University of Perugia | European Spallation Source | Linköping University | Institut Laue-Langevin

Novel ^{10}B-based detectors for Neutron Scattering Science

Helium Replacement in Italy - HeRe in Italy

J.C. Buffet, J.F. Clergeau, J. Correa, S. Cuccaro,
M. Ferraton, B. Guérard, F. Piscitelli, J.M. Rigal, P. Van Esch

PhD supervisor: F. Sacchetti, University of Perugia

R. Hall-Wilton, C. Höglund, K. Kanaki, A. Khaplanov

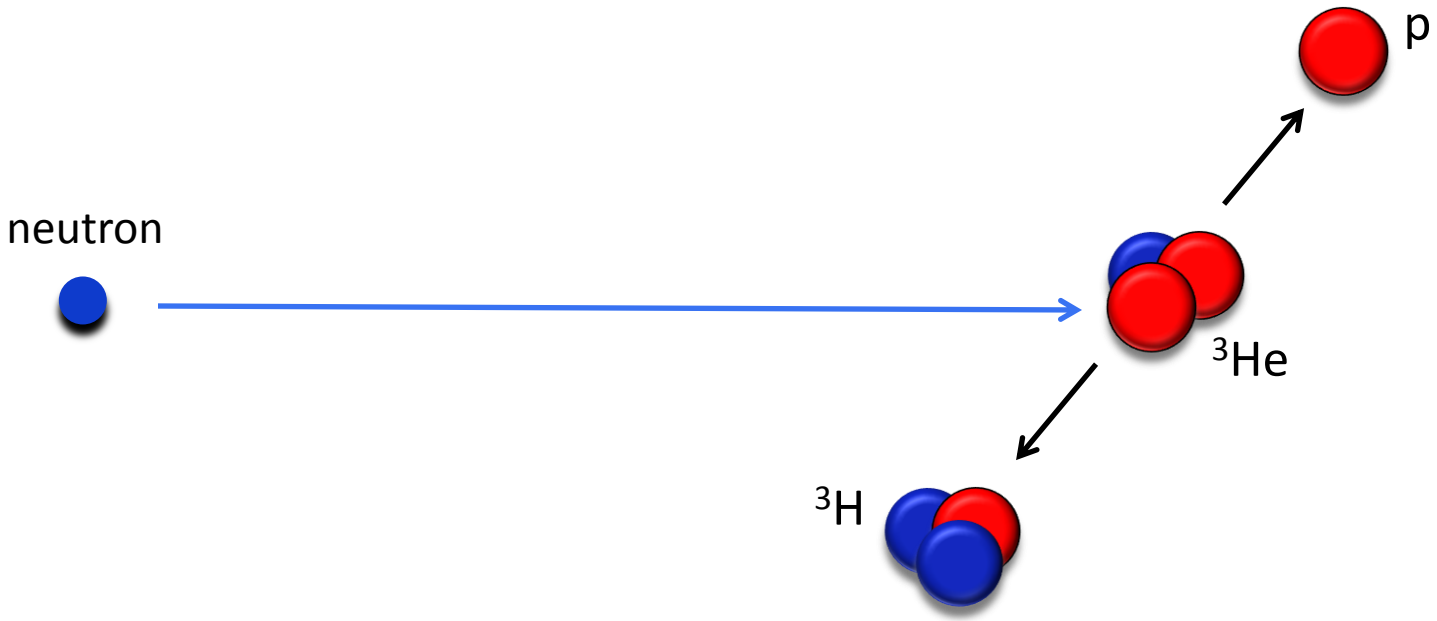
$$^3He + n \rightarrow {}^3H + p + 0.77MeV$$

Figaro @ ILL

Gas fill	8 bar ^{3}He + 2 bar CF_4
Area	0.2 m^2
Resolution	2 x 8 mm^2
Efficiency	60% @ 2.5Å

IN5 @ ILL

Gas fill	4.75 bar ^{3}He + 1.25 bar CF_4
Area	30 m^2
Resolution	2.6 x 2.6 cm^2
Efficiency	75% @ 2.5Å



