THE HIGH INTENSITY PROTON LINAC FOR CSNS

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CSNS CHINESE ACADEMY OF SCIENCES

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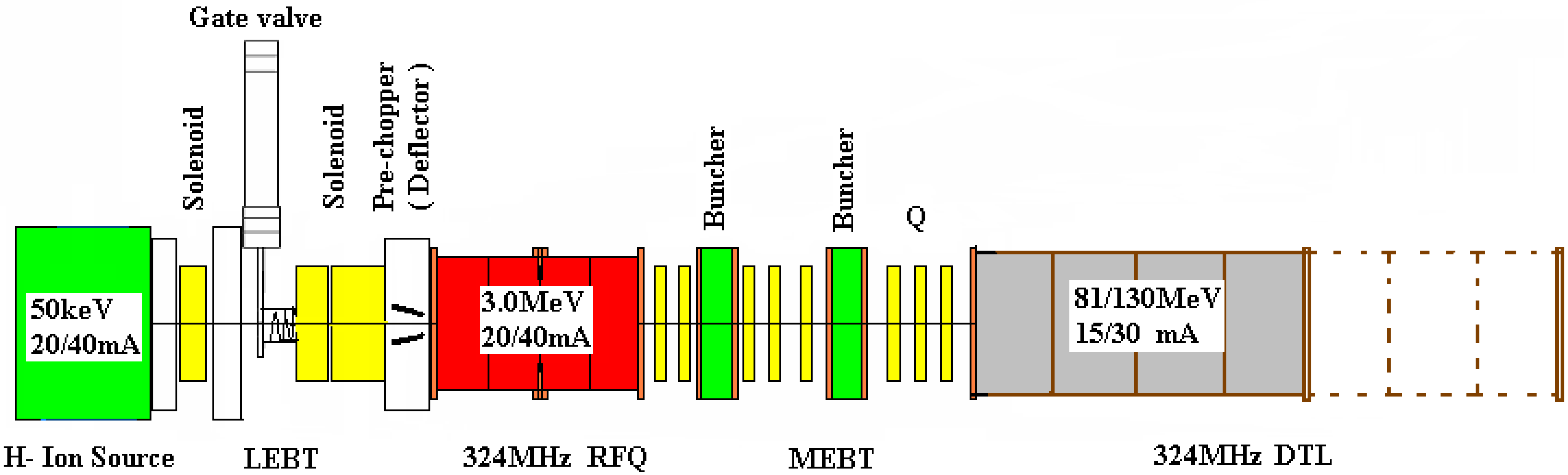
- Test stand of H^- ion source
- LEBT pre-chopper experiments
- Status of DTL prototype
- R&D progress of linac RF system
- R&D of beam diagnostic components
- Summary

Overview-linac



Layout of CSNS linac

- **Total length: ~42m**
- **Output energy/current: 81MeV/15mA (130MeV/30mA)**
- **Repetition rate: 25Hz**
- **Pulsed beam width: ~420μs**
- **Chopping rate: 50%**
- **Enough channel space for future upgrade**

Overview-ion source

Type of H⁻ ion source for CSNS

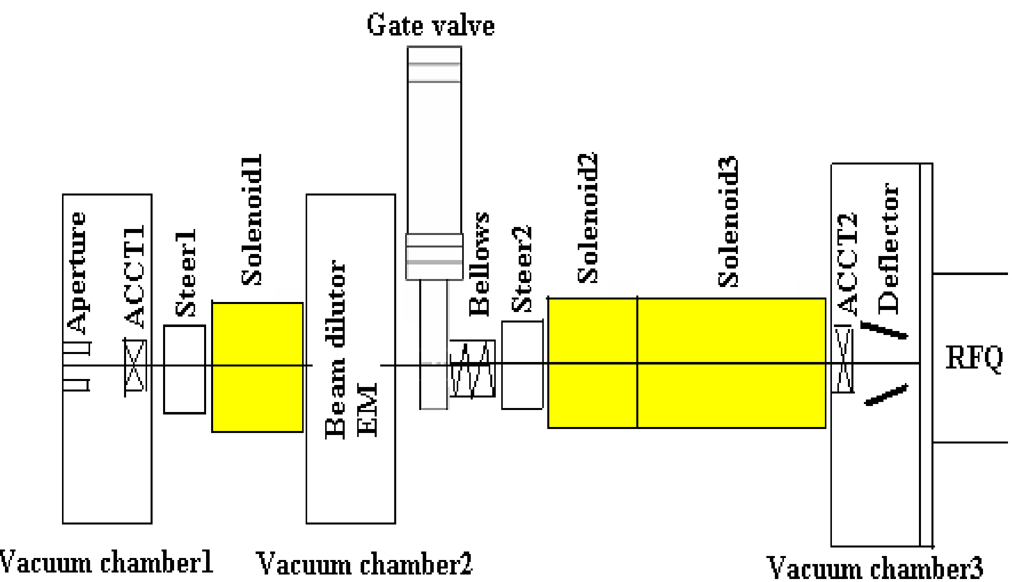
Penning Surface Plasma H⁻ ion Source

Main parameters of CSNS ion source (phase-I)

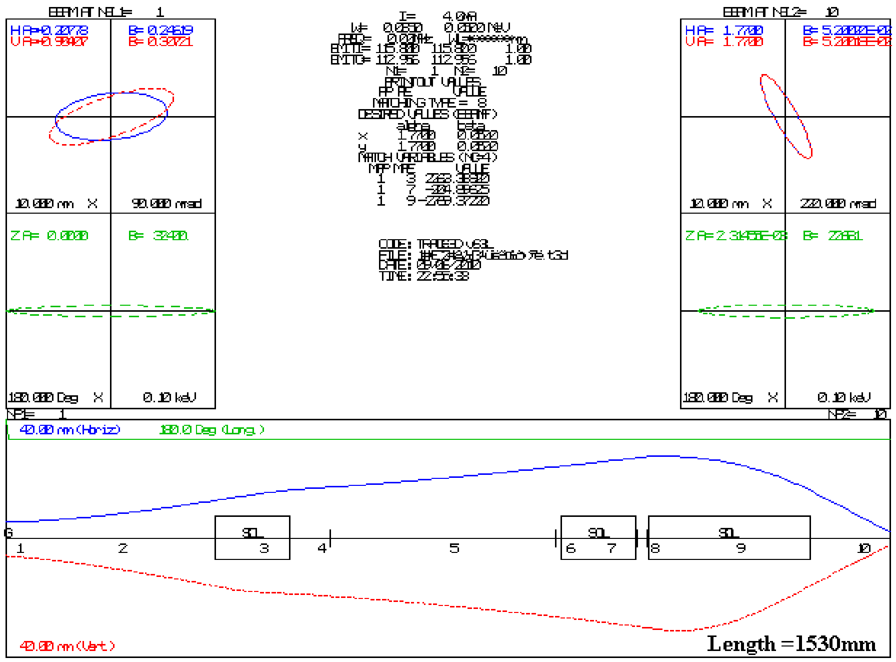
Ion	H^-
Energy (keV)	50
Pulsed beam current (mA)	20
Norm. rms. emittance (πmm.mrad)	<0.20
Repetition rate (Hz)	25
Pulsed beam width (μs)	~500
Lifetime (month)	~1

Overview-LEBT

➢ **The magnetic matching and focusing structure with three solenoids are adopted for LEBT. An electrostatic deflector as the pre-chopper is chosen to pre-chop the beam.**



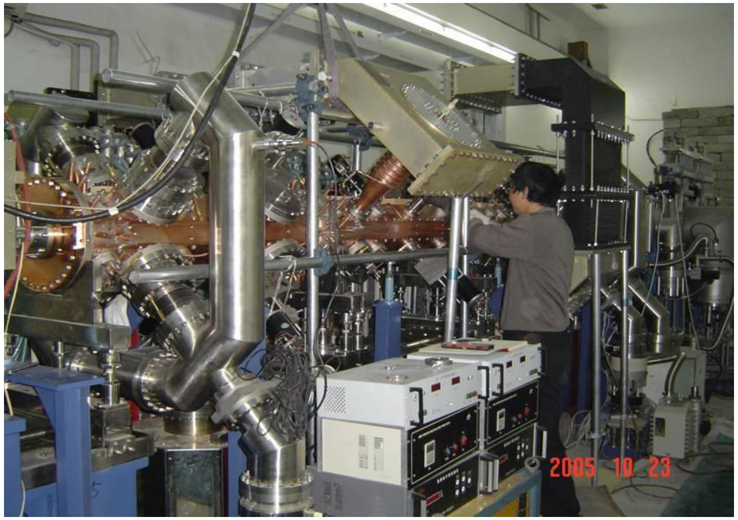
Layout of CSNS LEBT



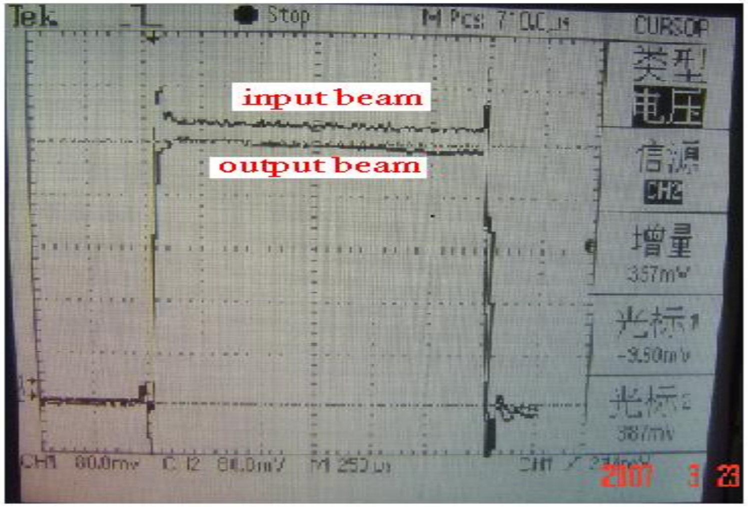
3 solenoids match the unsymmetrical beam into the symmetrical input beam of RFQ

Overview-RFQ

- A High-duty factor proton RFQ (4-vane type) accelerator for ADS (ADS RFQ) has been constructed at IHEP
- Nice performance with a transmission rate about 93% , an output beam current of 44.5mA and a duty of 7.15%.
- Progress in high-duty factor operation from about 7% to 15% is achieved



ADS RFQ in the installing process



44.5mA pulsed current with a transmission about 93% and beam duty factor of 7.15%.

