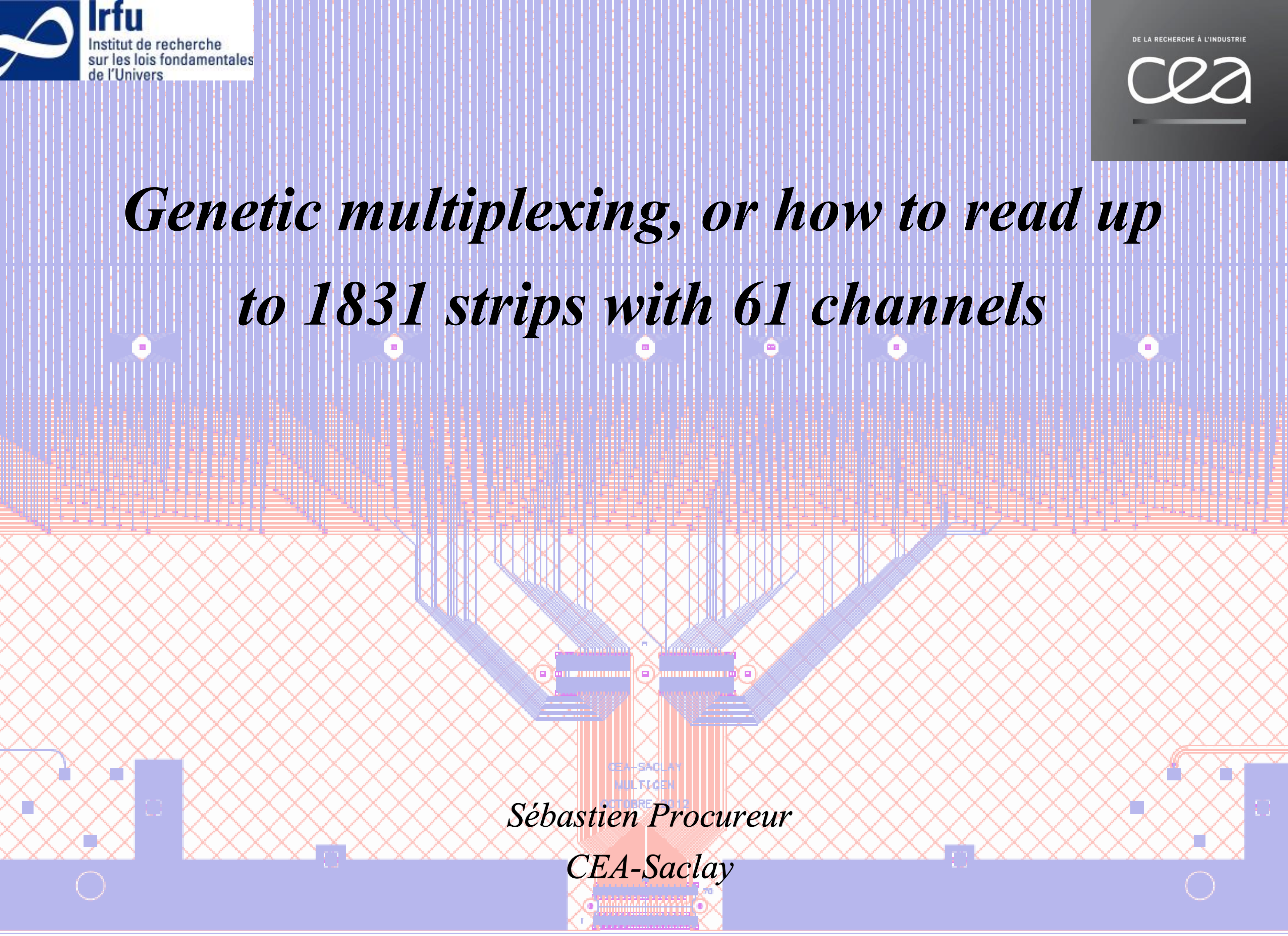
Genetic multiplexing, or how to read up to 1831 strips with 61 channels



Sébastien Procureur

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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

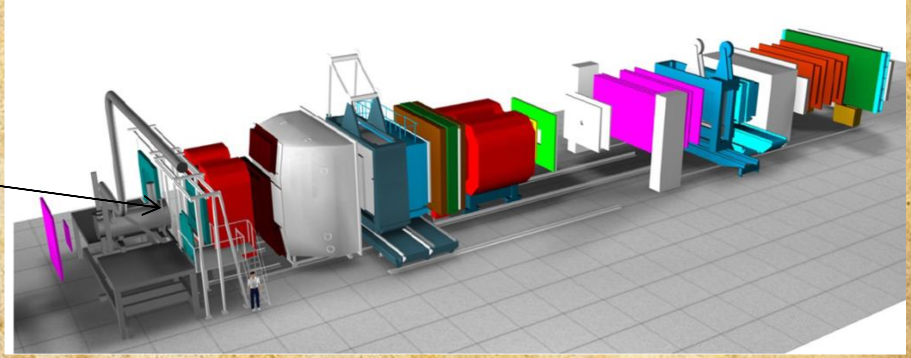
Obvious interest: lower the number of electronic channels

→ *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:

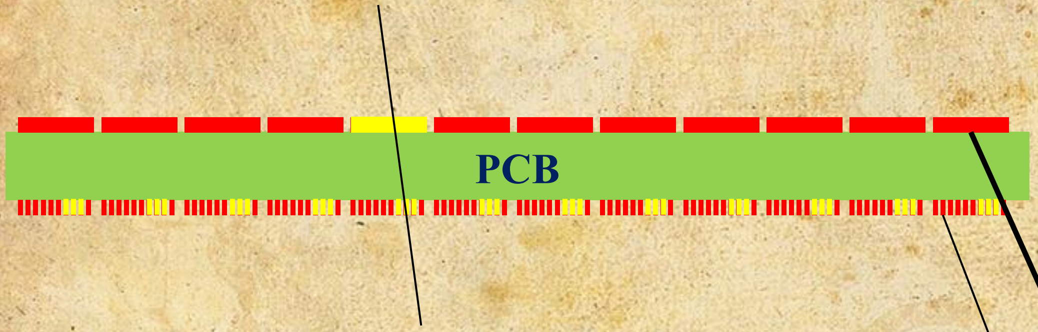
→ *degradation of S/N ⟹ can lower the detection efficiency*

