Short overview of SINAP activities

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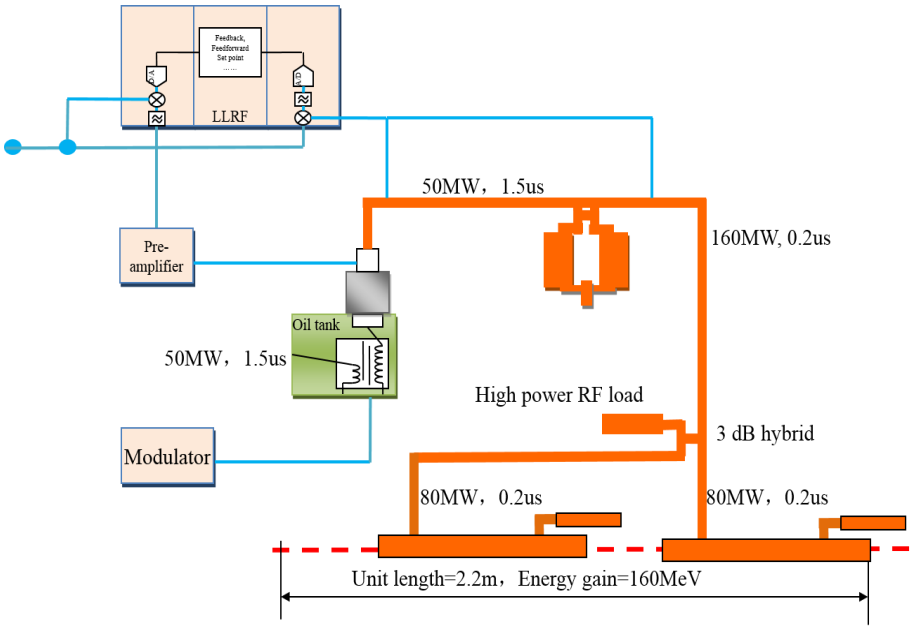
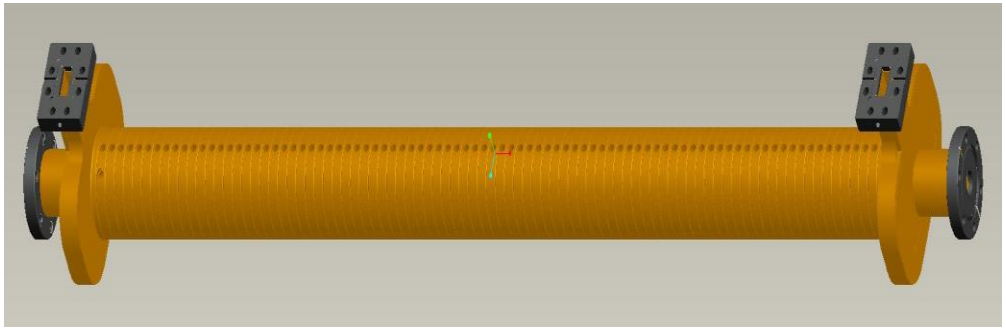
Barcelona, 11th Dec. 2018

Outline

- X-band RF acceleration unit
- X-band TDS RF unit
- Preliminary study of C-band injector
- 50MW X-band klystron from BVERI/CETC
- Summary

X-band RF acceleration Unit (80MV/m)

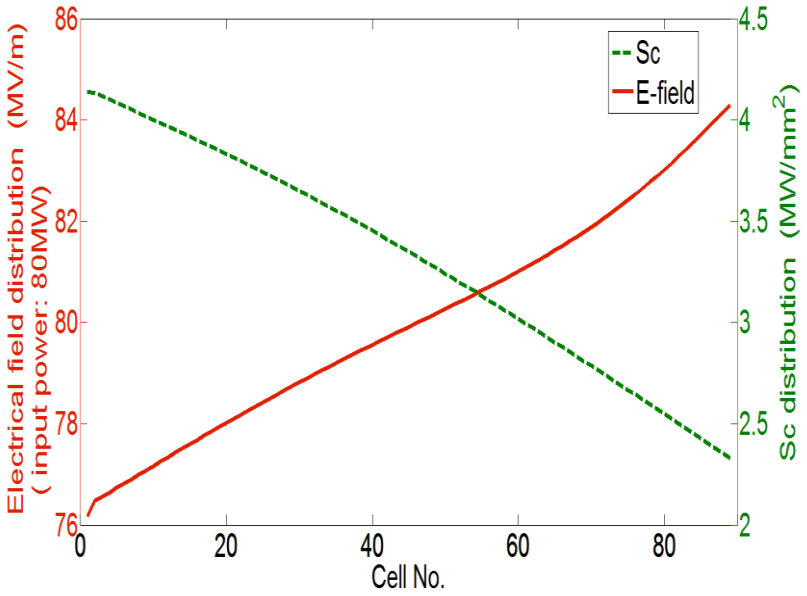


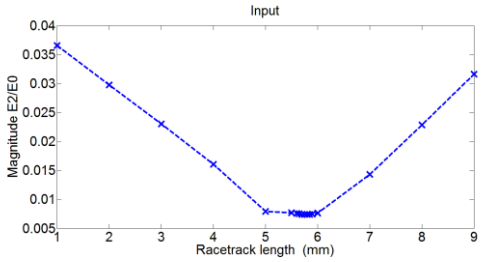


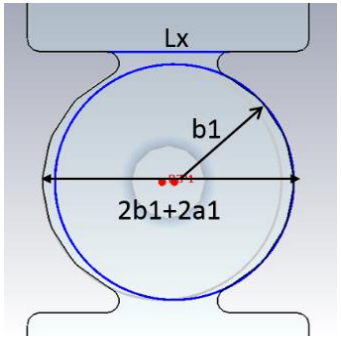
Frequency	11424MHz
Phase advance	4π/5
Cell No.	89+2
Effective length	944.73mm
Cell length, d	10.497mm
Iris thickness, 2a	1.5 mm
Ratio of elliptic radius	1.8
Aperture, a_r	4.3~3.05.mm
Group velocity, Vg/c	3.45%~1.12%
Shunt impedance, R	93.93–125.62 MΩ/m
Attenuation factor, τ	0.61
Filling time, t_f	150 ns
Sc	4.14~2.33 MW/mm^2
Emax/E0	2.68~2.02
Hmax/E0	2.68~2.39 mA/V
Input power, P_{in}	80MW @80MV/m

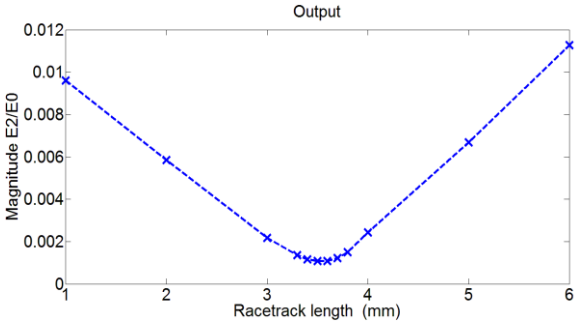
One-meter accelerating structure

- Aperture 2a is 7.4mm at least to suppress short-range wakefield;
- Accelerating gradient is increased from upstream to downstream, so that Sc could be reduced in the upstream;
- Dual-port and racetrack coupler is designed to eliminate dipole and quadr0pole field.



