The μ-RWELL detector for the Muon System Upgrade

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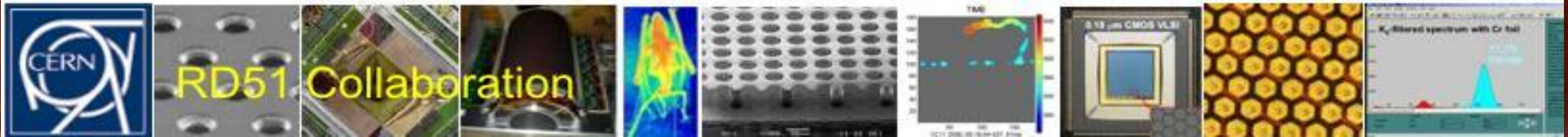
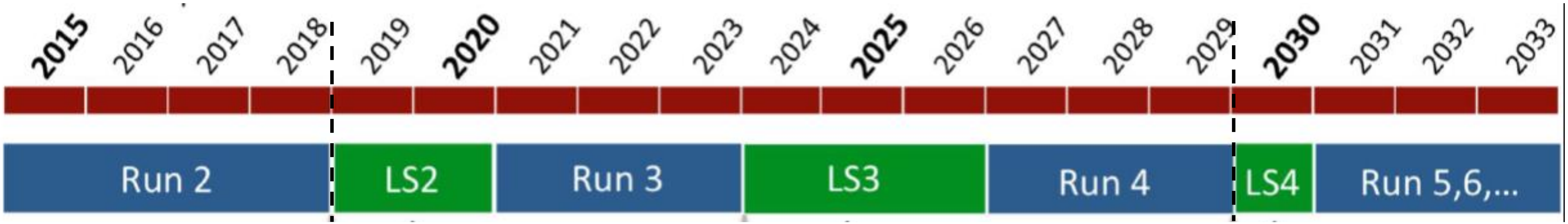
Laboratori Nazionali di Frascati - INFN



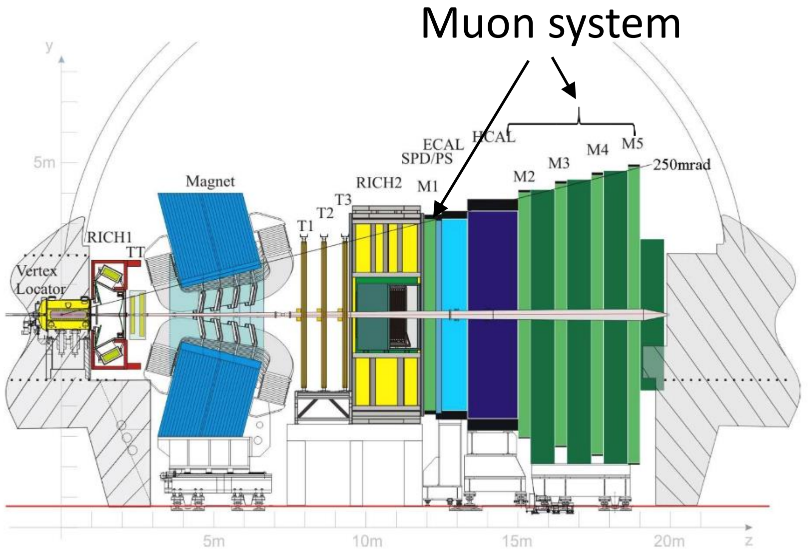
The LHCb Muon Apparatus



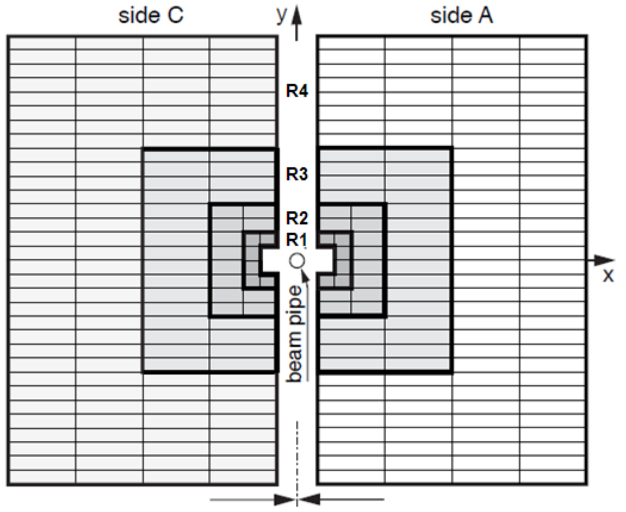
The Muon system has performed well in Run1 & Run2 @ 1-4x10^{32} (8 fb^{-1} collected)
→ tracking inefficiency from dead time at level of 1 % in Run1 and 2 % in Run2

Increase in luminosity has consequence

- large **increase in dead time induced inefficiency** (in most region of the detector the reconstructed hits are obtained by crossing large area X & Y strips)
- **increased** rate of **ghost hits** from accidental crossing of X-Y channels
- **increased pion misidentification**

