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Performances of large Pixelized Micromegas detectors in the COMPASS environment

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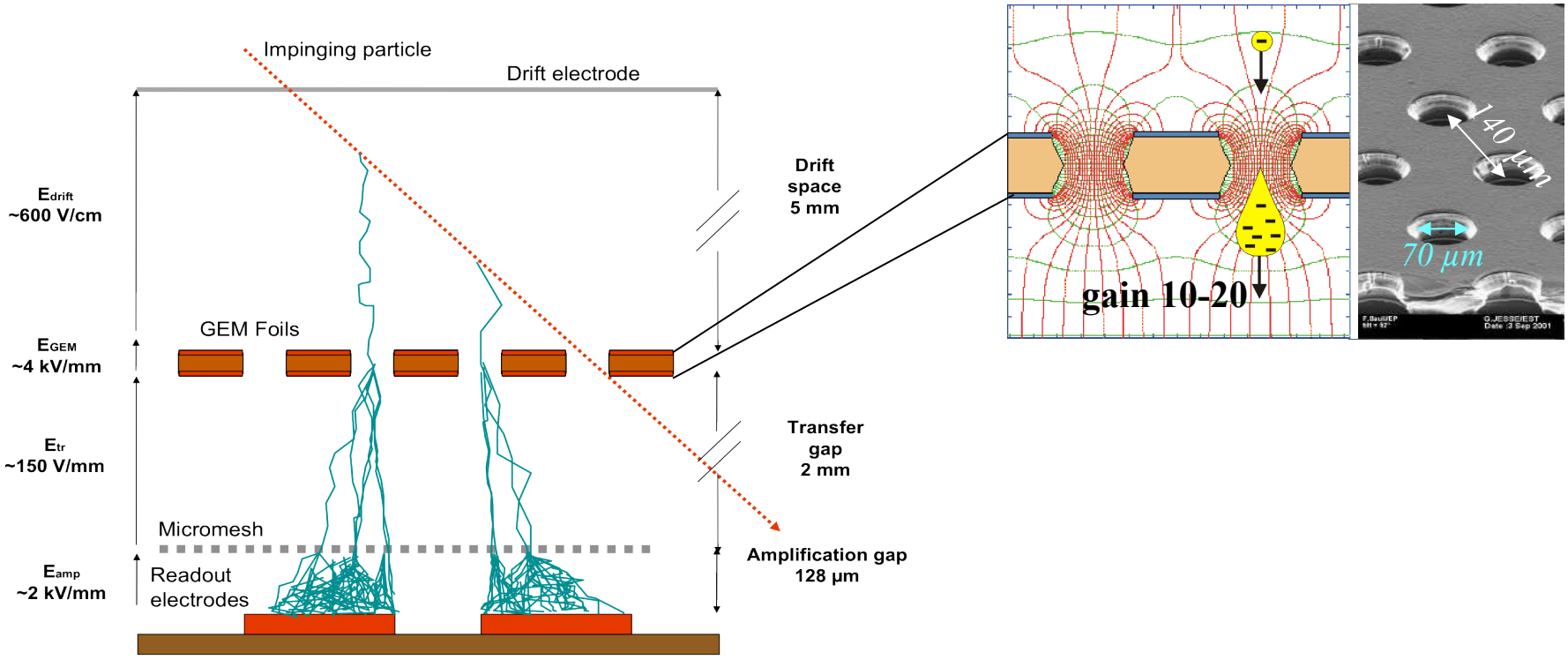
Outline

- Discharge reduction technologies
- Large size pixelized detectors
- Experimental setup
- Data Analysis
  - Elementary Clustering Algorithm
  - Cluster Merging
  - Correction of CoG position
  - Correction of Cross Talk in time
- Performances summary
  - 2011
  - 2012
- Conclusion
- Outlook

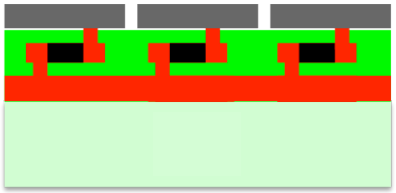
Discharge reduction technologies

- 2 solutions investigated to reduce the discharge rate :
- *Preamplification stage with a GEM foil*
  - Gain shared between amplification gap and GEM foil
  - Diffusion of the primary electron cloud

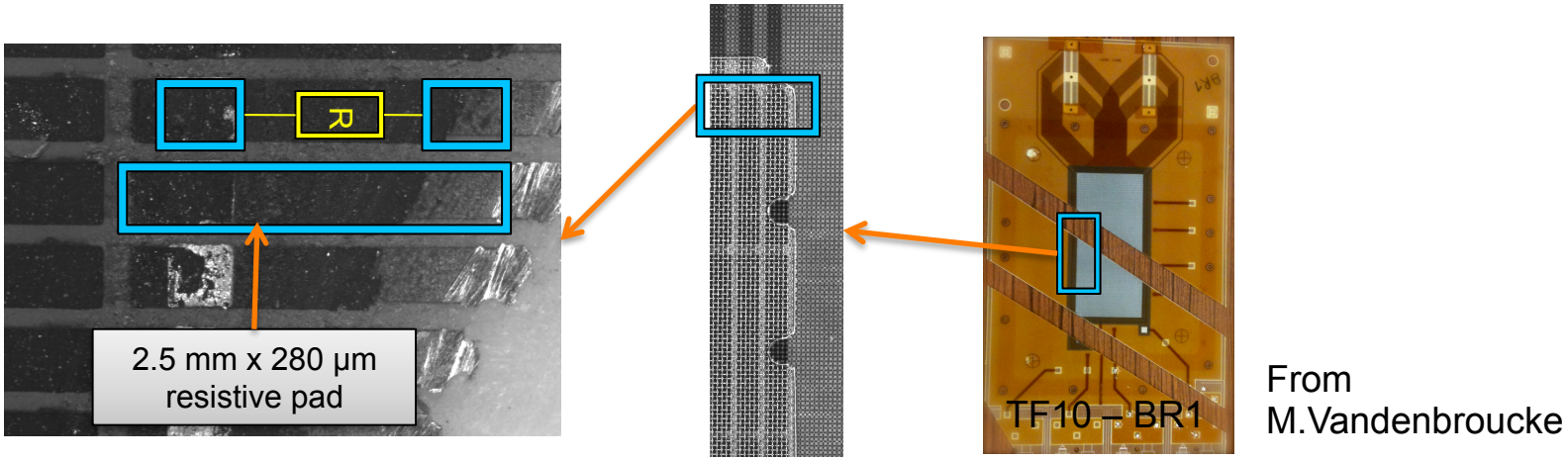


Discharge reduction technologies

- 2 solutions investigated to reduce the discharge rate :
- *Resistive layer on readout electrodes*
  - Quick rise of the electrode's potential
  - Limitation of the discharge intensity



Buried resistors "BR" connect strips to resistive pads

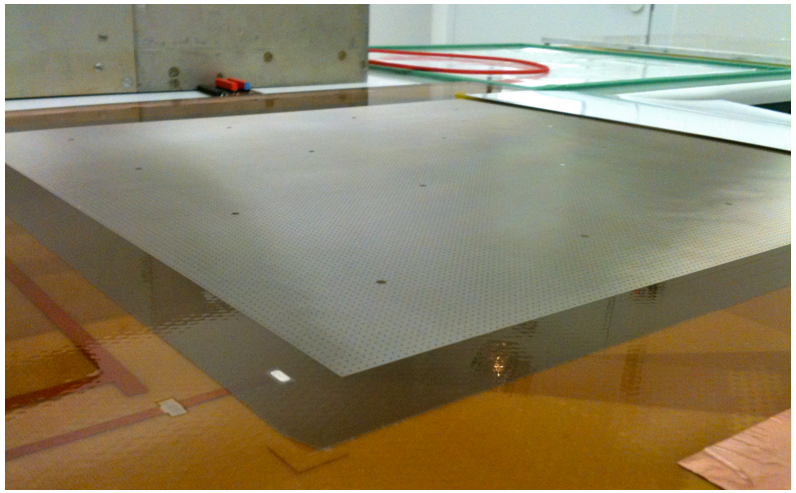


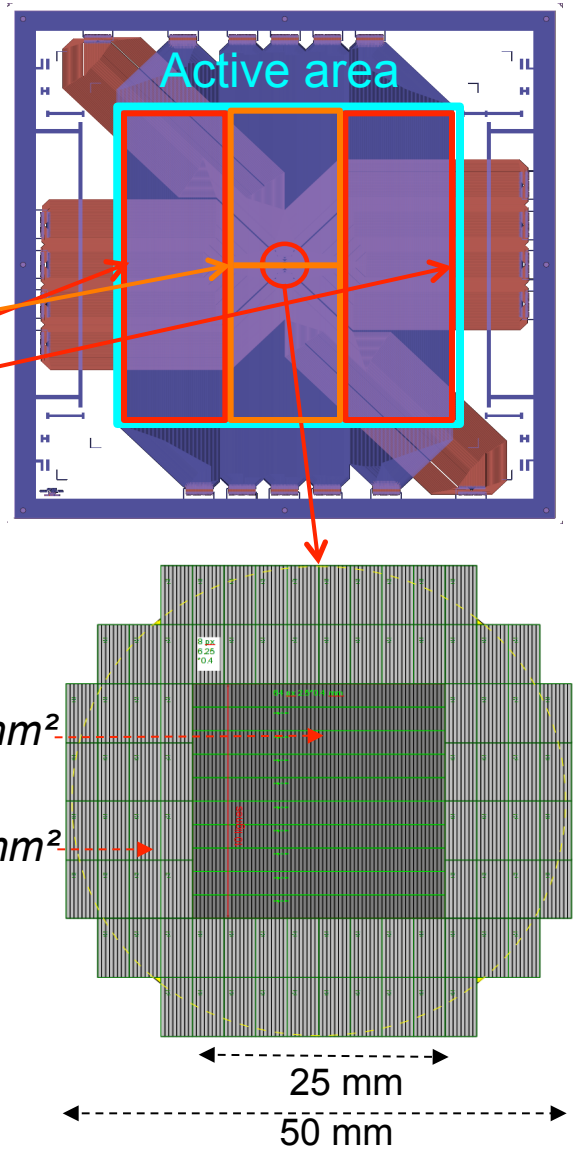
From M.Vandenbroucke

Large size detectors

Design of 2011 prototypes close to final one

- 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*





Experimental setup

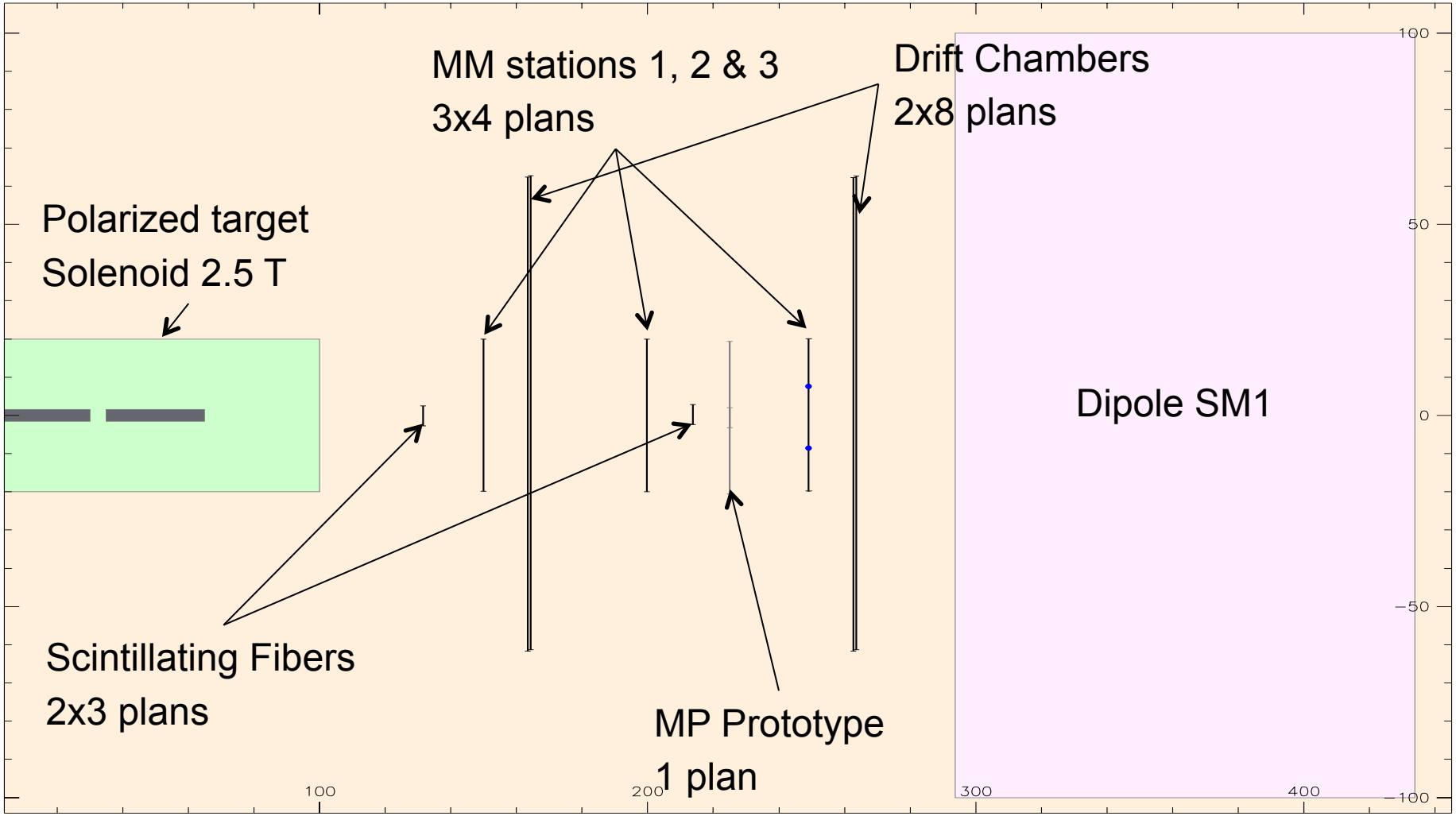
- 3 detectors tested in 2011 and 2012:
  - 2 PMM with GEM foil
  - 1 PMM with buried resistors

- All detectors tested in the COMPASS environment
  - *Up to 200 GeV muon and hadron beams*
  - *Flux from 10^5 to 10^7 μ(h)/s^{-1}*
  - *Fringe fields from polarized target and first dipole*

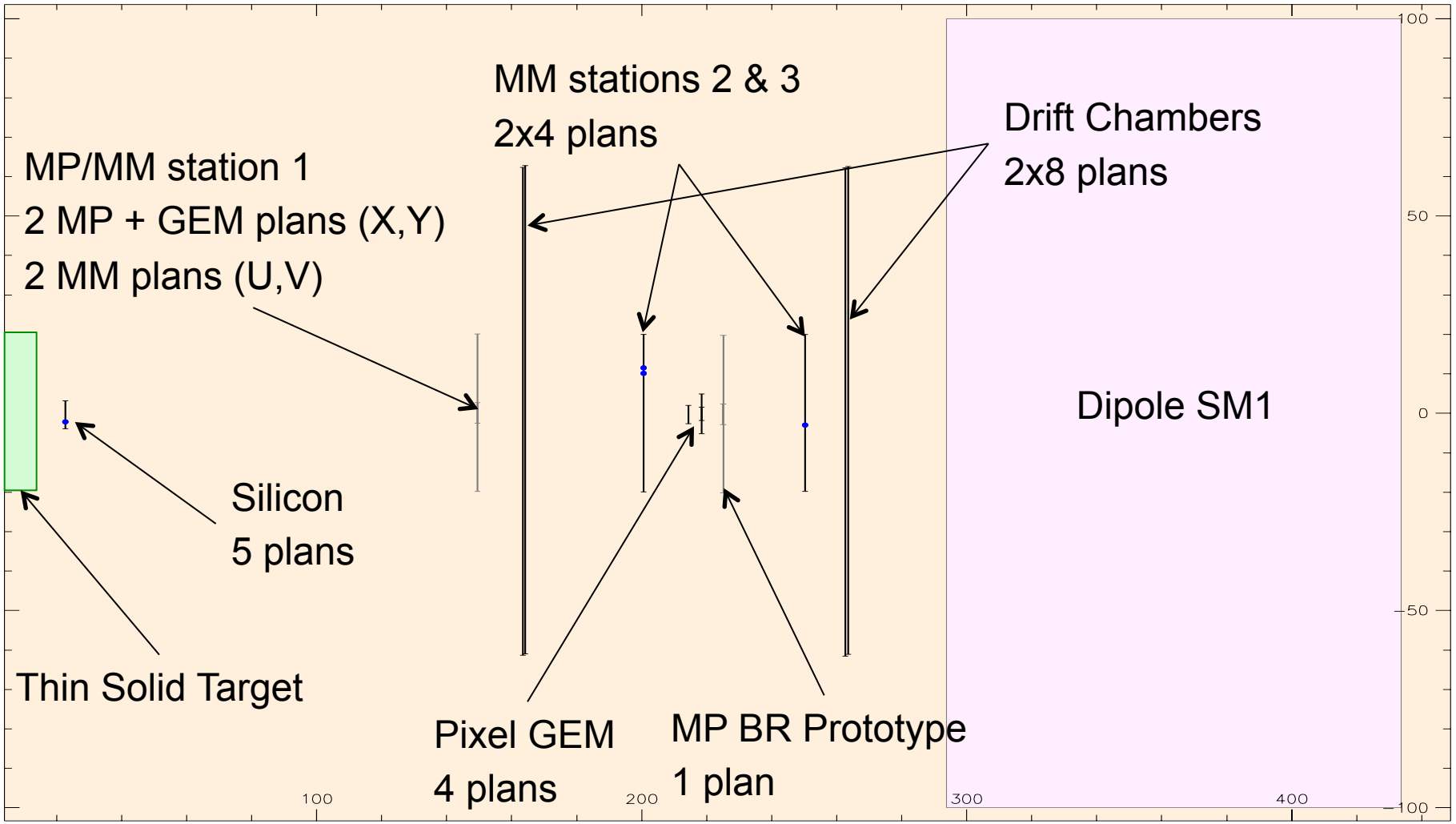
- Data acquisition and analysis
  - *Detectors integrated in the COMPASS DAQ system*
  - *Detectors response compared with tracks reconstructed by COMPASS software from other detectors*

Experimental setup : 2011

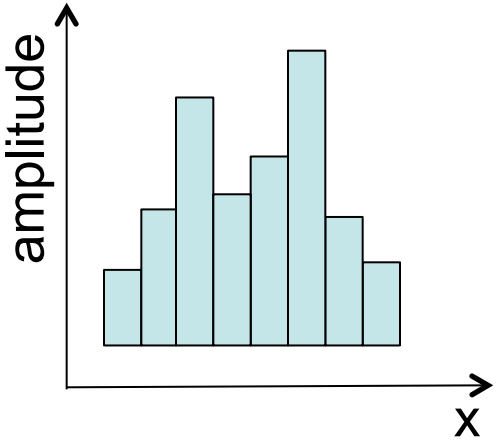
Projection 0.0 deg. Run 94827 Event 1048705 (1, 129) 0.0 ns Trigger(s) 10 16 30 Nhits 55