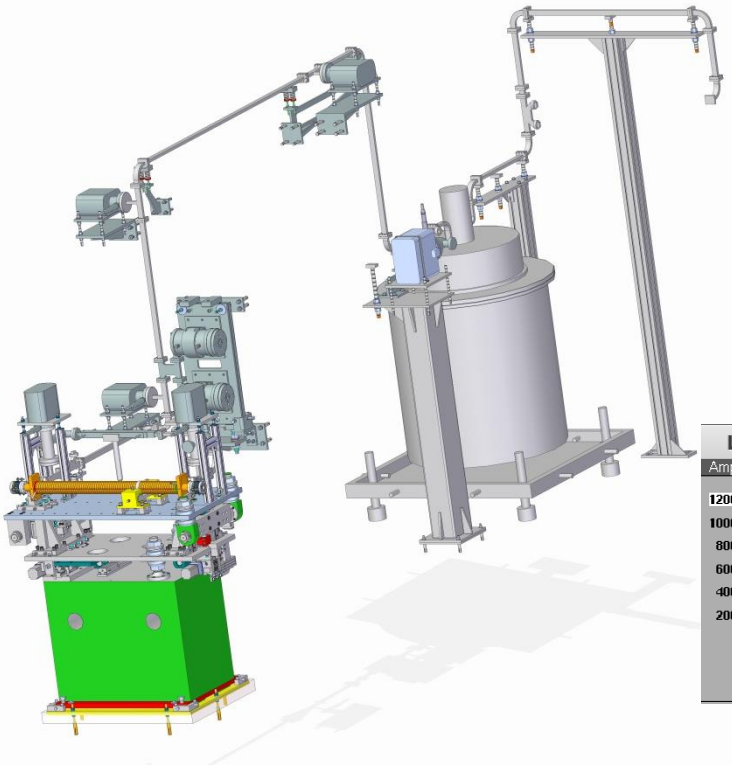


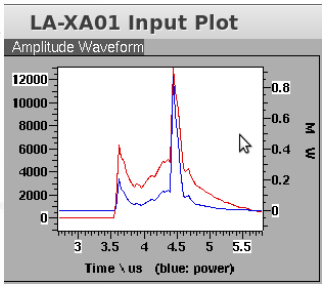


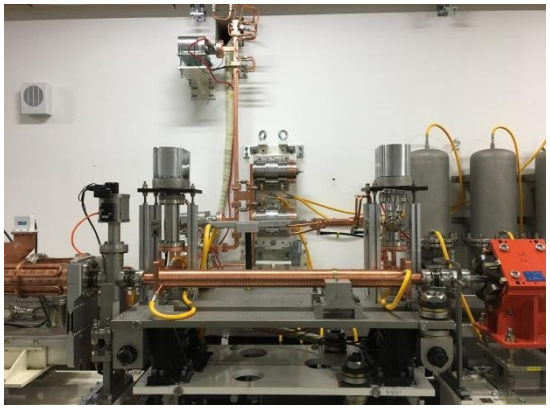


First X-band RF unit for SXFEL as linearizer

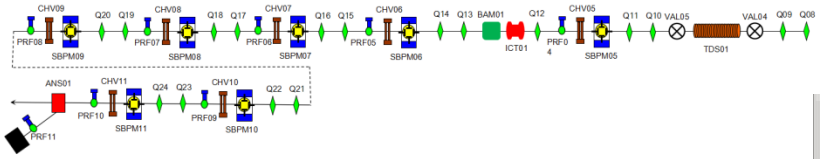
1. 6MW X-band klystrons;
2. 20MW modulator by SINAP;
3. One-meter length X-band accelerating structure;
4. Waveguide connection between amplifier and klystron;
5. One pulse compressor with TE0116, stabilized by two independent stable chiller;
6. Gradient not less than 20MV/m.
7. Movable support with 1um accuracy to suppress wakefield.



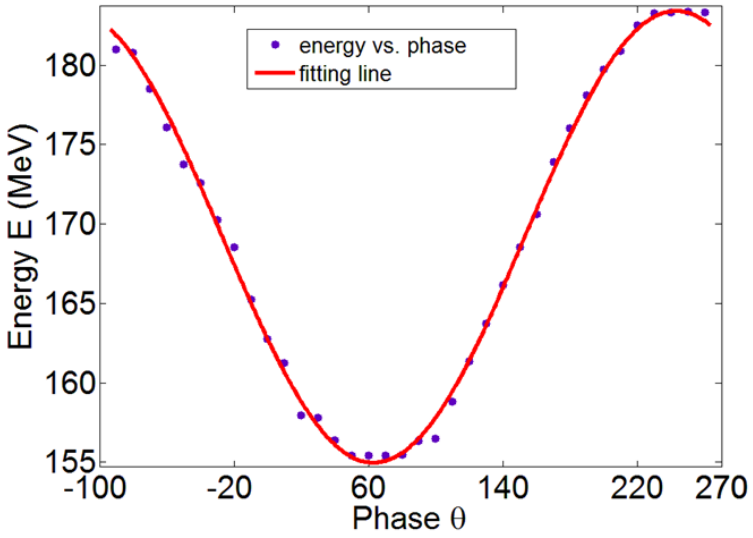




Beam operation results



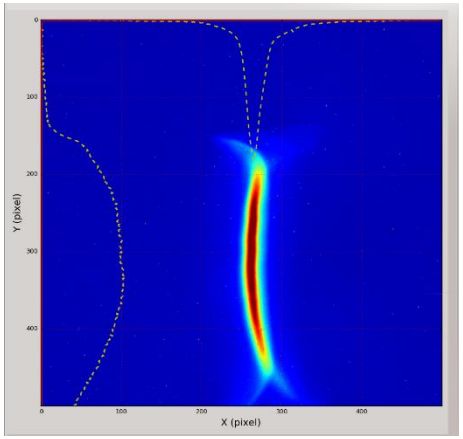
$$E = E_0 + A \cdot \sin\left(\theta + \theta_0\right)$$

