

Genetic multiplexing, or how to read up to 1831 strips with 61 channels

CEA-SACLAY
MULTIGEN
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Content

- *Potential of strip multiplexing for particle detection & first idea (double sided)*
- *Genetic multiplexing*
- *Results with a 50x50 cm² Micromegas prototype*
- *Some applications*
- *Conclusion and perspectives*

Multiplexing and particle detectors

Obvious interest: lower the number of electronic channels

→ easier integration, cabling, cooling

→ cheaper (~1€/channel)

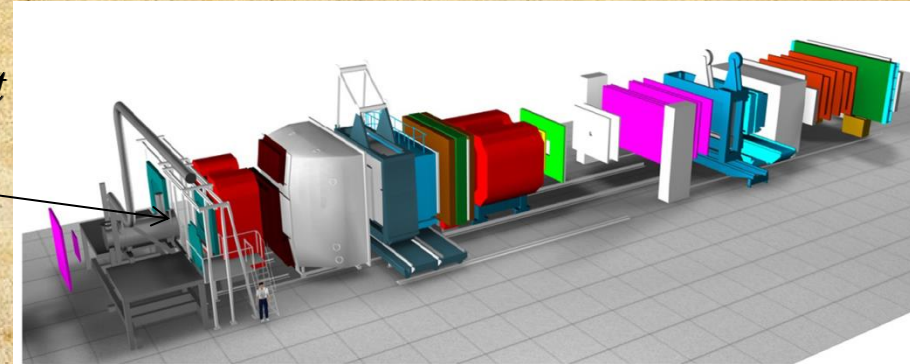
→ lower consumption

A classical example: the Compass experiment

→ 12 layers of Micromegas in the hottest region

→ 1,000 strips per layer, total rate ~ 30 MHz

⇒ only ~ 20 channels (2%) with signal for a given event



Risks of multiplexing:

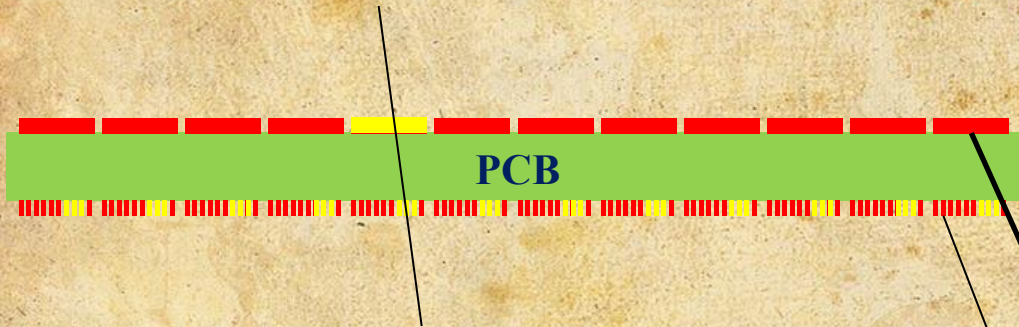
→ degradation of S/N ⇒ can lower the detection efficiency

→ ambiguities to solve (demultiplexing)

Multiplexing: first idea

→ Initiated by the need to equip the CLAS12 cosmic bench with large reference detectors (tracking)

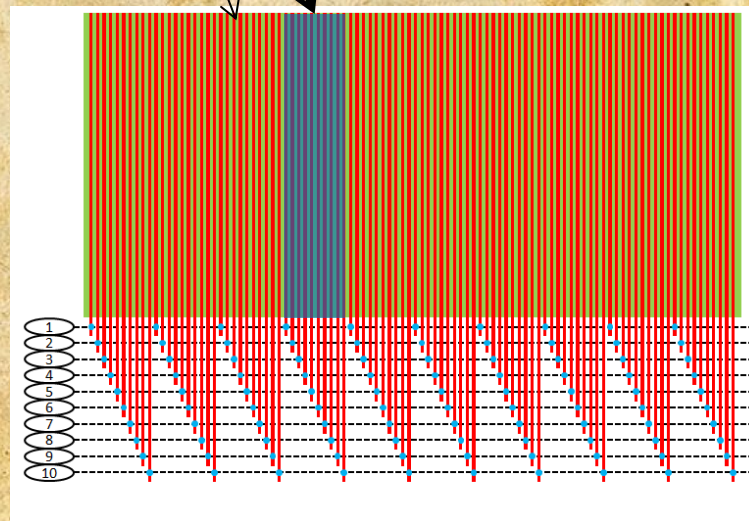
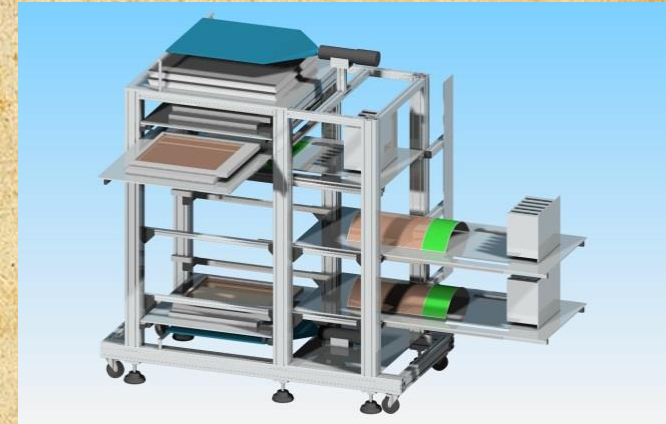
→ Stéphan Aune: 2 bulk MM on a single PCB (“double sided”)



- Top side with n_1 large strips (~ 1.5 cm)
- Bottom side with n_2 thin strips (~ 500 microns), repeated n_1 times

→ Detector with $n_1 \times n_2$ strips, and read by $n_1 + n_2$ channels

→ Optimum is $n_1 = n_2 = n/2 \implies p = n^2/4$



Double sided multiplexing

6 such detectors were built at the Saclay workshop, with an active area of $50 \times 50 \text{ cm}^2$, but:

→ thin strip sides don't reach the efficiency plateau

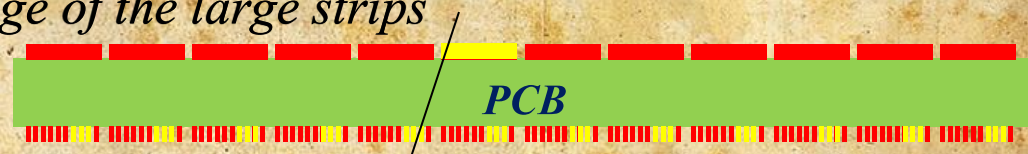
Thin strip capacitance: $2 \text{ nF} \Rightarrow 10\%$ of the real charge is collected
Partially compensated by the 1 cm drift gap

→ large strip sides reach the plateau...

