Neutron Science with Gaseuos Detectors Review and DRD1-WP9 Hints

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1st DRD1 Collaboration Meeting
CERN

Outline

- Neutron detection principles
  - Thermal neutrons
  - Fast neutrons
- ^{3}He
  - ^{3}He based detectors for thermal and fast neutrons
  - ^{3}He shortage
- Novel trends
  - Wire-based solutions
  - MPGD
  - RPC

I apologize if I did not cite some research in this talk for sake of time ….

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Neutron Interaction and detection

- Neutron interaction and detection critically depends on the neutron energy
  - ✓ This implies that also your detector must be «customized» for a specific neutron energy range
  - ✓ It is quite difficult to realize a detector for all neutrons

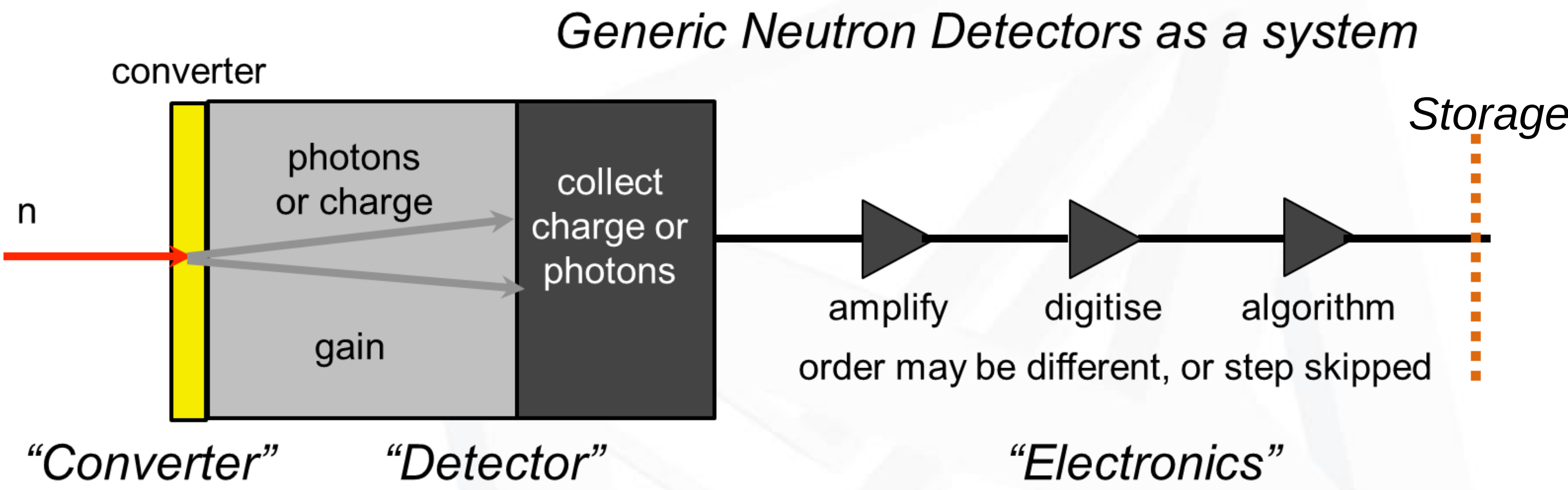
- Several classifications of neutrons based on their energies
  - ✓ Cold neutrons E_n<25 meV
  - ✓ Thermal neutrons 25 meV <E_n< 0.1 eV
  - ✓ Epithermal neutrons 0.1 eV <E_n< 100 keV
  - ✓ Fast neutrons 100 keV <E_n< 100 MeV
  - ✓ High energy neutrons E_n> 100 MeV

- Neutron interaction probability and detection efficiency depends on the macroscopic cross section as

$$\mathrm{P}(E,x) = 1 - e^{-\Sigma(E)x}$$

where Σ is called macroscopic cross section and is defined as the product of σ(E) i.e the cross section and and n i.e. the target density of scattering centres

Basic principle to realize a neutron detector

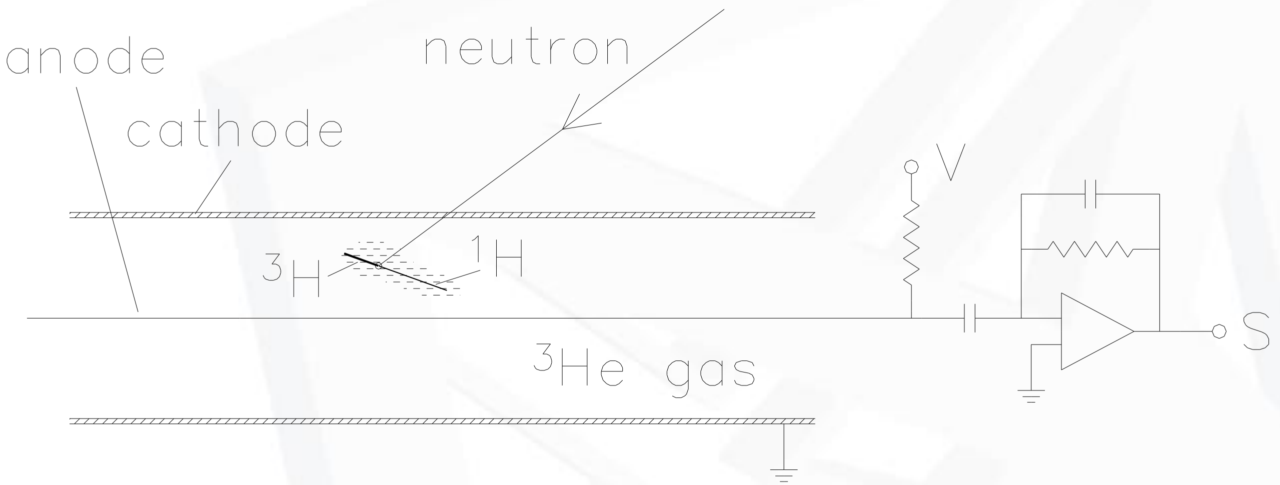


- Converter material depends on the neutron energy you want to detect
- Detector is optimized following the requirements of the neutron science you want to explore

Thermal neutrons

^{3}He based detectors: principle

n + ^{3}He → p + ^{3}H + 0.76 MeV $\sigma(\lambda)$ = 5333 barn * λ/1.8 Å



- Single Wire Proporional Chamber
- Increase n (density of scattering centres) by increasing pressure (up to several bars)
- Very rubust and simple geometry
- Relatively low operation voltages
- Most diffused geometry: ^{3}He-tubes

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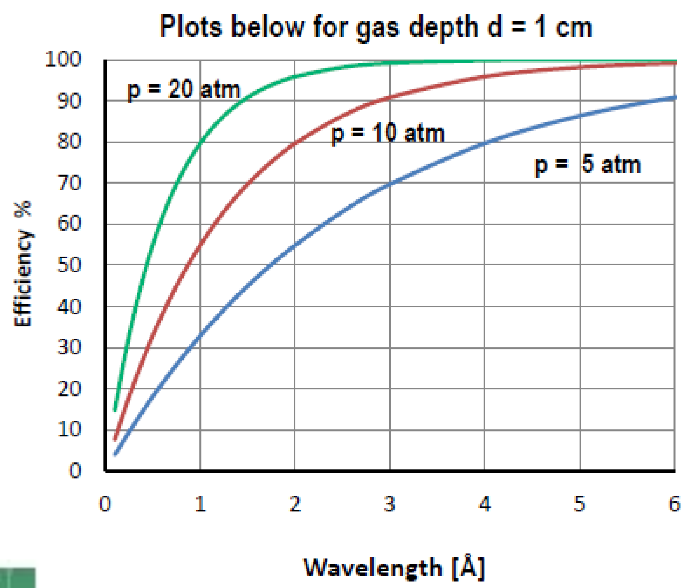
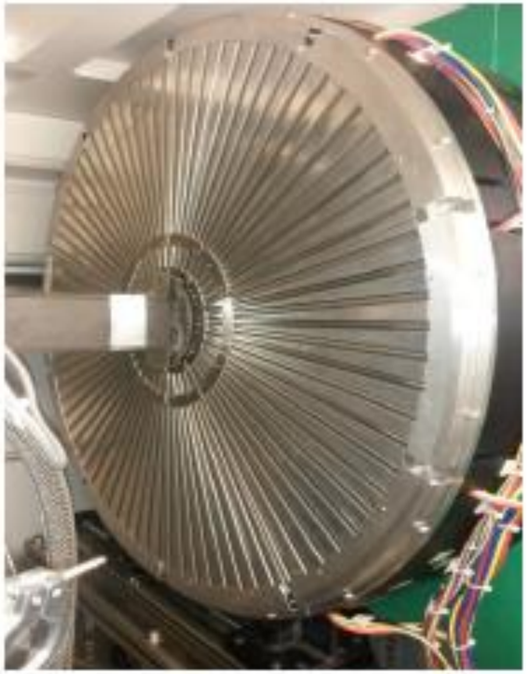
^{3}He tubes applications

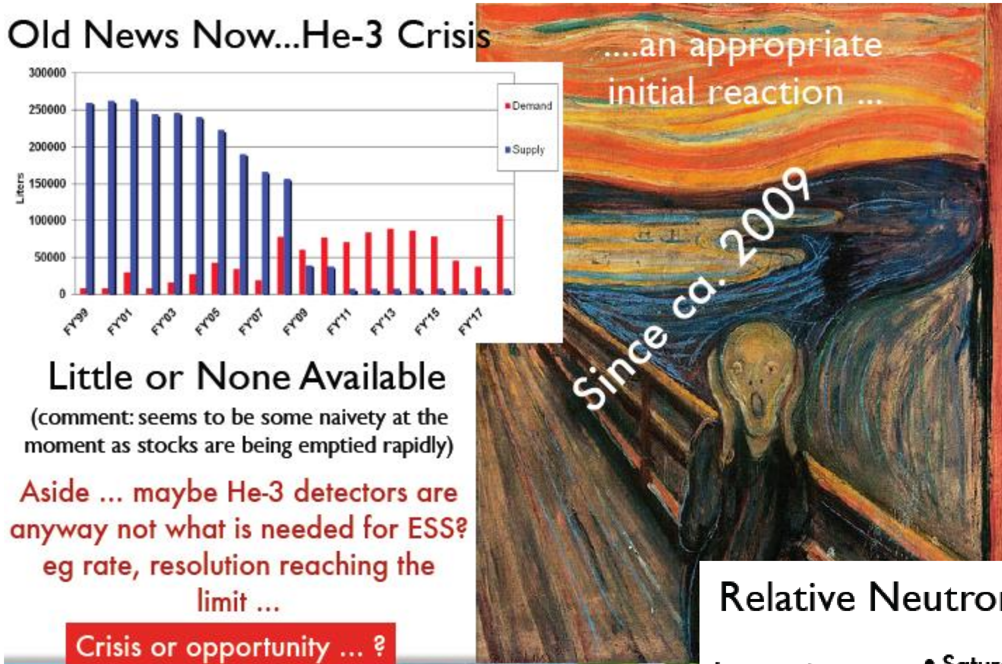
- Very high efficiency to thermal neutrons

- Wide application in all present «neutron science» facilities (i.e. spallation sources and reactors)
  - ✓ ISIS (UK)
  - ✓ SNS (USA)
  - ✓ ILL (FR)
  - ✓ J-PARC (JP)
  - ✓ …





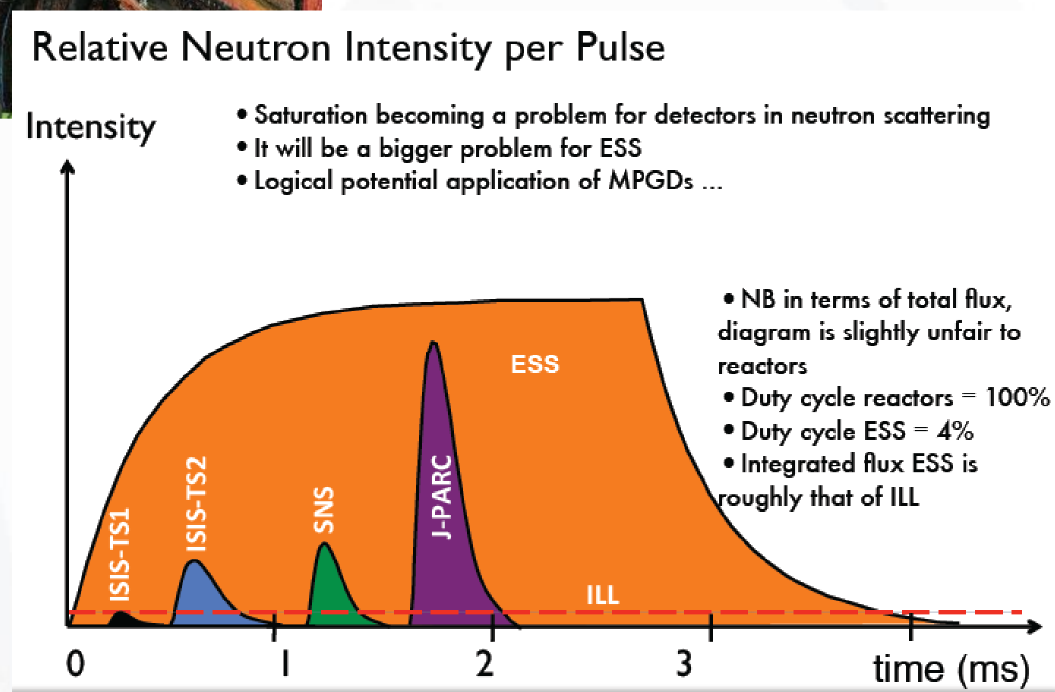
but…



Shortage of ^{3}He gas

^{3}He tubes (as SWPC) are limited in rate capability

→ Maybe an issue for future high intensity neutron sources like ESS



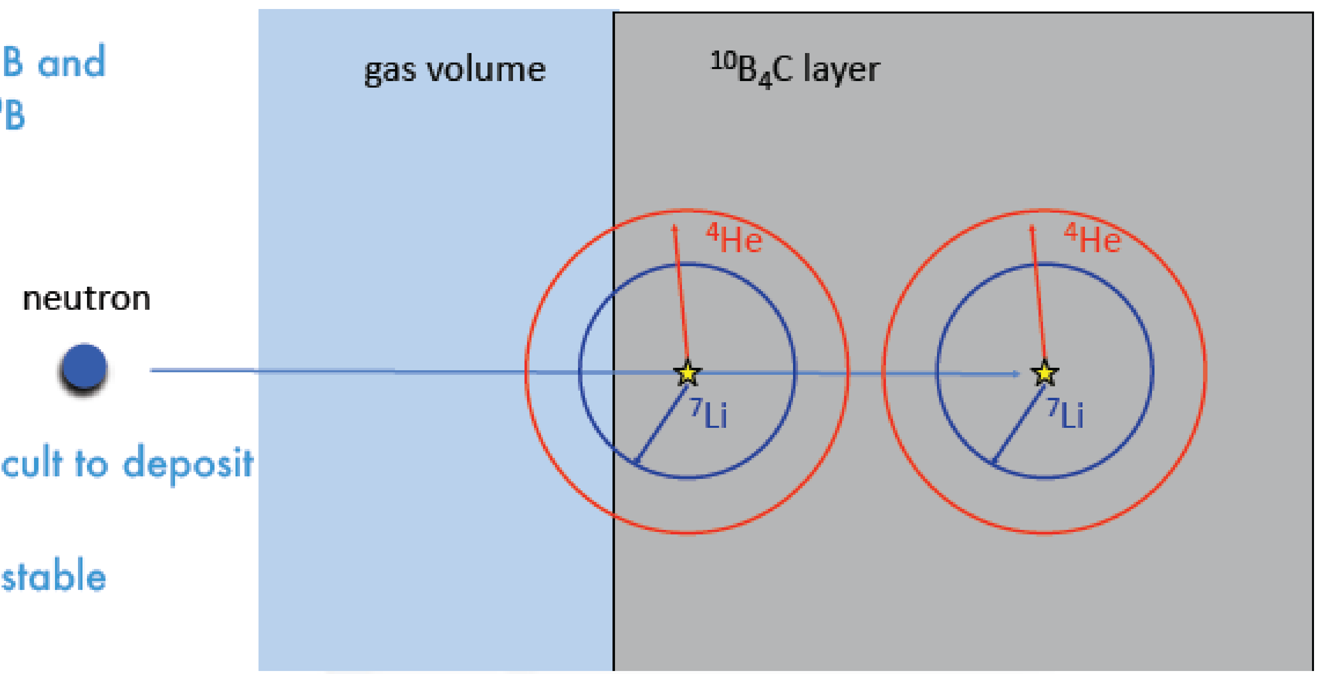
Thanks to R. Hall-Wilton

Most common alternative materials to ^3He: ^{10}B and ^6Li Solid converters (1/2)

$$
\begin{aligned}
{}^{10}B + n \rightarrow {}^{7}Li^{*} + {}^{4}He &\rightarrow {}^{7}Li + {}^{4}He + 0.48MeV\,\gamma\text{-ray} + 2.3\ \ MeV \quad (94\%) \\
&\rightarrow {}^{7}Li + {}^{4}He \qquad\qquad\qquad + 2.79\,MeV \quad (6\%)
\end{aligned}
$$

Efficiency limited at ~5% (2.5Å) for a single layer

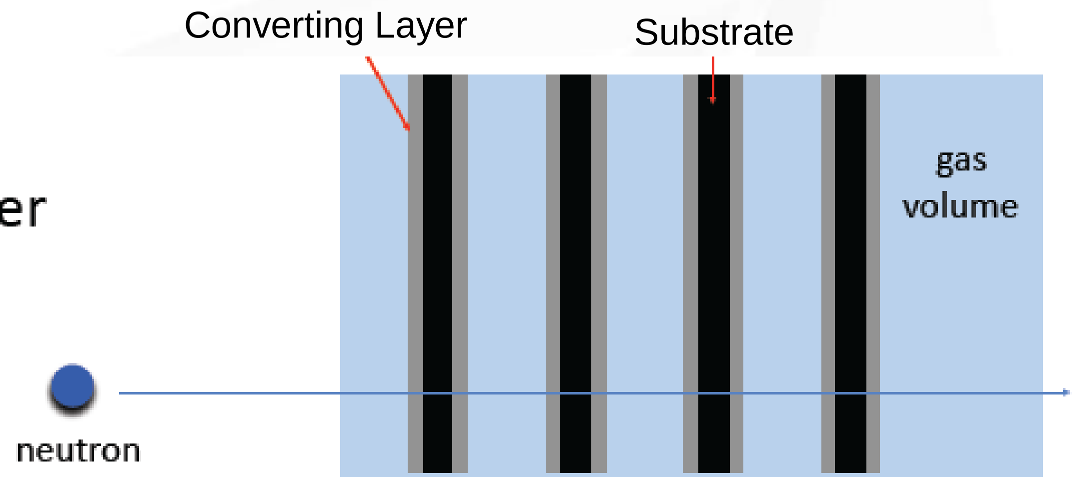
- ^{nat}B contains 80 at.% ^{11}B and 20 at.% ^{10}B



- Boron is difficult to deposit
- Use $^{10}B_4C$
- Conductive, stable

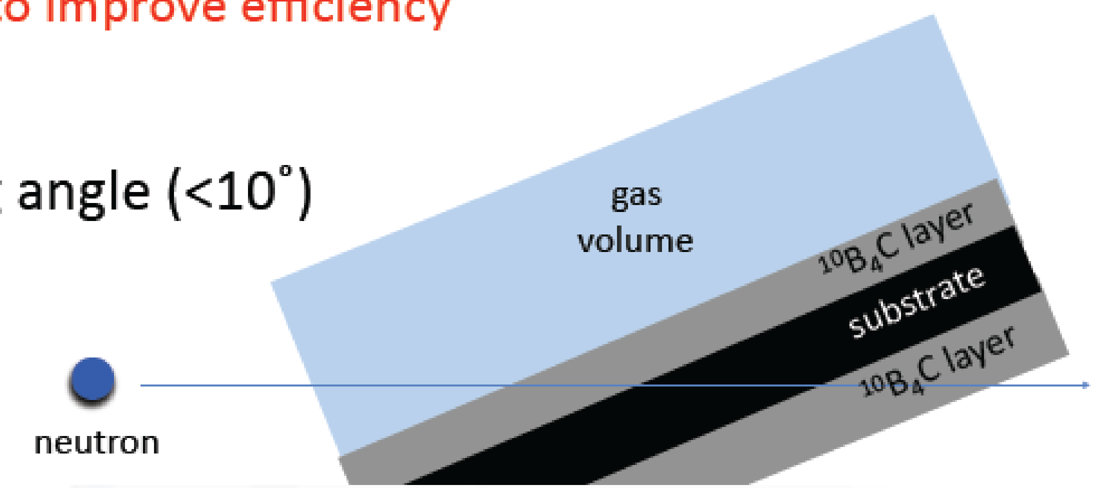
Most common alternative materials to ^3He: ^{10}B and ^6Li Solid converters (2/2)

1 Multi layer

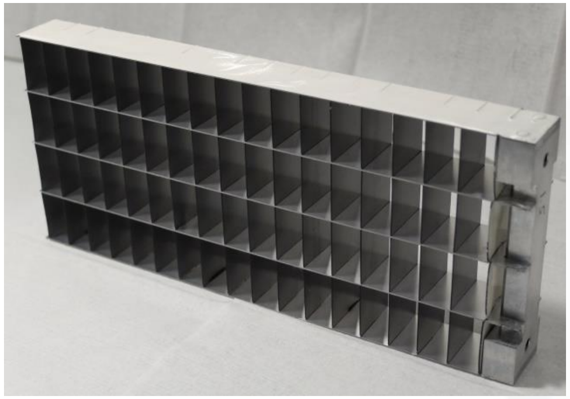


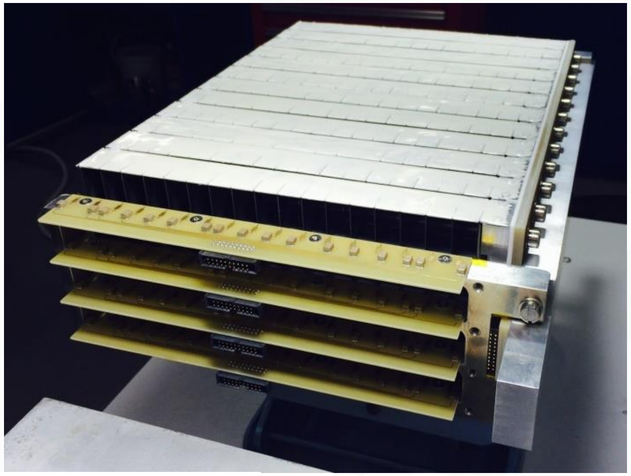
Generic approaches to improve efficiency

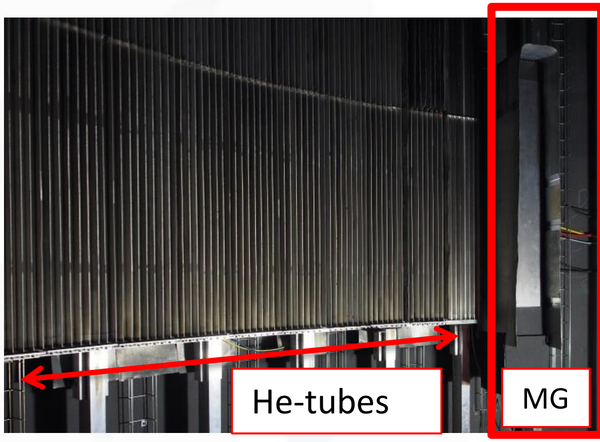
2 Grazing angle (<10°)

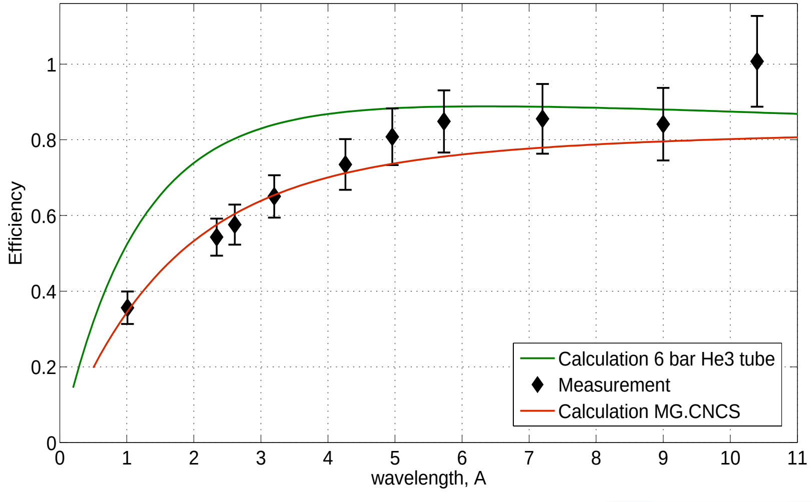


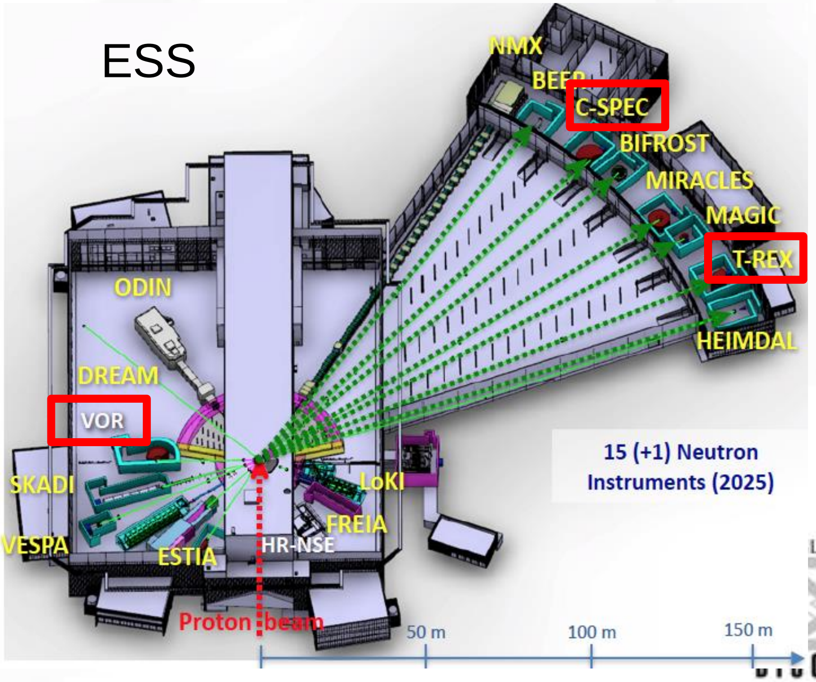
Novel wire-based solutions (mainly for ESS..)
MultiGrid detector – ^{10}B based





