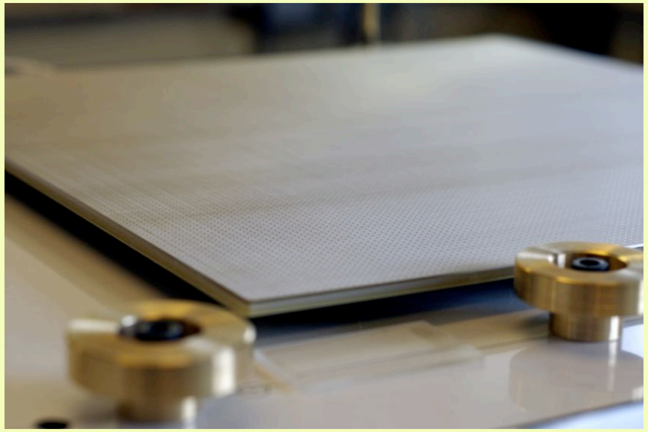
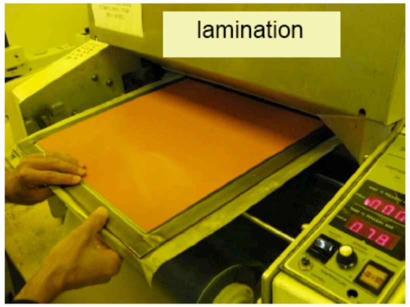
Large Bulk Micromegas for the T2K/TPC

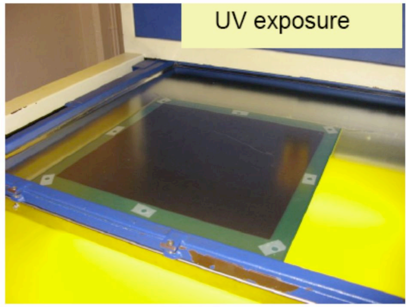
A. Delbart : CEA-Saclay/DSM-IRFU
Within the T2K/TPC Collaboration

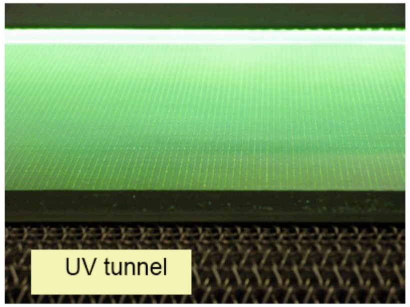
« bulk » Micromegas mesh integration
@ CERN/TS-DEM-PMT

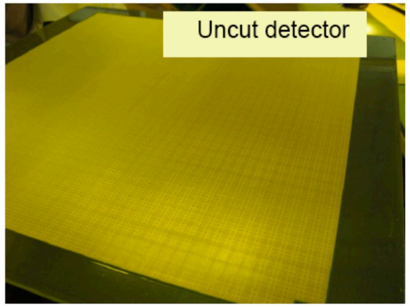
« bulk » Micromegas



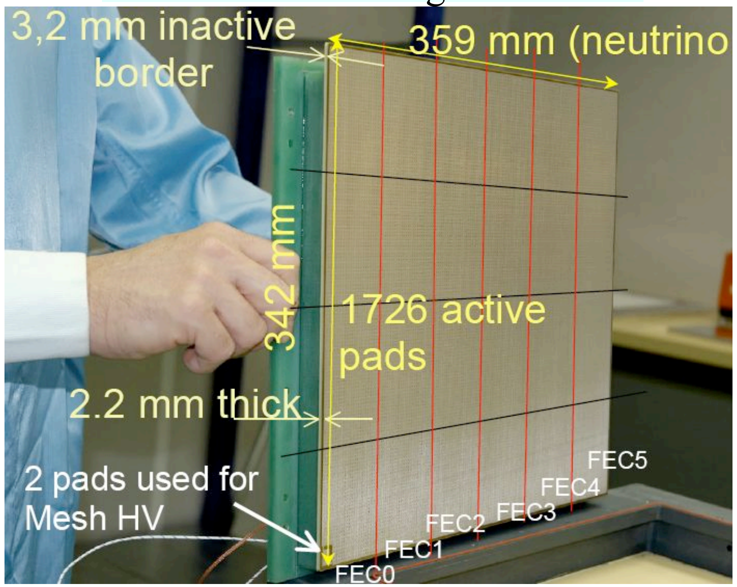


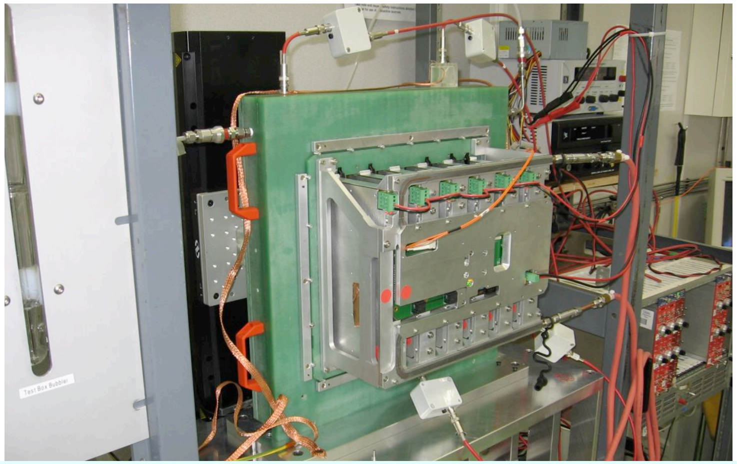






« bulk » Micromegas module





Module on calibration test bench @ CERN

Outline

- Micromegas : principle and standard technologies

- What is the « bulk » Micromegas and what is it for ?

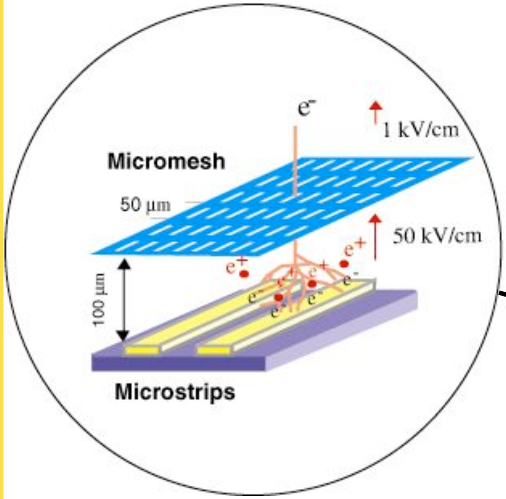
- 3 years of R&D and R&T towards large « bulk » Micromegas read with AFTER FEE for the TPCs of T2K/ND280 near detector
  - ✓ The T2K/TPC « bulk » Micromegas modules
  - ✓ Performances with AFTER FEE : Noise, 55Fe X-ray spectrum, Micromegas gain, sparking rate, and cosmic tracks reconstruction

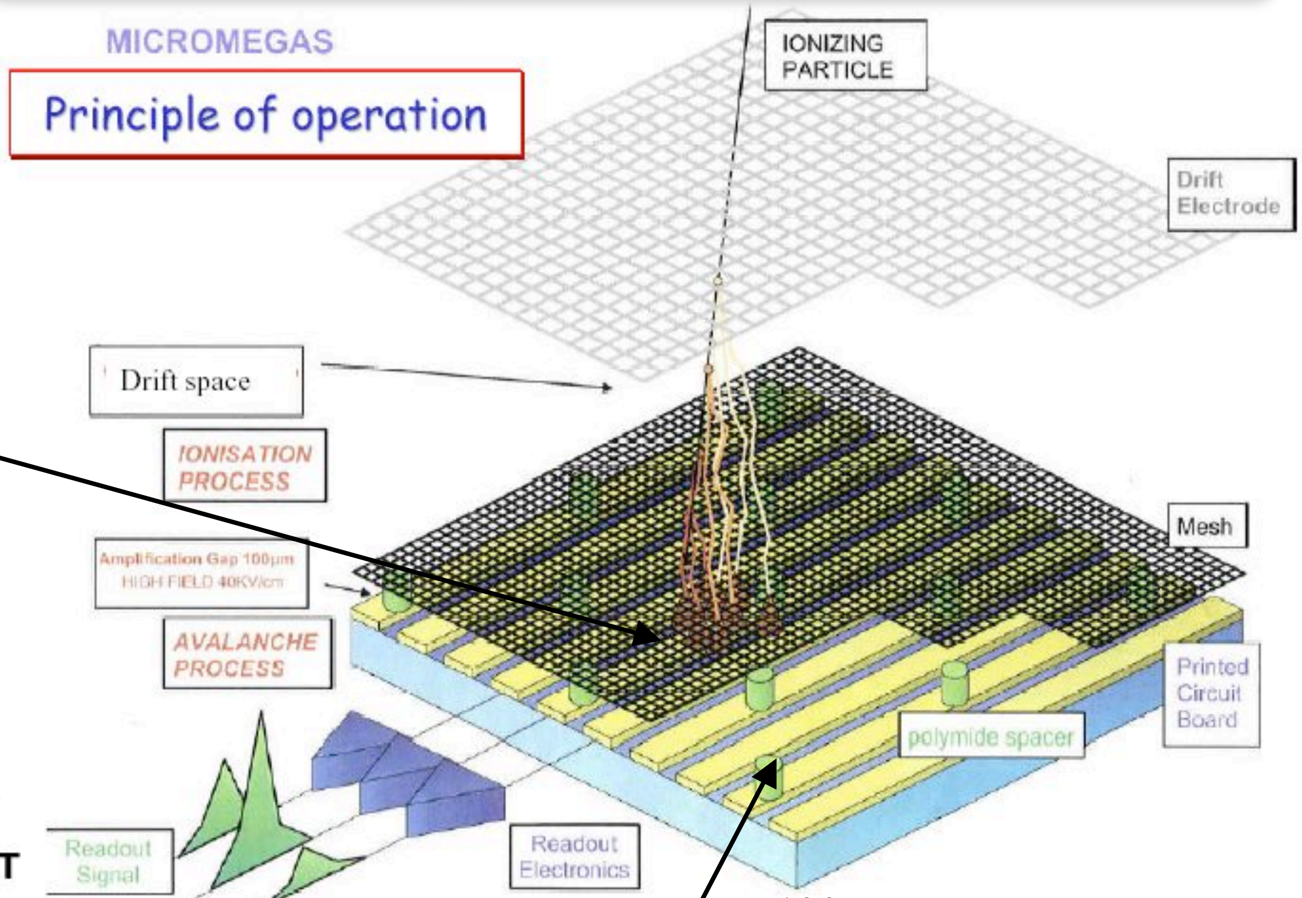
- Production of 84 Micromegas Modules @ CERN
  - ✓ Towards a high quality production
  - ✓ Calibration of Micromegas modules : uniformity of Gain and 5.9 keV energy resolution over the Micromegas active area (1726 channels)

- Conclusions & current bulk Micromegas developments

Micromegas

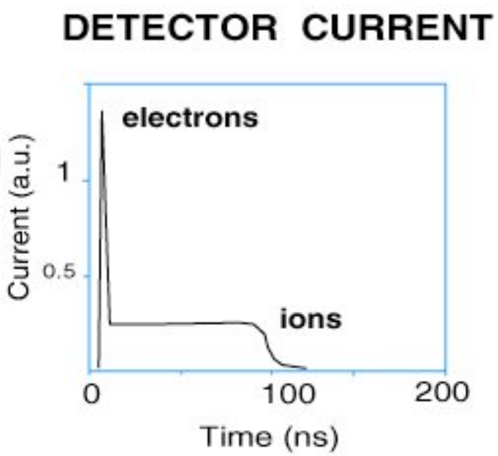
Micro Mesh Gaseous Structure, Y. Giomataris, Ph. Rebourgeard, J-P Robert and G. Charpak, NIM A376, 1996, p29





Fast ions collection

⇒ **High rate capabilities**



~100 µm gap

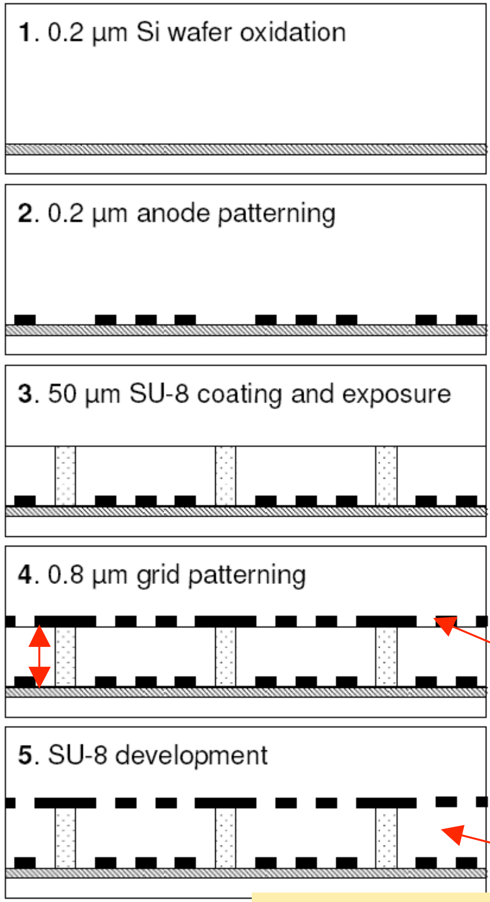
keeping the gap constant

- **Ni or Cu micromesh + pillars on PCB**
- **Self-supported copper micromesh**
- **« bulk » technology**
- **Recent InGrid techniques** : al mesh built over Si pixel chip by post-processing + possible SiProtect layer

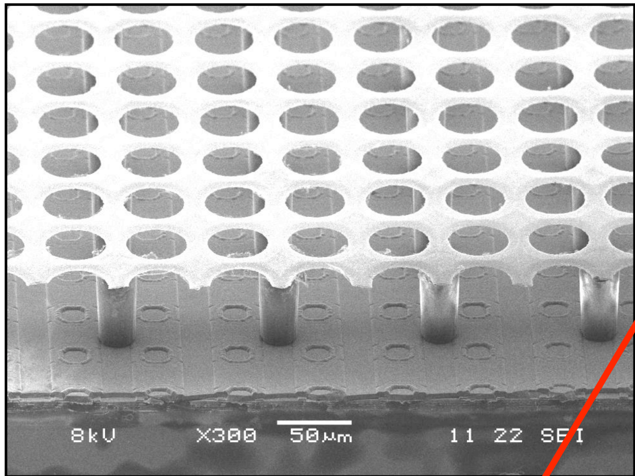
R&D InGrid (within the european R&D program EUDET)

Micromegas integration within the pixels sensor by post-processing of the Si wafers
Al grid, 0.8 µm thick, accurately positionned with respect to the pilars and pixels

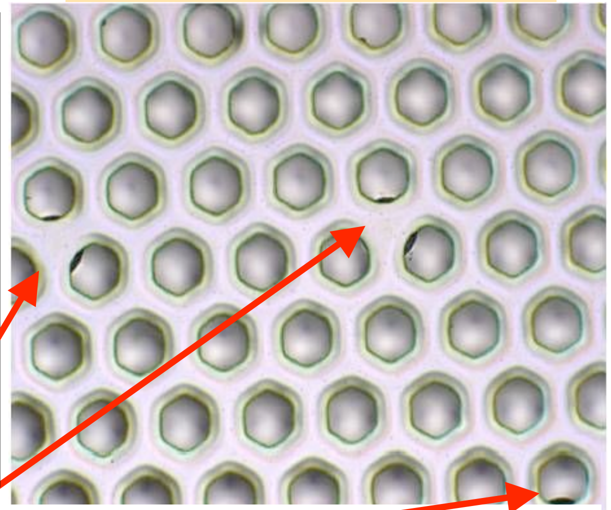
Si wafer Post-processing



Timepix chip + SiProt + InGrid

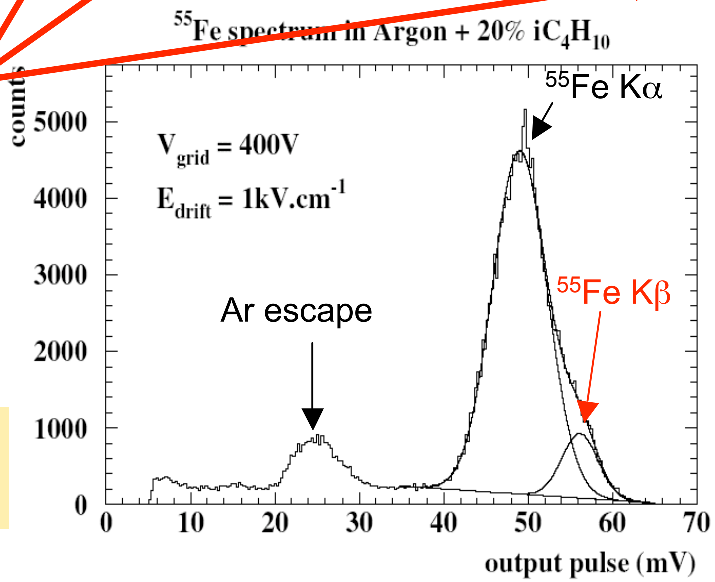


Aluminum grid 60 µm pitch



ϕ 40 µm pilars

No dead zones



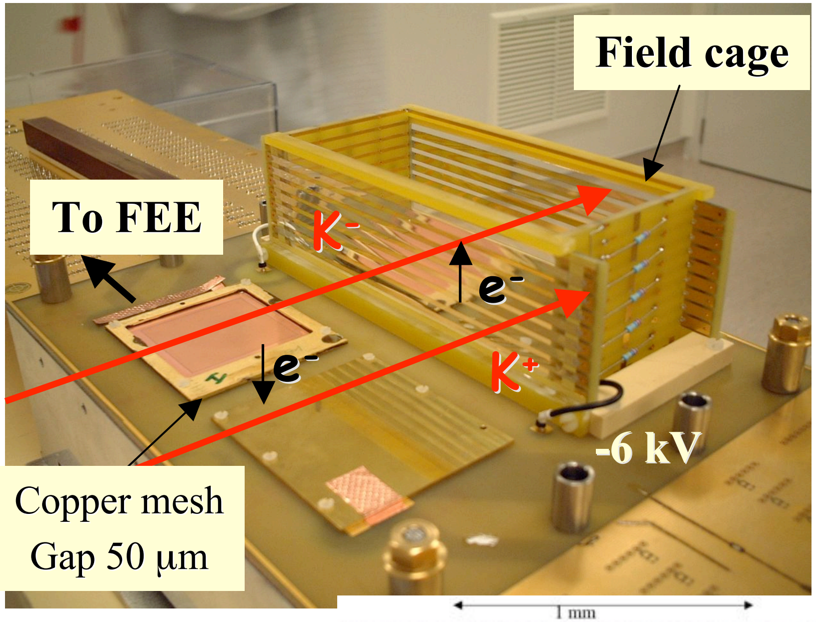
Excellent Energy resolution : σ_E/E = 6.5%.

