Shanghai Astronomical Observatory
Chinese Academy of Sciences

Demonstration SLR Experiment using Superconducting Nano-wire Single Photon Detector at 532 nm

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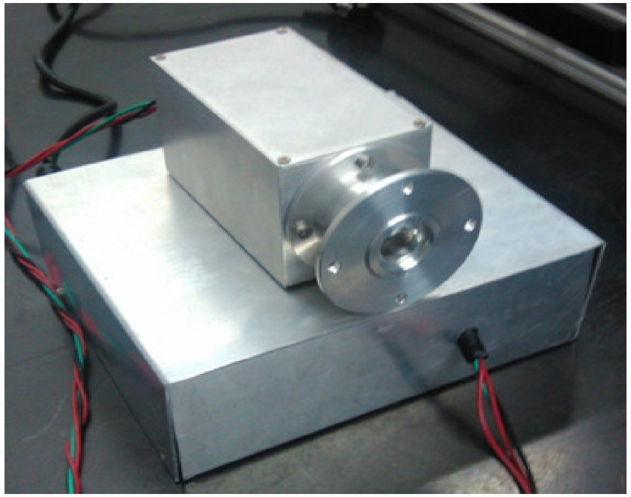
Overview

1. Introduction
2. Superconducting Nanowire Single Photon Detector(SNSPD)
3. Application in 1KHz SLR experiment
4. Conclusion

1. Introduction

- SPAD made by Czech Technical University with the chip diameter of 0.1mm are used in Shanghai SLR station in 1991.
- And the one with time walk compensation (C-SPAD) is being used since 1997 and the measuring precision with ps-laser is about 1.0 cm for LAGEOS.
- With the development of space debris laser ranging in Shanghai, it makes the demand of laser detector with low dark noise, high QE.
- The breadboard APD detector with the diameter of 0.5mm, QE ~ 40%, dark noise ~1kHz (200Hz gate signal), jitter ~500ps is developed by group of SHAO and East China Normal University for detecting echo from space debris.



1. Introduction

- The demonstration APD detector have been applied to laser measurement to space debris and validate its performances.
- C-APD detector developed by Czech Technical University is also used by for debris ranging.
  - Chip diameter of 0.5mm
  - QE ~ 40%
  - Dark noise ~18kHz (200Hz gate signal)
  - jitter ~500ps.

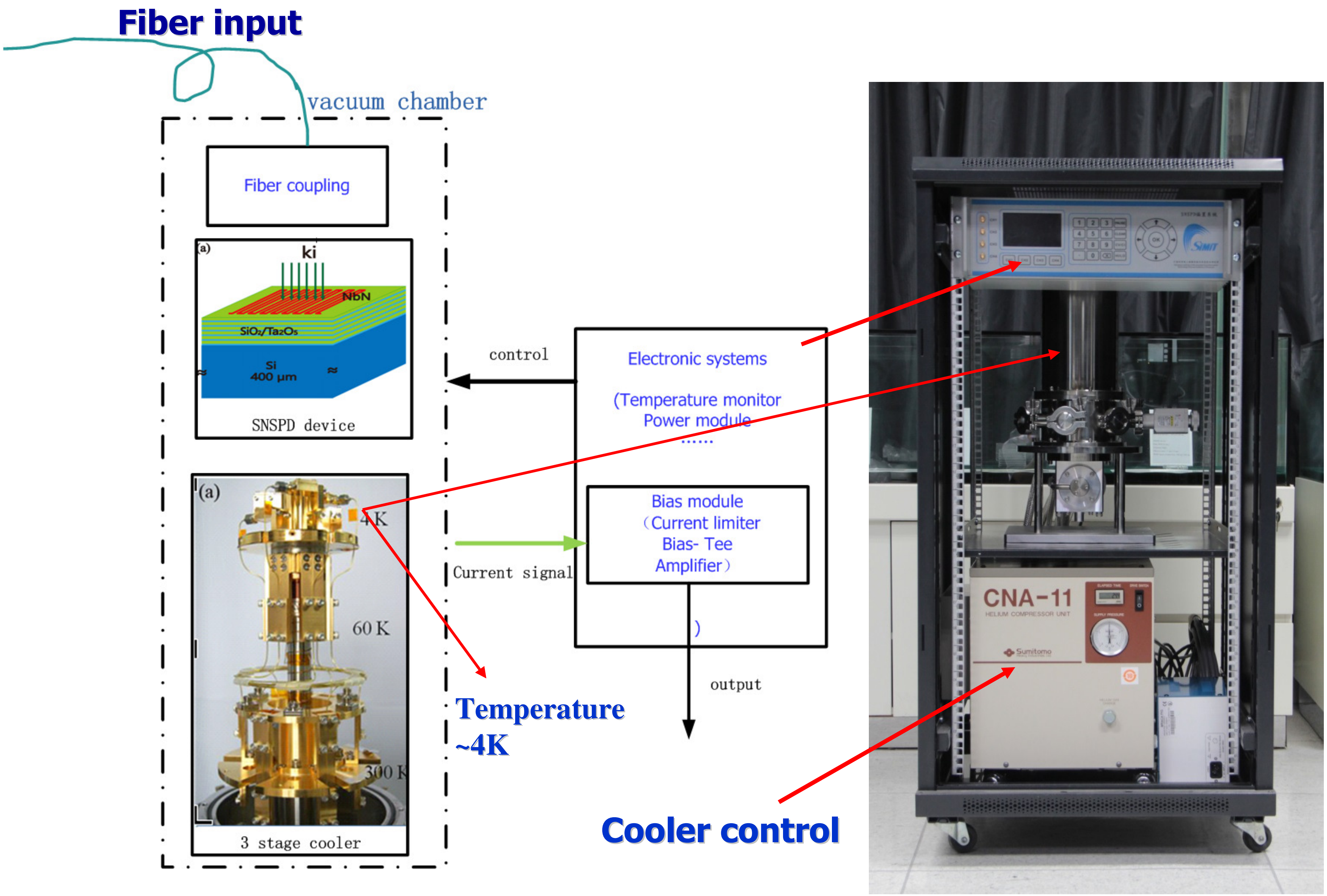
- For further developing and testing the performance of new type detector in the observation to space targets, the attention of Superconducting Nanowire Single-photon Detector (SNSPD) is paid in order to make a trial in the laser ranging.