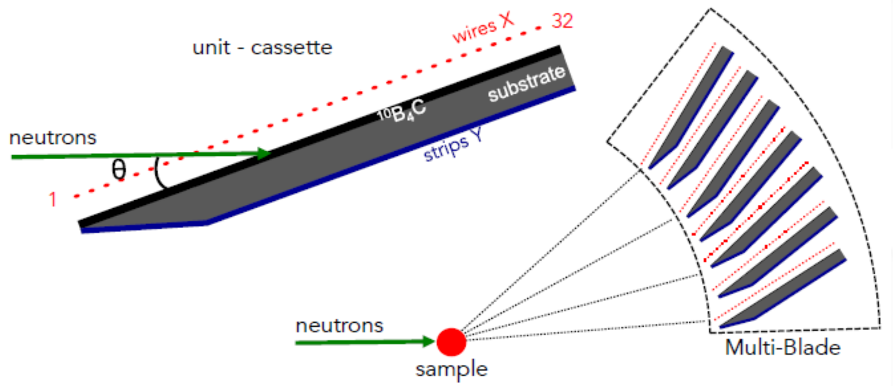


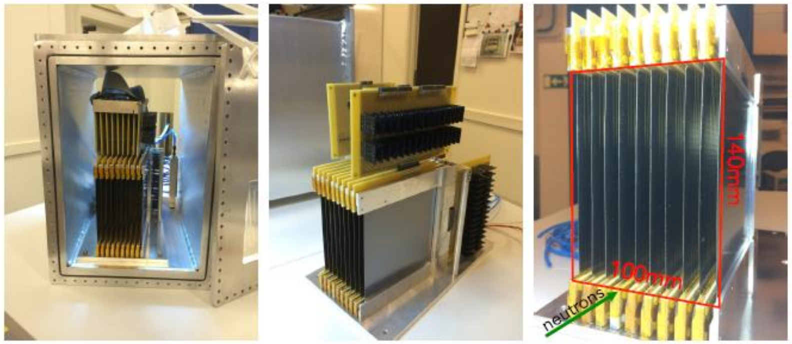


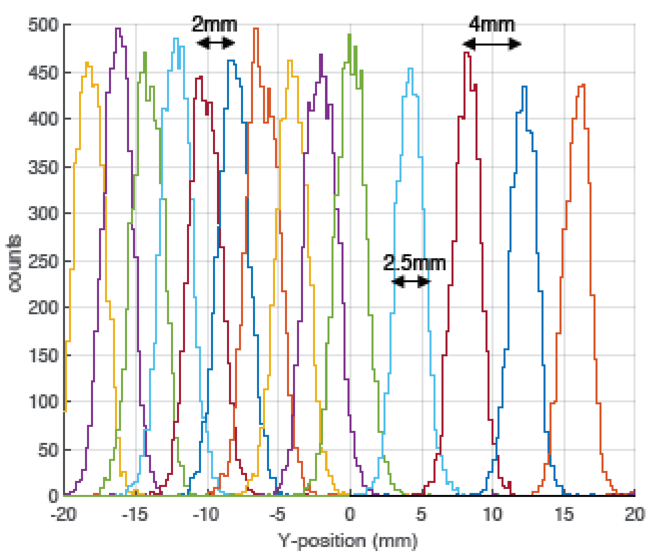


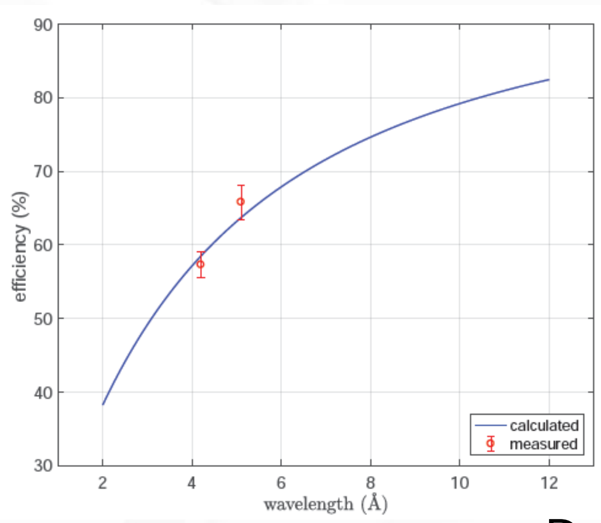
Multi-SWPC- Large area
High efficiency
Millimetric Spatial resolution
Developed by ILL and ESS

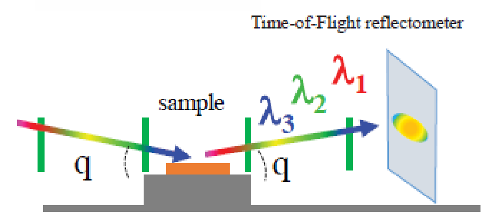
Novel wire-based solutions (mainly for ESS..)
MultiBlade detector – ^{10}B based











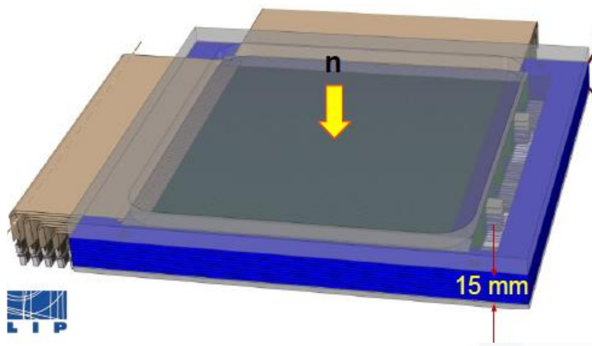
Developed by ILL and ESS

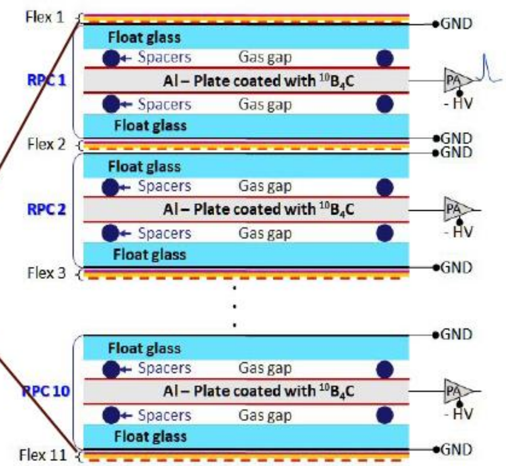
MWPC-based
High efficiency
Millimetric space resolution
High rate

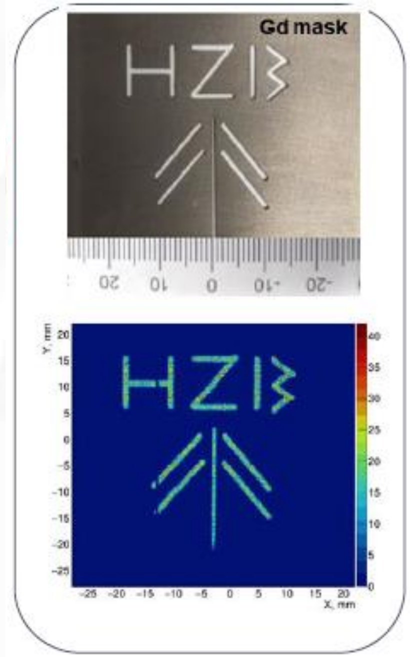
Application: FREIA / ESTIA
Reflectometry instruments at ESS

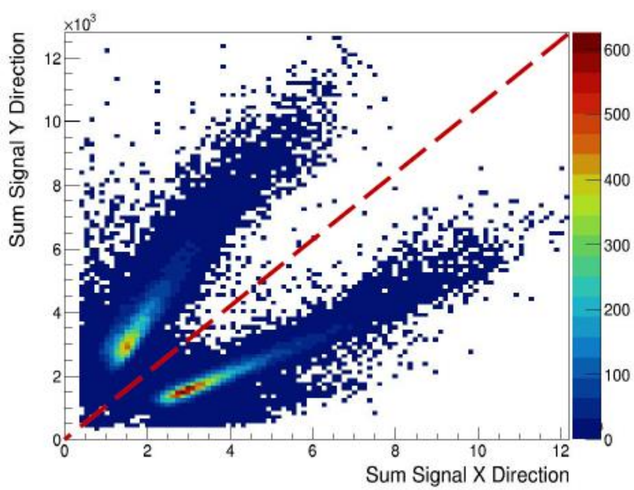
RPC for neutron detection

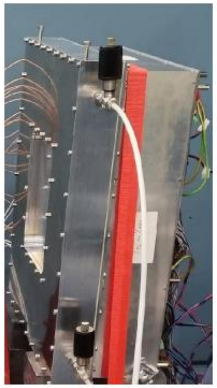
- **Multilayer configuration**
  - **Stack of 10 timing RPCs units**
- **XYZ position and timing**
  - **Sub-millimeter spatial resolution**
  - **Timing in the ns range**











Front: Aluminium entrance window (0.2 mm thicK)

Back: Front End Electronics and triggering boards (custom)

Front End Electronics
- Boards with 24 charge PAs (50 mV/pC)

Timing amplifier
- Polarity (bipolar)
- Wideband amplification (gain 60 @ 1GHz)
- LVDS output

DAQ - TRB3 (trb.gsi.de)
- 48 ch 10 ps TDC
- ADC addon (48 ch 40 MHz streaming ADCs)

MPGD for neutron detection

- MPGD detectors born for tracking and triggering applications (detection of charged particles)
- In order to detect neutral particles you need a converter
  - Thermal Neutrons: ^{10}Boron converter
    - Neutrons are detected using the productus (alpha,Li) from nuclear reaction eg: ^{10}B(n,alpha)7Li
  - Fast Neutrons: Polyethylene converter + Aluminium
    - Neutrons are converted in protons through elastic scattering on hydrogen

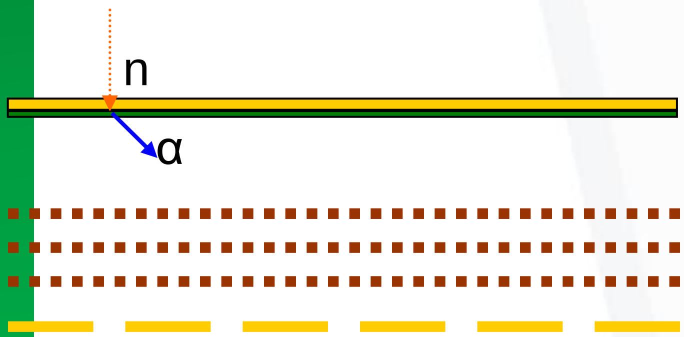
- MPGD offer the following advantages
  - Very high rate capability (MHz/mm^2) suitable for high flux neutron beams like at ESS
  - Submillimetric space resolution (suited to experiment requirements)
  - Time resolution from 5 ns (gas mixture dependent)
  - Possibility to be realized in large areas and in different shapes
  - Radiation hardness
  - Low sensitivity to gamma rays (with appropriate gain)
- Two dedicated workshops in the last years
  - https://indico.cern.ch/event/265187/ (2013)
  - https://indico.cern.ch/event/365840/ (2015)

For sake of time I skip all Micro Strip Gas Chamber application to neutron detection

I will concentrate on GEM, Micromegas and THGEM

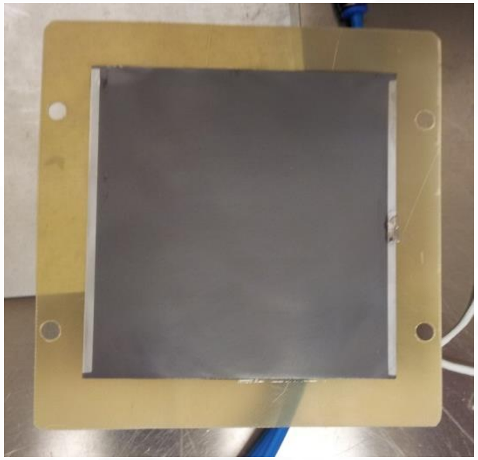
GEM thermal neutron detector

- Triple GEM detector equipped with an aluminum cathode coated with 1μm of B_4C: first bGEM prototype
- Exploit the $^{10}B(n,\alpha)^{7}Li$ reaction in order to detect thermal neutrons

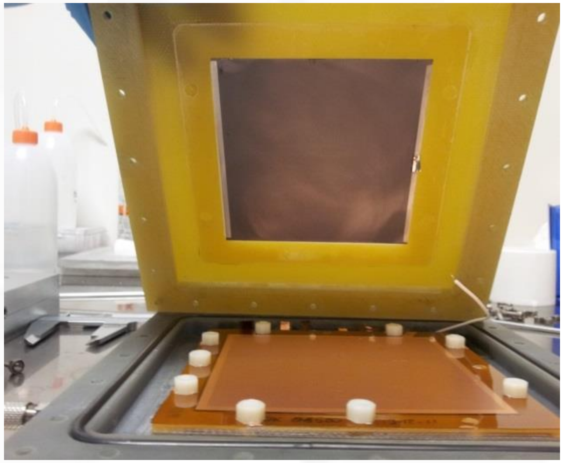


Detector Schematics

Low efficiency detector (few %)



B_4C coated aluminium cathode mounted on its support



B_4C coated aluminium cathode assembled inside the bGEM chamber layout

Several groups around the world (UNIMIB-INFN-CNR, CERN, J-PARC, CSNS …) developed similar solutions

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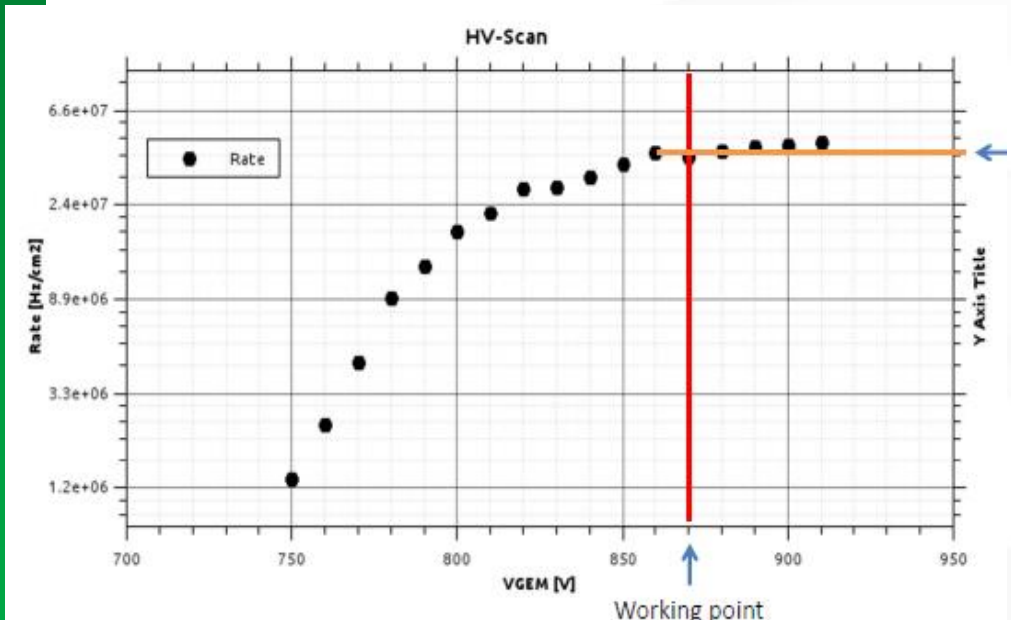
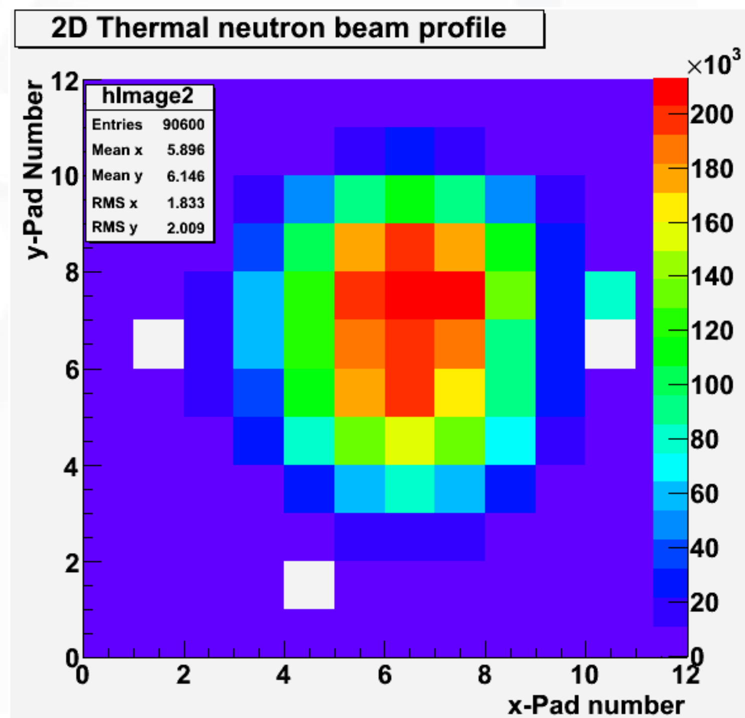
Performances



G. Croci et Al, 2013

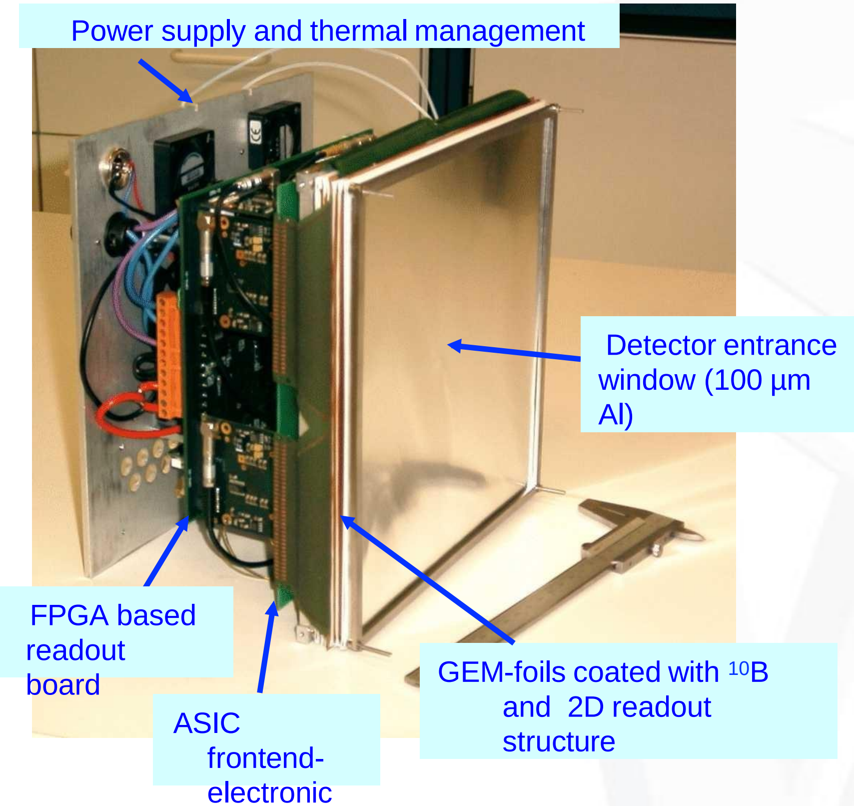
40 MHz/cm^2

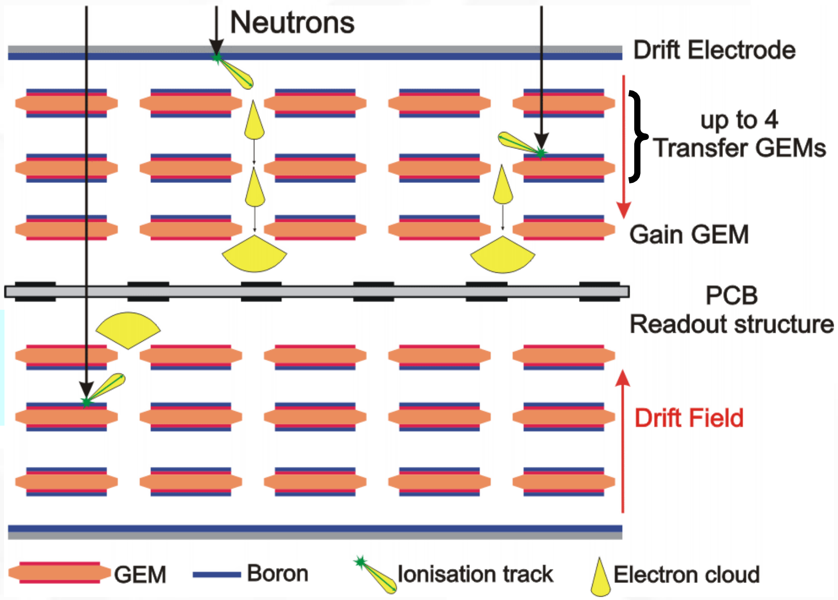


The CASCADE GEM detector

CASCADE

2D-200 CASCADE Detector (200x200 mm²)





- Each GEM has two ^{10}B layers
- Last GEM operated as amplifier
- 10 GEM foils for ~ 50% efficiency

DETNI

INFM - Perugia
Forschungszentrum Jülich
Hahn Meitner Institut - Berlin
Ruprecht Karls Universität - Heidelberg
AGH University of Sci. and Tech. - Krakow

Christian J. Schmidt et al (GSI, Darmstadt)

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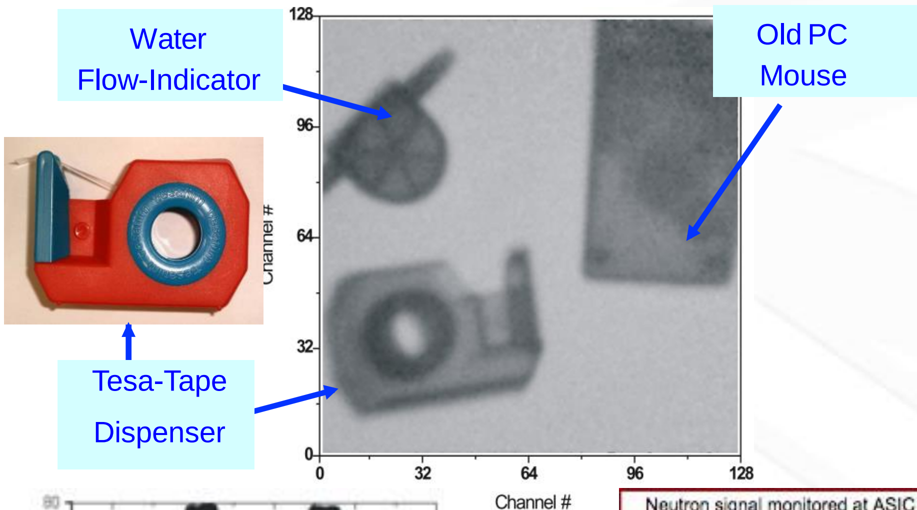
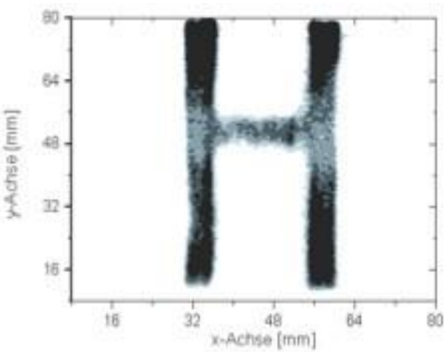
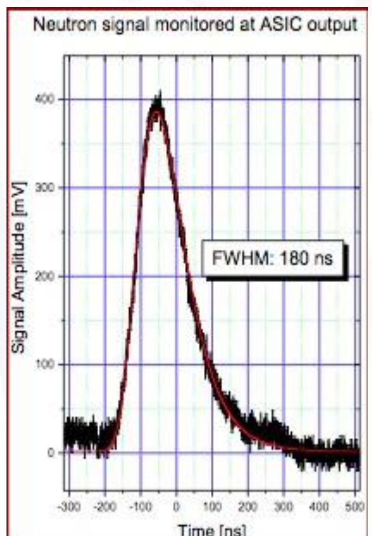
CASCADE GEM detector performances

