Irfu - CEA Saclay
Institut de recherche
sur les lois fondamentales
de l'Univers

MULTIPLEXING OF THE READOUT OF A TPC WITH PADS

A QUANTITATIVE STUDY

MAXENCE VANDENBROUCKE – RD51 MINI-WEEK – DECEMBER 2016

A TPC USING 2D MULTIPLEXING

What ?

-> Application of the "MultiGen" multiplexing concept to a full 2D Pixel readout
-> A ~ $40x40x40cm^3$ TPC read with a multiplexed pixels + metallic Micromegas
-> Need from 4 to 8 DREAM 64ch. Asics
-> Precision comparable to a tracking telescope

Why ?

-> Multiplexing grows with the square of electronics channels -> cheap 2D readout
-> One readout plane for one tracking system
-> TPC has a much larger acceptance compare to a tracking telescope
-> Compact and one single object
-> Could give the direction of the particle (multiple measurement)
-> Fun

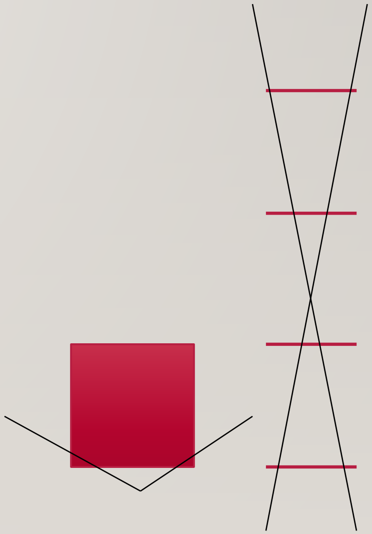
This study :

-> Simulation for a proof of concept for 2D multiplexing and reconstruction
-> Development of multiplexing and reconstruction algorithm
-> Performances comparison with a Muon Telescope

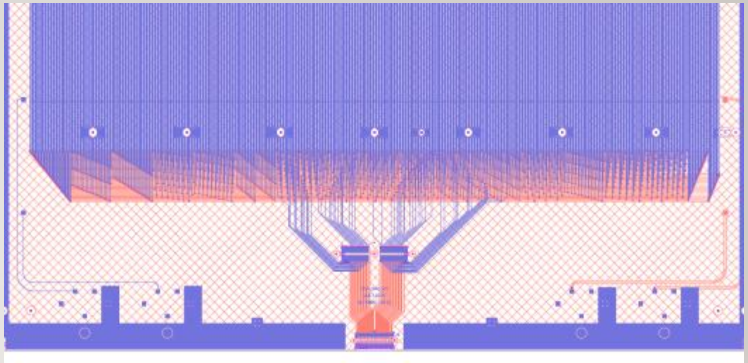
Applications ?

-> Muography
-> Case study for low rate TPC
-> Cosmic veto for low background experiment
-> Large Detector Characterization

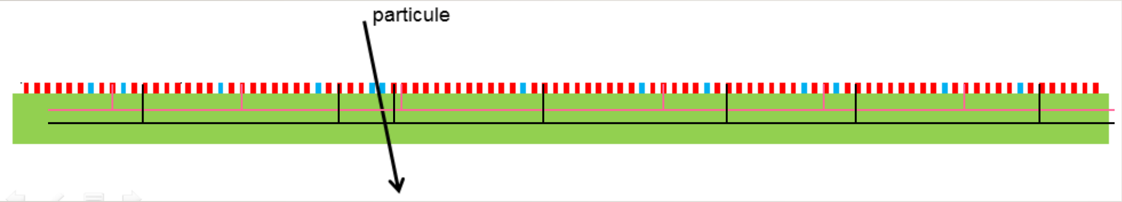
TPC acceptance vs Telescope

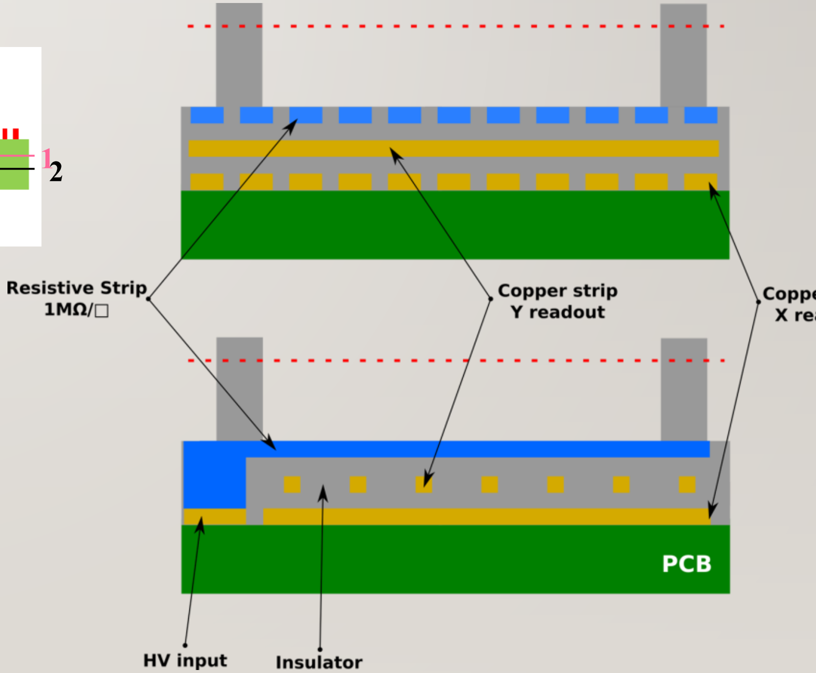


THE MULTIGEN 2D DETECTOR (2X1D)

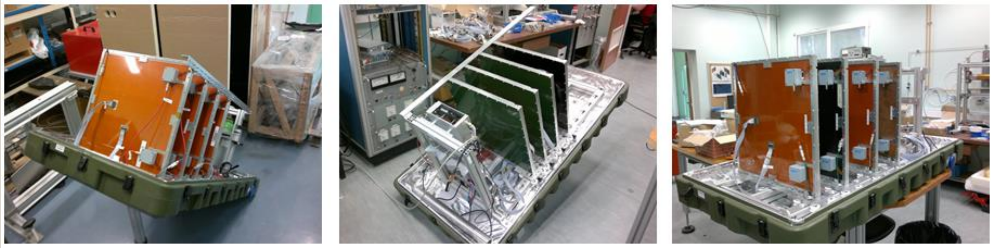


- Bulk Micromegas
- 50x50cm active area
- X-Y Strips using capacitive coupling
- "MultiGen" multiplexing 61 el. Ch. for 1024 strips (16.8 multiplexing factor)
- One pair of electronics channels are neighbor only once in the detector





Bouteille *et al.*, NIMA 834 (2016) 187–191

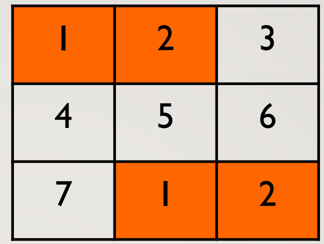


MULTIPLEXING PIXELS

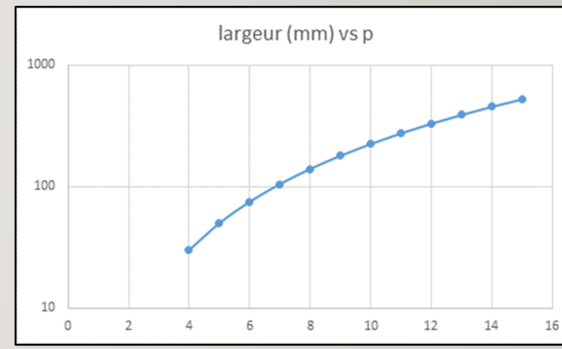
Number of channels (el.) and pixels (physical pads) :

Multiplexing in 2D = Neighboring pixels are direct neighbors *only one time*

ok



Not ok



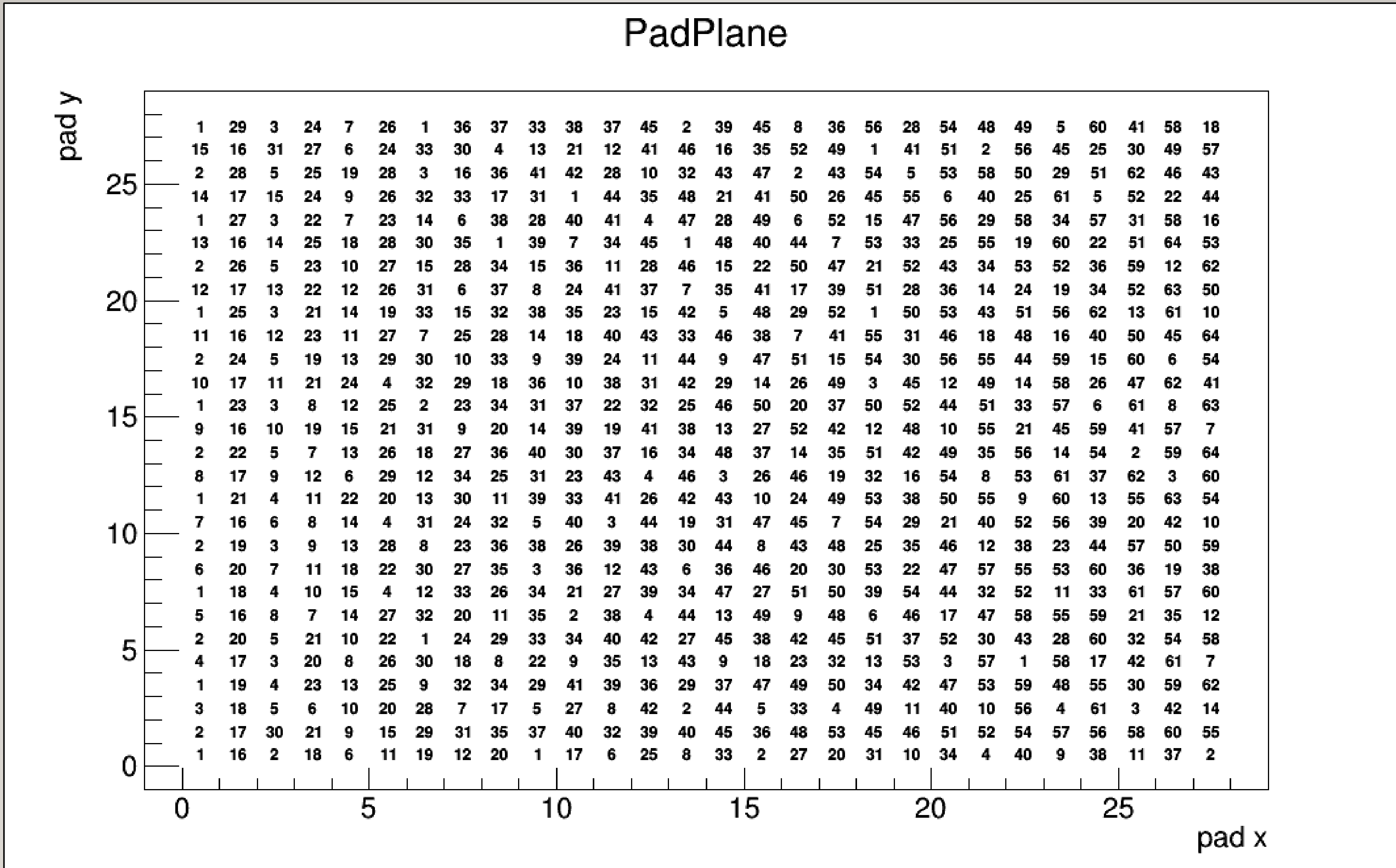
Npixels_max(q,p)=[q(q-1)/2+1] * [p(p-1)/2+1]
So 1 DREAM = 64ch = 8x8 => 29x29 pixels (841)