2. SNSPD

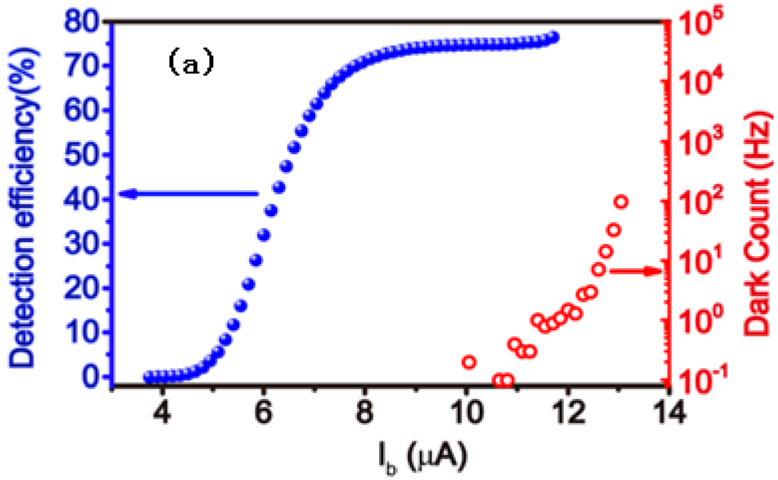
- In the last decade superconducting nanowire single-photon detector (SNSPD) have been largely improved and received considerable attention due to its outstanding performance, high QE, low noise, lower jitter.
- SNSPD with 1550nm wavelength have been used in:
  - long-distance quantum key distribution (QKD)
  - space-ground laser communication
  - depth imaging
  - on-chip characterization of nanophotonic circuits
- SNSPD may have excellent performance at shorter wavelength since the photons of shorter wavelengths have larger photon energy which cause high detection probability:
  - fluorescence spectroscopy detection at 635nm
  - Singlet oxygen luminescence detection at 1270 nm

2. SNSPD

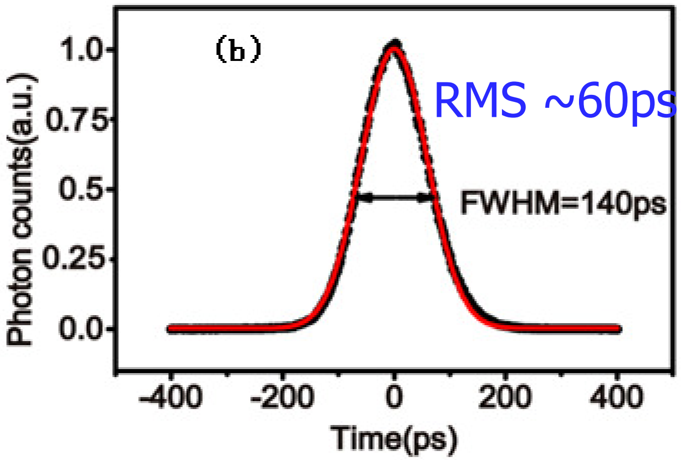
- **Cooperation with Chinese institute of CAS-----Shanghai Institute of Microsystem and Information Technology (SIMIT), the first version for 532nm laser detection is designed and developed.**
  - **SNSPD dedicated for 532nm:**
    - **Coupled with multimode fiber (MMF) with 50μm diameter (ϕ = 50 μm)**
    - **diameter of sensitive chip : 42 μm**
    - **chip working temperature : near 4K**
    - **maximum system detection efficiency (DE) of 75%**
    - **extremely low dark count rate of 0.1 Hz.**
    - **timing jitter is about 60ps**
    - **no gate**


