



DE LA RECHERCHE À L'INDUSTRIE



T2K/ND280 TPC MICROMEGAS MODULE PRODUCTION

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T2K/ND280-TPC collaboration

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CEA/Saclay (France), LPNHE Paris-VI-VII university (France),
RWTH Aachen University (Germany), TRIUMF (Canada),
UAB/IFAE Barcelona University (Spain), University of British
Columbia (Canada), University of Victoria (Canada),
Valencia University (Spain)*

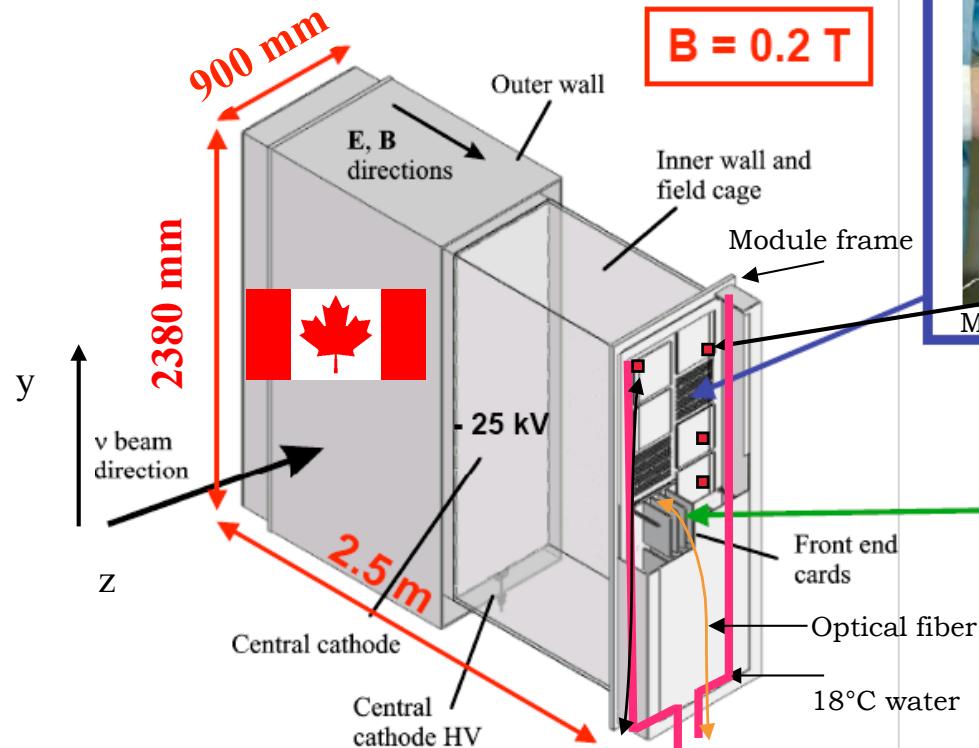


*2nd Workshop on neutrino Near Detectors based on gaseous TPCs
CERN, march20-213, 2017*

- Context and history : the TPCs of the ND280 near detector
- The T2K/TPCs readout planes
- Design of the bulk-micromegas modules and performances
- Production and QA/QC of the bulk-micromegas modules
- Conclusion and perspectives

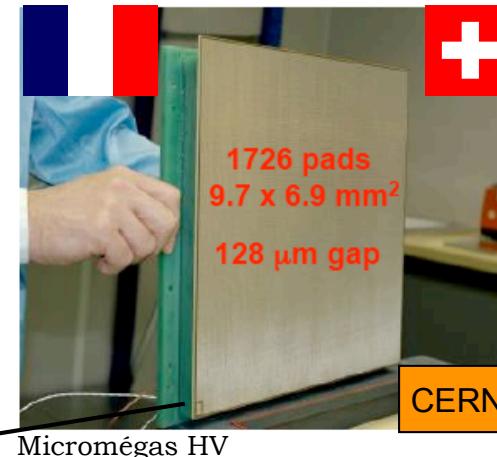
Specifications / performances

- ✓ MIP identification and momentum measurement
- ✓ Spatial resolution of $600 \mu\text{m}$ @ $z=1\text{m}$ ($\Delta p/p < 10\%$)



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

$36 \times 34 \text{ cm}^2$ « Bulk » MicroMegas



12 modules
per
Readout
plane

Total of
72 modules



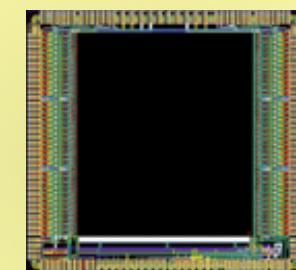
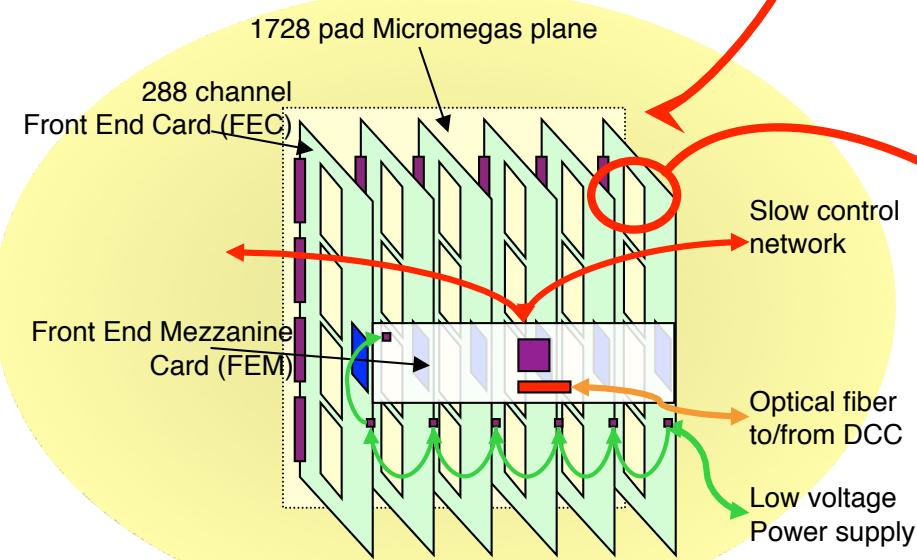
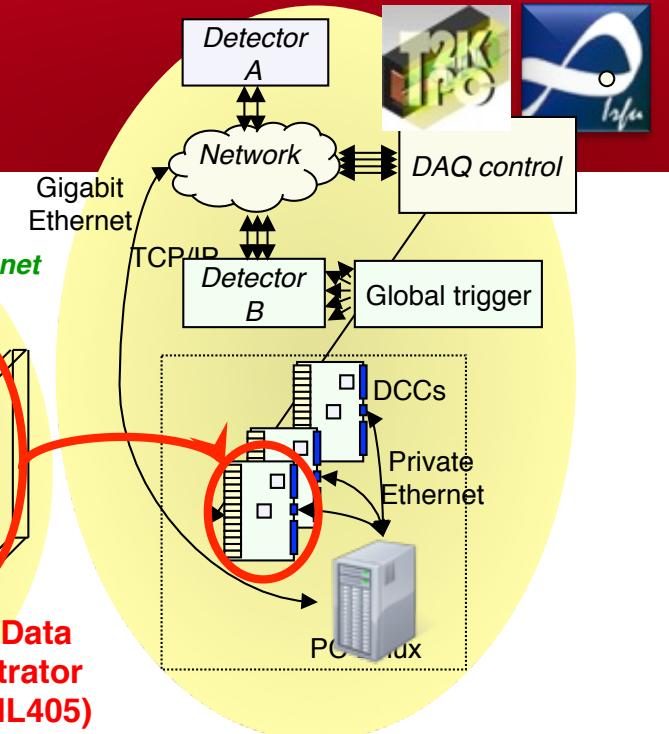
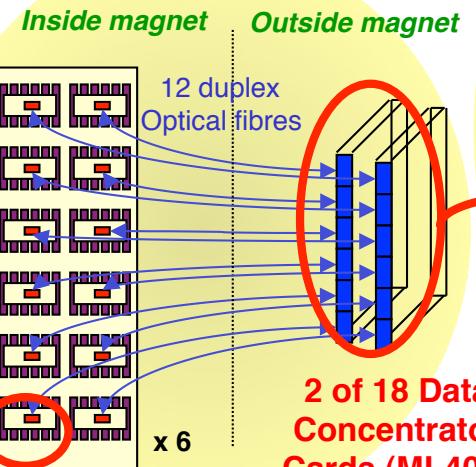
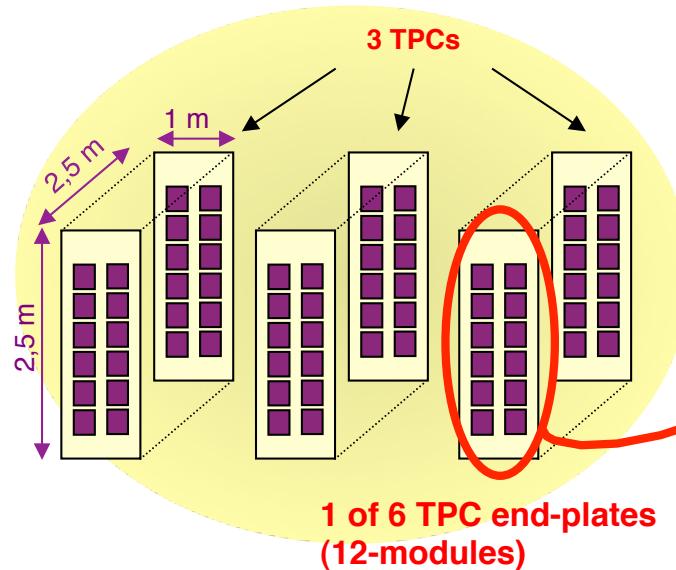
With On-detector FEE cooling mechanicals

FEE based on the ASIC AFTER

6 FECs + 1 FEM
per module

Total of
1728 ASICs
432 FECs
72 FEMs

THE ELECTRONICS READOUT

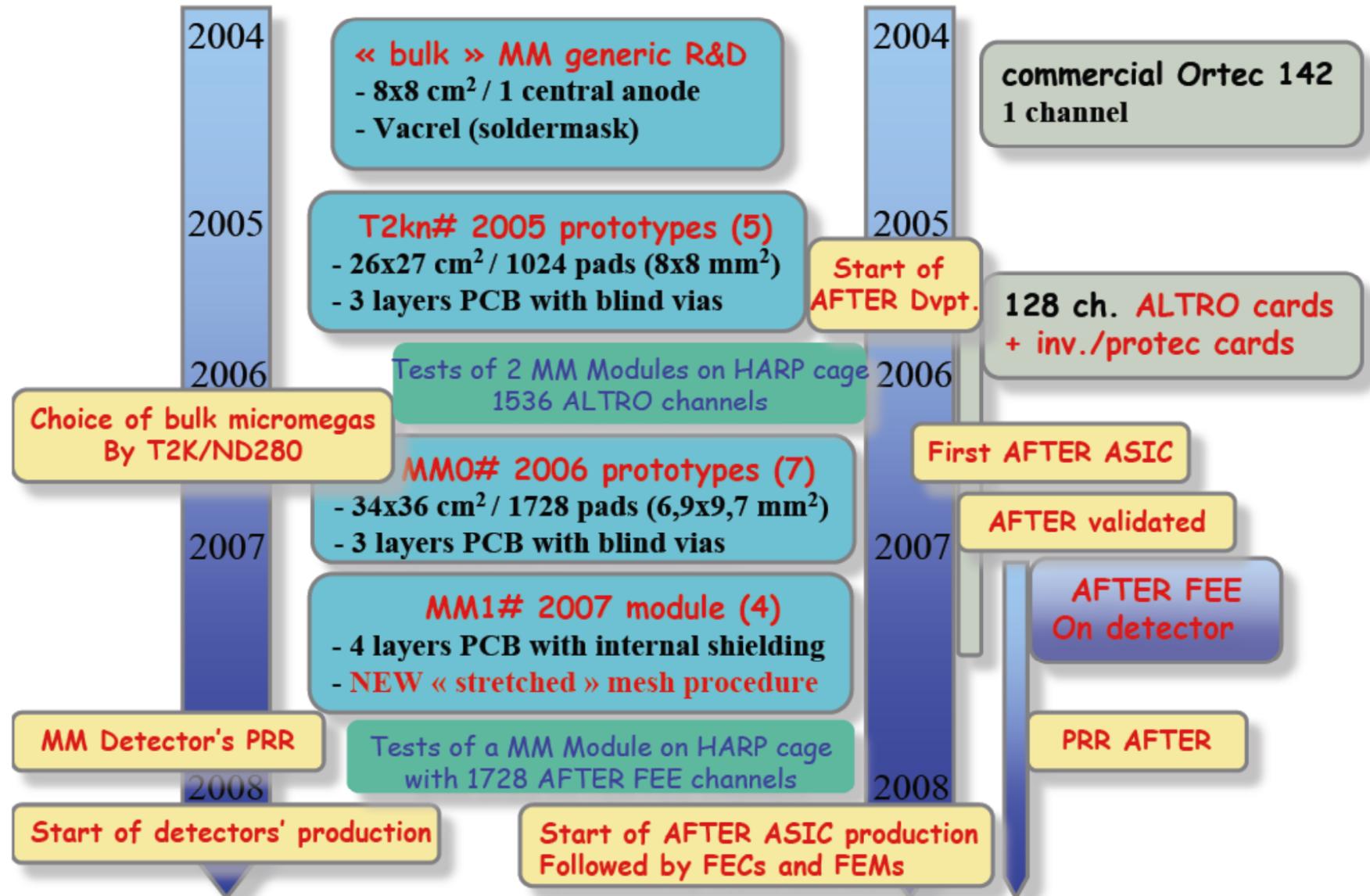


72 channel x 511 time buckets
Switched Capacitor Array

Ref. D. Calvet (IRFU)

MM Detector

AFTER FEE



Preliminary definition phase (april 2005 – september 2006)

- Tests of a demonstrator @ CERN of the 2 competing technologies Micromegas (Irfu) and GEMs on the HARP TPC cage (11/2015, ALTRO FEE)
- Electronics : Design of the AFTER ASIC for 1st foundery submission (03/06)

- Micromegas proposal is selected by the T2K collaboration in june 2006
- IRFU project launch on 09/28/2006 (Scientific council 11/30/2006)
- T2K/TPC collaboration is re-organized to cope with this technology choice

Detail design phase (september 2006 – november 2007)

- Tests of a Micromegas module @ CERN on HARP TPC (with AFTER FEE)
- Production phase « officially » @ IRFU launched on 11/30/2007

Production – Integration phase (november 2007 - october 2009)

