



Irfu - CEA Saclay

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Performances of large Pixelized Micromegas detectors in the COMPASS environment

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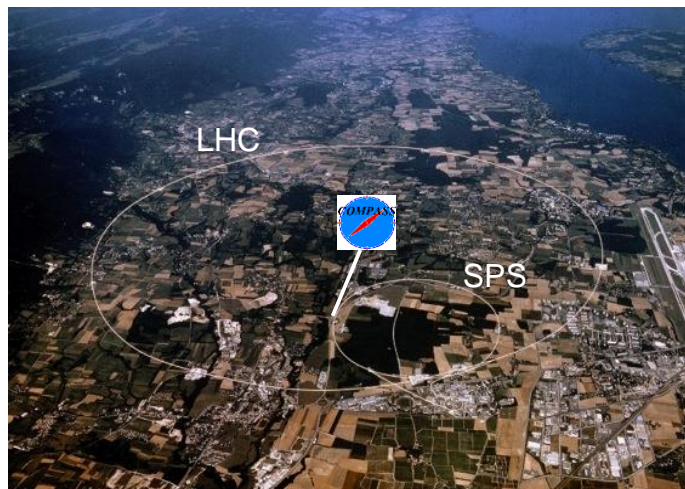
MPGD 2013 Conference

July 1st 2013

Zaragoza

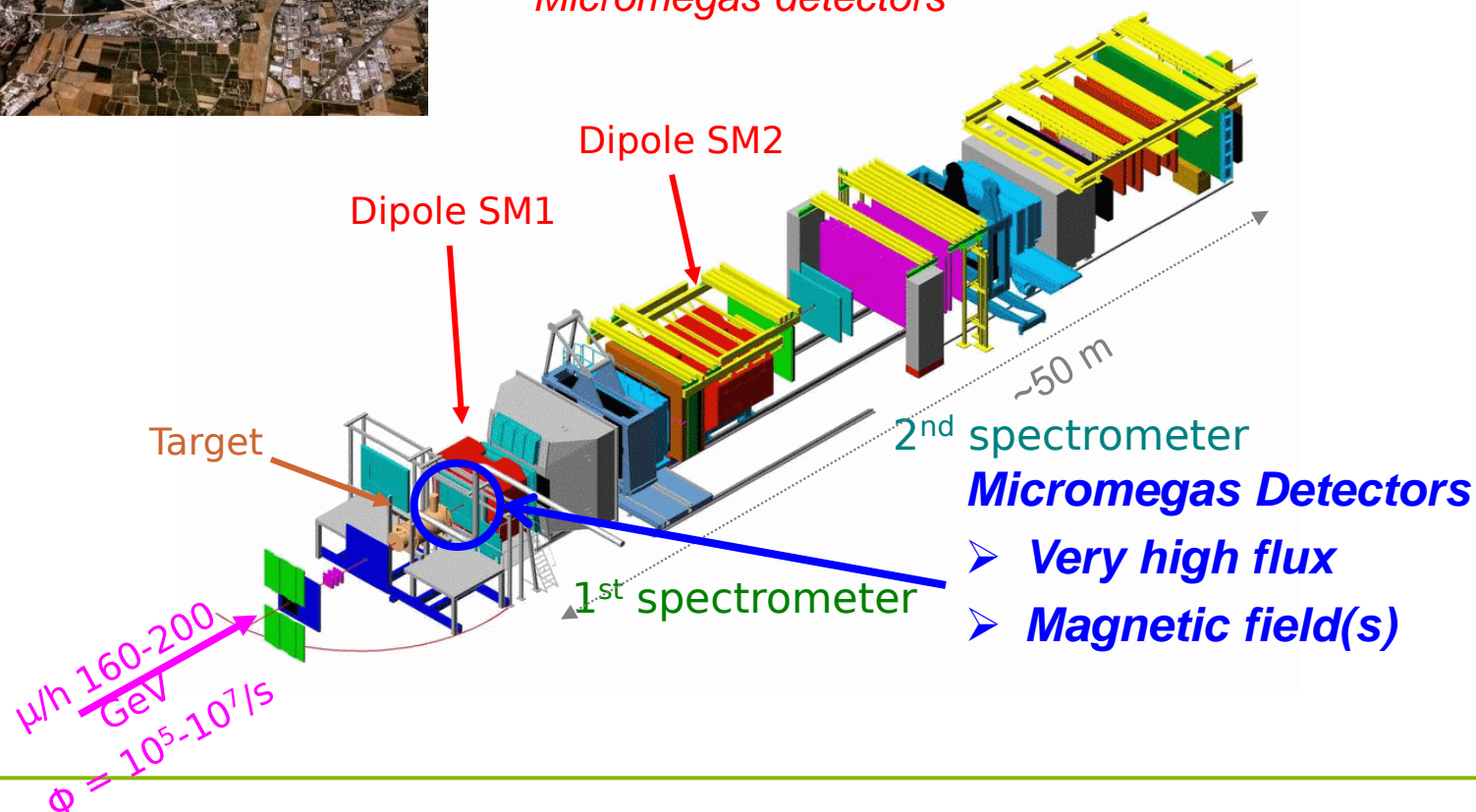
- The COMPASS Experiment at CERN
- The Pixel Micromegas Detector
 - Motivations
 - Discharge reduction technologies
 - Large size detectors readout
 - Front-end electronics
- Performance of Pixel Micromegas in the COMPASS spectrometer
 - Discharge rate
 - Efficiency
 - Spatial resolution
 - Time resolution
- Pixel Micromegas and track reconstruction
- Conclusion
- Outlook

The COMPASS experiment at CERN



COmmun **MU**on **P**roton **A**pparatus for **S**tructure and **S**pectroscopy

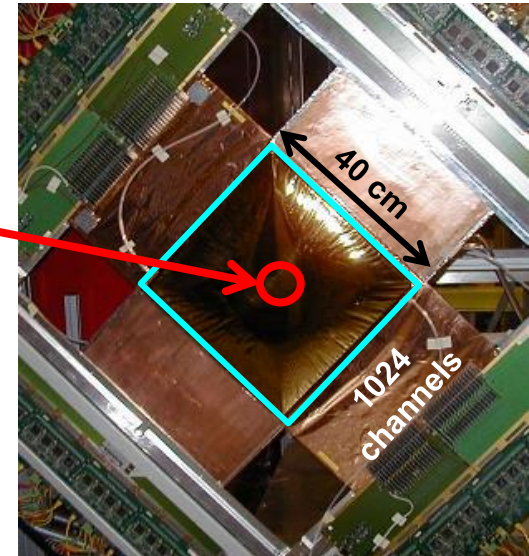
- High resolution spectrometer
- Very good spatial resolution ($<100\mu\text{m}$) required at small angle for kinematics and particle identification
- One of the first experiments to use GEM and Micromegas detectors



The Pixel Micromegas Project : motivations

- Present COMPASS Micromegas detectors : good performances but room for improvements :
 - *Blind center (5 cm diameter disk, beam area)*
 - *Discharges in hadron beam (0.1 discharge/s)*

- COMPASS II plans for 2015 :
 - Hadron beam up to 10^7 hadrons/s
 - *Need for a spark protected detector*
 - Better tracking in the beam area
 - *Need for a detector with active center*



■ ***Pixel Micromegas Project***

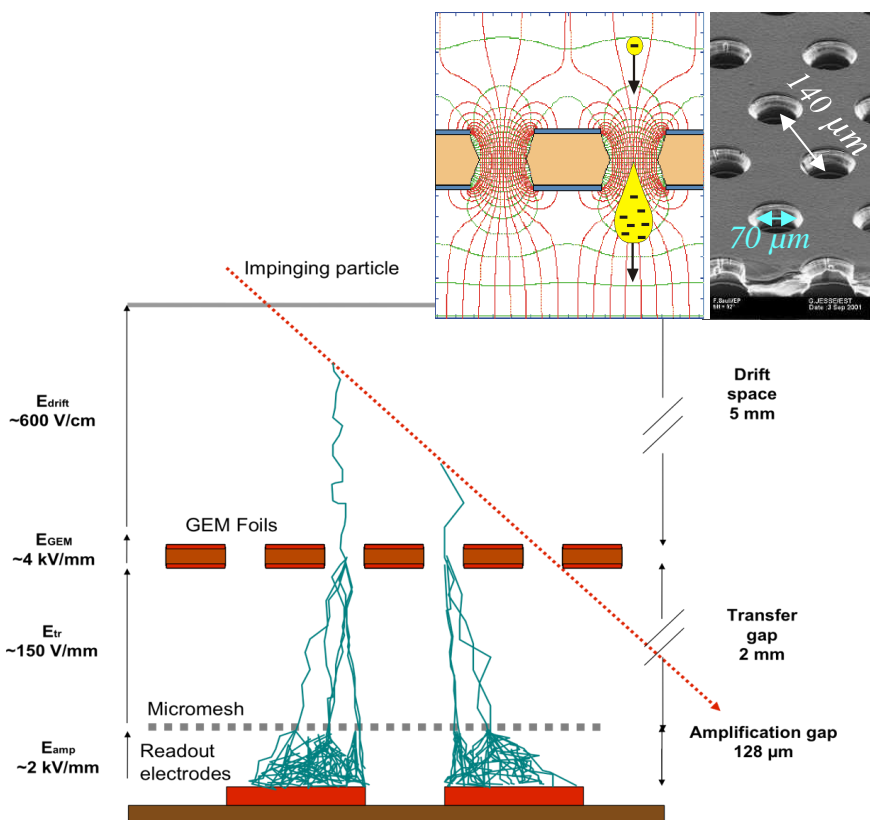
- *10 to 100 times fewer discharges compared to present Micromegas*
- *Read-out with pixels in the beam area*

Discharge reduction technologies

2 solutions investigated :