Large strip capacitance: $1 \text{ nF} \Rightarrow 17\%$ of the real charge is collected
Partially compensated by the 1 cm drift gap
Partially compensated by the cluster size of 1

→ ... but several noisy/dead strips (3% loss per strip!)

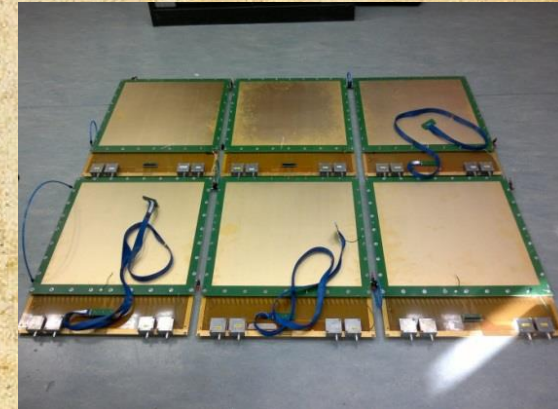
→ Ambiguity of localization on the edge of the large strips



→ Unsolvable ambiguity if more than 1 particle



→ Requires 2 working bulks



Multiplexing & information

Multiplexing inherently leads to a certain loss of information

- in the previous pattern, the information on which group of thin strips sees the particle is lost*
- this lost has to be compensated by an additional information, provided by another detector (large strip side)*

*The best way to multiplex would be to look for **redundant** information, and design a multiplexing pattern for which the lost information exactly coincides with the redundant one...*

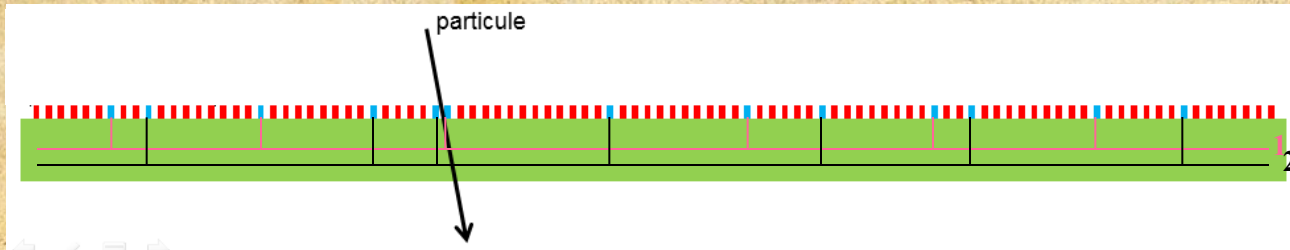
- Is there any redundancy in the detector's signal?*

Genetic multiplexing

Starting point:

→ *in most cases, a signal is recorded on at least 2 neighbouring strips*

We can make use of this redundancy, and combine channels with strips in such a way that 2 given channels are connected to neighbouring strips only once in the detector

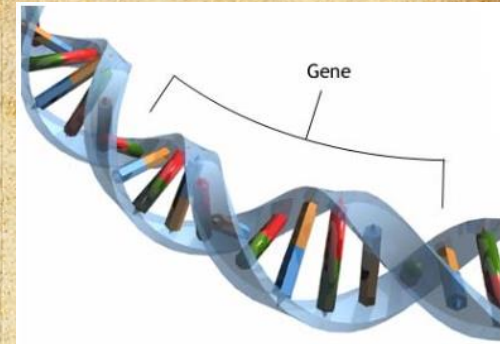


→ *blocks of thin strips are no longer identical*

→ *the localization of the particle doesn't require large strips anymore*

→ *the connection $\{\text{channels}\}_n \leftrightarrow \{\text{strips}\}_p$ can be represented by a p list of channel numbers*

For n channels, there are $a priori$ $n(n-1)/2$ unordered doublets combinations, and thus one can equip a detector with at most $p = n(n-1)/2 + 1$ strips



The sequence of channels uniquely codes the position on the detector...

Genetic multiplexing

Several possibilities to build the pattern, i.e. the sequence of p numbers:

→ generate the sequence randomly:

cannot build all the doublets

1 ₁	3 ₂	2 ₃	7 ₄	5 ₅	6 ₆	4 ₇
7 ₈	2 ₉	5 ₁₀	6 ₁₁	4 ₁₂	... ₁₃	

channel # strip #

→ build the t^{th} block from $1+k.i [n]$ (idea from Raphaël Dupré)

build all the doublets if n prime

1 ₁	2 ₂	3 ₃	4 ₄	5 ₅	6 ₆	7 ₇
1 ₈	3 ₉	5 ₁₀	7 ₁₁	2 ₁₂	4 ₁₃	6 ₁₄
1 ₁₅	4 ₁₆	7 ₁₇	3 ₁₈	6 ₁₉	2 ₂₀	5 ₂₁

→ idem, but simply use the first available channel

build almost all the doublets $\forall n$

1 ₁	2 ₂	3 ₃	4 ₄	5 ₅	6 ₆	7 ₇	8 ₈	9 ₉
1 ₁₀	3 ₁₁	5 ₁₂	7 ₁₃	9 ₁₄	2 ₁₅	4 ₁₆	6 ₁₇	8 ₁₈
1 ₁₉	4 ₂₀	7 ₂₁	2 ₂₂	5 ₂₃	8 ₂₄	3 ₂₅	6 ₂₆	9 ₂₇
2 ₂₈	6 ₂₉	1 ₃₀	5 ₃₁	9 ₃₂	3 ₃₃	7 ₃₄		

