Present and future Micromegas detectors at COMPASS

Damien Neyret

CEA Saclay IRFU/SPhN

Journées d'instrumentation sur les détecteurs gazeux

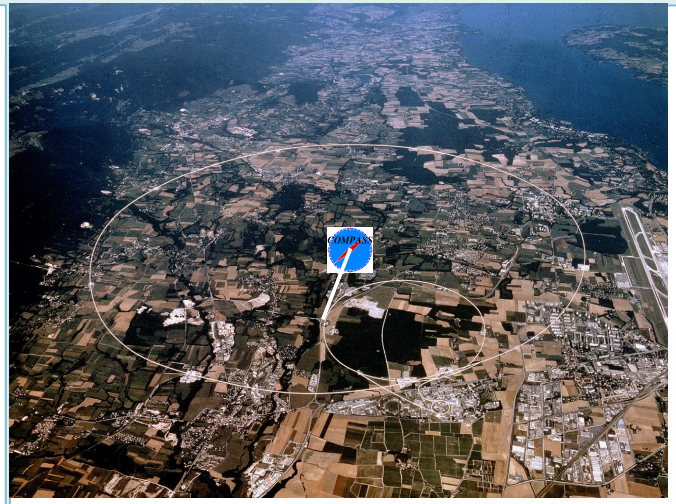
25/06/2014

Present Micromegas detectors at COMPASS and performances

New pixelized Micromegas detector project

Performances and prospects

The COMPASS experiment at CERN

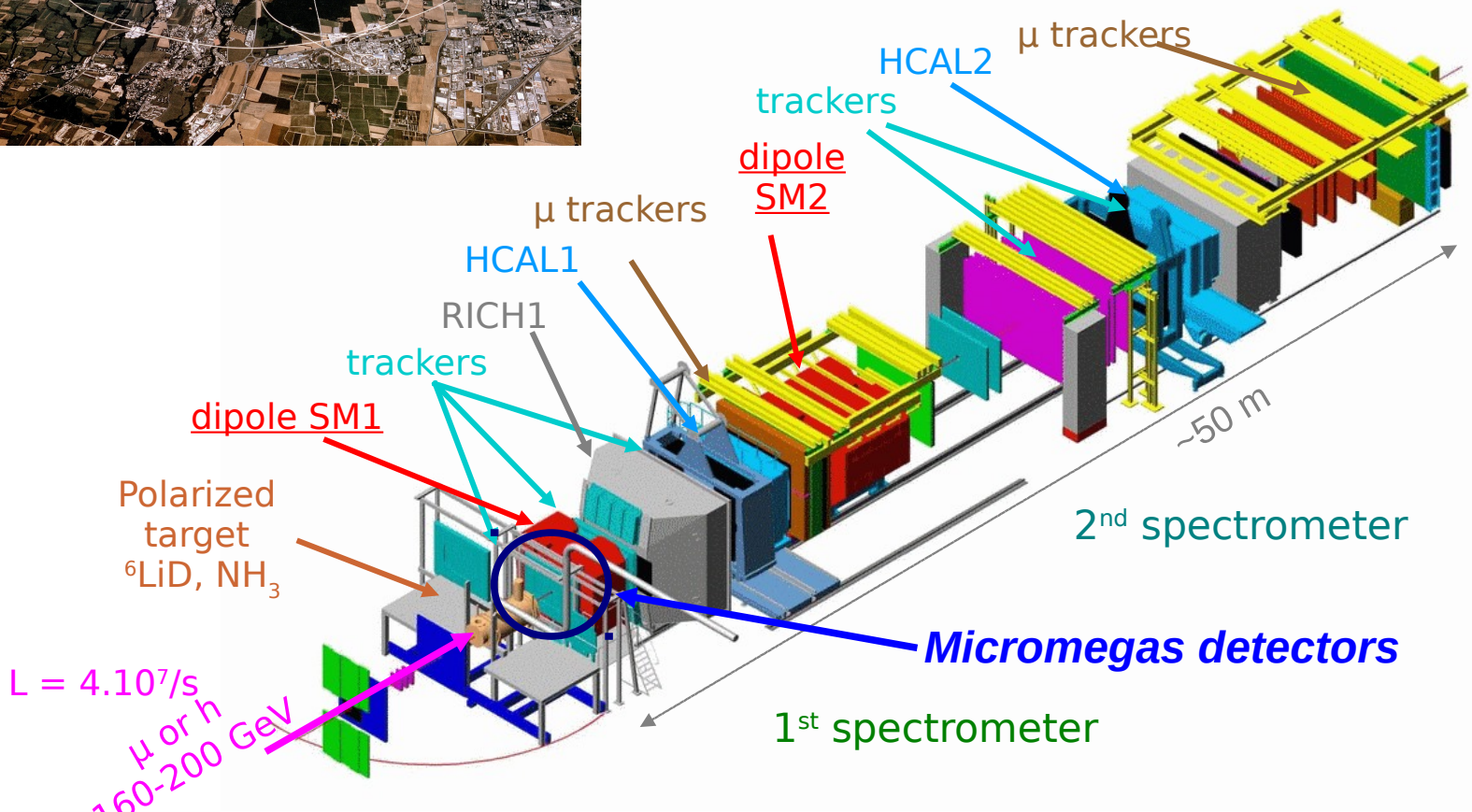


Muon or hadron beams on fixed target

2 spectrometers for small and large angles

Taking data from 2002 for nucleon structure studies

High statistic experiment (30kHz trigger rate)



Present COMPASS Micromegas detectors

Present Micromegas detectors

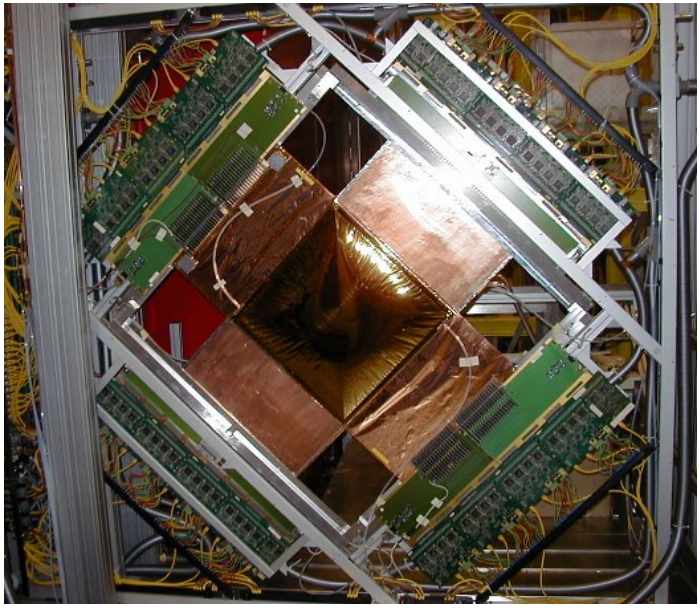
Light board sandwich with 40x40 cm² active area

70-100 µm and 10 ns resolutions

Light gas mixture Ne + 10% C_2H_6 + 10% CF_4 to limit discharge rate

3 stations of 4 planes (X, Y, U, V)

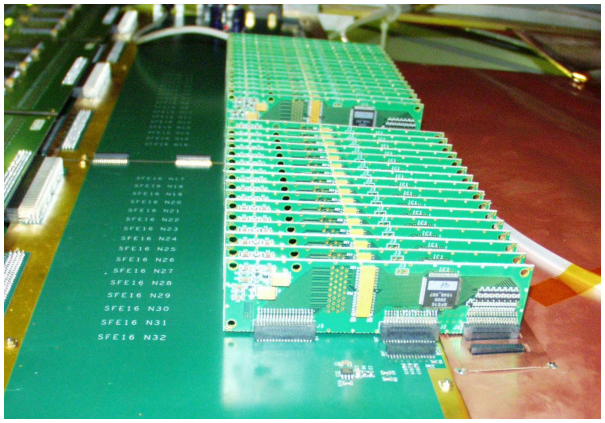
Blind in the center to avoid electronics occupation



Read-out electronics

Low-noise electronics using SFE16 chips (threshold ~ 4000 e^-)

TDC read-out of both leading and traling edges (1024 channels / plane)



COMPASS Micromegas gas system

Non recycling system

Gas mixture done in mixing chamber

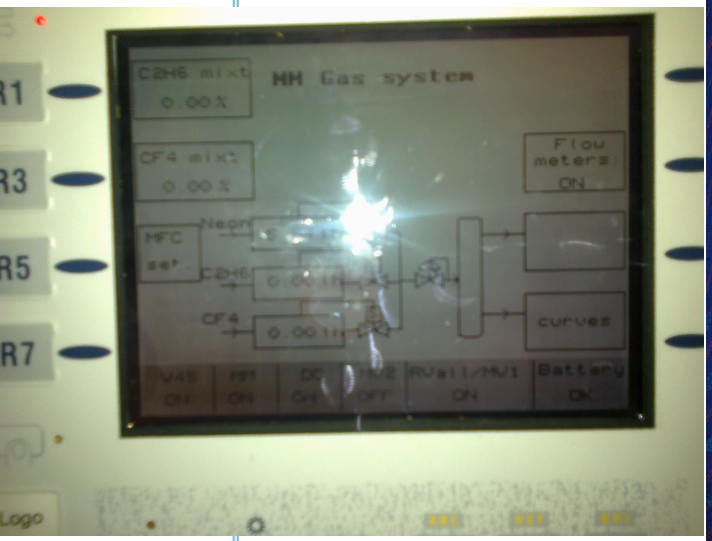
6 parallel lines, 2 detectors connected in serial

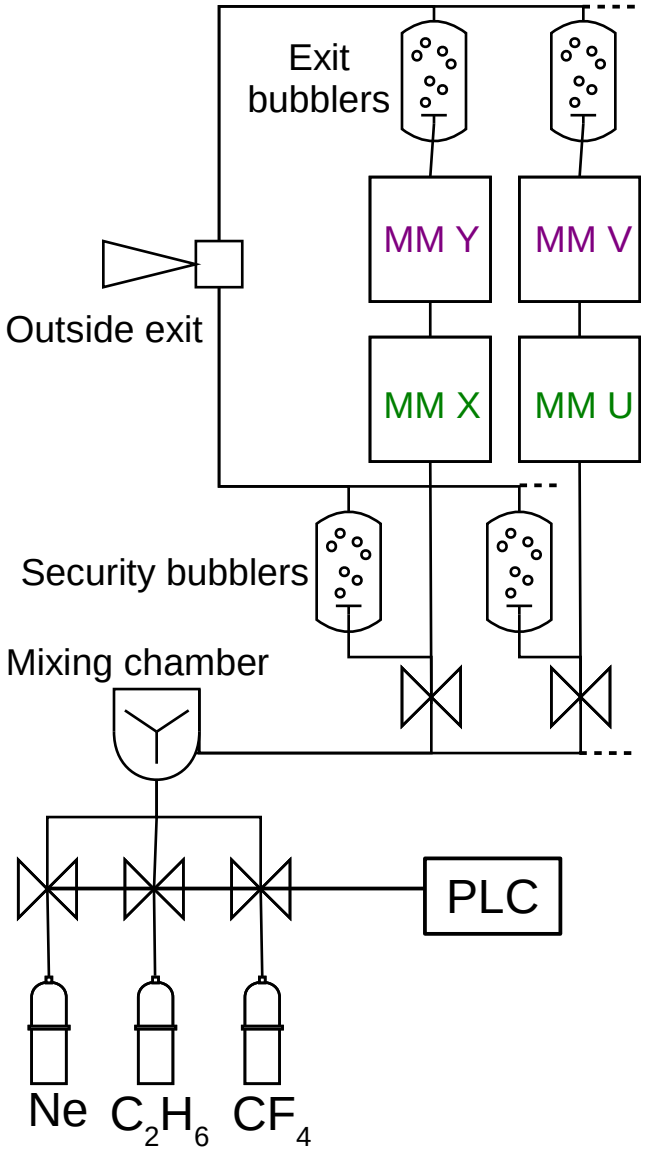
After having got through MM the gas is thrown outside

Gas mixture controlled by PLC

Mixing debimeter controlled by PLC

Gas mixture changed for hadron beam runs: less CF4 to reduce discharge probability





