# The LHCb Muon Detector at Upgrade II


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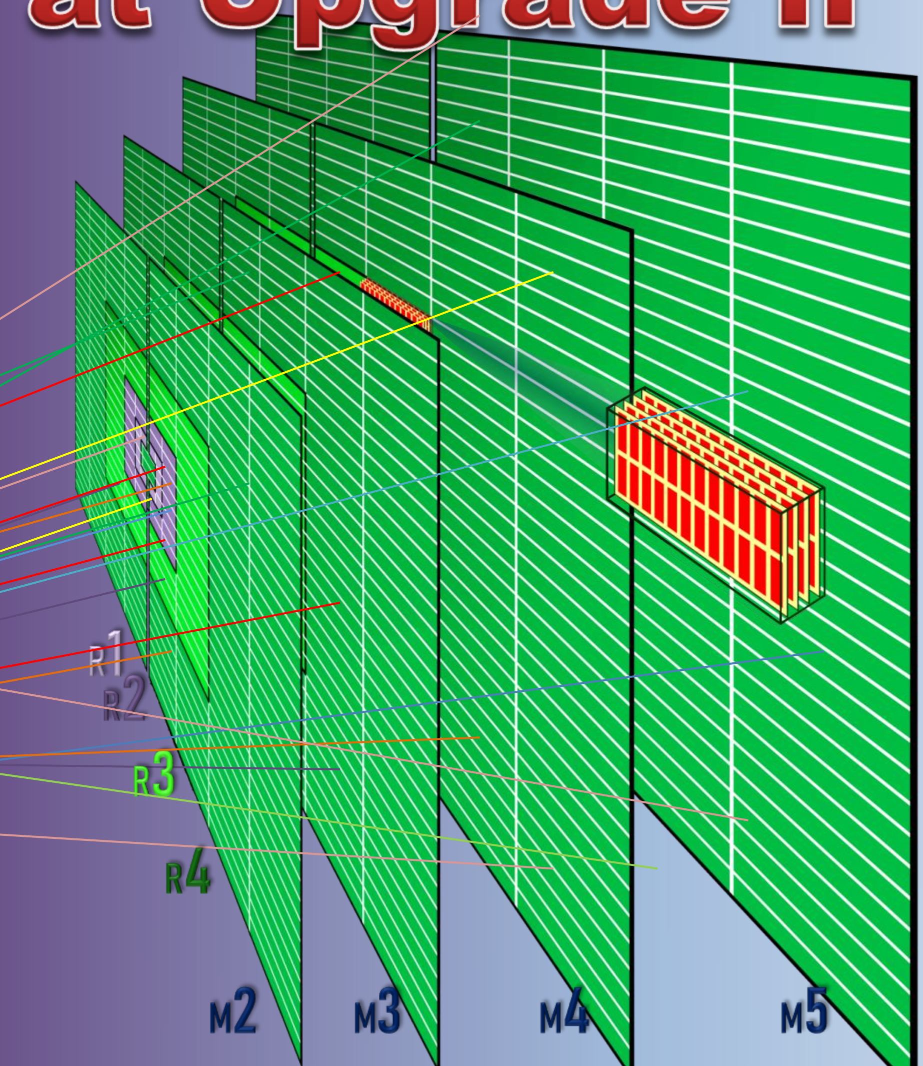
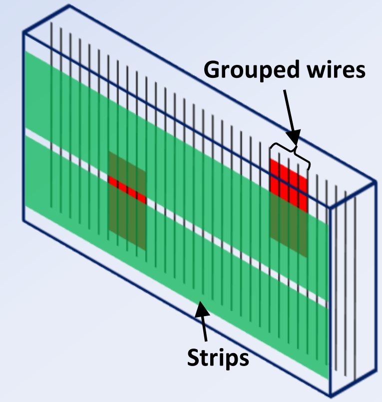
The LHCb Upgrade II is a great opportunity to improve the precision of the LHCb physics reach profiting of the LHC luminosity increase up to $2 \times 10^{34} cm^{-2} s^{-1}$ planned for Run 5, in 2032. In order to deal with the expected increase in the redout rate (a factor of ~10 w.r.t LHC Run 3 rates), the Muon Detector will be upgraded preserving its highly efficient $\mu$ detection capability >95% in a 25 ns window.

