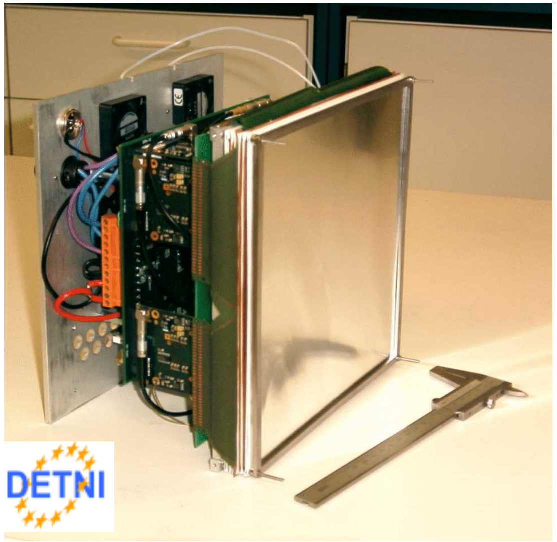
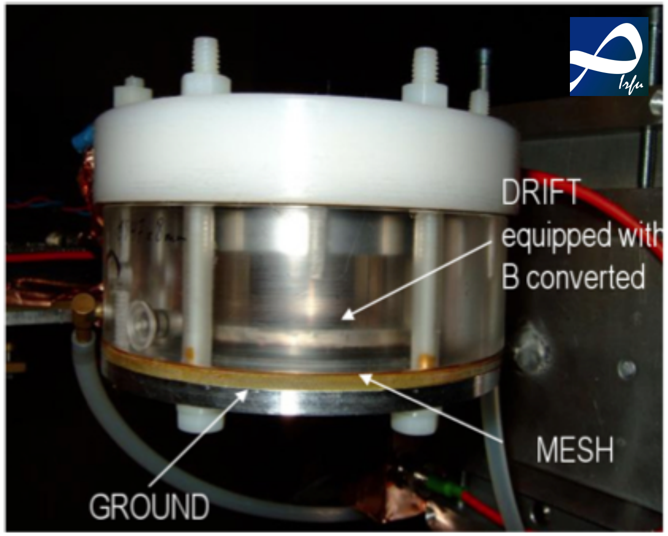
MPGDs for neutron detection applications

2D-200 GEM CASCADE



A. Delbart,
CEA/DSM-IRFU,
CE-Saclay, 91191 Gif-Yvette,
France

n-TOF 2D X-Y neutron micromegas beam profiler



INDUSTRY-ACADEMIA MATCHING EVENT
ON
MICRO-PATTERN GASEOUS DETECTORS

26-27 April 2012

Outline

- Neutron detection : applications, principles, commonly used detectors

- The « ^{3}He crisis » and the need for new & innovative high efficiency, large area ^{3}He free neutron detectors

- Some examples of neutron detectors using MPGDs :
  - for neutron radiography
  - for neutron beam profile & flux measurement
  - for Time Of Flight neutron spectroscopy
  - for nuclear reactor in-core neutron flux measurements

- Conclusions & perspectives

Neutron detection applications

Fundamental research

The **science** which can be made with the use of neutron beams is, in many cases, unbeatable or even inaccessible to any other methods thanks to the neutron unique properties. Use to investigate structure & dynamics of mater.

For experiments on high intensity neutron sources (SNS, ESS, …), **the high counting rate** is one of the key issues for small-angle neutron scattering experiments and neutron reflectometry for instance.

Homeland security

Neutrons can penetrate high density materials, which are opaque to X-rays, thus allowing the inspection of objects obstructed by a dense material

Detection of radioactive materials, explosives, chemical and biological warfare agents, narcotics for air and ground and sea transportations (cargo screening, airport security, …)

Nuclear safeguards

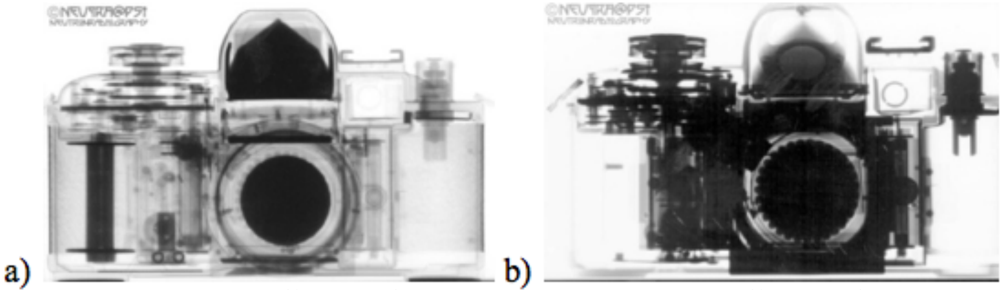
safeguards systems are installed at facilities that process, handle, use and store Pu, U, nuclear fuel, spent fuel or nuclear waste

Industrial applications

oil and gas exploration : use in conjunction with a neutron source to locate hydrogenous materials, severe 320°C temperature and vibrations environment

neutron scattering experiments for material science, food and medical research

Neutron radiography : Non destructive survey of materials



Neutron radiography X-ray radiography

Nuclear reactor instrumentation

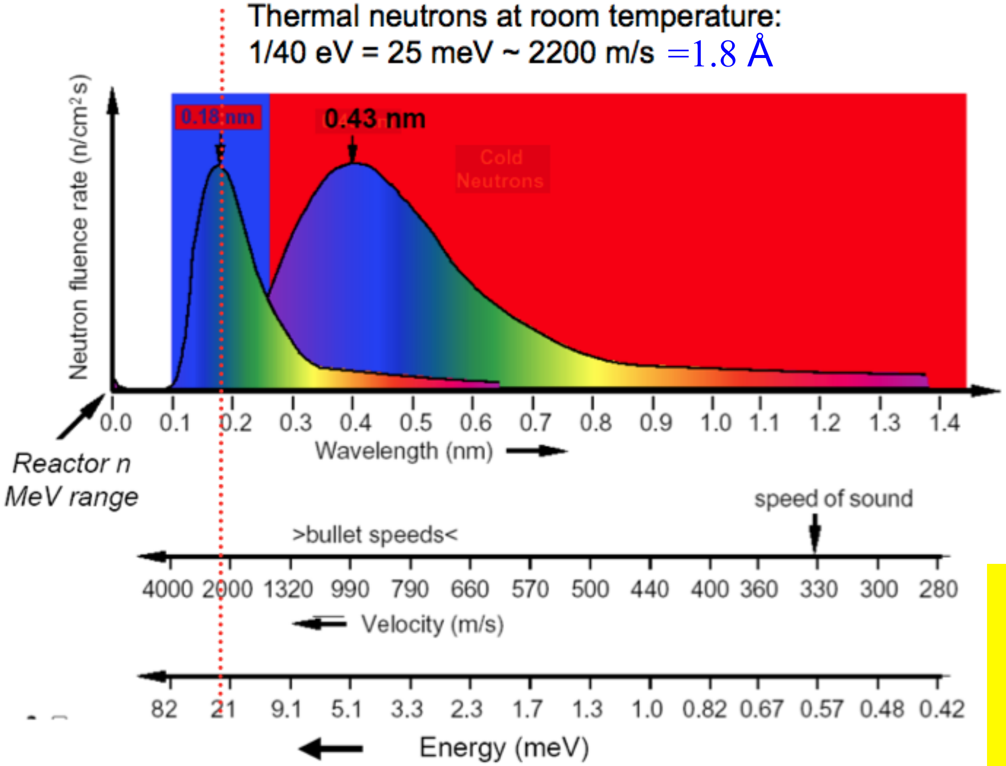
Control (neutron flux) & safety

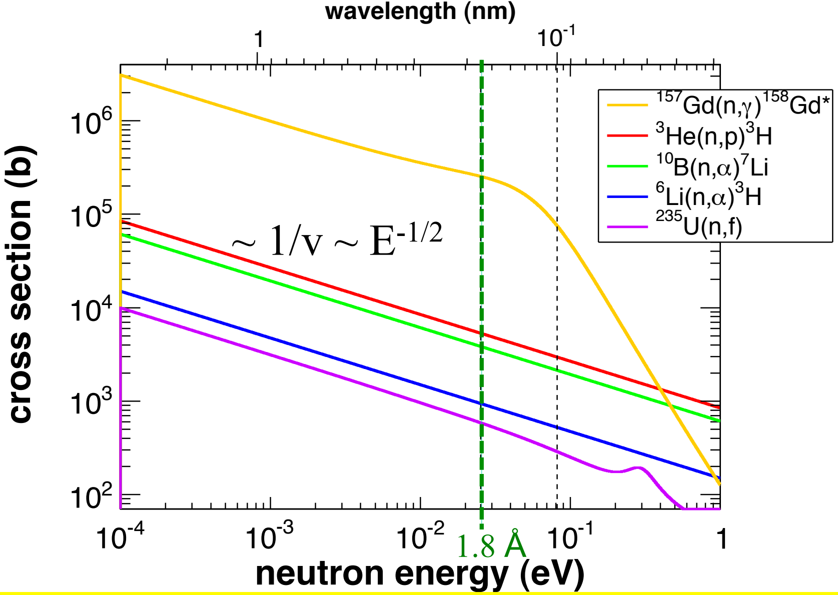
Out core (in measurement pits) : > 10^{10} n.cm^{-2}.s^{-1}, 10^{3} à 10^{4} Gy.h^{-1}of γ, 80 to 100°C.

In core (in guide tubes in the center of the fuel elements assembly) :
> 10^{14} n.cm^{-2}.s^{-1}, 10^{7} Gy.h^{-1} of γ, 320°C.

Detecting neutrons

As charge-neutral particles, neutrons can only interact via strong interactions and ionize via secondary reactions





2 ways to detect fast neutrons

– Thermalize → only provide neutron flux (lose position)

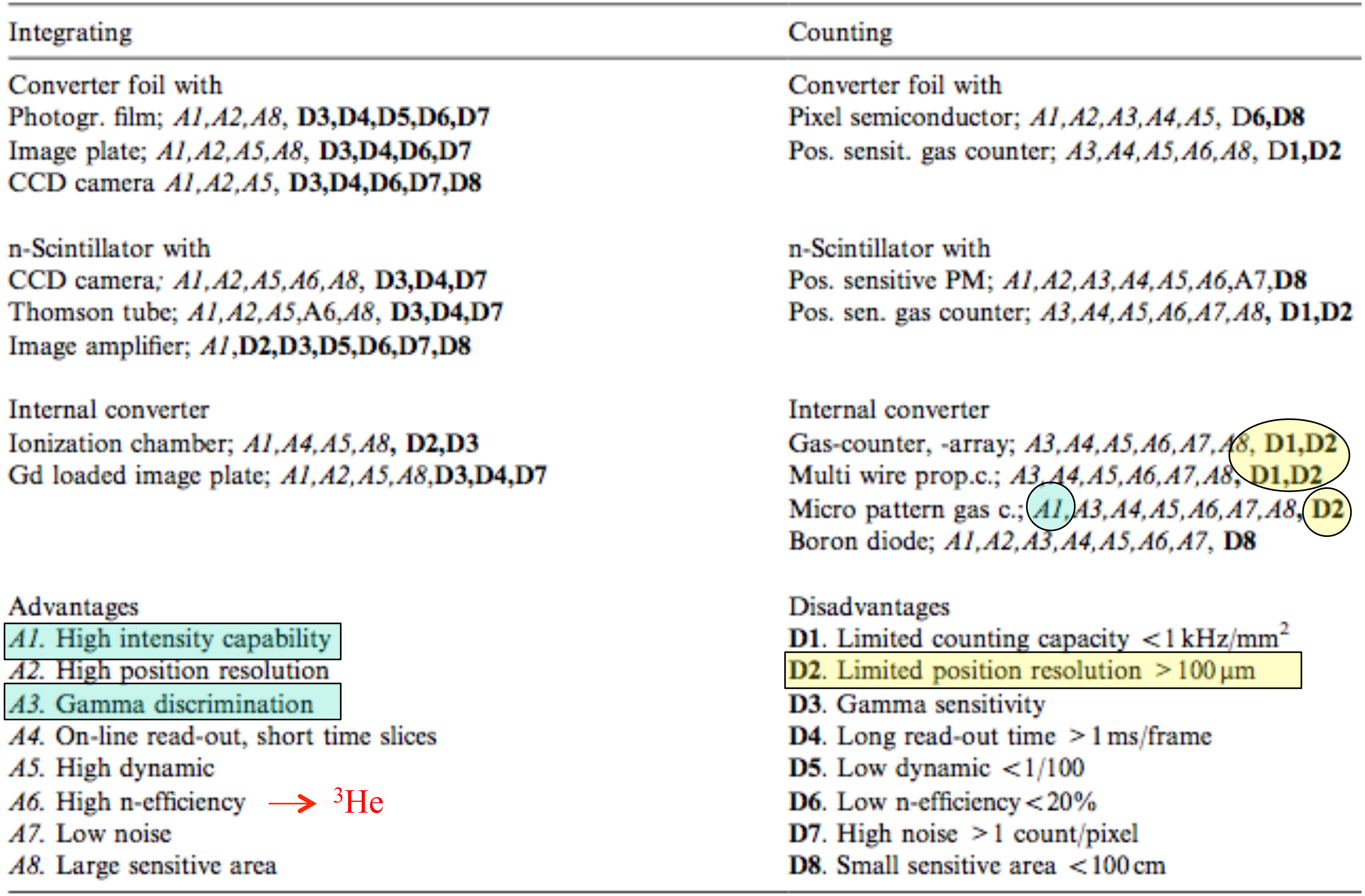
– Elastic scattering from protons at high energy : proton detection & reconstruction of recoils for time-of-flight (ToF)

Commonly Used thermal Neutron Reactions

		Reaction	Light fragment (l.fr)	Energy (MeV)	Heavy fragment (h.fr.)	Energy (MeV)	Natural abundance	25,3 meV Cross Section (b)
	gas	n (^{3}He, p) ^{3}H	p	0.57	^{3}H	0.19	1,4 10^{-4} %	5320
	solid	n (^{6}Li, α) ^{3}H	^{3}H	2.74	α	2.05	7,4%	942
93%		n (^{10}B, α) ^{7}Li +γ	α	1.47	^{7}Li	0.83	19.8%	3842
7%		n (^{10}B, α)	α	1.77	^{7}Li	1.01		
		n (^{235}U, l. fr.) h. fr.	l. fr.	⩽ 80	h. fr.	⩽ 60	0,7%	
		n (^{157}Gd, Gd) e⁻	Conversion electron	0.07–0.182			16%	255k
		n(^{113}Cd, Cd) e- + γs	Conversion electrons	0,558			20,7k	

Ref: A. Oed, NIM A 525 (2004) 62–68

Position sensitive detectors for thermal neutrons

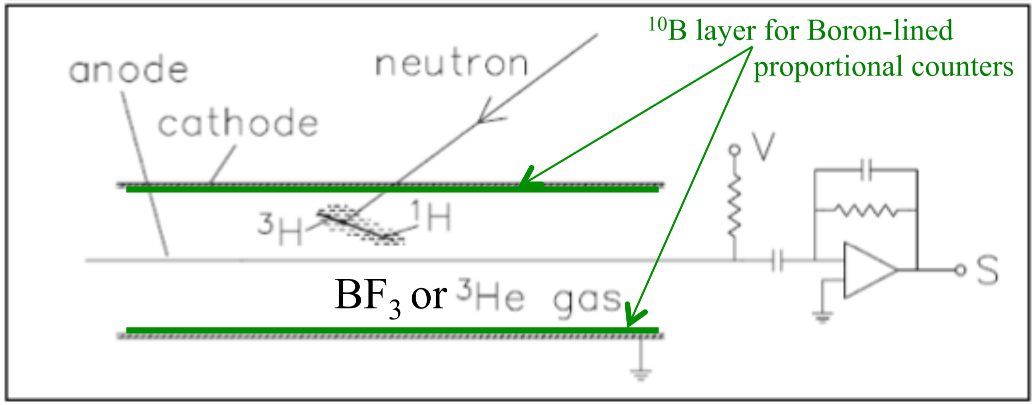


Integrating	Counting
Converter foil with	Converter foil with
Photogr. film; *A1,A2,A8*, **D3,D4,D5,D6,D7**	Pixel semiconductor; *A1,A2,A3,A4,A5*, **D6,D8**
Image plate; *A1,A2,A5,A8*, **D3,D4,D6,D7**	Pos. sensit. gas counter; *A3,A4,A5,A6,A8*, **D1,D2**
CCD camera *A1,A2,A5*, **D3,D4,D6,D7,D8**	
n-Scintillator with	n-Scintillator with
CCD camera; *A1,A2,A5,A6,A8*, **D3,D4,D7**	Pos. sensitive PM; *A1,A2,A3,A4,A5,A6*,A7,**D8**
Thomson tube; *A1,A2,A5*,A6,*A8*, **D3,D4,D7**	Pos. sen. gas counter; *A3,A4,A5,A6,A7,A8*, **D1,D2**
Image amplifier; *A1*,**D2,D3,D5,D6,D7,D8**	
Internal converter	Internal converter
Ionization chamber; *A1,A4,A5,A8*, **D2,D3**	Gas-counter, -array; *A3,A4,A5,A6,A7,A8*, **D1,D2**
Gd loaded image plate; *A1,A2,A5,A8*,**D3,D4,D7**	Multi wire prop.c.; *A3,A4,A5,A6,A7,A8*, **D1,D2**
	Micro pattern gas c.; *A1,A3,A4,A5,A6,A7,A8*, **D2**
	Boron diode; *A1,A2,A3,A4,A5,A6,A7*, **D8**
Advantages	Disadvantages
A1. High intensity capability	**D1**. Limited counting capacity $<1\,\mathrm{kHz/mm^2}$
A2. High position resolution	**D2**. Limited position resolution $>100\,\mu\mathrm{m}$
A3. Gamma discrimination	**D3**. Gamma sensitivity
A4. On-line read-out, short time slices	**D4**. Long read-out time >1 ms/frame
A5. High dynamic	**D5**. Low dynamic $<1/100$
A6. High n-efficiency → ^{3}He	**D6**. Low n-efficiency $<20\%$
A7. Low noise	**D7**. High noise >1 count/pixel
A8. Large sensitive area	**D8**. Small sensitive area <100 cm

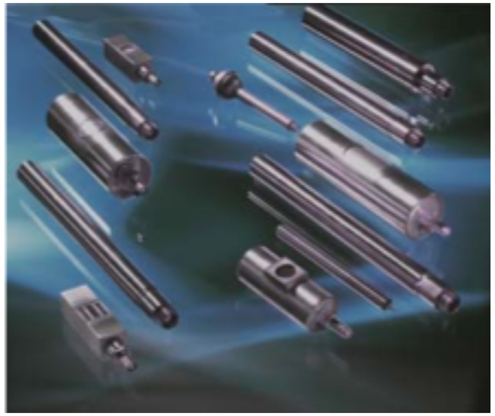
Ref: A. Oed, NIM A 525 (2004) 62–68

Commonly and worldwide used thermal neutron detectors

Gas proportional counters



γ lab. St Gobain (Fr)



centronics (UK)

Typical 25 mm diameter tube, 50 µm anode

C ~ 20 pF / $T_{collection}$ > 10 µs (!)