Overview-RFQ

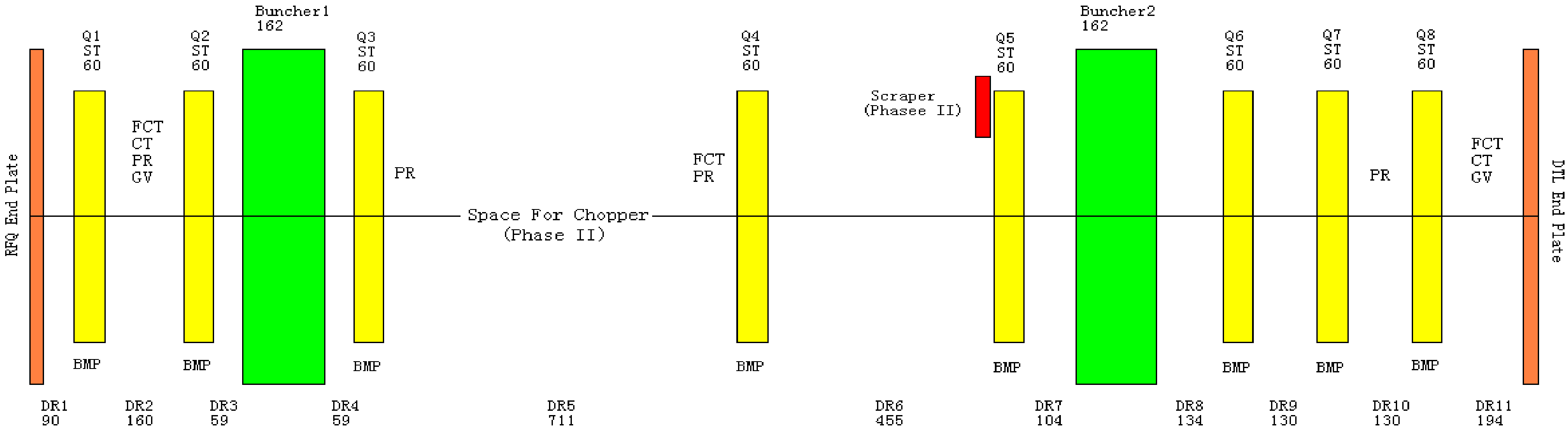
- Another new RFQ for CSNS RFQ needed, and the design is complete

Main parameters of CSNS RFQ

Parameters	CSNS	ADS
Frequency(MHz)	324	352.2
Injection Energy (keV)	50	75
Output Energy (MeV)	3.0	3.5
Pulsed beam current (mA)	40	50
Beam duty factor	1.05%	6%
Vane length (m)	3.603	4.731
Norm. rms input emittance (πmm.mrad)	0.2	0.2
Inter-vane voltage V (kV)	80	66.5
Maximum surface field (MV/m)	31.68(1.78Kilp)	33(1.8Kilp)
Average bore radius: r0 (mm)	3.565	2.93
Vane-tip curvature: ρt(mm)	3.173	2.93
Pulsed RF Power (kW)	510	630

Overview-MEBT

- **Total length =3030 mm**



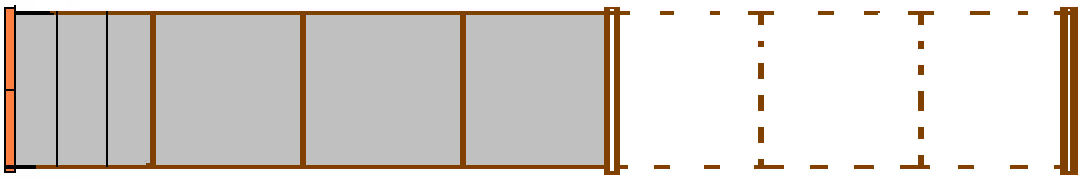
BPM=beam position monitor
PR=profile monitor
FCT=fast current monitor
CT=current monitor
Q=quadrupole magnet
ST=steering magnet
GV=gate vale

Layout of MEBT (similar to JPARC MEBT)

Alternative designs without chopper or even without MEBT are also being considered!

Overview-DTL

- DTL consists of four independent tanks and each tank is further divided into three short unit tanks with about 2.8 m in length for easy manufacture.
- Total 156 EMQs in two groups.
- The face angles of the drift tube increase from 0º to 60º to achieve the higher shunt impedance while keep enough space for housing the EMQs inside.
- The peak surface field keeps below 1.3 Kilpatrick.

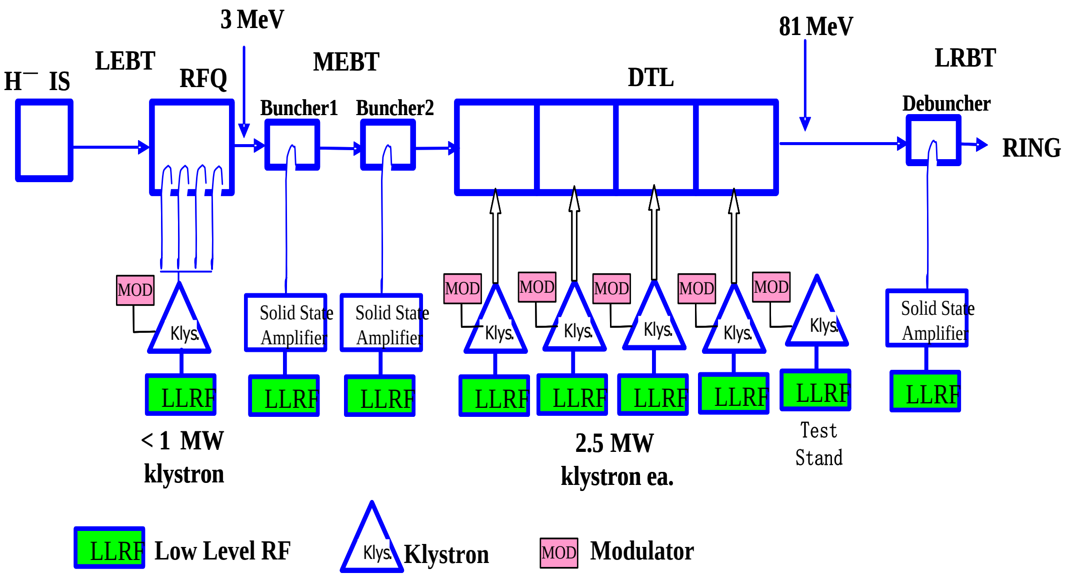


DTL tank main parameters

Cavity No.	1	2	3	4	Total
Output energy (MeV)	21.76	41.46	61.28	80.77	
Length (m)	7.99	8.34	8.50	8.87	33.68
Cell number	61	36	29	26	152
Cavity power dissipation (MW)	1.42	1.41	1.39	1.45	5.67
Total power dissipation (MW)	1.97	2.01	1.98	2.03	7.99
Acceleration gradient (MV/m)	2.2-3.1	3.1	3.1	3.1	
Synchronous phase (Degree)	-30~-25	-25	-25	-25	

Overview-Linac RF system

- One-RF-unit-per-cavity independent RF control design will be adopted.



Layout of CSNS linac RF system

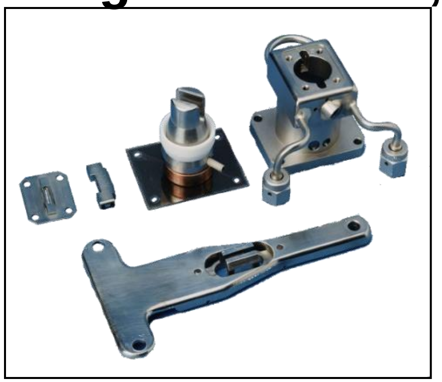
Basic requirements for CSNS klystron RF power source

Frequency	324 MHz
Klystron peak output power at saturation	2.5 MW (< 1 MW for RFQ)
Repetition rate	25 Hz
Beam voltage pulse width	700 μs
RF output power pulse width	650us (Max.)
Efficiency	55% (Min.)
Gain	50 dB (Min.)

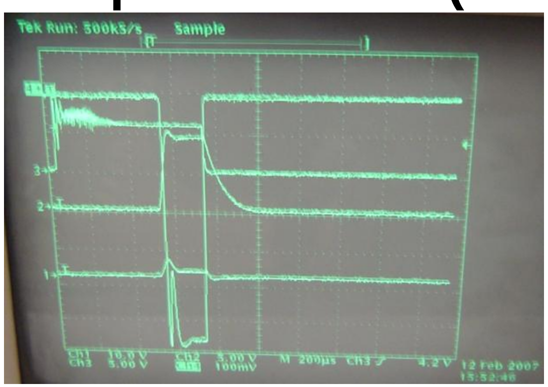
Test stand of H⁻ ion source

1. R&D of H⁻ ion source started with the domestic manufacture of the discharge chambers and the extraction electrodes.

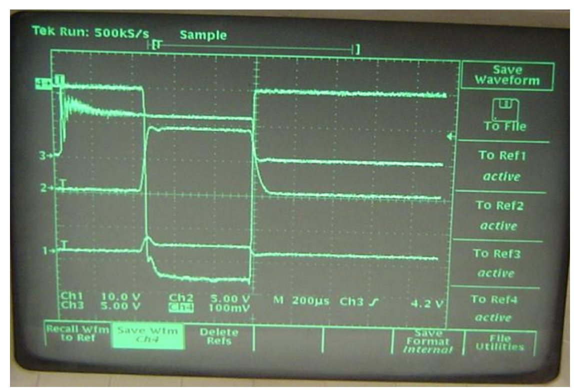
Discharge chambers, extraction electrodes



Good performance (Test results on RAL H- ion source test stand)



70mA beam at 50Hz and 200μs



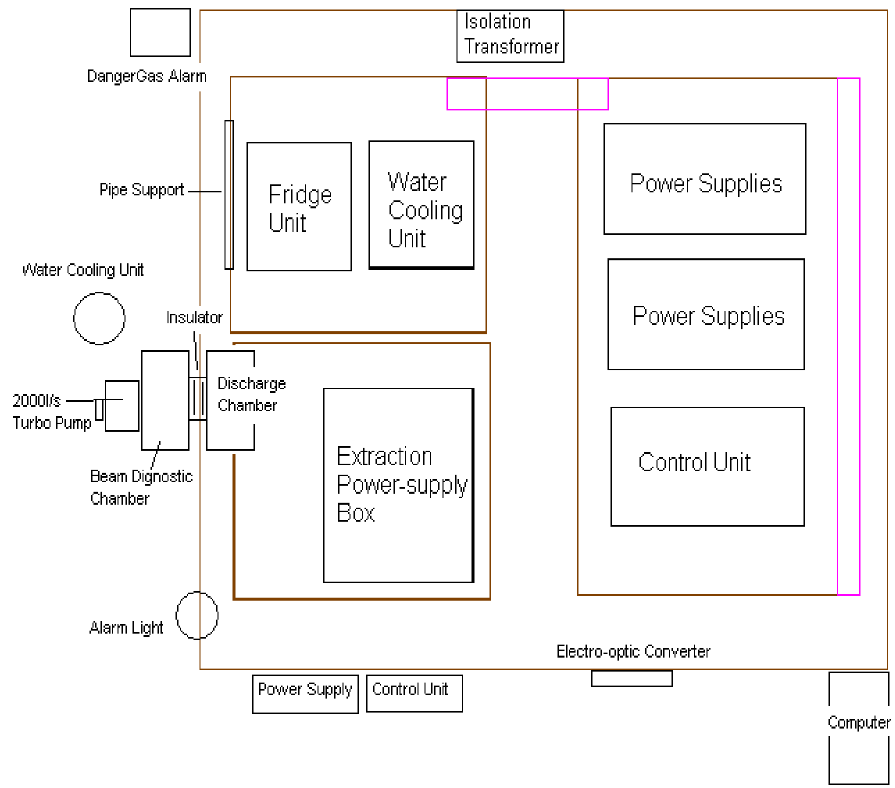
55mA beam at 50Hz and 500μs

Test stand of H⁻ ion source

2. The construction of the H⁻ ion source test stand was finished at the end of 2009.

Subsystem or components

- Main body of ion source
- Power supply system
- Control system
- Cesium delivery system
- Hydrogen delivery system
- Air and water cooling system
- Freon freezing system
- Vacuum system
- Beam diagnostic components
- Grounding system

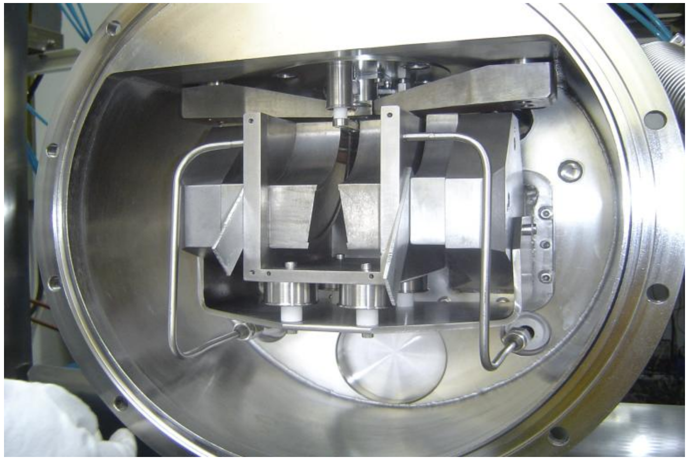


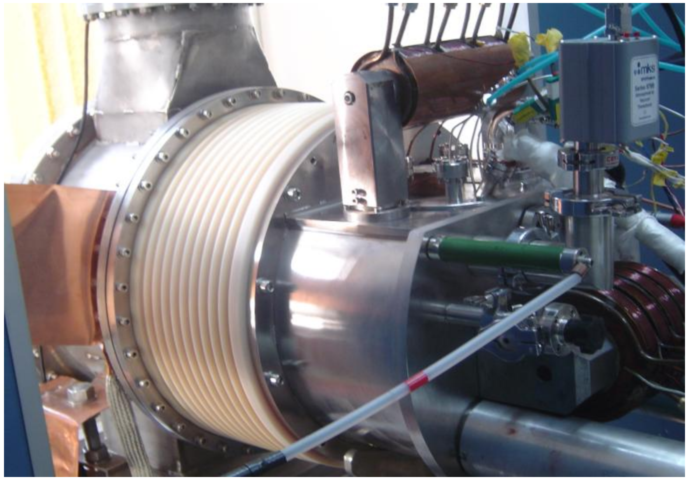
Layout of H- ion source test stand at IHEP