→ *ambiguities to solve (demultiplexing)*

Multiplexing: first idea

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

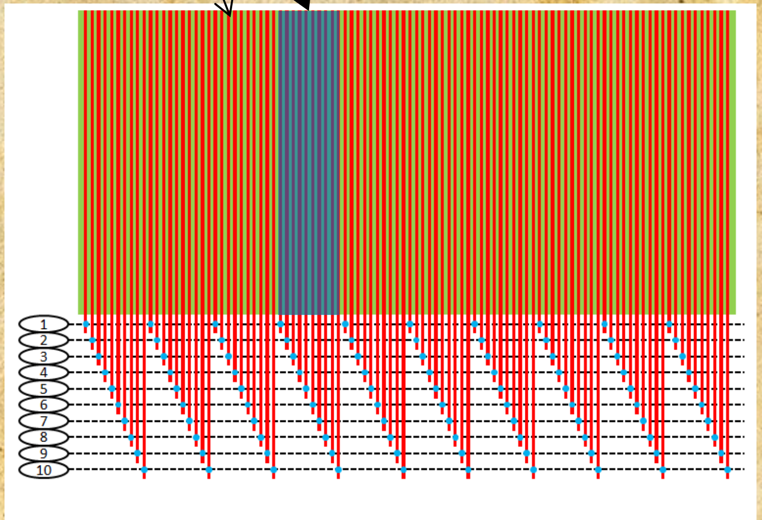
→ *Stéphan Aune: 2 bulk MM on a single PCB ("double sided")*



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

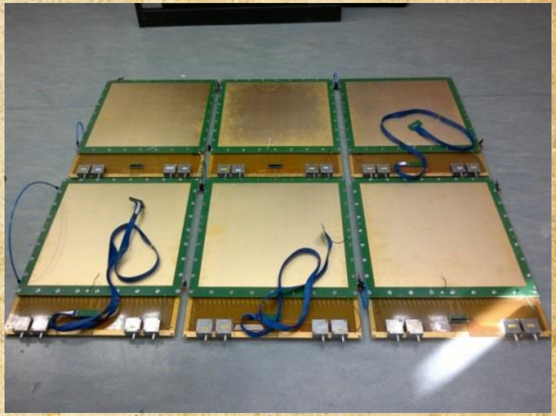
→ *Detector with $n_1 x n_2$ strips, and read by n_1+n_2 channels*

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



Double sided multiplexing

6 such detectors were built at the Saclay workshop, with an active area of 50x50 cm², but:



→ *thin strip sides don't reach the efficiency plateau*

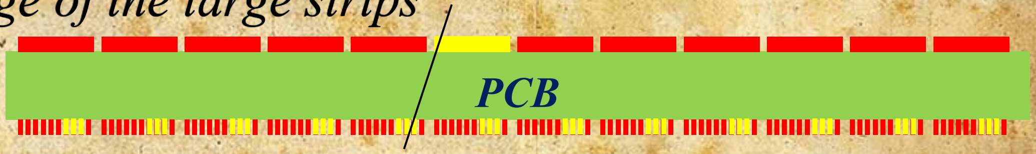
Thin strip capacitance: 2 nF ⟹ 10% of the real charge is collected
Partially compensated by the 1 cm drift gap

→ *large strip sides reach the plateau…*

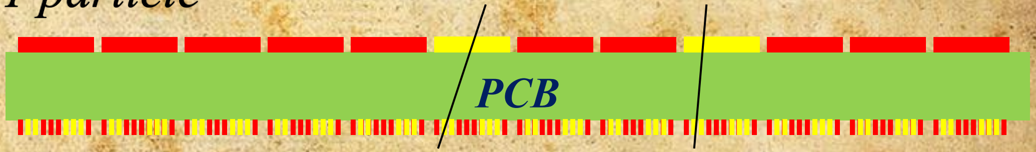
Large strip capacitance: 1 nF ⟹ 17% of the real charge is collected
Partially compensated by the 1 cm drift gap
Partially compensated by the cluster size of 1

→ *… 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…

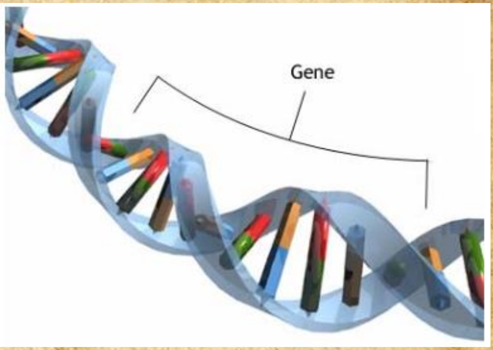
→ Is there any redundancy in the detector's signal?

