Commissioning of C-ADS Linac Beam Instrumentation

Yanfeng Sui
On behalf of CADS injector I BI group
IHEP, CAS, China

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

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- Commissioning of injector I Beam instrumentation
  - Beam position monitor
  - Beam current monitor
  - Beam emittance measurement
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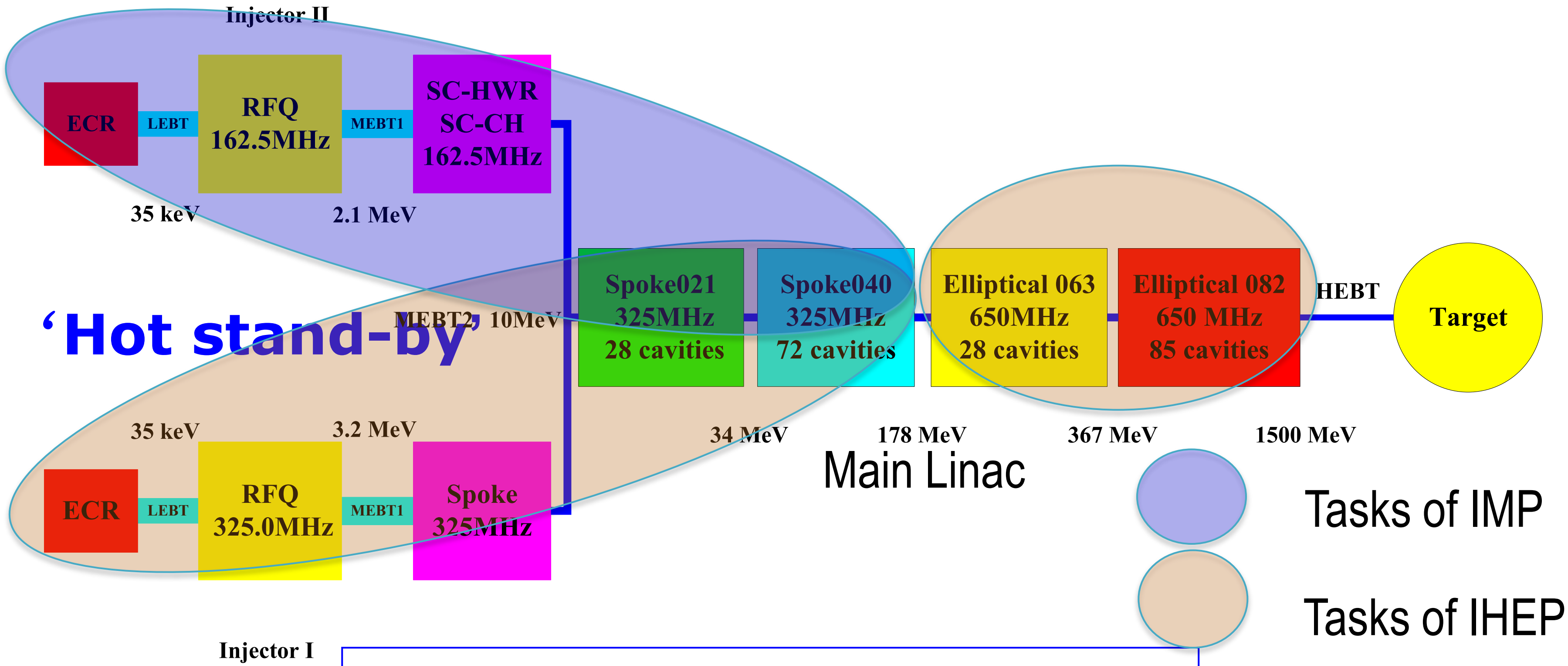
  - Beam loss monitor
- Conclusion


ADS Injector I, IHEP
Beijing
ADS Injector II, IMP
Lanzhou, Gansu Province
俄罗斯
蒙古
哈萨克斯坦
乌兹别克斯坦
土库曼斯坦
塔吉克斯坦
阿富汗
巴基斯坦
伊朗
伊拉克
土耳其
阿塞拜疆
叙利亚
埃及
沙特阿拉伯
苏丹
厄立特里亚
南苏丹
也门
埃塞俄比亚
肯尼亚
索马里
印度
尼泊尔
不丹
缅甸
老挝
泰国
越南
柬埔寨
马来西亚
Singapore
印度尼西亚
菲律宾
朝鲜
韩国
日本
黄海
日本海
鄂霍次克海
斯里兰卡
阿拉伯海
孟加拉湾
南海
巴布亚新几内亚
芬兰
爱沙尼亚
立陶宛
白俄罗斯
摩尔多瓦
希腊
黑海
Google

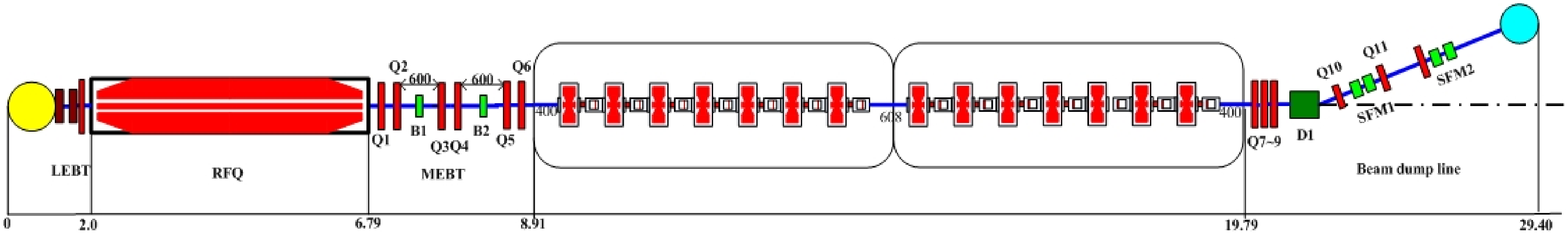
Introduction



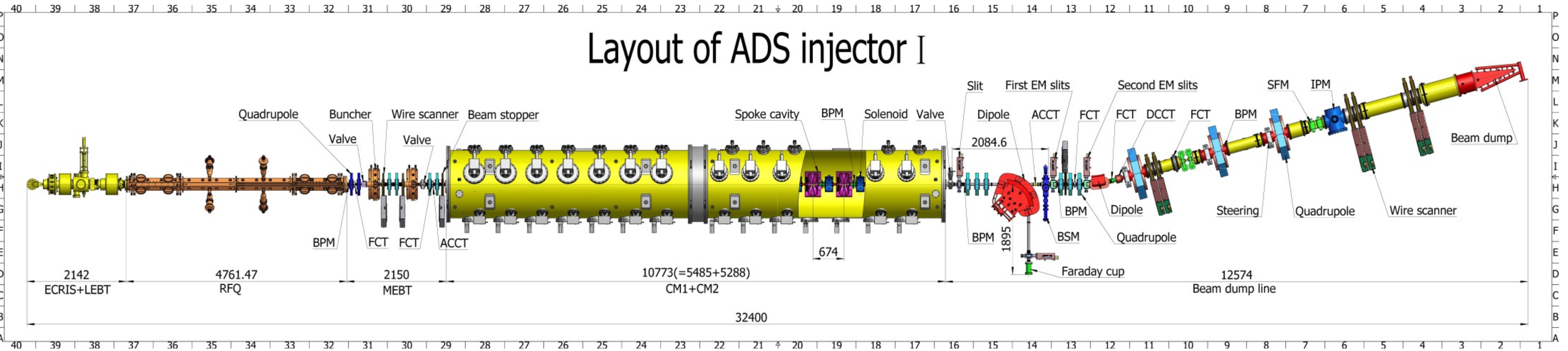
Two identical injectors on line, either with scheme injector I or with scheme injector II

Introduction

- Particle: proton
- RF frequency: 325 MHz
- Output energy: ~10 MeV
- Peak current: 10 mA
- Repetition rate: CW
- Beam power: 100 kW



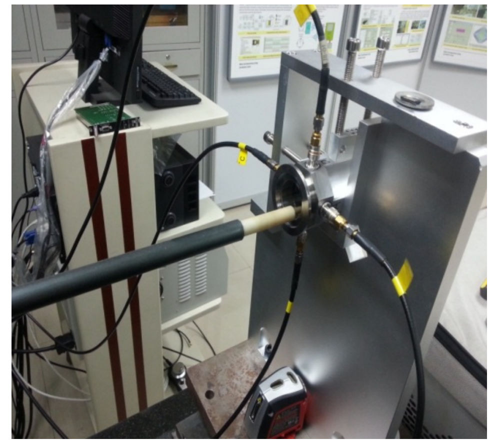
Beam instrumentation of CADS injector I

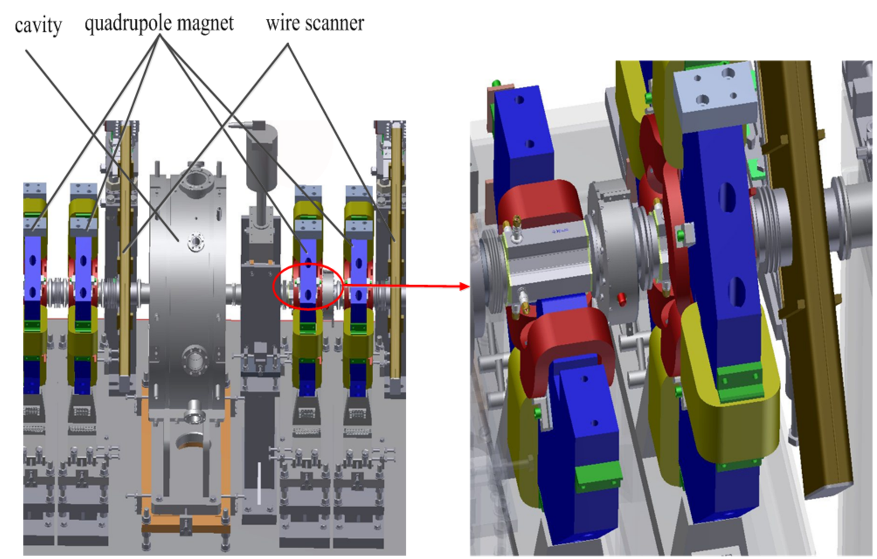


Device	Accuracy	Resolution	Quantity
Beam position monitor	±100um	30um	25
Wire scanner	±0.5mm	50um	4+3
Beam emittance unit	10%	-	2
Beam current monitor	0.1mA	0.01mA	9
Beam loss monitor	1%	-	8
Beam phase monitor	±1deg	0.5deg	3
Ionization beam profile monitor	1mm	200um	1
Electron scanner	1mm	300um	1

