Irfu - CEA Saclay
Institut de recherche sur les lois fondamentales de l'Univers

DE LA RECHERCHE À L'INDUSTRIE

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# Thermal neutron detection with high efficiency and high granularity, using large area Micromegas detectors

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CEA Saclay

# Micromegas concept

Two-region gaseous detector
*separated by a Micromesh* :

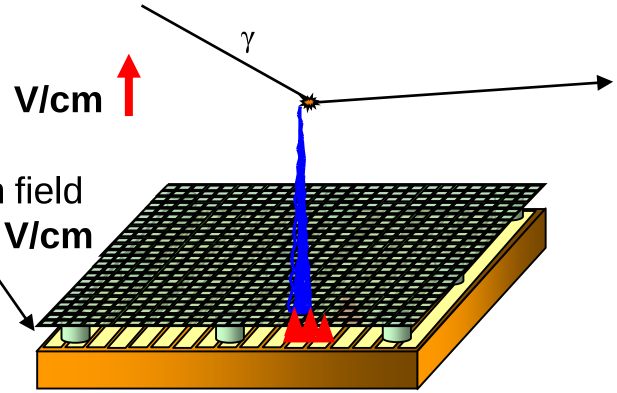
- Conversion region
  - Primary ionization
  - Charge drift towards A.R.
- Amplification region
  - Charge multiplication
  - Readout layout
    - Strips (1/2 D)
    - Pixels

➔ Very strong and uniform electric

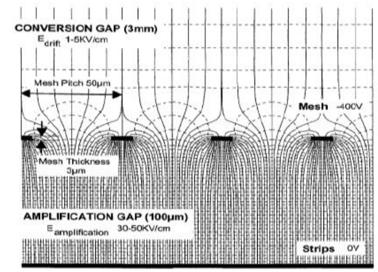
- metallic micromesh (typical pitch 50µm)
- sustained by 50-100 µm pillars
- simplicity
- single stage of amplification
- fast and natural ion collection
- discharges non destructive

**Drift** field
typical $\mathbf{10^{2\text{-}3}}$ **V/cm**

Amplification field
typical $\mathbf{10^{4\text{-}5}}$ **V/cm**

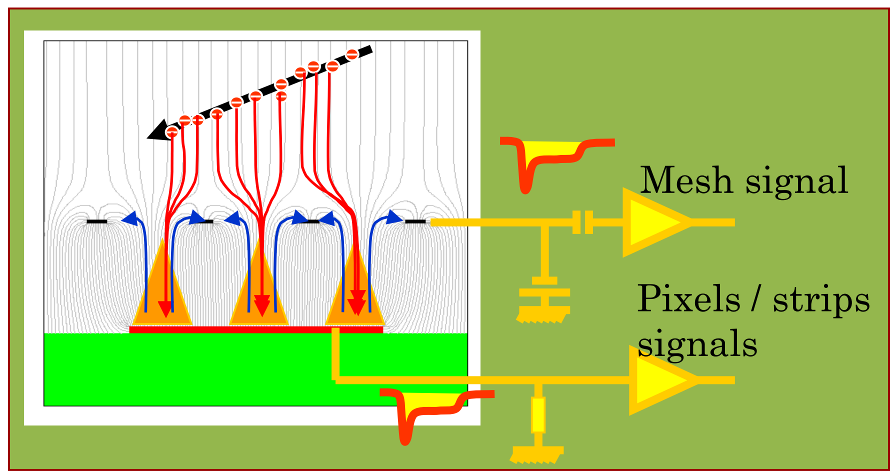



Amplification
gap: 50-100 µm




*MICROMEsh GAseous Structure*
*Giomataris, Charpak (1996)*
Y. Giomataris *et al.*, NIM A 376 (1996) 29

***In 1st Micromegas***
***Fishing line spacers have been used***

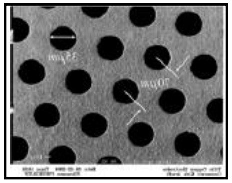


# The Micromegas detector

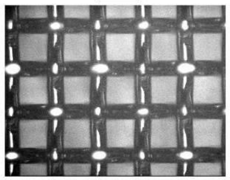
## Micro-mesh (cathode)

The metallic micro-mesh must be 5 to 30 mm thick with needed equivalent wires densities ranging from 500 to 2000 Lines Per Inch (LPI). Stainless steel woven meshes, electroformed Nickel meshes, or chemically etched copper meshes are used.

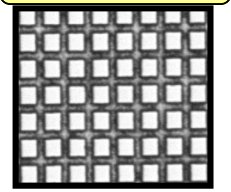
Chemically etched Copper mesh



500 LPI 304Lwoven mesh

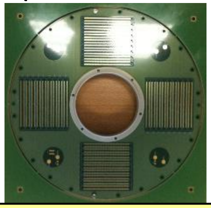


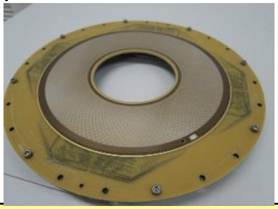
500 LPI Electroformed Ni mesh

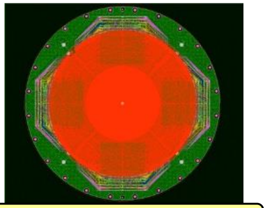


## Printed Circuit Board (anode PCB)

- It can be up to 1- 3 $m^2$ and down to 100 µm thin.
- Copper strips or pads can be ≈100 µm to few mm large and insulation between them as low as 50 µm.
- Copper is usually covered by a Ni/Au layer for a total thickness which must be kept as low as possible (down to 5 mm) with a « smooth » surface.





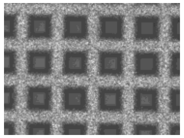


A Φ30 cm 12 layers PCB with 4000 x 4 $mm^2$ pads for the MINOS TPC (18000 blind vias)

## Drift electrode + neutron converter

- For **thermal neutrons**, it can be a thin aluminum foil or a metallic mesh covered by a 1-2 mm thick layer containing $^{10}B$ (such as $B_4C$) or by a ≈100 mm thick $^{6}Li$ layer.
- For **high energy neutrons**, a few mm thick polyethylene ($CH_2$) sheet is used.

An electroformed Ni mesh covered by a 2 µm thick $B_4C$ layer (Linköping Univ.)

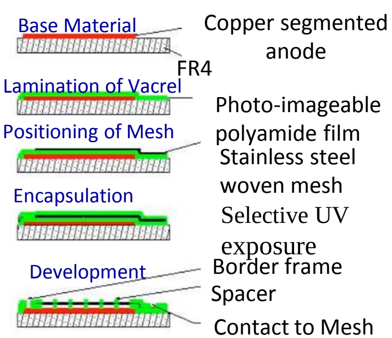


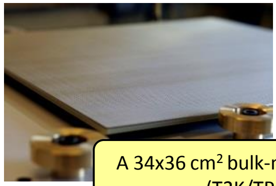
## Micromegas technologies

to realize the micro-mesh + anode PCB assembly

### Bulk-micromegas

Embedding of the mesh between two layers of insulating pillars by use of photolithography technics

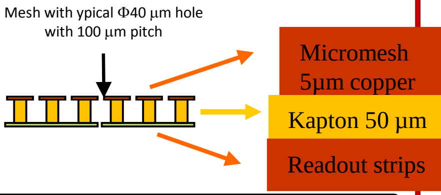


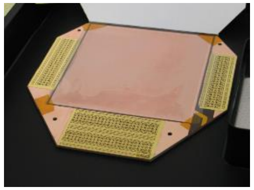
A 34x36 $cm^2$ bulk-micromegas (T2K/TPC)

### micro-bulk micromegas

Micromegas is built from a double sidded copper clad kapton foil by selective chemical etching of copper (mesh and anode strips) and kapton (insulating pillars).




A 10x10 $cm^2$ micro-bulk (NEXT prototype)



# Neutron detection with Micromegas

Neutron detection ➔ neutron to charge converter

- Solid converter: thin layers deposited on the drift or mesh electrode ($^{10}$**B**, $^{10}$**B$_4$C**, $^{6}$Li, $^{6}$LiF, U, actinides…)
  - ✓ Sample availability & handling
  - ✓ Efficiency estimation
  - × *Limitation on sample thickness from fragment range*
    *⇒ limited efficiency*
  - × Not easy to record all fragments
- Detector gas ($^{3}$He, $BF_3$…)
  - ✓ Record all fragments
  - ✓ No energy loss for fragments ⇒ reaction kinematics
  - ✓ No limitation on the size ⇒ high efficiency
  - × *Gas availability*
  - × Handling (highly toxic or radioactive gasses)
- Neutron elastic scattering
  - gas (H, He)
  - solid (paraffin etc.)
    - ✓ Availability
    - ✓ High energies
    - × Efficiency estimation & reaction kinematics

*Neutron detection with high efficiency (~50%):*

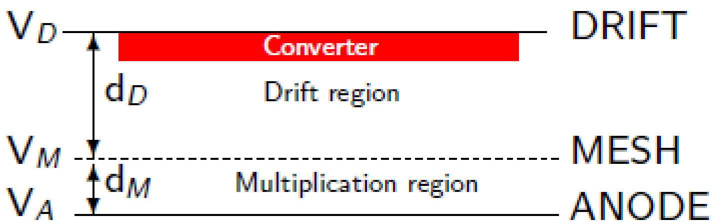
- $^{3}$He crisis
- Increased demand for neutron detectors
  - ➔Science
  - ➔Homeland security
  - ➔Industry

