Future Upgrades of LHCb Muon System

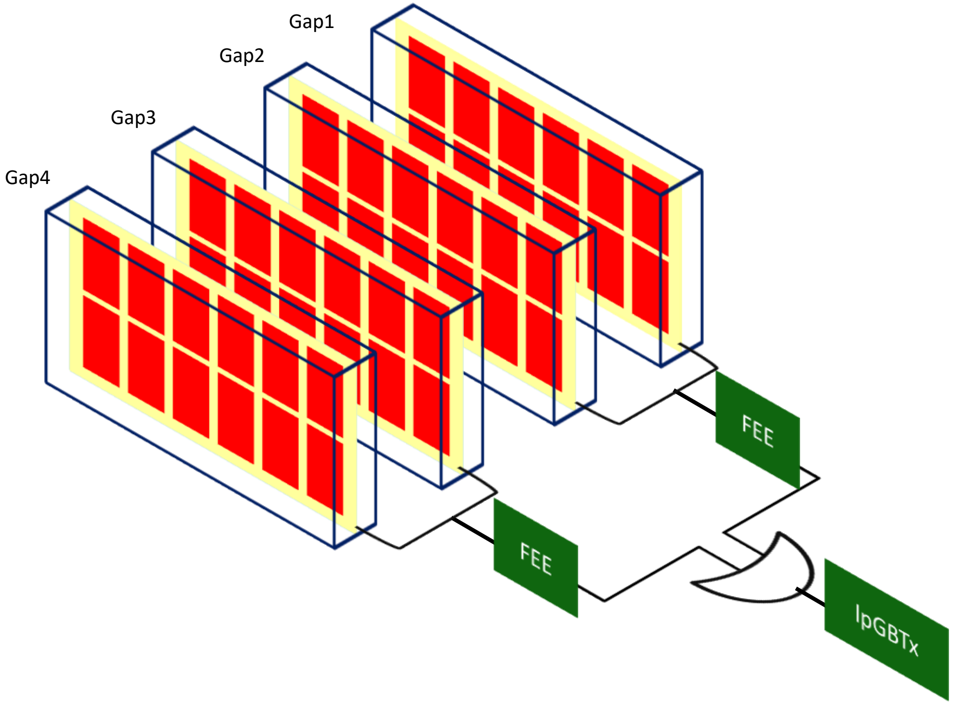
Simulation studies for a new Muon detector read-out at U2

F. Debernardis, A. Pastore
Università degli Studi di Bari, INFN Bari

Outline

- Motivation for a new read-out scheme for the Muon Detector at U2
- Simulation framework and first studies
- Evaluation of the Muon ID geometrical inefficiency with the new RO scheme
- Conclusion and outlooks

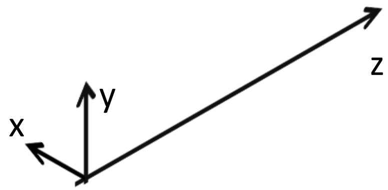
Proposal of a new read-out scheme



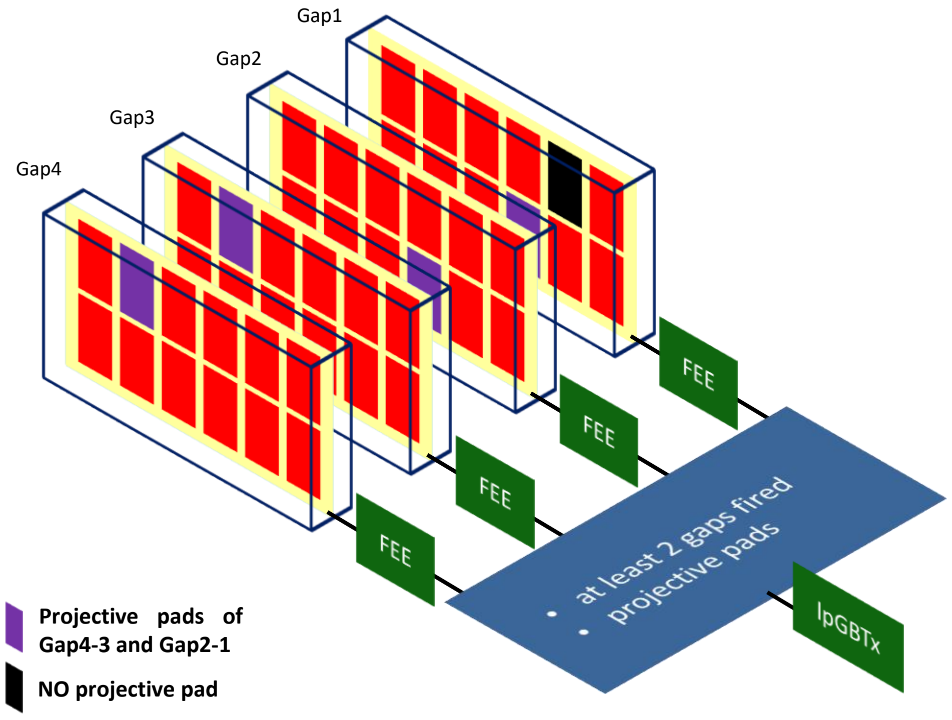
Current readout scheme

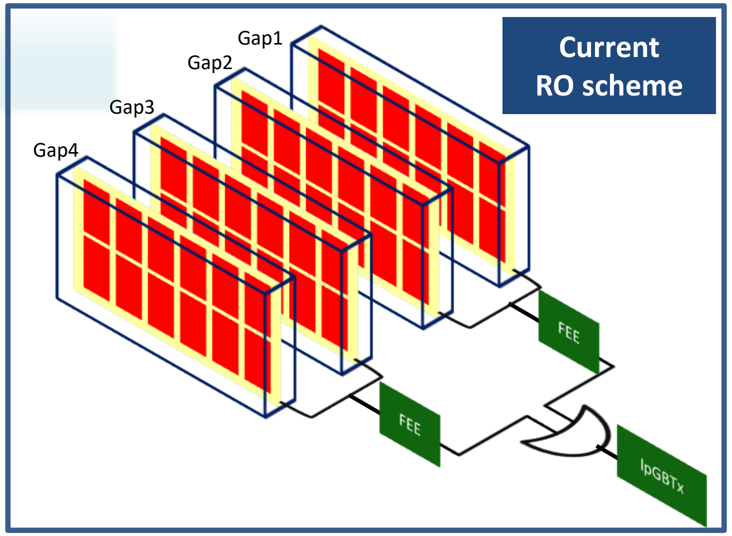
→ **OR of 2 gaps, again ORed at Front End Electronics (FEE) level**

→ **This 4 gaps OR generates a very high input rate, up to 90% in inner regions, due to single gap background signal.**



Proposal of a new read-out scheme

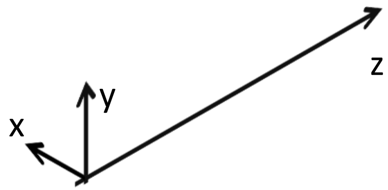




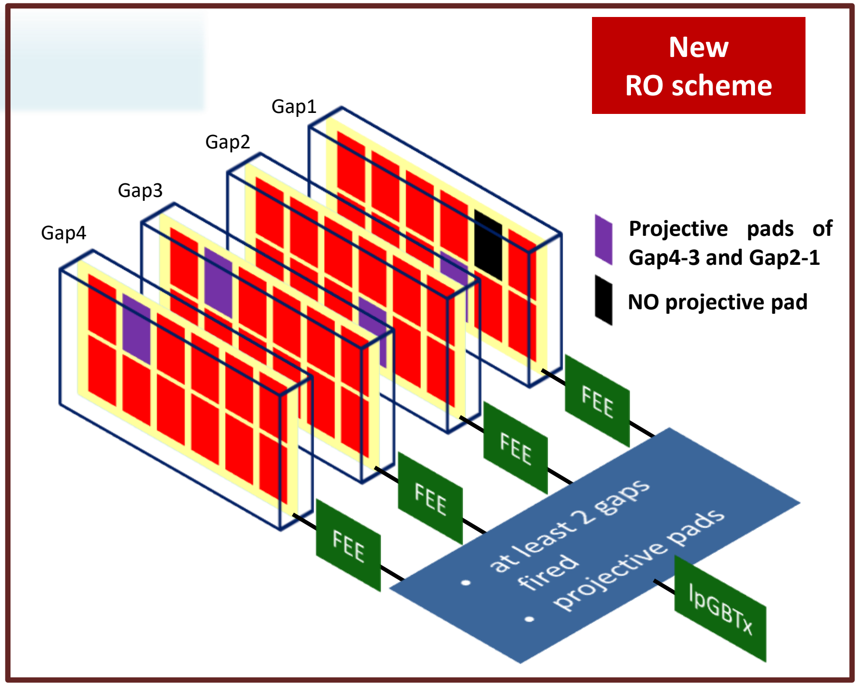
New readout scheme

→ <u>each gap is read-out separately</u>, requiring :

1. signal in at least 2 gaps out of 4 of a chamber
2. at least two projective logical pads fired in the two gaps

