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COMPASS

Performance of spark-protected Pixelized Micromegas detectors in the COMPASS environment

Florian Thibaud
CEA Saclay – Irfu/SPhN
florian.thibaud@cea.fr

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Outline

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- The COMPASS Experiment at CERN
- The Pixel Micromegas Detector
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  - Discharge reduction technologies
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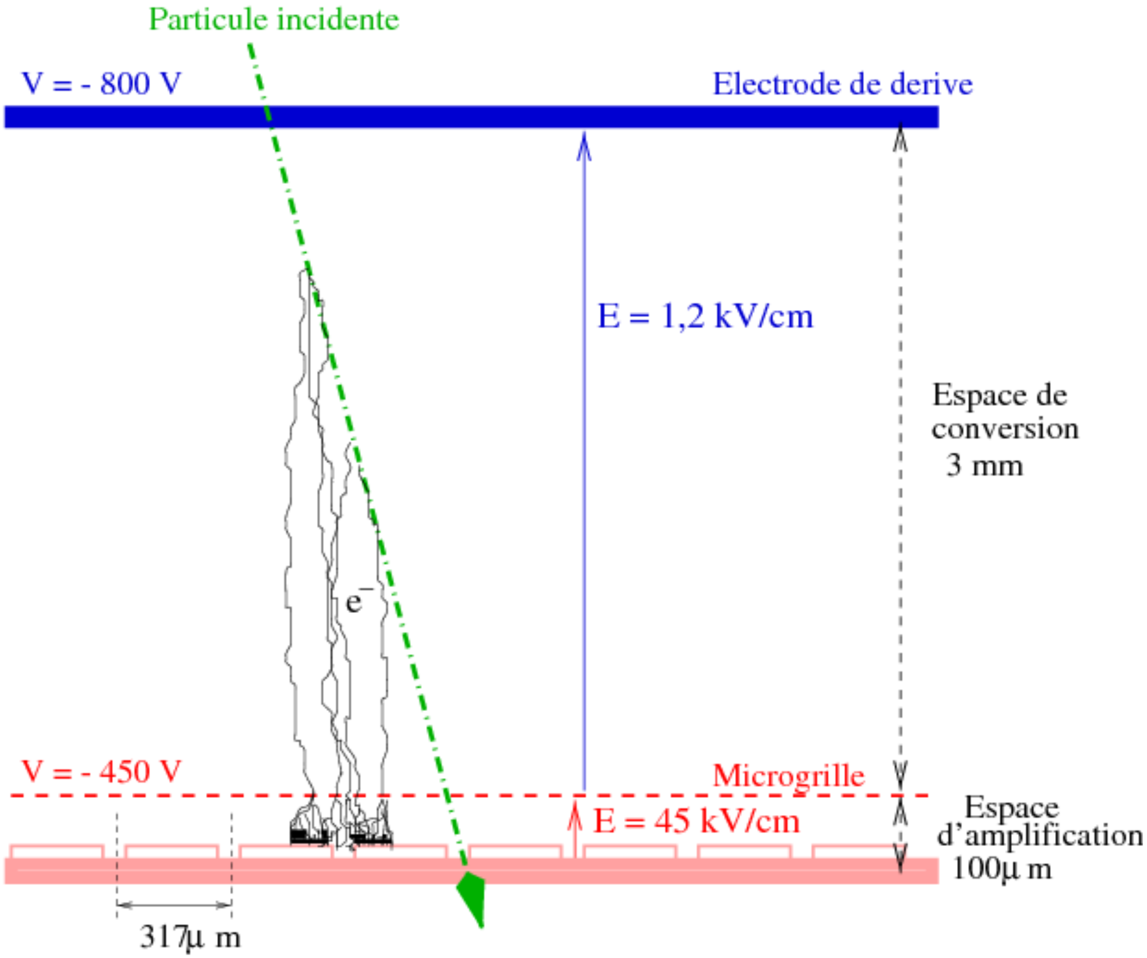
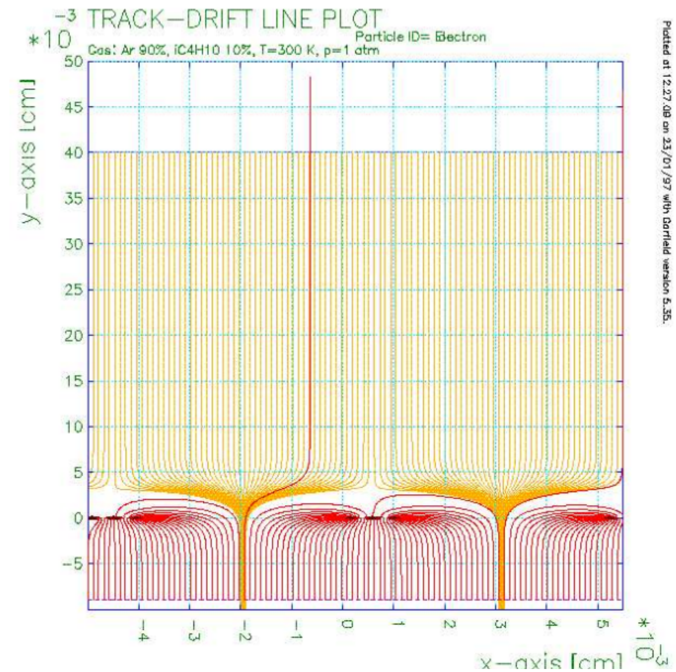
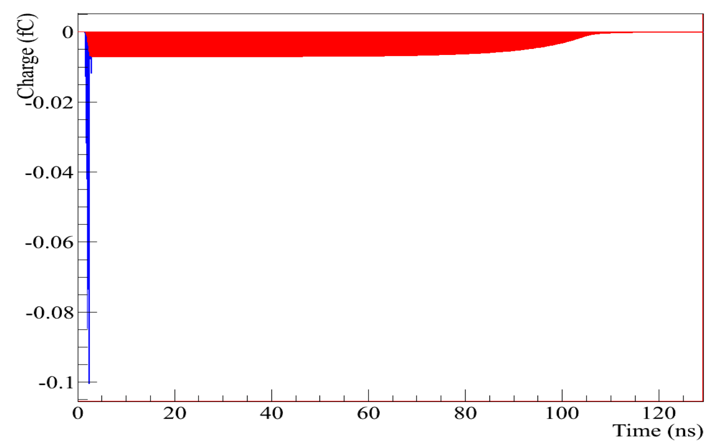
  - Discharge rate
  - Efficiency
  - Spatial resolution
  - Time resolution
- Pixel Micromegas and track reconstruction
- Conclusion
- Outlook

Micromegas detectors working principle

***MICRO**mesh **GA**seous **S**tructure*



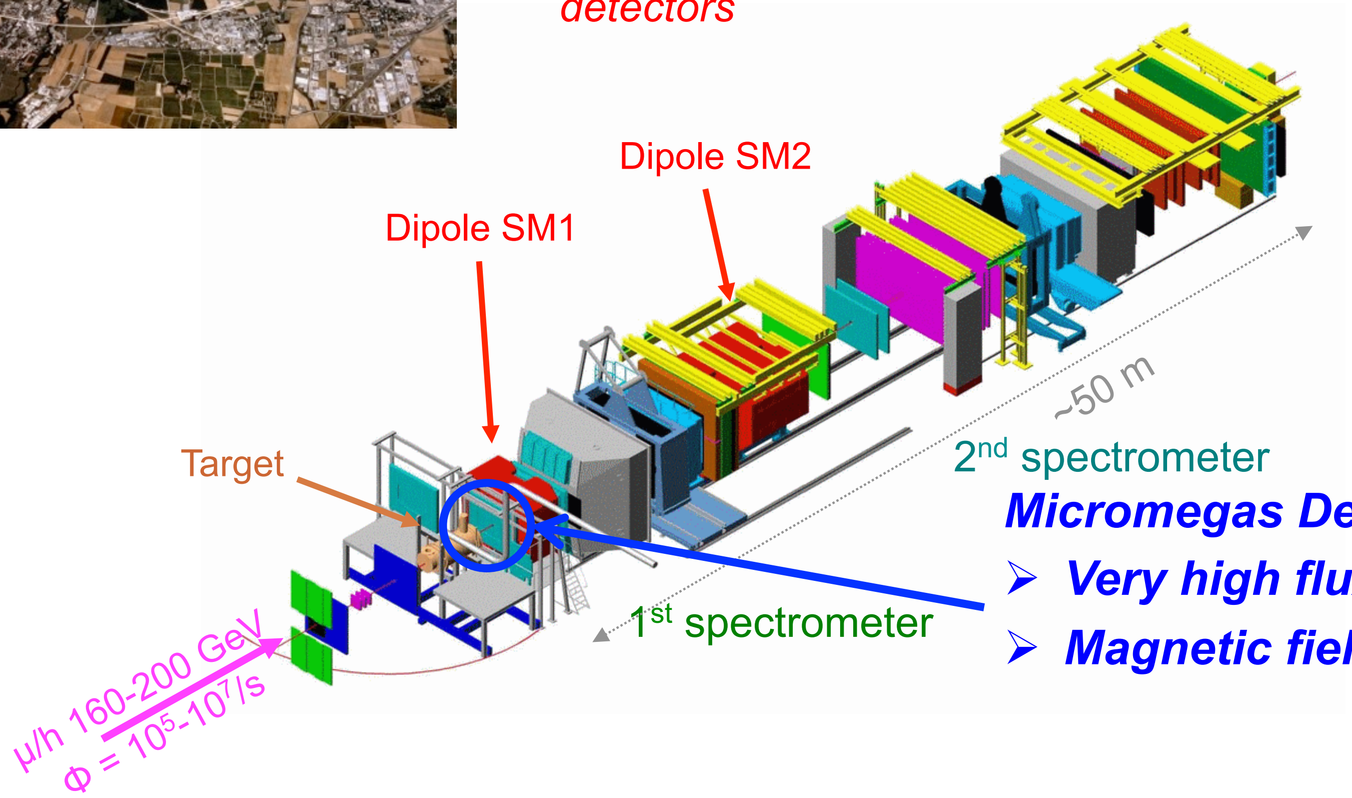




The COMPASS experiment at CERN

***CO**mmon **M**uon **P**roton **A**pparatus for **S**tructure and **S**pectroscopy*

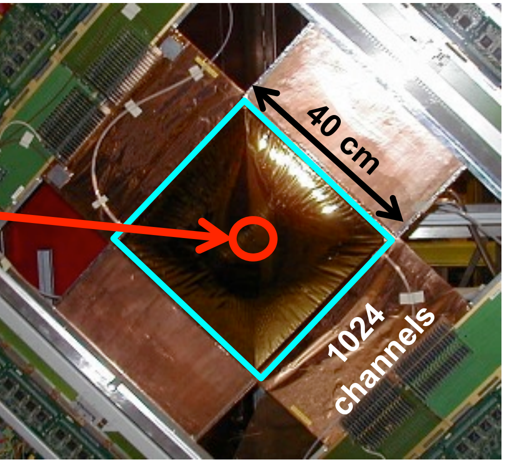
- *High resolution spectrometer*
- *Very good spatial resolution (<100μm) required at small angle for kinematics and particle identification*
- *One of the first experiments to use Micromegas detectors*



