Proton test beam facility at CSNS

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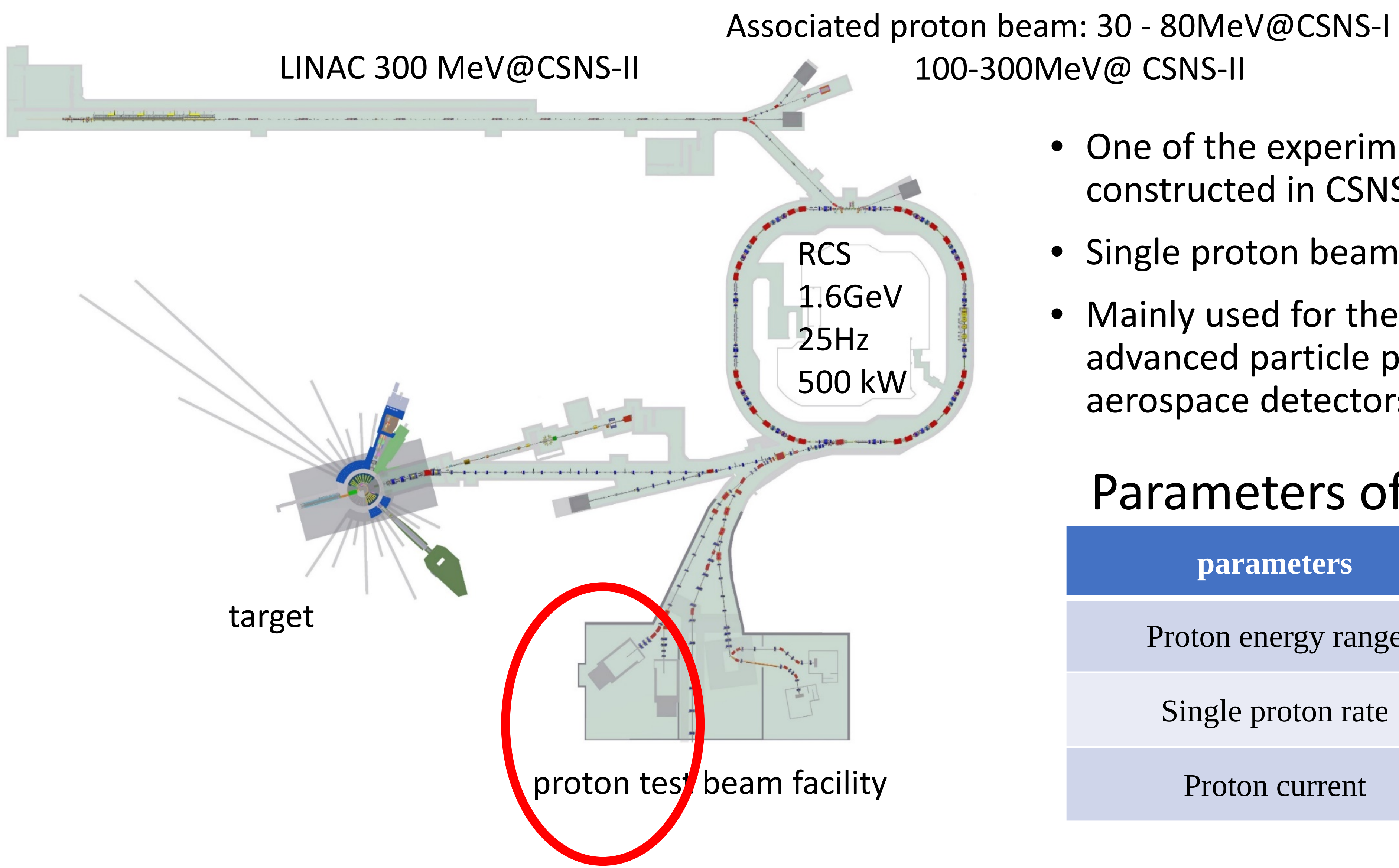
On behalf of the working group

2022.12.19

Outline

- Introduction of proton test beam at CSNS
- Preliminary design of detectors at proton test beam facility
  - Trigger
  - Beam telescope
  - Beam energy detector
  - Beam profile detector
  - Beam flux detector
- CSNS associated proton beam experimental platform
- Summary

location of proton test beam facility at CSNS



- One of the experimental stations will be constructed in CSNS Phase II
- Single proton beam
- Mainly used for the R&D and calibration of advanced particle physics detectors and aerospace detectors

Parameters of proton test beam

parameters	Design requirement
Proton energy range	0.8-1.6 GeV
Single proton rate	>1000 Hz
Proton current	$>2\times10^{6}$ n/cm^2/s

Single proton estimation

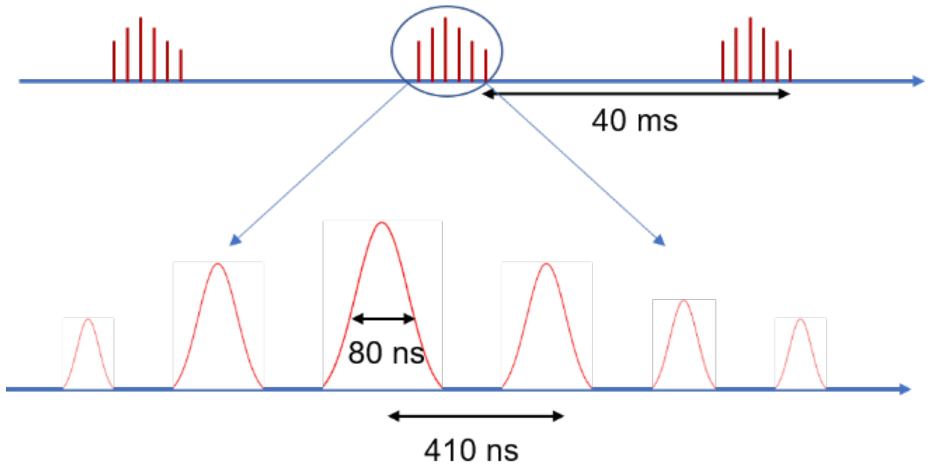
- The probability of the number of protons that may exist in each pulse conforms to the Poisson distribution::

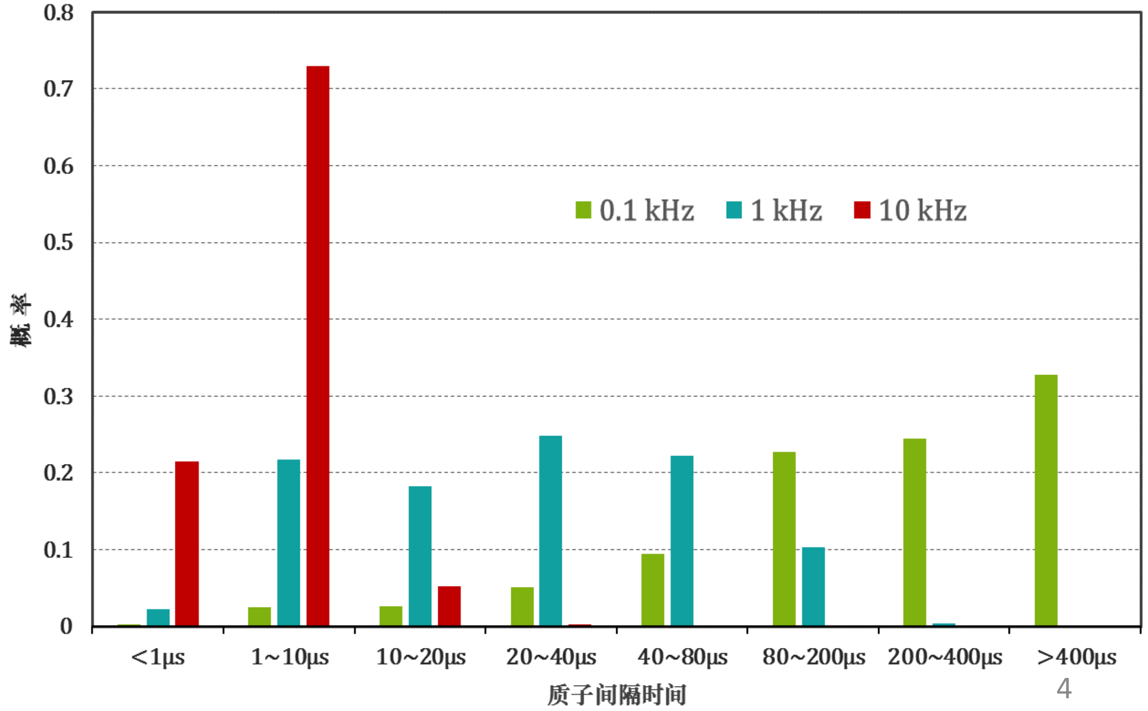
$$P(x=k)=\lambda^{\kappa}e^{-\lambda}/\kappa\,!$$

- λ is the expected value (average value) of the number of particles in each pulse, and k is the number of particles that may exist in each pulse.

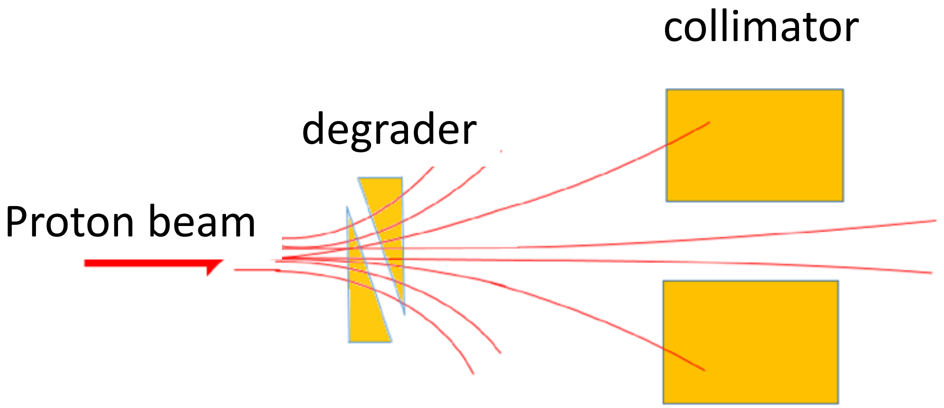
- Number of pulses between two adjacent proton events (μ) follows exponential relationship:

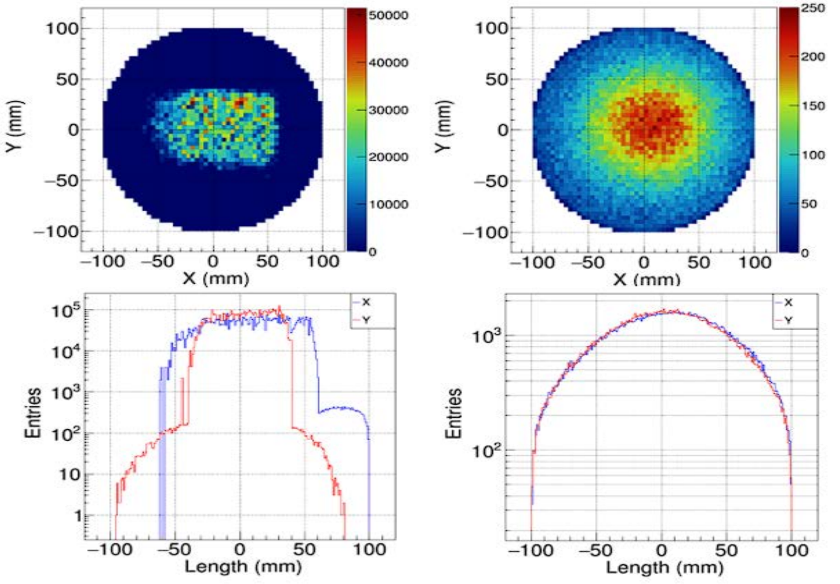
$$f(\mu)=\lambda\cdot(1-\lambda)^{\mu-1}$$





