Service d'Electronique, Détecteurs, et Informatique (Irfu/SEDI)
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Large high-efficiency thermal neutron detectors based on the Micromegas technology

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- Neutron detection with Micromegas
- Multilayer concept ***NMI3***
- 5 – layer prototype performance
- Towards ***SINE2020*** :
- Using Kapton meshes
- Implementing microbulk technology to have a stack
- Simulations – design – build of a prototype – measurements
- Summary + future plans

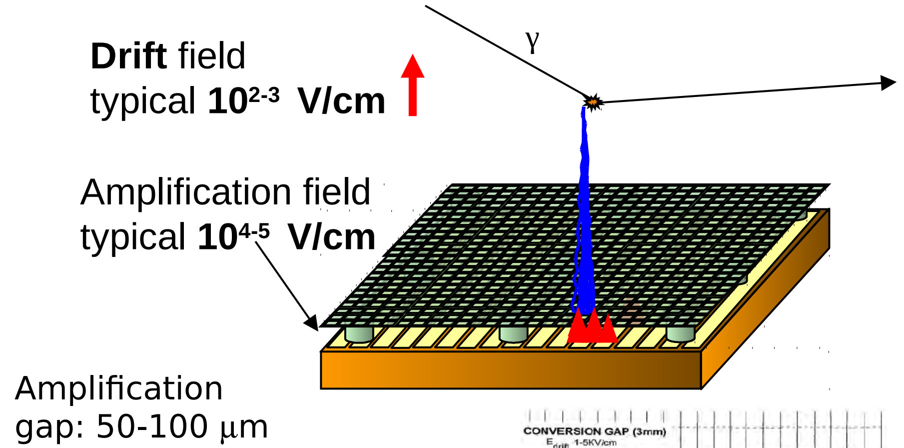
Micromegas concept

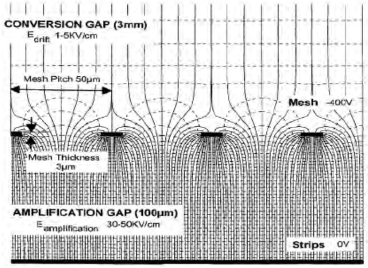
Two-region gaseous detector
separated by a Micromesh :

- 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

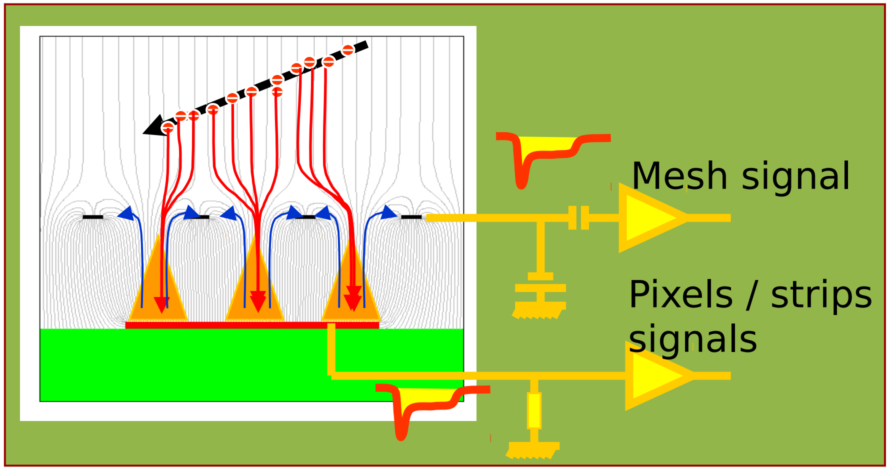
- metallic micromesh (typical pitch 50µm)
- sustained by 50-100 µm pillars
- simplicity
- single stage of amplification
- fast and natural ion collection
- discharges non destructive





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

In 1st Micromegas
Fishing line spacers have been used

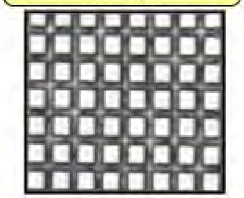


MICROMEGAS description + technologies (i)

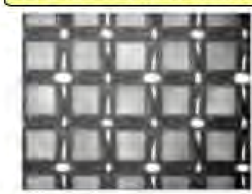
Micro-mesh (cathode)

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.

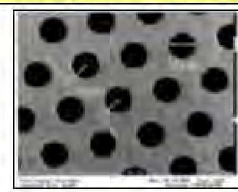
500 LPI Electroformed Ni mesh



500 LPI 304Lwoven mesh

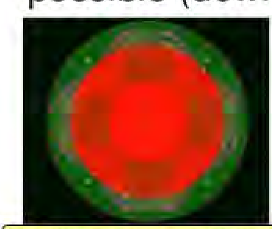


Chemically etched Copper mesh



Printed Circuit Board (anode PCB)

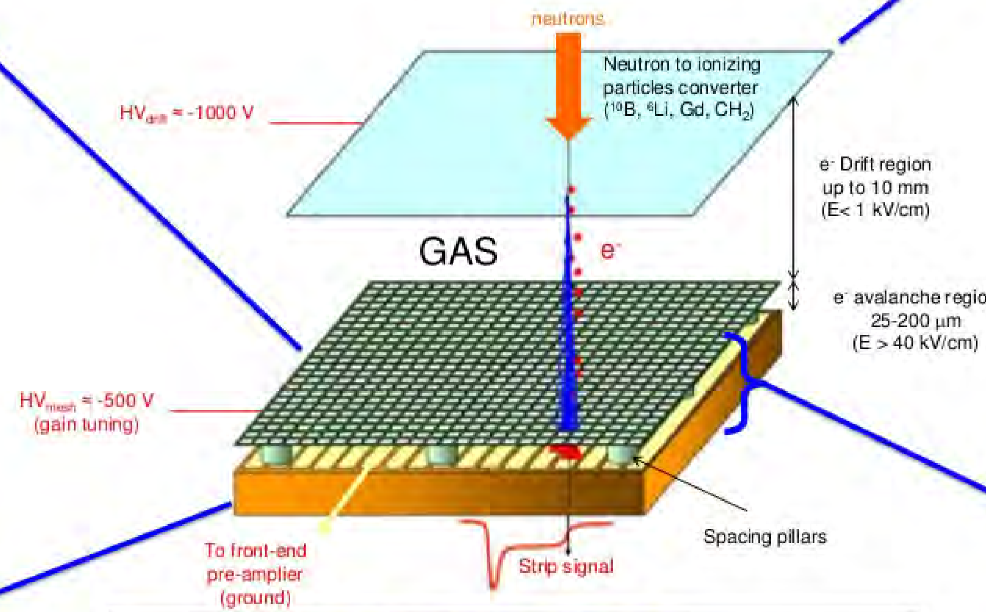
- ✓ It can be up to 1- 3 m^2 and down to 100 μm thin.
- ✓ Copper strips or pads can be ≈100 μm to few mm large and insulation between them as low as 50 μm.
- ✓ Copper is usually covered by a Ni/Au layer for a total thickness which must be kept as low as possible (down to 5 μm) with a « smooth » surface.



A Φ30 cm 12 layers PCB with 4000 x 4 mm^2 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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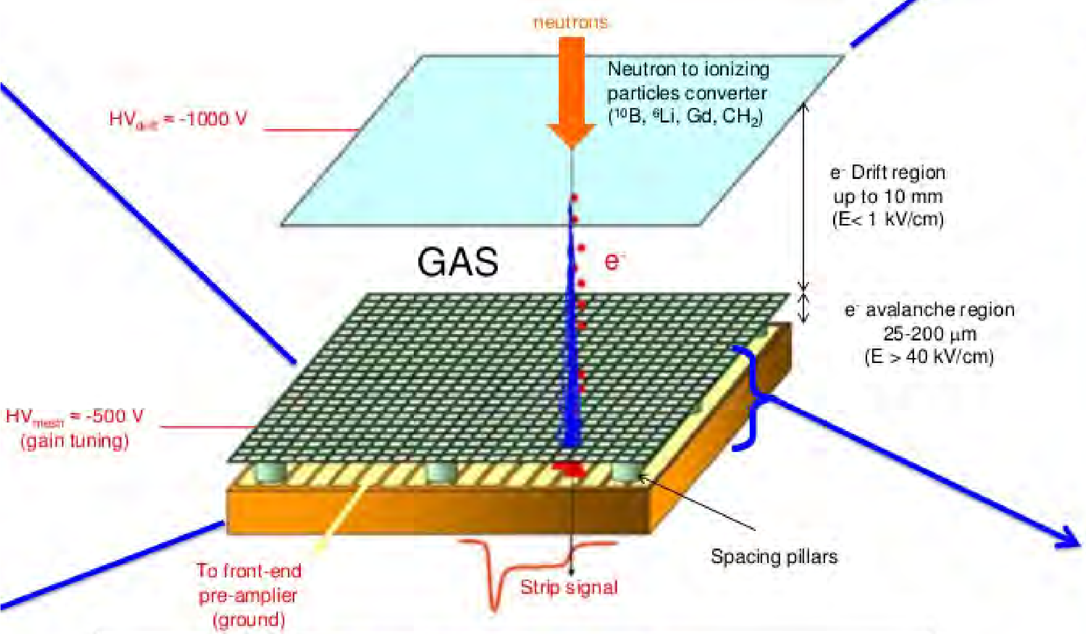

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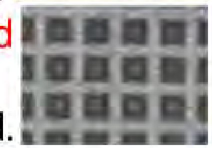
Drift electrode + neutron converter

- ✓ 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.

Low cost industriallized processes needed

- ✓ 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.)



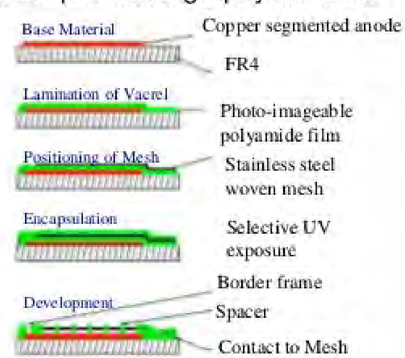
Micromegas technologies

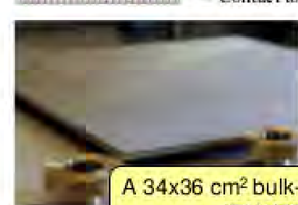
to realize the micro-mesh + anode PCB assembly

Bulk-micromegas

On-going technology transfer

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



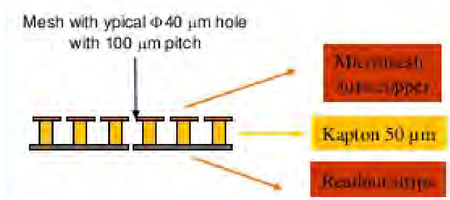


A 34x36 cm² bulk-micromegas (T2K/TPC)

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)

Neutron detection with Micromegas

Due to the so-called 3He shortage crisis, many detection techniques used nowadays for thermal neutrons are based on alternative converters. Thin films of ^{10}B or $^{10}B_4C$ are used to convert neutrons into ionizing particles which are subsequently detected in gas proportional counters, but only for small or medium sensitive areas so far.

Neutron detection → neutron to charge converter

- Solid converter: thin layers deposited on the drift or mesh electrode (**^{10}B, $^{10}B_4C$,** ^6Li, ^6LiF, U, actinides…)
  - ✓ Sample availability & handling
  - ✓ Efficiency estimation
  - ✘ *Limitation on sample thickness from fragment range ⇒ limited efficiency*
  - ✘ Not easy to record all fragments
- Detector gas (^3He, 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%):

- ^3He 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

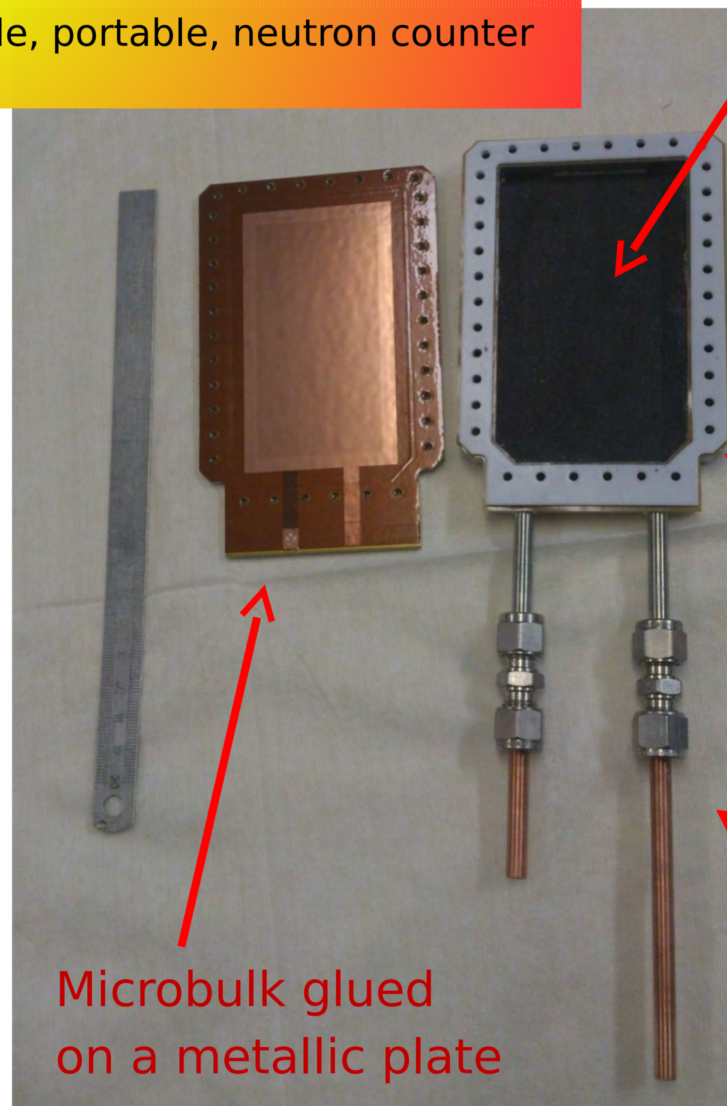
Ingredients to build a simple counter

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



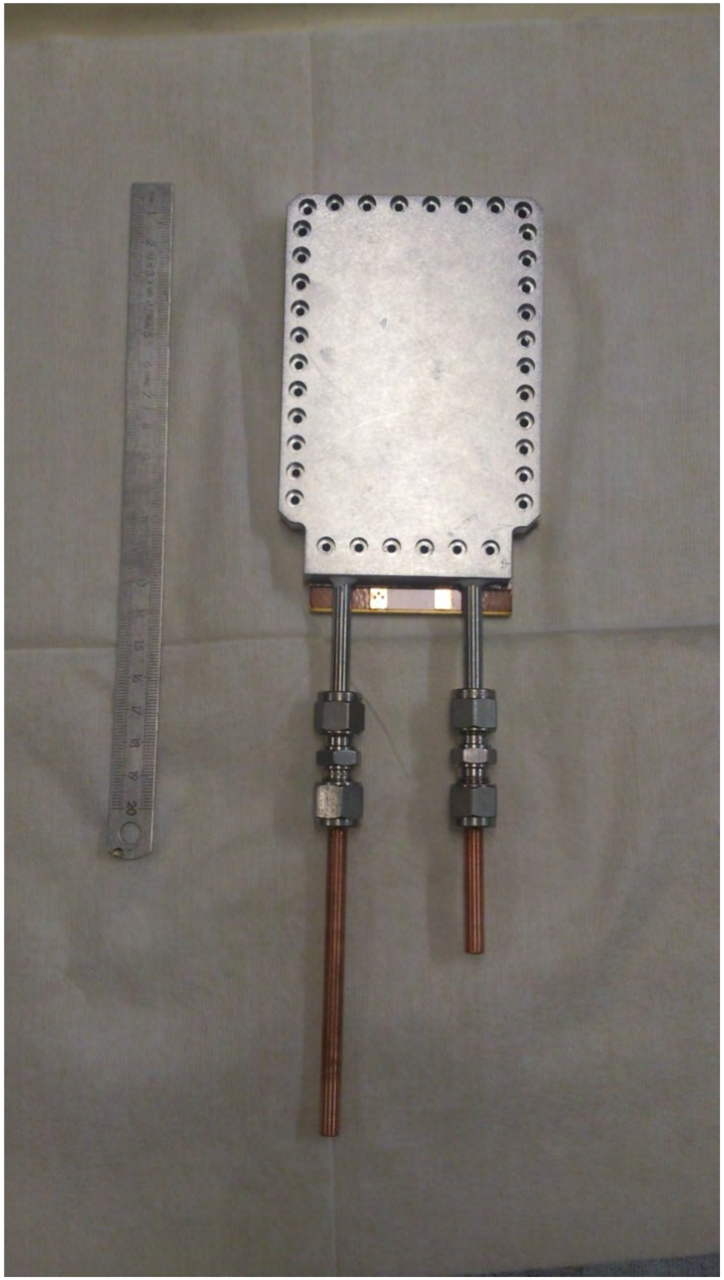
The ^{10}B layer is the less trivial part to build

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

Teflon / kapton joint

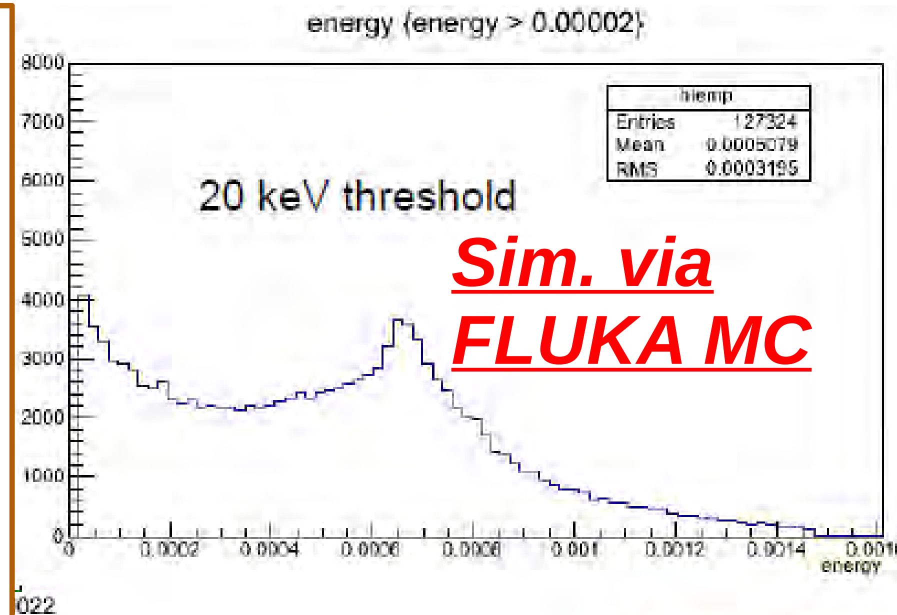
Gas tubes

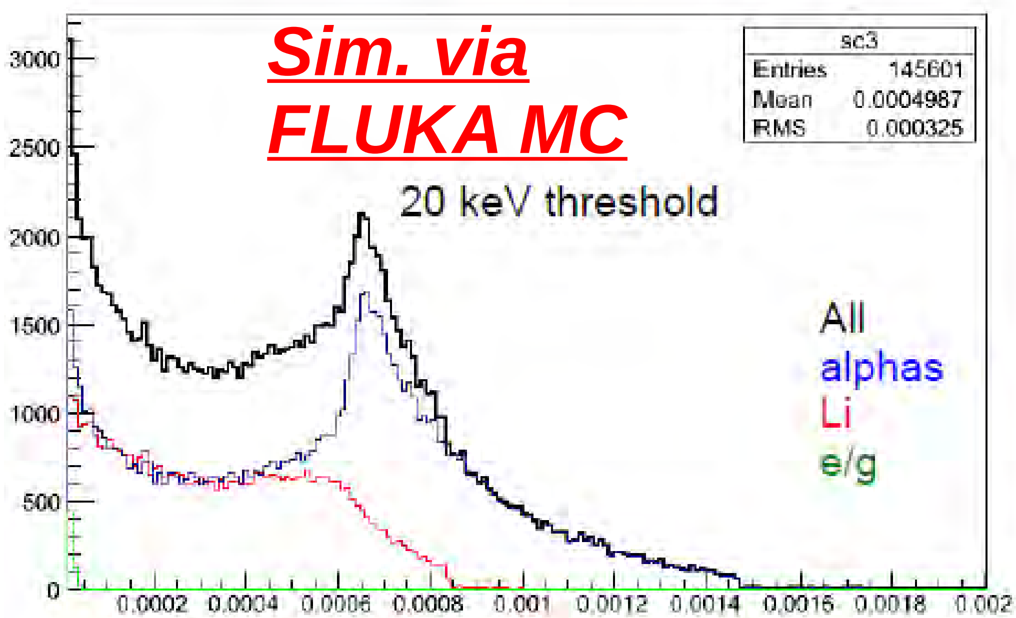
The Schlumberger neutron counter

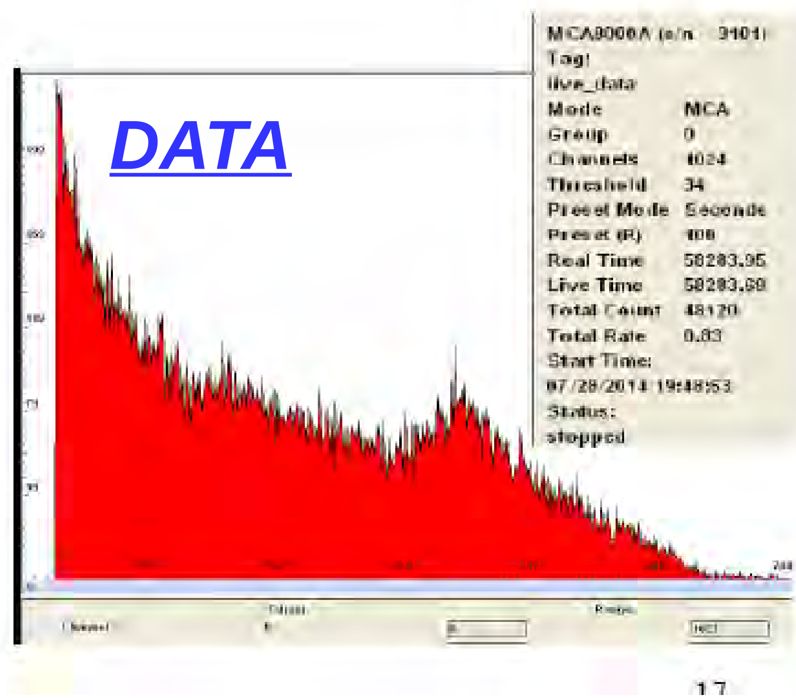


Performance

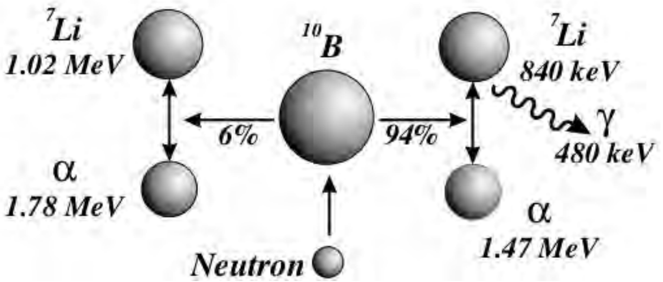
- 2 High voltages (+300V & +500V) for the mesh and the anode
- Single readout channel
- Operation in sealed mode (since July) – no gain loss
- *Measured efficiency: **4.3 – 5 %** (reference 3He tube)*



