Progress of the first proton test beam in China

Speaker: Hantao Jing (jinght@ihep.ac.cn)

On behalf of the HPES group

Institute of High Energy Physics of Chinese Academy of Sciences

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Outline

I. Motivation

II. Test Beam Facilities in Worldwide

III. CSNS and High-Energy Proton Experimental Station

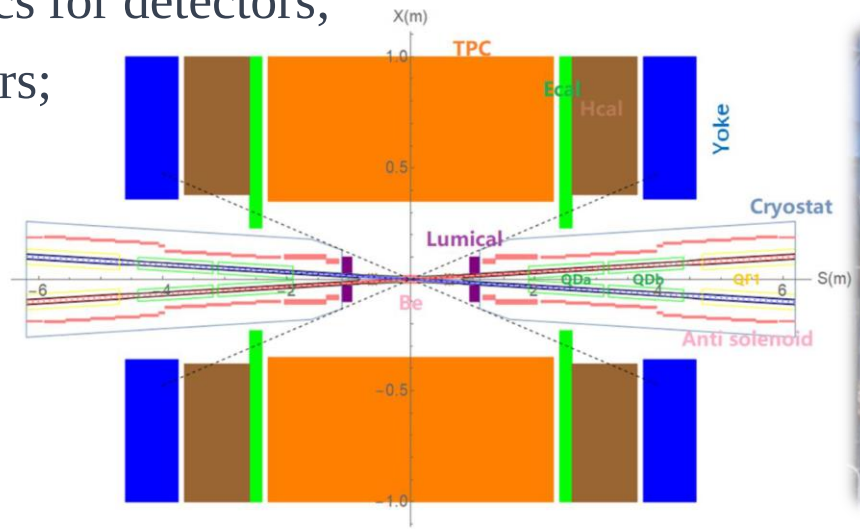
IV. Requirements for High-Energy Proton Beam Tests

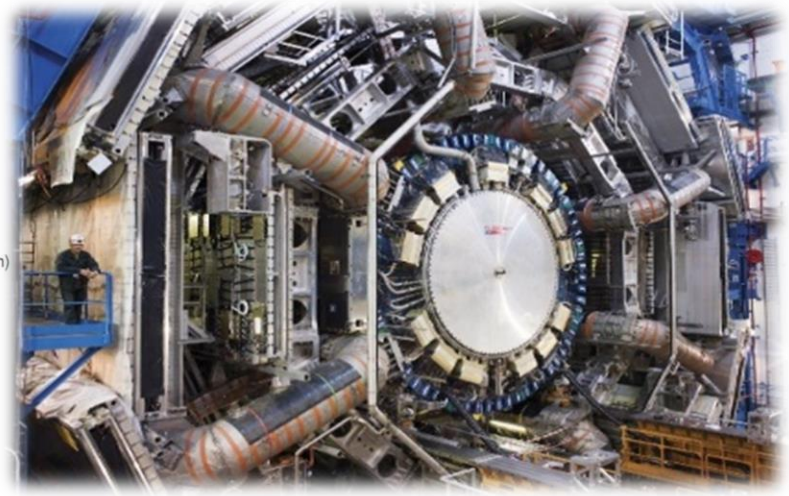
V. Detector System in Station

VI. Summary of Beam Parameters

1. Motivation

- High-performance particle detectors are very important to the establishment of many major national projects and key facilities.
- An advanced proton test beam is essential to the development of high-performance particle detectors.
- The demand of building an advanced proton test beam in China is becoming increasingly urgent.
  - ➢ High-resolution vertex detectors in collider experiments;
  - ➢ Advanced particle calorimeters in collider experiments;
  - ➢ Advanced and fast electronics for detectors;
  - ➢ Irradiation testing of detectors;



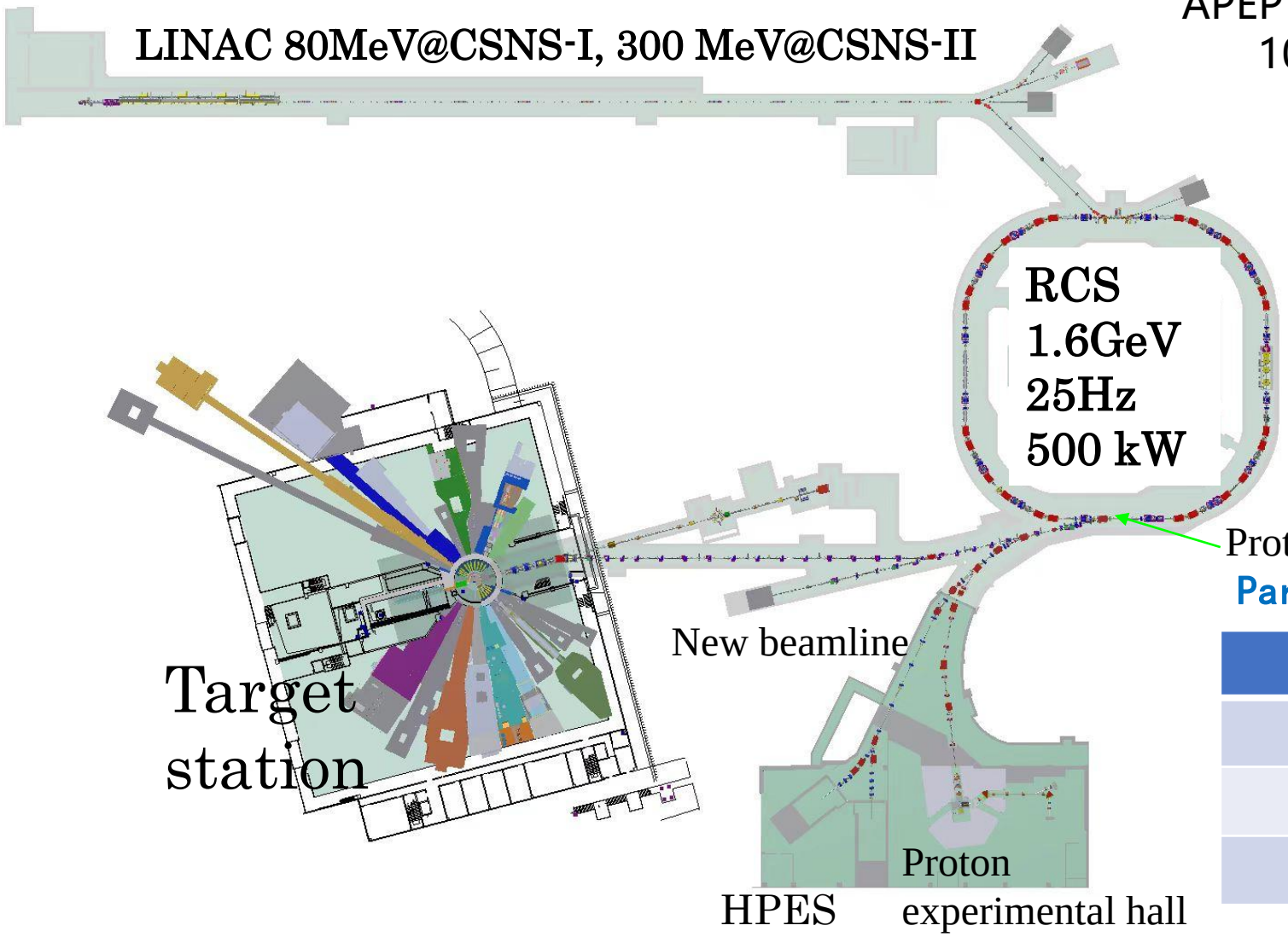


2. Test Beam Facilities Worldwide

Num	Facility Name	Institute	Test Beam Name	Nation	Particles Provided	Energy
1	CERN SPS North Area	CERN	H2, H4, H6, H8	Switzerland	primariy protons, hadrons, muons, electrons, pions	400GeV/c
2	CERN SPS North Area	CERN	H2-VLE, H4-VLE	Switzerland	pions, protons, kaons	80 GeV/c
3	CERN PS East Area	CERN	T9, T10	Switzerland	secondary	<15 GeV/c
4	DESY II TBF	DESY	TB21	Germany	electron	6.0 GeV
5	FTBF	FERMILAB	Beamline	USA	protons	120 GeV
6	IHEP protvino	IHEP Protvino	Beamline	Russia	protons	70 GeV
7	ESTB	SLAC	Beamline	USA	electron	2-20 GeV
8	IHEP protvino	IHEP Protvino	Beamline	Russia	protons, pions, muons, electrons(secondary)	1-45 GeV
9	Beijing TBF	IHEP Beijing	E3	China	protons,pions (secondary)	0.4-1.5 GeV
10	BTF	INFN	BTF-1	Italy	electron, position	50-750 MeV
11	RCNP	Osaka University	Beamline	Japan	protons	392 MeV
12	piE1 piM1	Paul Scherrer Institute (PSI)	Beamline	Switzerland	pions, muons, positrons, protons	10-450 MeV/c
13	PIF	Paul Scherrer Institute (PSI)	Beamline	Switzerland	protons	6-230 MeV
14	CSNS	IHEP CAS	HPES	China	proton	0.8-1.6 GeV