COMPASS Micromegas gas system

Irfu

cea

saclay

Non r

Gas mix

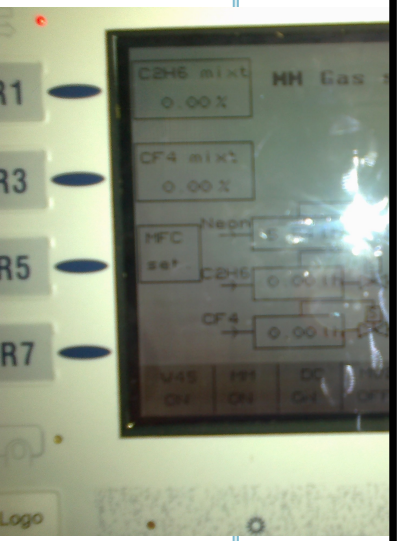
6 paralle

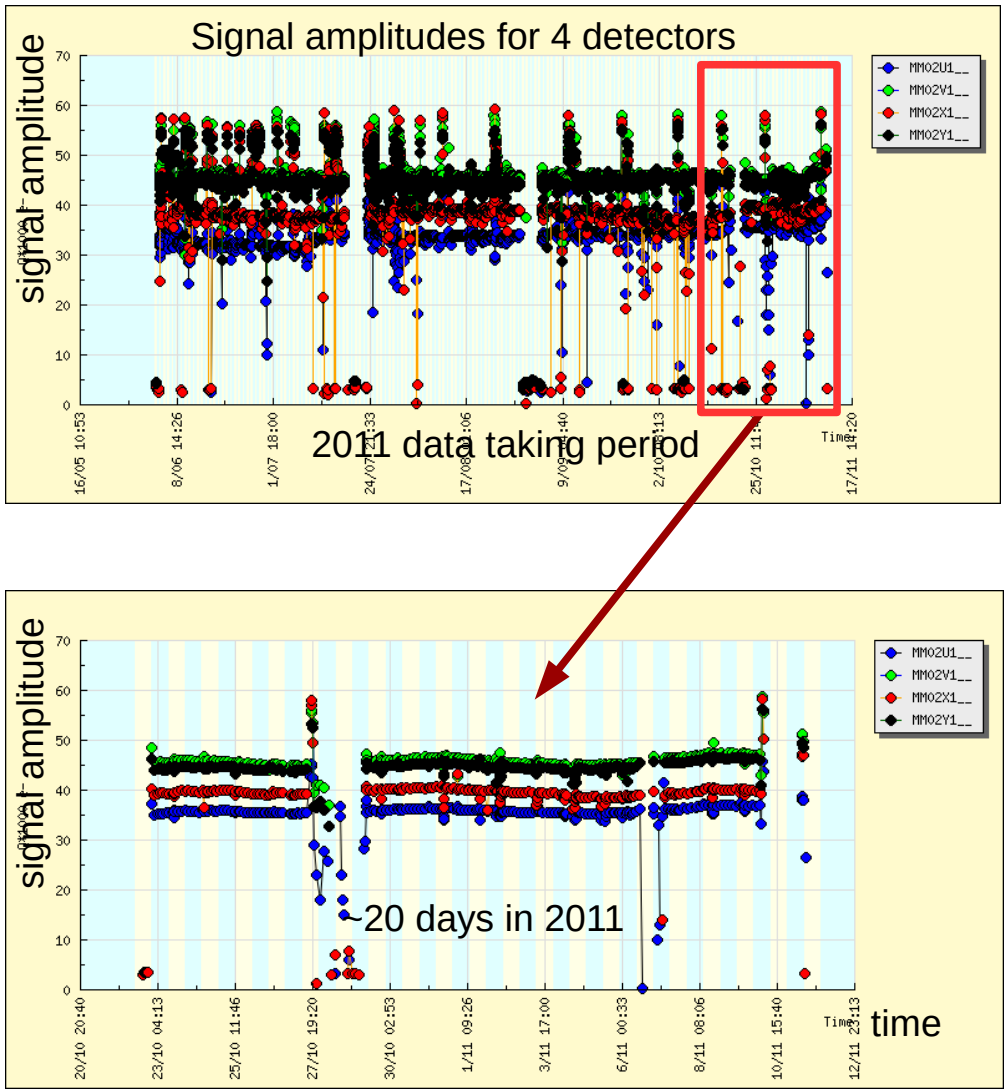
After hav
outside

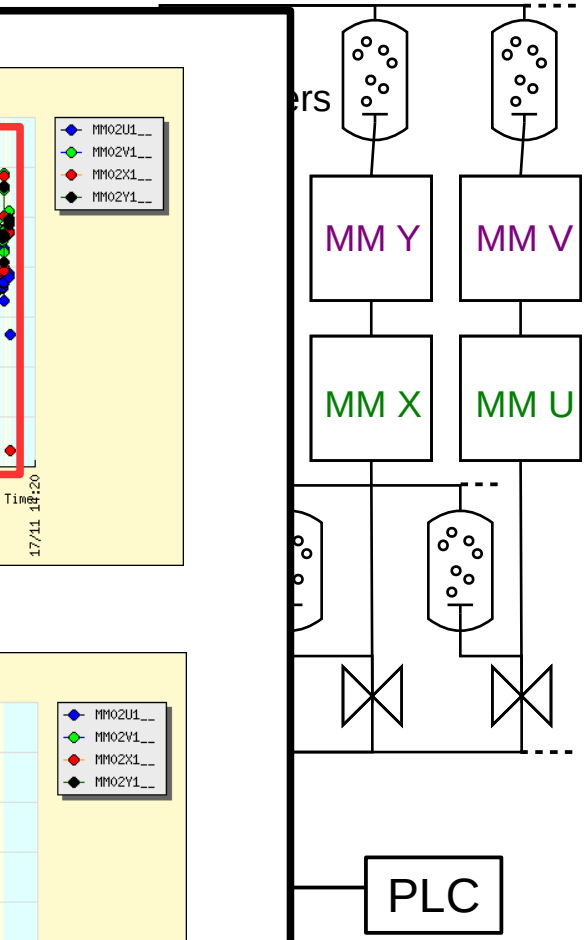
Gas r

Mixing d

Gas mix
CF4 to r







COMPASS Micromegas gas system

Irfu

cea

saclay

Non r

Gas mix

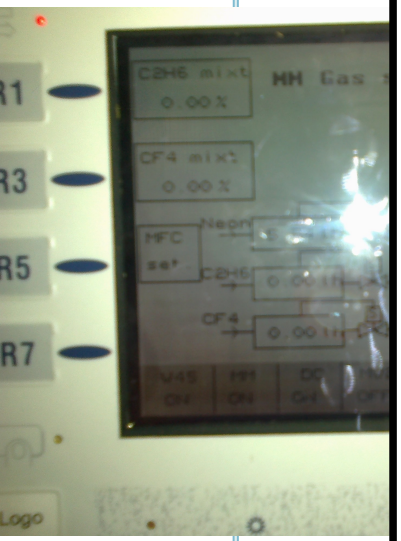
6 paralle

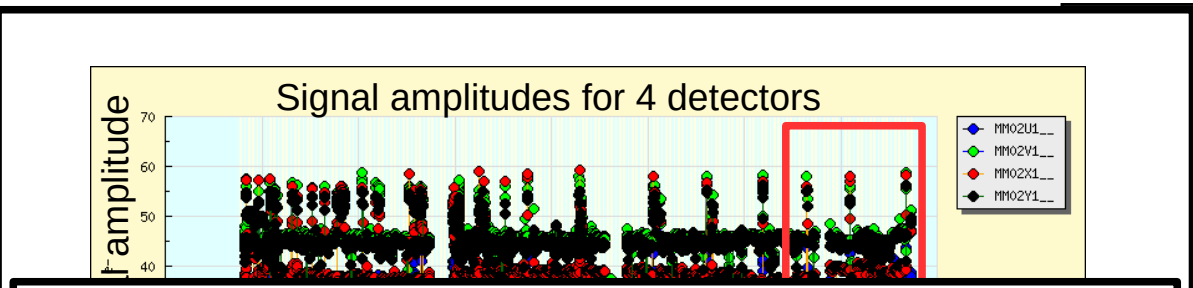
After hav
outside

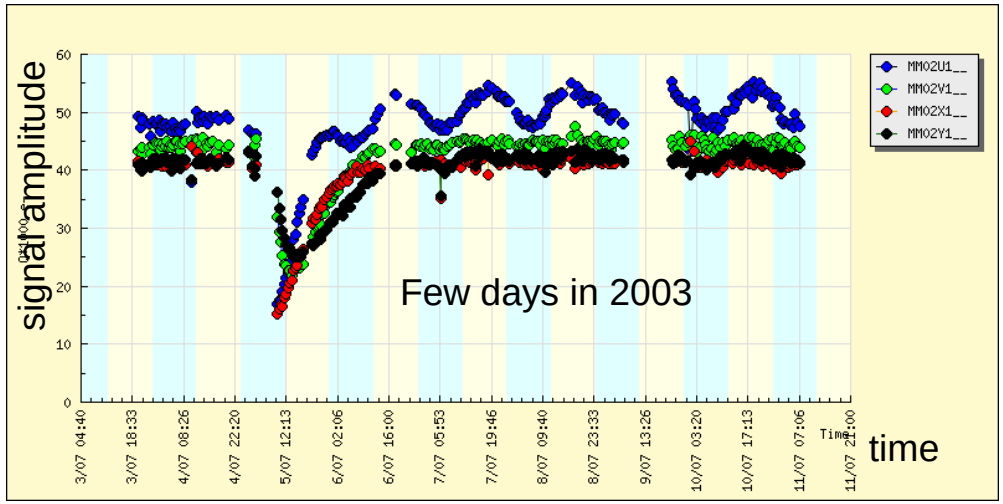
Gas r

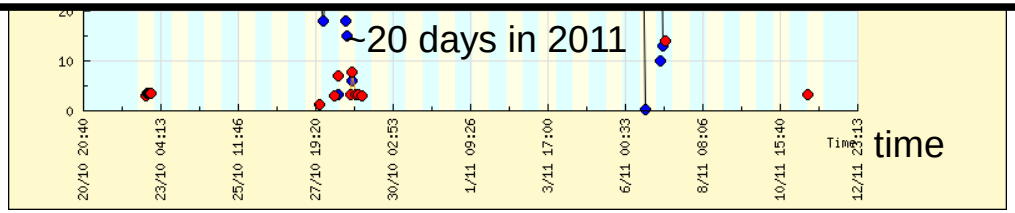
Mixing d

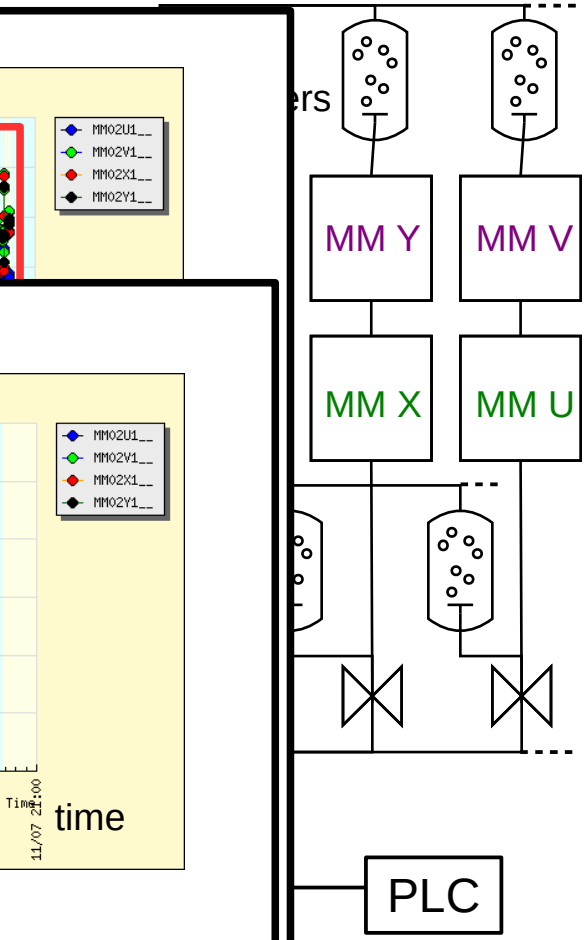
Gas mix
CF4 to r











Discharges in Compass MM detectors

Irfu
cea
saclay

Discharges already optimized

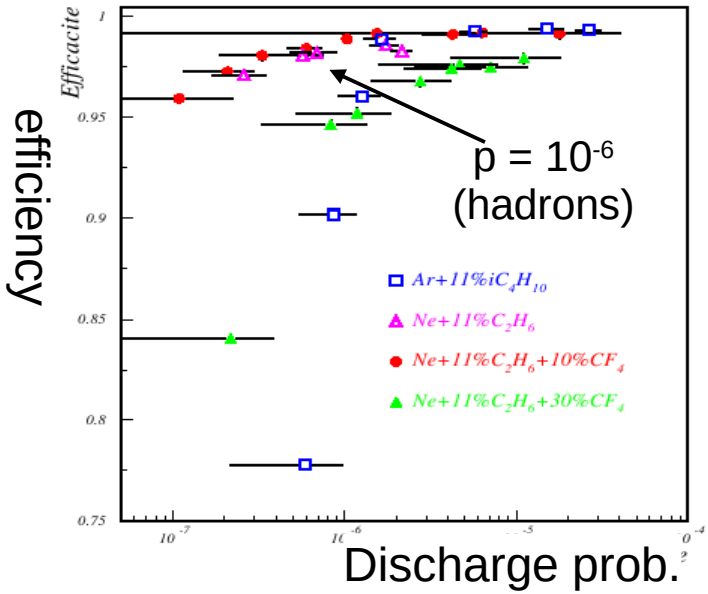
Light gas Ne-C_2H_6(-CF_4) selected

Moderate gain with low noise electronics

Each strip decoupled → low recovery time

→ Ok with muon beam

<0.1 disch./spill at high μ flux

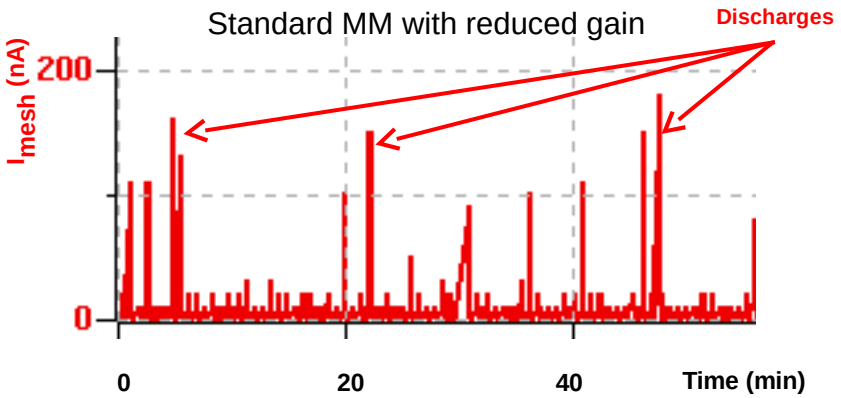


But limiting factor with hadron beam

Drift gap already increased in 2006-2007 (3.2 → 5mm)

0.5 to 1 disch./spill with 4.10⁷h/spill

Larger rate may reduce efficiency and damage the detector



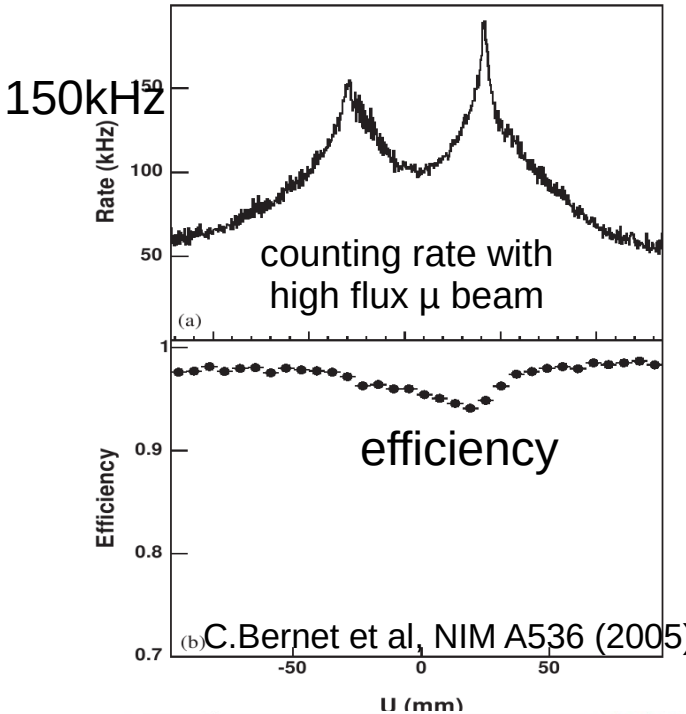
Performances of Micromegas with muon beam