Micromegas Detectors

- ***Very high flux***
- ***Magnetic field(s)***

The Pixel Micromegas Project : motivations



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

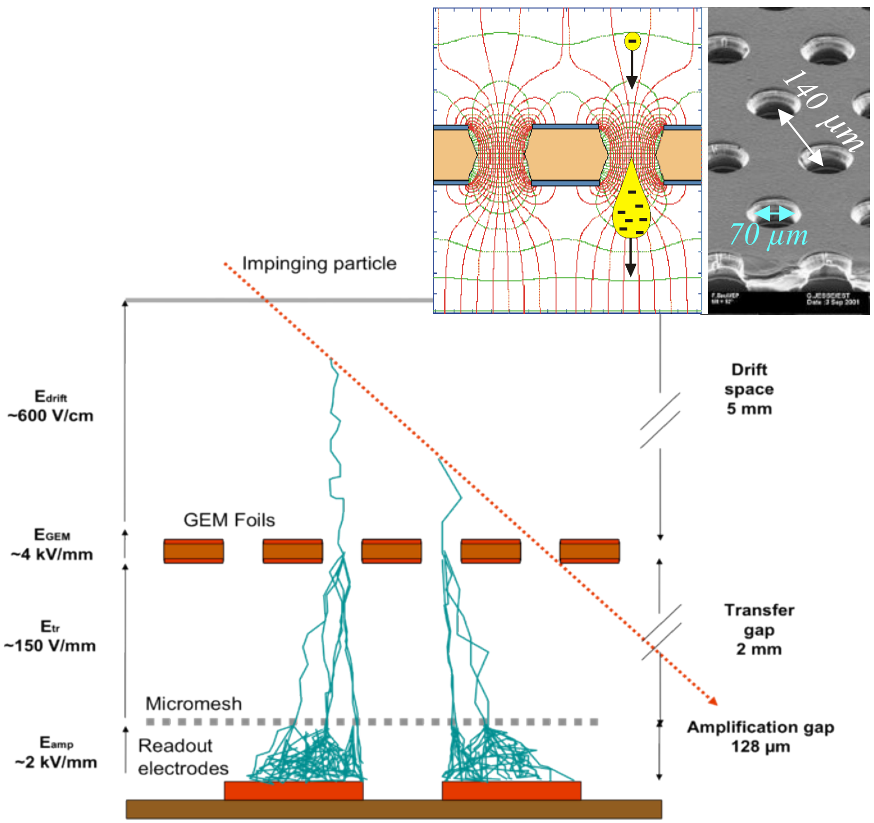
- COMPASS plans for 2015 and beyond :
  - Better tracking close to the beam, with a minimum material budget
    - ➢ *Need for Micromegas with active center*
    - ➢ *Need for discharge protected Micromegas (active center -> higher flux)*
  - Potential increase of hadron beam intensity :
    - ➢ *Need for discharge protected Micromegas*

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

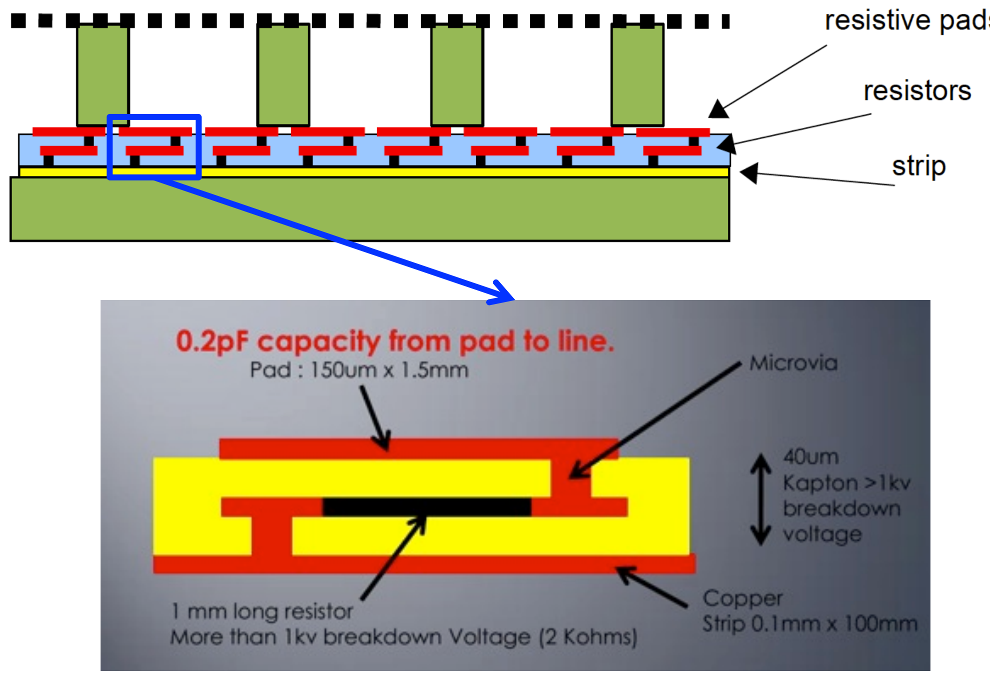
Discharge reduction technologies

2 solutions investigated :

- *Hybrid Micromegas + GEM detector :*
  - Gain shared between amplification gap and GEM foil
  - Diffusion of the primary electron cloud



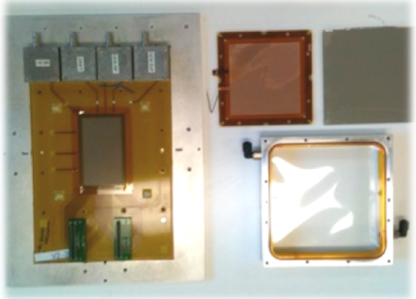
- *Resistive Micromegas with buried resistors*
  - Quick rise of the resistive pads' potential
  - Limitation of the discharge amplitude
  - Compatible with a pixelized readout

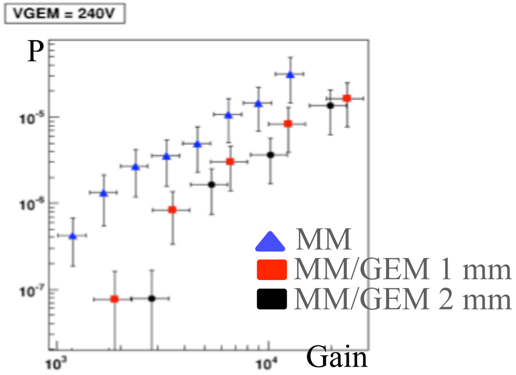


Design by Rui de Oliveira et al.

Detectors development

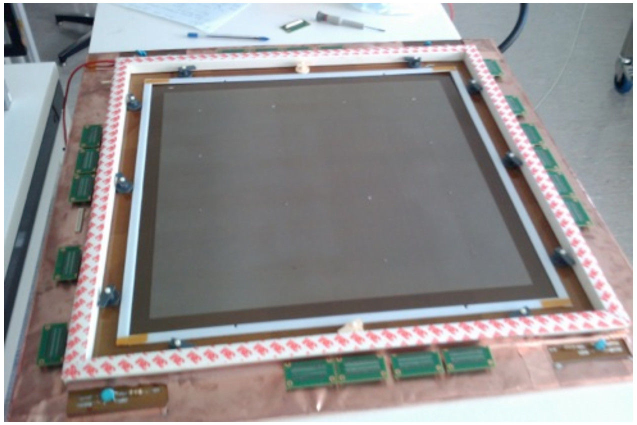
- **2009-2010** : Discharge-reduction studies on small prototypes in test beams (PS and SPS)





- **2009** : First pixelized prototypes (30 x 30 cm^2) tested in COMPASS
  - *Square pixels in the center*
  - *Light and integrated front-end electronics based on APV ASIC*

- **2010** : First 40 x 40 cm^2 prototype
  - *Rectangular pixels*
  - *Validation of geometry*

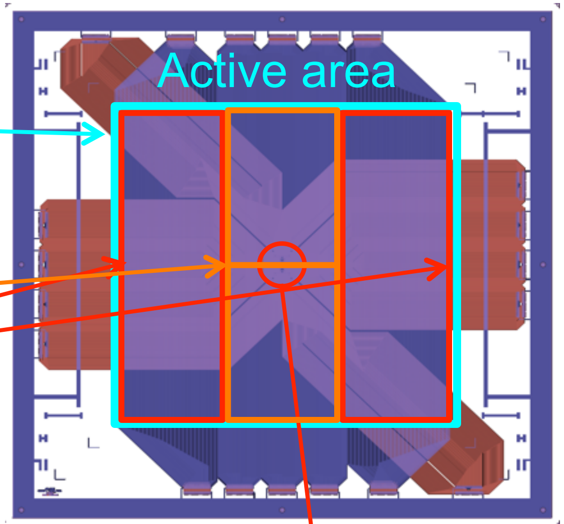


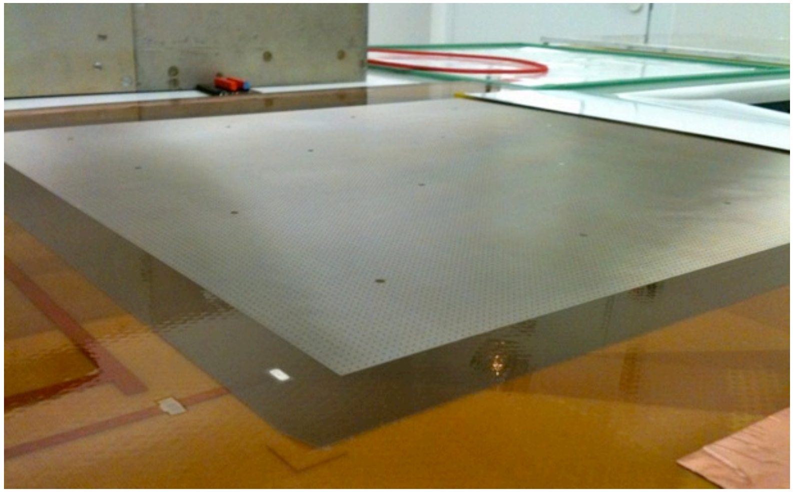
- **2011** : 3 40 x 40 cm^2 prototypes
  - *2 Hybrid detectors*
  - *1 Resistive prototype*

