

# Towards a high efficiency thermal neutron micromegas detector

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$^3\text{He}$  is a by product of Tritium production for use in nuclear weapons by Tritium  $\beta$ -decay into  $^3\text{He}$  with a half life of 12.3 years.

Only the US and Russia are providing significant amounts of  $^3\text{He}$ . With the end of the Cold War the  $^3\text{He}$  production from Tritium decay has been reduced significantly and since September 2001 the demand of  $^3\text{He}$  has increased drastically due to security programs launched in the US and other countries

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

The cost for a typical ILL 30 m<sup>2</sup>  $^3\text{He}$  detector (3000 l @ 4.5 bars) was 1.5 M€ (incl. 240 k€ for  $^3\text{He}$ ). It would cost 7.2 M€ (incl. 6 M€ for  $^3\text{He}$ ) today !!!

$^3\text{He}$  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  $\approx$ 20 kl/year available (US+Russia)

→ Need for alternatives !!

Ref : Bruno Guerard (ILL) & Karl Zeitelhack (FRM II)

### 3 working groups for large area detectors formed early 2010

- WG1: Scintillation detectors ( $\text{ZnS}/^6\text{Li}$  with wavelength shifting fibre readout)
- WG3:  $\text{BF}_3$  gas detectors
- **WG2: Development of large area detectors using  $^{10}\text{B}$  neutron converters :**
  - in  $\text{CF}_4$  gas detectors (ESS AB, ILL, Linköping University collab.)
  - with MPGD readout (GEM or micromegas)

**1/ To demonstrate experimentally the principle of a  $^{10}\text{B}$  multi-layers detector with performances close to those of  $^3\text{He}$  detectors**

**2/ To optimize design and fabrication in function of performance and cost**

**3/ To demonstrate the feasibility of a large scale detector by fabricating and testing one or several demonstrators with a sensitive area comparable to that of an IN5 module**

**Duration: 4 years (starting after final approval of the objectives and resources)**

Ref : B. Guerard (ILL)

*Present members of the Technical Working Group:*

Francois Boue (LLB)	Ron Cooper (SNS)	Ralf Engels (JCNS)
Debbie Greenfield (STFC)	Bruno Guerard (ILL)	Malte Hildebrandt (PSI)
Günter Kemmerling (JCNS)	Vladimir Kruglov (JINR)	Laszlo Rosta (BNC)
Nick Maliszewskyj (NIST)	Nigel Rhodes (STFC)	Graham Smith (BNL)
Kazuhiko Soyama (J-PARC)	Axel Steuwer (ESS)	Thomas Wilpert (HZ Berlin)

THEME [INFRA-2011-1.1.17.1  
[Infrastructures for Neutron  
Scattering and Muon Spectroscopy]

18 partners, 4,1 M€ (EC JRA, EC total 13,4 M€)  
CEA/LLB : WP13 facility support, 908 k€

**WT3:**  
Work package description

Grant agreement for: Combination of CP & CSA

Project Number <sup>1</sup>	283883	Project Acronym <sup>2</sup>	NMI3-II
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One form per Work Package

## Annex I - "Description of Work"

Project acronym: NMI3-II

Project full title: " Neutron Scattering and Muon Spectroscopy Integrated Initiative "

Grant agreement no: 283883

Date of last change: 2011-06-28

Preparation of the DoW date:

Work package number <sup>53</sup>	WP21	Type of activity <sup>54</sup>	RTD
Work package title	Detectors		
Start month	1		
End month	48		
Lead beneficiary number <sup>55</sup>	2		

## Objectives

Development of detector technologies to replace <sup>3</sup>He detector technology in neutron scattering applications. This work will concentrate on two tasks; the development of wavelength shifting fibre scintillator detectors and the development of solid10B gas detectors.