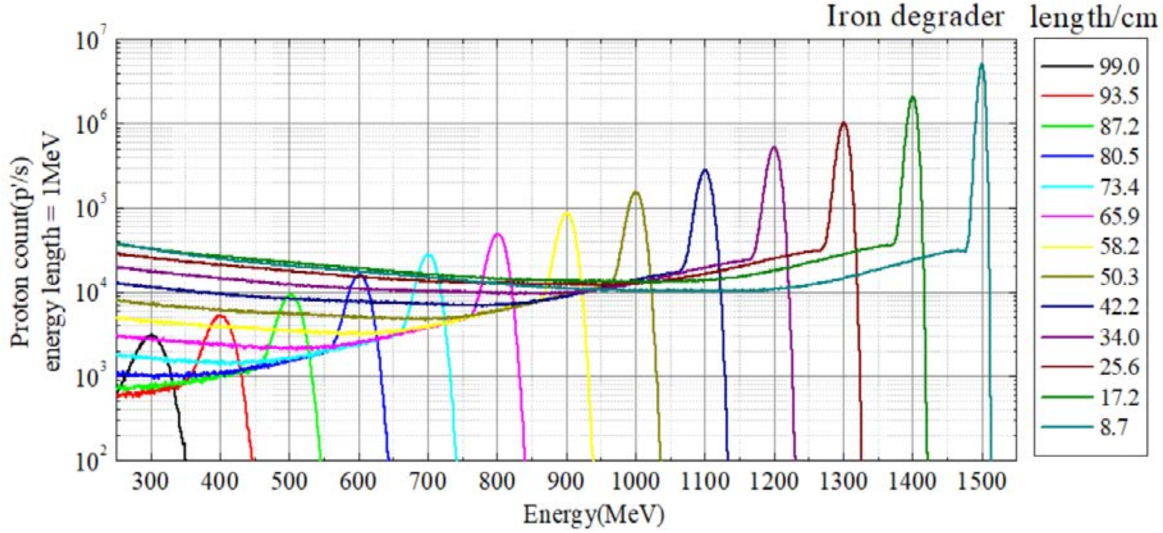
Energy degradation of proton





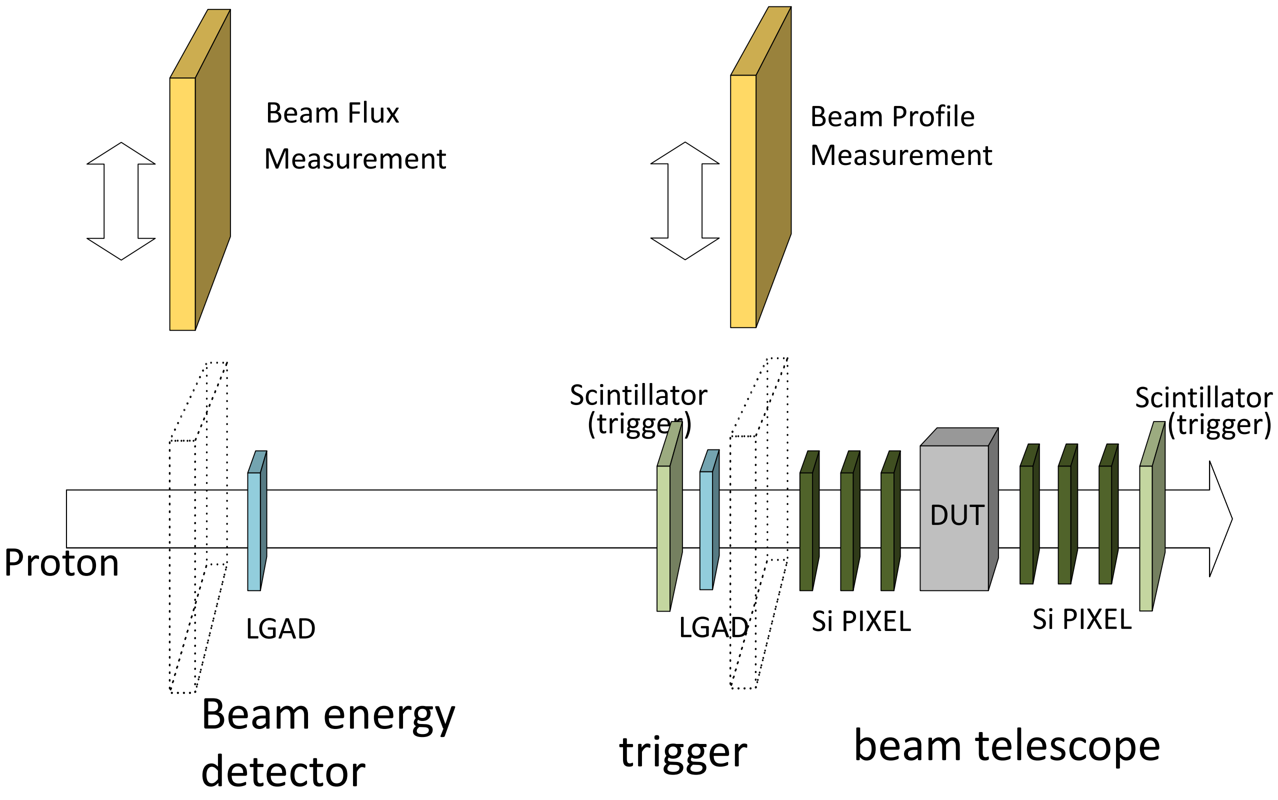
beam profile and distribution before and after the degrader

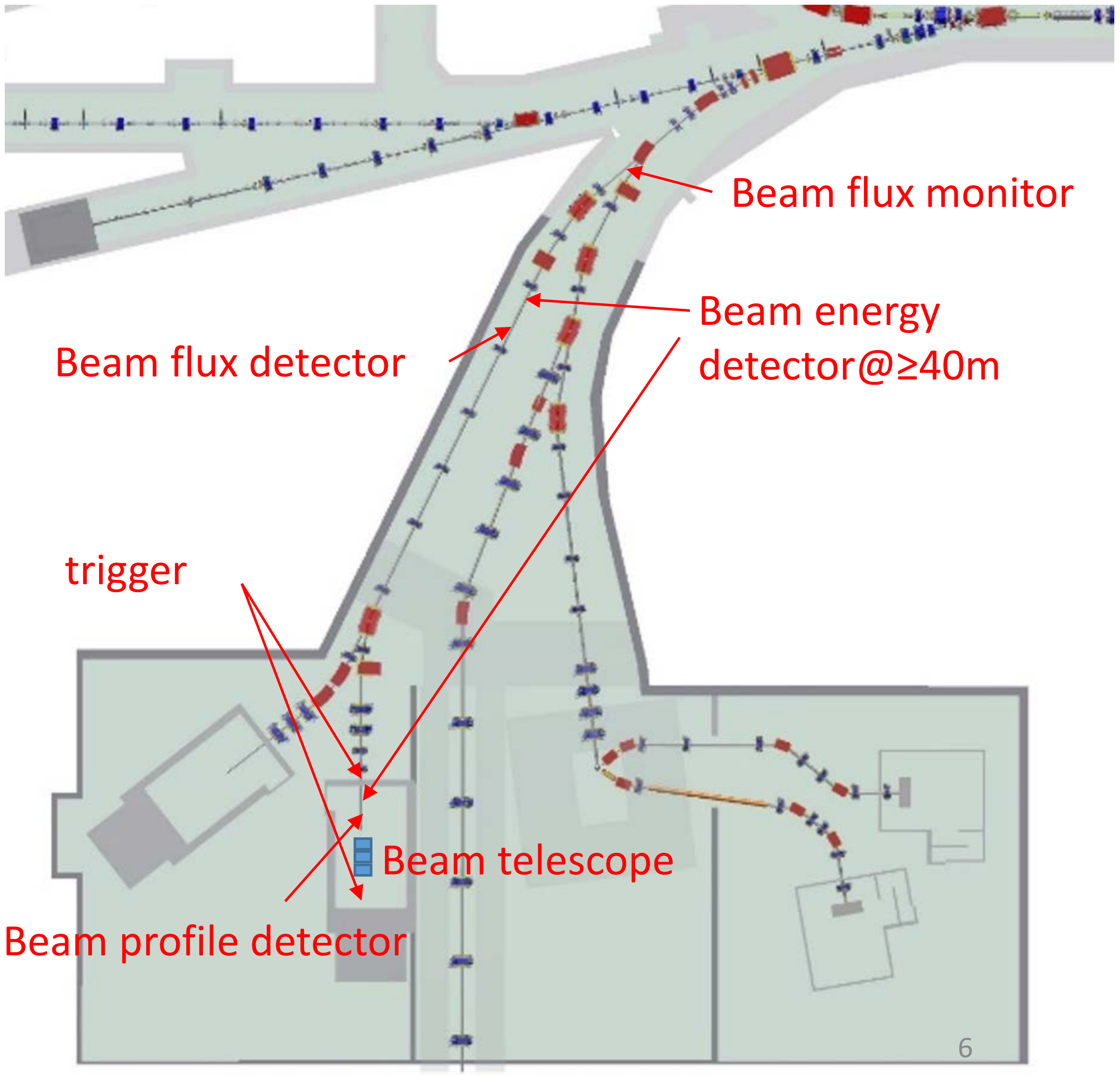
Initial proton beam energy is 1.6 GeV, the current is 1E7 proton/s. Gaussian distribution （ σ x=1.5 cm, σ y=1 cm）



Proton energy(MeV)	Proportion of protons with 160 π mm mrad	Proportion of protons with peak deviation of 0.5%
800	1.48E-02	3.10E-03
900	1.75E-02	4.31E-03
1000	2.03E-02	6.11E-03
1100	2.33E-02	8.30E-03
1200	2.66E-02	1.14E-02
1300	3.13E-02	1.66E-02
1400	3.79E-02	2.56E-02
1500	4.94E-02	4.22E-02

Beam test detectors





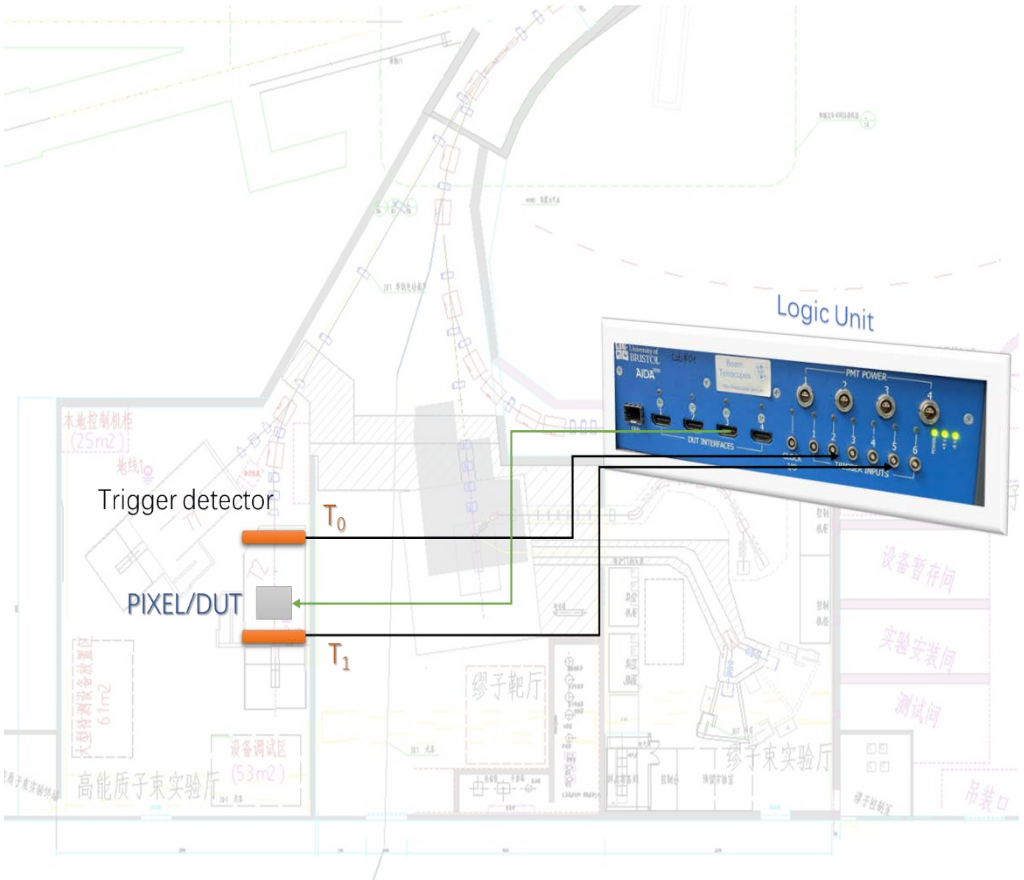
These detectors can be used individually or in combination for different DUT measurement and monitoring beams