Genetic multiplexing

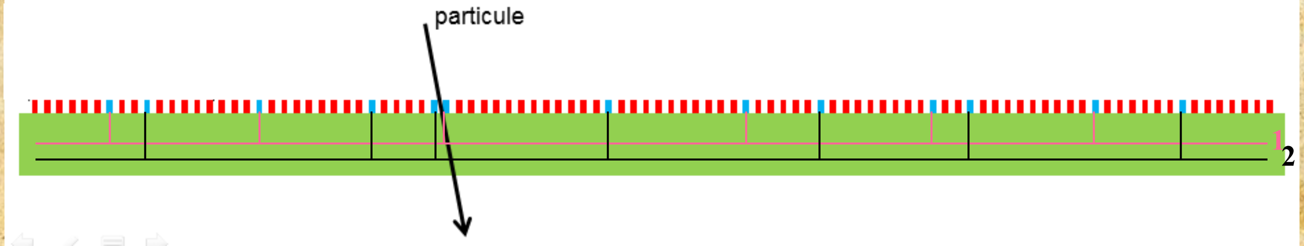
Starting point:

→ 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



The sequence of channels uniquely codes the position on 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*

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	$\cancel{2}1_9$	5_{10}	$\cancel{6}3_{11}$	4_{12}	$\ldots_{13}$	

channel # *strip #*

→ *build the i^{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 ∀ 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	$\varepsilon_1 x \varepsilon_2$	ε_1
Adaptable to higher flux	?	yes
X ray detection	no	yes
Edge effect	yes	no
Cluster size	≥ 1	≥ 2

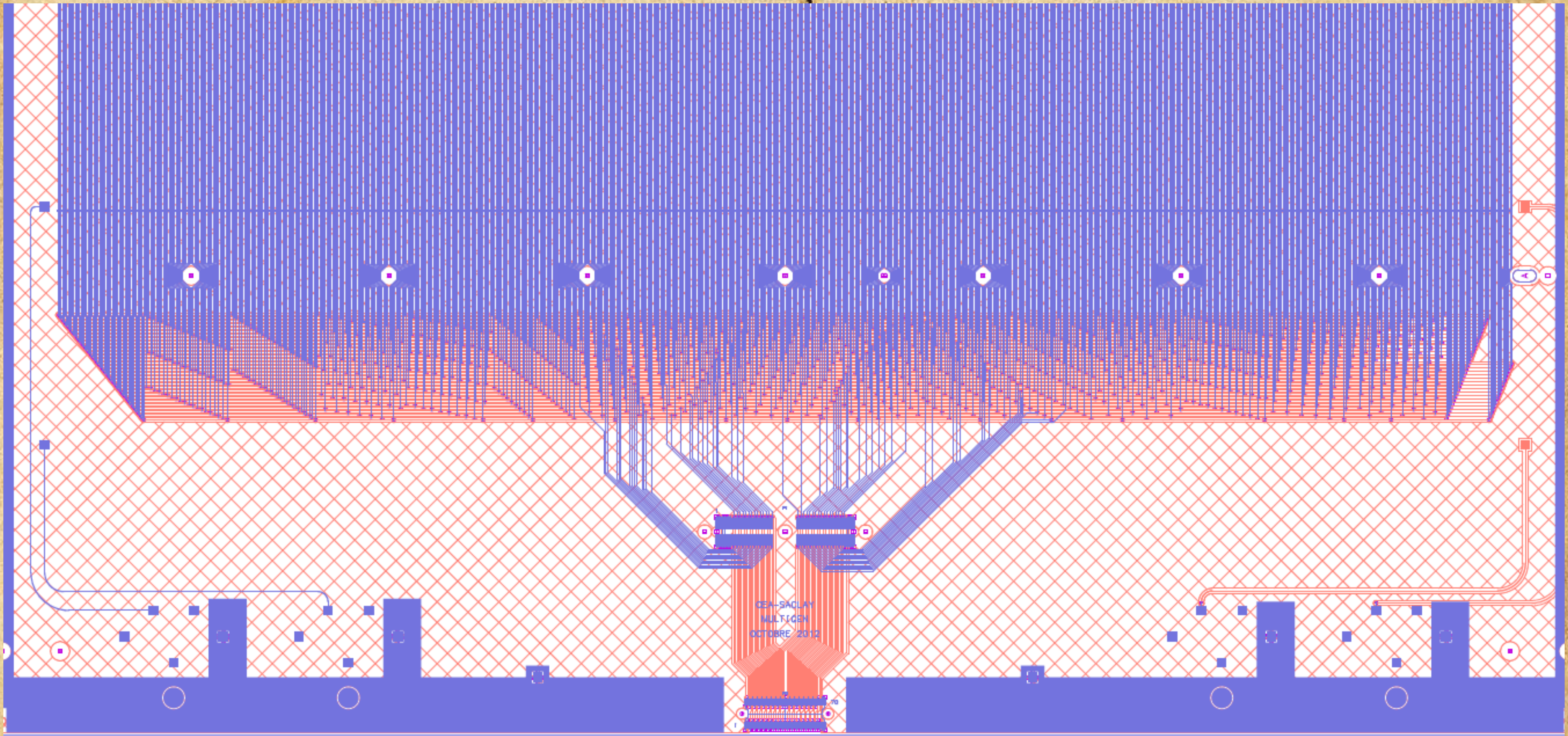
→ Patent n° 12 62815 (S. Procureur, R. Dupré, S. Aune):

« 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 equiped up to 61x60/2+1=1831 strips (~90 cm)