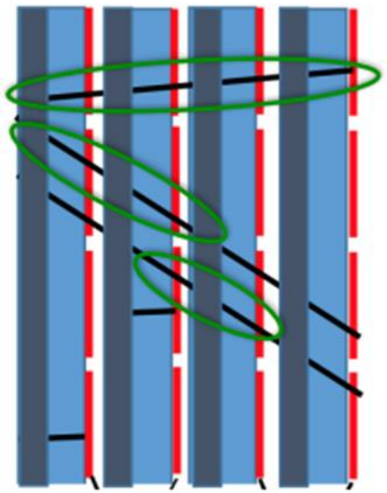


Need for new RO simulation studies



Evaluation of geometrical inefficiency

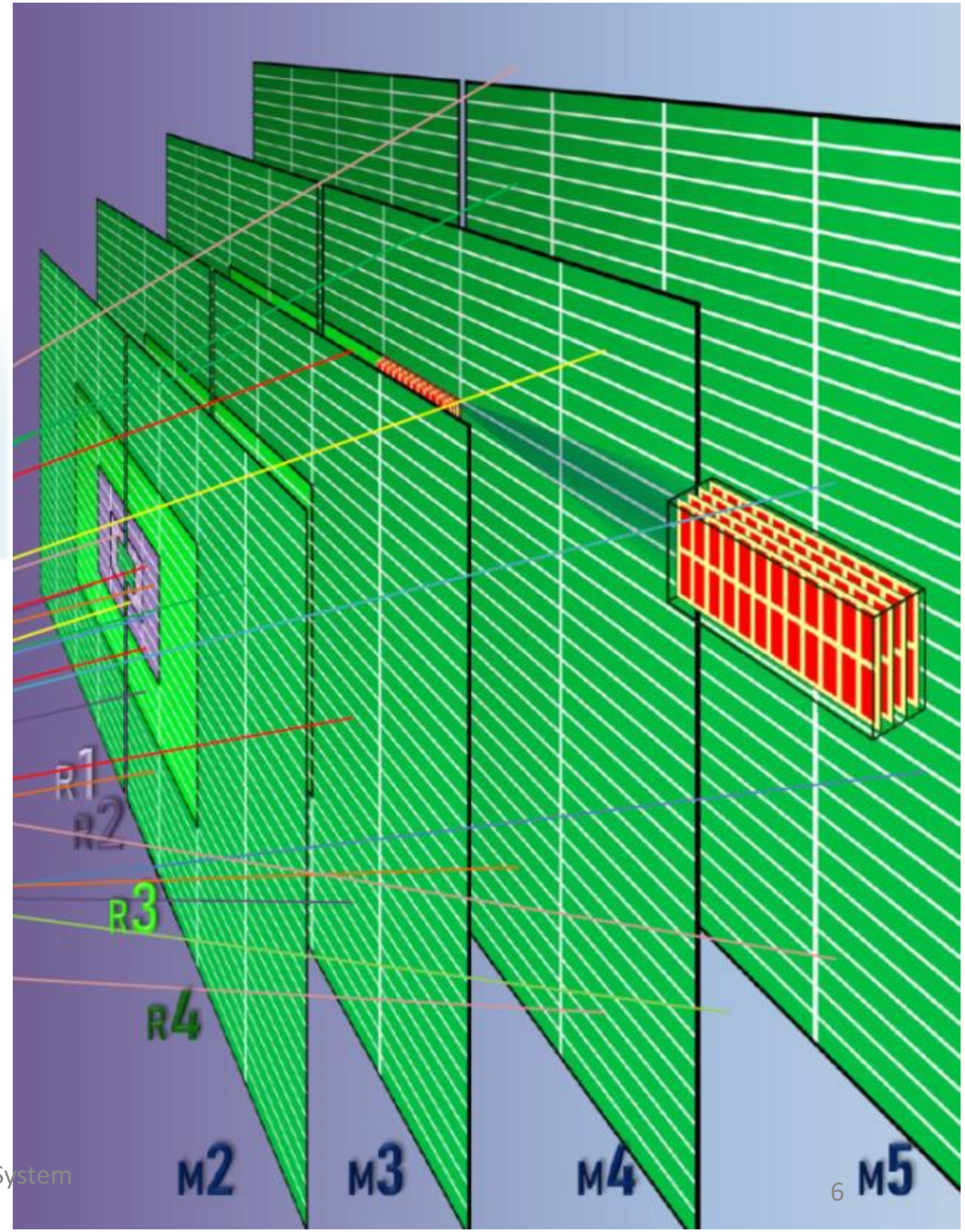
Geometrical inefficiency induced by a requirement of 2 projective pads fired out of 4 gaps is a crucial ingredient in detector design and in the readout choice



- Take muons in present simulation (any luminosity)
- Act at MC truth level (.sim), where hits simulated on the 4 chamber gaps are available
- For each station/region superimpose a mask corresponding to the chamber granularity and check measure the geometrical inefficiency
- For R1 and R2 (new detectors), optimise the inefficiency as a function of granularity

Proposal for a MC study for Upgrade 2
Matteo, Patrizia
muon software meeting, 17/02/2021

Setting the scene ……



Monte Carlo production

- Take muons in present simulation (any luminosity)

- Act at MC truth level (.sim), where hits simulated on the 4 chamber gaps are available

$J/\psi \to \mu^+\mu^-$ MC sample

Production (self)made on LNF machines

Gauss version: v55r0

- Events $J/\psi \to \mu^+\mu^-$: **216 000**

```
#importOptions("$APPCONFIGOPTS/Gauss/Beam7000GeV-md100-nu7.6-HorExtAngle.py")
importOptions('$APPCONFIGOPTS/Gauss/OneFixedInteraction.py')

#importOptions("$APPCONFIGOPTS/Gauss/EnableSpillover-25ns.py")

importOptions("$GAUSSOPTS/Gauss-Upgrade-Baseline.py")

importOptions('$DECFILESROOT/options/24142000.py’)

#geo = GaussGeo()
#geo.GeoItemsNames      += ["/dd/Structure/Infrastructure"]

importOptions("$GAUSSOPTS/DBTags-2022.py")
```

Gauss_Job

- Data sample :

  MC truth level (.sim)

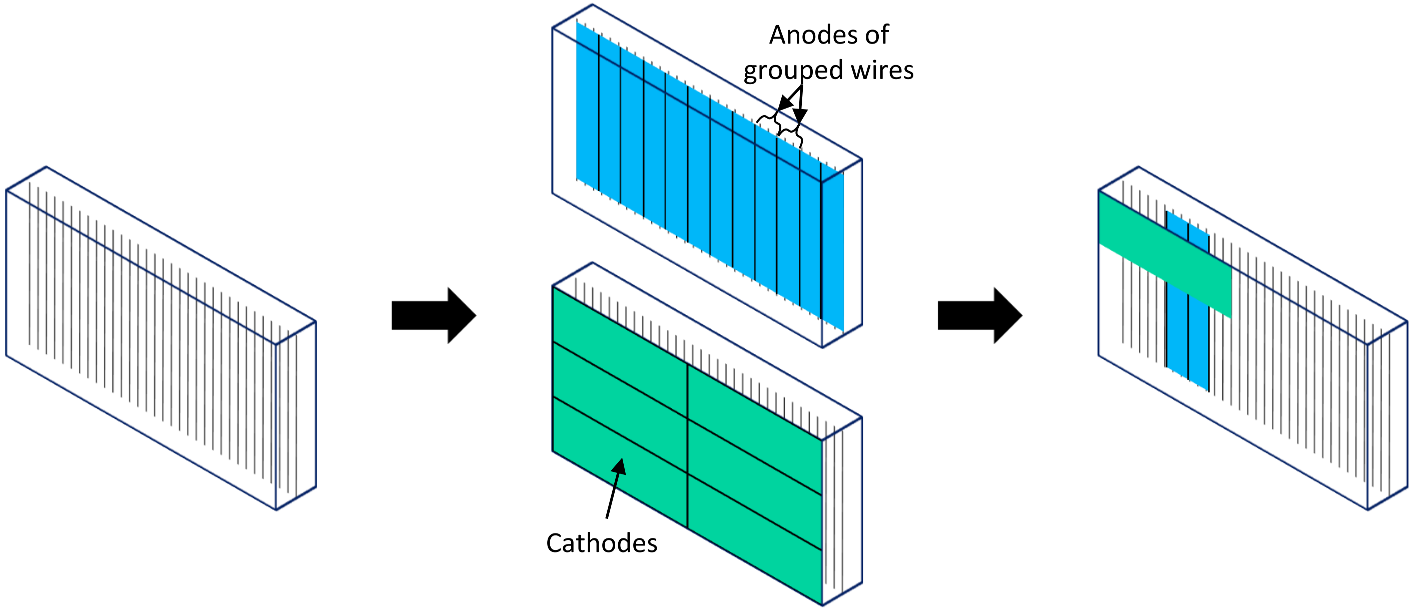
  $J/\psi \to \mu^+\mu^-$ events, with at least one $\mu^{+/-}$ (J/ψ daugther) detected by the Muon Detector with E>3GeV

MWPC granularity

- For each station/region superimpose a mask corresponding to the chamber granularity and check measure the geometrical inefficiency

MWPC - **PHYSICAL** pad granularity

$(\#x \times \#y)$	M2		M3		M4		M5	
	Anodes	**Cathodes**	**Anodes**	**Cathodes**	**Anodes**	**Cathodes**	**Anodes**	**Cathodes**
R1	48×1	8×8	48×1	8×8		12×8		12×8
R2	48×1	8×8	48×1	8×8		12×4		12×4
R3		48×2		48×2		24×2		24×2
R4	24×1		24×1		24×1		24×1	



