Service d’Electronique, Détecteurs, et Informatique (Irfu/SEDI)
Laboratoire Léon Brillouin (Iramis/LLB)

Neutron detectors based on the MICRO-Mesh Gaseous Structure (MICROMEGAS)

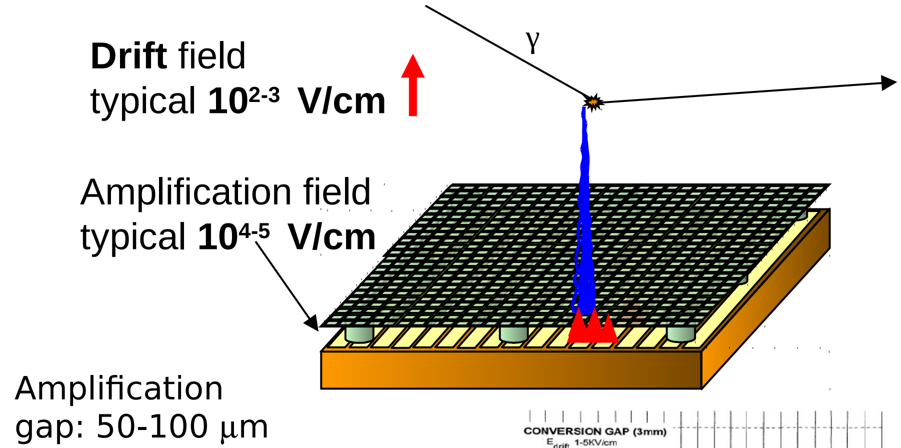
*A.Menelle (CEA/LLB), G.Tsiledakis, A.Delbart ,
D.Desforge, Y.Giomataris, T.Papaevangelou, A.Peyaud
(CEA/DSM-IRFU)*

Micromegas concept

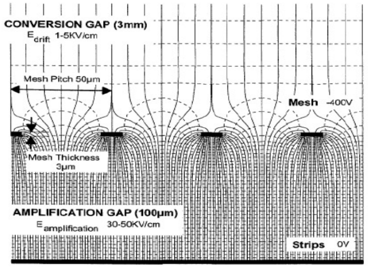
Two-region gaseous detector *separated by a Micromesh* :

- 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 field

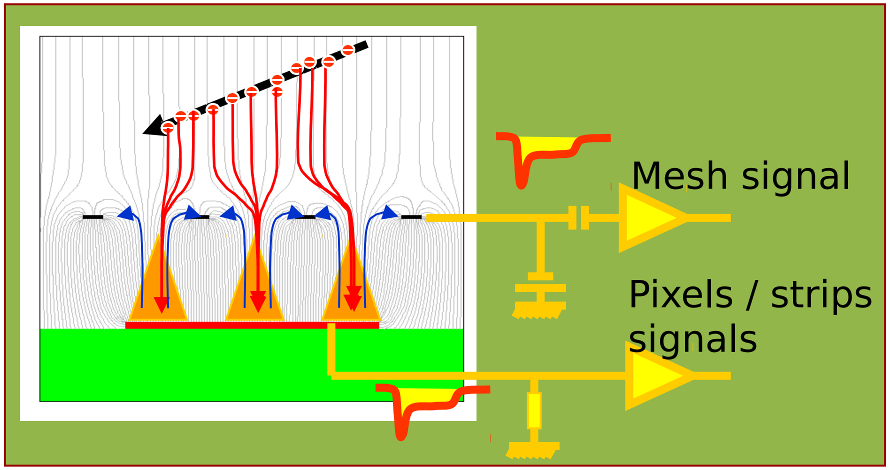


MICROMEsh GAseous Structure
Giomataris, Charpak (1996)
Y. Giomataris *et al.*, NIM A 376 (1996) 29



In 1st Micromegas
Fishing line spacers have been used

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

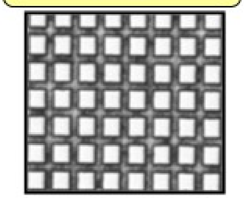


MICROMEGAS description + technologies (i)

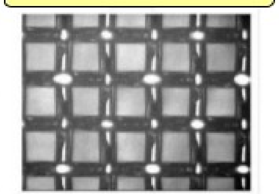
Micro-mesh (cathode)

The metallic micro-mesh must be 5 to 30 μm 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. New products are needed for high LPI thin meshes.

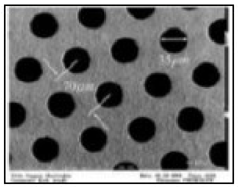
500 LPI Electroformed Ni mesh



500 LPI 304Lwoven mesh



Chemically etched Copper mesh



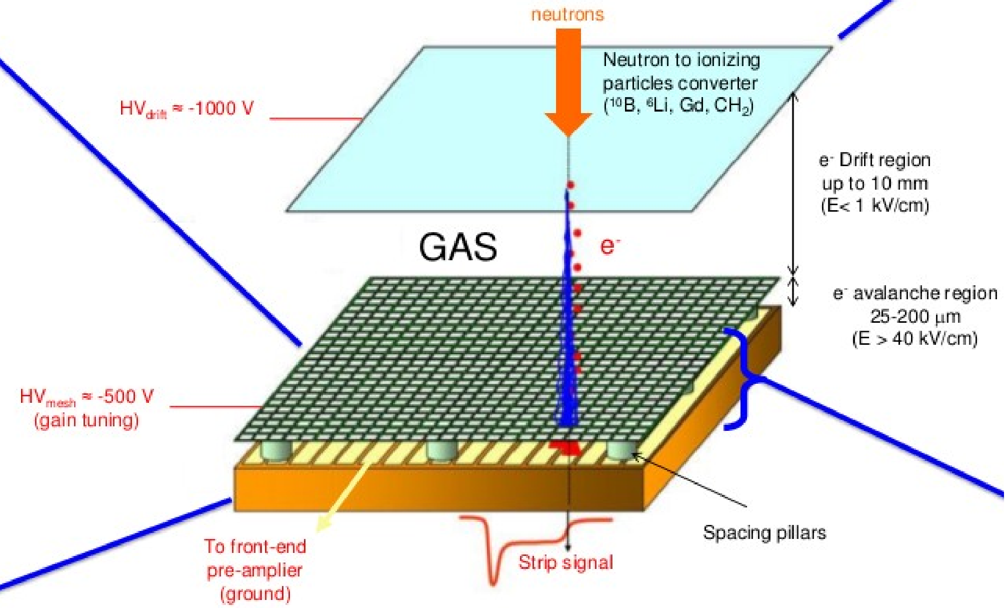
Printed Circuit Board (anode PCB)

- ✓ It can be up to 1- 3 m² 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 μm) with a « smooth » surface.

A Φ30 cm 12 layers PCB with 4000 x 4 mm² pads for the MINOS TPC (18000 blind vias)

Patented technology (CEA – EOS imaging)
G. Charpak, Y. Giomataris, Ph. Rebourgeard, J-P Robert
Y. Giomataris *et al.*, NIM A 376 (1996) 29

MICROMEGAS is a parallel plate gaseous structure which uses a thin metallic micromesh to define the high electric field region in which primary electrons are amplified by avalanche and collected on a micro-segmented Printed Circuit Board



Performances

- ✓ Intrinsic low sensitivity to γ photons (gas)
- ✓ High spatial resolution (down to 100 μm)
- ✓ Fast signals (< 1 ns)
- ✓ Short recovery time (~150 ns)
- ✓ High rate capabilities (> MHz)
- ✓ High gain (up to 10^6)

MICROMEGAS description + technologies (ii)

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G. Charpak, Y. Giomataris, Ph. Rebourgeard, J-P Robert
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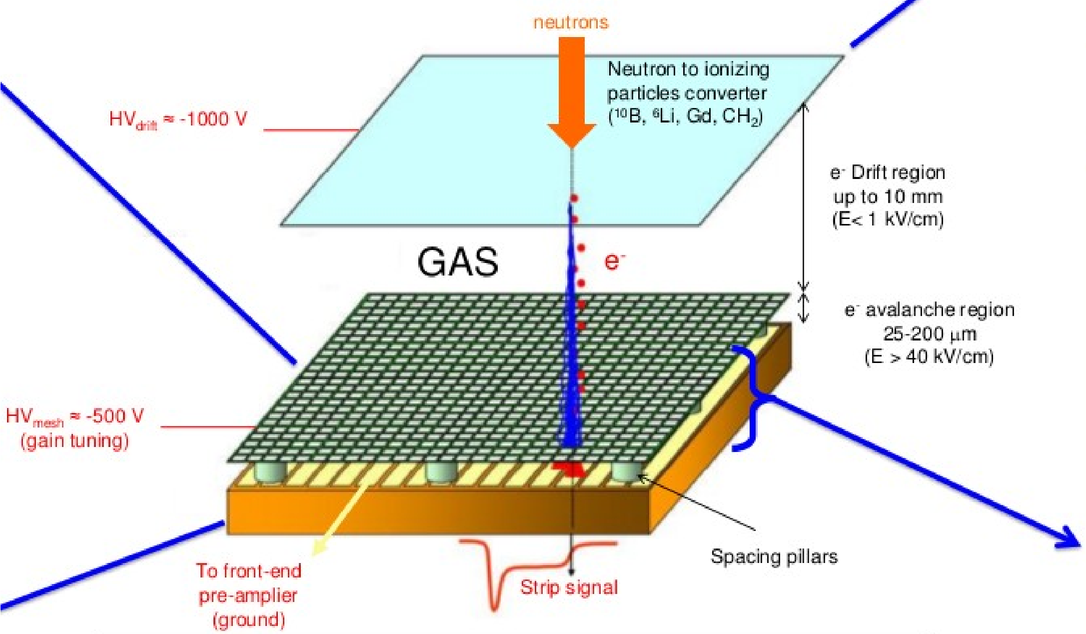

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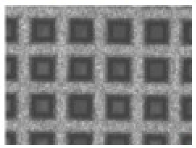
Drift electrode + neutron converter

- ✓ For **thermal neutrons**, it can be a thin aluminum foil or a metallic mesh covered by a 1-2 μm thick layer containing ^{10}B (such as B_4C) or by a ≈100 μm thick ^{6}Li layer.

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



Low cost industriallized processes needed

- ✓ For **high energy neutrons**, a few mm thick polyethylene (CH_2) sheet is used.

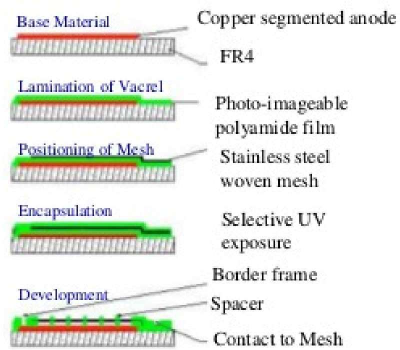
Micromegas technologies

to realize the micro-mesh + anode PCB assembly

Bulk-micromegas

On-going technology transfer

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

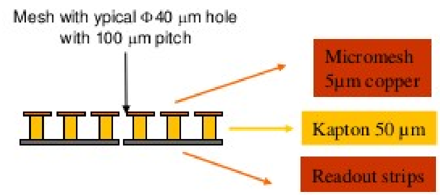


A 34x36 cm² bulk-micromegas (T2K/TPC)

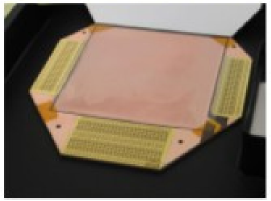
micro-bulk micromegas

Technology transfer to be done

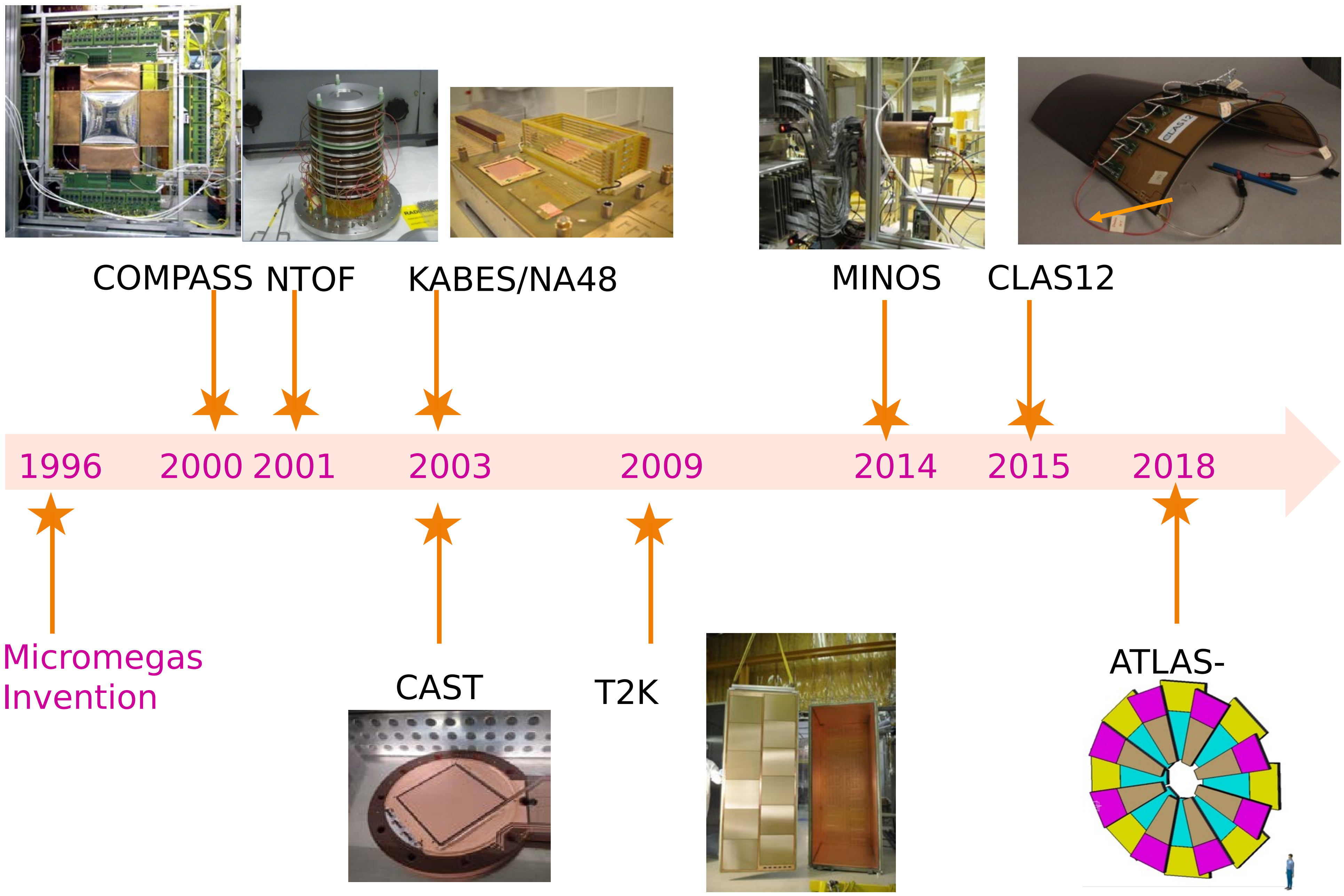
Micromegas is built from a double sidded copper clad kapton foil by selective chemical etching of copper (mesh and anode strips) and kapton (insulating pillars).