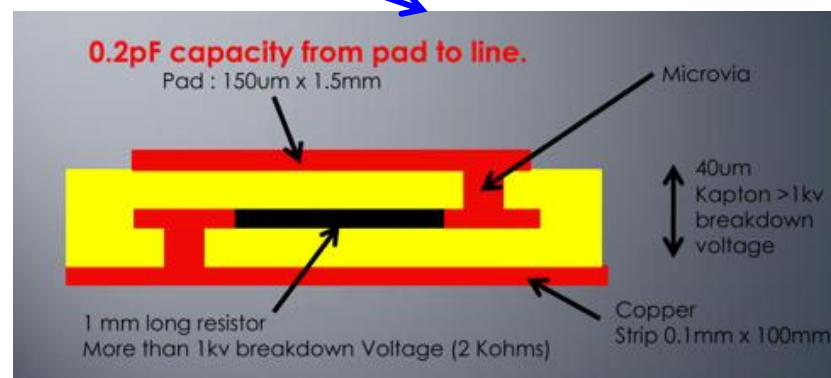
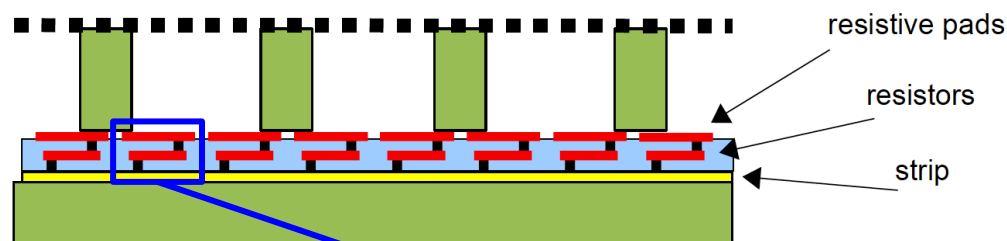
- **Preamplification stage with a GEM foil**

- Gain shared between amplification gap and GEM foil
- Diffusion of the primary electron cloud



- **Detector with resistive pads and buried resistors**

- Quick rise of the resistive pads' potential
- Limitation of the discharge amplitude
- **Compatible with a pixelized readout**

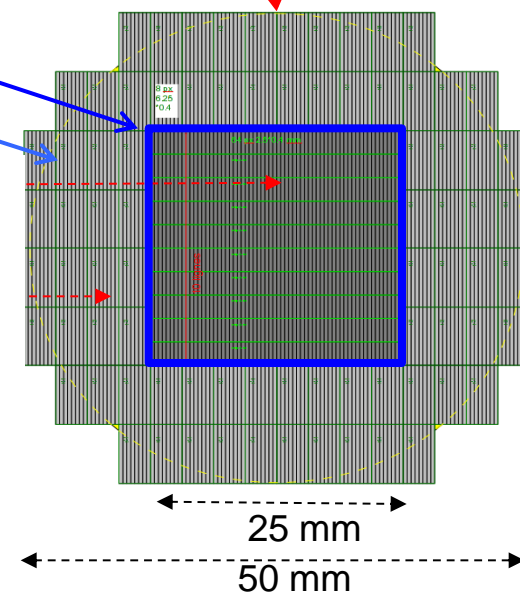
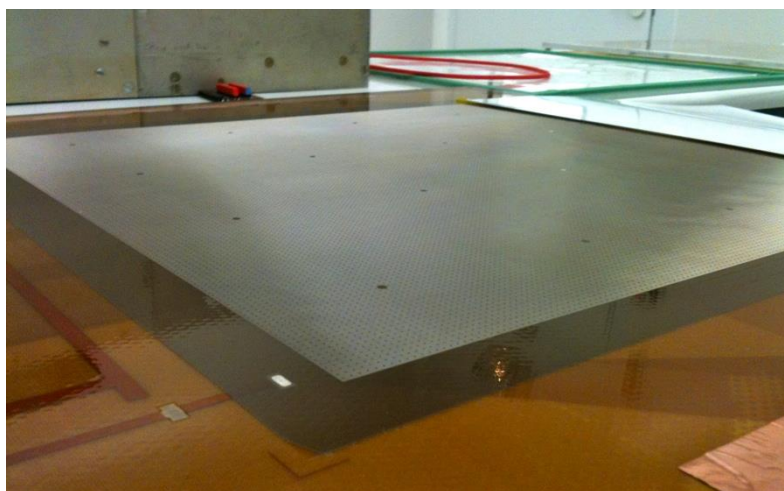
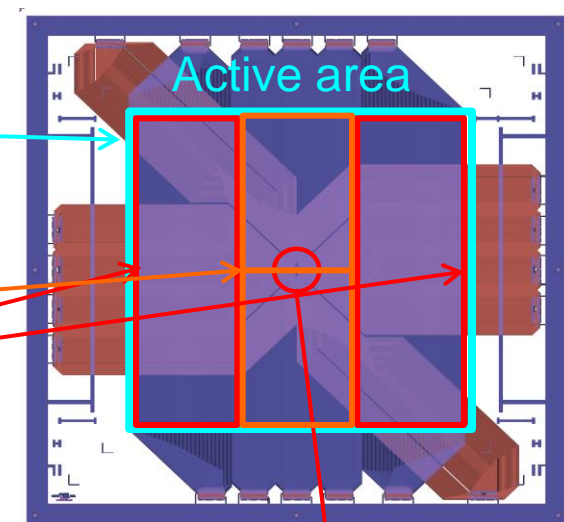


Design by Rui de Oliveira et al.

Large size detectors : readout

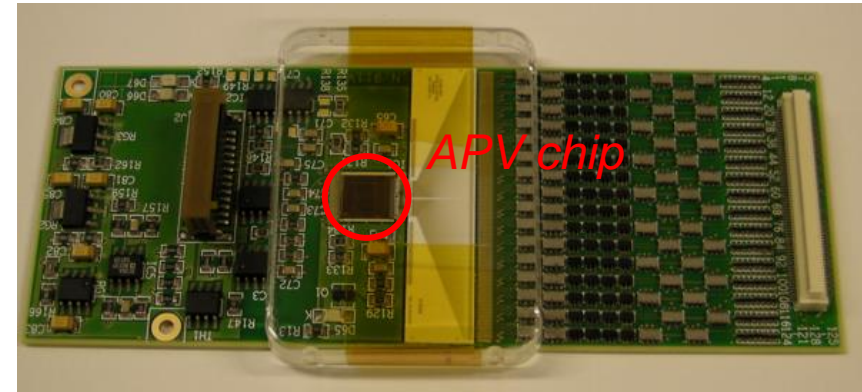
Nominal design after 3 years of development

- 40 x 40 cm² active area
- 2560 readout channels
 - 1280 strips
 - 768 of 400 μm x 20 cm (**center**)
 - 512 of 480 μm x 40 cm (**edges**)
 - 1280 rectangular pixels
 - 640 of 400 μm x 2.5 mm
 - 640 of 400 μm x 6.25 mm

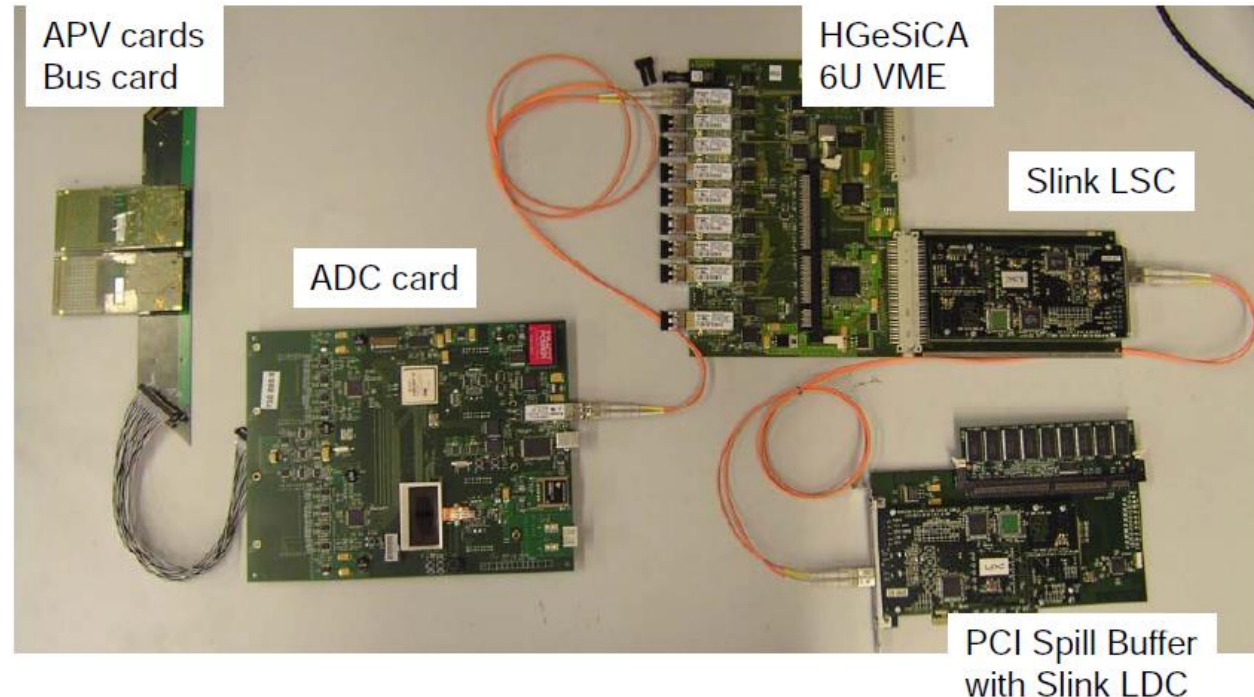


Large size detectors : front-end electronics

- APV card
 - Preamplification / shaping
- ADC board
 - Analog to digital conversion
- HGeSiCA board
 - Data concentrator
 - Trigger distribution



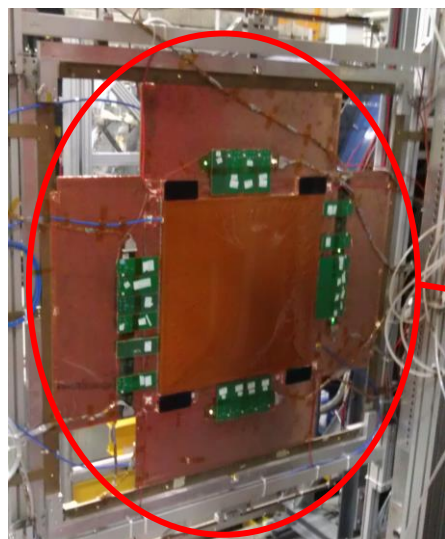
- Chain designed for COMPASS GEM and Silicon detectors by TUM