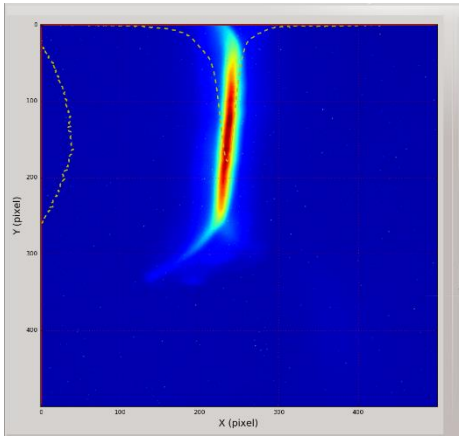


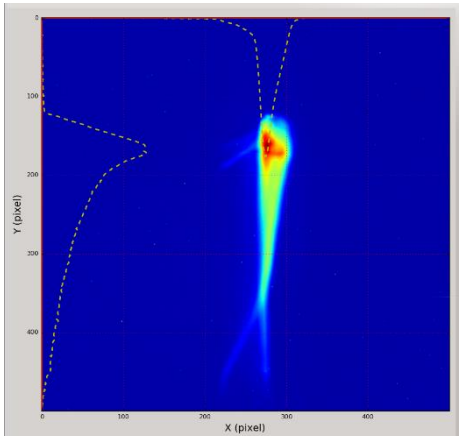
1. Only 15MV/m gradient reached.
2. Klystron output is unstable for different operation voltage.
3. Maybe klystron is not optimized to reach full power.

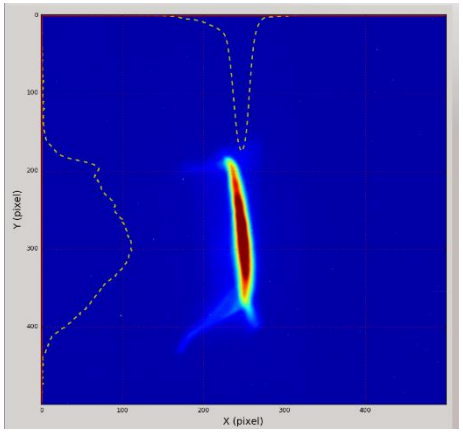
X-band Off

X-band On





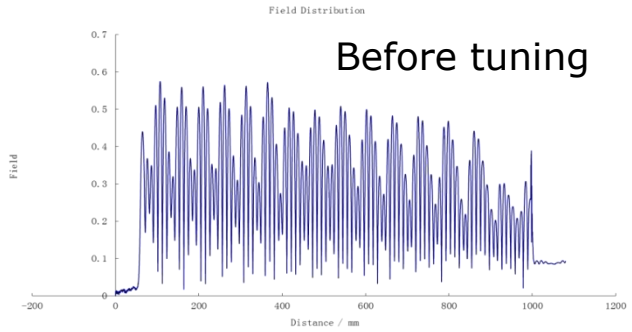




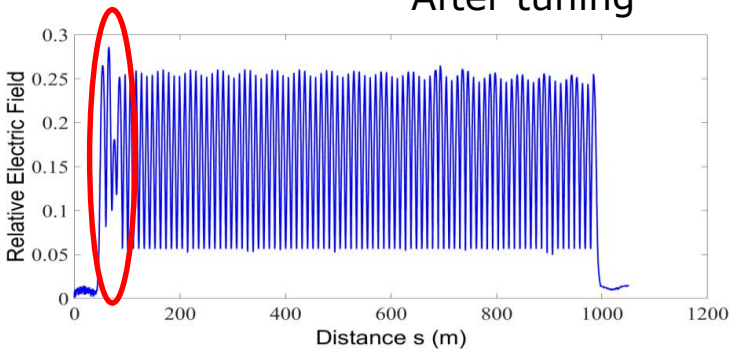
New one-meter X-band accelerating structure

1. Prototype is first try for design, fabrication, brazing and tuning, many problems happened, and it not good matching before tuning.
2. After prototype, one new structure is under fabrication now.