A radiography with the CASCADE GEM detector

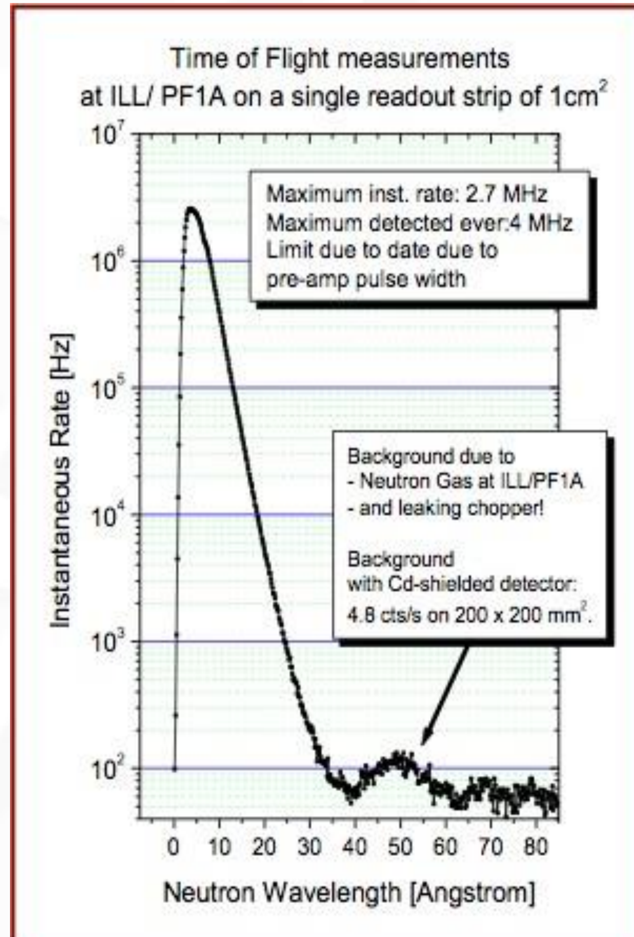




~ 1-3 mm spatial resolution
with 1.56 mm pixel size



TOF Dynamics Achieved with CASCADE

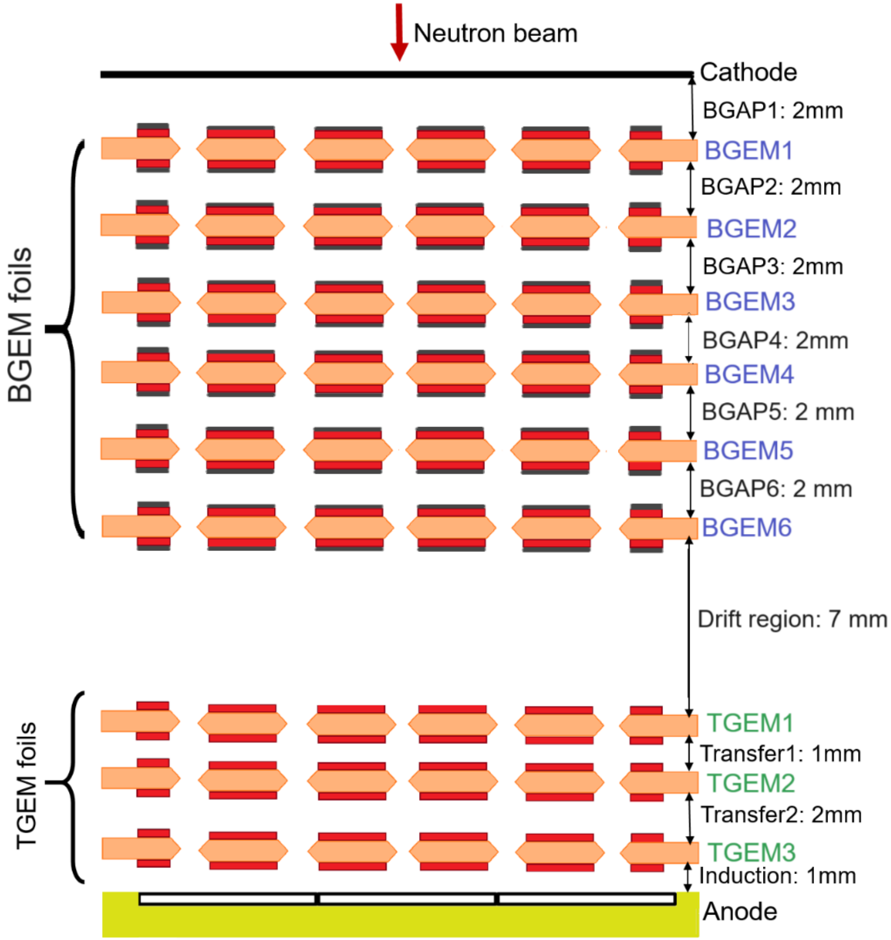


10 MHz/cm^2 counting rate capability

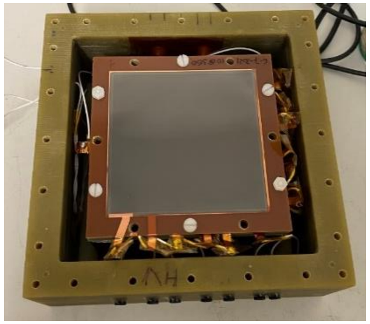
CEA DSM Irfu

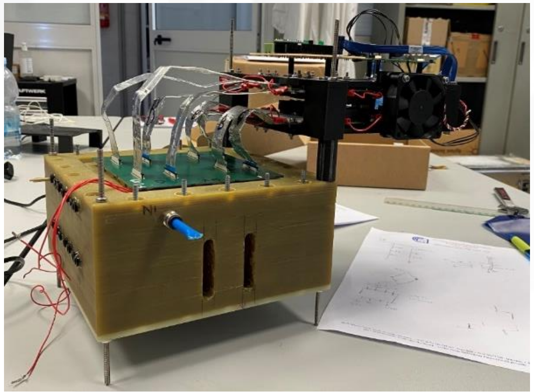
Christian J. Schmidt et al (GSI, Darmstadt)

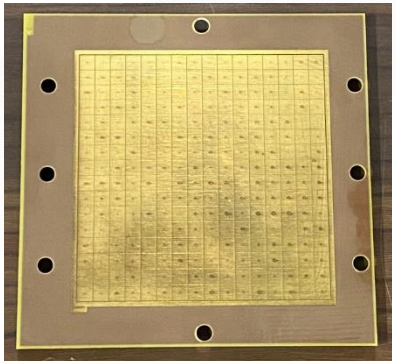
Multi Boron GEM detector



- GEM foils of **10x10 cm²** covered on both sides with 1µm of $^{10}B_4C$.
- Stacking of 6 Boron-coated (**BGEM**) foils coupled with three standard GEM foils.
- Gas Mixture **Ar-CO_2** (70%-30%).
- **Padded anode** made of 256 pads of 6x6 mm²
- 6MBGEM detector coupled with **GEMINI** electronic readout







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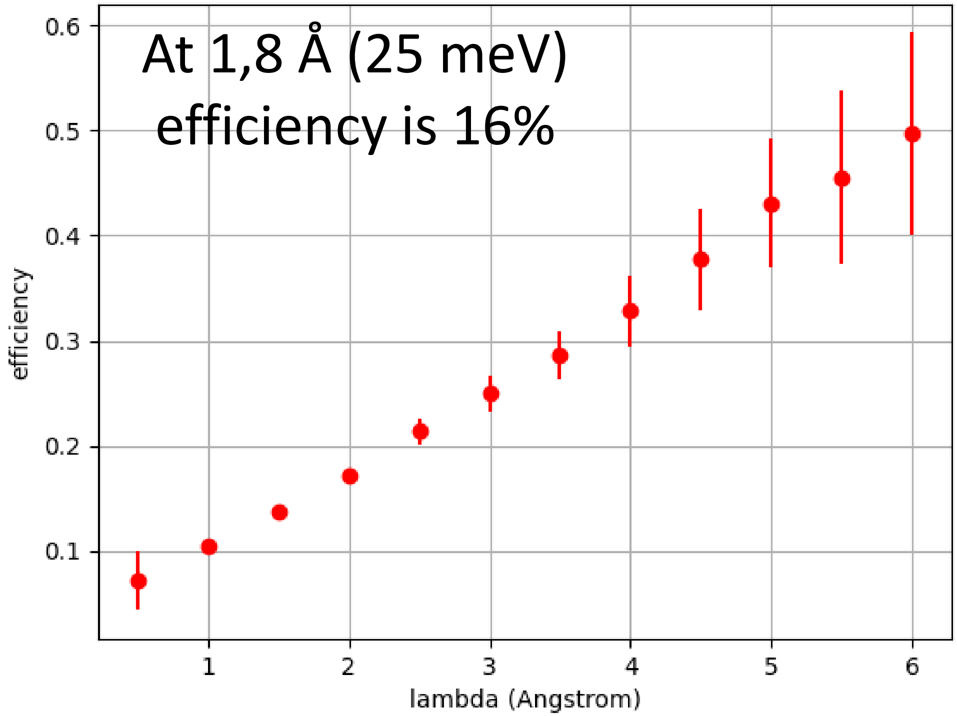
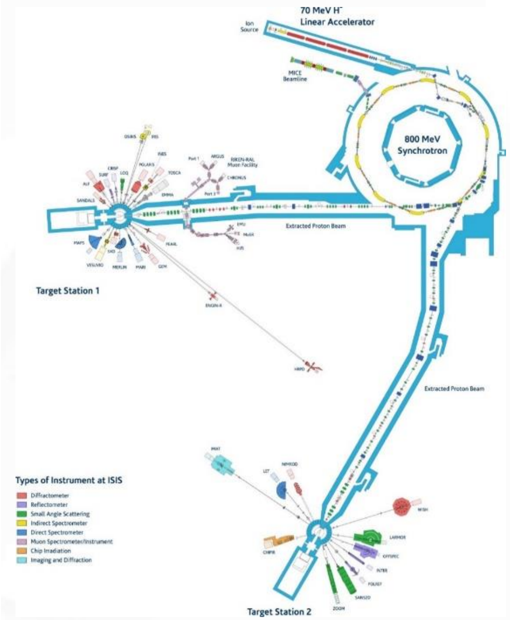
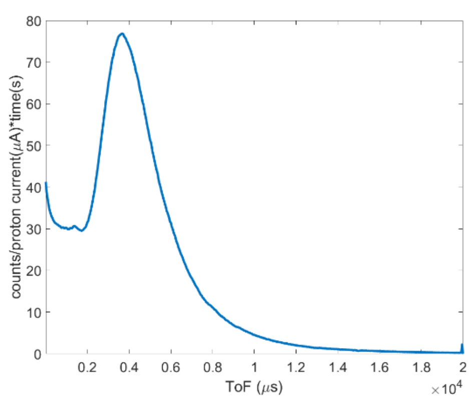
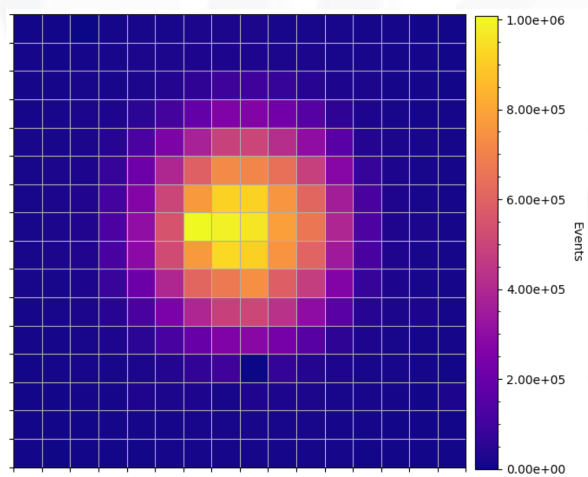
Multi Boron GEM detector performances

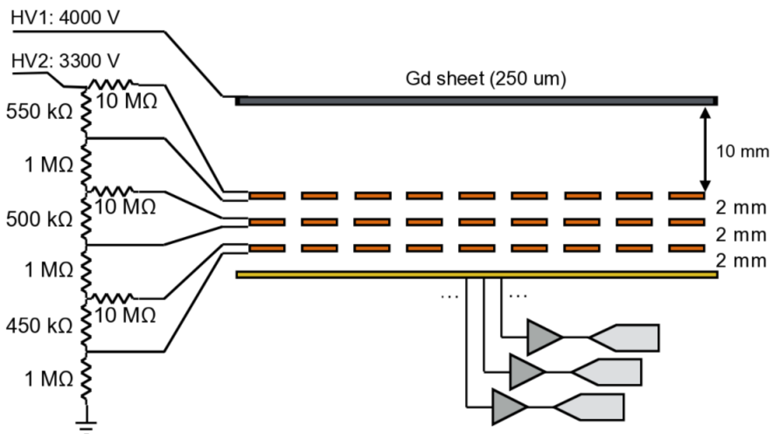


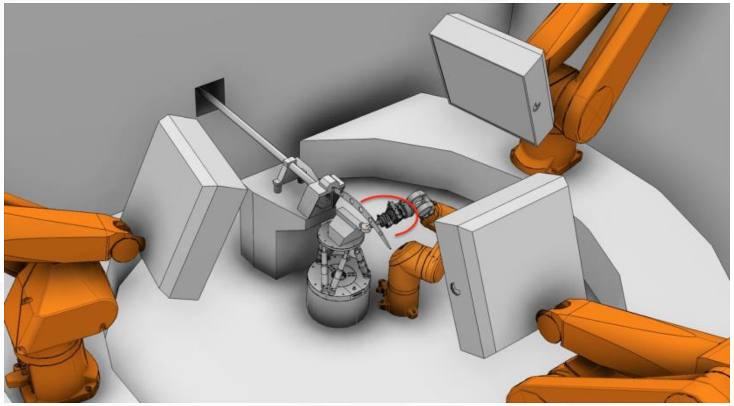


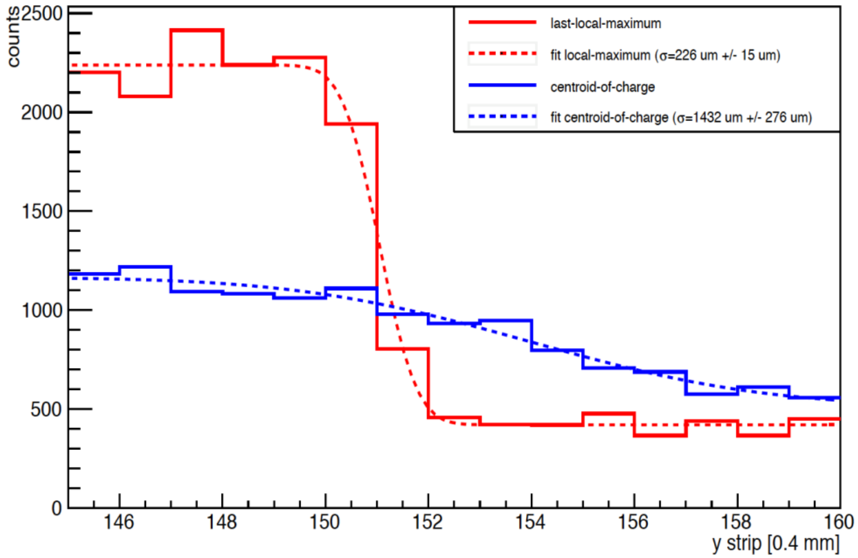




Gd-GEM for NMX @ ESS





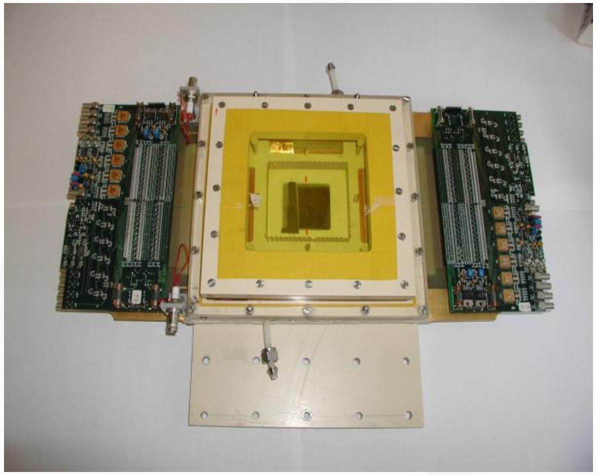


D. Pfeiffer et al, 2016 JINST 11 P05011

- Position resolution σ <300 μm reached with Triple GEM, APV-25
- Detection efficiency < 12 % at normal incidence of neutron

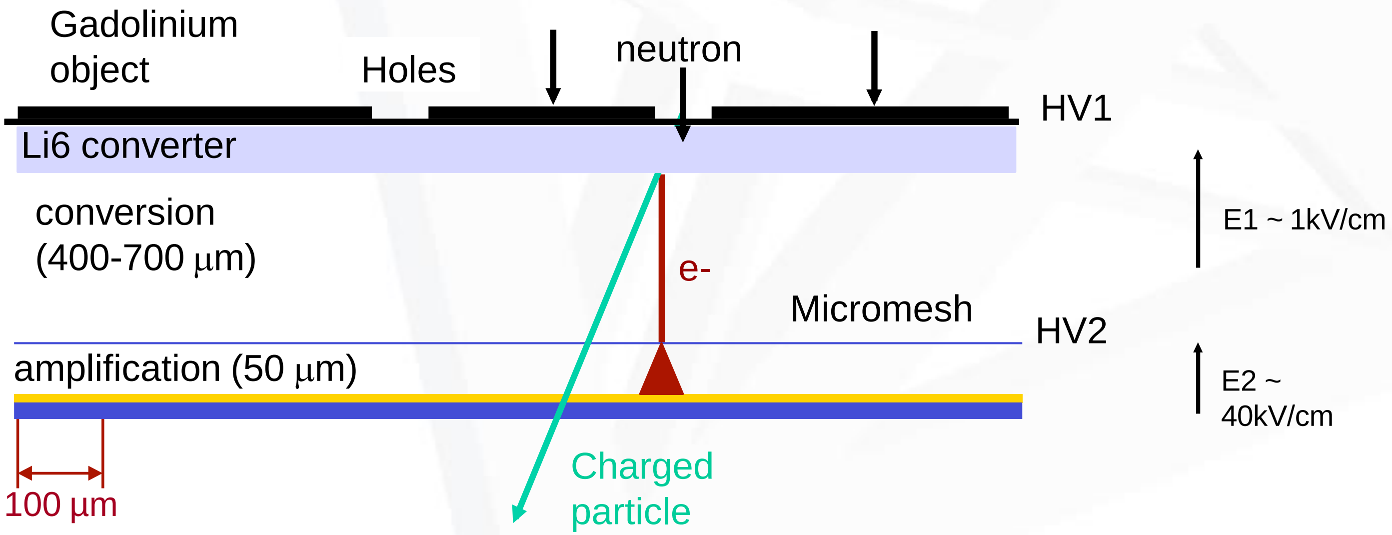
Micromegas for neutron radiography

- CEA/DSM-IRFU + CEA/DRT-LIST-DETECS collab.
- « classical » micromegas prototype



✓^{6}Li converter : 50 µm
✓Conversion gap : 400 µm
✓Amplification gap : 50 µm
✓Self-supported 50 µm micromesh
✓Gassiplex cards readout

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



Thanks to A. Delbart

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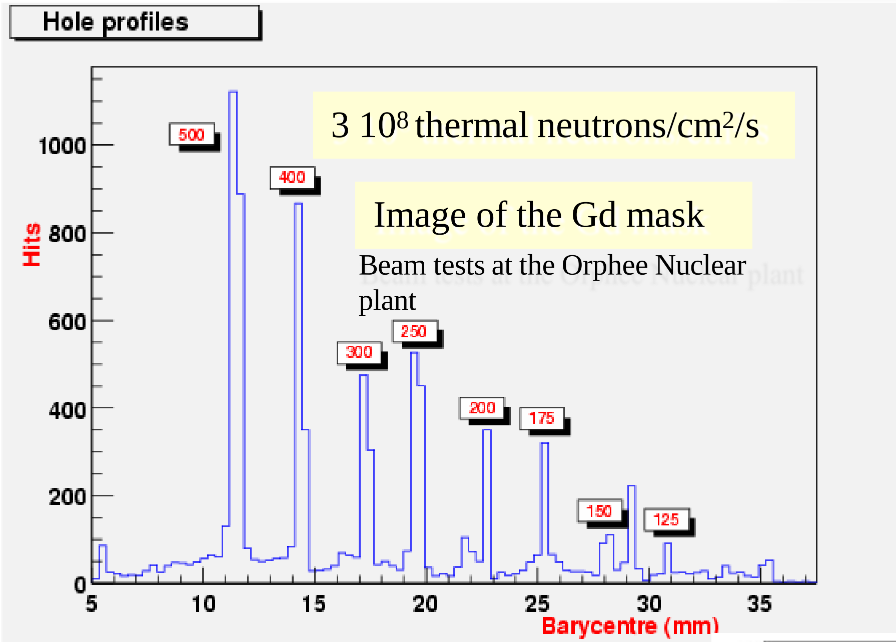
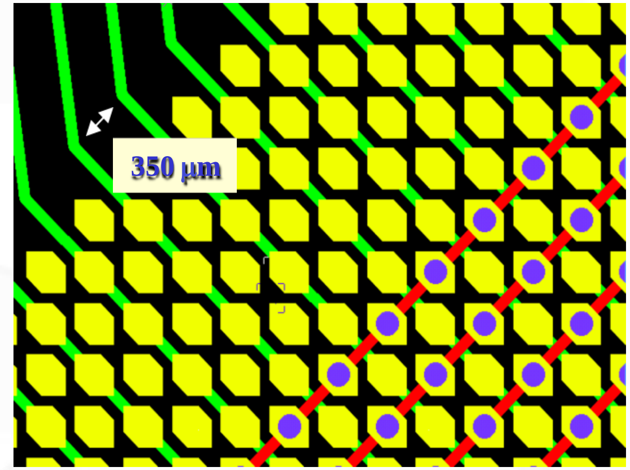
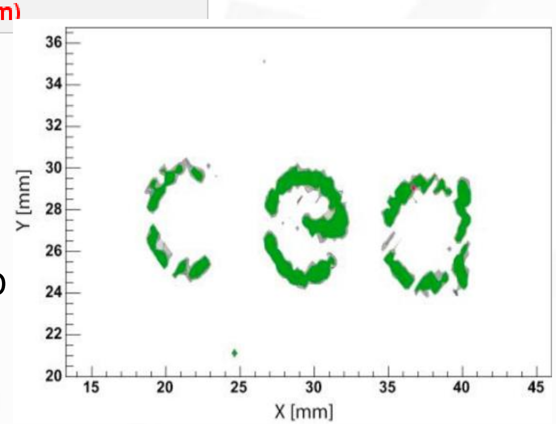
Imaging capabilities of the prototypes

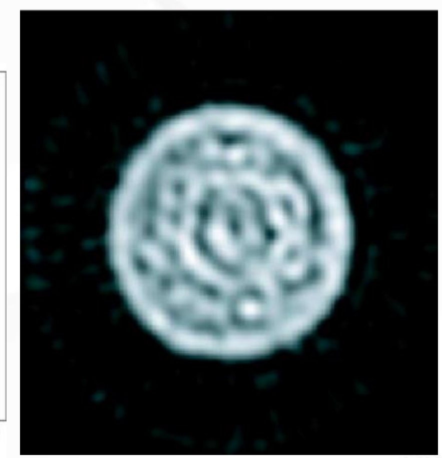
F. Jeanneau, IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 53, NO. 2, APRIL 2006





Tomographic image of a multi-wires cable (Ø6 mm, 12 wires, Ø0.5 mm each)





Distorted tomograhy reconstruction with ~160µm resolution because of the pillars supporting the "classical" micromegas mesh

Should be greatly improved today by use of the 2D micro–bulk

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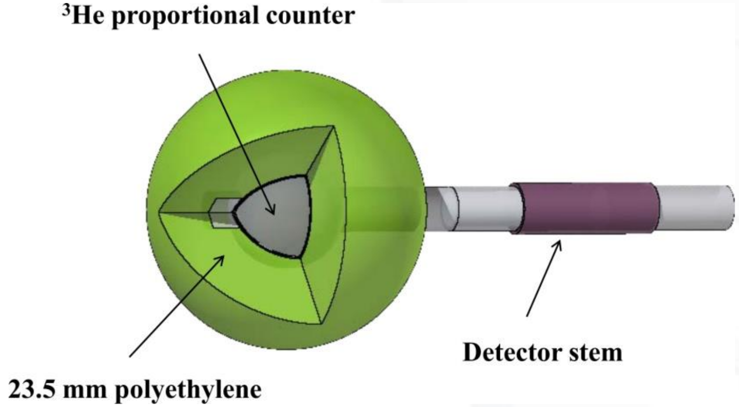
Thanks to A. Delbart

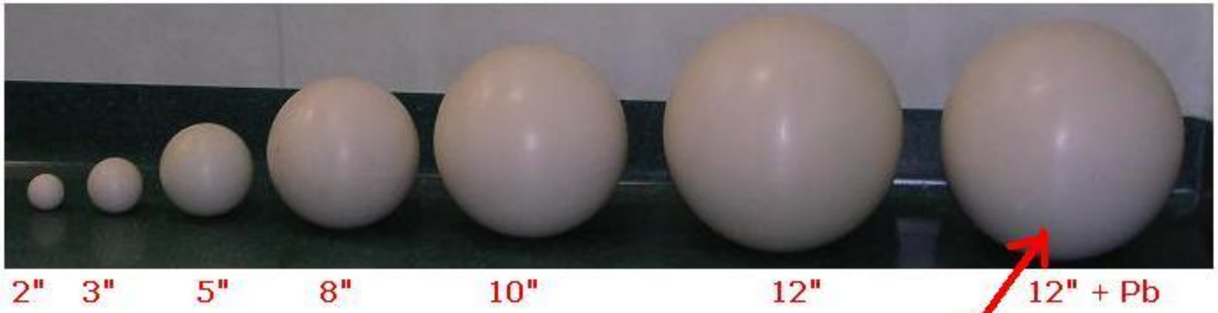
Fast neutrons

^{3}He tubes applications – fast neutrons

- ^{3}He detectors can be also used to detect fast neutrons if an appropriate moderator is placed around the detector

BONNER SPHERES



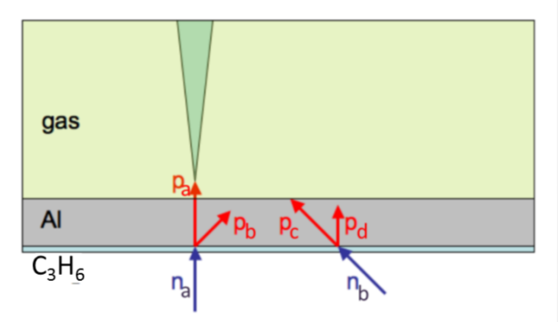


12"+Pb internal part

Typical fast neutron converter

Detection of recoiling protons produced by neutrons in plastic

Proton energy after the proton recoil: $E_p = En \cdot cos\theta_{n-p}{}^2$

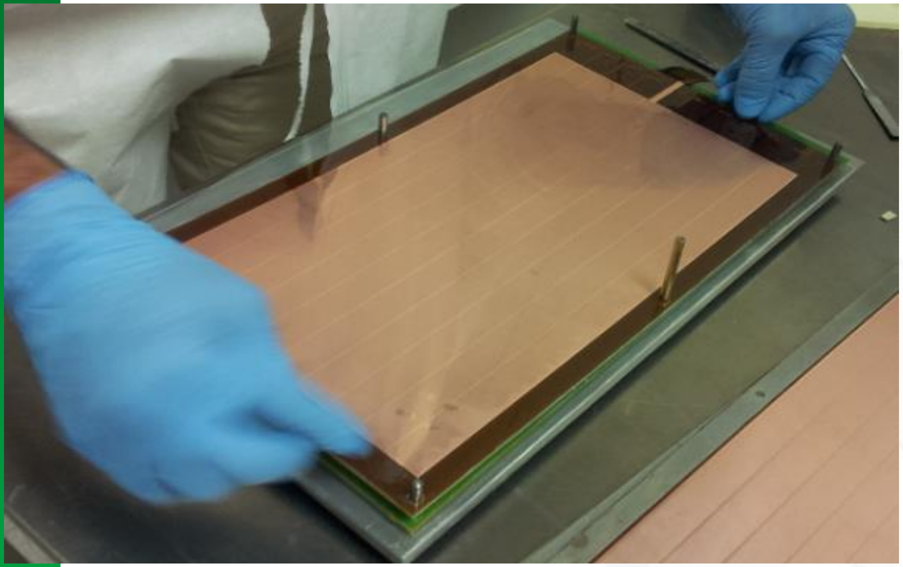


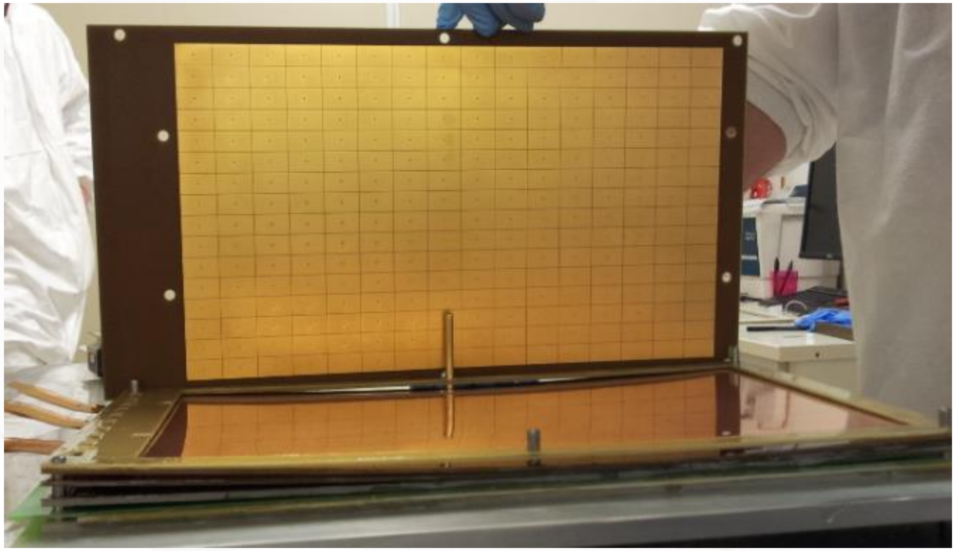
Not in scale.....