**Start : february 2012**

## WP21 Detectors

DETECTORS											
Acronym (1)	Staff effort allocated to project (man months)	Staff effort charged to project (man months)	Staff cost	Sub-contract	Consumables	Travel	Equipment charged to project (2)	Overhead Costs (3)	Total	%	EU contribution
STFC	30	19	99875	0	38100	10000	0	104889	252844	75%	189833
Jülich	29	19	129088	0	21000	8800	0	97718	256604	75%	192453
TUM	31	20	105000	0	44000	9000	0	94800	252800	75%	189800
HZB	36	24	112000	0	47750	10000	0	84000	253750	75%	190313
CNR	24	12	33000	0	5095	3000	0	25740	68835	75%	50126
BNC-RISP	18	9	32625	0	15000	8000	0	33375	89000	75%	66750
CEA	12	7	35000	0	10000	5000	0	21000	71000	75%	53250
ILL	observer	0	0	0	0	0	0	0	0		0
ESS	observer	0	0	0	0	0	0	0	0		0
<b>TOTALS</b>	<b>180</b>	<b>110</b>	<b>546,586</b>	<b>-</b>	<b>180,945</b>	<b>53,800</b>	<b>-</b>	<b>461,502</b>	<b>1,242,833</b>		<b>932,125</b>

*Table 1.1 Detector characteristics for large area inelastic scattering instruments based on  $^3\text{He}$  detectors*

	10 bar 25 mm diameter $^3\text{He}$
<b>Detector characteristics</b>	
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 $\mu\text{s}$
Area	15 – 40 $\text{m}^2$
Environment	Cryogenic vacuum

Ref : Karl Zeitelhack (FRM II)

“Alternative techniques to  $^3\text{Helium}$  based neutron detectors for neutron scattering applications. Proposal for a Joint Development Programme” by the Technical Working Group, February 24<sup>th</sup>, 2010

**Cost objective for solid : 100 k€/m<sup>2</sup>  
Incl. 60 k€ for boron layers  
i.e 2 k€ / boron layer (30 layers)**

Needs for hundreds of  $\text{m}^2$  for ESS

140  $\text{m}^2$  in 2019 for 7 detectors

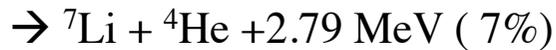
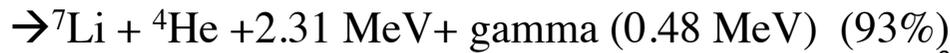
22 detectors in 2024

“This table does not represent the minimum required characteristics and it may be possible to provide an adequate replacement technology with less performance in some areas”

↪ Thermal neutrons to ionizing particles converters :

↪ Gas ( $^3\text{He}$ ,  $\text{BF}_3$  for thermal neutrons)

↪  $^6\text{Li}(n,\alpha)^3\text{H}$ ,  $^{10}\text{B}(n,\alpha)^7\text{Li}$ ,  $^{235}\text{U}(n,f)$ ,  $^{157}\text{Gd}(n,\gamma)^{158}\text{Gd}^*$  (with  $^6\text{Li}$  or  $^6\text{LiF}$ ,  $^{10}\text{B}/\text{B}_4\text{C}$ )