S. Procureur HDR, 2015

(^--- Actually not exactly true, only for square)

Q*P	NB OF EL. CHANNELS	MAX. PIXELS	SIZE (4mm pads)	SIZE (5mm pads)	SIZE (3mm pads)
8x8	64 ch. (1 ASIC)	29x29=841	11.6x11.6 cm^2	14.5x14.5 cm^2	8.7x8.7 cm^2
11x11	121 ch. (2 ASICs)	56x56=3136	22.4x22.4 cm^2	28x28 cm^2	16.8x16.8 cm^2
16x16	256 ch. (4 ASICs, 1/2FEU)	121x121= 14641	48.4x48.4 cm^2	60.5x60.5 cm^2	36.3x36.3 cm^2
22x22	484 ch. (8 ASICS, 1FEU)	232x232= 53824	92.8x92.8 cm^2	116x116 cm^2	69.6x69.6 cm^2

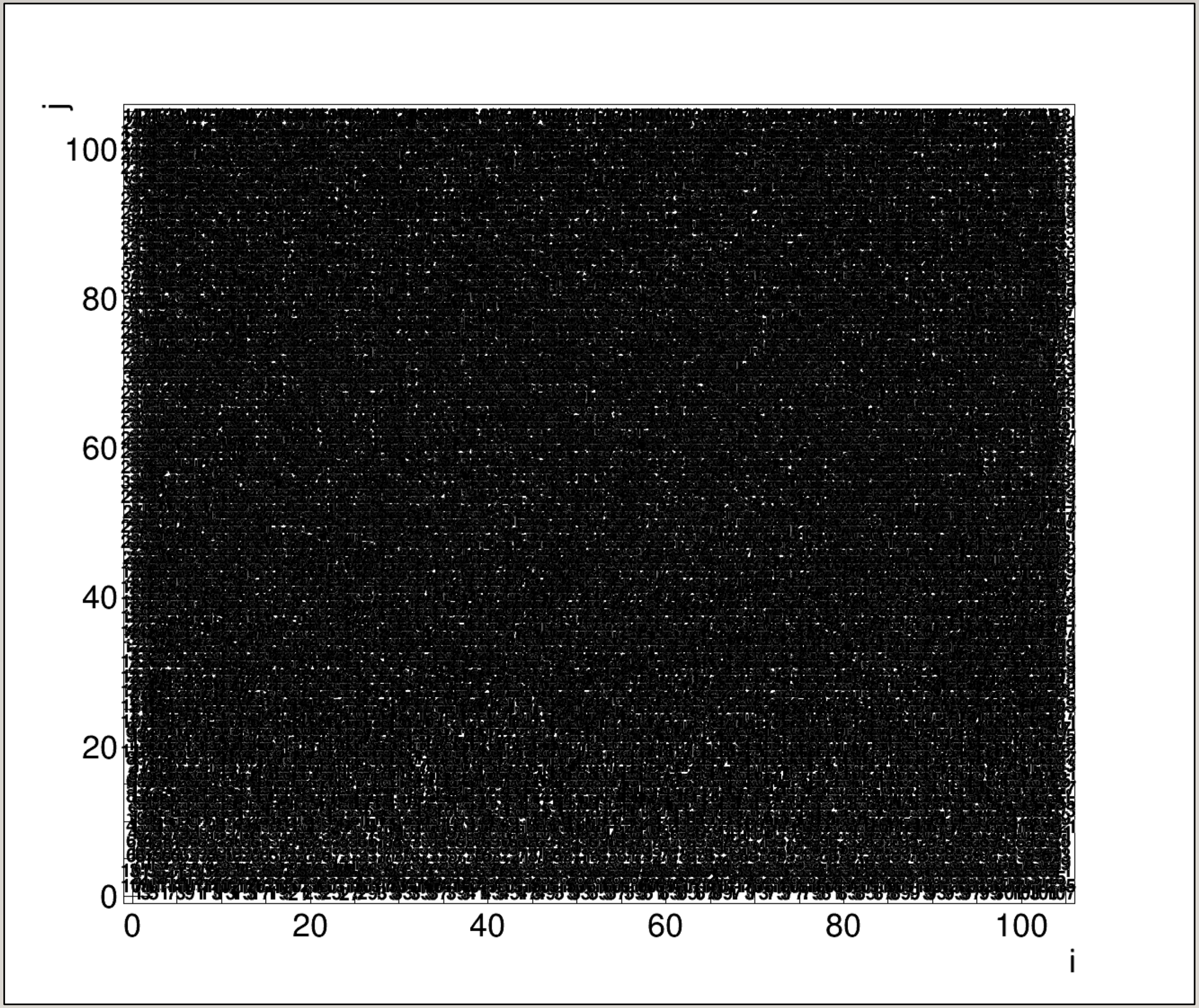
PADPLANE 8X8



8x8	64 el. channels	29x29 pixels	841 pixels

Nb. on pixel is the el. ch. Id.

