清華大學
Tsinghua University

ACCELERATOR LABORATORY of TSINGHUA UNIVERSITY

VIGAS (Very Compact Inverse-Compton-Scattering Gamma-ray Source) project in Tsinghua University

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on behalf of VIGAS team in Tsinghua University

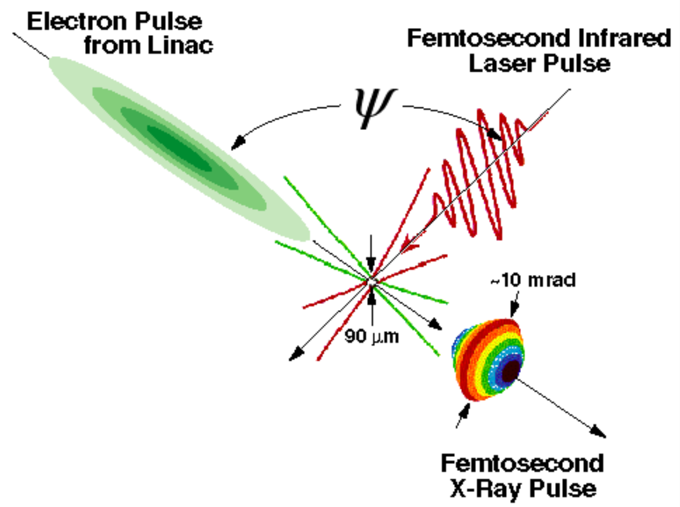
The 2025 International Workshop on the High Energy Circular Electron Positron Collider

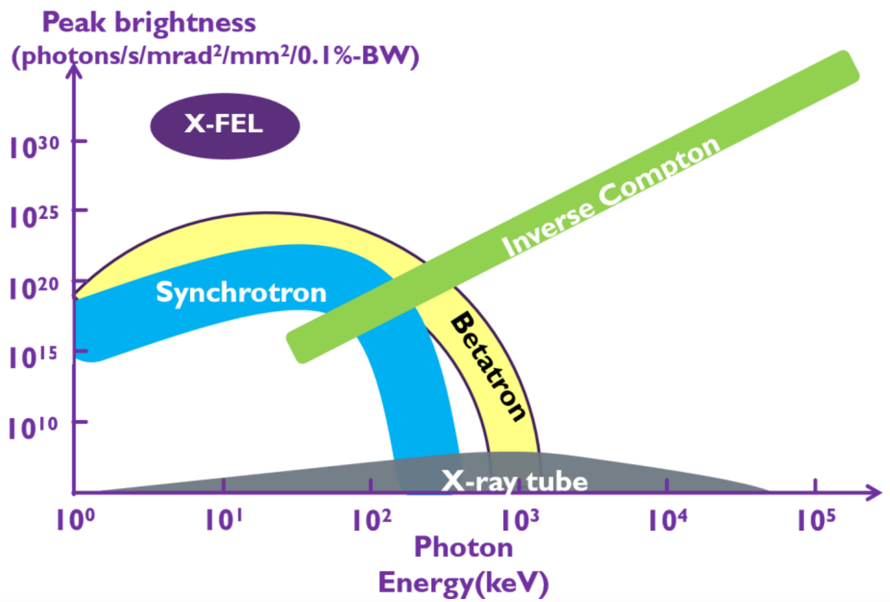
OUTLINE

- **Introduction**
- **Overview of the Beamline**
- **The S-band injector**
- **The X-band linac**
- **The laser System**
- **Progress and summary**

Introduction

VIGAS: **V**ery compact **I**nverse-compton-scattering **GA**mma-ray **S**ource





Characteristics

- Quasi-monochromatic
- Continuously adjustable Gamma-ray energy
- Small source size ~10um
- Controllable polarization
- Ultra-short pulse length (fs~ps)

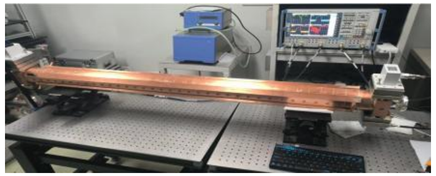
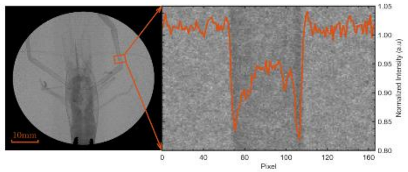
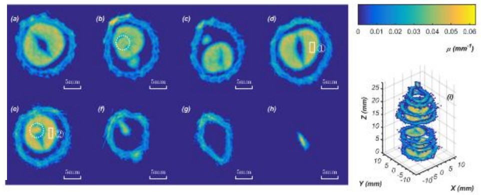
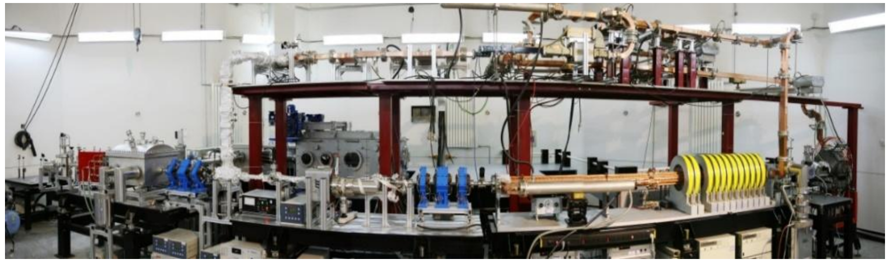
Advantages

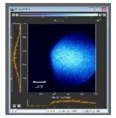
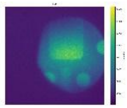
- High peak brightness
- Gamma-ray
- Compact
- Affordable

ICS Studies at Tsinghua

2001	2002	2006	2009	2011	2016	2021	2024	2025
Beginning of the TS studies in THU	Collaboration on TS with CAEP	Generation of the 1^{st} scattered X-ray signal at TTX, 4.6 keV, 1.7×10^5ph/s	Soft X-ray generation experiment using photocathode rf gun at the TTX, 290 eV, 1 ps, 6.4 x10^4ph/s	Generation of the 1^{st} hard X-ray pulse at TTX, 51.7 keV, 1.0×10^7ph/s	High-quality X-ray imaging experiment, 20-50 keV, 2.0×10^8ph/s	Beginning of VIGAS project	VIGAS installation complete	Generation of high-energy X-rays in VIGAS collision experiment



Introduction

Goals of VIGAS project:

- Gamma-ray energy: 0.2~4.8 MeV continuously adjustable
- Gamma-ray energy spectrum bandwidth(rms): <1.5% (w/ collimator)
- Photon production (photon/s):
  - $>4\times10^{8}$ @0.2~2.4 MeV; $>1\times10^{8}$ @2.4~4.8 MeV
- Photon production in 1.5% bandwidth (photon/s):
  - $>4\times10^{6}$ @0.2~2.4 MeV; $>1\times10^{6}$ @2.4~4.8 MeV
- Polarity: adjustable from linear to circular

Introduction

- Gamma-ray energy: 0.2~4.8 MeV continuously adjustable
  - Collision angle between electron bunch and laser: 180 degree

Laser energy:

- 800nm: 1.54 eV
- 400 nm: 3.08 eV

Electron energy:

- Maximum > 320 MeV
- Minimum < 92 MeV

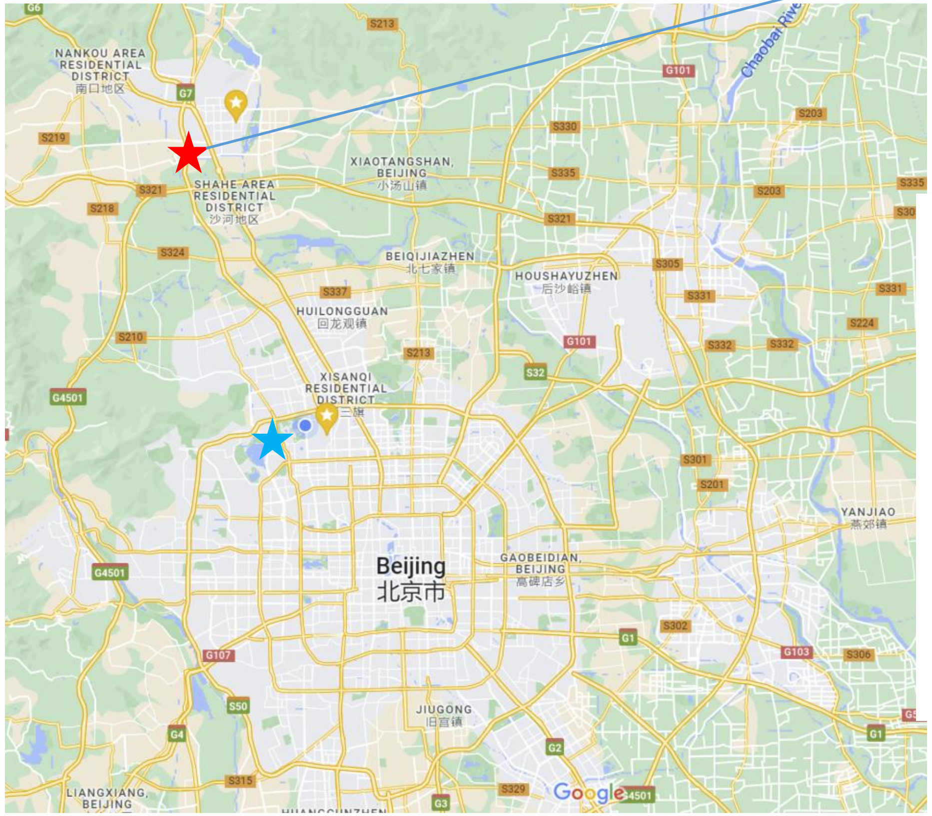
$$E_\gamma = \frac{4\gamma^2}{1 + \frac{a_0^2}{2} + \gamma^2\theta^2} E_L$$

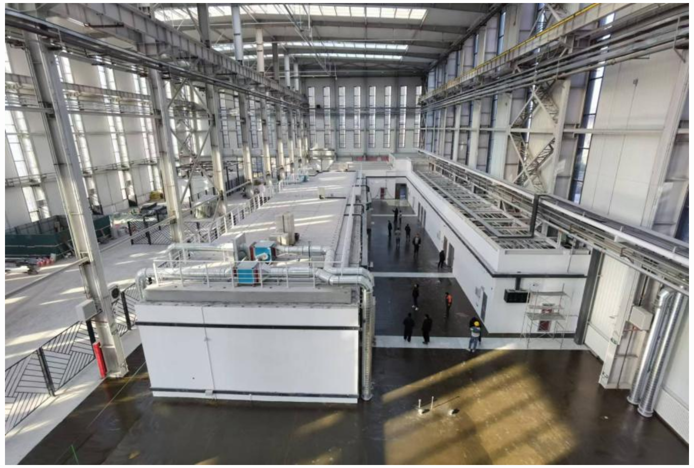
a_0: Normalized vector potential
E_γ: Gamma energy
E_L: Laser energy
γ: Electron energy
θ: Observation angle

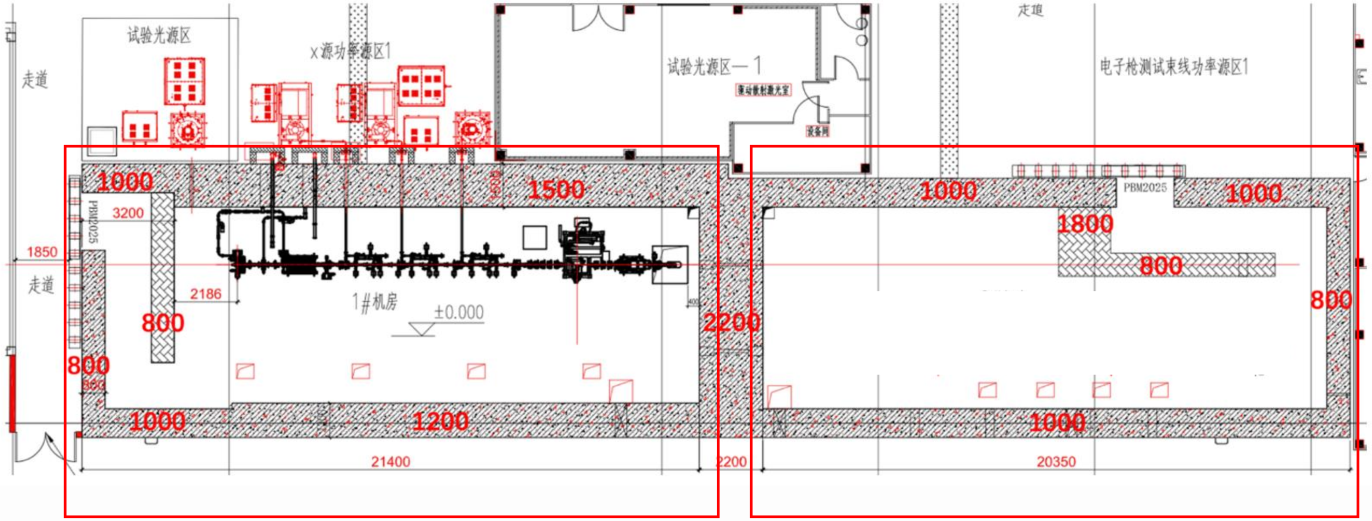
- 200 keV gamma-ray @800nm & 92 MeV electron
- 2.4 MeV gamma-ray @800nm & 320 MeV electron
- 4.8 MeV gamma-ray @400nm & 320 MeV electron

