T2K/ND280 TPC

FLASHBACK ON THE CONSTRUCTION

Alain Delbart (CEA-Irfu)

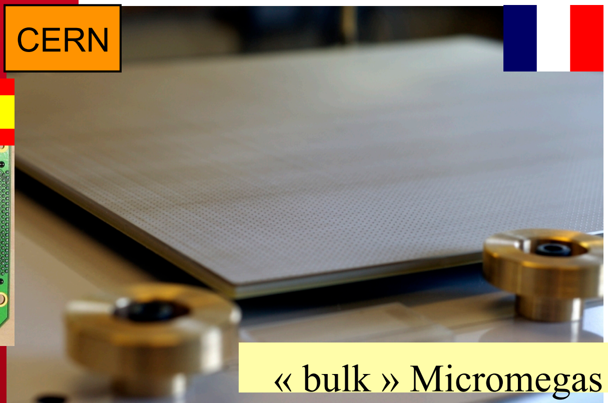
CEA - Saclay

DE LA RECHERCHE À L'INDUSTRIE

cea

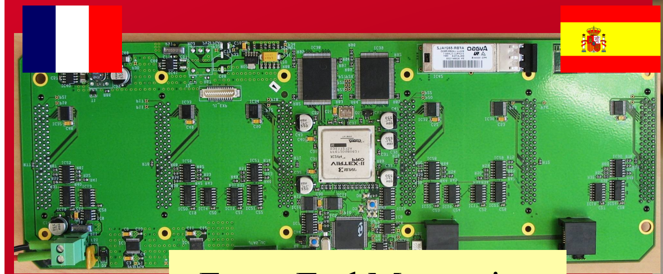
AFTER chip

CERN

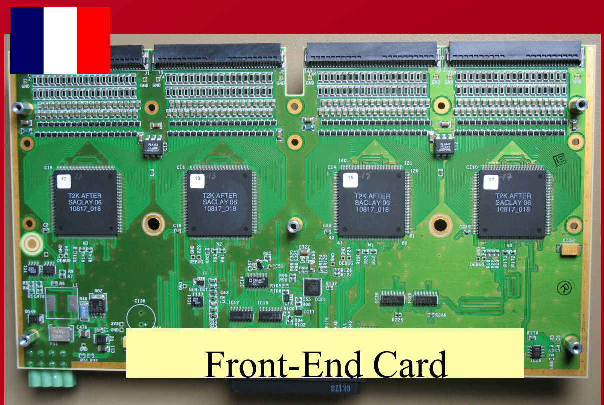


« bulk » Micromegas

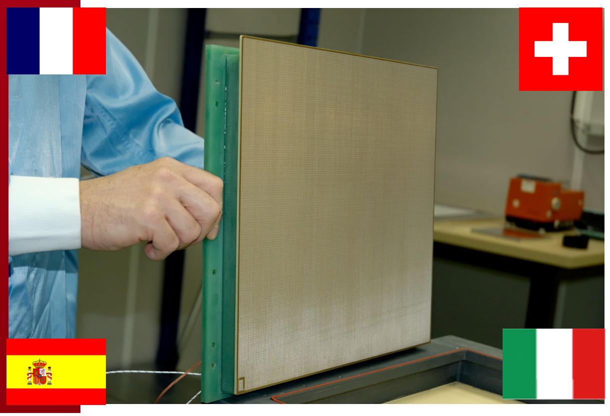
TPC-MOD-0 (@TRIUMF)



Front-End Mezzanine



Front-End Card



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DETECTORS, ELECTRONICS & COMPUTING DIVISION

SERVICE D'ELECTRONIQUE, DES DÉTECTEURS, D'INFORMATIQUE

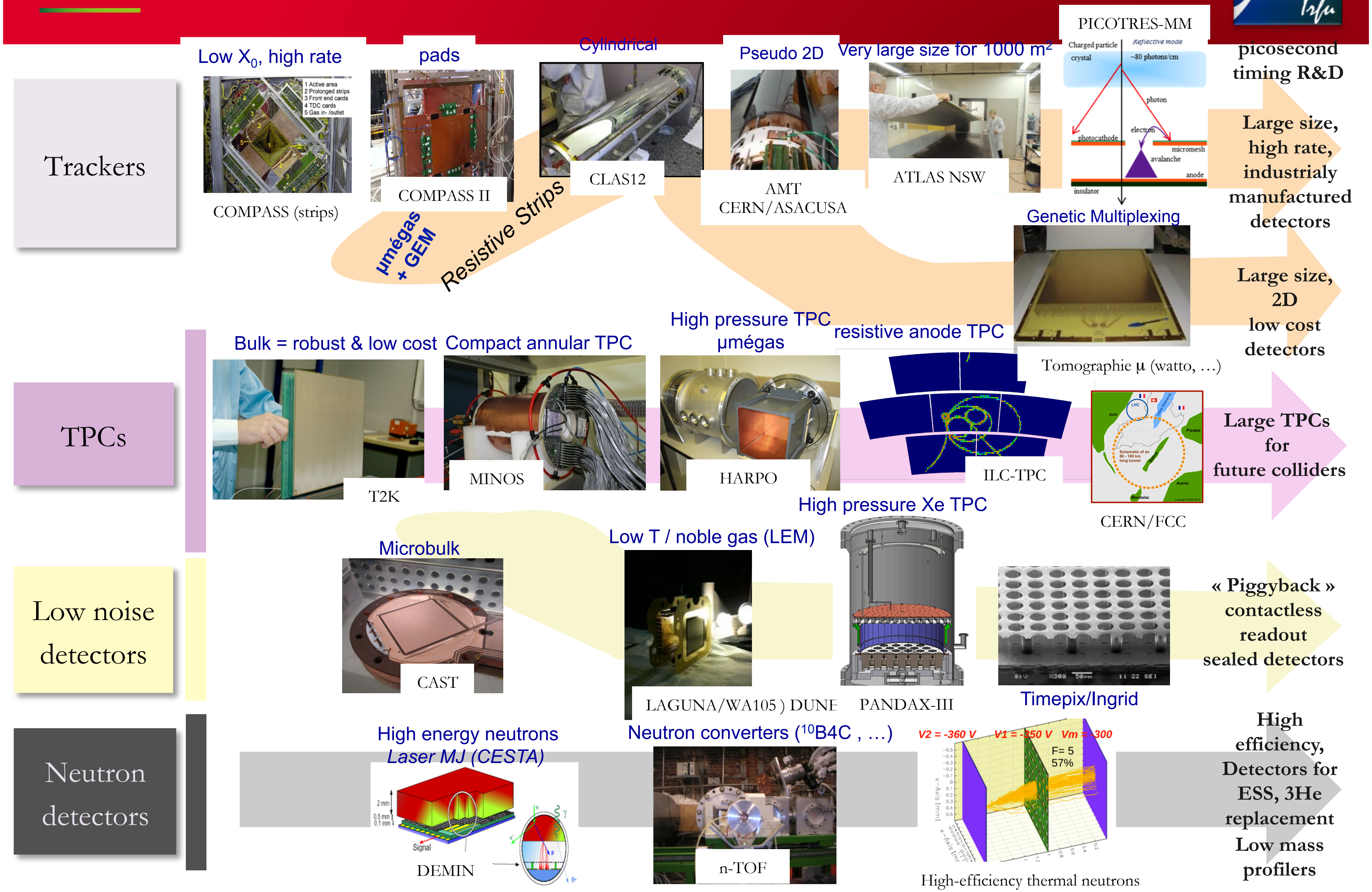
Workshop "Détecteurs gazeux" du réseau Instrumentation In2P3

Clermont-Ferrand, october 13, 2016

OUTLINE

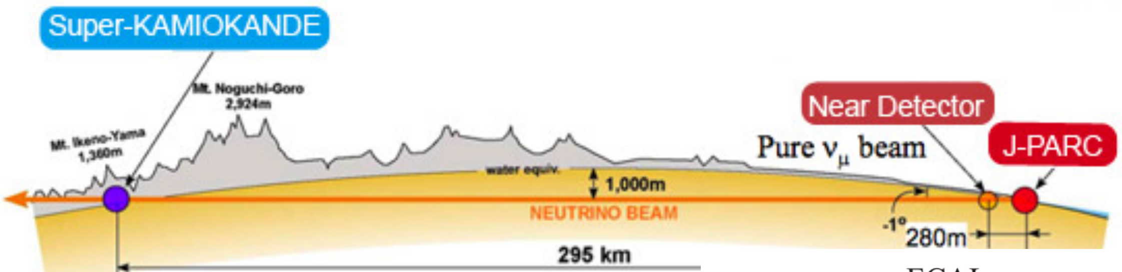
- Context : T2K and the TPCs of the ND280 near detector
- T2K/TPCs project organization and history
- Design of the bulk-micromegas modules and performances
- Feedback on the construction : organization, Q/C, yields of production, cost
- Some thoughts about the keys for success …

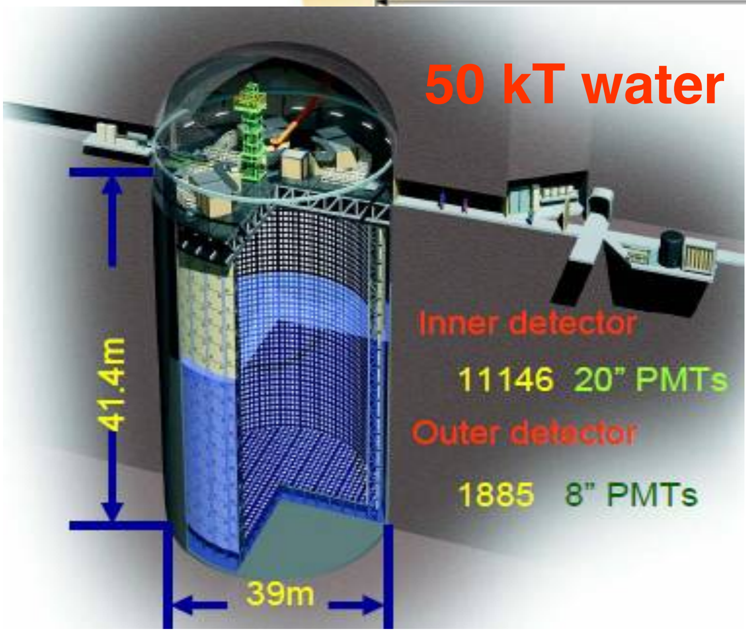
IRFU MPGDS ROADMAP

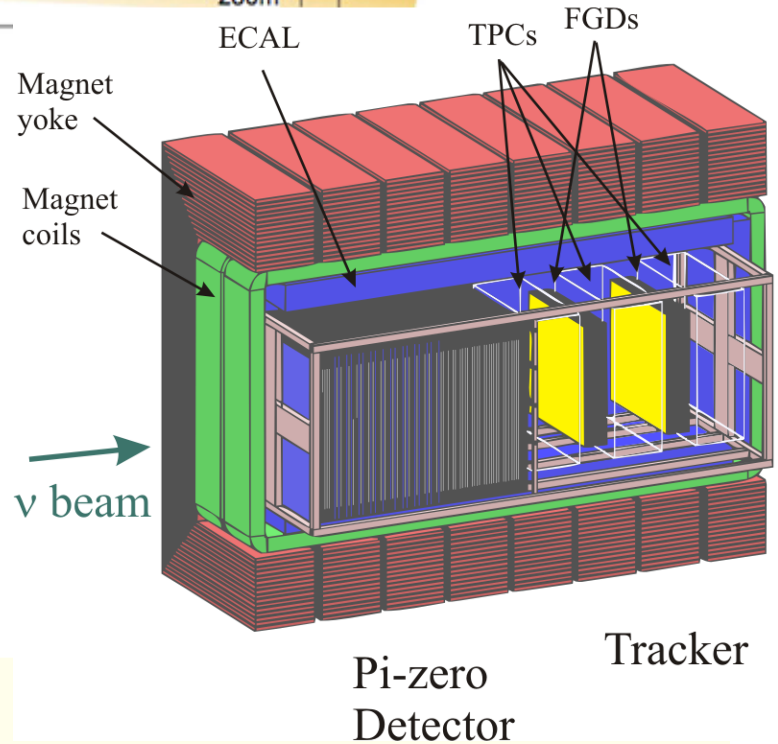


T2K COLLABORATION

~ 500 members, 59 national institutes, 12 countries



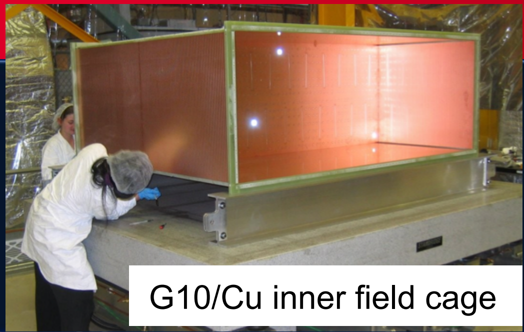


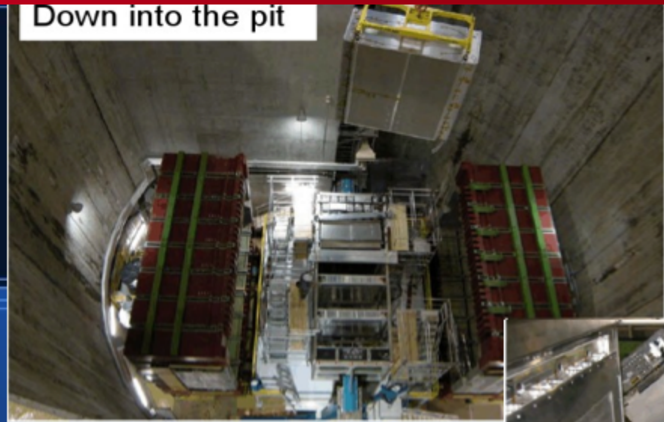


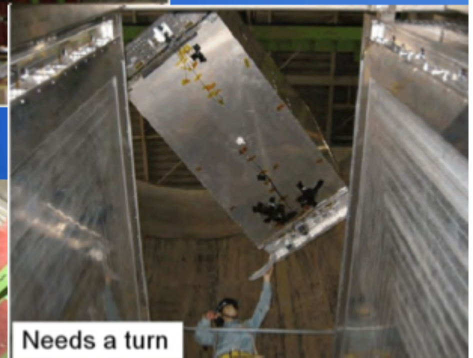
Main Physics Goal: neutrino oscillation

- νμ disappearance for improved accuracy on θ_{23}
- νe appearance to improve sensitivity to θ_{13}

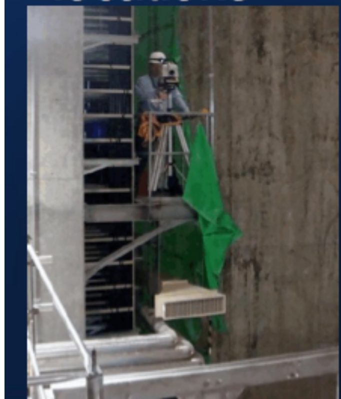
INSTALLATION OF THE TPCS IN ND280

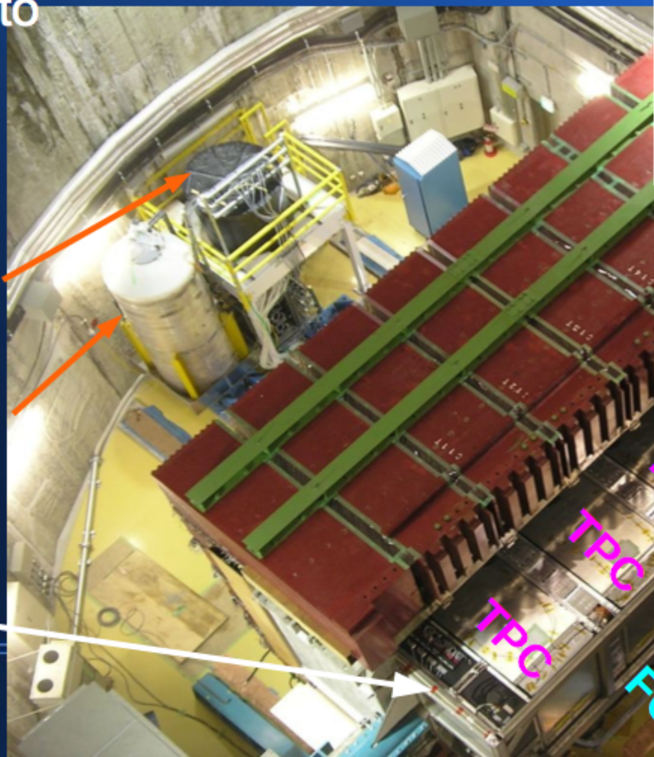






- Involved installing and removing scaffolding to connect all services
- Detectors "dropped" into place by crane
- Survey of detector locations