Detection efficiencies

~ 98-99% low particle flux

~ 96% high flux, up to 150kHz / channel

No effect of aging noticed up to now



C.Bernet et al, NIM A536 (2005) 61

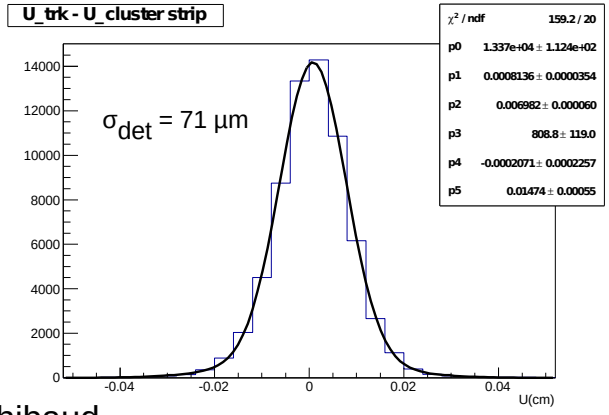
Resolutions

Spatial res. ~70μm

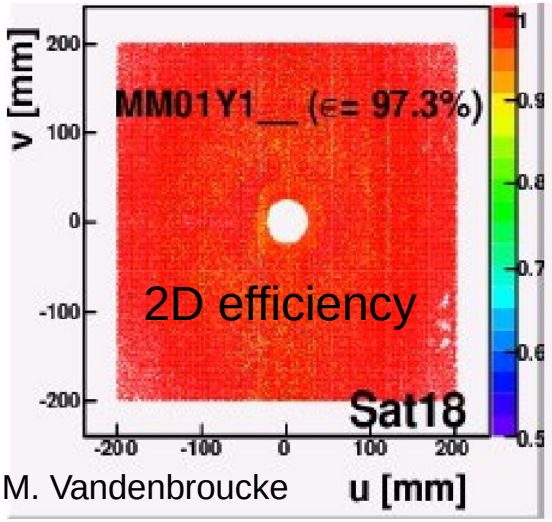
Increase to 100μm with magnetic field

Time res. Between 9 to 12 ns

Depends of amount of CF_4



F. Thibaud



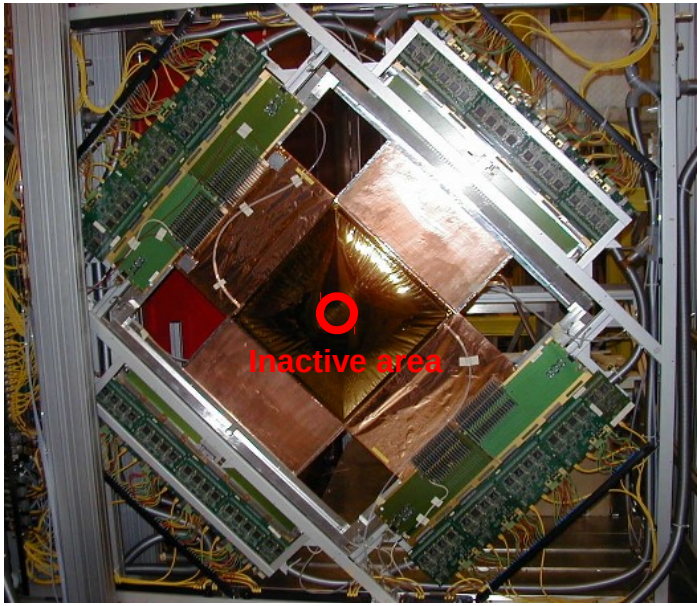
M. Vandenbroucke

New pixelized Micromegas project

Irfu cea saclay

Present Micromegas detectors

blind center in beam area, high discharge rate at hadron flux → room for improvements



Motivations for new MM detectors

Improved COMPASS tracking at very small angle with same material budget for new COMPASS program (DVCS studies)

Better stability at high muon and hadron flux

Main objectives of the project

Detectors active in beam area

Less discharge → stand 5 times higher flux

Integrated electronics (APV25 chips)

Robustness improved with bulk technology

Same size (114x58 cm²) as present MM

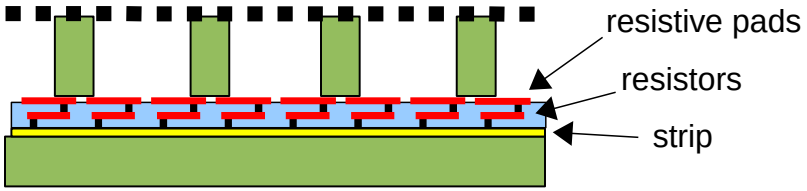
To be installed for the 2015 COMPASS beam period

Two solutions for discharge impact reduction

Resistive Micromegas

« Standard » resistive schemes not fully adapted for pixels

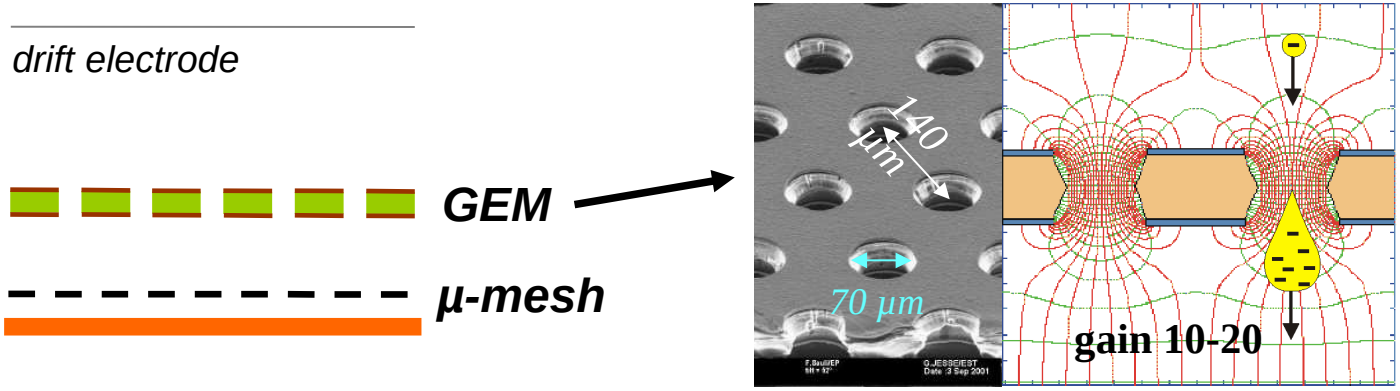
***Buried resistors** scheme proposed in 2010 by R. de Oliveira et al.*



Hybrid Micromegas with 1 GEM foil

Preamplification with a GEM foil (gain 10-20)

Micromegas stage at lower gain → fewer discharge

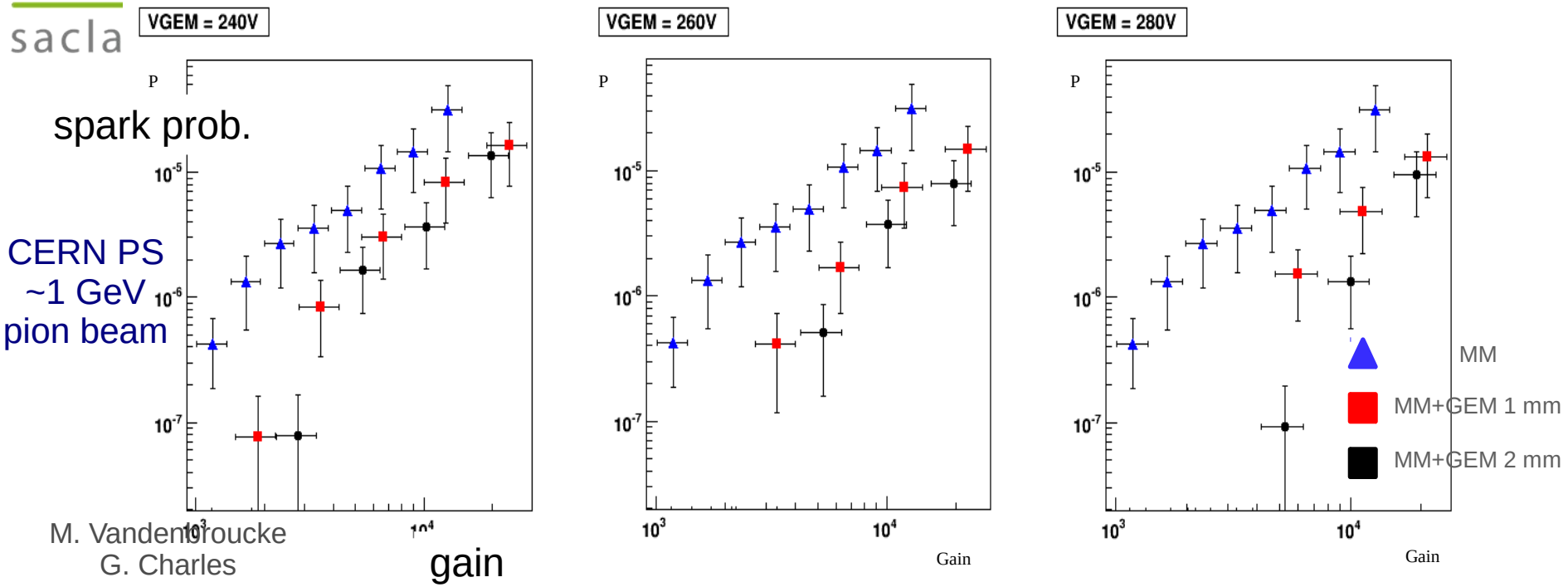


R&D on spark impact reduction

Common studies with CLAS12 group and with RD51 collaboration on small size detectors (6x10 cm² active area)

Hybrid detectors

Important reduction (>10) of discharge probabilities compared to standard MM



Resistive detector

No discharge visible as their amplitude are too small to be detected

Pixels read-out in the detector center

Too high flux for strips

Expected particle flux > 100kHz/mm²

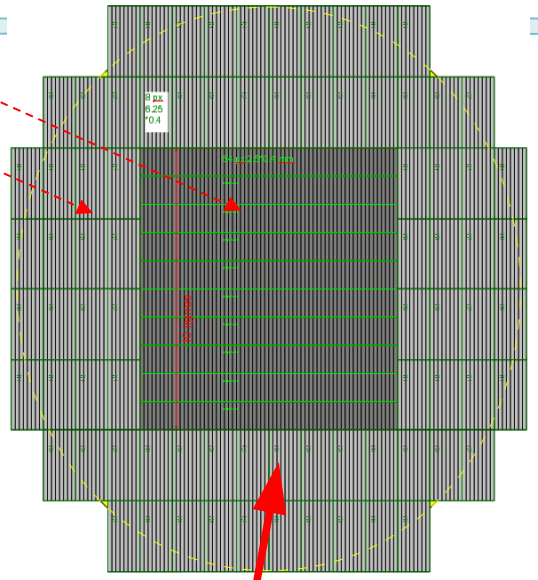
→ > 500kHz/channel if strip read-out

→ > 10% electronics inefficiency

***2.5x0.4** mm²*

***6.25x0.4** mm²*

1280 pixels



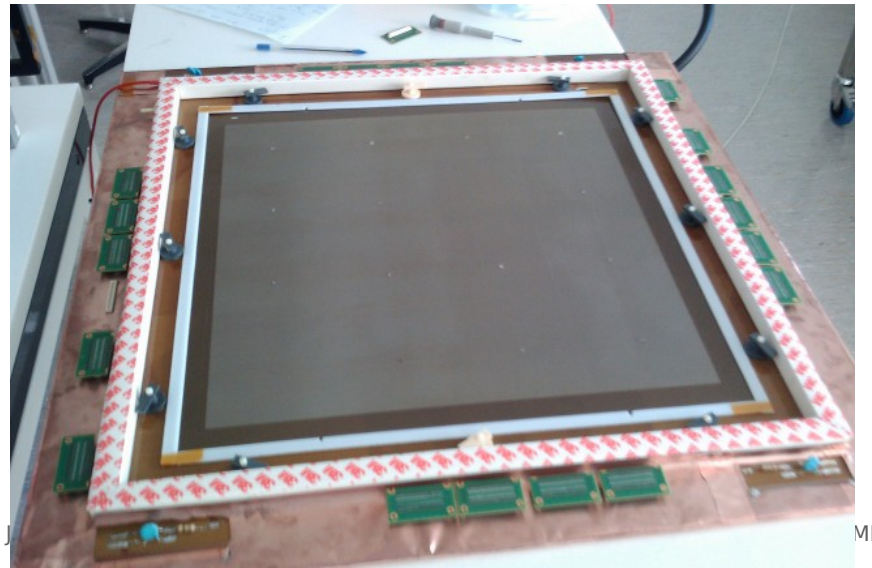
25 mm

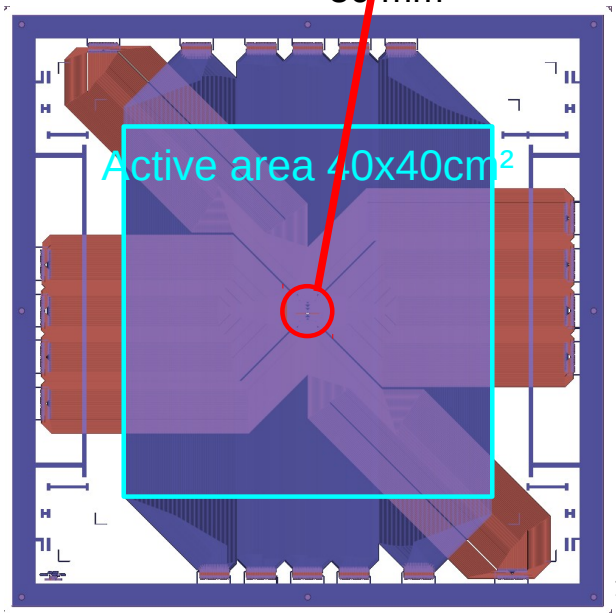
50 mm

Rectangular pixels

Keep spatial resolution in perpendicular dimension (400µm pitch like strips)