- For each subsystem : Production Readiness Review for ASIC:12/10/2007, Micromegas module : 10/12/2007, FEC:16/04/2008, FEM: 24/07/2008

- TPC tests @ Triumf (Canada) TPC-1 (Nov 2008), TPC-2 (juin 2009)
- Integration in ND280 @ Tokai TPC-1 (08/2009), TPC-2 (09/2009), TPC-3 (12/09)

« Large » readout plane surface ($\sim 2 \text{ m}^2$)

- Segmentation in individual readout modules

Very few access to readout planes during T2K data taking

- High quality and reliability of the detectors & Front-End Electronics is required

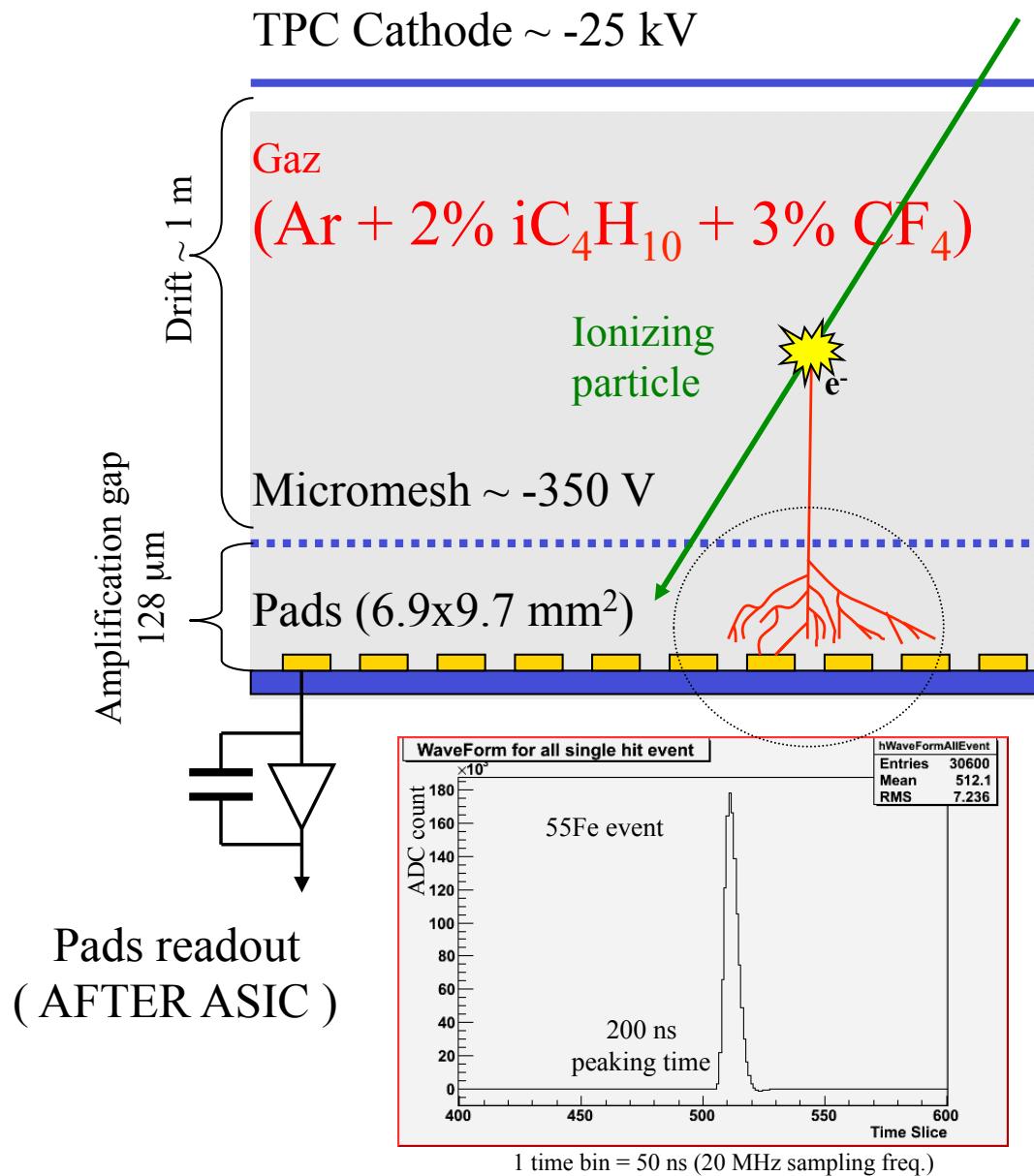
Maximizing the effective active area for track reconstruction

- Good uniformity of performances within a module (edges & corners included)
- Minimizing dead zones within a module & between active areas of modules

Readout plane Electric Field uniformity

- Avoiding insulating materials in the drift volume as much as possible
- Electrodes of readout modules must be aligned within 0.1 mm
- Electrodes of readout modules must be set at the same High-voltage
⇒ a good gain uniformity over these modules is required (within FEE performances)
- Minimizing the sparking rate (as low amplification gain as possible)
- Minimizing the dead time & voltage drop after a spark

THE CHOICE OF BULK-MICROMEGAS



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 cm/ μs @ 200 V/cm)
- ✓ minimization of the effect of impurities (mainly O₂) : > 30m att. Length

Drawbacks of micromegas technologies with separate mesh & anode PCB :

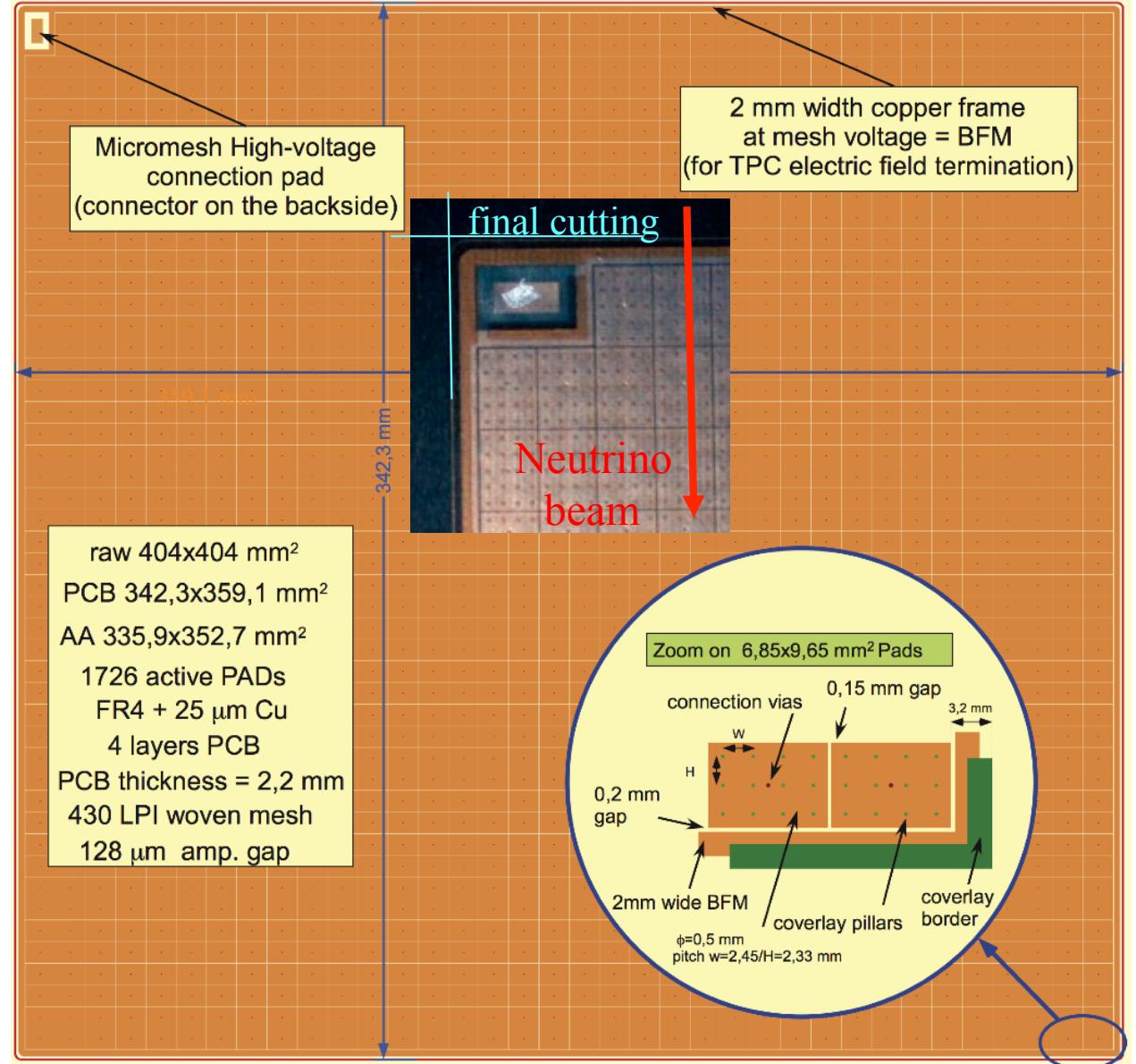
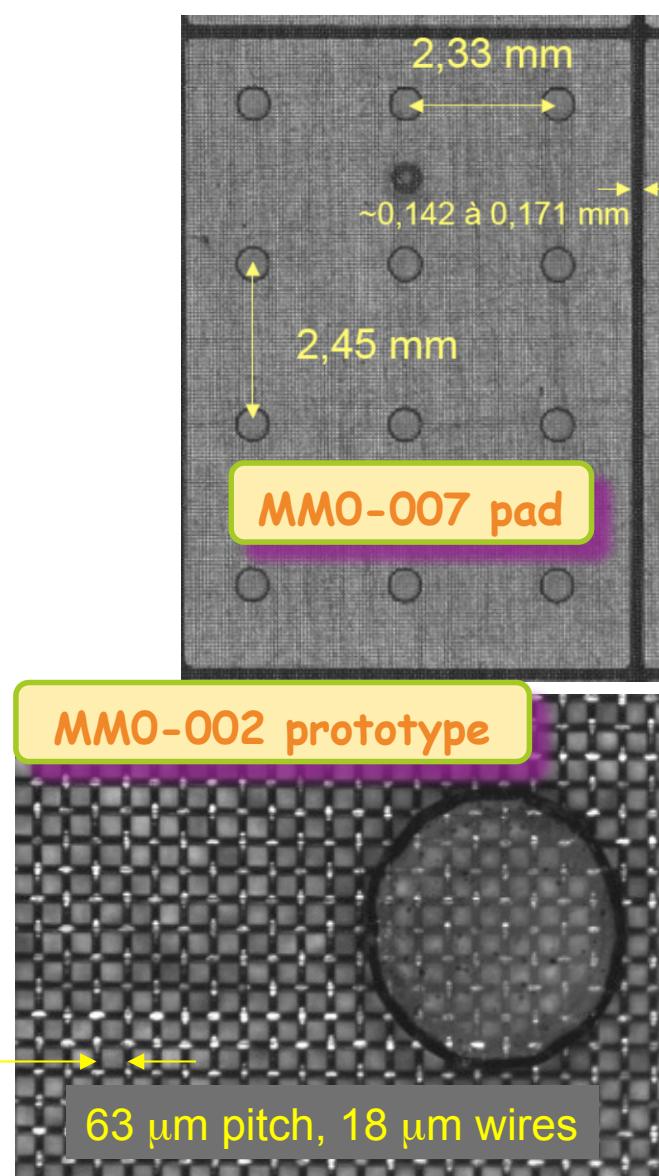
- "large" dead zones around active area + delicate assembly due to the mesh frame
- gap irregularities in corners

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

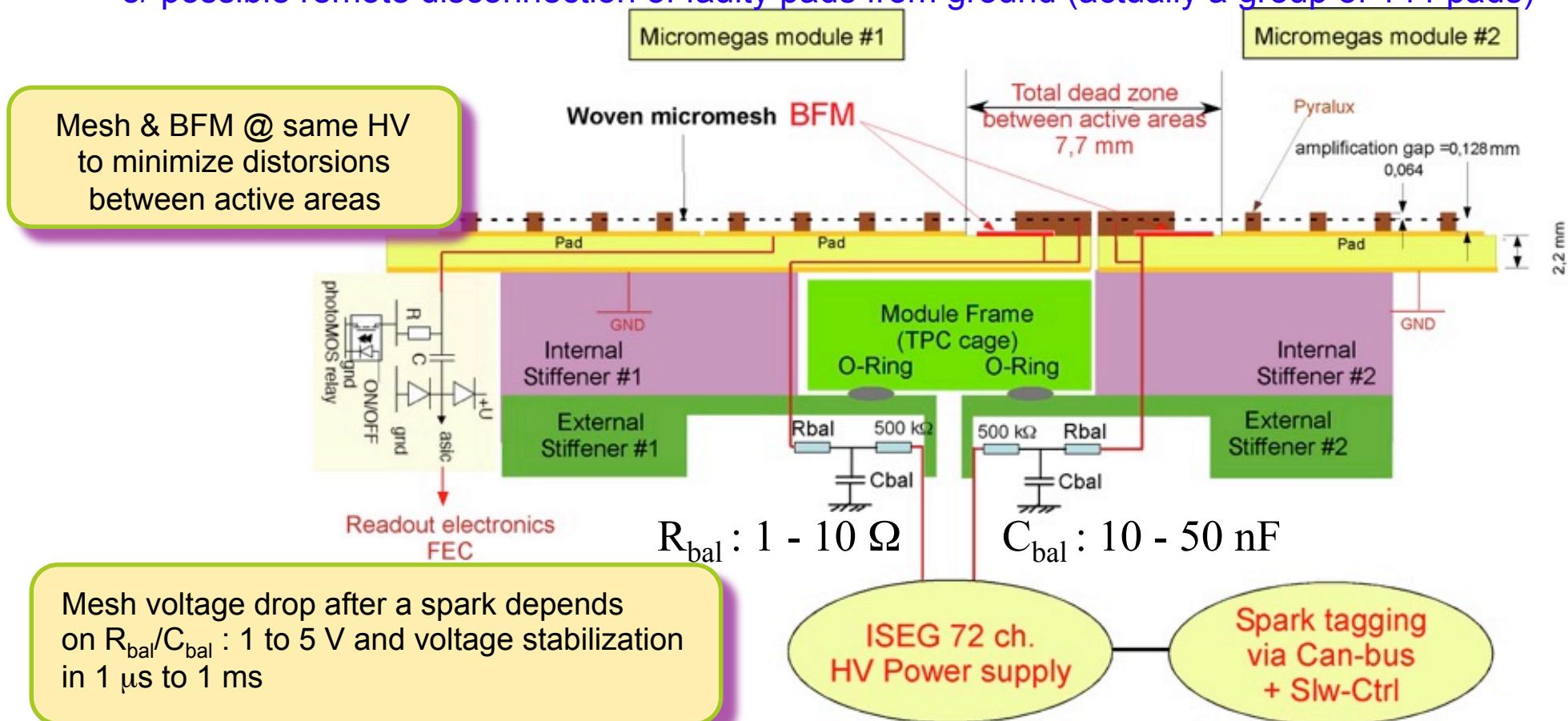
2005 HARP tests : NIM A574 (2007) 425-432