Footprint

Building area ~ 48,000m^2
Bunker for VIGAS accelerator:
21 m × 10 m







Accelerator section:
generating gamma ray

User section:
Gamma ray application

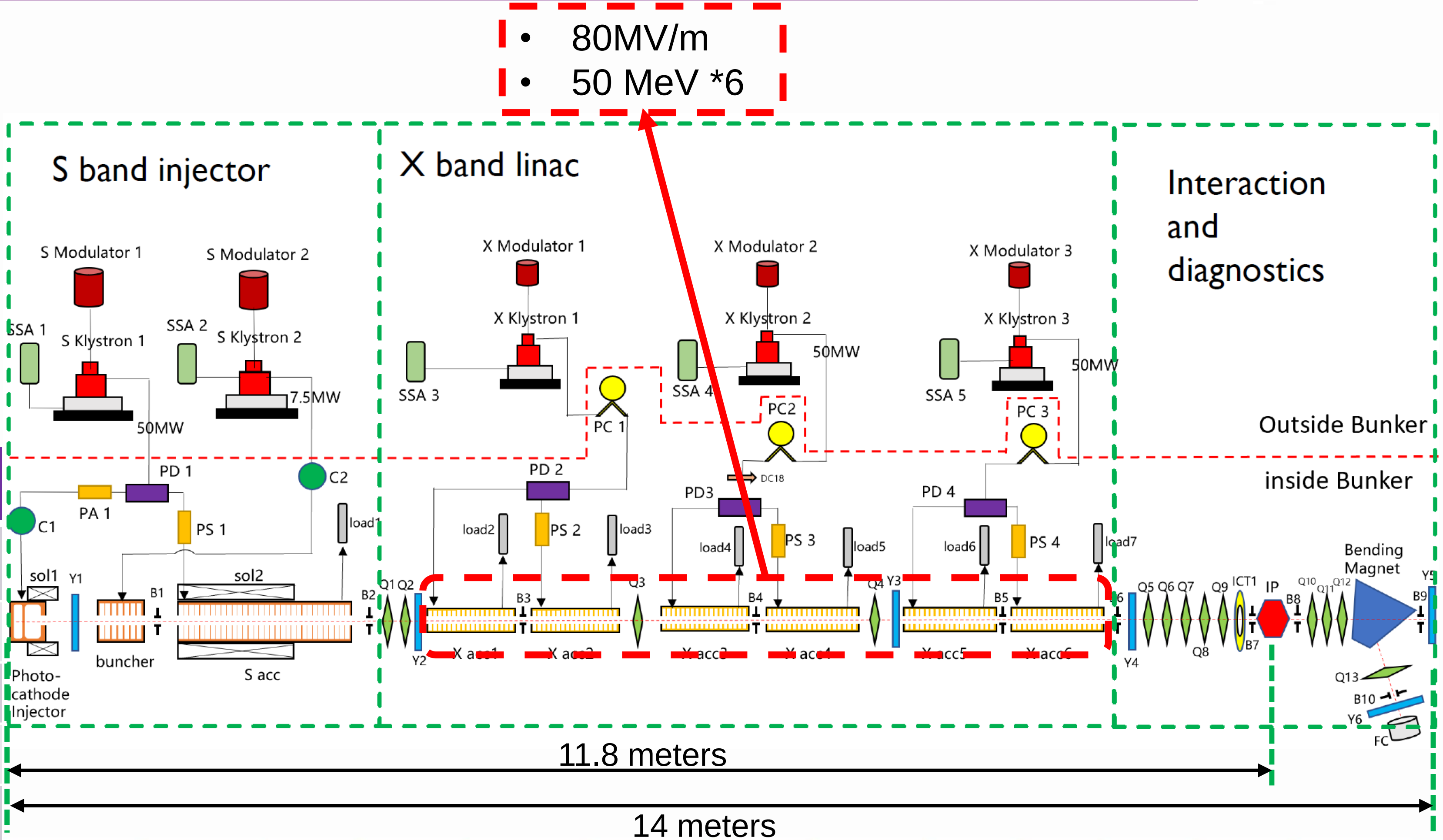
Overview of Accelerator System

VIGAS Subsystems:

- **Accelerators subsystem**
- Laser subsystem
- Detection subsystem
- Control and synchronization subsystem
- Radiation protection subsystem

Properties	Value
Electron energy	50-350 MeV tunable
Charge	>= 200 pC
Normalized emittance	< 0.6 mm mrad
RMS bunch length	< 2 ps
RMS energy spread	< 0.3%
RMS beam size @IP	< 20 um

Design parameters of accelerator subsystem

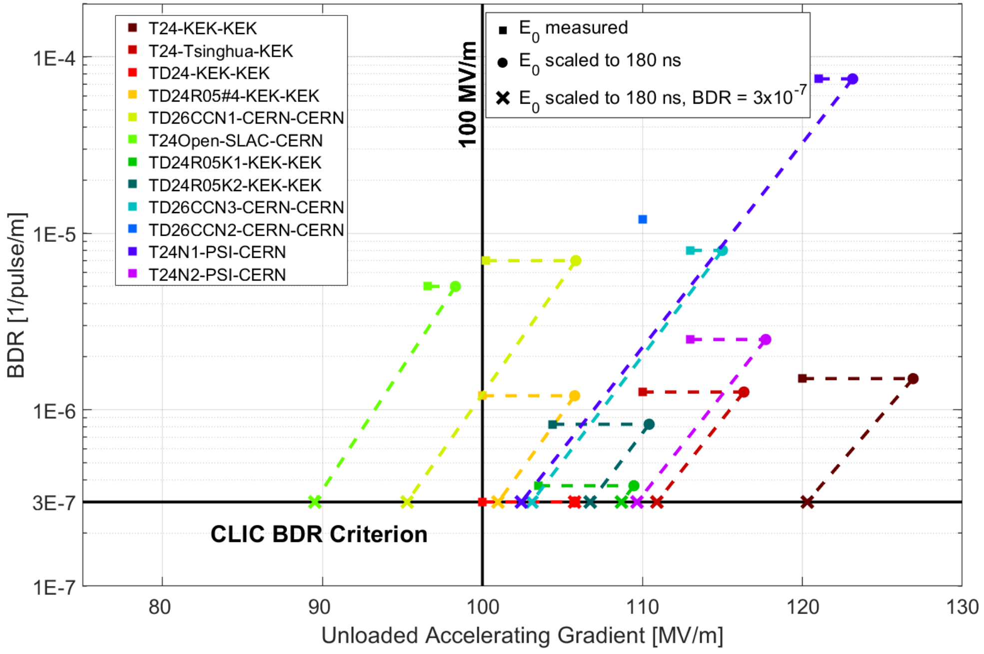


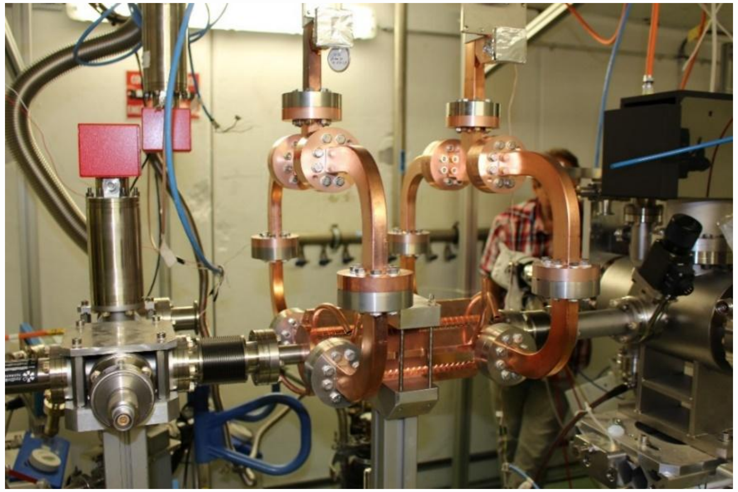
Abbreviation	ACC	B	C	ICT	IP	PA	PC	PD	PS	Sol	Y	Q
Description	Accelerating Structure	Beam Position Monitor	Circulator	Integrating Current Transformer	Interaction Point	Power Attenuator	Pulse Compressor	Power Divider	Phase Shifter	Solenoid	YAG: Ce Screen	Quadrupole

X-band high-gradient accelerating structure as main linac

- X-band Normal Conducting technology was proposed for linear collider NLC/JLC CLIC …
- > 100MV/m demonstrated globally
- ~km facility
- requires very low breakdown rate

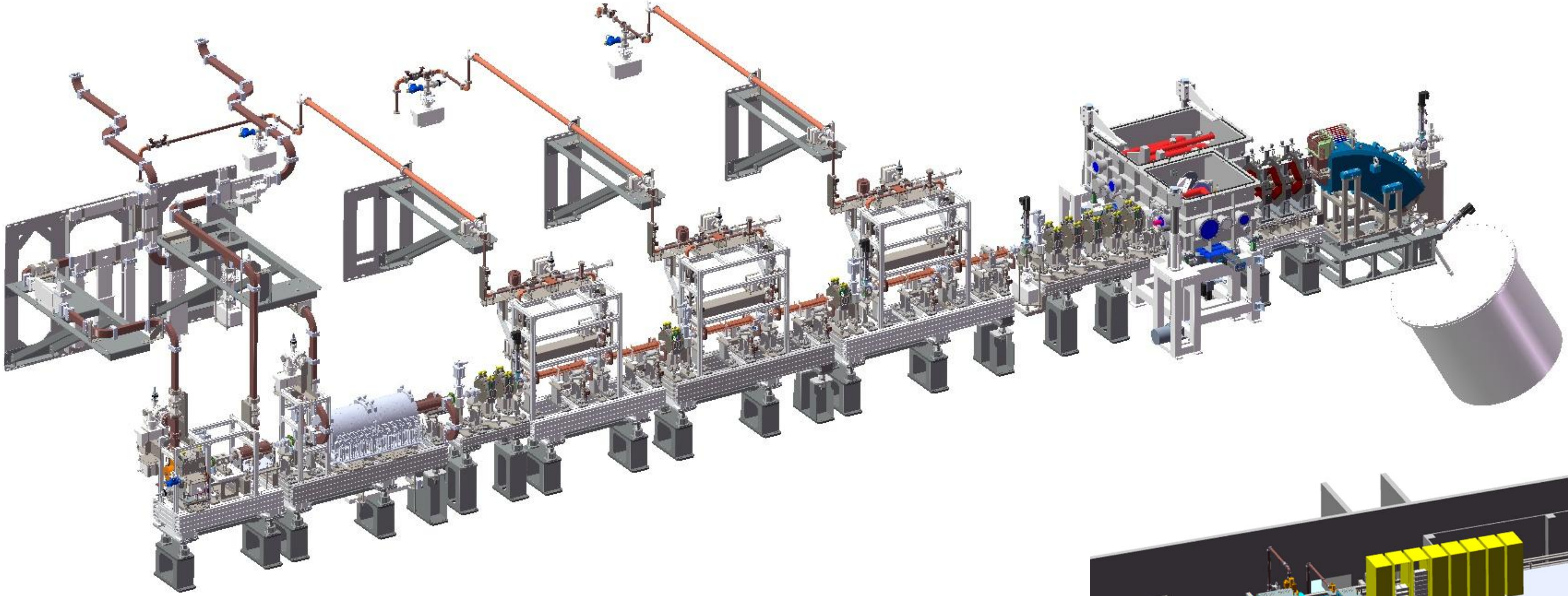
- 80MV/m 62.5cm @ 11.424GHz
  chosen as the main linac design for our
  12m-long 350MeV very compact facility