Fiber input
vacuum chamber
Fiber coupling
(a)
ki
NbN
SiO2/Ta2O5
Si
400 μm
SNSPD device
(a)
4K
60 K
300 K
3 stage cooler
control
Electronic systems
(Temperature monitor
Power module
......
Bias module
（Current limiter
Bias- Tee
Amplifier）
)
Current signal
output
Temperature
~4K
Cooler control
CNA-11
HELIUM COMPRESSOR UNIT
Sumitomo

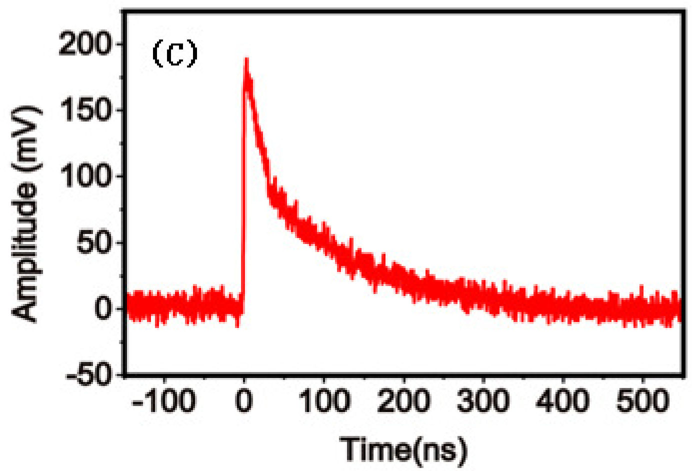
(a) **DE (left) and DCR (right) versus bias current. The DE is approximately 75% with DCR less than 1Hz.**



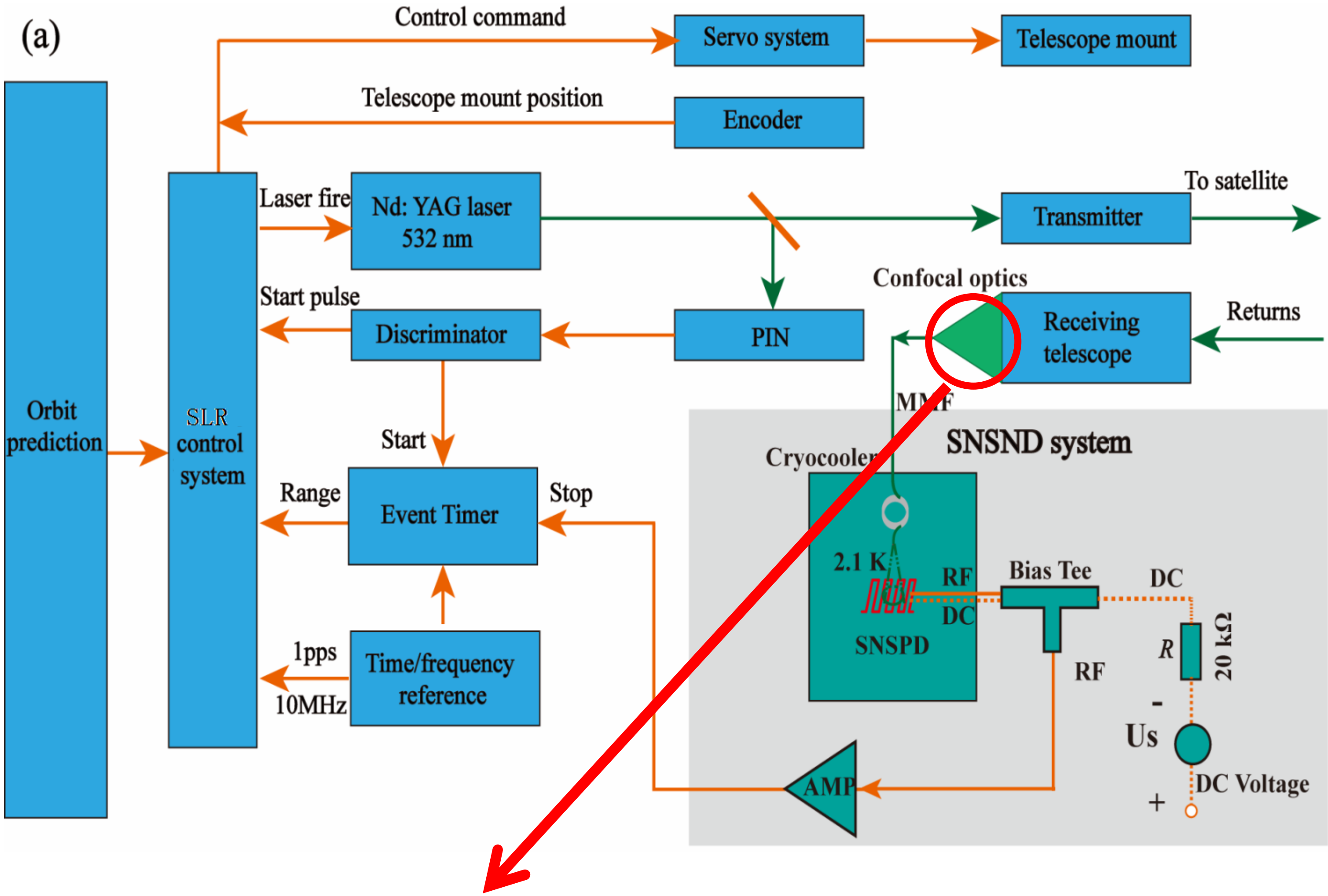
(b) **Histograms of the time-correlated photon counts measured at a wavelength of 532 nm. The red lines are the fitted curves using the Gaussian distribution.**