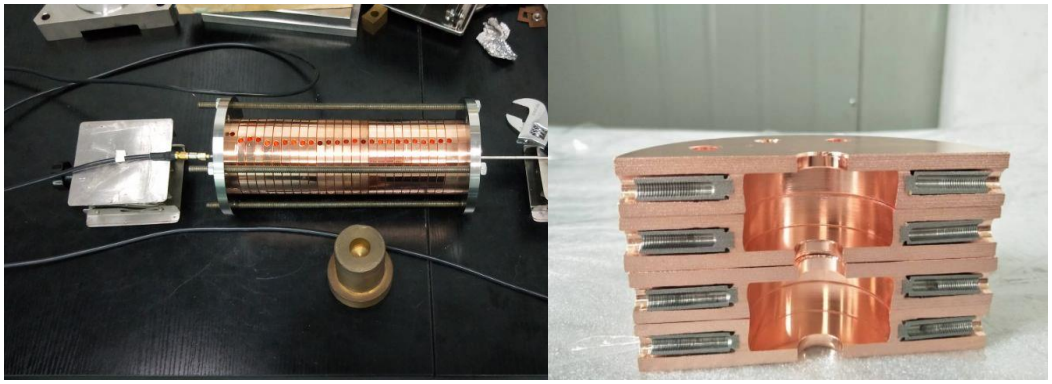
Before tuning

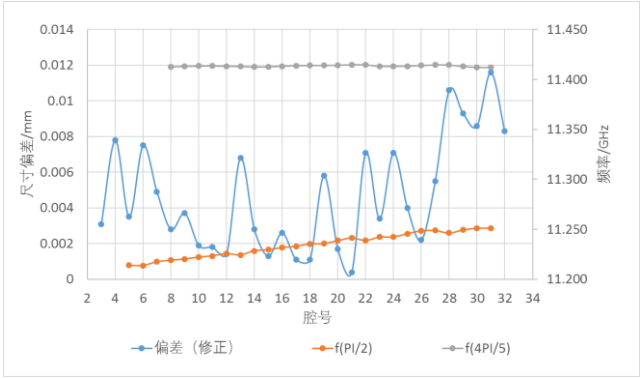


After tuning

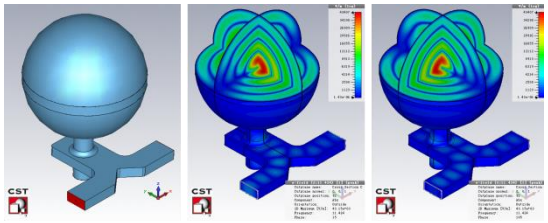


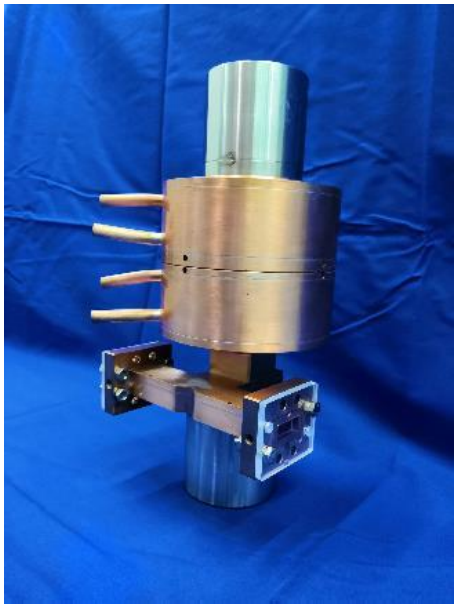
New structure fabrication



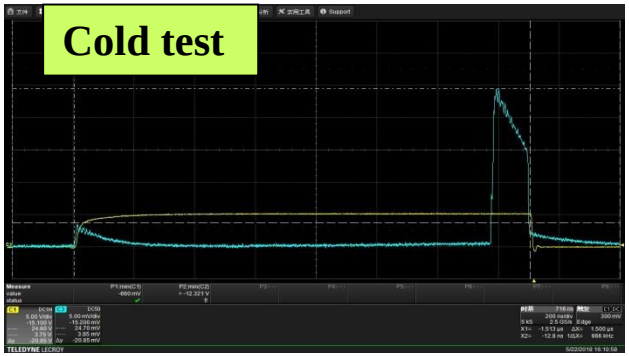


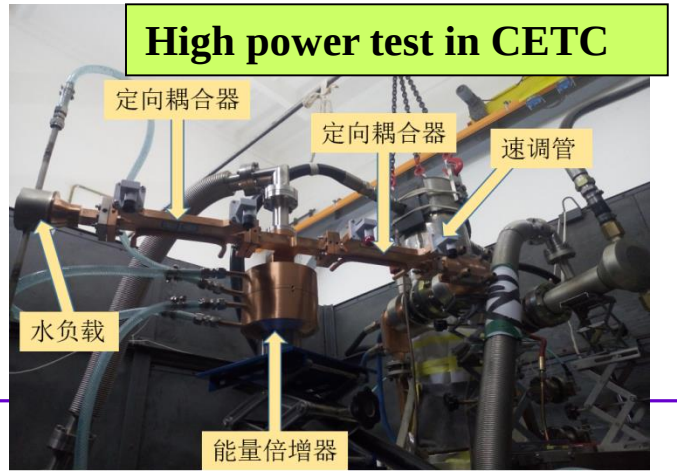
New spherical X-band pulse compressor

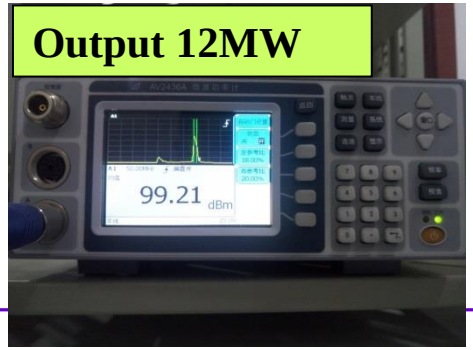




Frequency, f	11424 MHz
Mode	$TE_{1,1,4}$
Q_0	9.5×10^4
Coupling coefficiency	4.6
Energy factor	2.02
Average power factor	4.4
Peak power factor	6.4