2011 T2K TPCs : NIM A637 (2011) 26-47



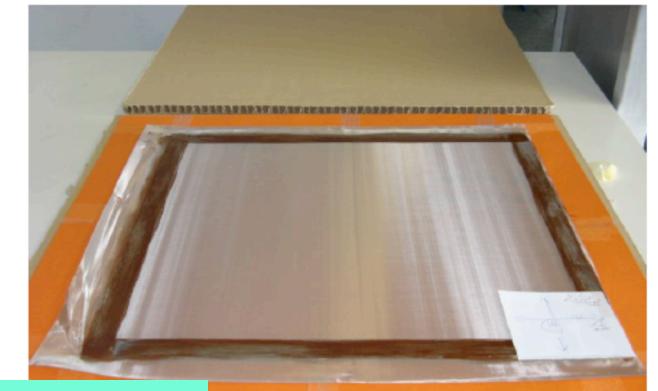
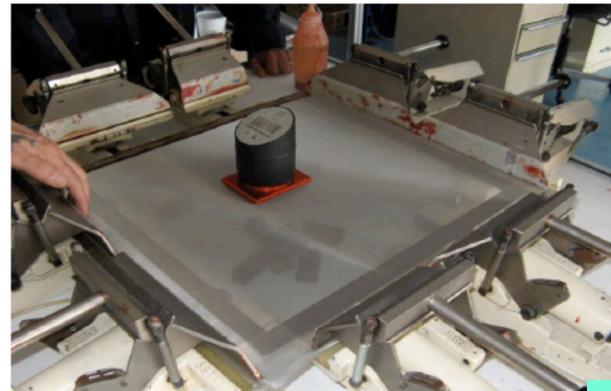
BULK-MICROMEGAS VS FIELD CAGE INTERFACE

- Minimize the electric field distortions with precise alignment of modules' mesh & BFM polarization
- Strategies to handle failures when a spark or a permanent short-circuit occurs by :
 - 1/ demanding module quality selection for very low failure probability (« burn-in » in air)
 - 2/ optimized pad & mesh polarization circuit to minimize the effects of a spark
 - 3/ possible remote disconnection of faulty pads from ground (actually a group of 144 pads)





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



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

PCB Q/C

(1) Base Material



Copper + Ni/Au
segmented
anode
FR4 PCB

(2) Lamination of Vacrel



Amp. Gap Photo-
imageable polyimide film
(2x64 µm)

1/ Mesh is stretched on an external frame



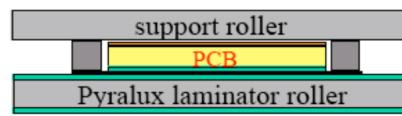
→

(3) Positioning of Mesh



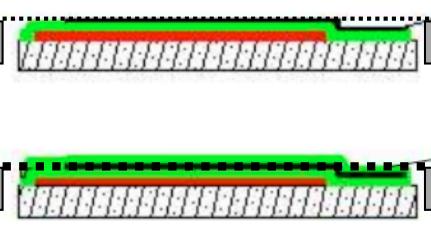
Stainless steel
Woven mesh
~30 µm thick

2/ and laminated with the PCB



→

(4) Encapsulation of Mesh



Top Photo-imageable
polyimide film (2x64 µm)

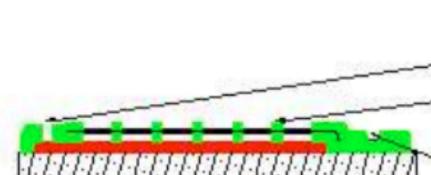
(5) UV exposure



Border frame

If $I > I_{Q/C}$

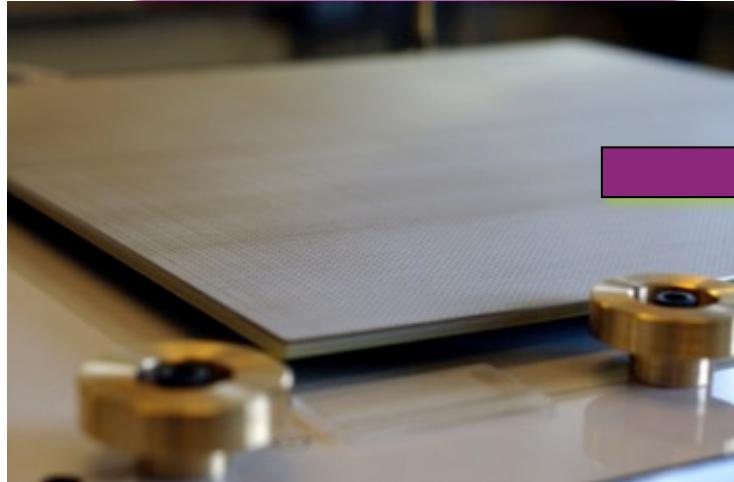
→ (6) Development of Contacts and Spacers
(7) Contact to Mesh



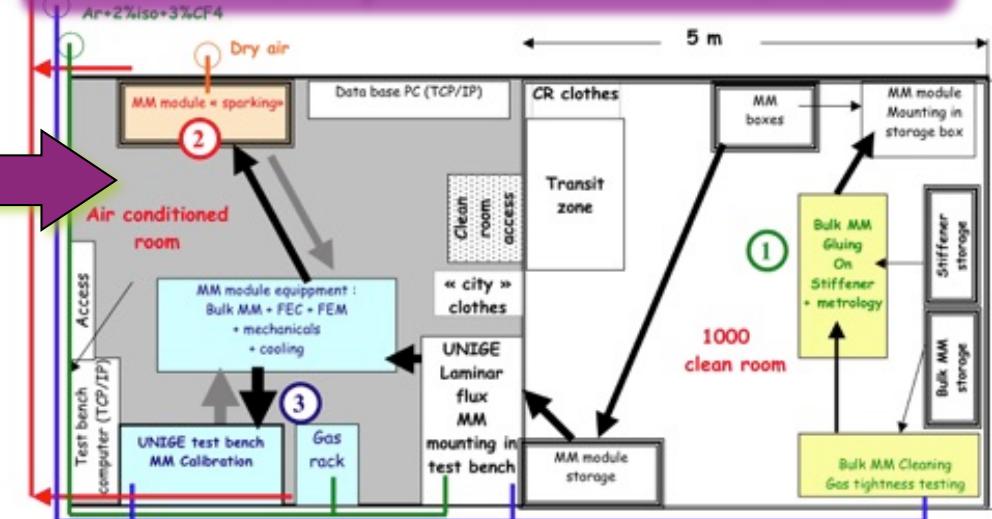
Spacers
Contact to Mesh

Global current Q/C on « Fakir » test bench

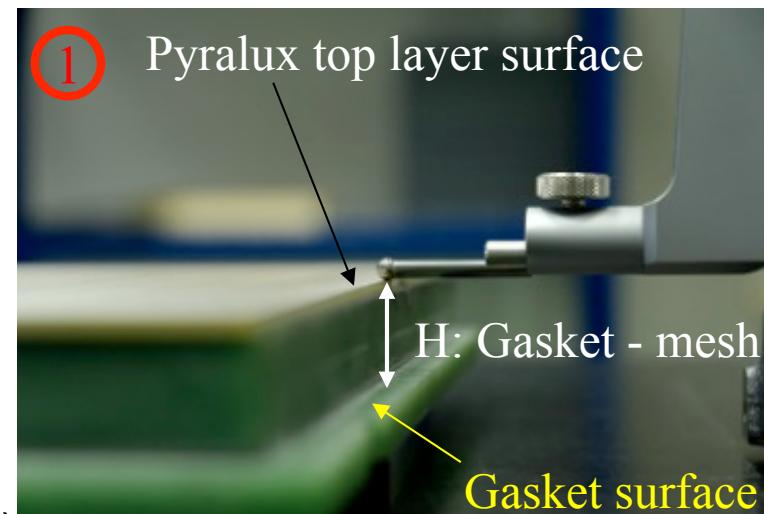
Module assembly & Q/C

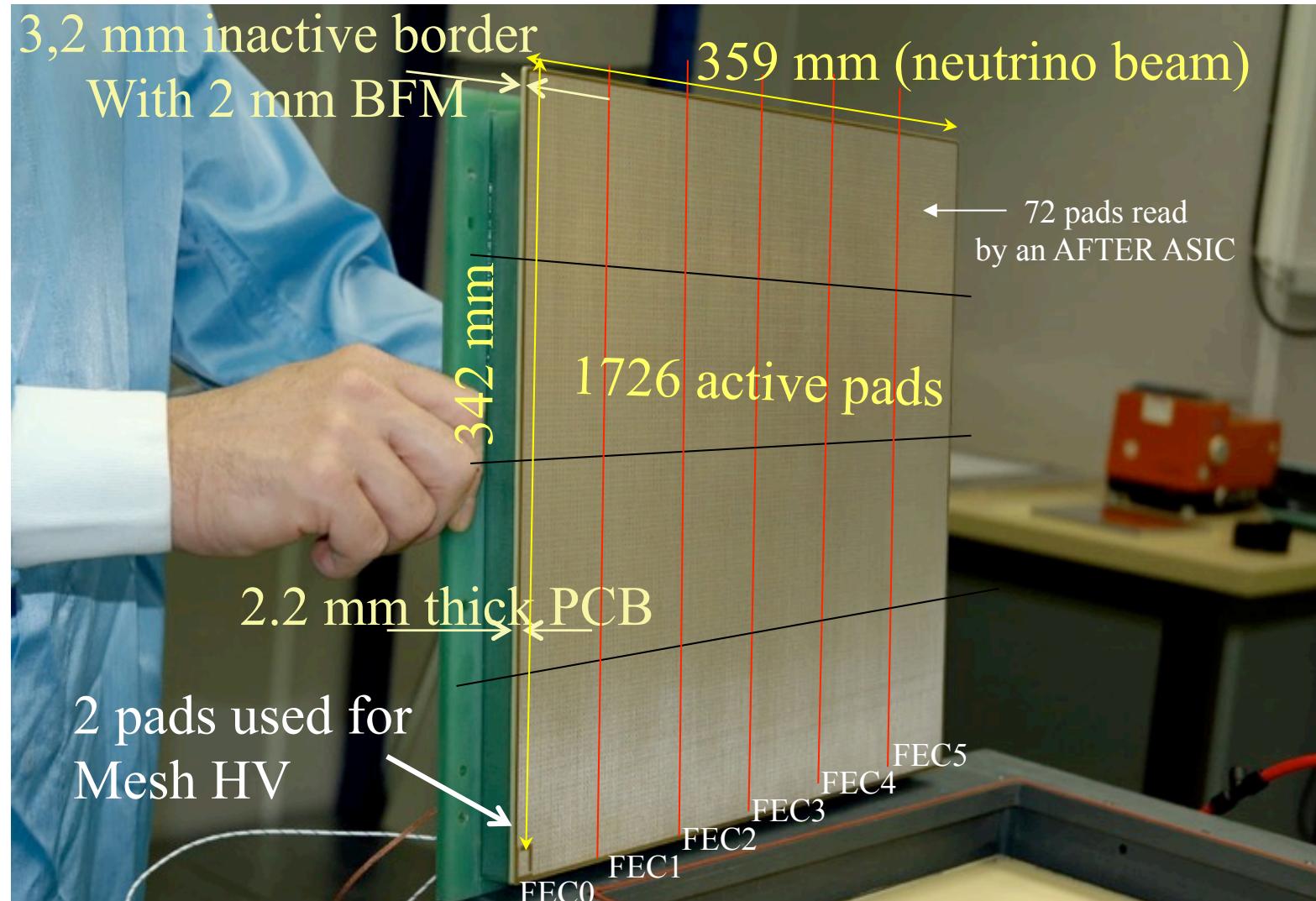


T2K/TPC Europe Production lab. @ CERN



- Assembly-tests of the modules @ CERN, in a lab in the CEA/IRFU CERN antenna bdg 182
- 4 technicians team (including 2 from UNIGE) & calibration by the T2K/TPC Europe collaboration : HV filter integration, mechanical metrology and gas tightness Q/C (1 module / day)