Large size detectors

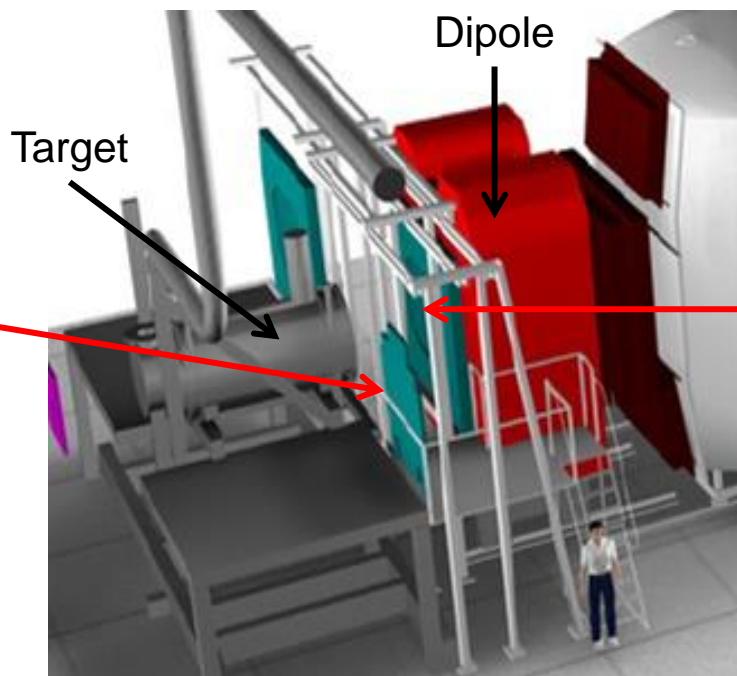
2012 : Pixel Micromegas are included in COMPASS

- 2 detectors with GEM foil (+1 spare) replace 2 standard Micromegas detectors
- 1 prototype with Buried Resistors is tested in hadron beam
- **All detectors participate to the physics data taking**
- **Spark resistant Micromegas detectors used as trackers at a flux up to 650kHz/cm² for the 1st time in a physics experiment**



PMM_2012.1 - GEM

PMM_2011.2 - GEM

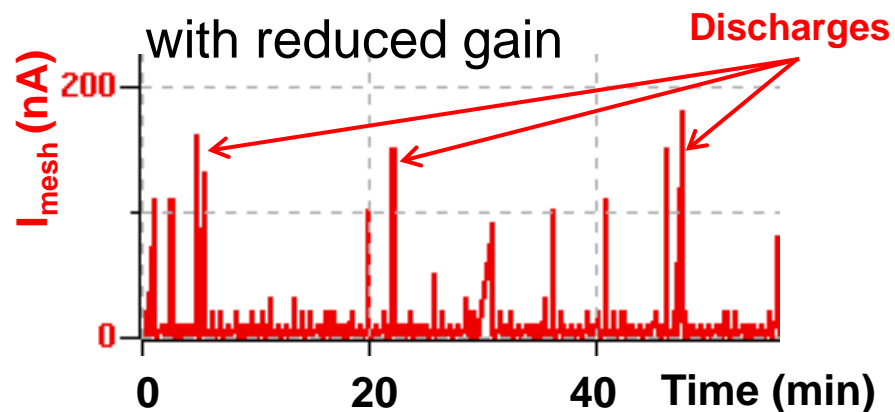


PMM_2011.3 - BR

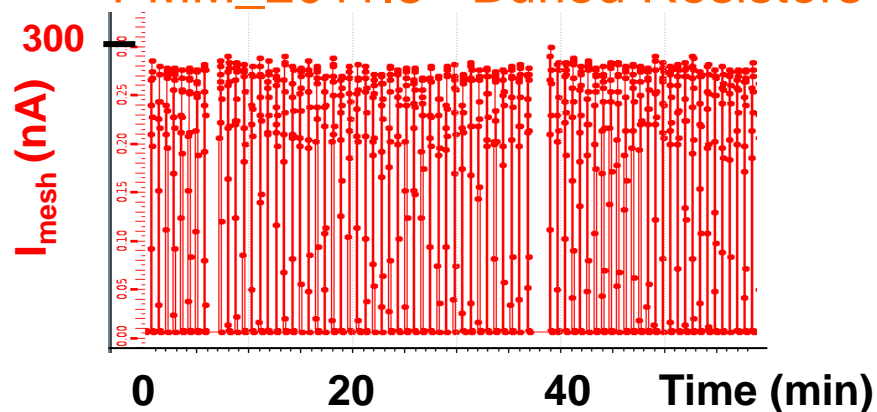
Discharges

- No discharge observed in nominal flux hadron beam on all PMM detectors

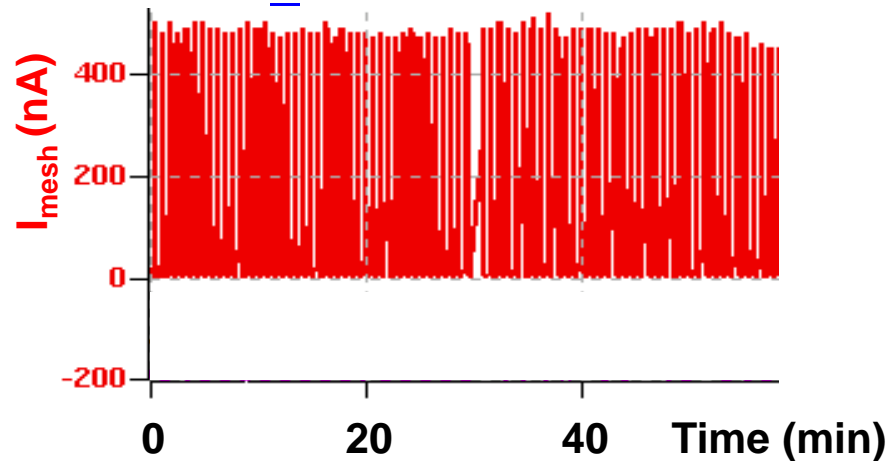
Standard MM
with reduced gain



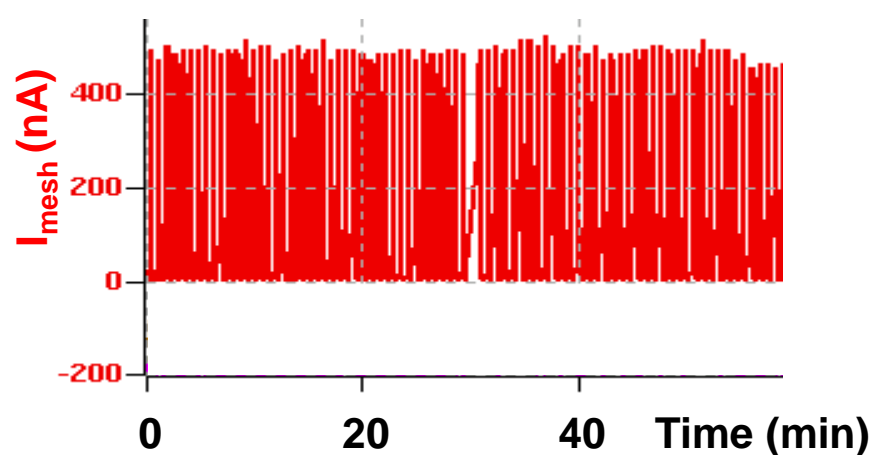
PMM_2011.3 - Buried Resistors



PMM_2012.1 - GEM

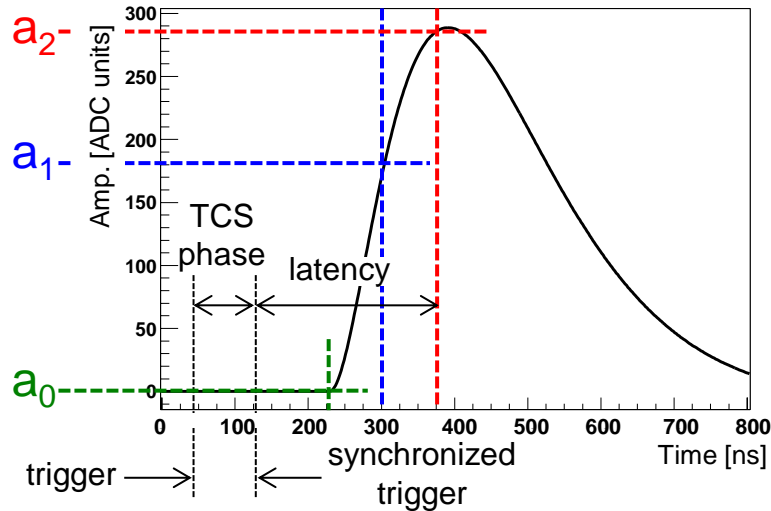


PMM_2011.2 - GEM

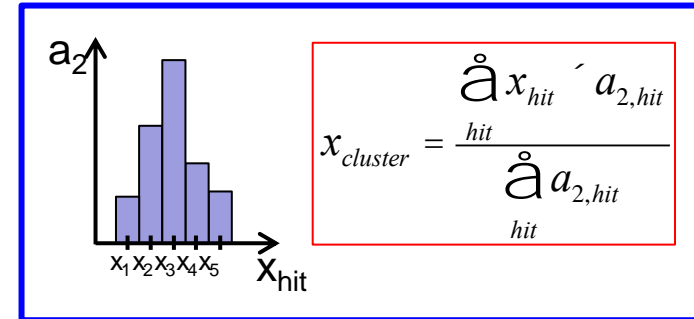


Large size detectors : data reconstruction

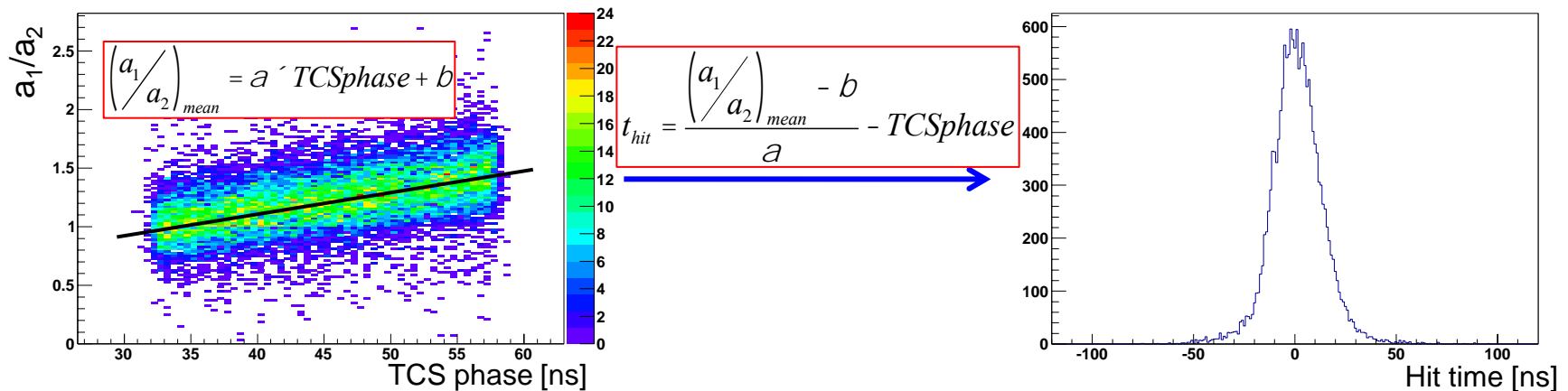
- APV : 3 amplitudes samples spaced by 75 ns at each trigger