^{3}He gas counters

P=5-10 bar (!)

V >850V (2 bar)

1.75 kV (10 bar)

Gain~ >20

BF$_3$ gas counters

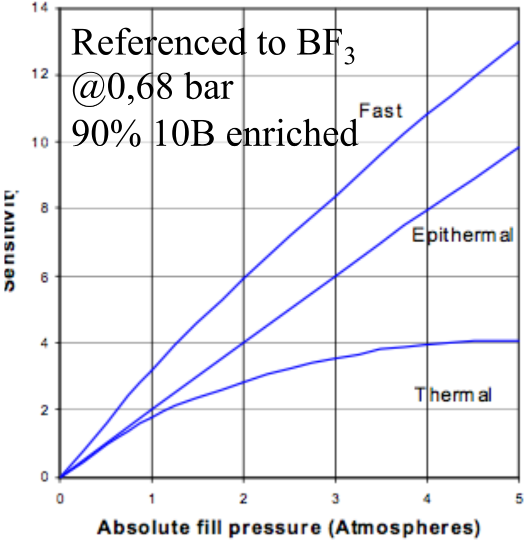
Toxic & corrosive

P ~ 0.5 – 1 atm

reV~ 2000 – 3000 V

Gain ~ 100-500

	10 bar 25 mm diameter 3He
Detector characteristics	
Neutron Efficiency	70% at 1 A
Gamma sensitivity	10^{-6}
Background	10 – 15 counts/h/m
Width	25 mm
Length	1 -3 m
Resolution	15 – 25 mm at FWHM
Local rate capability	50 kHz on a pixel
Global rate capability	50 kHz on a tube
Time resolution	1 µs
Area	15 – 40 m^2
Environment	Cryogenic vacuum



Referenced to BF$_3$
@0,68 bar
90% 10B enriched

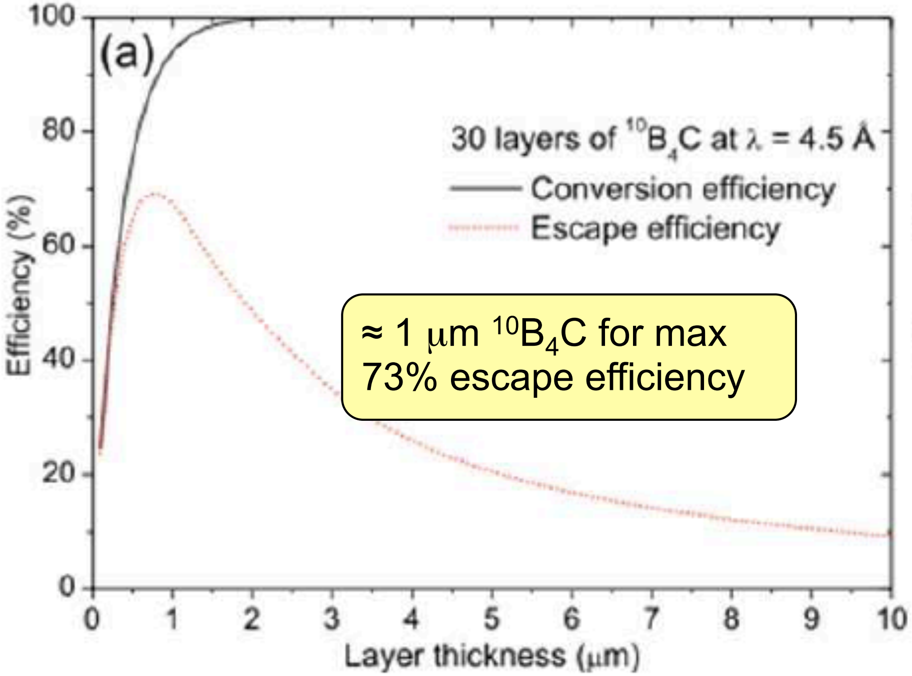
The 'SENSITIVITY' scale is the sensitivity of a 25 mm diameter ^{3}He couter using a comparable BF$_3$ as a reference

… and Boron-lined proportional counters (^{10}B conversion layer, Ar+CO$_2$ …)

Optimum converter layer thickness and detection efficiency

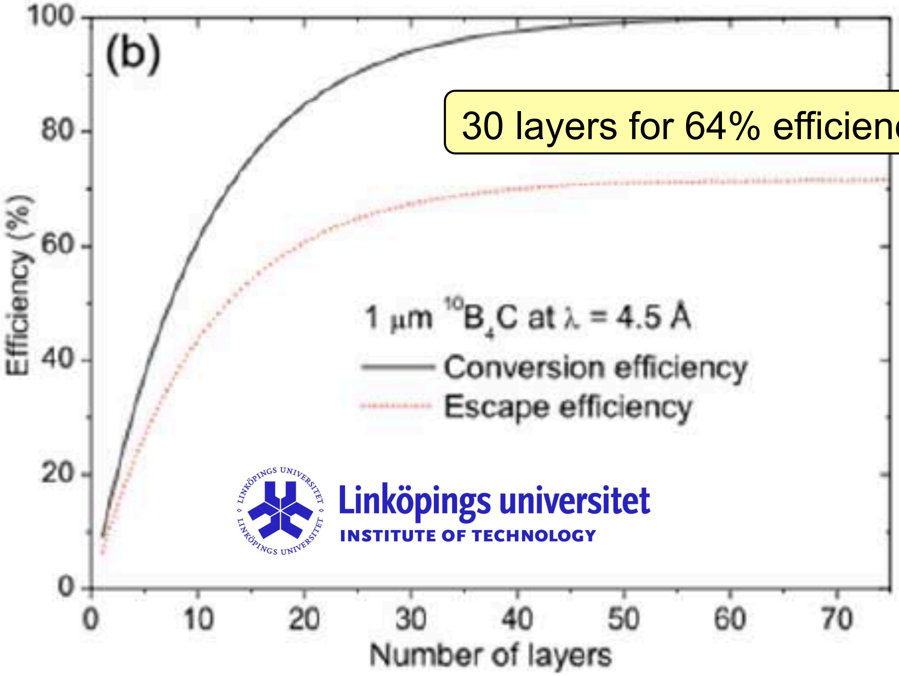
Ref: C. Höglund, J. Birch, *et al.* "B4C thin films for neutron detection", JVST, submitted (2011)

Efficiency vs. thickness (single layer)



≈ 1 µm $^{10}B_4C$ for max 73% escape efficiency

Efficiency vs. Number of layers



30 layers for 64% efficiency

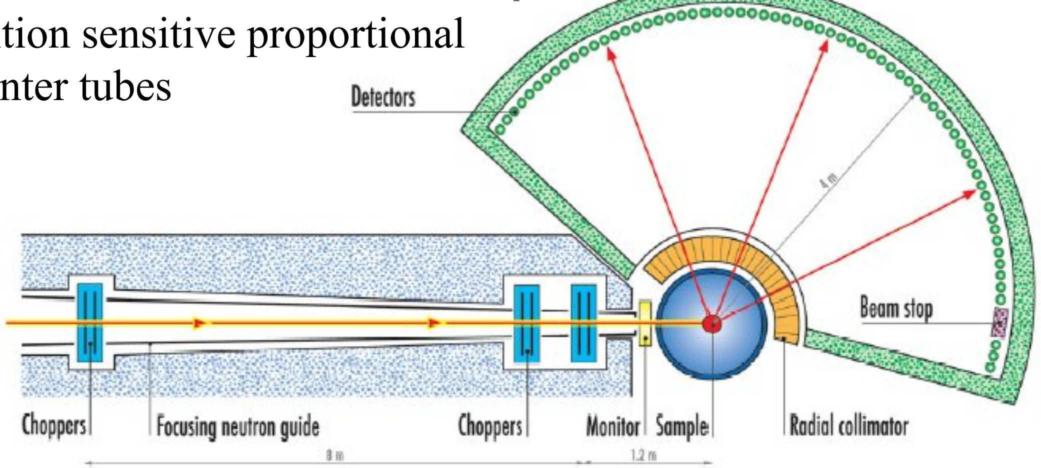
Other foil materials @1.8 Å

Foil material	Optimum foil thickness *d* (µm)	n Detection efficiency %
^{6}Li	112	13.6
^{6}LiF	29	5.8
^{10}B	3.4	6.4
Gd nat	~3.5	<11
^{235}U	6.4	0.7

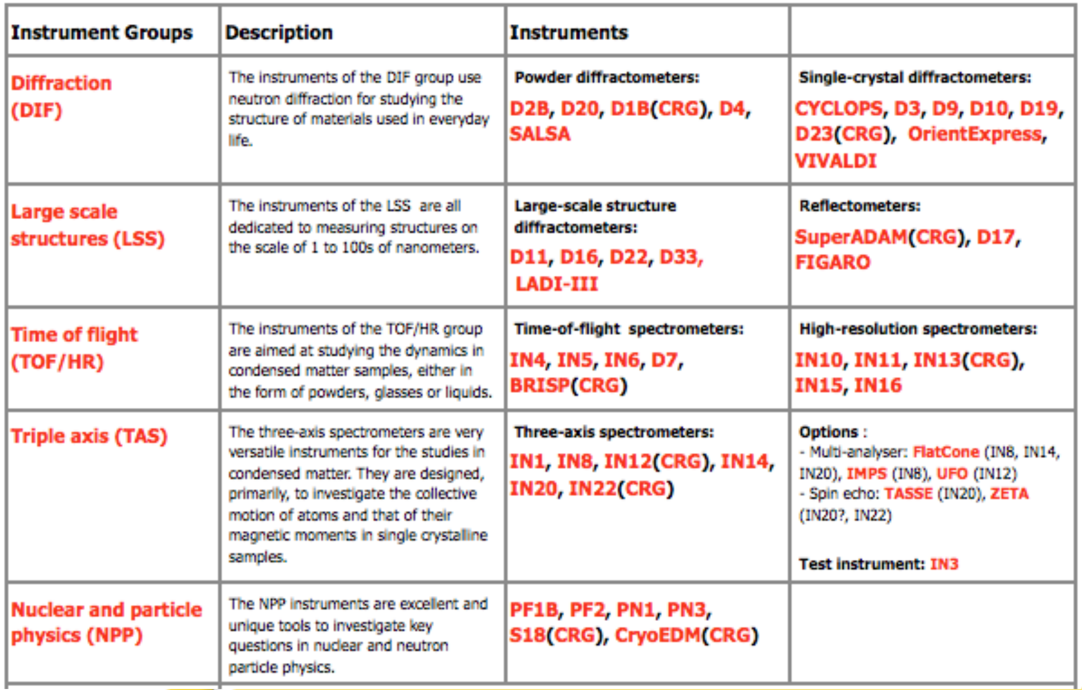
Ref: A. Oed, NIM A 525 (2004) 62–68

Beam-line IN5@ILL: a time-of-flight spectrometer for quasi-elastic and inelastic scattering

Position sensitive proportional
Counter tubes

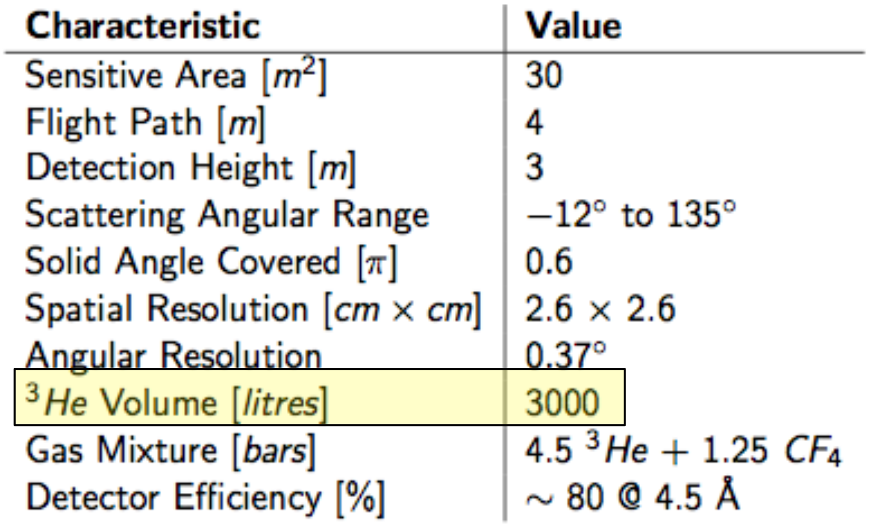


http://www.ill.eu/fileadmin/users_files/multimedia/IN5/ill_in5.swf



Instrument Groups	Description	Instruments	
Diffraction (DIF)	The instruments of the DIF group use neutron diffraction for studying the structure of materials used in everyday life.	**Powder diffractometers:** **D2B, D20, D1B(CRG), D4, SALSA**	**Single-crystal diffractometers:** **CYCLOPS, D3, D9, D10, D19, D23(CRG), OrientExpress, VIVALDI**
Large scale structures (LSS)	The instruments of the LSS are all dedicated to measuring structures on the scale of 1 to 100s of nanometers.	**Large-scale structure diffractometers:** **D11, D16, D22, D33, LADI-III**	**Reflectometers:** **SuperADAM(CRG), D17, FIGARO**
Time of flight (TOF/HR)	The instruments of the TOF/HR group are aimed at studying the dynamics in condensed matter samples, either in the form of powders, glasses or liquids.	**Time-of-flight spectrometers:** **IN4, IN5, IN6, D7, BRISP(CRG)**	**High-resolution spectrometers:** **IN10, IN11, IN13(CRG), IN15, IN16**
Triple axis (TAS)	The three-axis spectrometers are very versatile instruments for the studies in condensed matter. They are designed, primarily, to investigate the collective motion of atoms and that of their magnetic moments in single crystalline samples.	**Three-axis spectrometers:** **IN1, IN8, IN12(CRG), IN14, IN20, IN22(CRG)**	**Options :** - Multi-analyser: **FlatCone** (IN8, IN14, IN20), **IMPS** (IN8), **UFO** (IN12) - Spin echo: **TASSE** (IN20), **ZETA** (IN20?, IN22) **Test instrument: IN3**
Nuclear and particle physics (NPP)	The NPP instruments are excellent and unique tools to investigate key questions in nuclear and neutron particle physics.	**PF1B, PF2, PN1, PN3, S18(CRG), CryoEDM(CRG)**	

3m long position-sensitive proportional counters



Characteristic	Value
Sensitive Area [m^2]	30
Flight Path [m]	4
Detection Height [m]	3
Scattering Angular Range	$-12°$ to $135°$
Solid Angle Covered [π]	0.6
Spatial Resolution [$cm \times cm$]	2.6×2.6
Angular Resolution	0.37°
^3He Volume [$litres$]	3000
Gas Mixture [$bars$]	4.5 ^3He + 1.25 CF_4
Detector Efficiency [%]	$\sim$ 80 @ 4.5 Å

The ^{3}He crisis

^{3}He is a by product of Tritium production for use in nuclear weapons by Titium ß-decay into ^{3}He with a half life of 12.3 years.
End of the Cold War the ^{3}He : production from Tritium decay has been reduced and since September 2001 the demand of ^{3}He has increased drastically due to security programs

→ severe depletion of the existing ^{3}He stockpile and shortage.
→ Cost increase by a factor of 25 , from 80 €/l up to 2000 €/l.

