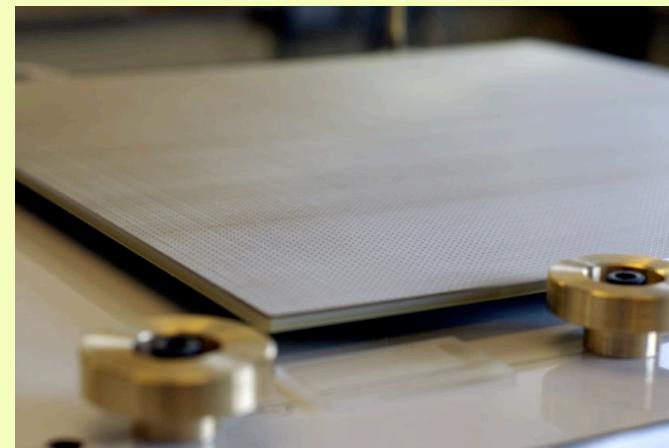
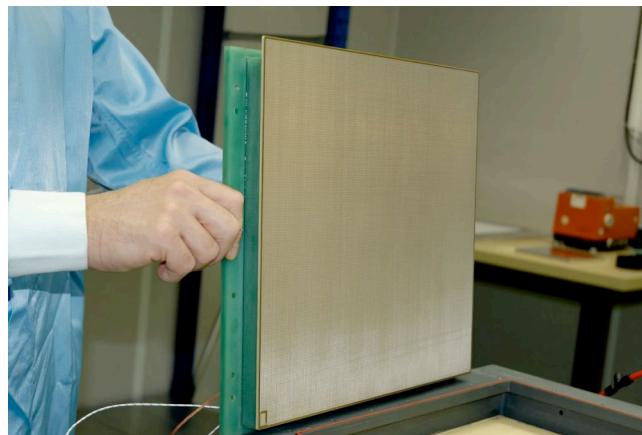
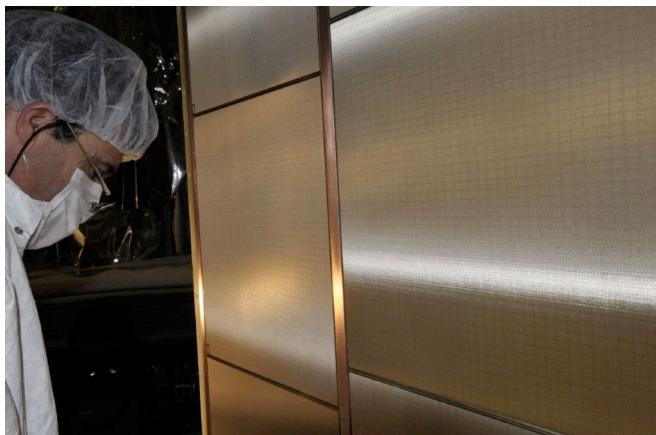


# T2K/TPC : a real example of large area production of MPGDs

« bulk » Micromegas



**A. Delbart**  
*CEA/DSM-IRFU,  
CE-Saclay, 91191 Gif-Yvette, France*





i r f u

cea

saclay

# Outline

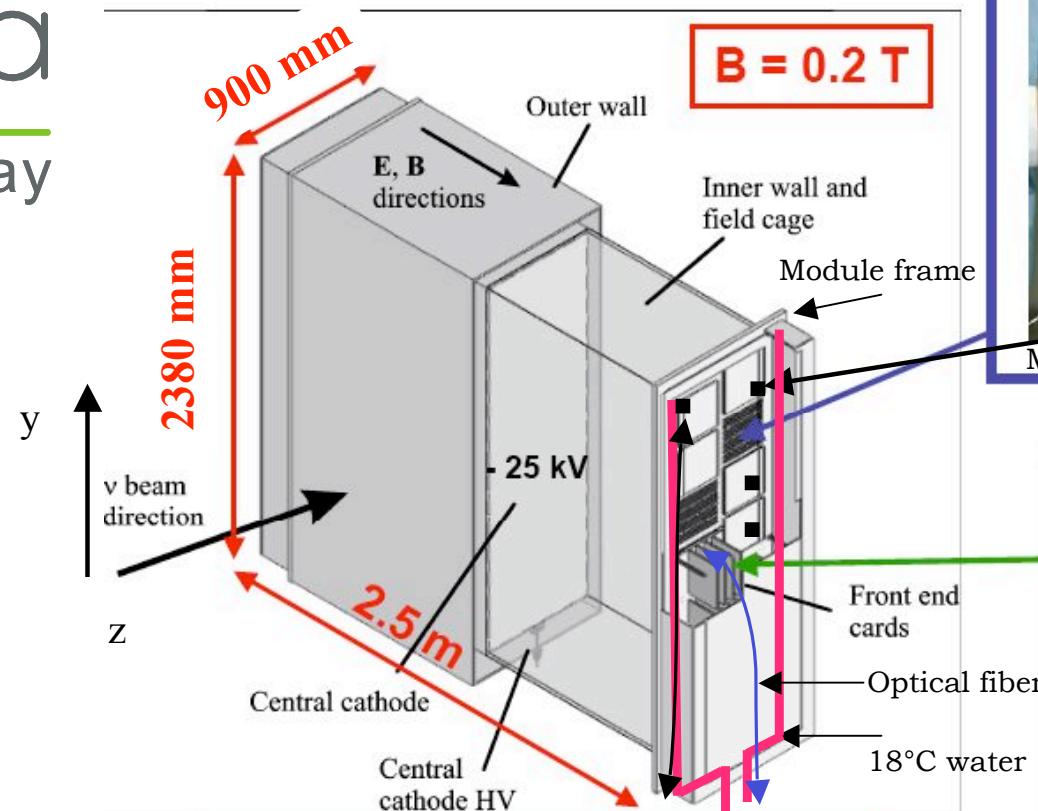
- The T2K/TPC
- The T2K/TPC bulk-micromegas readout modules
- Production of the bulk-micromegas modules
- Calibration results of 49 modules on  $^{55}\text{Fe}$  X-ray source test bench
- Ressources : Timescale & ressources (manpower & budget)
- Conclusion



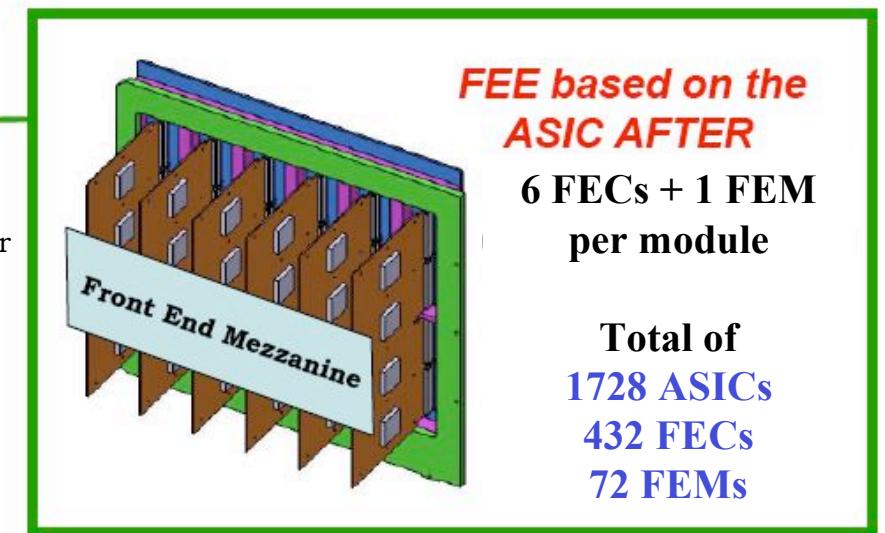
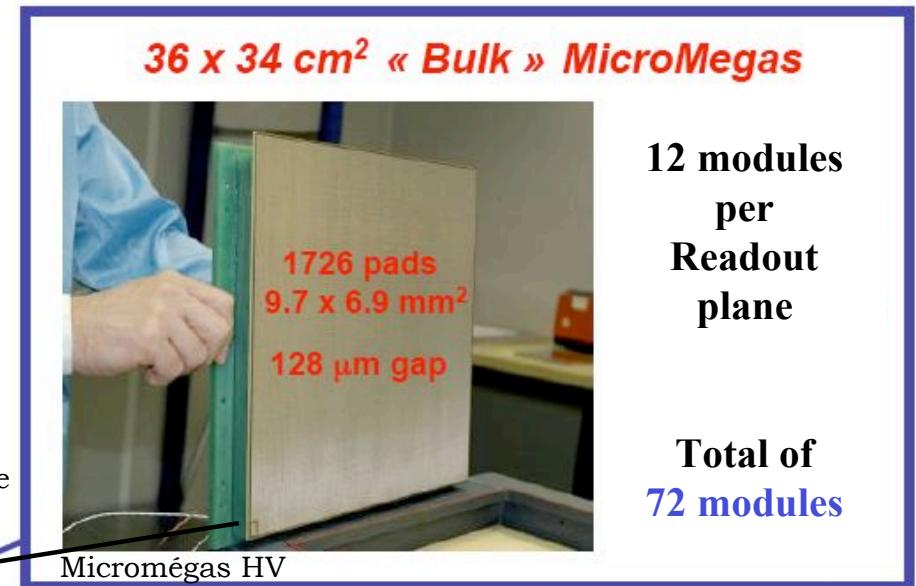
i r f u

ceci  
saclay

# The T2K/TPCs : the largest TPCs equipped with MPGDs



72 modules for  $\sim 9 \text{ m}^2$  active area  
 $\sim 120\text{k}$  electronic channels



With On-detector FEE cooling mechanicals



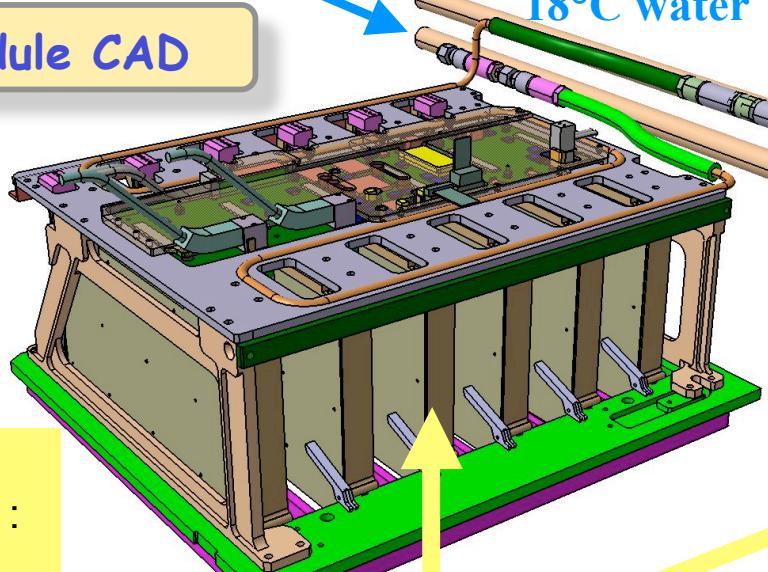
irfu

cea

saclay

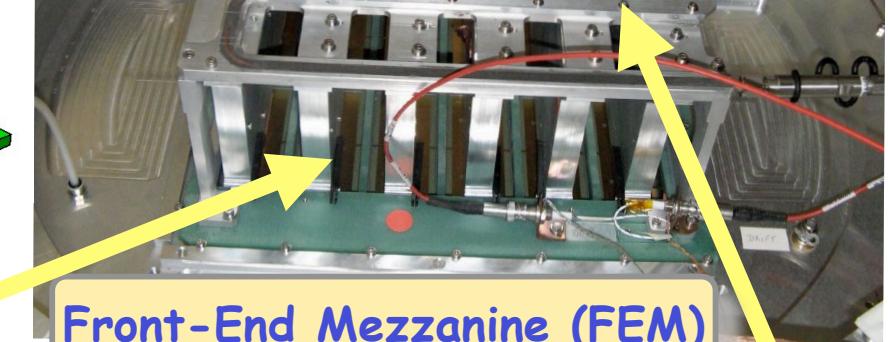
# Front-End Electronics of a micromegas module

Module CAD



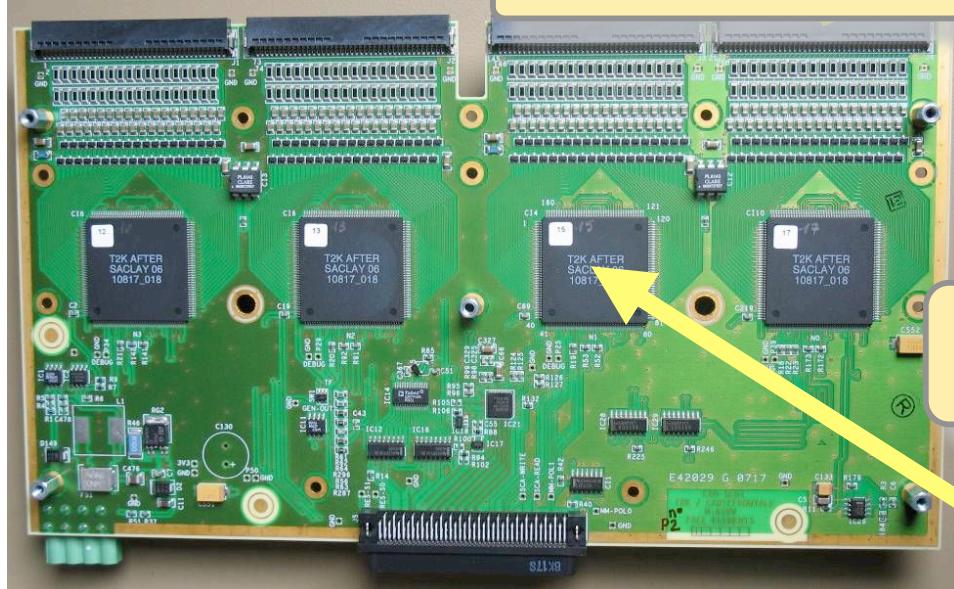
Total Cost of FEE  
(ASIC+FEC+FEM) :  
~3 € / ch.