- Sample a_2 used for **position reconstruction**

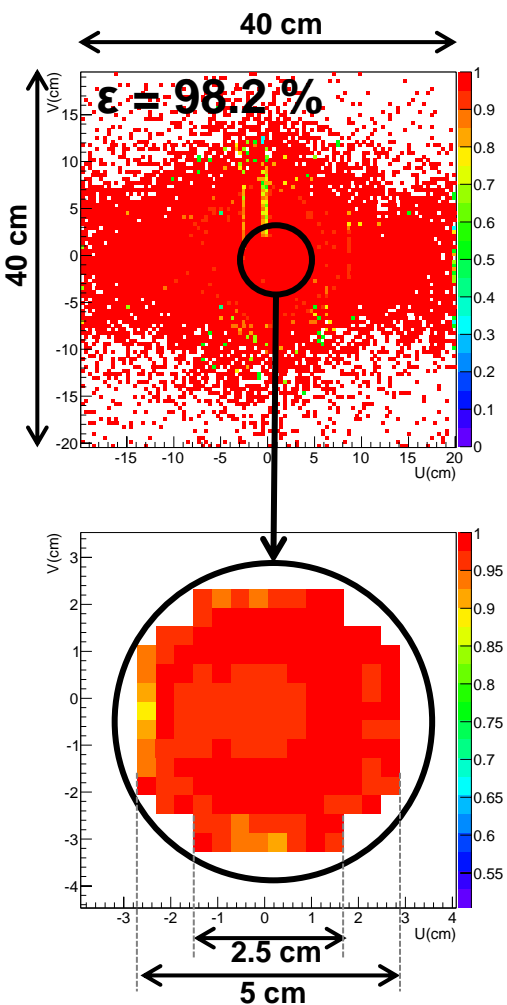


- Ratio a_1/a_2 used for **time reconstruction**

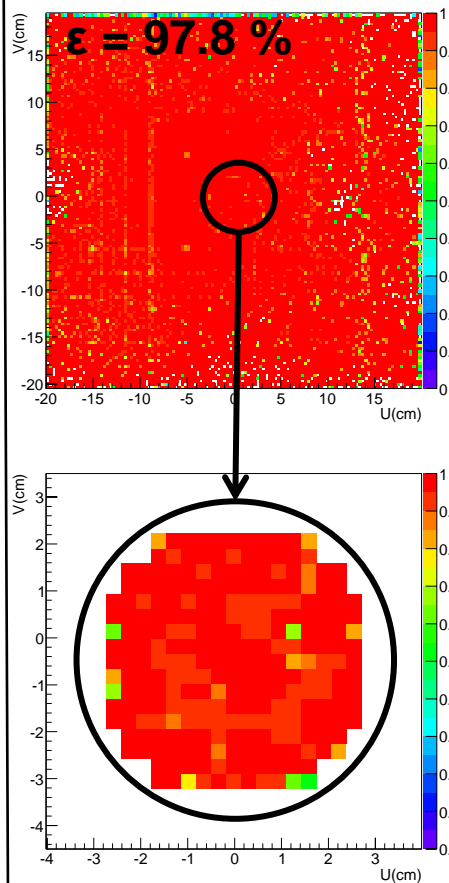


Efficiency ($\Phi=9 \times 10^5 \text{ s}^{-1}$)

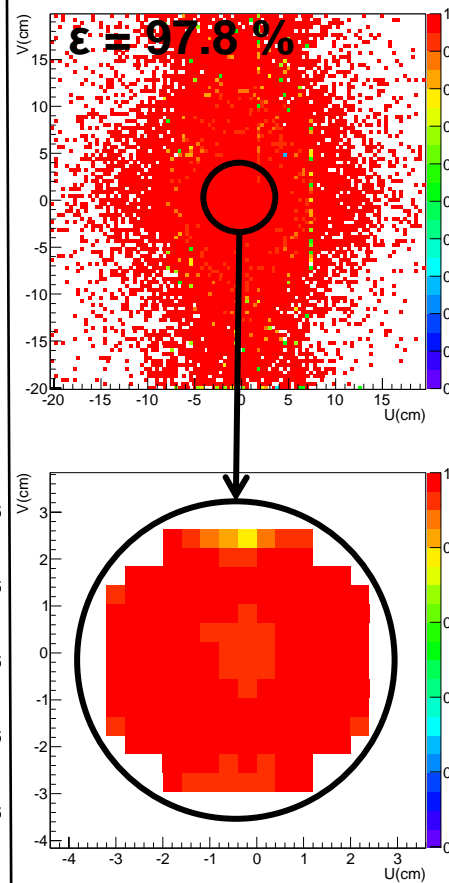
PMM_2012.1 - GEM



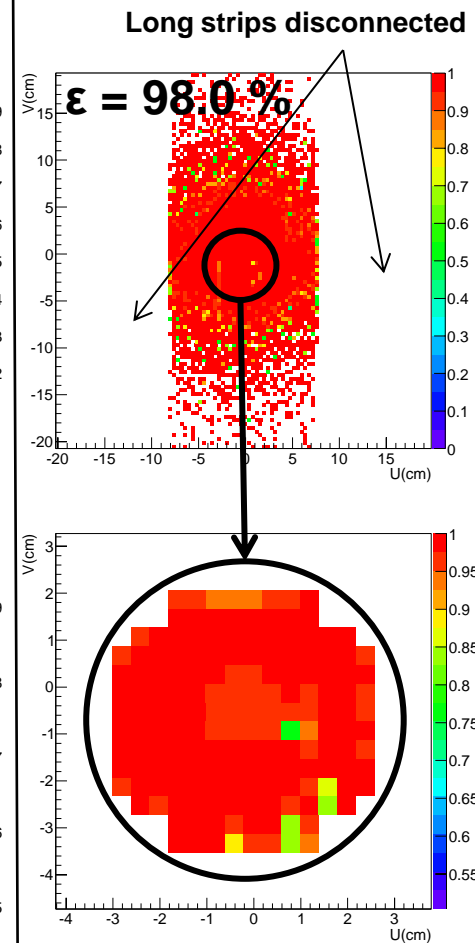
PMM_2011.1 - GEM



PMM_2011.2 - GEM



PMM_2011.3 - BR



Efficiency

| PMM_2011.1 | | | |
|-------------------|--|--|--|
| GEM | μ^+ $\Phi=9 \times 10^5 \text{ s}^{-1}$ | μ^- $\Phi=2 \times 10^7 \text{ s}^{-1}$ | μ^+ $\Phi=5 \times 10^7 \text{ s}^{-1}$ |
| Pixels | 97.9% | 97.1% | 95.7% |
| Strips | 97.8% | 97.4% | 97.0% |
| Global | 97.8% | 97.2% | 96.3% |

| PMM_2011.2 | | | |
|-------------------|--|--|--|
| GEM | μ^+ $\Phi=9 \times 10^5 \text{ s}^{-1}$ | μ^- $\Phi=2 \times 10^7 \text{ s}^{-1}$ | μ^+ $\Phi=5 \times 10^7 \text{ s}^{-1}$ |
| Pixels | 97.7% | 97.3% | 96.9% |
| Strips | 98.4% | 88.7%* | 86.7%* |
| Global | 97.8% | 93.8% | 92.3% |

| PMM_2012.1 | | | |
|-------------------|--|--|--|
| GEM | μ^+ $\Phi=9 \times 10^5 \text{ s}^{-1}$ | μ^- $\Phi=2 \times 10^7 \text{ s}^{-1}$ | μ^+ $\Phi=5 \times 10^7 \text{ s}^{-1}$ |
| Pixels | 98.4% | 98.0% | 96.8% |
| Strips | 97.8% | 97.0% | 97.0% |
| Global | 98.2% | 97.6% | 96.9% |

| PMM_2011.3 | | | |
|-------------------|--|--|--|
| BR | μ^+ $\Phi=9 \times 10^5 \text{ s}^{-1}$ | μ^- $\Phi=2 \times 10^7 \text{ s}^{-1}$ | μ^+ $\Phi=5 \times 10^7 \text{ s}^{-1}$ |
| Pixels | 97.9% | Not tested | Not tested |
| Strips | 98.1% | Not tested | Not tested |
| Global | 98.0% | Not tested | Not tested |

Efficiency > 95% for all detectors in all conditions

Slight decrease at highest flux :

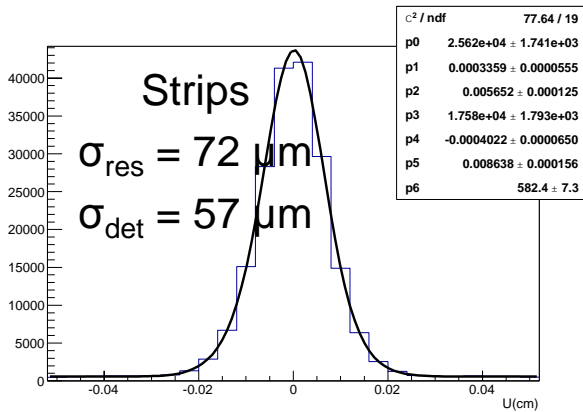
- *Pixels : ~ 1.5%*
- *Strips : < 1%*

*missing front-end card

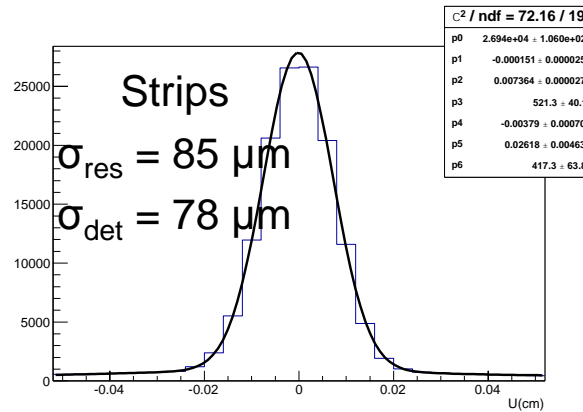
Spatial Resolution

- Residual plots with low flux and field off
- Detector resolution : $S_{detector} = \sqrt{S_{residual}^2 - S_{tracking}^2}$