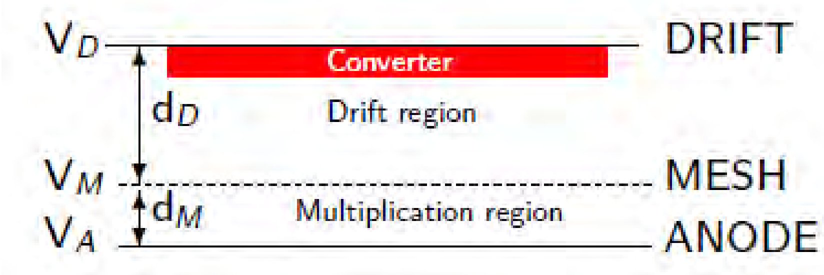




The multilayer concept (i)



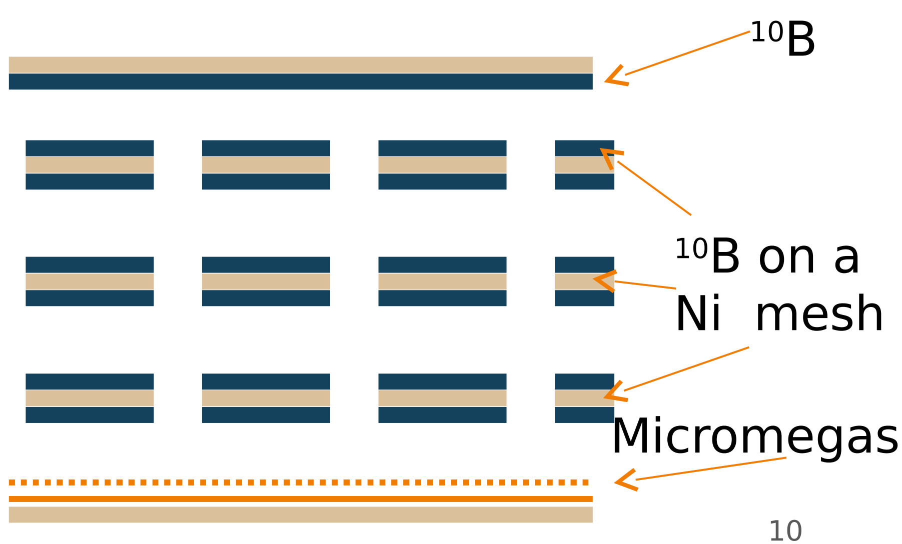
- A boron layer thicker than **1-2 µm** is **not efficient** due to the **absorption** of the reaction products
- Maximum efficiency that can be achieved in this case is of the order of **4-5 %**



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

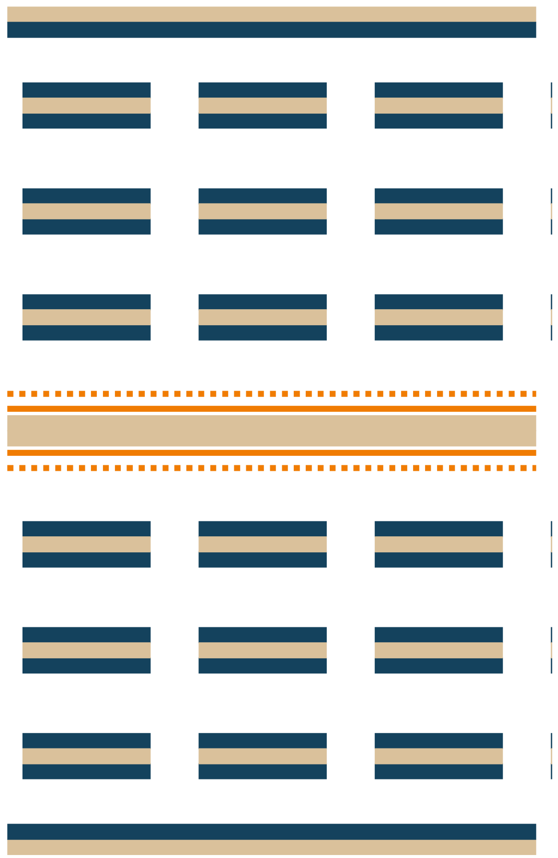
✓ Alternative: a tower of converter layers for each detector: ^{10}B deposited on thin metallic meshes
  - ➔ Less electronics
  - ➔ Less material

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



The multilayer concept (ii)

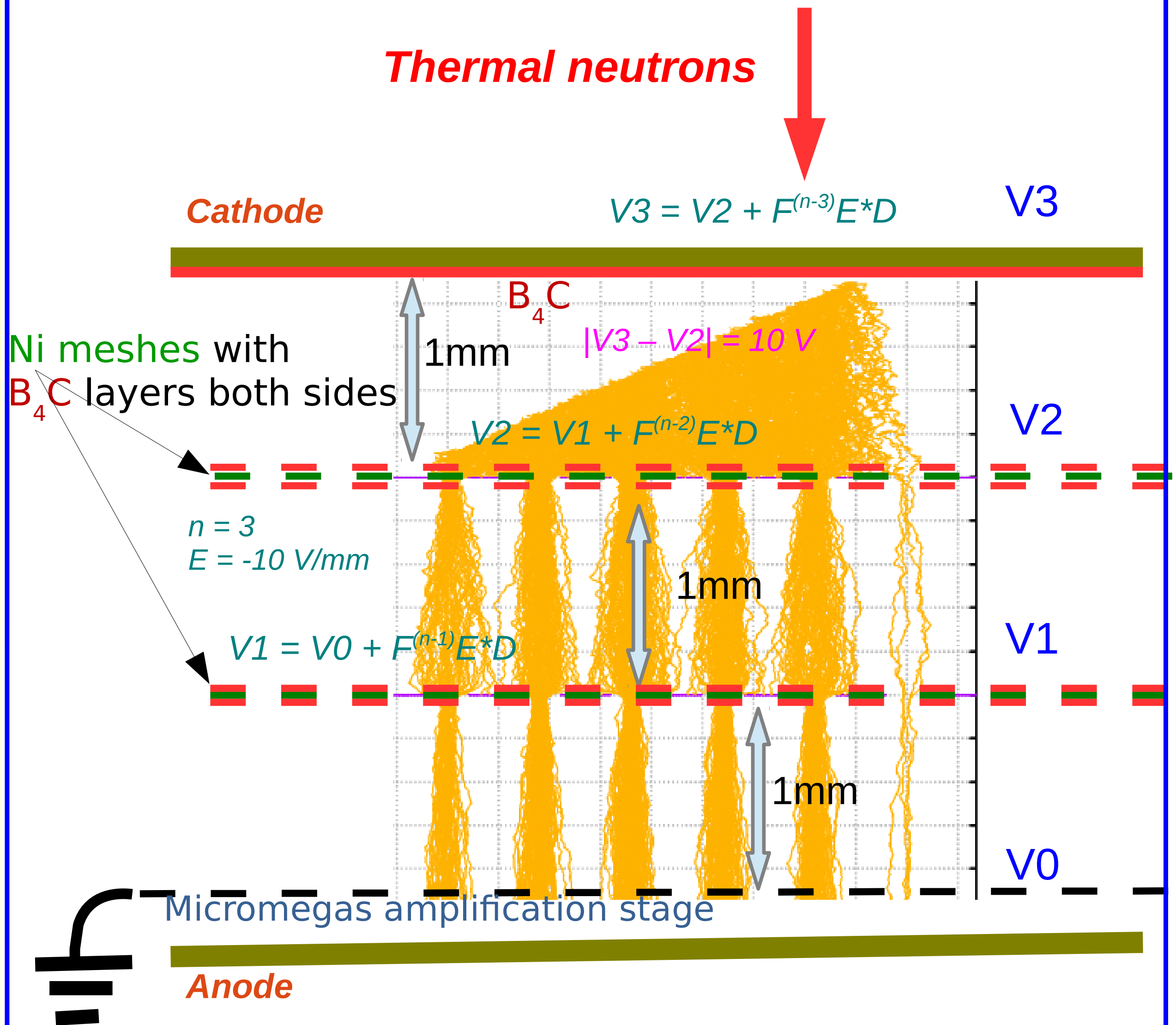
- One module can be consisted of a double-face Micromegas facing 7+7 ^{10}B layers
- Such a module can be ~1 cm thick!
- Material:
  - ✓ 0.2 – 0.3 μm PCB
  - ✓ 6 x 5 μm Ni
  - ✓ 2 x micromesh
  - ✓ 2 x 1 mm Aluminum case
- A stuck of such detectors can be used to increase   efficiency
- Detector can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



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

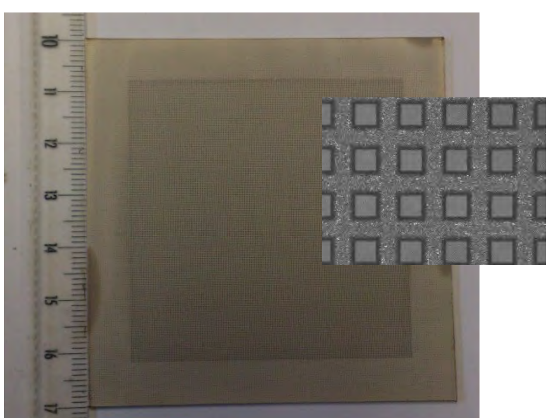


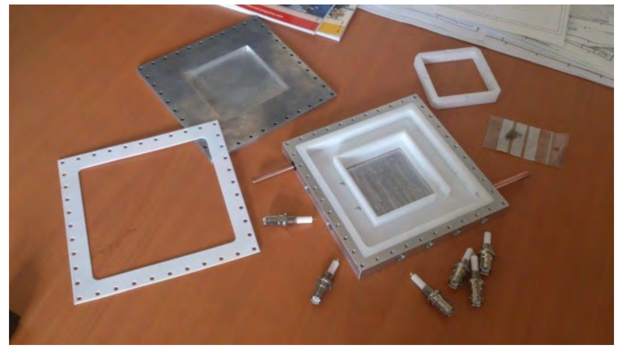
The NMI3 prototype

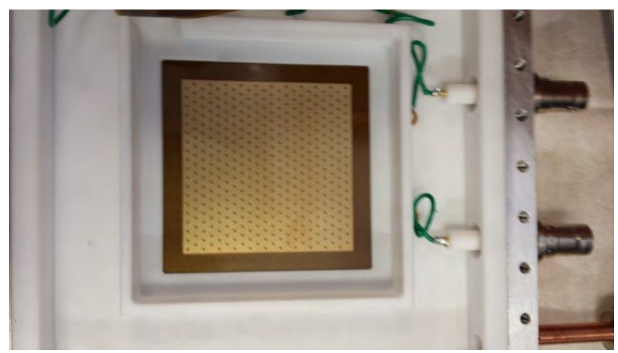
- Bulk Micromegas 5x5 cm^2
- Ni frames 7x7 cm^2
- Ni meshes 10% & 20% transparent
- Voltages applied with the help of kapton+Cu frames

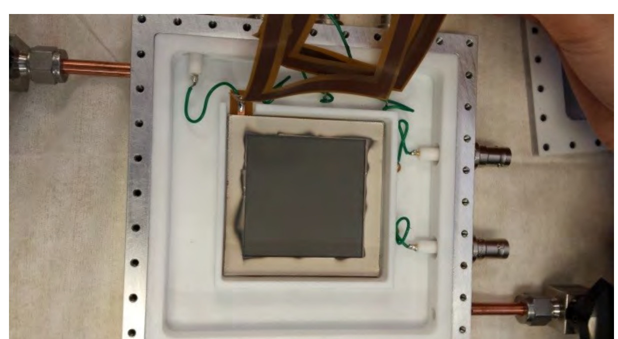
Ni meshes double coated with 1.5 μm B_4C layers

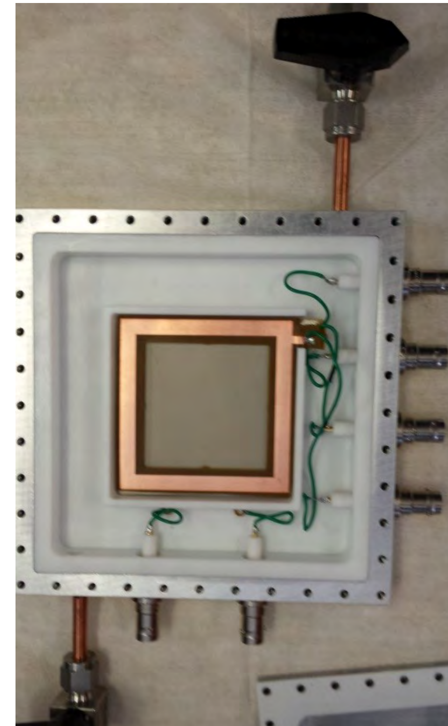
- *10% - 20% transparent*
- *5, 20, 120 μm thick*
- *50, 100, 500, 1000 LPI*
- *(Linköping University)*

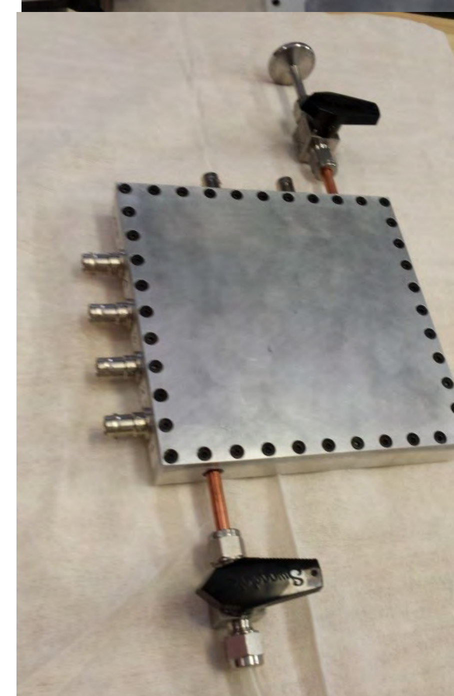












Detection efficiency – FLUKA MC (i)

Simplified geometry of a Micromegas prototype

2 mesh of Nickel: 4 µm

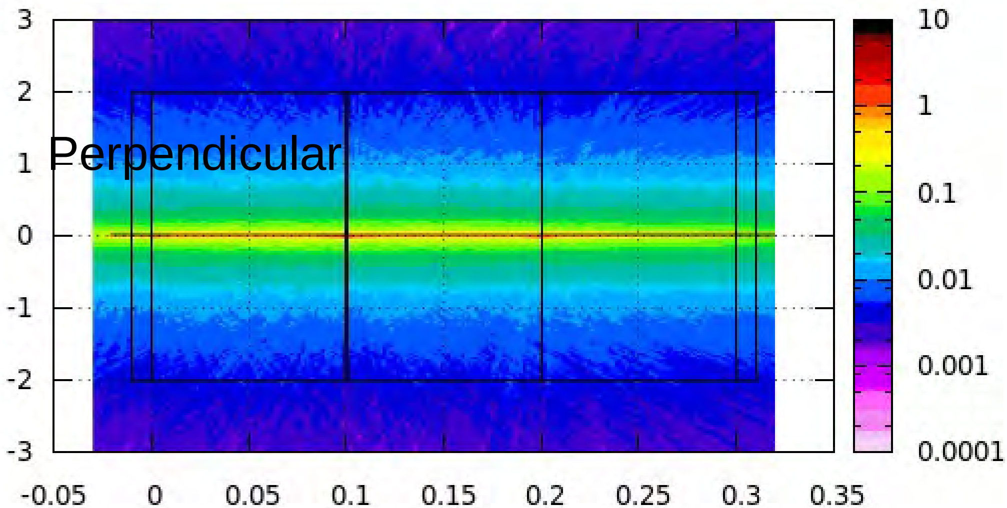
3 Gas layers CF_4: 1-2-5 mm

5 layers of converter B_4C: 2 µm

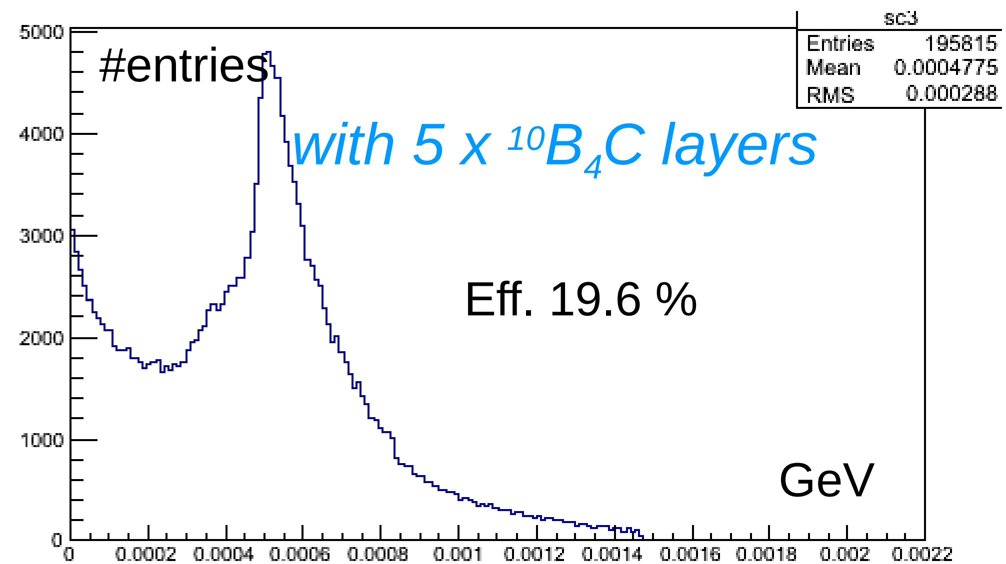
Neutron beam of 25 meV pencil-like parallel to z-axis

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/cm²/primary

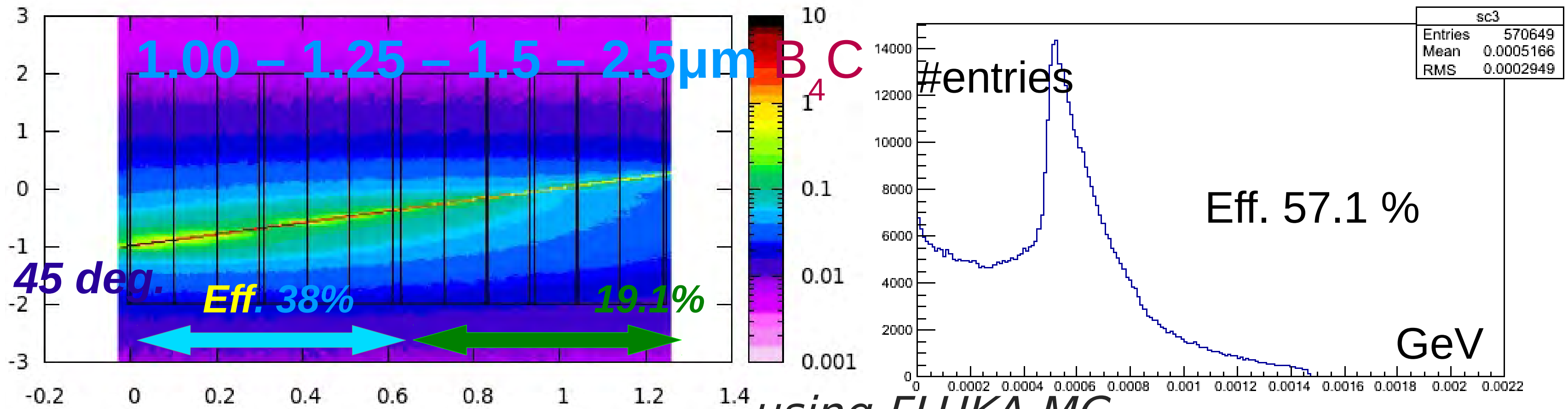


using FLUKA MC

Detection efficiency – FLUKA MC (ii)