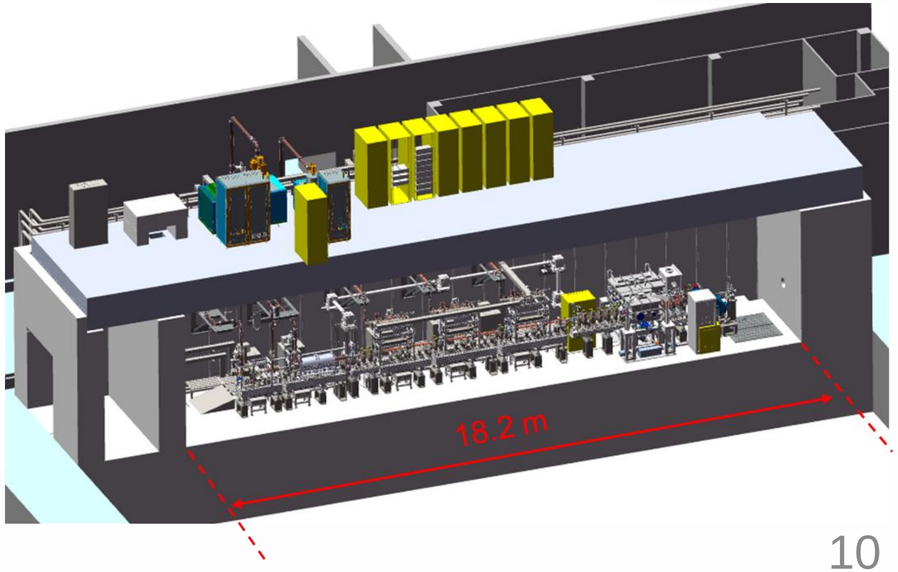




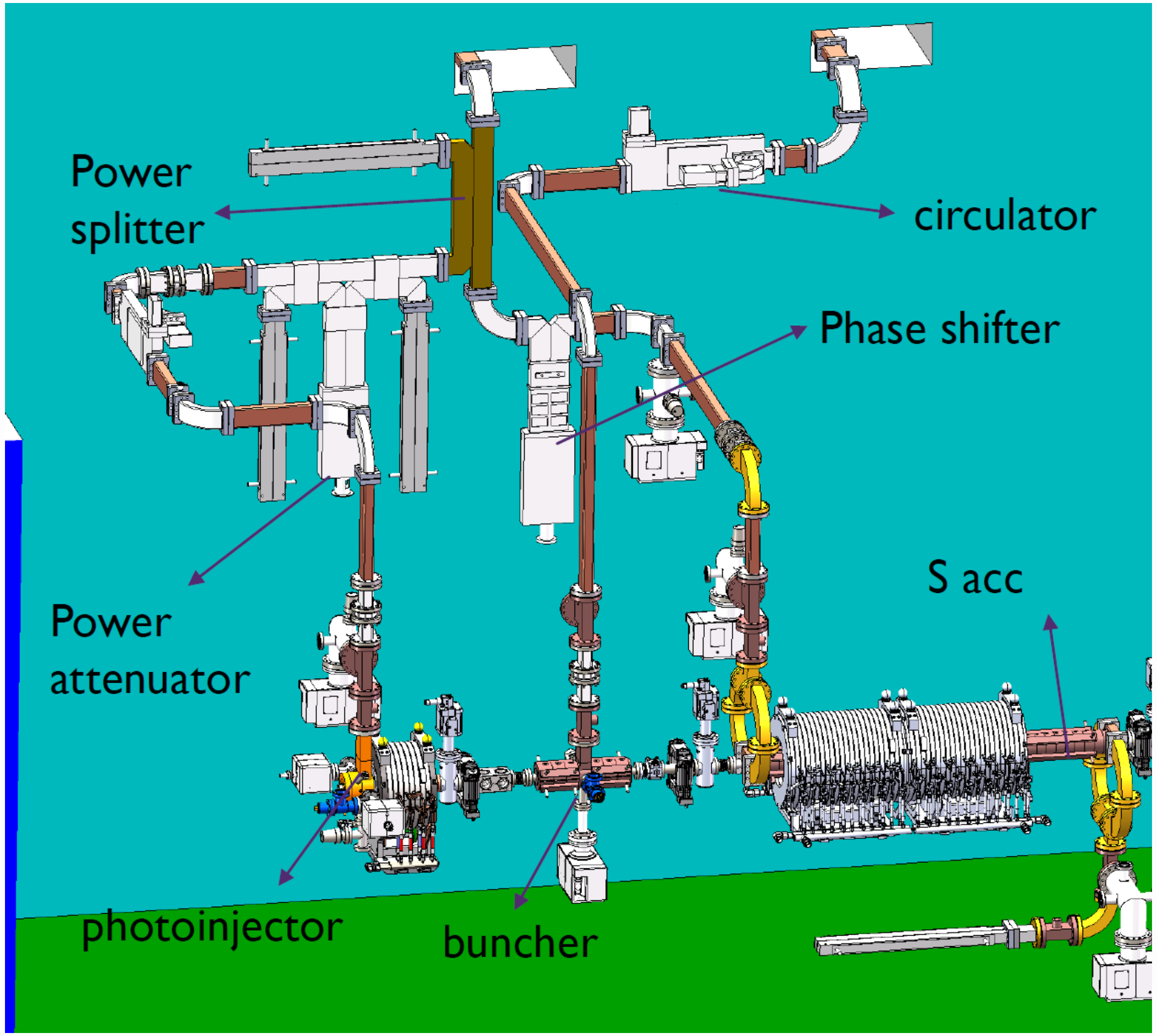
https://doi.org/10.1103/PhysRevAccelBeams.21.061001,
https://doi.org/10.1103/PhysRevAccelBeams.20.052001

Overview of Accelerator System





S-band waveguide system



- 50 MW power from Canon E3730A feeds for photoinjector and S acc
  - 5dB power splitter
  - Phase shifter for S acc phase control
- 7.5 MW power from Canon E3772 feeds for buncher
- Consider RF loss due to waveguides and components

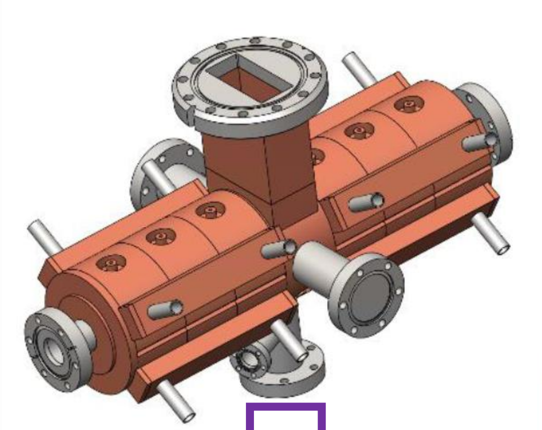
	Transmitted power (MW)	Needed power (MW)
Photoinjector	11.7	7
S acc	29	21
buncher	6.4	3

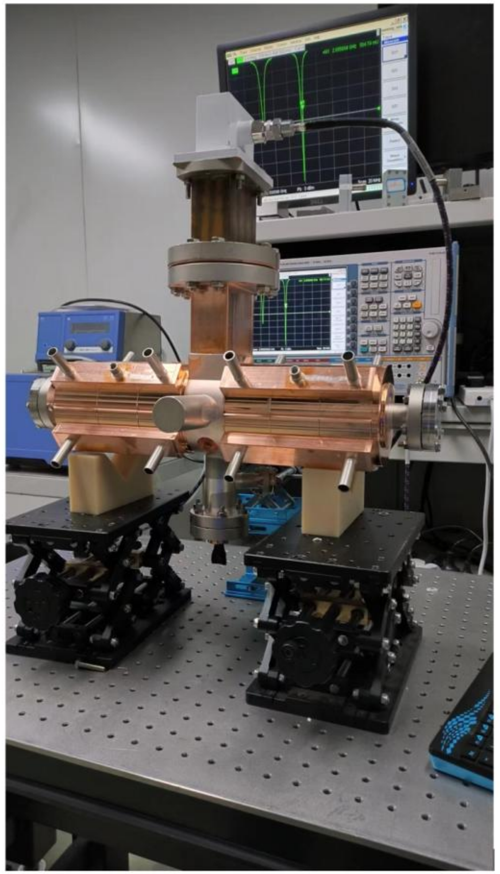
S-band injector & buncher

Zheng, Lianmin, et al.
NIMA 834 (2016): 98-107.

Parameters	Value	Unit
π mode frequency	2856	MHz
Q_0	14000	
Working field strength	100-120	MV/m
Emitting charge	>200	pC
Cathode material	Copper	
Quantum efficiency	$3.5\text{-}4\times10^{-5}$	
Emittance	~0.6	um

Parameters of S-band injector

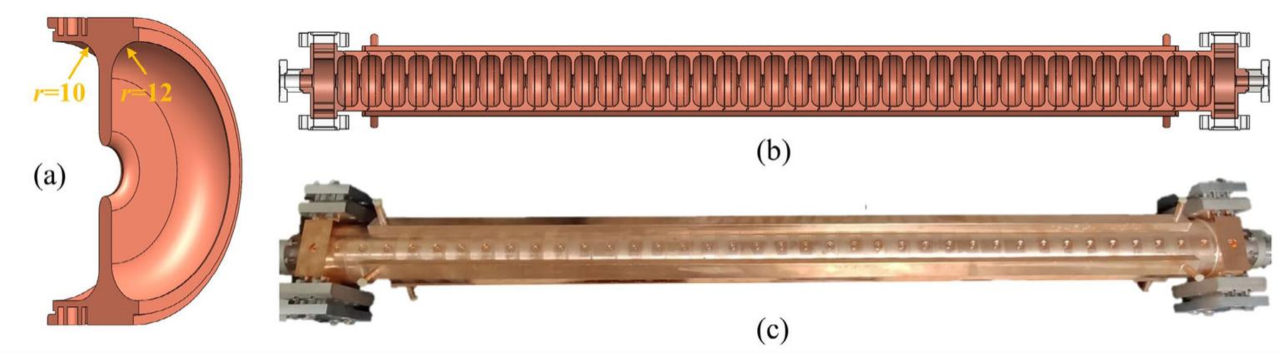


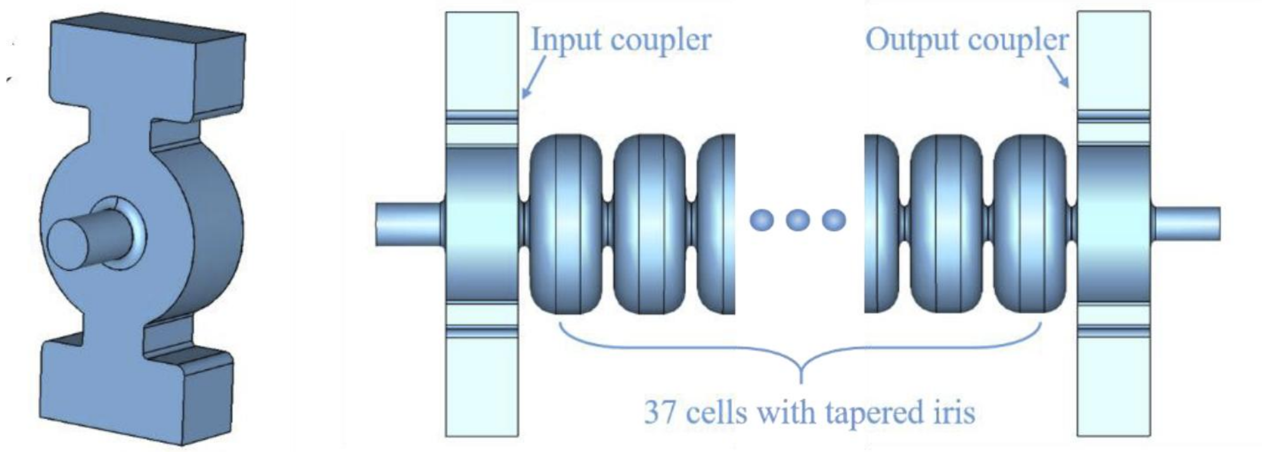


Parameters	Value	Unit
π mode frequency	2856	MHz
Q_0	17000	
Coupling coefficient	1.2	
Shunt impedance	50	MΩ/m
Working field strength	23	MV/m

Parameters of S-band 7-cell buncher

S-band TW acc





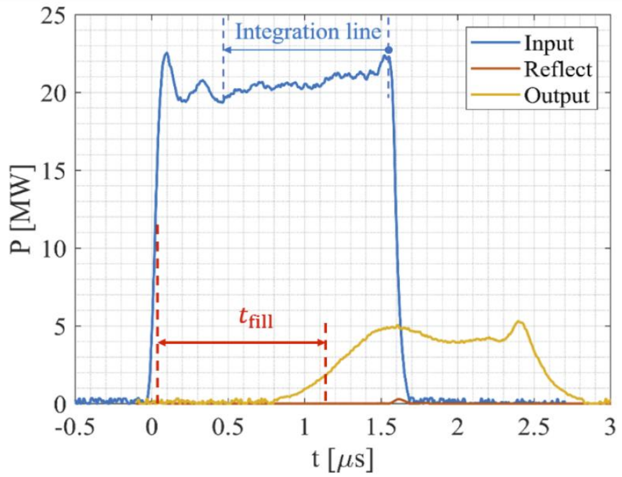
Design Parameters	Value	Unit
Frequency	2856	MHz
Phase advance	$3\pi/4$	
Length	1.535	m
Cell number	39	
Iris radius	10.22-8.13	mm
Iris thickness	5.7	mm
Iris elliptical ratio	1.8	
Filling time	1050	ns
Group velocity	0.72-0.30	%/c
Shunt Impedance	66-72	MΩ/m
Average Gradient	25.7@21MW	MV/m

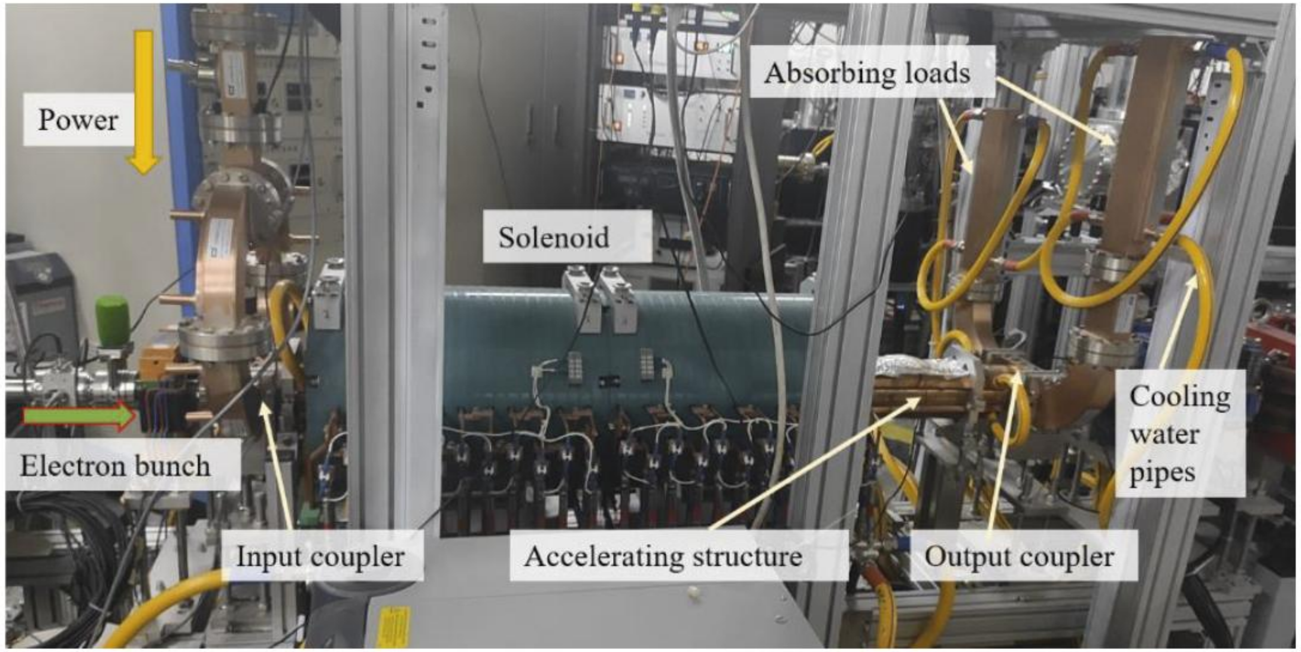
Lin, Xian-Cai, et al. *Nuclear Science and Techniques* 33.11 (2022): 147.