A 10x10 cm² micro-bulk (NEXT prototype)



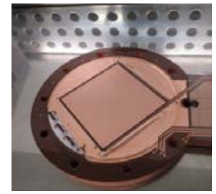
Micromegas applications

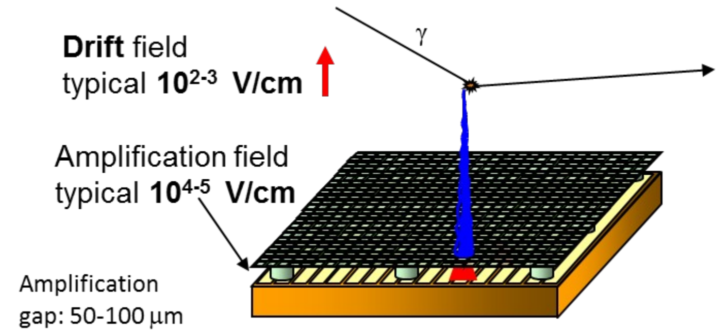


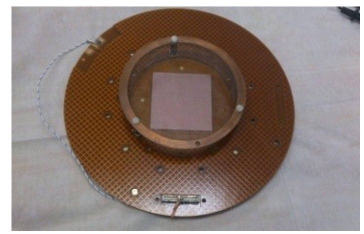
Micromegas R&D

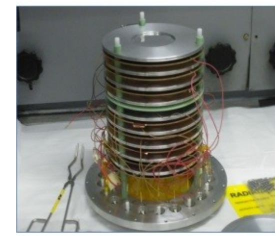
Experiments @ CERNs: New detectors & Continuous improvement

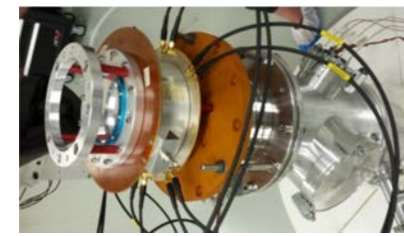
- CAST
  - Microbulk development
- nTOF
  - Microbulks for flux measurements
  - Microbulks for fission measurements
  - XY-Microbulk





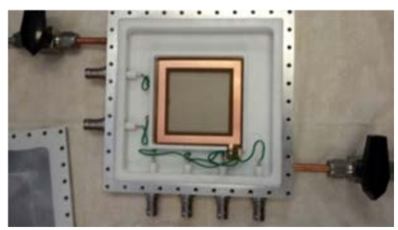


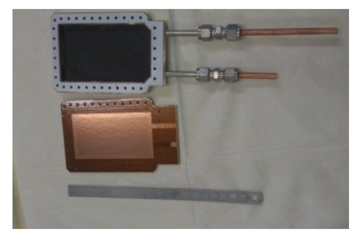




R&D for other projects

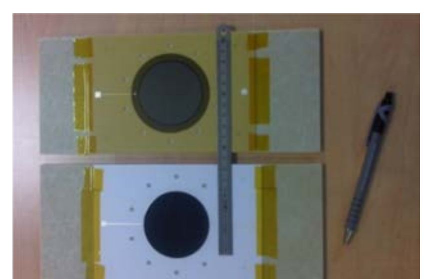
- NMI3
- Schlumberger
- Picosecond

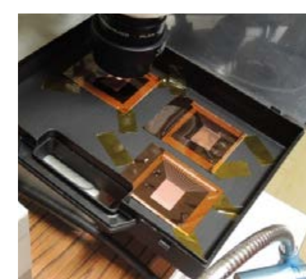




Detector technology R&D

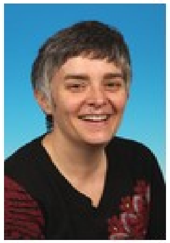
- Piggyback
- Thin mesh
- Kapton mesh
- XY-Microbulk
- Small gap Microbulk
- Resistive Micromegas





Micromegas R&D

People involved at SEDI



eferrer

Esther FERRER-RIBAS

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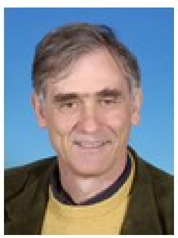
Service d'Electronique, des

- Chef de laboratoire
- Chef de projet
- Membre du CSTS



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Ioannis GIOMATARIS

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- Chef de projet
- Responsable scientifique

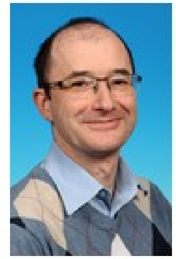
attie

David ATTIE

DSM//IRFU/SEDI/DEPHYS

Service d'Electronique, des [

- Chef de projet
- Membre du CU du service
- Membre du CSTS



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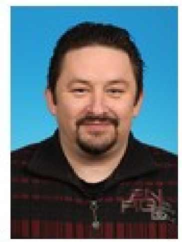
Alain DELBART

DSM//IRFU/SEDI/DePhys

Service d'Electronique, des

- Chef de projet
- Membre du CSTS



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Thomas PAPAEVANGELOU

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aunes

Stephan AUNE

DSM//IRFU/SEDI/DIR

Service d'Electronique,

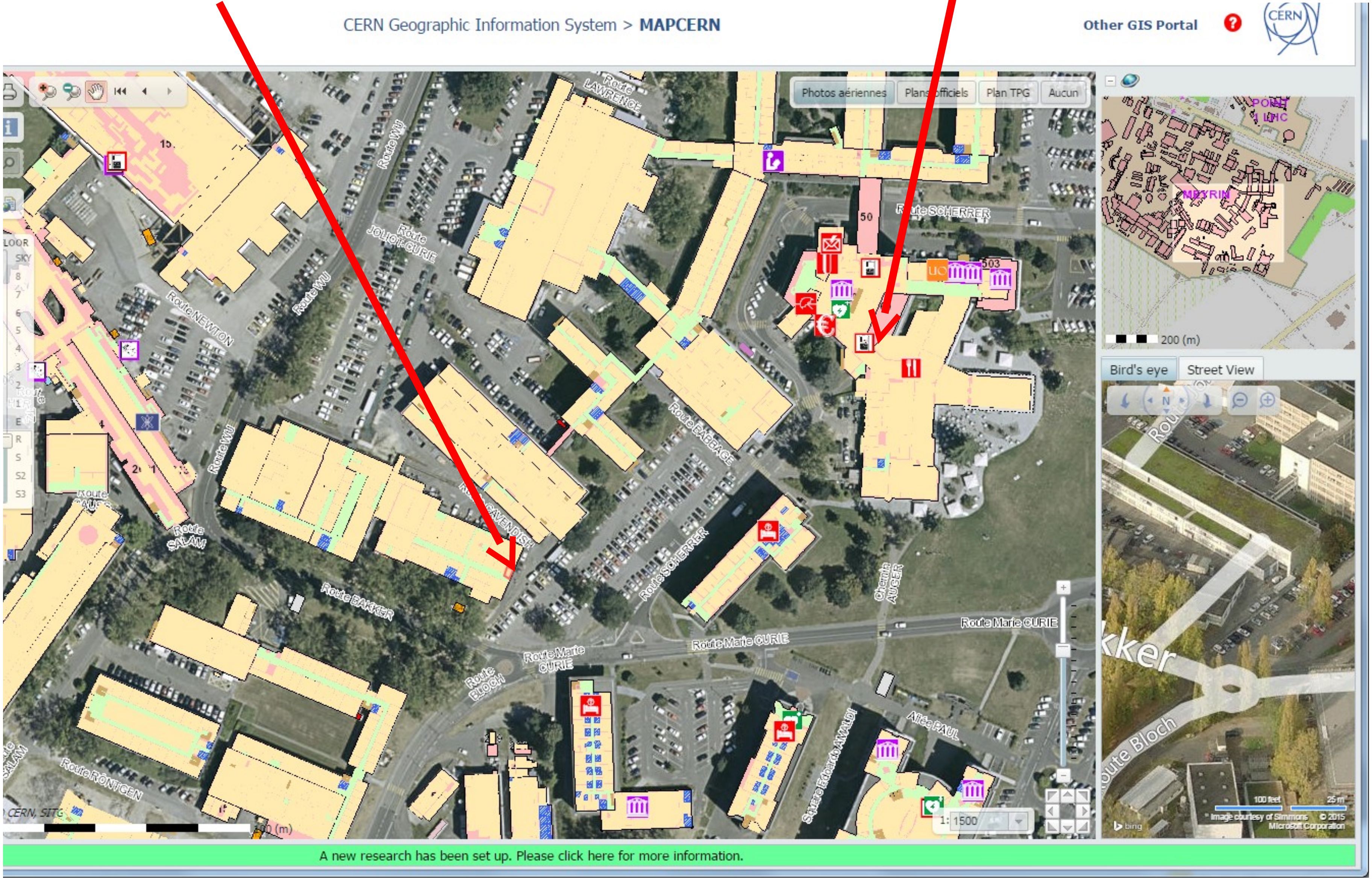
- Chef de projet

+ Fabian Jeanneau, Alan Peyaud, George Tsiledakis, Paul Serrano, Mariam Kebbiri…

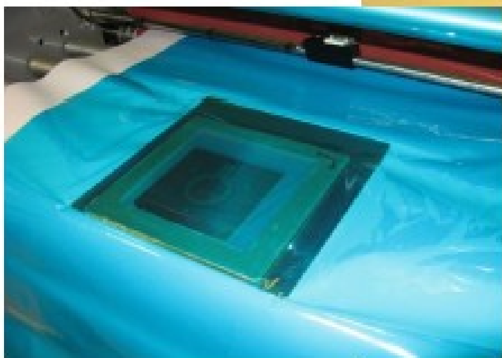
Micromegas R&D

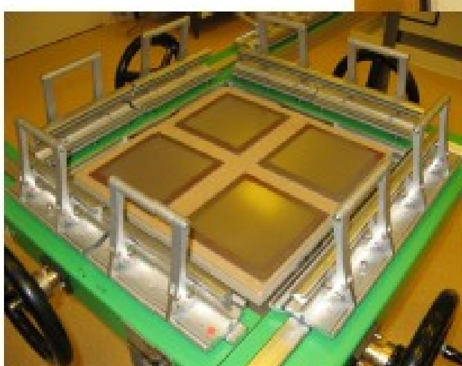
Close collaboration with the detector Lab of **De Oliveira, Rui** PH-DT-DD 102/R-018
tel: 73745 163931 (Rui.de.Oliveira@cern.ch)

