Muon Chapter

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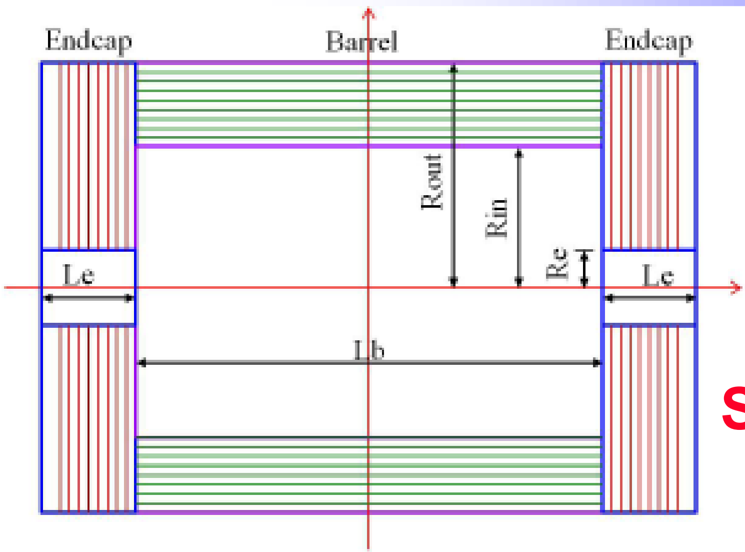
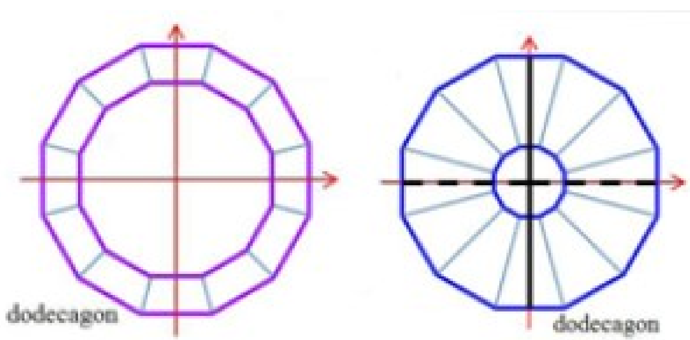
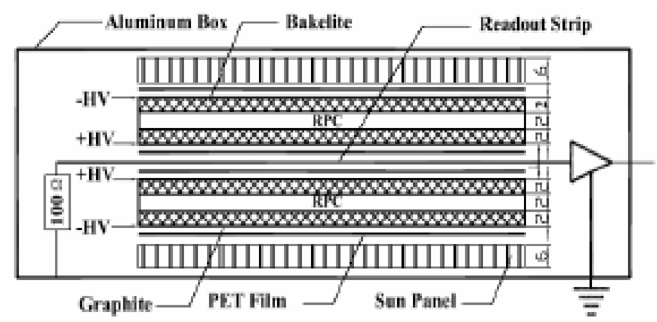
Muon System Overview







Structure:

- Between magnet iron yoke, outside HCAL
- Cylindrical barrel & two endcap system
- Solid angle coverage: 0.98 * 4π

Technology:

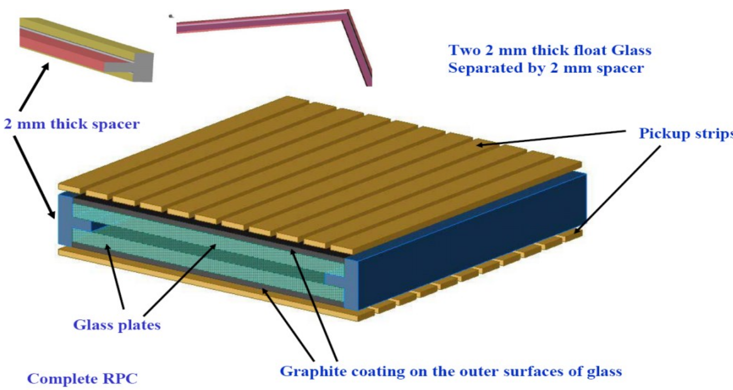
- Bakelite/glass RPC as baseline
- Many other options in consideration
  - μRWell
  - Micromegas, GEM
  - MDT, Scintillator Strip