Double sided vs genetic multiplexing

	Double sided	Genetic
Max number of strips for n channels	$n^2/4$	$n(n-1)/2+1 \sim n^2/2$
Process	2 bulk detectors	single bulk
Thickness/material	PCB ≥ 1.6 mm	PCB ≥ 0.1 mm
Detection efficiency	$\epsilon_1 \times \epsilon_2$	ϵ_1
Adaptable to higher flux	?	yes
X ray detection	no	yes
Edge effect	yes	no
Cluster size	≥ 1	≥ 2

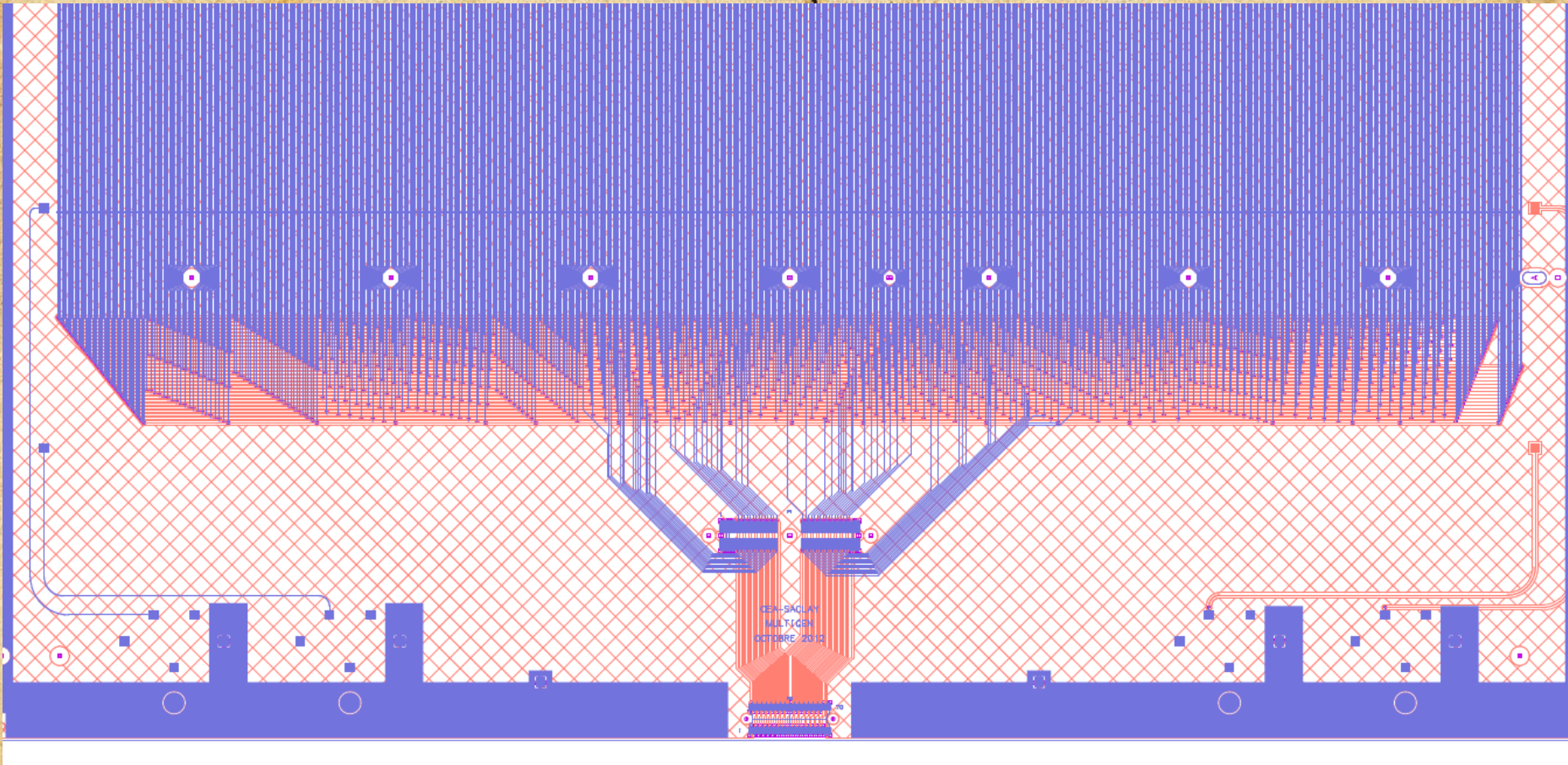
→ Patent n° 12 62815 (S. Procureur, R. Dupré, S. Aune):

« Circuit de connexion multiplexé et dispositif de connexion permettant notamment de réaliser un multiplexage »

Prototype

50x50 cm² active area, read with $n = 61$ channels (highest prime number below 64...)

- 488 micron pitch - $p = 1024$ strips - could have equipped up to $61 \times 60 / 2 + 1 = 1831$ strips (~90 cm)