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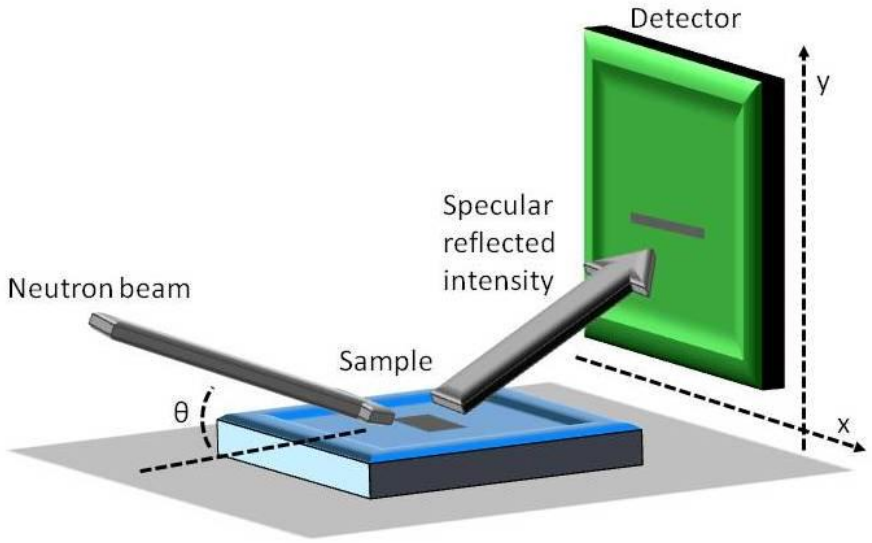
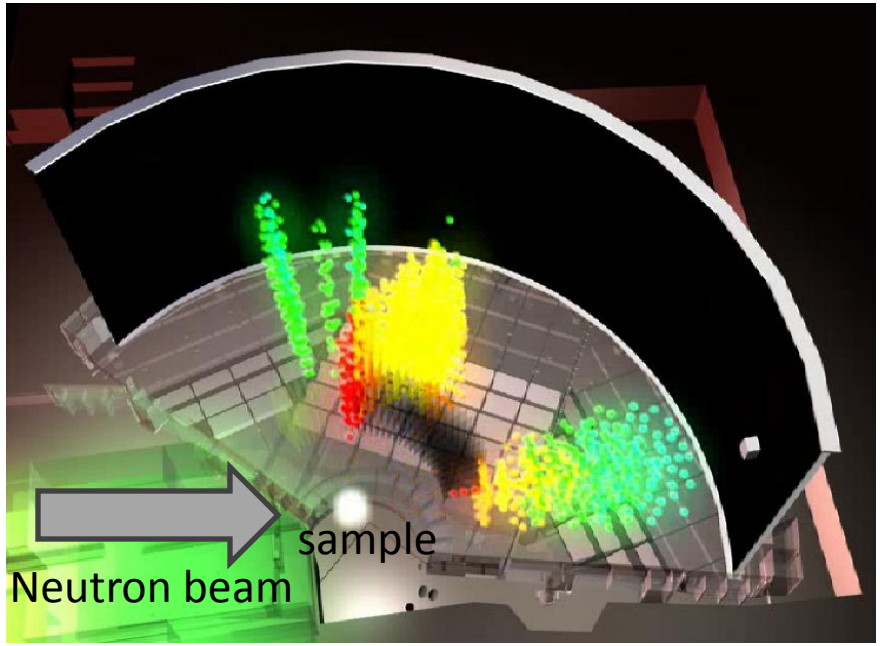
Neutron reflectometry



Neutron spectroscopy - ToF



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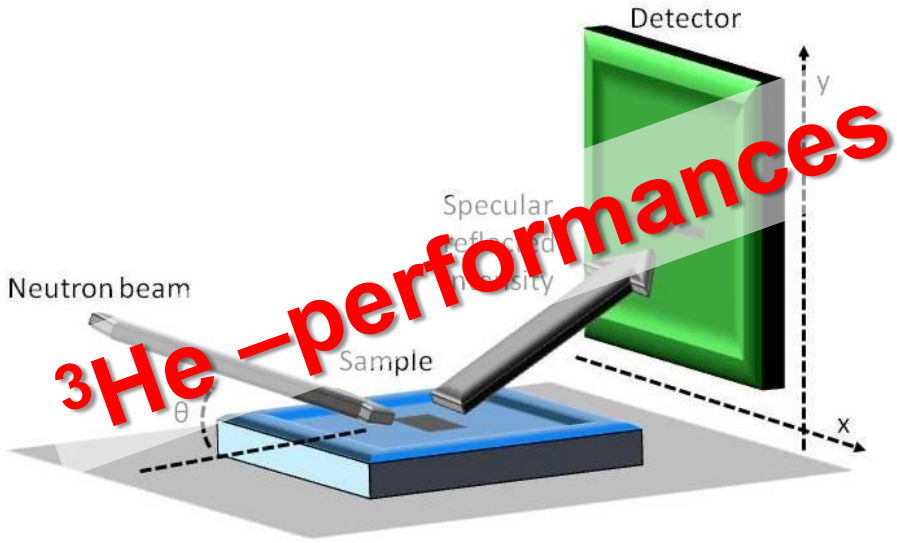
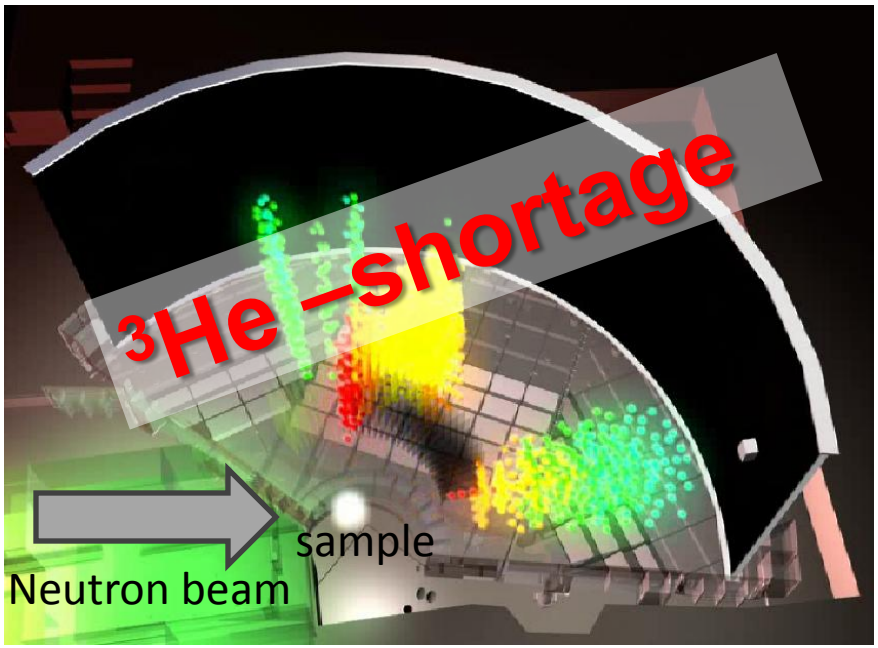


