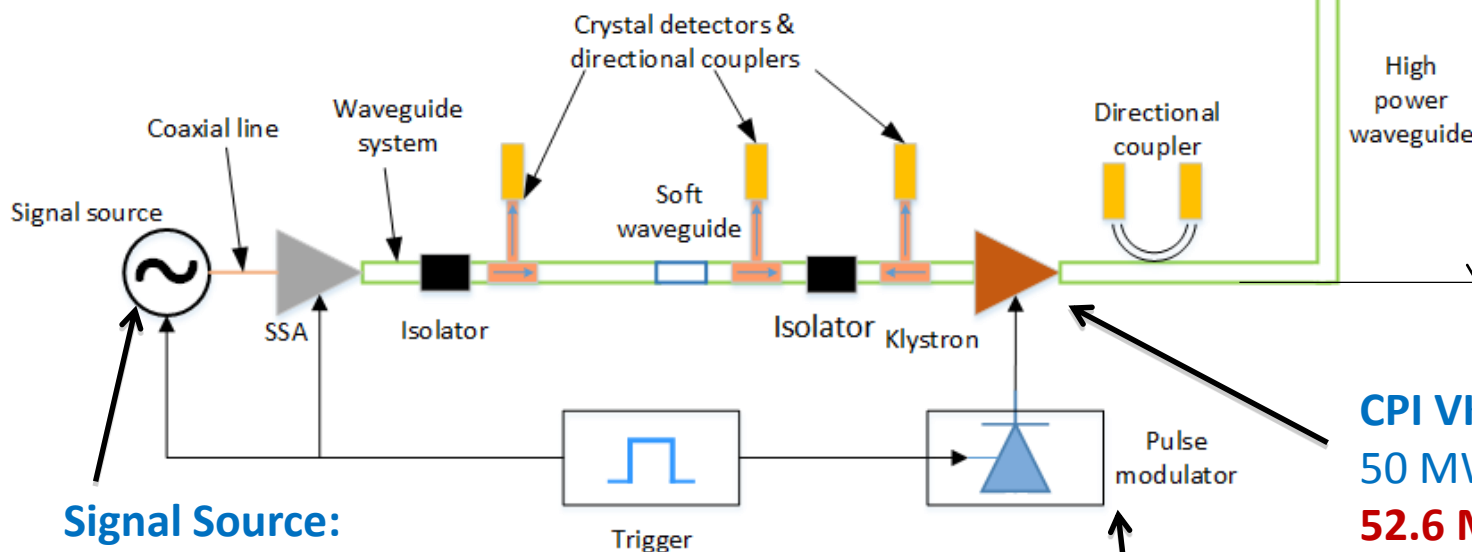
System diagram of TPoT-X



Power at DUT:
37.8 MW, 1.5 us or
55.0 MW, 180 ns
(tested)
190 MW, 180 ns
(expected)

Newly installed pulse compressor:
 Gain = 5.0, 1.5 us to 180 ns

Waveguide from source to load: 6 m
 Loss: -1.44 dB



Signal Source:
 11404 MHz~11444 MHz
 1.5 kW/5 us/100 Hz

ScandiNova solid state modulator
 Current Rep. Freq: 40 Hz

CPI VKX-8311B Klystron:
 50 MW, 1.5 us RF pulse
52.6 MW achieved!

TPoT-X pictures

TPoT-X bunker

Waveguide tunnel

Ion pump

Faraday cups

Structure under test

RF loads

Ion pump powers



Cooling

Outside of the bunker

Rack

Modulator

Medium power waveguide

Klystron

Waveguide tunnel



Recent activities at TPoT-X

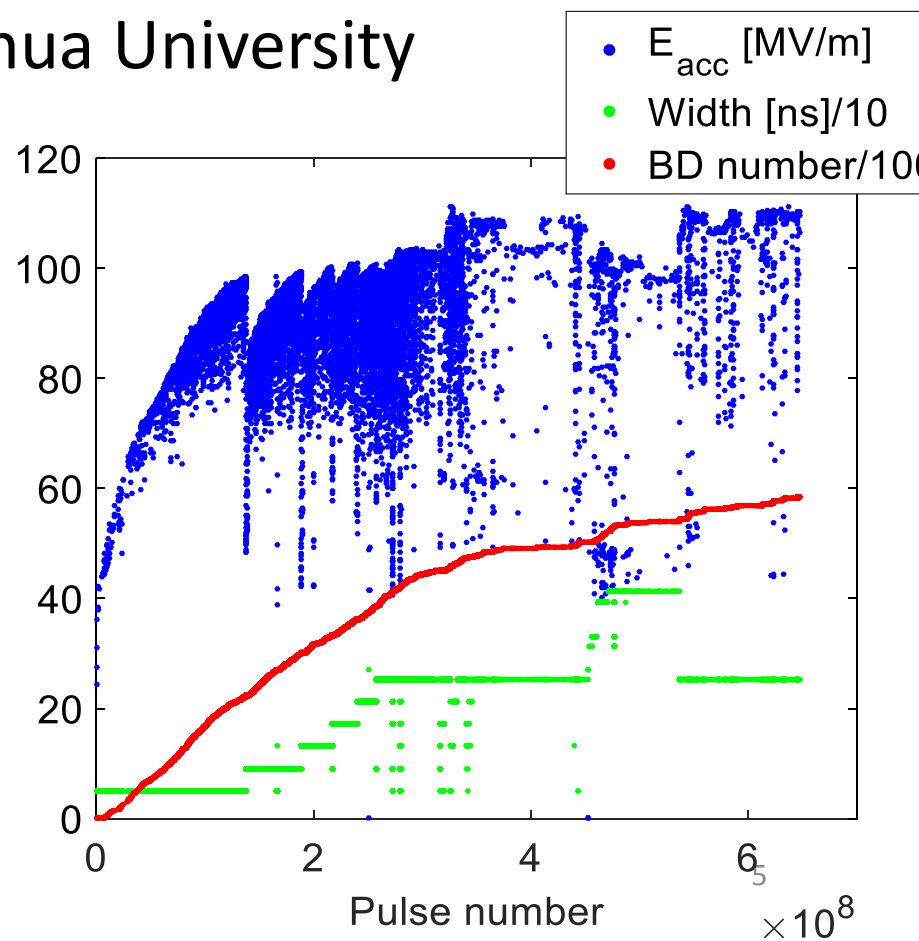
- RF stainless load test (finished before 2019)
- **T24 test (finished)**
- C12-Open structure test (conditioning)
- Corrugated pulse compressor (conditioning)