3. CSNS and High-energy Proton Experimental Station

3.1 Layout of CSNS



APEP 30 - 80MeV@CSNS-I
100-300MeV@ CSNS-II

- Development of advanced particle detectors and Astro-detectors
- Irradiation Effect Researches (System Level Tests, SPE experiments)

Parameters of High energy Proton Beam

Parameters	Design Value
Proton Energy	0.8-1.6 GeV
Repetition	24 Hz
Proton Flux	10^3-10^7 p/s

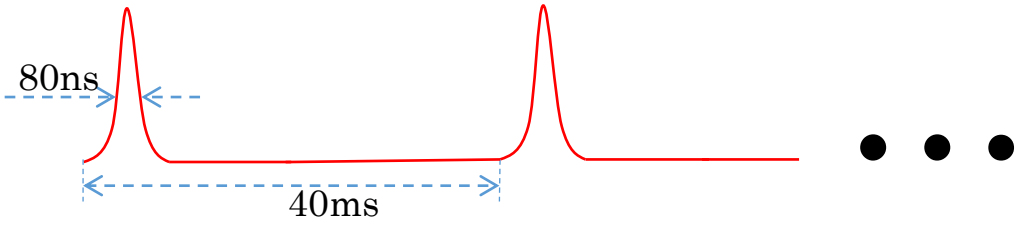
3.2 Time structure of extracted proton beam

0-0.25 ms
300 MeV
injection

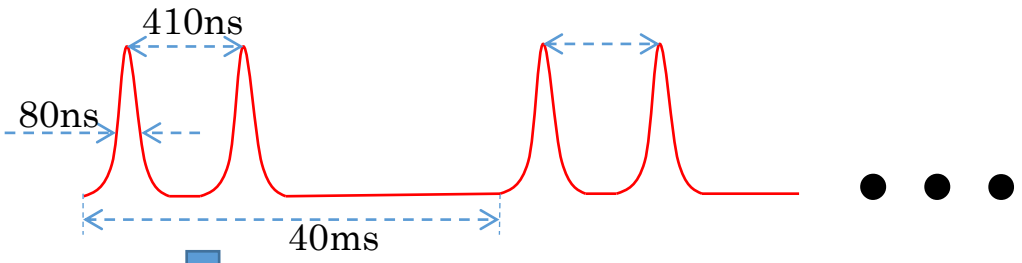
0.25-18.5ms
300-1600 MeV
accelerate

18.5-20 ms
1600 MeV
extract

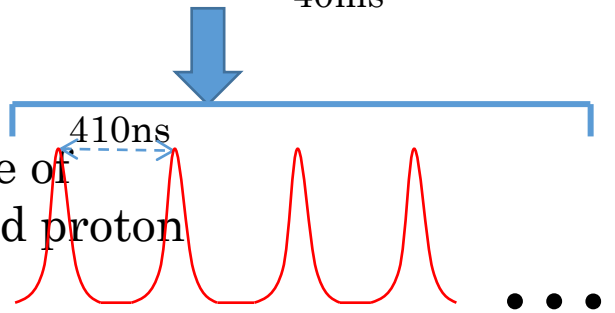
Special Mode
(single bunch)



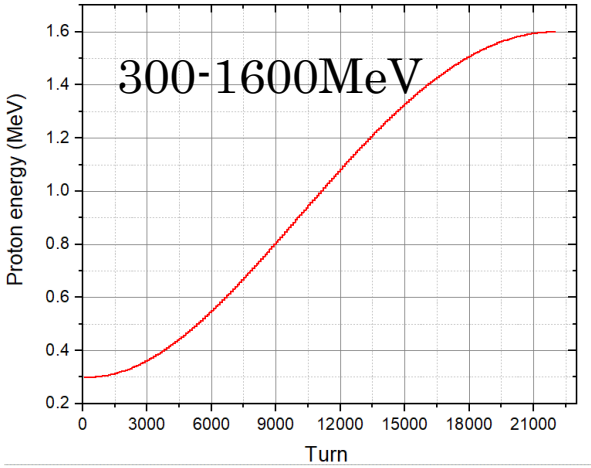
Normal Mode
(double bunch)

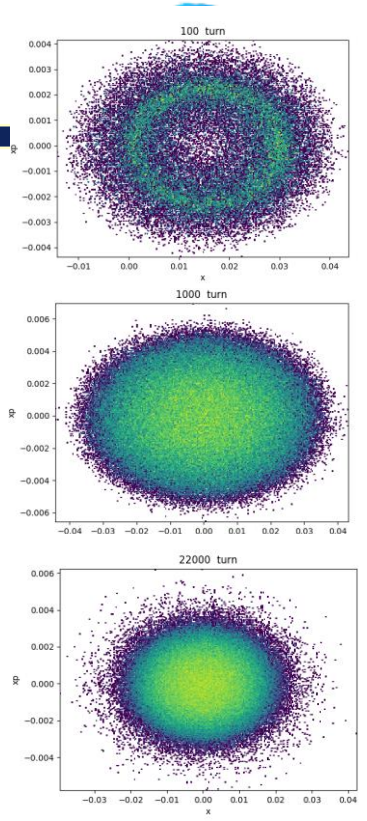


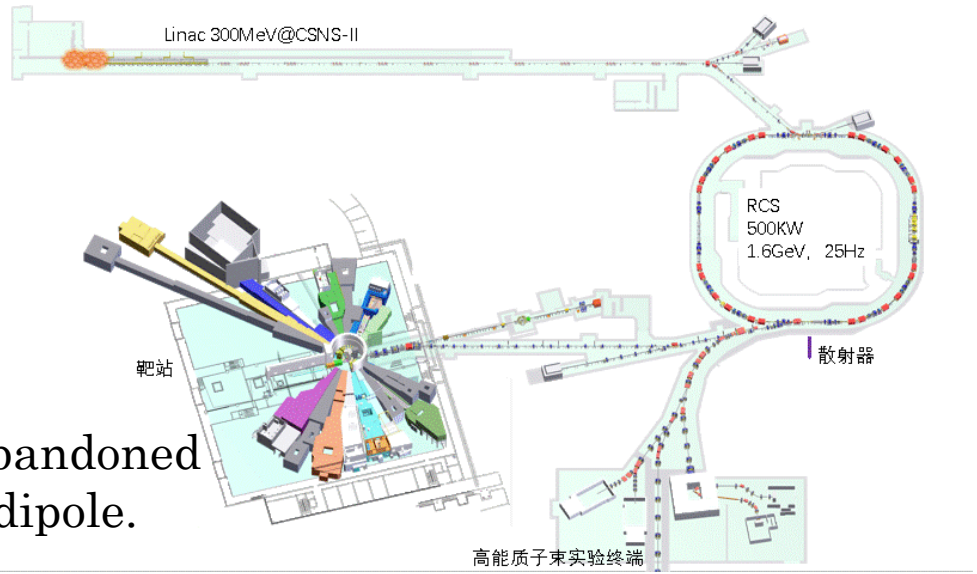
Time structure of
multi extracted proton



Variation of energy and profile
of the protons in 20 ms



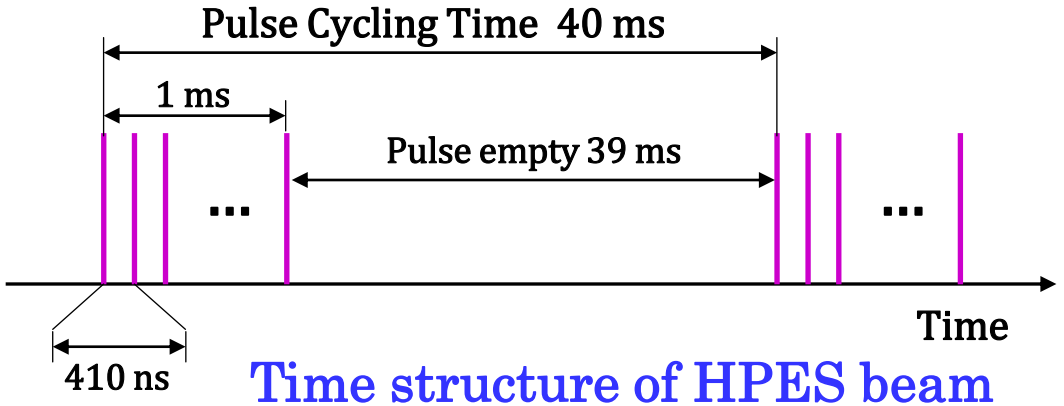




The last pulse is abandoned
due to the limit of dipole.