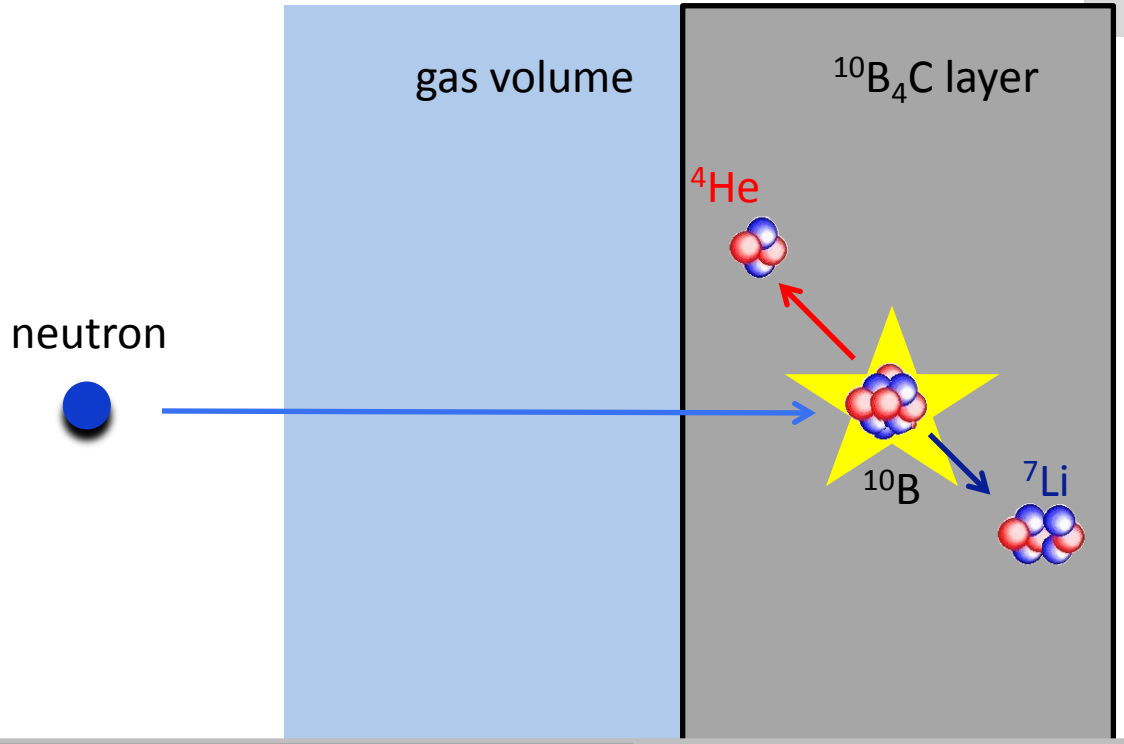
Neutron spectroscopy - ToF



Principle

$$^{10}B + n \rightarrow {}^{7}Li^{*} + {}^{4}He \rightarrow {}^{7}Li + {}^{4}He + 0.48MeV\,\gamma\text{-ray} + 2.3\ MeV \quad (94\%)$$
$$\rightarrow {}^{7}Li + {}^{4}He \qquad + 2.79\,MeV \quad (6\%)$$

^{10}B



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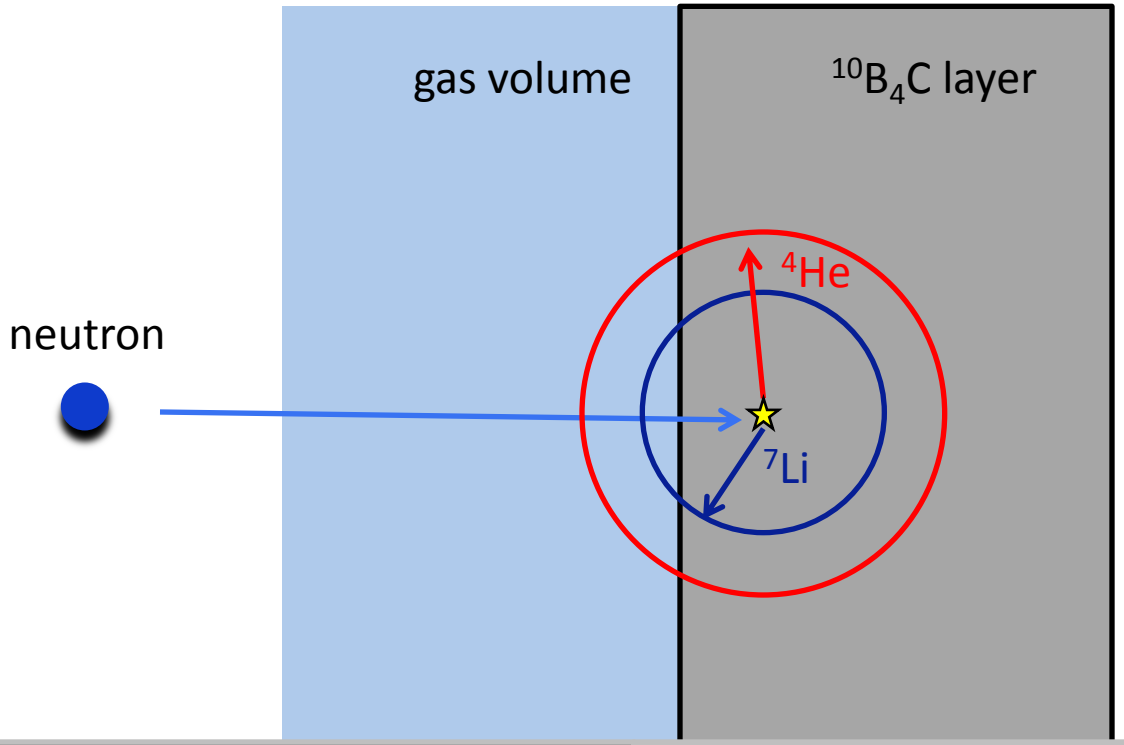