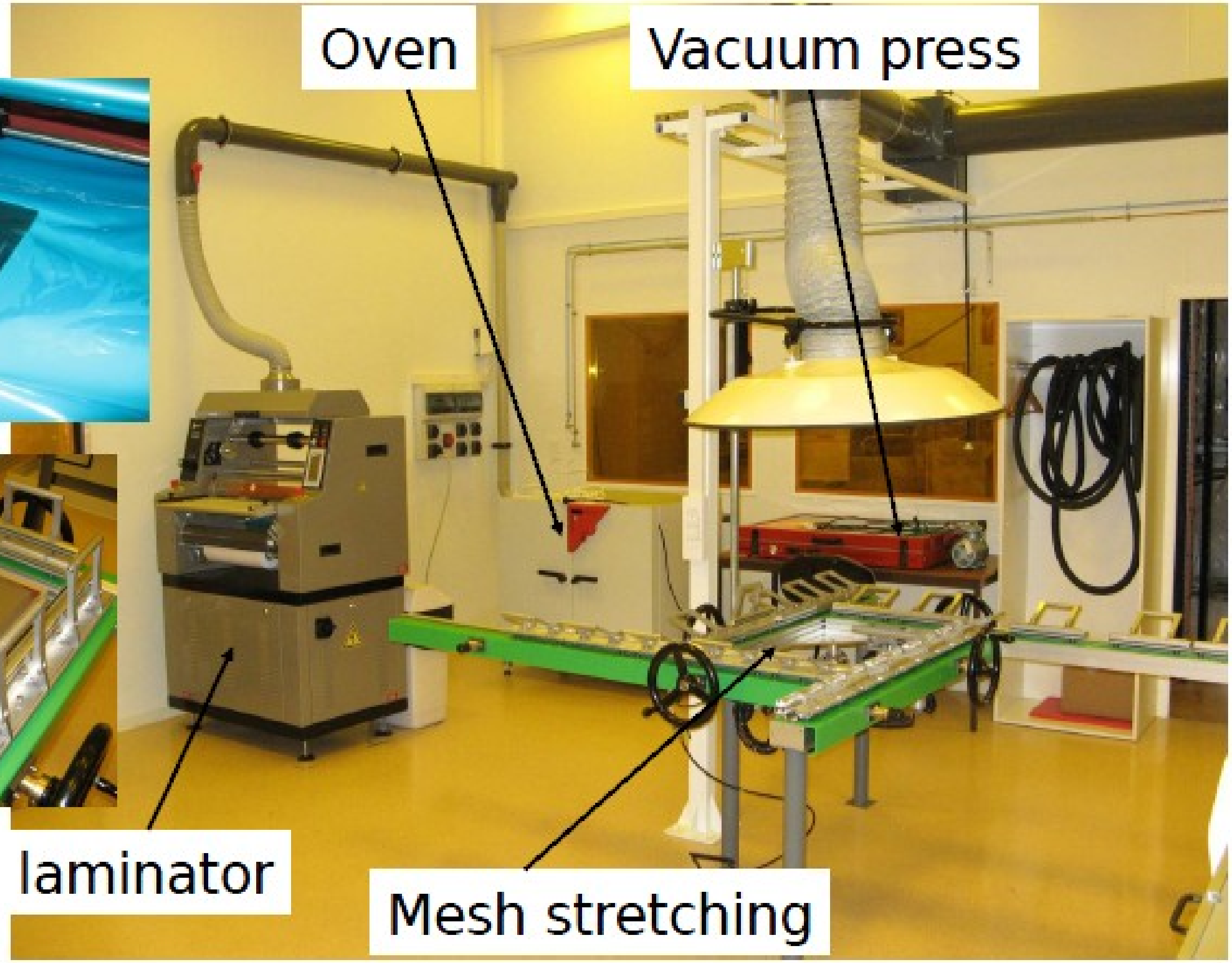
Main building – R1



The bulk lab @ SEDI, CEA Saclay







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

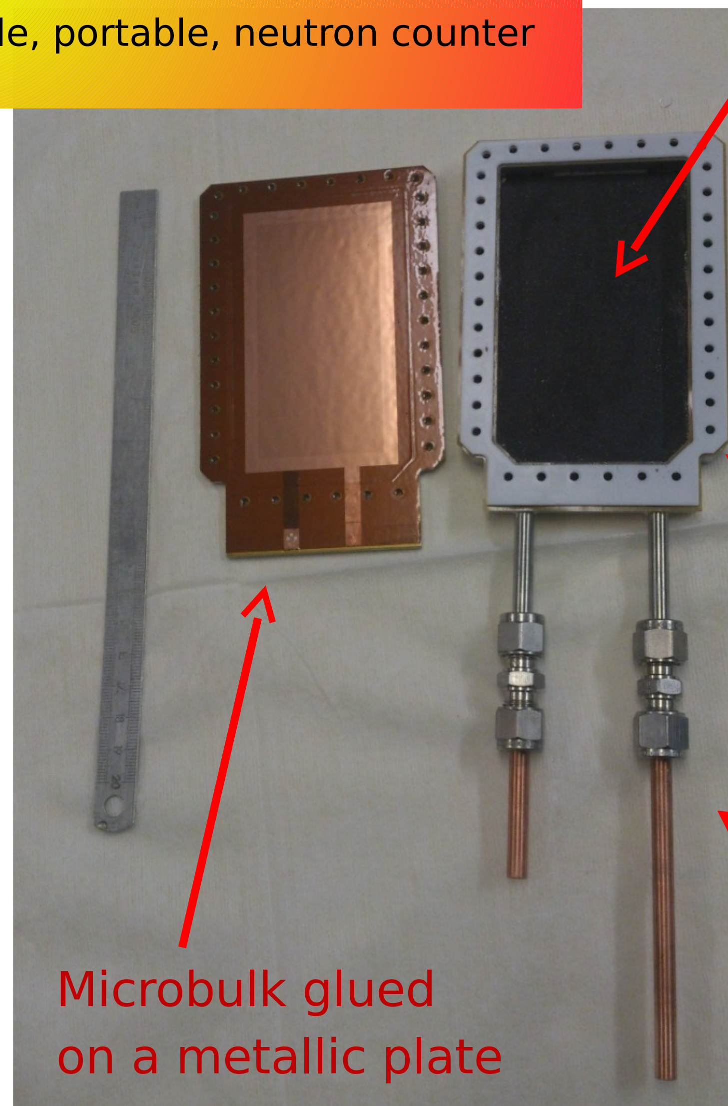
- Micro-Pattern Gaseous Detector (gain, fast timing, high rate, granularity, radiation hardness, simplicity…)
- Low mass budget
- Transparent to neutrons
- Large area detectors cheap & robust

Ingredients to build a simple counter

Gained lots of experience in Boron deposition

- Simple method with B powder @ SEDI (PatricK Magnier)
- Electrodeposition, Sputtering @ DRT (Ph. Bergonzo Lab)
- Collaboration with DRT & Linkoping University

Detector very interesting as a simple, portable, neutron counter for several facilities (i.e. LICORNE)



^{10}B layer (thick!) deposited on the inner part of the chamber

The ^{10}B layer is the less trivial part to build

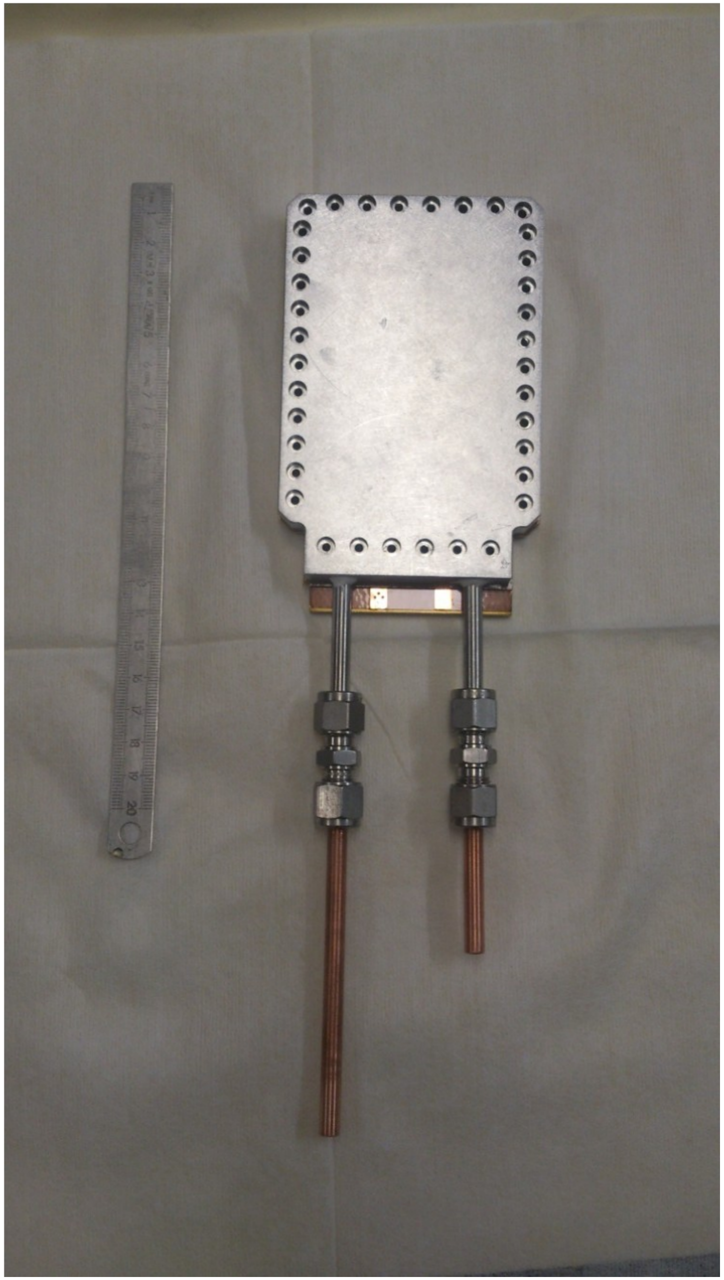
- Material availability
- Deposition methode
  - ✓ Sputtering
  - ✓ Evaporation
  - ✓ Electrodeposition
  - ✓ …

Teflon / kapton joint

Microbulk glued on a metallic plate

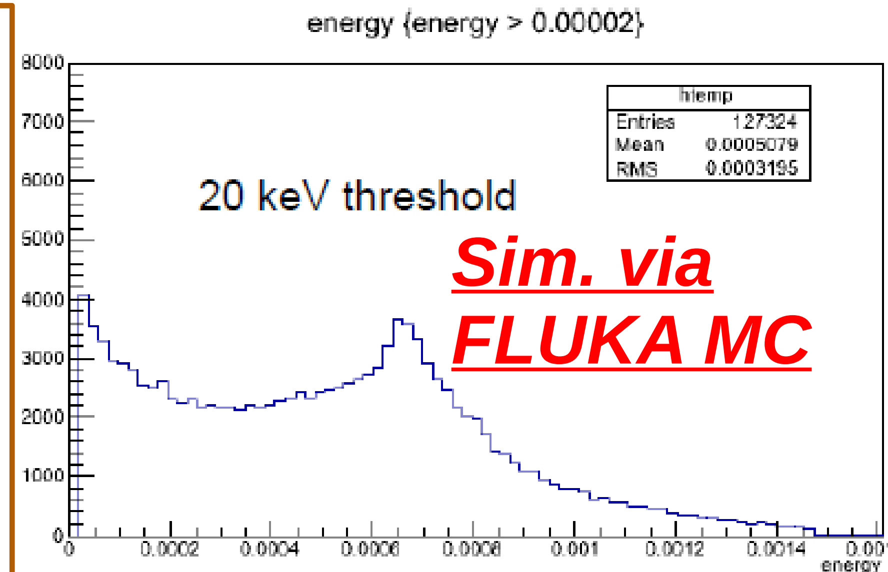
Gas tubes

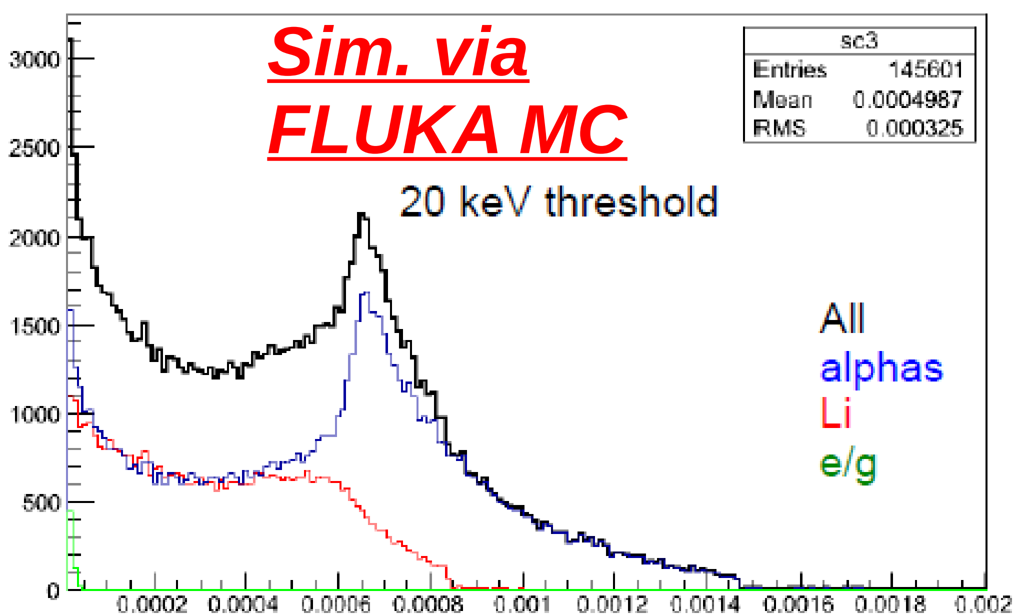
The Schlumberger neutron counter

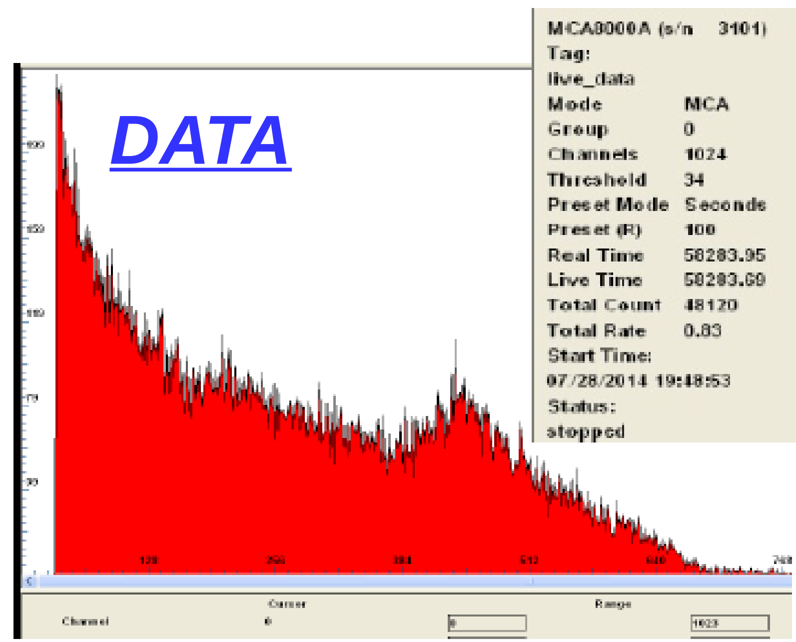


Performance

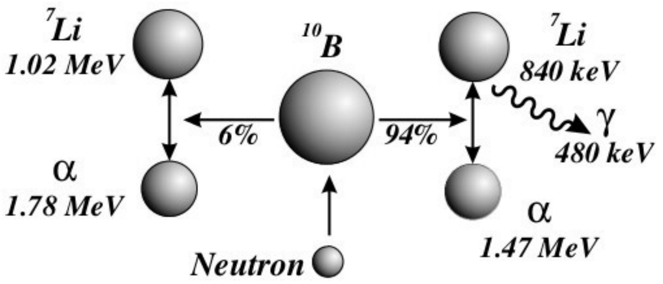
- 2 High voltages (+300V & +500V) for the mesh and the anode
- Single readout channel
- Operation in sealed mode (since July) – no gain loss
- *Measured efficiency: **4.3 – 5 %** (reference 3He tube)*



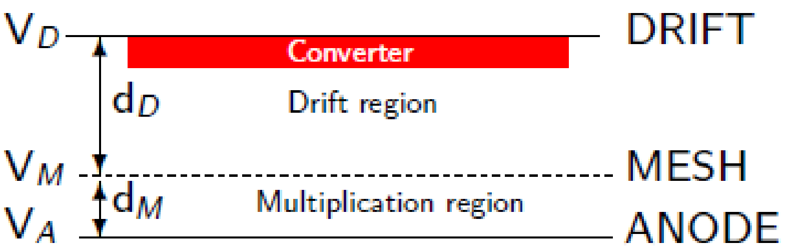




The multilayer concept (i)



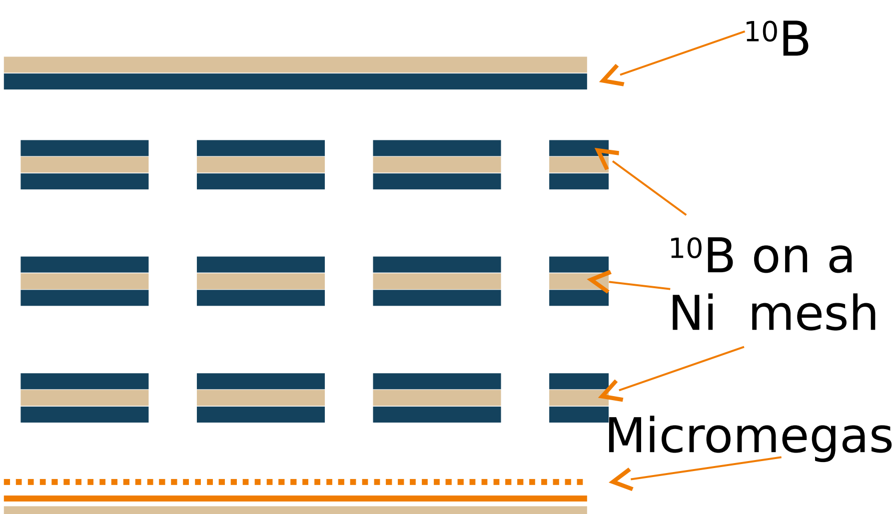
- A boron layer thicker than **1-2 µm** is **not efficient** due to the **absorption** of the reaction products
- Maximum efficiency that can be achieved in this case is of the order of **4-5 %**



- ✓ 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)

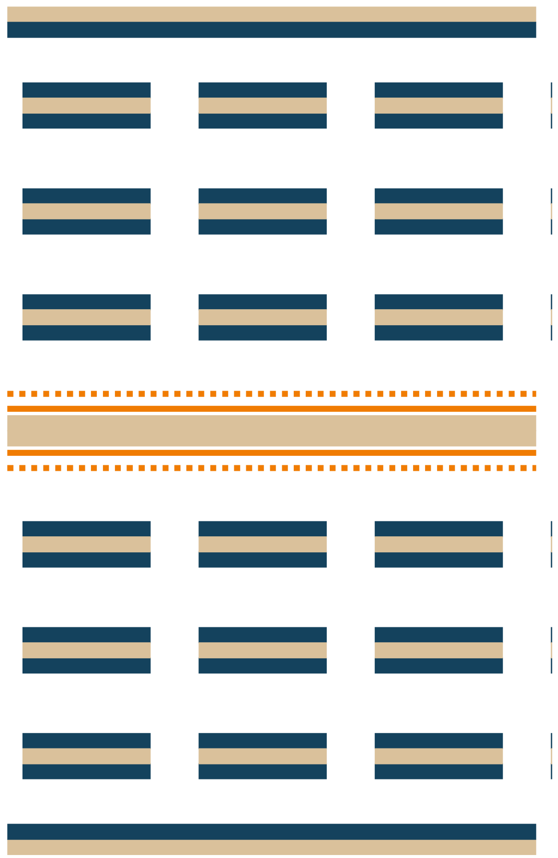


The multilayer concept (ii)

- 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*



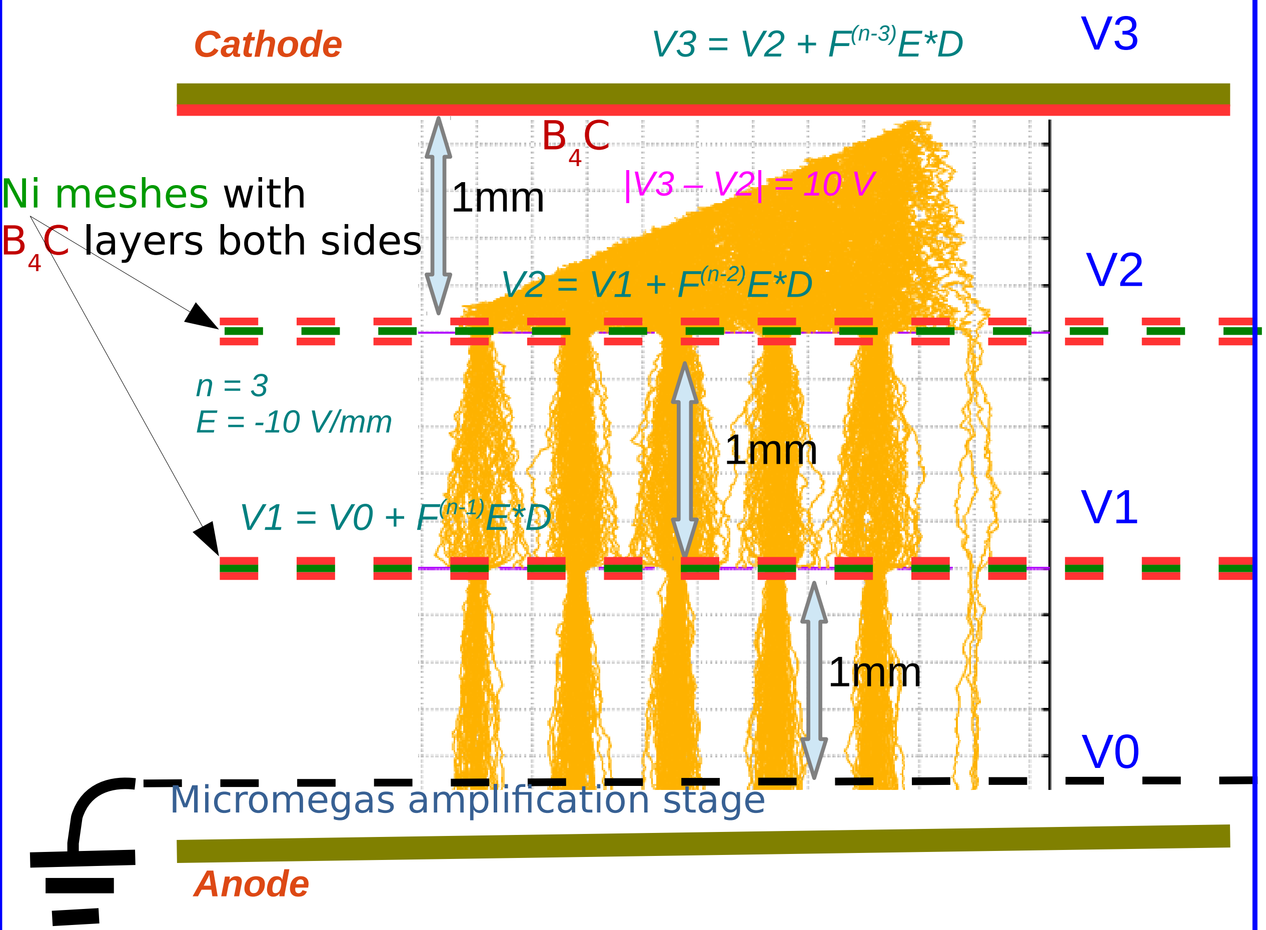
Concept

• Use developments of Micromegas technology in Saclay to demonstrate the feasibility of a large high-efficiency neutron detector with several $^{10}B_4C$ thin layers mounted inside the gas volume.

• Built a single detector unit prototype with overall dimension of ~ 15 x 15 cm² and a flexibility of modifying the number of layers of $^{10}B_4C$ neutron converters.

• Evaluate ***bulk*** (NMI3) / ***microbulk*** (SINE2020) technologies for the construction of large sizes detectors made a mosaic of such detectors.

Micromegas neutron detector

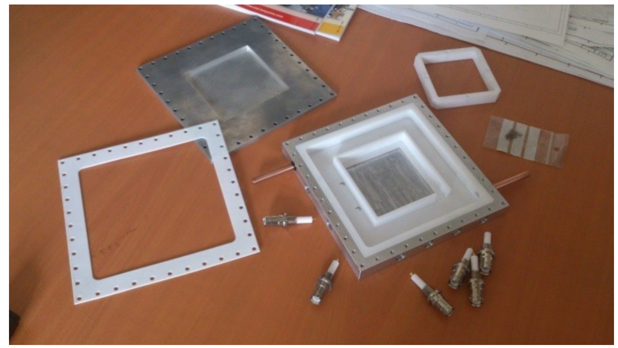


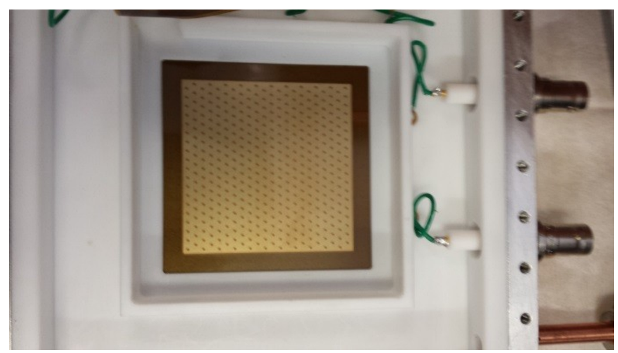
The NMI3 prototype

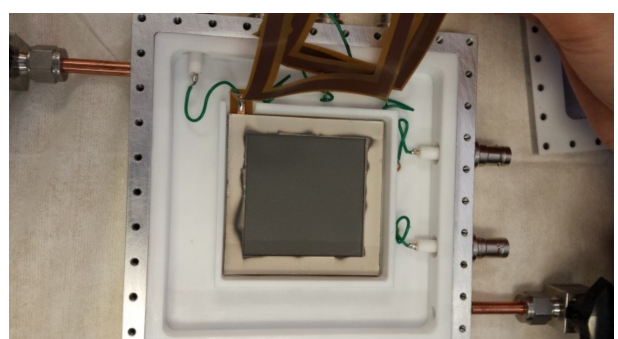
- Bulk Micromegas 5x5 cm^2
- Ni frames 7x7 cm^2
- Ni meshes 10% & 20% transparent
- Voltages applied with the help of kapton+Cu frames

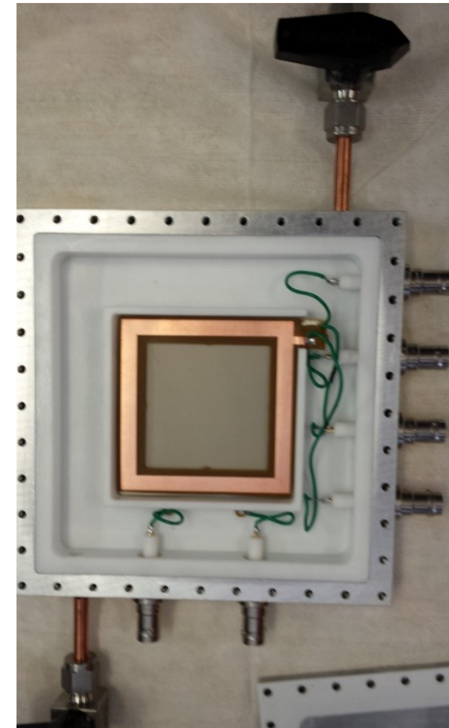
Ni meshes double coated with 1.5 μm B_4C layers