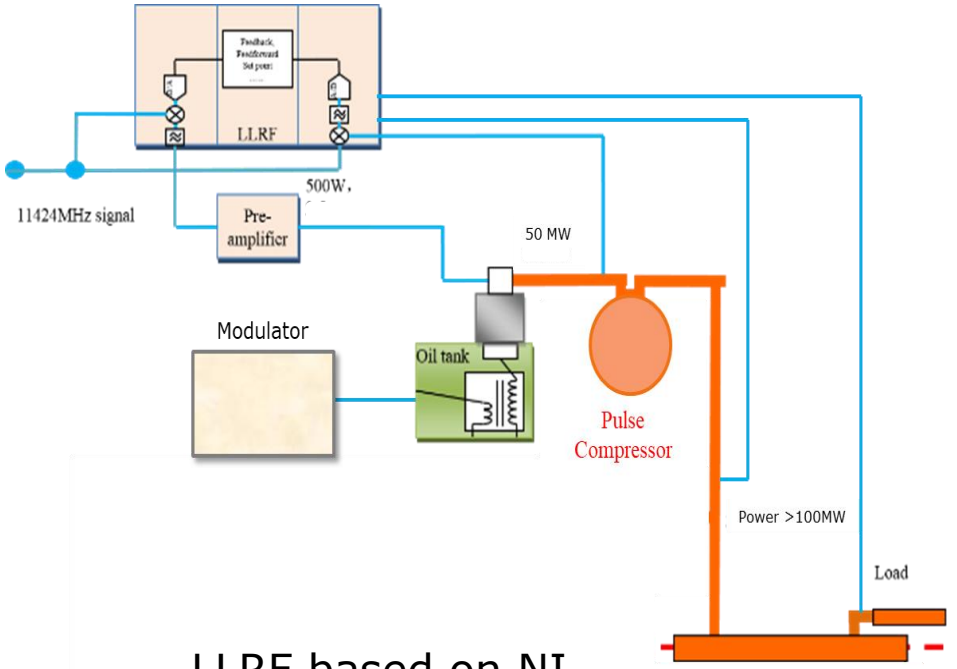






X-band high power test platform is under building

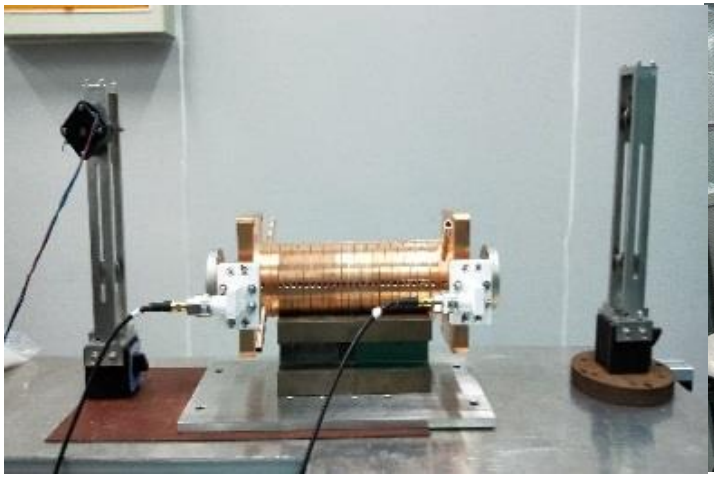
CPI--VKX-8311B + Modulator



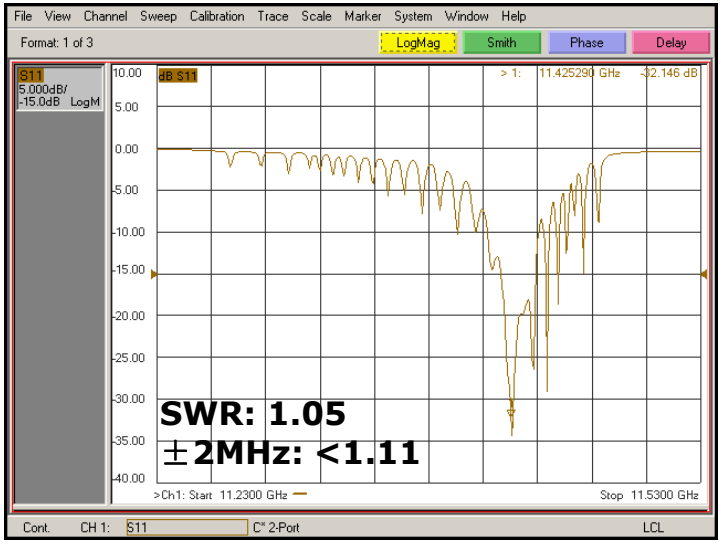
1.2kW X-band SSA

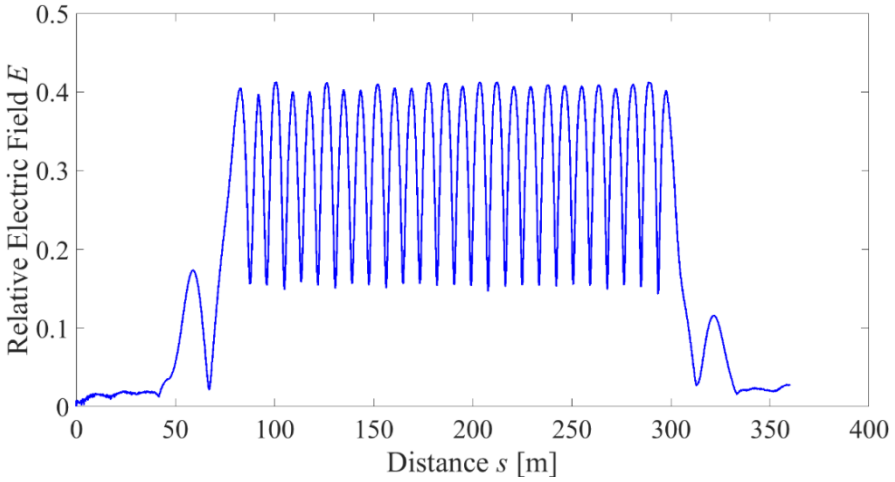
LLRF based on NI

T24(11.424GHz) prototype structure



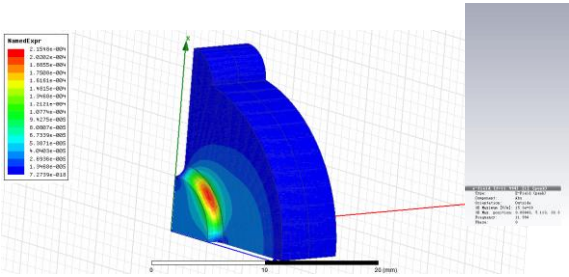
Frequency, f	11.424 GHz
Phase advance	$2\pi/3$
Cell No.	24 + 2
Cell length, D	8.7475 mm
Iris thickness, t	1.67 - 1.00 mm
Diameter, 2b	20.834 - 20.404 mm
Ratio of elliptic radius, $2t_b/t$	1.26-1.22
Aperture, a	3.15 – 2.35 mm
Group velocity, V_g/c	1.67% - 0.83%
Shunt resistance, R_a	108.05 – 146.56 MΩ/m
Q-factor, Q	6775 - 7099