Module tested on HARP cage (2007)



288 ch. with 4x72 ch. AFTER ASICs

AFTER  
ASIC



Front-End Card (FEC)



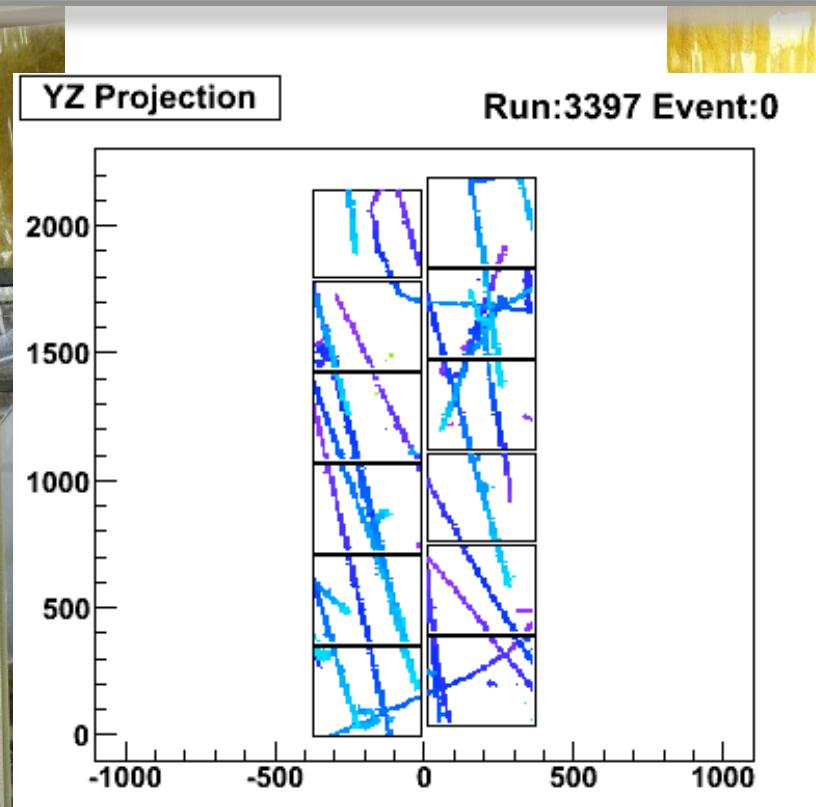
- 72 channels x 511 analog memory cells –  $F_s$ : 1-50 MHz
- Supports both input signal polarities with 4 Gain ranges
- Programmable peaking time (100 ns-2μs 16 values)
- M.I.P: 12-60 fC, with M.I.P. / noise: 100
- CMOS 0.35 μm Technology
- Also chosen to read the T2K/ND280 FGDs



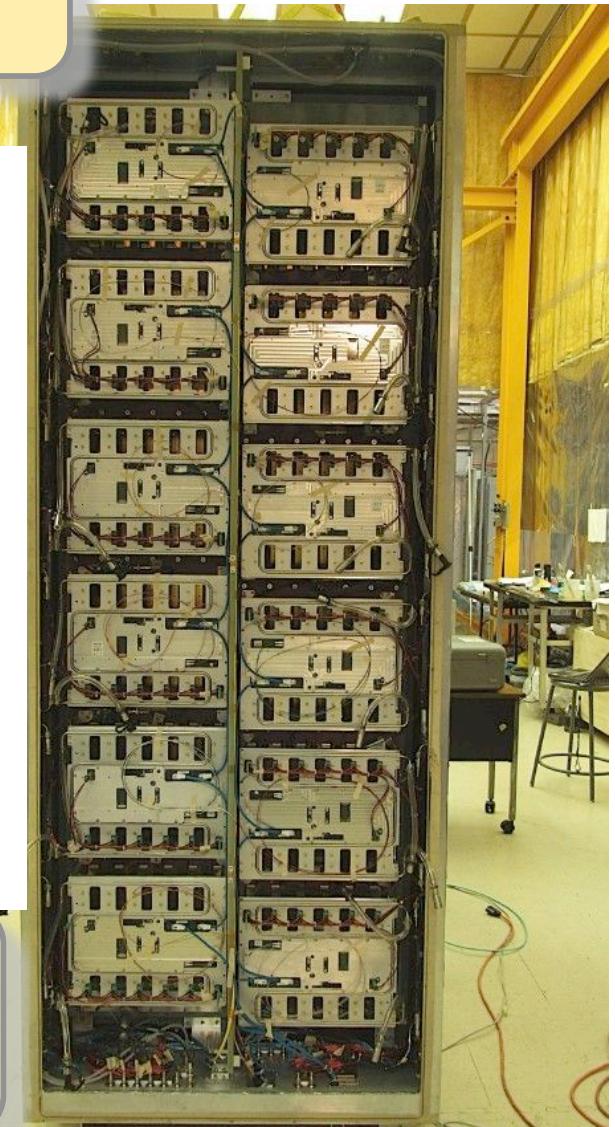
irfu

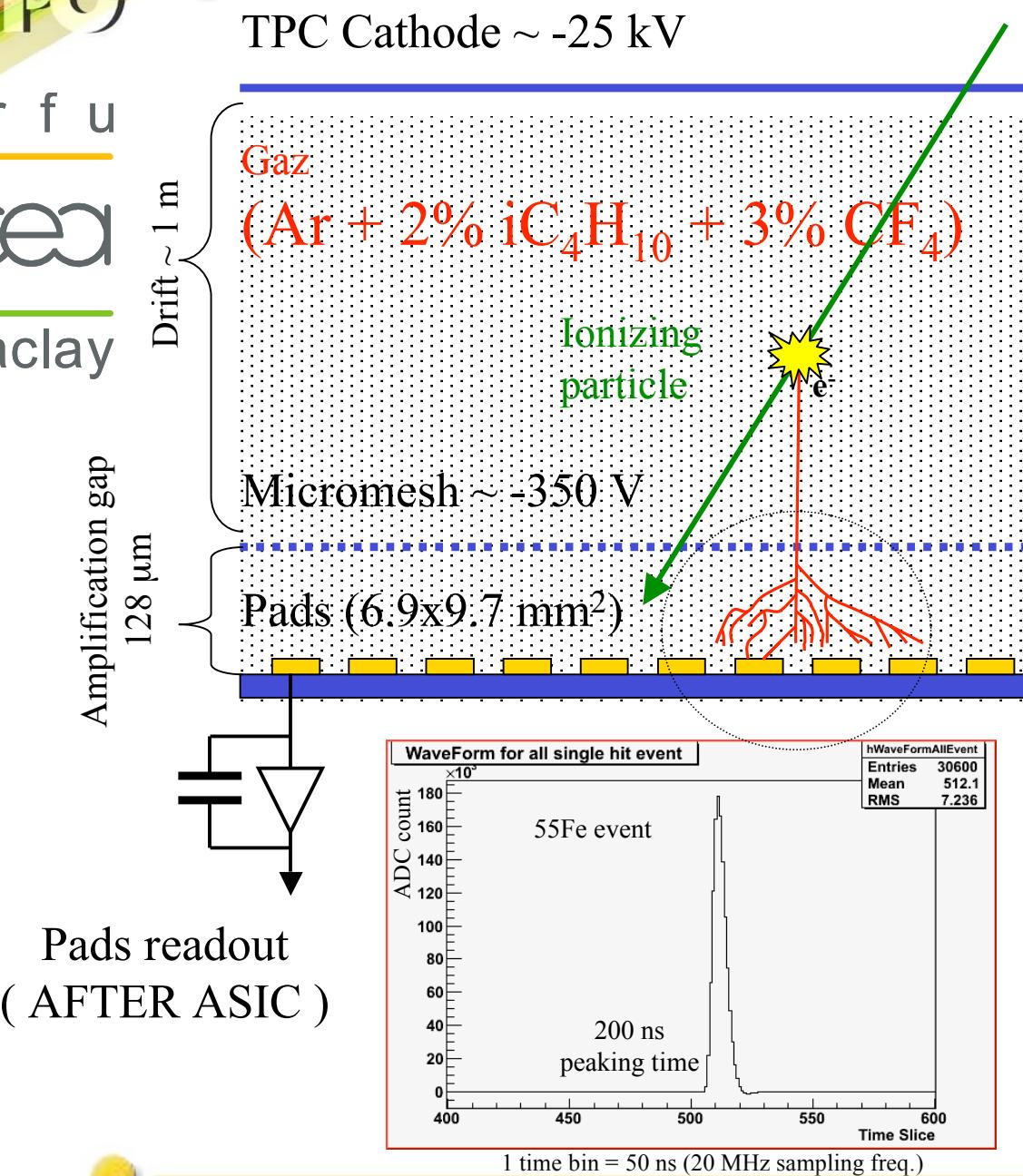
# The first fully equipped TPC @ Triumf

24 bulk-micromegas + FEE + mechanicals  
3 m<sup>2</sup> of bulk micromegas  
41472 FEE channels



Reconstructed cosmics  
by a a readout plane  
(beam tests @ TRIUMF on-going)





## a new gas mixture

- ✓ Non-flammable
- ✓ low tr. Dif. for small B ( $250 \mu\text{m}/\text{cm}^{1/2}$ )
- ✓ operation close to the maximum drift velocity ( $7.5 \text{ cm}/\mu\text{s}$  @  $200 \text{ V}/\text{cm}$ )
- ✓ minimization of the effect of impurities (mainly  $\text{O}_2$ ) :  $> 30\text{m}$  att. Length

## Drawbacks of micromegas technologies with separate mesh & anode PCB :

- "large" dead zones around active area + delicate assembly due to the mesh frame
- gap irregularities in corners

## Use of bulk-micromegas technology

- ✓ all-in-one detector : minimized blind areas, including edges and corners
- ✓ simple design, cheap & robust
- ✓ good uniformity of performances
- ✓ Production by CERN/TS-DEM-PMT

2005 HARP tests : NIM A574 (2007) 425-432

2007 HARP tests : NIM A602 (2009) 415-420



irfu

cea

saclay

# Key features of T2K/TPC « bulk » Micromegas

MICROMEGAS MODULE DIMENSIONS	342,3 x 359,1 mm <sup>2</sup>
Number of pads (per module)	1726
Pad dimensions	6.85 x 9.65 mm <sup>2</sup>
Mesh material	Stainless Steel 304L
Mesh pitch and thickness	63 µm / ~30 µm (after 20% lamination)
Insulating material	Pyralux PC 1025 (DuPont)
Gap	128 µm
Signal typical duration (AFTER, t <sub>peak</sub> =200 ns)	~600 ns
Pillars diameter (mask/real)	400 µm /500 µm x 12
Pad (thickness)	CU with Ni/Au coating (~30 µm )
Interpad (mask/real)	150 µm / 180 µm
PCB	Halogene free FR4
PCB thickness	2.2 mm (+/-0,1 mm)
PCB internal layers	2 (one routing, one shielding layer)
Operating Gain	1000 at -345 V
Maximum Voltage	~ - 460 V
“Natural” Sparking rate (cosmics in 4cm drift)	0.1/hour at gain=1000
Typical S/N with AFTER FEE @ 1000 gain	~300 (5.9kEV X-ray), >100 (MIP)
Energy resolution (55Fe 5.9 keV)	21% FWHM (9 % r.m.s)
Typical Gain non uniformity over 1726 pads	~2,7 % r.m.s
Spatial resolution (Ar+2%Isobutane+3%CF <sub>4</sub> )	~600 µm at 1m drift length



i r f u

ceci

saclay

# Production of the bulk-micromegas modules



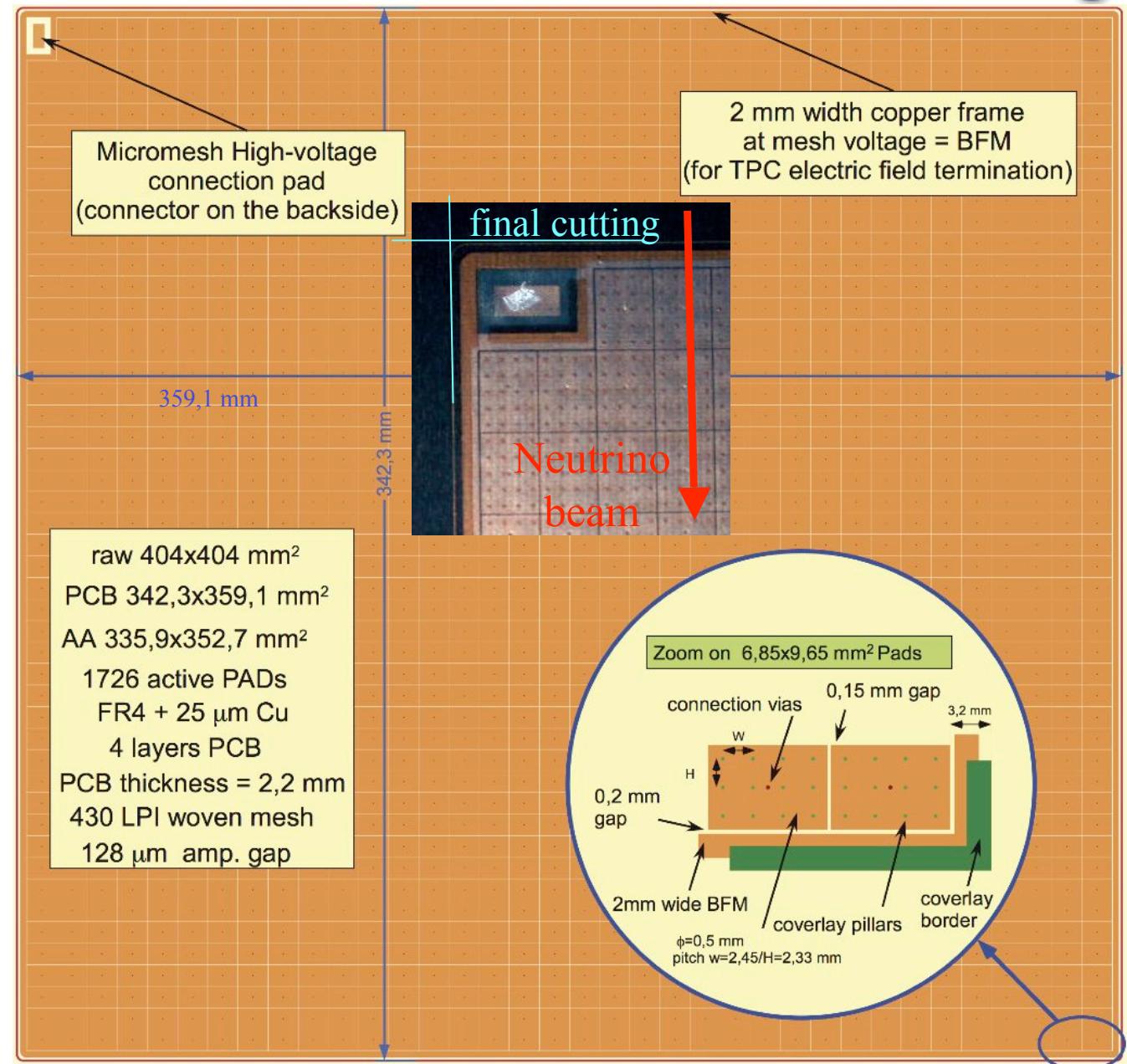
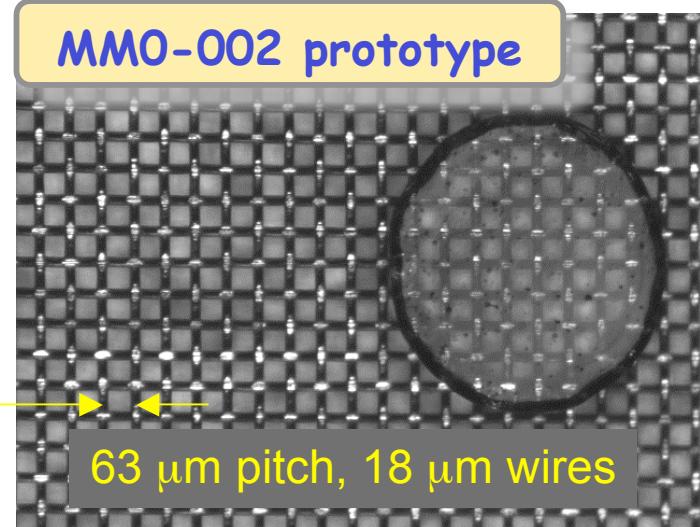