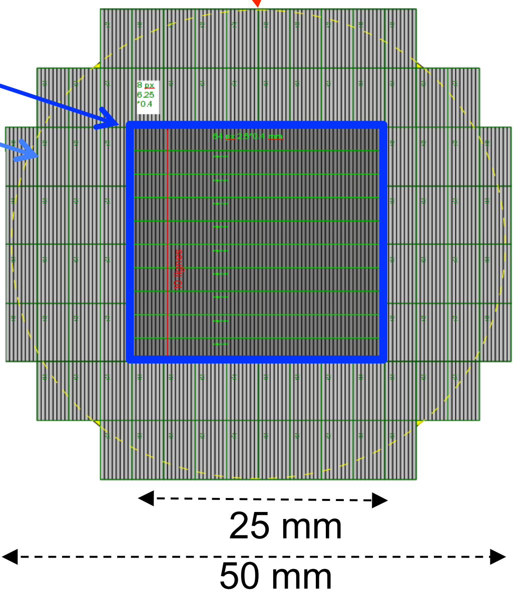
Large size detectors : readout

Nominal design after 3 years of development

- 40 x 40 cm^2 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*



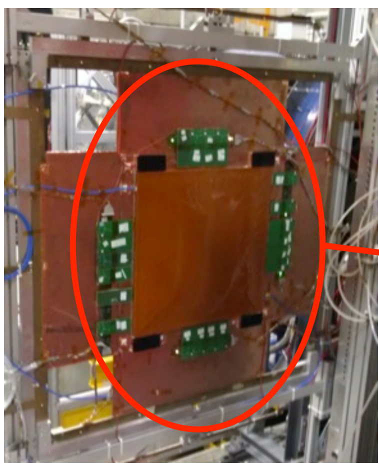




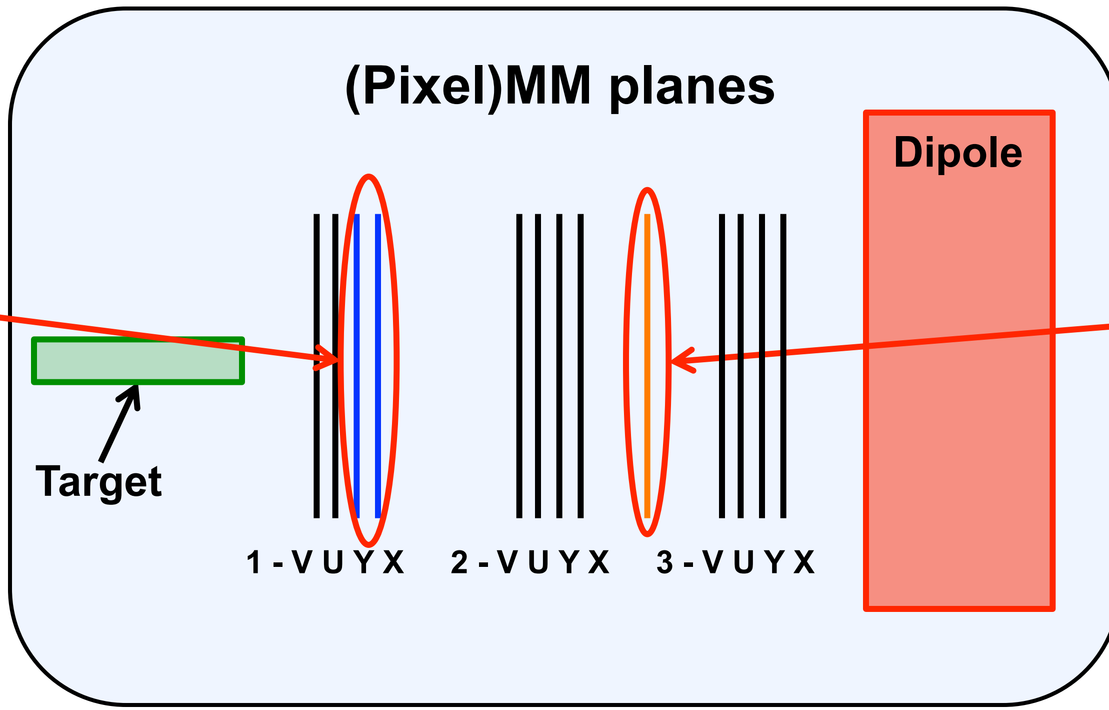
2012 : Pixel Micromegas included in COMPASS tracking

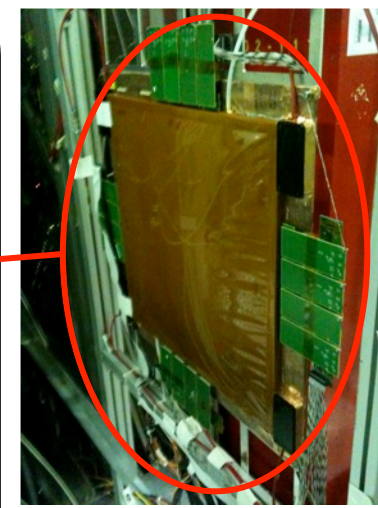
- *2 hybrid detectors replace 2 standard Micromegas detectors*
- *1 resistive prototype is tested in hadron beam*

- ***Micromegas detectors used for the first time at a so high flux (up to 8 MHz/cm^2) in a physics experiment***



PMM_2012.1
PMM_2011.2
Hybrid



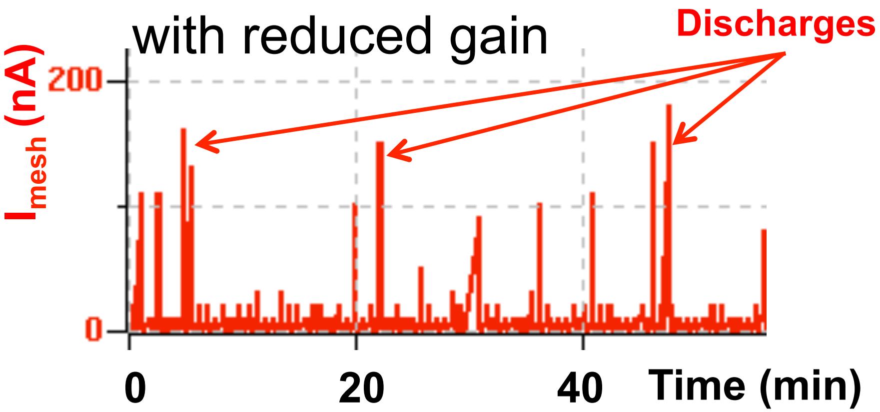


PMM_2011.3
Resistive

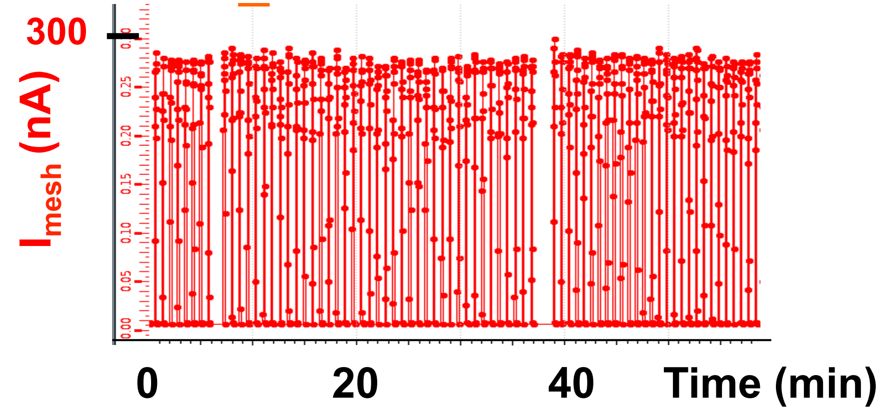
Discharges

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

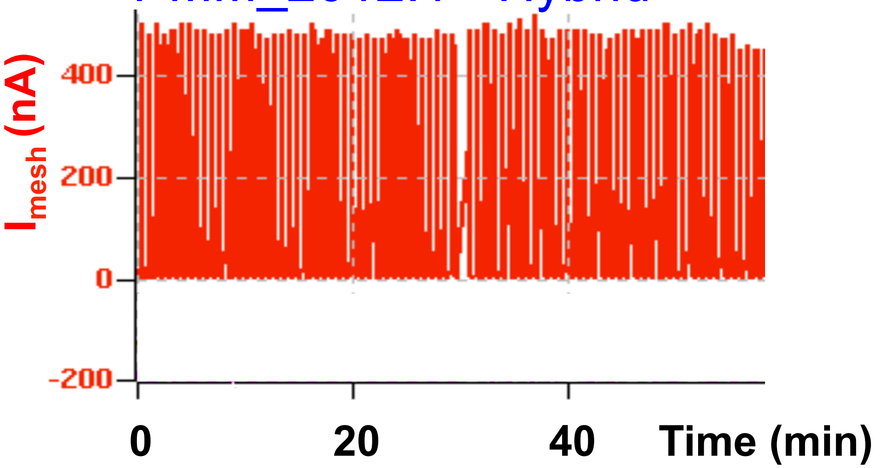
Standard MM
with reduced gain



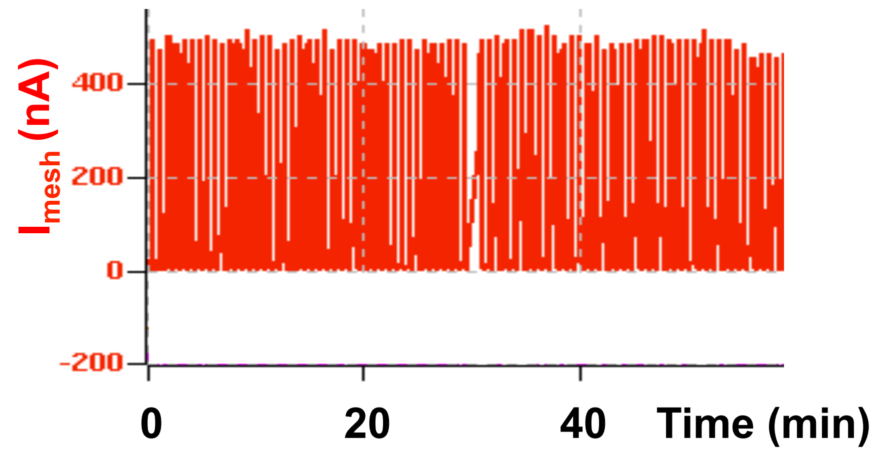
PMM_2011.3 - Resistive



PMM_2012.1 - Hybrid

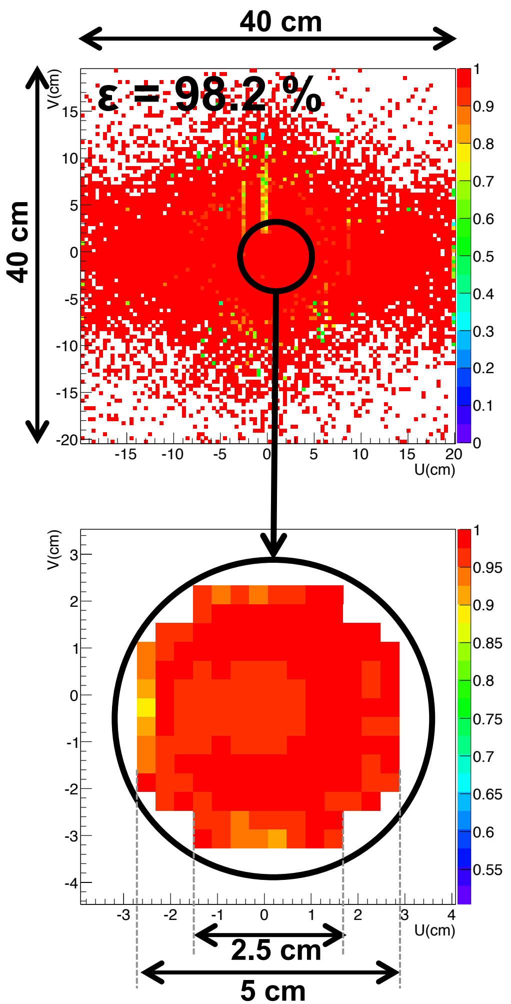


PMM_2011.2 - Hybrid

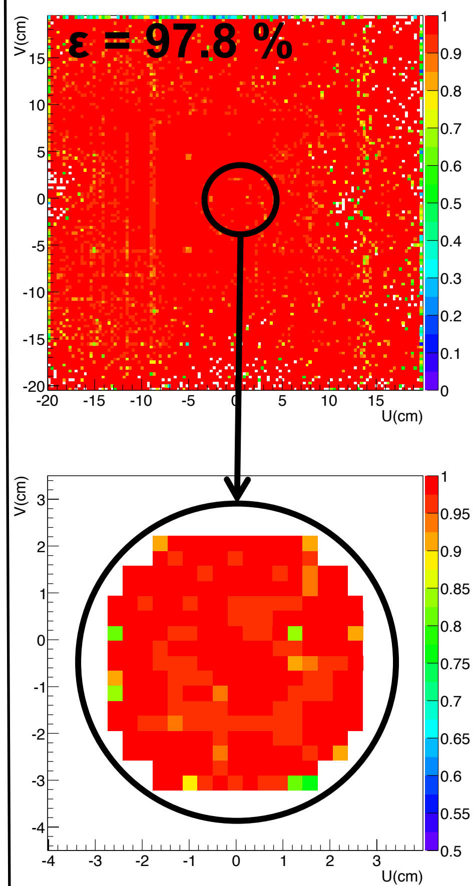


Efficiency ($\Phi = 9 \times 10^5\ s^{-1}$)