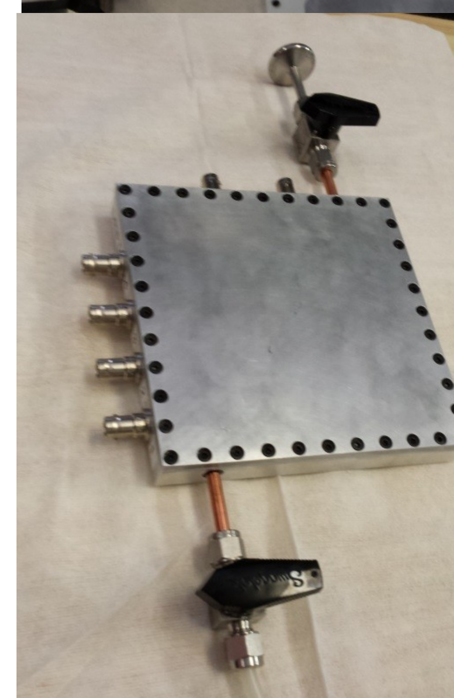
- *10% - 20% transparent*
- *5, 20, 120 μm thick*
- *50, 100, 500, 1000 LPI*
- *(Linköping University)*

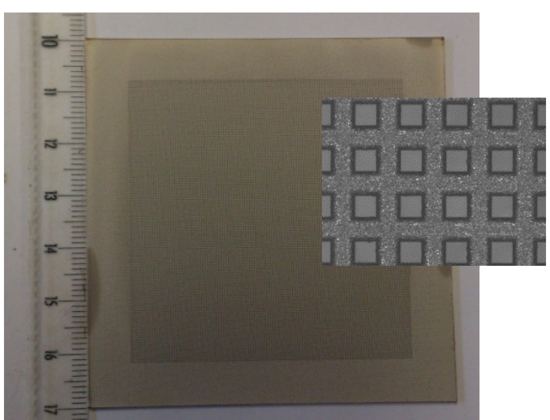








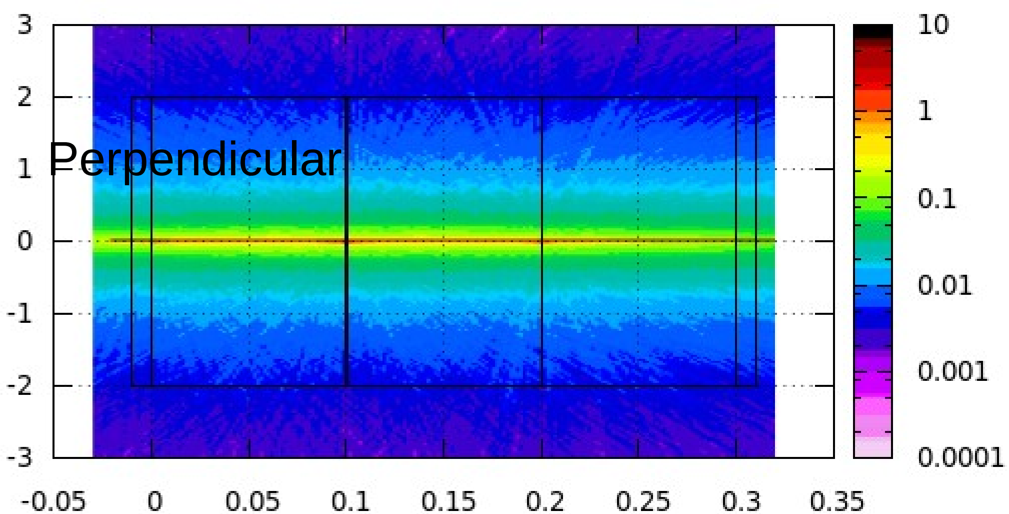




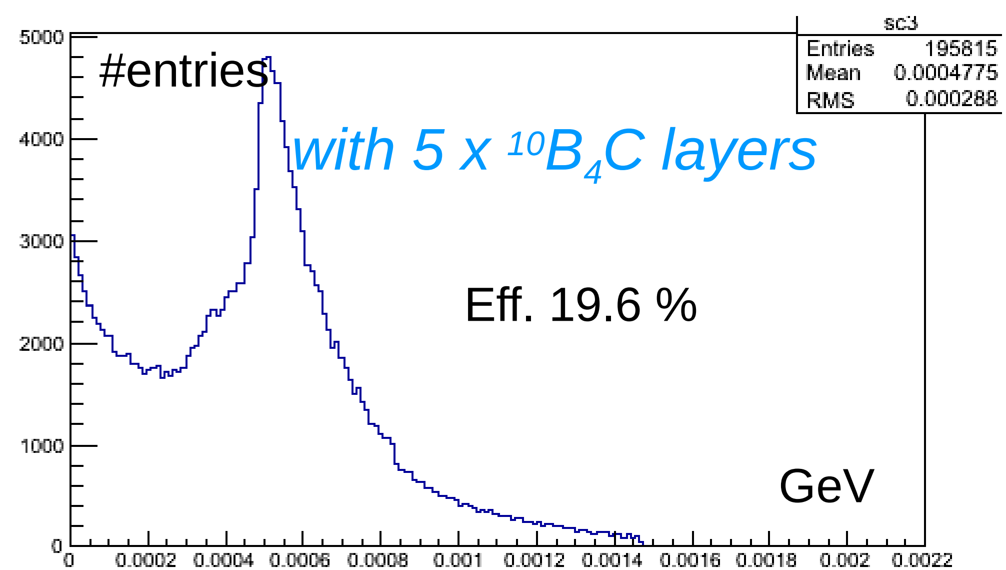
Detection efficiency – FLUKA MC (i)

Simplified geometry of a Micromegas prototype

2 mesh of Nickel: 4 µm
3 Gas layers CF_4: 1-2-5 mm
5 layers of converter B_4C: 2 µm
Neutron beam of 25 meV pencil-like parallel to z-axis
Energy Deposition is scored at the gas volumes
Calculated efficiency of detection : **19.6%**



Spatial distribution of ALL-PART fluence (tracklength density) normalized to particles/cm^2/primary

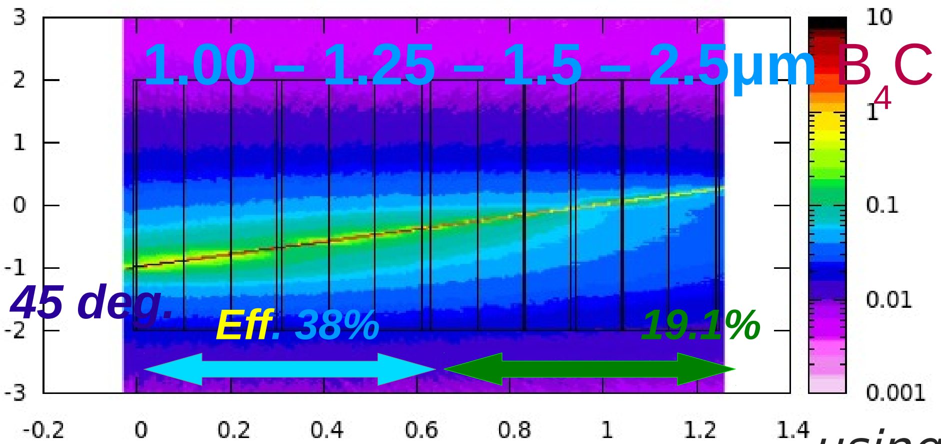


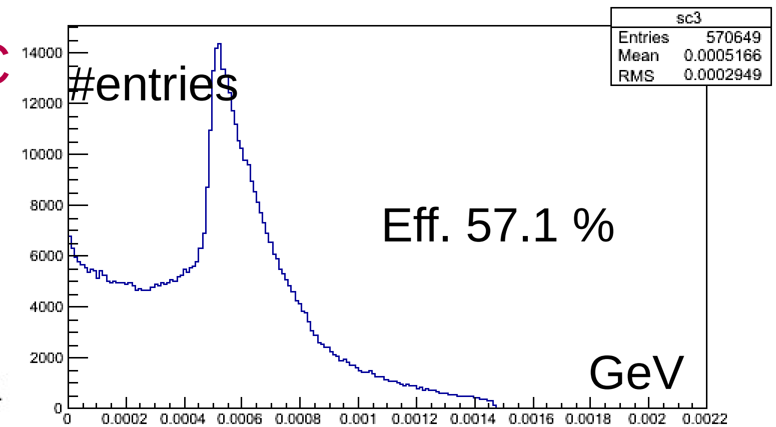
using FLUKA MC

Detection efficiency – FLUKA MC (ii)

A >50% thermal neutron efficiency is reached with a 2 cm stack of transfer meshes with B_4C layers on both sides, and a proper electric field configuration

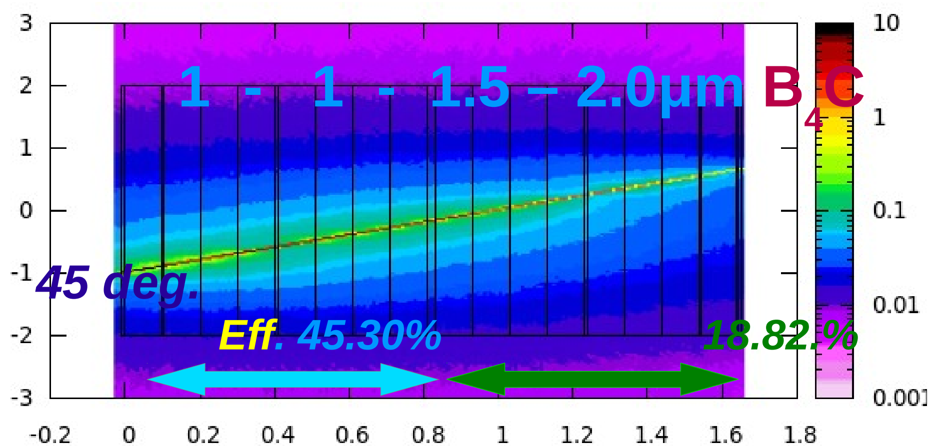
A “2-double 2-mesh detector unit” (20 B_4C layers)

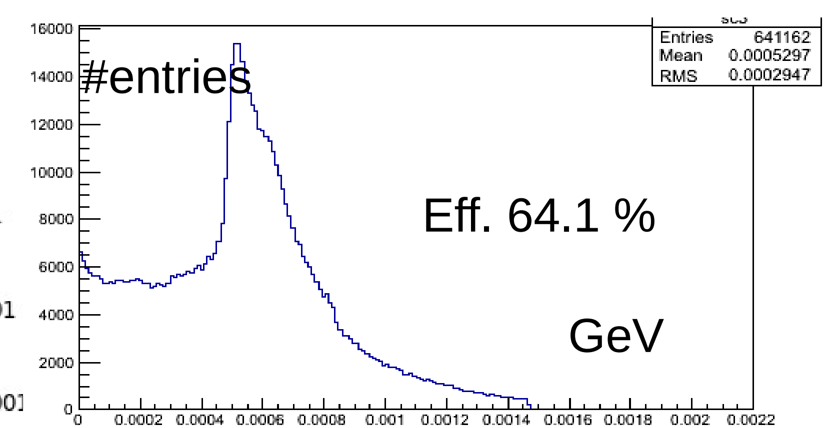




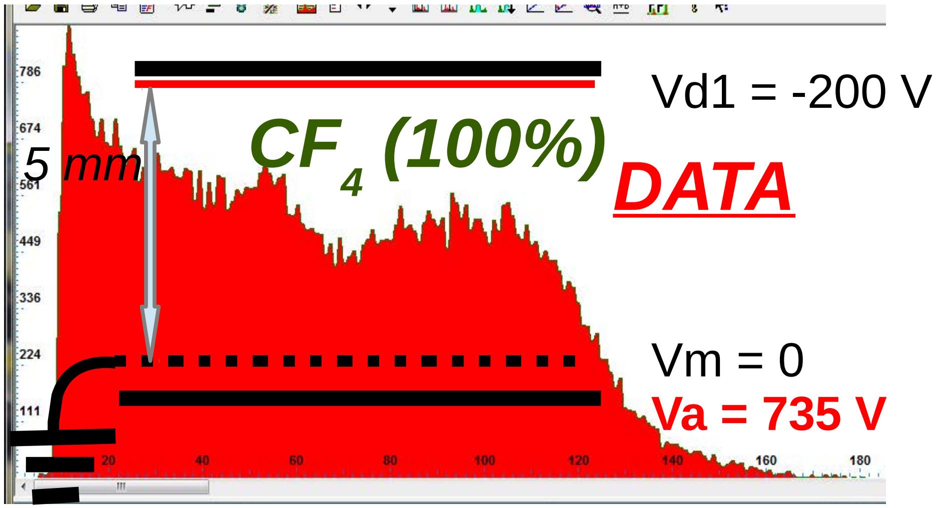
using FLUKA MC

A “2-double 3-mesh detector unit” (28 B_4C layers)