Test of T24_THU#1 structure

- T24 design, assembled/tuned/baked/bonded at Tsinghua University in 2014, test at KEK in 2014-2015 (**110 MV/m reached**).
- Sealed and sent back to Tsinghua University

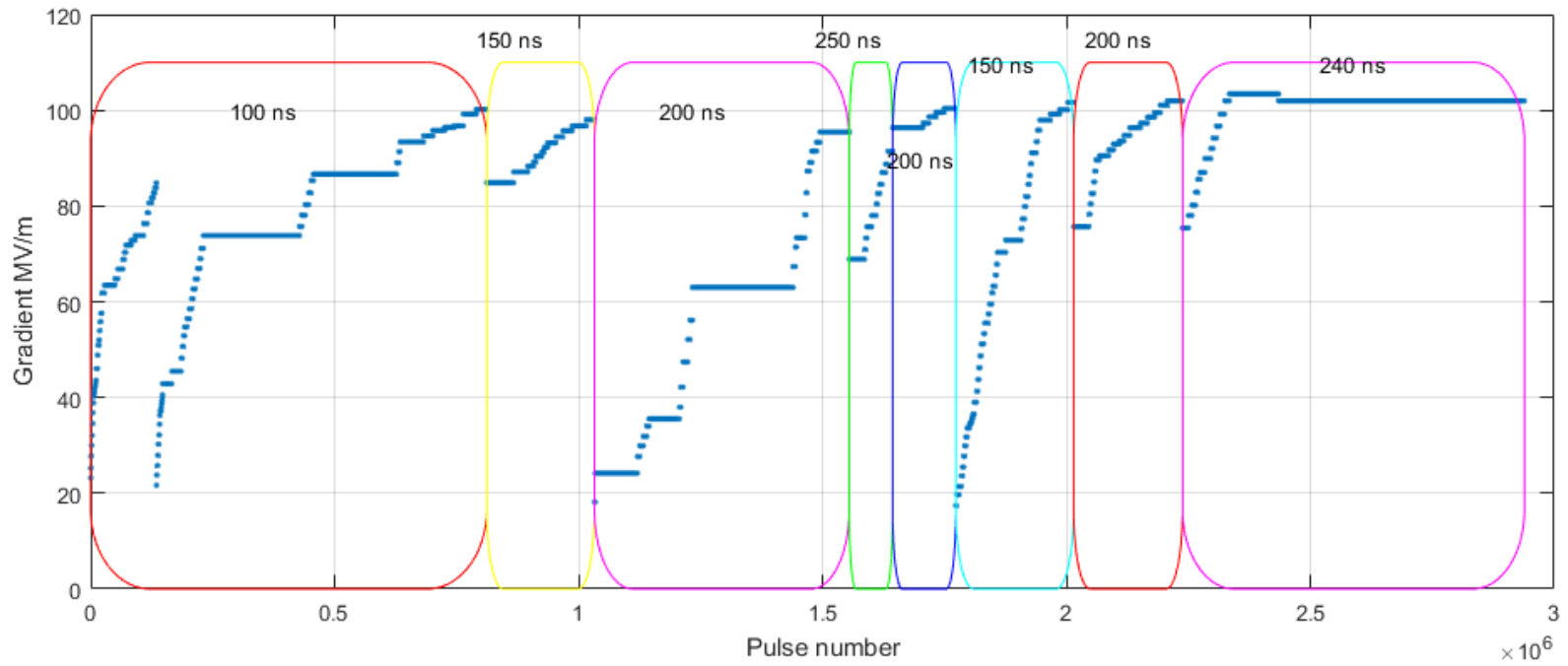
Parameters of high power tests
of T24_THU#1 at KEK

Input power	51.8 MW
Gradient	110.2 MV/m
BDR	1.26×10^{-6} bpp
Pulse width	252 ns
Total RF pulse	6.5×10^8
Total BD number	6000
Total RF-on time	3600 hours



Test of T24_THU#1 structure

- Test at TPoT-X as the warming up;
- Conditioning finished in 4 days (3×10^6 pulses), reached 103 MV/m at BDR rate = 5.56×10^{-6} /pulse, pulse width = 240 ns

