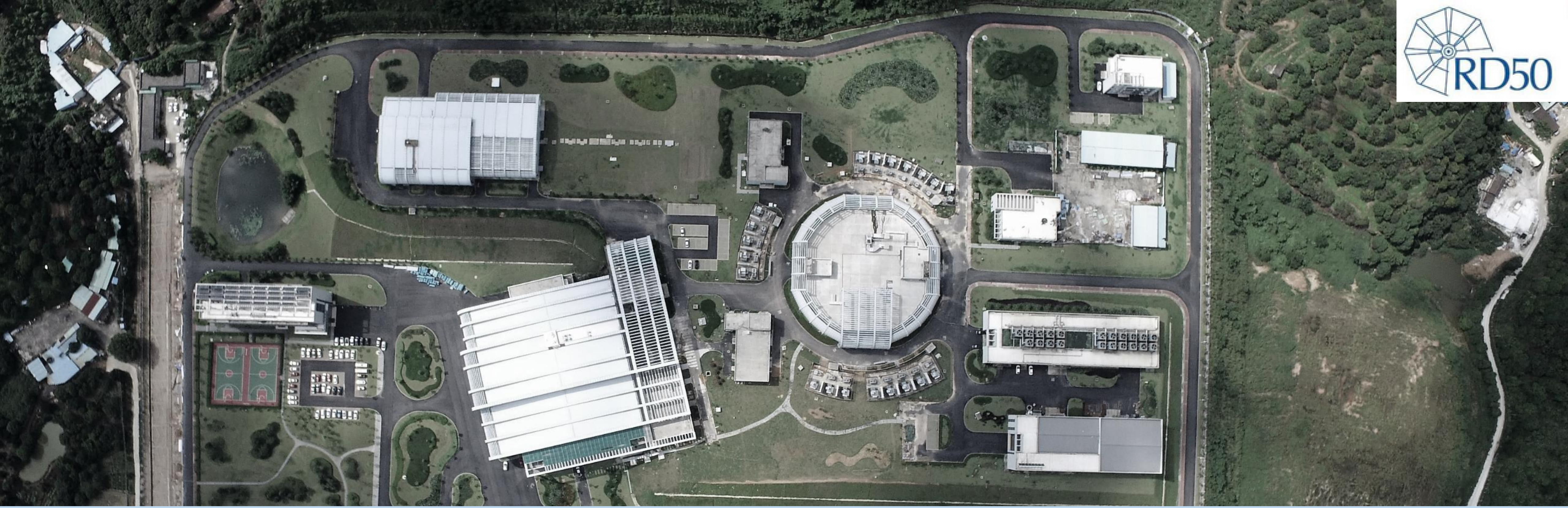


SiC Neutron Irradiation Study at CSNS

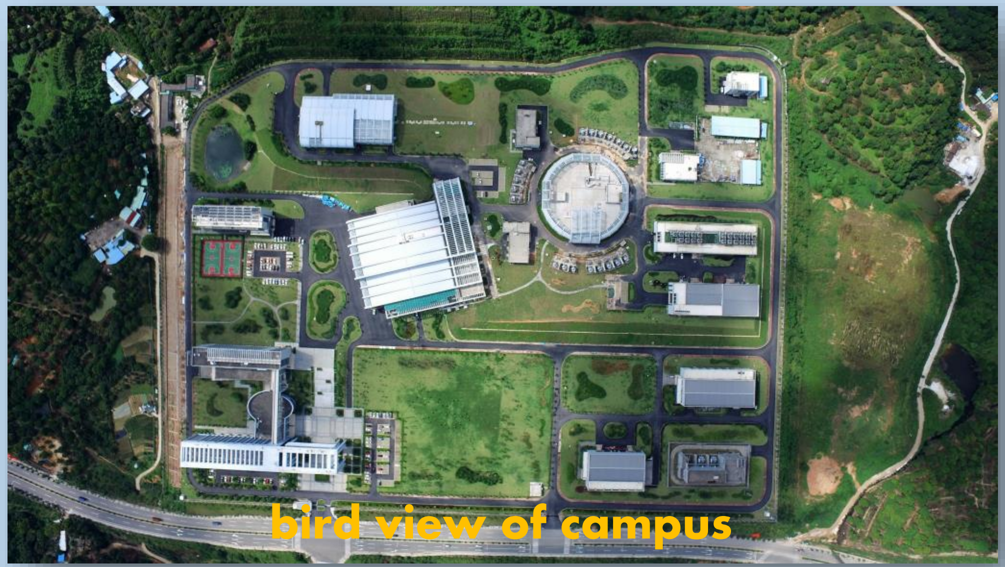
Ruirui Fan[1,2] Ze Long[3] Xinbo Zou[4] Xiaochuan Xia[3]

1. Spallation Neutron Source Science Center
2. Institute of High Energy Physics, CAS
3. Dalian University of Technology
4. ShanghaiTech University

Outline

- A short introduction of us (China Spallation Neutron Source, Beam extending application team)
- Motivation (SiC detector and neutron irradiation)
- Some latest results and analysis

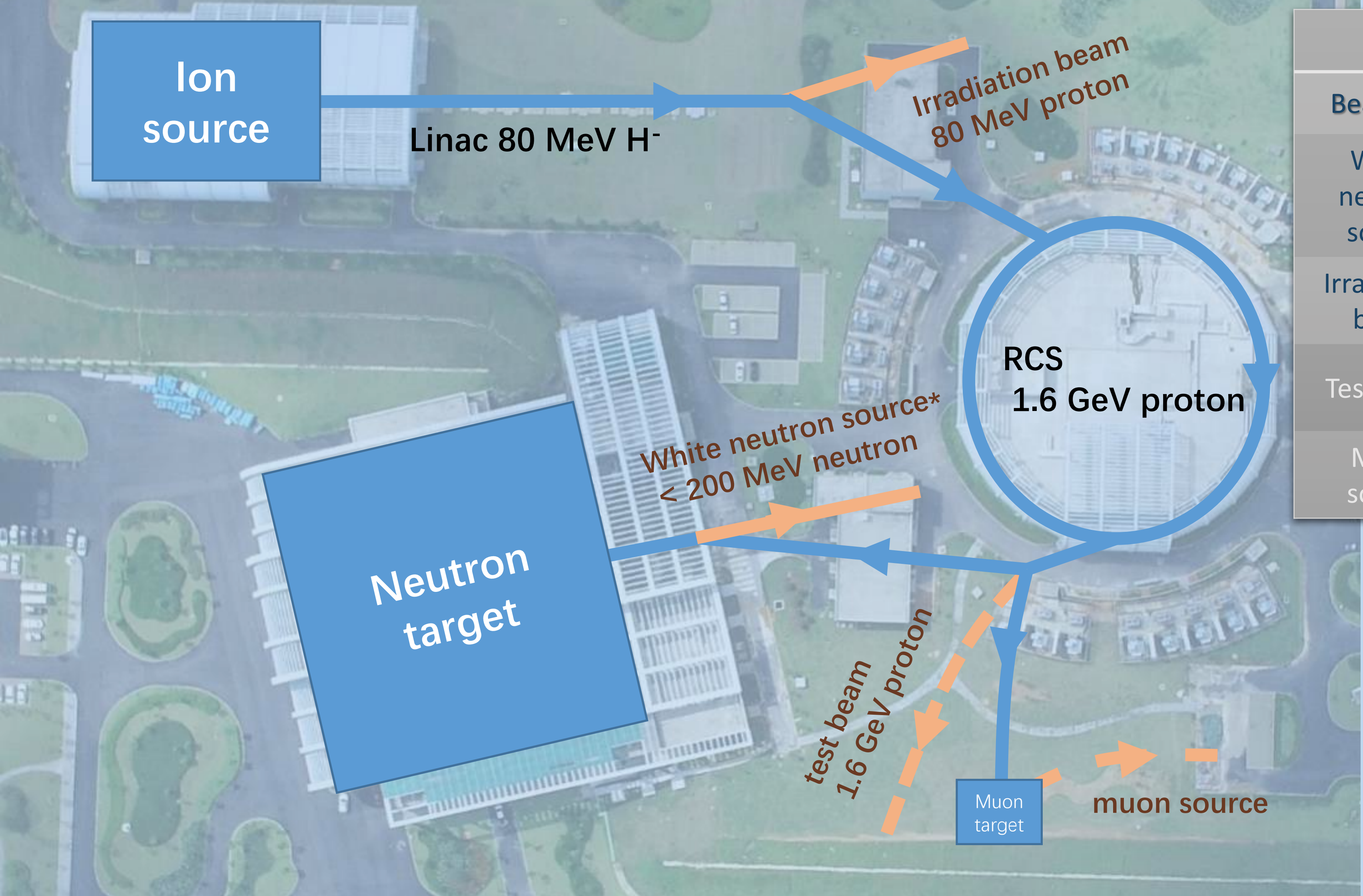
China Spallation Neutron Source



The China Spallation Neutron Source, located in Dongguan city, near Hong Kong, was established on August 28, 2017, with a budget of 2.3 billion yuan.
It consists of a 1.6 GeV proton accelerator with a repetition rate of 25 Hz and a beam power of 100 kW, will be 500 kW in next six years.

CSNS

CSNS beam extending application

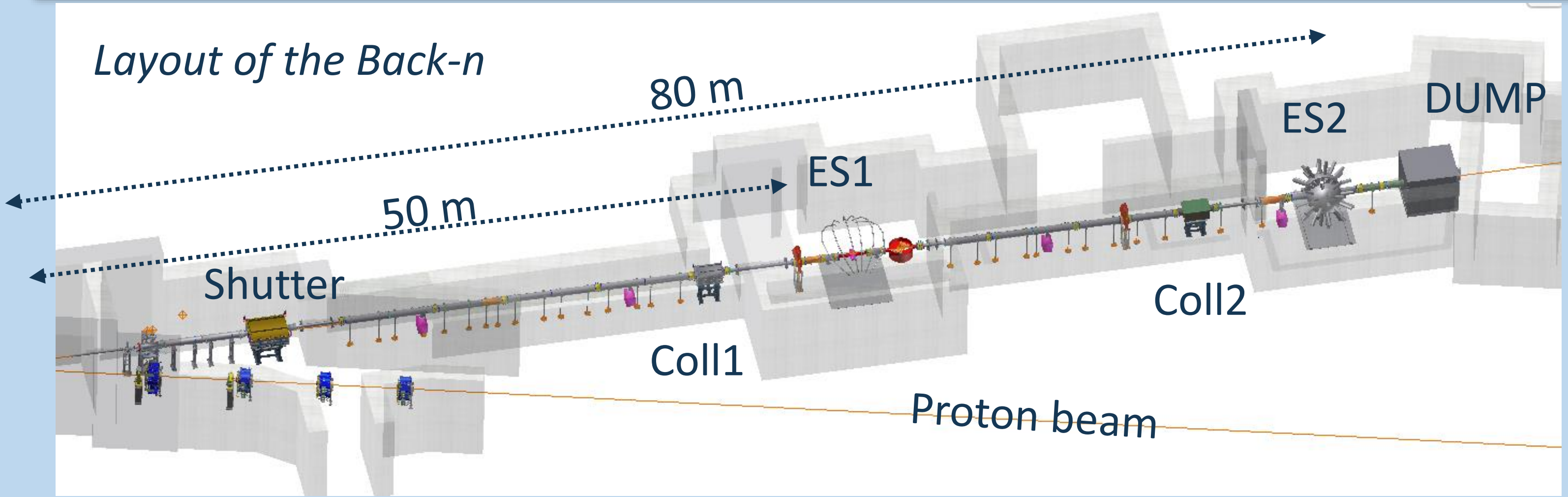


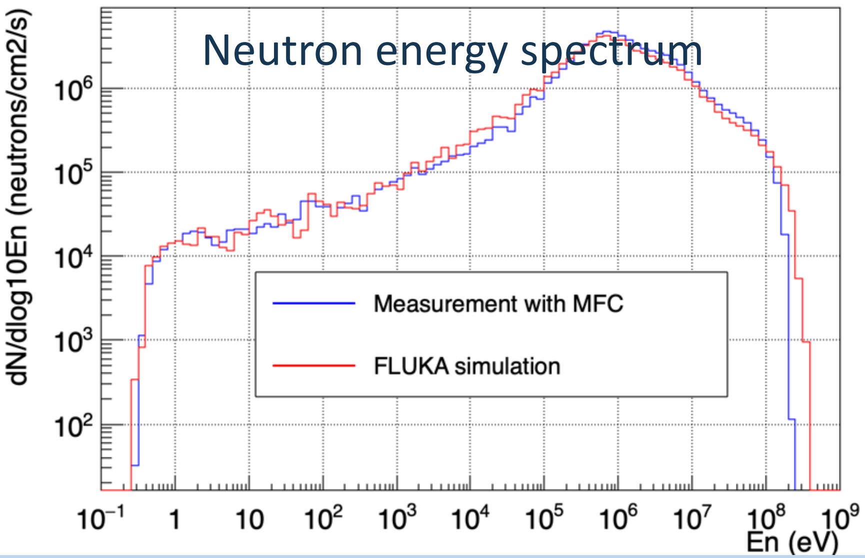
*white neutron means wide spectrum neutron, like "white light"