Beam position monitor

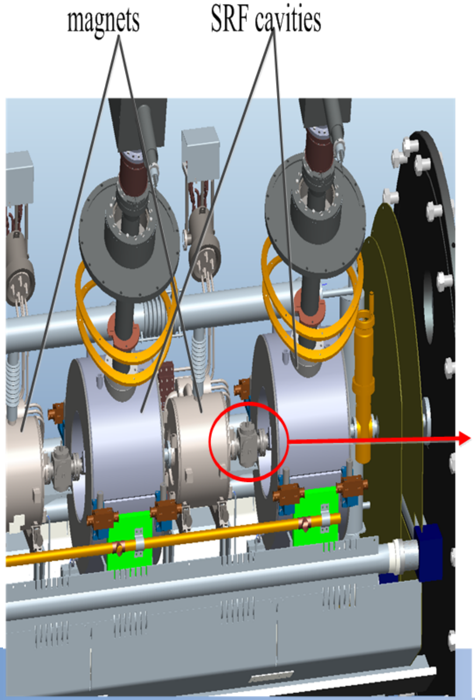
- Total of 25 BPMs have been installed along the Linac , including 14 Cold-BPMs
- The warm BPM-pickups are strip line type
- The BPMs are installed in the Q-magnets due to limited space

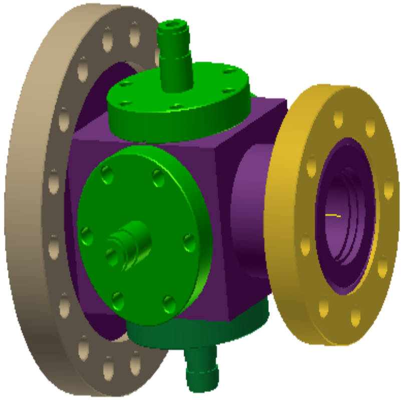




Beam position monitor

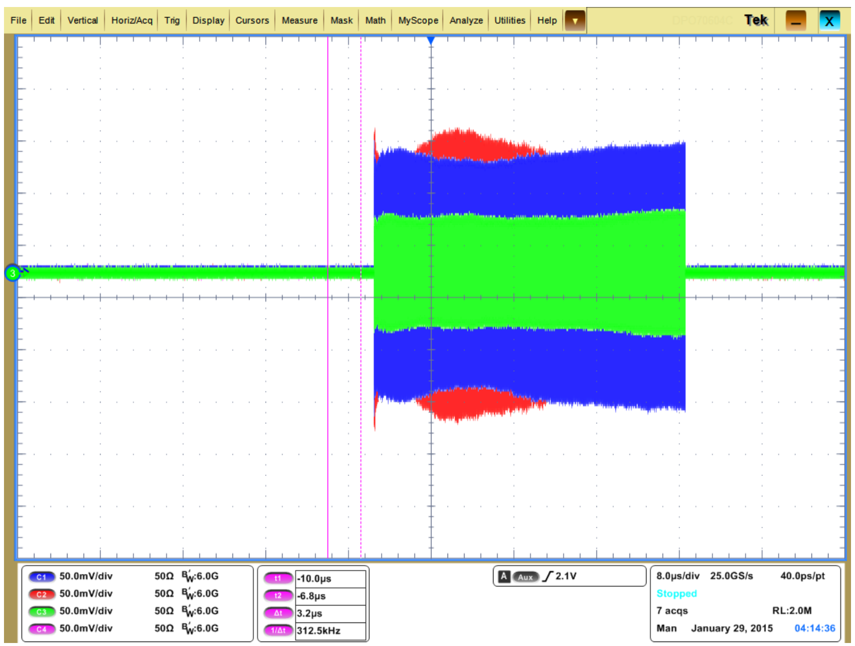
- Cold BPM pick-ups are buttons type due to space limitation
- Located between SCQ magnet and SRF cavity
- Several times cold test with liquid nitrogen (300K-80K) before installed in order to check the feed throughs and bellows

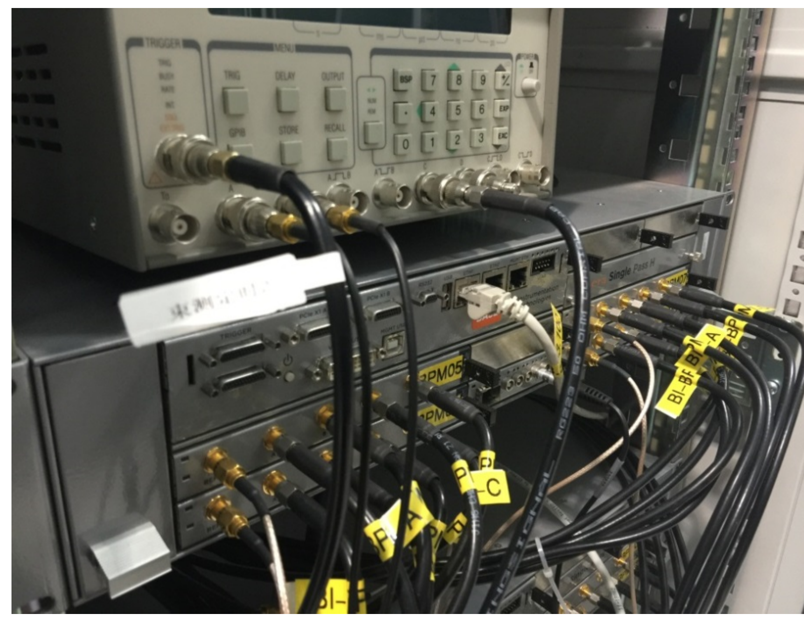




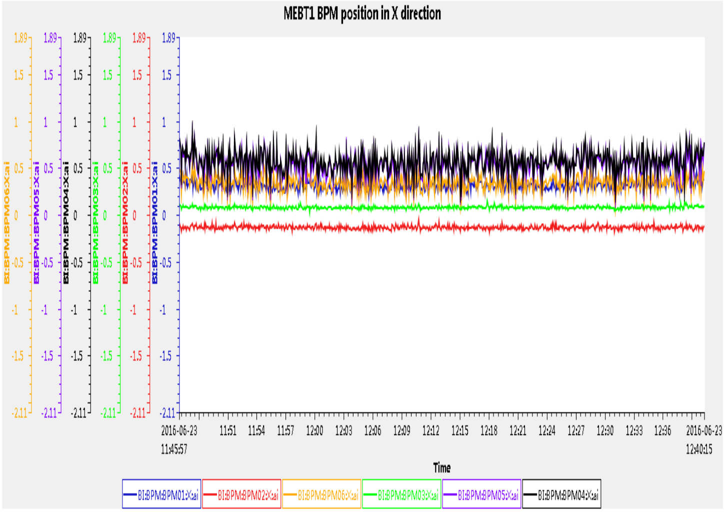
Beam position monitor

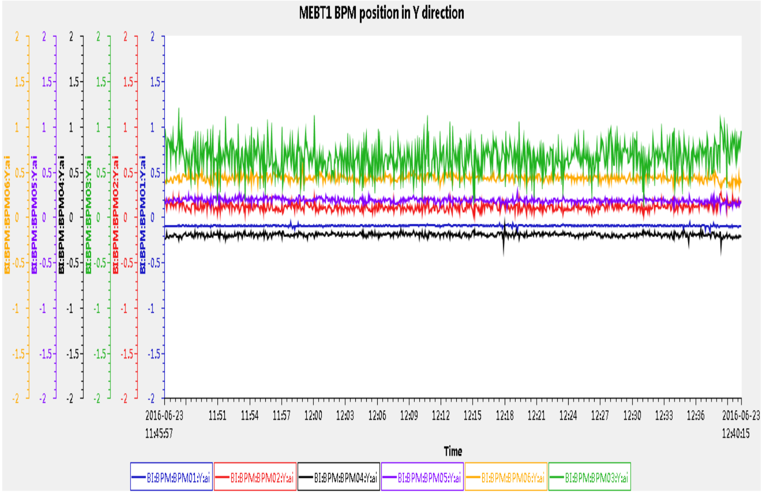
- Electronics
  - Libera single pass –H
  - Machine protection
  - Beam phase monitor





Resolution of BPMs in MEBT1

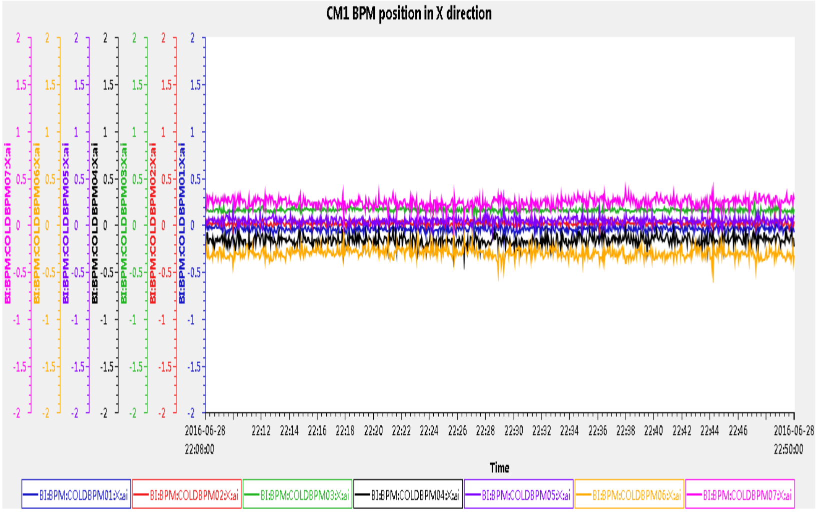


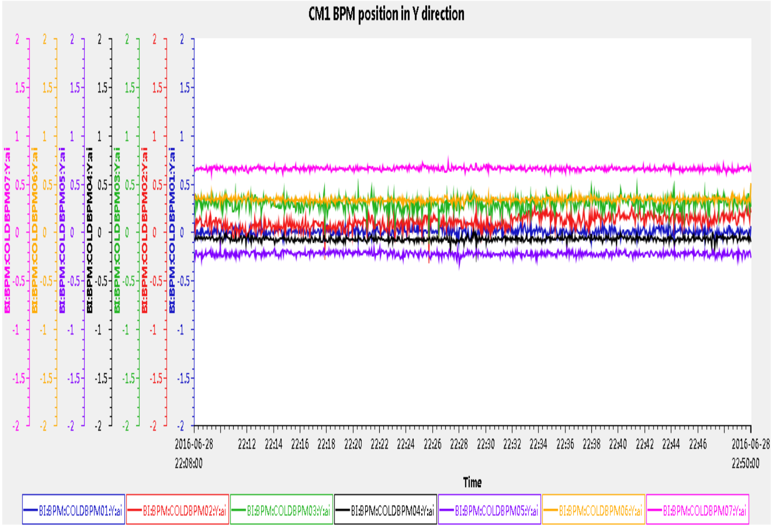


	X RMS(mm)	Y RMS(mm)
MEBT1-BPM01	0.046993	0.00454
MEBT1-BPM02	0.019046	0.038247
MEBT1-BPM03	0.012863	0.142989
MEBT1-BPM04	0.108435	0.019258
MEBT1-BPM05	0.110227	0.025085
MEBT1-BPM06	0.058482	0.033193

