A High Compression Ratio Channel Multiplexing Method for Micro-pattern Gaseous Detectors

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On behalf of μSTC group

μSTC： μ(muon) Scattering tomography & Transmission radiography imaging faCility

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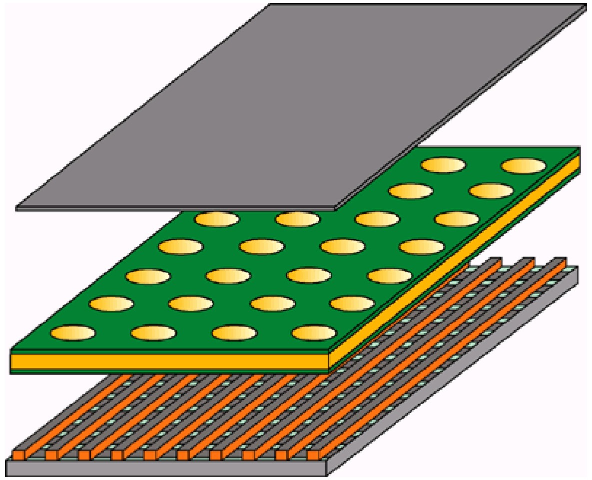
Outline

- Introduction of MPGD
- Multiplexing readout principles
  - Basic principles
  - Construct the usable multiplexing circuits
- Applied in muon imaging experiments
  - Channel multiplexing circuits for different size detectors
  - Extensible module design
- Prototype construction and muography experiments
- Summary

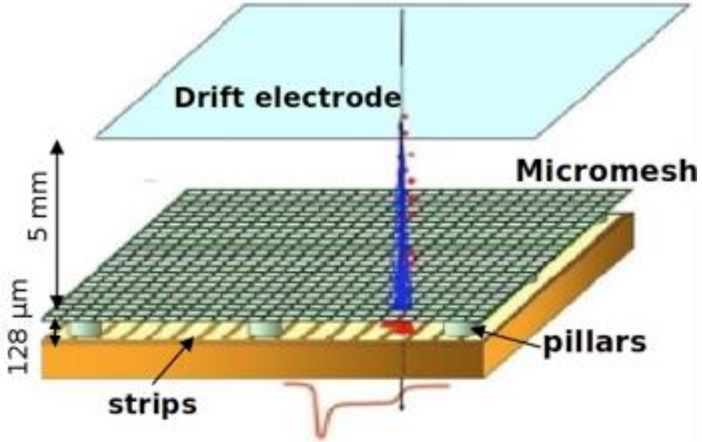
Micro Pattern Gaseous Detectors -- MPGD

- Gaseous ionization detectors consisting of microelectronic structures with sub-millimeter distances between anode and cathode electrodes.
  - Cost-effectively cover large areas with excellent spatial resolution
  - Ability to operate at high incident particle rates
- GEM, Micromegas, µRWELL, Thick-GEM, µGroove,…



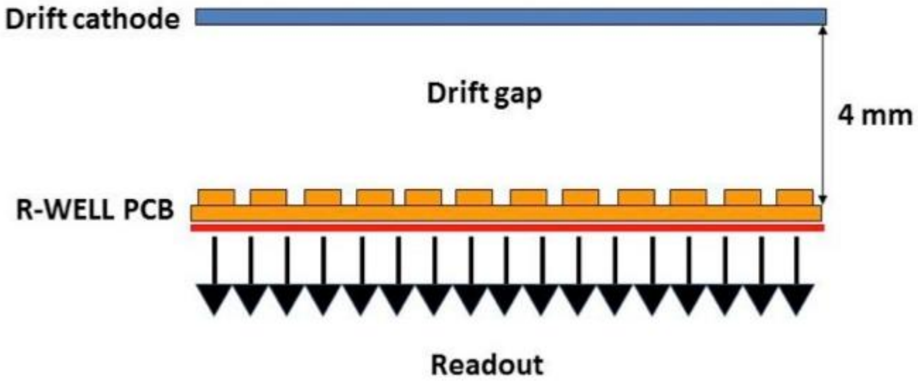
GEM

Credit: https://cerncourier.com/a/a-gem-of-a-detector/



Micromegas

DOI: 10.1088/1748-0221/7/05/C05001

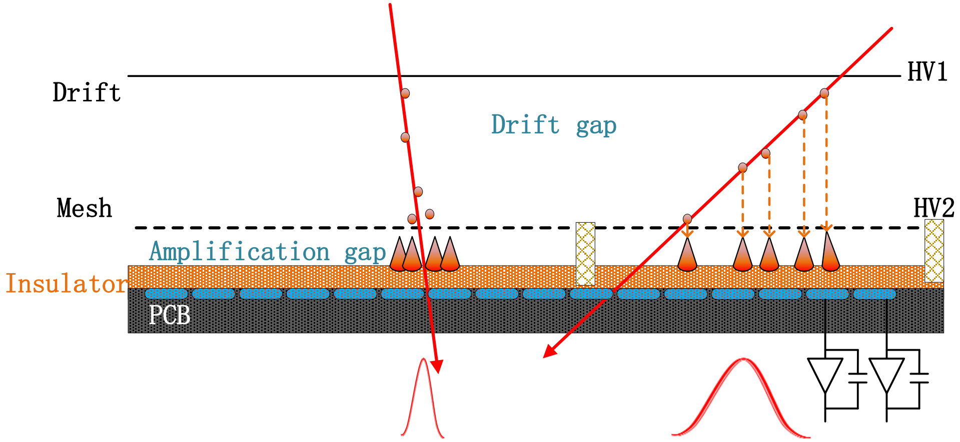


µRWell

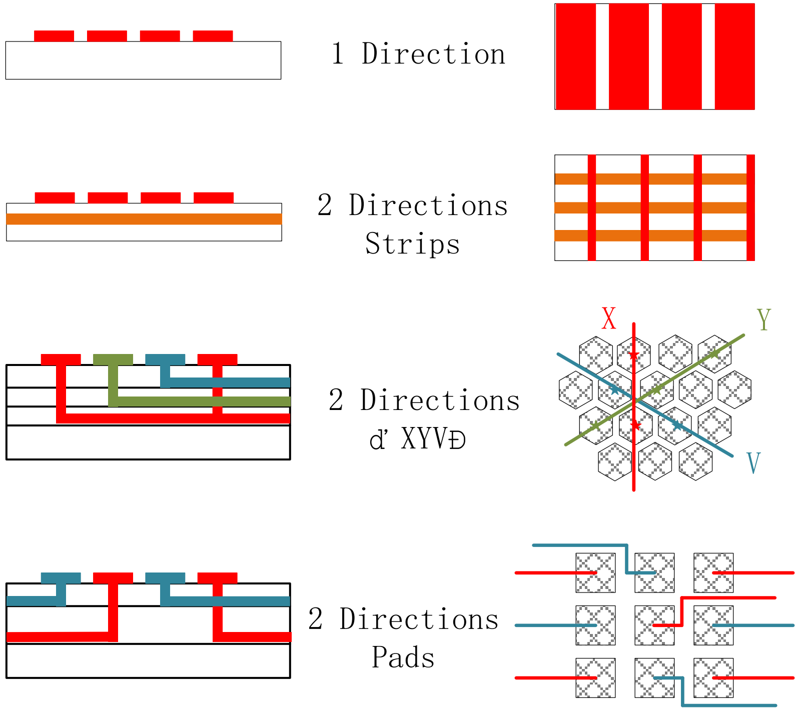
DOI: 10.1088/1748-0221/10/02/P02008

MPGD Readout Principle

- Using Micromegas detectors as an example
  - A fast electron signal and a relative slow ion signal
  - The primary ionization will spread within a range of several millimeters

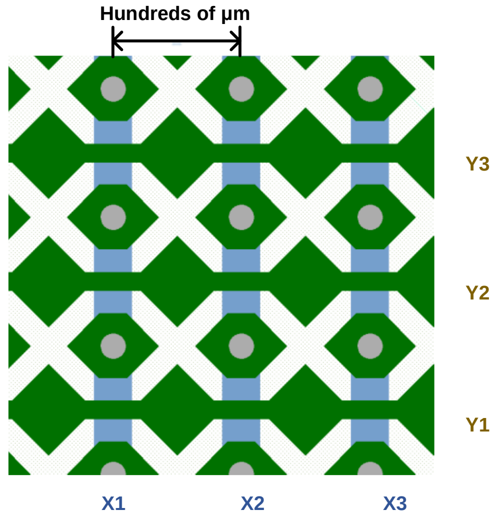


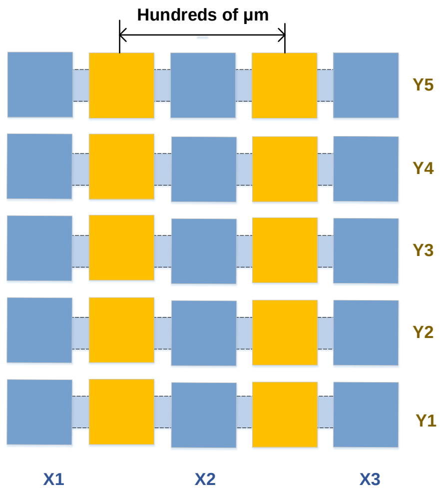
- Typical readout unit
  - 1D strip, 2D strips
  - 2D “XVY” pads, 2D pads



MPGD Readout Challenges

- Need large mount of readout channels
  - The spatial resolution depends on the position measurement
  - To obtain fine spatial resolution, the readout unit should be serval hundred micrometers





- Need complex readout electronics
  - Brings challenges in terms of system complexity, power consumption, processing capability, and cost.