Test stand of H^- ion source

Components of the main body

- Discharge chamber and its vacuum chamber
- Extraction electrode
- Cold box and its support
- Sector and Penning magnets
- Acceleration insulator
- Beam diagnostic chamber
- Acceleration electrodes
- vacuum chamber for the beam diagnostics





Main body of the ion source

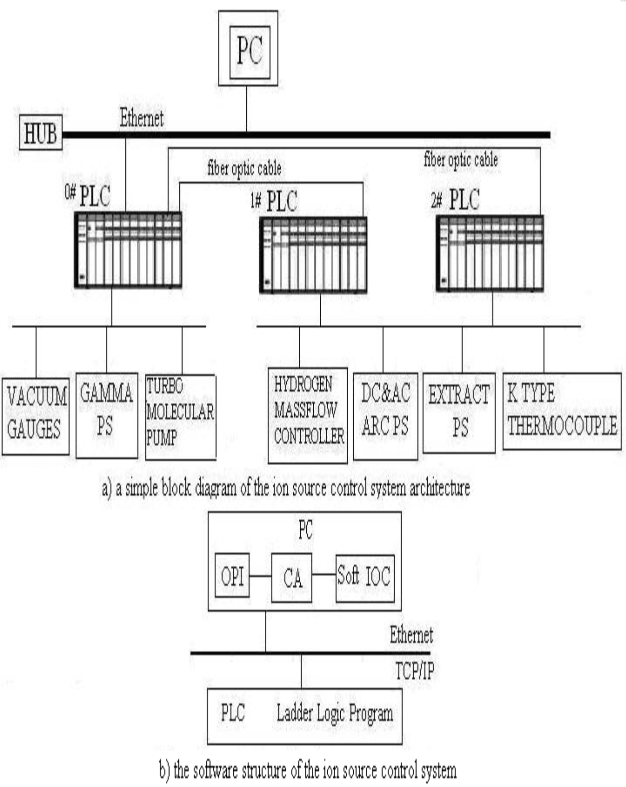
Test stand of H⁻ ion source

Power supply system

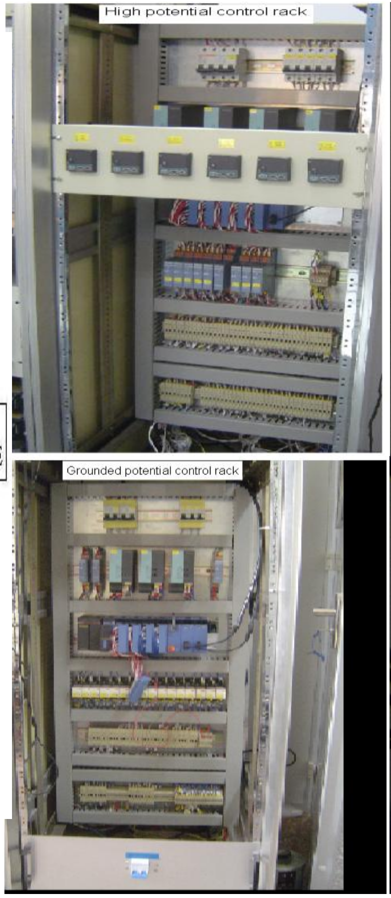
- DC/AC discharge power supply
- Extracting power supply
- Accelerating power supply
- Gas valve power supply
- Sector magnet power supply
- Penning magnet power supply
- Cs boiler power supply
- Cs transport power supply
- Isolating transformer

Test stand of H⁻ ion source

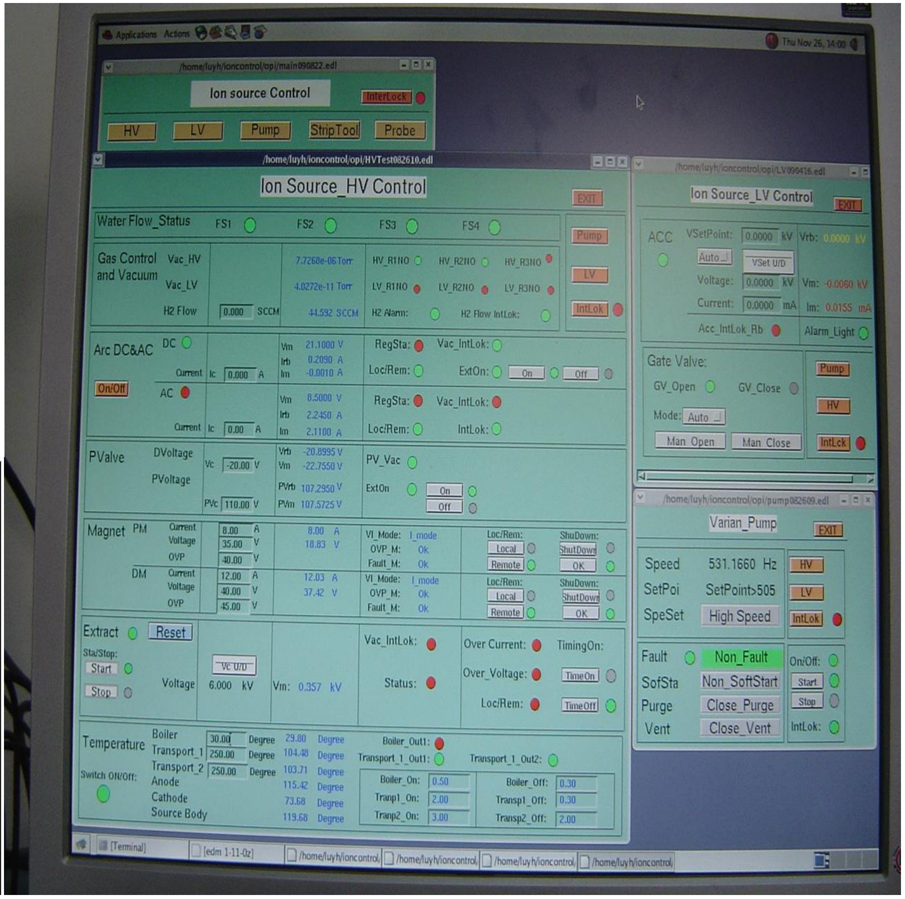
➢ **The control system is developed using Yokogawa FA-M3R Programmable Logic Controllers (PLCs) and Experimental Physics and Industrial Control System (EPICS).**



Schematic of the control system structure



Control rack

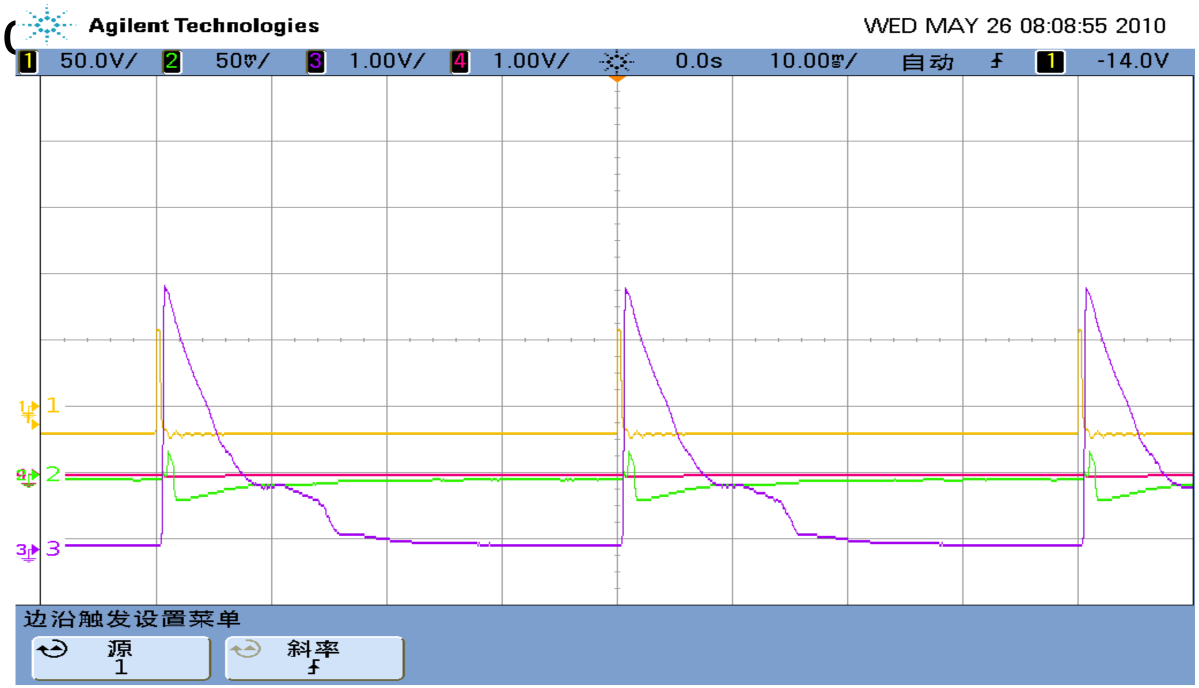


Graphical user interface by EDM

Test stand of H^- ion source

3. Commissioning of the source is in progress.

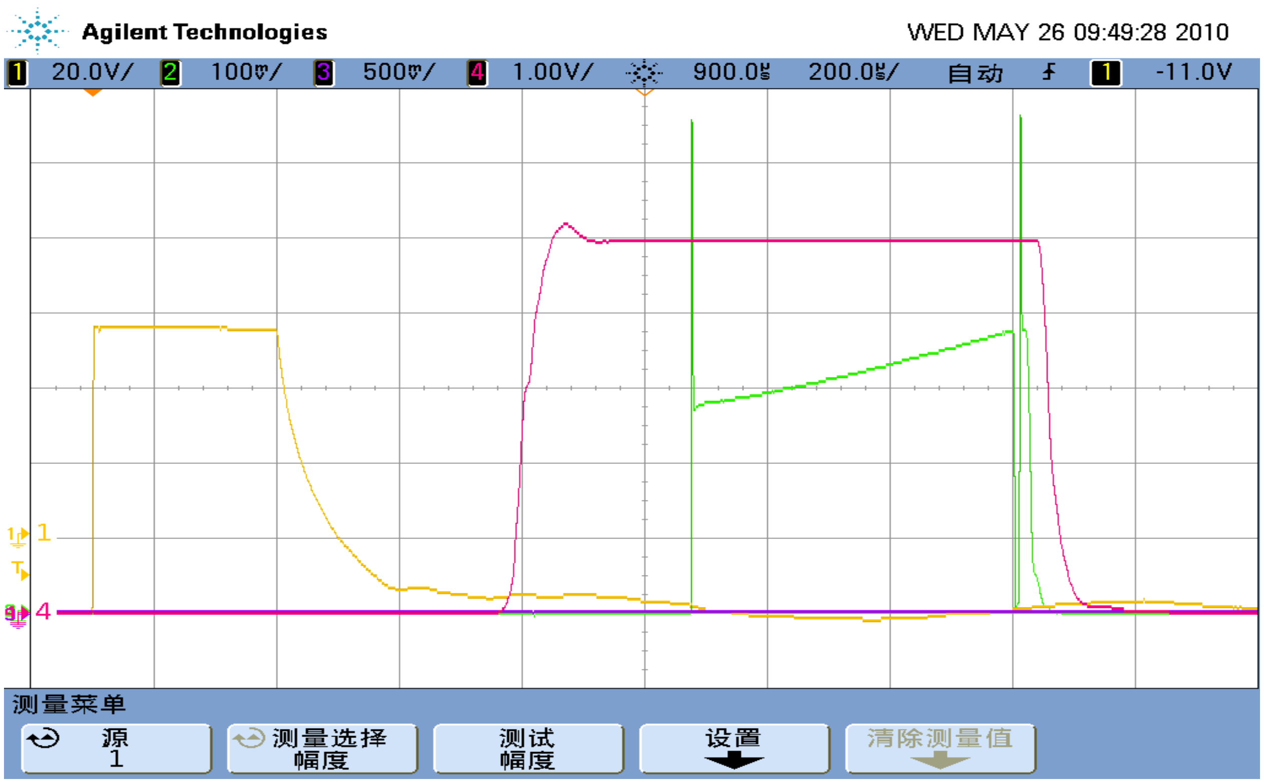
DC discharge to heat up the discharge



A typical DC discharge current curve (pink), the peak current about 18A and pulse width about 15ms