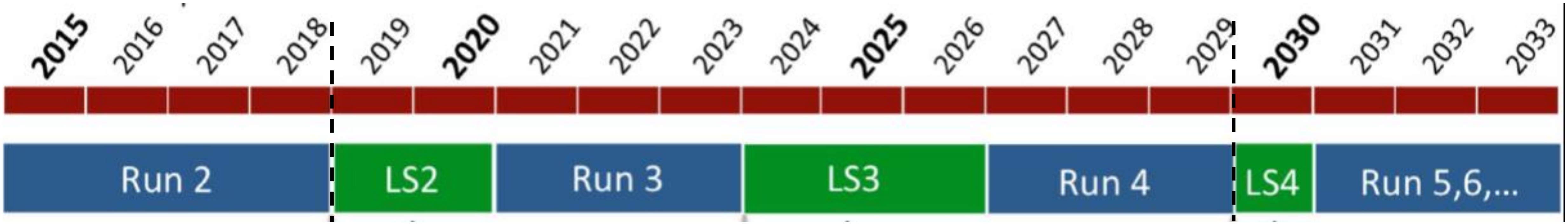


Current LHCb detector



Muon system:
5 stations x 4 regions

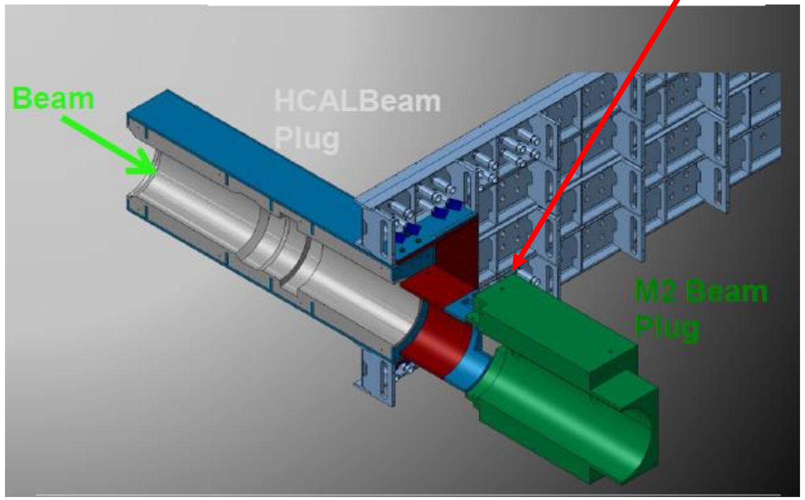
The LHCb Muon Apparatus

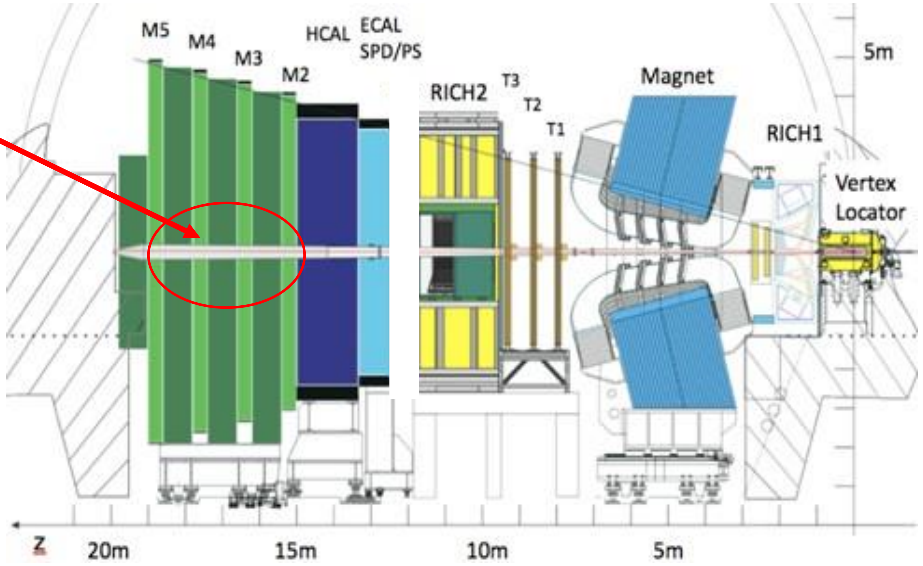


For **Run3 & Run4 @ 2x10^{33}** (foreseen to collect 50 fb^{-1}):

- Improving the beam pipe shielding

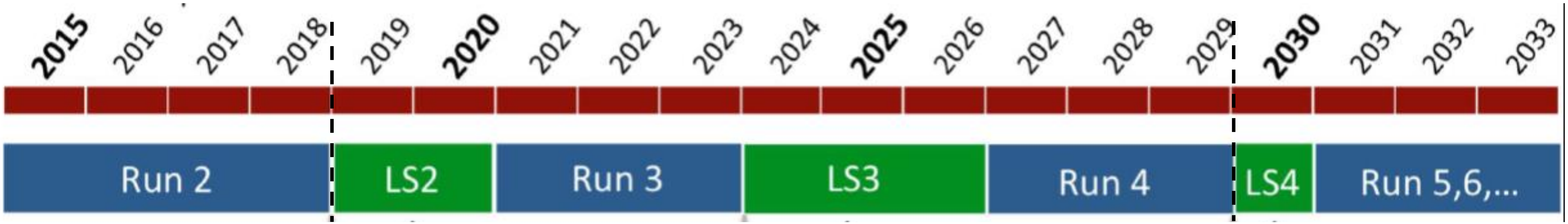
- Increasing the granularity of the most irradiated chambers

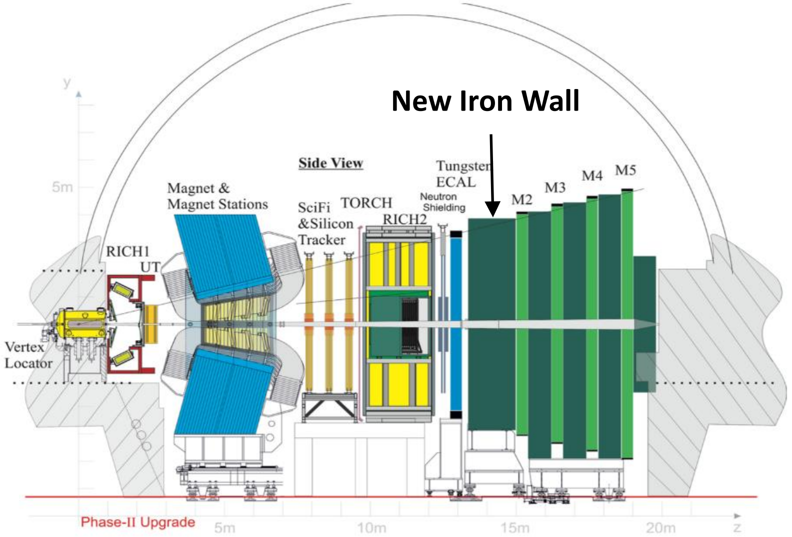




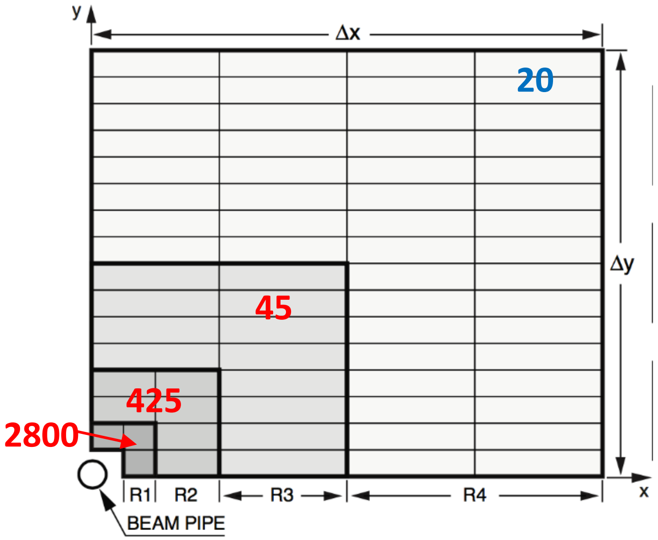
LHCb-INT-2017-019
LHCb-INT-2018-009

The LHCb Muon Apparatus





M2 station - max rate (kHz/cm^2)