Beam parameters			
Beamline	Particle	Energy	Flux
White neutron source	Neutron	0.5 eV -200 MeV	1E7 n/cm^{-2}/s
Irradiation beam	Proton	80 MeV	1E9 p/s
Test beam	Proton	1.6 GeV	1E3 – 1E8 p/s
Muon source	Muon	4 MeV	1E5 muon/pulse

A total of 4 beamlines are planned to be constructed, including a White neutron source, Irradiation beam, test beam and muon beam. The **white neutron** and **Irradiation beam** have been built, others are still in design.

Back-n white neutron source



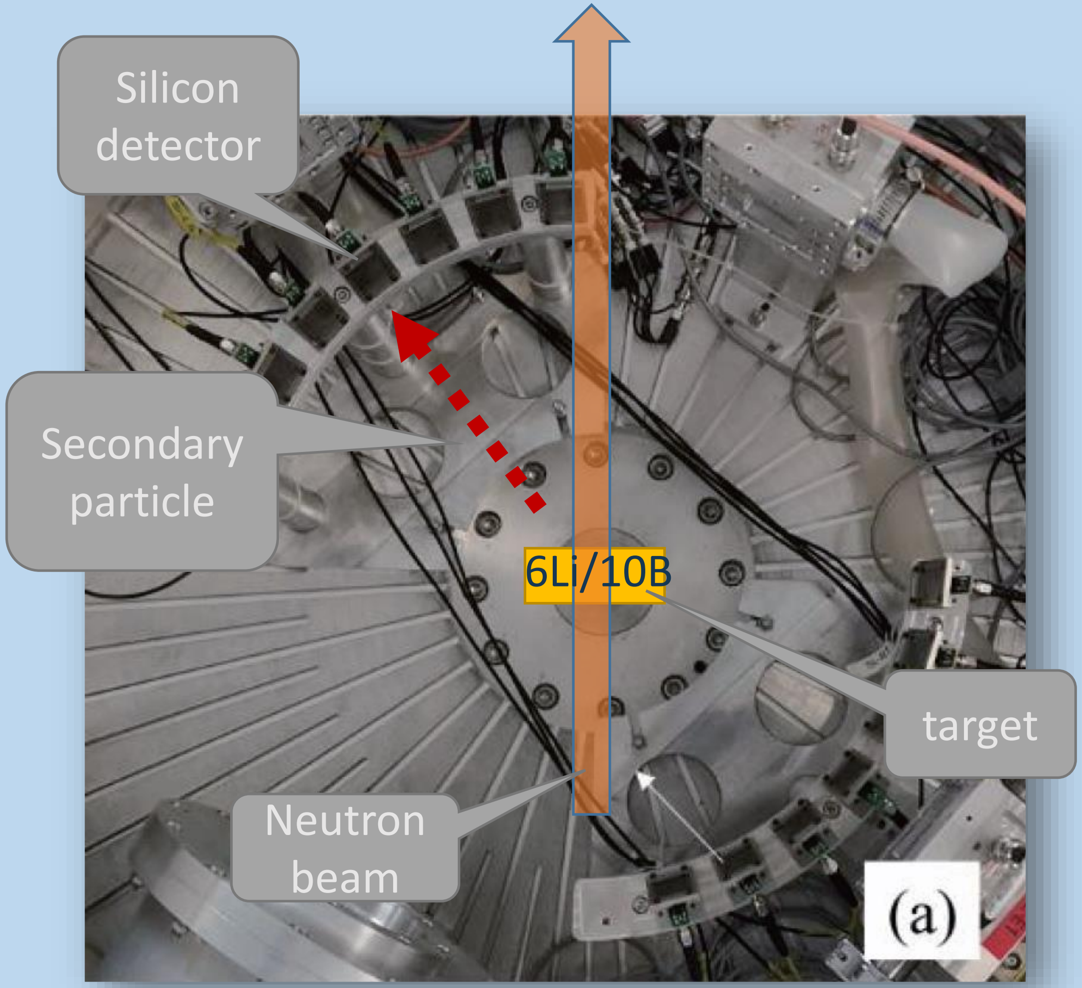


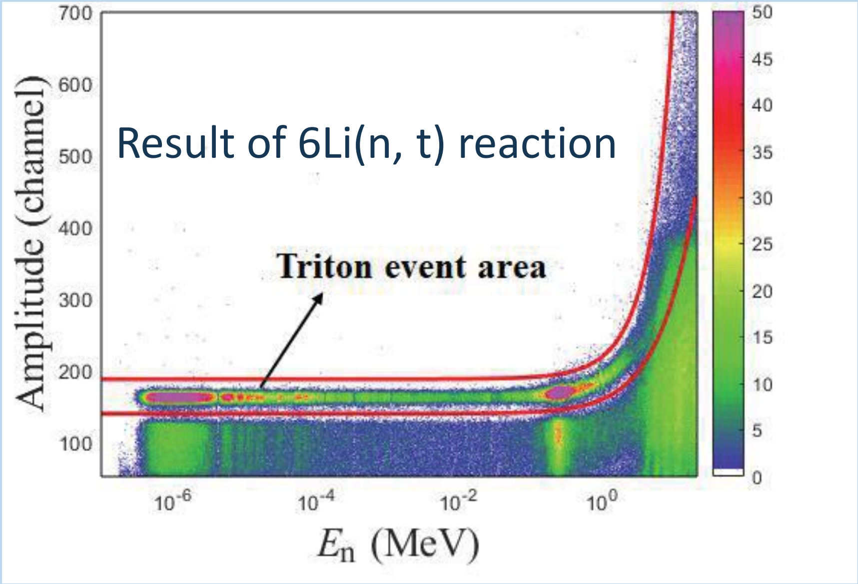
Shutter (mm)	Coll#1 (mm)	Coll#2 (mm)	ES#1 spot (mm)	ES#1 flux ($n/cm^2/s$)	ES#2 spot (mm)	ES#2 flux ($n/cm^2/s$)
Φ3	Φ15	Φ40	Φ15	1.27E5	Φ20	4.58E4
Φ12	Φ15	Φ40	Φ20	2.20E6	Φ30	7.81E5
Φ50	Φ50	Φ58	Φ50	4.33E7	Φ60	1.36E7
78×62	76×76	90×90	75×50	5.98E7	90×90	2.18E7

The Back-n is a high luminosity white neutron beamline at the China Spallation Neutron Source (CSNS). It started running in 2018 for various nuclear data measurements. Different sets of beam spots, collimator apertures and neutron fluxes at Back-n at 100 kW in proton beam power.

1. 2017 JINST 12 P07022
2. Eur. Phys. J. A (2019) 55: 115

Motivation





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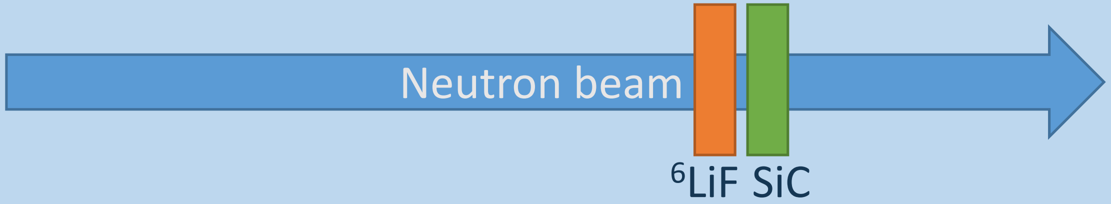
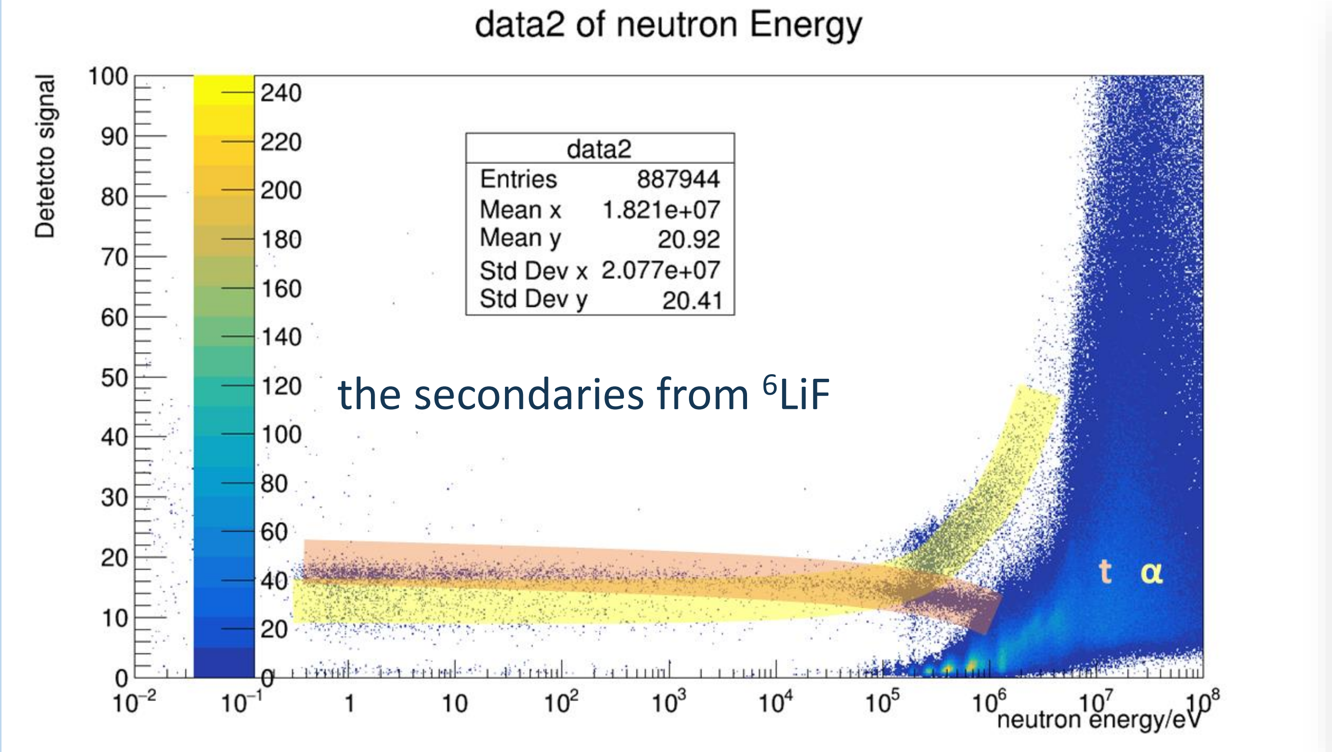
Because after high-energy neutrons irradiation, silicon detector array can only be installed around the beam.
The measurements of small cross-sections can not be performed because of the small acceptance of the silicon array.