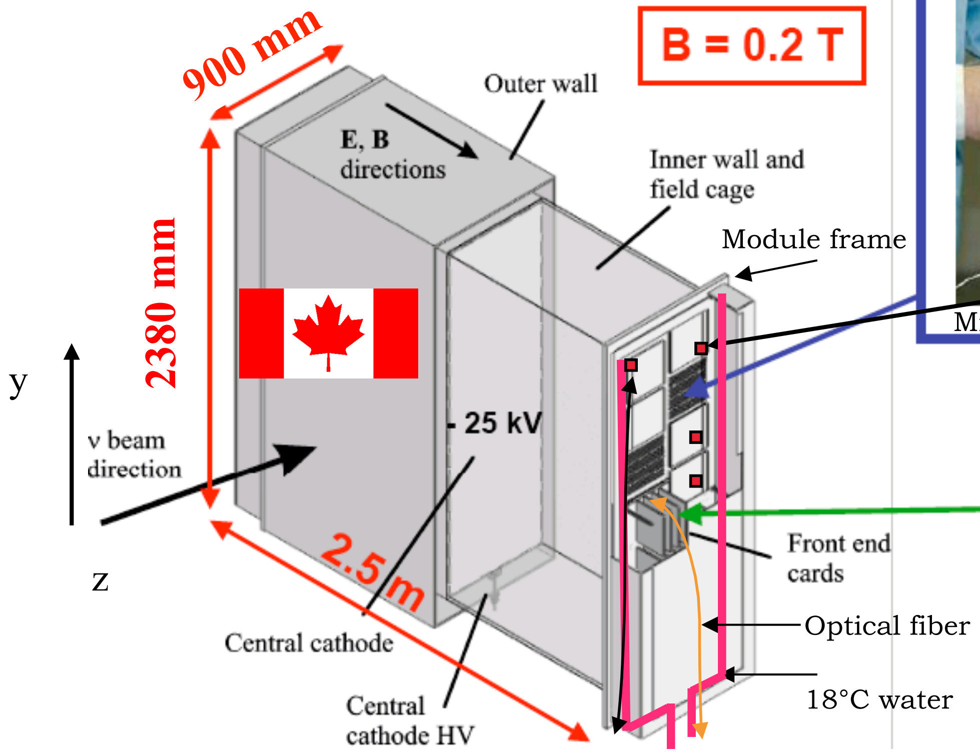


Blair Jamieson
TIPP 2011 June 11

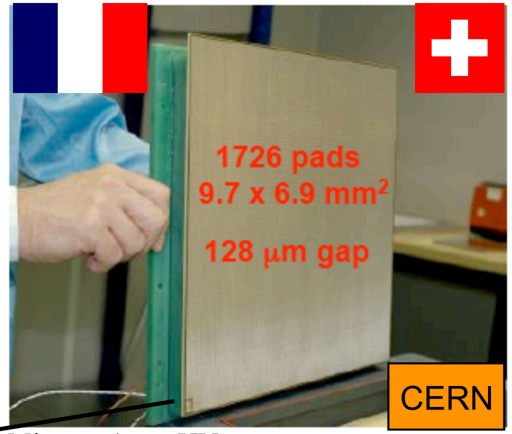
THE T2K/TPC : THE BULK-MICROMEGAS + AFTER ASIC READOUT

Specifications / performances

- ✓ MIP identification and momentum measurement
- ✓ Spatial resolution of 600 μm @ z=1m (Δp/p<10%)

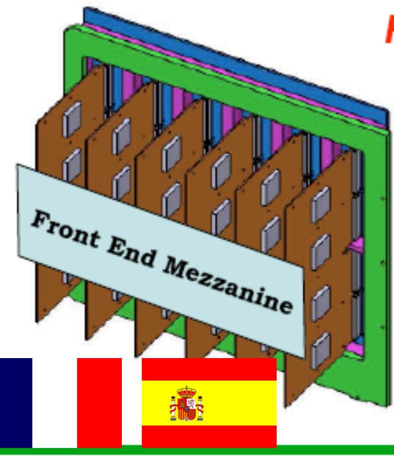


36 x 34 cm² « Bulk » MicroMegas



12 modules per Readout plane

Total of 72 modules



FEE based on the ASIC AFTER

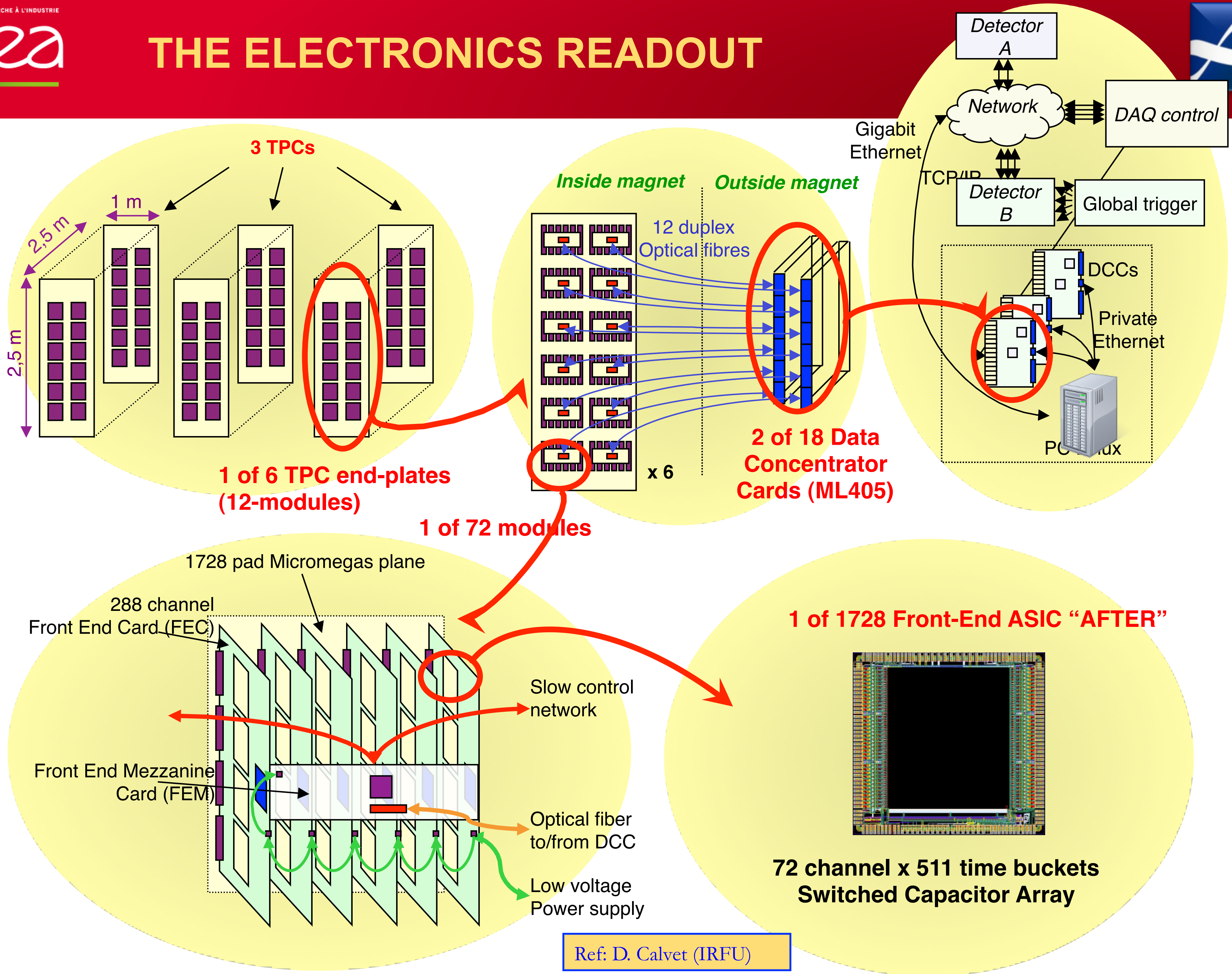
6 FECs + 1 FEM per module

Total of
1728 ASICs
432 FECs
72 FEMs

72 modules for ~9 m² active area
~120k electronic channels

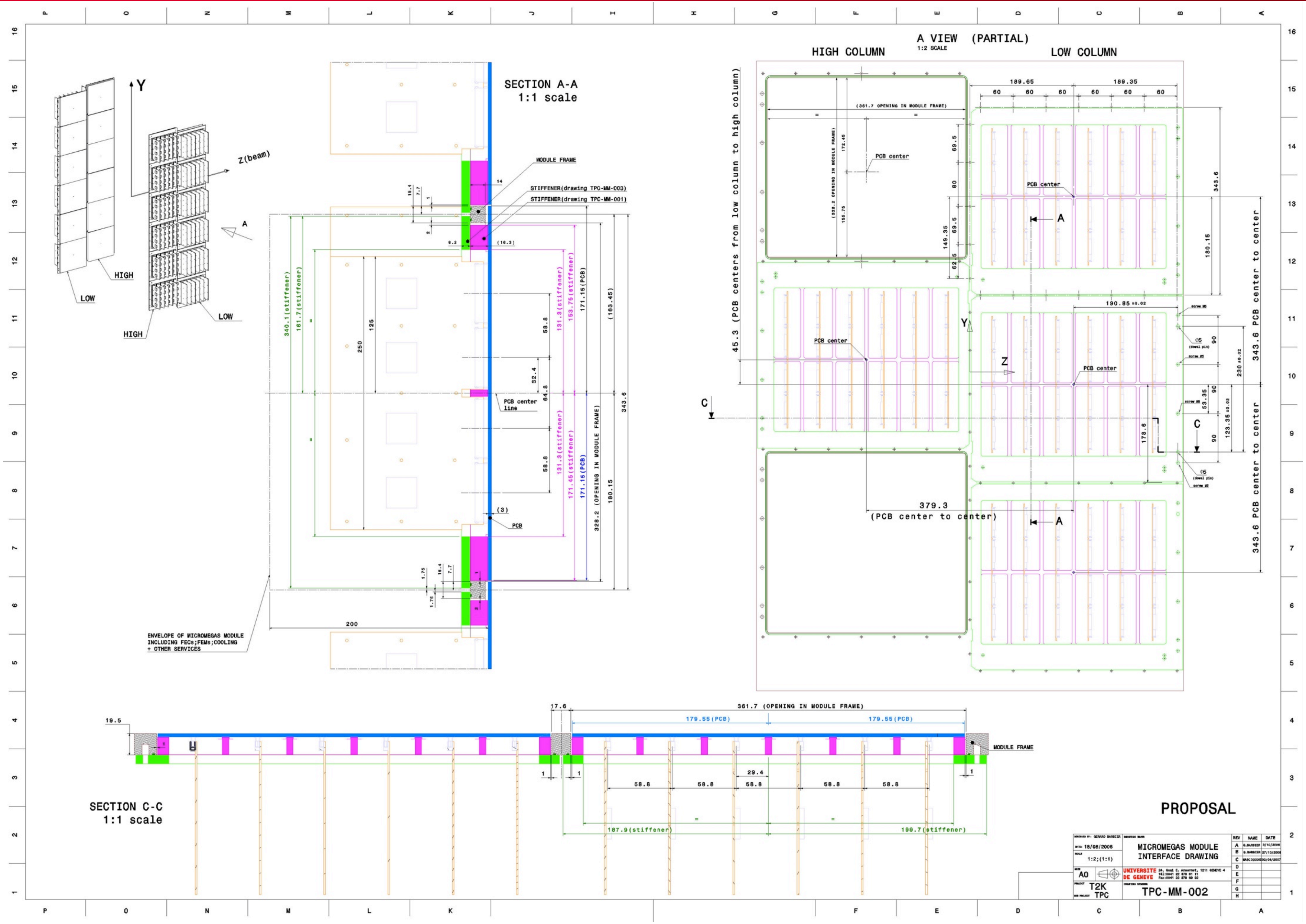
With On-detector FEE cooling mechanicals

THE ELECTRONICS READOUT



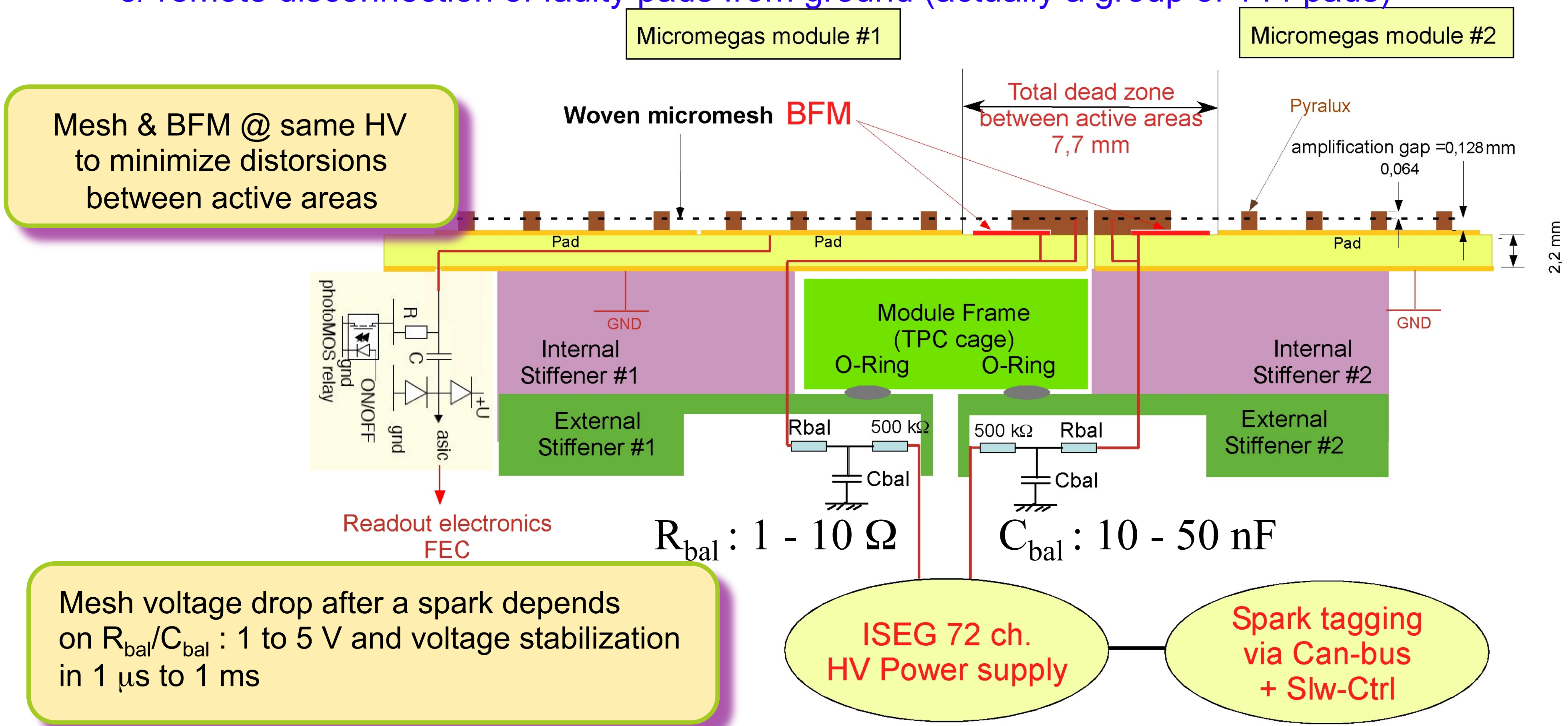
Ref: D. Calvet (IRFU)

MECHANICAL DESIGN : OF THE IMPORTANCE OF A REFERENCE INTERFACE DRAWING ….



BULK-MICROMEGAS VS FIELD CAGE INTERFACE

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



Mesh voltage drop after a spark depends on R_{bal}/C_{bal} : 1 to 5 V and voltage stabilization in 1 µs to 1 ms

HISTORY

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)

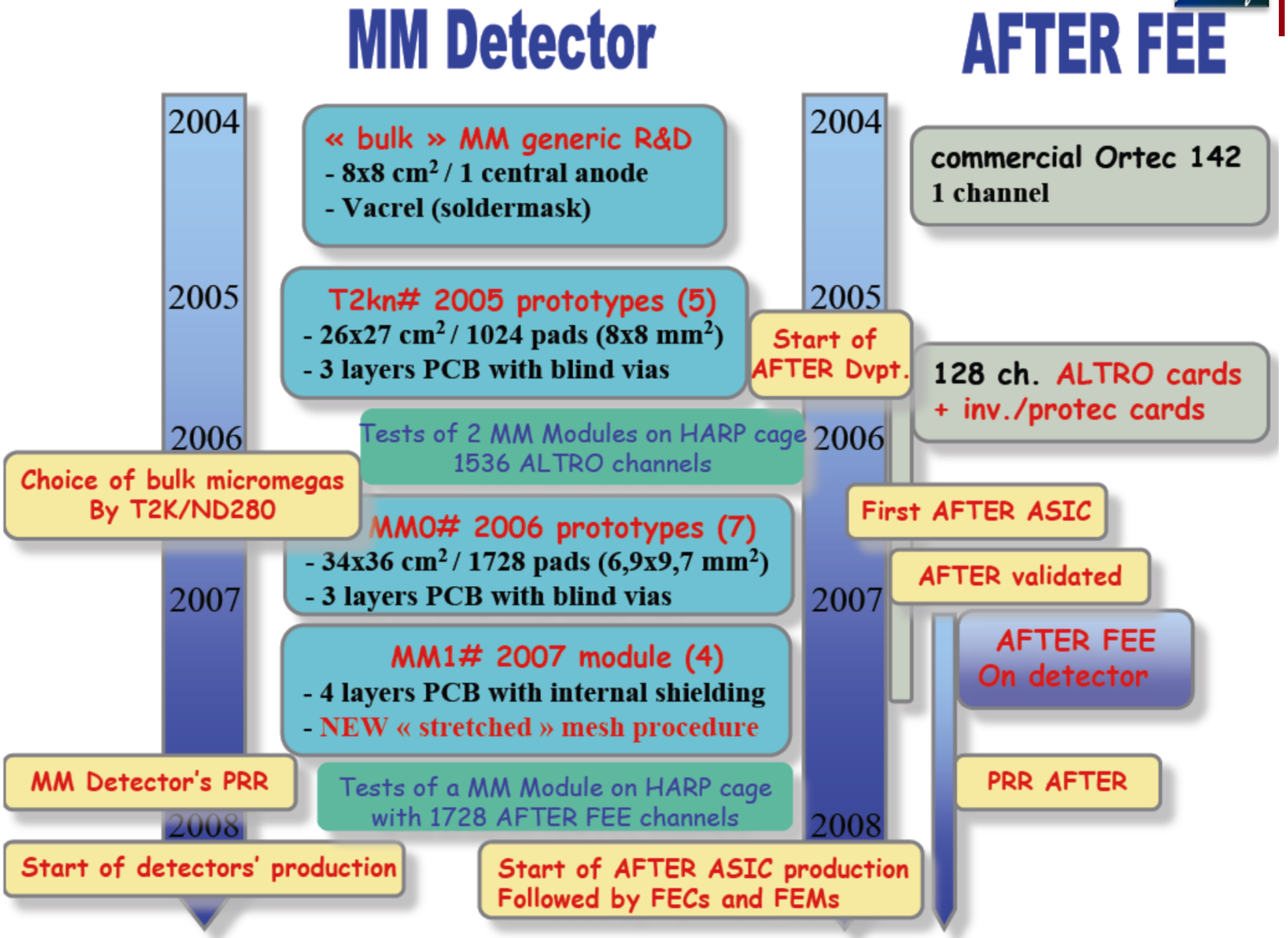
- Tests of a Micromegas module @ CERN on HARP TPC (with AFTER FEE)
- Production phase « officially » launch on 11/30/2007