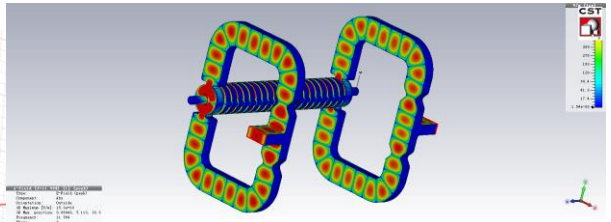


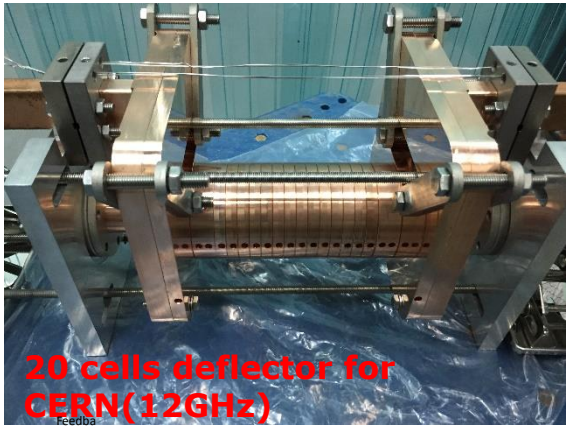


X-band deflectors for CERN, SXFEL and SHINE

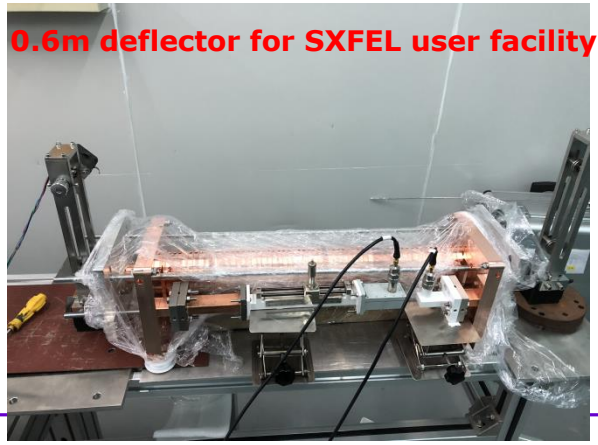
20-cell deflector for CERN	
Operating frequency	11.994 GHz
Phase advance per cell	120°
Length of cell	8.3317 mm
Structure length	230 mm
Iris aperture 2a	8 mm
Iris thickness	2.6 mm
Quality factor Q	6222
Group velocity: Vg/c	2.69%
Filling time	21 ns
Attenuation factor t	0.751
Input power	50 MW
Pulse length	100ns
Peak surface electric field	153 MV/m
Peak surface magnetic field	489 KA/m
Peak modified Poynting vector	4.5 MW/mm^2
Peak pulse surface heating	32K

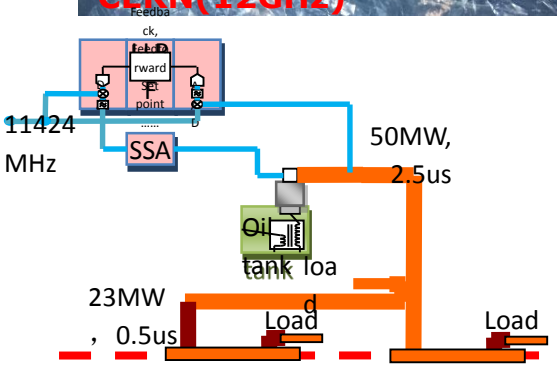


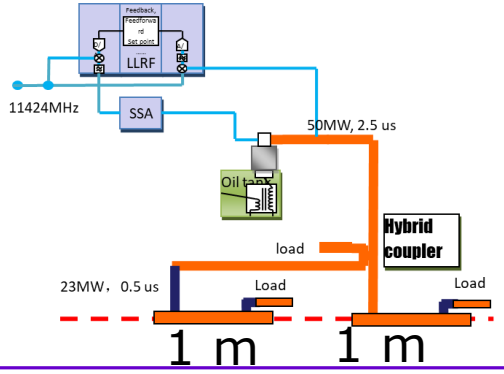




Deflector for SXFEL and SHINE		
Parameters	Value	Units
Frequency	11.424	GHz
Phase advance	120	Deg
Maximum power	50	MW
Transverse voltage	0~50	MV
Iris aperture 2a	10	mm
Repetition frequency	50	Hz

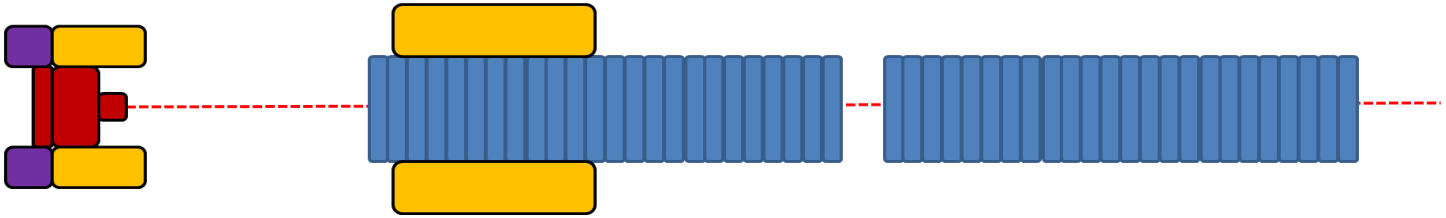




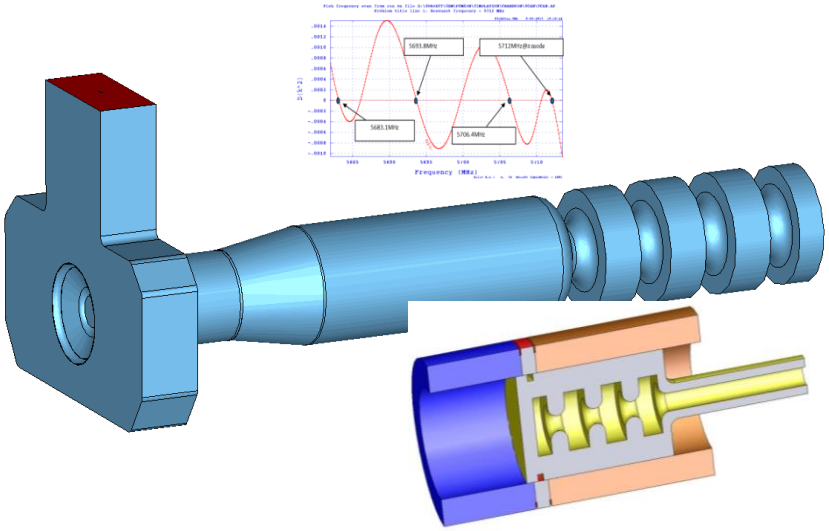


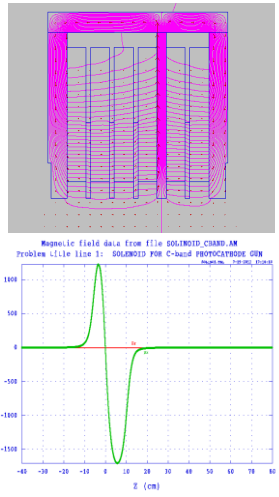
0.6 m 0.6 m

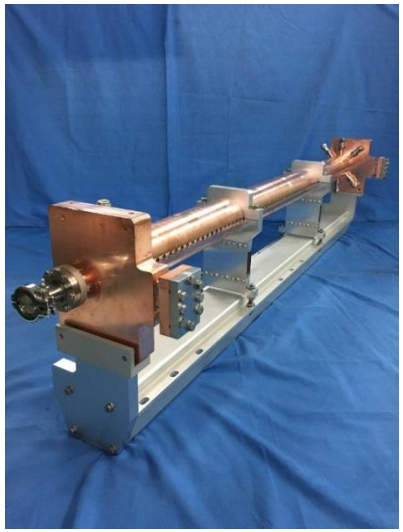
Preliminary study of C-band injector



1. One 3.6-cell C-band gun with coaxial coupler, gradient on cathode is 150MV/m, smaller laser spot is carried out to reduce thermal emittance. Mode separation is 5.6MHz from 5712MHz
2. Out energy is 7MeV, it's difficult to make emittance compensation, so solenoid is outside gun, and another small opposite solenoid is used to eliminate magnetic field on cathode.
3. Two 1.8-meter C-band accelerating structures same as SXFEL are used to boosting energy, and it has been verified to reach stable gradient of 45MV/m.