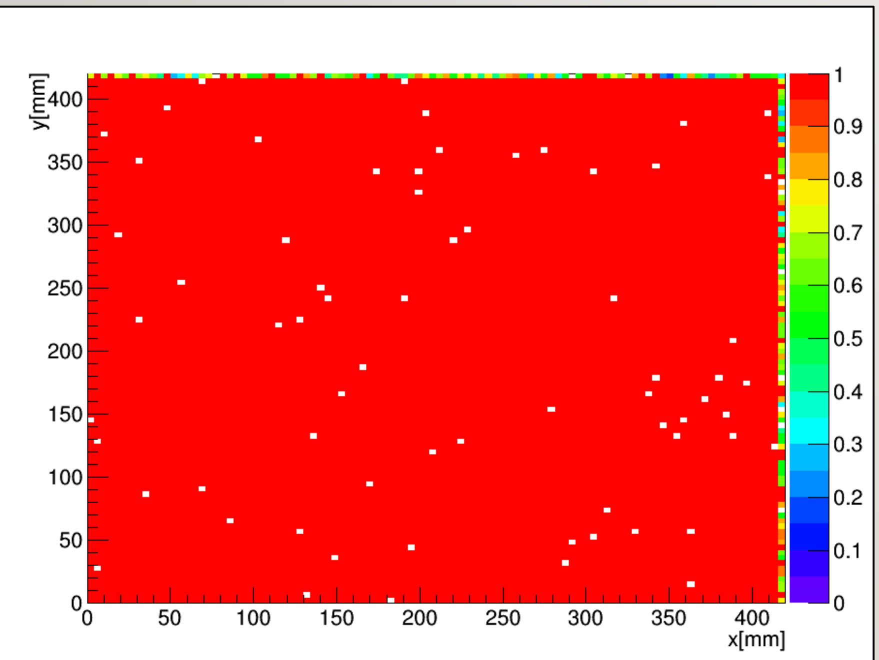
PADPLANE 15X15

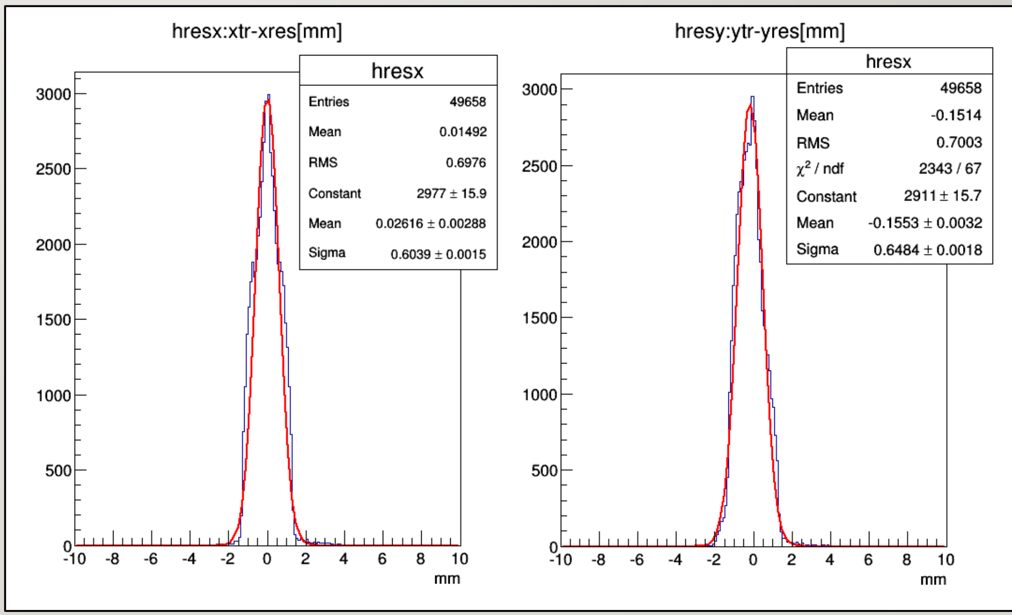


15x15	225 el. channels	106x106 pixels	11236 pixels

CHECK PADPLANE

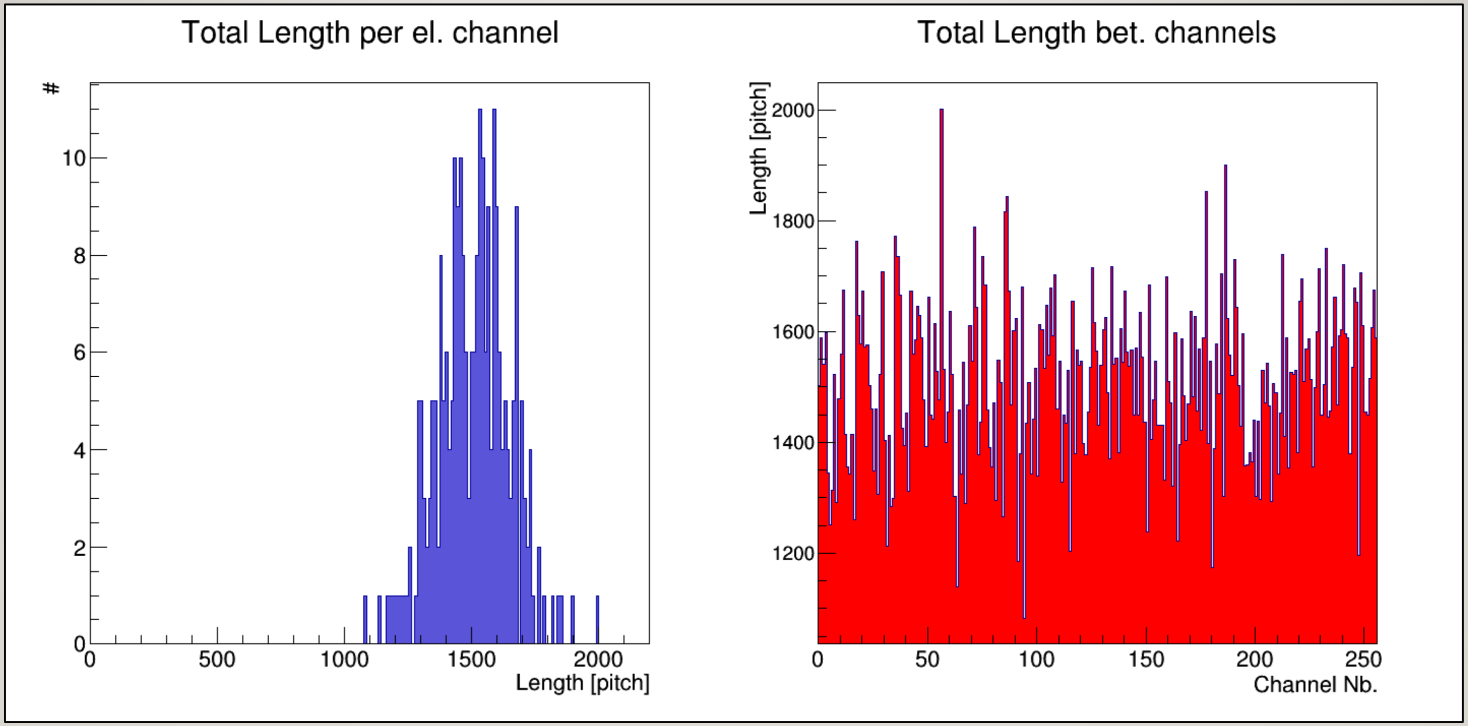
- First pass on all the full padplane to check for duplicates of channel pair
- Uses the detector as a 2D tracker to check is it possible to reconstruct position in a simple MC
- 15 x 15 padplane, 4mm sq. pixels, signal size = 4mm
- => 99.3% Efficiency, ~600µm resolution (no amplitude on pixels)



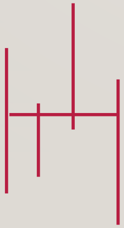


WIRE LENGTH

Length of wire connected to each el. Channel for a padplane of 120x120 pixels read by 256 channels. This corresponds to 56.25 multiplexing factor (nb. Pixels/nb of el. Ch.)



Length is calculated by the sum of the max. difference of position on each line



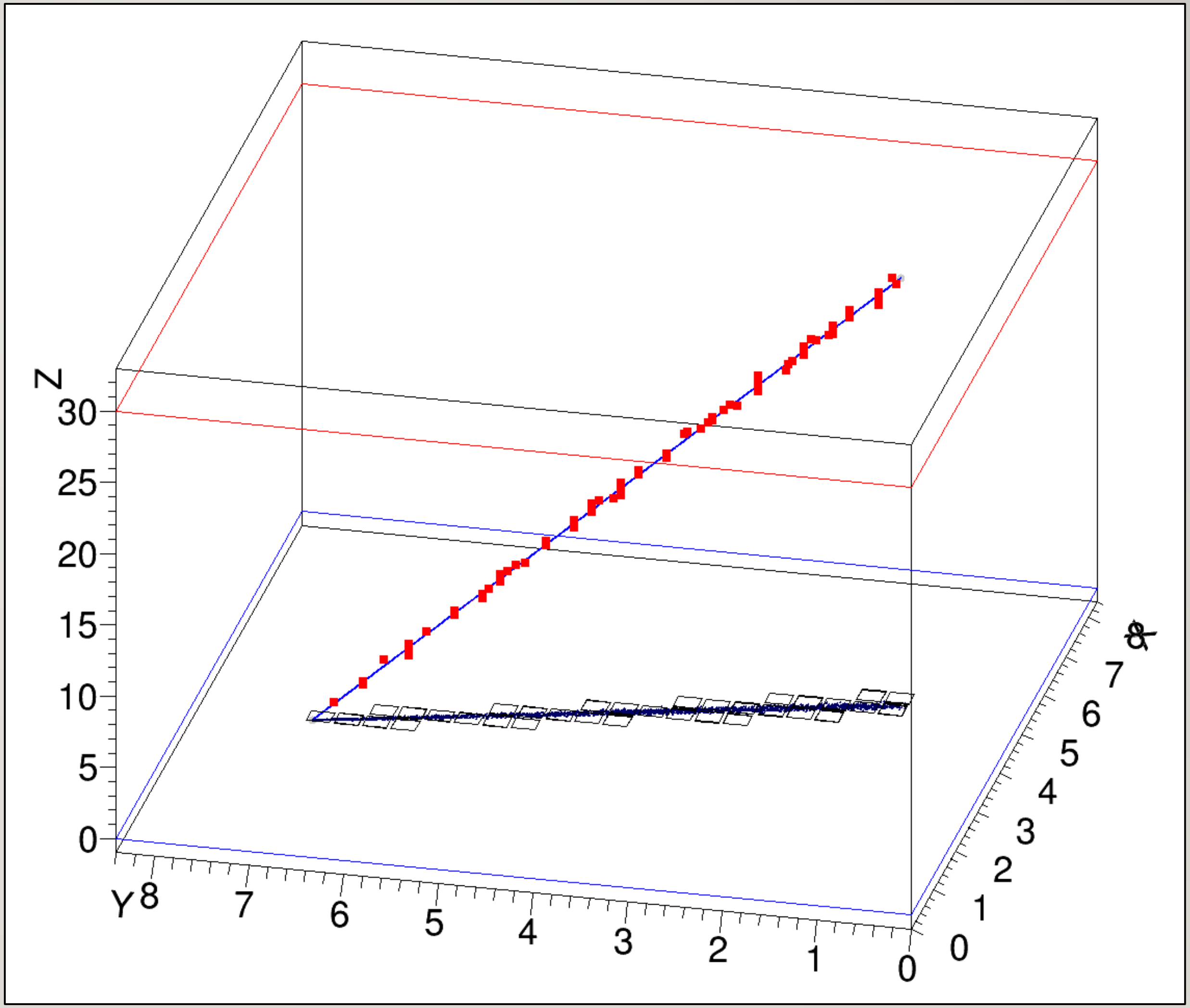
⇒ Avr. = 1507.6 => 6m with 4mm pitch (+routing…)