The cost for the ILL/IN5 30 m^2 ^{3}He detector (3000 l @ 4.5 bars) was 1.5 M€ (incl. 240 k€ for ^{3}He). It would cost 7.2 M€ (incl. 6 M€ for ^{3}He) today !!!

^{3}He demand for neutron scattering in 2009 – 2015 is estimated to 125 kl and the projected demand for US security applications is 100 kl for a ≈20 kl/year available (US+Russia)
Needs for hundreds of m^2 for ESS : 140 m^2 in 2019 for 7 detectors (22 detectors in 2024)

→ Need for alternatives !! (with close performances to a 10 bar 1 inch ^{3}He tube)

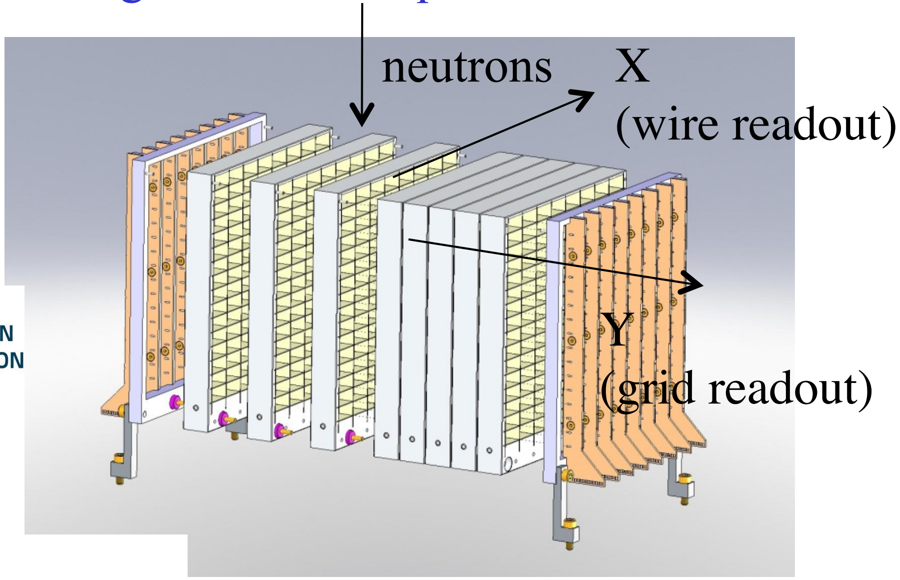
→ The NMI3-II/JRA FP7 program started in february 2012 …
« Neutron Scattering and Muon Spectroscopy Integrated Initiative »

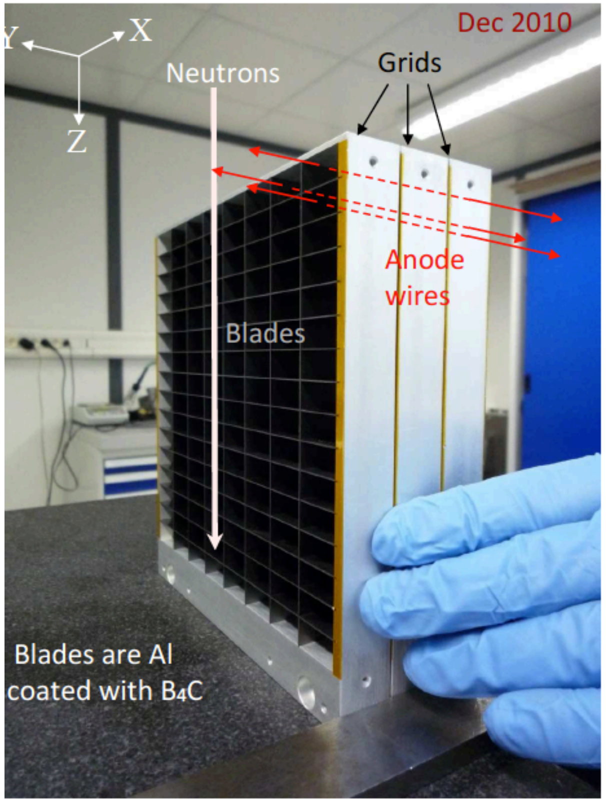
… and includes work packages to support R&D for ^{3}He alternatives

The ILL multi-grid area detector (ILL-Patent appl. #: 20110215251)

A grid is made of Boron-coated aluminum blades forming sections of square tubes

Stacking of several grids to make Boron coated tubes
The grids are electrically insulated
Anode wires are mounted in the middle of each tube

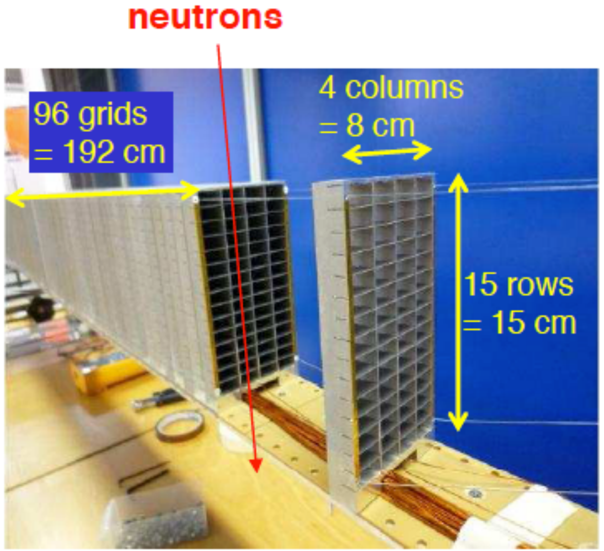




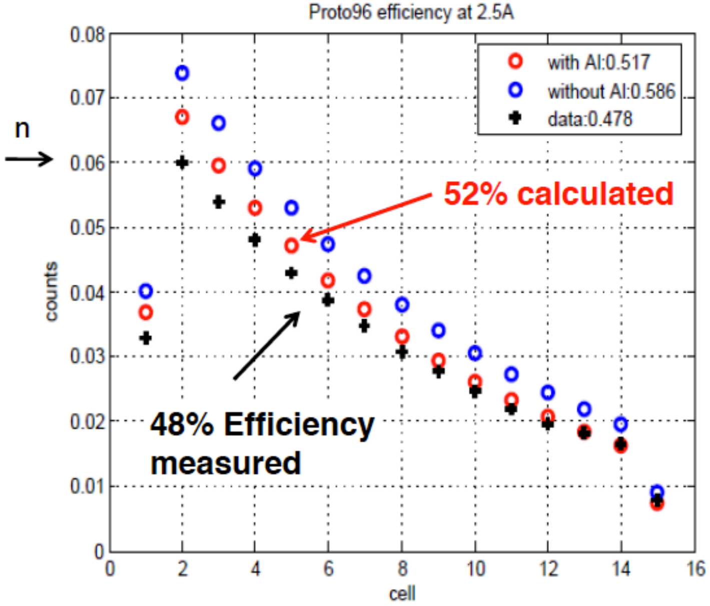
NEUTRONS FOR SCIENCE

EUROPEAN SPALLATION SOURCE

Linköpings universitet
INSTITUTE OF TECHNOLOGY



Proto #2, spring 2011

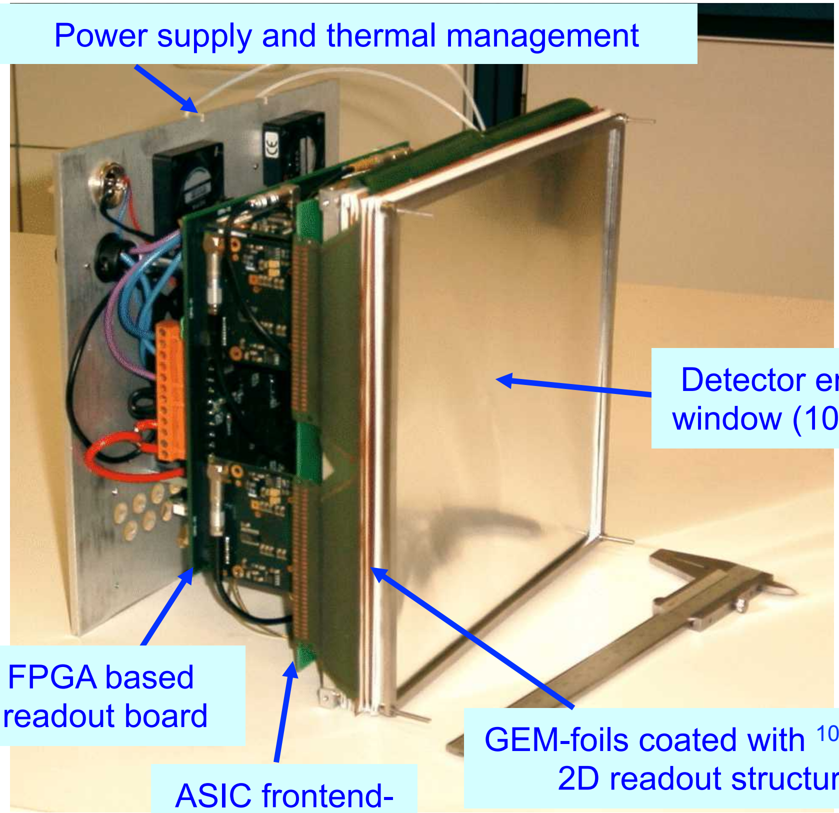


Ref: B. Guerard *et al.* ECNS-conference, July 2011, Prague

The CACADE GEM detector

Christian J. Schmidt et al (GSI, Darmstadt)

2D-200 CASCADE Detector (200x200 mm^2)



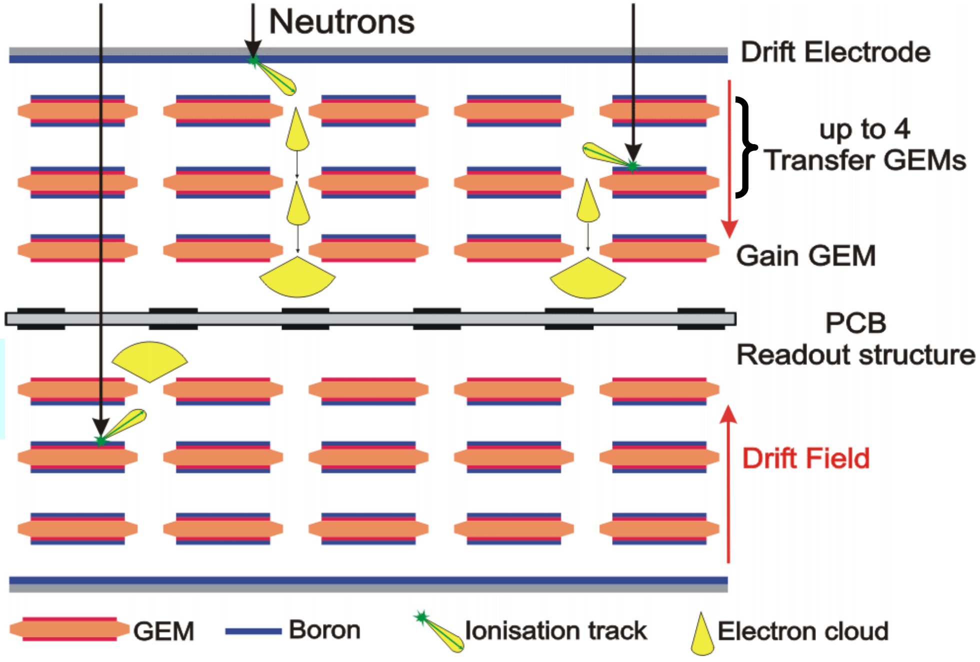
Power supply and thermal management

Detector entrance window (100 µm Al)

FPGA based readout board

ASIC frontend-electronic

GEM-foils coated with ^{10}B and 2D readout structure



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

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

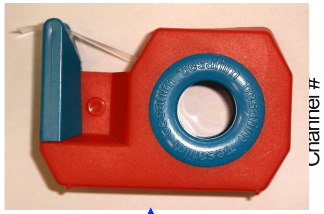
→ Other solutions based on Boron-coated straw tubes
→ room for innovative ideas to maximize conversion efficiency

2D-200 CACADE GEM detector performances

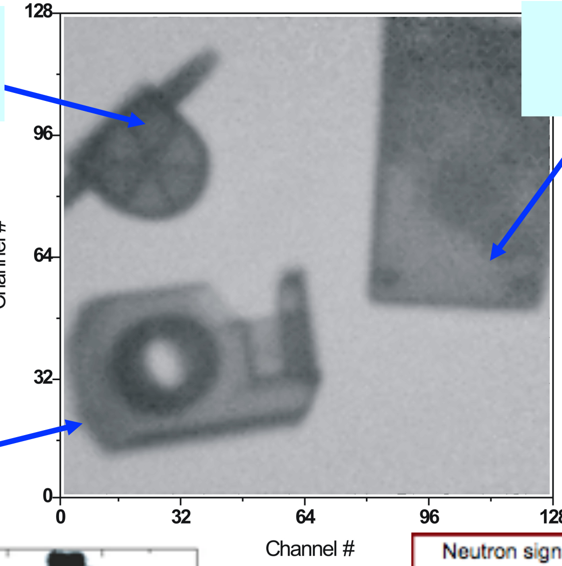
A radiography with the CACADE GEM detector

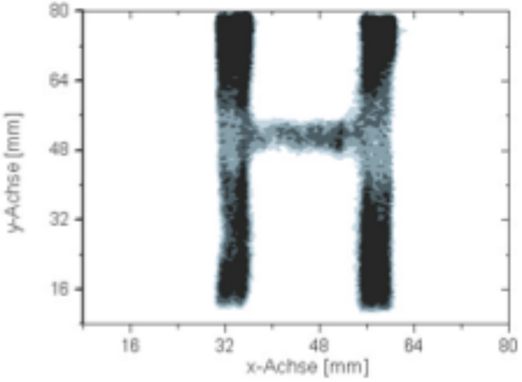
Water Flow-Indicator

Old PC Mouse

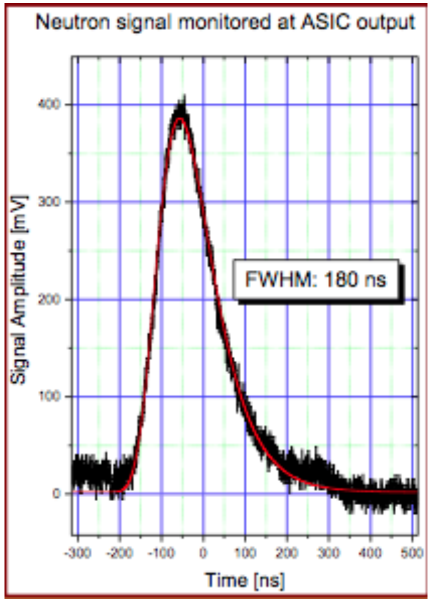


Tesa-Tape Dispenser

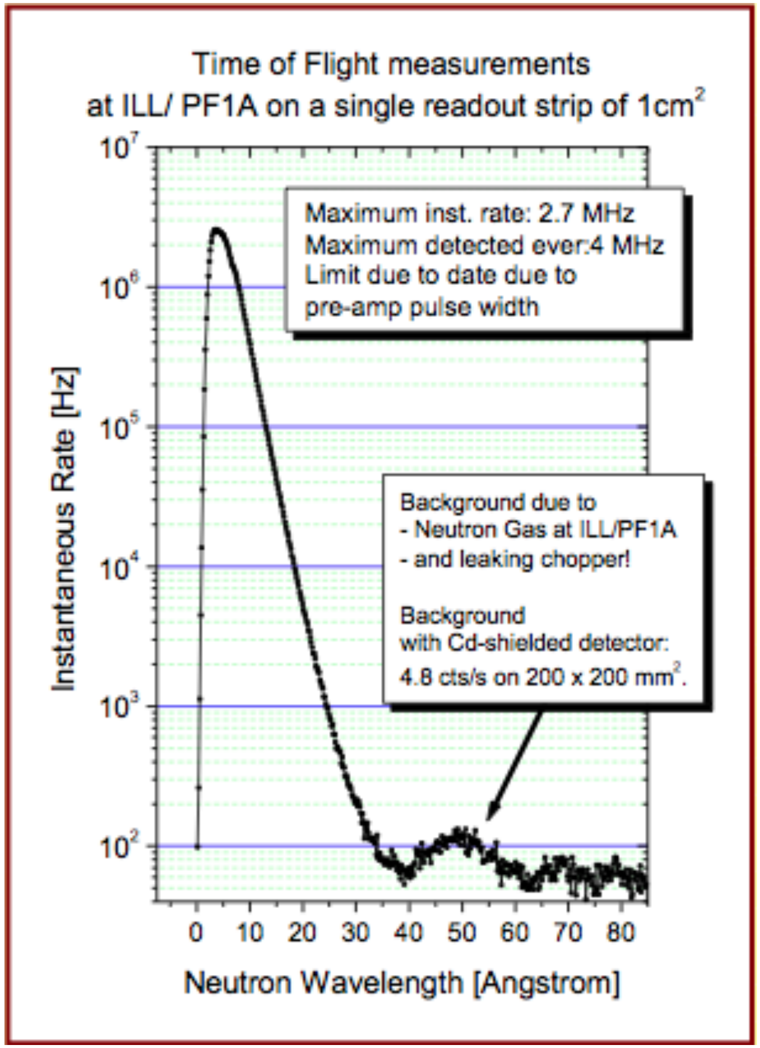




~ 1-3 mm spatial resolution
with 1.56 mm pixel size



TOF Dynamics Achieved with CASCADE

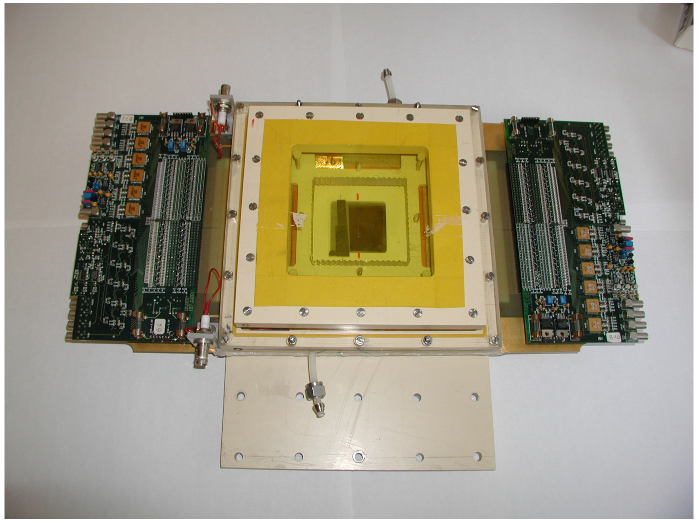


10 MHz/cm^2 counting rate capability

Ref:Christian J. Schmidt et al. (GSI Darmstadt)