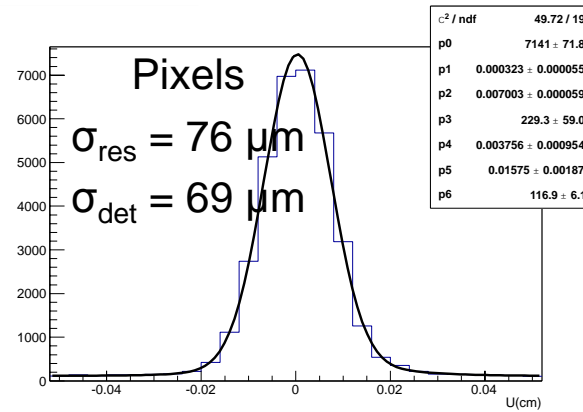
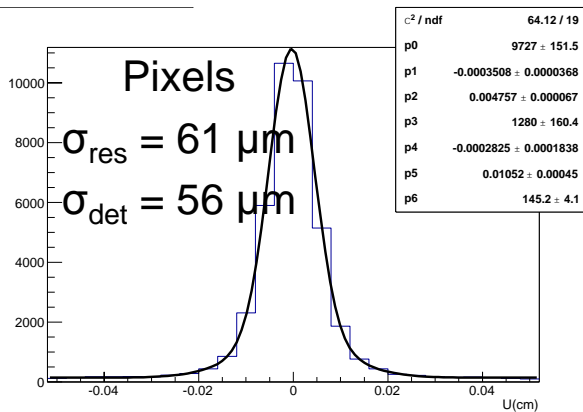
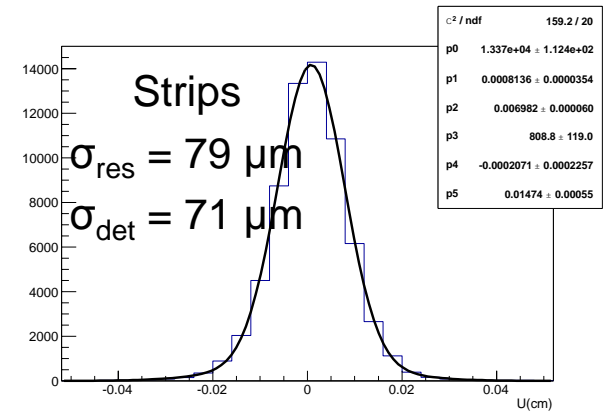
PMM_2011.2 - GEM



PMM_2011.3 - BR



MM02X (standard Micromegas)



➤ $\sigma_{PMM+GEM} < \sigma_{standard MM}$

➤ $\sigma_{PMM+BR} \gtrsim \sigma_{standard MM}$

- Dipole fringe field up to 0.2 T at the prototype position

| Detector | μ^+ $\Phi=9 \times 10^5 \text{ s}^{-1}$ Dip. OFF (μm) | μ^+ $\Phi=9 \times 10^5 \text{ s}^{-1}$ Dip. ON (μm) |
|-----------------------------------|---|--|
| PMM_2011.2 GEM (strips) | 57 | 56 |
| PMM_2011.2 GEM (pixels) | 56 | 58 |
| PMM_2011.3 BR (strips) | 78 | 119 |
| PMM_2011.3 BR (pixels) | 69 | 111 |
| MM02X (standard Micromegas) | 71 | 104 |

Far from dipole
➤ *No effect*

Close to dipole
➤ *Degradation (~ +50%)
similar for standard MM
and PMM_2011.BR*

| Detector | μ^+ $\Phi=9 \times 10^5 \text{ s}^{-1}$ (μm) | μ^+ $\Phi=4 \times 10^6 \text{ s}^{-1}$ (μm) | μ^- $\Phi=2 \times 10^7 \text{ s}^{-1}$ (μm) | μ^+ $\Phi=5 \times 10^7 \text{ s}^{-1}$ (μm) |
|-----------------------------------|---|---|---|---|
| MM01U (standard Micromegas) | 65 | 67 | 71 | 74 |
| PMM_2011.2 GEM (strips) | 56 | 57 | 68 | 72 |
| PMM_2011.2 GEM (pixels) | 57 | 57 | 79 PRELIMINARY* | 87 PRELIMINARY* |
| PMM_2011.3 BR (strips) | 119 | 139 | Not tested | Not tested |
| PMM_2011.3 BR (pixels) | 111 | 127 | Not tested | Not tested |
| MM02X (standard Micromegas) | 104 | 107 | Not tested | Not tested |

PMM + GEM

Strips :

- Degradation comparable to standard MM (~10-15%)

Pixels :

- Degradation (~50%) at the highest flux but still < 90 μm (preliminary result*)

PMM w/ BR

- Degradation worse than standard MM in the same region (25% compared to 3%)

Close to dipole

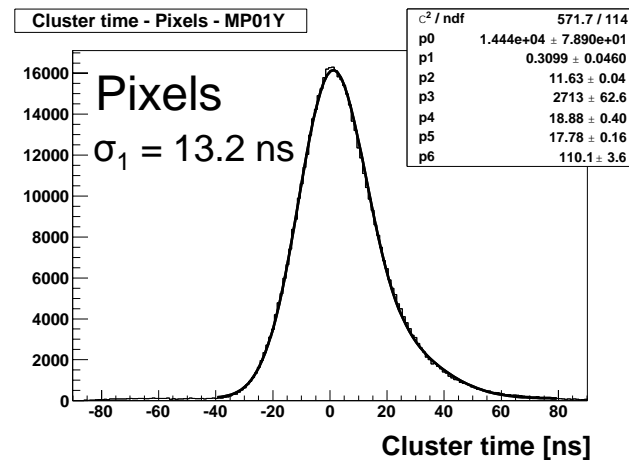
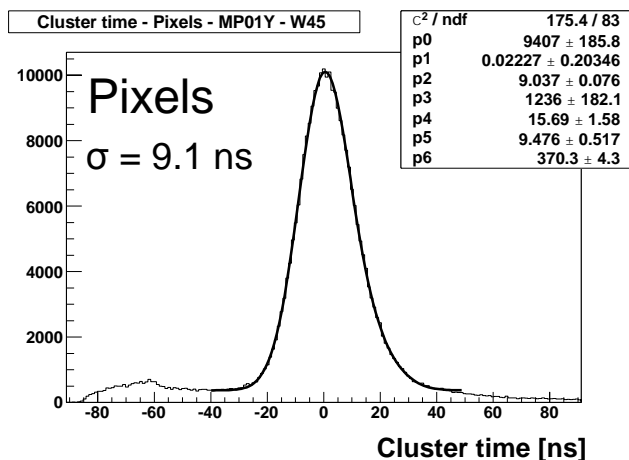
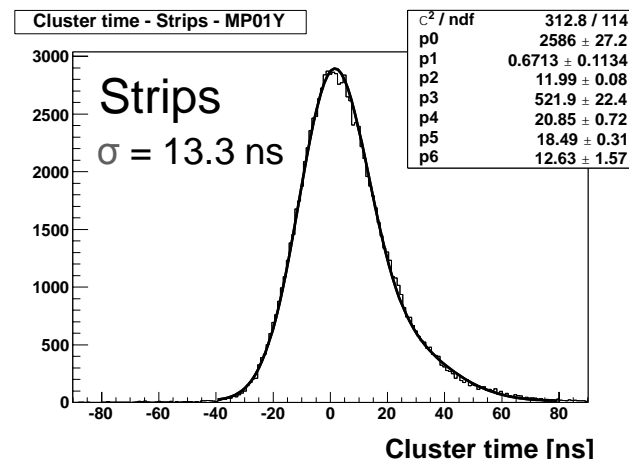
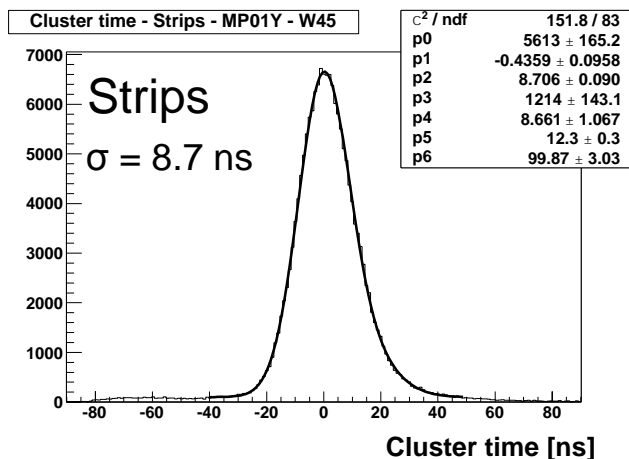
- *Lack of redundancy at small angle
➔ Poor tracking resolution