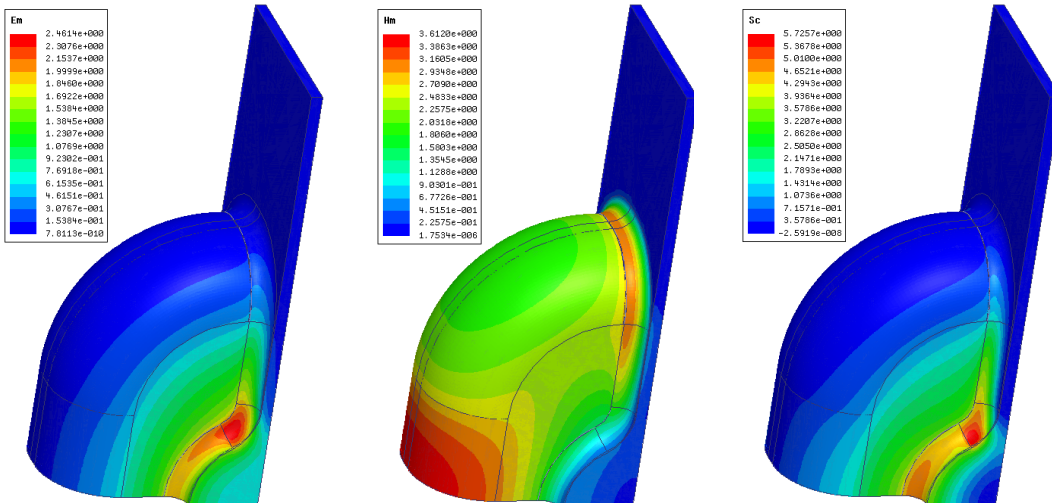
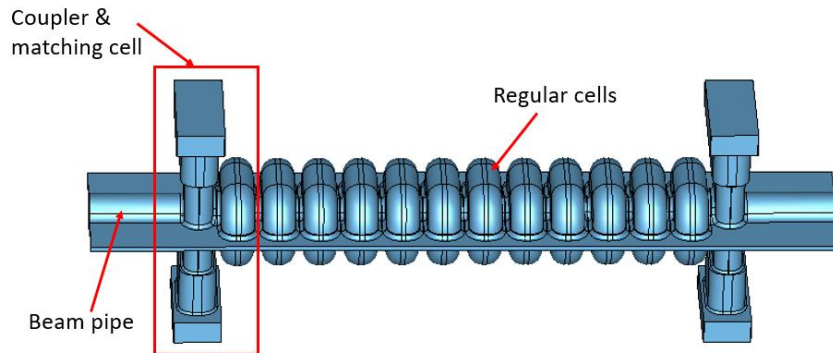


Recent activities at TPoT-X

- RF stainless load test (finished before 2019)
- T24 test (finished)
- **C12-Open structure test (conditioning)**
- Corrugated pulse compressor (conditioning)

C12-Open structure

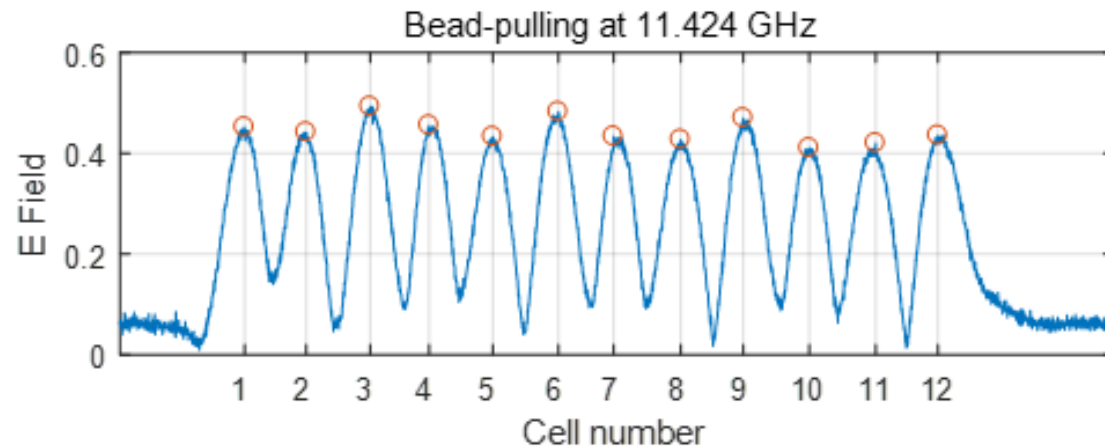
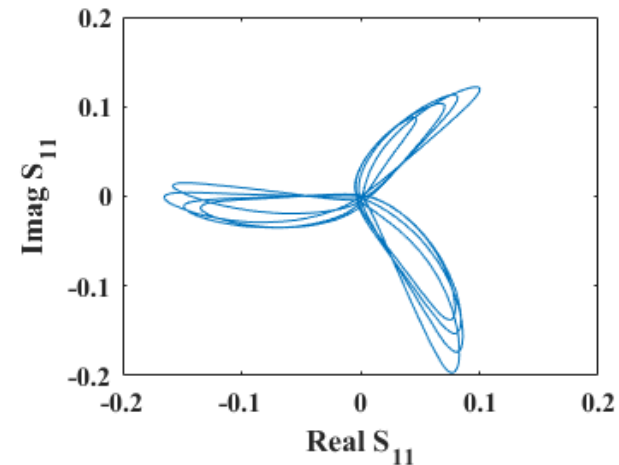
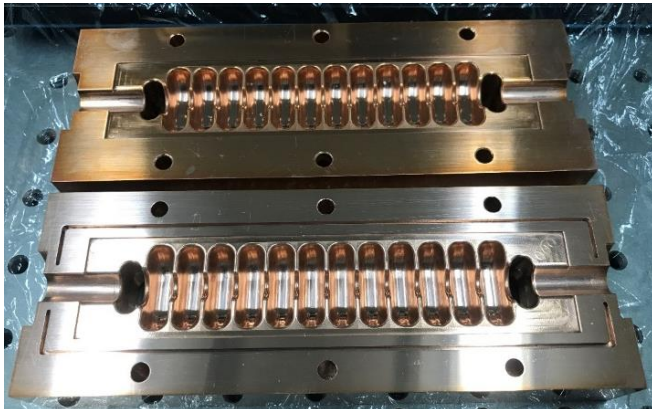
- Designed and manufactured a 12-cell open cell.
- Cell geometry was similar to the first cell of CLIC T24-Open (dimensions are scaled for 11424 MHz).