3.3 Limit of the HPES beam

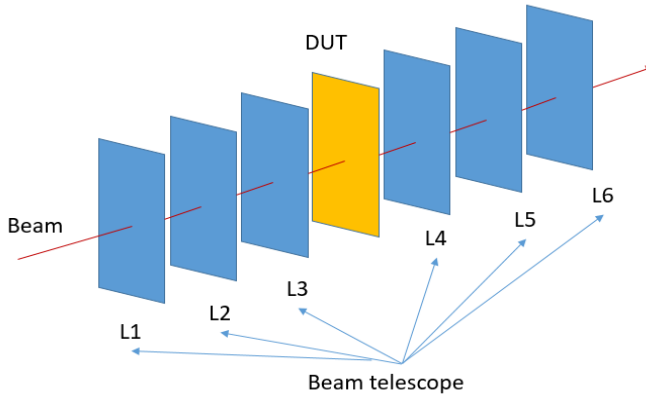
- Pulse time is 1ms * 25Hz, duty cycle of 2.5%.
  - Flux of one single pulse is high, while its length is short.
  - Low repetition of the pulses.
- Proton energy is only 1.6 GeV.
  - Positioning resolution is limited.
  - Less production of secondary ion beam.
  - Few types and energies of produced secondary mesons.

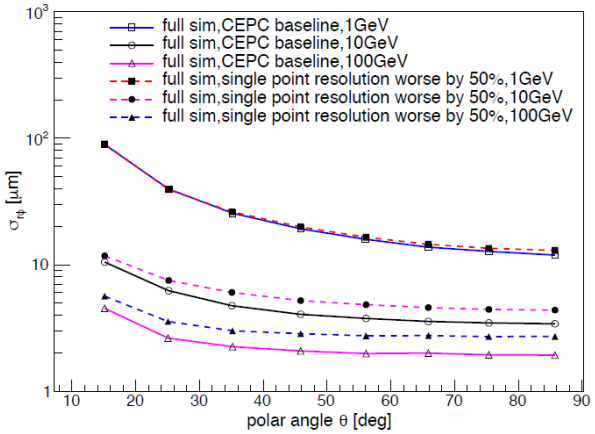


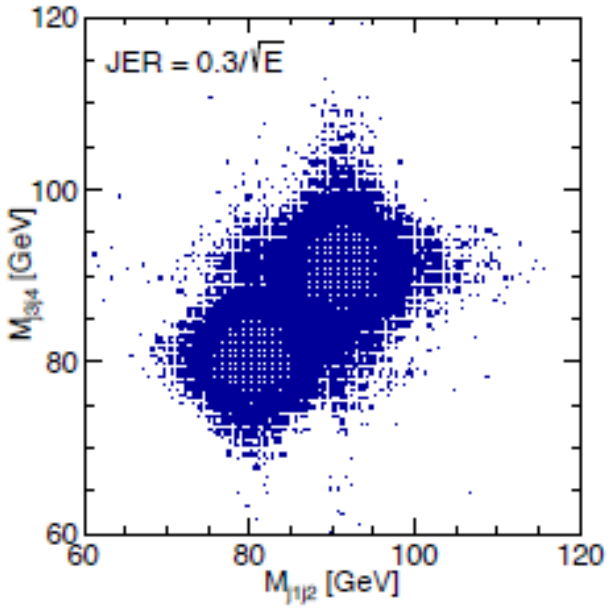
Time structure of HPES beam

4.1 Beam requirements from detector tests

- Two types of requirements from large-scale detection system:
  - track detectors (vertex detectors)
  - calorimeters.







- Track detectors: Low material budget and high spatial resolution, including the pixel detectors and TPC.
- Need particle track measurement provided by telescopes.
- Rec. res. ~ 3-10 μm for CEPC detectors.

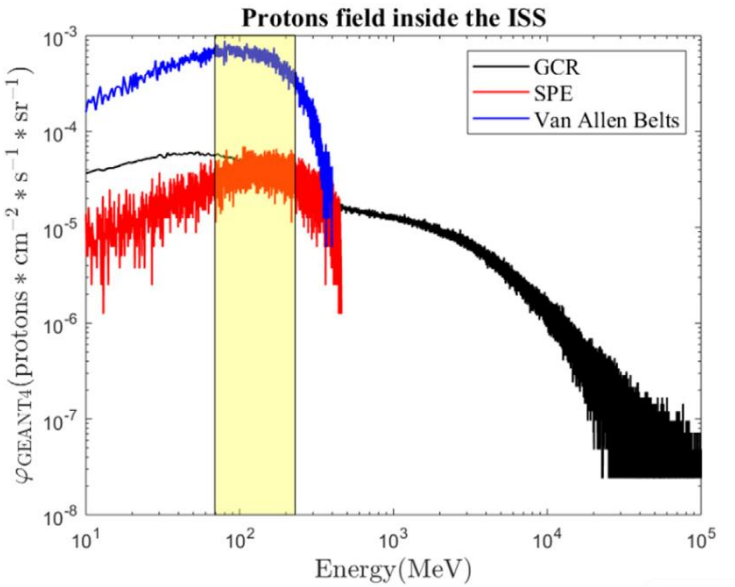
- Calorimeters: hadron calorimeters and E-M calorimeters.
- Requires the energy of each single proton.
- 3% is required to CEPC calorimeters to discriminate W/Z

4.2 Other beam requirements

The 1.6 GeV proton could play crucial role in the following fields:

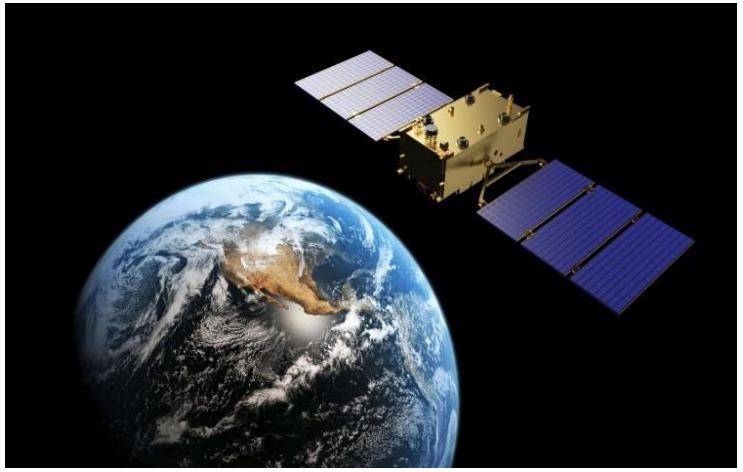
Cosmic ray effect on aerospace detectors

- Galactic cosmic protons in GeV are important.
- Influence of protons in this energy is in-ignorable to the scintillators and pixel detectors on the spaceship.
- A higher flux of proton beam is required, instead of the single particle beam.