Beam test detectors

No.	Detectors	Detector functions	Key parameters	The proposed technology
1	Trigger	Test initial time of the protons, and provide trigger signals	Time resolution < 1ns	Plastic scintillator
2	beam telescope	Provide reference tracks of protons with high precision	Position resolution < 10μm	Silicon pixel detector
3	Beam energy detector	Test Beam energy by time of flight	Energy resolution < 1%	LGAD
4	Beam profile detector	Test beam profile and uniformity	Position resolution < 150μm， more than 1200 channels	Micromegas detector
5	Beam flux detector	Test beam flux during commissioning	hit rate > 10^5/s	Plastic scintillator (try using SiC as a monitor)

1. Trigger

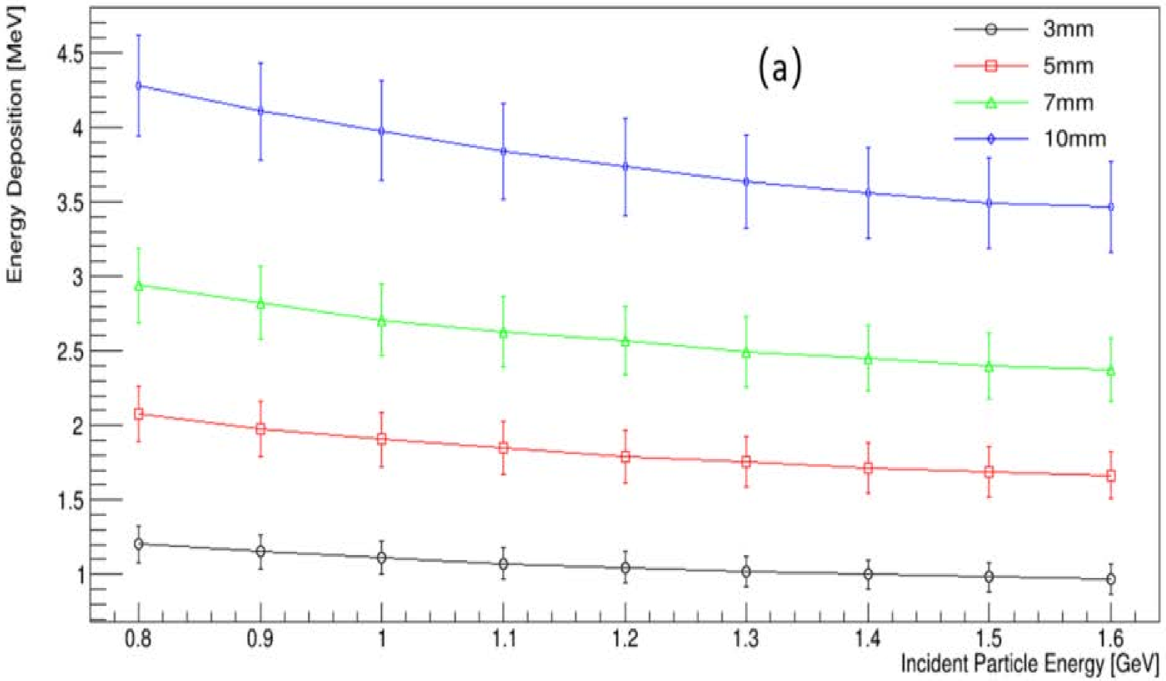
- Test initial time of the protons, and provide trigger signals for other detectors
- Include two layers, provide T0 (before DUT) and T1 (after DUT)
- Readout signals are connected to trigger Logic Unit for discrimination , timing and fan-out



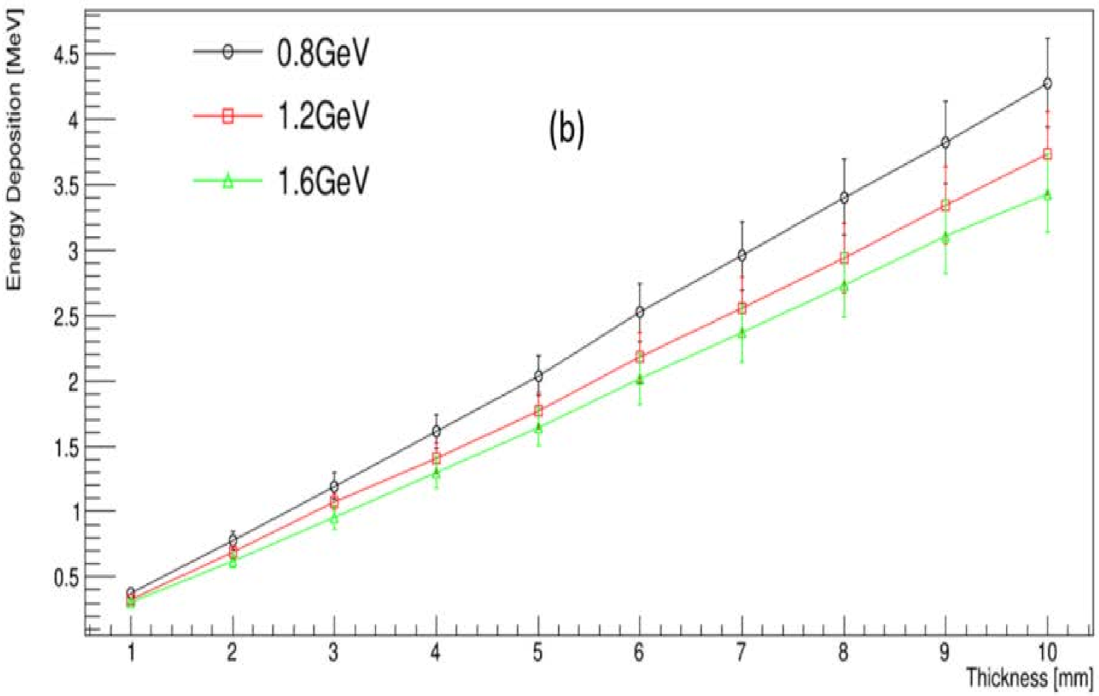
Design parameters

parameters	Design requirements
Hit rate	10kHz
Sensitive area	10cm × 10cm
Layer of detector	2
Readout channels	2CH X 2
Proton energy range	0.8~1.6GeV
Time resolution	<1ns
Time resolution of PMT single photon	< 100ps
FADC sampling rate	1Gsps
Sample Window Width	Adjustable, 16-2048ns
ADC	14bit
Dead time	<128ns
Dynamic range	1.5V

Simulation

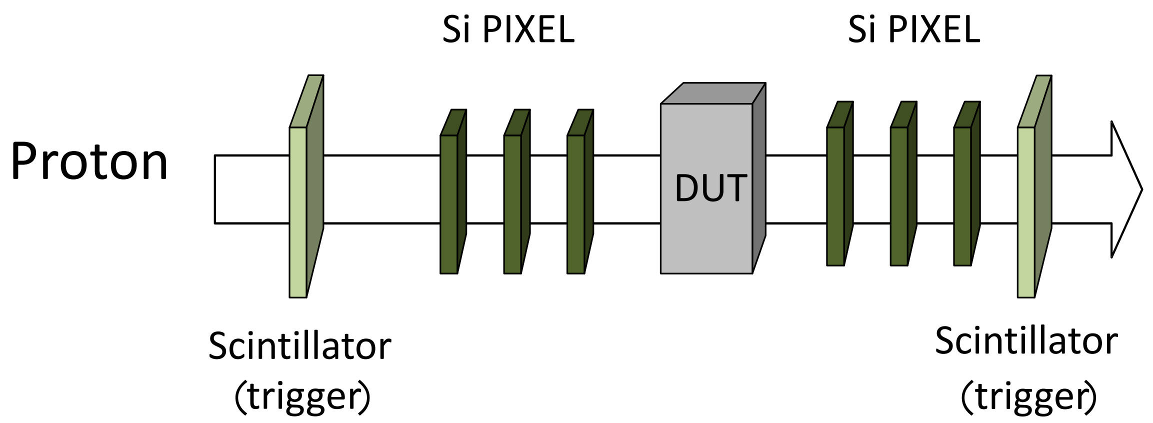


Energy deposition of proton beams with different energies in plastic scintillators



Energy deposition of proton beams in plastic scintillators with different thicknesses

