MICROMEGAS (MICROMEsh GASeous detector) based detectors and their present applications

OUTLINE

Micromegas description and principle of operation

Micromegas properties

Gain stability and uniformity

Energy resolution

Electron collection efficiency and transparency

Ion feedback suppression

Micromegas manufacturing

Meshes and pillars

“bulk” and “microbulk” technology

Gossip

Current and future applications

The COMPASS experiment

The T2K ND-280 TPC

The Large Prototype for the ILC

Micromegas neutron detectors

TPCs for Dark Matter search and neutrino studies

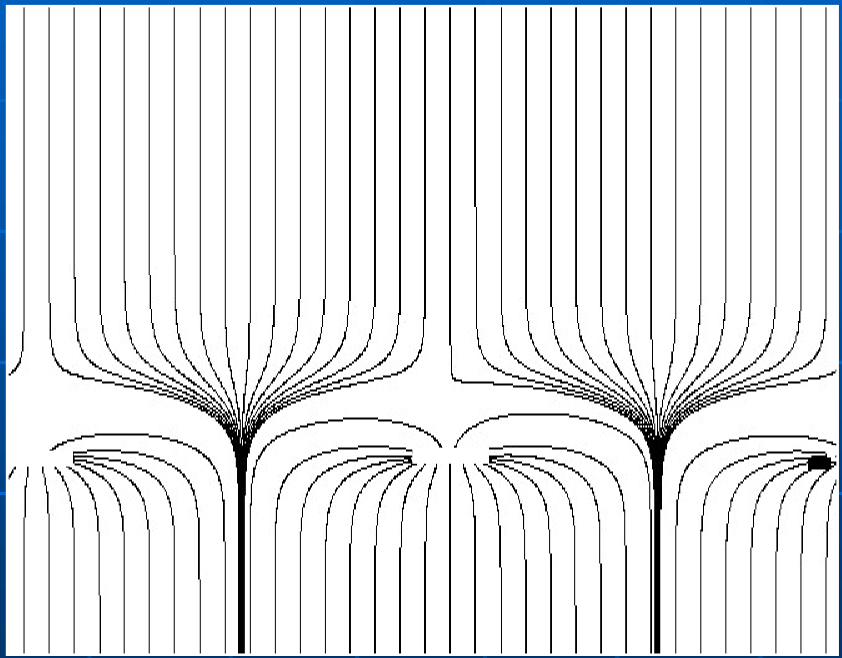
Atlas Muon System Upgrade (SHLC)

Micromegas: Principle of Operation

Micromegas: How does it work?

Y. Giomataris, Ph. Rebourgeard, JP Robert and G. Charpak,

NIM A 376 (1996) 29



E_{drift}/E_{amplif} ~ 200/60000= 1/300

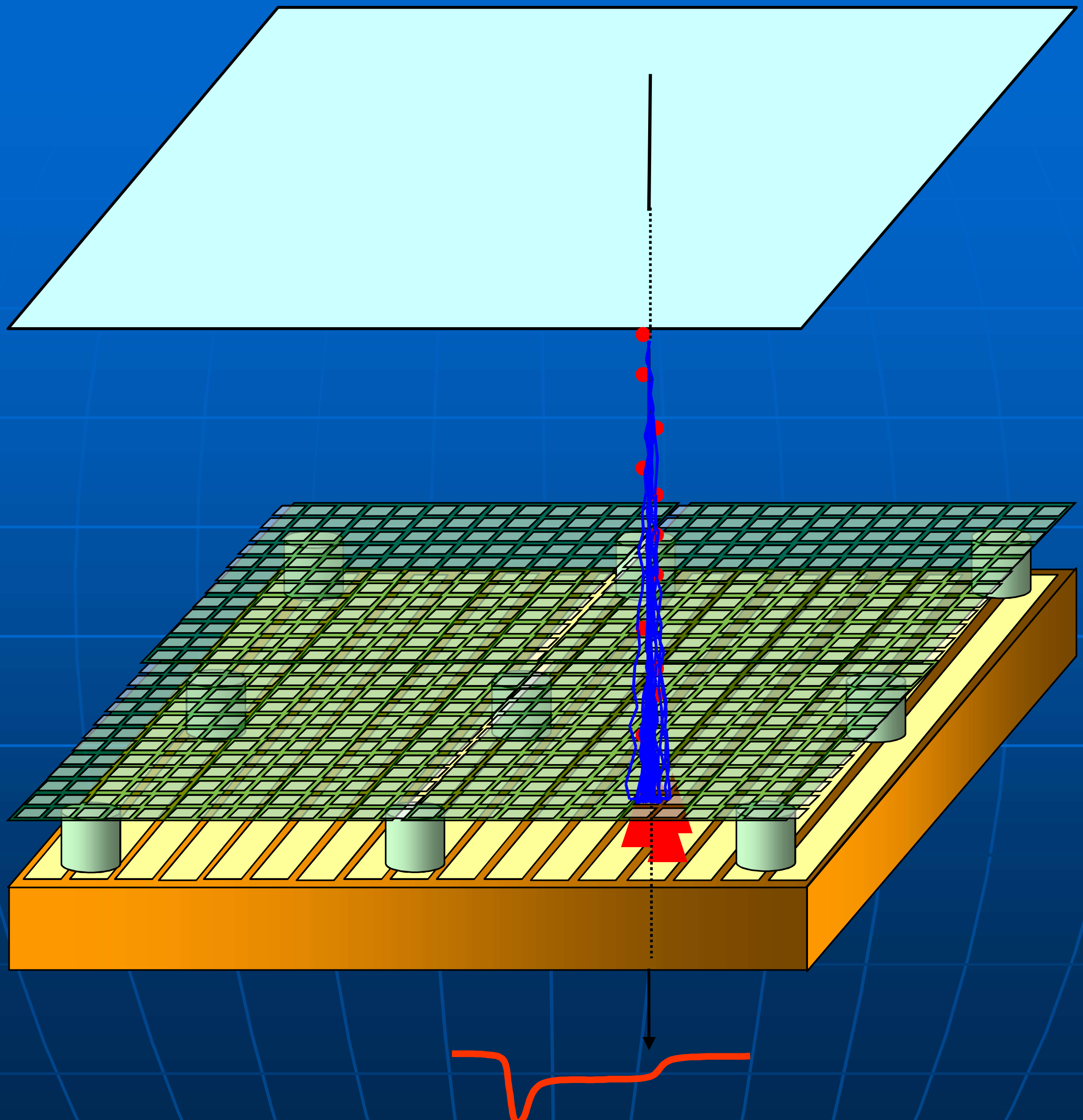
Belongs to the family of MPGD

Micromesh Gaseous Chamber: a micromesh supported by 50-100 μm insulating pillars, and held at V_{mesh} – 400 V (The anode is grounded)

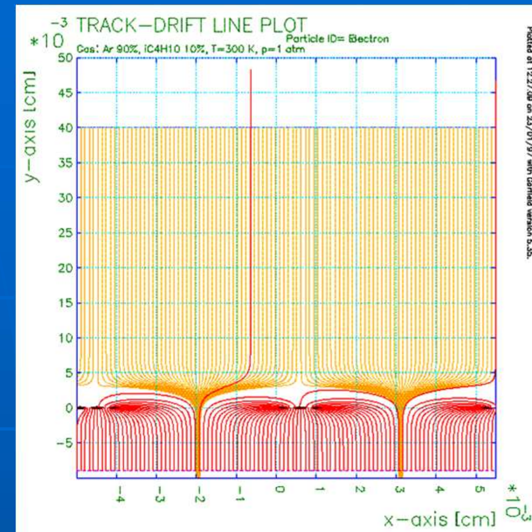
Multiplication (up to 10^5 or more) takes place between the anode and the mesh and the charge is collected on the anode (**one stage**)

Funnel field lines: electron **transparency** very close to 1 for thin meshes

Small gap: **fast** collection of ions

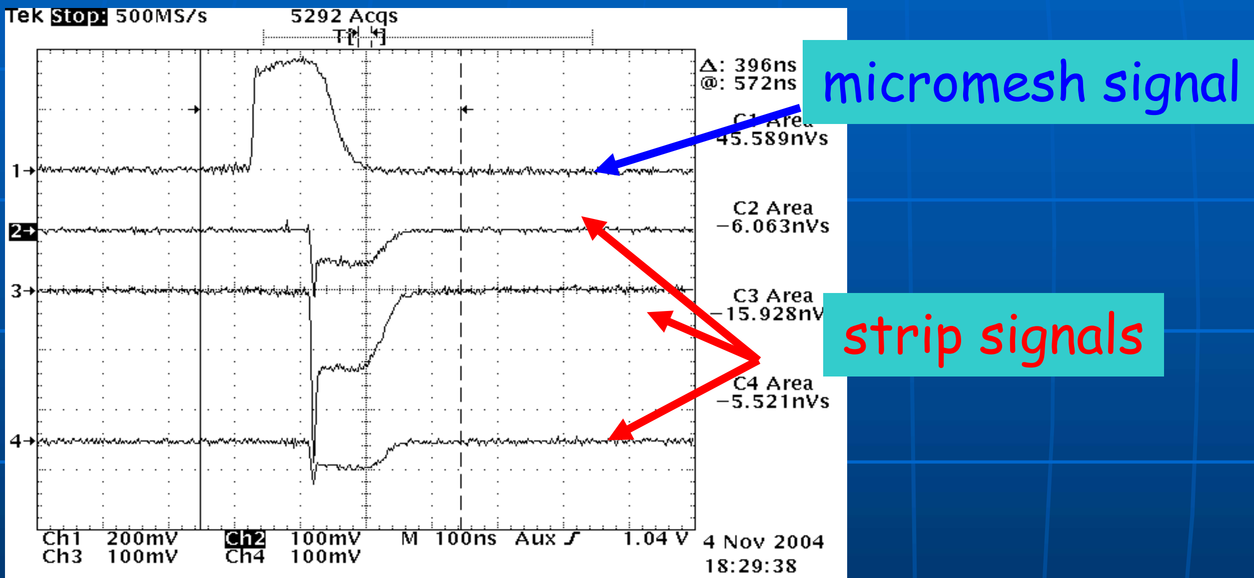


MicroMegas Signal formation and simulation

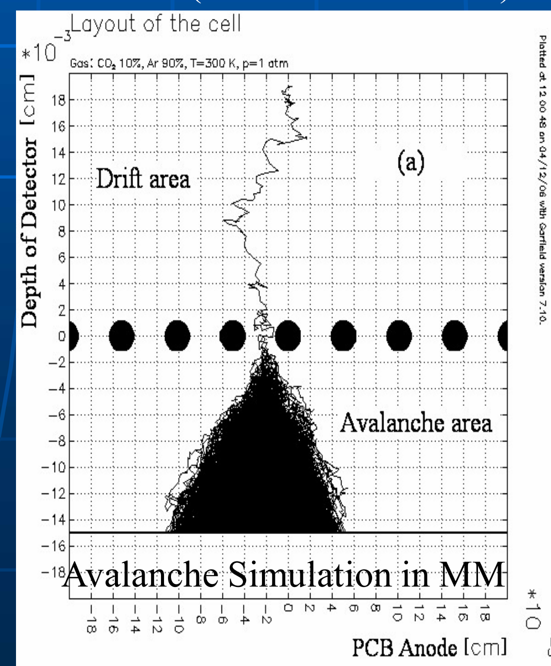


Electrons and ions drift line

in MM (Garfield Simulation)