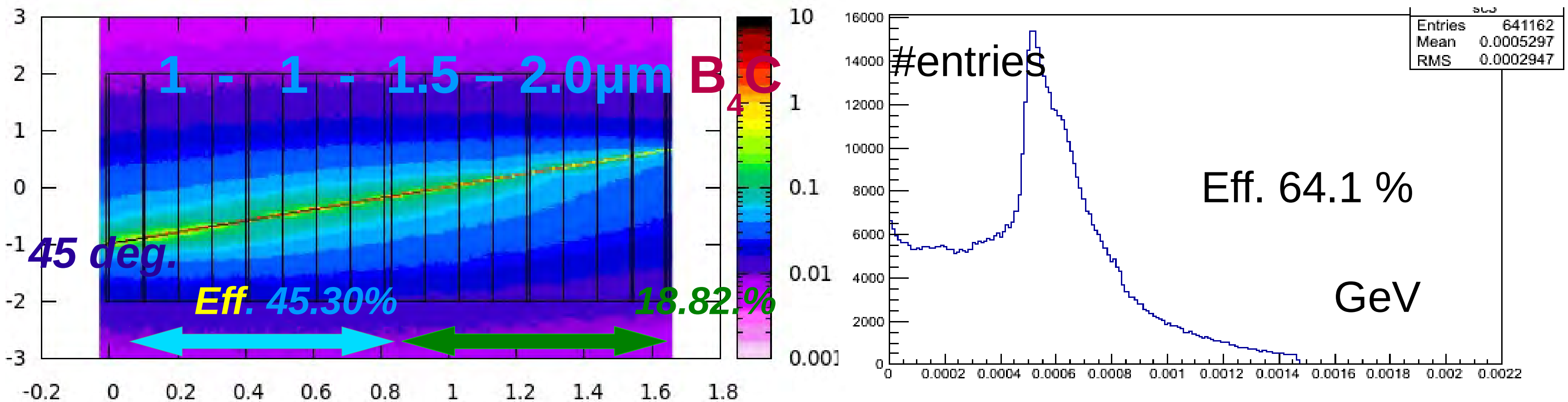
A >50% thermal neutron efficiency is reached with a 2 cm stack of transfer meshes with B_4C layers on both sides, and a proper electric field configuration

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

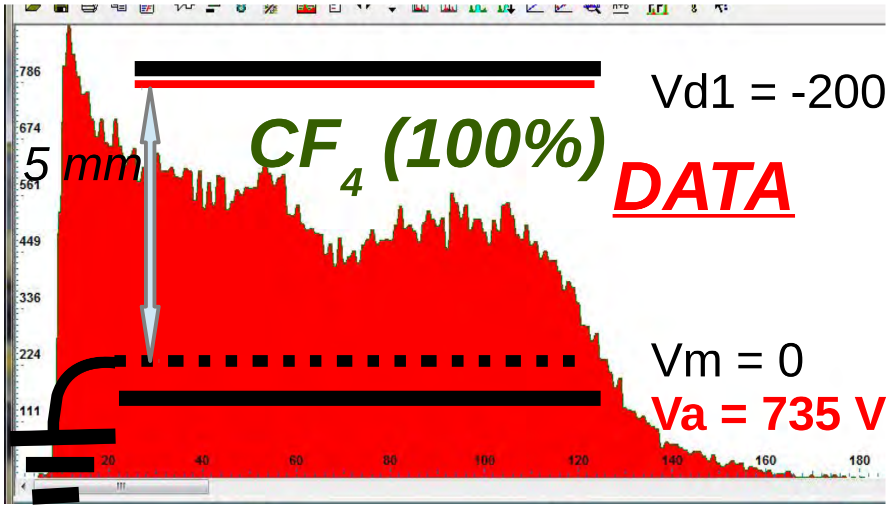


using FLUKA MC

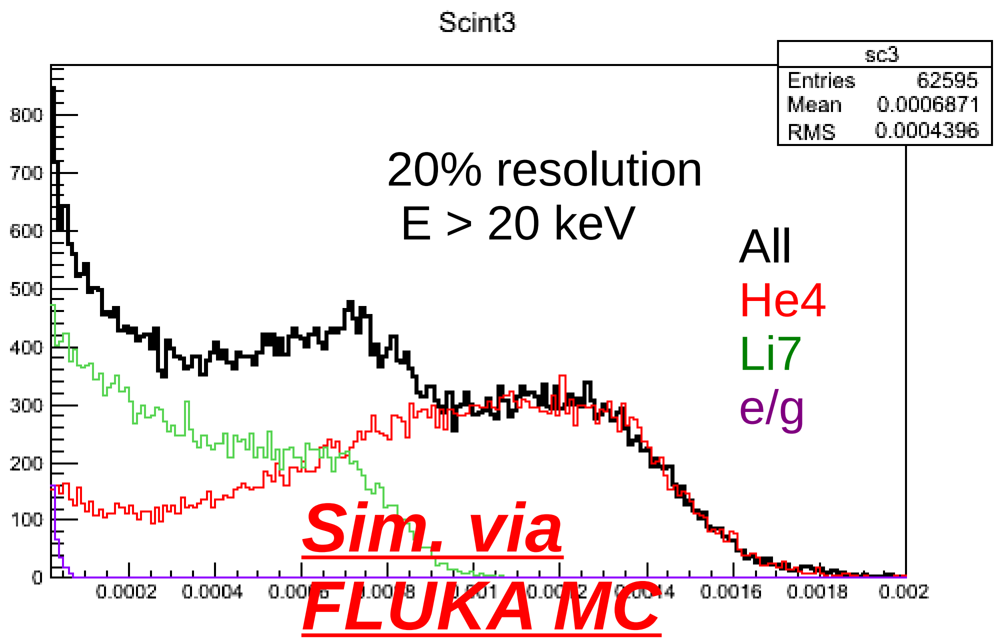
A “2-double 3-mesh detector unit” (28 B_4C layers)



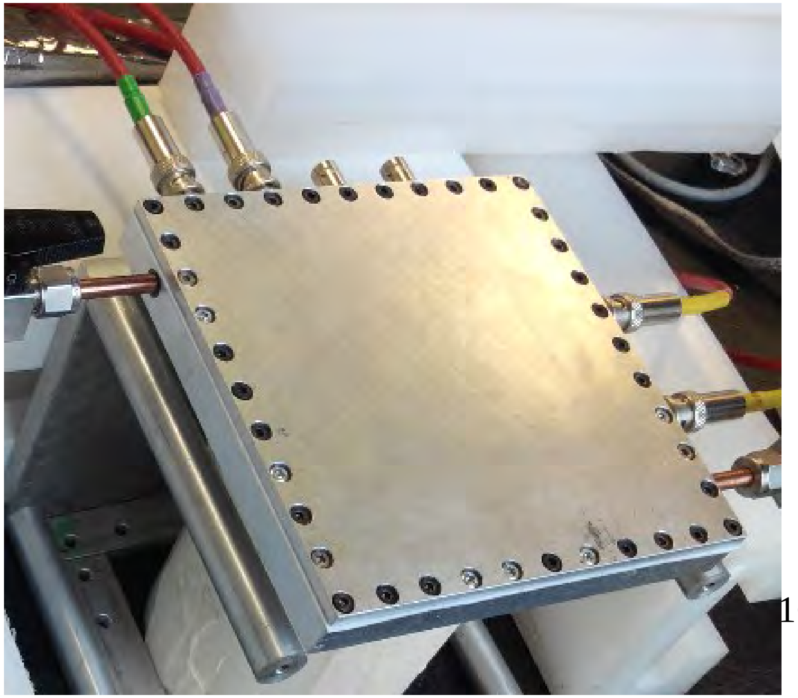
Measurements / simulations

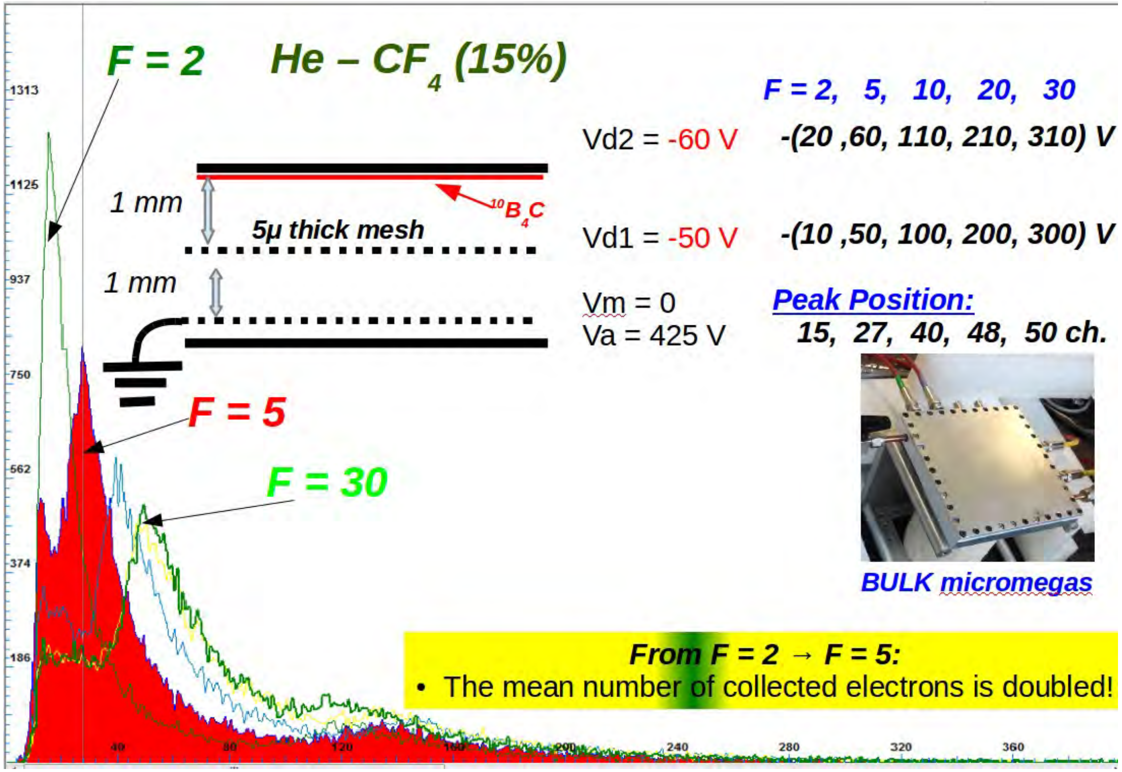


Cf-252 source
Total Rate ~ 13.16 Hz

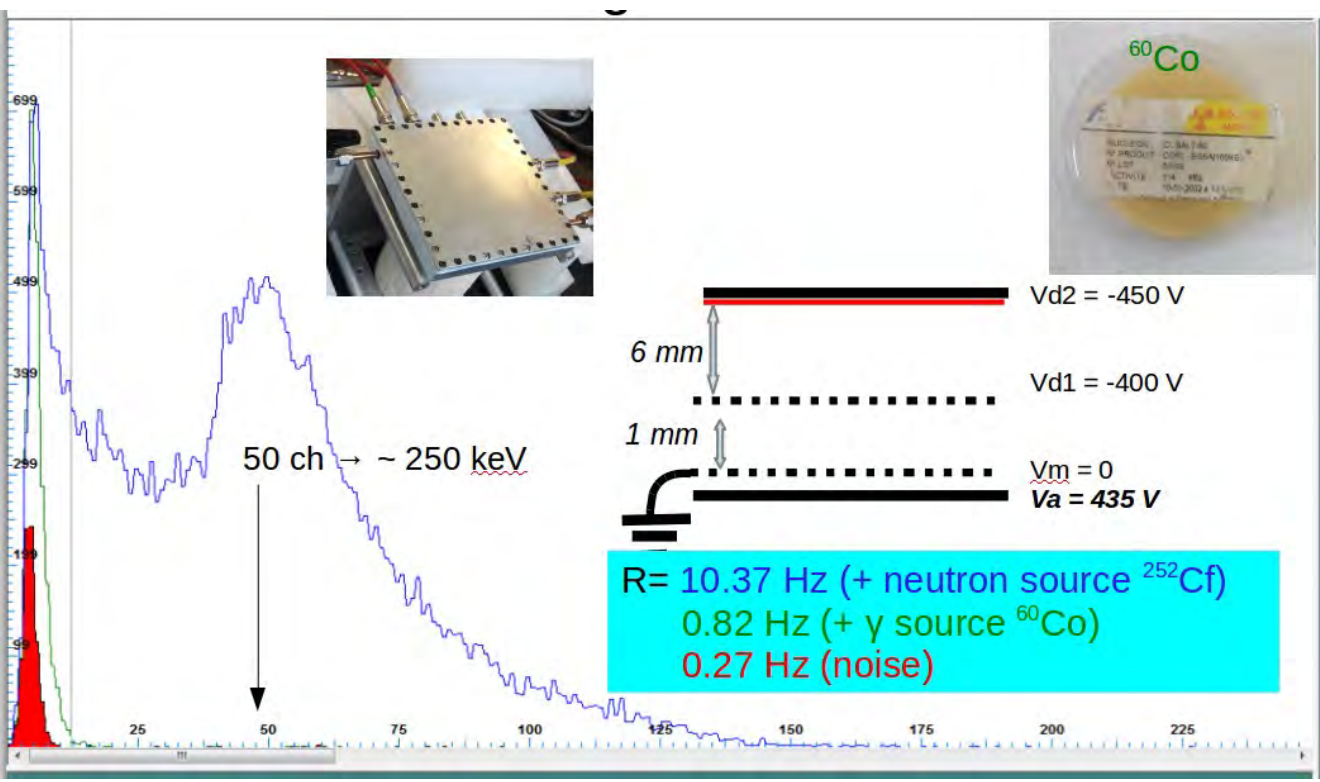


Here the ***Mesh*** channel was connected to ground, the ***Drift*** channels through a filter to a CAEN HV power supply, and the ***Anode*** through a preamplifier (PA) to a CAEN HV as well. The detector scores counts from thermal neutrons originated from the ^{252}Cf neutron source. The ***detector signal spectrum*** was measured using a Multi-Channel Analyzer program (MCA) to process detector signals produced by the detector, measure the pulse height and obtain the pulse height spectrum, which is the number of counts as a function of the MCA channel.

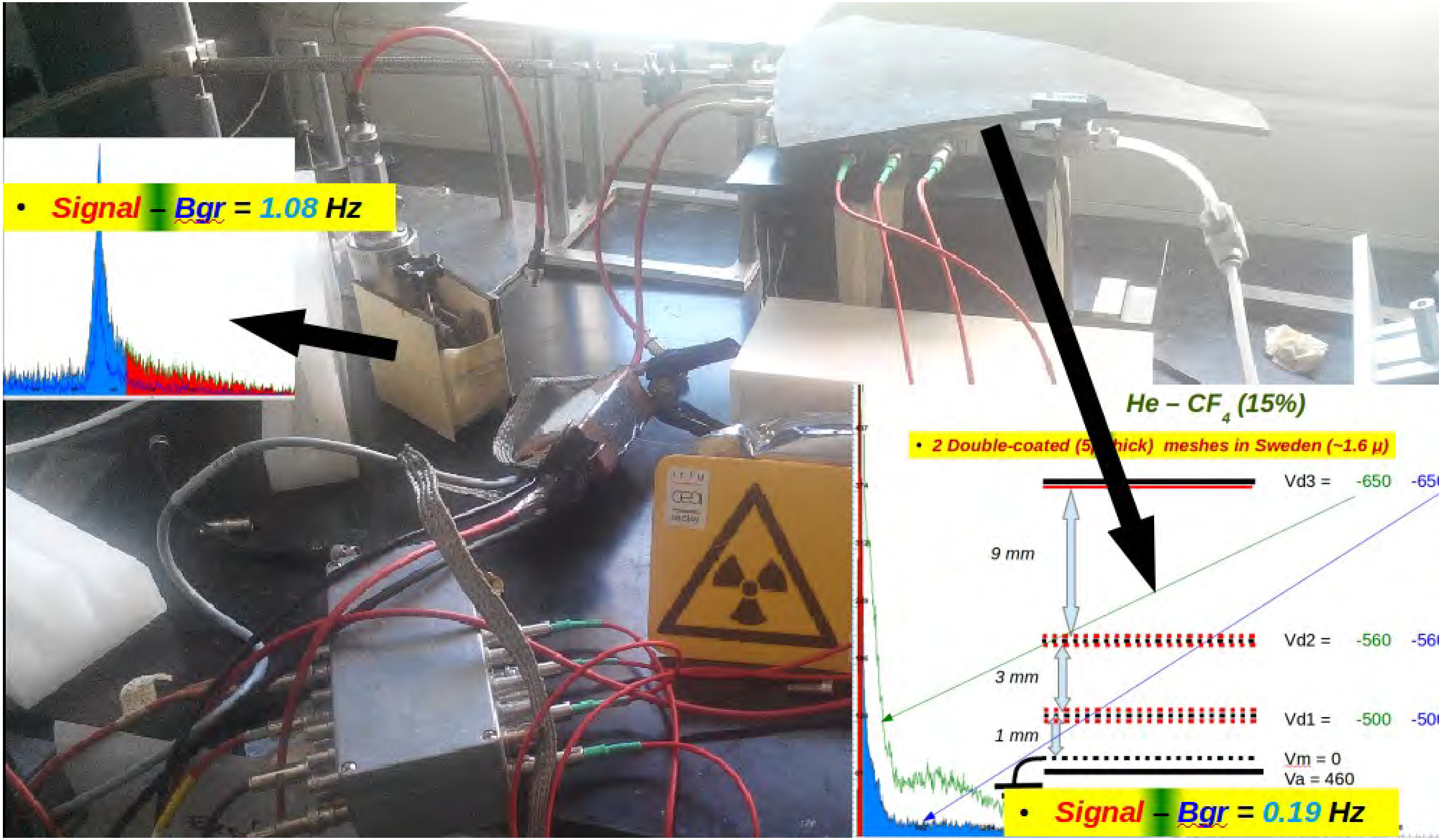




Data measured during 3000 s for each run for a field factor F = [2, 5, 10, 20, 30] to get the collected electrons from the single-coated aluminum end plate.



Data measured during 3000 s for each run, using a neutron source ^{252}Cf, a gamma source ^{60}Co and without any source in order to evaluate the level of the electronic noise and the contamination from gammas, on a single detector unit equipped with a B_4C single-coated aluminum end plate and two drift regions separated by a Ni mesh.



Evaluation of the thermal neutron detection efficiency of a single 2-mesh detector unit equipped with 5 layers of B_4C (right), compared to a ^{3}He tube detector (left).

5-layer prototype performance

Comparison with commercial ^{3}He tube:

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

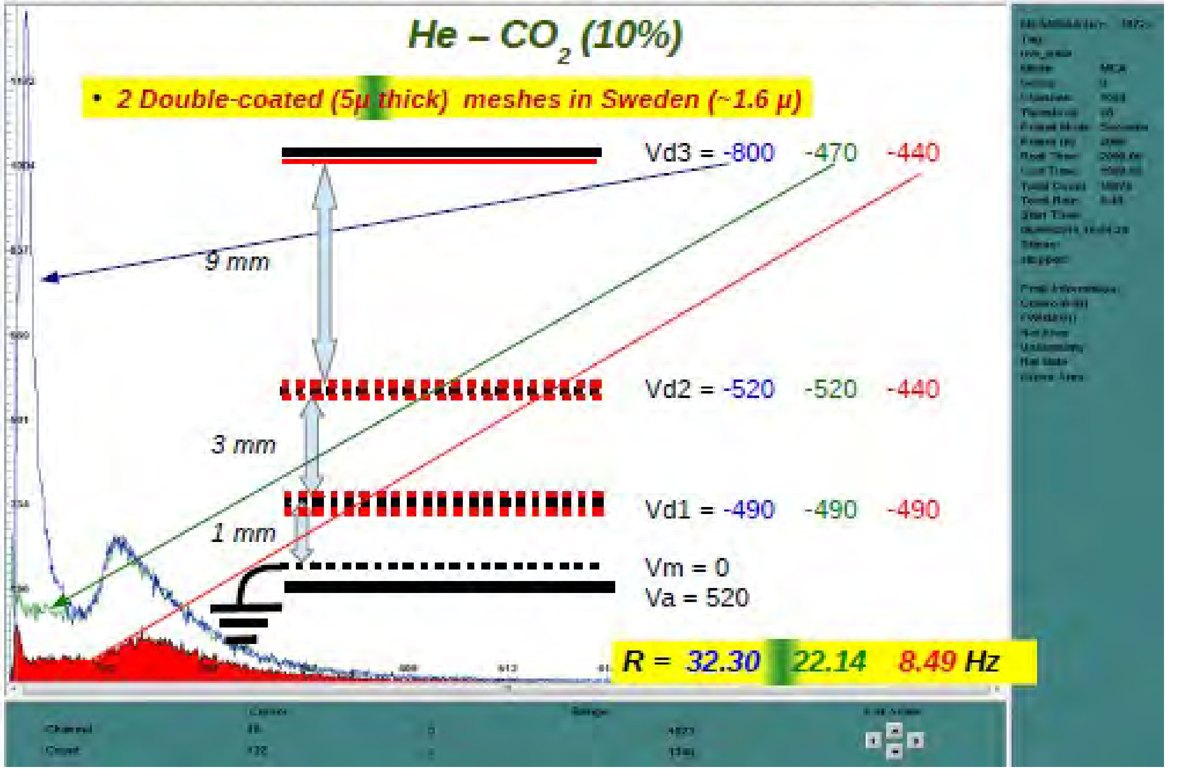
Satisfactory result

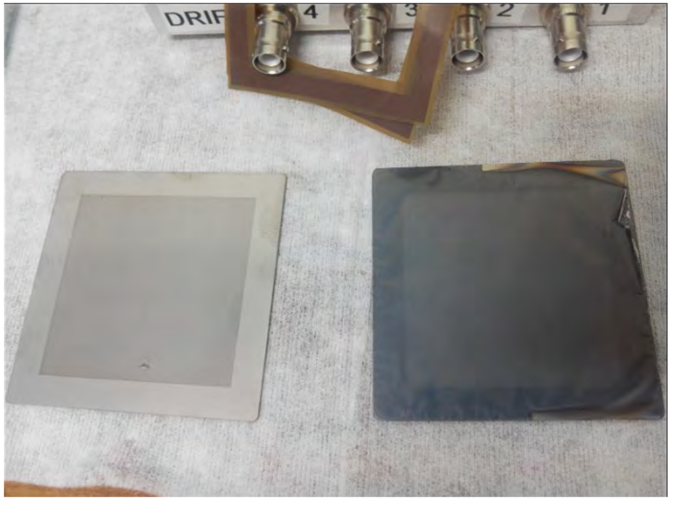
but:

- **Electron transmission too low when mesh thickness >> 5 µm**
- **Mesh deformed during B_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