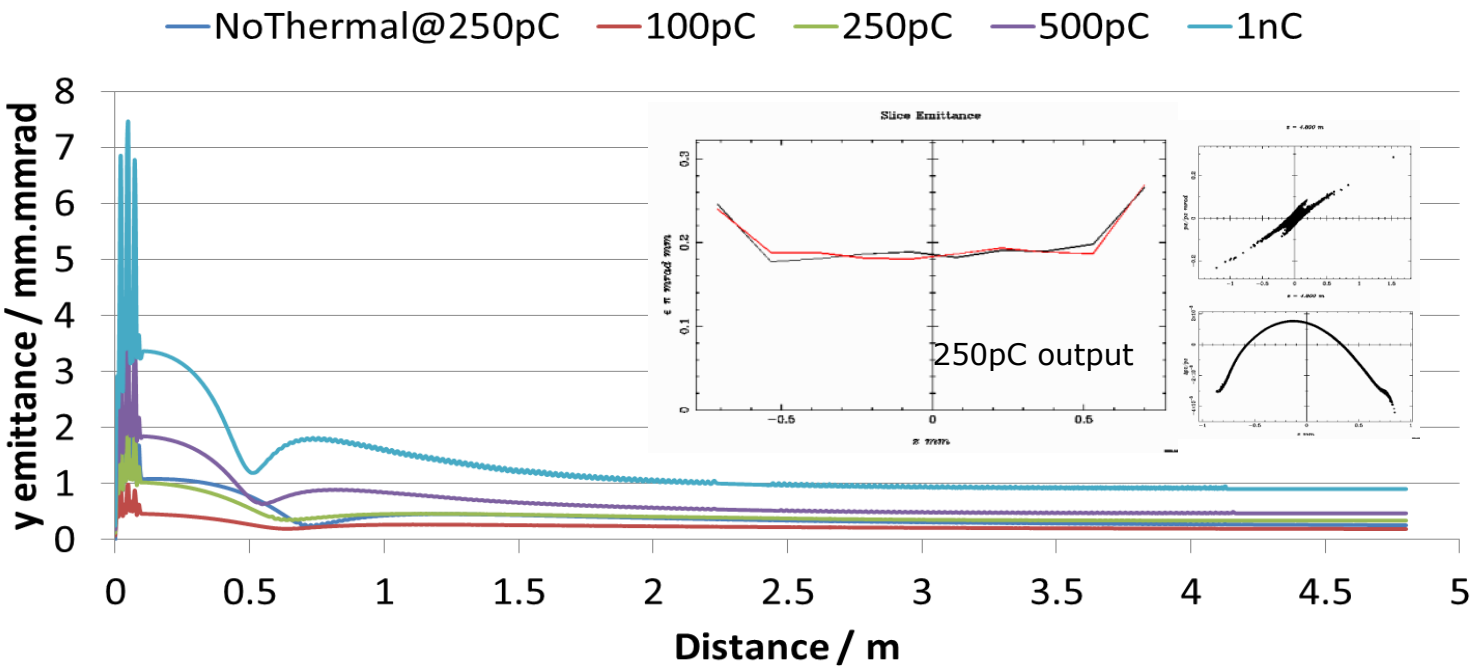






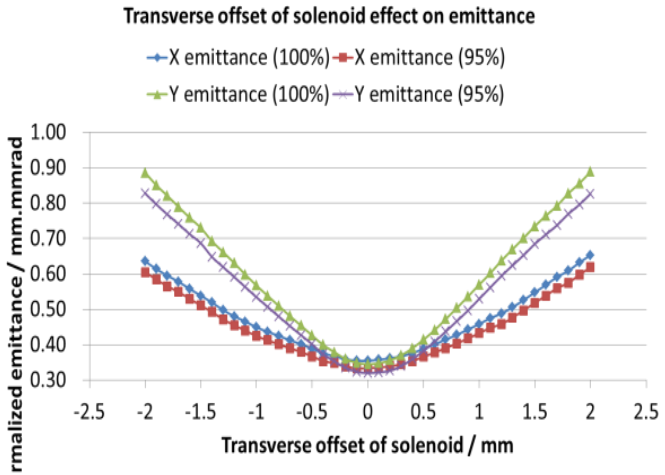
Emittance for different charge

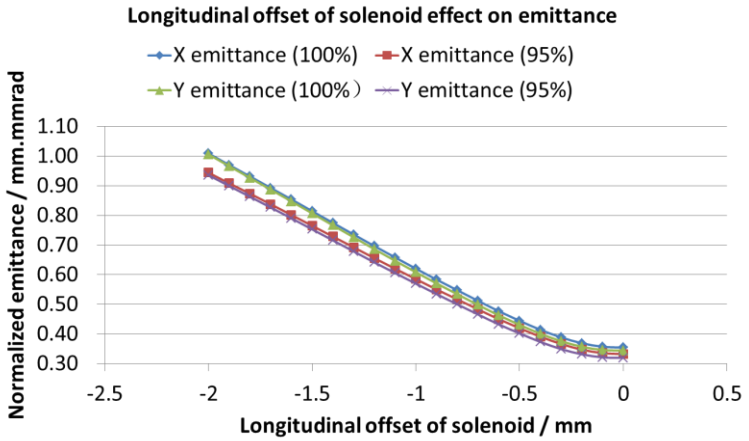
1. Emittance is different for different charge, results are 0.19, 0.34. 0.47, 0.9 mm.mmrad for 100pC, 250pC, 500pC and 1nC respectively, moreover 0.13, 0.23, 0.33 and 0.62 mm·mrad for 95% cut-off.
2. 250pC is typical charge of FEL operation, and its slice emittance is 0.19 mm.mmrad in most range.