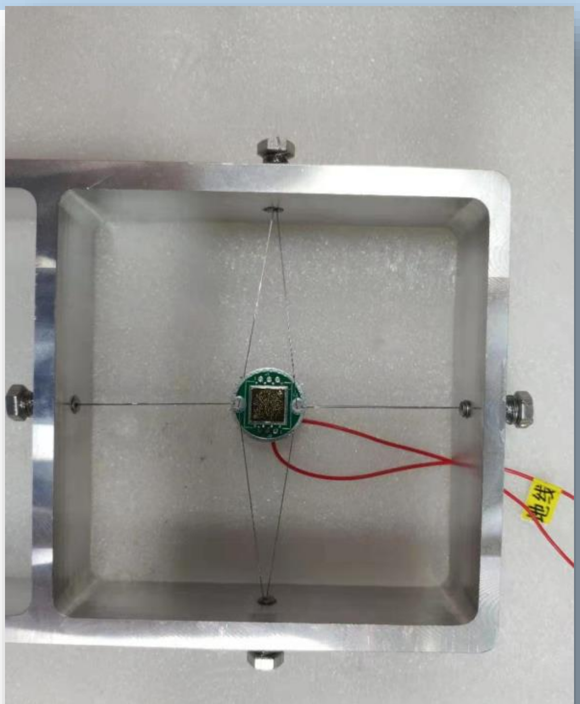
SiC for neutron experiment

A SiC detector was placed in the center of the beam, closer to the target, using a sandwich-like structure to obtain a 4-pi solid angle covering.



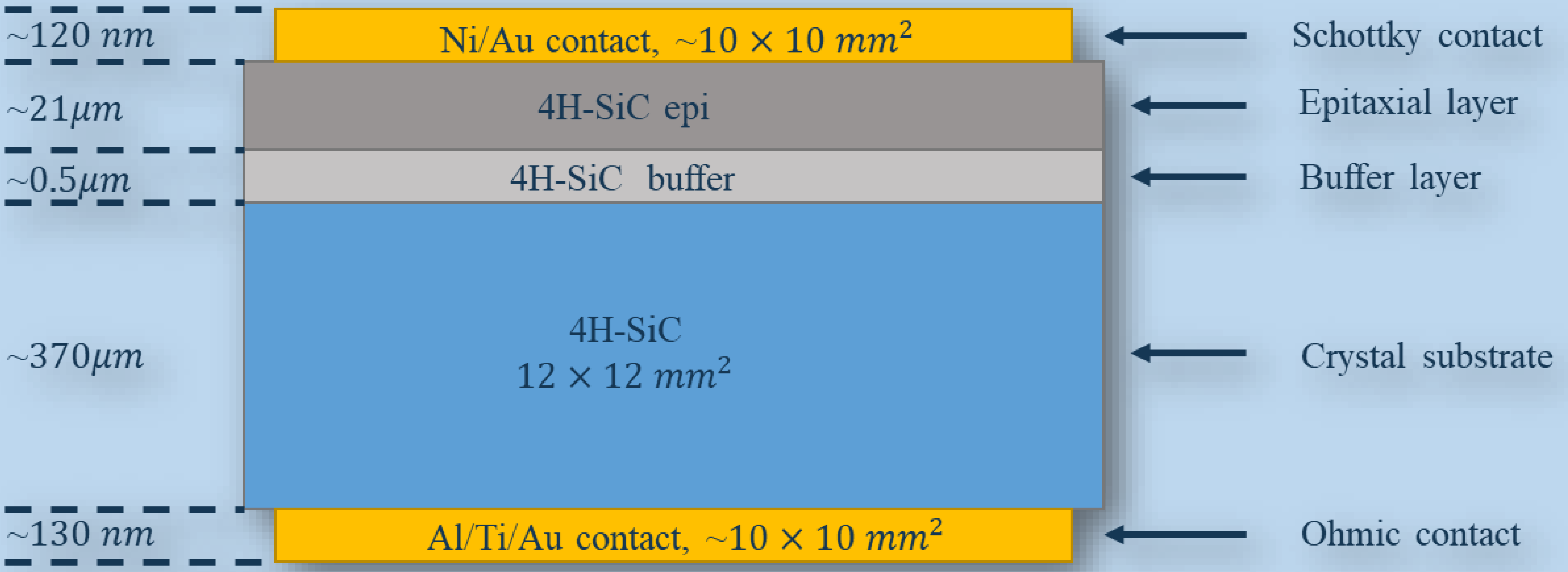
The irradiation time of the SiC detector is about 100 hours (20 kW), and the total neutron is more than 10^{10} cm^{-2}, and no performance change is found.





SiC detector

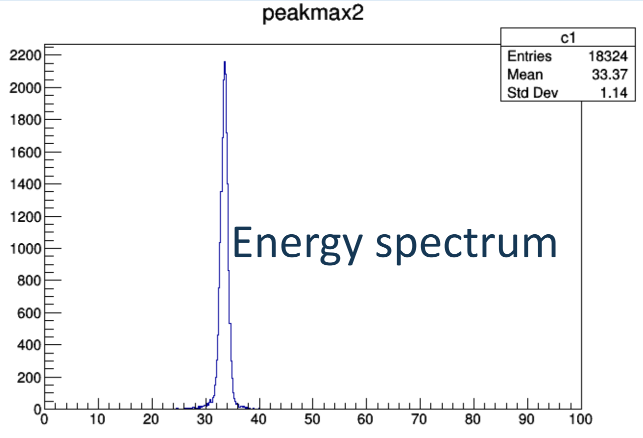
Structure of 4H-SiC detector

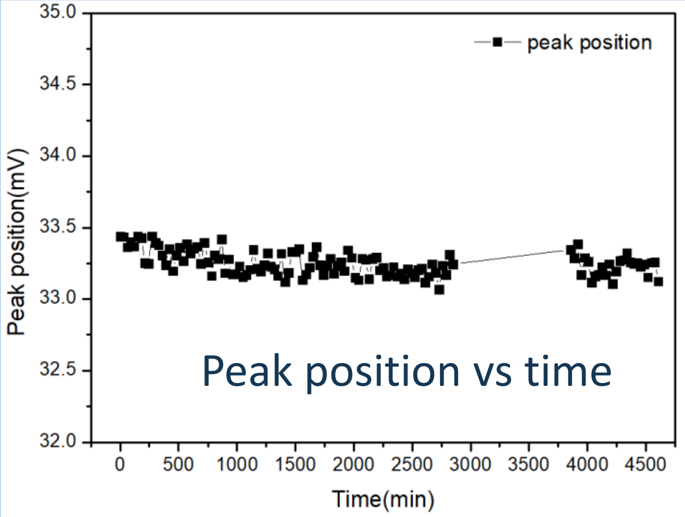


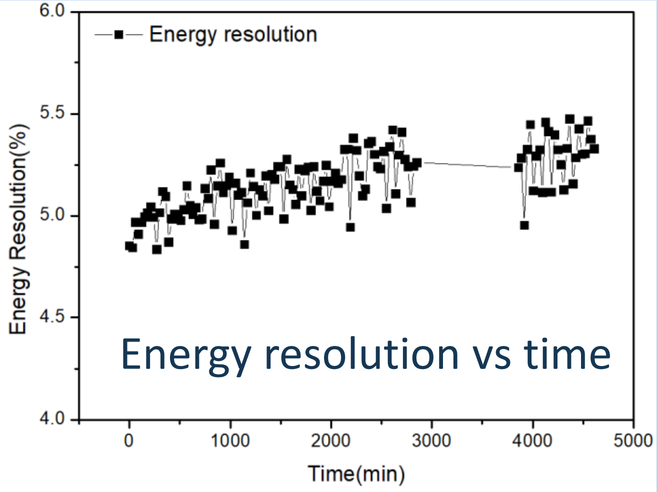
The silicon carbide detector used in our research comes from Dalian University of Technology, with the Schottky type.

Before irradiation

A long-term test (more than 4500minutes) is performed, during this test we keep the detector bias on as in the experiment. There is no obvious peak position change and energy resolution change during the long-term test before the detector is irradiated.