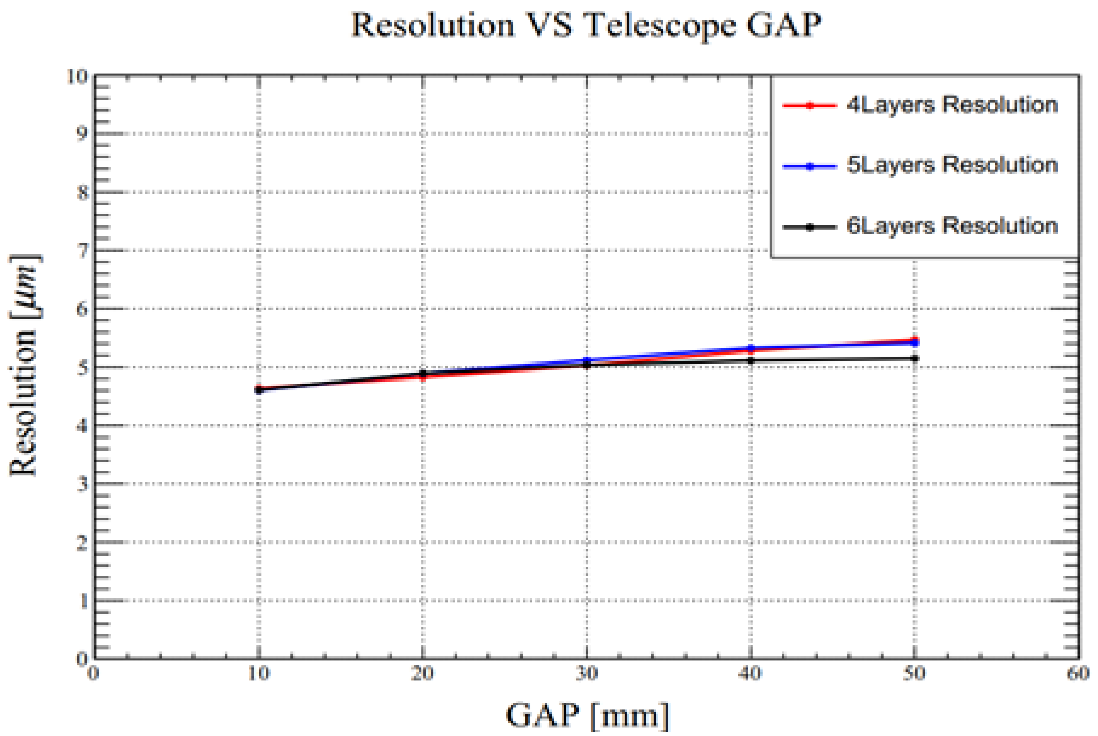
2. Beam telescope

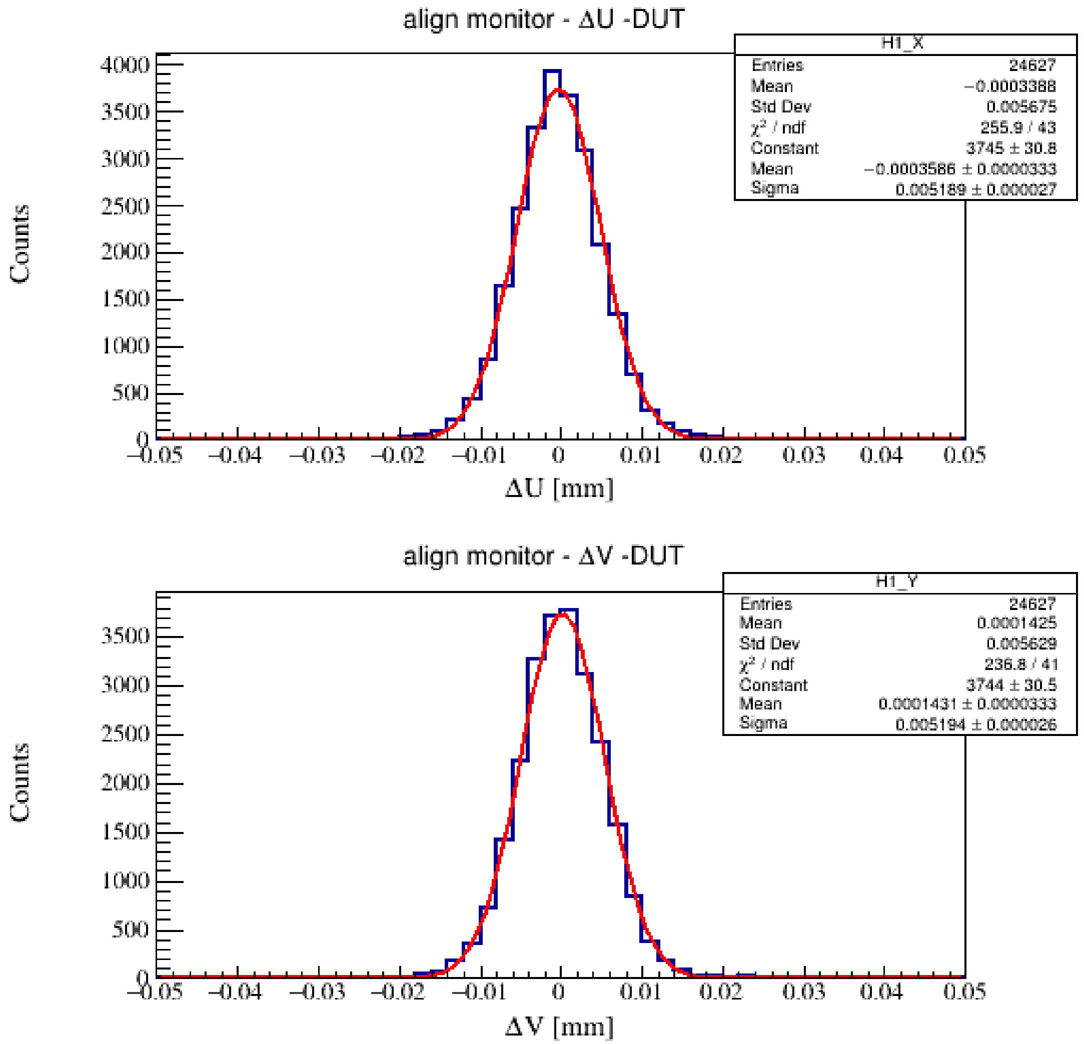


- For performance test of pixel sensor, strip sensor…
- Provide high-precision reference tracks of protons for the DUT (Device under test)

Parameters	Design requirenent
layers	6
Active area /layer	≥ 3 cm^2
Position resolution	≤ 10 μm
Material budget	50 μm silicon + <100μm kapton

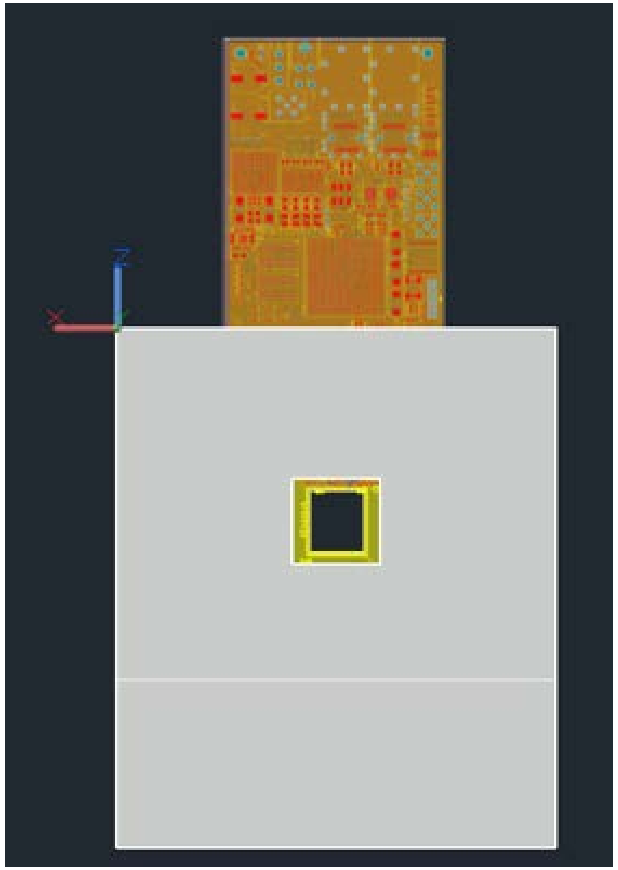
Simulation

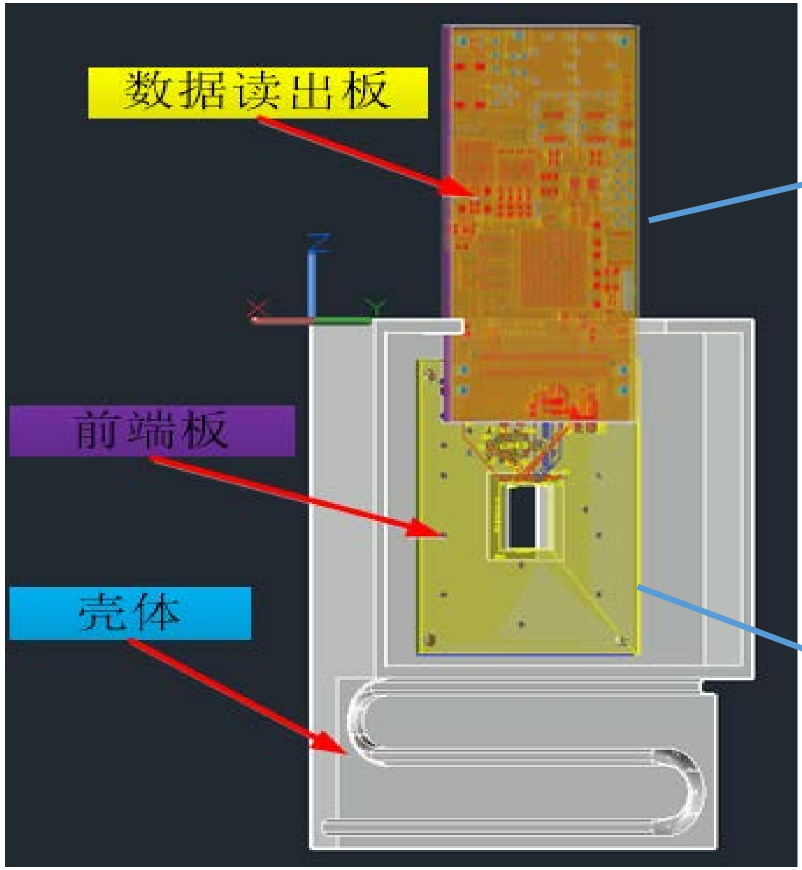




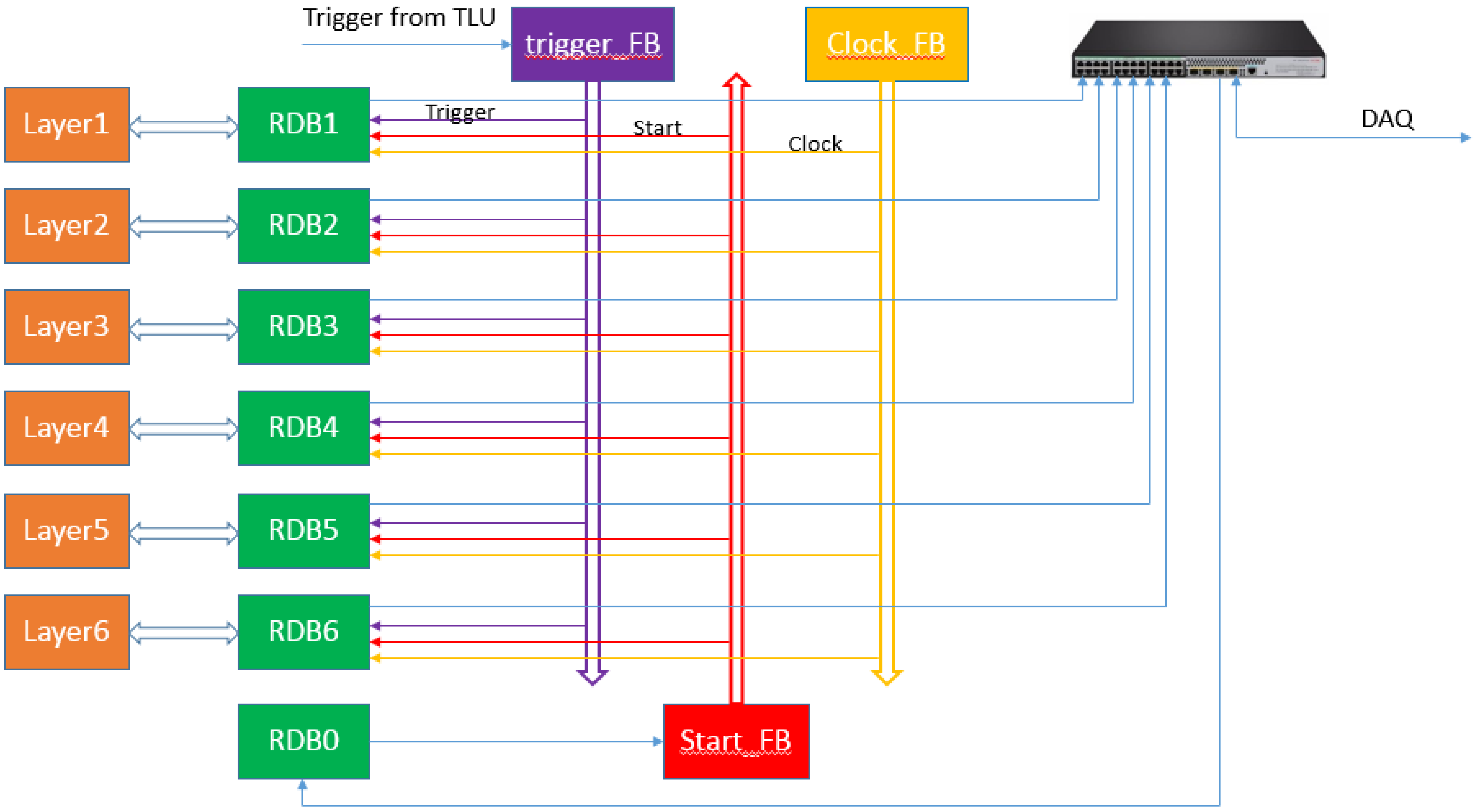
- For 1.6 GeV proton, the position resolution of about 5 μm can be achieved with pixel size of 20μm × 20μm
- Increase the gap between DUT and telescope, the resolution will become worse