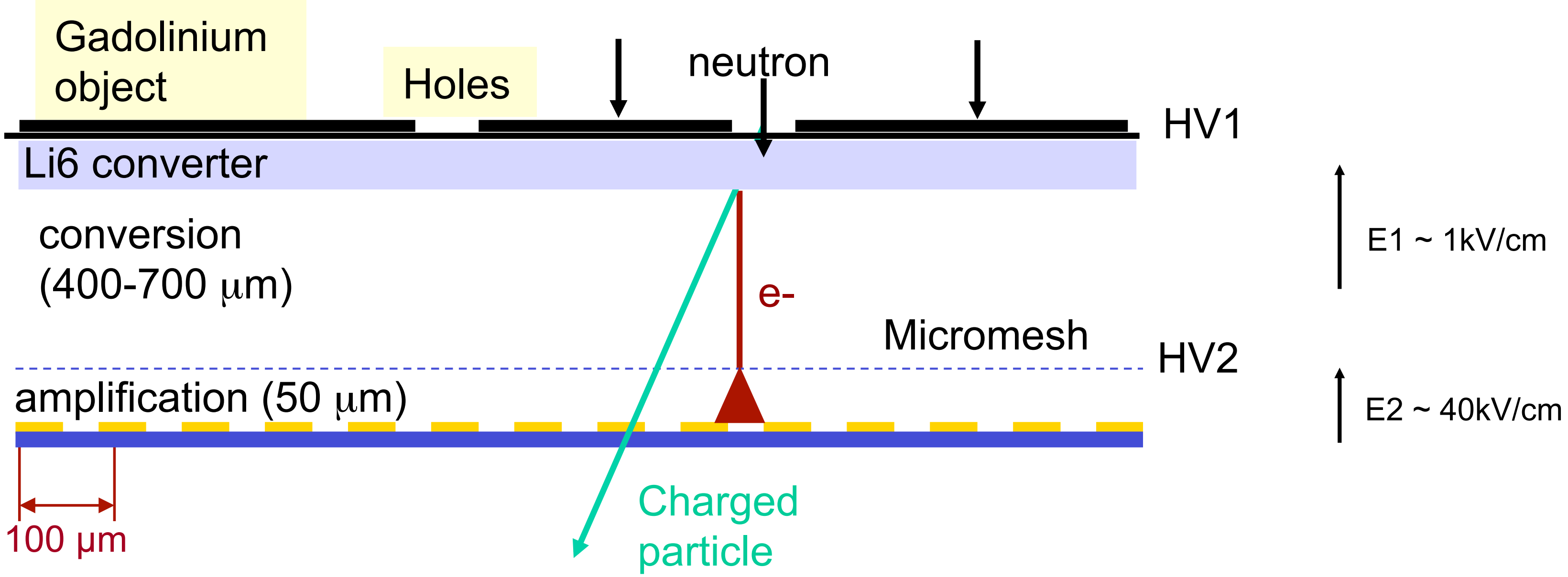
Micromegas for neutron radiography

- CEA/DSM-IRFU + CEA/DRT-LIST-DETECS collab.
- « classical » micromegas prototype
- proof of principle (1D 2002, 2D 2004)



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

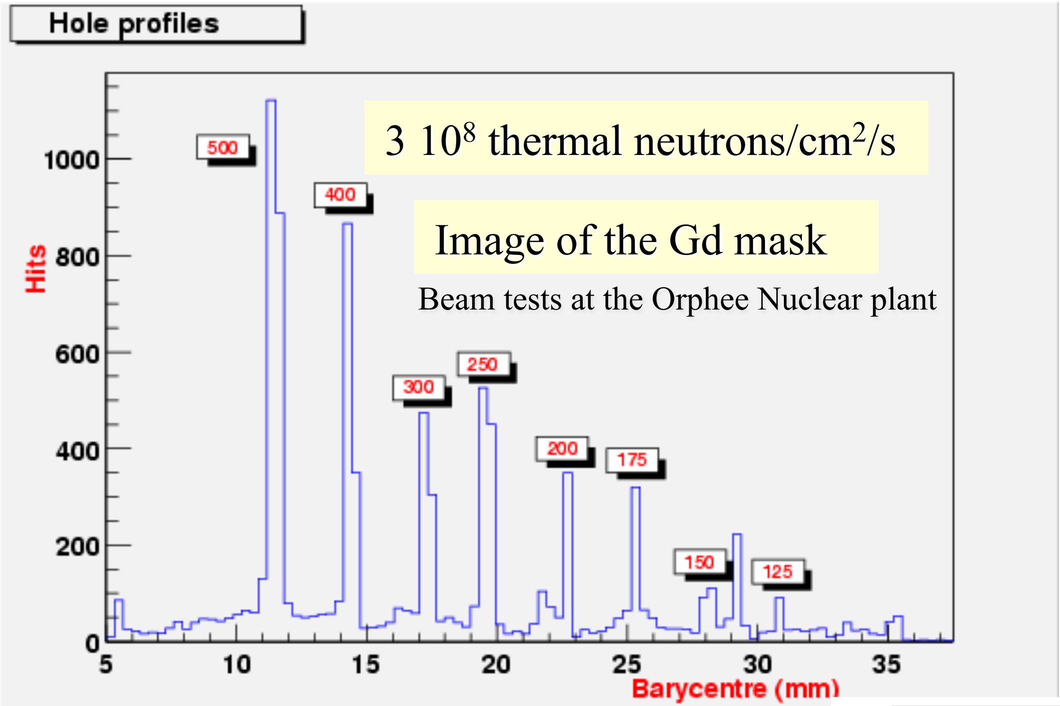
Imaging Mask: Gadolinium foil (5x5 cm², 25 µm thin) holes from 75 to 500 µm



alain.delbart@cea.fr / MPGDs for neutron detection applications (Industry-Academia matching event on MPGDs, Annecy, 26-27th april 2012)

Imaging capabilities of the prototypes

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



3 10^8 thermal neutrons/cm^2/s

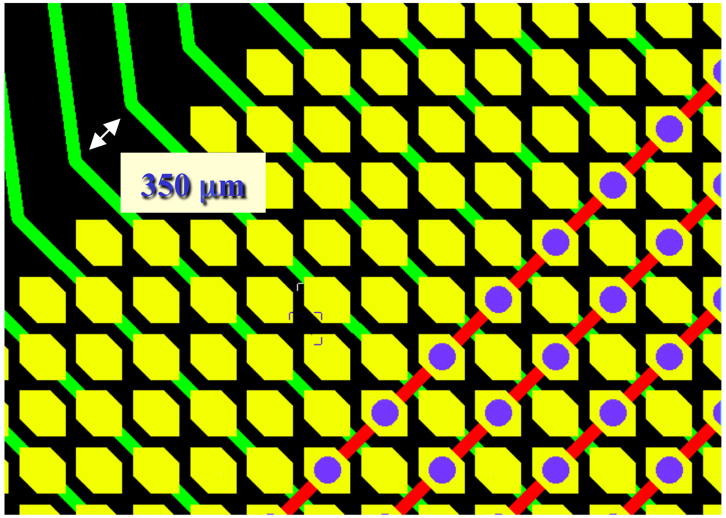
Image of the Gd mask

Beam tests at the Orphee Nuclear plant

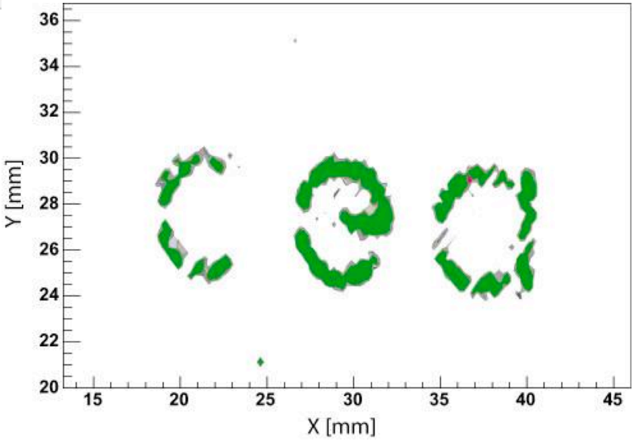
Distorted tomograhy reconstruction with ~160 µm resolution because of the pillars supporting the "classical" micromegas mesh

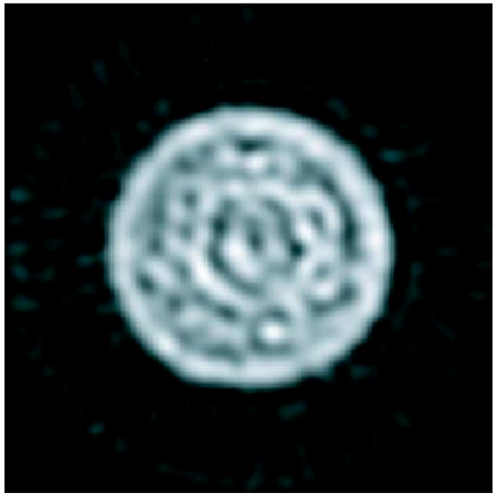
→ Should be greatly improved today by use of the 2D micro-bulk

→ To be continued …



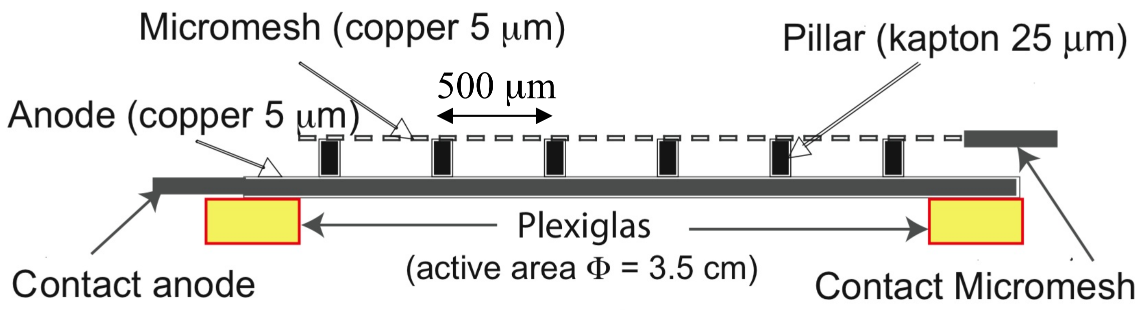
Tomographic image of a multi-wires cable (∅ 6 mm, 12 wires, ∅ 0.5 mm each)





n-TOF transparent neutron beam flux monitor

Micro-bulk technology for very low budget material detector
Use of 2 converters : $^{10}B(n,a)^{7}Li$ for up to 100 eV neutrons and $^{235}U(n,f)$ for 100 eV-1 MeV



Micromesh (copper 5 µm)

Pillar (kapton 25 µm)

500 µm

Anode (copper 5 µm)

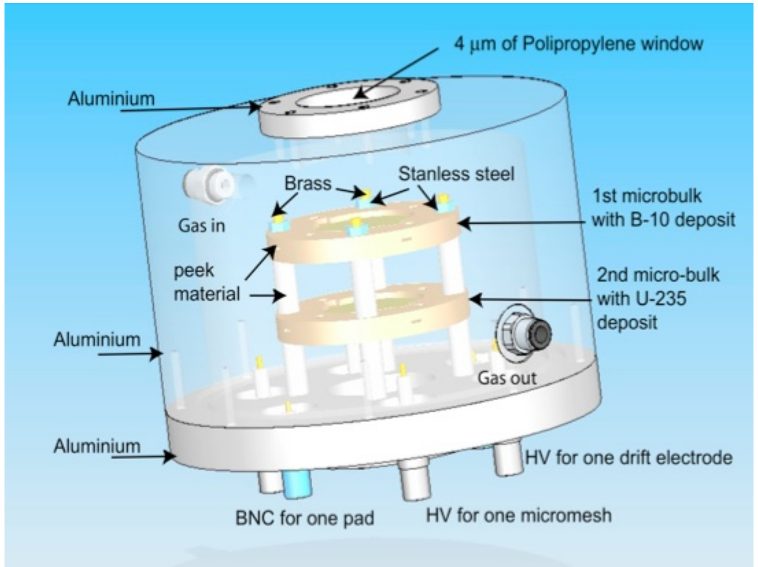
Plexiglas
(active area Φ = 3.5 cm)

Contact anode

Contact Micromesh

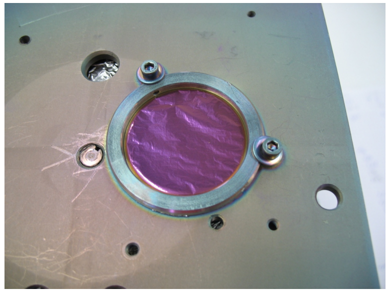
Specifications

- ✓ $Ar+2\%iC_4H_{10}+10\%CF_4$
- ✓ 35 mm diameter active area
- ✓ 1 plane Anode
- ✓ 1 channel : on-shelf fast current preamp. + 1GHz flash ADC



^{10}B Converter

- ✓ Sputtering from B_4C at CERN (0,6 µm)
- ✓ on 1 µm copper coated 12,5 µm Kapton foil
- ✓ ~1 µm on a Φ 35 mm



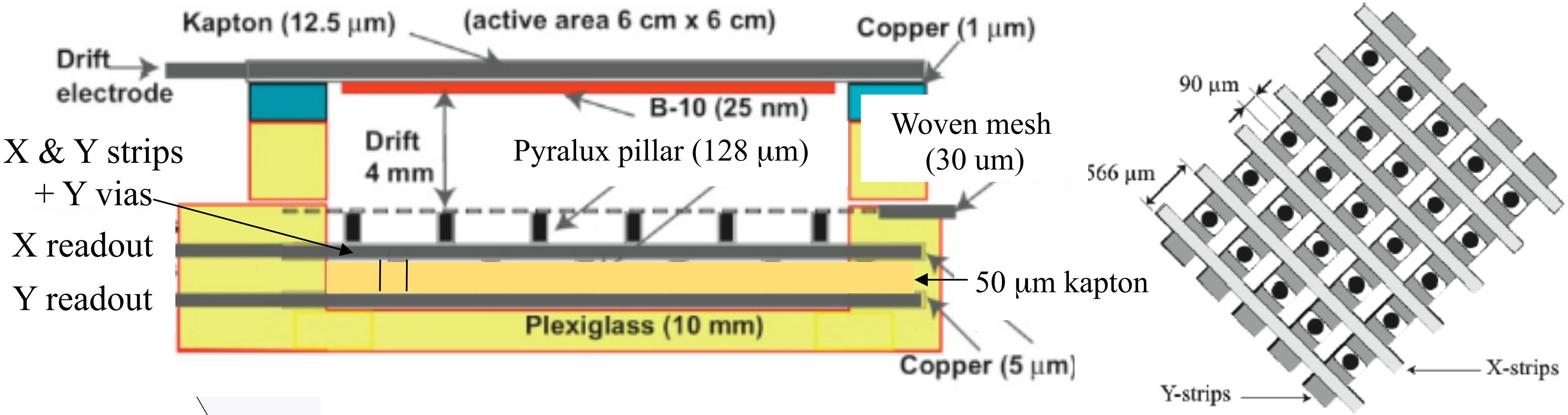
^{235}U Converter

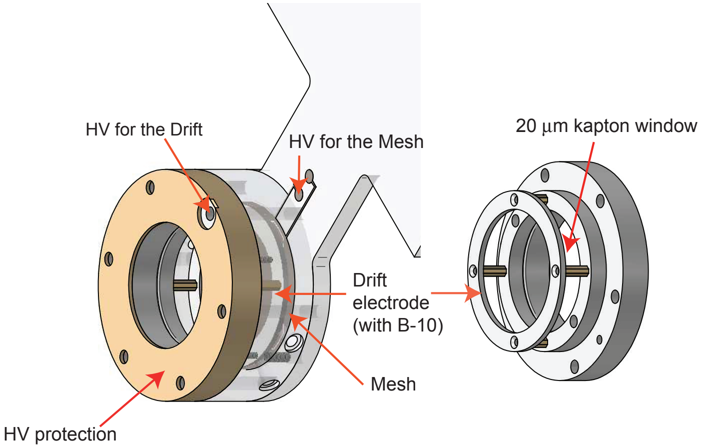
- ✓ Vaccuum Evaporation (1 mg ^{235}U @ 99,94%) at JRC-IRMM (Geel)
- ✓ on 1,5 µm aluminized mylar foil
- ✓ 1 mg on a Φ 20 mm

