A Two-Dimensional Readout Design for GEM-Based Detectors

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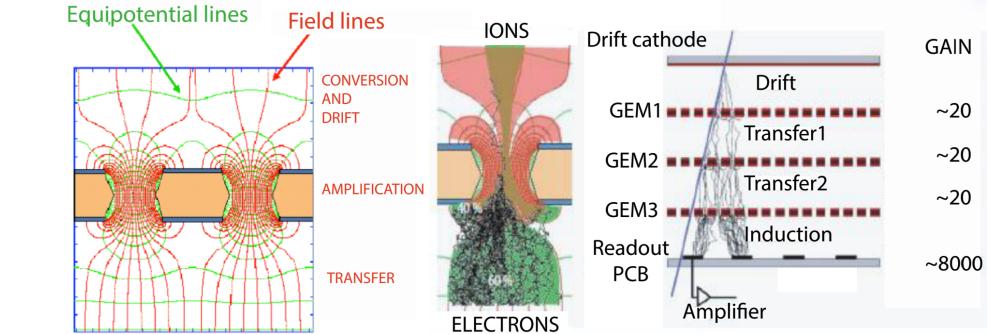
Contents

Contents

GEM Detectors

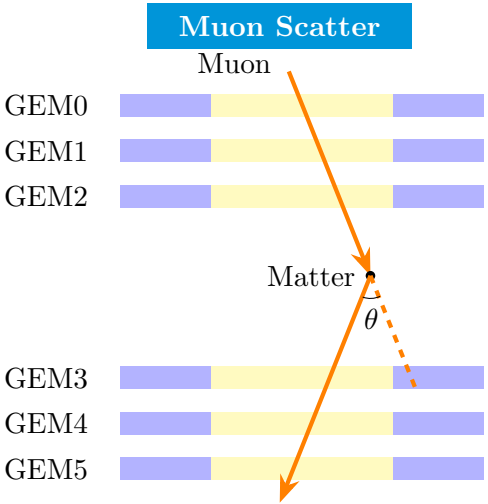
CMS GE2/1 detector as an example:

- High rate capability: 10^3 to 10^6 Hz/cm^2.
- Good spatial resolution: about 0.3 mm.
- High gas gain: more than 10^4.
- Good time resolution: less than 10 ns.
- No gain loss after 9 mC/cm^2 integrated charge.
- Easy to cover a large area.
- No aging effect.



Contents

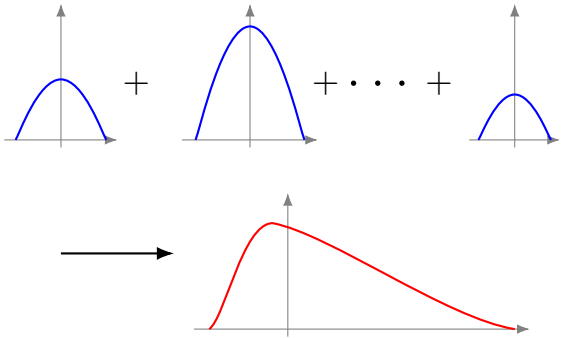
Motivation for Two-Dimensional Readout



- Need XY coordinates to reconstruct tracks.
- Get the XY coordinate at the same layer:
  - Improve position accuracy for track reconstruction.
  - Make calibration simpler.
  - Use fewer modules.
- More direct info on movement:
  - Less complicated data processing.
- Better at seeing complex stuff:
  - Easier to tell apart tracks when lots of particles are flying around.
  - Helps understand complicated events with multiple hits.