Parameters for 100 MV/m gradient		
	C12-Open	T24-Open
Input power [MW]	65.3	45.3
Output power [MW]	52.56	26.3
Filling time [ns]	14.7	48.2
Max surface E-field [MV/m]	255	264
Pulse temperature rise [K]	30	23
Max surface Sc [MW/mm²]	6.2	5.1
		8

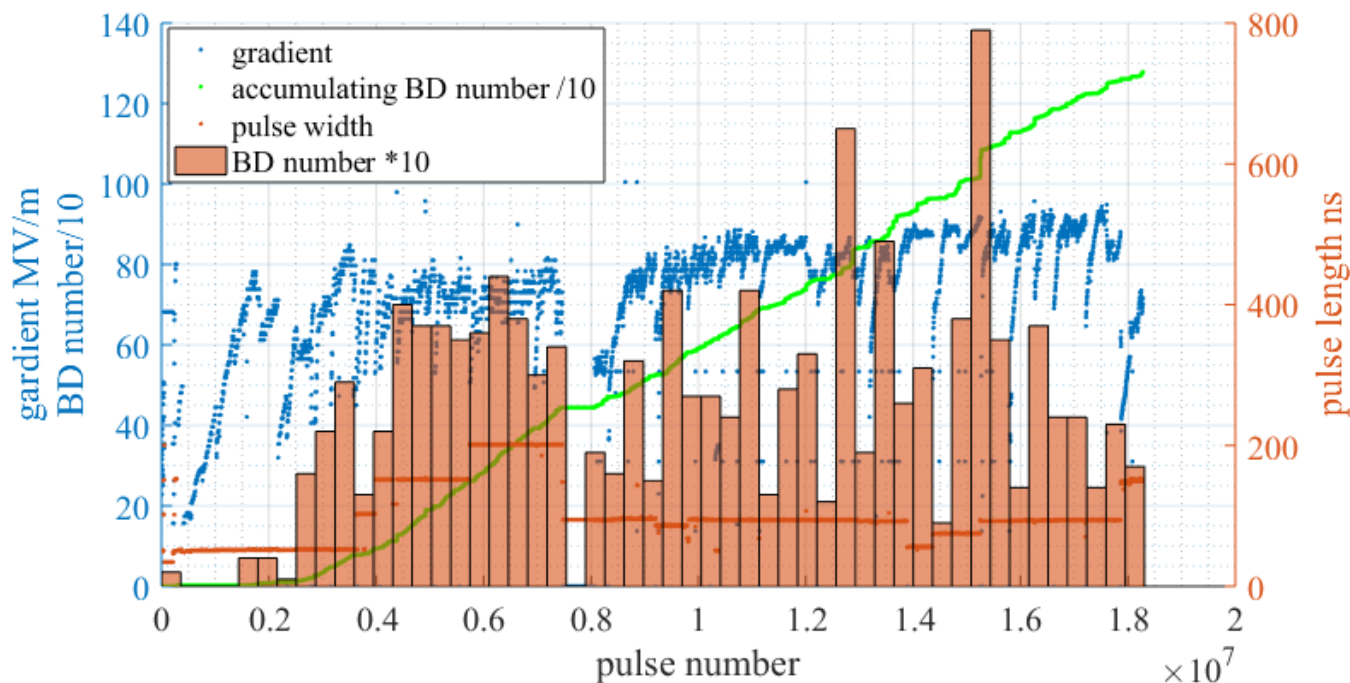
C12-Open structure

- Tuning wasn't performed and the field looks good.
- Structure was brazed by using **Silver-Copper based alloy**.



High power test of C12-Open

- Reached 87 MV/m with $BDR = 7 \times 10^{-5}$ /pulse and pulse width = 100 ns; now is still conditioning.
- Reference: when CLIC-T24-open reach same gradient, BD number = 5000, pulse number = 14 M (also T24-Open has lower Sc).



Dark current measurements

- Brazing using Silver-Copper based alloy is lower cost, however often **emits a significant dark current** for HG structures.
- The open structure cuts off the field, thus should be OK with Silver-Copper based alloy.
- Due to the dynamic range of oscilloscope, **no** significant dark current was **yet observed** for non-breakdown pulse (**upper limit : 20 mA**)

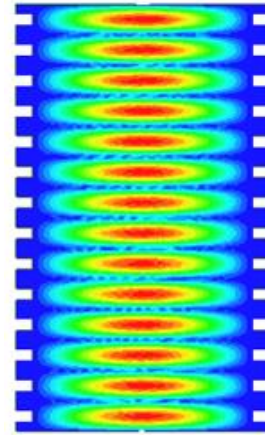
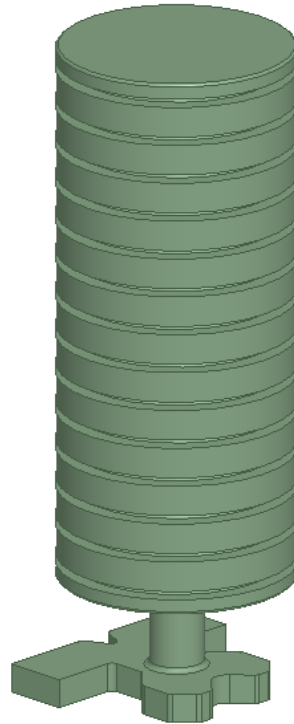
Recent activities at TPoT-X

- RF stainless load test (finished before 2019)
- T24 test (finished)
- C12-Open structure test (conditioning)
- **Corrugated pulse compressor (conditioning)**

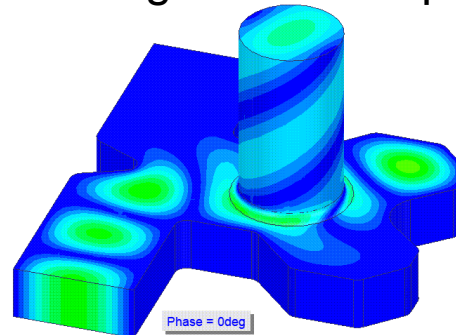
The design of RF pulse compressor

- A compact SLED-I RF pulse compressor using a cylindrical corrugate cavity was designed for TPoT-X.
- Peak power gain = 5 for 1.5 us -> 100 ns