Preliminary design

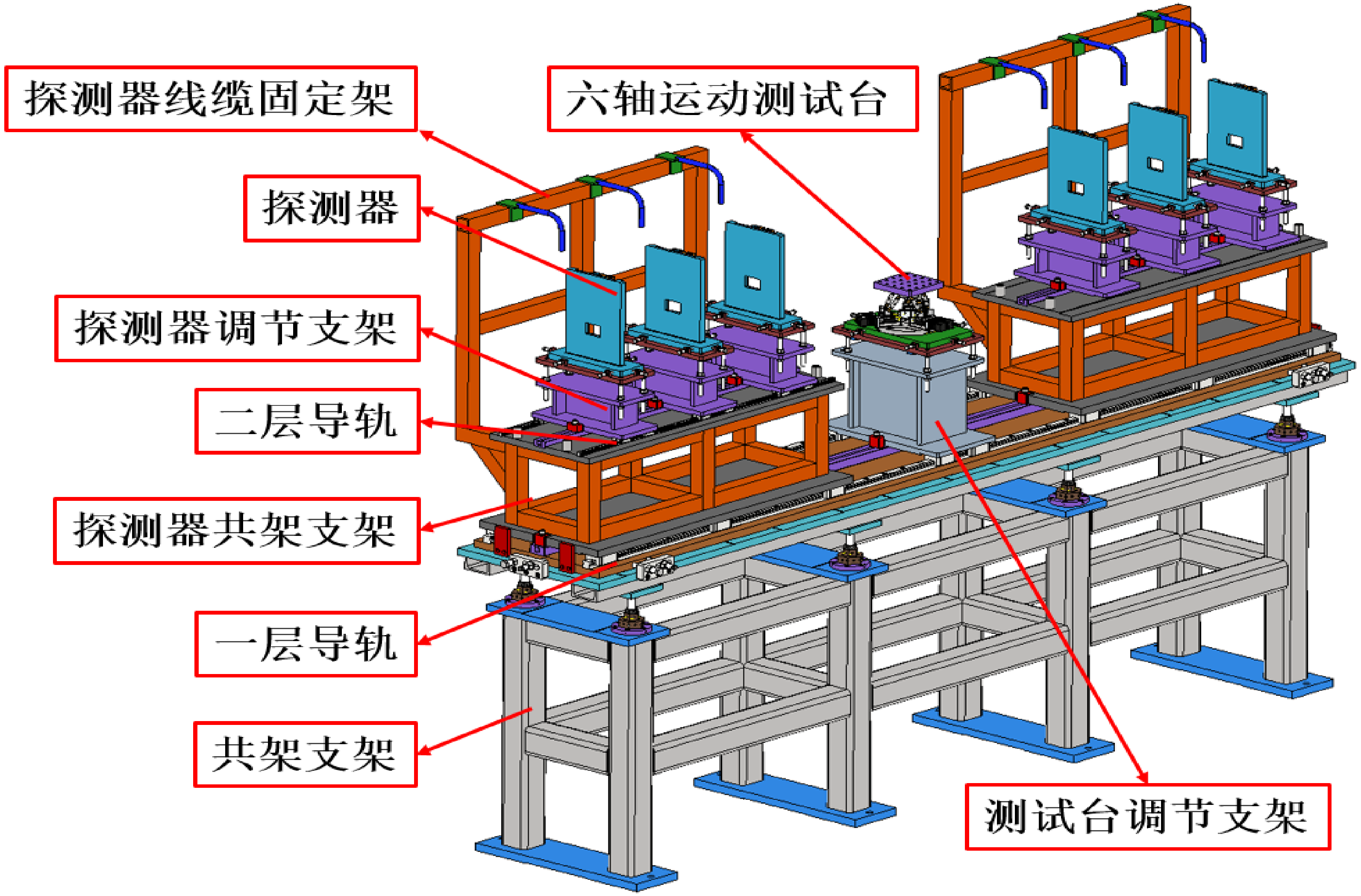




Readout electronics

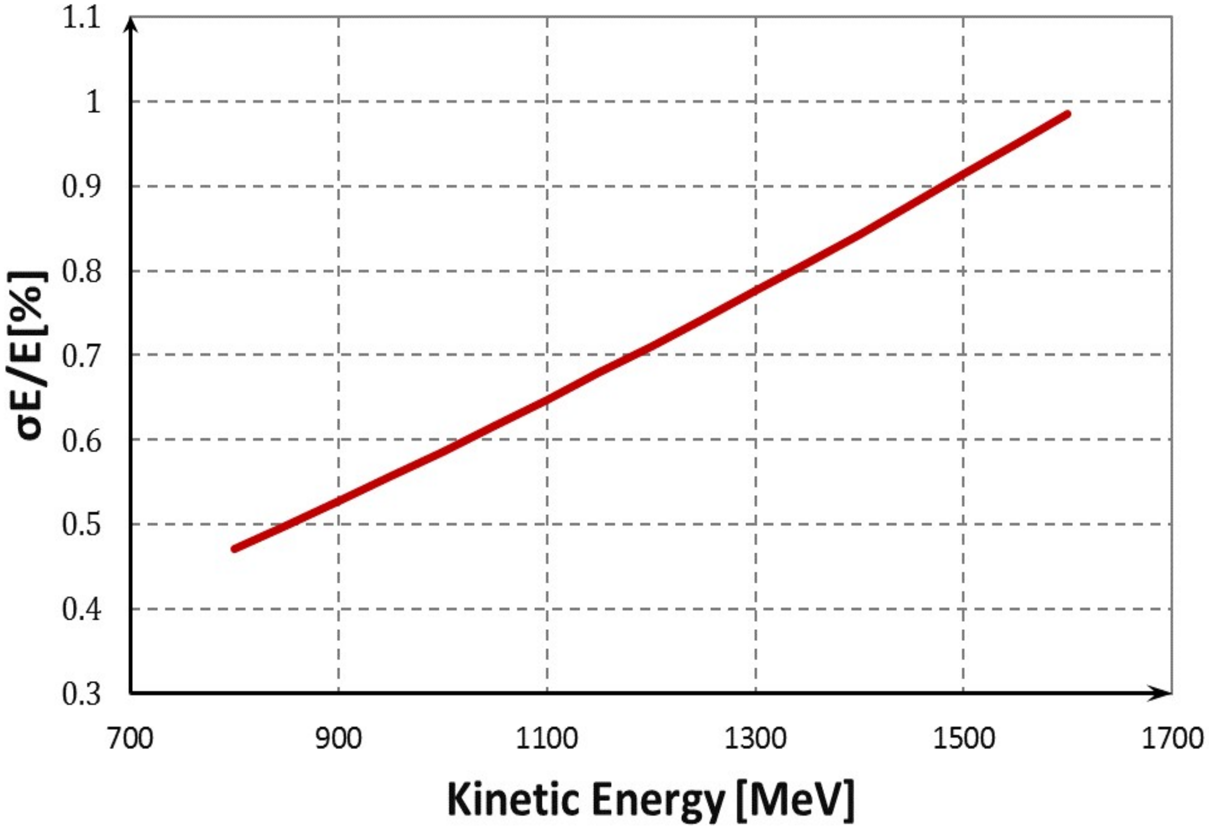


Design of mechanical support



3. Beam energy detector

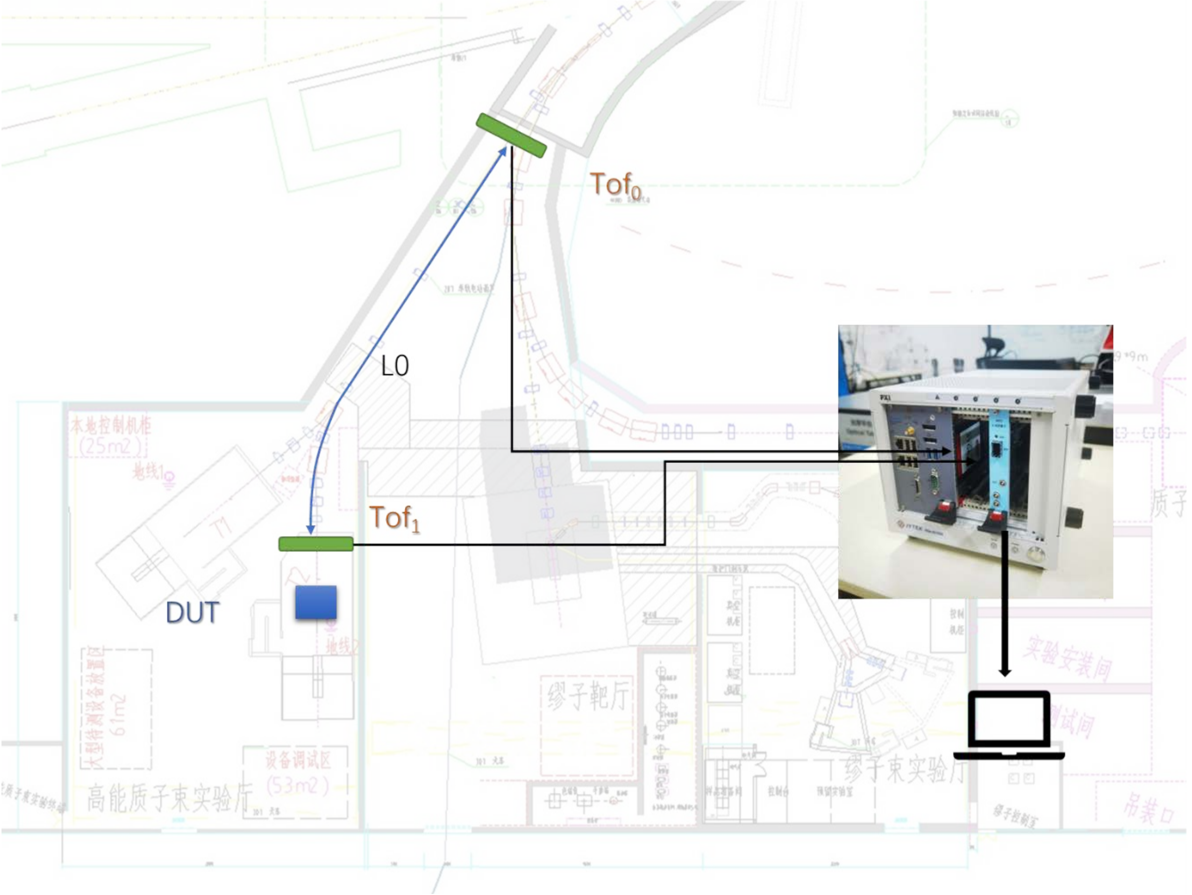
- After energy degradation, the beam energy can be 800 MeV
- To accurately measure the proton energies
- Adopt LGAD for measurement of the time of flight of the proton to determine the energy
- Two layers, distance is about 40m
- Time of flight of 800 MeV and 1.6 GeV proton are 158 ns and 143 ns respectively



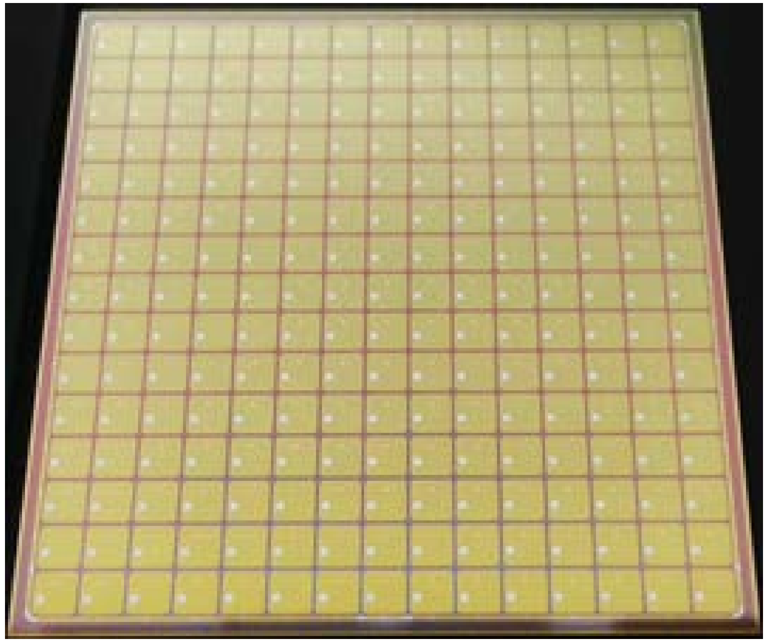
Energy resolution vs beam energy

Beam energy detector

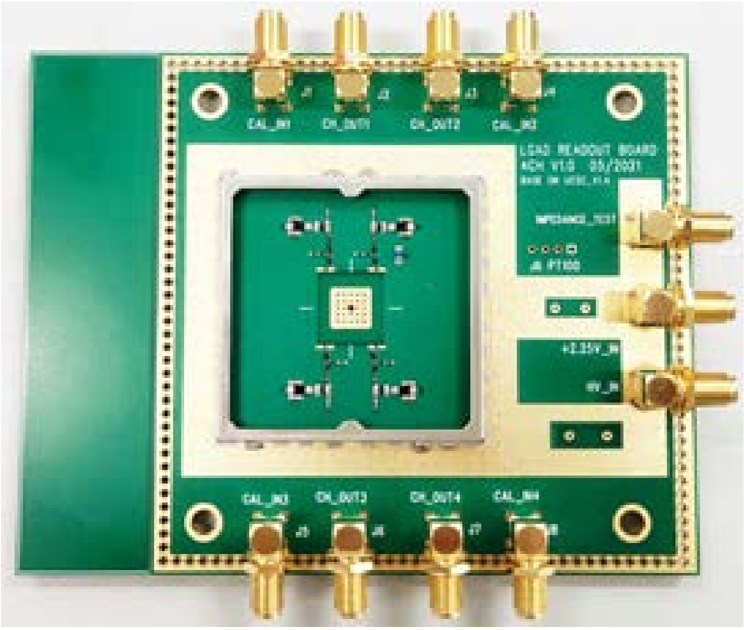
parameters	Design requirement
Active area	2cm*2cm
Time resolution	100ps
Readout channels	12
Proton energy range	0.8~1.6GeV
Energy resolution	1%
Waveform sampling rate	3.2-6.4Gs/s
ADC	8-12bit
bandwidth	1GHz