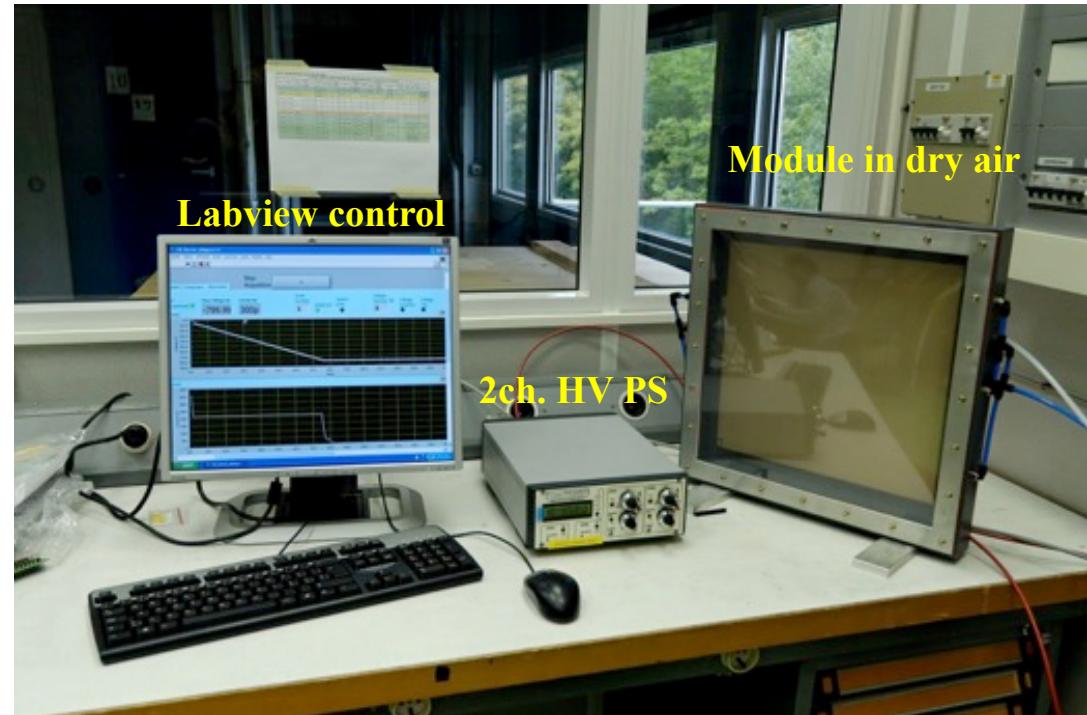


Bulk-micromegas detector cost (PCB+mesh+mesh integration+connectors): ~10 k€ /m²

- **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

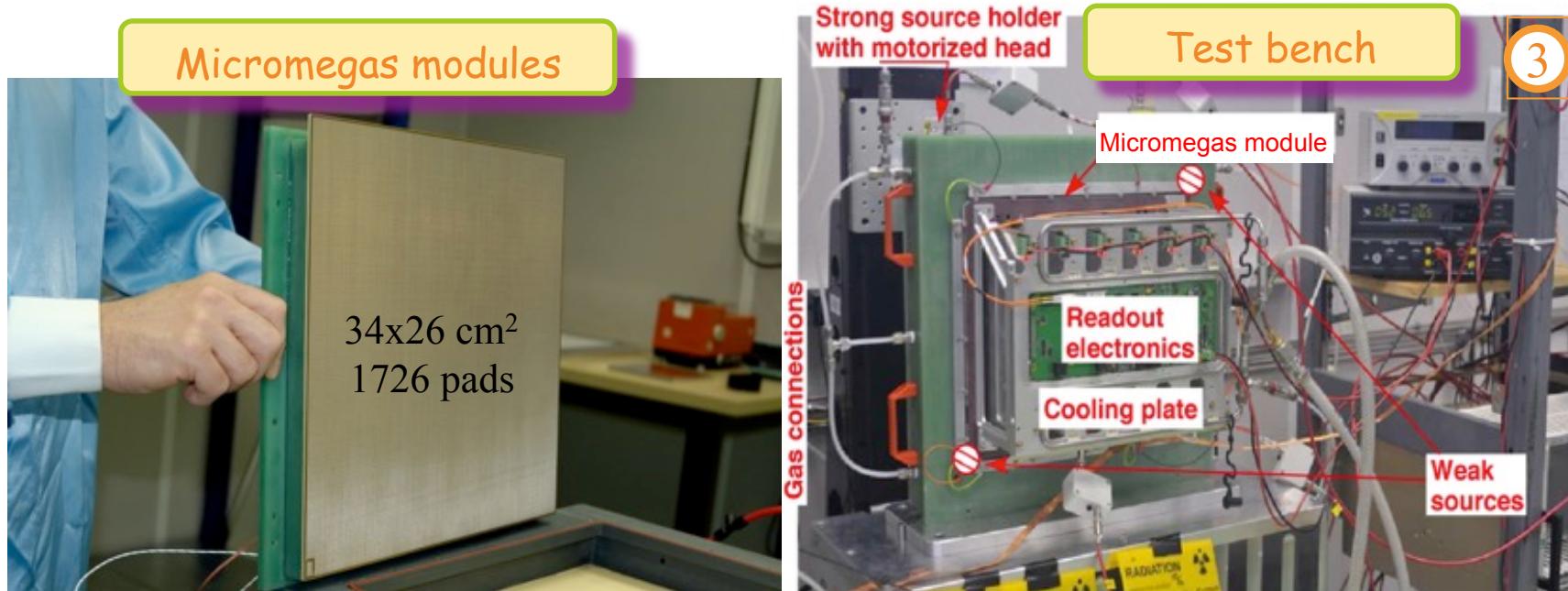
Typical values

- ✓ 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: BULK-MICROMEGAS MODULE QUALIFICATION

- ✓ Gas chamber filled with T2K/TPC gas mixture Ar+2%iC4H10+3%CF4 (2% relative precision)
- ✓ 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

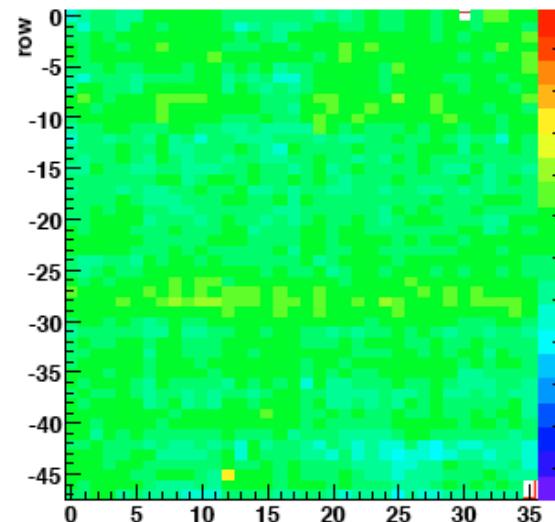


- ✓ **Full pad per pad calibration** : complete scanning of the active area with a X-Y motorized strong ^{55}Fe x-ray source, with on-line monitoring of sparking rate
- ✓ **Gain and ^{55}Fe 5.9 keV resolution** is measured for each of the 1726 pads with the T2K/TPC AFTER Front-End Electronics (400 evts / 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.

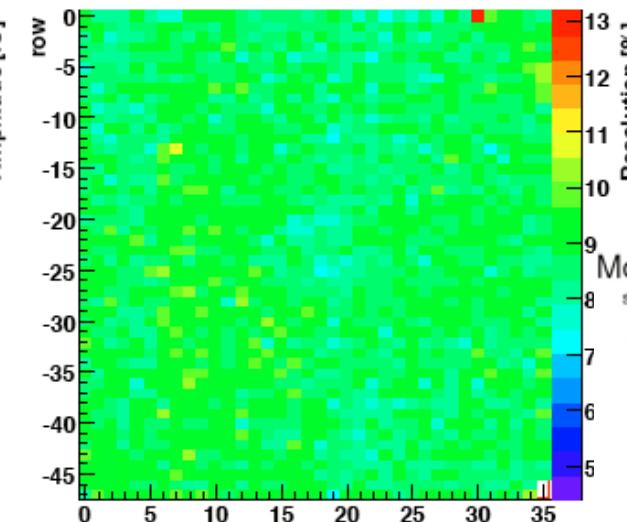
BULK-MICROMEGAS MODULE PERFORMANCES

1726 pads scan @ -350 V

Map of the gain (mean value)



Map of the resolution (sigma)



1 FEC dead ch.

^{55}Fe spectrum

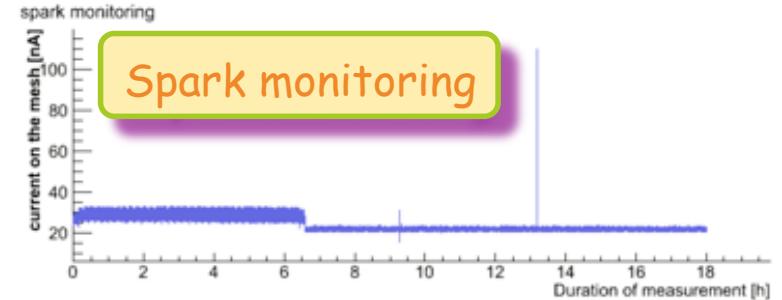
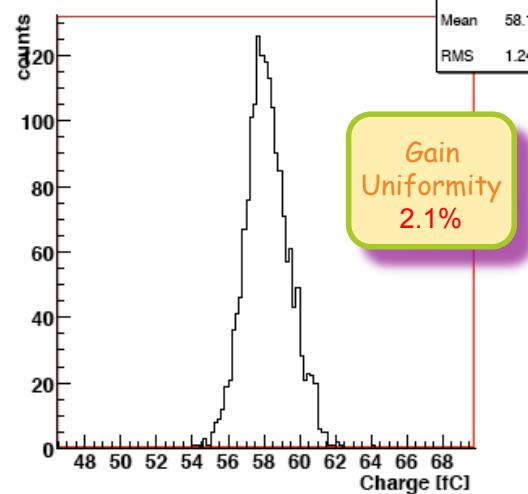
MM036, 350V



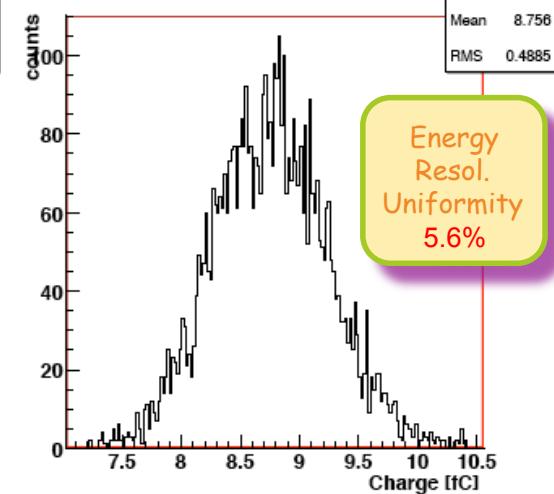
	Mean	RMS	χ^2/ndf	Constant	Mean	Sigma
Mean	51.07	18.86	105.9 / 13			
RMS				8739 ± 39.4		
χ^2/ndf					51.07 ± 0.02	
Constant						4.247 ± 0.017
Mean						
Sigma						

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

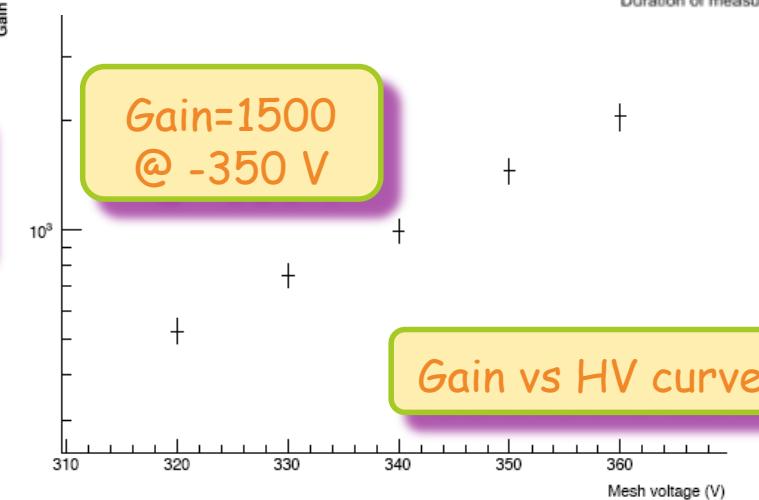
Spark monitoring

Distribution of the mean [fC]

Distribution of the resolution [%]



**Gain=1500
@ -350 V**

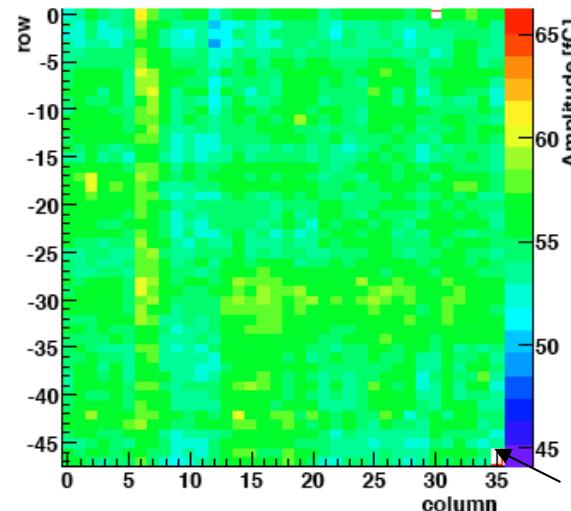


Gain vs HV curve

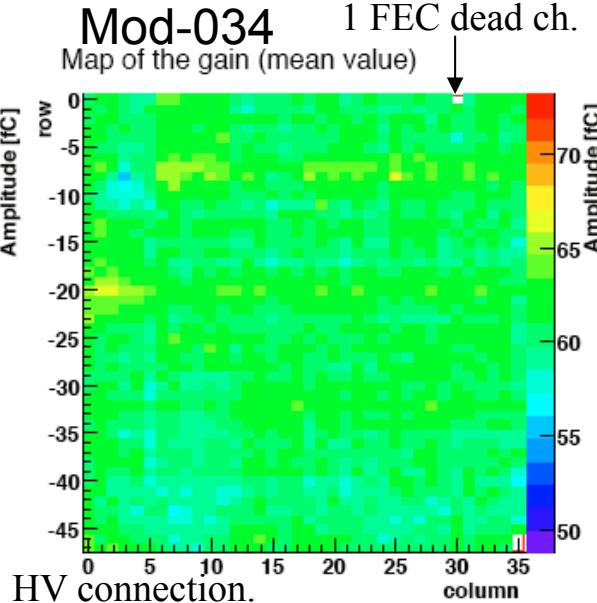
SCAN RESULTS : AMPLITUDE MAPS



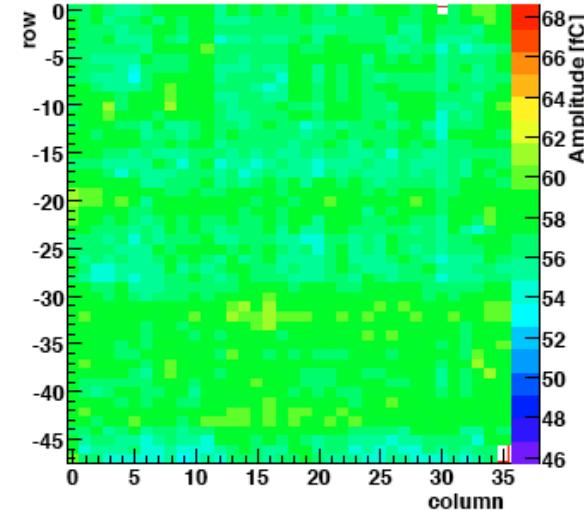
Mod-020
Map of the gain (mean value)



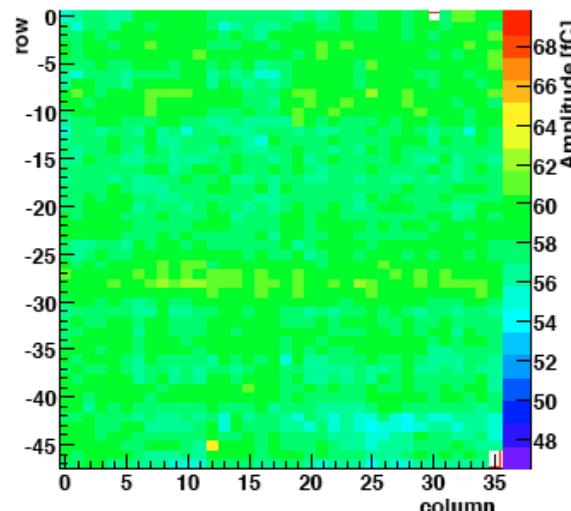
Mod-034
Map of the gain (mean value)