towards digital mini-TPCs

Collaboration NIKHEF-Saclay-CERN-univ. Of Twente

Some Micromegas technologies commonly used in physics experiments

NA48/KABES station

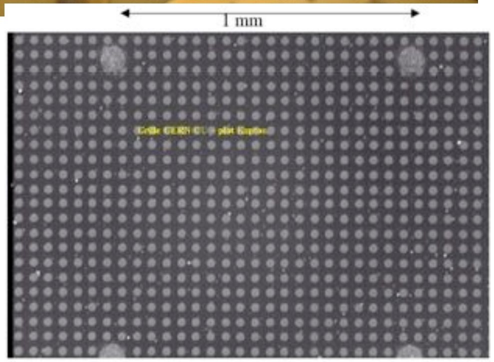


Kapton pillars On 5 µm thick Cu mesh with ϕ50mm holes

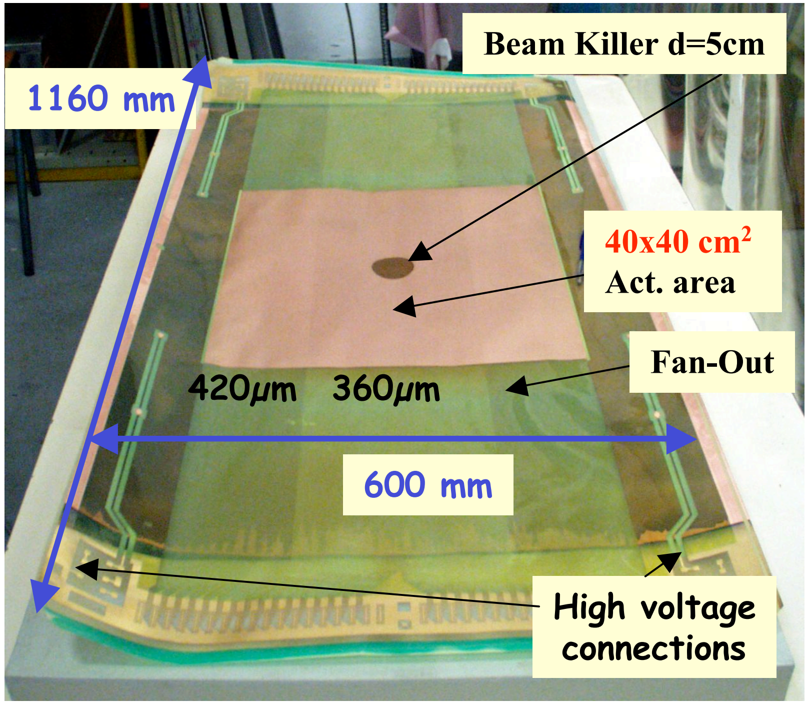
500 LPI (50 µm pitch)

Gap 50 µm (pillars' height)

Gap down to 12 µm tested



COMPASS Micromegas PCB



Solder mask pillars On PCB

3 mm thick Ni electroformed mesh

500 LPI

Gap 100 µm (or greater)

Lower pitch available : up to 1500 LPI

Drawback of these technologies :

- "large" dead zones around active area + delicate assembly due to the mesh frame
- gap irregularities in corners : amplification gap is obtained only when mesh HV is applied (Elec. Force)

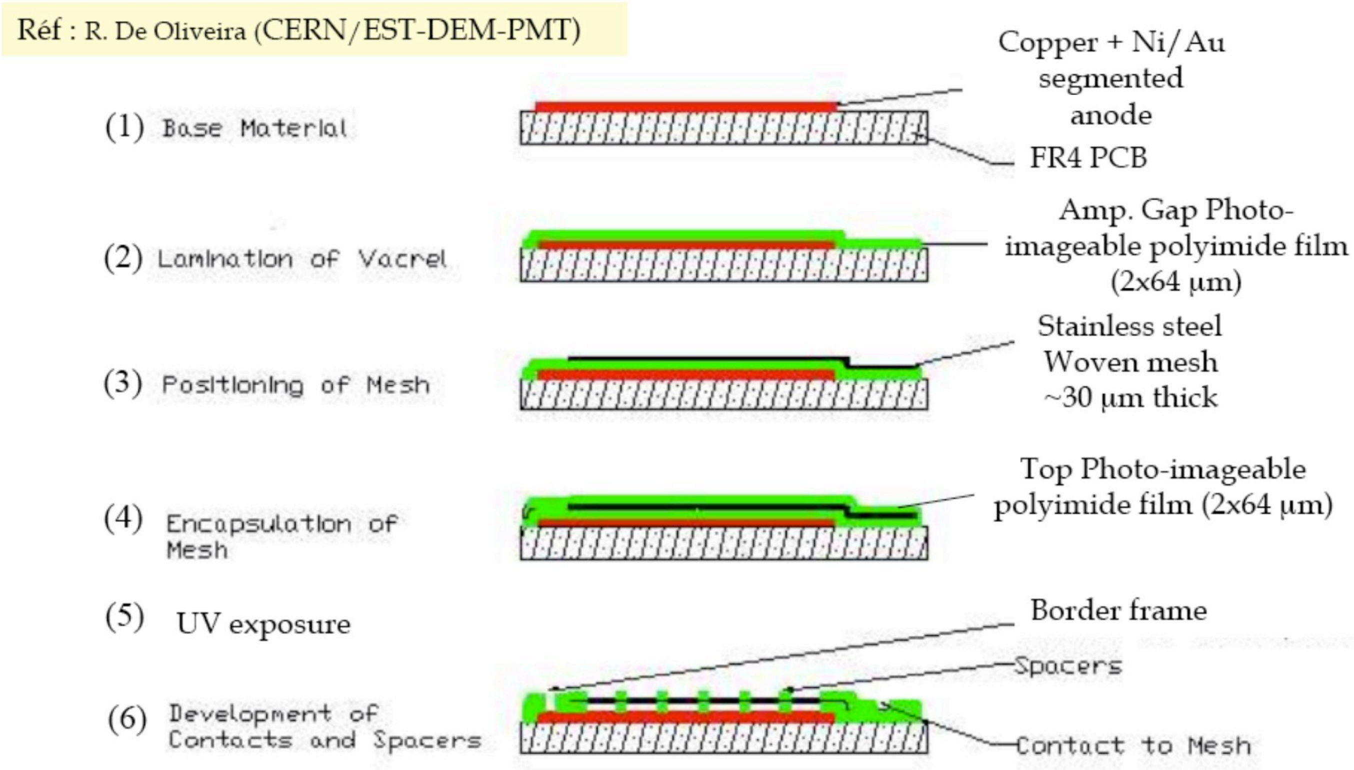
The « bulk » micromegas

✓ The « stretched » woven micromesh is laminated with the top pyralux layer

✓ UV exposure through the transparent areas of the mask (border+pillars) and chemical development of the unexposed areas makes the « bulk » micromegas

✓ The woven micromesh is locally encapsulated between the 2 layers of insulating material

✓ T2K/TPC : 2 mm wide border on the edges of the PCB and 20712 spacers



MM Detector

AFTER FEE

2004

« bulk » MM generic R&D
- 8x8 cm² / 1 central anode
- Vacrel (soldermask)

2005

T2kn# 2005 prototypes (5)
- 26x27 cm² / 1024 pads (8x8 mm²)
- 3 layers PCB with blind vias

2006

Tests of 2 MM Modules on HARP cage
Cosmics/1536 ALTRO channels

Choice of bulk micromegas
By T2K/ND280

MM0# 2006 prototypes (7)
- 34x36 cm² / 1728 pads (6,9x9,7 mm²)
- 3 layers PCB with blind vias

2007

MM1# 2007 module (4)
- 4 layers PCB with internal shielding
- NEW « stretched » mesh procedure

MM Detector's PRR

Tests of a MM Module on HARP cage
with 1728 AFTER FEE channels

2008

Start of detectors' production

2004

Ortec 142
1 channel

2005

Start of
AFTER Dvpt.

128 ch.
ALTRO cards

2006

First AFTER ASIC

AFTER validated

2007

AFTER FEE
On detector

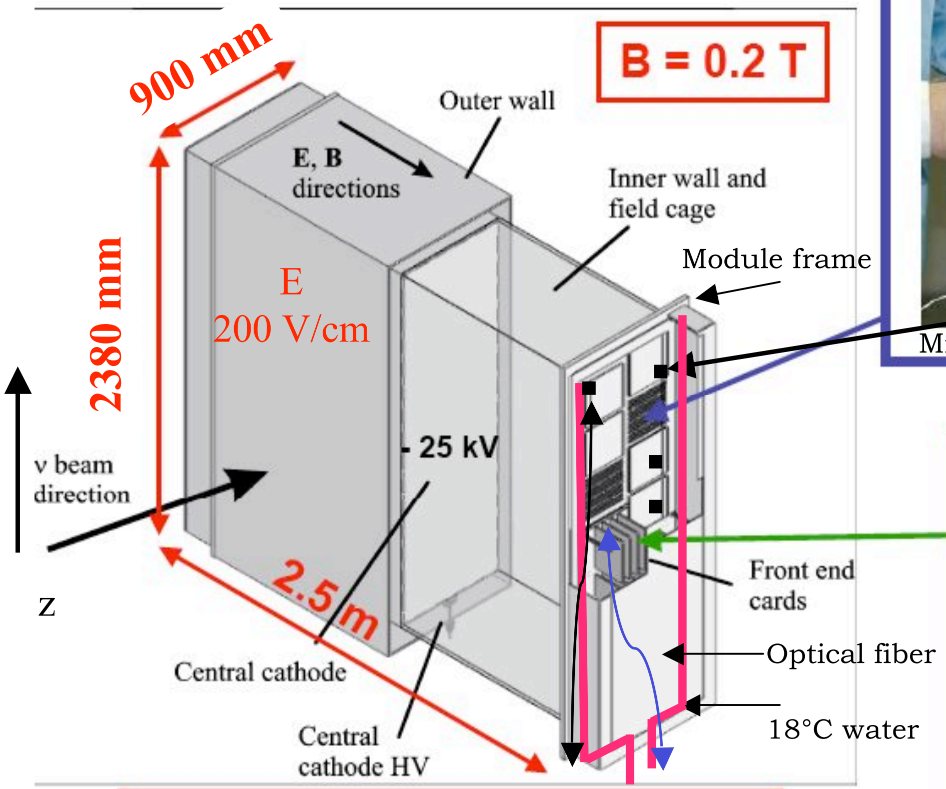
PRR AFTER

2008

Start of AFTER ASIC production
Followed by FECs and FEMs

The T2K/280m TPC

3 TPCs in ND280
12 modules / readout plane

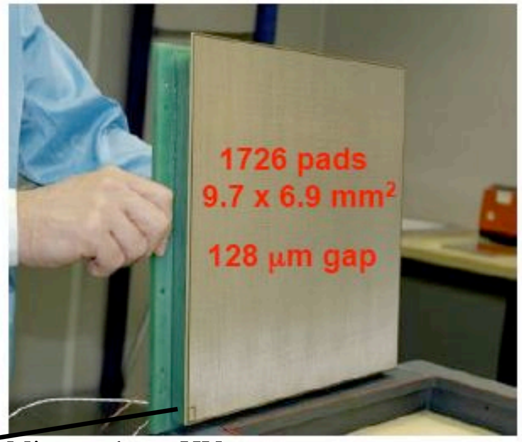


T2K requirements:
- σ(dE/dx) ≤ 10% for e,μ ID
- σ(p) / p < 10% @ 1GeV/c

Dead zones between 2 active areas
Δz=26,6 mm & Δy=7,7 mm

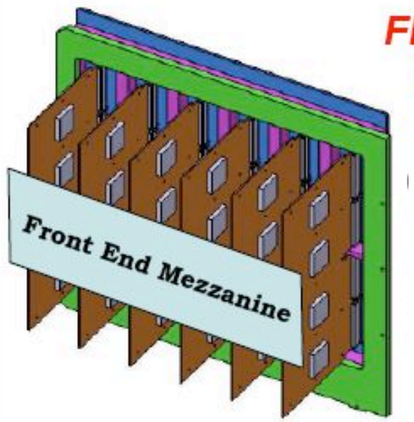
Gas choice : Ar+2%isobutane+3%CF_4

36 x 34 cm² « Bulk » MicroMegas



12 modules per Readout plane

Total of 72 modules



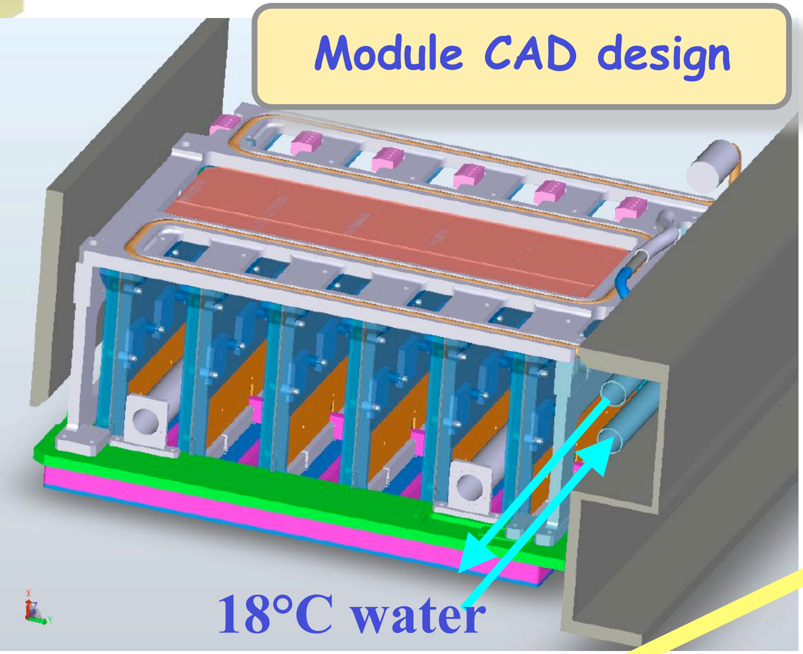
FEE based on the ASIC AFTER

6 FECs + 1 FEM per module
124272 channels
Total of
1728 ASICs
432 FECs
72 FEMs

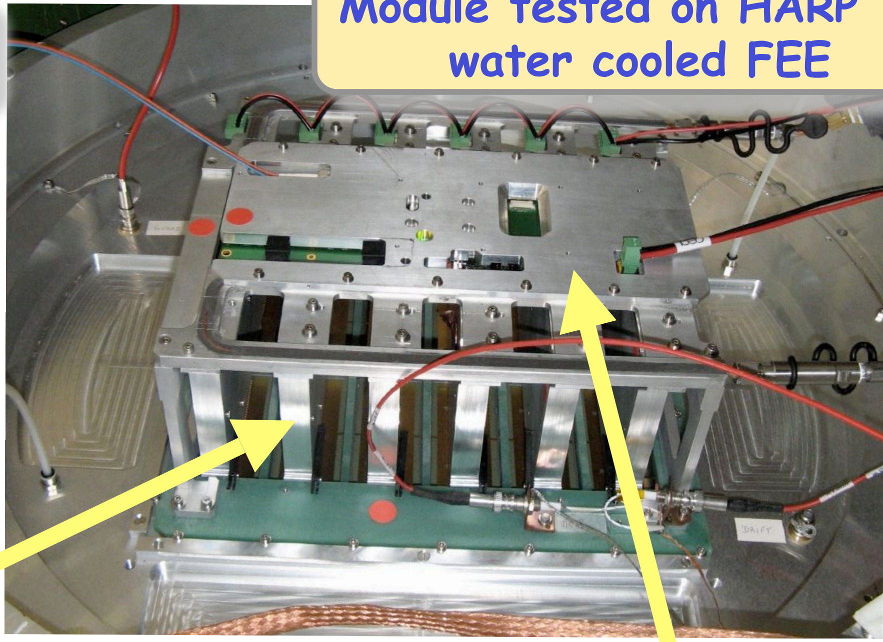
With On-detector FEE cooling mechanicals
- **432 FEC carapaces and shielding plates**
- **72 FEM carapaces and shielding**
- **72 cooling plates**