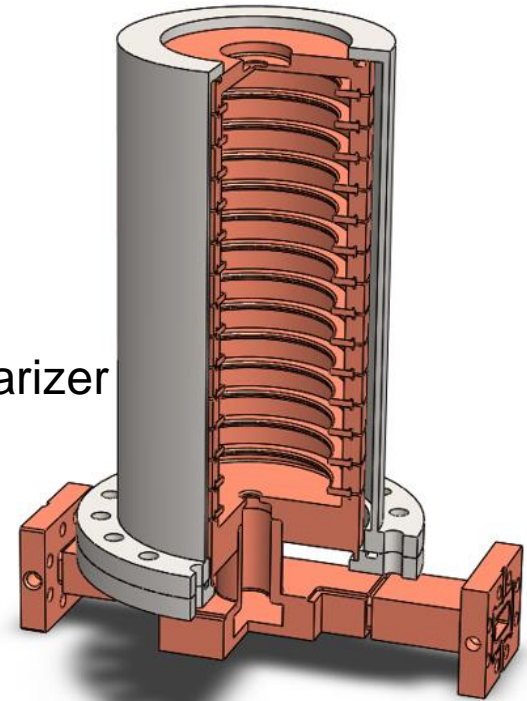
Operation frequency	11.424GHz
Mode	HE ₁₋₁₋₁₄
Cavity diameter ($2a$)	69.60 mm
Cavity length	191.52 mm
Corrugation depth (d)	6.56 mm
Corrugation distance (h_1)	10.68 mm
Corrugation width (h_2)	3.00 mm
Quality factor (Q_0)	115,000
Iris diameter	8.18 mm
Coupling coefficient (β)	3.5



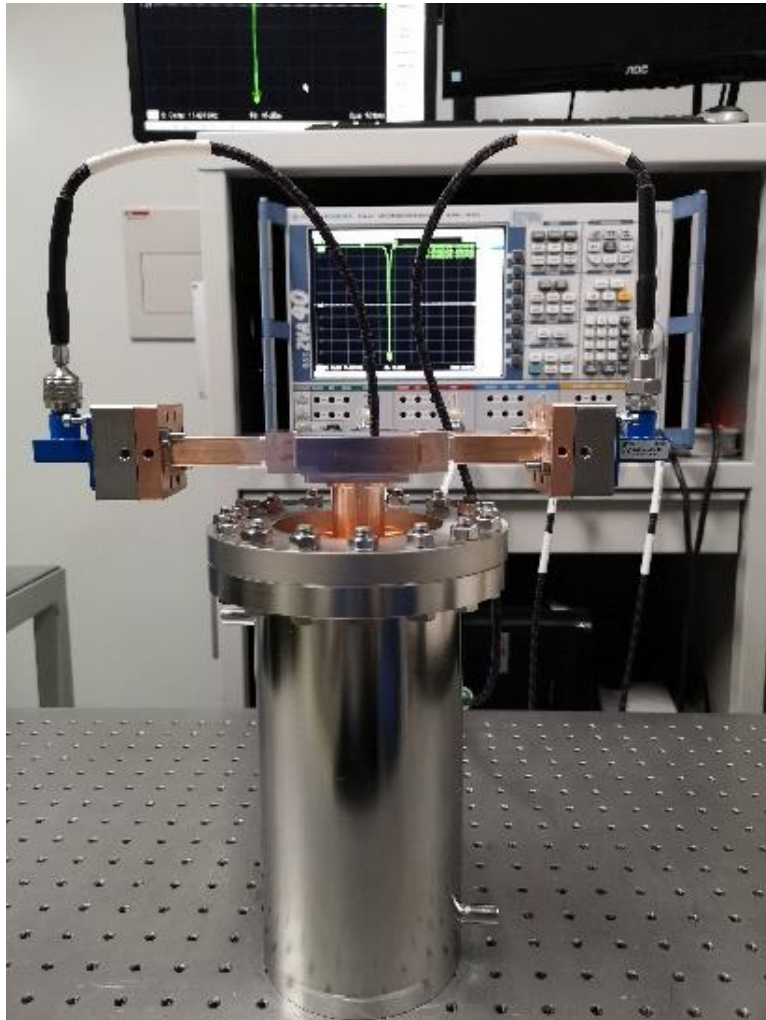
Rectangle->circular polarizer



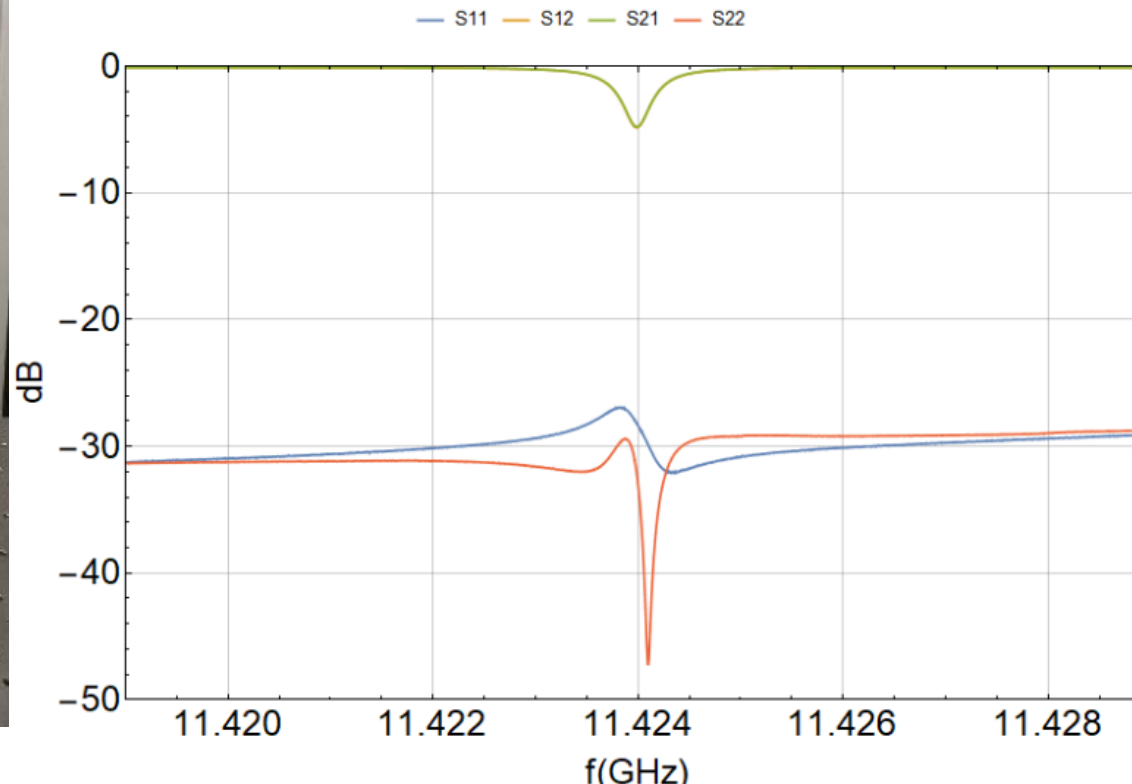
0 20 40 (mm)