- Warm bpm resolution is about 100um

Resolution of cold BPMs

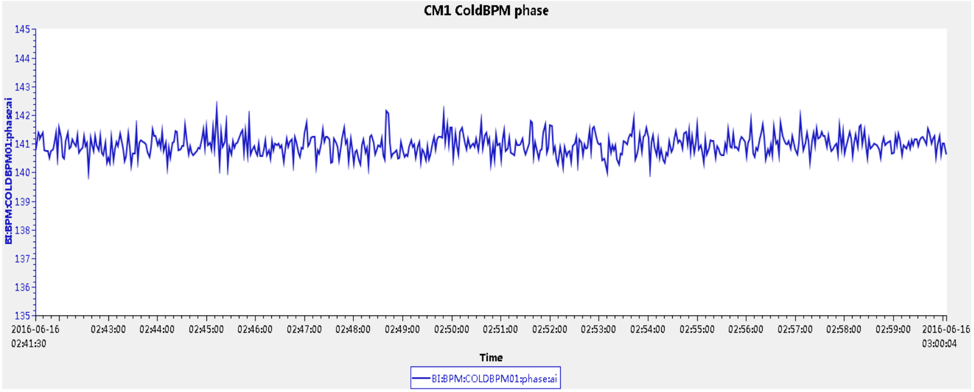




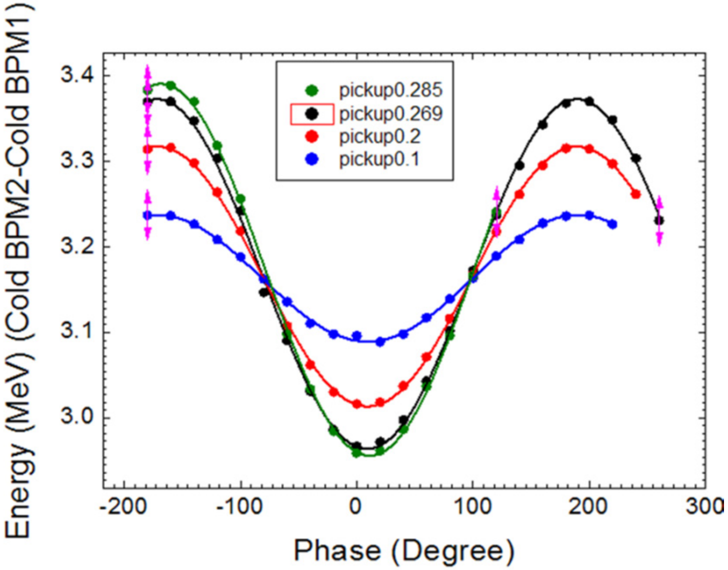
Cold BPM resolution

- Cold BPMs resolution is better than 30um

The phase measurement



Phase RMS 0.4degree



- **Cavity phases are scanned by using BPMs. The cold BPMs play important roles in determining the phase of cavities**

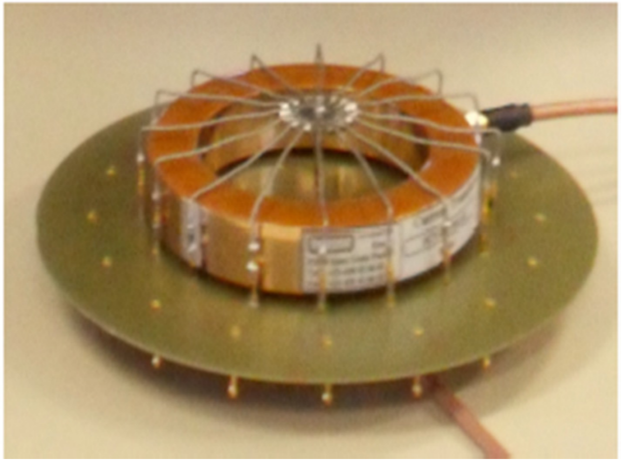
- **For the upstream cavity phase measurement, we detuned the downstream cavity and use the two following BPMs to measure energy.**

Beam current monitor

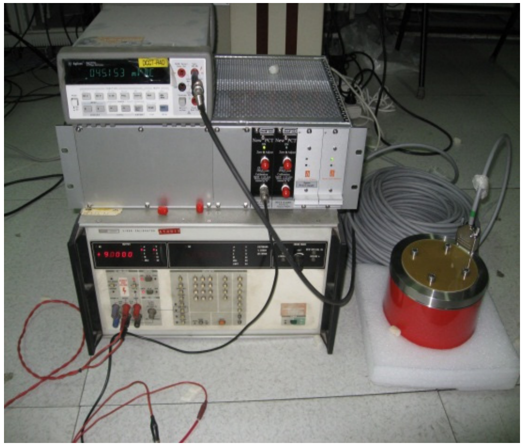
- Beam Current Monitors system is composed of AC Current Transformers (ACCT), Fast Current Transformers (FCT) and DC Current Transformers (NPCT).
- 3 ACCTs are located in LEBT, MEBT1 and MEBT2 separately for beam transmission measurement
- 2 FCTs located in MEBT1 and 3 FCTs located in MEBT2 also used for the measurement of beam energy.
- One NPCT in LEBT for ION source, The other NPCT in MEBT2 is used to measure the DC current of injector I.

Beam current monitor

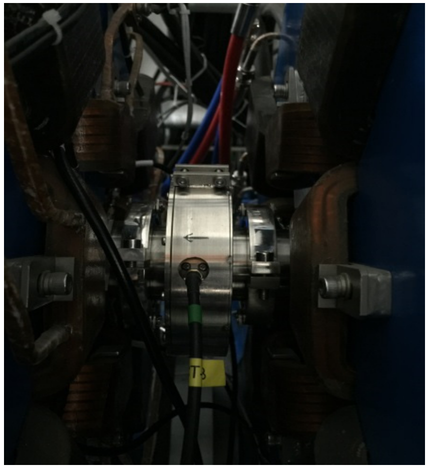
- All CTs are shielded and installed on the ceramic tubes
- All CTs are standard products and calibrated before installation