(c) **Oscilloscope persistence map of the response at a bias current of 10.0 μA. Recovery time of approximately 300 ns (dead time)**

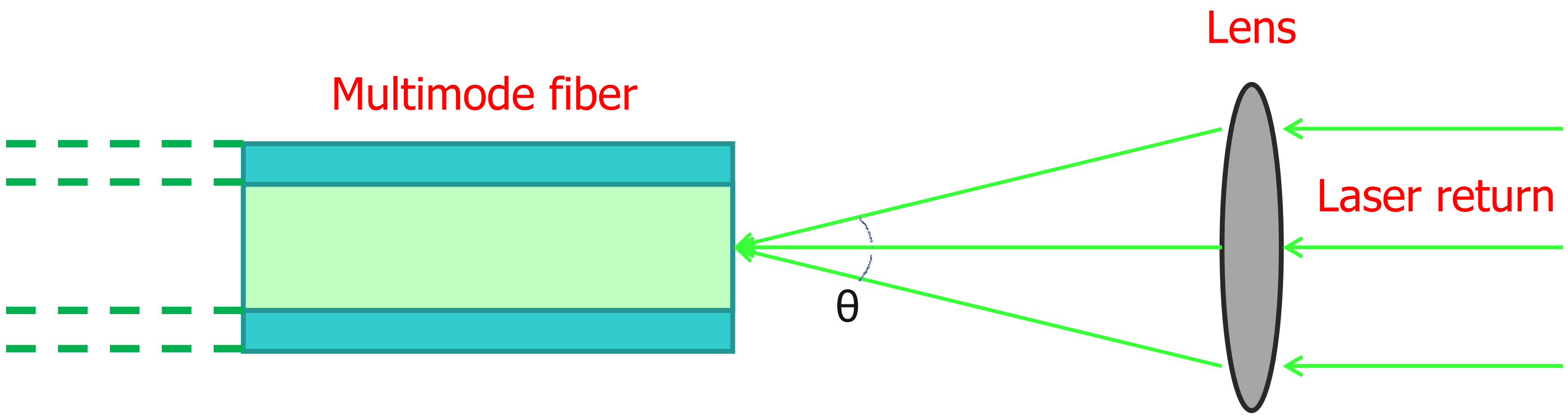


3. Application in SLR experiment



Confocal optics → small field of view

Receiving FOV of SNSPD



