Gas Detectors for Neutron Scattering Science

Lecture #1 (today) : Basic principles

Lecture #2 (tomorrow) : detector development for ILL and ESS

Eurizon Detector School 2023 - Wuppertal Bruno Guérard

Gas Detectors for Neutron Scattering Science

Lecture #1: Basic principles

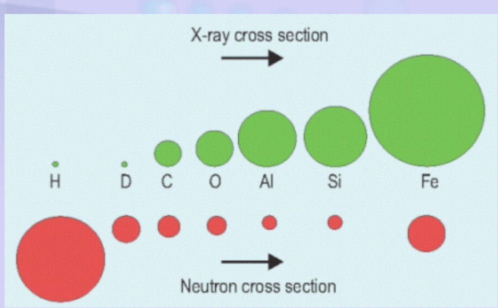
- Why are neutrons a unique probe for material studies ?
- Neutron sources: reactors and spallation
- Presentation of the ILL
- How do we detect neutrons ?
- Principle of ^{3}He detectors
- Detection parameters :
  - Neutron detection efficiency and background noise
  - Spatial resolution
  - Counting rate
  - …
- Examples of Applications: MWPCs, PSDs, and MSGCs

Lecture #2: Detector development for ILL and ESS

- ^{3}He: Trench-MWPC, MultiTube
- ^{10}B : MultiGrid, MultiBlade, Jalousie

Why are we using neutrons ?

Only thermal neutrons are relevant for Neutron Scattering Science



- **Energy similar to elementary excitation in solids**
- **Wavelength (1.8 Å) similar to inter-atomic distances**

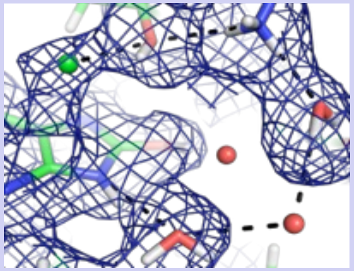
→ Simultaneous information on structure and dynamics of materials

- **Randomly sensitive to isotopes**

→ particularly sensitive to hydrogen atoms which are almost invisible to X-rays

Essential for studying Hydrogen-storage matrials, and organic molecular material

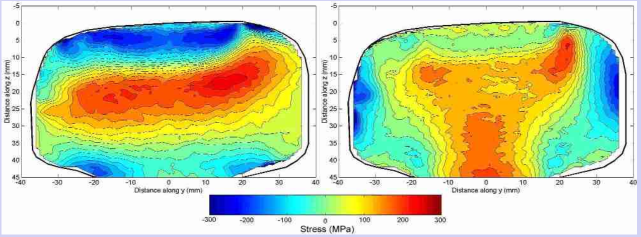
H sites in proteins



- **Interaction with most materials is weak**

→ sample can be stored in all sort of materials for studies in extreme conditions of pressure, temperature, or magnetic field

→ 3D mapping os stresses deep inside sample



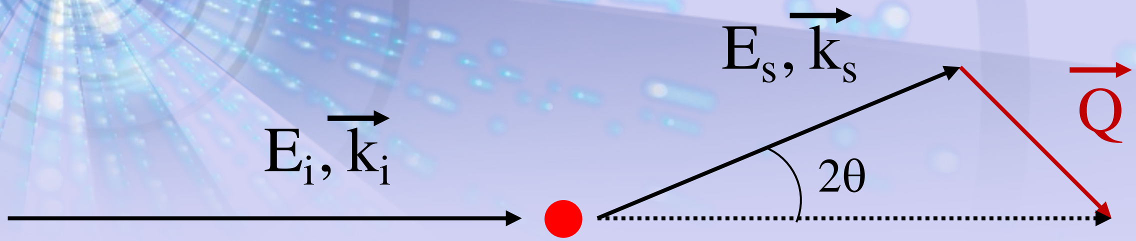
Observation of cracks in rails by residiual stress measurement

- **They possess a magnetic dipole moment**

→ They can probe magnetic structures

https://pan-learning.org/wiki/index.php/Introduction_to_neutron_scattering

Basic kinematics



$$p = \frac{h}{\lambda} = \hbar * k$$

Planck's constant $h = 6{,}63 \times 10^{-34}$ J s

Momentum transfer

$$\hbar\vec{Q} = \hbar(\vec{k}_s - \vec{k}_i)$$

Energy transfer

$$\hbar\,\omega = (E_s - E_i) = \hbar^2\,(k_s^2 - k_i^2) / (2m_n)$$

A scattering event is characterized by (Q,ω)

Elastic scattering (diffraction): $E_s = E_i$ → information on where the atoms are

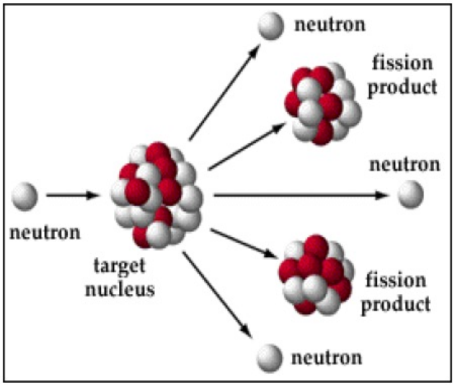
Inelastic scattering (spectroscopy): $E_s \neq E_i$ → information on how the atoms move

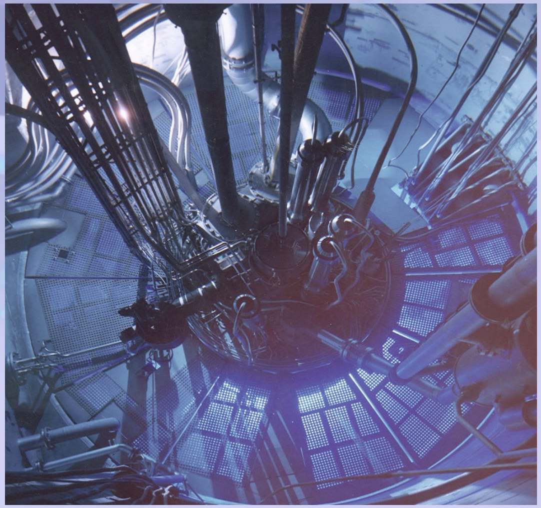
Neutrons are a unique probe of 'where atoms are and what atoms do'

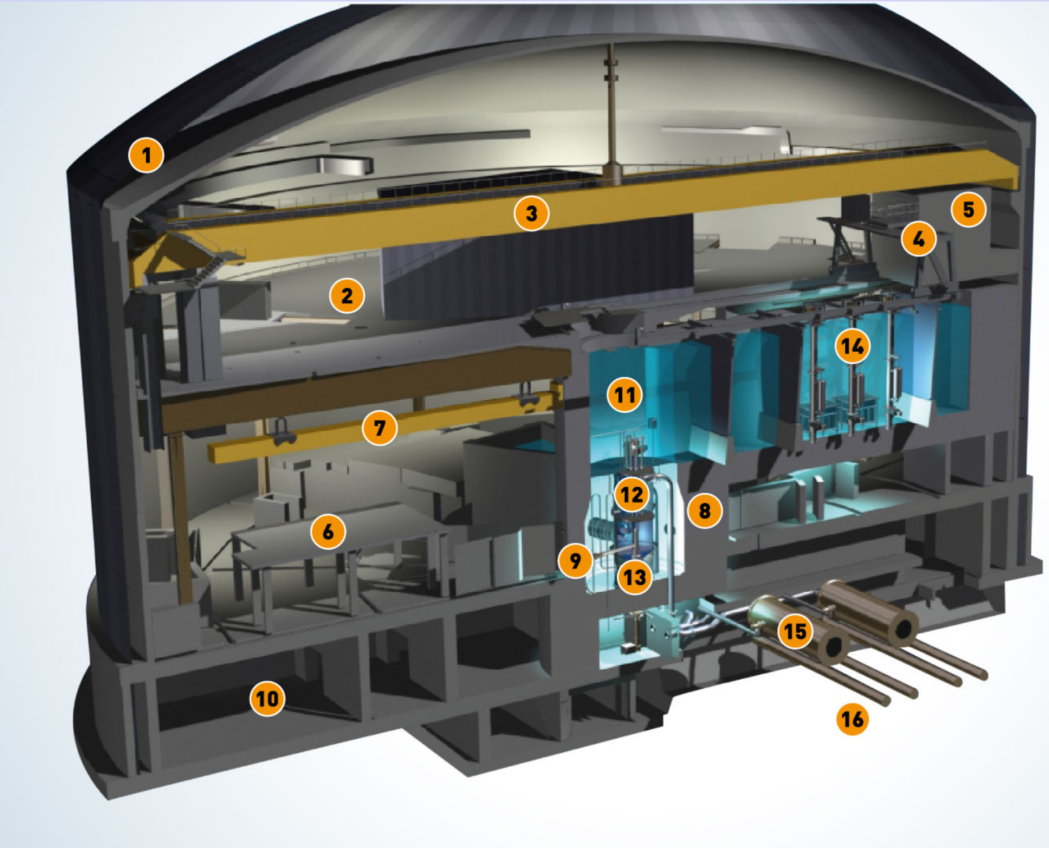
Neutron sources: 1/ Nuclear reactor

NEUTRONS
FOR SCIENCE ®

ILL
54 MW
Fuel cycle: 50 days
93% ^{235}U enriched fuel element
Flux = 1.2 x 10^{15} n/cm^2.s

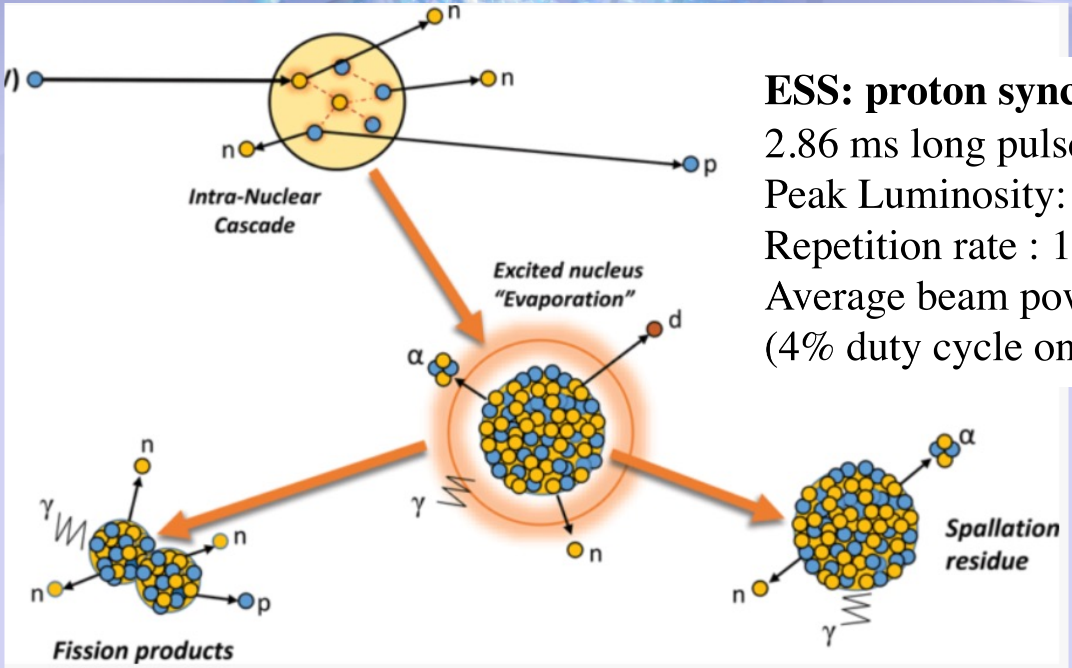






DOUBLE-WALLED REACTOR BUILDING ①
LEVEL D - REACTOR HALL ②
CRANE FOR REACTOR OERATIONS LEVEL D ③
GANTRY FOR HANDLING OF FUEL ELEMENTS ④
HOT CELL ⑤
LEVEL C - EXPERIMENTAL HALL ⑥
CRANE FOR EXPERIMENTAL OPERATIONS ⑦
BIOLOGICAL SHIELDING (CONCRETE) ⑧
COLLIMATED NEUTRON EXIT POINT ⑨
LEVEL B - REACTOR AUXILLARY EQUIPMENT ⑩
REACTOR POOL (LIGHT WATER) ⑪
HEAVY WATER (MODERATOR & FUEL ELEMENT COOLING) ⑫
FUEL ELEMENT ⑬
SPENT FUEL ELEMENTS STORAGE ⑭
HEAT EXHANGERS (PRIMARY/SECONDARY) ⑮
SECONDARY COOLING CIRCUIT 'DRAC RIVER) ⑯

Neutron sources: 2/ Spallation (ex:ESS)

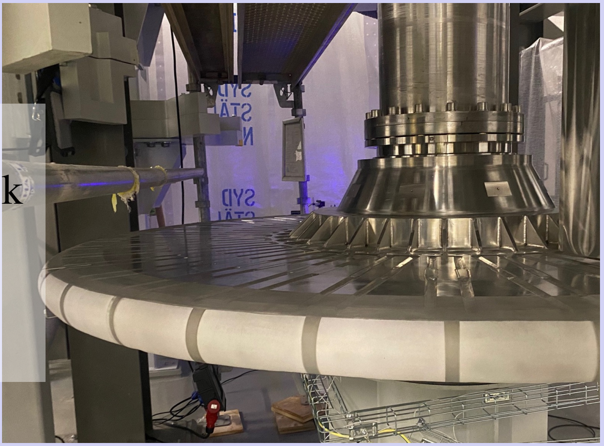


ESS: proton synchrotron
2.86 ms long pulse at 2 GeV
Peak Luminosity: 62,5 mA
Repetition rate : 14 Hz
Average beam power: 5 MW
(4% duty cycle on target)

Construction of the ESS
(recent photo)

At full power, ESS will be 100 times brighter than other existing spallation sources

ESS target
2.6 m diam. stainless steel disk containing tungsten bricks
Rotation speed: 23 RPM
Cooling: He gas



Status: first beam on target expected in 2025 / power reduced to 2 MW

The intensity of neutron beams is 10 orders of magnitude weaker than the intensity of X-Ray beams in synchrotron radiation facilities

→ **maximizing Signal/Noise is a prerequisite in neutron scattering instrumentation**

High signal →

- Detection efficiency must be high (> 50% for thermal neutrons)
- Material sample must have a sufficient volume (several mm^3) to produce enough measurement statistics in a reasonable time.

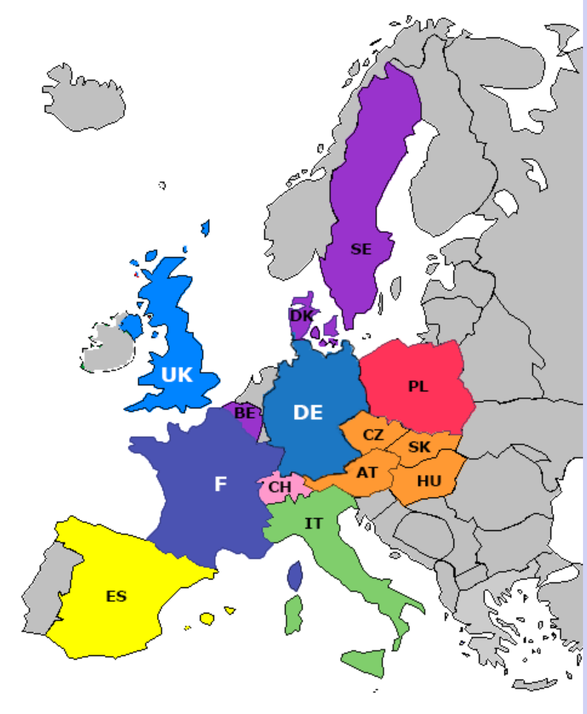
Low noise →

The detector should count a minimum of background events

- unwanted thermal neutrons (scattered from the different parts of the instrument, including the detector)
- fast neutrons
- gamma rays
- cosmic rays
- electronic noise

ILL

A neutron source operating 200 days/year (since 1971 !)
58.3 MW reactor
Fuel cycle: 50 days



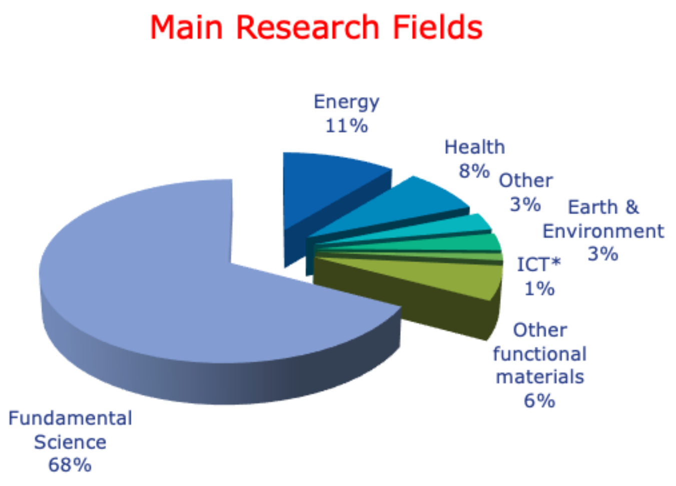
850 experiments/year

2000 users

38 countries

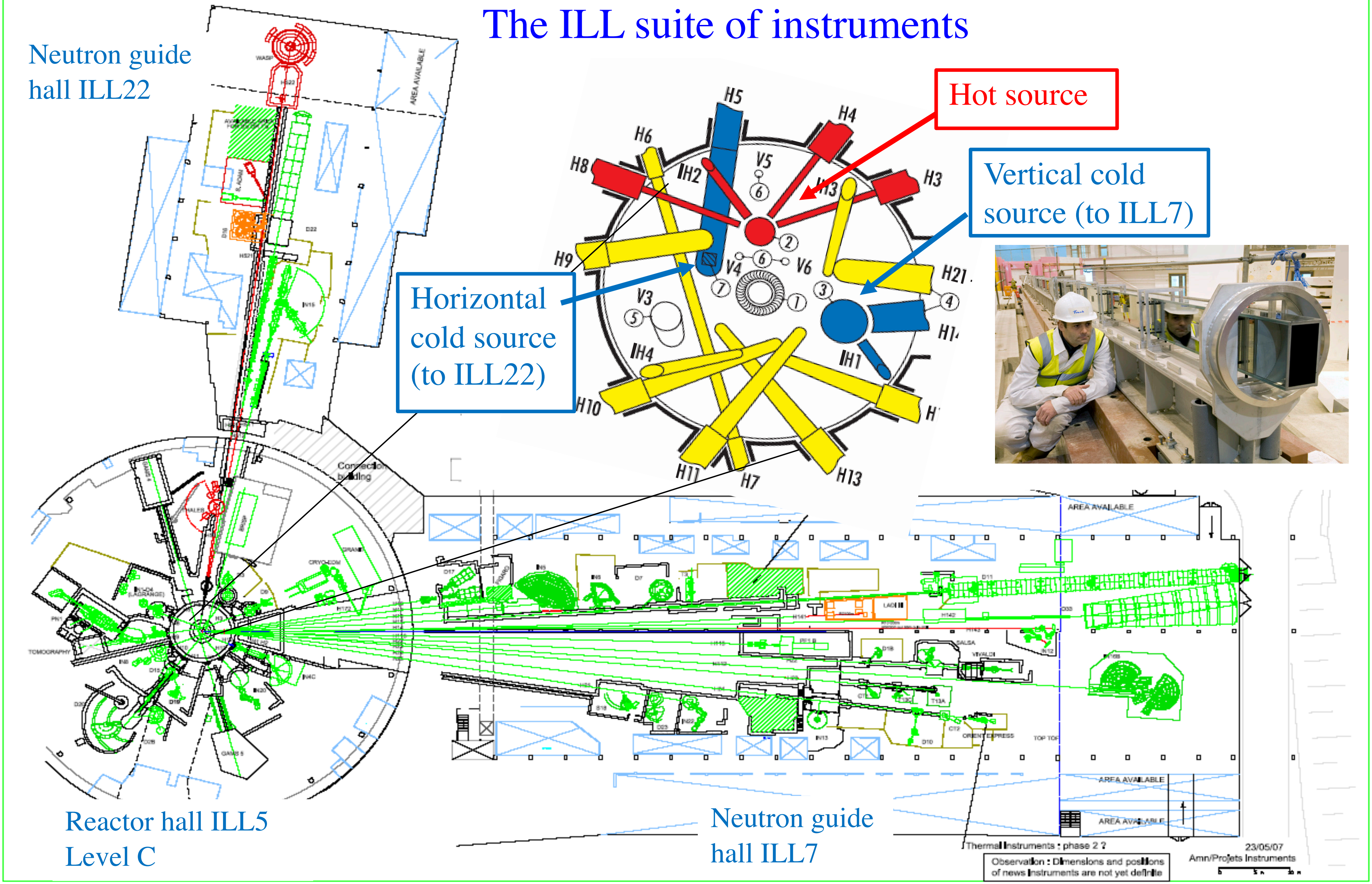
28 instruments + 10 CRG

650 publications/year



- Condensed matter physics
- Material science
- Chemistry
- Biology
- Nuclear and Particle physics

The ILL suite of instruments



Neutron guide hall ILL22

Hot source

Vertical cold source (to ILL7)

Horizontal cold source (to ILL22)

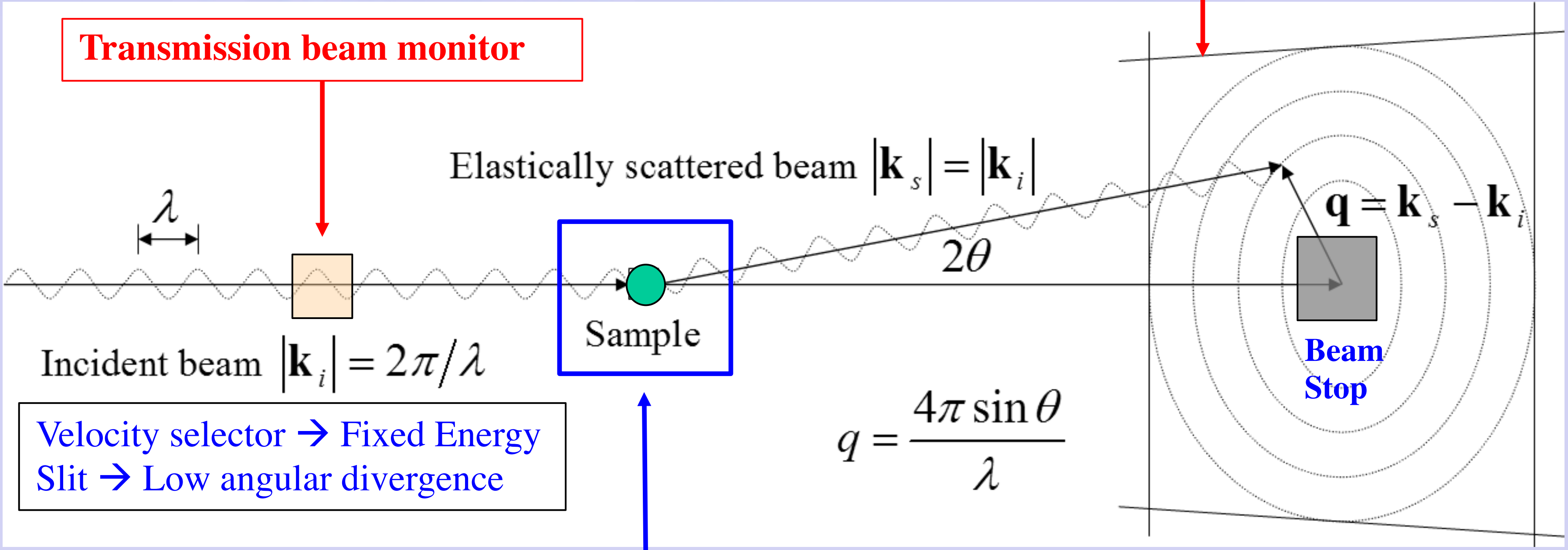
Reactor hall ILL5 Level C

Neutron guide hall ILL7

Example: SANS (Small Angle Neutron Scattering) instrument

Detector

- 2D localisation
- High counting rate
- High detection efficiency
- Gamma discrimination



$$q = \frac{4\pi \sin\theta}{\lambda}$$

Transmission beam monitor

Velocity selector → Fixed Energy
Slit → Low angular divergence

Sample environment

Low or high T° , Magnetic field, high Pressure, …etc
minimum neutron absorption and scattering

How to detect thermal neutrons ?

