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UNIVERSITA' DEGLI STUDI DI MILANO BICOCCA

ENEA

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Laboratori Nazionali di Frascati

Conceptual Study for

nGEM Detectors for the SPIDER neutron facility for nuclear fusion applications

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On behalf of a collaboration between
CNR – Universita' di Milano-Bicocca –
LNF Frascati – ENEA Frascati

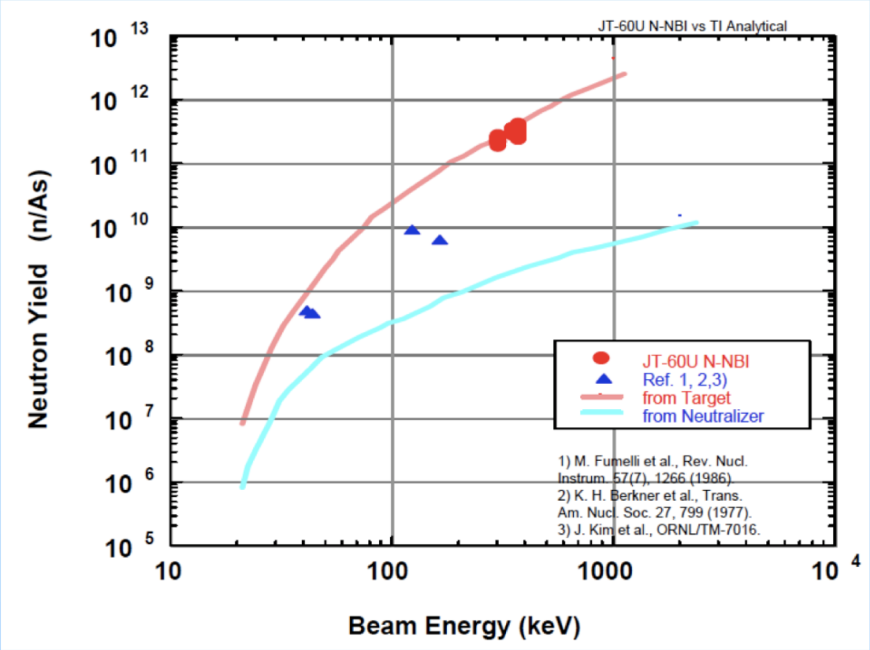
Outline

- Short description of the project
- Physics of the processes
- First design of the final nGEM detector prototype
- Previous neutrons measurements with nGEM detectors

Aim of the project

Diagnostic of a fast neutron beam generated by the interaction of deuterium ions of 100 keV with the beam dump, in order to detect any variation of the deuterium beam intensity up to 10% level.

Time resolution < 1s and space resolution < 20 mm are required.

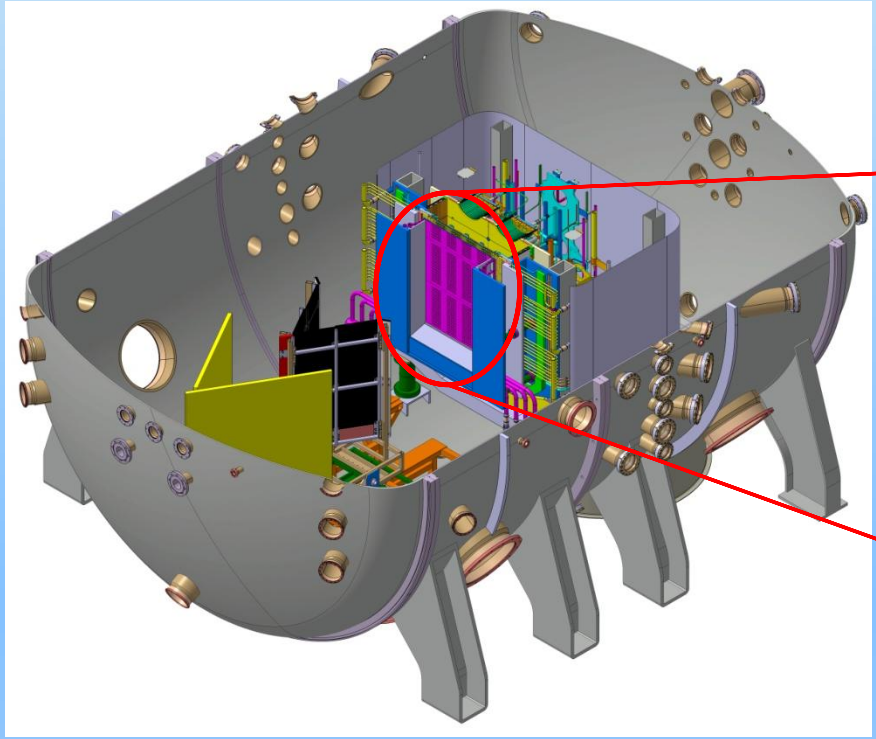


The deuterium beam is dump on a beam dump where it is implanted. The goal is to generate the DD reaction in order to recreate the nuclear fusion

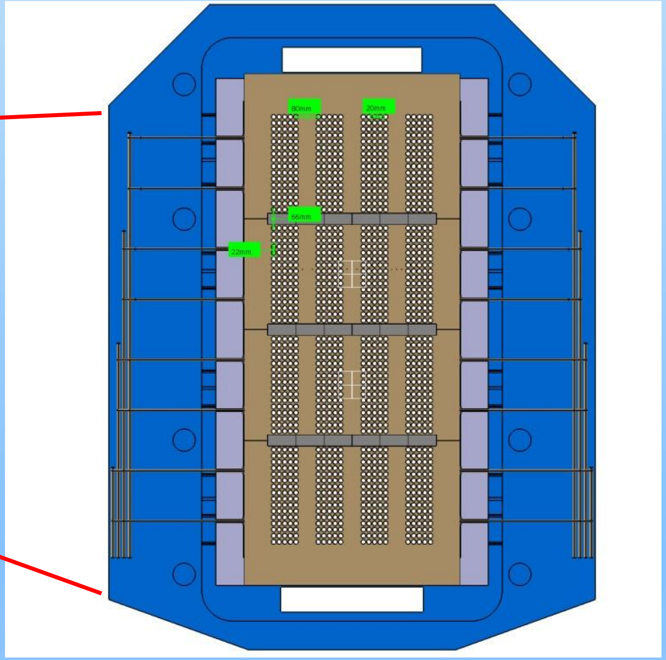
DD Reaction: $D + D \rightarrow {}^{3}He + n(2.45\ MeV)$

The SPIDER Facility Deuterium Beam

The SPIDER beam is not a unique full beam but it is composed by smaller circular beamlets. The beam is subdivided into 16 groups of beamlets and each group is composed by 5 * 16 beamlets. The dimensions of one beamlet is 20 * 22 mm. The energy of the deuterium ions is 100 keV.