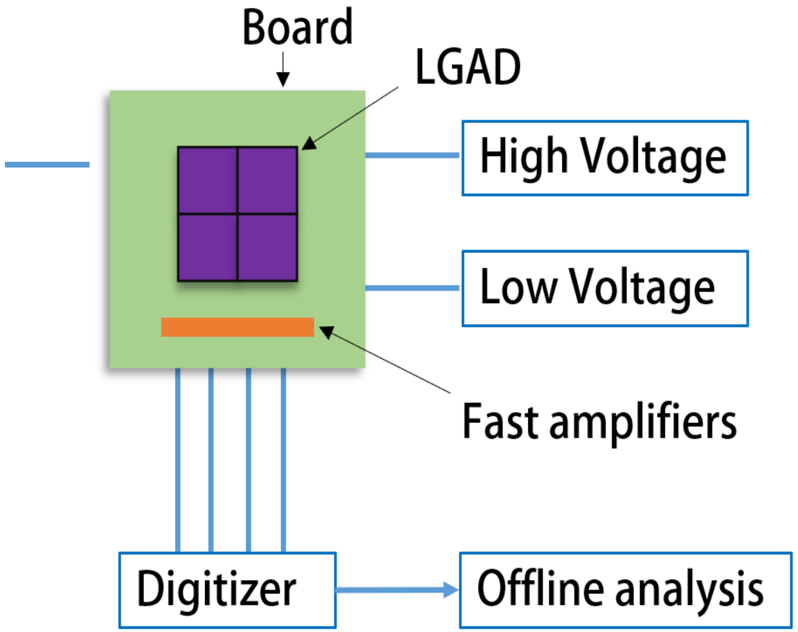
Preliminary design



2cm ×2cm sensor



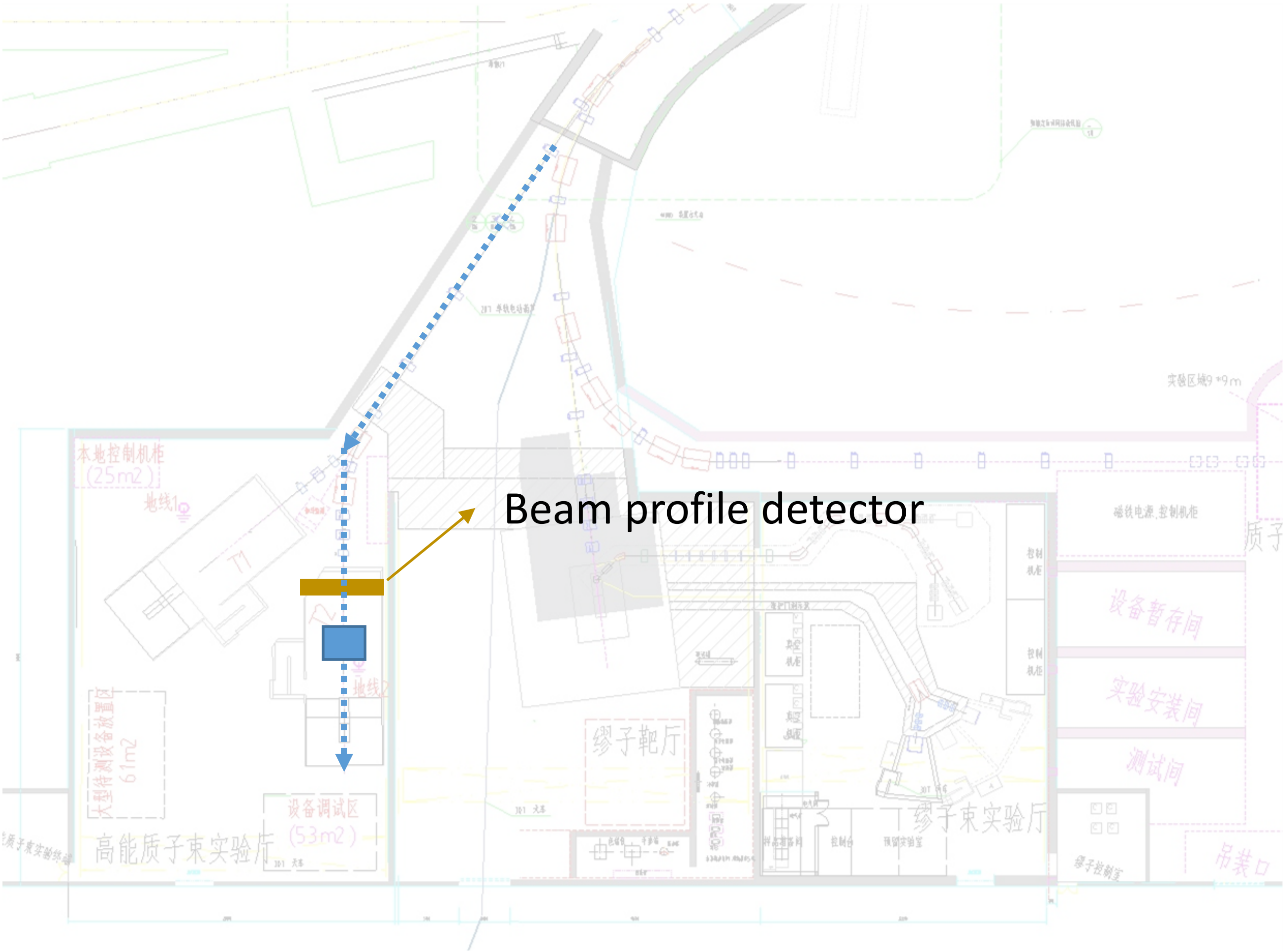
Readout board



Schematic of the system

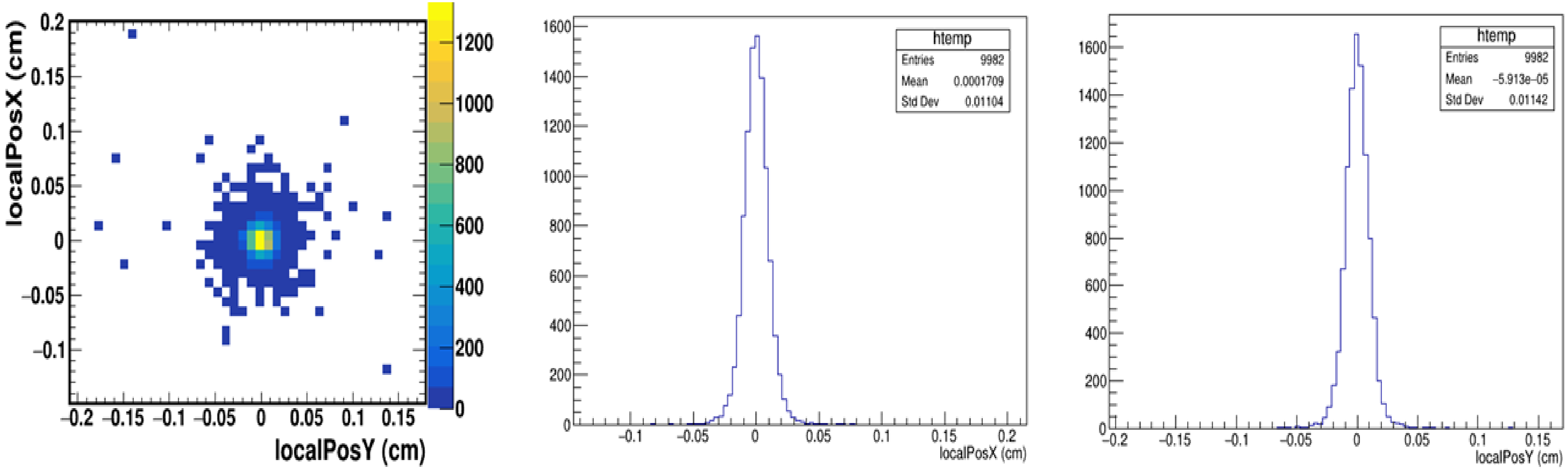
4. Beam profile detector

- For performance test of large area detectors (gaseous detectors, exceed the sensitive area of beam telescope)
- Monitor the beam profile, uniformity and stability of beam spot distribution during commissioning and the test



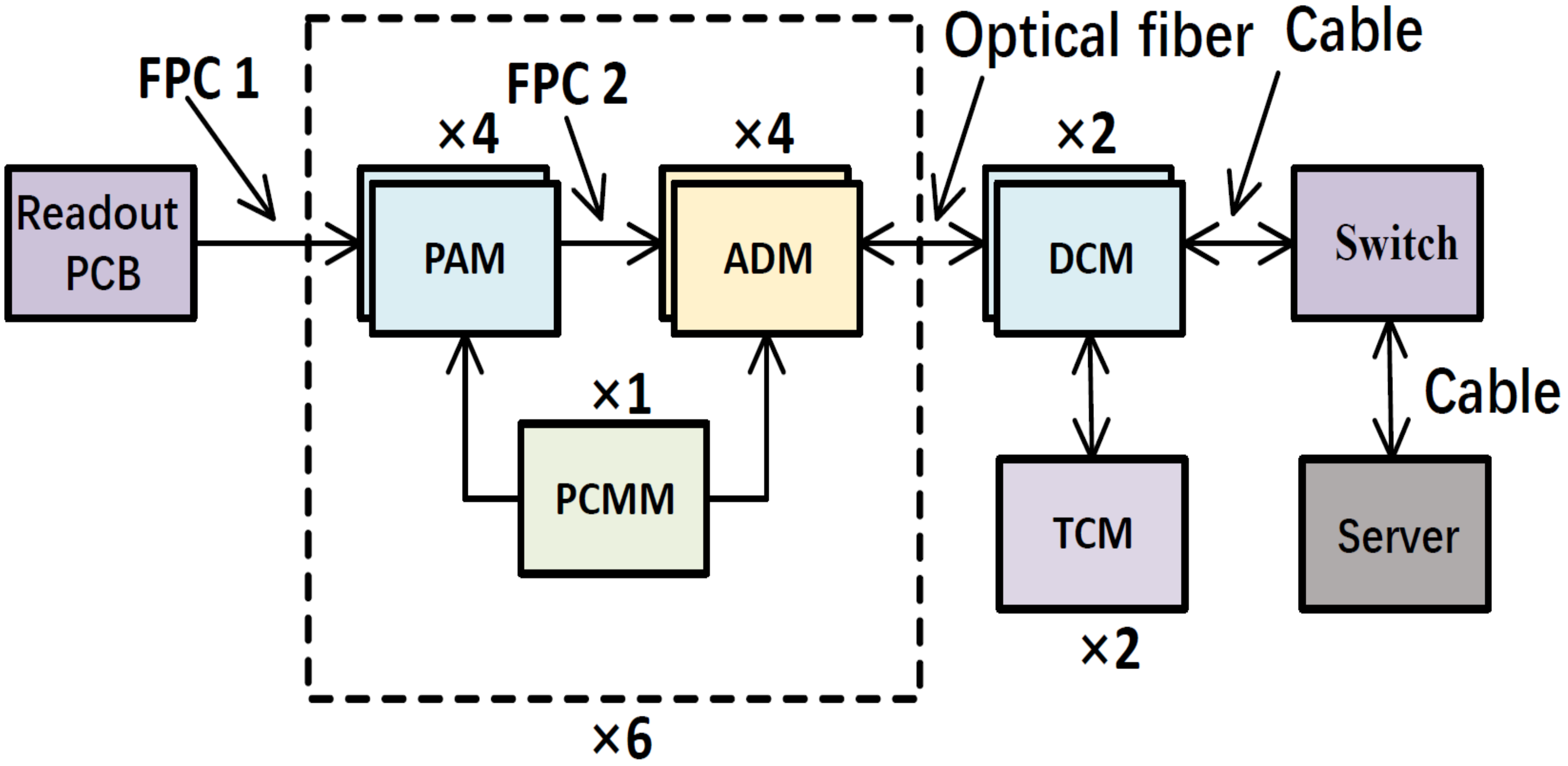
Beam profile detector

Parameters	Hit rate	Beam profile	Position resolution	Readout channels	Beam energy range	Detection efficiency
Design requirements	10kHz	ϕ100mm	150μm	2048	0.8~1.6GeV	97%@1.6GeV