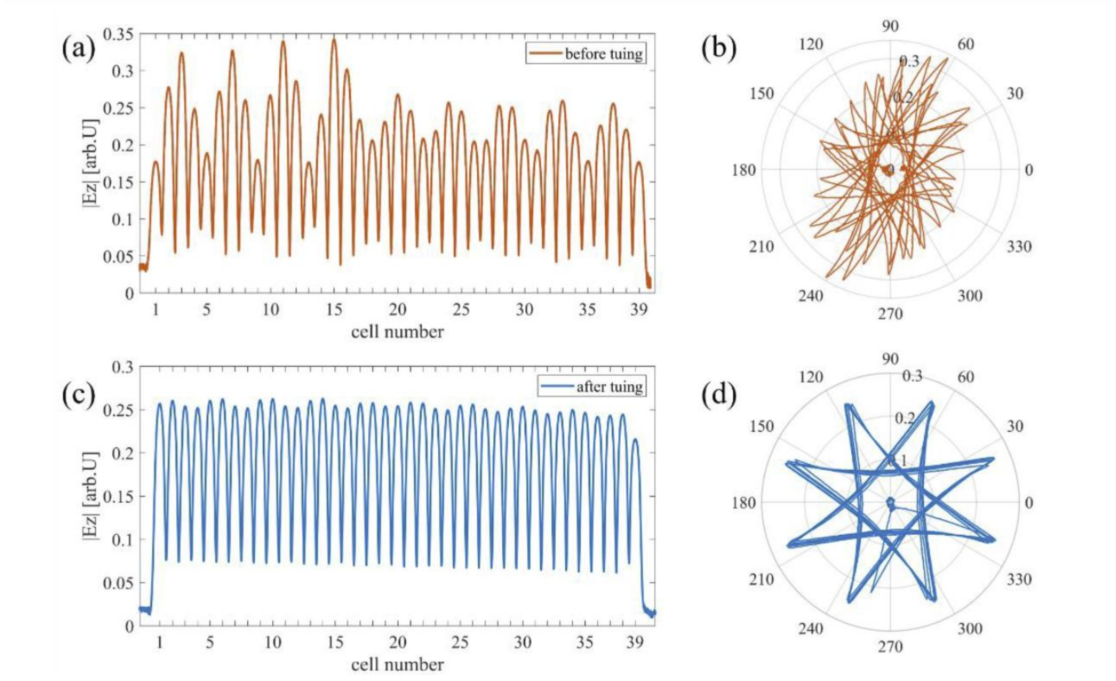
S-band TW acc

High power tested

- Conditioning:
  - 120 hours
  - 4 million pulses

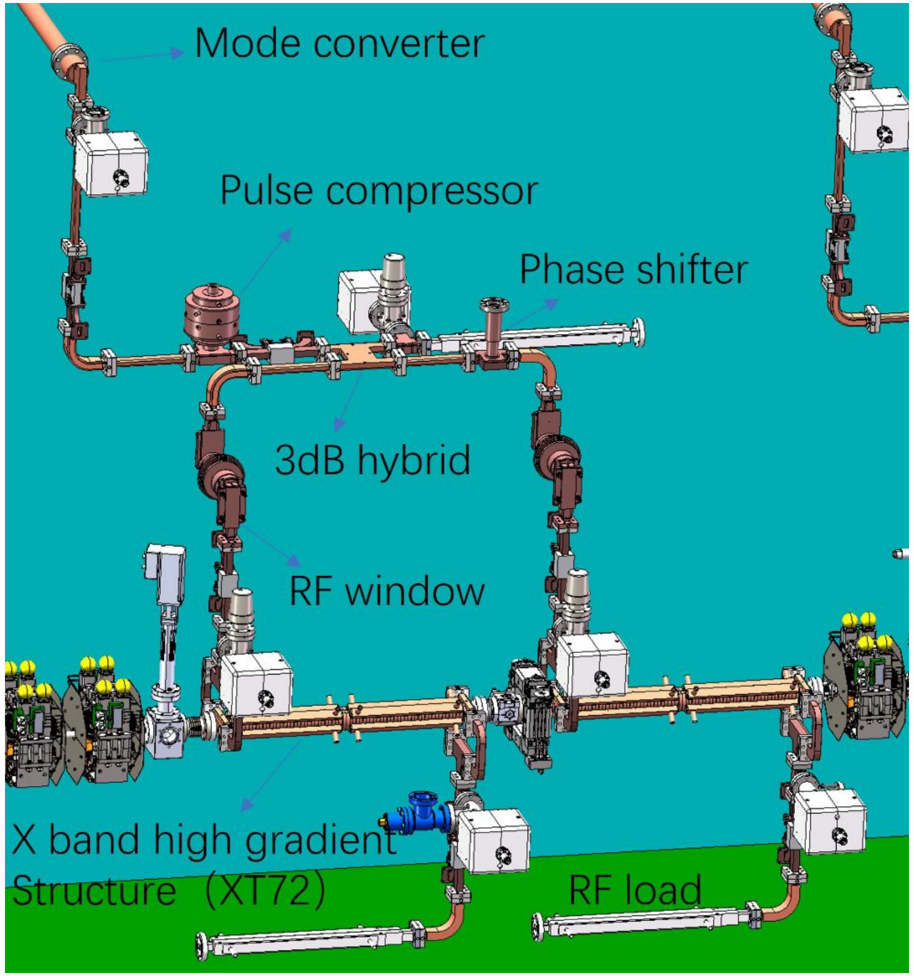






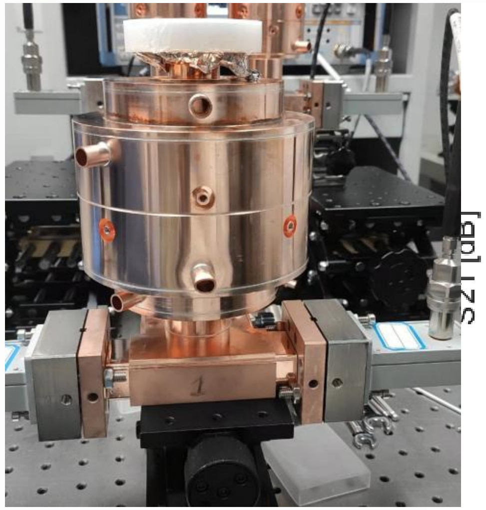
Parameters	Measurement	Simulation
Frequency	2.856 GHz	2.856 GHz
Phase advance	134.97°	135°
Gradient @20.7MW	24.2 MV/m	25.7 MV/m
Filling time	1090 ns	1050 ns

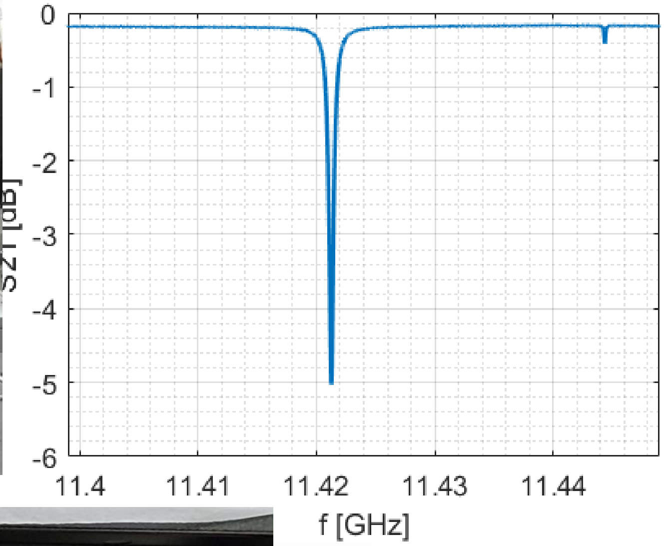
X-band waveguide system



- One klystron
  - 50MW, 1.5us
- One pulse compressor (SLED I type)
- Maximum rf loss due to waveguides and rf components from klystron to Xacc is about 0.9dB
- Peak power at Xacc input is about 91 MW if power compressor gives gain factor as 4.5
- Two X band high gradient structures
  - Average gradient ≥ 80 MV/m
  - Energy gain per structure > 50 MeV
  - Filling time < 150ns

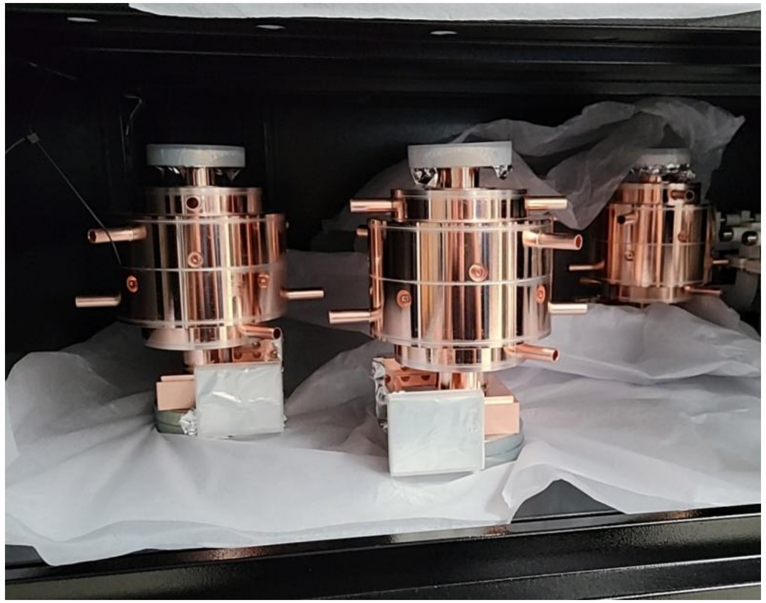
X-band pulse compressor

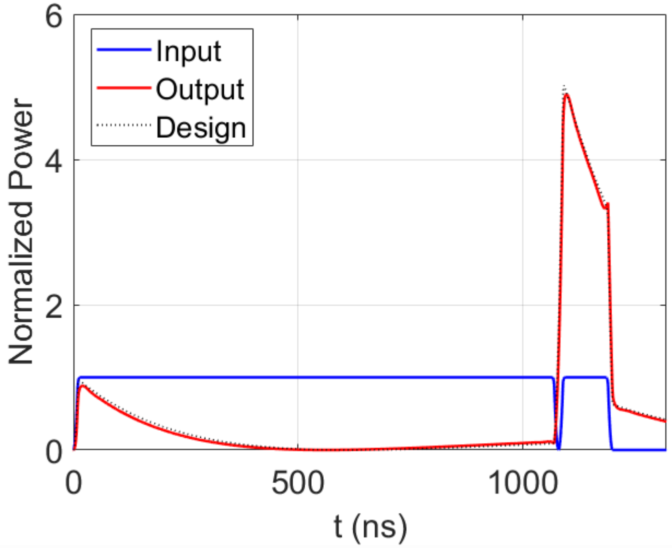


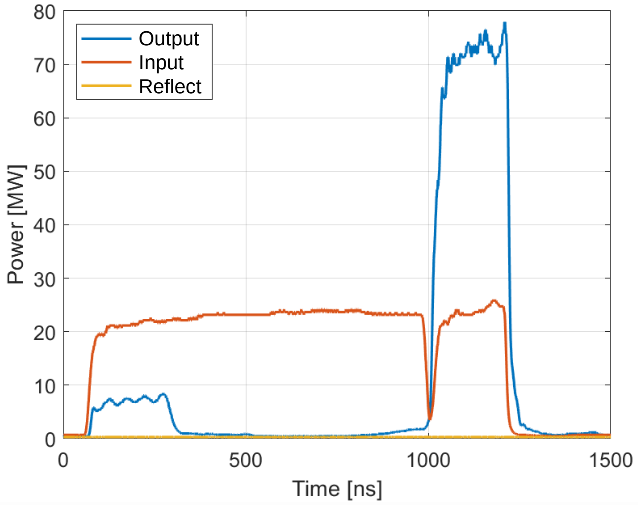


	f	Q_0	Q_e	β
Design	11.4240	9.2e4	2.63e4	3.5
Measure	11.4213	9.19e4	2.51e4	3.66
Mode 1	11.4213	9.25e4	2.52e4	3.67
Mode 2	11.4213	9.05e4	2.46e4	3.68

*Modes 1 and 2 are parameters of two polarization modes reconstructed from measured S-parameters (TE_{114})