Test stand of H⁻ ion source

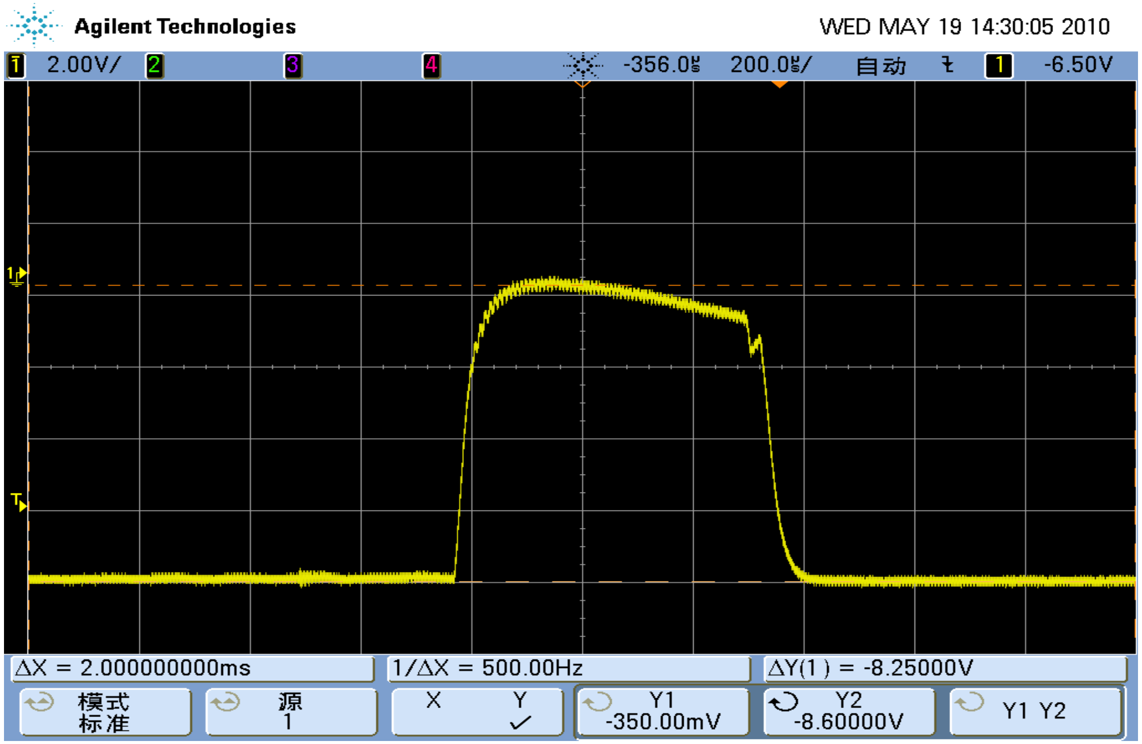
➢ Pulsed discharge and beam extraction



Pulsed discharge current (red) of 50A with a pulse width of 800μs and the extraction beam current (green) about 300mA with a pulse width of 520μs ， the voltage output of the piezoelectric hydrogen valve power supply is also shown (yellow).

Test stand of H⁻ ion source

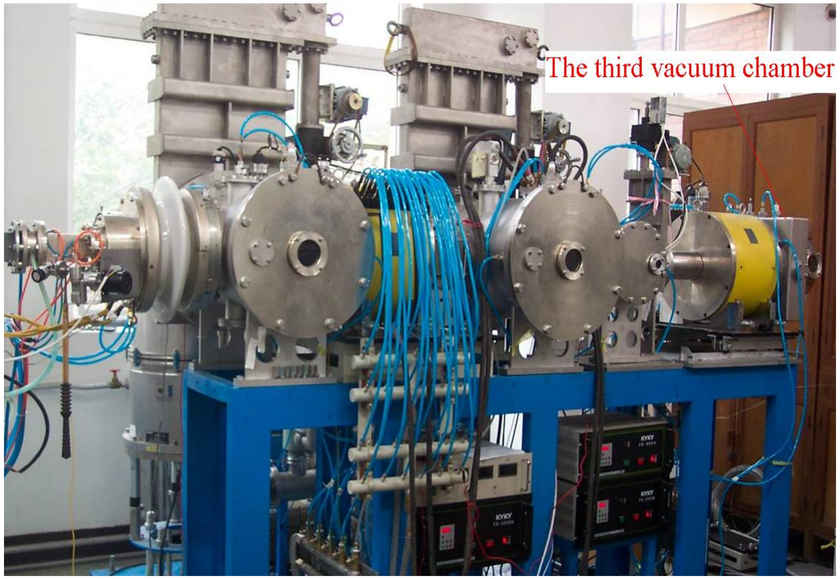
A stable H⁻ ion beam current of 53 mA with energy of 50 keV is got, the beam emittance measurement is being prepared.



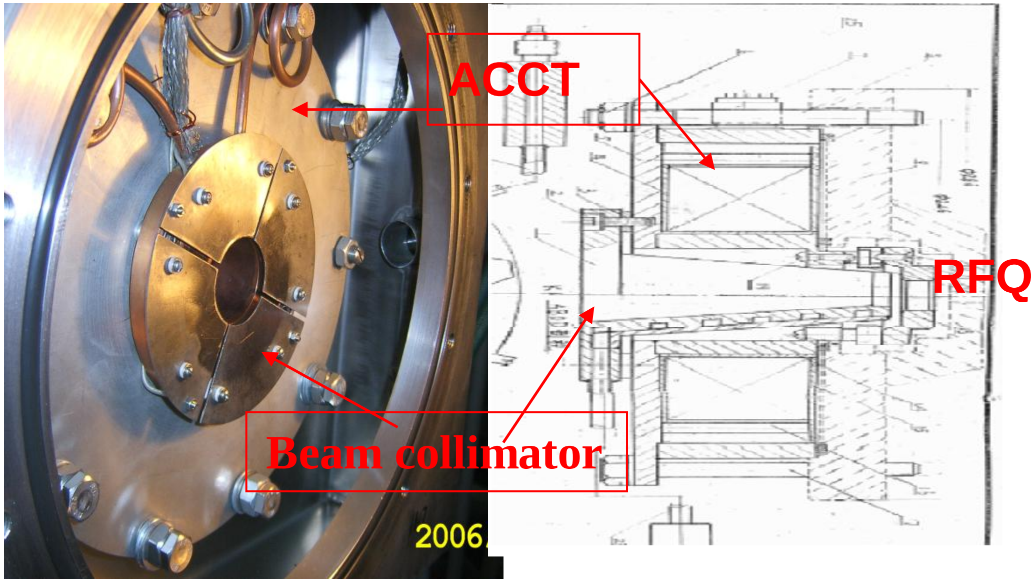
H⁻ ion beam with energy of 50 keV and a current of 53 mA

LEBT pre-chopper experiments

In order to examine the reliability of the CSNS pre-chopping design, a similar electrostatic deflector design is carried out based on the existent 352.2MHz ADS RFQ LEBT layout and the structure of the third vacuum chamber located at the entrance of RFQ.



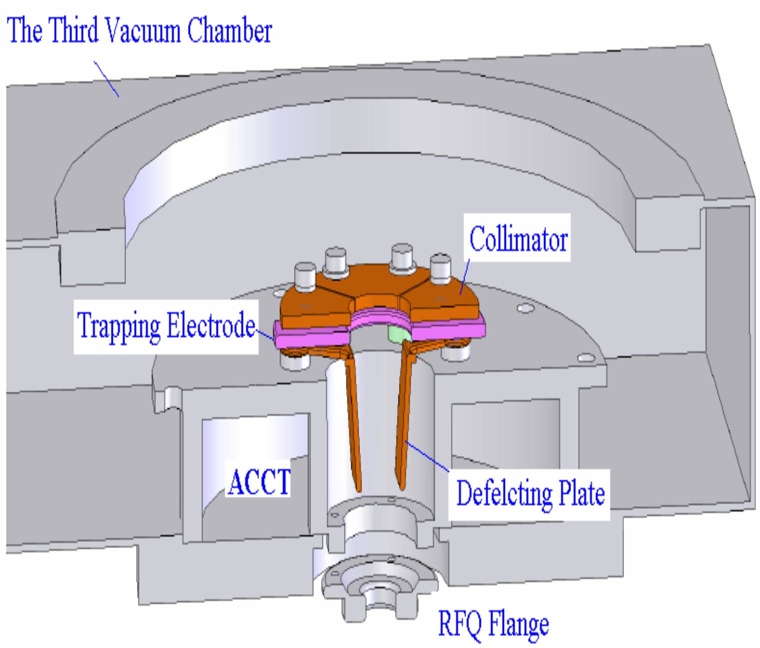
Layout of ADS RFQ LEBT

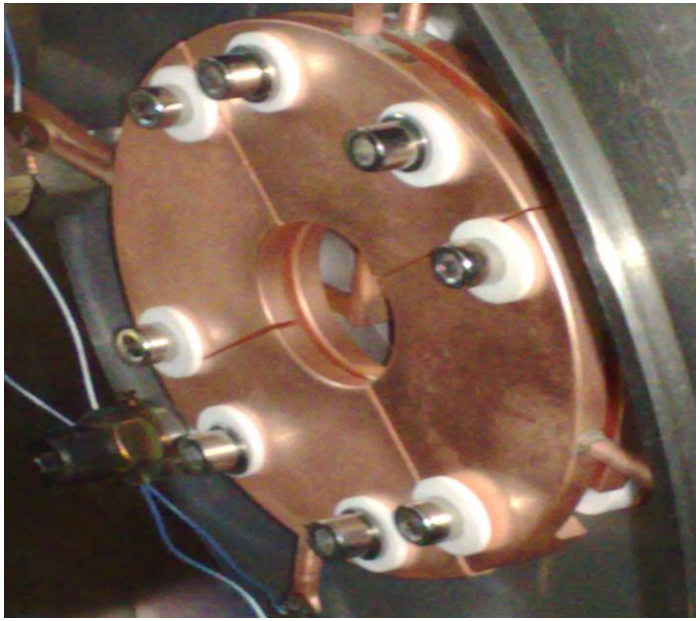


The internal structure of the third vacuum chamber

LEBT pre-chopper experiments

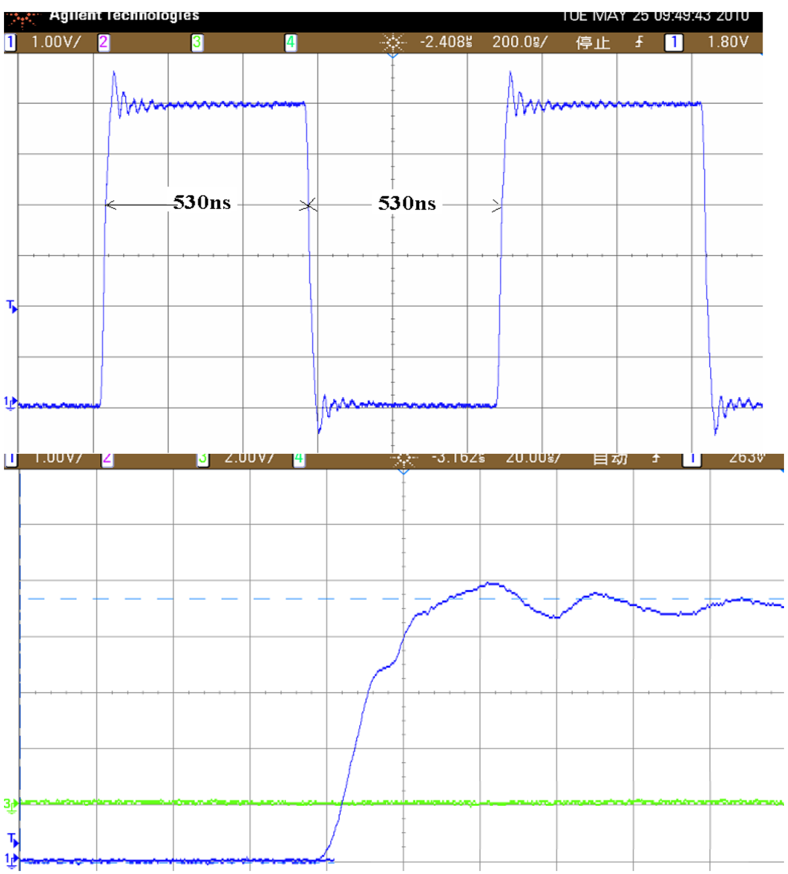
- **The deflecting plate length: 50mm**
- **The gap between plates: 20.16 ~33.84 mm (1.2*beam envelope)**
- **The width:25.2-42.3mm (1.5*beam envelope)**
- **The chopped beam is designed to lose in the RFQ cavity, and the needed deflecting voltage is 3.16kV.**