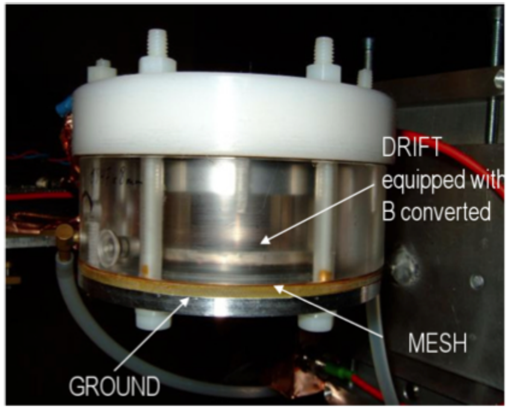
Ref: S. Andriamonge *et.al.*, proceedings of ND2010, International Conference on Nuclear Data for Science and Technology

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







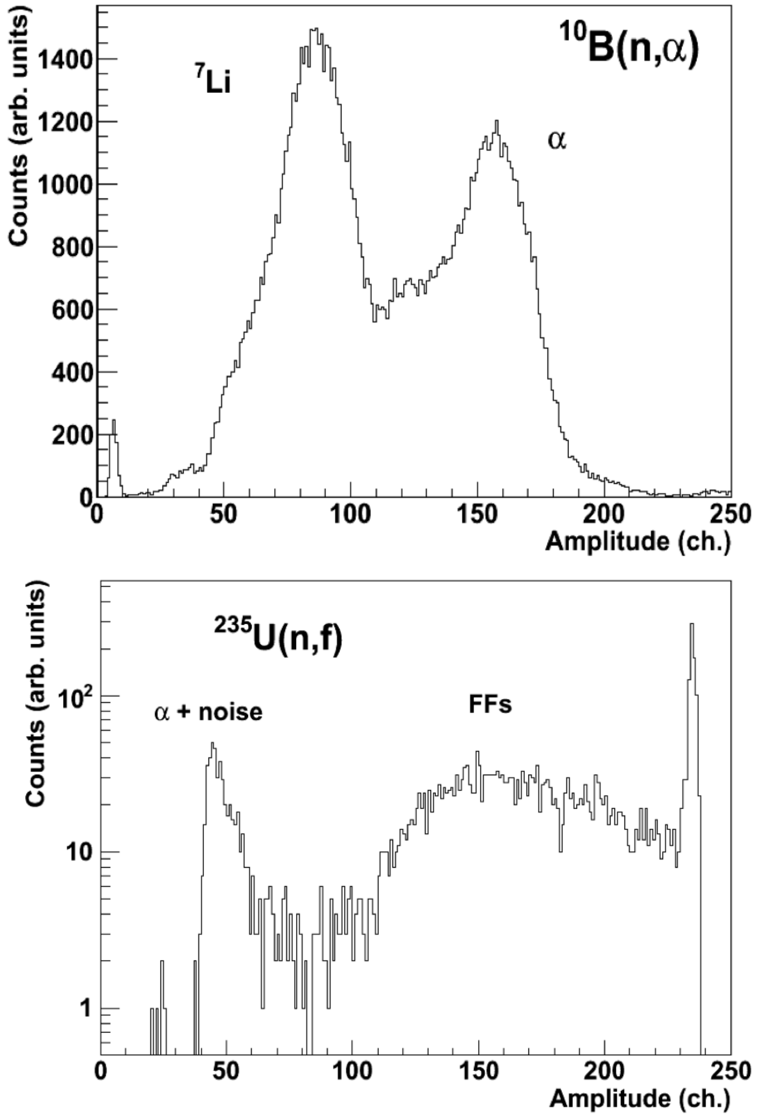
Specifications

- ✓ $Ar+2\%iC_4H_{10}+10\%CF_4$
- ✓ 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

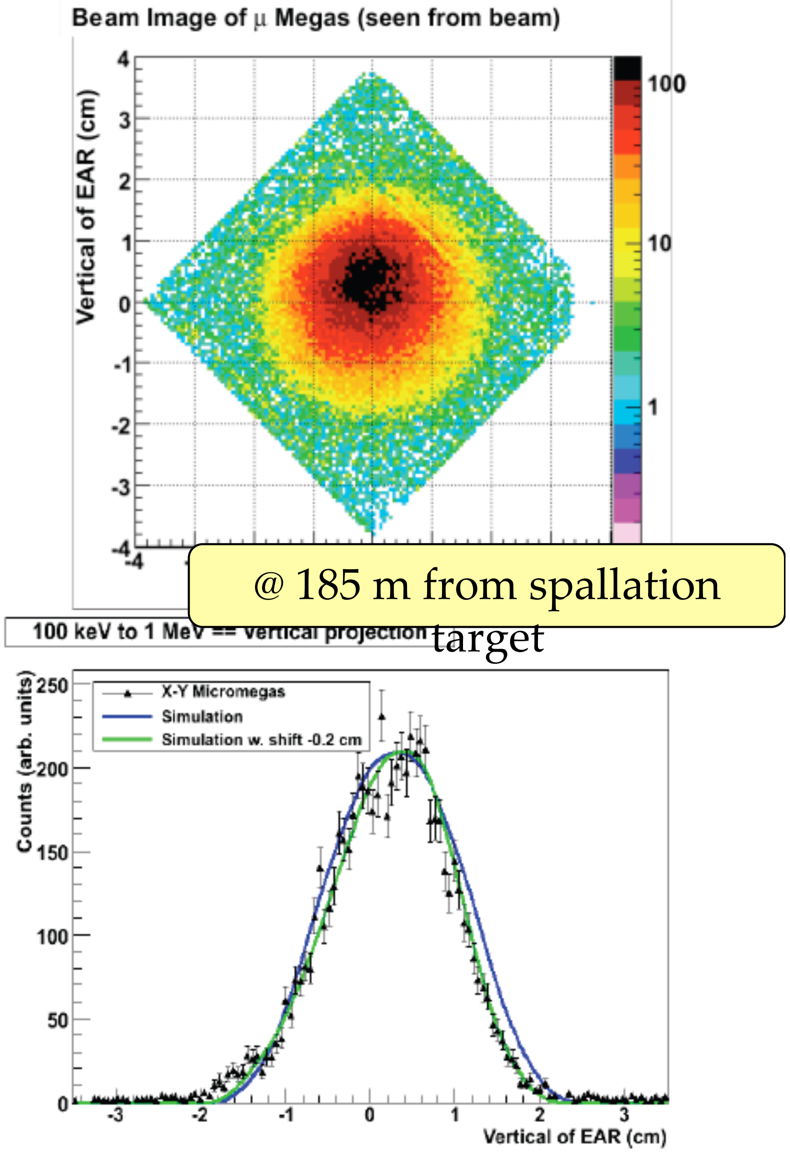
Ref: S. Andriamonge *et.al.*, proceedings of ND2010, International Conference on Nuclear Data for Science and Technology

n-TOF beam profile and flux monitor

n-TOF beam flux monitoring (2008)



n-TOF beam profile (2009)

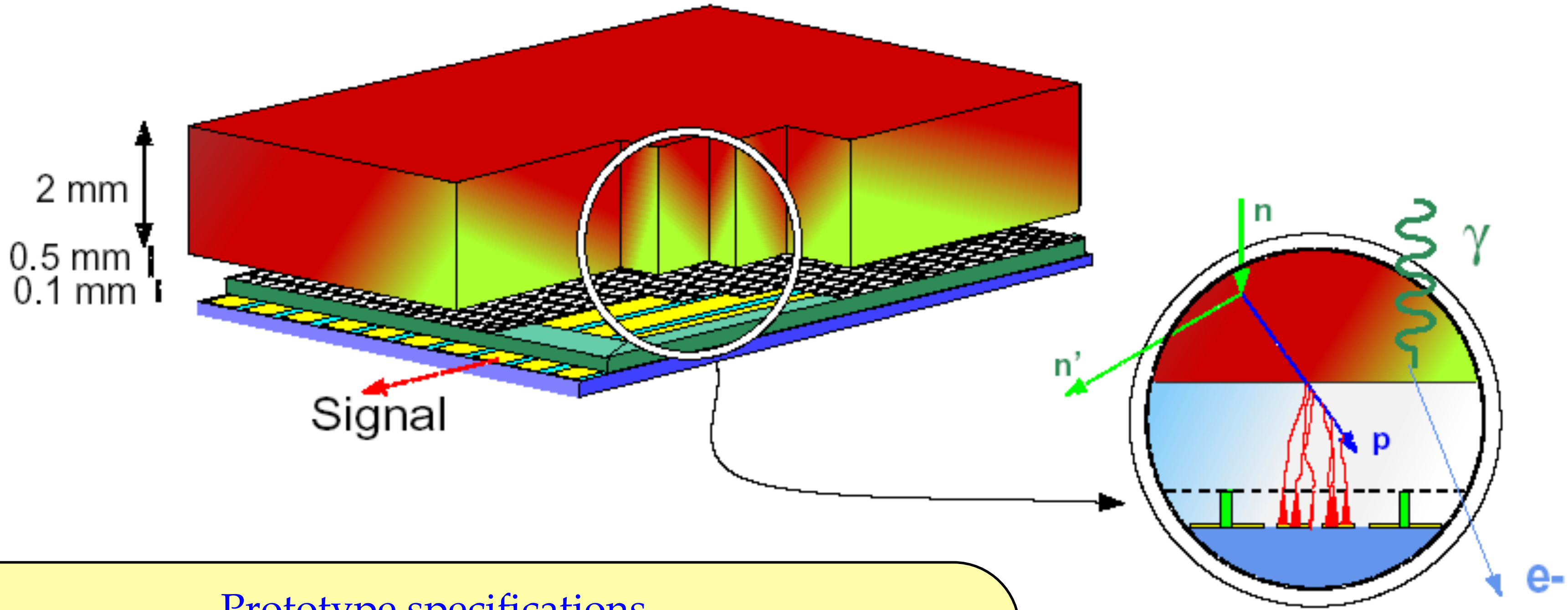


@ 185 m from spallation target

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

DEMIN : Micromegas Detector for Neutron spectroscopy for MégaJoules Laser and ICF experiments

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

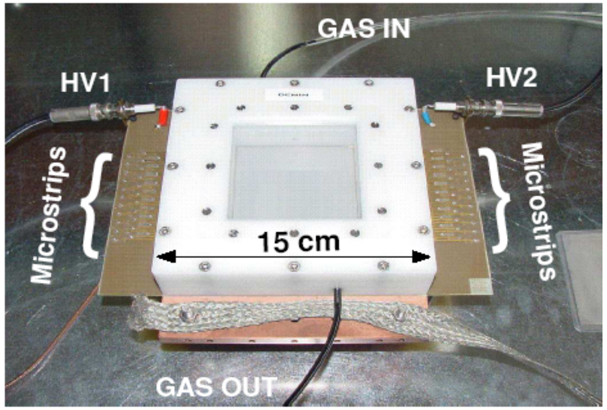


Prototype specifications

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

Front-end electronics

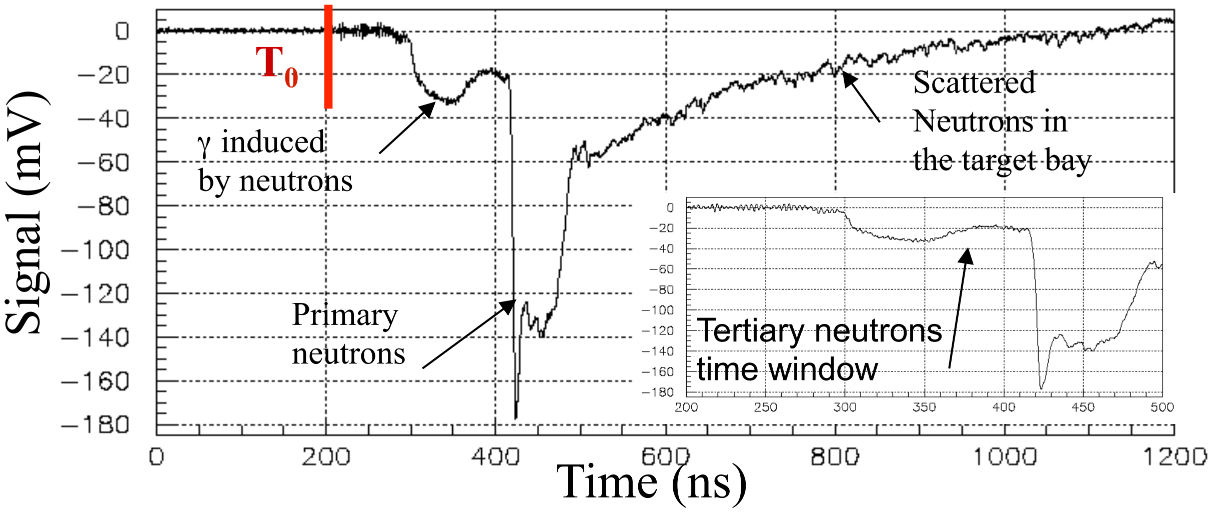
- ✓ Fast current preamp + MATACQ readout (SEDI)
- ✓ 40 electronic channels



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

DEMIN : performances @ OMEGA (Rochester, USA)

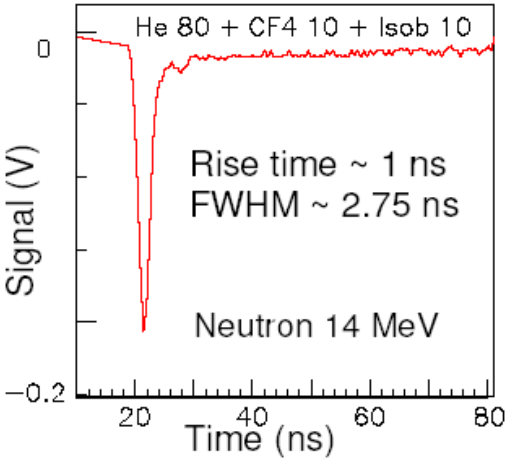
DT SHOT, 31769; 4.10^{13} n$_{14MeV}$



~> Pulse Shape

~> Time of flight : δE/E~1%

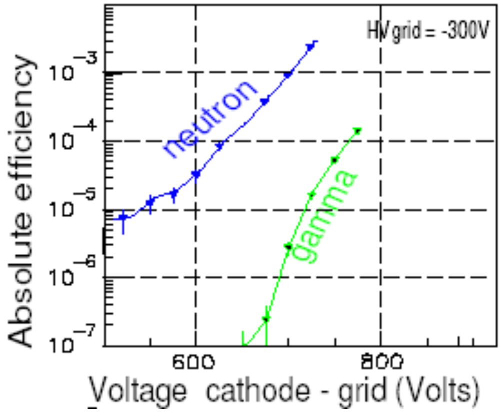
~> Low pile-up : pulse chain



30 eV/mm stopping power of 1 MeV e- in gas
→ the thinner drift gap, the better the γ rejection

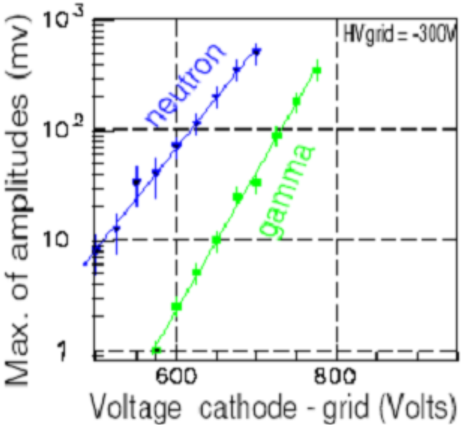
~> n/γ Discrimination

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



Efficiency Ratio

~> 10^2 to 10^3



Pulse Height Ratio

~> 20

DEMIN group (CEA/DIF/DCRE and IRFU)