The Muon Detector is made of four rectangular stations M2-M5, for a total area of 387 m², divided in R1-R4 regions and interleaved with 80 cm thick iron absorbers. Stations consist of 4-gaps multi-wire proportional chambers (MWPCs). As an example, the internal structure of a MWPC in M3 R3 is shown in the left. At right the gap internal structure.

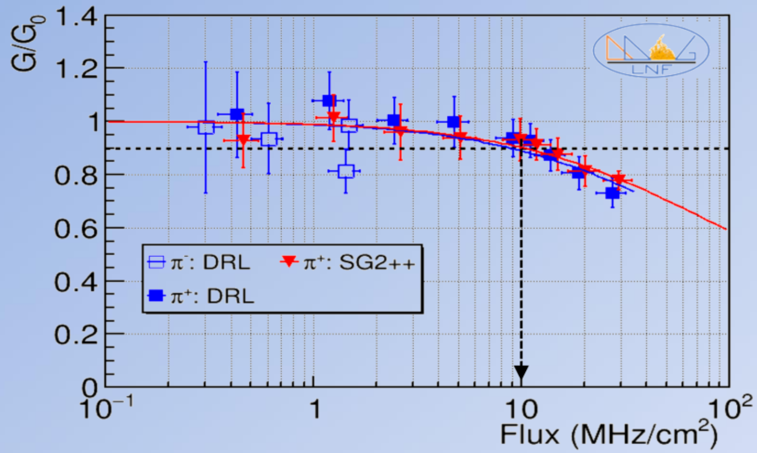
The estimated maximum rates are shown in the table. In an increased background and pileup environment, the MWPCs in the innermost R1-R2 regions need to be replaced. In the outer regions, they could be reused or replaced according to their state of aging. Another crucial modification for the Muon Detector performance optimisation is a new redout scheme for the logical pads thought for reducing background signals.



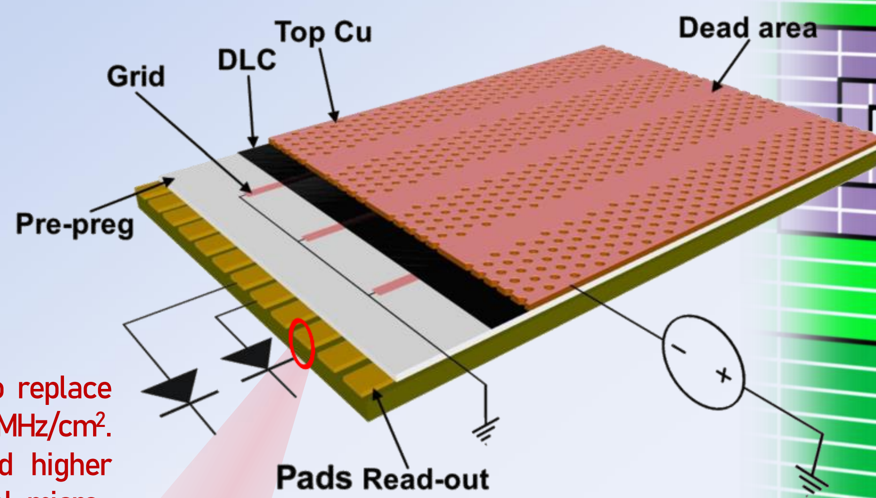



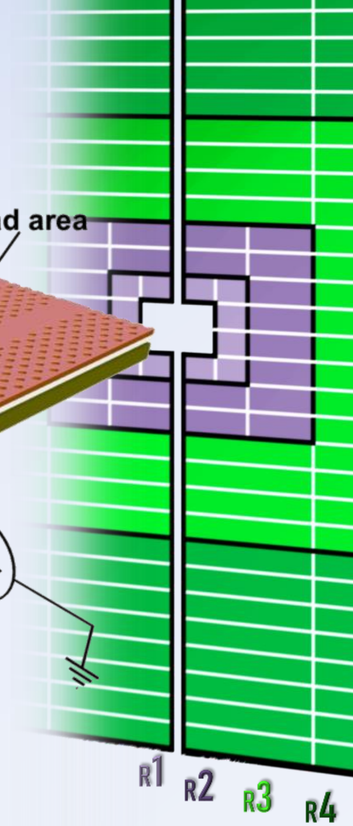

In each gap logical pads are logical AND of grouped vertical wires with strips or physical pads.