⇒ MultiGen MM are ~6m

⇒ This is manageable

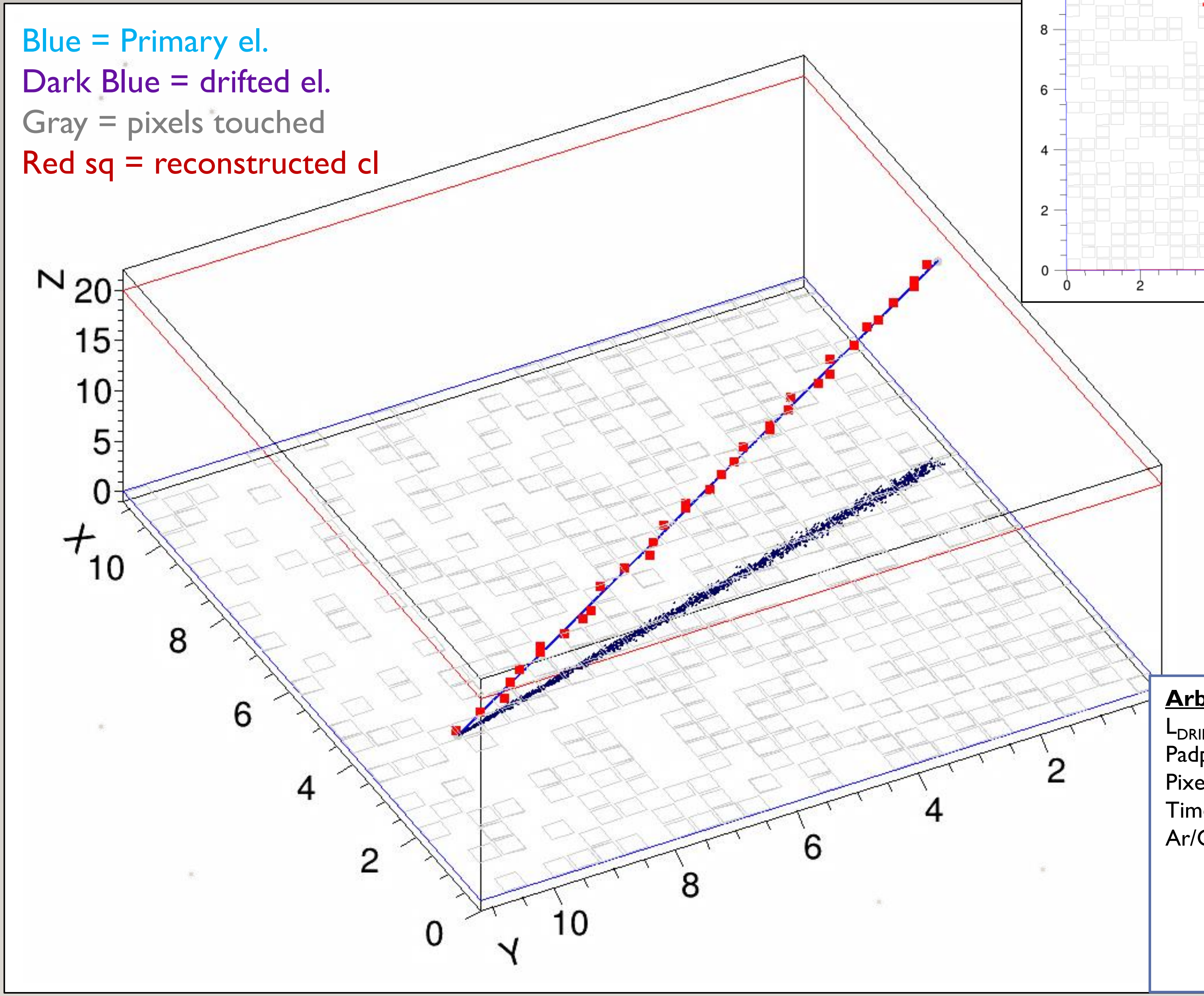
TPC SIMULATION

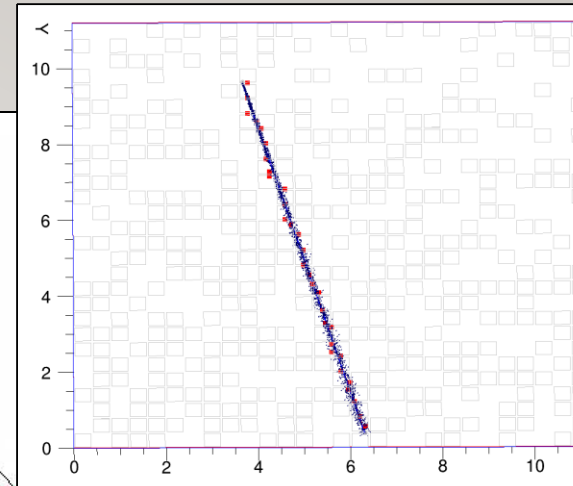
- MC STEPS
  - (A) generate tracks
  - (B) Ionization
  - (C) Drift to padplane
  - (D) Digitalization
  - (E) Reconstruction
  - (F) Track Fitting and Refit
  - (G) Histo filling



Arbitrary Nominal Parameters :
L_{DRIFT} = 20cm
Padplane = 8x8 (fast)
Pixel size = $4x4mm^2$
Time Bin size = 1µs
Ar/$C0_2$ 90/10 Mixture at 250V/cm:
-N_T=98 el./cm
-L. Diff. 0.157 sqrt(cm)
-T. Diff. 0.157 sqrt(cm)
-V_{DRIFT} 0.55cm/µs

ONE EVENT





Arbitrary Nominal Parameters

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Ar/CO_2 90/10 Mixture at 250V/cm:
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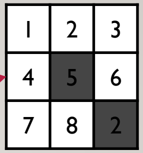
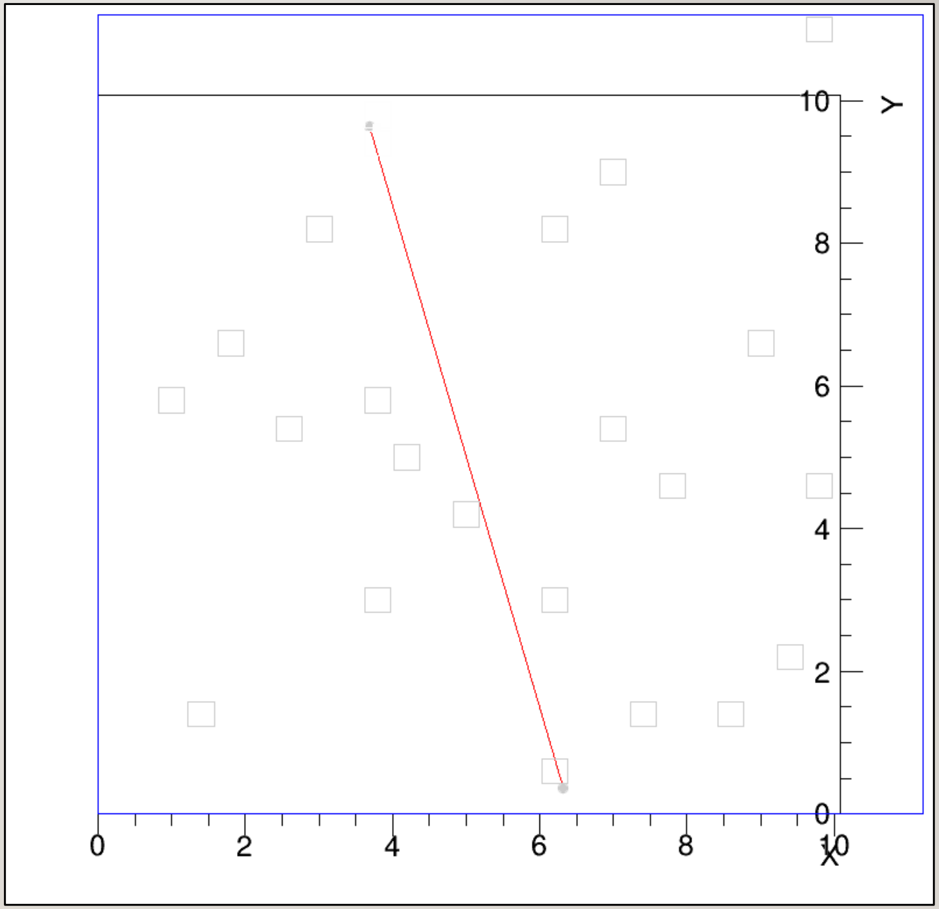
- T. Diff. 0.157 sqrt(cm)
- V_{DRIFT} 0.55cm/µs

CLUSTERING

- Clustering (from electronics channels to physical position) **is not trivial**
- Diagonal channels are badly reconstructed.
- Here we look at unique position from 2 channels, and add pads when they touched the cluster
- Division in Z per slices of 1 µs
- No amplitude
- This is probably not the best solution (Pattern recognition? Other than Z/time division ?)

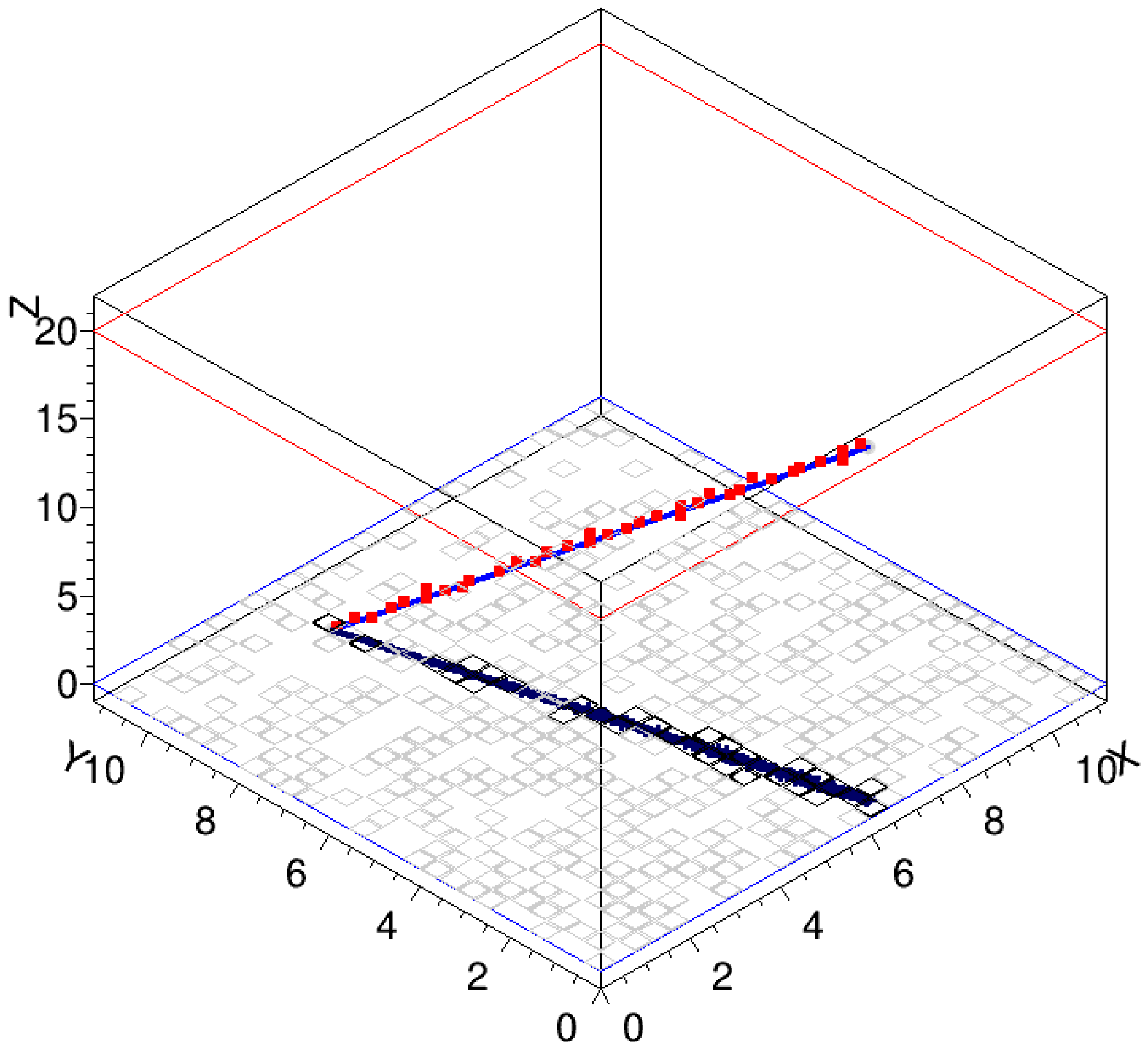




Red:fitted track
Gray o : entry/exit of particle
Gray Pixels : Active pixels
Colored Pixels : Used pixels
Sq. Marker : Cluster position

