

Thomson Scattering X-ray Source at Tsinghua University

Jiaru Shi

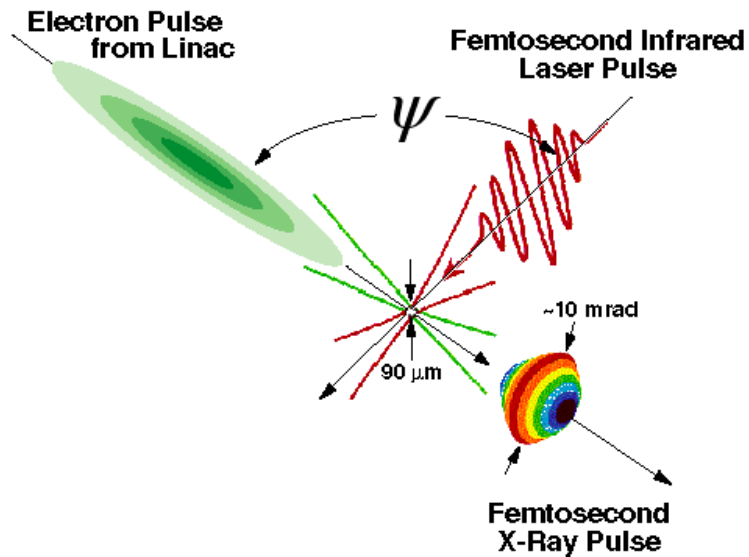
2017.3.10

For the TTX team

Outline

- Introduction
- Tsinghua Thomson-Scattering X-ray Source(TTX)
- XGLS project
- TTX with X-band structures
- Summary

Thomson scattering x-ray



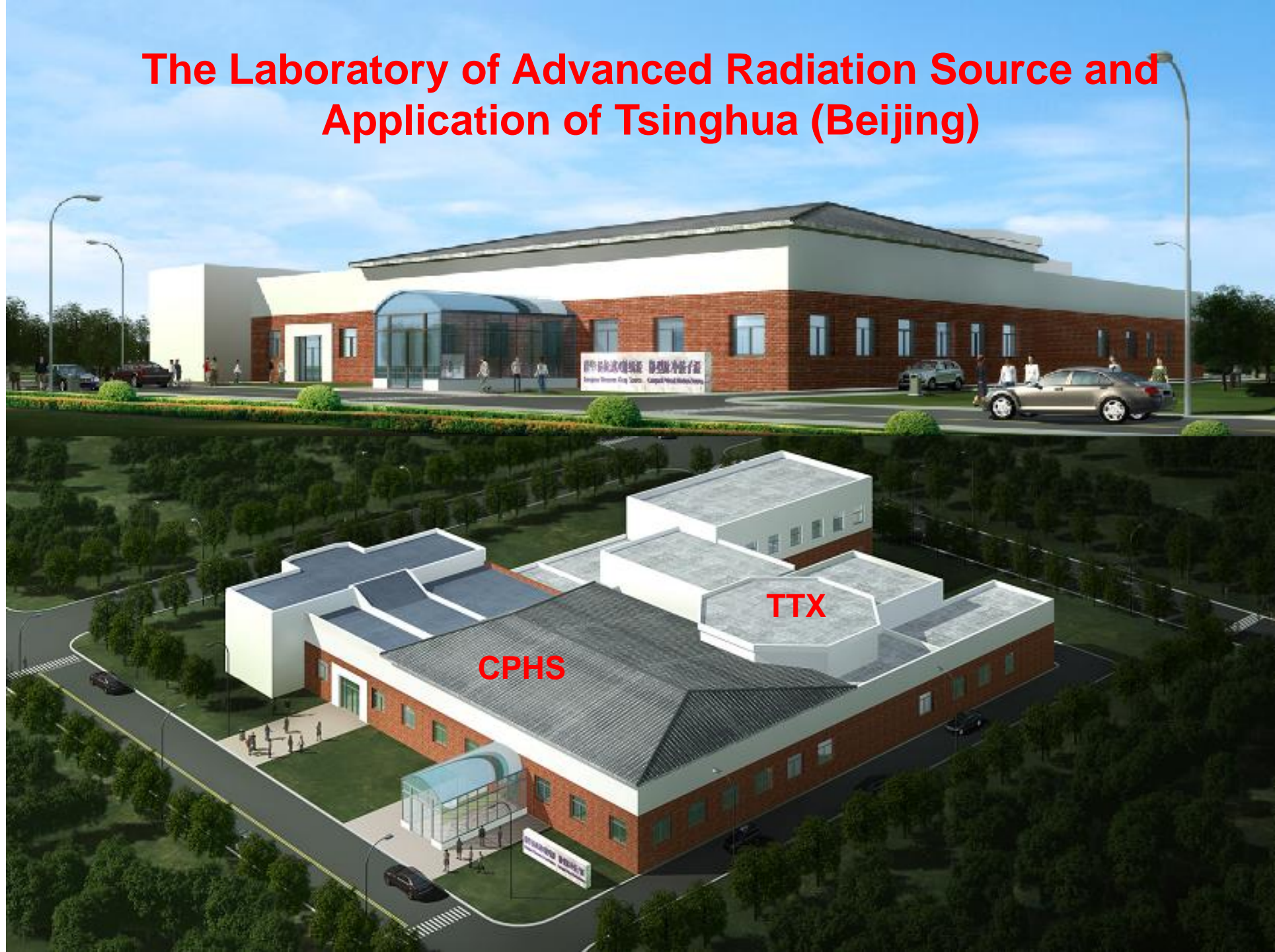
- Small source size (~30 μm)
- Adjustable for energy of X-ray
- Quasi-Monochromatic spectrum
- Radiation in a small angle ($\sim 1/\gamma$)
- Ultra-short X-ray Pulse
- Good synchronization for pump-probe
- High Peak Brightness
- Polarization
- compact and affordable
- ...

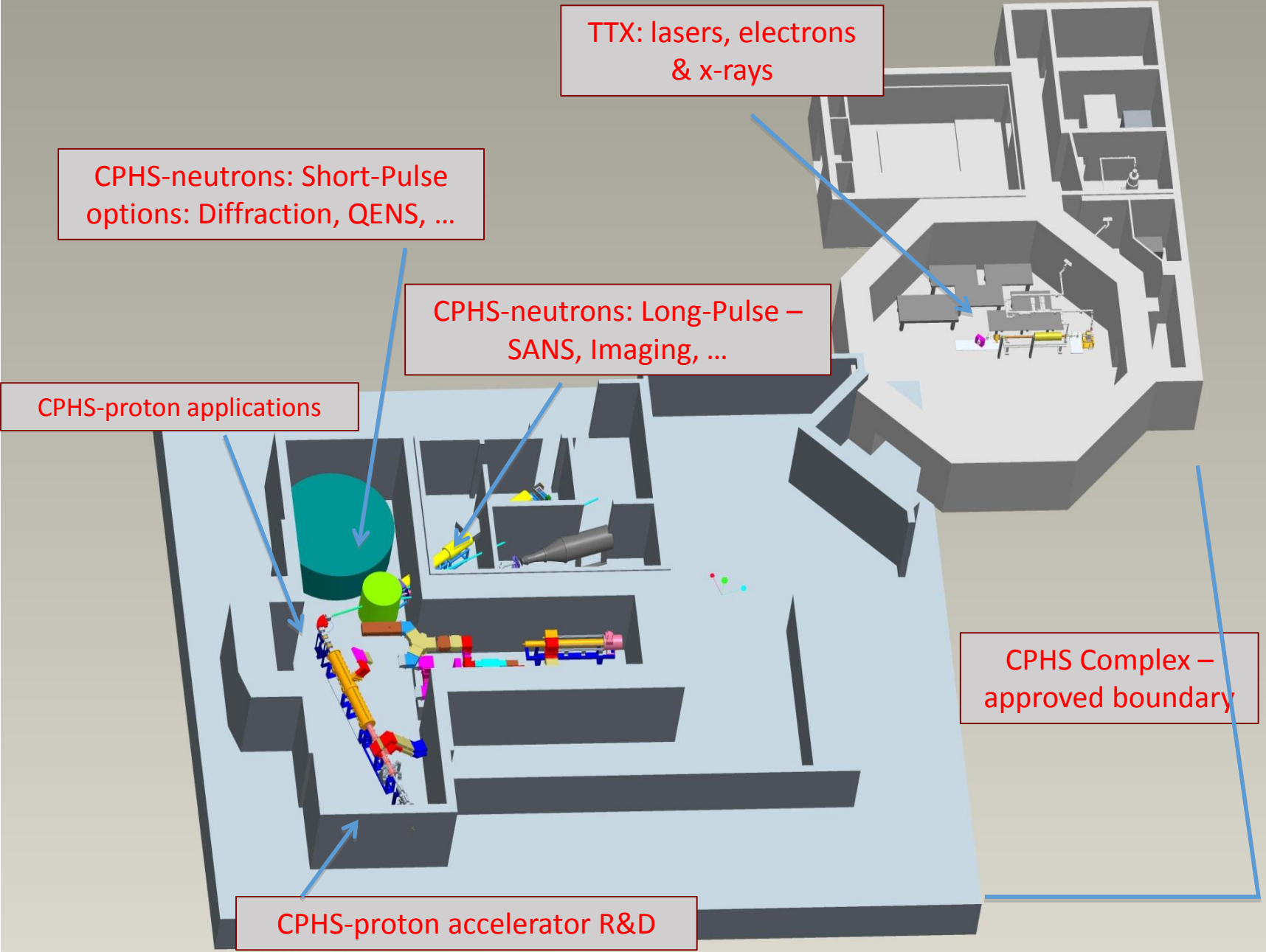
$$\omega_x = \frac{2\gamma^2(1 - \cos \psi)}{1 + a_0^2/2} \omega_0$$