| Region | | Max rate [kHz/cm²] | |
|---|---|---|---|
| M2 | R1 | 998 | to be replaced |
| | R2 | 98 | to be replaced |
| | R3 | 13 | replaced/reused |
| | R4 | 10 | replaced/reused |
| M3 | R1 | 575 | to be replaced |
| | R2 | 72 | to be replaced |
| | R3 | 8 | replaced/reused |
| | R4 | 3 | replaced/reused |
| M4 | R1 | 211 | to be replaced |
| | R2 | 30 | to be replaced |
| | R3 | 5 | reused |
| | R4 | 2 | reused |
| M5 | R1 | 179 | to be replaced |
| | R2 | 20 | to be replaced |
| | R3 | 4 | reused |
| | R4 | 2 | reused |

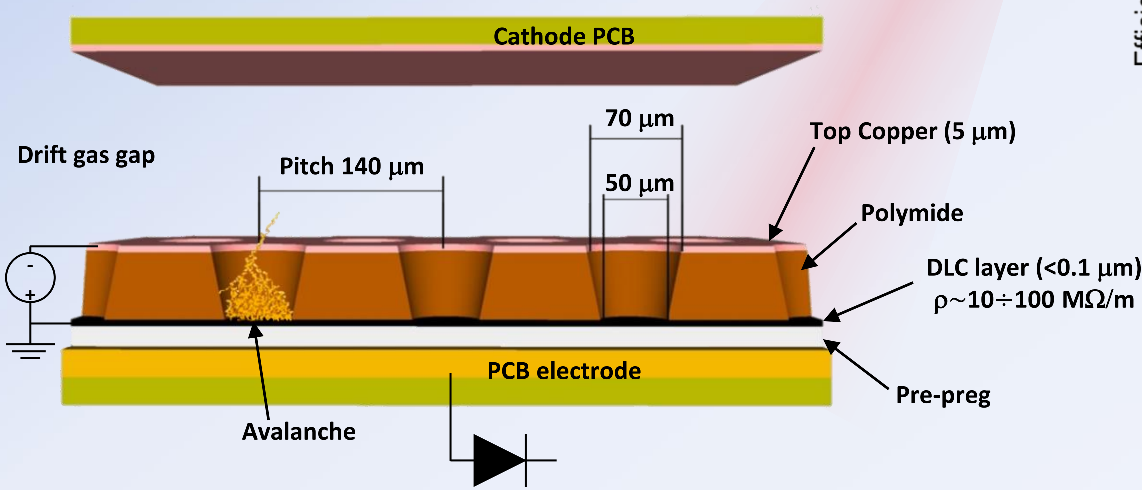


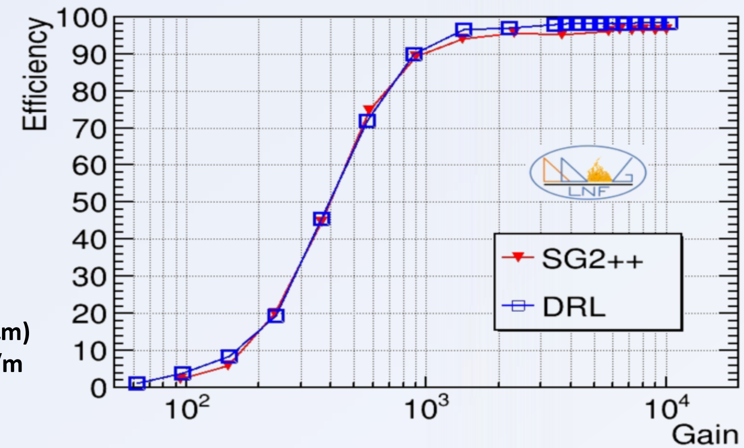

G. Bencivenni *et al.*, *The $\mu$–RWELL layouts for the high particle rate*, 2019 JINST289 14 C05014.