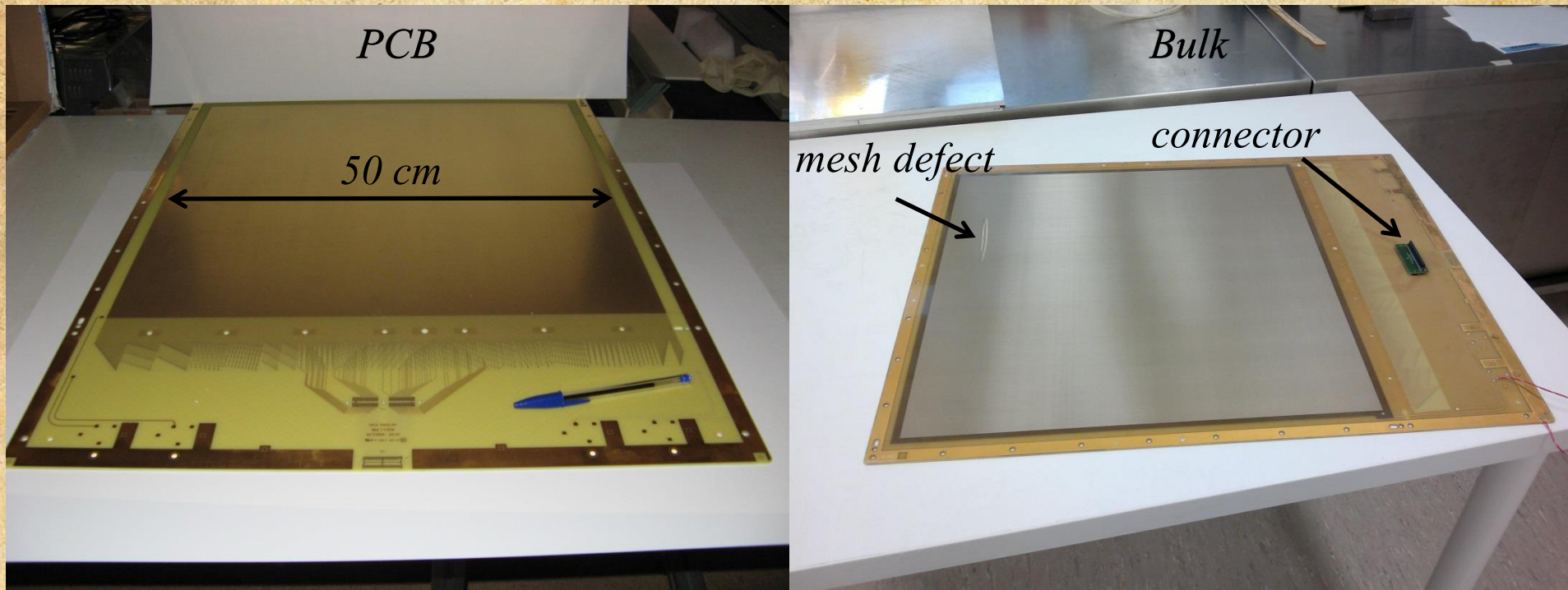


→ *Smallest k -uplet repeated: $k=15$*

Prototype

50x50 cm² active area, read with $n = 61$ channels (highest prime number below 64...)

- 488 micron pitch - $p = 1024$ strips - could have equipped up to $61 \times 60 / 2 + 1 = 1831$ strips (~90 cm)

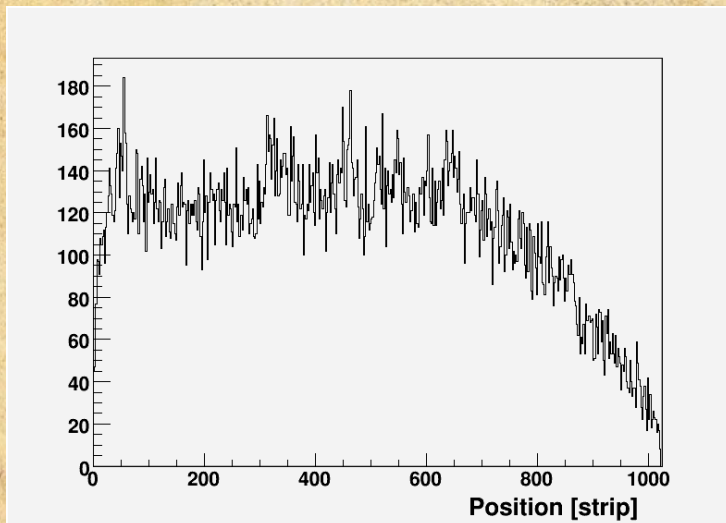
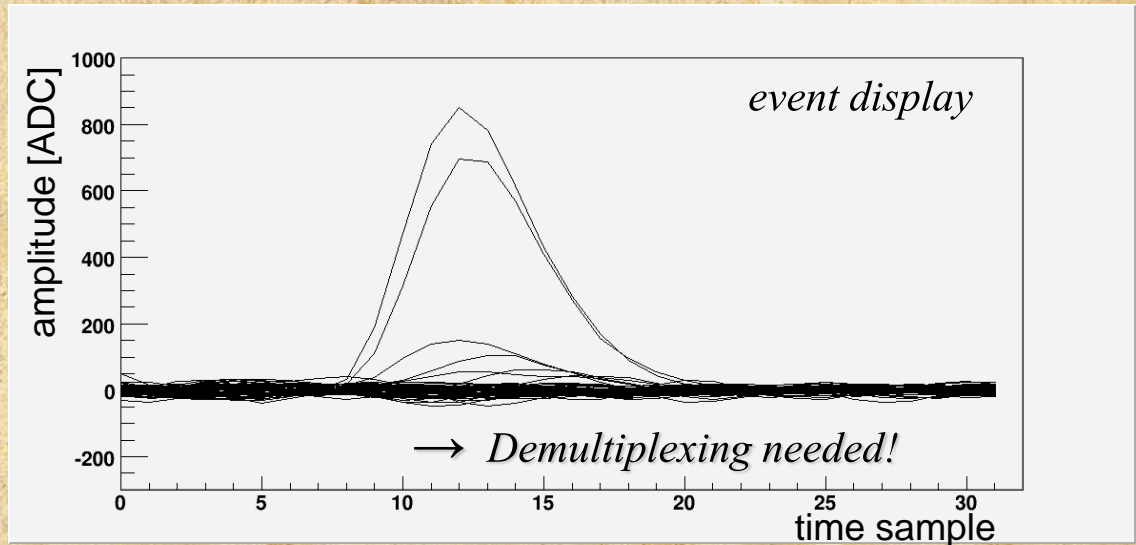


Strip capacitance: 1.3 nF (compared to 2 nF for thin strip from double sided)

Results with cosmics

Prototype tested in the CLAS12 cosmic bench (60x60 cm² couple of scintillators)