Energy of electron Scattering angle

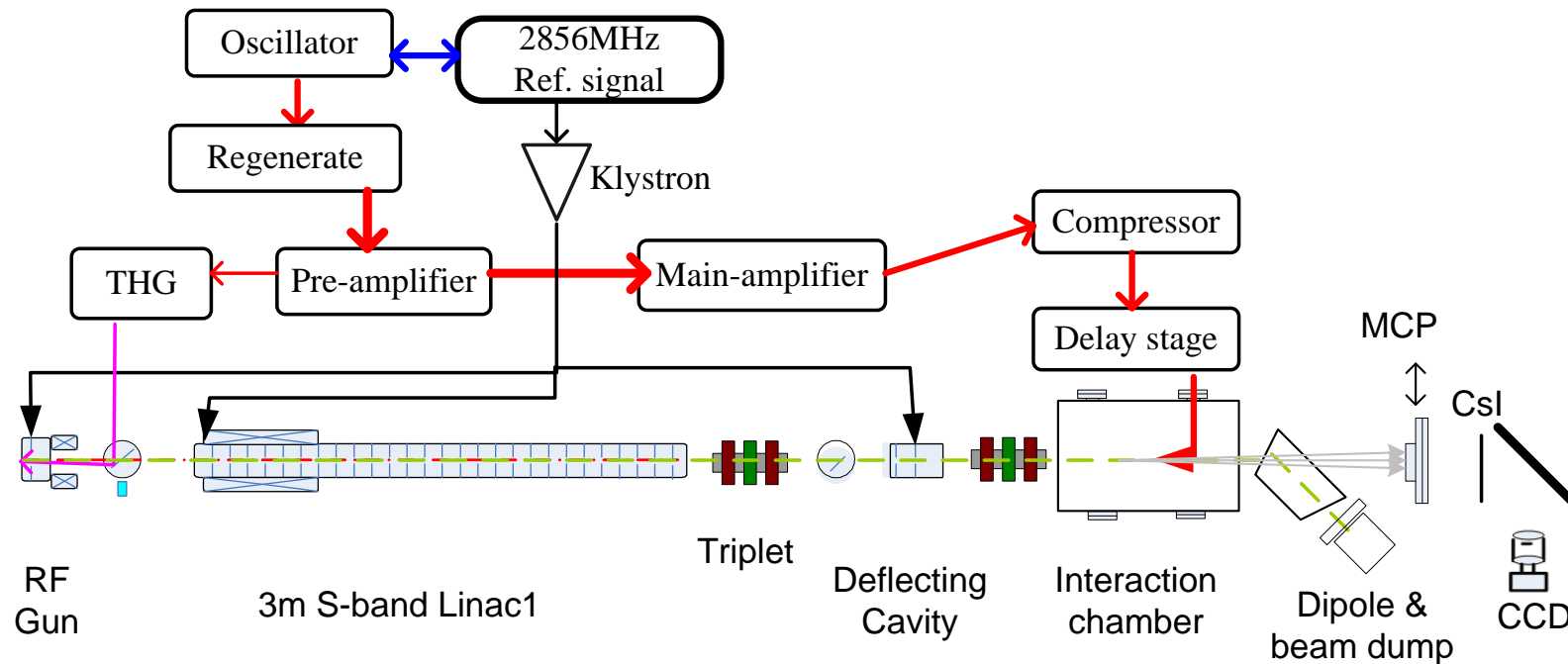
Frequency of laser

The Laboratory of Advanced Radiation Source and Application of Tsinghua (Beijing)



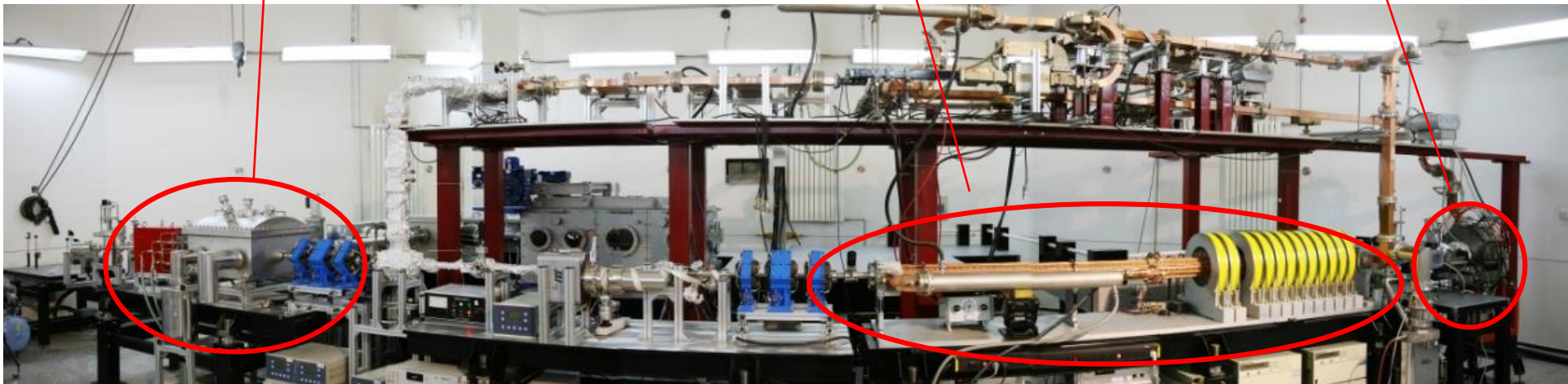
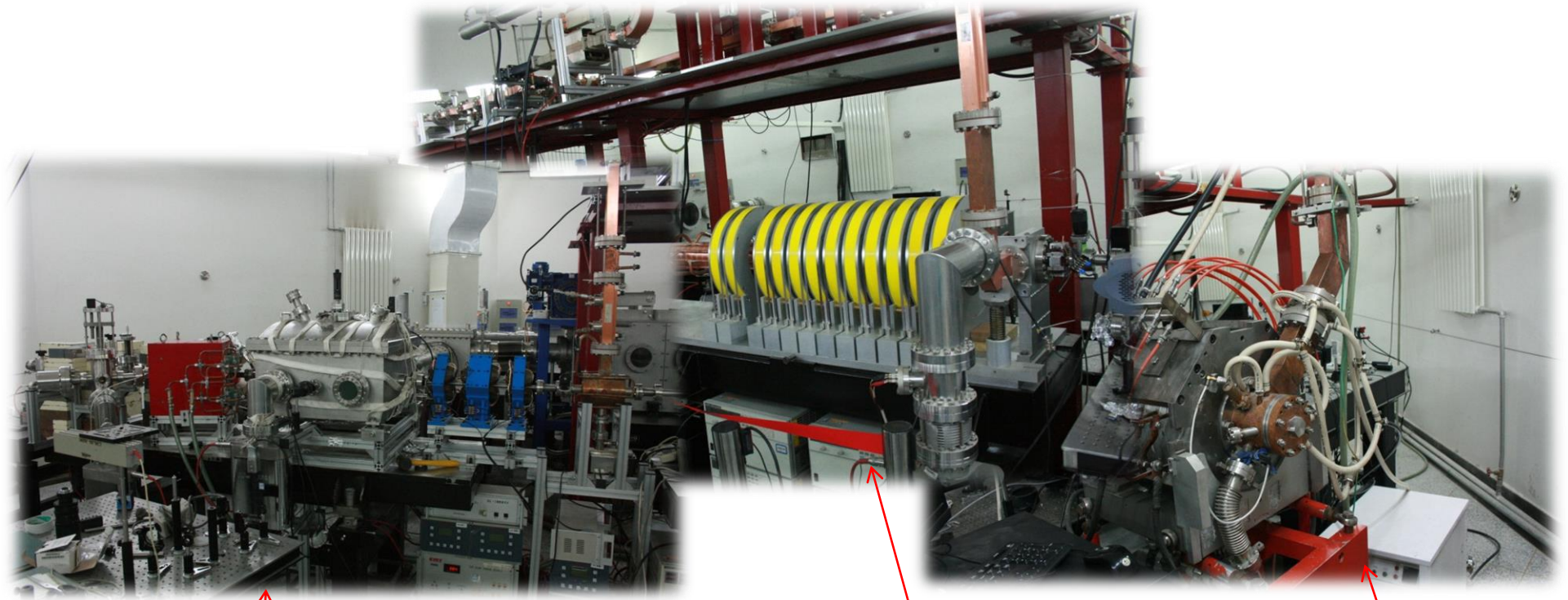


Tsinghua Thomson scattering X-ray source (TTX)



Electron beam		Laser beam		Parameters of Scattering X-ray	
Energy	45MeV	Wavelength	800nm	Photon energy	24(90deg)~48(180deg)kev
Bunch length	1~4ps	Pulse duration	~30fs	Pulse duration	0.16(90deg)~3(180deg)ps
Charge	~0.7nC	Pulse energy	~500mJ	Number photons	8.4X10 ⁶ (90deg)~5.5X10 ⁷ (180deg)
Beam size	30x25um	Beam size	~30um		

Electron beam line

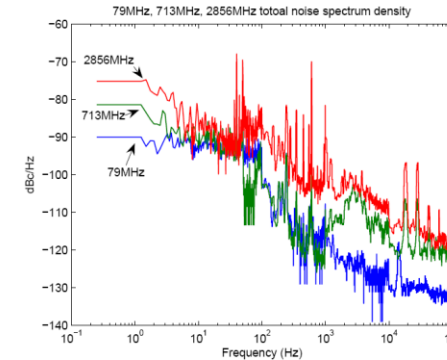
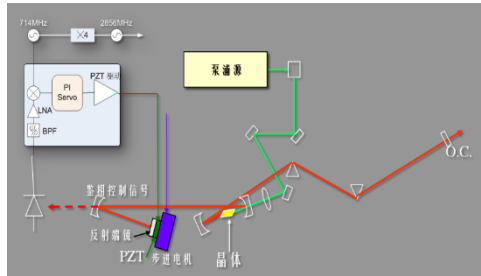