i r f u

cea

saclay

# The T2K/TPC bulk-micromegas anode plane





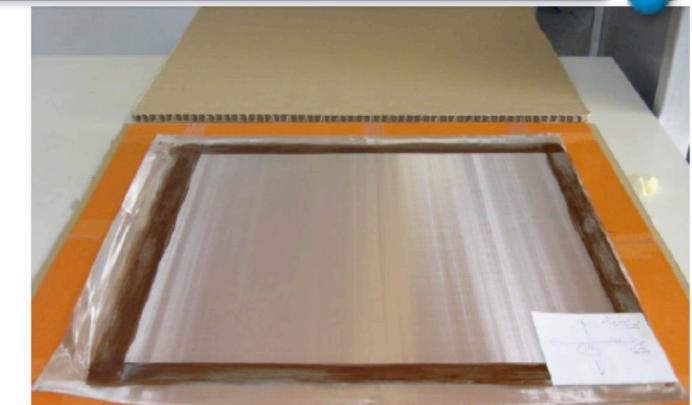
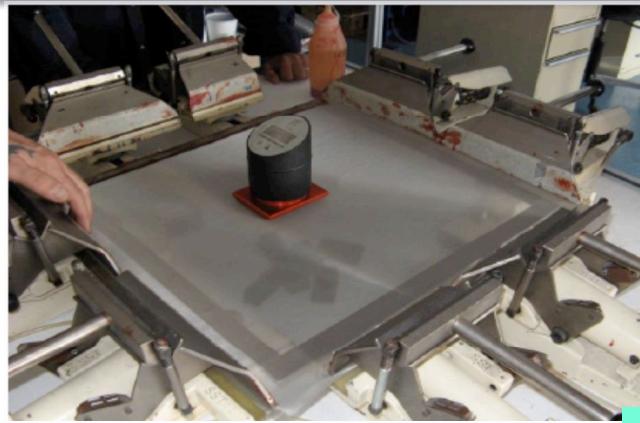
i r f u

cea

saclay

# The bulk-micromegas production process

- ✓ 12 N tension
- ✓ Sub-contractor
- ✓ 10/month



Réf : R. De Oliveira (CERN/EST-DEM-PMT)

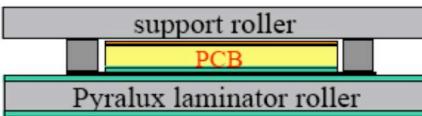
PCB Q/C

## Visual inspection

1/ Mesh is stretched on an external frame



2/ and laminated with the PCB



(1) Base Material



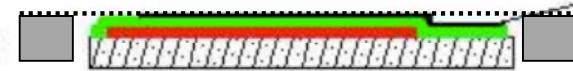
Copper + Ni/Au  
segmented  
anode  
FR4 PCB

(2) Lamination of Vacrel



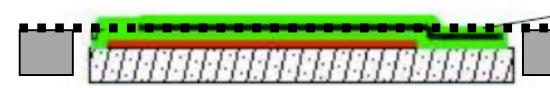
Amp. Gap Photo-  
imageable polyimide film  
(2x64  $\mu\text{m}$ )

(3) Positioning of Mesh



Stainless steel  
Woven mesh  
 $\sim 30 \mu\text{m}$  thick

(4) Encapsulation of  
Mesh



Top Photo-imageable  
polyimide film (2x64  $\mu\text{m}$ )

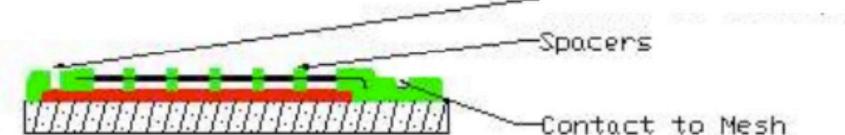
(5) UV exposure



Border frame

If  $I > I_{Q/C}$

(6) Development of  
Contacts and Spacers



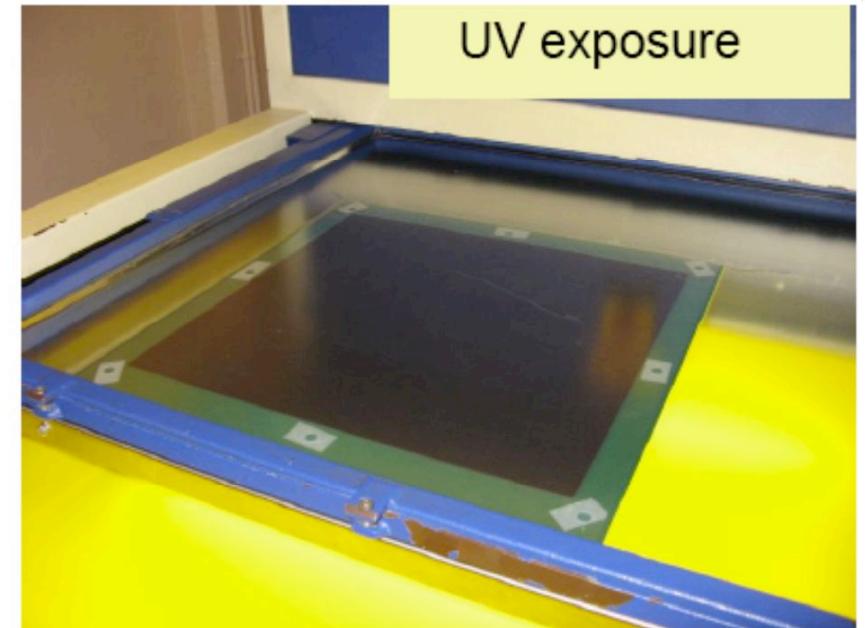
Spacers  
Contact to Mesh

Global current Q/C on « Fakir » test bench

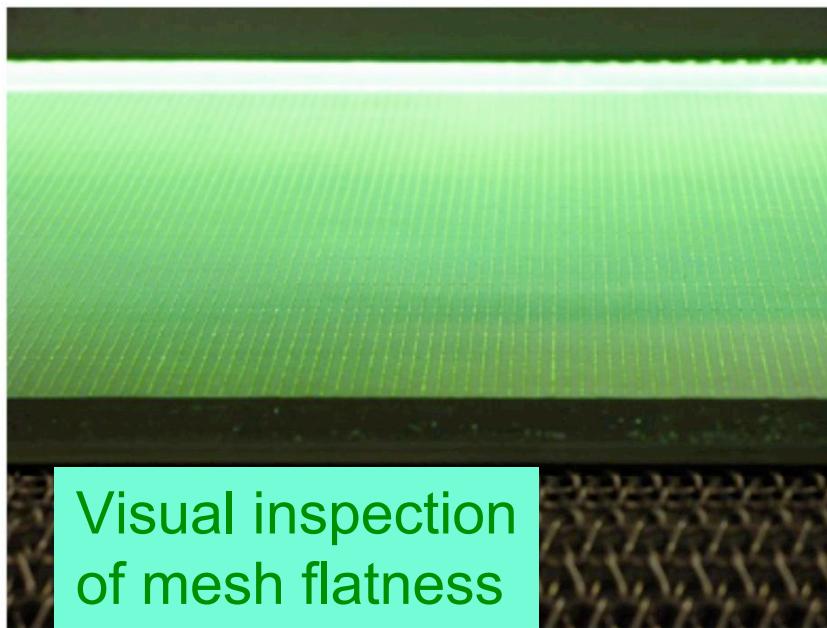
# Some pictures of mesh integration @ CERN/TS-DEM-PMT



lamination

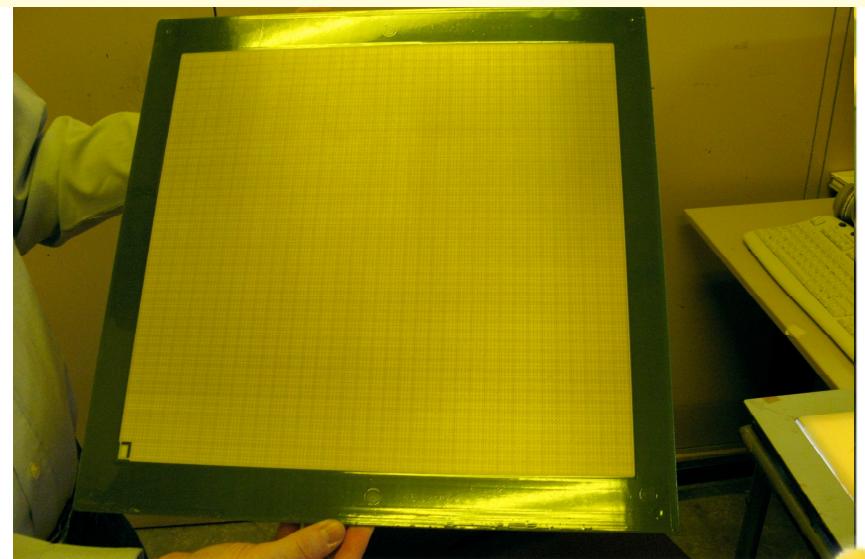


UV exposure



Visual inspection  
of mesh flatness

T2K/TPC bulk micromegas before cutting





i r f u

cea

saclay

# Mesh integration Quality controls

✓ Woven micromesh controls :

- Mesh is controlled for visual defects before and after stretching, and prior to be integrated onto the PCB

✓ Mesh integration Quality Controls :

- Electrical continuity of the HV connection
- Insulations of mesh-ground, mesh-BFM
- Visual inspection of the quality of the pyralux development

✓ Mesh-pads insulation Q/C : **the Global current Quality Control**

- All pads & BFM grounded with the « fakir » test bench
- $V_{mesh} = -600V$  is applied to the micromesh
- Global current  $I_G$  is measured with a 1 nA resolution
- Test is passed if  $I_G < I_{Q/C}$  5 nA, if not, pad per pad Q/C is done

✓ Pad-mesh insulation Q/C : **the pad per pad current Q/C**

- A pad is grounded with the « fakir » test bench and the current  $I_{pad}$  with  $V_{mesh} = -600V$  is measured for every pad (mapping)
- The number of pads for which  $I_{pad} > 10$  nA must be less than 2