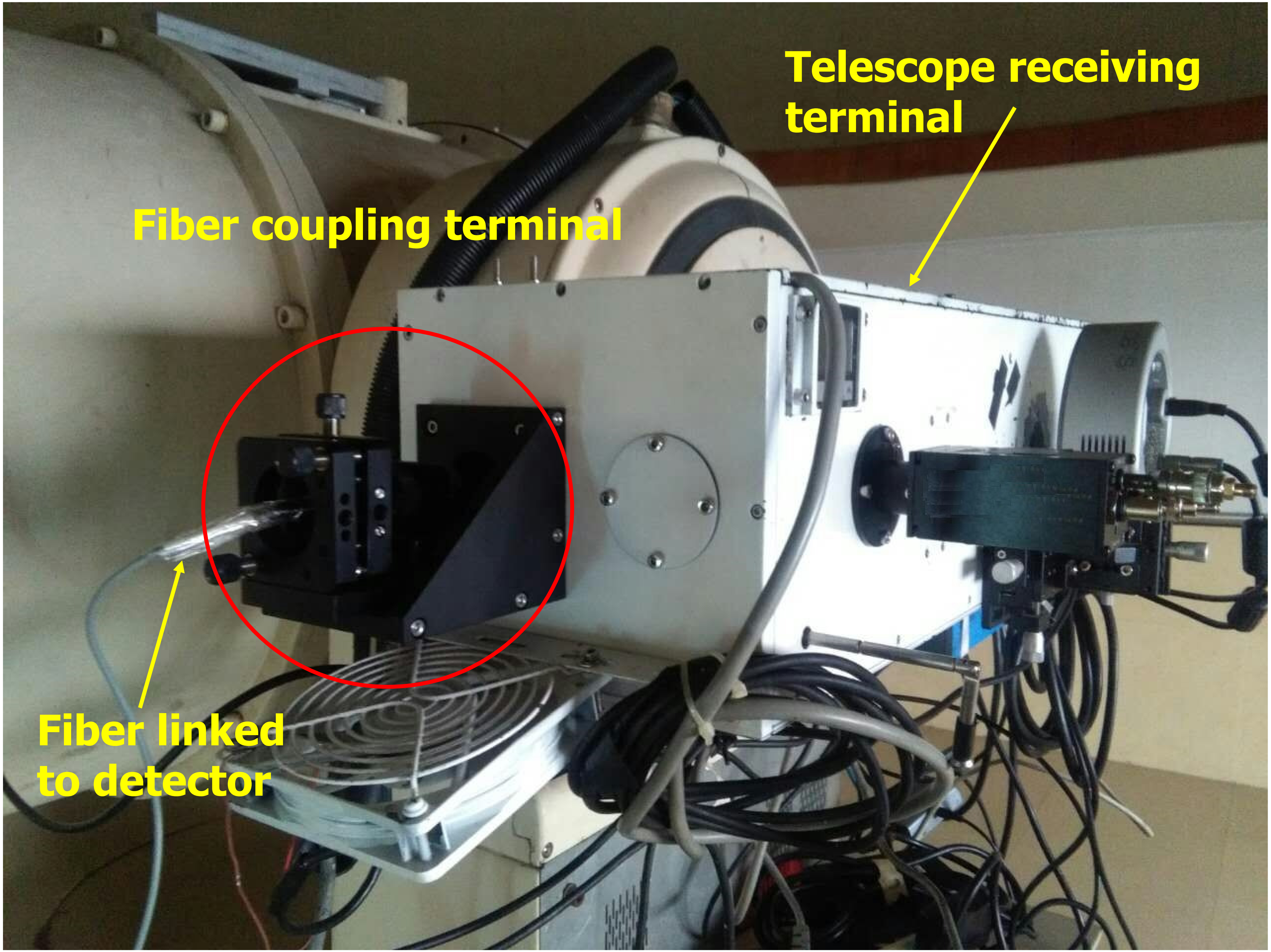
Limited by

1) Diameter of MMF (Multimode fiber): 50μm

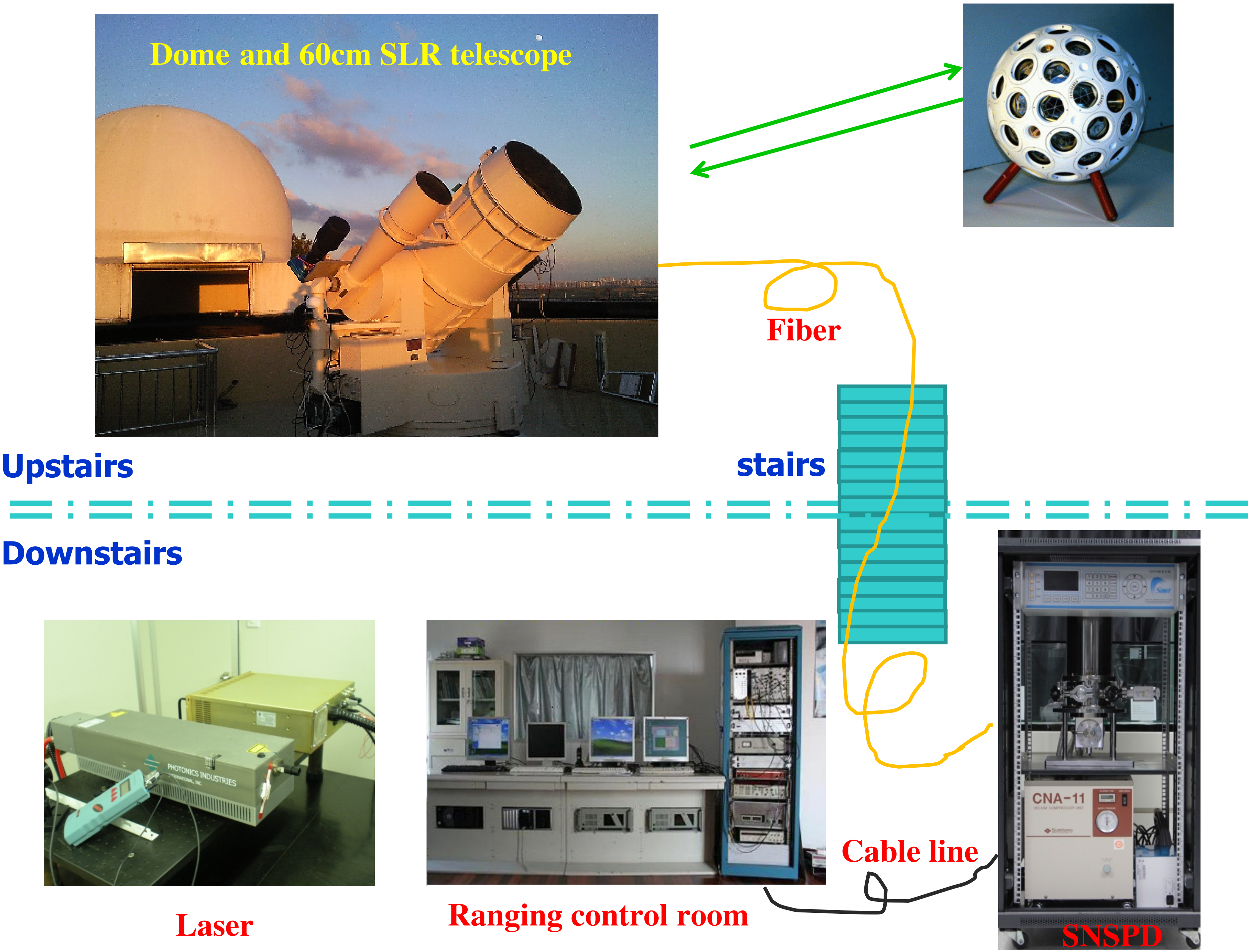
2) N.A (numerical aperture) of the fiber: sin(θ/2) = 0.18~0.23

SLR experiment has a fairly limited detector

FOV of ~ 10".