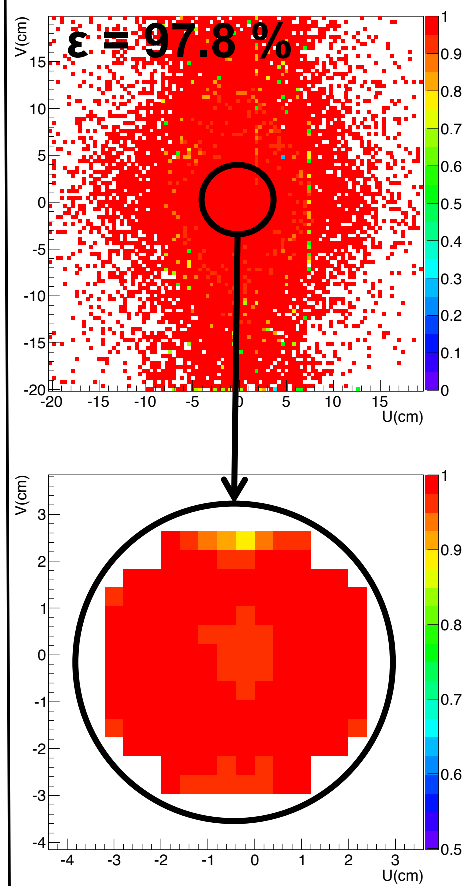
PMM_2012.1 - **Hybrid**



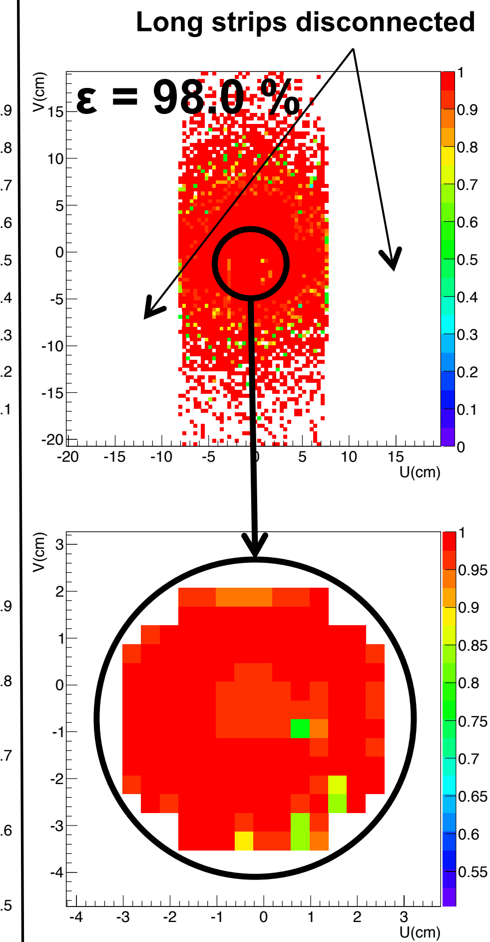
PMM_2011.1 - **Hybrid**



PMM_2011.2 - **Hybrid**



PMM_2011.3 - **Resistive**



Efficiency

PMM_2011.1 Hybrid	μ^+ $\Phi=9x10^5\ s^{-1}$	μ^+ $\Phi=5x10^7\ s^{-1}$
Pixels	97.9%	95.7%
Strips	97.8%	97.0%

PMM_2012.1 Hybrid	μ^+ $\Phi=9x10^5\ s^{-1}$	μ^+ $\Phi=5x10^7\ s^{-1}$
Pixels	98.4%	96.8%
Strips	97.8%	97.0%

PMM_2011.3 Resistive	μ^+ $\Phi=9x10^5\ s^{-1}$	μ^+ $\Phi=5x10^7\ s^{-1}$
Pixels	97.9%	Not tested
Strips	98.1%	Not tested

Efficiency > 95% in all conditions

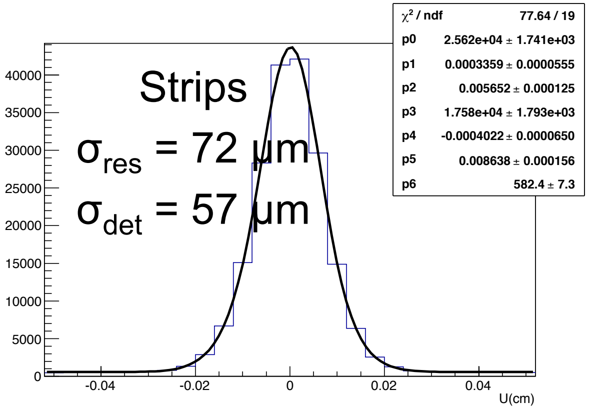
Slight decrease at highest intensity :

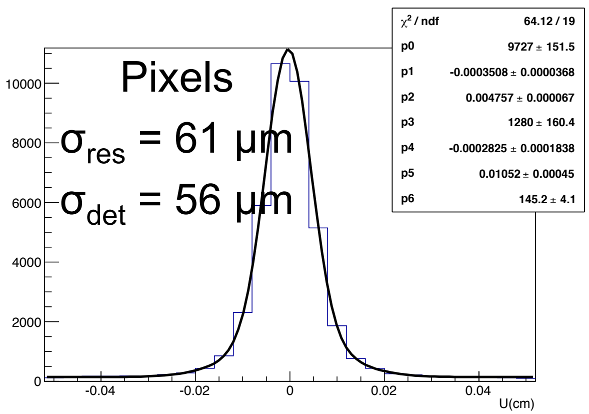
- *Pixels : ~ 1.5%*
- *Strips : < 1%*

Spatial Resolution

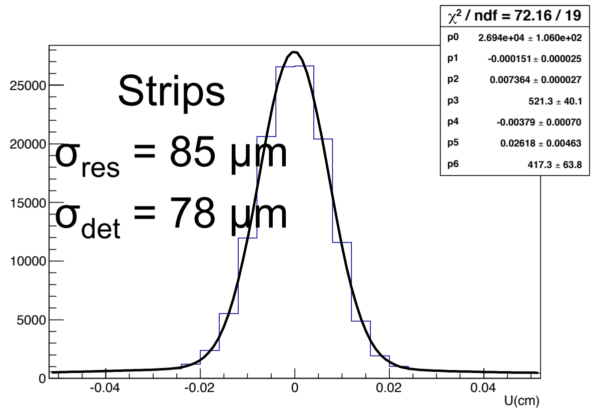
- Residual plots with low flux and dipole field off
- Dectector resolution : $\sigma_{detector} = \sqrt{\sigma^2_{residual} - \sigma^2_{tracking}}$

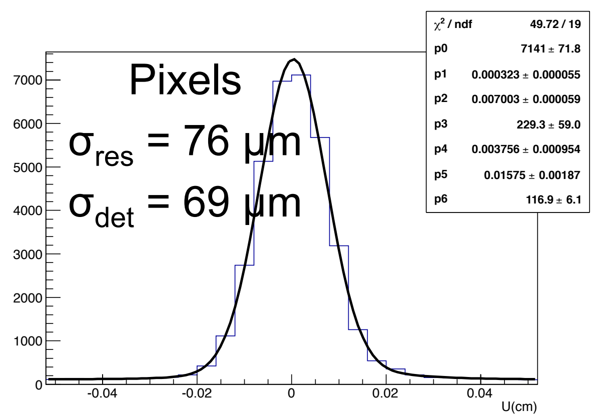
PMM_2011.2 - Hybrid



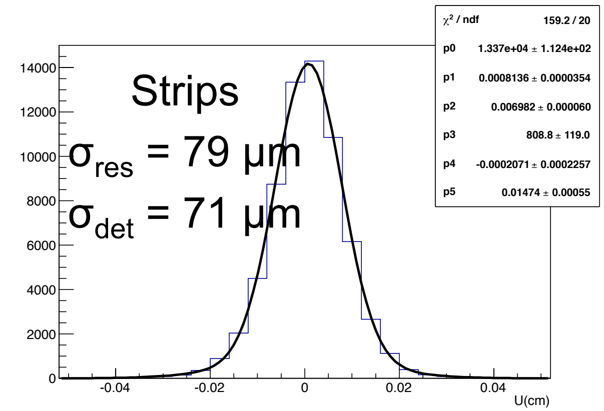


PMM_2011.3 - Resistive





MM02X (standard Micromegas)



- $\sigma_{PMM+GEM} < \sigma_{standard\ MM}$
- $\sigma_{PMM+BR} \sim \sigma_{standard\ MM}$

Spatial Resolution : influence of the beam flux

Detector	μ^+ $\Phi=9x10^5\ s^{-1}$ (µm)	μ^+ $\Phi=4x10^6\ s^{-1}$ (µm)	μ^+ $\Phi=5x10^7\ s^{-1}$ (µm)
MM01U (standard Micromegas)	65	67	74
PMM_2011.2 Hybrid (strips)	56	57	72
PMM_2011.2 Hybrid (pixels)	57	57	87 PRELIMINARY*
PMM_2011.3 Resistive (strips)	119 (78)	139	Not tested
PMM_2011.3 Resistive (pixels)	111 (69)	127	Not tested
MM02X (standard Micromegas)	104 (71)	107	Not tested

Hybrid PMM

Strips :

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

Pixels :

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

Resistive PMM

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

Close to dipole - resolution with dipole off in parenthesis

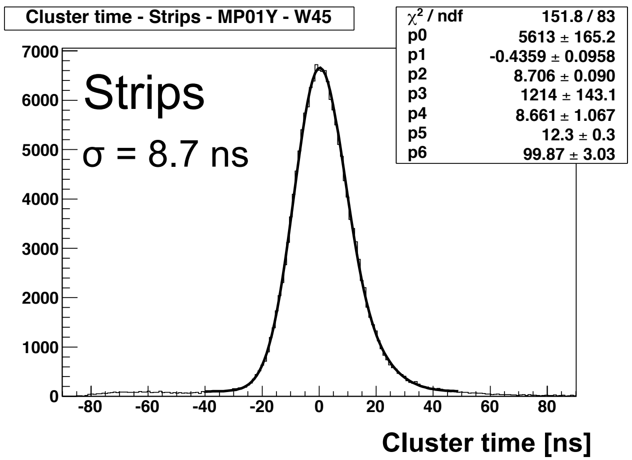
*Lack of redundancy at small angle
➔Poor tracking resolution