The kinetic energy of slow neutrons (relevant to materials science) is of the order of a few meV (not MeV !) → the (n,p) elastic scattering reaction is not applicable.

The best option to detect thermal neutrons is to use a **neutron convertor** that generates ionizing particles after the capture of a neutron.

These ionizing particles will produce …..
free electrons and ions, as well as photons

Gas detectors

- A pressure vessel containing some gas
- Electrodes for charge multiplication, and for neutron localization

Scintillator detectors

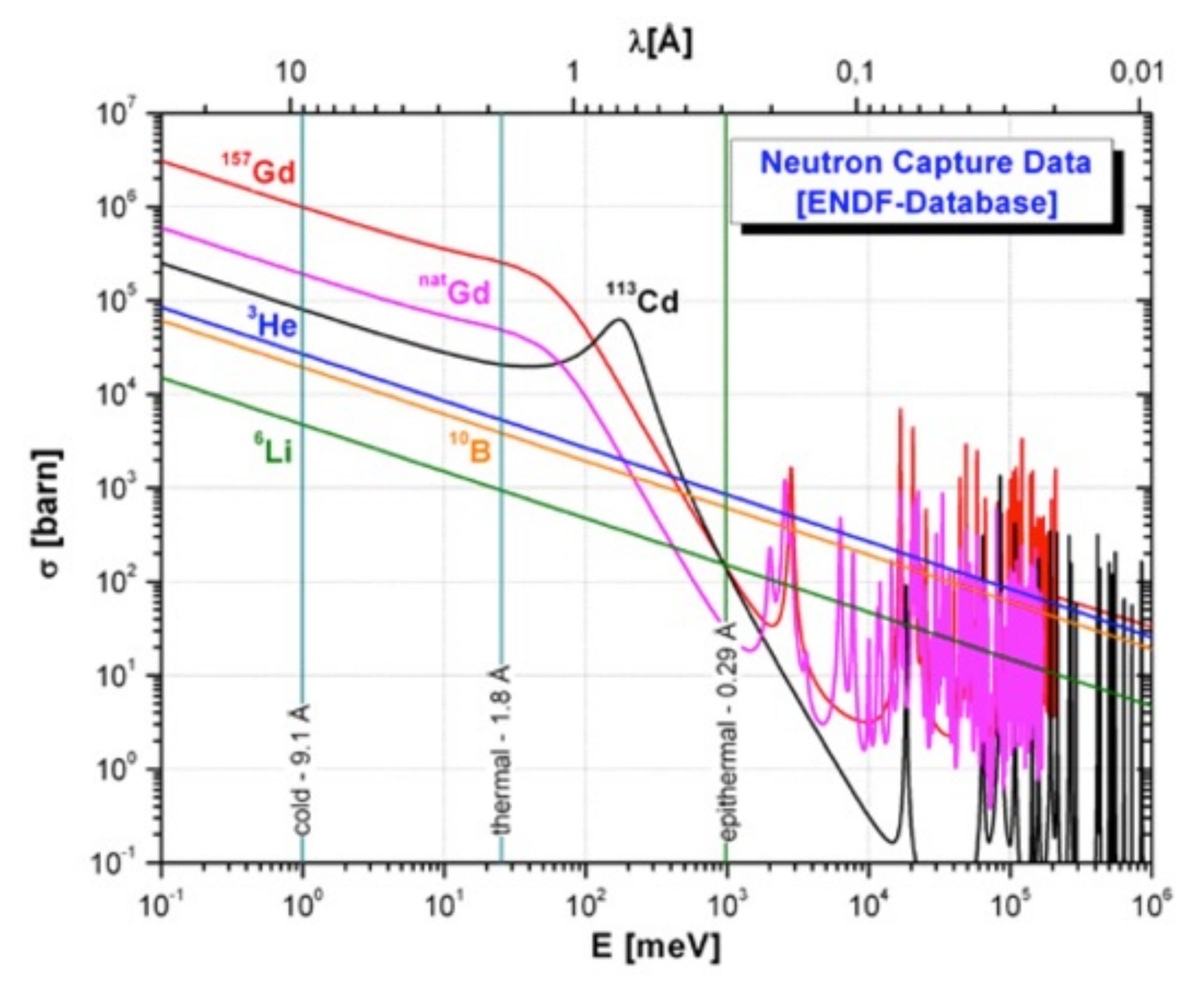
- A scintillator, optically coupled to a photon detector (Photo-Multiplier Tube, CCD, CMOS, Si-PM)
- The scintillator and the photon detector are coupled directly, or by optical devices like lenses, and fibers

Scintillator detectors are popular in several neutron institutes like ISIS in the UK
Gas detectors equip a vast majority of the instruments of the ILL
Most of the detectors planed for ESS will be based on gas detectors

Main convertor materials used in neutron detectors

	σ_a	Nat. isotopic fraction	Convertor / Detector type
$n + {}^{10}B \rightarrow {}^{7}Li + \alpha$ (2.78 MeV) 6% $\rightarrow {}^{7}Li^{*} + \alpha$ (2.31 MeV) 94% $\rightarrow {}^{7}Li + \gamma$ (0.48 MeV)	3840 barn	${}^{10}B$: 19.8%	${}^{10}B$ thin films in gas proportional counters
$n + {}^{3}He \rightarrow {}^{3}H + p$ (0.764 MeV)	5330 barn		${}^{3}He$ gas in gas proportional counters
$n + {}^{6}Li \rightarrow {}^{3}H + \alpha$ (4.78 MeV)	698 barn	${}^{6}Li$: 7.6%	${}^{6}LiF$ glass scintillators coupled to Photon counting devices
$n + {}^{14}N \rightarrow {}^{14}C + p$ (0.626 MeV)	1.8 barn		${}^{14}N$ gas in gas proportional counters
$n + {}^{235}U \rightarrow xn +$ fiss. frag. (~160 MeV) (average number of n produced ~ 2.5)	937 barn		${}^{235}U$ thin films in fission chambers
${}^{155}Gd + n \rightarrow {}^{156}Gd^{*}$ (8.54 MeV) $\rightarrow {}^{156}Gd + \gamma$'s + ce's ${}^{157}Gd + n \rightarrow {}^{158}Gd^{*}$ (7.94 MeV) $\rightarrow {}^{158}Gd + \gamma$'s + ce's	65 000 barn 255 000 barn	${}^{157}Gd$: 15,7%	Gd_2O_3 in photo-stimulable screens (image plate)

0.6 Internal Conversion Electron per neutron / Energy: 29-249 keV



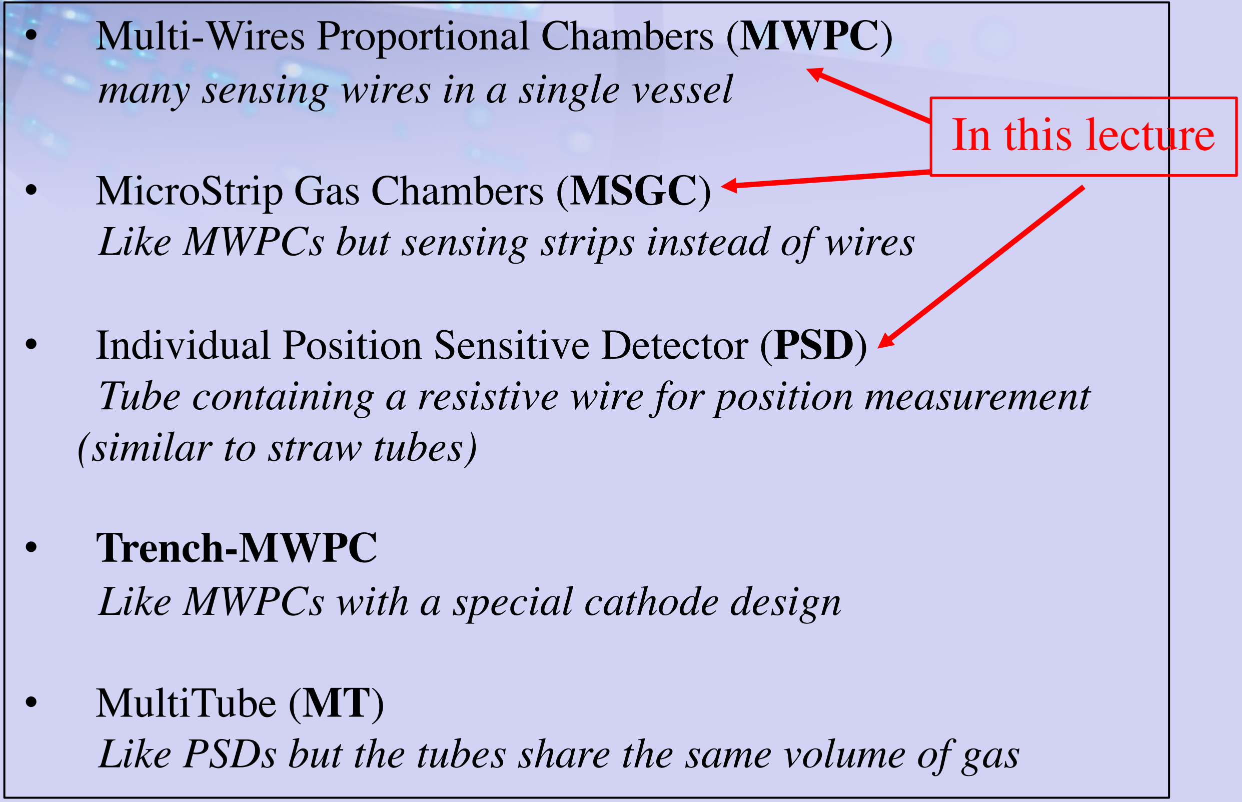
Capture cross-section versus Energy

For thermal neutrons, σ_c decreases with the Energy

Main gas detectors in operation or in advanced development

Neutron convertor: ^{3}He gas
Gas: ^{3}He-Ar-CO_2
Sealed pressure vessel.

Gas purity is provided by a
closed loop filtering system, or
by using low-outgasing materials.



In this lecture

- Multi-Wires Proportional Chambers (**MWPC**)
  many sensing wires in a single vessel
- MicroStrip Gas Chambers (**MSGC**)
  Like MWPCs but sensing strips instead of wires
- Individual Position Sensitive Detector (**PSD**)
  Tube containing a resistive wire for position measurement (similar to straw tubes)
- **Trench-MWPC**
  Like MWPCs with a special cathode design
- MultiTube (**MT**)
  Like PSDs but the tubes share the same volume of gas

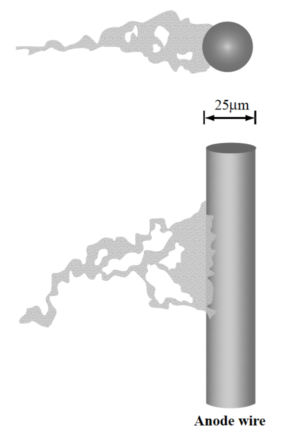
Neutron convertor: ^{10}B thin films
Gas: Ar-CO_2 (continuous flushing)

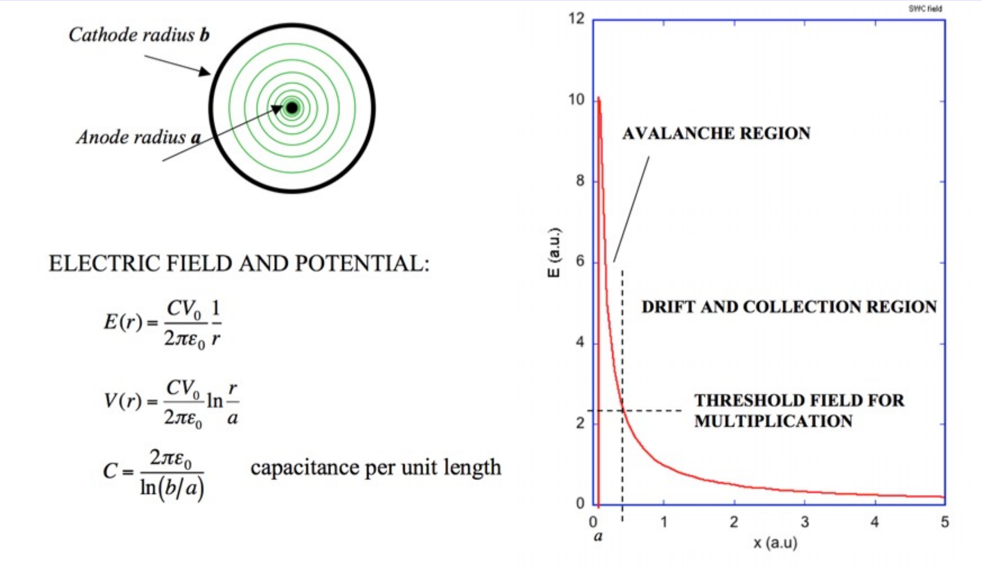
- MultiGrid (**MG**)
  ^{10}B films are oriented perpendicular to the neutron trajectory
- MultiBlade (**MB**) and **Jalousie** detector
  ^{10}B films are oriented at grazing angle

Example: the ^{3}He proportional counter

$^3He + n \rightarrow p + {}^3H$ + 764 KeV
5333 barns @ 1.8 angstroms (25 meV)

The p and the ^{3}H ionize the gas, producing a track of electrons and ions.
Electrons drift toward the anode wire, and ion toward the cathode (tube)
Stopping gas: Ar (to increase the density of electron-ion pairs along the track)
Quencher: CO_2





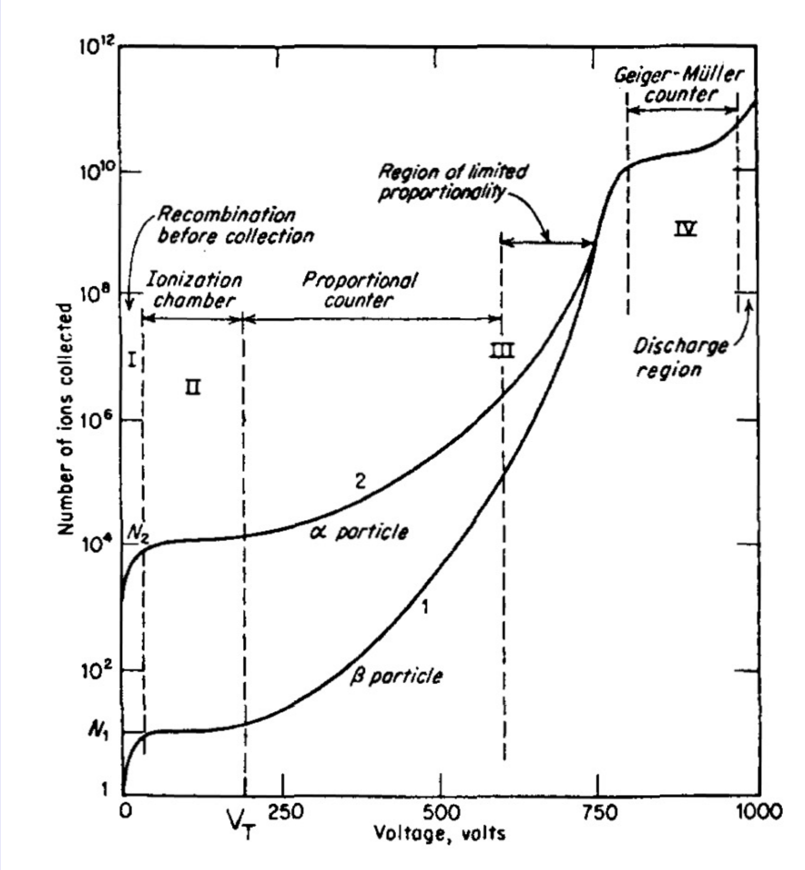
ELECTRIC FIELD AND POTENTIAL:

$$E(r) = \frac{CV_0}{2\pi\varepsilon_0}\frac{1}{r}$$

$$V(r) = \frac{CV_0}{2\pi\varepsilon_0}\ln\frac{r}{a}$$

$$C = \frac{2\pi\varepsilon_0}{\ln(b/a)}$$ capacitance per unit length

Electric Field inside a Proportional counter



The G(V) curve

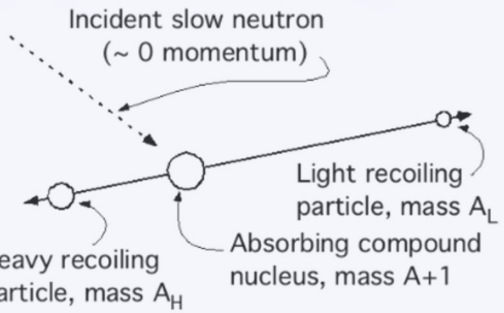
Pulse Height spectrum measured with a ^{3}He proportional counter

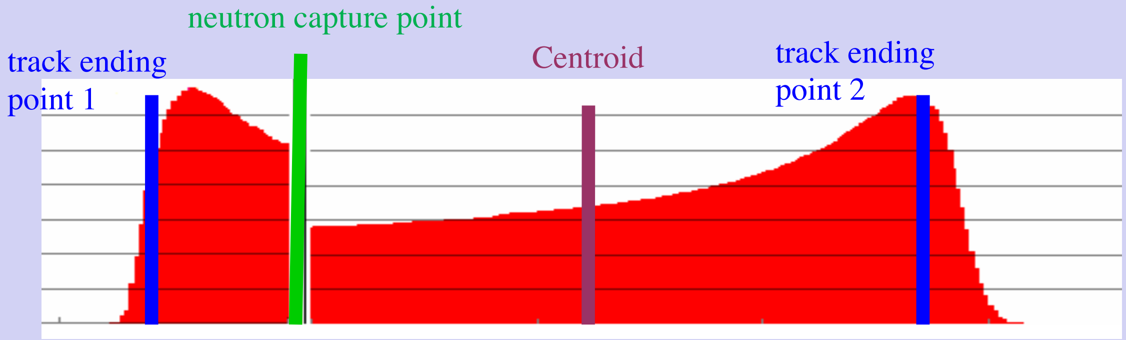
$$E_H = \frac{A_L}{A_H + A_L} Q \; , E_L = \frac{A_H}{A_H + A_L} Q$$

$$n + {}^3He \rightarrow {}^3H + {}^1H$$

$M({}^3H) = 3.0160492$ u

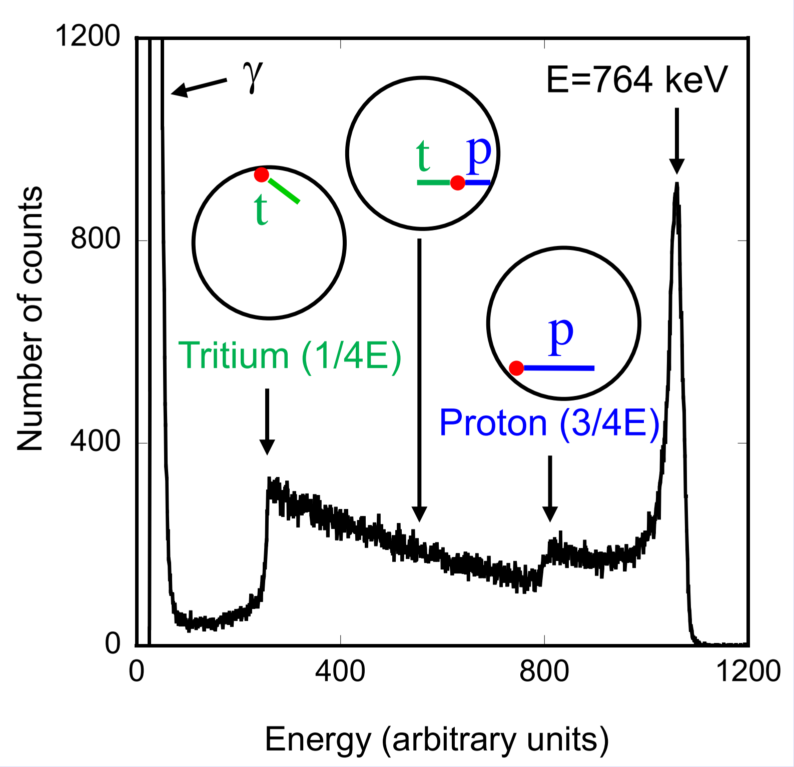
$M({}^1H) = 1{,}0072765$ u





Energy deposition along the ionization track

The COG of the track doesn't correspond to the neutron capture point



Pulse height spectrum measured with an Am-Be neutron source

Excellent gamma/neutron separation by energy discrimination !