1280 pixels + 1280 strips



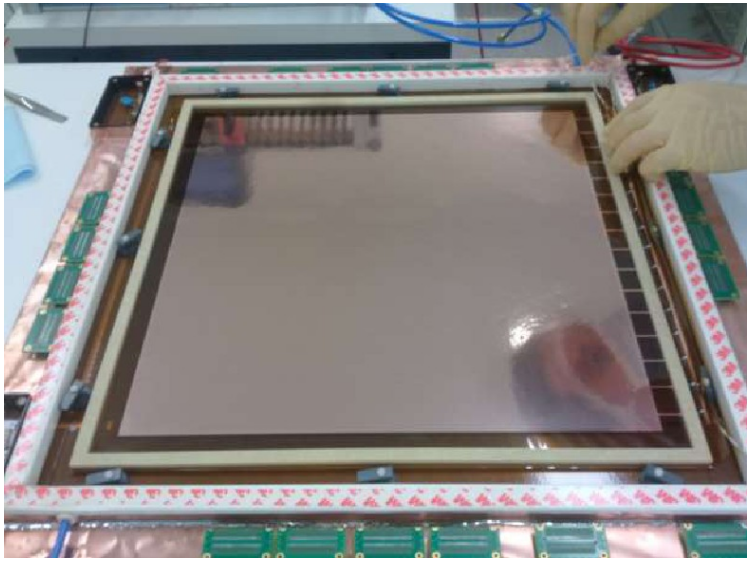


Development of full active size detectors

First prototypes

Built in 2009-2010 at CERN, finalized at Saclay

40x40 cm² active area, 65x65 cm² total size



Hybrid detectors

3 boards built at CERN / Saclay

Worked in real conditions at COMPASS in 2011-2012

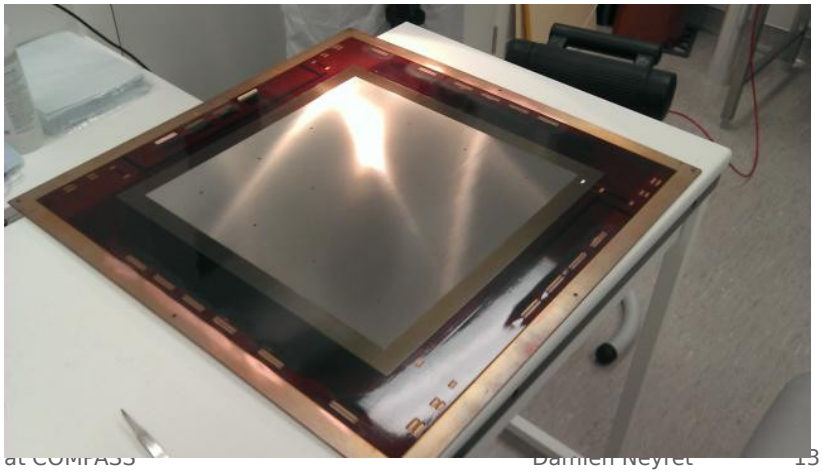
Used as trackers in 2012

Resistive prototype

Based on buried resistor scheme

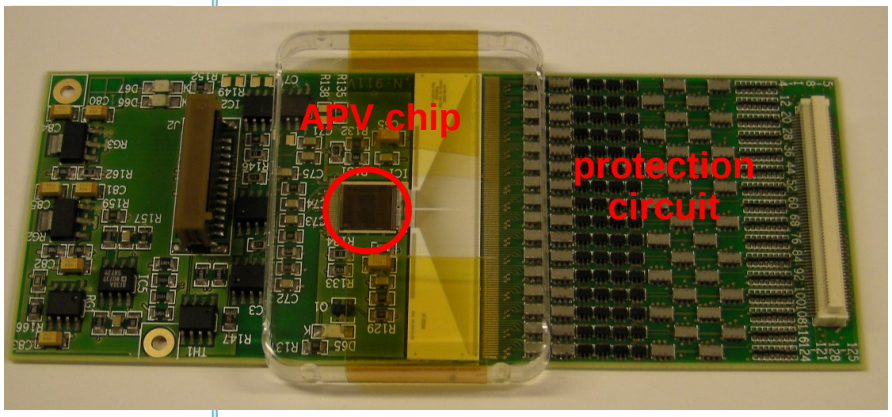
Built end of 2011 at CERN

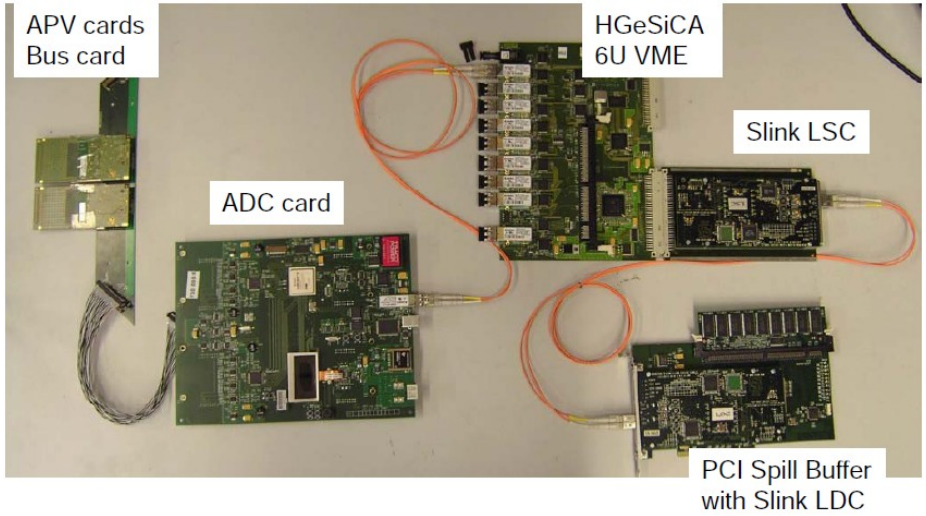
Tested in real condition in 2012



APV front-end electronics for pixelized MM

Irfu





Design from TUM Munich

Used in other COMPASS detectors (RICH, pixelGEMs,...)

APV cards

APV25-S1 chips for amplification and analog multiplexing

Specific changes done for MM read-out (protection circuit)

ADC boards

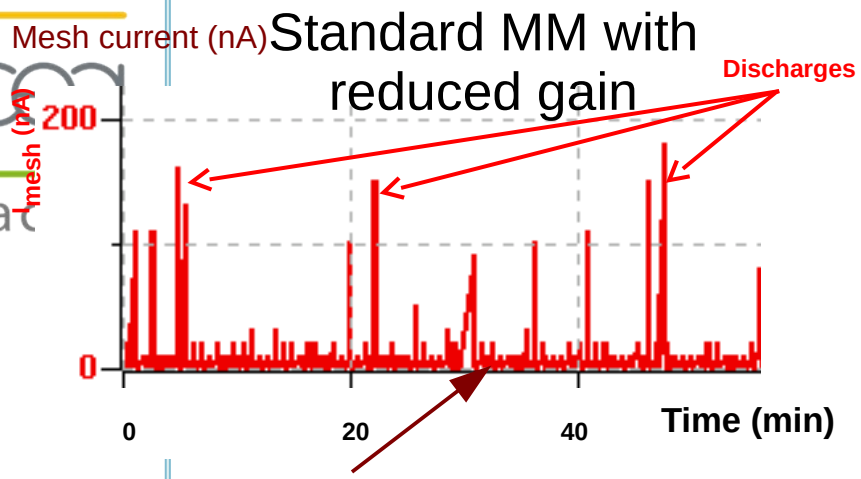
Digitalize analog signals from APV chips

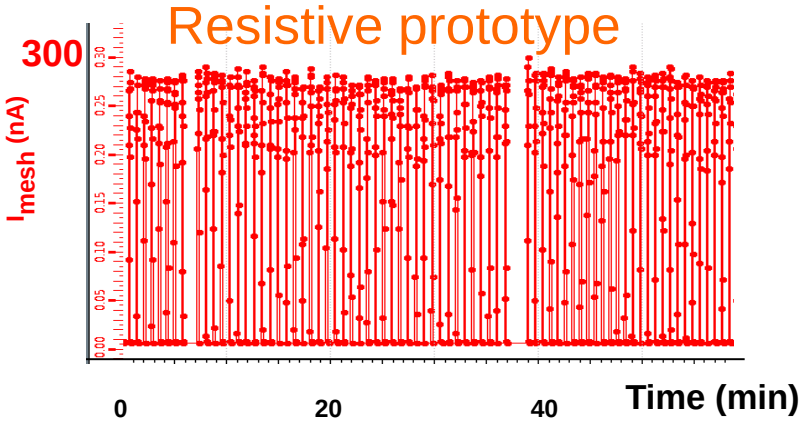
HGeSiCa VME cards

Data concentration and trigger distribution

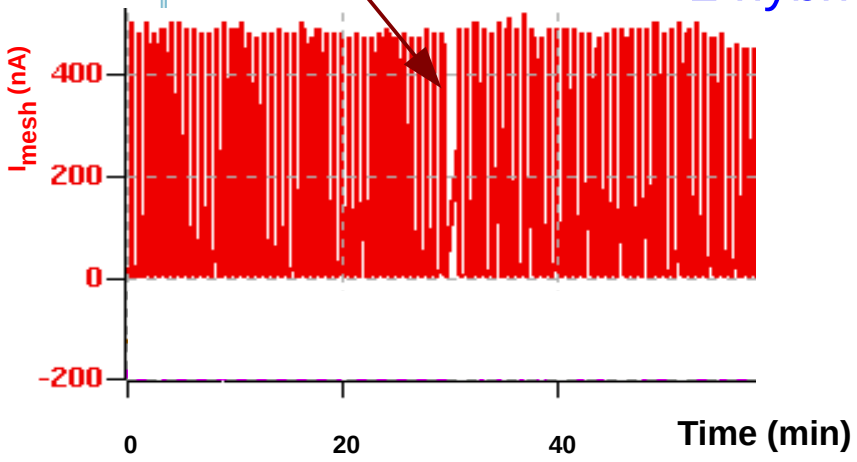
Discharge rates with high flux hadron beam

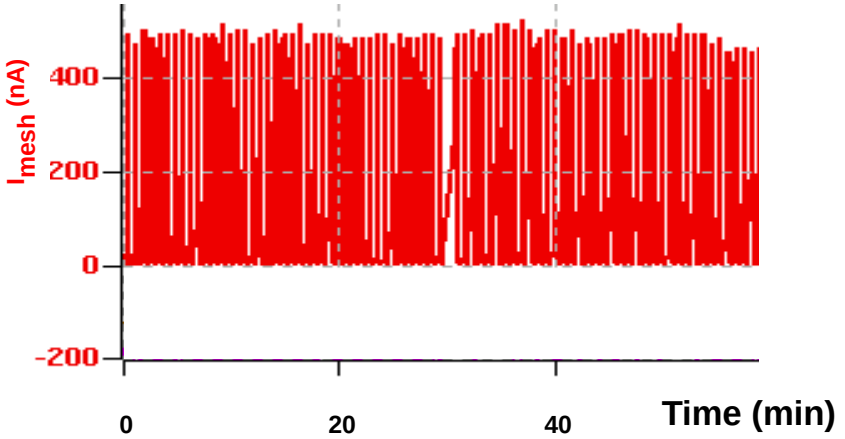
No discharge visible on new detectors





2 hybrid detectors

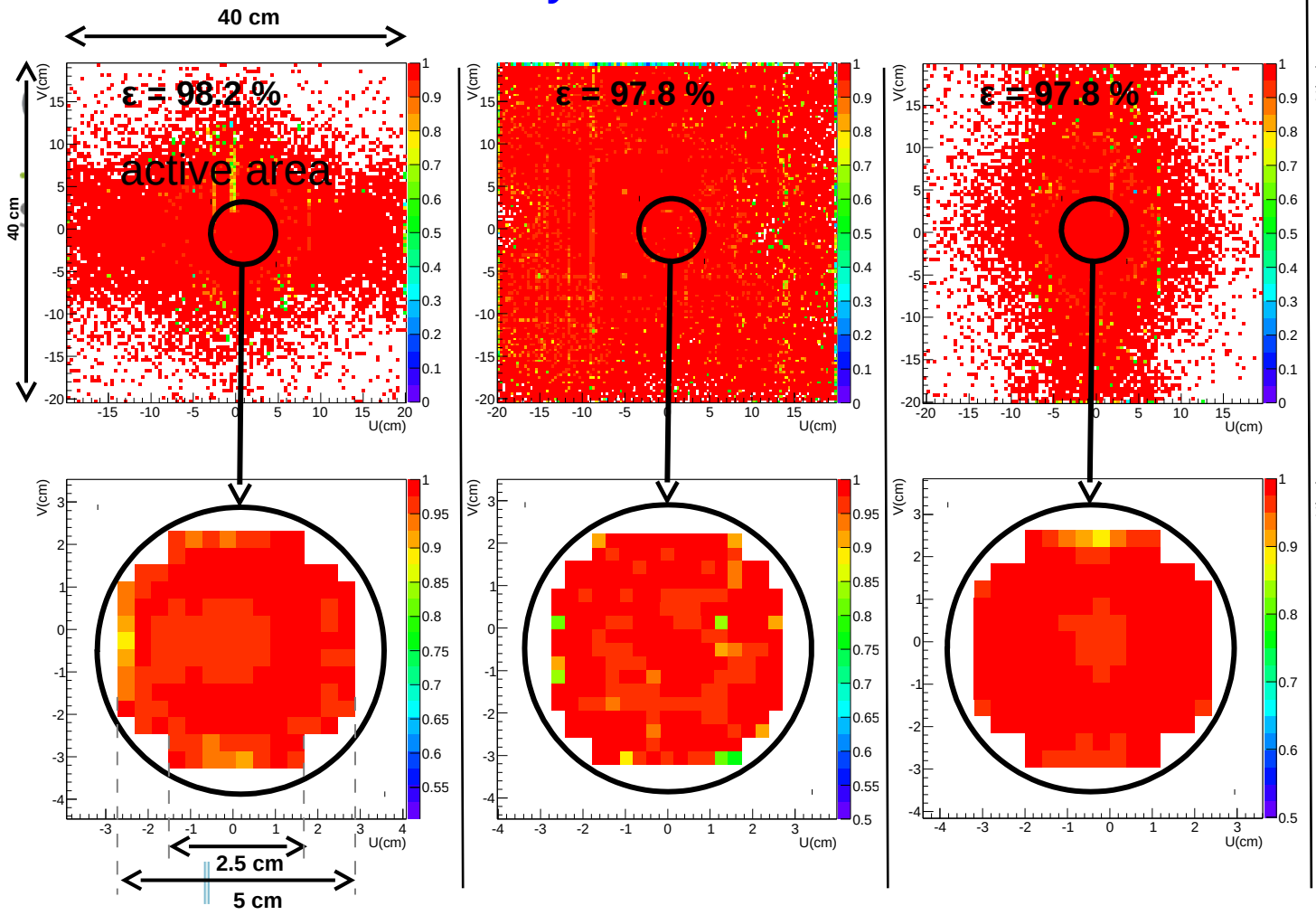




PixelMM 2D efficiencies at low μ flux

3 hybrid detectors

Resistive detector

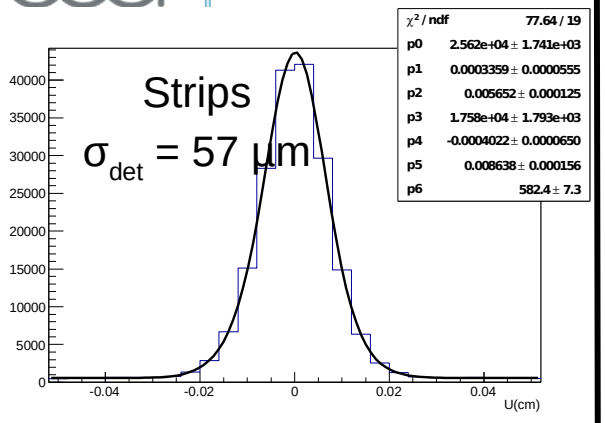


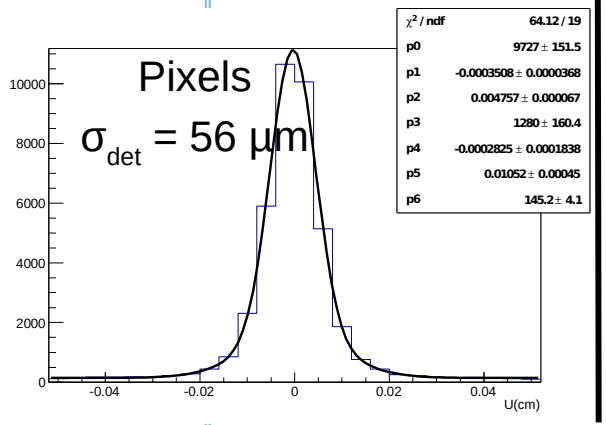
Plots from F. Thibaud

PixelMM spatial resolution at low μ flux

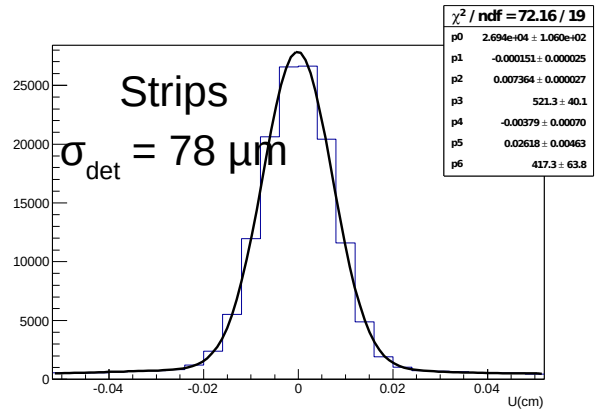
SM1 dipole off

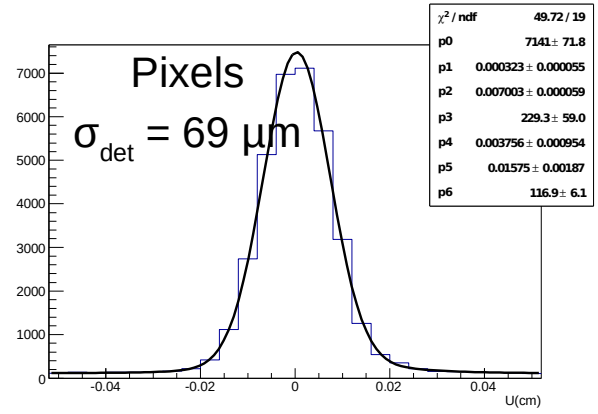
Hybrid detector



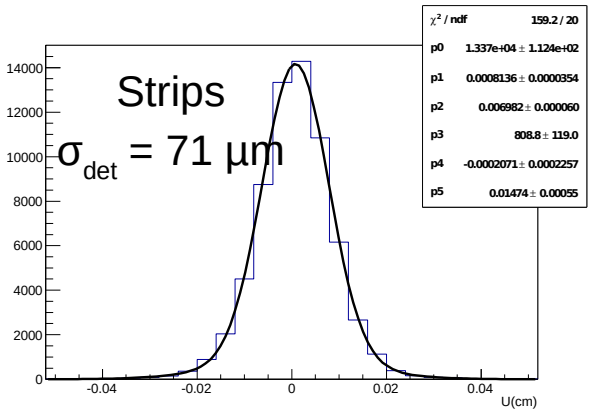


Resistive detector





Standard Micromegas



- *Resistive detector performance similar to std MM*
- *Best spatial resolution with hybrid detectors*