Solutions in Sparse Hit Events

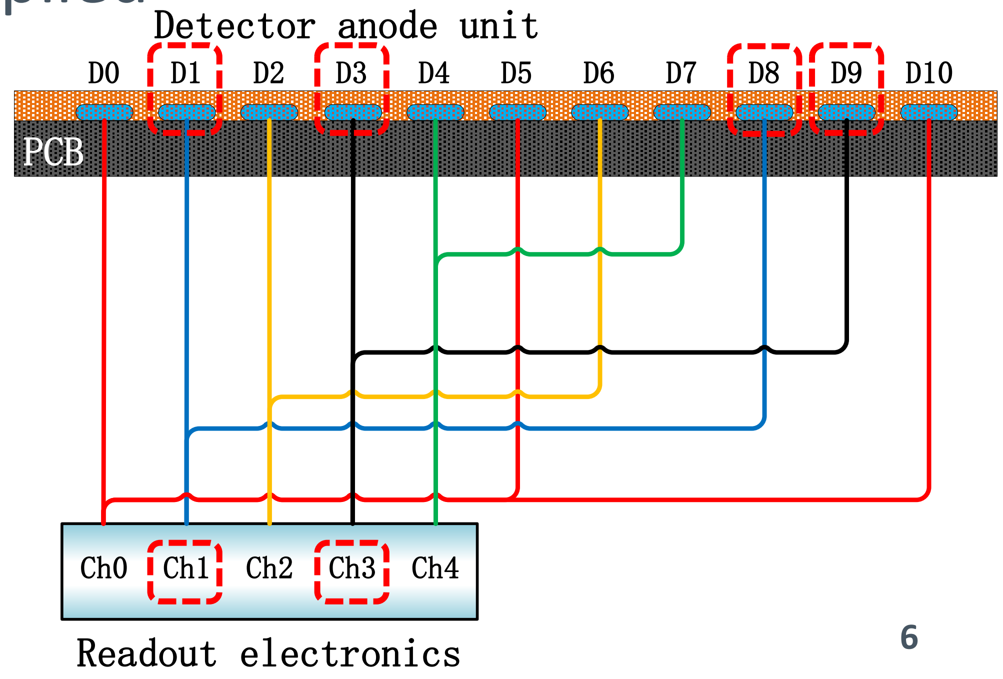
- Sparse hit
  - Means two particle would not hit the detector “simultaneously”

  ⇒Most of the time, only a few of the channels are fired
  - Most of the channels are in state of no signal
  - The fired unit at detector sides must be continues
- Channel multiplexing method can be applied

Eg:

1. At readout side:ch1 and ch3 are fired
2. The possible hit unit at detector side are

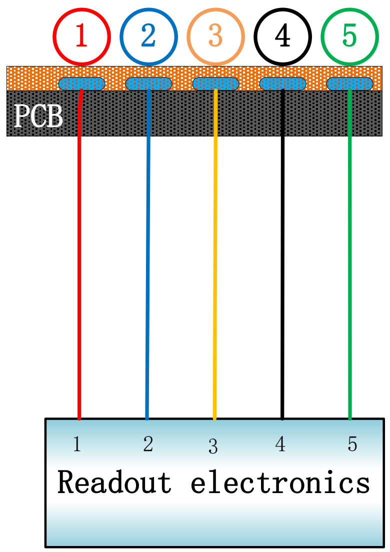
   1, 3, 8, 9
3. As the hit unit must be continuous, the real results is D8 and D9

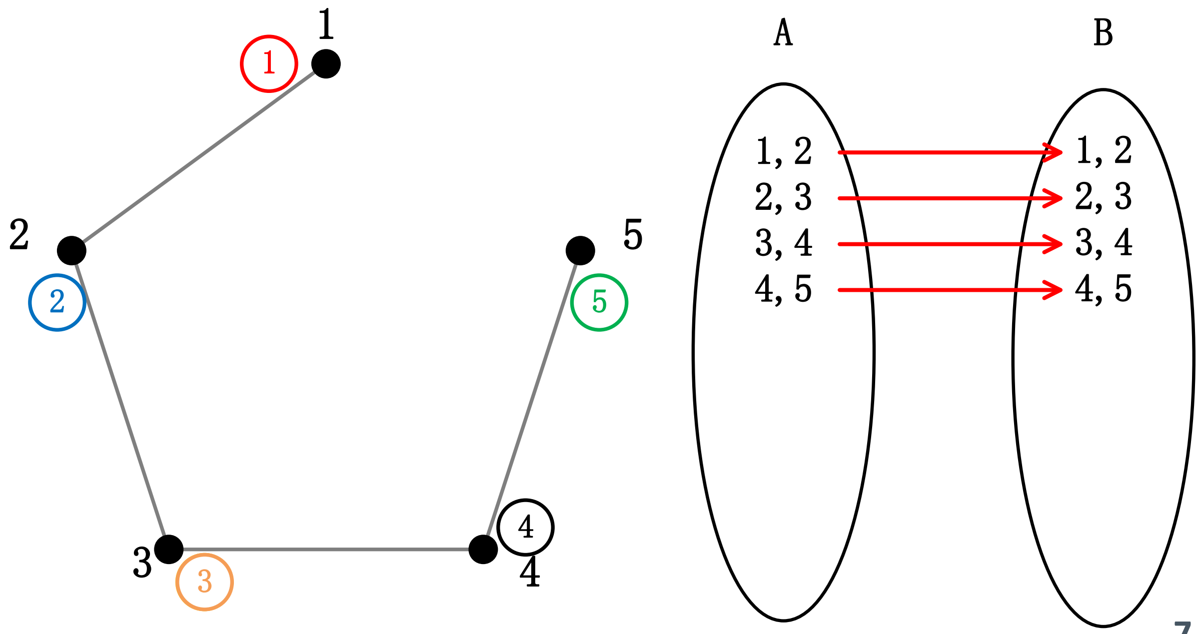


Basic multiplexing readout principles

- The construction of multiplexing graph
  - ①②③④⑤…stand for detector readout units
  - 1, 2, 3, 4, 5, … stand for number of readout electronics channels
  - The mapping of **a continuous detector channels** to **a unique pair of electronics channels**

Detector side





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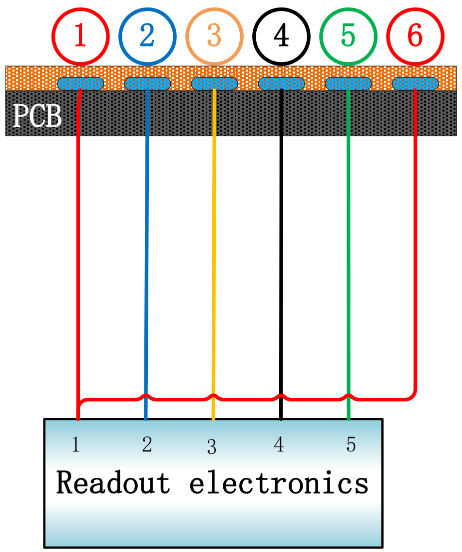

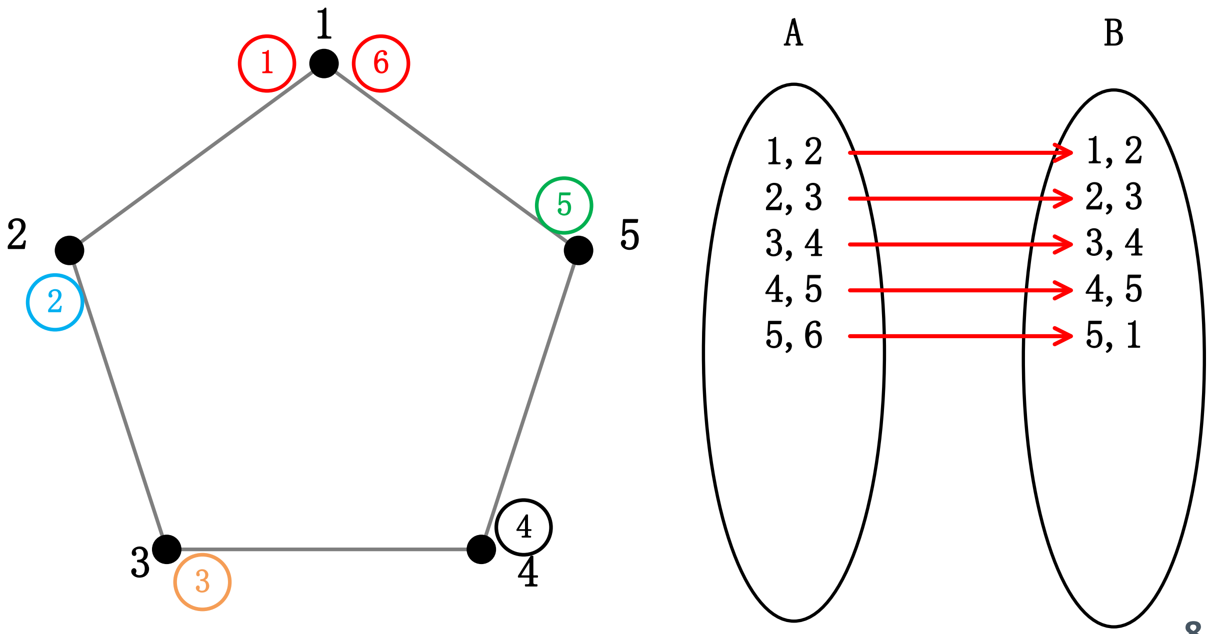

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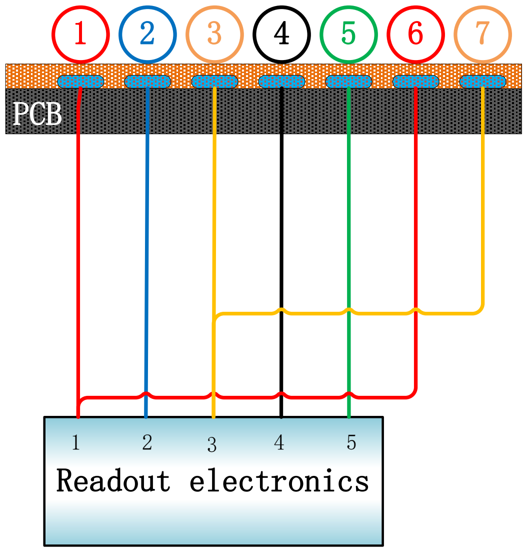