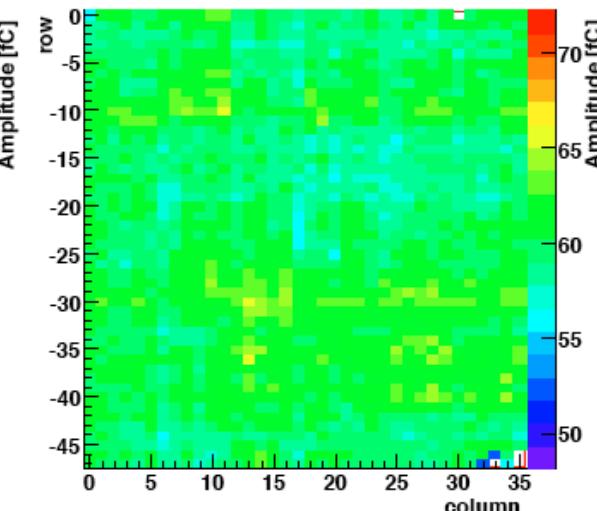
Mod-019
Map of the gain (mean value)



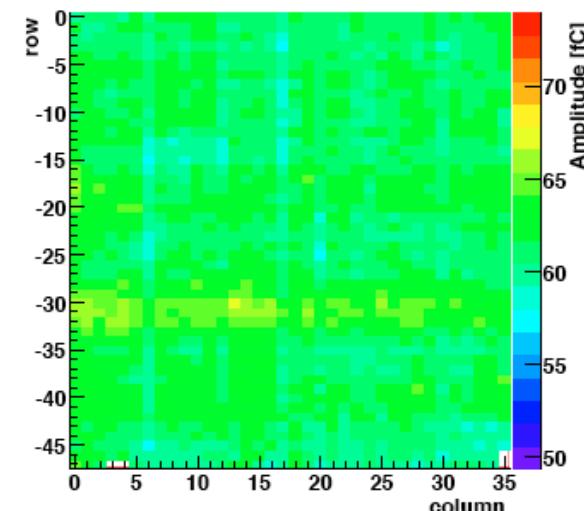
Mod-036
Map of the gain (mean value)



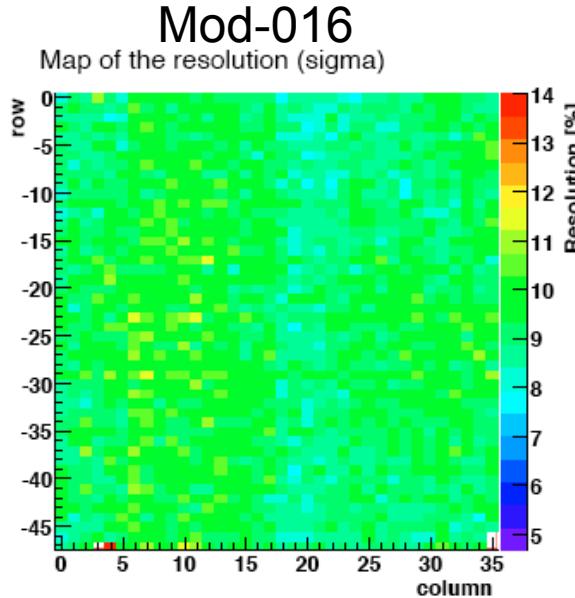
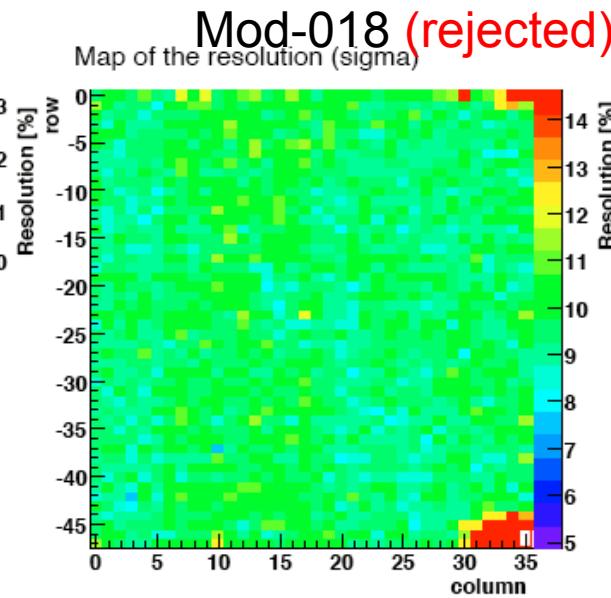
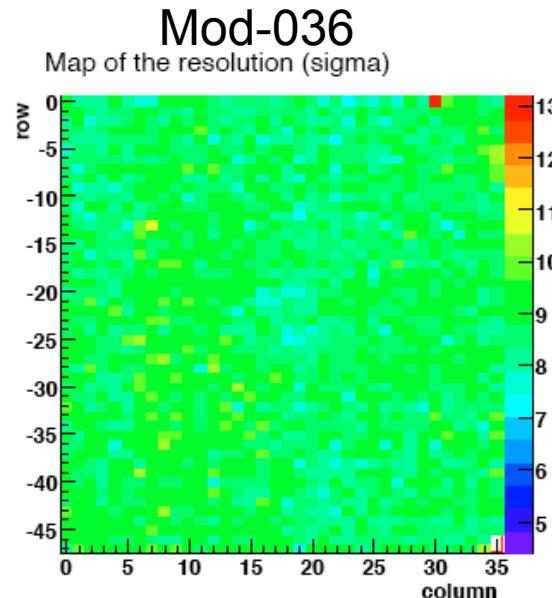
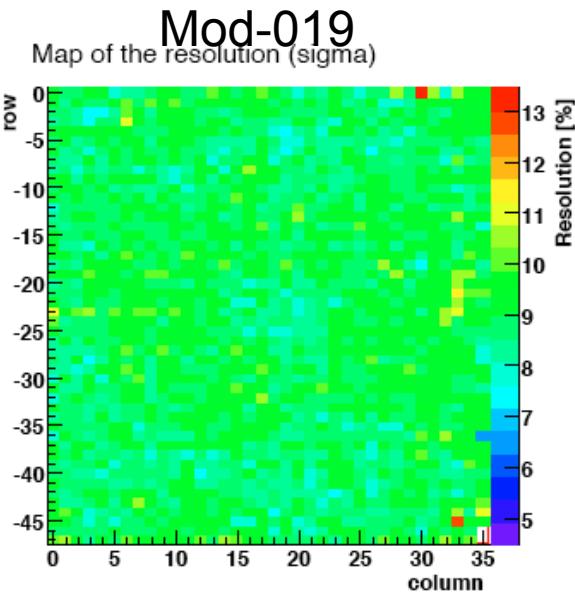
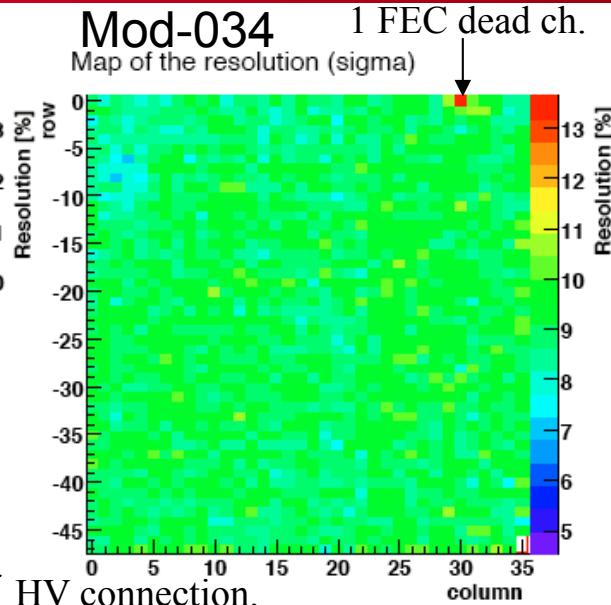
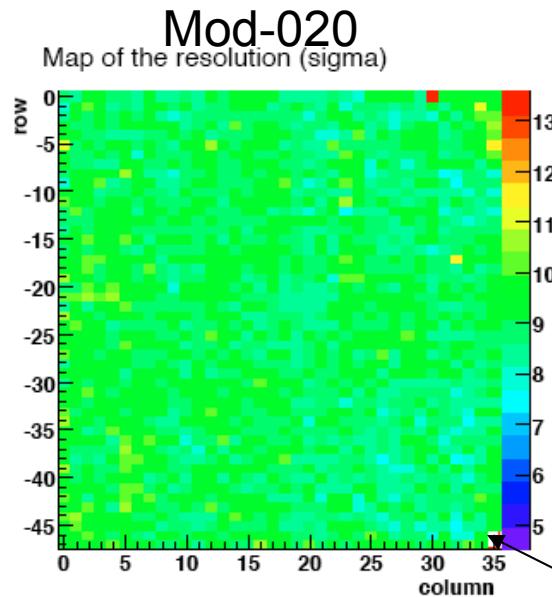
Mod-018
Map of the gain (mean value)



Mod-016
Map of the gain (mean value)



SCAN RESULTS : 5.9 KEV RESOLUTION MAPS



QUALITY AND YIELD OF THE PRODUCTION

Raw analysis with basic electronic calibration, but without any cluster selection
and without slow T,P variations corrections over the ~6 h scans ($\Delta G=3.3\% \pm 0.6\%$ for $\Delta P=1\%$ in TPC-0)

Module	Mean Charge C (fC)	Charge dev. σ (fC)	charge uniformity σ/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%	
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%	

1/2 TPC-MOD-0

rejected -

1/2 TPC-MOD-0

7 modules over 84 were rejected (83% yield)

Only 12 dead pads over the 132902 pads of the 77 modules validated

Gain uniformity over the active area of a module : **~2.8 %**

Gain uniformity over the first **77 modules** : **7%**

5.9 keV resolution : **$\sigma E/E \sim 9,0\%$** (5.9% uniformity over the active area)

5.9 keV resolution uniformity over the first **77 modules** : **2.5 %**

~0,1 spark/h @ 1500 gain (-350 V) for all the modules produced (after burn-in)

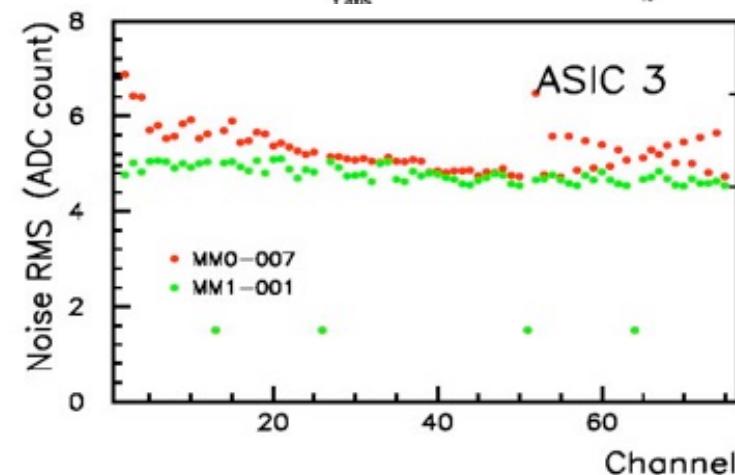
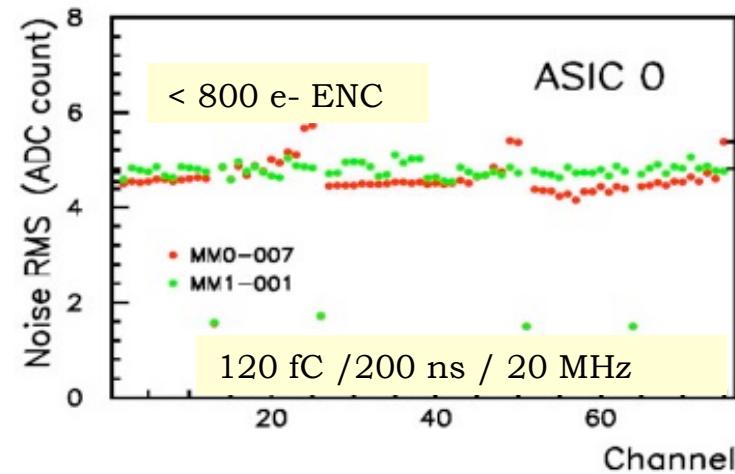
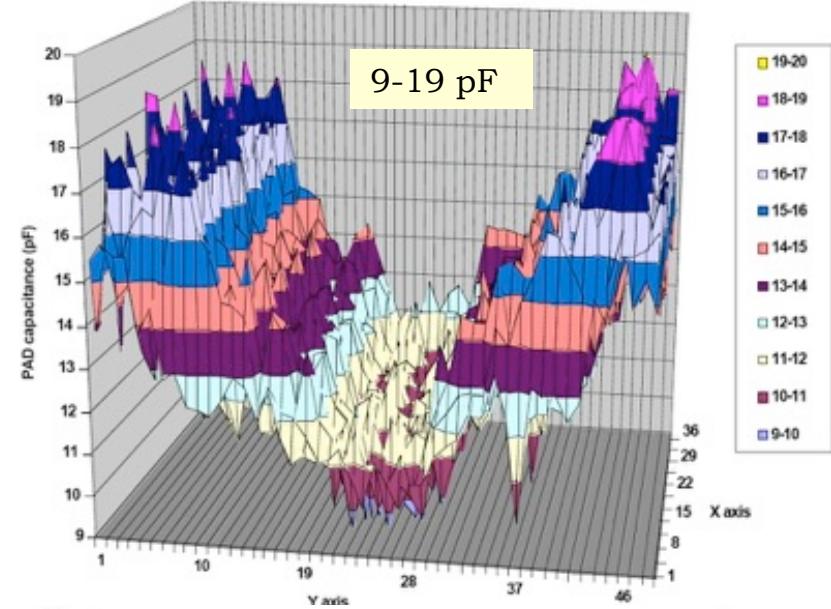
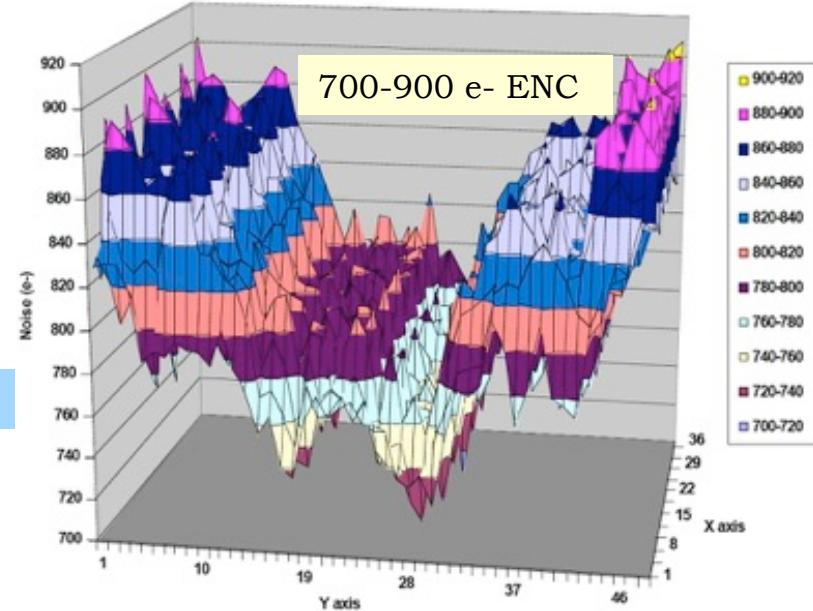
Mod_033	58	1,2	2,1%	9,0			Analysis of data is going on
Mod_031	62	1,9	3,1%	9,0			
Mod_037	65	2,0	3,1%	9,0			