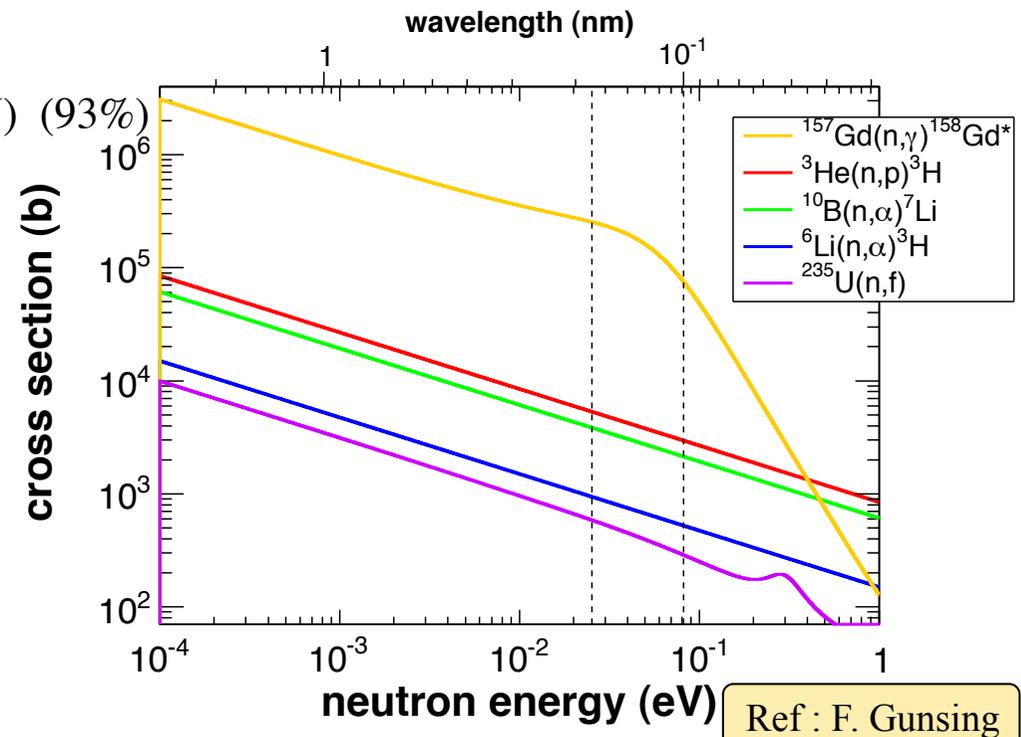


Natural isotopical fraction :

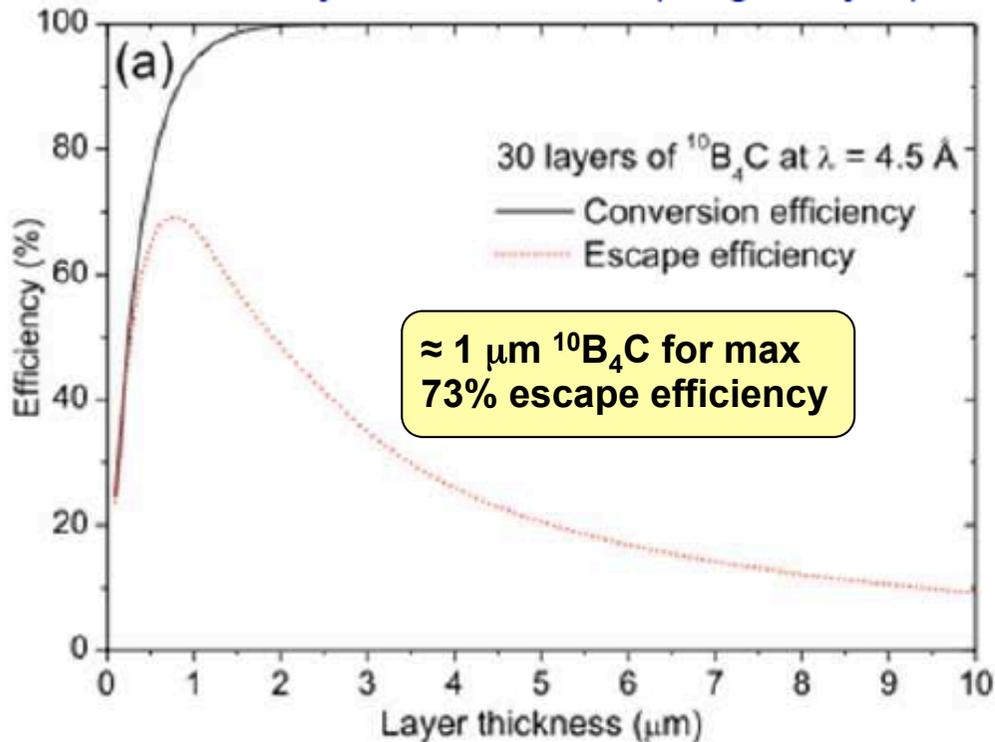
$^{10}\text{B}$ : 19.8% and  $^6\text{Li}$ : 7.6%