For Run5 & Run 6 @ 2x10^{34} (foreseen to collect 300 fb^{-1}):

- **Replace the HCAL** with **with a new Iron Wall**
- **Install new detectors on the Muon apparatus**

Muon Detector requirements:

- **Rate** up to 3 **MHz/cm2**
- **Efficiency** for single gap **> 95%** within a BX (25 ns)
- **Long stability** up to **6 C/cm2** acc. charge in **10 y** of operation
- **Pad cluster size < 1.2**

The μ-RWELL detector seems to be a good candidate for both low and high rate regions of the Muon System

The μ-RWELL

The R&D on μ-RWELL is mainly motivated by the wish of improving the Micro-Pattern Gaseous Detectors (MPDG) technology in terms of

- **stability under heavy irradiation (discharge suppression)**
- **construction technology (simplifying the assembly)**
- **Technology Transfer to industry (mass production)**

a MUST for **very large scale applications** in fundamental research at the future colliders as well as for technology dissemination beyond HEP

The original idea was conceived in 2009 @ LNF during the construction of the Cylindrical-GEM, to try to find a way to simplifying as much as possible the construction of the CGEM and its toolings. Only in the 2014 we really started a systematic study of this new technology (*) in collaboration with Rui de Oliveira

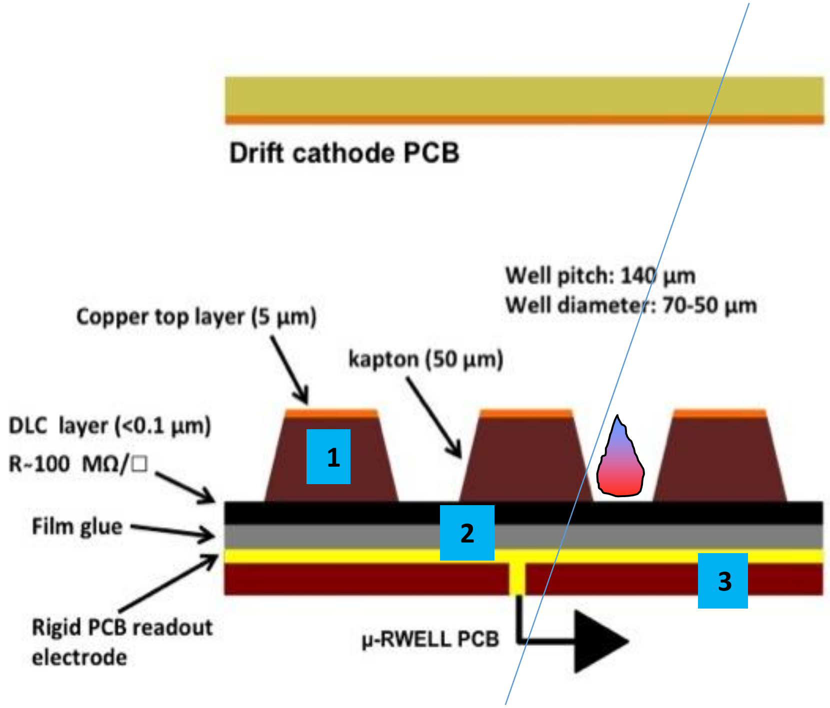
(*) **G. Bencivenni et al.,** "The micro-Resistive WELL detector: a compact spark-protected single amplification-stage MPGD", **2015_JINST_10_P02008**

The μ-RWELL: the detector architecture

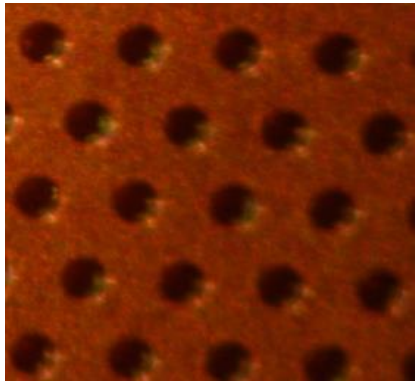
The **μ-RWELL is composed of** only **two elements**:
the **μ-RWELL_PCB** and the **cathode**

The **μ-RWELL_PCB, the core of the detector,** is realized by **coupling:**

1. a **WELL patterned kapton foil** as **amplification stage**
2. a **resistive stage**(*) for discharge suppression & current evacuation:
   - **i. Low Rate Scheme (LRS) <100 kHz/cm^2:** resistive layer grounded on the detector edge
   - **ii. High Rate Scheme (HRS) >1 MHz/cm^2**: more sophisticated resistive scheme (double DLC layers connected through vias to ground or a single DLC layer with a conductive grid at the bottom)
3. a **standard readout PCB**



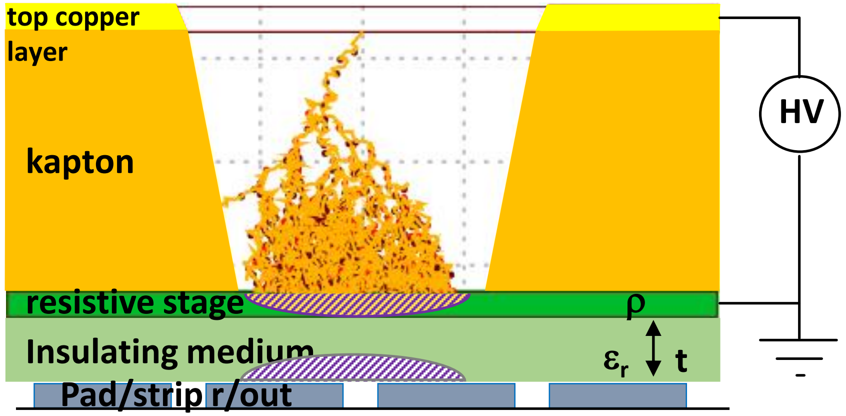
(*) DLC = Diamond Like Carbon
highly mechanical & chemical resistant



Principle of operation

Applying a suitable voltage between **top copper layer and DLC** the "**WELL" acts as multiplication channel for the ionization.**

The charge induced on the resistive foil is dispersed with a *time constant, τ = ρC ,* determined by