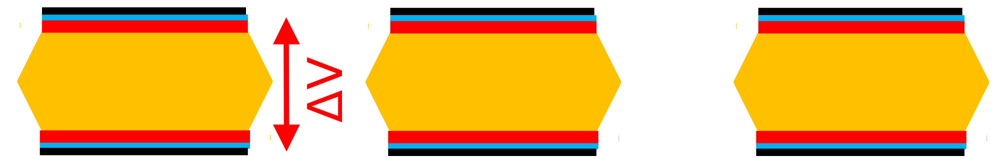




Alternative 1: Kapton mesh (GEM-type)

12.5 µm Kapton mesh

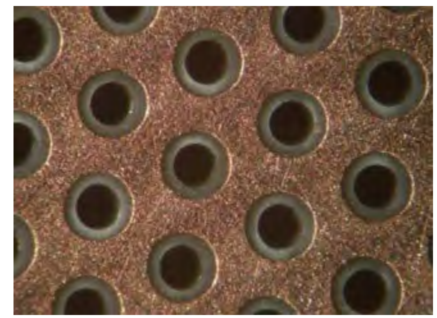
- double-side coated with 3-4 µm Cu
- double-side coated with 1 µm Ni
- double-side coated with 1.5 µm B_4C

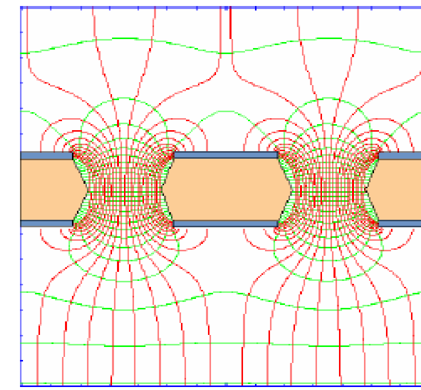


ΔV (10-50 V) applied between the two Cu layers
 electric field strong enough for sufficient electron transmission

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

GEM-type kapton mesh

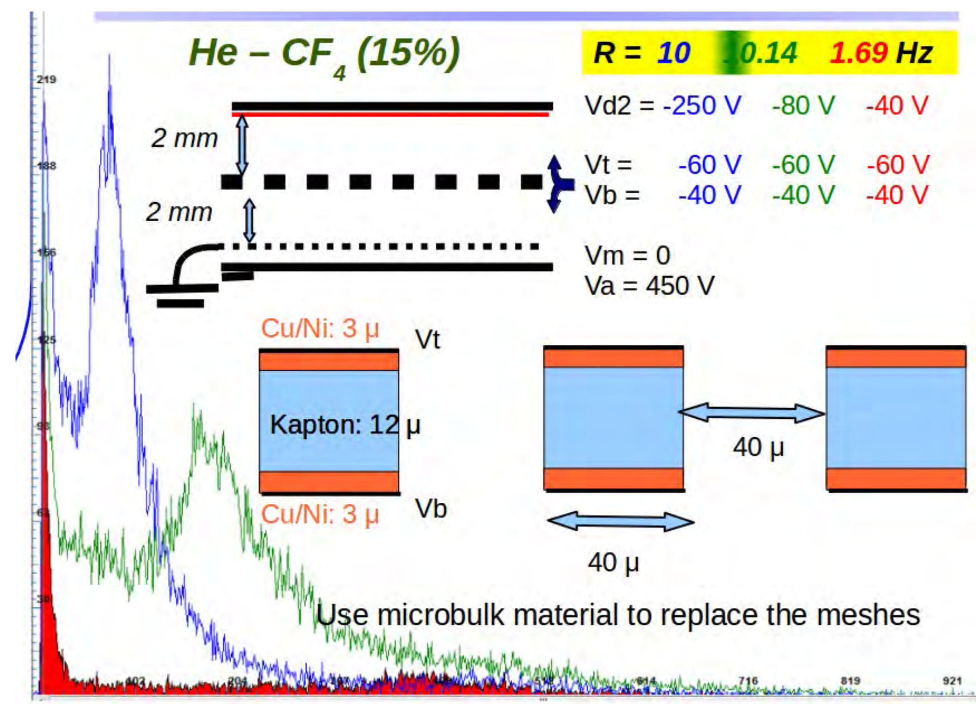




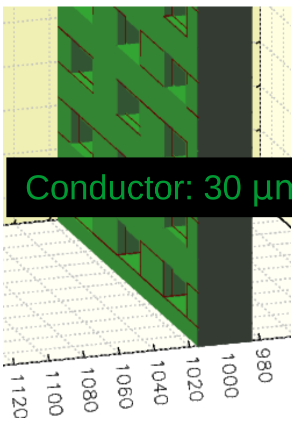
- ✓ **Mesh is cheap and robust**
- ✓ **Big surfaces possible (1×0.5 m^2)**

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

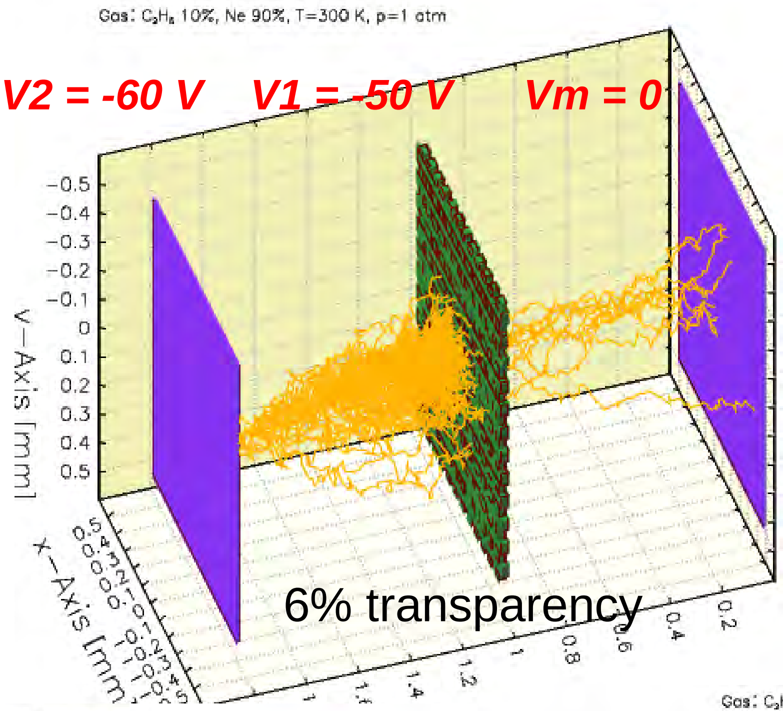
- ➢ Use pure ^{10}B
- ➢ Use a transparent mask (micromesh) during deposition of B_4C



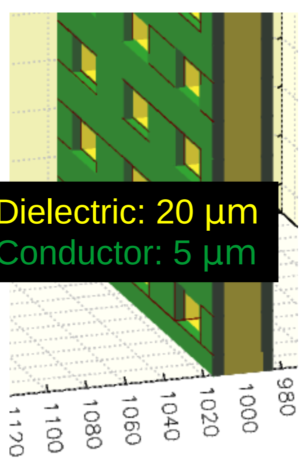
Simulation / box model (garfield-nebem)



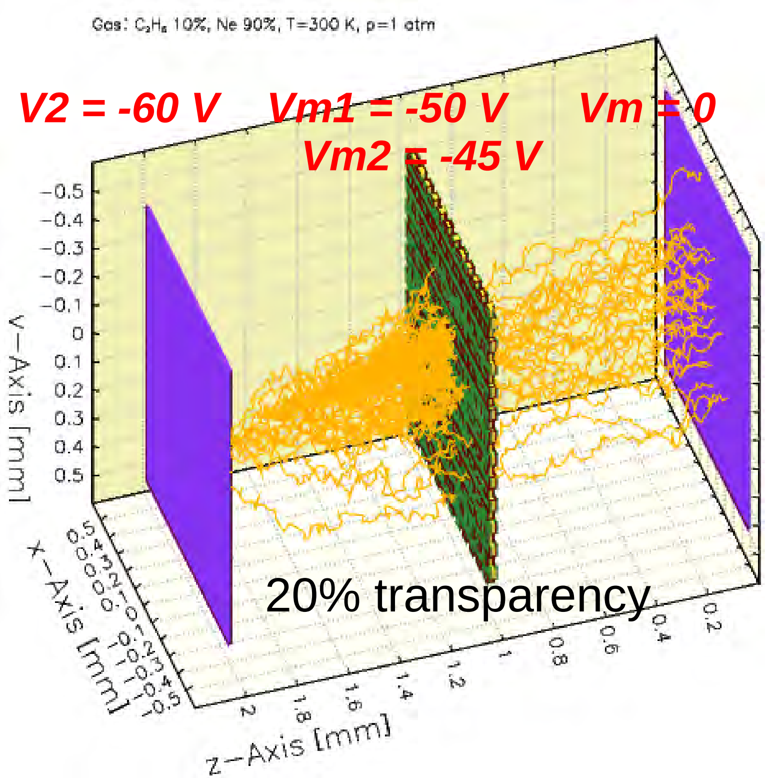
Box diam = 40 µm
Hole diam = 40 µm

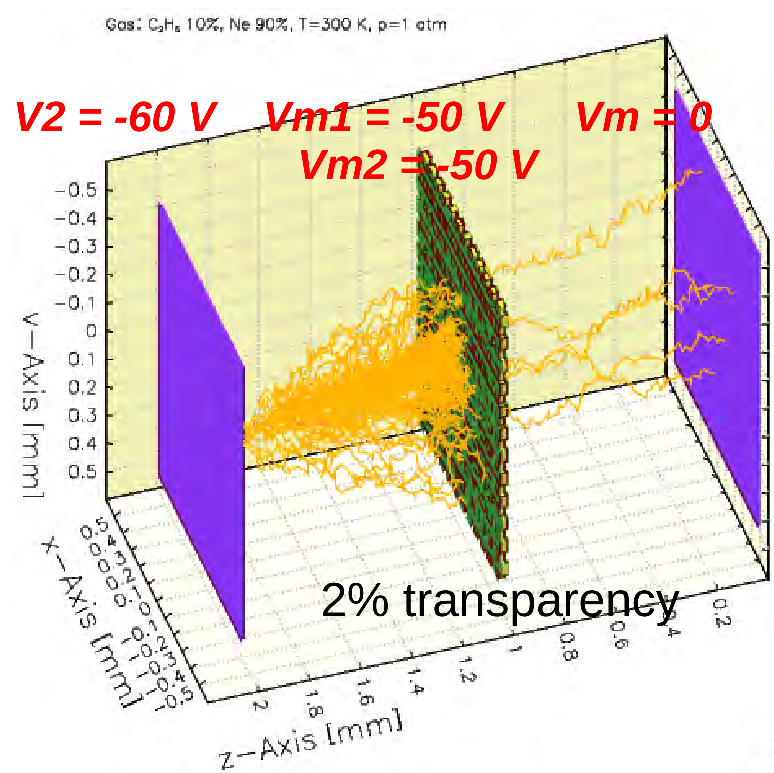


Ne – C_2H_6 (10%)

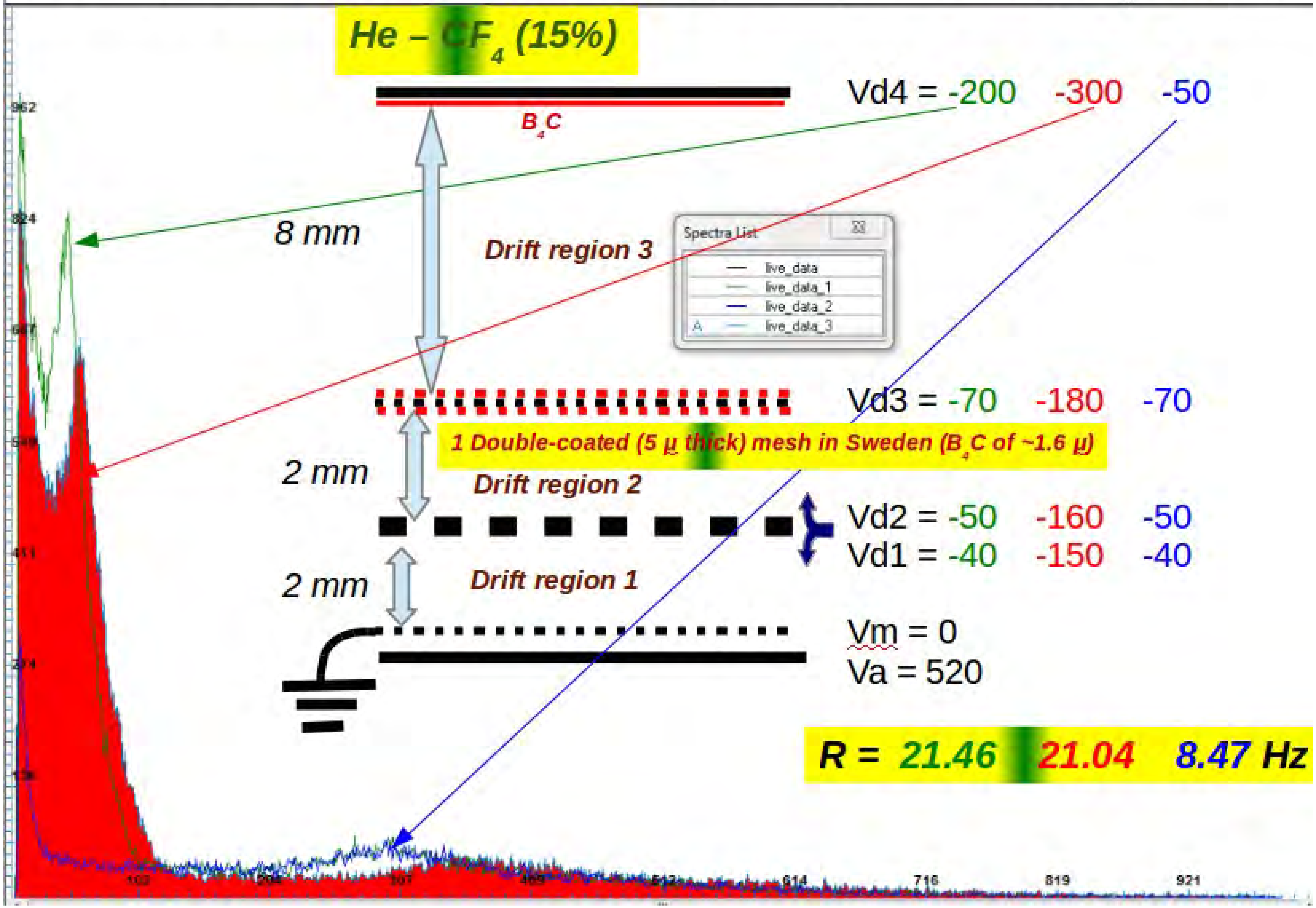


Box diam = 40 µm
Hole diam = 40 µm

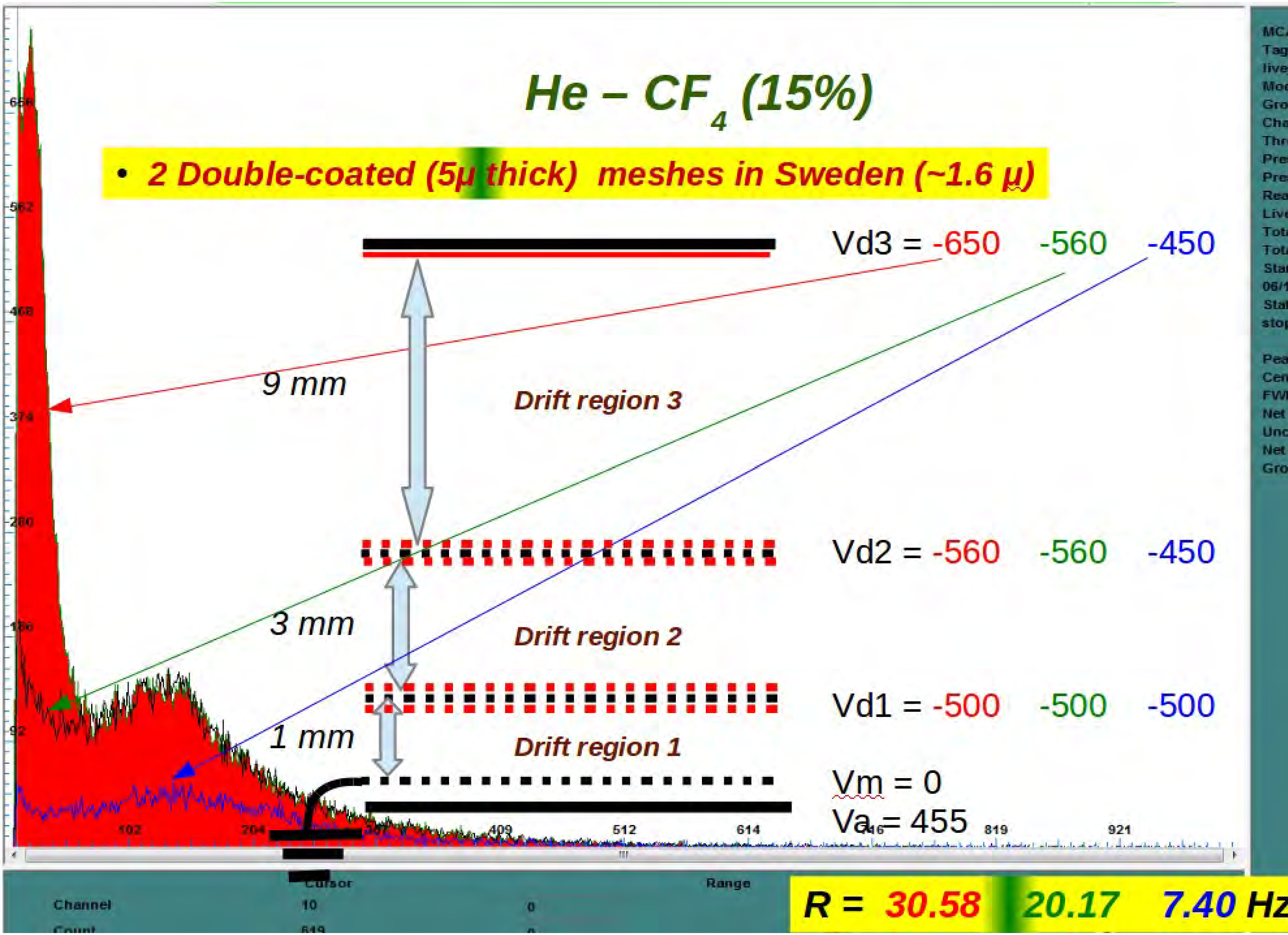




Using a GEM type mesh → 2 ind. V + 1 double coated B_4C mesh

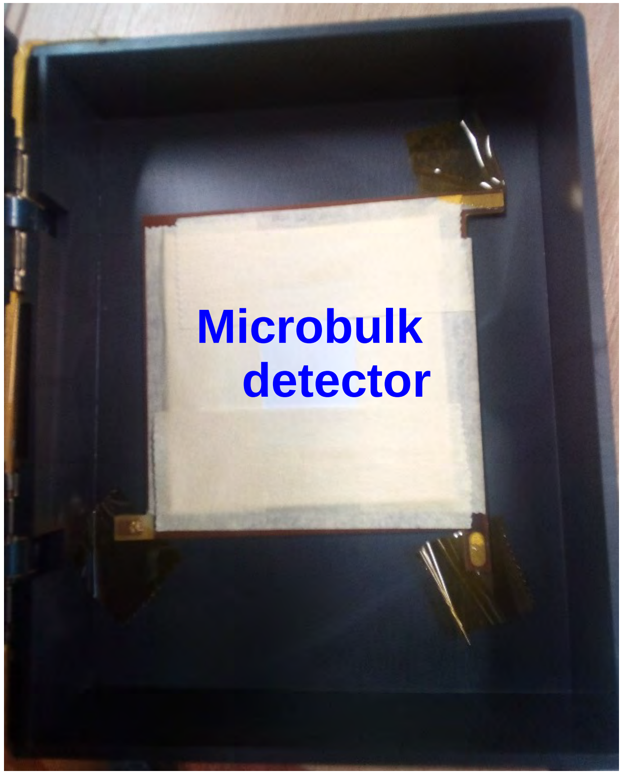


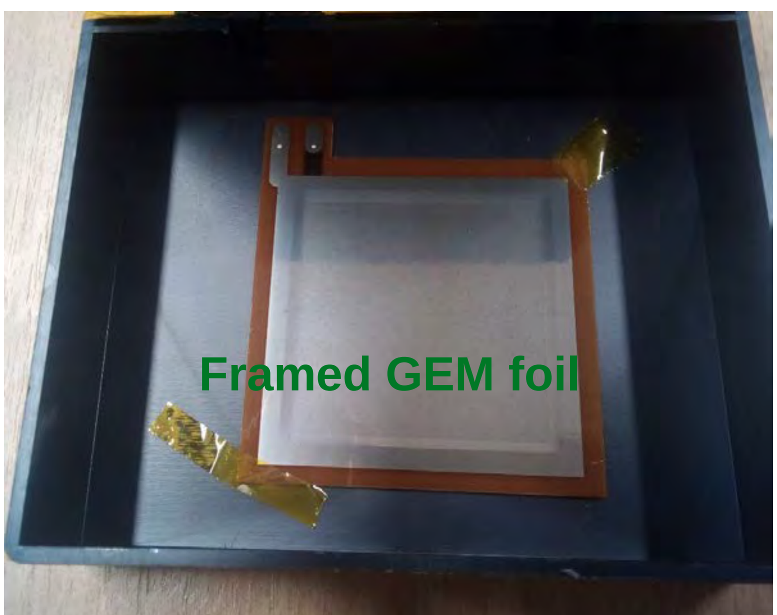
Data measured during 3000 s for each run, combining an uncoated GEM type kapton mesh and a double coated Nickel mesh in the same set-up.