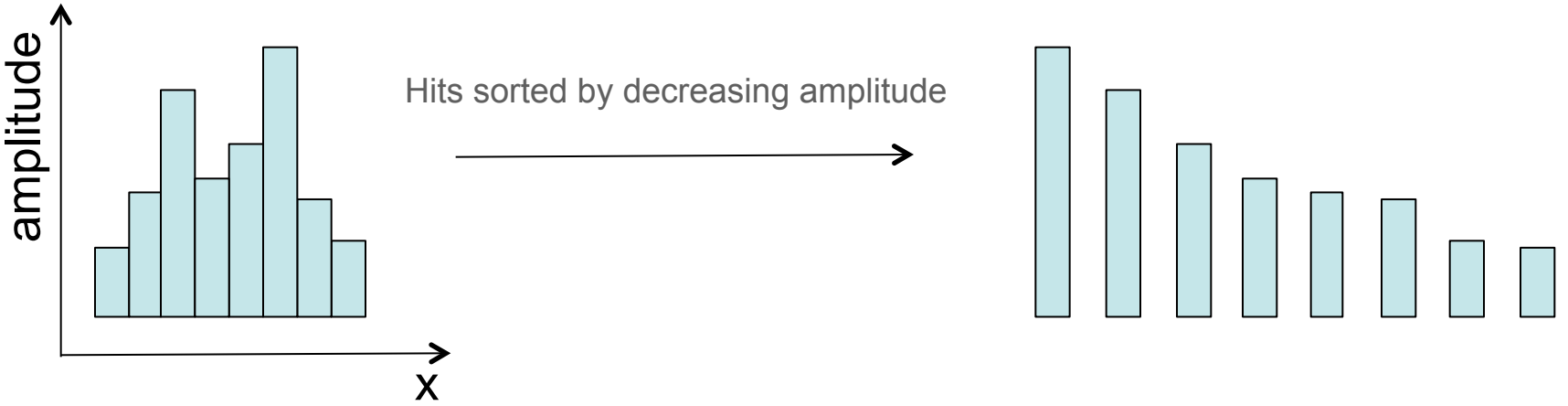
Experimental setup : 2012



Analysis : Position Finding Algorithm



Analysis : Position Finding Algorithm



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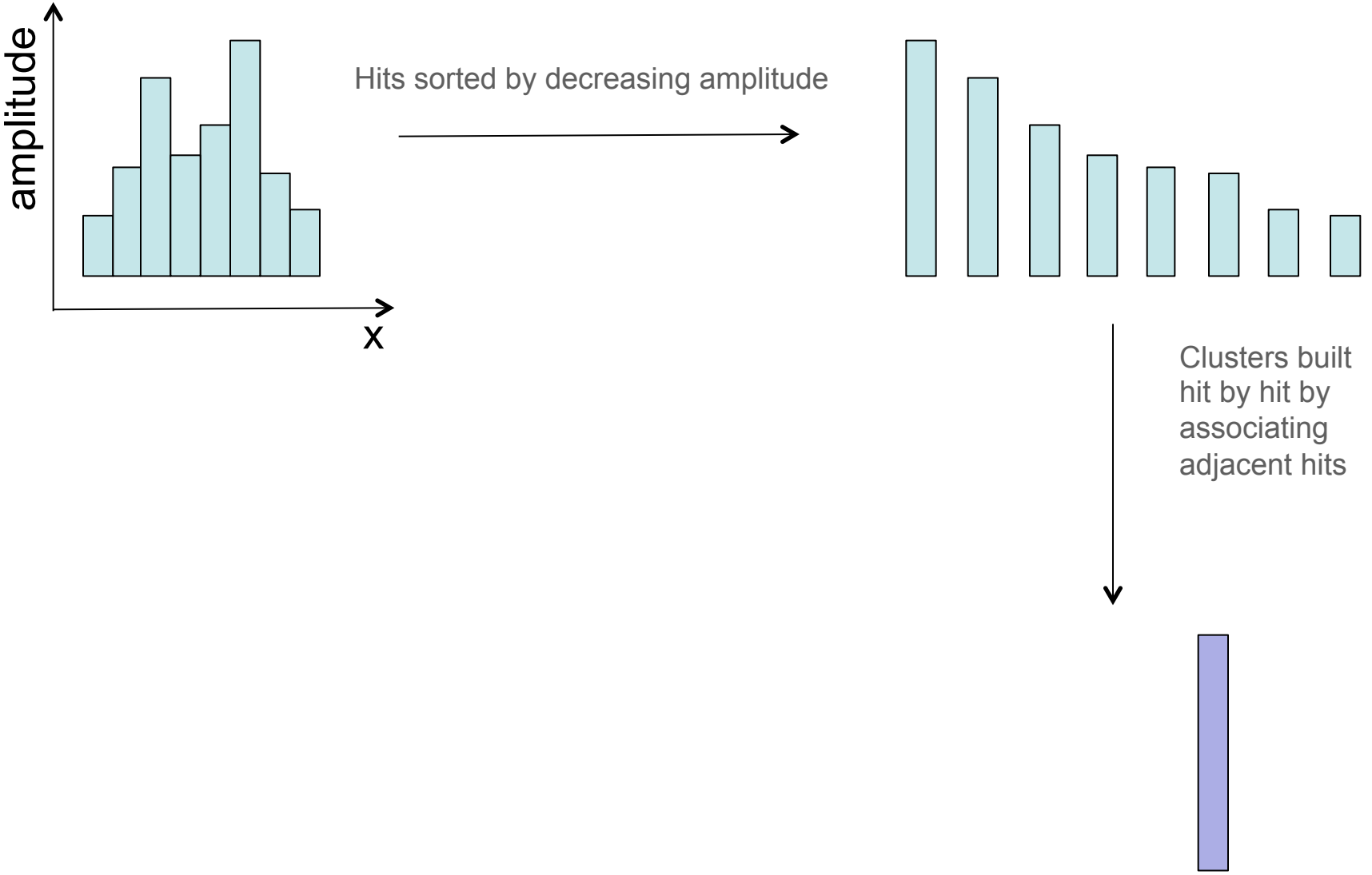

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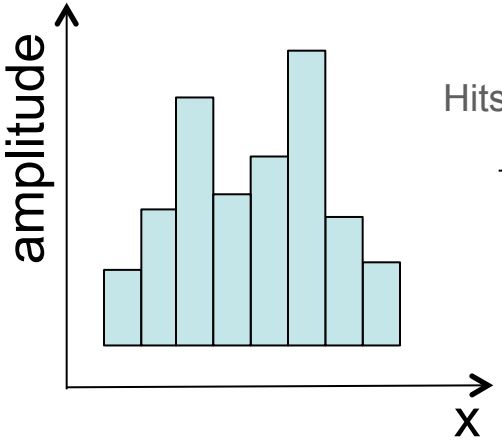
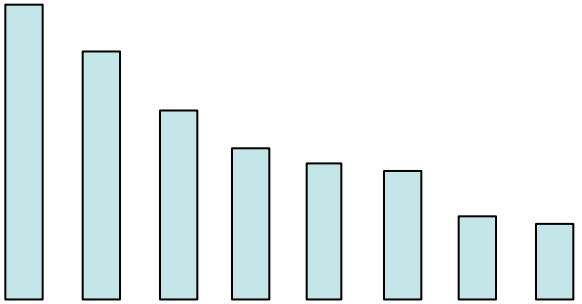
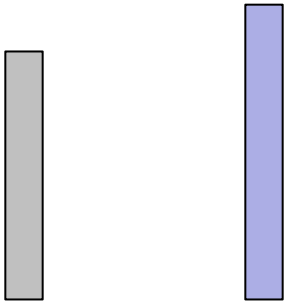


Hits sorted by decreasing amplitude



Clusters built hit by hit by associating adjacent hits

When a hit is not adjacent to an existing cluster, a new cluster is created



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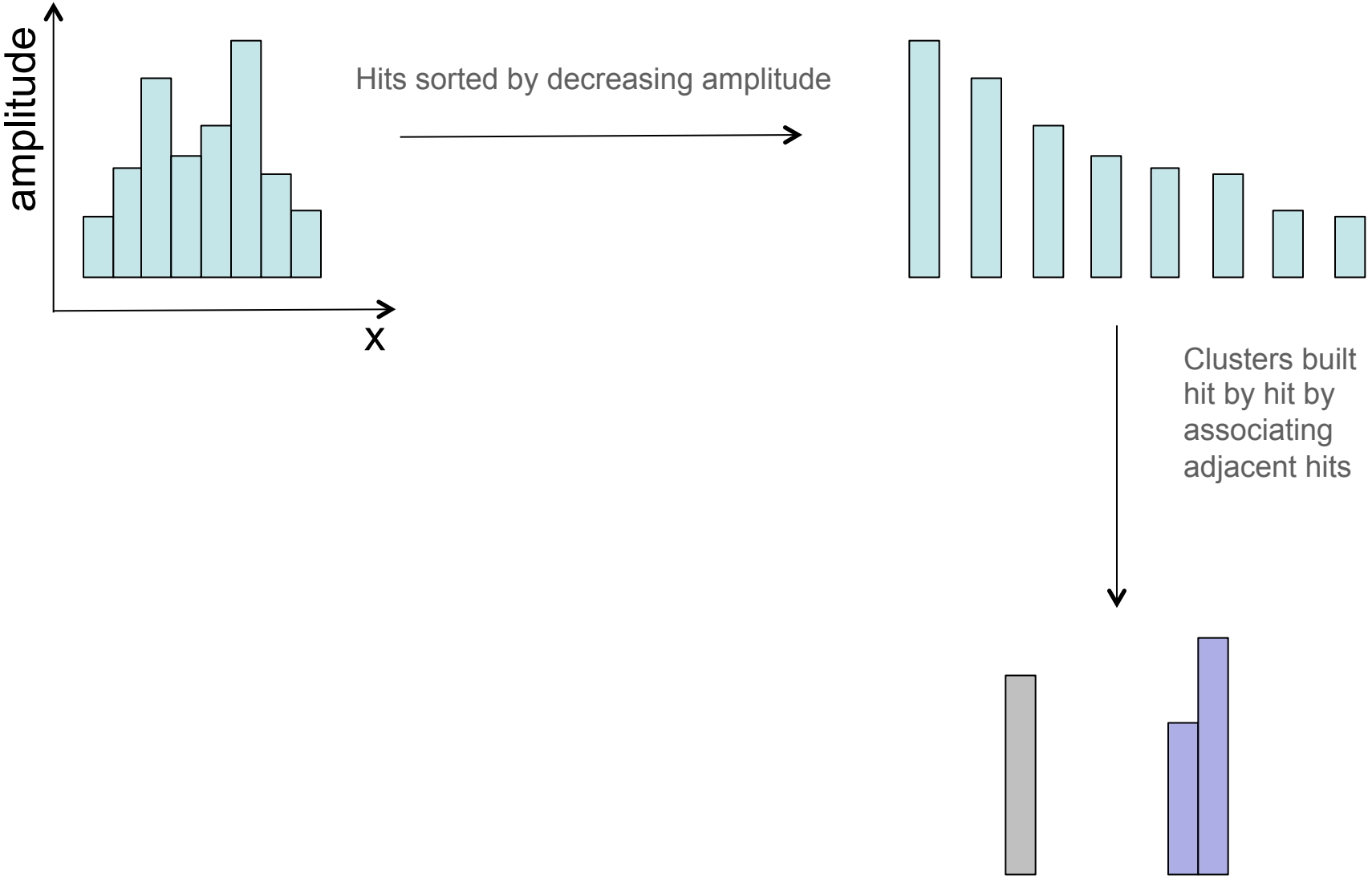

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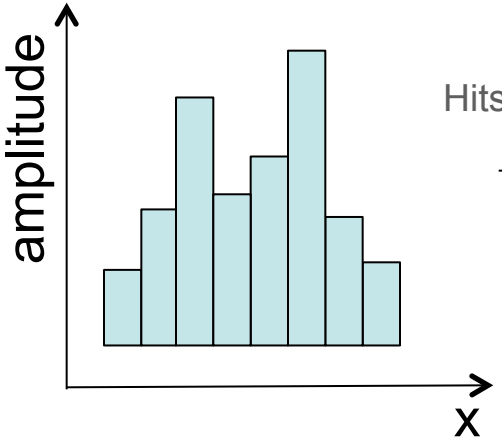

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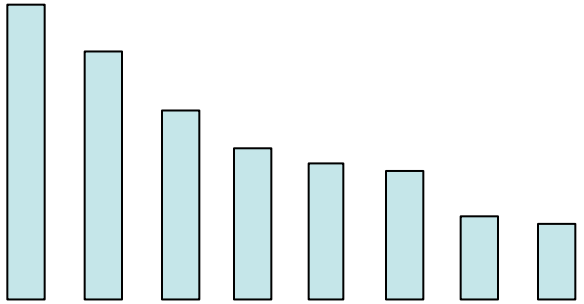
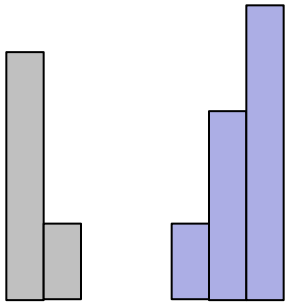
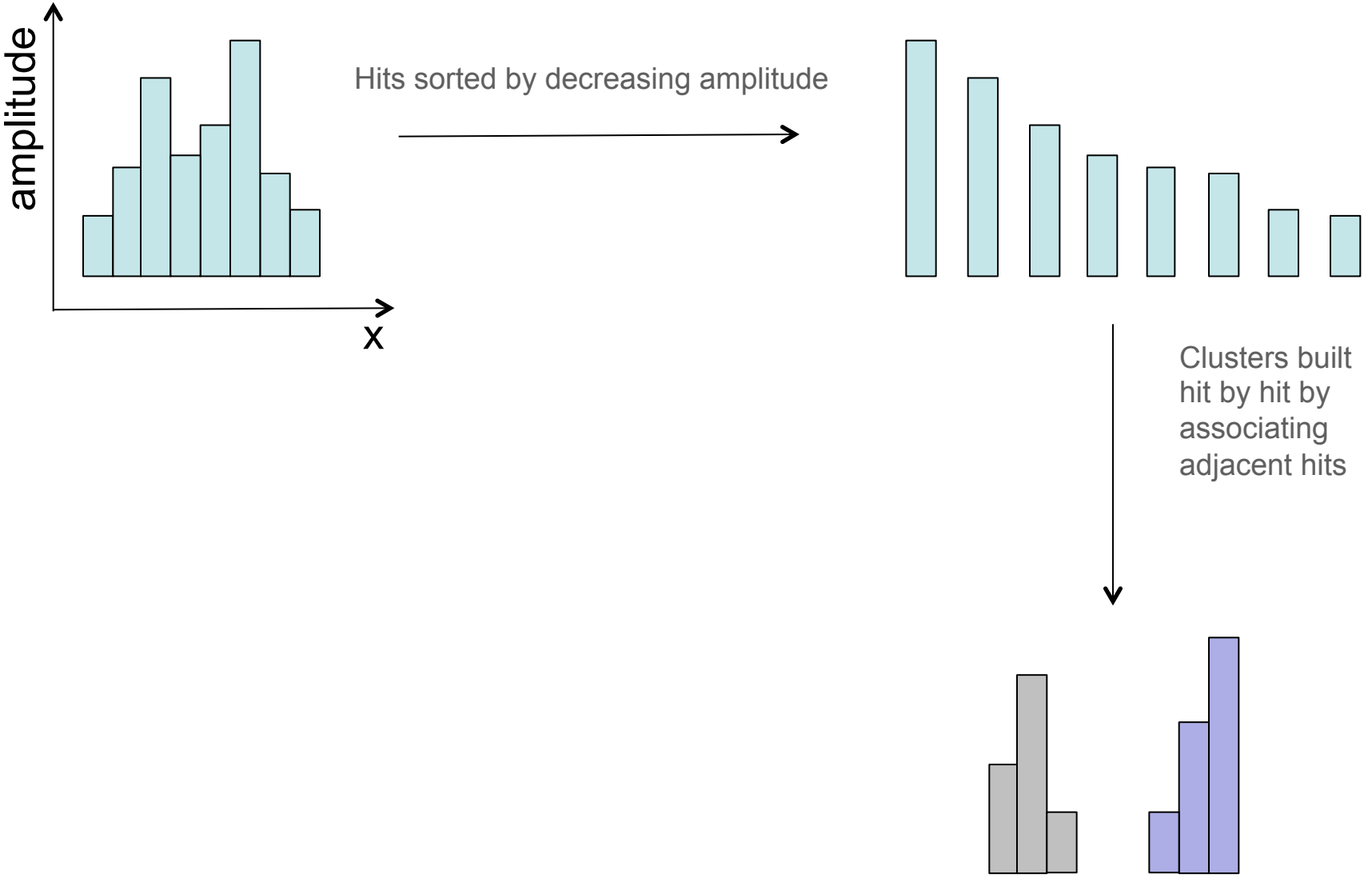


Clusters built hit by hit by associating adjacent hits

When a hit is adjacent to 2 clusters, ½ of its amplitude is added to each cluster



Analysis : Position Finding Algorithm



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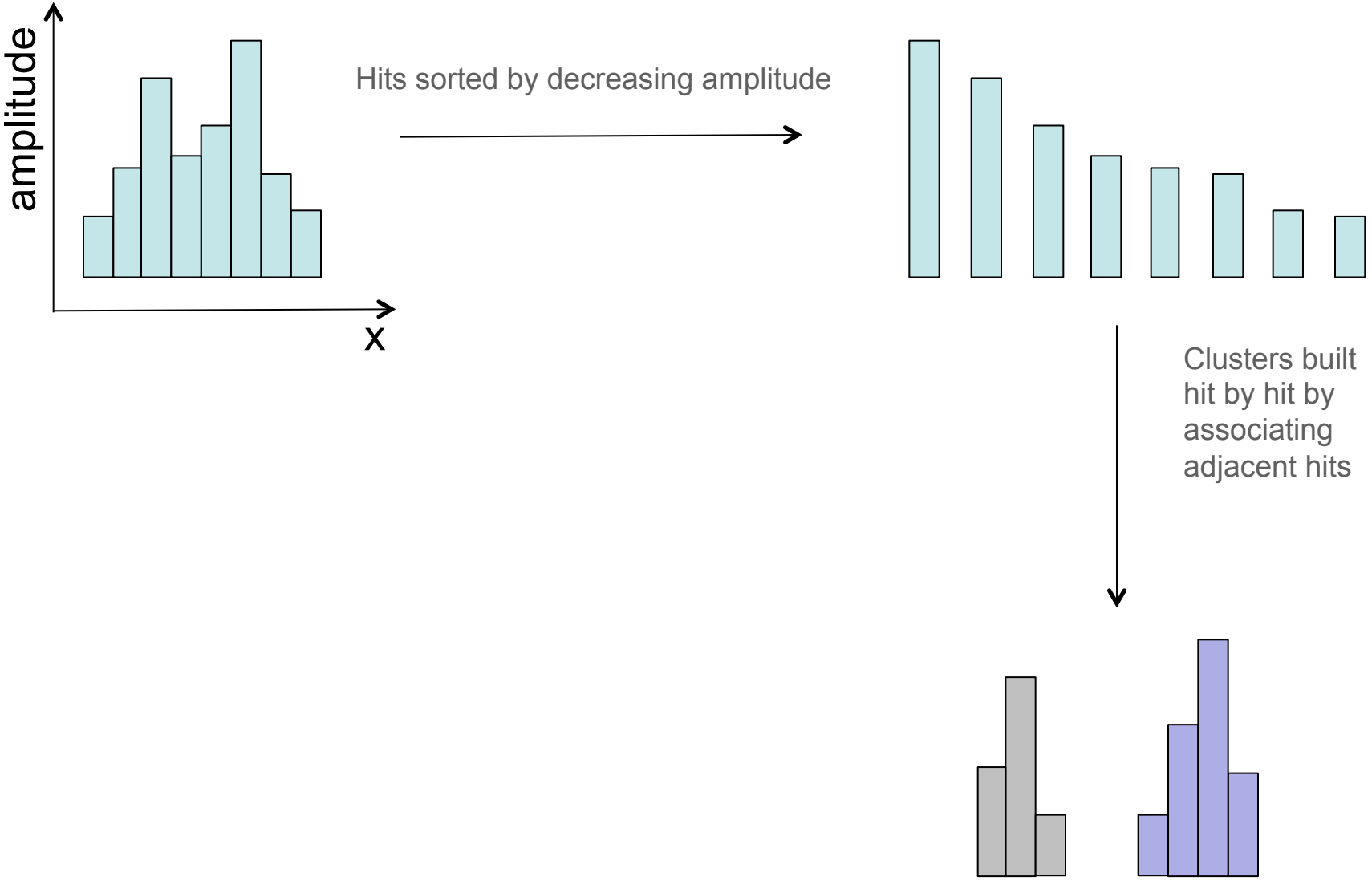
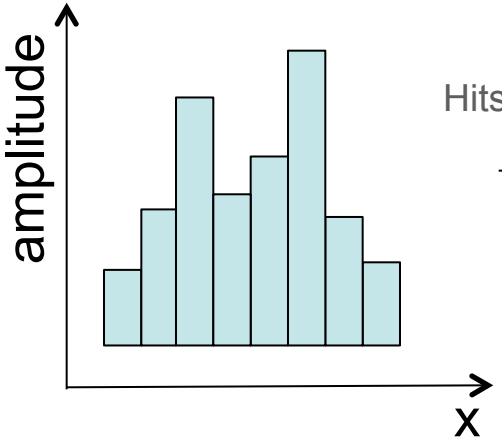
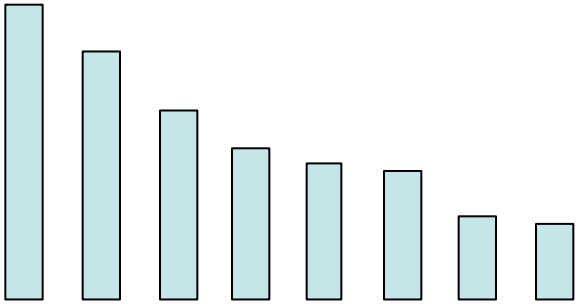


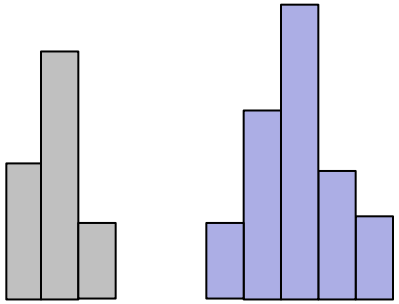
Analysis : Position Finding Algorithm



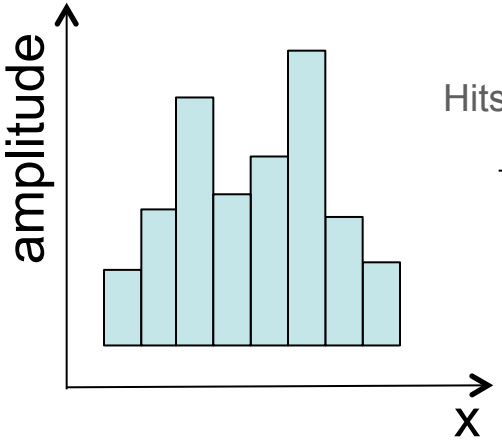
Hits sorted by decreasing amplitude



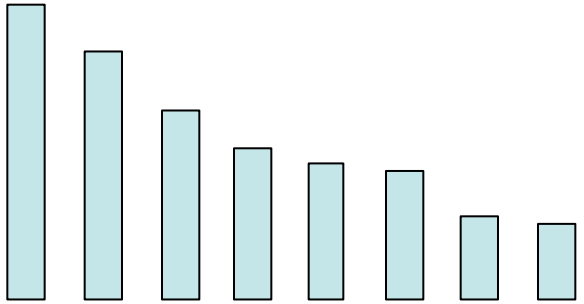
Clusters built hit by hit by associating adjacent hits



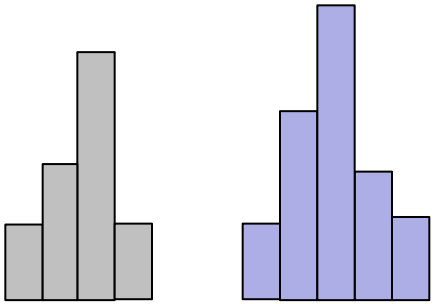
Analysis : Position Finding Algorithm



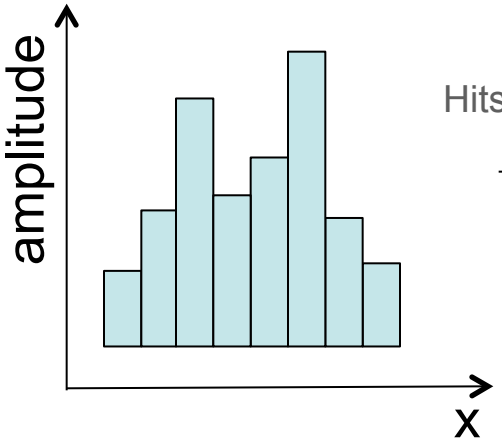
Hits sorted by decreasing amplitude



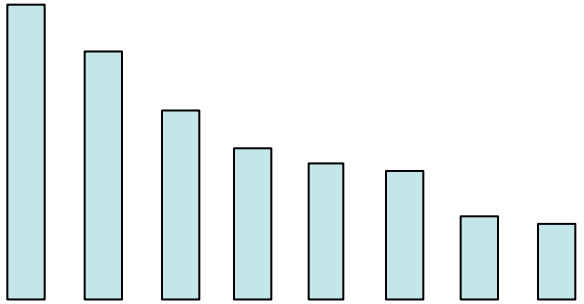
Clusters built hit by hit by associating adjacent hits