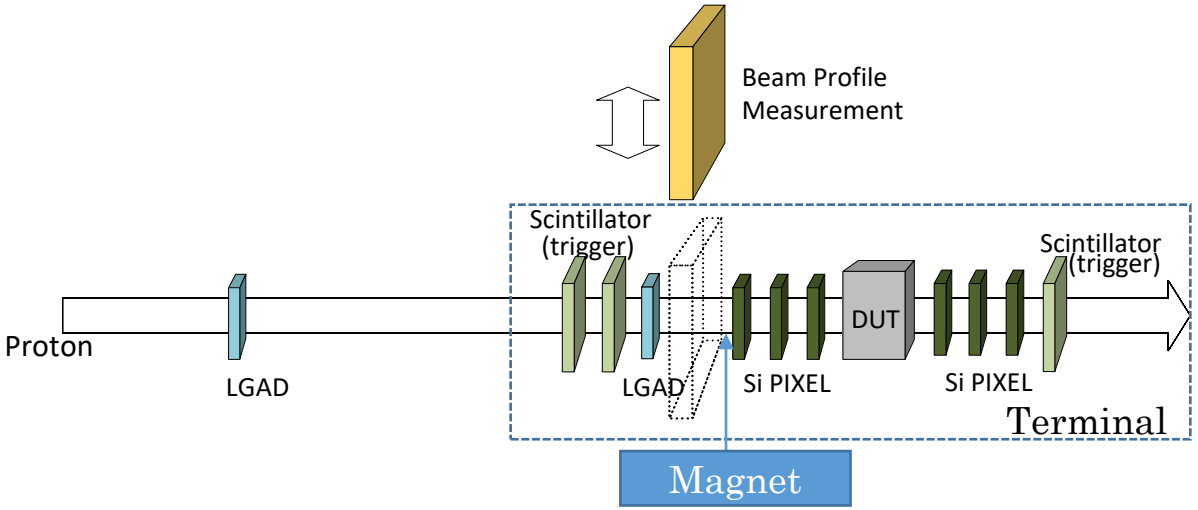


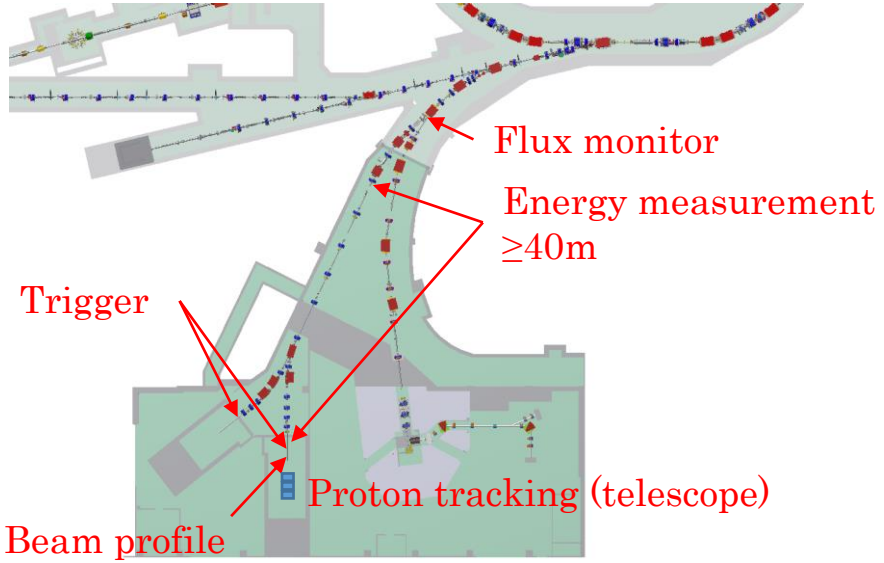
System-level test to satellites

- A GeV proton test beam will be important for the irradiation hardness study in chip, system and satellite level.



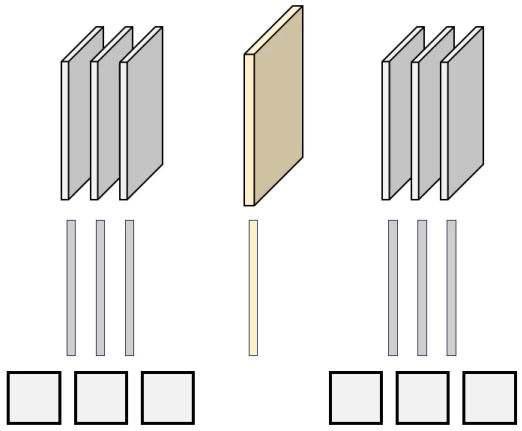
5. Detector System in Terminals





Num	Device	Function	Primary Parameters	Detector Technologies
1	Beam telescope	Proton track measurement	Spatial res < 10μm	Pixel detector
2	Particle energy measurement	Proton energy measurement	100 ps for LGAD resolution	LGAD detector
3	Trigger system	Provide trigger signals to all detectors	Time res. < 1ns	Scintillation fiber + fast PMT
4	Beam profile system	Profile the beam and measure the uniformity	Positioning res. < 150μm	Micromegas
5	Beam flux system	Long time proton flux measurement	Flux from 1~10^5 p/pulse	SiC detector
		Weak proton flux measurement		Plastic scintillation

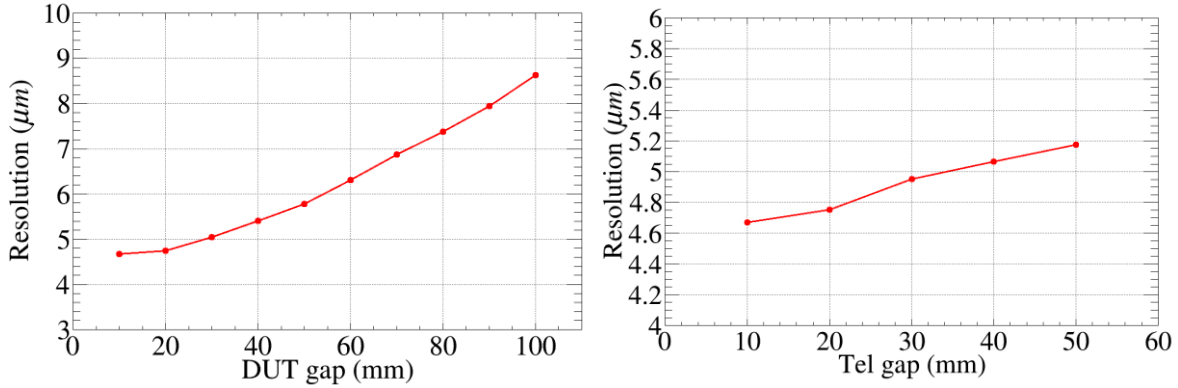
5.1 Proton Beam Telescope

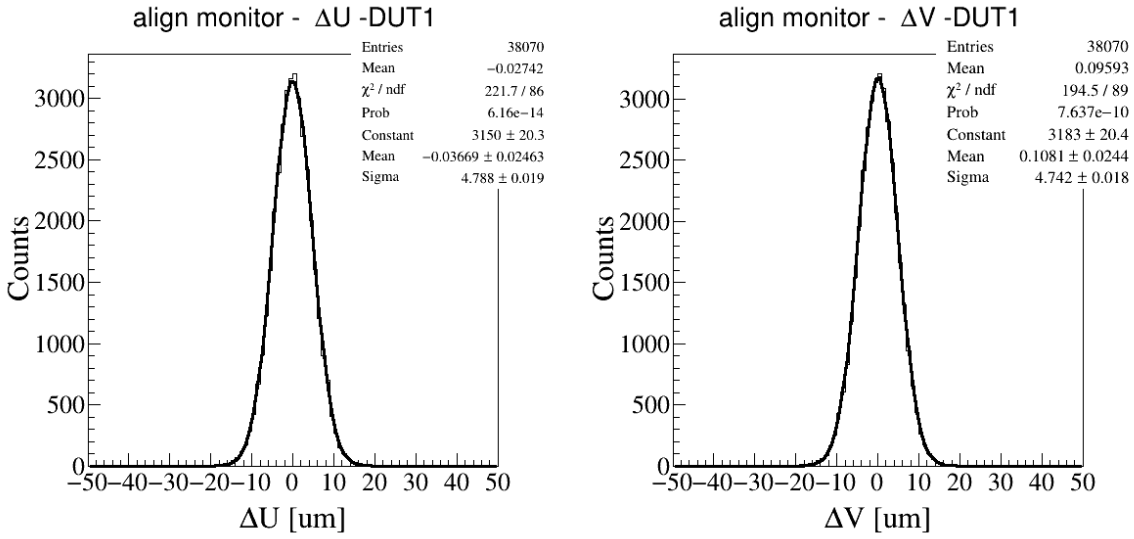


- The high-precision positioning detectors has become the primary technology in high-energy physics.
- The beam telescope is required to complete the testing of these detectors on the test beam:
  - Noise level and pixel quality inspection of each detector
  - Positioning of detectors on the assembly
- By using silicon pixel detectors on the beam telescope, it is possible to achieve an accuracy measurement of < 10 μm.

Many efforts have been done to survey the layout of detectors:

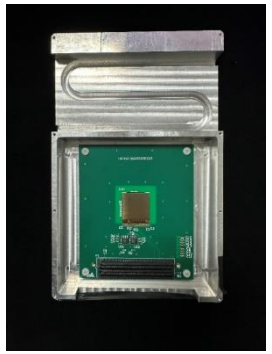
- DUT gap 20 mm & TEL gap 20 mm @ DUT depth 50 mm.