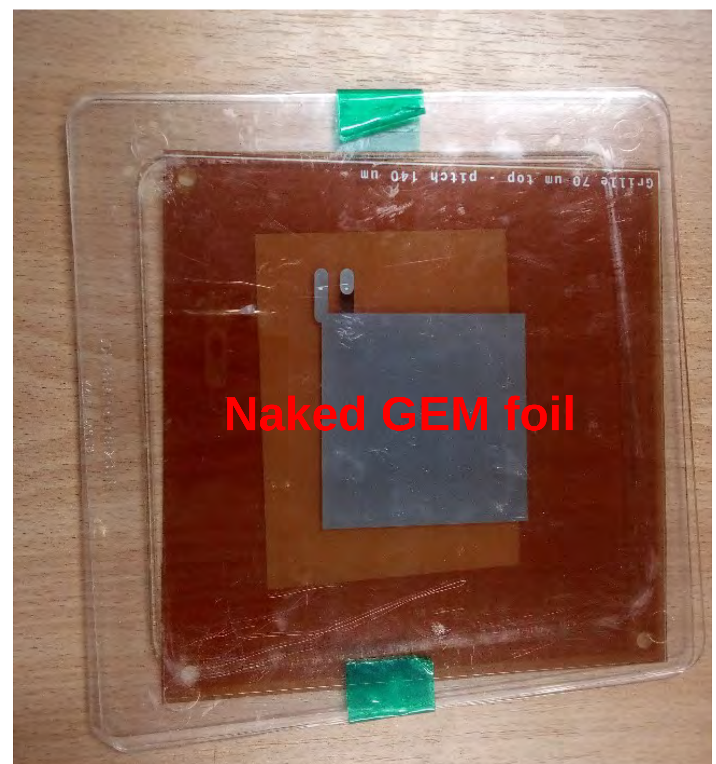


Data measured during 1500 s for each run, using a single 2-mesh detector unit equipped with 5 layers of B_4C .

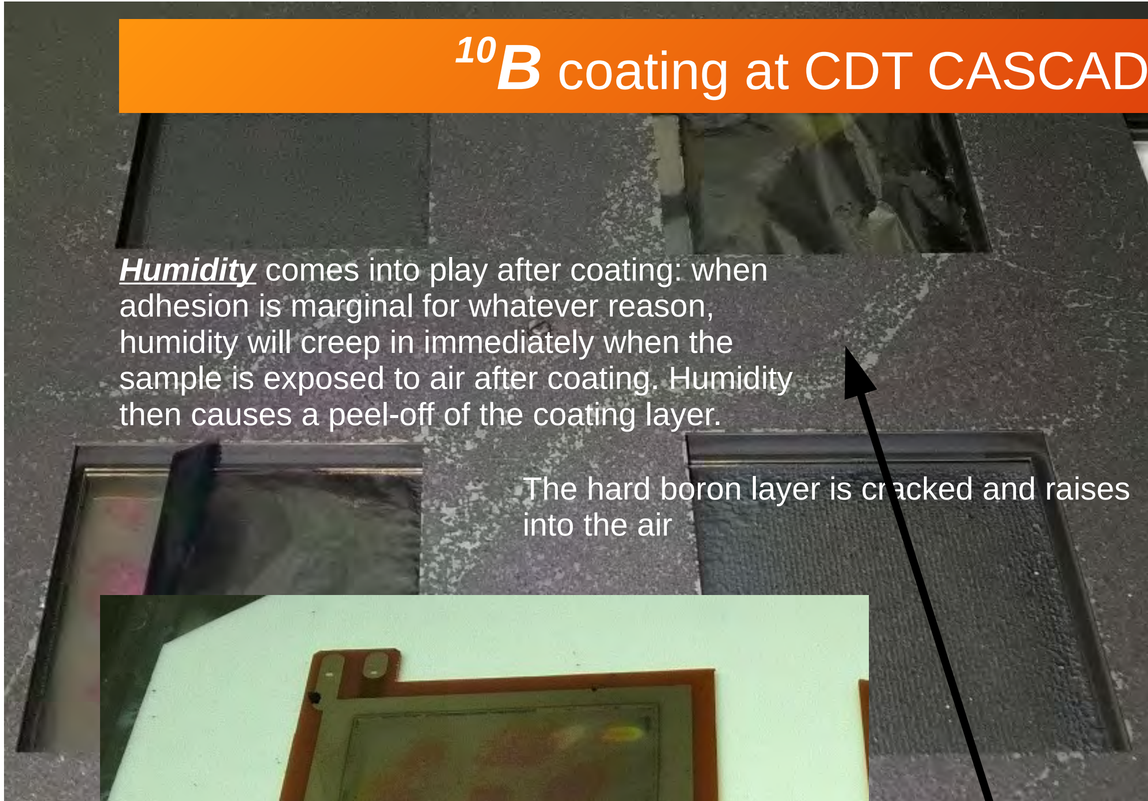
Devices with Nickel coating are received from CERN







^{10}B coating at CDT CASCADE Detector Technologies

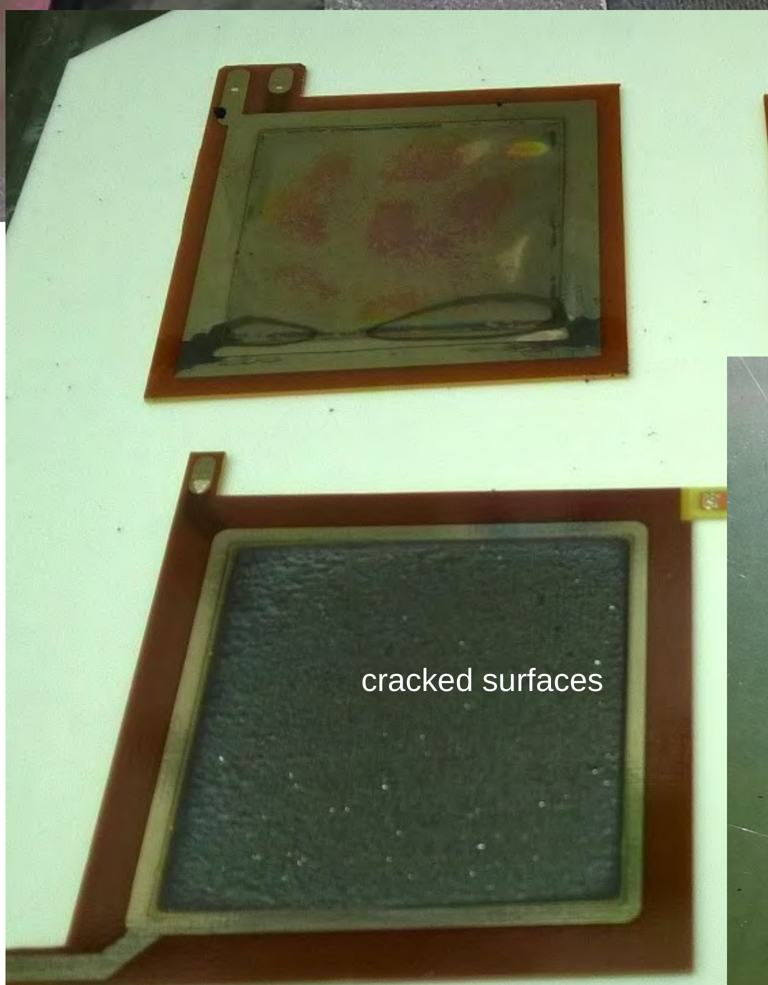


Humidity comes into play after coating: when adhesion is marginal for whatever reason, humidity will creep in immediately when the sample is exposed to air after coating. Humidity then causes a peel-off of the coating layer.

The hard boron layer is cracked and raises into the air

An electron beam evaporator is used to make the thin ^{10} B film

→ The coating looked good and stable as well as for the naked GEMs as for the reused framed GEMs (adhesion tests e.g. including tesa film tests and tests within a ultrasonic bath)



cracked surfaces

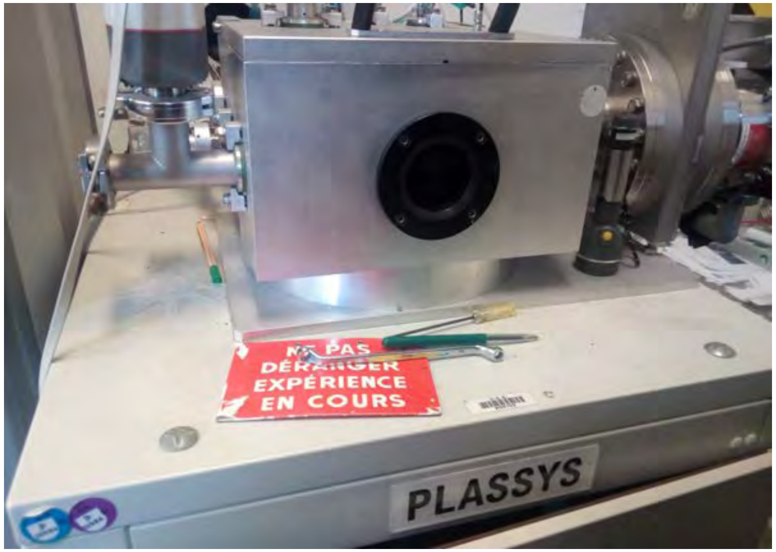
inside the frame holder for coating (thermal shield)

a reused framed GEM after special cleaning and treatment of the surface

==> Provide naked foils before framing

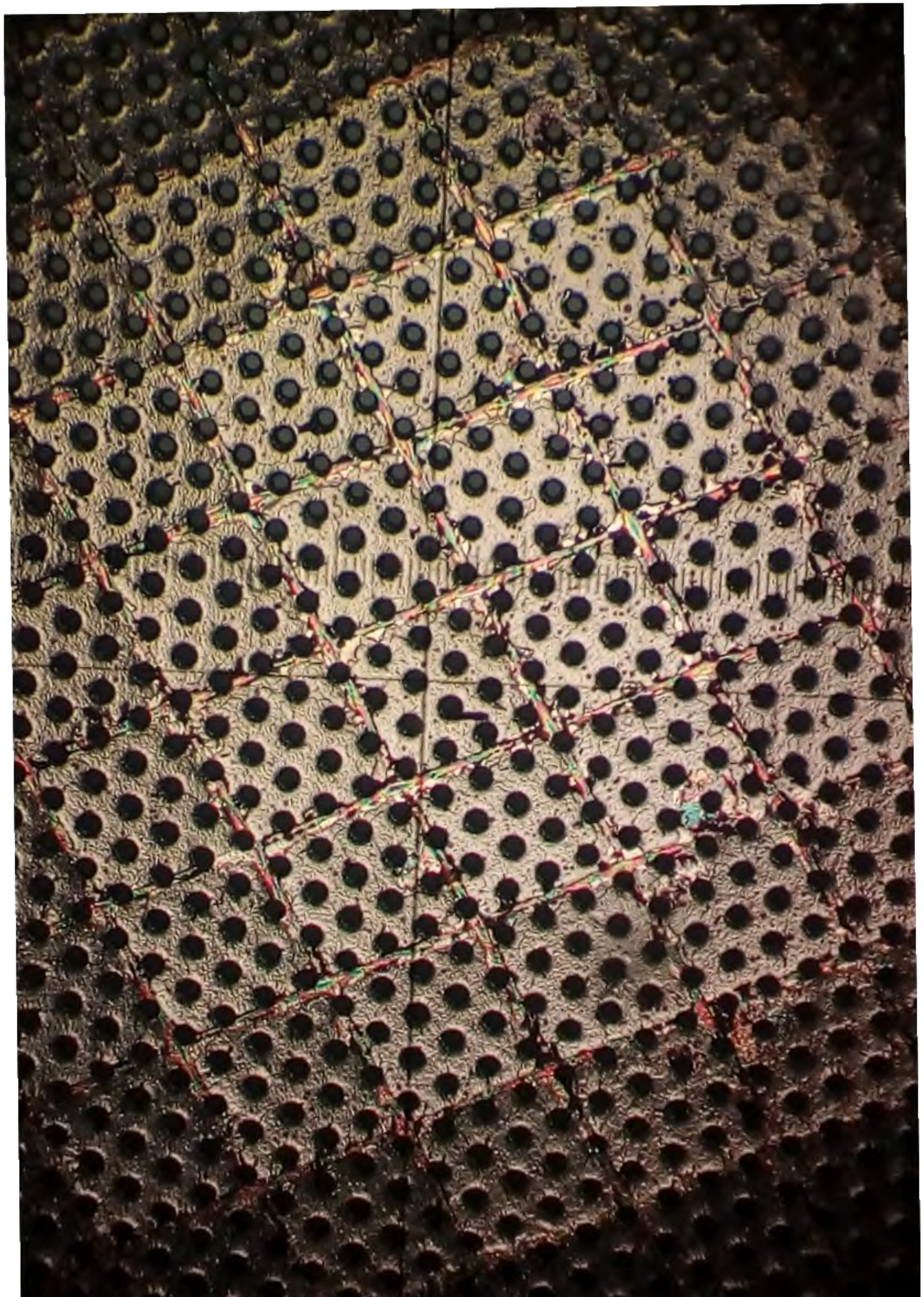
==> Need for GEMs (framed or unframed) as well as microbulk detectors ***without the nickel coating***

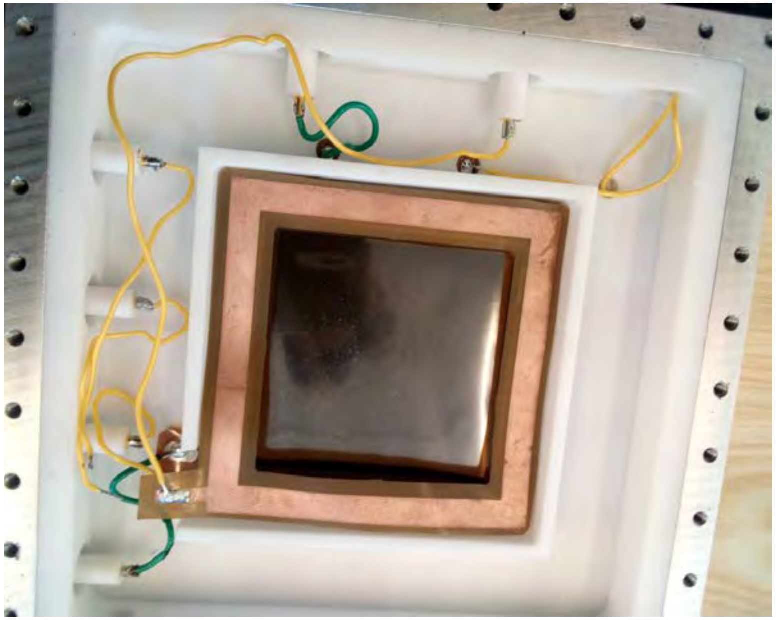
$^{10}B_4C$ coating with a PVD sputtering machine at CEA (by M. Pomorski)



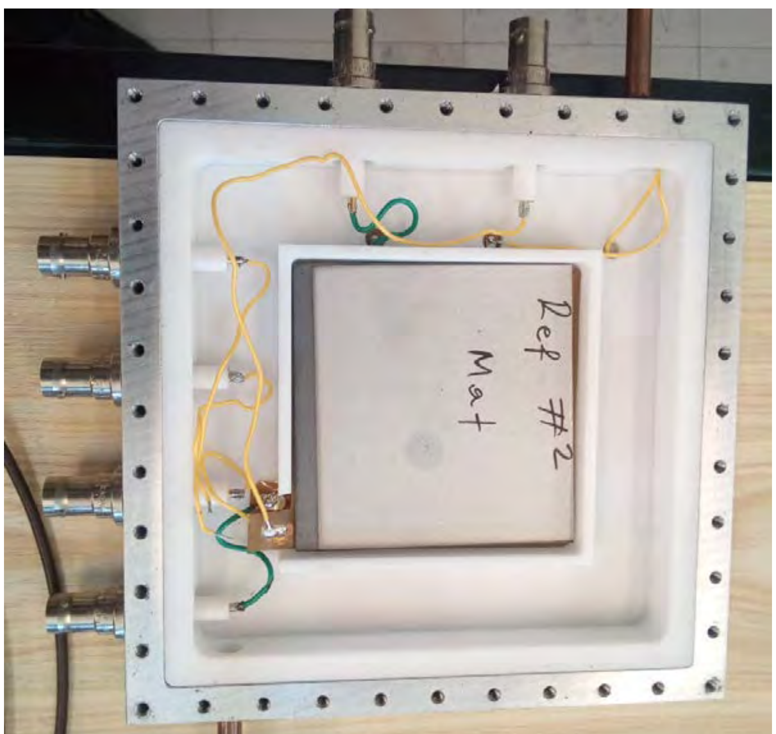
Coated with ~ 1 µm B_4C

Naked GEM foil in a sandwich panel
– mesh mask and protected plate –

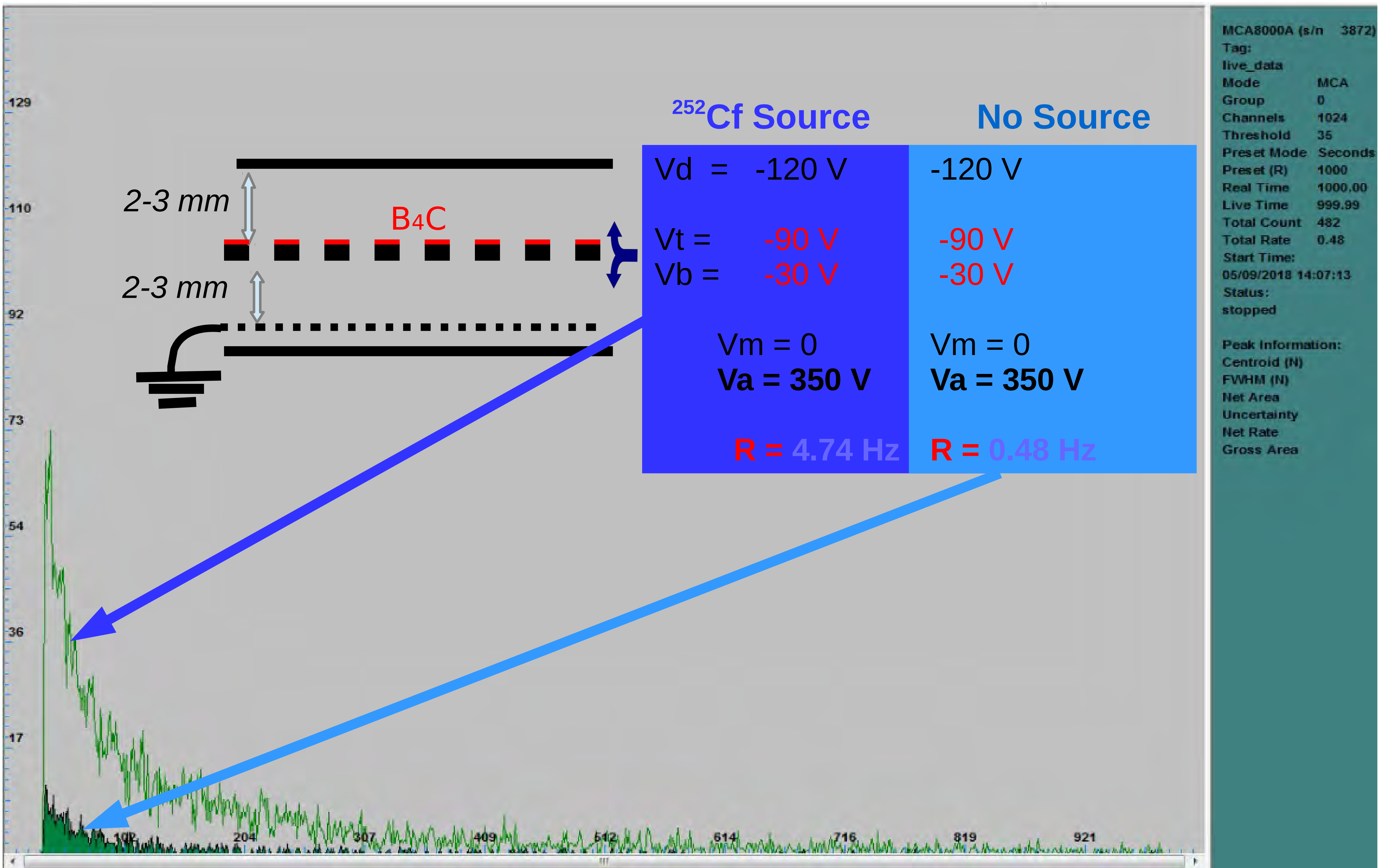




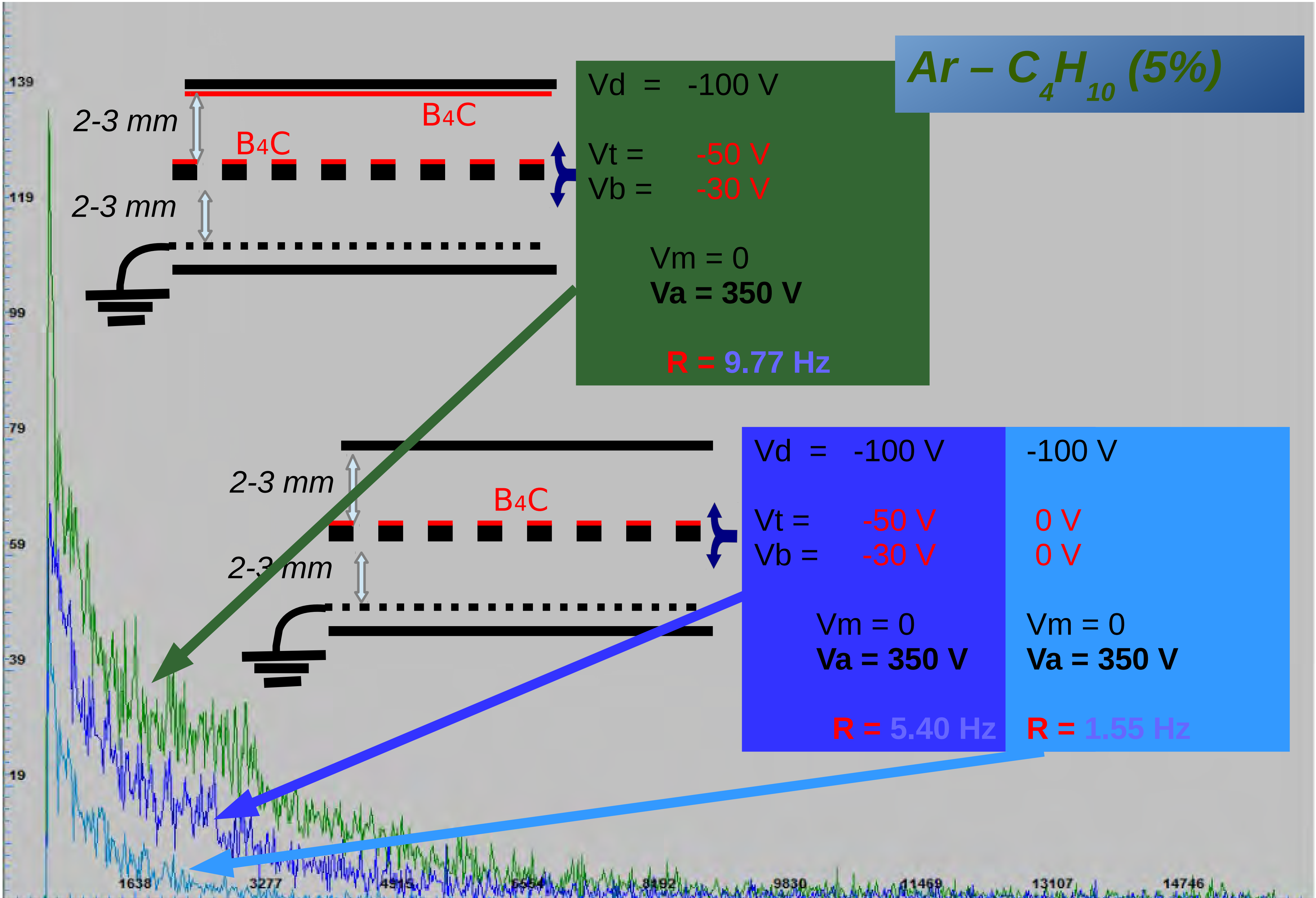

Source
Radioactive


Ref #2
Mat


File
Vertical
Timebase
Trigger
Display
Measure
P2:min(C1)
value -16 mV
mean -21.76 mV
min -22 mV
max -16 mV
sdev 1.92 mV
num 10
status
C1 DC1M
200 mV/div
16.0 mV ofst
436 mV
C2 DC50
1.00 V/div
0 mV offset
2.26 V