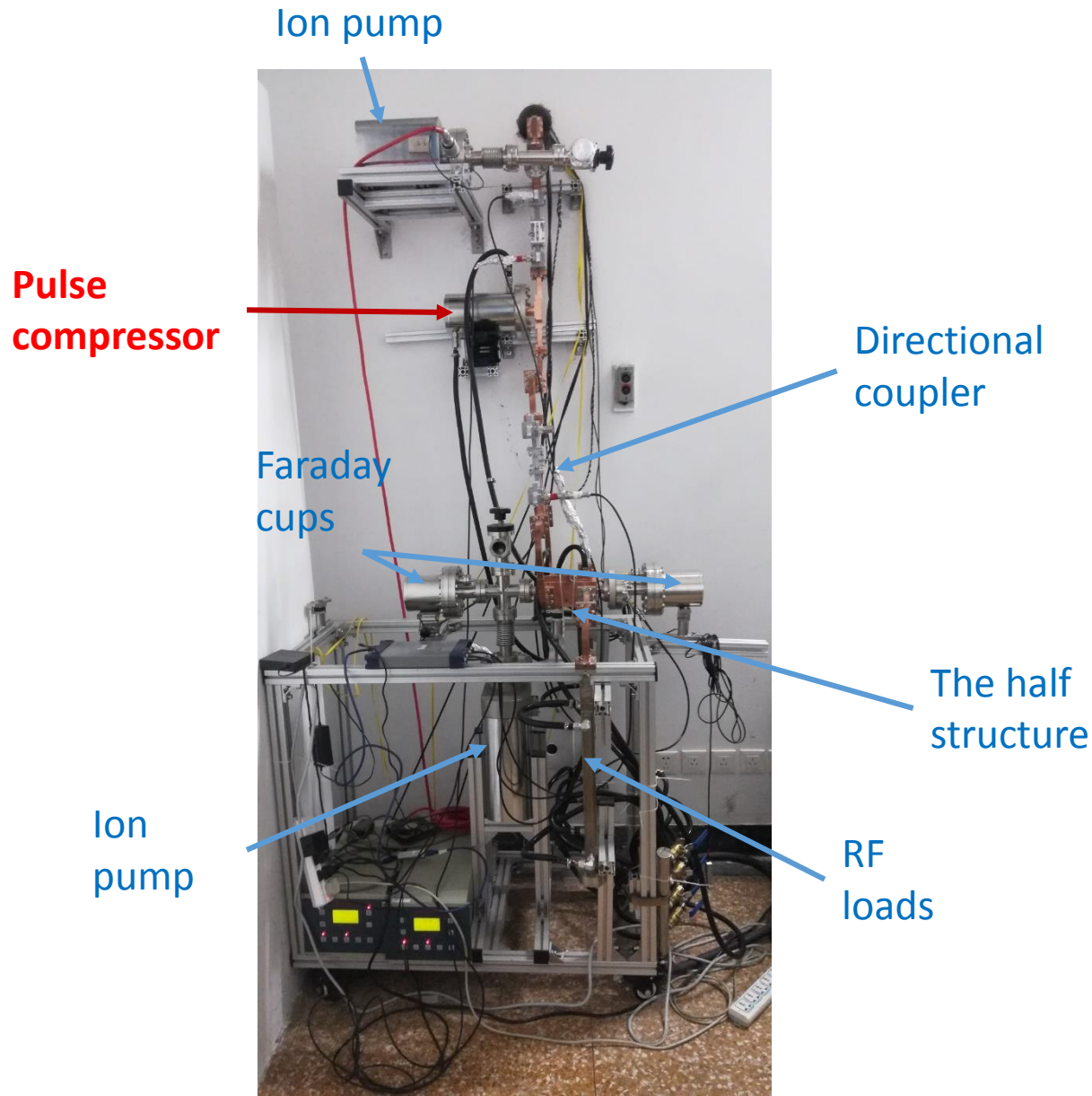
Cold measurements



	HFSS calculation	Measurements
Q_0 of corrugate cavity	115,000	116,750
β	3.5	3.67
Transmission in polarizer	99%	97%