Laser System



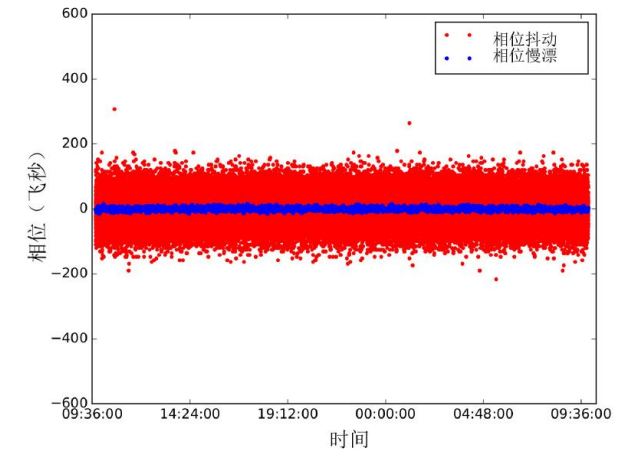
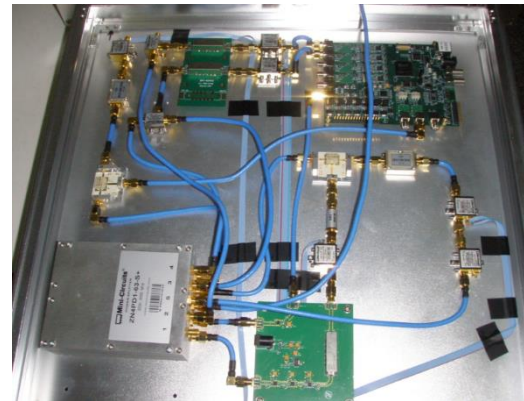
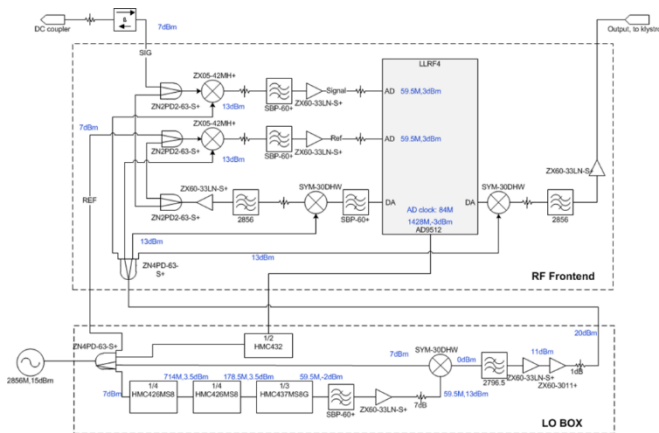
Timing jitter control and measurement

Synchronization system between microwave and laser



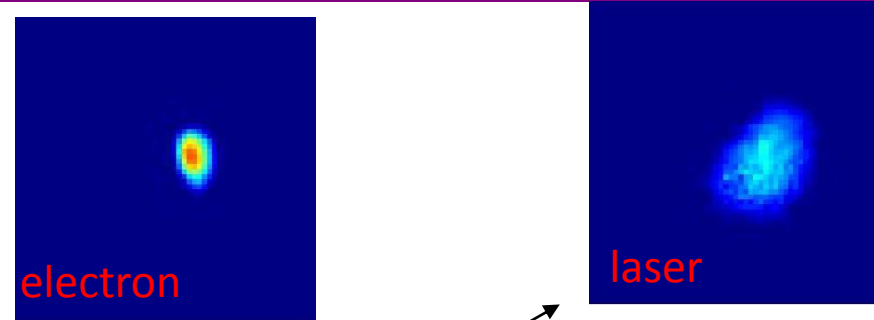
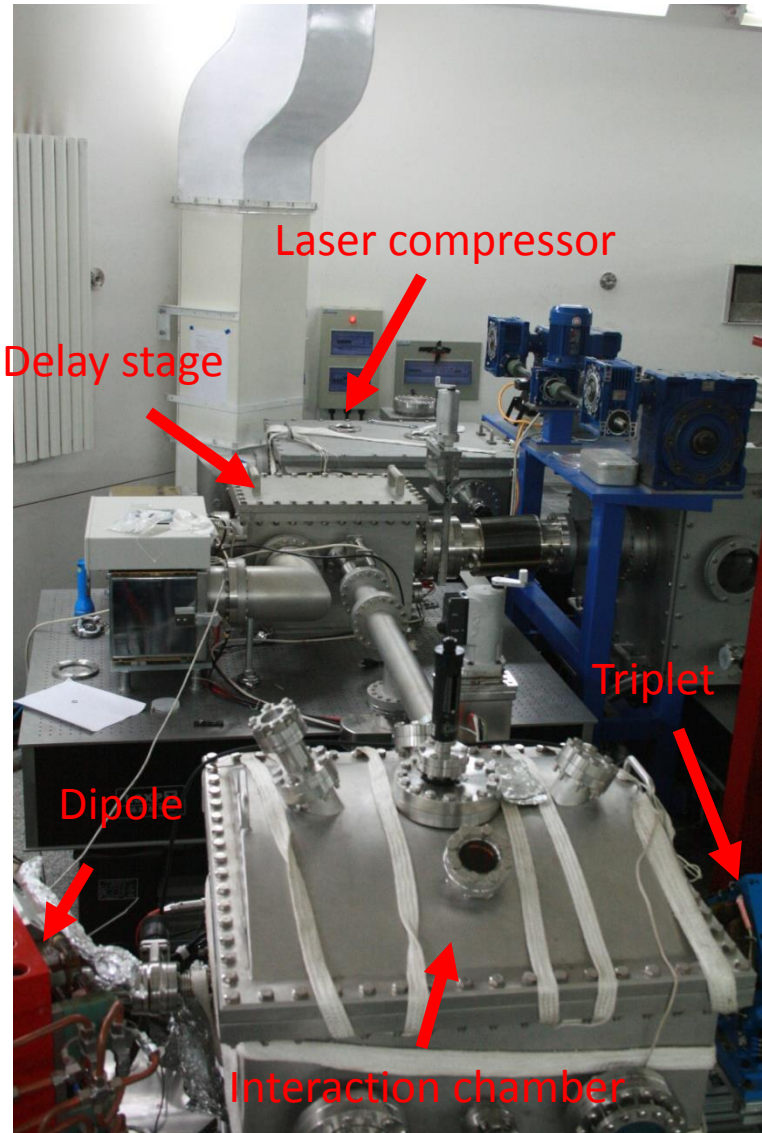
phase locking feedback loop based on harmonic phase noise measurement

Digital LLRF

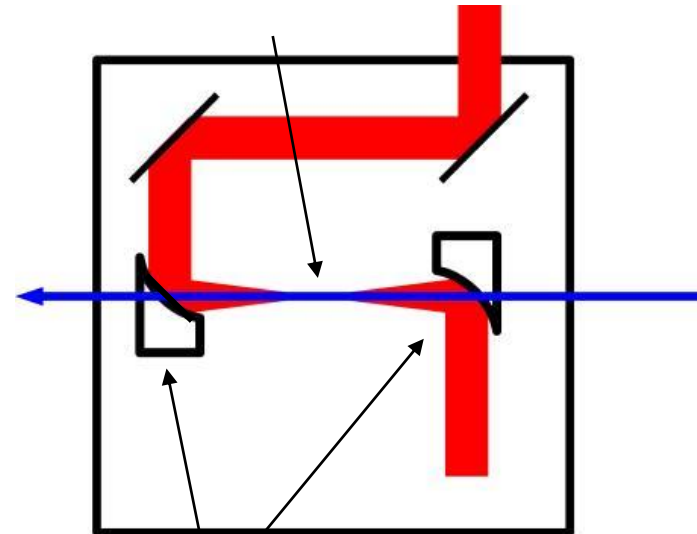


Timing jitter of this system $< 200\text{fs}$

Thomson Scattering Experiment



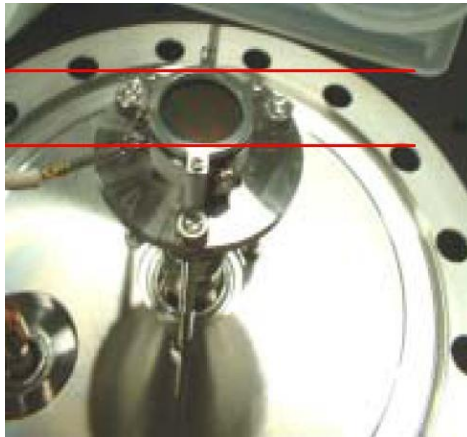
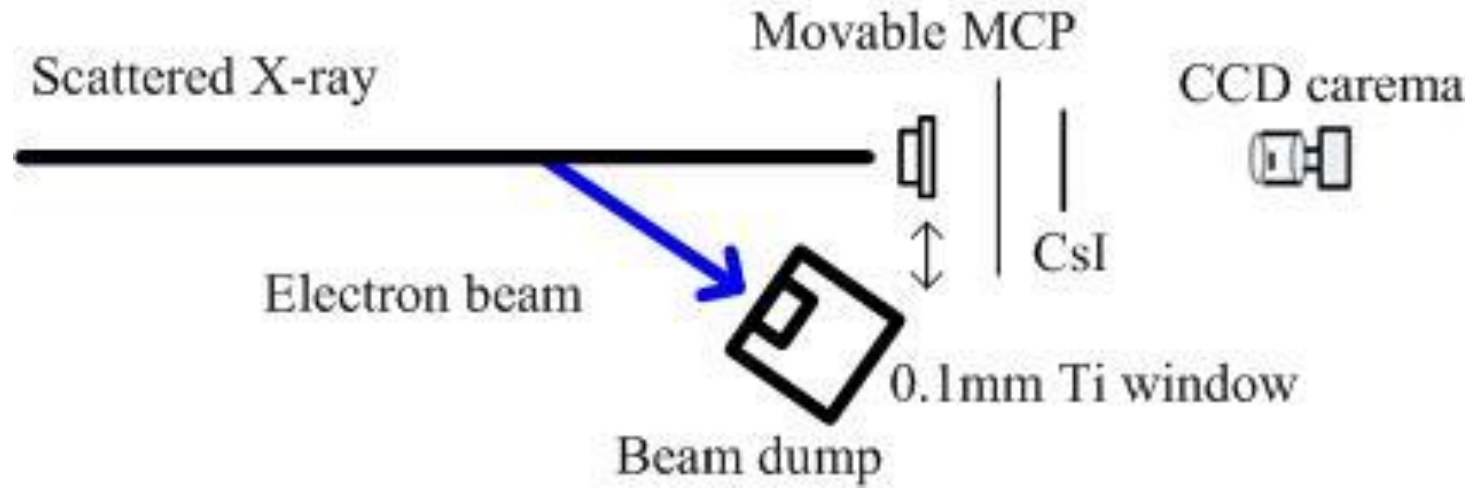
Ground glass screen for beam profile measurement at IP



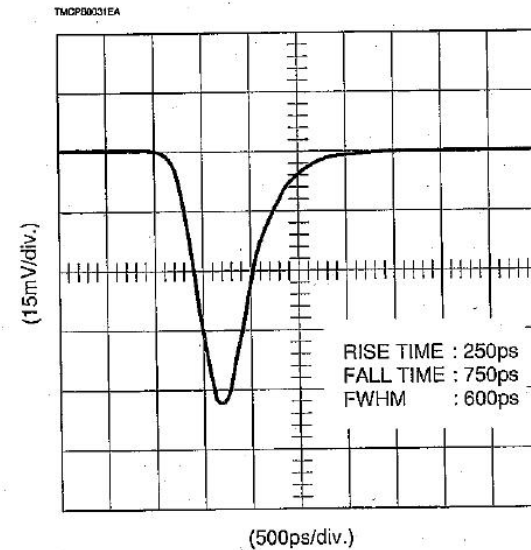
The laser is focused by a parabolic mirror with 4mm hole in center.