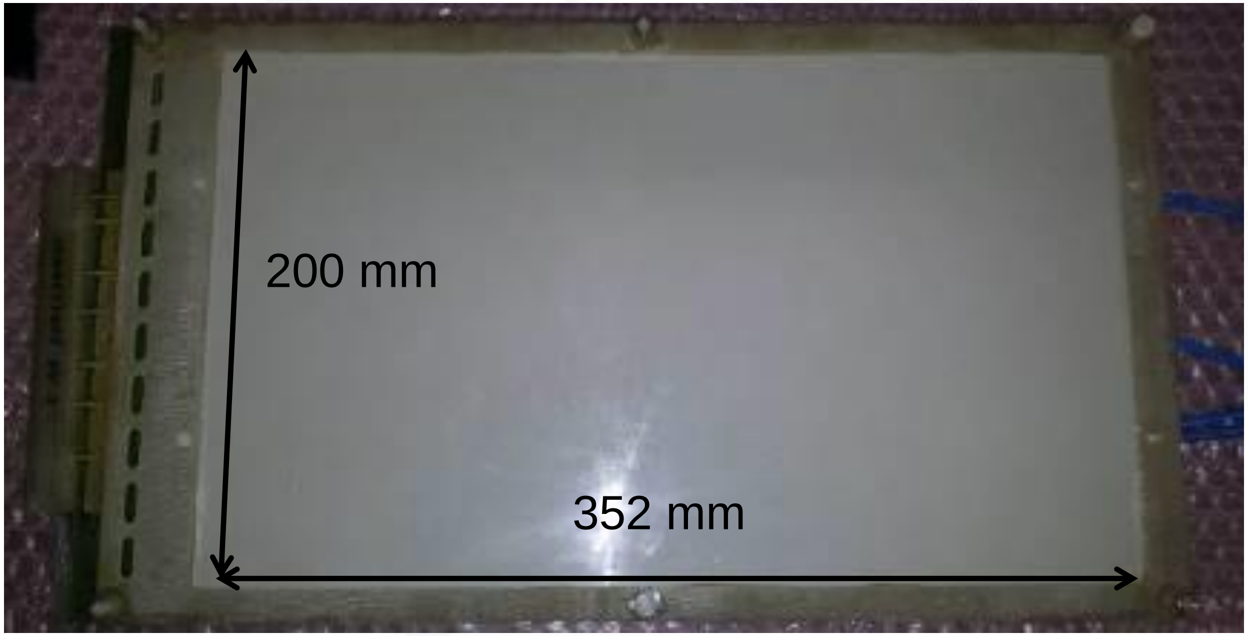
With this cathode only a proton recoiled by a neutron incident with an energy **and** an incidence angle above than a certain threshold can be detected by the charge particle detector, like GEM, MM, …

This introduces also a **directionality selection effect** to the detector,

nGEM fast neutron detector







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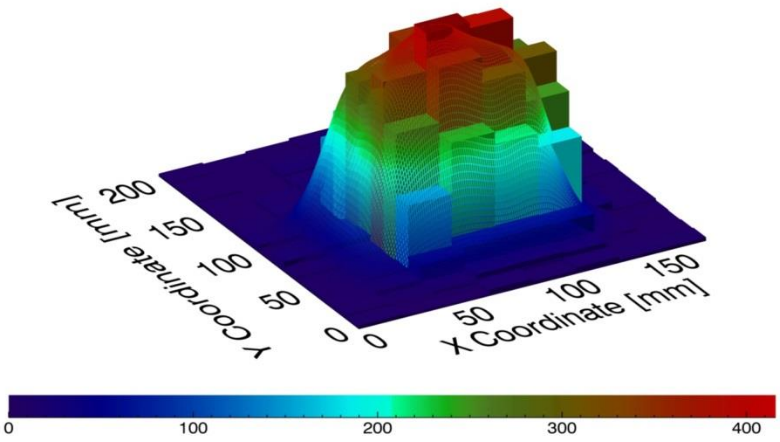
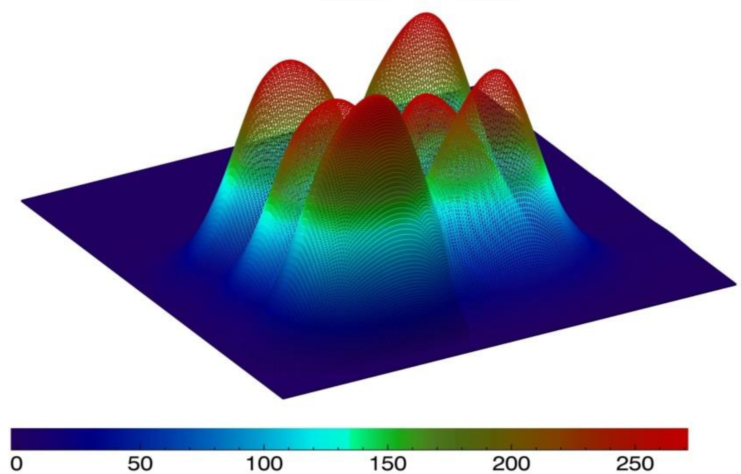
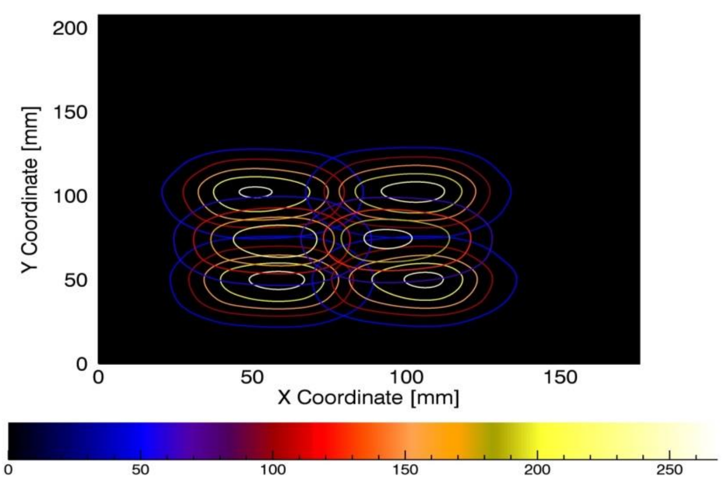
nGEM Imaging performance





	a0=MAX [count]	a1 = σ_x [mm]	a2 = σ_y [mm]	a3 = μ_x [mm]	a4 = μ_y [mm]
Beam 0	299.248	17.4720	14.5132	56.4488	48.9141
Beam 1	284.144	17.4720	14.5132	102.848	49.1036
Beam 2	284.677	17.4720	14.5132	53.2270	101.164
Beam 3	304.999	17.4720	14.5132	100.733	101.799
Beam 4	269.801	17.4720	14.5132	56.7838	73.0534
Beam 5	237.176	17.4720	14.5132	96.3992	73.5918



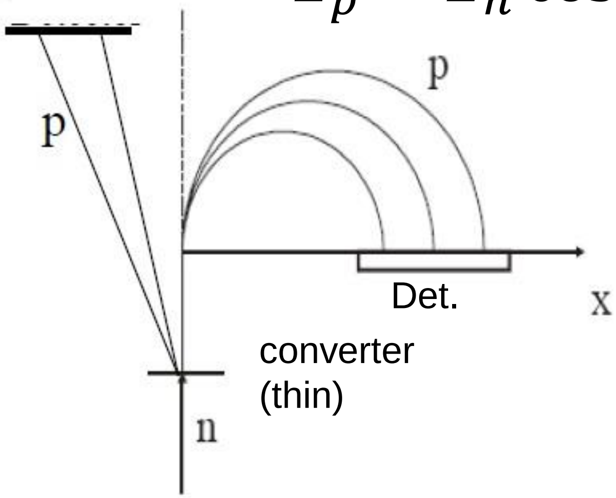
The detector is suitable for reconstructing different beams

GEM Neutron Spectrometer (for fusion neutrons)

TPR concept

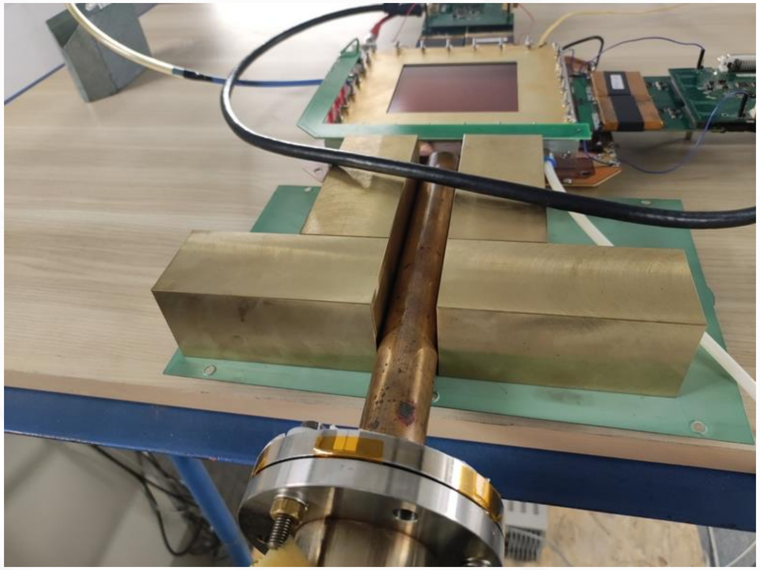
vacuum

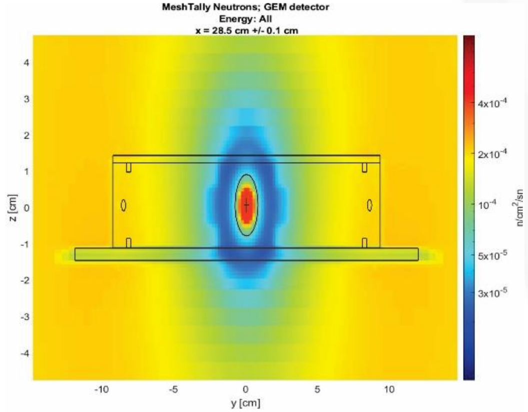
$$E_p = E_n \cos^2 \theta$$

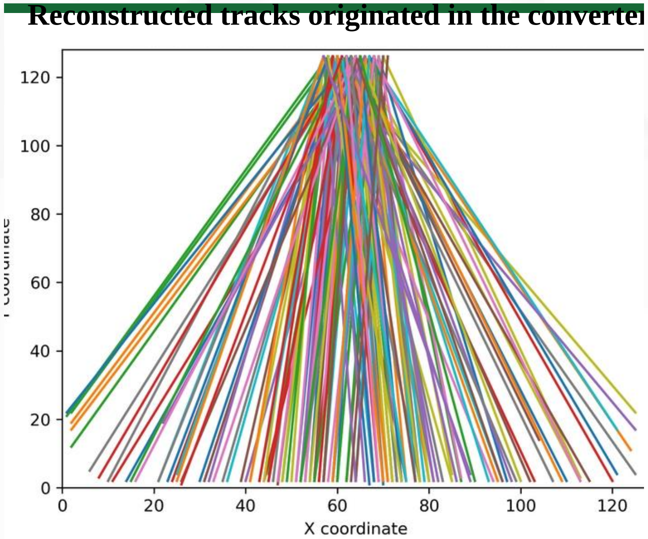


about 8%.

3.4 to 4.2 %

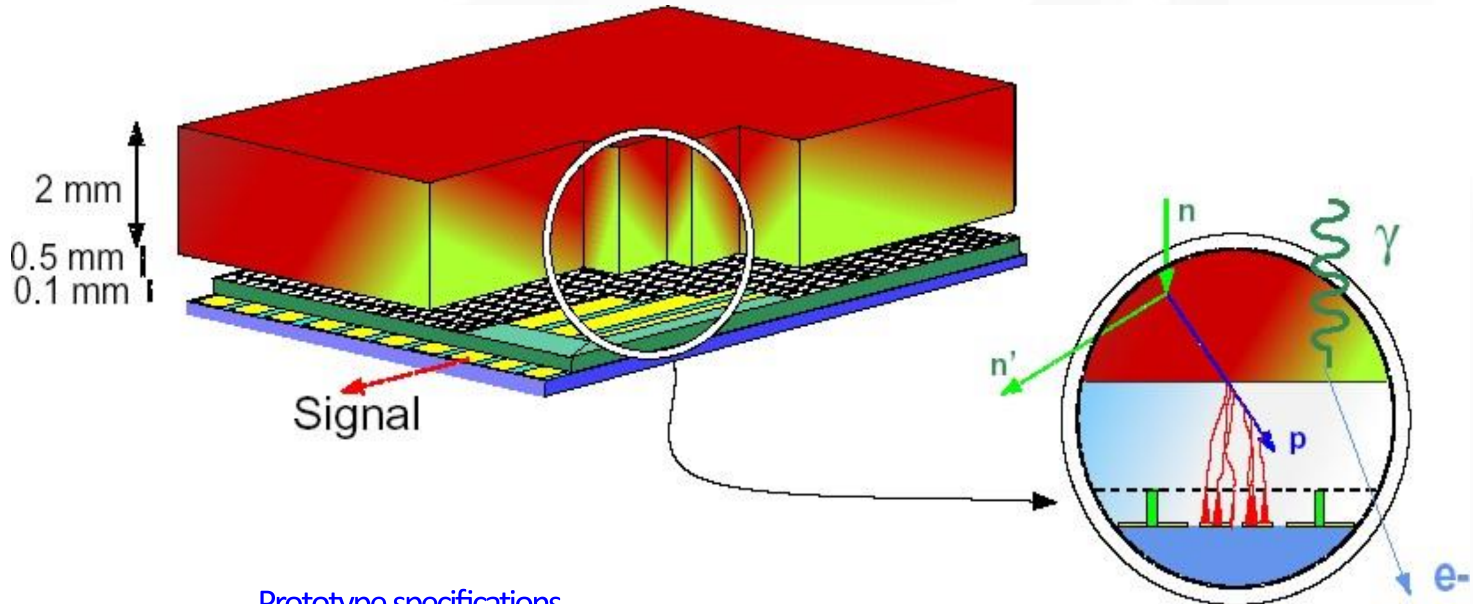






DEMIN : Micromegas Detector for Neutron spectroscopy for MégaJoules Laser and Inetial Confinement Fusion experiments

Up to 30 MeV neutron spectrum diagnostics for inertial confinment DD and DT fusion

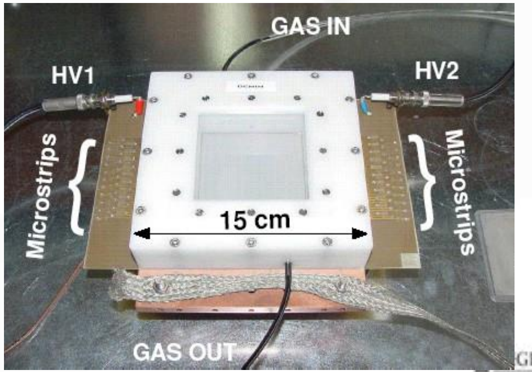


Prototype specifications

- ✓ 80x80 mm^2 « classical » micromegas with 40 x 1 mm width strips
- ✓ 500μm thick drift volume, filled with $He+10\%C_4H_{10}+10\%CF_4$
- ✓ CH_2 converter

Front-end electronics

- ✓ Fast current preamp +MATACQ readout (SEDI)
- ✓ 40 electronic channels



Ref: M. Houry et.al., NIM A 557 p648 (2006)

Thanks to A. Delbart

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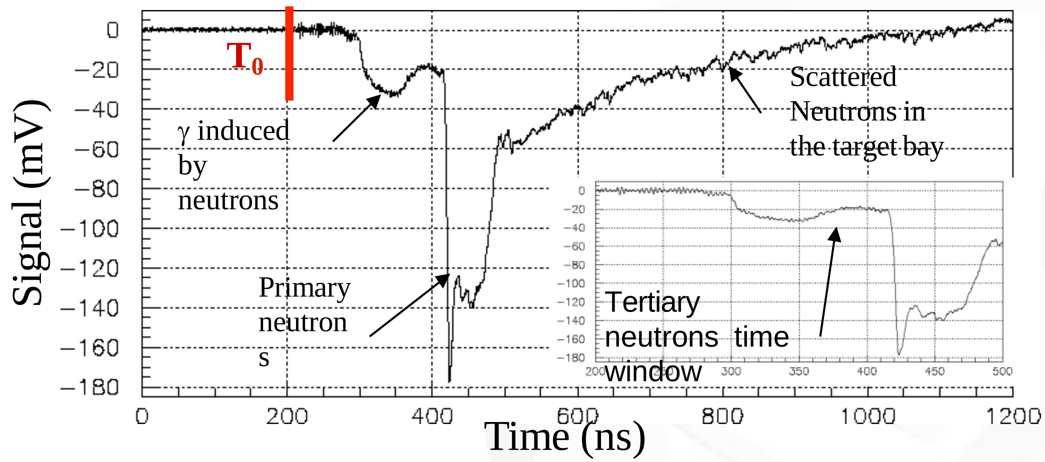
DEMIN : performances

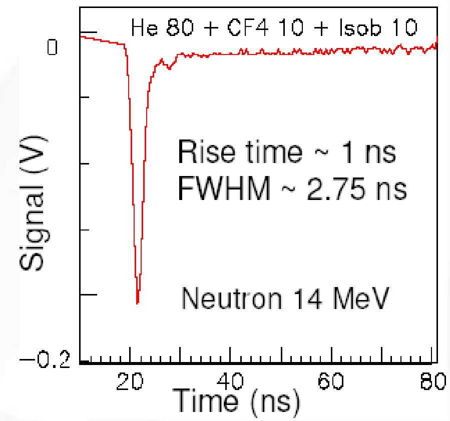
DT SHOT, 31769; 4.10^{13} n_{14MeV}



~> **Pulse Shape**

~> Time of flight : δE/E~1%

~> Low pile-up : pulse chain

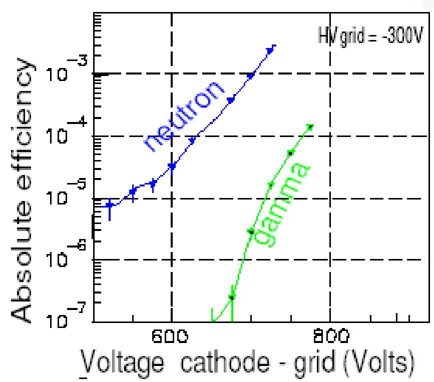


30 eV/mm stopping power of 1 MeV e- in gas

→ the thinner drift gap, the better the γ rejection

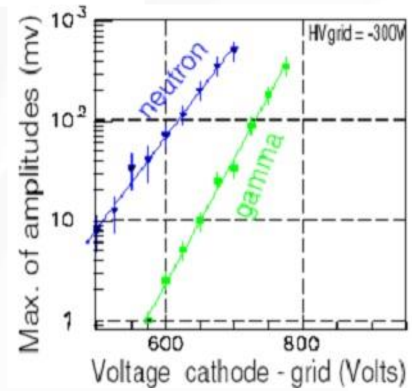
~> **n/γ Discrimination**

Ref: M. Houry et.al., NIM A 557 p648 (2006)



① **Efficiency Ratio**

~> 10^2 to 10^3



Pulse Height Ratio

~> **20**

Thanks to A. Delbart

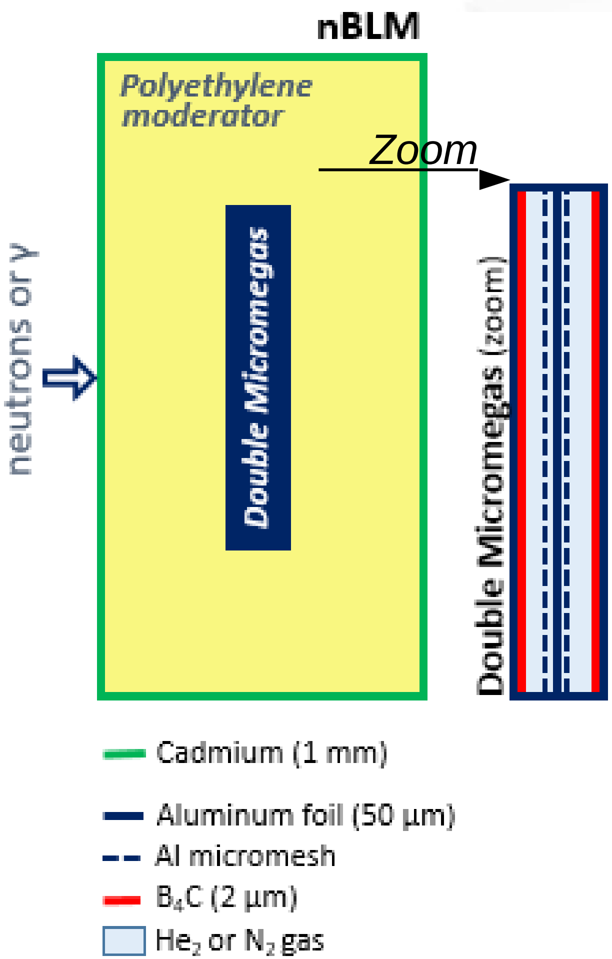
Micromegas Neutron beam loss monitor for ESS

Challenges

RF cavities emit γ's → background for ionization chambers used as BLMs

Imposible of beam tunning, loss origin of gammas

Continuous monitoring of small losses is needed



Signature of beam loss: **fast neutrons**

Cadmium envelop

→ to absorb the incident thermal neutrons

Polyethylene moderator

→ to thermalize the incident fast-neutrons

B_4C layer (1.5 - 2 µm)

→ Increase neutron detection efficiency

Double Micromegas: back to back

→ ~5mm drift → optimize for dynamic range

Gas: He_2 (≈ 1.1 bar) or N_2, Ne…

→ He is better for photon discrimination Addition of a quencher: CO2, methane, ...

Two objectives: **monitoring and safety**

Thanks to A. Delbart

Developed by CEA

Multi-layer converter + THGEM detector

Detector Concept:

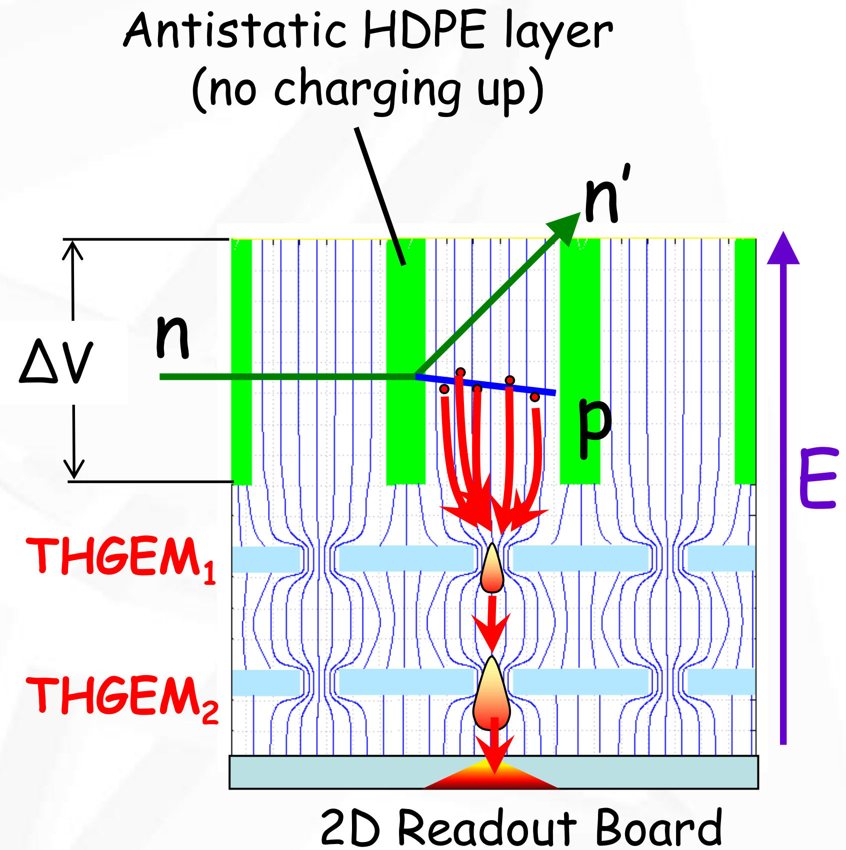
- n scatter on H in HDPE-radiator foils, p escape the foil.
- p induce e^- in gaseous conversion gap.
- e^- are multiplied and localized in THGEM-detector.
- Combine several 1D radiographs → 2D cross sectional tomography.