Mean	60,4	1,7	2,77%	9,1	0,54	5,92%
σ	4,9	0,4	0,63%	0,2	0,049	0,48%
σ / Mean	8,2%	21,9%	22,7%	2,5%	9,0%	8,1%

For all 32 modules
1-2 sparks in 10h
0,1 sparks/h
Confirmed on TPC

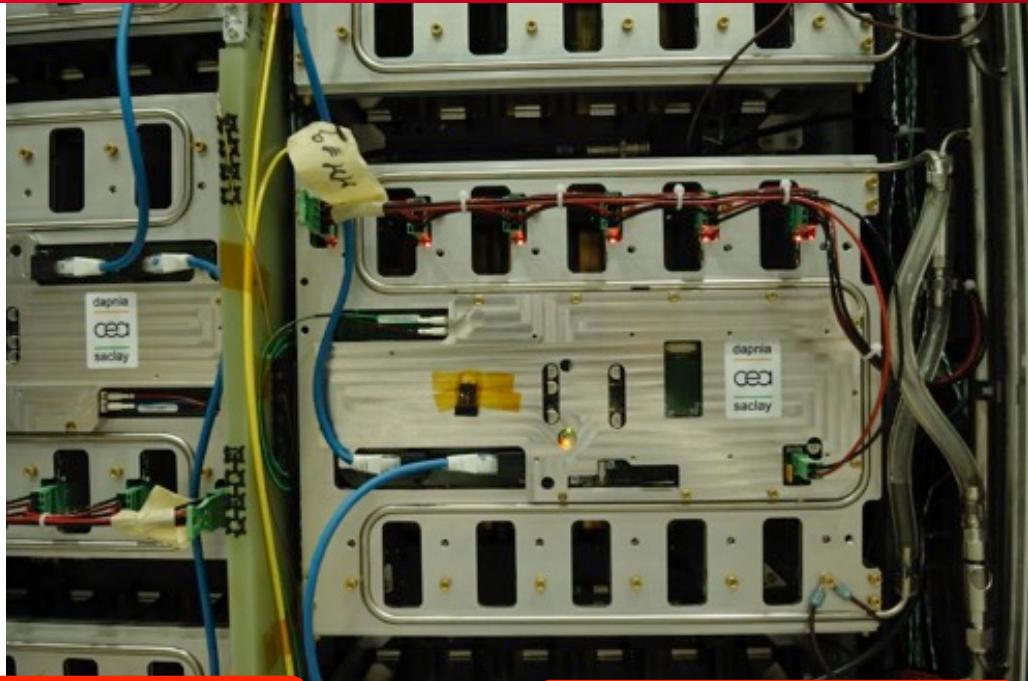
DETECTOR SENSOR + FEE : COUPLING THEM AS SOON AS POSSIBLE ...

Energy range : 120 fC / peaking time : 100 ns / SCA sampling freq. : 50 MHz

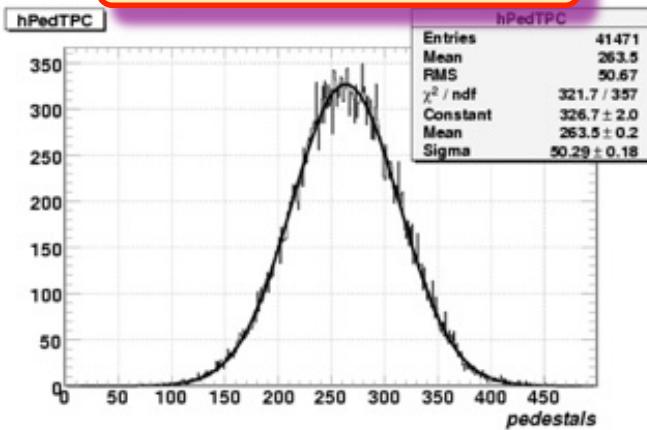


New routing and shielding provides better noise uniformity (~3%) and smaller sensitivity to pick-up noise.

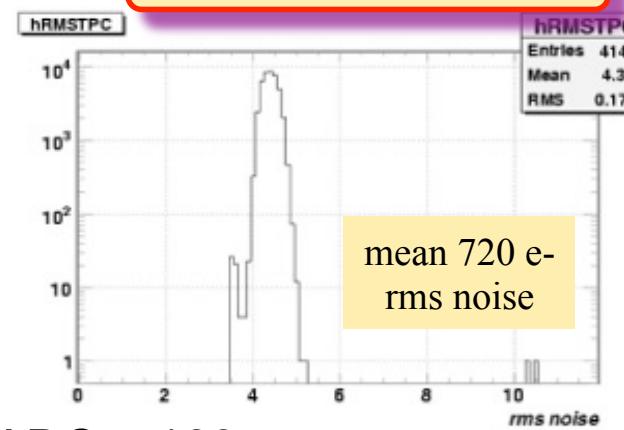
PEDESTALS & RMS NOISE LEVEL OF A READOUT PLANE MEASURED ON SITE @ JPARC.



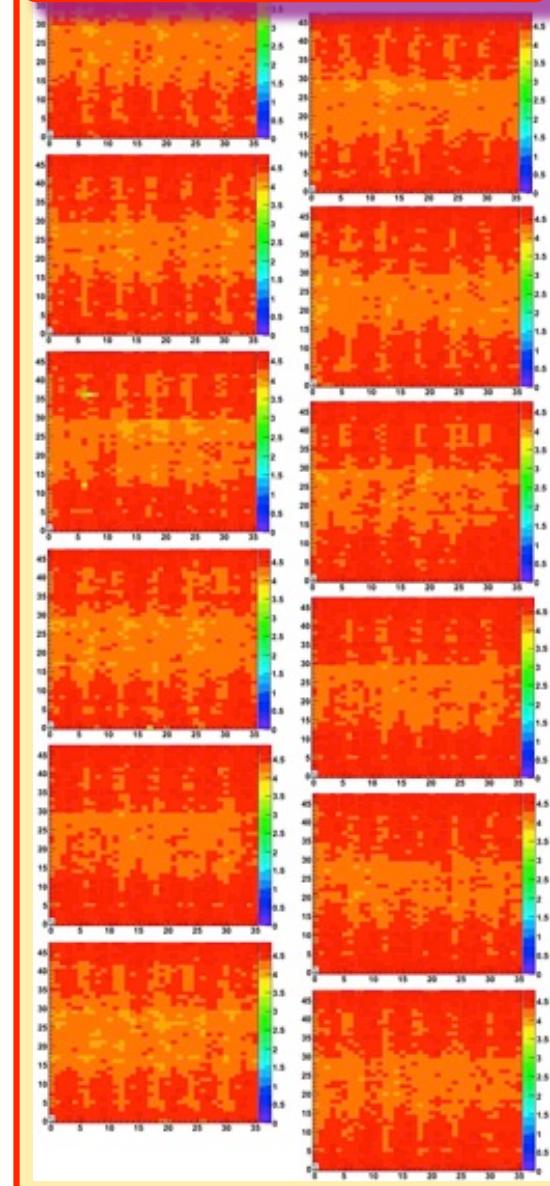
pedestals distribution



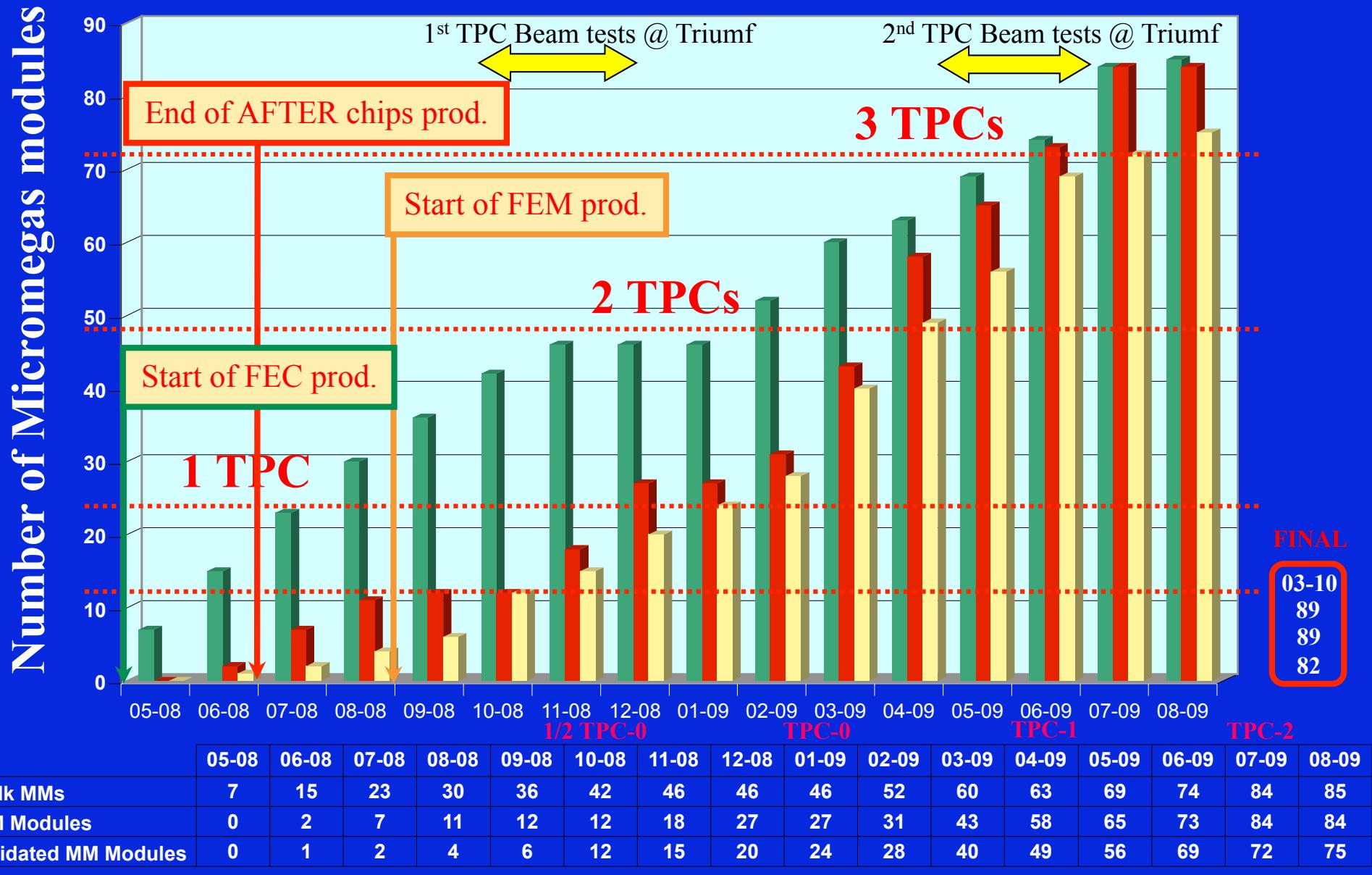
rms noise distribution

1 ADC \sim 160 e⁻

2D map of rms noise



~1.5 YEAR PRODUCTION



Component	needed	produced	OK	yield	spares	used spares
Micromegas PCBs	72	119	100	84%	7	
Bulk-micromegas	72	93	89	96%		
Bulk-micromegas modules	72	89	82	92%	10	2 HV filters repaired
AFTER ASIC (T2K+others)		5334	4726	89%	1220	R&D, ILC/TPC, ...
AFTER ASIC (TPC/FEC)	1728	2120			172	
AFTER ASIC (FGD)	300	400			100	
FEC (TPC+MM test bench)	444	514	499	97%	55	
FEM (TPC)	72	93	84	90%	8	1
DCCs (ML405 based kits)	18	20	9		3	
LV cables + R/O Optical fibers	6+12	9+15			3+3	
Cooling mechanicals	72	76			4	
LV + HV powersupply crates	2+1	3+2			1+1	24 spare HV ch.

- 12 dead channels (from bulk-micromegas) over 124272 channels !
- 6 years operation with only 1 FEM failure and 2 HV filters to repair (despite the 2011 earthquake !)