CLUSTERING (2)

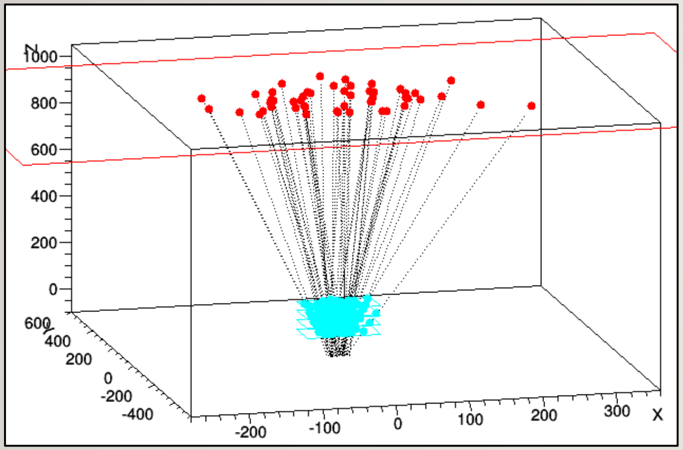
- Artificial time division creates bad events when too much channels are in one time bin (horizontal tracks):

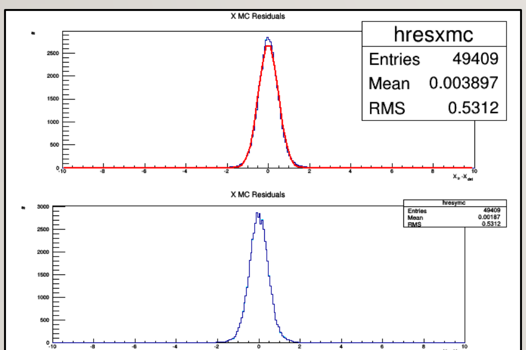


=> Limitation on track angle + refit to remove bg. clusters

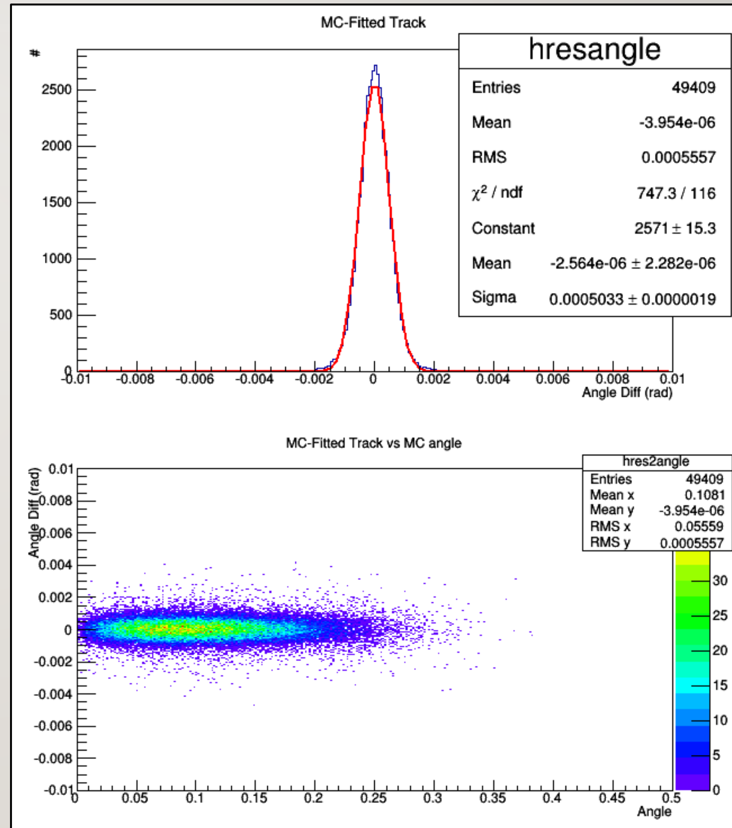
RESOLUTION OF A TELESCOPE

- Let's look at a muon telescope as a point of comparison (using a quick smearing MC):
  - « Watto » configuration with 400um resolution 90% efficiency, 4 detectors at 0 40 80 120cm
- Simulation reproduce watto's results





resolution projected at 10m =0.478cm

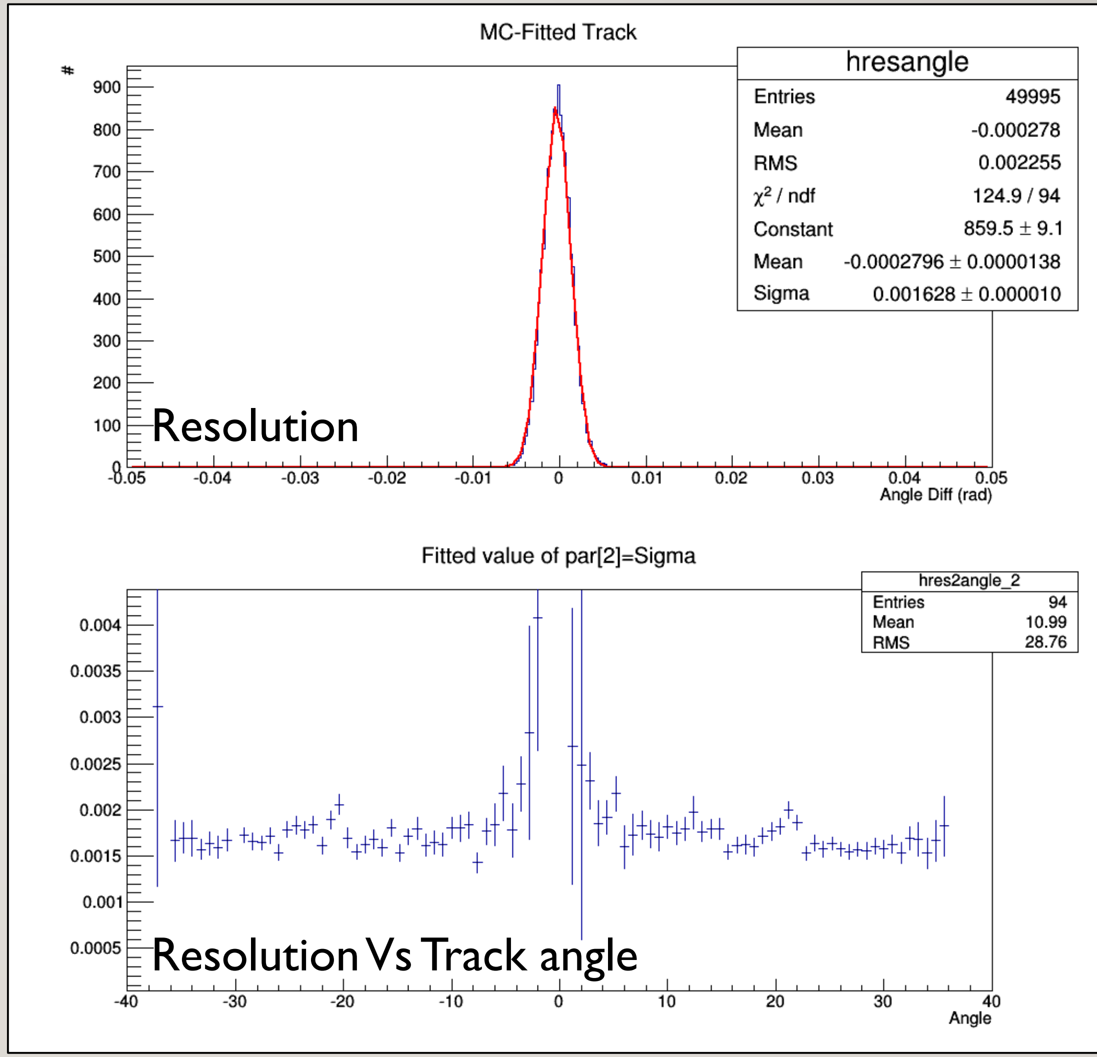


=> Angular resolution = 0.5mrad (goal)

TPC ANGULAR RESOLUTION

<u>Arbitrary Nominal Parameters :</u>

L_{DRIFT} = 20cm
Padplane = 8x8 (fast)
Pixel size = 4x4mm^2
Time Bin size = 1µs
Ar/$C0_2$ 90/10 Mixture at 250V/cm:
- N_T=98 el./cm
- L. Diff. 0.157 sqrt(cm)
- T. Diff. 0.157 sqrt(cm)
- V_{DRIFT} 0.55cm/µs



Nominal Resolution = 1.6mrad

TPC ANGULAR RESOLUTION

L_{DRIFT} (cm)	Ang. Res (mrad)
5	13.6
10	4.38
20	1.7
30	0.86
40	0.7

Diffusion sqrt(cm)	Ang. Res (mrad)
0.3	2.0
0.157	1.7
0.079	1.66
0.039	1.75

Gain Gas Electron	Ang. Res (mrad)
10	2.5
98	1.7
200	1.44

Multiplexing factor	Ang. Res (mrad)
3.1	1.5
4.1	1.5
6.1	1.6
12.3	1.7
12.9	1.5 (?)