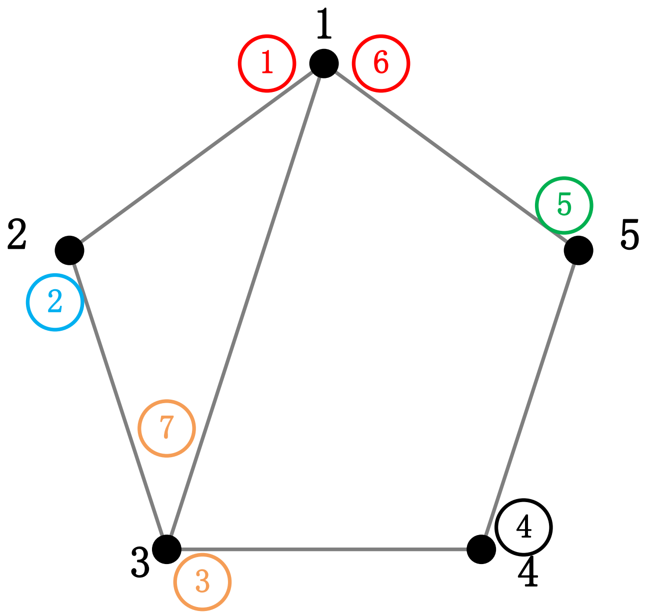

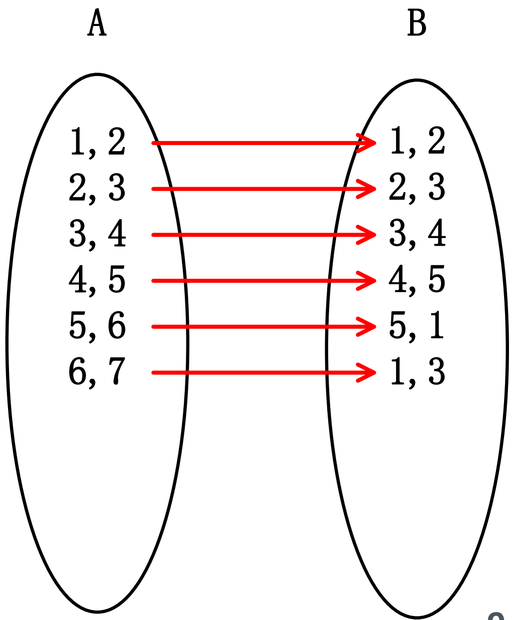

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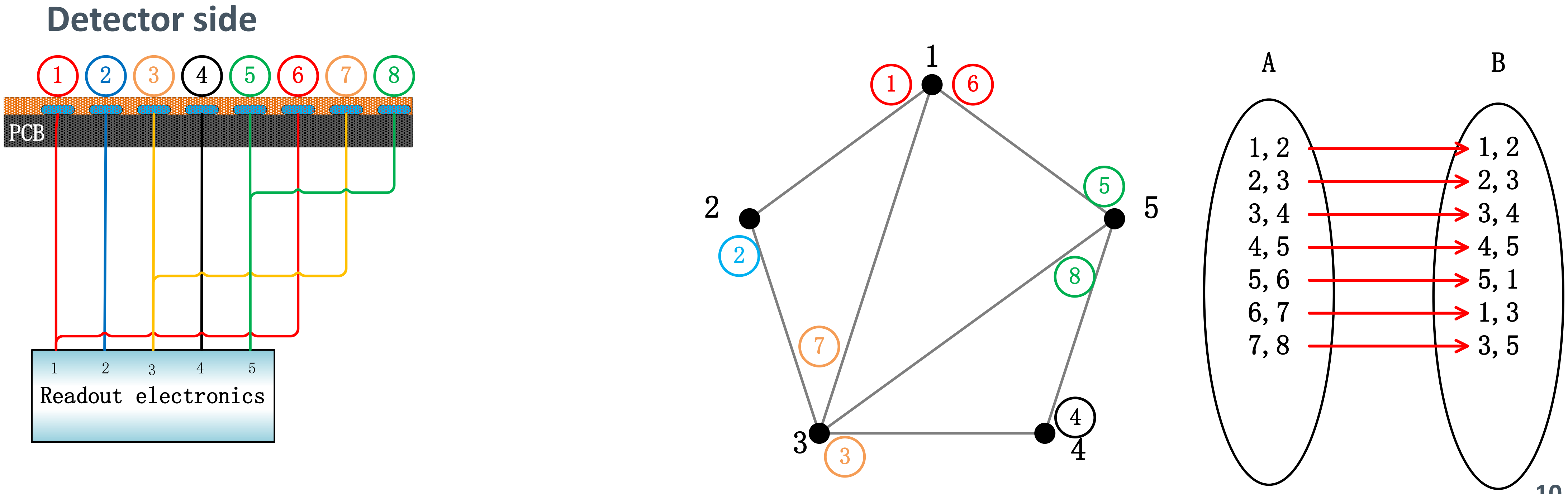

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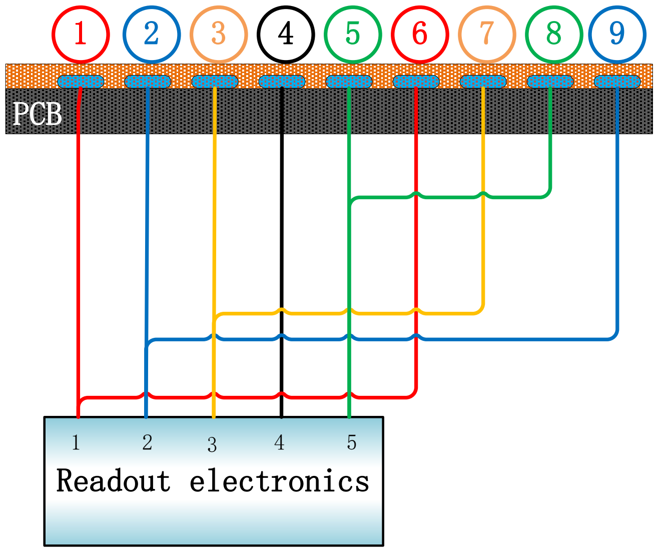

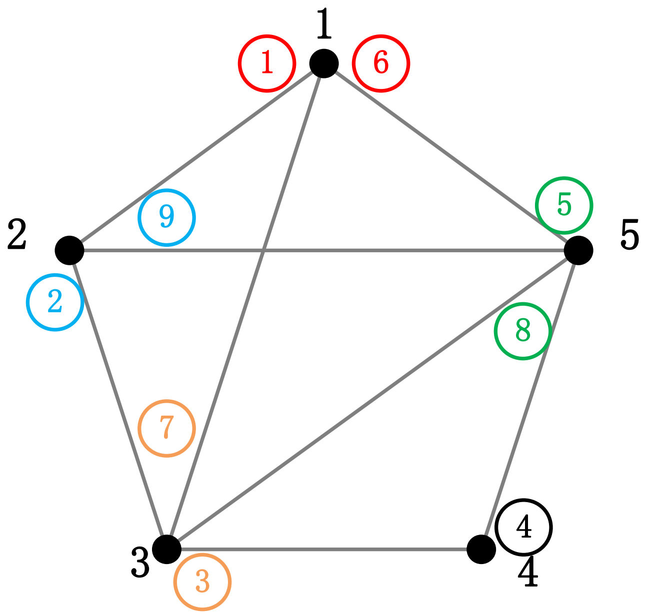

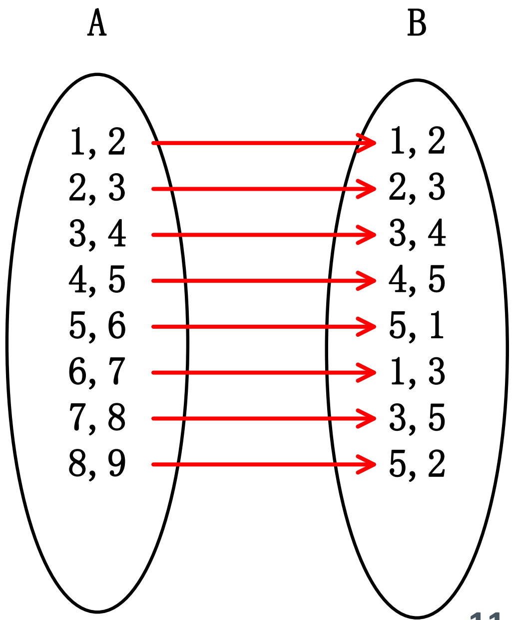

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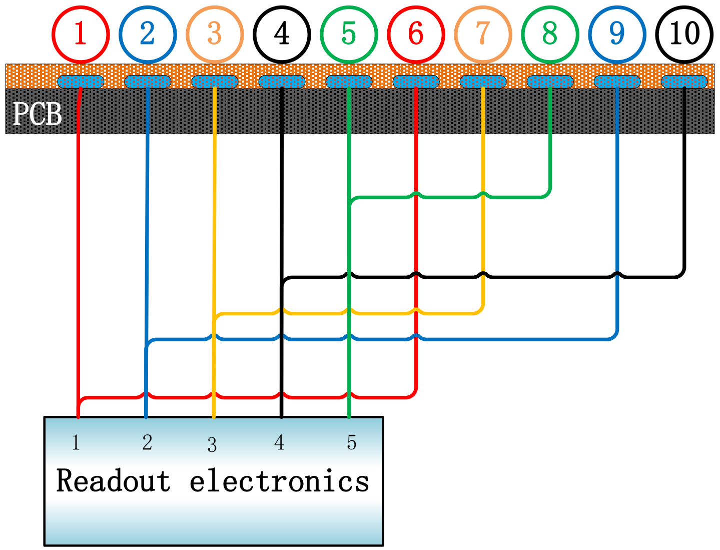