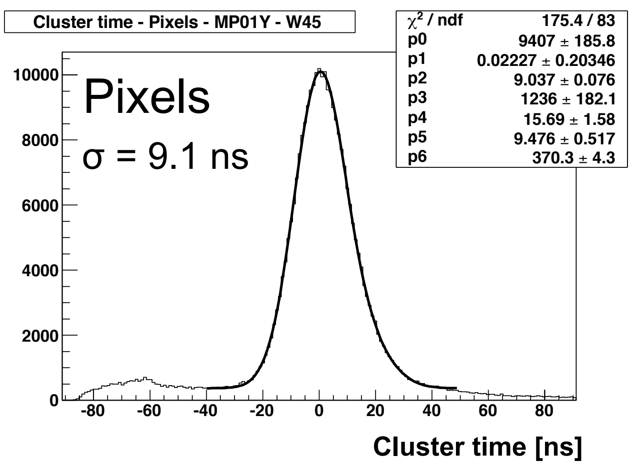
Time Resolution : Gas Mixture

PMM_2011.2 - **Hybrid**

Muon run

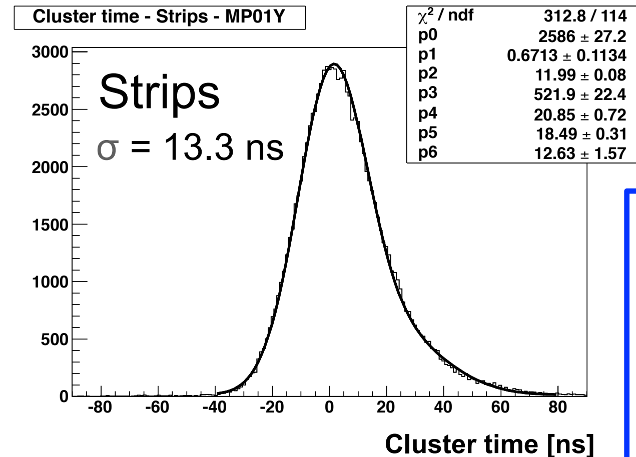
80% Ne + 10% C_2H_6 + 10% CF_4

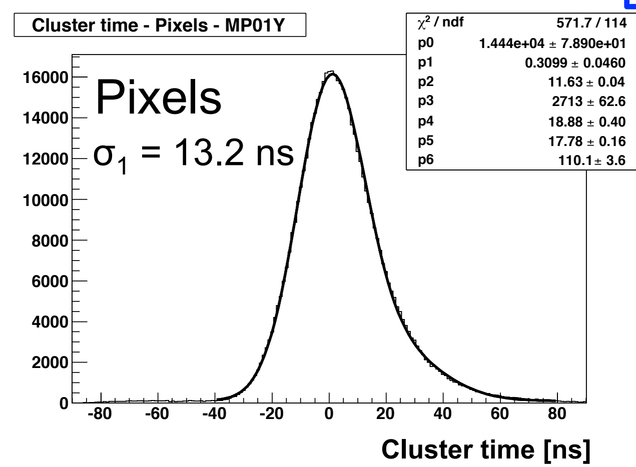




Hadron run

85% Ne + 10% C_2H_6 + 5% CF_4



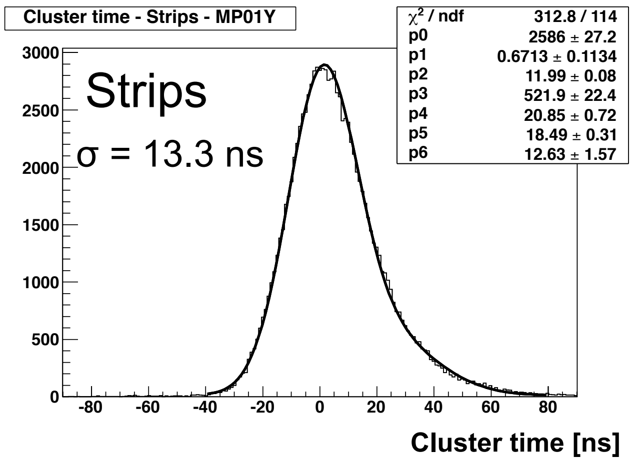


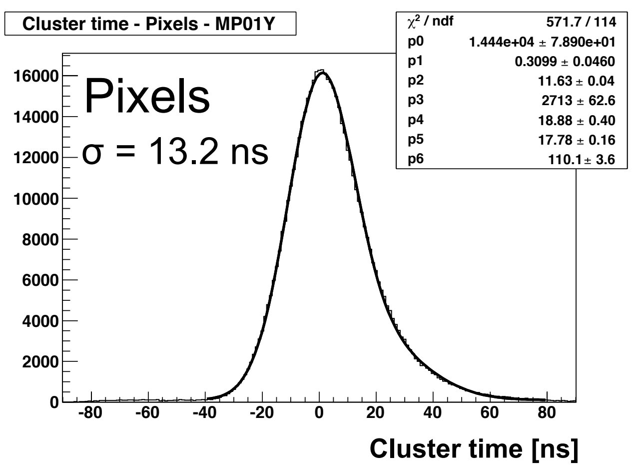
- *CF_4 10% -> 5% 40% degradation*
- *$\sigma_{HybridPMM} \sim \sigma_{MM}$*

Time Resolution : Hybrid vs Resistive

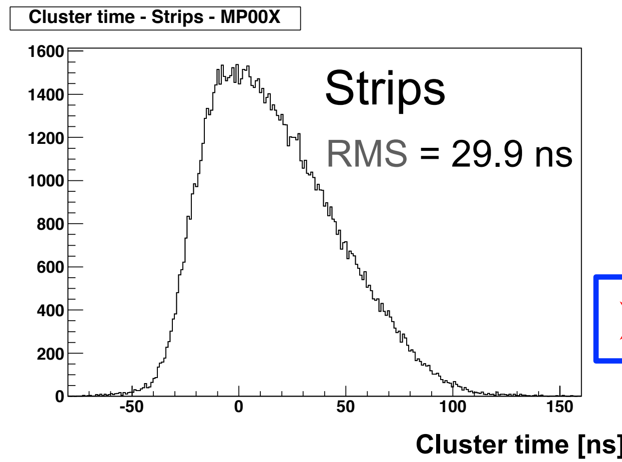
Hadron run : 85% Ne + 10% C_2H_6 + 5% CF_4

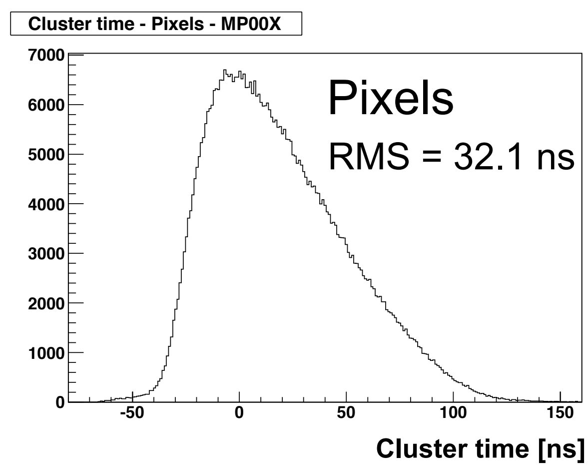
PMM_2011.2 - **Hybrid**





PMM_2011.3 - **Resistive**



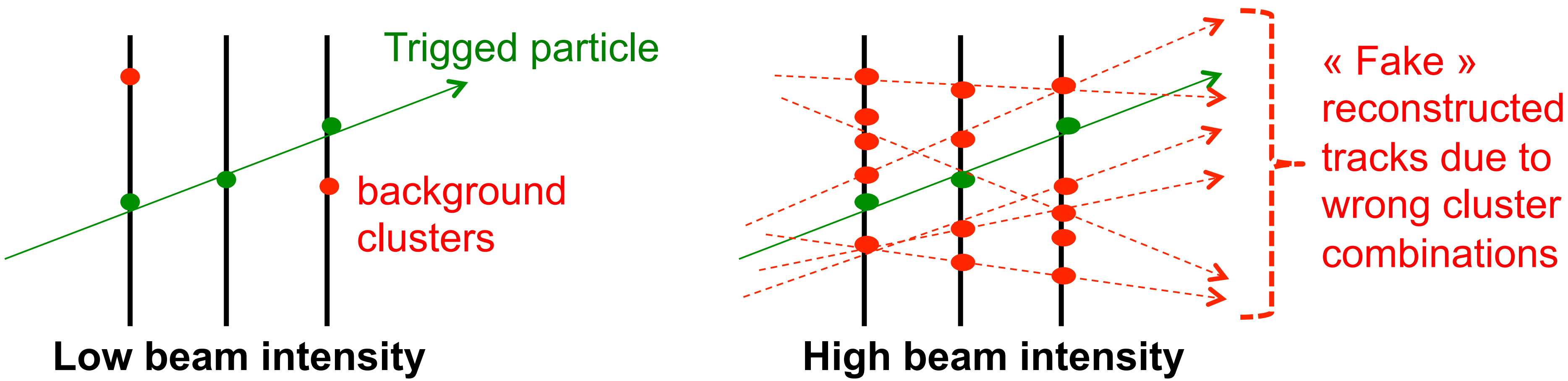


➢ $\sigma_{resistive} >> \sigma_{Hybrid}$

Pixel Micromegas and track reconstruction

- 2012 DVCS run - difficult conditions for tracking close to the beam :
  - Flux up to 8 MHz/cm^2 -> high background (beam + low energy electrons)
  - Only 5 detectors between target and dipole -> PMMs = 40% of the trackers

➢ High probability of combinatorial background -> fake tracks reconstructed



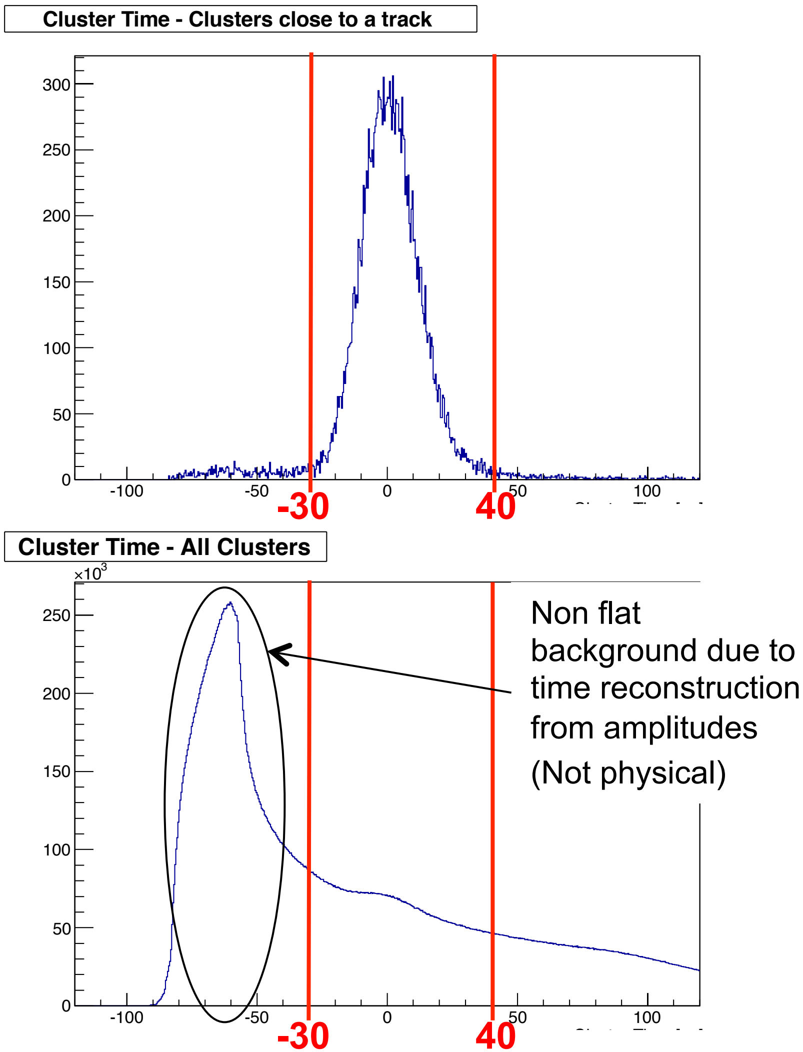
- Solutions to reduce combinatorial background at high beam intensity :
  - More detectors for very small angle tracking (12 Pixel Micromegas in 2015)
  - **Precise time cuts to exclude off time clusters**