Test bench of FCT and ACCT



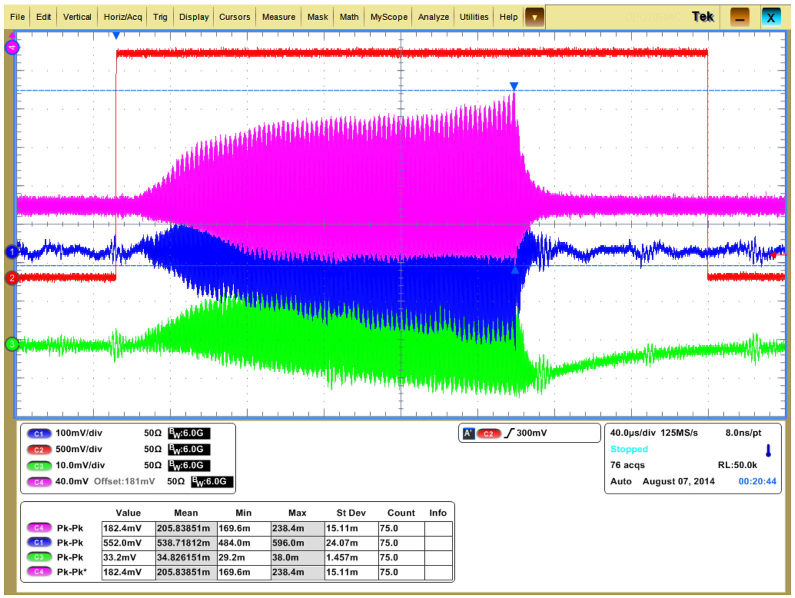
Calibration of DCCT

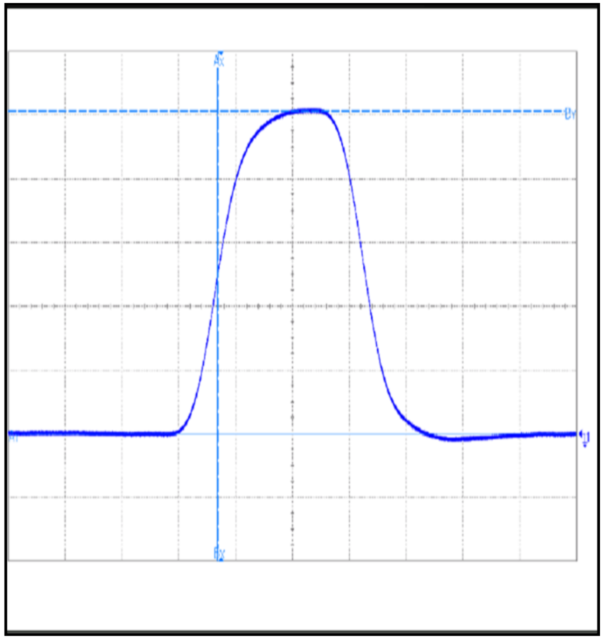


FCT between Q-magnet

Beam current monitor

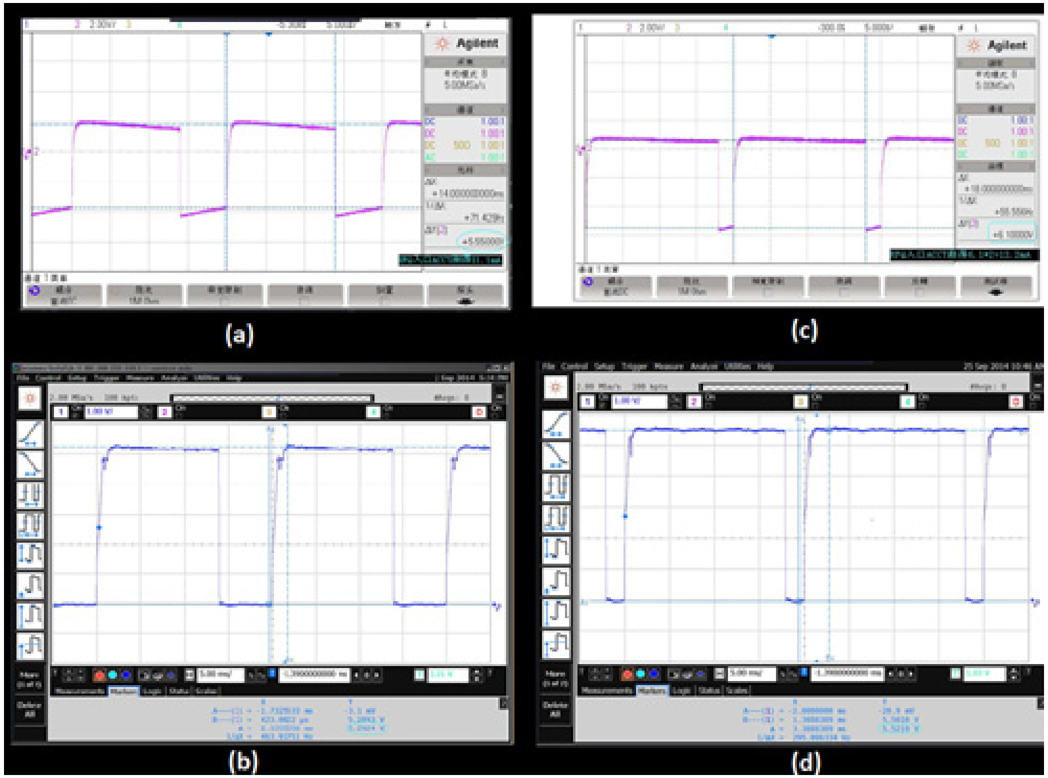
- Beam test





- Readout system
  - NPCT Based on PCI-4070+LABView+EPICS
  - ACCT Based on PCI-6120+LABView+EPICS

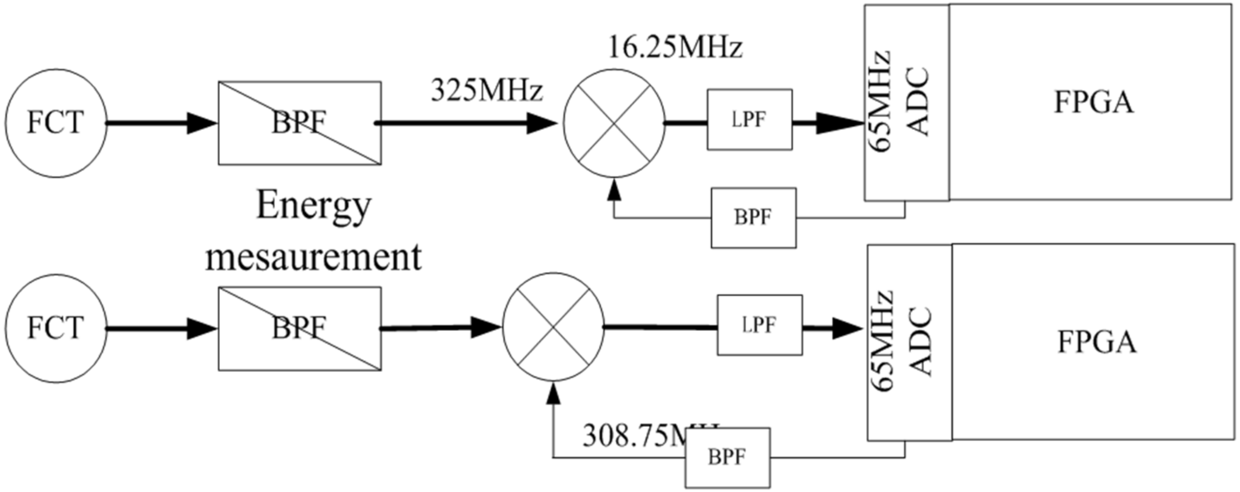
The transmission of RFQ



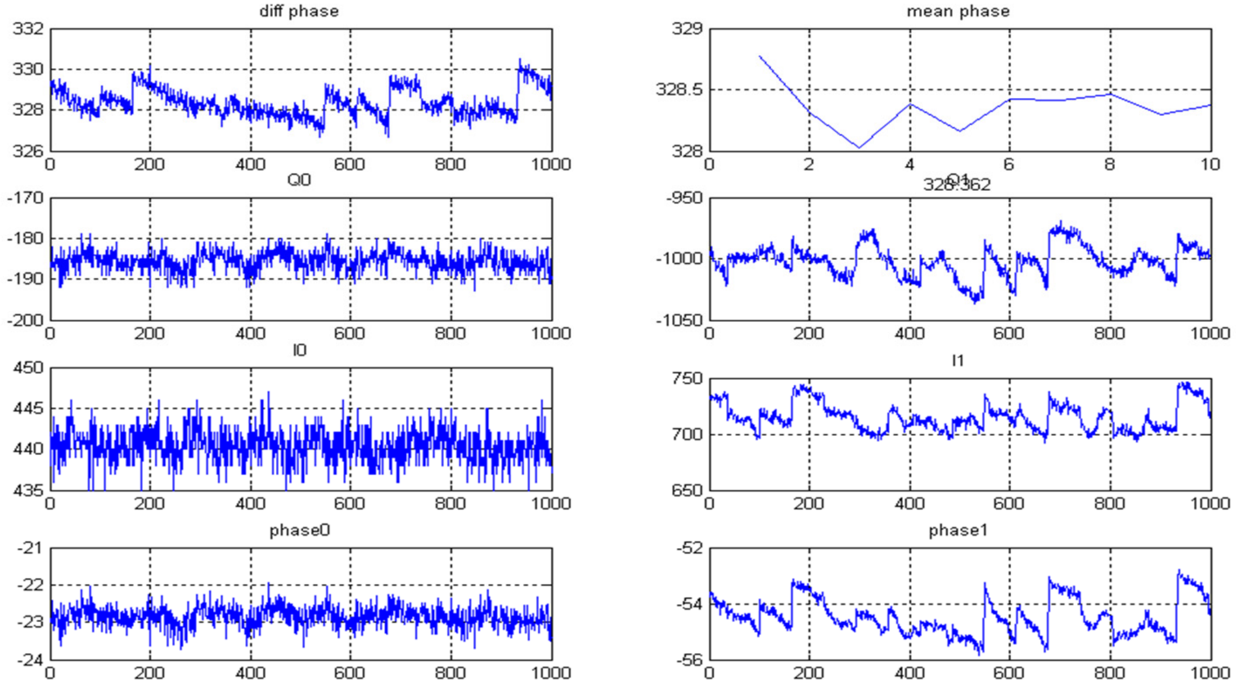
- 70% duty factor, 95% beam transmission efficiency
- 90% duty factor,11 mA,31 kW proton beam with 90% beam transmission efficiency

Beam energy measurement

- Beam energy is measured with the FCTs based on the TOF (Time-OF-Flight) method
  - Base on scope
  - Base on self-developed electronics



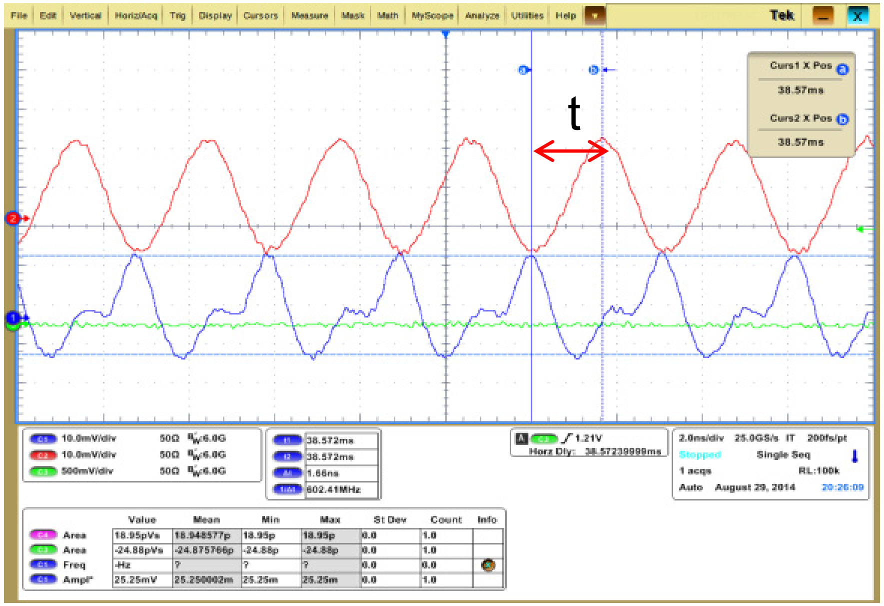
Beam energy measurement



Result of beam energy with self-developed electronics. Phase RMS 1 Deg.