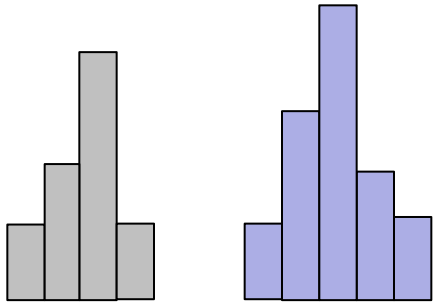
Analysis : Position Finding Algorithm



Hits sorted by decreasing amplitude



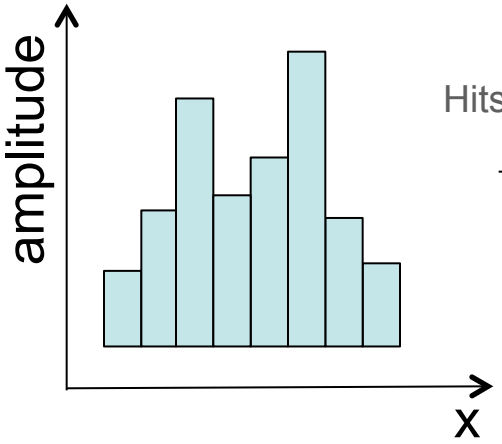
Clusters built hit by hit by associating adjacent hits



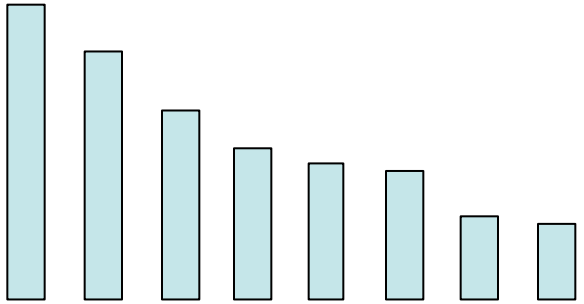
Center of gravity :

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

Analysis : Position Finding Algorithm



Hits sorted by decreasing amplitude

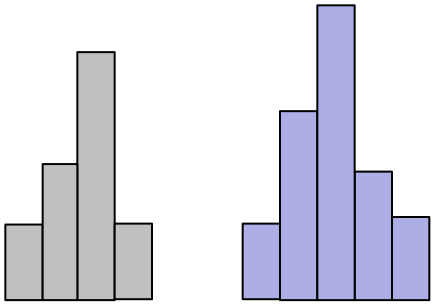


Clusters built hit by hit by associating adjacent hits

- Main advantage of this method : separation of fake clusters produced by the simultaneaous crossing of 2 close particles
- Better spatial resolution

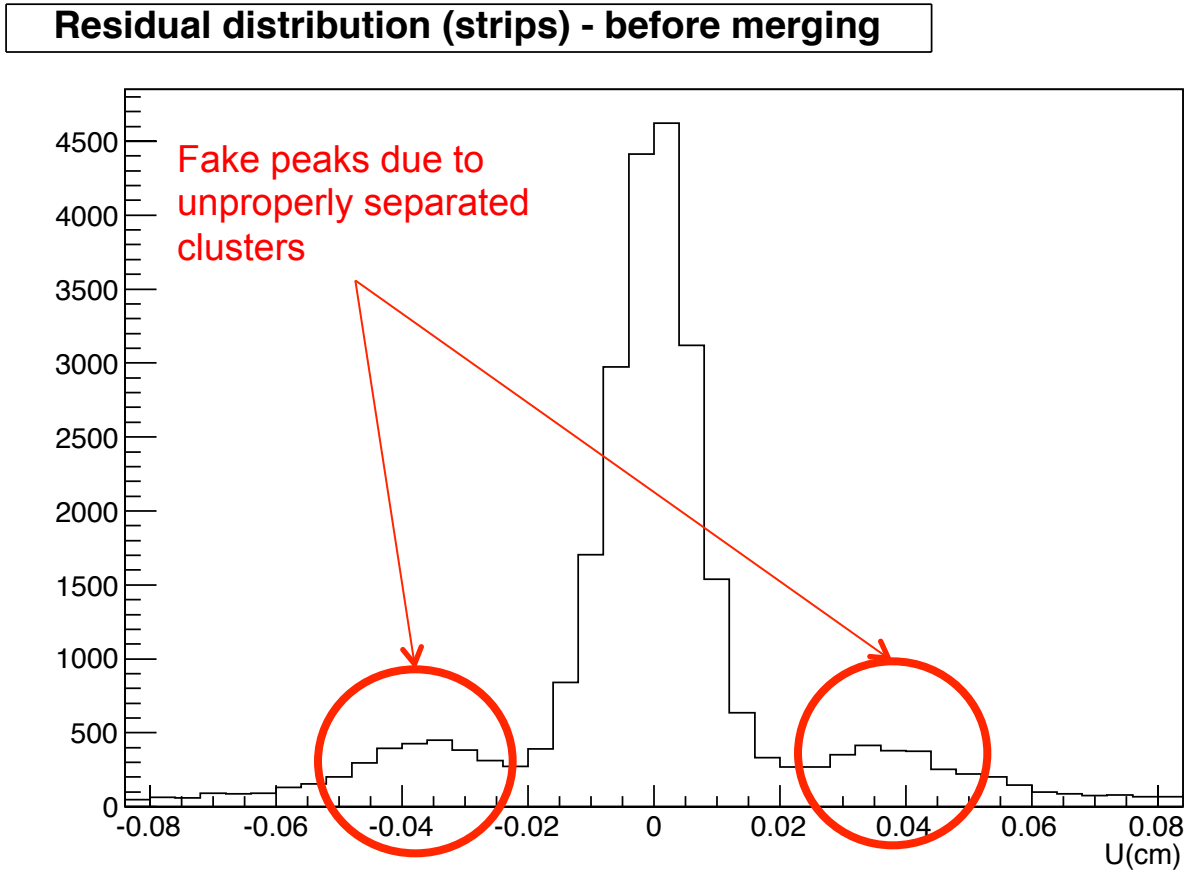
Center of gravity :

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



Analysis : Cluster merging

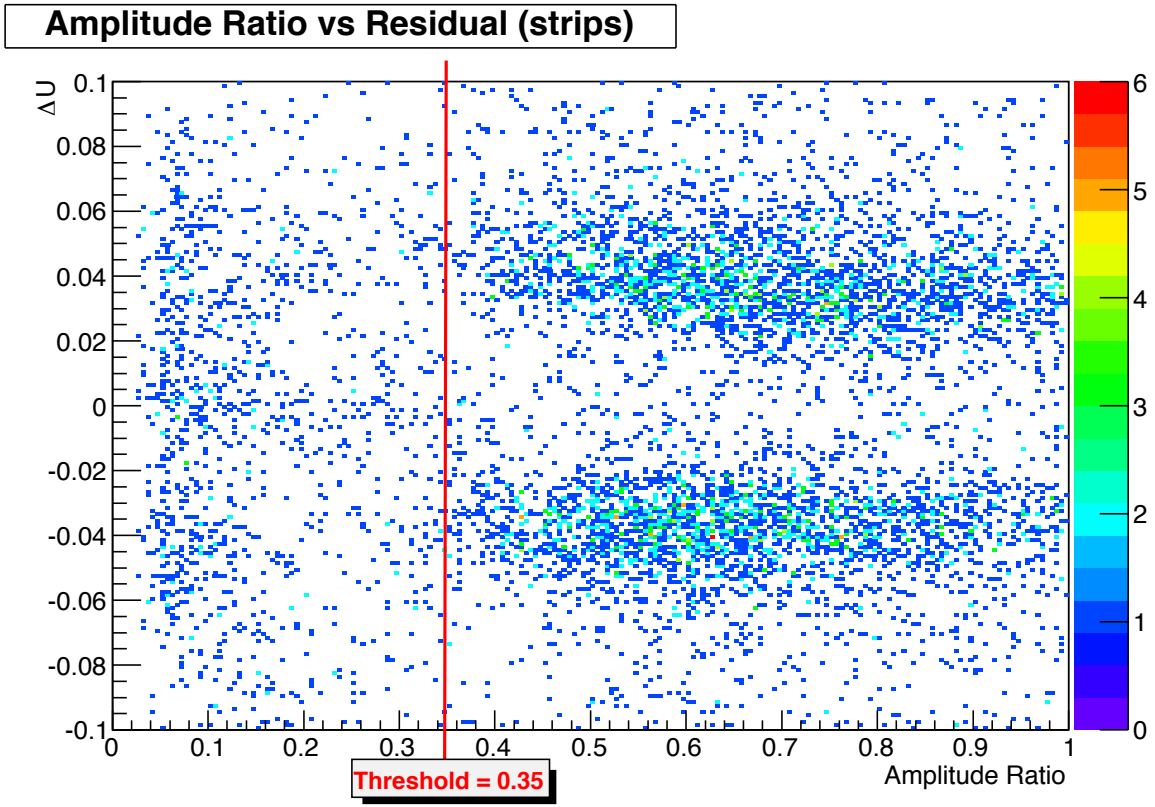
- With the previous method, each local minimum of amplitude sets a separation between 2 clusters, but sometimes they are produced by only one particle :



- A function is added to the clustering software to merge unproperly cut clusters.

Analysis : Cluster merging

- The selection of the clusters to be merged is done by using the amplitude ratio between the shared hit and the hit of maximum amplitude

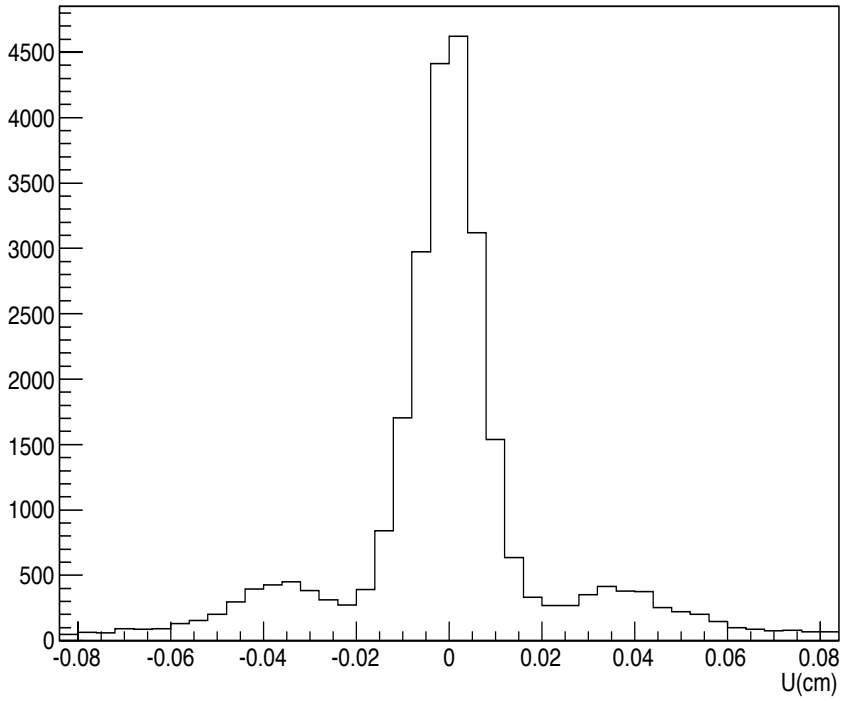


- The merging is applied to clusters for which the amplitude ratio $a_{\text{shared hit}} / a_{\text{main hit}}$ is above a certain threshold.

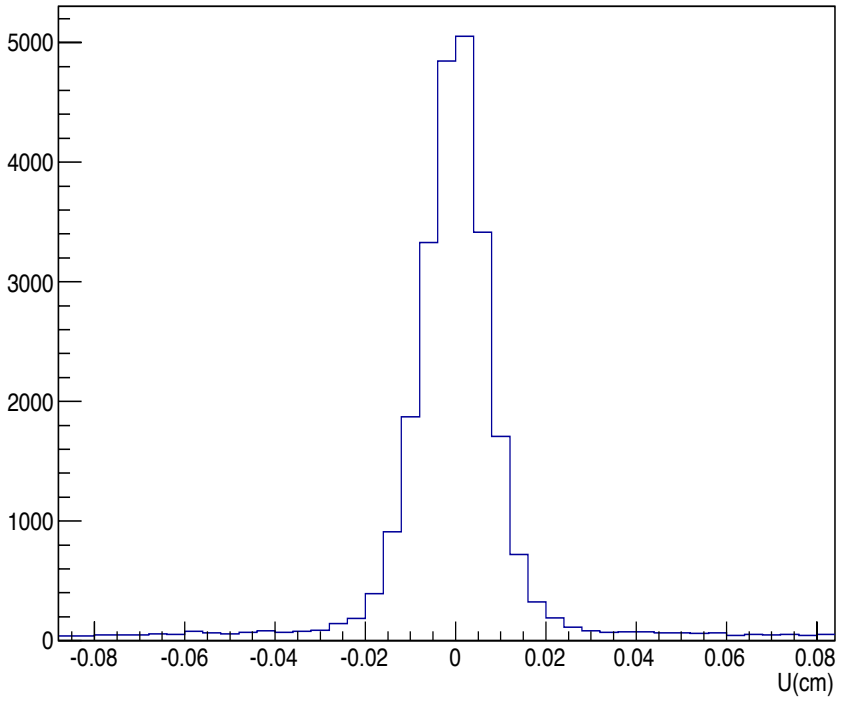
Analysis : Cluster merging

- After merging the fake peaks disappear :

Residual distribution (strips) - before merging

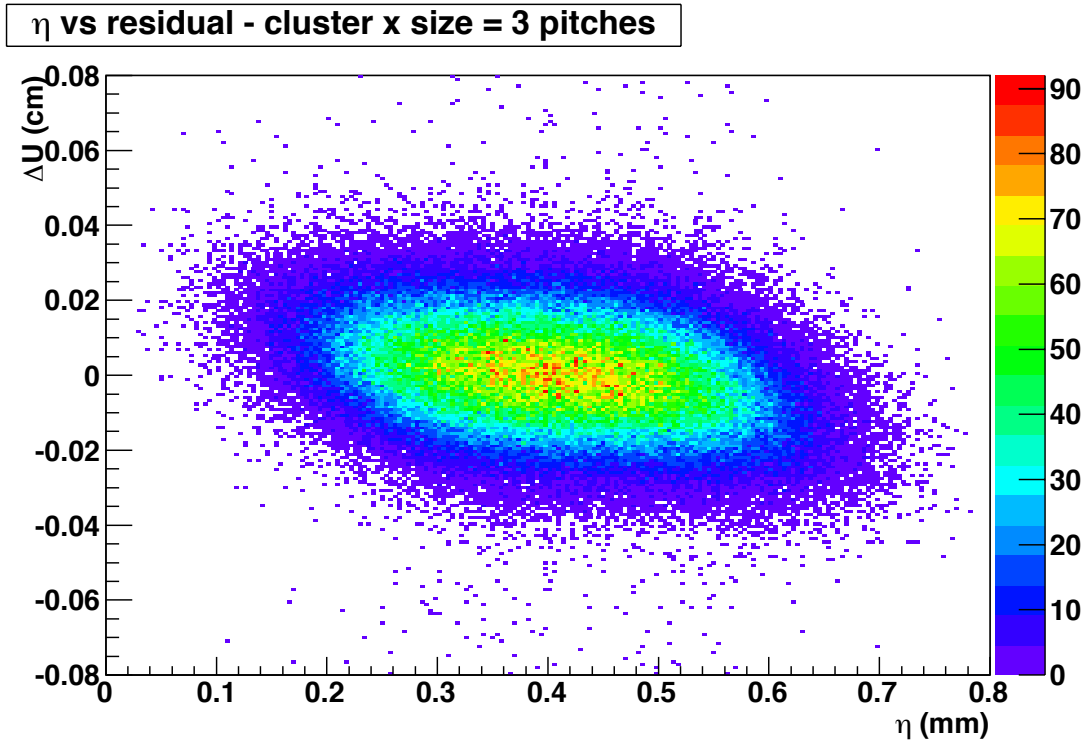


Residual distribution (strips) - after merging



Analysis : Cluster Position Correction

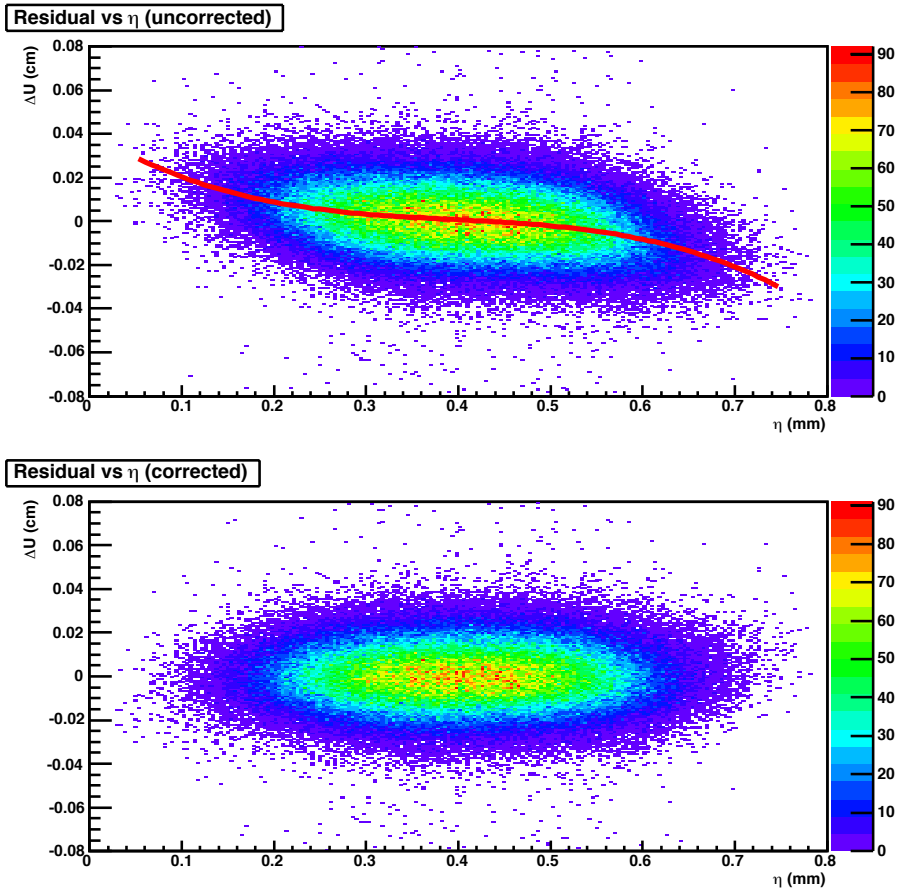
- Due to the discretisation of the readout strips (pixels) the position given by the center of gravity computation does not perfectly match the crossing point of the particle.
- A correction can be applied by introducing a variable $\eta = x_{CoG} - x_{\min}$ where X_{min} is the coordinate of the center of the left hit of a cluster.