Time Cuts

Amount of clusters on the **pixelized area** in the highest beam flux (up to 8 MHz/cm^2)

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%

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



Impact of Time Cuts on the track reconstruction

- **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^+ $\Phi = 5 \times 10^7\ s^{-1}$ 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%

- Amount of rejected events reduced by 90%
- Reduction of the combinatorial background

- Pixel MM time resolution = **crucial parameter** for tracking. Several options to improve it in the future :
  - Reduction of the drift space width (5 mm -> 3 mm)
  - Higher quantity of CF_4 in the gas mixture

Conclusion

- **2012 : Micromegas detectors used for tracking in a flux up to 8 MHz/cm^2 for the 1st time in a physics experiment**

- 2 spark-protection technologies used, **no spark observed in nominal intensity hadron beam**.

- **Hybrid Pixel Micromegas (3 detectors) :**
  - Conception requirements reached
    - **Efficiency > 95 %** at highest beam intensity (low intensity : 98 %)
    - **Spatial resolution < 100 μm** at highest beam intensity (low intensity, magnet off : 60 μm)
    - **Time resolution < 10 ns**

- **Resistive Pixel Micromegas (1 detector) :**
    - Efficiency ~ 98 % at low beam intensity
    - Spatial resolution ~ 70 μm at low beam intensity, magnet off
    - **Time resolution > 30 ns**

- **Tracking** : cut on cluster time (-30 ns to 40 ns) : **reduction of combinatorial background**

Outlook

- **Choice of spark-protection technology for the final detectors : Hybrid detectors**
  - Well known technology (3 large-size prototypes tested)
  - Better performance than the resistive detector
  - Easier to produce than resistive detectors

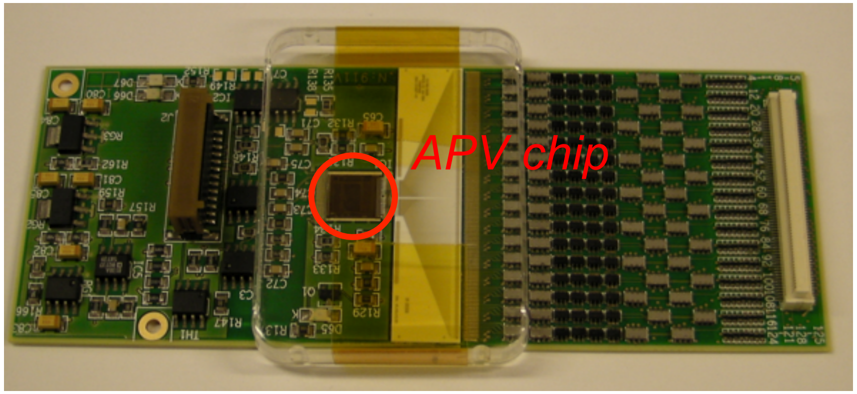
- **Production :** final detectors will be produced by the **CIREA-ELVIA company**.

- **Complete installation :** replacement of the 12 standard Micromegas by Pixel Micromegas foreseen for the first COMPASS II run in early 2015.

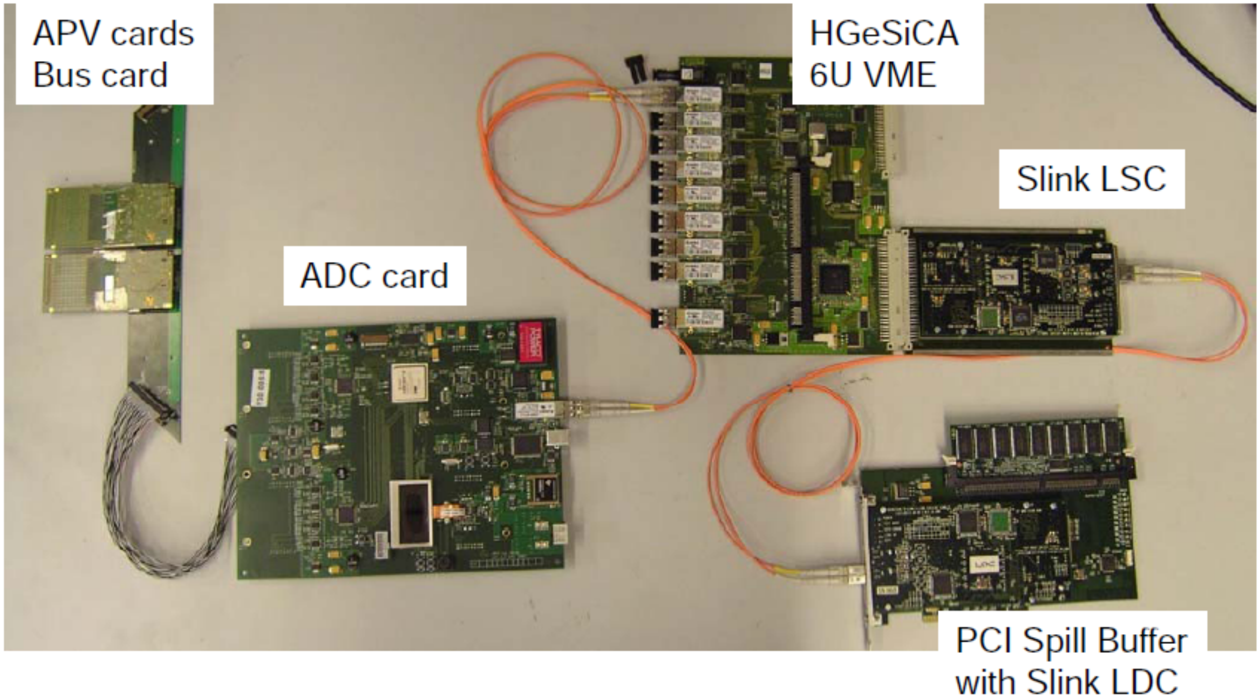
Backup Slides

Large size detectors : front-end electronics

- APV card
  - Preamplification / shaping

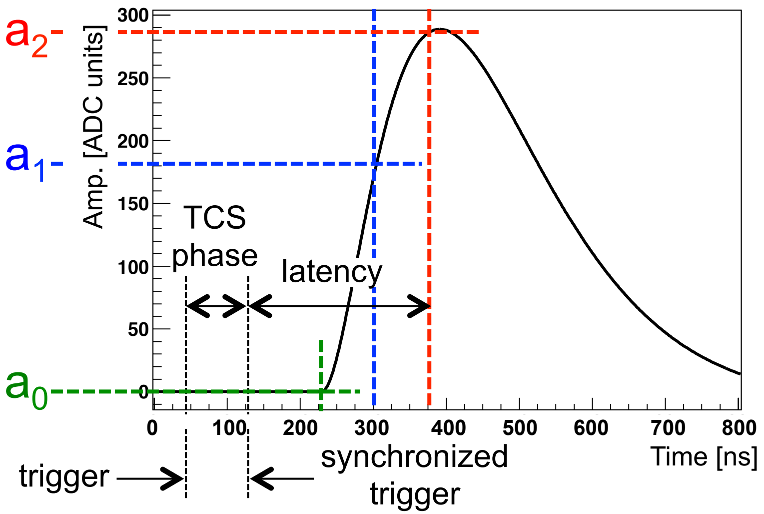


- ADC board
  - Analog to digital conversion
- HGeSiCA board
  - Data concentrator
  - Trigger distribution
- Chain designed for COMPASS GEM and Silicon detectors by TUM

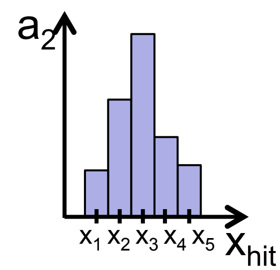


Large size detectors : data reconstruction

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

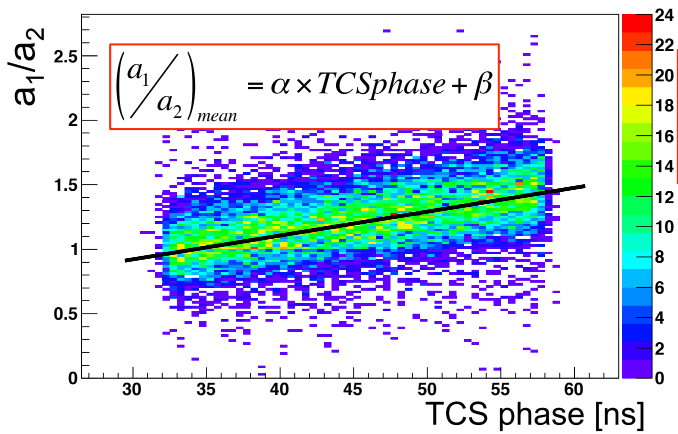


➢ *Sample* ***a_2*** *used for* ***position reconstruction***



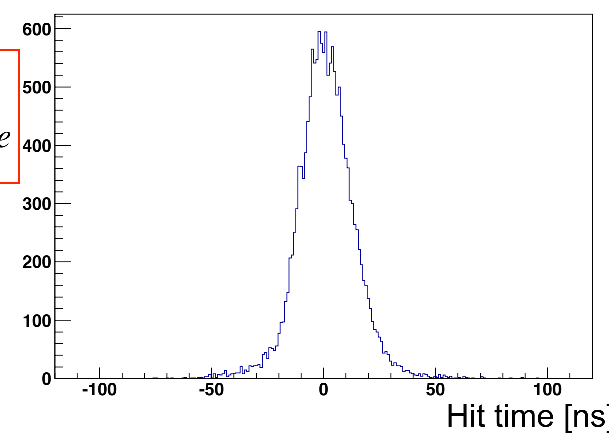
$$x_{cluster} = \frac{\sum_{hit} x_{hit} \times a_{2,hit}}{\sum_{hit} a_{2,hit}}$$