$^6\text{Li}$  is hygroscopic  $\rightarrow$   $^{10}\text{B}$  is chosen

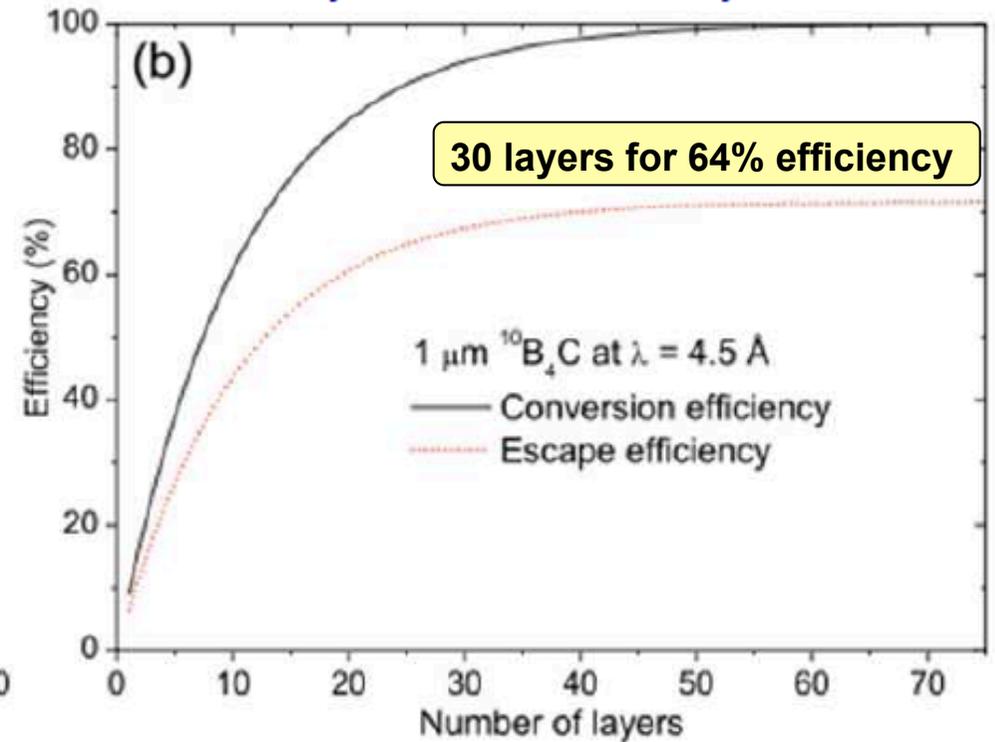
$E_n$ (meV)	$\lambda$ (\AA)
25.3	1.8
81	1.0