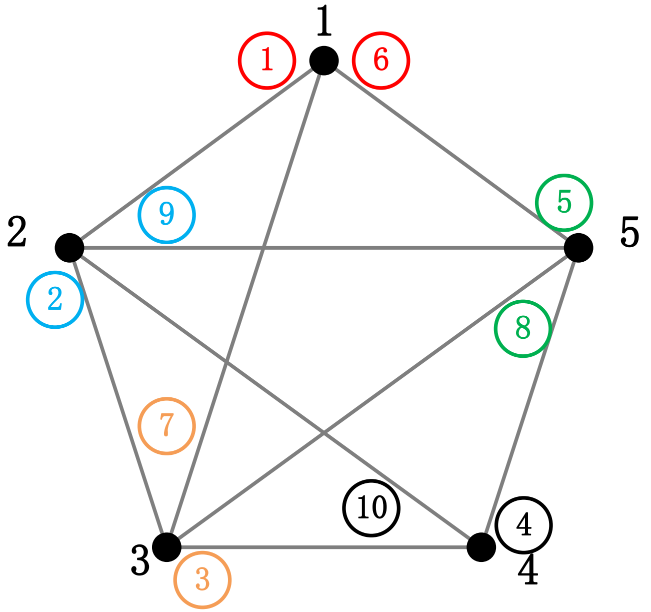

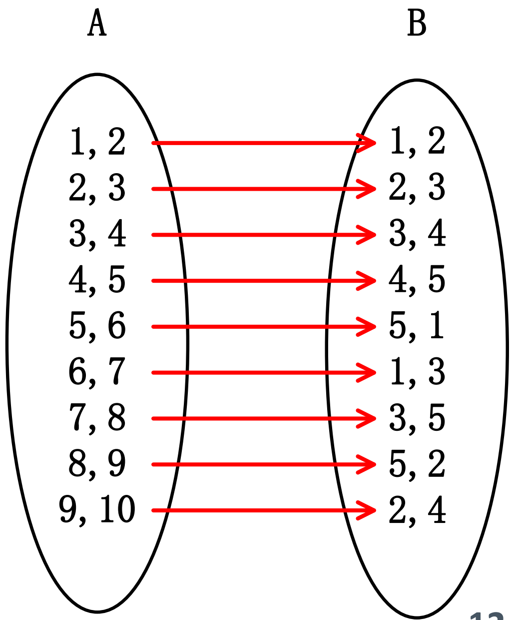

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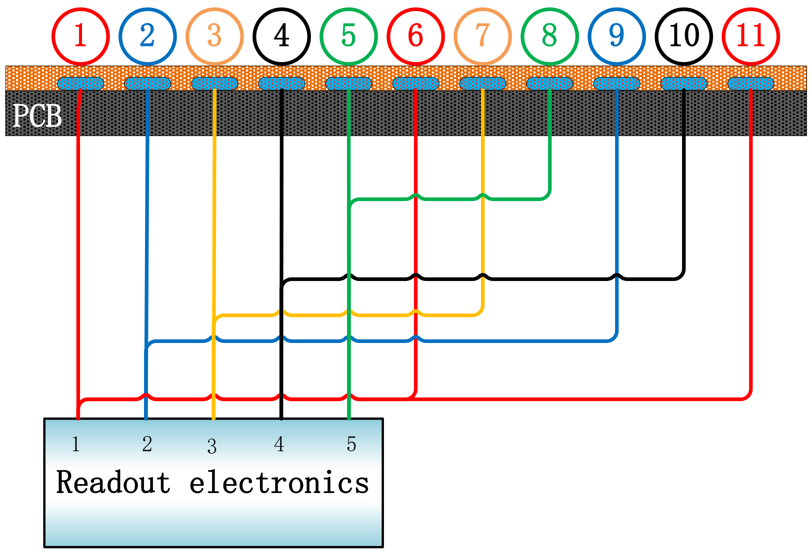
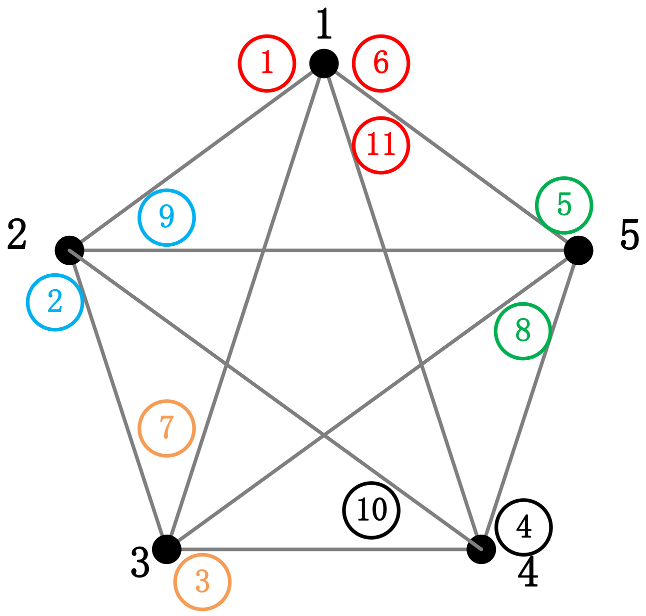
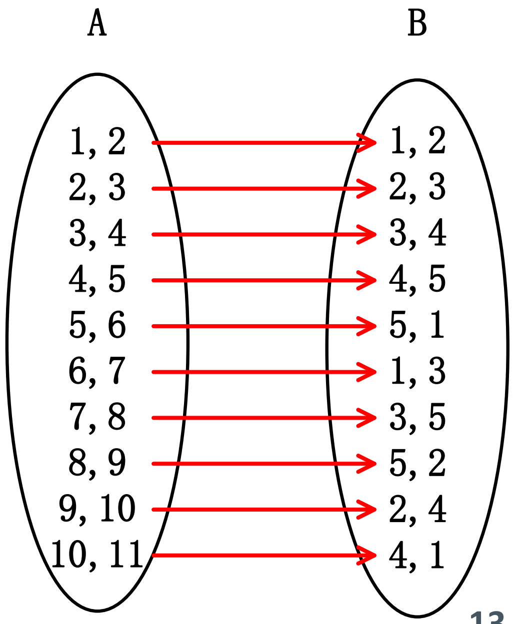


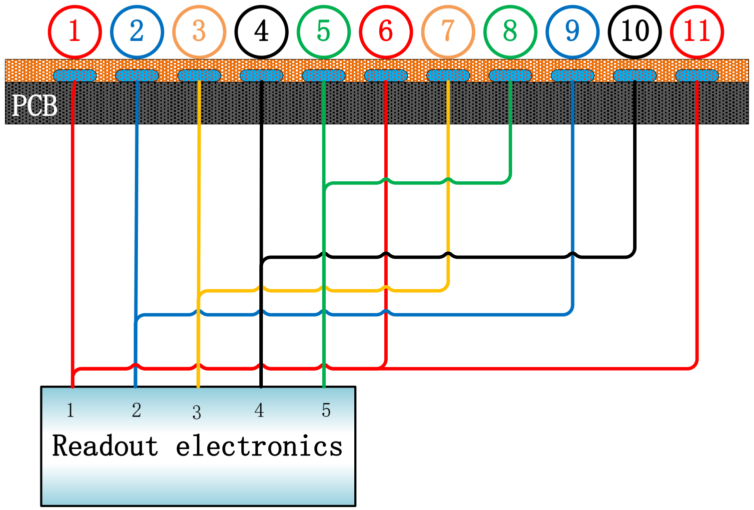


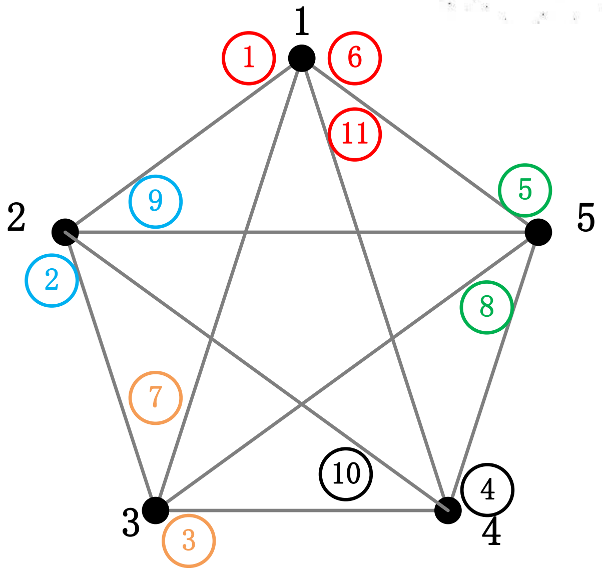


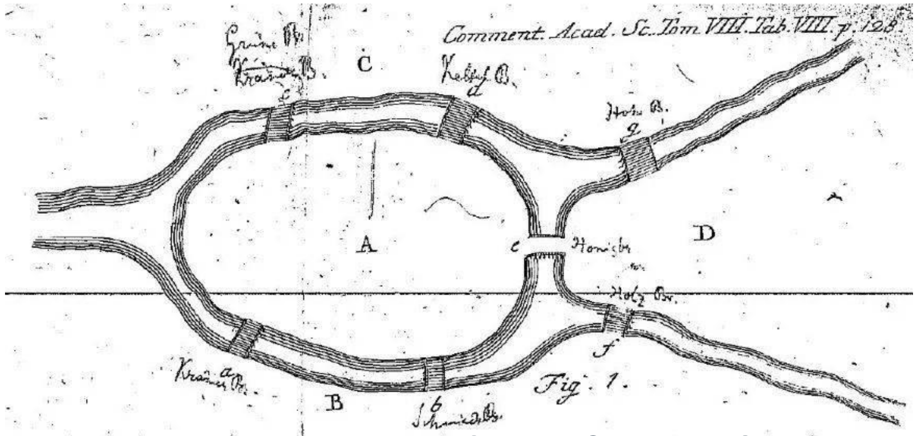
Basic multiplexing readout principles

- Multiplexing means construct the Euler path of the graph
  - Vertices stand for electronics channels
  - Edges stand for readout units of detector
  - If a graph has an Euler path