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

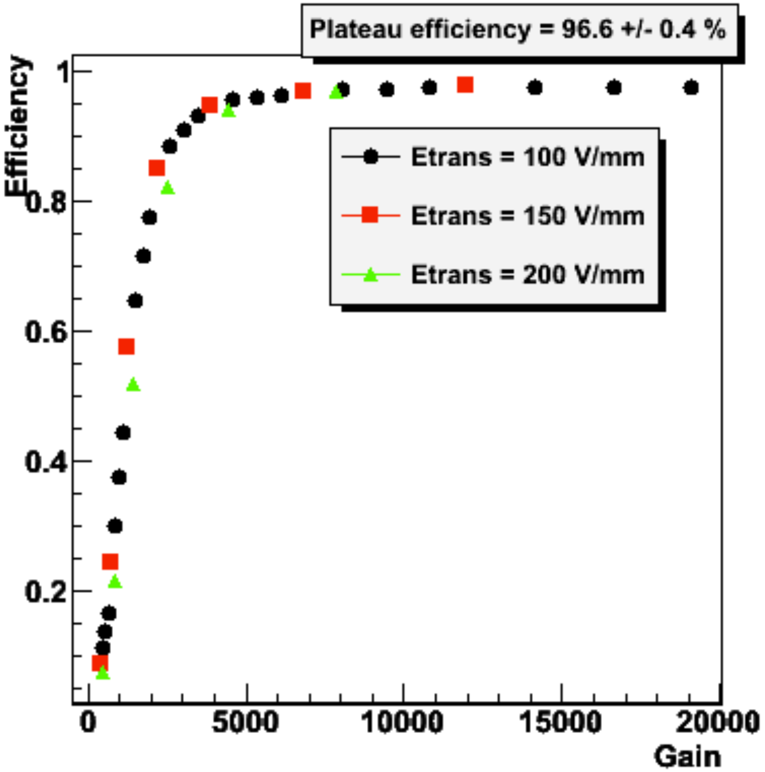


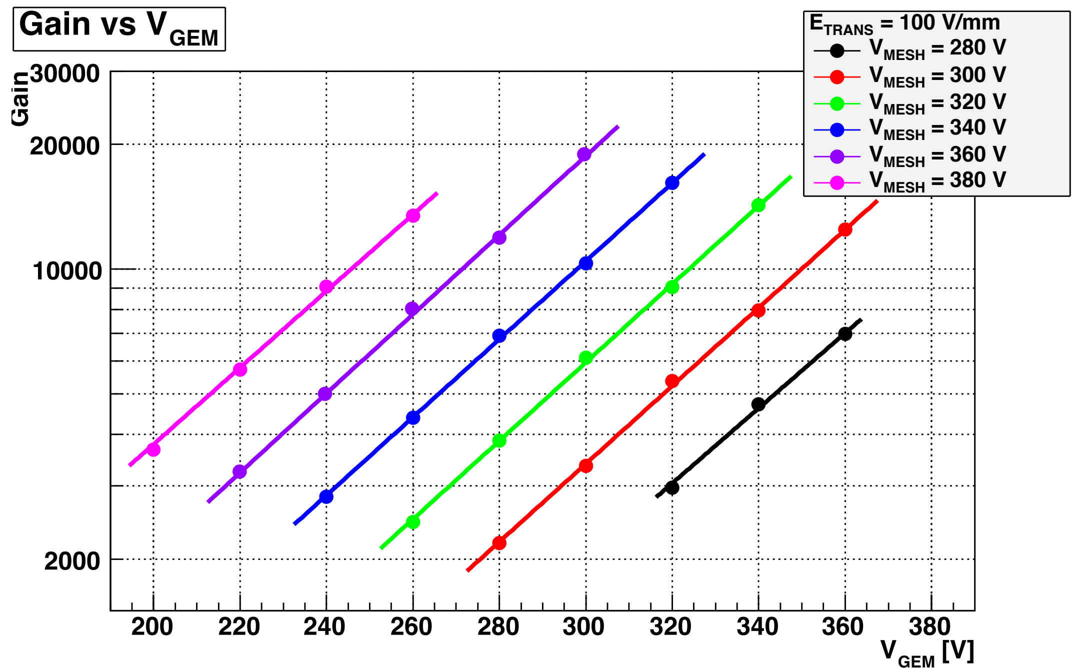
$$\left(\frac{a_1}{a_2}\right)_{mean} = \alpha \times TCSphase + \beta$$

$$t_{hit} = \frac{\left(\frac{a_1}{a_2}\right)_{mean} - \beta}{\alpha} - TCSphase$$

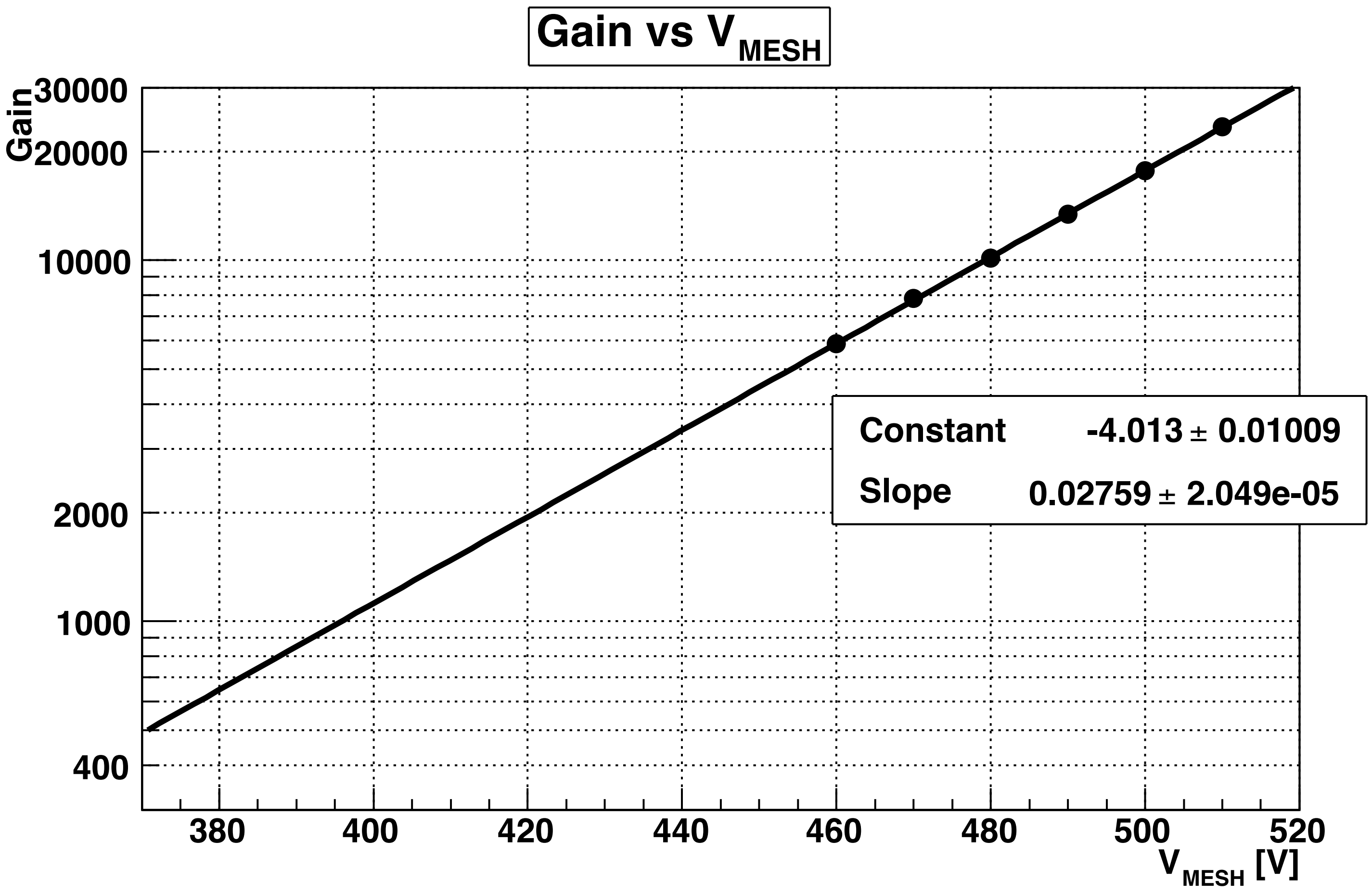


PMM + GEM : gain & efficiency





PMM BR : gain



Gain vs V MESH
Gain
30000
20000
10000
2000
1000
400
380
400
420
440
460
480
500
520
V MESH [V]
Constant -4.013 ± 0.01009
Slope 0.02759 ± 2.049e-05

Efficiency

PMM_2011.1 GEM	μ^+ $\Phi=9x10^5\ s^{-1}$	μ^- $\Phi=2x10^7\ s^{-1}$	μ^+ $\Phi=5x10^7\ s^{-1}$
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^+ $\Phi=9x10^5\ s^{-1}$	μ^- $\Phi=2x10^7\ s^{-1}$	μ^+ $\Phi=5x10^7\ s^{-1}$
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^+ $\Phi=9x10^5\ s^{-1}$	μ^- $\Phi=2x10^7\ s^{-1}$	μ^+ $\Phi=5x10^7\ s^{-1}$
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^+ $\Phi=9x10^5\ s^{-1}$	μ^- $\Phi=2x10^7\ s^{-1}$	μ^+ $\Phi=5x10^7\ s^{-1}$
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

Efficiency : hadron beam

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%

Spatial Resolution : influence of the dipole field

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

Detector	μ^+ Φ=9x10^5 s^{-1} Dip. OFF (µm)	μ^+ Φ=9x10^5 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

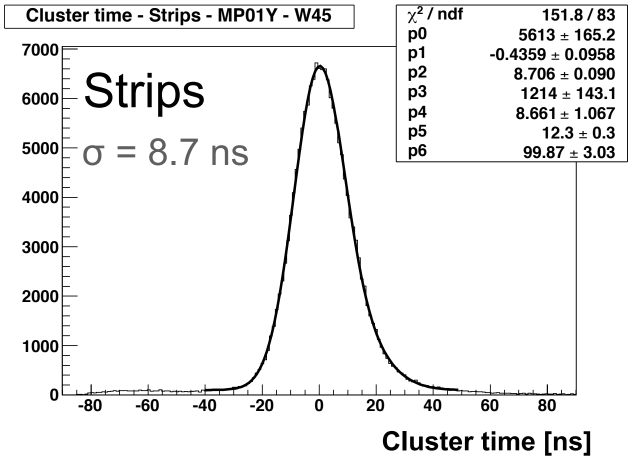
➢ *No effect*

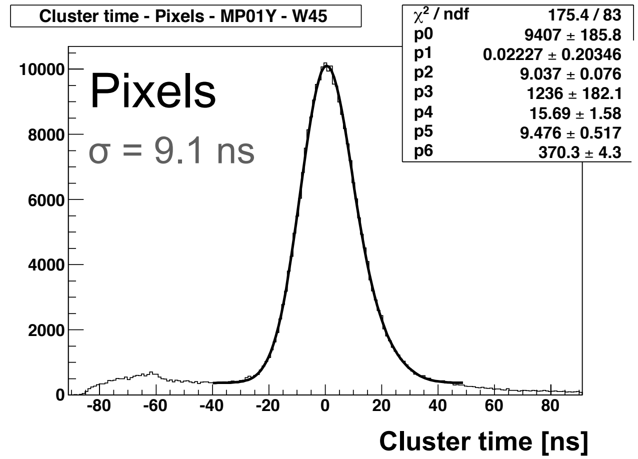
Close to dipole

➢ *Degradation (~ +50%) similar for standard MM and PMM_2011.BR*

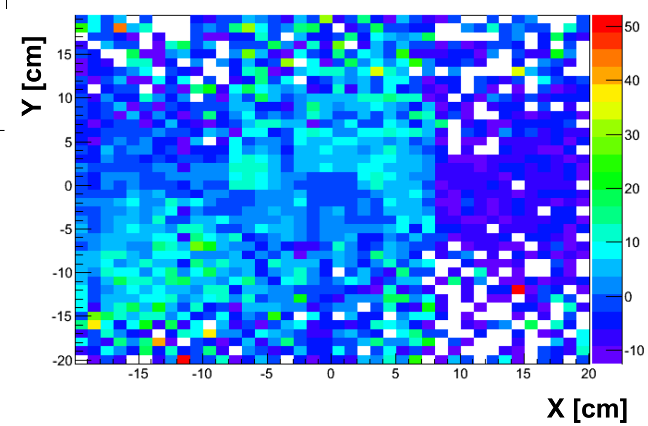
Time Resolution vs position

PMM_2011.2 (PixelMM w/ GEM)