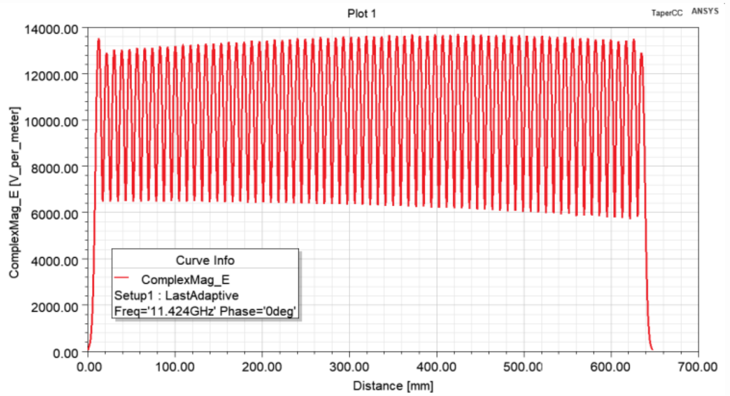




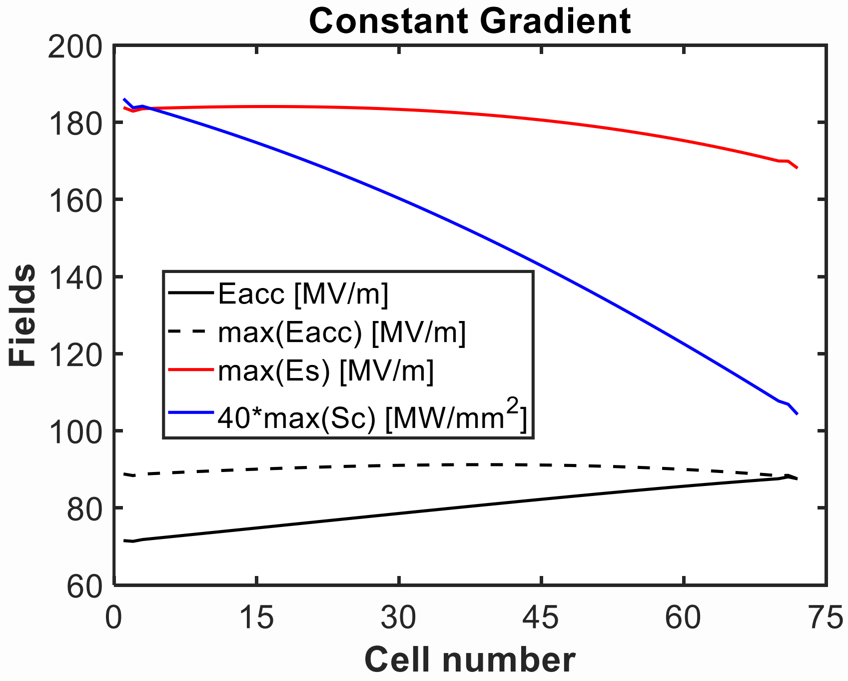
*Franzi, Matthew, et al. *PRAB*19.6 (2016): 062002.

X-band TW linac

- We switch to CG scheme with maximum surface field 20% lower than CI

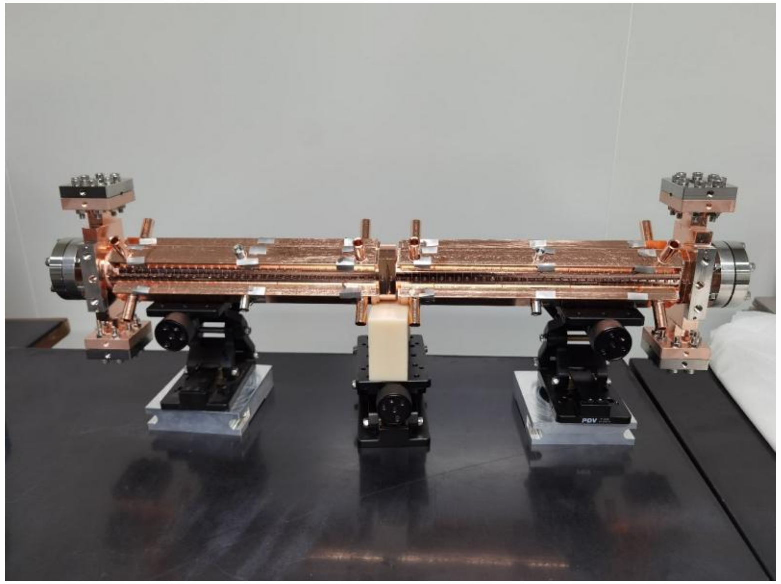


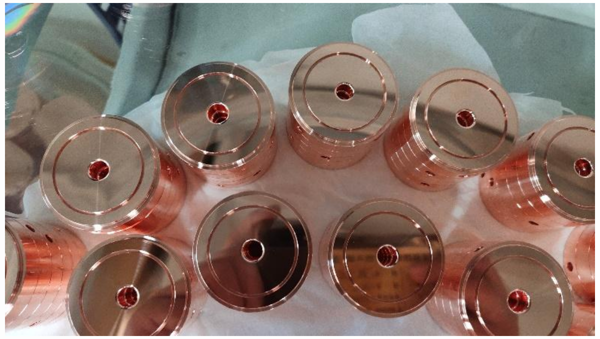
Parameters	CI	CG
Iris aperture a [mm]	3.5	3.92 ~ 3.12
Iris thickness d [mm]	1.8	1.8
Shunt imp. R [MΩ/m]	101	93 ~ 109
Group velocity v_g/c	2.20%	3.22% ~ 1.46%
Quality factor Q	6990	7020 ~6970
Filling time T_f [ns]	95	97
E_s [MV/m]	224	185
S_c [MW/mm^2]	5.65	4.50
β of pulse compressor	3.5	3.5
Pin @80MV/m with pc [MW]	81.3	80.1

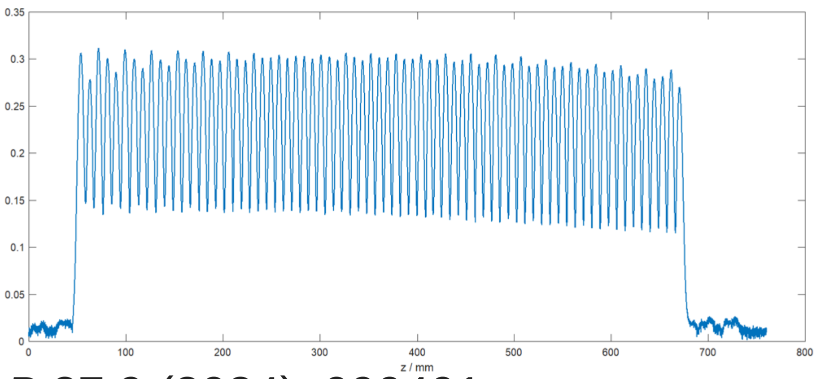


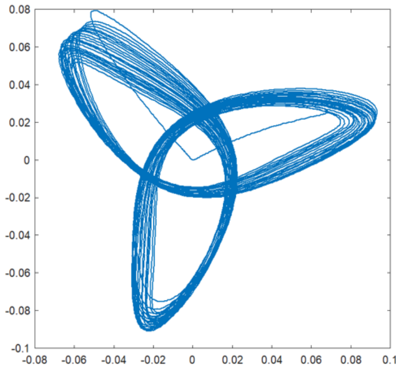
X-band TW linac

- XT72 (X-band Tapered structure with 72 cells)
- COST: CG 20% higher than CI
- Same Tuning procedure
- High power conditioning started from Oct. 20, 2023



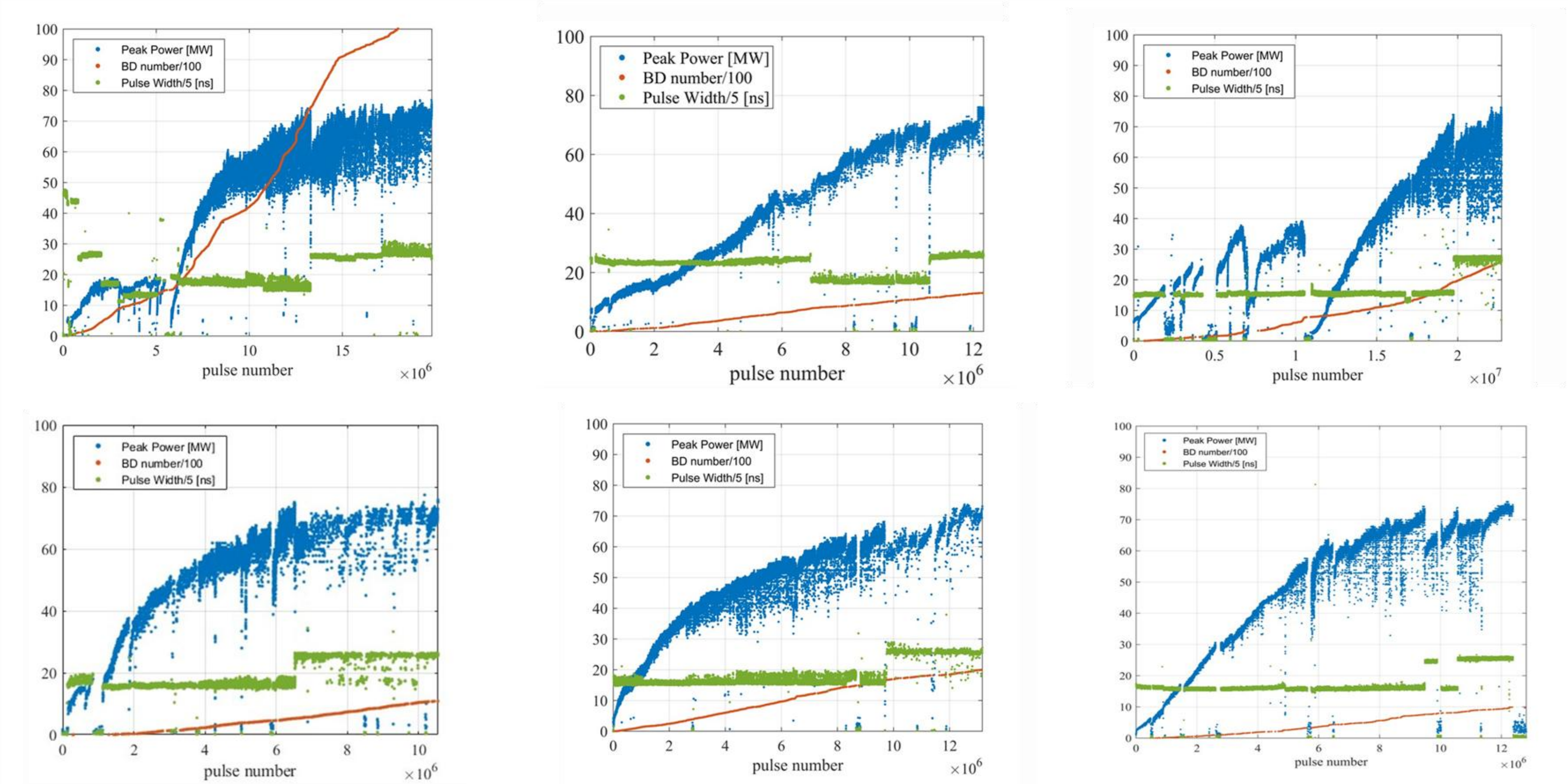






Gao, Qiang, et al. *PRAB* 27.9 (2024): 090401.

