SiC for Proton Beam Monitor

Ye He[1,2], Zijun Xu[2], Suyu Xiao[3], Xin Shi[2], Ming Qi[1], Xingchen Li[4]

[1]Nanjing University

[2]Institude of High Energy Physics, CAS

[3]Shandong Institute of Advanced Technology, Jinan, China

[4]Jilin University

The 41st CERN RD50 workshop

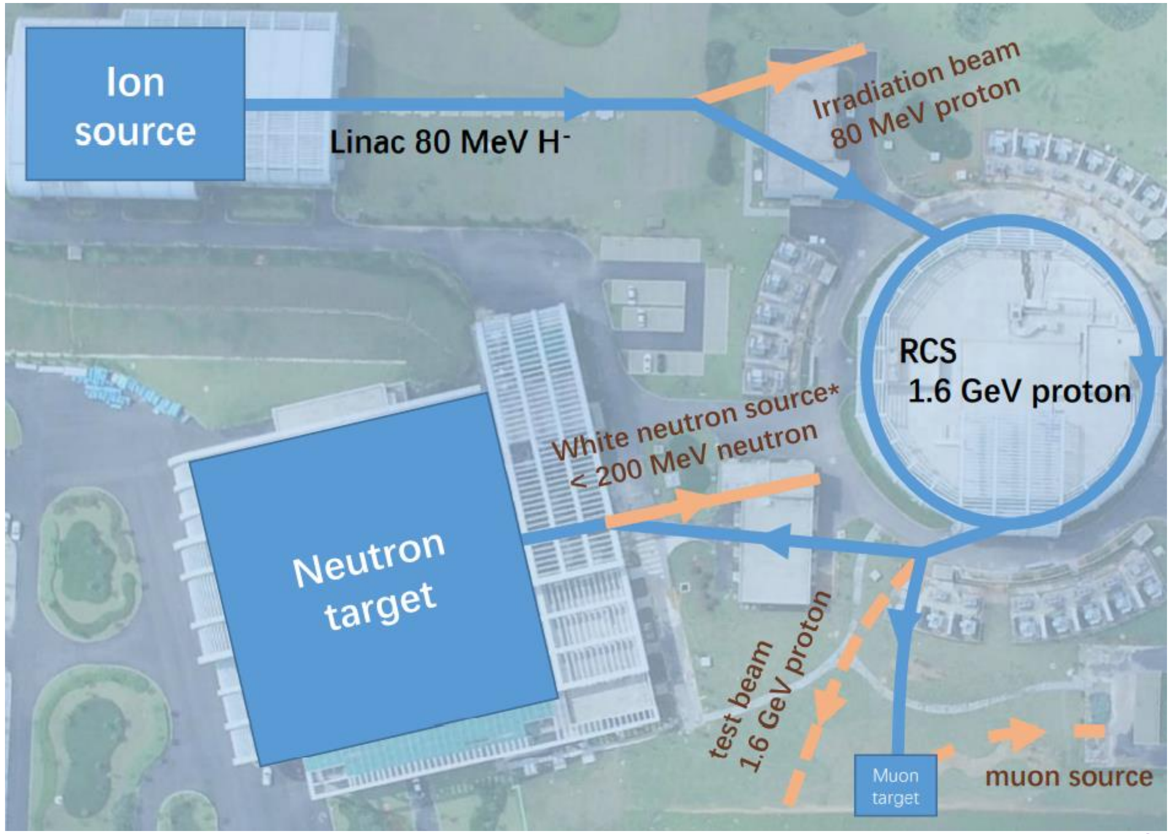
2022-11-30

heye@ihep.ac.cn

Introduction to CSNS

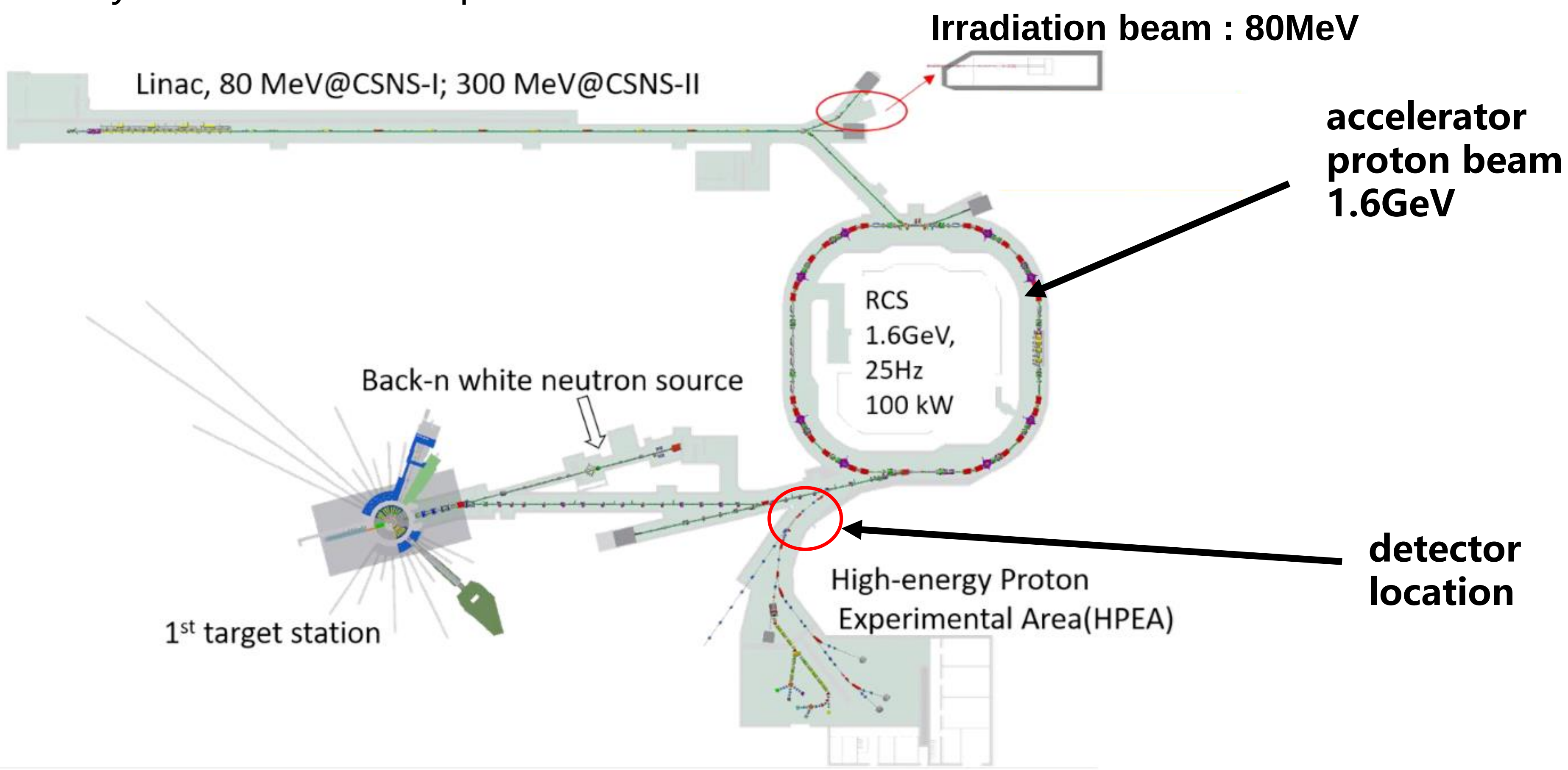
- China Spallation Neutron Source, located in Dongguan city, near Hongkong
- Consist of: White neutron source, Irradiation beam, proton test beam and muon beam
- Current progress:
    - The white neutron source and Irradiation beam have been built, others are still in design
    - Proton beam needs a beam monitor system