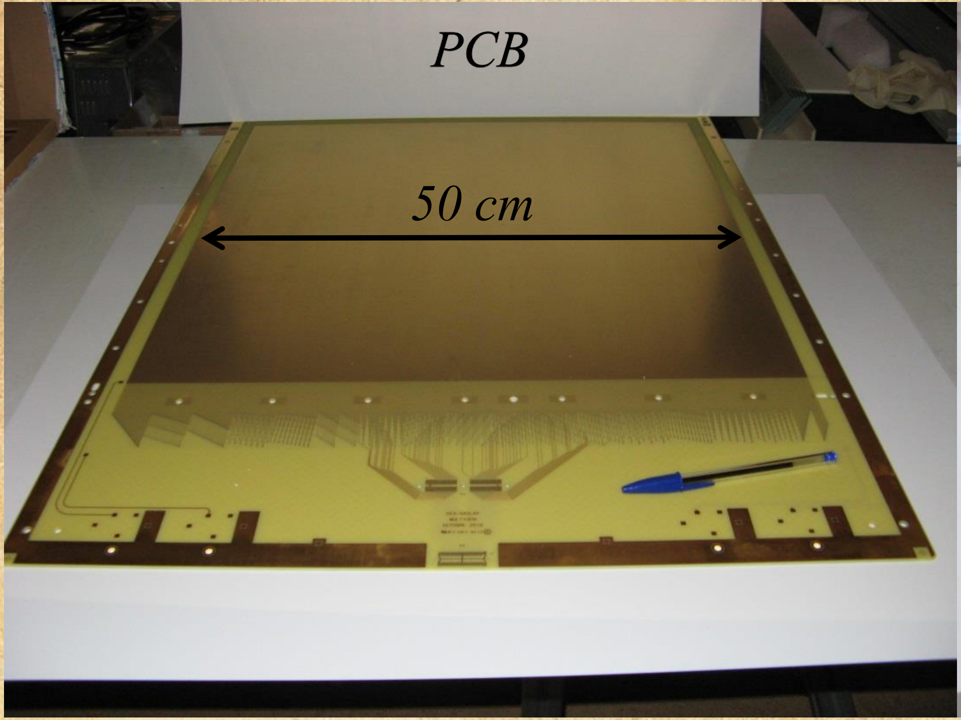


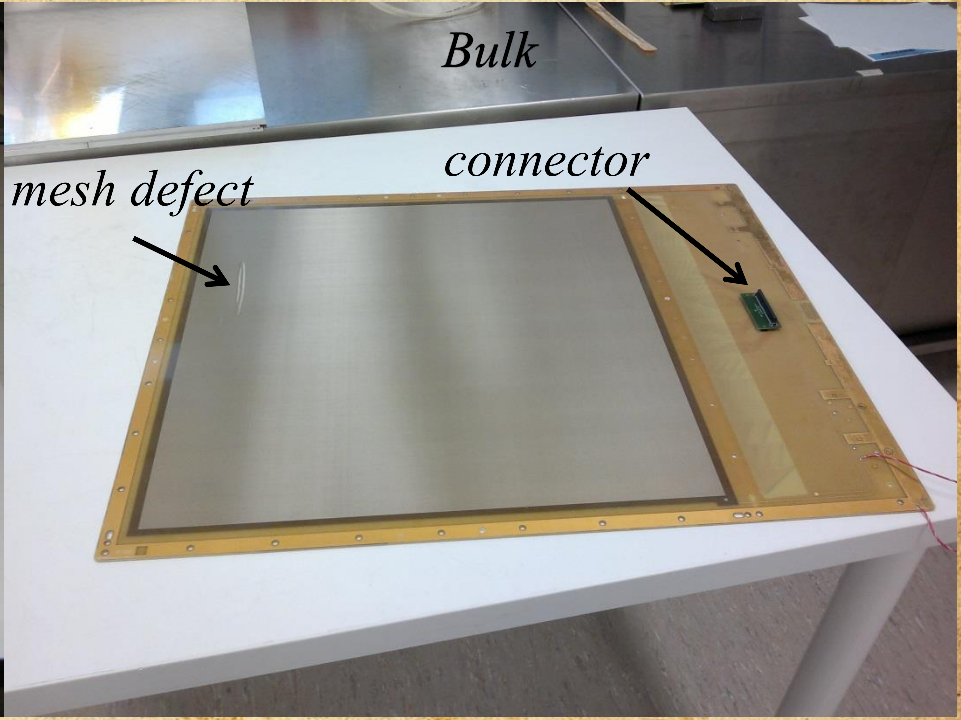
→ *Smallest k-uplet repeated: k=15*

Prototype

50x50 cm^2 active area, read with n = 61 channels (highest prime number below 64…)

- 488 micron pitch - p= 1024 strips - could have equiped up to 61x60/2+1=1831 strips (~90 cm)



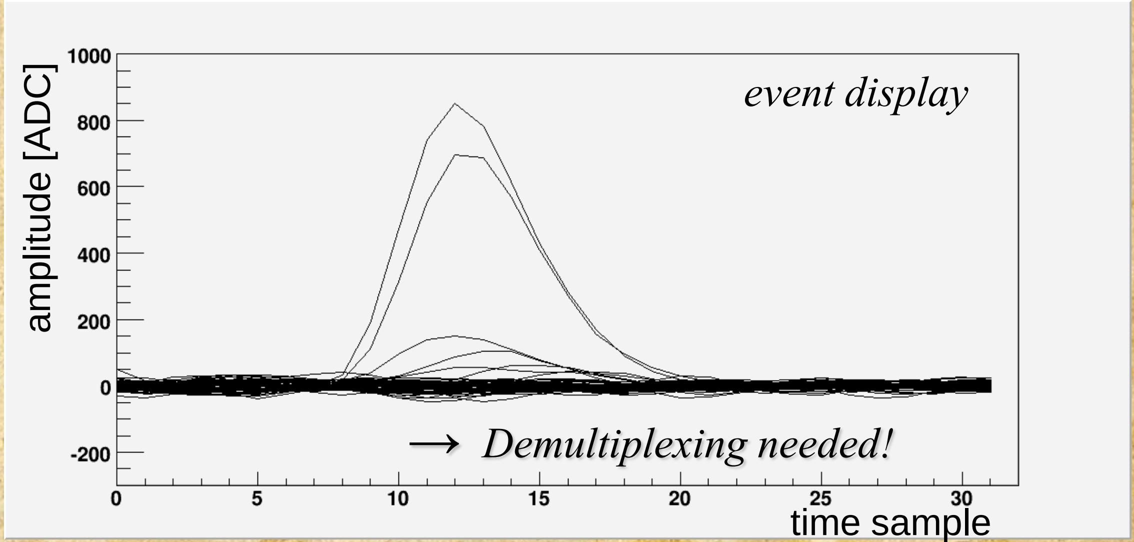


Strip capacitance: 1.3 nF (compared to 2 nF for thin strip from double sided)