Production – Integration phase (november 2007 - october 2009)

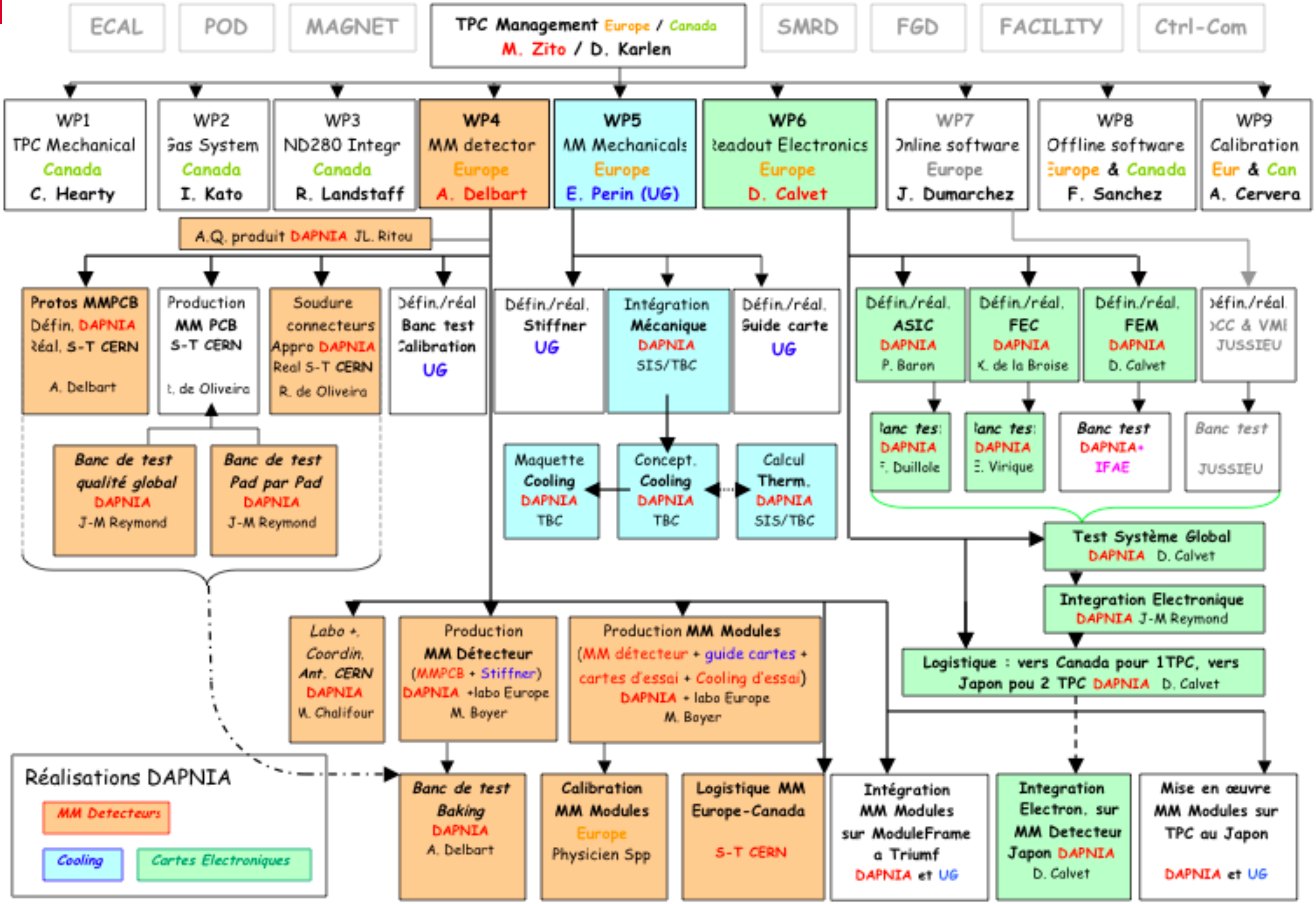
- For each sub-sytem : Production Readiness Review for ASIC:12/10/2007, Micromegas: 10/12/2007, FEC:16/04/2008, FEM: 24/07/2008

- 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)

3 YEARS OF R&D, 3 STEPS



T2K TPC PROJECT ORGANIZATION



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	
	"Mélamine" cover	CERN/TS-DEM-PMT	
	woven micromesh procurement	Saclay	or CERN/TS-DEM-PMT
	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/IFAE

14 pages …
More than 200 tasks

DESIGN GUIDELINES FOR THE T2K/TPCS

« Large » readout plane surface (~2 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

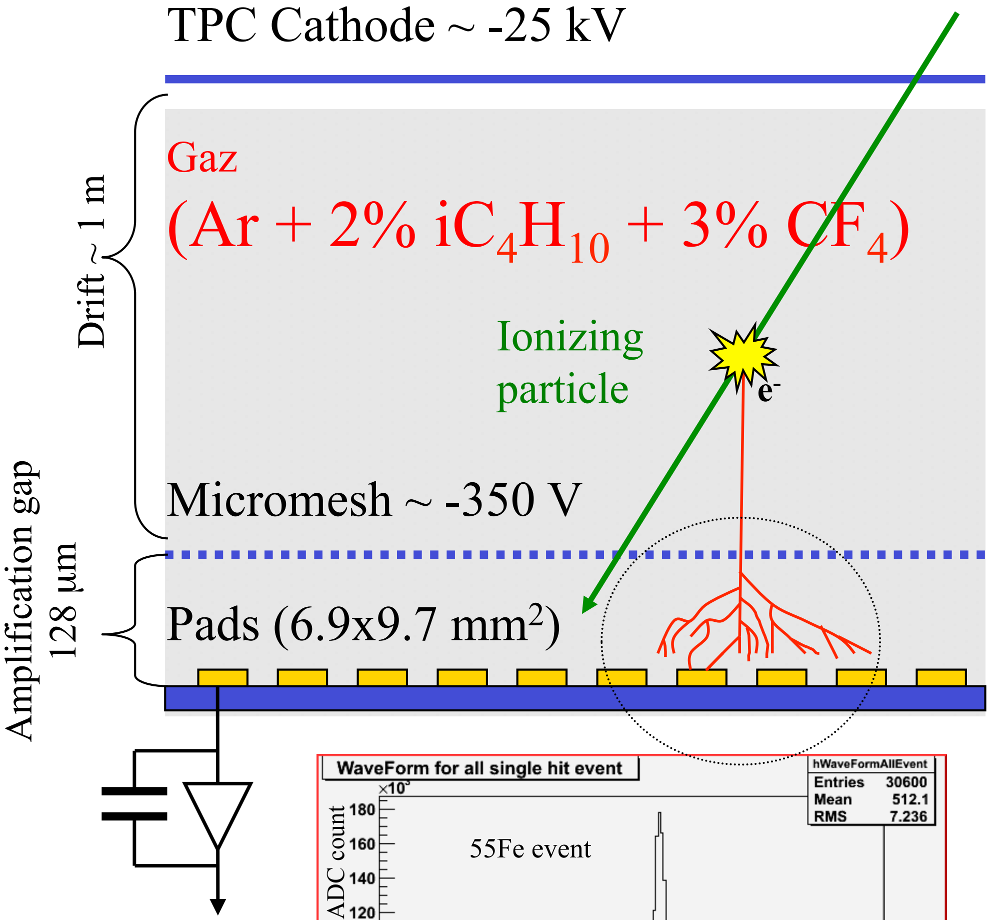
Readout plane Electric Field uniformity

- 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

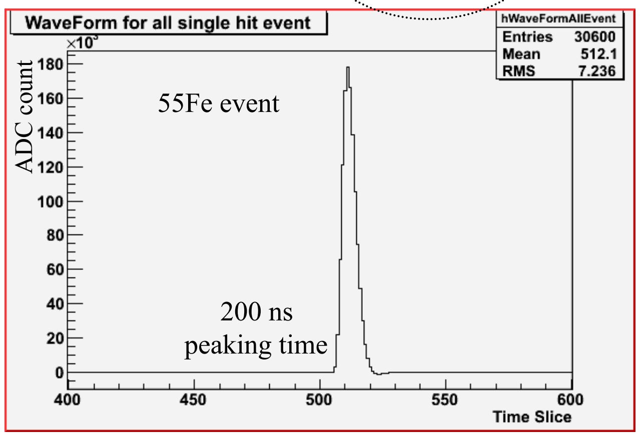
$\Rightarrow$ a good gain uniformity over these modules is required (within FEE performances)

- Minimizing the sparking rate (as low amplification gain as possible)
- Minimizing the dead time & voltage drop after a spark

THE CHOICE OF BULK-MICROMEGAS



Pads readout
(AFTER ASIC)



1 time bin = 50 ns (20 MHz sampling freq.)

a new gas mixture

- ✓ Non-flammable
- ✓ low tr. Dif. for small B (250 μm/cm$^{1/2}$)
- ✓ operation close to the maximum drift velocity (7,5 cm/μs @ 200 V/cm)
- ✓ minimization of the effect of impurities (mainly O_2) : > 30m att. Length

Drawbacks of micromegas technologies with seperate mesh & anode PCB :

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

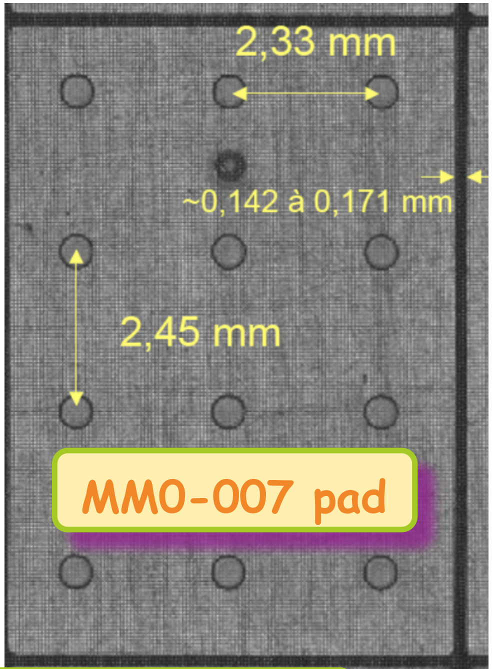
Use of bulk-micromegas technology

- ✓ 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

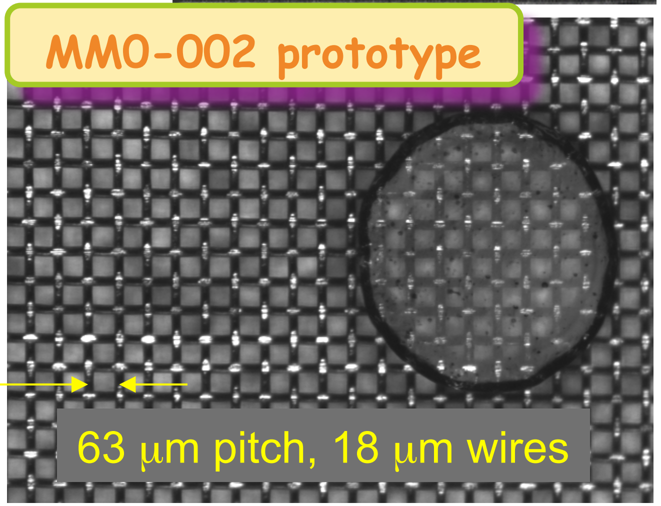
2005 HARP tests : NIM A574 (2007) 425-432

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

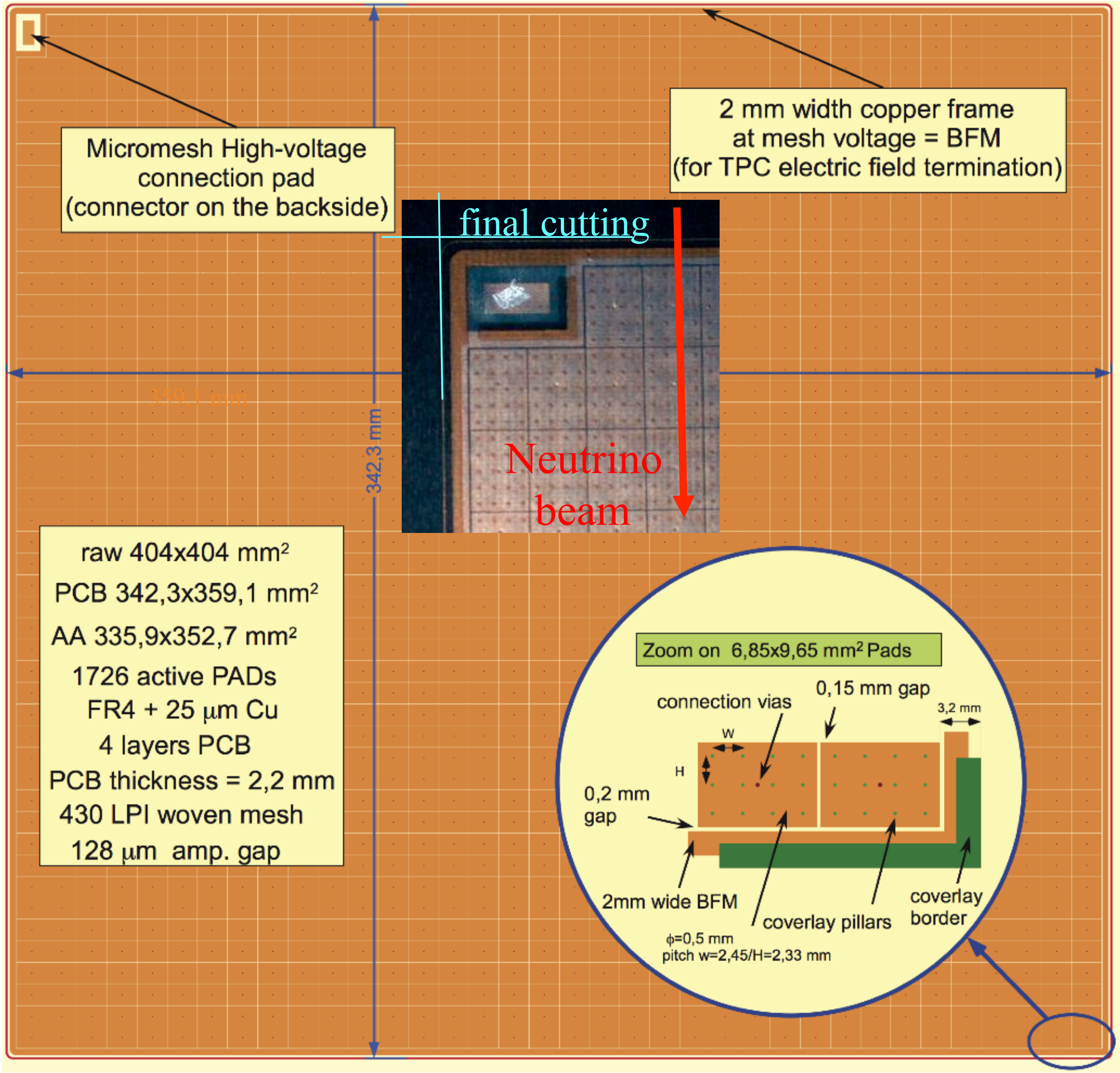
MM-PCB



2,33 mm
~0,142 à 0,171 mm
2,45 mm
MM0-007 pad



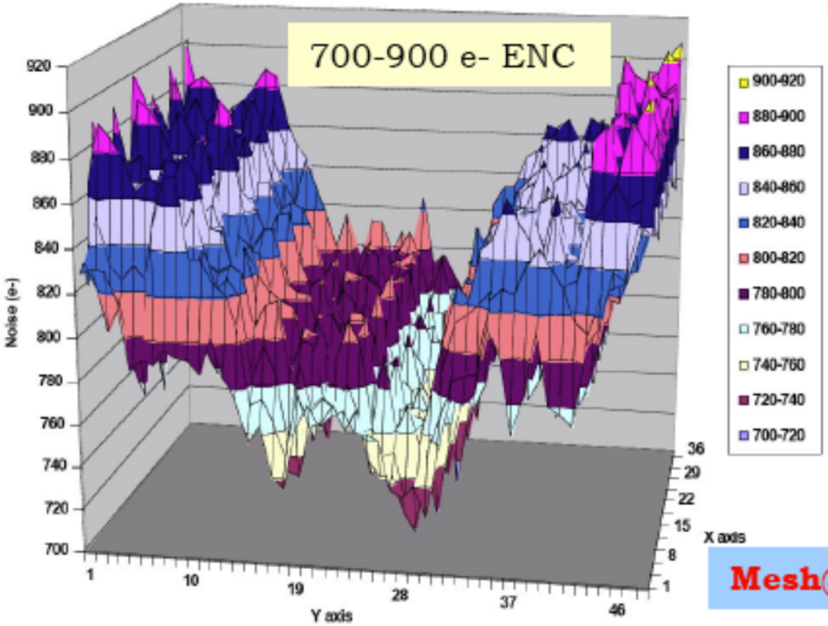
MM0-002 prototype
63 μm pitch, 18 μm wires