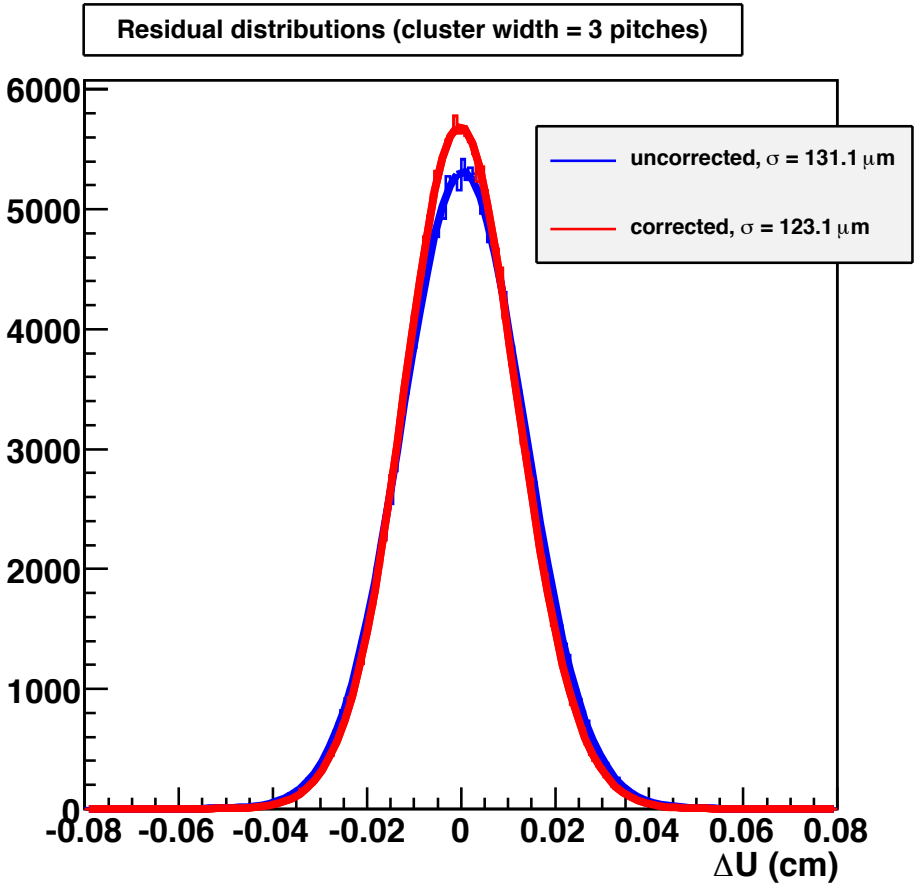


S.Uhl – Construction and Commissioning of the PixelGEM Tracking System of the COMPASS Experiment – Diploma Thesis

Analysis : Cluster Position Correction

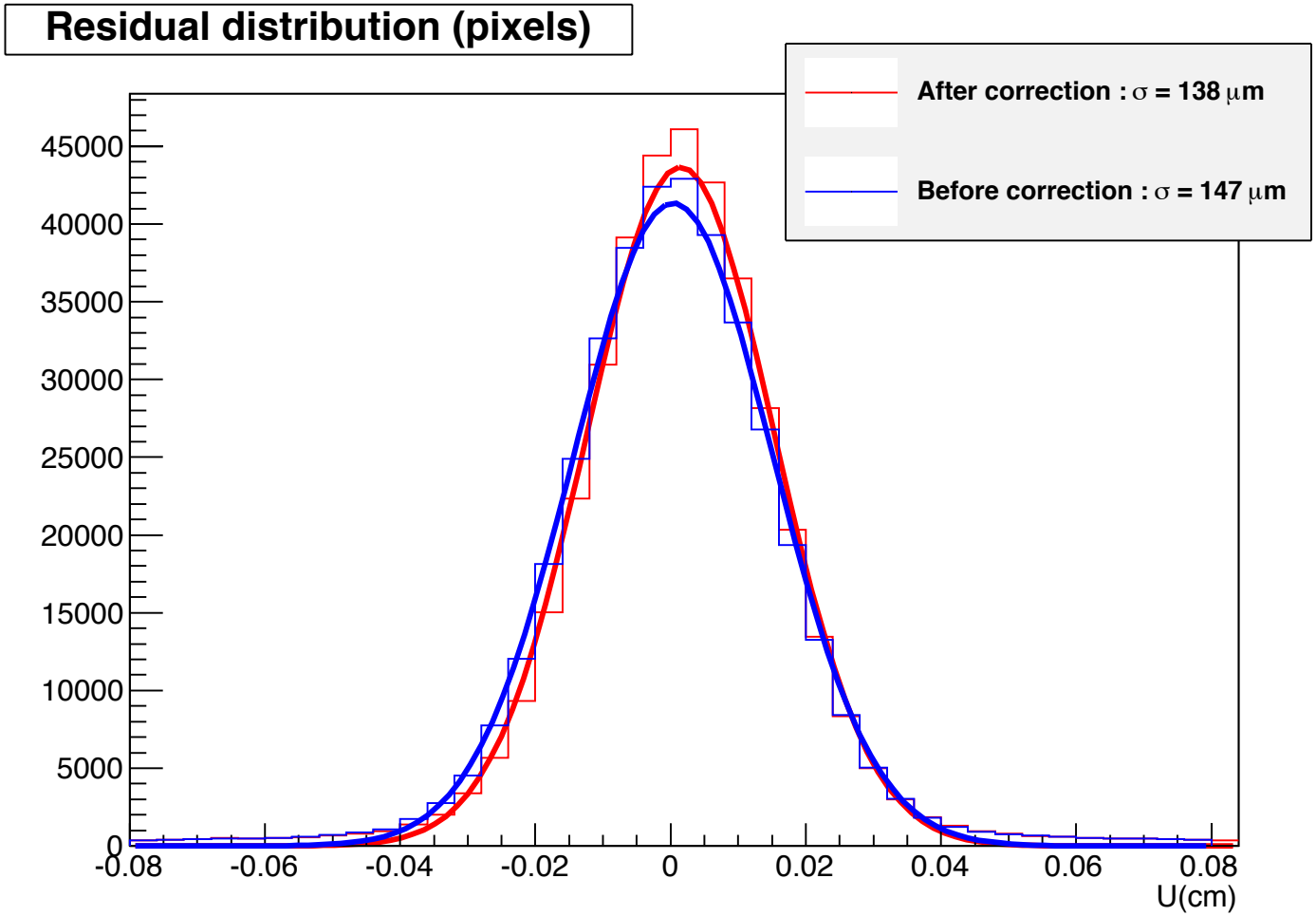
- The variation of η with the residual for each cluster width is fitted by a 3rd degree polynomial function which is used to correct the distribution.





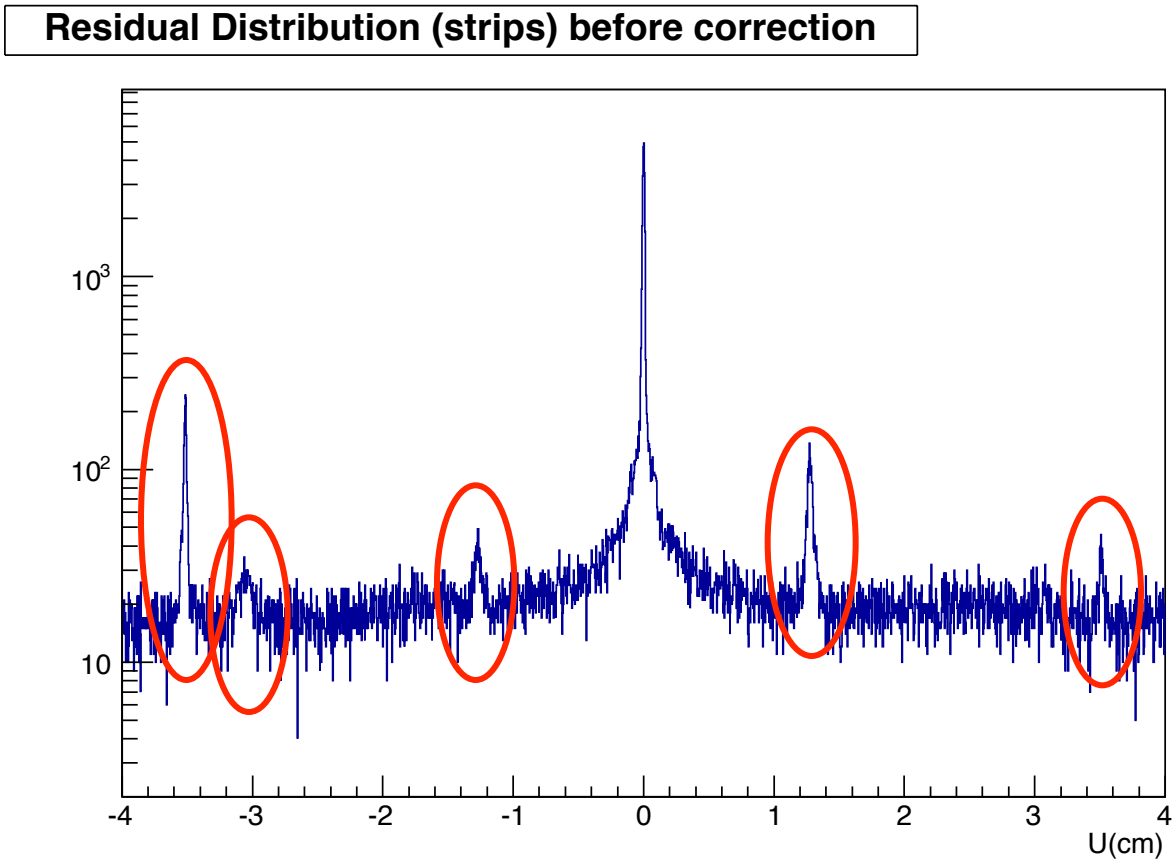
Analysis : Cluster Position Correction

- Applying this method for each statistically significant cluster width improves the global spatial resolution by 2-10 % :



Analysis : Correction of Cross-Talk in time

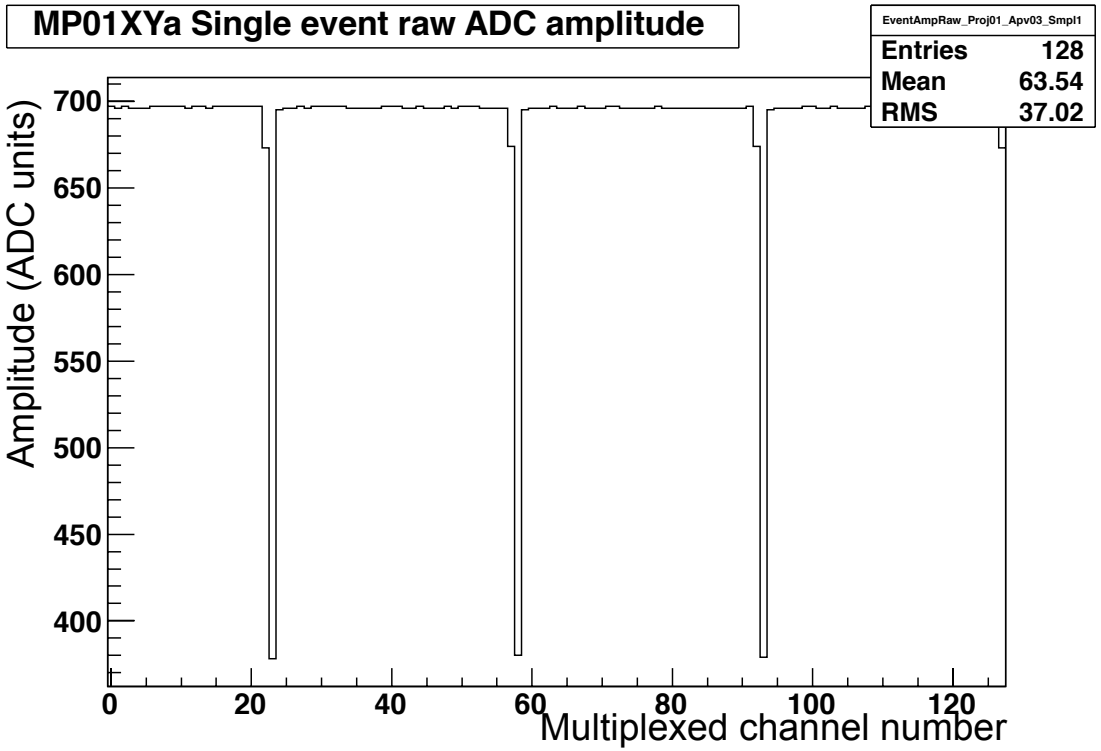
- When analyzing residual distributions, « fake peaks » were observed :



- An effect called « cross talk in time » was suspected

Analysis : Correction of Cross-Talk in time

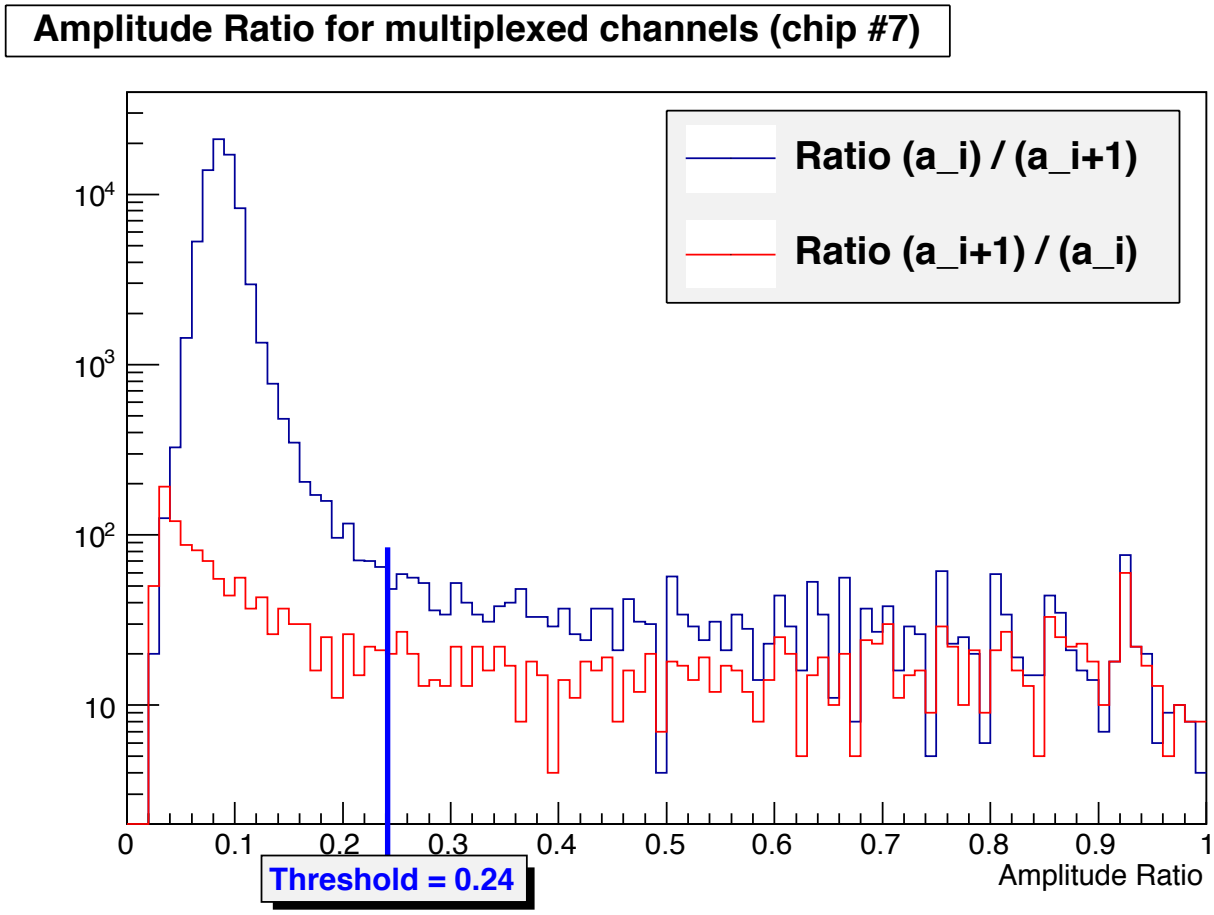
- Cross-Talk in time happens when the signals are sent from the APV to the ADC.
- Hits amplitudes are sent one after each other, and sometimes the amplitude measurement of a hit is affected by the previous or the following one :



- Consecutive channels are not necessarily neighbouring strips/pixels
- This effect produces non physical hits which can create fake clusters

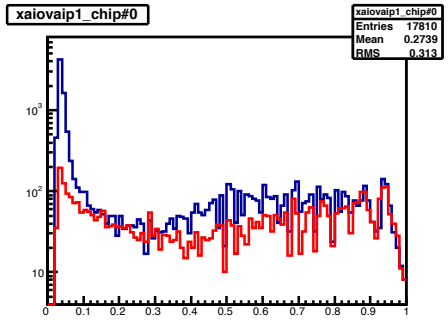
Analysis : Correction of Cross-Talk in time

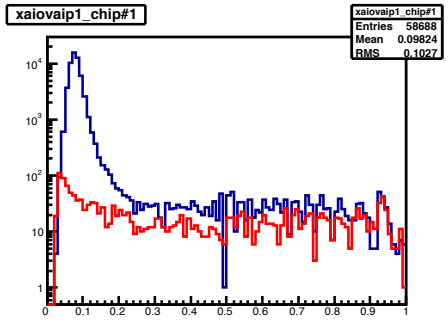
- Amplitude ratios for consecutive multiplexed hits are plotted for each APV chip.

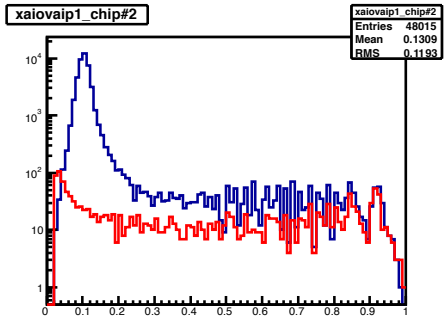


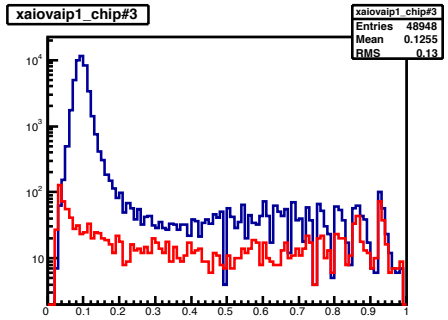
- Correction of hits amplitudes : $a_i^{corr} = a_i - threshold \times a_{i+1}$

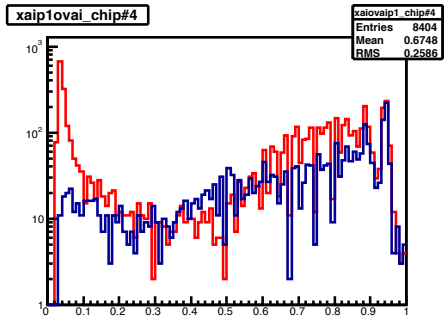
Analysis : Correction of Cross-Talk in time

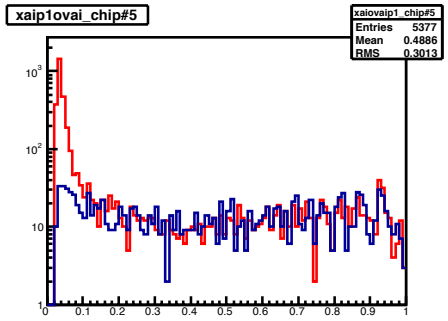


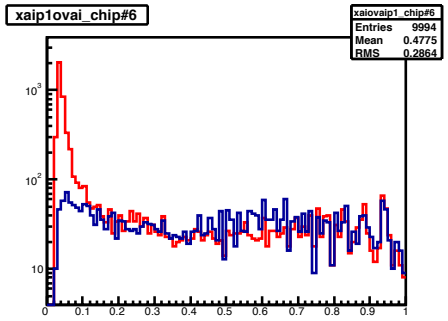


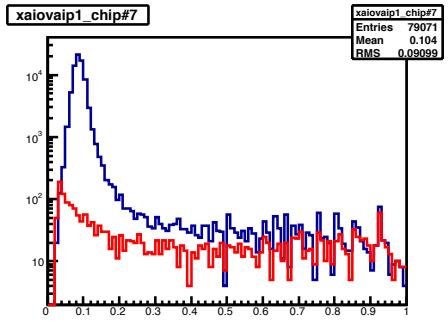


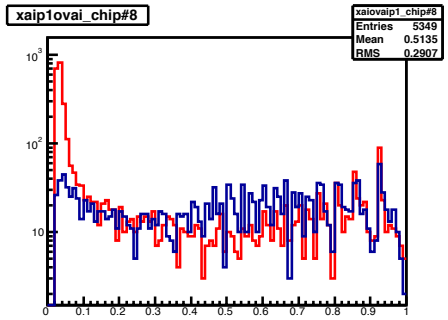


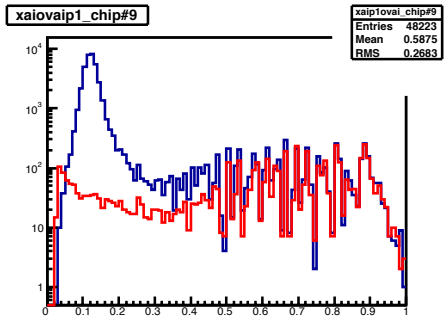


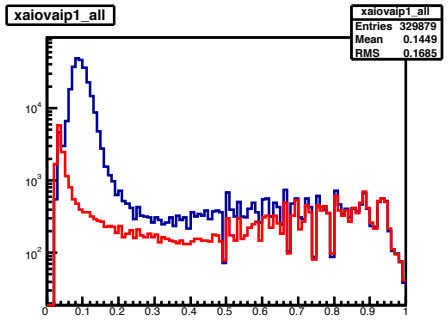


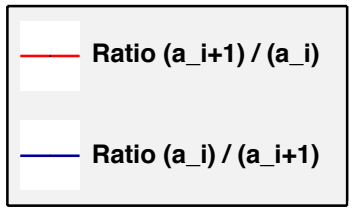








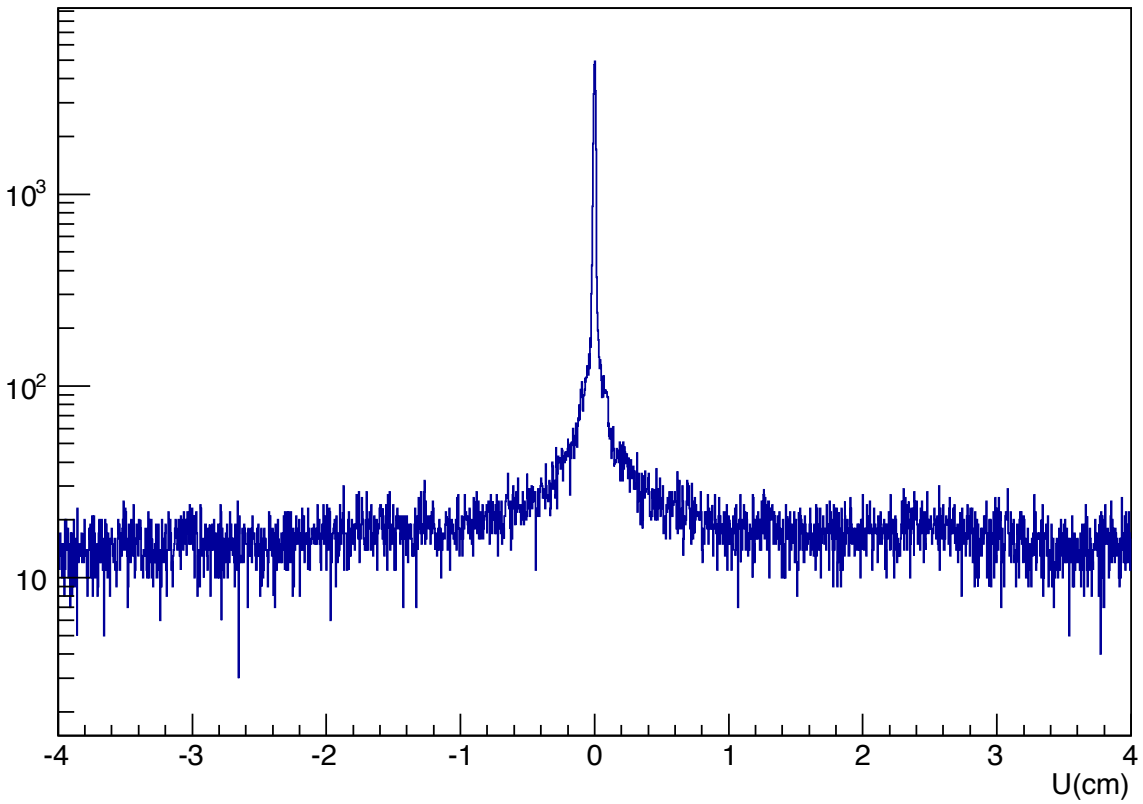




Analysis : Correction of Cross-Talk in time

- After correction, the fake peaks vanish.
- No efficiency loss is observed.
- Background probability decreases by around 10%.