Motivation of Delay Bar Implementation

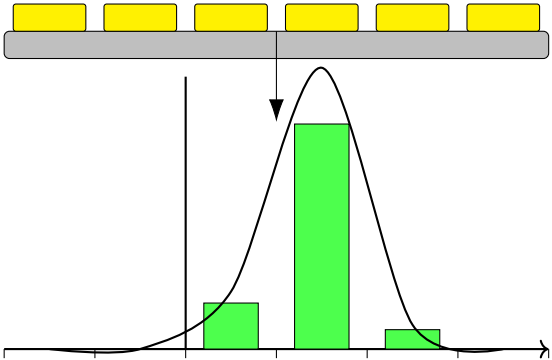
- Fewer readout paths needed.
- Simpler electronics:
  - Easier and cheaper to handle signals.
  - Smaller system, less power used.
- Energy info with less channels:
  - Get energy details without extra energy readouts.
- Better position details from timing:
  - Get finer resolution without adding more wires.
- Helps with crowded events:
  - Separate hits that happen close together in time.
  - Easier to figure out complex events.



- Combine all signals into a single output.
- Use the rising edge to determine the timing.
- The area of the output waveform represents the charge.

Contents

Spatial period settings of the readout strip



- Top gray: strip physical extent.
- Top yellow: integrated signal.
- Green bars: signal magnitude per strip.
- Curve: charge distribution profile.

Optimize resolution, maintain signal.

- CMS GEM cluster ∼2 mm diameter.
  - 1 mm pitch: ∼2 strips signal.
  - Centroid: precise position.
- ∼1 mm pitch optimizes balance:
  - **Spatial Resolution:** Finer is better tracking.
  - **Signal Discrimination:** Limit to 2-3 strips.
- Localize charge: maintain signal integrity.
- Pitch choice impacts detector complexity/cost.

The Evolution of Readout Strip Shape

Key Improvements:

- Space Efficiency: Less dead space between strips.
  - Significant reduction: from 0.2mm×0.6mm to 0.2mm×0.2mm.
  - More active detection area.
- Enhanced Symmetry: Improved uniformity in both X and Y directions.
- Streamlined Design: Simpler technical implementation.
  - Larger area available for drilling and connections.

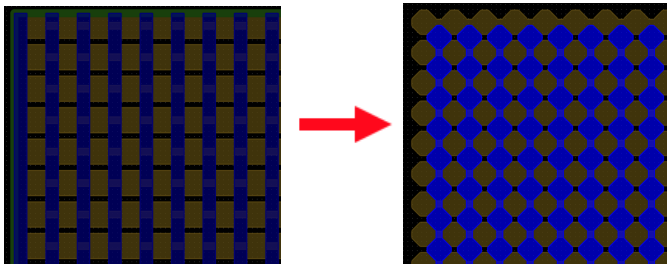


Figure 1: RO Strip Shape: Ver. 1 (Left) vs. Ver. 2 (Right)

- Signal Compensation: Inner layer strips are slightly larger.
  - This compensates for signal attenuation during propagation.

Delay line

- Delay time decision: less than rise time.
- Single delay line: 20.0 ± 3.0 ns.
- Resolution error estimation: $\Delta x = 0.7$ mm.
- Number of delay lines in each group according to:
  - Signal attenuation.
  - Cumulative loss.
- Delay line advantage:
  - Time difference to position.
  - Simple coordinate calculation.
  - Enables spatial measurement with few RO.

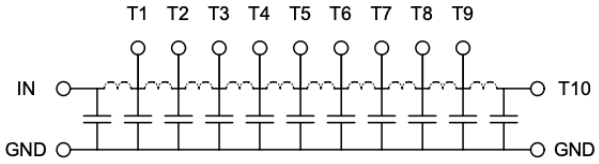


Figure 2: Delay line

$$x = \frac{t_A - t_B}{2T_{delay}} L, \quad T_{delay} = n\sqrt{LC} = nt_D$$

$$\Delta x = \frac{\partial x}{\partial T_{delay}} \times \Delta T = 0.7mm$$

2D readout design

Readout Design Details:

- Two x, two y readout regions.
- 81 strips per region.
  - Avoid signal reduction with many strips.
- Doubled readout strip length.
  - Improved space utilization.
- Cost in each block(160mm × 160mm)
  - 8 readout channels per block.
  - 4 blocks per readout board.
- Orthogonal x/y for 2D position.
- Stacked layers on PCB vertically.
- Compact detector structure.