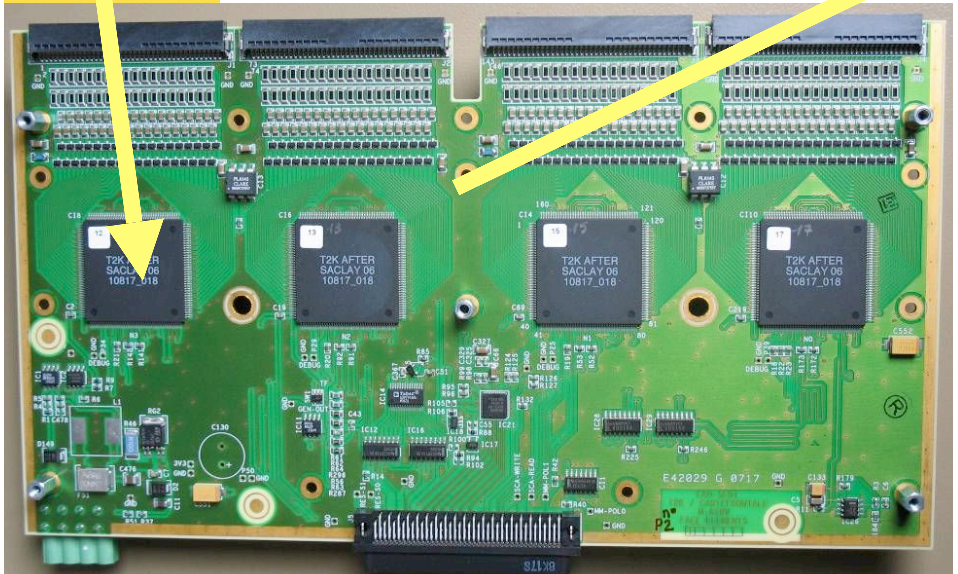
The T2K/TPC module 2007 prototype

Module CAD design

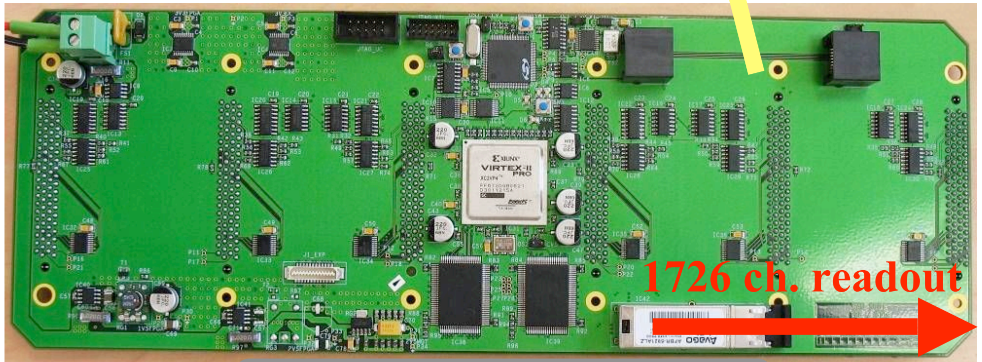


Module tested on HARP TPC
water cooled FEE





288 ch. Front-End Card with 4x72 ch. AFTER ASICs



Front-End Mezzanine

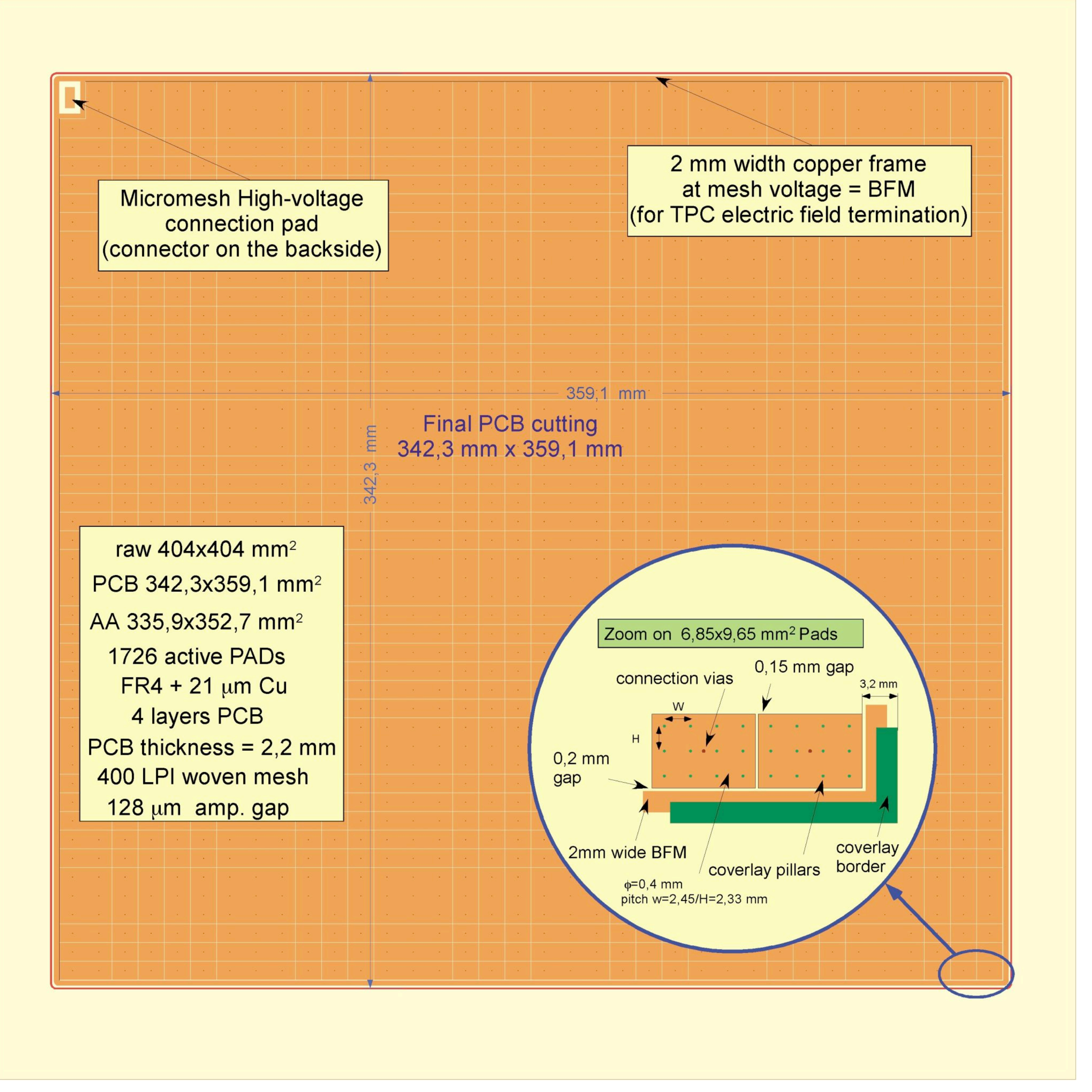
Production began in 2008

- ✓ **Micromegas by CERN/TS-DEM-PMT**
- ✓ **Modules assembled & tested by the T2K/TPC Europe collab. @ CERN**

Key features of T2K/TPC « bulk » Micromegas

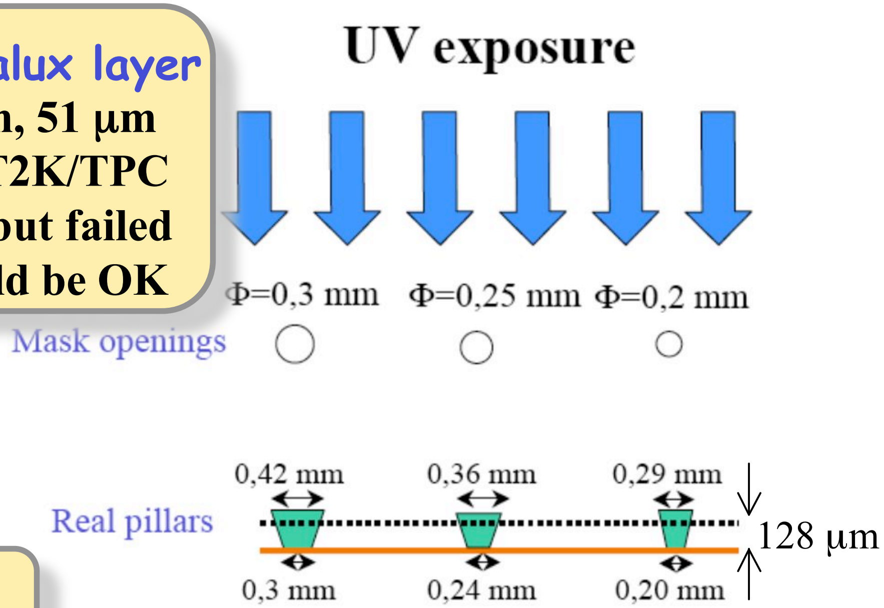
MICROMEGAS MODULE DIMENSIONS	342,3 x 359,1 mm^2
Number of pads (per module)	1726
Pad dimensions	6.85 x 9.65 mm^2
Mesh material	Stainless Steel 304L
Mesh pitch and thickness	63 µm - 2x18 µm (20% less after lamination)
Insulating material	Pyralux PC 1025 (DuPont)
Gap	128 µm
Signal typical duration	~100 ns
Pillars (mask) on a pad	400 µm x 12
Pad (thickness)	CU with Ni/Au coating (~25 µm)
Interpad	150 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	~ - 400 V
"Natural" Sparking rate (cosmics in 1cm 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)	18-20% FWHM
Typical Gain non uniformity over 1726 pads	~2,7 % r.m.s
Space resolution	~600 µm at 1m drift length

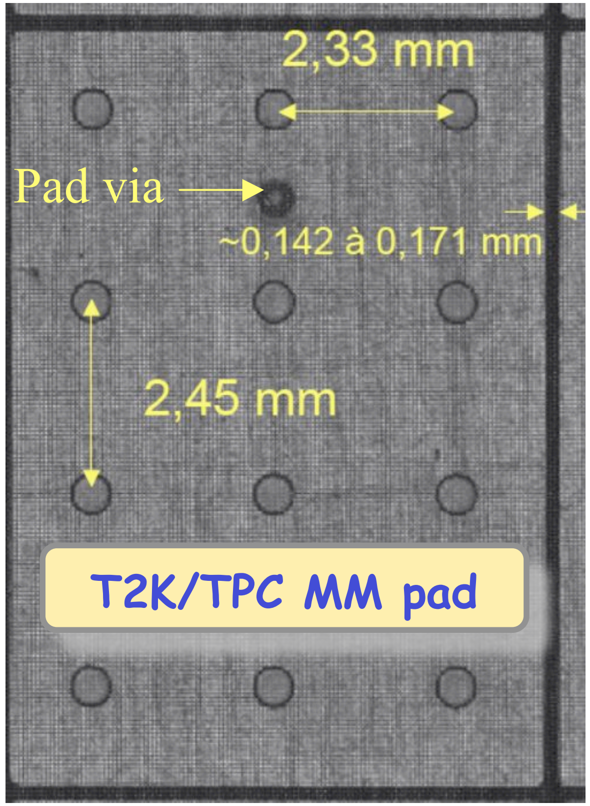
The T2K/TPC Micromegas anode PCB



Pillars and mesh specifications

Available Pyralux layer
25 mµ, 38 µm, 51 µm
2x64 µm for T2K/TPC
64 µm tested but failed
2x51 µm should be OK

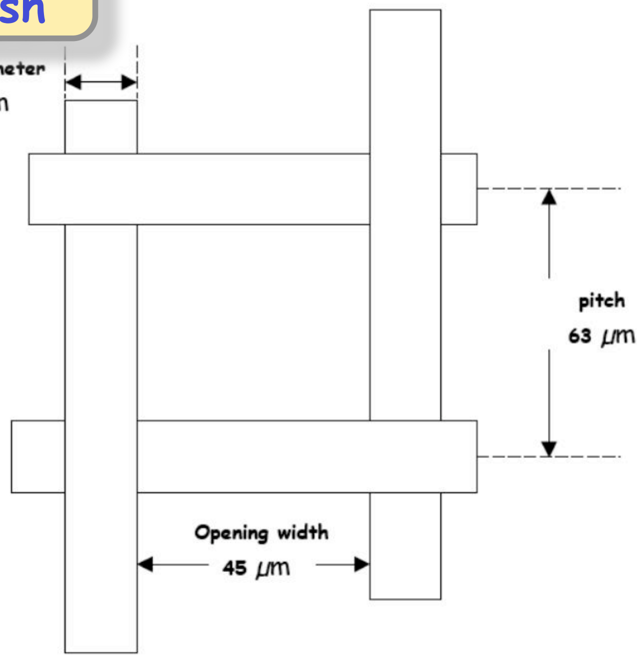


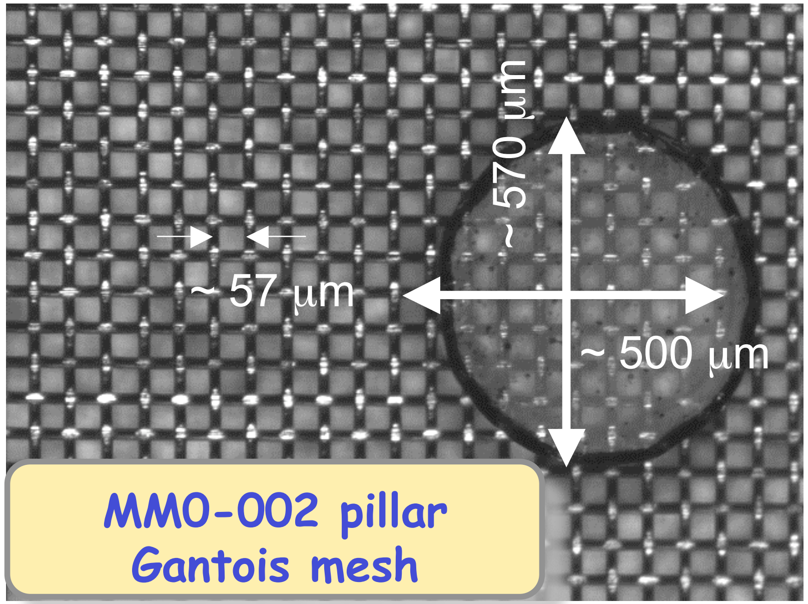


T2K/TPC MM mesh
400 LPI BOPP mesh

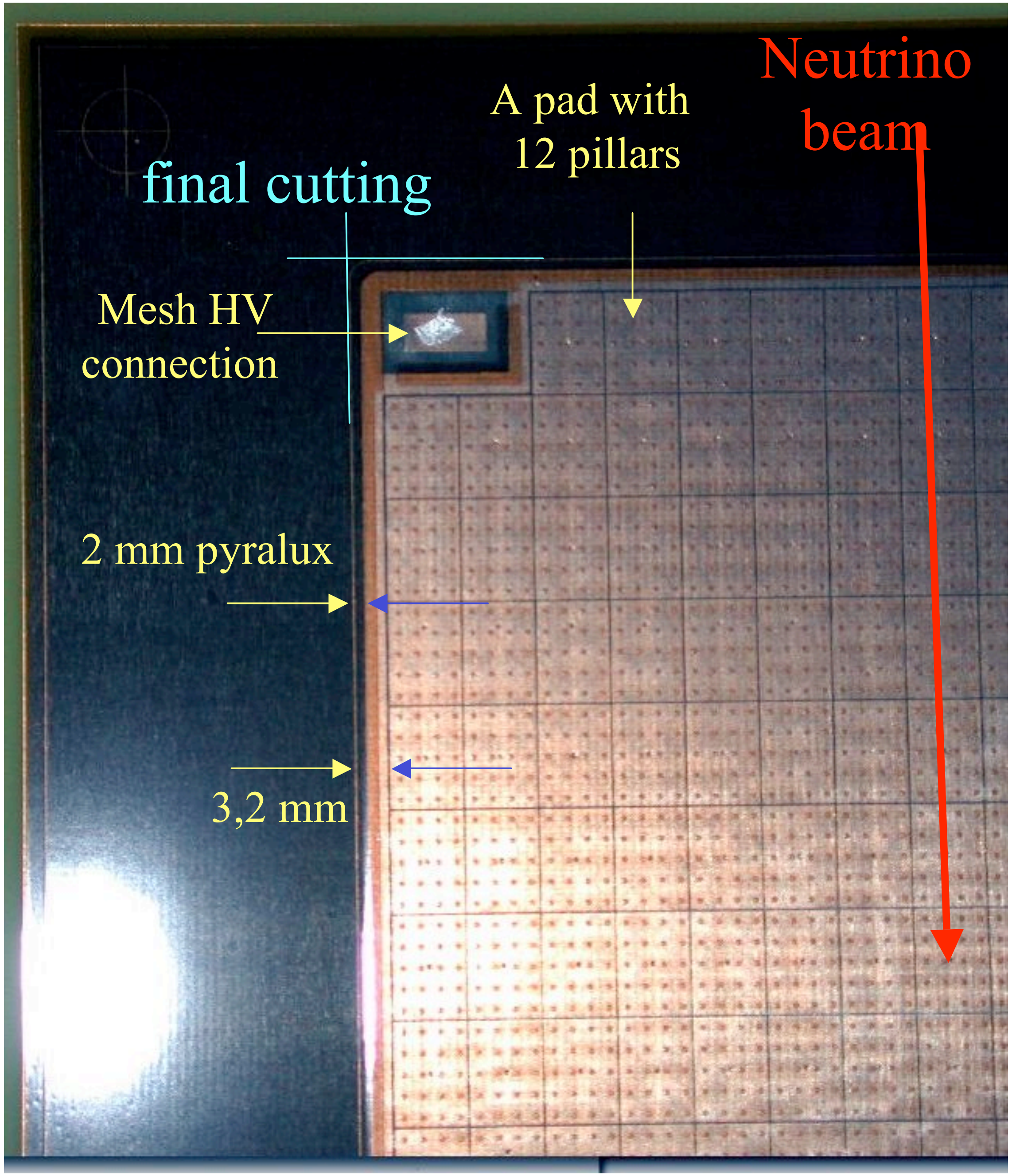
Ref:SD45/18

- 304 L stainless steel
- 20% calendered
- ~30 µm thick

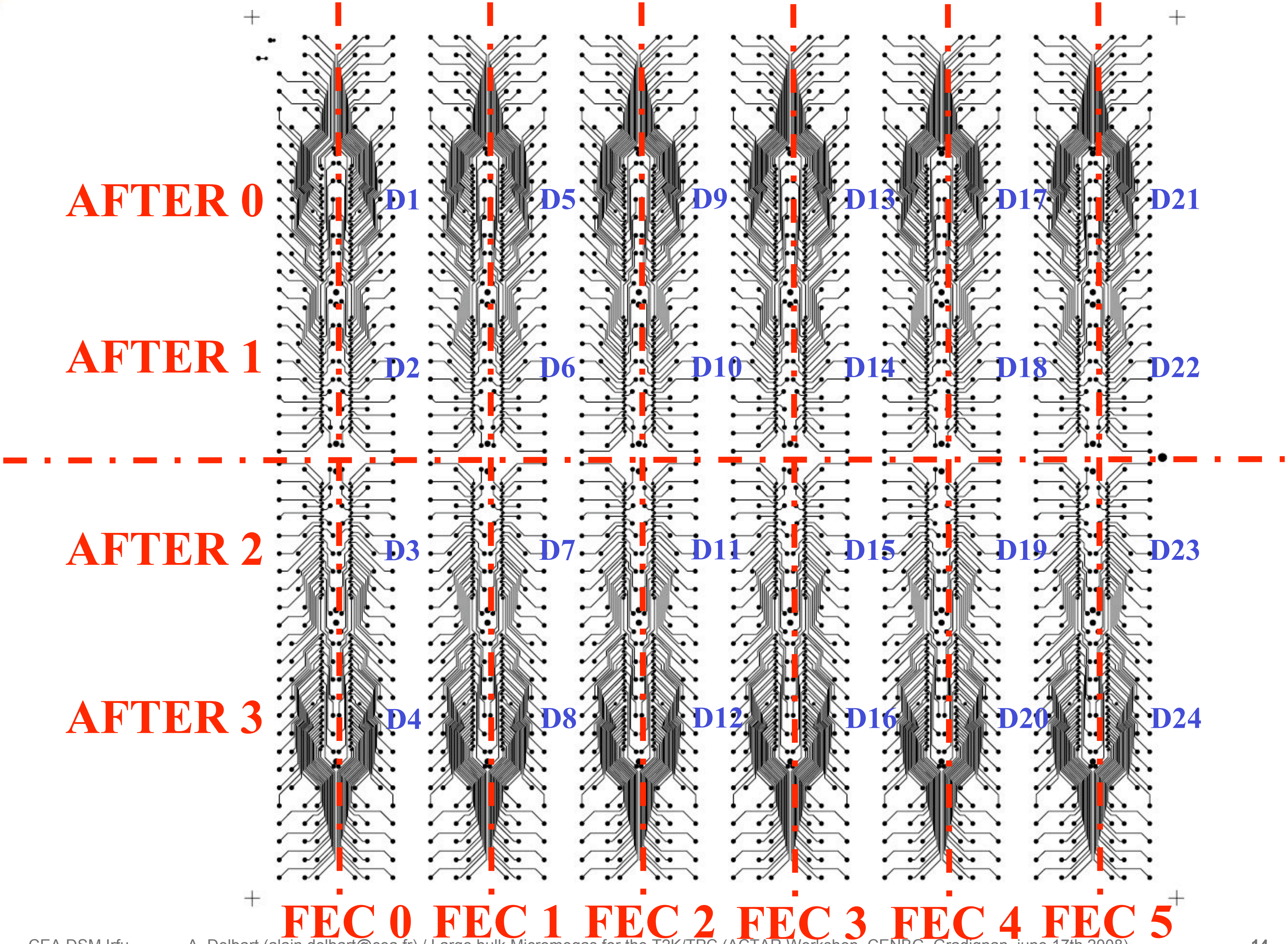




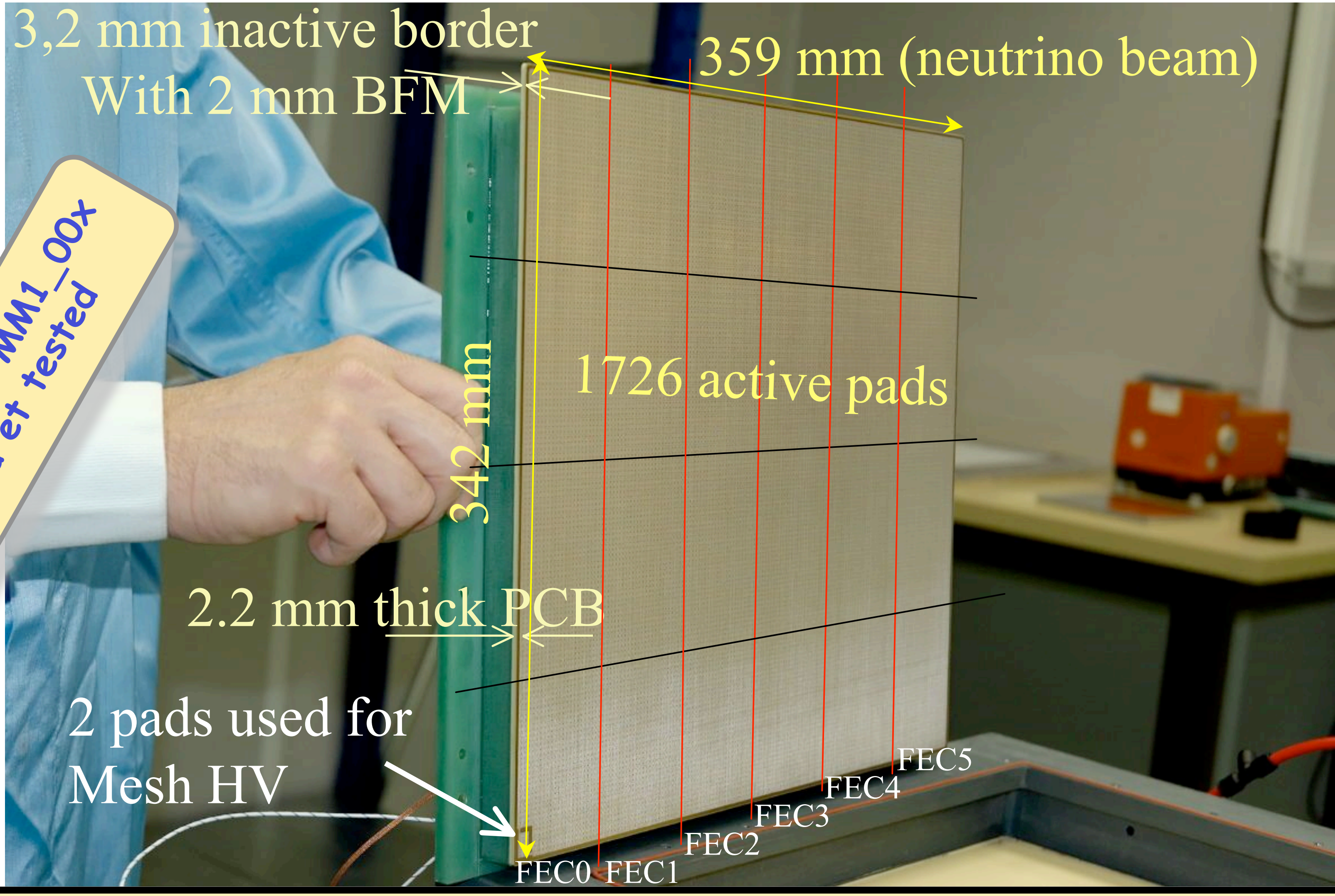
A T2K/TPC bulk Micromegas before final cutting