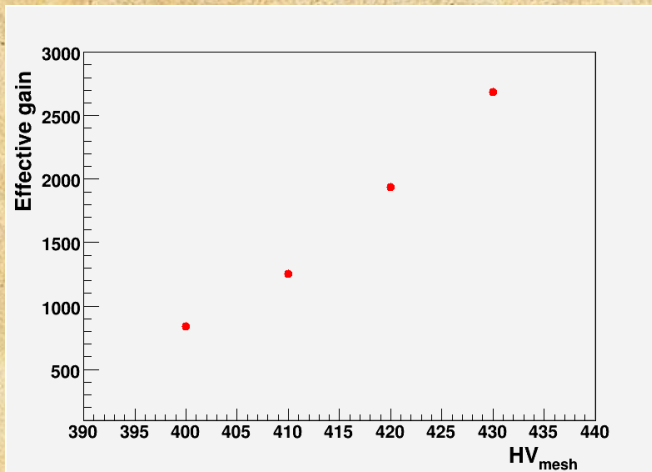
- *1 cm drift gap*
- *128 micron amplification gap*
- *Gas: Ar+5%isobutane*
- *$E_{drift} = 300$ V/cm*
- *1.5 m cable (70 pF/m)*
- *T2K electronics (AFTER)*
- *Shaping time: 200 ns*
- *Sampling frequency 60 ns*
- *Offline common mode subtraction*



- *Almost all strips OK (1020/1024)*
- *position distribution as expected*
- *mean noise on strips: 3,950 electrons*

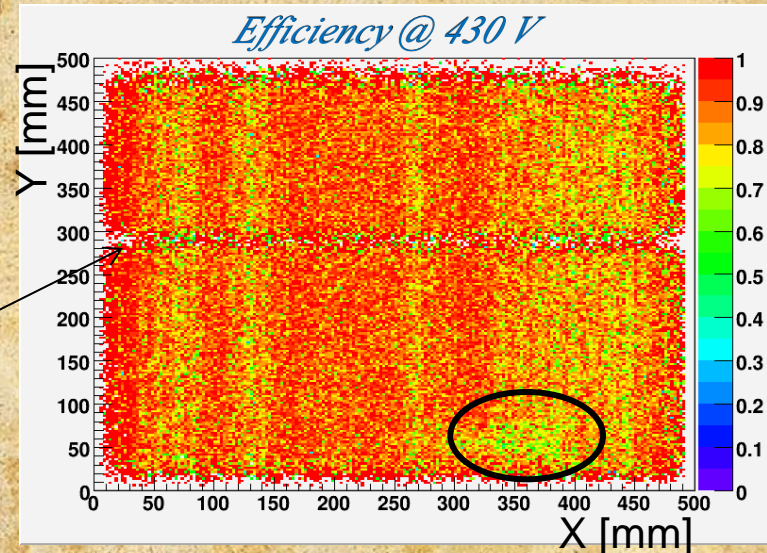
Results with cosmics

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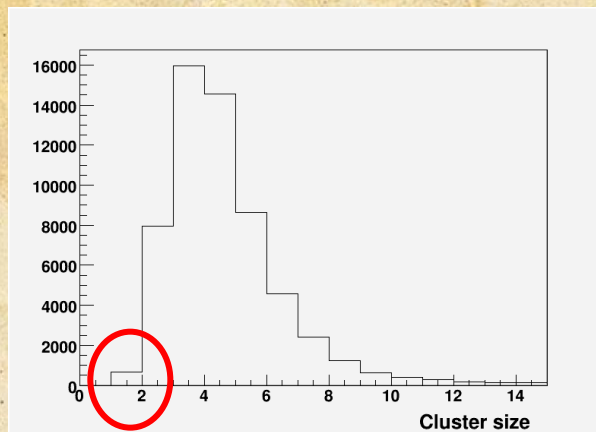


→ *good effective gains in spite of large capacitances*

artefact of the cosmic bench



→ *~ 90%, but not maximal gain*



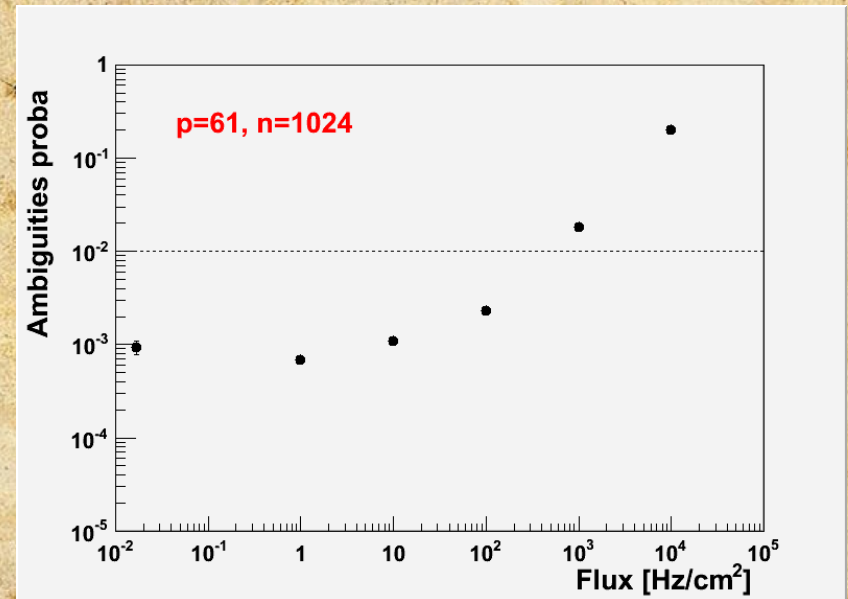
→ *< 2% of events with a cluster size of 1 (cannot be localized), as expected*

