R&D for an L-band photocathode RF gun with high bunch charge

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Outline

- Background & Motivation
- R&D Content and Objectives
- Existing research basis
- Funding requirements

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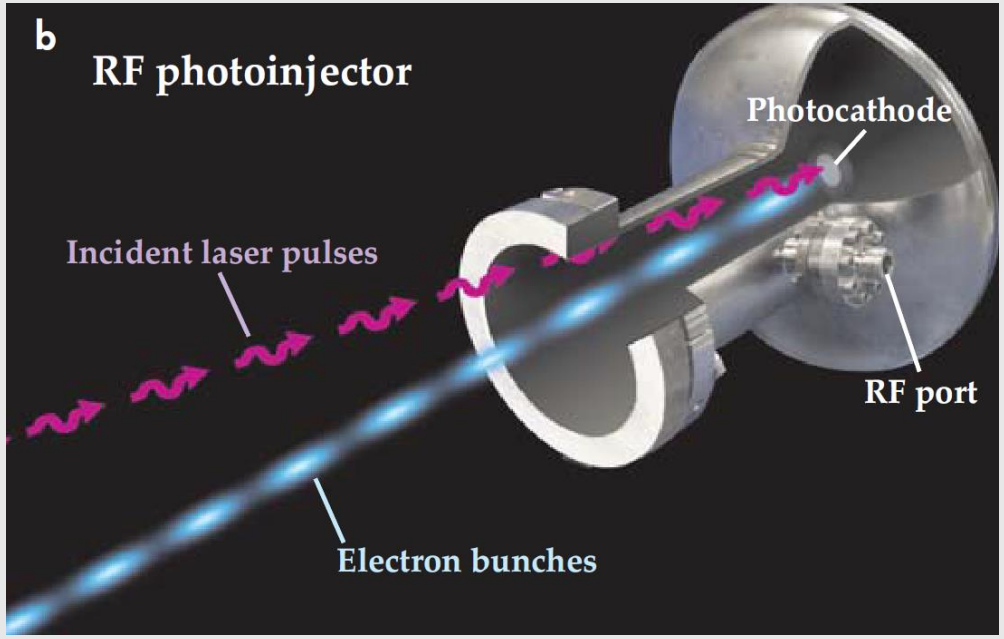
Background & Motivation

Advantages of a photocathode RF-Gun

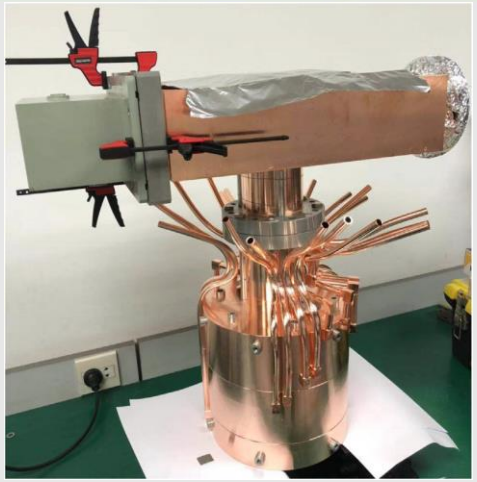
A short pulse laser with a certain wavelength (usually UV) is incident on the photocathode material to produce photoelectrons, which are extracted through a high gradient electric field formed by RF power. Common types of photocathode RF-Gun including **S-Band、L-Band、C-Band and VHF band for CW operation.**



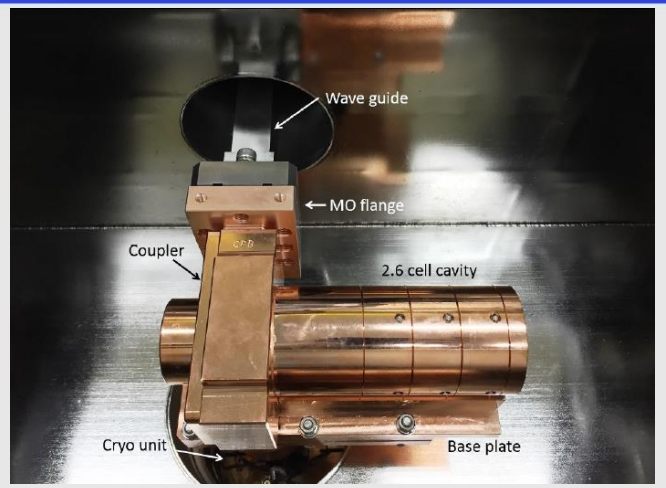
1. The transverse and longitudinal distribution of electron beam are determined by the incident laser, which can realize **short or even ultrashort** pulse beam
2. The electron beam with **specific longitudinal density distribution** can be realized through **laser pulse shaping**
3. Small initial thermal emittance and **high gradient field** on the cathode surface (necessary to obtain **high bunch charge** electron beam with **a small emittance**)