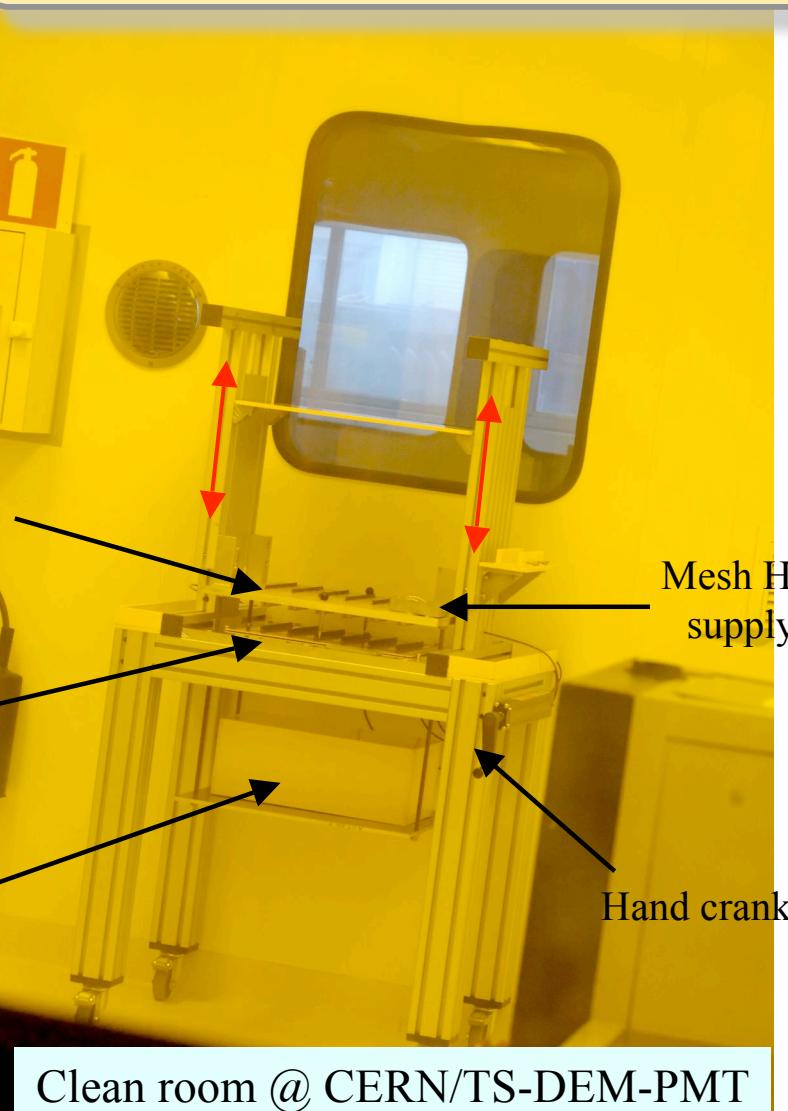
« fakir »  
Plate with  
Spring probes

Bulk MM

200 kg  
load

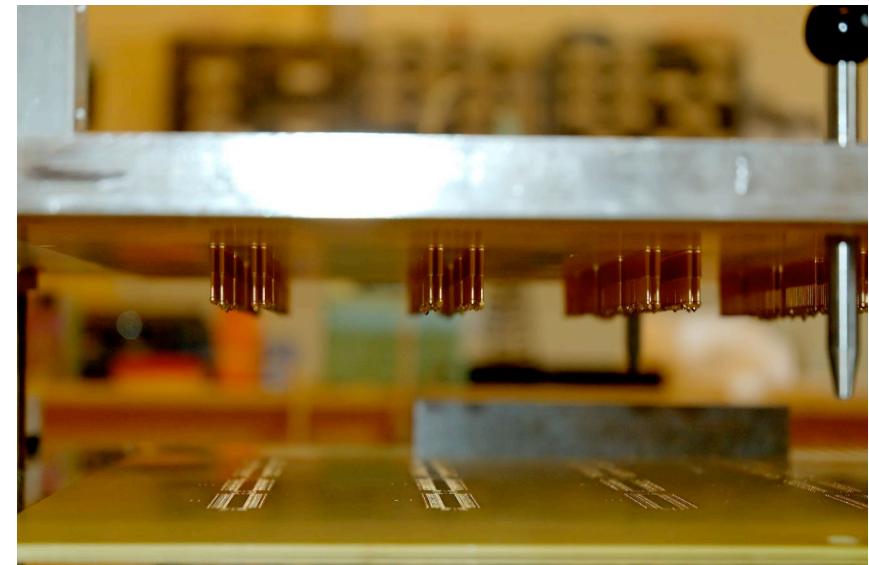
Mesh HV  
supply

Hand crank



This test bench is used at each critical step of integration of the micromesh in order to ground the pads BEFORE the connectors are soldered

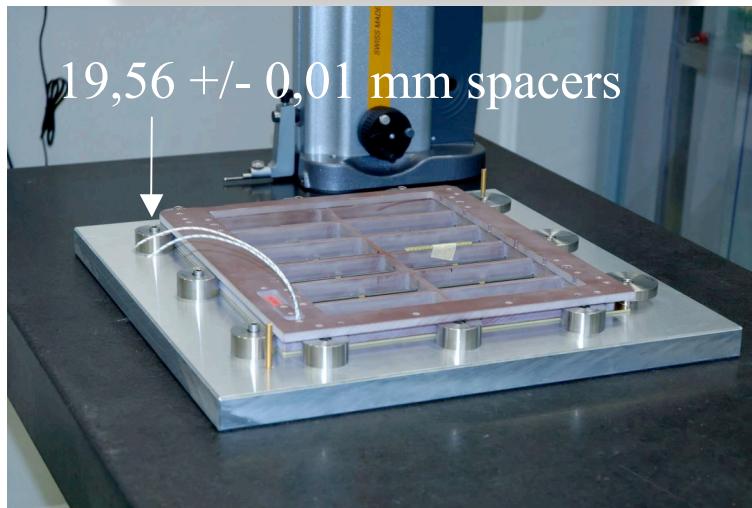
1728 individual spring probes are used to globally and quickly evaluate the quality of the insulation between the mesh and **the whole active area** by grounding all the pads with the spring probes



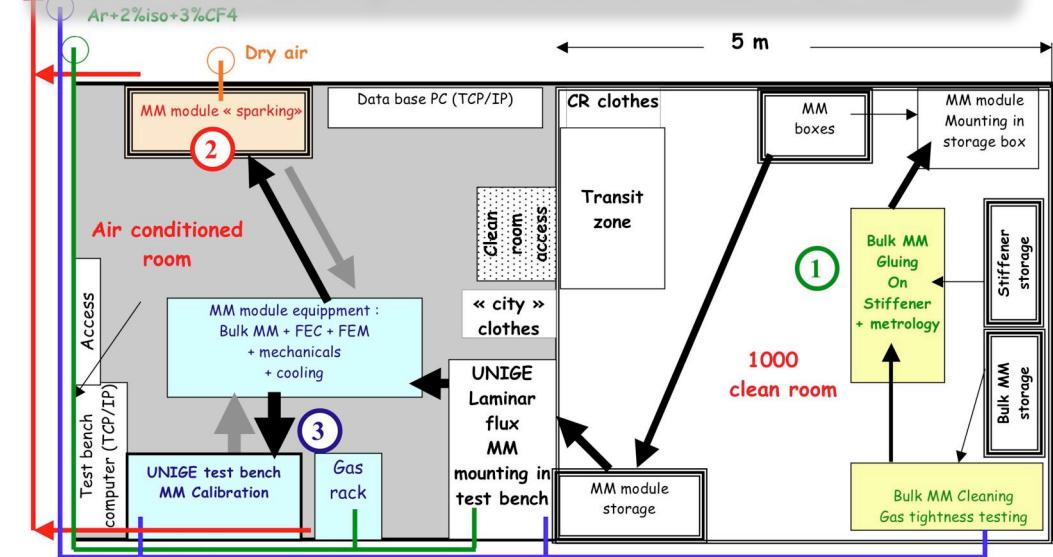
Mesh HV is set @ -600 V  
typical measured current is 4 nA

①

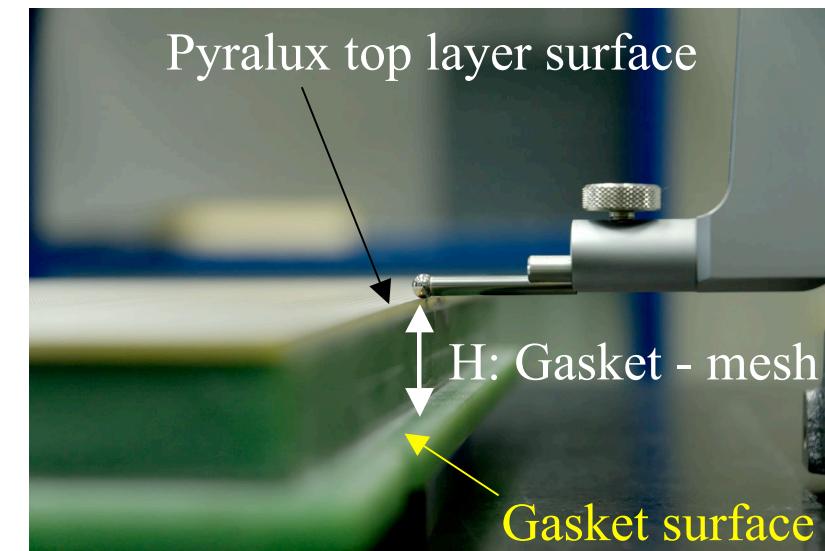
## Module assembly &amp; Q/C



## T2K/TPC Europe Production lab. @ CERN



**Module assembly :** bulk-micromegas gluing on mechanical stiffener with control of the H=19,5 mm dimension, HV filter integration, mechanical metrology and gas tightness Q/C (1 module / day)



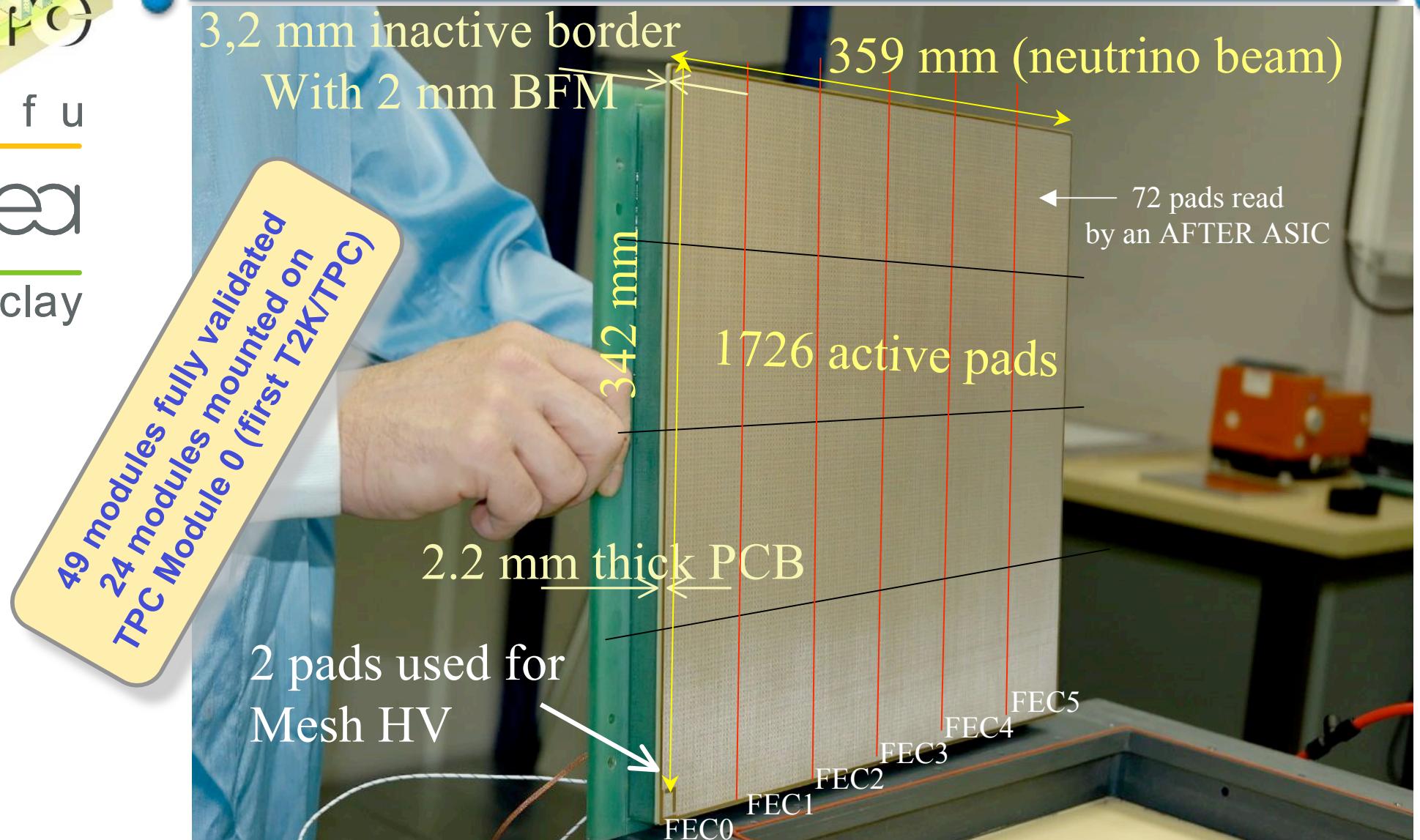


i r f u

ceo

saclay

# From bulk-micromegas to a detector module



## Production cost of Bulk-micromegas

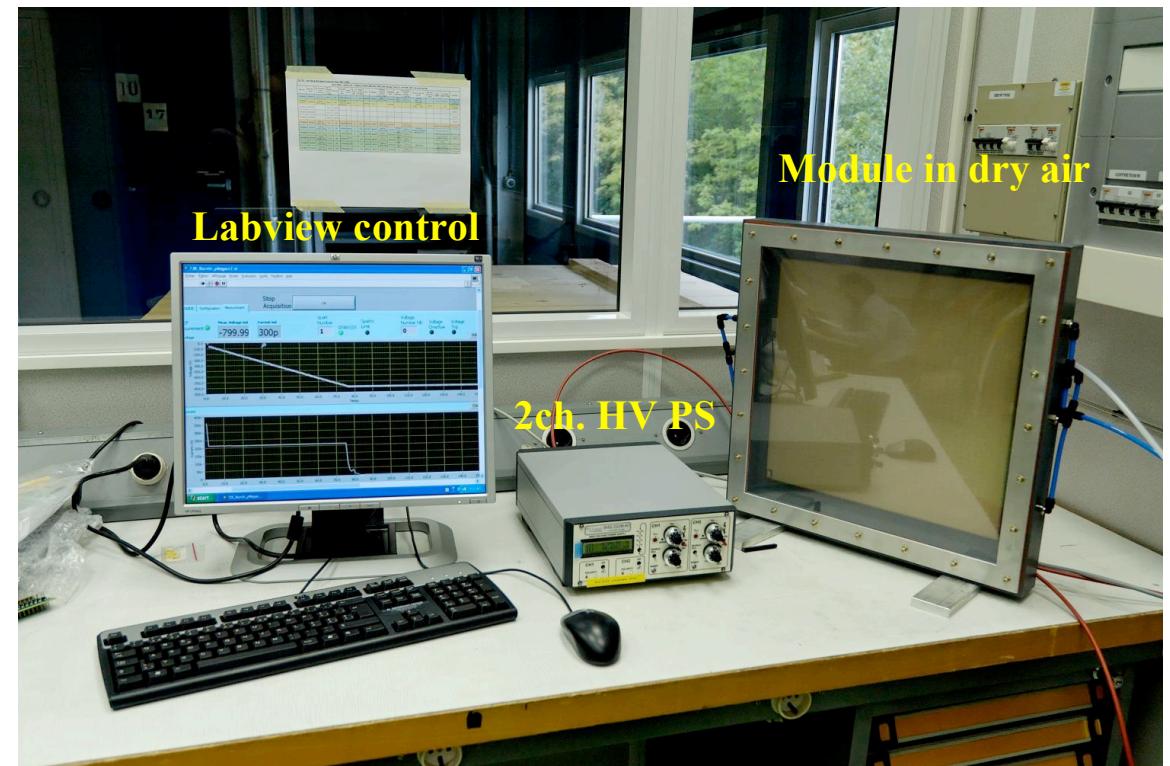
cost/ bulk MM : 800 € (PCB+mesh integration) + 230 € (connectors +  
connectors' soldering + mesh stretching) + 120 €(mesh) ~1,15 k€ (~10 k€ /m<sup>2</sup>)