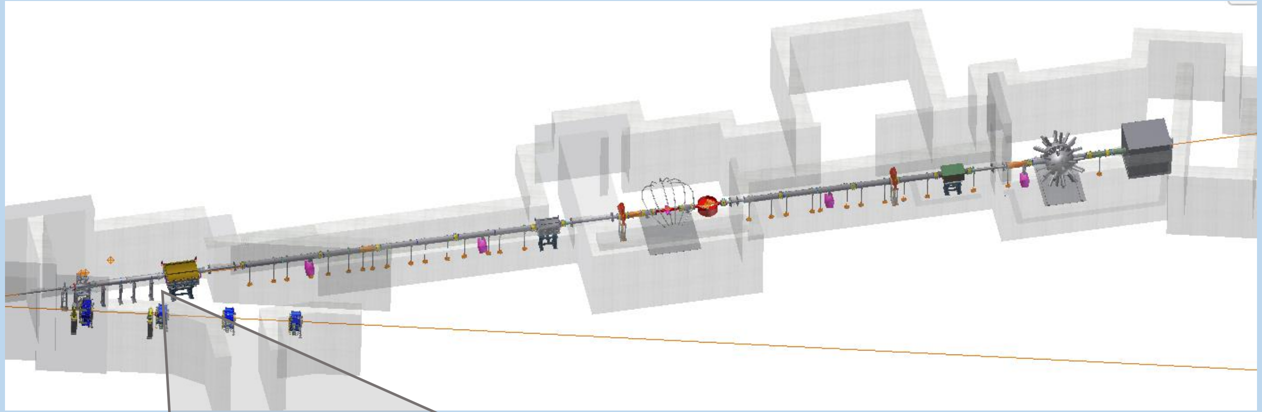


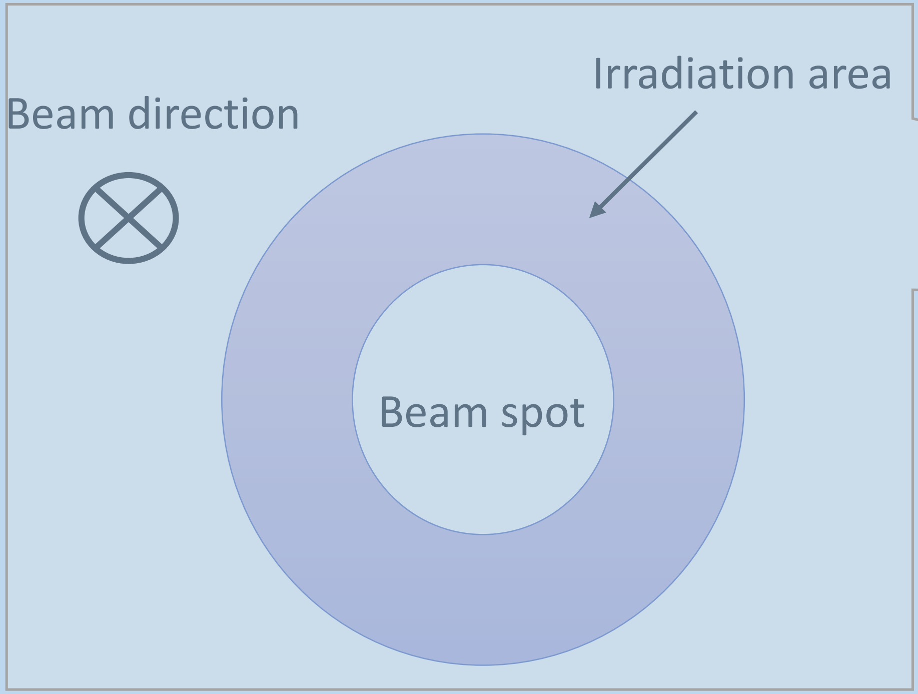


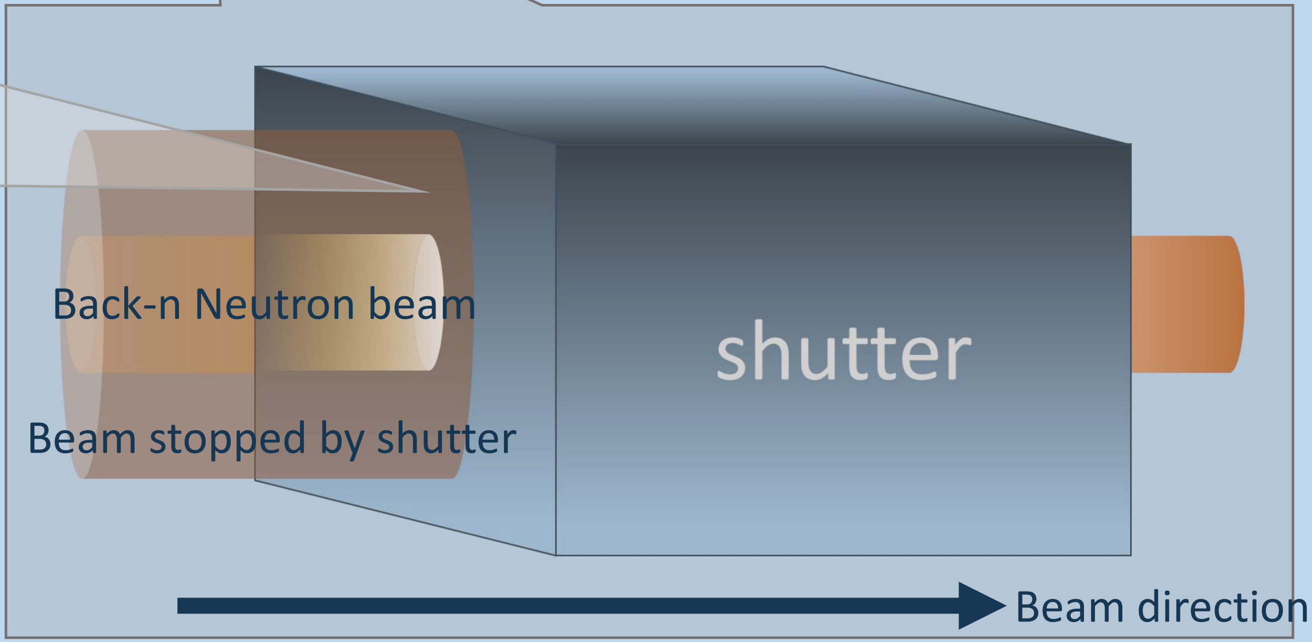


Irradiation environment

In front of the shutter, a high-intensity irradiation area like a ring (few centimeters wide depending on collimator diameter) can be obtained by using the neutron beam blocked. This Irradiation area can give a neutron flux of 10^8 n/cm^{2}s. With the same energy spectrum of the Back-n. (thermal to 200 MeV, peak at 1 MeV)







Irradiation of SiC

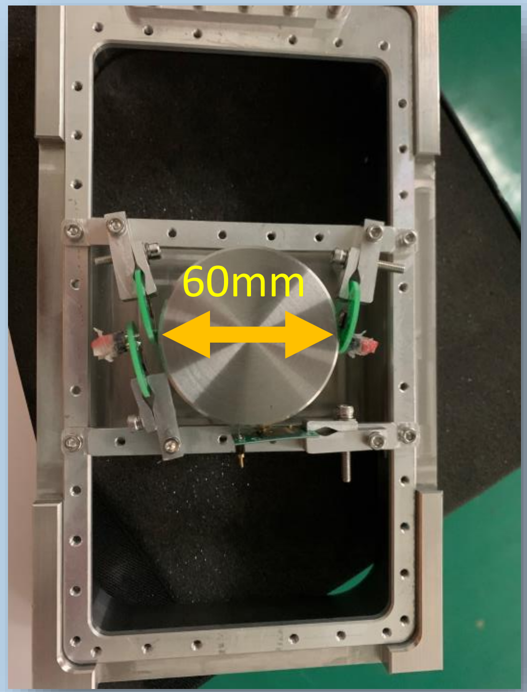
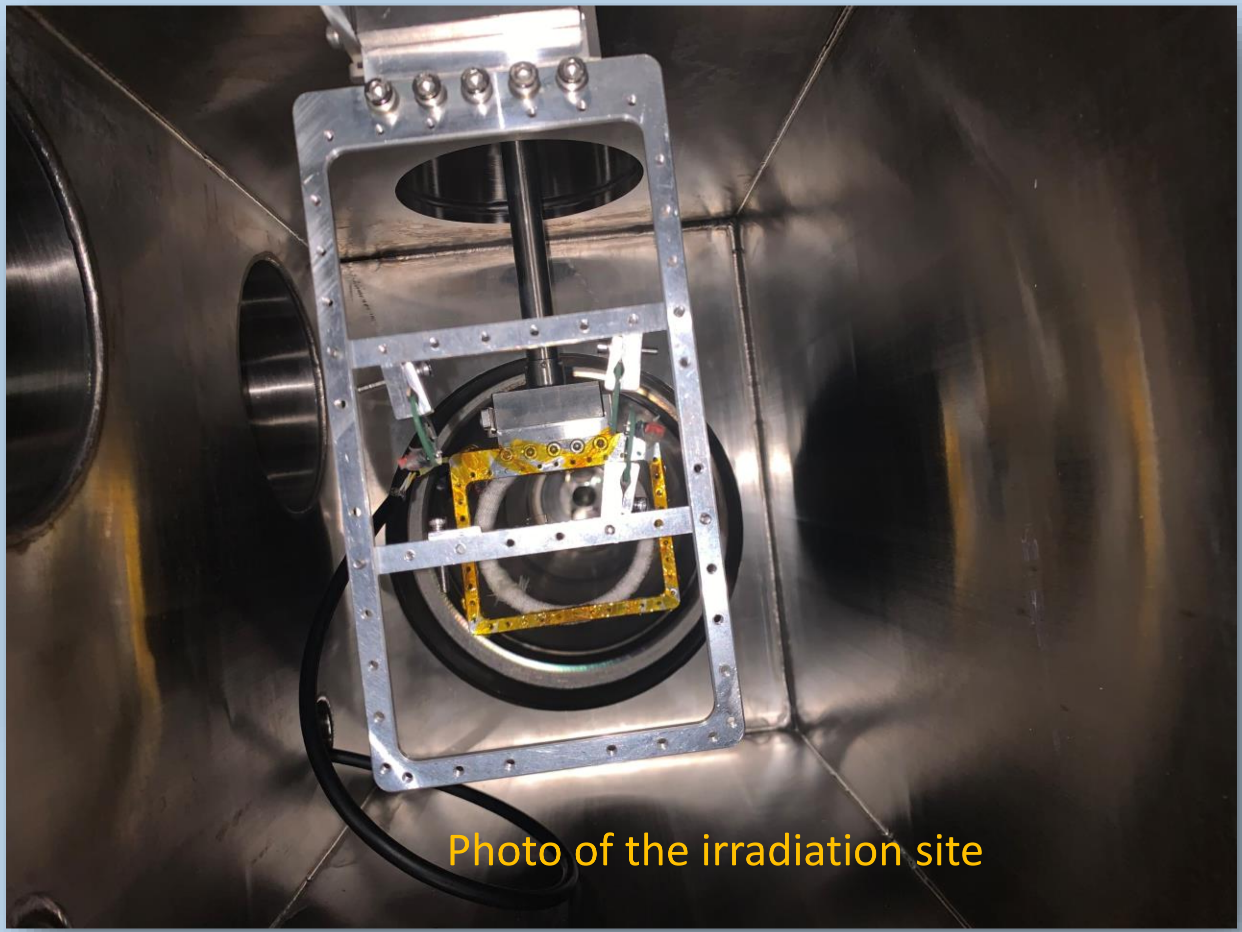


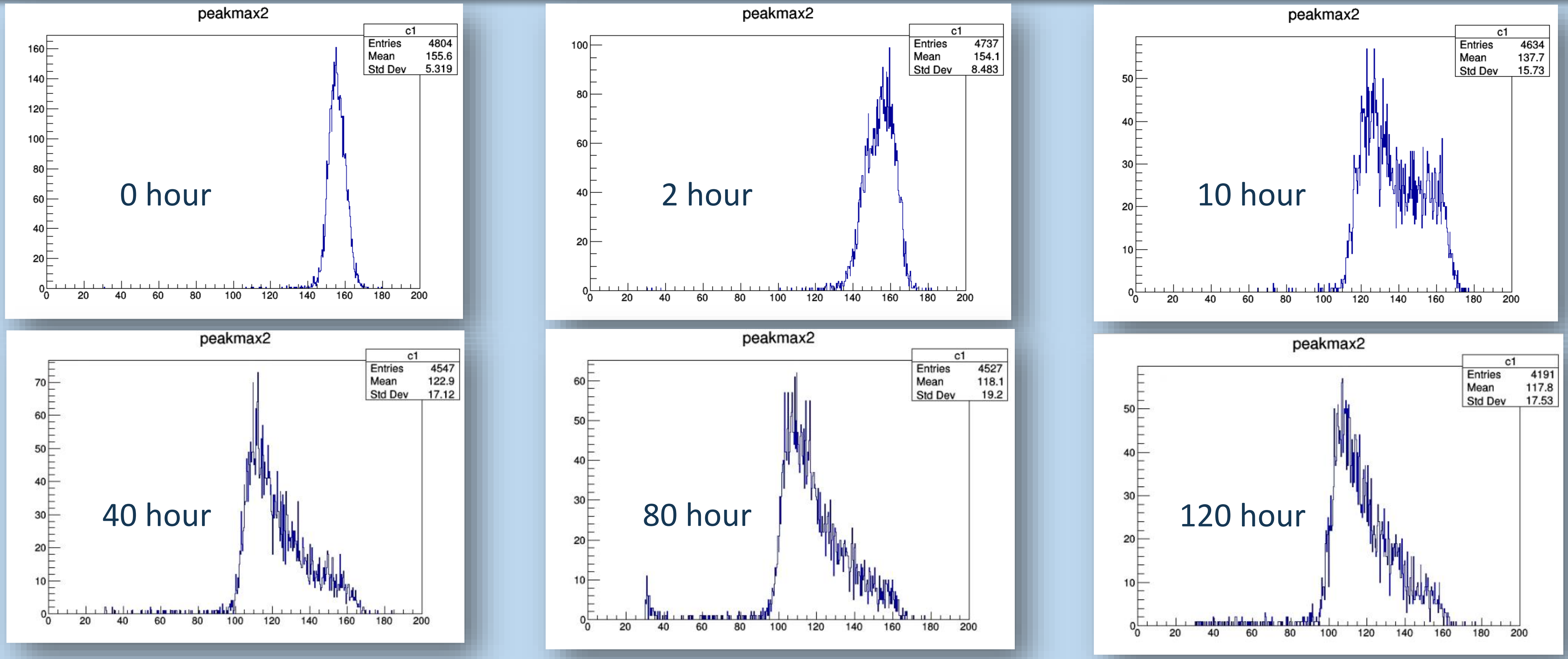
Photo of detector installation, the metal in the middle is the beam spot simulation structure



After 15 days of neutron irradiation, the neutron dose received is about 10^{14} cm^{-2}.