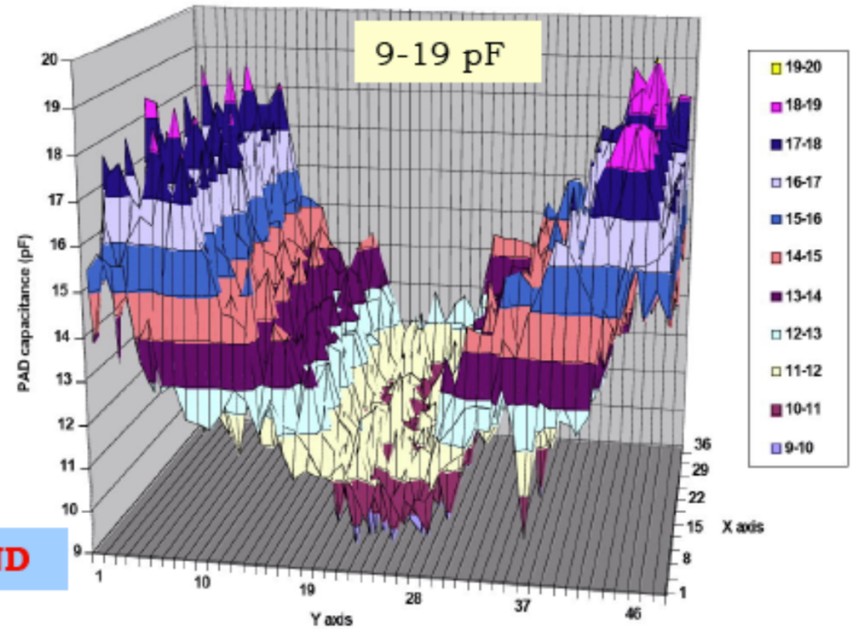


Micromesh High-voltage
connection pad
(connector on the backside)
2 mm width copper frame
at mesh voltage = BFM
(for TPC electric field termination)
final cutting
Neutrino
beam
342,3 mm
raw 404x404 mm²
PCB 342,3x359,1 mm²
AA 335,9x352,7 mm²
1726 active PADs
FR4 + 25 μm Cu
4 layers PCB
PCB thickness = 2,2 mm
430 LPI woven mesh
128 μm amp. gap
Zoom on 6,85x9,65 mm² Pads
connection vias
0,15 mm gap
3,2 mm
W
H
0,2 mm
gap
2mm wide BFM
coverlay pillars
coverlay
border
ϕ=0,5 mm
pitch w=2,45/H=2,33 mm

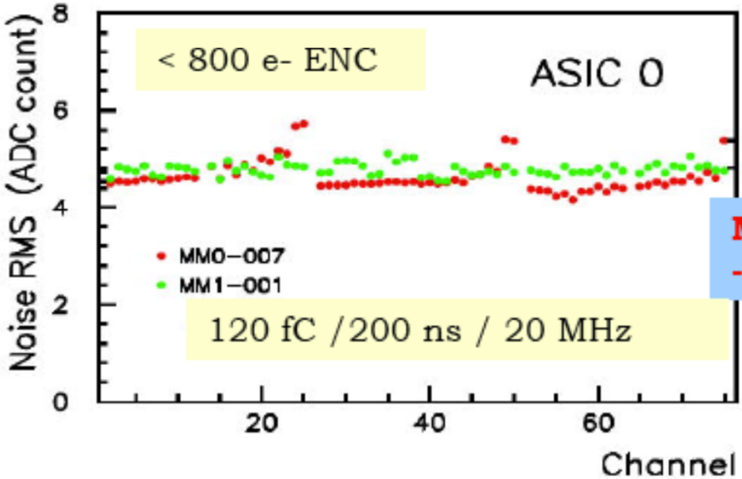
DETECTOR SENSOR + FEE : COUPLING THEM AS SOON AS POSSIBLE …

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

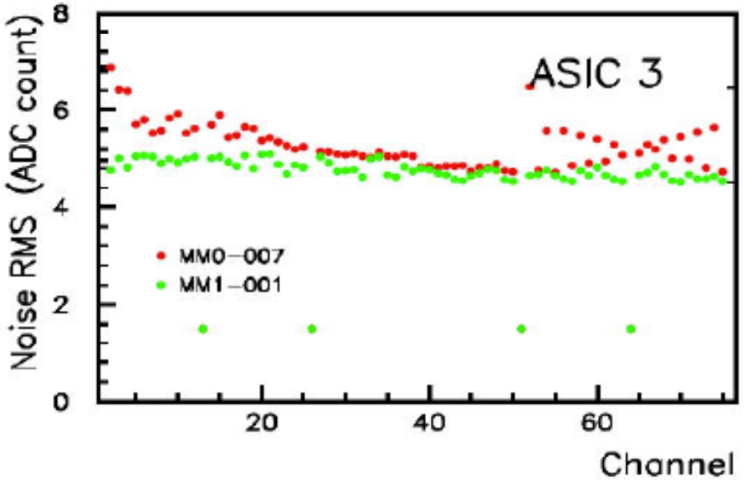




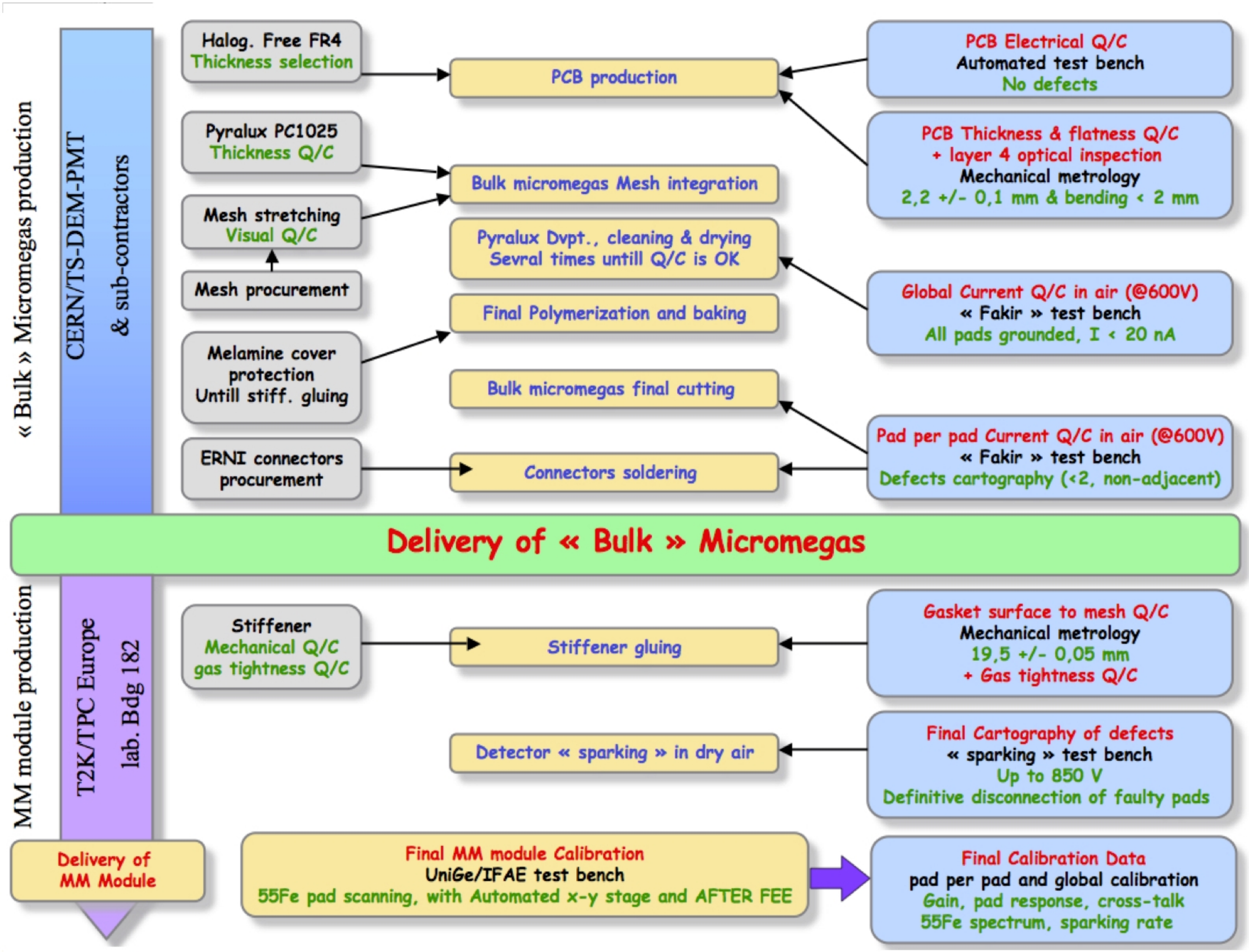
Mesh@GND



Mesh= -350V

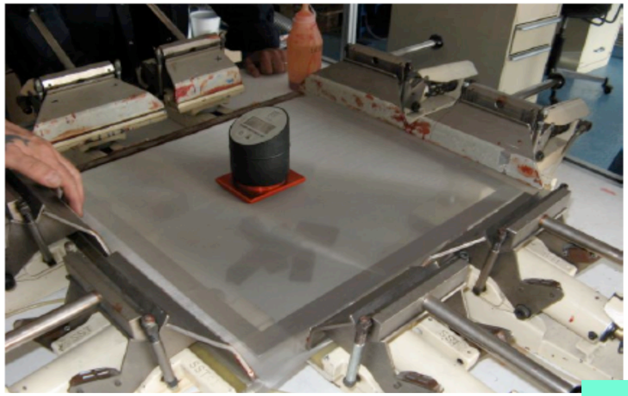


MODULE PRODUCTION QUALITY CONTROL



BULK-MICROMEGAS PRODUCTION @ CERN

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



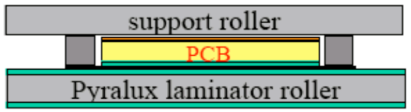
Réf : R. De Oliveira (CERN/EST-DEM-PMT)

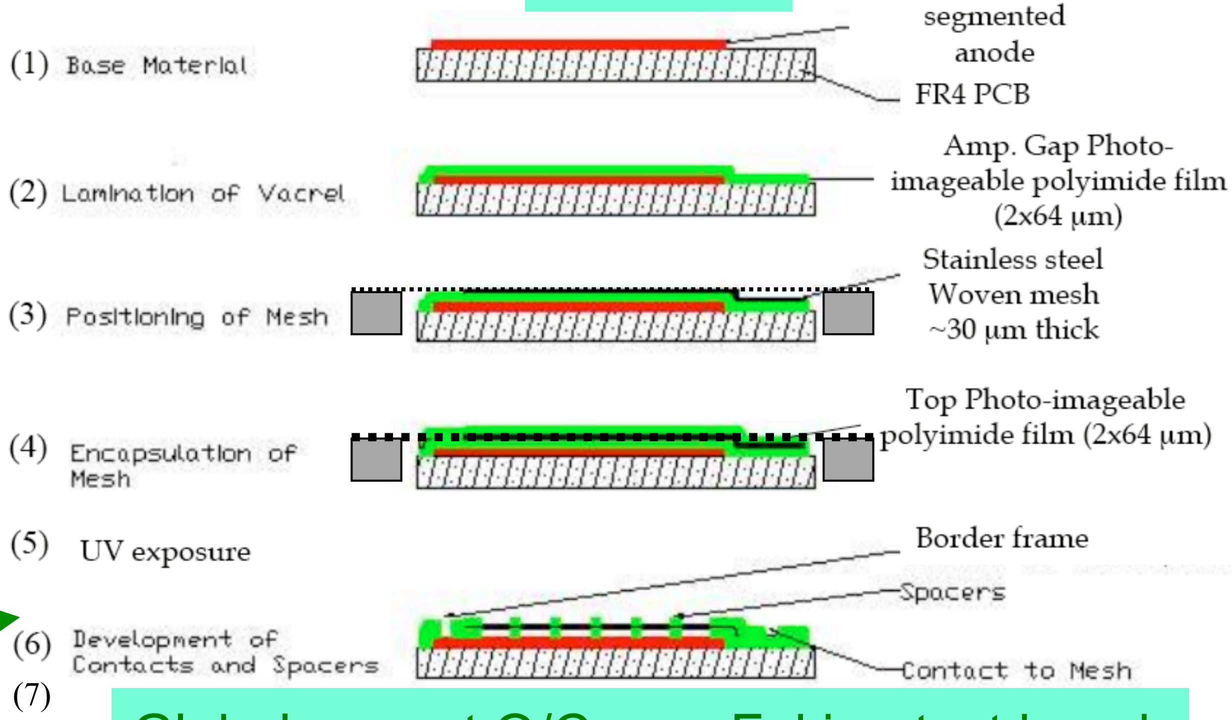
PCB Q/C

Visual inspection

1/ Mesh is stretched on an external frame

2/ and laminated with the PCB





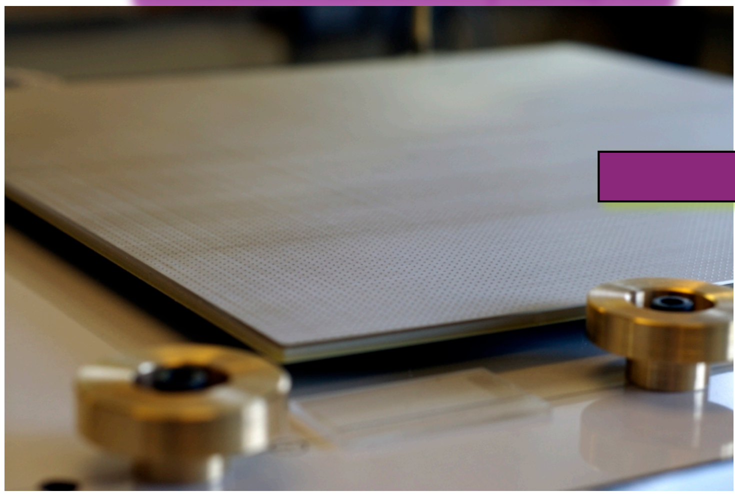
If $I > I_{Q/C}$

(7)

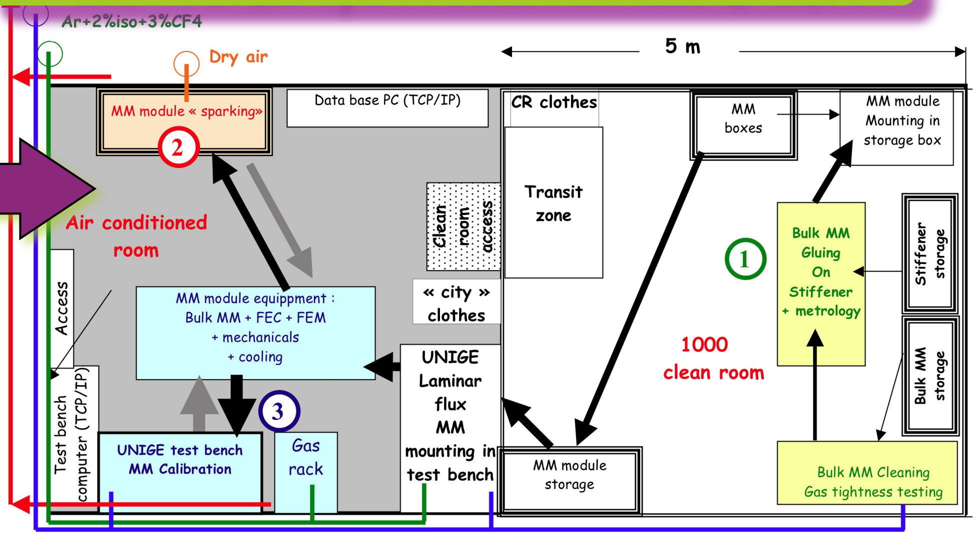
Global current Q/C on « Fakir » test bench