Residual Distribution (strips) after correction

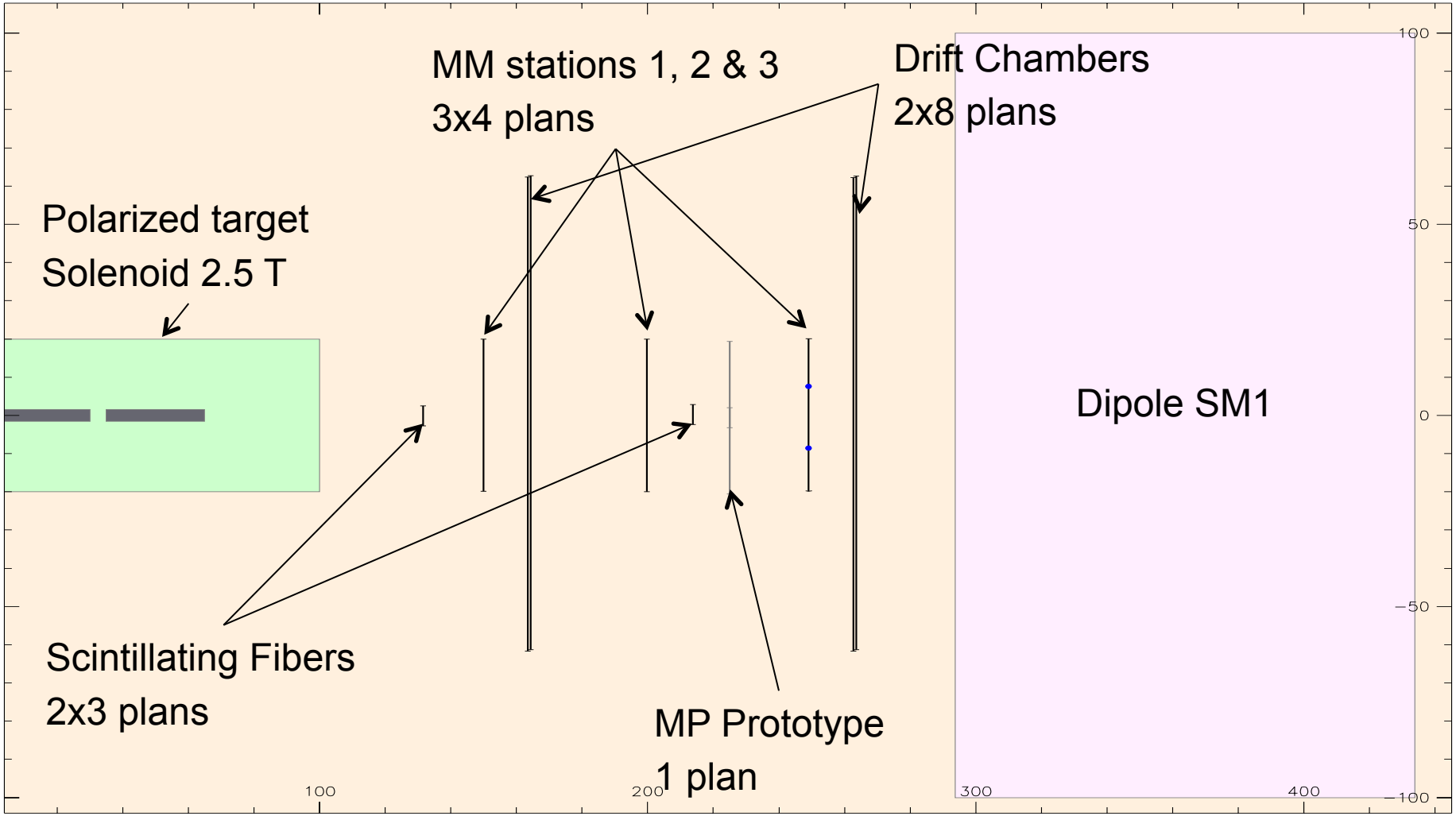


Performances summary : 2011

Physics data taking with polarized target (2.5 T) and high muon flux : 10^7 μ^+/s

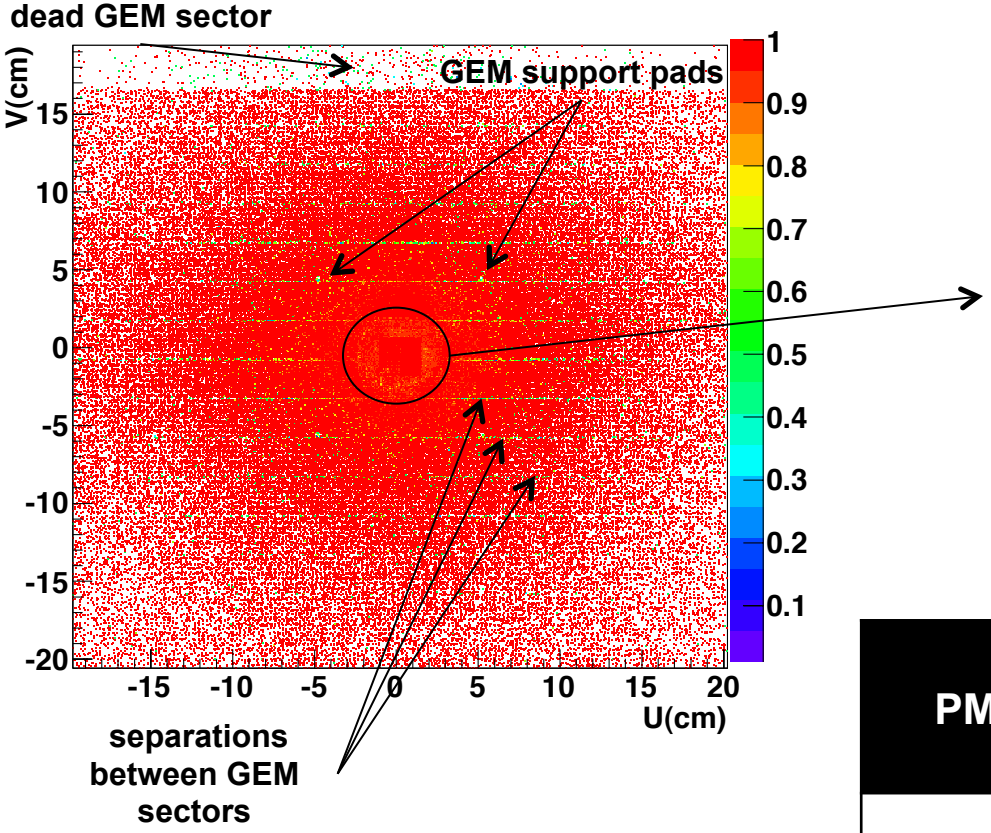
- June-July 2011 : first MP+GEM prototype
- July-October 2011 : second MP+GEM prototype
  - Noise on an APV chip (pixel part) until half september
  - Detector misaligned (1cm) in beam after half september
- End of October : resistive MP prototype

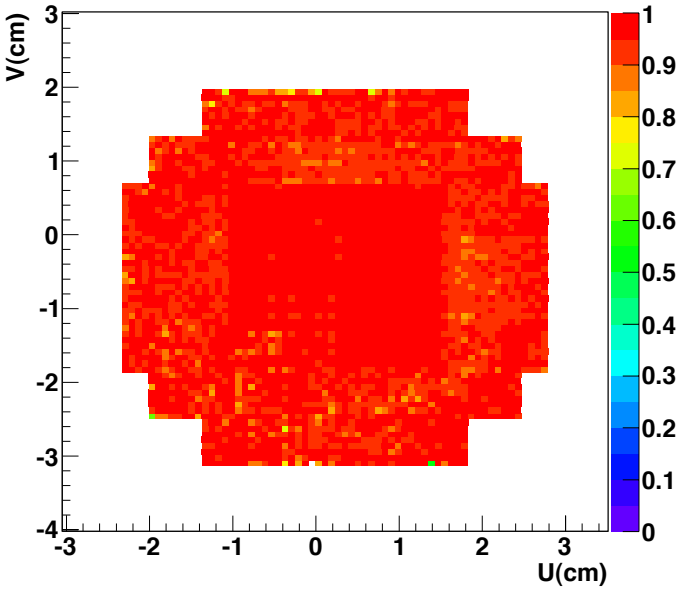
Performances summary : 2011



Performances summary : 2011

- PMM + GEM : Efficiency
  - *2011_1 prototype – voltages 300 V / 320 V - Gain ~ 6000*

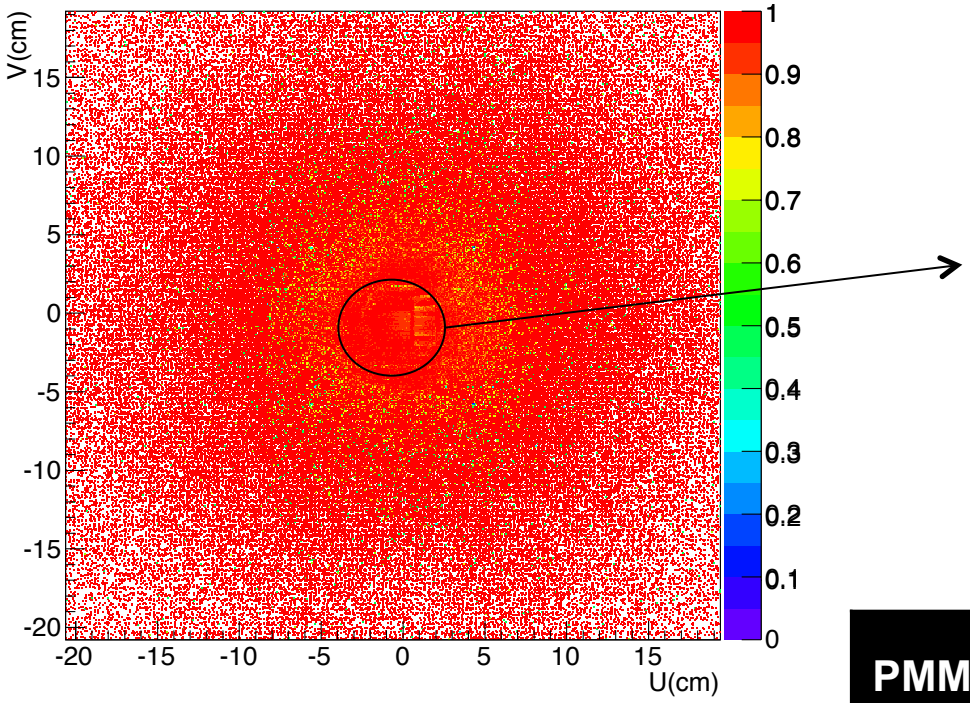


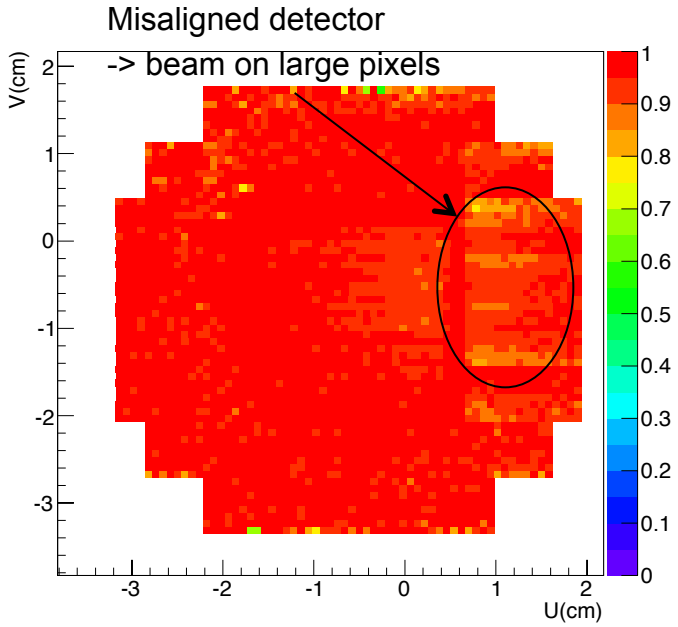


PMM_2011_1	Eff. High Flux (dead sector excluded)
Pixels	95.9%
Strips	96.5%
Global	96.1%

Performances summary : 2011

- PMM + GEM : Efficiency
  - *2011_2 prototype – voltages 300 V / 320 V - Gain ~ 6000*

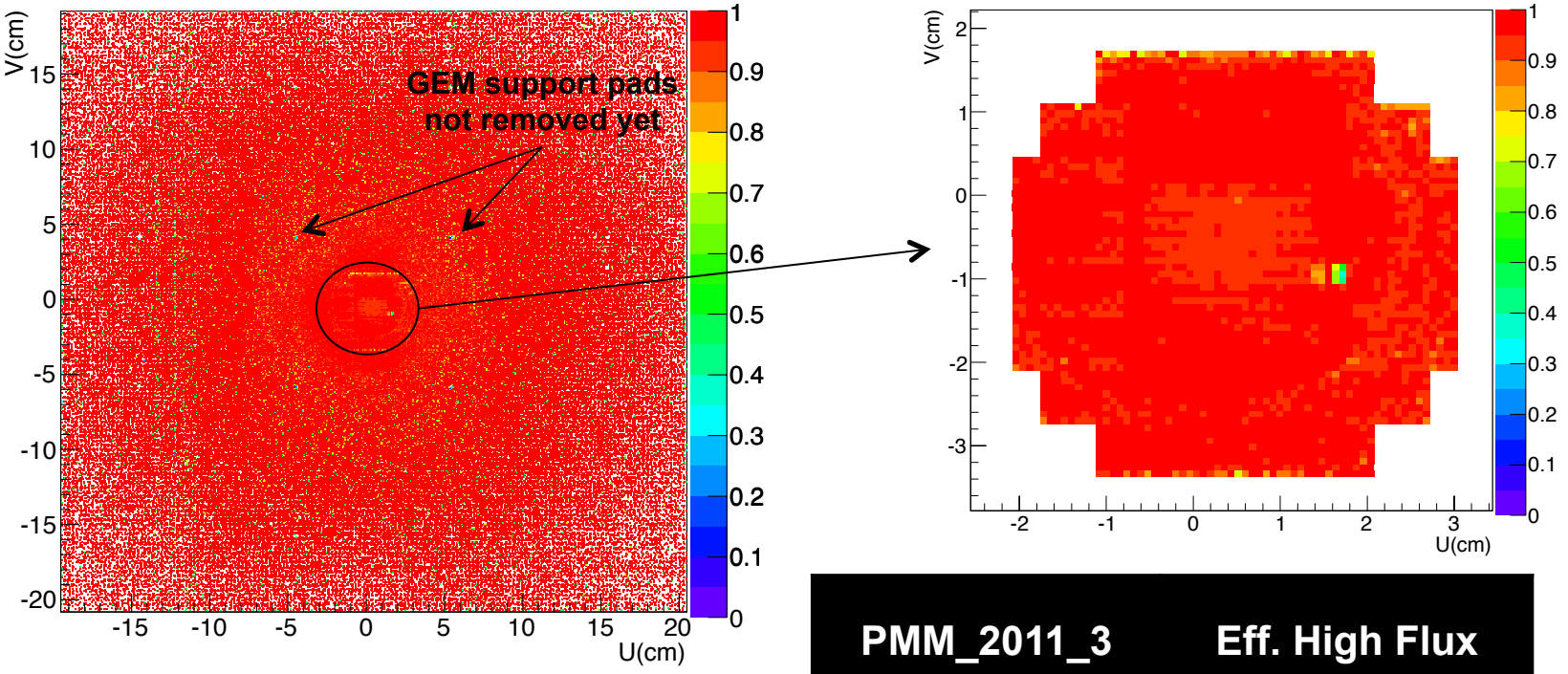




PMM_2011_2	Eff. High Flux	Eff. Low Flux
Pixels	94.9%	98.9%
Strips	96.8%	99.0%
Global	95.7%	99.0%

Performances summary : 2011

- PMM with Buried Resistors : Efficiency
  - ➢ *mesh voltage 470 V - Gain ~ 8000*

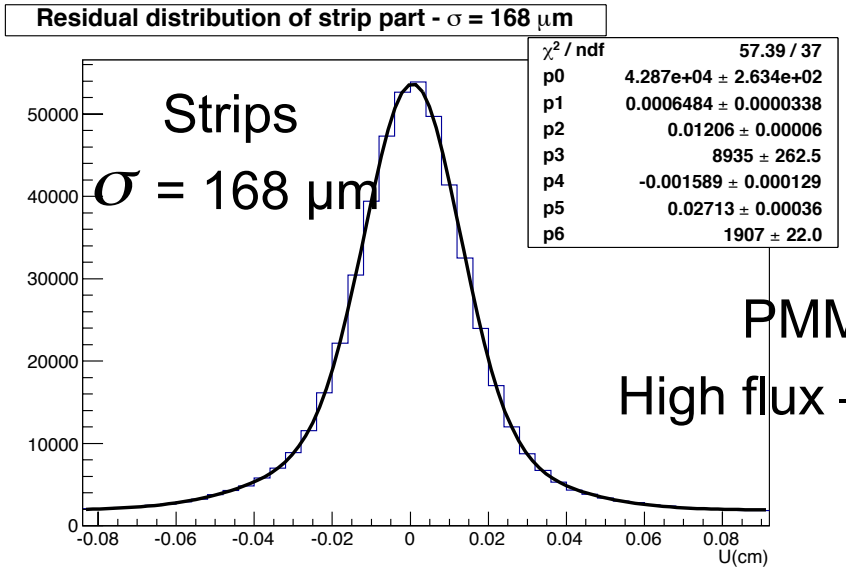


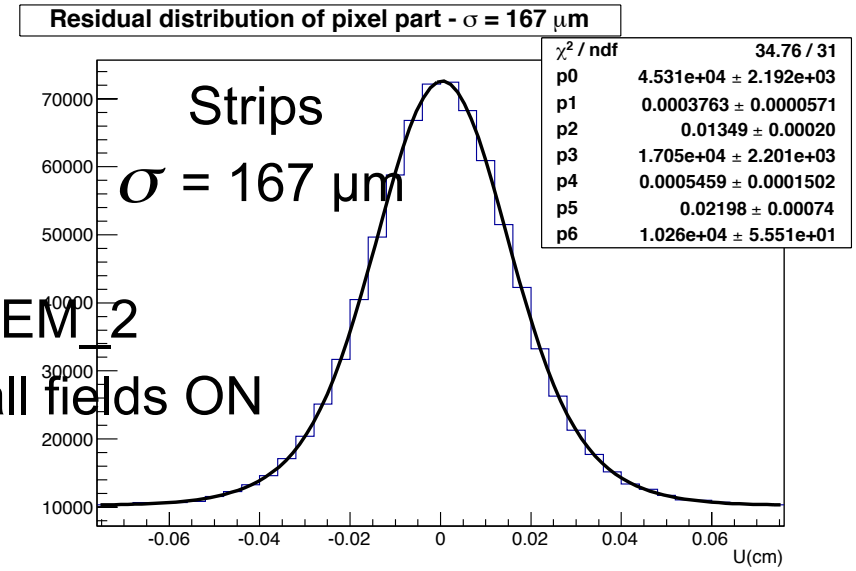
Quickly built in Saclay before Installation

- ➢ several cut channels

PMM_2011_3	Eff. High Flux
Pixels	95.7%
Strips	97.5%
Global	96.4%

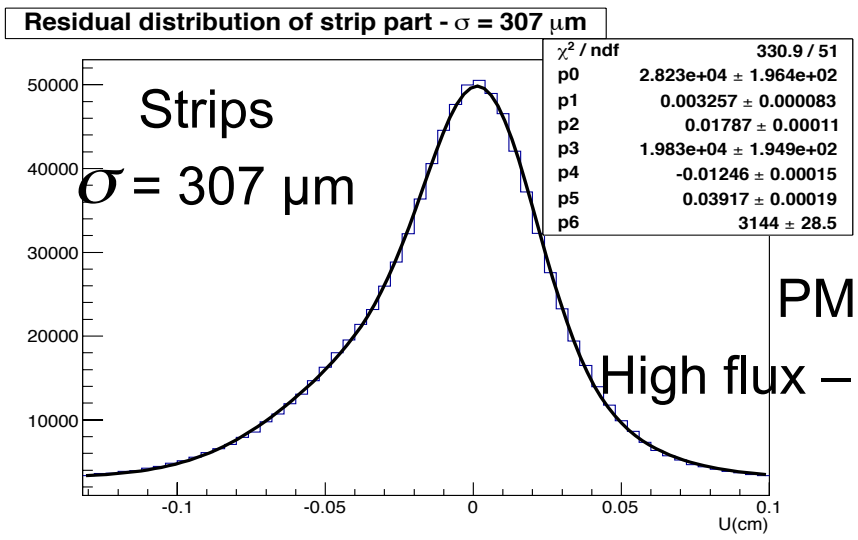
Performances summary : 2011 - Resolution