Background & Motivation --- Typical application

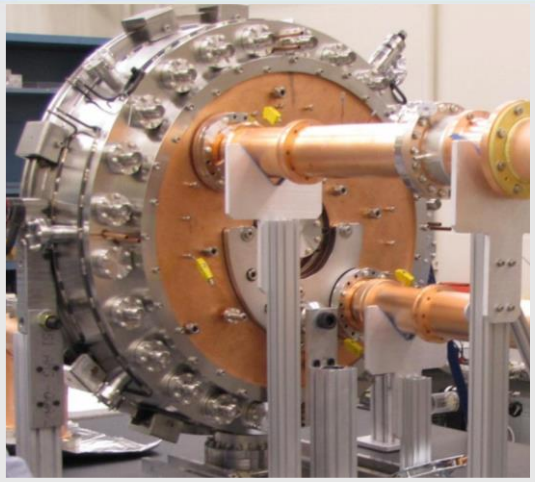
S-Band



L-Band



C-Band



VHF

	Cathode field	Typical beam parameters	Application
S-band	120MV/m	0.5-1μmrad@500pC-1nc 10Hz-120Hz	LCLS，SXFEL
L-band	60MV/m	0.6μmrad@500pC 10Hz/4.5MHz（670μs Macro pulse）	EuroFEL
C-band	160MV/m	——	——
VHF	20-30MV/m	100-300PC@0.4-0.6 CW operation/1MHz	LCLSII，SHINE

Background & Motivation

1. For CEPC Linac injector

Parameter	Symbol	Value		Unit
		e^+ injection	e^- injection	
Bunch Charge	q	**10**	**1**	nC
Transverse Emittance	$\epsilon_\perp$	100	100	mm.mrad

① A thermionic cathode electron gun and subharmonic bunching system are considered in Linac baseline design. The scheme selection of **injection timing** is very complex and low flexibility due to the existence of subharmonic RF frequency.

f	SHB1	SHB2	Linac	DR	booster	collider
MHz	143	572	2860	650	1300	650

② If a photocathode RF-Gun is considered as an alternative, it can replace the thermionic gun and subharmonic bunching system, and the injection timing is **very flexible**

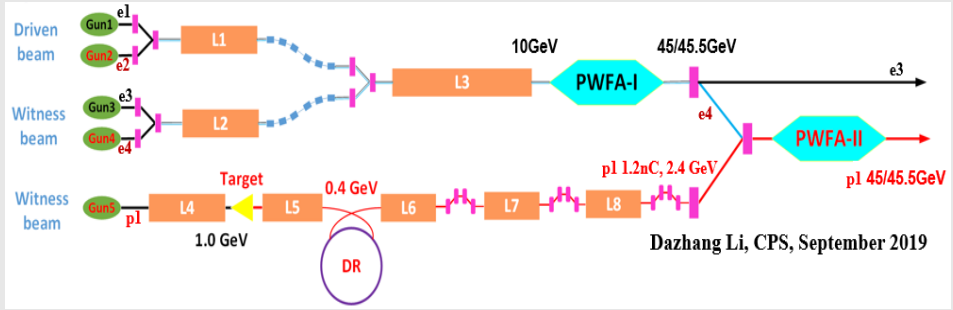
③ And the Linac injector can produce electron beam with **much smaller emittance**