Results with cosmics

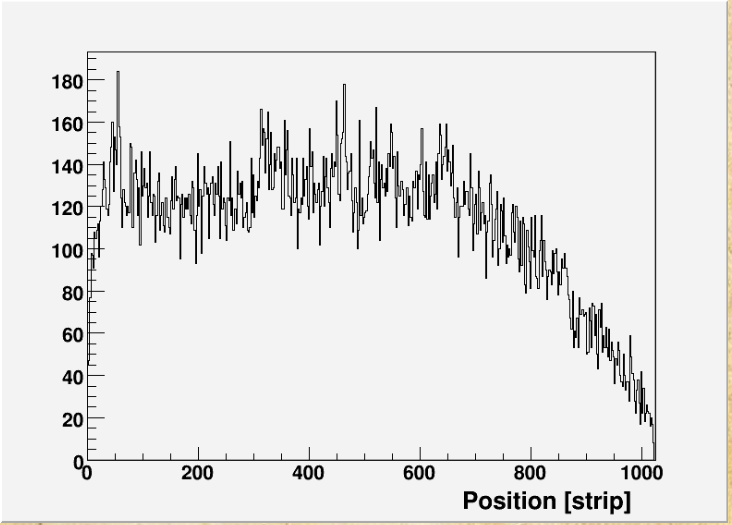
Prototype tested in the CLAS12 cosmic bench (60x60 cm² couple of scintillators)

- *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*



event display

→ *Demultiplexing needed!*



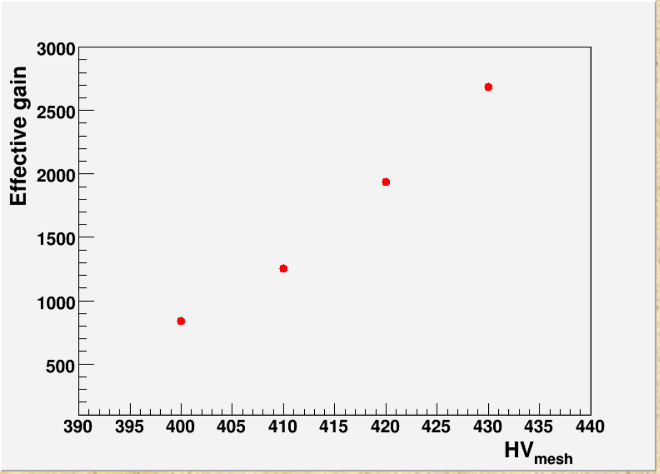
→ *Almost all strips OK (1020/1024)*

→ *position distribution as expected*

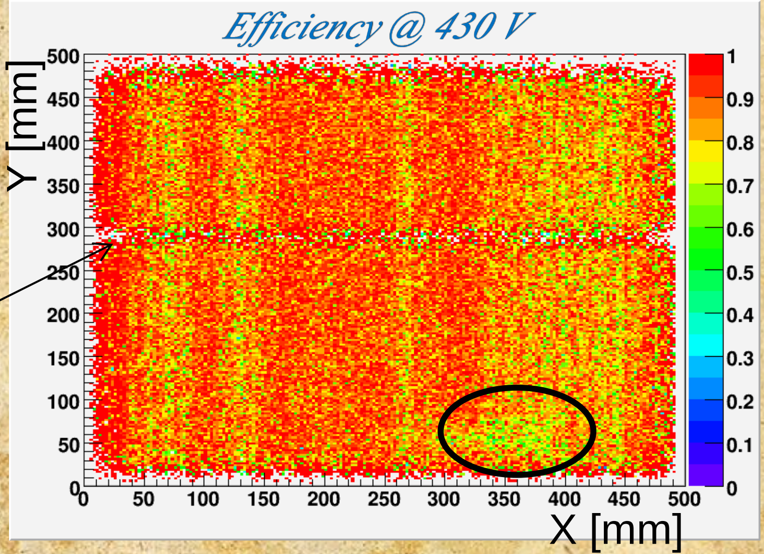
→ *mean noise on strips: 3,950 electrons*