Electron and ion signals seen by a fast (current) amplifier

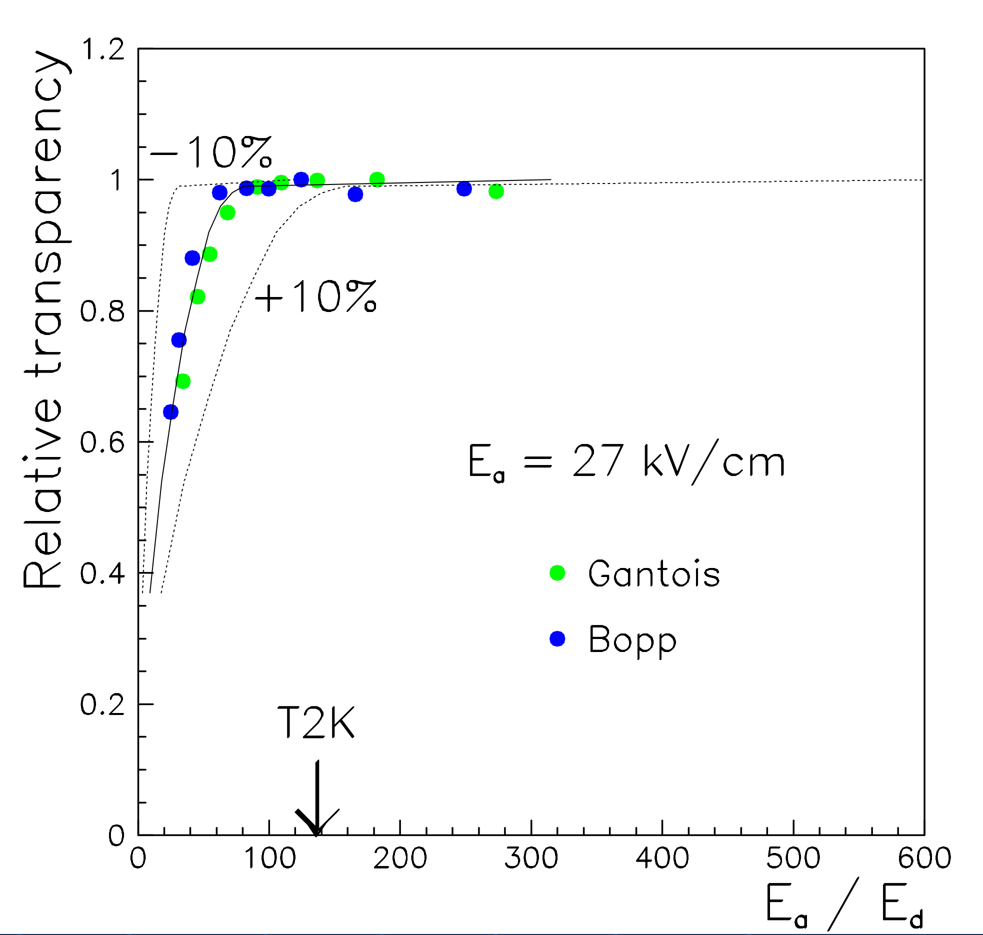


Transparency

Collection efficiency reaches a plateau (100%) at high enough field ratio

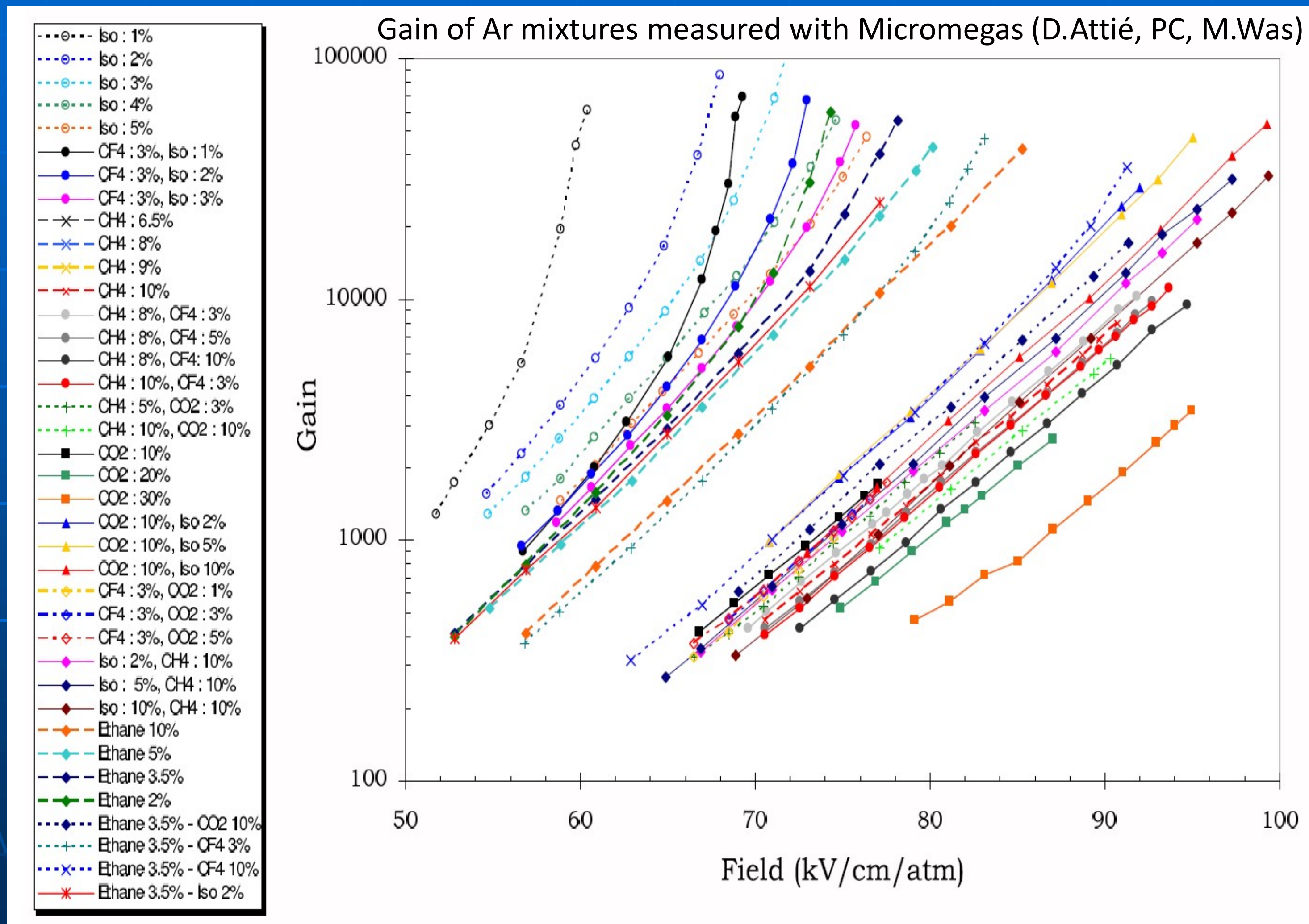
Micromesh

	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

Gain for different gas mixtures



G. Croci (CERN & University of Siena)

Gain: some thoughts about

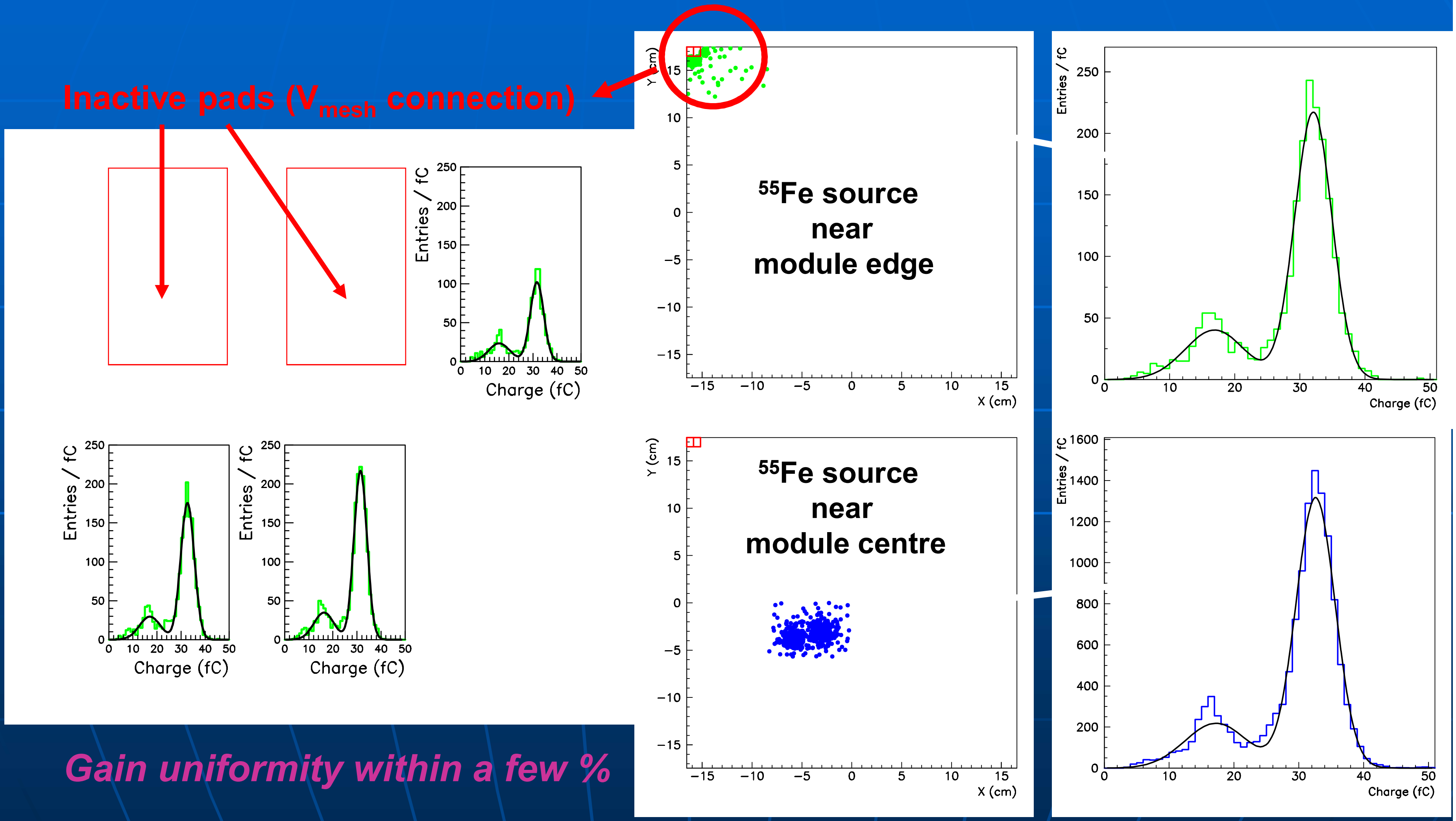
➢photon emission: can re-ionize if the gas is transparent in the UV domain and make photo-electric effect on the mesh. This increases the gain, but causes instabilities. This is avoided by adding a (quencher) gas, usually a polyatomic gas with many degrees of freedom (vibration, rotation) to absorb UVs

➢molecular effects : molecules of one type can be excited in collisions and the excitation energy can be transferred to a molecule of another type, with sufficiently low ionization potential, which releases it in ionization (Penning effect) :

$$eA \rightarrow eA^*$$

$$A^*B \rightarrow AB^+e$$

Gain uniformity



Gain uniformity within a few %

Energy Resolution

- Excellent energy resolution

  11.7 % @ 5.9 keV

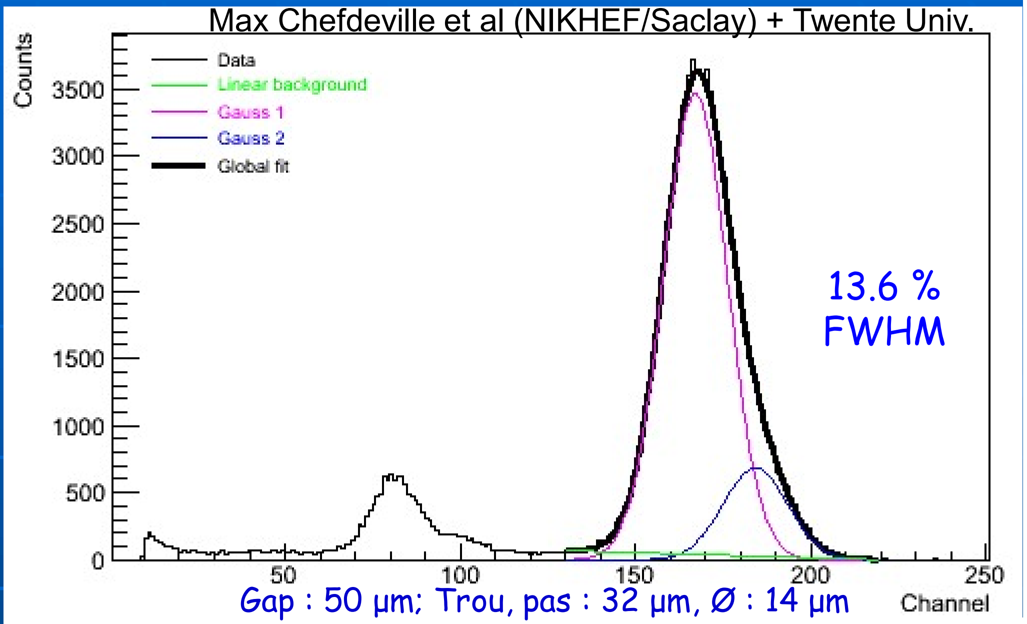
  in Ar 95%, CF4 3%, Iso 2%

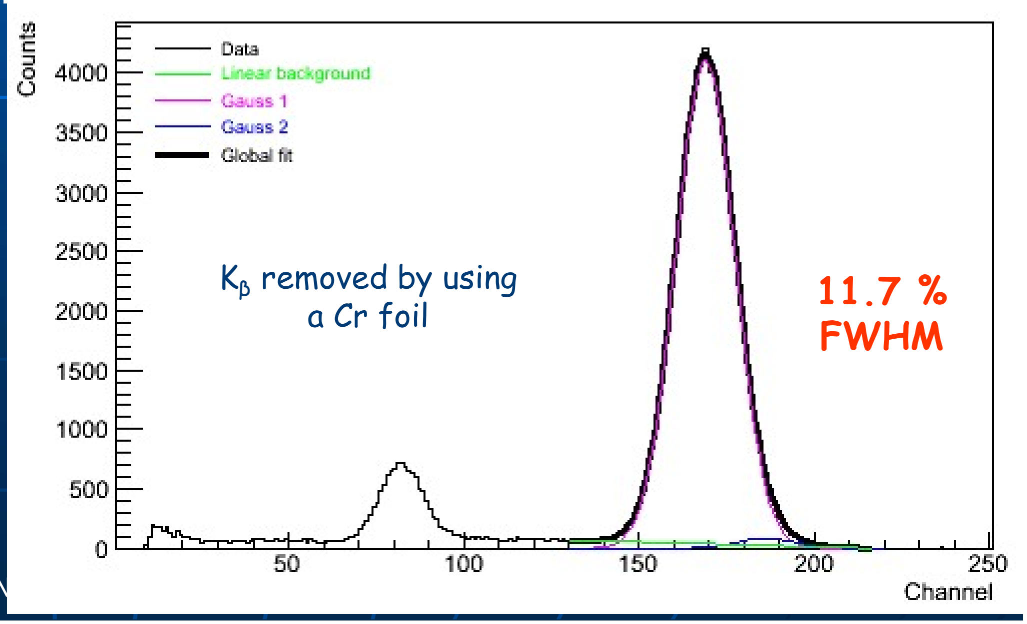
  That is 5% in r.m.s.

  obtained by grids postprocessed on silicon substrate.