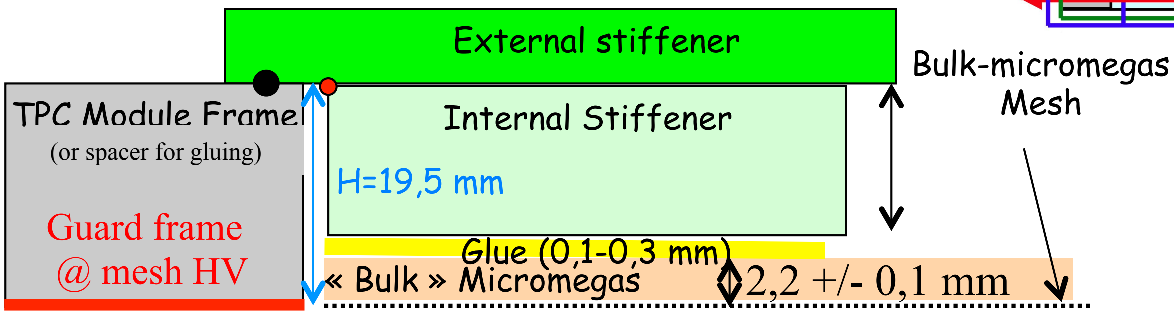
MODULE ASSEMBLY

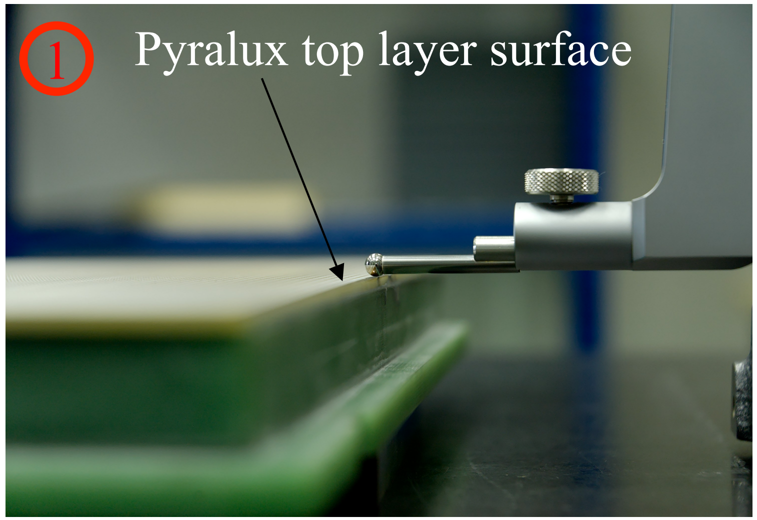
Module assembly & Q/C



T2K/TPC Europe Production lab. @ CERN

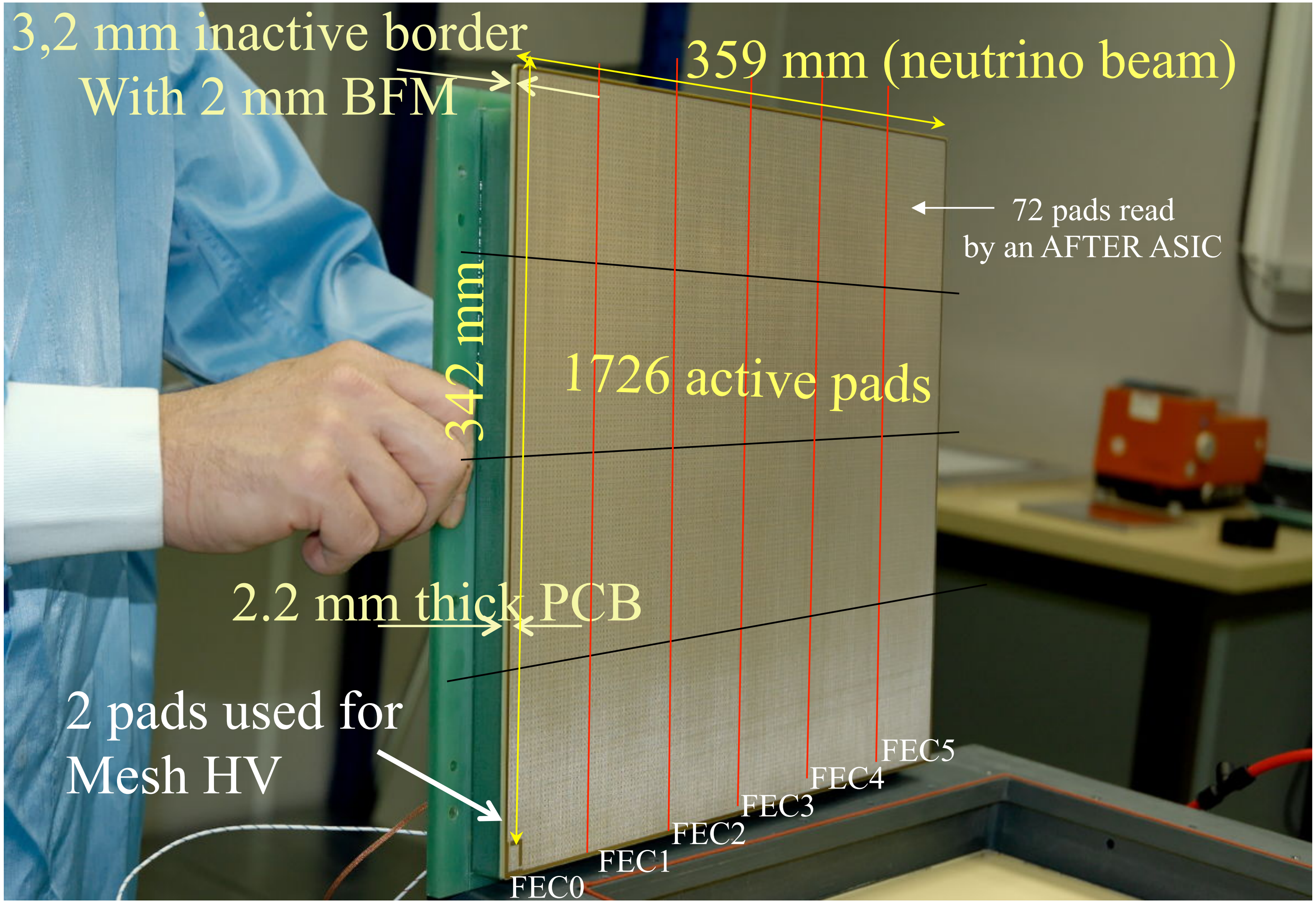






- Assembly-tests of the modules @ CERN, in a lab in the CEA/IRFU CERN antenna bdg 182
- 4 technicians team (including 2 from UNIGE) & calibration by the T2K/TPC Europe collaboration

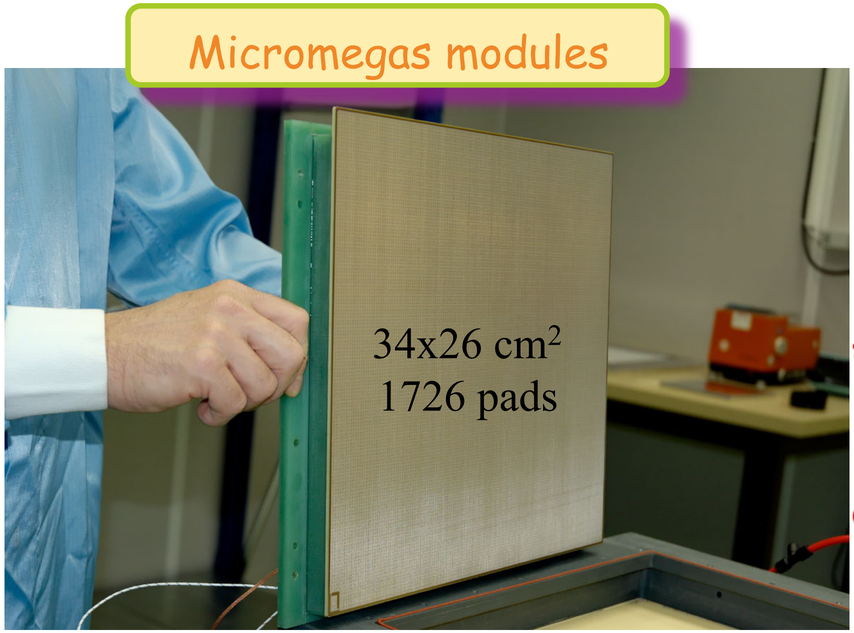
A BULK-MICROMEGAS MODULE

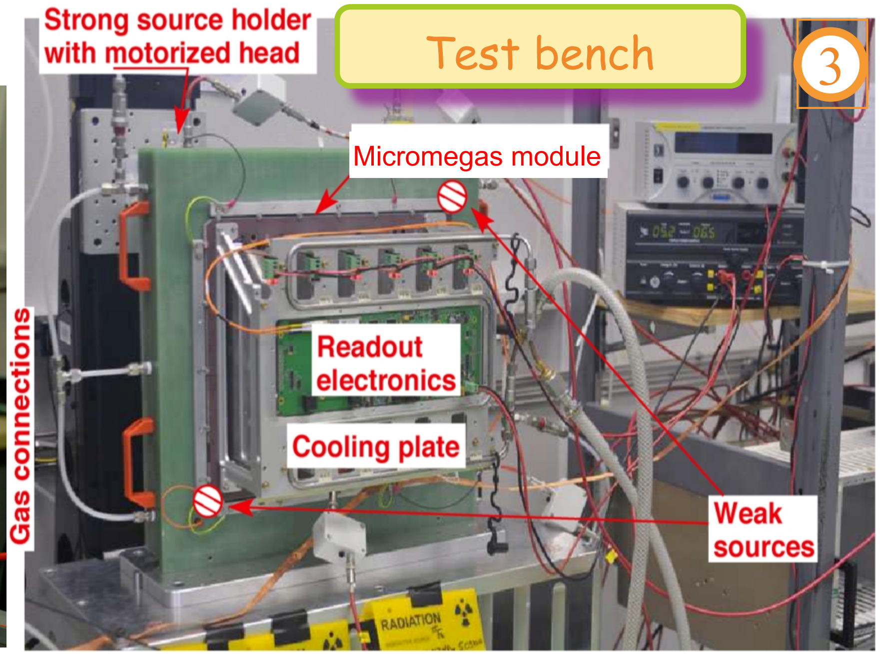


Bulk-micromegas detector cost (PCB+mesh+mesh integration+connectors): ~10 k€ /m^2

BULK-MICROMEGAS MODULE QUALIFICATION

✓ Gas chamber filled with T2K/TPC gas mixture $Ar+2\%iC_4H_{10}+3\%CF_4$



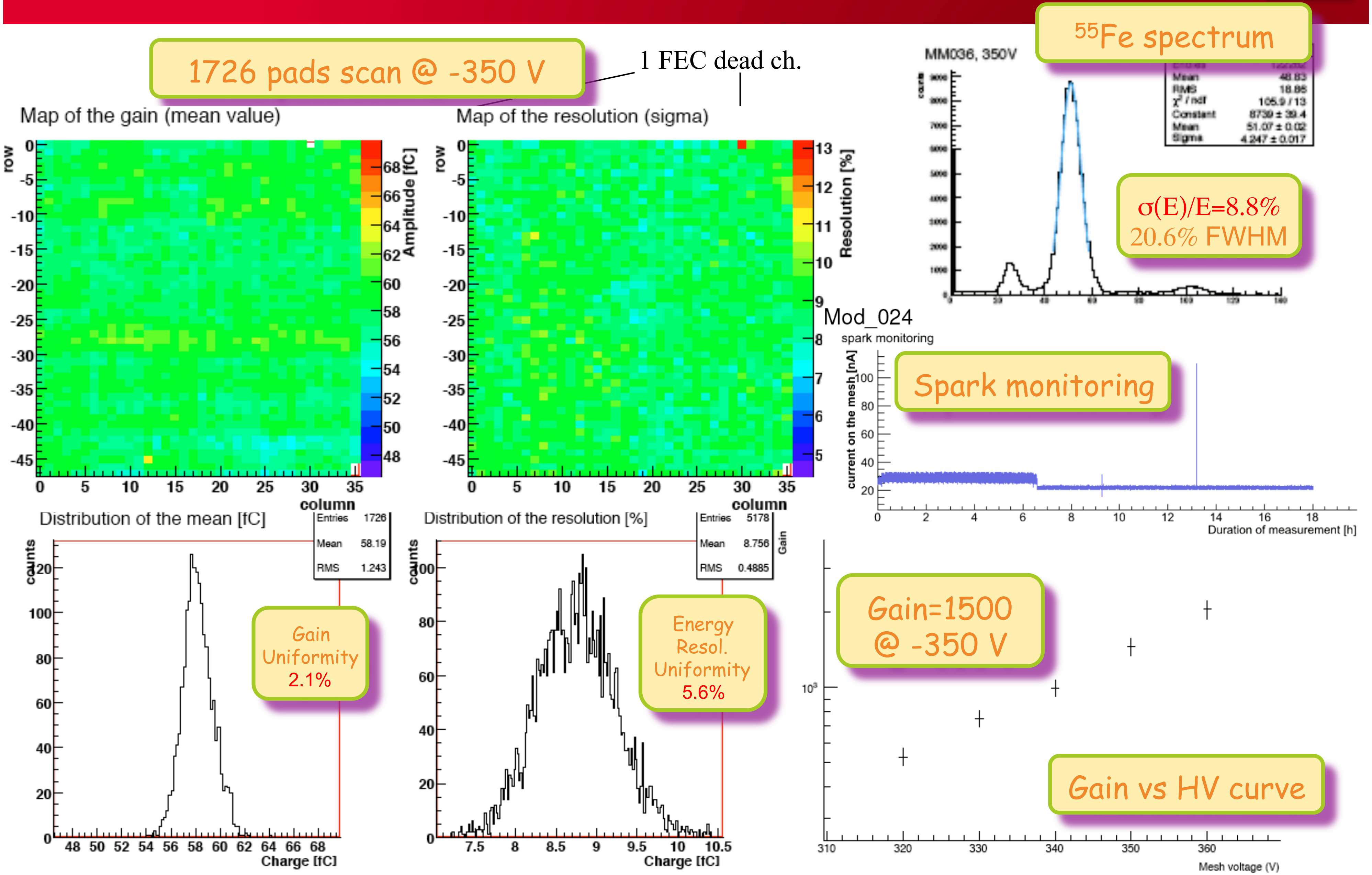


✓ Full pad per pad calibration : complete scanning of the active area with a X-Y motorized strong ^{55}Fe x-ray source, with on-line monitoring of sparking rate

✓ 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)

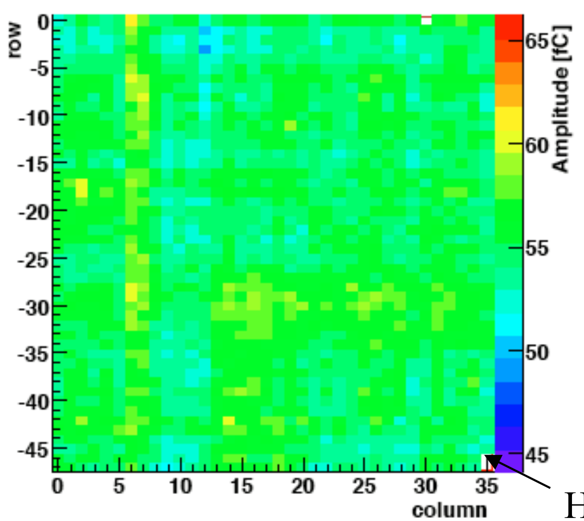
✓ Gain Vs High-Voltage is measured in the center of the detector (320-360 V)

BULK-MICROMEGAS MODULE PERFORMANCES



Mod-020

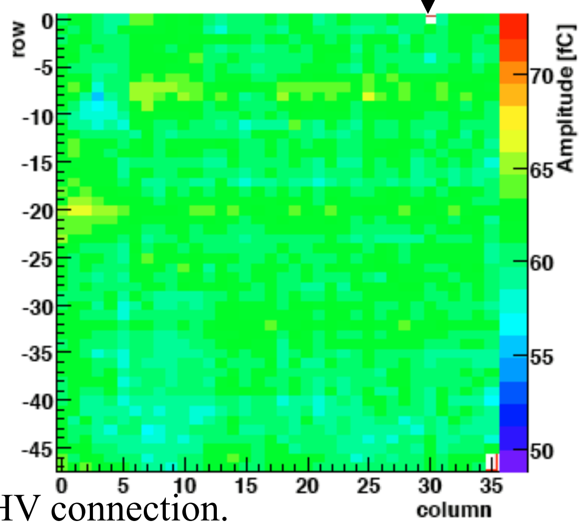
Map of the gain (mean value)



Mod-034

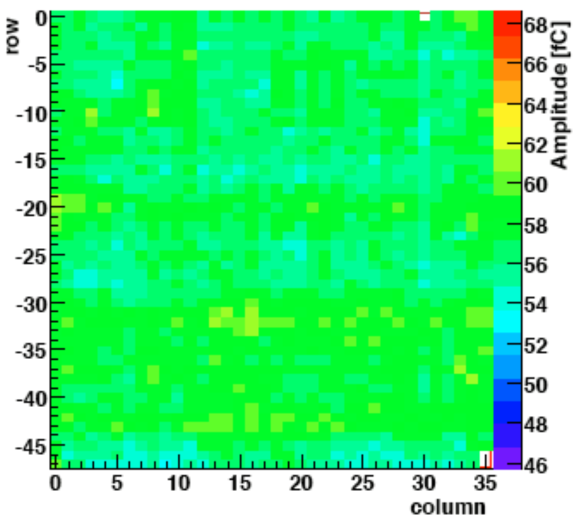
1 FEC dead ch.

Map of the gain (mean value)



Mod-019

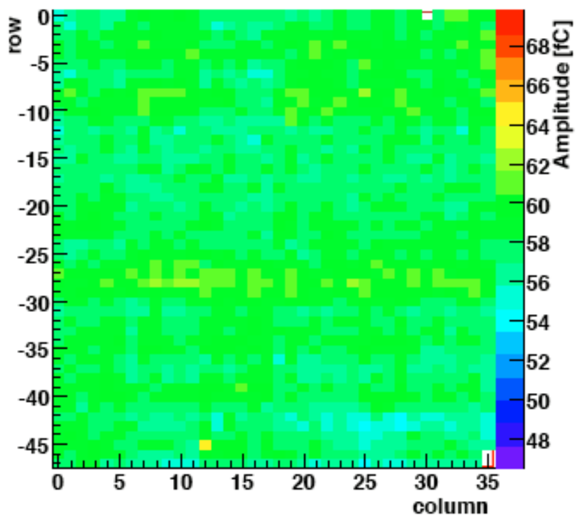
Map of the gain (mean value)



HV connection.