Telescope receiving terminal
Fiber coupling terminal
Fiber linked to detector


Dome and 60cm SLR telescope
Fiber
Upstairs
stairs
Downstairs
CNA-11
Cable line
Laser
Ranging control room
SNSPD

Calibration test

- **Laser :**

  532nm wavelength

  1 kHz repetition rate

  1 mJ per pulse

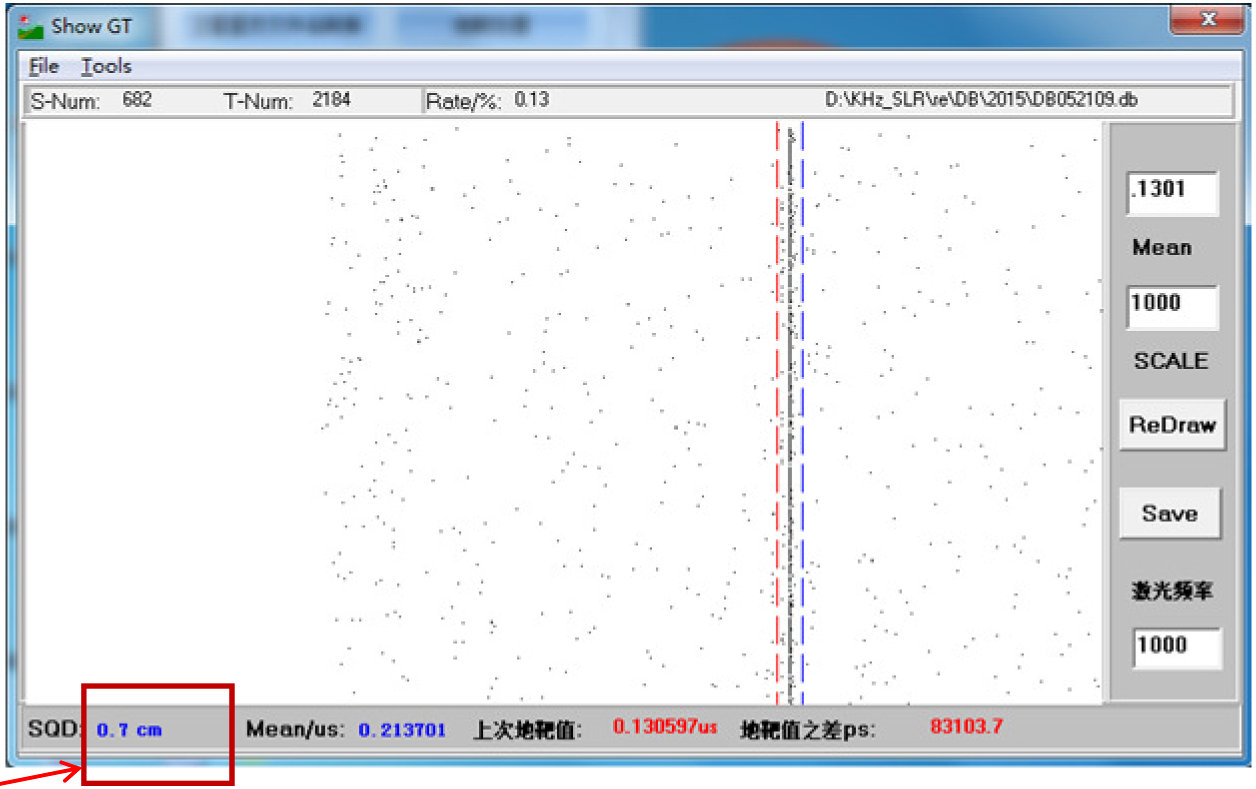
  30 ps pulse width

  0.6 mrad divergence

- **Event timer:**

  ET-A033

- **Calibration Precision (RMS): 0.7cm**



3. Application in SLR experiment

- **Due to the small receiving FOV for the demonstrated SNSPD, it is difficulty to make the collimation of transmitted and received laser signal.**
  - **Measuring the sensitive area of detector by countering the number of stop pulse through tracking star**
  - **Adjusting coude path of laser beam to make the stability of pointing**
  - **improving the telescope tracking performance**
- **Due to no gate control, many stop pulses will be recorded by ET to make data processing difficult.**
  - **Setting the gate control on ET to make less stop pulses recorded.**
  - **The first two stop pulses within each measuring period (1kHz) are used for data processing in order to increase the number of laser echoes.**