  Similar results obtained with bulk Micromegas

  $F = 0.14, N_e = 229$



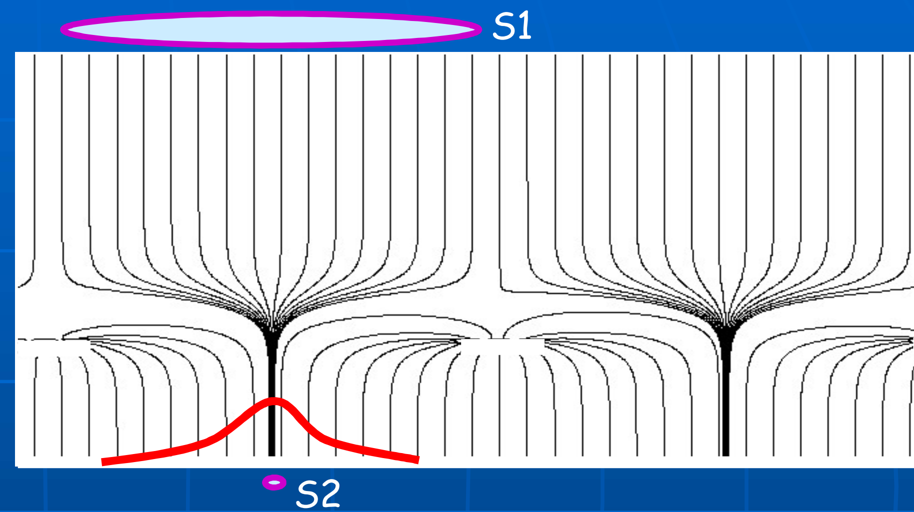


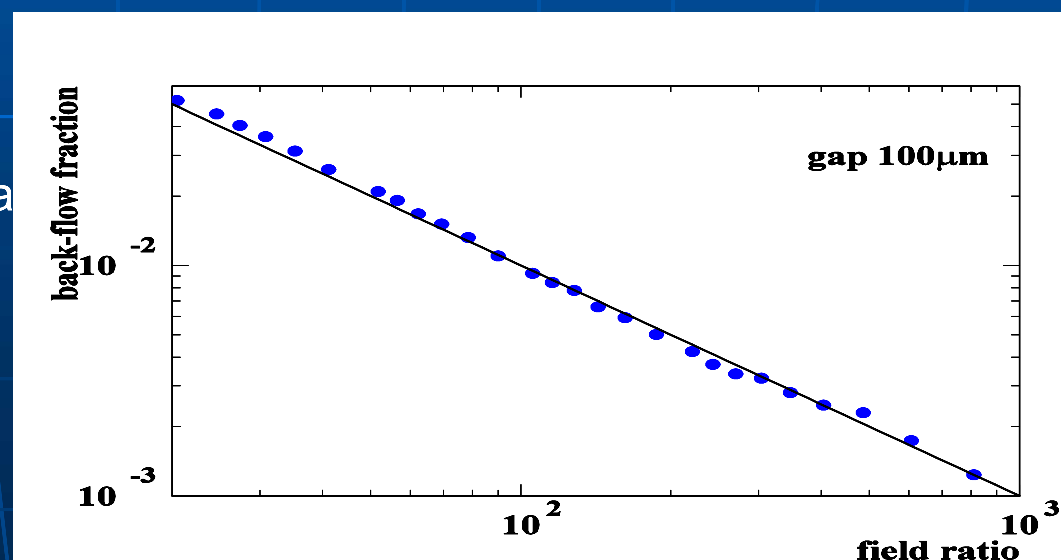
Natural suppression of ion backflow

Electrons are swallowed in the funnel, then make their avalanche, which is spread by diffusion.

The positive ions, created near the anode, will flow back with negligible diffusion (due to their high mass). If the pitch is comparable to the avalanche size, only the fraction $S_2/S_1 = E_{DRIFT}/E_{AMPLIFICATION}$ will make it to the drift space. Others will be neutralized on the mesh : optimally, the backflow fraction is as low as the field ratio.

This has been experimentally verified.





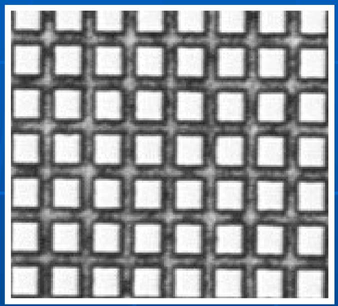
MicroMegas Production Tecniques

MicroMegas Manufacturing

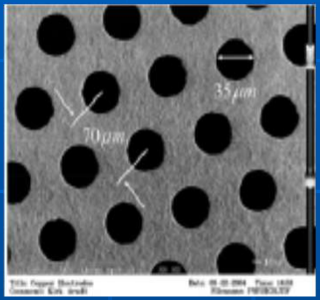
MESHES

Many different technologies have been developped for making meshes (Back-buymers, CERN, 3M-Purdue, Gantois, Twente…)

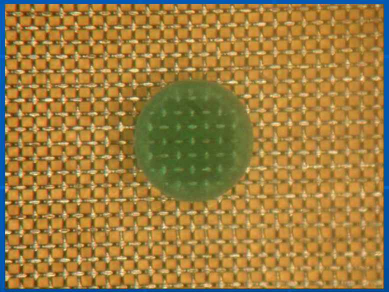
Exist in many metals: nickel, copper, stainless steel, Al,… also gold, titanium, nanocristalline copper are possible.



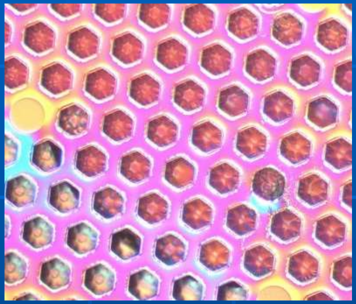
Electroformed



Chemically etched



Wowen



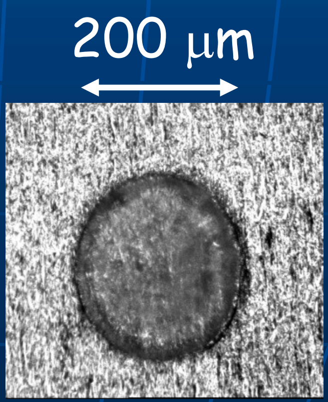
Deposited by vaporization

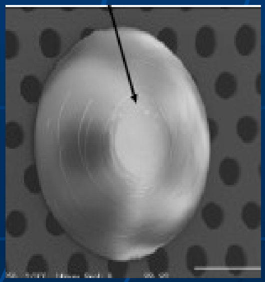
Laser etching, Plasma etching…

PILLARS

Can be on the mesh (chemical etching) or on the anode (PCB technique with a photoimageable coverlay). Diameter 40 to 400 microns.

Also fishing lines were used (Saclay, Lanzhou)



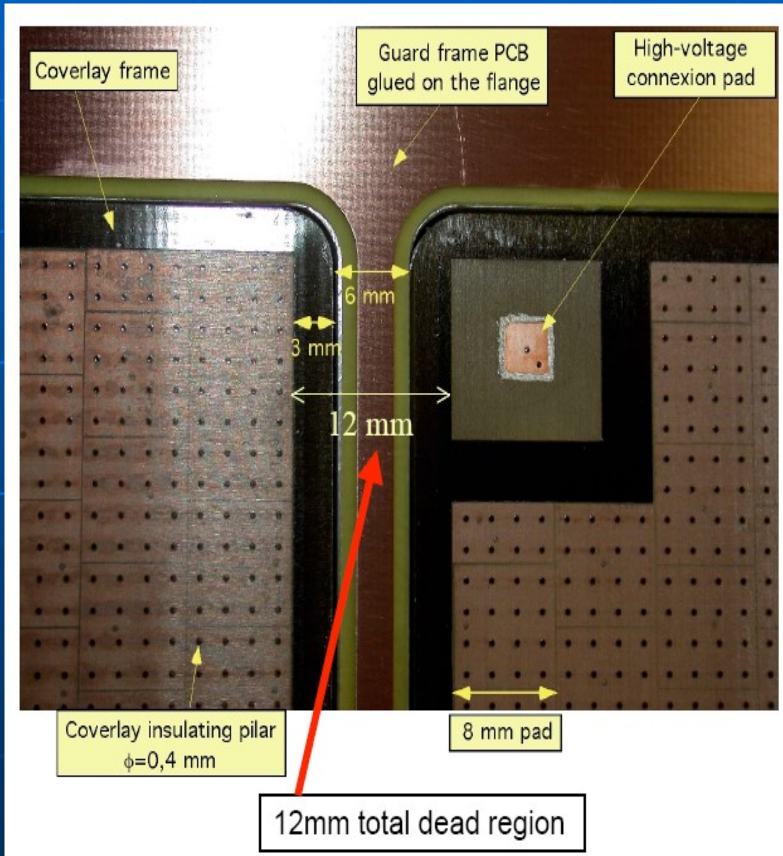


The Bulk technology

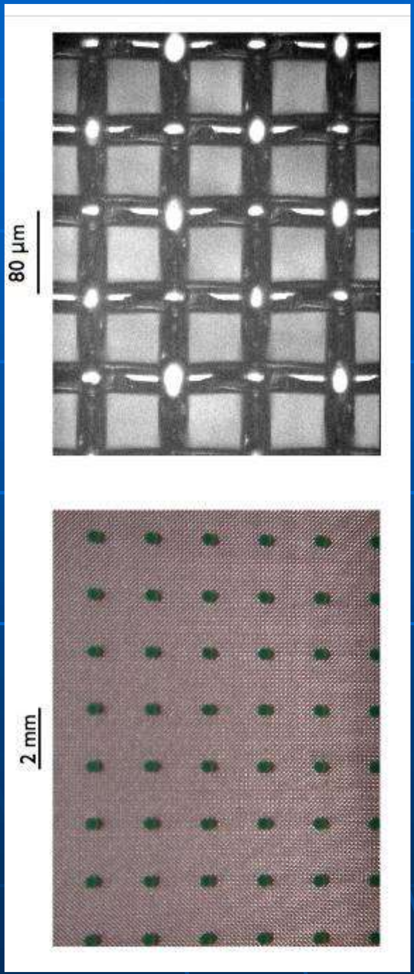
Fruit of a CERN-Saclay collaboration (2004)
Mesh fixed by the pillars themselves :

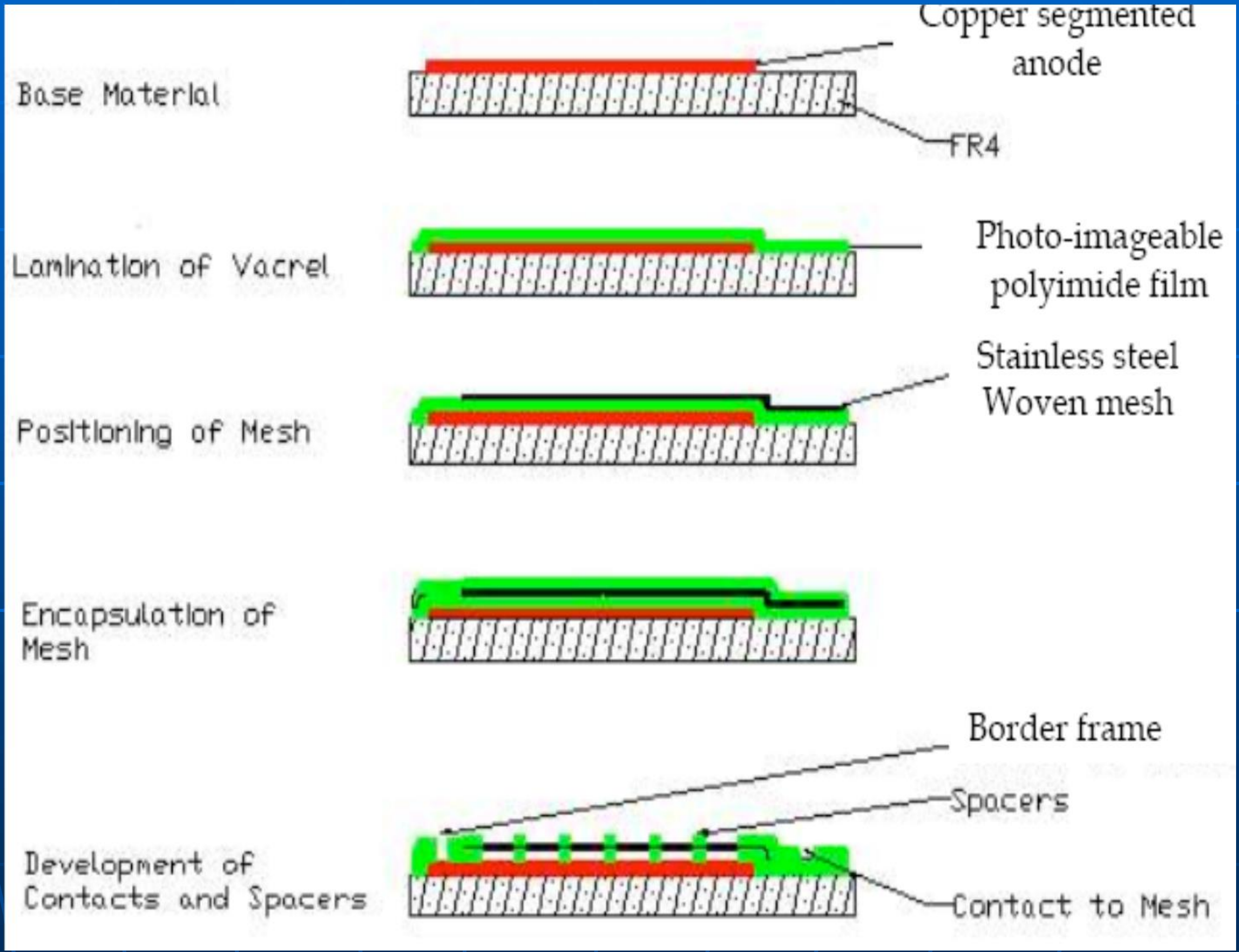
- -No frame needed : fully efficient surface
- -Very robust : closed for > 20 μ diameter dust
- -Possibility to fragment the mesh (e.g. in bands)
- … and to repair it