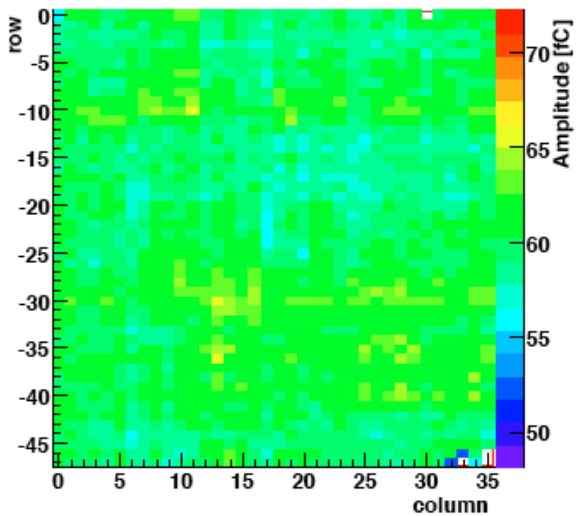
Mod-036

Map of the gain (mean value)



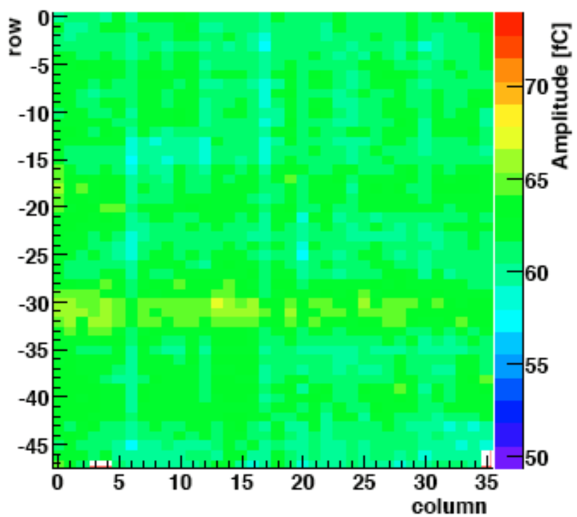
Mod-018

Map of the gain (mean value)

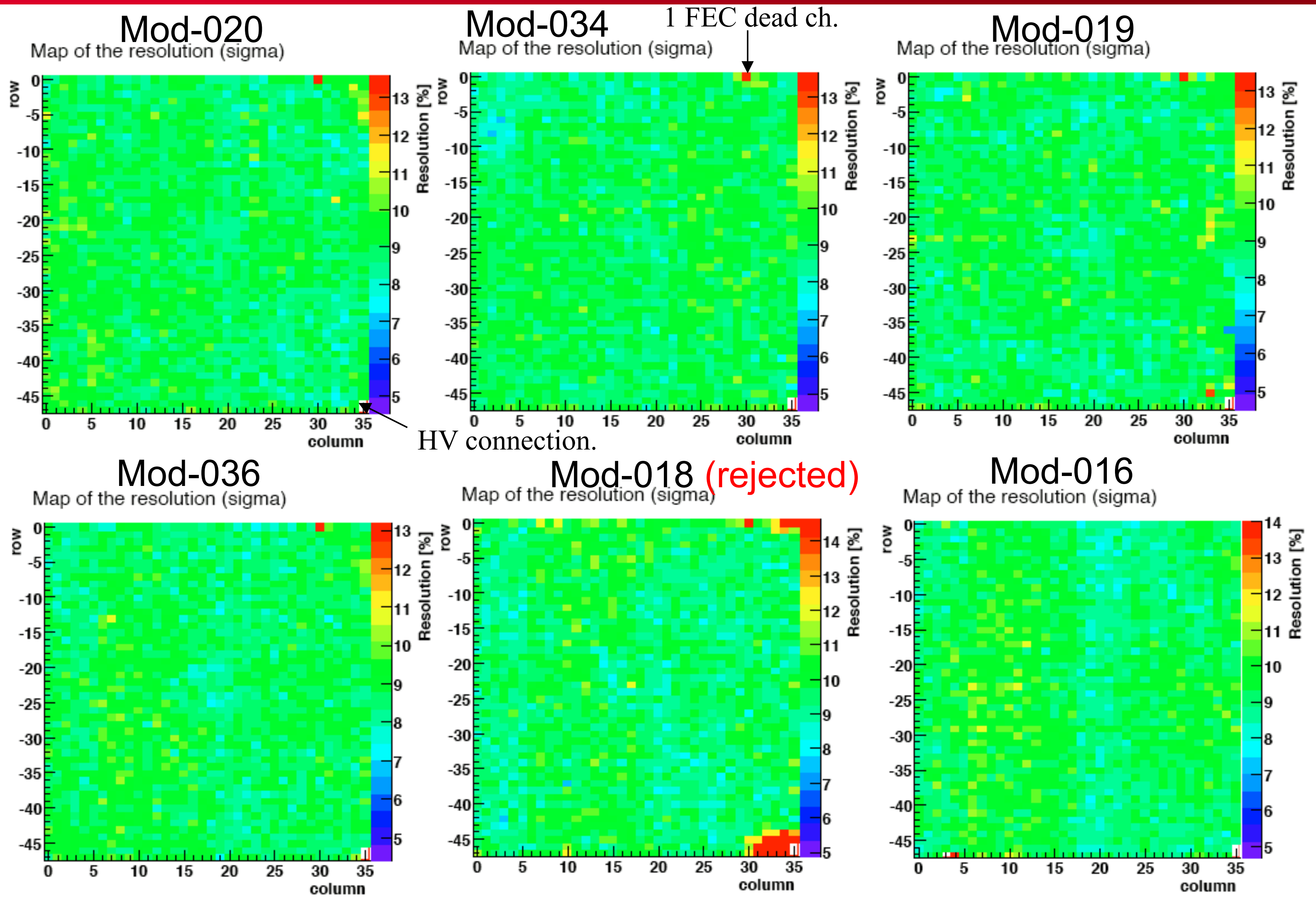


Mod-016

Map of the gain (mean value)



SCAN RESULTS : 5.9 KEV RESOLUTION MAPS



QUALITY OF THE FIRST 1/3 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 (ΔG=3.3%+/-0.6% for ΔP=1% in TPC-0)

1/2 TPC-MOD-0

1/2 TPC-MOD-0

… TPC-MOD-1

rejected

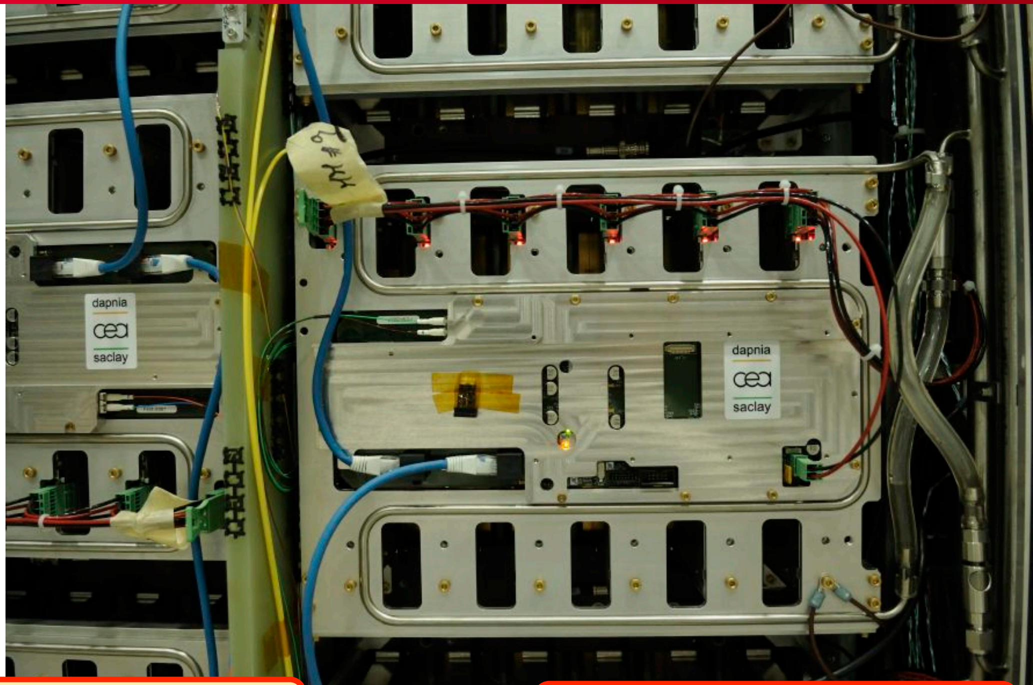
Module	Mean Charge C (fC)	Charge dev. σ (fC)	charge uniformity σ/C	5,9 keV resol. σE/E	resol dev. σ(σE/E)	resol uniformity σ(σE/E)/(σE/E)	comments
Mod_001	59,0	2,90	4,9%	9,4	0,59	6,3%	Charge is not corrected for pad capacitance dispersion
Mod_007	55,0	1,90	3,5%	9,5	0,46	4,8%	
Mod_010	49,5	1,60	3,2%	9,3	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% σE/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_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%**

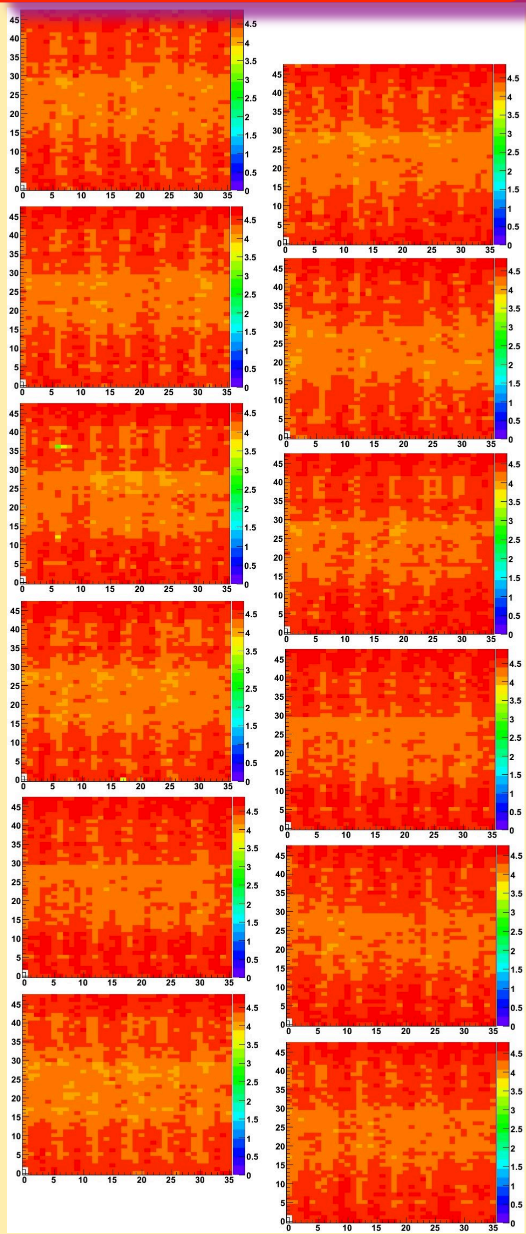
7 modules over 84 were rejected (83% yield)
Only 12 dead pads over the 132902 pads of the 77 modules validated
Gain uniformity over the active area of a module : ~2.8 %
Gain uniformity over the first 77 modules : 7%
5.9 keV resolution : σE/E= 9,0% (5.9% uniformity over the active area)
5.9 keV resolution uniformity over the first 77 modules : 2.5 %
~0,1 spark/h @ 1500 gain (-350 V) for all the modules produced (after burn-in)

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

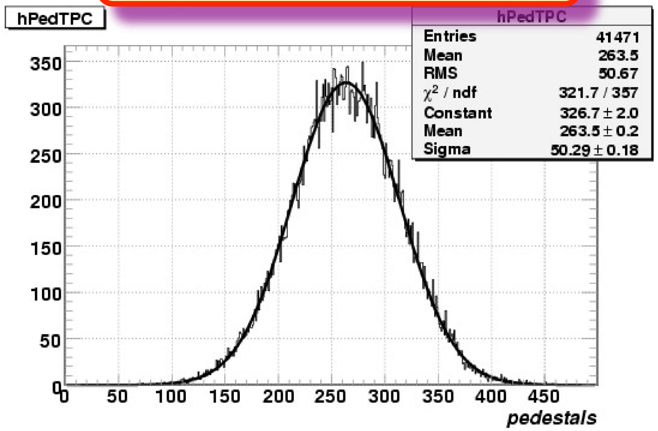
PEDESTALS & RMS NOISE LEVEL OF A READOUT PLANE MEASURED ON SITE @ JPARC.



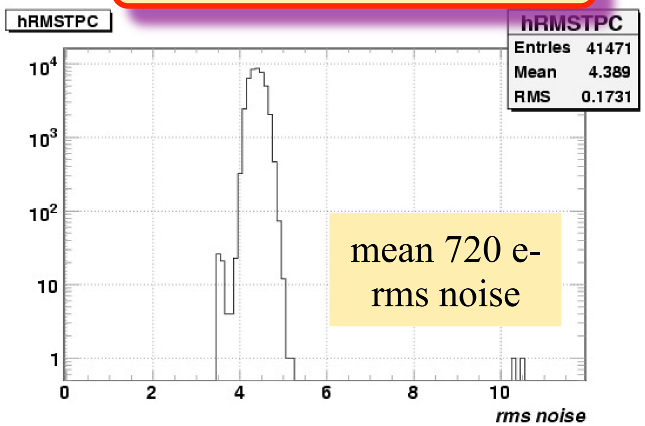
2D map of rms noise



pedestals distribution

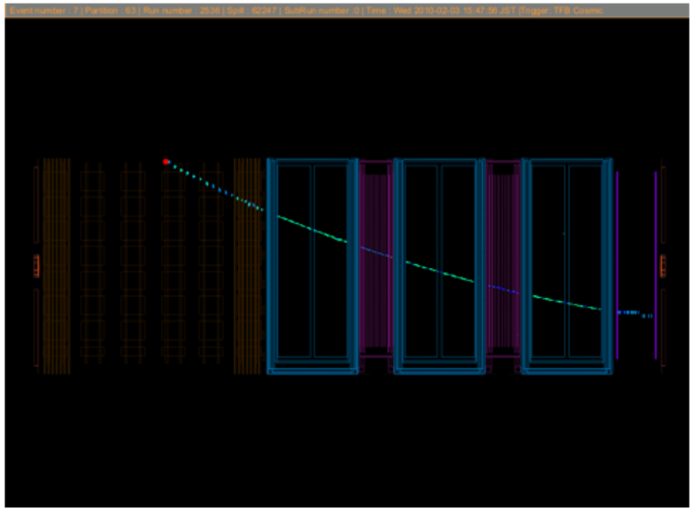


rms noise distribution

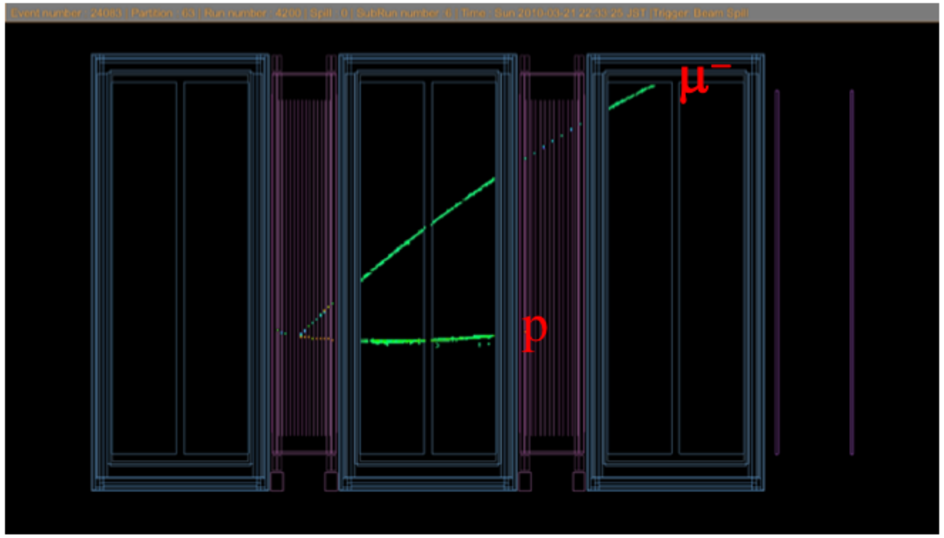


NEUTRINO EVENTS RESCONSTRUCTED IN ND280 TPCS

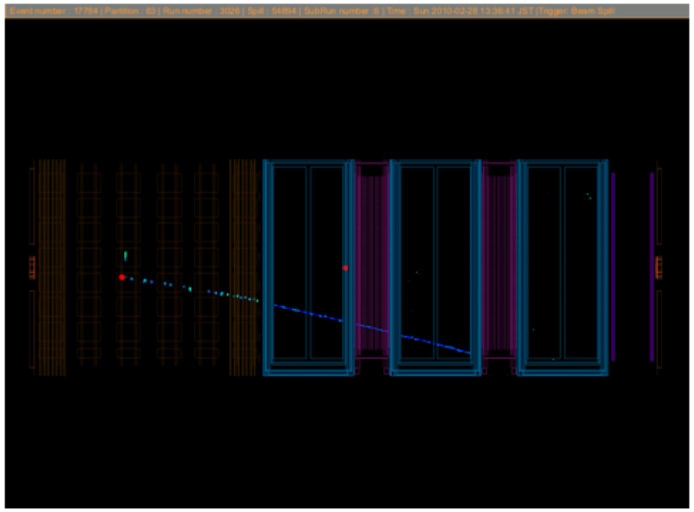
Cosmic track reconstructed across all detectors