### Efficiency vs. thickness (single layer)



### Efficiency vs. Number of layers



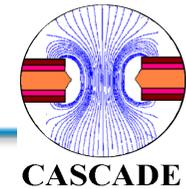
**Prof. Jens Birch**



**Linköpings universitet**  
 INSTITUTE OF TECHNOLOGY

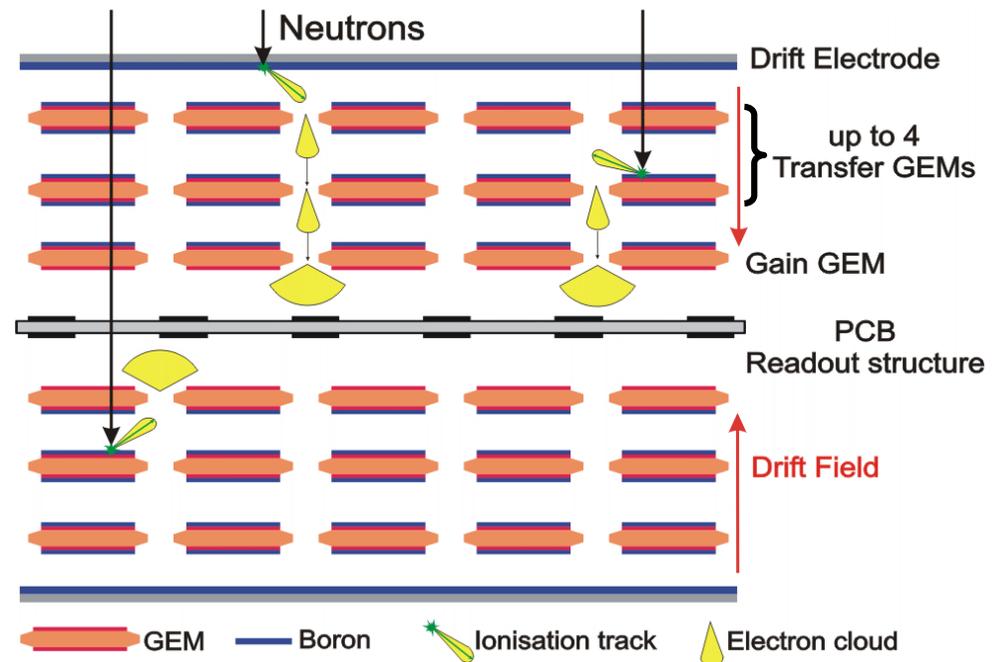
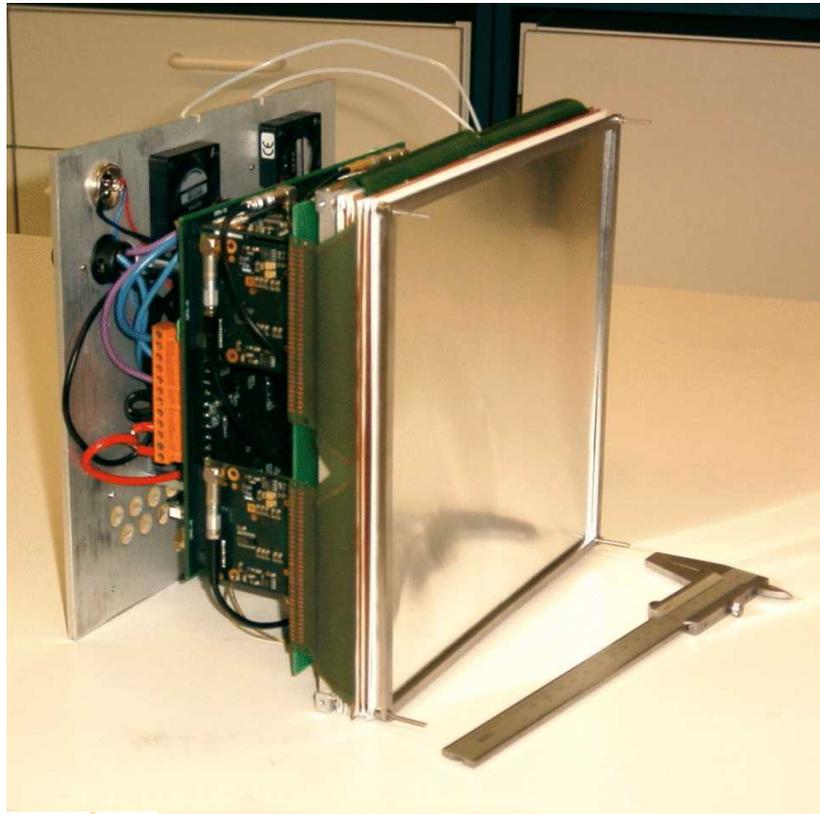
Thin Film Physics Division  
 Linköping University (LiU), Sweden

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



Christian J. Schmidt et al (GSI, Darmstadt)

## 2D-200 CACADE Detector



- Each GEM has two  $^{10}\text{B}$  layers
  - Last GEM operated as amplifier
  - 10 GEM foils for 50% efficiency
- large area detectors, cost, dead zones, uniformity, conversion efficiency ?