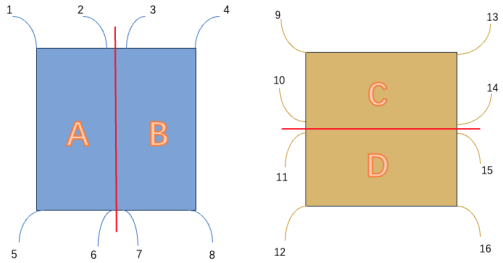


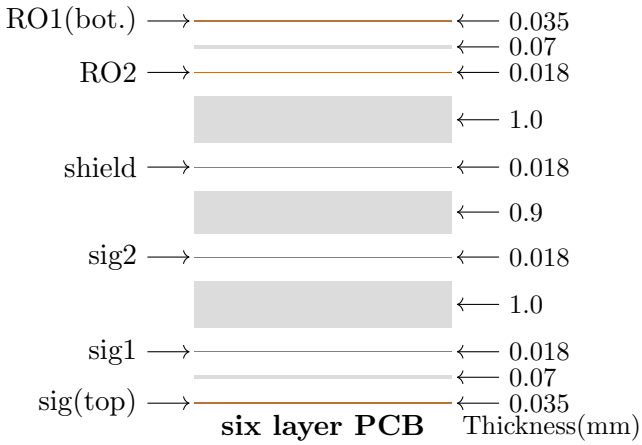
Figure 3: Readout arrangement, left is for x and right is for y.

Layered Readout:

- Two layers stacked vertically on PCB.
- Muon signals propagate sequentially.
- Orthogonal x/y detection planes.

Six-layer PCB design

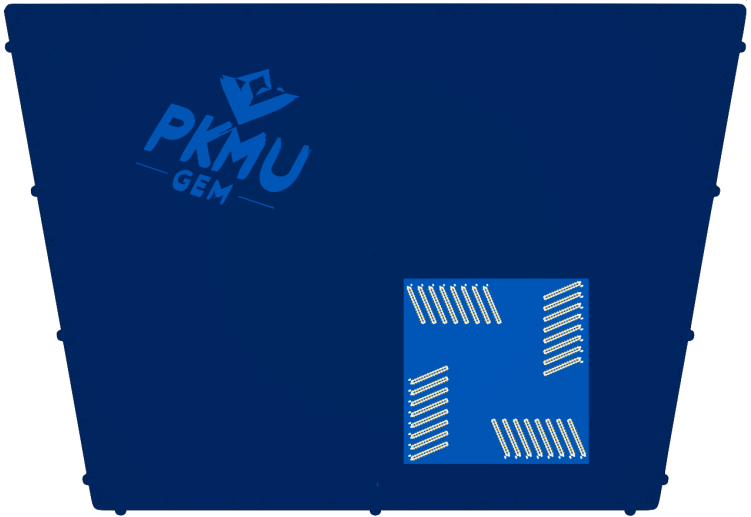
- Use the thinest dielectric layer: 0.07mm.
  - Minimize the signal attenuation.
- Symmetric arrangement of PCB structure:
  - Helps prevent board warpage.
- Internal signal layer(sig1, sig2):
  - Provide increased routing space, supporting high-density designs.
- Shield layer: Reduces Electromagnetic Interference (EMI).
- Multiple ground planes (implied):
  - Impedance control.



Overview of RO PCB

Future Plan:

- Optimize parameters by testing various scenarios, focusing on:
  - Strip pitch,
  - Delay time,
  - Number of delay bars per group.
- Design an interface for the following electronics.
- Contact the board factory to finalize the specifications.
- Adapt the RO stripe to a trapezoidal shape.



Contents

Summary and Future Plan

Summary:

- Get 2D coordinates at once for better track finding.
- Use delay lines to need fewer readout channels, which costs less.
- Optimizes readout strips for better space use and balance.
- Use timing to get better position detail, good for many particles.
- One output signal simplifies analysis and keeps charge data.

Future Plan:

- A part of large-area GEM cosmic ray detection platform.
- Integrate into PKMu for dark matter or QE studies.
- Enhance the present design to work with muon beams.