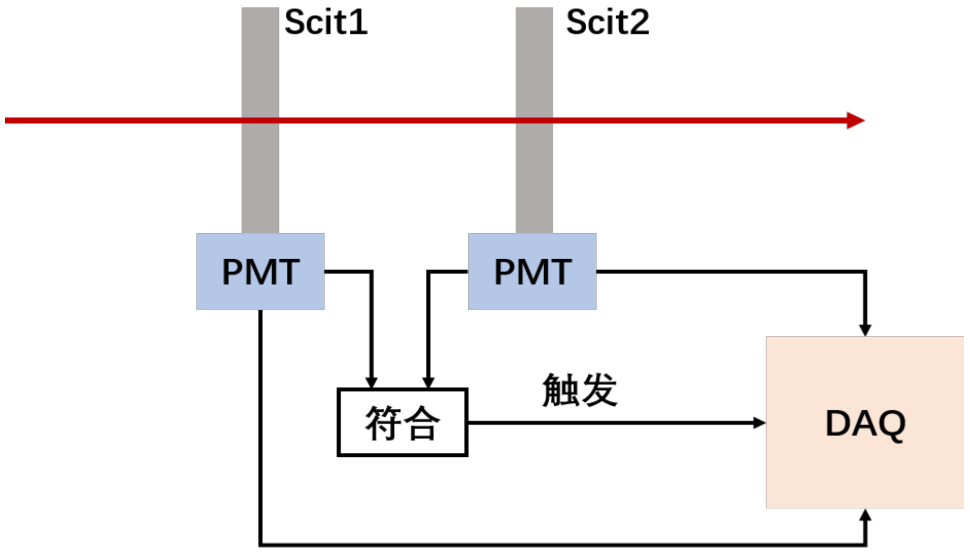
Two dimensional distribution of protons and projection distribution in X and Y directions

Readout electronics



5. Beam flux detector

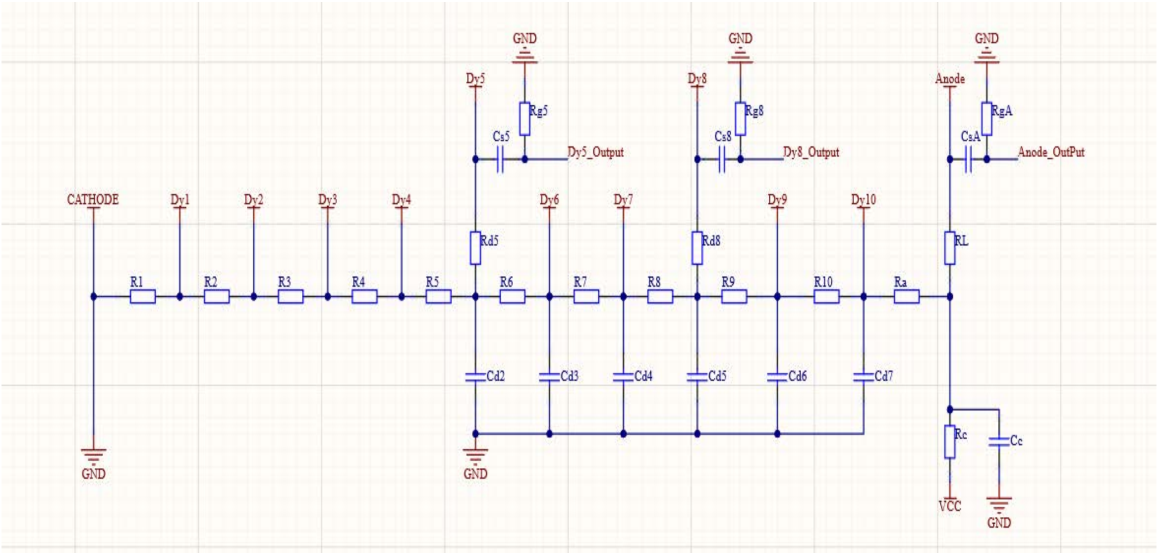
- To test beam flux during commissioning or monitor beam flux during running
- Scintillator +PMT



No.	parameters	Design requirements （500 kW）
	Layer	2
2	Sensitive area	> 10mm×10mm（Scintillator） 5mm×5mm（SiC）
1	thickness	10mm
1	Hit rate	> 10^5/s
3	Readout electronics	Sampling rate: 1 GHz； Bandwidth: 150 MHz； ADC: 12 bit Input sinals: -1.48V-1.48V

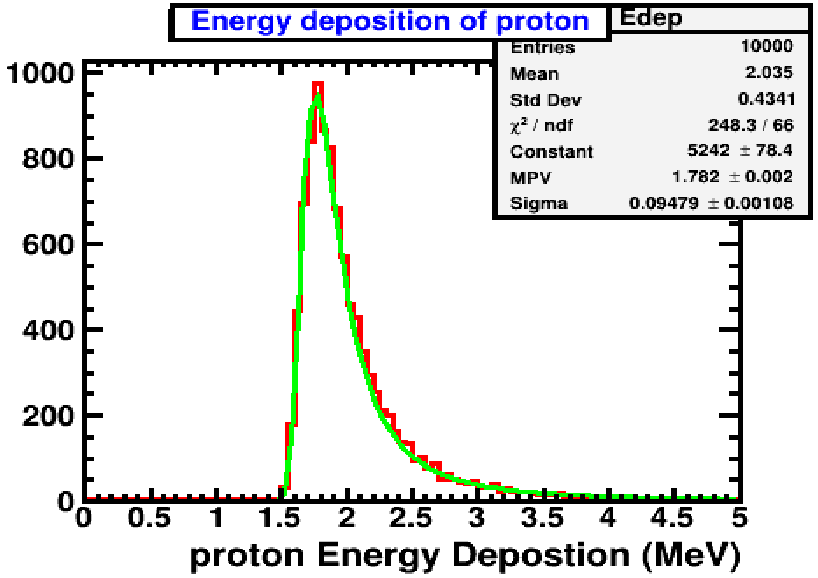
Dynamic range

- Adopts scheme of multi readout signals from PMT to achieve a large dynamic range of 30000, which has been successfully applied to the DAMPE experiment
- The signals from the 5th, 8th dynode and anode of the PMT can cover the dynamic range of 0.2mip-20000mip
- Meet the application requirements of the current measurement

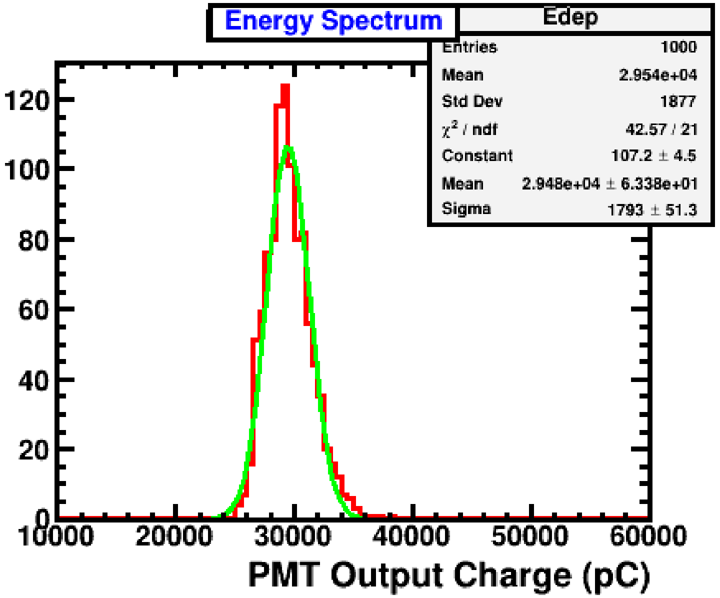


Readout electrode	gain	Dynamic range	Output signal
Anode	1×10^6	0.2mip-20mip	0.12pC/ns-12pC/ns
8^{th} dynode	6.5×10^4	3.1mip-310mip	0.12pC/ns-12pC/ns
5^{th} dynode	1000	200mip-20000mip	0.12pC/ns-12pC/ns

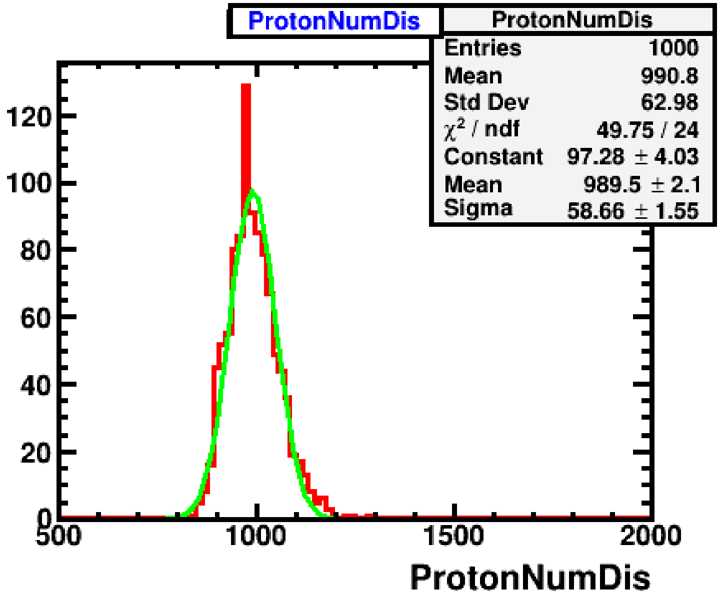
Simulation



Energy deposition of a single proton



PMT output charge
for 10^4 protons



Numbers of protons after reconstruction

Working group

- CSNS

(test beam, beam profile detector, beam flux detector)

  - Hantao Jing, Ruirui Fan, Hanyi, …

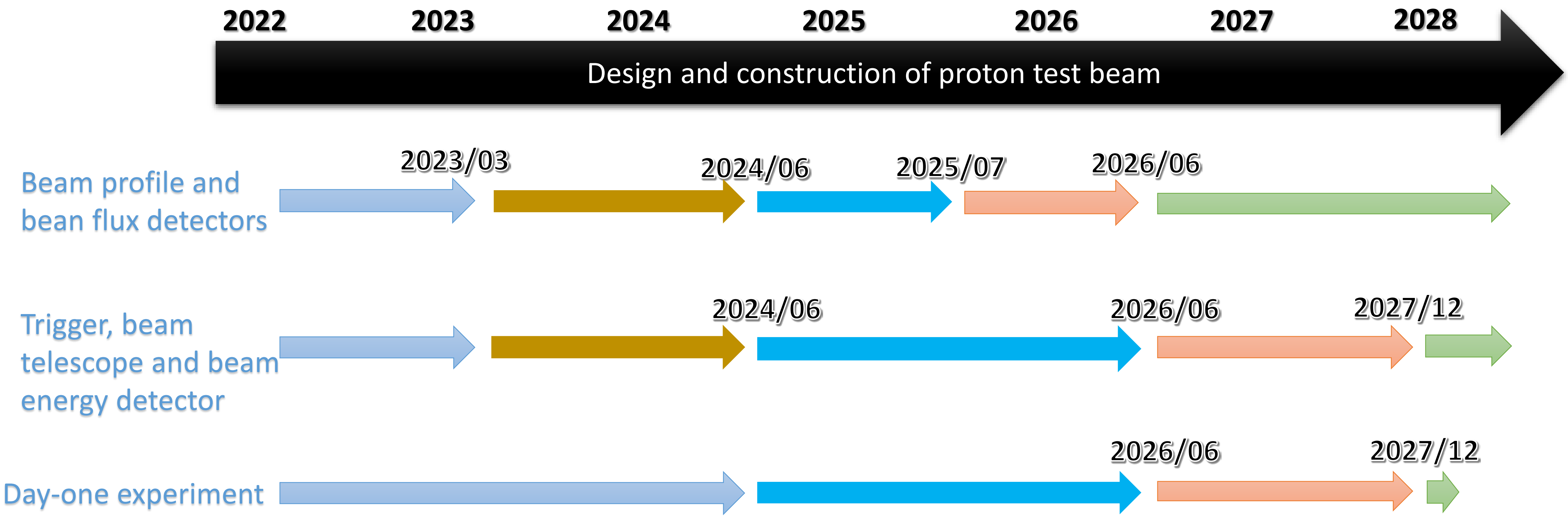
- EPD

(beam telescope, trigger, , beam energy detector and beam flux detector ,DAQ)