T2K/TPC Micromegas anode PCB, routing layer



The T2K/TPC Micromegas module



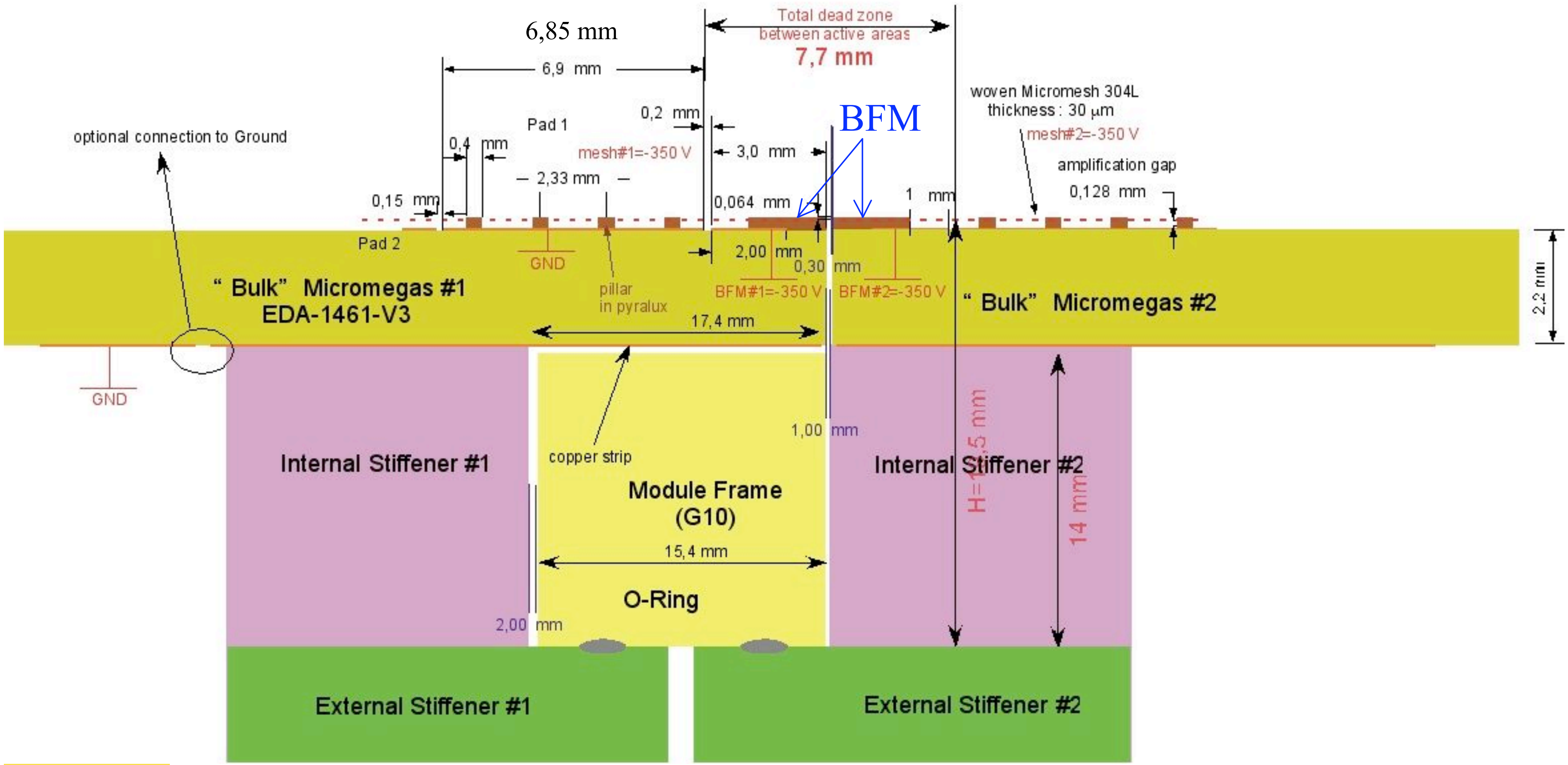
3 MM0_00x & 5 MM1_00x produced et tested

- a 30 μm thick 400 Lpi woven micromesh is embedded between 2 layers of pyralux
- 4 layers PCB with internal shielding layer & 6,85x9,65 mm pads / 7x9,8 mm pitch
- 128 μm amp. gap / 12 x ϕ0,4 mm pillars per pad / « stretched » mesh procedure
- 93% of PCB surface is active area / less than 2 faulty pads per module

MM Module integration on TPC readout plane

Very few access to modules : High quality & reliability of Micromegas is required
Mechanics : the 12 Micromegas micromesh planes should be aligned within 0,1 mm
Electric field : the 12 Micromegas micromesh should be @ same HV (within 0,1 V)
Gain Vs mesh HV uniformity from a modules to another is required (within FEE performances)
FEE design to minimize HV drop (spark) & capable of maintaining HV if local short-circuits occur

Cross section of the 2 Micromegas detectors mounted on the Readout plane (Y direction)



Noise/capacitance measurement with AFTER FEE

Ref: P. Baron,X. De la Broise,E. Delagnes, E. Virique

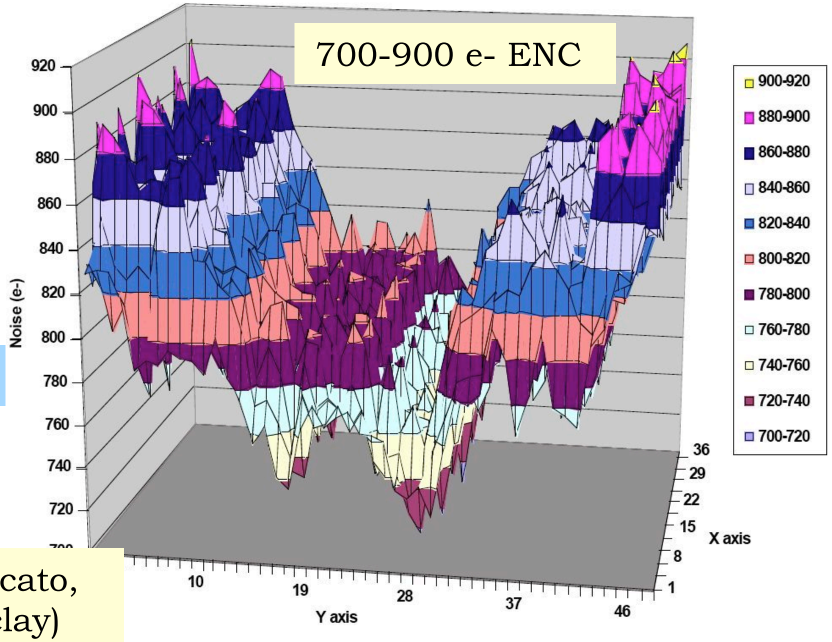
Energy range : 120 fC /peaking time : 100 ns / SCA sampling freq. : 50 MHz

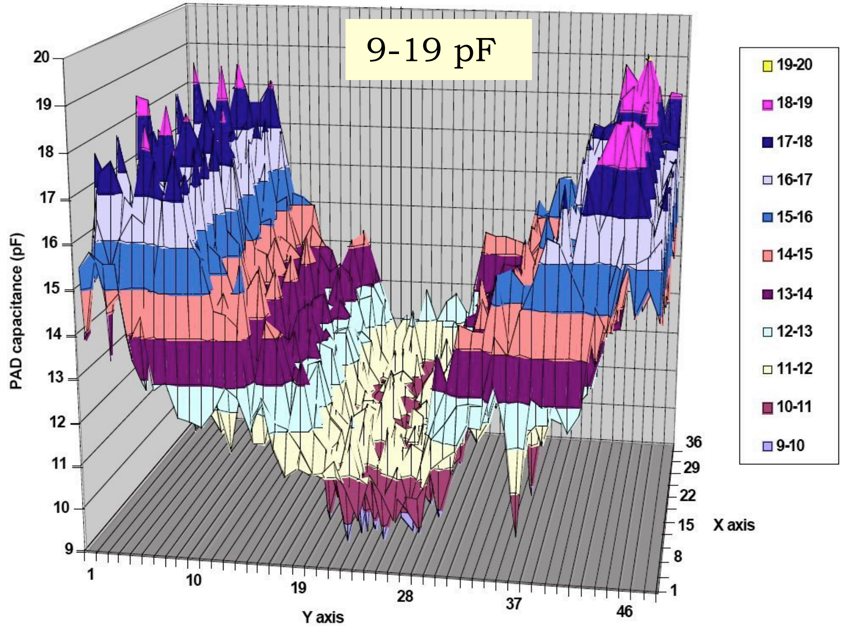
Irfu

cea

saclay

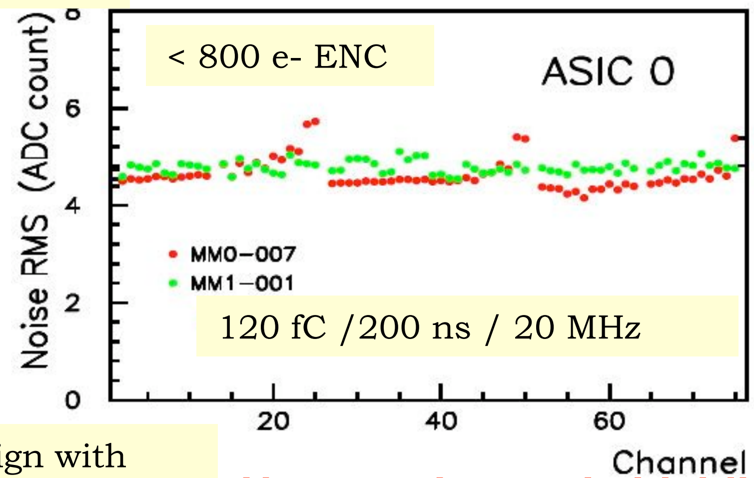
Mesh@GND

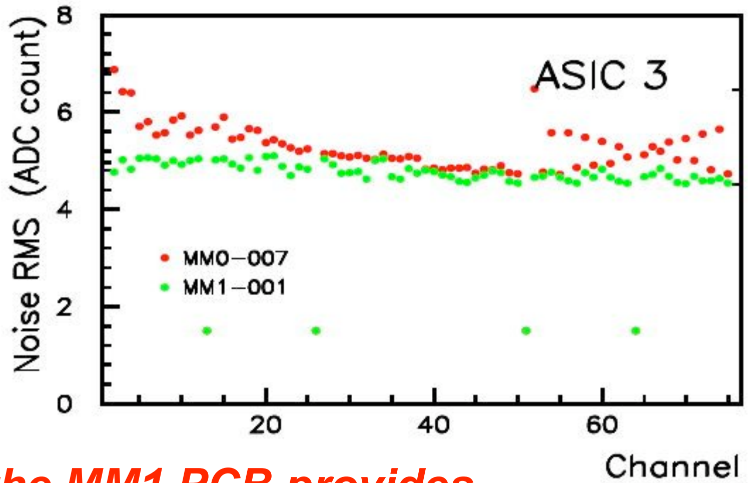




Ref: E. Mazzucato, F. Pierre (Saclay)

Mesh= -350V



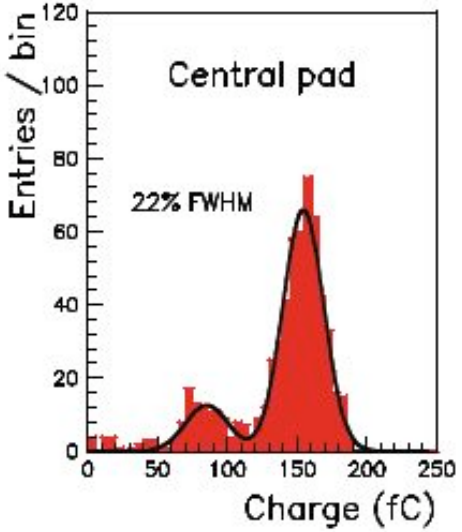


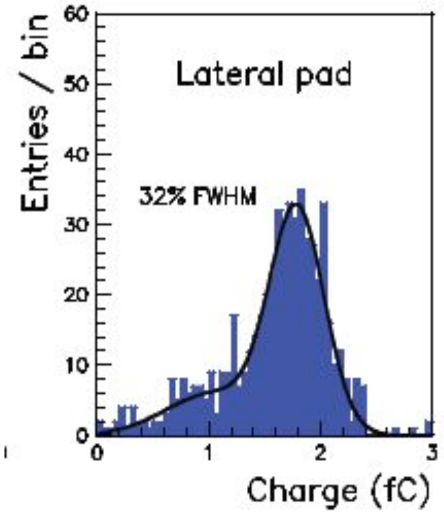
PCB Design with
M. Sanchez / S. Baiteche
CERN-TS-DEM

New routing and shielding in the MM1 PCB provides better noise uniformity (~3%)and smaller sensitivity to pick-up noise.

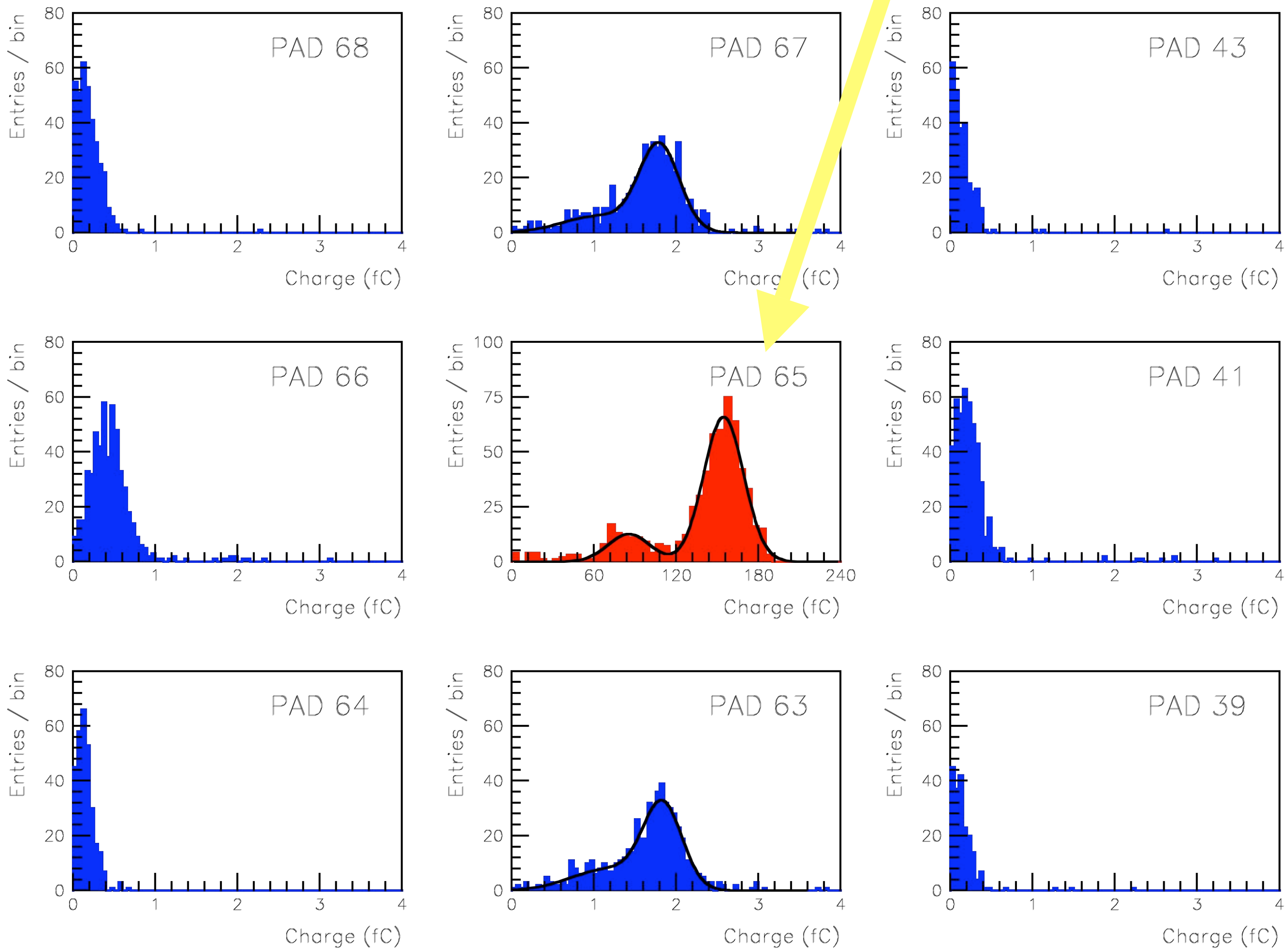
Cross-talk with AFTER FEE

^{55}Fe source
V_{mesh} = - 385 V
Gas Gain~4000





5.9 keV contained in 1 pad

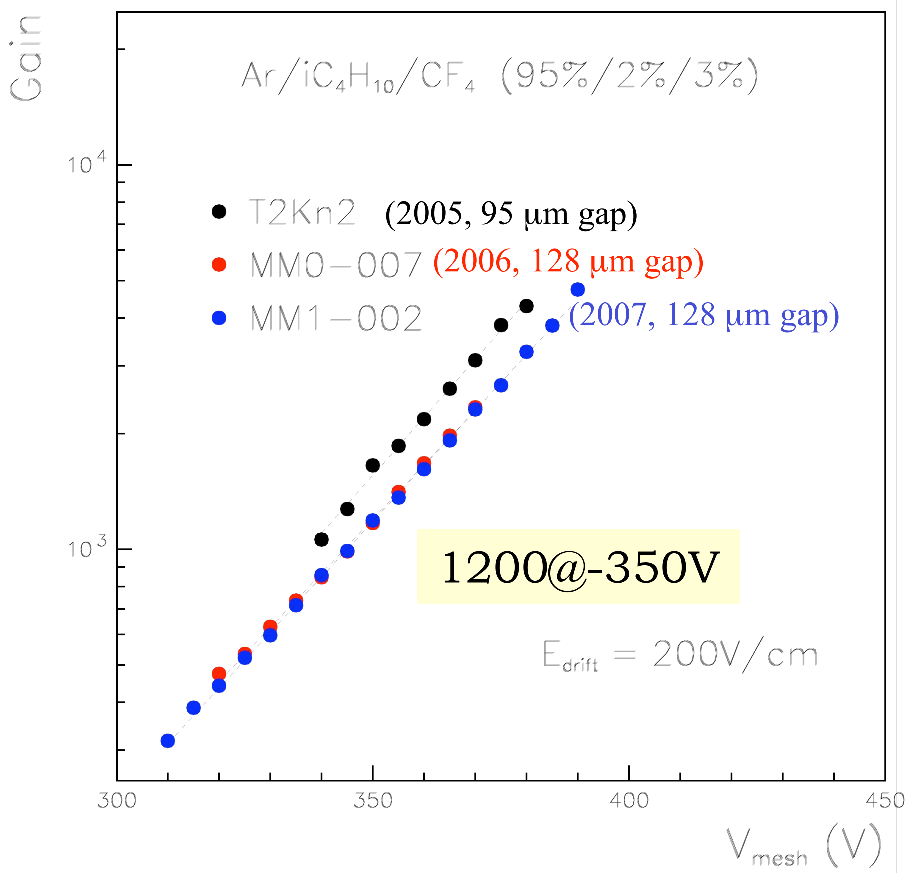


Observed total cross-talk ~ 1.2 % (AFTER+FEC+MM PCB)
~ 2.5 pF parasitic capacitor