The deflector installed in the third chamber

LEBT pre-chopper experiments



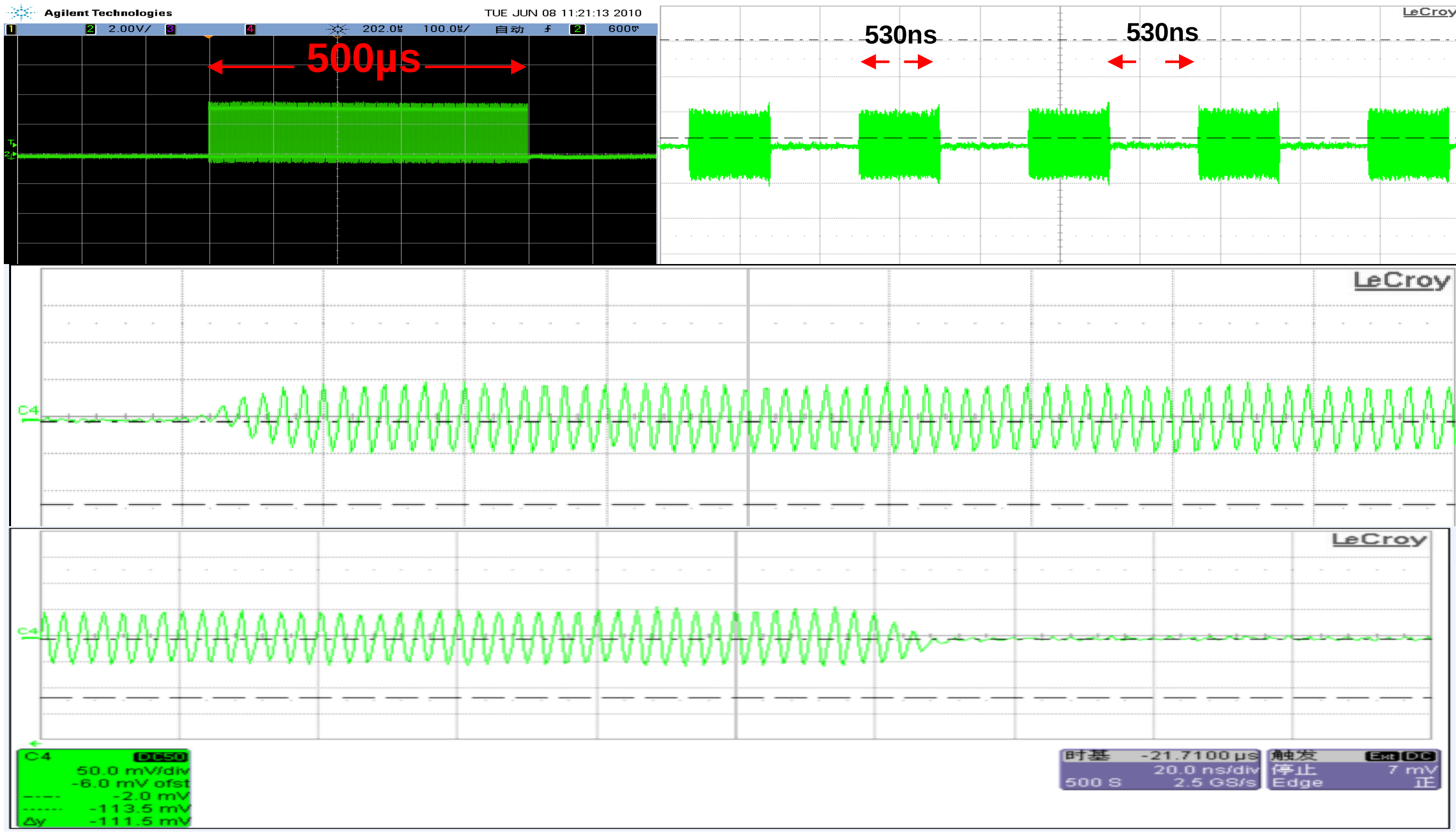
Parameters asked for the power supply

- Maximum output voltage: 6kV
- Pulsed power: 500W
- Average power: 6.25W
- Rise and fall time: <15ns
- Capacitance of the load ~15pF
- Micro repetition frequency 0.9433MHz
- Micro pulse width 530ns
- Macro repetition frequency 25Hz
- Macro pulse width 600μs

The voltage output of the power supply without beam load, the rise time (0-5kV) is about 20ns, the rise time (0-3kV) is about 12ns

LEBT pre-chopper experiments

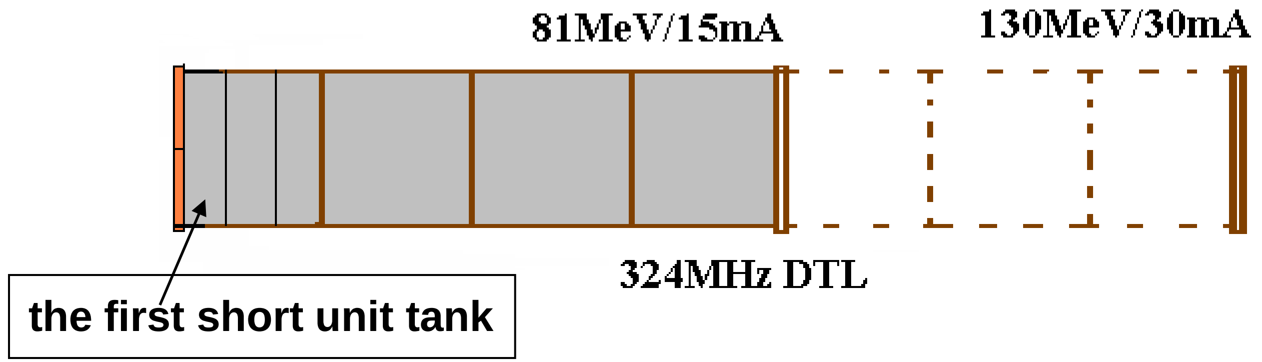
- The rise and fall time of the chopped beam is about 15ns (about 4-5 RF periods, a RF period is 2.84 ns).



Chopped beam signal of the BPM at the exit of RFQ, both the rise and fall time are about 4-5 RF periods (a RF period is 2.84 ns)

Status of DTL prototype

TUP061 by Dr. Yin



The following items are chosen as the DTL R&D project:

(1) Manufacture of the first short unit tank;

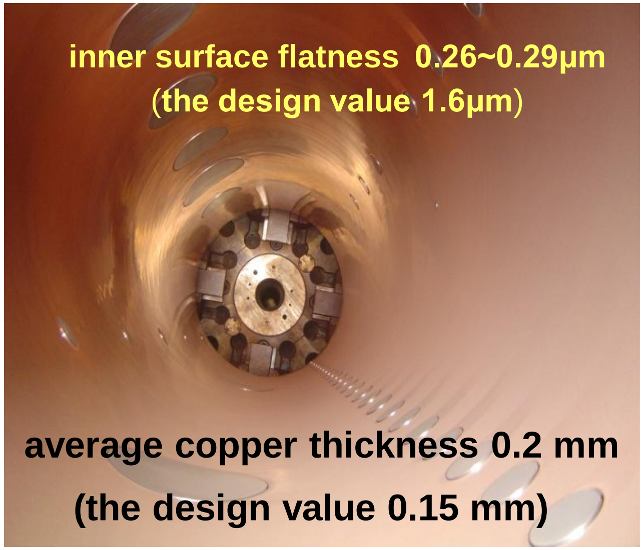
(2) Manufacture of the 28 quadrupole magnets and the 28 drift tubes for the first unit tank.

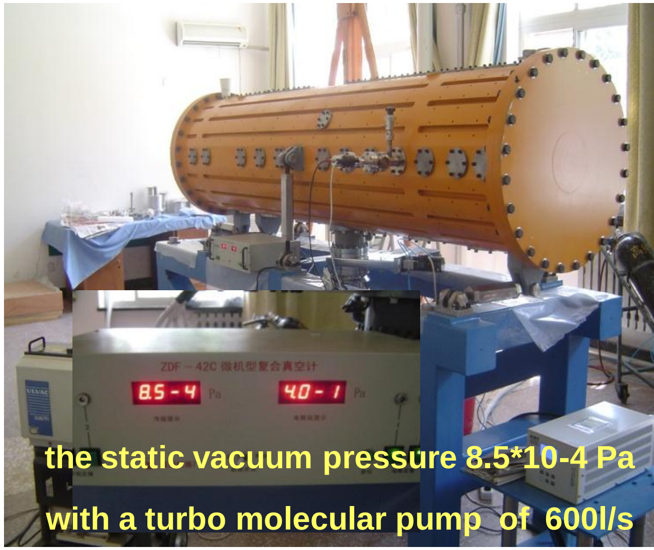
Status of DTL prototype

DTL Tank Manufacture

- The polish of the inner surface and the fine machining of the ports finished, the washing will be carried out in this month.

- **Material: carbon steel tube**
- **Length: 2.8m**
- **Inner diameter: 566 mm.**
- **The inner surface: coated with OFC by using the periodic reverse copper electroforming method**
- **It contains 9 large ports and approximate 60 small ports.**
- **There are twelve straight water cooling channels embedding into the tank outside wall.**





the first unit tank prototype module

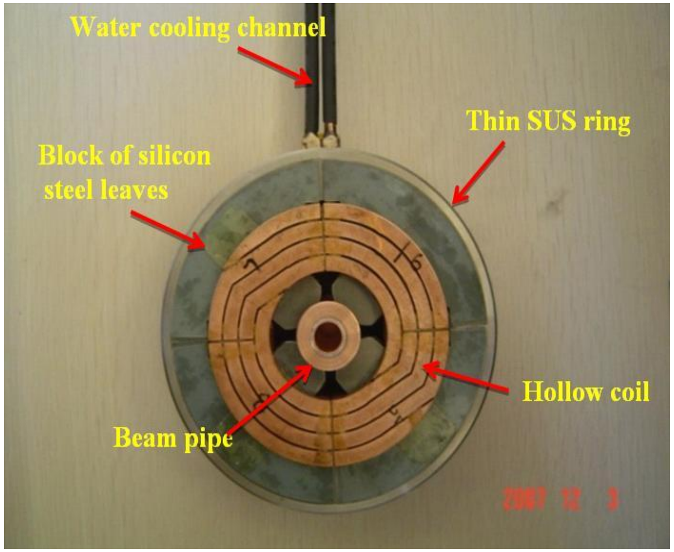
Status of DTL prototype

Electromagnet Quadrupoles

Design parameters of the Q-magnets and the DTs for the low-energy part of the DTL

Magnet aperture diameter (mm)	15
Yoke out diameter (mm)	118
Core length (mm)	35.0
Magnetic field gradient (T/m)	75
Effective length (mm)	41.3
Core material	Silicon steel 50WW470
Thickness of steel leaf (mm)	0.5
Number of turns per pole	3.5
Integrated field *GL* (T)	3.1
Water flow rate (l/min)	1.0
Max. excitation current (A)	528
Conductor area (mm^2)	18.75
Current density (A/mm^2)	28.16
Resistance of coil (mΩ)	4.25
Inductance of coil (μH)	31.66
DT aperture diameter (mm)	12.0
DT outer diameter (mm)	148

The SAKAE type coil is used. Both the wire cutting and the periodic reverse copper electroforming methods are applied in the SAKAE type coil in the manufacture process.