Background & Motivation

2. Plasma WakeField Accelerating, an alternative of Linac

Basic beam requirements

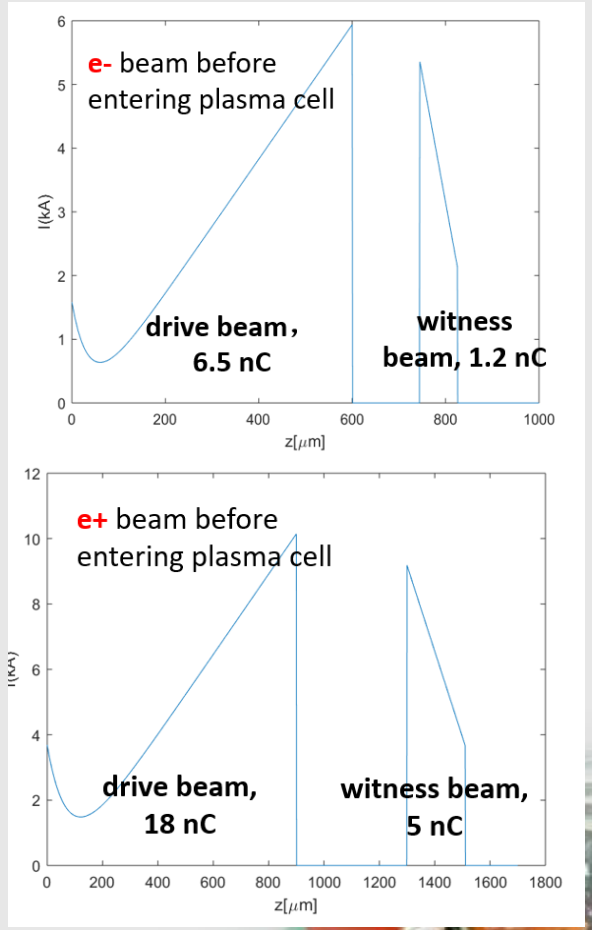
	e1	e2
Energy (GeV)	10/10	10/10
Bunch Charge (nC)	5.8	15
Bunch length (ps)	2/0.267	3/0.7
Energy Spread	~/0.2%	~/0.2%
N_Emittance (μm·rad)	<50*/<100	<50*/<100
Bunch Size (μm)	20	30



① Required a high **peak current** and **small transverse emittance** of electron beam in the plasma cell → **high bunch charge** + bunch compression in main LINAC + **laser drive photocathode**

② Specific triangle and trapezoidal **longitudinal distribution** beam for **High Transformer Ratio** in plasma cell → **Laser pulse shaping** in injector + longitudinal shaping preservation

③ A photocathode RF-Gun with high bunch charge is the **first choice** of PWFA electron source



Background & Motivation

3. For future development (FEL & others)

① As an electron source for producing small emittance and short pulse electron beam, photocathode RF-Gun is an essential core equipment of FEL injectors. At present, almost all the FEL projects use photocathode RF gun as electron sources.

② To develop first photocathode RF-Gun at IHEP. (almost all RF-Guns were developed by Tsinghua University, S, L, VHF...)

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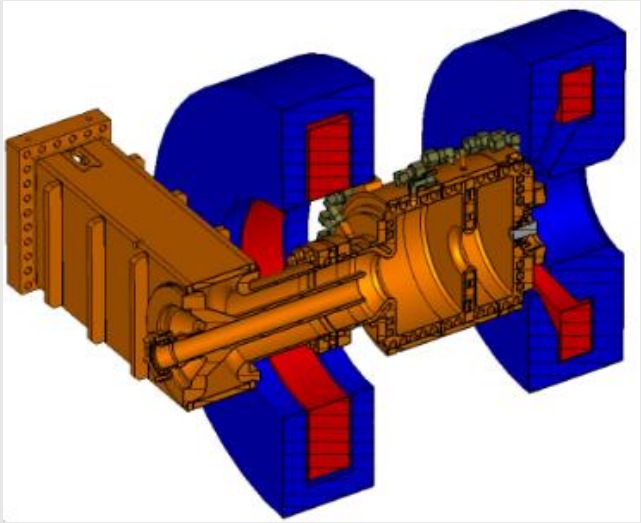
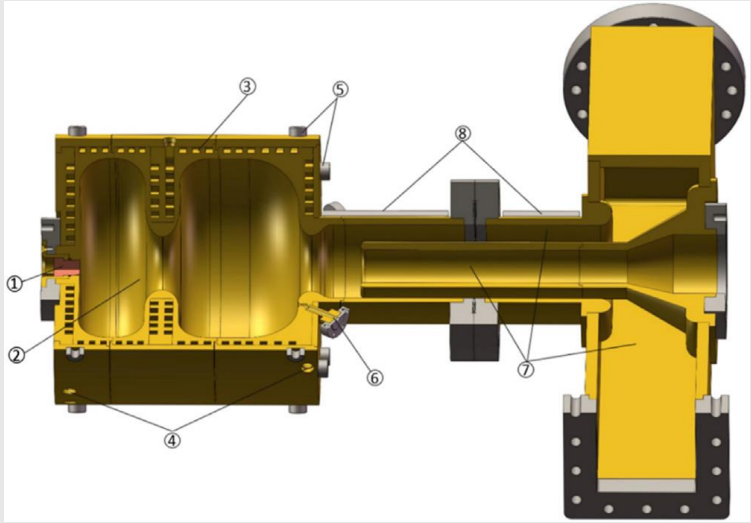
R&D Content and Objectives