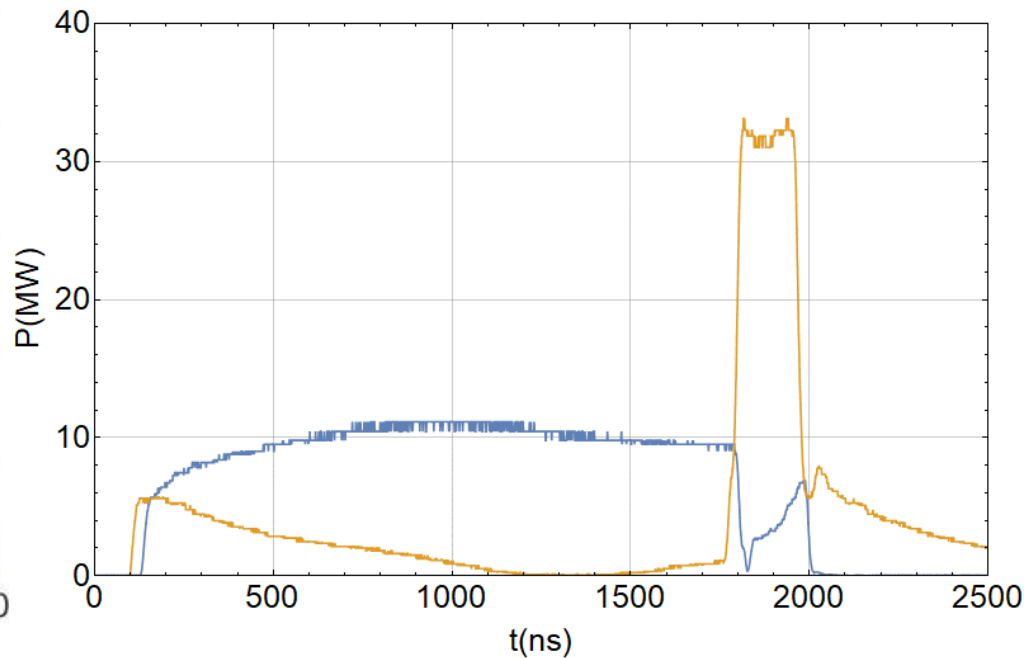
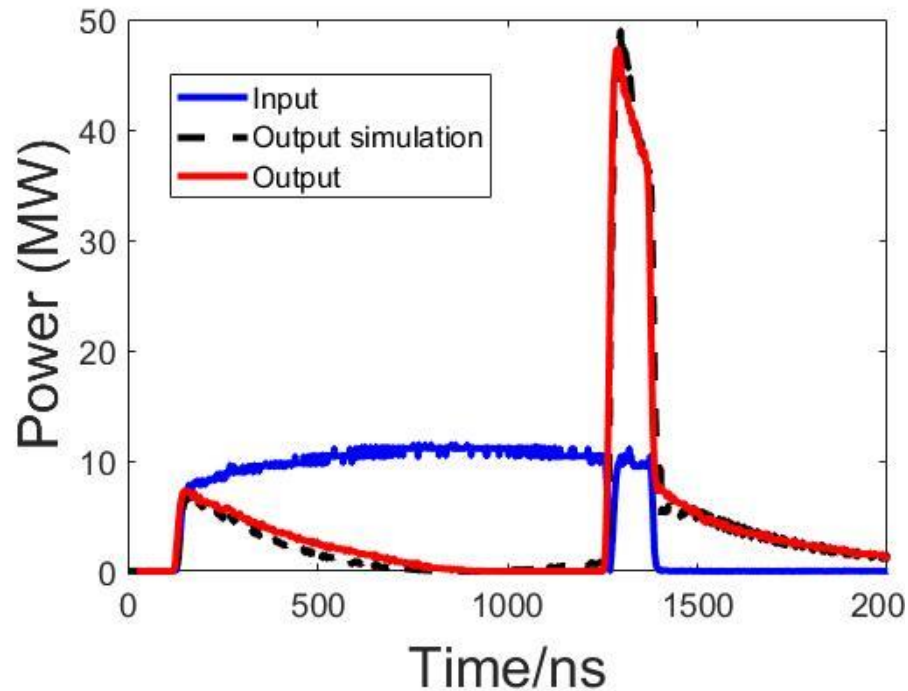
Installation and operation



- The pulse compressor is tuned manually by a chiller during operation.
- The chiller temperature is 30 °C right now.

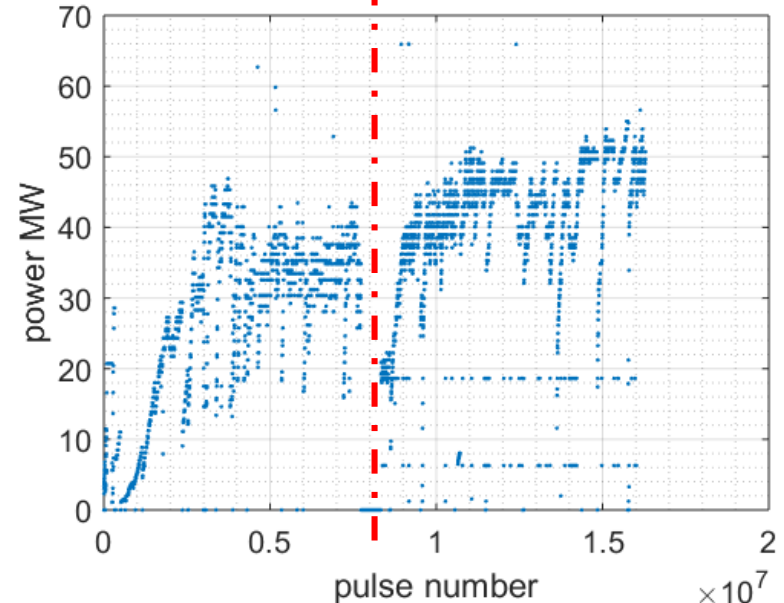
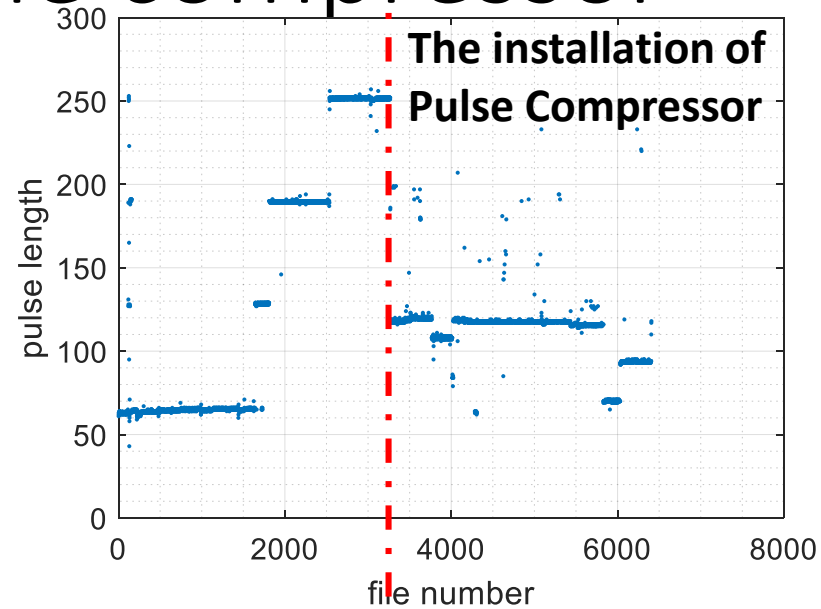
Amplitude modulation