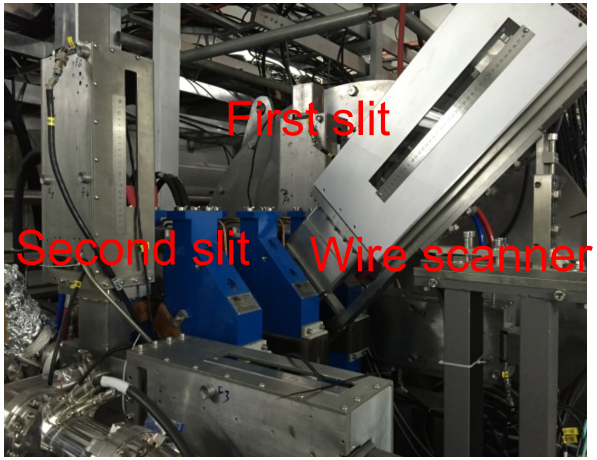
The energy of RFQ

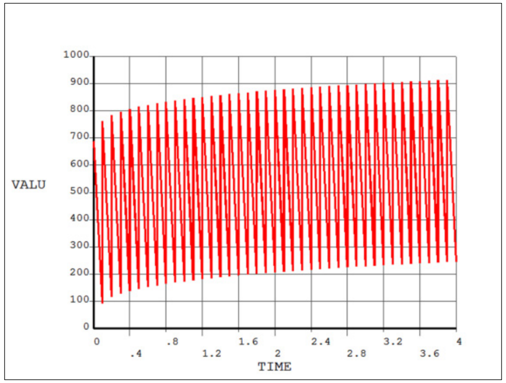
- Two FCTs for beam energy measurement with scope
  - Carefully alignment
  - Using scope measuring the phase between two FCTs signals
  - T=nT0+t
  - Beam energy 3.199MeV

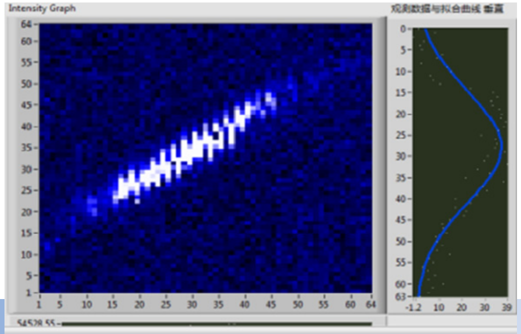


Beam emittance measurement

- Double-slit system is chosen for its adaption to different beam conditions and the robustness
- The first slit is 0.2mm, the tungsten plated on stainless steel with cool water
- The heat load is simulated with the duty factor 0.1%
- The distance between two slits is about 300mm
- The second slit is 0.1mm, and a faraday cup at the downstream