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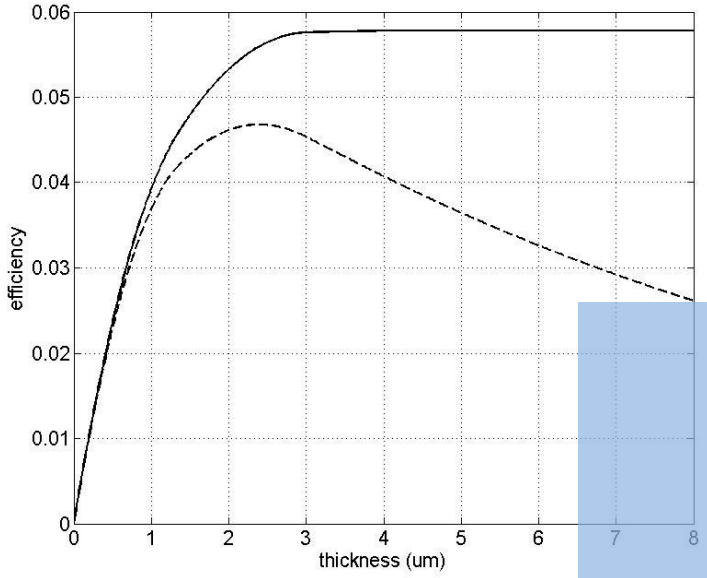