Technical route：L-Band NC1.6 cell photocathode RF-Gun

- ✓ L-Band has **a long RF linear region**, which is effective to generate **large bunch charge** and is possible to realize the **simultaneous generation of driving beam and witness beam** in one RF period
- ✓ **Large acceleration aperture** is effective to extract **large bunch charge**
- ✓ **High gradient on cathode surface** is effective to generate **low emittance beam**





L-Band photocathode RF-Gun	
Frequency （MHz）	1300
Cathode gradient (MV/m)	60-80
Peak rf power (MW)	6.5-12MW
RF pulse length (μs)	≥10
RF repetition (Hz)	1-100
Energy at gun exit (MeV)	7-8

R&D Content and Objectives

Content 1：L-Band RF-Gun cavity

- The physical design, RF design, water cooling structure optimization and **mechanical design** of 1.3GHz/1.6cell RF-Gun cavity
- Design and development of a 1.3GHz/15MW **ceramic window**
- Processing and cold test of 1.3GHz/1.6Cell **prototype cavity**
- **High power test**

Content 2：Laser pulse shaping of UV laser and beam test

- Research on UV drive laser (Ti: sapphire laser and **third** harmonic generation)
- Longitudinal pulse shaping experiment (pulse generation with **specific distribution**)
- **Single** bunch and **two-bunches** generation experiment
- From metal cathode to **Cs_2Te** (High QE, high bunch charge at low laser power)

R&D Content and Objectives

Objectives in Stage 1

- Complete the design and development of a L-band photocathode RF-Gun cavity
- Build a high-power test bench for L-band cavity
- High power test with a copper cathode（**60MV/m@6.5MW，70MV/m@9MW**, 80MV/m is limited by the power of L-band klystron）

Objectives in Stage 2

- UV laser realizes a single pulse **5mJ** and **1mJ** after third harmonic generation
- Preliminarily realized the **longitudinal shaping** of UV laser for beam experiment
- Build a short beam line for **beam experiment** and obtain an electron bunch at the exit of RF-Gun with a **5nC** bunch charge

R&D Content and Objectives

Long term objectives

- The drive laser generates two laser pulses with fixed interval, which are used for two electron bunches required by PWFA (drive beam and witness beam for electron). Bunch charge reaches **6.5nc/1.2nc**, and the longitudinal distribution is **fully adjustable**
- Upgrade the L-band klystron (increase peak RF power) to increase the bunch charge
- Develop a liquid nitrogen cooled photocathode RF-Gun (**Cold RF gun**) to pursue higher cathode field and larger bunch charge **(>80MV/m, >15nC)**

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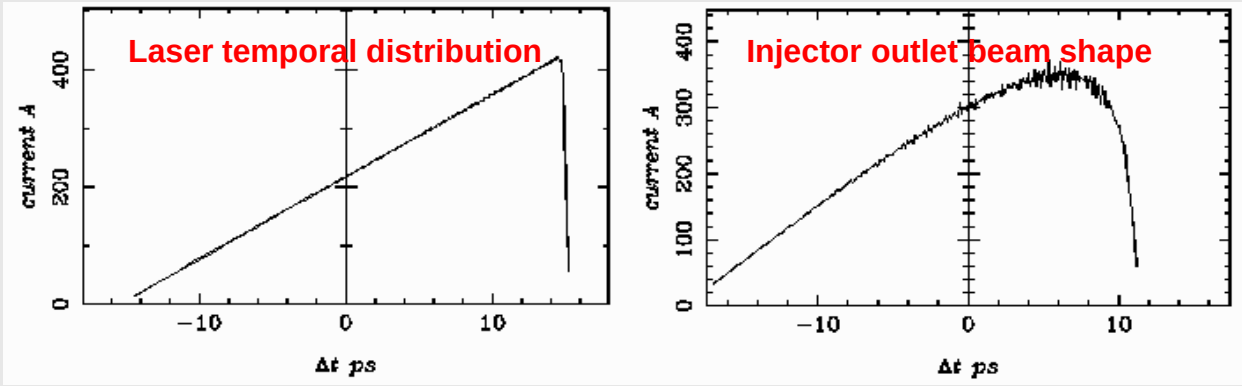
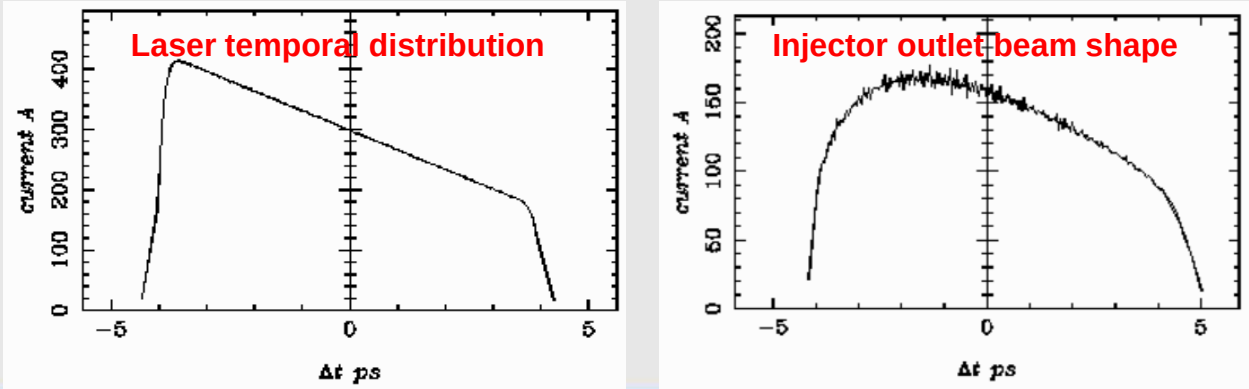
Existing research basis