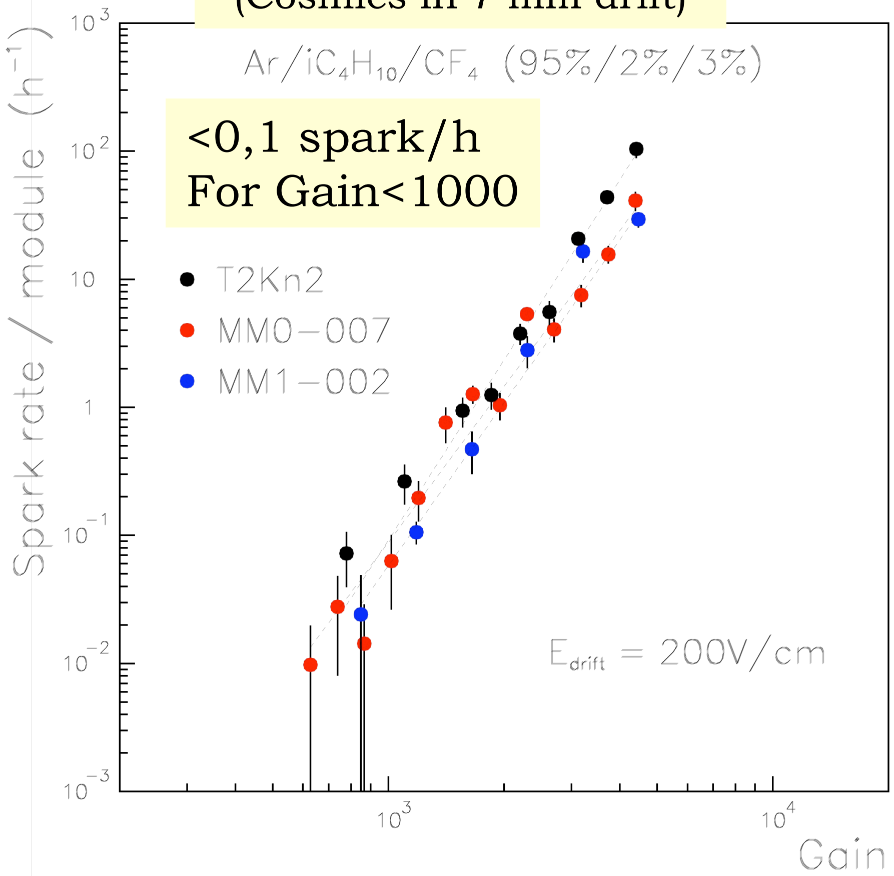
Gain & sparking rate

- Main constraints for the T2K/TPC: non-flammable, low transverse diffusion for small B, operation close to the maximum drift velocity and minimization of the effect of impurities
- baseline T2K/TPC gas : $Ar+2\%C_4H_{10}+3\%CF_4$
- Transv. Diff. 240 $\mu m/cm^{1/2}$, drift velocity 6,5 cm/μs @ 200V/cm (Magboltz & measured on harp cage)

Gain Vs V_{mesh}

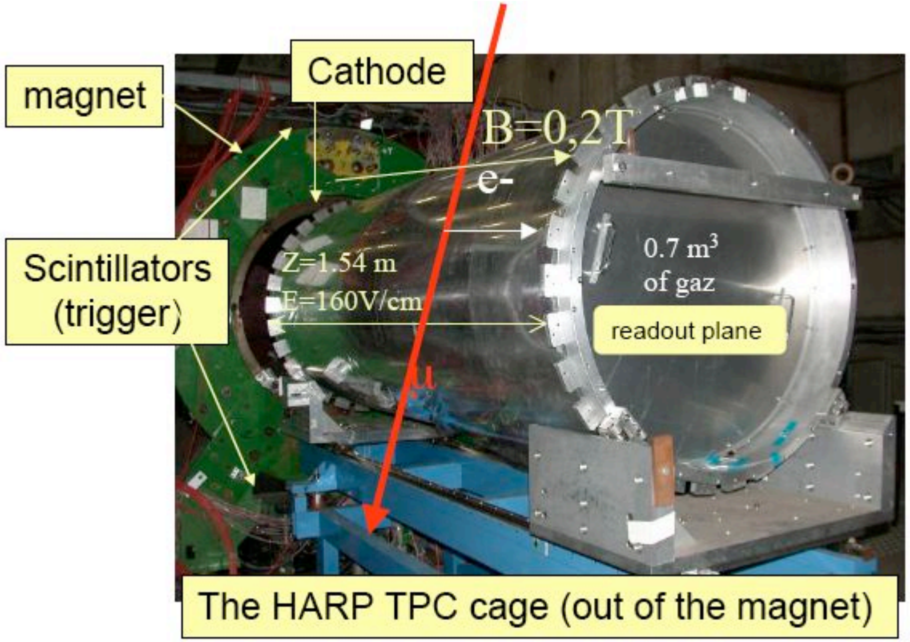


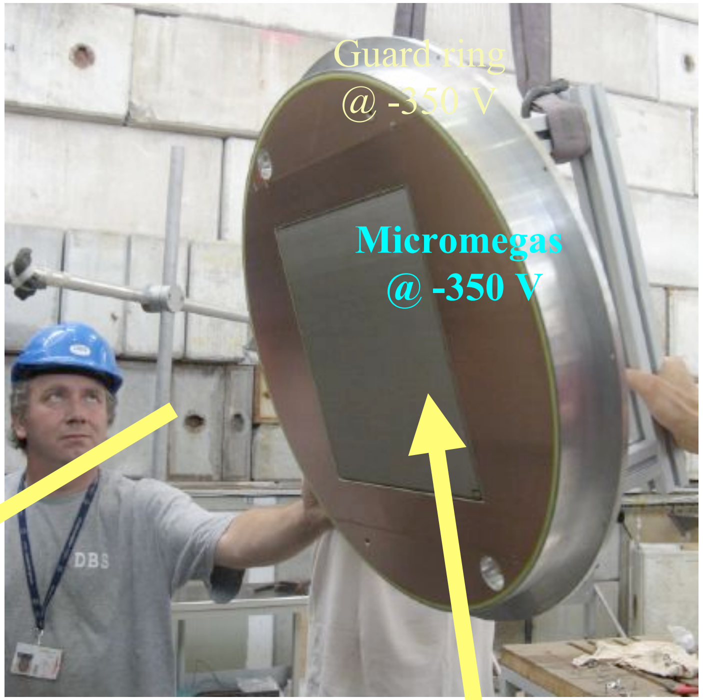
Sparking rate Vs Gain
(Cosmics in 7 mm drift)

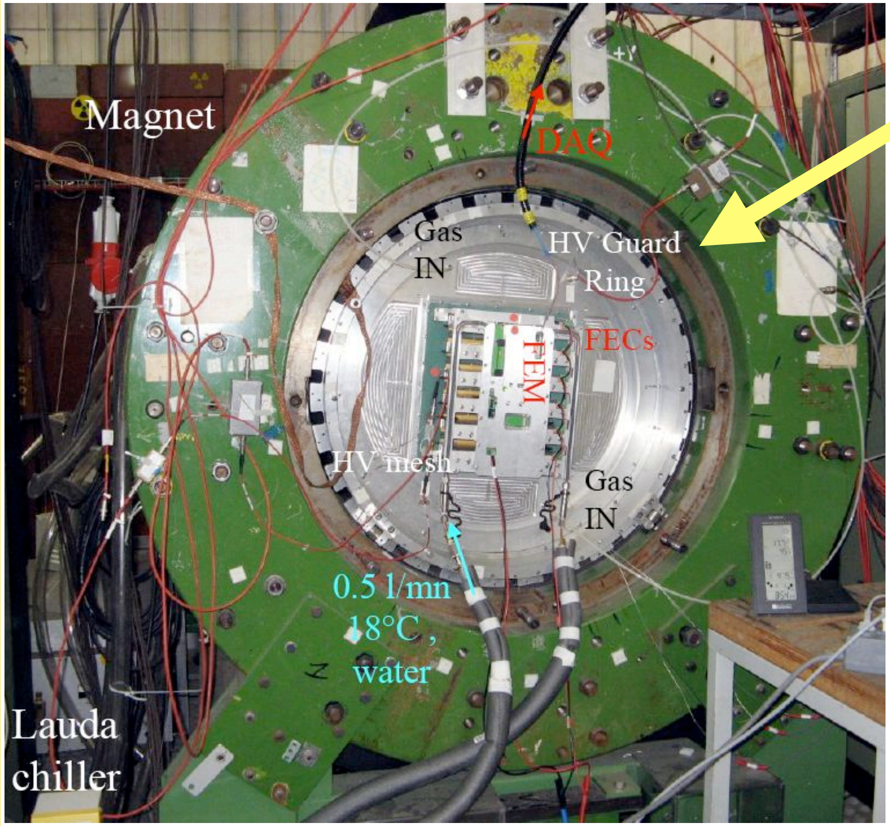


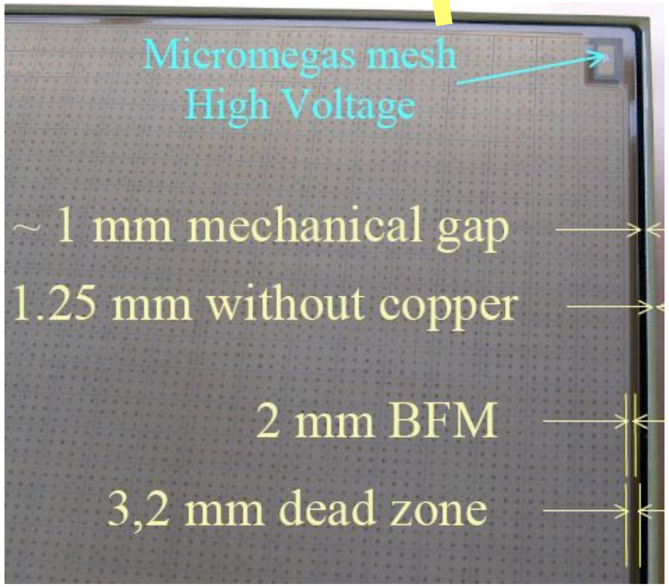
- ***Good Gain uniformity from one Module to another* (to be confirmed on production)**
- ***The T2K/TPC will be operated at moderate gas gains of about 1000 where spark rates / module are sufficiently low (< 0.1/hour). TPC dead time < 1% achievable.***

Micromegas Module tests on HARP TPC (2007)





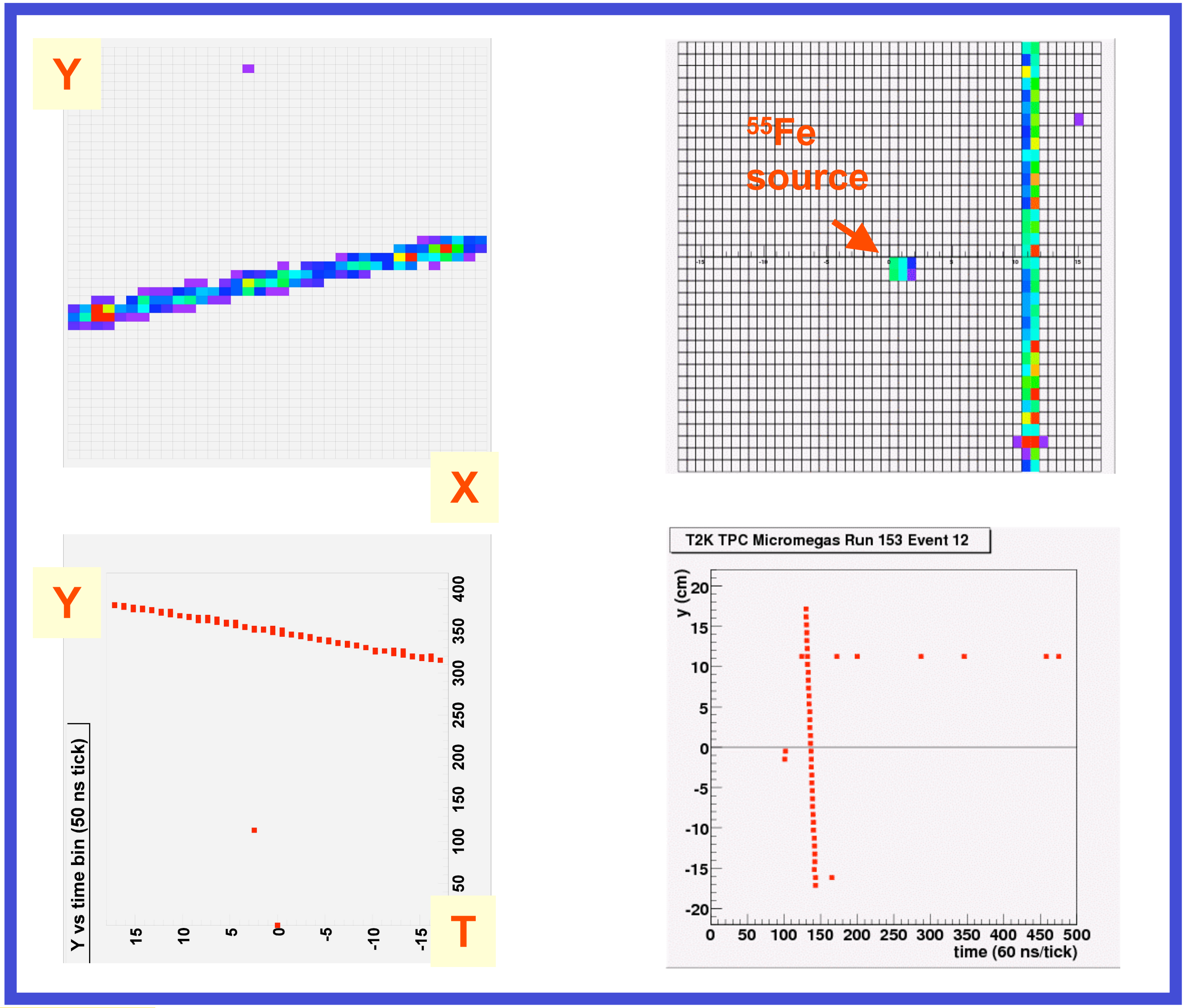




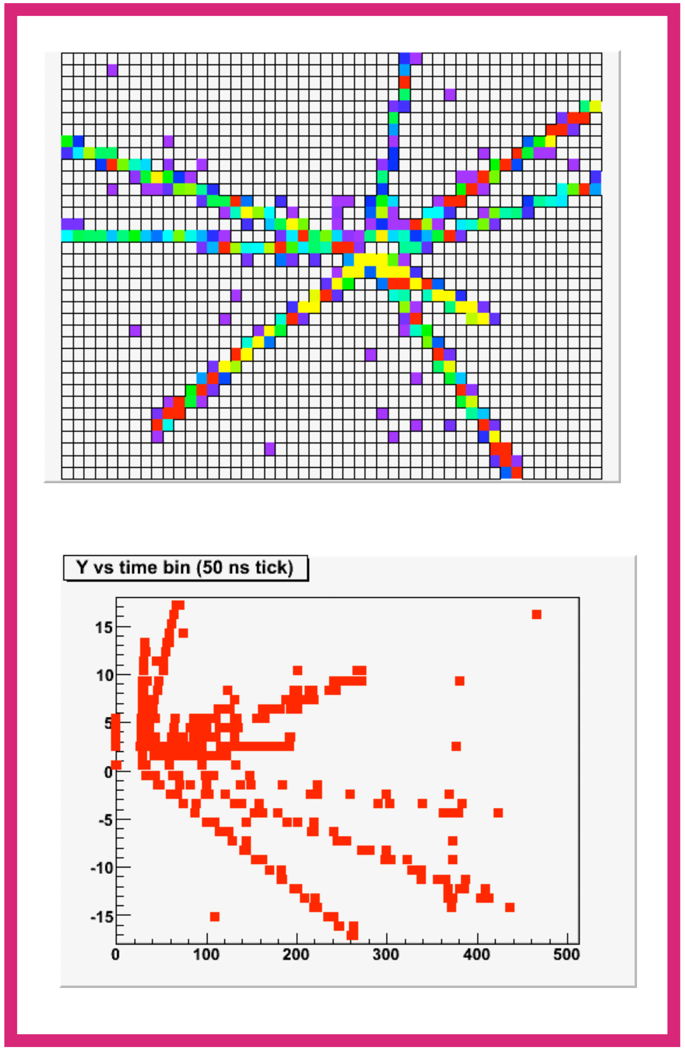
Event display of tracks in HARP TPC @ CERN