Baseline Design

Parameter	Possible range	Baseline
Lb/2 [m]	3.6 – 5.6	4.0
Rin [m]	3.5 – 5.0	4.4
Rout [m]	5.5 – 7.2	7.0
Le [m]	2.0 – 3.0	2.6
Re [m]	0.6 – 1.0	0.8
Segmentation	8/10/12	12
Number of layers	6 – 10	8
Total thickness of iron	$6 - 10\lambda$ ($\lambda = 16.77$ cm)	8λ (136 cm) (8/8/12/12/16/16/20/20/24) cm
Solid angle coverage	$(0.94 - 0.98) \times 4\pi$	0.98
Position resolution [cm]	$\sigma_{r\phi}$: 1.5 – 2.5	2
	σ_z : 1 – 2	1.5
Detection efficiency ($E_\mu > 5$ GeV)	92% – 99%	95%
Fake($\pi \to \mu$)@30GeV	0.5% – 3%	$< 1\%$
Rate capability [Hz/cm^2]	50 – 100	~60
Technology	RPC	RPC (super module, 1 layer readout, 2 layers of RPC)
	μRWell	
	Micromegas	
	GEM	
	(s)TGC	
	MDT	
	Scintillating strip	
Total area [m^2]	Barrel	~4450
	Endcap	~4150
	Total	~8660

Resistive Plate Chamber (RPC)

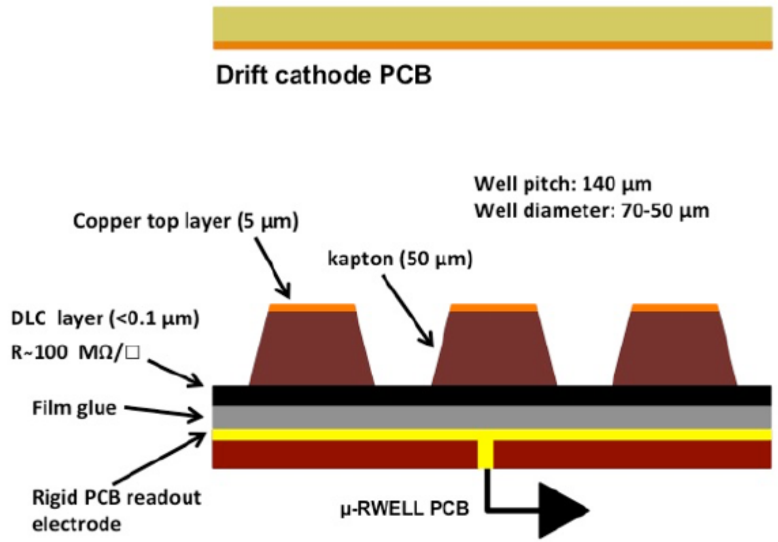
Parameters		Bakelite	Glass
Bulk resistivity [$\Omega \cdot$ cm]	Normal	$10^{10} \sim 10^{12}$	$> 10^{12}$
	Developing	$10^8 \sim 10^9$	
Max unit size (2 mm thick) [m]		1.2×2.4	1.0×1.2
Surface flatness [nm]		< 500	< 100
Density [g/cm^3]		1.36	2.4~2.8
Min board thickness [mm]		1.0	0.2
Mechanical performance		Tough	Fragile
Rate capability [Hz/cm^2]	Streamer	100@92% [97]	
	Avalanche	10K	100@95% [98]
Noise rate [Hz/cm^2]	Streamer	< 0.8	0.05 [99]



- ✓ Low cost, easy construction
- ✓ Position resolution: 5-10 mm
- ✓ Time resolution: ~ 1 ns

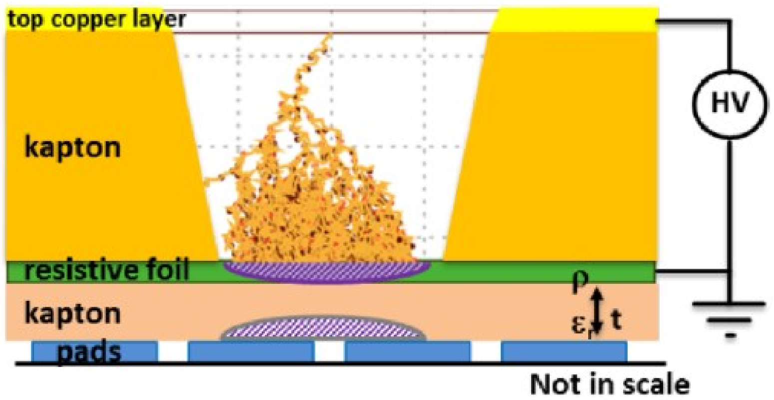
Signal efficiency > 95% for muon pT > 4 GeV with 8 layers