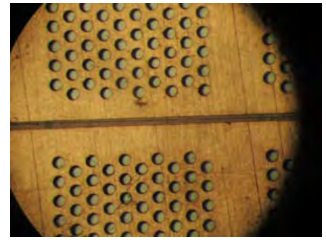


252Cf Source
No Source
Vd = -120 V
-120 V
Vt = -90 V
-90 V
Vb = -30 V
-30 V
Vm = 0
Va = 350 V
Vm = 0
Va = 350 V
R = 4.74 Hz
R = 0.48 Hz
2-3 mm
B4C
2-3 mm
129
110
92
73
54
36
17
102
204
307
409
512
614
716
819
921
MCA8000A (s/n 3872)
Tag:
live_data
Mode MCA
Group 0
Channels 1024
Threshold 35
Preset Mode Seconds
Preset (R) 1000
Real Time 1000.00
Live Time 999.99
Total Count 482
Total Rate 0.48
Start Time:
05/09/2018 14:07:13
Status:
stopped
Peak Information:
Centroid (N)
FWHM (N)
Net Area
Uncertainty
Net Rate
Gross Area

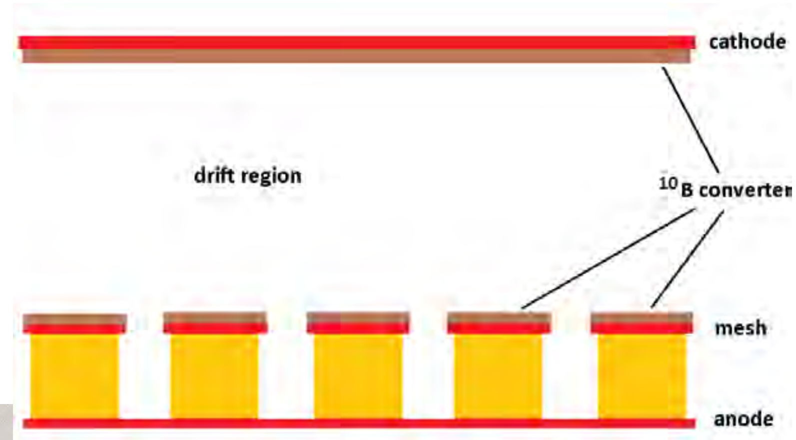


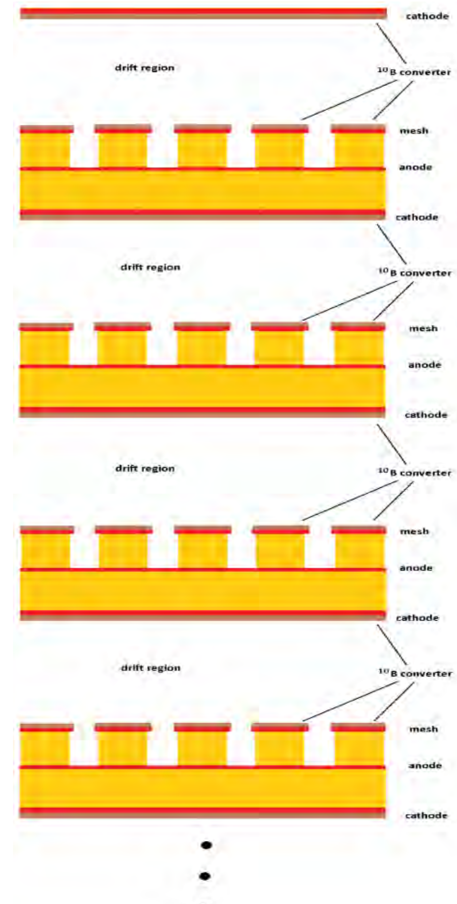
Ar – C4H10 (5%)
2-3 mm
B4C
B4C
2-3 mm
Vd = -100 V
Vt = -50 V
Vb = -30 V
Vm = 0
Va = 350 V
R = 9.77 Hz
2-3 mm
B4C
2-3 mm
Vd = -100 V
Vt = -50 V
Vb = -30 V
Vm = 0
Va = 350 V
R = 5.40 Hz
-100 V
0 V
0 V
Vm = 0
Va = 350 V
R = 1.55 Hz
139
119
99
79
59
39
19
1638
3277
4915
6554
8192
9830
11469
13107
14746

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)



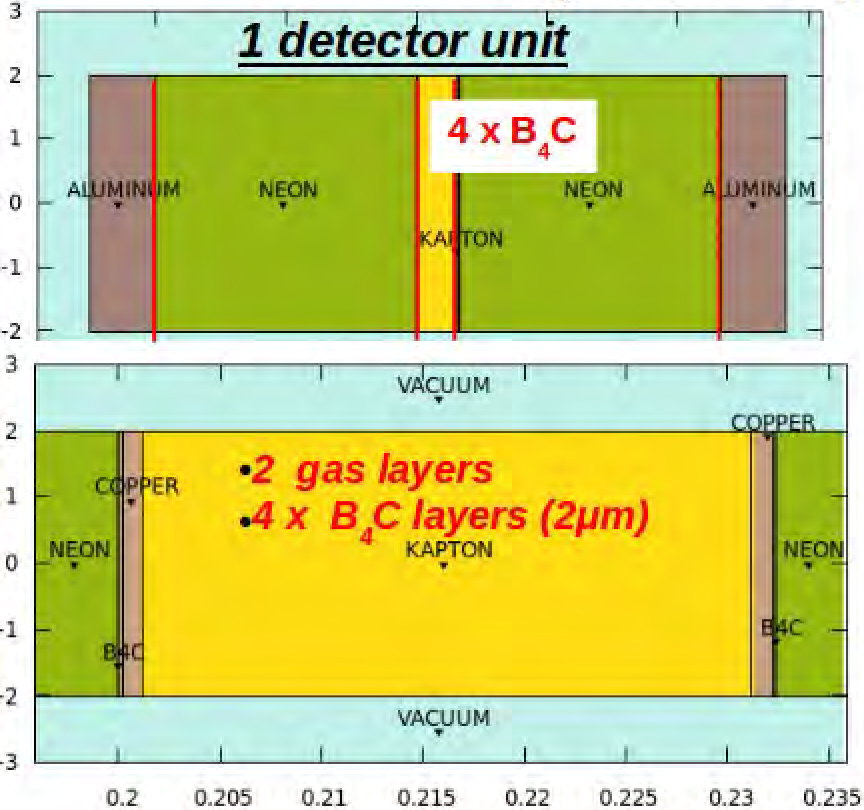


- ✓ Unit can be very thin (~1 mm)
- ✓ Low material budget
- ✓ Common / independent readout possible

- 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 several 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.

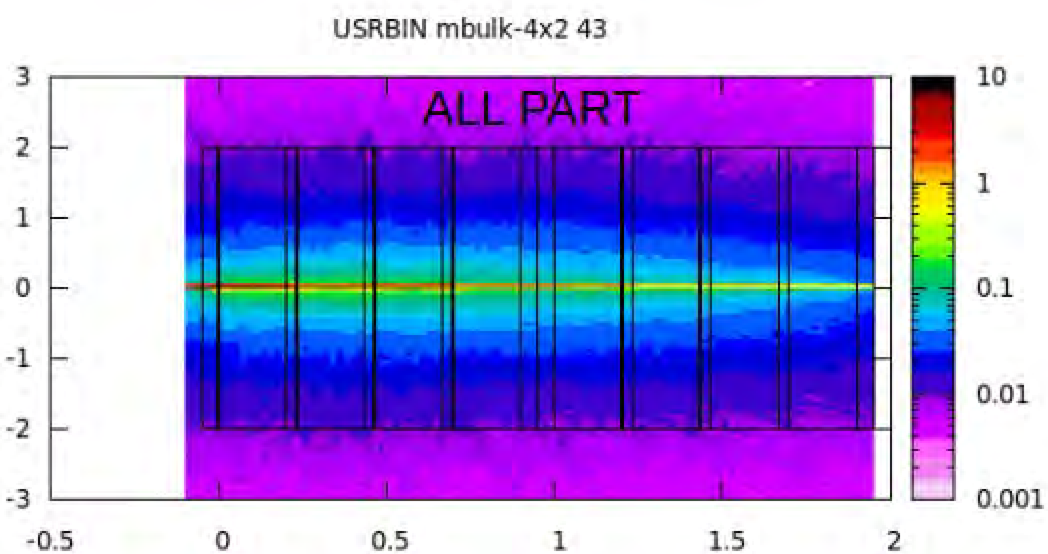
Implementing the microbulk technology

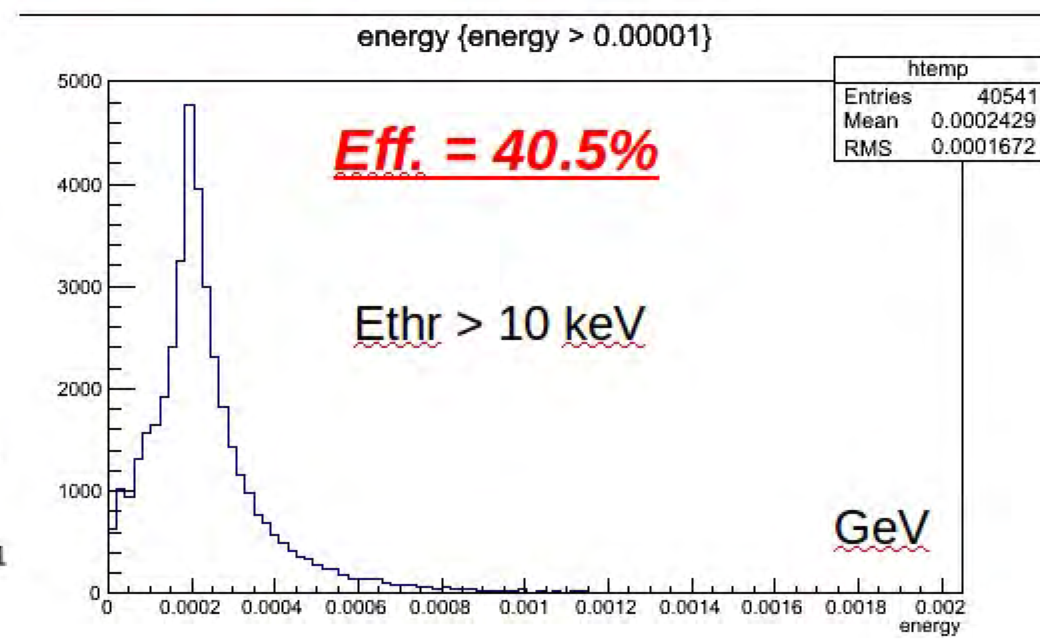


- 2 Al end plates 4 x 4 cm: 0.5 mm thick
- 2 Gas layer Neon: 2 mm thick
- 4 layers of converter B_4C: 2 μm thick
- 1 Kapton layer: 300 μm thick
- 2 Copper layers: 10 μm thick

using FLUKA MC

- ***2 x 4 detector units***
- ***8 gas layers***
- ***16 x B_4C layers (2μm)***

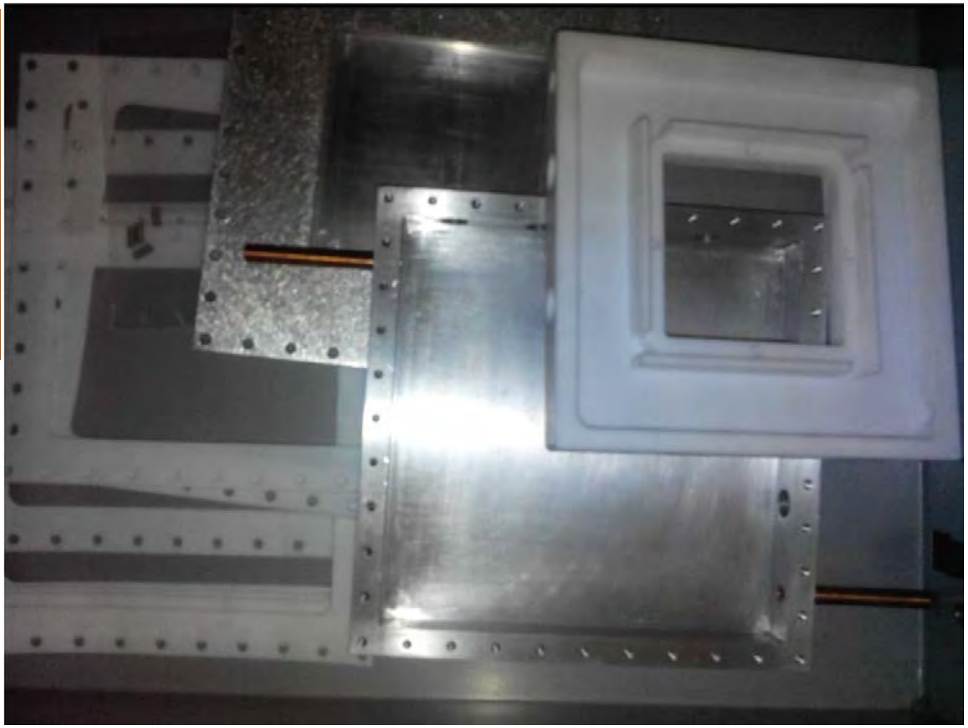




SINE2020 Work Program

Original idea :

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



- ***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 back-to-back microbulk 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 and/or ^{10}B*** on Micro-bulk raw material are on going
- ***Simplified concept : Start testing*** of a prototype where mesh is replaced by micro-bulk layer

Outlook

SINE2020: tests of coating with ^{10}B the microbulk / kapton (GEM type) meshes, testing of the prototype + measurements with neutron sources and optimization of the applied electric field and the gas distances for various gas mixtures to achieve the maximum recorded thermal neutron efficiency.

● Testing the new GEM foils with/without frame and the microbulk detectors that were ordered from CERN and were sent in Heidelberg to be coated double-sided by the CDT GmbH company with pure ^{10}B . Problems on Nickel coated devices but seem to work with the conventional Copper coated ones.

● Continue $^{10}B_4C$ depositions at CEA and Sweden (Linkoping University??) by using a mesh like a mask in front of the kapton mesh for achieving a not uniform deposition hoping there will be no problems with the thermal expansion. Low power deposition with sputtering without heating and plasma/Ar cleaning of kapton mesh before coating to avoid oxidation. First results on depositing $^{10}B_4C$ on Nickel coated GEM foils look very promising.

● New simulations with Nebem/garfield 3D are planned taking into account the GEM type mesh where 2 independent voltages can be applied on top/bottom, and estimate the transmission of electrons for different gases.

Summary

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

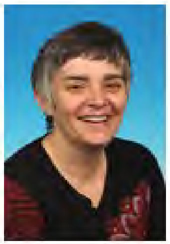
- A Micromegas equipped with several metallic (Ni) thin meshes coated with B_4C in both sides
  - ✓ Efficiency improvement as expected by the simulations
  - × Small electron transmission for thick (robust) meshes
  - × Deformation & fragility for thin meshes. Problem for large surface detectors
- A 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... Tests with ^{10}B in Cu or **B_4C in Ni**
- A stack of Microbulks coated with B_4C
  - ✓ Low material, thin detector
  - – Deposition of B_4C on the foil is difficult. Under study... Tests with ^{10}B

A large high-efficiency multi-layered Micromegas thermal neutron detector: 2017 JINST12 P09006

Back-up slides

Micromegas R&D

People involved at SEDI



eferrer

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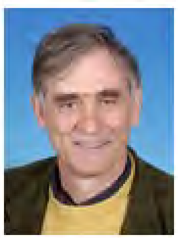
DSM//IRFU/SEDI/DEPHYS
Service d'Electronique, des

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



ioa

Ioannis GIOMATARIS

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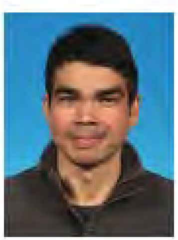
- Responsable scientifique



attie

David ATTIE

DSM//IRFU/SEDI/DEPHYS
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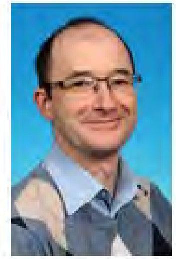
- Membre du CU du service
- Membre du CSTS



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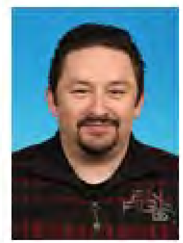

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Service d'Electronique,

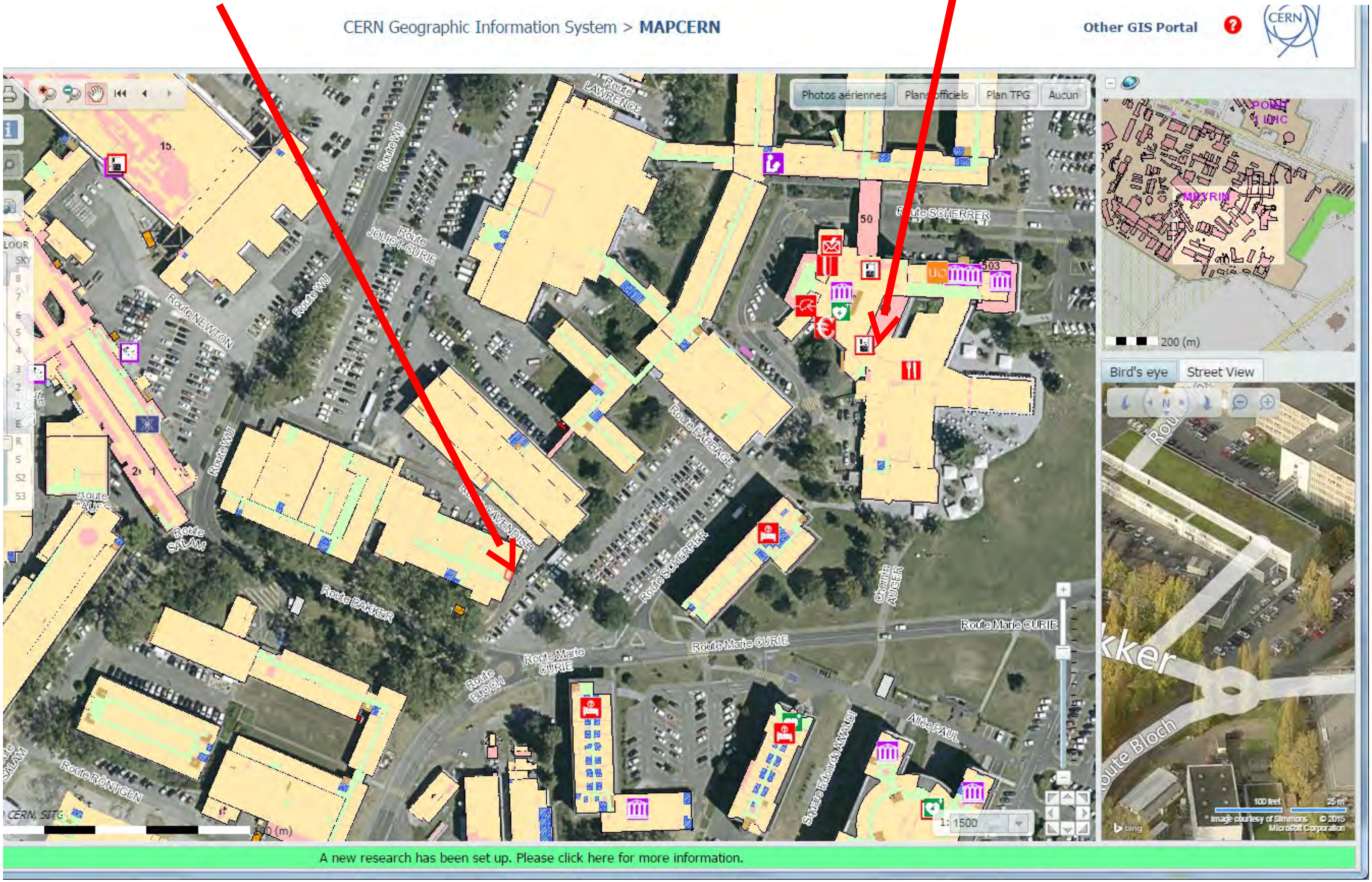
- Chef de projet

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

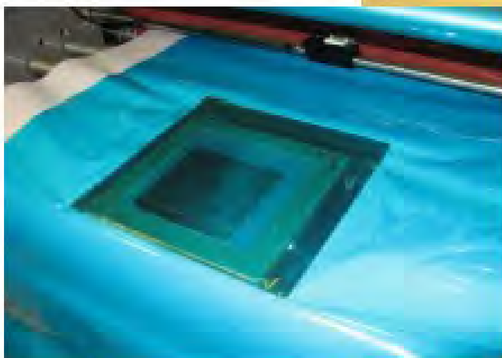
Micromegas R&D

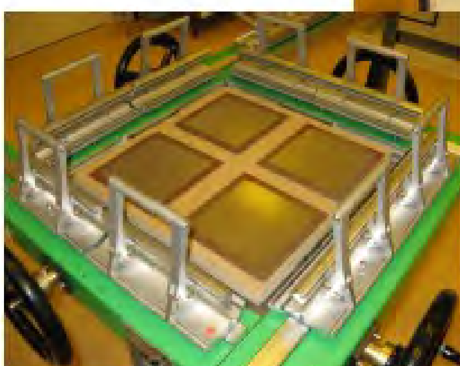
Close collaboration with the detector Lab of **De Oliveira, Rui** PH-DT-DD 102/R-018
tel: 73745 163931 (Rui.de.Oliveira@cern.ch)