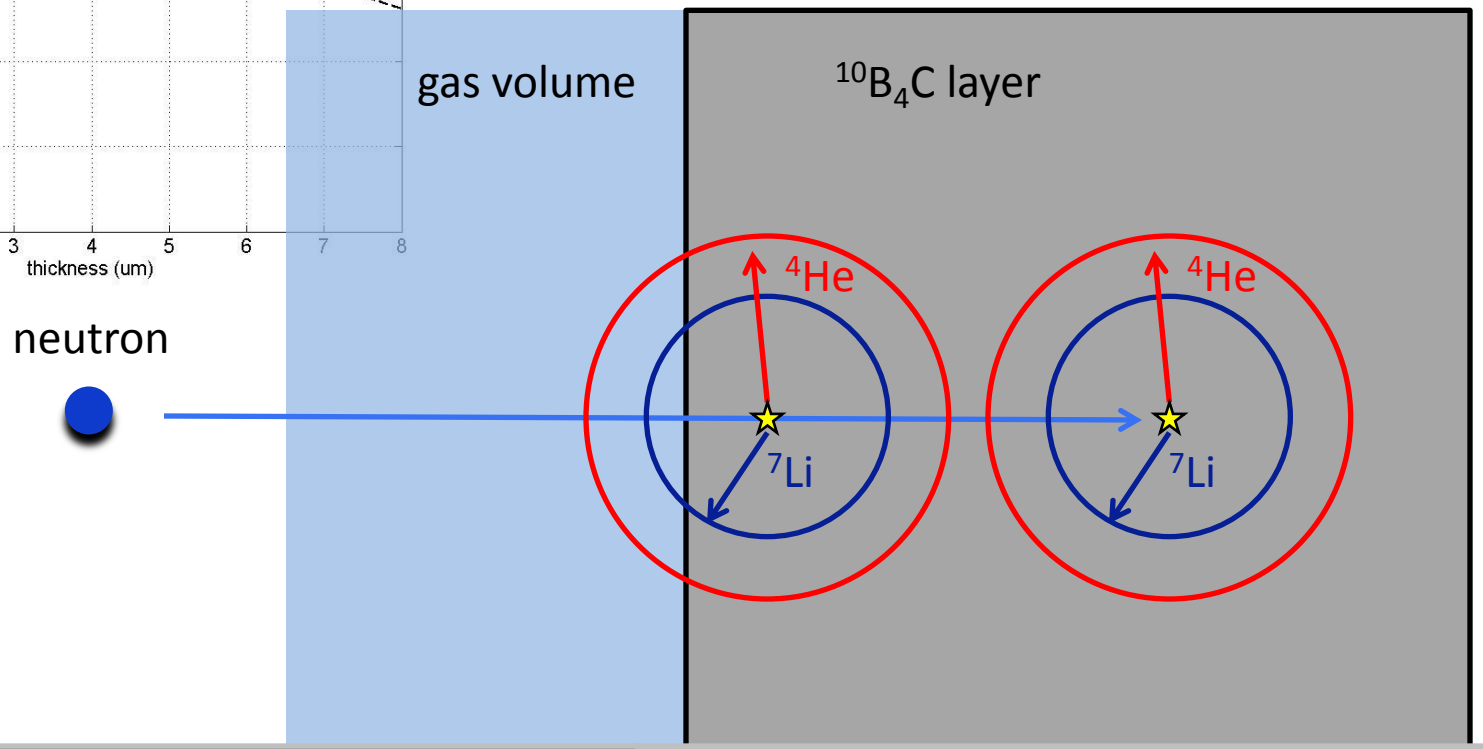
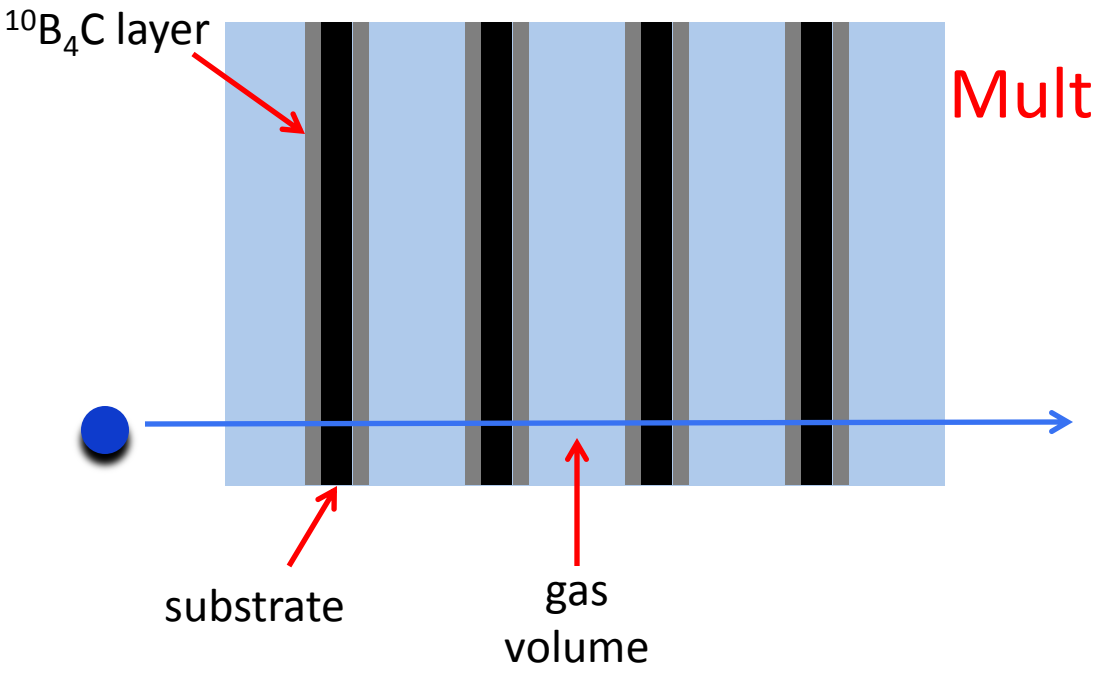
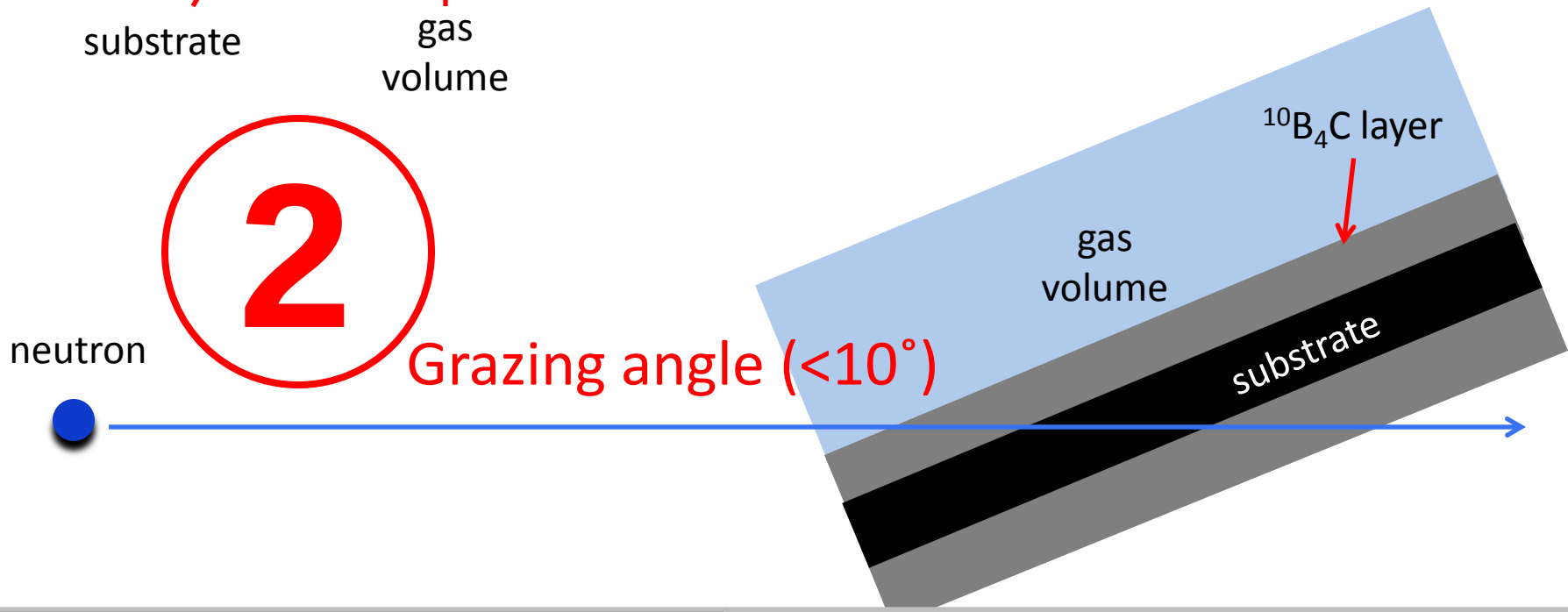