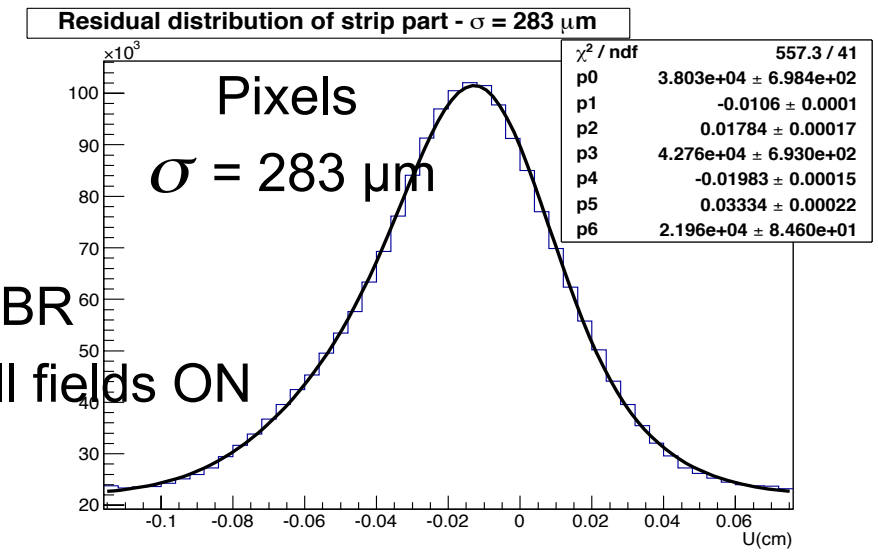




PMMGEM_2

High flux – all fields ON





PMMBR

High flux – all fields ON

Performances summary : 2011

- Spatial resolution : influence of flux and fringe fields (all values in µm)

Detector	Low flux Dip. OFF Sol. OFF	Low flux Dip. ON Sol. OFF	Low flux Dip. OFF Sol. ON	Low flux Dip. ON Sol. ON	High flux Dip. ON Sol. OFF	High flux Dip. ON Sol. ON
MM02X	73	99	92	109	116	118
MM03X	62	164	80	300	265	288
MP+GEM (strips)	52	107	X	117	149	123
MP+GEM (pixels)	82	111	X	135	179	147
MP BR (strips)	X	X	100	222	X	268
MP BR (pixels)	X	X	91	224	X	271

Gain higher than standard

Gain lower than standard

- **PMM+GEM**
- **All Fields OFF**
  - Good performances
- **Dipole ON**
  - Degradation depending on the distance to the dipole
- **Solenoid ON**
  - Degradation is worse
- **High Flux**
  - Degradation is worse

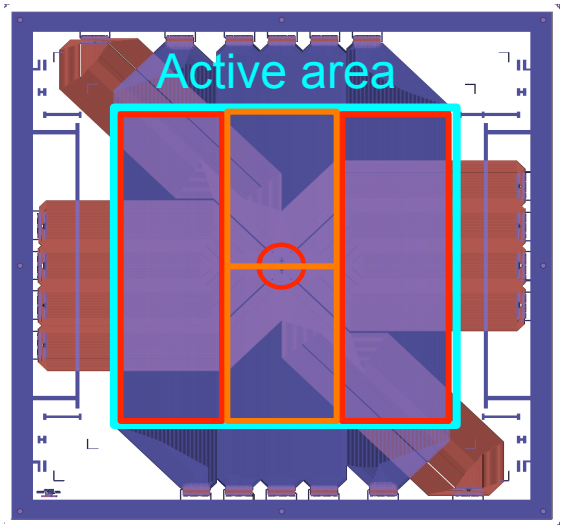
- ***Degradation similar to old Micromegas in the same region***

- **PMM + BR**
- **Same behaviour when increasing field and flux**
- **Intrinsic resolution seems slightly worse compared to PMM + GEM**

Performances summary : 2012

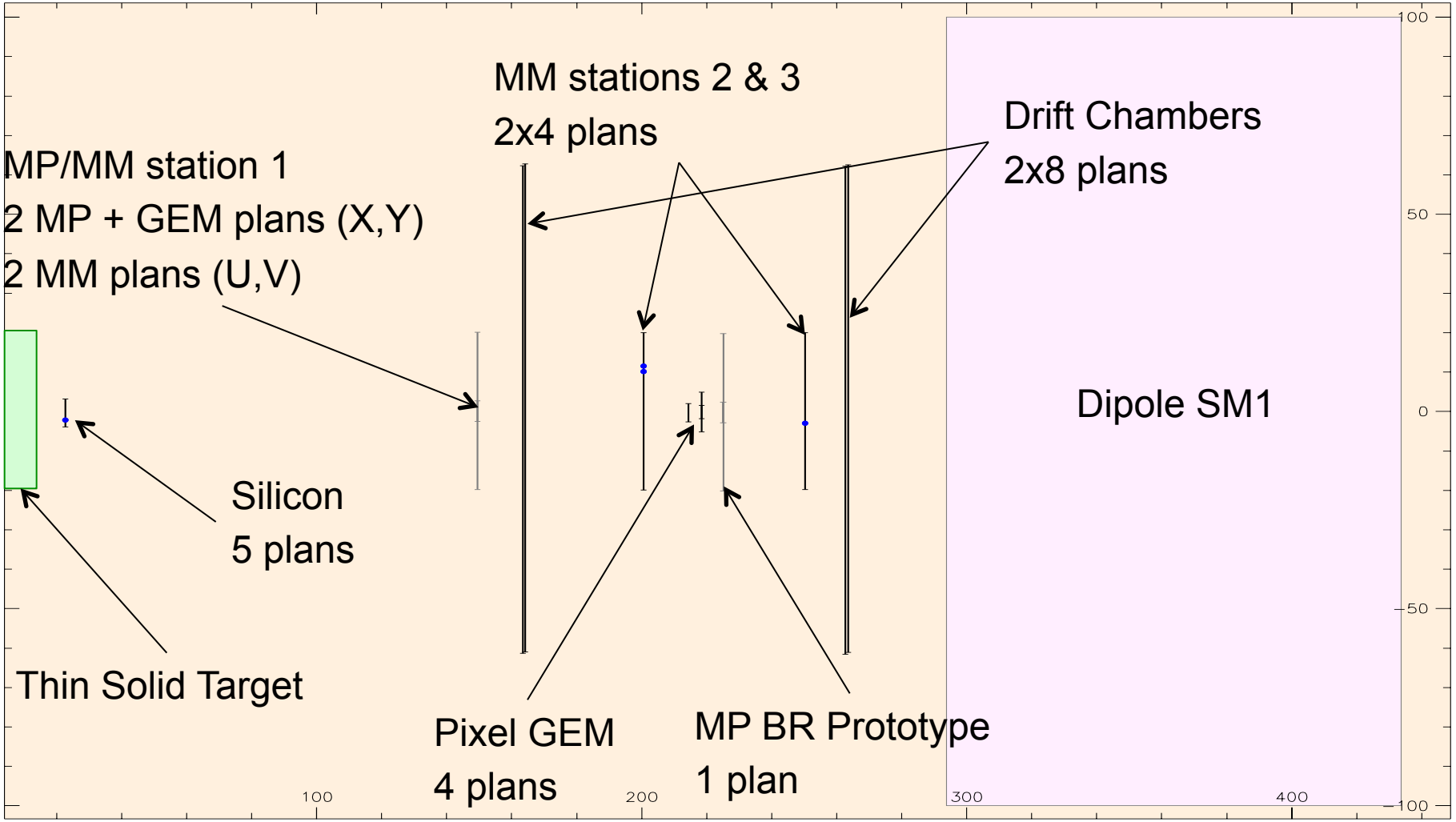
Physics data taking with solid target (NOT polarized) and high muon and hadron flux : 5.10^6 $\mu^-(h^-)/s$

- 2 Micromegas replaced by 2 MP+GEM detectors in the first station
  - ➢ Electronics problem : noise on large strips due to new cards
    - 25% long strips deactivated on MM01X
    - 50% long strips deactivated on MM01Y



- Resistive MP prototype
  - ➢ All large strips deactivated

Performance summary : 2012



Performances summary : 2012

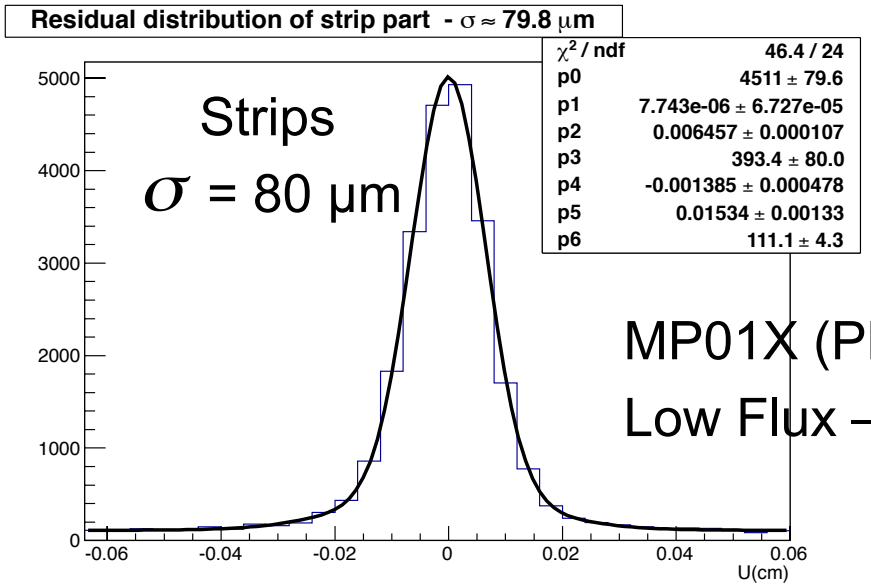
- Efficiency

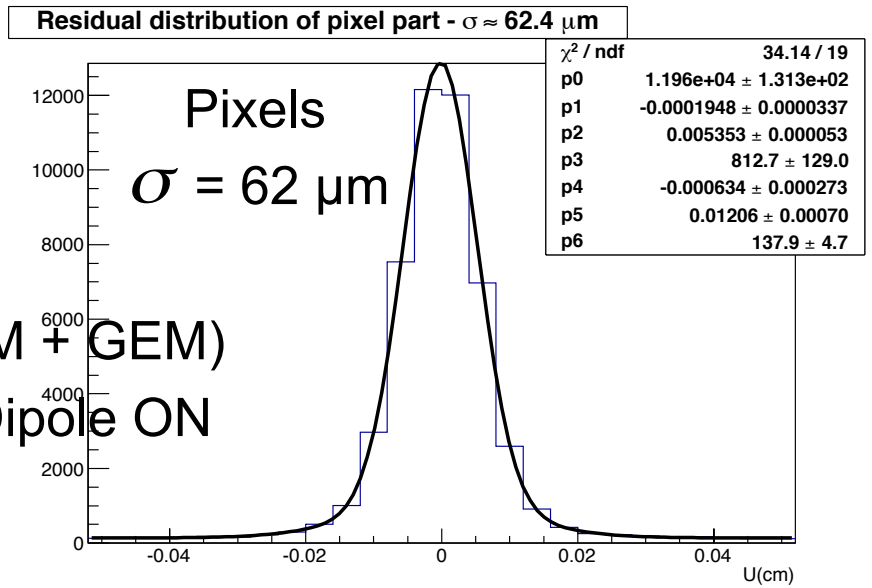
MP01X	Eff. High Flux muons	Eff. High Flux hadrons	Eff. Low Flux muons
Pixels	97.0%	95.5%	98.4%
Strips	97.7%	97.0%	97.8%
Global	97.1%	96.6%	98.2%

MP01Y	Eff. High Flux muons	Eff. High Flux hadrons	Eff. Low Flux muons
Pixels	97.5%	94.3%	97.7%
Strips	97.8%	97.0%	98.4%
Global	97.6%	96.3%	97.8%

MP00	Eff. High Flux muons	Eff. High Flux hadrons	Eff. Low Flux muons
Pixels	97.3%	96.5%	97.9%
Strips	98.2%	96.7%	98.1%
Global	97.4%	96.7%	98.0%

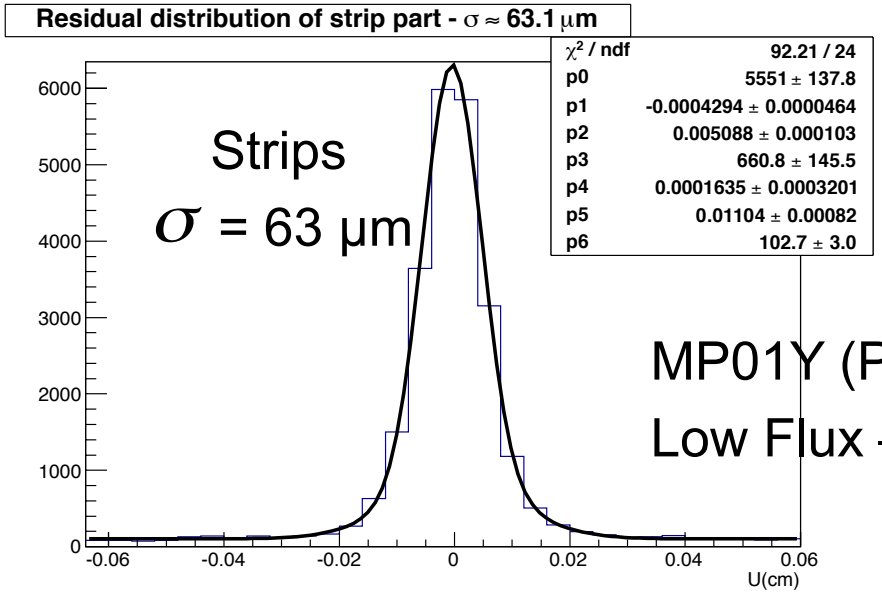
Performance summary : 2012 - Resolution

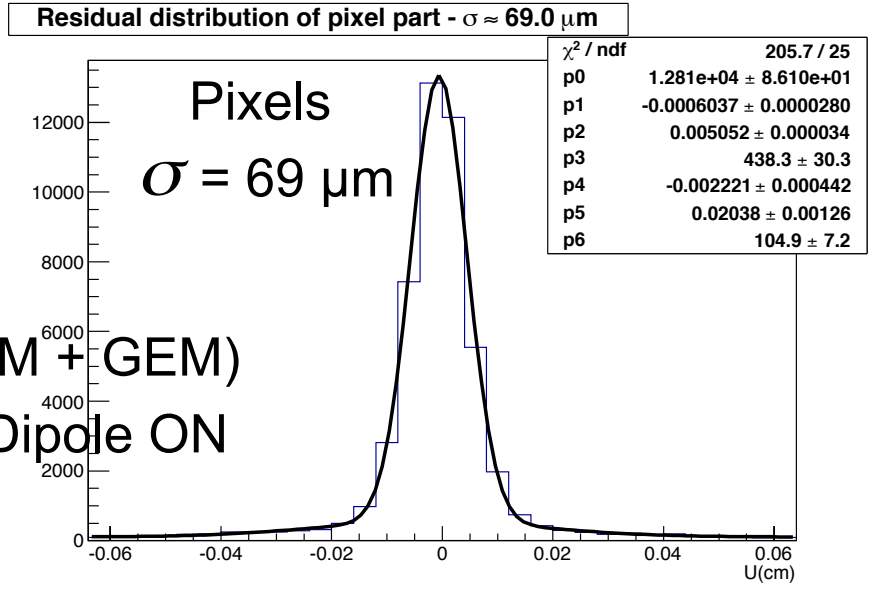




MP01X (PMM + GEM)

Low Flux – Dipole ON





MP01Y (PMM + GEM)

Low Flux – Dipole ON

Performances summary : 2012

- Spatial resolution : influence of flux and fringe field (all values in µm)

Detector	Low flux muons Dip. OFF	Low flux muons Dip. ON	High Flux muons Dip. ON	High flux hadrons Dip. ON
MM02X	76	102	102	115
MM03X	71	234	273	232
MP01X GEM (strips)	68	69	75	112
MP01X GEM (pixels)	58	58	98	88
MP00 BR (strips)	80	115	136	133
MP00 BR (pixels)	82	119	138	148

- **MP01X (PMM+GEM)**
- **Dipole OFF**
  - Good performances
- **Dipole ON**
  - No degradation (too far from dipole)
- **High Flux**
  - Degradation

- **MP00 (BR)**
- **Dipole OFF**
  - Good performances, slightly under PMM +GEM
- **Dipole ON**
  - Degradation similar to Old Micromegas in the same region
- **High Flux**
  - Degradation similar to MM and PMM + GEM

Conclusion

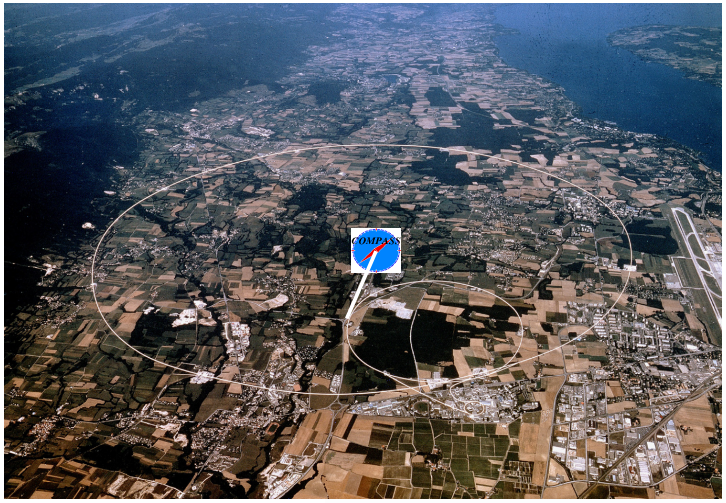
- 3 Detectors tested in real COMPASS conditions, with two spark-reduction technologies
- Good efficiency for all the detectors, even at high flux
- Good intrinsic resolution, slightly better for detectors with GEM foils compared to detectors with Buried Resistors
- Degradation of the resolution caused by fringe fields (similar to old Micromegas detectors)

Outlook

- *Analysis*
  - Improve resistance to magnetic fields : voltage settings, offline correction…
  - Try to improve resistive prototype resolution with an offline correction
- *New Detectors*
  - Prototypes to be tested in 2012 produced by CIREA

Spares

The COMPASS experiment at CERN

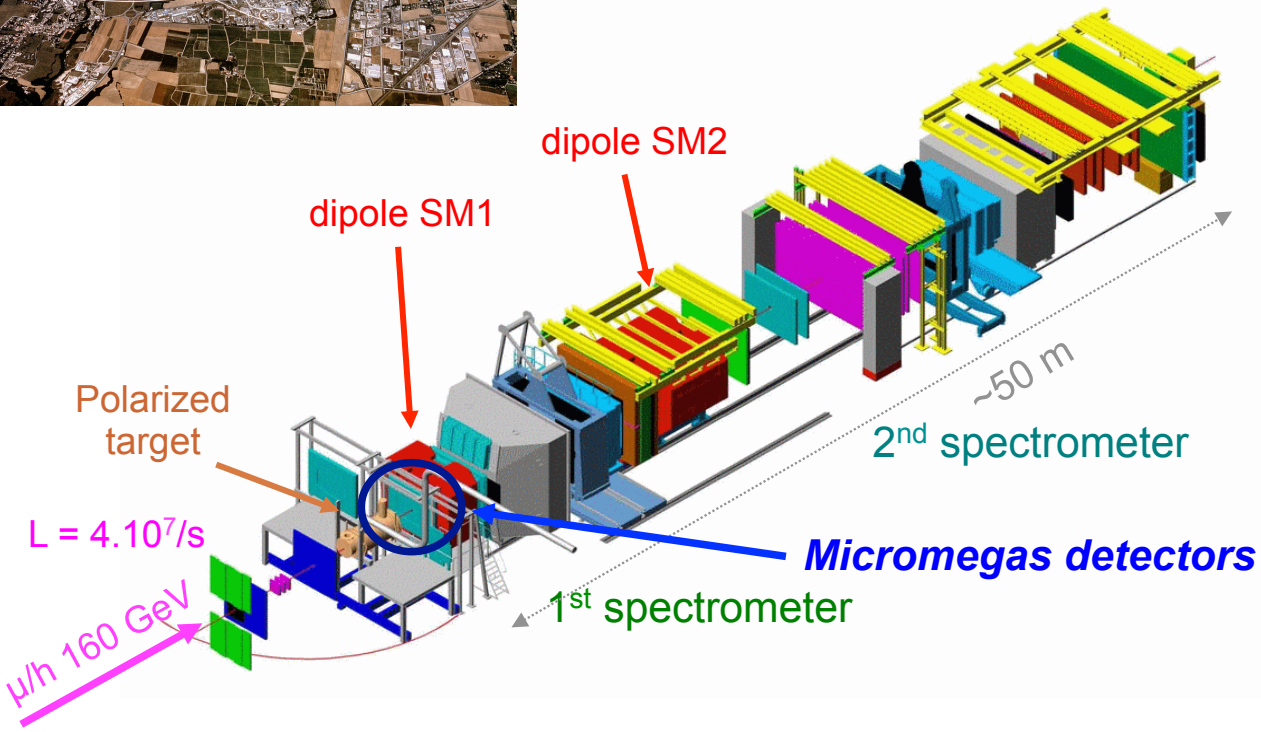


Dedicated to nucleon structure and spectroscopy studies

High resolution spectrometer at small and large angles

High statistic experiment (30kHz trigger rate)

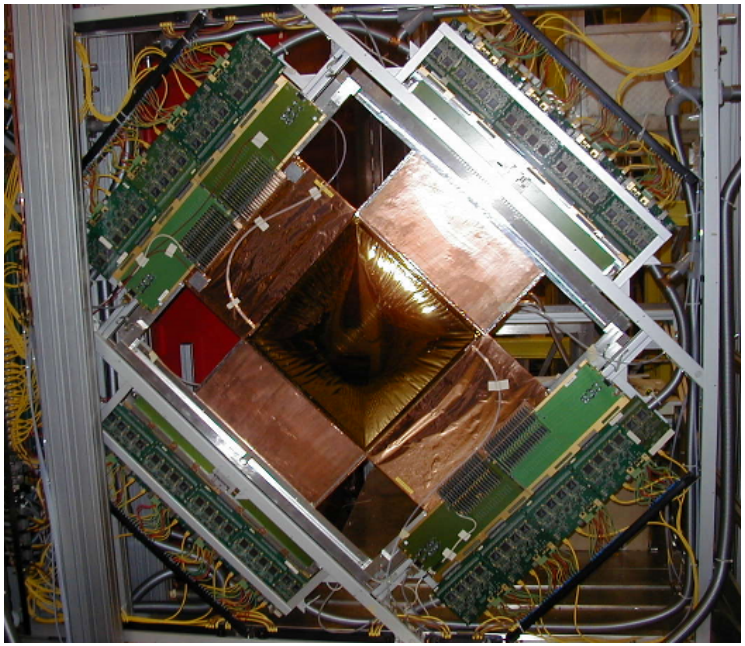
Very good spatial resolution (<100µm) required at small angle for kinematics and particle identification