Plots from F. Thibaud

PixelMM time resolution at high flux

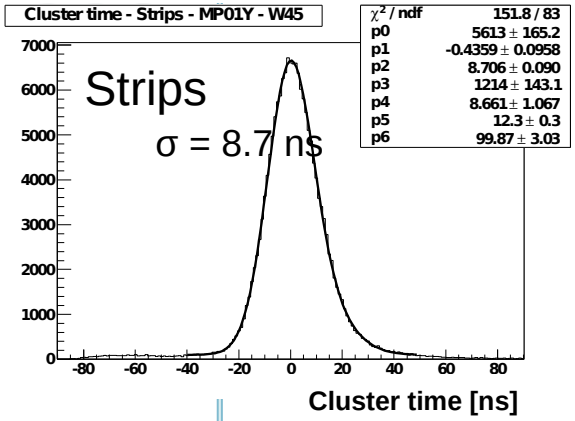
Irfu

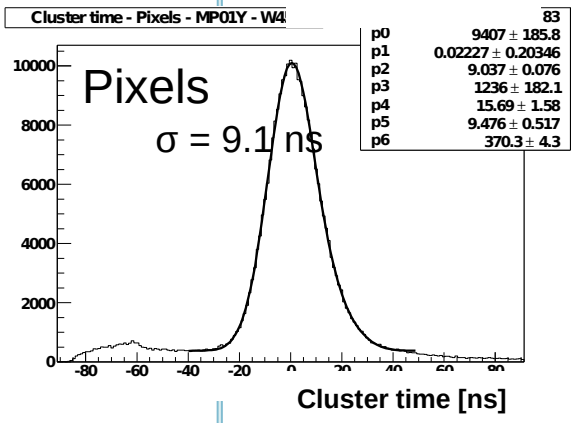
Hybrid detector

Resistive detector

DVCS run:

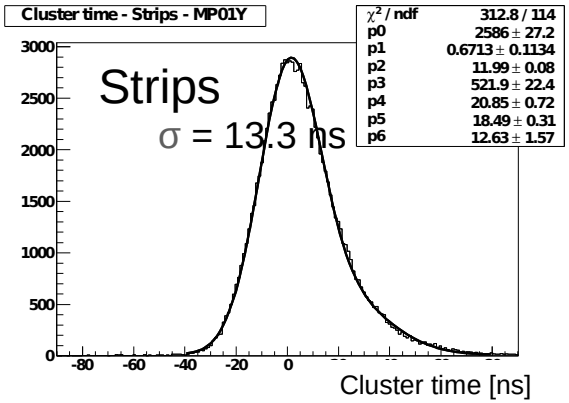
80% Ne + 10% C_2H_6 + 10% CF_4

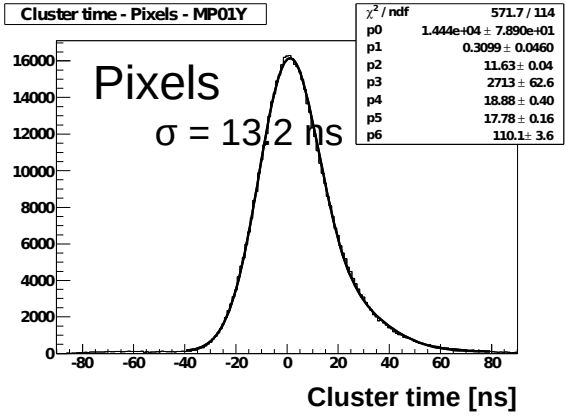




Hadron run:

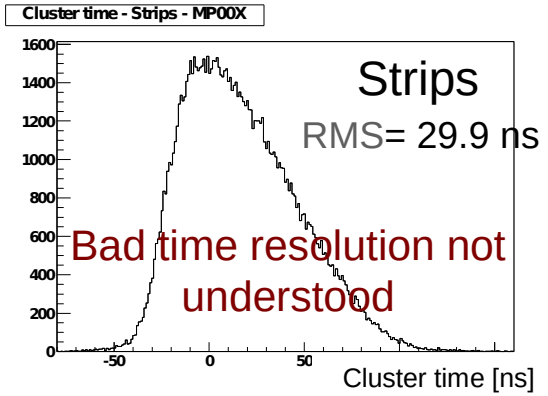
85% Ne + 10% C_2H_6 + 5% CF_4

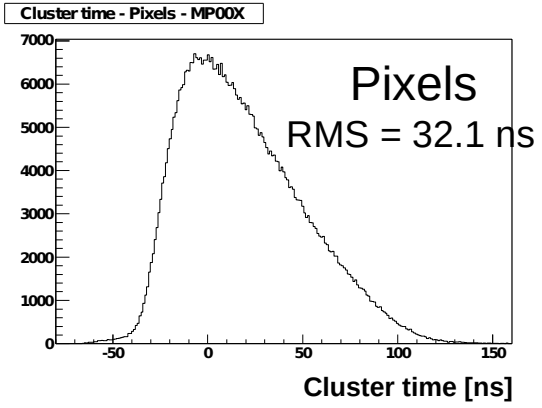




Hadron run:

85% Ne + 10% C_2H_6 + 5% CF_4





Plots from F. Thibaud

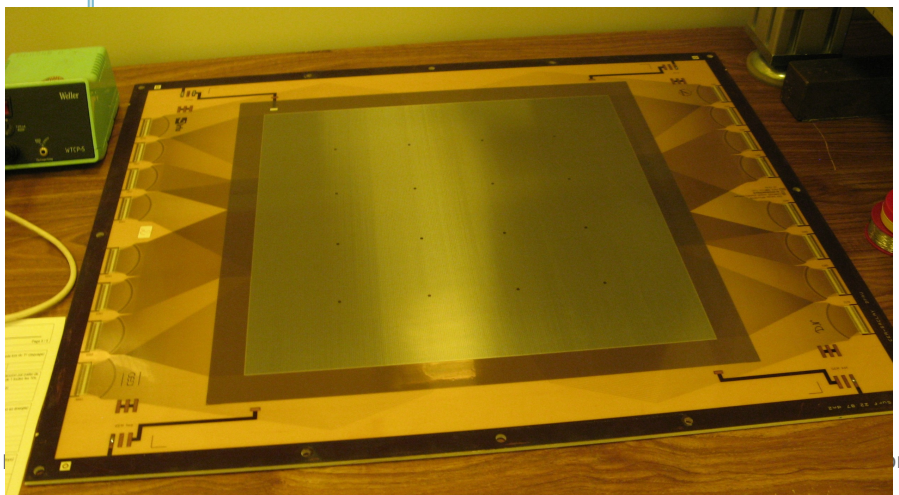
Preparations for the MM board production

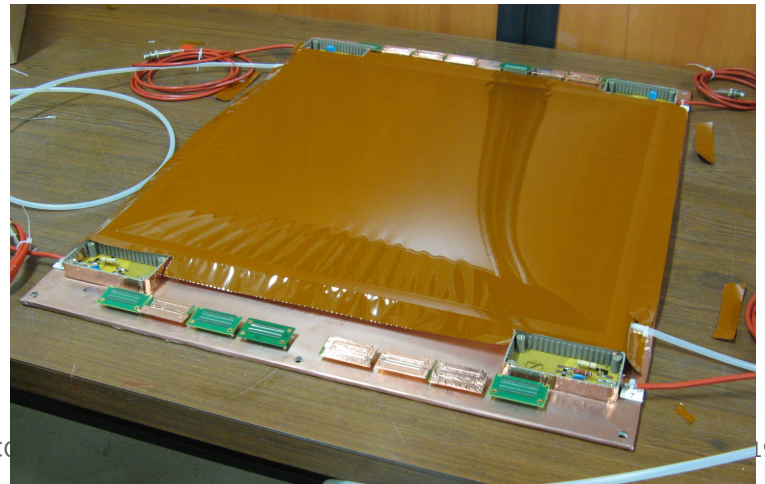
Choice of MM+GEM hybrid detection

- *Better spatial and time resolutions than resistive detector*
- *No solution yet for serial production of buried resistor boards*

MM technology transfer to industry

- *Collaboration between IRFU and CIREA / ELVIA group (PCB producer) since 2011, partner on « SPLAM » ANR agency funding*
- *ELVIA masters bulk technology since mid-2012*
- *First prototypes built by ELVIA in autumn 2012: 40x40 cm² active area, 72x58 cm² total size, with reduced number of pixels*





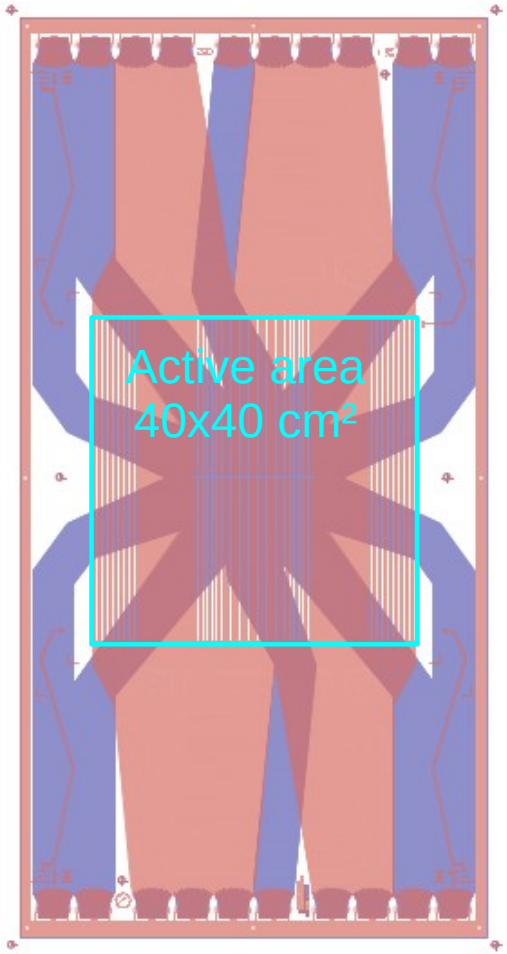
Developments for the production of final MM detector boards

2 challenges for the production

- *Large size PCB (114x58 cm²) with very thin design in the pixel area (60µm thin strips with 60µm insulation)*
- *Gluing of 200 µm thin PCB – 4 mm Rohacell foam sandwich*

Steps before prod. of large size PCB

- *First ELVIA prototypes with simplified design (less pixels) → good excepted some glue on pixel area*
- *Intermediate size 80x60 cm² board with full pixel design → gluing not perfect, 1 detector under test, 2 more in production*
- *Nominal size 114x58 cm² PCB expected this month, etching quality to be checked before to make board sandwich*



Prospects for the detector production

Irfu cea saclay

Choice of detector size end of summer

- *Nominal size (114x58 cm²) detector preferred if ELVIA able to produce them*
- *Intermediate size (80x60 cm²) detector to be selected otherwise, coupled with an adapting mechanics*

Configuration for the 2014 beam period

- *2 intermediate size detectors + 2 CERN prototypes installed for 2014 data taking*
- *Commissioning of new detectors, data used for preparations of the calibration and data reconstruction*

Production for the 2015 run

- *Production to be started in October 2014*
- *Installation of detectors at COMPASS in winter and spring 2015*
- *12 detectors to be installed and ready in April 2015*

Conclusions

Present COMPASS detectors can be improved

- *Good performances: efficiencies, spatial and time resolutions*
- *But limitations with hadron beam due to discharge rates*
- *And detection must improved in the beam area for the next COMPASS studies*

Hybrid detectors proven to be very promising concept

- *Discharge rate strongly decreased*
- *Performance as good as or better than standard Micromegas*

Production for the 2015 run to be started

- *Developments on board production to be completed for the summer*
- *Objective: all detectors installed for the 2015 run*

Buried resistor MM boards promising but further studies required

- *Bad time resolution not understood*
- *R&D necessary for serial production of resistive boards*