Not in scale

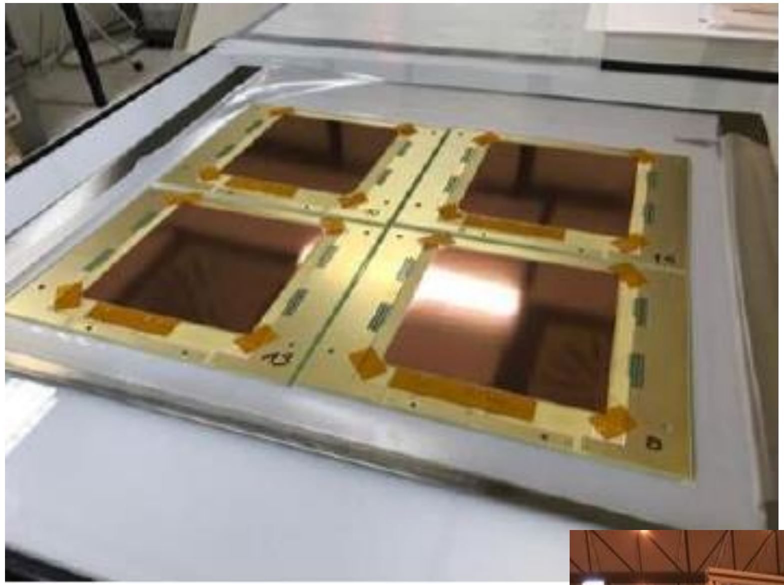
- the ***surface resistivity, ρ***
- the ***capacitance per unit area,*** which depends on the **distance between the resistive foil and the pad/strip readout plane*, t***
- the ***dielectric constant*** of the insulating medium, ε_r ***[M.S. Dixit et al., NIMA 566 (2006) 281]***

- **The main effect of the introduction of the resistive stage is the suppression of the transition from streamer to spark**
- As a drawback, the **capability to stand high particle fluxes is reduced**, ***but an appropriate grounding of the resistive layer with a suitable pitch solves this problem (see High Rate scheme)***

Technology Transfer to Industry

The engineering and industrialization of the μ-RWELL technology is one of the crucial ingredient for future applications. Transferring the manufacturing process to industry will allow a cost-effective mass production: a must for the construction of muon systems at future HEP Colliders

Manufacturing process of the single resistive layer has been already tested at the ELTOS SpA (http://www.eltos.it) for the Low Rate Scheme



$1.2 \times 0.5 m^2$ μ-RWELL

In the framework of the **CMS-Phase2 muon upgrade** (*) different prototypes of **small/large size Low Rate Scheme μ-RWELLs** has been built at ELTOS (**$1.2 \times 0.5 m^2$ & $1.9 \times 1.2 m^2$) and**

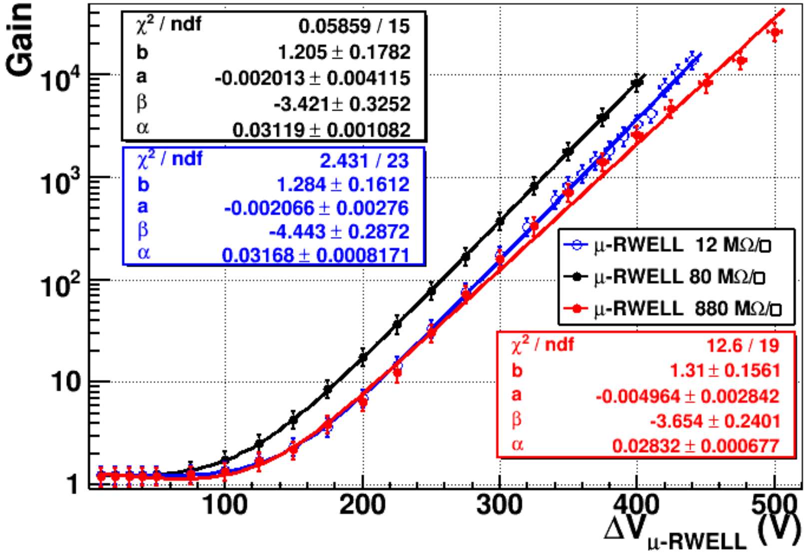
→ Prototypes successfully tested at CERN (detector efficiency > 98% & rate capability up to 40 kHz/cm^2)

(*) Collaboration with CMS-Muon people:
L. Benussi, L. Borgonovi, P. Giacomelli, A. Ranieri, M. Ressegotti, I. Vai, V. Valentino