The Piccolo micromegas

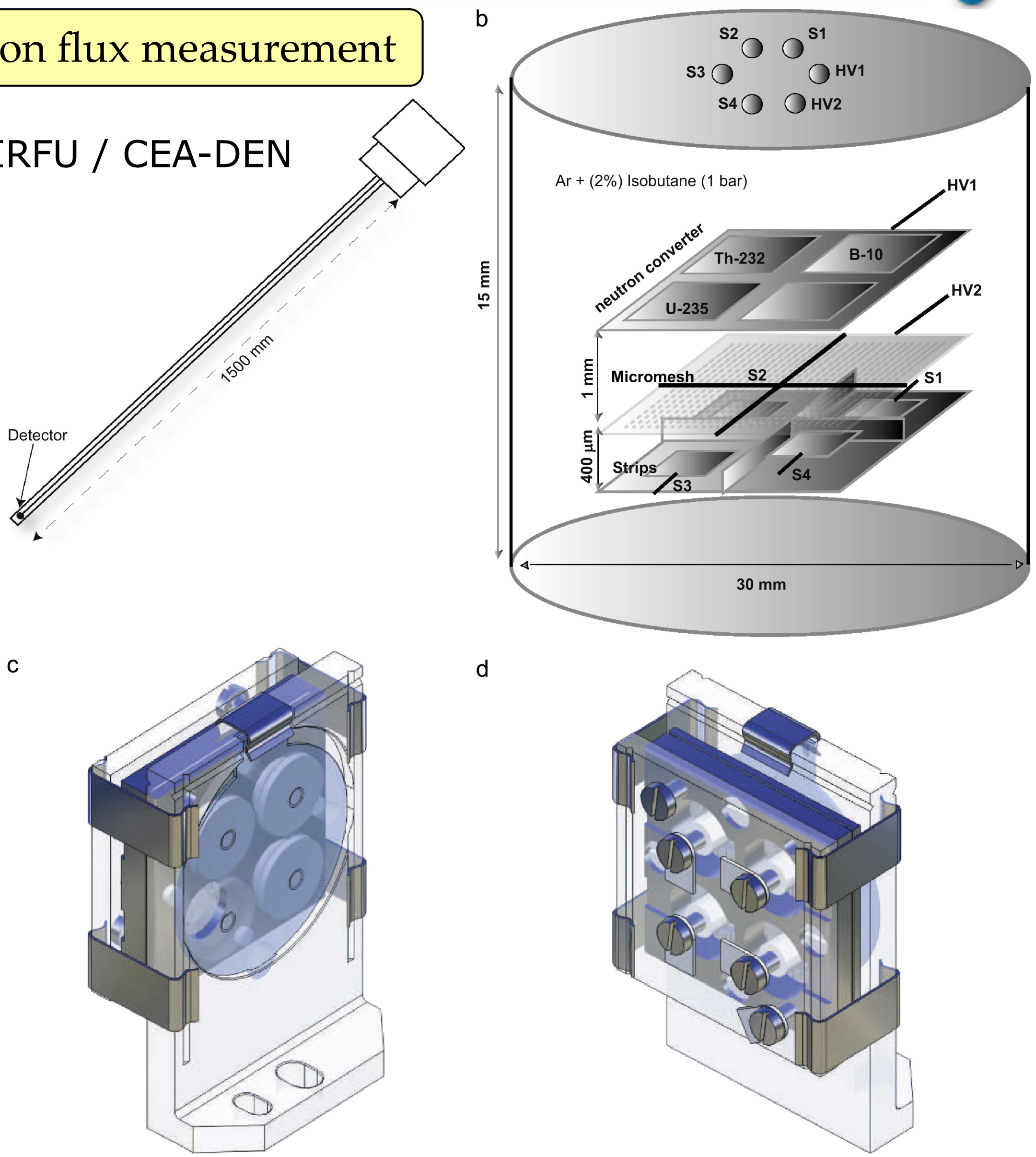
In-core Nuclear plant integrated neutron flux measurement

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

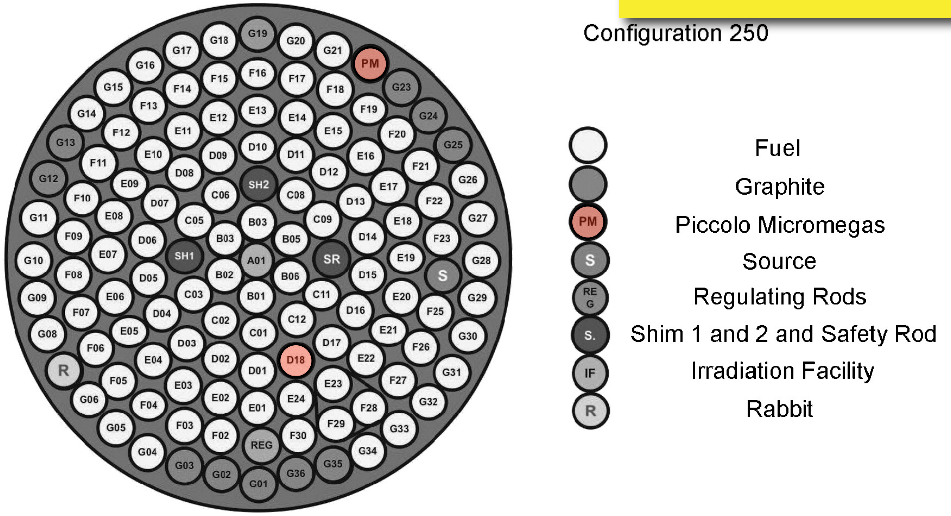
- ✓ 4 individually polarized anode channels
- ✓ 2 readout modes :
  - counting mode with fast current preamp. + 1GHz flash ADC + MATACQ (SEDI)
  - current mode by mesh current reading for high reactor power

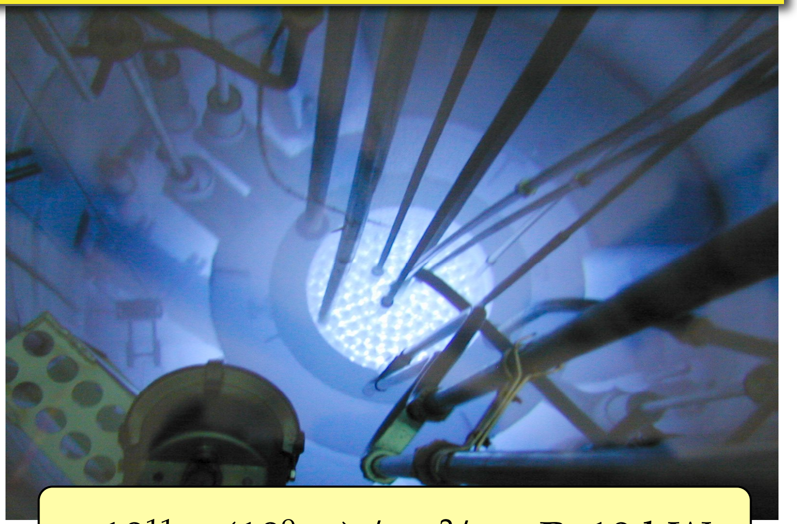


Ref: J. Pancin *et al.*, Nuclear Instruments and Methods in Physics Research A 592 (2008) 104–113

Piccolo micromegas : performances

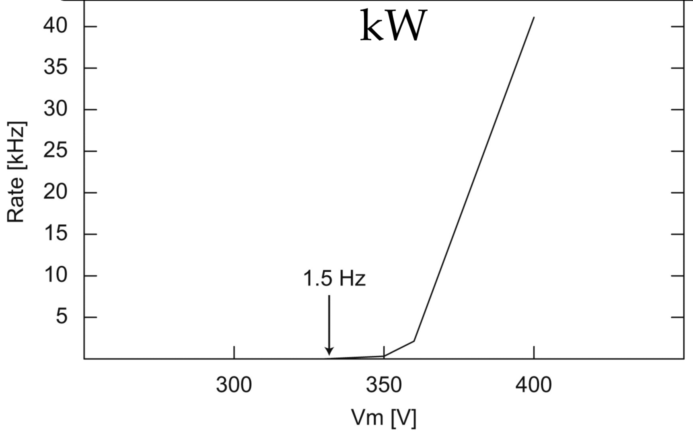
Piccolo inside a 1 MW TRIGA reactor (Gasaccia)



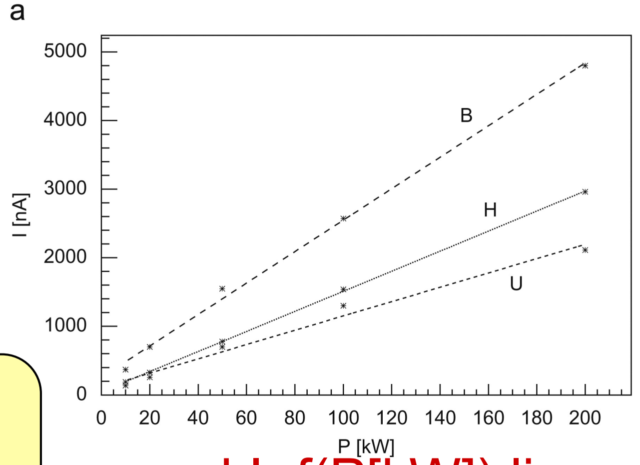


~10^{11} n (10^{9} γ) /cm^{2}/s @ P=10 kW

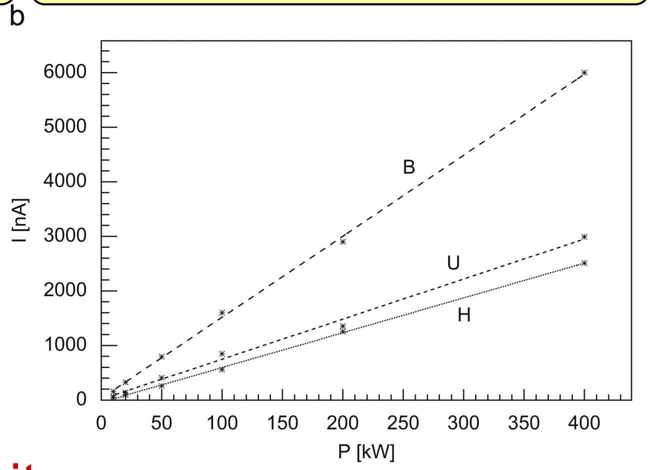
Counting rate Vs Vmesh @ P=0 kW



Current Vs reactor P in center



Current Vs reactor P in edges



good I=f(P[kW]) linearity

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

- Good linearity and n/γ discrimination
- Space charge effects & ageing needs to be studied at high flux

Conclusions and perspectives

More & more developments of neutron detectors using MPGDs for neutron beam flux and profile measurements, neutron spectroscopy (TOF measurements) and neutronography (Germany, Italy, France, Japan …)

MPGDs benefits for neutron detection

- Sub-mm spatial resolution for neutron thomography
- Sub-μs time resolution for TOF measurement (see DEMIN, CASCADE)
- High MHz (and more) counting rate intrinsic capability
- Radiation hardness and

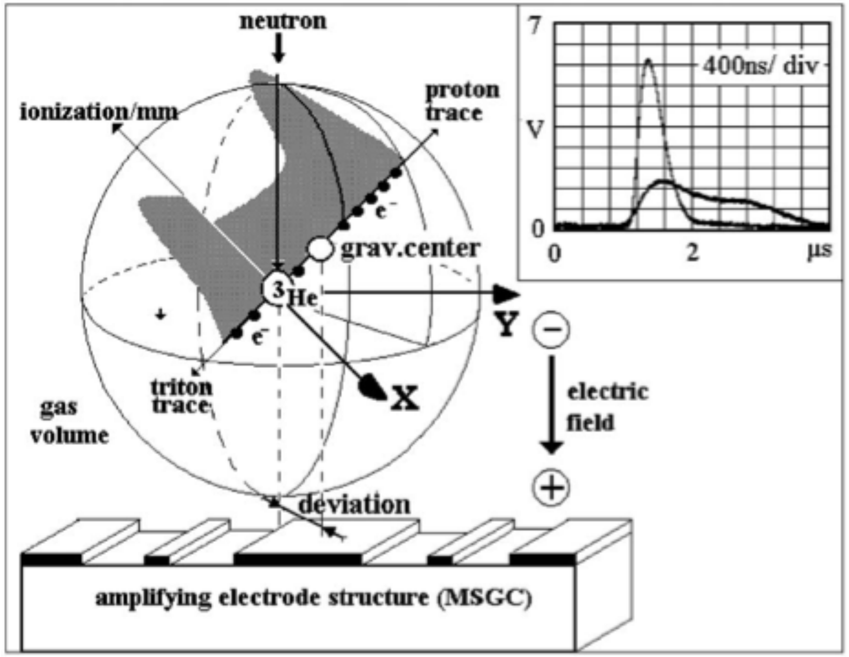
Prospectives

- Novel transparent micro-bulk structure for X-Y 2D neutron beam profile and flux monitoring detector (new 2D readout thin micro-Bulk)
- TPC for fission fragments, n-alpha reactions, or neutron elastic scattering….. (micro-Bulk, Bulk, GEMs)
- High precision neutron radiography (new 2D readout micro-Bulk with hidden pillars, GEMs)
- Large detectors for spallation source (neutron diffraction….) and for alternative to ^{3}He based detectors (Large, low cost, Bulk detectors, multi-stage CASCADE GEMs)

Backup slides

Other limitations of gaseous proportional counters

Limited position resolution on the neutron interaction localisation



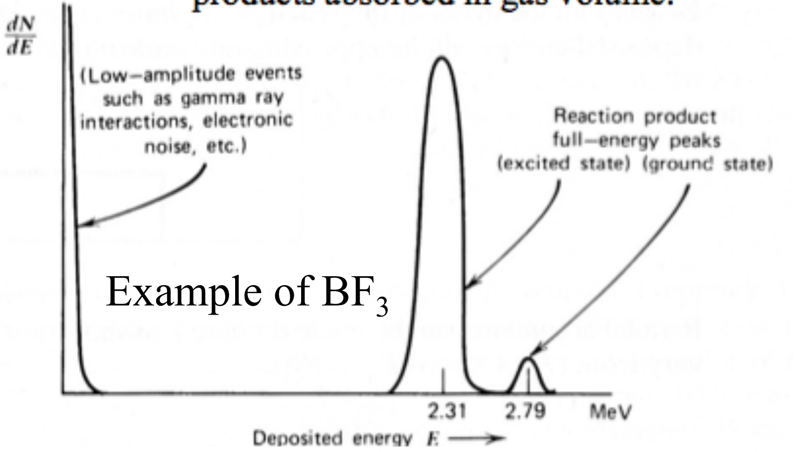
Ranges of proton and triton of the n (^{3}H,p)^{3}H reaction and charge-centroid deviation in some gases

Gas (1 bar)	Trace length (mm)	Trace length (mm)	Mean deviation (mm)
	proton	Triton	
He	61	20	**36**
Ar	12	4	**7.4**
Xe	6.17	1.85	**3.94**
C_4H_{10}	3.38	0.93	**2.3**
CF_4	4.4	1.6	**2.5**

The so-called « wall effect »

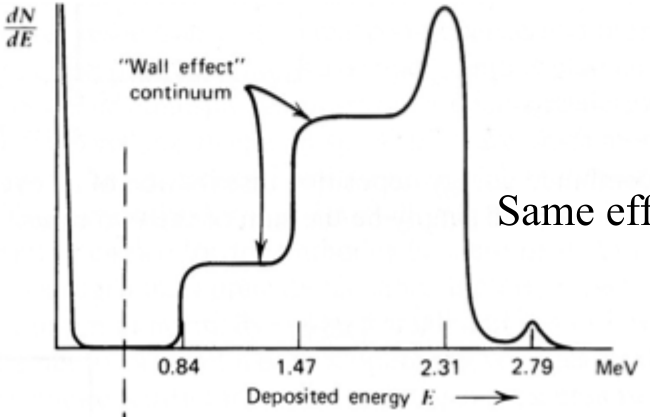
The spectrum reflects detector response rather than neutron energy ….

"Ideal" response: large tube, all reaction products absorbed in gas volume.