Attenuation length in Ar+2%isobutane+3%CF_4 measured greater than 30 m

Cosmic rays in the TPC



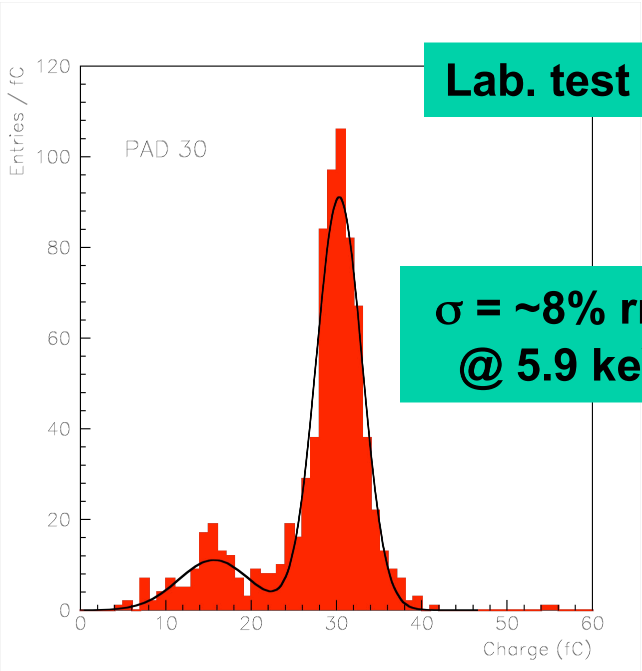
15 GeV/c p-Pb interactions in front of the TPC



55Fe X-ray source spectrum (with AFTER FEE)

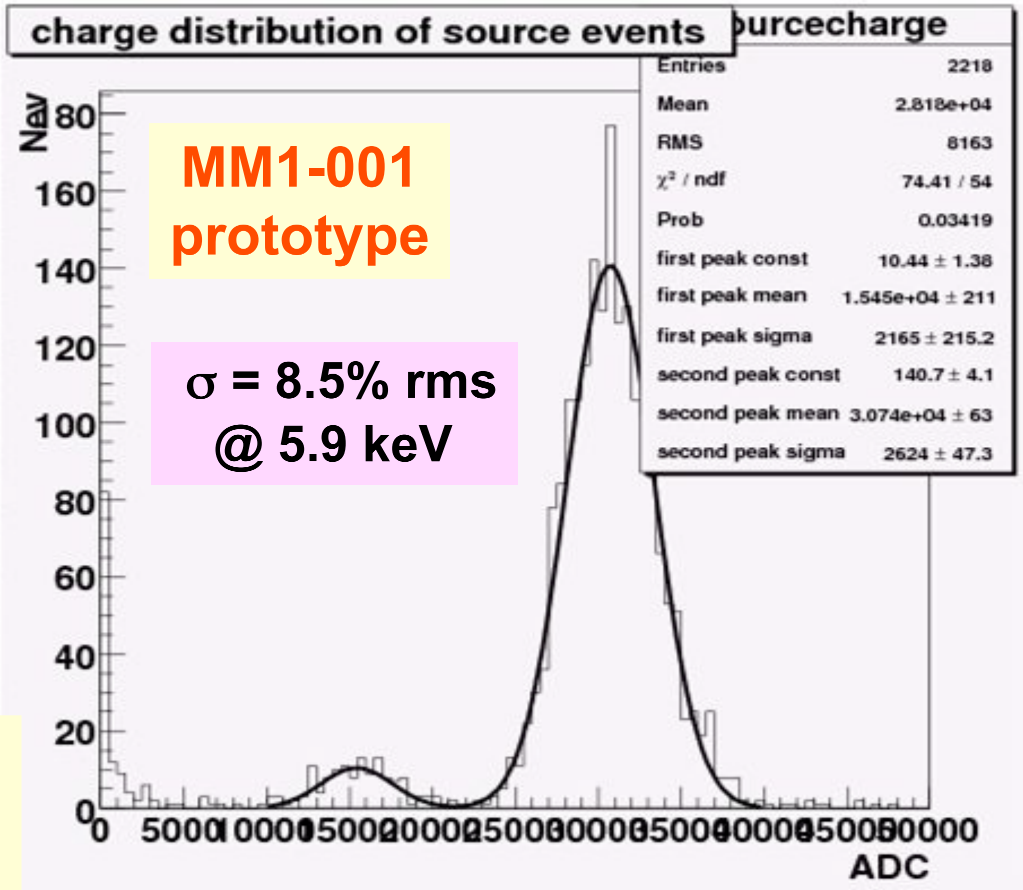
Source located 1.54 m from MM detector (HARP TPC)

E=160V/cm B=0.2T



Lab. test

σ = ~8% rms @ 5.9 keV



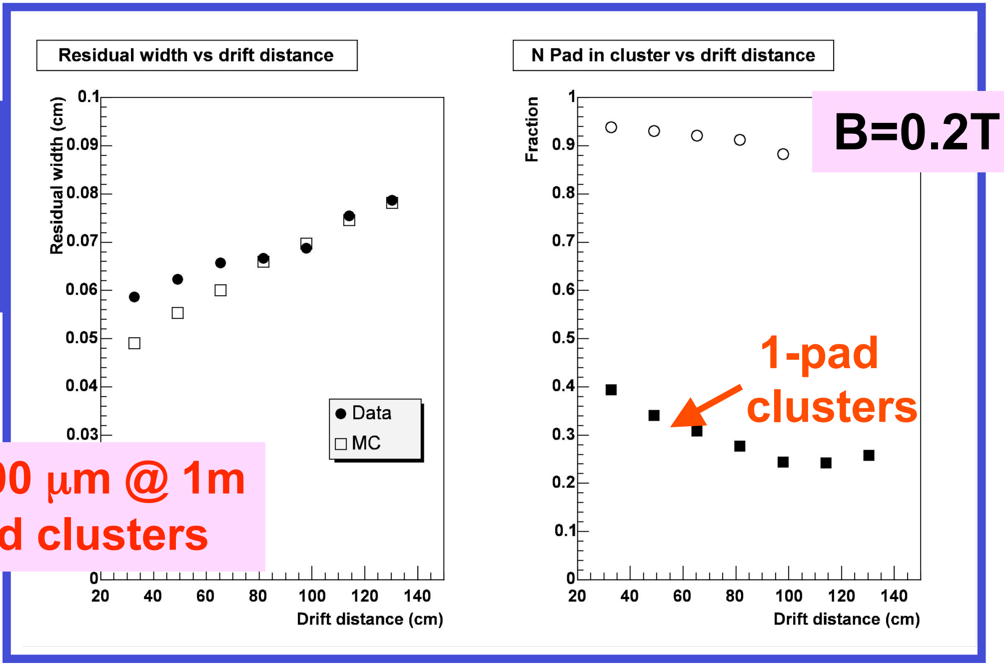
MM1-001 prototype

σ = 8.5% rms @ 5.9 keV

Energy resolution consistent with lab. test results
18-20% FWHM 5.9 keV resolution

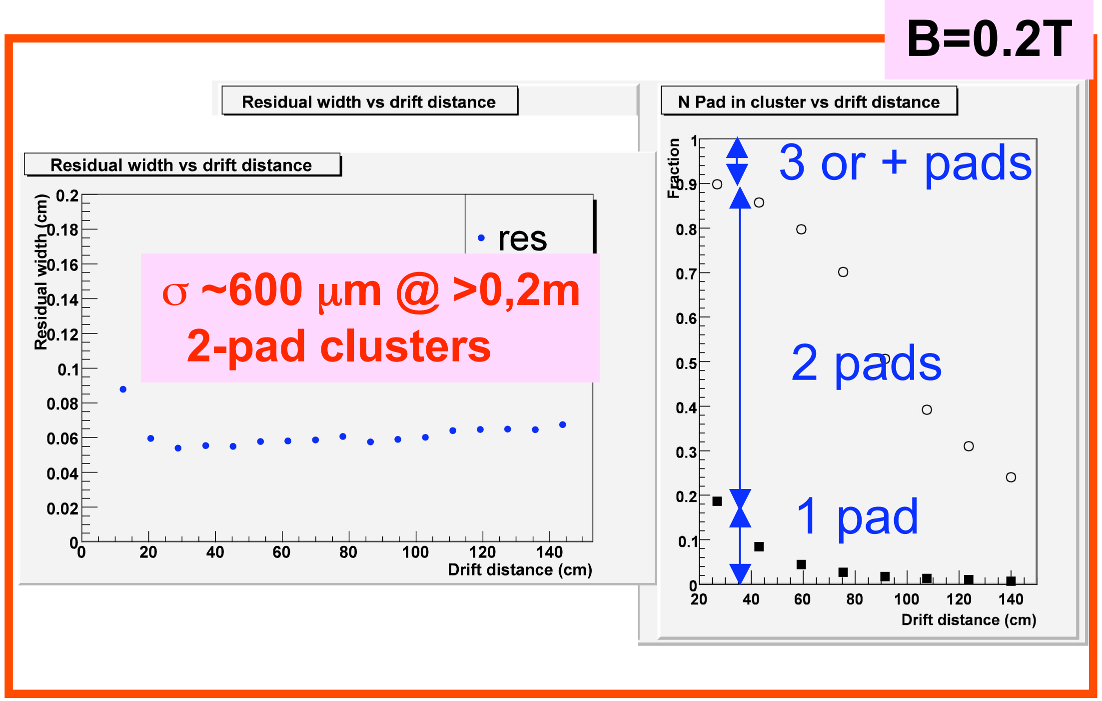
Space point resolution in HARP TPC

2005, 1024 $8\times8mm^2$ pads ALRO FEE



J. Bouchez et al., Nucl.Instrum.Meth.A574:425-432,2007

2007, Production module With AFTER FEE (low-noise) 1726 x $(6.9\times9.7)mm^2$ pads



- *Improved space point σ for 2-pad clusters*
- *Larger fraction of > 1-pad clusters*

Expected resolutions for a 70 cm track in the T2K TPC for B=0.2T:

σ(p) / p < 8% @ 1GeV/c

σ(dE/dx) < 9%

⇒ fulfills requested resolutions of 10% on both P @ 1 GeV/c & dE/dx

Production Flow-Chart of 84 T2K/TPC Micromegas Modules @ CERN

CERN/TS-DEM-PMT bulk Micromegas prod. facility

- PCB production
- PCB electrical Automated Quality Control + thickness & flatness metrology
- Bulk micromegas production
- Global current quality control in Air (@-600 V)
- Bulk micromegas final cutting
- Global current & pad per pad current quality control in Air (@-600V)
- Connectors soldering

Detector's delivery

T2K/TPC Europe Production lab. @ CERN/bdg. 182

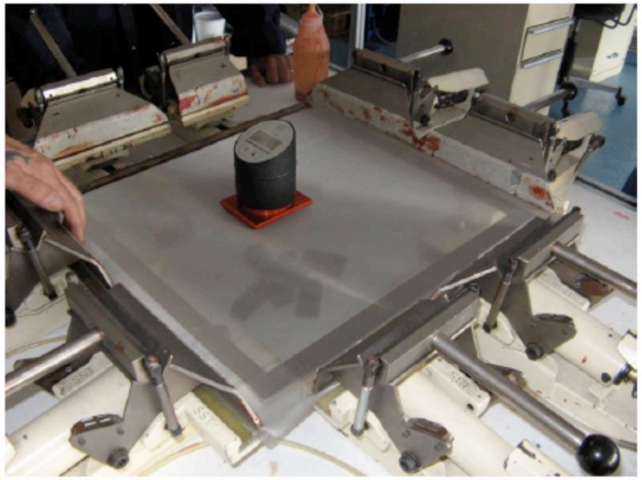
- Mechanical Stiffener gluing
- Gas tightness & thickness metrology
- Detector « baking » in dry air (~1day, increasing HV up to - 900 V)
- Final gain calibration on UNIGE/IFAE test bench
- 55Fe pad scanning, with Automated x-y stage and AFTER FEE

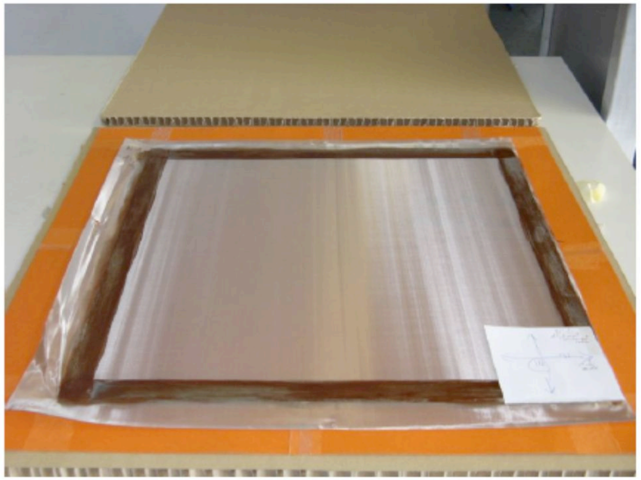
Module Storage

T2K/TPC bulk Micromegas Quality Controls

Visual inspection

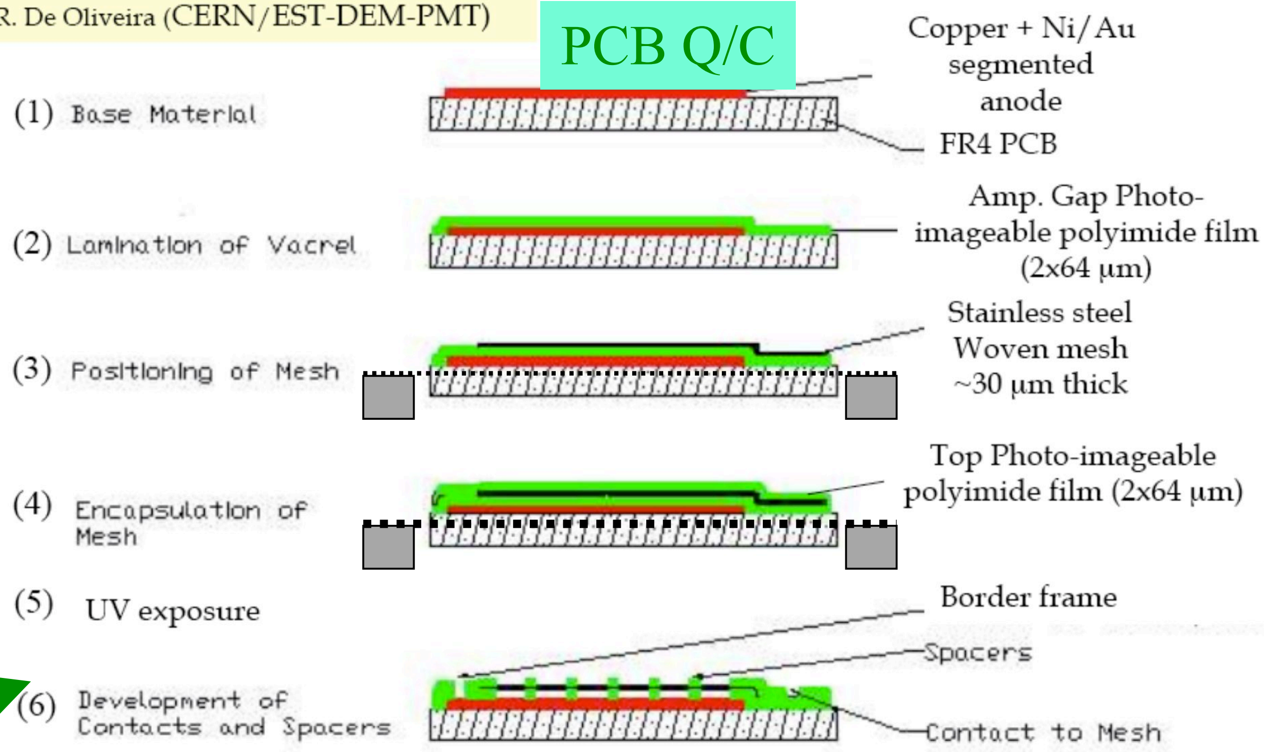
- ✓ 12 N tension
- ✓ Sub-contractor
- ✓ 10/month





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

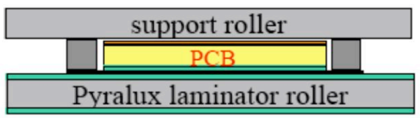
PCB Q/C



Visual inspection

1/ Mesh is stretched on an external frame

2/ and laminated with the PCB



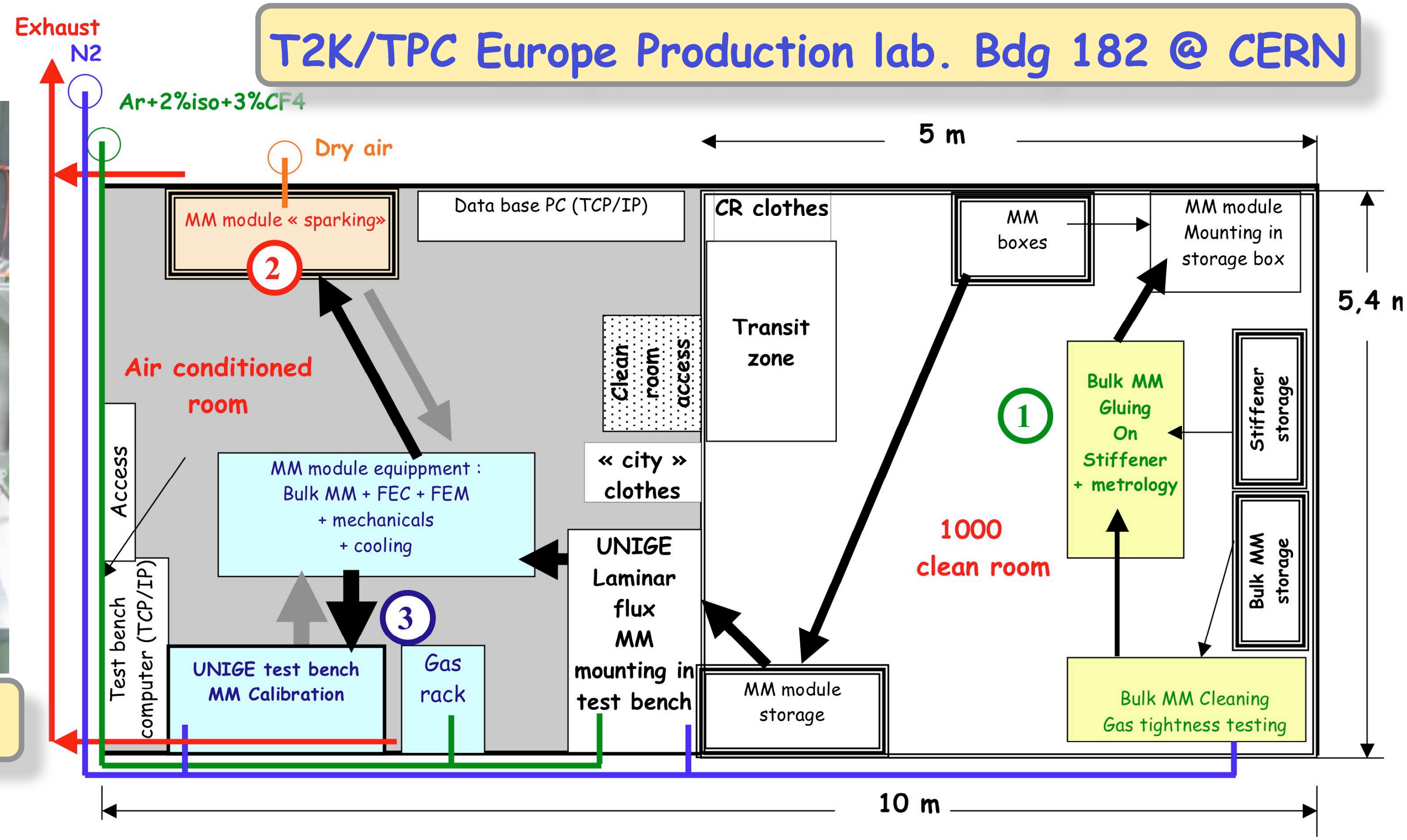
If $I > I_{Q/C}$ 10 nA

Global current Q/C (@-600V)