    ⇒It can be used as a multiplexing graph



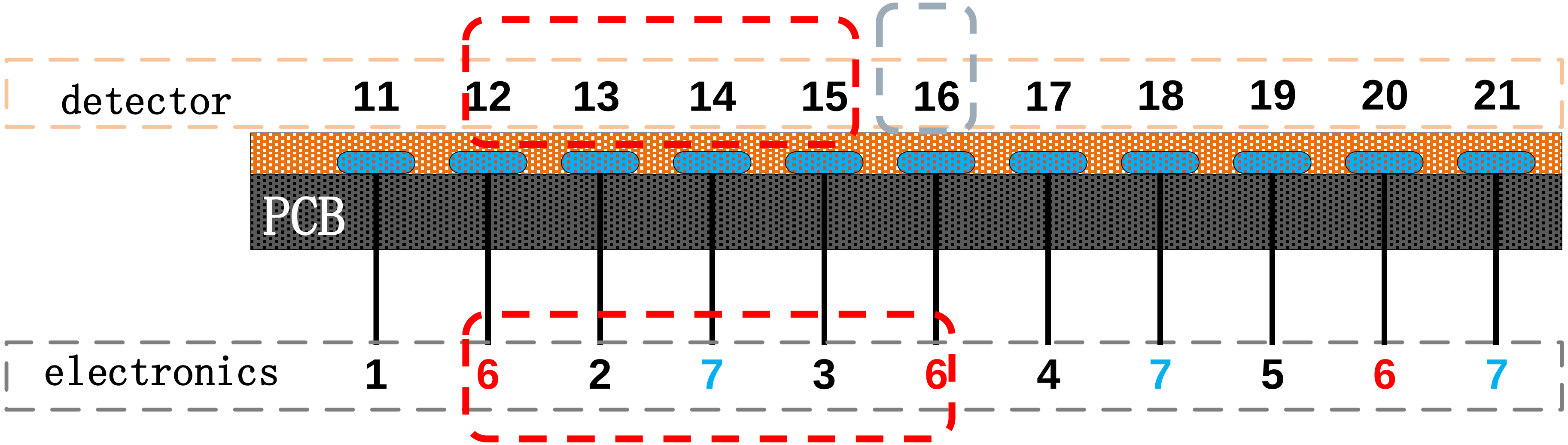




Seven Bridges of Königsberg

More about multiplexing readout

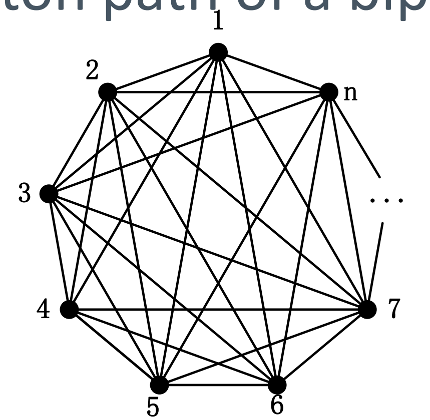
- It not enough to just construct an Euler path
- More constrains:
  - The distance between two reused channel must be as large as possible

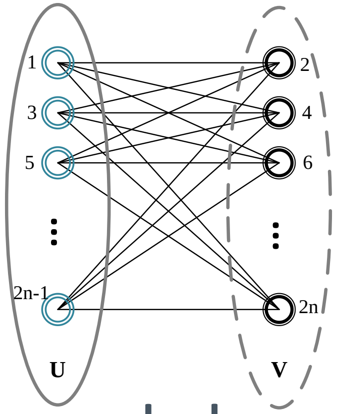


  - Each channel of readout electronics should be used in equal

Construct the usable multiplexing graph

- Two possible ways:
  - The Hamilton path of a complete graph
  - The Hamilton path of a bipartite graph



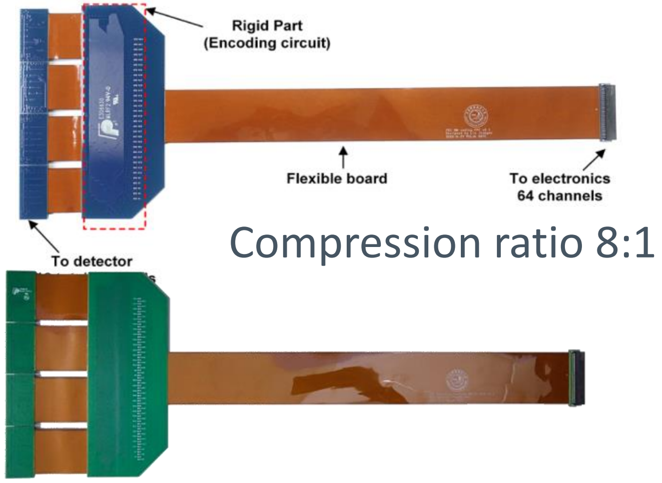


- The minimal distance between two reused channel is (N-4)
  - N stands for the number of readout electronics channels
  - Inspired by these two papers:
    - Jimbo Shuji, The Eulerian Recurrent Lengths of Complete Graphs
    - Jimbo Shuji, On the Eulerian recurrent lengths of complete bipartite graphs and complete graphs

The channel encoding multiplexing circuit

- The Eulerian graph theory, to describe the scheme of electronic channel multiplexing
- Two different schemes
  - Hamilton Circuit Coding Readout Scheme
    - For Complete Graphs
    - For bipartite graph

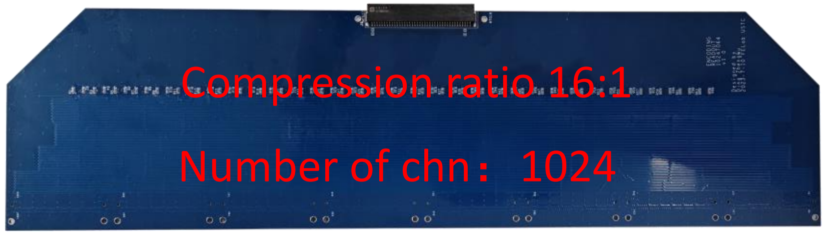
Number of chn： 512

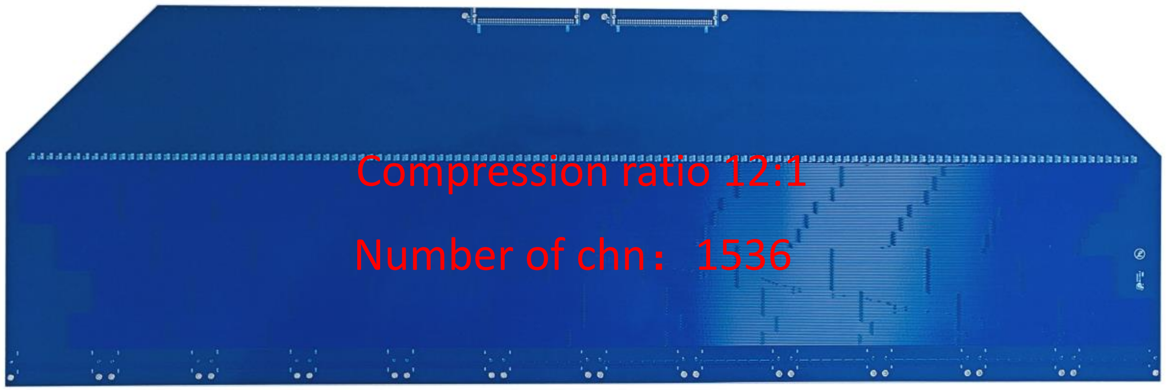


Compression ratio 8:1

Number of chn： 386

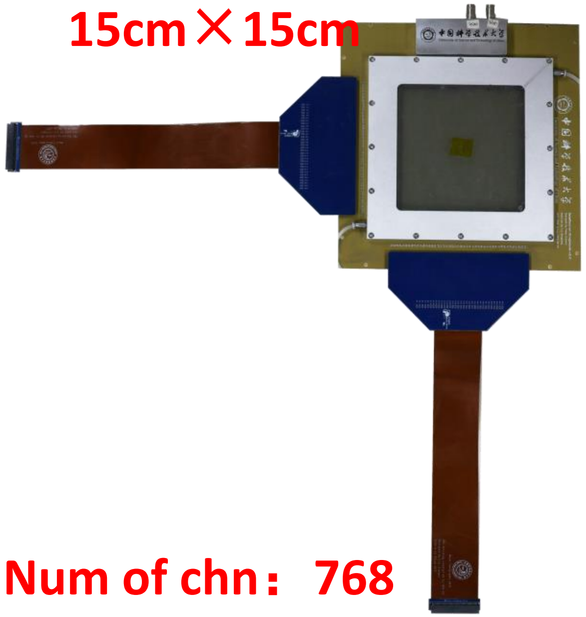
Compression ratio 6:1

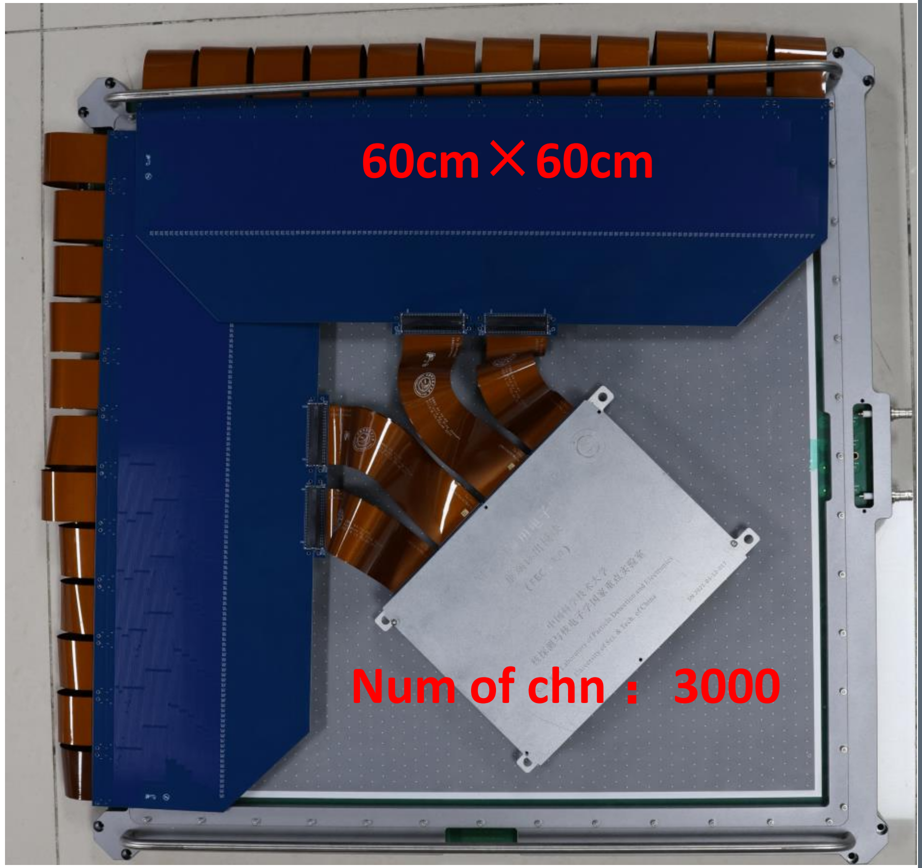




Applied in readout single of Micromegas

- Three different type of encoding circuits are designed
  - 384 detector channels to 64 readout channels
  - 1024 detector channels to 64 readout channels
  - 1536 detector channels to 128 readout channels