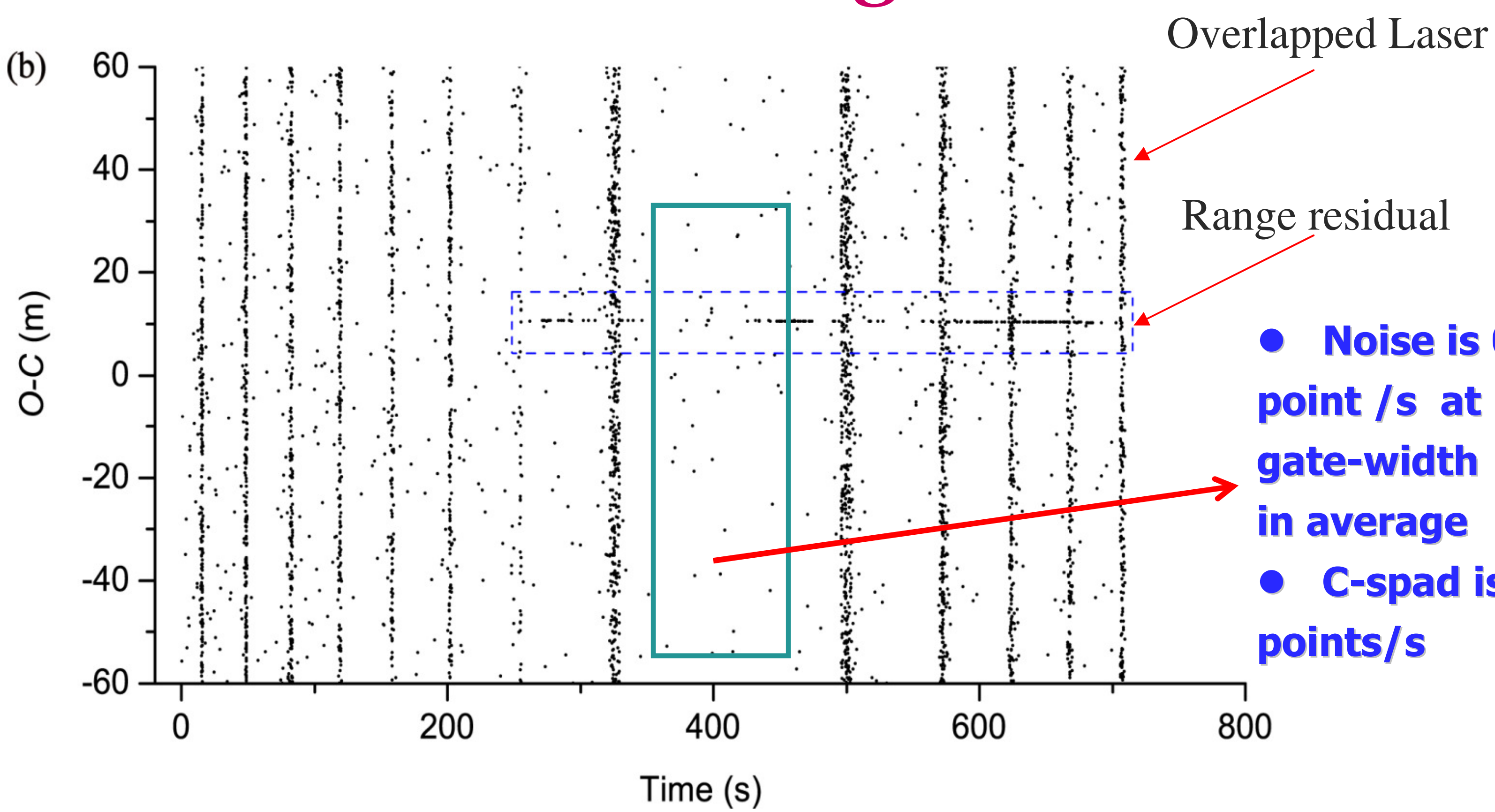
3. Application in SLR experiment

After the preparative works have been done, laser measurement to satellites was performed.

Date: 2015.05.21

- **Target: Lares**
- **Receiving telescope: 60 cm**
- **Transmitting telescope: 21 cm**
- **Pointing accuracy of the telescope after star calibration is about 5''**

Measuring results



- **Noise is 0.4 point /s at 70m gate-width in average**
- **C-spad is 136 points/s**

- **Due to the major coupling loss from telescope receiving terminal to MM Fiber to detector, the return ratio is not high, much lower than the expected one.**
- **The precision of measuring satellites is about 8.0 mm.**
- **BUT the noise is much lower than C-SPAD and APD to help enlarge gate width for measuring to space debris.**

4. Conclusion

- **SNSPD is firstly applied in SLR**
- **The measuring precision achieves around 8.0 mm**
- **Due to low fiber coupling efficiency the return rate do not achieve the expected goal.**
- **The way of fiber coupling link will**
  - **make the detector be set in the stable condition to improve stability.**
  - **make less noise from background**
- **Ultra low dark-counts also make high SNR.**