Thomson Scattering Experiment

- X-ray detector

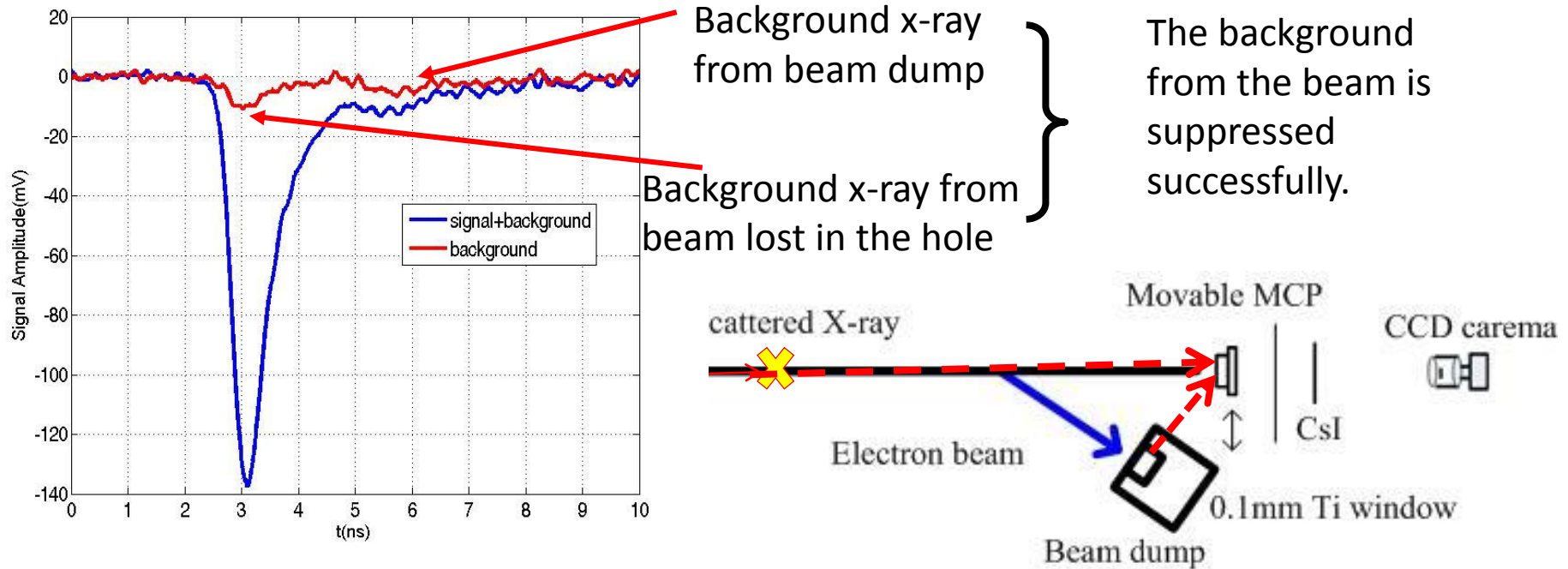


F4655-11 MCP from Hamamatsu



Thomson Scattering Experiment

- Typical X-ray signal and background

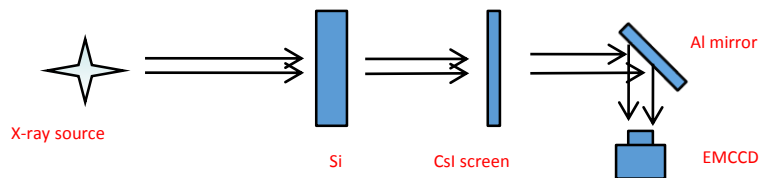


- Electron beam and laser beam parameters of experiment

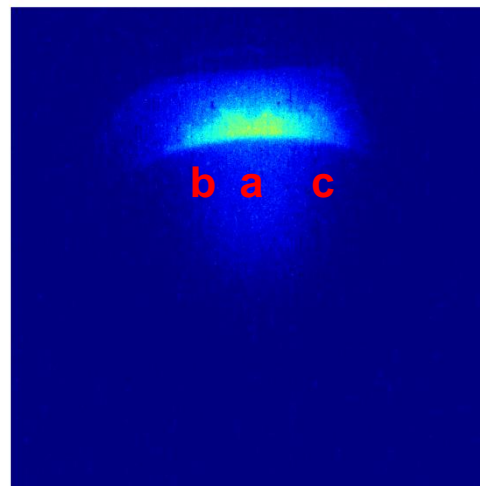
	laser	electron beam
Energy	800nm	46.7 MeV
Intensity	~300mJ	0.2nC
Beam size	100um	50um
Pulse width	~60fs	~2ps
Emittance		3mm mrad

Measured X-ray flux: $\sim 1.2 \times 10^6$

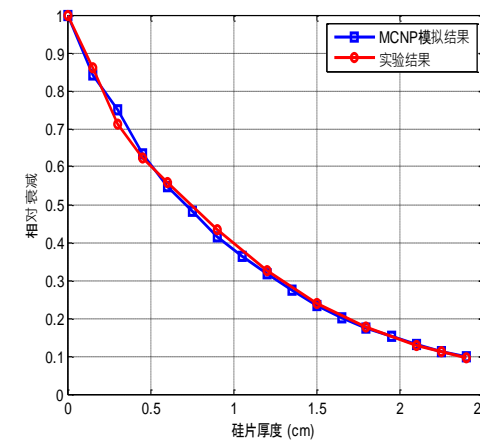
X-ray spectrum measurement



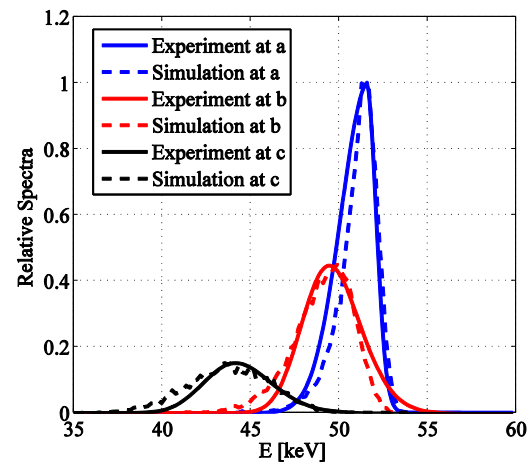
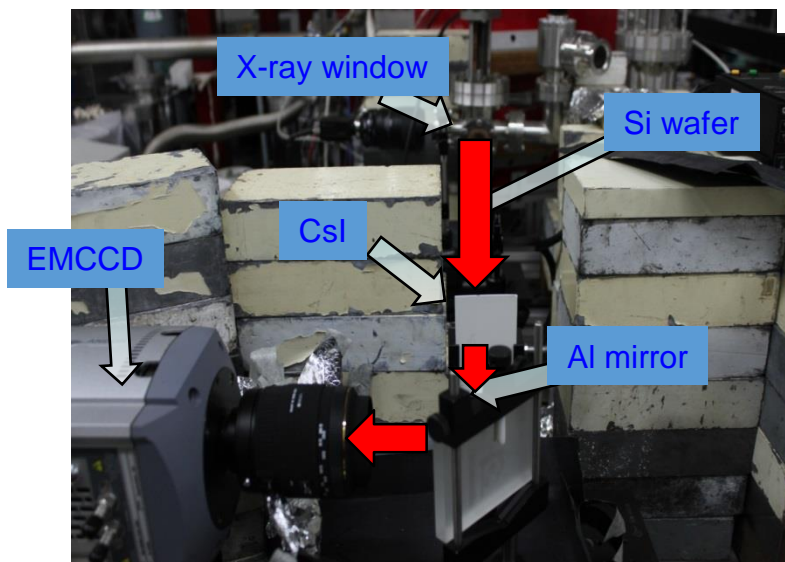
Scheme of Experiment