**Micromegas for neutrons**

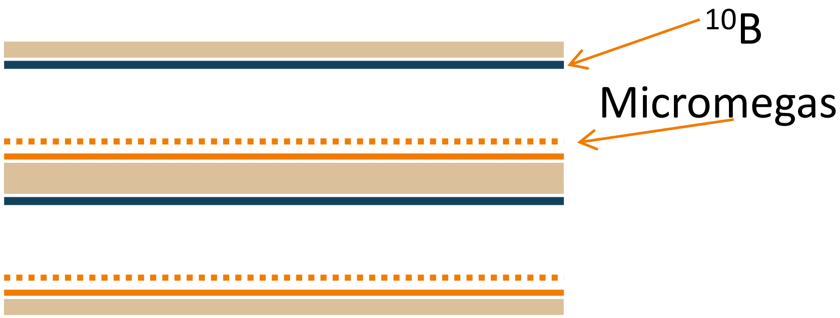
- Micro-Pattern Gaseous Detector (gain, fast timing, high rate, granularity, radiation hardness, simplicity…)
- Low mass budget
- Transparent to neutrons
- Large area detectors cheap & robust

# The multilayer concept

- A boron layer thicker than **1-2 μm** is **not efficient** due to the **absorption** of the reaction products
- Maximum efficiency that can be achieved in this case is of the order of **4-5 %**

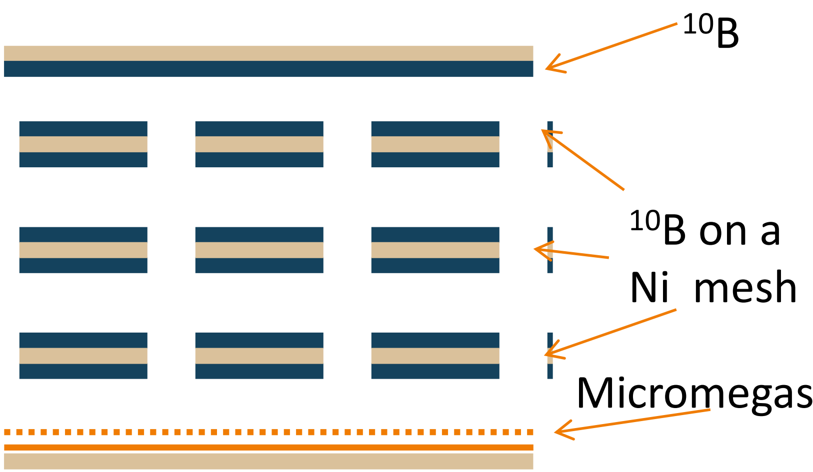



✓ One solution: a tower of detector-converter layers
  - ➔ Many detectors
  - ➔ Lots of material



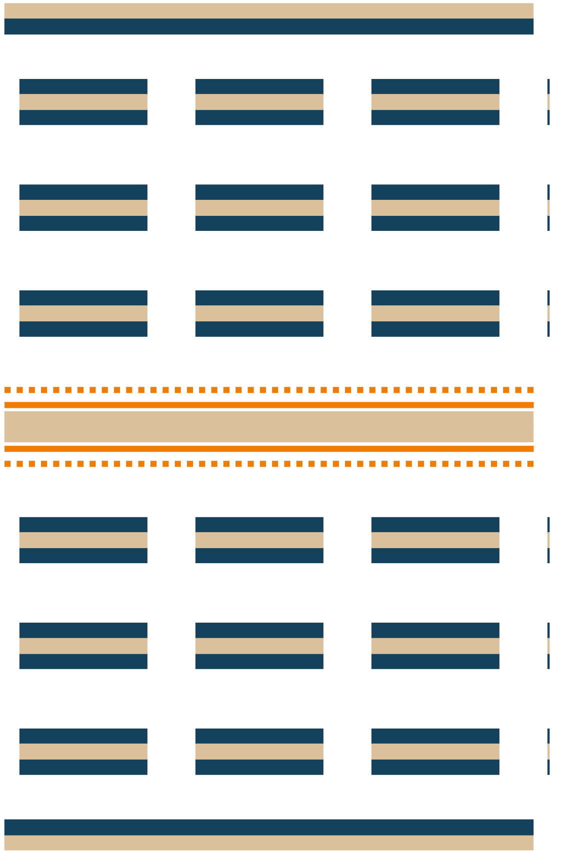

✓ Alternative: a tower of converter layers for each detector: $^{10}B$ deposited on thin metallic meshes
  - ➔ Less electronics
  - ➔ Less material

  Difficulty: drift the produced charges to the detector through the mesh holes (proper configuration of the electric field)



# The multilayer concept

- One module can be consisted of a double-face Micromegas facing 7+7 $^{10}B$ layers
- Such a module can be ~1 cm thick!
- Material:
  - ✓ 0.2 – 0.3 μm PCB
  - ✓ 6 x 5 μm Ni
  - ✓ 2 x micromesh
  - ✓ 2 x 1 mm Aluminum case
- A stuck of such detectors can be used to increase efficiency
- Detector can be tilted by 45$^{o}$ in respect to the neutron direction.

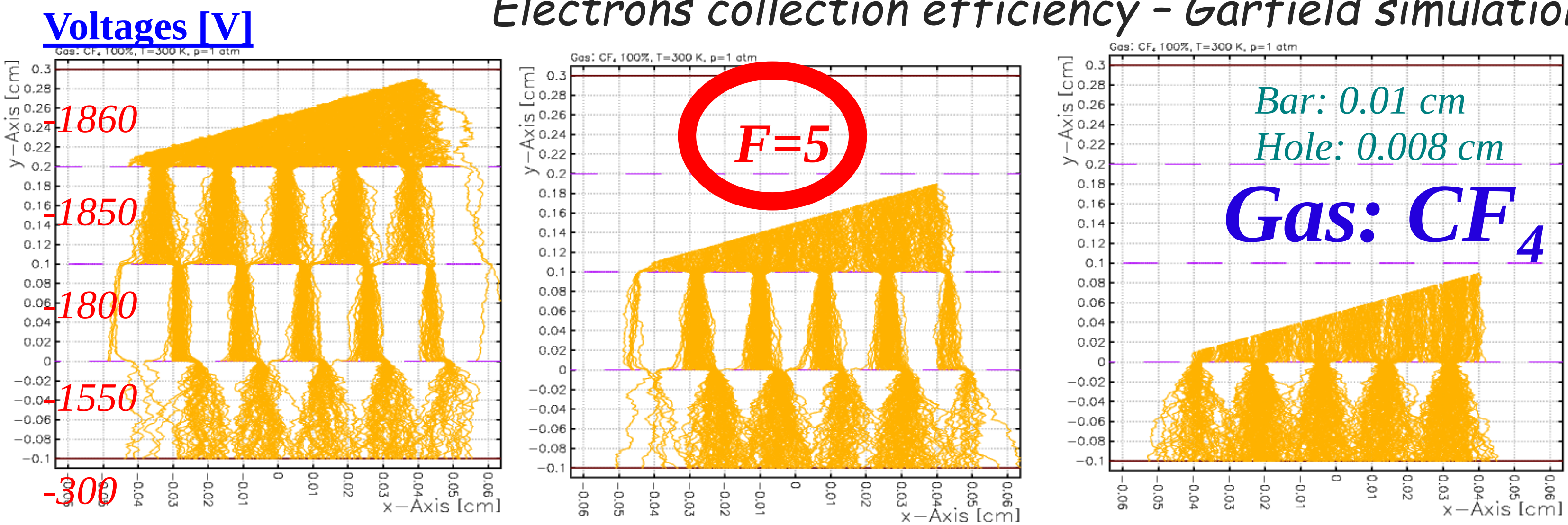


Status:

- *Monte-Carlo studies to optimize the electron transmission & sample thickness*
- *Prototype for performance studies*