Irfu

cea

saclay

Spares

PixelMM spatial resolution at low μ flux

SM1 dipole off

Hybrid detector

Strips

σ_{res} = 72 μm

σ_{det} = 57 μm

Pixels

σ_{res} = 61 μm

σ_{det} = 56 μm

Resistive detector

Strips

σ_{res} = 85 μm

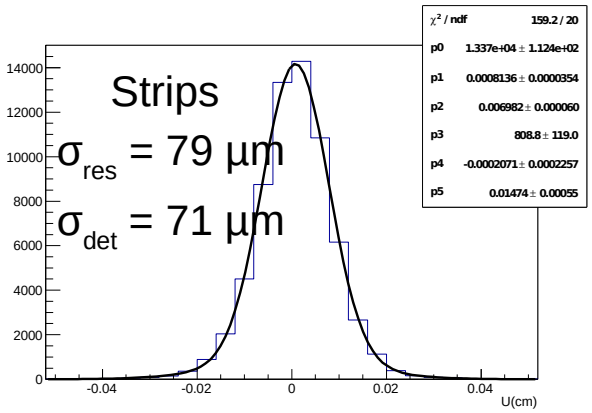
σ_{det} = 78 μm

Pixels

σ_{res} = 76 μm

σ_{det} = 69 μm

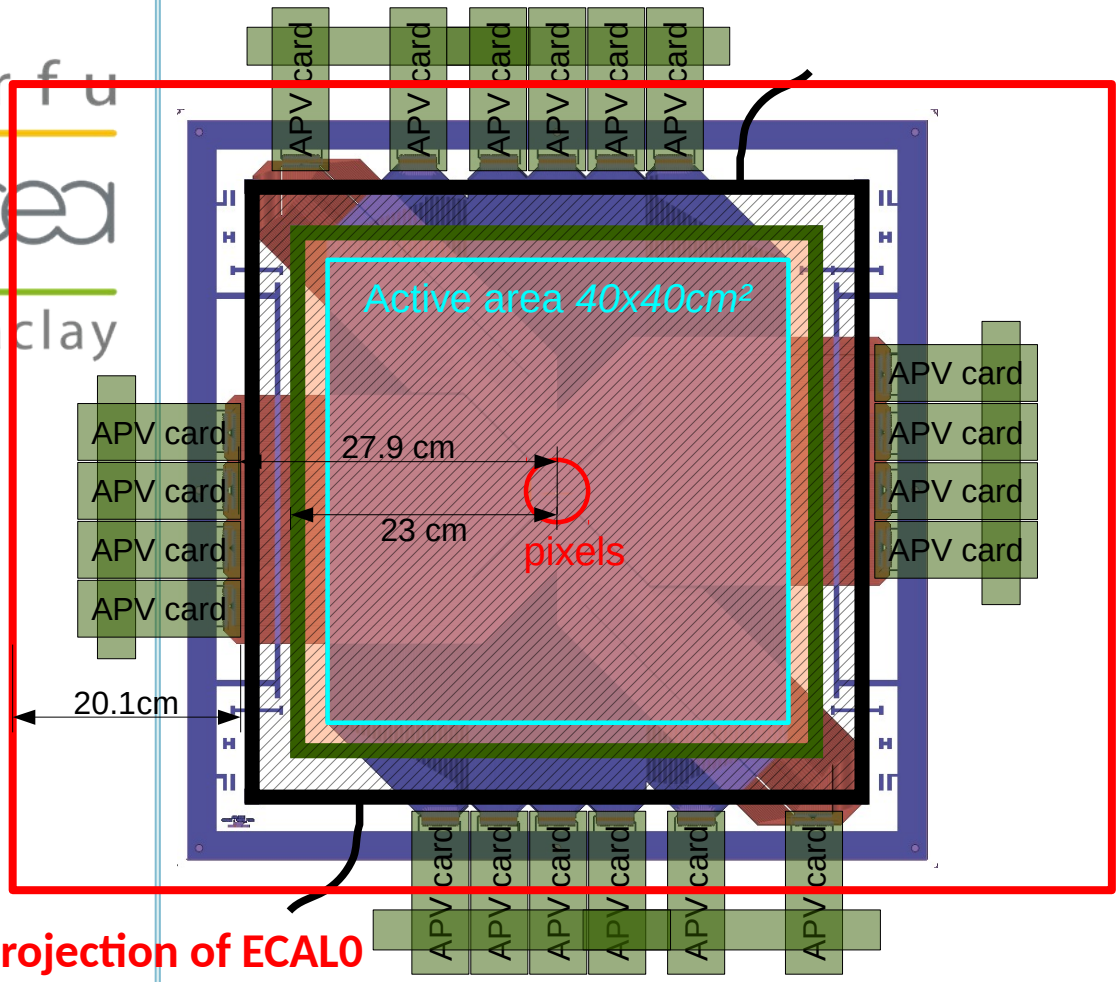
Standard Micromegas



- *Resistive detector performance similar to std MM*
- *Best spatial resolution with hybrid detectors*

Plots from F. Thibaud

Adaptation of pixelMM for DVCS run



Projection of ECAL0 hole at 1.51m (for XY) 96 × 69 cm2

FE electronics in acceptance

APV cards shifted out of the acceptance for DVCS run

20cm extension cards put between the detectors and the APV cards

Introduce a 50% increase of raw electronic noise, but only 10-20% after common mode correction

Incidents during the 2012 run

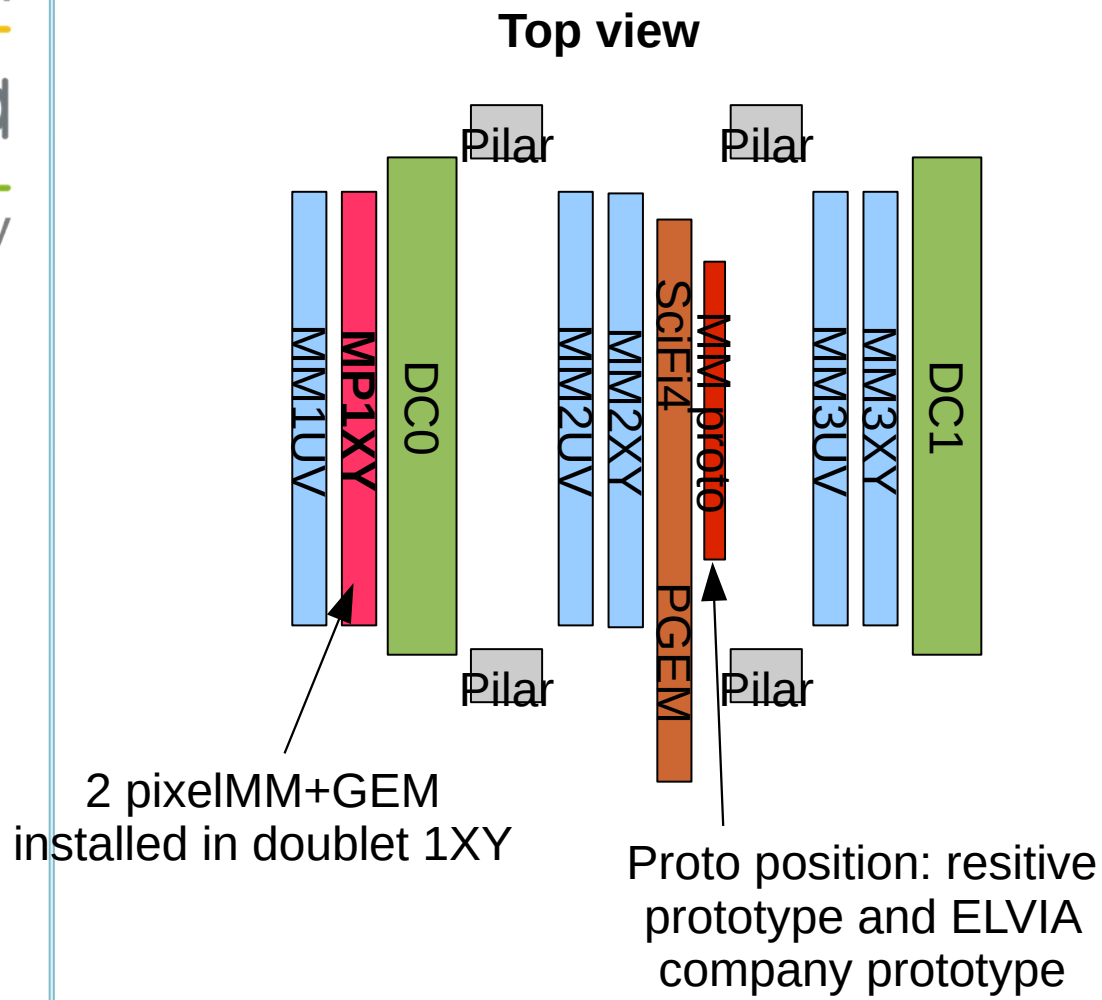
MM

- *Usual front-end errors on hotlink connectors, happened ~6 times during the 2012 run*
- *1 leaky detector in 2Y, finally replaced the 31/8*
- *Also problem with thresholds (bad connection of buffer cards) happened ~5 times*
- *Increasing noise level not related with thresholds, origin not clear, LOAD -A helped sometimes, happened more particularly in November*

pixelMM

- *Trips and large current on 1Y since mid-August, due to short between mesh and some channels -> APV card disconnected from 128 strips, detector finally replaced by spare the 15/11 (spare was leaky and had to be repaired before)*
- *2 failures of APV cards -> replaced (1/8 and 30/11)*
- *Wrong mapping file set in October, finally fixed the 15/11*

PixelMM in 2012



Summary of pixelMM efficiencies

PMM_2011.1 GEM	μ+ Φ=9x105 s-1	μ- Φ=2x107 s-1	μ+ Φ=5x107 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+ Φ=9x105 s-1	μ- Φ=2x107 s-1	μ+ Φ=5x107 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+ Φ=9x105 s-1	μ- Φ=2x107 s-1	μ+ Φ=5x107 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+ Φ=9x105 s-1	μ- Φ=2x107 s-1	μ+ Φ=5x107 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%*

*disconnected front-end card

Results from F. Thibaud

Summary of pixelMM spatial resolution

Detector	μ+ Φ=9x105 s-1 Dip. OFF (μm)	μ+ Φ=9x105 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

Large effects of SM1 fringe field

Far from dipole

- *No effect*

Close to dipole

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

Results from F. Thibaud

pixelMM spatial resolution vs beam flux

Detector	μ+ Φ=9x105 s-1 (μm)	μ+ Φ=4x106 s-1 (μm)	μ- Φ=2x107 s-1 (μm)	μ+ Φ=5x107 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 < 90μm* ***(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

Results from F. Thibaud

Summary of pixelMM time resolution

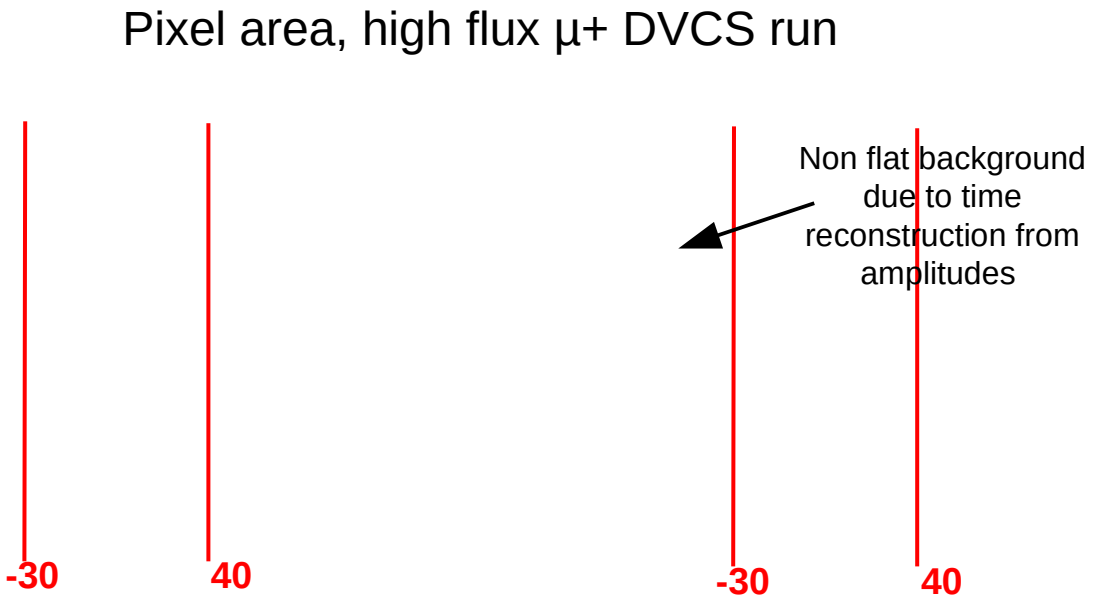
Detector	PMM_2011.1 GEM (strips)	PMM_2011.1 GEM (pixels)	PMM_2011.2 GEM (strips)	PMM_2011.2 GEM (pixels)	PMM_2012.1 GEM (strips)	PMM_2012.1 GEM (pixels)	PMM_2011.3 BR (strips)	PMM_2011.3 BR (pixels)	Standard Micromegas
μ+ Φ=5x107 s-1	8.8	9.7	8.7	9.1	*12.4**	*10.3**	Not tested	Not tested	9.3
π -, K- Φ=4x106 s-1	Not tested	Not tested	13.3	13.2	13.3	13.0	29.9	32.1	12.6

*due to PCB curvature

- *σPMM+GEM ~ σMM*
- *σPMM+BR ~ 2.5 x σPMM+GEM*

Results from F. Thibaud

Impact of time cut



Impact of time cut in pixel area

- *70% less clusters, background probability reduced from 11 to 2.9%*
- *Efficiency reduced by ~2%*
- *Reduce warnings/errors in Coral by reducing combinatorial background (30% → 3% events with nb of tracks >1000)*

Conclusions

Irfu cea saclay

MM

- *Quite smooth data taking in 2012, few problems (gas leak, front-end errors, slow-control buffer card) but less than 2011*
- *Good efficiency of MM detectors, >95% in high flux muon beam*
- *Spatial resolution ok excepted for station 3 due to the SM1 fringe field*

pixelMM

- *Important electronic noise in some configuration, not yet fully understood but seems to be linked to some APV cards → tests to be done with new cards to be produced*
- *1 APV cards disconnected on 1Y strips during data taking period > 1 month due to trips, finally replaced by spare*
- *Smooth data taking otherwise, in particular in pixels area where tracking detectors were rare during DVCS*
- *Resistive pixelMM tested but performances not as good as MM+GEM*

About material budget

Material budget without GEM foil similar to MM

Board: 0.205% X0 (includes 0.057% X0 honeycomb)

Mesh: 0.05% X0

Drift: 0.027% X0

Gas mixture and enclosure: 0.037% X0

Total: 0.319% X0

Present MM: 0.287% X0

Budget of GEM foil or resistive layer

Standard GEM foil: 0.067% X0

Copper thickness can be reduced to 2µm → 0.035% X0

Resistive layer: 0.084% X0, mostly due to silver paste in vias

Replacement of honeycomb for spare pixelMM sandwich

Rohacell XT71 foam 4mm thick: 0.076% X0

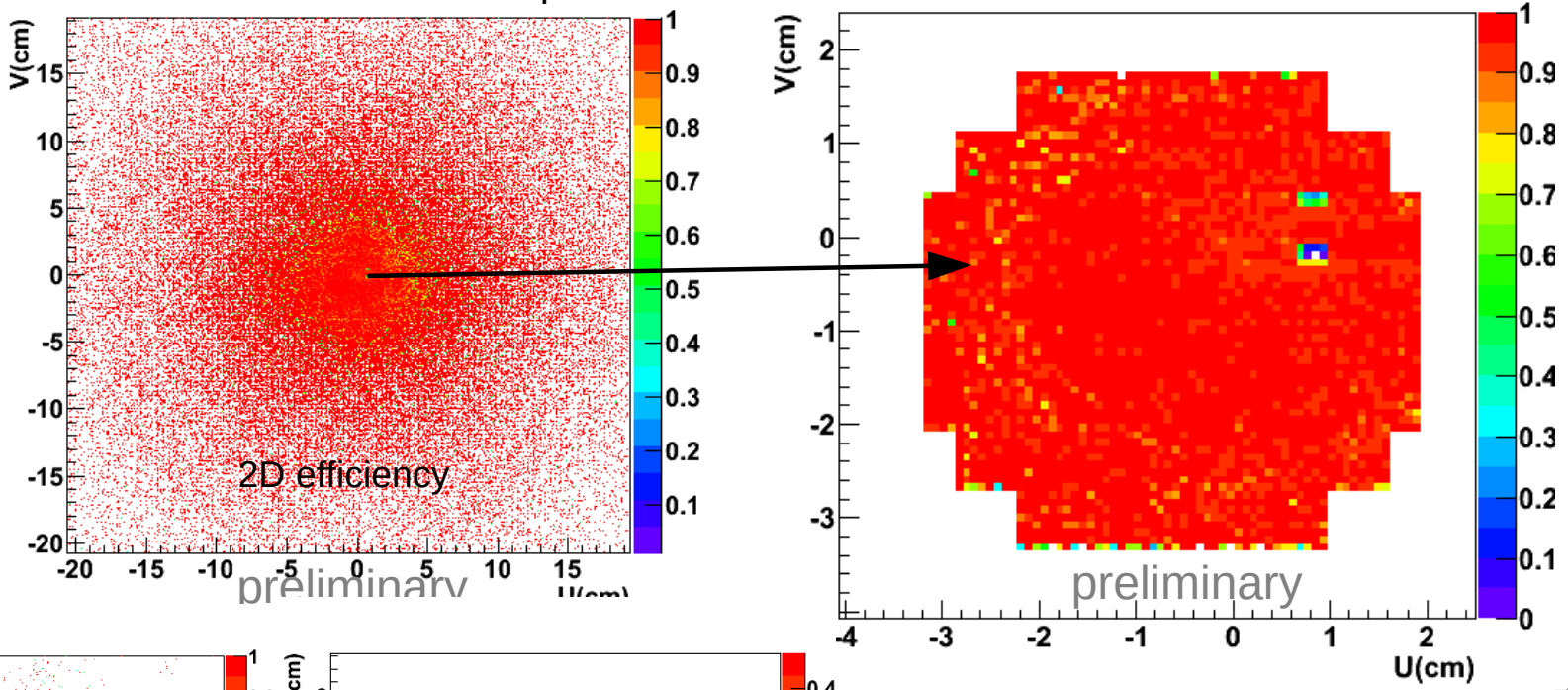
5cm diameter hole in foam foreseen in center area