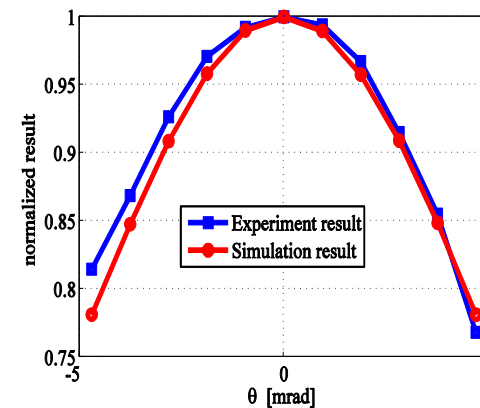
X-ray profile



Intensity vs Si' thickness



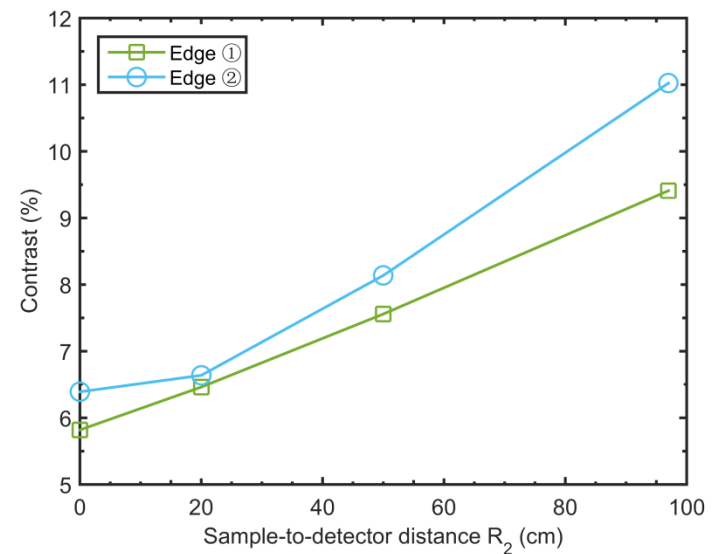
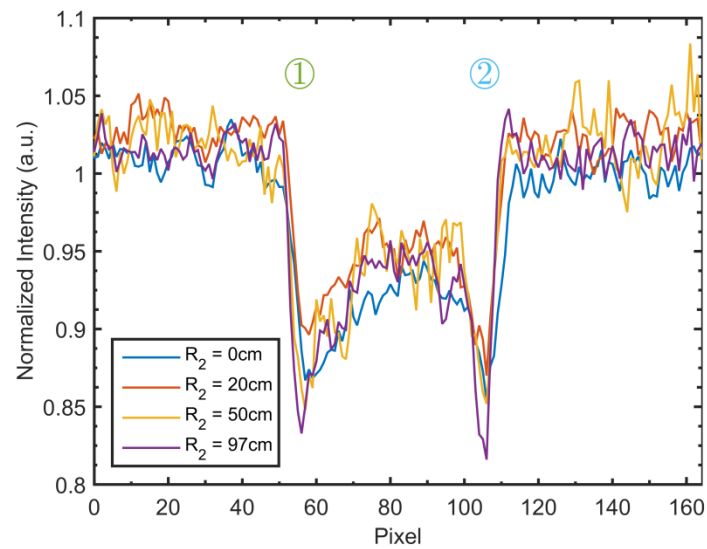
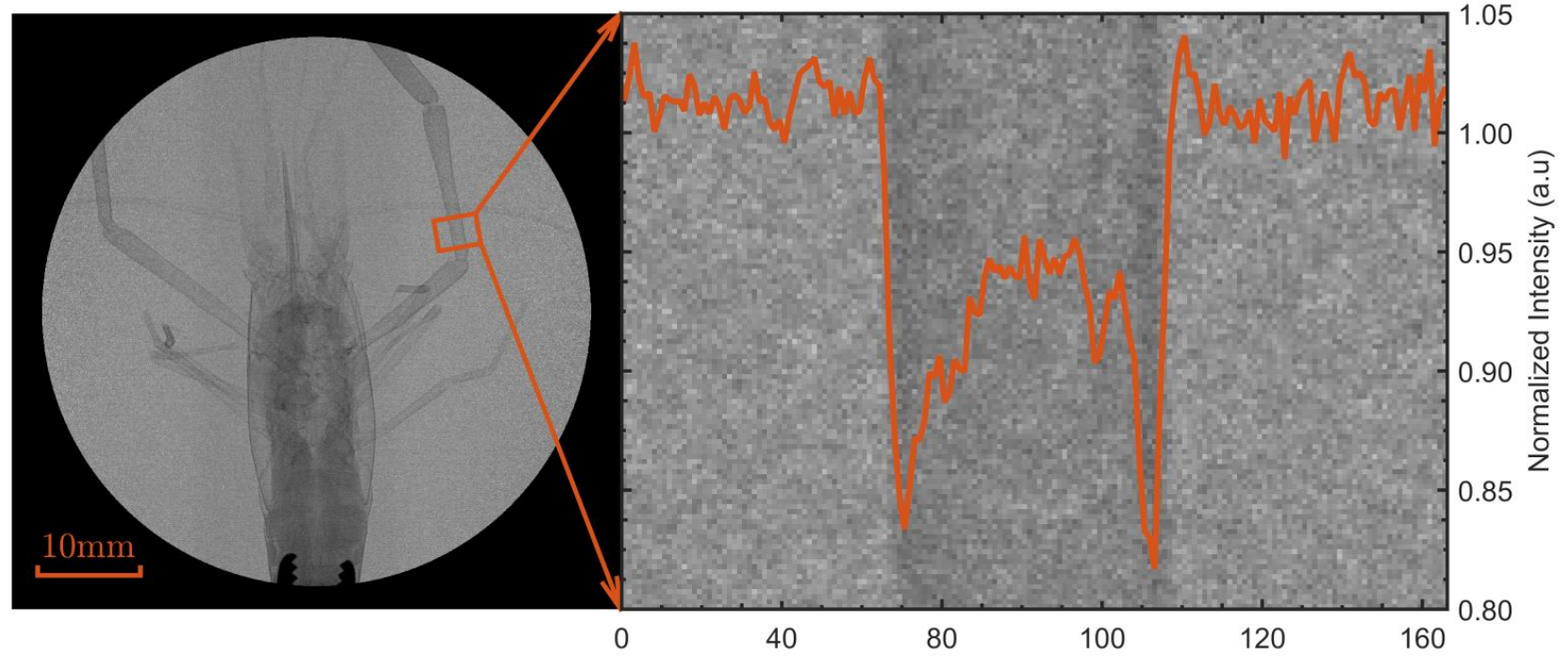
Spectrum at a,b,c

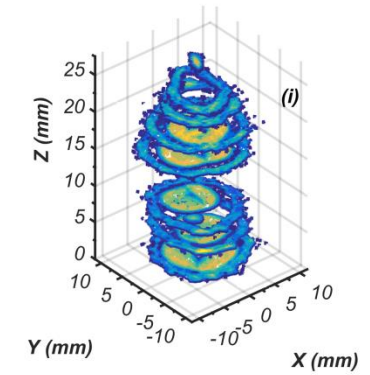
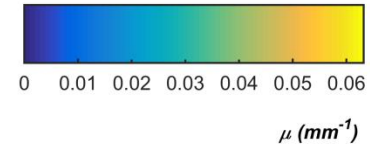
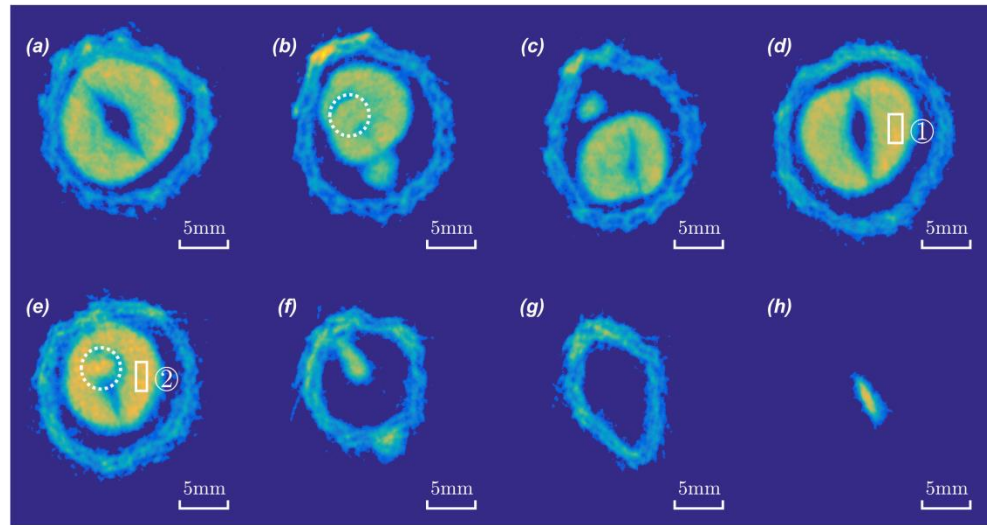


Energy Vs Scattering Angle

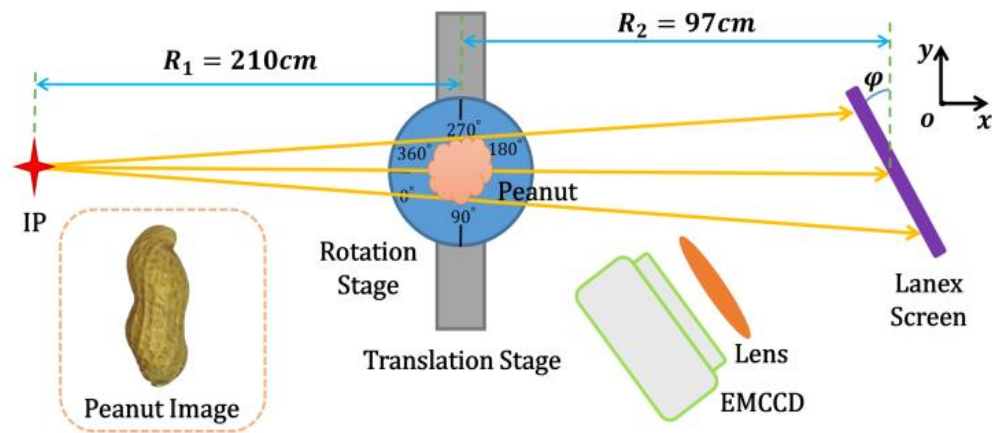
X-ray phase contrast image

Z. Chi





Peanut



Thomson scattering γ -ray Source: XGLS

- Be part of the Laboratory of Advanced Radiation Source and Application of Tsinghua (Xian)
- Under construction

Photon energy (MeV)	0.1	0.665	1.25	2.0	2.5	3.0
Energy stability	<1%					
Photons per shot	>1×10 ⁷	>10 ⁸				
Collimation angle (mrad)	1.26	0.49	0.36	0.28	0.25	0.23
Bandwidth in collimation angle	<3% rms					
Stability of Photon number	<10% rms					
Radiation pulse length(ps)	<3 ps rms					
repetition rate	<10Hz or single shot					

Thomson scattering γ -ray Source: XGLS

Electron beam

Energy	60~400	MeV
Beam charge	0.1~0.5	nC
Energy spread (rms)	<0.3%rms	
Energy jitter (rms)	<0.3%rms	
Nor. emittance	<1@0.5nC	mm mrad
Pulse duration(rms)	1~3	ps
Charge jitter (rms)	<3%	
Focused beam size (rms)	~15@0.5nC	um
Jitter of focused beam size (rms)	<3% beam size	
Jitter of beam position (rms)	<15% beam size	
Arriving time jitter (rms)	<0.5	ps
Repetition rate	5~10	Hz

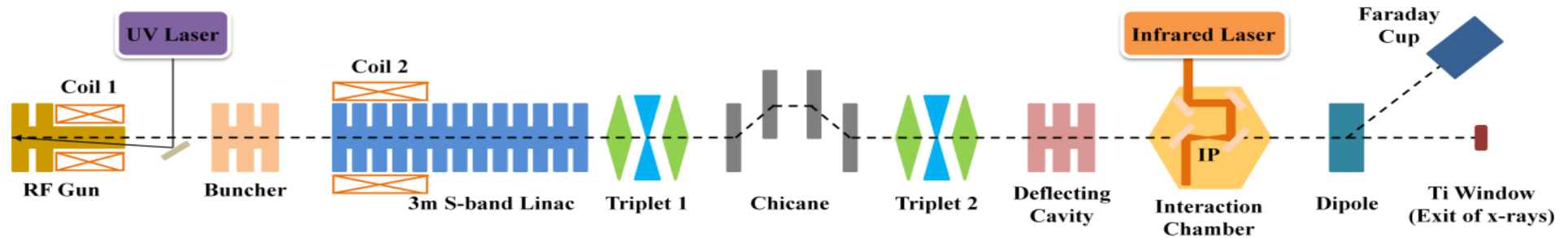
S-band photo-injector + S-band main linac, the total length is ~60m