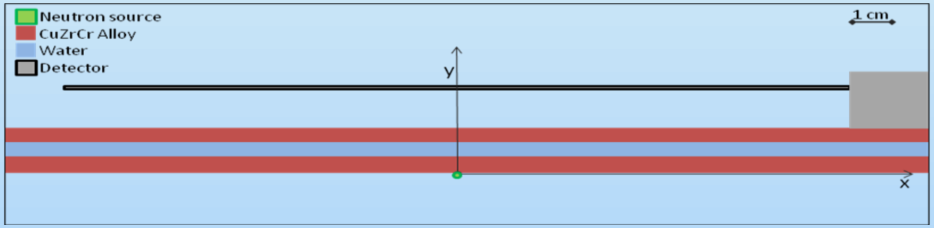
The SPIDER facility



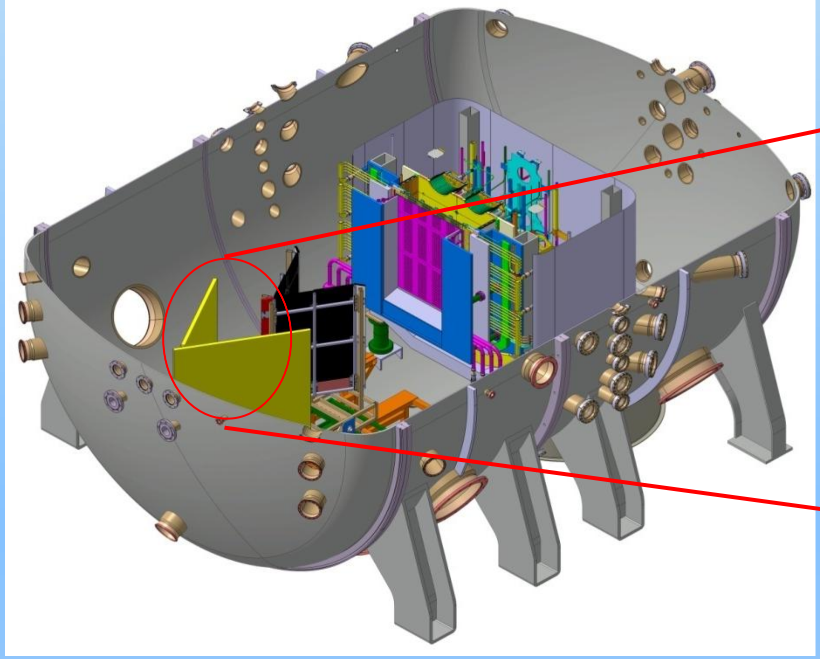
The beamlets composition of the deuterium beam

The SPIDER Facility Beam Dump

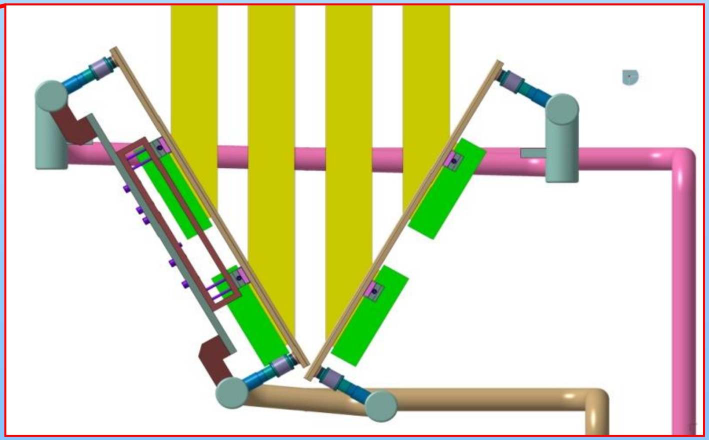
The SPIDER beam dump is composed by three layers: the two external layers are composed by CuCrZn alloy (99% Cu) and the central one contains water. The beam dump is inclined by 30 degrees with respect to the deuterium beam direction.



First CuCrZn thickness = 5.8 mm
Water layer thickness = 6.2 mm
First CuCrZn thickness = 5.8 mm



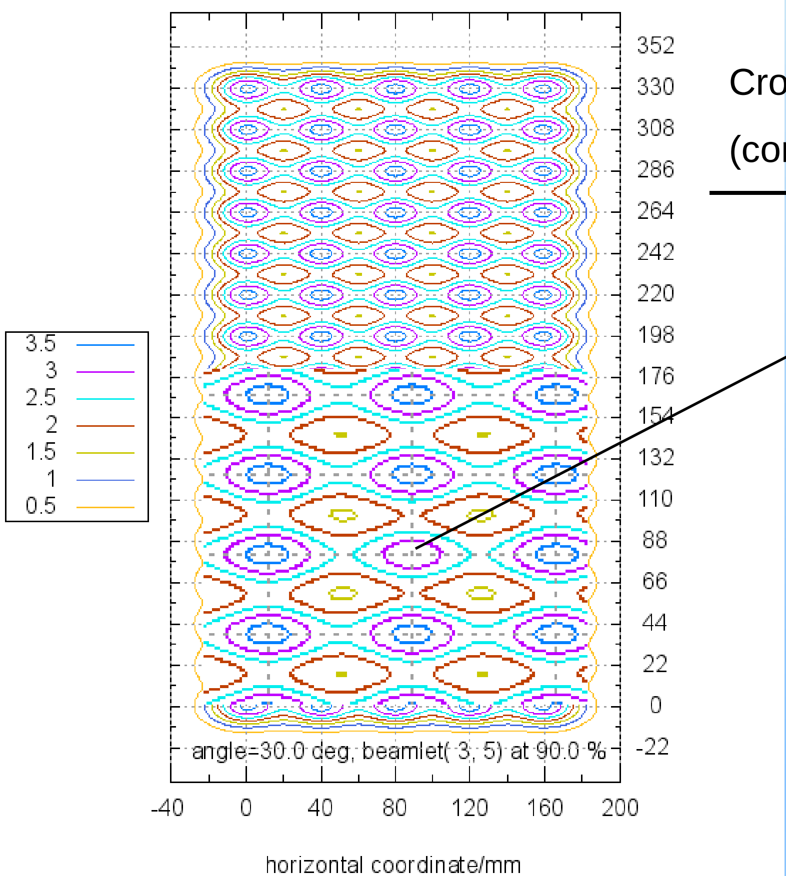
The SPIDER facility



The beamlets composition of the deuterium beam

The deuterium beam composition on the beam dump

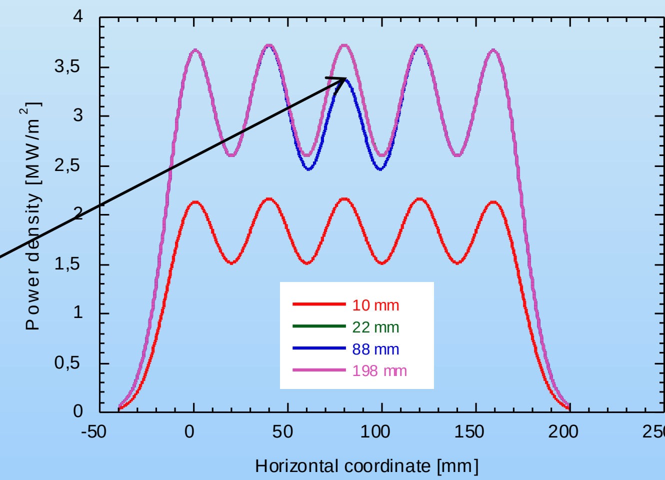
The power of one of the 16 groups of beamlets is shown here. Each group has 5 * 16 beamlets. Contours represent the power (MW/m^2) of each beamlet.



Contour plot of the power density profile of a 5X16 beamlets matrix hitting the beam dump. The power density levels are in MW/m2.
The beamlet element (3,5) is at 90 % of full power.