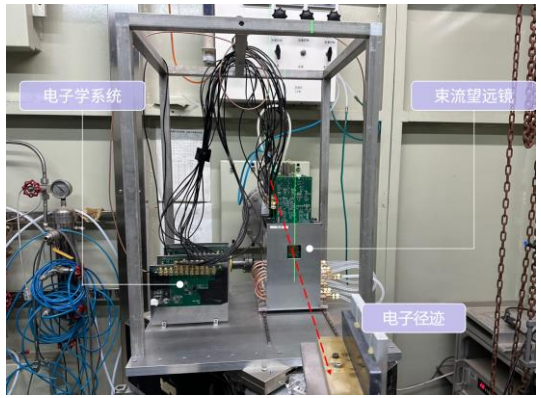


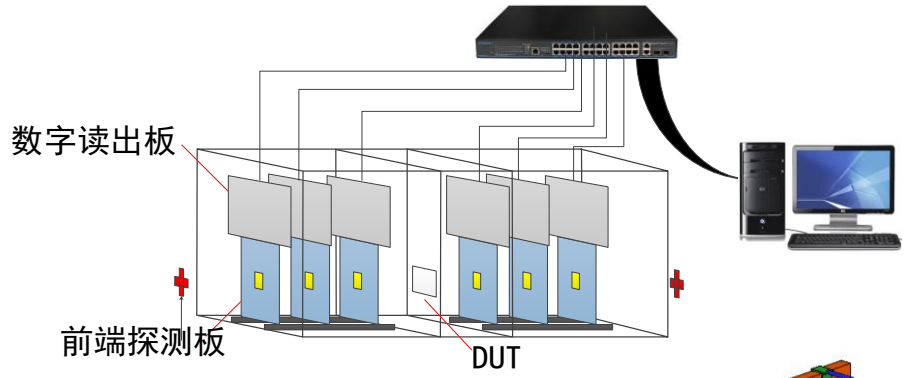


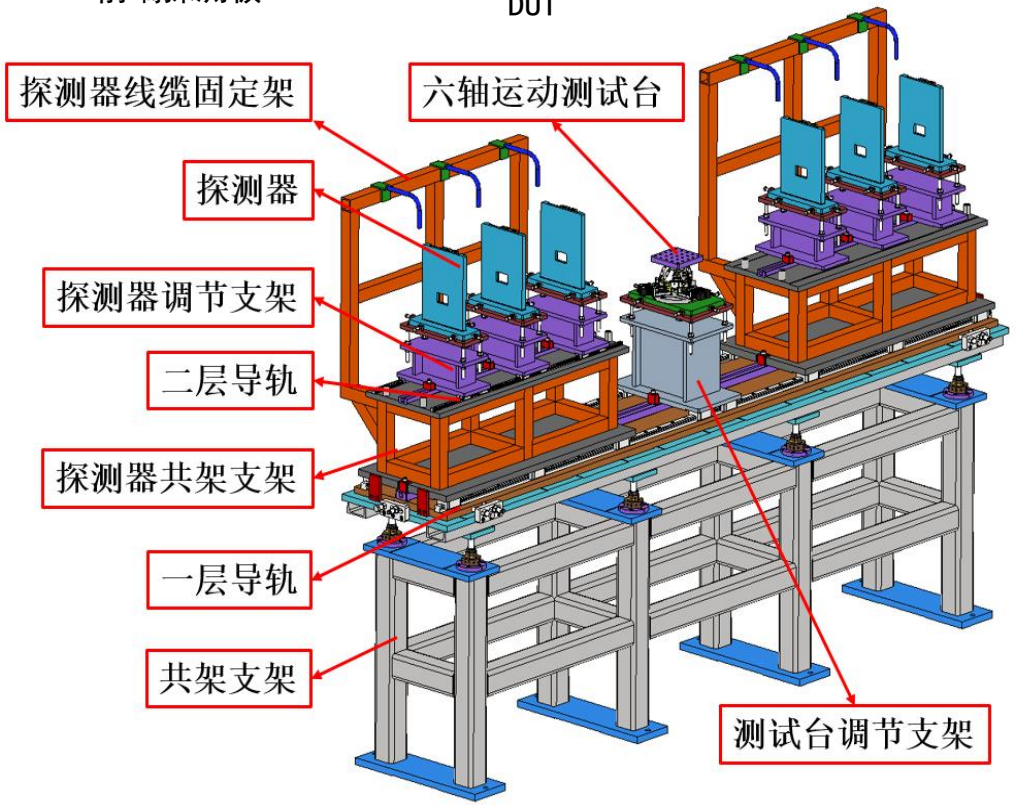
5.1 Proton Beam Telescope

- High precision meas. to proton beam of HPES
- Parameters：
  - Number of modules：6
  - Sensitive area > 3cm^2/module
  - Positioning resolution ≤ 10 μm
- Usage：
  - High precision test of CEPE track detectors.
  - High precision test of advanced position detectors.
  - Test to proton imaging scenarios



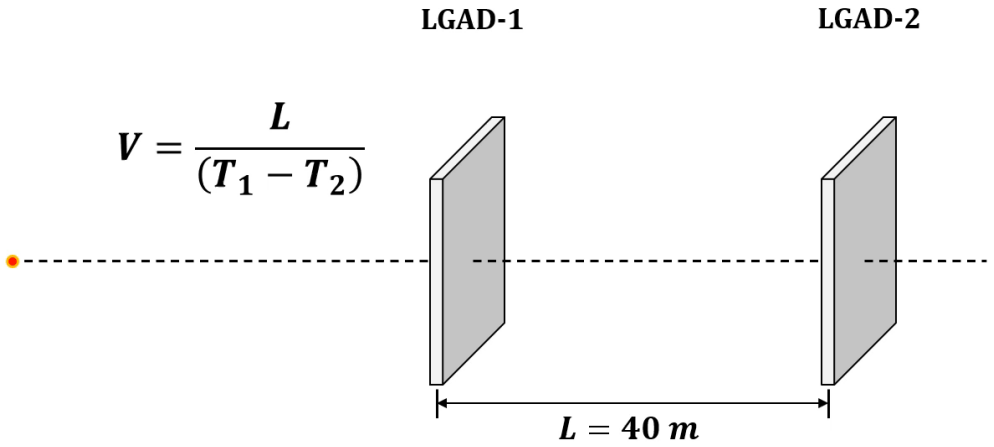


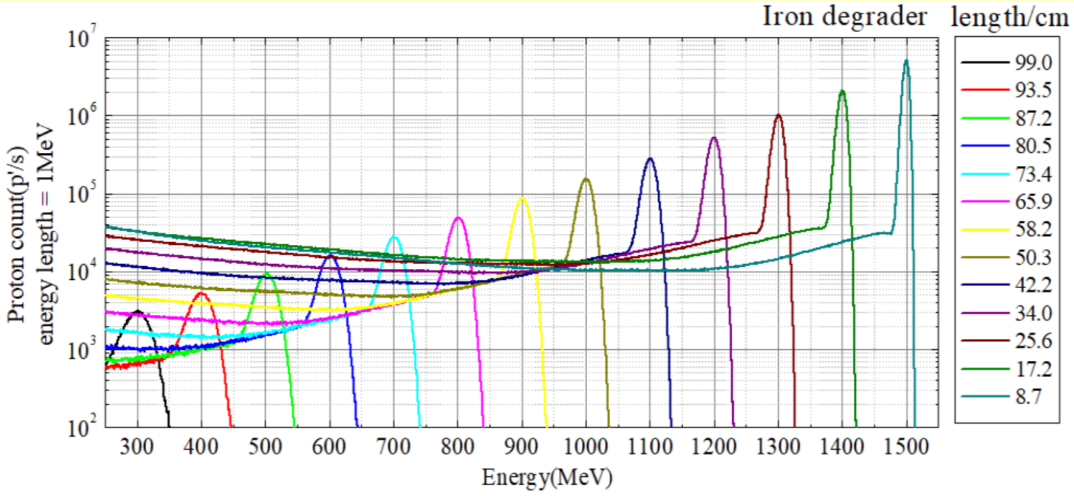


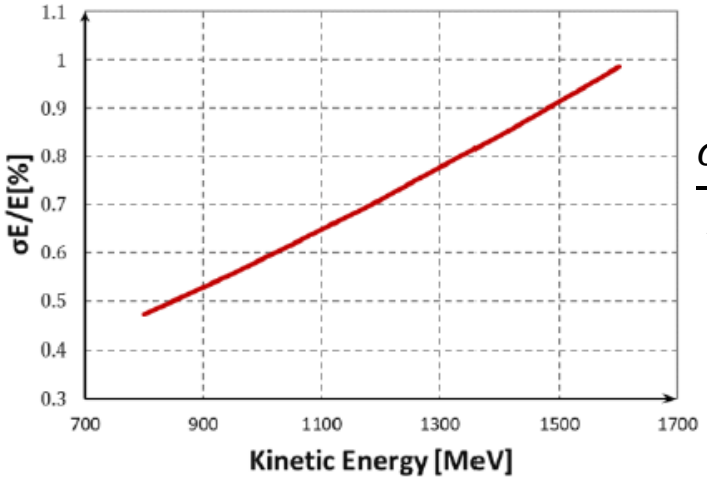


5.2 Proton Energy Measurement

- Calorimeter test need proton in various energy from 0.8~1.6 GeV.
- A proton energy meter is needed for the energy-degraded protons.
- Time of flight method for energy meas.
- Flight distance: max. 40 m.
- Detector time res.: ≤ 100 ps