**μRWELLs in R1 R2** of all stations are planned to replace the MWPCs in view of the foreseen Upgrade II high rates, max ~1 MHz/cm$^2$. Indeed, this technology has both higher rate capabilities and higher granularity with respect to the current MWPCs. They are novel micro-pattern gaseous detector in which a matrix of blind holes (well) acts as an amplification stage for the ionization produced in the drift gas gap. The Diamond-Like-Carbon (DLC) resistive layer allows to achieve large gains ($\geq 10^4$), suppressing the spark transition.

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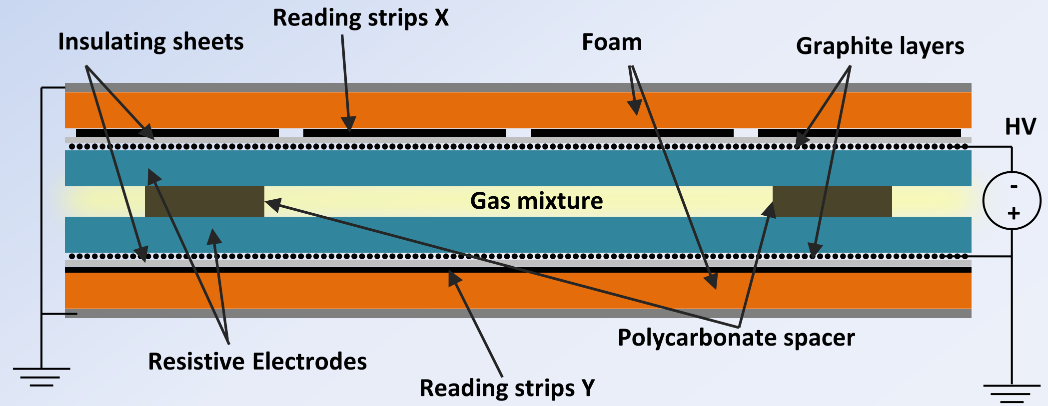
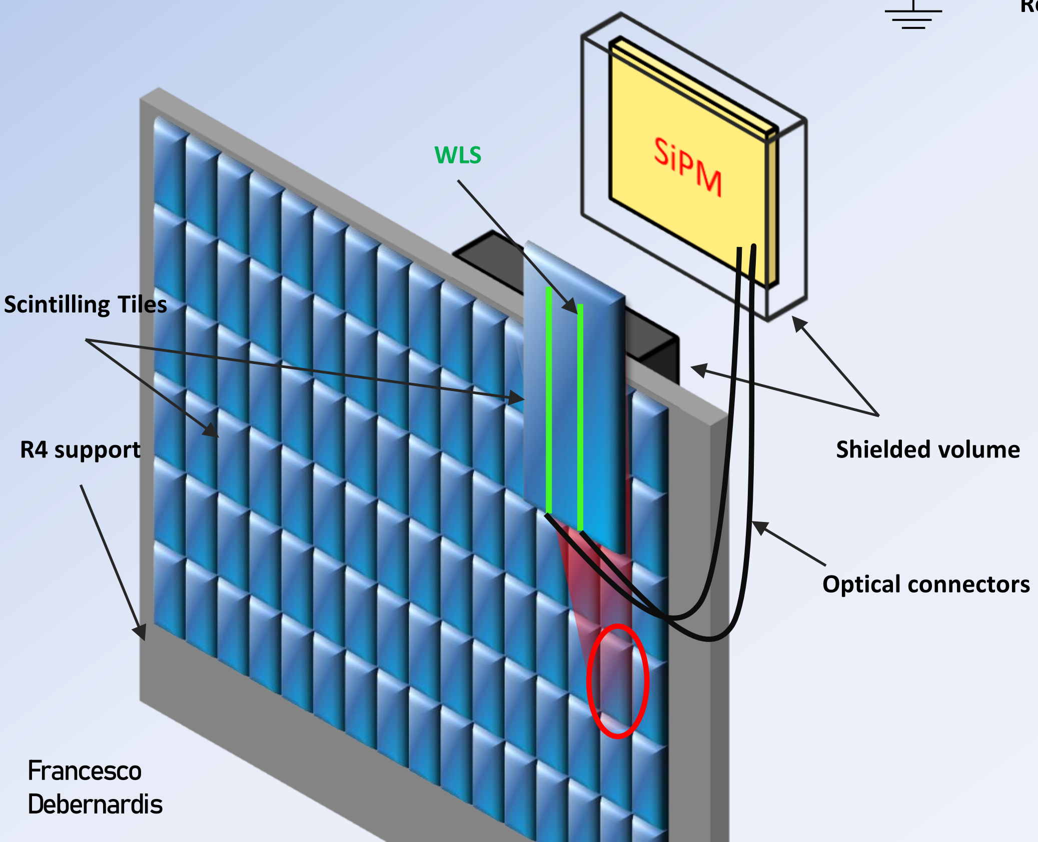
# Other options considered for R4 region