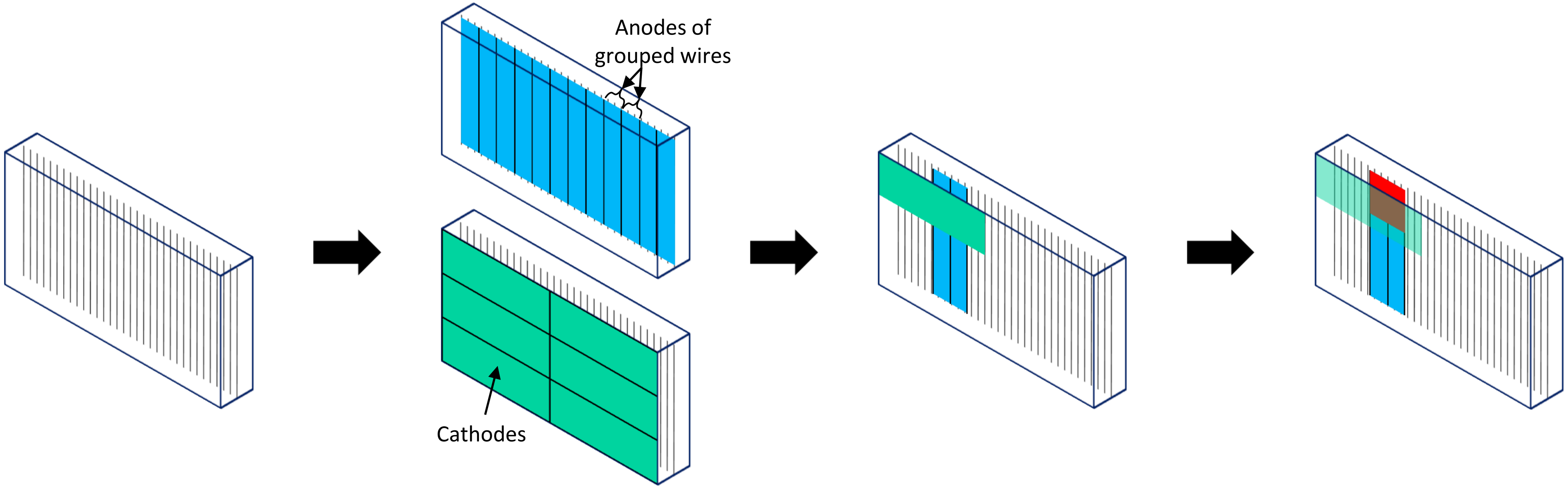
MWPC granularity

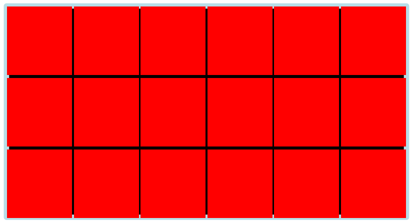
MWPC - **PHYSICAL** pad granularity

$(\#x \times \#y)$	M2		M3		M4		M5	
	Anodes	Cathodes	Anodes	Cathodes	Anodes	Cathodes	Anodes	Cathodes
R1	48×1	8×8	48×1	8×8		12×8		12×8
R2	48×1	8×8	48×1	8×8		12×4		12×4
R3		48×2		48×2		24×2		24×2
R4	24×1		24×1		24×1		24×1	

LOGICAL pad granularity

$(\#x \times \#y)$	M2	M3	M4	M5
R1	48×8	48×8	12×8	12×8
R2	48×4	48×4	12×4	12×4
R3	48×2	48×2	12×2	12×2
R4	24×1	24×1	6×1	6×1





example of generic logical pad matrix

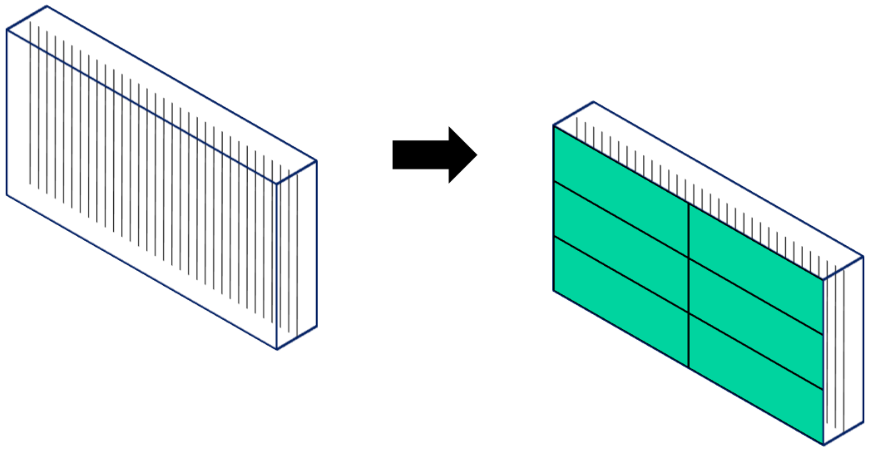
R1-R2 granularity, μRWELL option

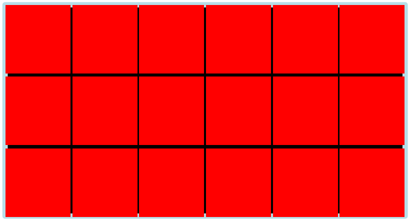
Assuming :

→ current geometrical configuration for each chamber
→ current dimensions for all gaps in a chamber

LOGICAL pad granularity

μRWELL option				
$(\#x \times \#y)$	M2	M3	M4	M5
R1	32×28	32×28	32×28	32×28
R2	64×14	64×14	64×14	64×14





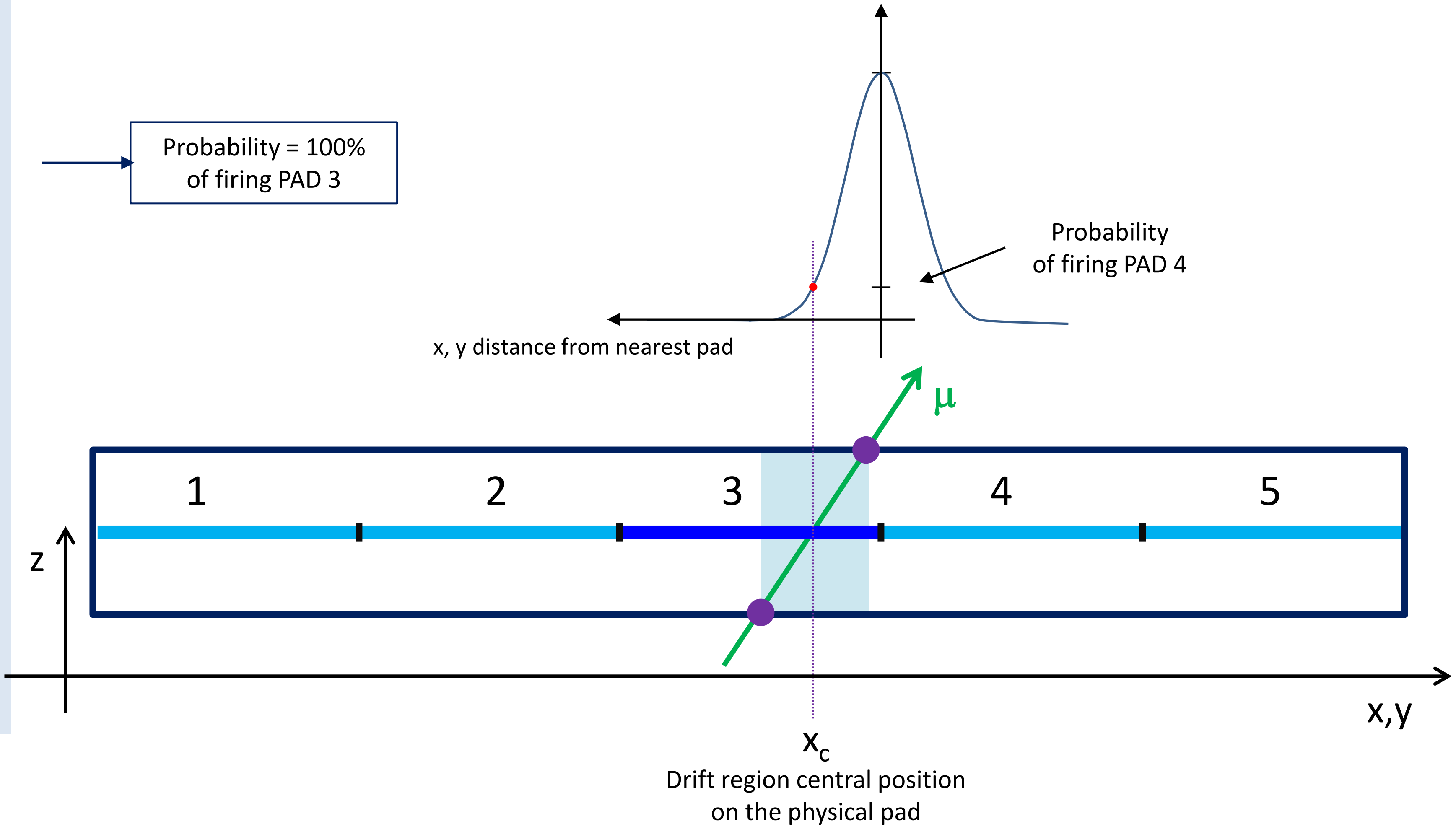
example of generic logical pad matrix

Fired physical pads

The search for fired physical pads in a gap exploits:

- Drift regions of electrons produced by the gas ionisation when a muon crosses the gap
- Electrical coupling of the **nearest** adjacent physical pad
- Parameters used for the probability crosstalk function:

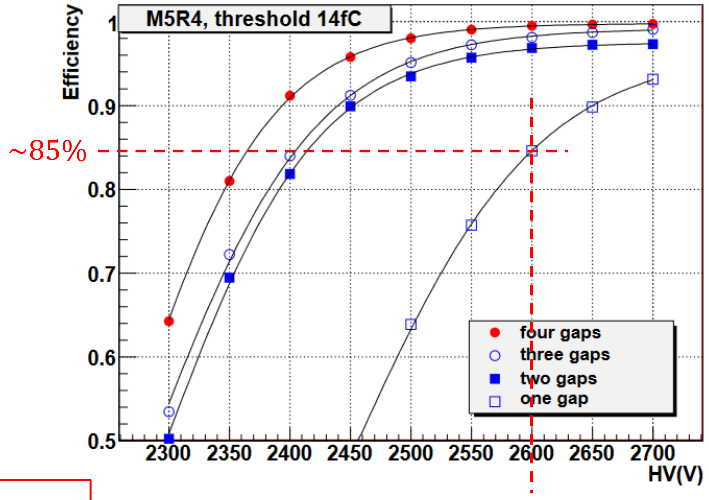
  https://gitlab.cern.ch/lhcb-conddb/SIMCOND/-/blob/master/Conditions/Muon/ReadoutConf/Modules.xml