Setting the operational HV of the detector

^{3}He detectors are operated in pulse mode: each event is processed individually by front-end electronics

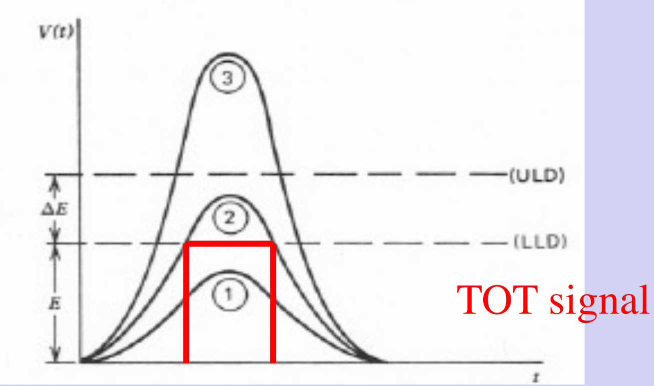
- Pre-amplifiers convert the current signal produced by the detector into a voltage signal.
- Then the signal is shaped to integrate the charge, by using either analog or digital circuits.
- The event is counted if its height is above the discrimination threshold.

This discrimination threshold is usually set at 3 times the peak of the electronics noise

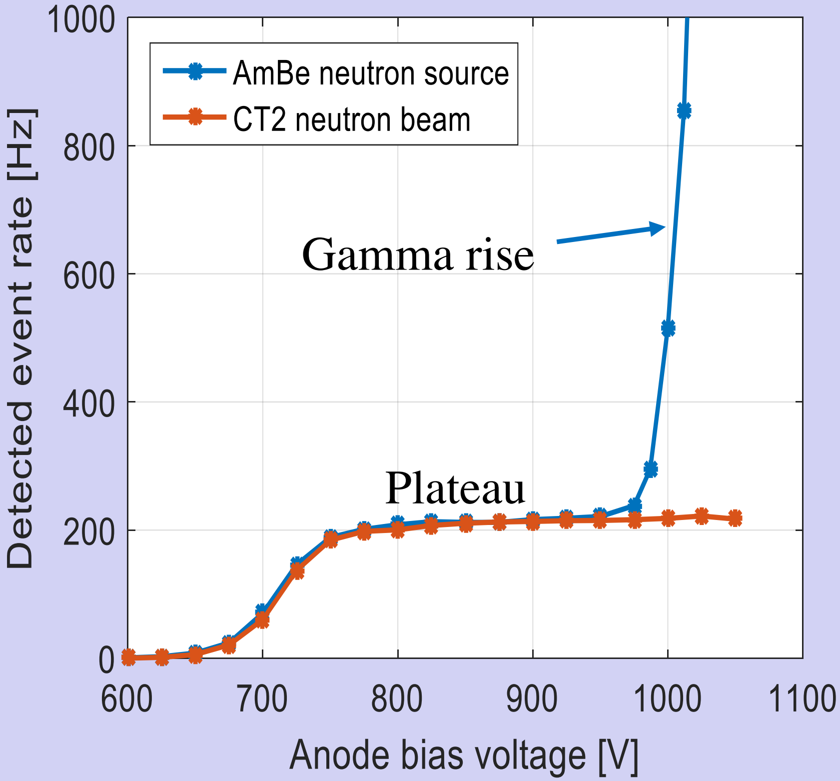
Intrinsic Detection efficiency

$$\varepsilon_i = P_{capture} \times P_{trigger}$$

P_c = probability of a neutron capture
$P_{trigger}$ = Trigger efficiency



Signal discrimination



Detection parameters

Localization 1D or 2D // **resolution** from mm to cm

Sensitive area : from 10 cm^2 to 30 m^2 // **uniform** response

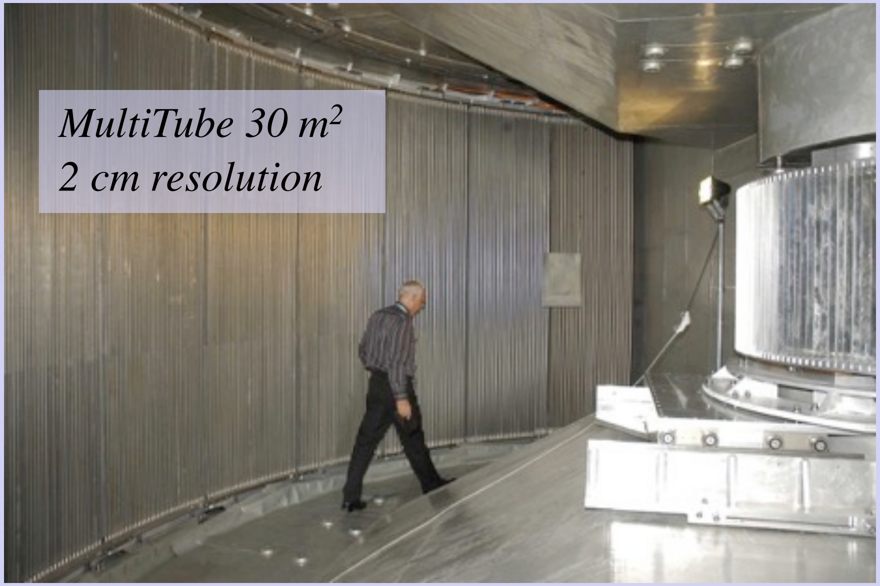
High efficiency for thermal neutrons with minimum sensitivity to background noise (gamma rays and fast neutrons)

Detection efficiency must be **stable** in time (detector lifetime >=10 years)

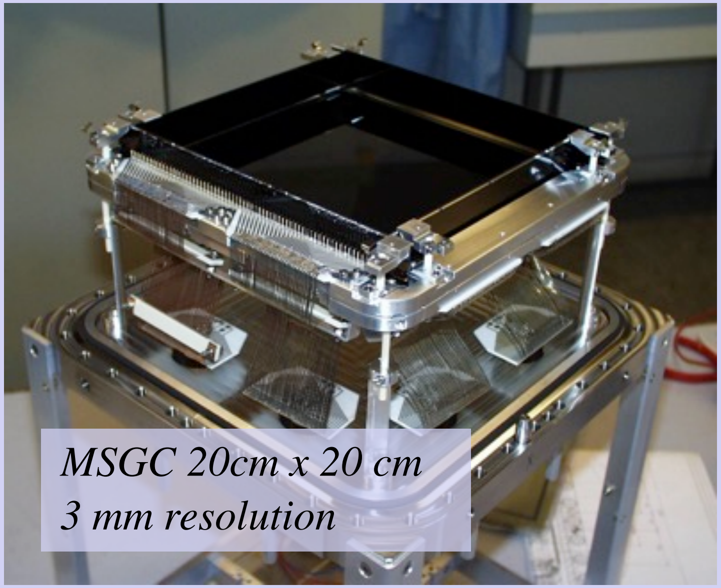
Counting rate: from a few Hz up to several MHz (global) and 10 kHz /pixel

Operation in **vacuum** for some applications

The detector must be optimised for each instrument



MultiTube 30 m^2
2 cm resolution

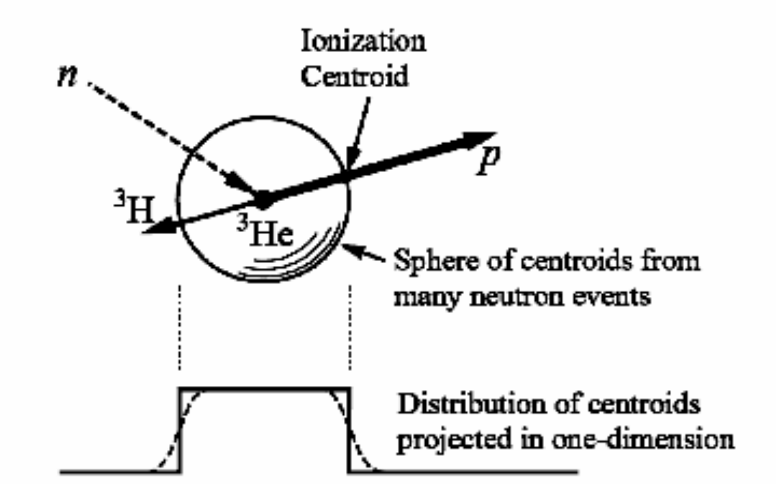


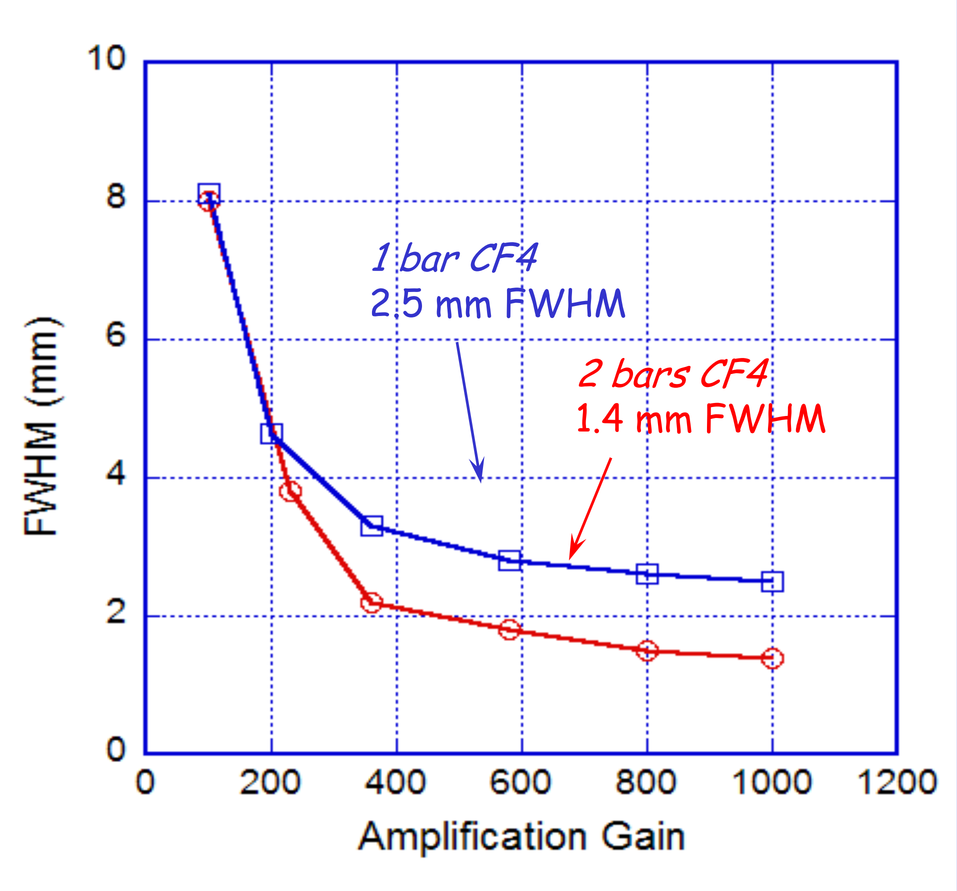
MSGC 20cm x 20 cm
3 mm resolution

^{3}He detectors cover most of the instrumental requirements at ILL
They will be used also at ESS, together with $_{10}$B film detectors

Spatial resolution

The stopping power of ^{3}He being low, an additive gas is required to reduce the length of the ionization tracks
Ex: Ar, CF_4





Position resolution versus amplification gain and stopping gas pressure

Detection efficiency versus ^{3}He pressure

^{3}He gas is the only gas used as neutron convertor

1 cm.bar ^{3}He corresponds a capture probability = 13%

High gas pressure and/or high conversion gap

$$p_c = e^{-\mu_w . l_w} . \left(1 - e^{-\mu_{3He} . l_{3He}}\right)$$

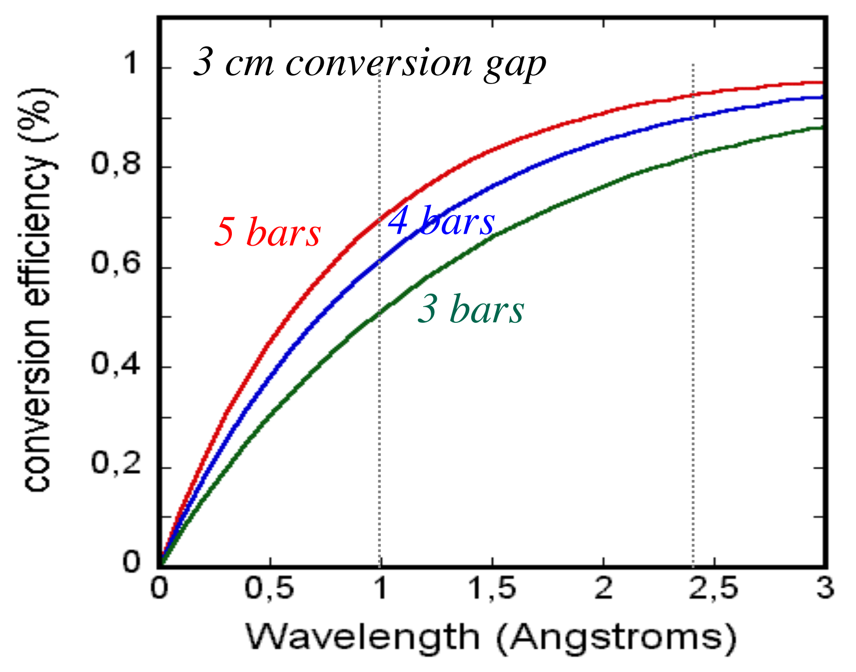
μ_{3He} is the absorption coef of ^{3}He

l_{3He} is the conversion gap

$\mu = \rho . \sigma$

ρ *atomic density*

σ *interaction cross-section*



Neutron capture probability versus ^{3}He pressure

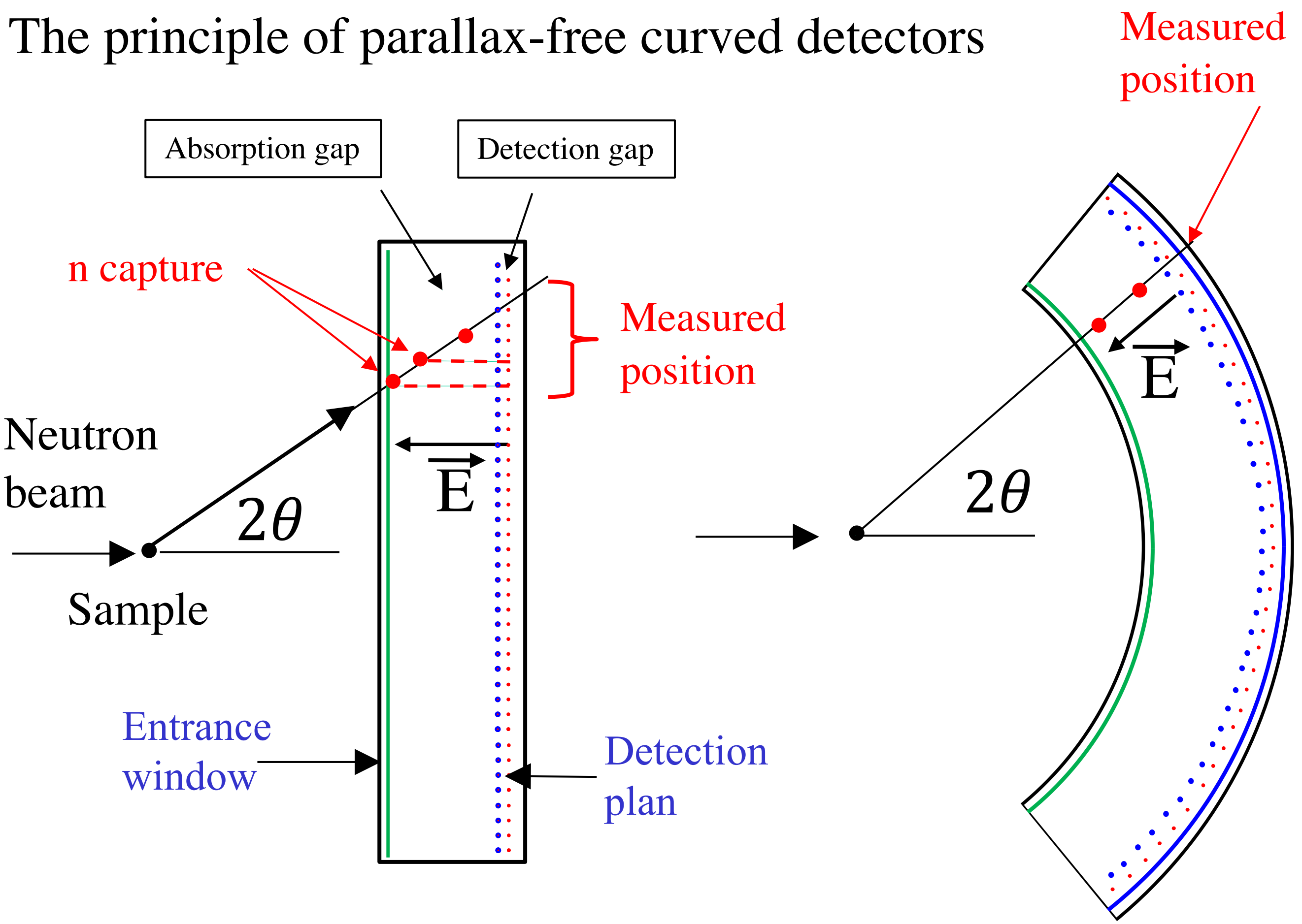
High detection efficiency → High ^{3}He pressure, or large conversion gap

Thick detector window* → neutron absorption + neutron scattering

* concerns detector vessels with flat windows; not tube detectors

- TOF resolution is degraded
- parallax error → spatial resolution is degraded

The principle of parallax-free curved detectors



Planar detector → the measured position depends on the conversion depth

Curved detector → One coordinate is independant from the conversion depth

Banana detectors: A good example of cross-fertilization between scientific instrumentation and medicine

1968: LETI patent

The first banana detector was developed for neutron scattering

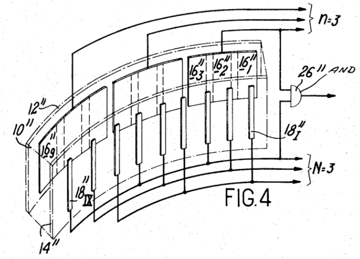
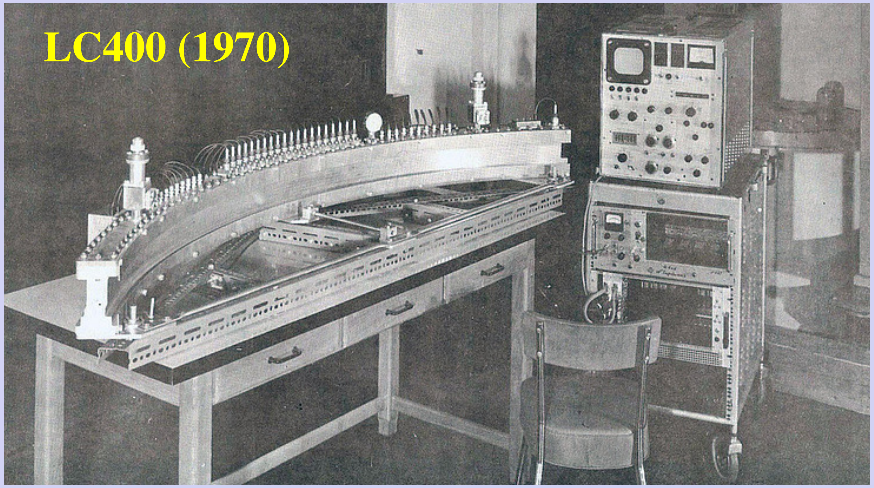