  - Jianchun Wang, Mingyi Dong, Sen Qian, Zhijun Liang, Xin Shi, Hongyu Zhang…

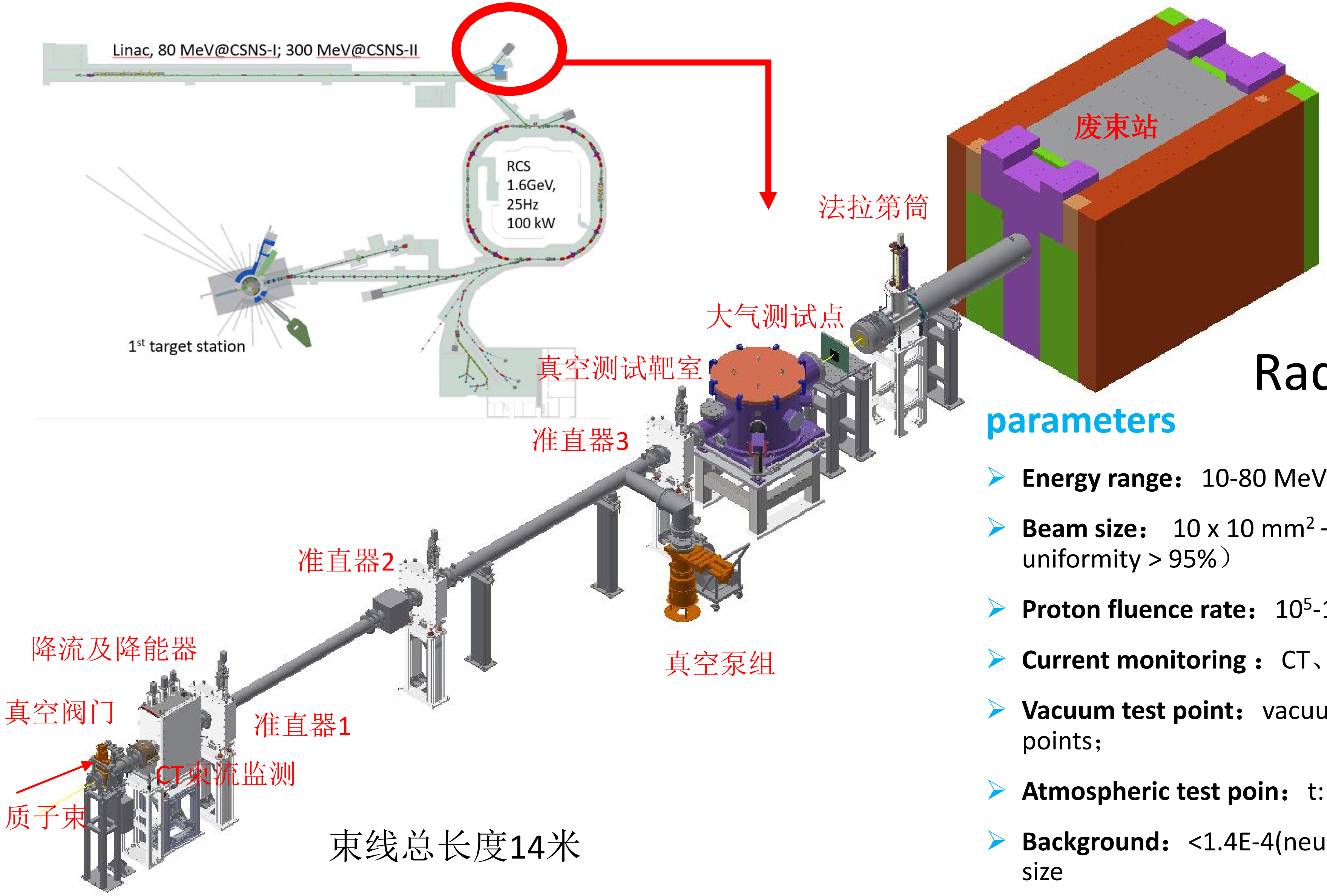
- Finished the preliminary design report
- Will have internal review on Dec.28

Schedule of proton test beam



- **The schedule will be further improved, and each step may be finished in advance**

CSNS associated proton beam experimental platform(APEP)



CSNS-I 30-80 MeV

CSNS-II 100-300MeV

Radiation test

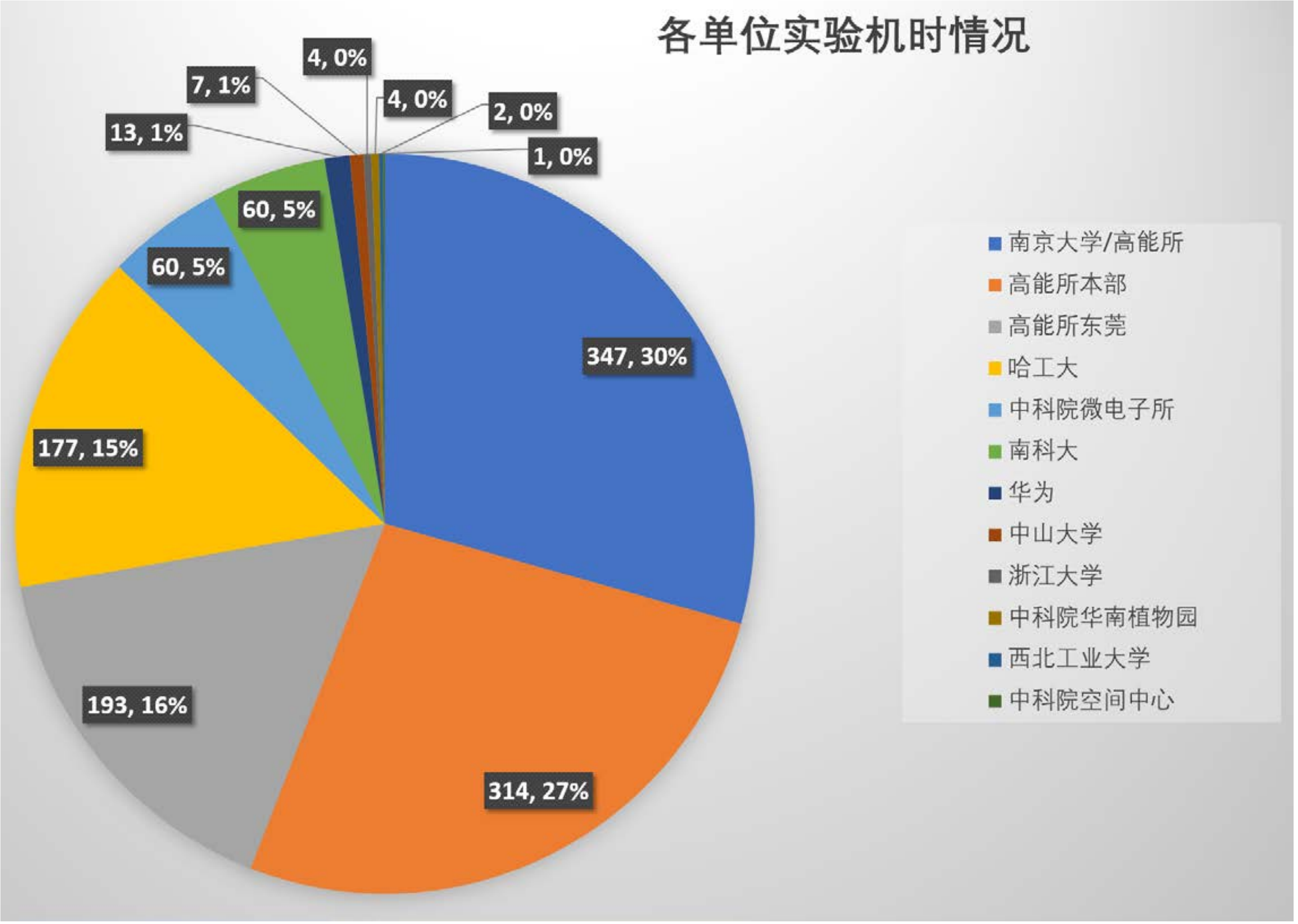
parameters

- **Energy range：** 10-80 MeV (能散(FWHM)<8.65% @>30MeV)
- **Beam size：** 10 x 10 mm^2 – 50 x 50 mm^2（continuously adjustable, uniformity > 95%）
- **Proton fluence rate：** 10^5-10^{10} p/cm^2/s
- **Current monitoring ：** CT、Faraday cylinder and irradiation dose sensors
- **Vacuum test point：** vacuum: 10^{-3} Pa, space size: 50cm×Ø0.8m，5 test points；
- **Atmospheric test poin：** t: remote control sample stand
- **Background：** <1.4E-4(neutron) and <3.4E-5(gamma) @20 x 20 mm^2beam size

First run（2021.10-2022.11）

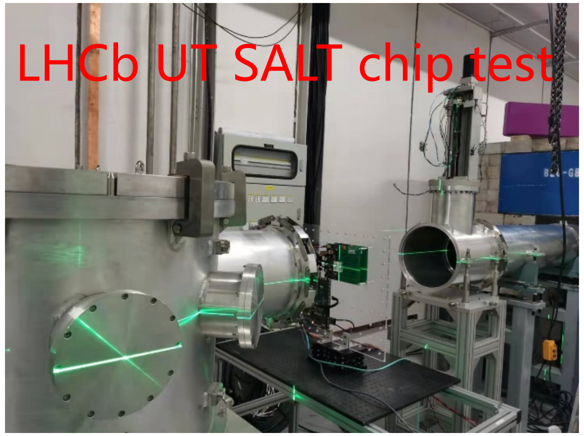
- Total beam time: 1193 hrs
- 11 institutes and universities are involved；
- Total number of samples:113；

- 661 hrs for IHEP users；
- Huawei (Dongguan) will be a potential major user

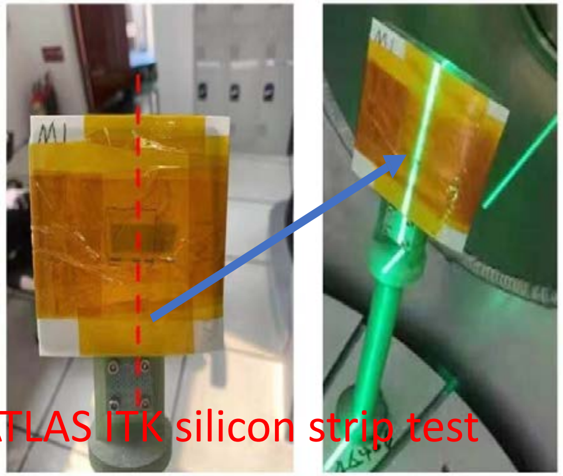


Typical Experiments - High Energy Physics/Particle Physics

- LHCb UT SALT chip radiation test, IHEP
- ATLAS MUX64 chip radiation test , Nanjing University/IHEP
- ATLAS ABCStar chip radiation test, IHEP
- ATLAS ITK silicon strip radiation test, IHEP
- Trigger detector test, IHEP
- COMET Muon beam monitor test, Sun Yat-sen University



On March 12, 2022, ATLAS ITk officially approved the qualification task of evaluating APEP as an international site for proton irradiation of silicon strip quality assurance.
Professor Unno, a silicon detector expert from KEK, served as the technical director, Shi Xin from IHEP served as the local director, and Dr. Li Hui of Tsinghua University carried out the specific experimental task, which is expected to be completed within one year.



Summary

- Proton test beam facility will be constructed in CSNS Phase II for advanced detector R&D and calibration
- Finished the preliminary design of the beam test detectors, which include trigger, beam telescope, beam energy detector, beam profile detector and beam flux detector. Mature and available technologies will be adopted
- Another beam at CSNS (associated proton beam experimental platform) can provide radiation test for the detectors and ASIC chips

Thanks for your attention!