Preliminary results: efficiencies

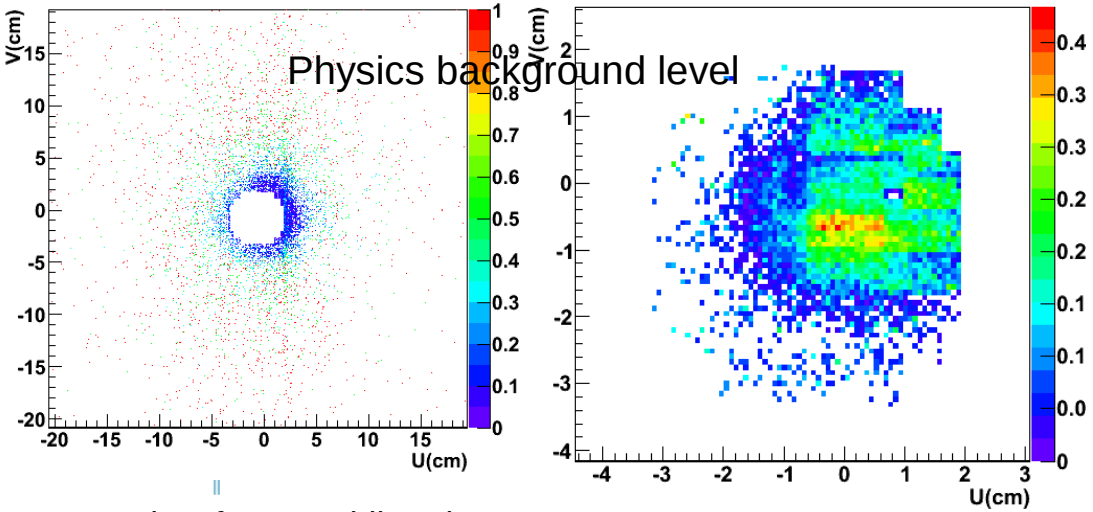
Irfu cea saclay

Standard muon run

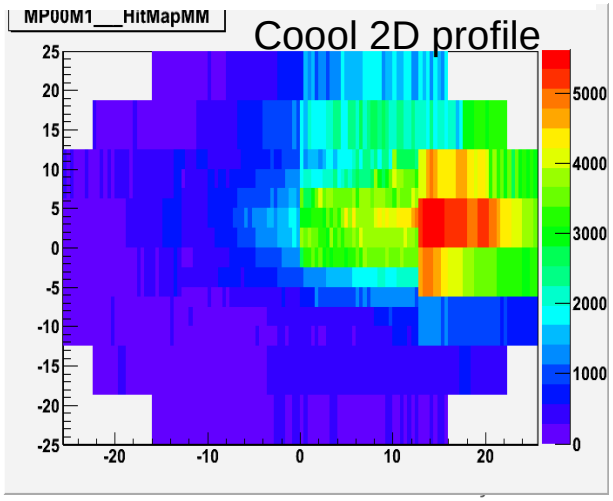
2nd pixelMM+GEM detector



Physics background level



Coool 2D profile

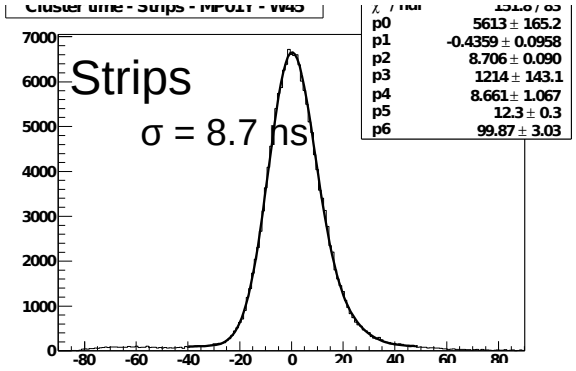


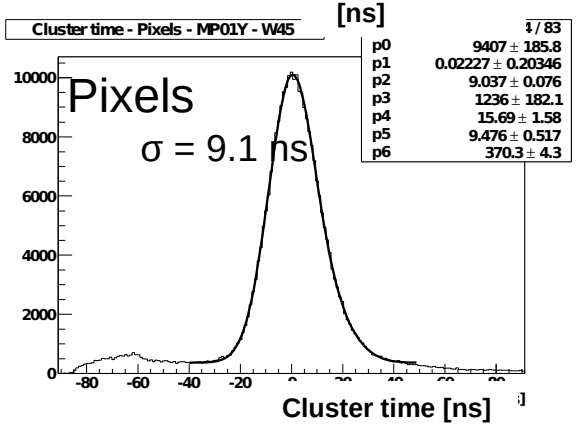
Plots from F. Thibaud

PixelMM time resolution at high flux

Hybrid detector

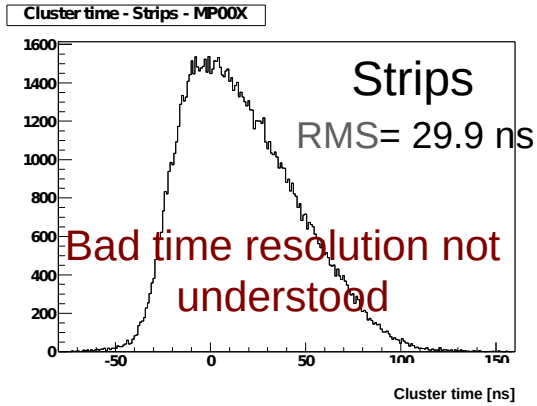
80% Ne + 10% C_2H_6 + 10% CF_4

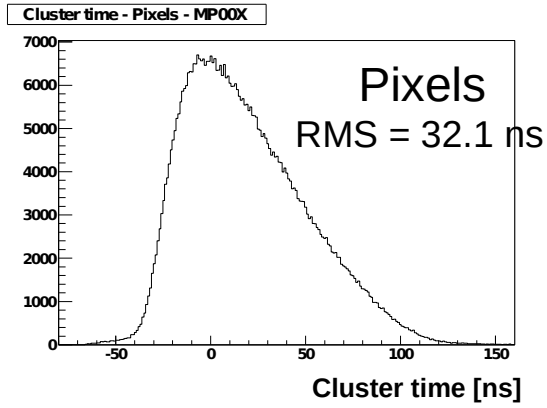




Resistive detector

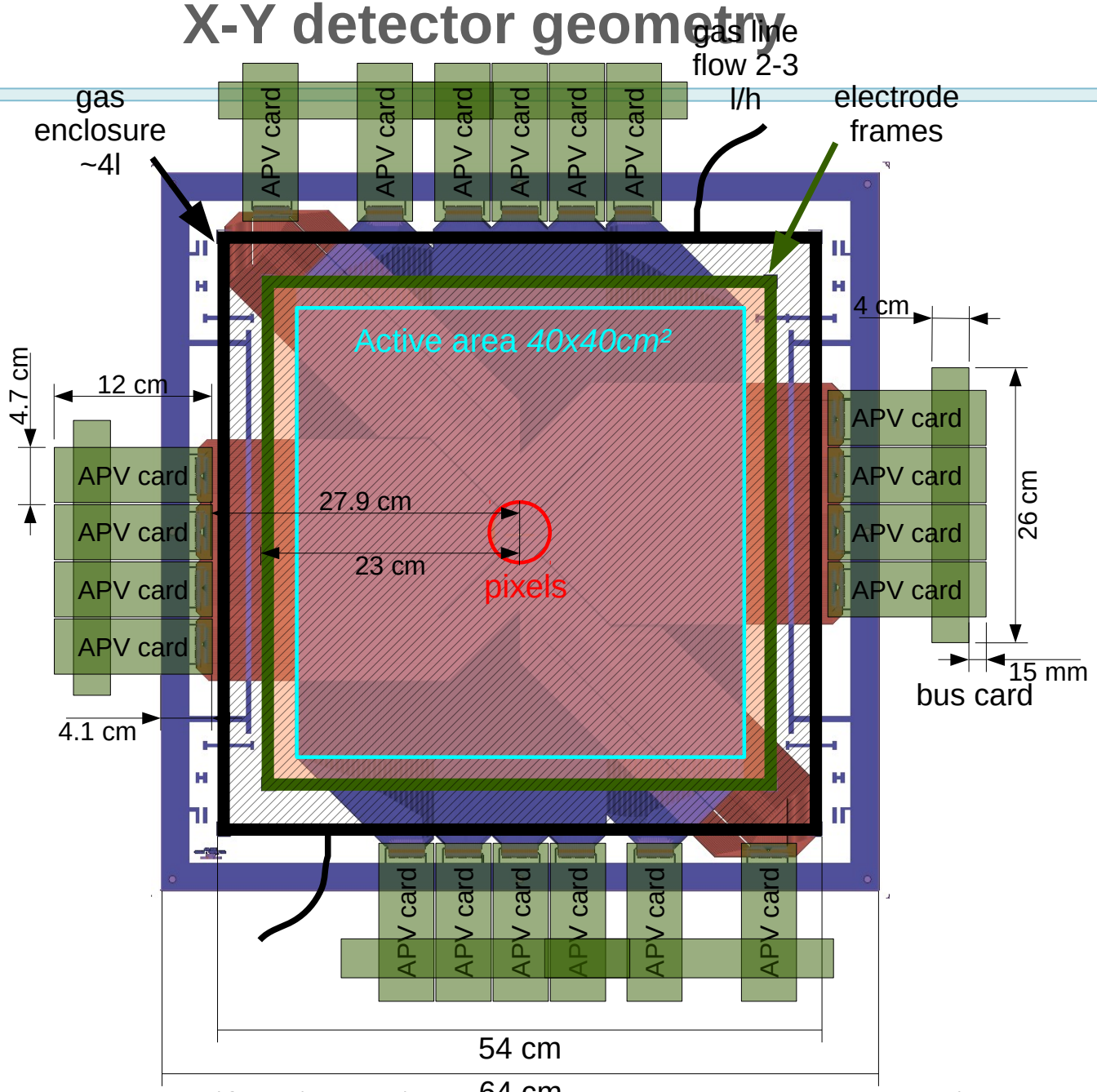
85% Ne + 10% C_2H_6 + 5% CF_4



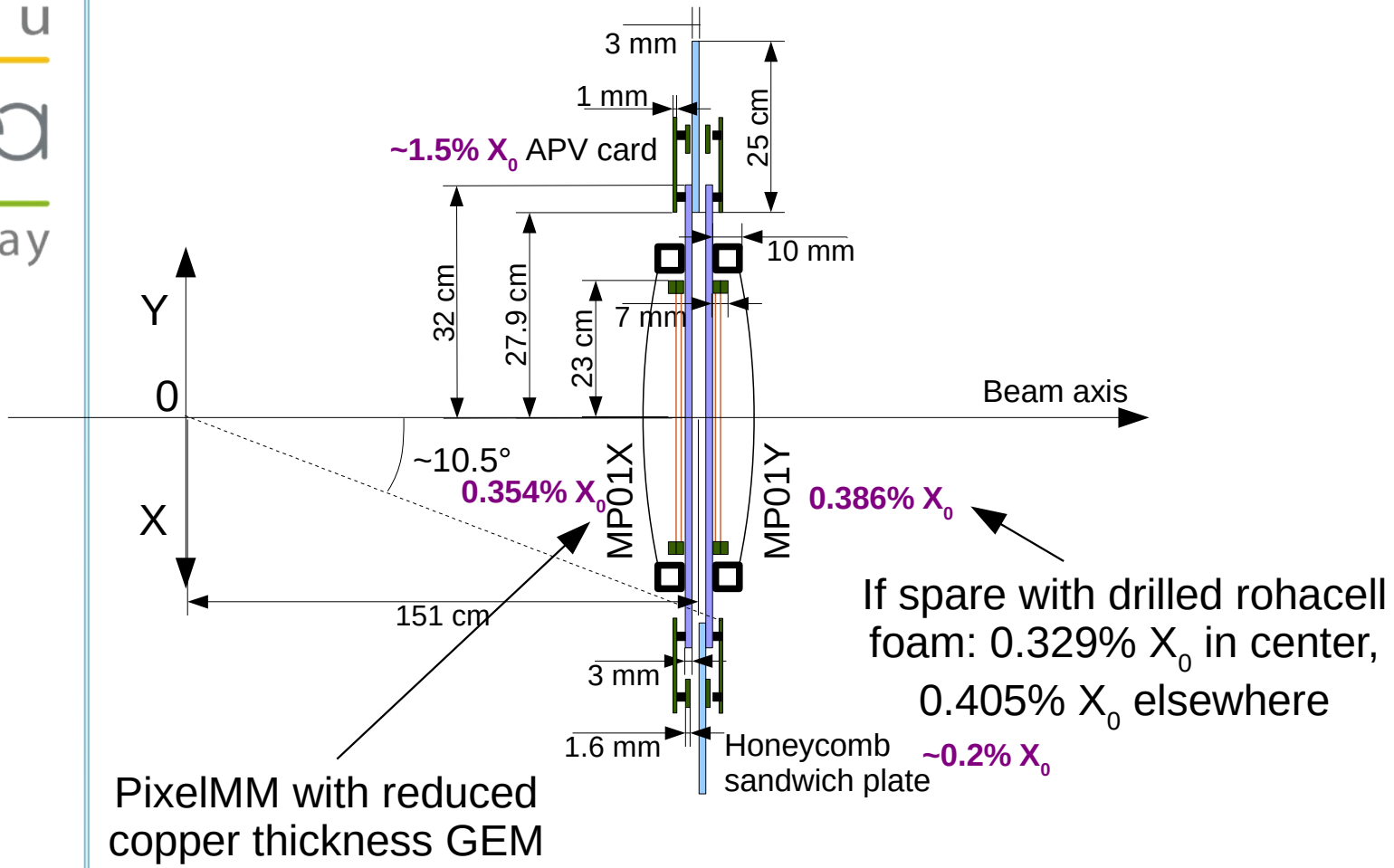


Plots from F. Thibaud

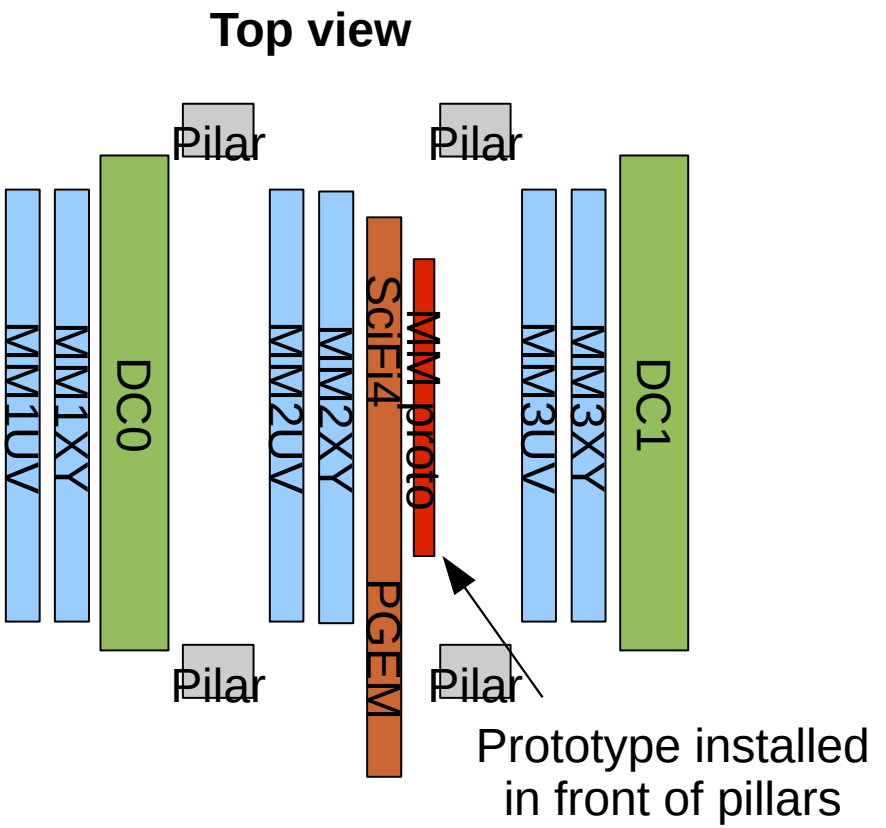
X-Y detector geometry

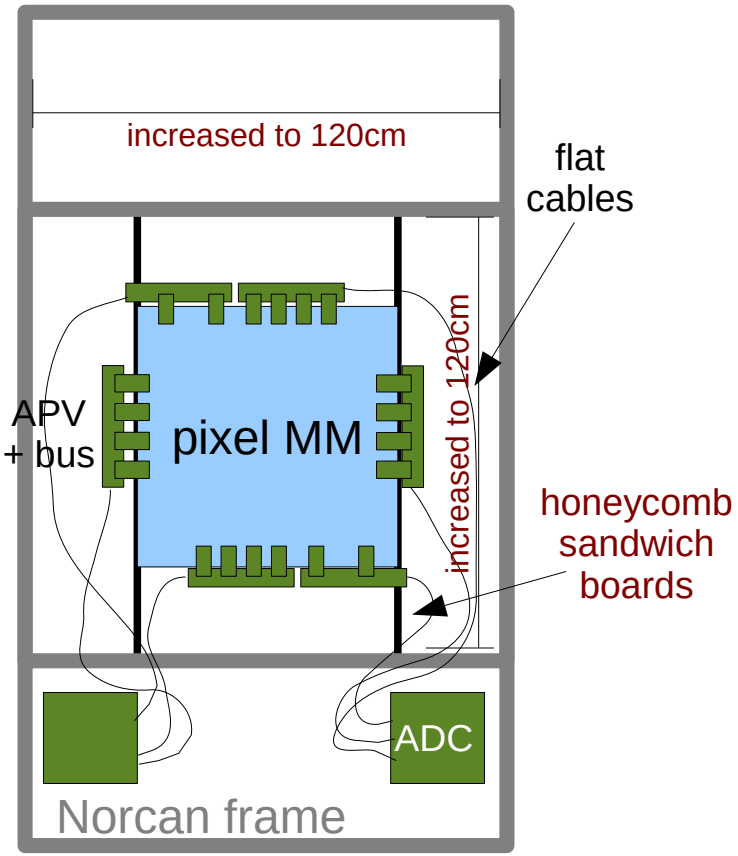


Lateral geometry and material budget



Installation of prototypes in 2011





History in 2011

1st pixelMM+GEM installed end of May

2nd pixelMM+GEM replacing 1st one beginning of July

Some problems with read-out electronics finally fixed in September

Resistive pixelMM installed end of October

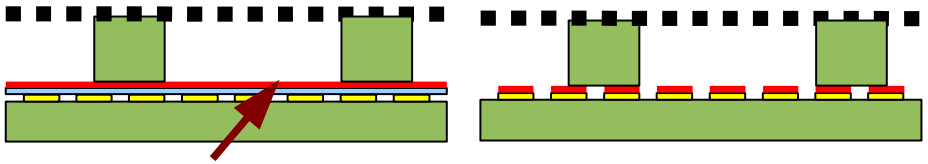
Two solutions to reduce discharge rate

Resistive Micromegas

Resistive layer on top of anode to reduce discharge amplitudes

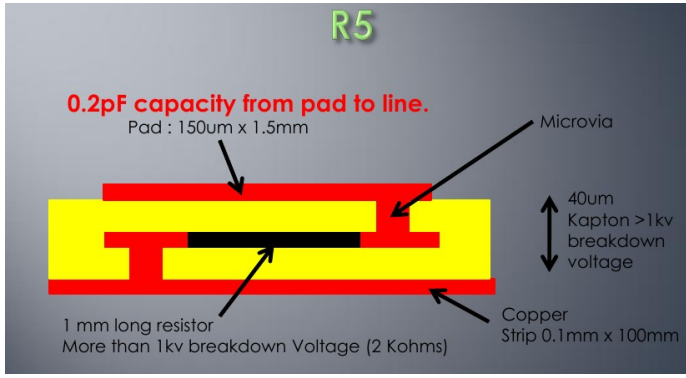
With or without isolator layer

Several evolutions ongoing in the domain



resistive layer on isolator

resistive paste on strips

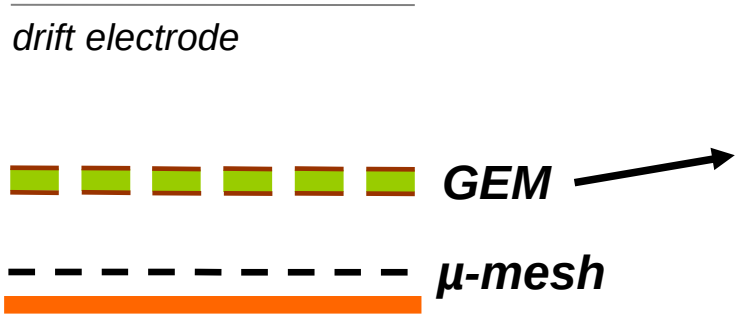


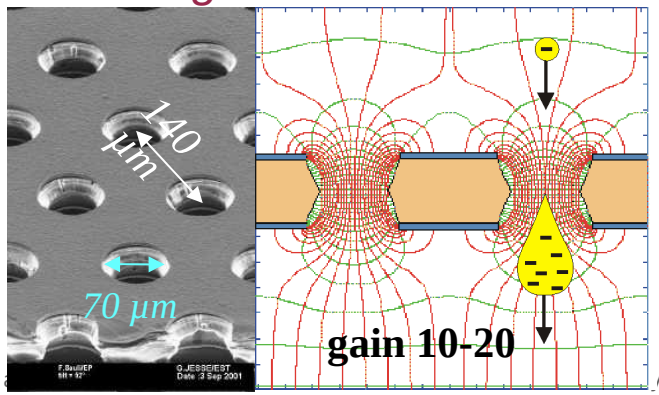
Buried resistors design of R. de Oliveira et al.

Micromegas + 1 GEM foil

Preamplification with a GEM foil (gain 10-20)

Micromegas stage at lower gain → less discharge





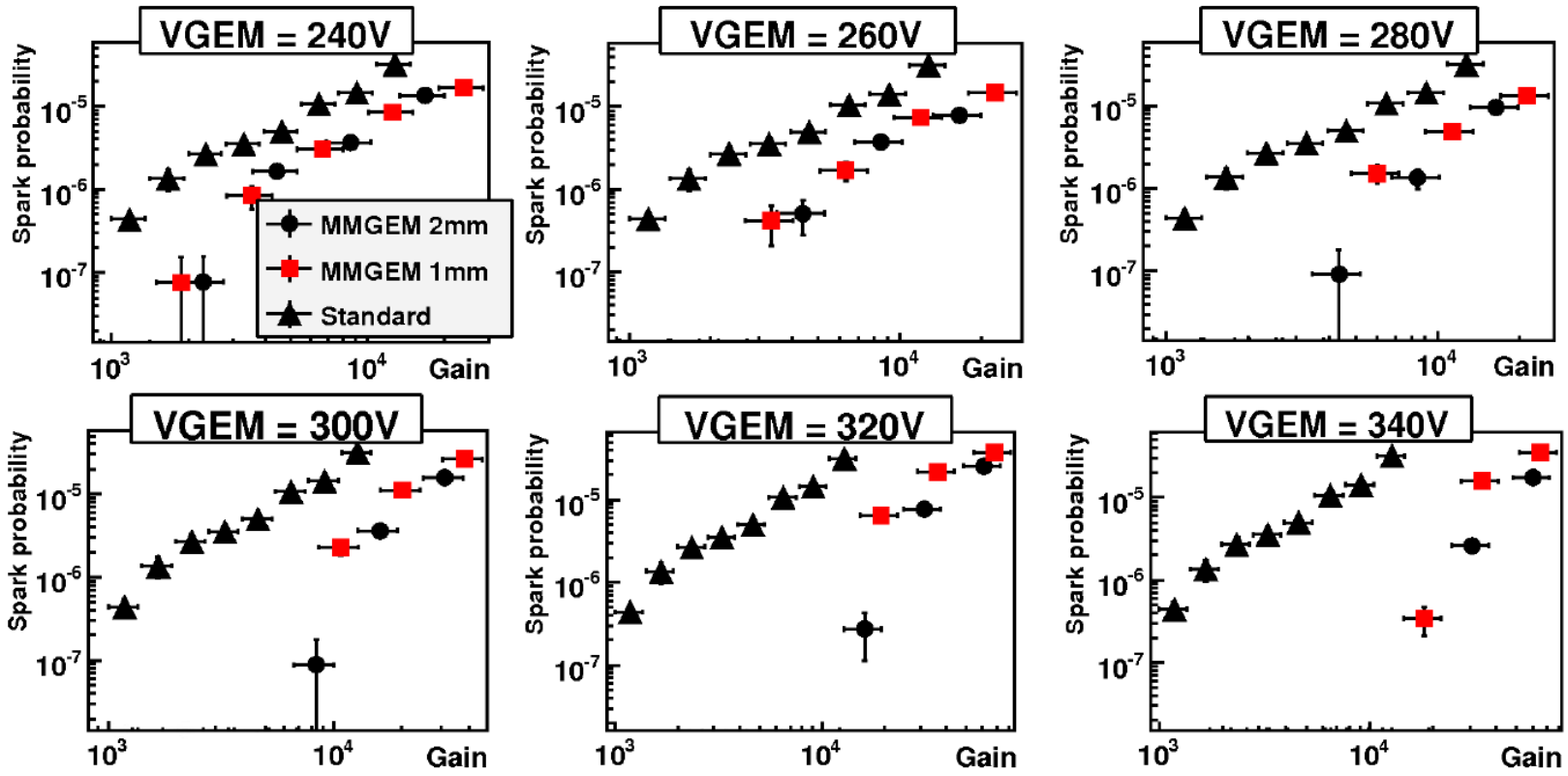
Spark probability of MM+GEM (2010 PS tests)

Irfu

sac