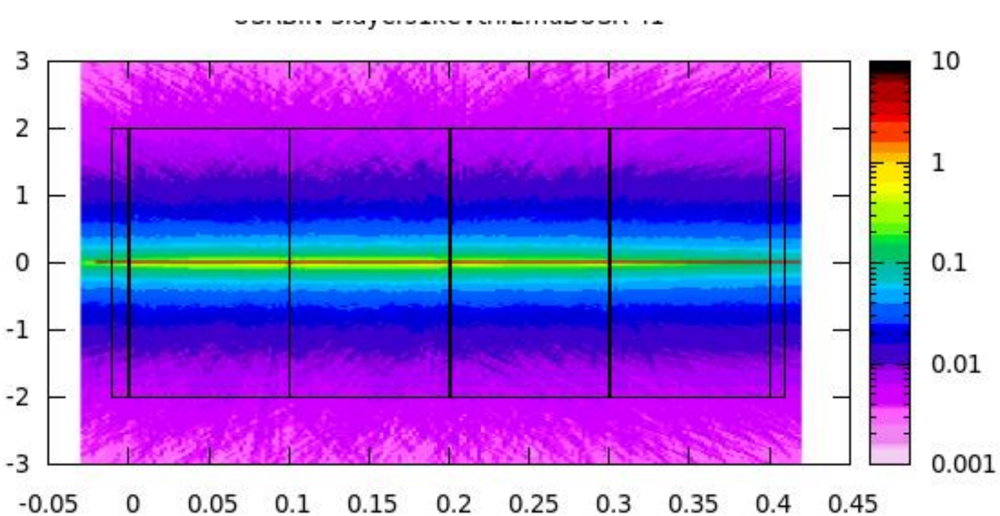
# Simulation of a 7-layer unit

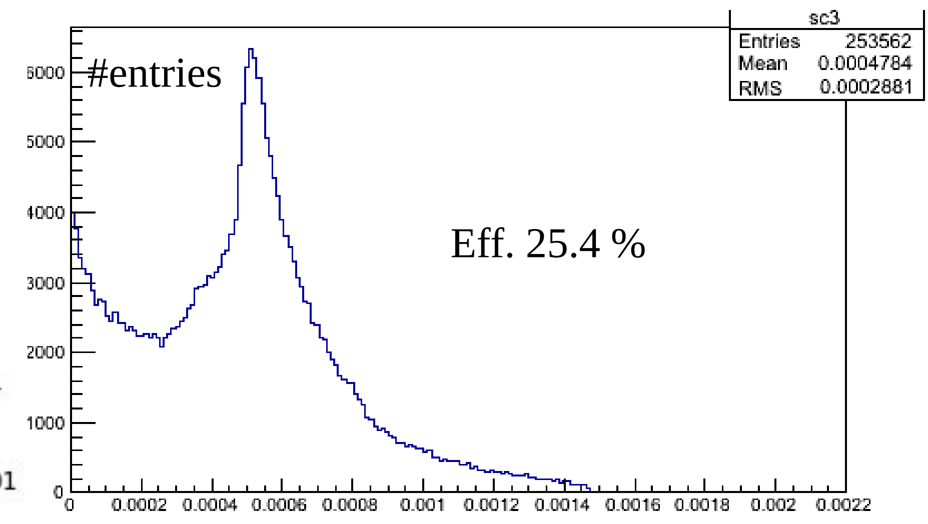
*Electrons collection efficiency – Garfield simulations*




35% 53% 77%

*Perpendicular beam on the Al frame with En = 0.025 eV, Eth = 1 keV, 2µm $B_4C$ – 7 layers, 1E6 primaries*

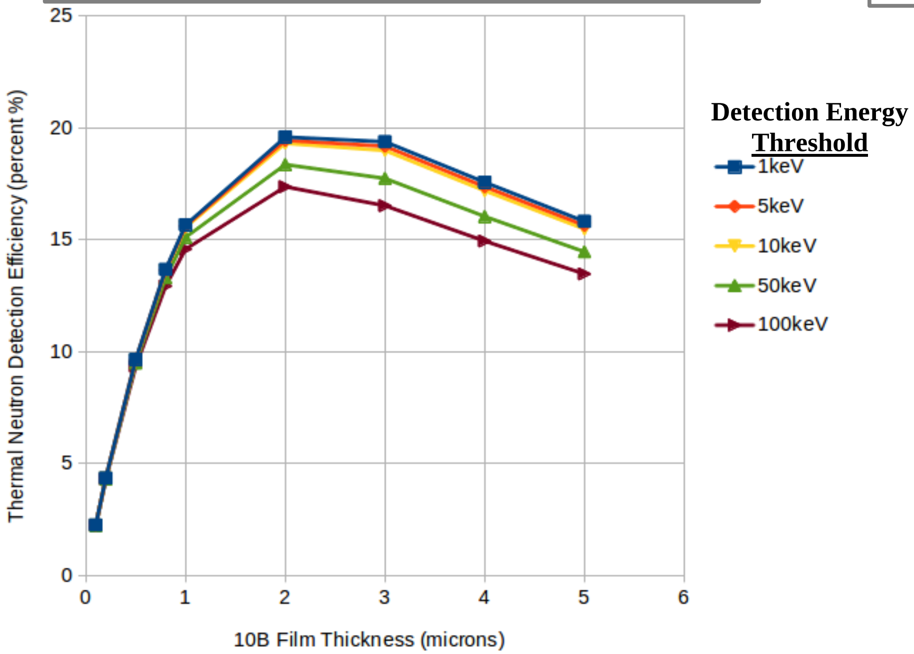




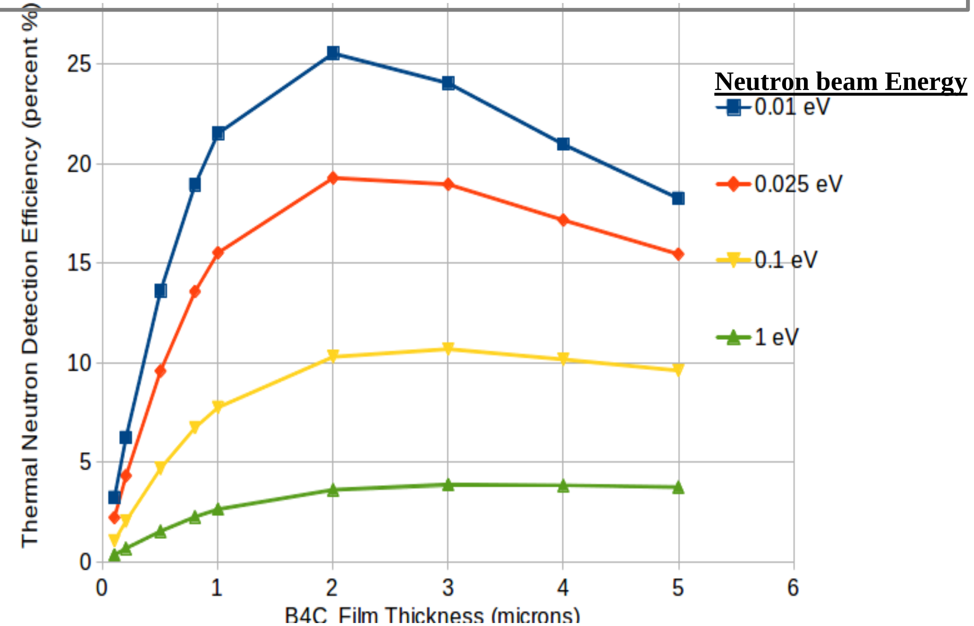
# Efficiency

*1 unit with 5 x $^{10}B_4C$ layers*

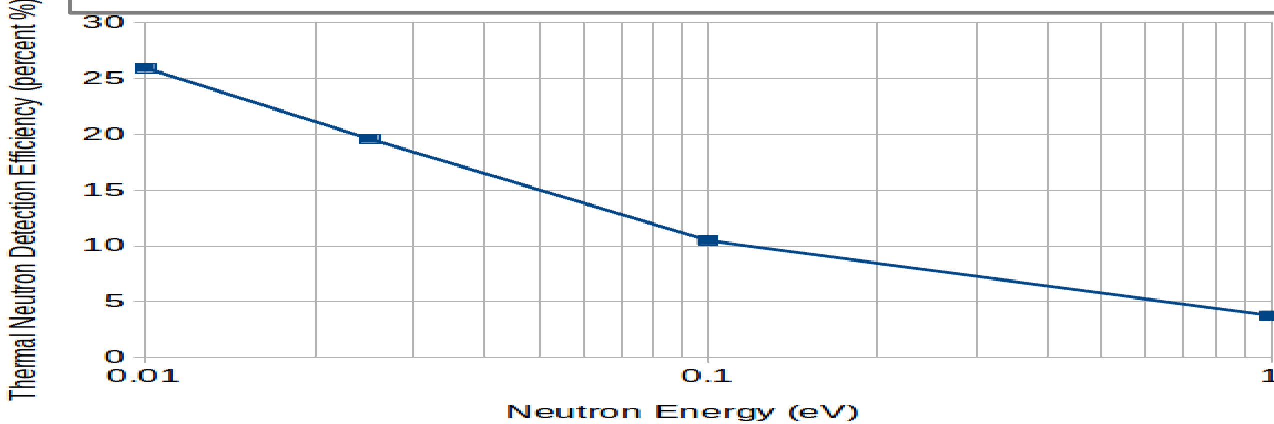
**Thermal Neutron Detection Efficiency for various detection thresholds**