Present COMPASS Micromegas detectors

- Main characteristics
  - *Large size 40x40 cm² with deported electronics*
  - *Reduced discharge rate with light gas and low noise electronics*
  - *Very good performances (70-100µm, 10ns resolution)*

- Room for improvements
  - *Blind center (5cm diameter disk, beam area)*
  - *Discharge rate in amplification gap is limiting factor with hadron beam*



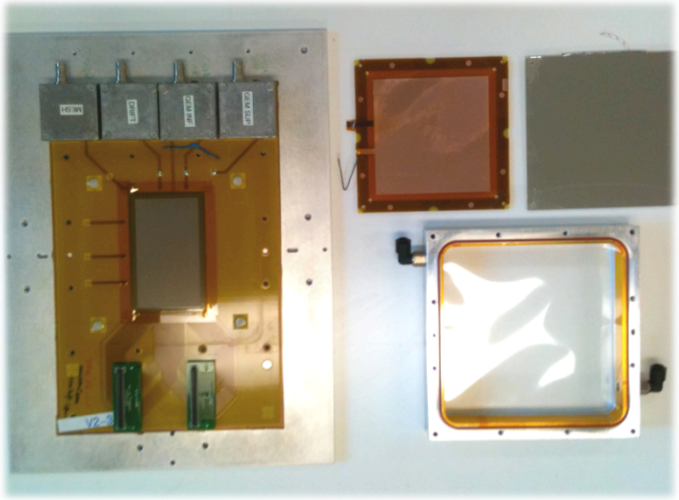
The Pixel Micromegas Project

- Main Objectives
  - *Fewer Discharges -> Stand five time higher flux hadron beams*
  - *Detector active in beam area*

- New MM detector to design with :
  - *10 to 100 times fewer discharges compared to present MM*
  - *Read-out with pixels in the detector center (beam area)*
  - *Integrated electronics (APV25 chips)*
  - *Improved robustness (bulk technology)*

R & D on discharge rate reduction technologies

TF 10 Prototypes :



- 144 strips with 400µm pitch read by AFTER/T2K FEE
- 5mm drift gap
- 128 µm amplification gap
- 56.7×100mm^2 active area
- Gas 5% iC_4H_{10} / 95% Ar
- Different detectors :
  - *Bulk MM made at CERN and CEA,*
  - *Different meshes*
  - *2 MM with GEM pre-amplification with 1 and 2 mm transfer gap*
  - *2 MM with a resistive layer + isolation on strip (kapton of 1MΩ/□ and resistive paste of 10MΩ/□) and 2 MM with resistive paste on strip*

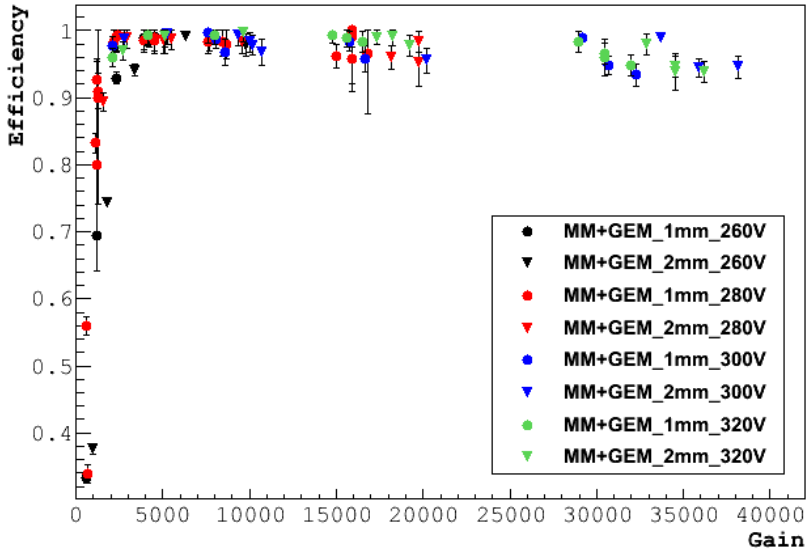
- *Performance studies at SPS in 170 GeV muon beam*
- *Discharge rate reduction studies at PS in 0.2 to 3 GeV hadron beam*
- Common R&D with CLAS 12 Saclay group

From M.Vandenbroucke

R & D on discharge rate reduction technologies

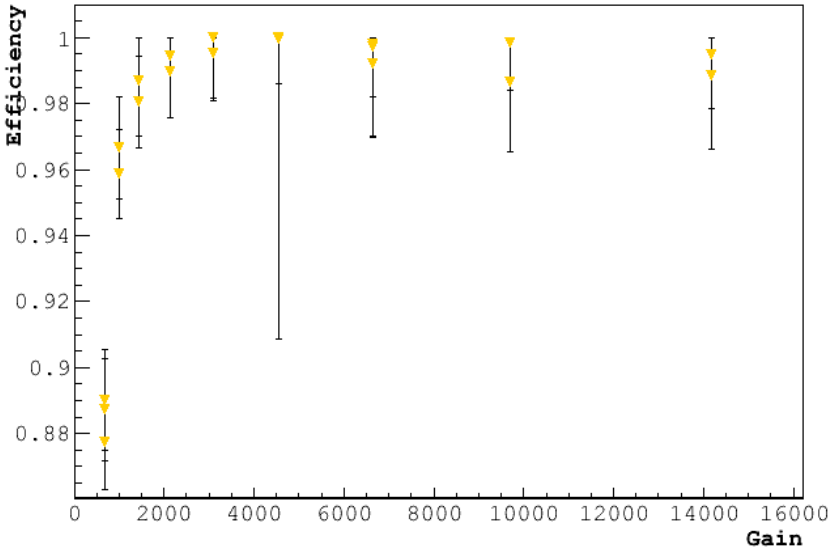
- 170 GeV/c muon beam at SPS (RD51 Beam time) :
  - ➢ *Efficiency plots*

MM + GEM



➢ *MM + GEM detectors : up to 98%*

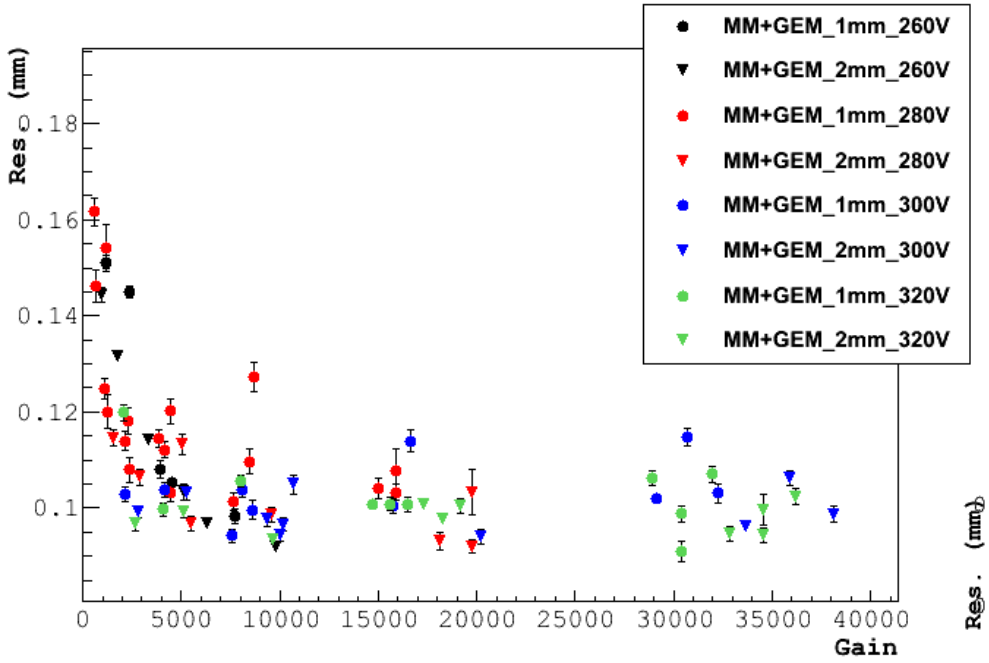
MM with Buried Resistors

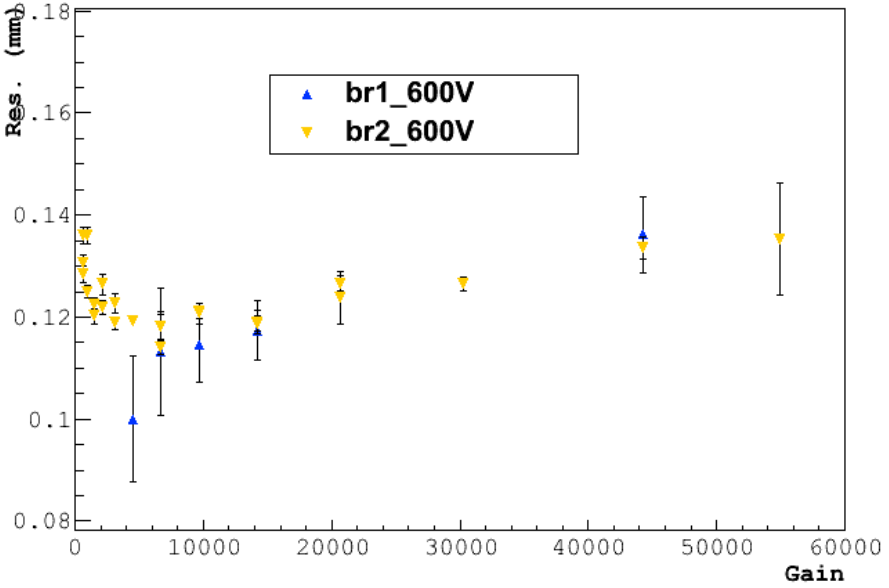


➢ *Above 99% for BR2 detector*

From M.Vandenbroucke

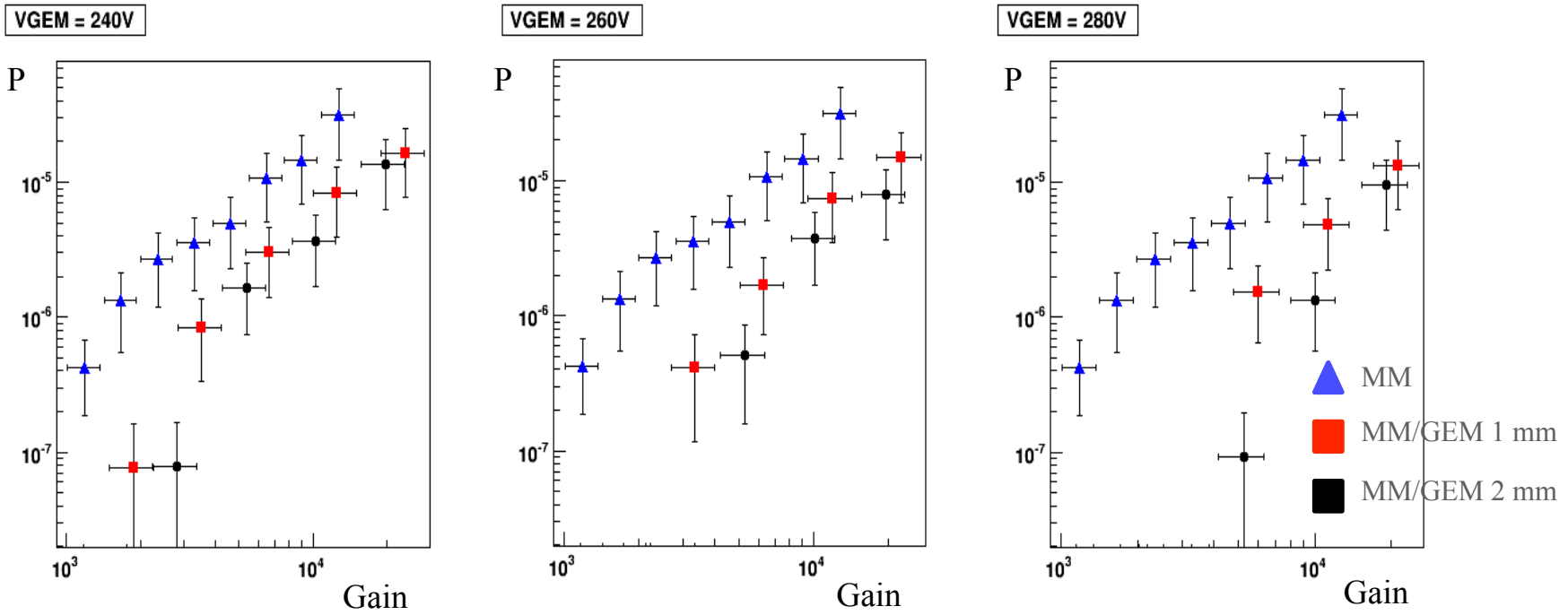
R & D on discharge rate reduction technologies





R & D on discharge rate reduction technologies

- [MM+GEM] discharge rate in 0.2 to 3 GeV/c hadron beam (CERN PS)



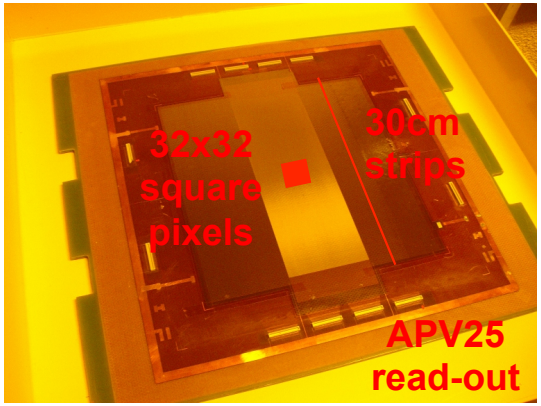
  - *A GEM pre-amplification reduces the discharge rate by at least a factor 10*

- Resistive detector discharge rate:
  - *No discharge has been detected on resistive detectors with the experimental setup*

From M.Vandenbroucke

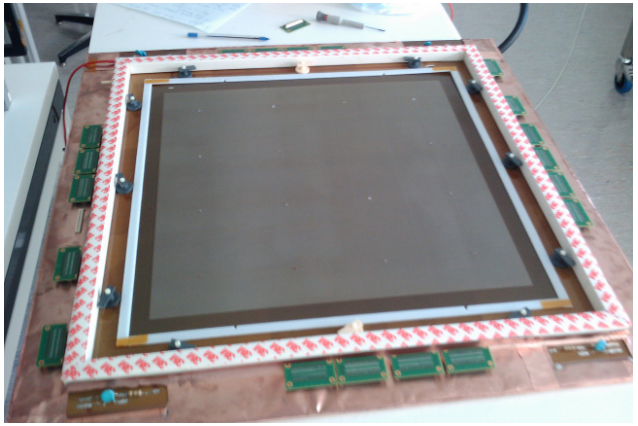
Large size prototypes

- 2009 : First prototypes
  - *Square pixels in the center, APV read-out with MM detectors*
  - *Comparisons bulk / non-bulk*



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

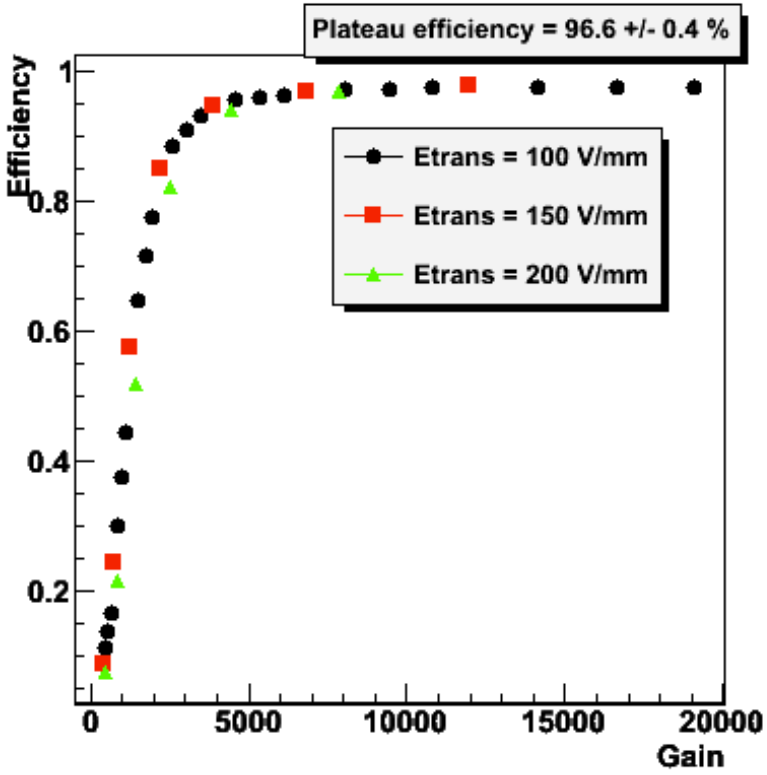
- 2011 : 3 40 x 40 cm^2 prototypes
  - *2 large size PMM+GEM detectors*
  - *1 large size Buried Resistors prototype*

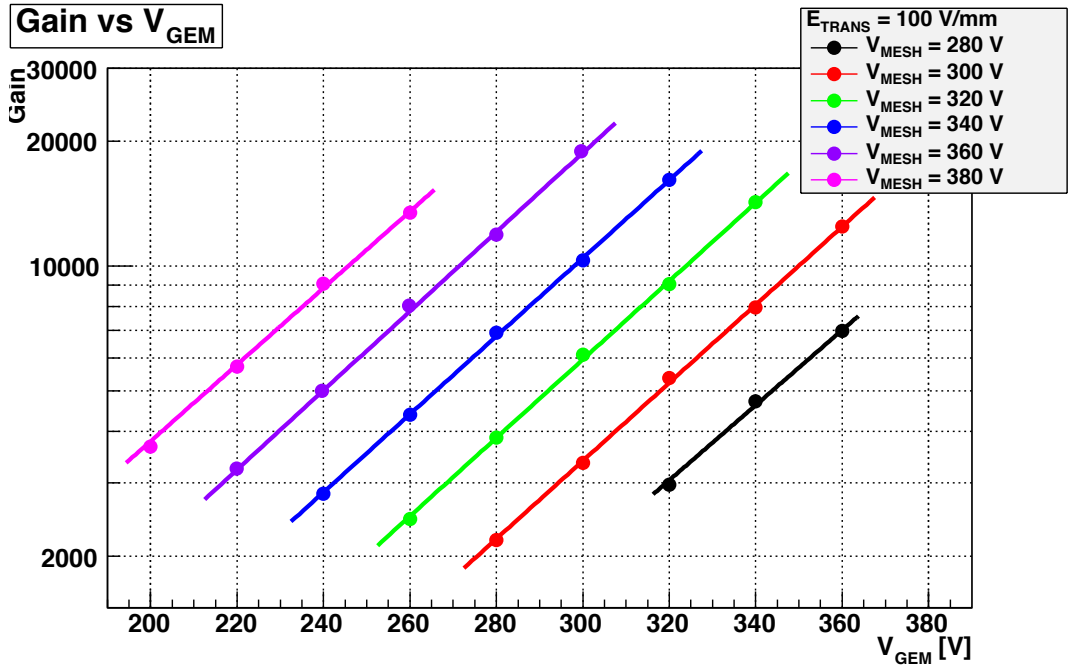


- 2012 :
  - *2 old MM detectors replaced by PMM+GEM + 1 spare*
  - *Buried Resistors prototype still in beam*

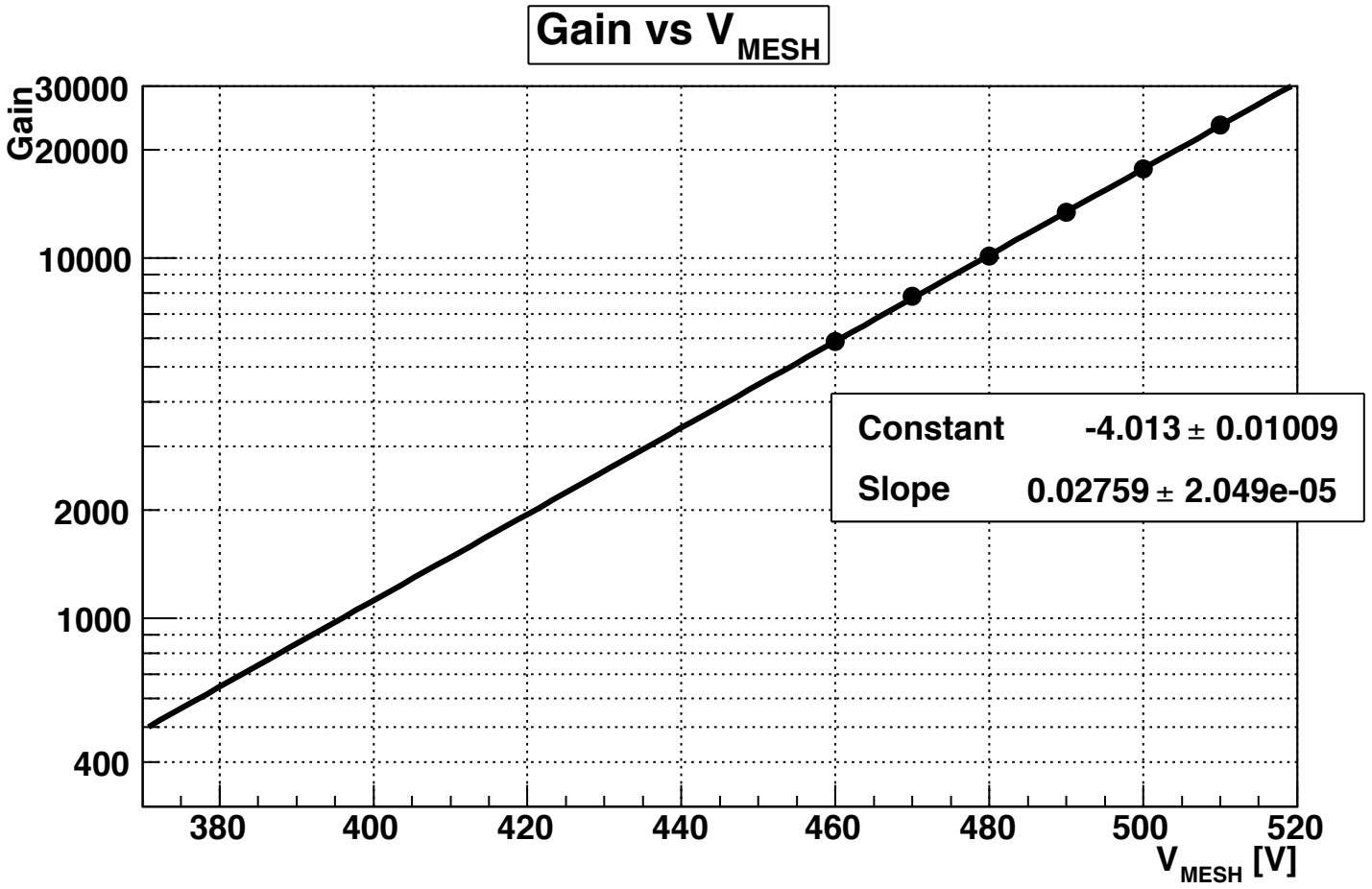
- PCB+Bulk & GEM foils produced at CERN
- Detectors built in Saclay