Used by the T2K TPC under construction



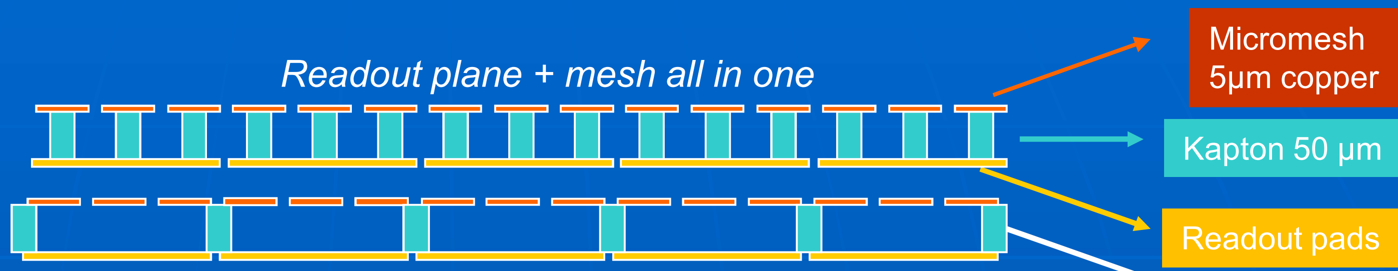
The Bulk technology





Micromegas development - Microbulk

Readout plane + mesh all in one



Lower capacitance
Under development

An I. Giomataris and R. De Oliveira idea

Microbulk Technology

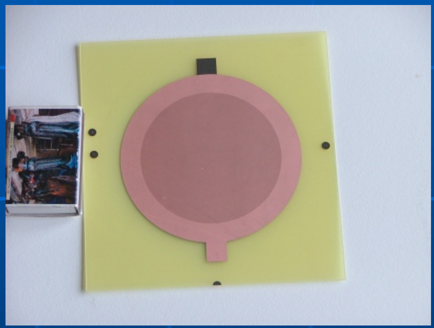
The pillars are constructed by chemical processing of a kapton foil, on which the mesh and to the readout plane are attached. *Mesh is a mask for the pillars!*

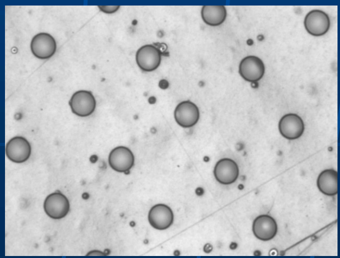
Typical mesh thickness 5 µm, gap 50/25 µm

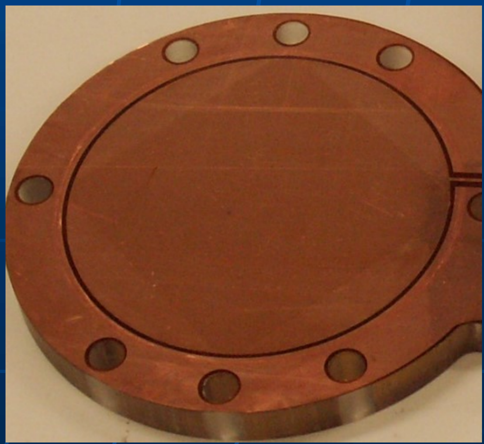
The advantages of a bulk micromegas but with enhanced performance.

***In addition: uniformity,* clean materials, stability**

- ✓ **Energy resolution**
- ✓ **Low intrinsic background**
- ✓ **Low mass detector**
- ✓ **Very flexible structure**



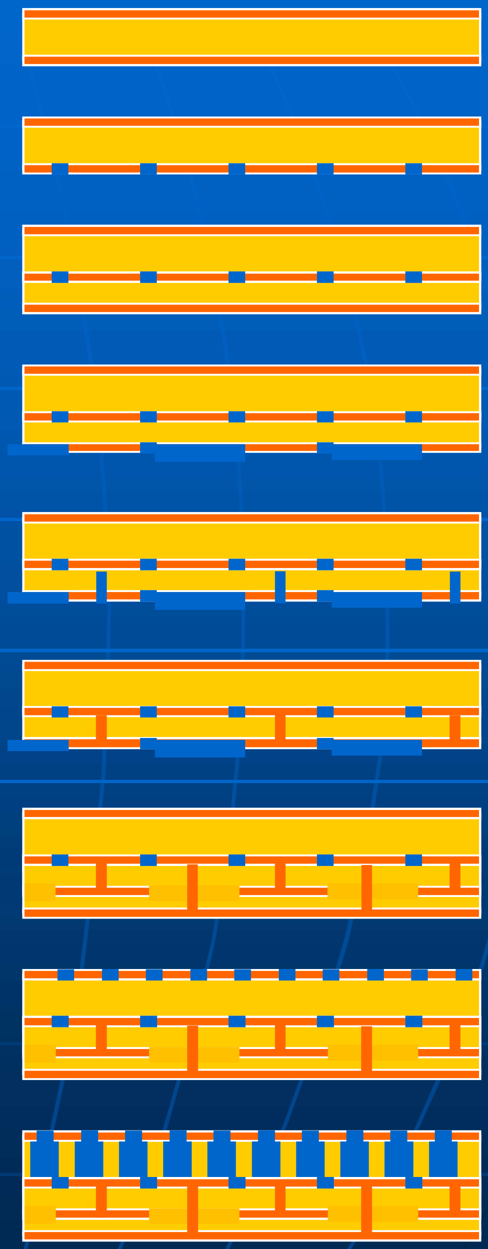




- × **Higher capacity**
- × **Fabrication process still improving**
- × **Fragility / mesh can not be replaced**

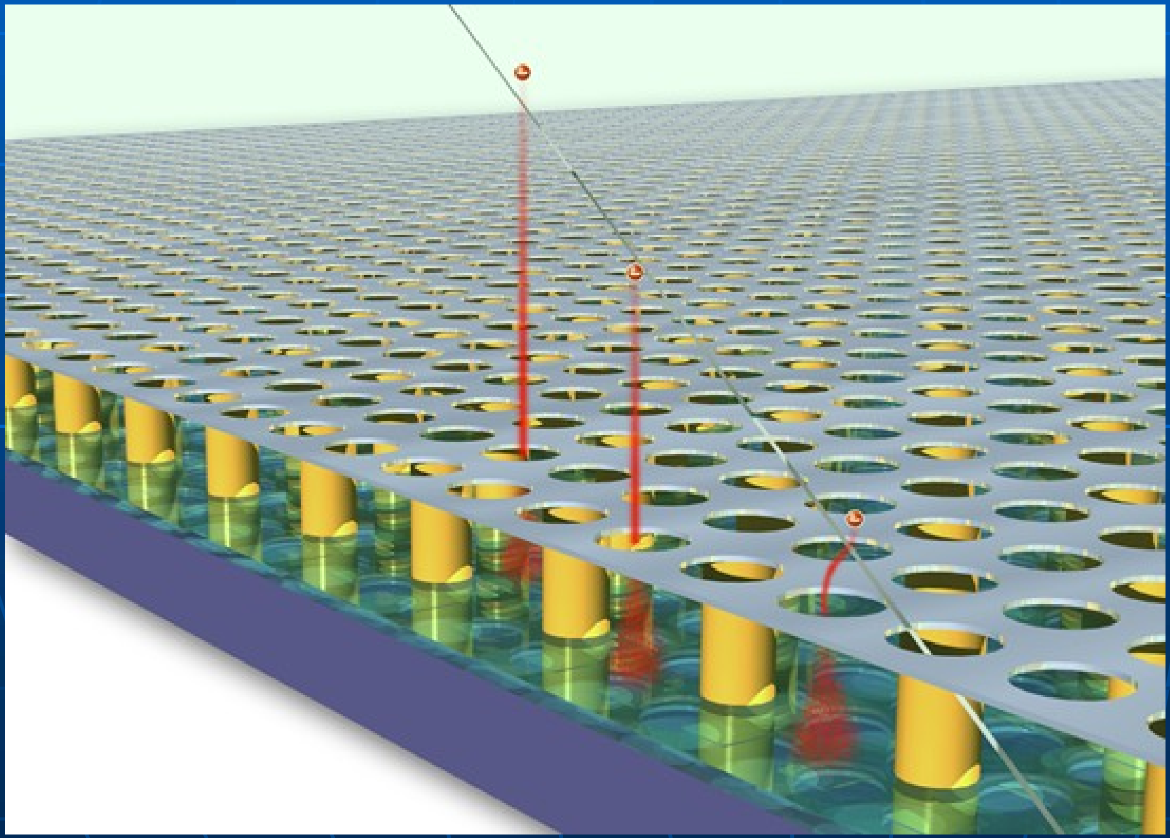
Building a Microbulk

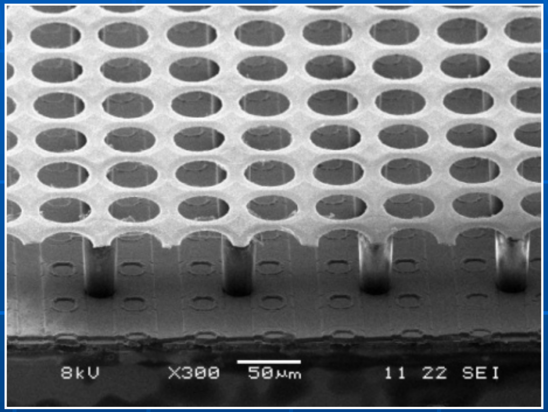
- Kapton foil (50 µm), both side Cu-coated (5 µm)
- Construction of readout strips/pads (photolithography)
- Attachment of a single-side Cu-coated kapton foil (25/5 µm)
- Construction of readout lines
- Etching of kapton
- Vias construction
- 2nd Layer of Cu-coated kapton
- Photochemical production of mesh holes
- Kapton etching
- Cleaning



Gossip

- Gaseous pixel detector
  - Narrow drift gap (~ 1 mm)
  - Electron from traversing particle drifts towards grid and is focused into one of the holes
  - Thereafter a gas avalanche is induced ending at the anode pad of the pixel chip

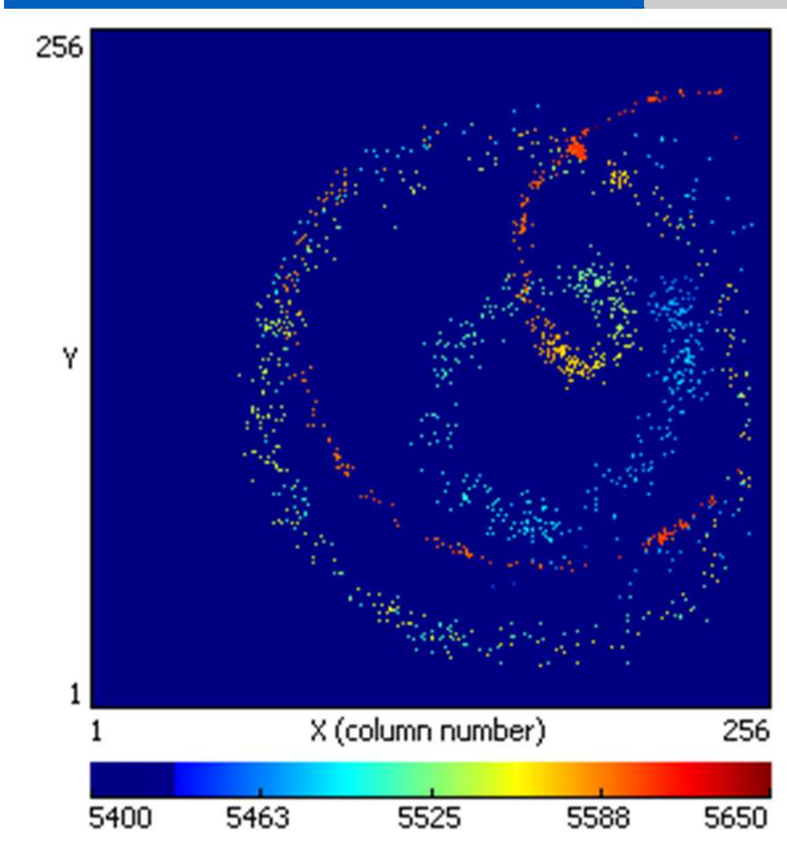


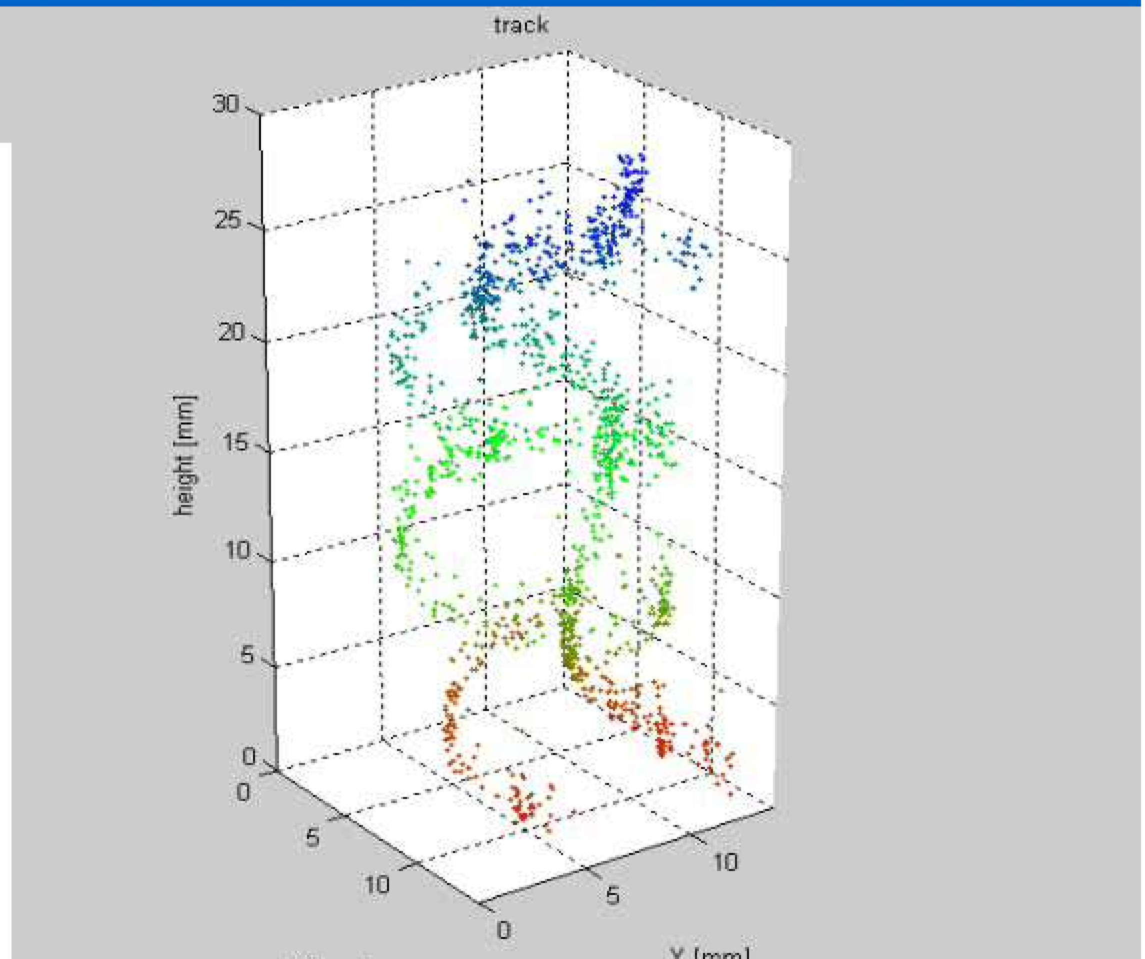


Ref: Harry van der Graaf, Nikhef

And how it works……

B = 0.2 T

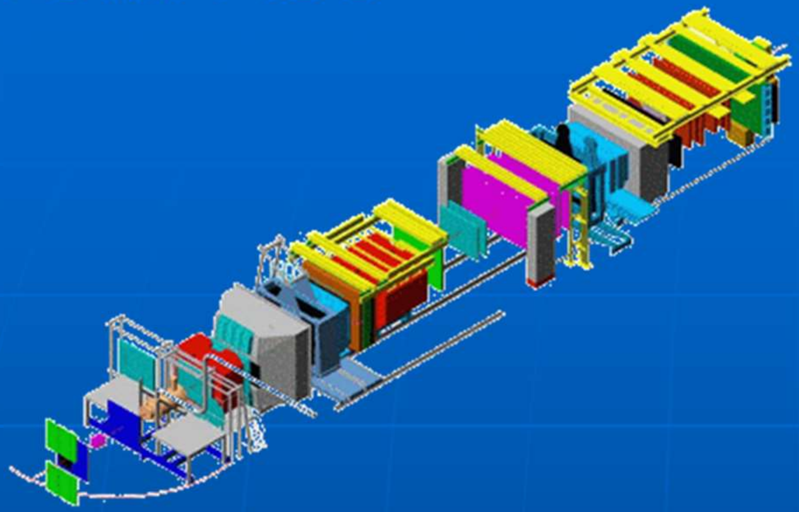




A 5 cm^3 TPC (two electron tracks from ^{90}Sr source)