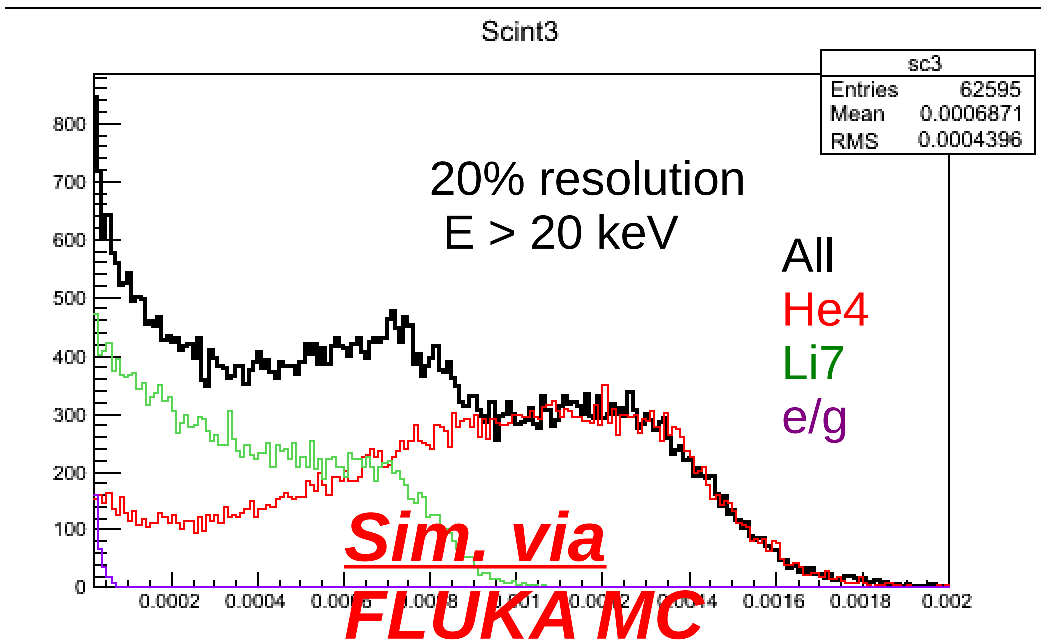


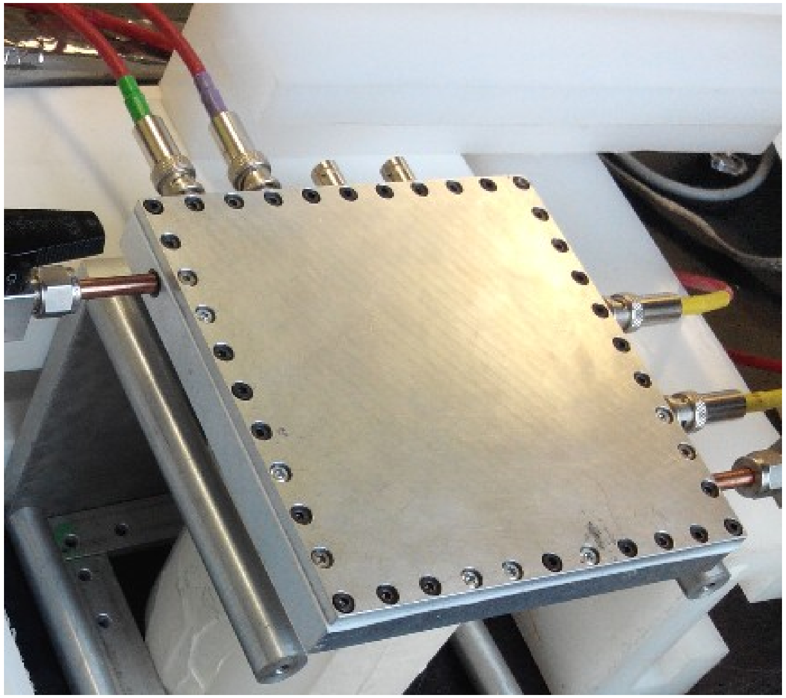
Measurements / simulations



Cf-252 source

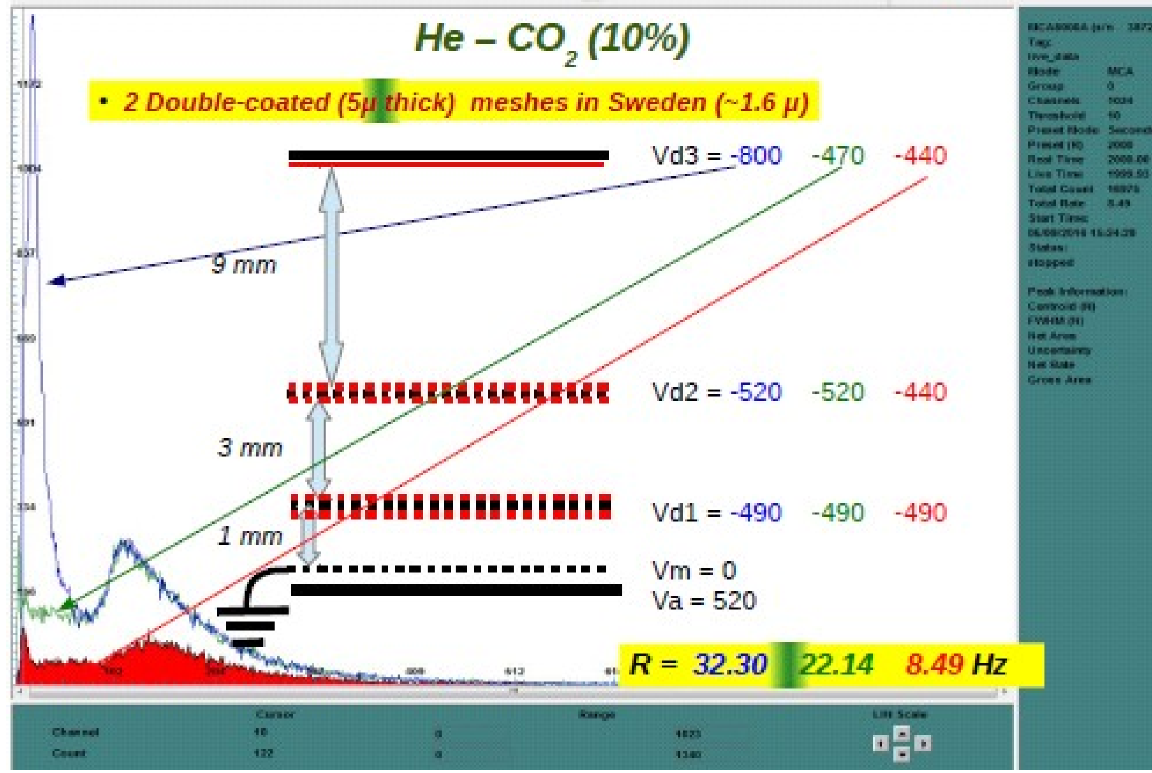
Total Rate ~ 13.16 Hz





5-layer prototype performance

A single 2-mesh detector unit → ***F=7***, 5 ***x B$_4$C*** layers



Comparison with commercial ^{3}He tube:

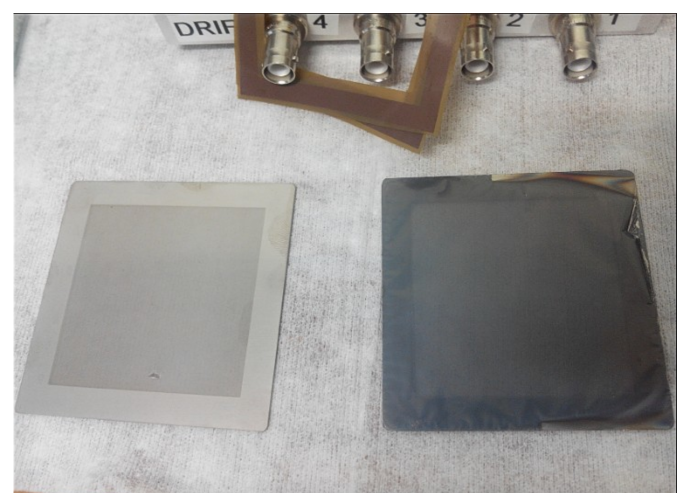
Count rate {^{3}***He / MM***} = 5.5
Assuming ^{3}He eff. ~ 95%
➔ ***MM eff ~ 18%***

Satisfactory result

but:

- **Electron transmission too low when mesh thickness >> 5 µm**
- **Mesh deformed during B$_4$C deposition if thickness << 20 µm**

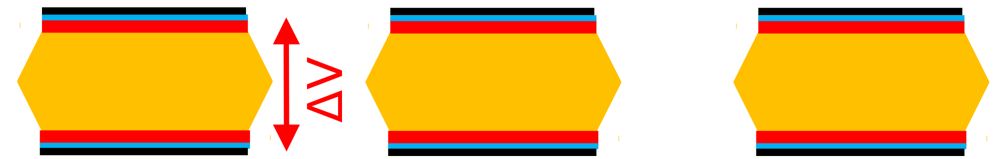
 Difficult to operate with more than 3 layers per unit with large area Ni meshes



Alternative 1: Kapton mesh (GEM-type)

12.5 µm Kapton mesh

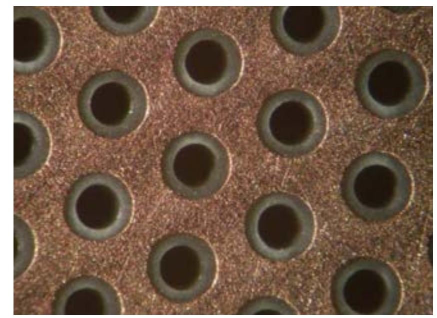
- double-side coated with 3-4 µm Cu
- double-side coated with 1 µm Ni
- double-side coated with 1.5 µm B_4C

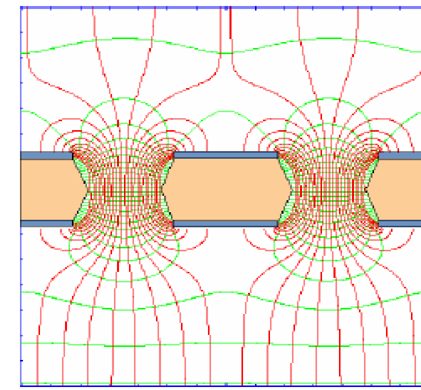


ΔV (10-50 V) applied between the two Cu layers
 electric field strong enough for sufficient electron transmission

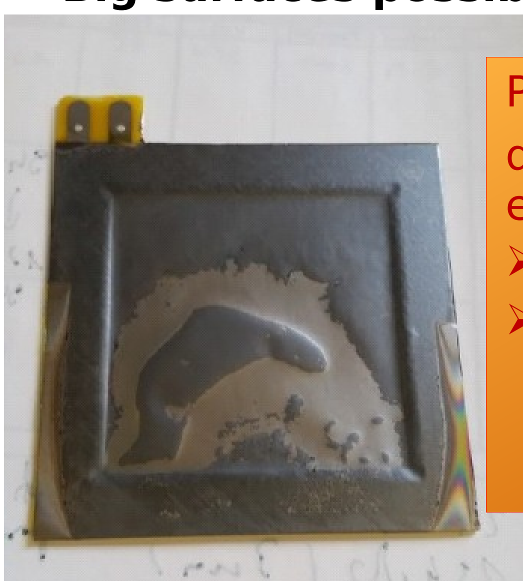
- ➢ Small voltage for top layer (< 500 V)
- ➢ Small amplification possible to compensate electron losses *(factor 2-3)*

GEM-type kapton mesh



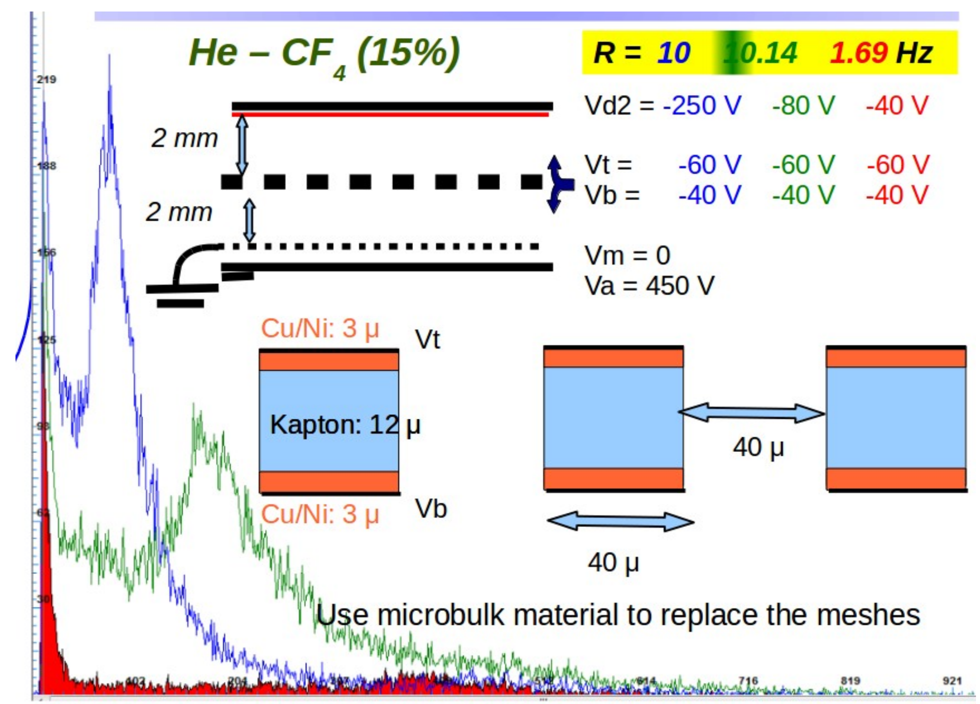


- ✓ **Mesh is cheap and robust**
- ✓ **Big surfaces possible (1×0.5 m²)**



Problem with $^{10}B_4C$ deposition: thermal expansion.