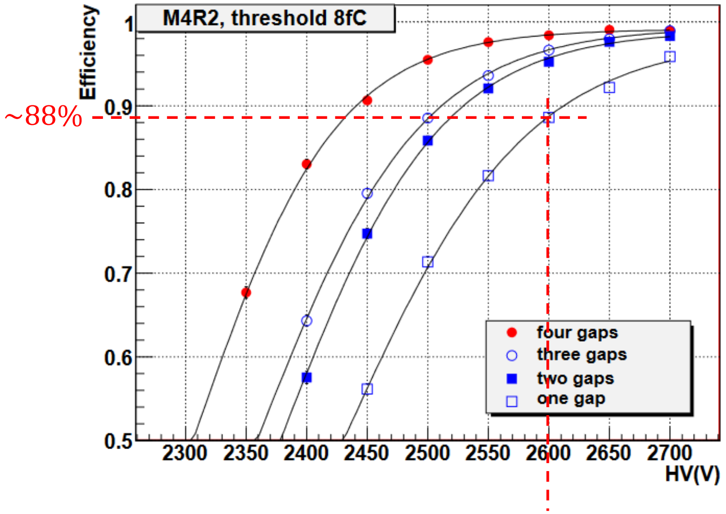


μRWELL option
assuming the same as MWPC

Single gap Time Efficiency

As preliminary evaluation,
Single gap Time Efficiency (Sg*TE*)
equal to: **85%**

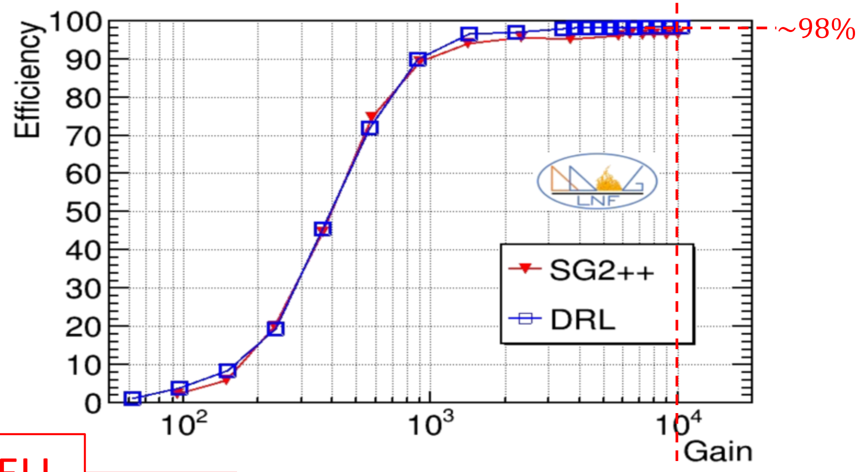




The LHCb Collaboration et al 2008 JINST 3 S08005

MWPCs

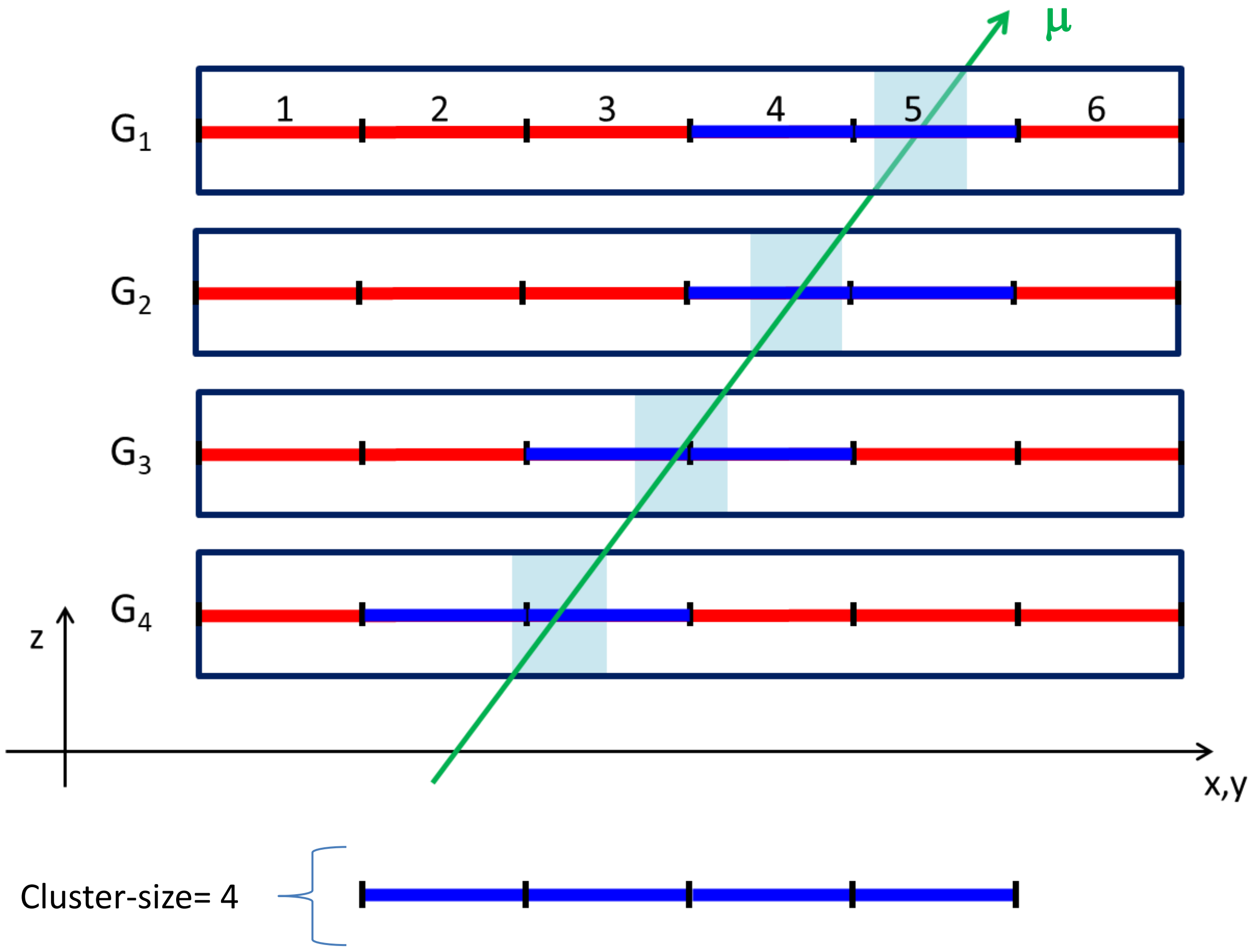
As preliminary evaluation,
Single gap Time Efficiency (Sg*TE*)
equal to: **98%**



μRWELL

Consistency check: cluster size

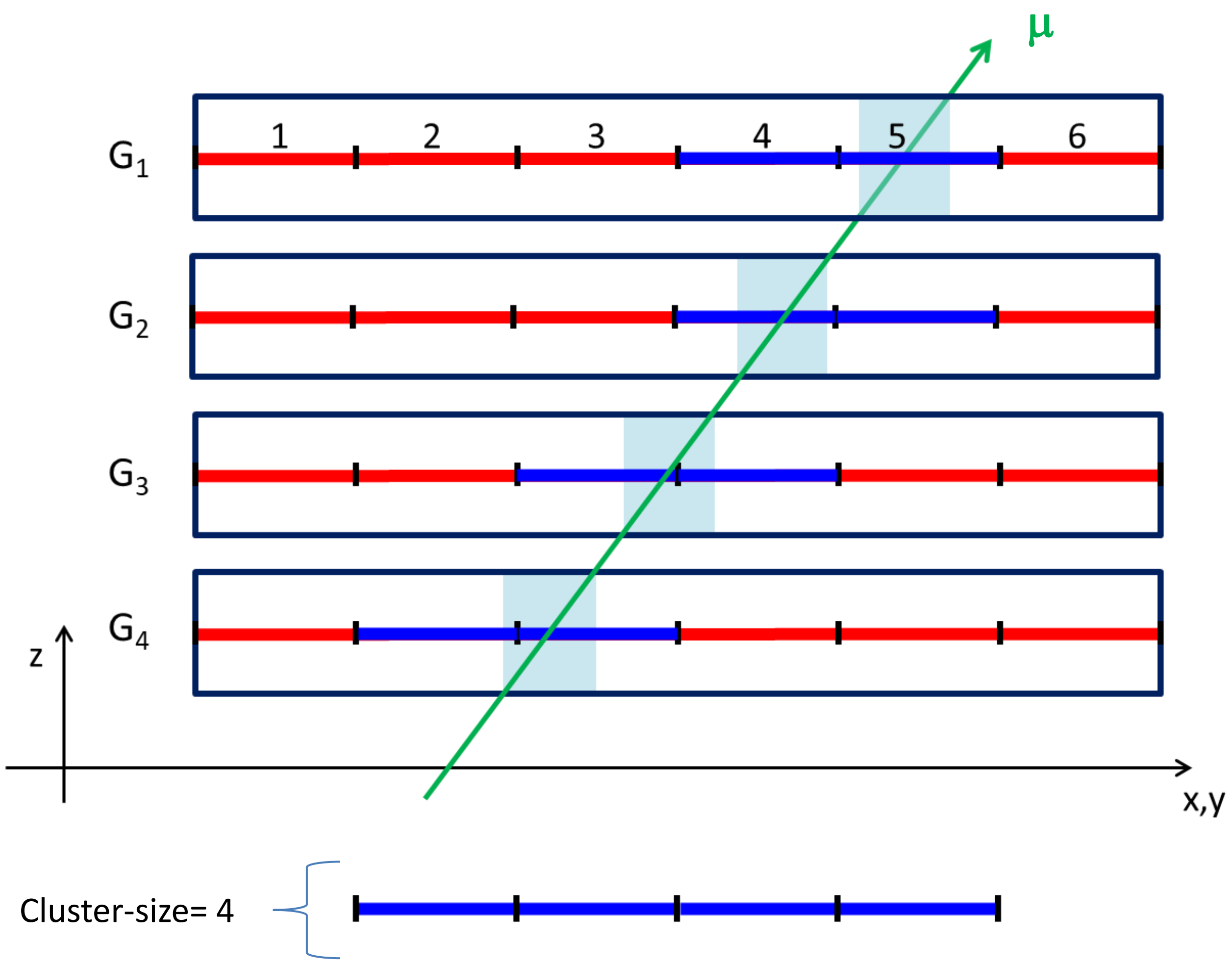
Current definition:
the number of fired adjacent **logical** pads obtained with the 4-gaps ORed.