## ② « burn-in » of the detector in dry air

- Goal : «burn-in» is done by «forced-sparking» to remove dusts and tiny asperities on both mesh & pads' surface for a safe operation of detectors in TPC gas.
- The module is mounted in a chamber filled with dry air and all the pads are directly connected to ground. High-Voltage is progressively increased up to ~900 V
- Semi-automated test bench with monitoring of Voltage, Current, and sparking rate
- Map of the defects

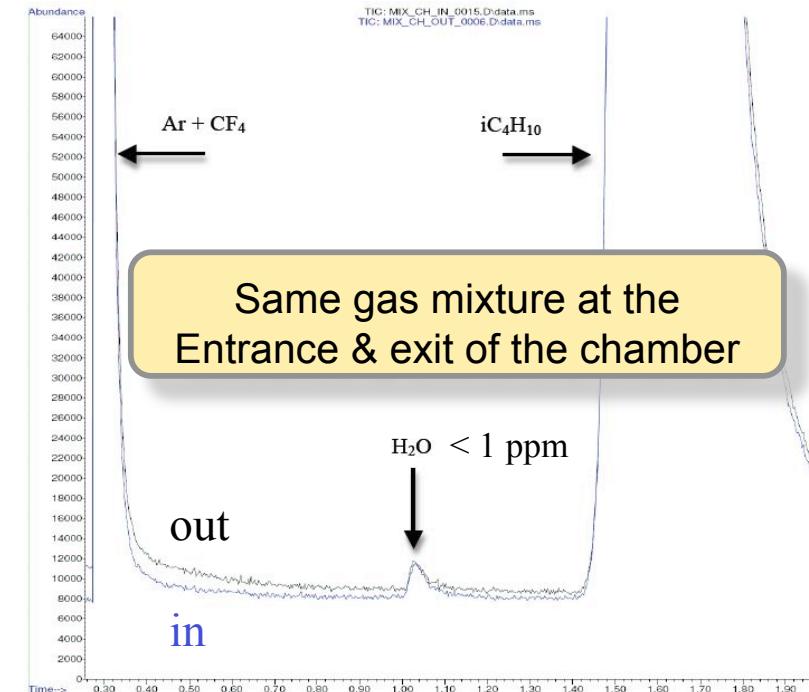
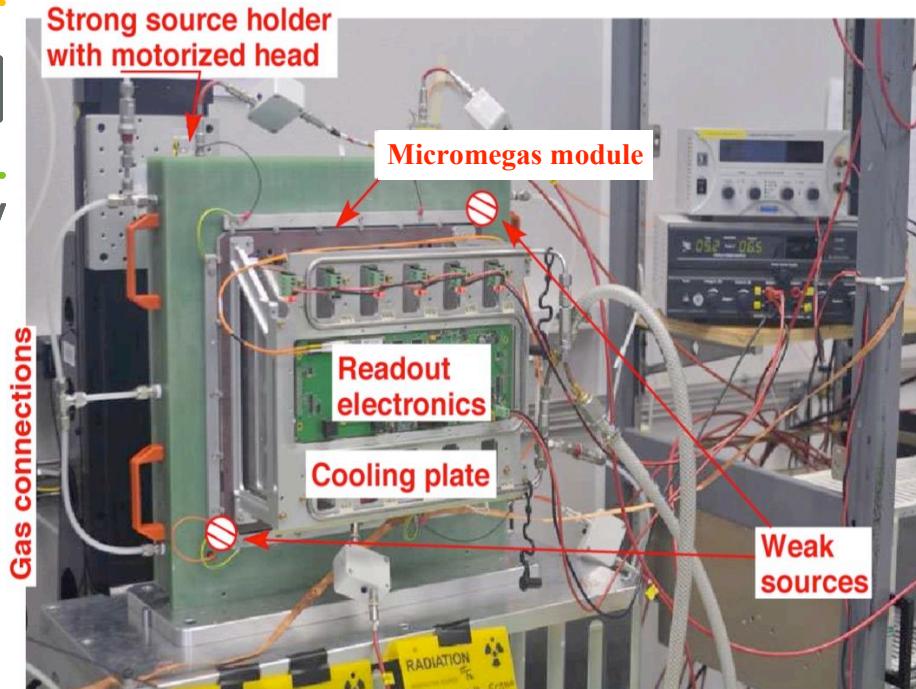
### Typical values

- ✓ first spark at ~ 700 V
- ✓ some « weak » pads with repeated sparks @ ~ 870V
- ✓ maximum HV : ~ 910-940 V
- ✓ All pads OK at the end of the process except for 4/32 modules which have 1 pad in short-circuit



# ③ $^{55}\text{Fe}$ X-ray source calibration test bench

- ✓ 4 cm drift gas chamber, 10 l/h gas flow with controlled 1 mbar overpressure
- ✓ Module interface with gas chamber is identical to interface with T2K/TPC
- ✓ Ar+2% $\text{iC}_4\text{H}_{10}$ +3% $\text{CF}_4$  bottles ( 2% relative precision of the mixture composition)



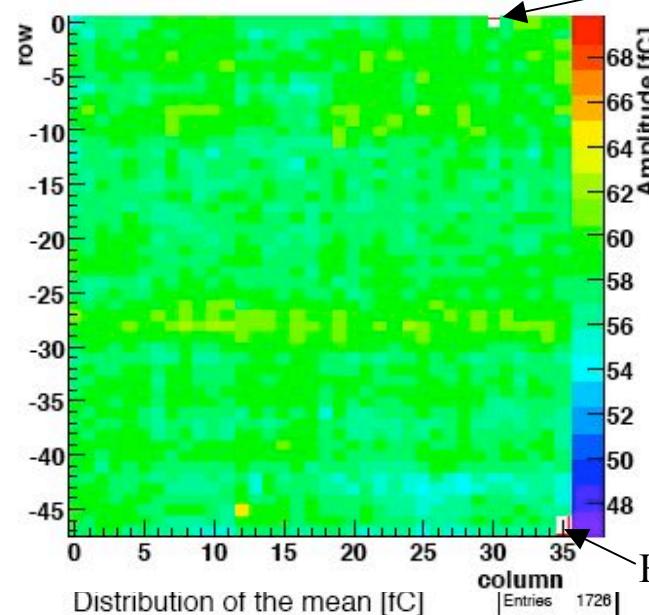
- ✓ **Full pad per pad calibration** : complete scanning of the active area with a X-Y motorized strong  $^{55}\text{Fe}$  x-ray source
- ✓ **Gain and  $^{55}\text{Fe}$  5.9 keV resolution** is measured for each of the 1726 pads with the T2K/TPC Front-End Electronics (400 evts / pads)
- ✓ **Gain Vs High-Voltage** is measured in the center of the detector (320-360 V)
- ✓ Monitoring during the 6 hours scan of the module : weak sources signals in chamber corners, monitoring chamber in series with test bench, atm. pressure, room T, and sparks.



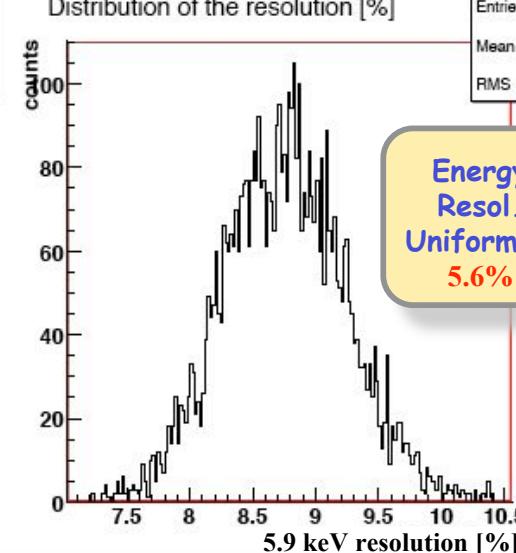
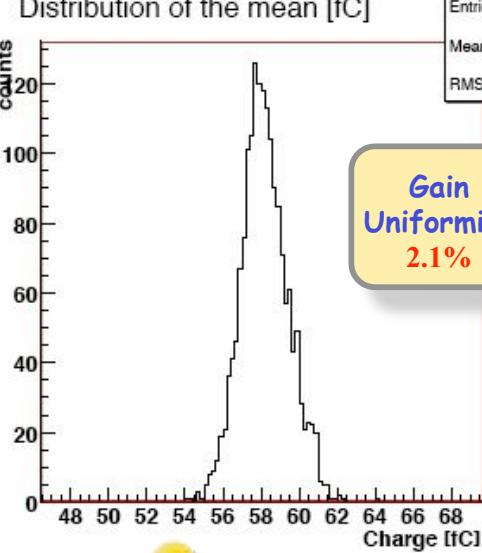
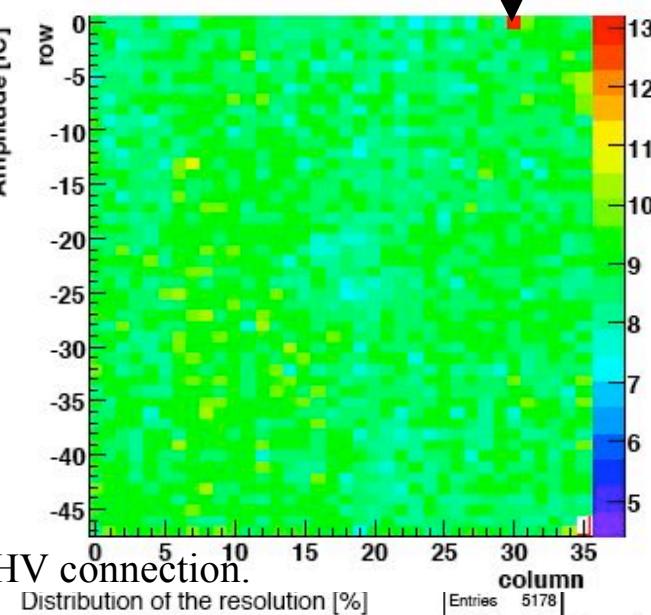
# An example of Module calibration : MOD-036

1726 pads scan @ -350 V

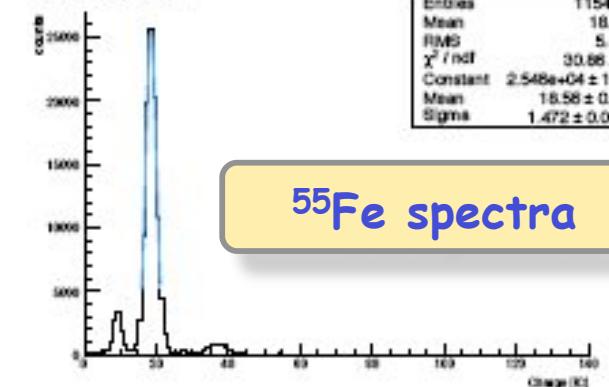
Map of the gain (mean value)



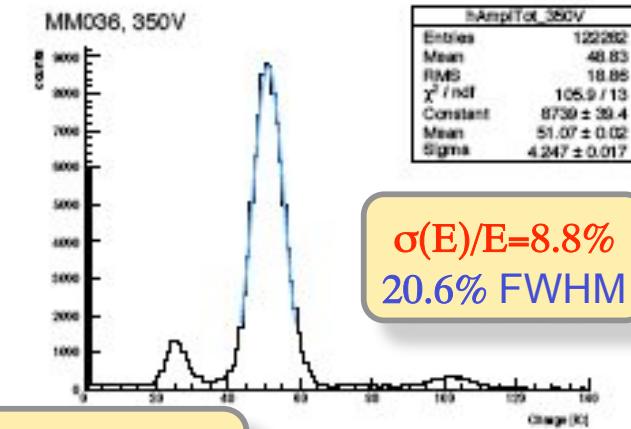
Map of the resolution (sigma)