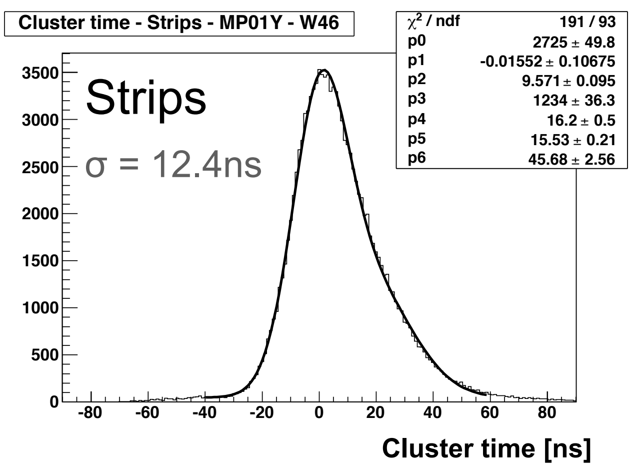


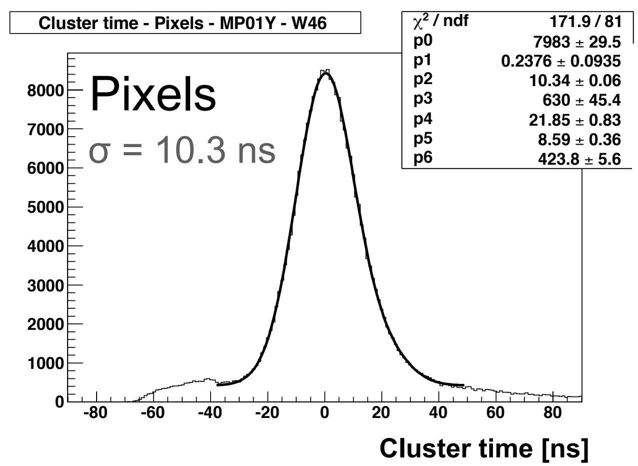


Mean cluster time vs position

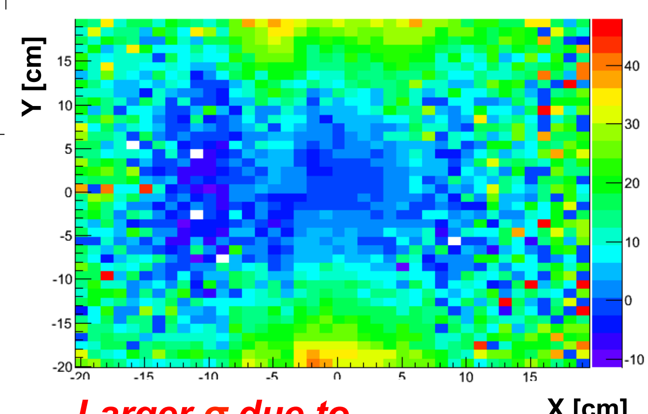


PMM_2012.1 (PixelMM w/ GEM)



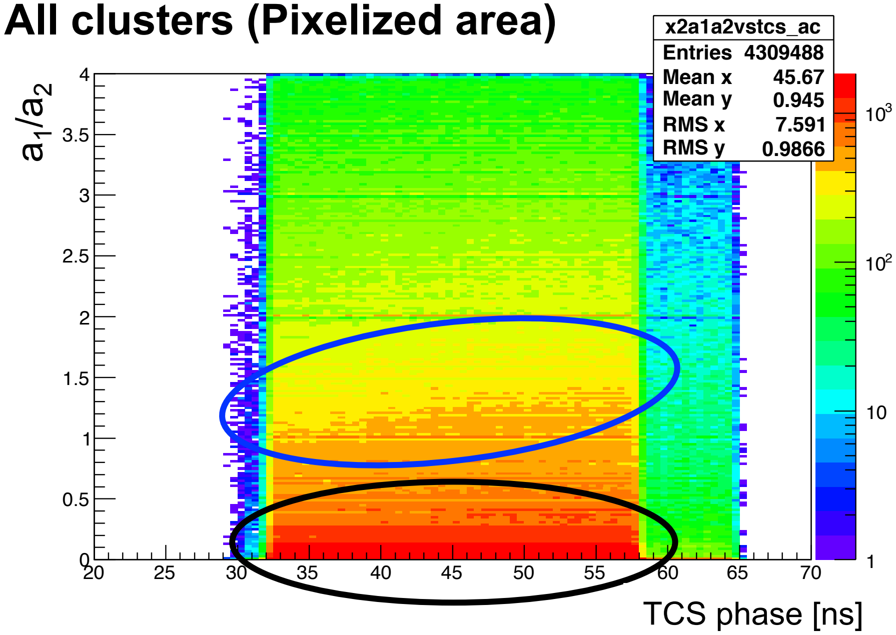


Mean cluster time vs position

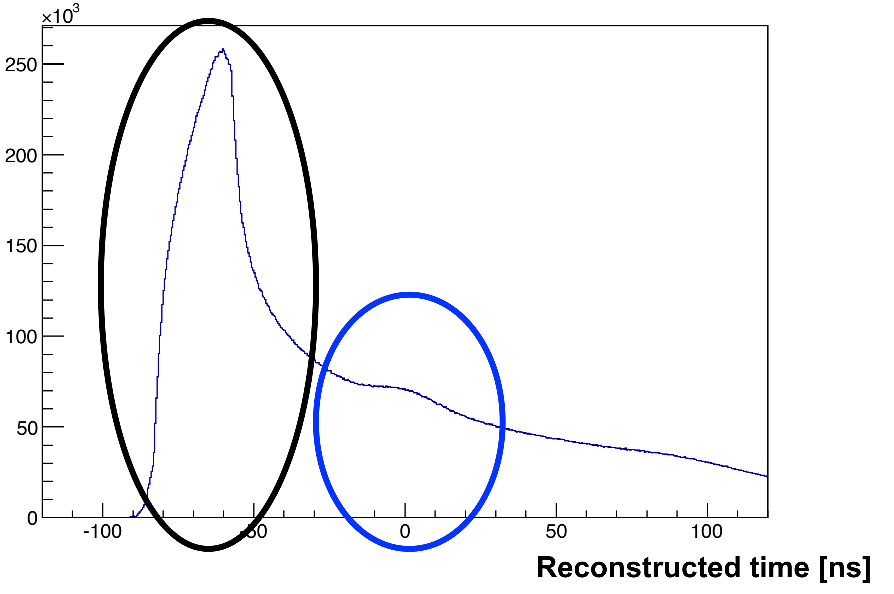


Larger σ due to detector curvature

All clusters (Pixelized area)



All clusters (Pixelized area)



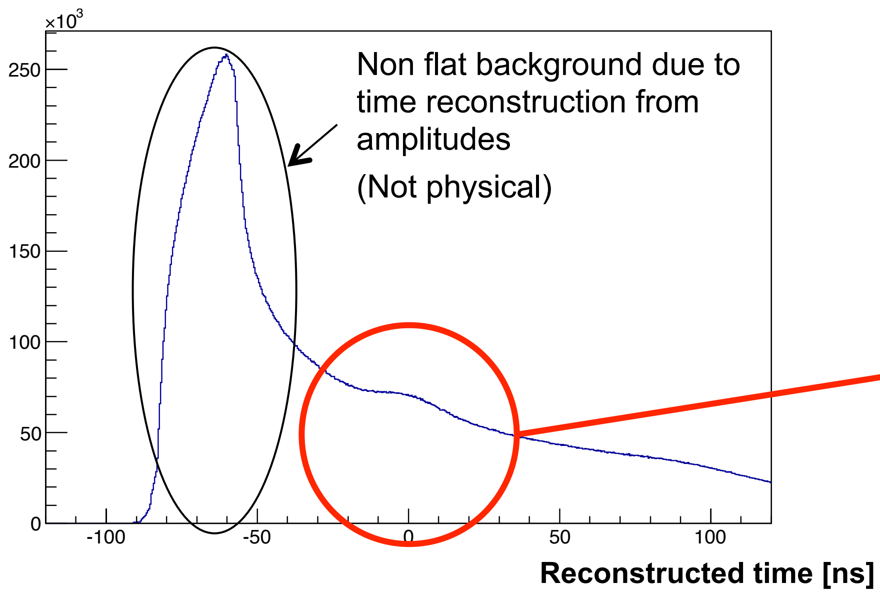
Pixel Micromegas and track reconstruction

2012 High flux muon run ($5x10^7$ μ^+/s):

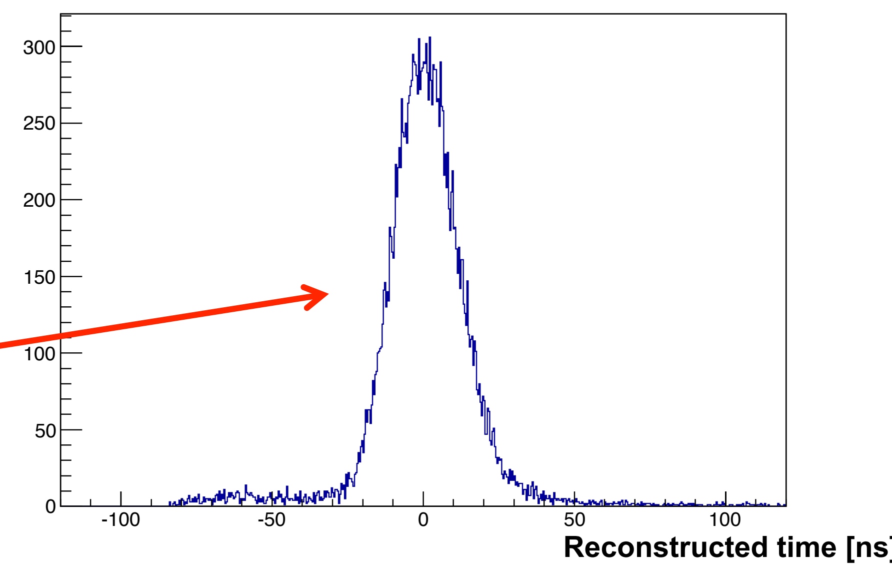
- 2 Hybrid PMM integrated in the tracking
- Difficult conditions for tracking close to the beam :
  - Beam flux up to 8 MHz/cm^2 -> high background
  - Only 5 detectors between target and dipole -> PMMs = 40% of the trackers

➢ High probability of combinatorial background

All clusters (Pixelized area)



Clusters close to a track (Pixelized area)



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

Impact of Time Cuts on the track reconstruction

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%