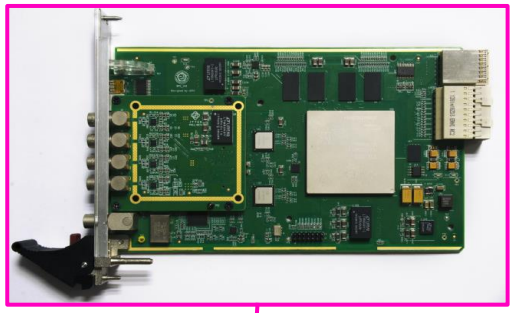


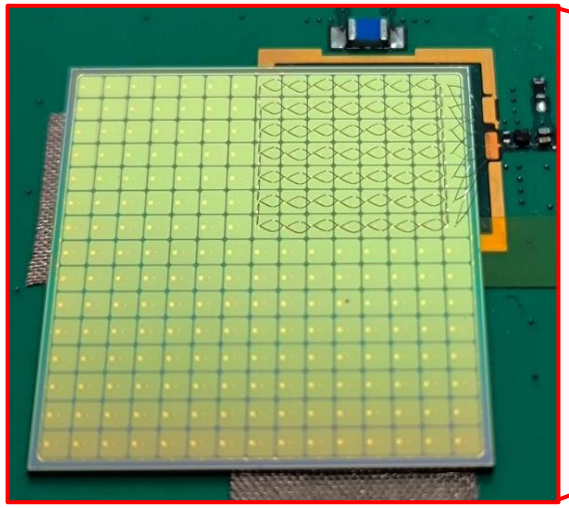
$$\frac{\sigma_E}{E} = \gamma(\gamma+1)\frac{\sigma_T}{T}$$

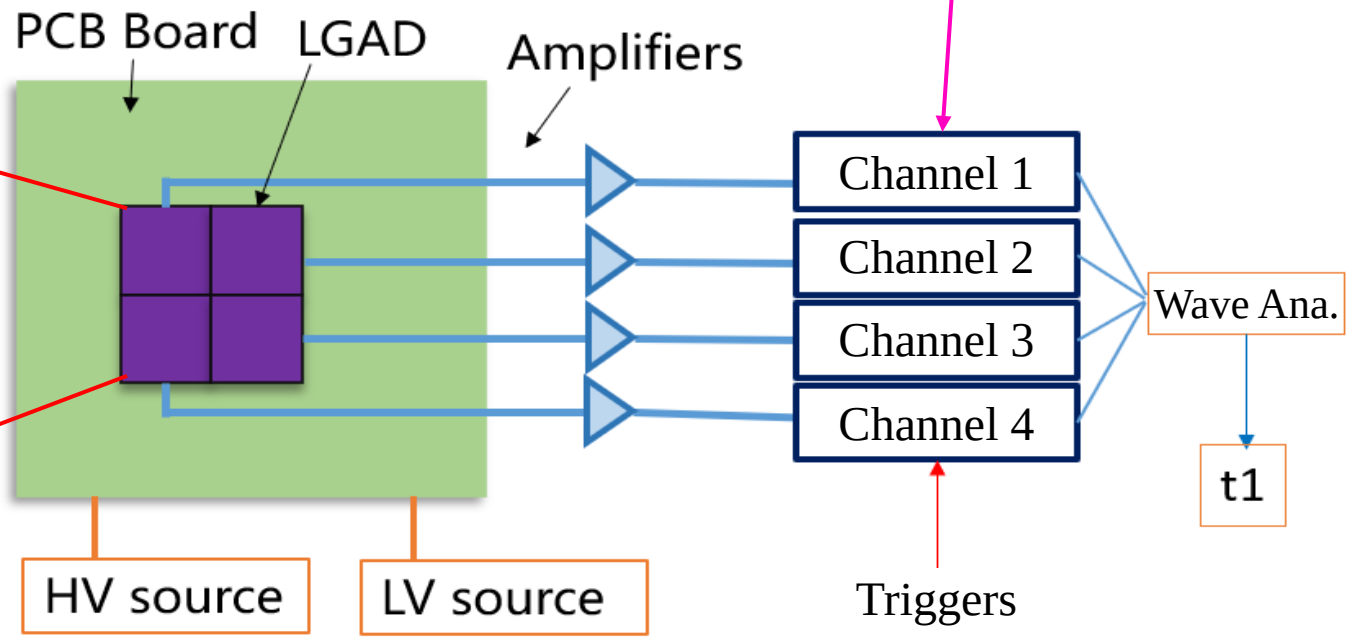
- Device resolution on proton energy < 1% @ flight distance 40m & detector time res. 100 ps.

5.2 Proton Energy Measurement

- Proton flight time is measured by LGAD.
- PXIe-X1012 of EverACQ is applied as the DAQ.
  - 6.4 Gsps
  - 2 GHz
- Latest test shows the time resolution of LGAD is < 70 ps, which meets the requirement,

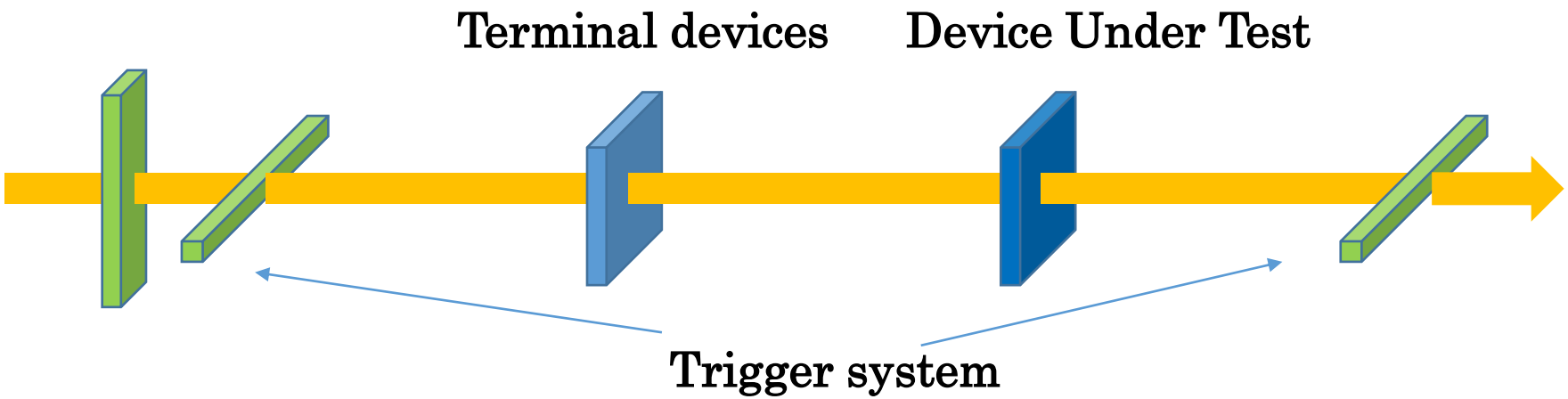






5.3 Trigger System

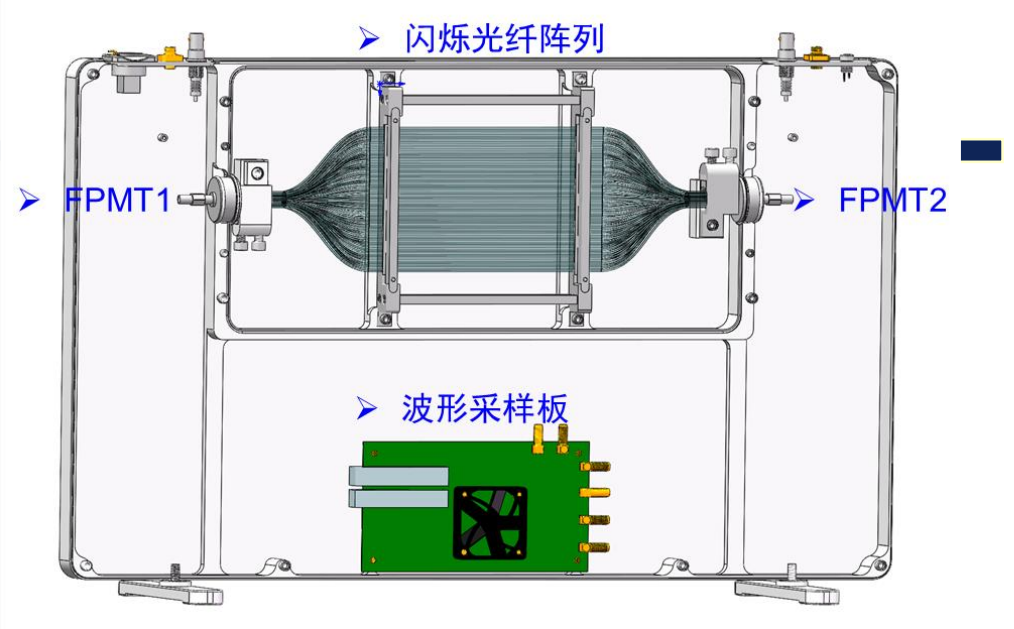
- Provide DAQ window reference for all detectors.
- “Two in Front + One in Back” ：
  - Two in Front ： X-Y 2D limit. Only responds to the beam area to suppress background.
  - One in Back ： Tripple correspond. Make sure the proton passes the detector.
- Scintillator + Fast PMT: trigger time resolution < 1 ns.
- Trigger signals: TTL, NIM, et al.