CSNS 中国散裂中子源 China Spallation Neutron Source



Beam monitor system for CSNS

- Design a beam monitor system for the CSNS proton test beam



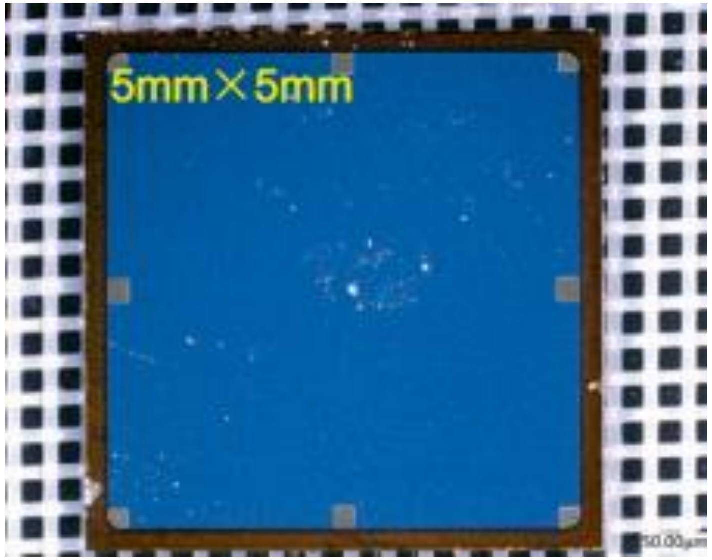
- Set at the beginning
- Can see real-time fluence

- The beam is expected to test run next summer

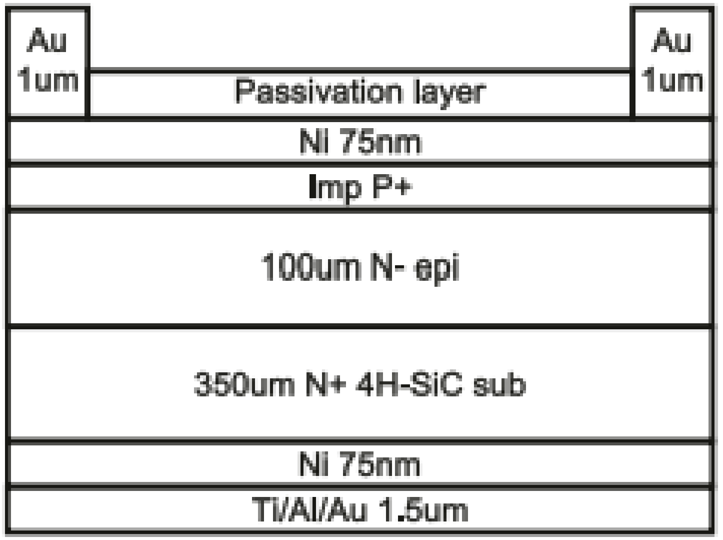
Sensor in the beam monitor system, SiC

- Advantage of SiC towards Si:
  - Higher radiation hardness potential
  - Lower dark current
  - Without cooling system
  - Fast response
- Fit the requirements of beam monitoring