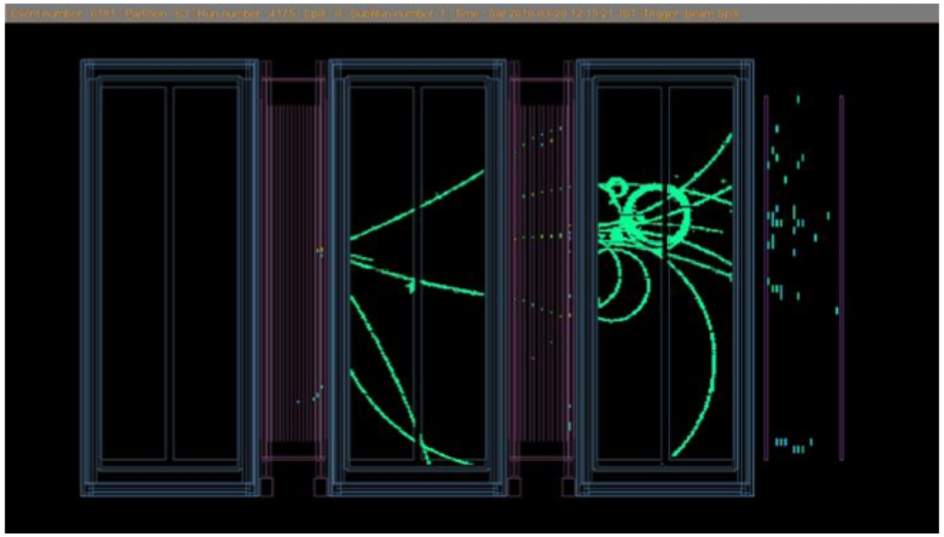
Clean CC interaction in FGD1



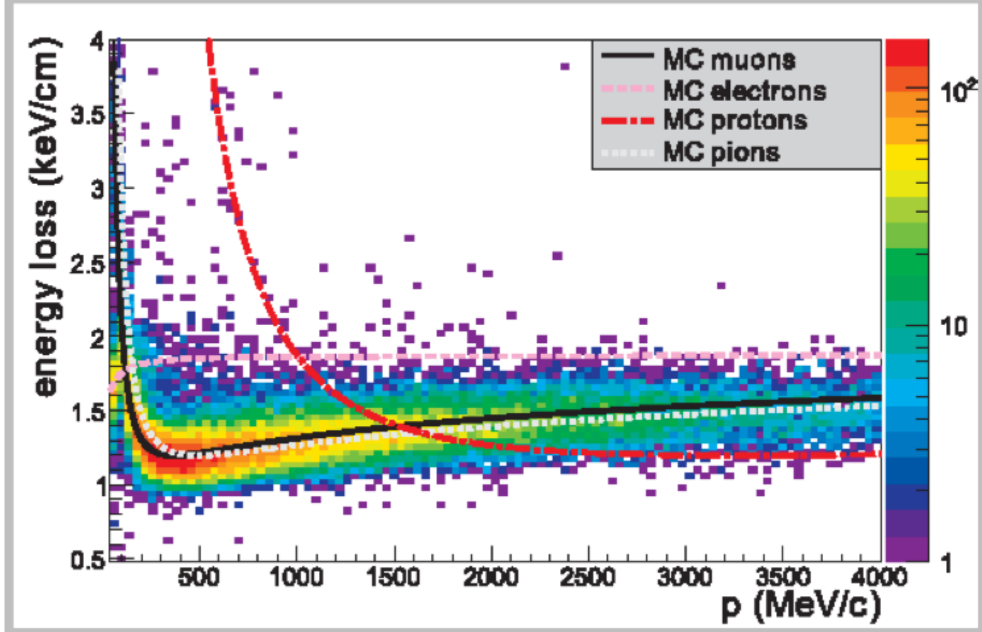
ν interaction in P0D sending single negative track into TPC1/FGD1/TPC2

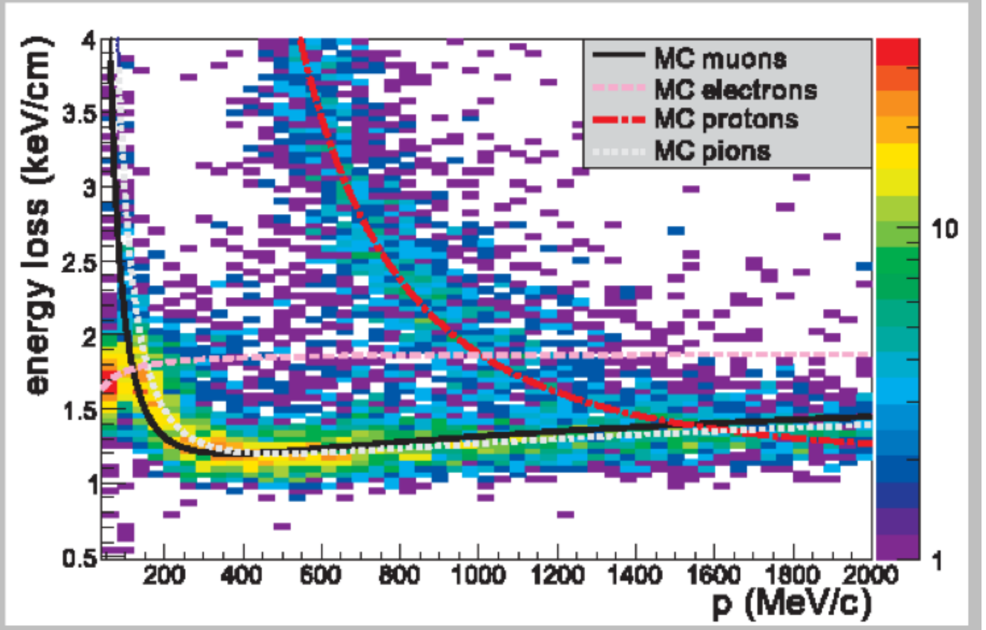


Interaction in FGD1 with shower in FGD2



Through-going muons and neutrino interactions in ND280

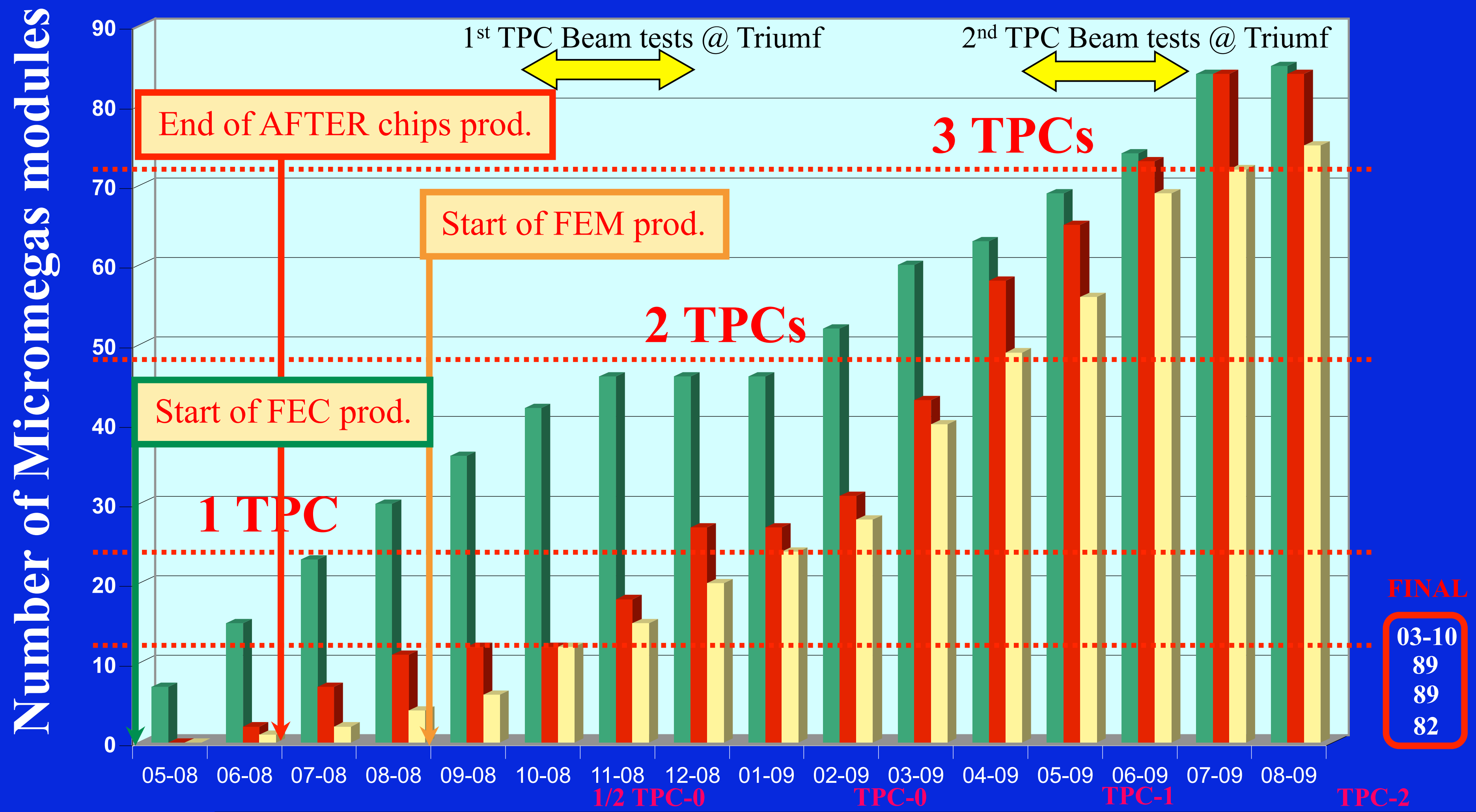




Negative tracks: μ^-, e^-

Positive tracks: p, π^+, e^+

1.5 YEAR OF PRODUCTION



	05-08	06-08	07-08	08-08	09-08	10-08	11-08	12-08	01-09	02-09	03-09	04-09	05-09	06-09	07-09	08-09
Bulk MMs	7	15	23	30	36	42	46	46	46	52	60	63	69	74	84	85
MM Modules	0	2	7	11	12	12	18	27	27	31	43	58	65	73	84	84
Validated MM Modules	0	1	2	4	6	12	15	20	24	28	40	49	56	69	72	75

PRODUCTION YIELD

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 !)

COST : R&D VS PRODUCTION : MM MODULE & FEE

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€

1.1+2.1 € /ch. (Front-End Electronics TOTAL)

0.5+2.6 k€ /mod. (Module mechanicals)

0.6+1.5 k€ /mod. (Bulk-Micromegas)

1.1+4.1 k€ /mod. (Bulk-MM Module TOTAL)

SOME KEYS FOR SUCCESS ?

- Importance of the support of the R&D group of SEDI in the early stages of the development (2005, Y. Giomataris / P. Colas) and of the synergy between detector physicists (Spp) and detector & electronics engineers (SEDI)

- Early definition of the Work Breakdown Structure in the T2k/TPC collaboration
- bi-weekly videoconferences and 3 collaboration meetings / year

- Readout detector & Front-End Electronics within one lab responsability

→ Efficiency in the global evolution of the system and its

- Importance of the Production Readiness Reviews (PRR)

- Choice to localize the production, Q/C and validation of the detectors at CERN

→ Boost in the (bulk)-micromegas spread in the RD51 community

→ Strong support from the T2k-TPC european labs (module assembly & tests)

- Importance of the excellent collaboration between IRFU & CERN/EN-ICE-DEM

- Importance of the « integration » of a Quality Assurance manager in every stage of the development (design, prototyping, production, commissionning)

- Excellent collaboration between the engineers+technicians & physicists

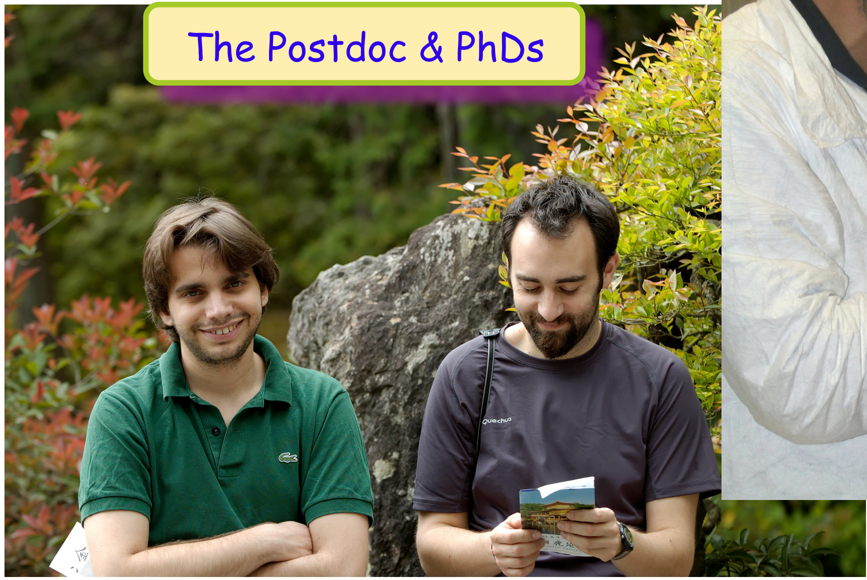
DETECTORS ARE MADE BY MEN & WOMEN !

The experience of the elders

IRFU-CERN collaboration

PI Physicist & project manager

The Postdoc & PhDs

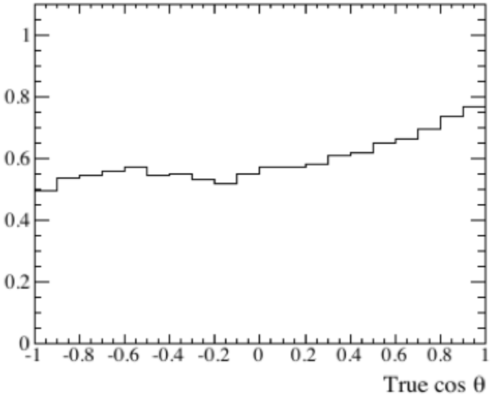


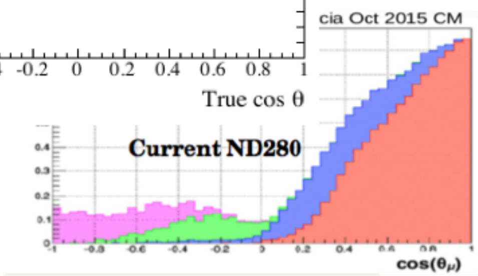
Tourism in Vancouver

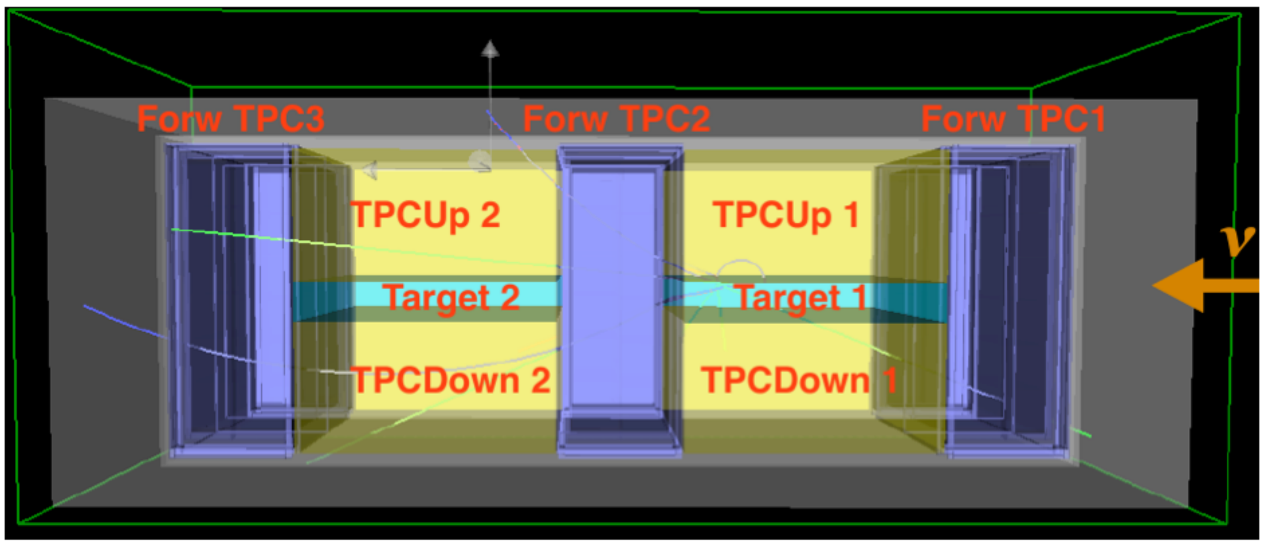
BACKUP

THE UPGRADE OF THE T2K EXPERIMENT

- We are currently studying an upgrade of the near detector ND280 comprising 4 additional TPCs and two new active targets
- Aim: acceptance over the full polar angle, with better tracking inside the target and lower proton threshold
- T2K-II will require a 2-3% precision on the expected n of events at SK (5% today) to match the 400 nue appearance events
- Workshop at CERN November 8-9th (open to all interested)
- New detectors to be installed ~2020