Compact γ -ray source

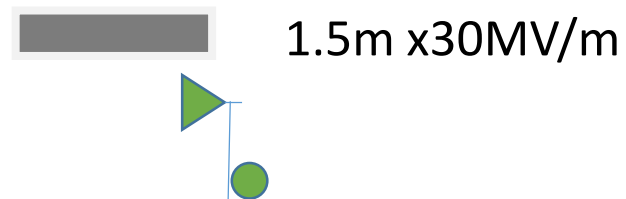
- Demand for photons above 2MeV with narrow energy spread.
- To meet the requirement:
 - Energy of e-beam: 200MeV / 320MeV
 - Wavelength of laser: 400nm / 800nm
- Compact within ~10m
 - Limited length of the experiment hall
 - Tabletop facility

TTX linac upgrade plan

2016:



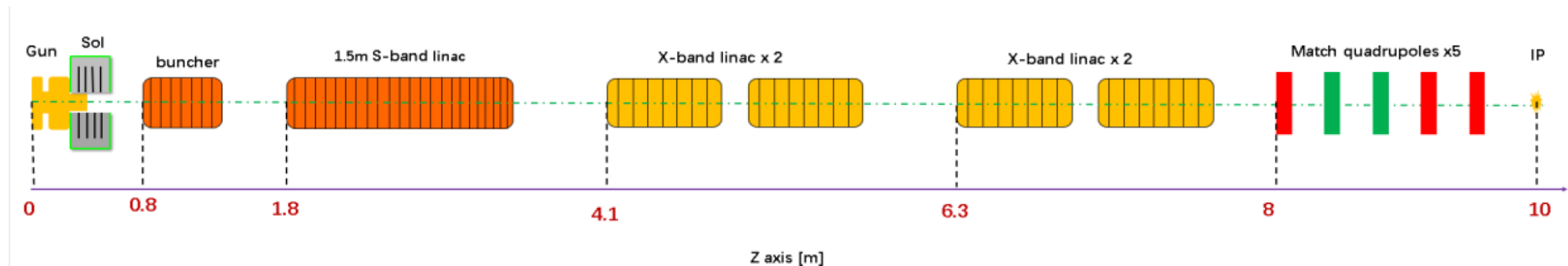
In 1 year



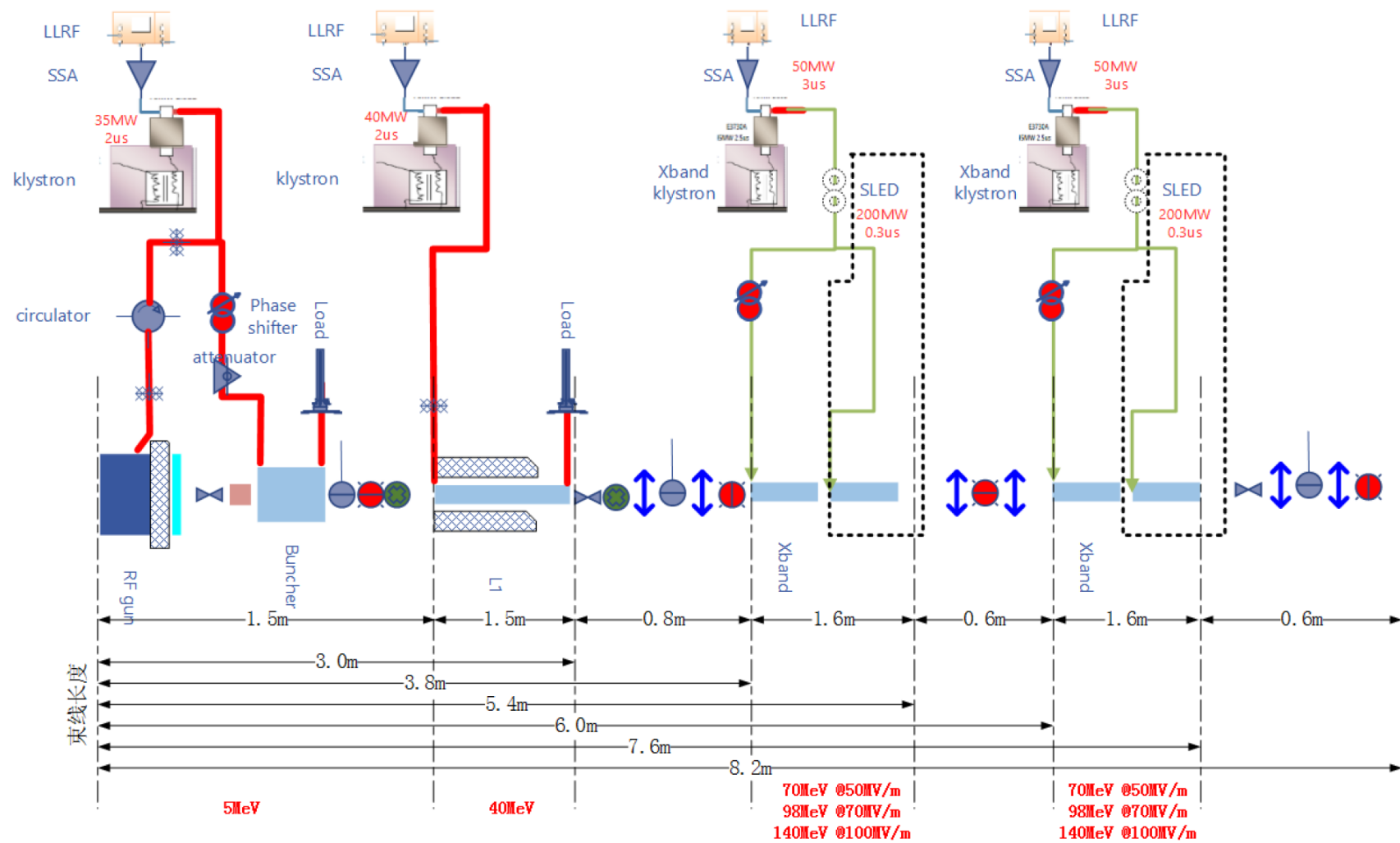
In 3~5 year



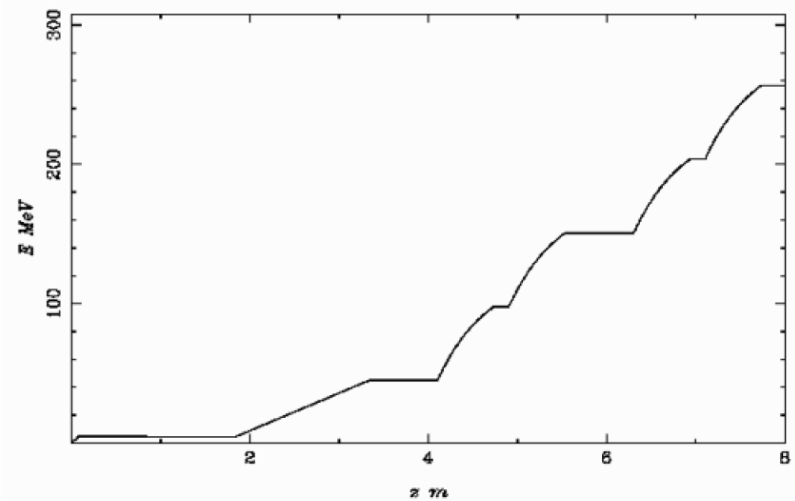
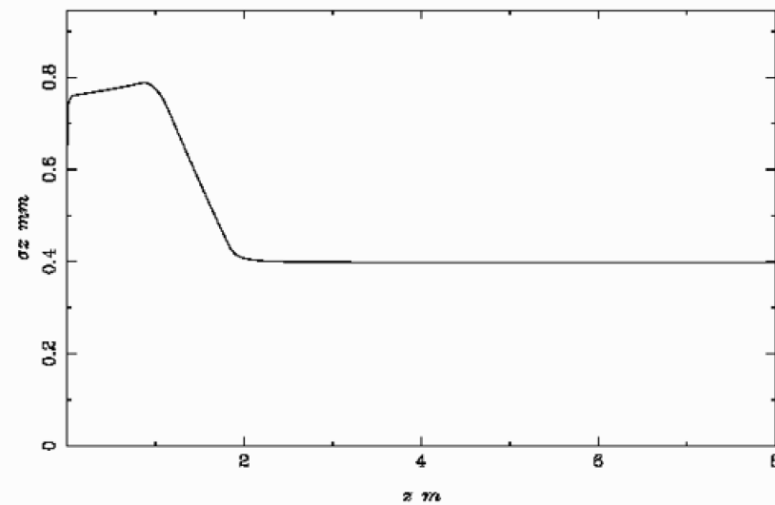
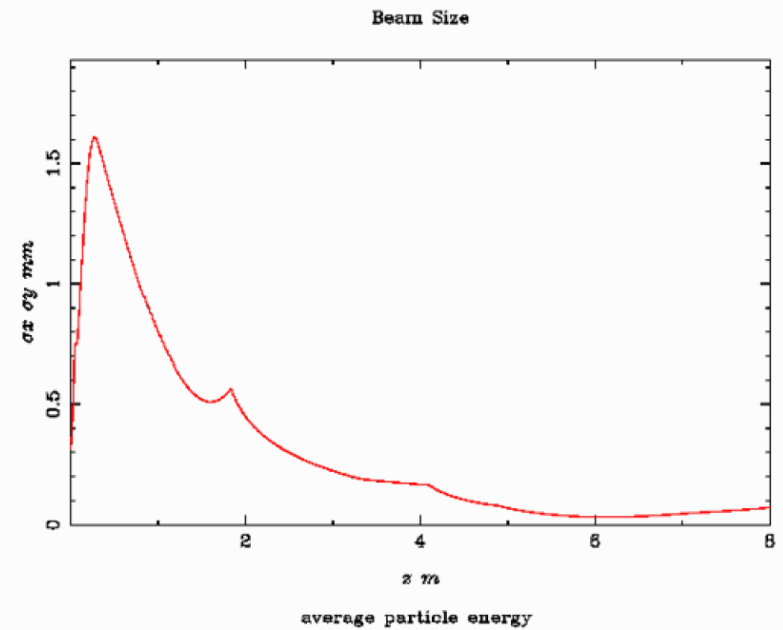
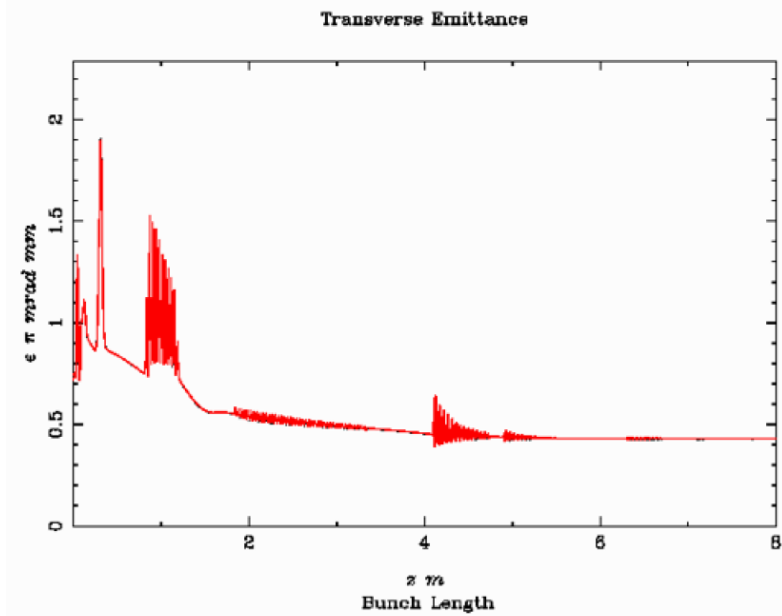
New beam line