## RPCs

Are an interesting option thanks to high space and time resolution, as well as ease of construction, robustness and low cost per unit area.
In order to preserve the detector performance at rates up to ~10 kHz/cm$^2$ in an increased background and pileup environment, the bulk resistivity of the electrodes and/or the electrode and gap thickness and/or the average charge per event must be reduced. These options are currently under study. They offer several advantages as a lower operating voltage and a reduced charge per avalanche which in turn implies an increased lifetime of the chambers as well as an increased rate capability and time resolution.




## SCI-Tiles

Are an interesting option thanks to high detector efficiency ~98% and a good time resolution ~ 1 ns, furhtermore they are not expensive and easy to produce and assemble.
The system consists of a Scintilling-Tiles based detector, readout via Wave Lenght Shifting fibers (WLS) and Silicon Photo-Multipliers (SiPM) that deteriorate rapidly with radiation. Thus, in the very harsh LHCb environment, SiPMs need to be located in a neutron-shielding and cooled-down volume on the back side of the tiles support. Another possibility could be to replace the SiPMs periodically keeping their performances always at their best.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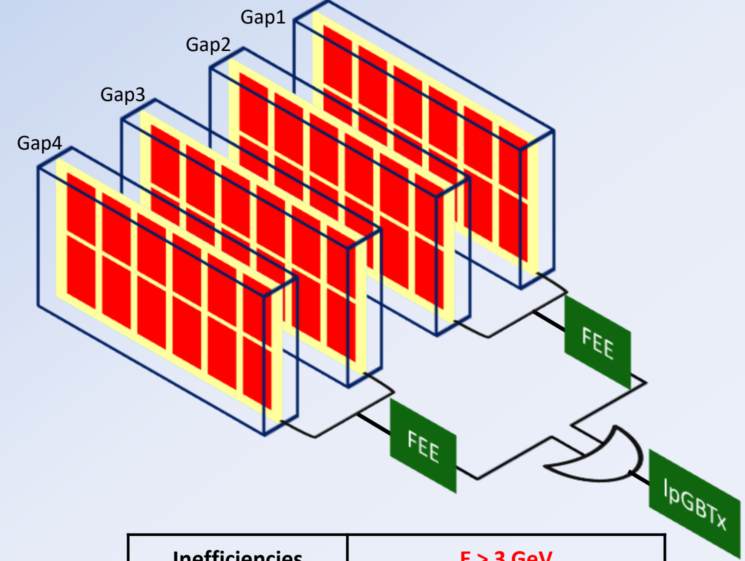
# New readout scheme for Upgrade II

Currently, the readout scheme of one chamber consists in the OR of 2 gaps, again ORed at Front-End Electronics (FEE) level, as shown at right. This 4-gaps-OR generates a very high rate by low energy particles, up to 90% in inner regions, due to single gap background signal.