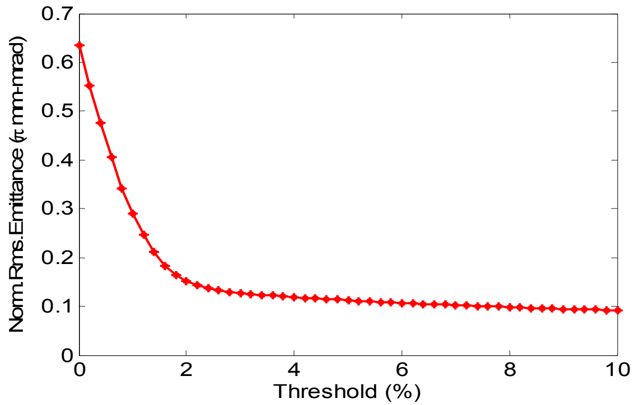


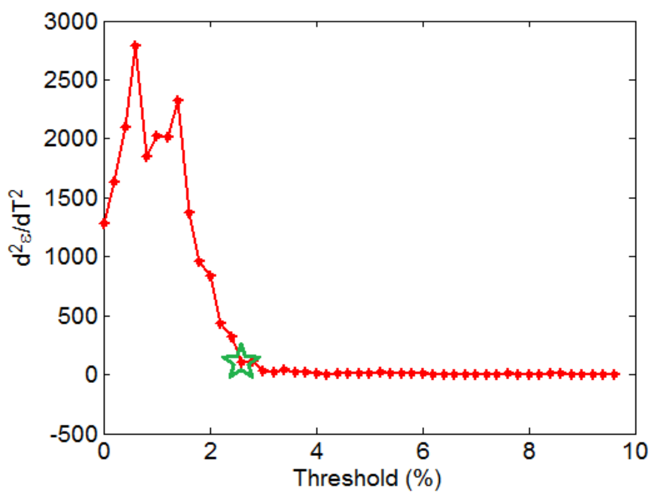


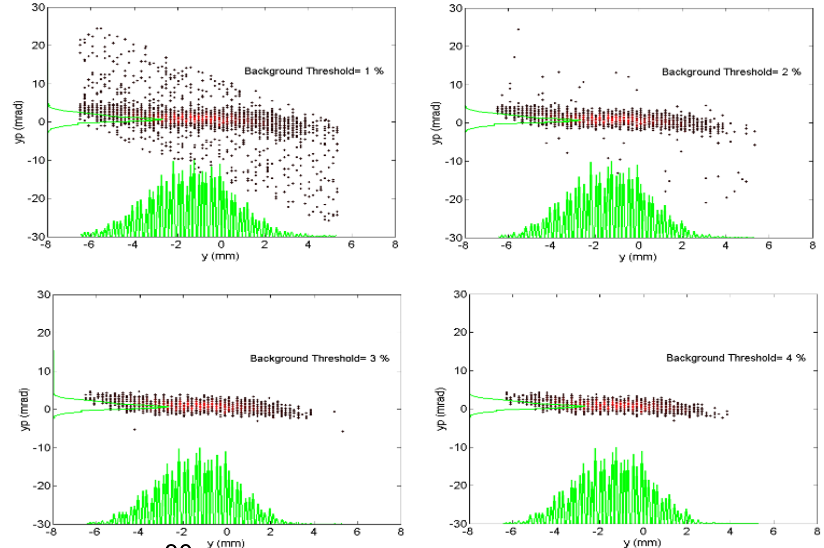
Example of beam emittance

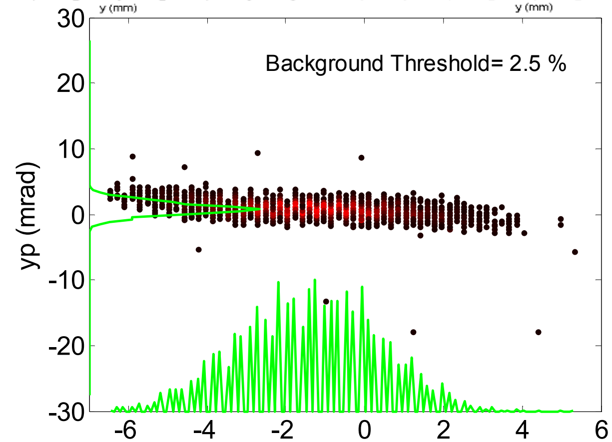
The beam emittance of RFQ

- Double slits emittance measurement





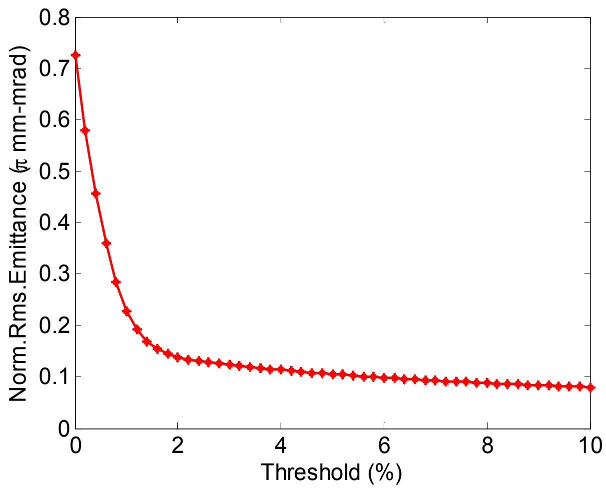


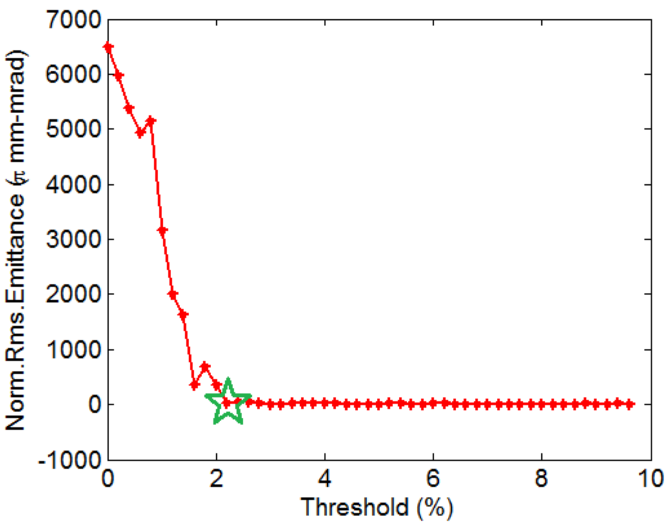


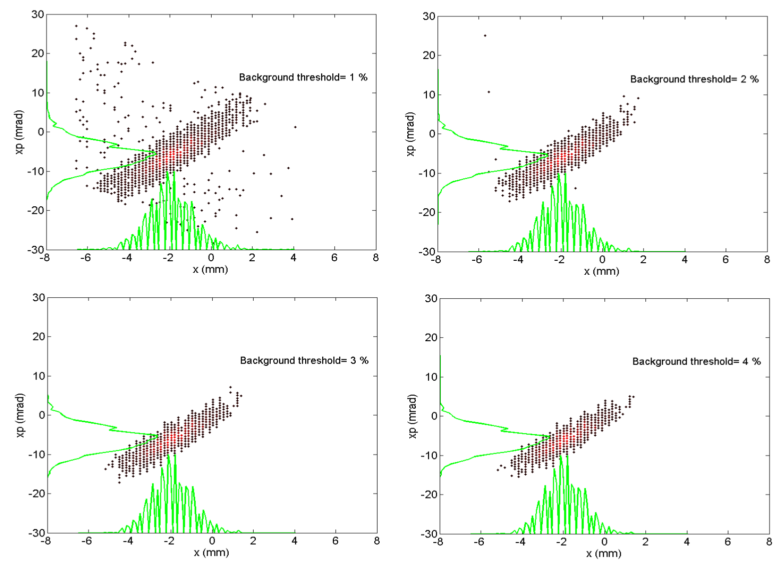
εn,rms=0.1347 πmm.mrad

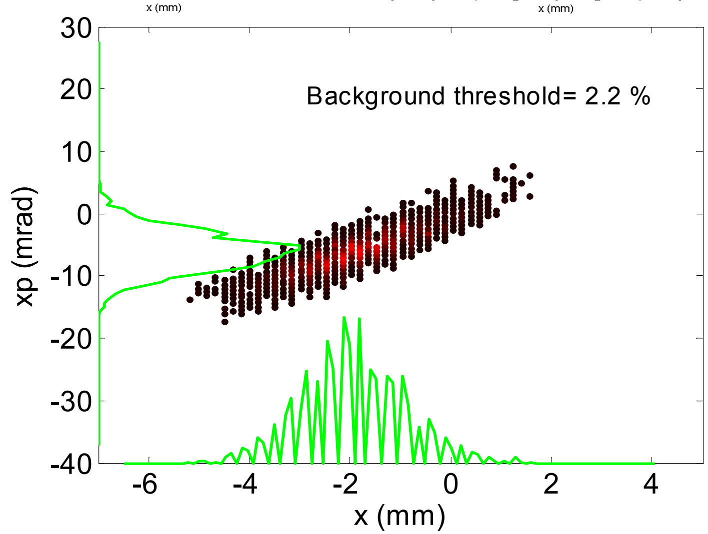
α=0.4578, β=1.91 mm/mrad

The beam emittance of RFQ





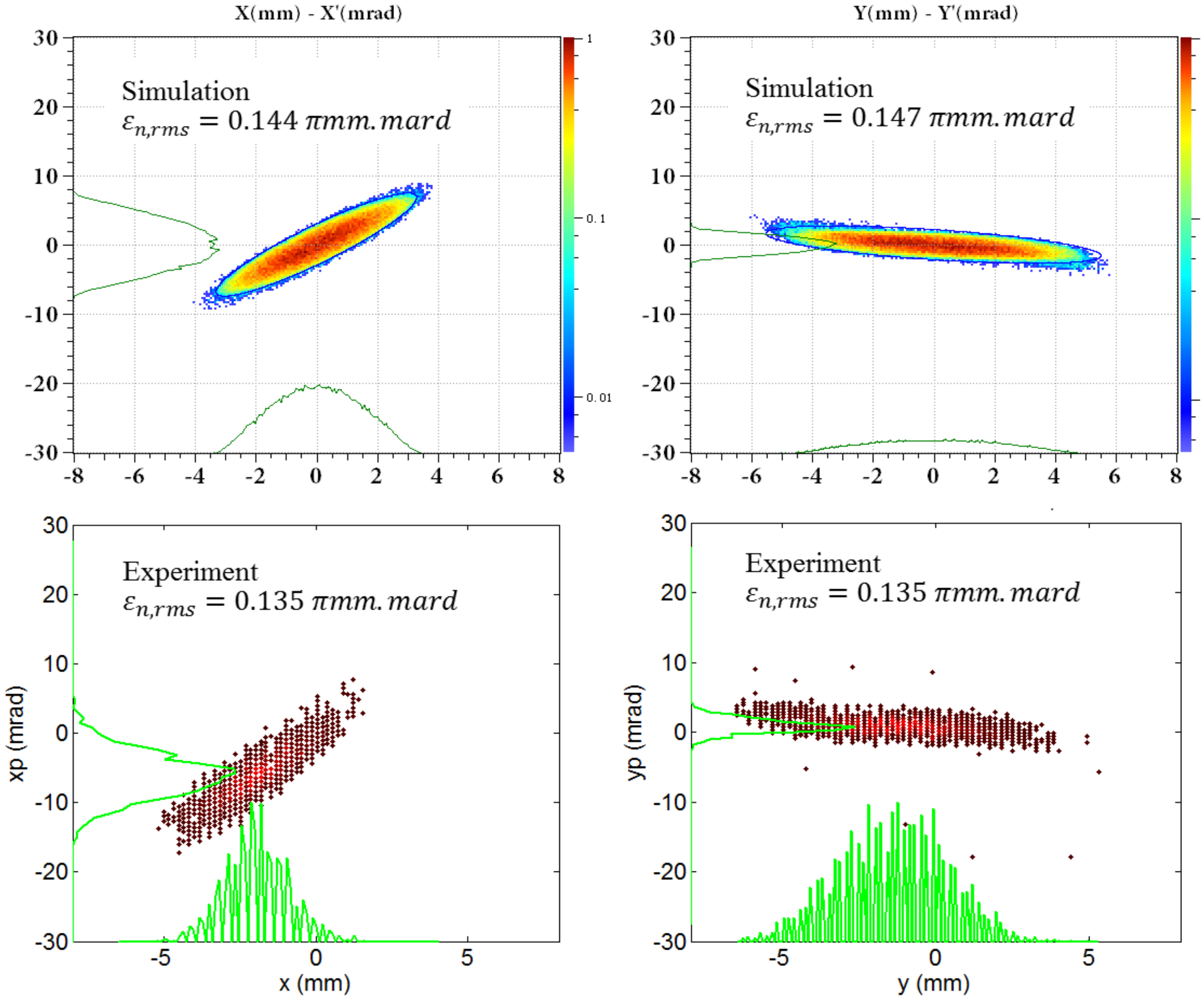




$$\varepsilon_{n,rms} = 0.1345\ \pi mm.mrad$$

$$\alpha = -1.82, \beta = 0.66\ mm/mrad$$

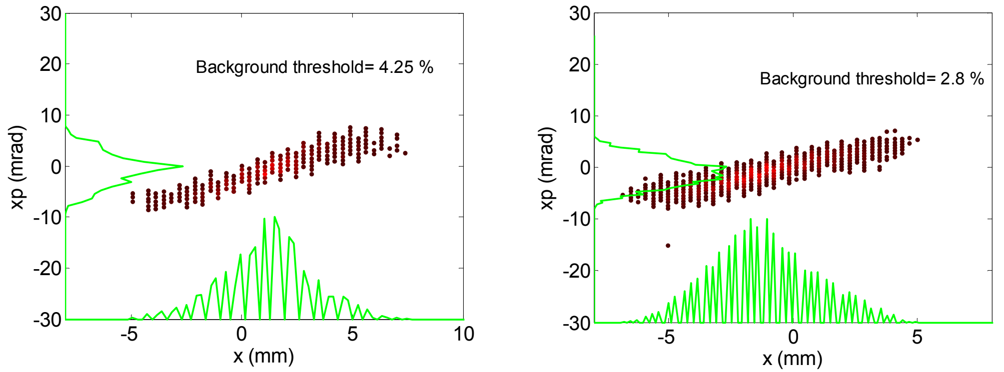
The beam emittance of RFQ



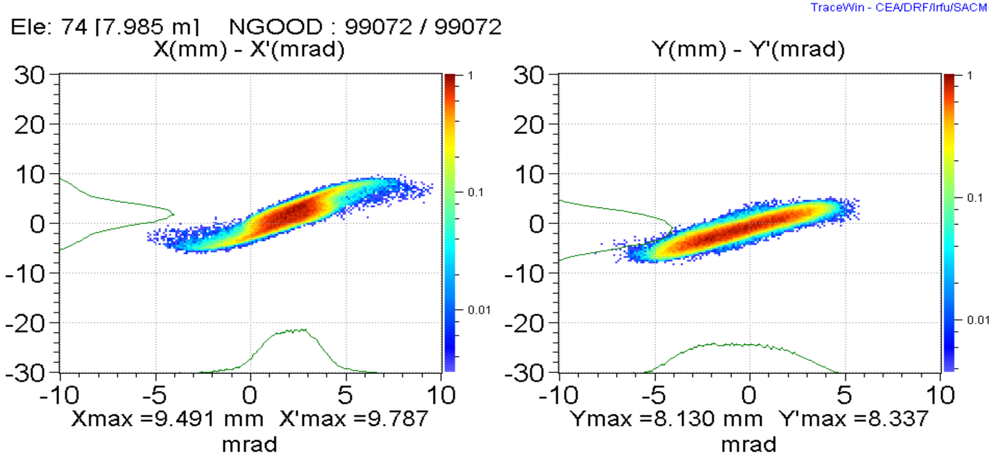
CM1 beam emittance

Transverse emittance measurement results V.S simulation at the exit of CM1 with nominal design

Measured



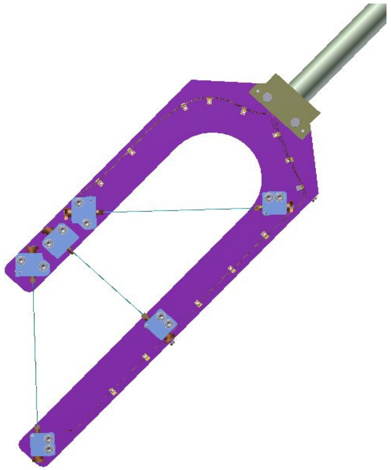
Simulated with errors

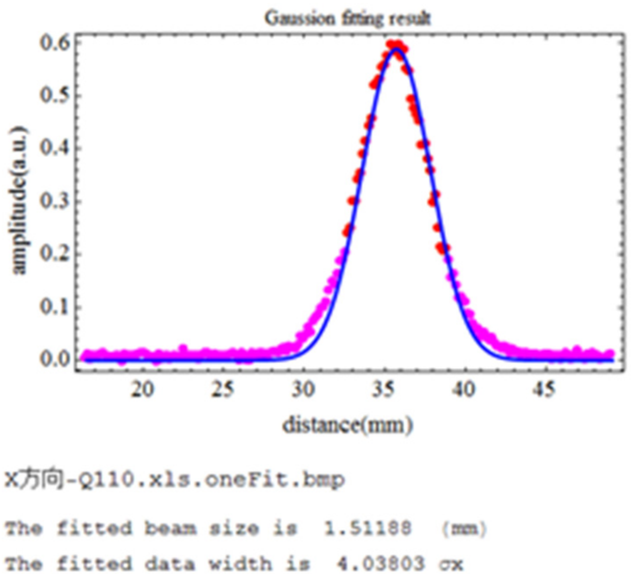


Parameters		$\alpha x/\alpha y$	$\beta x/\beta y$ (mm/mrad)	$E_{n,rms,x/y}$ (π mm.mrad)
CM1 exit	Simulation results (with errors)	-1.68/-2.12	1.28/2.07	0.28/0.28
	Measurement (Double slits)	-2.12/-1.97	1.56/1.81	0.29/0.27

Beam profile monitor

- The wire scanner with three tungsten wires (H,V,U) mounted on the fork is used
- Beam pulse frequency is reduced to 10Hz and the beam pulse length reduced to 100us or less to ensure the wire safe.
- The motion control and DAQ is based on PXI
- The wire scanners are also used to obtain beam emittance base on Quad-scan