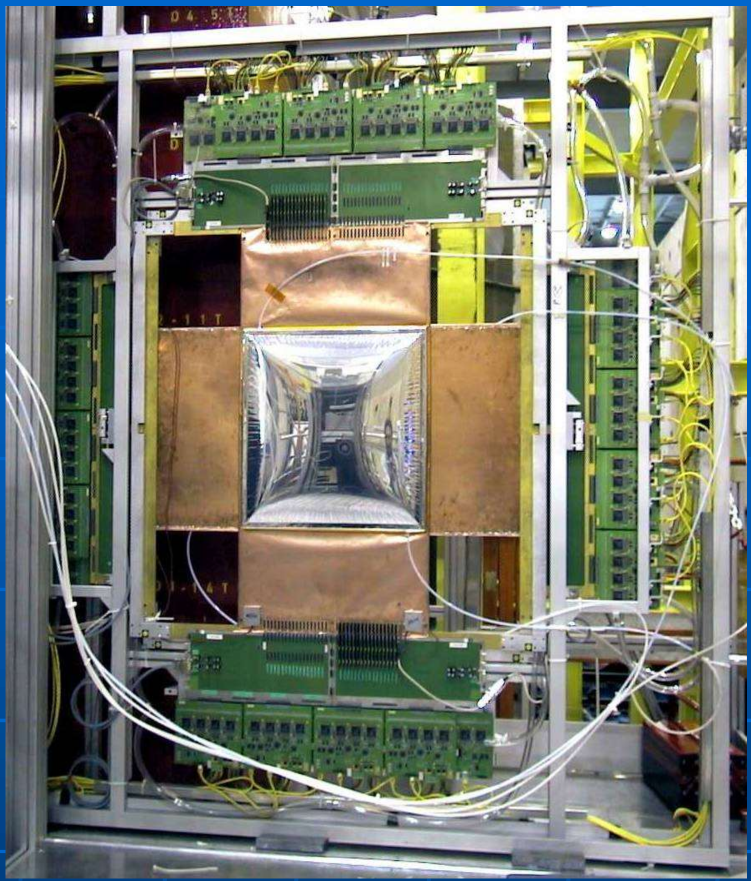
MicroMegas Applications in Physics Experiments

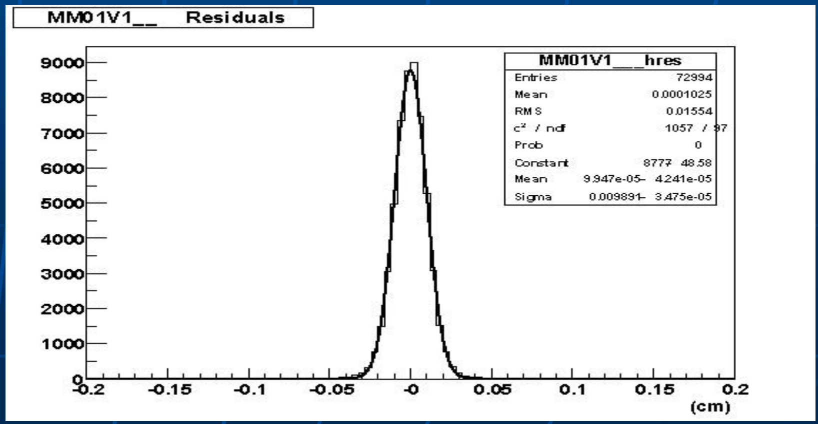
COMPASS



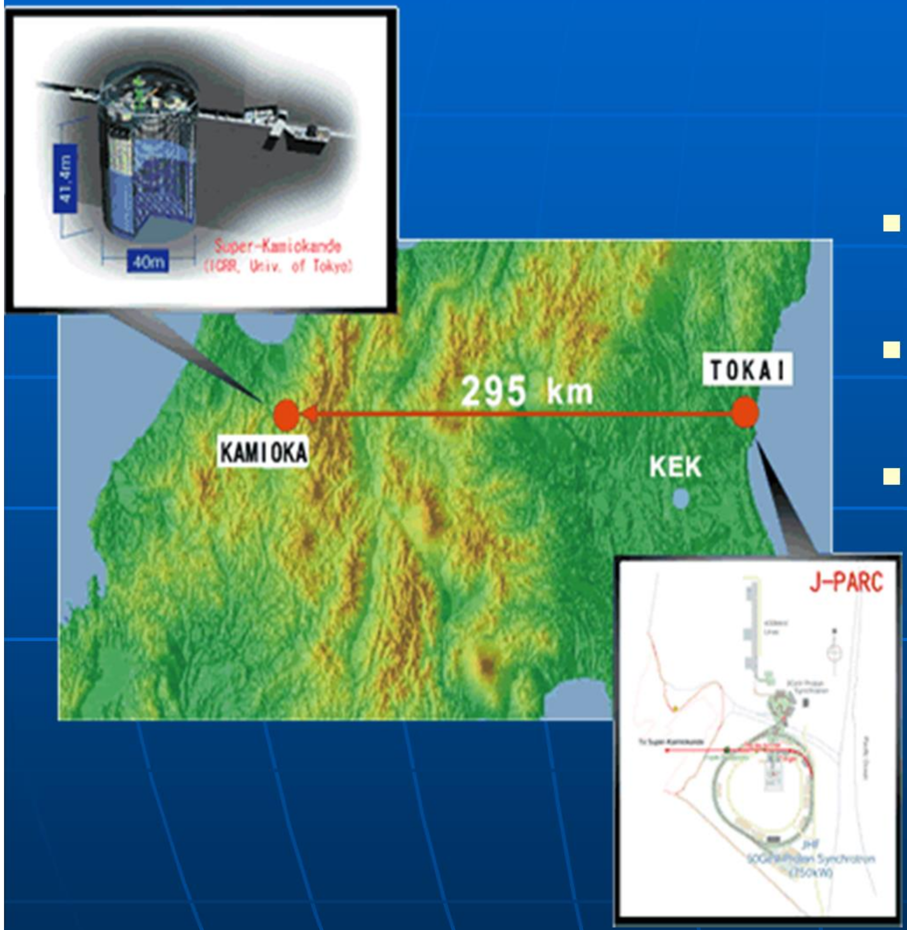
- MIP detection for measuring the nucleon spin structure
- High particle flow : 105 kHz/cm2
- Sparks give less than 1 per mil dead time
- Space resolution < 70 μm with 350 μm strips
- The largest Micromegas up to one year ago (40x40 cm^2)
- In operation at CERN since 2002

  efficiency>97%





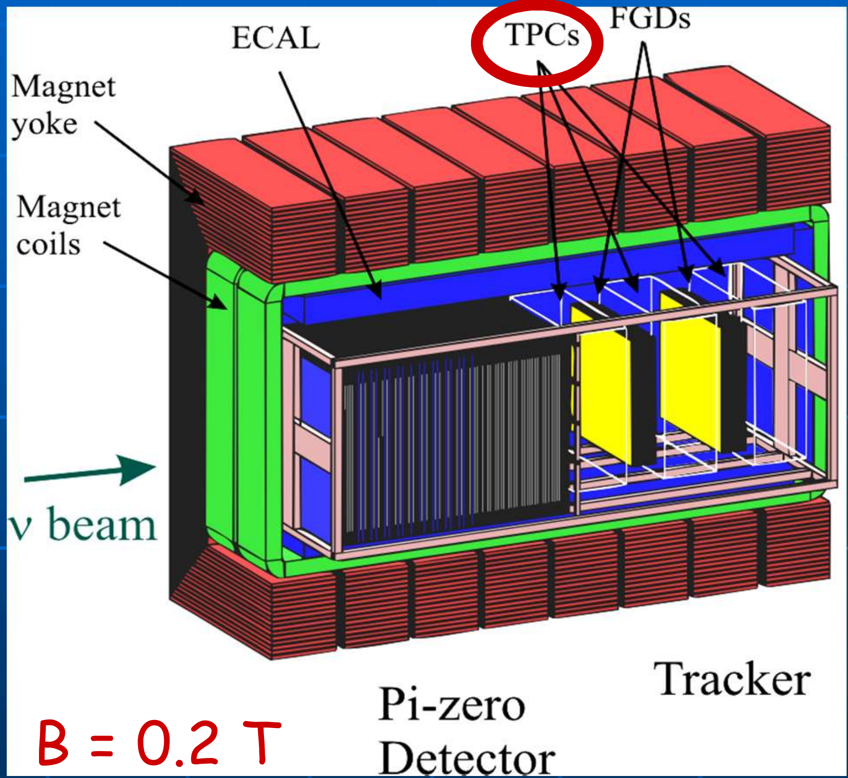
T2K : Tokai to Kamiokande



- Long Base Line neutrino experiment with an intense beam (0.75MW)
- Aiming at θ_{13} , neutrino oscillation measurements.
- 2 detectors: far (SK) and near at 280 m from target

Purpose of ND280

- Measure the neutrino spectrum before oscillation.
- Measure the intrinsic ν_e beam contamination from μ and kaon decays.
- Measure the π^0 production in Neutral Current with neutrino flux close to the one at SK.
- Measure the exclusive cross-sections at the relevant energies (< 1Gev).
- Measure nuclear effects that are relevant at these energies



Bulk-MICROMEGAS (T2K design)

Bulk-MICROMEGAS characteristics:

- all-in-one detector → *anode + mesh*:
  - Simple design, robust and cheap
  - Massive production
  - Good uniformity
  - Minimized blind areas (edges, corners)
- Saclay design and production by CERN/TS-DEM-PMT

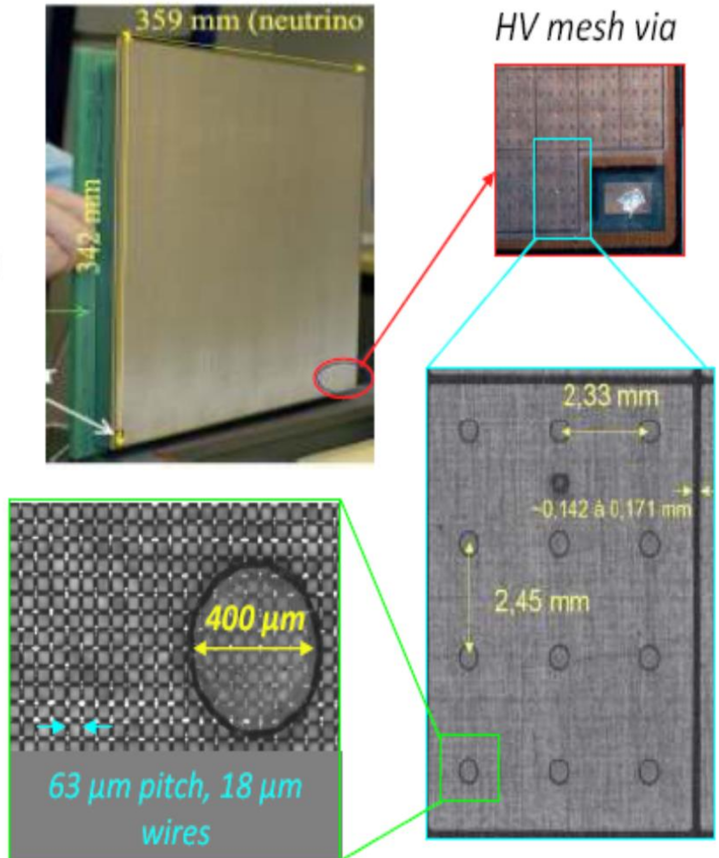
T2K bulk-MM:

- 128 μm amplification gap
- Large surface **34x36 cm²**
- **1726** active pads (6.9 x 9.7 mm²)
- 48 rows, 36 columns of pads
- 12 MICROMEGAS detectors per plan
- **72** MM for 3 TPCs
- Total equivalent surface about **9 m²**