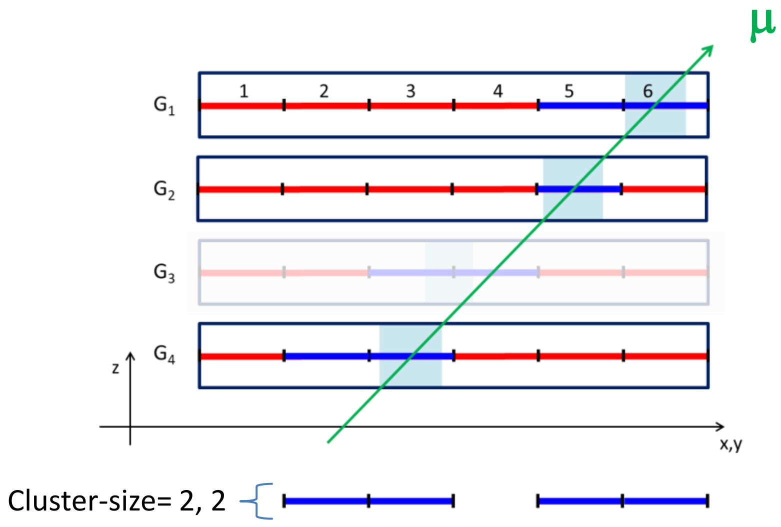
Cluster of fired logical pads seen by the electronics.

Consistency check: cluster size

Current definition:
the number of fired adjacent **logical** pads obtained with the 4-gaps ORed.



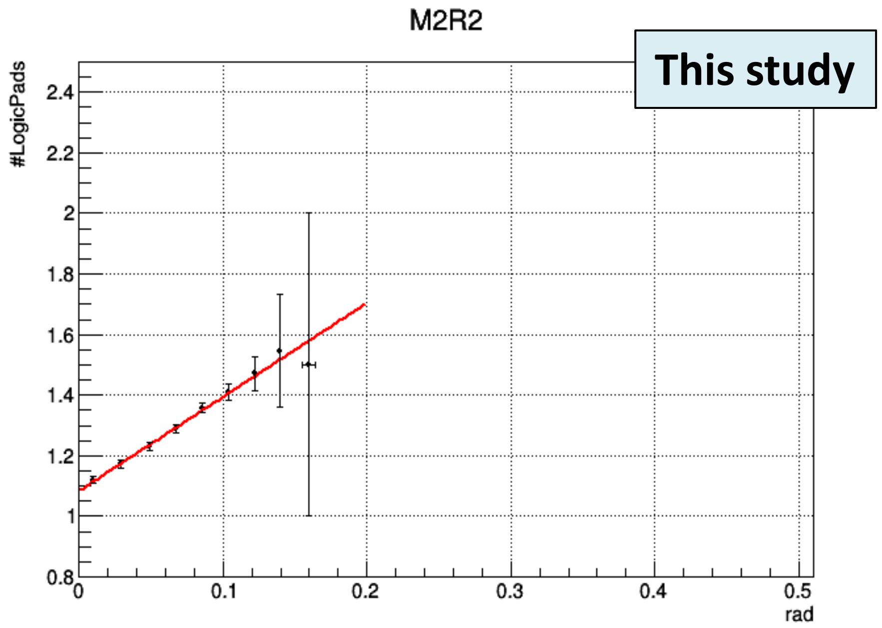
Cluster of fired logical pads seen by the electronics.

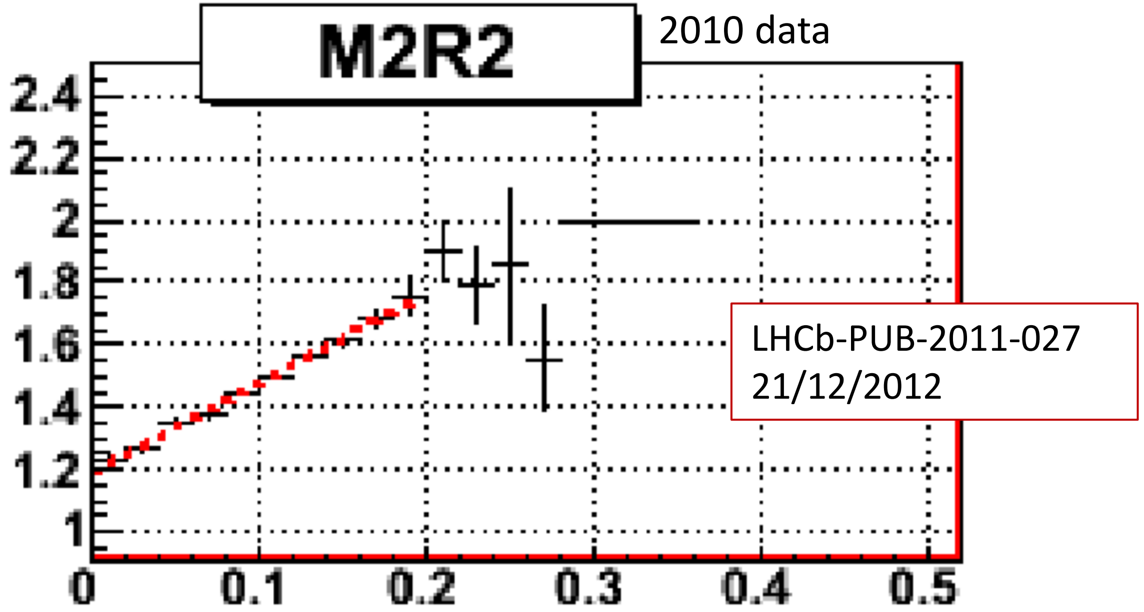


Muon cluster size vs <θ>

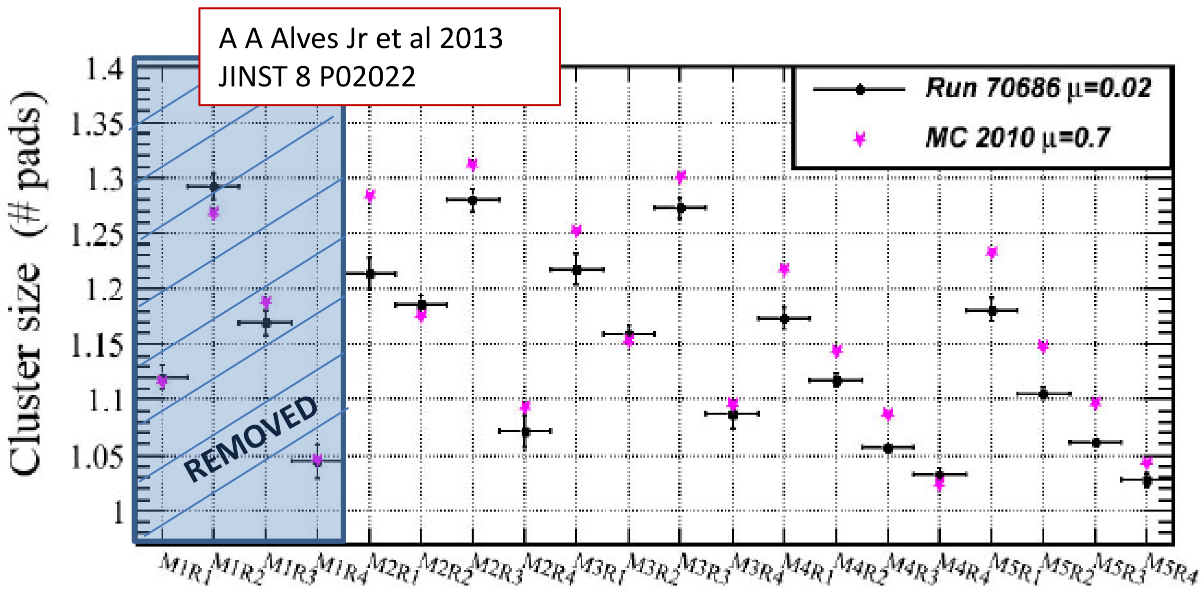
For each region of each station, the simulated muon average cluster size dependency on its mean angle (xz plane) has been evaluated and compared with previous results (Run1 data).

- Muons daughter of J/ψ
- $E_{\mu} > 10\ GeV$
- Cluster-size < 5

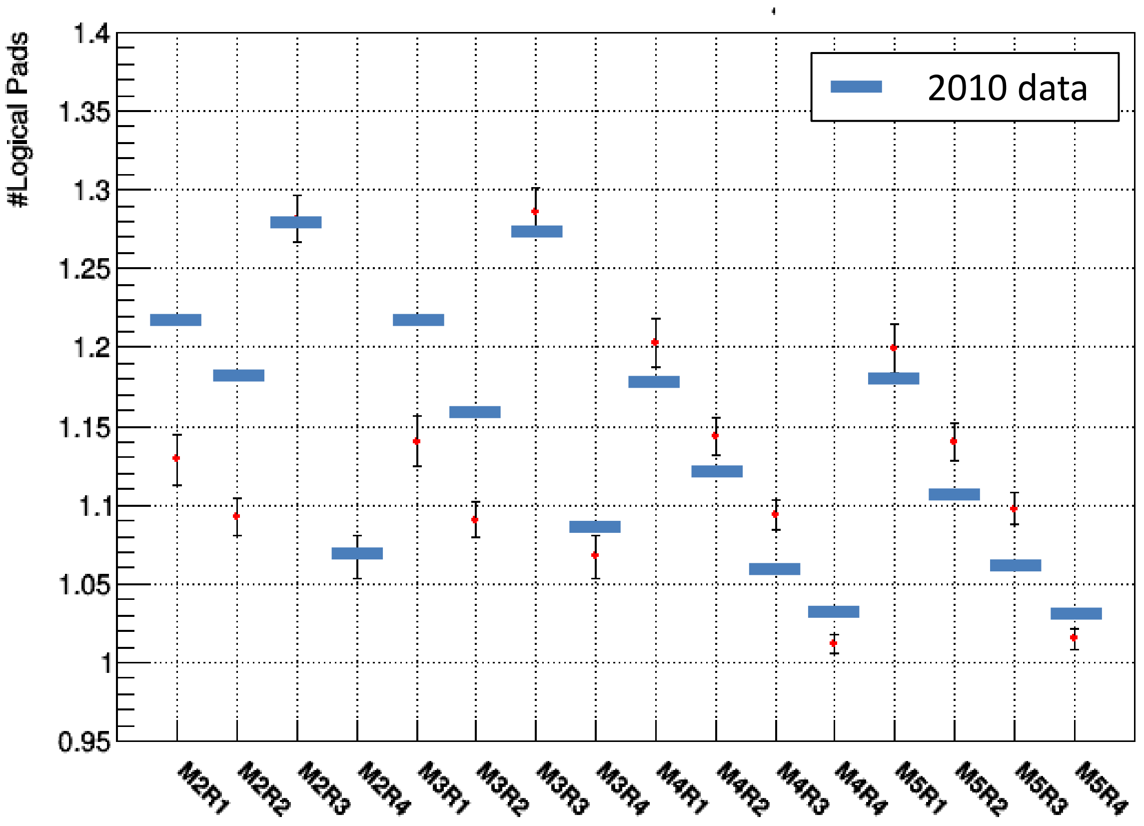




Average μ cluster size comparison



$SgTE = 100\%$



For the measurement of particle rates, cluster size and time resolution, events triggered by some minimum bias condition, independently of the muon detector response, were used:

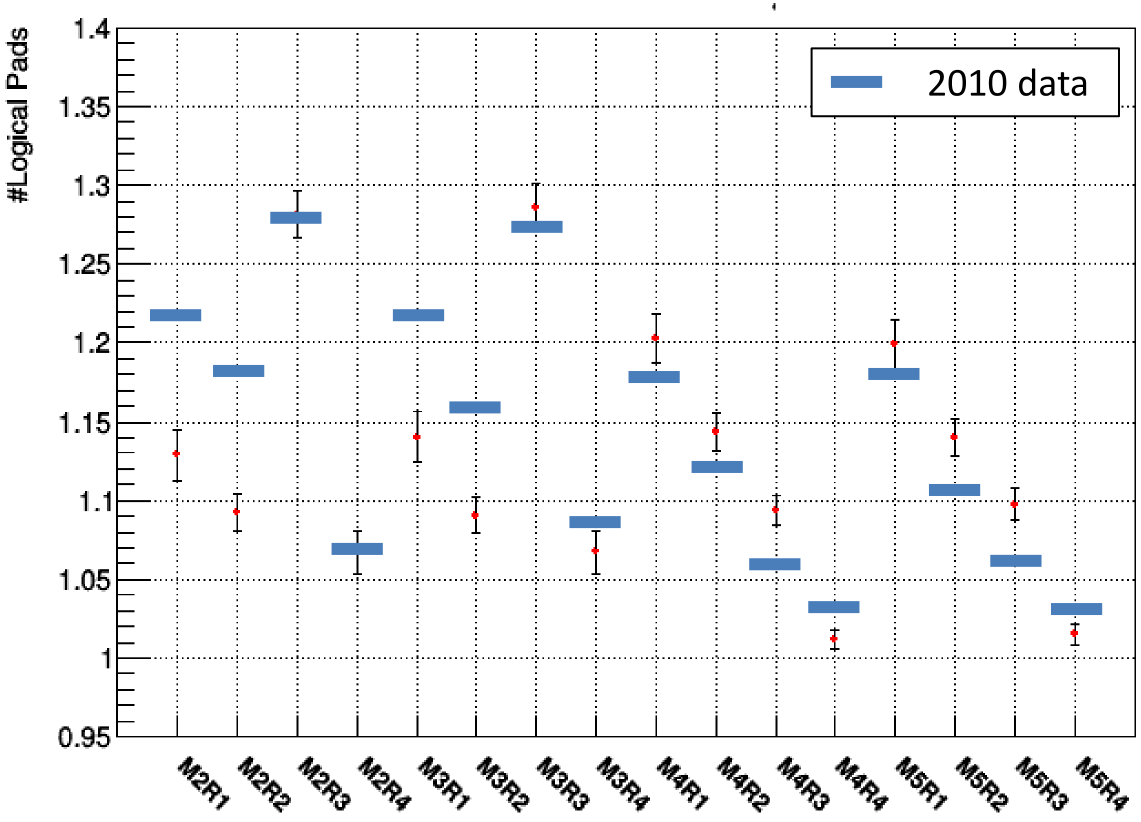
- minimum bias trigger (L0MB), requiring the total energy released in the HCAL to be more than 320 MeV;
- "microbias" single track trigger (microbias), requiring some hits compatible with a track in the VELO or first tracking stations.