- NJU SiC PIN of 5mm × 5mm



electrode

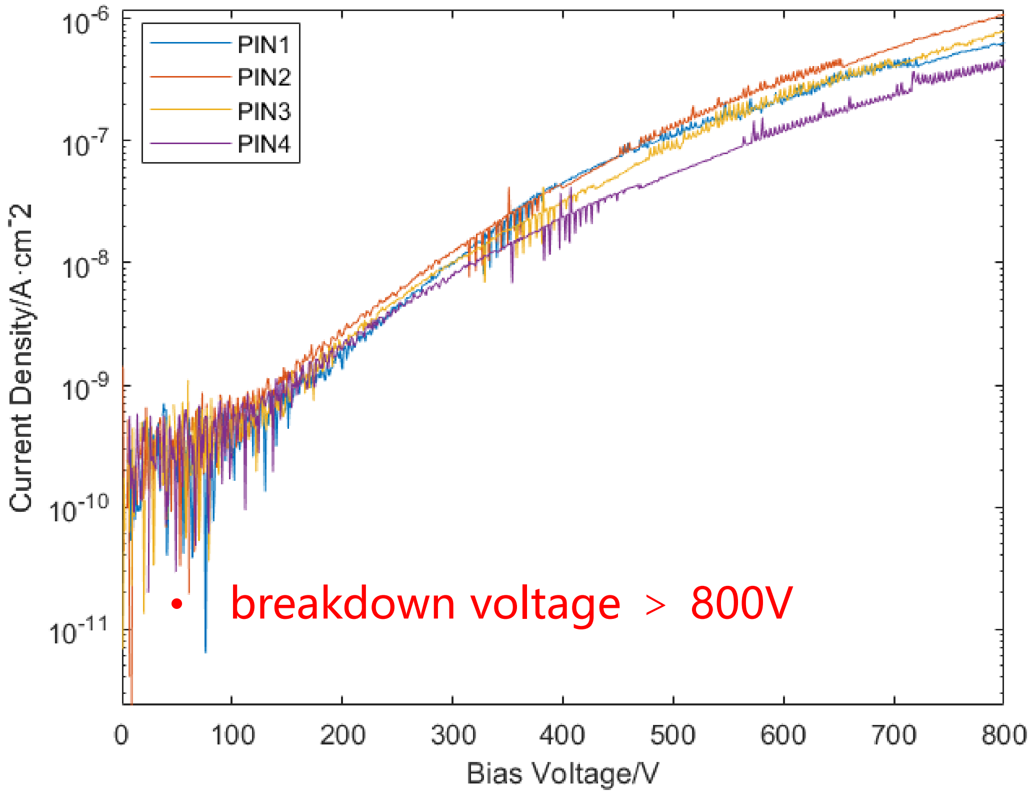


electrode

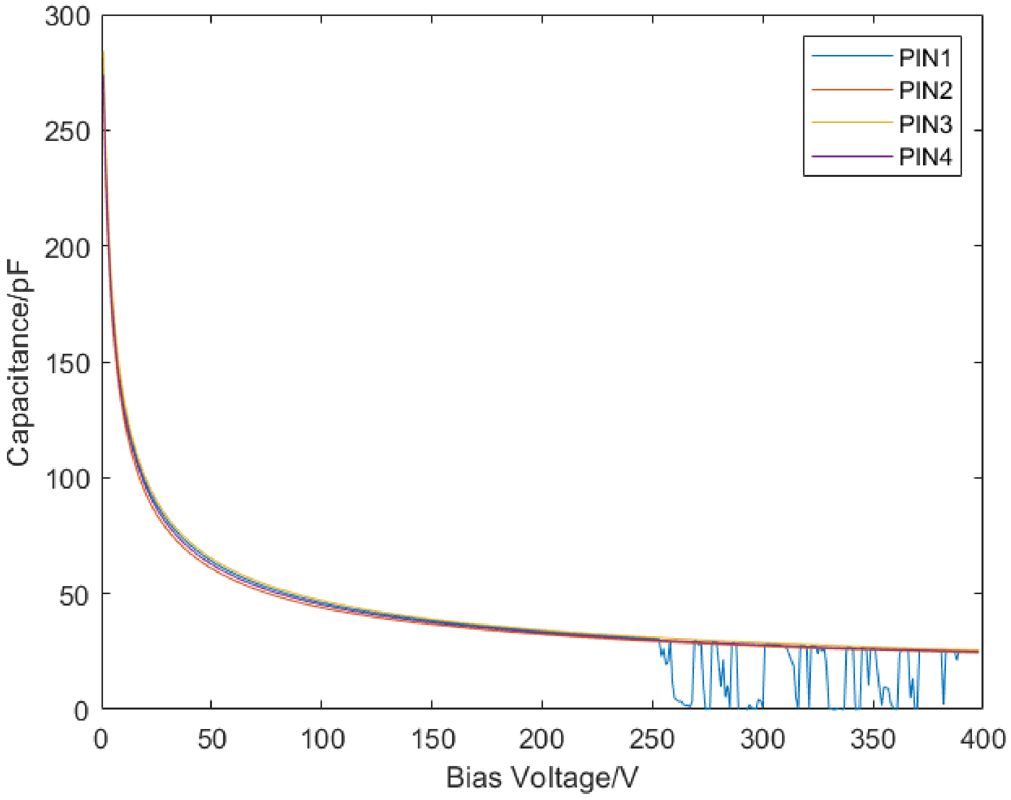
Performance of SiC PIN sensors

- Test 4 PIN sensors with the same size of 5mm×5mm

IV tests



CV tests



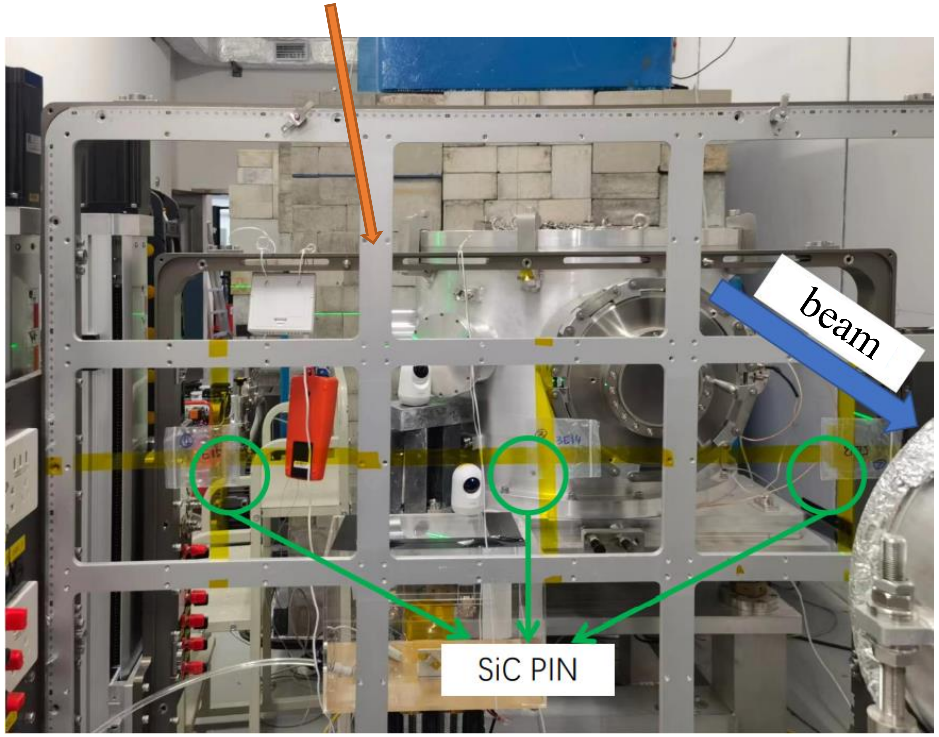
- All the sensors have good performance

SiC irradiation with 80MeV proton beam

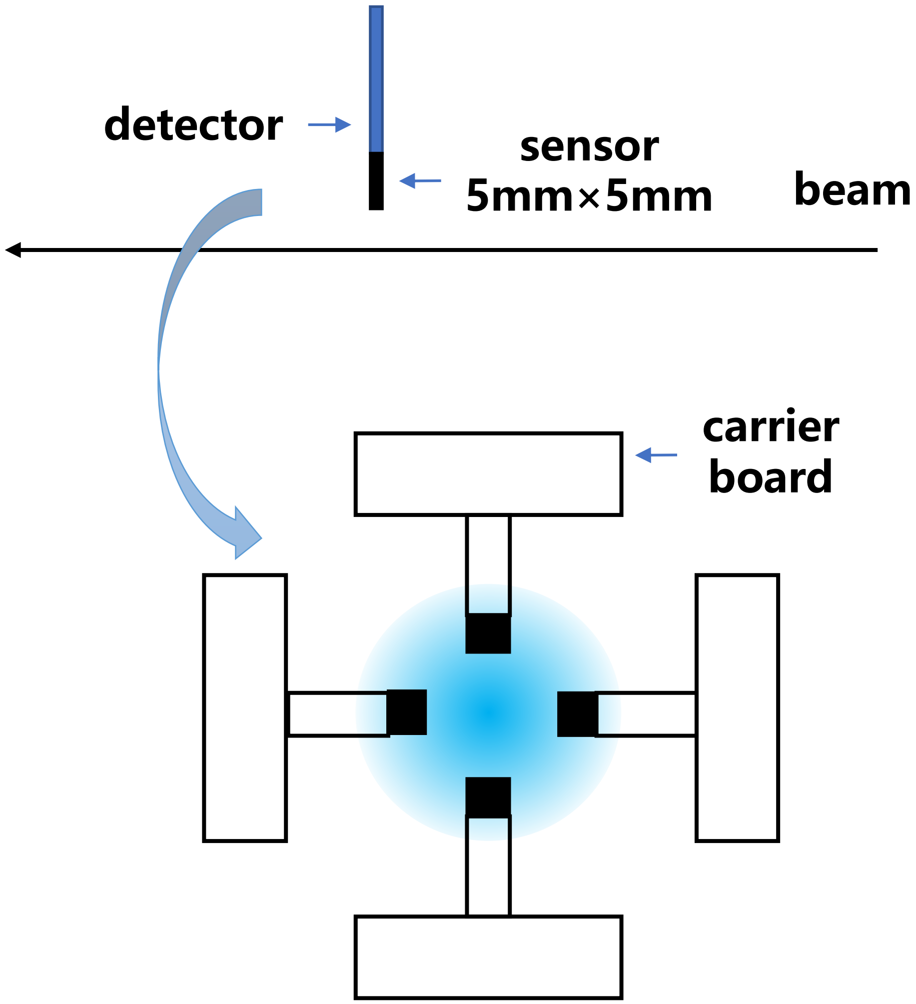
- Estimation of irradiation in CSNS beam:
  - Run 5000h a year
  - NIEL: 0.6
  - Total proton : 3e14
- three irradiation level: 1e13, 3e14, 1e15
- beam parameter:
  - 80MeV proton beam
  - fluence 4.59e9 /(cm²·s)
  - NIEL:1.4

	n	n_{eq}	run time
1	5.00E+13	3.50E+13	2h7m10s
2	3.00E+14	2.10E+14	12h43m20s
3	1.00E+15	7.00E+14	42h30m

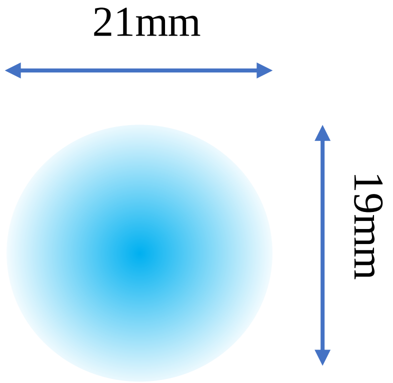
- The sensors are under test

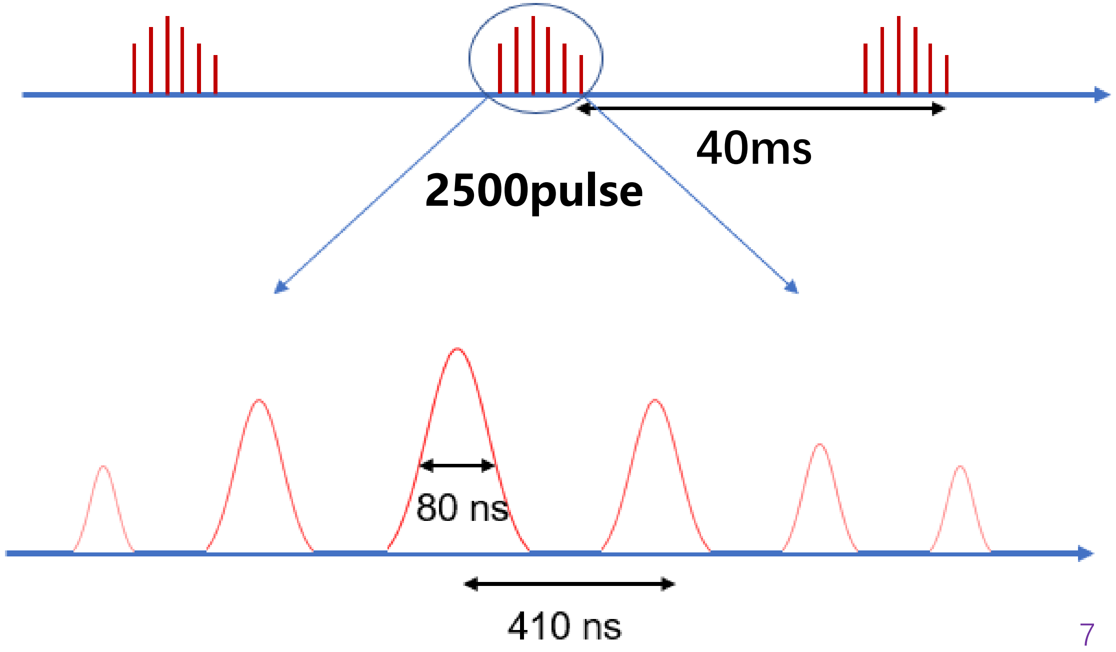


Design of beam monitor system



- proton beam
- energy:1.6GeV
- fluence:2.35e8 proton/s
- profile: σ_x = 21mm , σ_y = 19 mm
- pulse duration: 80 ns
- pulse interval: 410 ns
- bunch interval: 40ms