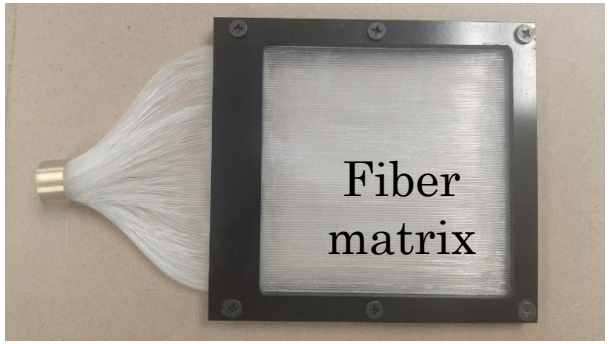


5.3 Design of Trigger System

- Scintillation fiber matrix
- Depth of fiber is 2mm.
- Low material budget and the influence on proton energy.

Parameter	Value
Max. Count rate	10kHz
Sensitive area	10cm*10cm
Number of detector	3 set
Electronics Channels	2CH X 3set
Proton energy range	0.8~1.6GeV
Time resolution of trigger signal	<1ns
Time resolution of PMT SPE	< 100ps

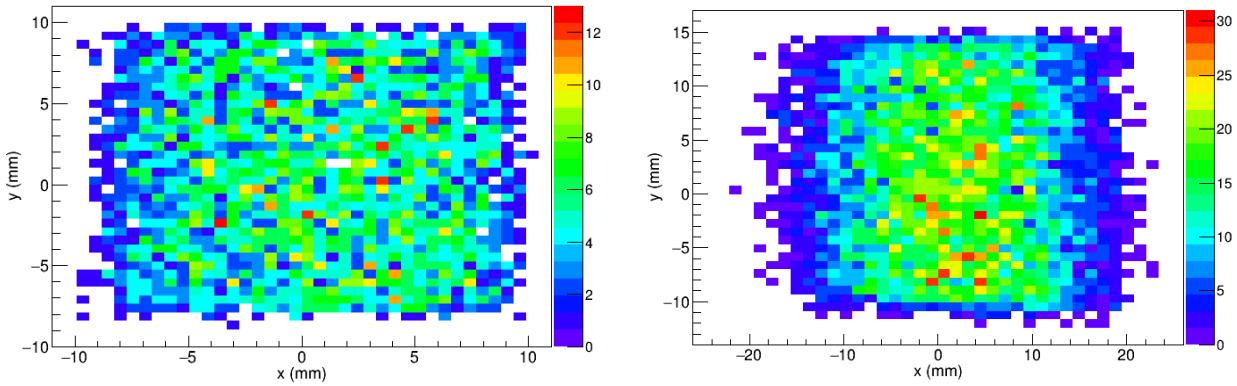




DAQ board

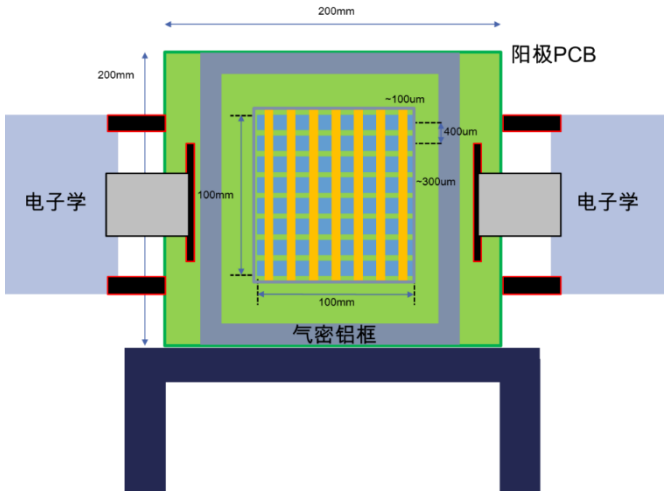
5.4 Beam Profile System

- Provide the origin profile of proton beam
- **Requirements：**
  - Size of weak test beam： 10*10mm^2~30*30mm^2；
  - Size of irradiation beam： 10*10mm^2~100*100mm^2；
  - Position resolution： **150μm**；
- **Technology: Micromegas**
  - High detection efficiency (>95%)
  - High count rate (Max in MHz)
  - Low ion reflux, low space charge effect at high counting rates
  - Time resolution (~ns) and spatial resolution (~10^2 μm) meet the requirements
  - Mature technology, stable process, and low development cost

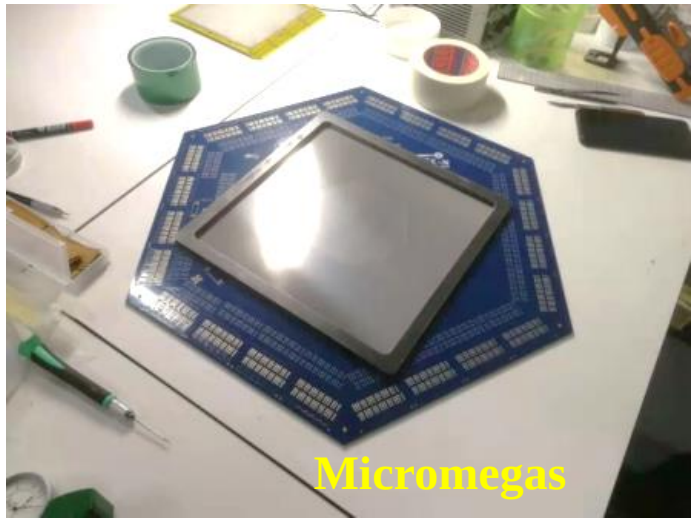


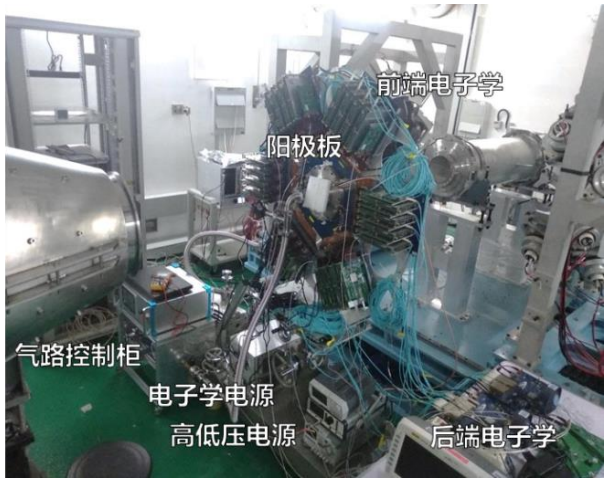
Beam profile size in terminal (G4 Sim) ~2.5×2.5 cm^2

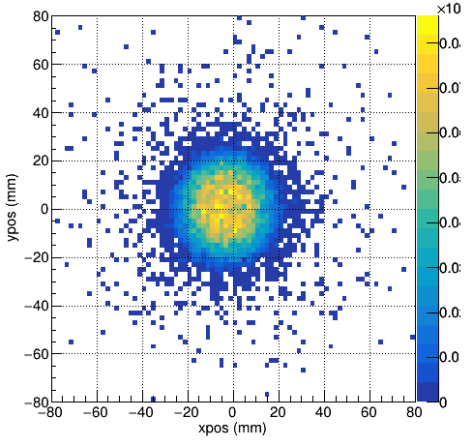
Count rate	10 kHz
Sensitive area	10 cm*10 cm
Position res.	150 μm
Num. of DAQ channels	2048