Efficiency ~ 5% @ 2.5Å
(saturated above 3μm)



Principle: two ways to increase efficiency





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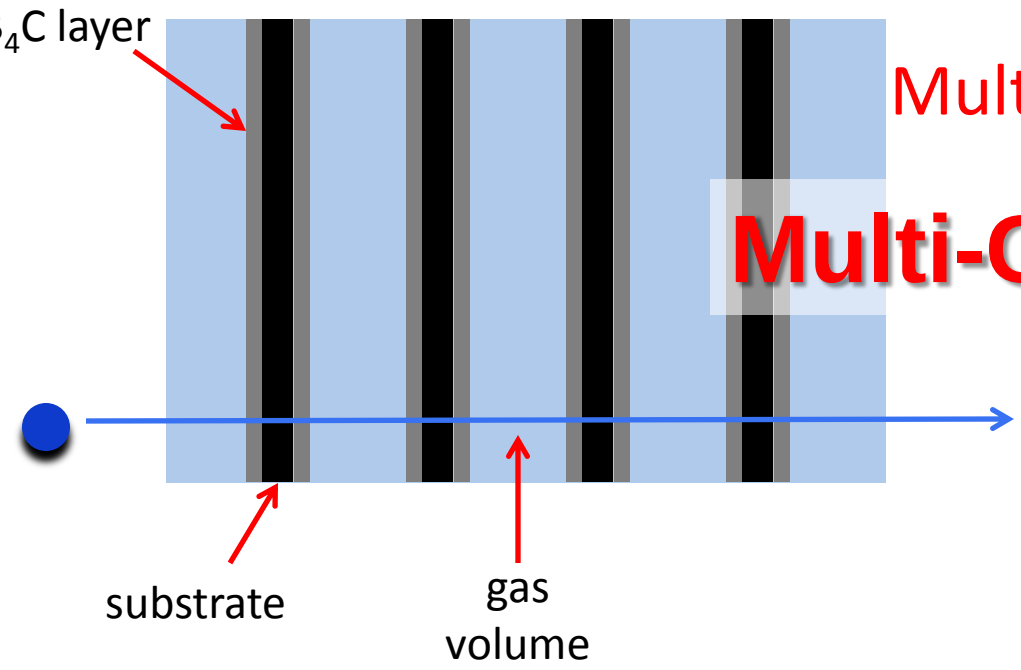
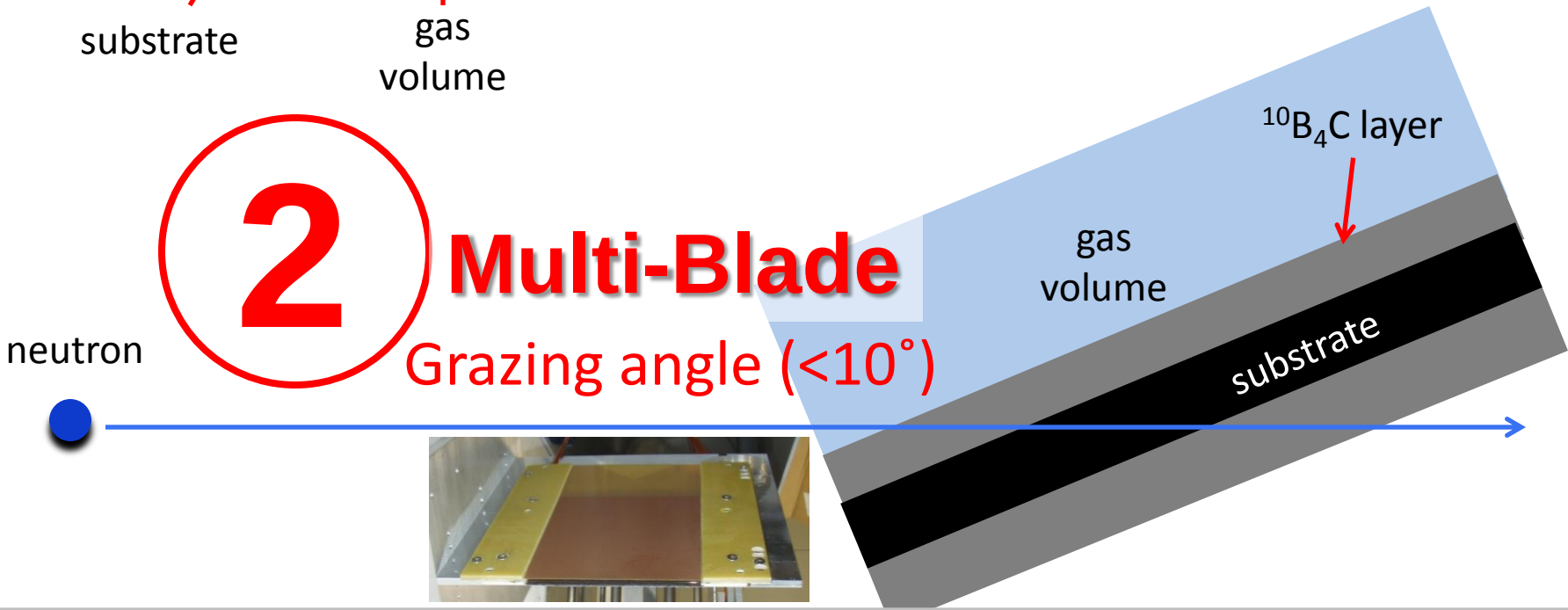


Multi layer

Multi-Grid **1**

2 **Multi-Blade**

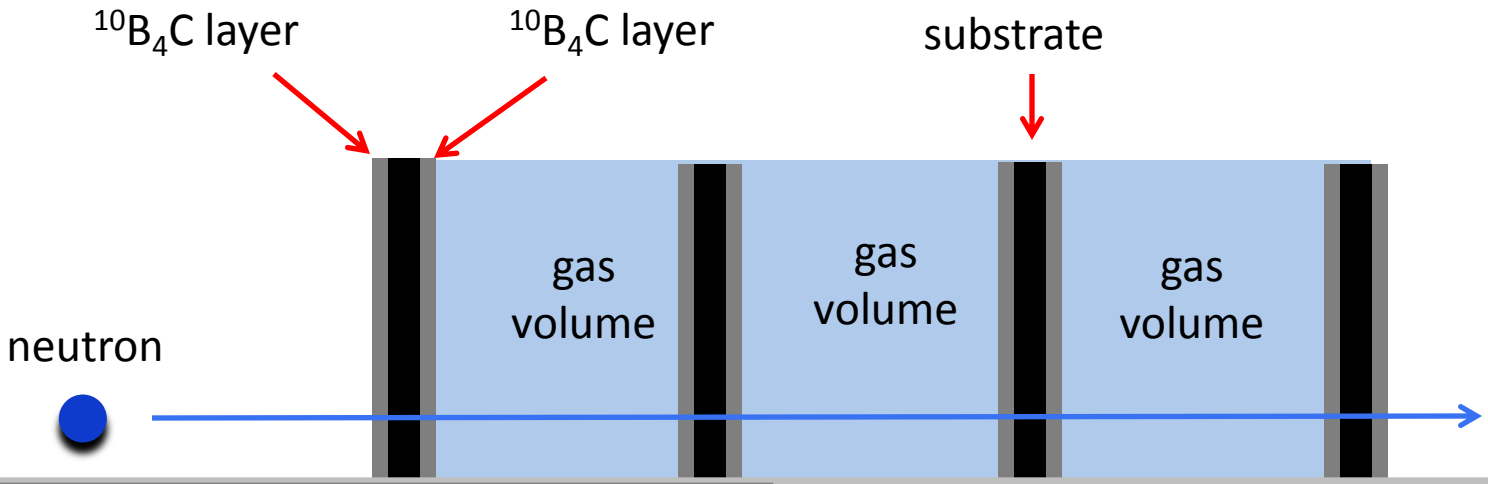
Grazing angle (<10˚)