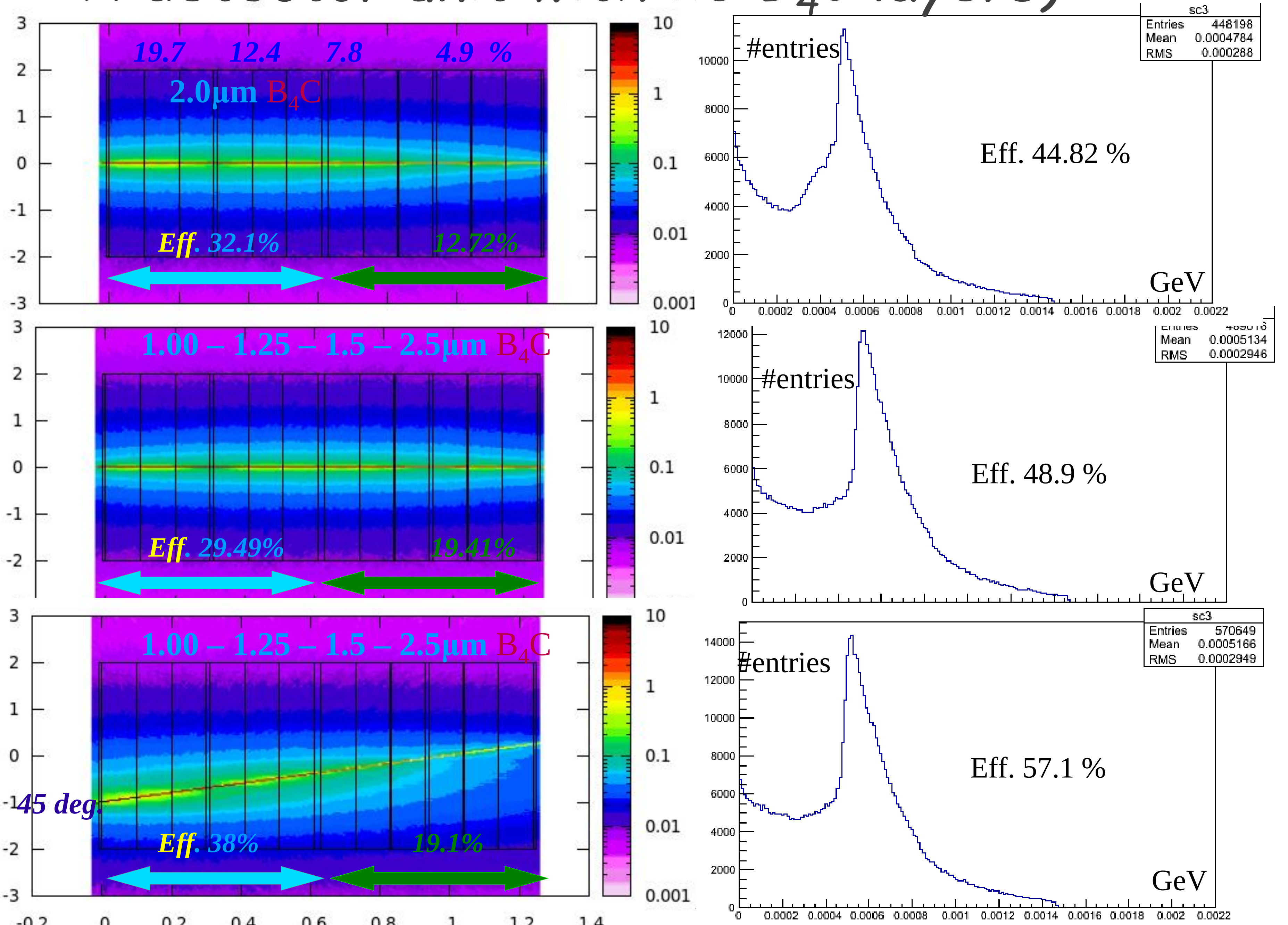

**Neutron Detection Efficiency for various neutron beam energies with detection threshold at 10 keV**




**Thermal Neutron Detection Efficiency for various neutron beam energies with detection threshold at 1 keV and thickness of B4C at 2µm**



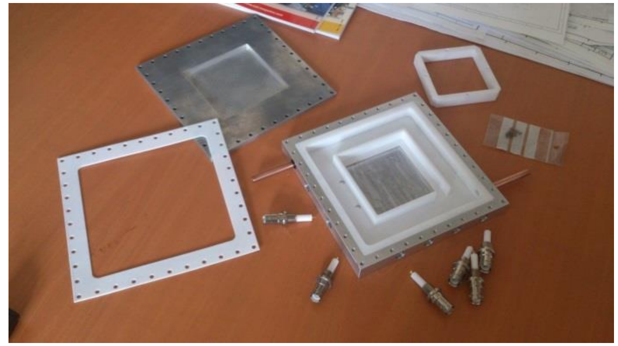
# A detector unit with 20 $B_4C$ layers)

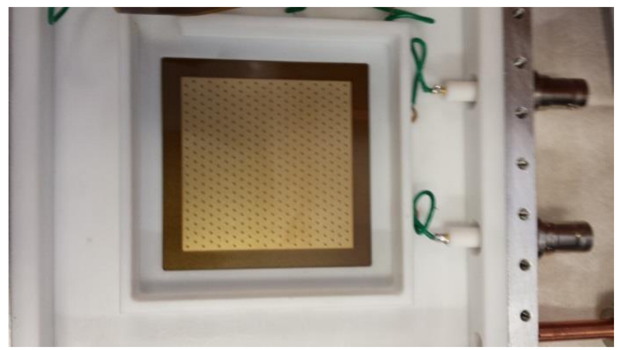


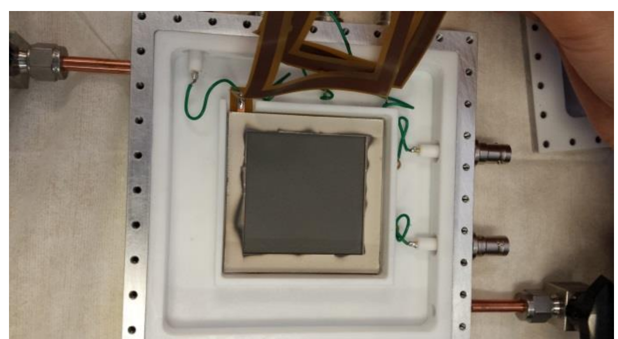
# The Micromegas prototype

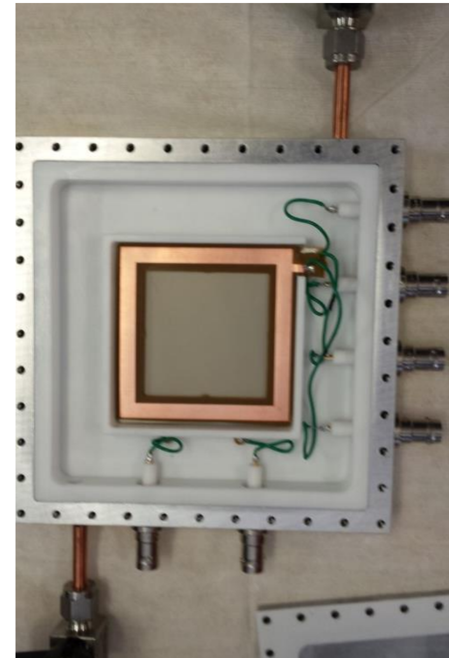
- Bulk Micromegas 5x5 cm$^2$
- Ni frames 7x7 cm$^2$
- Ni meshes 10% & 20% transparent
- Voltages applied with the help of kapton+Cu frames
- *Ni meshes double coated with 1.5 μm $B_4C$ layers*
  - *10% - 20% transparent*
  - *5, 20, 120 μm thick*
  - *50, 100, 500, 1000 LPI*

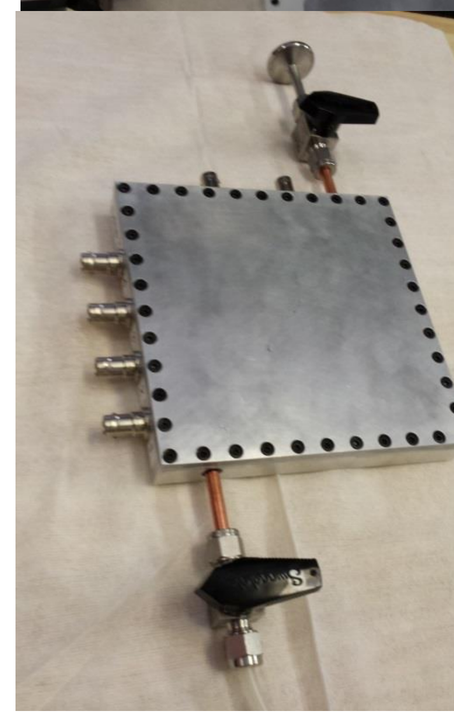
  *(Linköping University)*

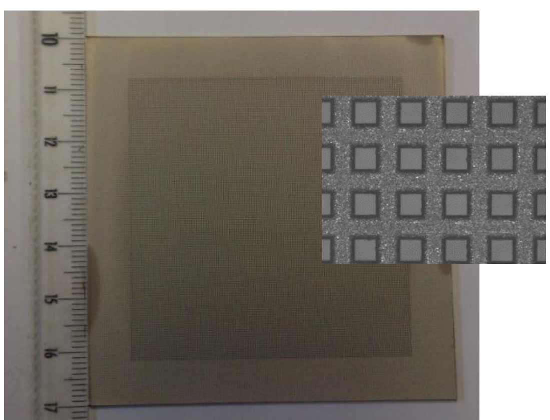












# 5-layer prototype performance

Comparison with commercial ³He tube:

Count rate {³*He / MM*} = 5.5
Assuming ³He eff. ~ 95%
➔ ***MM eff ~ 18%***

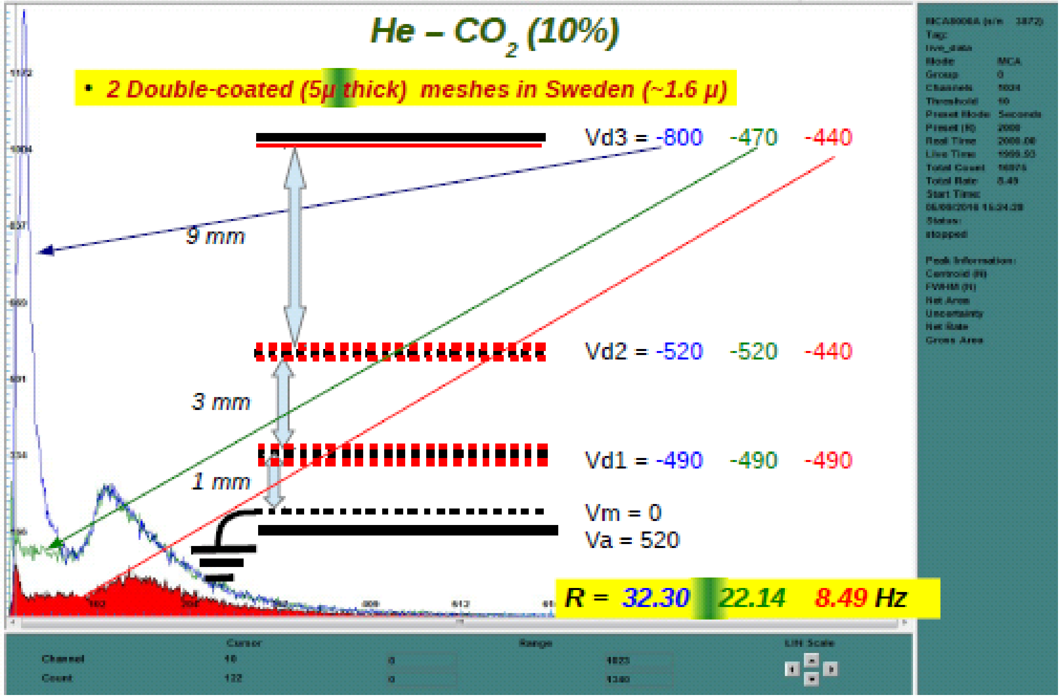
*Satisfactory result*

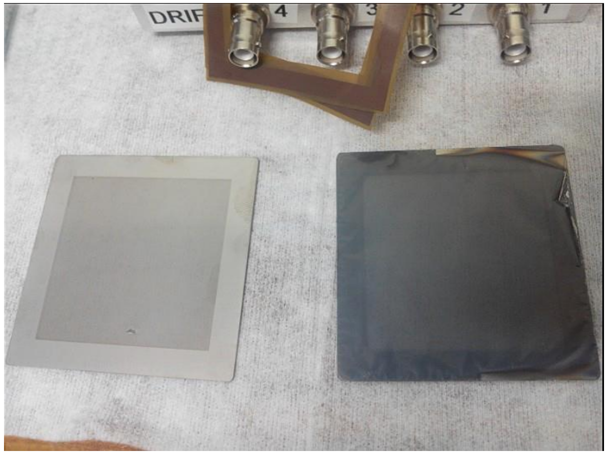
**but:**

- **Electron transmission too low when mesh thickness >> 5 μm**
- **Mesh deformed during $B_4C$ deposition if thickness << 20 μm**

➔ *Difficult to operate with more than 3 layers per unit with large area Ni meshes*

A single 2-mesh detector unit → ***F=7***, 5 x $B_4C$ layers



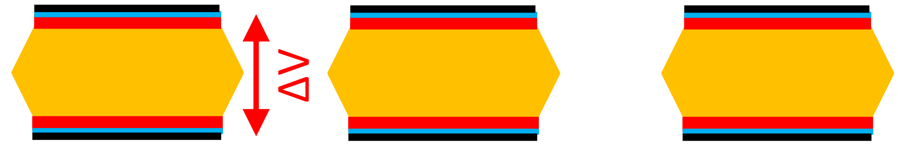



# Alternative 1: Kapton mesh (GEM-type)

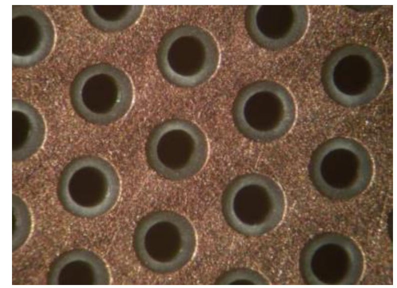
12.5 μm Kapton mesh
- double-side coated with 3-4 μm Cu
- double-side coated with 1 μm Ni
- double-side coated with 1.5 μm $B_4C$

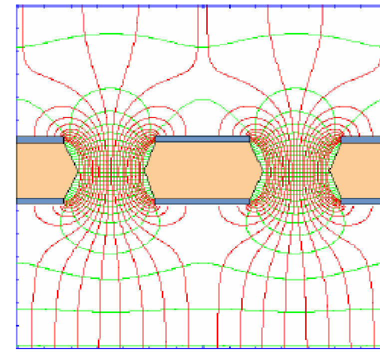
ΔV (10-50 V) applied between the two Cu layers
➔ electric field strong enough for sufficient electron transmission
- ➢ Small voltage for top layer (< 500 V)
- ➢ Small amplification possible to compensate electron losses *(factor 2-3)*

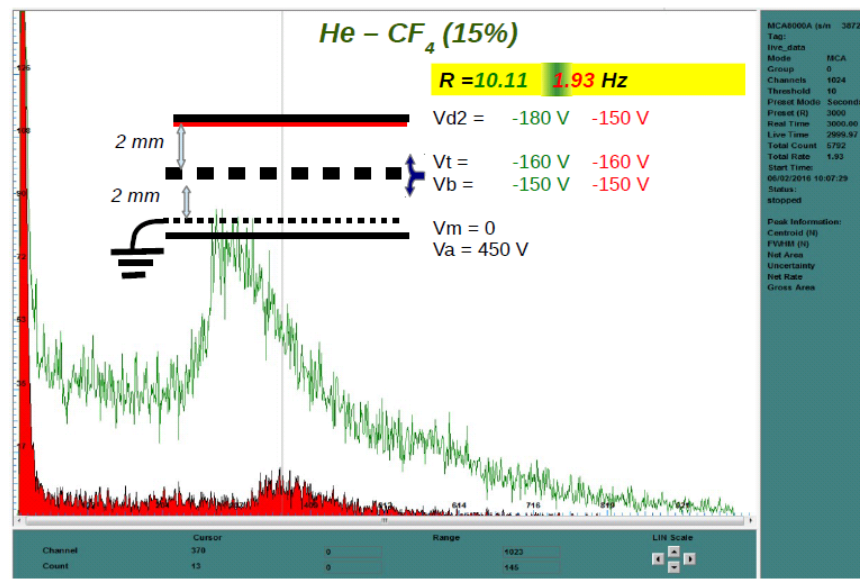
- ✓ **Mesh is cheap and robust**
- ✓ **Big surfaces possible (1×0.5 m²)**




GEM-type kapton mesh







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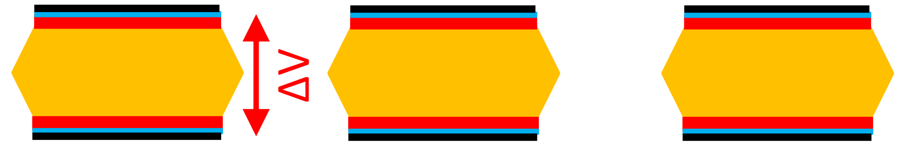


ΔV (10-20 V) applied between the two Cu layers
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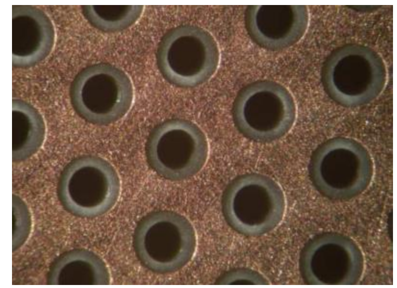
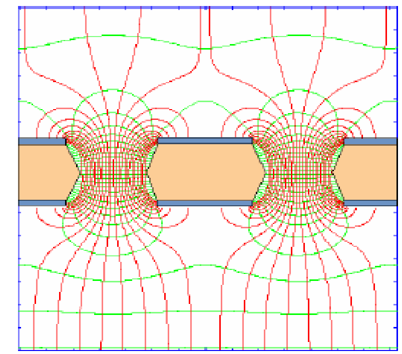
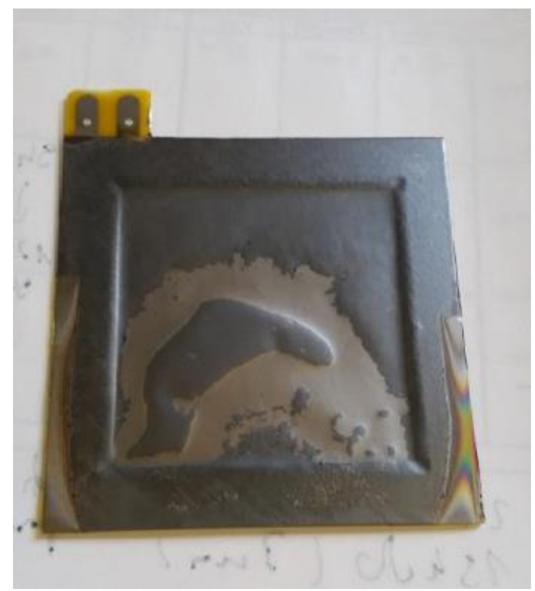
GEM-type kapton mesh





- ✓ **Mesh is cheap and robust**
- ✓ **Big surfaces possible (1×0.5 $m^2$)**

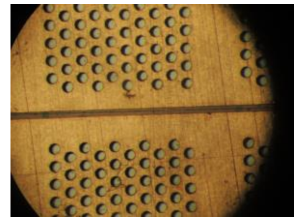
Problem with B4C deposition: thermal expansion.
- ➢ Use pure $^{10}B$
- ➢ Use a transparent mask (micromesh) during deposition of $B_4C$

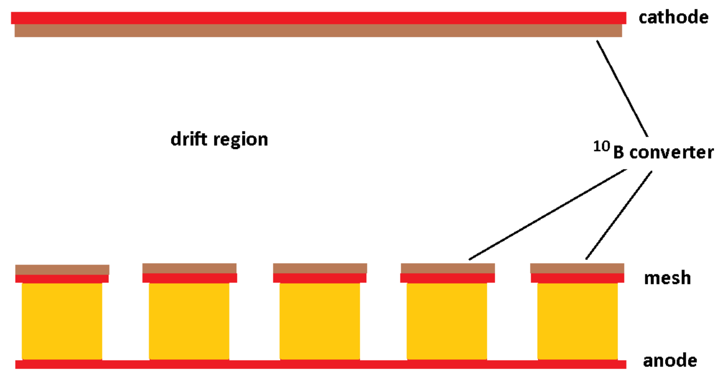


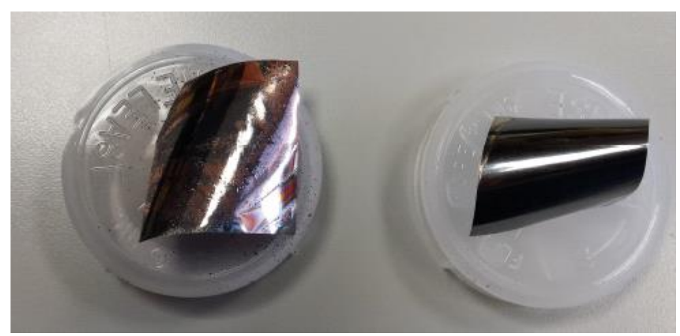
# Alternative 2: Microbulk stack

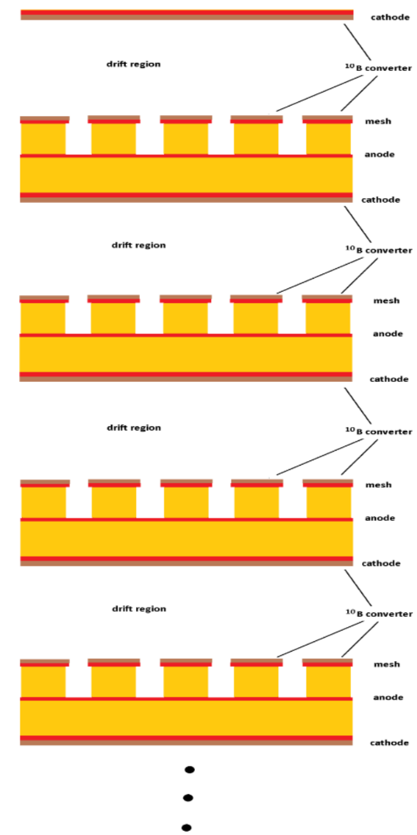
- Microbulk is also a Kapton mesh, Cu-coated.
- Boron can be deposited on the Microbulk surface
  ➔ double efficiency
  - Ni or Au coating needed
  - × Same problem from thermal expansion coefficients
- Units can be stacked without limitation, using only 3 voltages (same cathode, mesh, anode voltages)

✓ Unit can be very thin (~1 mm)
✓ Low material budget
✓ Common / independent readout possible





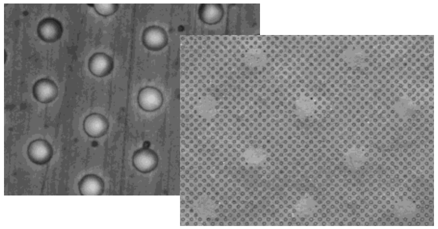
# Summary

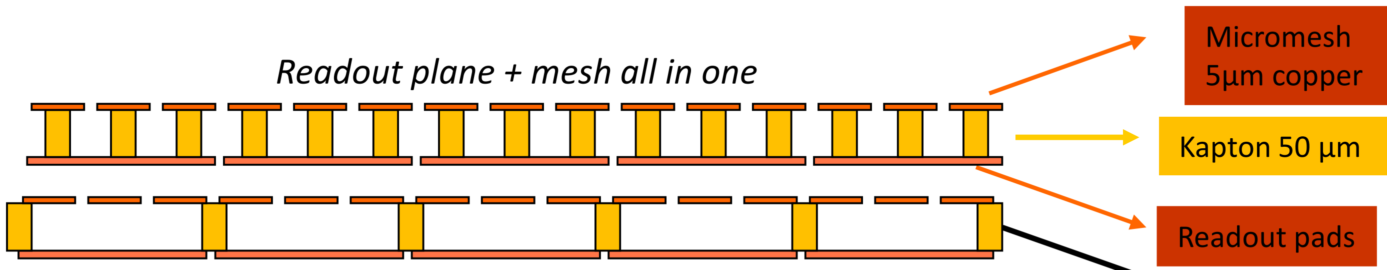
We are examining possible ways to increase the detection efficiency for thermal neutrons, using solid neutron-to-charge convertors:

- A Micromegas equipped with several metallic (Ni) thin meshes coated with $B_4C$ in both sides
  - ✓ Efficiency improvement as expected by the simulations
  - × Small electron transmission for thick (robust) meshes
  - × Deformation & fragility for thin meshes. Problem for large surface detectors
- A Micromegas equipped with GEM-type meshes coated with $B_4C$ in both sides
  - ✓ Good electron transmission. Amplification during transmission easy
  - ✓ Small voltages
  - ✓ Robustness. Large surface detectors possible with low cost
  - × Deposition of B4C on the foil is difficult. Under study
- A stack of Microbulks coated with $B_4C$
  - ✓ Low material, thin detector
  - × Deposition of B4C on the foil is difficult. Under study.

*Thank you!*

# *Microbulk Micromegas technology*






Lower capacitance
Under development

## <u>Microbulk Technology</u>

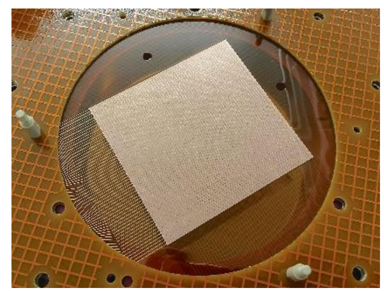
*By I. Giomataris and R. De Oliveira*

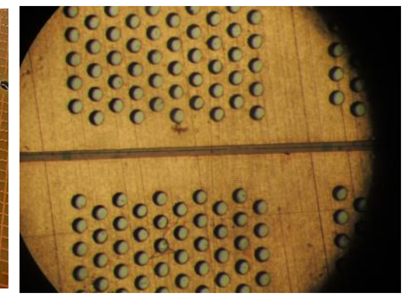
The pillars are constructed by **chemical processing** of a **kapton foil**, on which the mesh and the readout plane are attached. ***Mesh is a mask for the pillars!***

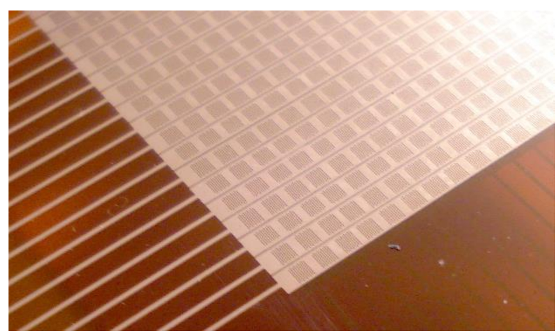
*Typical mesh thickness 5 µm, gap 50/25 µm*

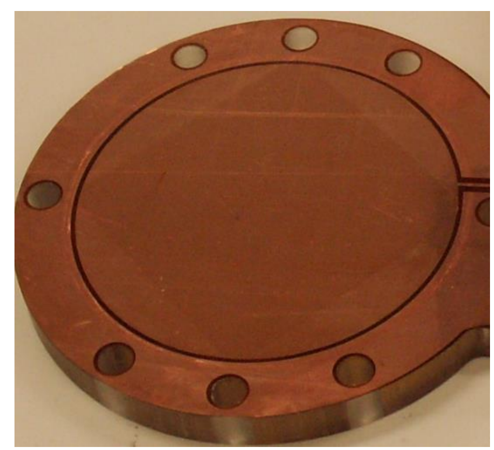
- ✓ **Energy resolution** (down to 10% FWHM @ 6 keV)
- ✓ **Low intrinsic background & better particle recognition**
- ✓ **Low mass detector**
- ✓ **Very flexible structure**
- ✓ **Long termstability**

- × Higher capacity
- × Fabrication process complicated
- × Fragility / mesh can not be replaced









# The "real XY structure"

**Bulk Micromegas are too massive to be in a neutron beam in parallel with x-section measurements**

**X-Y Microbulks are quite massive compared to the single-anode ones**

**A permanent profiler (+flux monitor!) would be useful for n_TOF EAR1 & EAR2, NFS, GELINA**

***RD51 Project*, 15kE for CEA, UniZar & Demokritos:**
**"real" X-Y microbulk by mesh segmenting**

Motivation:

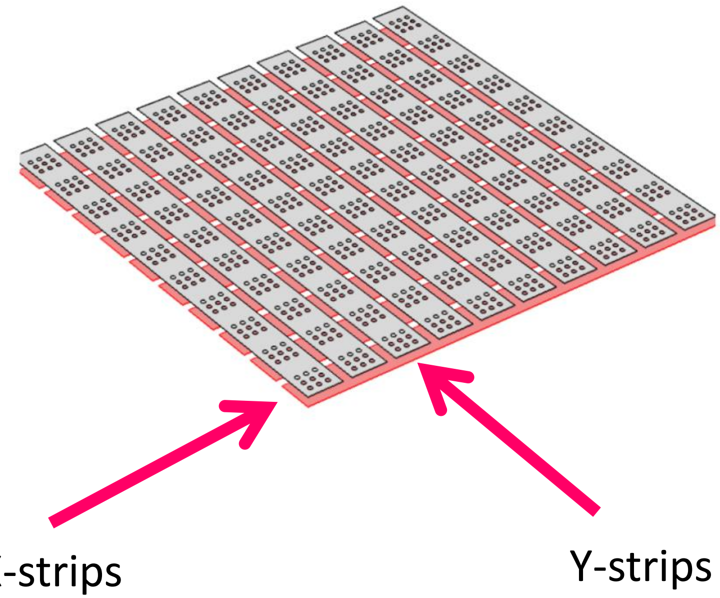
- ✓ Microbulk production simplification
- ✓ Mass minimization
- ✓ Large surfaces with high radiopurity possible

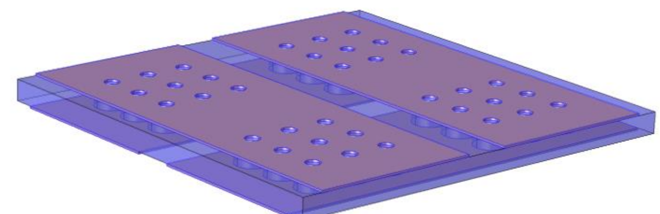
Ideal for:

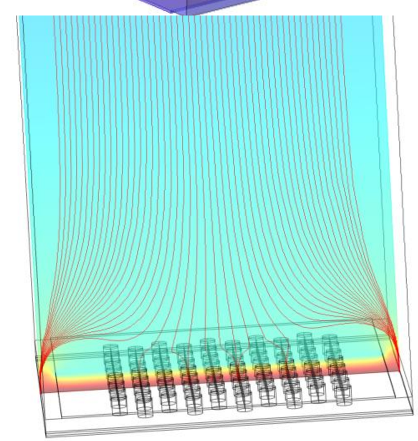
- ➢ Low mass neutron beam profilers/detectors
- ➢ Large area low background detector

Challenges:

- ➢ **No common mesh signal to use as event trigger**.
  The strips information has to be used for that purpose.
- ➢ **Special readout electronics should be used for the mesh strips**
- ➢ Special circuitry for providing the mesh-strips HV should be built.



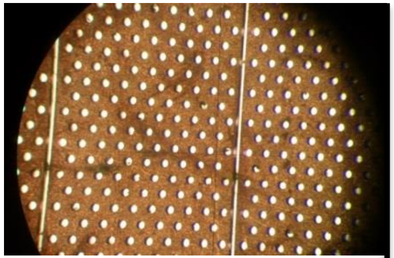





# XY Prototype evolution

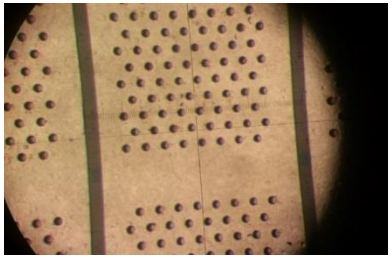
First batch:

- × Problems during etching due to holes topology.
- × Many strips in short circuit.



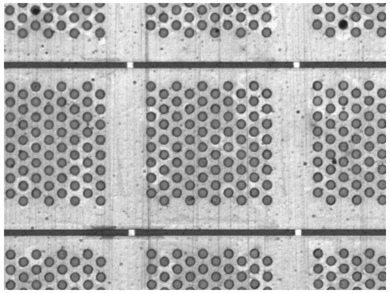
Second batch

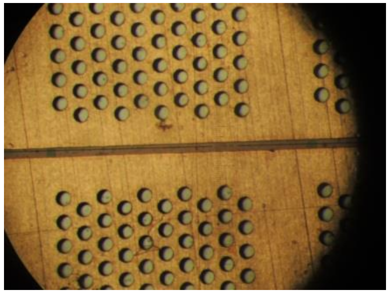
- Etching OK with the new topology
- All detectors working
- × Bad energy resolution due to large gaps (~150 µm)



Third batch

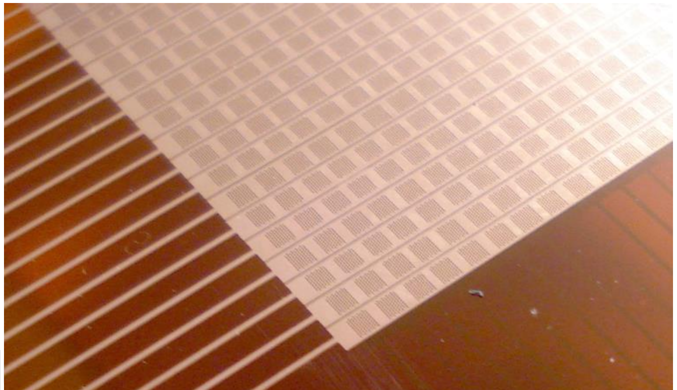
- Holes ∅ 60/50 µm
- Gaps reduced to 35 µm
- Energy resolution OK!

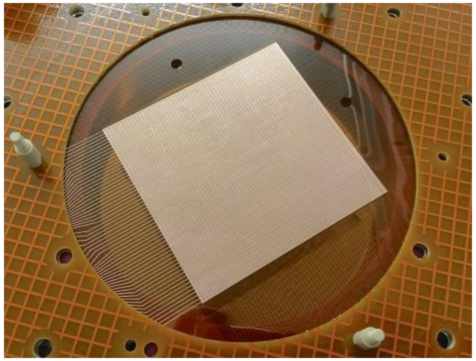


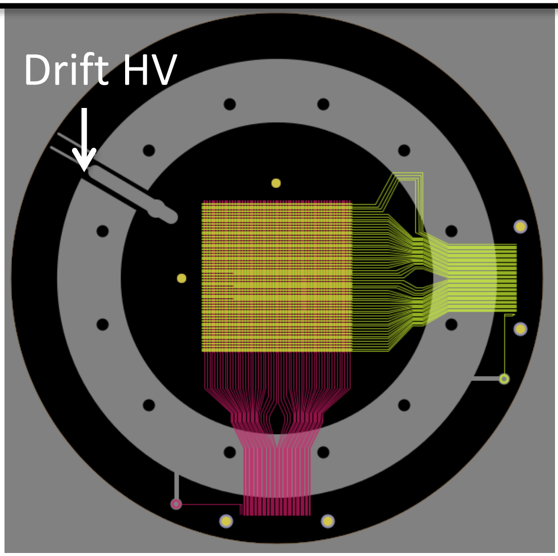


**The first detectors produced:**

- 58 x 59 strips on a 6 x 6cm$^2$ area (**1mm** thickness)
- Mesh hole:~ 60µm / Pitch: 100 µm.







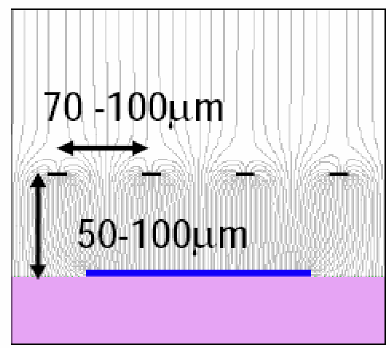
# Micro Pattern Gaseous Detectors (MPGD)

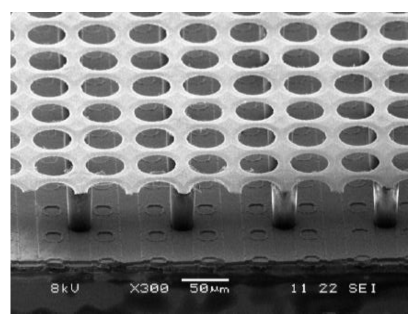
*Best technology for gaseous detector readout:*

## Micro Pattern Gaseous Detectors

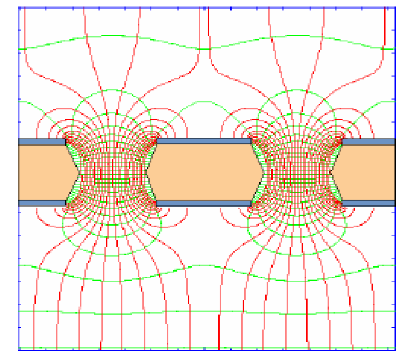
- high granularity
- more robust than wires
- no E×B effect
- fast signal & high gain
- low ion feedback
- better ageing properties
- easier to manufacture
- lower cost
- big surfaces

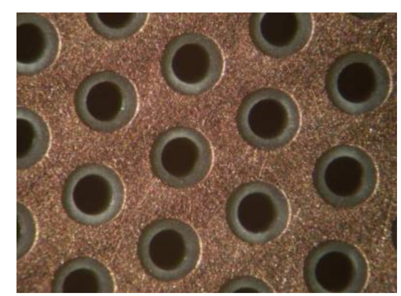
**Micromegas**



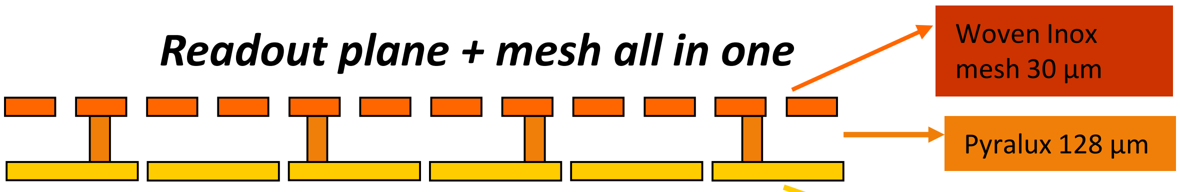

**GEMs**



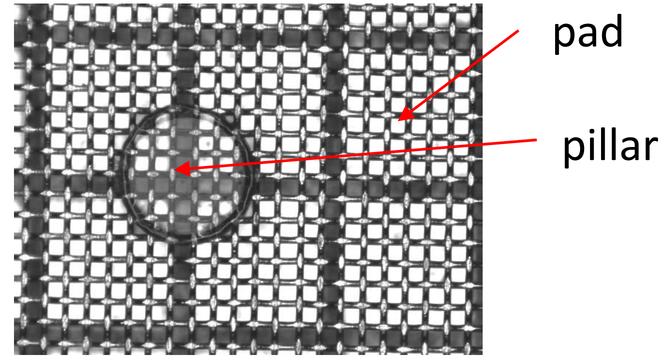


# Bulk Micromegas technology

***Readout plane + mesh all in one***




Well established technique

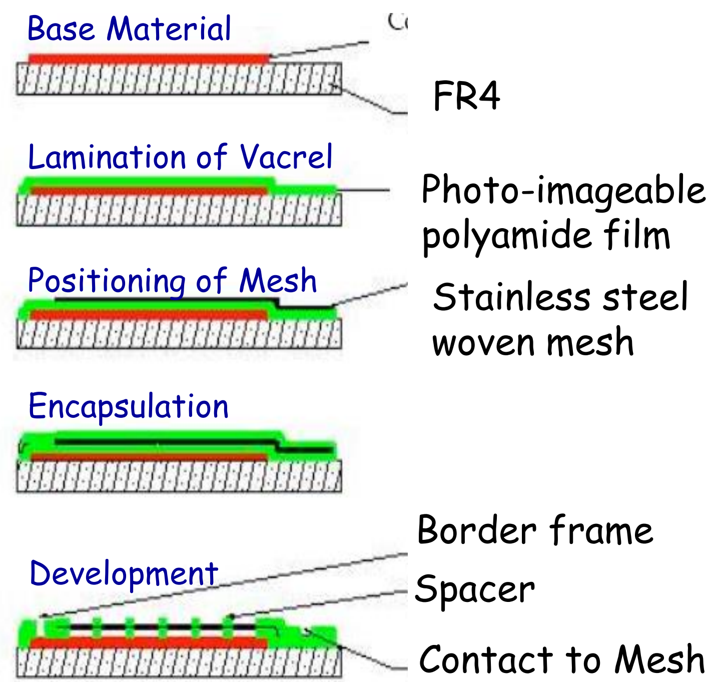



*Result of a CERN-Saclay collaboration (2004)*

**Process to encapsulate the mesh on a PCB (mesh = stretched wires)**

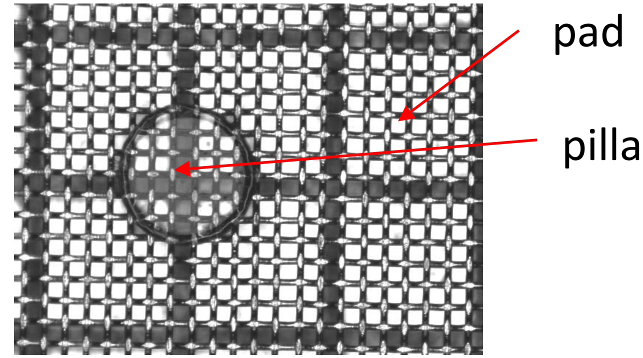
*Motivations for using bulk Micromegas the mesh is held everywhere:*

- *the mesh is held everywhere*
- *robustness (closed to dust)*
- *can be segmented*
- *repairable*
- ***large area detectors feasible and robust!***




I. Giomataris *et.al.*, NIM A560 (2006) 405

# Bulk Micromegas technology

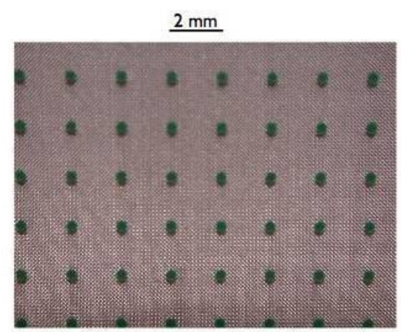


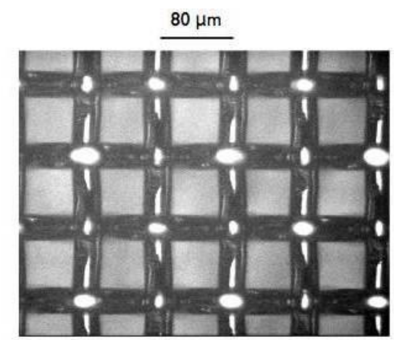

<u>Bulk</u> Micromegas: The pillars are attached to a woven mesh and to the readout plane

*Typical mesh thickness 30 µm, gap 128 µm*

Uniformity, robustness, lower capacity, easy fabrication, no support frame, small surrounding dead region ➔

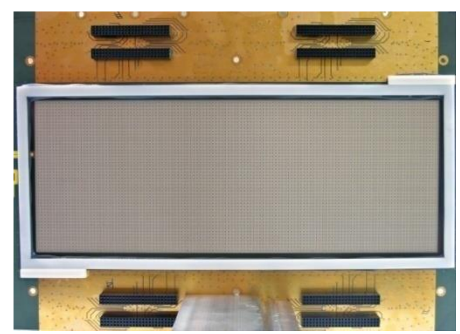
- ✓ **Large area detectors feasible and robust!**
- ✓ **Curved surfaces**
- ✓ Mass production!



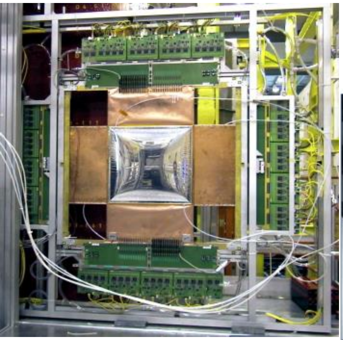



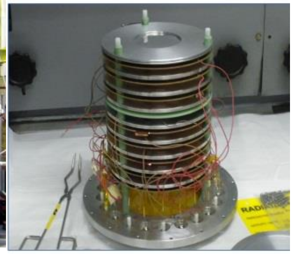

*Mesh thickness & bigger gap: some disadvantages in special applications*:

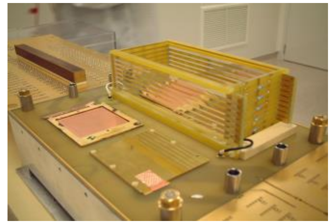
- ✗ Good but limited energy resolution (~18% @ 6keV)
- ✗ Restrictions on materials

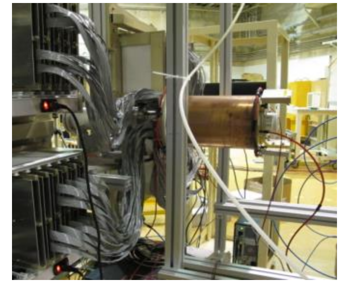


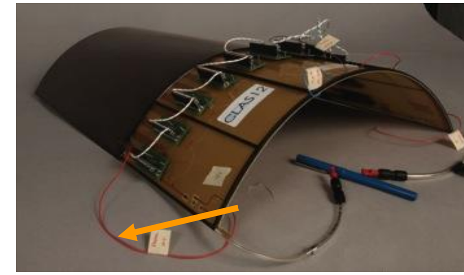
# Micromegas applications









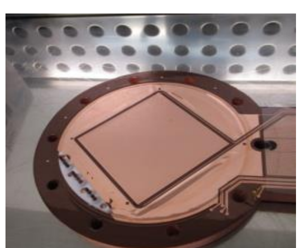


COMPASS NTOF KABES/NA48 MINOS CLAS12

1996 2000 2001 2003 2009 2014 2015 2018

Micromegas Invention

CAST



T2K

ATLAS-NSW