→ *not an issue with (shifted) resistive strips*

Genetic multiplexing and flux

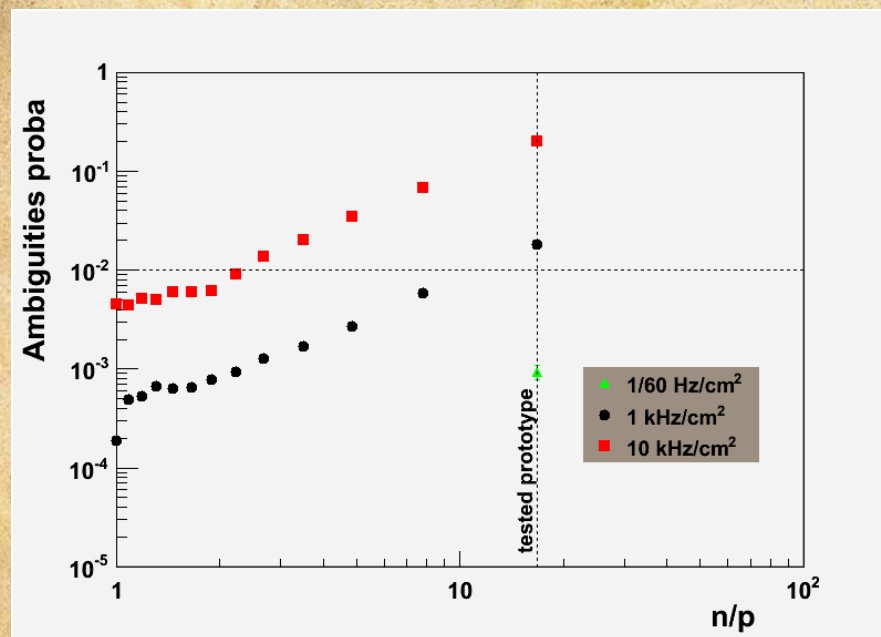
1st simulation of the ambiguity probability at \neq flux and for \neq degrees of multiplexing

- Same geometry (gaps, size, pitch)
- Primary electrons on Poisson distribution
- Transverse diffusion
- Time window: 100 ns
- Assume independent particles



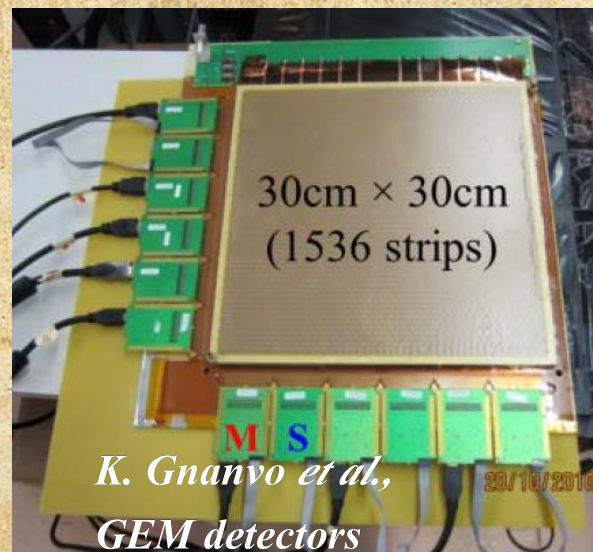
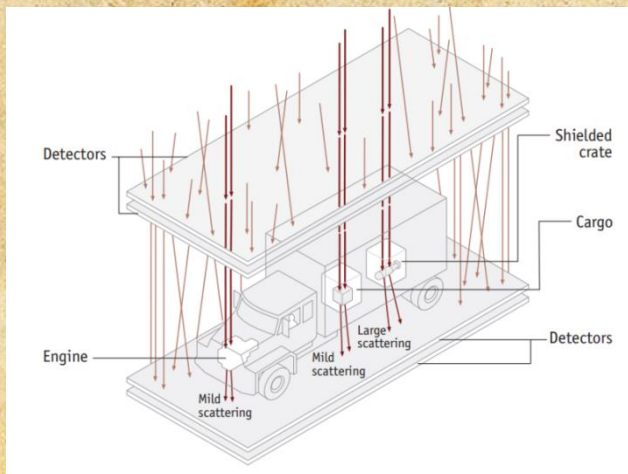
→ can stand up to 0.5 kHz/cm² in this configuration (1 MHz in total)

→ at 10 kHz/cm², the electronics can be reduced by a factor of 2 (1% ambiguities)

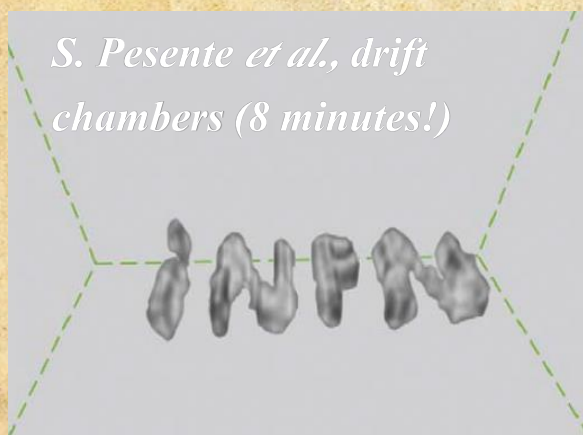


Some applications

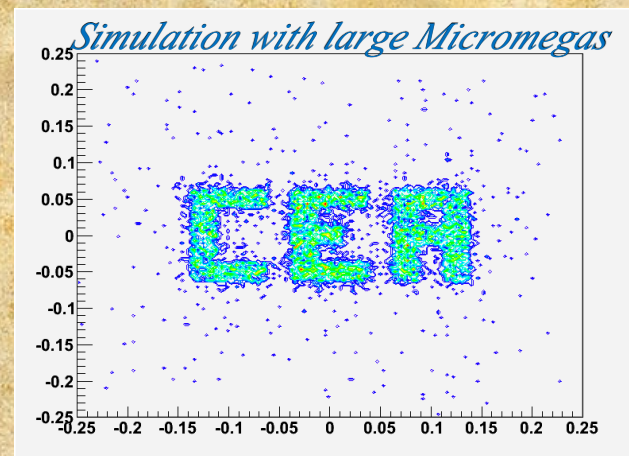
→ **Homeland security**: scan large volumes requires large detectors with high resolution
recent studies on scans with cosmic muons