→ First large size MPGD based TPCs

T2K bulk-MM

HV mesh via

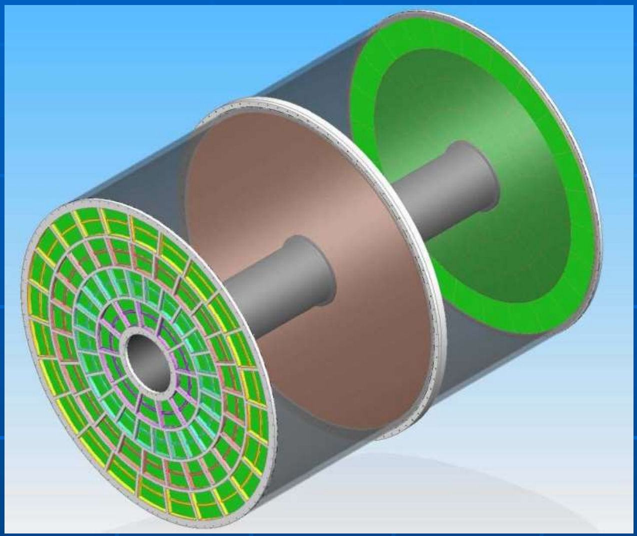


Mesh, pillar zoom

Pad details

ILC-TPC prototypes

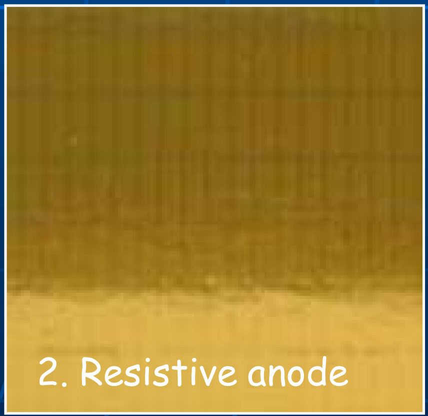
- Need for ILC: measure 200 track points with a transverse resolution ~ 100 μm
  - example of track separation with 1 mm x 6 mm pad size:
    - → 1,2 × 10^6 channels of electronics
    - → $\sigma_{z=0}$ > 250 μm amplification avalanche over one pad



- Two R&D MicroMegas activities:

→ 1. Decrease the pad size: narrowed strips, pixels

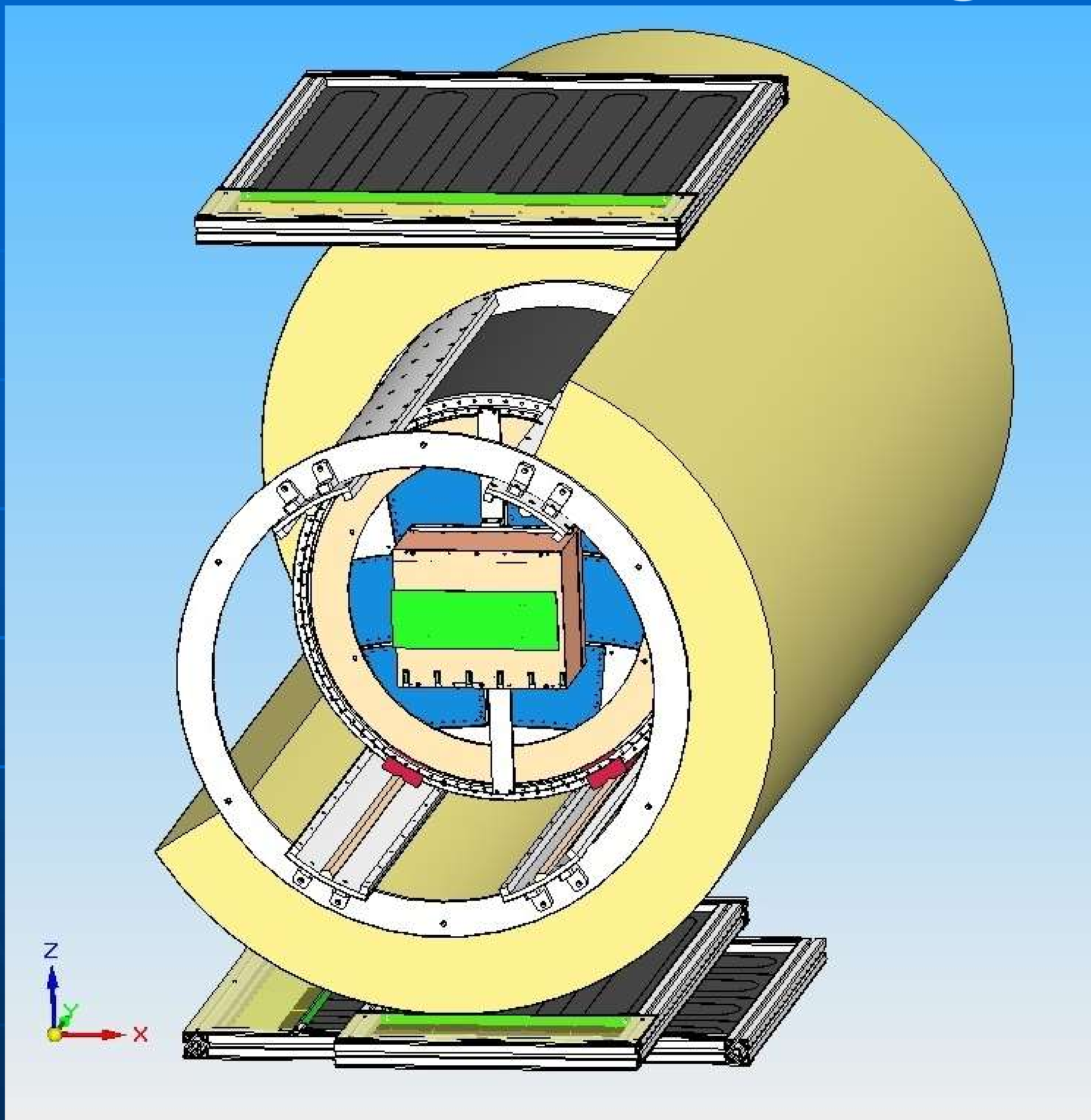
+ single electron efficiency
– need to identify the electron clusters



→ 2. Spread charge over several pads: resistive anode

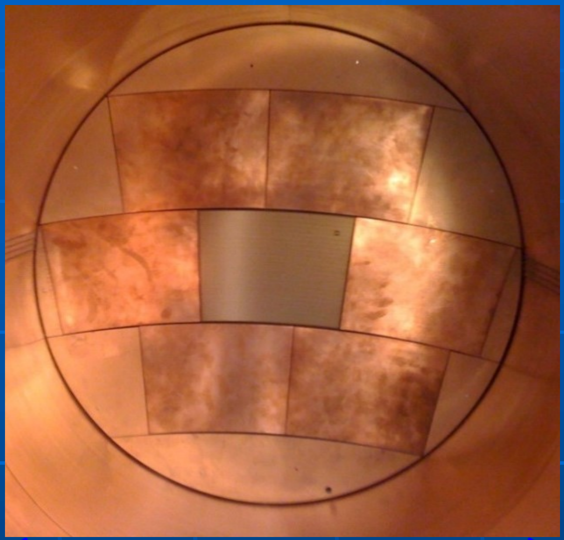
+ reduce number of channels, cost and budget
+ protect the electronics
– limit the track separation
– need offline computing
– time resolution is affected

ILC-TPC Large Prototype

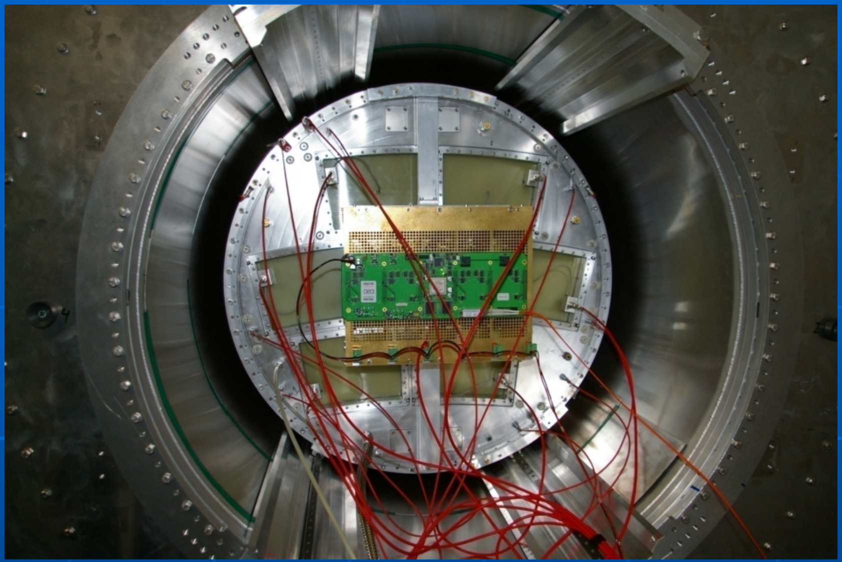


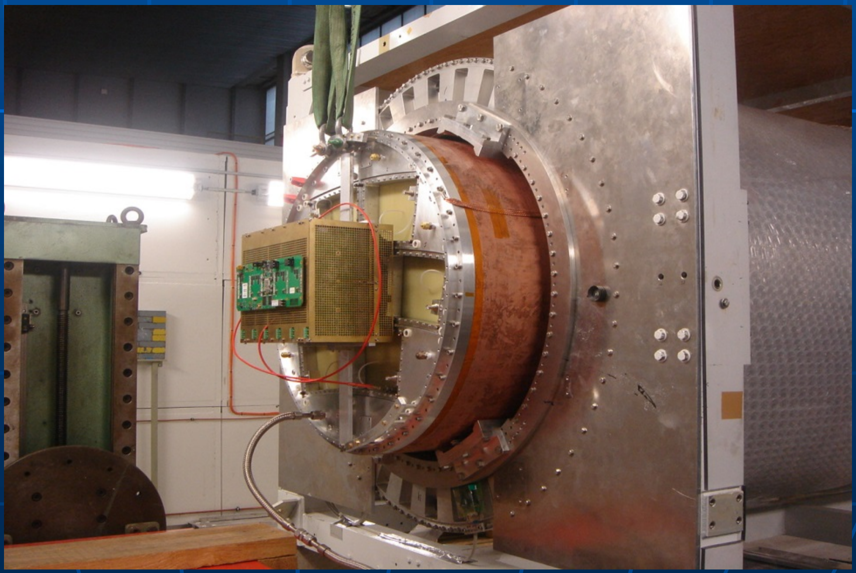
- Built by the collaboration
- Financed by EUDET
- Located at DESY: 6 GeV e- beam
- Sharing out :
  - magnet : KEK, Japan
  - field cage : DESY, Germany
  - trigger : Saclay, France
  - endplate : Cornell, USA
  - Micromegas : Saclay, France, Carleton/Montreal, Canada
  - GEM : Saga, Japan
  - TimePix pixel : F, D, NLc

- 60 cm long TPC
- Endplate ø = 80 cm of 7 interchangeable panels of 23 cm:
  - Micromegas
  - GEMs
  - Pixels: TimePix + GEM or Micromegas



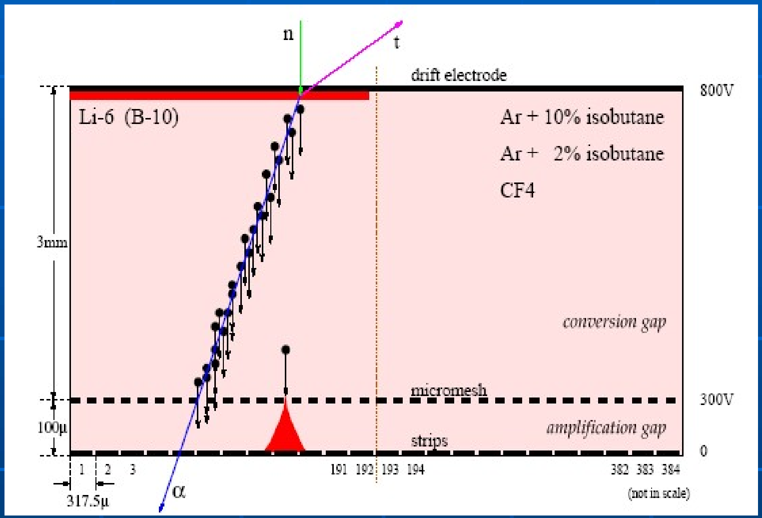
80 cm

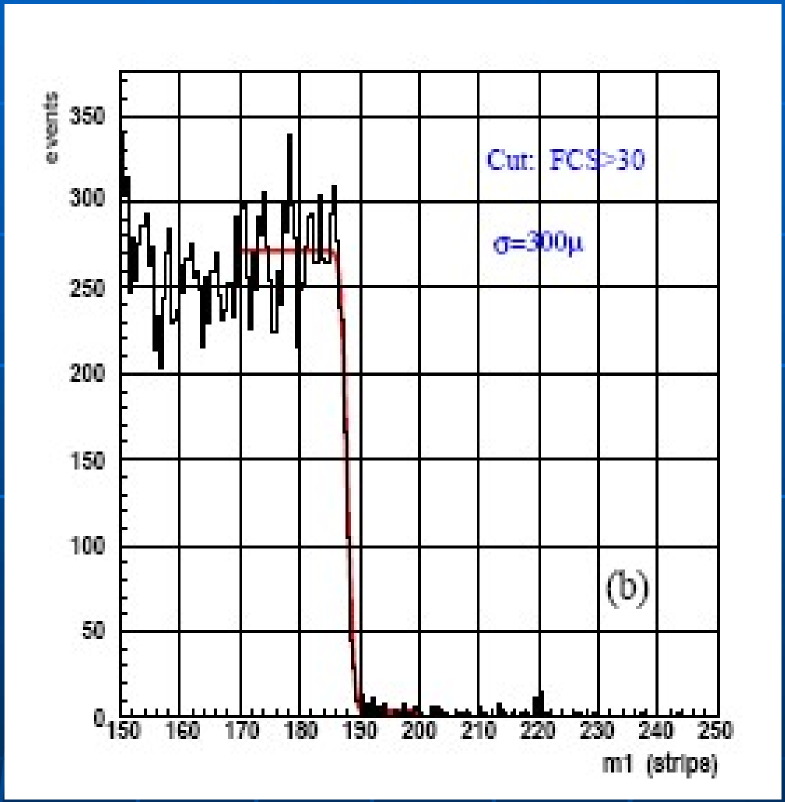




Neutron detection

- Use a converter to extract alphas

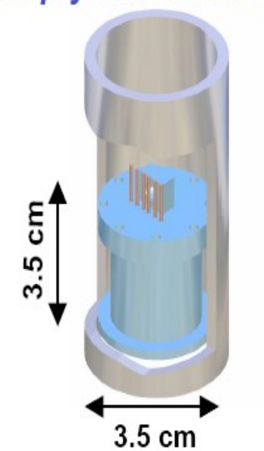




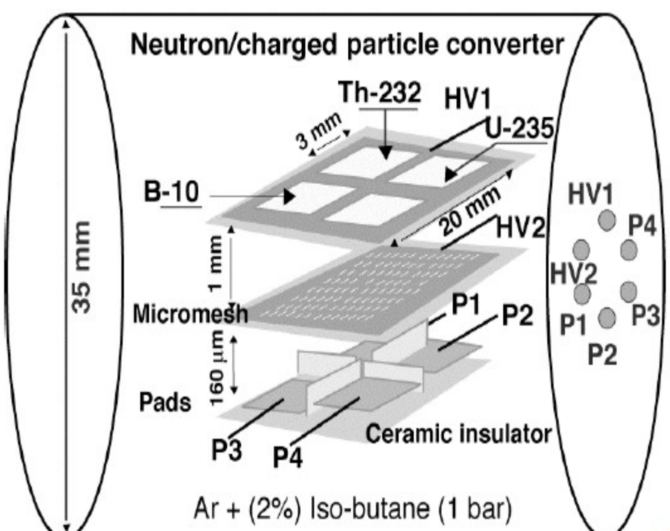
- Numerous applications: neutron tomography, neutron detection in hostile environments

Piccolo Micromegas for in-core nuclear reactor neutron flux measurements

View of Piccolo-Micromegas placed inside the empty rod of TRIGA reactor



Schematic view of the Piccolo-Micromegas detector (in horizontal position).