TTX layout new

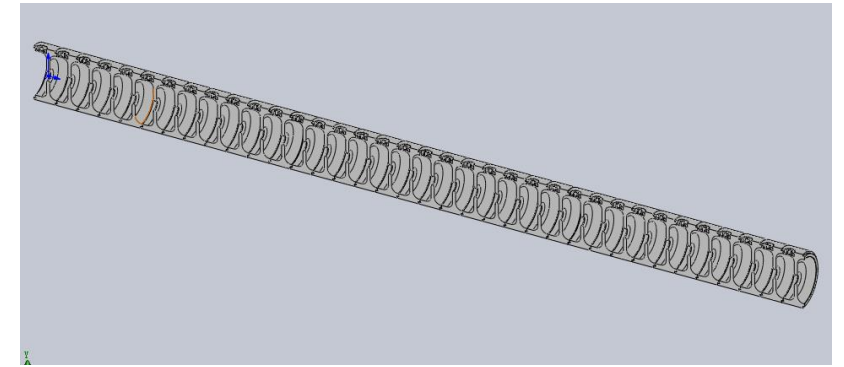
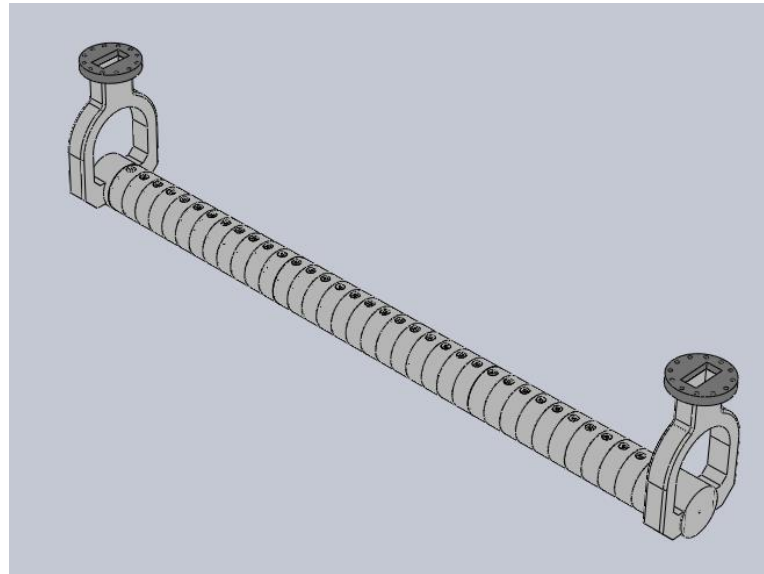
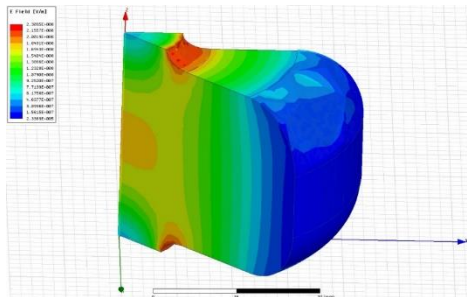


Beam parameters in ASTRA



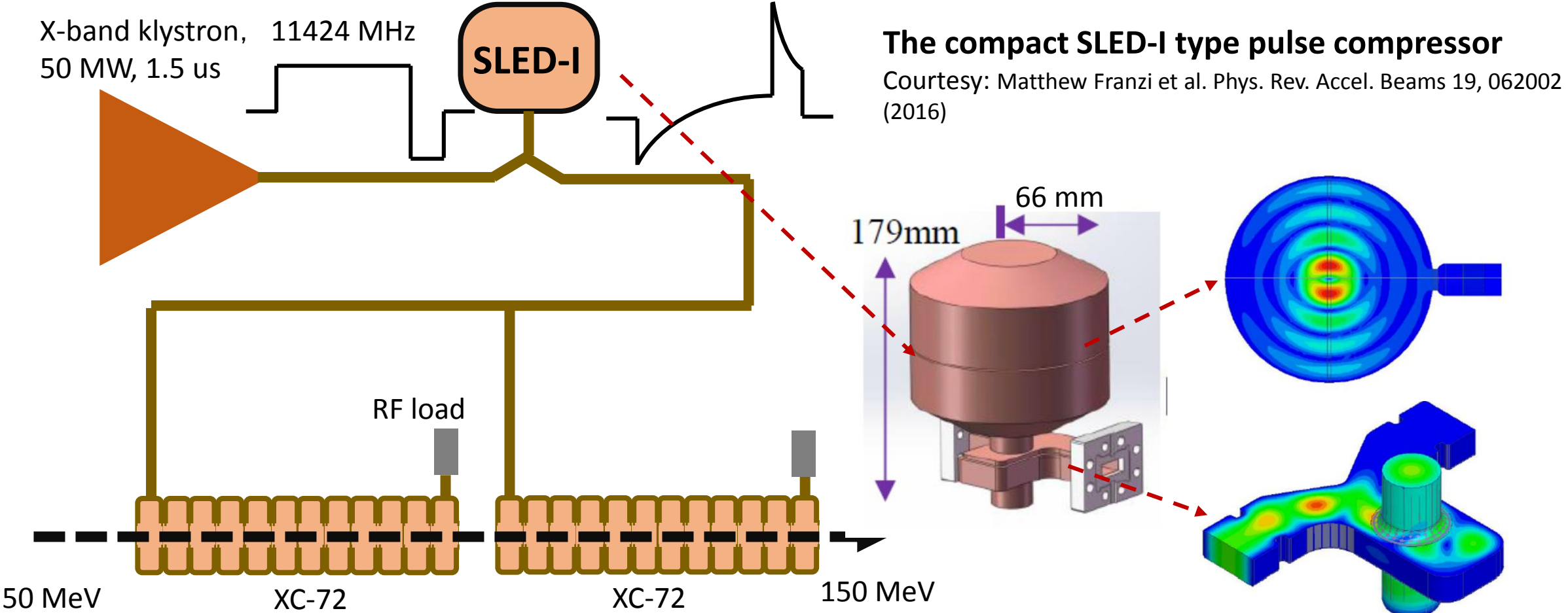
TTX Next

- Replace the 3-m linac with 1.5m x30MV/m



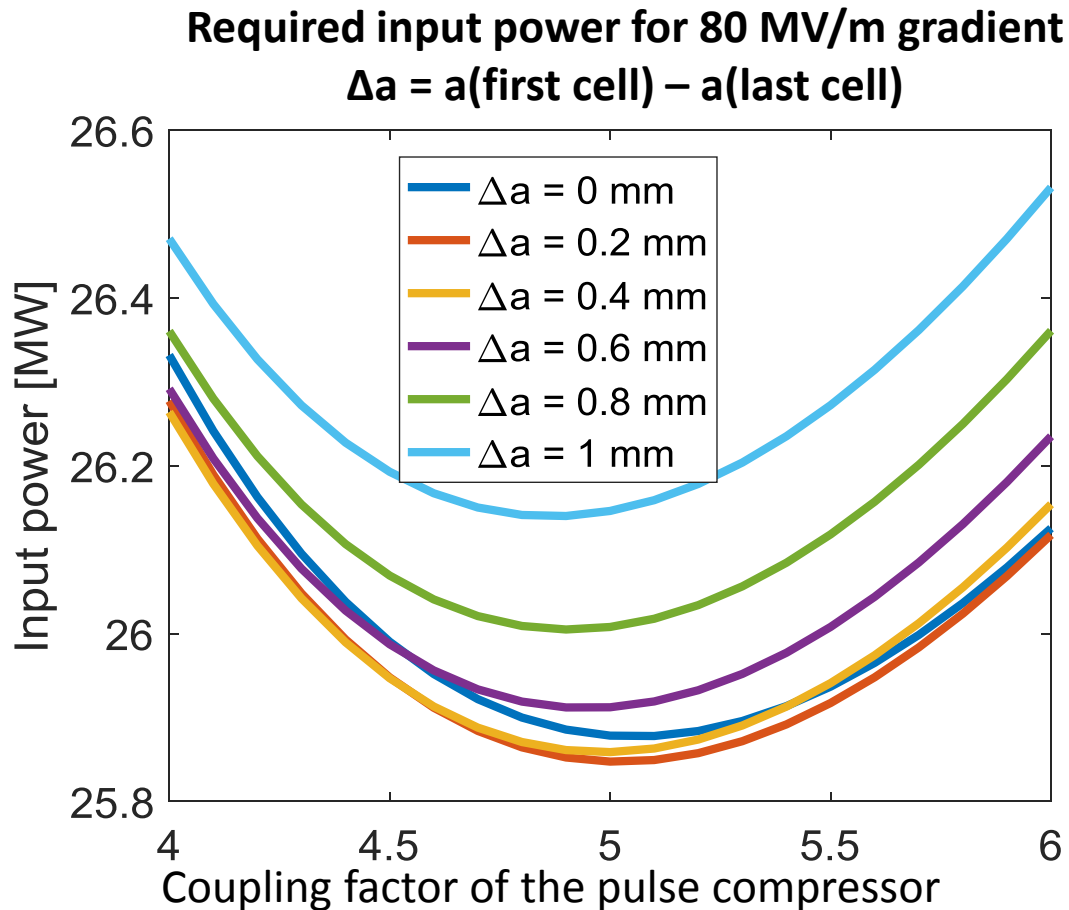
Parameters	Units
Length	1.5m
Mode	$3/4\pi$
Cell length	39.3mm
Number of cells	38(with coupler)
f	$\sim 2856\text{MHz}$
a	10.6mm-8.1mm
v_g/c	0.83%~0.3%
R_s	64.6M Ω /m~71.8M Ω /m
Filling Time	960ns
Eacc(Pin=30MW)	30MV/m

X-band System



XC72 accelerating structure

- Due to the pulse compressor, the constant impedance structure has similar performance to the one of tapered iris aperture (constant gradient).
- The constant impedance structure is much easier to be fabricated.