→ *high resolution*
small size

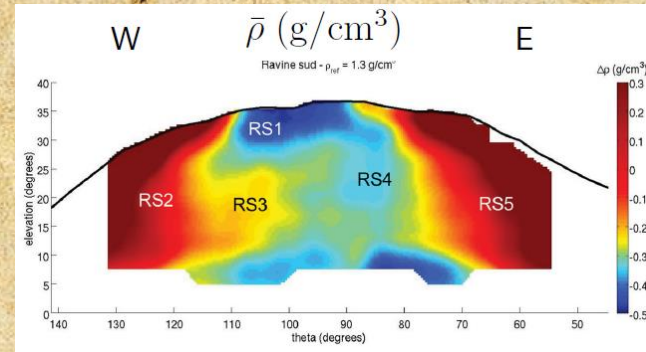


→ *large area,*
poor resolution



Some applications

- *Muon tomography for volcanology: requires large detectors with low consumption*
first results with 80x80 cm² scintillators (~1 cm resolution)



→ *~ 50 W for the whole installation, hostile environment*

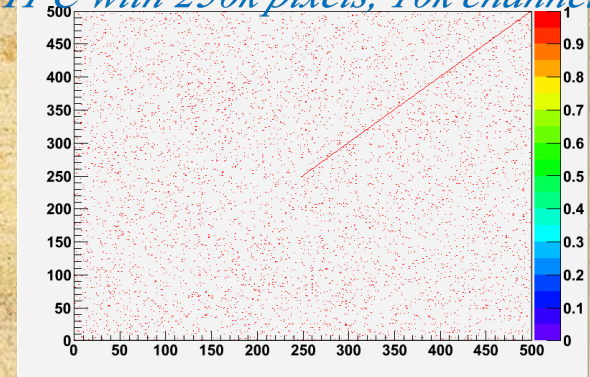
- Dosimetry

need light, portative setup → low consumption

- Applications in particle physics

- *sLHC project: > 1,000 m² of MPGDs, millions of electronic channels (~1€/channel)*
- *ILC TPC (~ 1 million pads): random multiplexing?*

TPC with 250k pixels, 10k channels



Conclusion & perspectives

Modern particle physics and many more applications require:

→ *large area setups*

→ *high spatial resolution*

→ *integration, low consumption*

→ *tight budget!*

Multiplexing becomes more and more feasible thanks to advances in instrumentation & electronics

→ *concept of genetic multiplexing validated with a Micromegas*

→ *almost no multiplexing at a spectrometer level ⇒ a lot to be done*

Optimization needed for a given flux/configuration

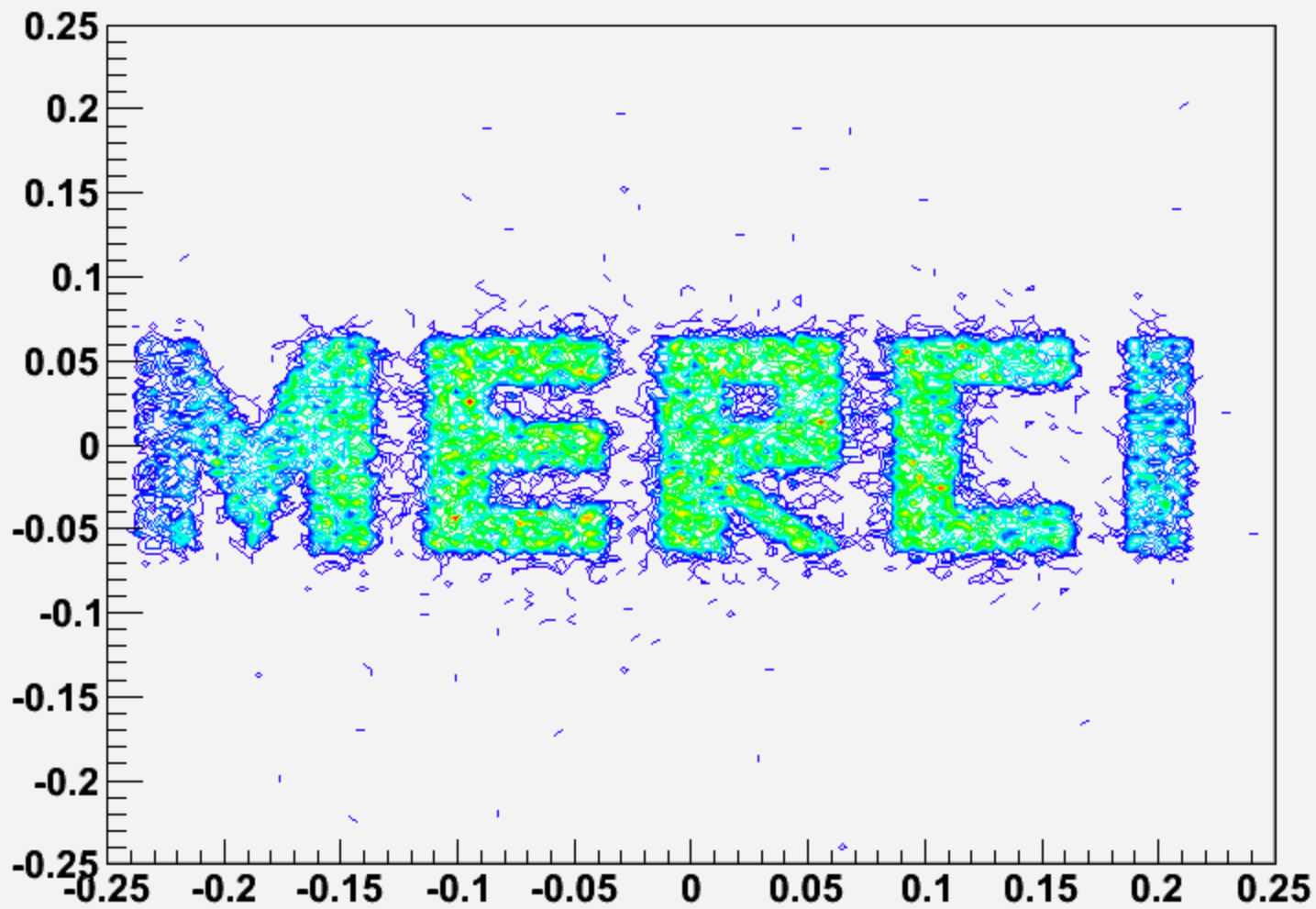
→ *if n channels suffice for 99% of the interesting events, is it relevant to have $2n$, $3n$ channels more for the remaining 1%?*