High-gradient performance of xt72



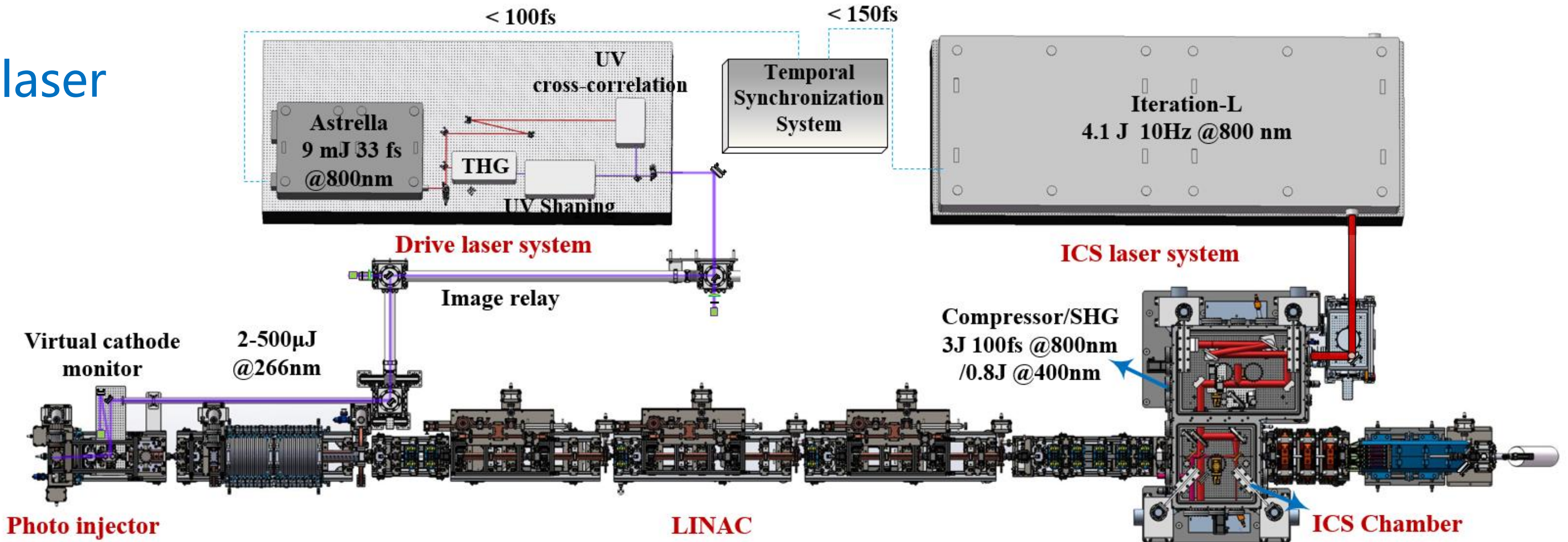
- All 6 accelerating structures were conditioned
- To reach 80MV/m, ~15 million pulses, About 100 hours of conditioning at 40Hz

Laser system of VIGAS

➢ **The Laser system layout of the VIGAS facility Schematic**

- Photo-injector driving laser
- Inverse Compton Scattering laser

➢ **Parameters of the laser system**



	Central wavelength	Pulse width (FWHM)	Pulse energy	rate	Beam size (RMS)	Temporal distribution	Spatial distribution	Energy jitter (RMS)	Laser- RF itter (rms)
Driving laser	~267 nm	5~10 ps	2~500 μJ	10 Hz	0.2~2 mm	Quasi-flat top	Quasi-flat top	< 2%	< 100 fs
ICS laser	800 nm /400 nm	0.1~10 ps	>1.5 J@800 nm / >0.8 J@400 nm	10 Hz	< 10 μm	Gaussian	Gaussian	< 1.2 %	< 150 fs

Photo-injector driving laser

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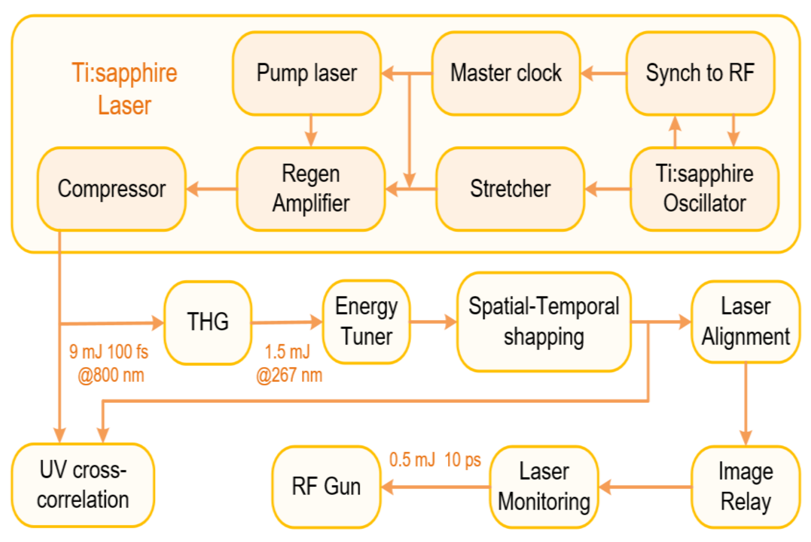
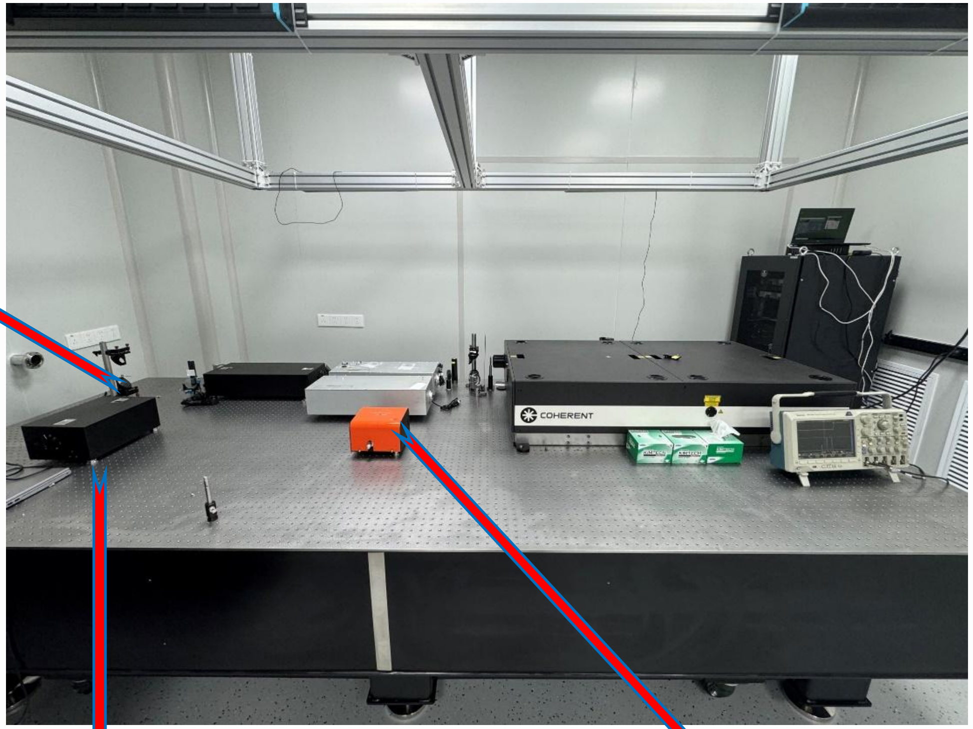
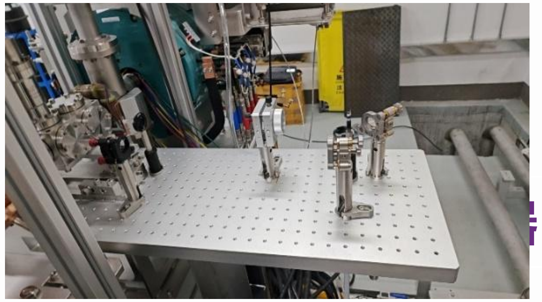
➢ Schematic of the driving laser



Energy tuner、spatial-temporal shaping

Image relay





Laser monitoring

UV cross-correlation

Third harmonic generation

Experimental results

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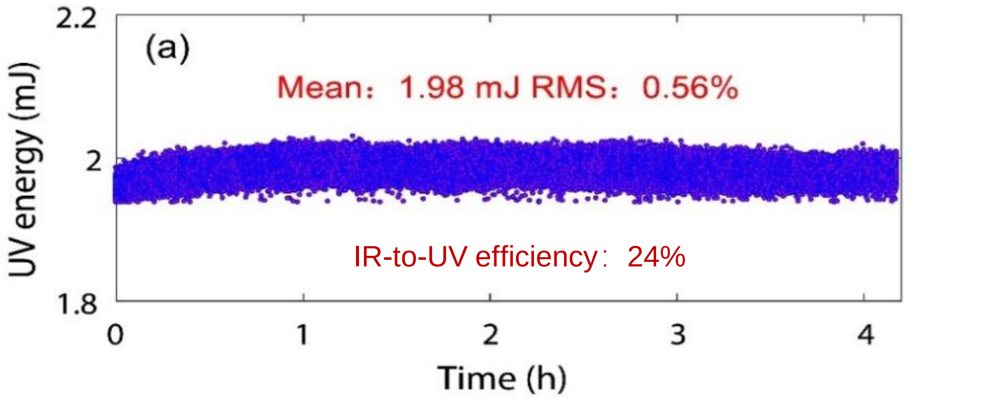
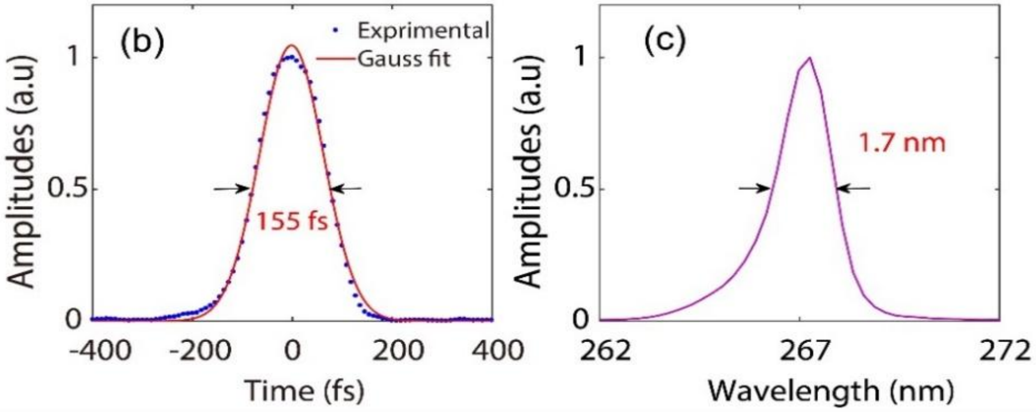
- Output of THG

The UV laser pulse energy and stability

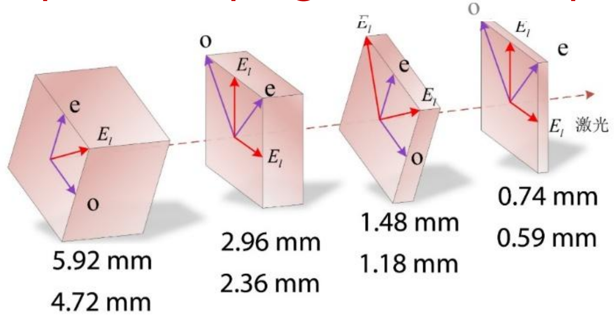




Pulse duration

Spectrum

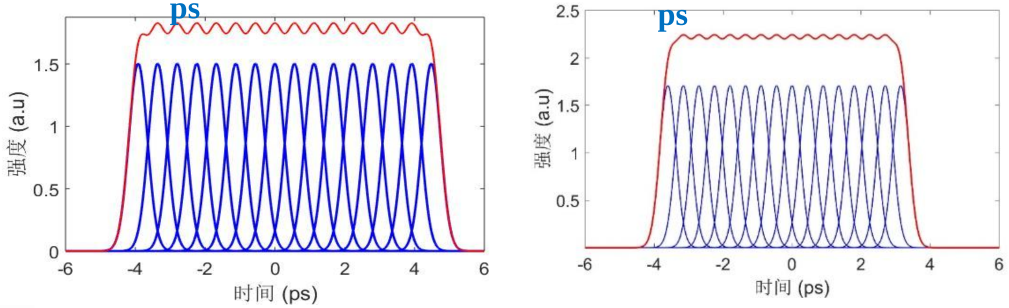
- Temporal shaping of UV laser pulse



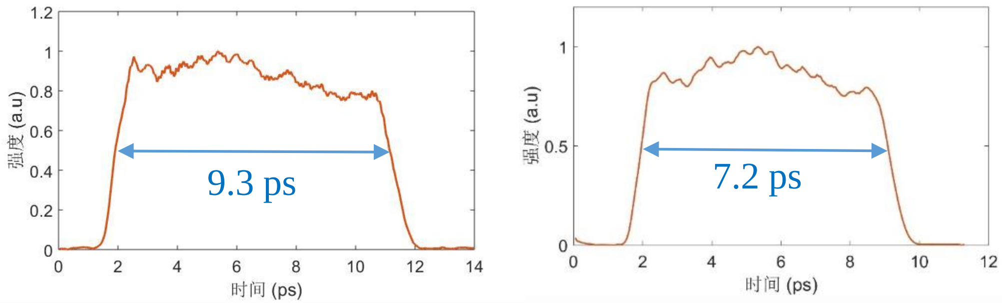
Pulse stacking of α-BBO crystals

Pusle spacing：0.56 ps

Pusle spacing： 0.45 ps



Theoretical



Experimental

Experimental results

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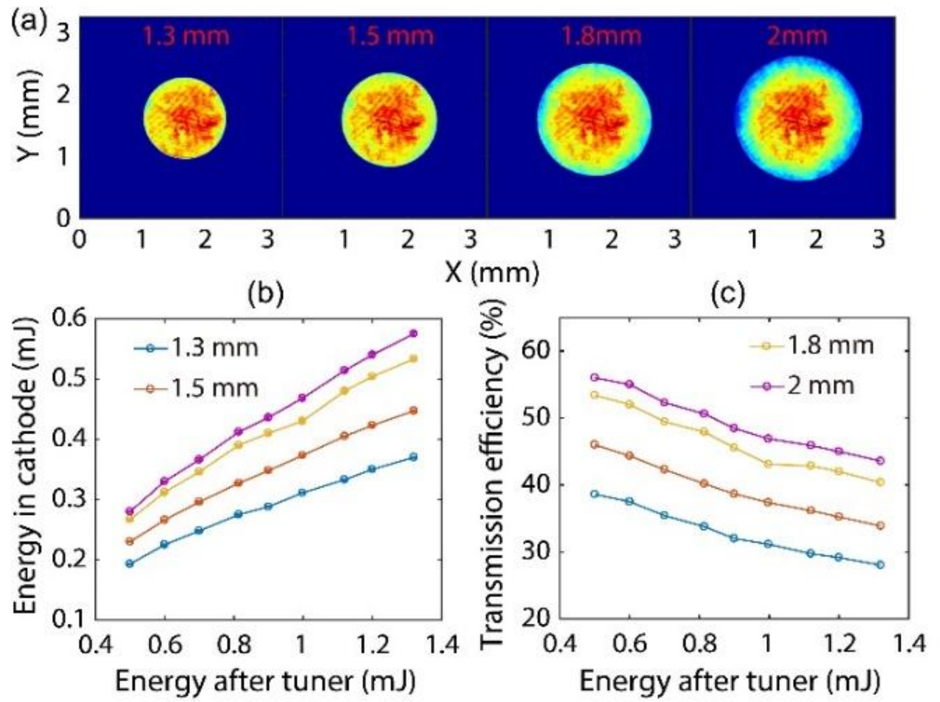
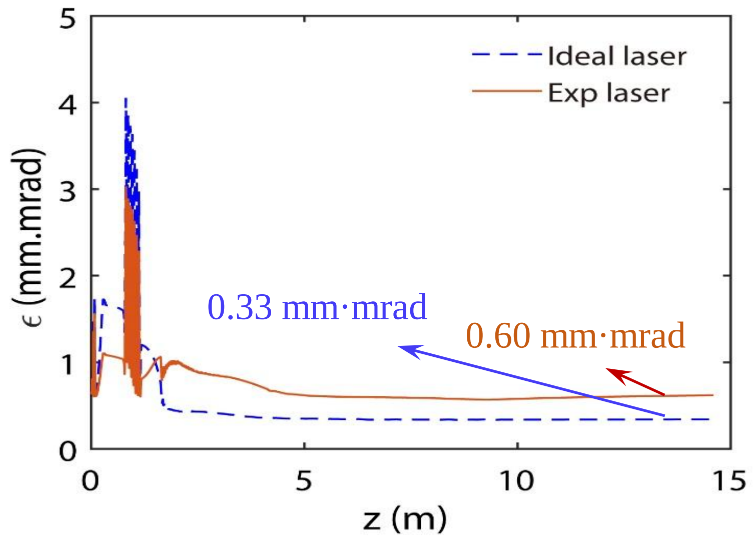
• Spatial shaping of UV laser pulse