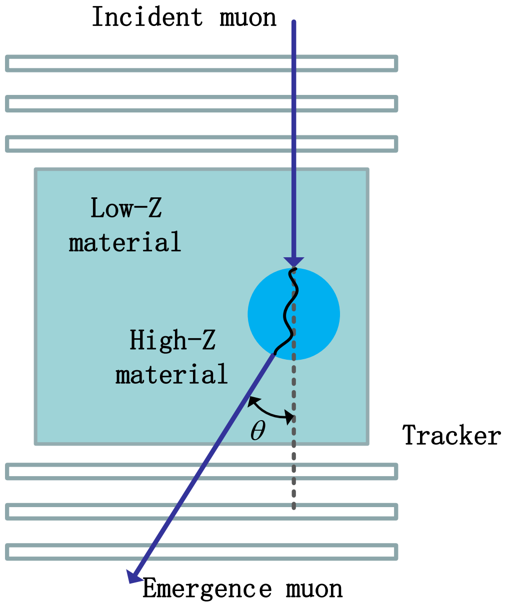




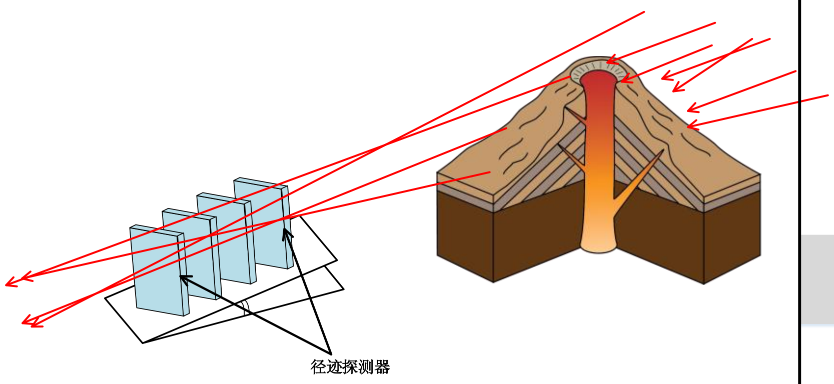
Applied in cosmic-ray muon image

- Cosmic muons are produced by cascade of reactions induced by primary cosmic-ray accelerated at astrophysical sources
- It can be used as a natural probe to “inspect” the inner structure of the large objects.

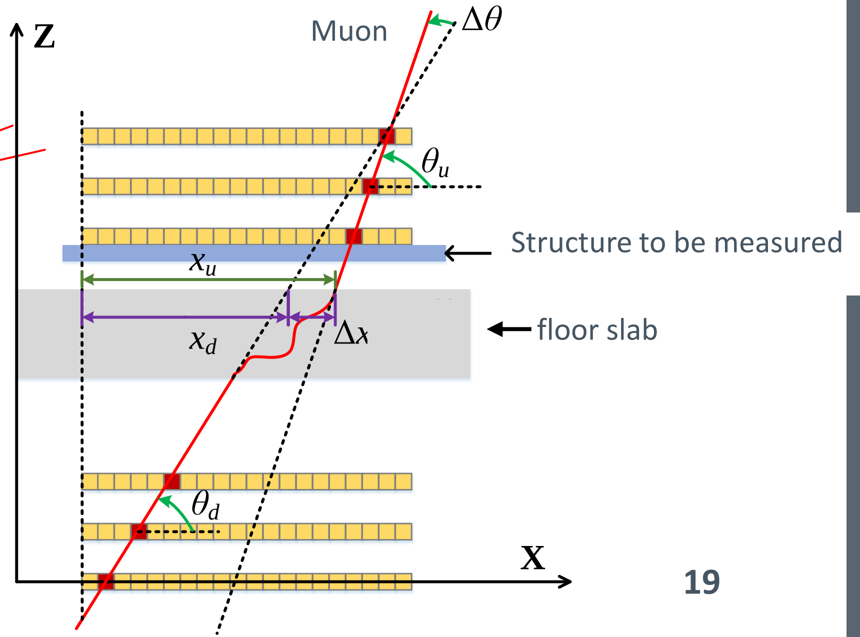
Muon Tomography



Muon Radiography



Muon Metrology



Schematic design

- μSTC： μ(muon) Scattering tomography & Transmission radiography imaging faCility

μSTC-T for tomography

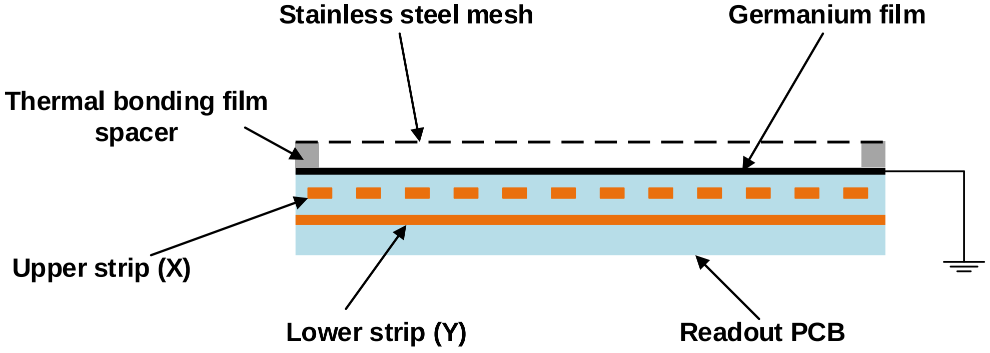
μSTC-R for radiography

Design goals:

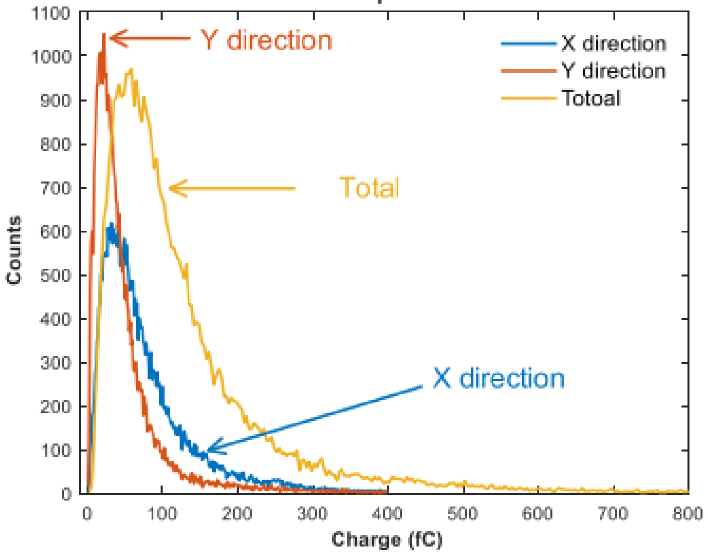
- Up to 60 ×60 cm^2 active area;
- < 200 μm spatial resolution for single detector layer;
- Rotatable horizontally and vertically for μSTC-R.

Small size prototype for tomography

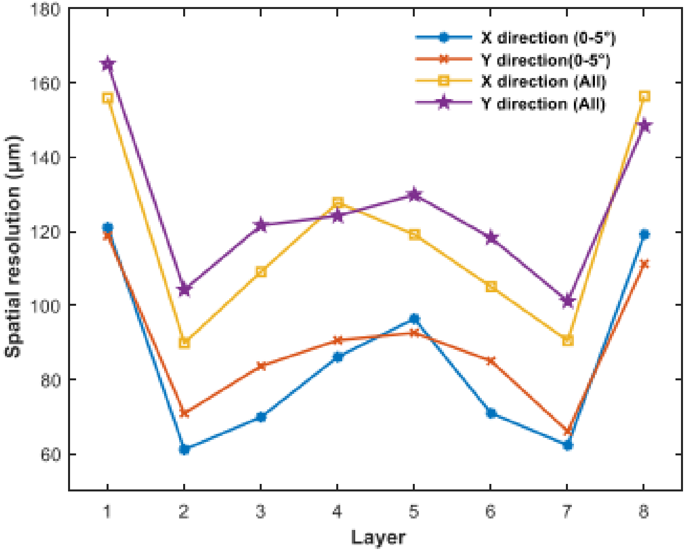
- First μSTC-T prototype:
  - 8 layers of 15cm × 15cm Micromegas
  - ~100 μm resolution
  - Compression ratio 6:1