Time Resolution : Gas Mixture

PMM_2011.2 - GEM

Muon run : 80% Ne + 10% C₂H₆ + 10% CF₄

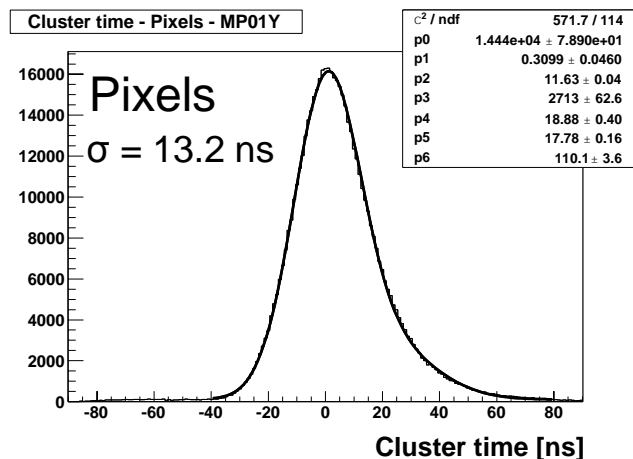
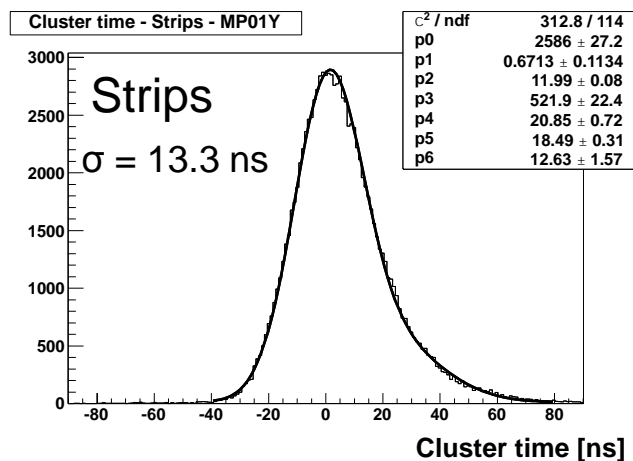
Hadron run : 85% Ne + 10% C₂H₆ + 5% CF₄



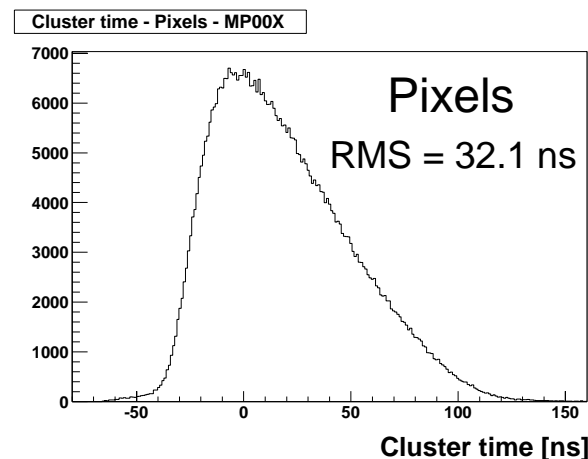
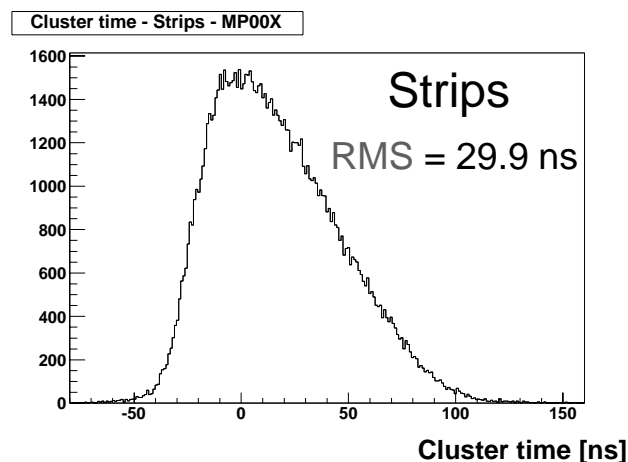
Time Resolution : GEM vs BR

Hadron run : 85% Ne + 10% C₂H₆ + 5% CF₄

PMM_2011.2 - GEM



PMM_2011.3 - BR



Time Resolution

- Summary of time resolution measurements (in ns)

| Detector | PMM_2011.1 GEM (strips) | PMM_2011.1 GEM (pixels) | PMM_2011.2 GEM (strips) | PMM_2011.2 GEM (pixels) | PMM_2012.1 GEM (strips) | PMM_2012.1 GEM (pixels) | PMM_2011.3 BR (strips) | PMM_2011.3 BR (pixels) | Standard Micromegas |
|---|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|------------------------------|------------------------------|------------------------|
| μ^+ $\Phi=5 \times 10^7 \text{ s}^{-1}$ | 8.8 | 9.7 | 8.7 | 9.1 | 12.4* | 10.3* | Not tested | Not tested | 9.3 |
| π^-, K^- $\Phi=4 \times 10^6 \text{ s}^{-1}$ | Not tested | Not tested | 13.3 | 13.2 | 13.3 | 13.0 | 29.9 | 32.1 | 12.6 |

$$\triangleright \sigma_{PMM+GEM} \sim \sigma_{MM}$$

$$\triangleright \sigma_{PMM+BR} \sim 2.5 \times \sigma_{PMM+GEM}$$

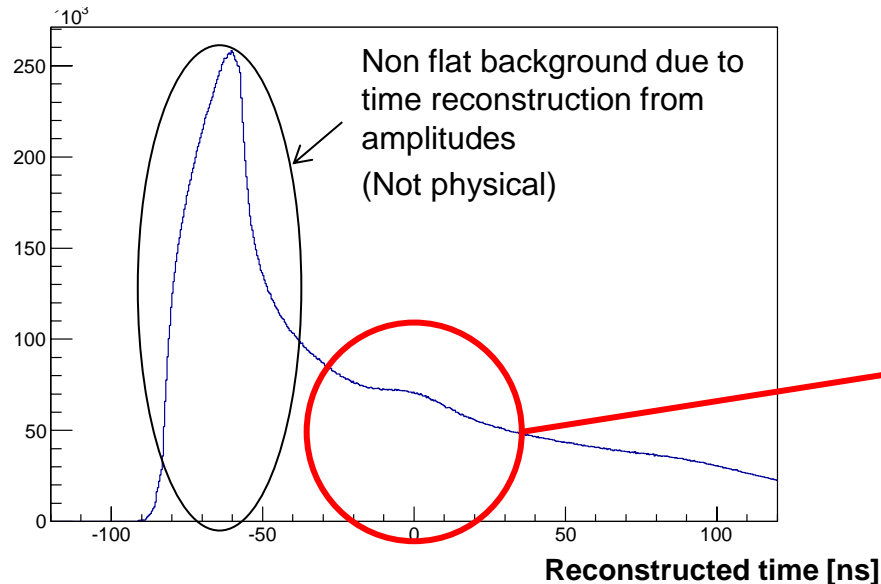
*due to PCB curvature

Pixel Micromegas and track reconstruction

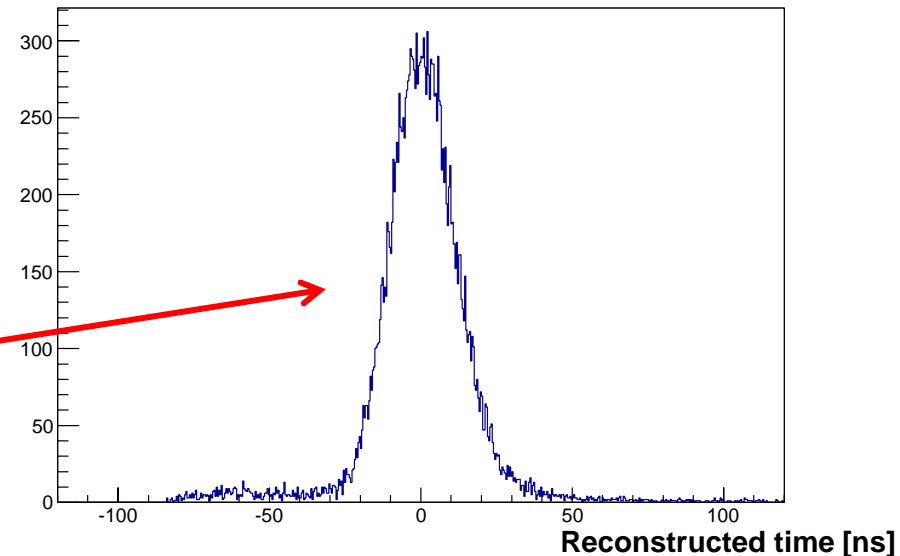
High flux muon run ($5 \times 10^7 \text{ s}^{-1}$):

- 2 PMM+GEM integrated in the tracking (BR off beam)
- Difficult conditions for track reconstruction in the beam area :
 - Beam flux up to 650 kHz/cm^2
 - Only 5 planes between target and dipole -> **PMMs = 40% of the trackers**

All clusters (Pixelized area)



Clusters close to a track (Pixelized area)



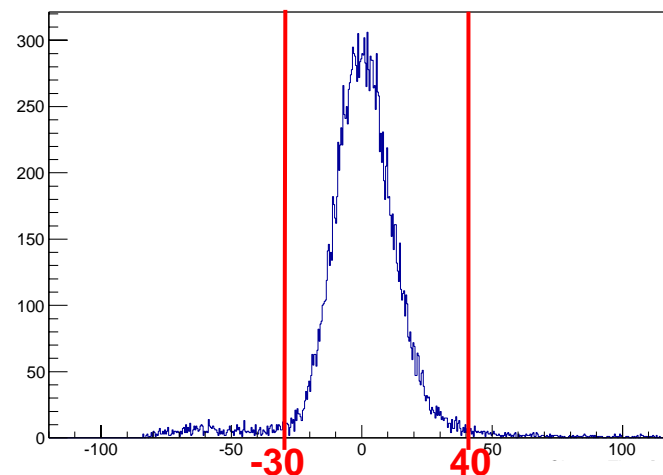
- **Necessity for precise time cuts on PMM to reduce combinatorial background**

Time Cuts

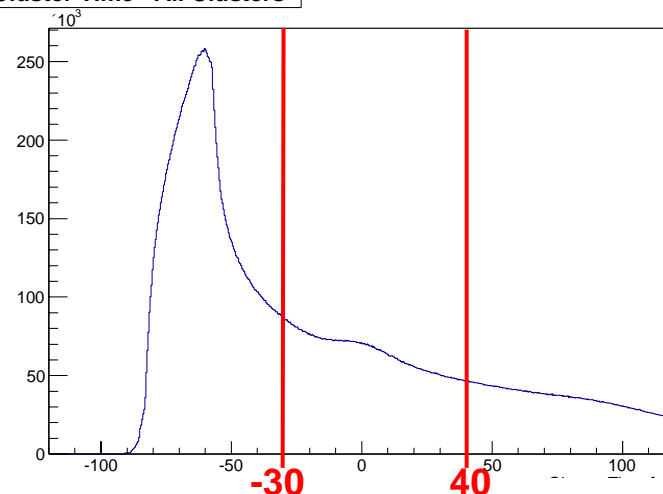
Amount of clusters on the **pixelized area** in the highest beam flux (650 kHz/cm²)

| PMM.2011.2 GEM Pixel Plane | Number of clusters (reduction) | Efficiency | Background probability |
|--|---|-------------------|-----------------------------------|
| No Cuts | 2145513 | 95.7% | 11% |
| Cut on cluster time (- 30ns<t<40ns) | 634167 (-70 %) | 93.6% | 2.9% |