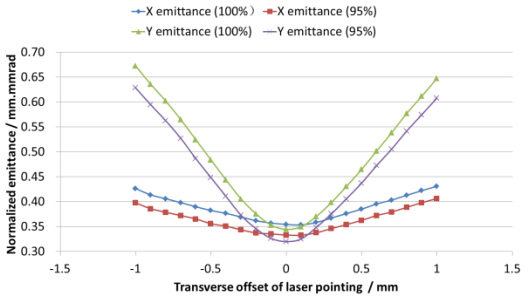


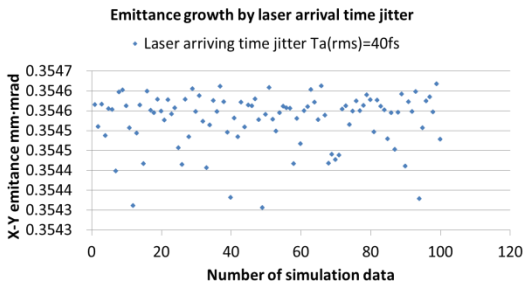
Jitters: solenoid, laser, RF

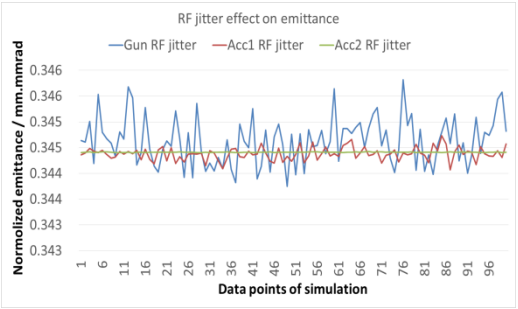
1. Emittance is most sensitive to solenoid transverse and longitudinal offest, but it's about 0.03mm.mmrad increased by 0.1mm alignment tolerance.
2. Emittance also could be impacted by laser spot, arrival time, and RF magnitude and phase jitter, however it's very slight by real laser and RF jitter. To some extent it could be neglected comparing with solenoid.



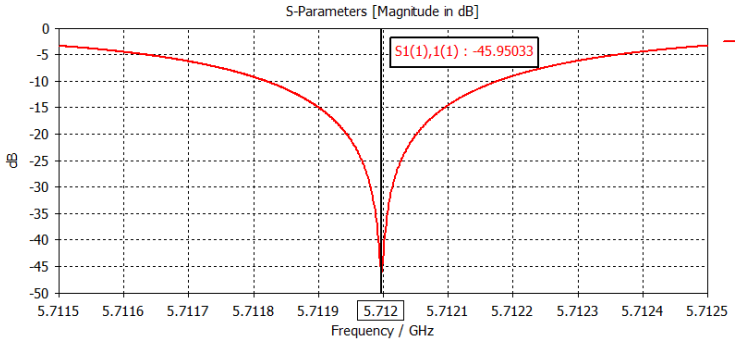


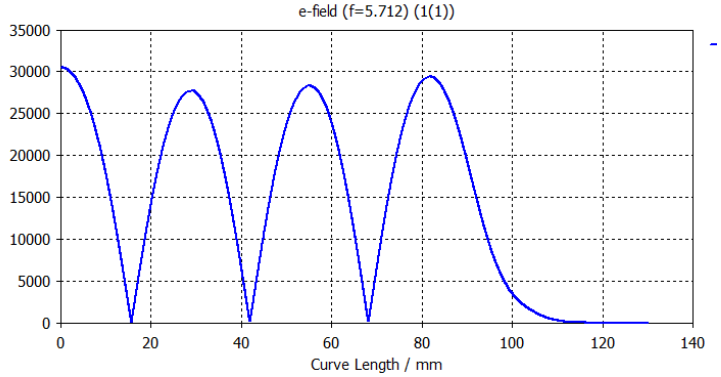






3-D RF design


S-Parameters [Magnitude in dB]
S1(1),1(1) : -45.95033
dB
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
5.7115
5.7116
5.7117
5.7118
5.7119
5.712
5.7121
5.7122
5.7123
5.7124
5.7125
Frequency / GHz

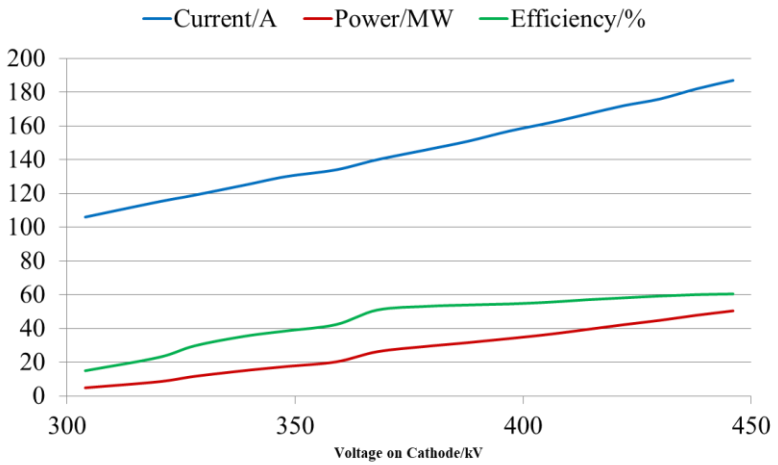

e-field (f=5.712) (1(1))
35000
30000
25000
20000
15000
10000
5000
0
0
20
40
60
80
100
120
140
Curve Length / mm

50MW X-band klystron from BVERI/CETC (total five tubes)

Parameter	Target	1701#	1801#	1802# (on testing)
Frequency	11.424GHz	11.402GHz↘ 11.378GHz	11.424GHz	11.424GHz
Peak power	≥50MW	36MW@11.384 GHz	51MW	50.4MW
Repetition rate	120pps	20pps	10pps	10pps
Pulse length	≥1.5μs	1.5μs	1.5μs	1.5μs
Gain	≥50dB	50.2dB	52.6dB	48.7dB
Efficiency	≥40%	49.8%	55.6%	60.4%(COM)
-3dB BW	≥30MHz	42MHz	38MHz	36MHz
Voltage on Cathode	450 KV～ 470KV	420kV	452kV	446kV
Current	≤250A	172A	203A	187A
Forcing	PPM or EM	EM	EM	EM

50MW X-band klystron from BVERI/CETC (total five tubes)

1. Total 5 tubes.
2. 1601, 1701, 1801, 1802, 1803.
3. 1701, 1801 and 1802 are tested, and 1803 is being baked now.



Output power of one port in two ports.

Next plan

- Continue fabricate new one-meter X-band accelerating structure.
- Continue build X-band high power platform.
- High power test of X-band spherical pulse compressor and T24.
- Finish TDS structure, and high power test.
- Deep optimization on C-band injector, and mechanical design. Also preparing fabrication and beam test in the future.