Detector design:

-) Foils thickness (2.5 MeV neutron)
-) Gas gap thickness (Deposited Energy)
-) Converter height (Axial resolution)
-) Number of converter foils (Detector Length)

Detector Performances:

-) Spatial Resolution
-) Efficiency of transport e- in small gap
-) Detector Efficiency



Cortesi et al. 20012 *JINST 7 C02056*

Conclusions

- The concept of a neutron detector is quite difference from the concept of charged particle detector
  - You have to face mainly with the «efficiency» challenge
- ^{3}He crisis and the need of high rate capability detectors fostered several novel applications
- Novel wire, RPC and MPGD solutions have been successfully developed in the last 10-15 years and are considered enough mature to be used in future spallation sources like ESS
- In WP9 we have to start from this point and further advance

General remarks to realize a neutron detector
A possible WP9 Guideline

- Detectors must be chosen/DESIGNED for the specific application. Typical application is “counting above threshold”

Requirements to be considered when designing neutron detectors:

- Gamma-ray sensitivity
- Count rate
- Time/space resolution
- Environment (B field, temperature etc)
- Low budget material
- Low intrinsic radioactivity

Digitize! (if possible)

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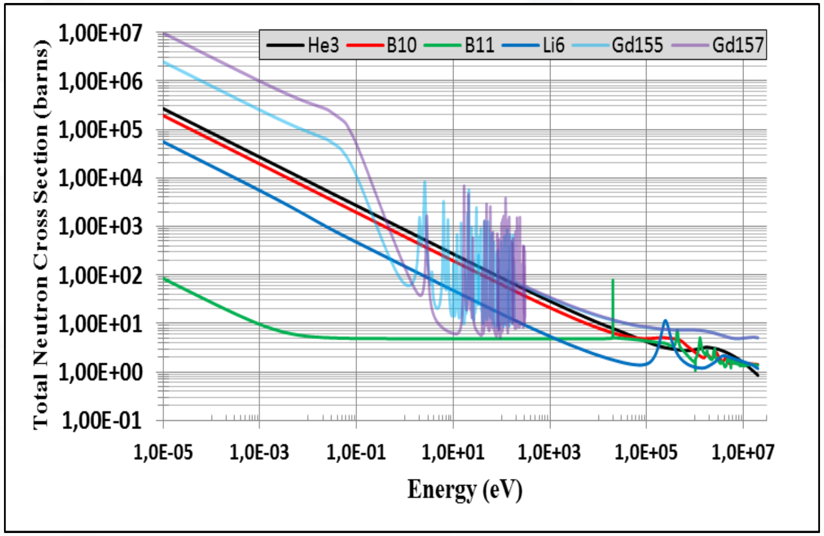
Spare Slides

Neutron Interaction and detection (2/2)

- In order to realize a neutron detector we thus need a material with a sufficiently high cross section. Nature offers some (but not many materials with such features)
- These materials are used to "convert" neutrons into charged particles
- Neutrons interact with nuclei through the strong force and thus through nuclear intections

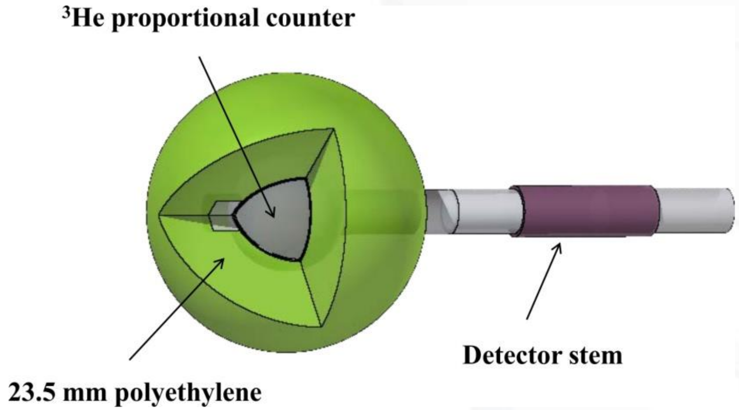
- n + ^{3}He → ^{3}H + ^{1}H + 0.764 MeV
- n + ^{6}Li → ^{4}He + ^{3}H + 4.79 MeV
- n + ^{10}B → ^{7}Li* + ^{4}He→^{7}Li + ^{4}He + 0.48 MeV γ +2.3 MeV (93%)
  → ^{7}Li + ^{4}He +2.8 MeV (7%)
- n + ^{155}Gd → Gd* → γ-ray spectrum → conversion electron spectrum
- n + ^{157}Gd → Gd* → γ-ray spectrum → conversion electron spectrum
- n + ^{235}U → fission fragments + ~160 MeV
- n + ^{239}Pu → fission fragments + ~160 MeV

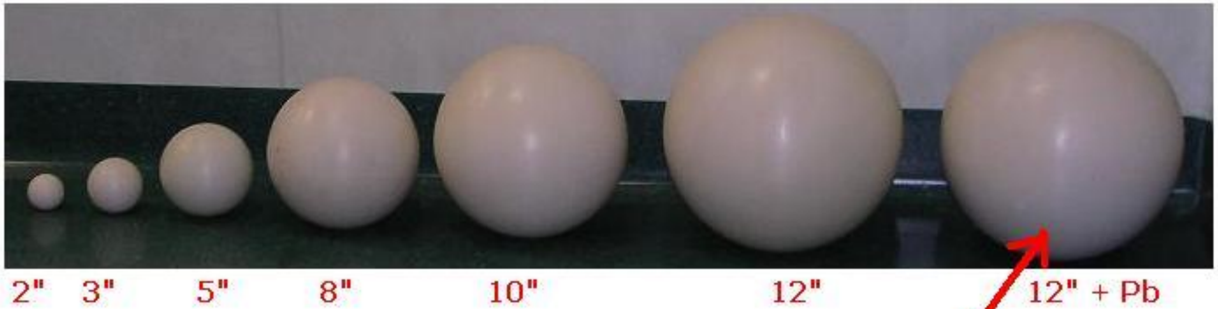


^{3}He tubes applications – fast neutrons

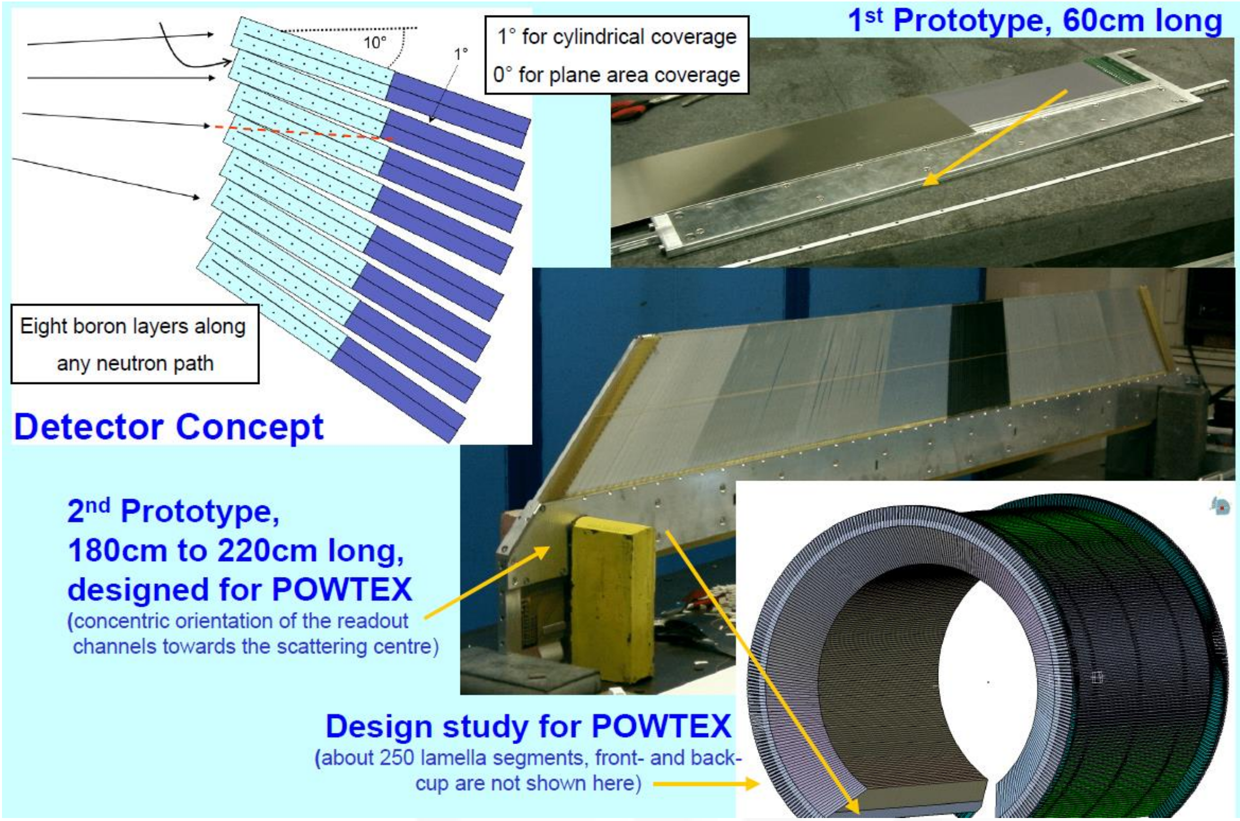
- ^{3}He detectors can be also used to detect fast neutrons if an appropriate moderator is placed around the detector

BONNER SPHERES

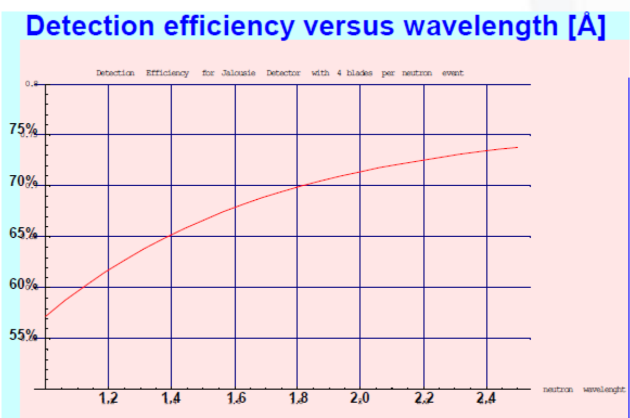




Novel wire-based solutions

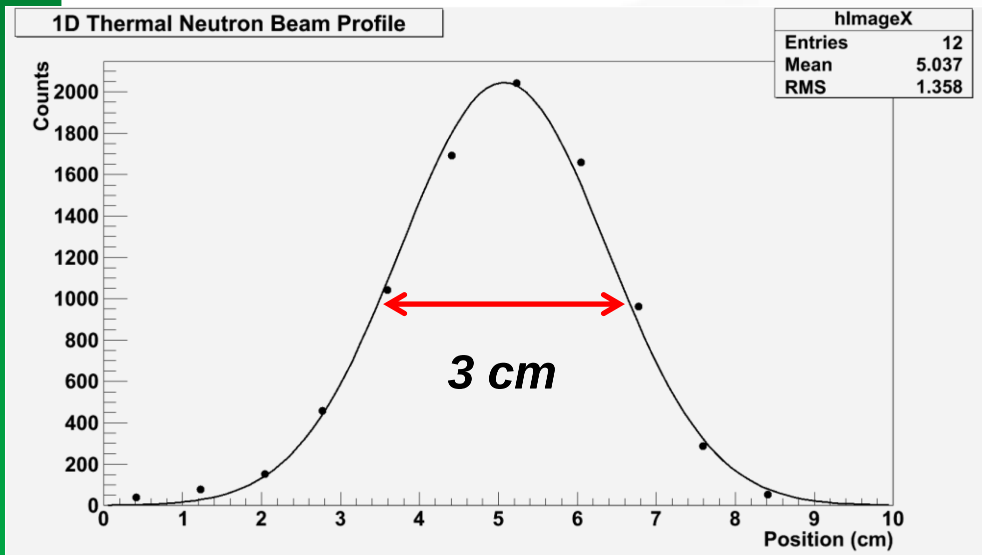


Developed by Heidelberg CDT©



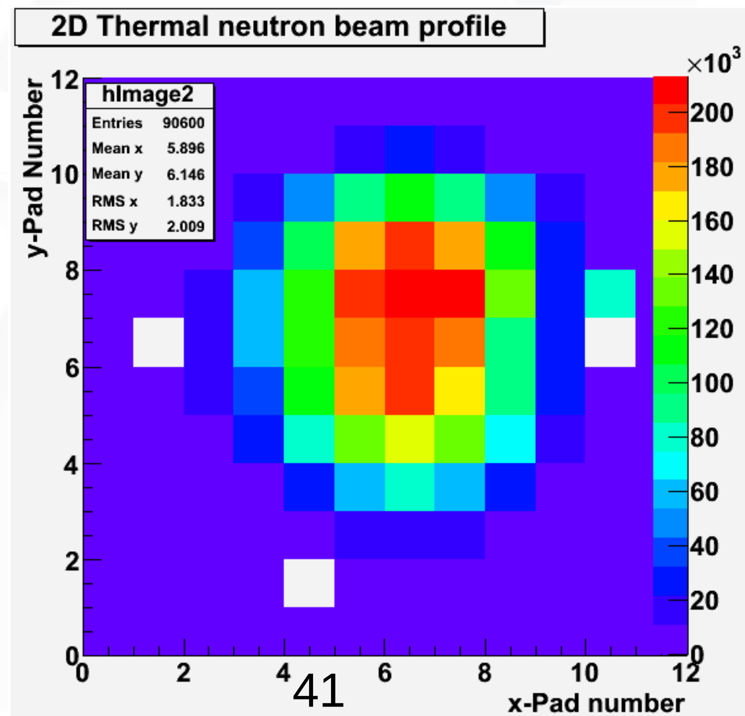
- **Accumulate detection efficiency through:**
  - 8 boron layers
  - inclined boron layers (10°) to increase effective absorption depth
  - **Result: 70% (1.8A) and 55% (1A)**
- **Spatial resolution:** FWHM = 5 mm at ambient counting gas pressure
- **TOF-resolution** below FWHM = 10 μs due to many folded anode readout wires within the depth of one lamella.
- **High Count rate capacity** of 2 MHz (10% dead time) per module due to the segmented and individually read out Kathode structure.
- **Very low γ-background:** Low Z converter material ^{10}B, the high energy of the α can easily be detected and small drift gaps amplify the enormous difference in ionization density, a fast electron from gamma interaction creates in the counting gas as opposed to an alpha particle from neutron conversion.
- **Long term stability** due to continuous purge of cheap counting gas through detector.

Measurement of ISIS-vesuvio 2D thermal neutron beam profile

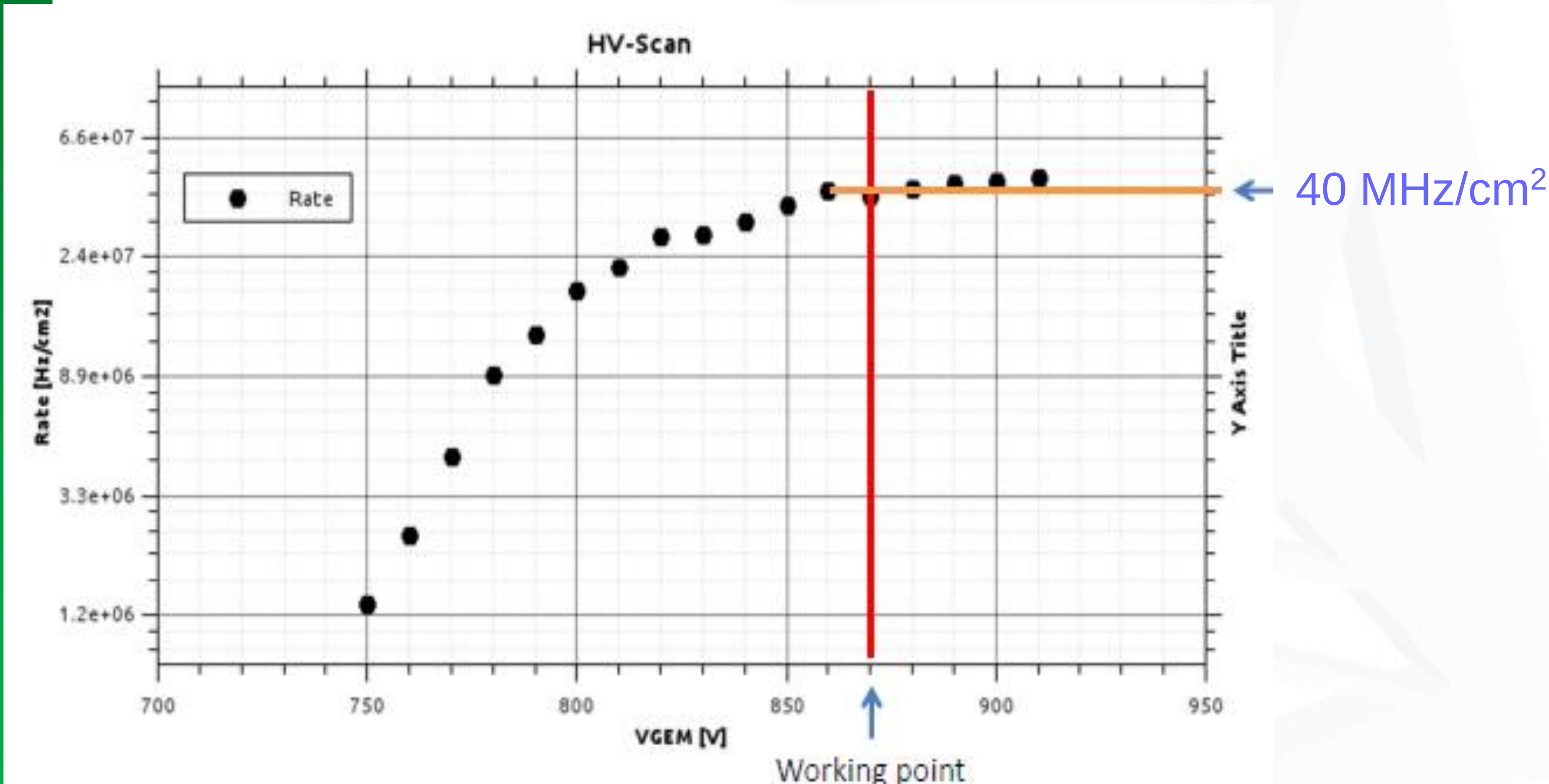


G. Croci et Al, NIMA (2013)

The measured FWHM is around 3 cm compatible with ISIS-Vesuvio data



Thermal neutron measurements as a function of detector gain

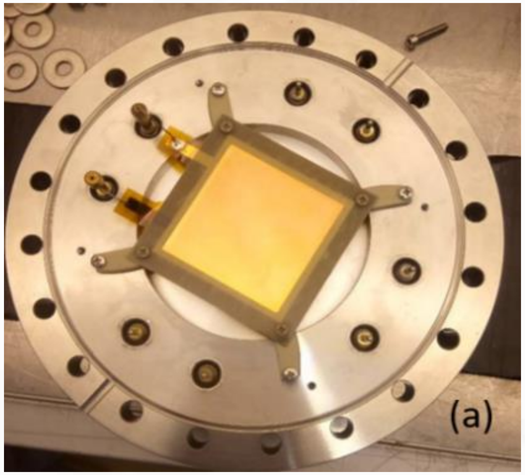


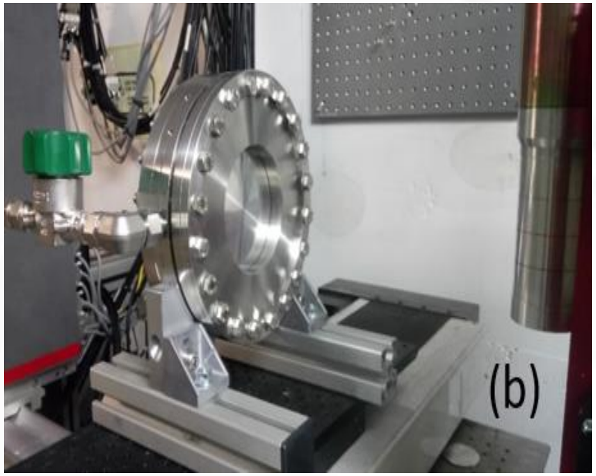
Comparable with X-ray GEM rate capability (1MHz/mm^2 = 100 MHz/cm^2)

Expected rate with Φ = 7.88 x 10^8 n/cm^{2}s and ε_{GEM} = 5% is **39.4 MHz/cm^2**

NitroGEM neutron beam monitor

- The NitroGEM monitor has been designed for use on high intensity neutron beamlines
- Nitrogen:
- Low efficiency: N_2 absorption cross section 1.9 barn at 1.8 Å
- **Reaction: n+^{14}N->p+^{14}C, 620 keV proton energy**
- Good to measure gamma/neutron separation, efficiency
- Standard GEM from CERN:
- Standard electronics used to readout ^{3}He tubes at ISIS





Developed by ISIS

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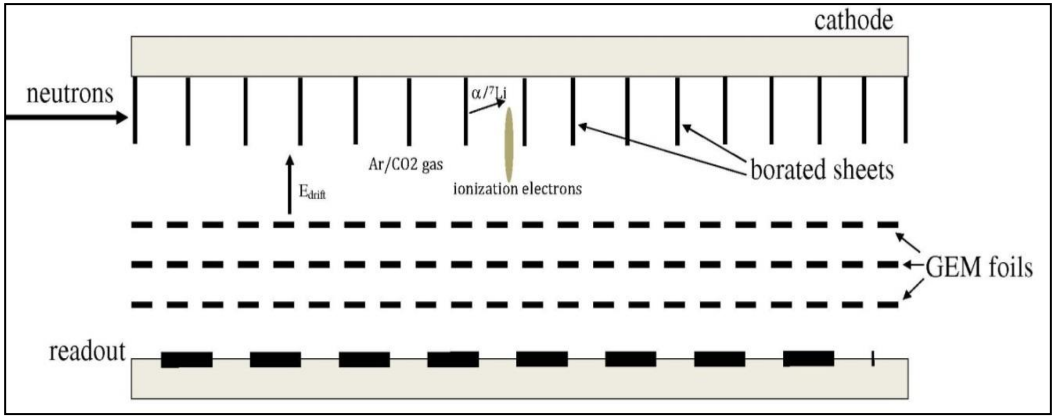
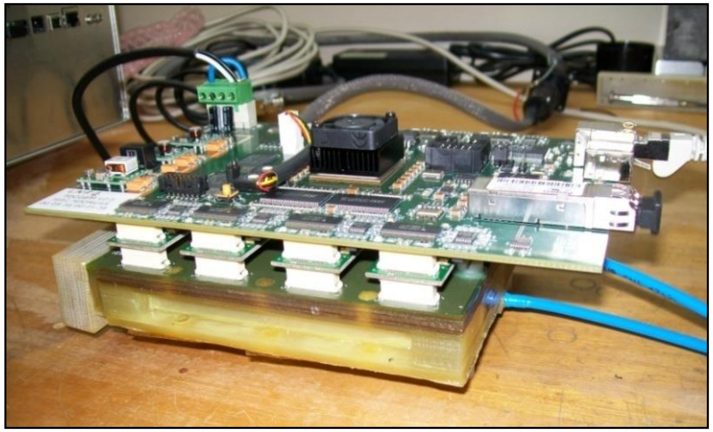
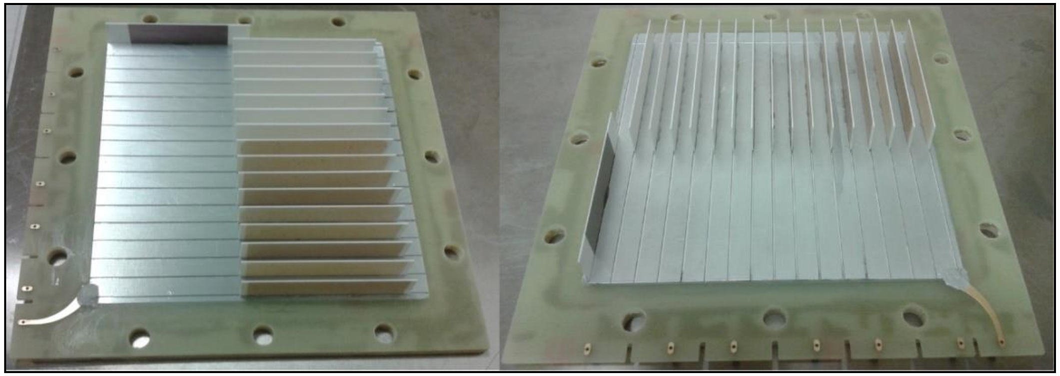
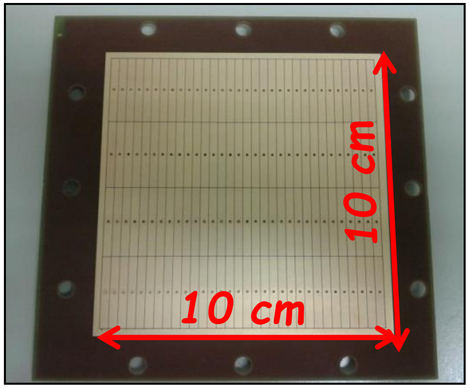
Side-on neutron GEM detector

We developed a new prototype increasing the number of borated strip to 16, in order to obtain an higher efficiency.









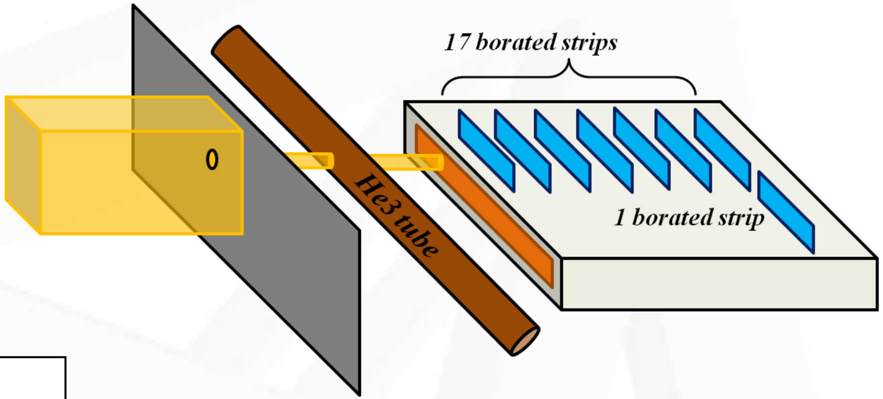
Now we used an anode with PADs having a different geometry. There are 32x4 PADs and each PAD is 3x24 mm².

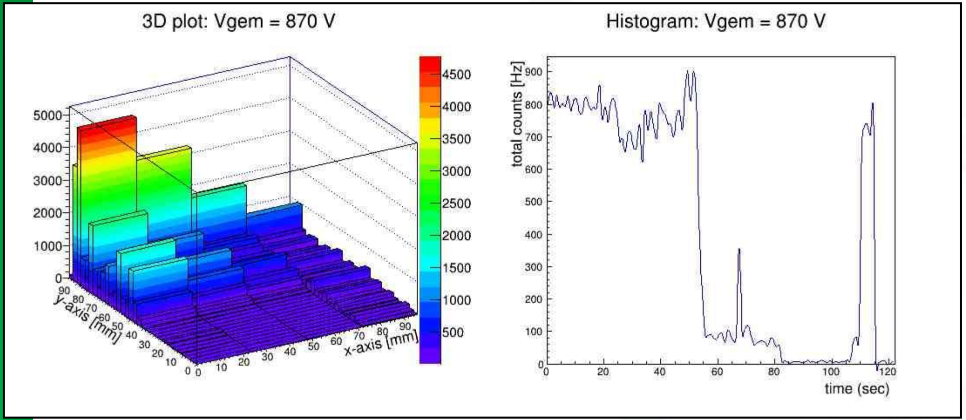
Now we used ceramic strips (Al2O3) 500 μm thick.

Detector window is placed on the side of the anode with 32 PADs. In this way detector is able to measure also position of small spot beams impinging on the side-on window.

Side-on neutron GEM detector performance

We estimated detector efficiency, making a comparison with an ^{3}He tube which has a 100% absolute efficiency at the used peak energy of 5,11 meV.