$1.9 \times 1.2 m^2$ μ-RWELL

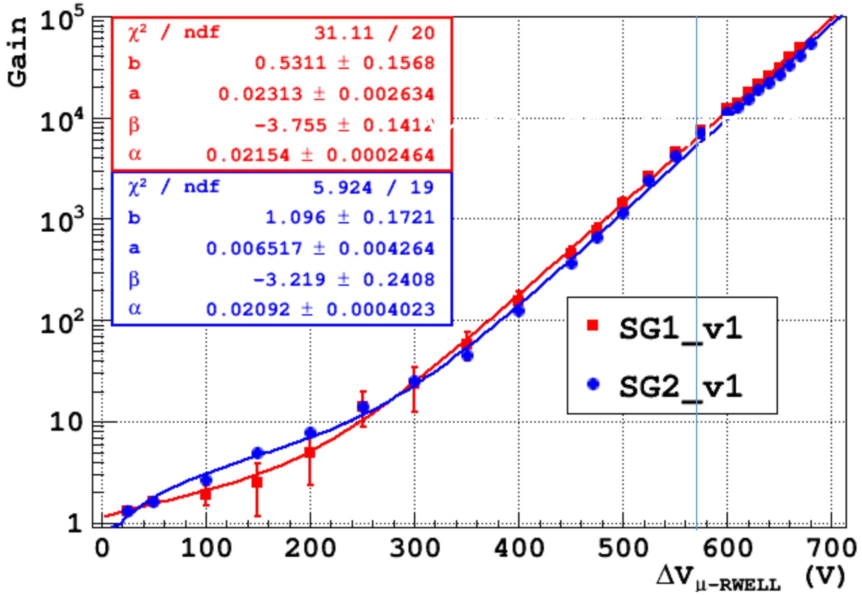
Detector Gain

Ar/iC_4H_{10}= 90/10



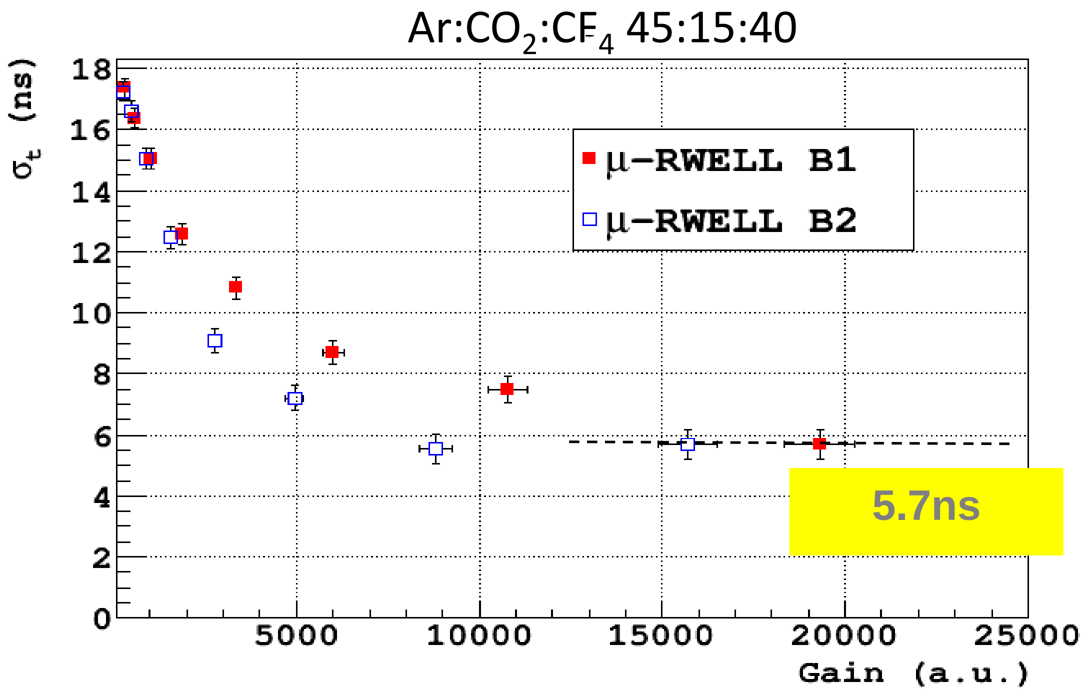
Prototypes with different resistivity have been tested with **X-Rays** (5.9 keV), with **Ar/iC_4H_{10}= 90/10** gas mixture, and characterized by measuring the **gas gain** in **current mode**.

$Ar/CO_2/CF_4$= 45/15/40



Some recent prototypes achieved a Gain ~10^5 in $Ar/CO_2/CF_4$= 45/15/40

Time Performance



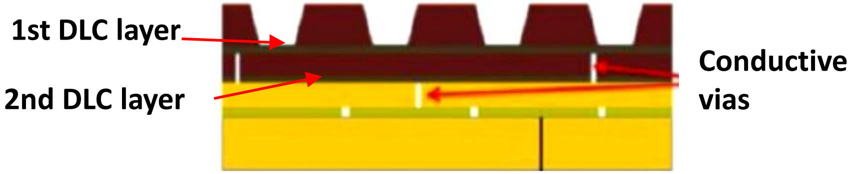
To achieve a high efficiency in the bunch-crossing (25ns), the detector requires a high time resolution: the **use of a fast and high primary ionization gas mixture** (Ar/CO2/CF4) together with **the fast electronics VFAT2** (*) allow to measure a **time resolution of 5.7 ns**. **No ultimate μ-RWELL time resolution due to FEE saturation effect**
Measurements done with GEM by LHCb group gave **σ_t = 4.5 ns with VTX chip, constant fraction discriminator**(**).

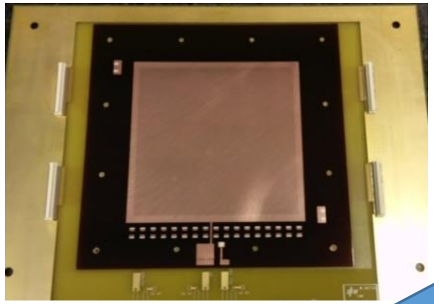
(*) P. Aspell "VFAT2: A front-end system on chip providing fast trigger information, digitized data storage and formatting for the charge sensitive readout of multi-channel silicon and gas particle detectors" , Proceedings of TWEPP-07, (2007)
(**) *G. Bencivenni et al, "Performance of a triple-GEM detector for high rate charged particle triggering", NIM **A** 494 (2002) 156*

The High Rate versions

The idea is to reduce the path of the current on the resistive stage with a sort of 3-dimensional evacuation scheme (Double DLC layers) or an optimized 2-dimensional one (Single DLC layer)

Double DLC Layers



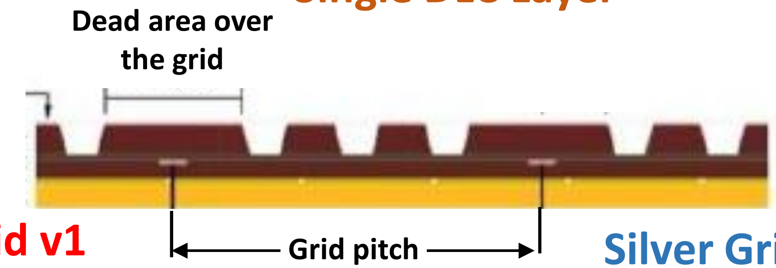


NO dead area
→ **geo. acceptance : full**

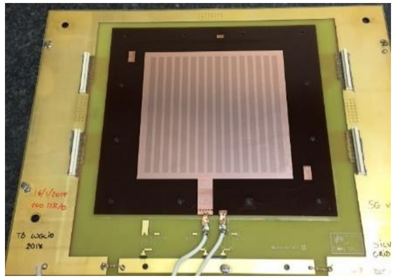
WARNING: the prototypes work well but the **industrialization of the double-resistive** layers is **difficult** due to the **manufacturing process of the conductive vias**

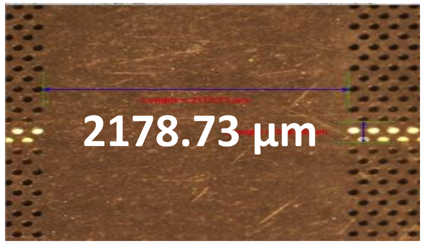
Easier industrialization process: single layer