- SLED-I compressor generates an un-flat pulse.
- Using amplitude modulation (By manipulating the signal generator) can reshape the pulse to a flat one.
- The cost : a lower gain factor (average: 4->3.2)



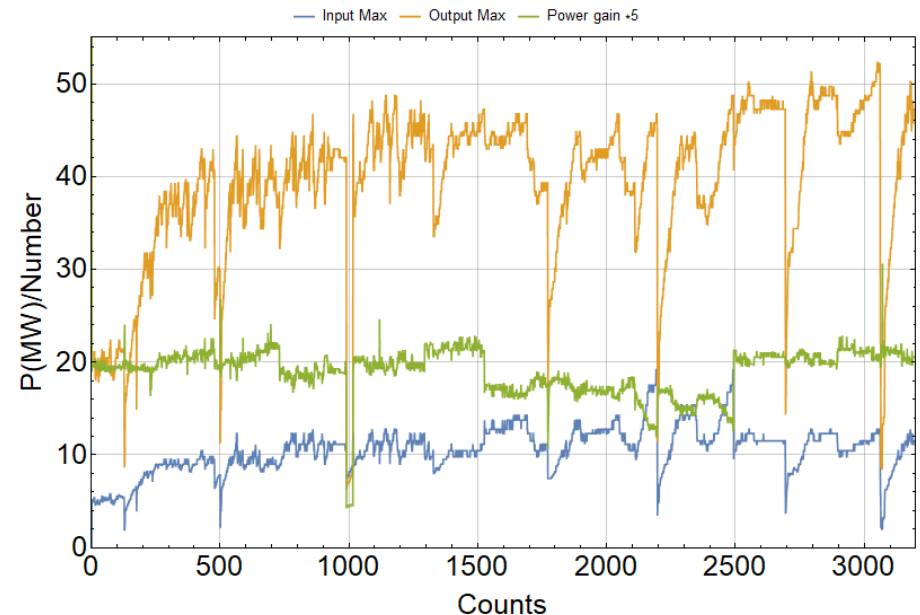
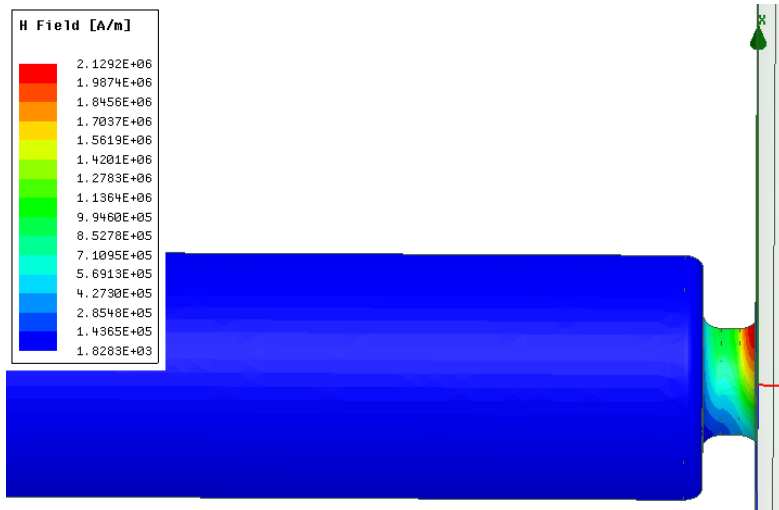
High power tests of the compressor

- The output power reaches 55 MW.
- Breakdowns happened more frequently in the pulse compressor while ramping the power up.
- The power can go up, but now is mainly limited by the breakdown of the test structure (C12-open).



Pulse heating issue

- Significant field enhancement at the joint iris: For 10 MW, 1 us input power, **max pulse heating ~ 275 K**
- This heating may cause deformation -> β is changed -> gain factor is changed.
- **Seems OK now**, need investigation for full power operation (for 35 MW, 1 us input, **$\Delta T \sim 970 K$**)



Future plans—Test facility upgrade

Issues	Comment
Pulse modulator	Upgrade repetition rate from 40 Hz to 50 Hz.
Pulse compressor	For higher power level, up to 300 MW with pulse length 100 ns.
Variable power splitter	Capable of testing two devices, make TPot-X more efficient
BD detect method	Add PMT(X-ray detector), reflect power into auto conditioning system for a more reliable BD judgement.
Auto conditioning system	Make it more flexible for pulse compressor.
Dipole magnet	Measuring dark current energy spectrum.

Future plans—Test plans

Structures	Date
T24_THU_#1	Finished
Half structure	Proceeding
X-band 3.5 cell photocathode gun	Sept, 2019
A single cell structure rescaled from 11.7 GHz	Oct, 2019
T24_THU_#2	To be discussed
Choke-mode single cell structure	
TTX XC-72 structure	
Field emission/dark current study in 1.5-cell gun	

Thank you!

Acknowledgements:

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