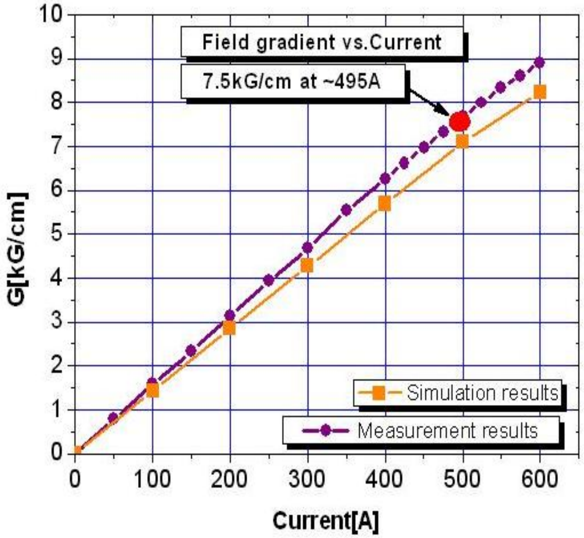


The EMQ assemblies

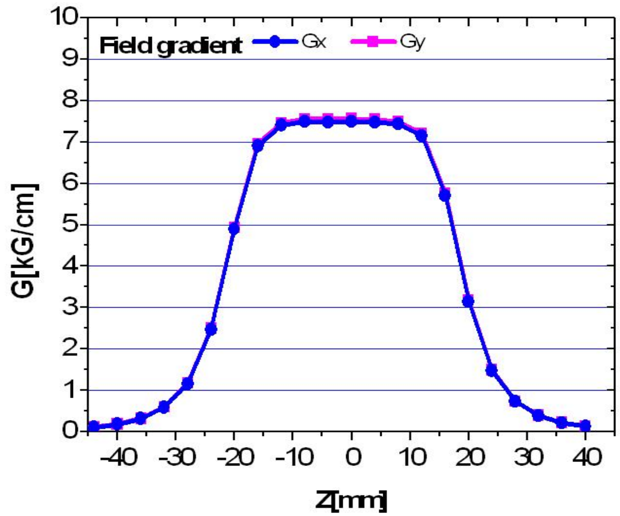
Status of DTL prototype

Electromagnet Quadrupoles

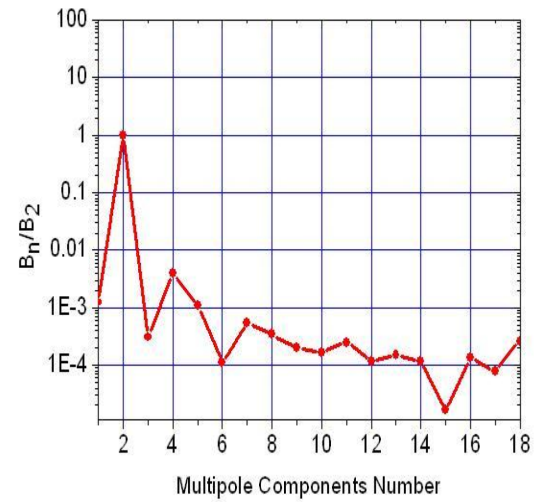
The 28 EMQs have been fabricated and measured. The measured results are basically agreed with the calculated ones.



The measured magnet field gradient versus the excitation current in transverse plane



The measured effective length is 42.8 mm, which is a little longer than the design one by about 3.7%.

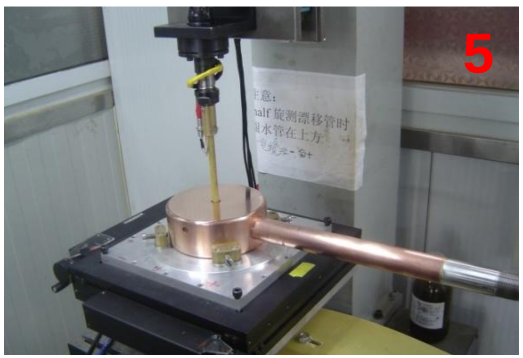


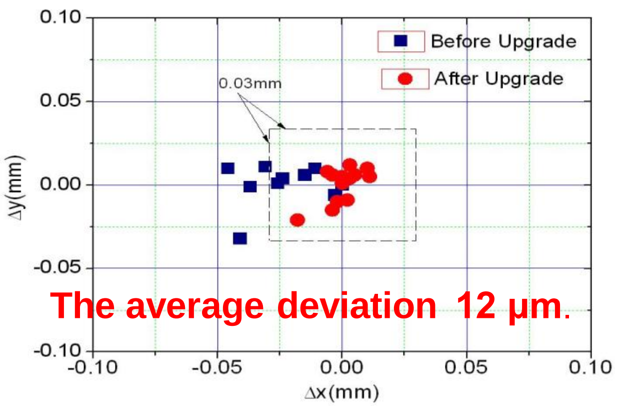
The measured higher-order components is less than 0.3% in comparison with the quadrupole component

Status of DTL prototype

DT Fabrication

The batch manufacture of DTs is in progress. Up to now, 9 DTs have been manufactured and measured, the measured deviation of the mechanical center from the magnetic field center is within the tolerance ± 30μm. The remanent DTs will be completed in this month.





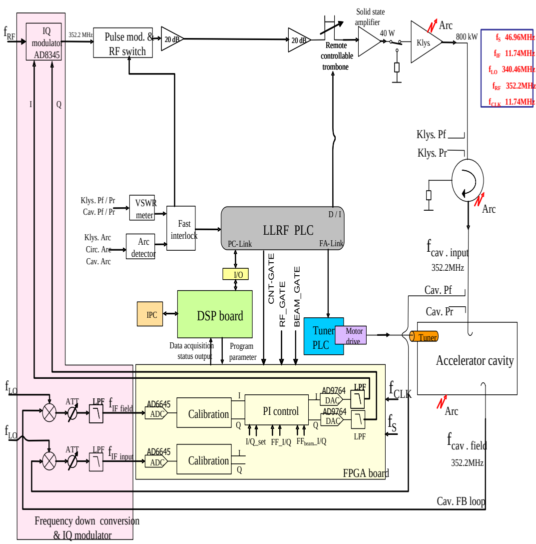
The deviation of the mechanical center from the magnetic field center

R&D progress of linac RF system

THP046 by Dr. Li

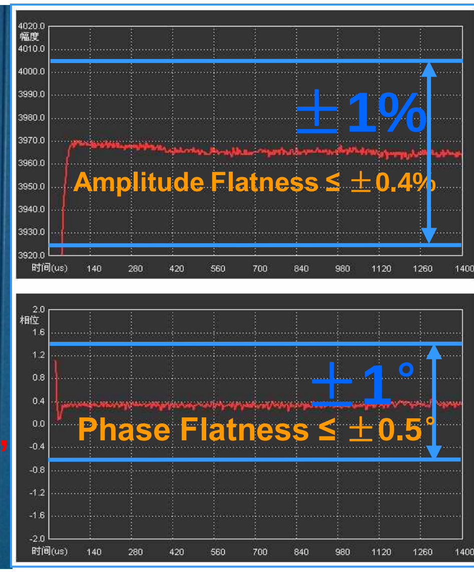
Digital Low Level RF (LLRF) Prototype

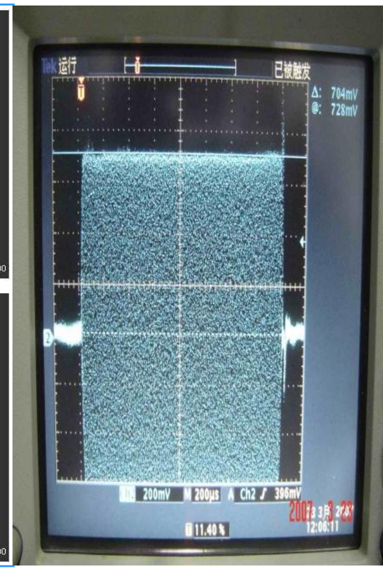
By taking use of the ADS RFQ accelerator, a digital low level RF prototype for CSNS was developed. The field variation can be maintained within ±1% in amplitude and ±1° in phase during the beam commissioning.



Block diagram of LLRF

19” standard racks profile



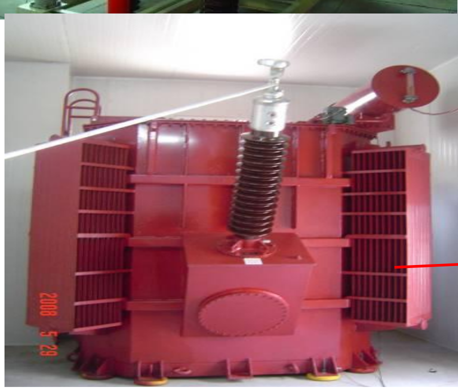


Cavity RF field signal, RF pulse width is 1.4 ms

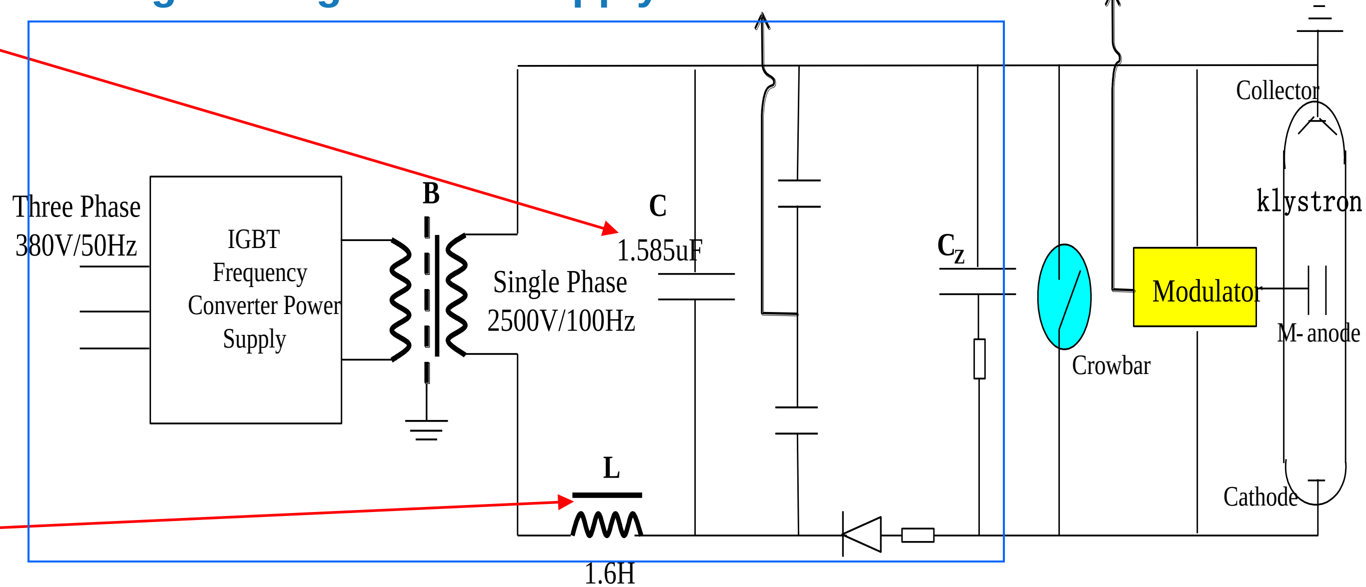
R&D progress of linac RF system

AC Series Resonance High Voltage Power Supply for Pulse Klystron (-120kV/50A)

Its basic features are AC series-resonant charging and pulse synchronized discharging. The natural resonance frequency of LC circuit is designed to 100 Hz.