Cluster Time - Clusters close to a track



Cluster Time - All Clusters



- Clusters : -70%
- Small loss in efficiency (<2%)
- Important decrease of background probability

Observable : Amount of events with too many tracks or combinations generated by the COMPASS reconstruction software in the zone between the target and the first dipole

| μ^+ $\Phi=5 \times 10^7 \text{ s}^{-1}$ 650 kHz/cm ² | Number of tracks > 1000 (% of #events) | Number of combinations > 20000 (% of #events) |
|---|---|--|
| No Cuts | 29.8% | 0.5% |
| Cut on cluster time (- 30ns < t < 40ns) | 3.1% | 0.1% |

- Rejected events : -90%
- Reduction of the combinatorial background

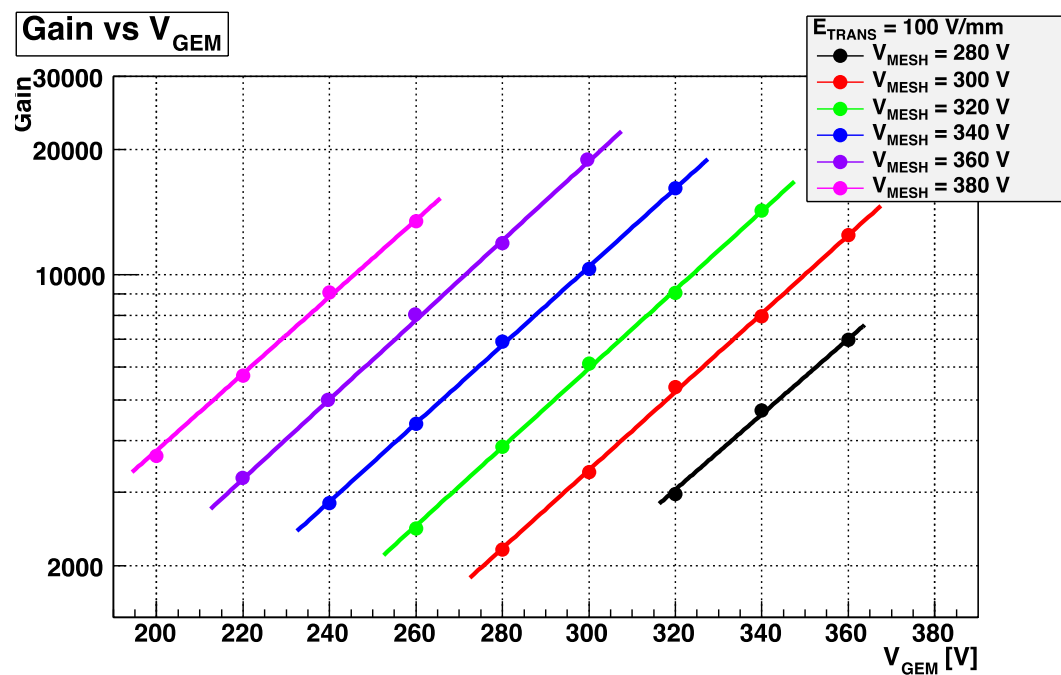
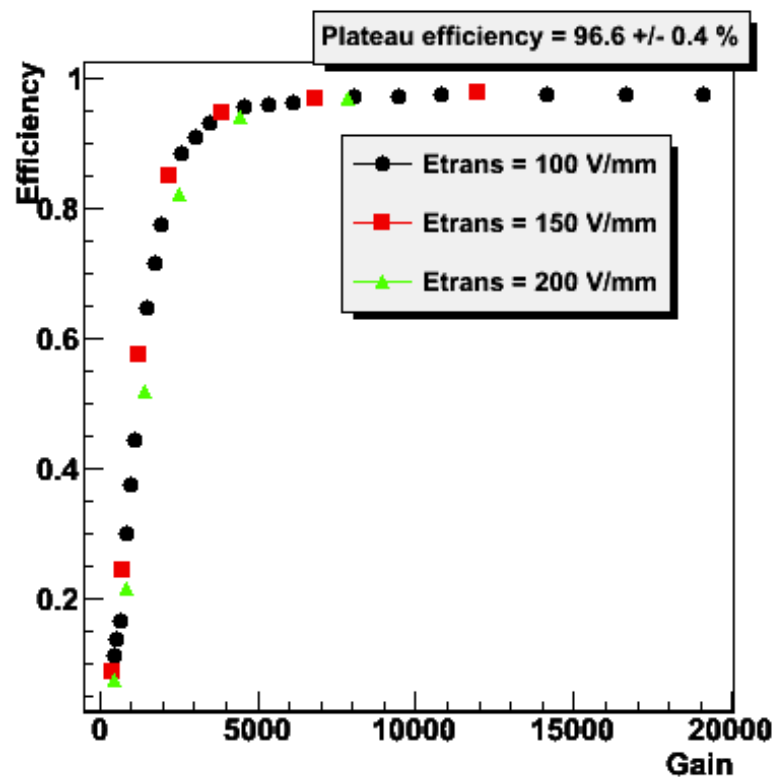
Conclusion

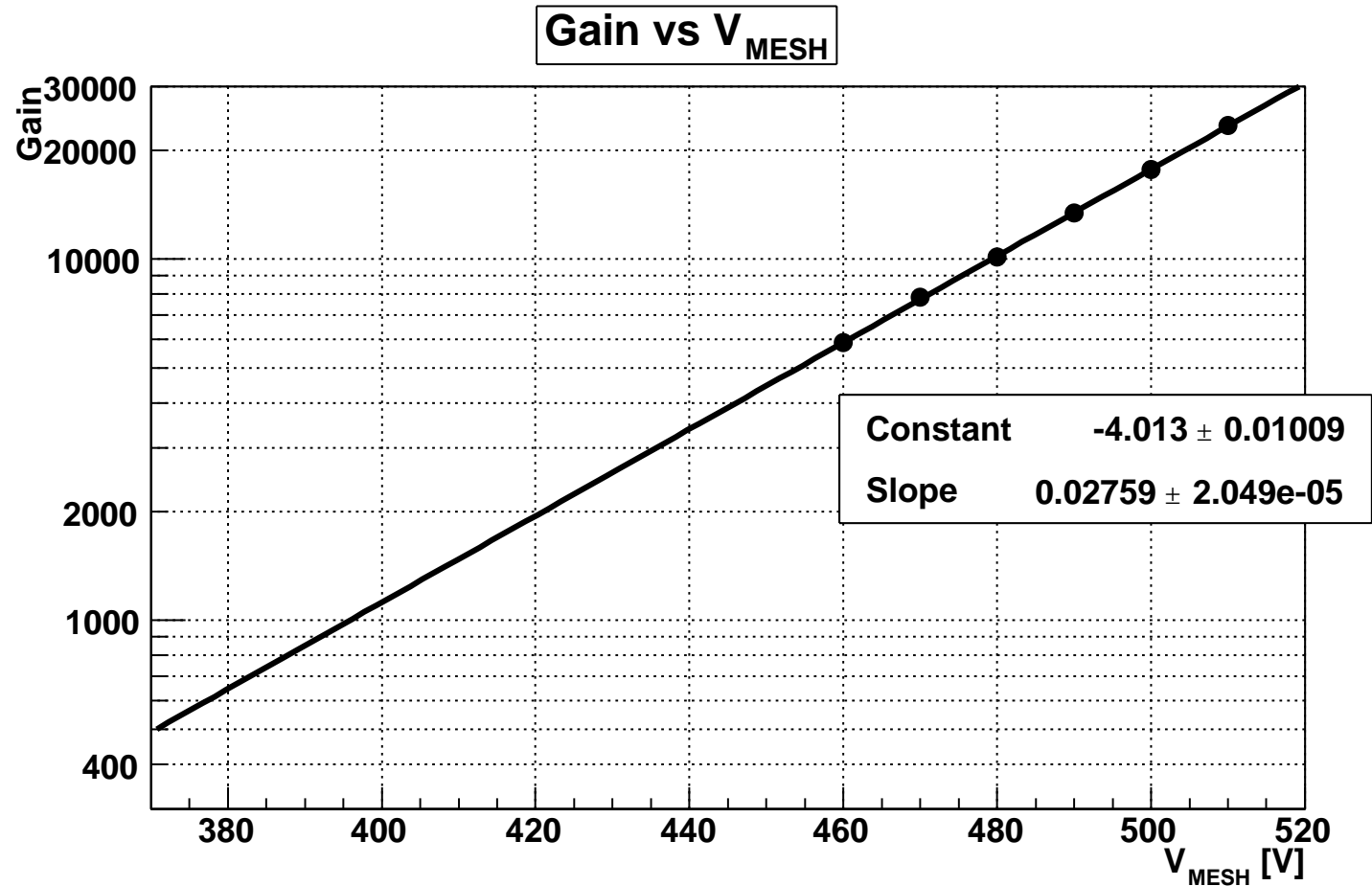
- **Micromegas detectors used as trackers in a flux up to 650kHz/cm² for the 1st time in a physics experiment**
- 2 spark-protection technologies used, **no spark observed in nominal intensity hadron beam.**
- **Efficiency** : low flux >98%; high flux > 95%
- **Spatial resolution** :
 - **PMM+GEM** :
 - Better than standard COMPASS MM (**55-60μm** vs 65-70μm)
 - Flux : degradation at 600 kHz/cm² comparable to standard COMPASS Micromegas
 - **PMM w/ BR** :
 - Comparable to standard COMPASS MM (**~70-80μm**)
 - Flux : degradation more important than standard MM
- **Time resolution** :
 - **PMM+GEM** : **~9-10 ns** (10% CF₄), ~13 ns (5% CF₄)
 - **PMM w/ BR** : ~30 ns (5% CF₄)
- **Tracking** : cut on cluster time (-30ns to 40ns) : **-90% rejected events**

- **Choice GEM/BR** : *a priori* GEM due to better performance, but studies on BR still ongoing.
- **Production** : final detectors will be produced by the **CIREA-ELVIA company** (see talk by Damien NEYRET during RD51 meeting).
- **Complete installation** : replacement of the 12 standard Micromegas by Pixel Micromegas foreseen for the COMPASS II run in early 2015.