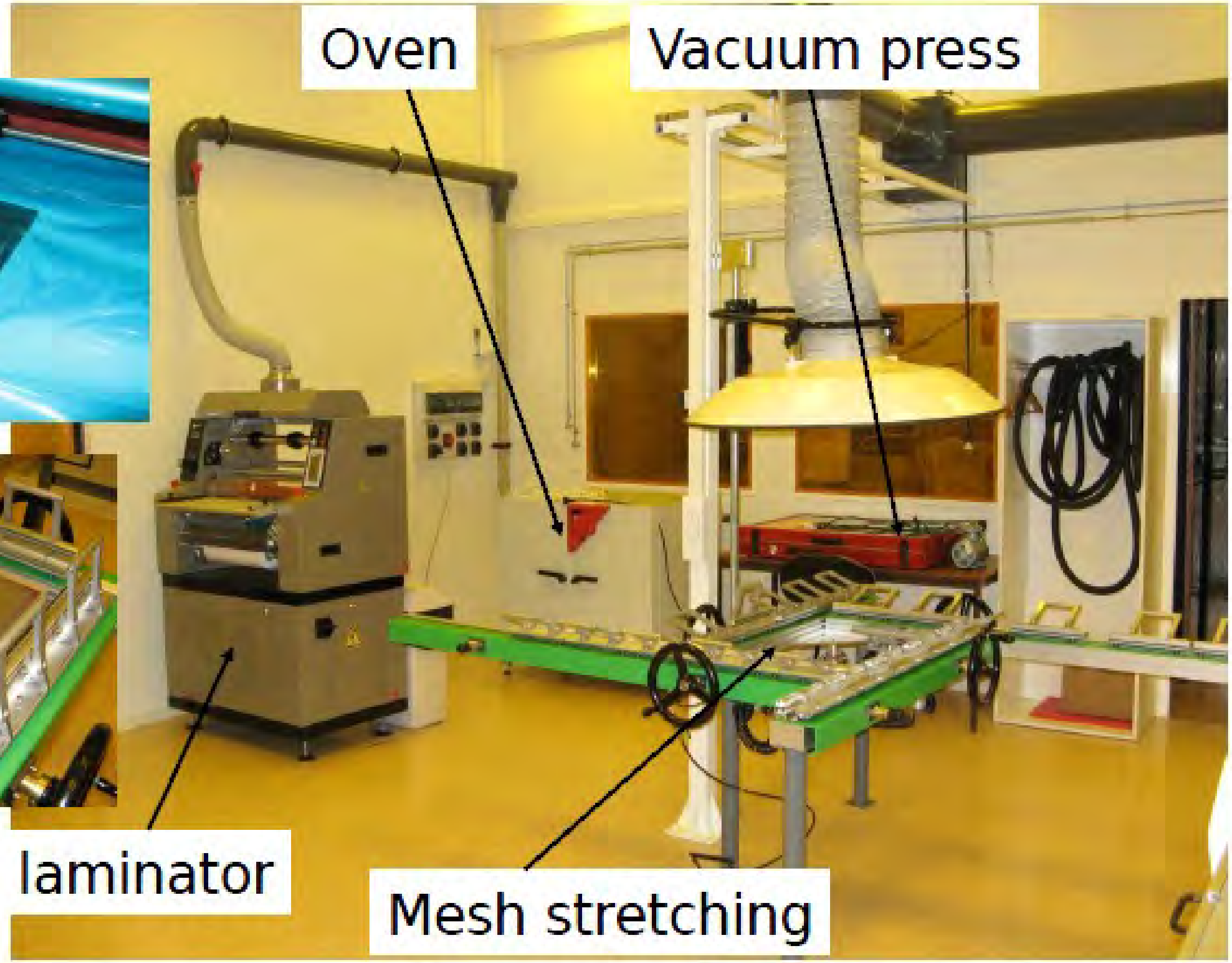
Main building – R1



The bulk lab @ SEDI, CEA Saclay







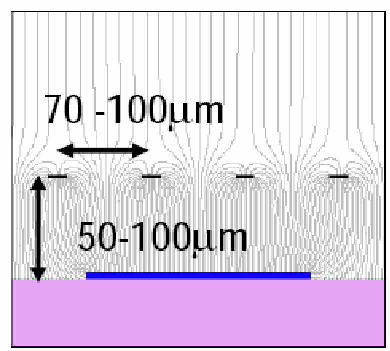
Micro Pattern Gaseous Detectors (MPGD)

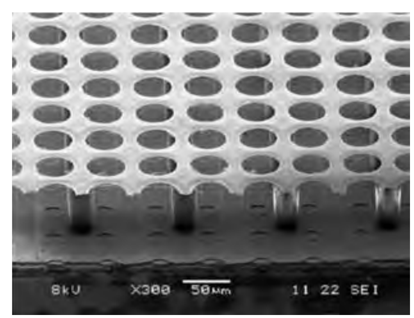
Best technology for gaseous detector readout:

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

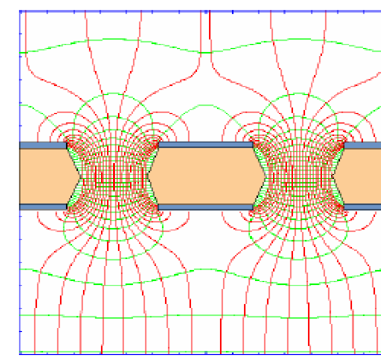
- high granularity
- more robust than wires
- no E×B effect
- fast signal & high gain
- low ion feedback
- better ageing properties
- easier to manufacture
- lower cost
- big surfaces

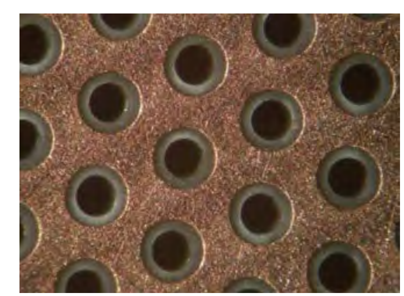
Micromegas





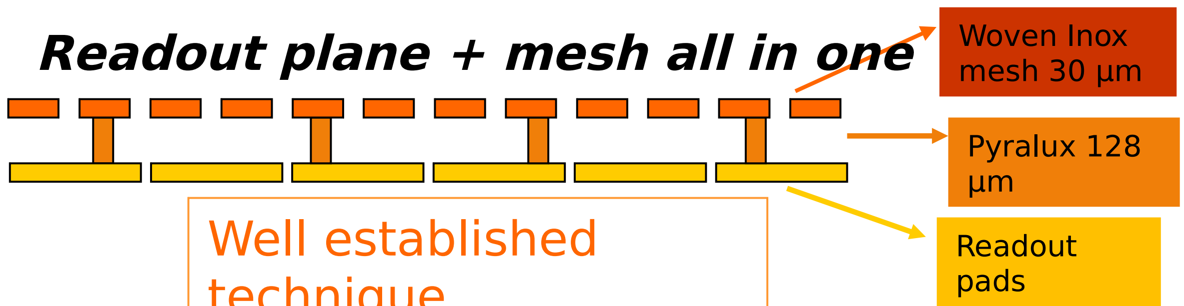
GEMs



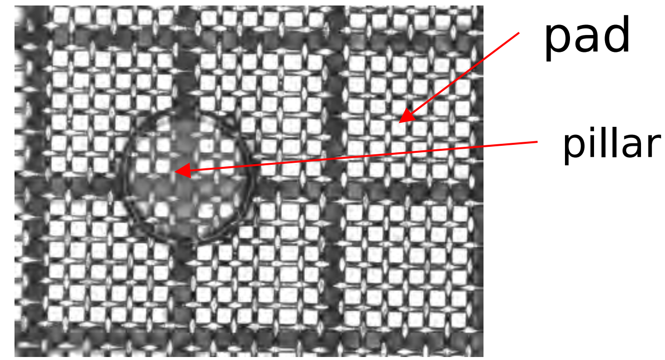


Bulk Micromegas technology

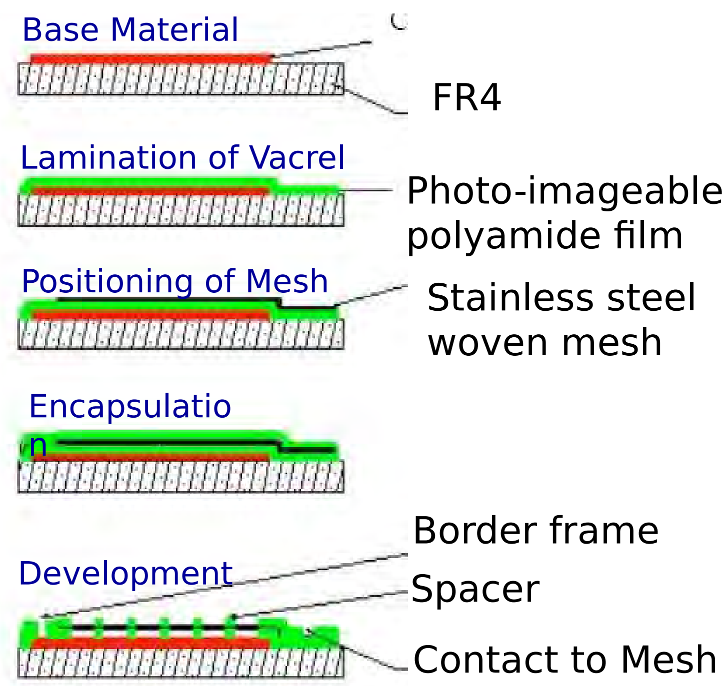
Readout plane + mesh all in one



Well established technique



Result of a CERN-Saclay collaboration (2004)



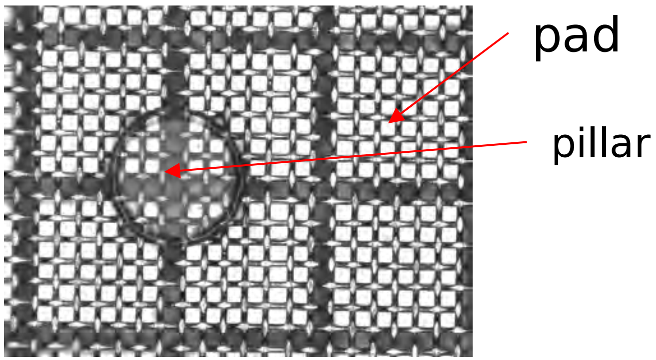
Process to encapsulate the mesh on a PCB (mesh = stretched wires)

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!***

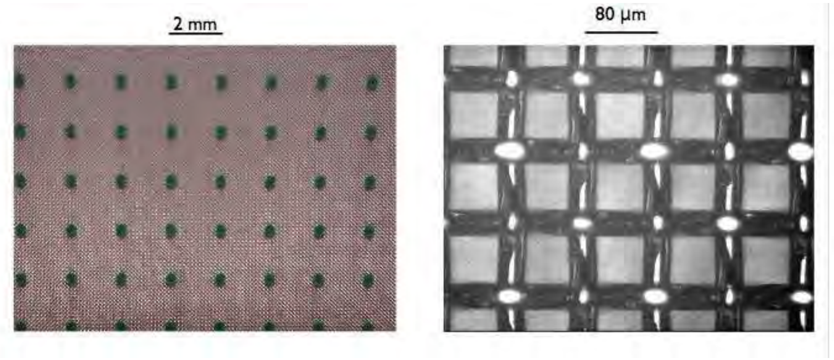
I. Giomataris *et.al.*, NIM A560 (2006) 405

Bulk Micromegas technology



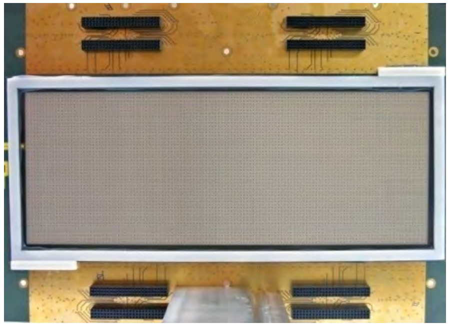
<u>Bulk</u> Micromegas: The pillars are attached to a woven mesh and to the readout plane

Typical mesh thickness 30 µm, gap 128 µm



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

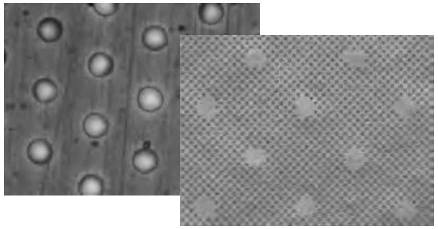
- ✓ **Large area detectors feasible and robust!**
- ✓ **Curved surfaces**
- ✓ Mass production!

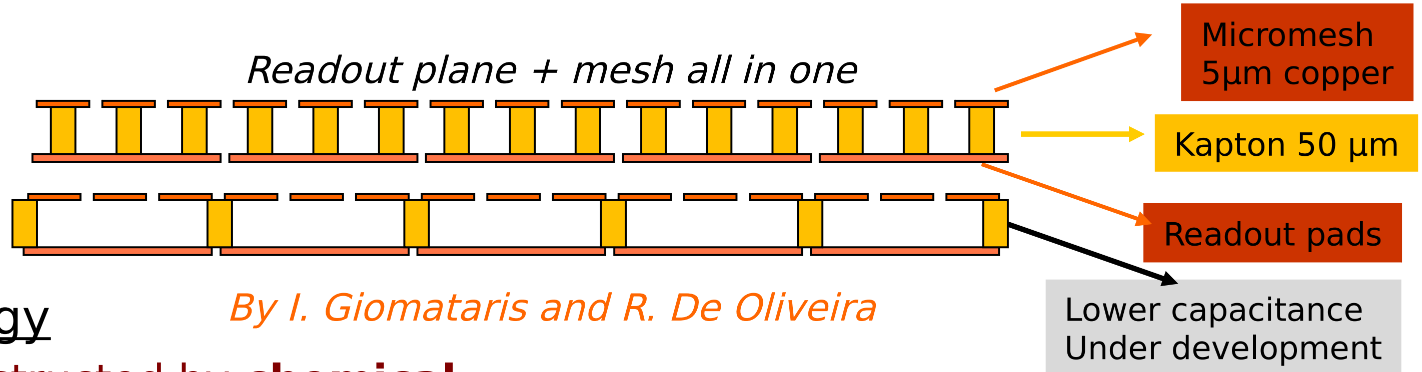


Mesh thickness & bigger gap: some disadvantages in special applications:

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

Microbulk Micromegas technology



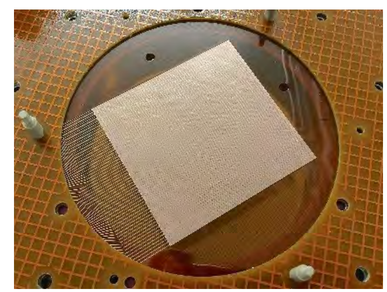


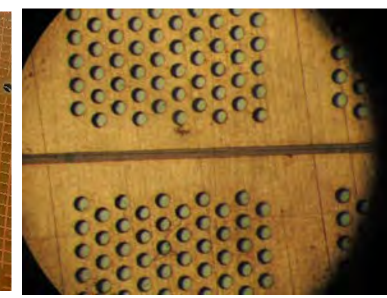
By I. Giomataris and R. De Oliveira

Microbulk Technology

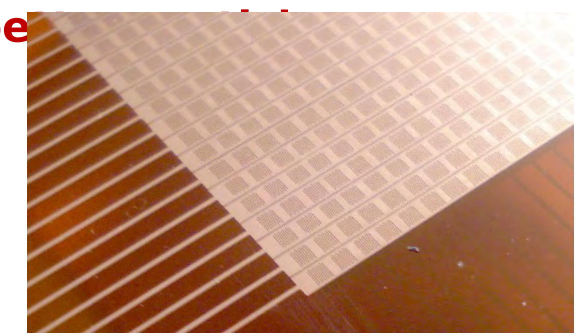
The pillars are constructed by **chemical processing** of a **kapton foil**, on which the mesh and the readout plane are attached. ***Mesh is a mask for the pillars!***

Typical mesh thickness 5 µm, gap 50/25 µm





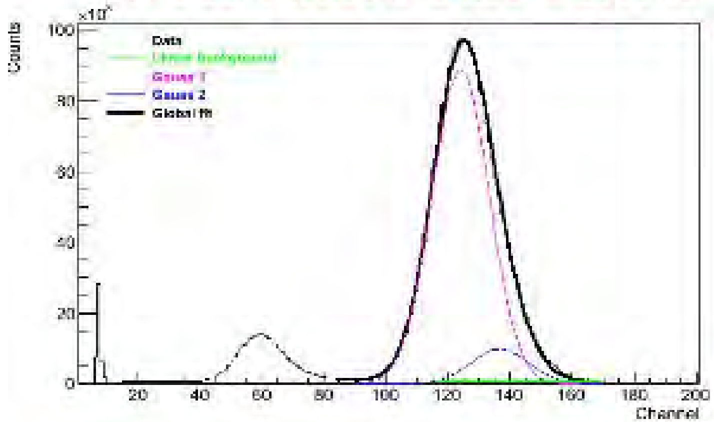
- ✓ **Energy resolution** (down to 10% FWHM @ 6 keV)
- ✓ **Low intrinsic background & be**
  recognition
- ✓ **Low mass detector**
- ✓ **Very flexible structure**
- ✓ **Long termstability**



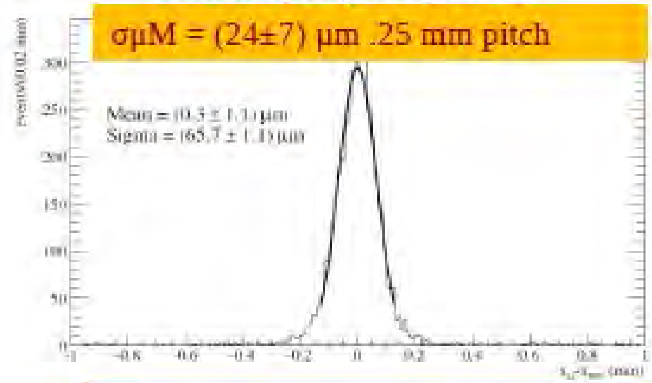
- ✘ Higher capacity
- ✘ Fabrication process complicated
- ✘ Fragility / mesh can not be replaced

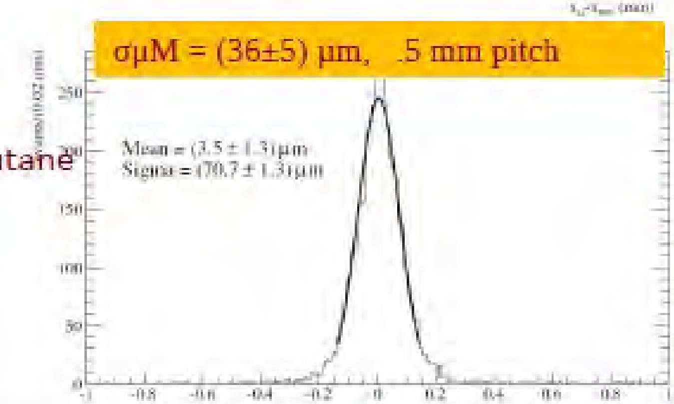
Energy and spatial resolution & stability

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

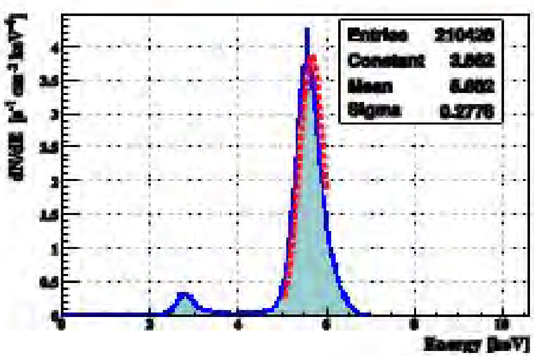


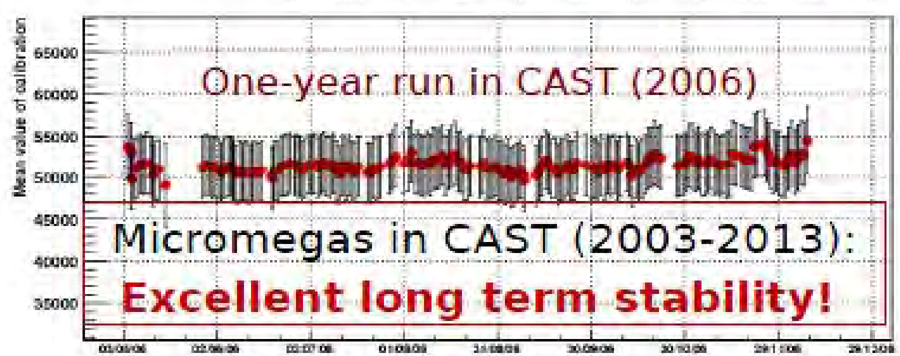
Bulk: Spatial resolution measurements for the MAMA project (sLHC)