High Voltage Power Supply

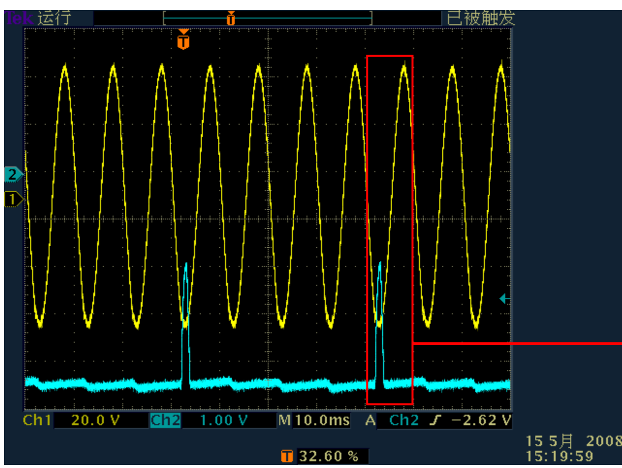


The schematic diagram of -120 kV /50 A high voltage power supply

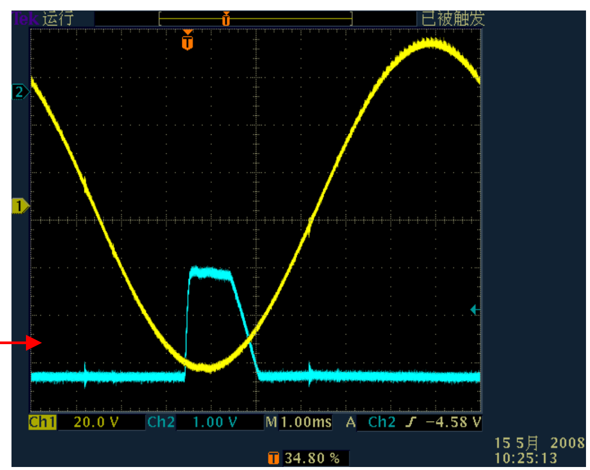
R&D progress of linac RF system

AC Series Resonance High Voltage Power Supply for Pulse Klystron

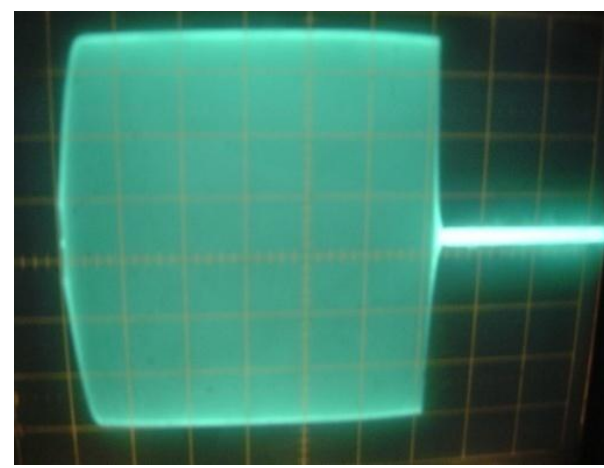
The measured Q0 > 350, AC to DC conversion efficiency is up to 88%. The performance of the system basically agrees with simulation results. In addition, to reduce AC noise and volume of the components, a new design to increase AC resonance frequency up to 400Hz is also ongoing.



AC resonance charging voltage



The klystron modulation anode voltage

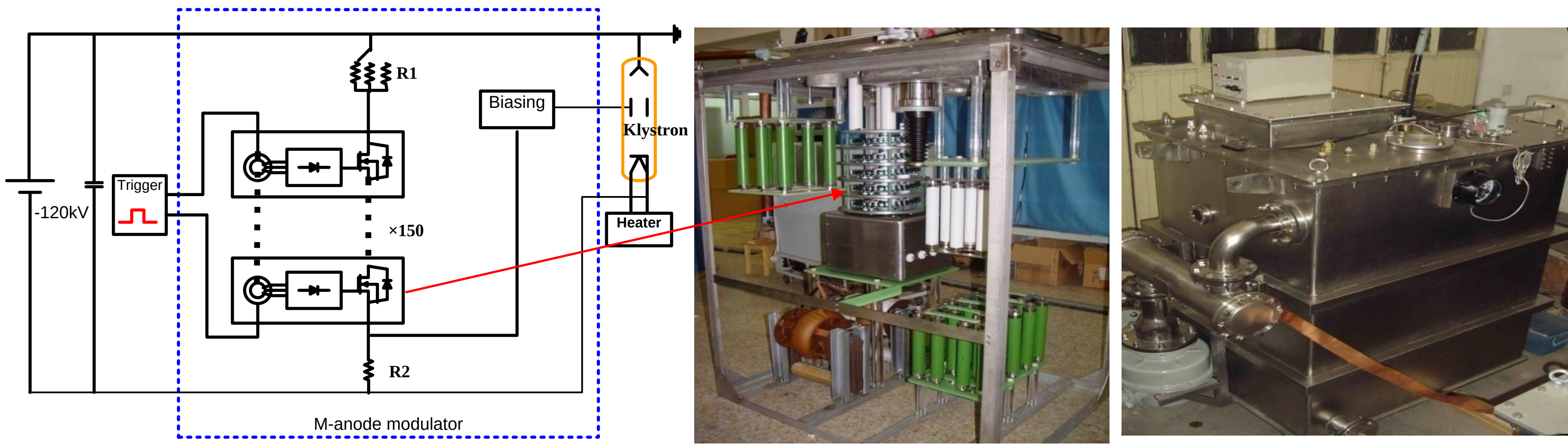


The klystron output RF power

R&D progress of linac RF system

M-Anode Modulator

M-anode modulator generates klystron anode pulse voltage by switching the cathode voltage through dividing resistors (R1 and R2). The high voltage semiconductor switching device mainly consists of 150 FETs in series configuration, it can withstand -120kV movement voltage.

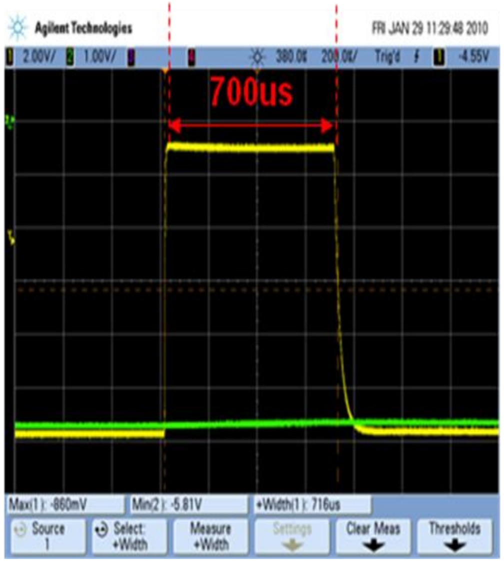


The schematic (left), the internal (middle) and external (right) structures of modulator prototype

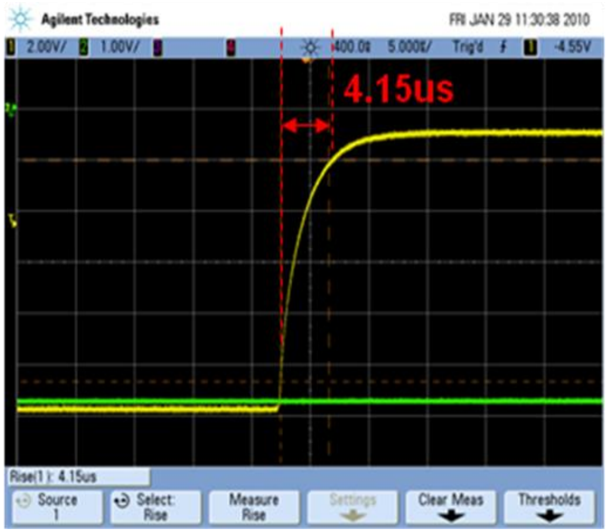
R&D progress of linac RF system

M-Anode Modulator

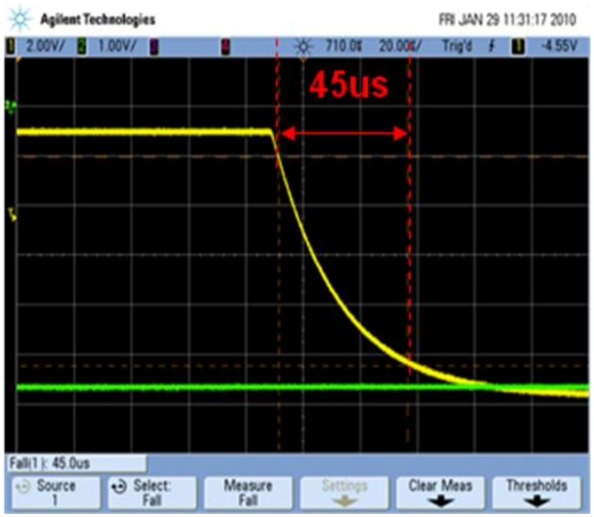
Unloaded high voltage test (no klystron load) is carried out on a condition of 25 Hz /110 kV /700μs.



700μs m-anode pulse



4.15μs rise time

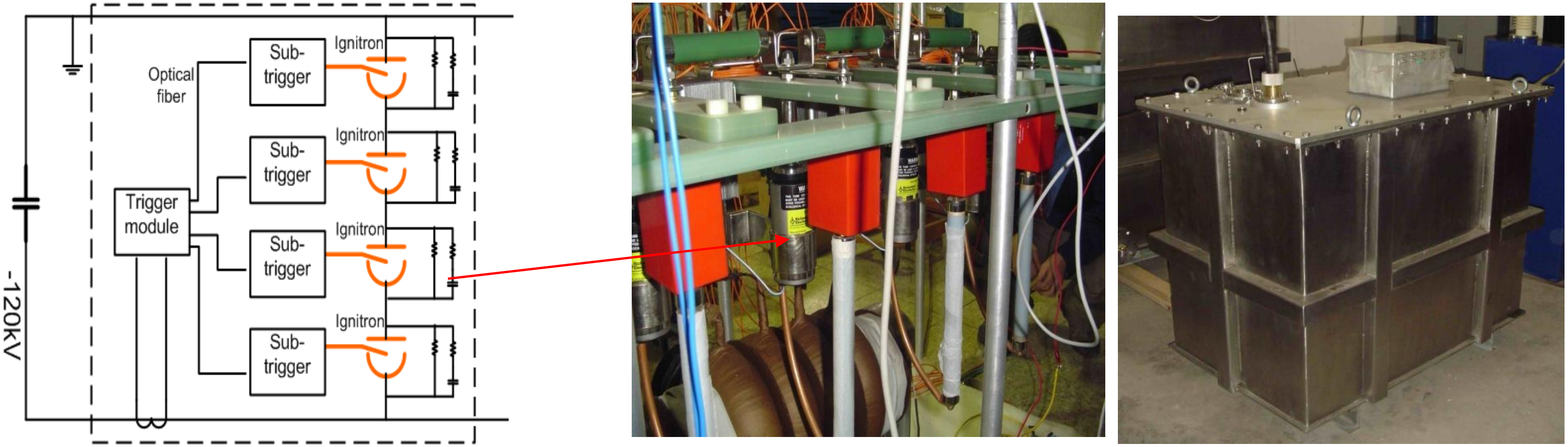


45 μs fall time

R&D progress of linac RF system

Crowbar prototype

CSNS crowbar prototype is a ignitron type. 4 ignitrons (7703EHVNP, 50kV /100kA) are in series configuration. Each ignitron is driven by one sub-trigger module. The control signals of the four sub-modules are fed from a 4-output trigger module via glass optical fiber.