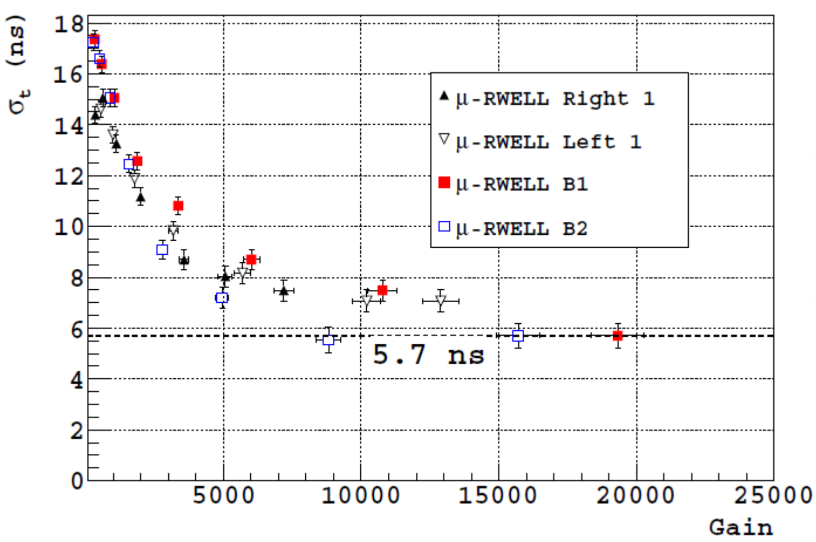
Other Options



Micro-RWell technology

- MPGD with two PCBs: a standard GEM Drift cathode PCB and a µRWell PCB
- Amplification stage couples directly with readout: low/high rate option



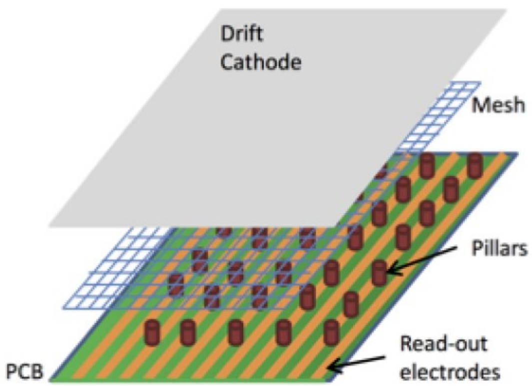


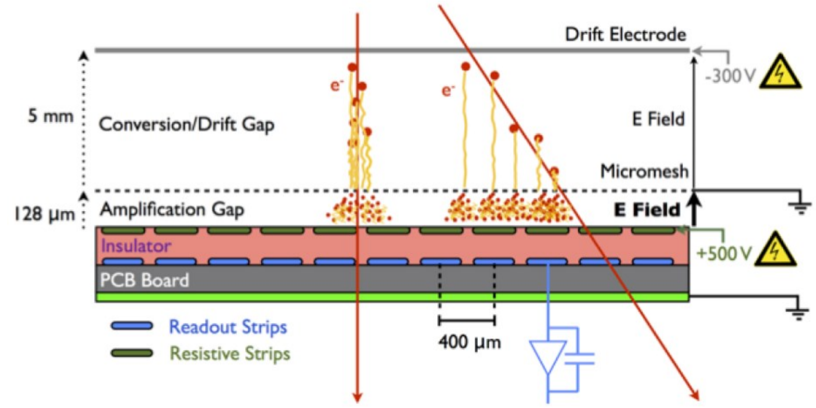
- ✓ Much simpler than many other MPGDs, such as GEMs or MicroMegas
- ✓ Rate capability: a few tens of KHz/cm^2
- ✓ Position resolution: ~60 µm
- ✓ Time resolution: 5-6 ns

Other Options

Micro Mesh Gaseous Structure (Micromegas)

- A planar drift electrode, a gas gap of a few millimeters thickness as conversion and drift region, and a thin metallic mesh typically 100–150 μm distance from the readout electrode as the amplification region.
- Good spatial resolution < 100 μm, time resolution ~ 10ns
- High rate capability: ~10MHz/cm^2
- Vulnerability to sparking
- Large active area (10^{4}m^2) Micromegas still under development