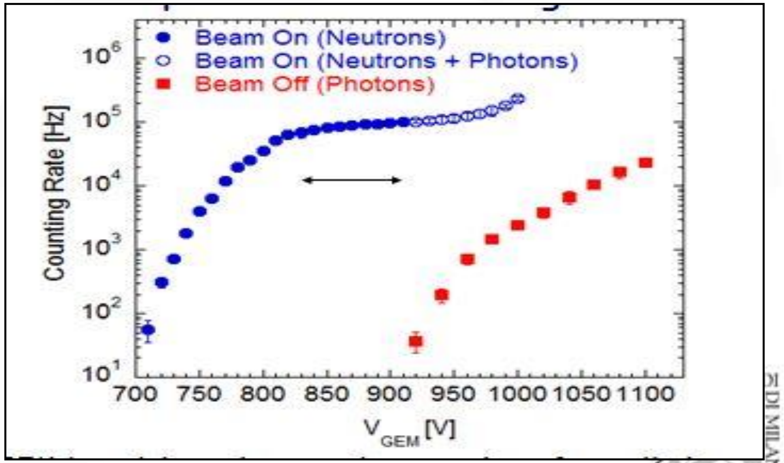




Detector efficiency was evaluated on both detector sides:

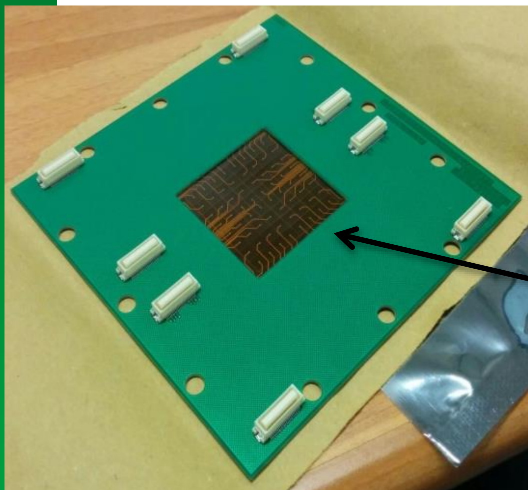
- 16 strips efficiency = ***31 ± 1*** %
- 1 strip efficiency = ***2,8 ± 0,5 %***

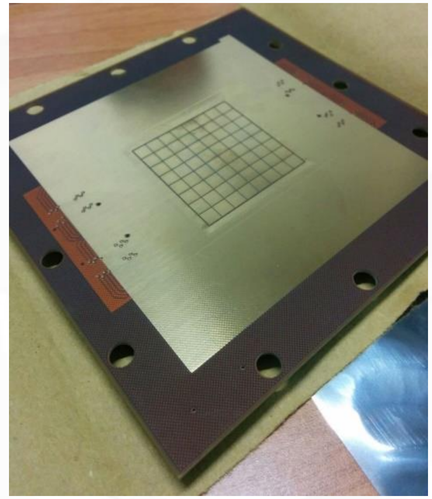
	S-GEM	^{3}He Tube
Overall mean counts [s^{-1}]	1863	6011
Background mean counts [s^{-1}]	21	1586
Signal/Background	87.7	2.8
Efficiency [%]	31	99



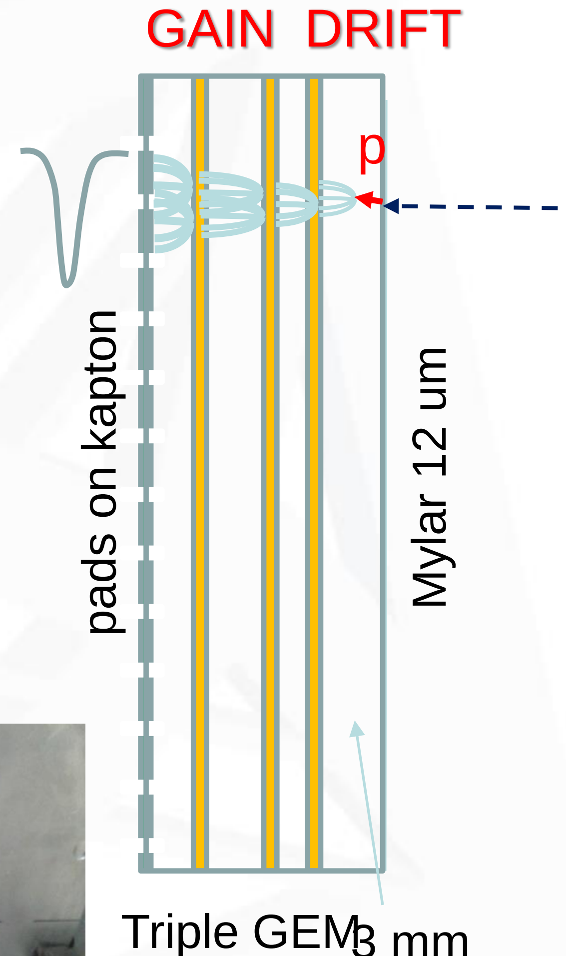
Low gamma sensitivity.

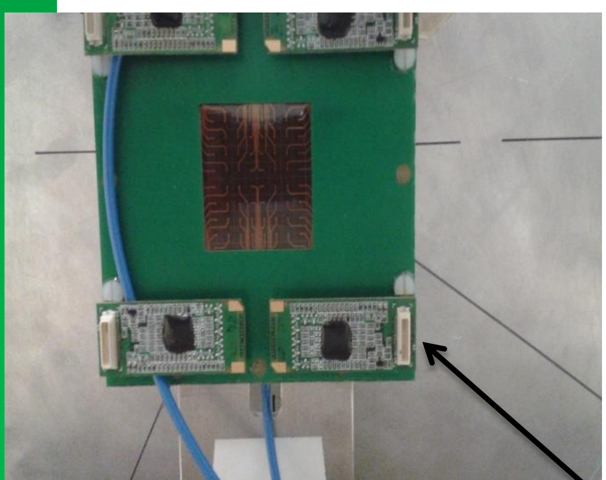
Low massNeutron GEM Beam Monitor

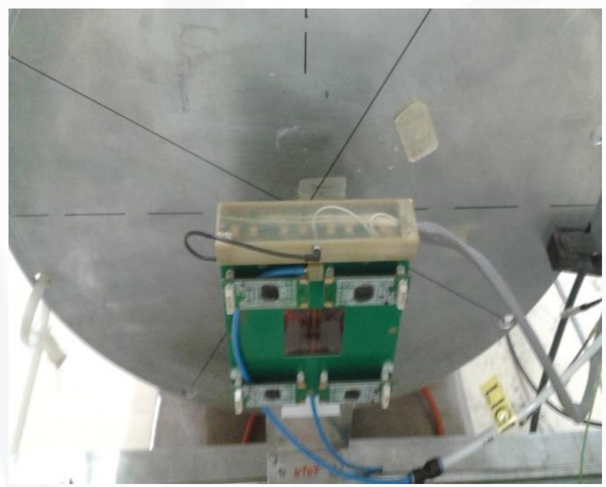




Kapton Pads



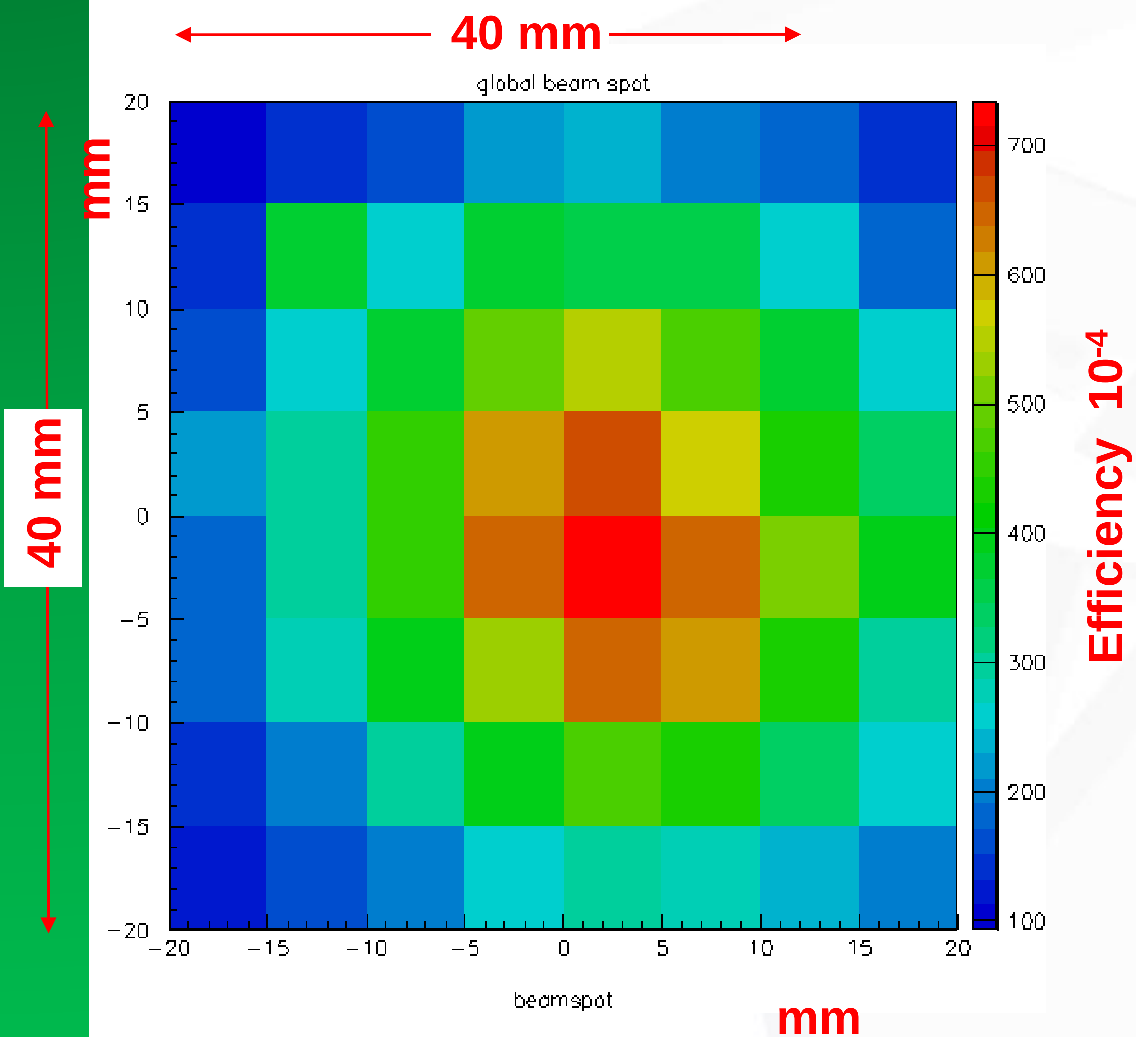


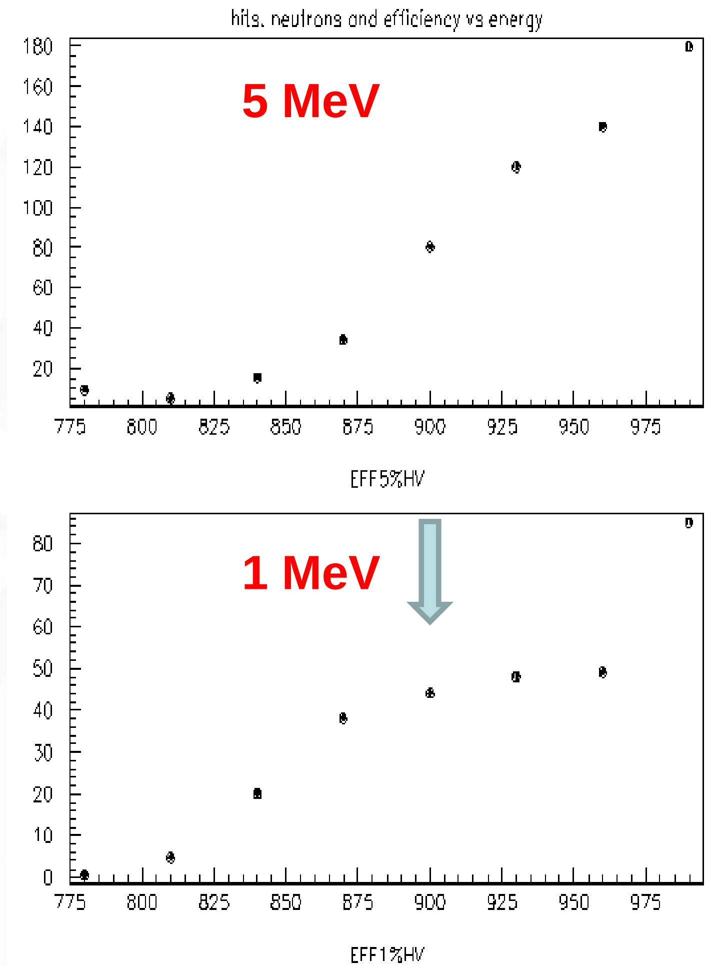


Electronics out of the beam

Low Material Budget !

Beam Monitor : fast neutron efficiency (nTOF)





F. Murtas measurements

ITER Neutral Beam Test Facility at Consorzio RFX

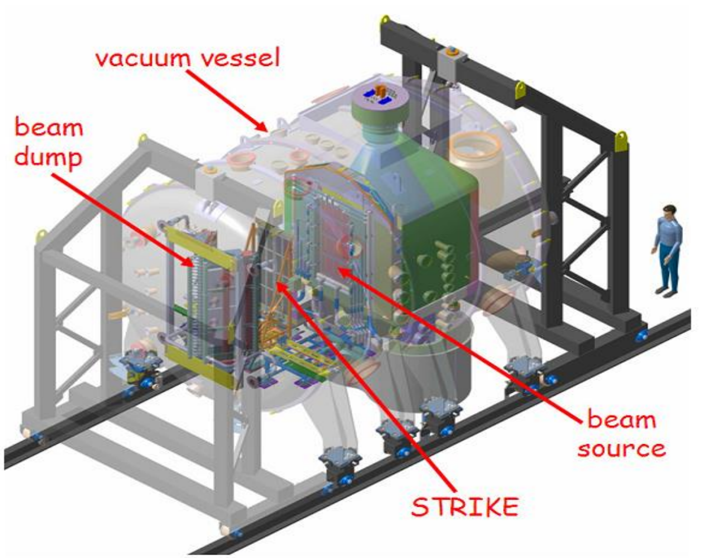
The ITER project requires additional heating by two **neutral beam injectors**, each accelerating up to 1 MV at 40 A beam of negative deuterium ions for one hour.

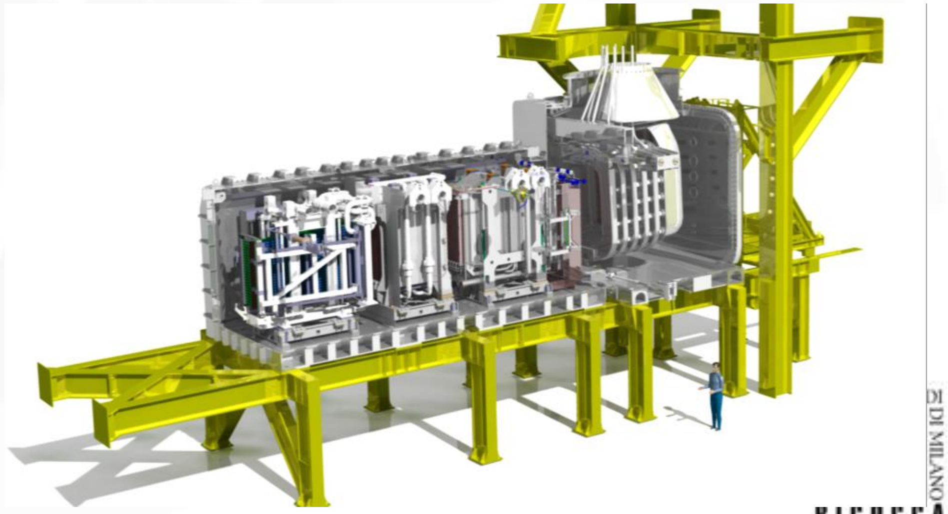
SPIDER

- Beam of H^-/D^- at 100 KeV
- Current density:355 A/m²(H) 285A/m²(D)
- Surface : >1 m²
- Deviation from the uniformity : <±10%
- Pulse length : 3600 s

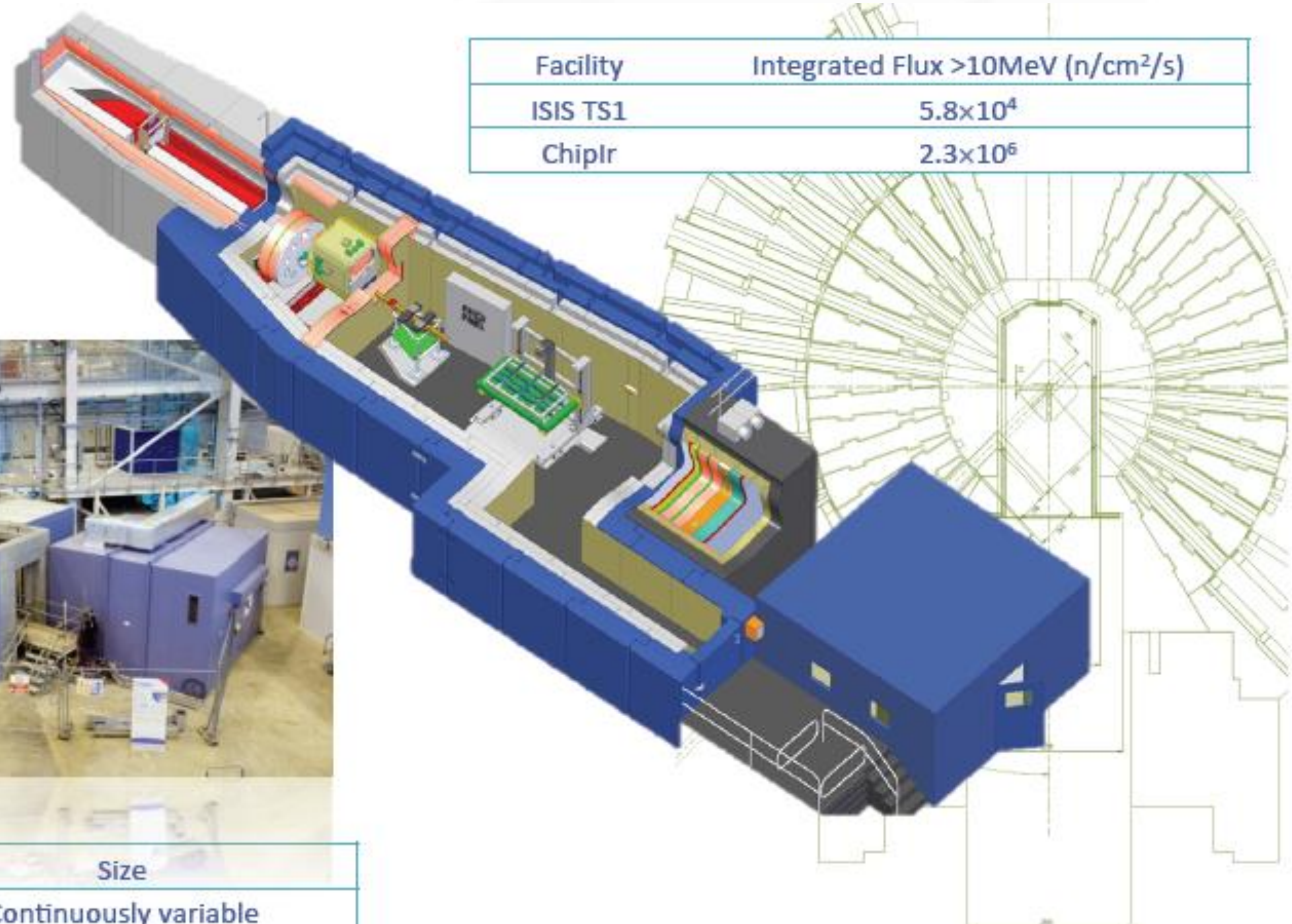
MITICA

- Beam of H^-/D^- at 0.87(H)/ 1MeV(D)
- Current:49 A (H)/ 40 A (D)
- Surface: >1 m²
- Deviation from the uniformity : <±10%
- Beam divergence < 7 mrad
- Pulse length: 3600 s





ChipIR



Facility	Integrated Flux >10MeV (n/cm²/s)
ISIS TS1	5.8×10^{4}
ChipIr	2.3×10^{6}

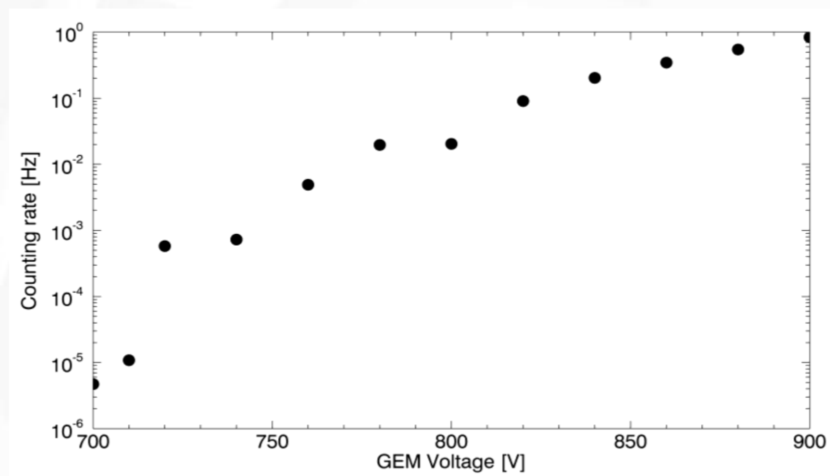
Beam	Size
Collimated	Continuously variable 250mm×250mm to 1mm×1mm
Flood	Fixed sizes 1000m×1000mm 500mm×500mm

Fast neutron beam monitor at CHIPIR-ISIS

- CHIPIR is a new beam-line dedicated to the irradiation of microelectronics with atmospheric-like neutrons; it has been built on the second target station of the ISIS spallation source
- Specifically dedicated to the study of single event effects and its design is therefore optimized to extract a neutron spectrum as similar as possible to the atmospheric one with intensity increased by a factor up to 10^9 depending on configuration.

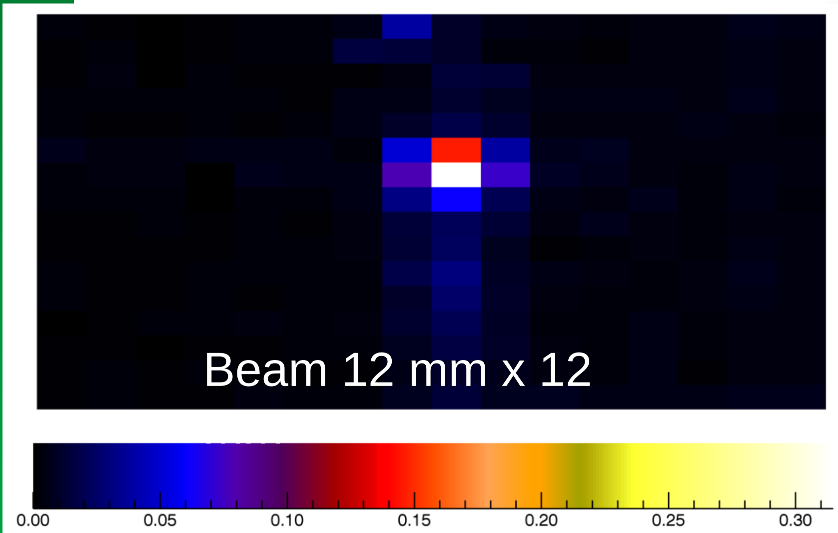
nGEM installed in Chipir

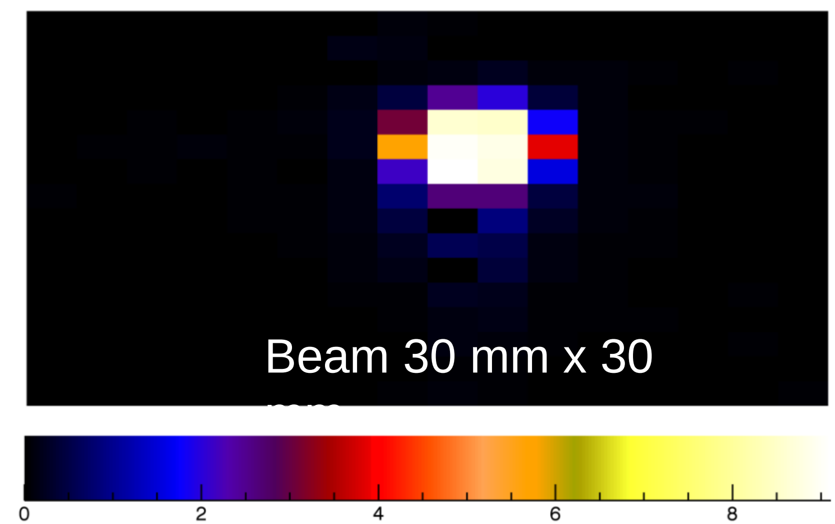
Working point determinaton

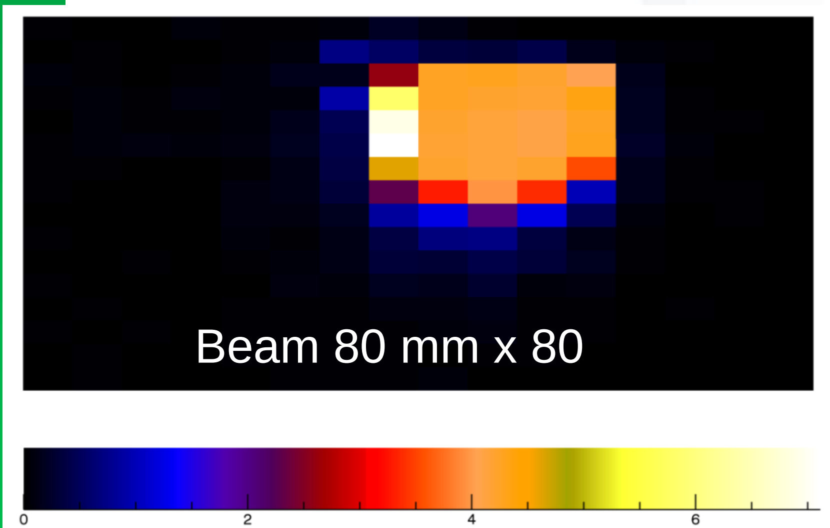


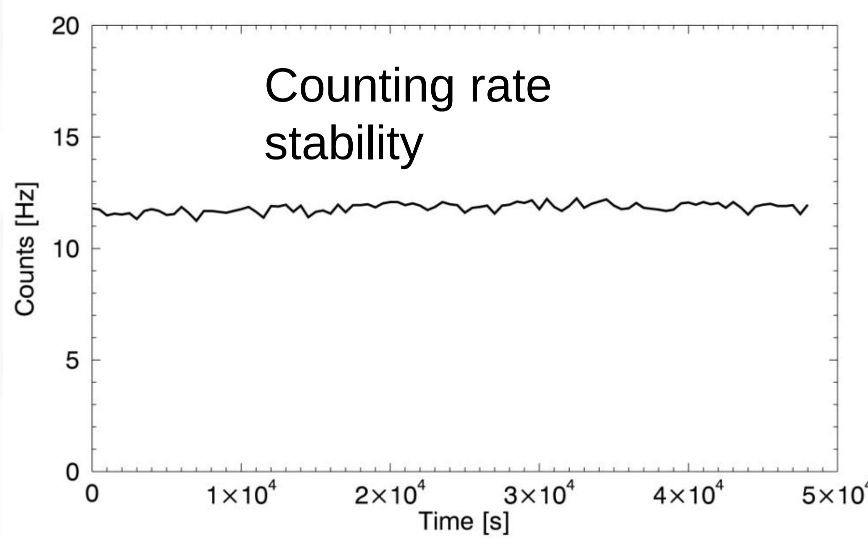
nGEM characterization for CHIPIR-ISIS

nGEM used to measure different beam sizes.