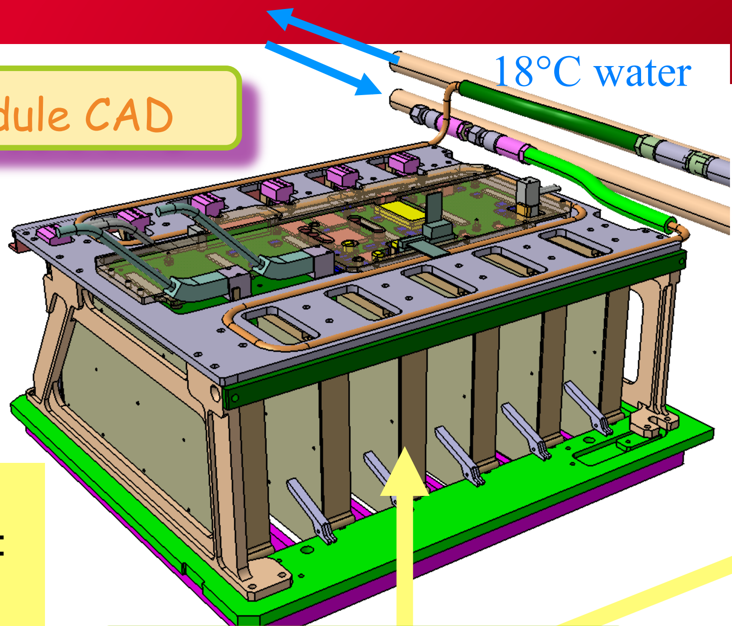




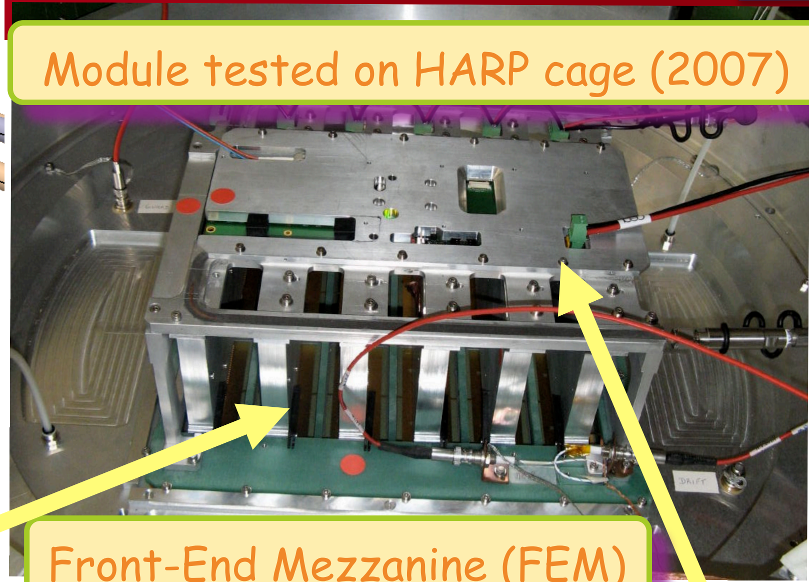


FRONT-END READOUT ELECTRONICS

Module CAD



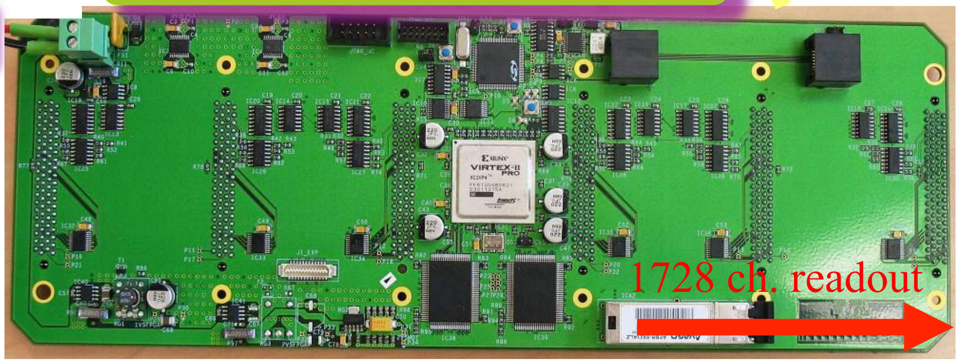
Module tested on HARP cage (2007)

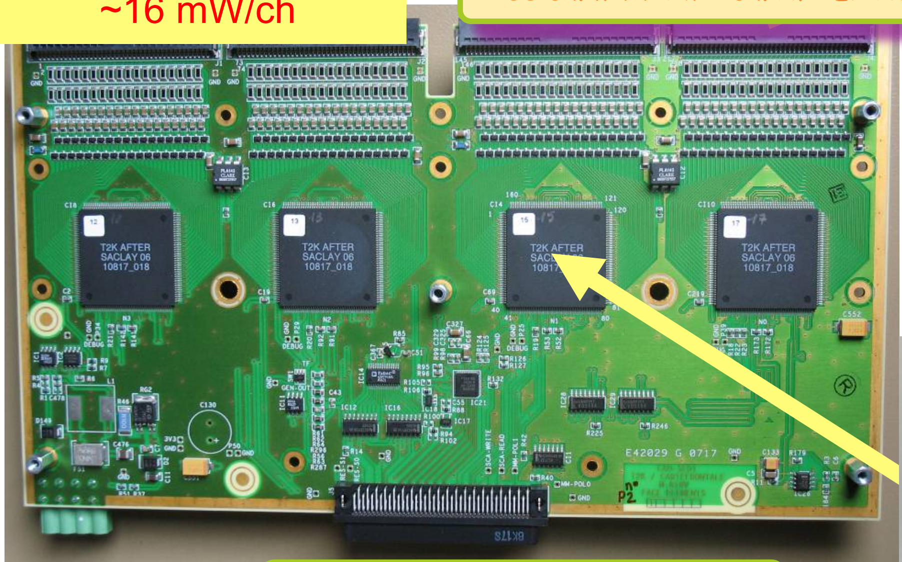


Total Cost of FEE
(ASIC+FEC+FEM) :
~2 € / ch.
Power consuption :
~16 mW/ch

288 ch. with 4x72 ch. AFTER ASICs

Front-End Mezzanine (FEM)

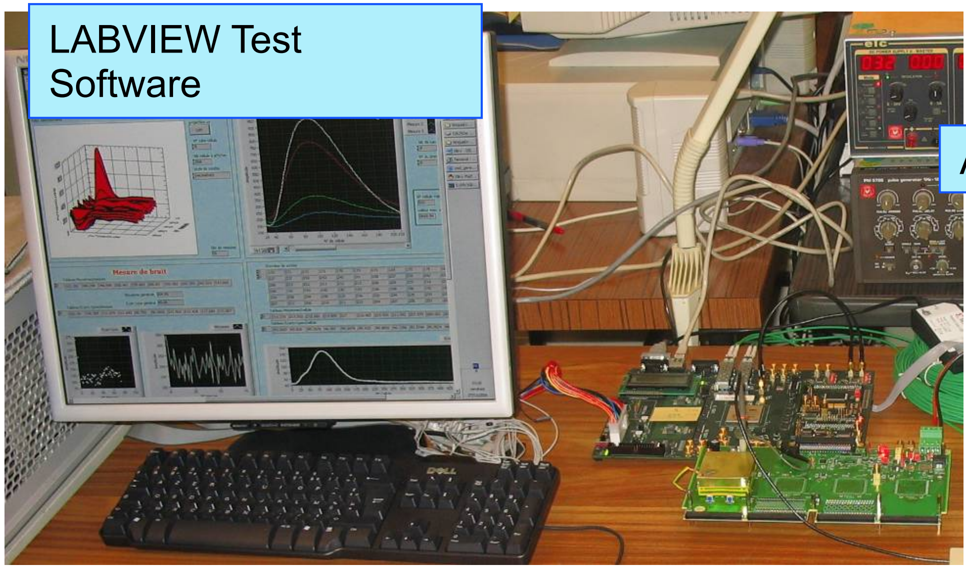


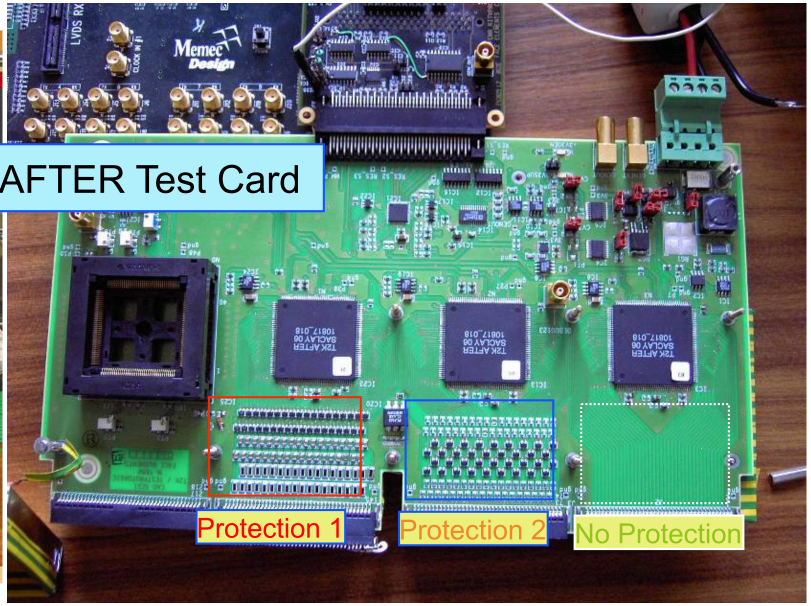


Front-End Card (FEC)

AFTER ASIC

AFTER CHIP PRODUCTION





Test bench

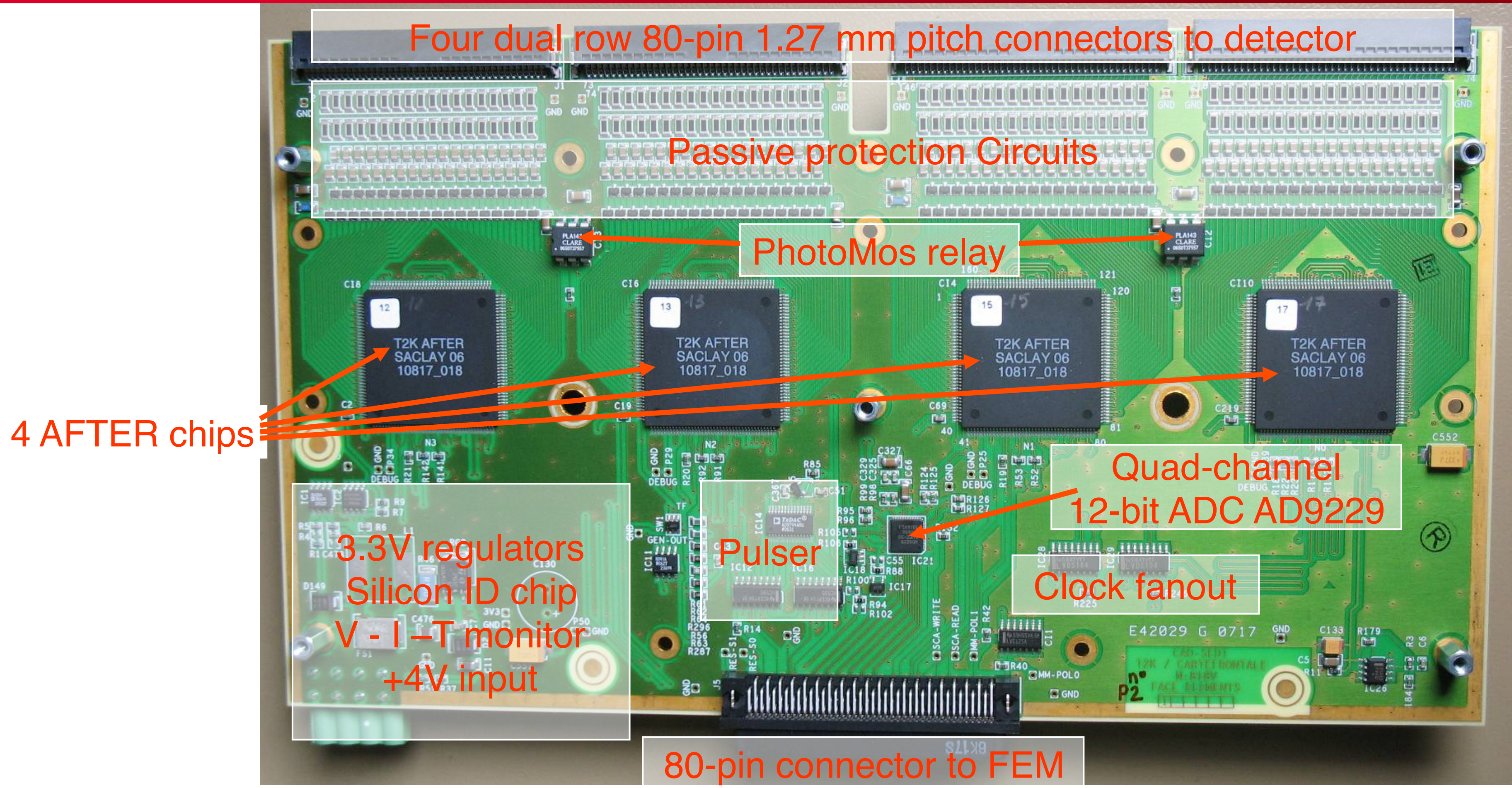
- AFTER test card served as pre-prototype of Front-End Card
- Xilinx Virtex 2 Pro eval. kit as pre-prototype of FEM board for readout
- DAQ and Analysis with Ethernet PC and LabView

Production of the AFTER chip is finished

- 5334 chips produced; 4726 OK; Yield: 89%
- 1800 chips delivered to T2K (TPC + FGD + monitoring chamber)

D. Calvet

FRONT-END ANALOG CARD (FEC) PRODUCTION



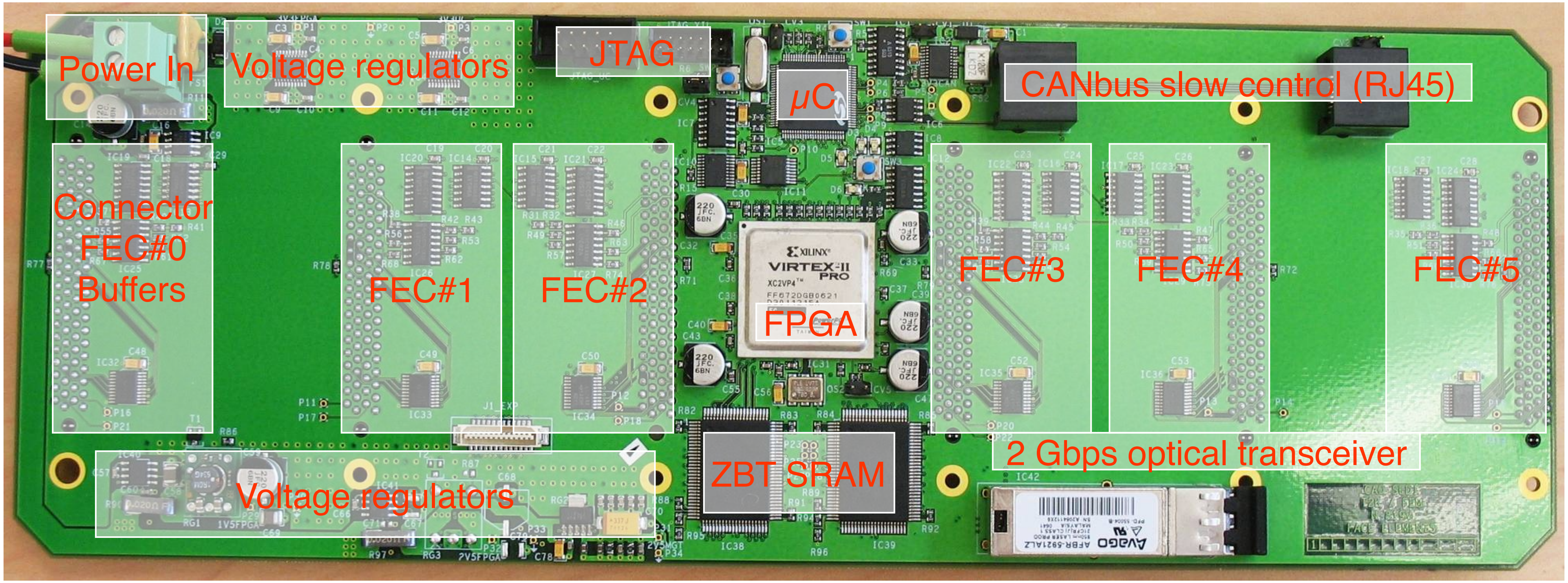
Features

- All design concepts validated on AFTER test board
- 1 FEC reads out 288 channels – 6 layer PCB
- Consumption: 1 A – 4 W

→ 514 FECs produced and 499 validated (97% yield)

D. Calvet

FRONT-END DIGITAL MEZZANINE CARD (FEM) PRODUCTION



93 cards produced and 84 validated on test bench (90% yield)

- Drive 6 FECs and aggregate data produced (1728 channels, 5.7 Gbps)
- Buffer one event (raw data), i.e. ~10 Mbit
- Deliver data to DCC upon request: raw data or zero-suppressed (one programmable threshold per channel)
- Configuration and slow control, voltage, current, temperature monitoring

D. Calvet