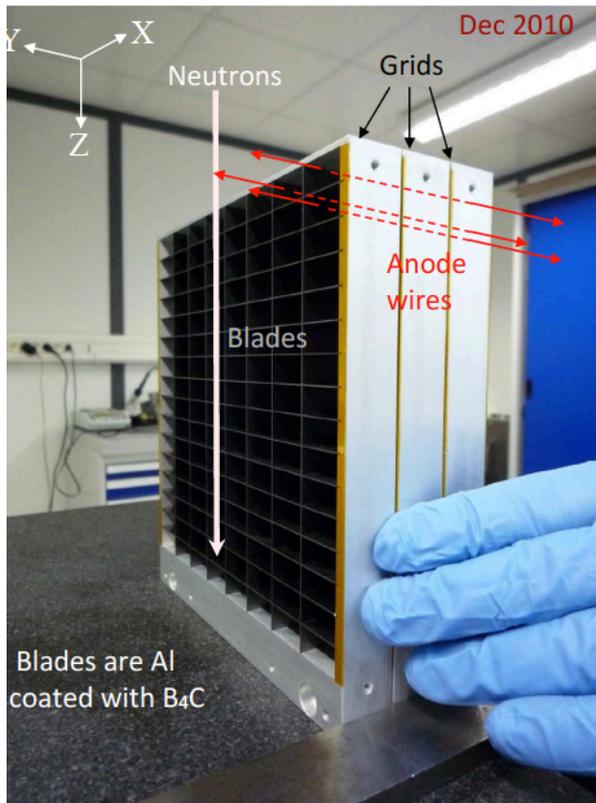
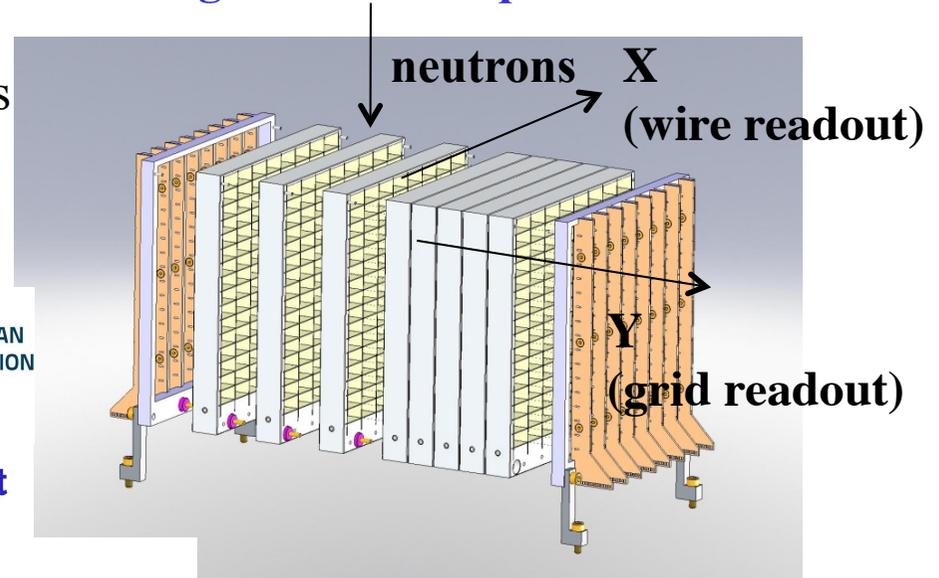
→ other Boron-coated straw tubes but “clever” idea ...



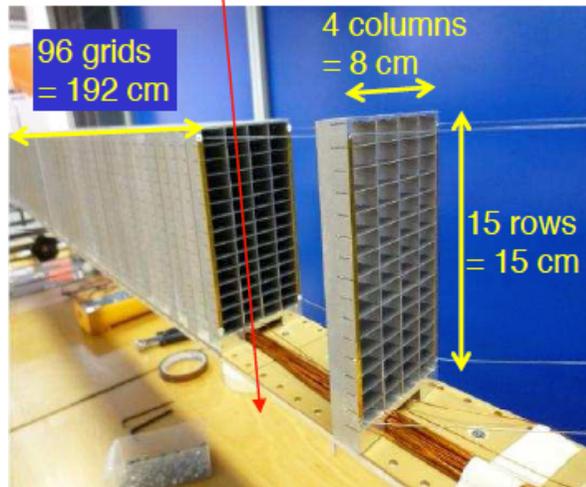
INFM - Perugia  
 Forschungszentrum Jülich  
 Hahn Meitner Institut - Berlin  
 Ruprecht Karls Universität - Heidelberg  
 AGH University of Sci. and Tech. - Krakow

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

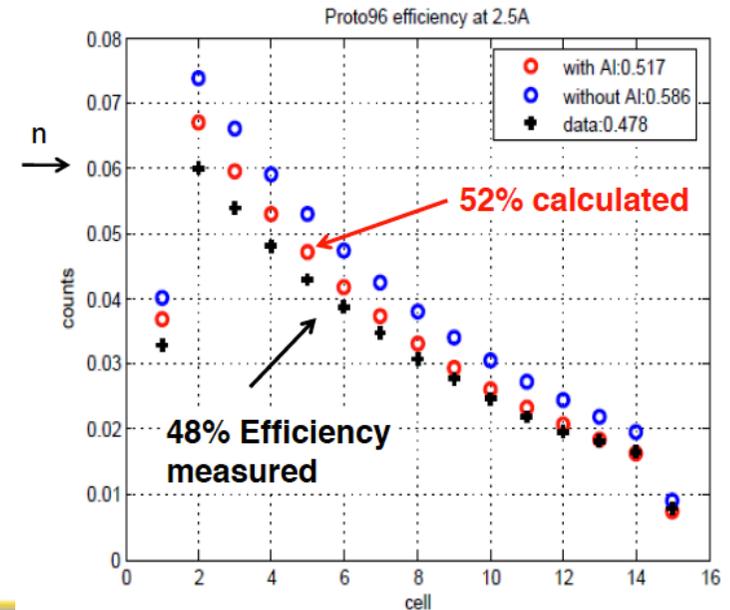
Stacking of several grids to make Boron coated tubes  
 The grids are electrically insulated  
 Anode wires are mounted in the middle of each tube  
 Z is not useful