2 MM+GEM prototypes

1 and 2mm distance between mesh and GEM foil



2 effects which explain discharge rate reduction:

- lower gain on mesh stage (charges deposited between GEM and mesh)
- charge dispersion between GEM and mesh (charges before GEM)

Status of read-out electronics

APV cards

20 cards produced in 2009, a few with problems (noise, bad bonding)

10 cards produced in 2010, almost all noisy due to problems during bonding, repair under study

50 cards produced in 2011, a few with problems (errors on component cabling)

Ok to fully equip 2 detectors (20 / detector)

Bus cards

12 buses available, at the limit for 2 detectors (6 / detector)

New buses under production at TUM with better distribution of synchronization signals, 15 buses ordered for pixelMM project

ADC boards

8 bought from TUM, ok for 4 detectors (3 / doublet)

Problems on read-out electronics

Synchronization between APV and ADC really touchy at 40MHz read-out, require fine tuning of the clock phases which may move with external conditions

→ copper plates installed on ADC boards to improve cooling

→ situation should be improved with the new bus cards

Errors during LOAD commands with new ADC cards, due to bad swing of the serial I2C signal (1.9V instead of 2.3V)

→ source identified: wrong values of 4 resistors, to be fixed soon

Time Resolution vs position

PMM_2011.2 (PixelMM w/ GEM)

Strips

σ = 8.7 ns

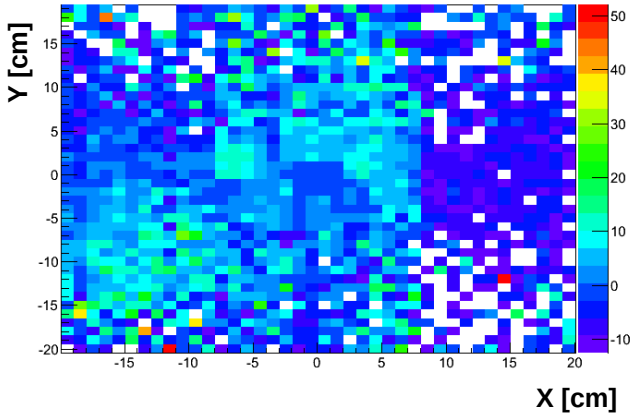
Cluster time [ns]

Pixels

σ = 9.1 ns

Cluster time [ns]

Mean cluster time vs position



PMM_2012.1 (PixelMM w/ GEM)

Strips

σ = 12.4ns

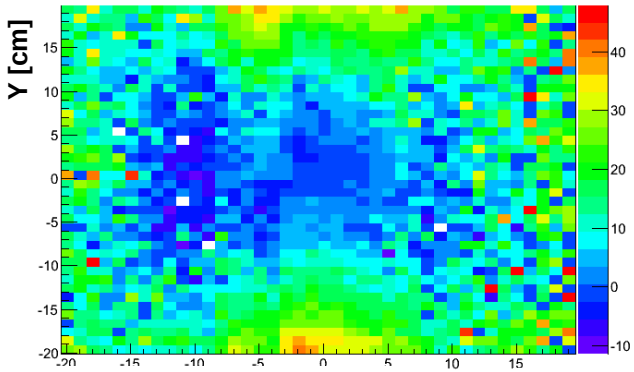
Cluster time [ns]

Pixels

σ = 10.3 ns

Cluster time [ns]

Mean cluster time vs position



Larger σ due to detector curvature

MM protection circuit