The UV laser beam size（1.3mm、1.5mm、1.8mm、2mm）spatial distribution、pulse energy and transmission efficiency in the photo-cathode, the maximum pulse energy is 0.58 mJ，the maximum transmission efficiency is 56%。



• Simulation of the beam normalized rms emittance

The beam normalized rms emittance simulated by GPT code based on the ideal flat-top distribution (blue dashed line) and the experimental results (orange solid line) of the driving laser.

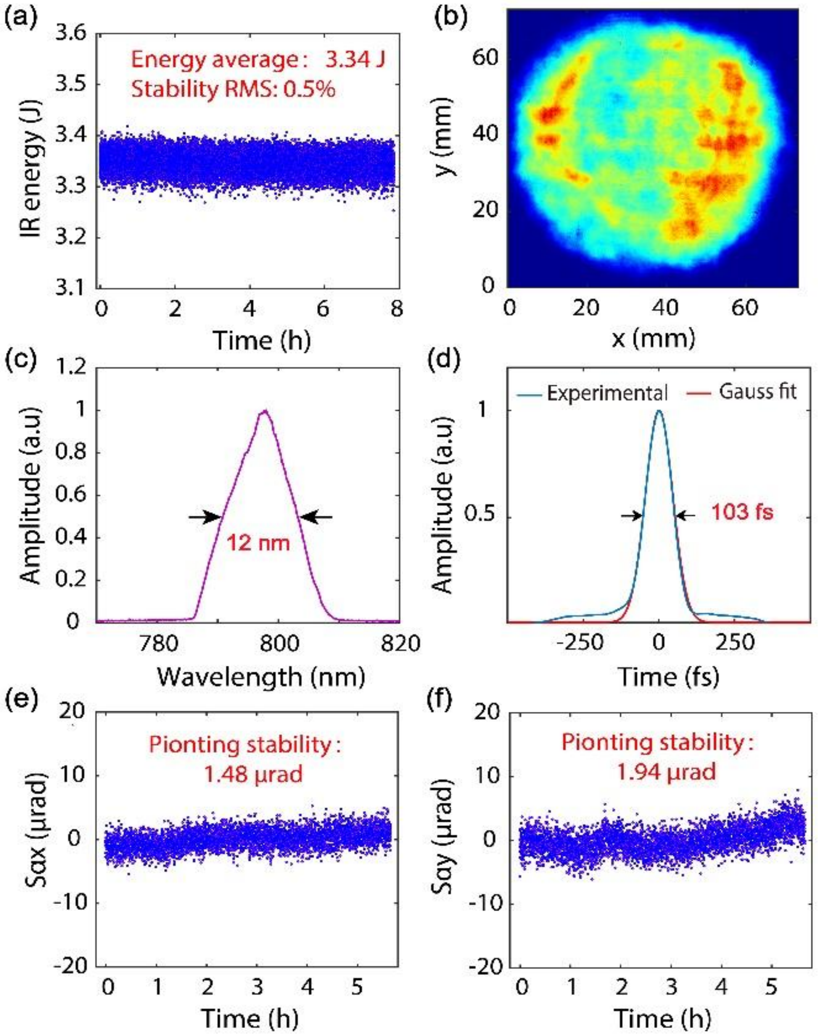


z=14 m，Q=200 pC

$\varepsilon_{\text{ideal}} = 0.33$ mm·mrad，$\varepsilon_{Exp} = 0.60$ mm·mrad

ICS laser

The 30 TW Ti:sapphire laser device was completed in April 2025.

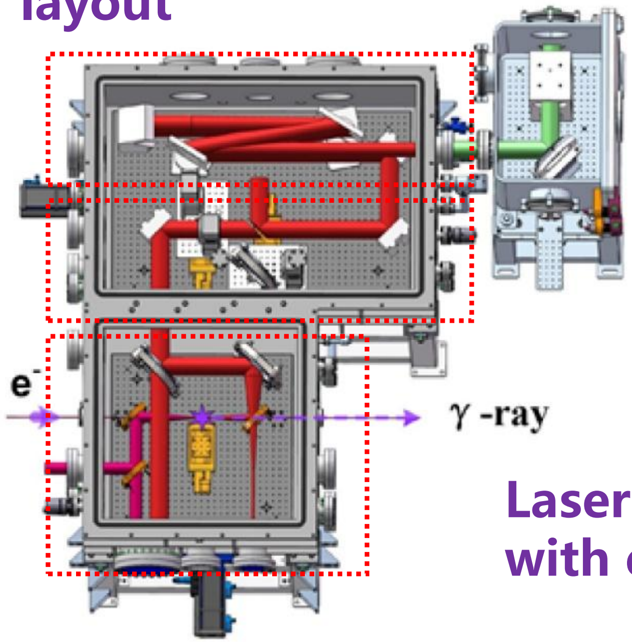


30 TW Ti： spphire	Measurements
Central wavelength	798.14 nm
Spectrum （FWHM）	12 nm
Pulse energy	3.28 J
Pulse width (FWHM）	103 fs
Energy stability (RMS)	0.52%（16hrs）
Point stability (RMS)	X: 1.48 μrad； Y:1.94 μrad
Laser-RF jitter (rms)	＜80 fs

ICS laser transmission and modulation

Tsinghua University

- Optical layout

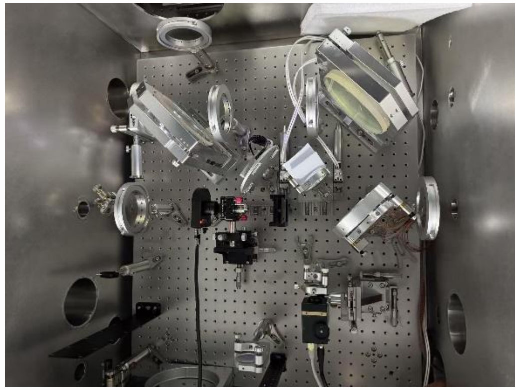


Pulse compressor

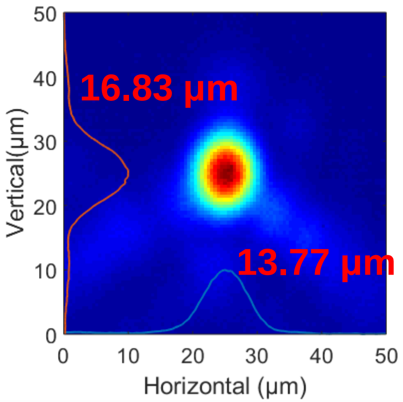
Second harmonic generation and polarization adjuster

Laser focus and scattering with electron beam

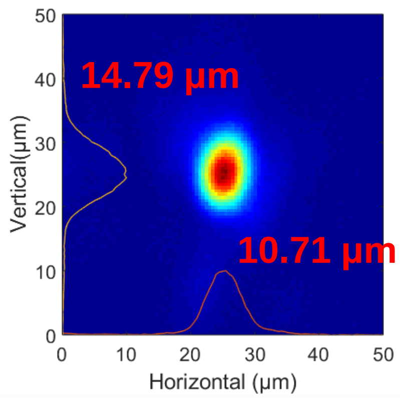
- Setup in vacuum chamber



Laser focus profile



Wavefront correction



SHG and Focusing Characteristics of High-Energy Lasers

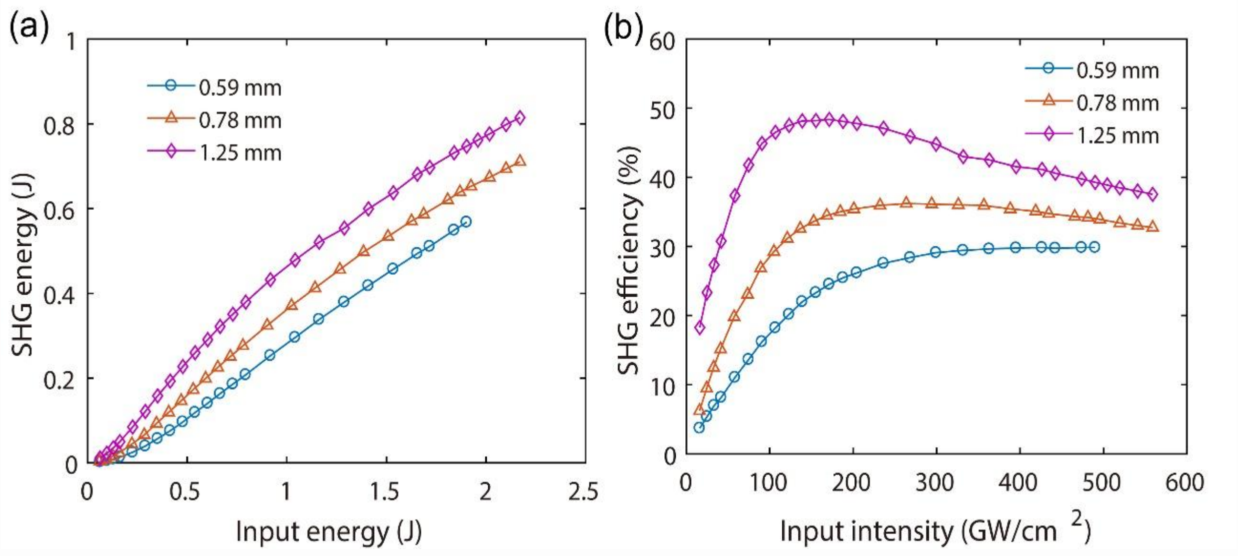
Tsinghua University

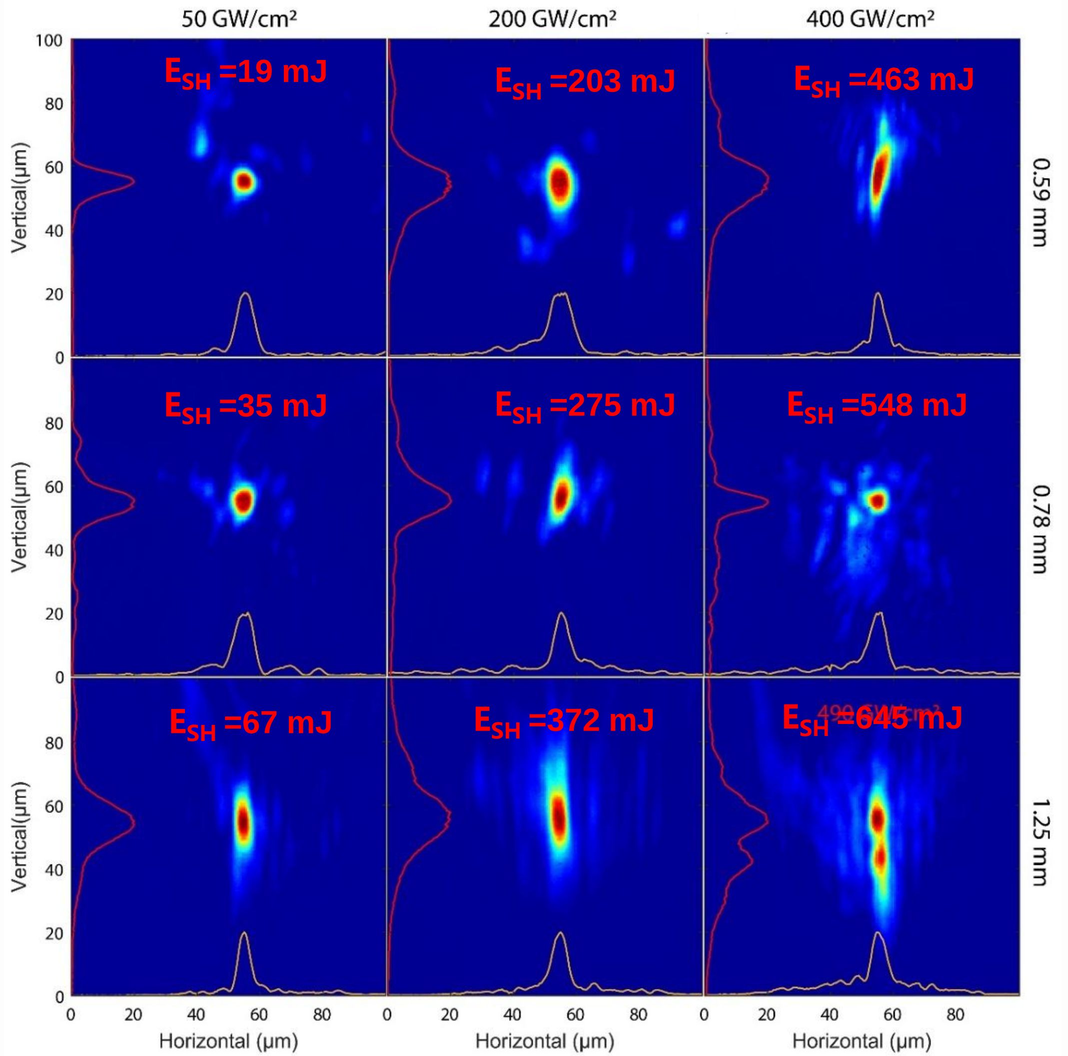
Generate higher-energy gamma rays ($> 1 \times 10^8$ photons·s^{-1} @2.4~4.8 MeV) by increasing the photon energy of the scattering laser (800 nm → 400 nm, $E_{SH} > 0.8$ J).