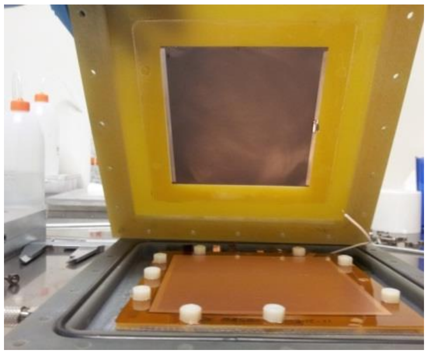




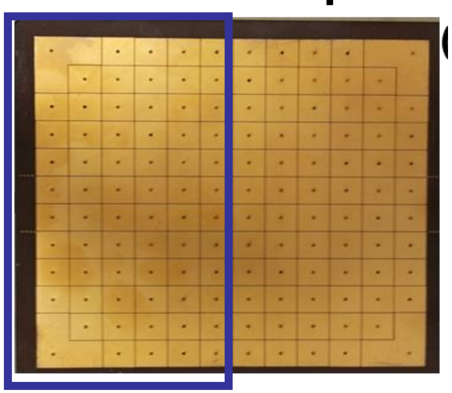


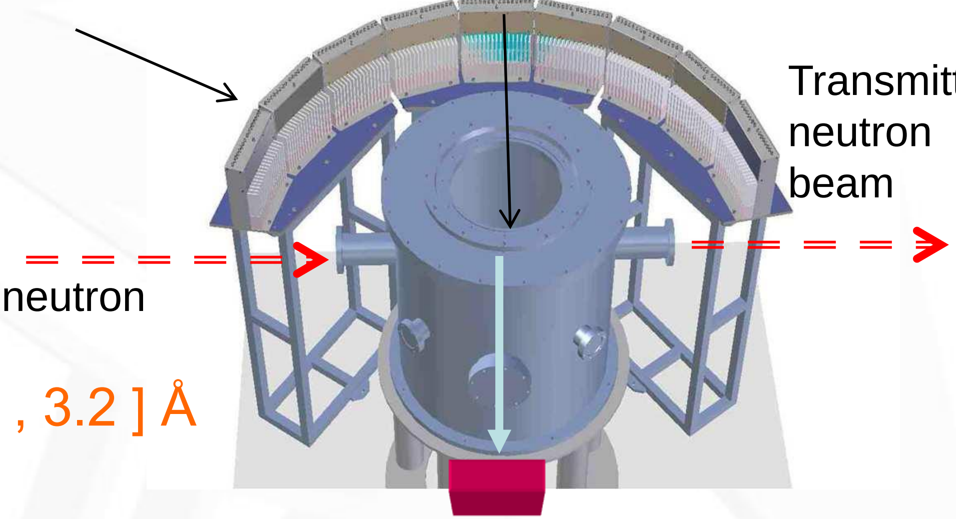
First test of GEM detector for neutron diffraction measurements

GEM – borated cathode



128 8x8 mm^2 pads





λ = [0.17 , 3.2] Å

Interface with ISIS-DAE: Time of Flight measurement perfomed using standard ISIS TOF DAE → First Time a GEM is inside standard ISIS DAQ System

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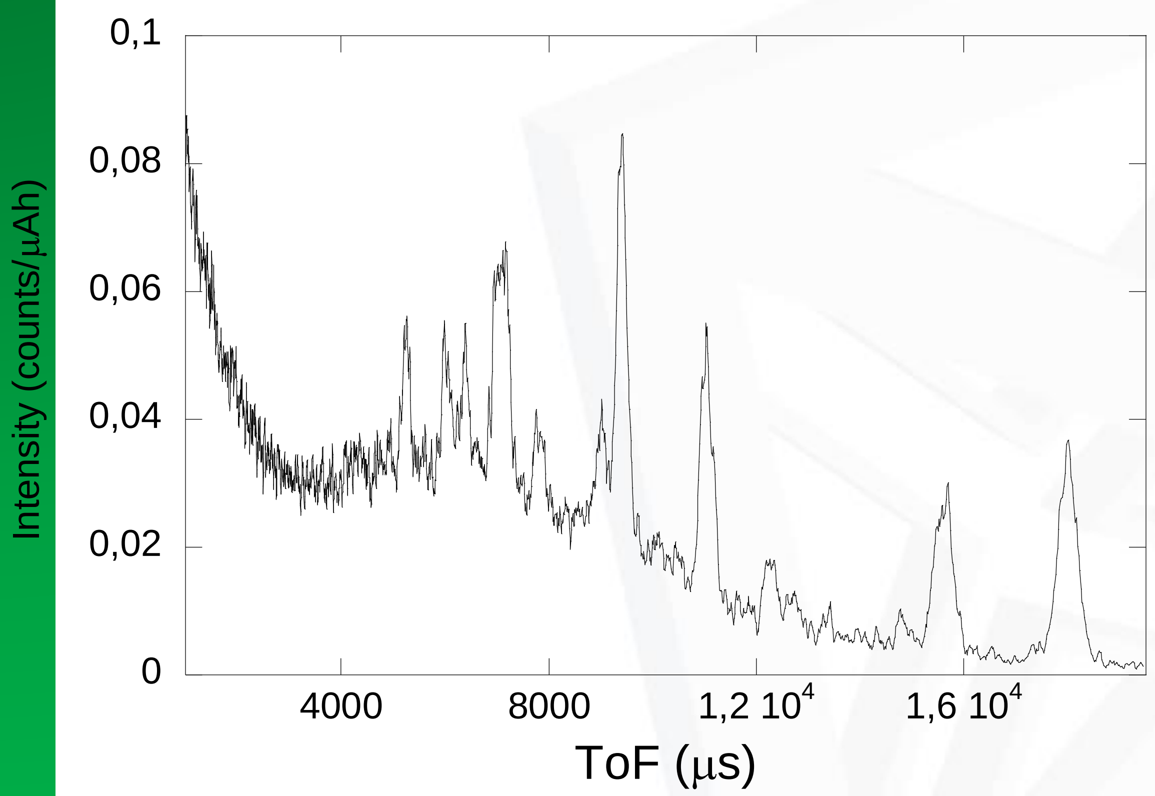
First test of GEM detector for neutron diffraction measurements



- TOF- diffractogram recorded from a **bronze sample** by the GEM detector (to our knowledge the first ever neutron diffractogram recorded by a GEM....)
- Time measurements: 18 hours

G. Croci et Al, 2014 *EPL* **107** 12001

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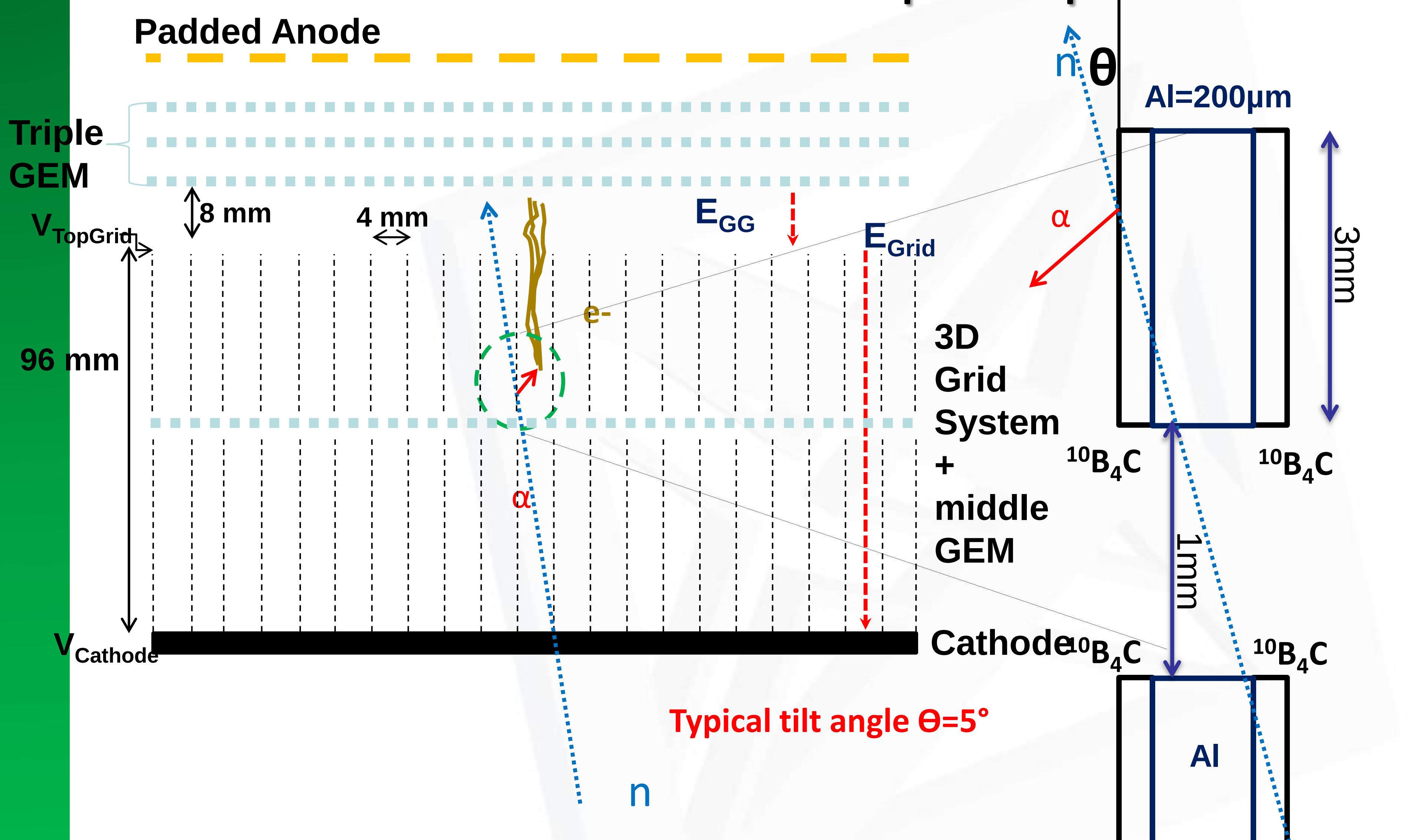
BAND-GEM detection principle



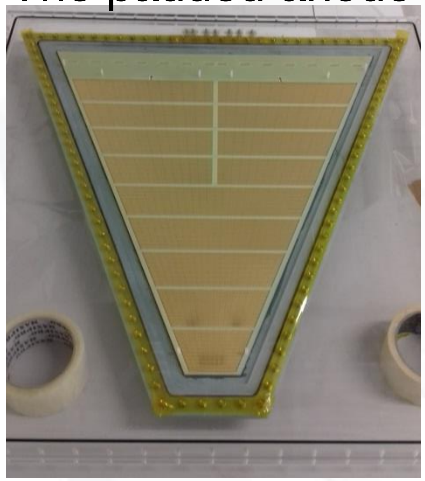
Aluminum grids coated on both sides with $^{10}B_4C$

Using low θ values (few degs) the path of the neutron inside the B_4C is increased → Higher efficiency when detector is inclined

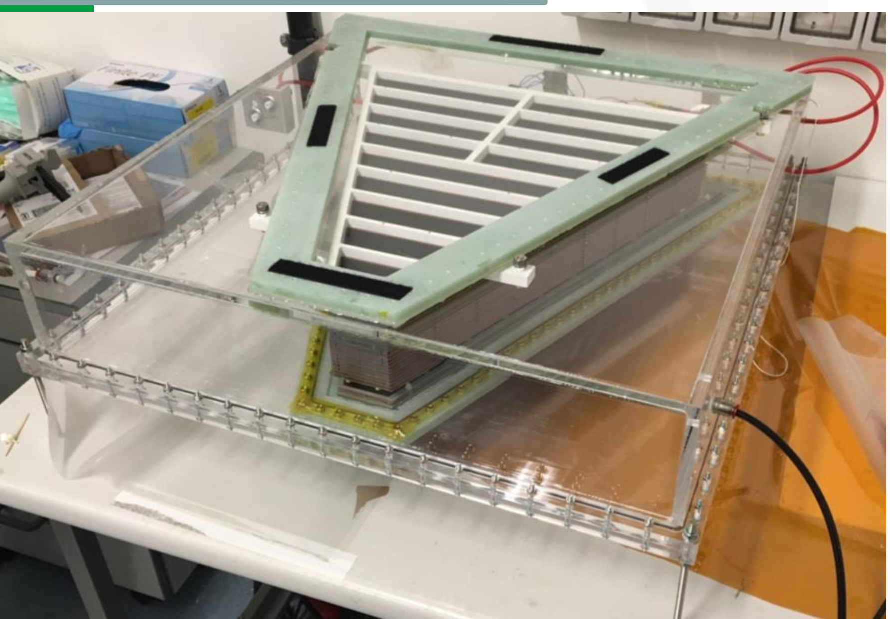
BAND-GEM full-module: design and construction

The GEM foil

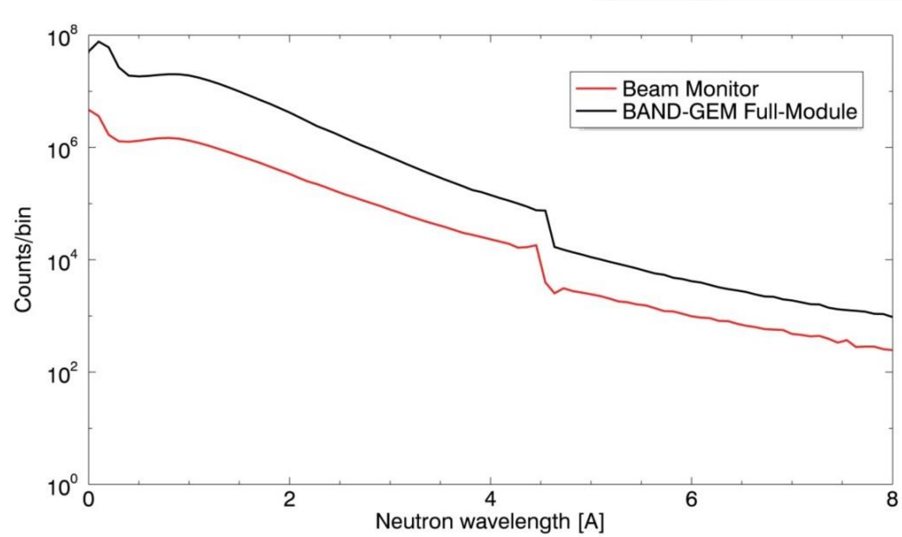
The padded anode

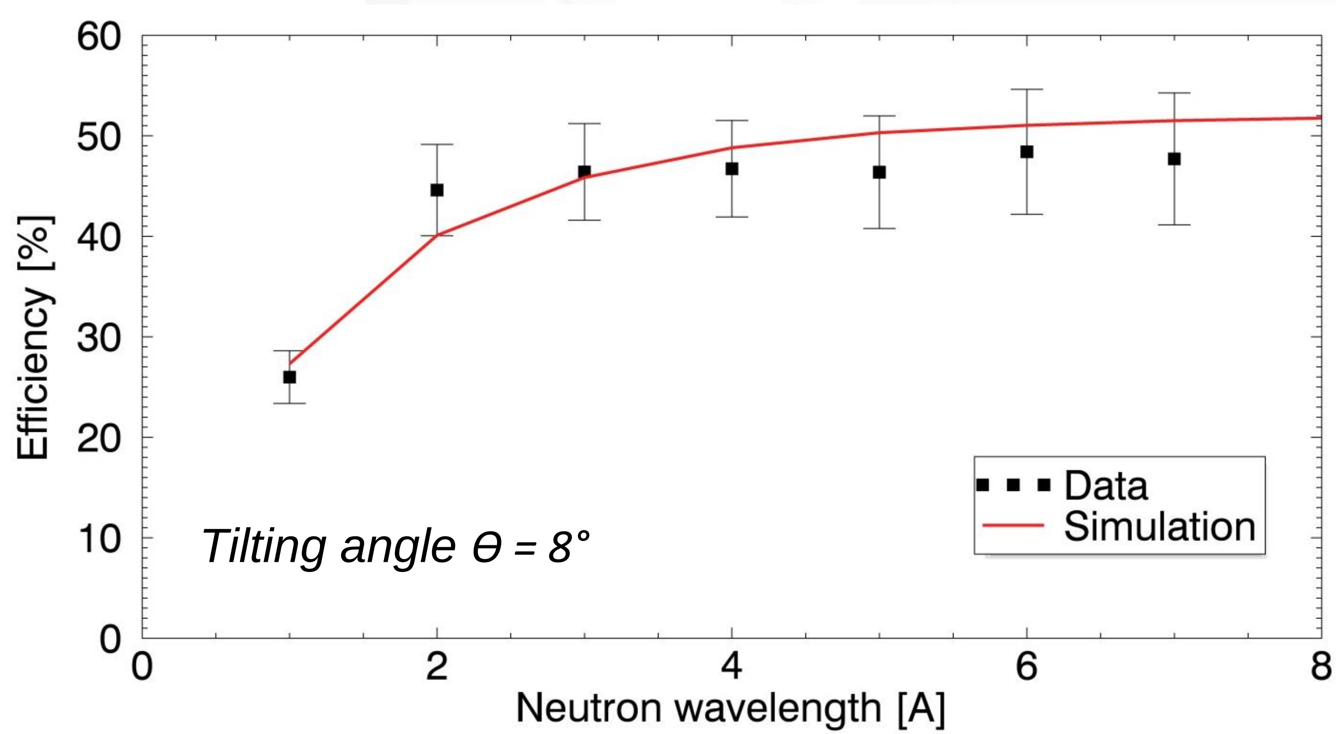


The 3D-C assembled



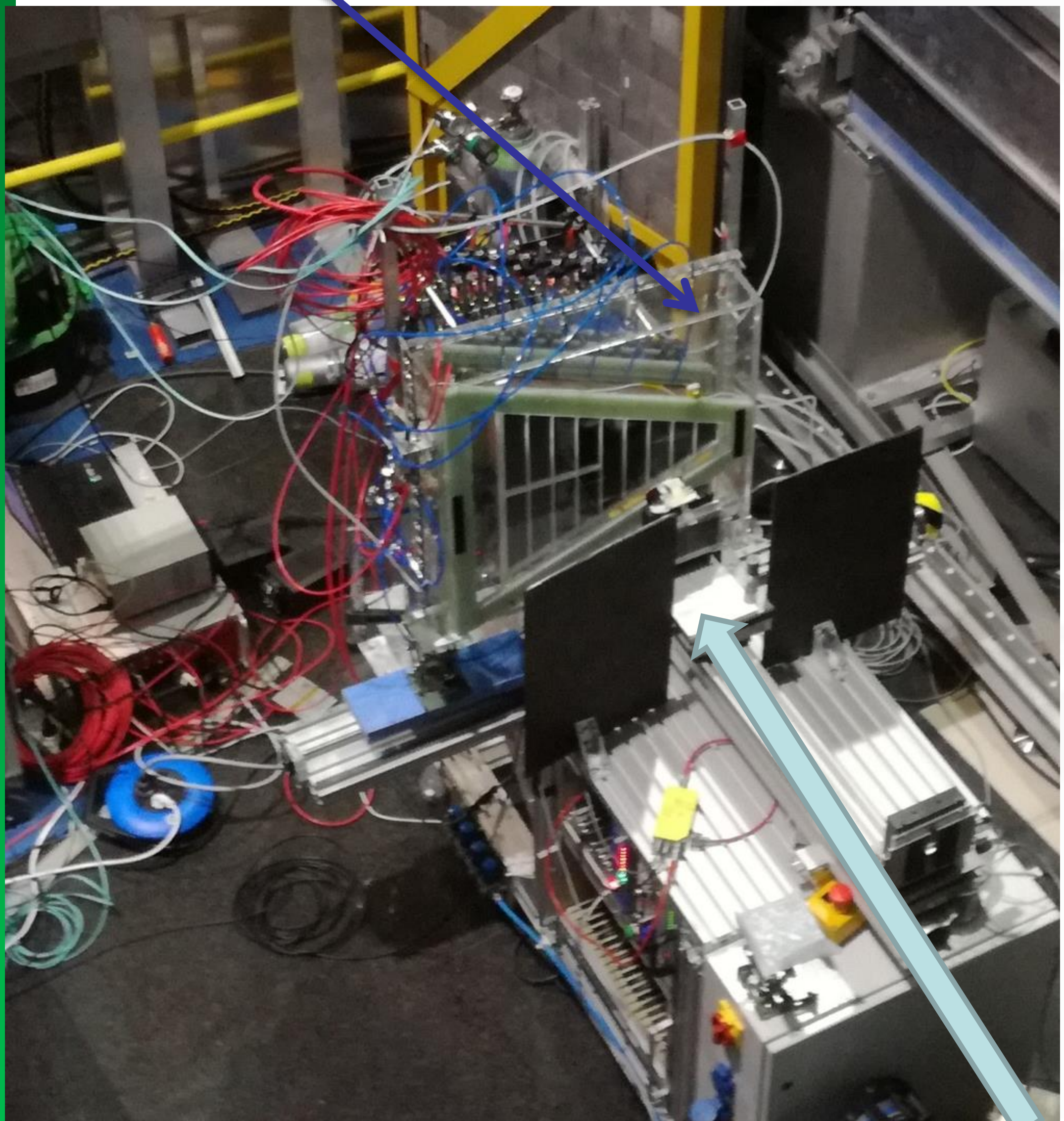
Efficiency vs neutron wavelength





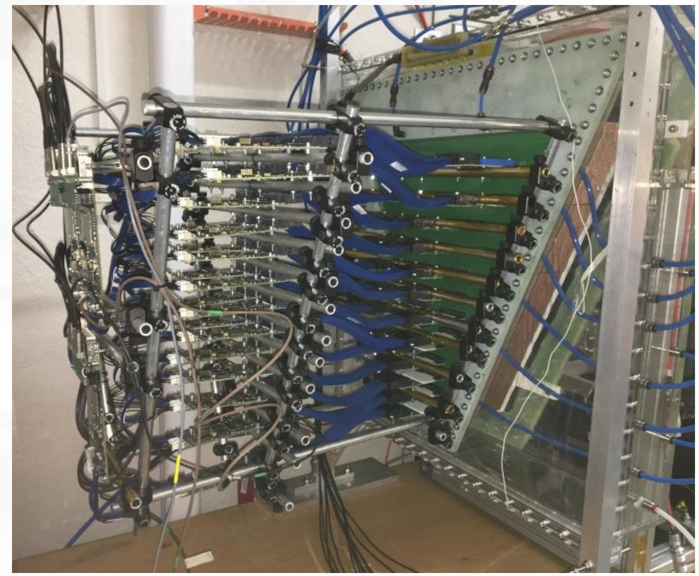
Test of the full-module @ TREFF

BAND-GEM



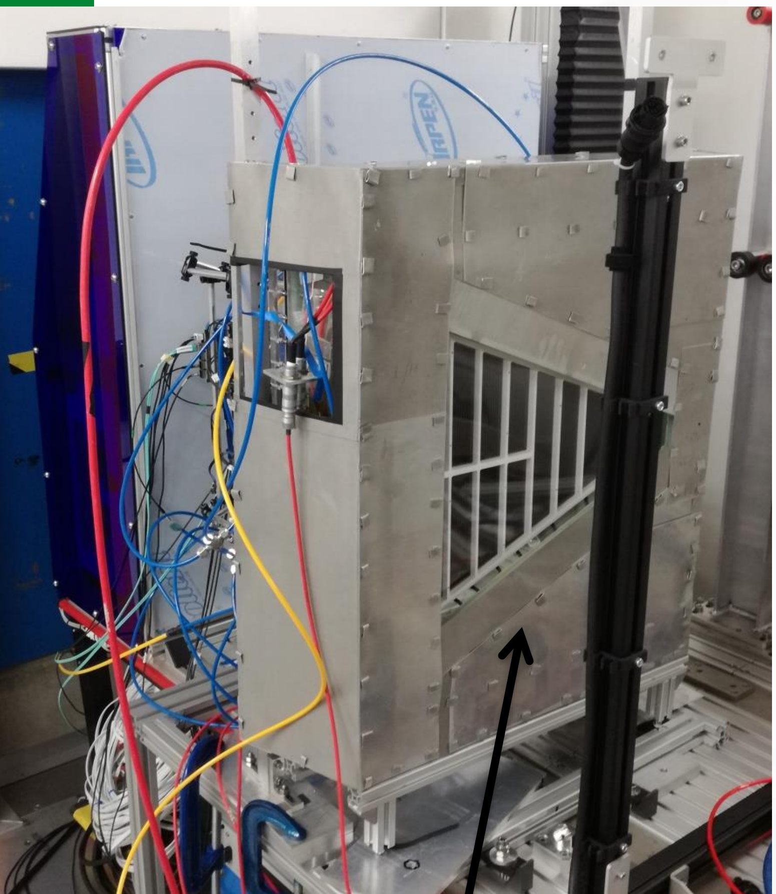
Neutron beam

BAND-GEM with GEMINI electronics



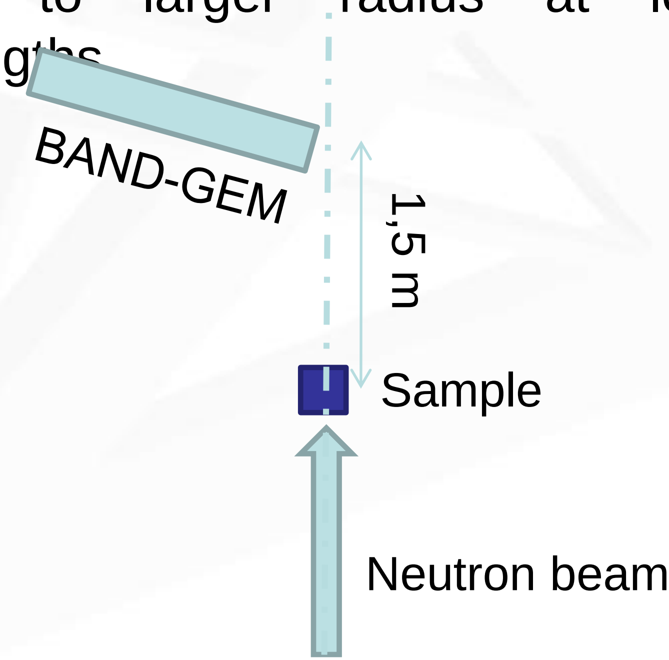
Monochromatic neutrons with wavelenght λ=4.78 Å

Test of the full-module @ LARMOR beam line (SANS instrument). Preliminary results.