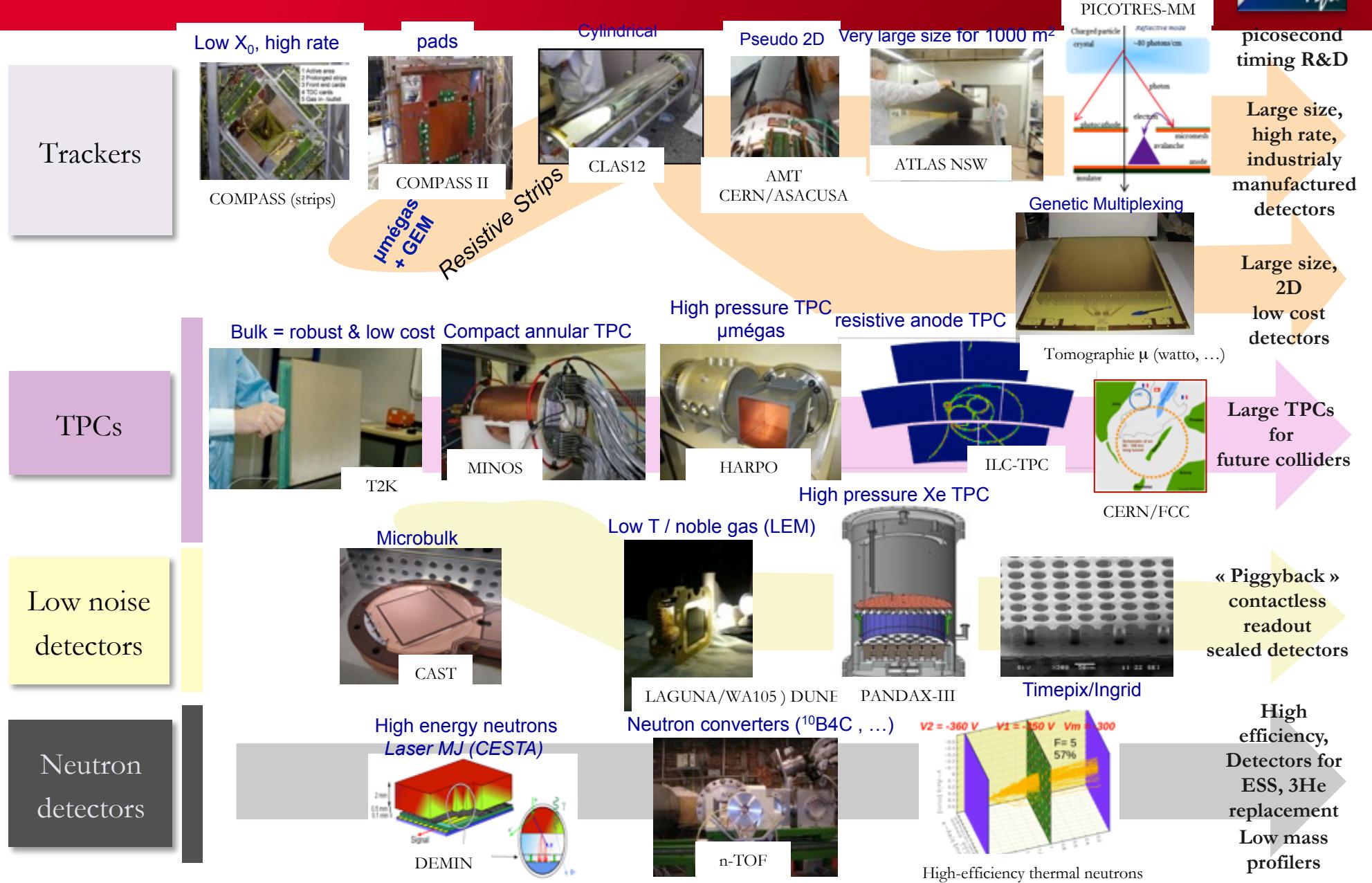
over 7 years 3 m.year for mgt, 19 m.year for elec. 12 men.year for detect. 4 men.year meca

Component	Investment (k€) R&D / prod.	Manpower (FTE x year)	Total Cost (1 FTE~140 k€)
ASIC design, test & production (2 runs; 5000 chips)	80 / 91	6	1010
Analog Front-End Cards (444 cards)	35 / 139	6	1000
Digital Front-End Cards (85 cards)	27 / 43	6	912
Front-End Electronics TOTAL	142 / 273	18	2922
Module mechanicals (76)	36 / 196	4	795
Bulk-Micromegas (82)	51 / 115	9	1431
Bulk-MM Module TOTAL	87 / 311	13	2226
T2K/TPC laboratory, equipments & tests (+ management FTE)	35 + 60	6	935
Total	229 k€ / 664 k€	37 FTE	~6.1M€

- The production and QA/QC of the bulk-micromegas modules for T2K/TPCs was done in ~1.5 years. The 72 modules installed in 2009 are still today operating smoothly with the required performances.
- The bulk-micromegas technology is mature and used as the “baseline” micromegas technology in many experiments around the world.
- Two industrials (ELVIA, Fr and ELTOS, It), CERN/EN-ICE-DEM (Rui de Oliveira) and IRFU/ MPG workshop have the know-how to produce bulk-micromegas.
- QA/QC and validation of the bulk-micromegas modules was done by the european T2K/TPC collaboration at CERN with the final Front-End Electronics.
- Based on this successfull experience and the one aquired in the development of the ILC/TPC prototypes, the T2K/TPC upgrade can make use of the resistive bulk-micromegas as a baseline design to minimize the number of electronics channels and avoid the need of the spark-protection of the Front-End ASICS.

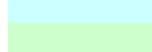


IRFU MPGDS ROADMAP



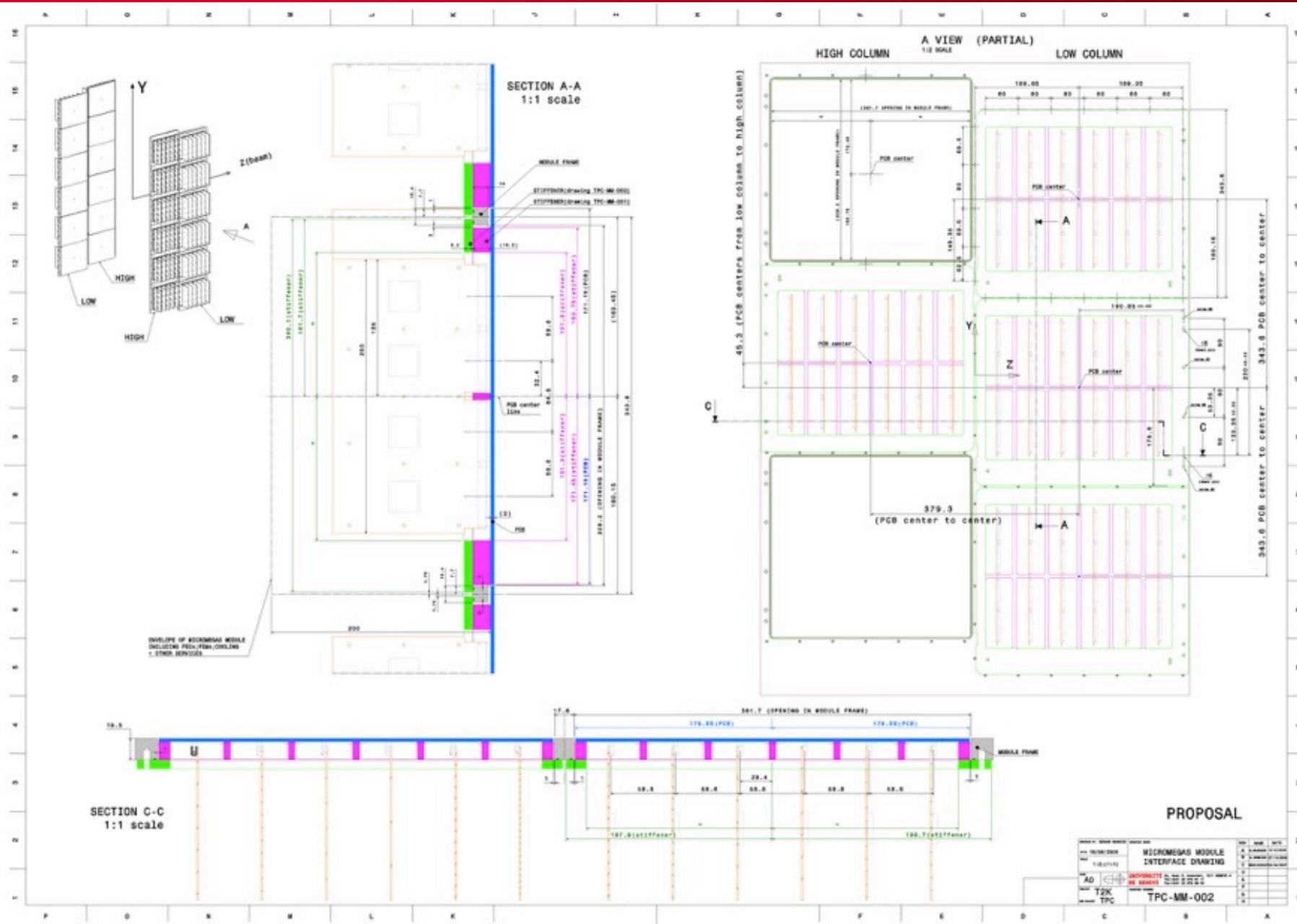
T2K/TPC WORK BREAKDOWN STRUCTURE



A. Delbart T2K/TPC WP4&5&6 WBS
 11/06/07 V2
 Validated october 2007
 Currently under validation

WBS#	Task	Responsible Institute	Other Manpower or Funding
1 0000	TPC Mechanical	Triumf / Victoria	
2 0000	Gas System	Triumf / Victoria	
3 0000	ND280 Integration	Triumf / Victoria	
4 0000	Micromegas detector	Saclay	
4 1000	Bulk Micromegas Production	CERN/TS-DEM-PMT	
4 1100	PCB	CERN/TS-DEM-PMT	
	Raw FR4 materials & PCB production	CERN/TS-DEM-PMT	
	FR4 & PCB production metrology	CERN/TS-DEM-PMT	
	PCB electrical control & optical metrology	CERN/TS-DEM-PMT	
	Micromegas PCB thickness and flatness metrology	CERN/TS-DEM-PMT	
4 1200	bulk micromegas	CERN/TS-DEM-PMT	
	Pyralux PC1025 procurement	CERN/TS-DEM-PMT	
	"Méamine" cover	CERN/TS-DEM-PMT	
	woven micromesh procurement	Saclay	
	24 mesh frames	CERN/TS-DEM-PMT	
	mesh stretching in external company	CERN/TS-DEM-PMT	
	logistics for mesh stretching : CERN > external company	CERN/TS-DEM-PMT	
	logistics for connectors (& mesh ?) procurement : Saclay > CERN	Saclay	
	Bulk micromegas production	CERN/TS-DEM-PMT	
	global visual mesh flatness control	CERN/TS-DEM-PMT	
4 1300	Bulk Micromegas Quality Control	Saclay	
	Q/C "fakir" test bench	Saclay	
	HV powersupply, DAQ	Saclay	
	On production Bulk Micromegas global current Q/C (on "Fakir")	CERN/TS-DEM-PMT	
	Bulk Micromegas pad per pad Q/C (on "Fakir")	Saclay	UNIGE/IAFE

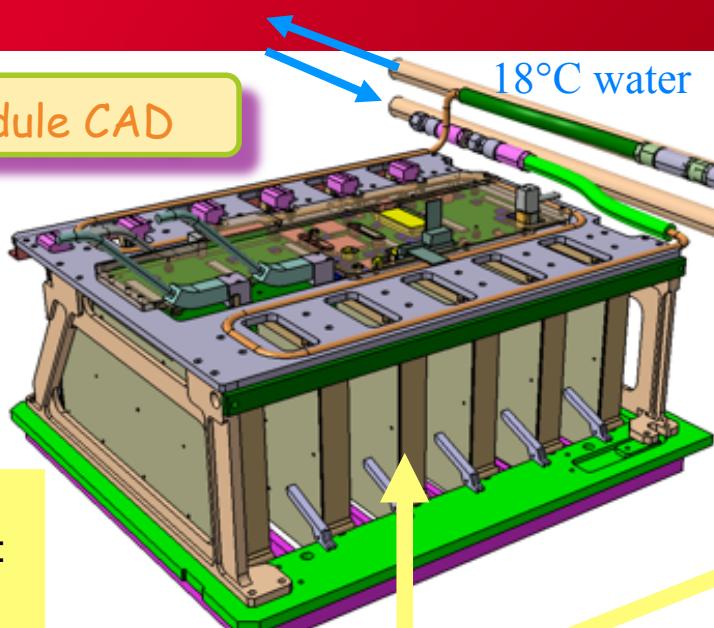
14 pages ...
 More than 200 tasks



FRONT-END READOUT ELECTRONICS



Module CAD



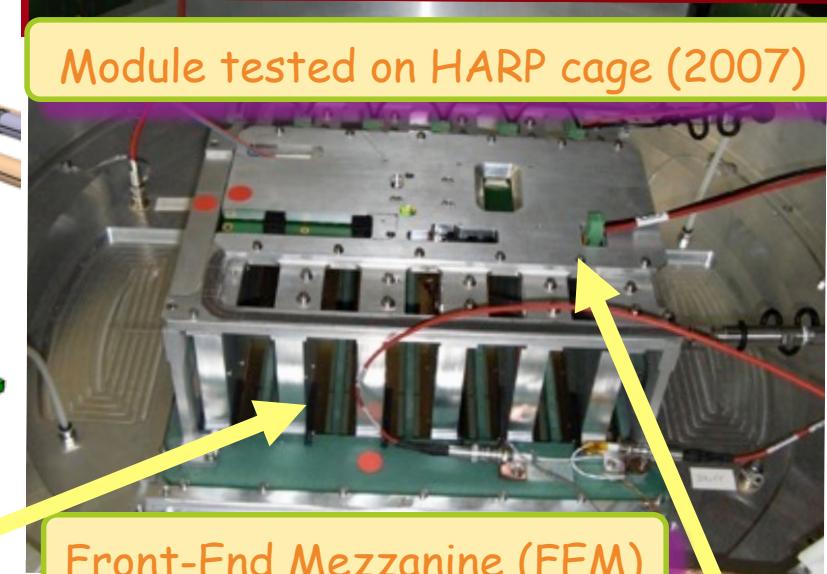
Total Cost of FEE
(ASIC+FEC+FEM) :

~2 € / ch.