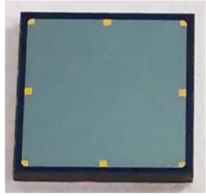




Design of readout system

sensor, amp → digitizer → console

NJU SiC PIN
5mm×5mm



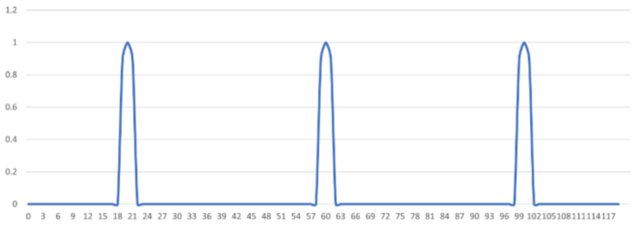
a carrier board with a
pre-amplifier, and 20dB
gain main amplifier

plan to use
CAEN DT5742

- 16 channels
- 5G/s sampling rate

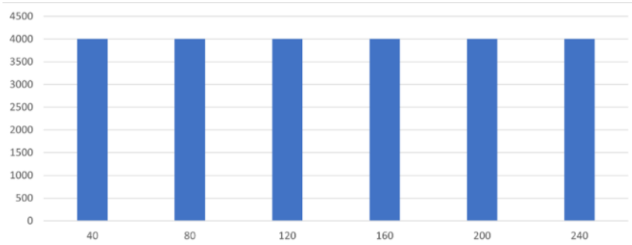
The real-time waveform and
the number of passing
protons display on the screen

Amplitude/mV



Time/ns

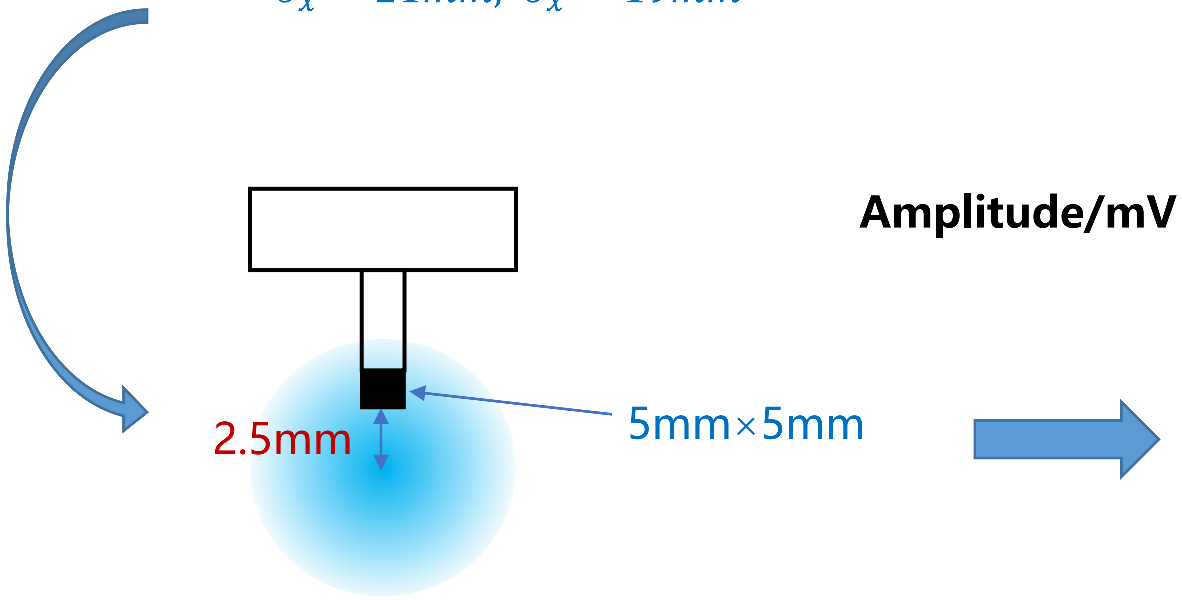
Number



Time/ms

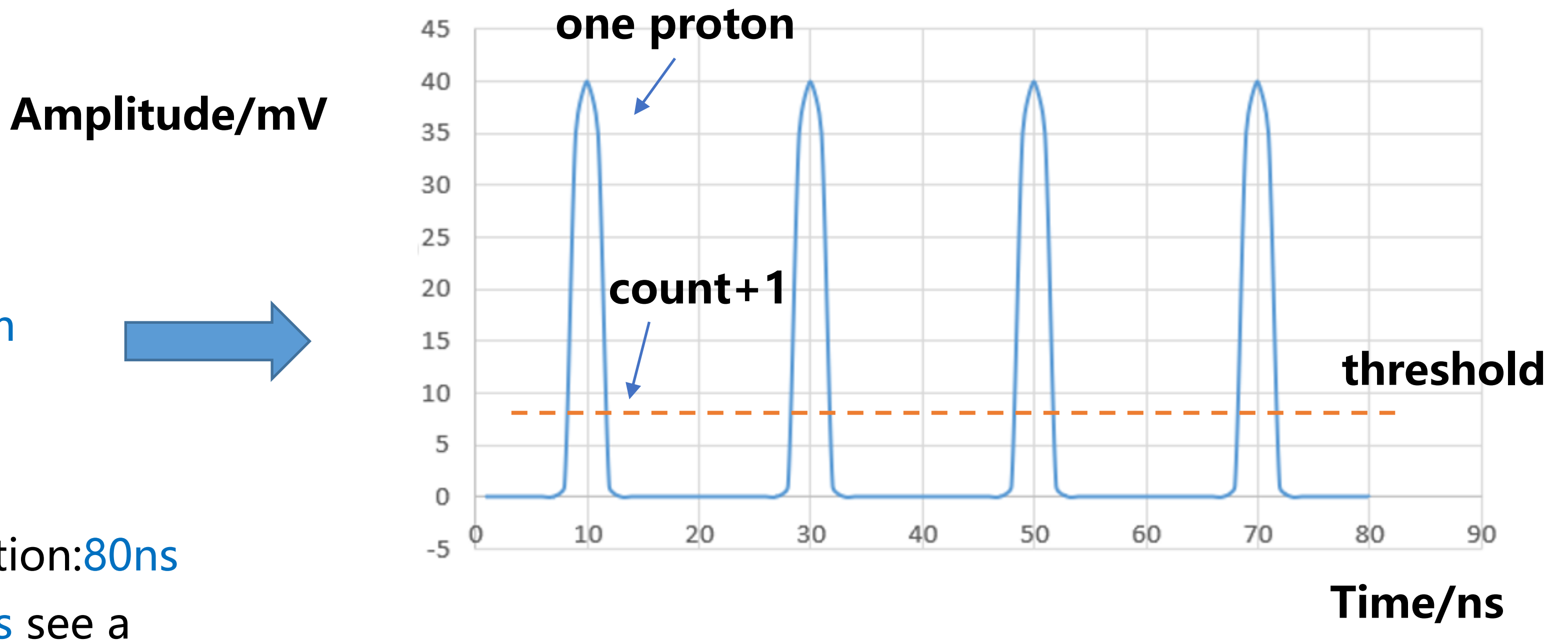
Proton counting scheme

- The profile is a Gaussian distribution:
  - $\sigma_x = 21mm,\ \sigma_x = 19mm$



- The number of proton crossing the sensor per pulse:
  - $N \approx 3.7$
- Pulse duration:80ns
- About 20ns see a waveform.

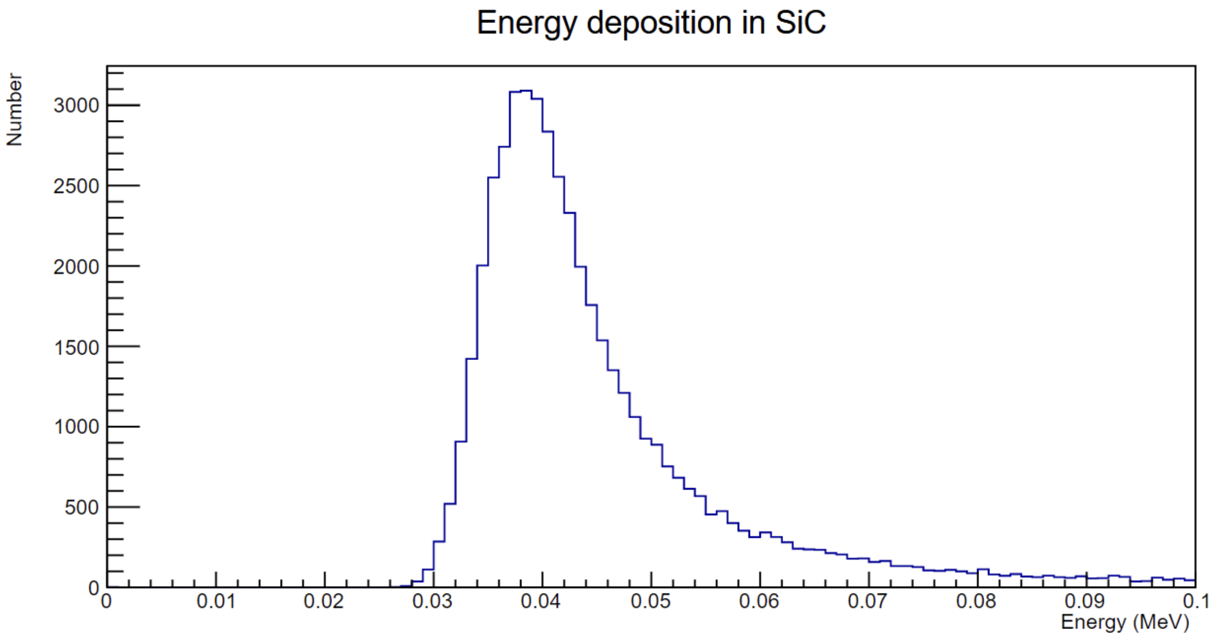
- Set a threshold and counting the number of crossing protons



- Send the message to console

Simulation of beam energy deposition

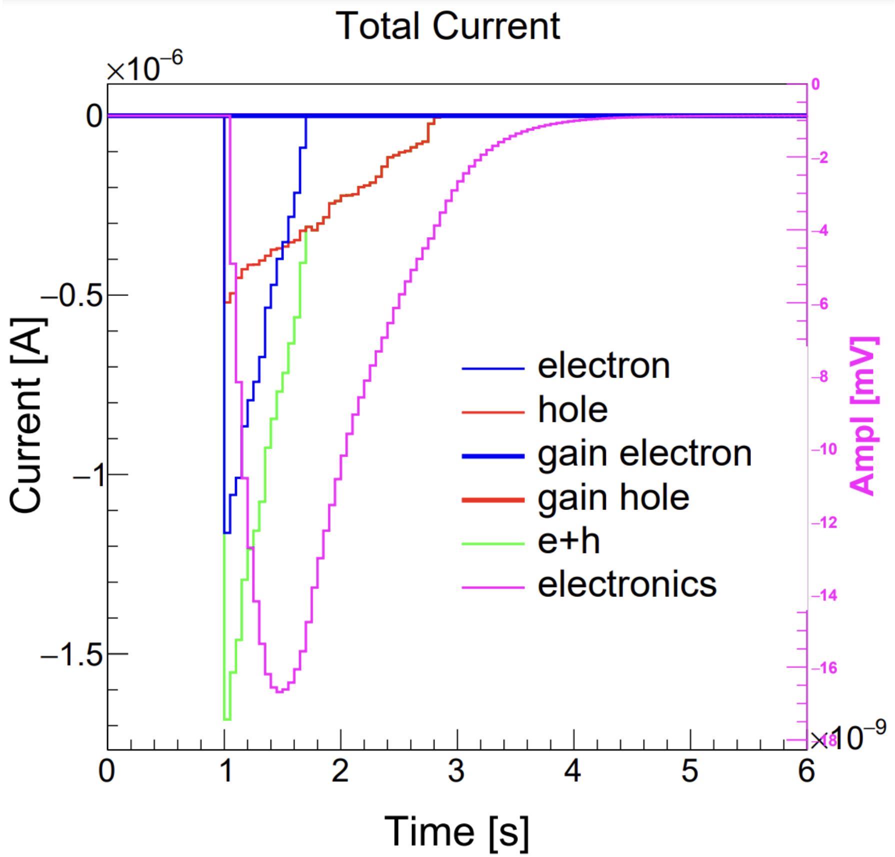
- RASER[1][2] , a fast simulation tool developed by IHEP
- Simulate the energy deposition distribution of particles hitting SiC detectors (total 50,000)
- The energy deposition follows a Landau distribution
- The average energy deposition is 0.056MeV
- MPV is 0.04MeV



1.Micromachines, 2022(1),13,46

2.Front. Phys., 10:718071

- Simulate the current and voltage generated by the one proton



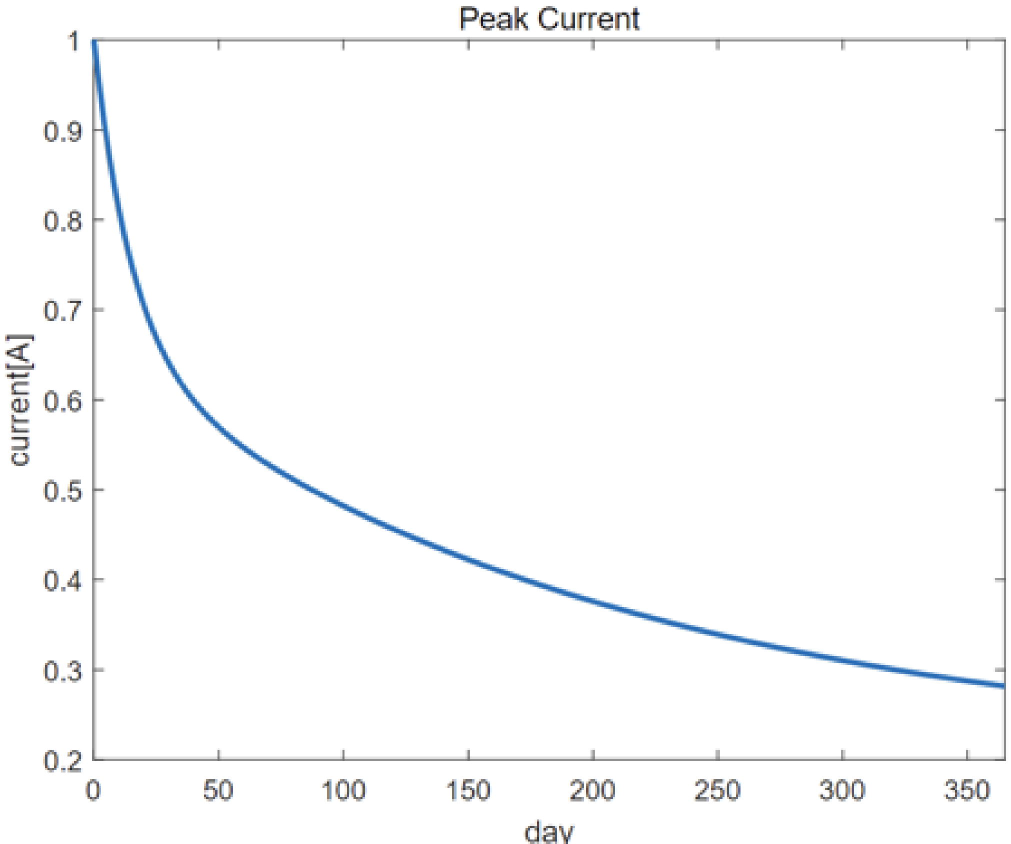
Simulation of irradiation

- Use the performance curve of 6H-SiC[1] with irradiation fluence to simulate the performance of 4H-SiC
- The relationship between output current and irradiation satisfies:

$$I = 1 - p_1\left(1 - e^{-\frac{\Phi}{\Phi_{c1}}}\right) - p_2\left(1 - e^{-\frac{\Phi}{\Phi_{c2}}}\right)$$

$p_1=0.3487$ $\phi_{c1}=0.1322$

$p_2=0.4488$ $\phi_{c2}=1.8162$



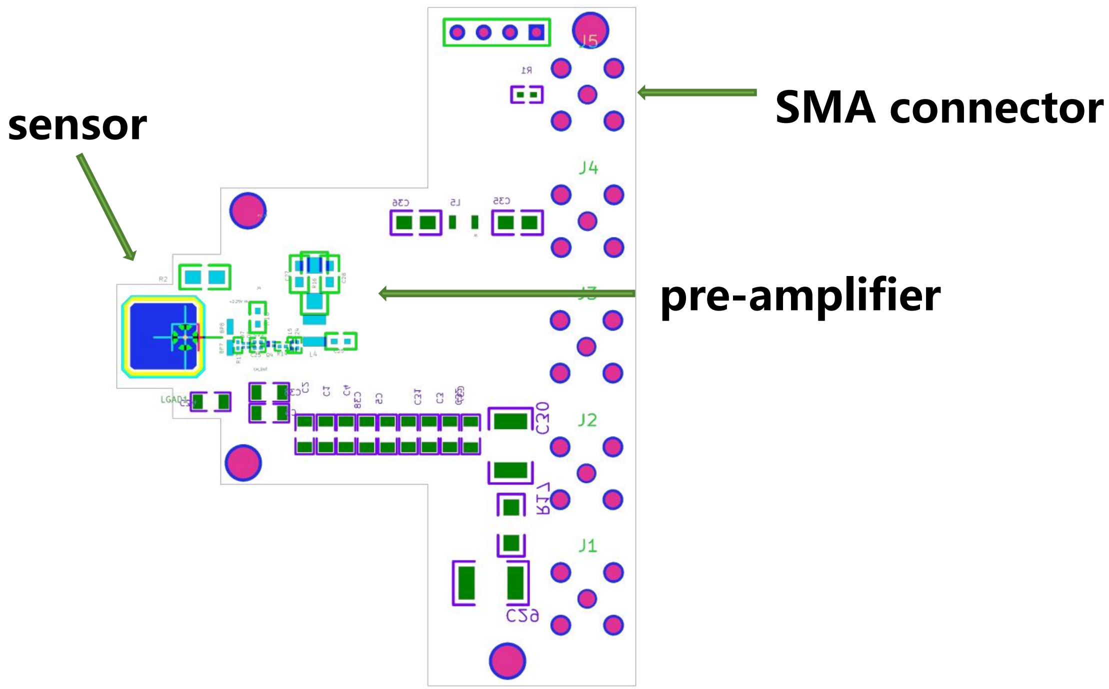
- After working one year, the efficiency falls about 70%
- Enter the irradiation time and the maximum voltage measured at this moment to get the number of protons at this moment

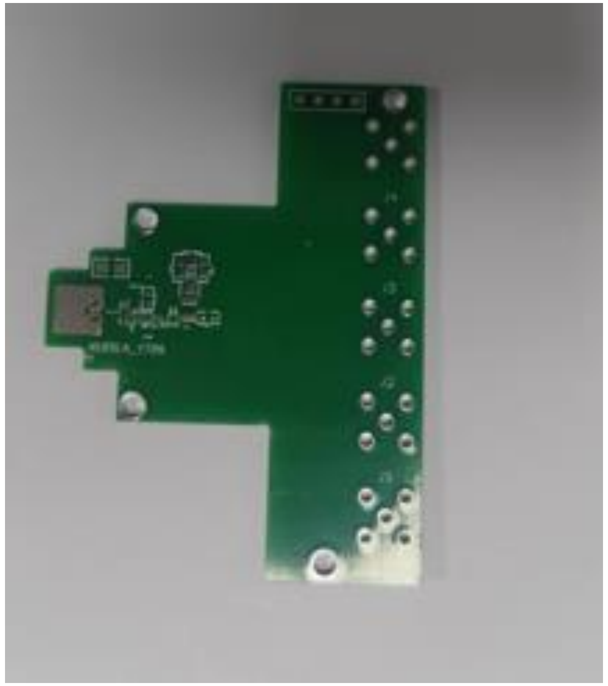
```
Irradiation time(day): 30
Maximum voltage(mV): 1121.22
Number of protons: 100
```


1. Q. Liu et al., "Effect of Very High-Fluence Proton Radiation on 6H-SiC Photoconductive Proton Detectors"

Carrier board design

- The carrier board designed to set SiC PIN and pre-amplifier

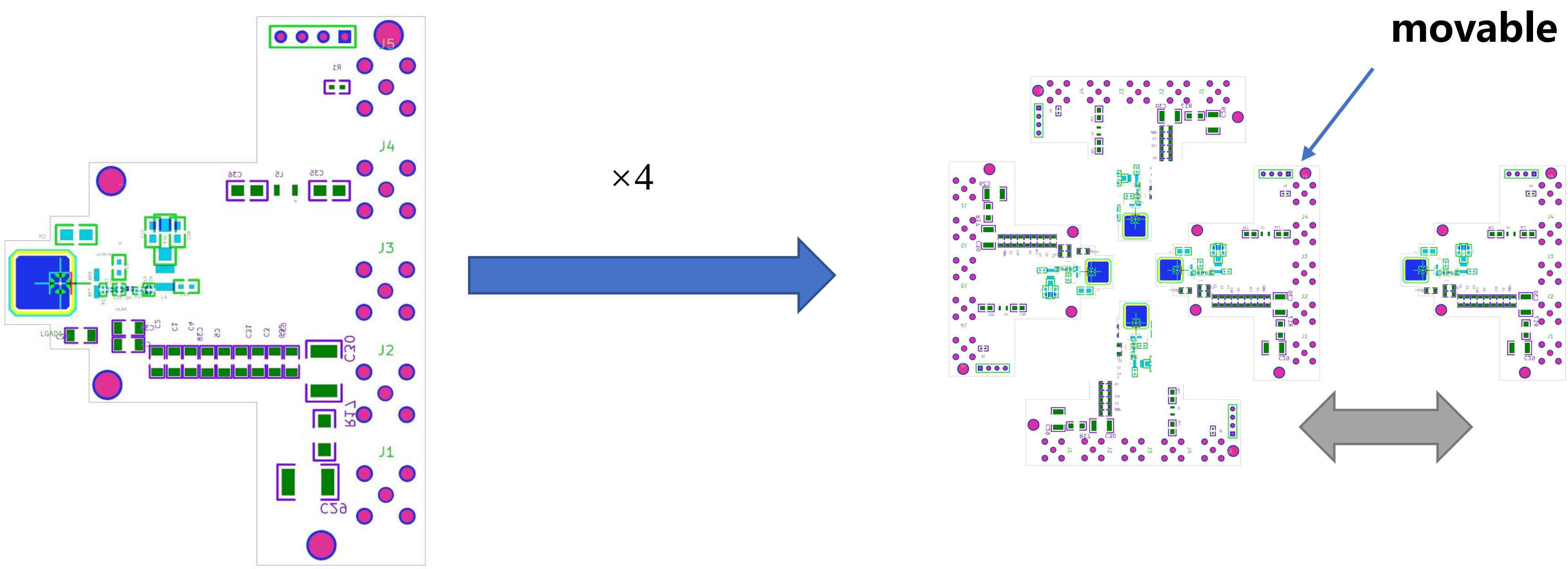




- MIP can generate about 0.9fC when crossing the sensor
- Expecting to amplify a 0.9fC charge signal to 5mV voltage signal

Carrier board arrangement

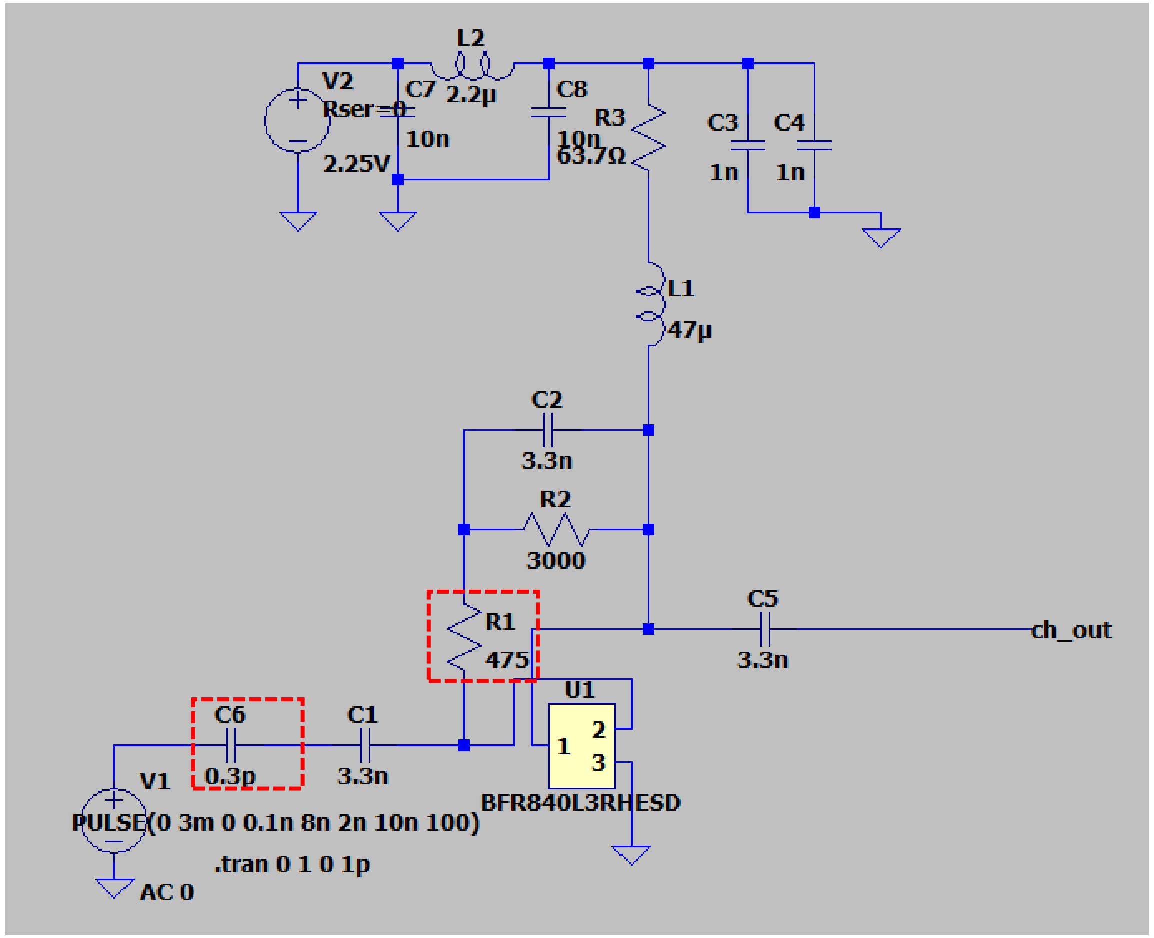
- Plan to place the four carrier boards like this:



- The boards all designed to be movable
- Adjust the distance between sensor and beam
- Set the board at a proper location

Simulation of the pre-amplifier

schematics



- follow the UCSC board[1][2] design

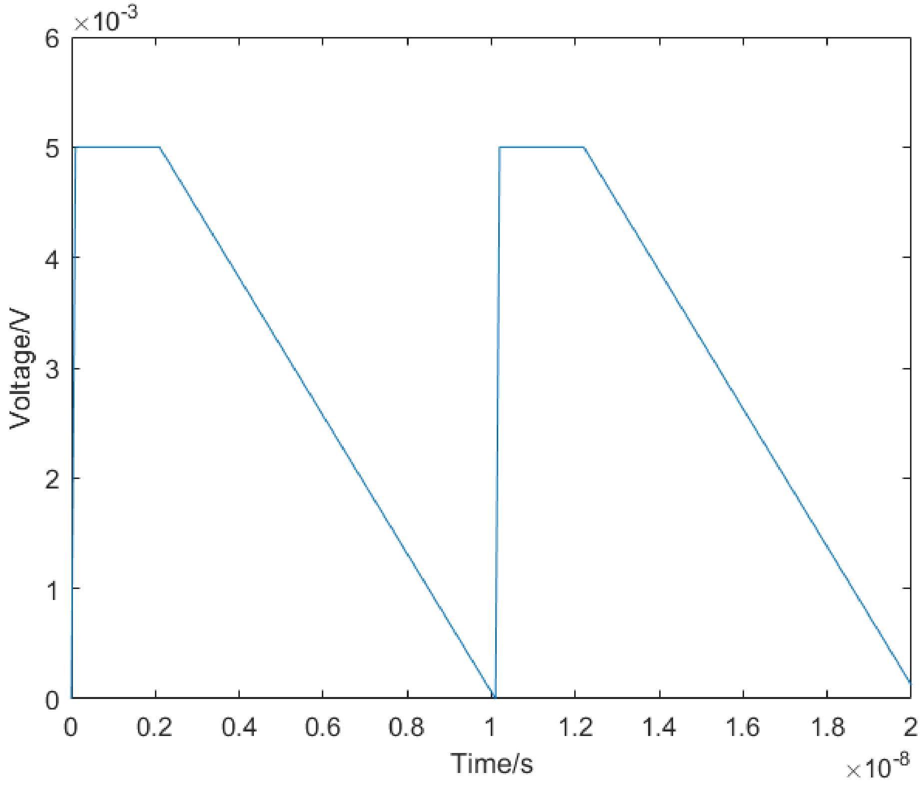
1.https://twiki.cern.ch/twiki/bin/view/Main/UcscSingleChannel

2. Z. Galloway, et al., Properties of HPK UFSD after neutron irradiation up to 6 × $10^{15} n_{eq} cm^{-2}$, Nucl. Instrum. Methods A 940 (2019) 19-29

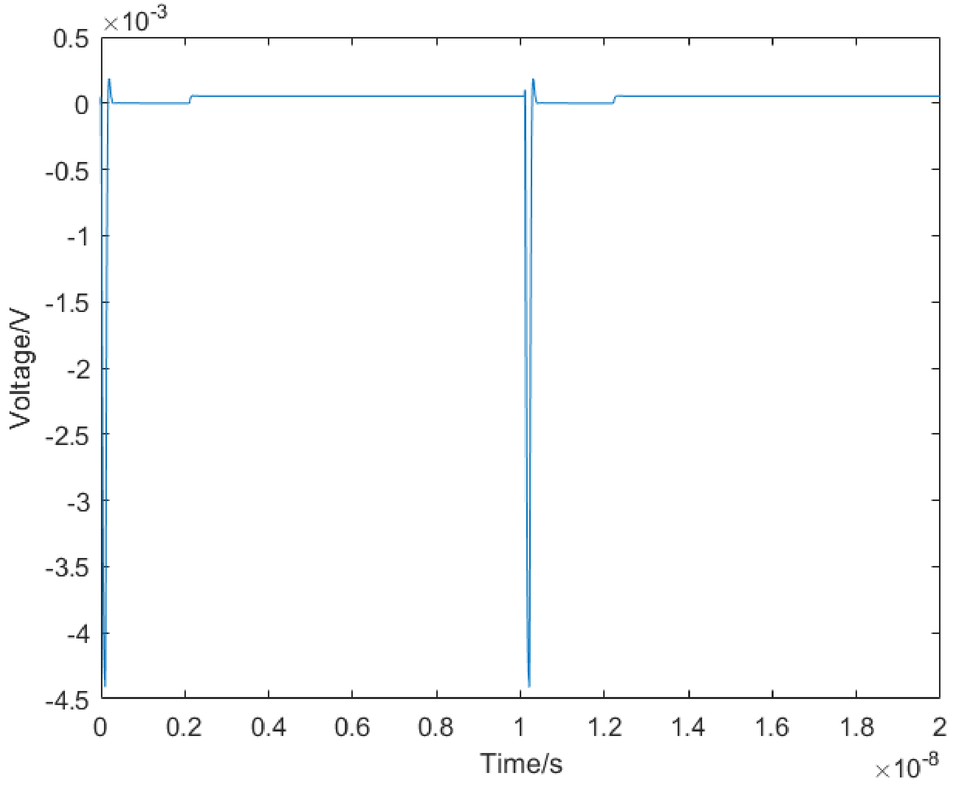
- From simulation :
  - value of R1 decides gain
  - value of C6 is proportional to input charge
  - V1 and C6 simulate the signal generated from sensor

