# Recent results of GEM-based thermal neutron detectors

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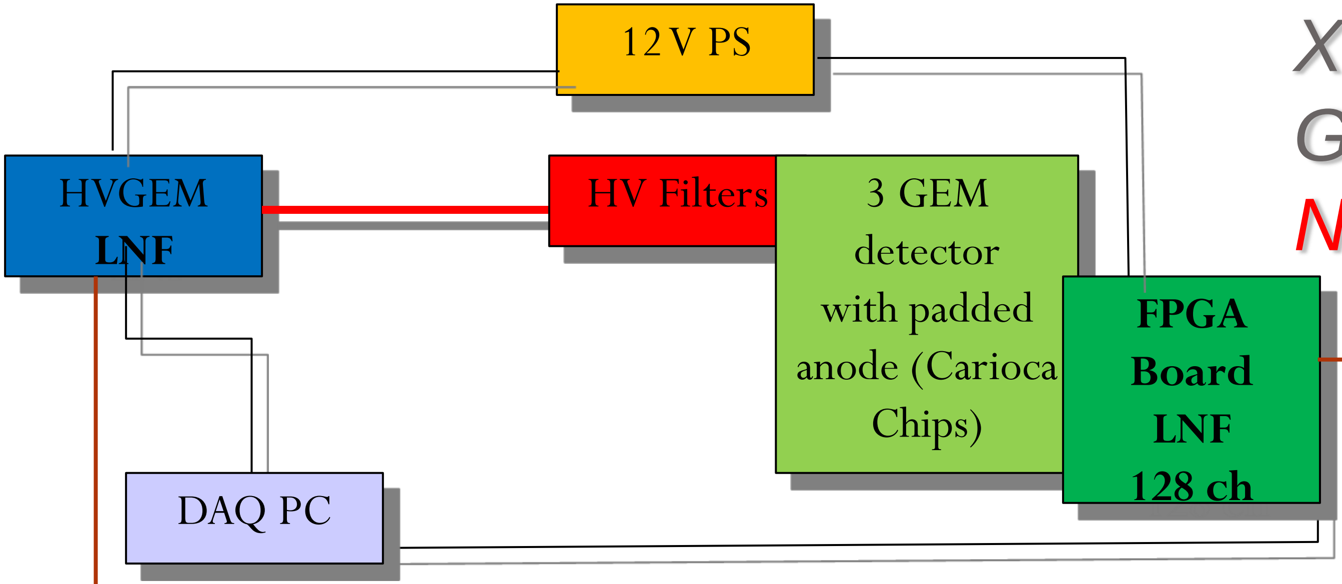
# OUTLINE

- Why and how to use GEM-based detectors to detect neutrons

- THERMAL NEUTRON DETECTORS
  - Rate capability tests
  - Comparison with 3He in Diffraction experiments
  - High efficiency detector

- Conclusions and Future Perspectives

# Complete GEM detector system

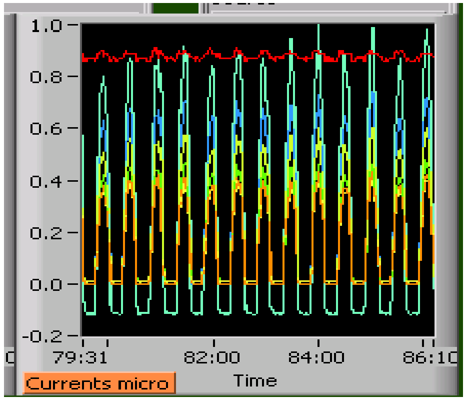


*Charged particles*

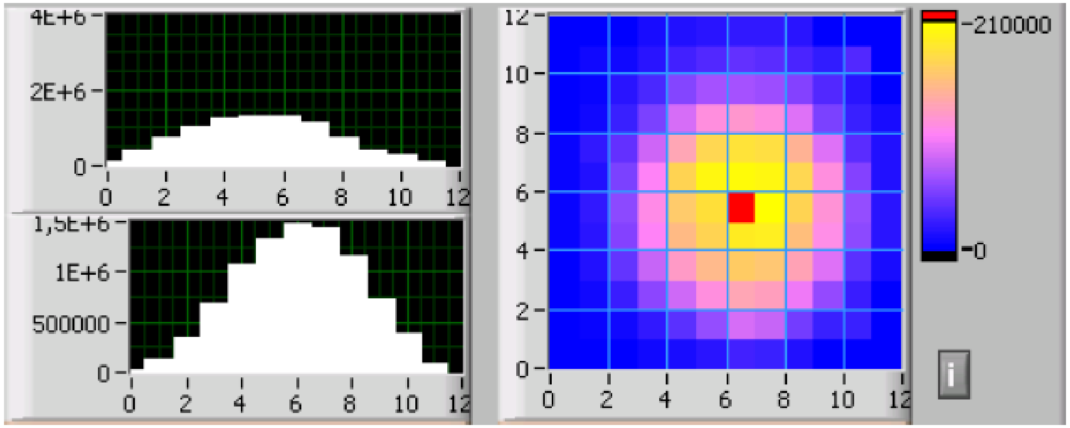
*X Ray*

*Gammas*

*Neutrons*



Current Monitor



2D monitor with pads readout

Possibility to set time slices from 5 ns up to 1 s

# WHY AND HOW TO USE GEMS TO DETECT NEUTRONS

- GEM 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 $^{10}$B(n,alpha)7Li
  - Fast Neutrons: Polyethylene converter + Aluminium
    - Neutrons are converted in protons through elastic scattering on hydrogen

- GEMs 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)

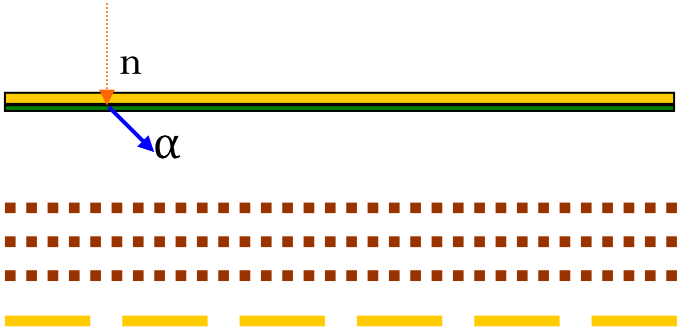
# THERMAL NEUTRON DETECTORS

- bGEM
    - Rate capability measurements
    - Test in a real diffraction experiment

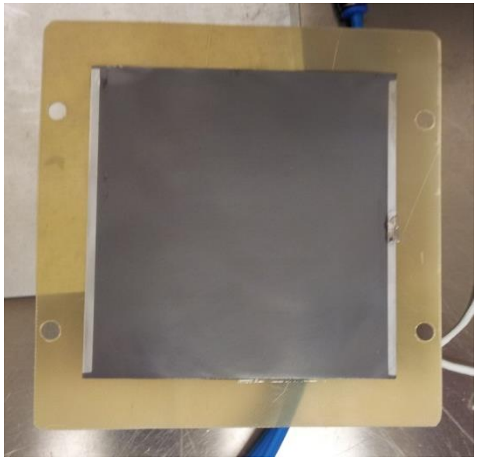
- BAND-GEM
    - Efficiency measurements

# bGEM thermal neutron detector

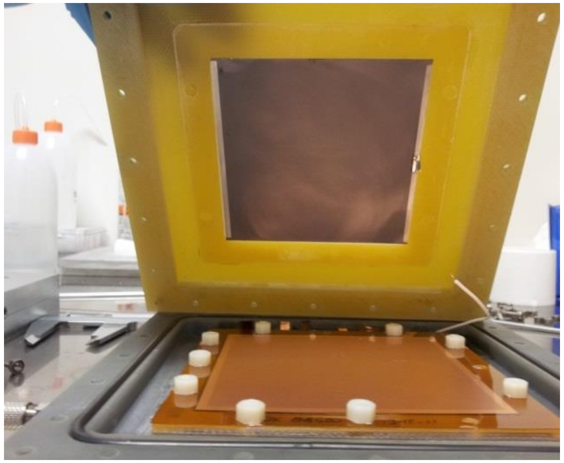
- Triple GEM detector equipped with an aluminum cathode coated with 1µm of $B_4C$: first bGEM prototype
- Exploit the $^{10}B(n,\alpha)^{7}Li$ reaction in order to detect thermal neutrons



**Detector Schematics**



$B_4C$ coated aluminium cathode mounted on its support



$B_4C$ coated aluminium cathode assembled inside the bGEM chamber layout

Low efficiency detector (few % maximum)

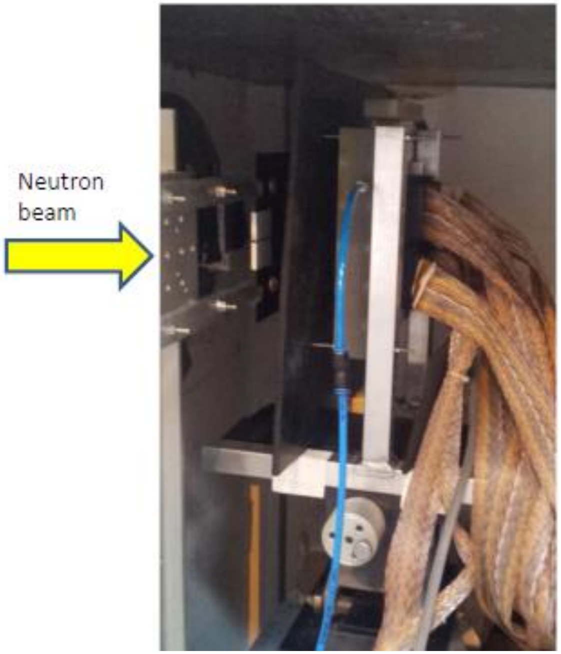
# Rate Capability

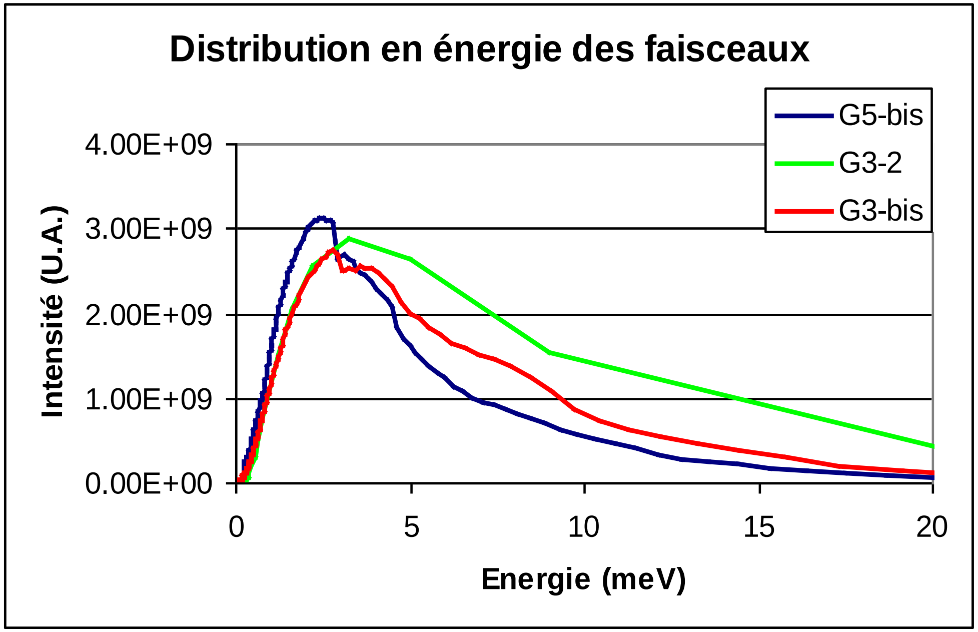
*Test rate capability under neutron irradiation*

# Neutron Rate capability measurements

- GEM-based detectors have proven very high-rate capabilities (up to 1MHz/mm$^2$)
  → This was shown with X-rays, <u>not yet with neutrons</u>
- Radiation hardness of the electronics to neutrons may be a reason of concern

Measurement at the G3-2 irradiation station at the ORPHEE reactor (LLB-Saclay)





Thermal ($E_{peak}$ = 3.5 meV) neutron flux: 7.88 x 10$^8$ n/s cm$^2$
Full beam about 2cm x 3 cm0

Measurements of Rate capability, Linearity and Stability

# Linearity and Rate capability through a comparison with a fission chamber

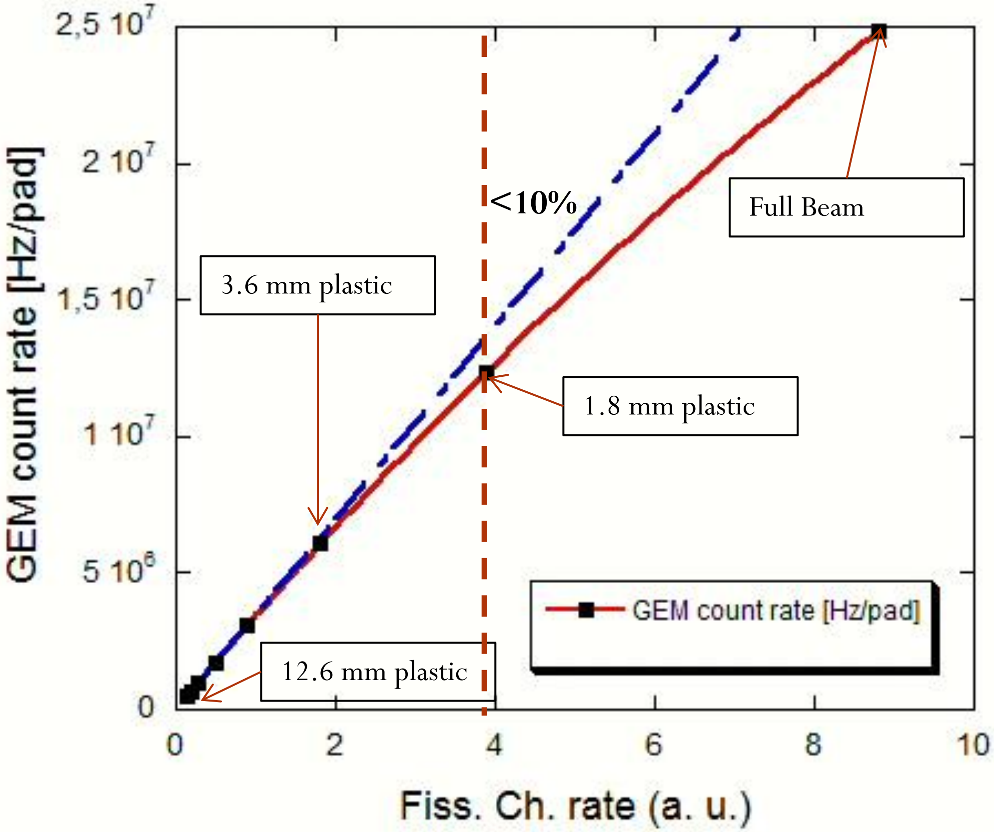
Beam attenuated with a series 1.8 mm calibrated plastic slabs credited with a beam reduction of a factor 2 each

$y = a\,x / (1 + b\,x)$ $x$ = FC rate; $y$ = GEM rate

**a = 3,5191e+06 [Hz/(pad a.u.)]**

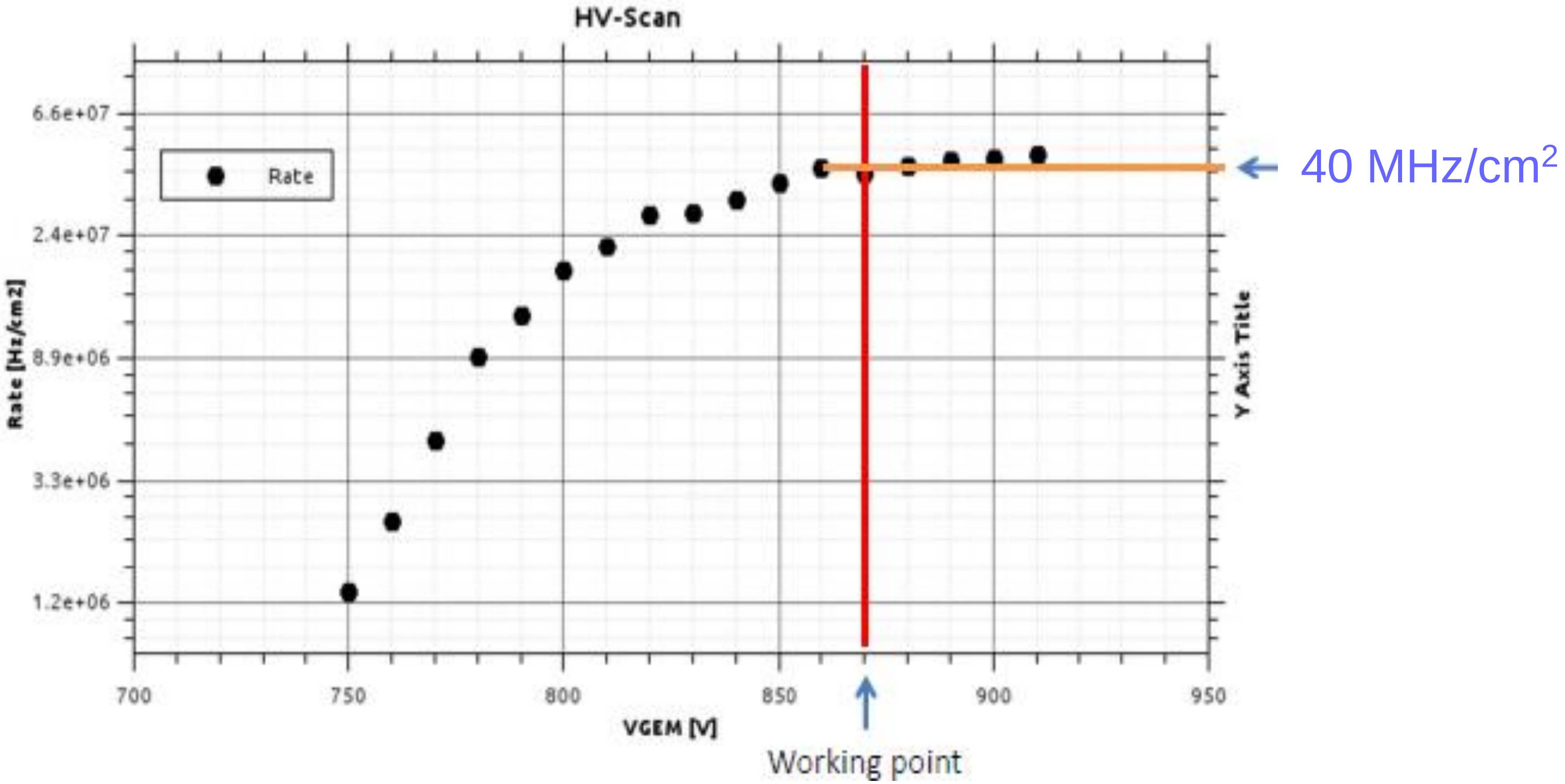
**b = 0,028143 [a.u.$^{-1}$]**

Electronics saturation above 10 MHz/cm$^2$ system; Saturation time = b/a **= 8.0 ns**



Pad
Dimension
8x8 mm$^2$

# Thermal neutron measurements as a function of detector gain



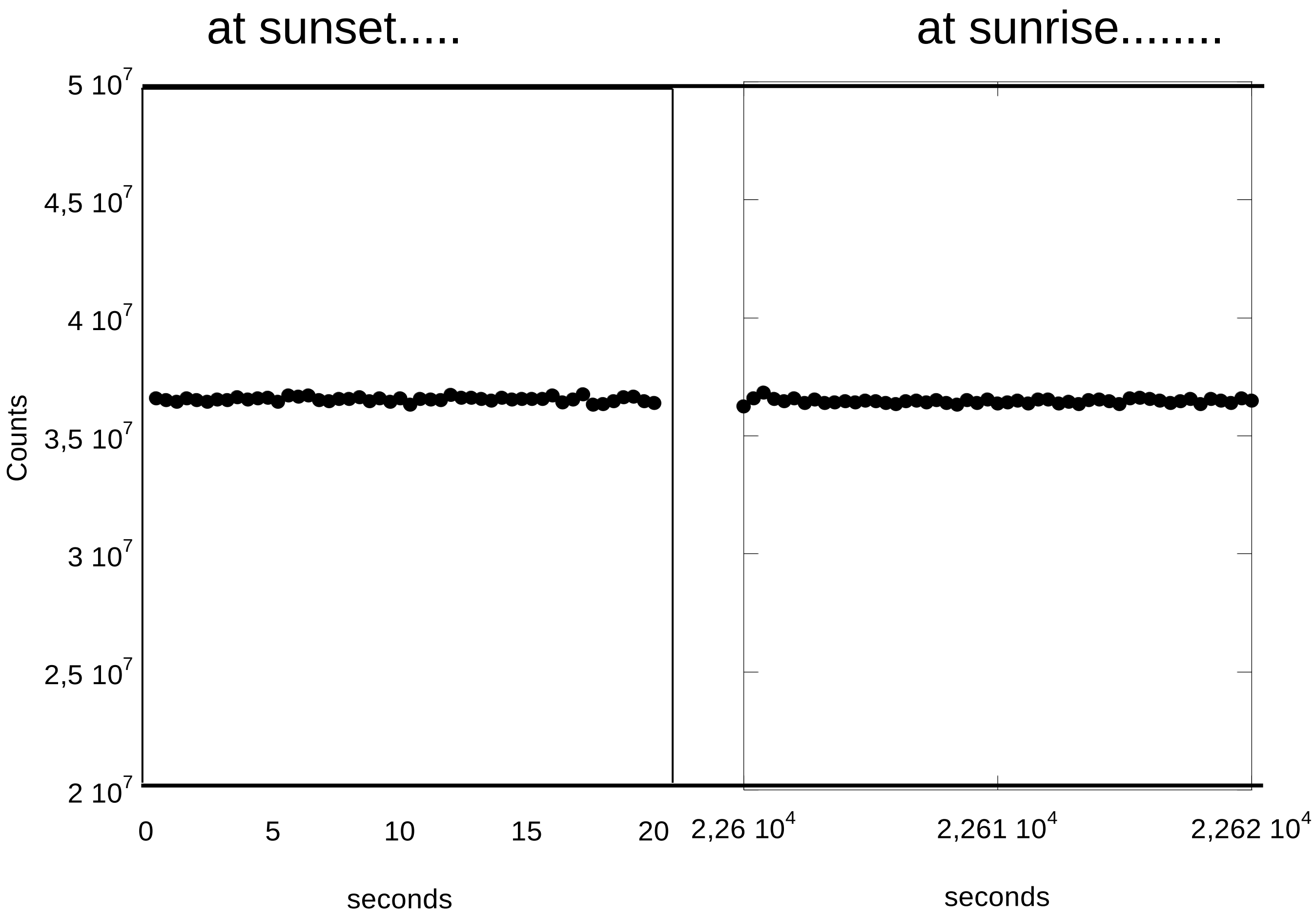
40 MHz/cm$^2$

Working point

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

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

# Stability: integrated counts into a 0.4 s interval for an all-night long run....



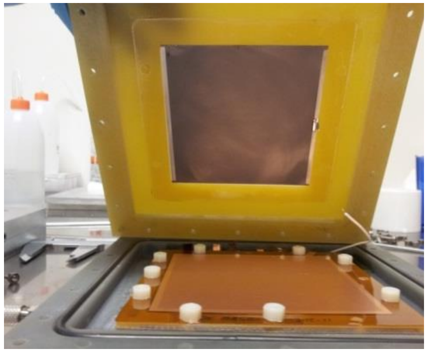
Mean: 3.6604 $10^7$ cps   Median: 3.6603 $10^7$ cps   Std Dev: 1.4 x $10^5$ cps

# Neutron Diffraction experiments

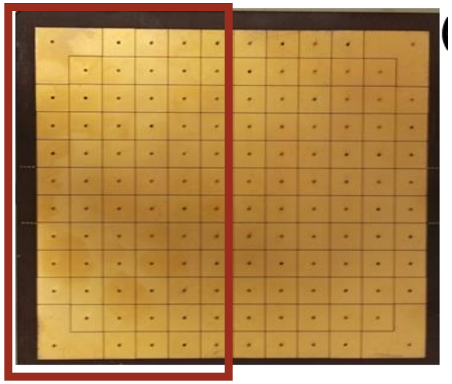
*First time a GEM was tested in a «real» experiment!*

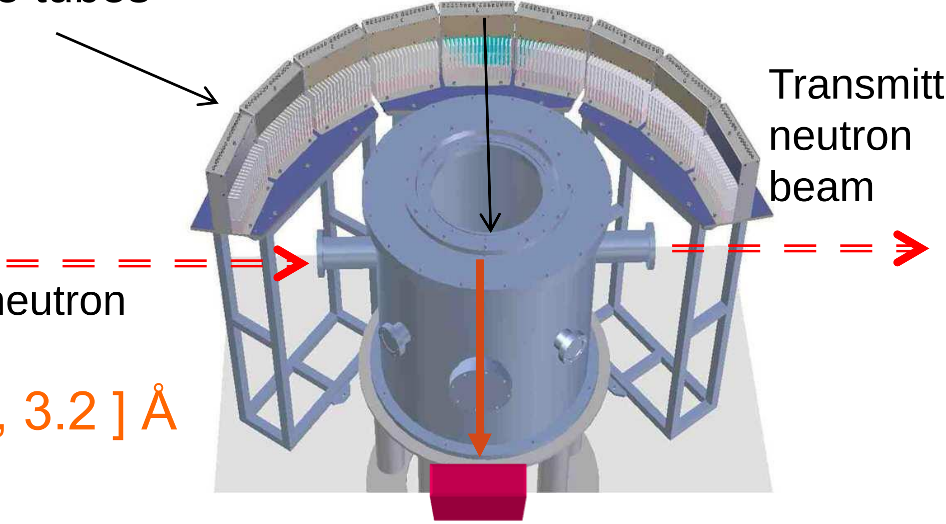
# First test of bGEM detector for neutron diffraction measurements

**bGEM – borated cathode**



**128 8x8 mm$^2$ pads**





$^3$He tubes

INES sample position

Transmitted neutron beam

Incident neutron beam

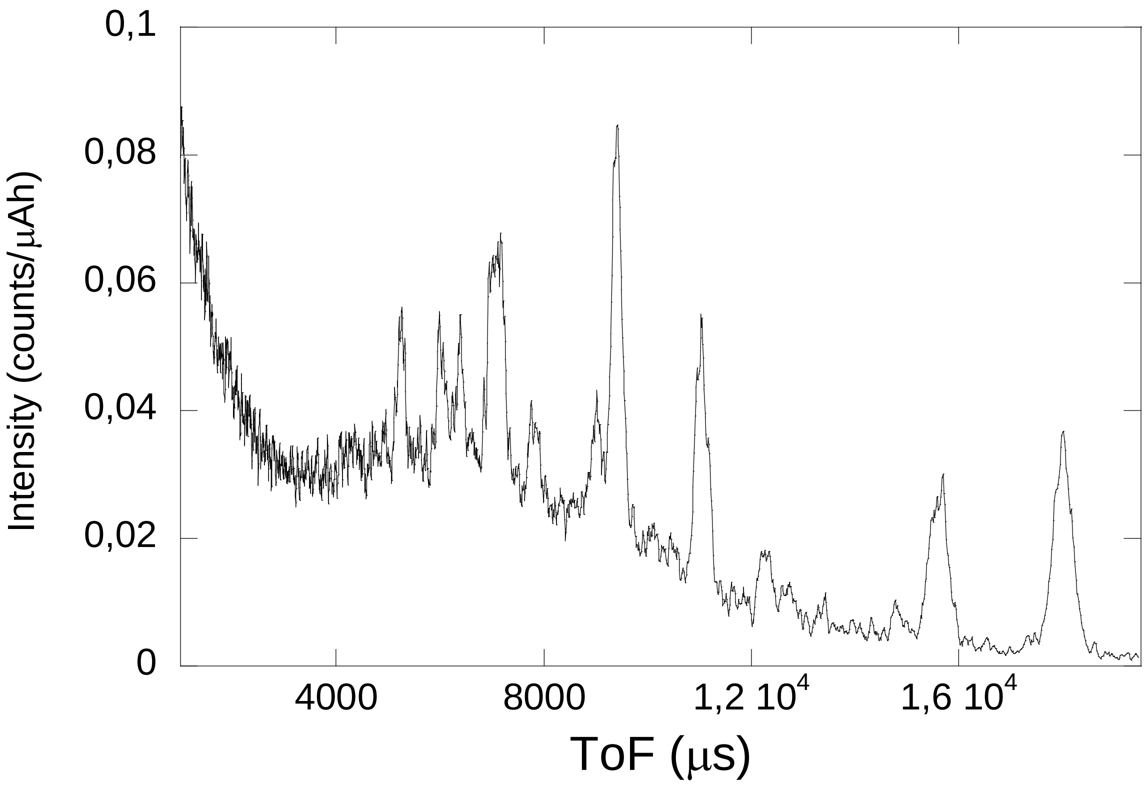
λ = [ 0.17 , 3.2 ] Å

GEM position

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

*In collaboration with E. Schooneveld and A. Scherillo*

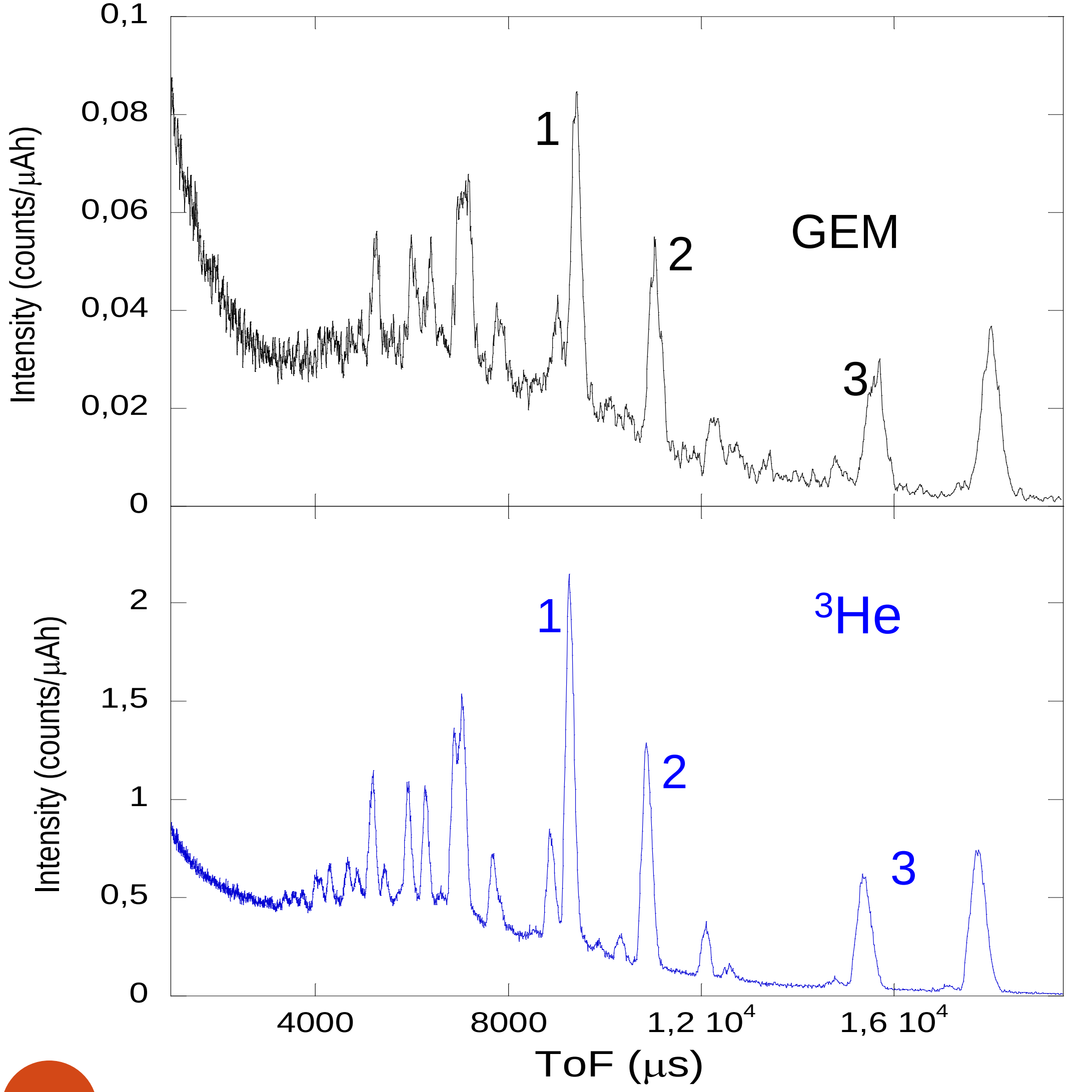
# First test of bGEM detector for neutron diffraction measurements



- 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

# Comparison with INES $^3$He tubes at 90°

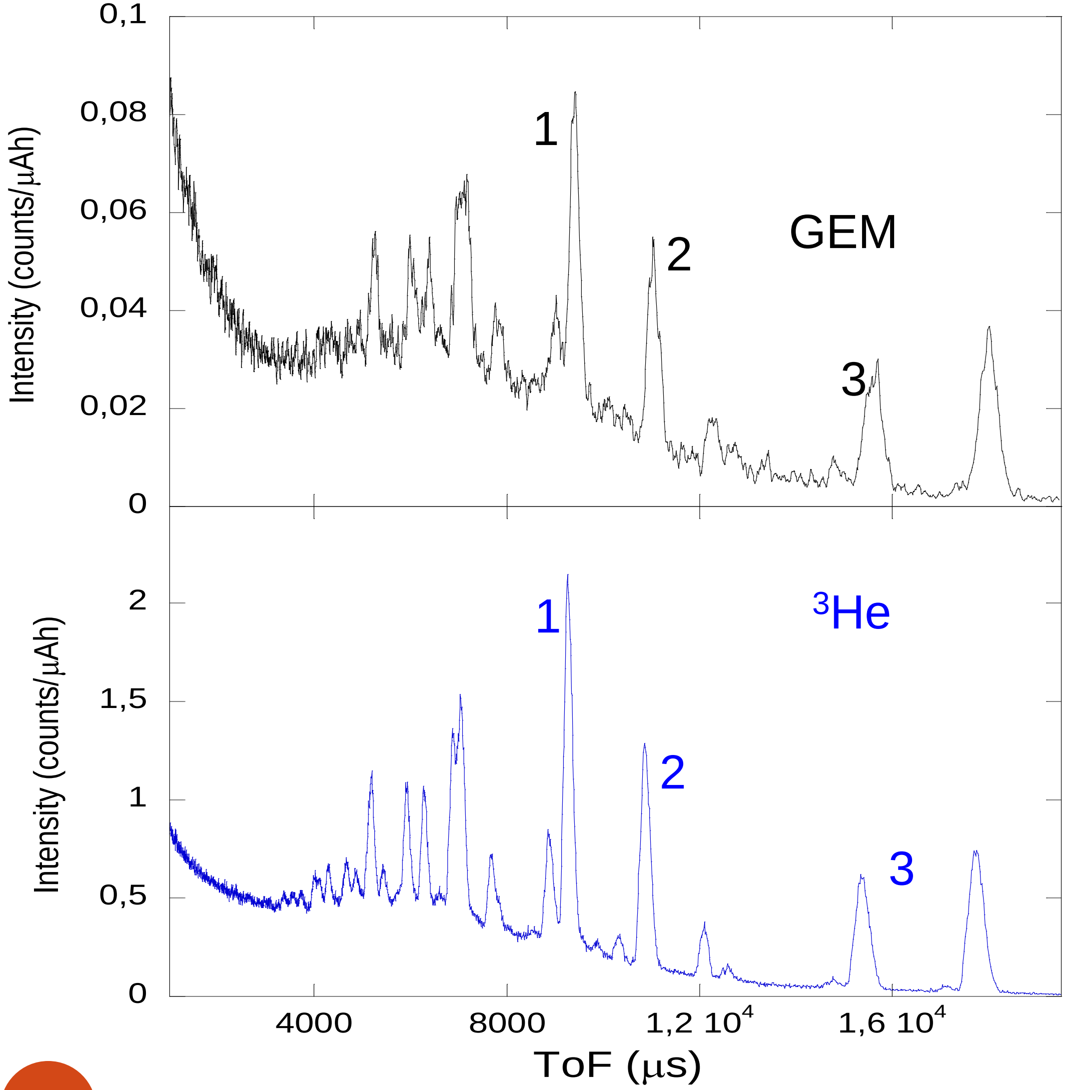


Resolution dominated by the **wider angular extention** of bGEM

**FWHM** for selected Peaks

| | GEM | $^3$He |
|---|---|---|
| Peak 1 | 240±12 | 195±4 |
| Peak 2 | 322±18 | 231±5 |
| Peak 3 | 446±48 | 336±6 |

# Comparison with INES $^3$He tubes at 90°

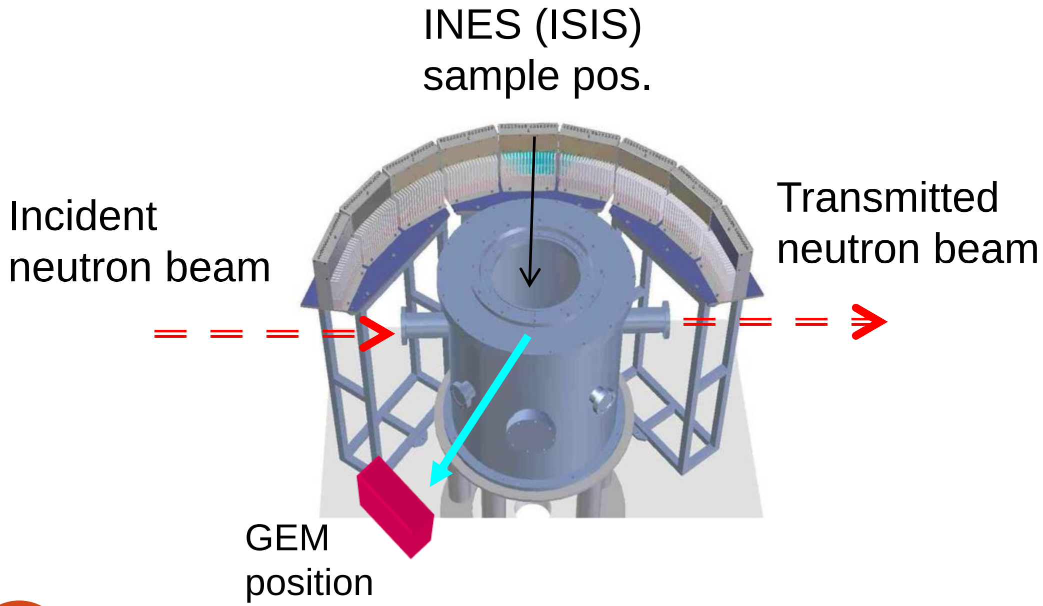


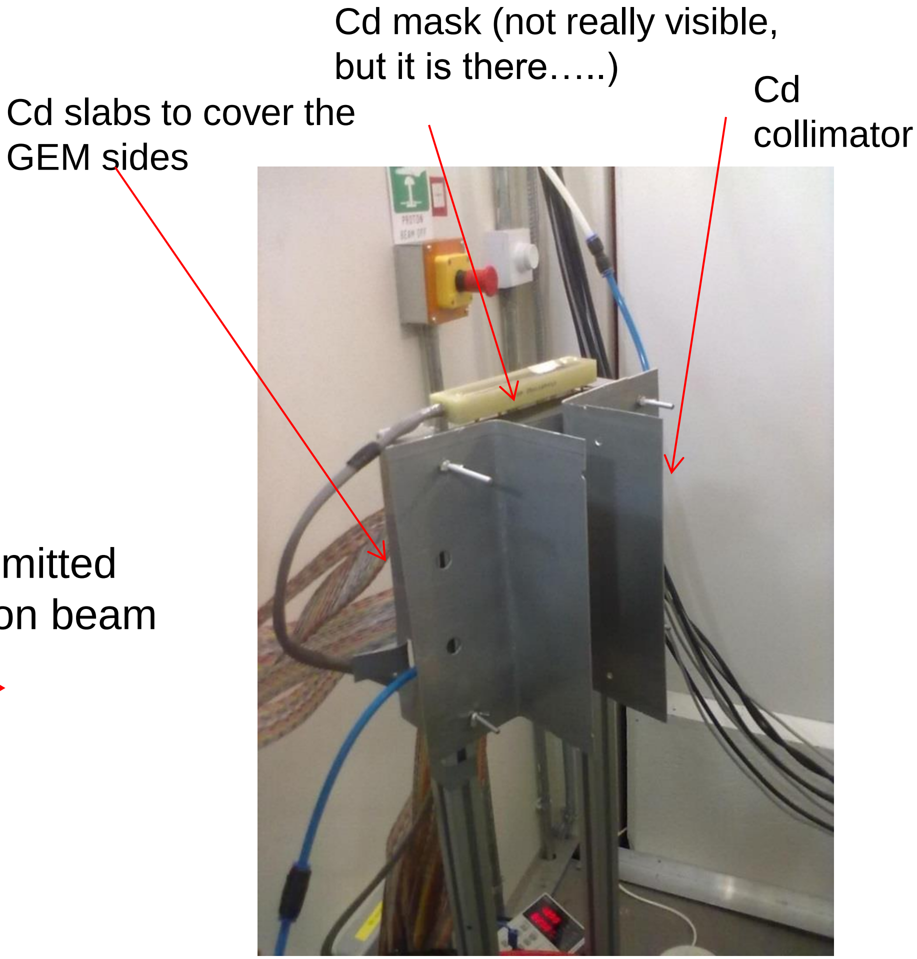
**S/B** for selected peaks

| | GEM | $^3$He |
|---|---|---|
| Peak 1 | 1.6 ±0.2 | 2.3±0.1 |
| Peak 2 | 2.3 ± 0.4 | 2.8±0.1 |
| Peak 3 | 4.9±1.5 | 5.3±0.4 |

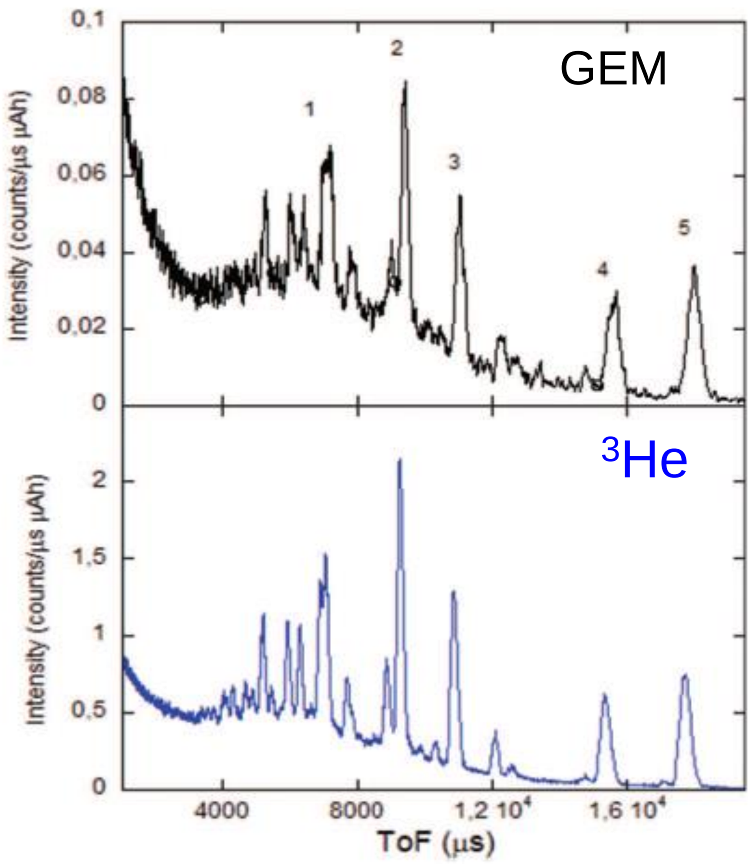
# Second Test of bGEM detector for neutron diffraction measurements

- bGEM with enriched borated cathode
- Cd mask and **rough** collimator
- The bronze sample is different
- The same bGEM position (90° ) was no longer available → FOCUSSING



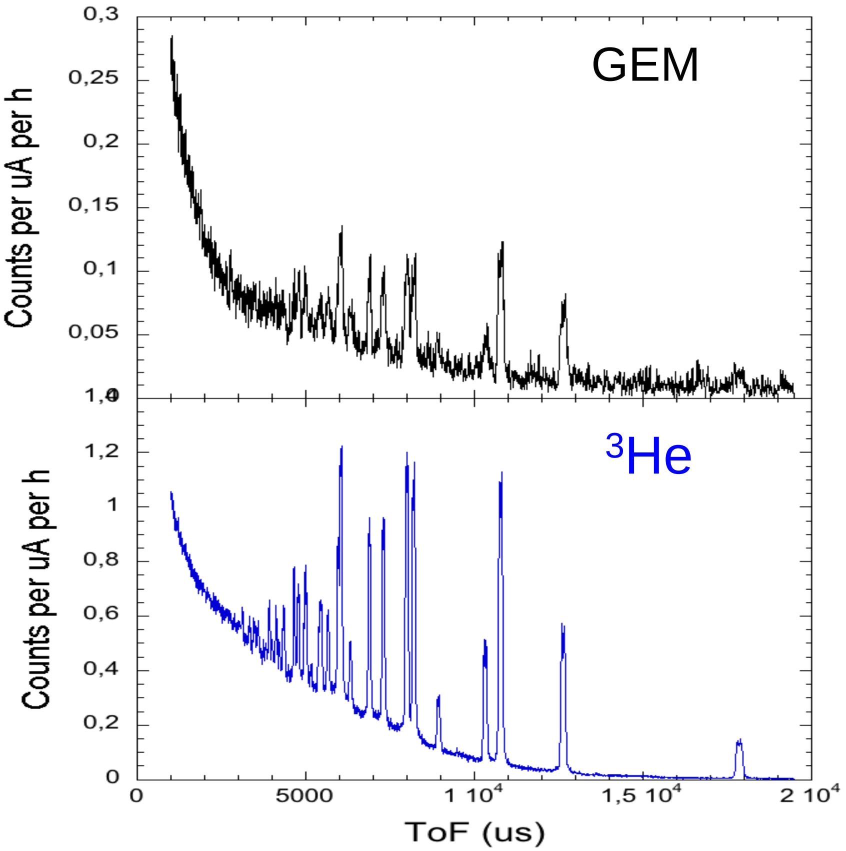


# Efficiency comparison with corresponding $^3$He tubes



1st test (natural boron)

He$^3$ counted 25 times the all GEM



2nd test (enriched cathode)

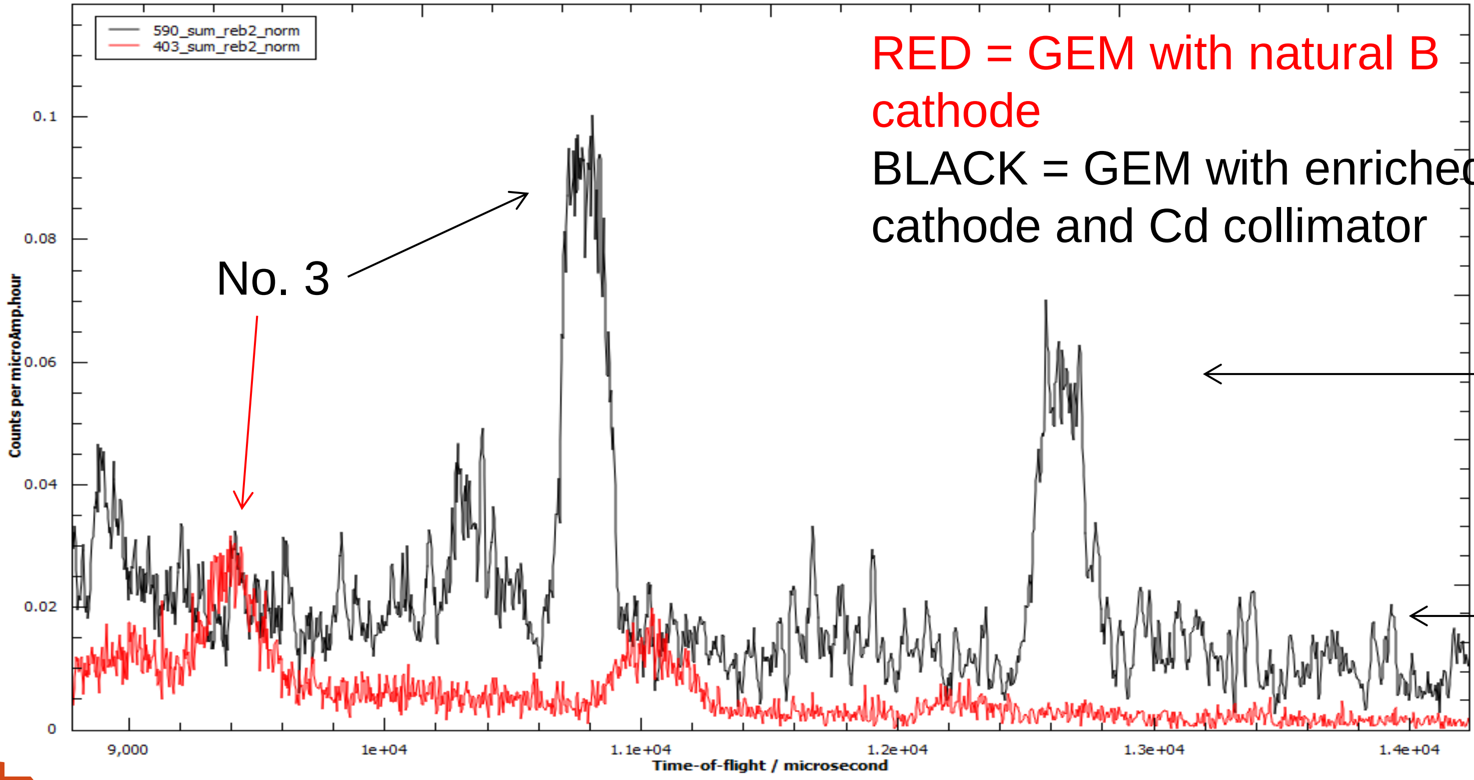
He$^3$ counted 8 times the all GEM

# Improvement in S/B ratio (1): effect of the enriched Boron

***S/B can be compared on selected peaks***

*A direct comparison of count rates between the 1st and 2nd test is without meaning (different position and different sample).*

As an example, in peak No. 3 (see graph) the **improvement in S/B is about a factor 2.5**



RED = GEM with natural B cathode

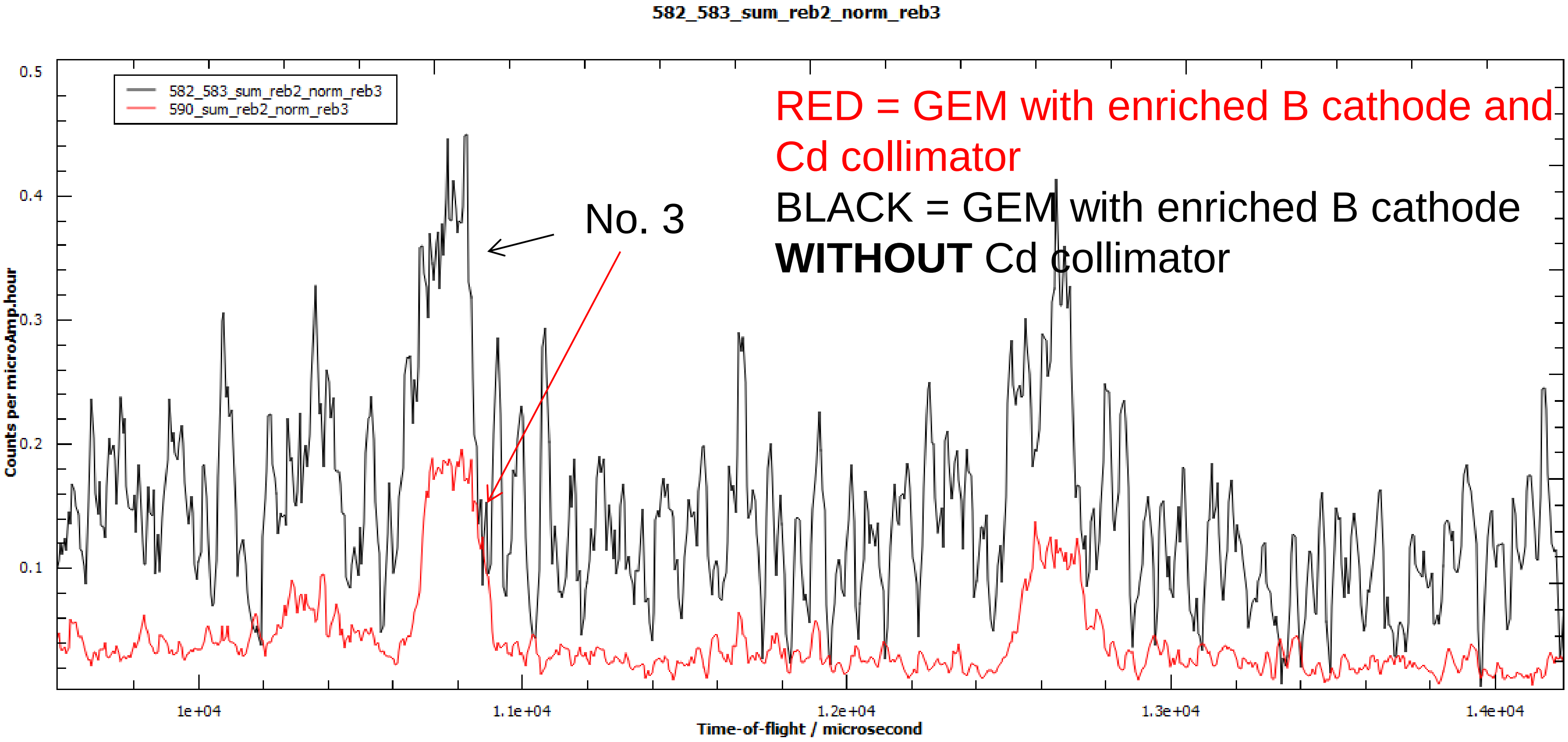
BLACK = GEM with enriched B cathode and Cd collimator

Peak Height

Background Level

# Improvement in S/B ratio: collimator effect

The improvement in S/B due to the collimator is very low, about a factor 0.25 again on peak 3 (thus even a <u>rough</u> Cd collimators improves S/B). However thus could mean that a well done collimator could provide a significant improvement in the S/B ratio.



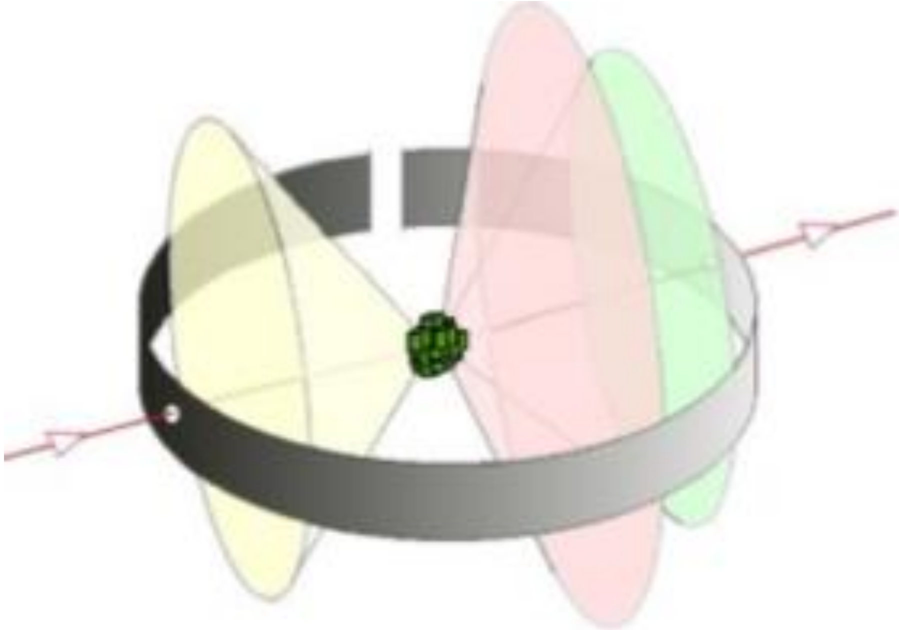
No. 3

RED = GEM with enriched B cathode and Cd collimator

BLACK = GEM with enriched B cathode **WITHOUT** Cd collimator

# Debye-Scherrer cones

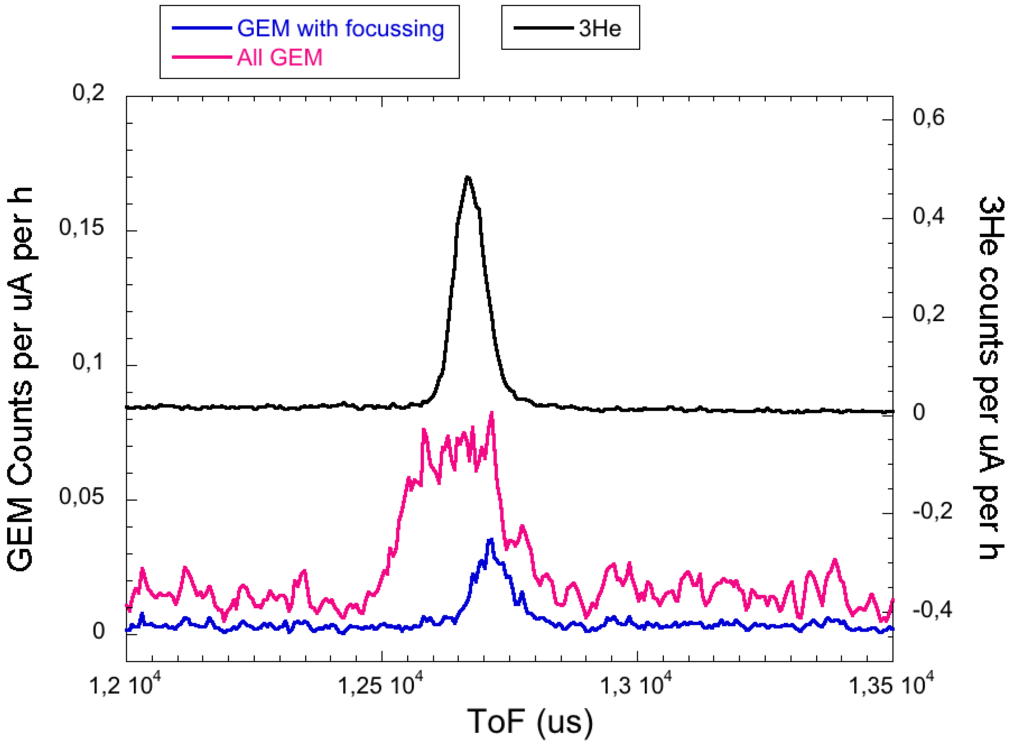
- A randomly oriented polycrystalline sample (e.g. a powder) contains a very large number of crystallites
- A beam impinging on the sample will find a representative number of crystallites in the right orientation for diffraction
- Diffraction occurs only at specific angles, those where Bragg’s law is satisfied



# Focussing to improve bGEM resolution

Resolution improves summing spectra of pads that lie on the same Debey-Scherrer cone, i.e. summing the pads that have a **costant Lsenϑ**

$$d = \frac{h \cdot ToF}{2mL \cdot sen\vartheta}$$



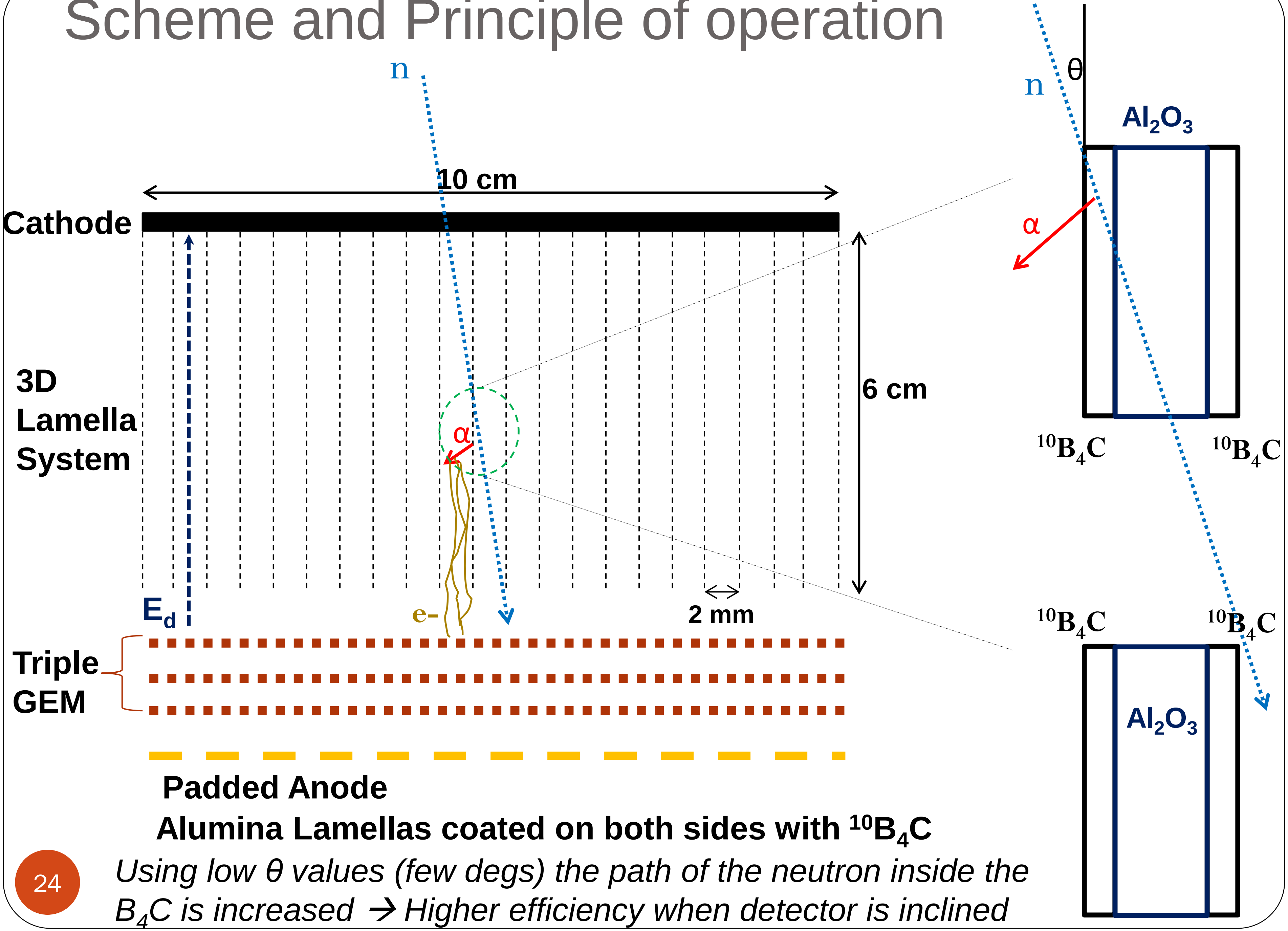
| Counting area | ToF [us] | FWHM (us) |
|---|---|---|
| All GEM | 12648,66 | 229,9 |
| Focussed GEM | 12714,22 | 79,43 |
| $^3$He | 12673,94 | 77,43 |

The **focussing** (thanks to **2D readout**) improves significantly the **resolution** that now is **comparable with the $^3$He tubes within 2%**.

# BAND-GEM detector

*A further step towards a high efficiency GEM based neutron detector*

# Scheme and Principle of operation

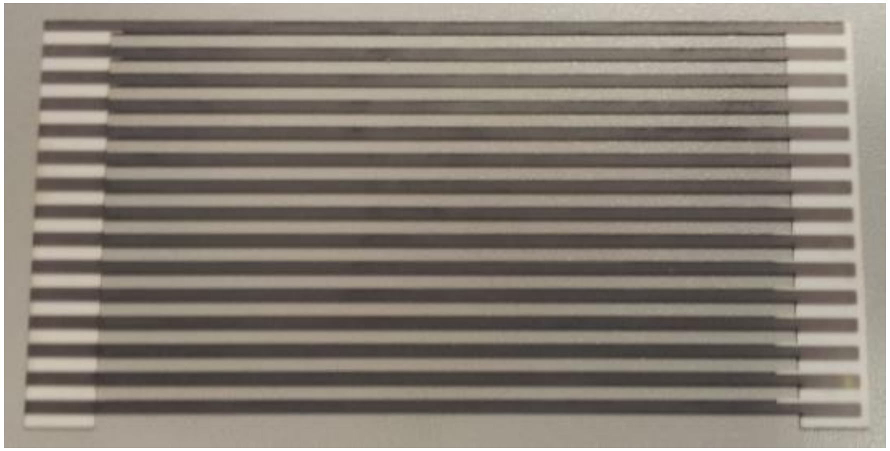


**Alumina Lamellas coated on both sides with $^{10}B_4C$**

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

# $^{10}B_4C$ Coating on the lamellas

**Deposition done by Dr. Carina Hoglund**



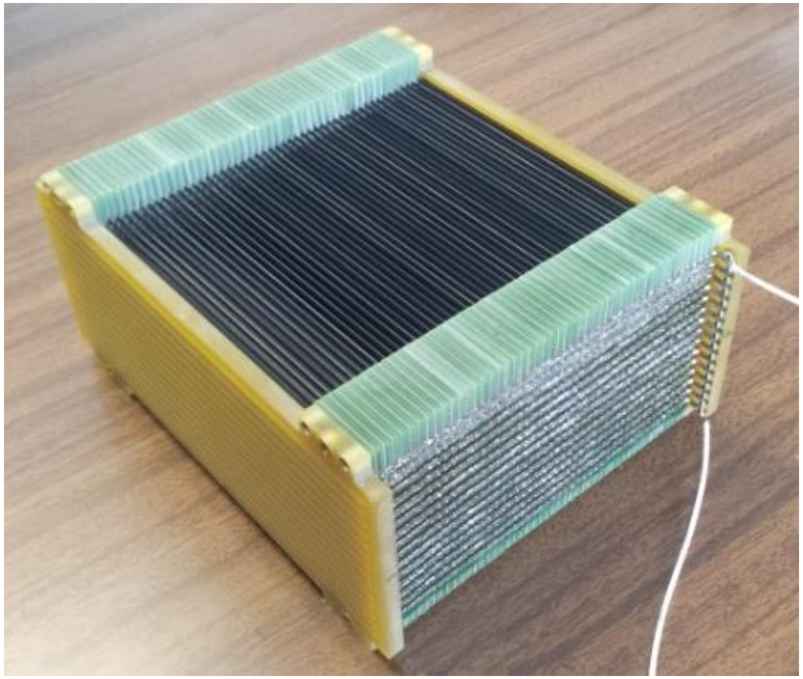
The resulting coated lamellas

A 1 µm $^{10}B_4C$ coating has been deposited on both sides of the lamella and on all the 15 strips

**In total more than 50 lamellas have been coated**
**50 Lamellas are necessary to assembly the first detector prototype**

**Boron quantity has been determined through neutron absoprtion measurements (performed at ISIS-ROTAX beamline)**

# Detector Assembly

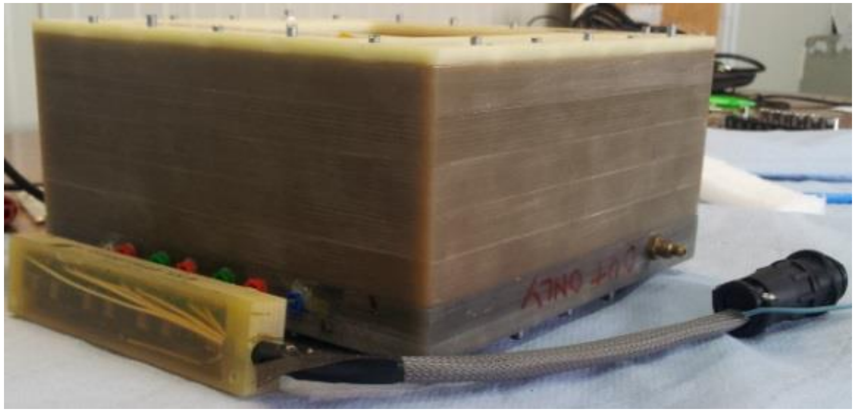


The full Lamella System

An aluminium cathode (few microns thick) has been mounted on top

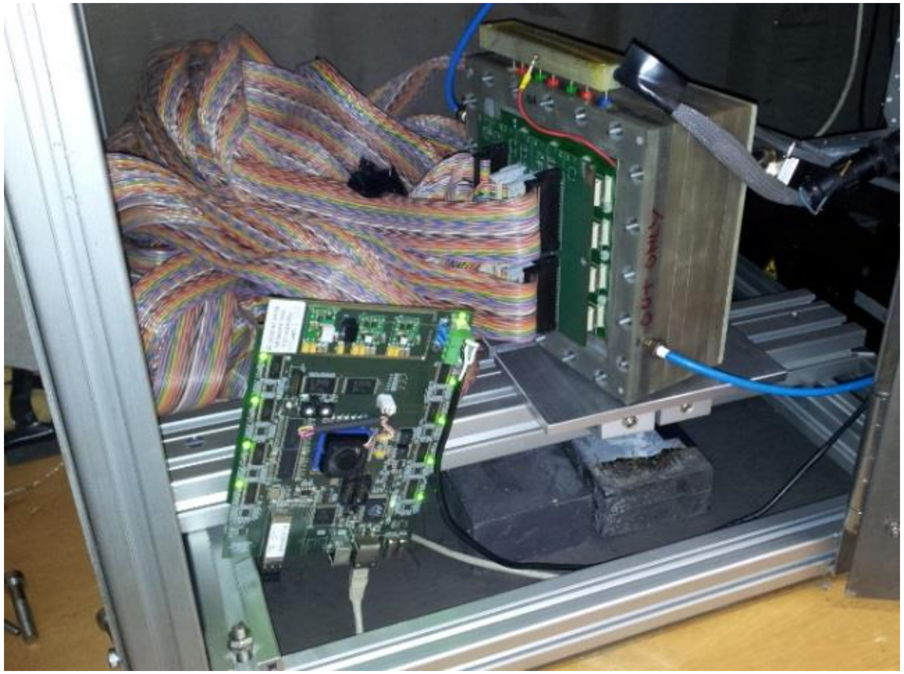
**REALIZED IN COLLABORATION WITH ARTEL SRL**

# Detector test with X-Rays

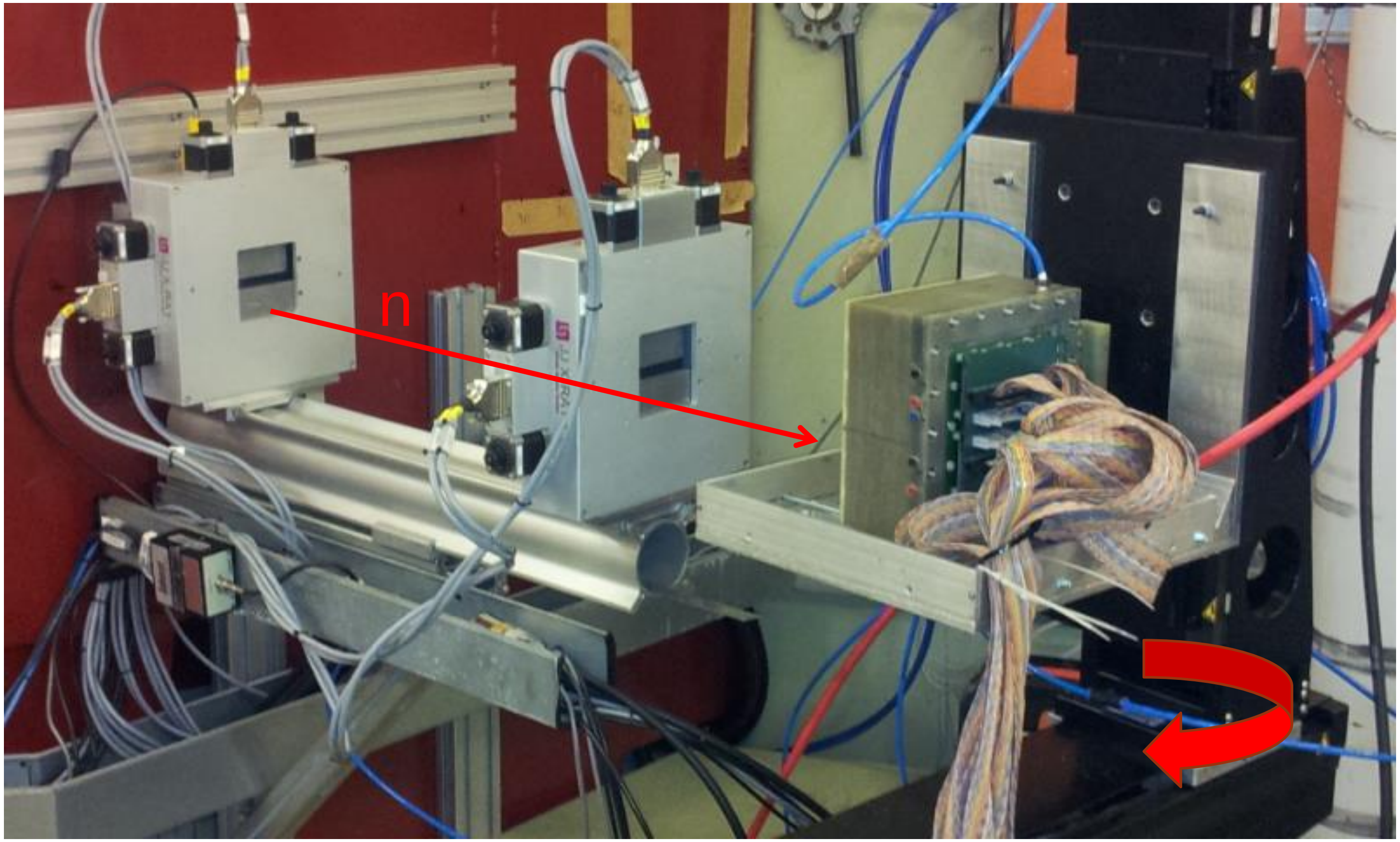


Detector completed

Test with X-Rays (in IFP-lab)

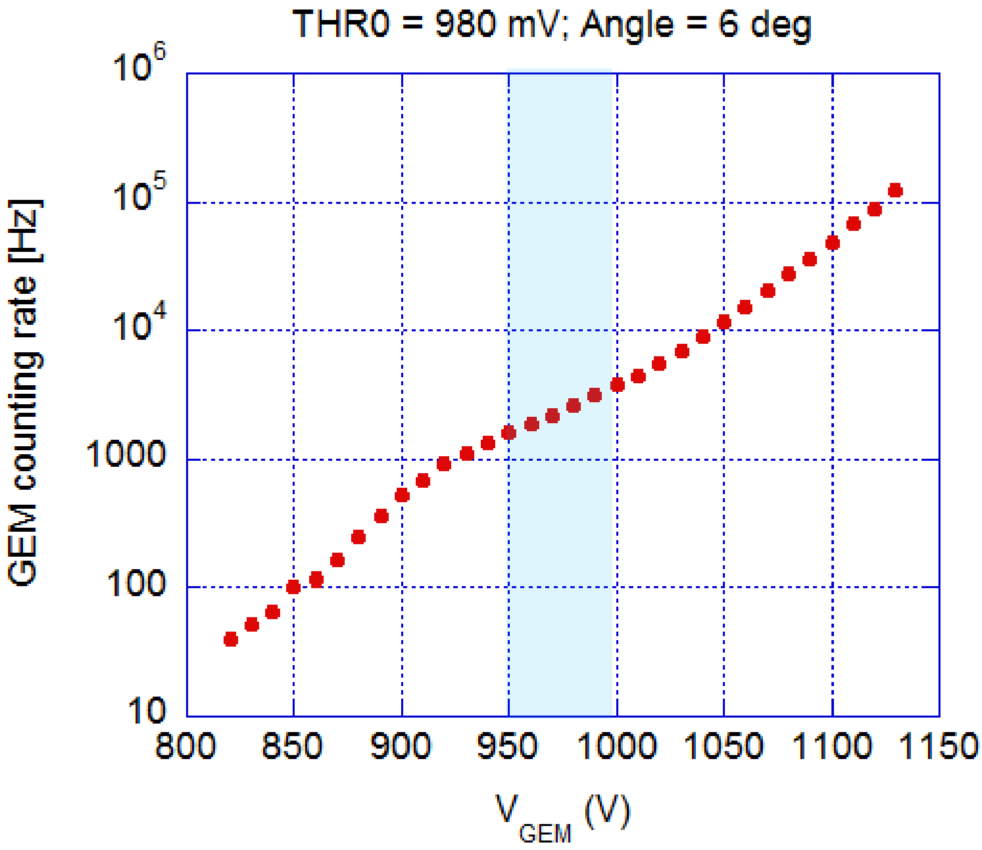


# Detector test at IFE (JEEP II Reactor, RD2D beamline)



Monochromatic neutron beam: possibility to select two wavelenghts:
λ = 1.54 Å, E = 34.5 meV
λ =  2 Å, E = 20.45 meV
Possibility to set different beam sizes

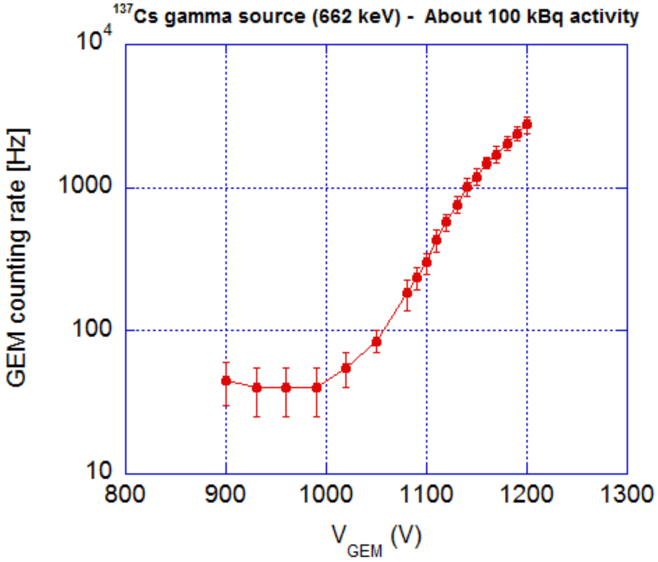
# High Voltage Scan – Working point



$E_d$ = 230 V/cm
$E_{t1}$=$E_{t2}$= 3 kV/cm; $E_i$ = 5 kV/cm

Mixture Ar/CO2 70%/30% 230 cc/min

Need to understand the gamma ray background component. On-site measurment with a gamma source

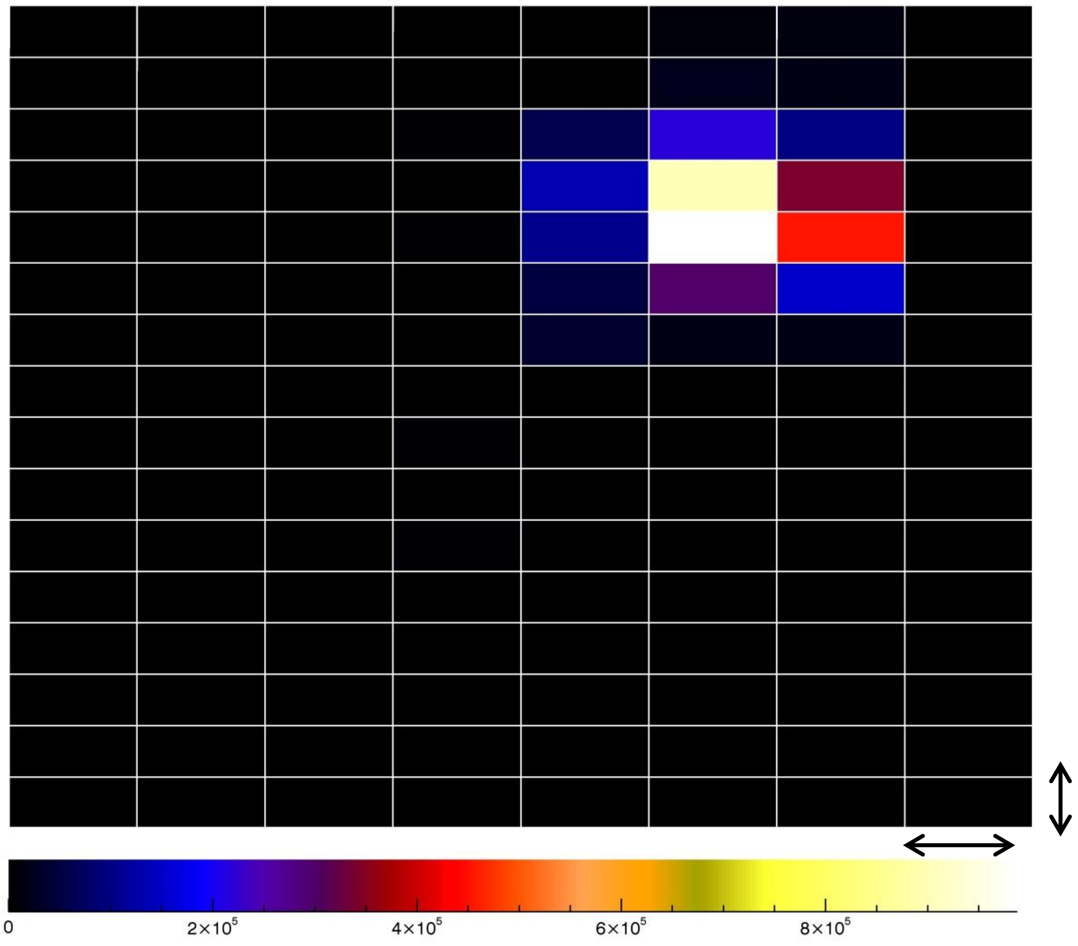


VGEM working point values are higher than usual one (870 V)

Neutron energy $E_n$ = 34.5 meV

ON-GOING ANALYSIS

# Beam Profile Reconstruction



6 mm

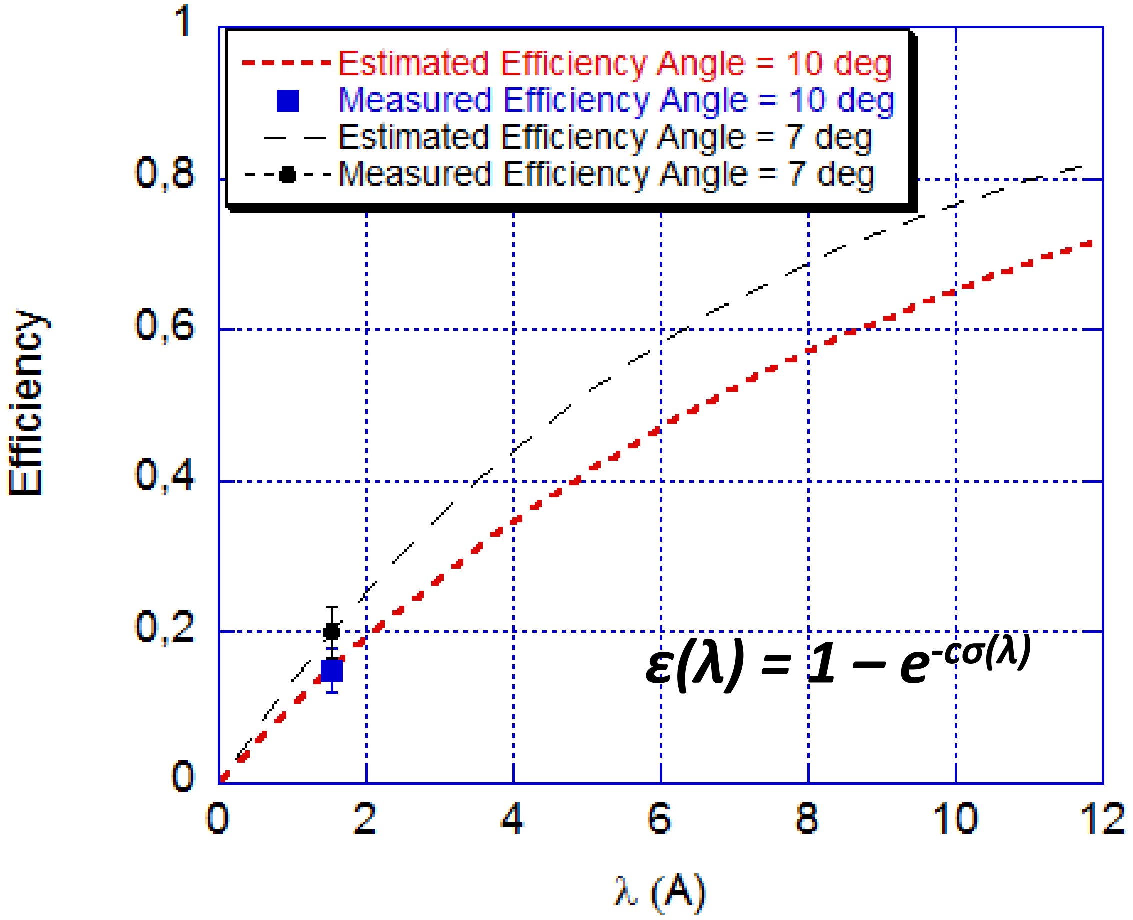
12 mm

$E_d$ = 230 V/cm
$E_{t1}$=$E_{t2}$= 3 kV/cm;
$E_i$ = 5 kV/cm

Mixture Ar/CO2
70%/30%
Angle = 10 degrees

VGEM = 980 V

# First efficiency estimation as a function of wavelenght



$$\varepsilon(\lambda) = 1 - e^{-c\sigma(\lambda)}$$

Where $\sigma(\lambda) = \lambda / \lambda_0$

If $\lambda=\lambda_0=1.54$ A $\varepsilon=0.15$ for 10 degrees and $\varepsilon==0.20$ for 7 degrees (Angle with respect neutron direction)

# Conclusions

- GEM-based thermal neutron detectors have been successfully realized and tested. They provide:
  - Real-time neutron beam profile with a portable system (HV System + CARIOCAS & MBFPGA LNF)
  - Measurements with the necessary space resolution (pad dimension)
  - Stability in time
  - High rate capability under neutron irradiation
  - Comparable results to 3He tubes in a real diffraction experiment
- First prototype of higher efficiency realized
  - About 15% efficiency reached at En = 34.5 meV
  - Need to understand the angular effect (data analysys still on-going
  - Need to understand Gamma ray background rejection
  - Already Working on a revised detector version
  - New GEMINI electronics almost ready

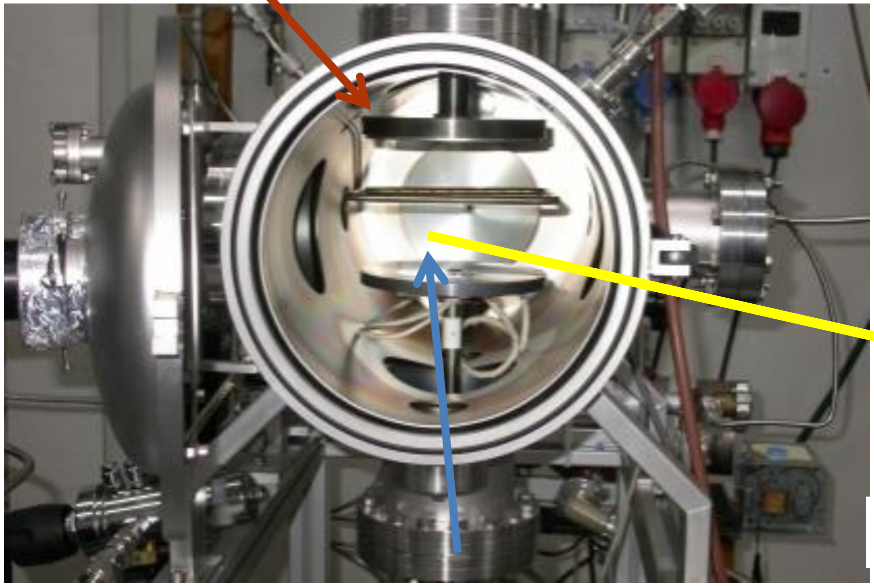
# Relationship with the industry

- HVGEM : MPElettronica – Rome (Italy)
- CARIOCA Chips: Artel SRL – Florence (Italy)
- MB-FPGA: Athenatek – Rome (Italy)
- GEM FRAMES: Meroni & Longoni – Milan (Italy)
- GEM Foils: CERN
- Detector construction: LNF-INFN (Frascati) and IFP-CNR (Milano)

# Spare Slides

# RF plasma sputtering system for $B_4C$ coating at IFP-CNR (Milano,Italy)

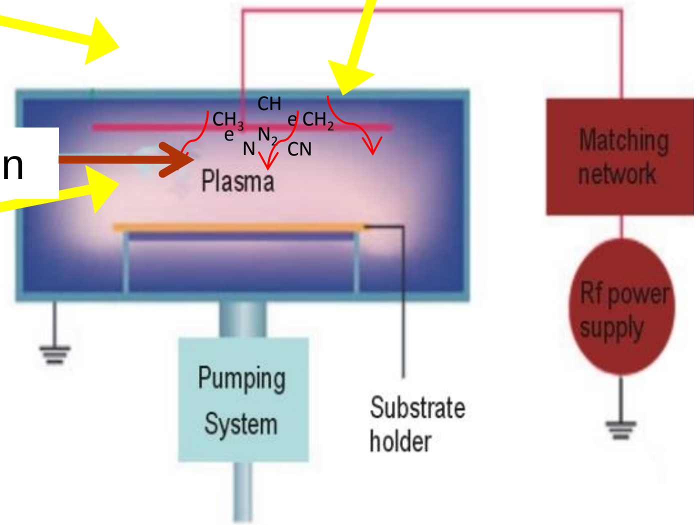
$B_4C$ target



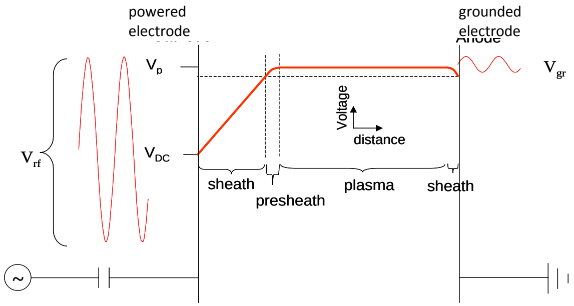
Courtesy of E. Vassallo (IFP-CNR)

*Atoms, Radicals Molecules , Ions and Electrons*

Gas Injection

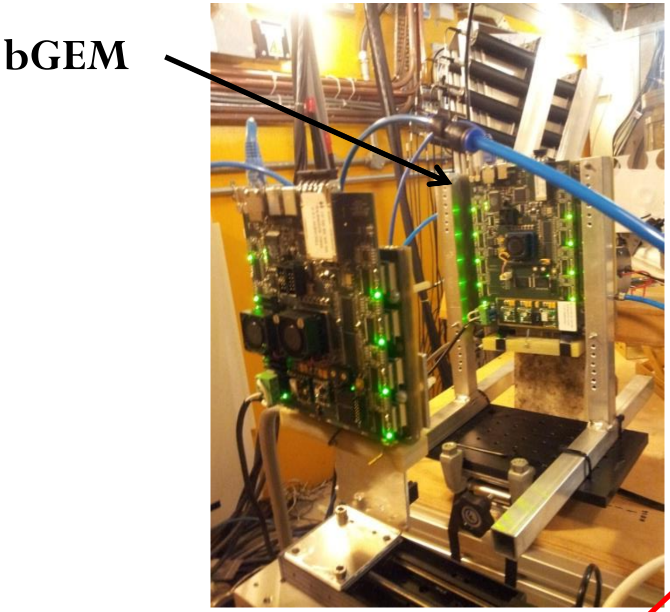


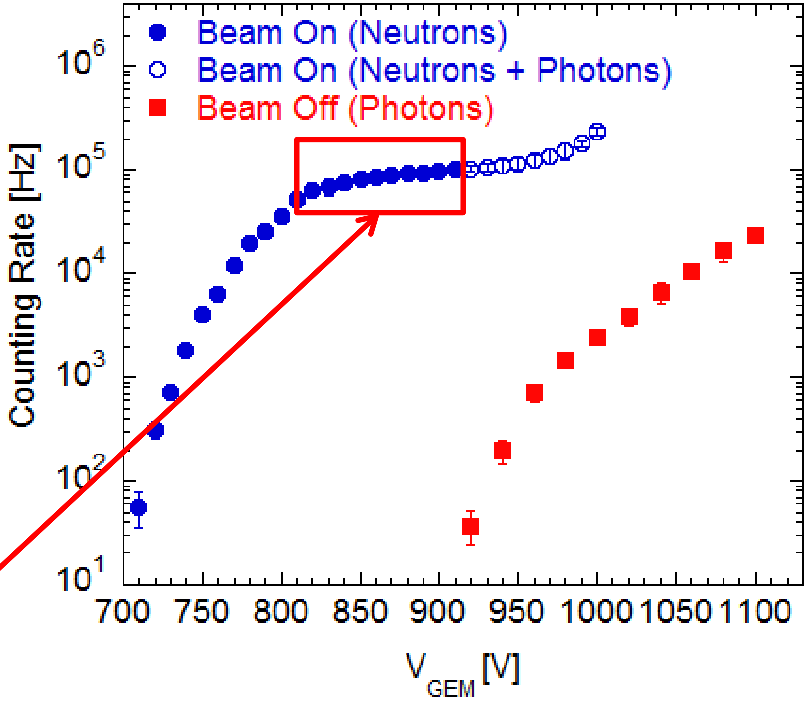
**Plasma deposition area**



Time-average voltage profile across electrodes in rf discharge

# Thermal neutron measurements as a function of detector gain (wp and γ-rejec) at ISIS-Vesuvio



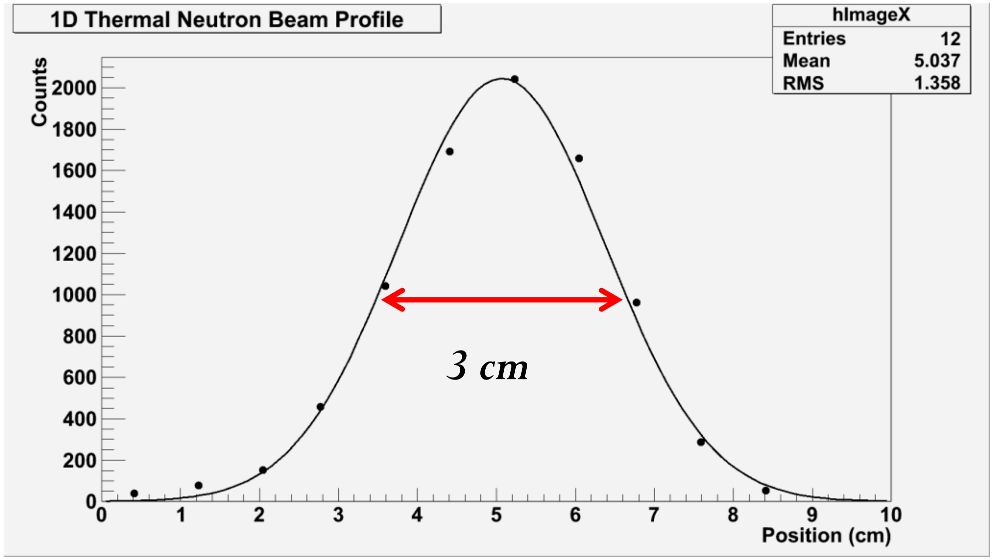


G. Croci et Al, NIMA (2013), In Press

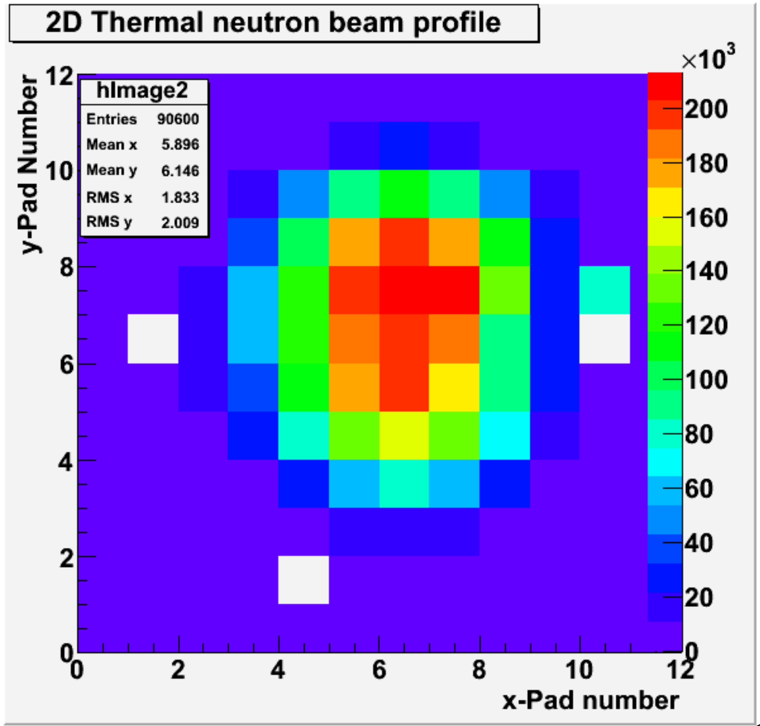
- **A wide plateau** is present for 820 V <$V_{GEM}$ < 910 V → This confirms that the detector is revealing all the alpha particles emitted from the $^{10}B(n,\alpha)^{7}Li$ reaction. The detector reached its maximum efficiency.
- The detector is gamma-background free with $V_{GEM}$ < 900 V

- At $V_{GEM}$ =870V corresponding to a GEM effective gain of 100, the measured efficiency is about (0.95±0.08)% , very similar to the expected one 0.86%

# Measurement of ISIS-vesuvio 2D thermal neutron beam profile

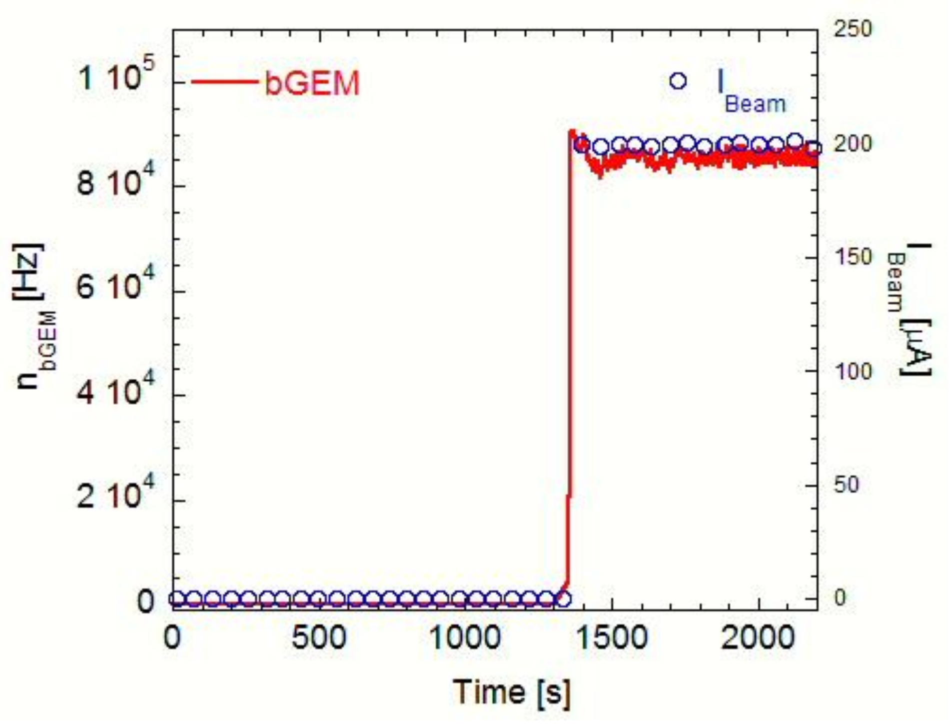


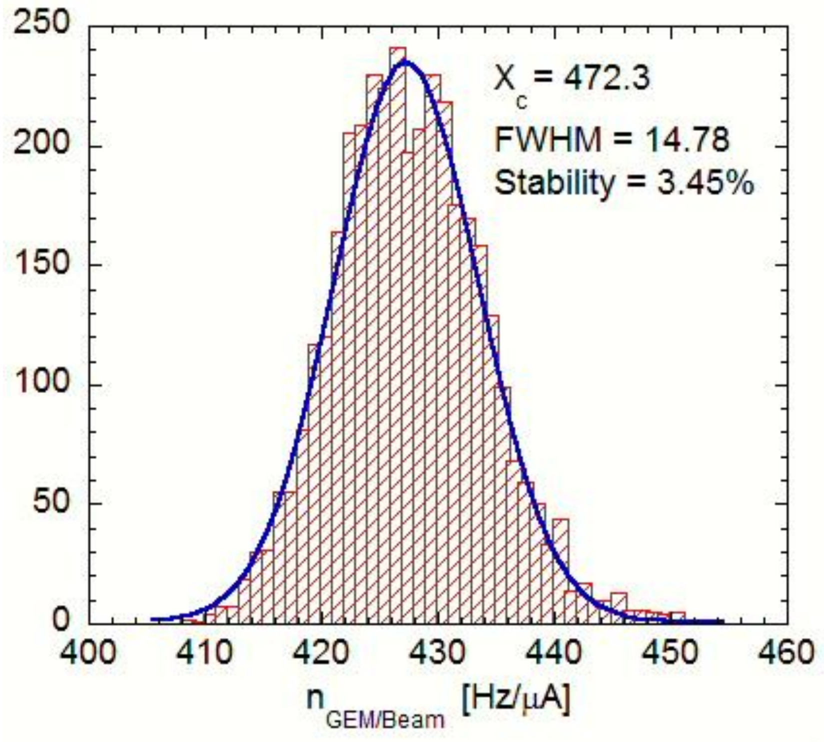
G. Croci et Al, NIMA (2013), In Press



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

# Detector Counting Rate Stability in time

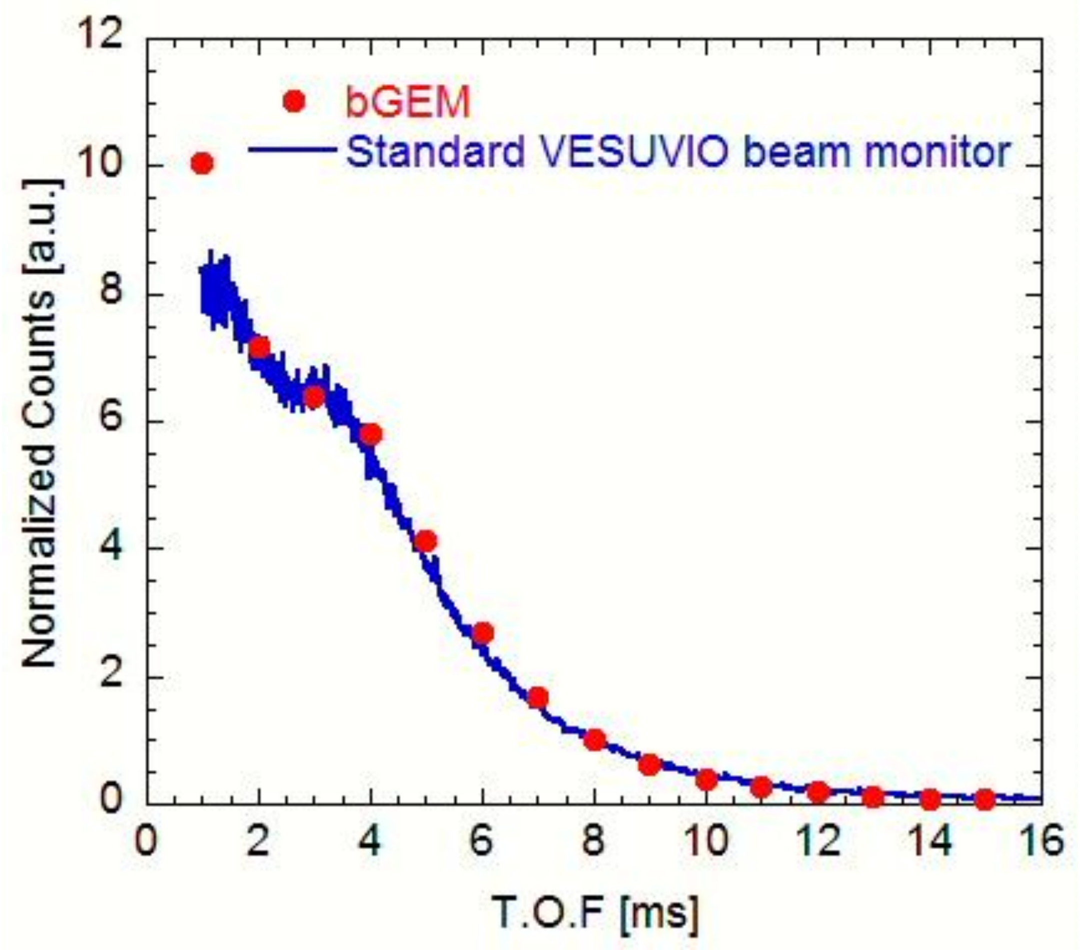




- **bGEM counting rate exactly follows the ISIS beam**
- **Measured% of counting rate variation with time = 3.5 %**
- **Stability is a very important feature for a beam monitor**

G. Croci et Al, NIMA (2013), In Press

# Thermal neutrons time of flight spectrum



G. Croci et Al, NIMA (2013)

**Performed using the FPGA-MB**

**The TOF spectrum was measured using the multi-gate property of FPGA-MB.**

**The spectrum is compatible with TOF spectrum measured by standard Vesuvio beam monitors**