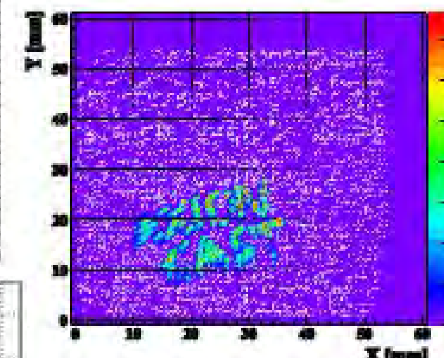


Microbulk: 55Fe Calibration with Ar – 5% isobutane @ 1 bar **FWHM @ 6 keV = 11.5 %**

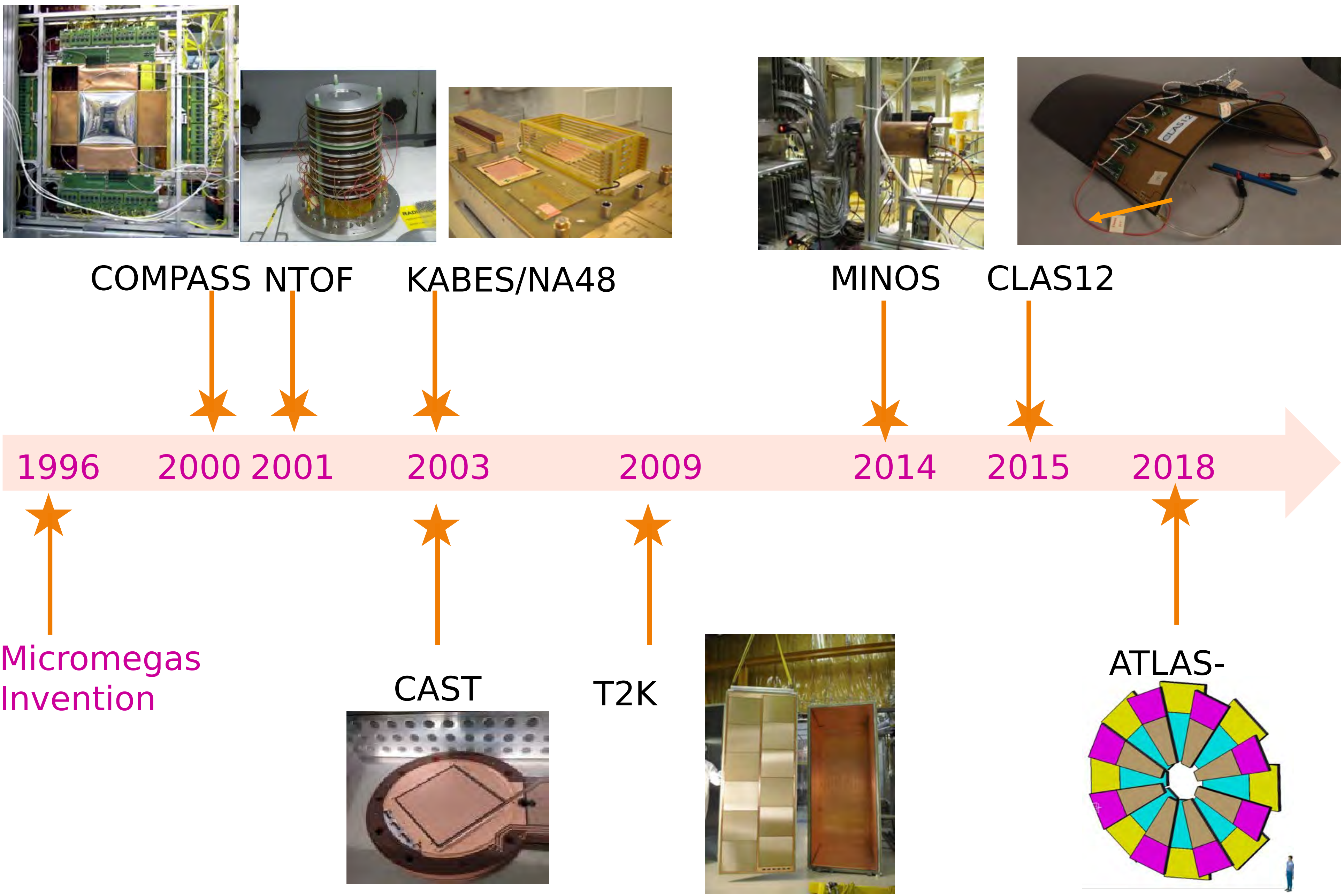




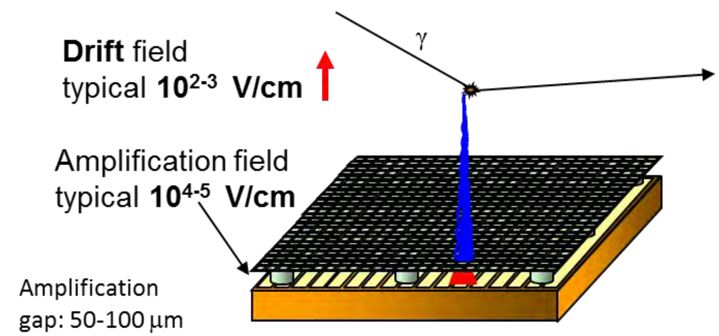
Microbulk: Image taken using a collimator with the words "axion cast"



Micromegas applications



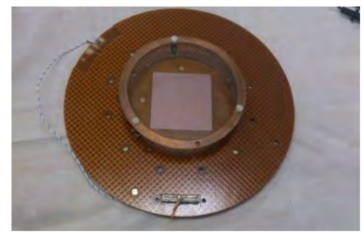
Micromegas R&D

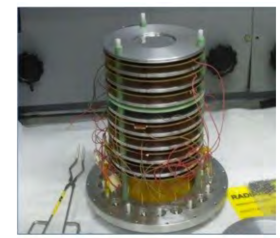


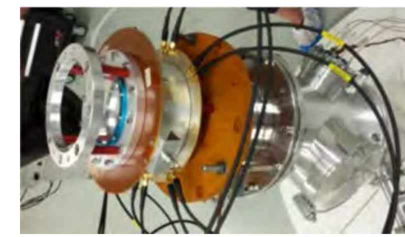
Experiments @ CERNs: New detectors & Continuous improvement

- CAST
  - Microbulk development

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

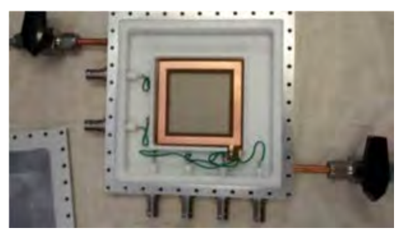


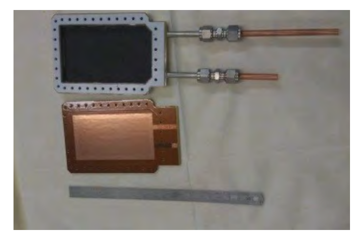




R&D for other projects

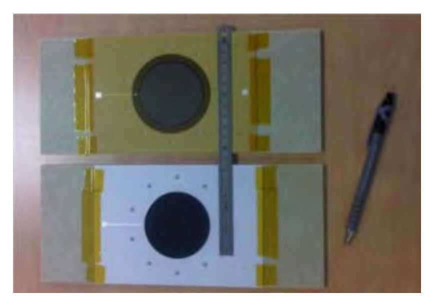
- NMI3
- Schlumberger
- Picosecond





Detector technology R&D

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



Micromegas and thermal neutrons *-back in 2004-*

- First tests for thermal neutrons (2D imaging study) done in 2004 with ^{6}Li converter, zone ~ 6 x 6 cm^2
- Neutron beam ~ 0.025 eV at the Orphée reactor (CEA-Saclay)
- Measured spatial resolution ~ 160 µm
- Encouraging results BUT: signal losses (degraded homogeneity)
- Partial end of developments for thermal neutrons

Now, new technologies are available (bulk and microbulk) and further improvements...

"Neutron Imaging With a Micromegas Detector":
F. Jeanneau et al., IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 53, NO. 2, APRIL 2006

$$^{6}\mathrm{Li} + ^{1}_{0}\mathrm{n} \rightarrow ^{3}\mathrm{H}\ (\text{at } 2.73\ \mathrm{MeV}) + \alpha\ (\text{at } 2.05\ \mathrm{MeV})$$

Reaction Q-Value = 4.78 MeV

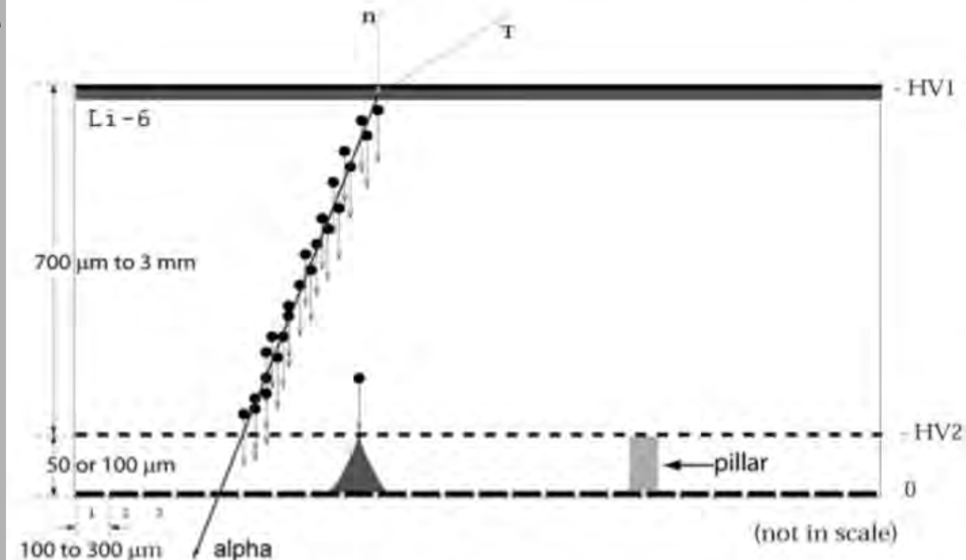
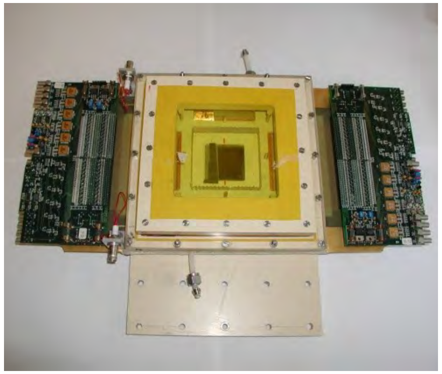
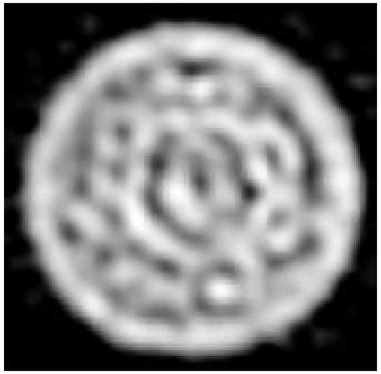


Fig. 1. Micromegas principle for neutron detection.

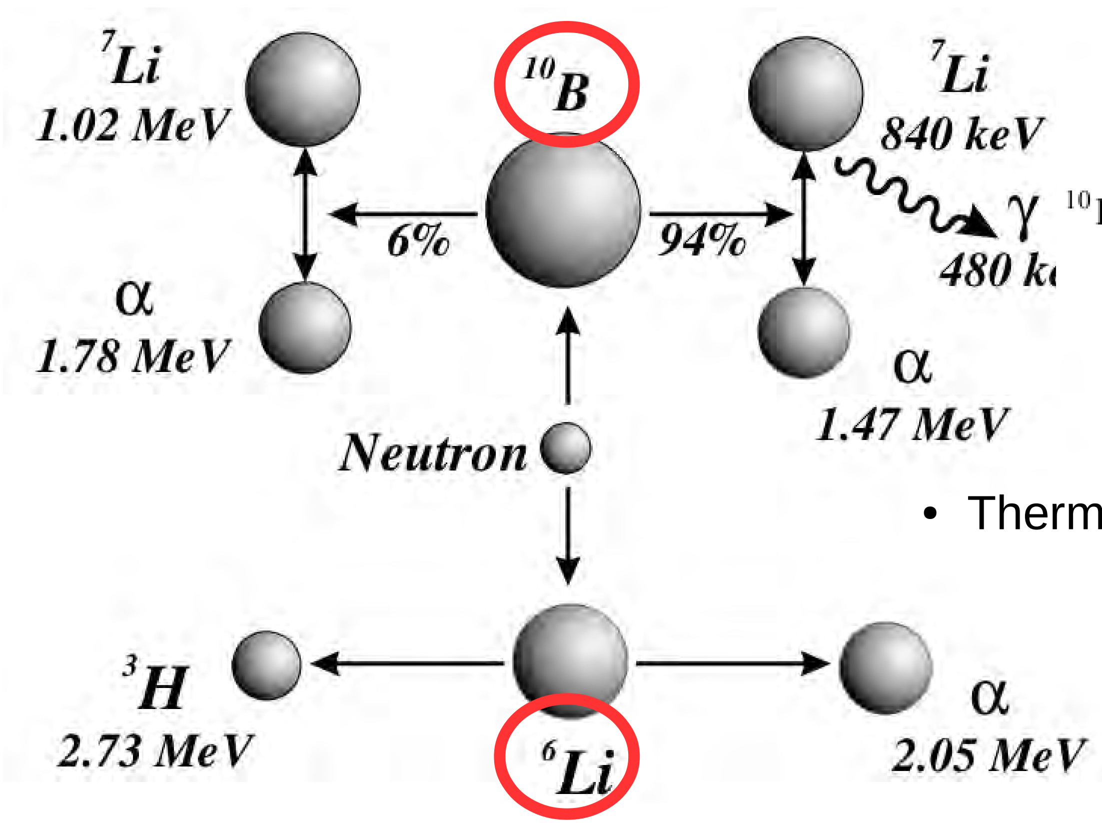


Micromegas thermal neutron detector in 2004



Tomographic reconstruction of a 6mm cable made of 12 wires of 0.5mm

Common neutron interactions used for thermal neutron detectors



$$^{10}\text{B} + ^{1}_{0}\text{n} \rightarrow \begin{cases} ^{7}\text{Li}^{*} \text{ (at 1.015 MeV)} + \alpha \text{ (at 1.777 MeV)}, \\ \text{Reaction } Q\text{-Value} = 2.792 \text{ MeV (to ground state)}, \\ ^{7}\text{Li}^{*} \text{ (at 0.840 MeV)} + \alpha \text{ (at 1.470 MeV)} \\ \text{Reaction } Q\text{-Value} = 2.310 \text{ MeV (1st excited state)} \end{cases}$$

- Thermal neutron absorption cross-section: 3840 b

$$^{6}\text{Li} + ^{1}_{0}\text{n} \rightarrow ^{3}\text{H (at 2.73 MeV)} + \alpha \text{ (at 2.05 MeV)}$$
$$\text{Reaction } Q\text{-Value} = 4.78 \text{ MeV}$$

- Thermal neutron absorption cross-section: 940 b

D.S. McGregor et al. / Nuclear Instruments and Methods in Physics Research A 500 (2003) 272–308

$^{10}B(n,a)^{7}Li$ and $^{6}Li(n,a)^{3}H$

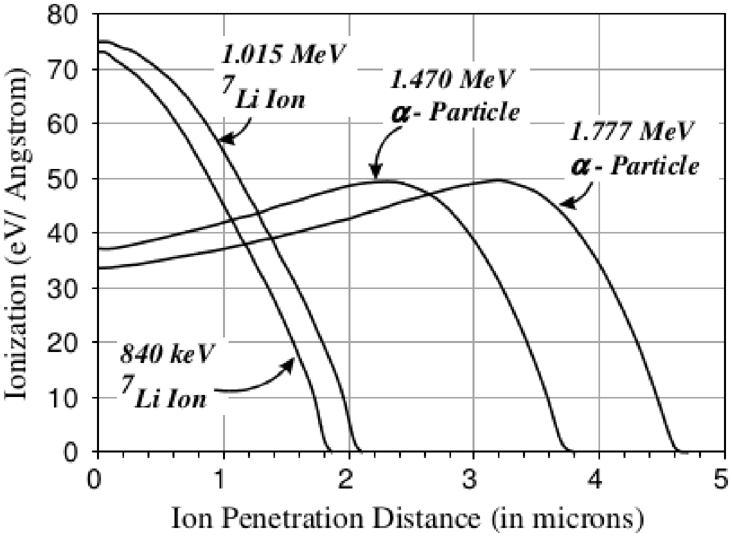


Fig. 5. $^{10}B(n,\alpha)^{7}Li$ reaction product energy loss in a ^{10}B film as described by the Bragg distribution.

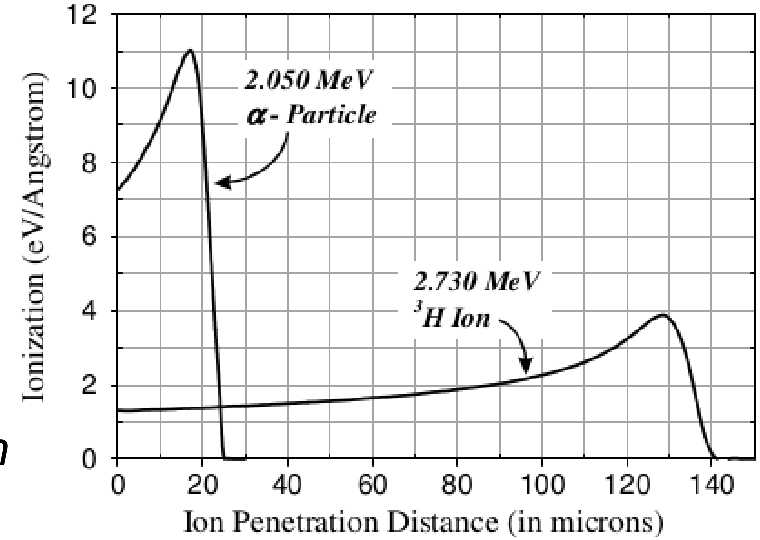


Fig. 9. $^{6}Li(n,\alpha)^{3}H$ reaction product energy loss in a pure ^{6}Li film as described by the Bragg distribution.

The average range for a 0.840 MeV 7Li ion in boron is 1.6 μm and the average range for a 1.47 MeV alpha is 3.6 μm.

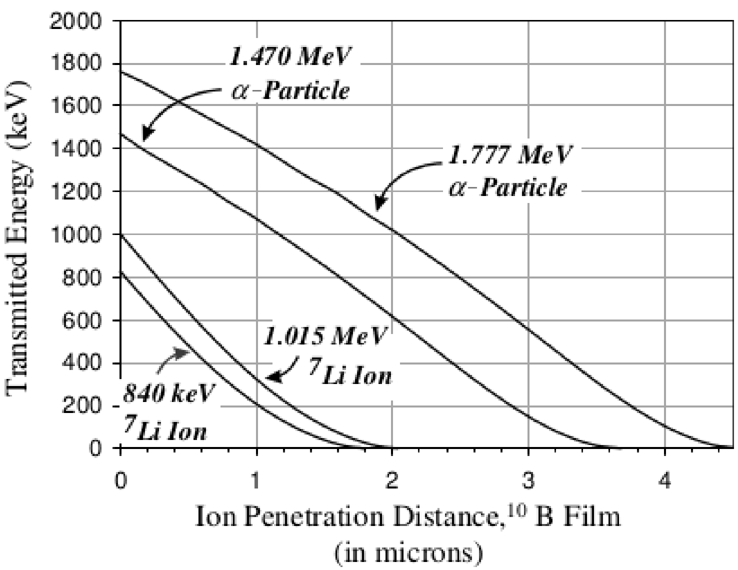


Fig. 6. Energy deposited into the detector is simply the original particle energy minus the energy lost through self-absorption. Shown are the particle energies remaining from the $^{10}B(n,\alpha)^{7}Li$ reaction as a function of transit distance through pure boron.

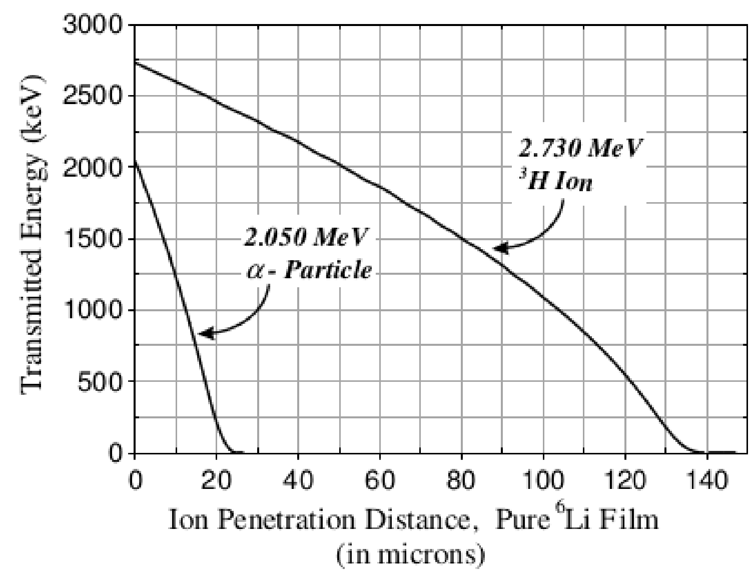


Fig. 10. Energy deposited into the detector is the original particle energy minus the energy lost through self-absorption. Shown are the particle energies remaining from the $^{6}Li(n,\alpha)^{3}H$ reaction as a function of transit distance through pure Li.