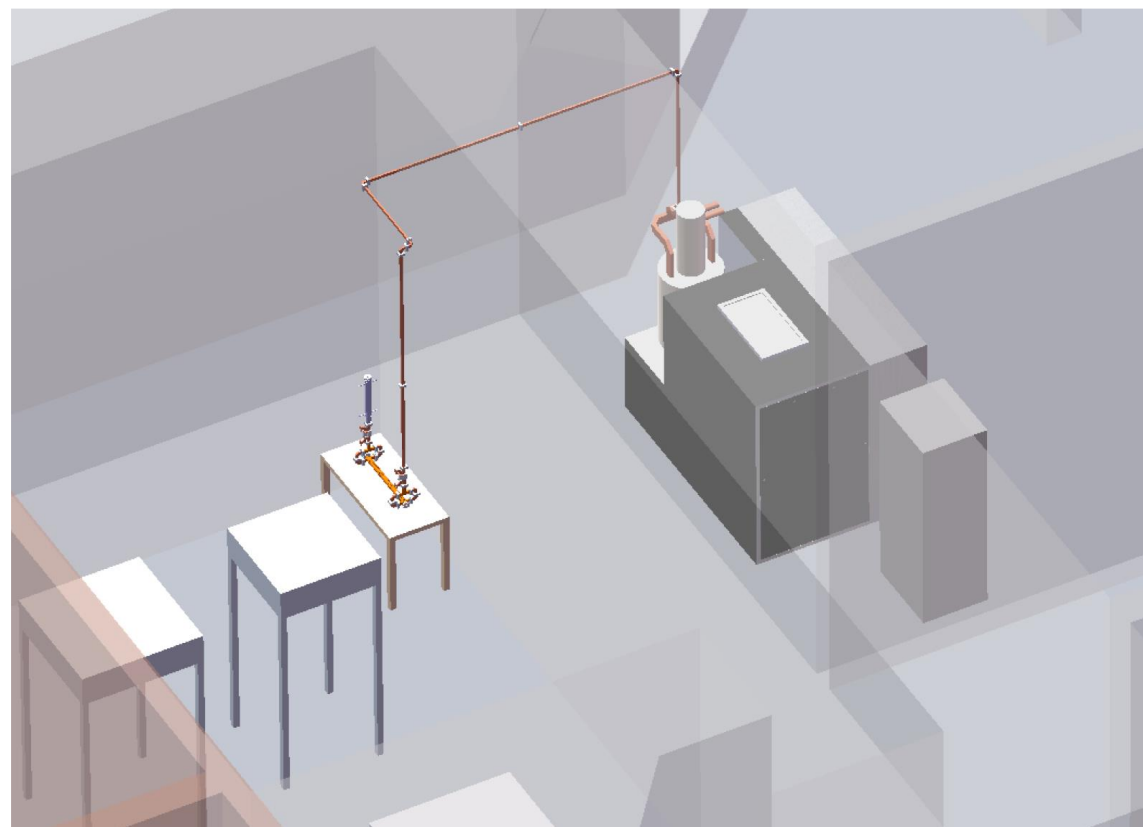
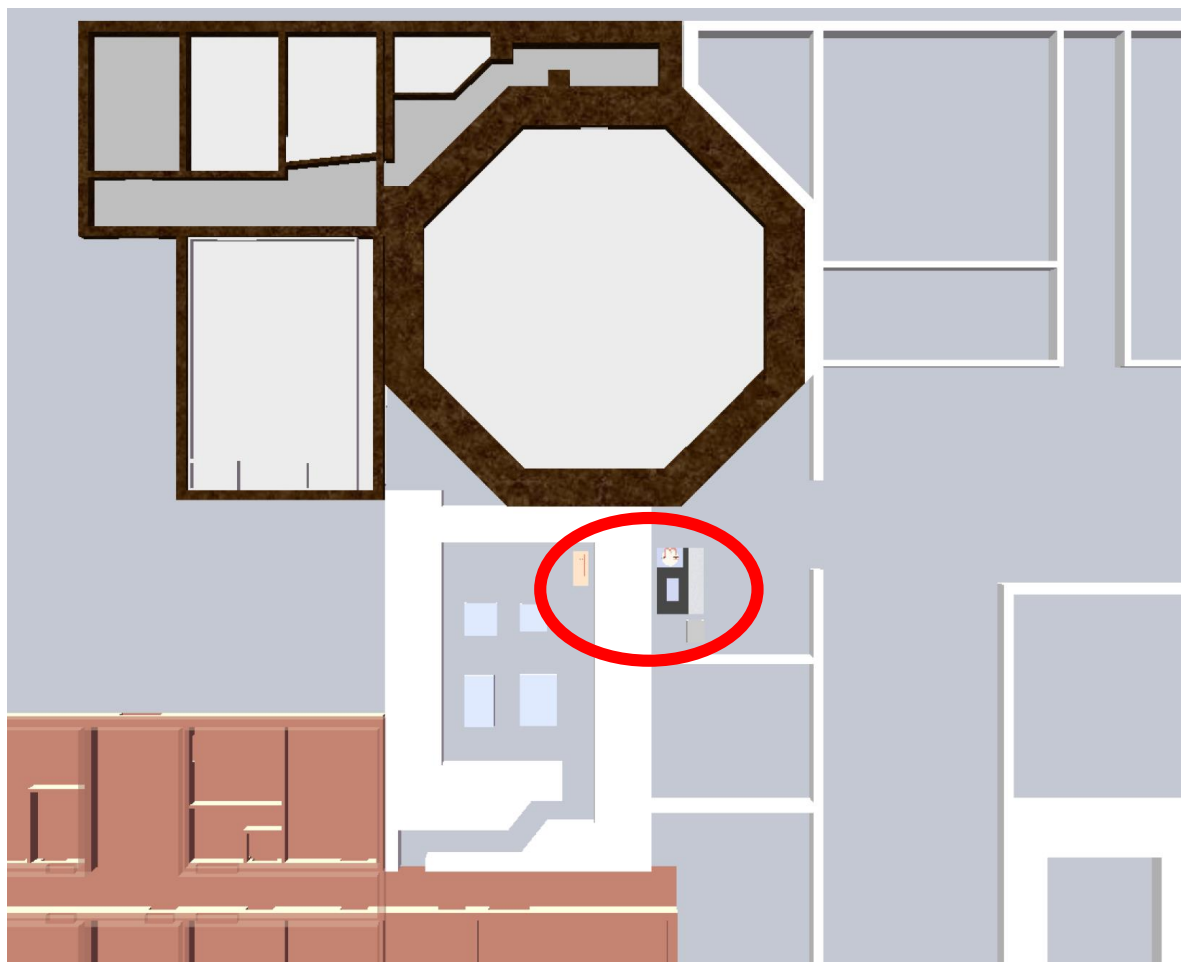
Frequency	11424 MHz
Length	65 cm*2
Working mode	$2\pi/3$
Working gradient	80 MV/m
Iris aperture a	3.5 mm
Iris thickness d	1.8 mm
Shunt impedance	103 M Ω /m
Group velocity v_g/c	2.24% c
Q -factor	7180
Filling time	94 ns
Max E_s	196 MV/m
Max S_c	4.96 MW/mm ²
Coupling factor of the pulse compressor	3.5
Required Input power from klystron [MW]	13.7 MW*2

Estimate delivery Apr. 2017

- CPI 8311B Klystron
 - 11.424GHz
 - 50MW
 - Factory test in March
- ScandiNova K2-3 modulator
 - 127MW
 - 410kV, 310A
 - Factory test done in Feb.
- Microwave amps
 - 1.2kW SSA @ 11.424GHz

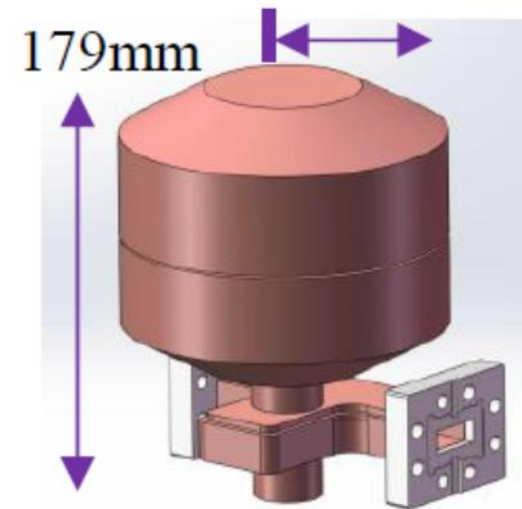
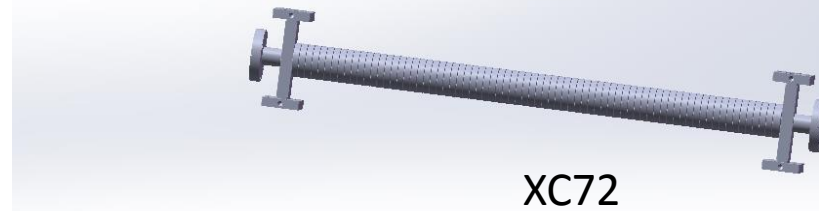


Tsinghua High-power X-band test stand



Tsinghua High-power X-band test stand

- T24-THU#1
- XC72 – conditioning
- X-band pulse compressor
- Power switch
 - Test stand/Beam-line
- X-band gun test
- ...



Summary

- TTX, on campus, high beam quality
- XGLS, on Xi'an site
 - Towards higher energy, better stability. Under construction
- Compact γ -ray source
 - 300MeV linac designed to fit TTX site
- TTX upgrade plan
 - S-band @30MV/m replacement
 - X-band unit aiming 70~80MV/m demonstration
 - 150MeV with two X-band 600mm structures in 3-5 years
 - Pulse compressor and XC72 (constant impedance structure) in pipeline