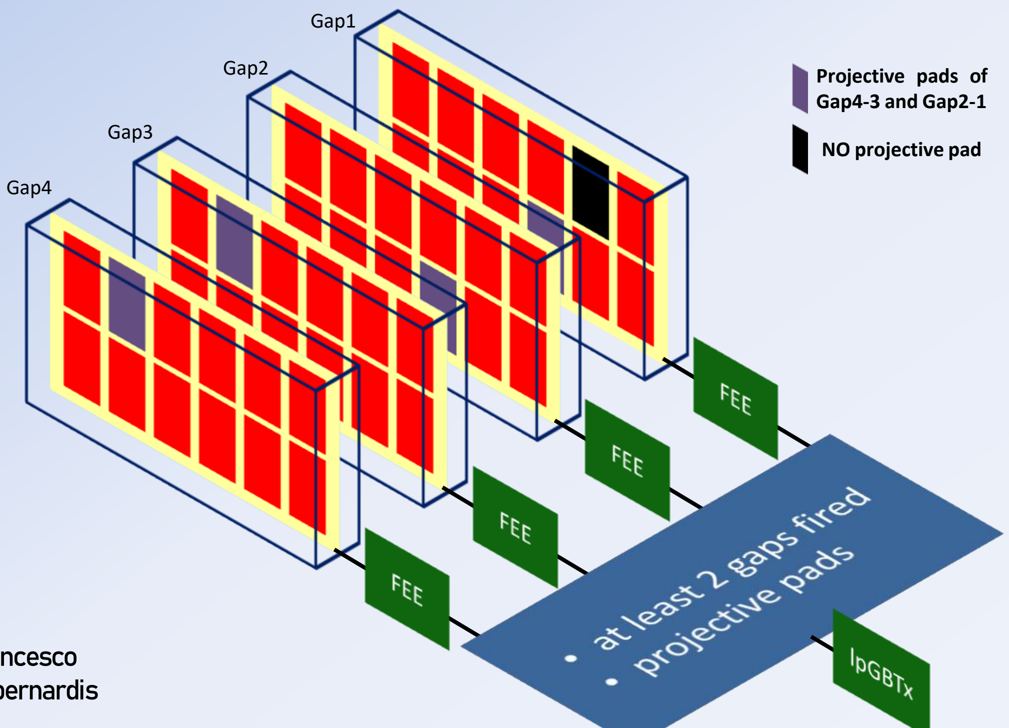



For Upgrade II, in order to get rid of this effect, a new readout scheme has been proposed in which each gap is readout separately, requiring:

- signal in at least 2 gaps out of 4 at the same time
- at least two projective logical pads fired in the two gaps

The single gap readout is expected to reduce by ~30-40% the input rate to each FEE channel. The contribution from uncorrelated hits is expected to be additionally reduced by a factor ~3 thanks to the requirement of 2 fired gaps at the same time. A first detailed study has been done on a (high threshold) Monte Carlo sample in order to analyse inefficiencies eventually induced by this new readout scheme in the current Muon Detector configuration. Specific attention is payed to the identification of low energy muons, tipically large angle particles that could not fire projective pads. As shown in the table, the first results are encouraging: for all stations the inefficiency induced by the new readout scheme is in general greater than 1% for most <3GeV muons that would not be identified anyway by the muon PID. The study is progressing, taking into account specific aspects such as time inefficiency.

| | | Inefficiencies $\mu^{-/+}$ of all energies | E > 3 GeV (the range used for physics) |
|---|---|---|---|
| M2 | R1 | -7,14% | - 0.43% |
| | R2 | -5.03% | - 0.40% |
| | R3 | -3.79% | - 0.46% |
| | R4 | -2.73% | - 0.38% |
| M3 | R1 | -5.66% | - 0.71% |
| | R2 | -2.48% | - 0.63% |
| | R3 | -1.54% | - 0.70% |
| | R4 | -1.37% | - 0.83% |
| M4 | R1 | - 3.21% | - 0.60% |
| | R2 | - 1.61% | - 0.68% |
| | R3 | - 1.13% | - 0.77% |
| | R4 | - 1.53% | - 1.14% |
| M5 | R1 | - 3.77% | - 0.44% |
| | R2 | - 1.70% | - 0.72% |
| | R3 | - 1.17% | - 0.73% |
| | R4 | - 2.02% | - 1.23% |

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