Power consuption :
~16 mW/ch

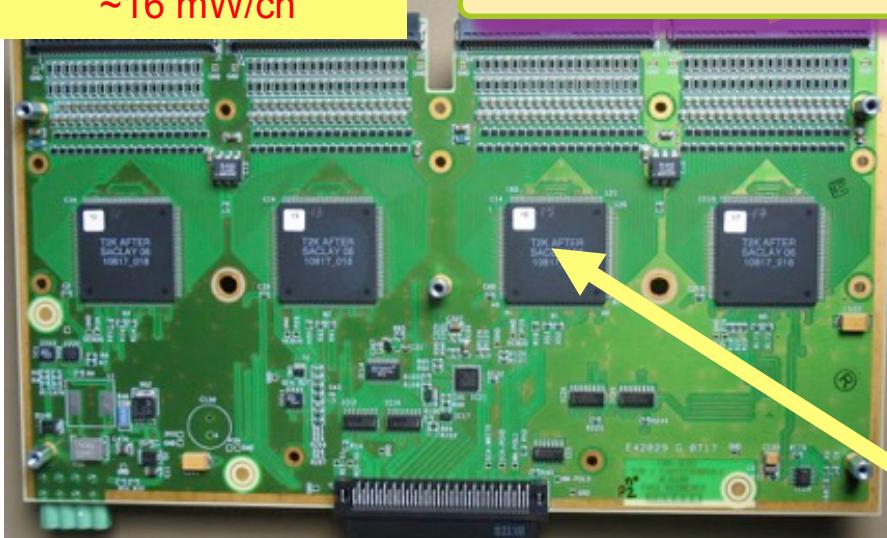
18°C water

Module tested on HARP cage (2007)



Front-End Mezzanine (FEM)

288 ch. with 4x72 ch. AFTER ASICs



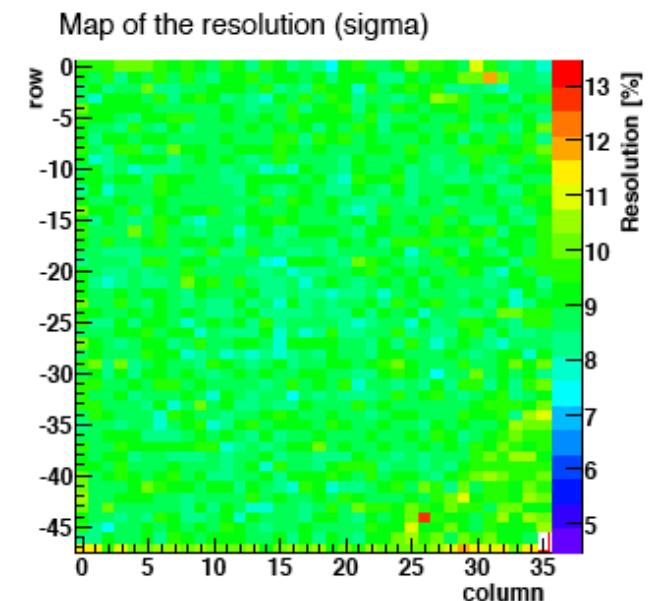
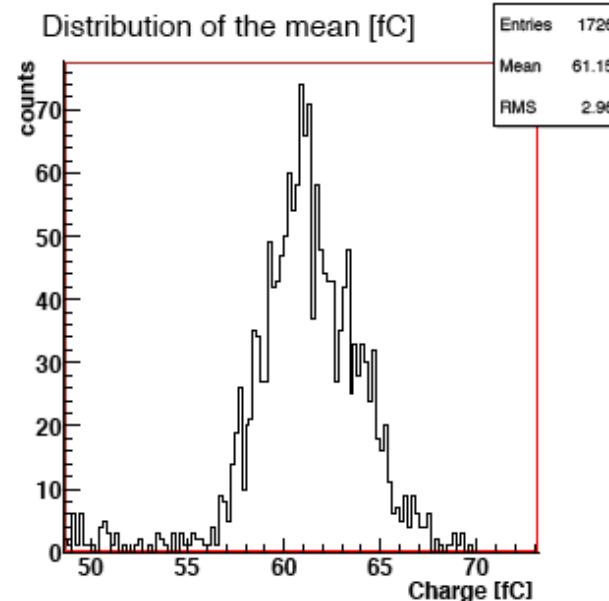
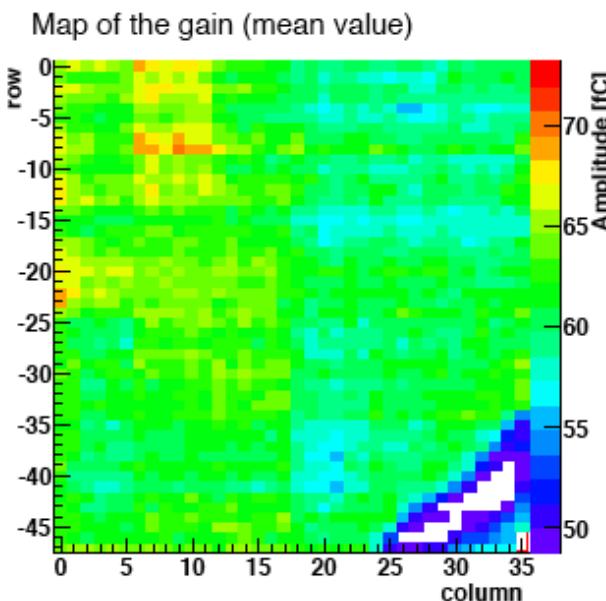
Front-End Card (FEC)

AFTER
ASIC

1728 ch. readout

EXAMPLES OF REJECTED MODULES

REJECTED

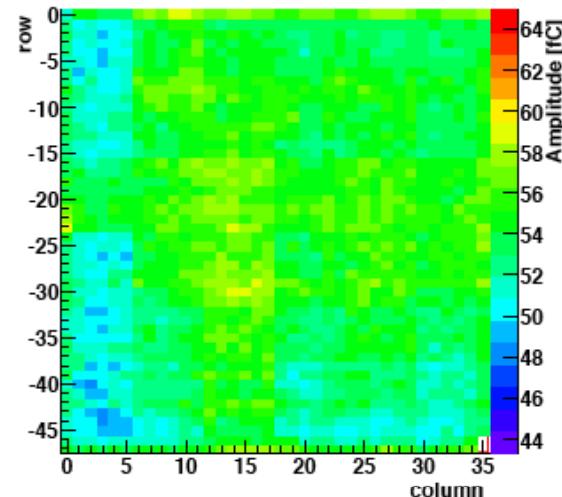


EXAMPLES OF REJECTED MODULES



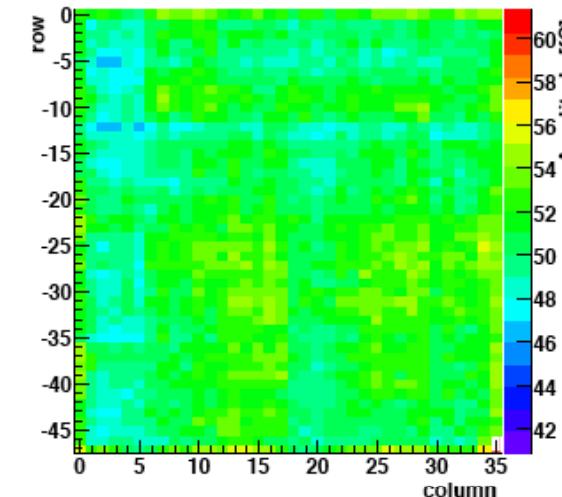
MM102, run #7, box #

Map of the gain (mean value)



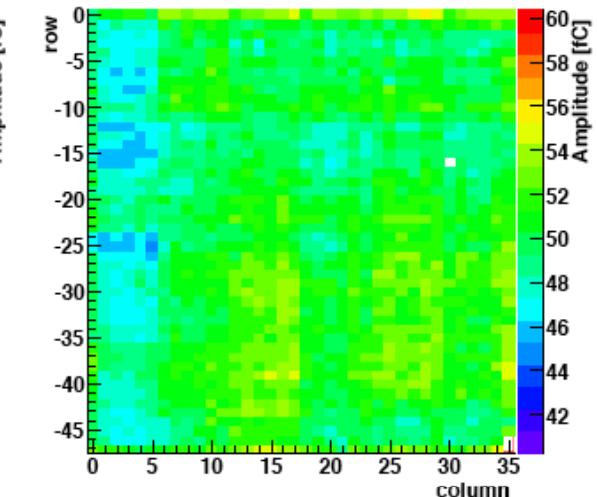
MM103, run #6, box #

Map of the gain (mean value)

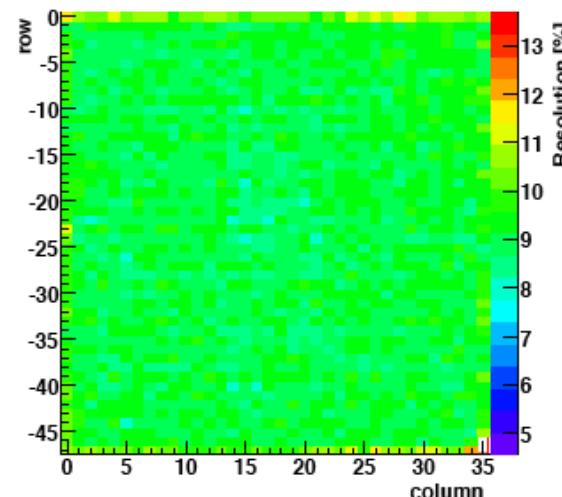


MM104, run #31, box #

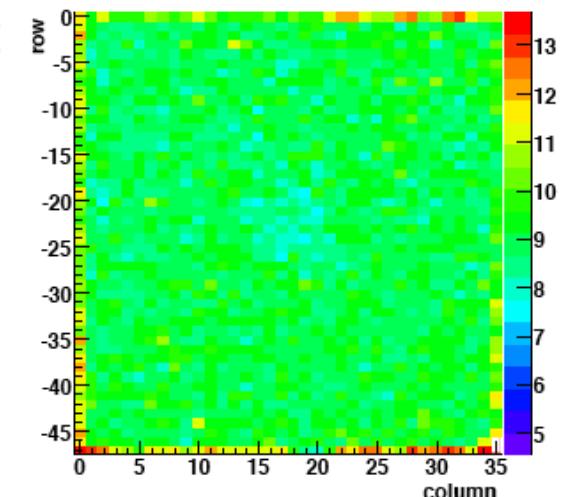
Map of the gain (mean value)



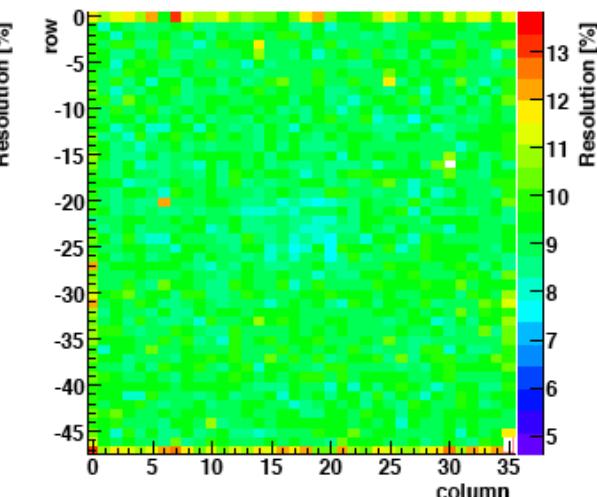
Map of the resolution (sigma)



Map of the resolution (sigma)



Map of the resolution (sigma)

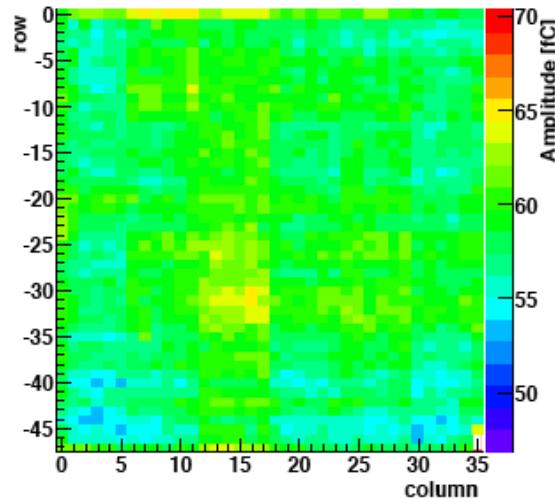


EXAMPLES OF REJECTED MODULES



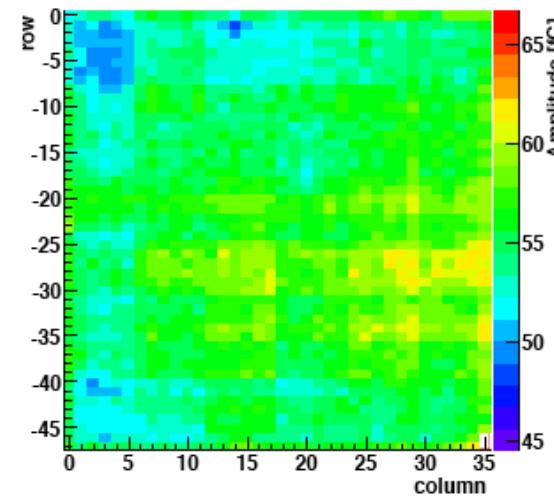
MM100, run #9, box #

Map of the gain (mean value)



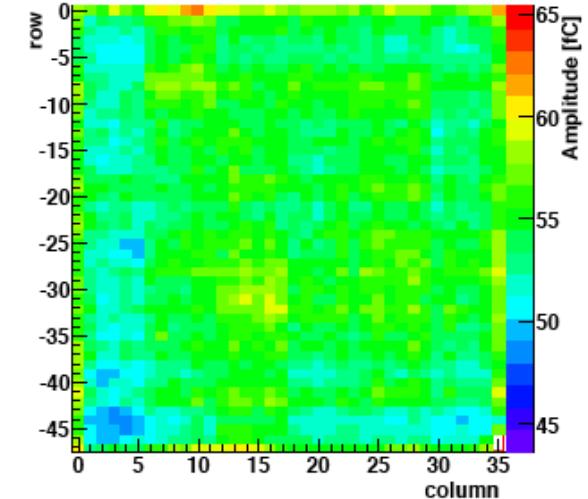
MM101, run #8, box #

Map of the gain (mean value)

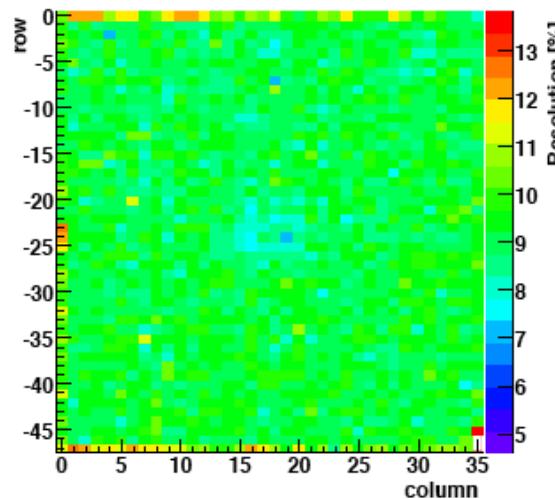


MM107, run #6, box #

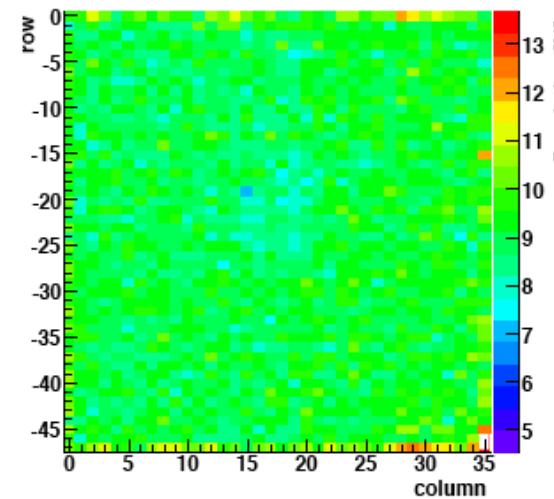
Map of the gain (mean value)



Map of the resolution (sigma)



Map of the resolution (sigma)



Map of the resolution (sigma)