Results with cosmics

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

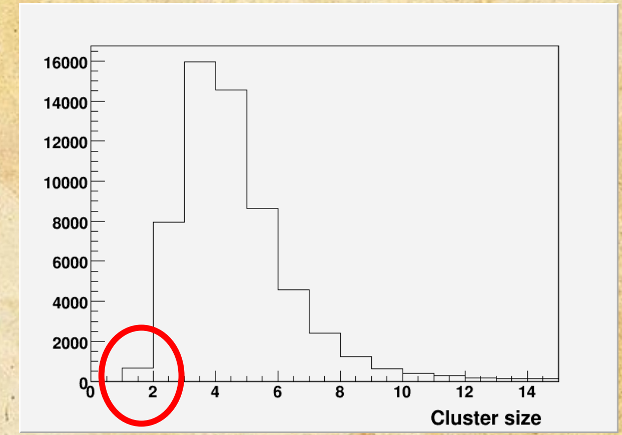


→ *good* ***effective*** *gains in spite of large capacitances*



artefact of the cosmic bench

→ *~ 90%, but not maximal gain*



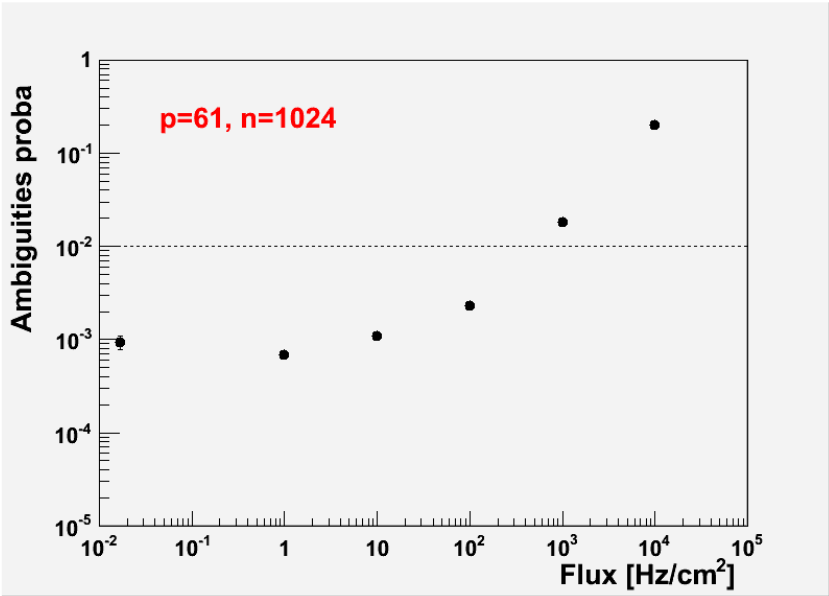
→ *< 2% of events with a cluster size of 1 (cannot be localized), as expected*

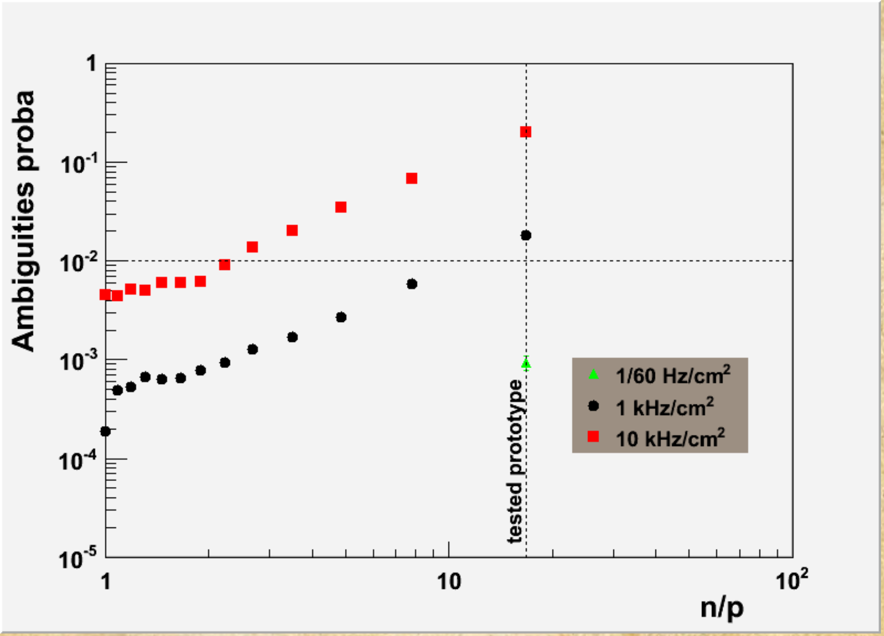
→ *not an issue with (shifted) resistive strips*

Genetic multiplexing and flux

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

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





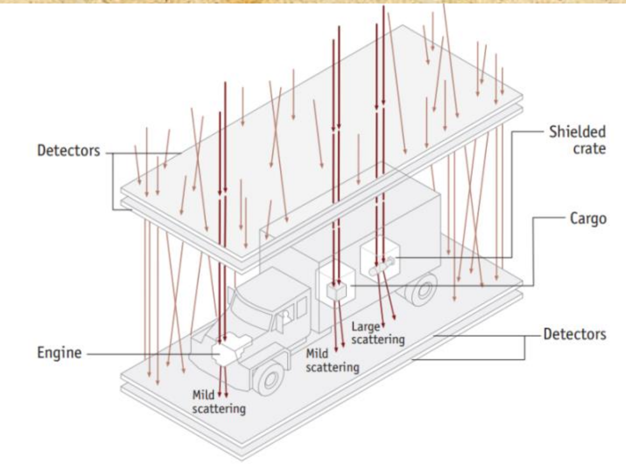
→ can stand up to 0.5 kHz/cm^2 in this configuration (1 MHz in total)

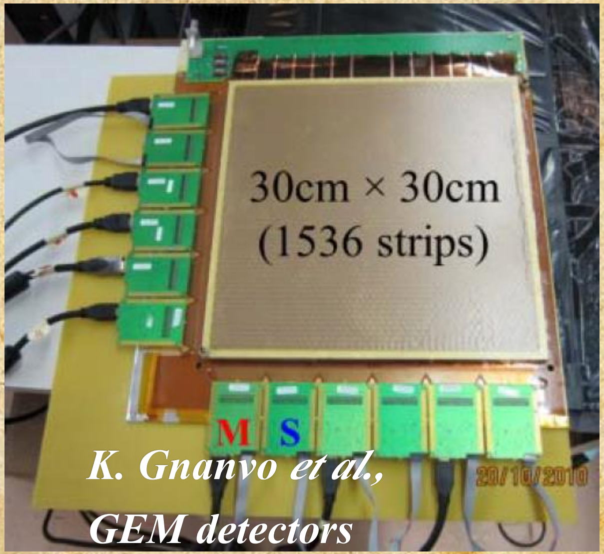
→ at 10 kHz/cm^2, the electronics can be reduced by a factor of 2 (1% ambiguities)

Some applications

→ ***Homeland security**: scan large volumes requires large detectors with high resolution*