Cross section

(constant z)

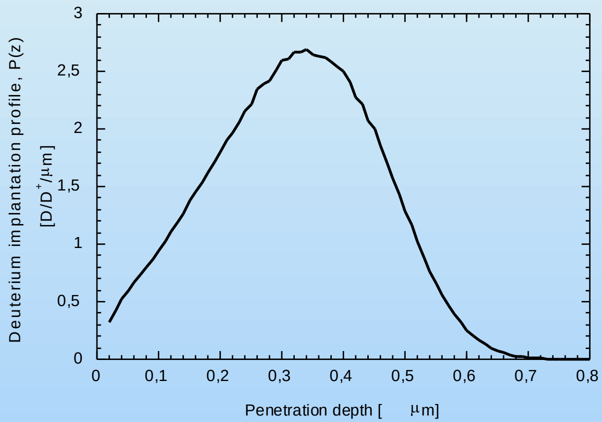


The beamlet (3,5 – z = 88 mm) has 90% of the full power → The nGEM detector has to be able to detect a variation of the power intensity in one beamlet through the neutron rate measurement

Since the beam dump is 30 degrees inclined, the actual (elliptical) beamlet dimension on the beam dump is 40 mm * 22 mm

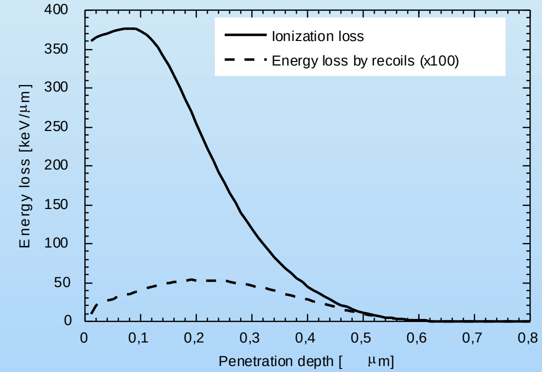
Physics in the beam dump (1)

Deuterium ions are stopped into the beam dump and some of them are implanted into it.



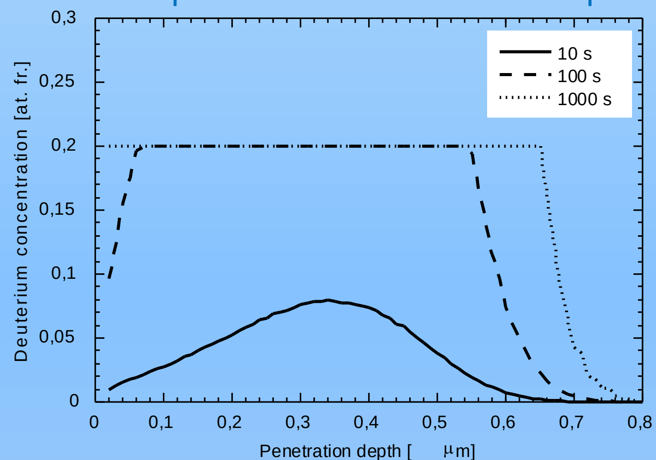
Penetration depth distribution of implanted deuterium in the beam dump.

Deuterium ions lose their energy due to collisions with electrons and nuclei.
All the energy is lost in the first 0.5 um



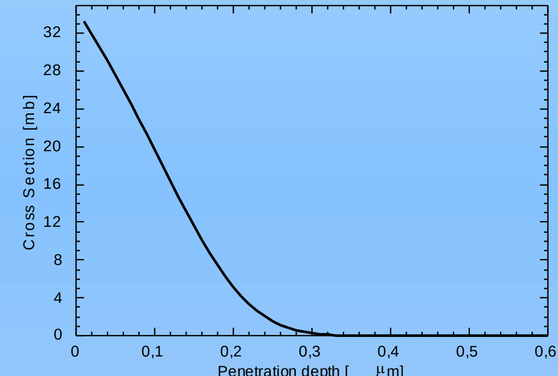
Electronic (ionization) energy loss of deuterium ions vs. penetration depth.
Also shown is the energy loss due to recoiling target atoms (x100)

After a period, some of the deuterium ions are implanted into the beam dump



Deuterium concentration profile at different times after switching on of the deuterium beam.

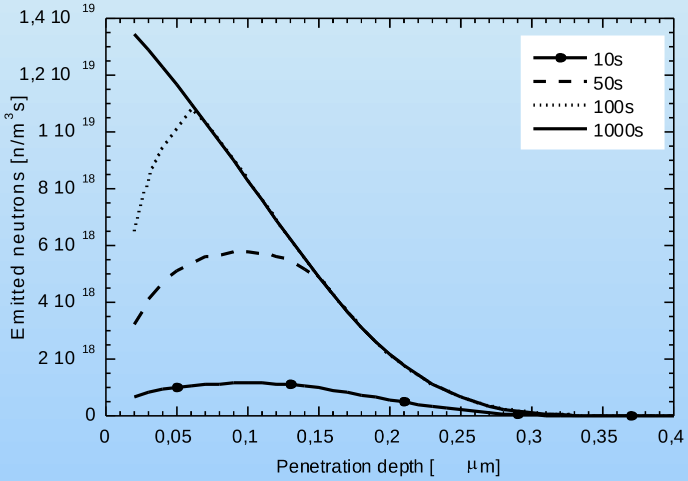
Deuterium ions in the beam are able to interact with the implanted deuterium ions through the DD reaction, when the deuterium concentration in the beam dump is saturated



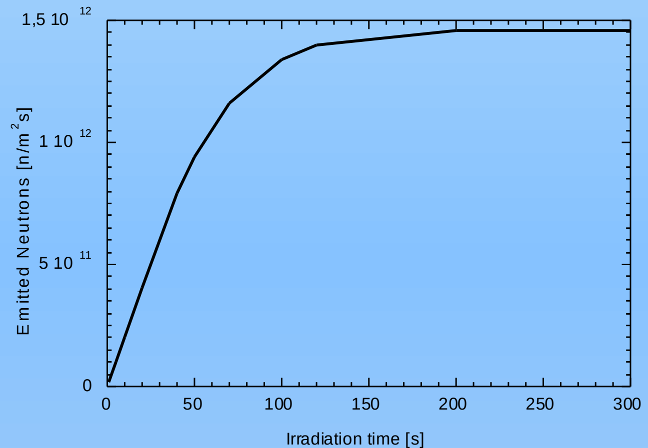
Cross Section for the D(d,n)^{3}He reaction as function of penetration depth

Physics in the beam dump (2)

The neutron yield (y) depends on the penetration depth of the deuterium ions and on the irradiation time and is given by the formula $y = \phi \sigma n_d$, where ϕ is the deuteron flux entering the dump, σ is the cross section for the DD reaction and $n_d(x,y,z)$ is the density of deuterium nuclei in the dump.



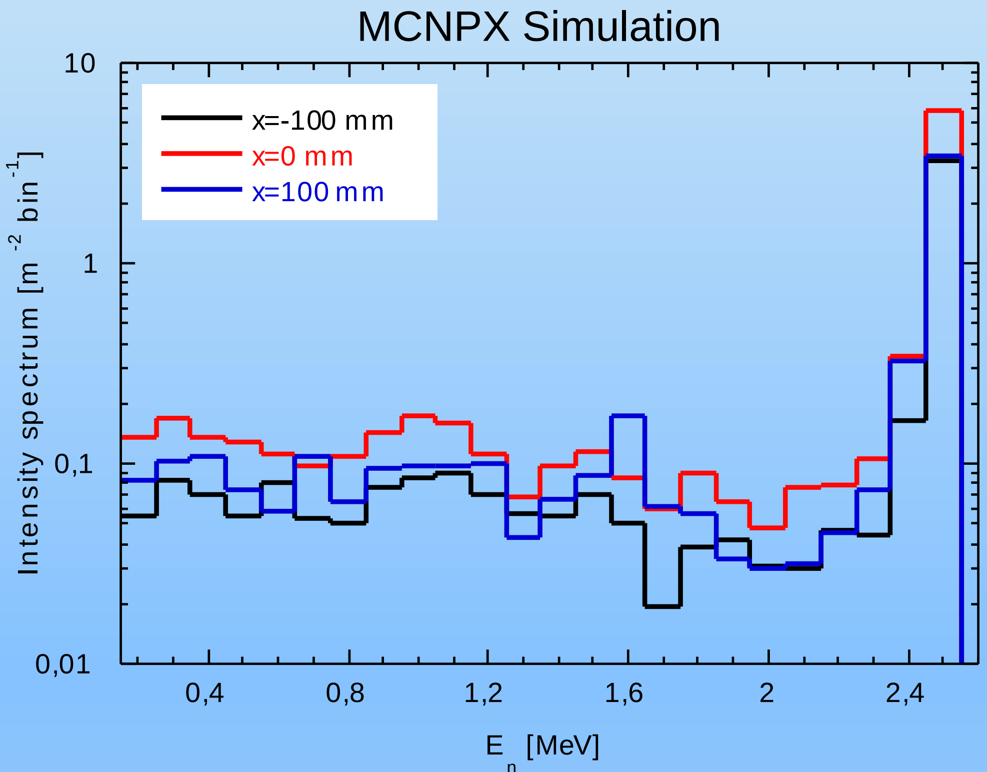
Integrating the previous formula ($y = \phi \sigma n_d$) the total irradiation rate b is obtained $b = \phi \int \sigma \cdot n_D dz$



Neutron emission rate as a function of the irradiation time.

Neutrons energy spectrum

- After a neutron is emitted with an energy of 2.45 MeV, it may undergo different processes before reaching the detector:
  - Scattering in the beam dump
  - Scattering in the SPIDER materials

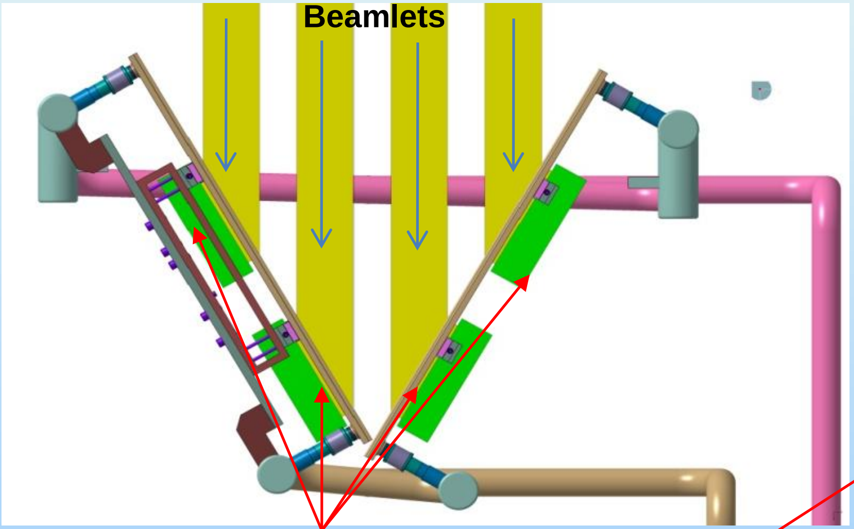


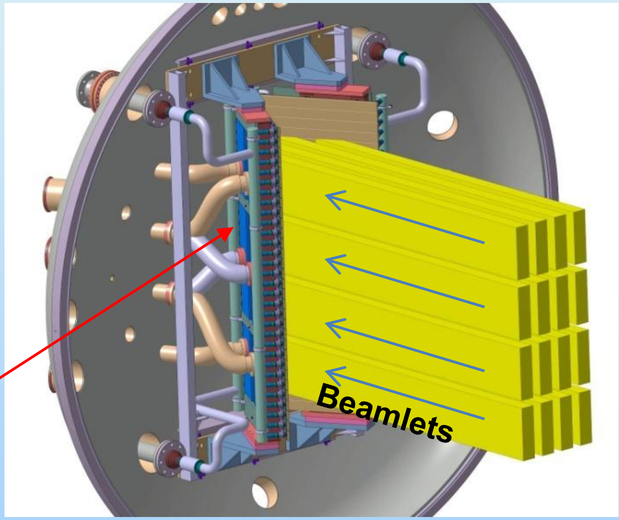
Neutron energy spectrum at three positions on the detector surface with z=0 and x=-100 mm (black), 0 mm (red) and 100 mm (blue).

The Diagnostic system: the nGEM detectors

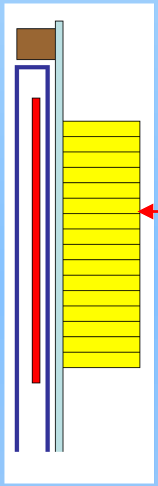
- Triple GEM detector (standard GEM foil)
- GEM foil dimensions : 35.2 cm x 20 cm
- 3 mm/ 1 mm / 2 mm/ 1 mm Gaps
- Pads readout with 16*10 = 160 pads
- Pad dimensions 20 x 22 mm^2 → 2 pads per beamlet
- Al or Cu Cathode equipped with a polyethene (CH_2) layer used to convert neutrons into protons
- Gas mixture Ar/CO_2 70%/30%
- Active LHCb type power supply (HV GEM)
- FE Electronics: CARIOCA (open to other counting chip solution)
- Installed behind the beam dump in a tank at room pressure, at a 30 cm from the neutron sources *(the beam dump is in vacuum)*
- Gas pipes and HV cables reach the detector passing into a tube that connects the tank with outside

Localization of the detectors units

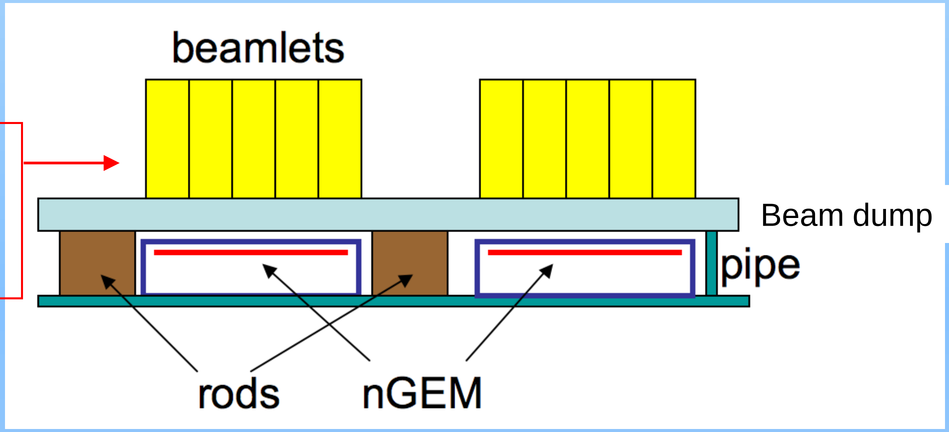




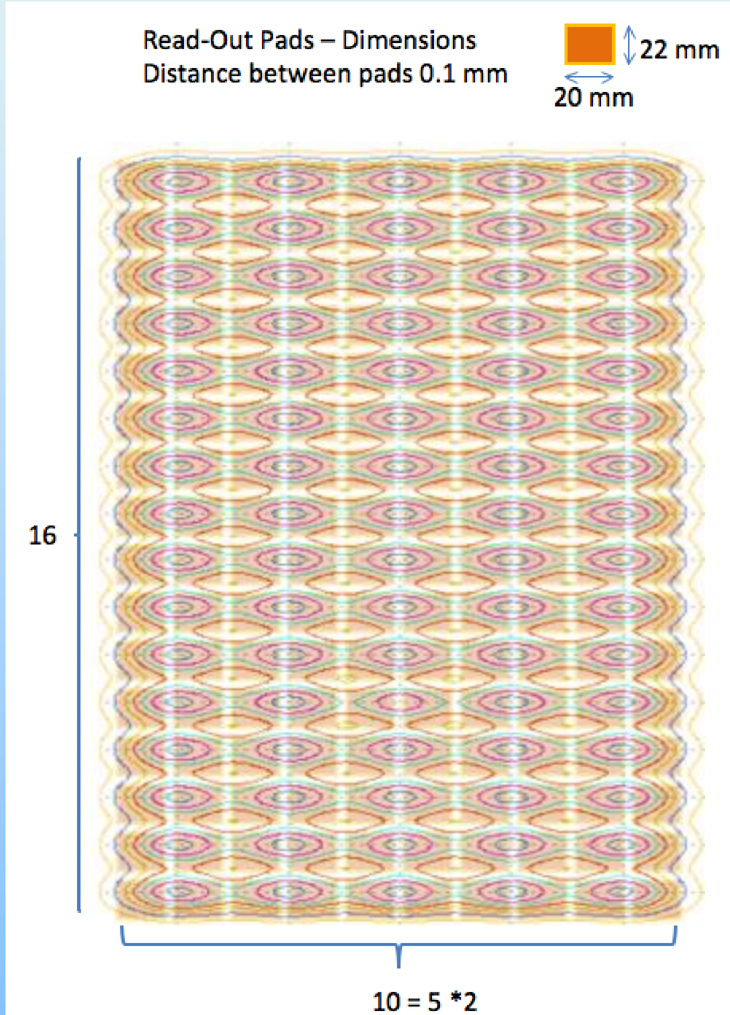
Detector boxes just behind the beam dump



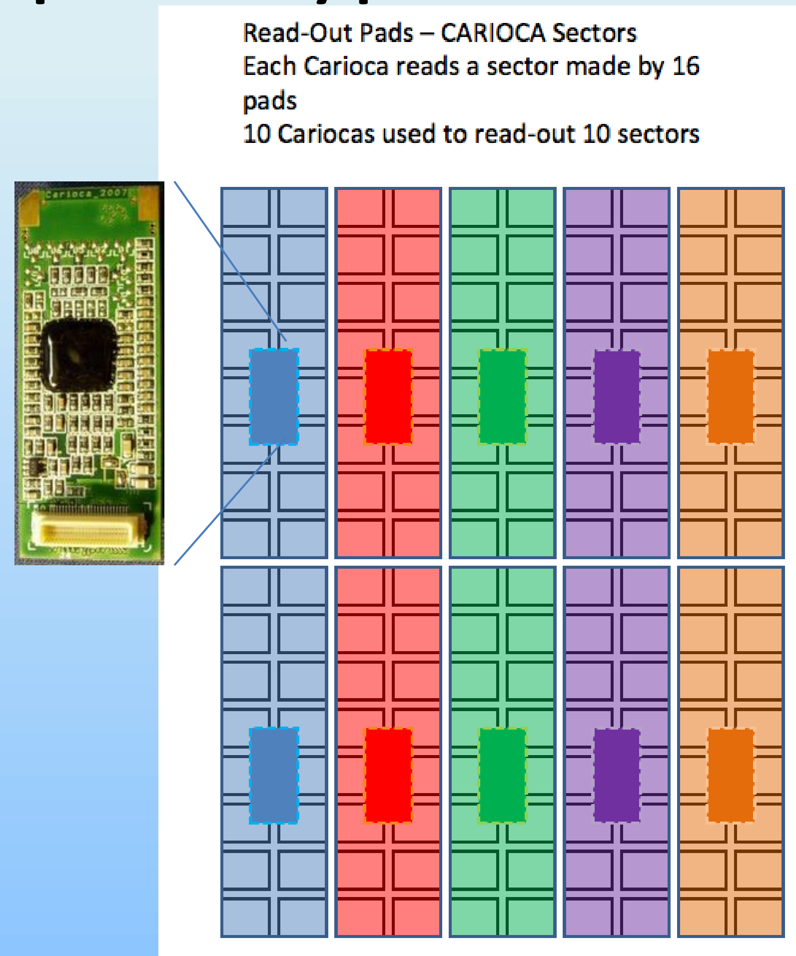
Side and top views of the nGEM location facing the beamlet footprints on the SPIDER beam dump.



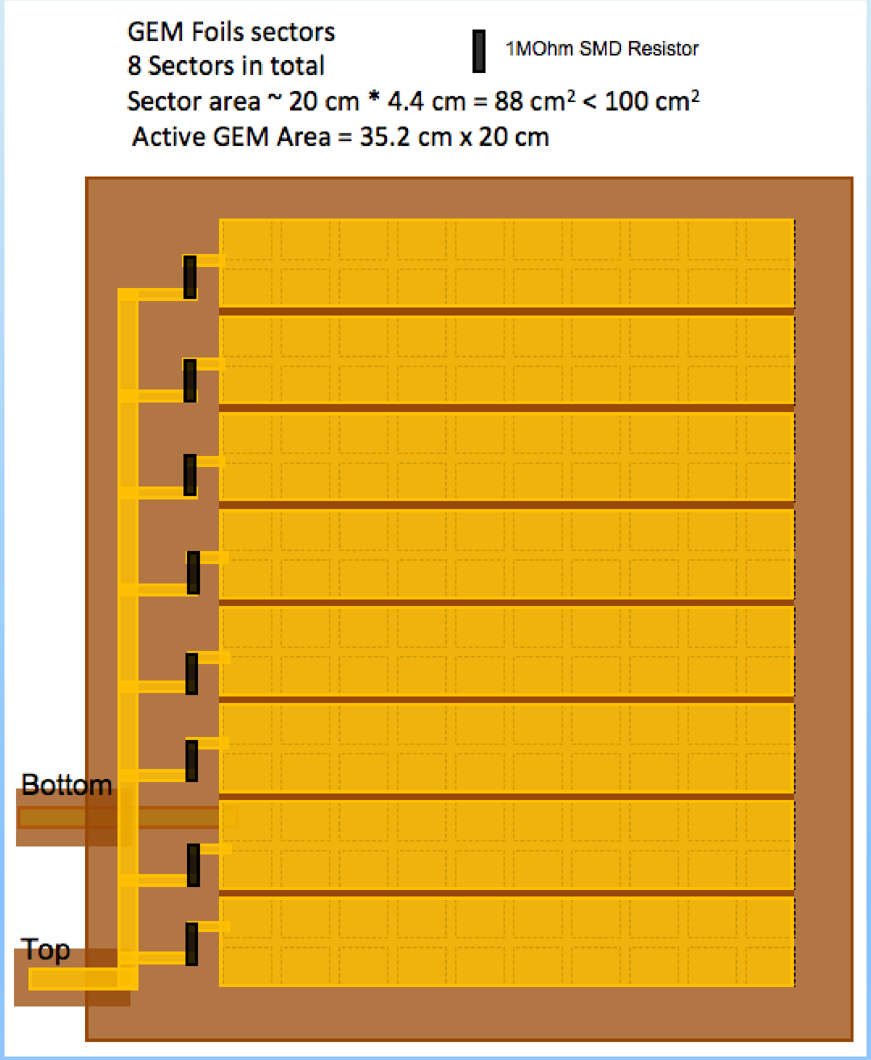
Sketch of the first prototype: Readout

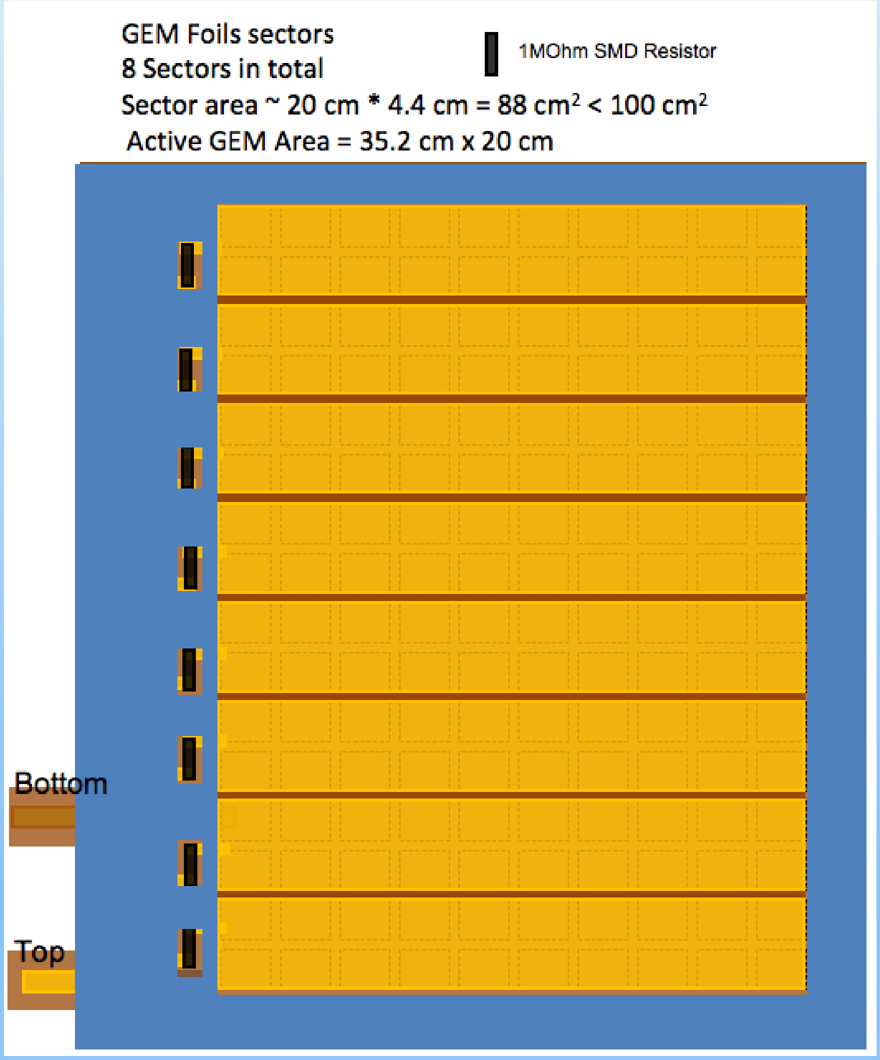


Each beamlet is facing two pads



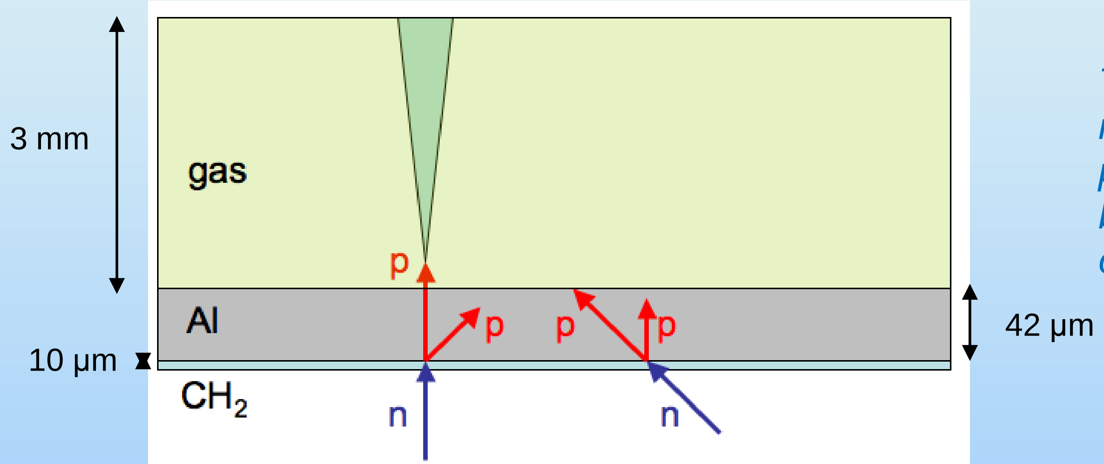
Sketch of the first prototype: GEM foils and frames





The new Cathode (Al-CH_2) n/p converter

- CH_2 converts neutron into protons due to the high hydrogen relative concentration (n-p reaction)



The energy cut is needed in order to preserve the beamlets composition of the original beam

Intensity flux variation measurement
2 pads associated with one beamlet

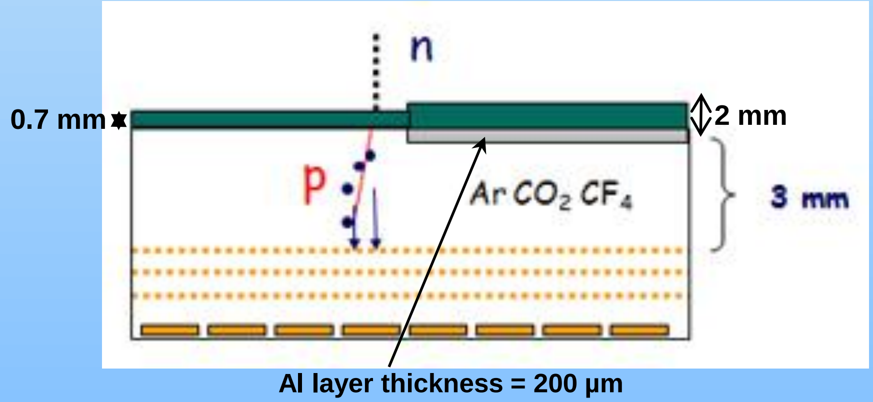
Only protons, that are emitted perpendicularly to the CH_2 layer and that are generated by neutrons impinging normally to the CH_2 surface, give information about intensity variation

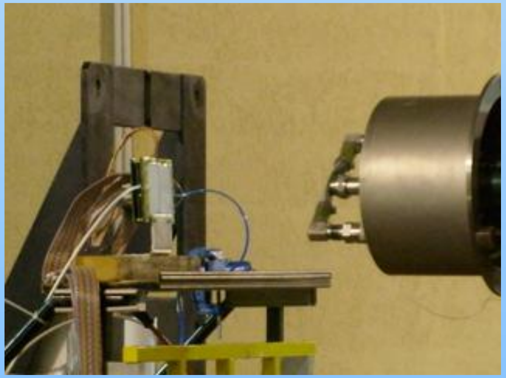
The Al layer thickness is optimized in order to stop all the protons that are not normally emitted → When entering the gas, "good" protons have a residual energy of 1.42 MeV (from neutrons of 2.45 MeV) → A track is created into the gas and in 3 mm gap an average energy of about 60 keV is released.

<u>Simulation are in progress in Frascati (ENEA) and Milano (CNR – University of Milano Bicocca)</u>

Previous measurements with a nGEM detector prototype for fusion application (1)

- Triple GEM detector divided into two subunits of equal area and different sensitivity:
  - One sensitive to 2.5 MeV neutrons (DD reaction)
  - One sensitive to 14 MeV neutrons (DT reaction)
- The two halves of the detector have different thicknesses of Al+CH_2 layer in order to discriminate between energy
- Readout Anode : 128 readout pads 6x12 cm^2 organized in a matrix 16x8



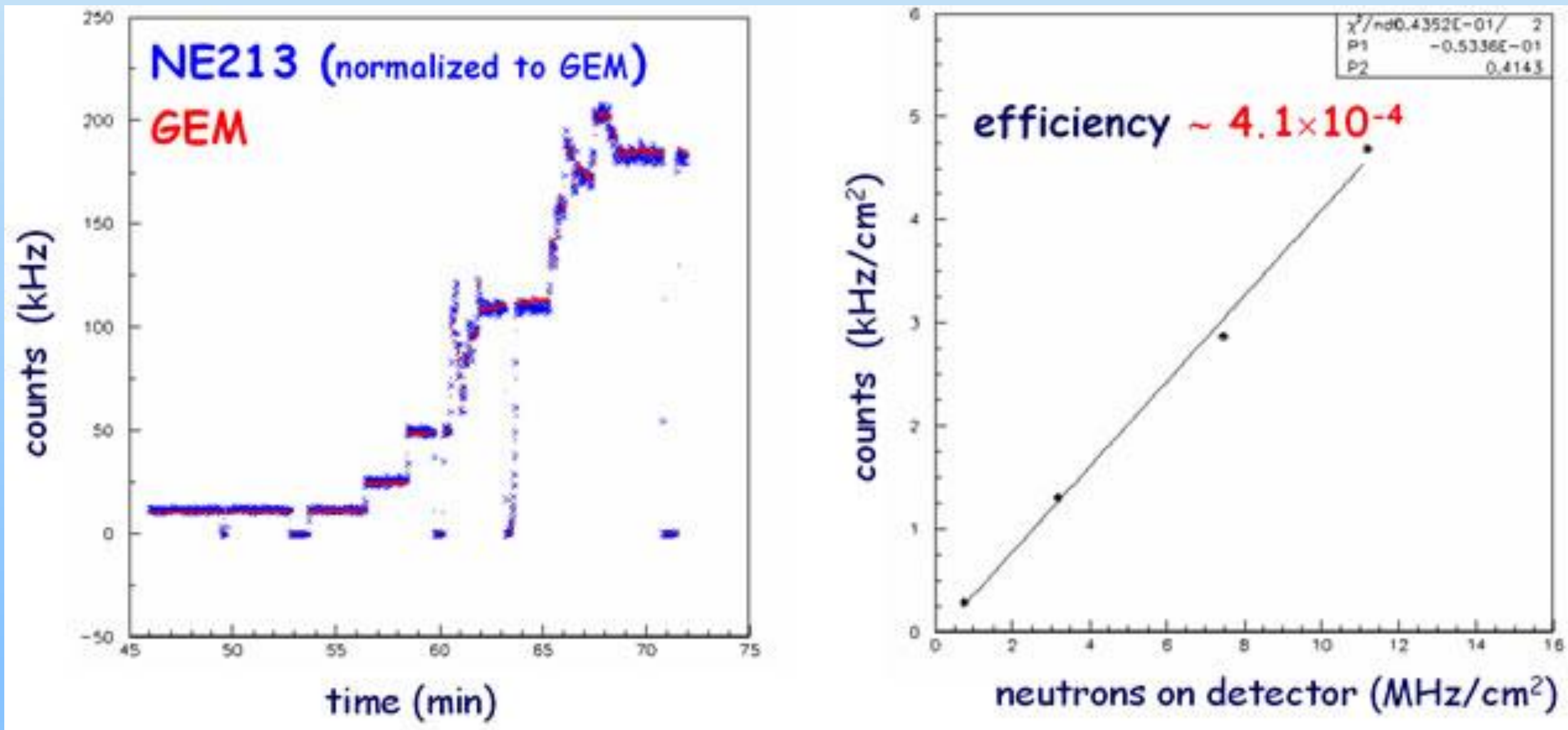


Some beam tests have been done at FNG (Frascati Neutron Generator) at ENEA Frascati for the measurements of high neutron flux produced by strong nuclear reaction Deuterium-Deuterium e Deuterium-Tritium: Neutron of 2.5 MeV e 14 MeV are respectively produced.

B. Esposito et Al, "Design of a GEM-based detector for the measurement of fast neutrons", NIM A, 617 (2010), 155 - 157

Previous measurements with a nGEM detector prototype for fusion application (2)

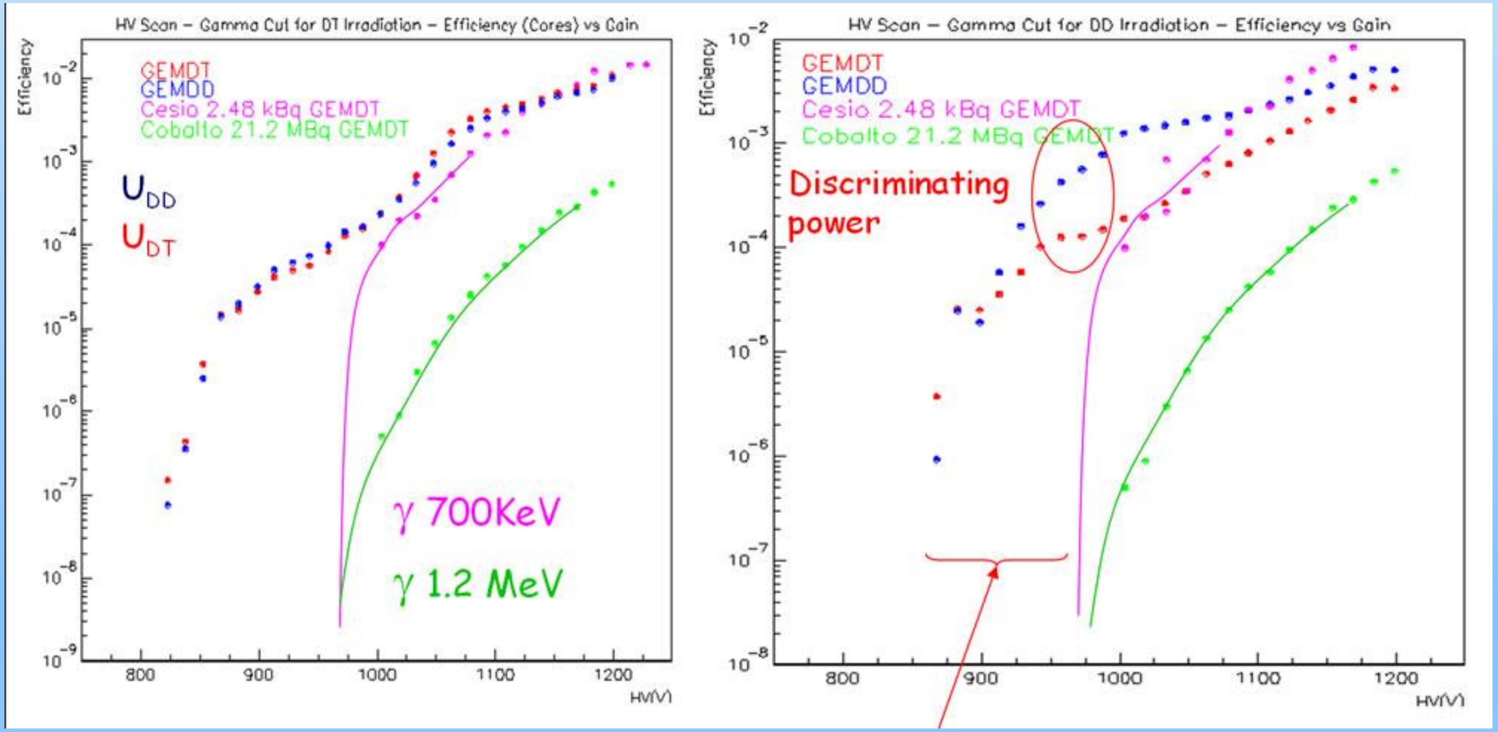
The efficiency has been measured comparing the rate of GEM monitor with a NE213 scintillator placed at few meters from the target.



B. Esposito et Al, "Design of a GEM-based detector for the measurement of fast neutrons", NIM A, 617 (2010), 155 - 157

Previous measurements with a nGEM detector prototype for fusion application (3)

The active area of this monitor has been divided into two parts with the neutron converter optimized for the two energies 2.4 and 14 MeV: the efficiency measurements (see the figure below) shows not only a zone at low gain with no photons contamination but also a good discrimination between the two types of neutrons.

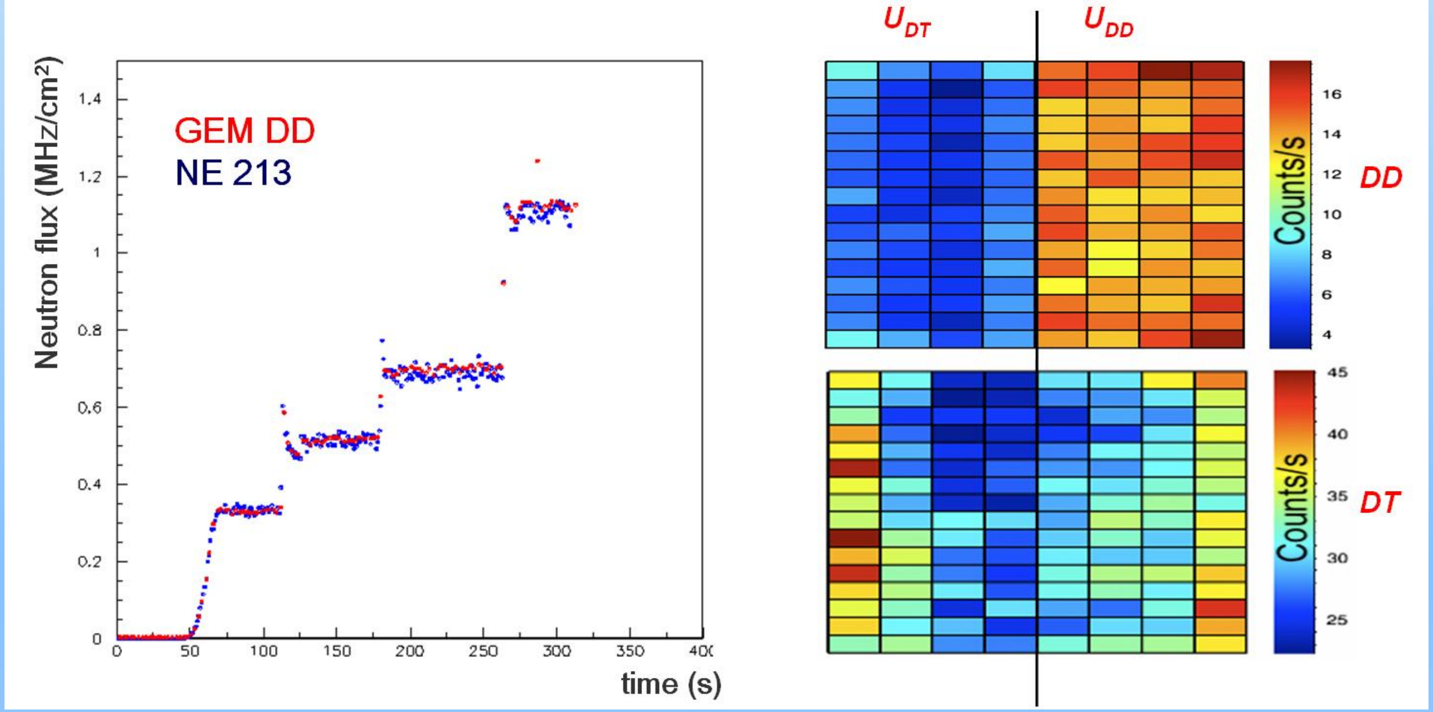


B. Esposito et Al, "Design of a GEM-based detector for the measurement of fast neutrons", NIM A, 617 (2010), 155 - 157

Gain Region in which the nGEM is able to fully discriminate between neutrons and gammas

Previous measurements with a nGEM detector prototype for fusion application (4)

Thanks to 128 pads (organized in 16 rows) the chamber is able to measure both the 14 MeV and 2Mev neutron.
The total counting rate has been compared with the measurement done with a liquid scintillator NE213 detector, placed 10 m far from the neutron source: as shown in the figure on the left : a good linearity up to the maximum flux for FNG (12MHz/cm^2) has been obtained.



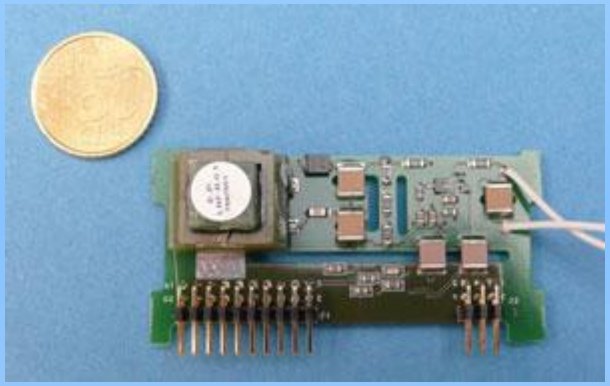
DD neutrons

DT neutrons

B. Esposito et Al, "Design of a GEM-based detector for the measurement of fast neutrons", NIM A, 617 (2010), 155 - 157

Counting rate of the left (DD sensitive) and right (DT) parts of the detector

New HV GEM module



New device for triple GEM power supply.

Compared with the previous version, each channel now has a high sensitivity current meter able to detect the GEM discharge.

Main characteristics :

-Standard NIM two units.

-USB & CAN-OPEN protocol communication interface.

- 7 independent channels full isolation at 5kV vs. GND:
  + 6 channels from 0 to 700V max current 150μA
  + 1 channel from 0 to 1400V max current 100μA

-Current protection programmable for all channels (single value).

- 7 current readouts for each channel :
  + low range : from 10nA to 6μA
  + high range: from 100nA to 40μA

5 Modules already produced and delivered:
2 INFN Roma, 2 INFN Cagliari, 1 INFN Frascati CMS

For any other detailed information please contact
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Conclusions

- A test beam with gammas (high gain on nGEMs) is ongoing in Frascati
- Next neutron test beam in November 2010
- Proposal (T3.22/d1) already presented to RFX concerning the use of nGEM detectors in spider
  - They fulfil the requirements in term of space and time resolution
  - They are cheap and can instrument large areas with respect to other proposed solutions (Diamond detectors)
- Building and test of a 10x10 chamber equipped with the new kind of n/p converter cathode → Efficiency measurements at FNG in Frascati (Early 2011)
- Simulation of the new type of converter chatode (Early 2011)
- First final dimension prototype → Late 2011
- 16 nGEM detectors should be produced in order to equip all the beam dump, total area of about 1.5 m^2 → 2012
- The final detector will be HV powered using the new HV GEM module
- Proposal for R&D on new counting chips to be developed → we are open to everybody that is interested in joining efforts!!

New electronics for GEM detectors

It should be a counting device similar to Medipix but with a channel density of about 1ch/mm^2 :

- Optimized for GEM detector (generally from silicon detector or wire chambers)
- Sensitivity between 5 fC up to 2 pC
- Time gate between 1 μs and 10 sec (internal or external)
- Preamp, Discrimination and counting
- Double threshold for energy measurements
- Matrix structure for low assembling cost
- input channel bound bonding or pins
- output channels wire bonding on the same chip side
- First stage of the project : 16-25 channels in a 16x16 mm^2
- Second stage of the project : 256 channels in a 16x16 mm^2