Example of BF_3

Obs. response due to partial energy loss in tube walls

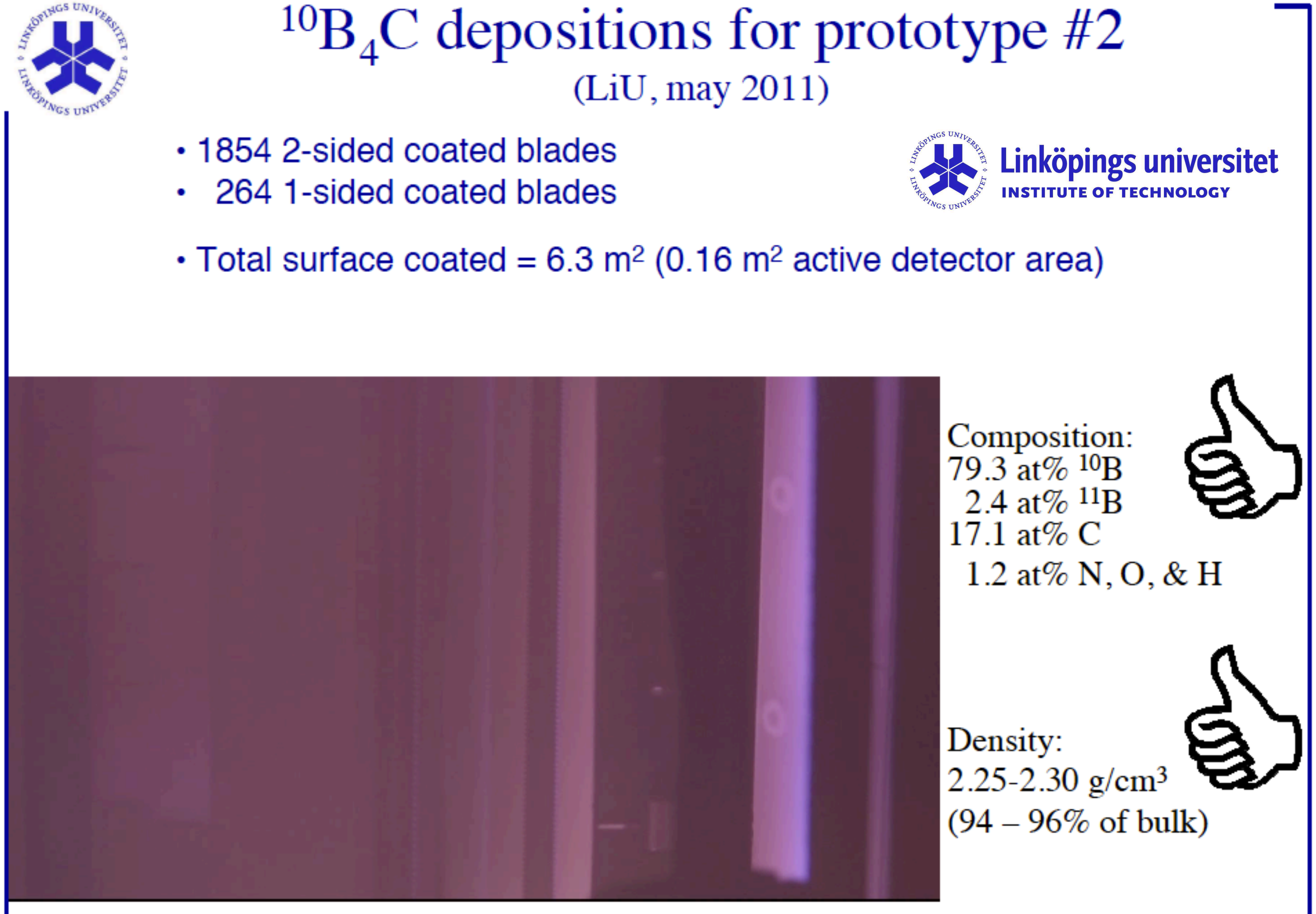


Same effect in BF_3

Ref: A. Oed, NIM A 525 (2004) 62–68

B_4C thin film deposition @ Thin Film Lab, Linköping Univ.

$^{10}B_4C$-Coatings Patent appl. #: PCT/SE2011/050891



$^{10}B_4C$ depositions for prototype #2

(LiU, may 2011)

Linköpings universitet
INSTITUTE OF TECHNOLOGY

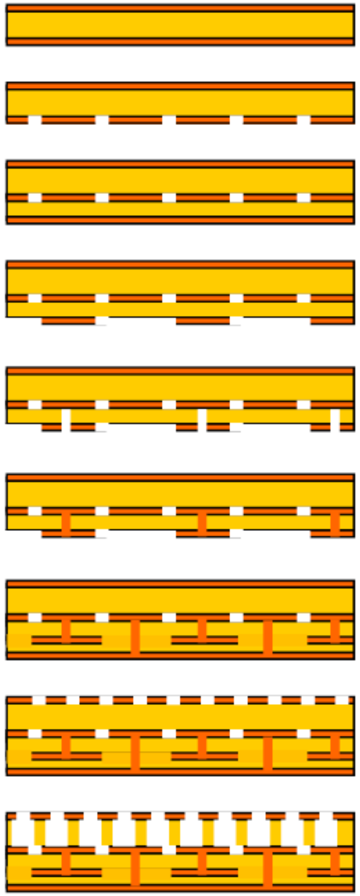
- 1854 2-sided coated blades
- 264 1-sided coated blades
- Total surface coated = 6.3 m² (0.16 m² active detector area)

Composition:
79.3 at% ^{10}B
2.4 at% ^{11}B
17.1 at% C
1.2 at% N, O, & H

Density:
2.25-2.30 g/cm³
(94 – 96% of bulk)

Ref: J. Birch, *Development of Thin-film 10B-based neutron detectors,* Saclay 2011-11-30

2D readout Micro-bulk manufacturing process



Building a Microbulk

- Kapton foil (50 μm), both side Cu-coated (5 μm)
- Construction of readout strips/pads (photolithography)
- Attachment of a single-side Cu-coated kapton foil (25/5 μm)
- Construction of readout lines
- Etching of kapton
- Vias construction
- 2nd Layer of Cu-coated kapton
- Photochemical production of mesh holes
- Kapton etching
- Cleaning

alain.delbart@cea.fr / MPGDs for neutron detection applications (Industry-Academia matching event on MPGDs, Annecy, 26-27th april 2012)

Comparison of bulk & micro-bulk technologies

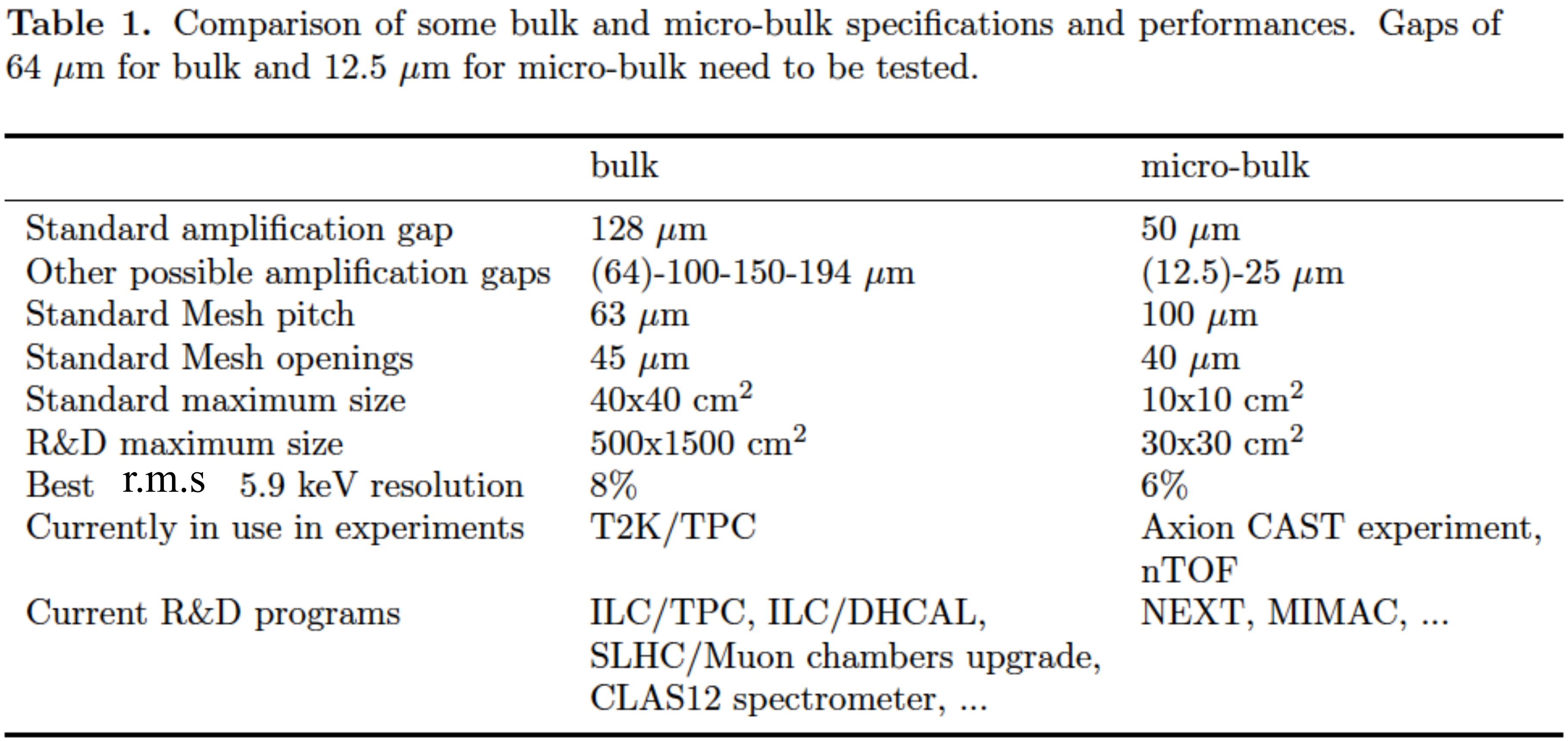


Table 1. Comparison of some bulk and micro-bulk specifications and performances. Gaps of 64 μm for bulk and 12.5 μm for micro-bulk need to be tested.

	bulk	micro-bulk
Standard amplification gap	128 μm	50 μm
Other possible amplification gaps	(64)-100-150-194 μm	(12.5)-25 μm
Standard Mesh pitch	63 μm	100 μm
Standard Mesh openings	45 μm	40 μm
Standard maximum size	$40x40\ cm^2$	$10x10\ cm^2$
R&D maximum size	$500x1500\ cm^2$	$30x30\ cm^2$
Best r.m.s 5.9 keV resolution	8%	6%
Currently in use in experiments	T2K/TPC	Axion CAST experiment, nTOF
Current R&D programs	ILC/TPC, ILC/DHCAL, SLHC/Muon chambers upgrade, CLAS12 spectrometer, ...	NEXT, MIMAC, ...

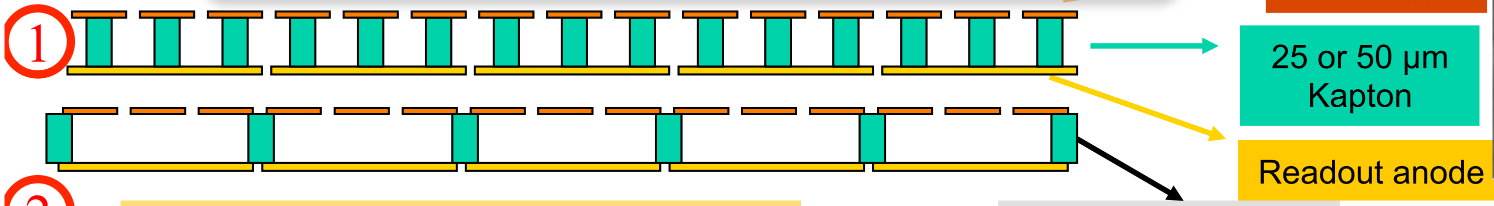
- Large size
- Large scale production

- Low-budget material
- Excellent energy resolution

Ref: A. Delbart *et.al.*, GLA2010, proceedings of 1st International Workshop towards the Giant Liquid Argon Charge Imaging Experiment

The micro-bulk micromegas

Same manufacturing techniques as GEM :
Copper & Kapton etching of a copper cladded Kapton



Micromesh
5 µm copper

25 or 50 µm
Kapton

Readout anode

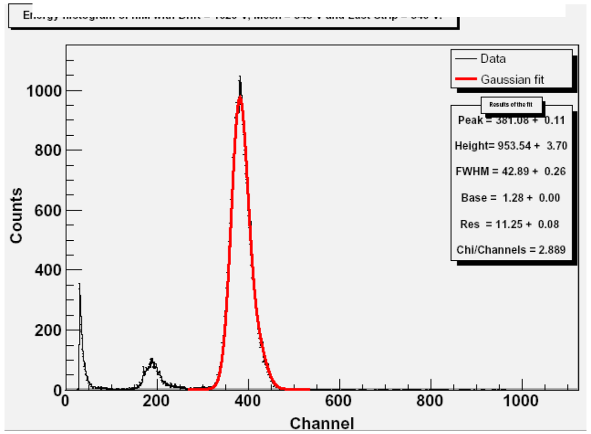
Lower capacitance
Under development

CEA-CERN Patent 09 290 285.0 (2009)

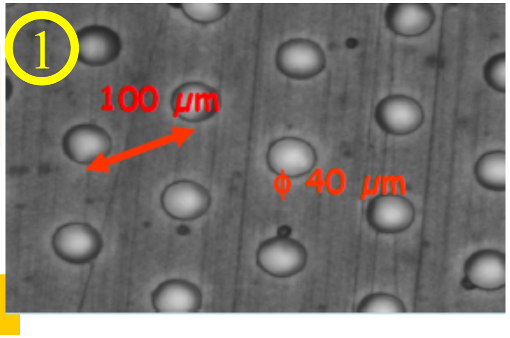
- "All-in one" structure mesh+anode
- Excellent Energy resolution

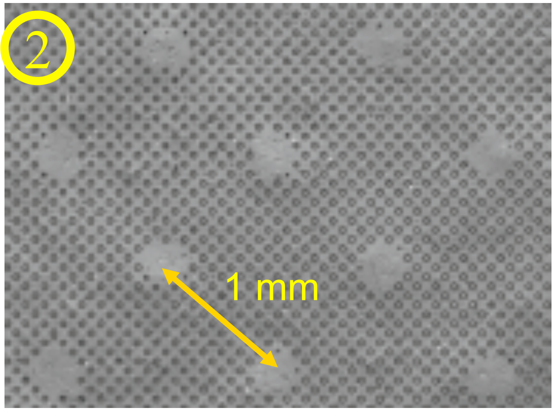
  11% FWHM @ 5,9 keV, 6 % @ 22 keV, 1,5 % @ 5 MeV)
- Good uniformity
- Low materiel budget detector
- Flexible structure
- Low intrinsic radioactivity
- Fabrication process still improving
- Fragile
- Limited sizes (<100 cm^2)

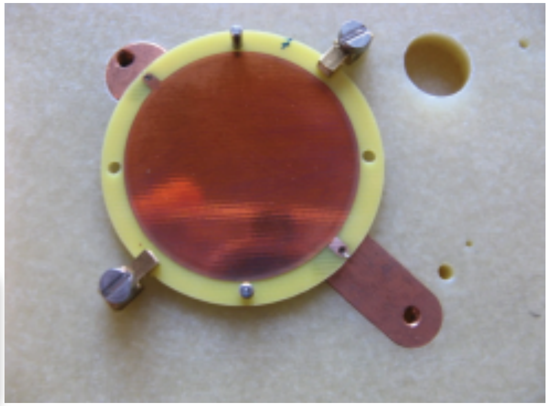
11% FWHM at 5.9 keV
Ar + 5% Iso at **1 bar**



Better mesh transparency & 12 µm gap under development



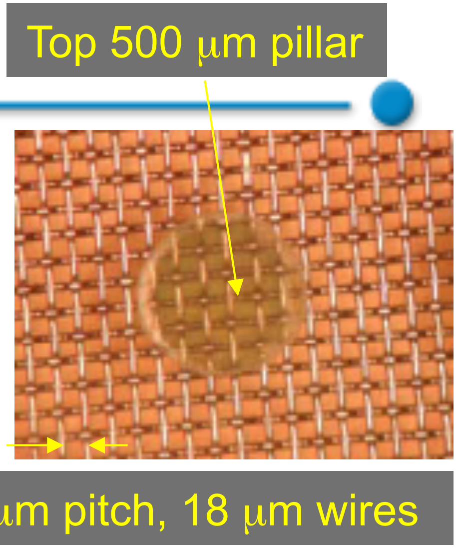




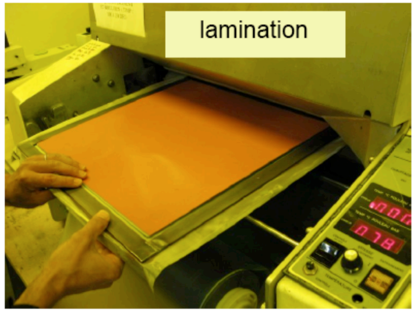
Ref: S. Aune et al. NIM A 604, 15-19, 2009
S. Andriamonje et al. JINST 4, MPGD2009 conf. proceedings

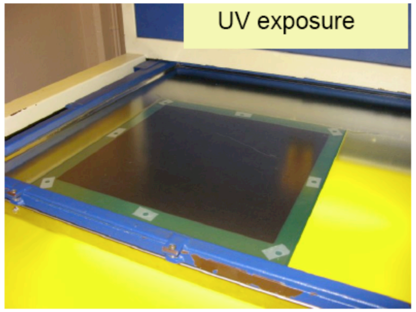
The bulk-micromegas

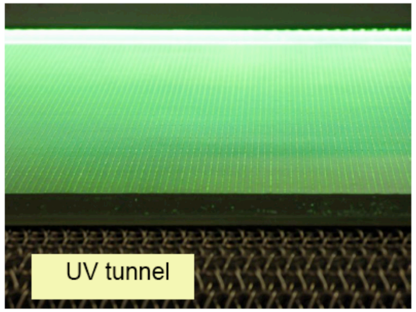
- First prototypes in 2004. CERN-TS-DEM/Irfu collaboration
- A woven micro-mesh is embeded between 2 layers of photo-imageable material. Amplification gap of 128 μm is standard, 104 μm should be ok, 64 μm is tricky
- No farme, no mechanics → % level dead zones
- Up to 40x40 cm^2 is standard
- Robust, Industrial process

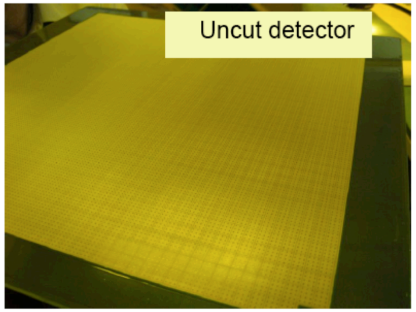

Top 500 μm pillar

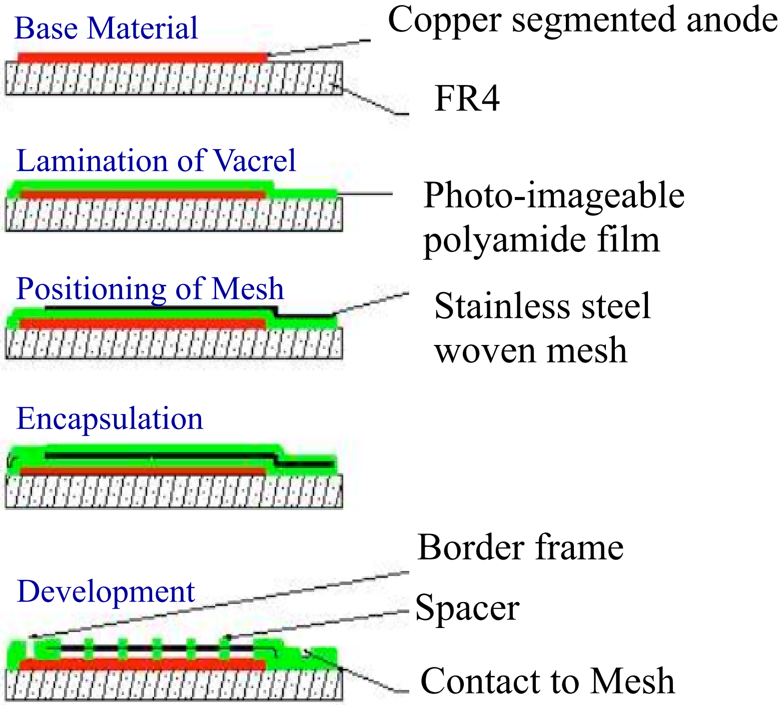
63 μm pitch, 18 μm wires










Base Material

Copper segmented anode

FR4

Lamination of Vacrel

Photo-imageable polyamide film

Positioning of Mesh

Stainless steel woven mesh

Encapsulation

Development

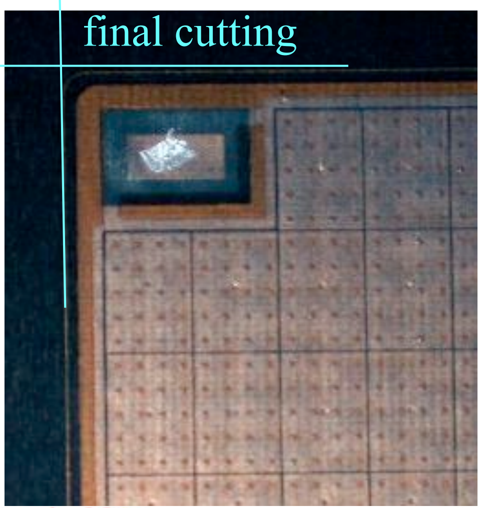
Border frame

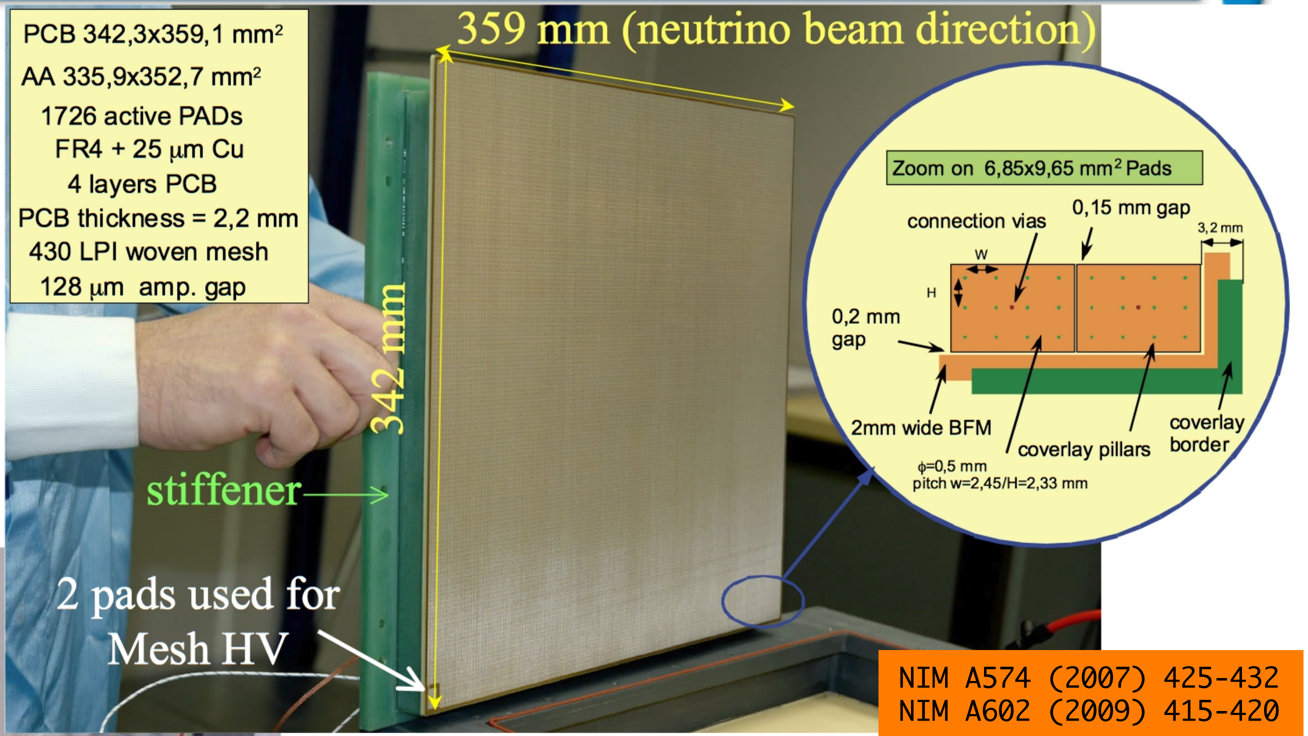
Spacer

Contact to Mesh

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

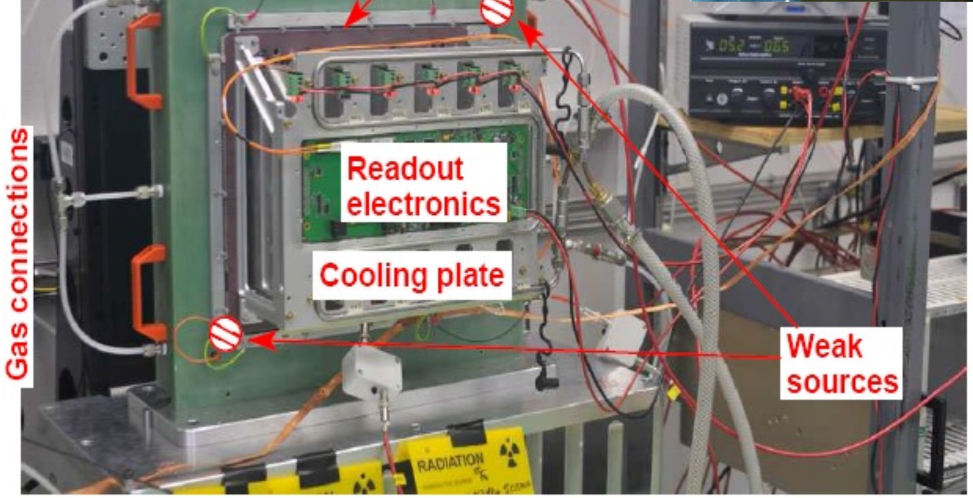
The T2K/TPC bulk-micromegas





PCB 342,3x359,1 mm²
AA 335,9x352,7 mm²
1726 active PADs
FR4 + 25 μm Cu
4 layers PCB
PCB thickness = 2,2 mm
430 LPI woven mesh
128 μm amp. gap

NIM A574 (2007) 425-432
NIM A602 (2009) 415-420



1 year production of 10 m^2

- bulk-MM produced @ CERN-TS-DEM
- 115 PCBs produced
- 86 modules produced (6 rejected)

Finalement, 72 détecteurs + 8 spares

- 10 faulty pads / 124000 !

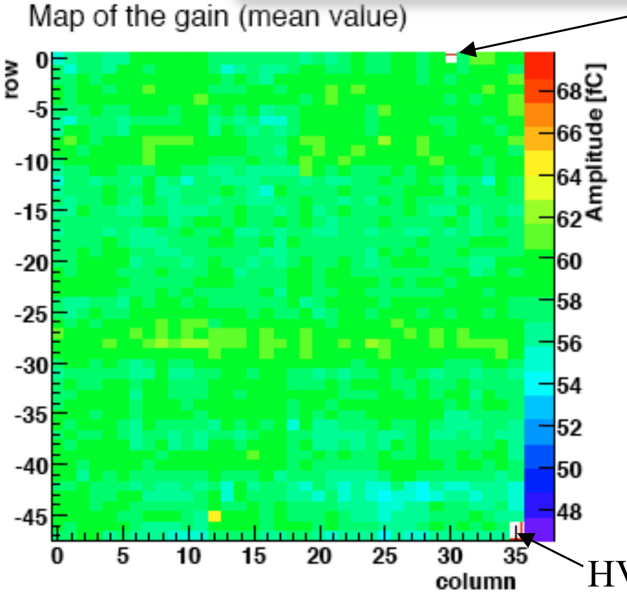
Bulk-micromegas detector cost : ~10 k€ /m^2
(80% of the cost in the 4 layers PCB !)

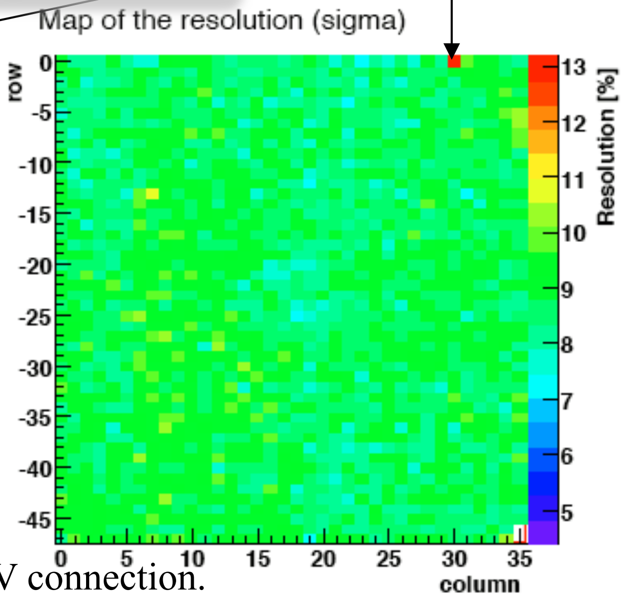
Ref: A. Delbart *et.al.*, TIPP2009 conference proceedings NIM A preprint doi:10.1016

T2K/TPC Module calibration : a uniform production

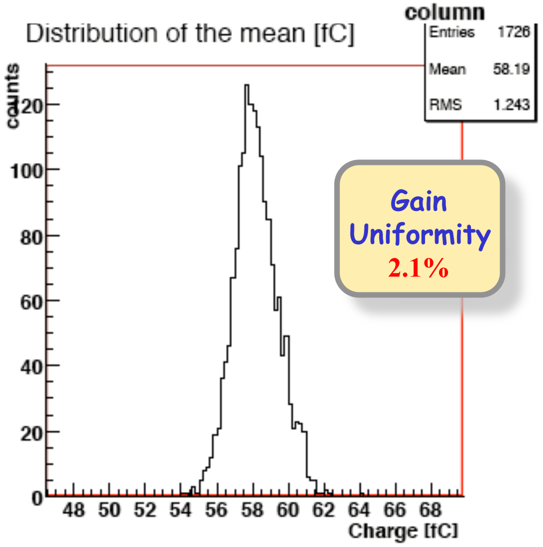
1726 pads scan @ -350 V

1 FEC dead ch.

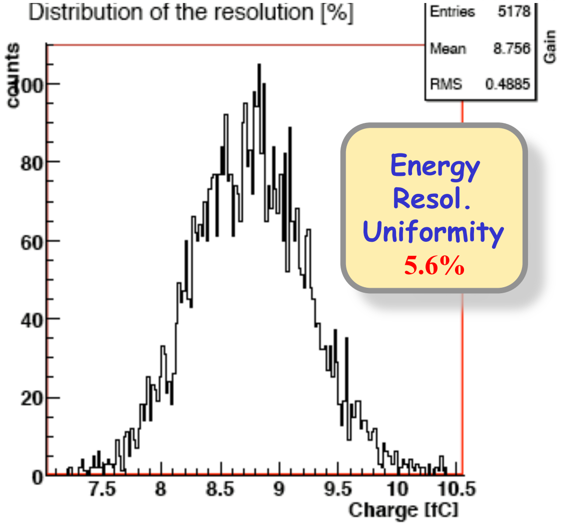




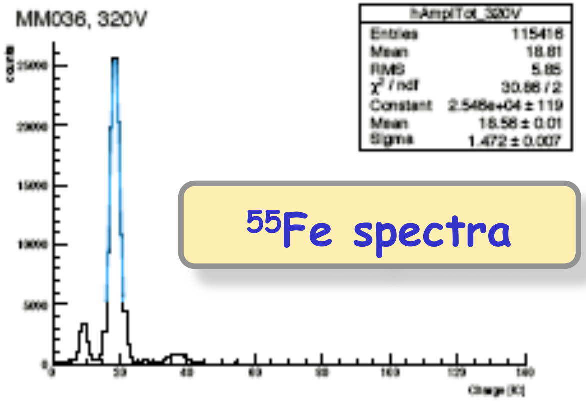
HV connection.



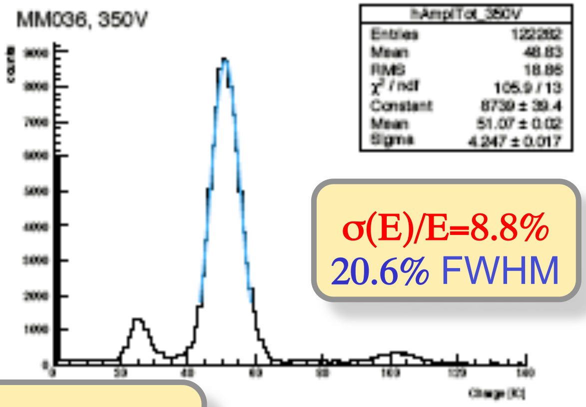
Gain Uniformity 2.1%



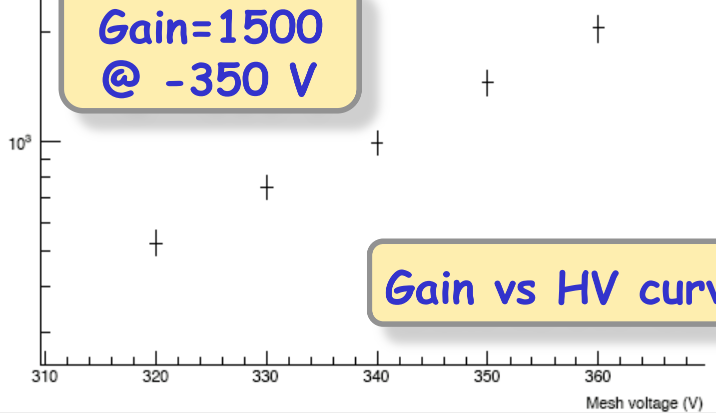
Energy Resol. Uniformity 5.6%



^{55}Fe spectra



σ(E)/E=8.8%
20.6% FWHM



Gain=1500 @ -350 V

Gain vs HV curve

CEA DSM Irfu

8% performance uniformity over the 86 modules