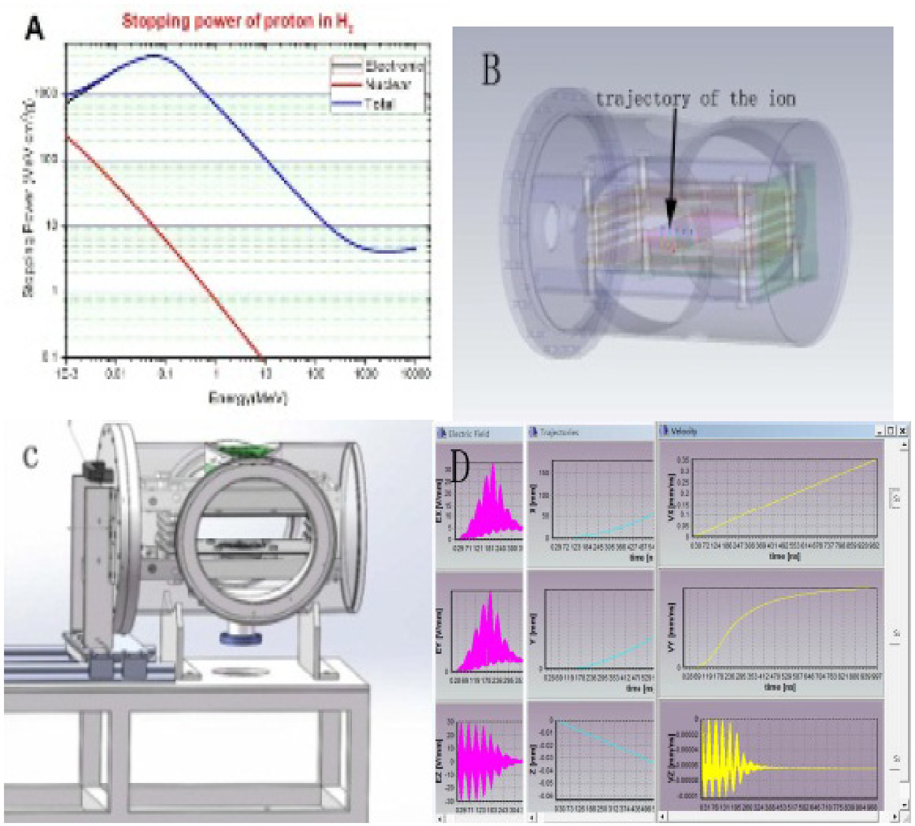
Example of Transverse Profile

Beam profile monitor

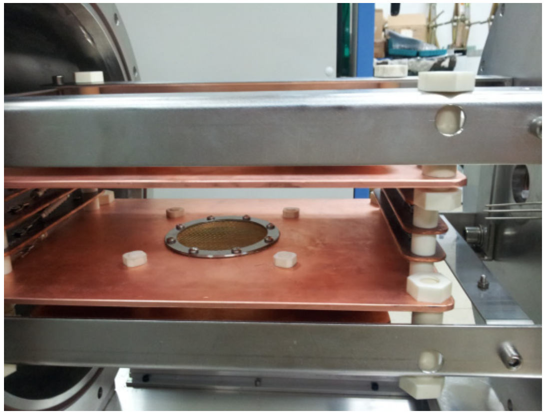
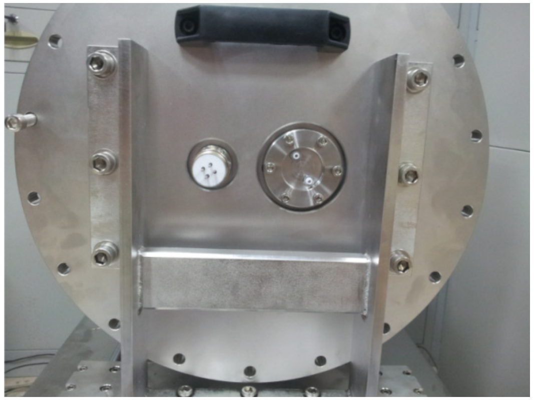
- Two non-invasive beam profile measurement methods were developed for the CADS Injector I Proton Linac. IPM and electron scanner.
- IPM detect the ionized products from a collision of the beam particle with residual gas atoms or molecules present in the vacuum pipe

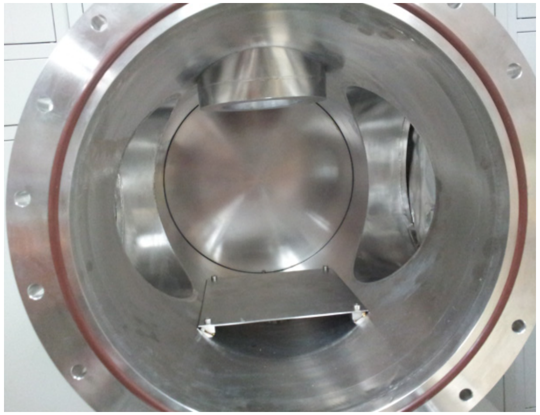
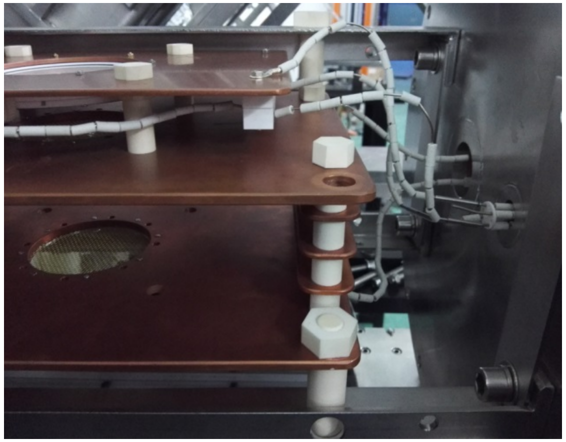
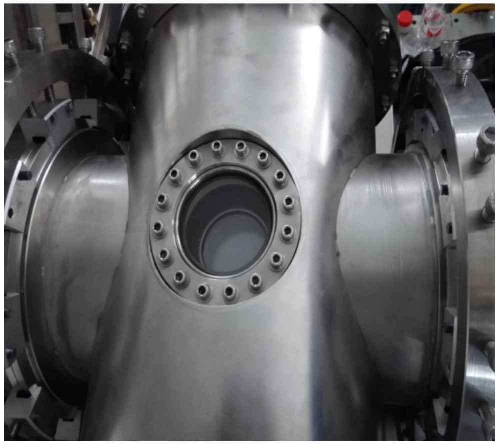
Non-invasive beam profile (IPM)

Parameter	Value
electric field intensity(V/m)	1e5
Distance of two big plate (cm)	8
Size of MCP (mm)	Φ 75
Size of EGA (mm)	Φ 70
Detectors	Screen
Work mode	Ions
magnetic field	0



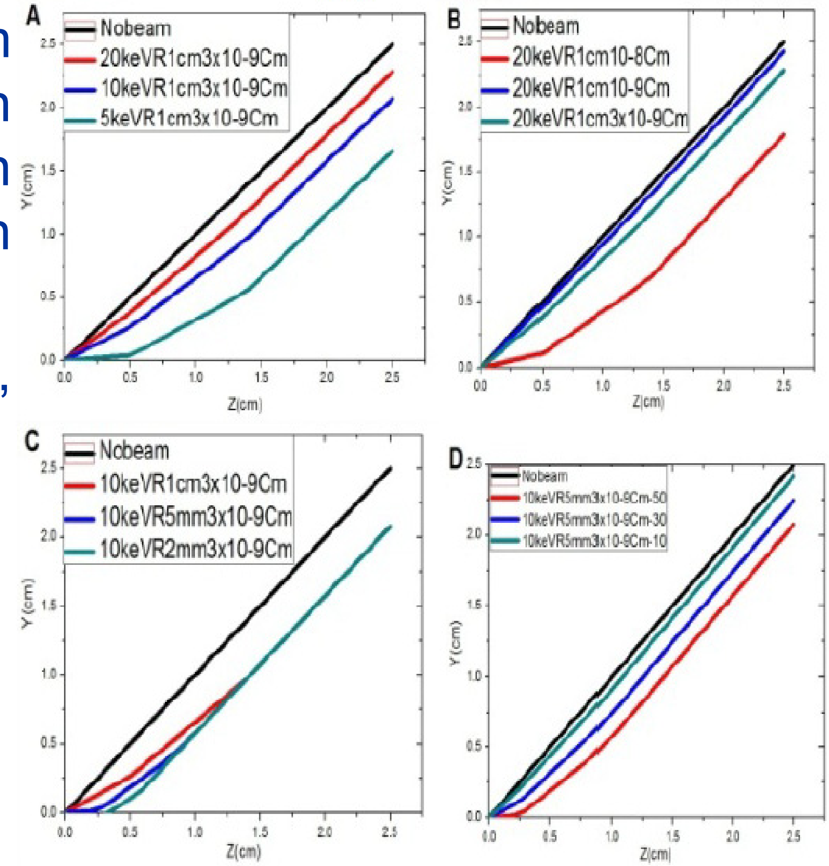
Non-invasive beam profile (IPM)

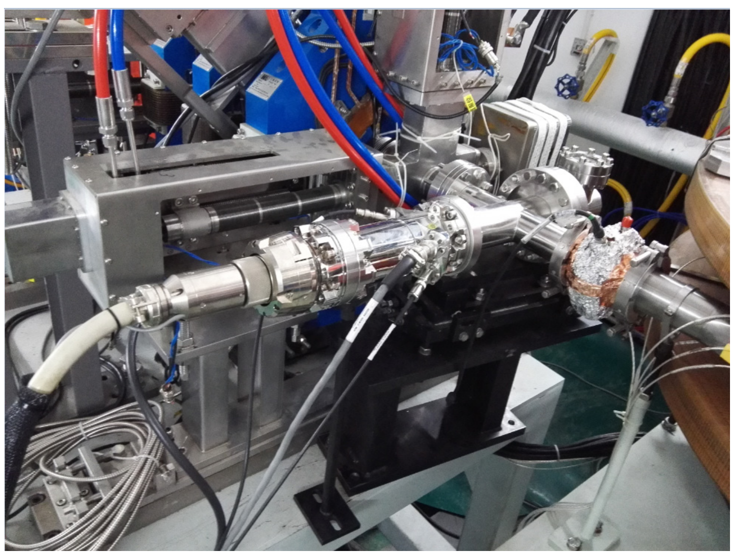



Non-invasive beam profile (electron scan)