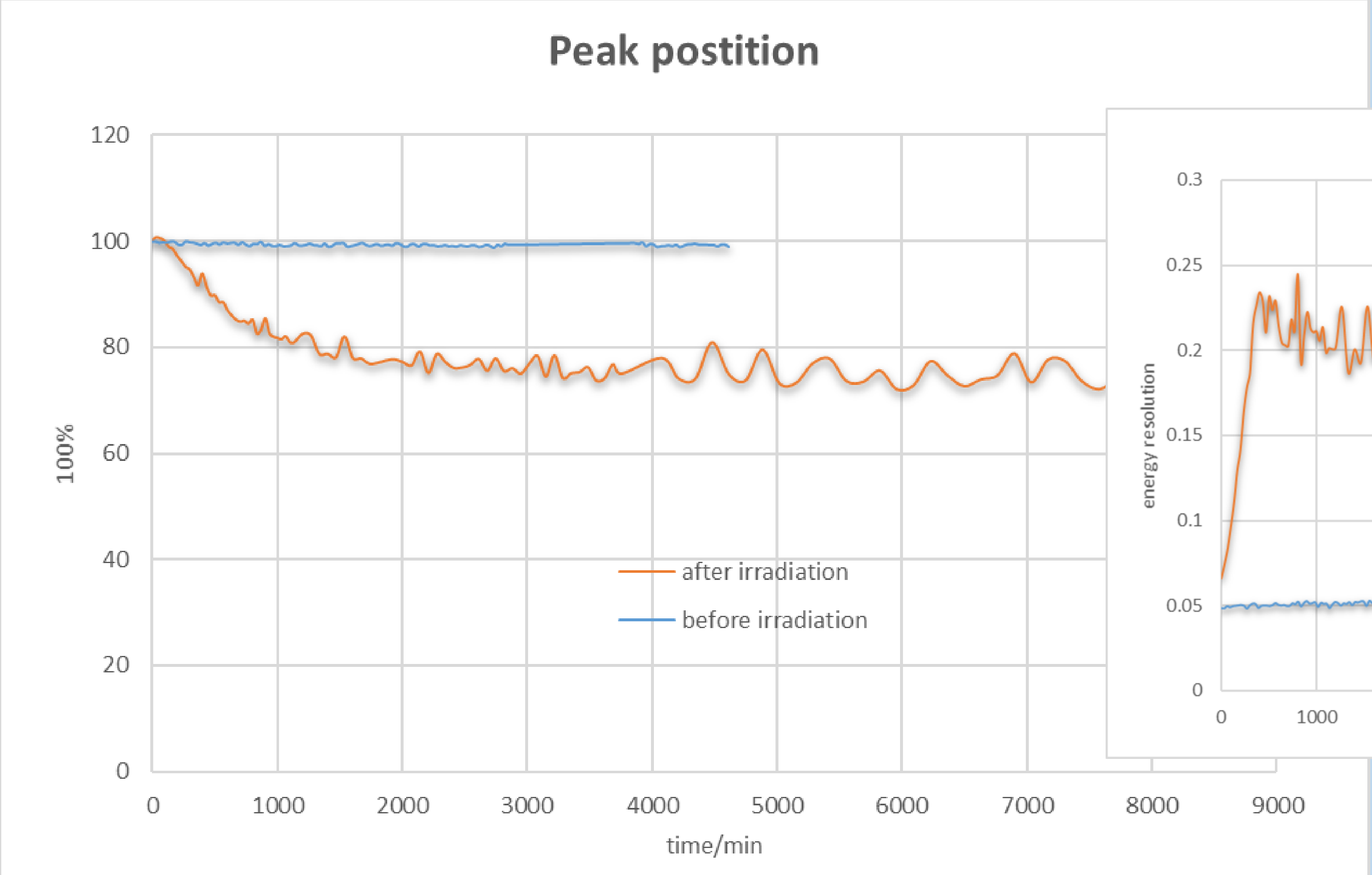
It is equivalent to 3000 hours of experiments on the beamline, compared to a typical nuclear data measurement experiment that generally does not exceed 300 hours.

Performance of irradiated SiC

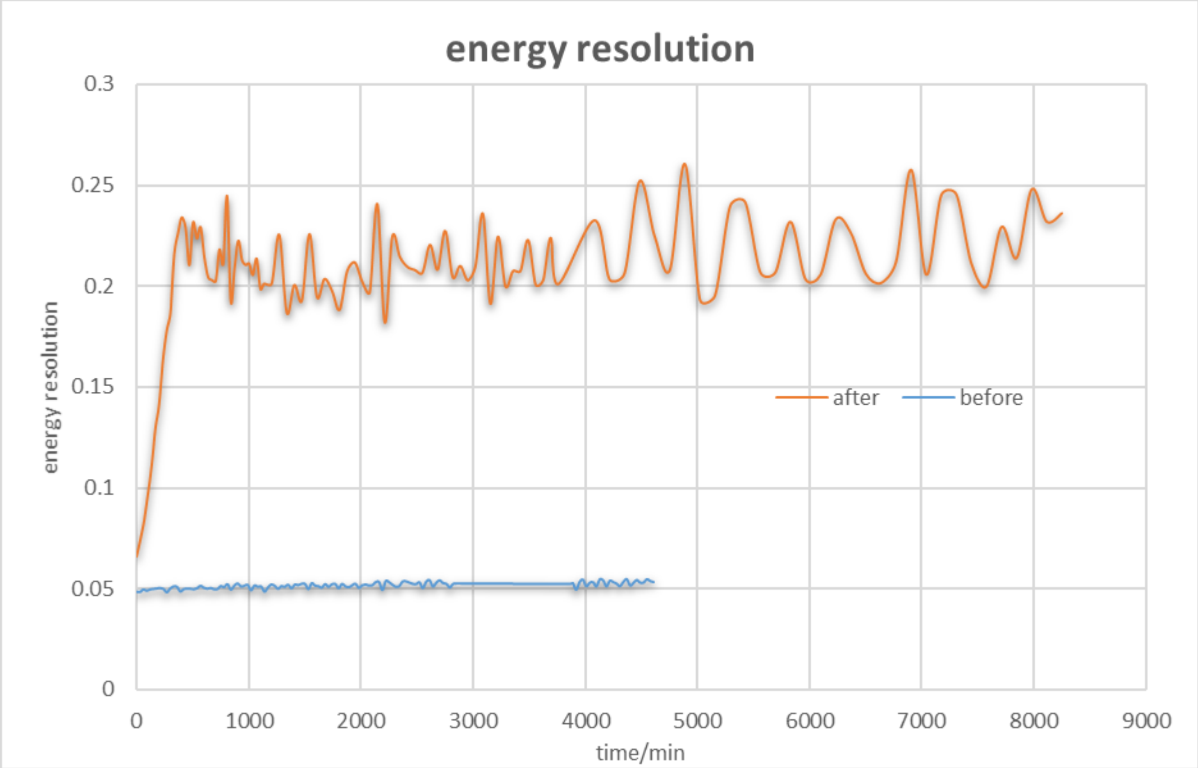


As the bias-on time increases, the peak position moves to the left and the resolution decreases. The state of the detector can be restored if the bias is reset.

Comparison

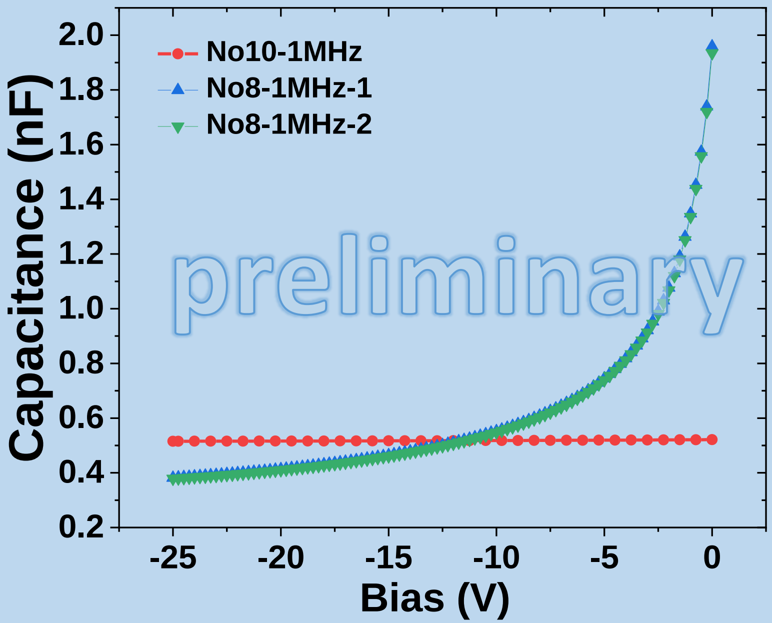


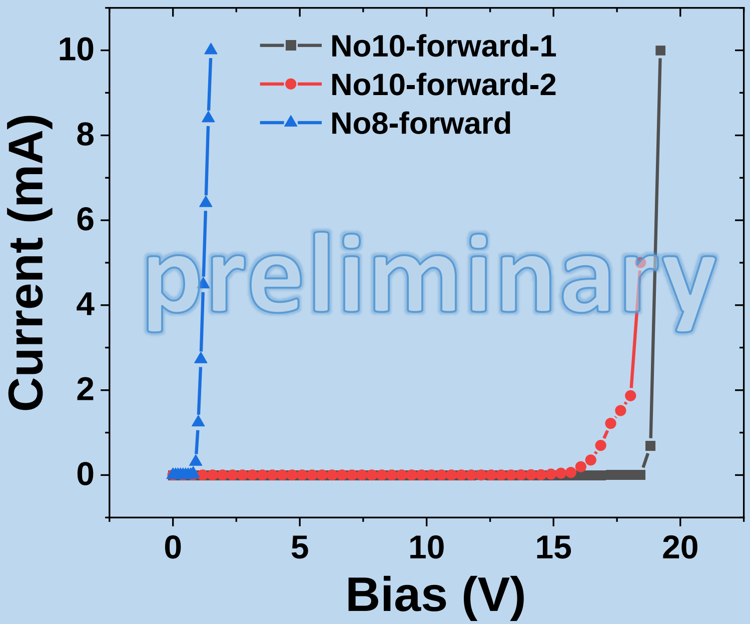
Peak postition
120
100
80
60
40
20
0
100%
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
time/min
after irradiation
before irradiation

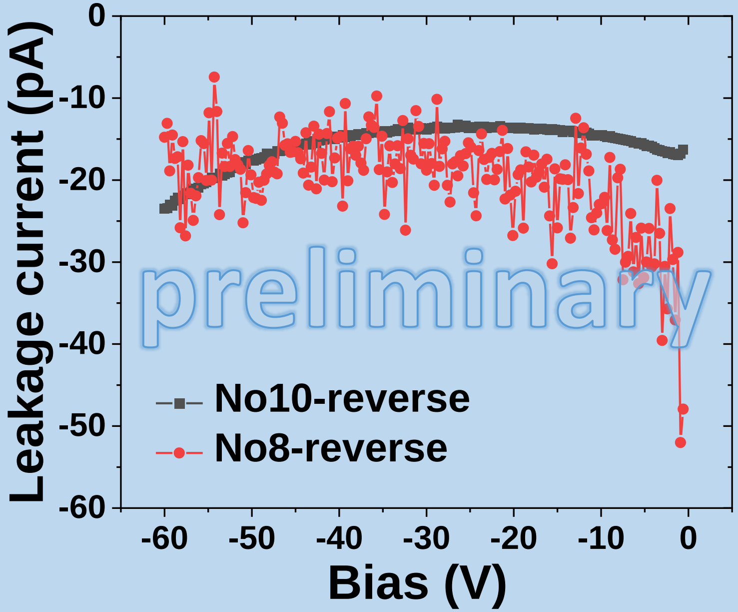


energy resolution
0.3
0.25
0.2
0.15
0.1
0.05
0
energy resolution
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
time/min
after
before

I/V & C/V Comparison







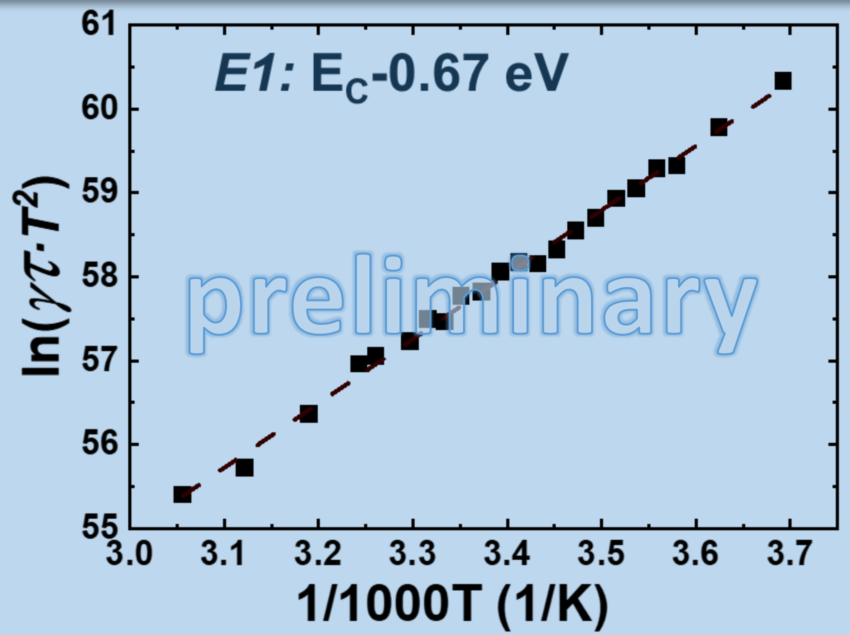
Two detectors were compared, one fresh and one irradiated.

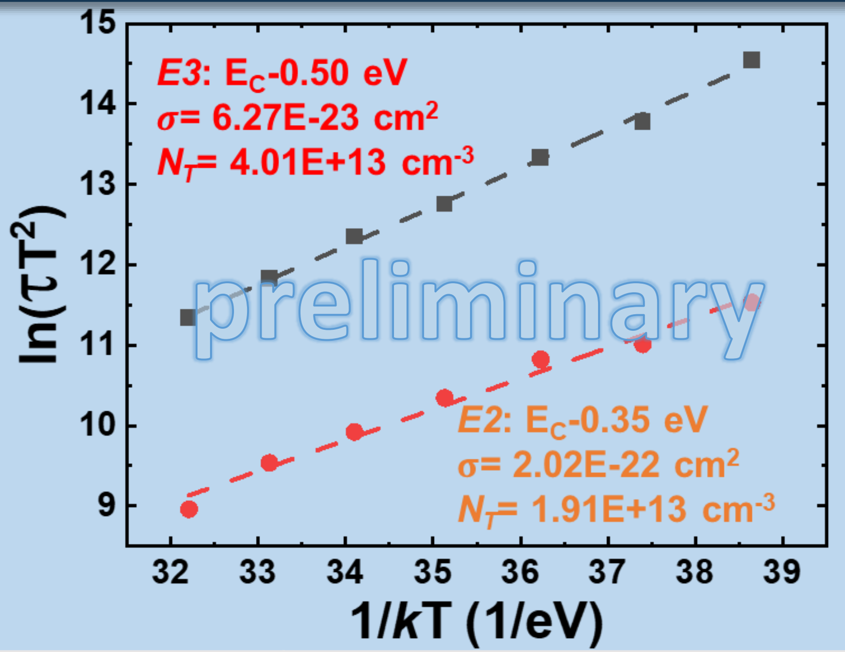
Conclusion:

- Sample8(fresh) shows normal Schottky junction characteristics.
- From IV and CV, sample10(irradiated) don’t show the Schottky junction characteristic.

SiC detector tested by DLTS

Fresh





Irradiated

	Activation energy (eV)	Capture cross-section (σ) (cm^2)	Trap concentration N_T (cm^{-3})	Process
E1	E_C-0.67 ± 0.01	2.07E-14	3.31E+14	Fresh
E2	E_C-0.35 ± 0.03	6.27E-23	1.91E+13	Irradiated
E3	E_C-0.50 ± 0.03	2.02E-22	4.01E+13	Irradiated

Summary

- Neutron irradiation can cause a decrease in performance of the Schottky SiC detector.
- I/V and C/V test shows that the Schottky junction characteristic disappears
- DLTS indicates two electron traps (E2 & E3) in irradiated sample
- More detailed work to be continued…

CSNS can provide opportunities for detector irradiation and applied research.

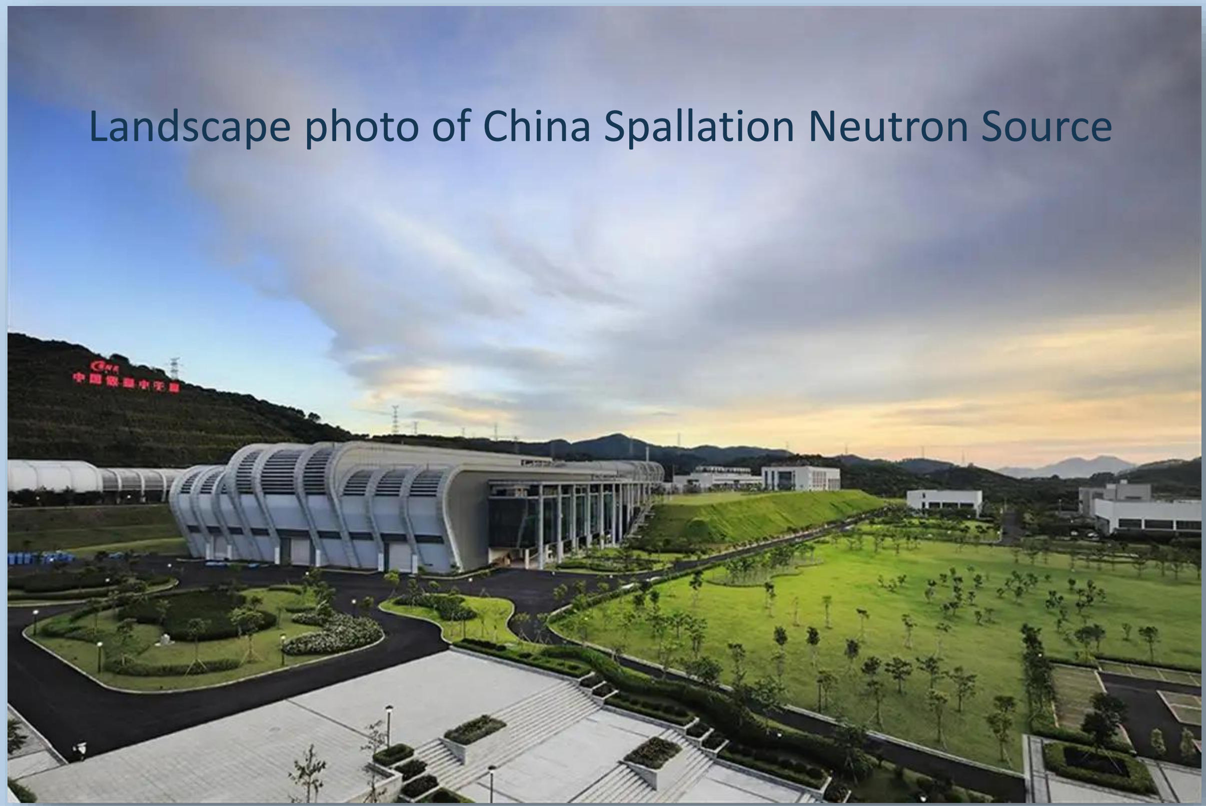
Thank you and welcome proposal !

Apply for Beam Time:

White neutron: https://backn.csns.ihep.ac.cn/

Proton: https://apep.csns.ihep.ac.cn/

MAIL: fanrr@ihep.ac.cn



Backup

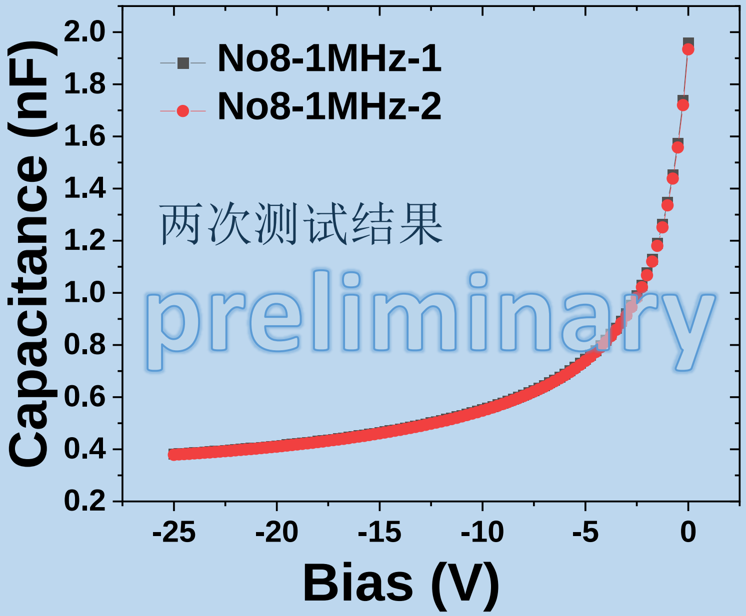
Test conditions (300K):

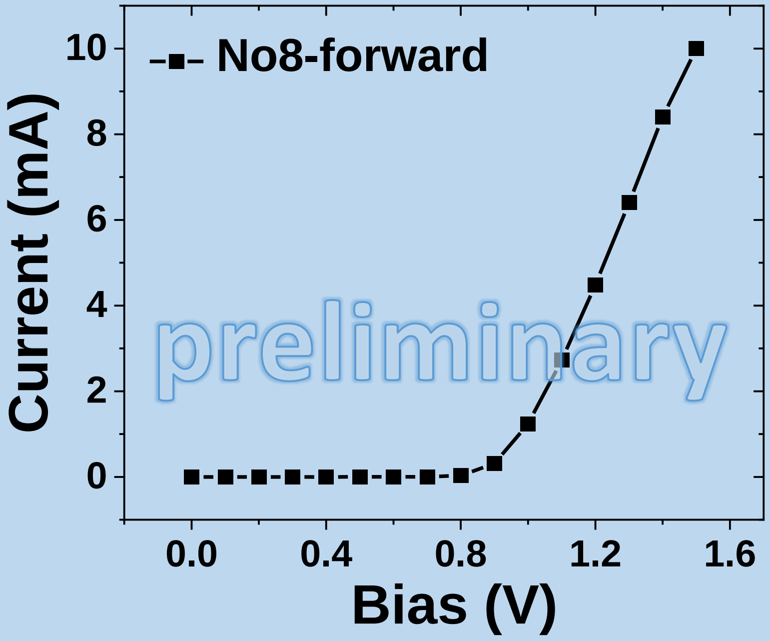
- Reverse bias range: 0_-60V
- Forward IV: (max 10mA)

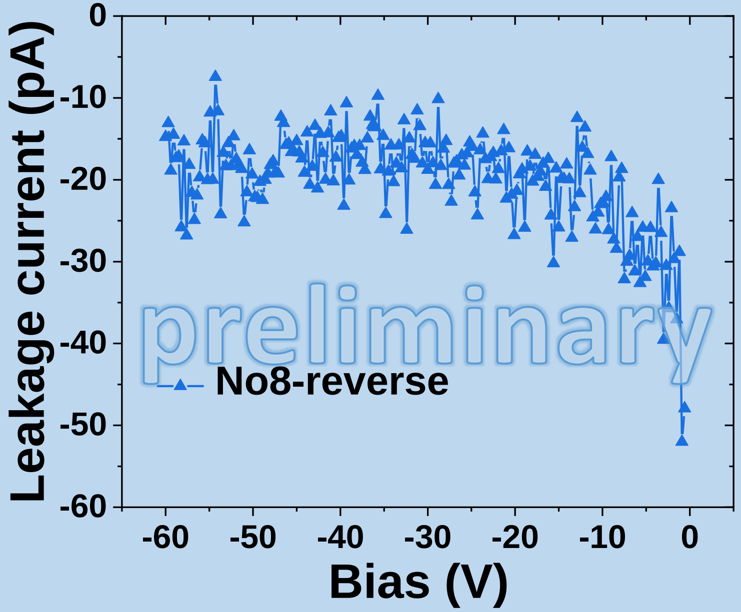
CV:

- bias range (-25V);
- frequency: 1MHz;
- AC amplitude:50mV

Sample8-fresh: IV and CV characteristics at RT

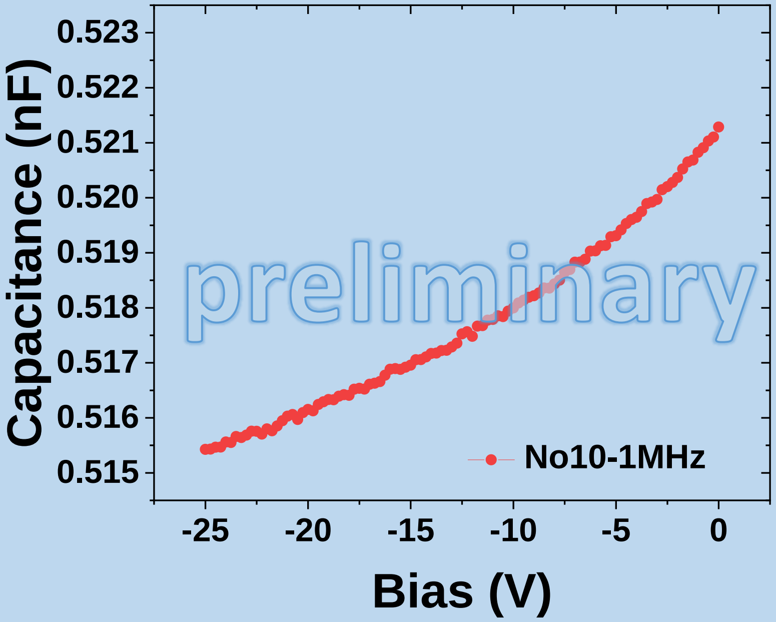


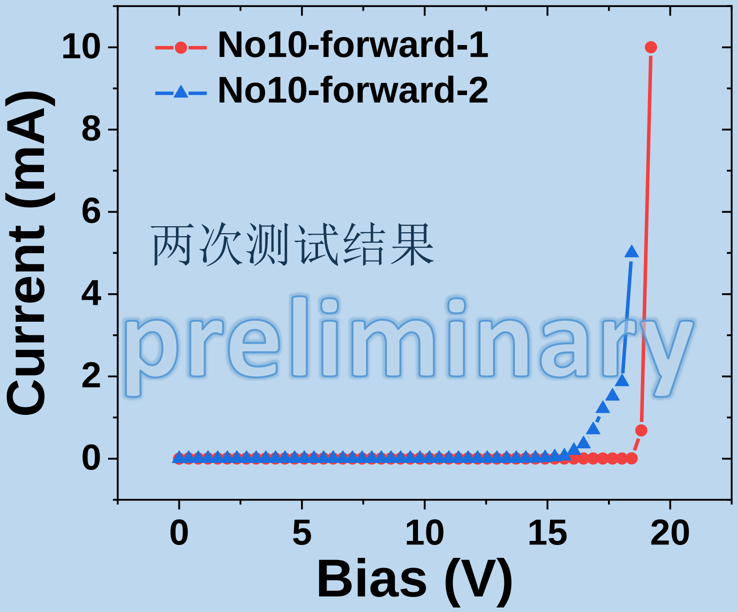


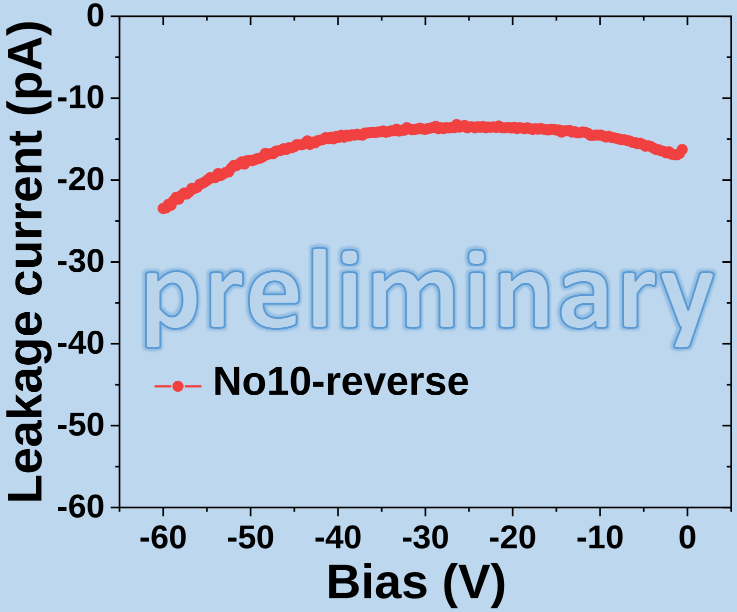


- When −25V, the capacitance is 0.37nF.
- For forward IV characteristics, turn-on voltage is around 1V.
- For reverse IV characteristics, leakage current is −14.78pA at −60V.

Sample10-irradiated: IV and CV characteristics at RT

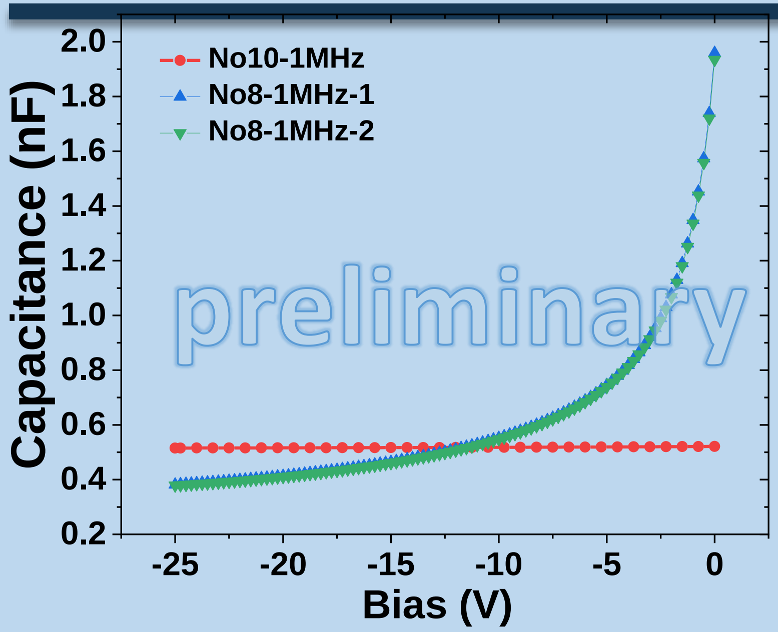


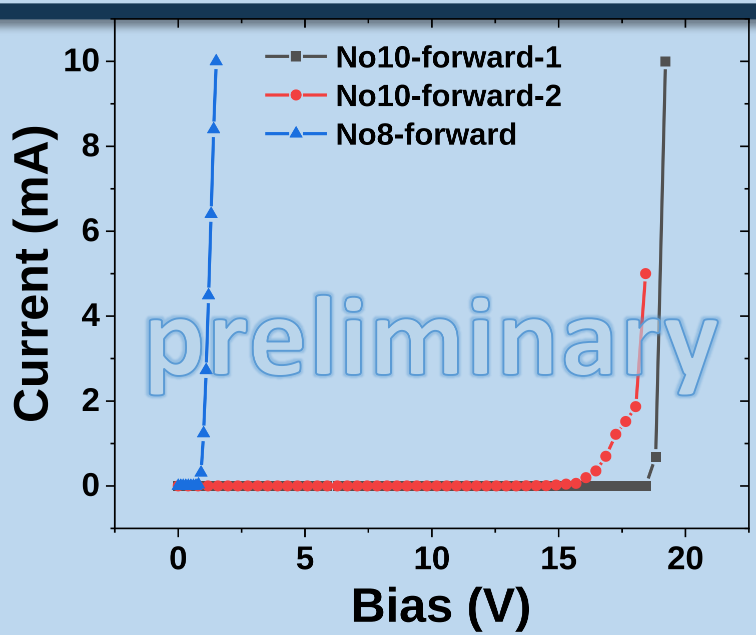


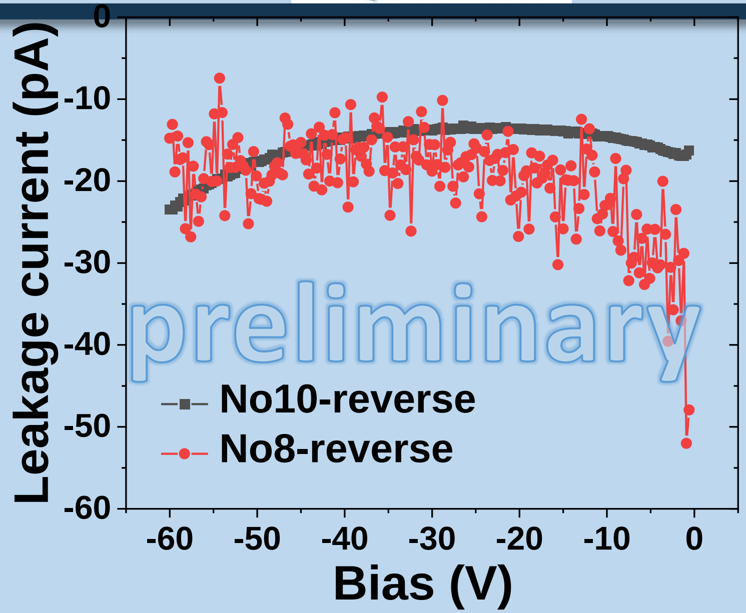


- Capacitance is nearly stable when varying reverse bias.
- For forward IV characteristics, turn-on voltage is above 15V.
- For reverse IV characteristics, leakage current is -23.47pA at -60V.

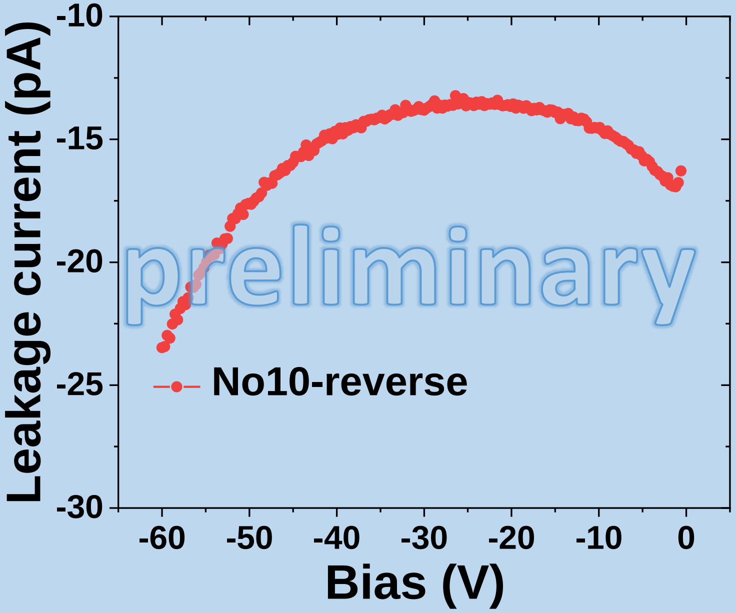
Comparison





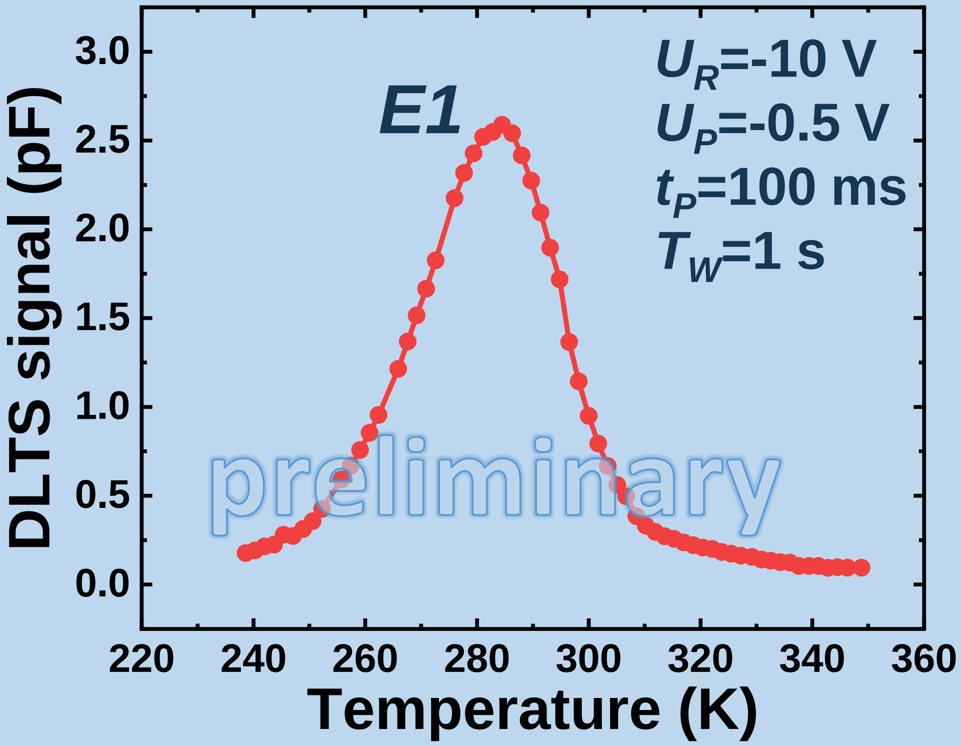


- Sample8 shows normal Schottky junction characteristics.
- From IV and CV, sample10 don't show the Schottky junction characteristic.

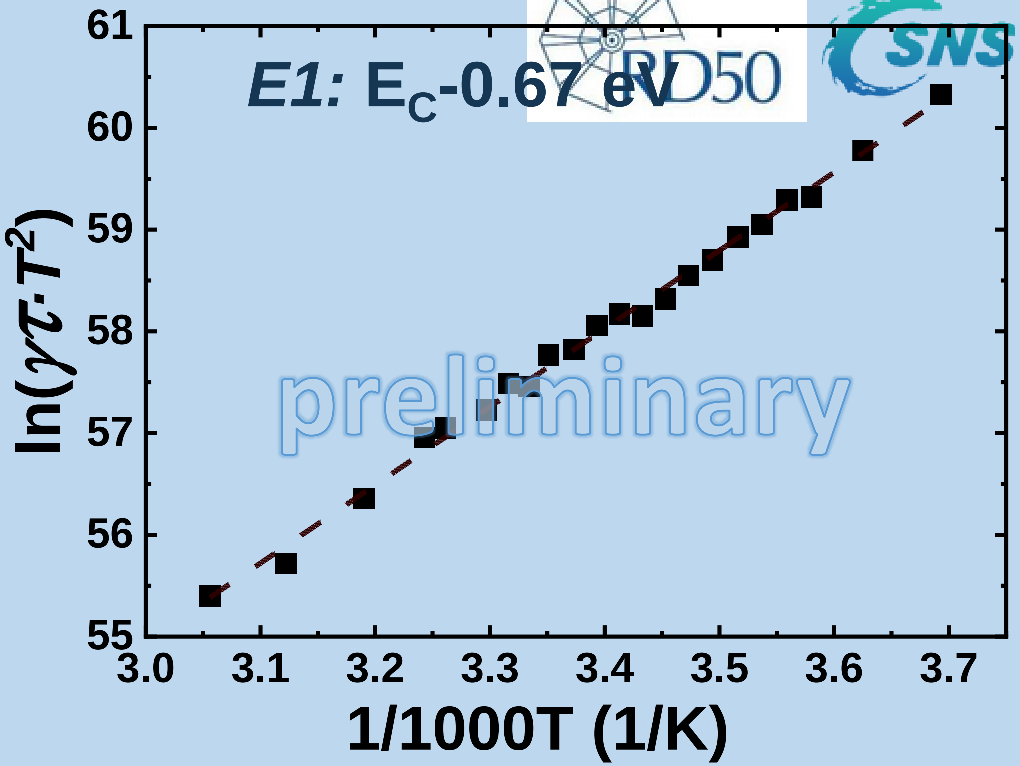


Leakage current (pA)
-10
-15
-20
-25
-30
-60
-50
-40
-30
-20
-10
0
Bias (V)
No10-reverse
preliminary

Deep level transient spectroscopy (DLTS) for fresh sample



Arrhenius plot

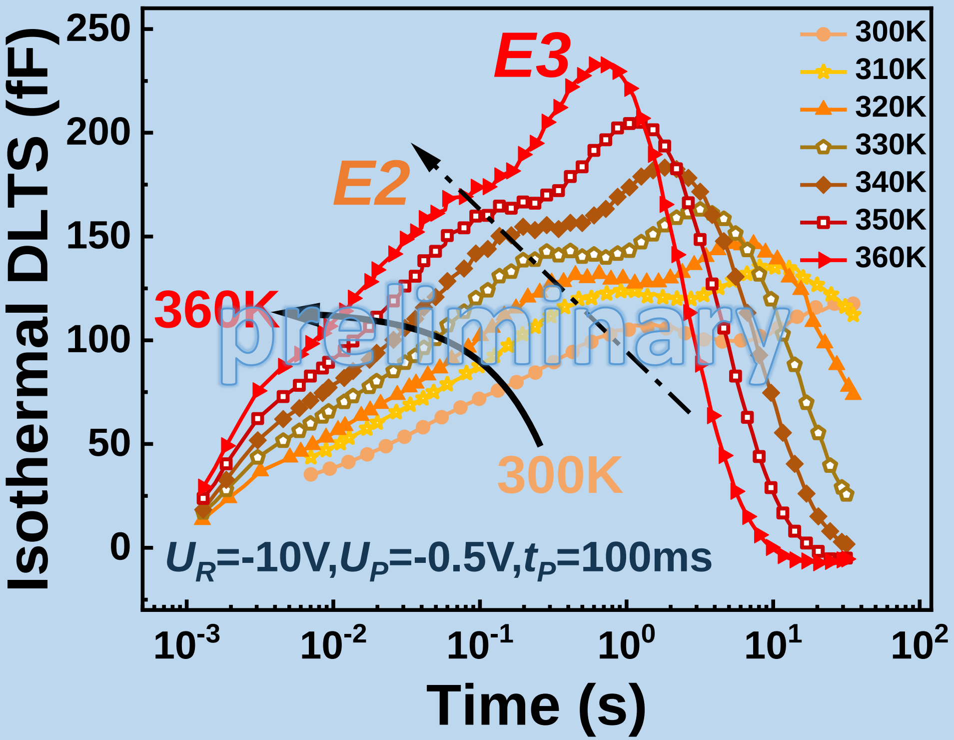


- One electron trap was observed around 280K labeled as E1 by DLTS.

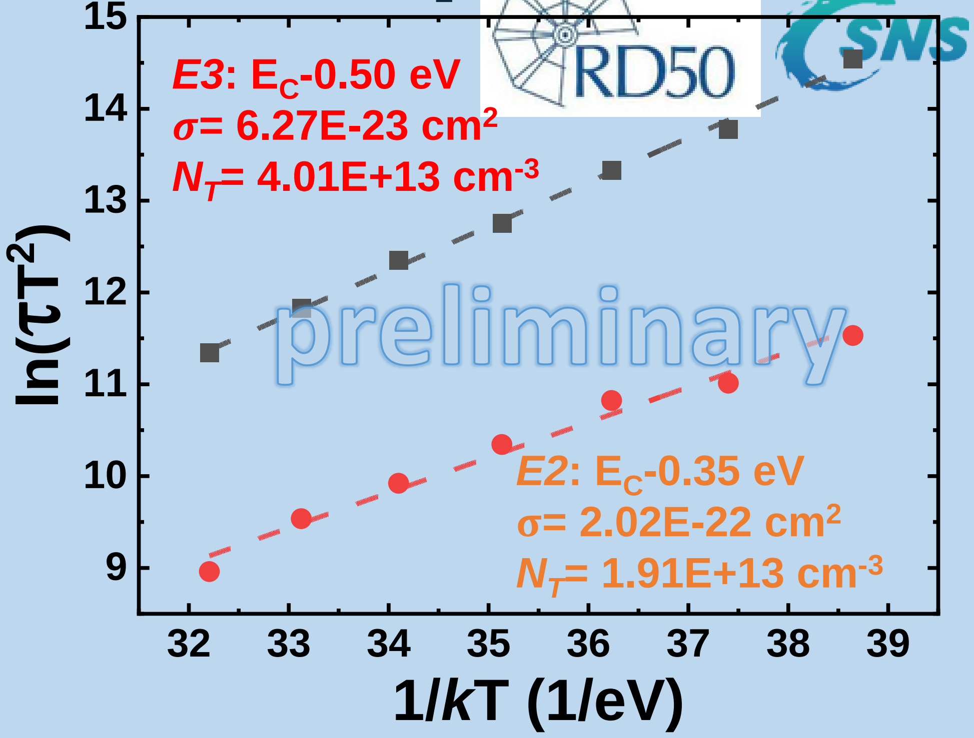
***E1* properties:**

- activation energy: E_C-0.67 eV;
- capture cross-section: 2.07E-14 cm^2;
- trap concentration: 3.31E+14 cm^{-3};

Isothermal DLTS for irradiated sample



Arrhenius plot



- Using DLTS test at isothermal conditions, from 300-360K, two signal peaks were observed corresponds to two electron traps (***E2*** & ***E3***) in irradiated sample.
- *E3* has **higher signal amplitude** and **longer emission time constant** than *E2*, indicating *E3* is dominated trap and has deeper activation energy.
- With increasing temperature, peaks (corresponds to τ) are shifting towards shorter time side.
- By Arrhenius plot, trap properties of ***E2*** & ***E3*** can be extracted.

Comparison of trap properties

	Activation energy (eV)	Capture cross-section (σ) (cm^2)	Trap concentration N_T (cm^{-3})	Process
E1	E_C-0.67 ± 0.01	2.07E-14	3.31E+14	Fresh
E2	E_C-0.35 ± 0.03	6.27E-23	1.91E+13	Irradiated
E3	E_C-0.50 ± 0.03	2.02E-22	4.01E+13	Irradiated

- In fresh sample, one electron trap *E1* (0.67eV) was observed by DLTS.

After irradiation:

- two electron traps *E2*(0.35eV) & *E3*(0.50eV) were detected by DLTS at isothermal condition
- capture carrier ability (σ) of traps was suppressed
- trap concentration of traps was decreased