Multi-Grid

Principle: Multi-Grid

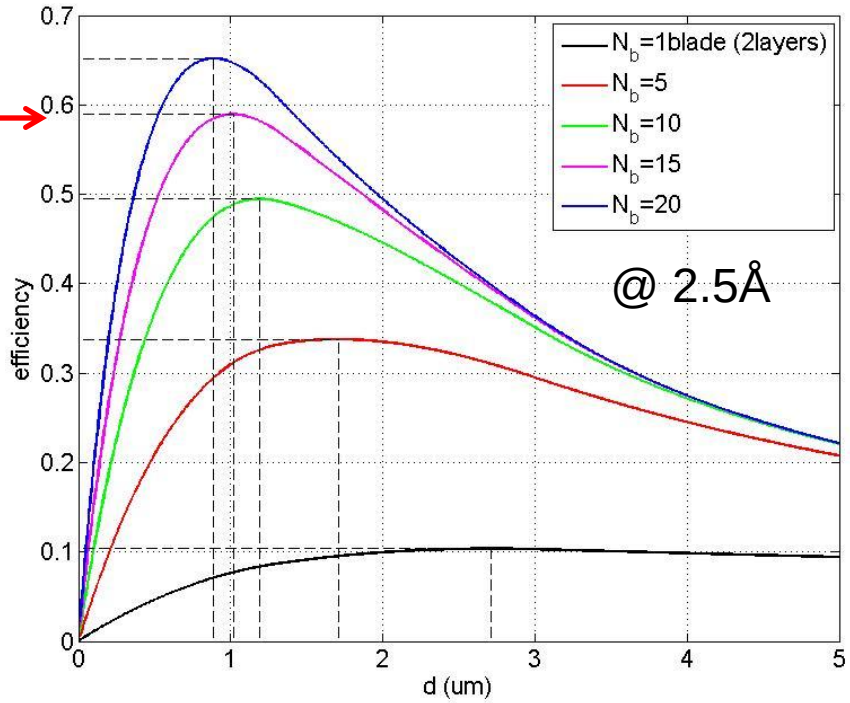
F. Piscitelli et al., 2013 *JINST* **8** P04020

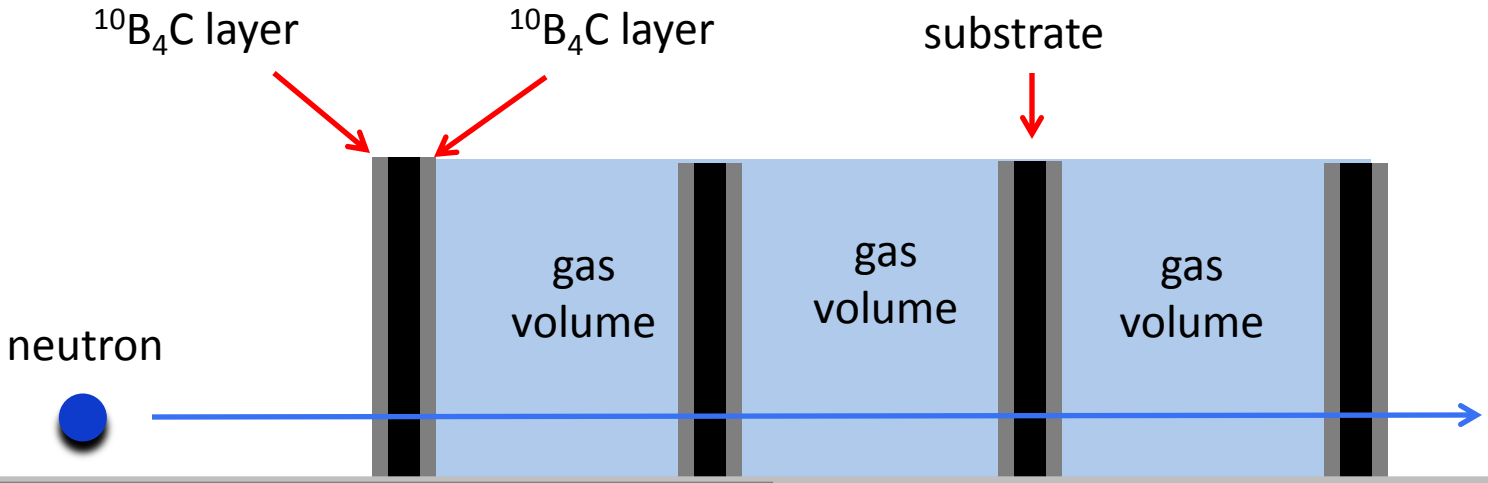


Principle: Multi-Grid

F. Piscitelli et al., 2013 *JINST* **8** P04020

58%
with 30 layers
of 1µm
(No Aluminium)