Vdrift µs/cm	Ang. Res (mrad)
0.03	2.86
0.55	1.7
1.1	1.28

Time Bin µs	Ang. Res (mrad)
0.1	1.2
0.5	1.3
1.	1.7
1.5	2.3
3	7

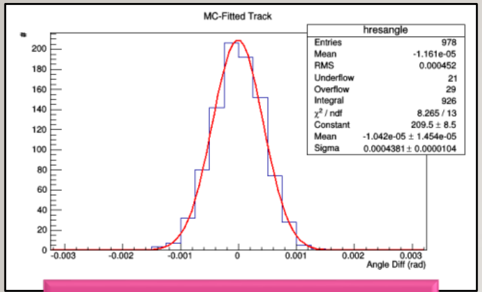
Pixel Size mm	Ang. Res (mrad)
2	0.9
3	1.2
4.	1.7
5	1.9
10	5.5

Padplane size (el ch)	mrad
8x8 (11.2cm)	1.7
11x11 (22cm)	1.66
15x15 (42cm)	1.59

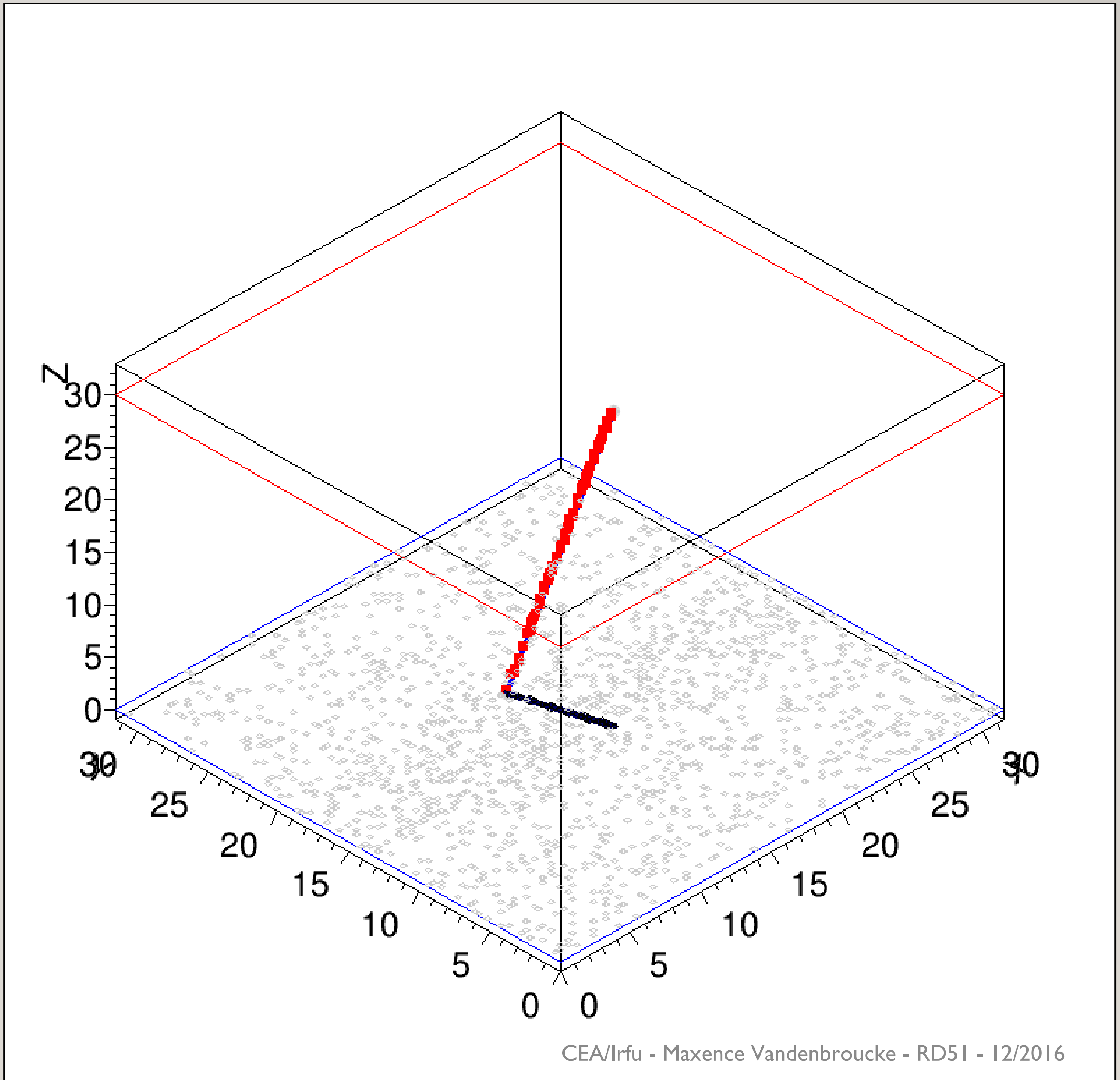
Blue: nominal parameters

=> TPC size, Pixels size and Drift length crucial.

OPTIMIZATION FOR SPATIAL RESOLUTION



Res. = 0.44 mrad !



"Optimized" Parameters :

L_{DRIFT} = 30cm

Padplane = 15x15

Pixel size = 3x3mm^2

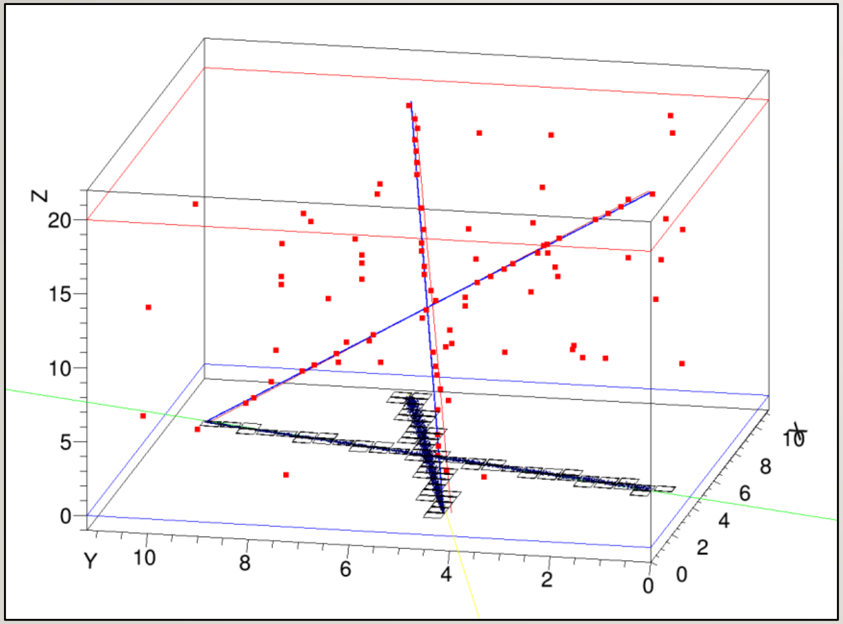
Time Bin size = 0.5µs

Ar/$C0_2$ 90/10 Mixture :

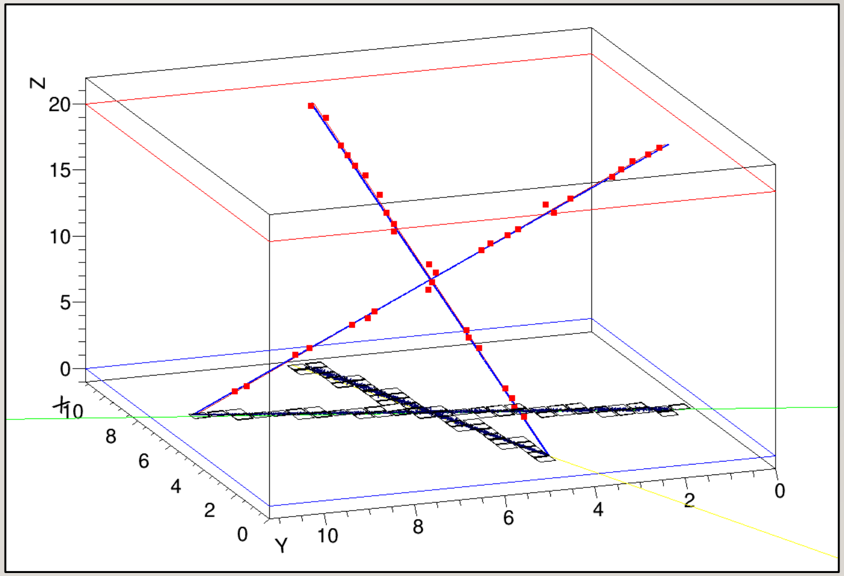
- N_T=98 el./cm
- L. Diff. 0.157/2 sqrt(cm)
- T. Diff. 0.157/2 sqrt(cm)
- V_{DRIFT} 0.55cm/µs

DOUBLE TRACKS?

- A device of this size will see a significant proportion of double track events with cosmic ray:
- this gives a lot of background (see reconstructed red cluster below)
- **=> Track fitting is not enough, it requires pattern recognition**
- With pattern recognition, double tracks are reconstructed well

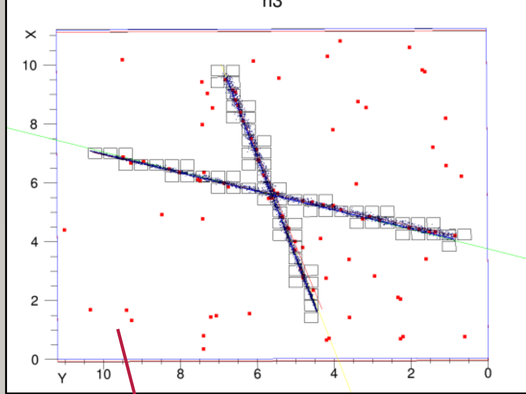


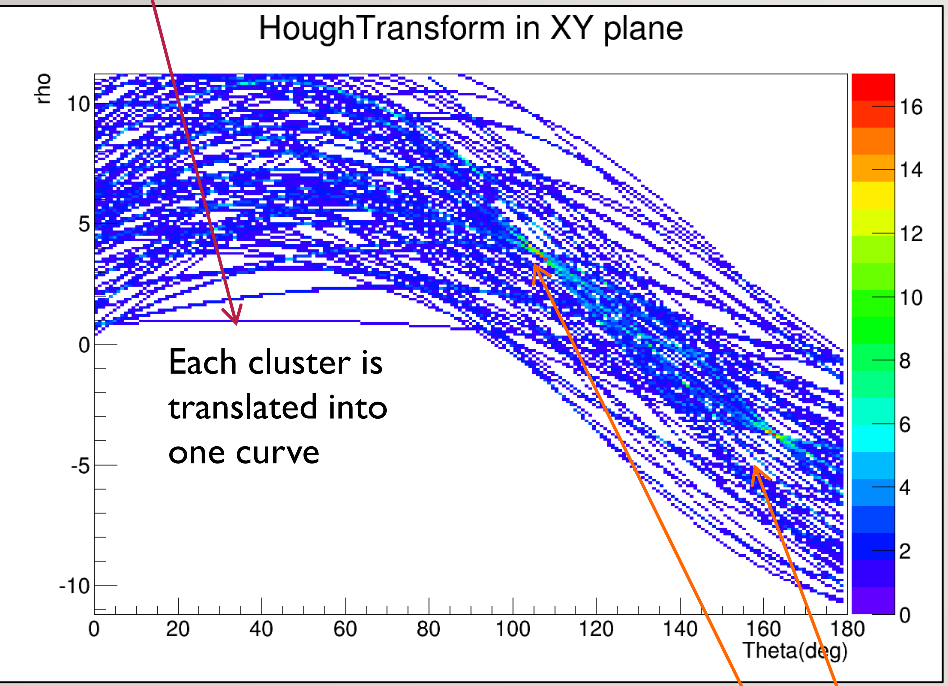
Double tracks in highly multiplexed TPC (13)