Low noise, High DE and high measuring precision

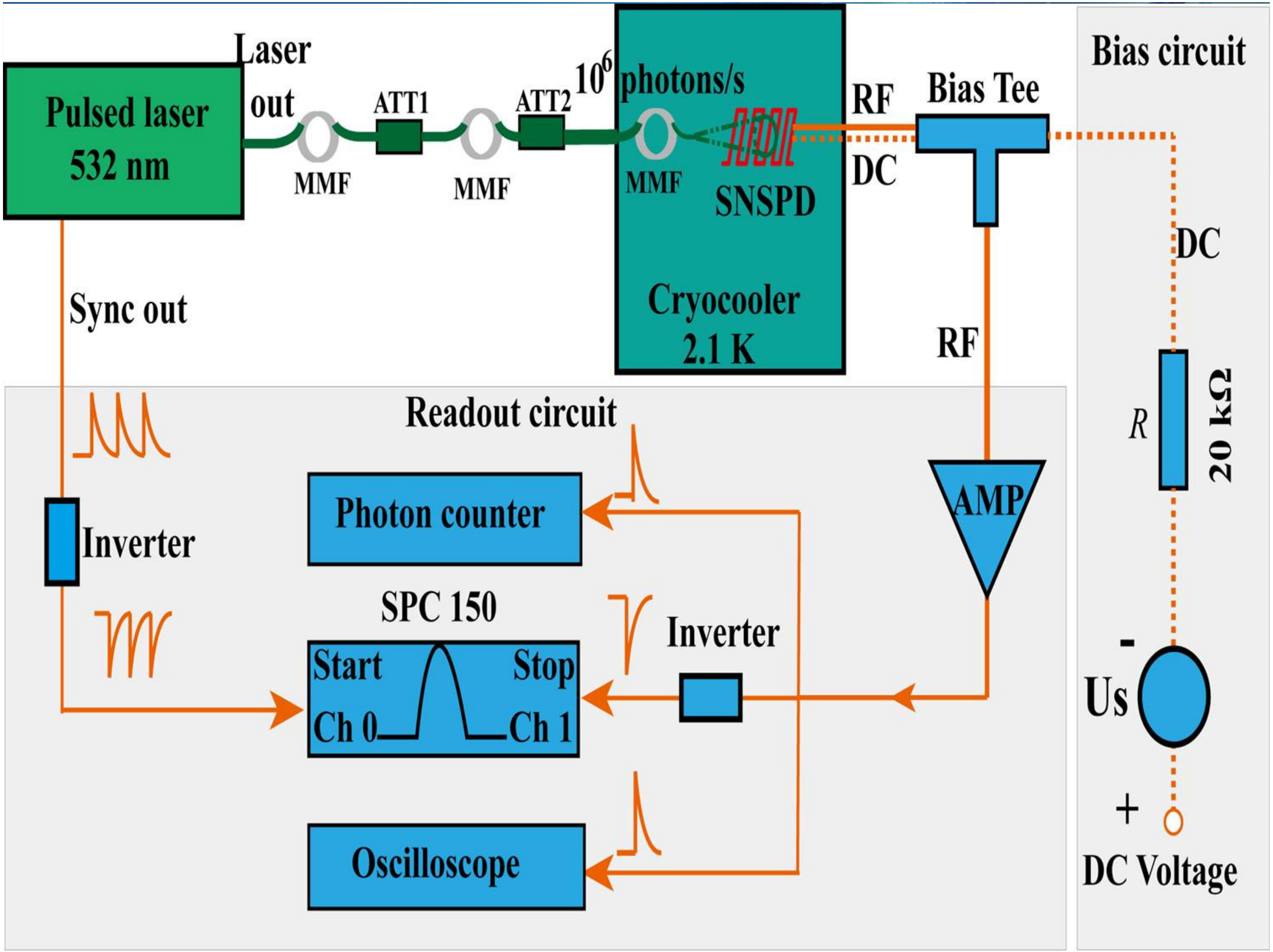
4. Conclusion

- **Next step:**
  - **Fiber coupling in the detector and telescope should be strictly aligned in the future for weak photon.**
  - **100 μm or 200 μm fiber for SNSPD with the diameter of sensitive chip 50 μm is being developed.**
  - **The detector with the larger sensitive chip (100 μm -200 μm) will be considered to make larger FOV observation.**

4. Conclusion

- **Prospect:**
  - **The detector with the characteristics of High EQ, Low noise, Low jitter is perfect to laser measurement, for high repetition SLR , lunar ranging.**
  - **Much better performance than APD in the wavelength of 1064nm, which is a good choice for 1064nm laser ranging to space debris or other applications.**
  - **Fiber coupling may lead to better results in daylight ranging for its coupling to prevent background noise into the fiber.**

Thank you



Pulsed laser
532 nm
Laser
out
ATT1
ATT2
MMF
MMF
MMF
10^6 photons/s
SNSPD
Cryocooler
2.1 K
RF
DC
Bias Tee
Bias circuit
DC
RF
R
20 kΩ
AMP
Sync out
Readout circuit
Inverter
Photon counter
SPC 150
Start
Stop
Ch 0
Ch 1
Inverter
Oscilloscope
-
Us
+
DC Voltage