• $J/\psi \rightarrow \mu^+\mu^-$ MC sample

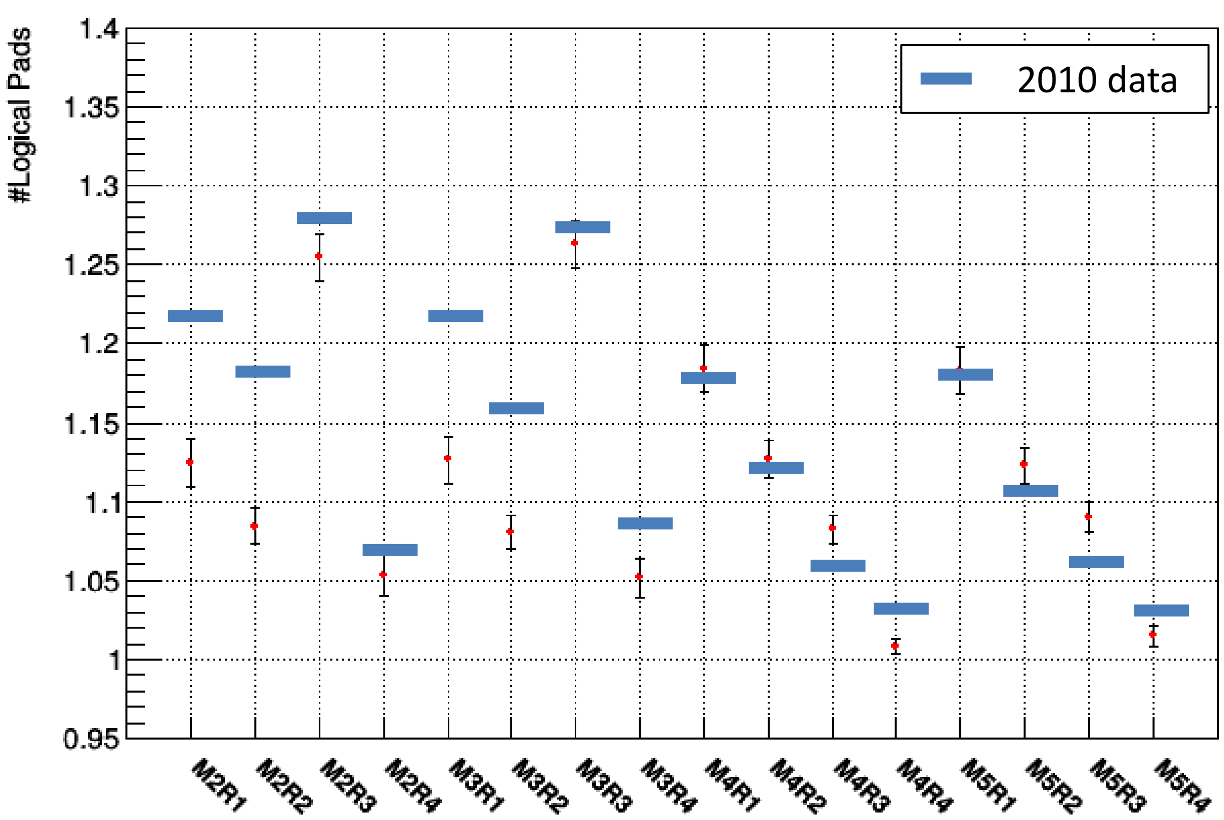
Average μ cluster size comparison

• $J/\psi \rightarrow \mu^+\mu^-$ MC sample

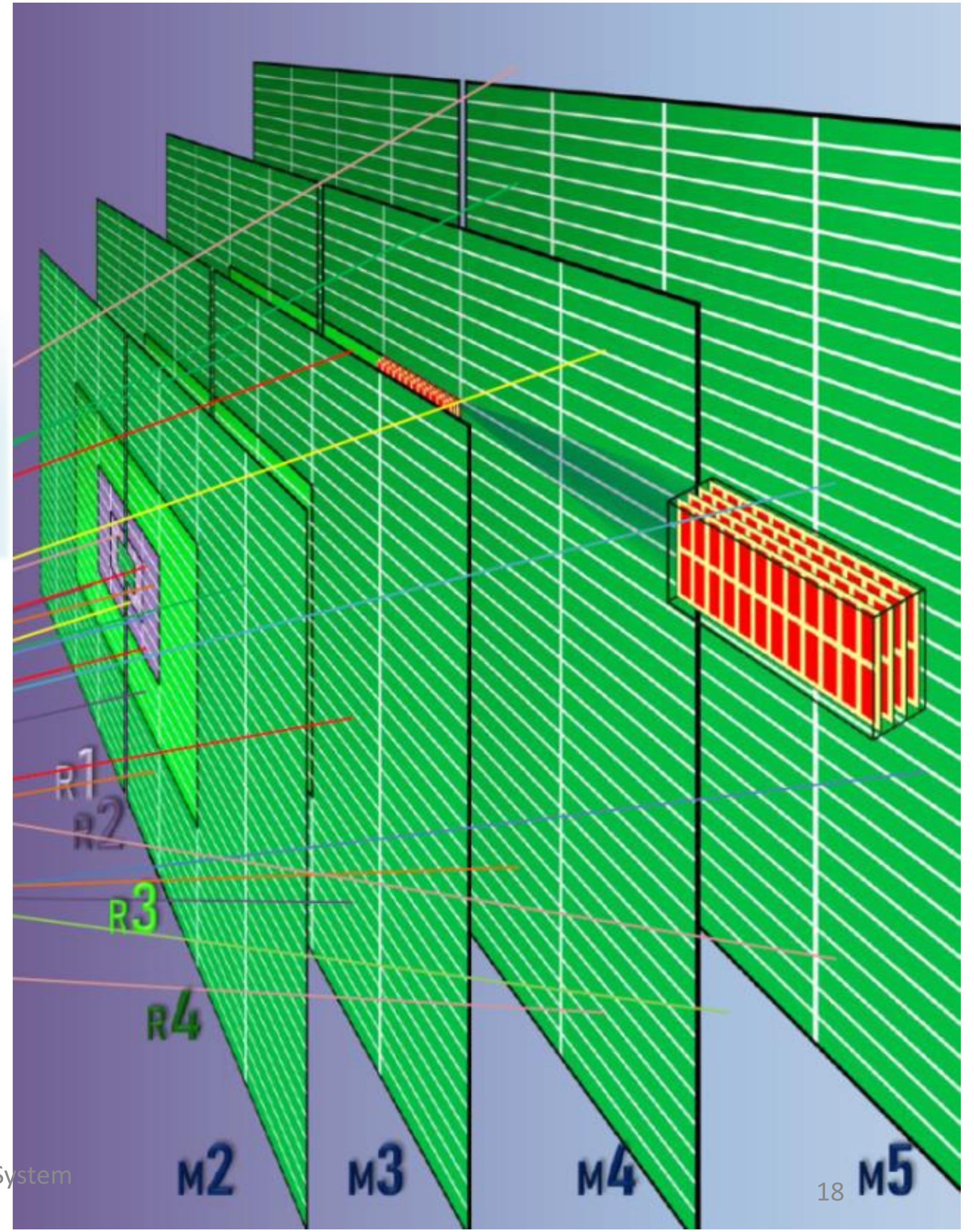
$\mathbf{SgTE = 100\%}$



$\mathbf{SgTE = 85\%}$



μ identification and the new RO scheme



Current μ identification requirements

p [GeV/c]	Required stations	
	IsMuon	IsMuonLoose
$p < 3$	*Always false*	*Always false*
$p < 6$	M2 & M3	At least two of M2–M4
$6 < p < 10$	M2 & M3 & (M4 || M5)	At least three of M2–M5
$p > 10$	M2 & M3 & M4 & M5	At least three of M2–M5

Different identification variables can be constructed…The first identification variable is a boolean decision, called **IsMuon**, obtained from the extrapolation of a long or a downstream track through the muon stations, making a statement about whether a track is consistent with a muon hypothesis.

Optimization of the muon reconstruction algorithms for LHCb Run 2

LHCb-PUB-2017-007 (21/02/2017)

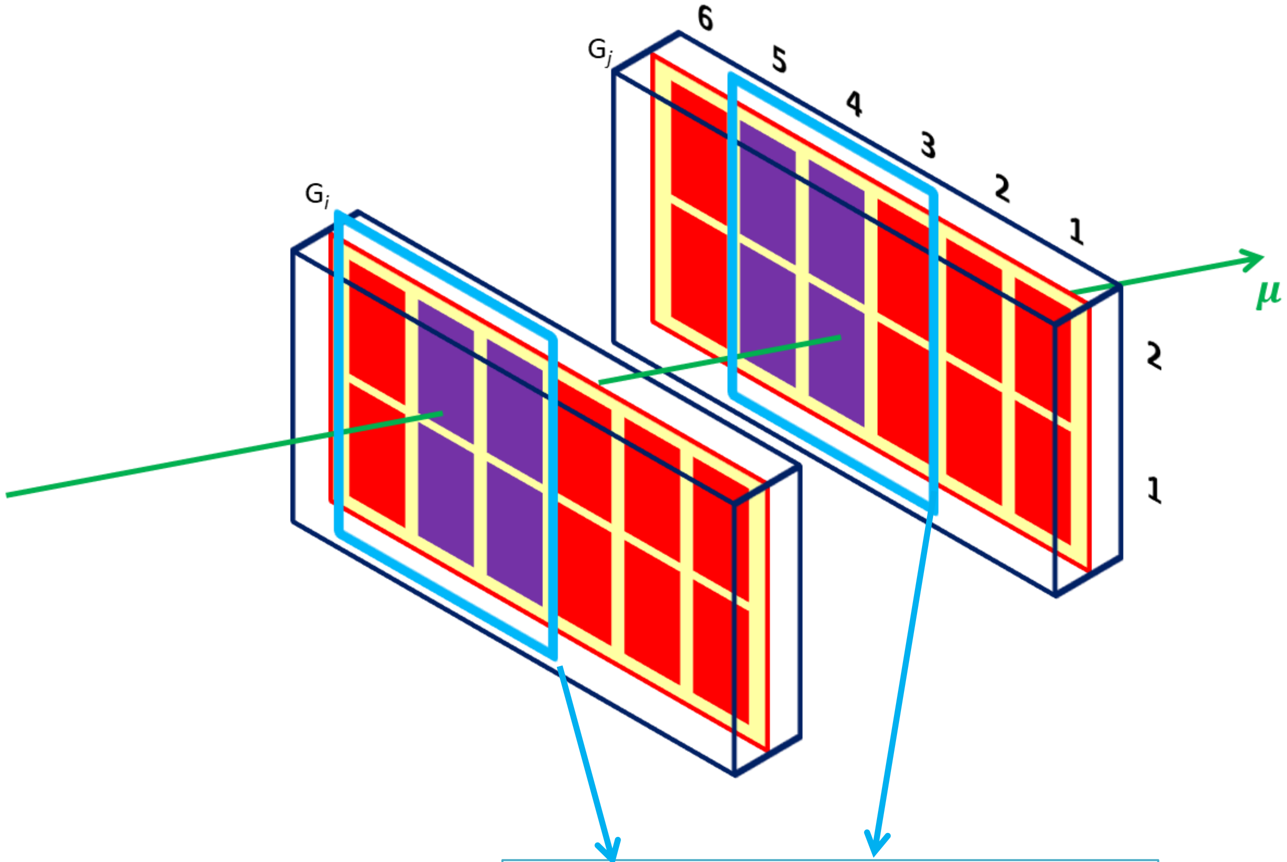
μ identification with the new RO scheme

New proposal:

→ <u>each gap is read-out separately</u>, requiring :

1. signal in at least 2 gaps out of 4 in a chamber
2. at least two projective logical pads fired in the two gaps

Projectivity NOT to be requested in M234-R4 where the 2 bi-gaps are physically ORed



- logical pads that could be fired
- violet pads are projective to each other

Geometrical inefficiency of the new RO scheme

µRWELL (*SgTE* = 98%) +
present MWPCs (*SgTE* = 85%)

Muons crossing R1R2 with respect to muons crossing all R1R2R3R4 regions

$3\ \mathrm{GeV/c} < p_{\mu} < 6\ \mathrm{GeV/c}$ (M2 & M3)

		R1 || R2		R3 || R4	R3	R4
INEFFICIENCY	-1.10% ± 0.08%	-1.66% ± 0.34%	(7.8%)	-1.07% ± 0.08%	-4.20% ± 0.30%	//
		≈ -0.1%		≈ -1%		

$6\ \mathrm{GeV/c} < p_{\mu} < 10\ \mathrm{GeV/c}$ (M2 & M3 & (M4 \|\| M5))

		R1 || R2		R3 || R4	R3	R4
INEFFICIENCY	-1.07% ± 0.06%	-0.63% ± 0.15%	(10.0%)	-1.12% ± 0.07%	-3.87% ± 0.22%	-0.01% ± 0.01%
		≈ -0.07%		≈ -1%		

$p_{\mu} > 10\ \mathrm{GeV/c}$ (M2 & M3 & M4 & M5)

		R1 || R2		R3 || R4	R3	R4
INEFFICIENCY	-2.00% ± 0.04%	-0.28% ± 0.02%	(50.1%)	-3.83% ± 0.08%	-5.52% ± 0.12%	-1.51% ± 0.08%
		≈ -0.1%		≈ -1.9%		

Exploring the impact of projectivity in M234R4 (projectivity only)

µRWELL (*SgTE* = 100%) +
present MWPCs (*SgTE* = 100%)

Muons crossing R1R2 with respect to muons crossing all R1R2R3R4 regions

Only one bigap fired at MC level: projectivity can't be requested (muons at edges)

Projectivity equivalent to only two adjacent gaps

$3\ \mathrm{GeV/c} < p_\mu < 6\ \mathrm{GeV/c}$ (M2 & M3)

		R1 || R2		R3 || R4	R3	R4	
INEFFICIENCY	-6.47% ±0.18%	-1.51% ±0.32%	(7.8%)	-6.96% ±0.19%	-1.05% ±0.16%	-9.25% ±0.25%	2.71% + 6.54%
		≈ -0.1%		≈-6.4%			

$6\ \mathrm{GeV/c} < p_\mu < 10\ \mathrm{GeV/c}$ (M2 & M3 & (M4 || M5))

		R1 || R2		R3 || R4	R3	R4	
INEFFICIENCY	-4.89% ±0.13%	-0.59% ±0.15%	(10.0%)	-5.45% ±0.14%	-0.67% ±0.10%	-7.82% ±0.20%	2.34% + 5.48%
		≈ -0.1%		≈-4.8%			

$p_\mu > 10\ \mathrm{GeV/c}$ (M2 & M3 & M4 & M5)

		R1 || R2		R3 || R4	R3	R4	
INEFFICIENCY	-1.53% ±0.03%	-0.26% ±0.02%	(50.1%)	-2.94% ±0.07%	-0.44% ±0.03%	-7.02% ±0.15%	1.77% + 5.25%
		≈ -0.1%		≈ -1.4%			

Exploring the impact of projectivity in M234R4

μRWELL (*SgTE* = 98%) + present MWPCs (*SgTE* = 85%)

Muons crossing R1R2 with respect to muons crossing all R1R2R3R4 regions

Only one bigap fired at MC level: projectivity can't be requested (muons at edges)