FIG.4

R. Allemand

E. Roudaut

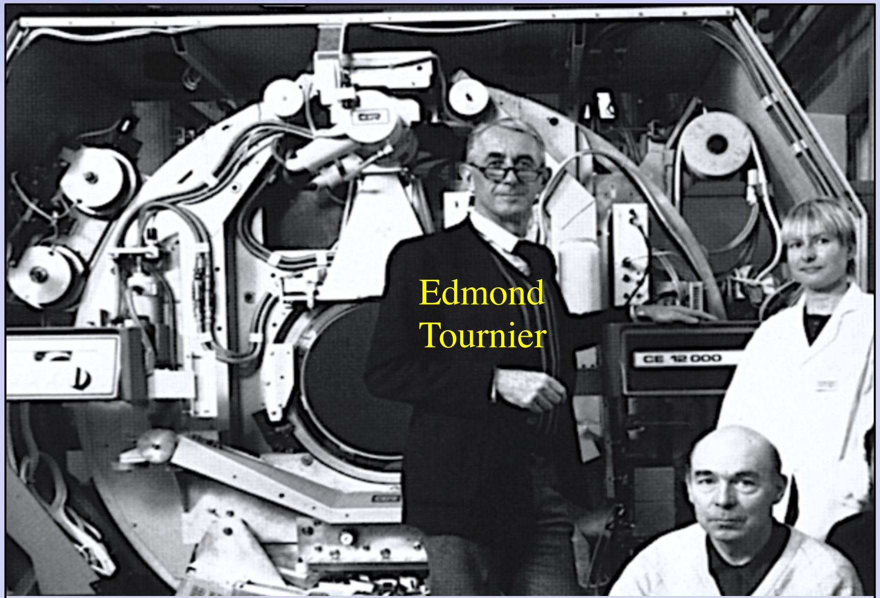


LC400 (1970)

The LC400 (400 channels) developed by LETI is the first curved 1D detector ever built

The **D1B** powder diffractometer was the first instrument of the ILL to use this technique

Gas : BF_3 + no gas amplification



Edmond Tournier

The first ever built full-body X-Ray scanner

- Developed between 1974 and 1976 by LETI-CENG in Grenoble
- The detector, a curved X-Ray MWPC, is an adaptation of the detector developed for D1B at ILL (BF_3 was replaced by Xenon)

Background noise: Neutron scattering in the detector window

Scattering & absorption measured @ 2.5 Å, with a position sensitive counter tube, and a sample of Aluminium (5083), 5 mm thick

Measured beam attenuation = 5,92%
Calculated absorption = 1.72 %
→ scattering = 4.2%

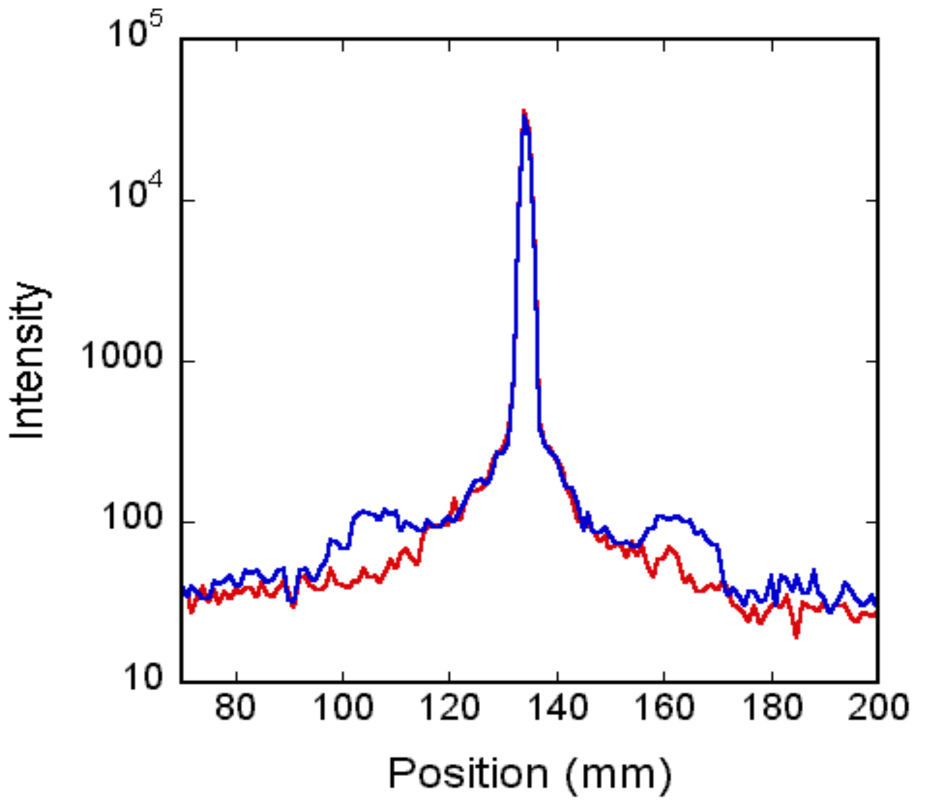
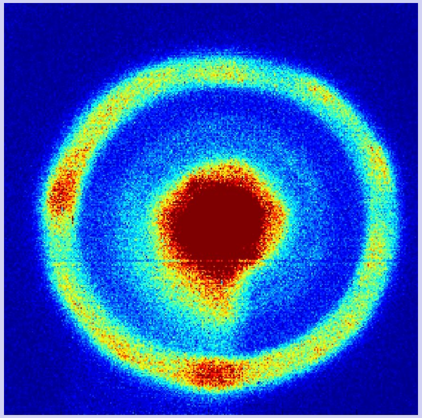


Image obtained with a 10 mm thick Aluminium sample in front of a 2D detector



Counting rate limitation in a ^{3}He proportional counter

2 main origins for counting rate limitation

1/ Electronics : Pile-up of analog signals

2 events must be separated in time to produce distinct signals

The minimum interval of time between 2 events to ensure that they won't overlap is called the **dead time**

The pile-up limitation affects all the volume of a detector cell that corresponds to one readout channel

→ modularity (reduction of the cell volumes) helps increasing the global counting rate, but also high Electric field, fast gases, …

2/ Detector : Space charge effect

The positive ions produced by preceding events create a parasitic electric field opposite to the amplifying Electric field → the amplification gain is reduced

Space charge effect is local; it increases with the neutron flux, and with the amplification gain.

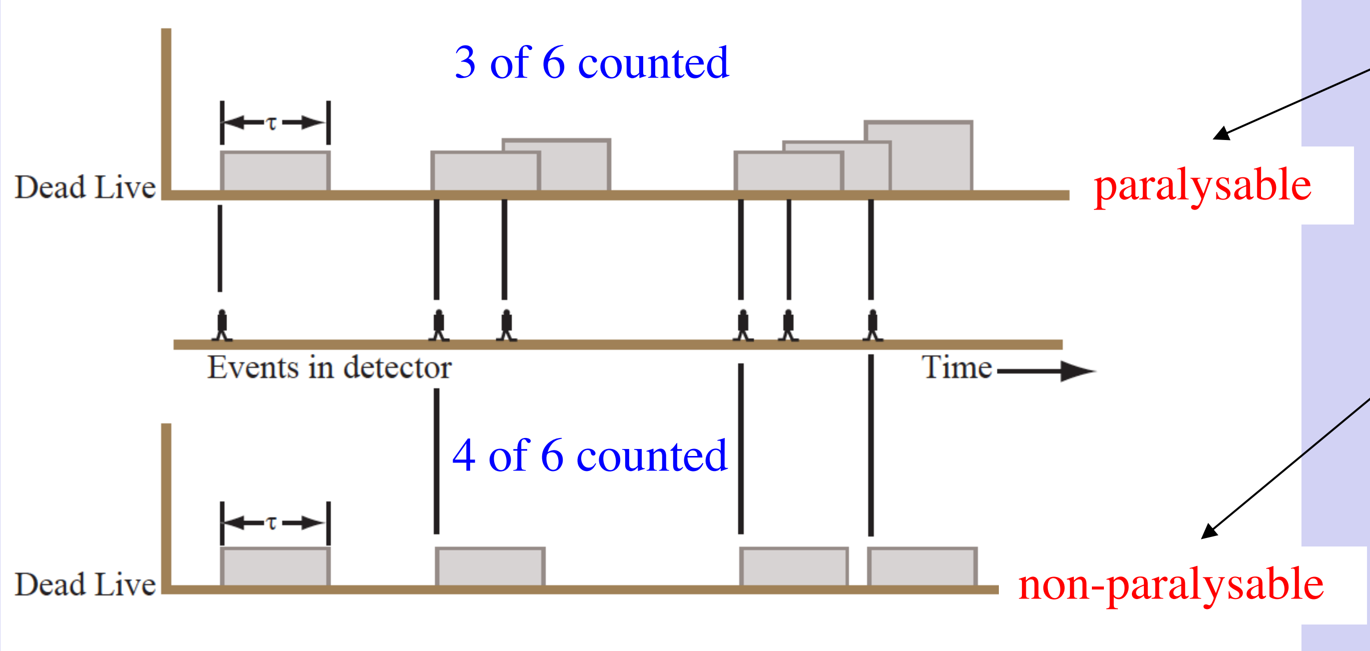
→ Low amplification gain is better, as well as high electric field, fast gases,..

Paralyzable or non paralyzable systems

In a paralyzable system, an interaction that occurs during the dead time after a previous interaction extends the dead time

In a non paralyzable system, it does not

m = counting rate
n = interaction rate
τ = dead time



3 of 6 counted

paralysable

4 of 6 counted

non-paralysable

$m = n.e^{-n.\tau}$

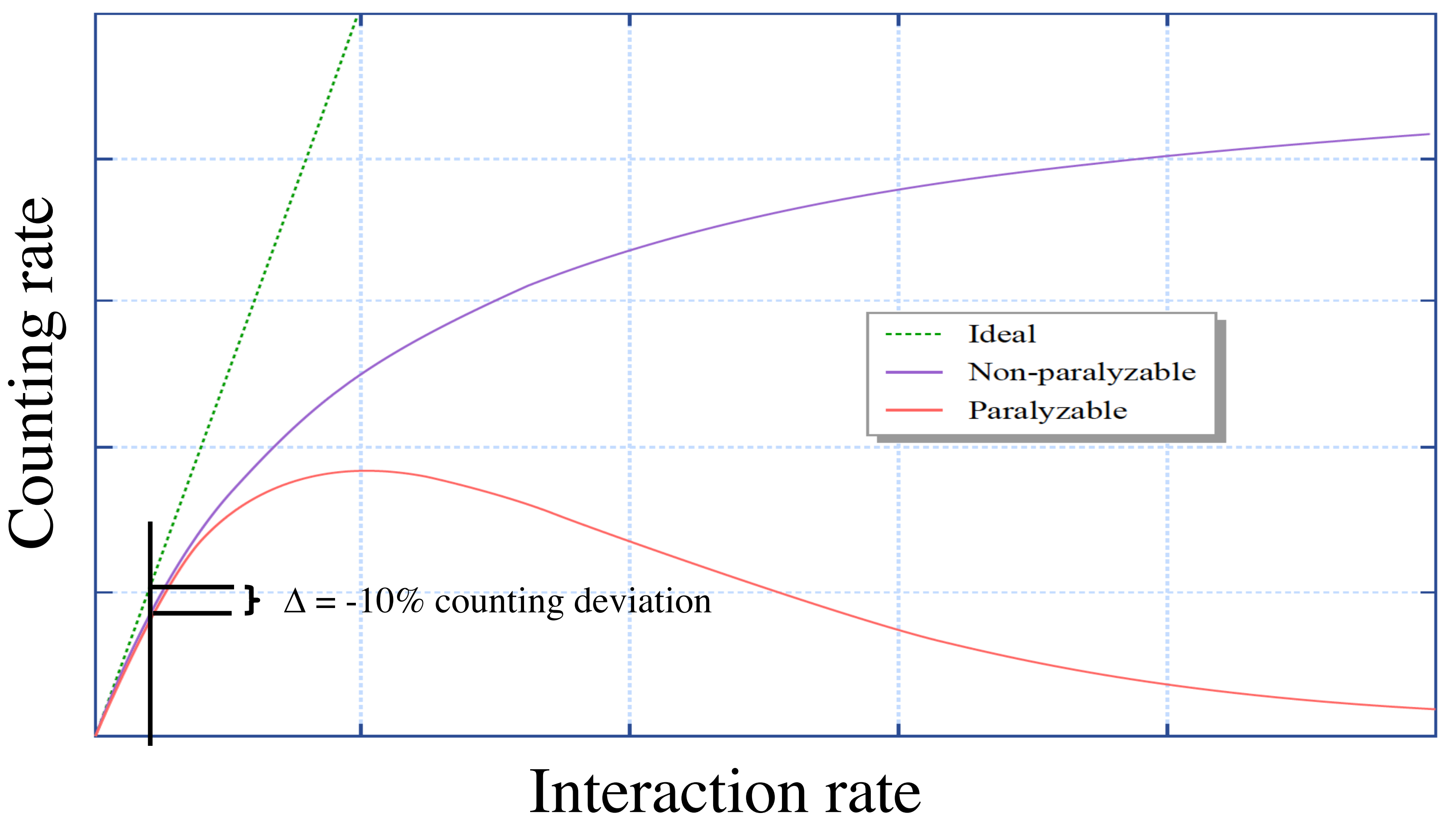
See “radiation Detection and Measurement” (G. Knoll)

Fraction of all the time the detector is dead = $m.\tau$
Rate of lost events = $n.m.\tau$

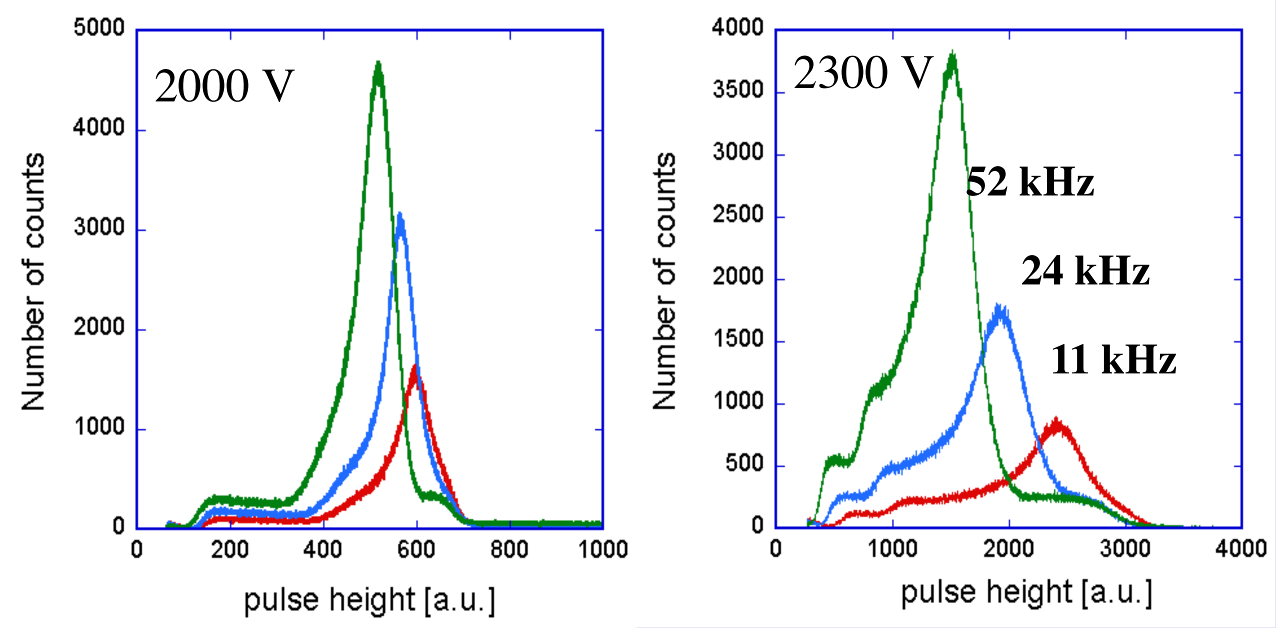
We can also write:
Rate of lost events = $n – m$

→ $n = m / (1 - m.\tau)$

Counting rate versus interaction rate

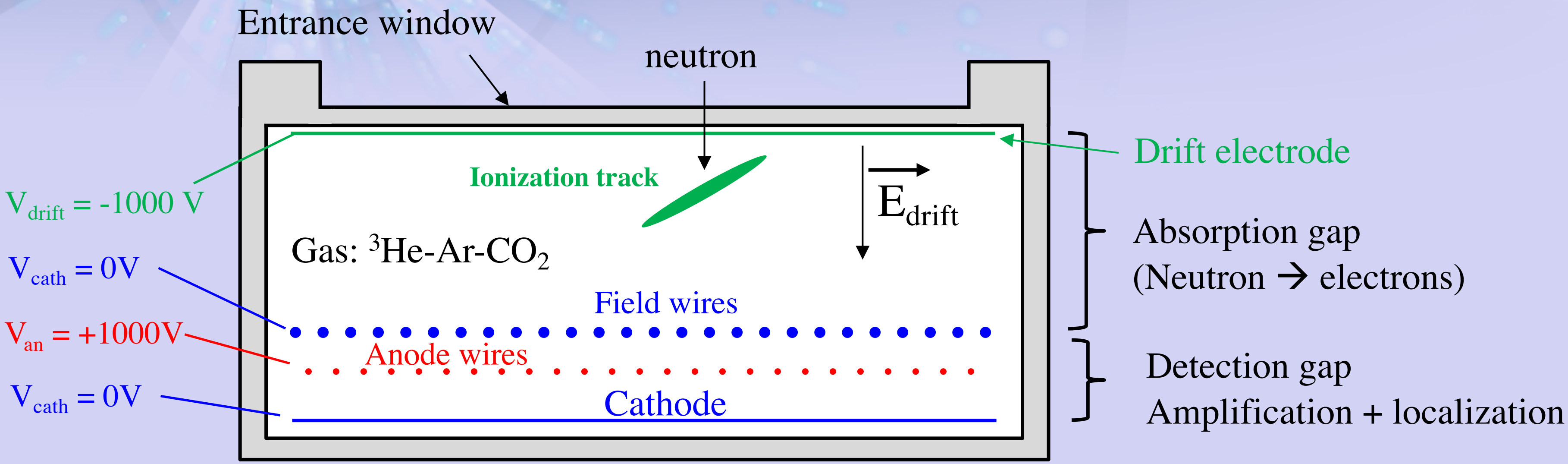


Space charge effect



Variation of the detector response in function of the beam flux for 2 different HV

Principle of MWPCs (Multi Wires Proportional Chamber)

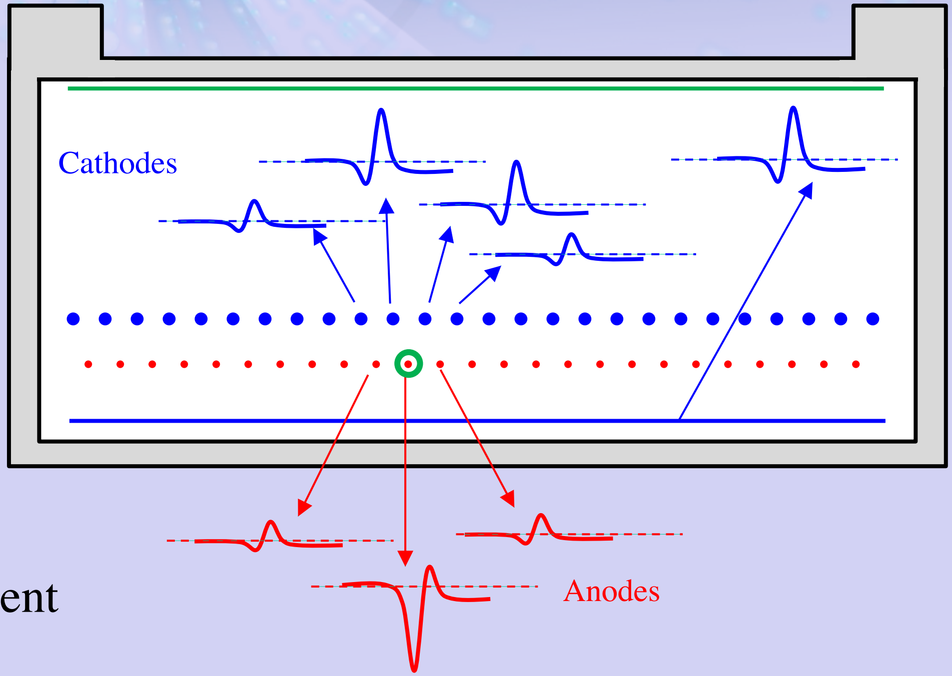


A neutron is captured by an atom of ^{3}He (or ^{10}B)

→ 2 ionizing particles are emitted in opposite directions

→ Electron-ion pairs are created in the gaz along the ionization track

Primary electrons drift along the E_{drift} lines, toward the amplification gap



Event Multiplicity
(average number of active channels per event)