- Using a low energy electron beam instead of a metal wire to sweep through the beam. The deflection of electron beam by the collective field of the high intensity beam is measured
- Gun- A Kimball Physics electron gun, model EMG-4212, 20kV, 10uA

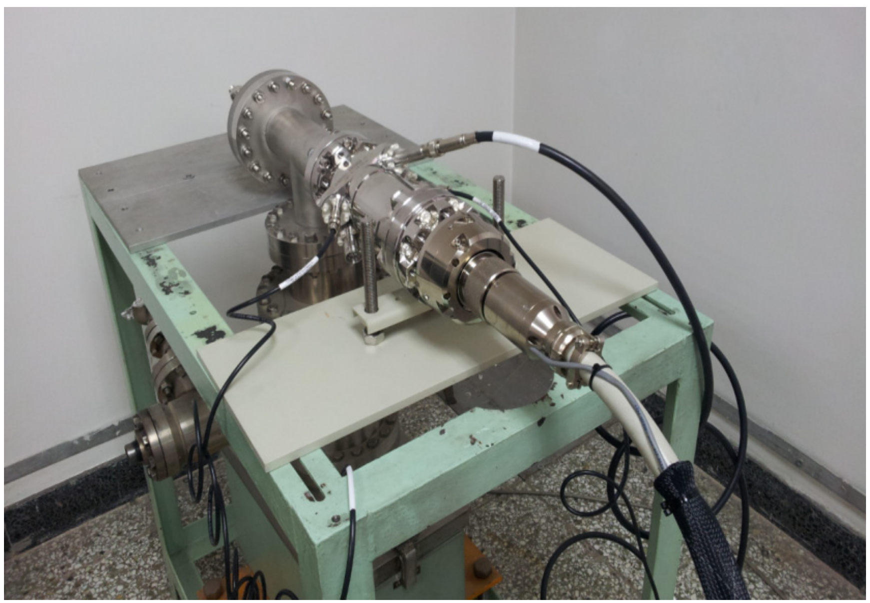


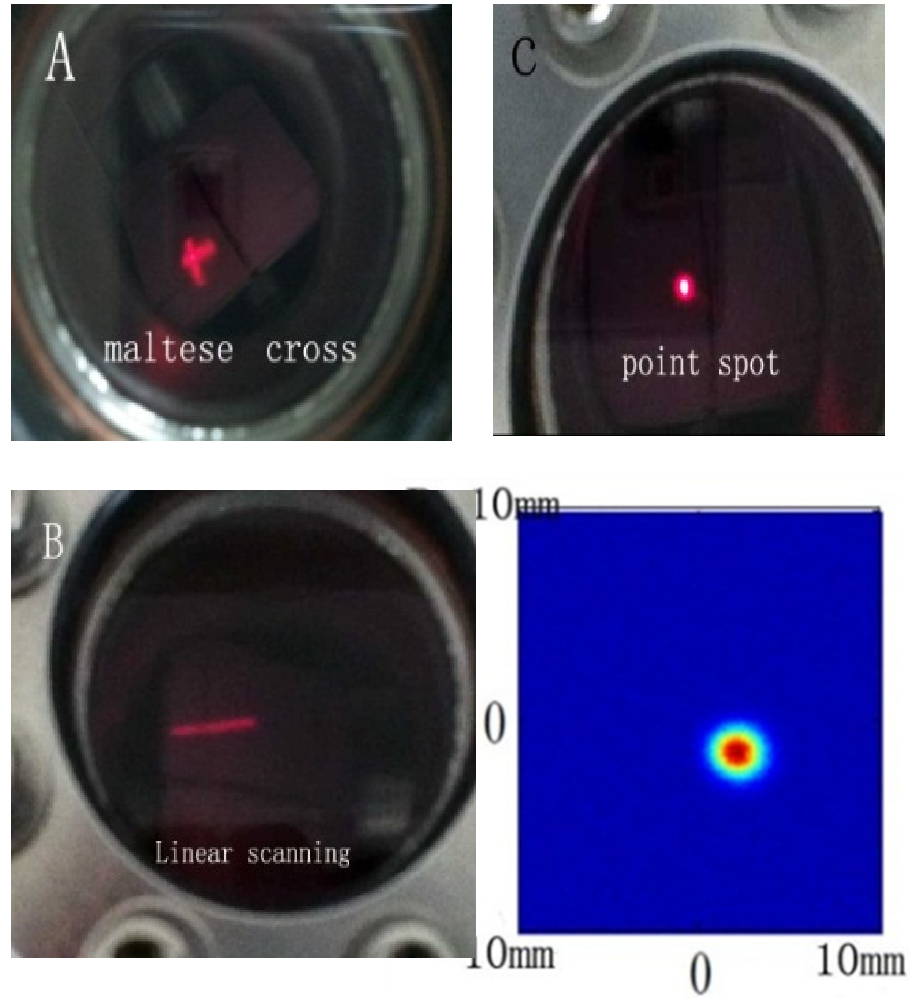


calculated deflection as a function of the probe electron energy, linear density of proton , distance between the detector and the centre of the proton beam

Non-invasive beam profile (electron scan)

- Electron gun was test in the stand
- Different beam spot on the screen





First commissioning of electron scanner

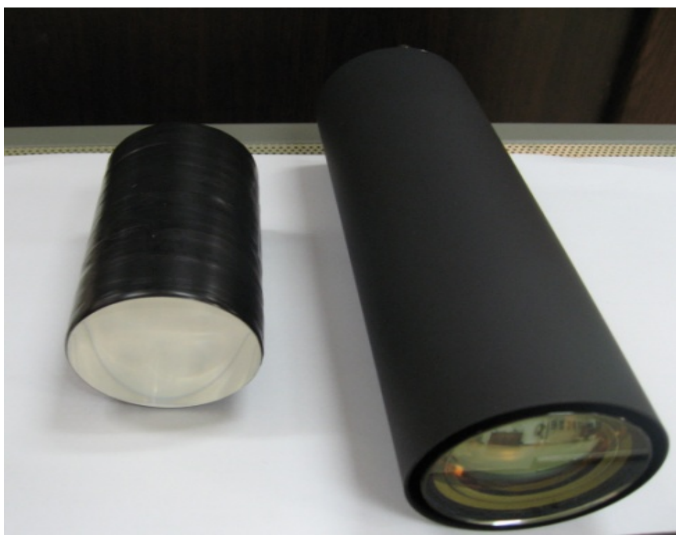
- No clear deflection observed on the screen
  - The low energy beam is easily affected by nearby magnetic field and geomagnetic field
  - Experiment is done with narrow pulse
- Promotion
  - Replace camera with an gated one
  - Long pulse beam

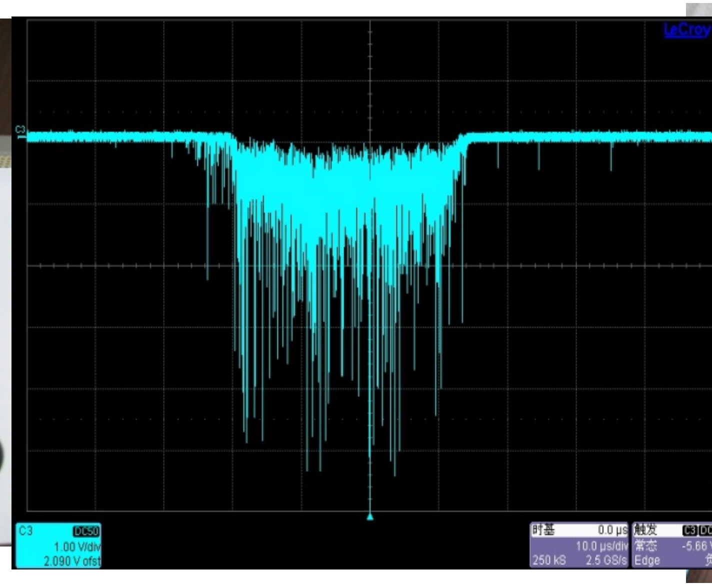
Beam loss monitor

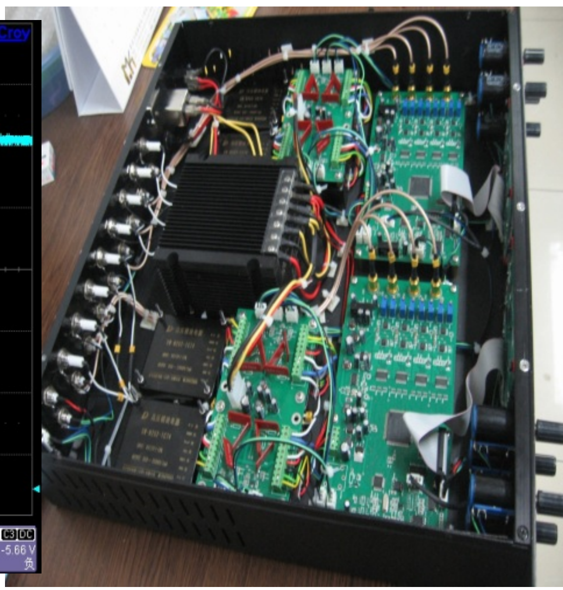
- Ionization chambers will be the main beam loss detector. But at low energies(<10MeV), ionization chambers are not effective to detect beam loss due to the shielding.
- The differential current measurement between two beam position monitor will be the primary input to the fast machine interlock system.

Beam loss monitor

- For the high energy, plastic scintillator + PMT as the fast beam loss monitor will be used for machine protection







Conclusion

- The beam diagnostics system works very well and the characteristic of beam is measured.
- The RFQ and CM1 & CM2 tuning are finished. The cold BPMs act important roles in super conduct section tuning.
- The measurement results are checked with two or more instruments for important beam parameters.
- To establish more stable and safety operation, more improvement should be done to the interlock system.
- To measure the longitudinal bunch profile in high power beam and tune the longitudinal matching, some longitudinal diagnostic should be developed such as non-intercepting bunch shape monitor based on the IPM principle and so on.

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中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences