RPC and Scintillator Option Muon Detector Cost Evaluation

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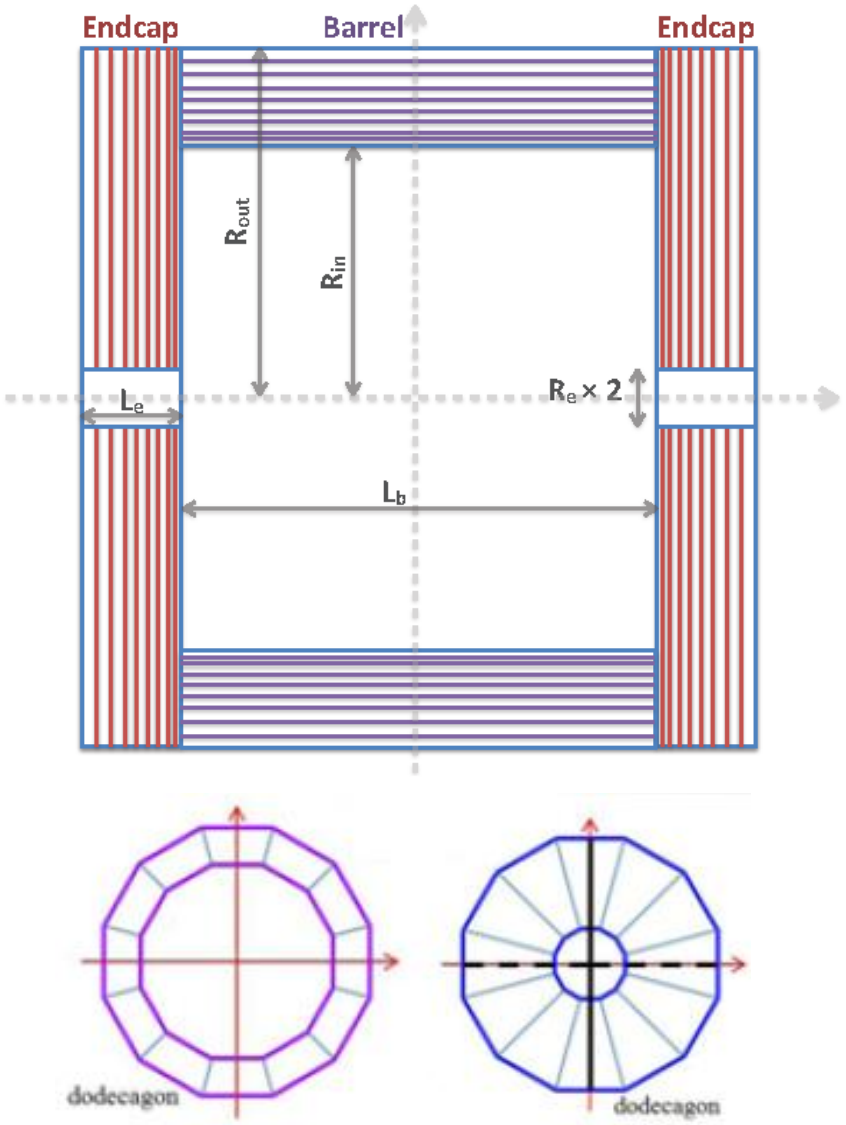
Muon Detector Overview



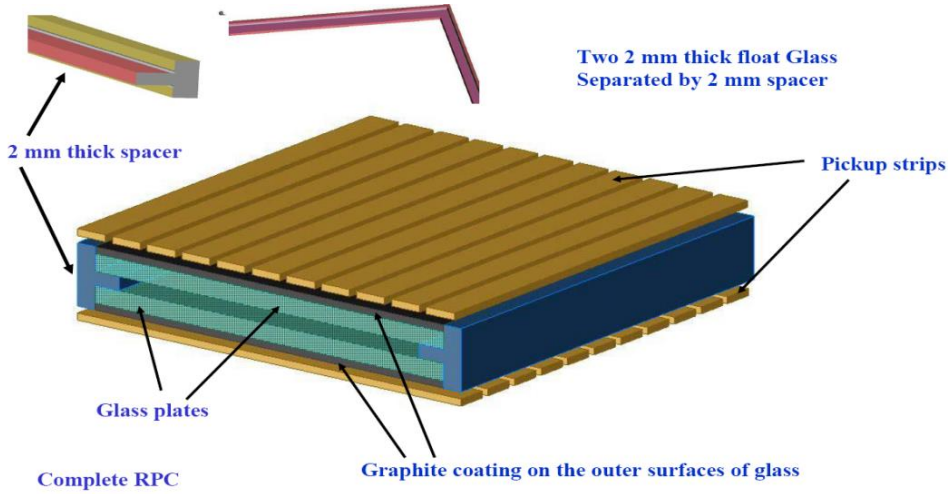
Structure:

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

Three detector options:

- RPC as baseline
- Scintillator strips
- μRWell with IDEA detector

RPC Baseline



Resistive Plate Chamber (RPC)