$N_{cathodes} > N_{anodes}$

Signal development

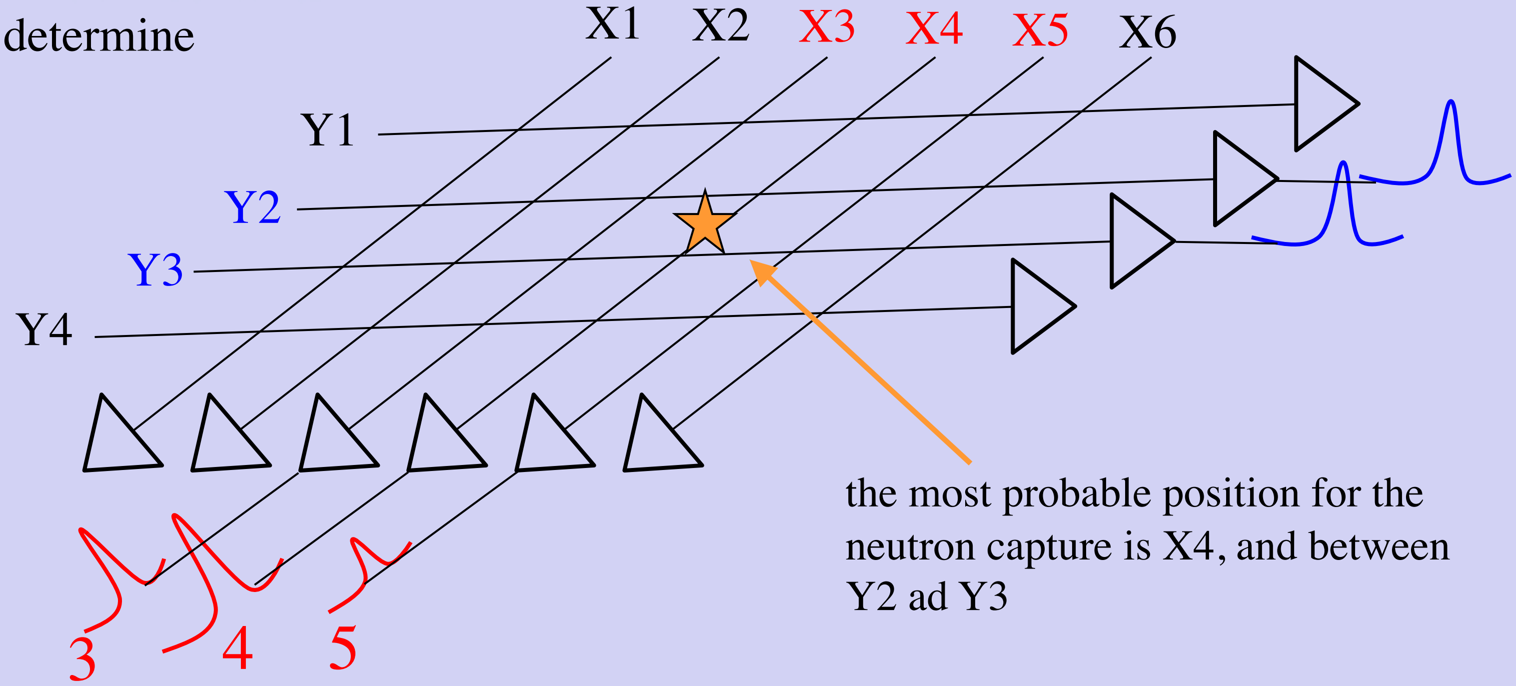
Each electron generates an avalanche

Secondary electrons and ions are created around the anode wires with Gain = $N_{sec} / N_{primary}$

A current signal is induced on the neighbouring electrodes by the movement of charges

Particles are localized at the intersection of the active electrodes by time coincidence

The time coincidence between X and Y signals allows to determine the position in X and Y



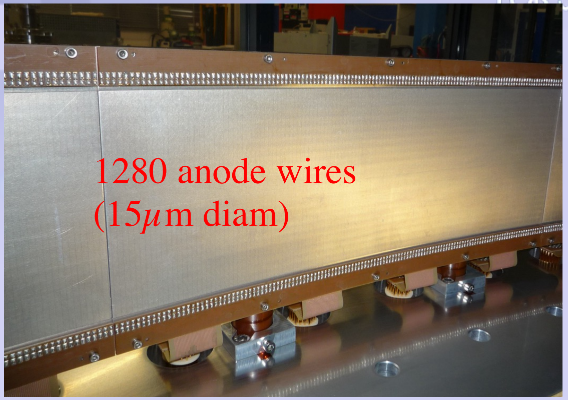
the most probable position for the neutron capture is X4, and between Y2 ad Y3

The D1B Powder Diffractometer

1D localization MWPC

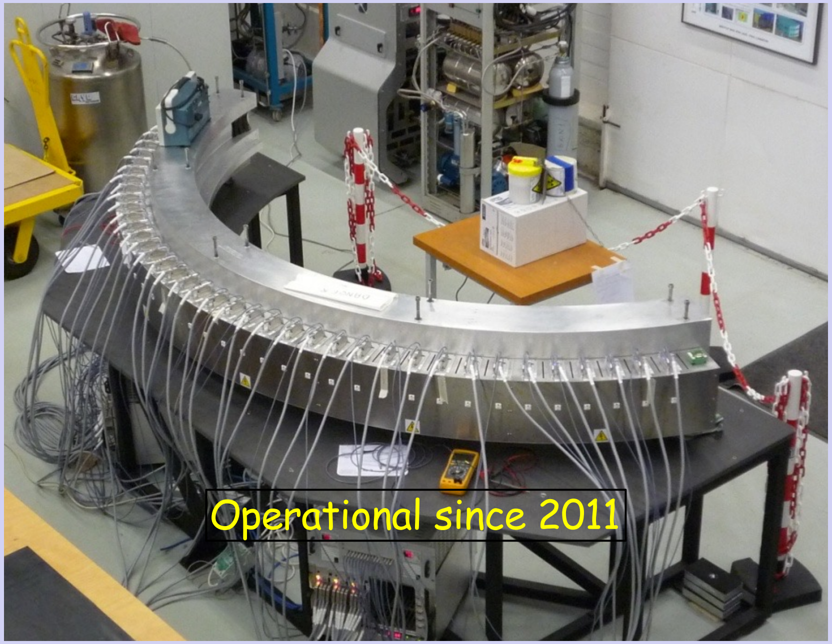
In 2008, the ILL started the development of a new MWPC :

- Better spatial resolution 0.2° → **0.1°**
- Larger angular range 80° → **128°**
- Larger Height: 10 cm → 12 cm
- Higher counting rate : matrixial readout → **individual readout**
- Higher efficiency : 60% @ 2.52Å → 80%

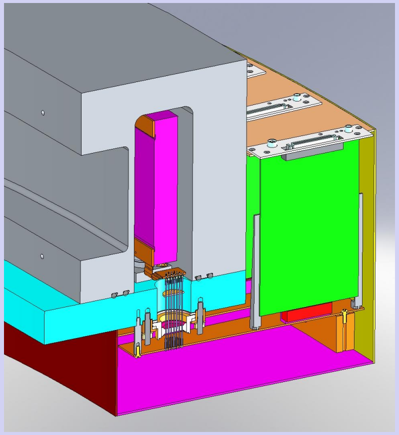


1280 anode wires
(15μm diam)

1280 Anode wires every 2.6 mm
Radius: 1500 mm
Window : 7mm
Gap : 22mm
Gas : 5 bar ^{3}He + 1 bar CF_4
Voltage : $V_a = 2050V$, $V_C = 410V$
Volume ^{3}He used: 145 liter.bar



Operational since 2011



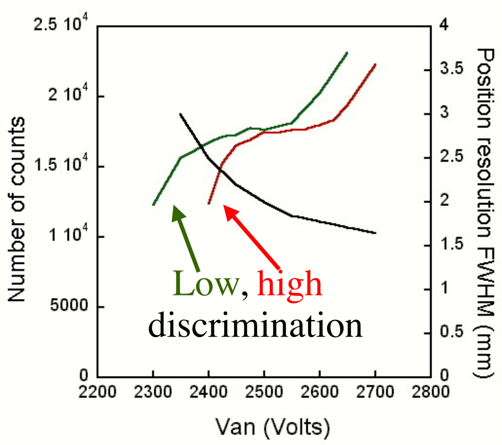
Simple 1D MWPC design

- Planar flange
- 12 cm anode wires → no field wires
- No drift electrode

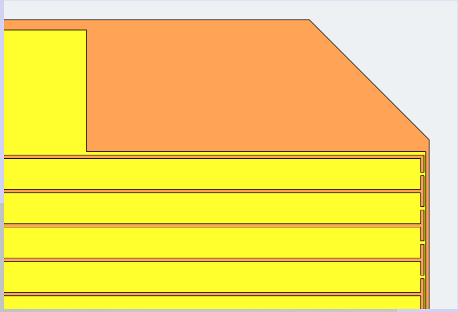
D19 Single Crystal Diffractometer

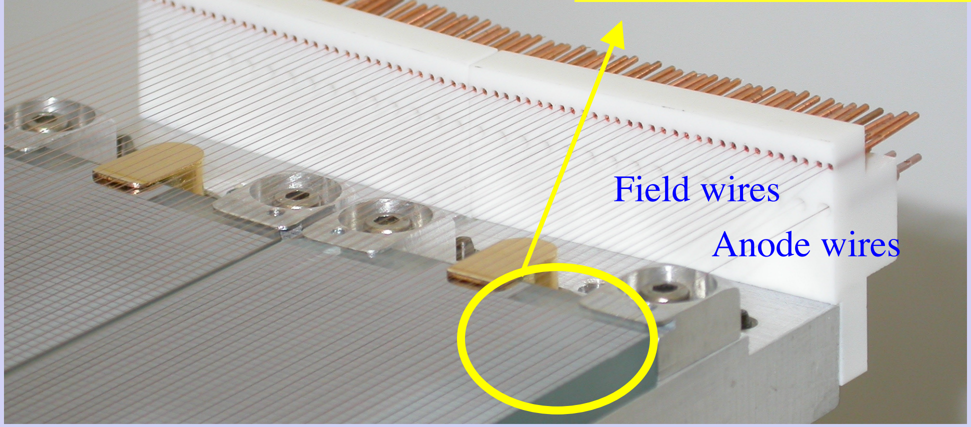
Curved 2D MWPC

operational since 2005



Glass electrode (Y cathode)





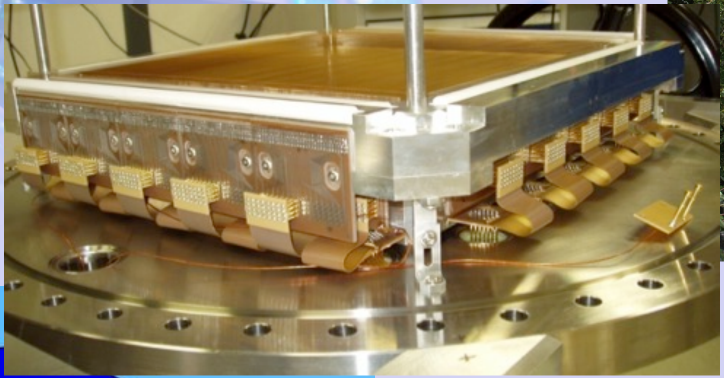
20 MWPC modules
640 anode wires every 2.5 mm
1280 field wires every 1.25 mm
Angular coverage: 120° x 29°
Radius: 750 mm
Window : 8 mm
Gap 30 mm
Gas : 4 bar ^{3}He + 1 bar CF_4

Only low outgasing materials → no need for gas purification

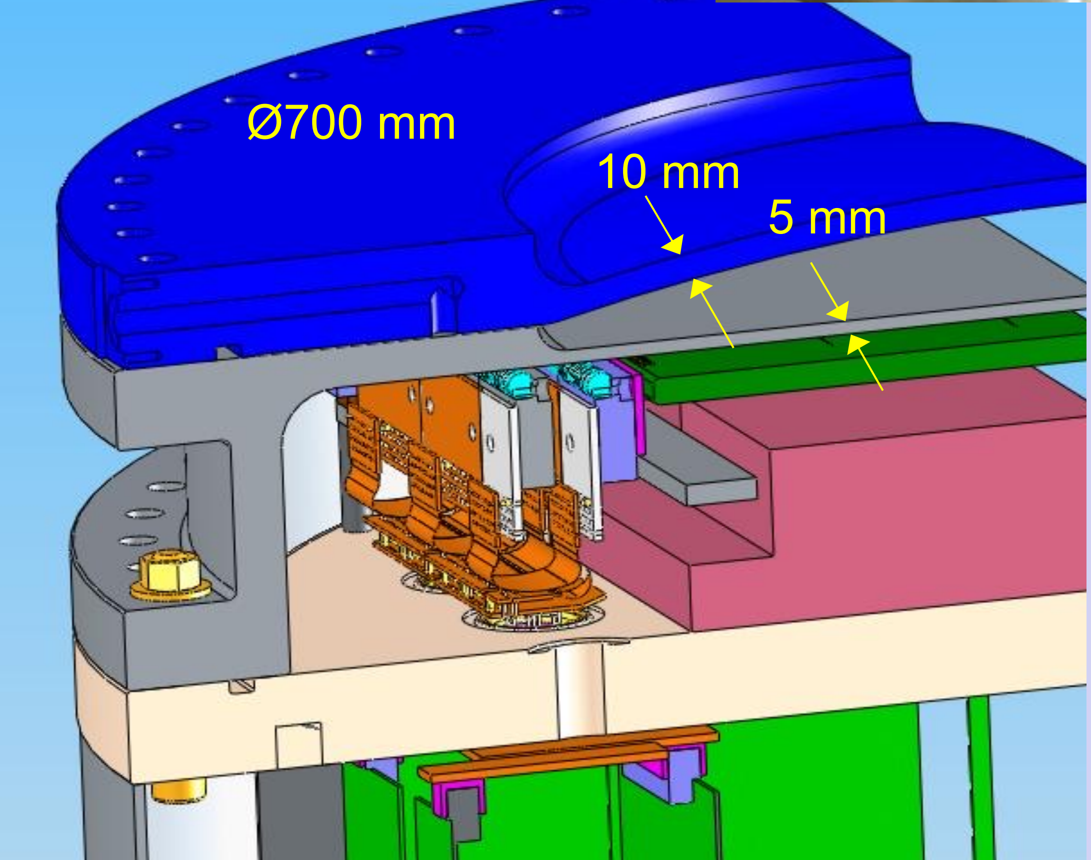
Long wires → Field wires → Drift electrode

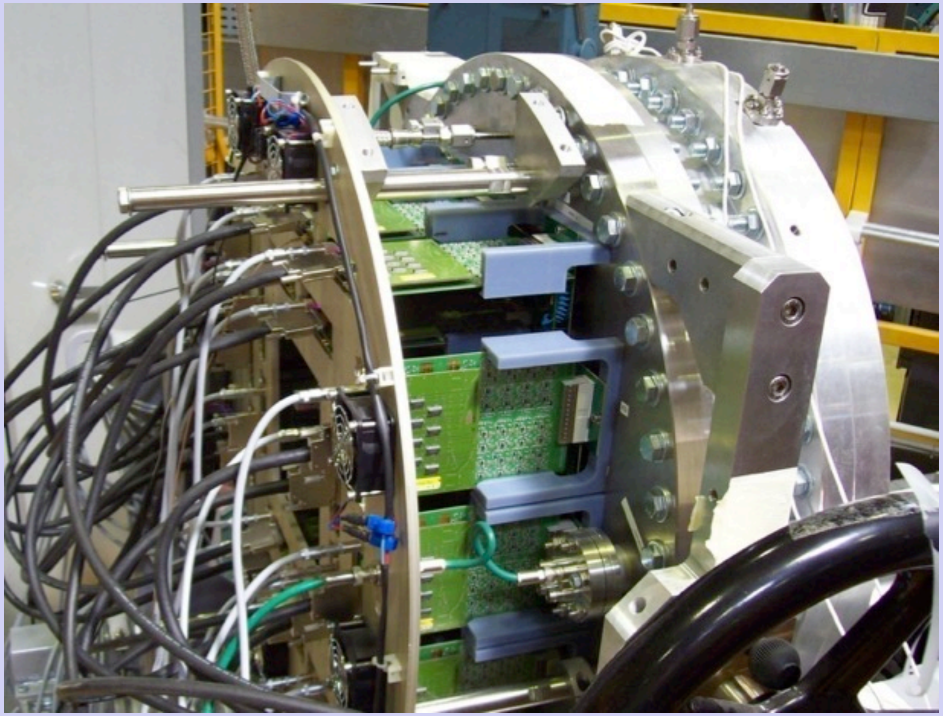
MILAND (Millimetre Large Area Neutron Detector)

- 32 cm x 32 cm sensitive area
- 1 mm readout pitch (640 channels)
- 5 mm conversion gap (+ 20 mm optional)
- 15 bars gas pressure (13.5 ^{3}He + 1.5 CF4)
- TOT (Time-Over-Threshold) processing



36 participants from 10 institutes (LLB, ISIS, GKSS, FRM-II, LIP, BNC, Tokyo University, ESRF, SNS, ILL)





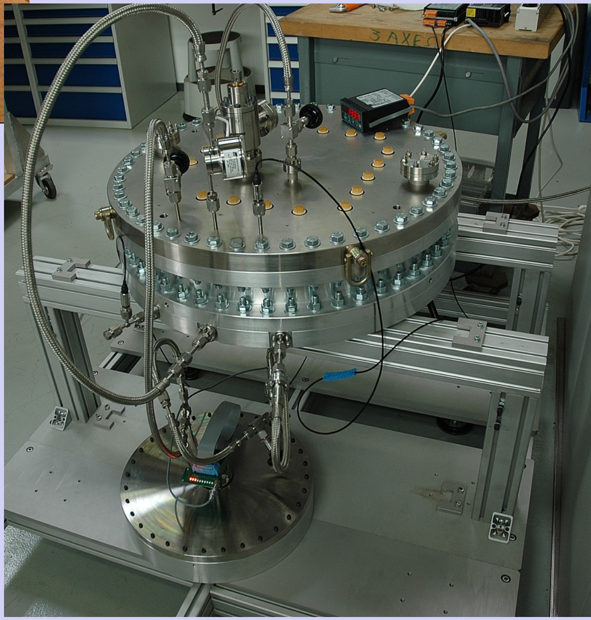
pressure vessel fabrication

TIG welding of 20 HV 37pts feedthroughs connectors and gas feedthroughs

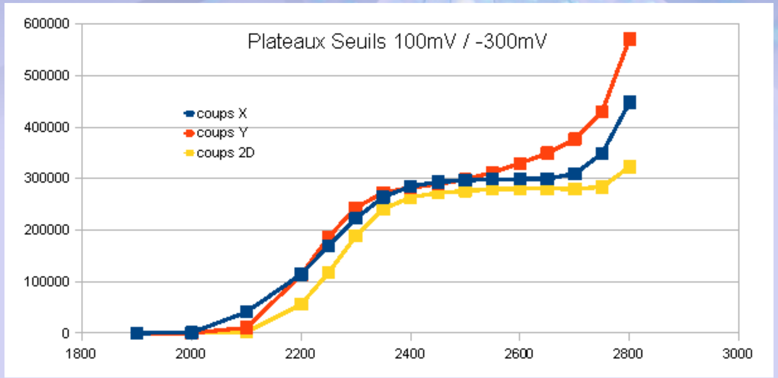
Gas tightness control

Pressure test (0 to 21.5 bar)

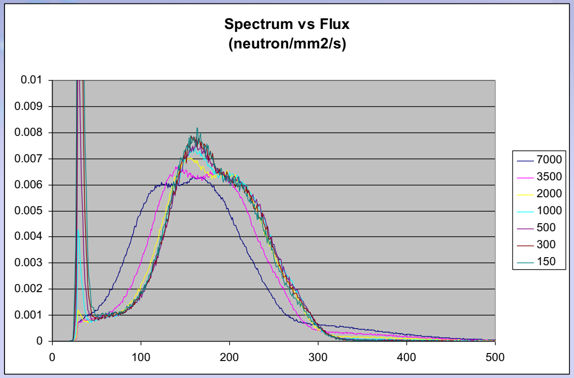
Temperature pressure compensation



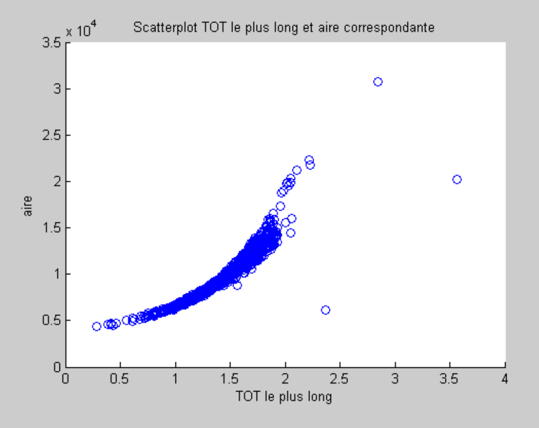
MILAND results



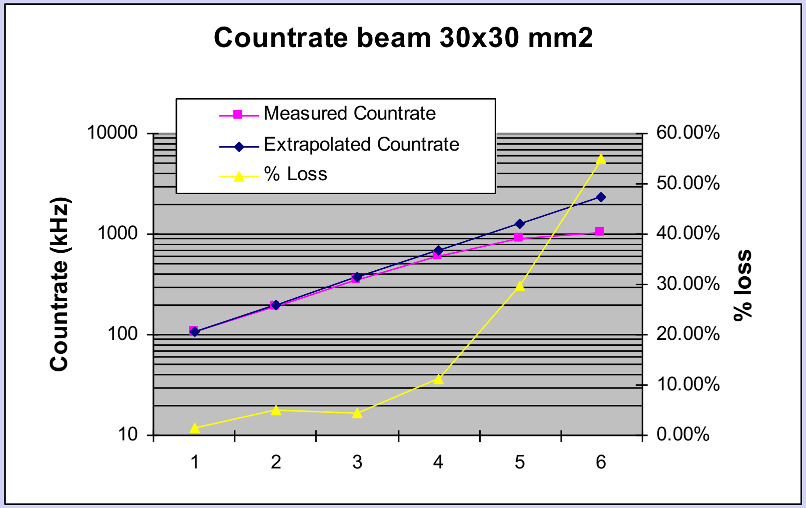
Counting curves for X, Y and XY coinc



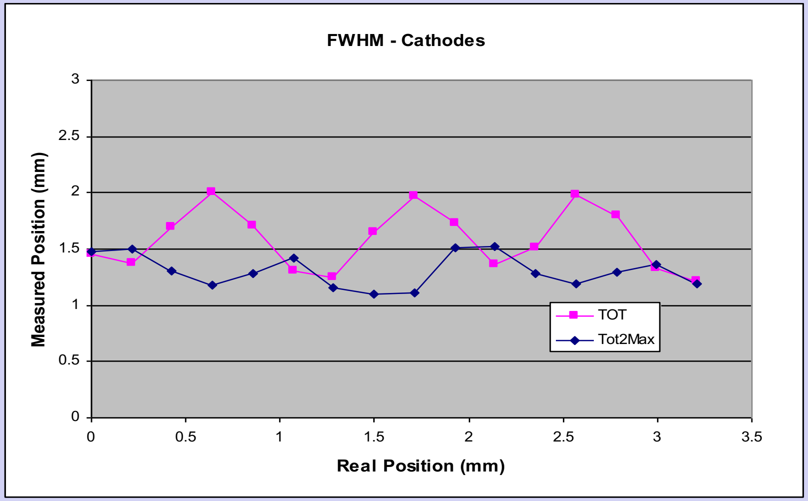
Pulse height spectra for different beam fluxes