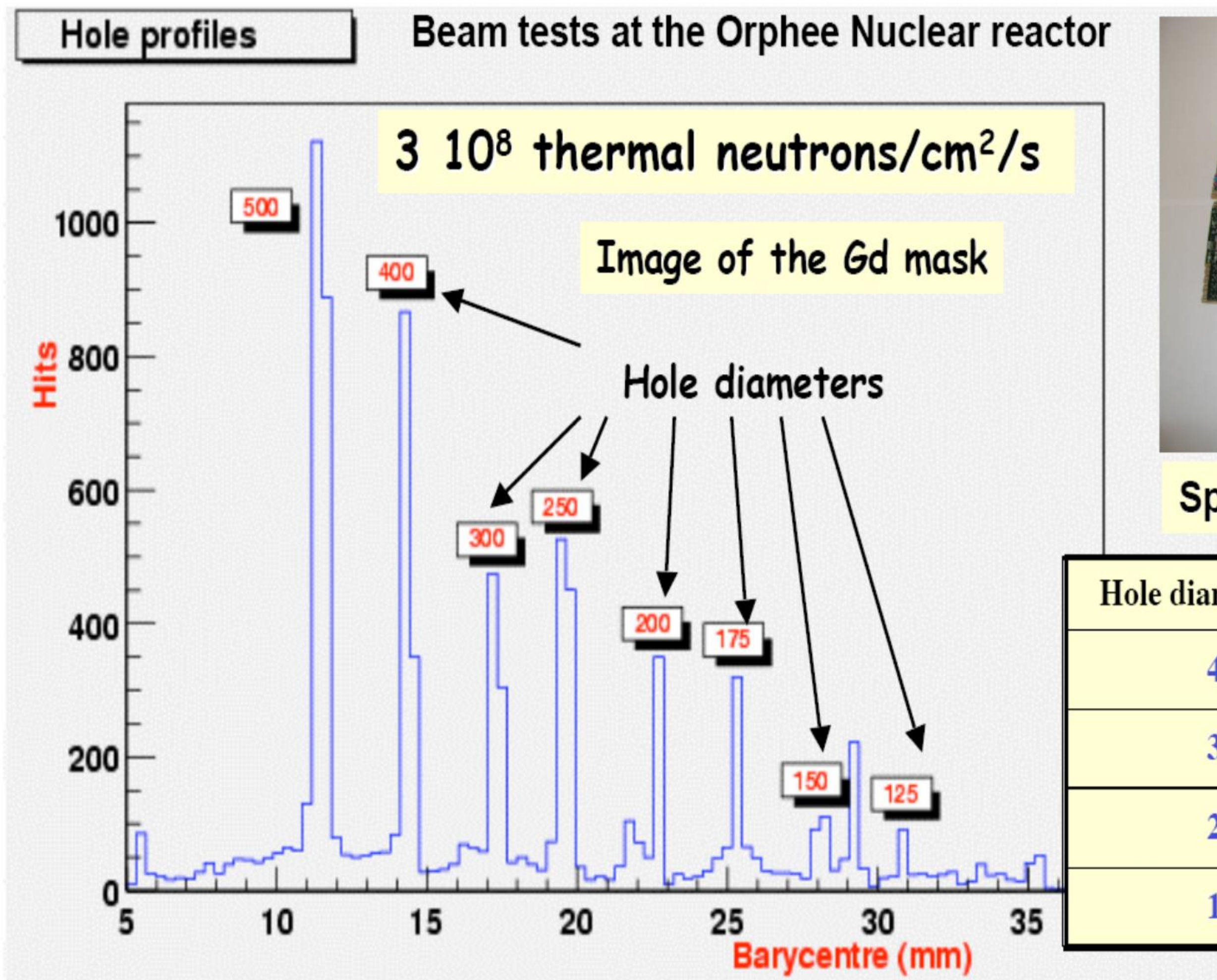


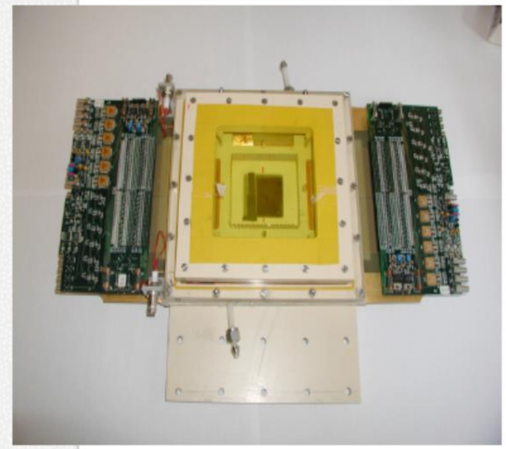
Main characteristics:

- **Very small Micromegas detector** (Max 35 mm) for empty or instrumented rod of nuclear reactor
- **Detector loading:**
  - ^{10}B (10 µm deposit) for thermal neutron energy
  - ^{235}U (0.01 mm deposit) for monitoring
  - ^{232}Th (0.1 mm deposit) for neutron with energy larger than fission threshold (~ 1 MeV)
  - without deposit for the recoil nucleus of H and He
- **Different amplification gap** in each compartment in order the dynamic range of the collected charge
- **Specific material** for: - high temperature environment
  - low activation
  - small perturbation of the neutron flux
- **Sealed**
- **Abble to measure**:- **very high** flux (current preamp) and **very low** flux (charge preamp)

Micromegas application to neutron imaging 1D (1)

Imaging Mask: Gadolinium foil (5x5 cm², 25 µm thin) holes from 75 to 500 µm



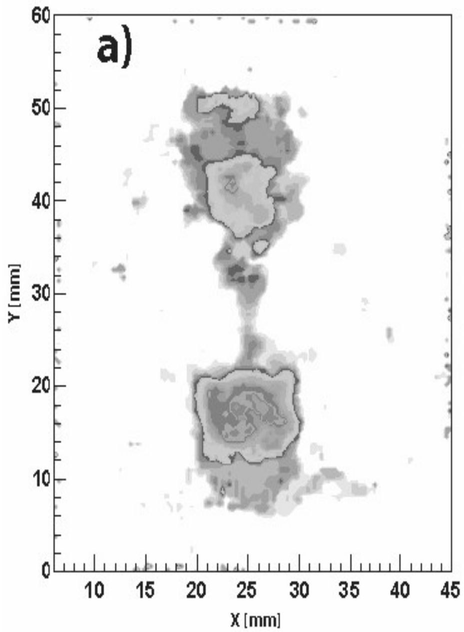


Spatial resolution

Hole diameter (μm)	σ +/- $\Delta\sigma$ (μm)
400	58 +/- 5
300	57 +/- 19
200	63 +/- 8
160	43 +/- 4

Neutron Radiography : see gas (H_2) through glass and metal

Micromegas application to neutron imaging 2D (2)



a) Image of a perfume sample contained in a glass tube (invisible with the neutron). One recognizes on the figure, the various parts of the perfume sample , the plunging tube and the diffuser. The places where the plastic is denser are also identified. On the other hand despite the good spatial resolution the image is not perfect.

Very useful for rocket engine studies

Dark matter search

- Look for recoiling nuclei (few 100 keV)
- Directionality : see the ‘wind of wimps’ : 24h-modulation of the direction

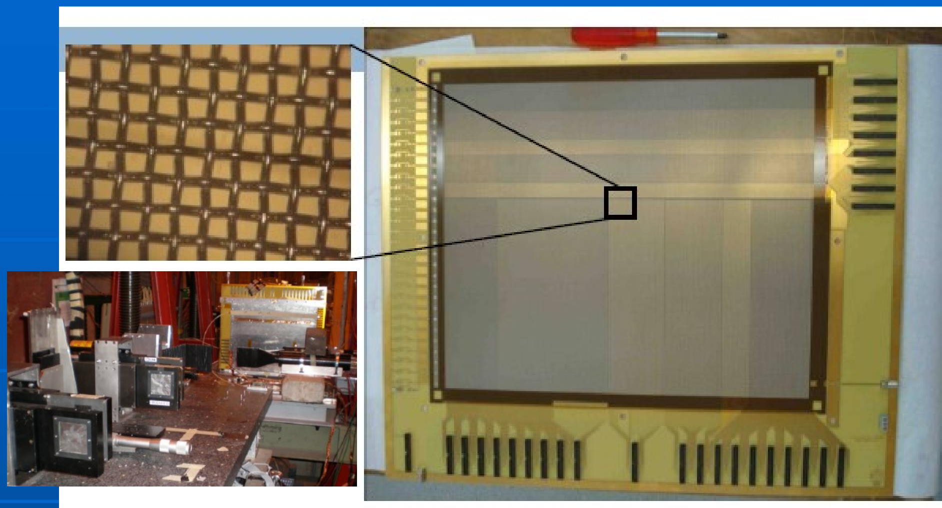
Negative Ion TPC

Take an attaching gas (CS_2, CH_3NO_3), drift negative ions, they are stripped in the amplification region. Very slow drift, but very low diffusion