Next steps for genetic multiplexing:

- *Flux studies to validate the preliminary simulations*

- *Resistive, multiplexed Micromegas to further increase S/N (ELVIA, this year)*

→ *Goal: 1m^2 detector with 100 micron 2D-resolution and < 200 channels*

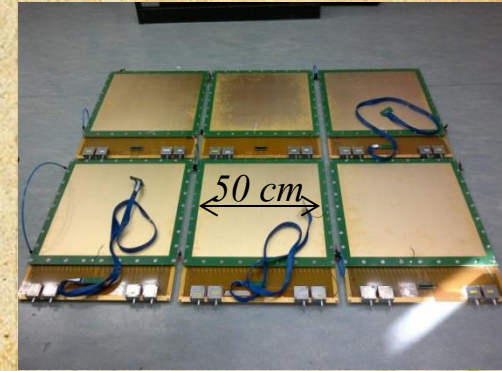


Back up

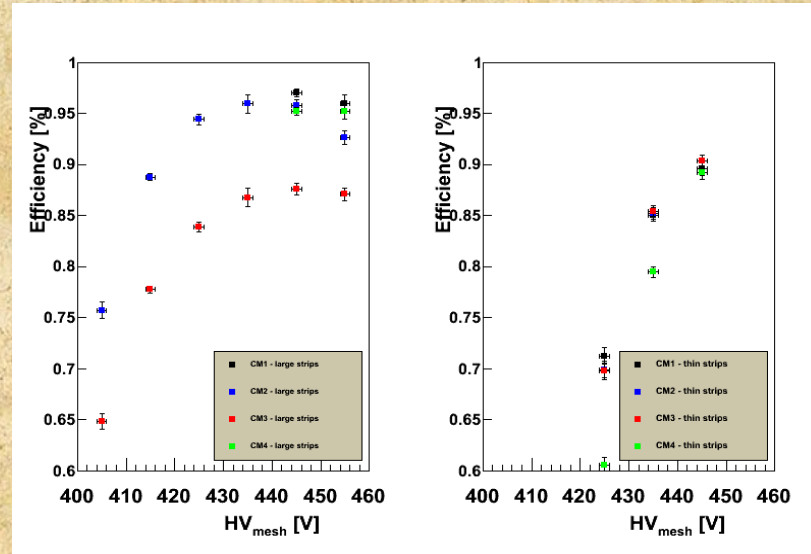
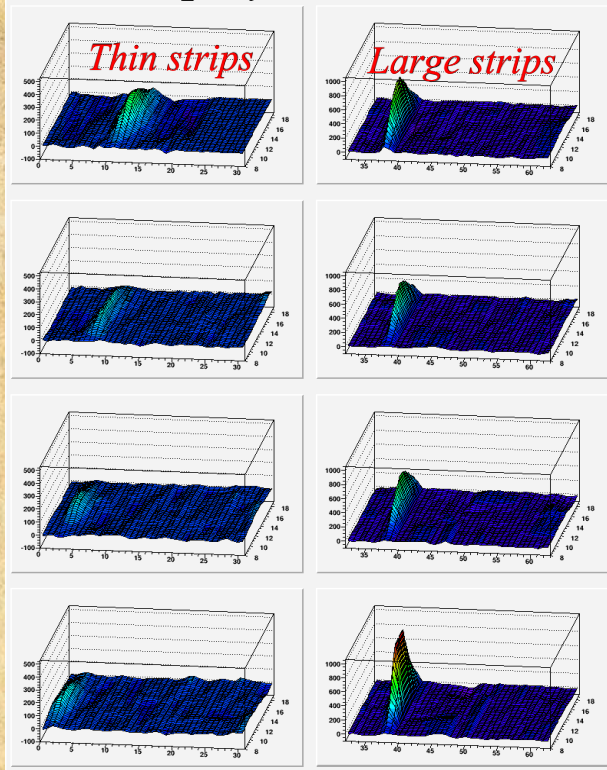
Double sided multiplexing

→ 6 such detectors were built at the Saclay workshop, with an active area of $50 \times 50 \text{ cm}^2$

- Top side with 32 large strips ($\sim 1.5 \text{ cm}$)
- Bottom side with 32 thin strips (488 microns), x32



Event display with 4 detectors



→ Efficiency plateau reached for large strips only

Genetic multiplexing

A signal can be deposited on more than 2 strips... so the repetition of k -uplets ($k > 2$) should be checked

→ A priori no problem, as there are much more k -uplets than doublets...

→ But the repetition of small k -uplets does appear in this construction:

$$C_n^k = \frac{n!}{k!(n-k)!}$$

$i=1$	1	2	3	4	5	6	7	8	9	10	11
$i=2$	1	3	5	7	9	11	2	4	6	8	10
$i=3$	1	4	7	10	2	5	8	11	3	6	9
$i=4$	1	5	9	2	6	10	3	7	11	4	8
$i=5$	1	6	11	5	10	4	9	3	8	2	7

Repetition of the triplet
9-1-5

→ Can be improved by reordering the blocks:

$i=1$	1	2	3	4	5	6	7	8	9	10	11
$i=3$	1	4	7	10	2	5	8	11	3	6	9
$i=2$	1	3	5	7	9	11	2	4	6	8	10
$i=4$	1	5	9	2	6	10	3	7	11	4	8
$i=5$	1	6	11	5	10	4	9	3	8	2	7

Repetition of the
quadruplet 3-6-9-1