- ➢ Use pure ^{10}B
- ➢ Use a transparent mask (micromesh) during deposition of B_4C



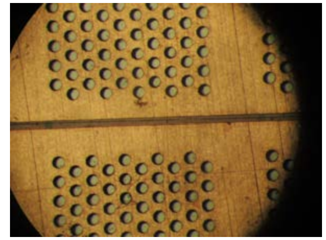
Alternative 2: Microbulk stack

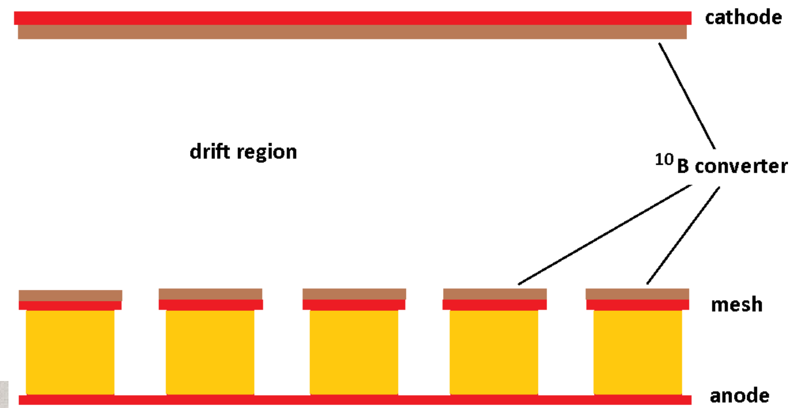
- Microbulk is also a Kapton mesh, Cu-coated.
- Boron can be deposited on the Microbulk surface
   double efficiency
  - Ni or Au coating needed
  - × Same problem from thermal expansion coefficients
- Units can be stacked without limitation, using only 3 voltages (same cathode, mesh, anode voltages)

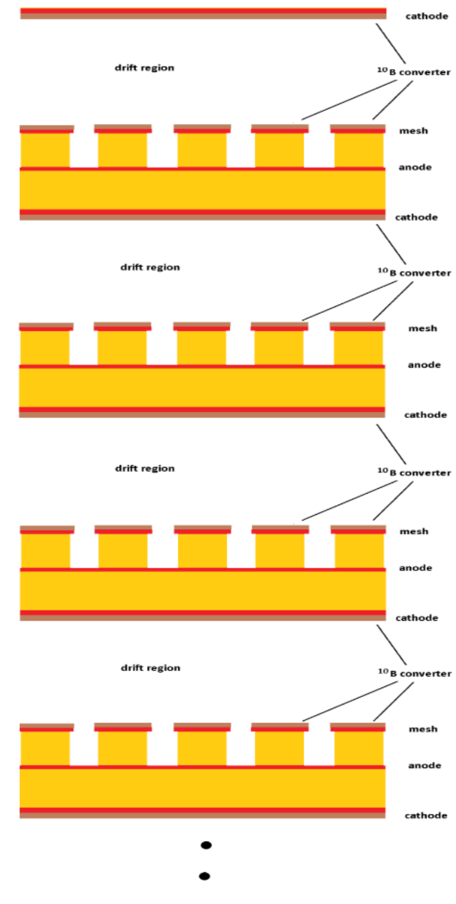
✓ Unit can be very thin (~1 mm)

✓ Low material budget

✓ Common / independent readout possible





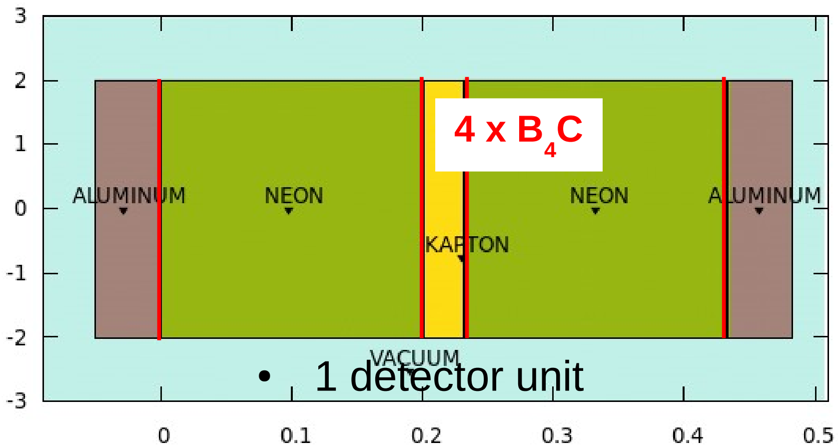


- We have done some tests trying to deposit B_4C on Microbulk raw material.
- The deposition on the copper doesn't work, but on the Nickel coated copper it looks great, even after 2 months from the time the deposition was done.
- So, Nickel coated Microbulks seems it is the good way to proceed.

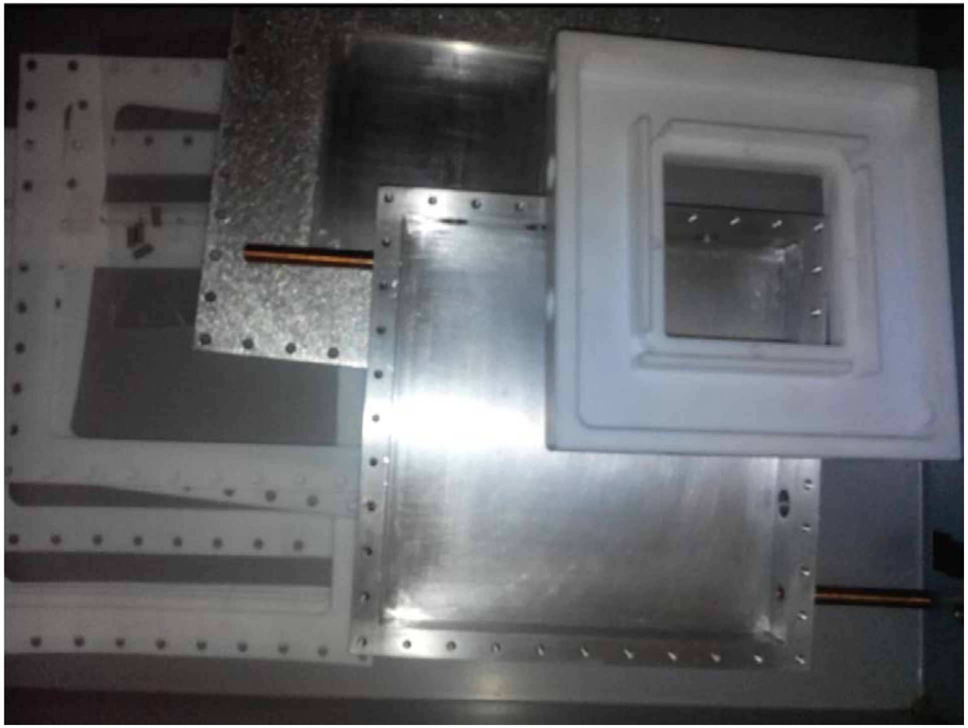
The ***main advantage of the microbulk*** detector is that there is no PCB and the readout pads are supported directly on 50 μm pillars which support the micromesh. Neutron scattering from such an arrangement should be very low and thus it should be possible to stack several layers one behind the other without adversely affecting the incoming neutrons.

SINE2020 Work Program

Original idea :
Move to microbulk to have thinner PCB layer and enable the stacking of detectors to improve the detection efficiency



- 1 detector unit



- ***Micro-bulk micromegas*** → Novel geometry of large scale neutron detector: a mosaic of micro-bulk micromegas coated with $^{10}B_4C$.
- ***Simulations***: of first concept by placing 4 micro-bulk micromegas detector units, the neutron efficiency is 40%
- ***A prototype*** was designed and built: a modular 15x15x2 cm^3 chamber in which up to 4 kapton micro-bulk micromegas can be stacked
- ***Tests to deposit B_4C*** on Micro-bulk raw material are on going
- ***Simplified concept : Start testing*** of a prototype where mesh is replaced by micro-bulk layer

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 B_4C on the foil is difficult. Under study
- A stack of Microbulks coated with B_4C
  - ✓ Low material, thin detector
  - × Deposition of B_4C on the foil is difficult. Under study.

Back-up slides

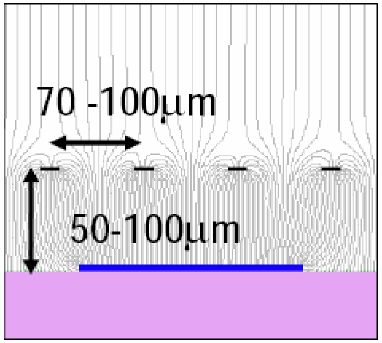
Micro Pattern Gaseous Detectors (MPGD)

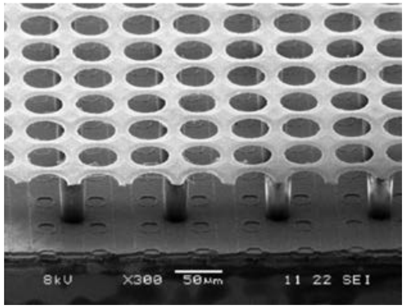
Best technology for gaseous detector readout:

Micro **P**attern **G**aseous **D**etectors

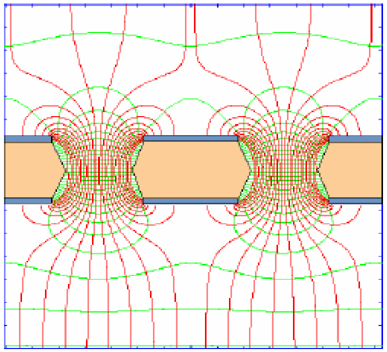
- high granularity
- more robust than wires
- no E×B effect
- fast signal & high gain
- low ion feedback
- better ageing properties
- easier to manufacture
- lower cost
- big surfaces

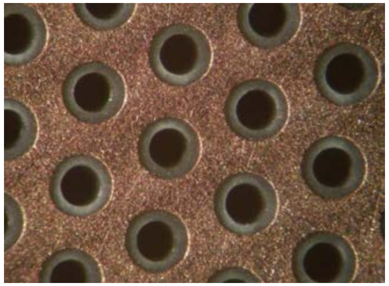
Micromegas





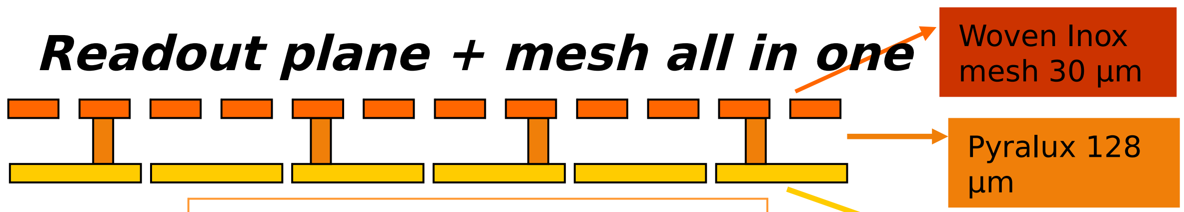
GEMs



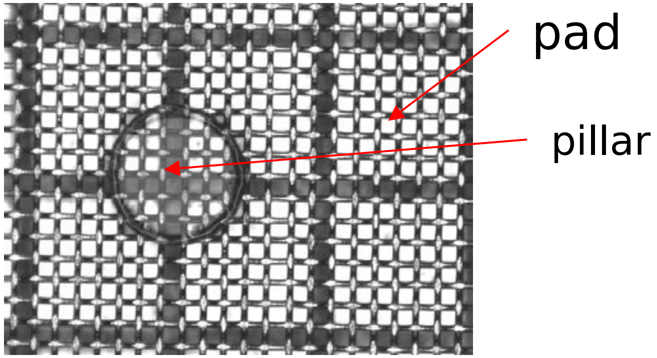


Bulk Micromegas technology

Readout plane + mesh all in one

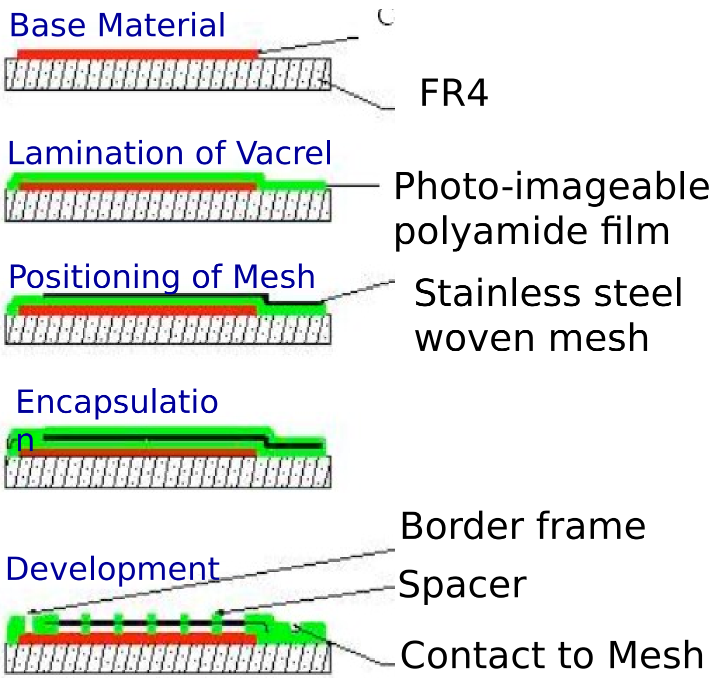


Well established technique



Result of a CERN-Saclay collaboration (2004)