Charge signal versus TOT (numerical integration of the digitized signal)



Counting rate versus flux



Spatial resolution for 2 algorithms based on the TOT signal

MILAND results

- ✓ Detection efficiency 70% @ 2.5 Angstroms
- ✓ Spatial resolution: 1 mm FWHM (1.2 mm)
- ✓ Reduced Parallax error 5 mm gap + High pressure (15 bars)
- ✓ Global counting rate τ : 0.7 MHz @ 10% neutron lost
- ✓ Gamma sensitivity $< 10^{-8}$
- ✓ Counting uniformity : variance <= 5%
- ✓ Counting stability (variation $< 10^{-4}$ / hour)

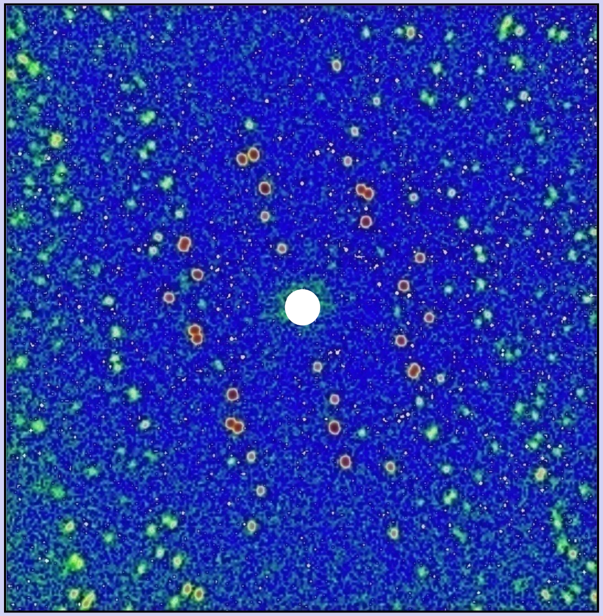
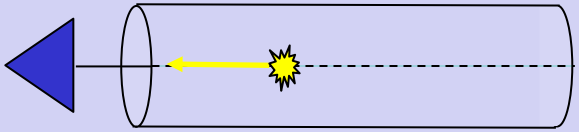


Image obtained on the D16 instrument with a **lysozyme** crystal

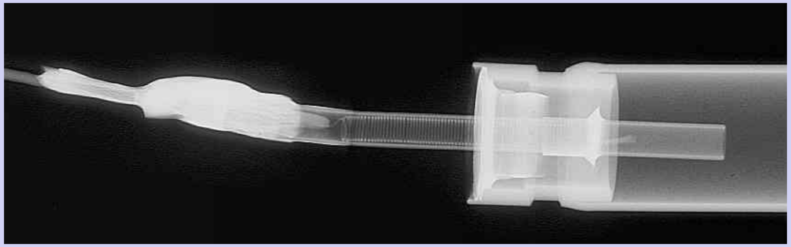
Proportional counter tubes

Not used anymore !

Single ended



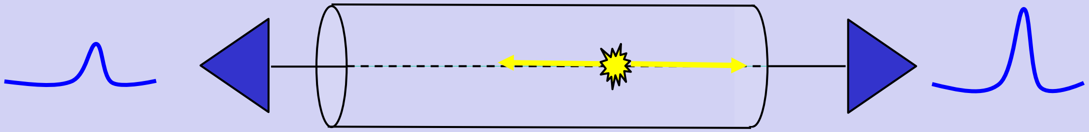
we can only know that the neutron interacted in the tube



2001: Reuters Stokes started the development of a 1 m long, 8 mm diam. PSD for D22

Used for SANS, reflectometry, TOF spectrometry

Double ended (also called PSD)



The position along the tube is measured by charge division, using pulse height of the 2 signals

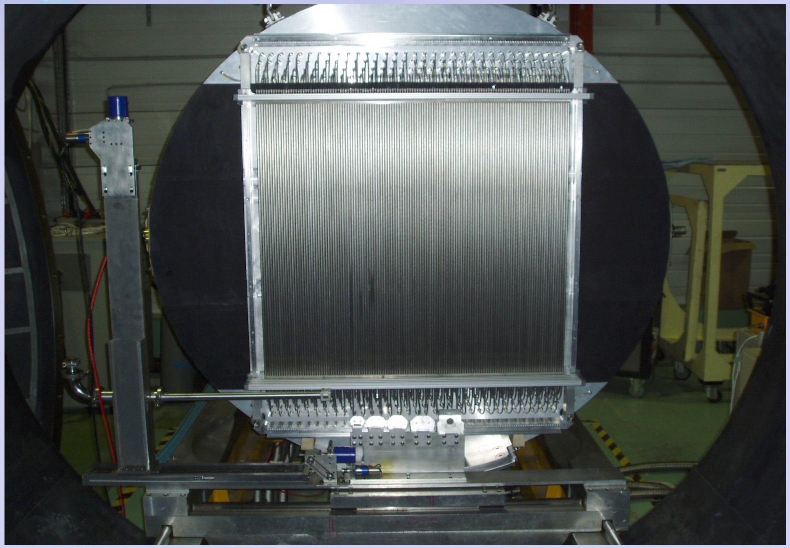
A 2D detector consisting of several PSDs mounted side by side is called a MultiTube

Application: PSDs for Small Angle Neutron Scattering

From large MWPC …

XY measured by coincidence of 2 orthogonal wire frames (max count rate 200 KHz)

…to PSDs (2004)

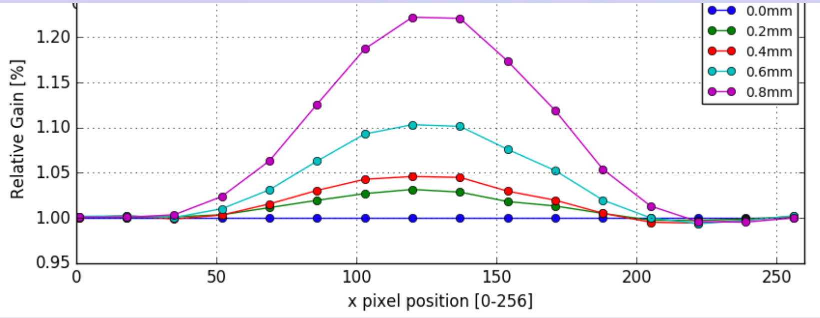


128 PSD covering 1 m^2 of sensitive area.
Position measurement by charge division
X = L . S2/(S1+S2)
Tube diam.: 8 mm. Pressure: 15 bars

Parallel charge division readout of independent detection elements combine the advantages of good spatial resolution in 1D together with high global counting rate

PSD Results

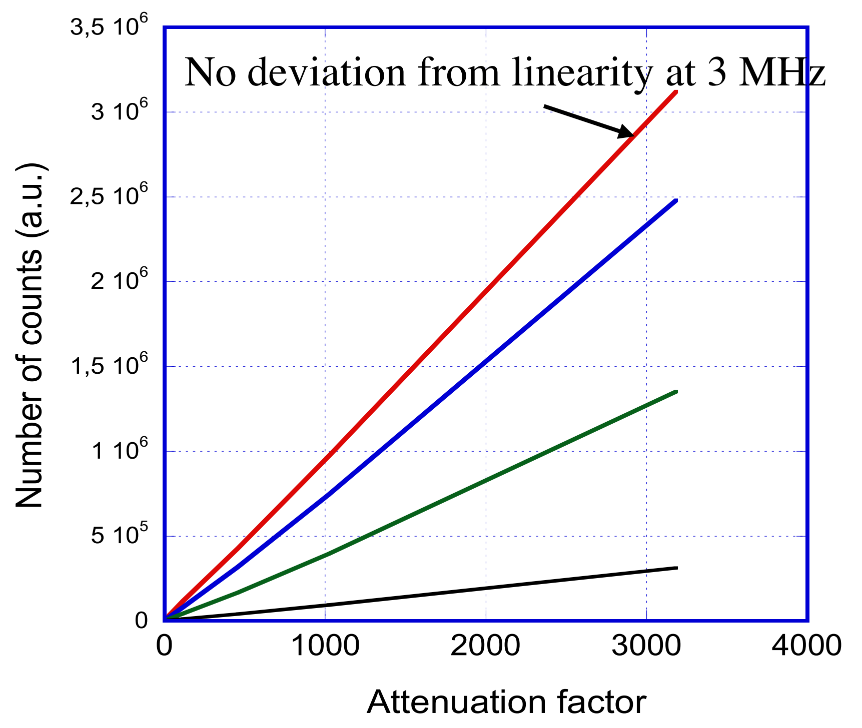
Gain variation versus tube sagging



→ +25% for D=0.8 mm

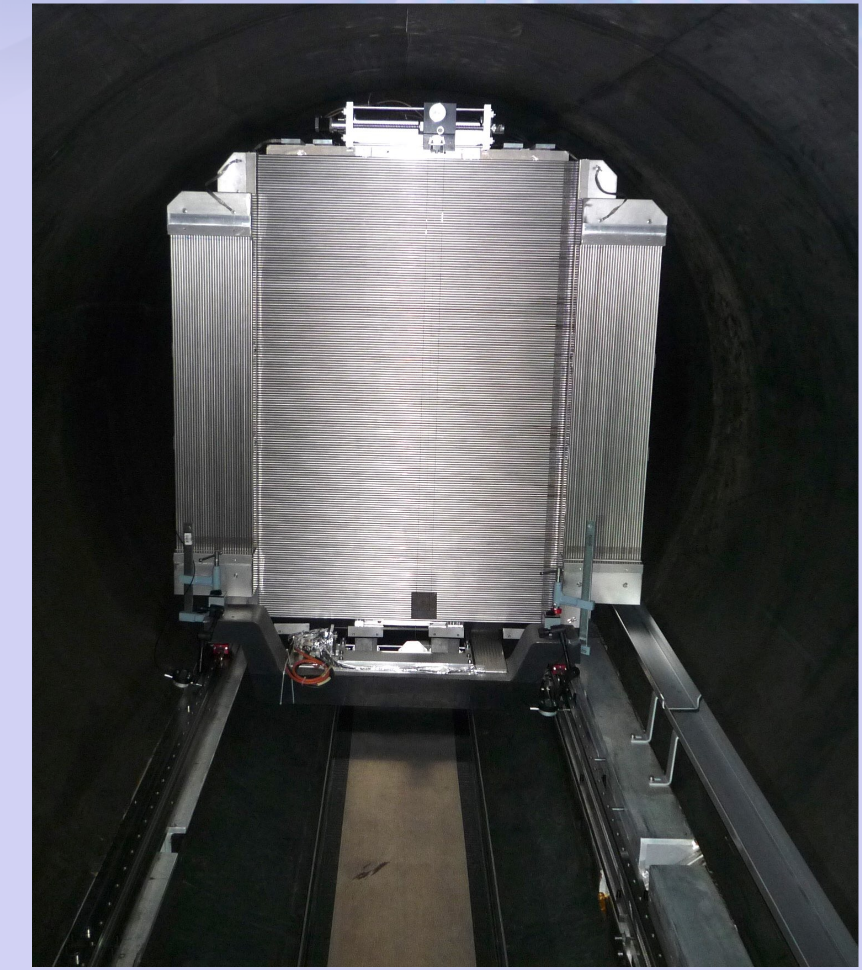
For optimal uniformity and reduced failure risk, the deformation limit was set at 0.2 mm

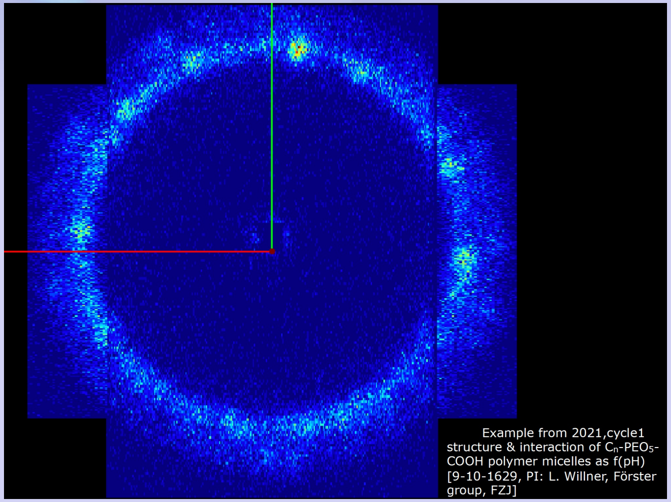
counting rate


No deviation from linearity at 3 MHz

- ✓ X 50 compared to MWPC
- ✓ better time resolution
- ✓ lower background noise
- ✓ lower parallax error

D11 SANS instrument: in 2021, we replaced the 20 years old 1 m^2 MWPC (still operational) by a 2 m^2 panel of 8 mm PSDs





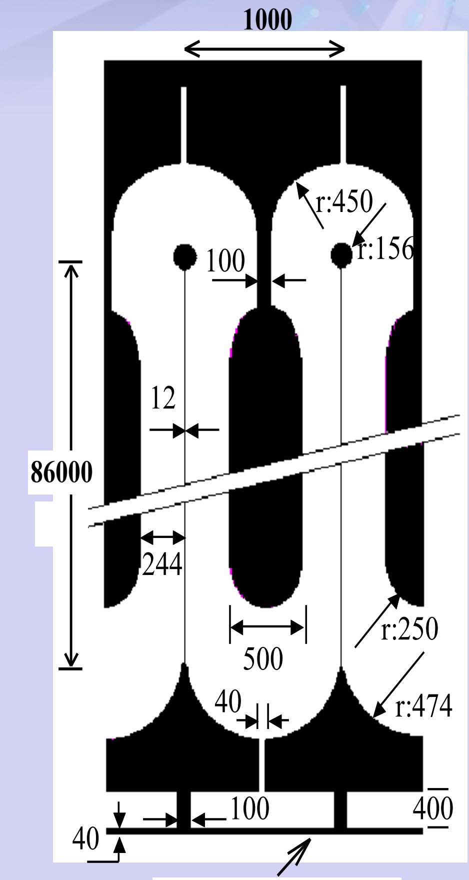
Example from 2021,cycle1 structure & interaction of C_n-PEO_5-COOH polymer micelles as f(pH) [9-10-1629, PI: L. Willner, Förster group, FZJ]

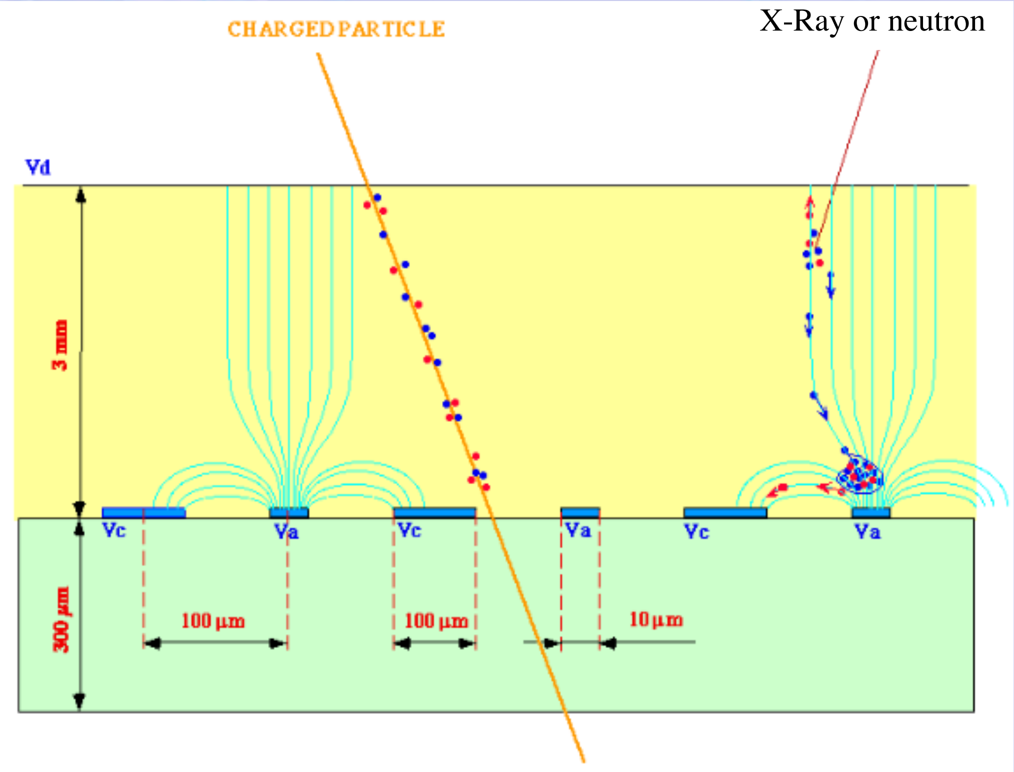
256 ^{3}He (10bar) PSDs.

- 2.5x larger solid angle coverage (0.9m2 to 2.1m2)
- 20x higher count-rate (up to 5 MHz)
- 50% increase in dynamic Q-range
- Easier maintenance

MSGC

(1988, A. Oed)





Main limitations of MSGCs:
limited size, 1D localization

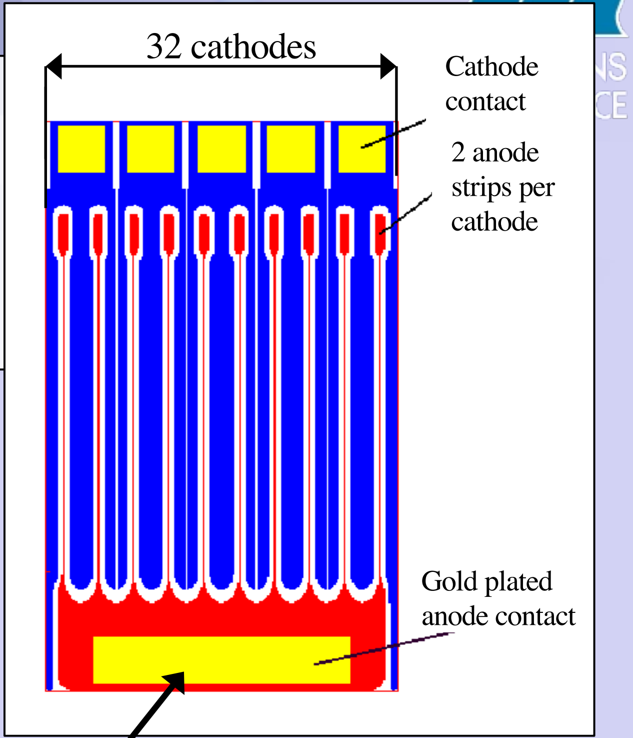
The D20 Powder Diffractometer

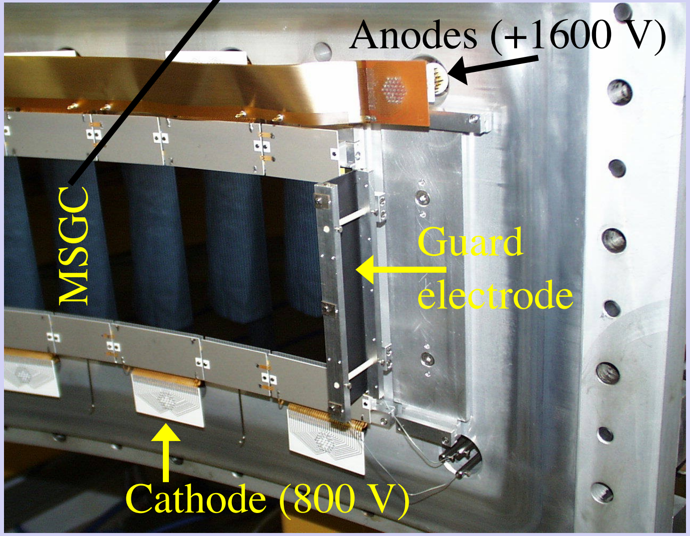
1D localization MSGC

48 MSGC plates
1536 readout channels every 2.6 mm / 0.1°
Horiz angle : 154° / Height: 15 cm
Radius: 1500 mm
Window : 7mm
Gap 50mm
Gas : 2.8 bar ^{3}He + 1.2 bar CF_4