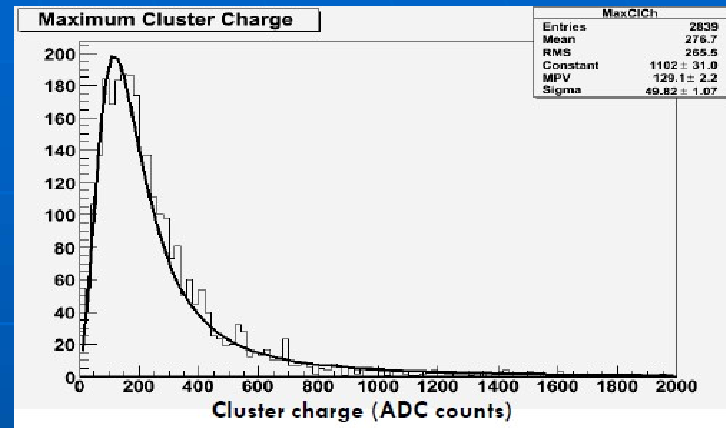
More neutrino physics

Neutrinoless double-beta decay in ^{136}Xe

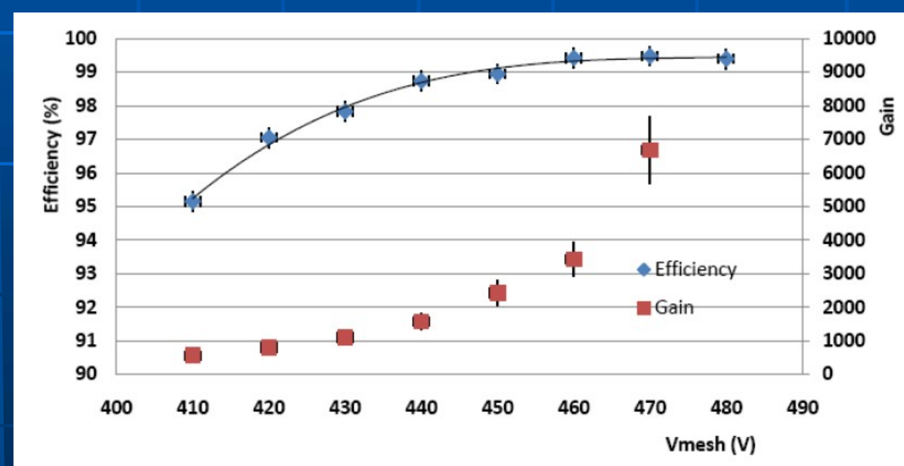
Atlas Muon System upgrade



MAMMA Micromegas Prototype



Half-size large area bulk micromegas mesh



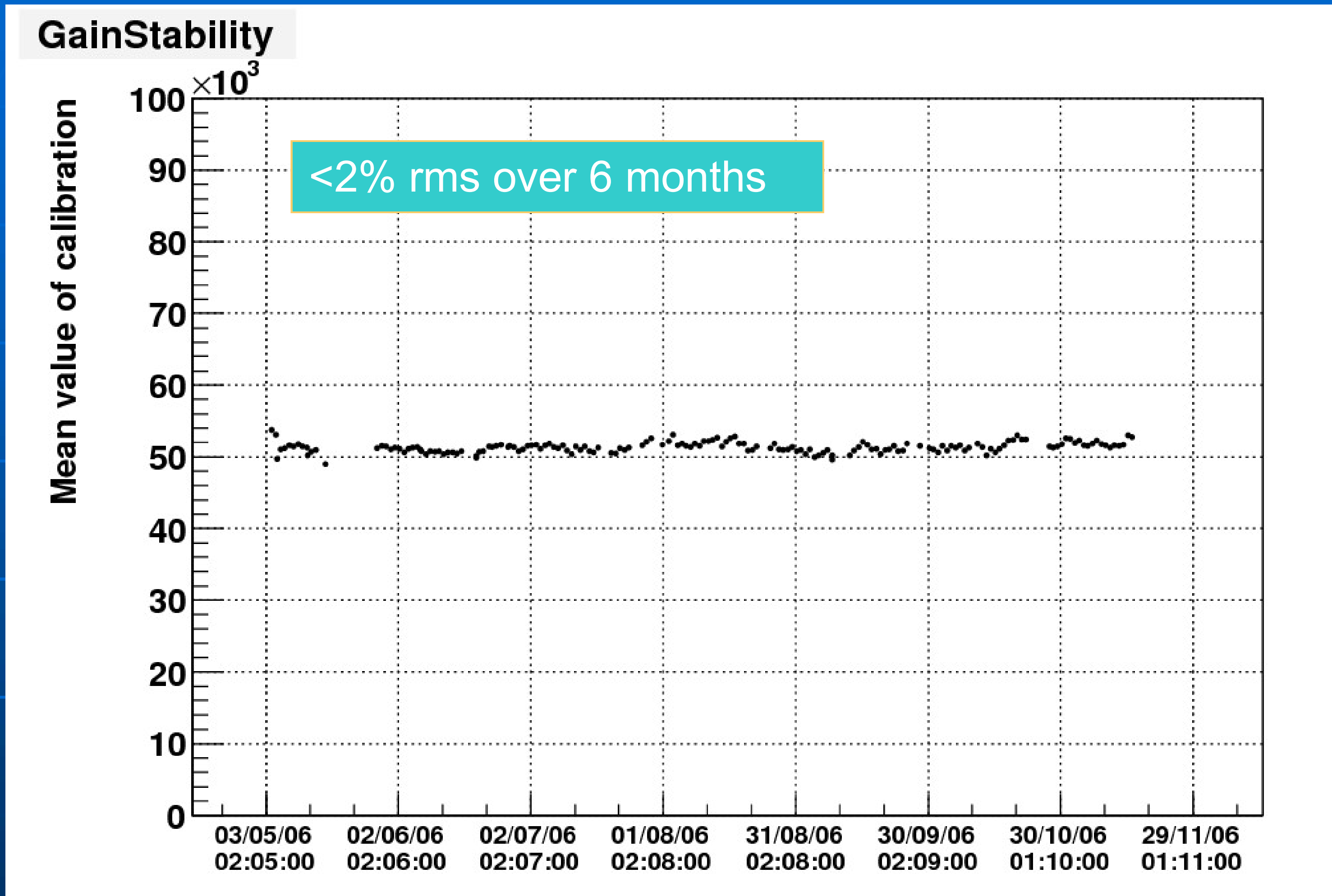
Gain and efficiency of the first prototype

Conclusions

- MicroMegas is a good-performing micro-pattern gas detector
  - High gain
  - Low Ion Backflow
- It is flexible and many production techniques exist for meshes and pillars
- Widely used in physics experiments
- More applications coming in the near future

Spare Slides

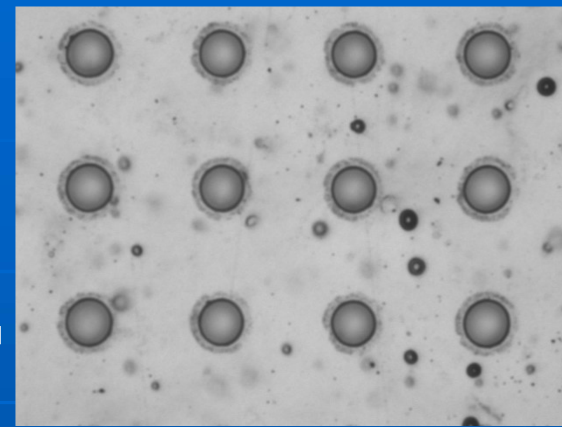
Gain stability

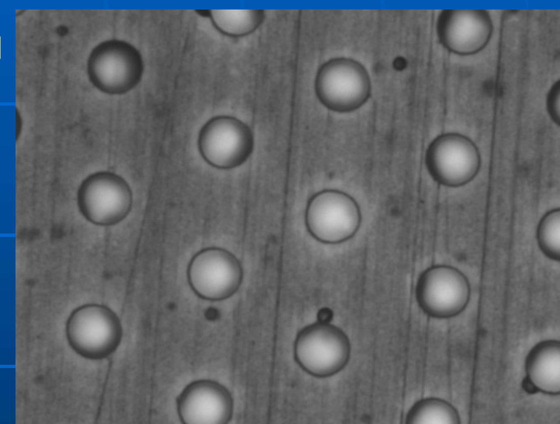


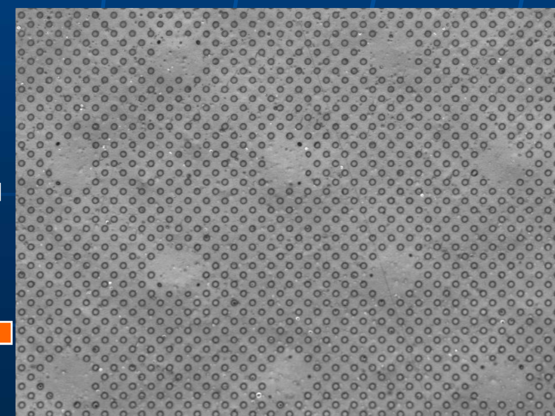
Very good gain stability (G. Puill et al.) Optimization in progress for CAST

Mesh types

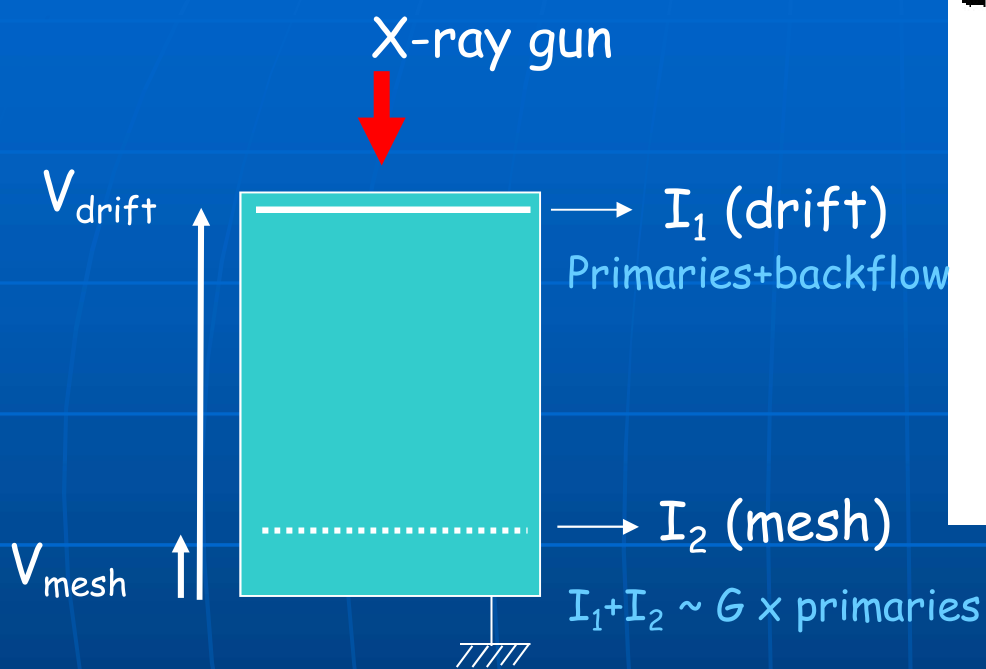
- A "standard for 50 μm gap: 30 μm holes placed in 100 μm pitch
- Alternative: hexagonal arrangement for better optical transparency
- Pillars: Areas without holes & full etching underneath normal holes
  - ✓ Less material / capacity

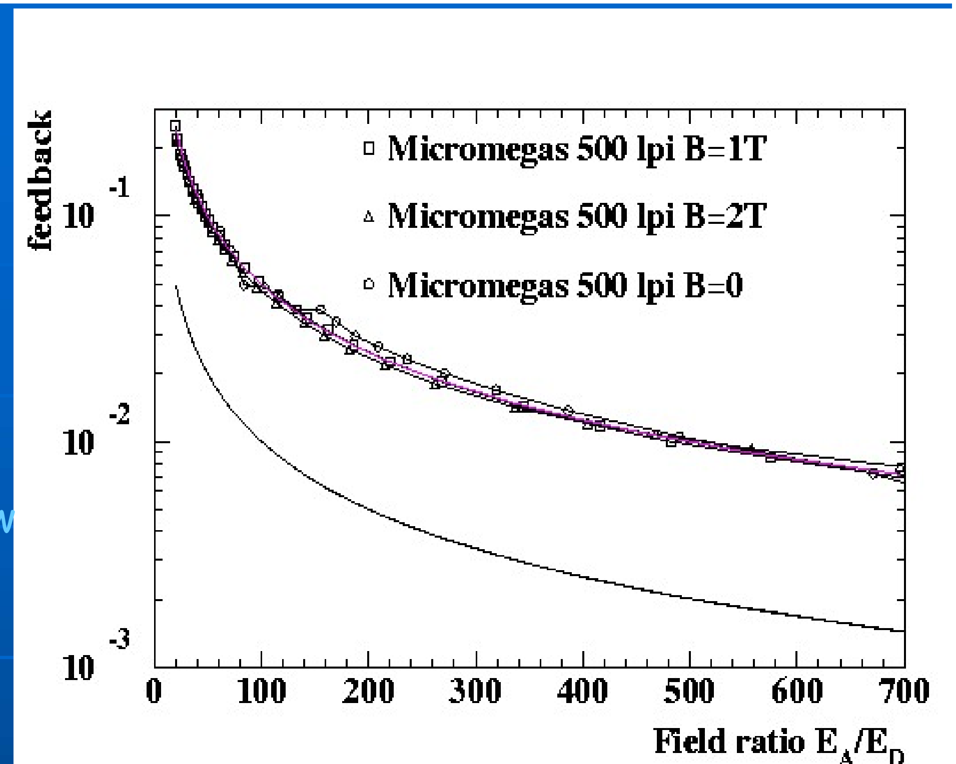






Ion backflow measurements





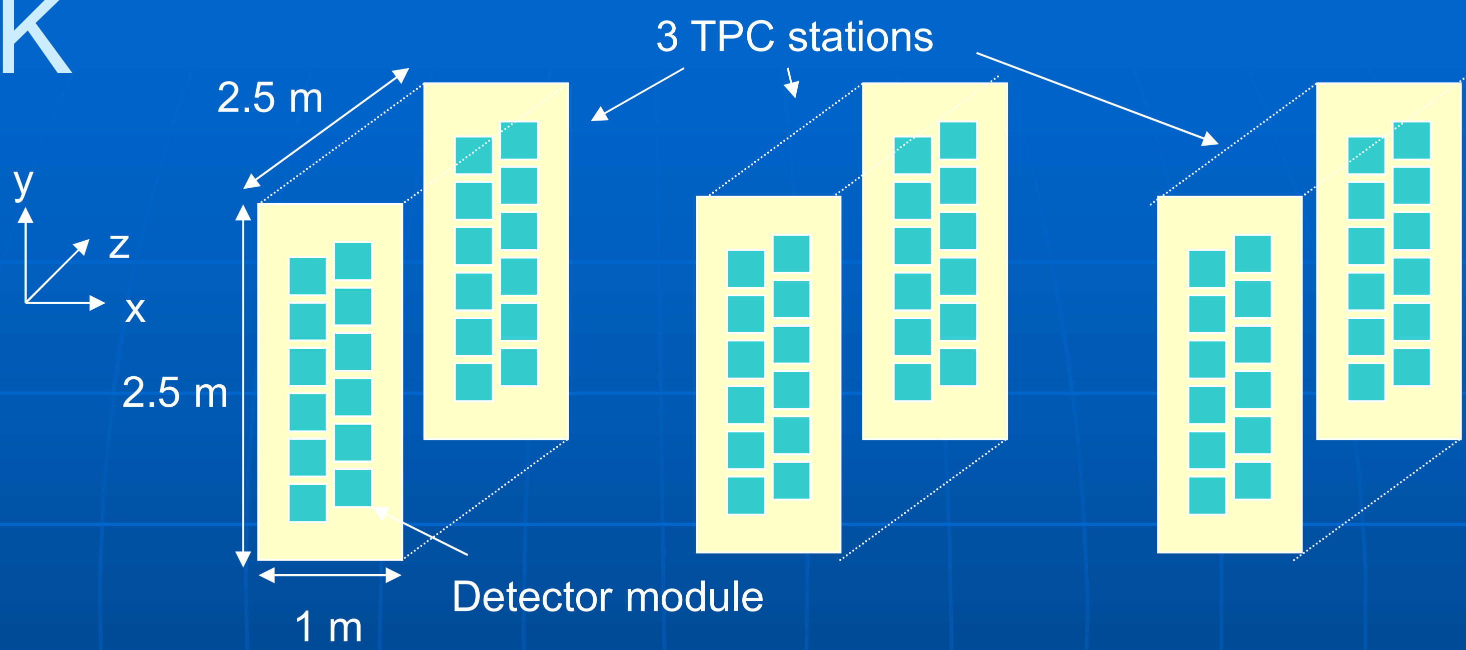
One gets the primary ionisation from the drift current at low V_{mesh}

One eliminates G and the backflow from the 2 equations

The absence of effect of the magnetic field on the ion backflow suppression has been tested up to 2T

P. Colas, I. Giomataris and V. Lepeltier, NIM A 535 (2004) 226

T2K



Started in December 2004, should take data end 2009

- 3 TPCs stations; each with 2 planes of detector modules

→ From the beginning, think wide operating ranges, flexible hardware modular architecture, design staging