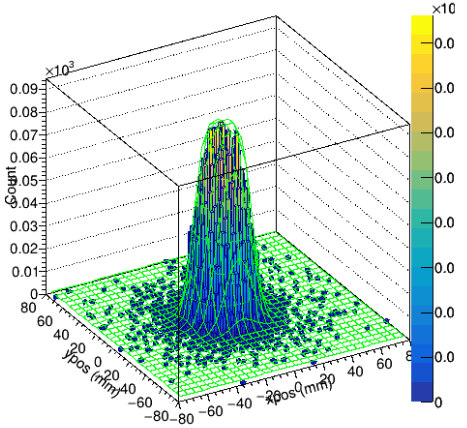


5.4 Beam Profile System





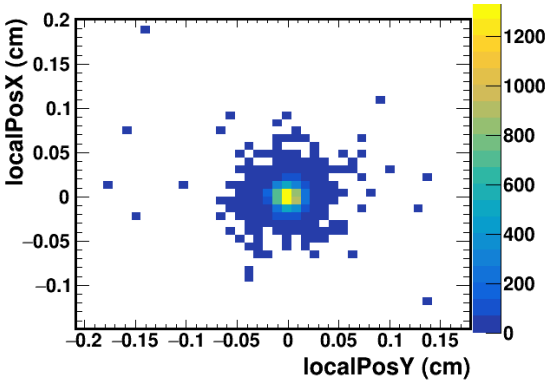




- **Technology has been verified on CSNS Back-n**

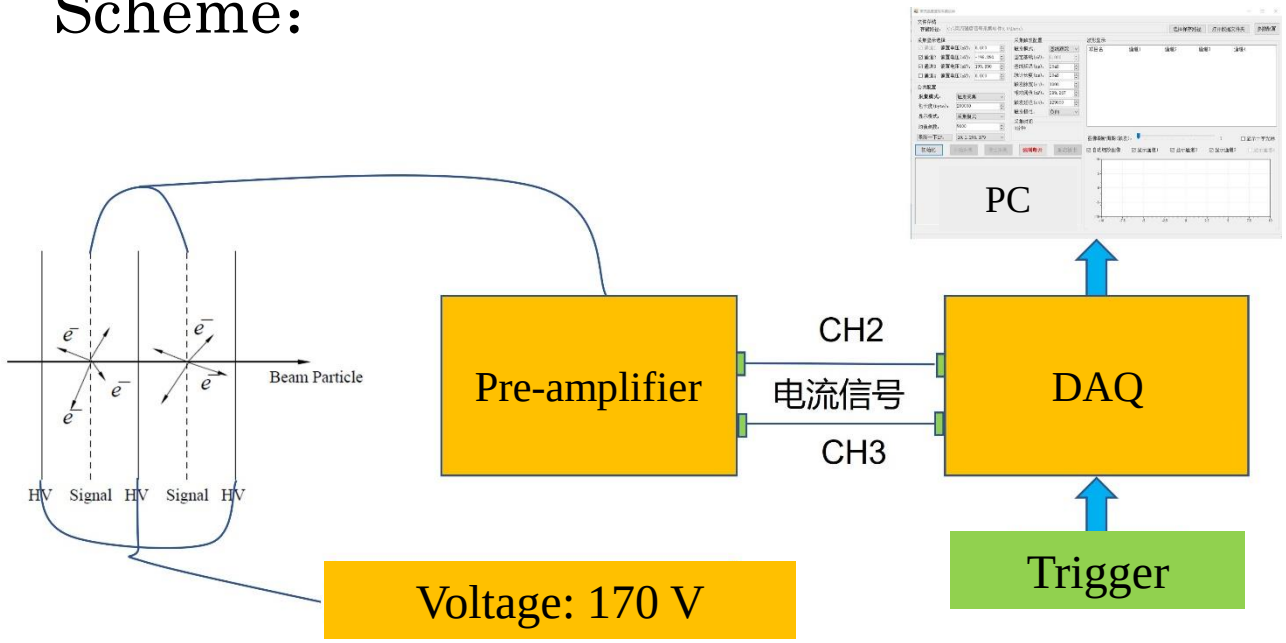
Result:

- Beam Center $(x_0,\ y_0)$: (-3.1mm, 0.6mm)
- Beam radius: 17.7±0.1mm
- Position res. : 100 μm



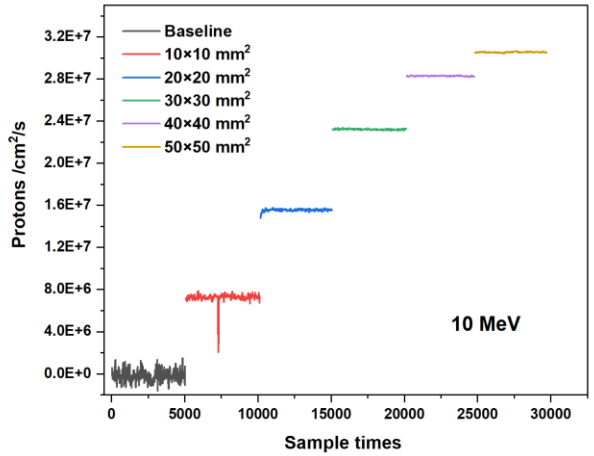
5.5 Secondary electron emitting monitor

Scheme:



Photon:

Verification result using APEP 10 MeV proton:



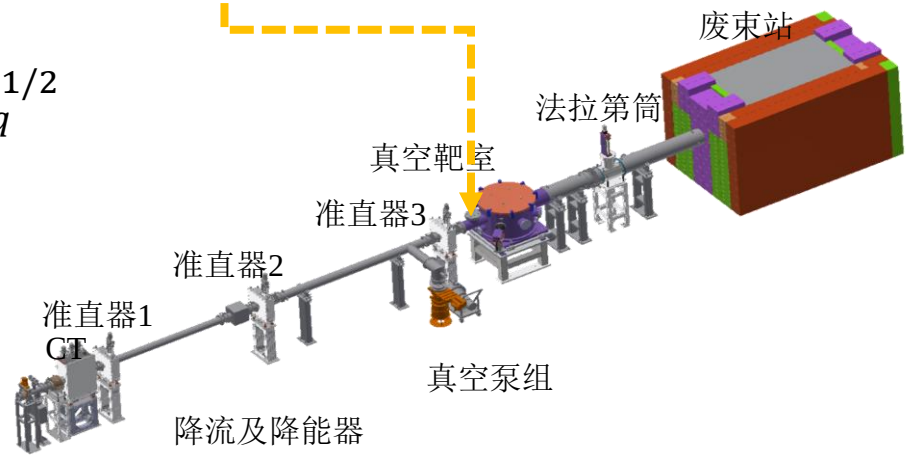
Secondary electron ejection factor of proton on Al foil:

$$\varepsilon = 38.26\, E_{eq}^{-1/2}$$

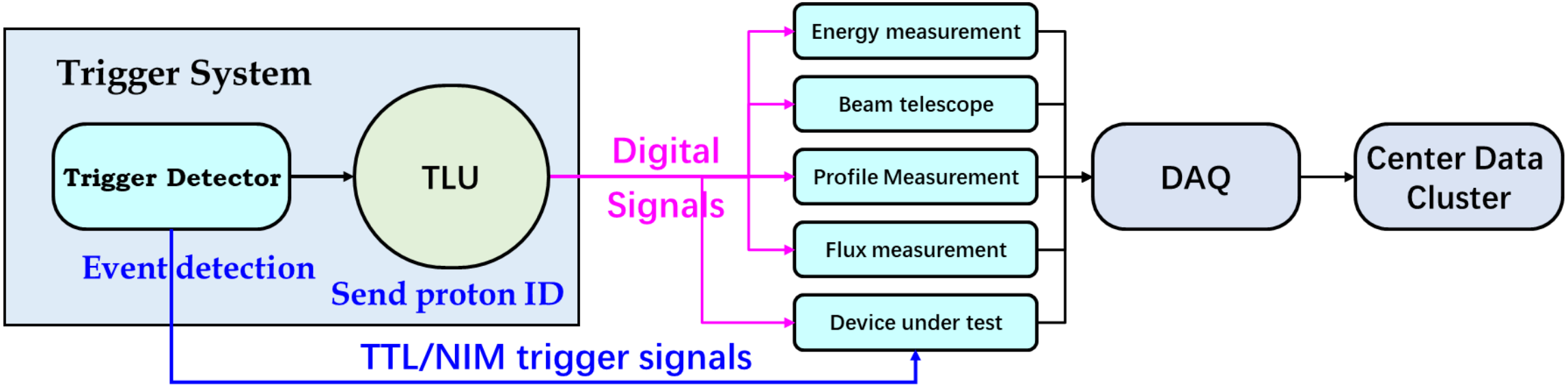
Parameters:

Al depth: 10μm layers: 5

Voltage: >100V proton flux: 10^6~10^8 p/s



5.6 Trigger Logic Unit (TLU)



- User data and terminal detection system data need to achieve event level data alignment.
- The trigger logic unit (TLU) provides a reference for HPES to achieve data alignment.
- Responsible for providing digital trigger signals to various detection systems.

- **At least 32 digit bit.**
- **IP passing time < 410ns**
- **Compatible of AIDA TLU strategy.**

More details will be given in Guo's talk in Tuesday morning!

6 Summary of Beam Parameters

Performance	Parameters
Flux without collimator	>2×10^6 p/s
Frequency of weak beam	<10 kHz@500 kW
Beam size	≤（20mm×20mm）
Repetition	24 Hz
Pulse length	1.0~1.5 ms
Proton energy	0.8-1.6 GeV
Spatial resolution	<10 μm

Thank you for your attention!

Look forward to cooperating with you!