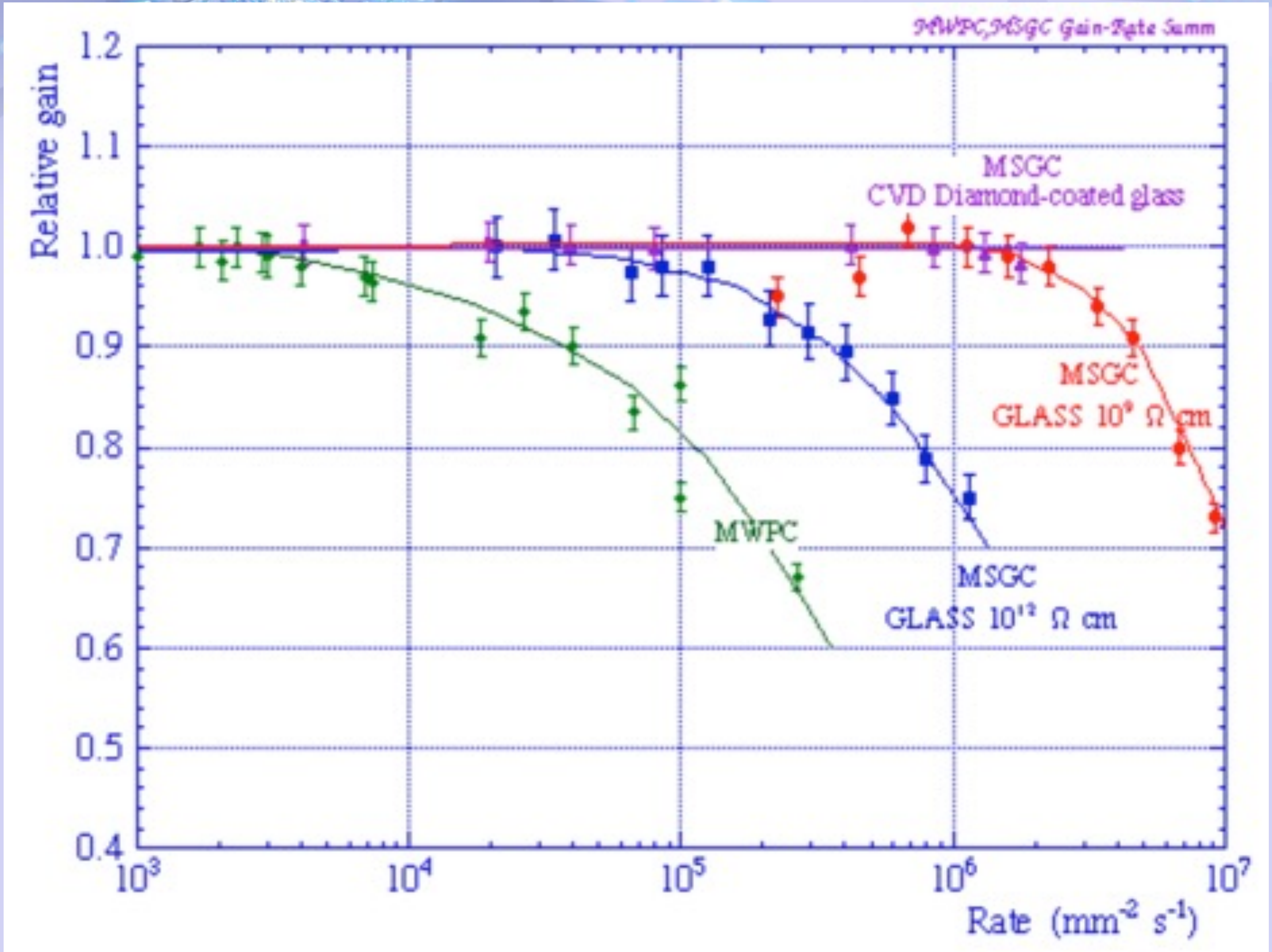
The introduction of MSGCs by Anton Oed in 1988 has been a technical breakthrough in the field of radiation detectors

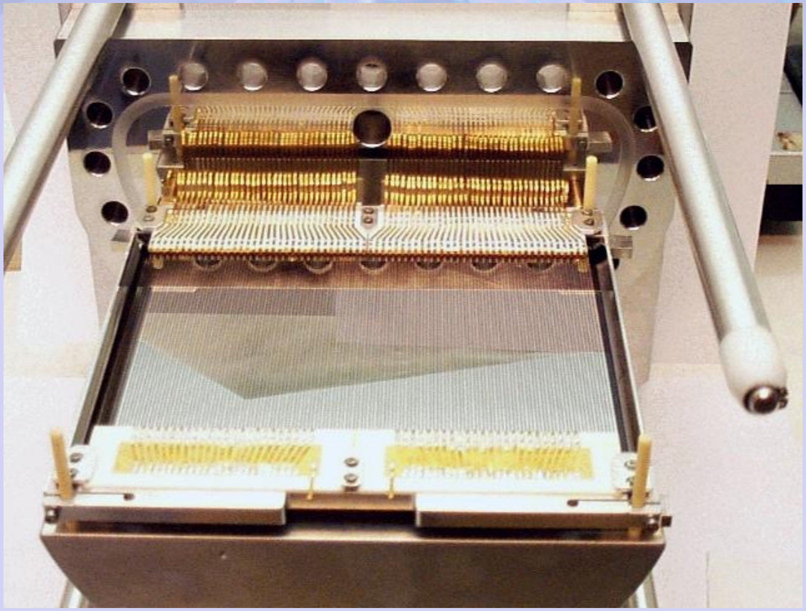
cross-fertilization **Neutron Science → High Energy Physics**
MSGC → micro-pattern gas detectors (GEM, Micromegas, …)



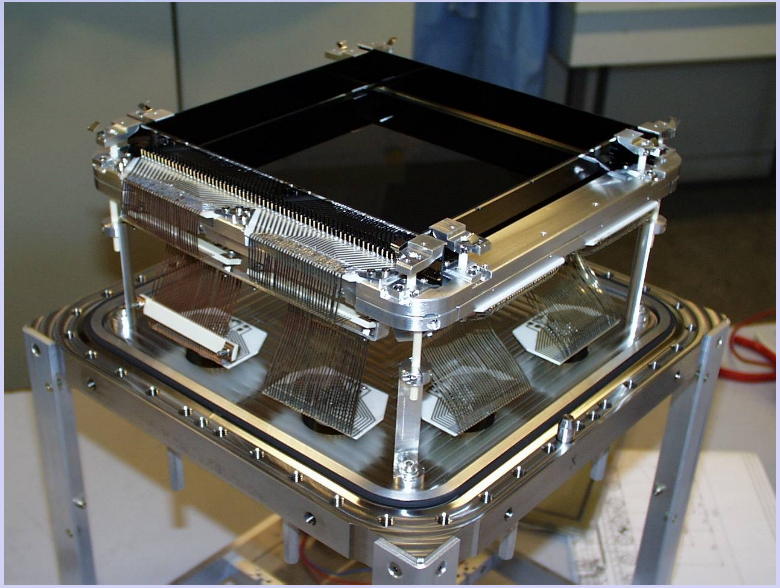


MSGC Counting rate





D4 powder diffractometer (in operation since 2000)
Modular MSGC (9 modules)
145° Horiz. (2 scans) x 5.7° Vert.
Position resolution : 2.5 mm (0.14°)
Gas pressure : **15 bars** 3He + 0.3 bar CF4
Detection efficiency : 90% (@ 0.7 Å)



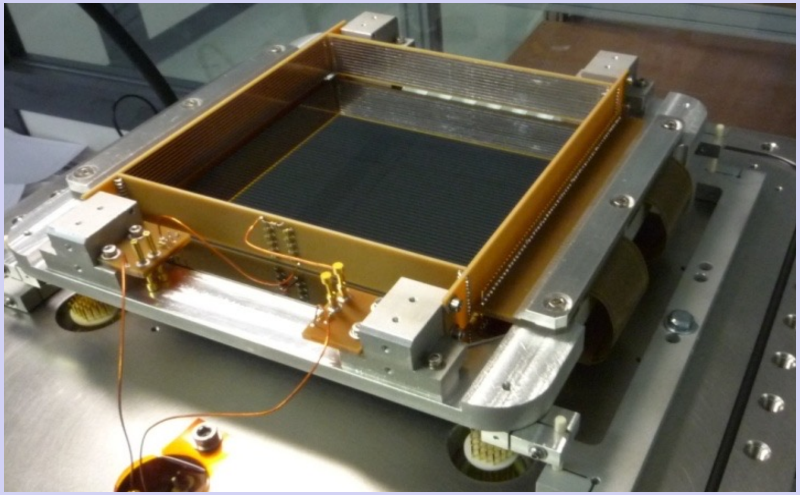
Bidim19
Position resolution : 3 mm
Useful area: 192 mm x 192 mm
94% efficiency at 2.4 Angstroms
used on D19 during 2 years

MSGC: parallel readout of the strips by charge division

(story of a failure)

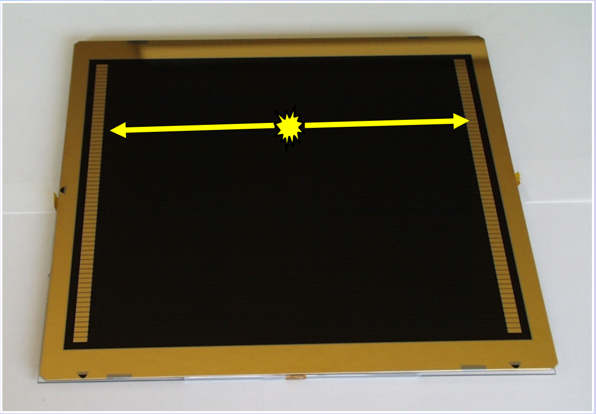
Goal
- 2D localization
- Resolution 1 mm x 1 mm
- high counting rate : 50 kHz/anode and 5 MHz/detector

Target instruments: reflectometers

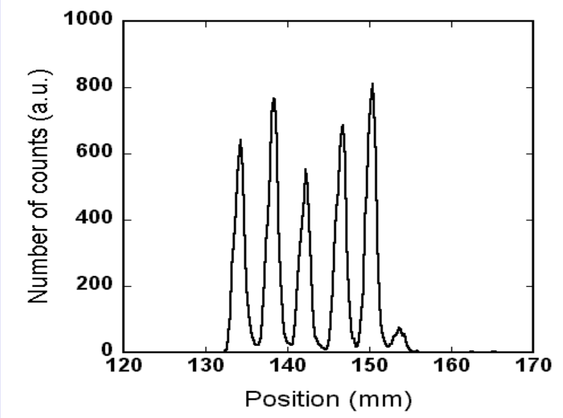


12 µm anode strips (not visible) engraved on a Schott S8900 glass plate

Rear side of the MSGC coated with a cathode plane



The position of each neutron is measured by charge division by reading both ends of the anode strips



Resolution: 1.3 mm FWHM measured with 2 bars CF_4

- Charging up of the surface of the glass → space charge effect
- The resistance of the anodes is too high (30 kOhms) → signals are too slow (time constant varies like RC)

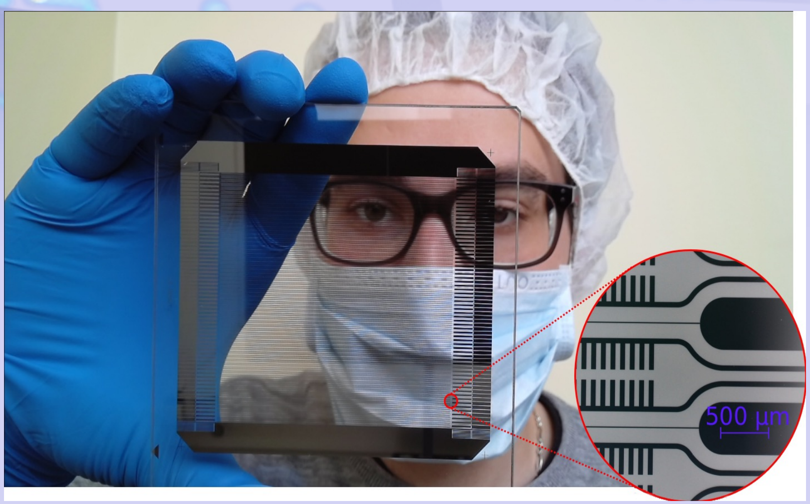
the SINE2020 project (story of a failure - continued)

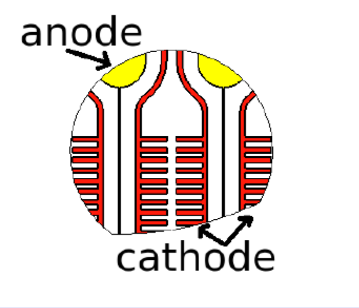
Oct 2015 → Oct 2019

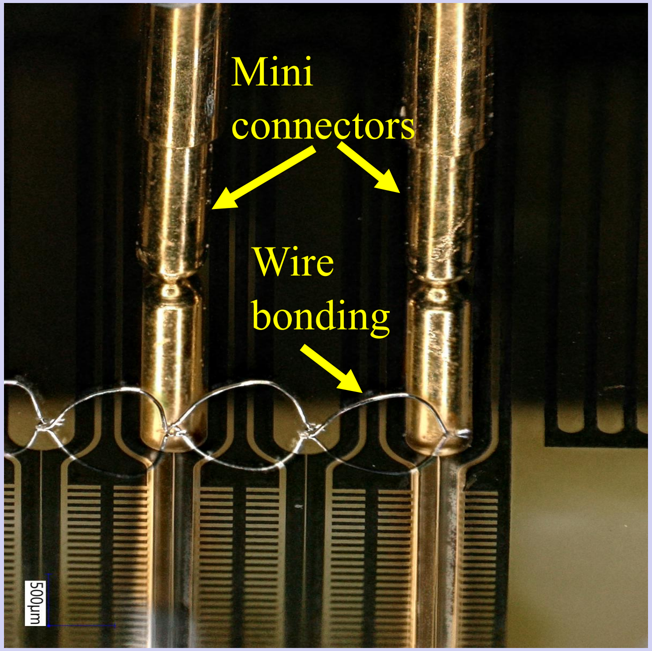
TASK 9.3: Development of a ^{3}He based microstrip gas with a novel 2D readout

- Charge division of resistive cathodes instead of anodes → allows to optimize the resistance parameter
- anodes and cathode strips engraved on the same side to avoid glass charging up

One challenge was to design a high density cathode connector based on spring test probes, and to develop wire bonding techniques for the anode strips

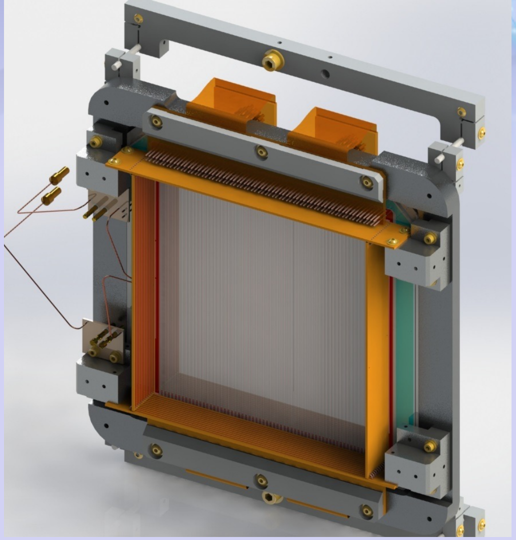


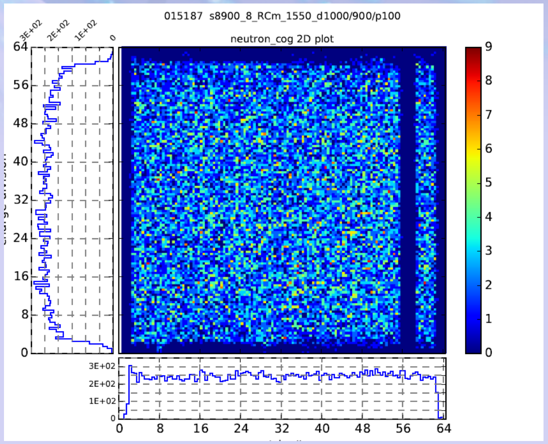




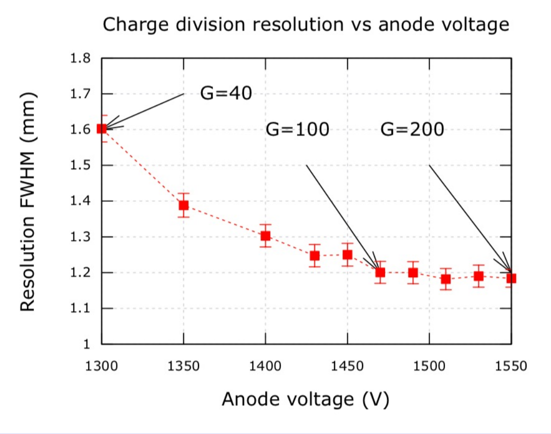
(story of a failure - End)

A 64 mm x 64 mm MSGC has been fabricated and tested

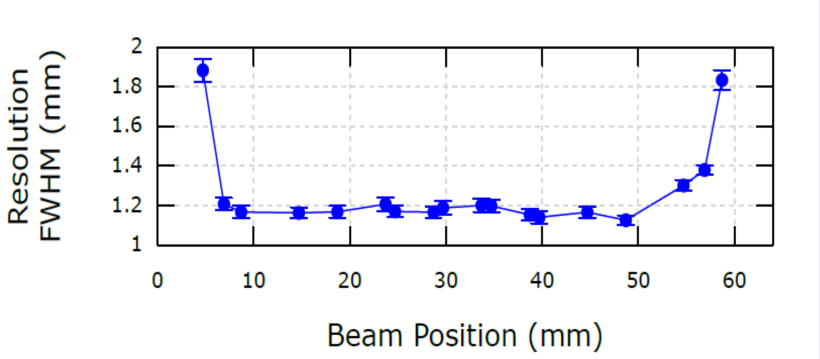




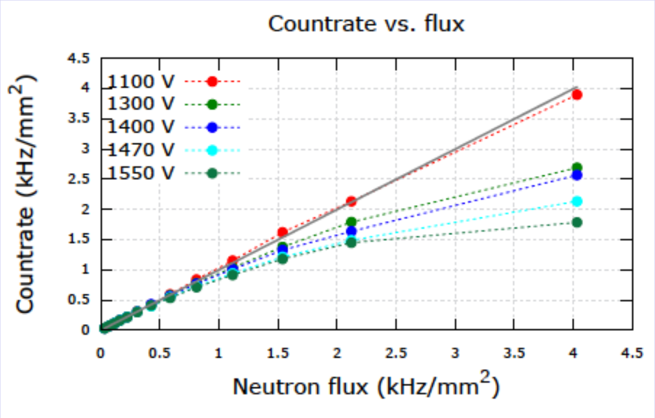
Good response uniformity !
(except contact problems)



The spatial resolution strongly depends on the amplification gain
→ High gain required



Good position resolution and fast signals !



… but 1 kHz/mm2 max @ 10% counting loss (MSGC are supposed to operate at much higher counting rate than MWPC)

Conclusion: A few things to remember about ^{3}He neutrons detectors

Similar to other gas detectors for MIP presented in former lectures, except ...

- ^{3}He is a perfect neutron convertor, but it is rare and expensive (around 2500€/litre.bar in 2022) → the detector vessel must be sealed, and dead volumes must be minimized.
- ^{3}He only serve as a neutron convertor; a stopping gas, and a quencher must be added (a standard gas mixture is ^{3}He/Ar/CO_2)
- The pressure of stopping gas needed depends on the spatial resolution required.
- The number of electron-ion pairs generated in the gas for one event is 100 times higher for neutrons than for MIP → gas amplification is lower
- Stainless steel tubes and Aluminium vessel allow to use a high gas pressure, up to 15 bars (Aluminium is relatively transparent to neutrons)
- The diversity of the neutron instruments impose to develop specific detectors
- MSGCs are intrinsically more performing than MWPC, but challenging to operate
- MWPC are still broadly used in neutron scattering science; they do the job !

NEUTRONS
FOR SCIENCE ®

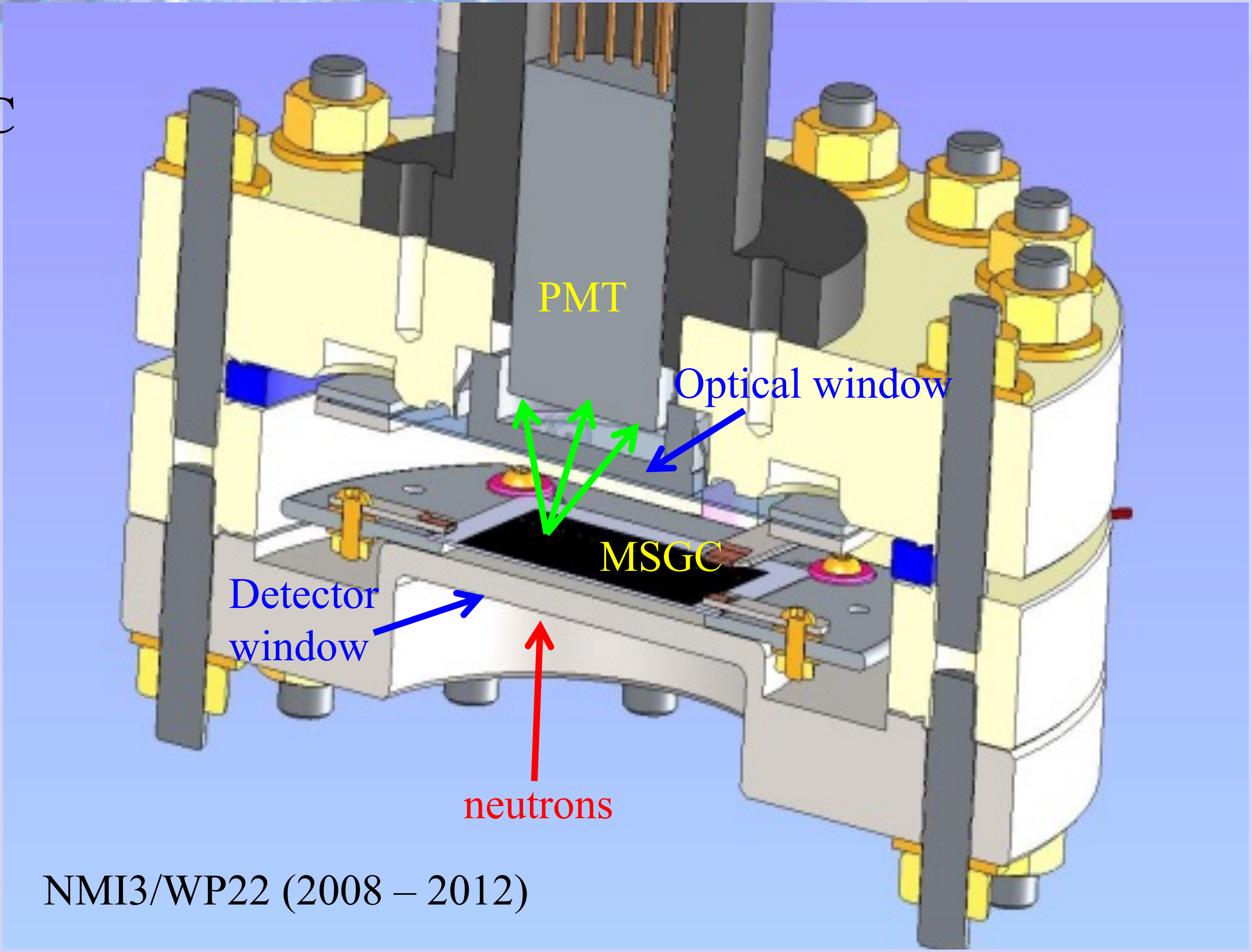
Thank you!