Preliminary bean dynamics study

- According to the beam parameters required by PWFA, the preliminary simulation results show that using an L-band photocathode RF-Gun can produce the required longitudinally specific distribution of electron beam, and the transverse emittance meets the requirements. (**Shu Guan**)



- Charge **6.5 nC**
- Rms norm. emit=10.7 um
- Beam transmission =100%

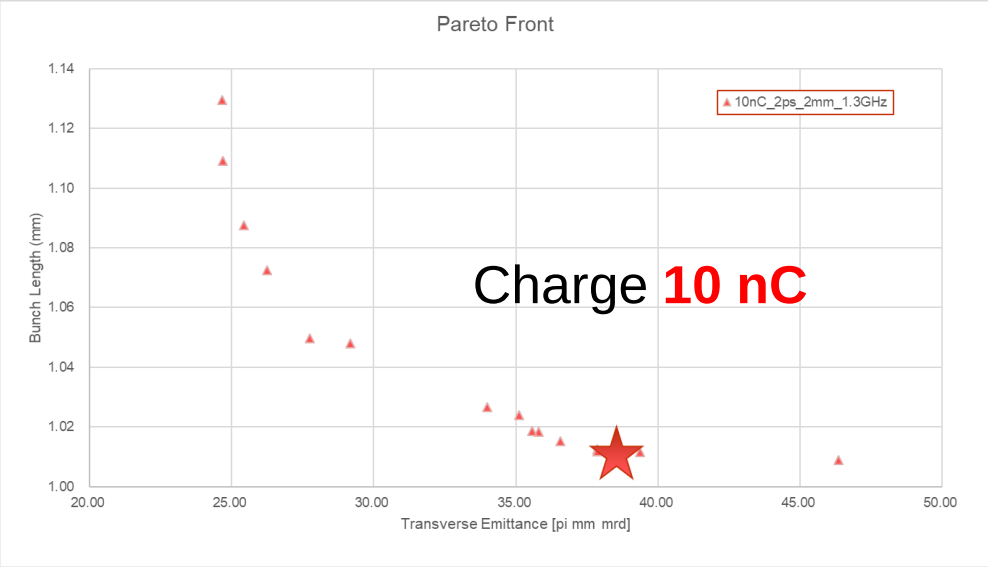


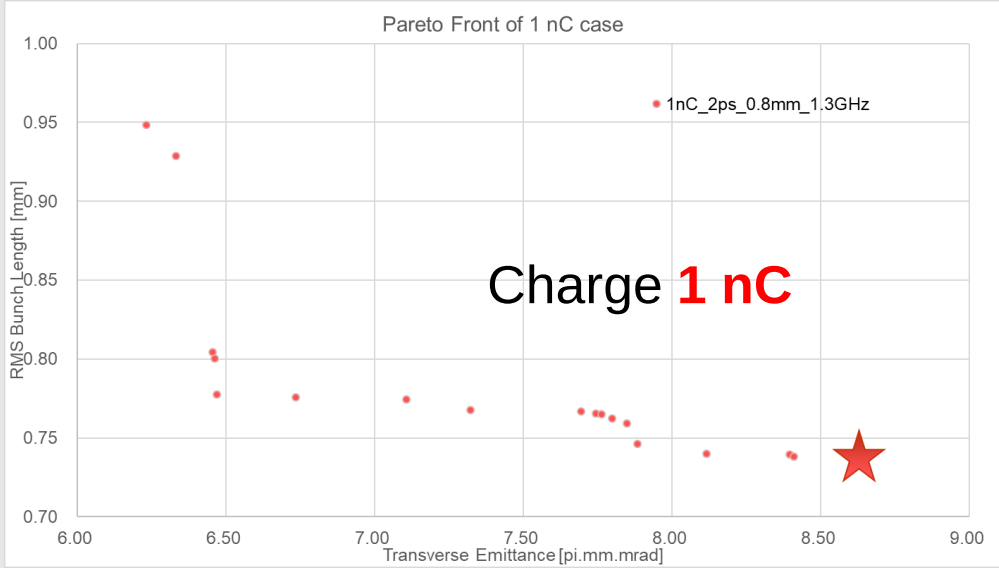
- Charge **1.2 nC**
- Rms norm. emit=4.8 um
- Beam transmission =100%

Existing research basis

Preliminary bean dynamics study

- According to the beam parameters required by electron injection (1nc e^-) and positron injection (10nc e^-) of CEPC Linac, the preliminary simulation results show that using an L-band photocathode RF-Gun can produce electron beams that meet the requirements. (**Xin TianMu**)





Existing research basis

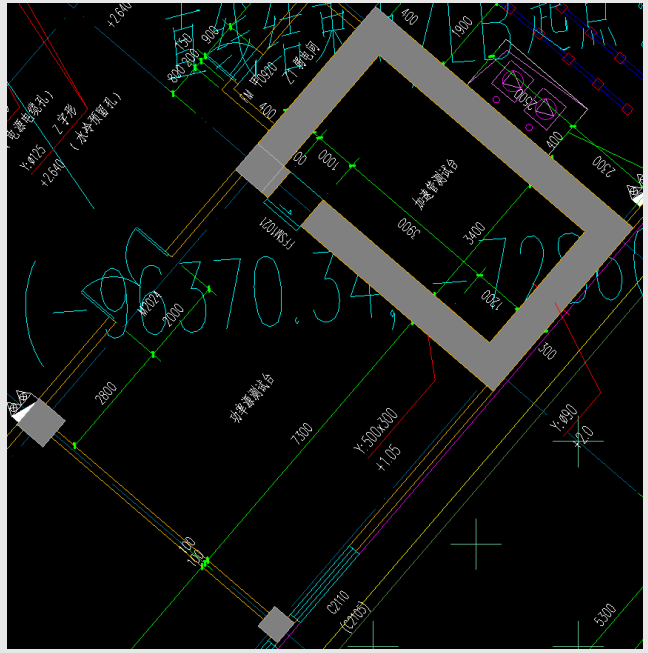
Existing equipment and test site

- Already have an L-band klystron (Prof. Jie Gao) from Thales in France. The specific parameters of this klystron are 1300MHz/2ms/5MW/100kW. And it can also work at short pulse mode, such as **1300MHz/10μs/10MW/10kW**, so as to meet the peak power required for the first stage high power test of the L-band photocathode RF gun (Maximum up to **10MW**)
- Also have a solid-state modulator can be used for L-band klystron (pulse width can be adjusted to > **10μs**)

Existing research basis

Existing equipment and test site

- The test benches in Yuquan Lu No.9 hall and Huairou HEPS Linac power source hall both can be used as test site for L-band RF-Gun high-power test



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Funding requirements

Stage 1（Total：1.40-1.50 Million）

- L-band 1.6Cell RF cavity, **0.9M** (Tsinghua quotes for **2M** only for prototype cavity)
- L-band ceramic window, **0.1M**
- Copper cathode and load-in system, **0.1M**
- Build the test bench (vacuum equipment, inflatable waveguide, LLRF and control system, **0.3-0.4M**)

Stage 2（Total：~4.50 Million）

- UV laser with a single pulse **5mJ@100Hz** and experiment on longitudinal shaping, **3M**
- Beam line for beam test, **0.5M**
- **Cs_2Te** photocathode and its load-lock system, **1M**

Long term（Total： ）

- Upgrade the L-band klystron or **Cold RF-Gun**, ???

Thanks!