MM Module Q/C & final calibration

T2K/TPC Europe Production lab. Bdg 182 @ CERN

Calibration test bench



(2) « forced » sparking test bench : « burn-in » of the detector to burn dusts and smooth tiny asperities of either micromesh or copper pad

➢ Mesh HV is increased by 10 V steps up to 900-950 V, in dry air, detector is in a controlled sparking operation at each step (Sparking rate measurement)

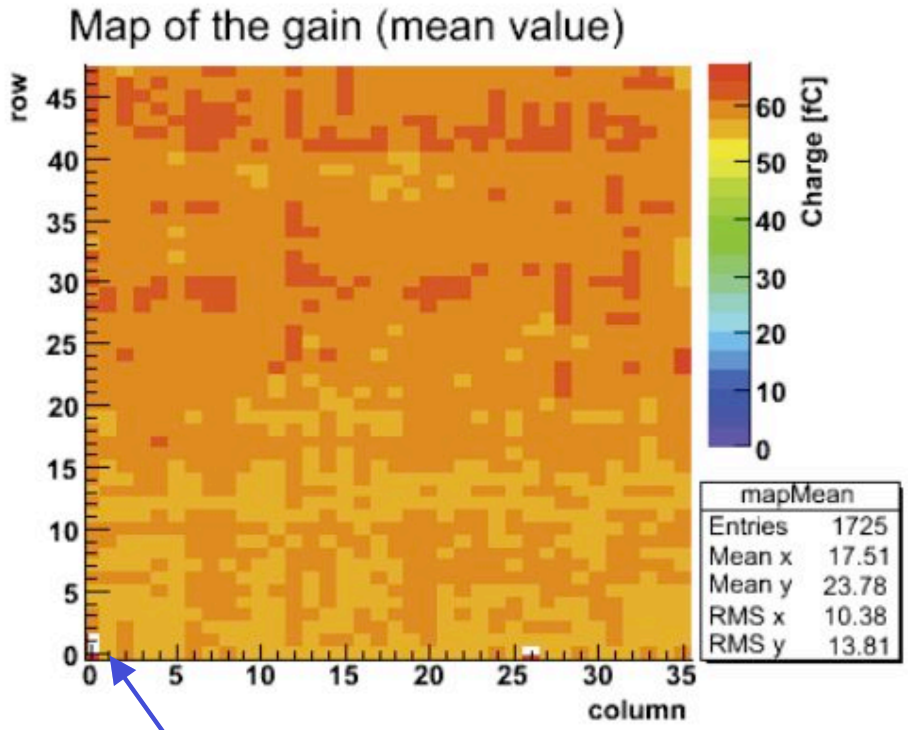
(3) Calibration test bench : full pad per pad calibration with gain, PRF, cross-talk, 55Fe 5.9 keV resolution and sparking rate measurements

First Micromegas Module calibration
Gas Gain uniformity map of MM-002

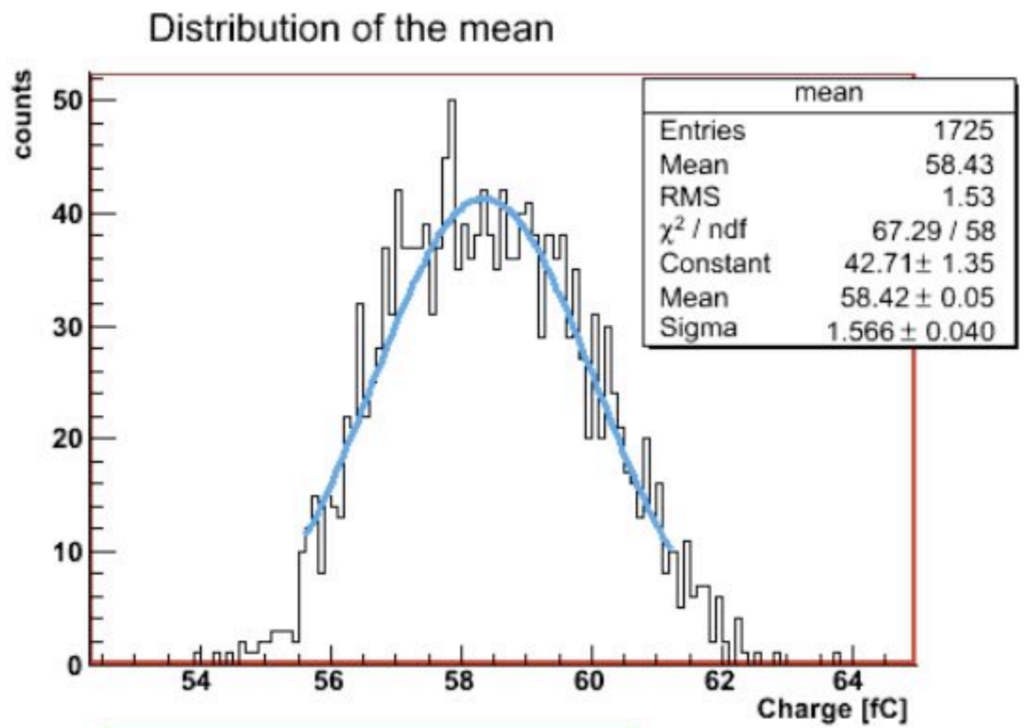
1726 pads

55Fe source Scan in ~12 hours

Gain variation: 2.7 %



HV pads (inactive)



Vmesh=-350V

First Micromegas Module calibration
5.9 keV resolution uniformity map of MM-002

Irfu

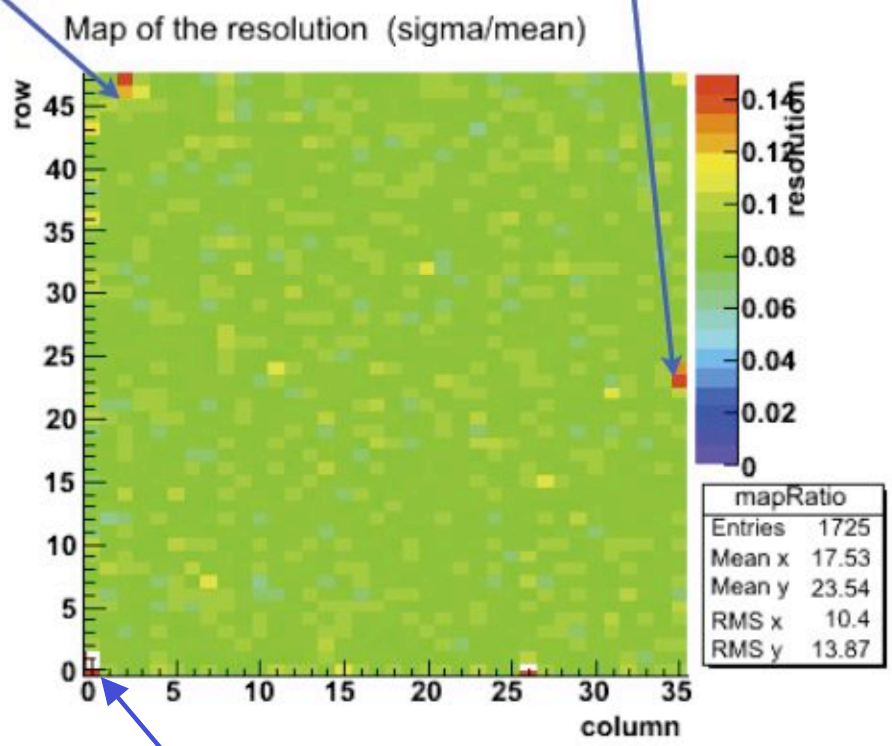
1726 pads

55Fe source scan in ~12 hours

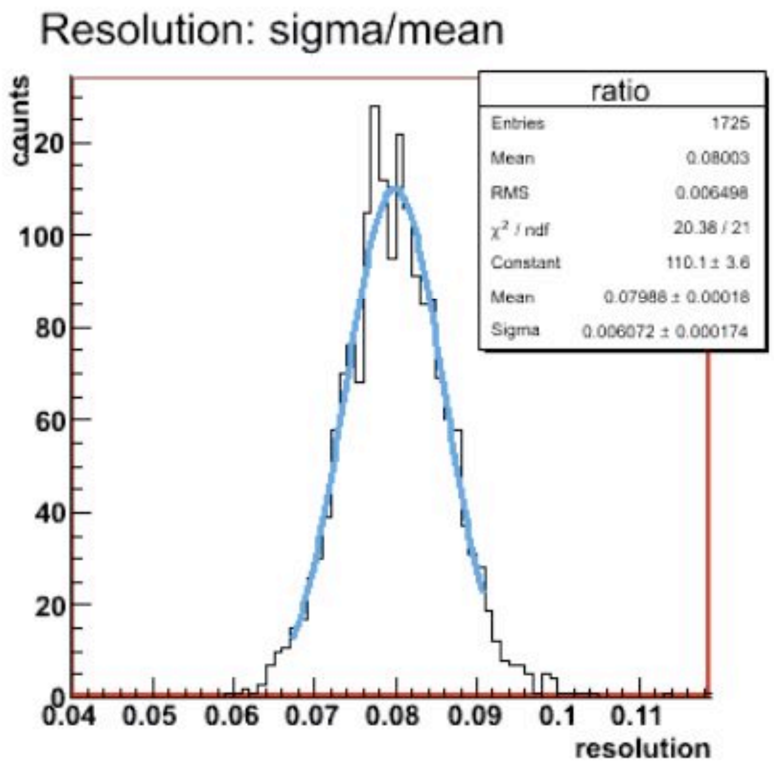
Energy resolution: 8 %

Defect on mesh

Centering pin problem



HV pads (inactive)



Vmesh=-350V (G~1200)

Status of bulk MM & Module production (8/month)

- 8 bulk Micromegas produced, with NO faulty pads (+8 june 20th)
- Module assembly and calibration just began ⇒ goal of 48 (2 TPCs) in march 2009

T2K TPC - bulk MM & MM Module Production (June, 16th, 2008)

Batch #0&1 : 34x36 cm2, 1728pads 6,875x9,685 mm2, Multi-pass cleaning, Ni/Au Cu, with BFM, Φ0,4 mm mask openings

PCB ref.	PCB fab. Date	PCB thickness e / bending b	pad Cu thickness	PCB Q/C	bulk MM fab. Date	mesh batch	nb. of faulty pads	Global current @ 600V	Mod.	Stiffener	Assembly Date	mesh-gasket surface metrology	"burn-in" max HV current	Gain Non uniformity (rms)	5,9 keV 55Fe FWHM	comments
T2K-MM001	04/04/08	2,137 mm +0,052/-0,091	28 μm	OK	05/05/08	batch 1	0	5 nA	MOD-001	S52/001	10/06/08	19,496 mm +0,046/-0,016	13/06/08 950 V 2 nA			ready to calibrate
T2K-MM002	04/02/08	2,178 mm +0,043/-0,063	28 μm	OK	14/02/08 Φ0,3 mm mask open.	Sefar	0		MOD-002	V1, n°	18/02/08		19/02/08 970 V 2 nA	2,70%	18%	bad resolution at centering pin location
T2K-MM003	04/04/08		25 μm	1 opened												rejected
T2K-MM004	29/04/08		39 μm	1 opened												rejected
T2K-MM005	29/04/08		23 μm	2 opened												rejected
T2K-MM006	29/04/08	2,190 mm +0,050/-0,027	36 μm	OK	06/05/08	Batch2	0	4 nA	MOD-006		week 26					ready to assemble
T2K-MM007	29/04/08	2,216 mm +0,033/-0,020	44 μm	OK	06/05/08	Batch2	0	5 nA	MOD-007		week 25					ready to assemble
T2K-MM008	29/04/08	2,163 mm +0,071/-0,063	37 μm	OK	05/05/08	Batch1	0	3 nA	MOD-008		week 26					ready to assemble
T2K-MM009	29/04/08	2,181 mm +0,028/-0,021	33 μm	OK	05/05/08	Batch 1	0	4 nA	MOD-009		week 26					ready to assemble
T2K-MM010	29/04/08	2,212 mm +0,026/-0,029	24 μm	OK	07/05/08	Batch2	0	4 nA	MOD-010		week 26					ready to assemble
T2K-MM011	29/04/08	2,137 mm +0,058/-0,065	26 μm	OK	07/05/08	Batch2	0	5 nA	MOD-011		week 27					ready to assemble

Bulk MM produced by O. Pizzirusso (CERN/TS-DEM-PMT), Module assembly & calibration by T2K/TPC Europe

Conclusions

✓ The bulk Micromegas technology is well adapted to build large segmented (>m^2) readout plane surfaces : few % dead zone (in&between modules), simple design

✓ The « bulk » Micromegas is close to be a mature technology

- Well defined & under control manufacturing process, very high quality insulation between mesh and anode PCB, seems robust & reliable, should be able to be industrialized

- All in one « cheap » detector : T2K/TPC bulk micromegas cost ~1,15 k€

800 € (PCB+mesh integration) + 130 €(connectors soldering + mesh stretching) +120 €(mesh) +100 €(connectors)

- Typical reproductible performances

  - ➢ low « natural » sparking rate : <0,1 spark/h (@1000 gain)
  - ➢ 5.9 keV FWHM resolution : **~ 20 %**
  - ➢ Gain uniformity over the bulk micromegas surface : **~3% r.m.s**

✓ 84 bulk Micromegas modules are under production by T2K/TPC (12 months)

✓ Possible design parameters : up to 600 LPI mesh, current max size limited by anode PCB (~400x500 mm^2) to ~1000x550 mm^2 , <100 µm Amp. Gap to be tested

Current Bulk Micromegas developments

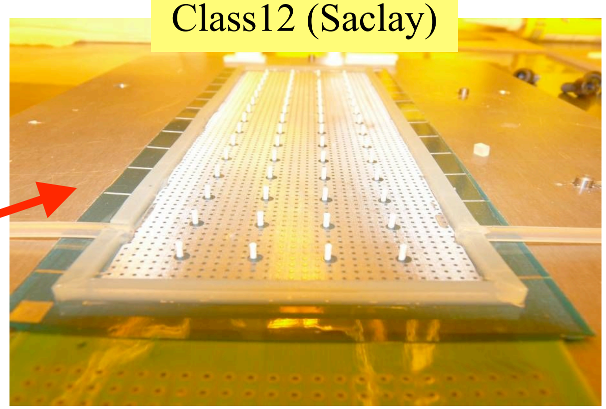
✓ Bulk Micromegas was first used for neutron spectroscopy applications (CEA/DEMIN detector)

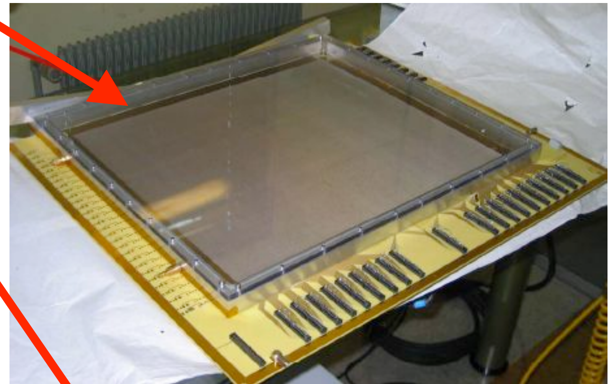
✓ Class12 @Jefferson lab, USA : prototypes under study :low material budget detector (0,1 mm thick PCB), cylindrical shape (ϕ500 mm)

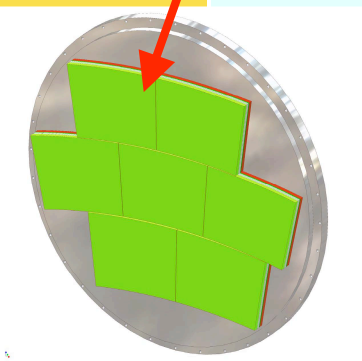
✓ Super LHC/ATLAS Muon chambers upgrade : 5 kHz/cm^2 flux, ~2 m^2 ch. , 100 μm/5 ns resolutions

✓ ILC/DHCAL : on-detector ASICs, 1cm^2 pads, 35.10^4 channels, prototype beam tests in august

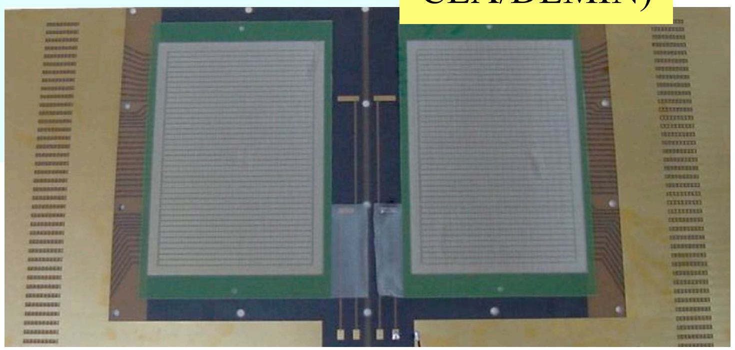
✓ ILC/TPC : 4T magnetic field, high flux, <10^{-3} ion backflow, <50 μm resolution @ short drift distance (resistive foil R&D), very high readout electronics density (>10^6 channels)