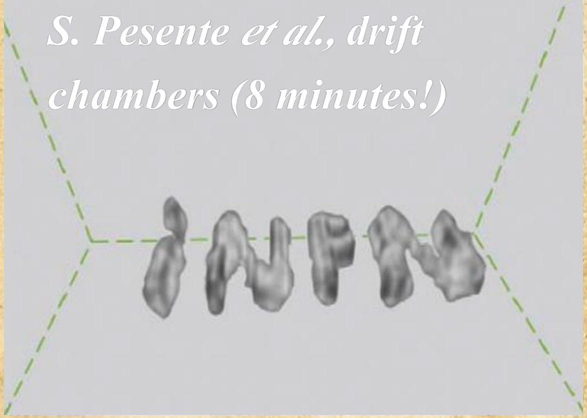
recent studies on scans with cosmic muons





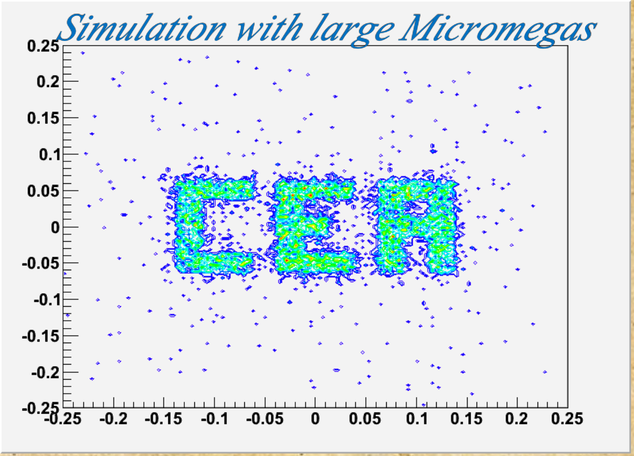
K. Gnanvo et al., GEM detectors

→ high resolution
small size



S. Pesente et al., drift chambers (8 minutes!)

→ large area,
poor resolution



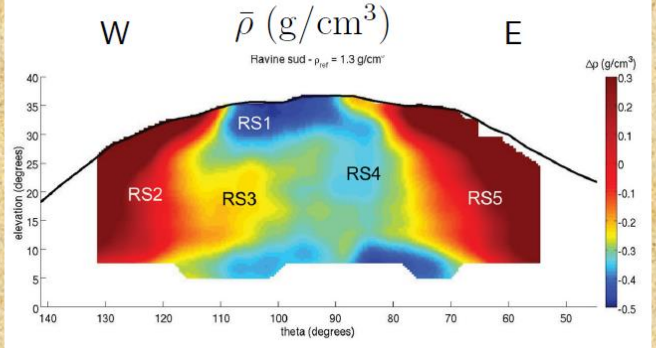
Simulation with large Micromegas

Some applications

- *Muon tomography for* ***volcanology****: requires large detectors with low consumption*

first results with 80x80 cm² scintillators (~1 cm resolution)

N. Lesparre et al.



→ ~ 50 W for the whole installation, hostile environment

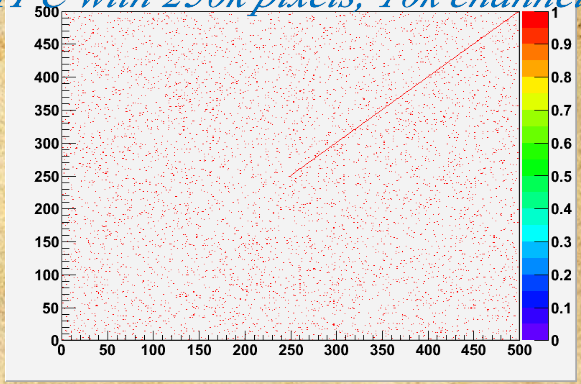
- ***Dosimetry***

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

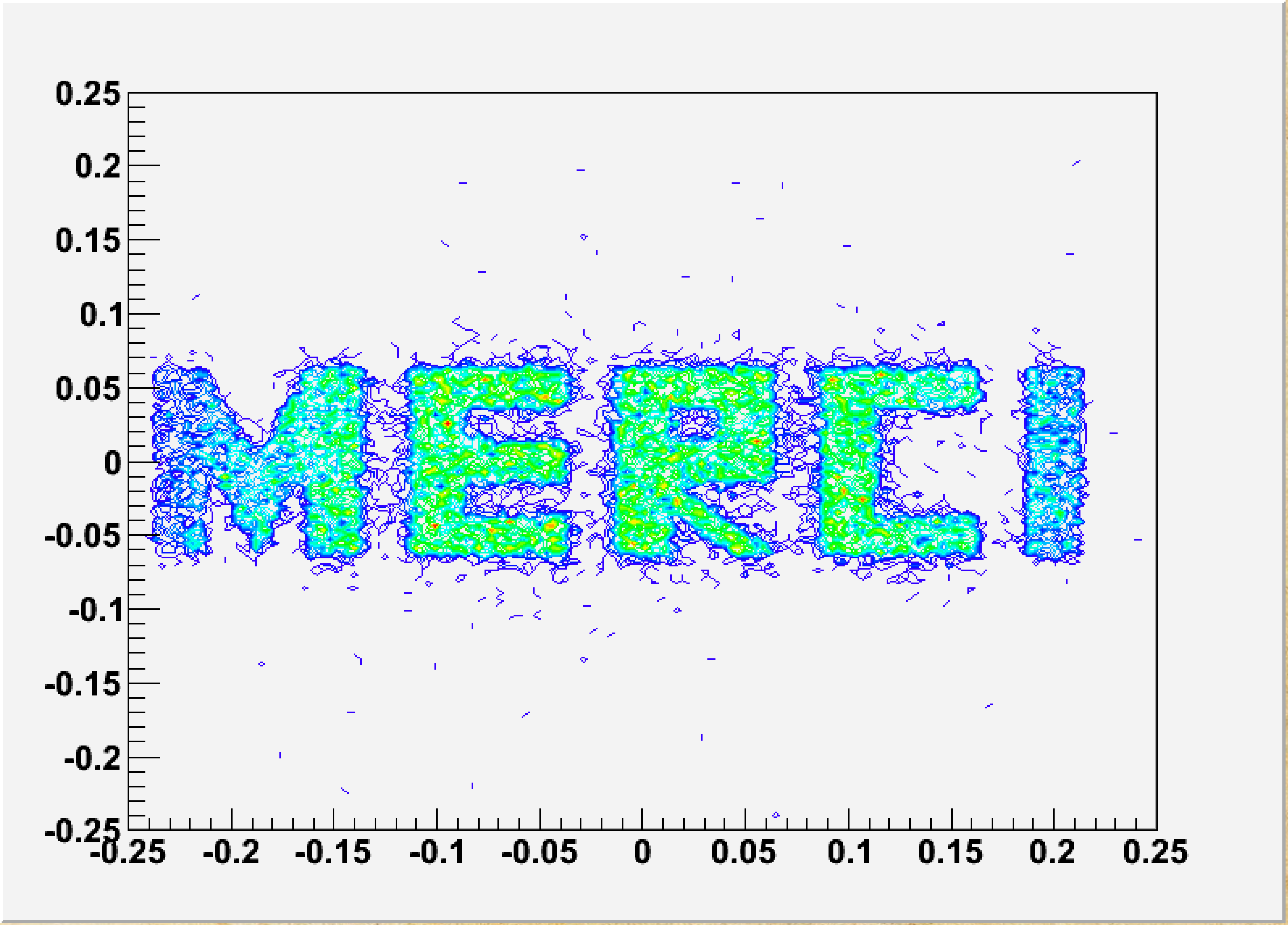
→ *if n channels suffice for 99% of the interesting events, is it relevant to have 2n, 3n channels more for the remaining 1%?*