Extra slides

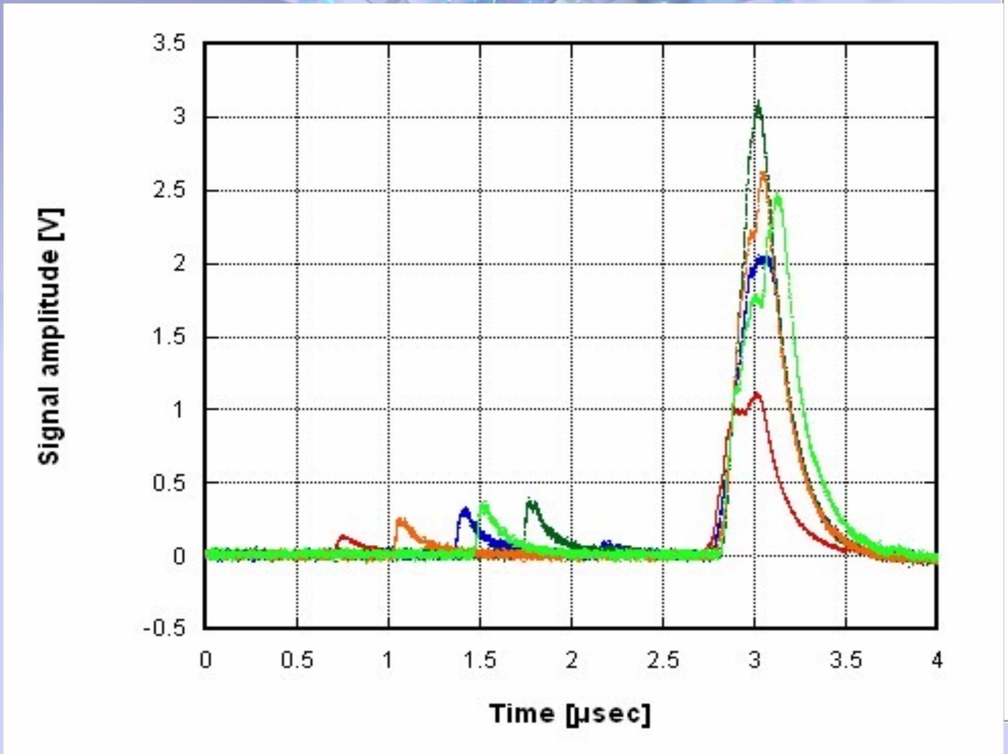
GSPC (Gas Scintillating Proportional Chamber)

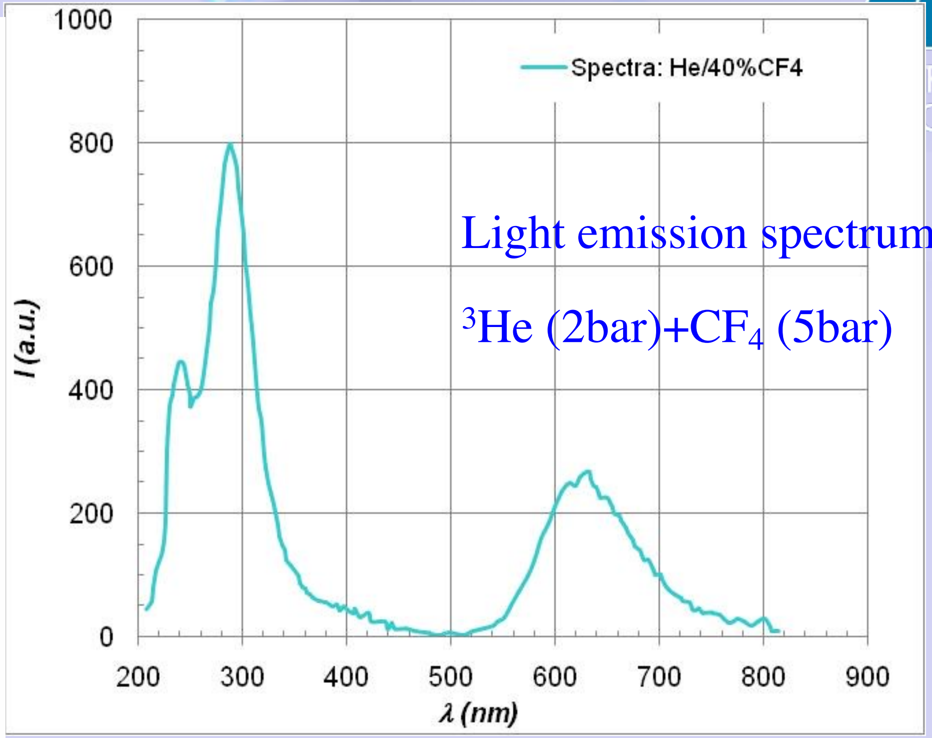
Measuring the light produced during the avalanches

- MSGC



NMI3/WP22 (2008 – 2012)





Light emission spectrum

^{3}He (2bar)+CF$_4$ (5bar)

Primary and secondary light measured with a PMT

Material	λ max. emission (nm)	Light Yield (photons/neutron)	Decay (ns)
Li glass (Ce) (GS20)	395 nm	~7,000	75
LiI (Eu)	470	~51,000	1400
ZnS (Ag) - LiF	450	~160,000	>1000
CF$_4$ gas amplification	300 - 600	G*2000 (G: detector gain)	25

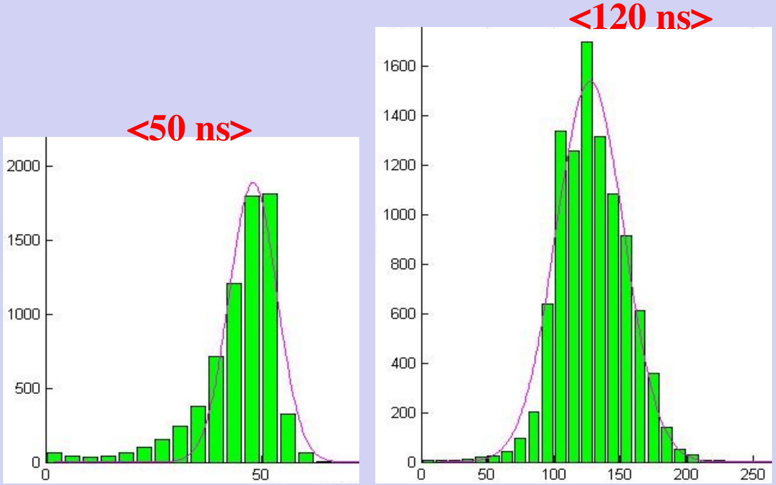
Scintillation light decay time

primary light: 15 ns

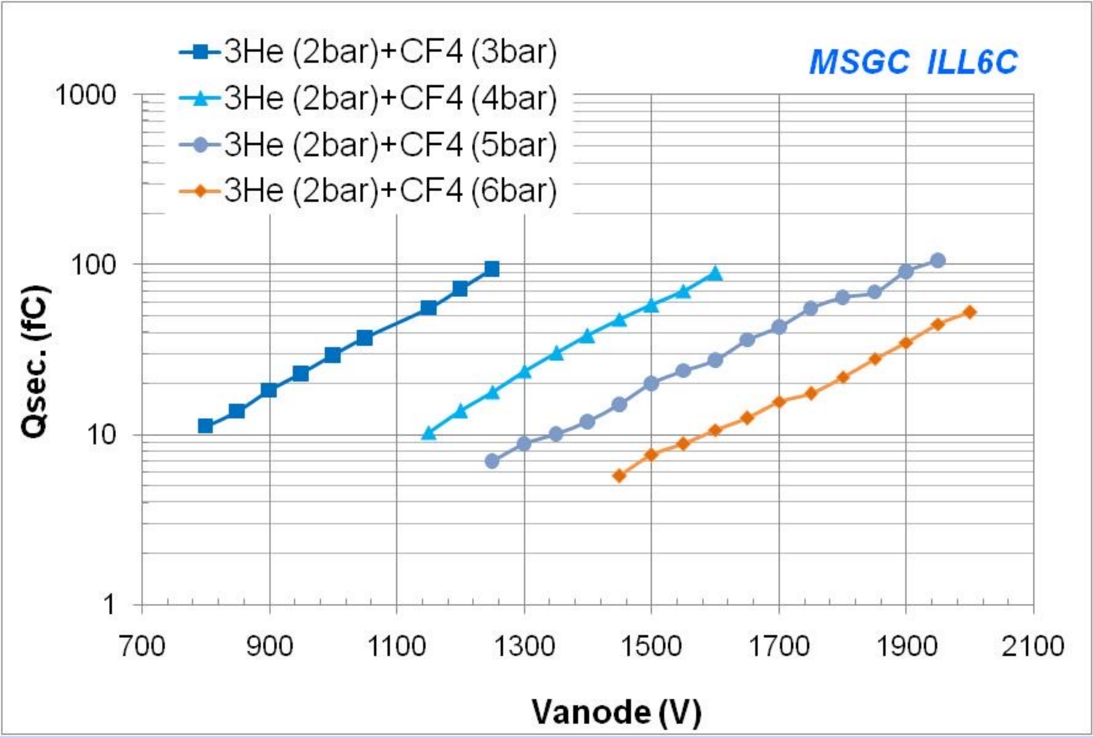
Second. light : 25 ns

Typically 100 ns total dead time taking into account the track charge collection time

→ 1 MHz counting rate @ 10% dead time correction



Primary (left) and secondary (right) light pulse TOT distribution

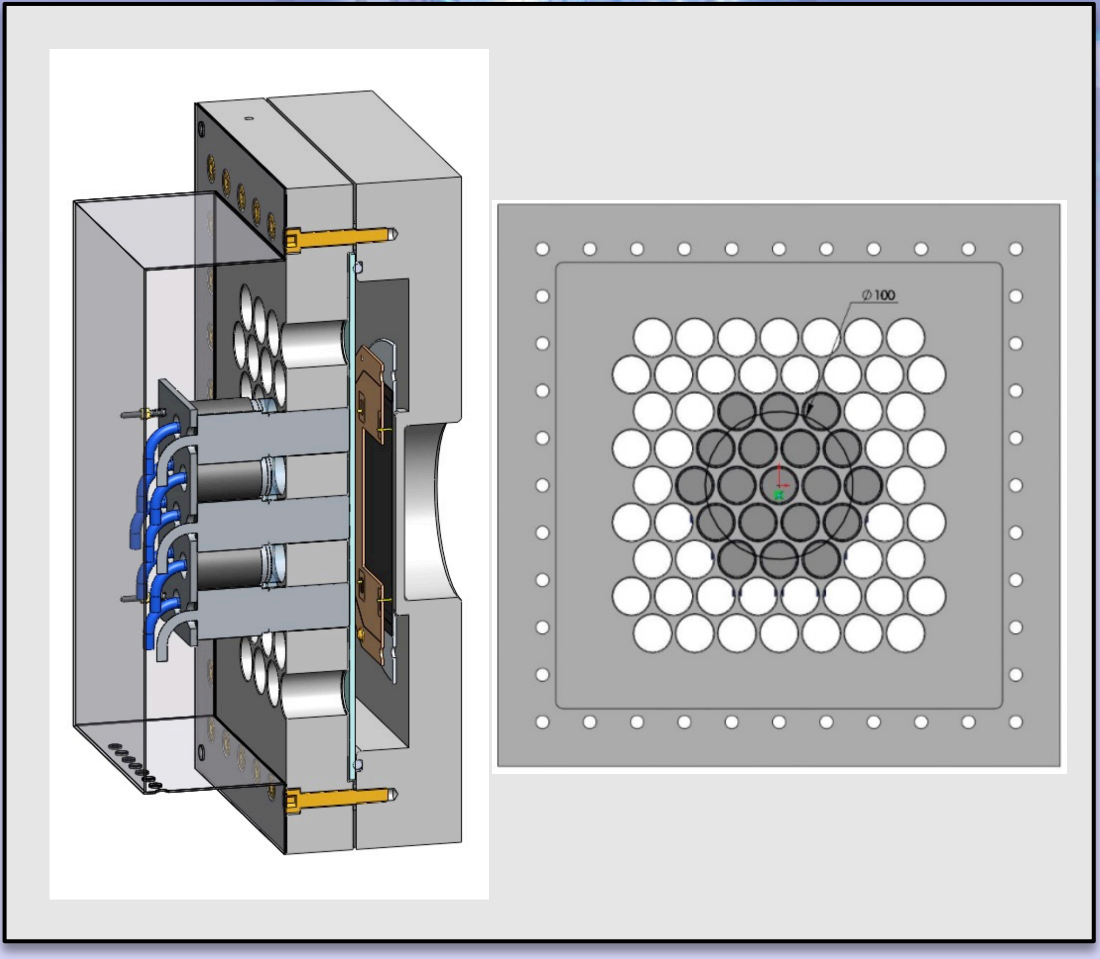


Conditions to reach 0.5 mm FWHM position resolution ?

→ 6 bars of CF4

→ amplification gain =1000

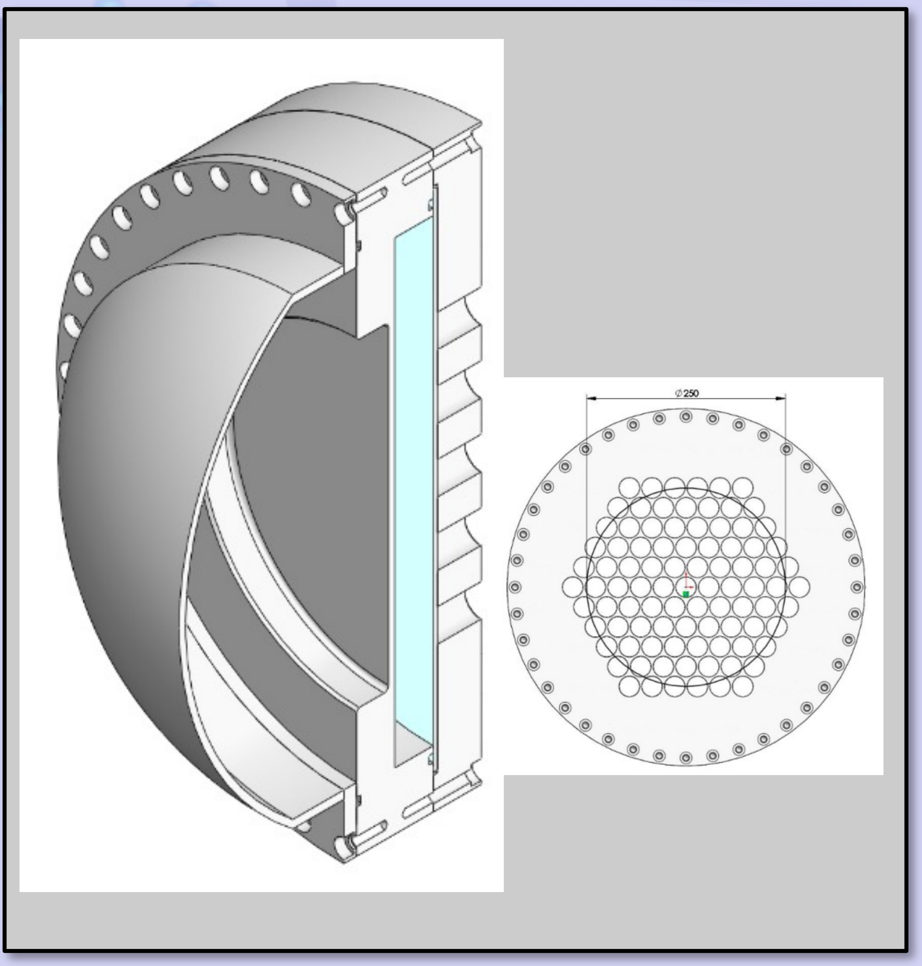
MSGC is unique in the fact that it can be operated at High pressure of CF4



GSPC19 (window: 10 cm diam)

0.7 mm resolution measured

Very nice development, but too complicated !



GSPC91 (project)

Window: 25 cm diam

- Pixel and Hexagonal MWPCs

Pixel readout MWPC

Local count rate ~ 50 KHz/pixel

A large area pixel detector would be very expansive in terms of electronics

Requires ASIC development

Multi-events recognition MWPC

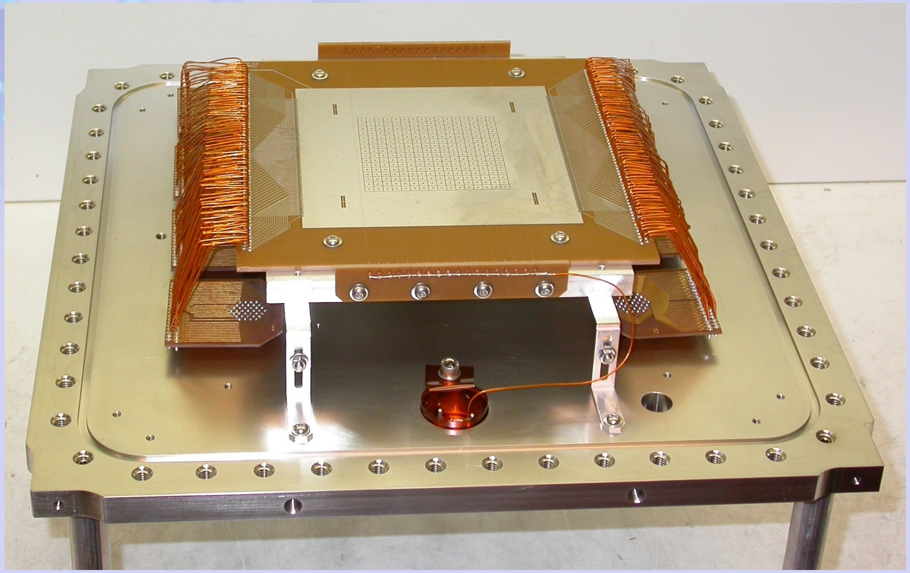
Sensitive area = overlap of 3 wire frames mounted at an angle of 60°

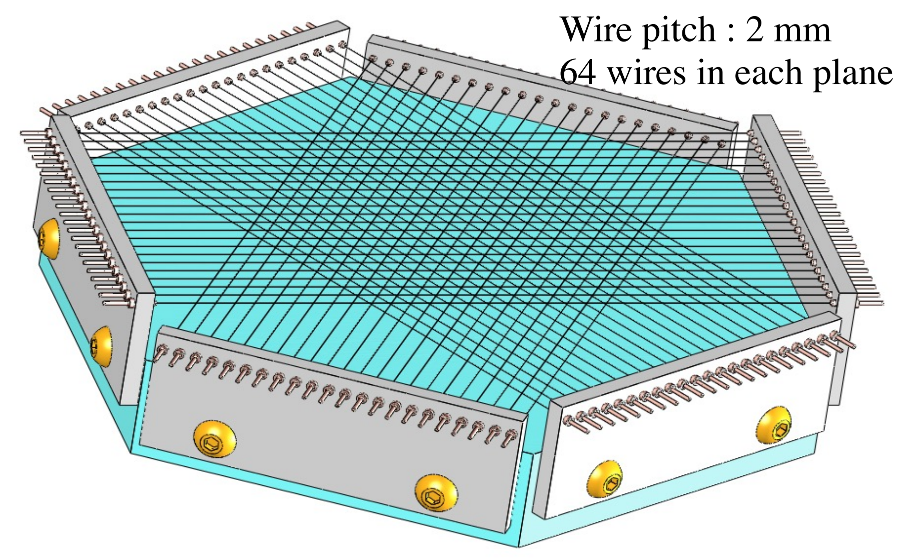
The number of readout channels is multiplied by 1.8 compared to a standard detector with similar sensitive area and spatial resolution

2 simultaneous neutrons can be localised without any ambiguity.

Requires FPGA development

Area: 80 mm x 80 mm
pixel size: 5 mm x 5 mm





Wire pitch : 2 mm
64 wires in each plane