- Crystal parameters

KDP， Type-Ⅰ at 800 nm：θ=44.9°，Φ=45°

	1	2	3
thickness/ mm	0.59	0.78	1.25
Size/mm	75	85	85



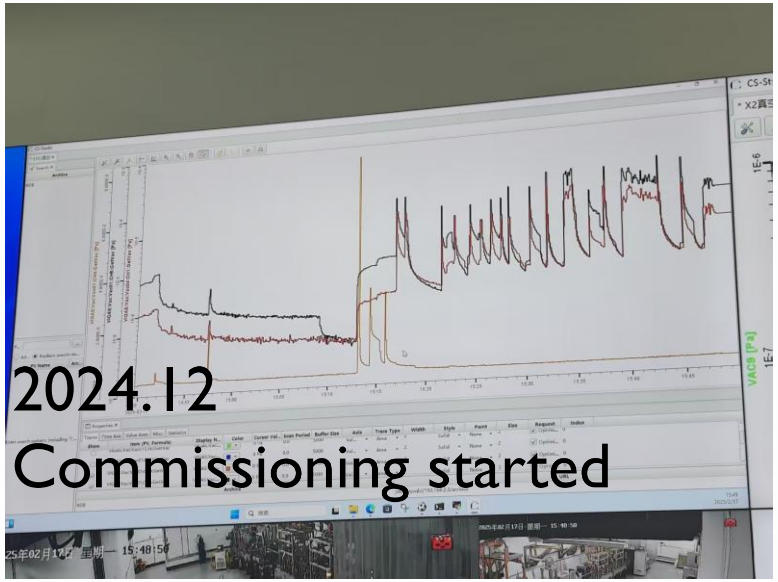


Progress and summary

2023.9

2024.06
Bunk ready

2024.11 finish installing



2024.12
Commissioning started

- Commissioning of RF power source was started from the end of 2024
- Conditioning of the S-band and X-band RF modules was started in the first quarter of 2025
- Beam has been detected on the YAG screen in March

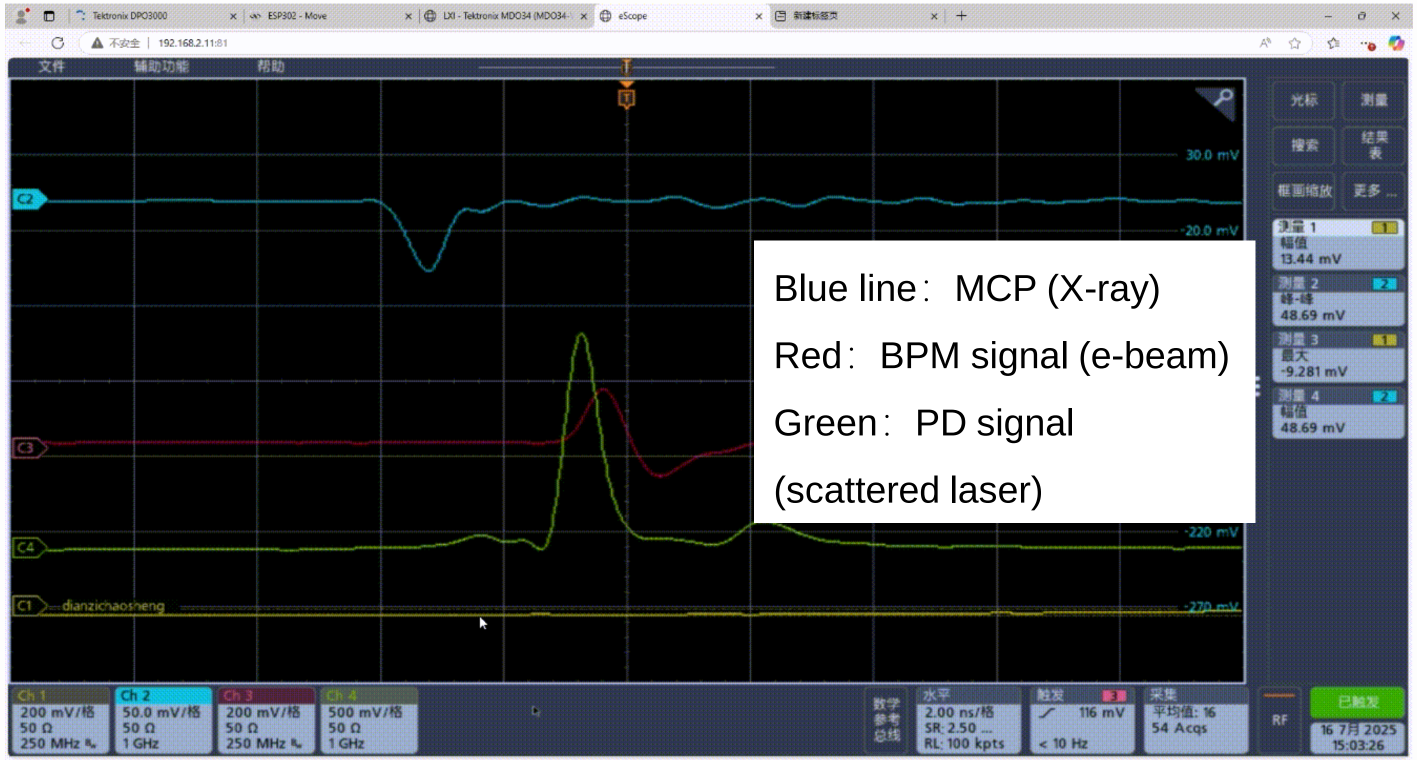
Signal of RF power

Beam on YAG sceen

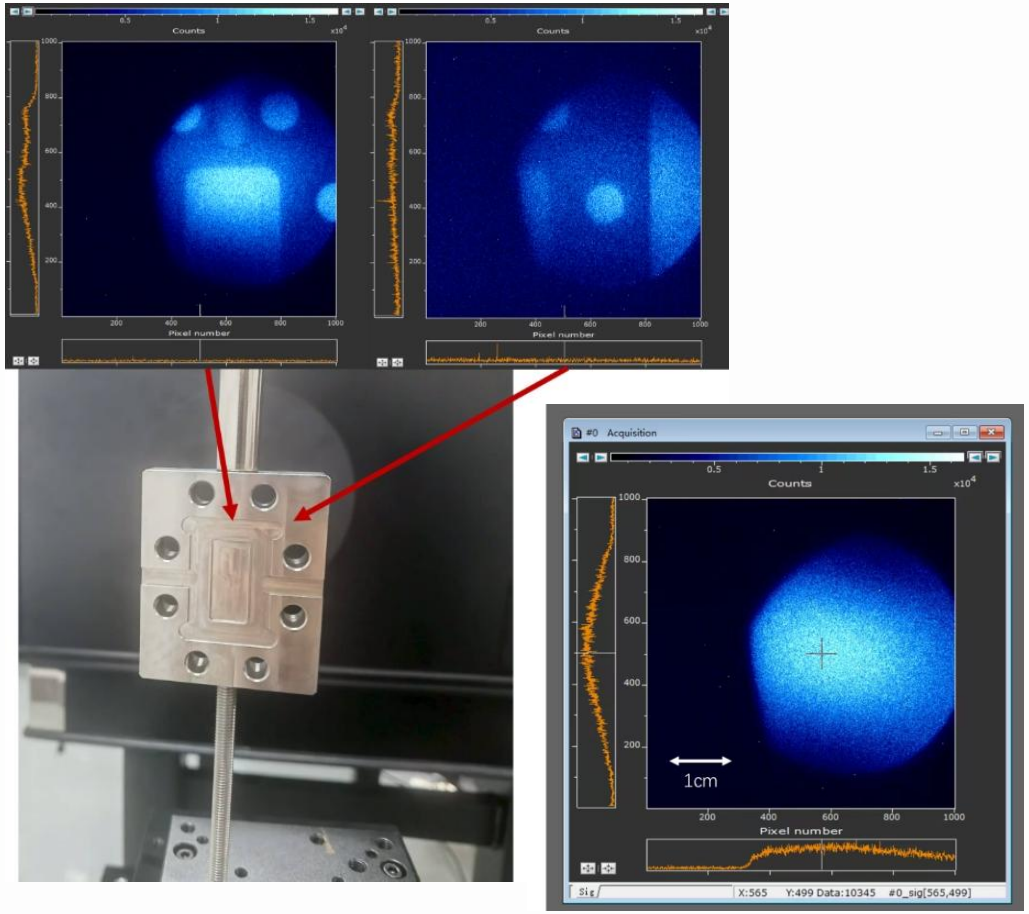
Beam passing through bending magnet

Progress and summary

Successful generation of high-energy X-rays in collision experiment in mid-2025



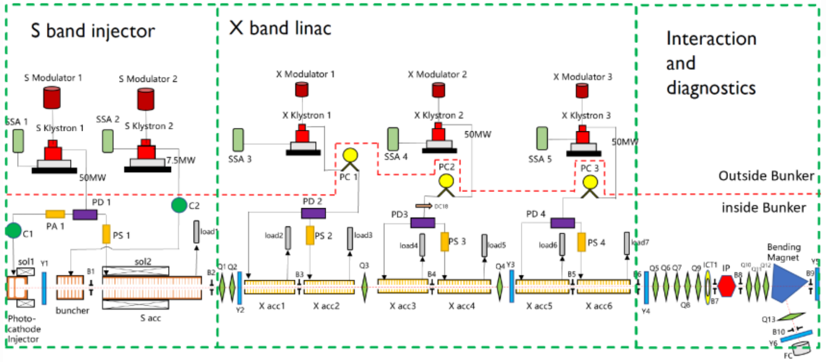
During the adjustment of the relative delay between the e-beam and the scattered laser, the X-ray signal detected by the MCP



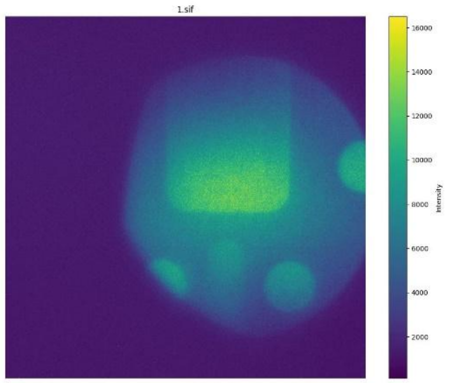
The X-ray (~500keV) spot 9 m from the interaction point

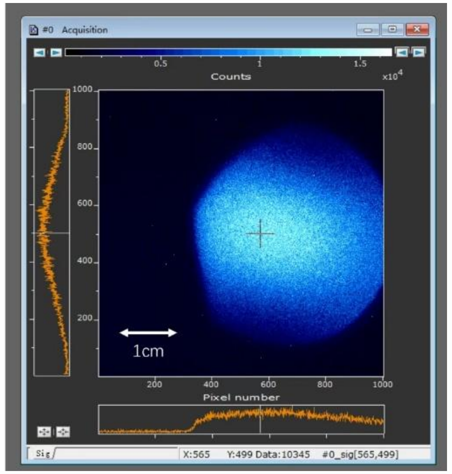
Progress and summary

- **VIGAS/compact ICS source, total ~13.5m, up to 350MeV beam energy, 4.8MeV photon**
- **High-gradient X-band main linac**
- Installation completed in 2024
- Successful generation of high-energy X-rays in collision experiment in 2025
- Beam and scattered laser are under optimization
- **80MV/m reached** @Module #1 and #2 with beam energy of total 300MeV. Still conditioning Module #3.



Abbreviation	ACC	B	C	FC	ICT	IP	PA	PC	PD	PS	Sol	Y	Q
Description	Accelerating Structure	Beam Position Monitor	Circulator	Faraday Cup	Integrating Current Transformer	Interaction Point	Power Attenuator	Pulse Compressor	Power Divider	Phase Shifter	Solenoid	YAG: Ce Screen	Quadrupole





Thank you for your attention!