- 12 Segmentation
- 8 layers
- Total absorber thickness: 6.7λ
- Total area
  - Barrel ~ 4450 m^2
  - Endcap ~ 4150 m^2
  - Total ~ 8600 m^2

Cost estimation

- RPC Material cost \$200/m^2
- ~ 1.7 M\$
  - Not including labor cost
- 5.5X10^4 channel
  - 3 cm strip width, 1-D readout, 2 ends for barrel, 1 end for end-cap
- Electronics ~ 0.5 M\$
  - \$10/channel
- Gas cost
  - ~ 0.4 M\$/year
  - Based on Belle-II operation
- Total cost ~ 2-3 M\$

Preliminary Design for Scintillator Option

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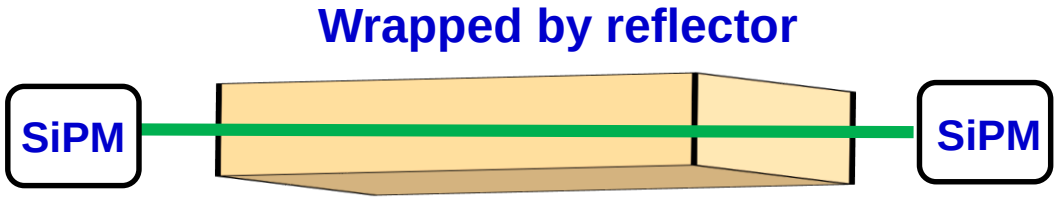
Scintillator strip Barrel:

$8206 \times 50 \times 10$ mm

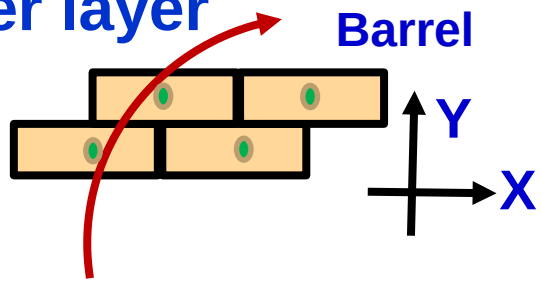
or $2708 \times 50 \times 10$ mm (yoke has three rings in barrel)

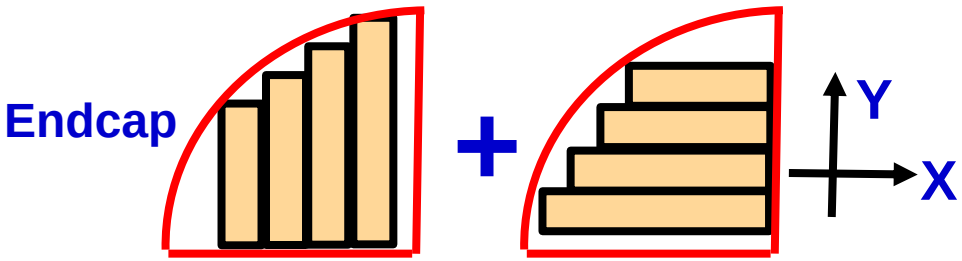


Endcap:

$L \times 50 \times 10$ mm

Two layers of scintillator to compose a super layer





Size dependent on yoke design

Scintillator Option Parameters

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Expected performance:

- Time resolution $\sigma_t = 50$ ps
- Z position resolution: σ_z =1 cm for one sub-layer and 0.7 cm for one super layer
- Spatial resolution: $\sigma_{r\phi}$ =1.44 cm for one sub-layer and 0.72 cm for one super layer (comparable with RPC)

Cost estimation based on MATHUSLA and Belle-II experience:

- In total, ~2×10^4 scintillator strips (area: 8000m^2), 1.6×10^5 m WLS fiber, and 3.8×10^4 SiPM.
- ~2.9M $ for the barrel and endcap.
- Cost for electronics: about $20-$40/channel.

	Price ($)	Cost ($)
Scintillator	10/Kg	~800K
WLS fiber	3/m	~500K
SiPM	20/Unit	~800K
Electronics	20/SiPM	~800K
Total		2.9M

Conclusion

✓ **Two options for relatively low cost muon detector design**

- **RPC design as baseline**
  - **Mature and robust technique**
  - **Mass production: low cost and easy construction**
  - **Operation/maintenance issue**
- **Scintillator strip design as alternative**
  - **Comparable cost with RPC**
  - **Easy construction**
  - **Operation/maintenance advantage**

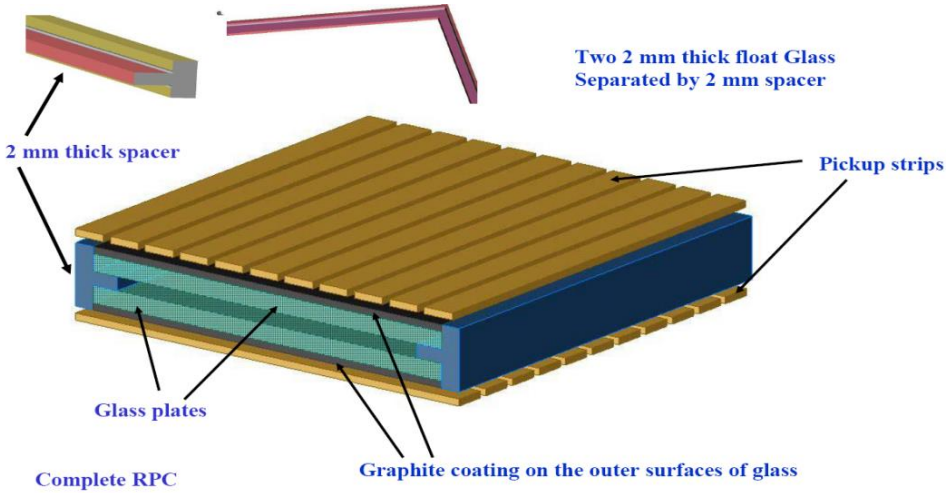
Backup

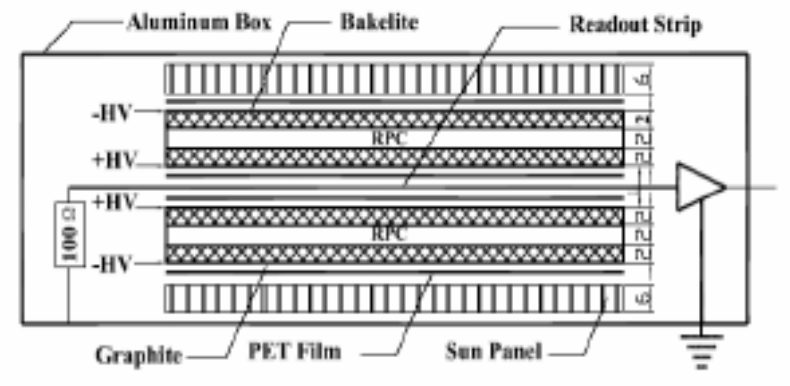
Baseline Parameters

Parameter	Possible range	Baseline
Lb/2 [m]	3.6 – 5.6	4.14
Rin [m]	3.5 – 5.0	4.40
Rout [m]	5.5 – 6.2	6.08
Le [m]	1.0 – 2.0	1.72
Re [m]	0.6 – 1.0	0.50
Segmentation in ϕ	8/10/12	12
Number of layers	3 – 10	8
Total thickness of iron	6 – 10λ (λ = 16.77 cm)	6.7λ (112 cm) (8/8/12/12/16/16/20/20) cm
Solid angle coverage	(0.94 – 0.98)×4π	0.98
Position resolution [cm]	$\sigma_{r\phi}$: 1.5 – 2.5	2
	σ_z: 1 – 2	1.5
Time resolution [ns]	< 10	1 – 2
Detection efficiency (P_μ > 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	
Total area [m^2]	Barrel	~4450
	Endcap	~4150
	Total	~8600

- **Preliminary study done with simple geometry and simulation configurations**
- **Muon efficiency > 95%**
- **Pion fake rate < 1%**

Baseline: RPC Option





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- ✓ Low cost, easy construction
- ✓ Position resolution: 1-2 cm
- ✓ Time resolution: ~ 1 ns
- ✓ Rate capability: ~100 Hz

Baseline: RPC Option

Bakelite vs. Glass

Parameters		Bakelite	Glass
Bulk resistivity [$\Omega \cdot$ cm]	Normal	$10^{10} \sim 10^{12}$	$> 10^{12}$
	Developing	10^{8}~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]

Scintillator Based Option

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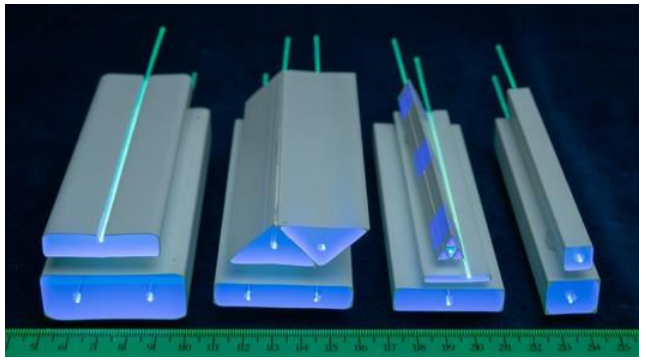
Belle-2, MINOS, MINERvA, MATHUSLA:

- Extruded scintillator from FermiLab: $5/kg.
- Wave length shift (WLS) fiber inside scintillator to collect photons and guide light.
- Use SiPM at both ends, small size, low cost and can work at high magnetic field.
- Excellent time resolution: ~50 ps (goal).
- Double-channel readout for good spatial resolution:

  $\sigma_z \sim 1$ cm

  similar performance compared to RPC.



- ✓ Good position and timing resolution
- ✓ Easy to build: scintillator+WLS+SiPM.
- ✓ Flexible shape: fit in any yoke design
- ✓ Low cost
- ✓ Easy for operation and maintenance:
  - No gas
  - High voltage less than 100 V
  - Not sensitive to temperature and humidity