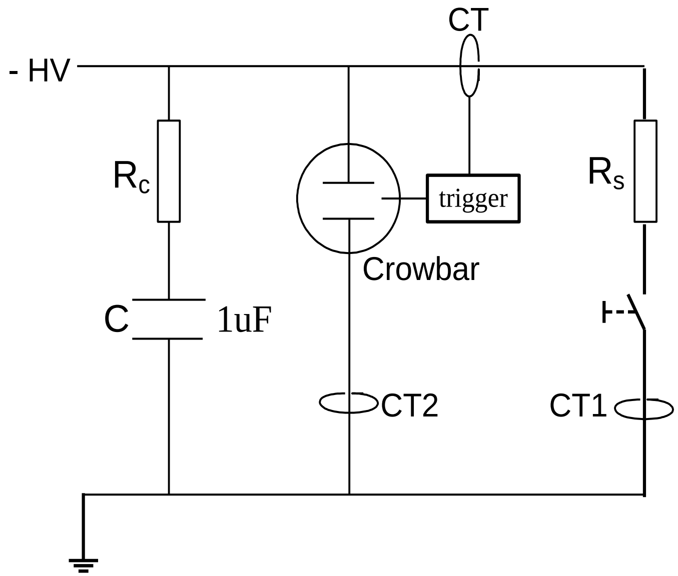


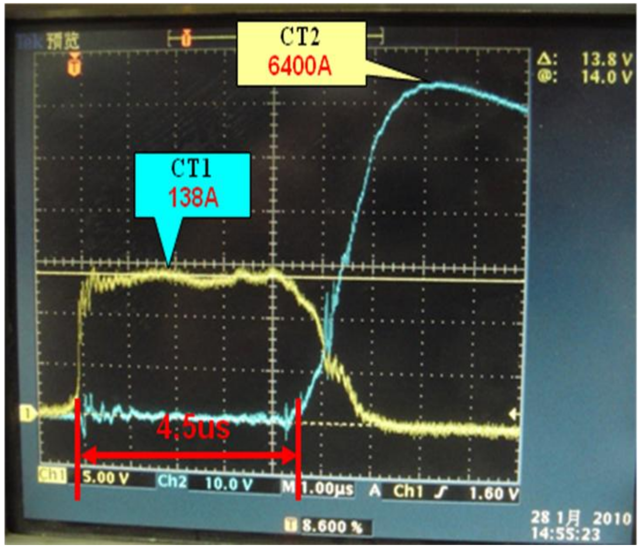
Block diagram (left), internal (middle) and external structure (right) of CSNS crowbar

R&D progress of linac RF system

Crowbar prototype

A high voltage test stand is set up to carry out crowbar full voltage (-120kV) over current trigger-to-discharging test.





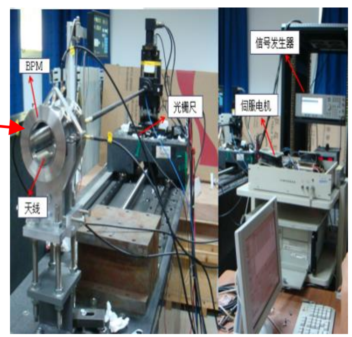
Crowbar test circuit (left), delay time from triggering to discharging is 4.5μs (right)

R&D of beam diagnostic components for linac

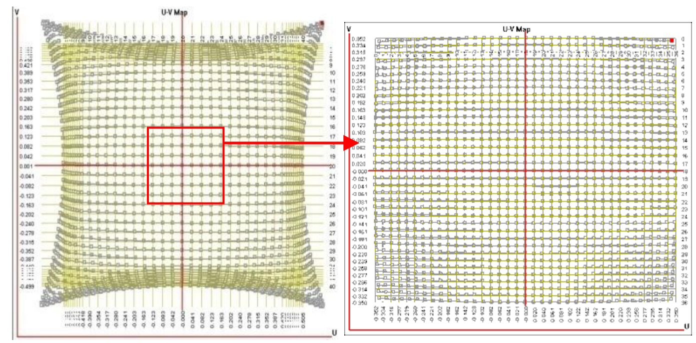
Prototypes of the stripe line type Beam Position Monotor (BPM) , the Wire Scan (WS) , the Beam Loss Monitor (BLM) and the Fast Beam Loss Monitor are complete, tests of the prototype are in progress. The fabrication of the movable double slits for emittance measurement is also ongoing.

BPM

Prototype of BPM

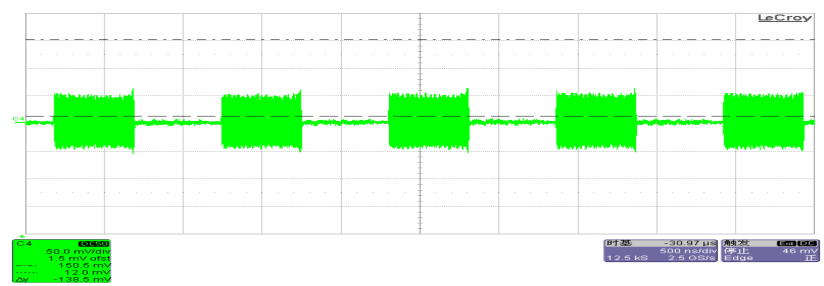


The calibration of BPM on test bench



The calibrated results: The response of probe shows a good symmetry and linearity)

LR-BPM signal processing electronics of the Bergoz

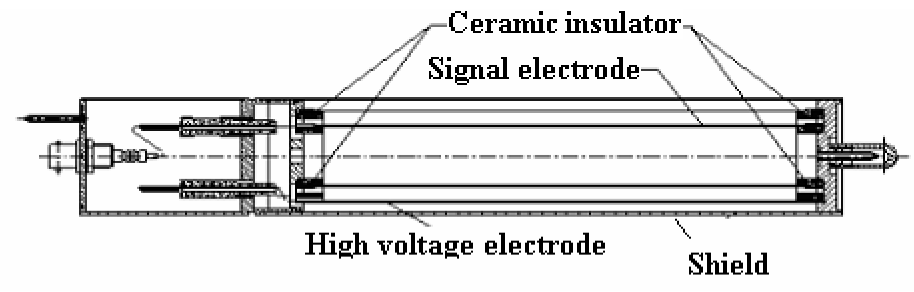


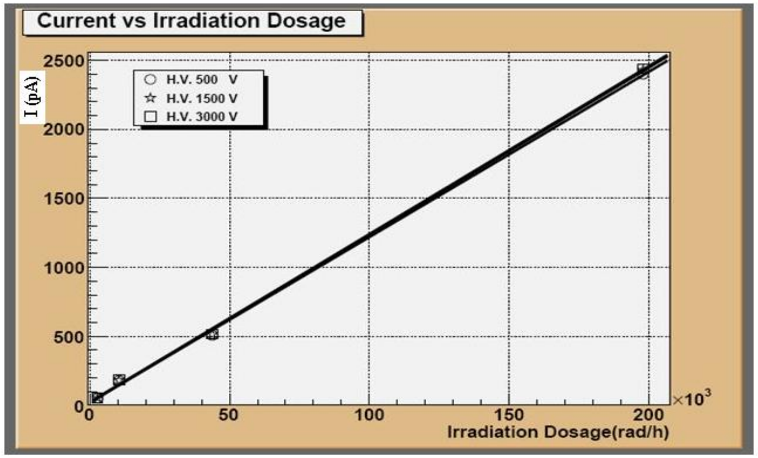
Beam signal of BPM in chopping experiment

R&D of beam diagnostic components for linac

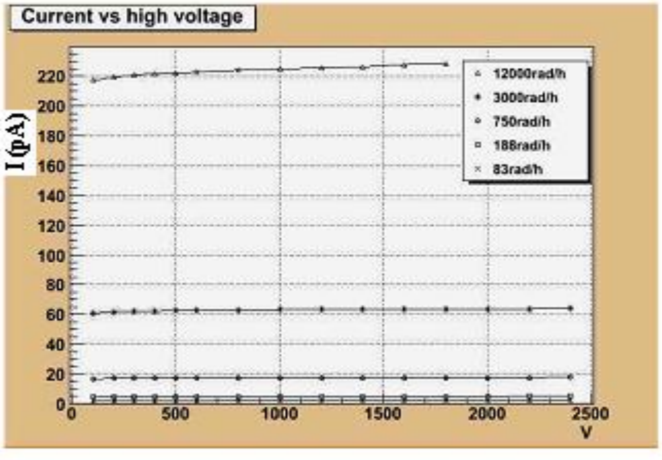
BLM

The response of BLM to the irradiation dosage is basically linear (about 15pA/rad/h), and the response is not dependent on the high voltage in the range from 100V to 2400V.





Current versus irradiation dosage

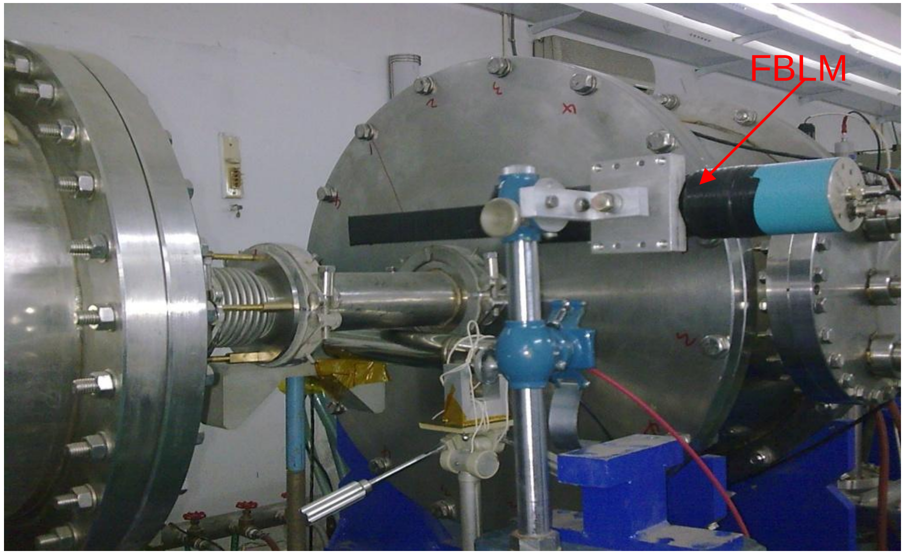


Current versus high voltage

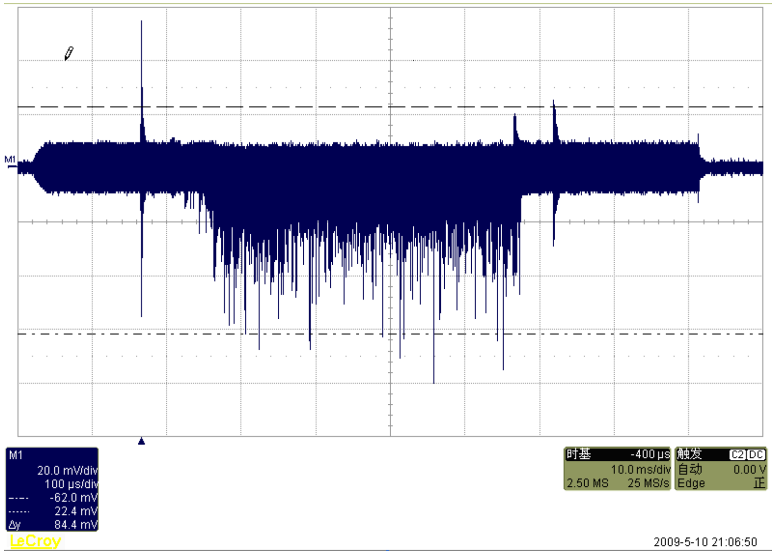
R&D of beam diagnostic components for linac

FBLM

Mainly consists of a plastic scintillator (NE102A) and a Photomultiplier Tube PMT (XP2020).



FBLM installed on ADS RFQ beam line



Signal of FBLM in the ADS RFQ experiment

Summary

CSNS R&D projects of linac have extended to many aspects including the test stand of the H^- ion source, the pre-chopper in LEBT, RFQ, prototype of DTL, RF system and beam diagnostics etc. The good results, the key technologies and the experience got from the R&D projects are highly beneficial to the construction of CSNS linac.

Thank you!