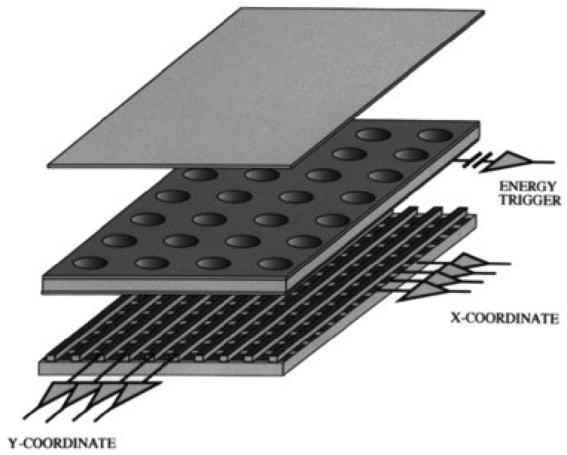


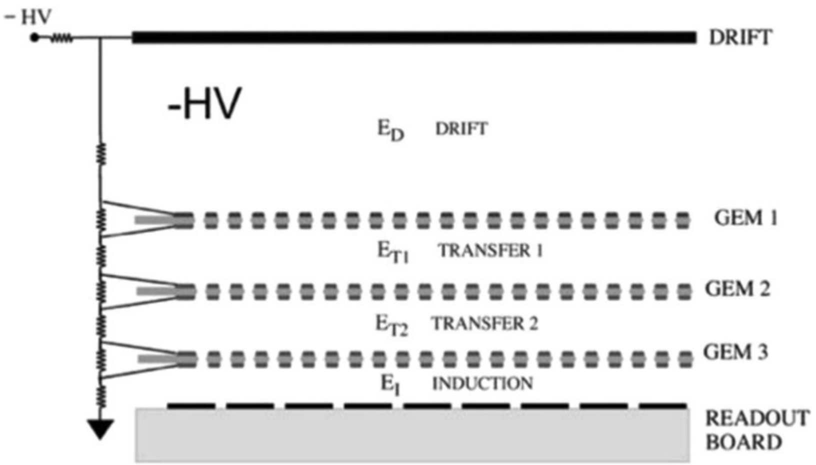


Other Options

Gas Electron Multiplier (GEM) technology

- Gaseous ionization detector using copper-clad Kapton foil (50-70 μm thick) with etched holes (30-50 μm diameter) for gas amplification.
- Very good spatial resolution ~ diameter, time resolution ~10-20ns
- High rate capability: ~10MHz/cm^2
- Vulnerability to sparking
- Complexity of assembly procedure: stretching and gluing GEM foils





Other Options

Monitored Drift Tube (MDT) technology

- Wire chamber: an anode wire at center of tube and a metallic cathode (aluminum) with gas in between
- Good spatial resolution ~ 80μm , good time resolution ~10ns
- Rate capability: ~500Hz/cm^2

Scintillator Strips technology

- Plastic scintillator material can be extruded into strips longer than 5 m. Use wave-length shifting (WLS) fibers to shift the light spectrum to match the response of Si photo-diodes (SiPM) or multi pixel photo counters (MPPC)
- Construct compact and rigid modules with 1-D or 2D readout strip arrays
- Spatial resolution ~ 3 cm, time resolution < 1 ns

Ongoing Studies

Muon system as an add-on

- Simulation study with built-in calorimeter / TCMT geometry, also integrated with yoke and magnet system
- Complementary to Calorimeter
  - Effect as a tail catcher / muon tracker (TCMT)
    - JER with/wo TCMT
  - Preliminary test with fast simulation: the level of improvement depends on the energy deposited in the muon detector, ranging from 1% (energy compensation ~ 1GeV) to 8% (energy compensation ~ 10GeV or more)

Non-isolated muon efficiency

- Simulation study using LICH (PFA) muon ID algorithm
- Check muons inside jets

Future R&D

- ✓ **Long-lived particles optimization: explore new physics scenario of long-lived particles and exotic decays. Optimize detector parameters and technologies.**
- ✓ **Layout and geometry optimization: detailed studies on the structure of the segments and modules. The geometry and dimensions need to be optimized together with the inner detectors, in particular the ECAL and the HCAL.**
- ✓ **Gas detectors: Study aging effects, improve long-term reliability and stability.**
- ✓ **All detectors: Improve massive and large area production procedures and readout technologies.**