<u>Next steps for genetic multiplexing:</u>

- Flux studies to validate the preliminary simulations

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

→ ***Goal: 1m² detector with 100 micron 2D-resolution and < 200 channels***

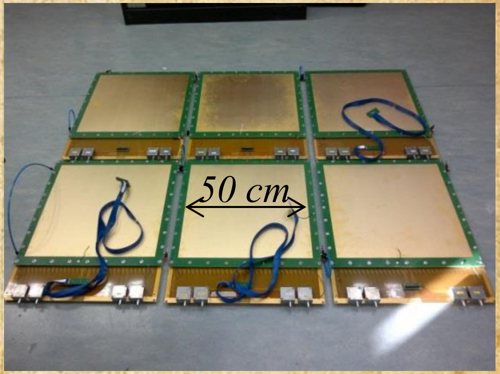

0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.25
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
0.25
MERCI

Back up

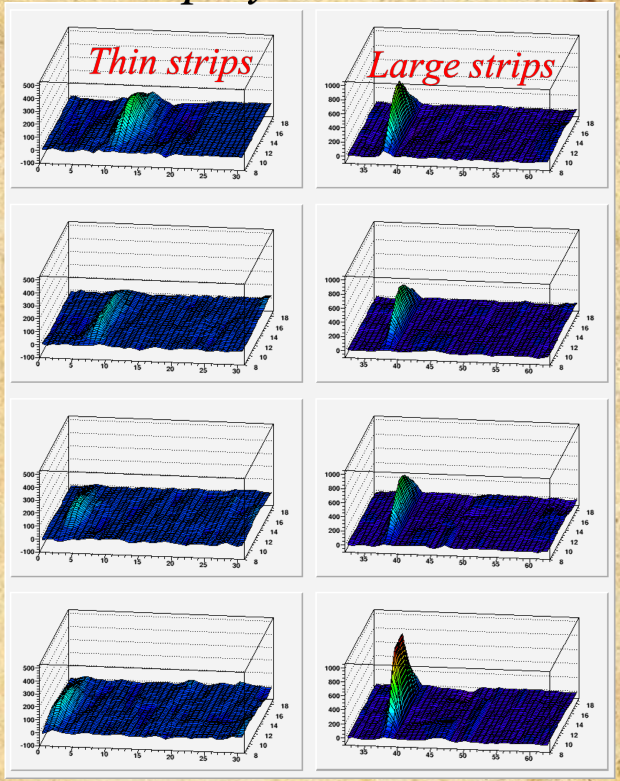
Double sided multiplexing

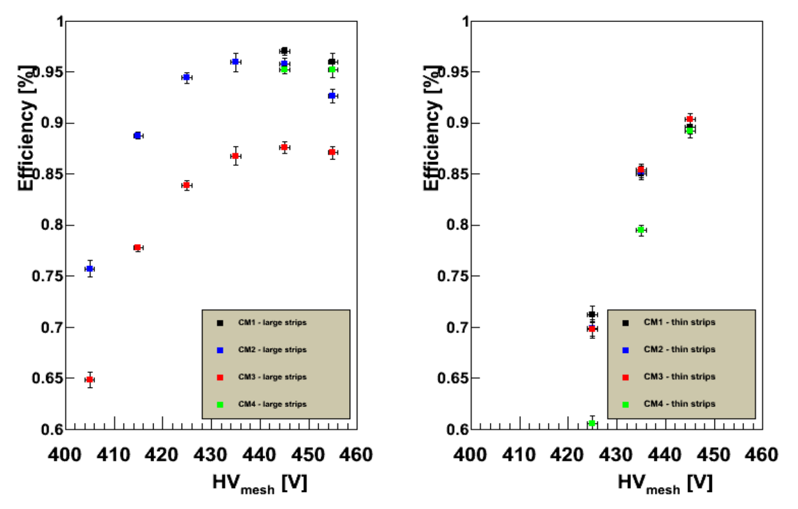
→ *6 such detectors were built at the Saclay workshop, with an active area of 50x50 cm²*

- *Top side with 32 large strips (~1.5 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…*

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

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

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