Single DLC Layer



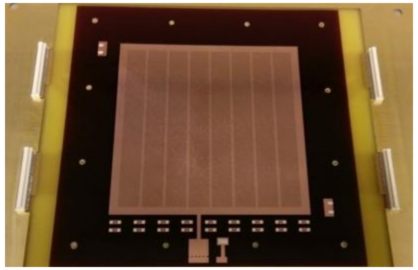
Silver Grid v1

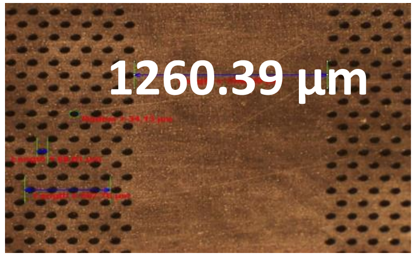




grid-pitch 6 mm
dead area 2 mm
→ **geo. acceptance: 66%**

Silver Grid v2

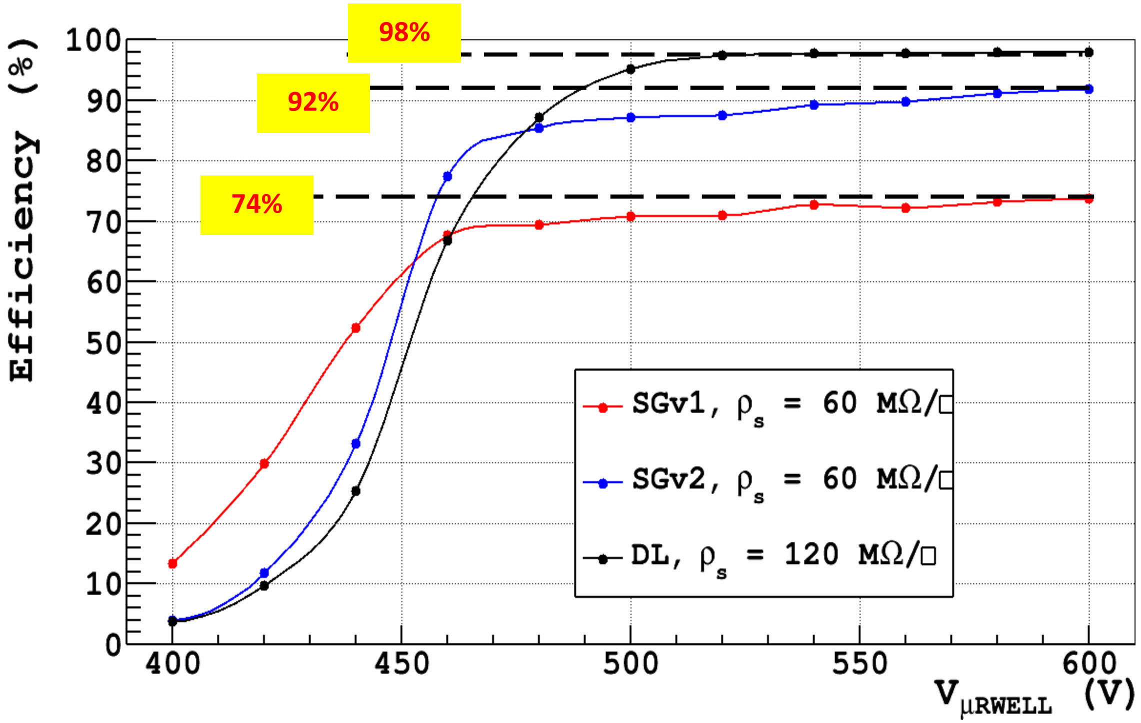




grid-pitch 12 mm
dead area 1 mm
→ **geo. acceptance: 90%**

HR layouts performance

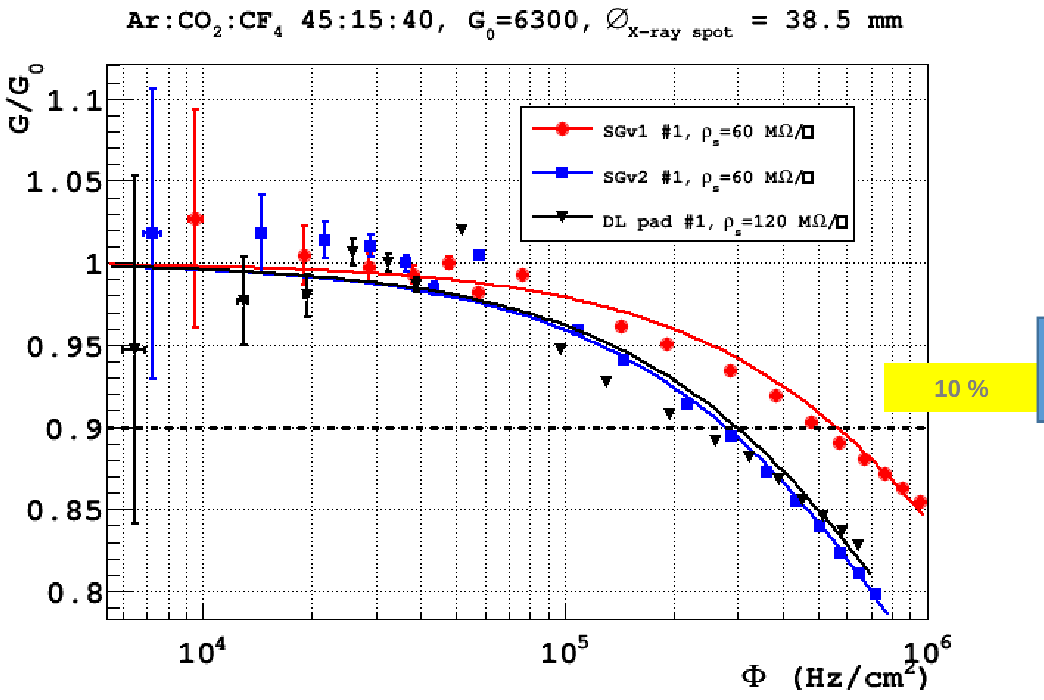
Ar:CO_2:CF_4 45:15:40 – Muon Beam - Ed = 3 kV/cm

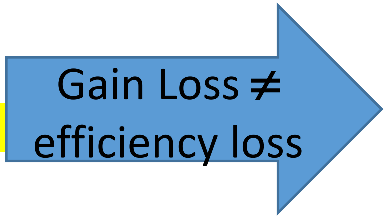


As expected the **Double layers prototype** reaches **full tracking efficiency** – **98%** (NO DEAD ZONE in the amplification stage).
The **Silver Grid v1 & v2** show lower efficiency **(74% -92%) BUT higher than their geometrical acceptance** (**66% and 90%** respectively), thanks to the **efficient electron collection mechanism** that **reduce the effective dead zone.**

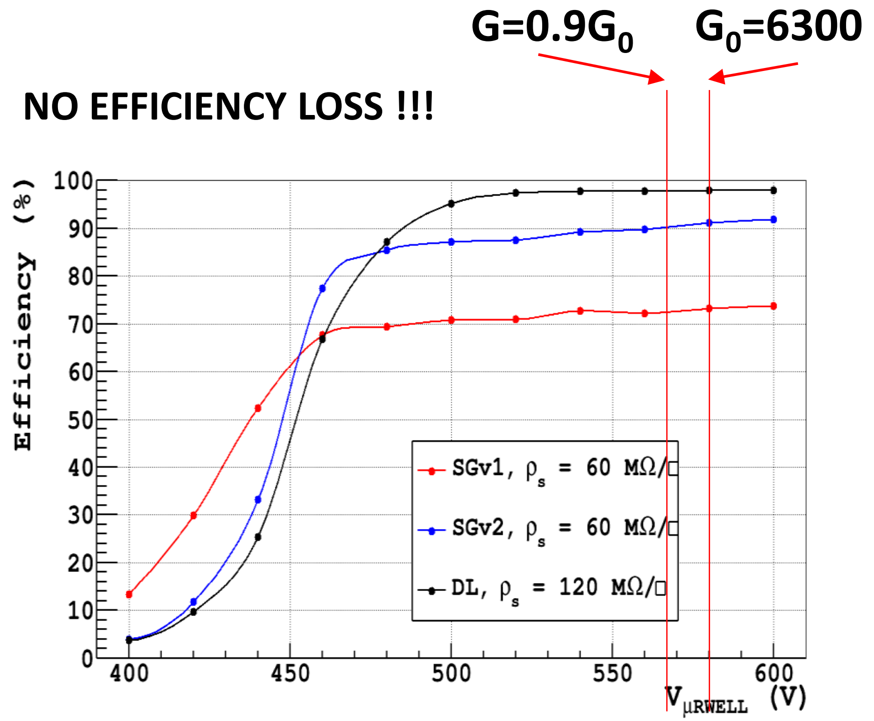
→ With the optimized SG2 version ($SG2^{++}$ w/95% geometrical acceptance) we hope to achieve almost full efficiency (97-98%).

Gain drop measurement w/5.9 X-ray





NO EFFICIENCY LOSS !!!



The **gain drop** is due to the **Ohmic effect** on the resistive layer and depends on the **evacuation stage and DLC surface resistivity.**

Since the **primary ionization of 5.9 keV is ~7 times larger than a m.i.p and accepting a 10% gain drop, a rate capability of few MHz/cm² is achieved**

It must be stressed that **10% drop of G_0=6300** allows **still to operate the detector at full efficiency**.

Summary

Recent R&D on a novel MPGD architectures lead to the introduction of the μ-RWELL in the MPGDs world.
The μ-RWELL is a very promising technology showing important advantages for large area applications in harsh environment: the detector is compact, simple to assemble and intrinsically spark-protected

- **gas gain > 10^4**
- **rate capability > 1 MHz/cm^2 (HR version)**
- **time resolution ~ 5.7 ns**

R&D/engineering in progress:

- Low rate (<100kHz/cm^2) :
  - small and large area prototypes built and extensively tested
  - Technological Transfer to industry is ongoing with good achievements
- High rate (>1 MHz/cm^2):
  - R&D well advanced, completed by end of 2018
  - prototypes show very good performance

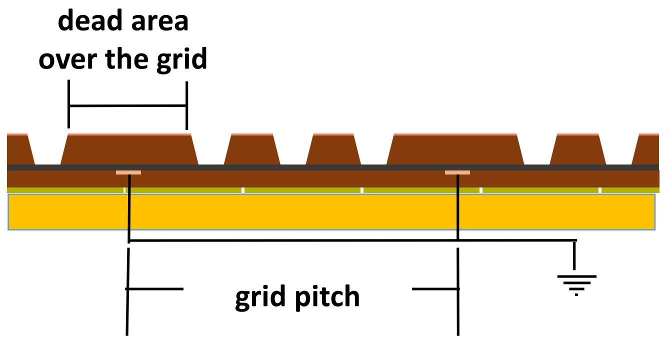
A new highly-integrated frontend ASIC is required for the Phase II Upgrade

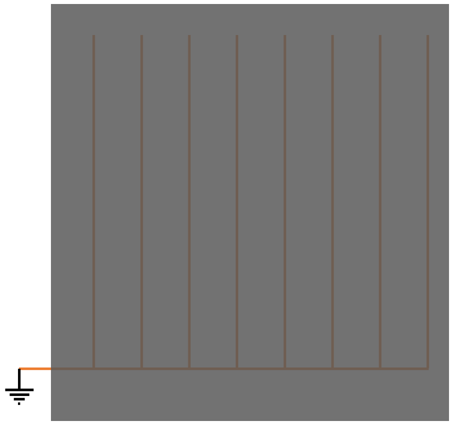
Thanks for your attention

New ideas for the HR version

The aim is **to maintain a very short path for current moving on the resistive layer,** while **simplifying the construction process.**
Two ideas are now under development: **silver grid and resistive grid on the bottom of the DLC**

High Rate scheme	Resistivity [MΩ/□]	Dead Area over grid	Grid Pitch	Geometrical efficiency [%]	Type
Silver Grid 1 (SG1)	60-70	2 mm	6 mm	66	conductive grid
Silver Grid 2 (SG2)	60-70	1,2 mm	12 mm	90	conductive grid
Resistive Grid (RG)	60-70	-	6 mm	Full	resistive grid





The **conductive grid** on the bottom of the amplification stage **can induce instabilities due to discharges over the DLC surface, requiring for the introduction of a dead zone on the amplification stage. This is not the case for the resistive grid scheme.**

The LHCb Muon Apparatus

The Muon system has performed well in Run1 & Run2 @ 1-4x10^{32} (8 fb^{-1} collected)

→ **tracking inefficiency from dead time at level of 1 % in Run1 and 2 % in Run2**

Increase in luminosity has conseguence

- **large increase in dead time induced inefficiency** (in most region of the detector the recostructed hits are obtained by crossing large area X & Y strips)
- **increased** rate of **ghost hits** from accidental crossing of X-Y channels
- **increased pion misindentification**