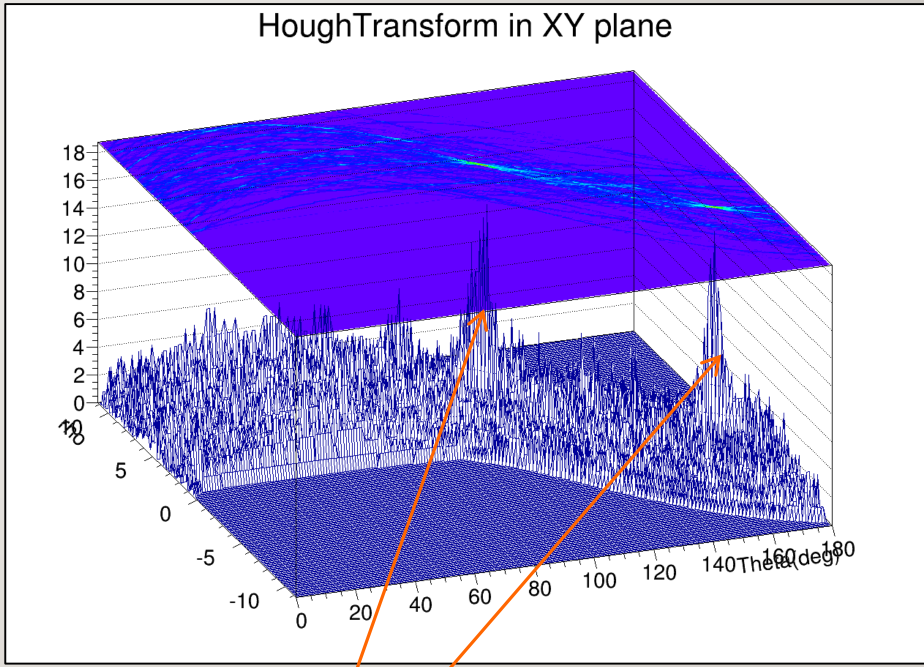


Double tracks in low mutiplexed TPC (4)

PAT. REC. : HOUGH TRANSFORM



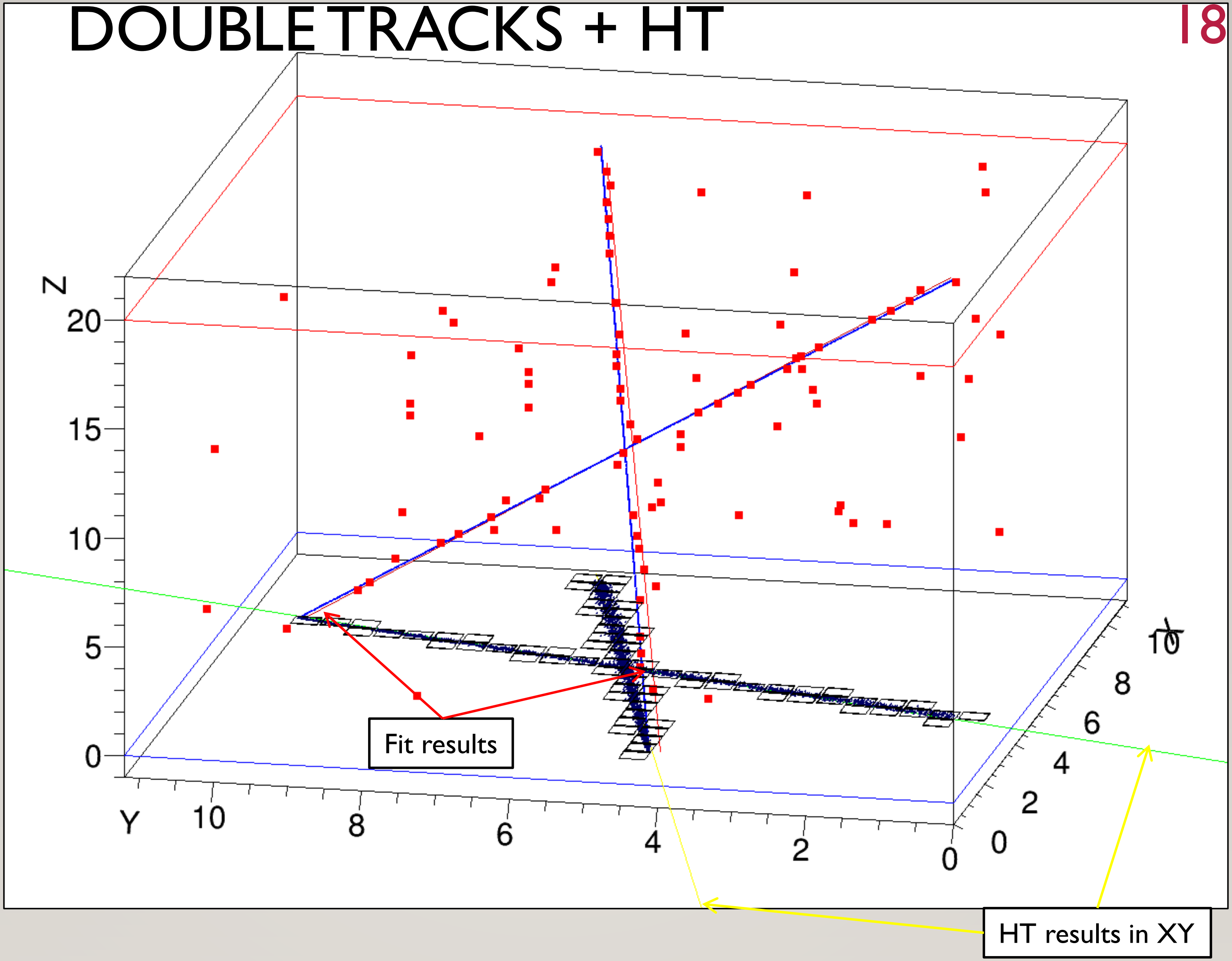




Local Maxima give track parameters in the XY plane

+ Cluster selection in the XY plane + fit = ok !

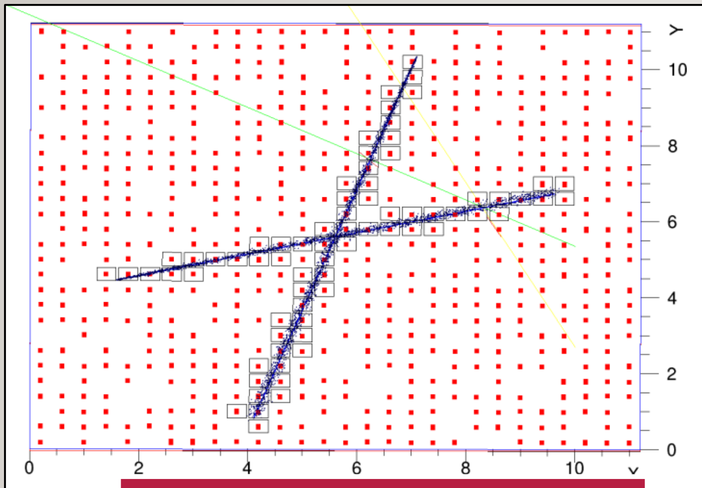
DOUBLE TRACKS + HT

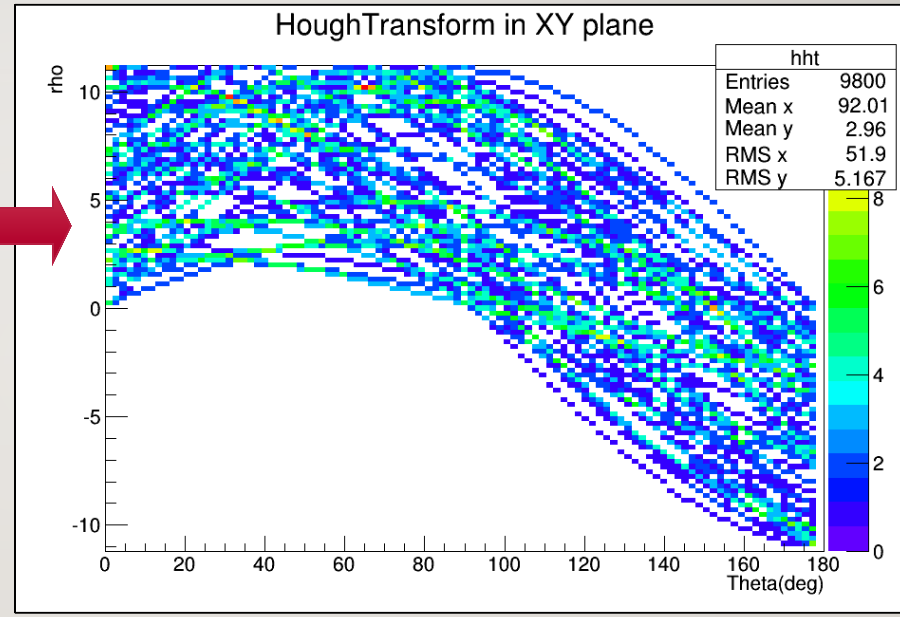


First test shows 5mrad resolution with double tracks events

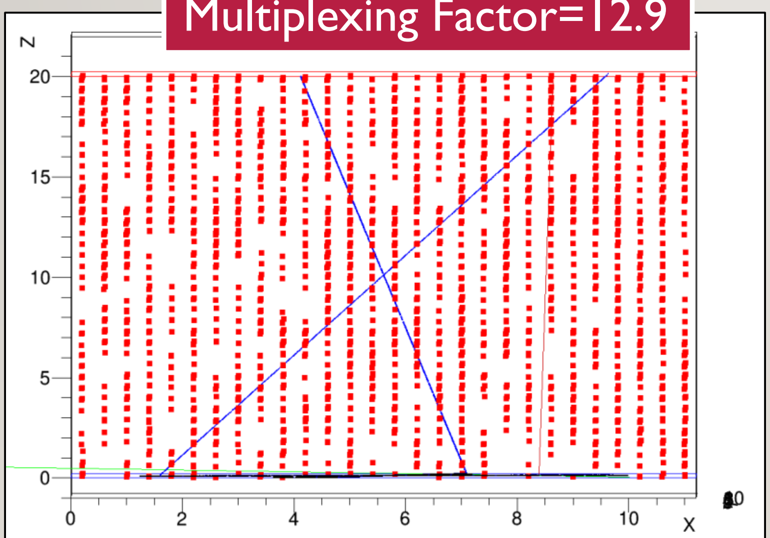
HT WITH NO CLUSTERING ?