Projectivity equivalent to only two adjacent gaps

$3\ \mathrm{GeV/c} < p_\mu < 6\ \mathrm{GeV/c}$ (M2 & M3)							
		R1 || R2		R3 || R4	R3	R4	
INEFFICIENCY	-14.02% ±0.24%	-1.66% ±0.34%	(7.8%)	-15.23% ±0.26%	-4.20% ±0.30%	-19.33% ±0.32%	10.32% + 9.01%
		≈ -0.1%		≈-13.9%			

$6\ \mathrm{GeV/c} < p_\mu < 10\ \mathrm{GeV/c}$ (M2 & M3 & (M4 || M5))							
		R1 || R2		R3 || R4	R3	R4	
INEFFICIENCY	-12.31% ±0.19%	-0.63% ±0.15%	(10.0%)	-13.77% ±0.20%	-3.87% ±0.22%	-18.39% ±0.27%	11.26% + 7.13%
		≈ -0.1%		≈-12.2%			

$p_\mu > 10\ \mathrm{GeV/c}$ (M2 & M3 & M4 & M5)							
		R1 || R2		R3 || R4	R3	R4	
INEFFICIENCY	-6.04% ±0.06%	-0.28% ±0.02%	(50.1%)	-12.01% ±0.12%	-5.52% ±0.12%	-21.99% ±0.23%	14.33% + 7.66%
		≈ -0.1%		≈ -5.9%			

Conclusion and Outlooks

- Intense work to explore potentialities and drawbacks of the proposed new read-out scheme for the Muon Detector at U2
- Simulation analysis framework set up successfully from scratch
- First comparison with RunI-II data validate the analysis framework itself
- First evaluation of the Muon ID geometrical inefficiency with the new RO scheme shows encouraging results and exclude AND of bi-gap for M234R4
- Now looking at (2015) data, and at a low threshold minimum bias on-going MC production, to study f_c coefficient

backup

Single gap time inefficiency

A preliminary evaluation has been done, considering the

tiTh ≡ time inefficiency Threshold = 10%, 20%

- Present pads configuration
- µRWELL options

MC muon TRACK		Filtered muon TRACK
(St, Rg, Ch, Gp)		(St, Rg, Ch, Gp)
(2, 4, 117, 4)	->	(2, 4, 117, 4)
(2, 4, 117, 3)	->	(2, 4, 117, 3)
(2, 4, 117, 2)	->	(2, 4, 117, 2)
(2, 4, 117, 1)	->	(2, 4, 117, 1)
(3, 4, 117, 4)	->	(3, 4, 117, 4)
(3, 4, 117, 3)	→ *if (random->Uniform() > **tiTh**)* save gap *else* delete gap	(3, 4, 117, 3)
(3, 4, 117, 2)	->	deleted
(3, 4, 117, 1)	->	(3, 4, 117, 1)
(4, 4, 117, 4)	->	deleted
(4, 4, 117, 3)	->	deleted
(4, 4, 117, 2)	->	(4, 4, 117, 2)
(4, 4, 117, 1)	->	(4, 4, 117, 1)

Analised

Geometrical inefficiency of the new RO scheme *(detailed)*

Muons crossing R1R2 with respect to muons crossing all R1R2R3R4 regions

present MWPCs (*SgTE*= 85%)

$3\ \mathrm{GeV/c} < p_\mu < 6\ \mathrm{GeV/c}$ (M2 & M3)					
	R1 || R2		R3 || R4	R3	R4
MC truth	1387	(7.8%)	16469	4171	11980
NO projectivity	1387		16469	4171	11980
YES projectivity	1304		16295	3998	11980
INEFFICIENCY	-5.98% ± 0.62%		-1.06% ± 0.08%	-4.15% ± 0.30%	//

$6\ \mathrm{GeV/c} < p_\mu < 10\ \mathrm{GeV/c}$ (M2 & M3 & (M4 || M5))					
	R1 || R2		R3 || R4	R3	R4
MC truth	2703	(10.0%)	24455	7149	16779
NO projectivity	2703		24455	7149	16779
YES projectivity	2578		24183	6878	16778
INEFFICIENCY	-4.62% ± 0.39%		-1.11% ± 0.07%	-3.79% ± 0.22%	-0.01% ± 0.01%

$p_\mu > 10\ \mathrm{GeV/c}$ (M2 & M3 & M4 & M5)					
	R1 || R2		R3 || R4	R3	R4
MC truth	65273	(50.1%)	64919	38261	25732
NO projectivity	65273		64918	38260	25732
YES projectivity	61488		62422	36136	25345
INEFFICIENCY	-5.80% ± 0.09%		-3.84% ± 0.08%	-5.55% ± 0.12%	-1.50% ± 0.08%

μRWELL (*SgTE* = 98%) + present MWPCs (*SgTE* = 85%)

$3\ \mathrm{GeV/c} < p_\mu < 6\ \mathrm{GeV/c}$ (M2 & M3)					
	R1 || R2		R3 || R4	R3	R4
MC truth	1389	(7.8%)	16469	4171	11980
NO projectivity	1389		16469	4171	11980
YES projectivity	1366		16293	3996	11980
INEFFICIENCY	-1.66% ± 0.34%		-1.07% ± 0.08%	-4.20% ± 0.30%	//

$6\ \mathrm{GeV/c} < p_\mu < 10\ \mathrm{GeV/c}$ (M2 & M3 & (M4 || M5))					
	R1 || R2		R3 || R4	R3	R4
MC truth	2711	(10.0%)	24455	7149	16779
NO projectivity	2711		24455	7149	16779
YES projectivity	2694		24180	6872	16778
INEFFICIENCY	-0.63% ± 0.15%		-1.12% ± 0.07%	-3.87% ± 0.22%	-0.01% ± 0.01%

$p_\mu > 10\ \mathrm{GeV/c}$ (M2 & M3 & M4 & M5)					
	R1 || R2		R3 || R4	R3	R4
MC truth	65407	(50.2%)	64919	38261	25732
NO projectivity	65407		64918	38260	25732
YES projectivity	65221		62433	36149	25344
INEFFICIENCY	-0.28% ± 0.02%		-3.83% ± 0.08%	-5.52% ± 0.12%	-1.51% ± 0.08%

Exploring the impact of projectivity in M234R4 (projectivity only, detailed)

µRWELL (*SgTE* = 100%) + present MWPCs (*SgTE* = 100%)

Muons crossing R1R2 with respect to muons crossing all R1R2R3R4 regions

Only one bigap fired at MC level: projectivity can't be requested (muons at edges)

Projectivity equivalent to only two adjacent gaps

$3\ \mathrm{GeV/c} < p_\mu < 6\ \mathrm{GeV/c}$ (M2 & M3)

		R1 || R2		R3 || R4	R3	R4	
NO projectivity	18094	1391	(7.8%)	16507	4180	12014	
YES projectivity	16924	1370		15358	4136	10903	
INEFFICIENCY	-6.47% ±0.18%	-1.51% ±0.32%		-6.96% ±0.19%	-1.05% ±0.16%	-9.25% ±0.25%	2.71% + 6.54%
		≈ -0.1%		≈-6.4%			

$6\ \mathrm{GeV/c} < p_\mu < 10\ \mathrm{GeV/c}$ (M2 & M3 & (M4 || M5))

		R1 || R2		R3 || R4	R3	R4	
NO projectivity	27531	2711	(10.0%)	24499	7159	16815	
YES projectivity	26185	2695		23163	7111	15500	
INEFFICIENCY	-4.89% ±0.13%	-0.59% ±0.15%		-5.45% ±0.14%	-0.67% ±0.10%	-7.82% ±0.20%	2.34% + 5.48%
		≈ -0.1%		≈-4.8%			

$p_\mu > 10\ \mathrm{GeV/c}$ (M2 & M3 & M4 & M5)

		R1 || R2		R3 || R4	R3	R4	
NO projectivity	131978	65408	(50.1%)	65102	38373	25813	
YES projectivity	129956	65236		63190	38205	24000	
INEFFICIENCY	-1.53% ±0.03%	-0.26% ±0.02%		-2.94% ±0.07%	-0.44% ±0.03%	-7.02% ±0.15%	1.77% + 5.25%
		≈ -0.1%		≈ -1.4%			

Exploring the impact of projectivity in M234R4 *(detailed)*

μRWELL (*SgTE* = 98%) + present MWPCs (*SgTE* = 85%)

Muons crossing R1R2 with respect to muons crossing all R1R2R3R4 regions

$3\ \mathrm{GeV/c} < p_\mu < 6\ \mathrm{GeV/c}$ (M2 & M3)

		R1 || R2		R3 || R4	R3	R4	
NO projectivity	18052	1389	(7.8%)	16469	4171	11980	
YES projectivity	15522	1366		13961	3996	9664	
INEFFICIENCY	-14.02% ±0.24%	-1.66% ±0.34%		-15.23% ±0.26%	-4.20% ±0.30%	-19.33% ±0.32%	10.32% + 9.01%
		≈ -0.1%		≈-13.9%			

$6\ \mathrm{GeV/c} < p_\mu < 10\ \mathrm{GeV/c}$ (M2 & M3 & (M4 || M5))

		R1 || R2		R3 || R4	R3	R4	
NO projectivity	27487	2711	(10.0%)	24455	7149	16779	
YES projectivity	24102	2694		21088	6872	13693	
INEFFICIENCY	-12.31% ±0.19%	-0.63% ±0.15%		-13.77% ±0.20%	-3.87% ±0.22%	-18.39% ±0.27%	11.26% + 7.13%
		≈ -0.1%		≈-12.2%			

$p_\mu > 10\ \mathrm{GeV/c}$ (M2 & M3 & M4 & M5)

		R1 || R2		R3 || R4	R3	R4	
NO projectivity	131801	65407	(50.1%)	64919	38261	25732	
YES projectivity	123841	65221		57121	36149	20074	
INEFFICIENCY	-6.04% ±0.06%	-0.28% ±0.02%		-12.01% ±0.12%	-5.52% ±0.12%	-21.99% ±0.23%	14.33% + 7.66%
		≈ -0.1%		≈ -5.9%			

Only one bigap fired at MC level: projectivity can't be requested (muons at edges)

Projectivity equivalent to only two adjacent gaps