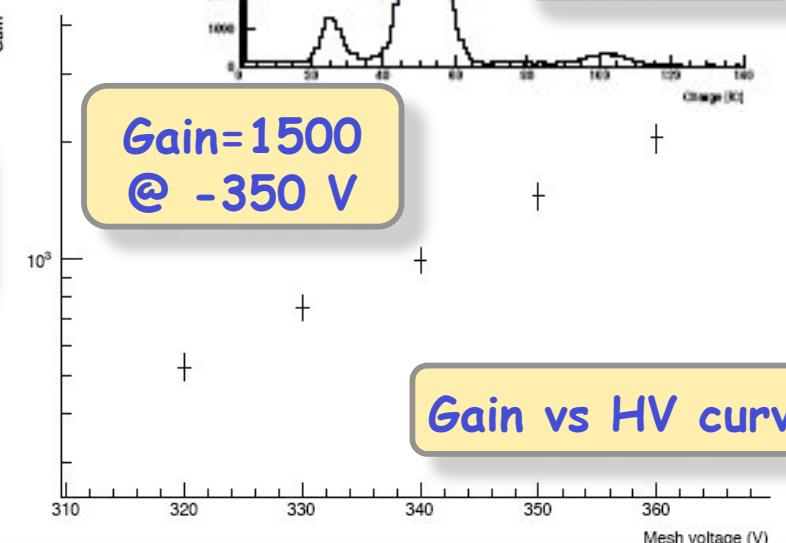
MM036, 320V



55Fe spectra



$\sigma(E)/E = 8.8\%$   
20.6% FWHM



Gain vs HV curve



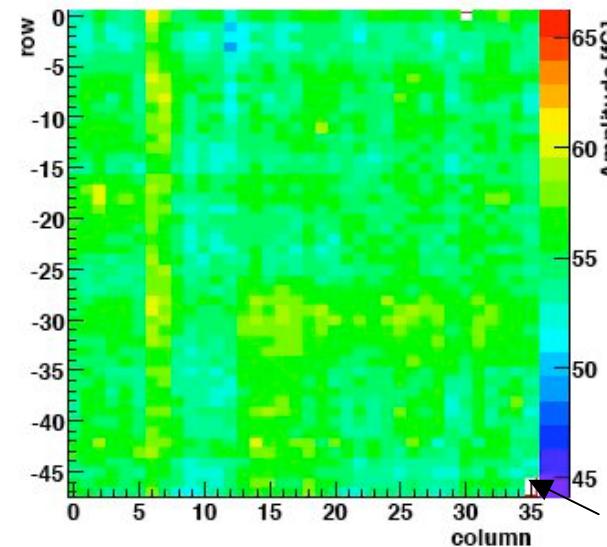
# Gallery of scan results : amplitude maps (-350V)

i r f u

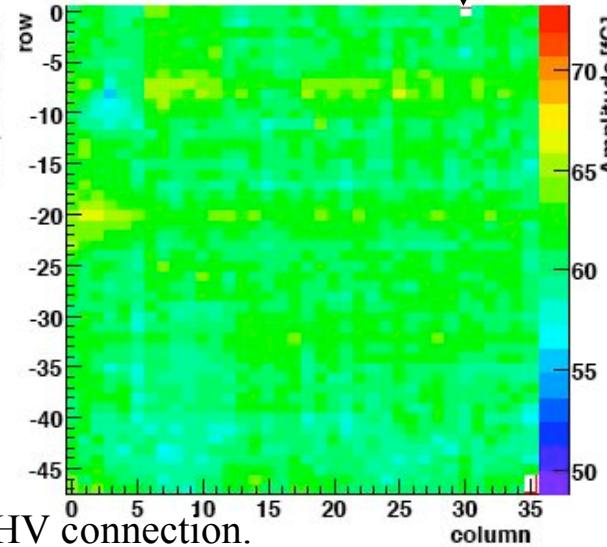
cea

saclay

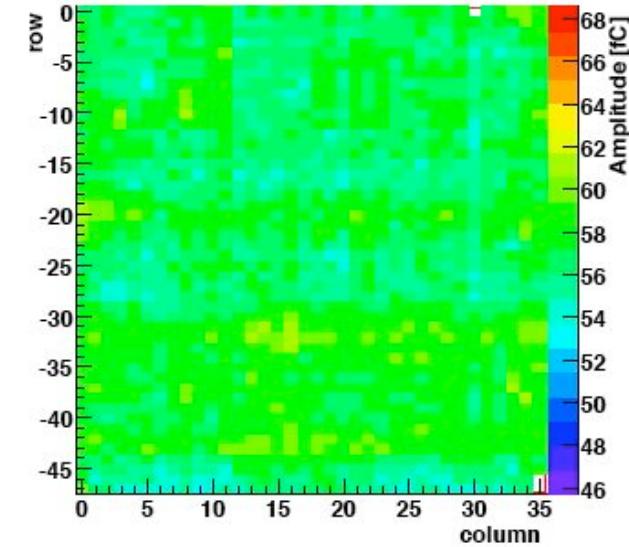
**Mod-020**  
Map of the gain (mean value)



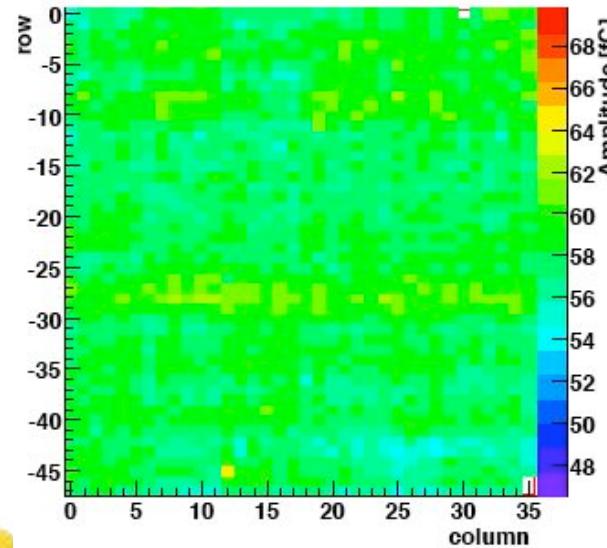
**Mod-034**  
Map of the gain (mean value)



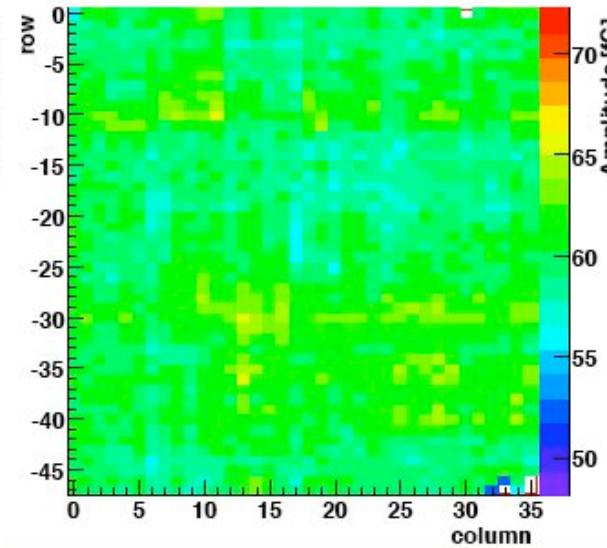
**Mod-019**  
Map of the gain (mean value)



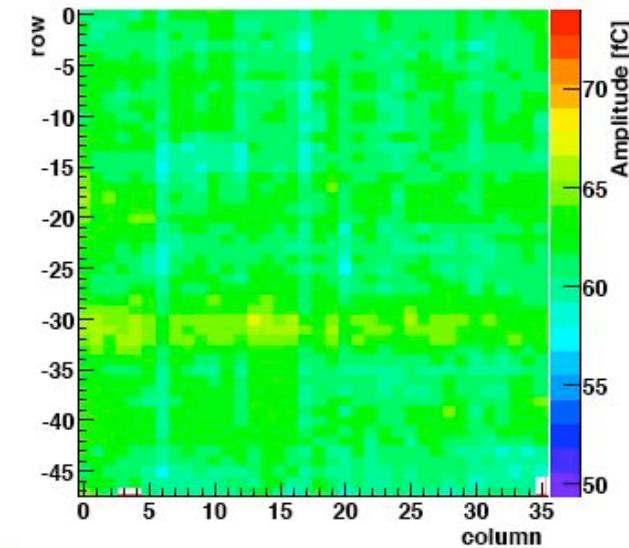
**Mod-036**  
Map of the gain (mean value)



**Mod-018**  
Map of the gain (mean value)



**Mod-016**  
Map of the gain (mean value)





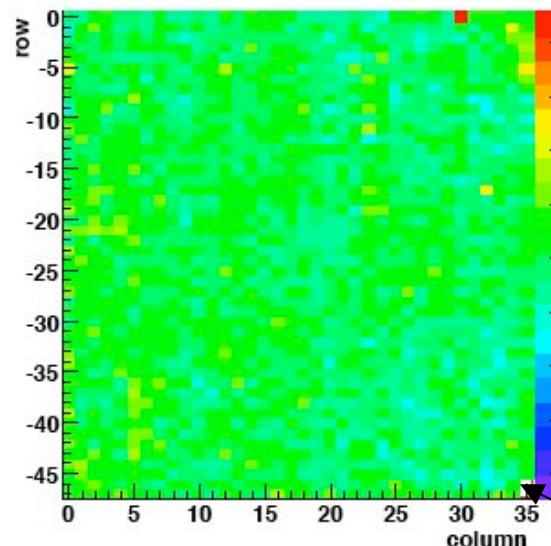
# Gallery of scan results : 5.9 KeV resolution maps (-350V)

i r f u

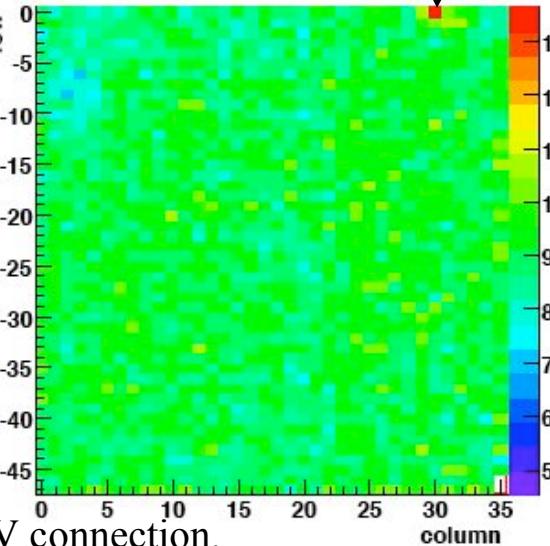
ceci

saclay

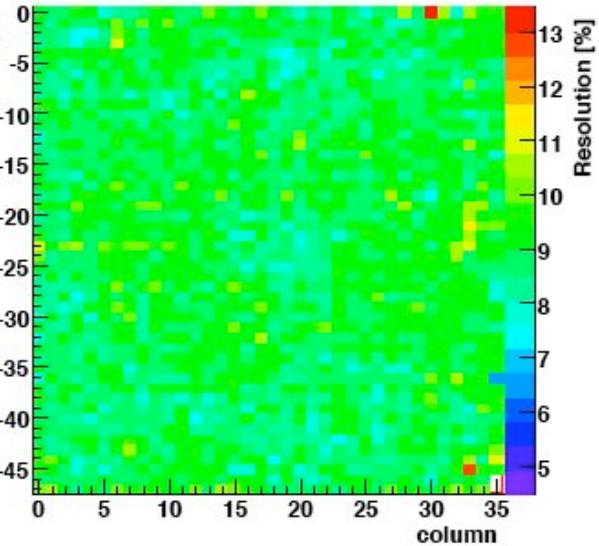
**Mod-020**  
Map of the resolution (sigma)



**Mod-034**  
Map of the resolution (sigma)

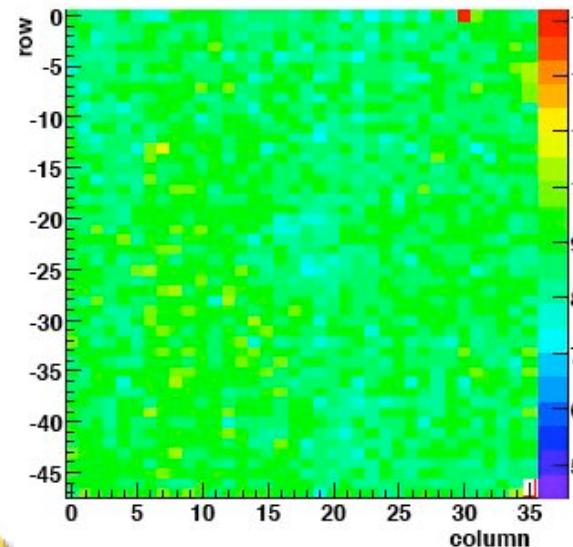


**Mod-019**  
Map of the resolution (sigma)



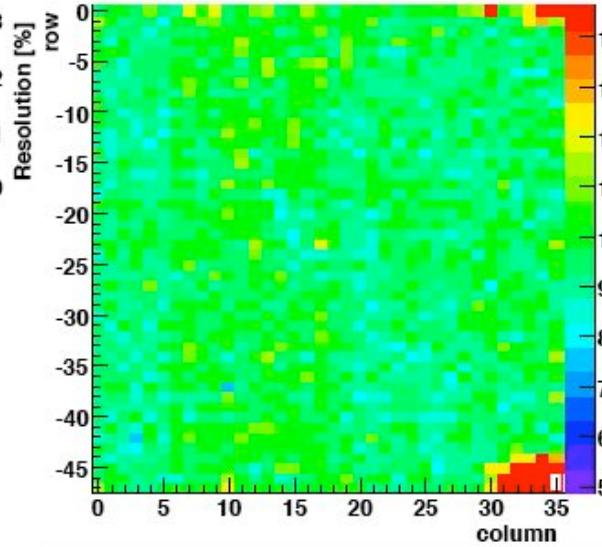
**Mod-036**

Map of the resolution (sigma)



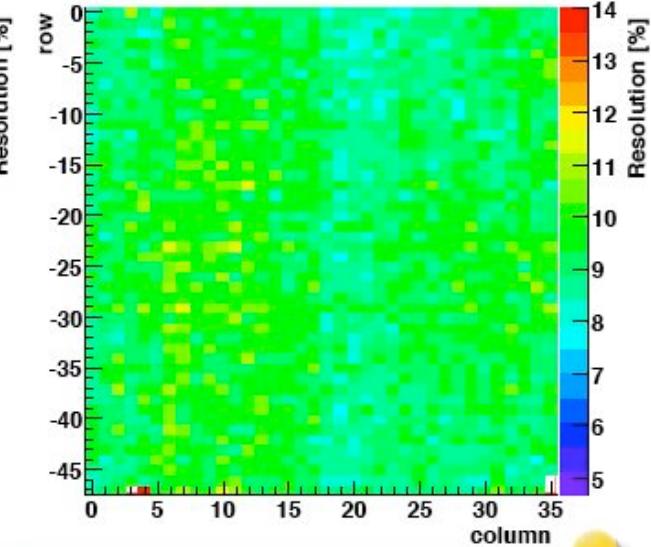
**Mod-018**

Map of the resolution (sigma)



**Mod-016**

Map of the resolution (sigma)



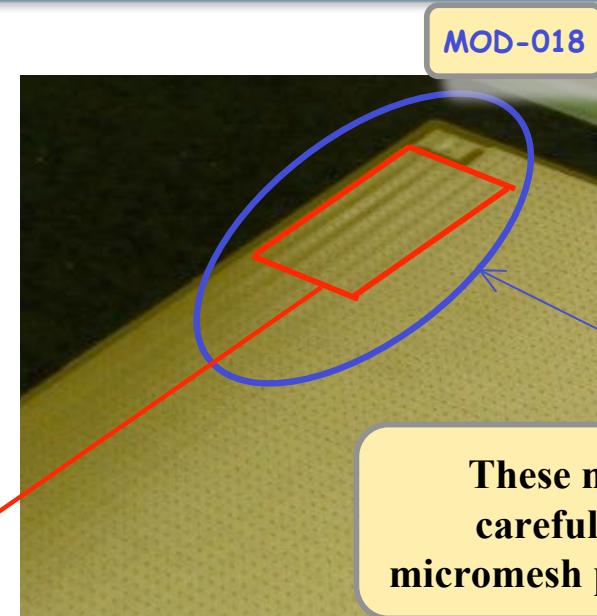
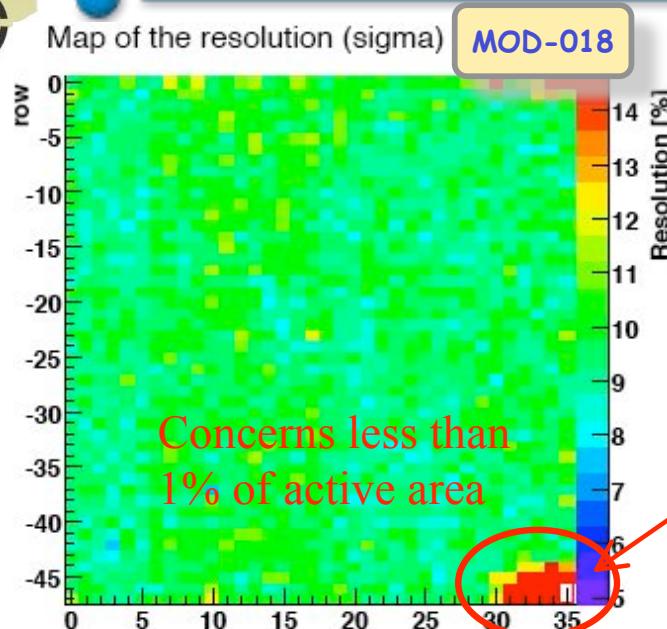


i r f u

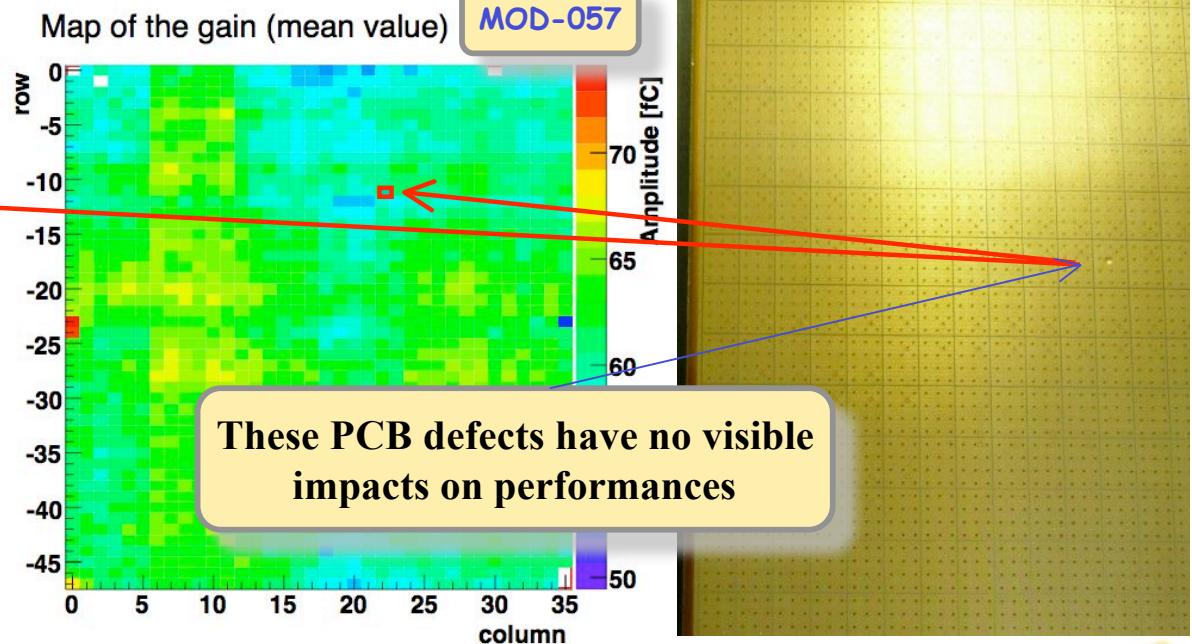
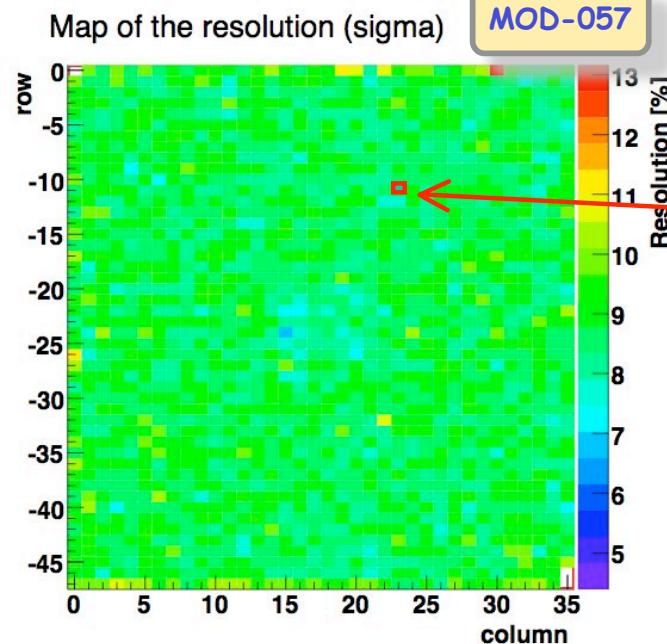
cei

saclay

# Consequences of PCB & mesh defects



These mesh defects are avoided by carefull inspection of the streched micromesh prior its integration on the PCB



These PCB defects have no visible impacts on performances



irfu

cea

saclay

# Amplitude & 5.9 keV resolution @ -350V (TPC-MOD-0)

Module	Mean Charge C (fC)	Charge dev. $\sigma$ (fC)	charge uniformity $\sigma/C$	5,9 keV resol. $\sigma E/E$	resol dev. $\sigma(\sigma E/E)$	resol uniformity $\sigma(\sigma E/E)/(\sigma E/E)$	comments
Mod_001	59,0	2,90	4,9%	9,4	0,59	6,3%	Charge is not corrected for pad capacitance dispersion
Mod_007	55,0	1,90	3,5%	9,5	0,46	4,8%	
Mod_010	49,5	1,60	3,2%	9,3	0,46	4,9%	
Mod_012	55,0	2,10	3,8%	8,9	0,52	5,8%	
Mod_016	61,7	1,36	2,2%	9,3	0,55	5,9%	
Mod_014	58,5	1,70	2,9%	9,4	0,63	6,7%	
Mod_011	71,6	1,57	2,2%	9,2	0,60	6,6%	
Mod_006	70,5	1,73	2,5%	9,4	0,57	6,1%	14% $\sigma E/E$ on a border (8 pads)
Mod_013	58,7	1,18	2,0%	9,3	0,57	6,1%	
Mod_008	60,0	2,42	4,0%	9,2	0,53	5,7%	
Mod_009	71,3	2,10	2,9%	9,2	0,54	5,9%	
Mod_015	58,7	1,62	2,8%	9,0	0,56	6,2%	
Mod_017	59,6	1,60	2,7%	9,3	0,59	6,3%	
Mod_022	63,5	1,96	3,1%	9,0	0,53	5,9%	
Mod_024	63,6	1,26	2,0%	9,1	0,49	5,4%	For all 49 modules 1-2 sparks in 10h 0,1 sparks/h Confirmed on TPC
Mod_036	58,2	1,25	2,1%	8,8	0,49	5,6%	
Mod_051	64,4	1,54	2,4%	9,0	0,50	5,6%	
Mod_023	58,9	1,40	2,4%	8,8	0,50	5,7%	
Mod_020	55,2	1,50	2,7%	9,0	0,52	5,8%	
Mod_034	61,0	1,36	2,2%	9,1	0,50	5,5%	
Mod_029	63,7	1,64	2,6%	9,3	0,56	6,0%	
Mod_019	57,2	1,32	2,3%	8,9	0,53	5,9%	
Mod_025	62,5	1,80	2,9%	9,4	0,66	7,1%	14% $\sigma E/E$ on a border (6 pads)
Mod_030	60,5	1,54	2,5%	9,2	0,54	5,9%	14% $\sigma E/E$ in corner (8 pads)

Raw analysis with basic electronic calibration but **without** any cluster selection nor slow T,P variations corrections over the ~6 h scans (analys is on-going)

for instance,  $\Delta G = 3.3\% \pm 0.6\%$  for  $\Delta P = 1\%$  was measured in TPC-0



irfu

cea

saclay

rejected →

rejected →

# Amplitude & 5.9 keV resolution @ -350V (TPC-MOD-1)

Module	Mean Charge C (fC)	Charge dev. $\sigma$ (fC)	charge uniformity $\sigma/C$	5,9 keV resol. $\sigma E/E$	resol dev. $\sigma(\sigma E/E)$	resol uniformity $\sigma(\sigma E/E)/(\sigma E/E)$	comments
Mod_026	63,2	1,64	2,6%	9,1	0,52	5,7%	820V max in dry air !
Mod_018	60,3	1,54	2,6%	9,6	0,60	6,3%	14% $\sigma E/E$ in a corner (20 pads)
Mod_027	58,3	1,75	3,0%	9,0	0,54	6,0%	14% $\sigma E/E$ on a border (9 pads)
Mod_021	54,2	1,60	3,0%	8,7			12% $\sigma E/E$ on a border (4 pads)
Mod_028	53,8	1,40	2,6%	8,8			
Mod_033	58	1,2	2,1%	9,0			
Mod_031	62	1,9	3,1%	9,0			
Mod_037	65	2,0	3,1%	9,0			
Mod_038	59,8	1,4	2,3%	9,1	0,63	6,9%	bad resol on 2 borders 30 pads
Mod_039	56	1,4	2,4%	8,6	0,51	5,9%	
Mod_044	59,1	1,6	2,7%	8,8	0,53	6,0%	
Mod_047	58,1	1,5	2,6%	8,7	0,48	5,5%	
Mod_046	56,9	2,2	3,8%				
Mod_053	56	1,3	2,3%	8,7	0,53	6,1%	
Mod_054	57,6	1,4	2,5%	8,9	0,52	5,8%	
Mod_045	tested @ Saclay : still 35nA not solved : to pass on test bench						35 nA dark current @ CERN
Mod_055	59	1,7	2,9%	8,7	0,53	6,1%	
Mod_056	60,5	1,5	2,5%	8,5	0,50	5,9%	
Mod_057	59,7	1,3	2,2%	8,8	0,53	6,0%	
Mod_040	assembled : rejected						3 pads broken
Mod_043	61,38	2,2	3,5%	8,8	0,60	6,8%	2 zones with mesh waves
Mod_068	57,41	1,3	2,3%	8,7	0,51	5,9%	
Mod_069	59,46	2,3	3,9%	9,0	0,54	6,0%	bad gain upper left corner
Mod_070	59,38	1,6	2,7%	9,1	0,51	5,6%	
Mod_071	62,06	1,5	2,5%	8,7	0,52	6,0%	
Mod_075	58,2	1,5	2,5%	8,9	0,54	6,1%	
Mod_0xx	baking 17/04/2009						Batc#9 xx=68 to 75
Mod_06x	baking week 17-18						x=0 to 7 (batch#8)
Mod_06x	assembly week 18						x=0 to 7 (batch #8)
Mod_078	tested april 24th						Batc#10 xx=76 to 83
Mod_076	63,26	1,9	3,0%	8,8	0,54	6,1%	

<b>Mean</b>	<b>59,9</b>	<b>1,7</b>	<b>2,76%</b>	<b>9,0</b>	<b>0,54</b>	<b>5,92%</b>
$\sigma$	4,2	0,3	0,59%	0,3	0,044	0,48%
$\sigma / \text{Mean}$	7,0%	21,1%	21,3%	2,9%	8,2%	8,1%

49 modules tested (2/3)

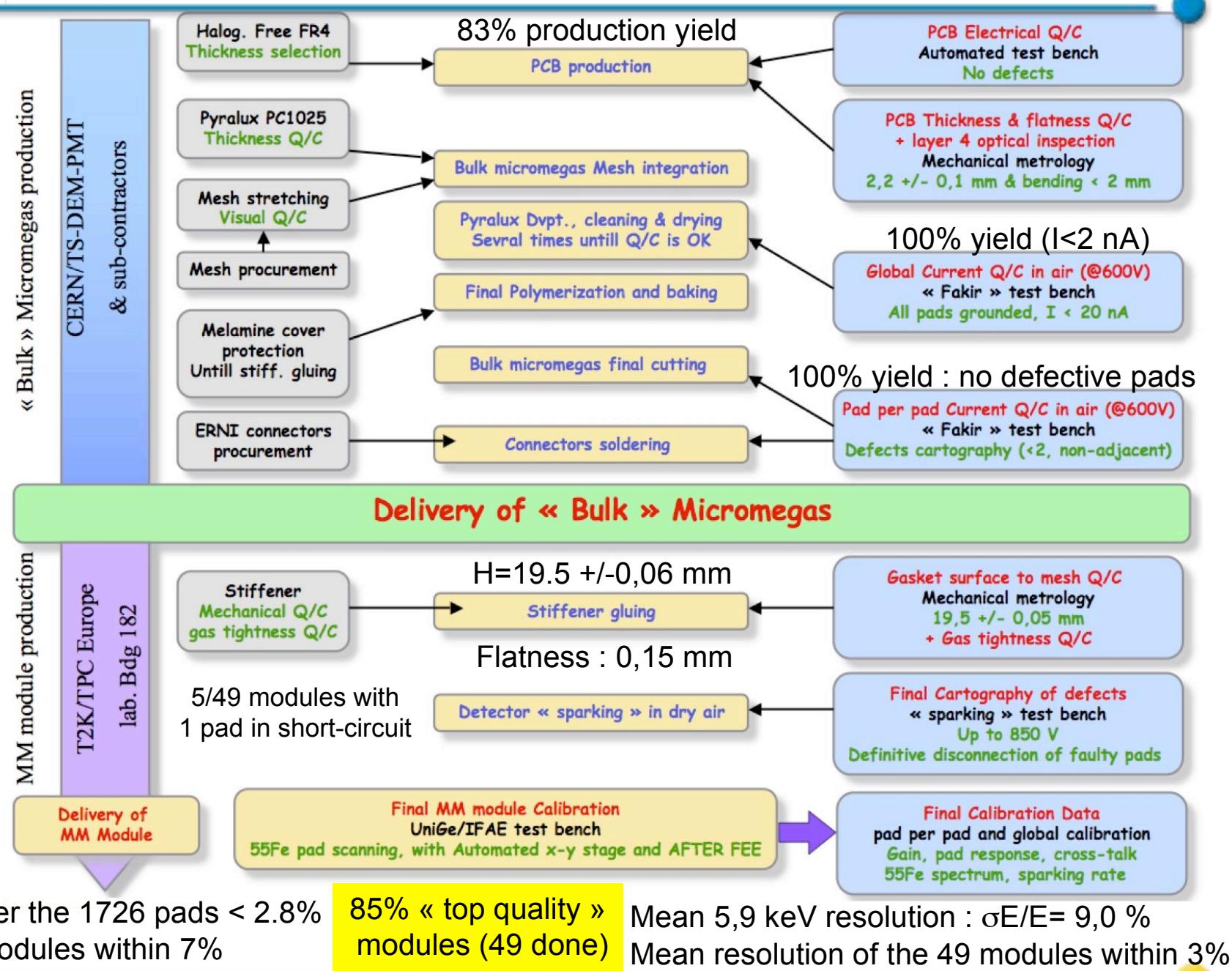


i r f u

ceci  
saclay

# Quality of the bulk-micromegas modules

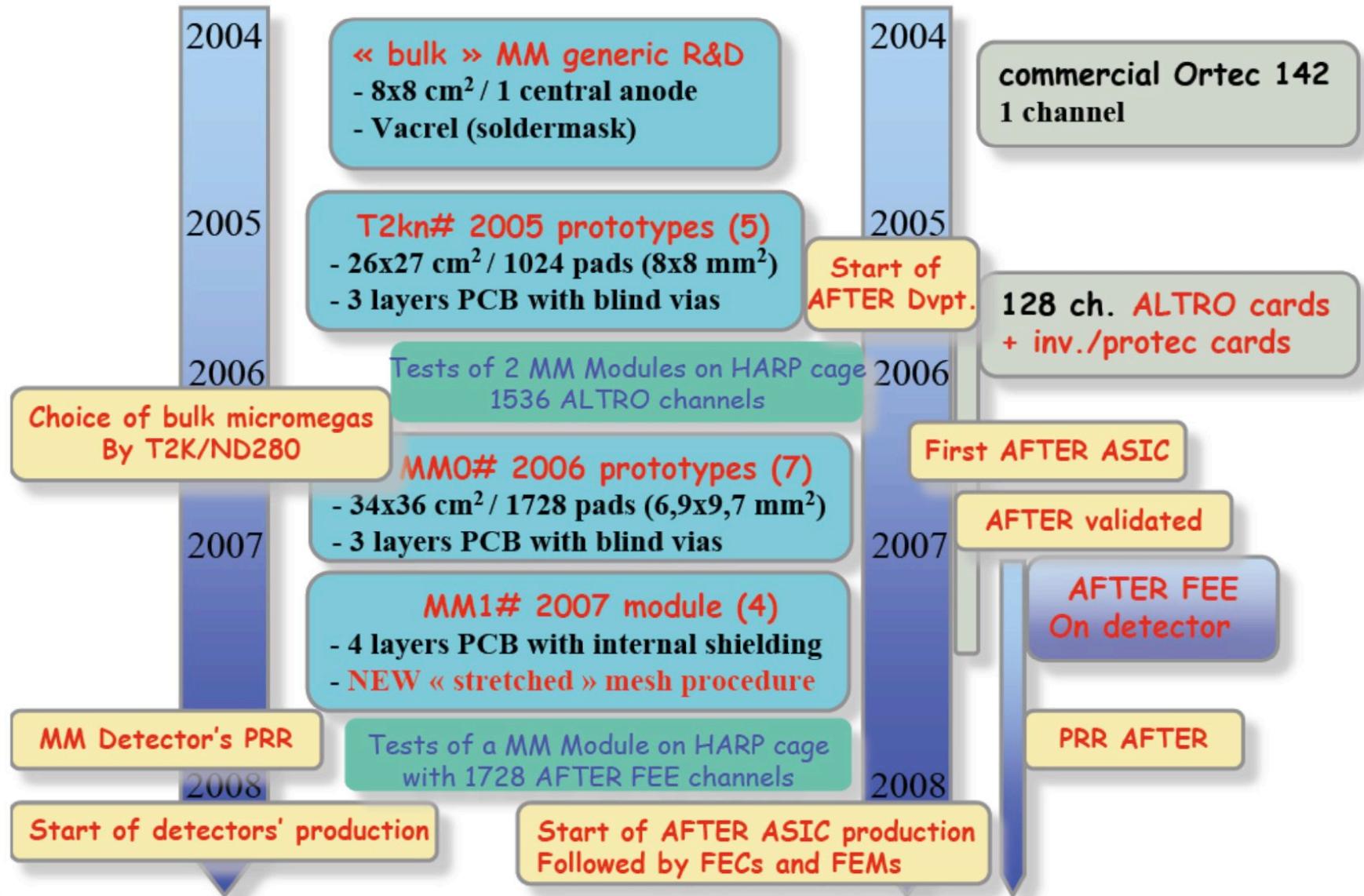
8/58 bulk-MM  
with a local defect  
of mesh flatness  
( $\sigma E/E \sim 14\%$  resol.  
on <1% of active area)



# 3 years of R&D+T, a year of production

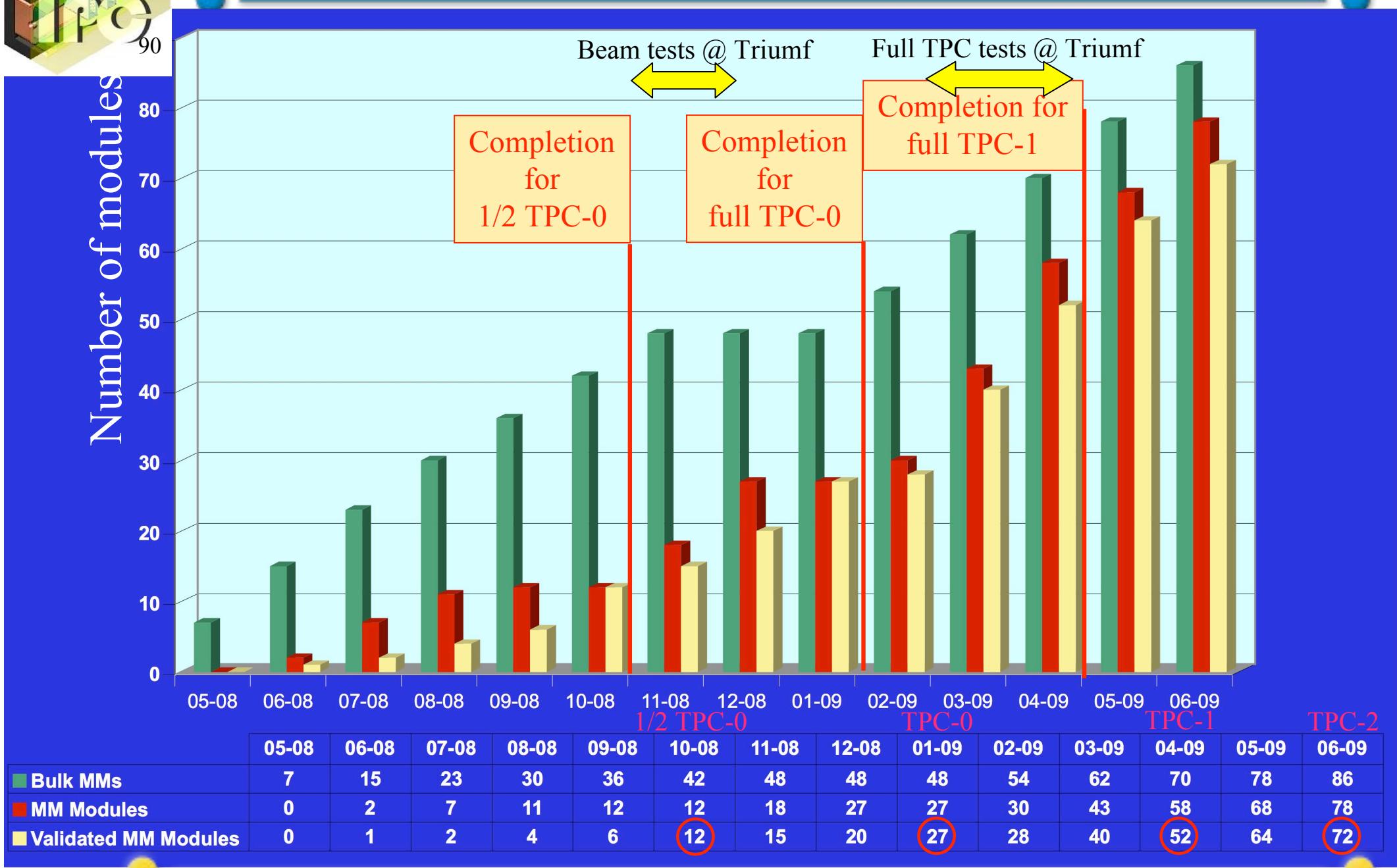
## MM Detector

## AFTER FEE





# T2K/TPC Bulk-micromegas production : ~1 year





irfu

cea  
saclay

## Resources : 2005-2007 (R&amp;D) + 2008 ... (prod)

## Saclay/IRFU ressources (Services not included)

Component	Investment (k€)	Manpower (FTE x year)	Total Cost (1 FTE~140 k€)
ASIC design, test & production (2 runs; 5000 chips)	80 / 90	6	1010
Analog Front-End Cards (390 cards)	70 / 90	6	1000
Digital Front-End Cards (85 cards)	30 / 42	6	912
Front-End Electronics TOTAL	180 / 222	18	2922
Module mechanicals (84)	65 / 170	4	795
Bulk-Micromegas (84)	75 / 96	9	1431
Bulk-MM Module TOTAL	140 / 266	13	2226
T2K/TPC laboratory, equipments & tests (+ management FTE)	35 + 60	6	935
Total	415 k€ / 488 k€	37 FTE	~6.1M€



i r f u

cea  
saclay

# Conclusion

- 3 years of R&D on bulk-micromegas modules (detectors & Front-End Electronics) for ~1 year of high-yield & high-quality production
- Production is going on for a scheduled completion by summer 2009
  - All AFTER ASICs produced & validated (4750 good chips, 89% yield)
  - 2/3 of the FECs & FEM produced & validated (300 FECs & 50 FEMs)
  - 2/3 of the bulk-micromegas produced & validated (80% « top quality »)
  - 2/3 of the bulk-micromegas modules produced & validated on test bench
- Very good uniformity of the performances of the bulk-micromegas modules
  - Only 6 dead pads over the 84 574 pads of the 49 modules tested
  - Gain uniformity over the active area of a module : ~2.8 %
  - Gain uniformity over 49 modules : 7%
  - 5.9 keV resolution :  $\sigma E/E = 9,0\%$  (5.9% uniformity over the active area)
  - 5.9 keV resolution uniformity over 49 modules : 2.5 %
  - 0,1 spark/h @ 1500 gain (-350 V)
- The critical step of the production of these large area MPGDs is the mesh integration which first demands a high-quality stretched micromesh



i r f u

cea  
saclay

# T2K/TPC Micromegas modules contact persons

Physics leader  
T2K/TPC co-spokesman

Marco Zito, IRFU / Saclay  
[marco.zito@cea.fr](mailto:marco.zito@cea.fr)

Project leader  
coordination

Alain Delbart, IRFU / Saclay  
[Alain.delbart@cea.fr](mailto:Alain.delbart@cea.fr)

Bulk MM production

Rui de Oliveira, CERN / TS-DEM-PMT  
[Rui.de.oliveira@cern.ch](mailto:Rui.de.oliveira@cern.ch)

Bulk MM technician

Olivier Pizzirusso, CERN / TS-DEM-PMT  
[Olivier.pizzirusso@cern.ch](mailto:Olivier.pizzirusso@cern.ch)

AFTER FEE

Denis Calvet, IRFU / Saclay  
[Denis.Calvet@cea.fr](mailto:Denis.Calvet@cea.fr)

Prod. Lab (bdg 182)  
Phone : 7 9707

Didier Pierrepont, IRFU / Saclay  
[Didier.pierrepont@cern.ch](mailto:Didier.pierrepont@cern.ch)

Module mechanics

Franck Cadoux, UNIGE, Geneva  
[Franck.cadoux@unige.ch](mailto:Franck.cadoux@unige.ch)

Quality Assurance

Julien Giraud, IRFU / Saclay  
[julien.giraud@cea.fr](mailto:julien.giraud@cea.fr)

Calib. Test bench

Andrea Ferrero, UNIGE, Geneva  
[Andrea.ferrero@cern.ch](mailto:Andrea.ferrero@cern.ch)