- Could we avoid the computing expensive task of clustering by sending all possibilities directly to the pattern reco algo ?

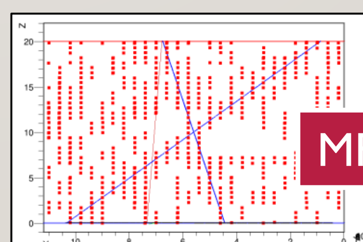




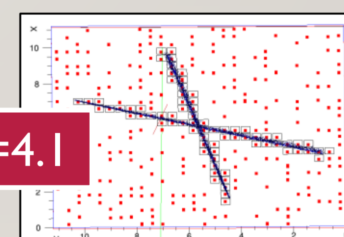
Multiplexing Factor=12.9



-> impossible with highly mutliplexed readout,
Difficult with low multiplexing
-> Clustering is definitely needed

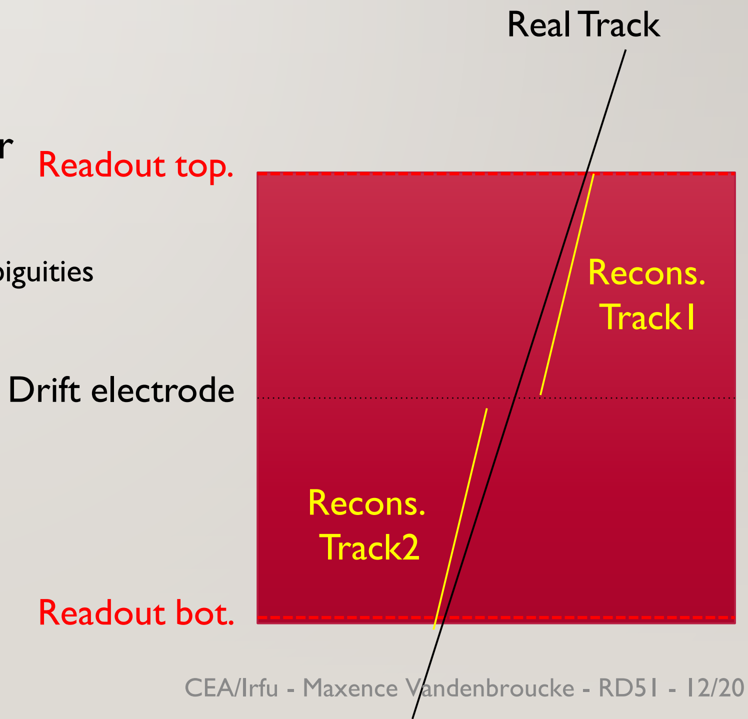


MF=4.1



CONCLUSION

- Simulations should that it is possible to operate a TPC using a "MultiGen" multiplexing approach however challenging
- Simulated performances better than telescope in term of resolution
- The construction of a prototype is considered at Saclay
- Routing will be difficult
- TPC should be mm metallic to avoid large cluster size
- My preferred option :
  - 2 readouts of 256 ch. (=1FEU) on top of each other
    - Correction for systematics errors
    - Possibility to rotate multiplexed pattern to avoid certain ambiguities
    - No HV in contact with outside world
    - Fix the Z of the tracks
  - 3mm pitch ($36x36cm^2$)
  - Drift for each readout of ~20cm
  - Ar/CO_2 : slow and easy gas
  - Drift field 250V/cm (=5kV for drift)

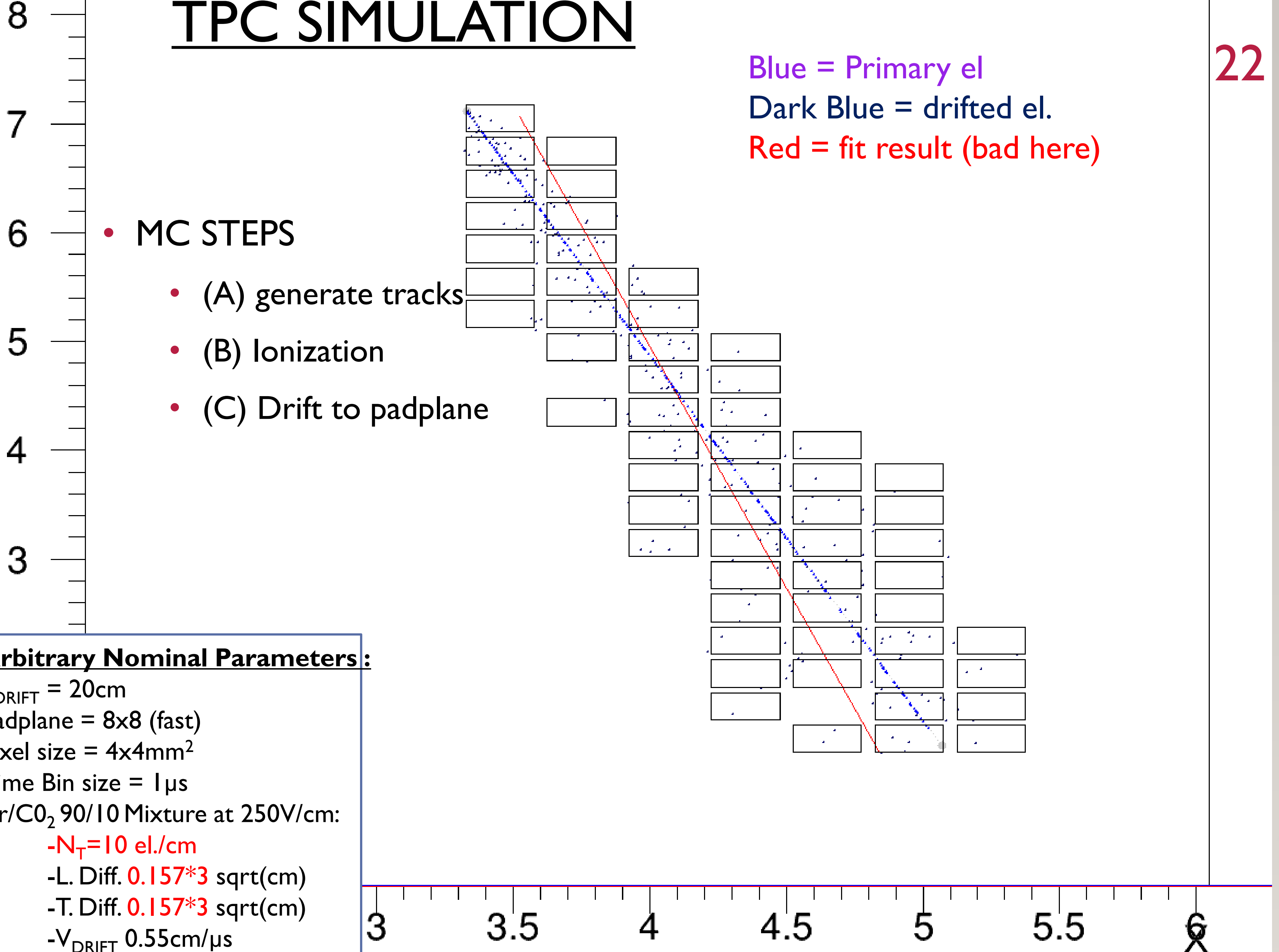


SPARE MATOS

TPC SIMULATION

Blue = Primary el
Dark Blue = drifted el.
Red = fit result (bad here)

- MC STEPS
  - (A) generate tracks
  - (B) Ionization
  - (C) Drift to padplane



Arbitrary Nominal Parameters :

L_{DRIFT} = 20cm
Padplane = 8x8 (fast)
Pixel size = 4x4mm^2
Time Bin size = 1µs
Ar/$C0_2$ 90/10 Mixture at 250V/cm:
- N_T=10 el./cm
- L. Diff. 0.157*3 sqrt(cm)
- T. Diff. 0.157*3 sqrt(cm)
- V_{DRIFT} 0.55cm/µs

MUTLIPLEXING FACTOR

Defined here as the number of pixels over the number of electronics channels:*

For a 28x28 pixels padplane :

Number of el. channels	Multiplexing factor	Avr. Length In pitch
256	3.1	21
192	4.1	28
128	6.1	41
64	12.3	81
61	12.9	82

*MultiGen 1024/61=16.8

ABOUT THE MAXIMUM PIXELS :

Maximum Channels per square :

Si on a un carré de 5 de coté, le nombre de voisins par place est :
2 3 3 3 2 (=13)
3 4 4 4 3 (=18)
3 4 4 4 3
3 4 4 4 3
2 3 3 3 2

soit 13*2 + 3*18 = 80

or chaque channel ne pouvant avoir que (maxchannel-1) au total (sinon plus unique les voisins), le nombre total de voisins max est maxchannel*(maxchannel-1)

Donc ici il faut que
maxchannel*(maxchannel-1)>74 => maxchannel = 10

Le nombre total de voisins d'un rectangle X*Y est
totalvoisin = 2*(2*2+(X-2)*3) //premier et dernier ligne
+ (Y-2)*(4*(X-2)+(2*3))
= 4XY-2X-2Y

Si X=Y totalvoisin=$4X^2$-4X
Si X=Y c'est un carré, le pire cas.

Si on prend totalvoisin=maxchannel(maxchannel-1) on obtient comme borne superieure (wolfram) :

maxchannel = 1/2*(sqrt(16X^2-16X+1)+1)
Ou
X = 1/2*(sqrt(a^2-a+1)+1)
a=maxchannel

pour 5*5 il faut 10 channels, on trouve par exemple :
06 09 07 05 08
04 00 08 02 04
05 01 03 07 01
06 02 00 06 08
01 09 05 03 09

//

Or ca veut dire que pour 4*5 -> 62 totalvoisin, 9 channel ok

on trouve :
07 04 05 02
03 00 07 01
02 06 08 00
08 01 04 02
03 05 06 07

Notons que c'est plus que $N_{max}(p_1,p_2)=(p_1(p_1-1)/2+1)*(p_2(p_2-1)/2+1)$
$N_{max}(3,3)=4*4$