MIP spectrum

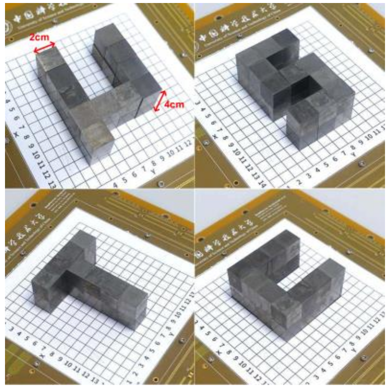


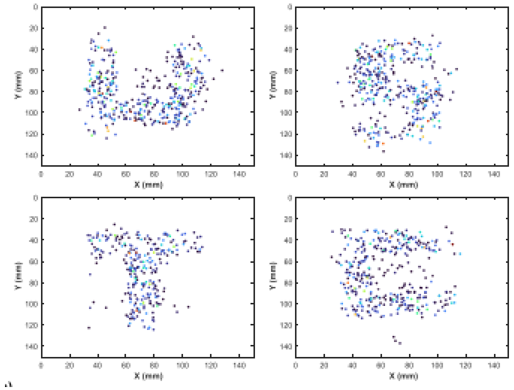
Position resolution



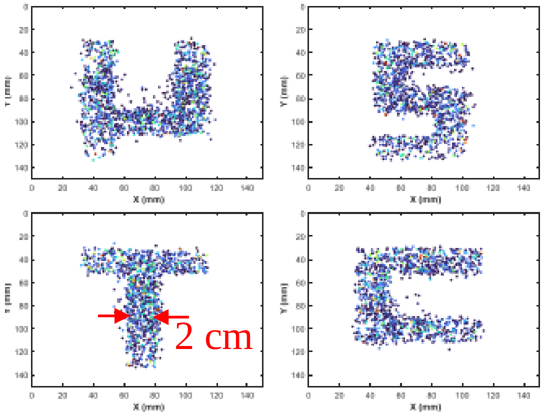
Small size prototype for tomography

› First μSTC-T prototype: tomography with small size objects

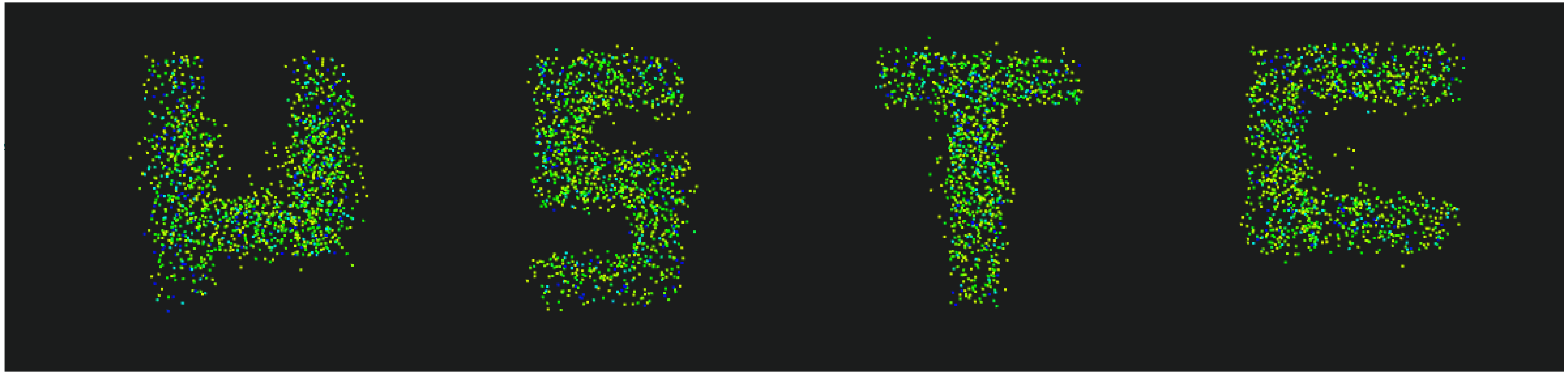




4-hour exposure



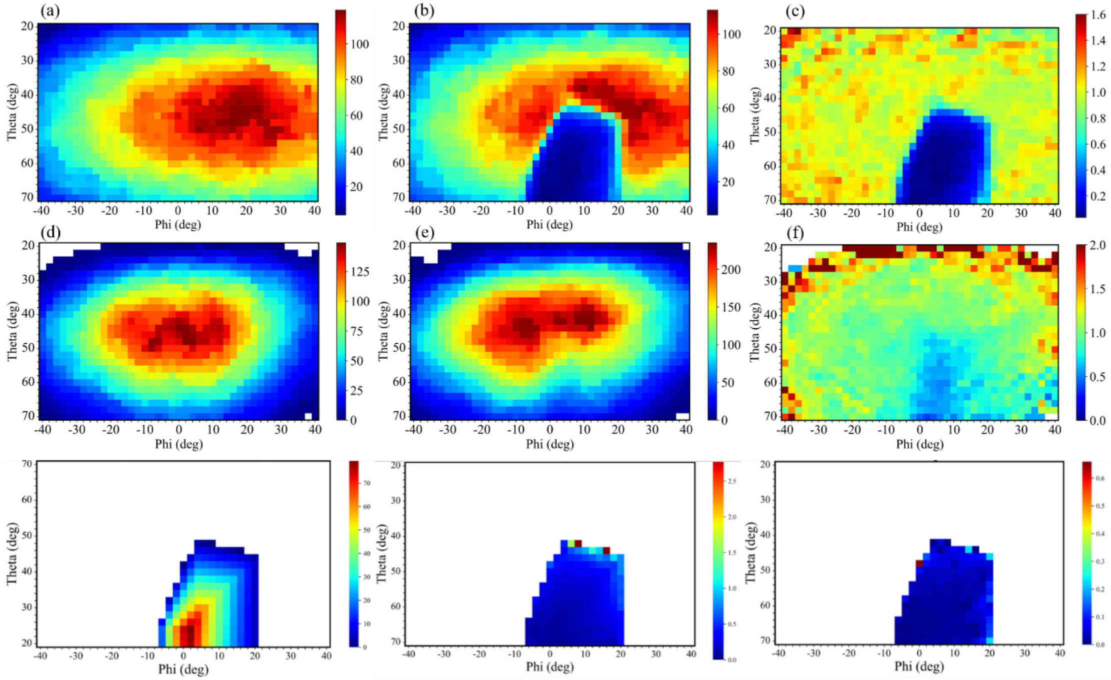
24-hour exposure



Small size prototype for radiography

› First μSTC-R prototype:
  - 4 layers of 15cm×15cm Micromegas
  - ~100 μm resolution

Radiography with a building for verification test



Middle size prototype

- Second generation of μSTC prototypes: (2021.01-now)
  - Upgrading with the larger detectors of 40 $\times$40 cm^2
  - Compression ratio 8:1 and 16:1

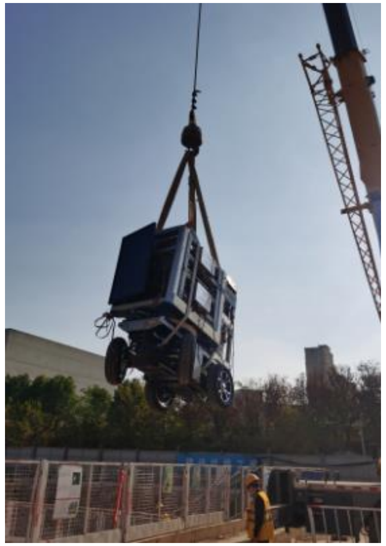
Tomography μSTC-T-G2
8layer, total number of channel: 16k

Radiography μSTC-R-G2
4layer, total number of channel: 8k

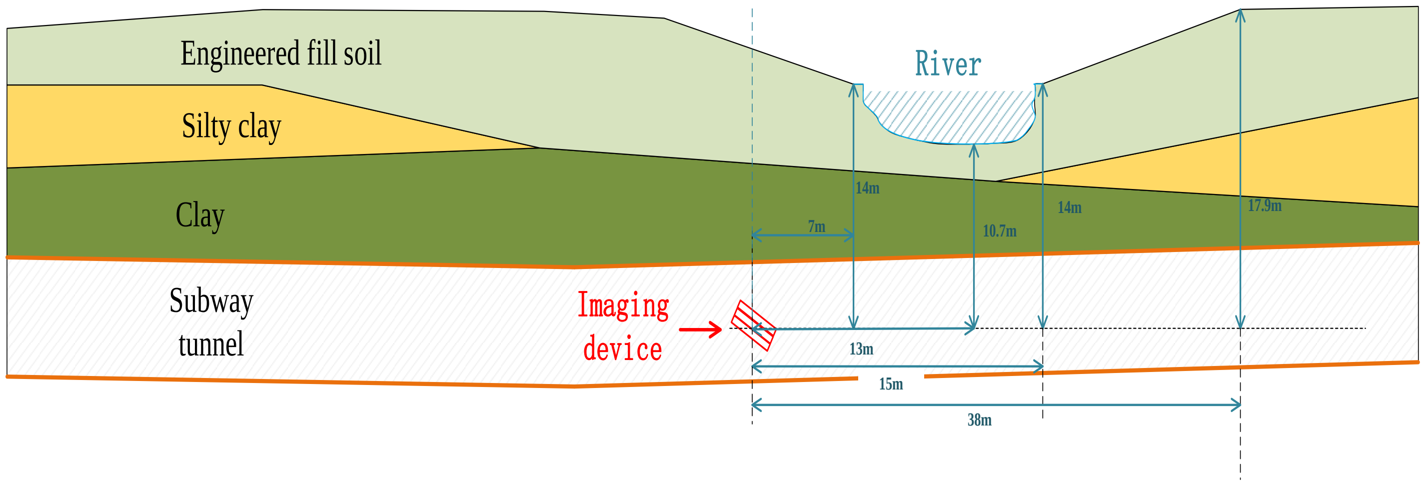
Radiography in subway tunnel

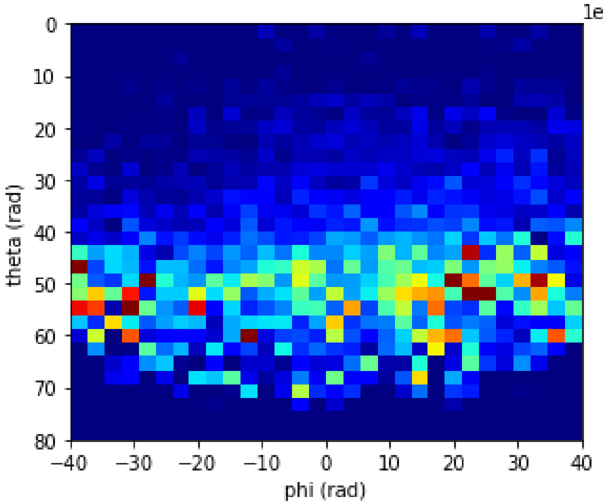
- A river flows over the tunnel
- Operating Environment: Construction site
  - Large amount of dust
  - Presence of water vapor
  - Strong vibrations