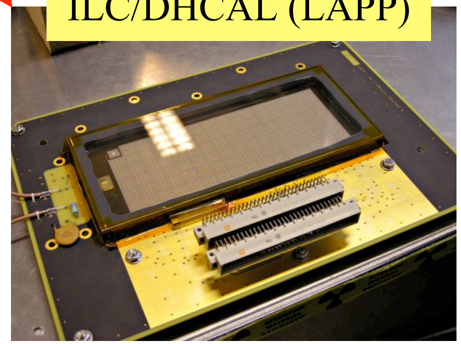






ACTAR ? …



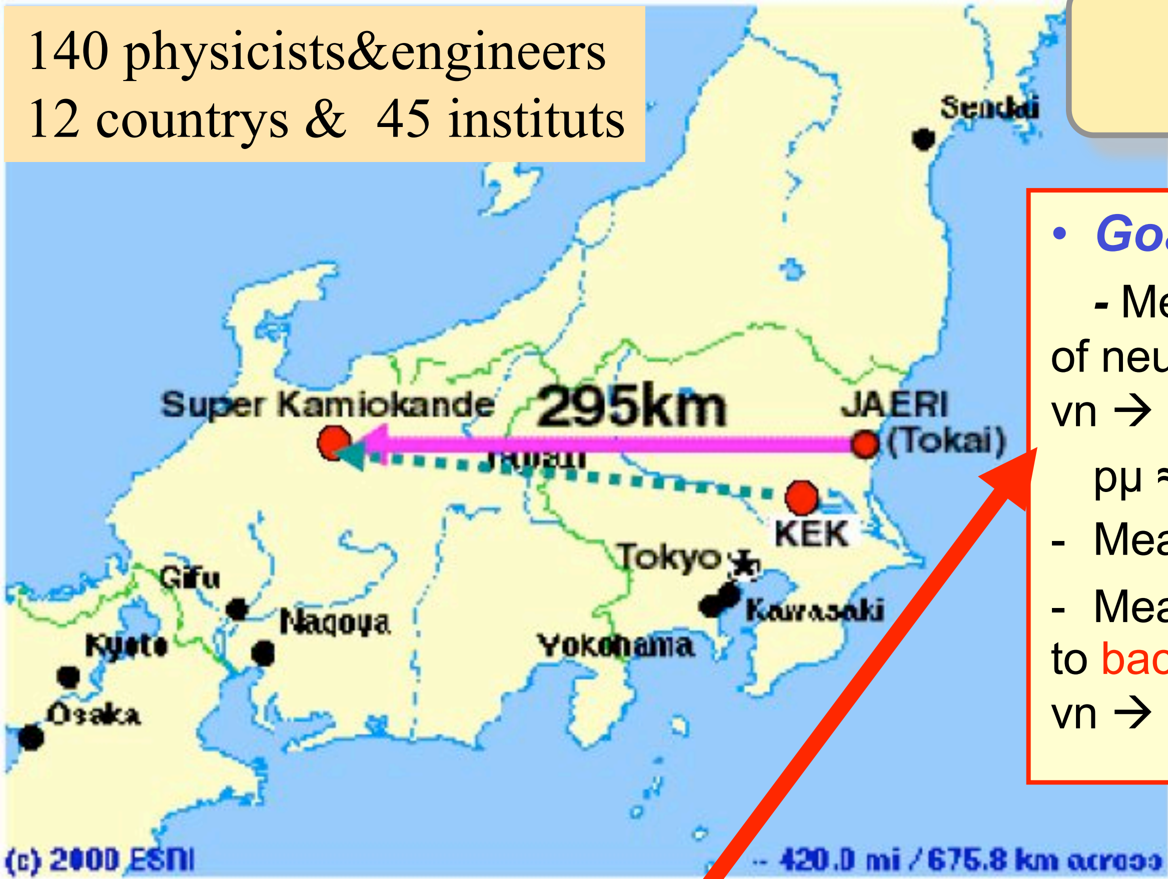


Backup slides

TheTokai to Kamioka (T2K) experiment

140 physicists&engineers
12 countrys & 45 instituts

Start of experiment
September 2009



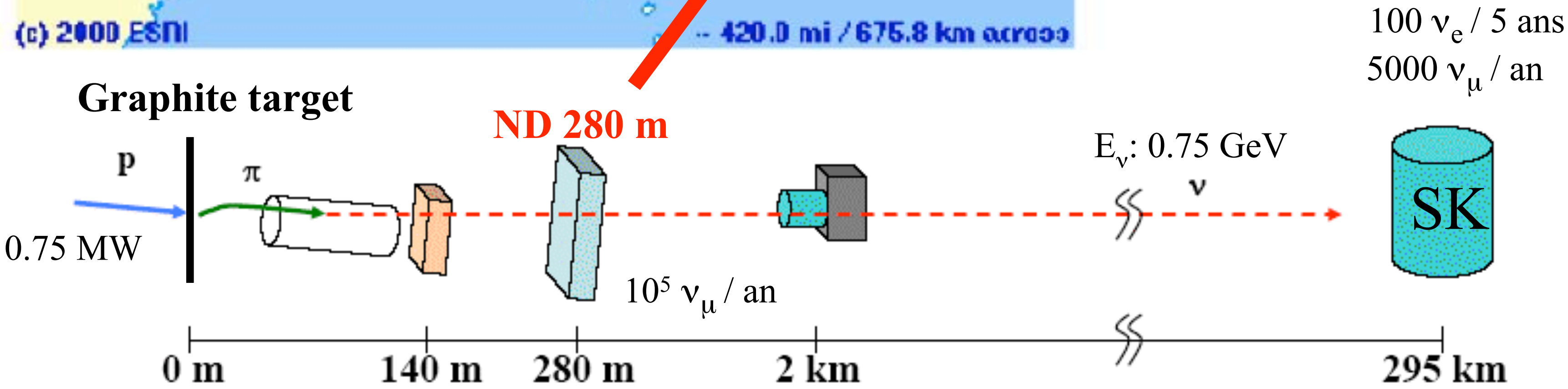
- ***Goal of the ND280m :***

  - Measure the flux & spectrum of neutrinos thanks to CCQE $\nu n \rightarrow \mu\text{-}p$ interactions

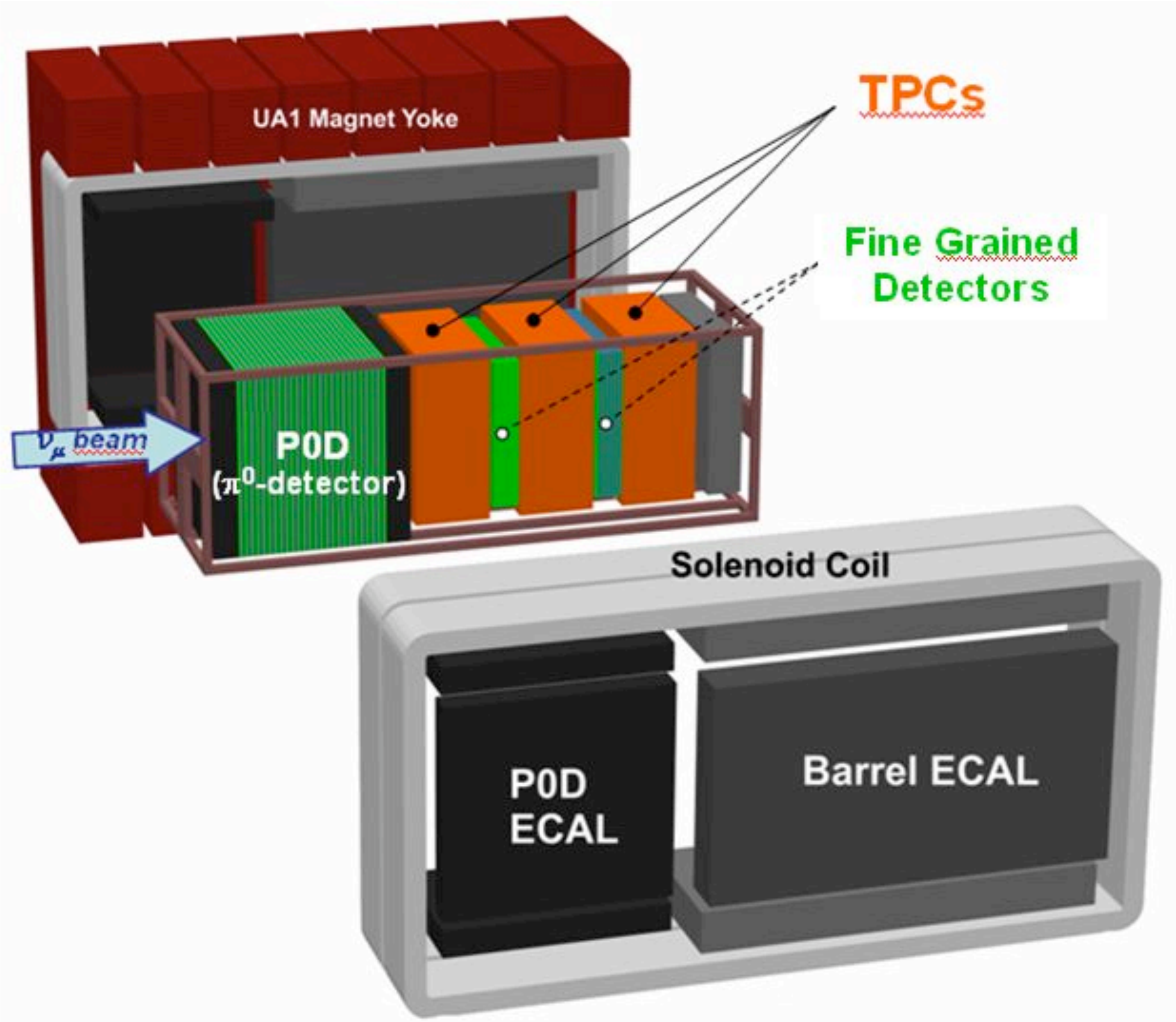
  $p\mu \approx 1$ GeV/c,

- Measure ν_e contamination

- Measure NC which contribute to background on ν_e in SK :
$\nu n \rightarrow \nu n\ \Pi^0$



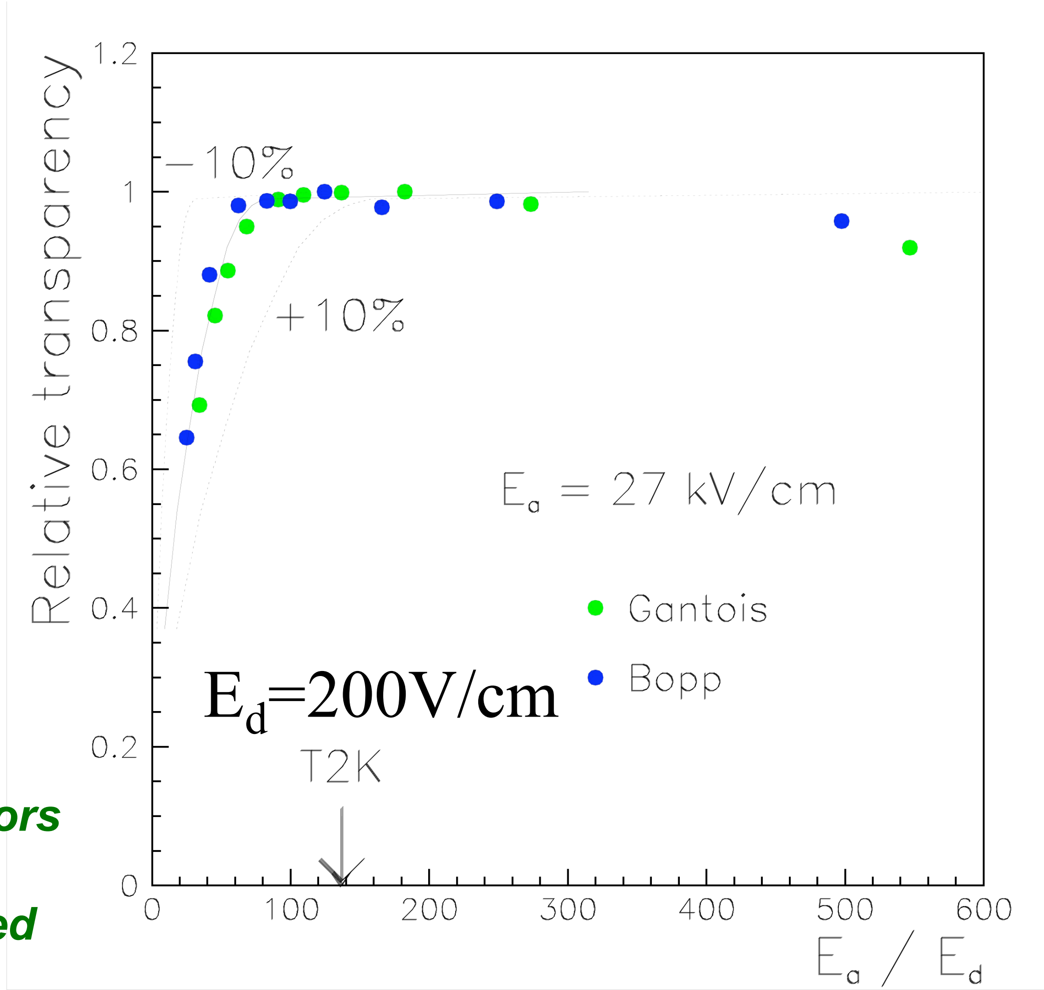
The T2K/TPC in the Near Detector, ND280m



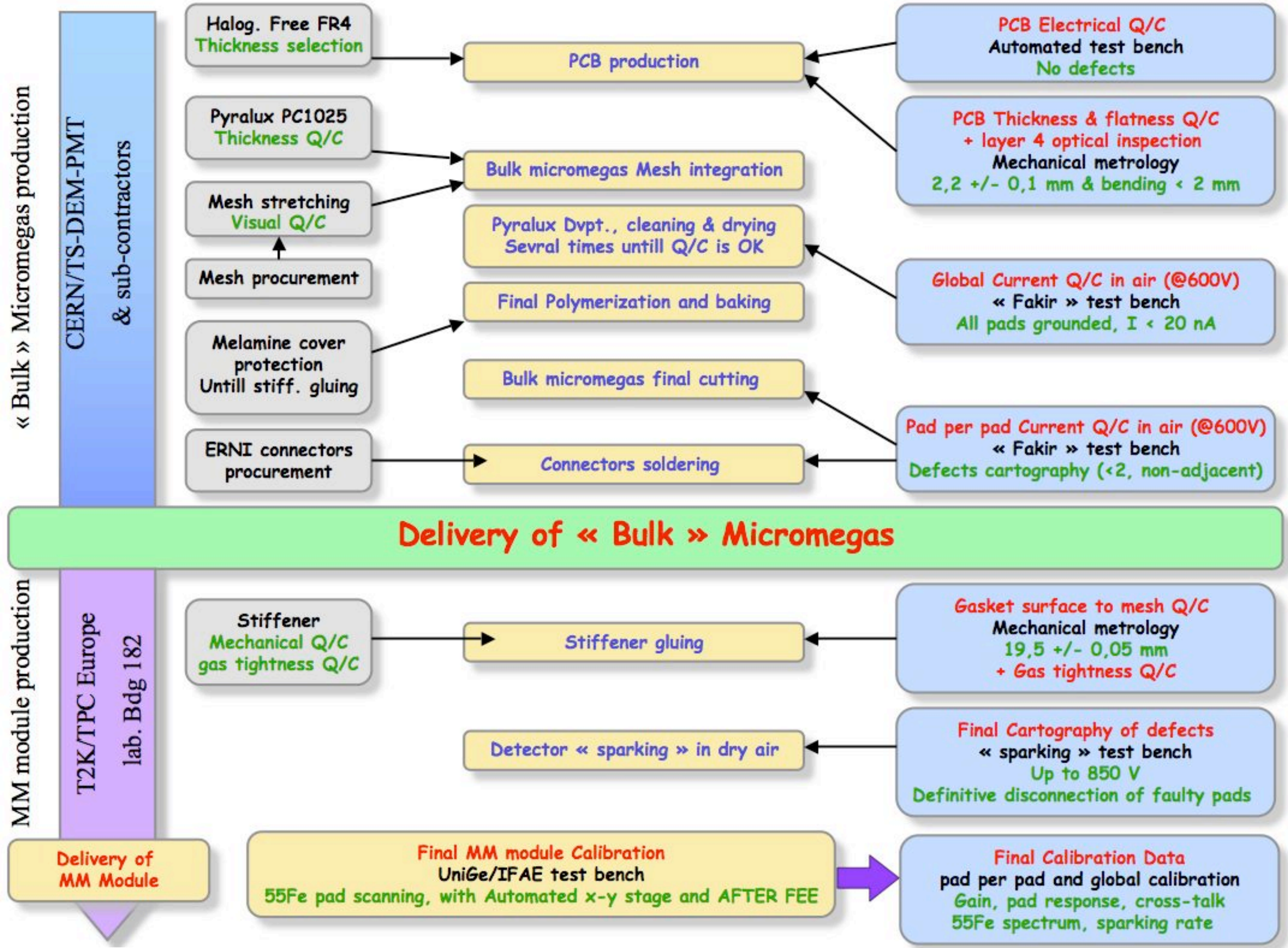
Micromesh electron transparency

Micromesh

	Gantois	Bopp
Pitch (μm)	57	63
ϕ (μm)	19	18



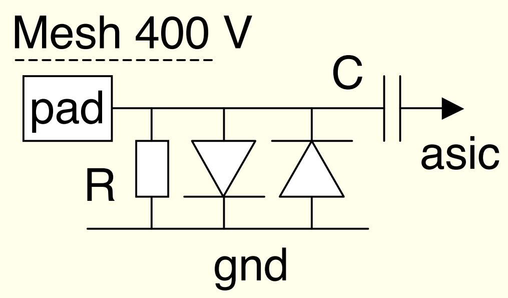
Operation point of MicroMegas detectors in T2K is in the region where high micromesh transparencies are obtained


« Bulk » Micromegas production
CERN/TS-DEM-PMT
& sub-contractors
Halog. Free FR4
Thickness selection
PCB production
PCB Electrical Q/C
Automated test bench
No defects
Pyralux PC1025
Thickness Q/C
Bulk micromegas Mesh integration
PCB Thickness & flatness Q/C
+ layer 4 optical inspection
Mechanical metrology
2,2 +/- 0,1 mm & bending < 2 mm
Mesh stretching
Visual Q/C
Pyralux Dvpt., cleaning & drying
Sevral times untill Q/C is OK
Mesh procurement
Final Polymerization and baking
Global Current Q/C in air (@600V)
« Fakir » test bench
All pads grounded, I < 20 nA
Melamine cover
protection
Untill stiff. gluing
Bulk micromegas final cutting
Pad per pad Current Q/C in air (@600V)
« Fakir » test bench
Defects cartography (<2, non-adjacent)
ERNI connectors
procurement
Connectors soldering
Delivery of « Bulk » Micromegas
MM module production
T2K/TPC Europe
lab. Bdg 182
Stiffener
Mechanical Q/C
gas tightness Q/C
Stiffener gluing
Gasket surface to mesh Q/C
Mechanical metrology
19,5 +/- 0,05 mm
+ Gas tightness Q/C
Detector « sparking » in dry air
Final Cartography of defects
« sparking » test bench
Up to 850 V
Definitive disconnection of faulty pads
Delivery of
MM Module
Final MM module Calibration
UniGe/IFAE test bench
55Fe pad scanning, with Automated x-y stage and AFTER FEE
Final Calibration Data
pad per pad and global calibration
Gain, pad response, cross-talk
55Fe spectrum, sparking rate

MM catastrophic failure strategy

- Aim : operate the TPC without distortion of the electric field in case faulty pads (frequent sparking or short-circuit) occur between 2 “Repair Opportunity “
- Strategy :
  - 1/ demanding module quality selection for very low failure probability
  - 2/ study of detector failure modes with long duration operation tests
  - 3/ Implement & test Pad polarization/protection circuits (B&C) on test FEC

A. typical circuit



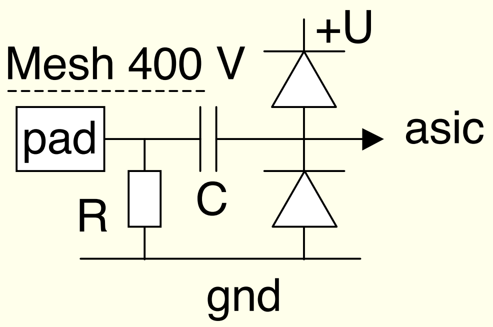
used on Harp setup

Shutdown HV if problem

Need of a Wire grid

Ref: D. Calvet

B. Few pad/mesh shorts

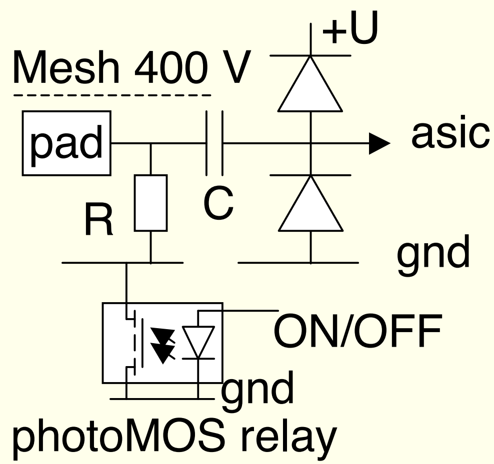


Used on Compass but need HV R and C if permanent shorts;

Let current from HV flow as long as acceptable

R=100 MΩ → I=4 μA /pad

C. Catastrophic shorts



T2K/TPC choice on FEC

Slow control command to isolate group of pads (144) from GND if problem