Simulation of the pre-amplifier

Input: 3mV, 0.9fC charge signal

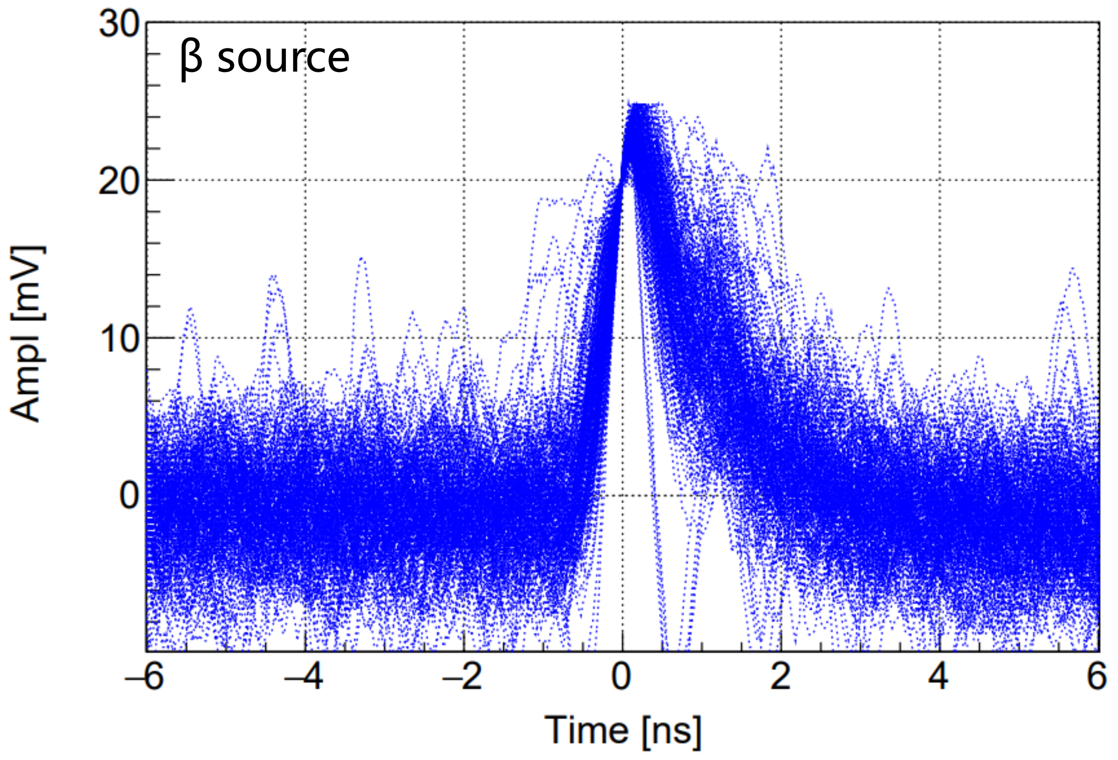


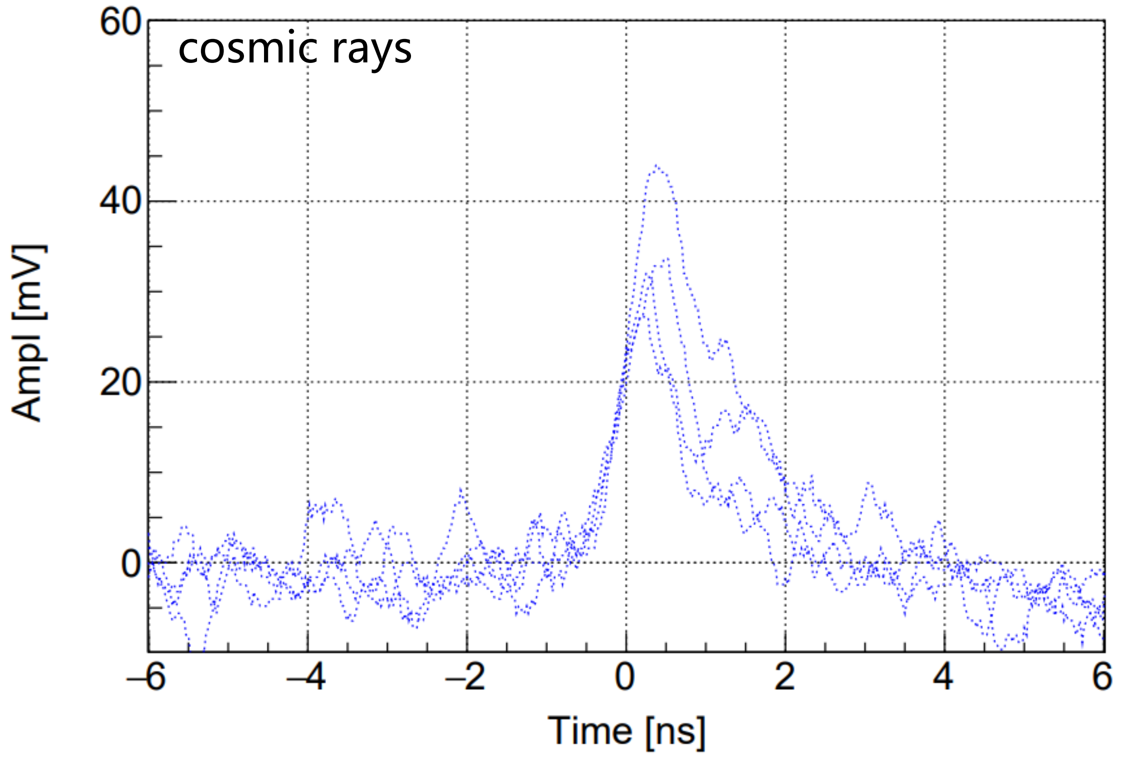
Output: 4.5mV



- The board can amplify charge 0.9fC to voltage 4.5mV

Test result of β source and cosmic rays

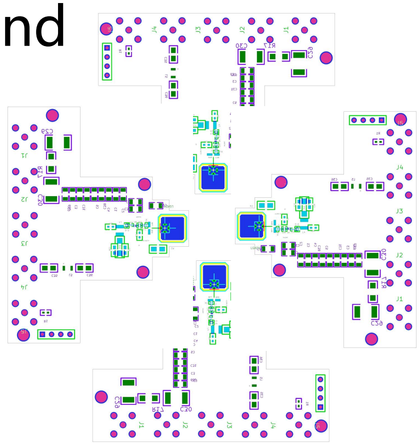




- Signal 2ns, 30mV
- Proton comes each 20ns
- See the waveform precisely

- 1 signal per hour
- The efficiency is below 10%
- Current electronics needs improvement

Summary and plan



- Design a beam monitor system for CSNS 1.6GeV proton test beam, and have finished the basic design and counting scheme

- Test of NJU SiC PIN and carrier board performance
  - IV and CV : done
  - Irradiation: in progress
  - β-source and cosmic ray : done

- Simulation on the sensor and pre-amplifier gives direction for improvement

- Plan to improve the performance of the carrier board

Thanks for your listening!