Adaptability to harsh environments confirmed
Device successfully operated in challenging conditions



- The device is placed inside the tunnel, aligned at a 30-degree angle to the river channel
  - Measure muon flux in both the 30° and -30° directions
  - Test for river data: 12 days
  - Test for reference data: 6 days



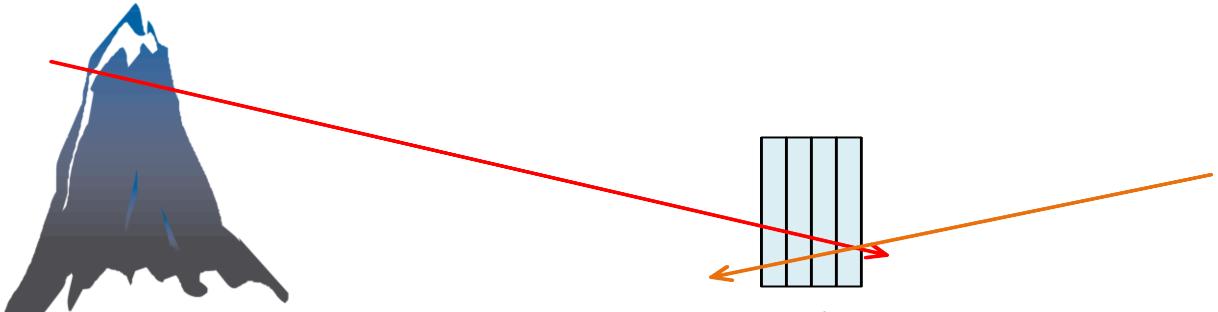


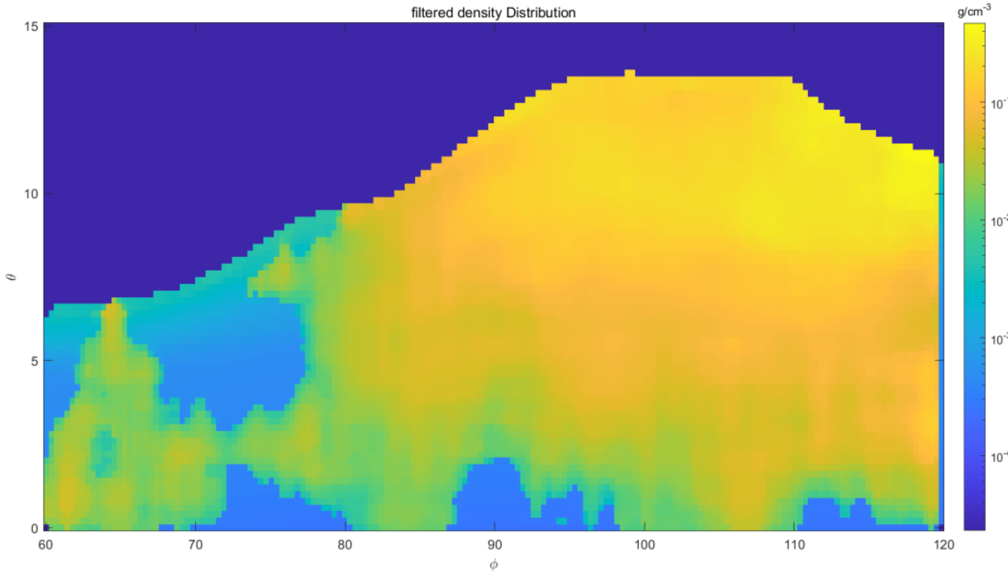
Radiography of Mt. Dashu

- An ancient volcano formed 65 million years ago
- Nearby the urban area of Hefei city
- Altitude of the mountain and facility （μSTC-R-G2） is 280m and 60 m respectively

Radiography of Mt. Dashu

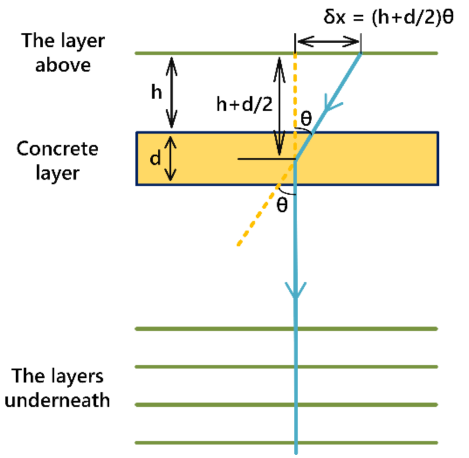
- The μSTC-R-G2 was set at horizontal angle
  - Recording muons from both mountain side and the other side (for reference)
- Test for duration more than 4 months
  - Winter -> Next Spring

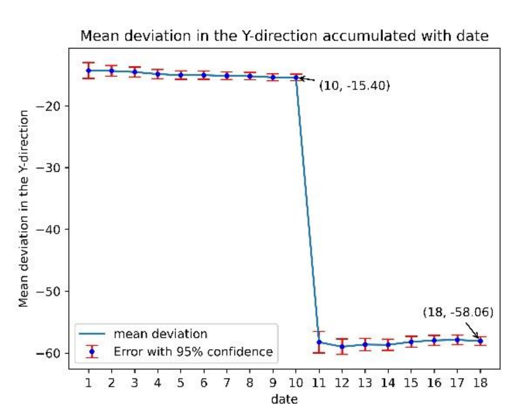


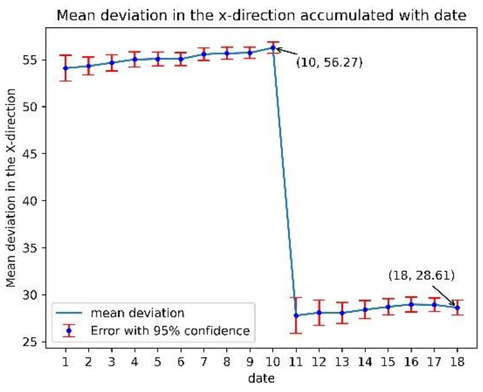


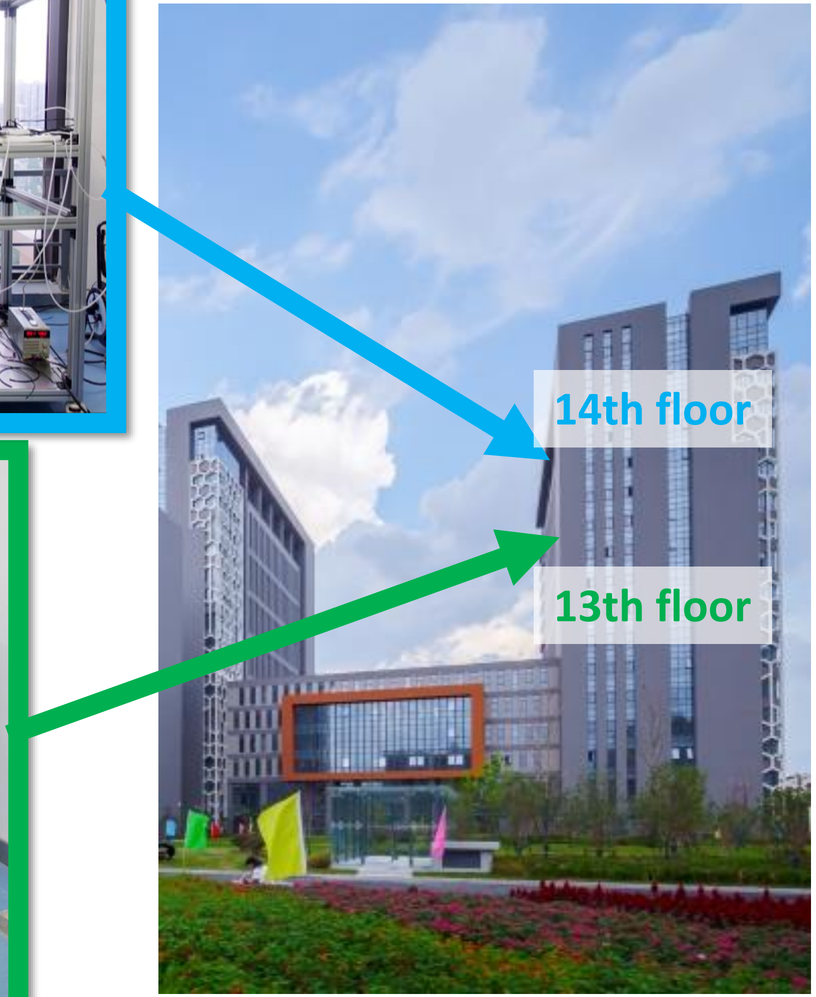
Muon metrology: displacement measurement experiment

› Measuring Tiny Displacements of Large-scale Objects Using Muon Trajectories as Straight Lines
  - Two sets of devices collaborating









Summary

› We prosed serval channel multiplexing readout methods for the MPGDs and designed the readout circuits

› We built high resolution facilities (μSTC) for muography study using Micromegas detector, low noise electronics and encoding readout method.

› We carried out the experimental tests on high-z samples (tungsten, lead, etc.), subway tunnel, and an ancient volcano. The performance including high resolution, Long-term stability and environmental adaptability were verified.

Outlook

› Higher compression ration circuit can be designed and test

› A larger detector device is under construction and will shorten the imaging time.

Thank you！ Cảm ơn！

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