Backup Slides

PMM + GEM : gain & efficiency





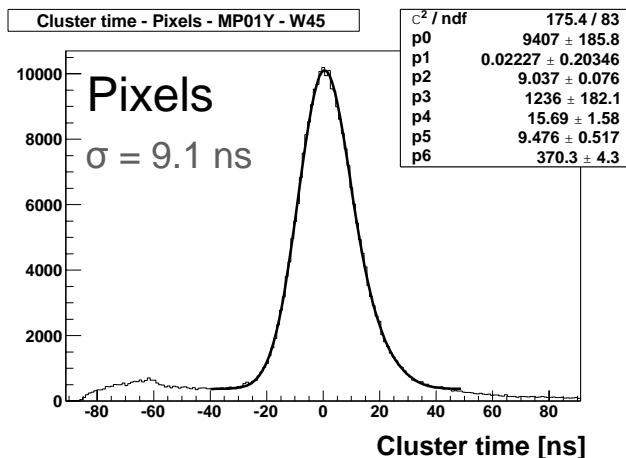
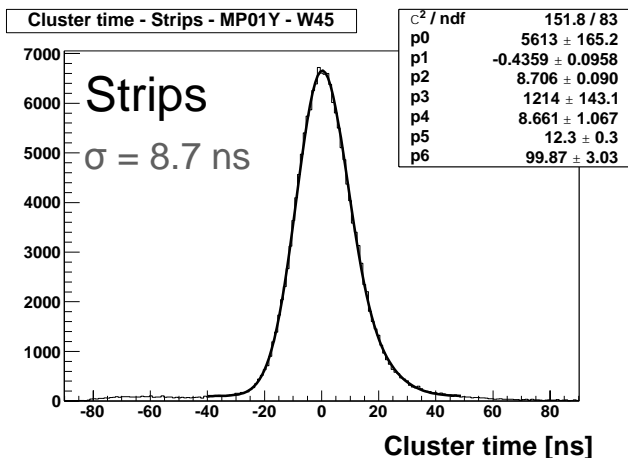
| MP01X | Eff. High Flux hadrons |
|--------------|-------------------------------|
| Pixels | 96.5% |
| Strips | 97.0% |
| Global | 96.6% |

| MP01Y | Eff. High Flux hadrons |
|--------------|-------------------------------|
| Pixels | 96.3% |
| Strips | 97.0% |
| Global | 96.3% |

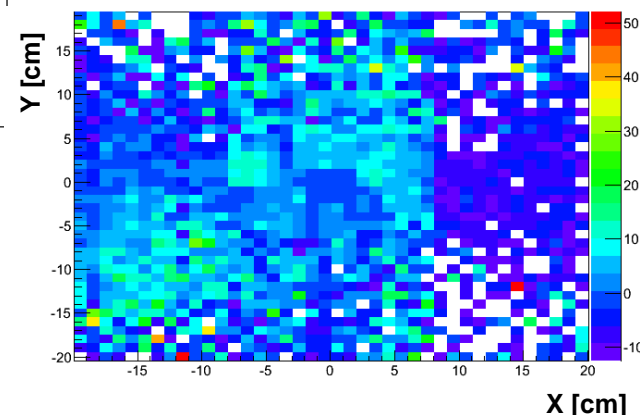
| MP00 | Eff. High Flux hadrons |
|-------------|-------------------------------|
| Pixels | 96.5% |
| Strips | 96.7% |
| Global | 96.7% |

Time Resolution vs position

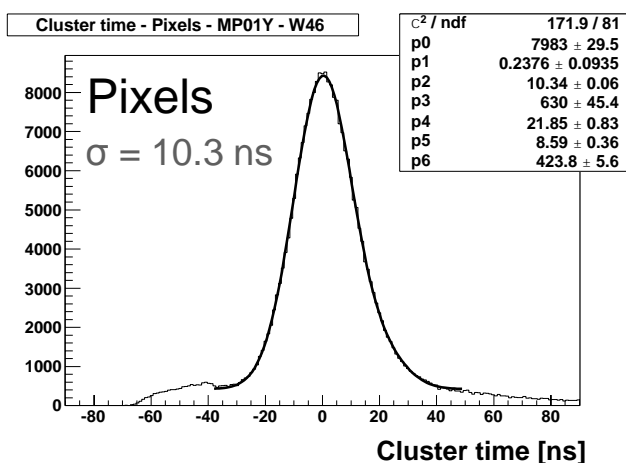
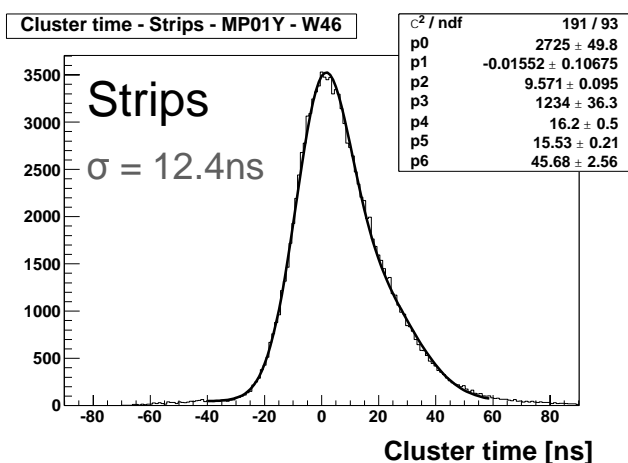
PMM_2011.2 (PixelMM w/ GEM)



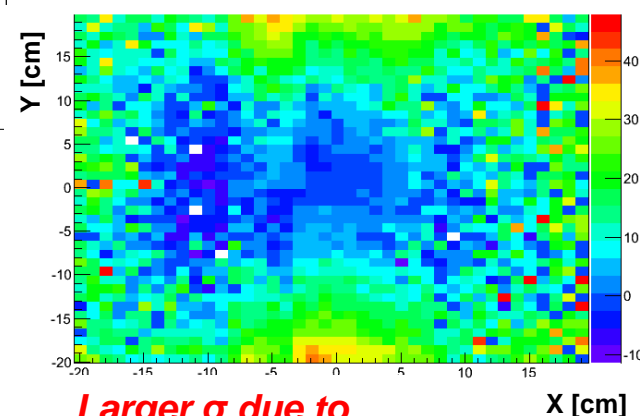
Mean cluster time vs position



PMM_2012.1 (PixelMM w/ GEM)

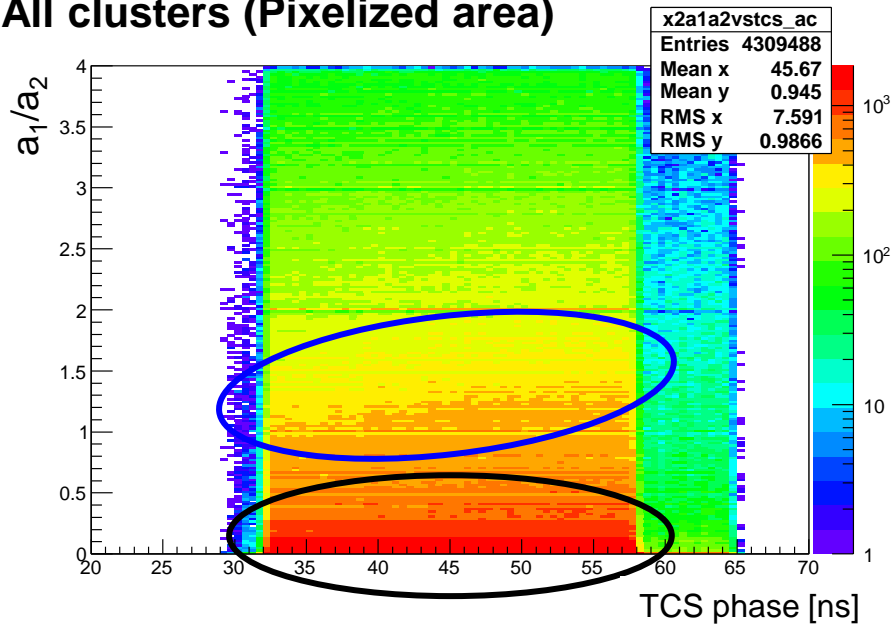


Mean cluster time vs position

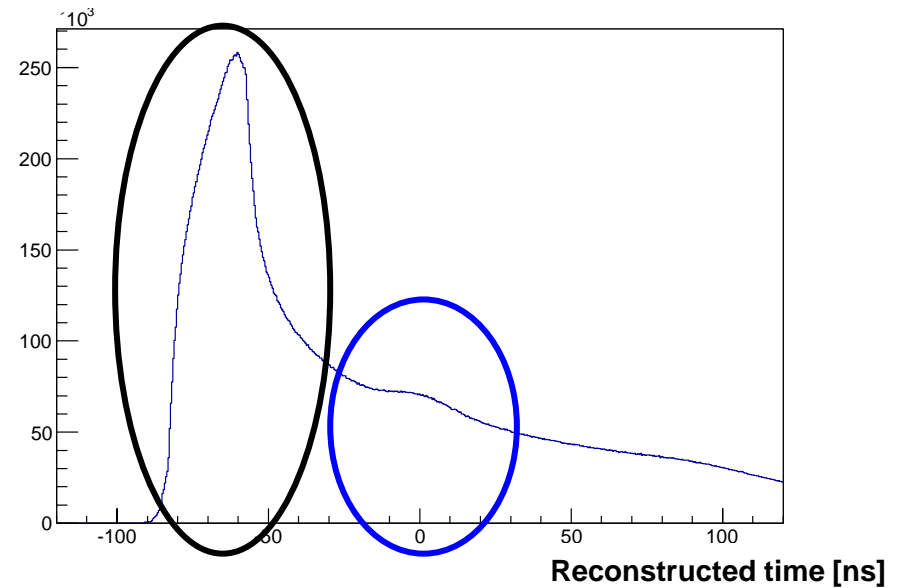


Larger σ due to detector curvature

All clusters (Pixelized area)



All clusters (Pixelized area)



| μ^+ PMM_2011.2 - GEM Pixel Plane ~22500 events | #tracks/event (between target and SM1) | %events w/ primary vertex(#tracks/vertex) |
|---|--|--|
| No Cuts | 1.47 | 41.7(2.132) |
| Cut on cluster time (- 30ns<t<40ns) | 1.54 | 43.2(2.135) |

+ 5%

+ 4%