PMM + GEM : gain & efficiency



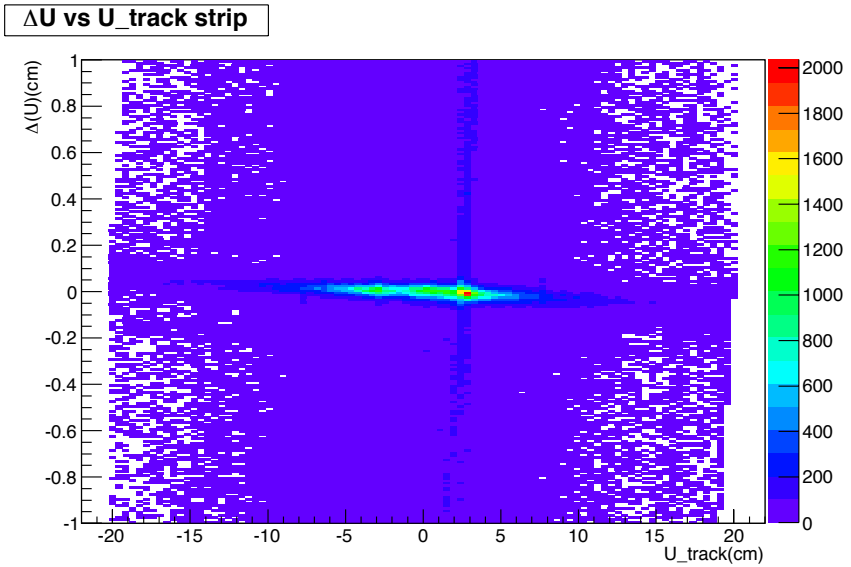


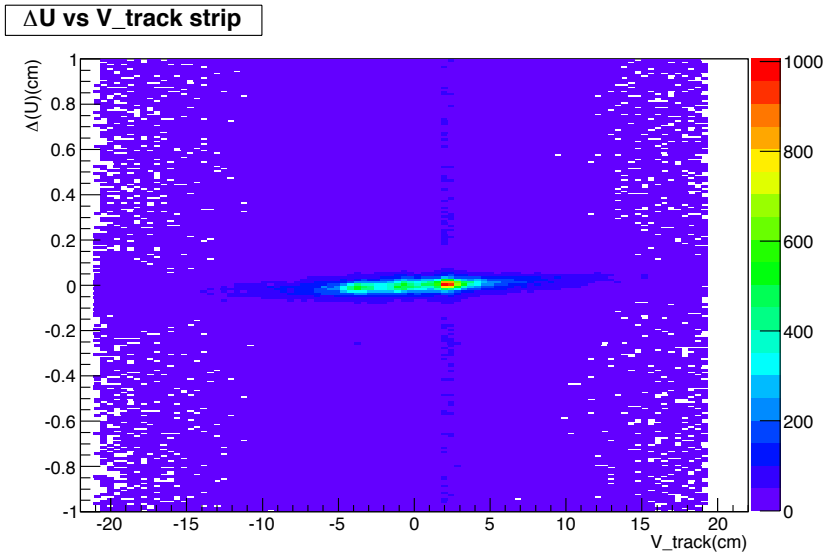
PMM BR : gain


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

Analysis : Correction of detector's orientation

- Detector's translation/rotation along/around the beam axis has to be corrected :
  - Variation of the residual in x vs the x coordinate of tracks gives the right position
  - Variation of the residual in x vs the y coordinate of tracks gives the right orientation





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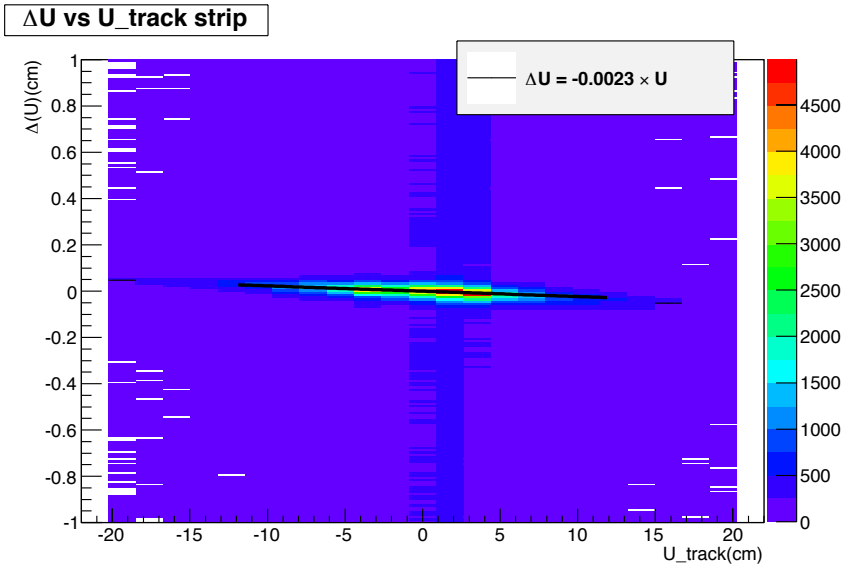

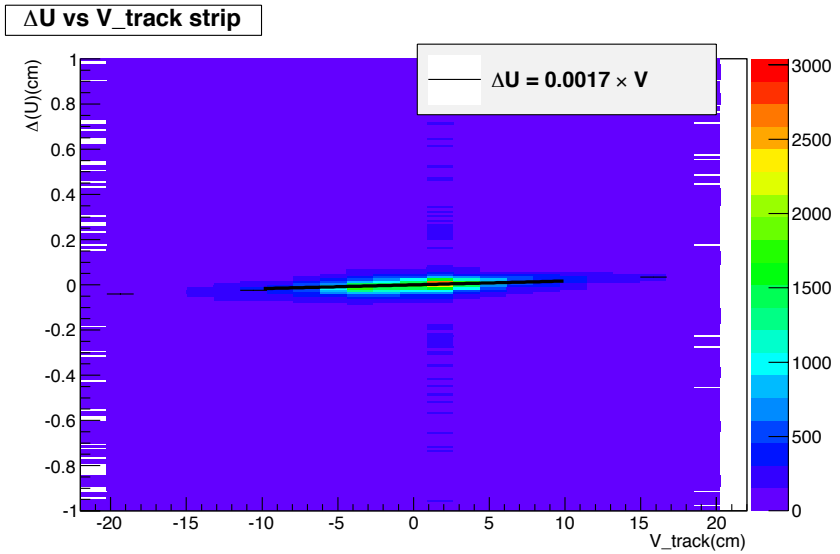

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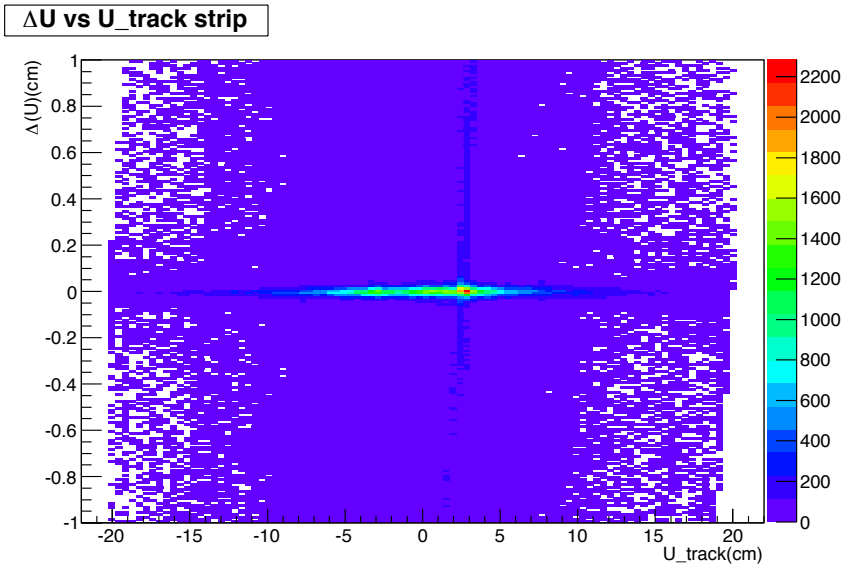
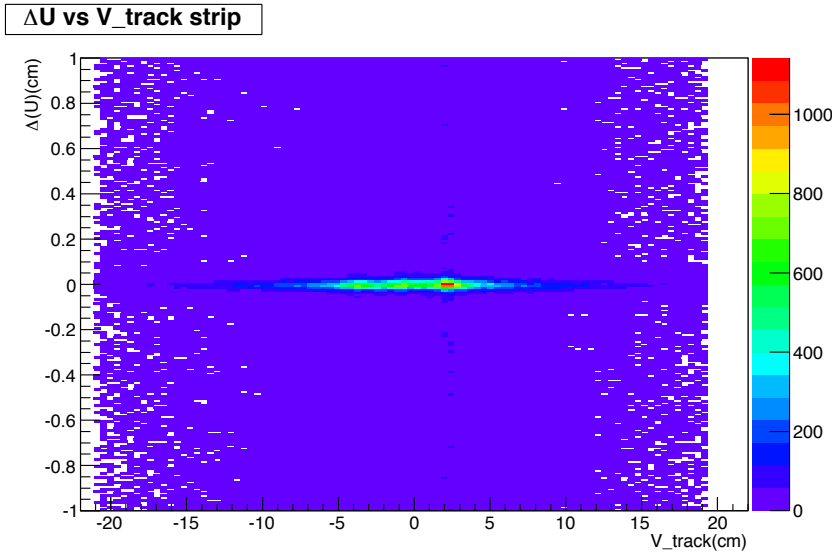
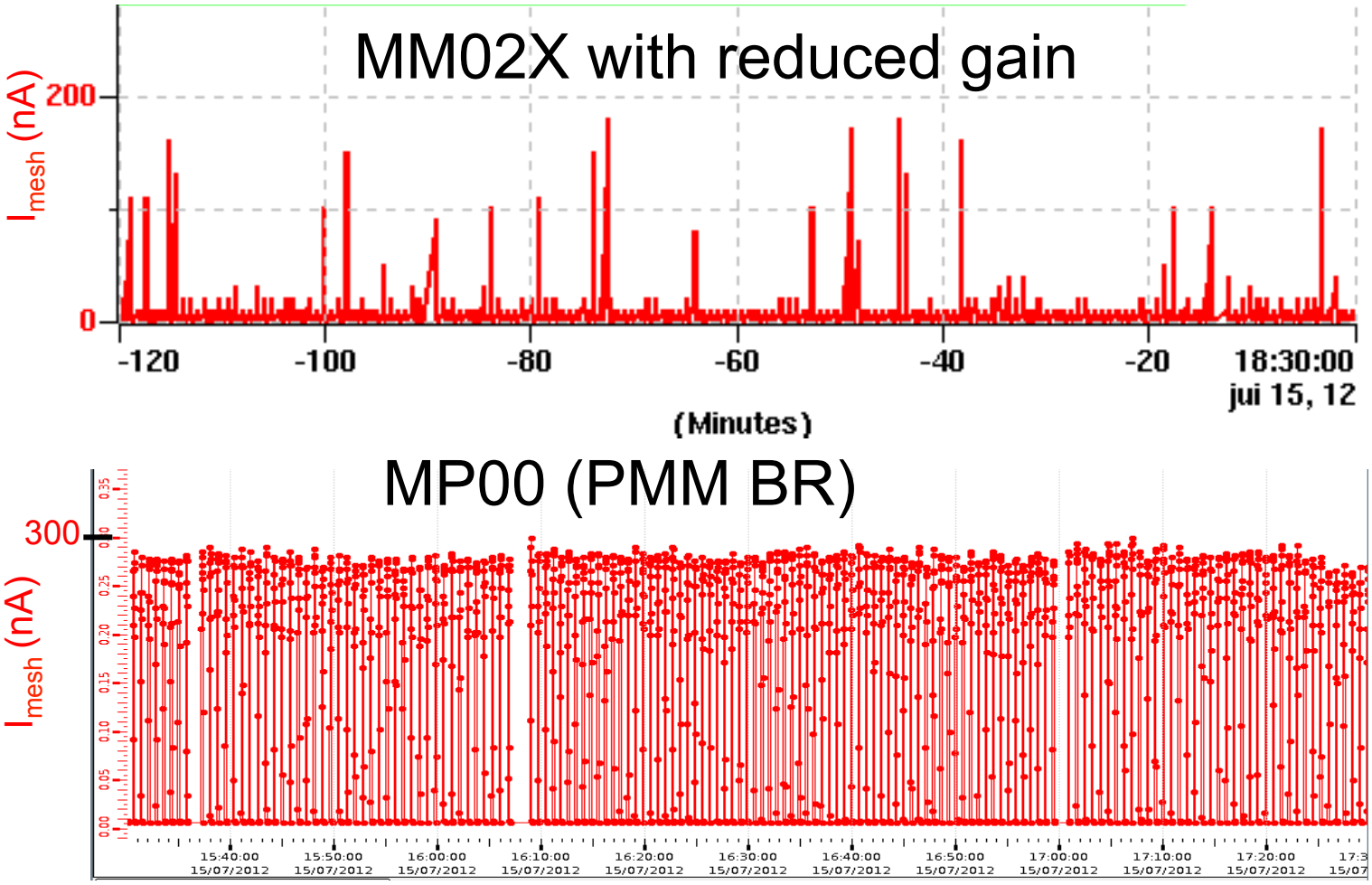
- Detector's translation/rotation along/around the beam axis has to be corrected :
  - Variation of the residual in x vs the x coordinate of tracks gives the right position
  - Variation of the residual in x vs the y coordinate of tracks gives the right orientation





Performances summary : 2012 - Discharges

- No discharge seen in 2012 high flux hadron beam on all PMM detectors



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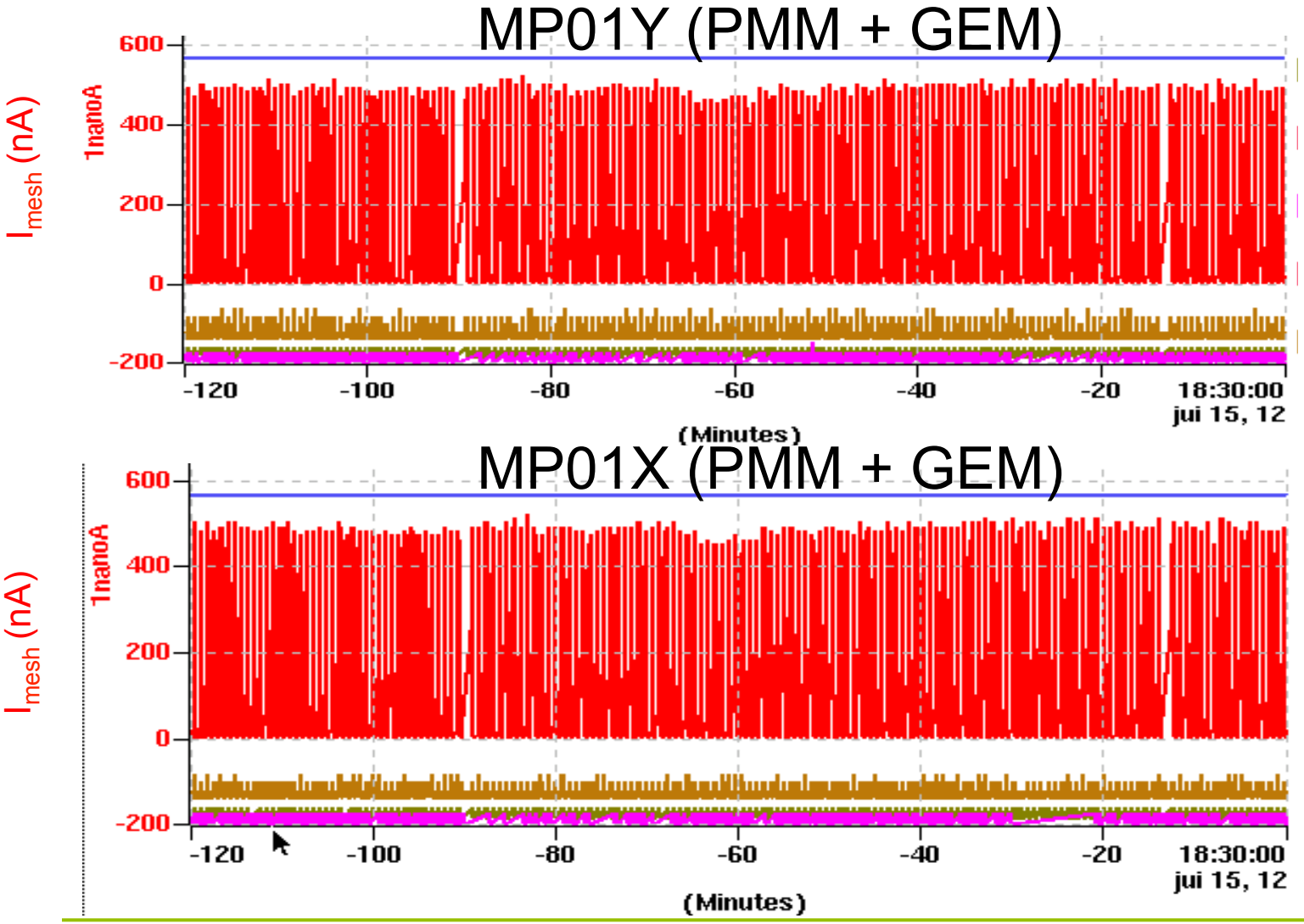
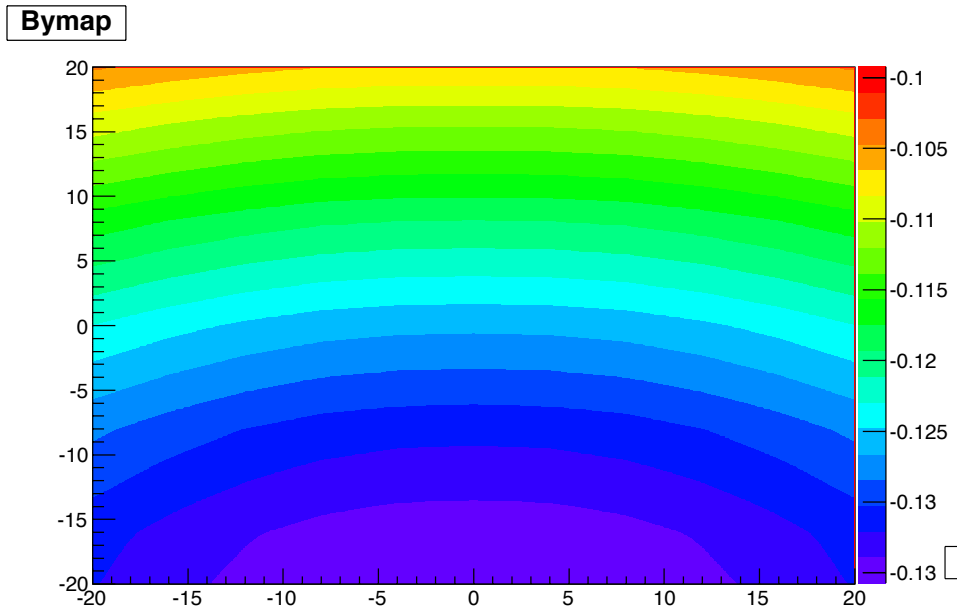


Field maps

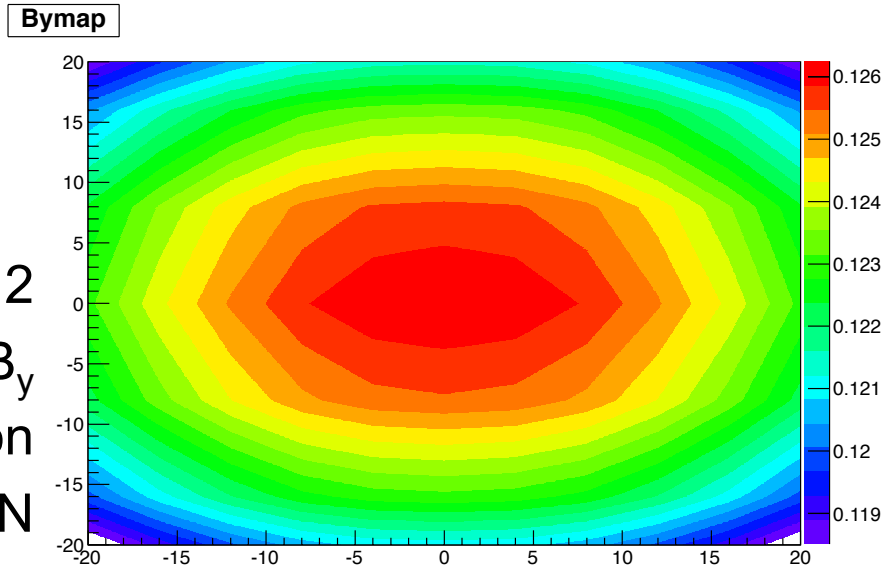


2011

B_y

Prototype position

solenoid ON + dipole ON



2012

B_y

Prototype position

No Solenoid + dipole ON