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

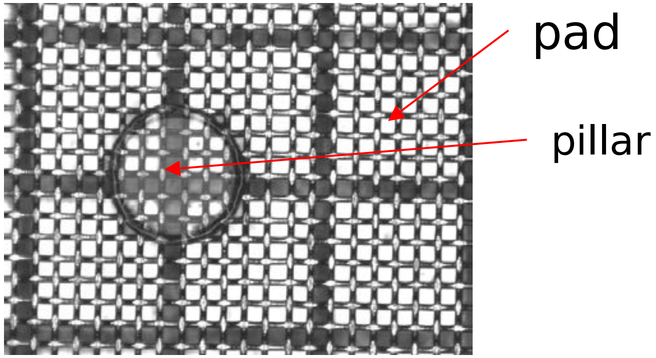


Motivations for using bulk Micromegas the mesh is held everywhere:

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

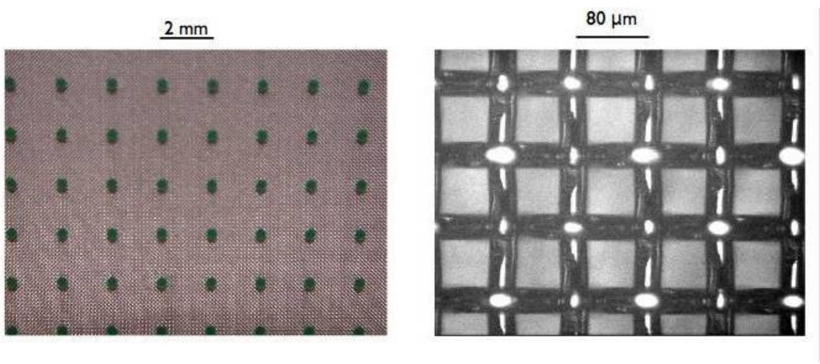
I. Giomataris *et.al.*, NIM A560 (2006) 405

Bulk Micromegas technology



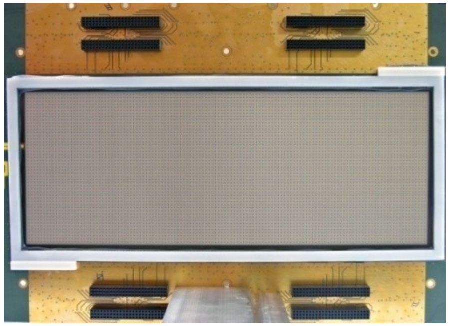
Bulk Micromegas: The pillars are attached to a woven mesh and to the readout plane

Typical mesh thickness 30 µm, gap 128 µm



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

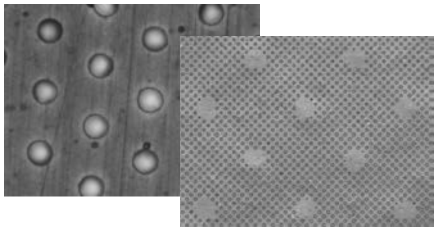
- ✓ **Large area detectors feasible and robust!**
- ✓ **Curved surfaces**
- ✓ Mass production!

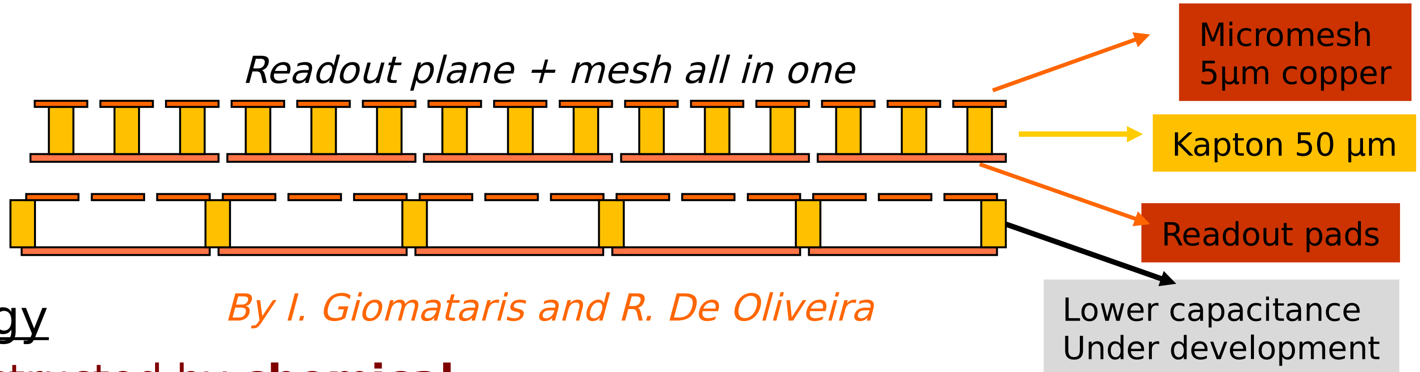


Mesh thickness & bigger gap: some disadvantages in special applications:

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

Microbulk Micromegas technology



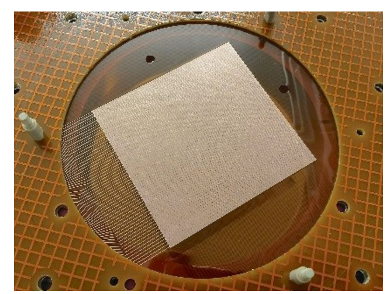


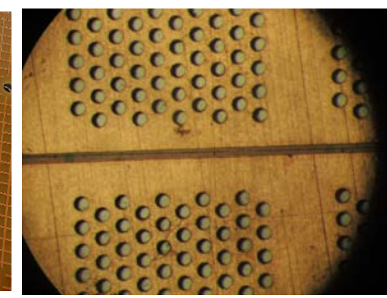
By I. Giomataris and R. De Oliveira

Microbulk Technology

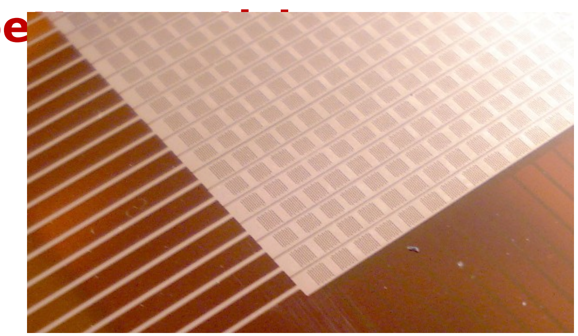
The pillars are constructed by **chemical processing** of a **kapton foil**, on which the mesh and the readout plane are attached. ***Mesh is a mask for the pillars!***

Typical mesh thickness 5 µm, gap 50/25 µm





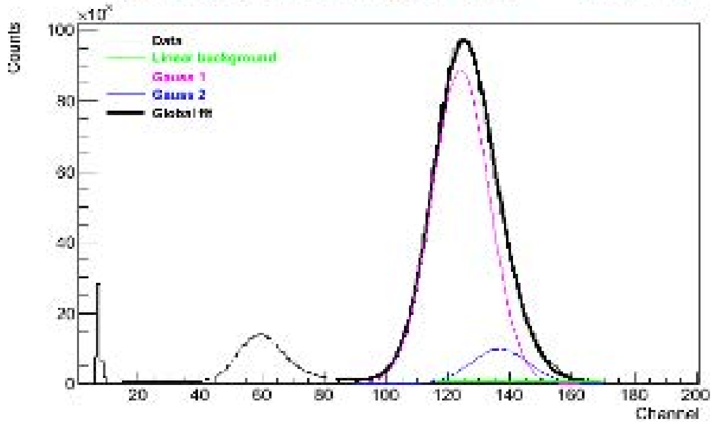
- ✓ **Energy resolution** (down to 10% FWHM @ 6 keV)
- ✓ **Low intrinsic background & be… recognition**
- ✓ **Low mass detector**
- ✓ **Very flexible structure**
- ✓ **Long termstability**



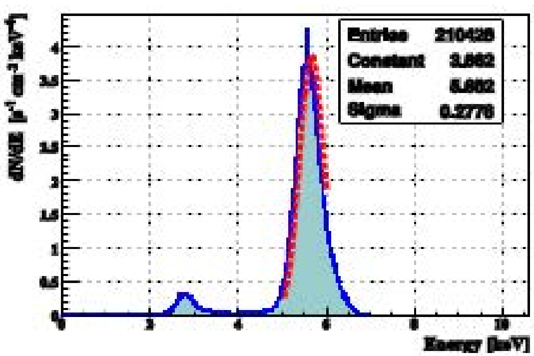
- ✘ Higher capacity
- ✘ Fabrication process complicated
- ✘ Fragility / mesh can not be replaced

Energy and spatial resolution & stability

Bulk: 55Fe Calibration with Ar – 5% isobutane
@ 1 bar **FWHM @ 6 keV = 17.6 %**

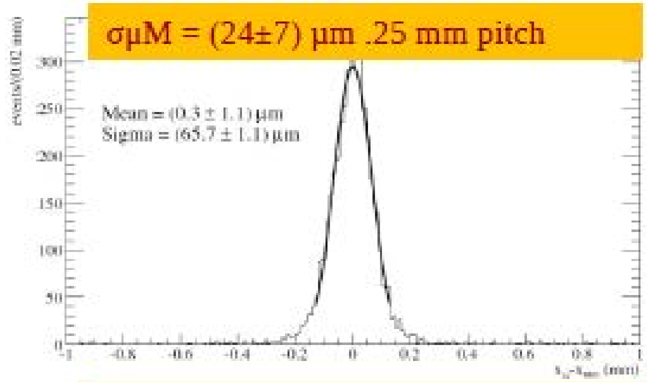


Microbulk: 55Fe Calibration with Ar – 5% isobutane
@ 1 bar **FWHM @ 6 keV = 11.5 %**

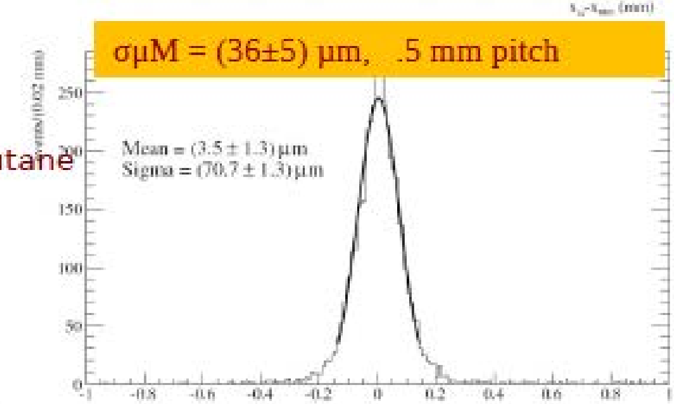


Bulk: Spatial resolution measurements for the MAMA project (sLHC)

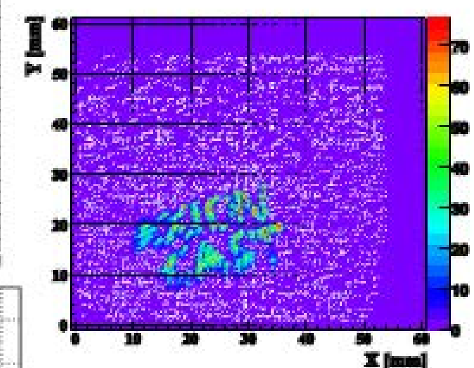
σμM = (24±7) μm .25 mm pitch

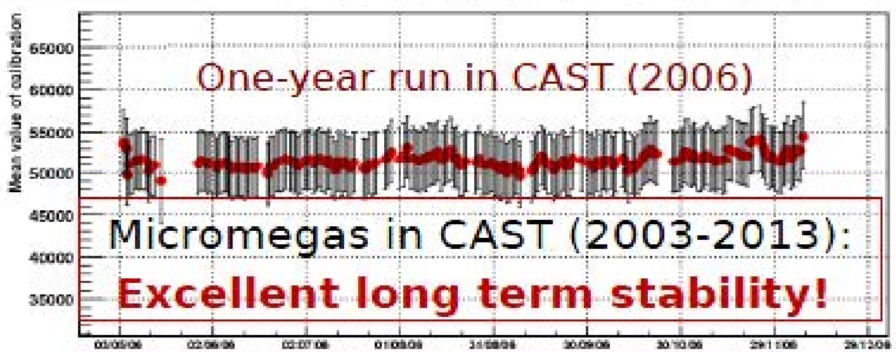


σμM = (36±5) μm, .5 mm pitch



Microbulk: Image taken using a collimator with the words "axion cast"





Micromegas in CAST (2003-2013):
Excellent long term stability!

280 x 210 mm