neutrons



**Proto #2, spring 2011**



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

<sup>10</sup>B<sub>4</sub>C-Coatings Patent appl. #: PCT/SE2011/050891



## <sup>10</sup>B<sub>4</sub>C depositions for prototype #2 (LiU, may 2011)

- 1854 2-sided coated blades
- 264 1-sided coated blades
- Total surface coated = 6.3 m<sup>2</sup> (0.16 m<sup>2</sup> active detector area)



Composition:  
79.3 at% <sup>10</sup>B  
2.4 at% <sup>11</sup>B  
17.1 at% C  
1.2 at% N, O, & H



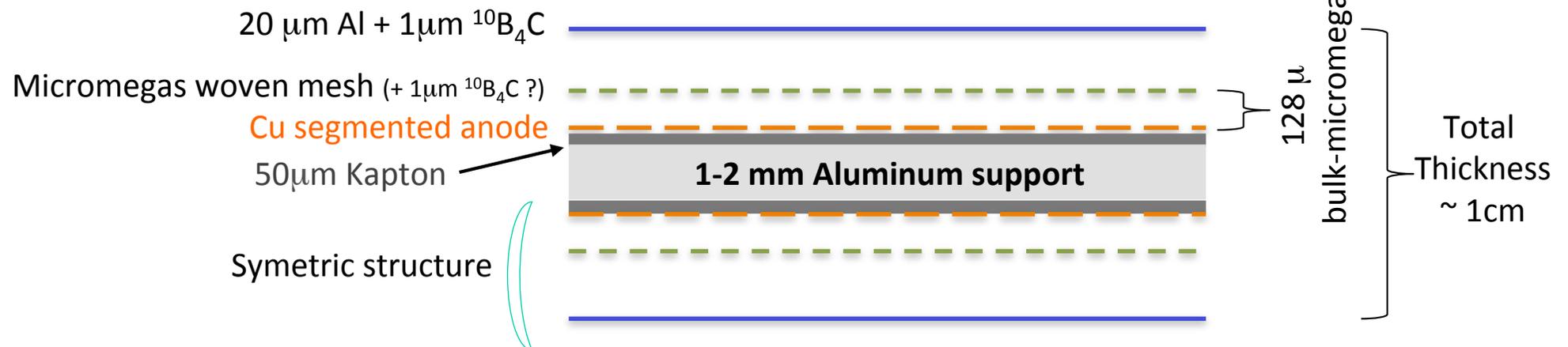
Density:  
2.25-2.30 g/cm<sup>3</sup>  
(94 – 96% of bulk)



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

# Ideas for a high-efficiency Micromegas neutron detector for $^3\text{He}$ alternatives

- back-to-back Structure with bulk-micromegas technology (large area)
  - expected detection efficiency  $\sim 7\%$  (with  $2 \times 10^{10} \text{B}_4\text{C}$  layers)
  - 10 modules can « theoretically » be stacked for  $\sim 50\%$  efficiency
  - up to  $50 \times 50 \text{cm}^2$  active modules to pave a  $3 \times 10 \text{m}^2$  detection panel
  - 1D or 2D anode segmentation with serialized readout
  - $5 \times 5 \text{cm}^2$  readout pads or 2D X-Y ( $\approx 15 \text{mm}$  spatial resolution requirement)
- but what about occupancy/pile-up (up to  $10^8$  neutrons/s) ?
- electronic readout ? Digital readout with  $< 1 \mu\text{s}$  time resolution ?



→ **But Micromegas is capable of far more (spatial & time resolutions). Applications ?**

for instance, need for sub-mm resolutions on  $30 \times 30 \text{cm}^2$  or mm resolutions on  $100 \times 100 \text{cm}^2$

→ **Complete specifications to be defined and simulations & actual design to be done ...**