For Run3 & Run4 @ 2x10^{33} (foreseen to collect 50 fb^{-1}):

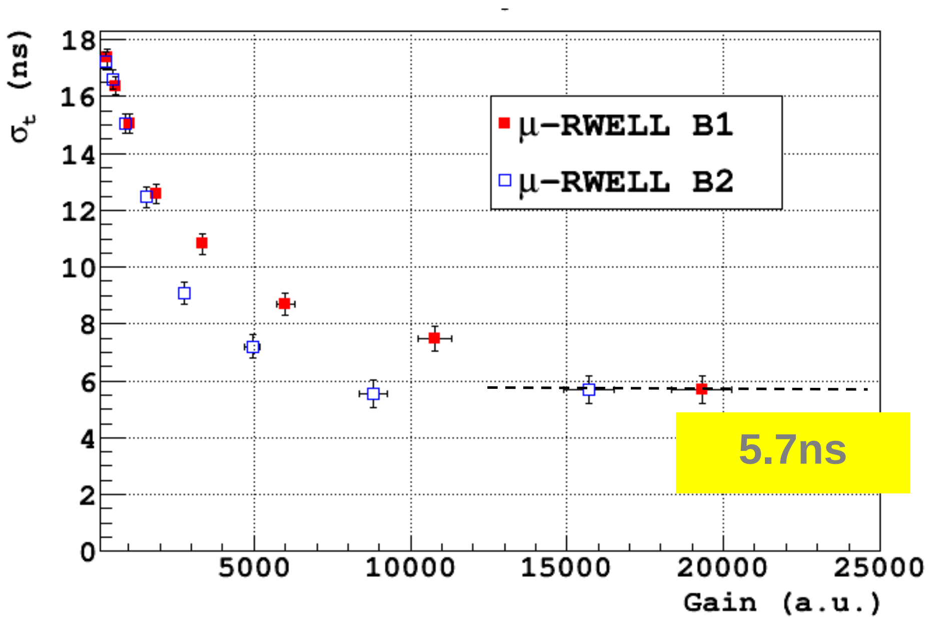
- **improving the beam pipe shielding** and **increasing the granularity** of the forward-inner chambers (M2R1, M2R2 & M3R1 – removing the OR of contiguous channels) will allow to reduce the **inefficiency from 25% to 4.5%**

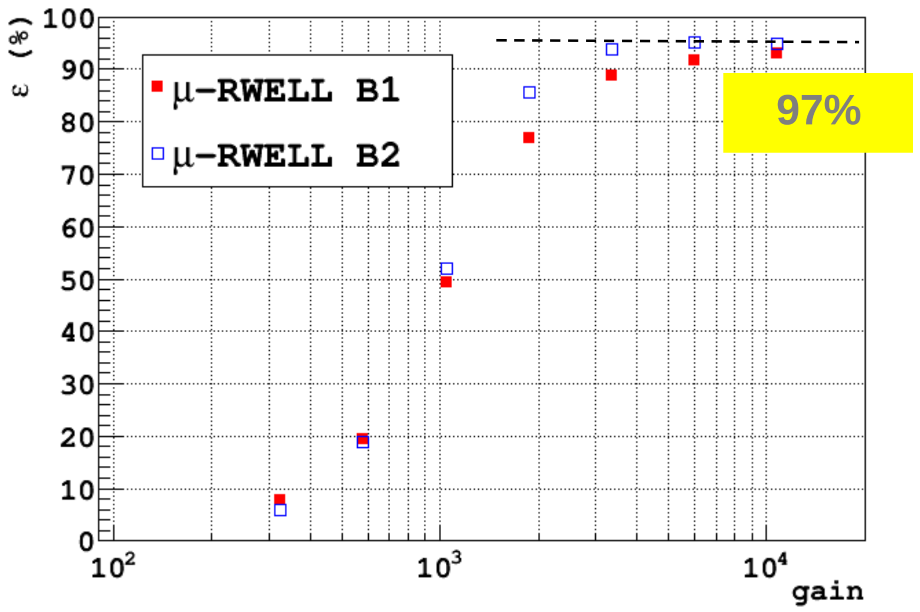
For Run3 & Run4 @ 2x10^{34} (foreseen to collect 300 fb^{-1}):

- **Replace the HCAL** with with **a new optimezed Iron Wall** and **install new detectors**, more radiation tollerant and with an order of magnitude higher readout granularity

Time Performance

Ar:CO_2:CF_4 45:15:40





A time resolution of 5.7 ns has been measured with a fast electronics (VFAT2). The saturation at 5.7 ns is dominated by the FEE. To be compared with past measurements done by our LHCb with GEM: σ_t = 4.5 ns with VTX chip and CF discriminator

[G. Bencivenni et al., NIM A 494 (2002) 156]

Main detector features

The **μ-RWELL** is a **single-amplification stage**, intrinsically **spark protected** MPGD characterized by:

- ***simple assembly procedure***:
  - ***only two components*** → ***μ-RWELL_PCB + cathode***
  - no critical & time consuming **assembly** steps:
    - ***no gluing***
    - ***no stretching*** **(→** no stiff & large frames needed)
    - ***easy handling***
  - ***suitable for large area with PCB splicing technique w/small dead zone***
- ***cost effective:***
  - 1 PCB r/o, 1 μ-RWELL foil, 1 DLC, 1 cathode and **very low man-power**
- ***easy to operate:***
  - very simple HV supply → only ***2 independent HV channels*** or a trivial ***passive divider*** (while 3GEM detector → 7 HV floating/channels)

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For Run5 & Run 6 @ 2x10^{34} (foreseen to collect 300 fb^{-1}):
Replace the HCAL with **with a new optimezed Iron Wall** and **install new detectors on the Muon apparatus**, more radiation tollerant and with an order of magnitude higher readout granularity

Rates at $2x10^{34}$

The following max rates for Phase II are obtained by scaling the Phase I extrapolation

	kHz/cm^2		kHz/cm^2		kHz/cm^2		kHz/cm^2
M2R1	2800	M3R1	1900	M4R1	650	M5R1	550
M2R2	425	M3R2	220	M4R2	85	M5R2	55
M2R3	45	M3R3	19	M4R3	9	M5R3	7
M2R4	20	M3R4	5	M4R4	3	M5R4	4

Detector requirements:

- **Rate** up to 3 **MHz/cm2**
- **Efficiency** for single gap **> 95%** within a BX (25 ns)
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