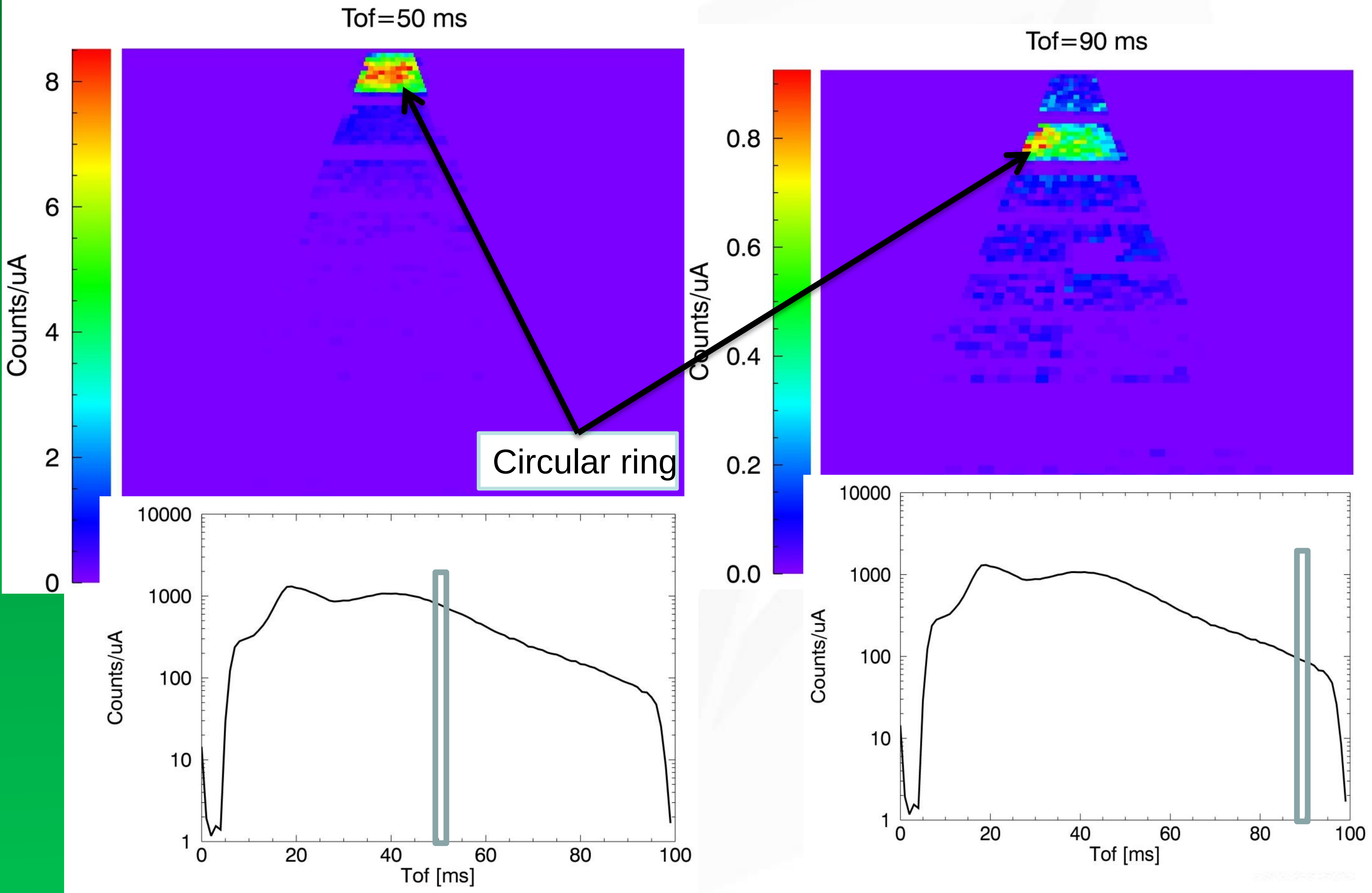


BAND-GEM full module with Cd mask

SANS measurement performd with a concentrated ludox silica dispersion sample.
With this sample, the expected 2d map on the detector position is a circular ring moving to larger radius at longer wavelengths.



Test of the full-module @ LARMOR beam line (SANS instrument). Preliminary results.



General remarks to realize a neutron detector

- Detectors must be chosen/DESIGNED for the specific application. Typical application is “counting above threshold”

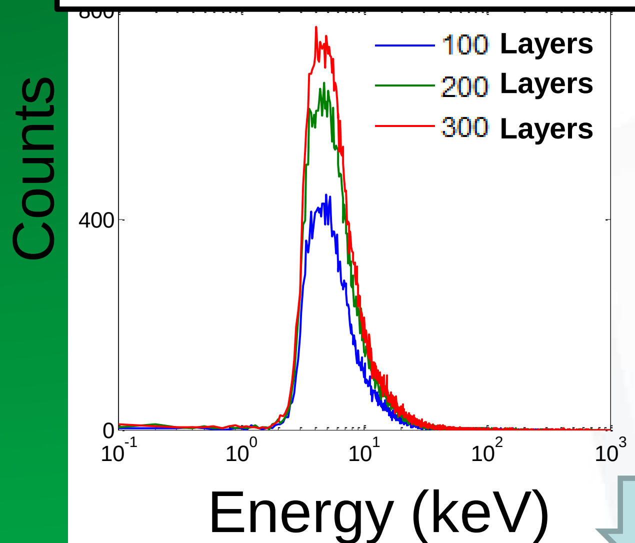
Requirements to be considered when designing neutron detectors:

- Gamma-ray sensitivity
- Count rate
- Time/space resolution
- Environment (B field, temperature etc)

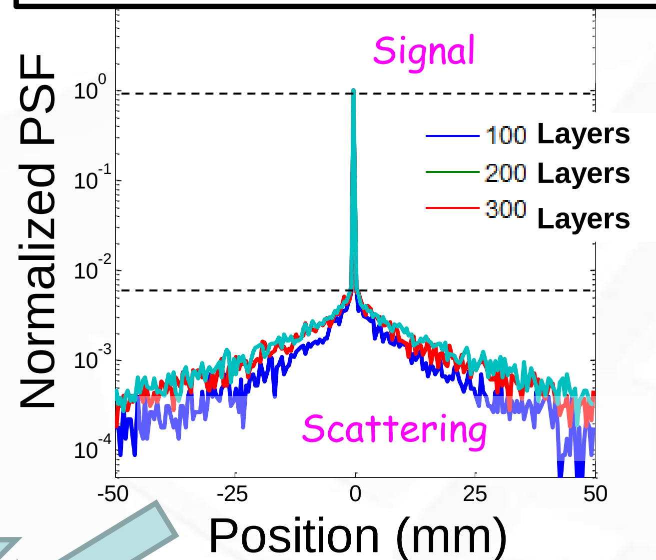
Digitize! (if possible)

Multi-layer converter + THGEM detector Performance

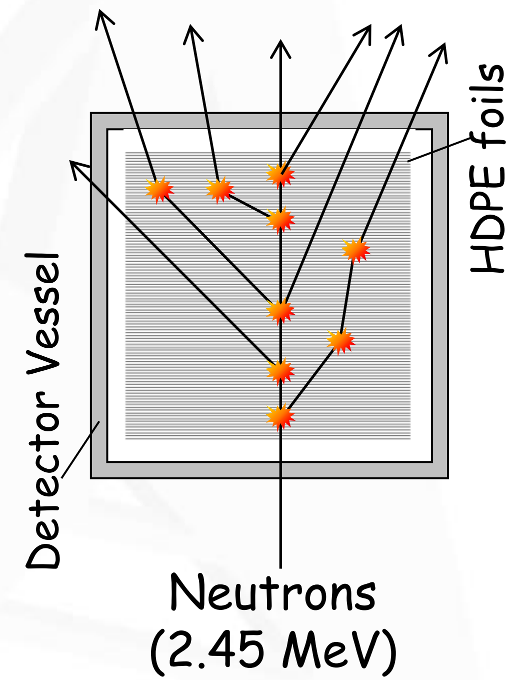
Deposited Energy Spectrum

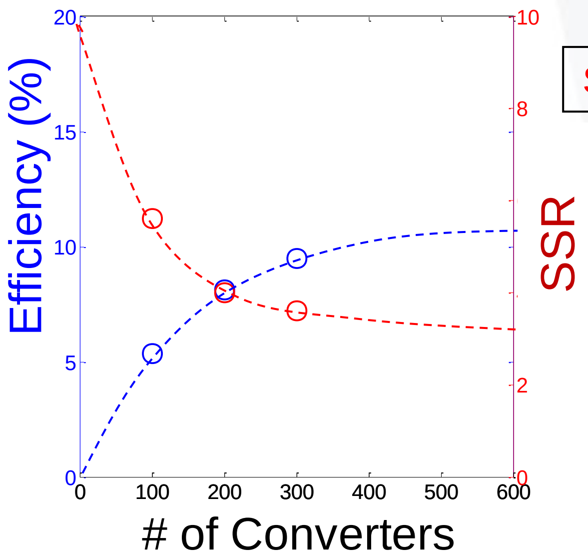


Distribution of the deposited charge



Parameters
-) HDPE Thickness = 0.4 mm
-) Gas Gap = 0.6 mm



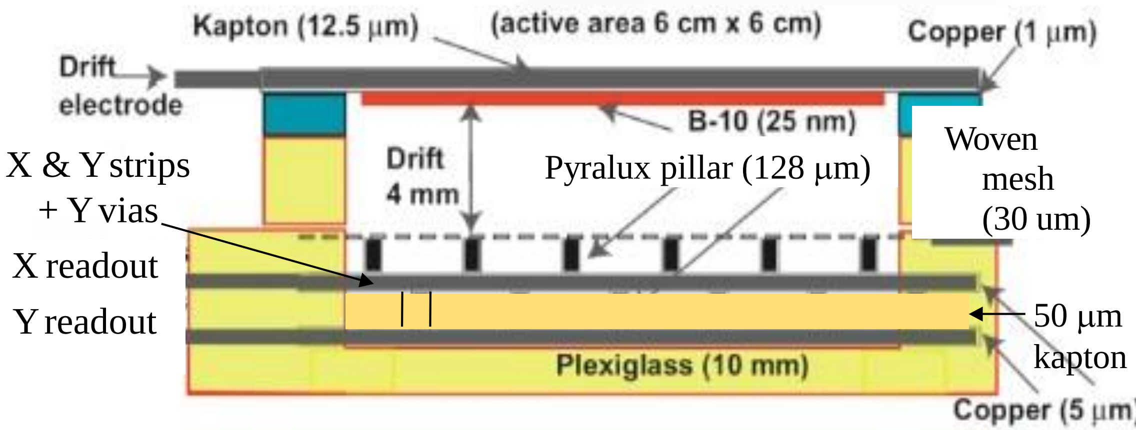


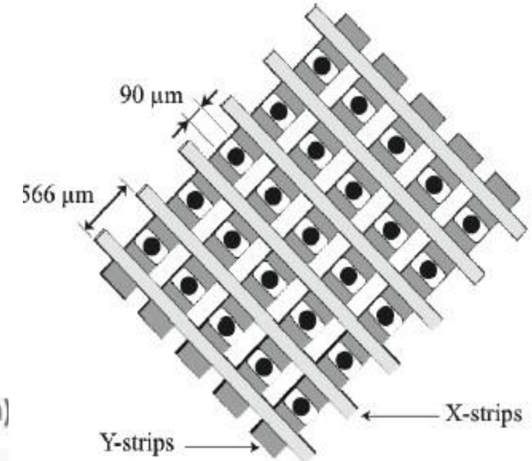
SSR = Signal-to-Scattering ratio

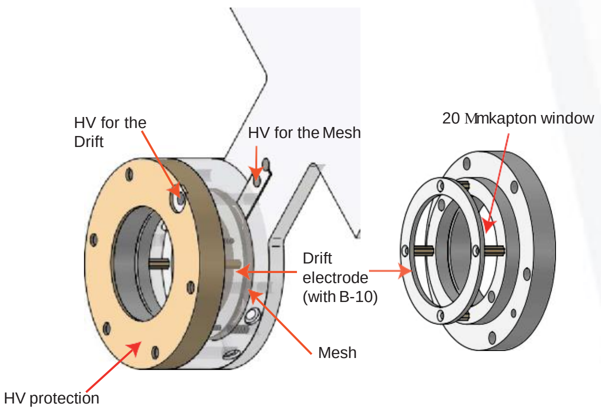
Cost effective solution: 300 HDPE layer
Conversion Efficiency ➔ ~8%

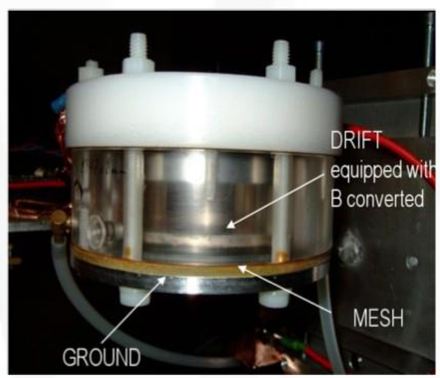
CERN/n-TOF 2D X-Y neutron beam profiler

128 μm Bulk-micromegas technology with 2D X-Y readout (CAST-like) Use of $^{10}B(n,a)^{7}Li$ for up to 1 MeV neutron conversion









Specifications

- ✓Ar+2%iC_4H_{10}+10%CF_4
- ✓6x6 cm^2 active area
- ✓Φ 60 mm, 24 nm $^{10}B_4C$ layer on a 1 μm copper coated 12,5 μm Kapton foil
- ✓212 channels : readout with 2 x 96 ch. Gassiplex cards

Ref: S. Andriamonge et.al., proceedings of ND2010, International Conference on Nuclear Data for Science and Technology

Thanks to A. Delbart

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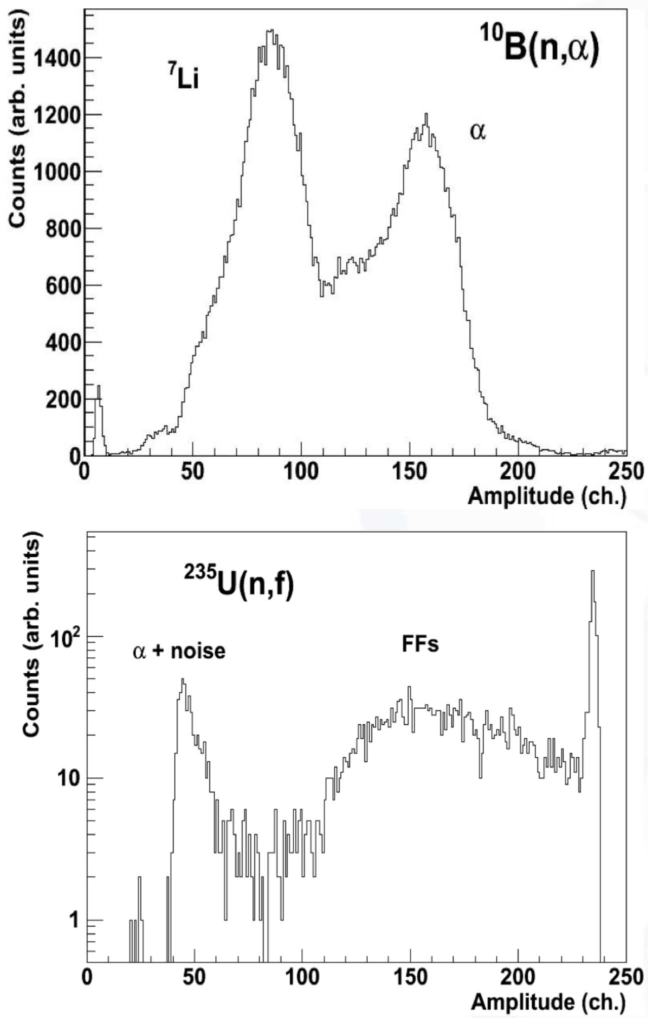
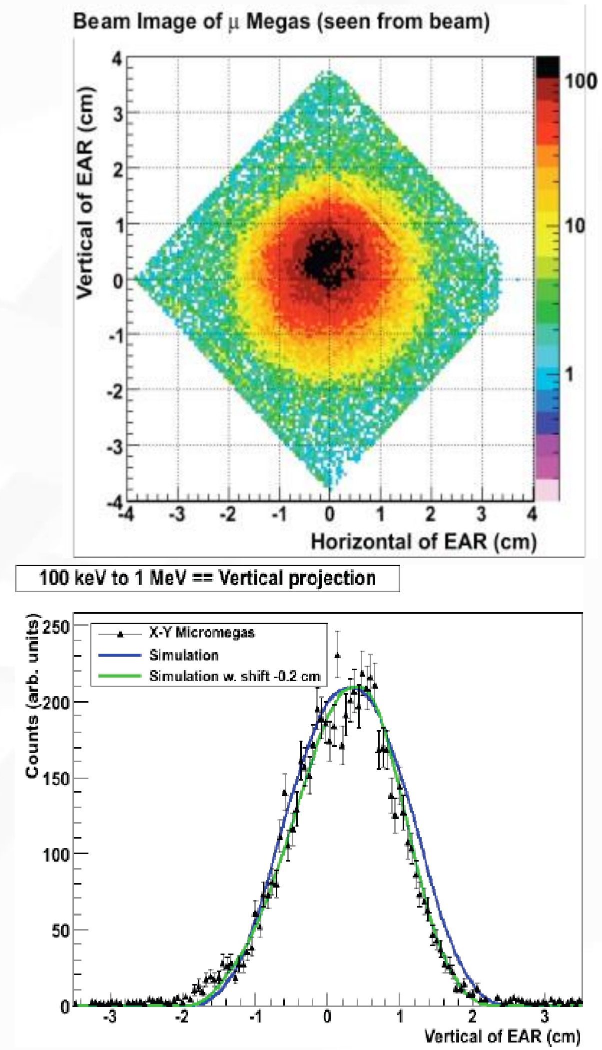
n-TOF beam profile and flux monitor

n–TOF beam flux monitoring (2008)



n–TOF beam profile (2009)

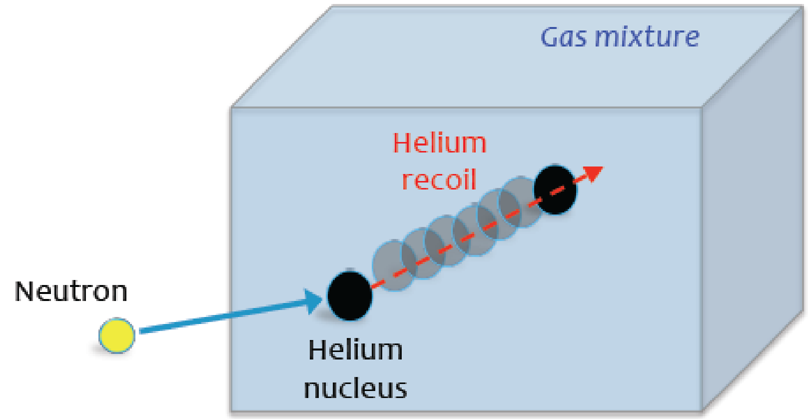


Ref: S. Andriamonge et.al., proceedings of ND2010, International Conference on Nuclear Data for Science and Technology

Thanks to A. Delbart

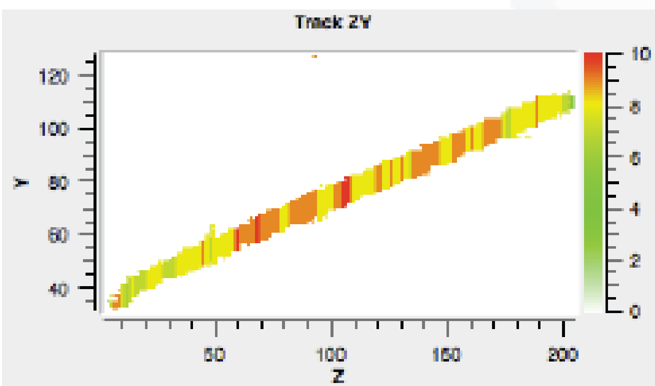
Micromegas in Mimac Fastn

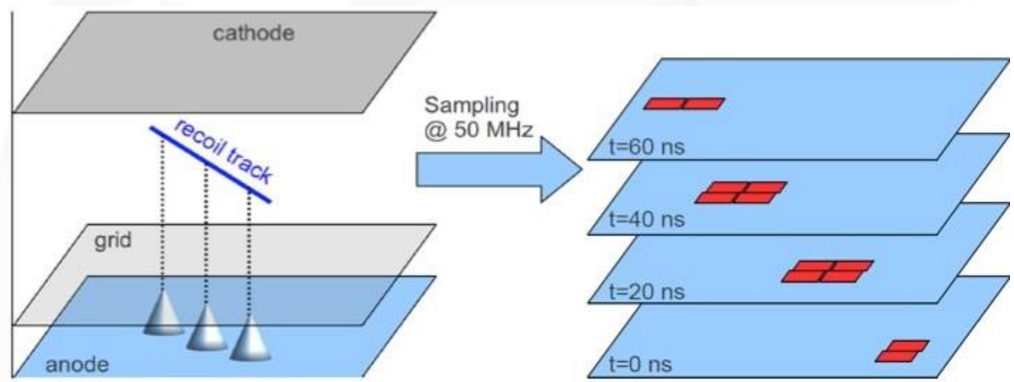
- Detection of recoiling neutron energy after scattering with a fast neutron
- Drift in a ionization chamber
- Amplification using a Micromegas
- Read-out on a pixelated anode sampled at 20 ns.



$\text{Recoil}_{\text{Energy max}} = 64\ \%_{\text{Neutron Energy}}$

Example of a recoil track in
He/Co2 80/20



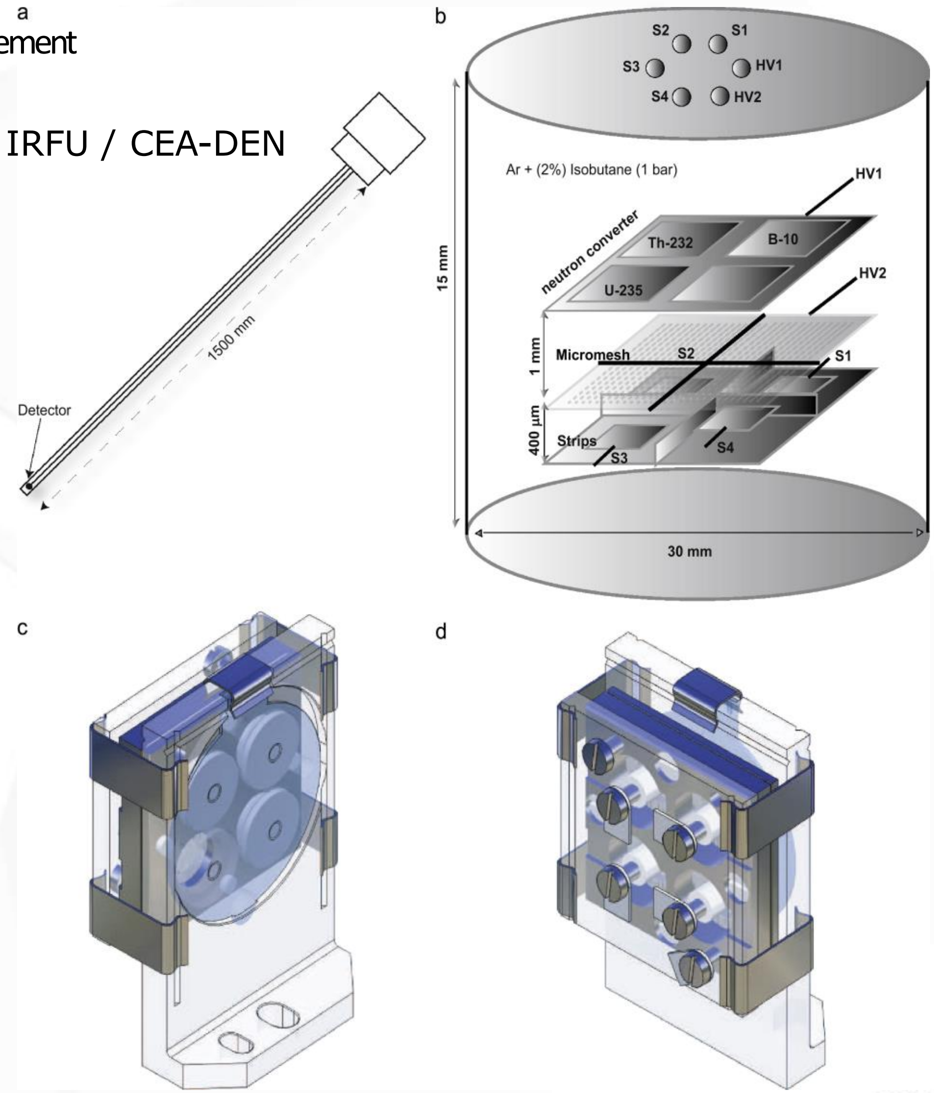


Developed by Grenoble

The Piccolo micromegas

In–core Nuclear plant integrated neutron flux measurement

Piccolo collaboration (TRADE WG) : IRFU / CEA-DEN



Specifications

✓Small sealed 10 cm^3 micromegas (160 µm)
✓Standard design, with woven bulk type mesh
✓Non-flammable Ar+2%iC_4H_{10}
✓Wide neutron energy sensitivity with :

- ^{235}U et 10B, thermal to several MeV
- ^{232}Th , En > 1 MeV
- H recoils , thermal to several MeV

✓Designed for use in the extreme conditions of a reactor core (heated water 300°C, radiation)
✓Use of stainless steel & ceramic materials

✓4 individually polarized anode channels
✓2 readout modes :

- counting mode with fast current preamp. + 1GHz flash ADC + MATACQ (SEDI)
- current mode by mesh current reading for high reactor powe

- Tested at TRIGA reactor in Italy

Ref: J. Pancin et al., Nuclear Instruments and Methods in Physics Research A 592 (2008) 104–113

Thanks to A. Delbart