Multi-Grid

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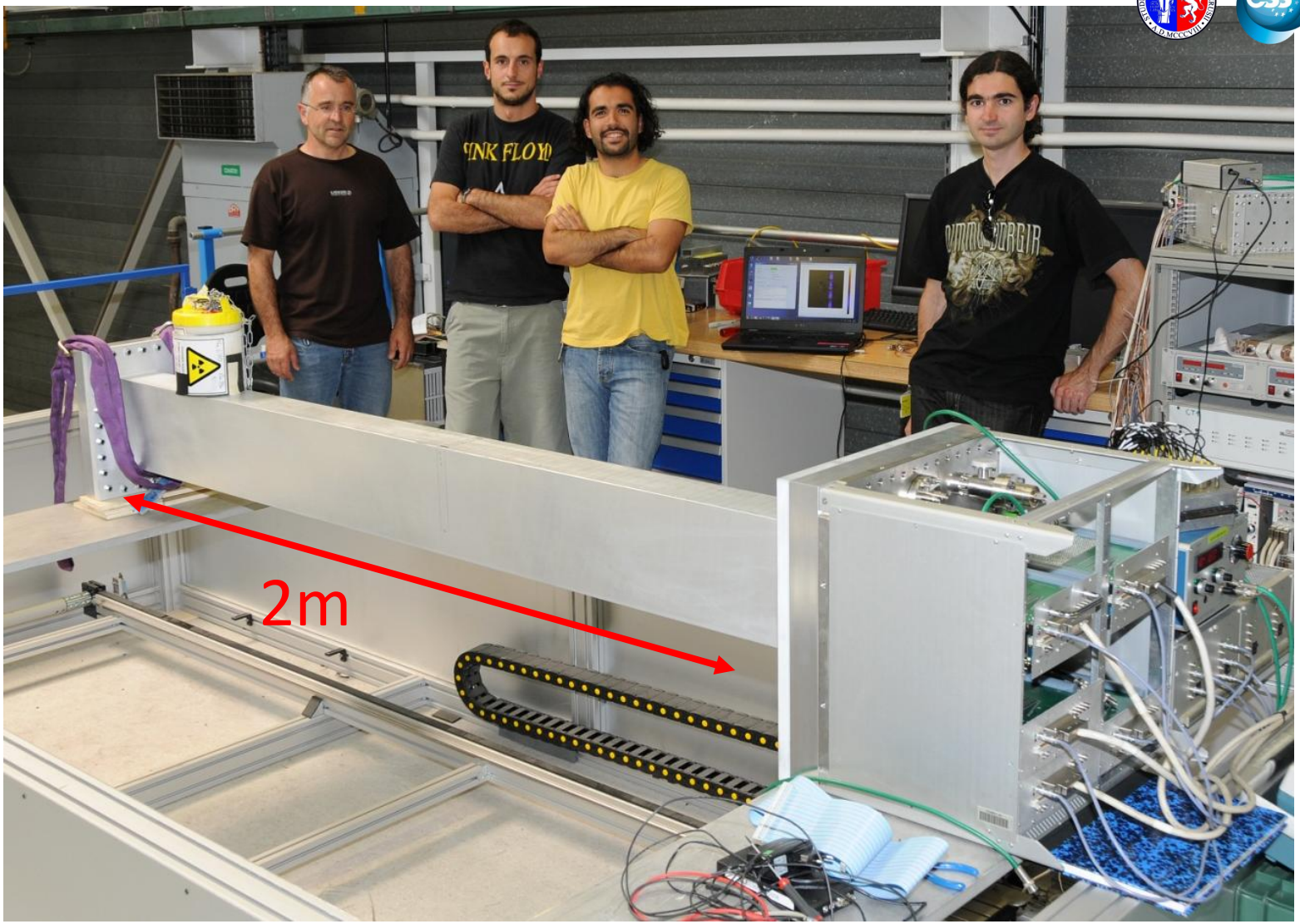
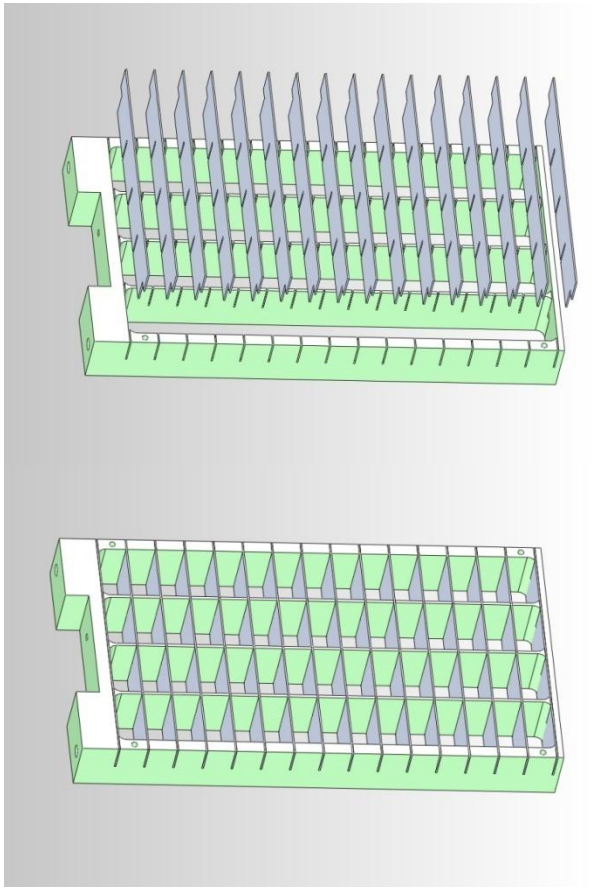
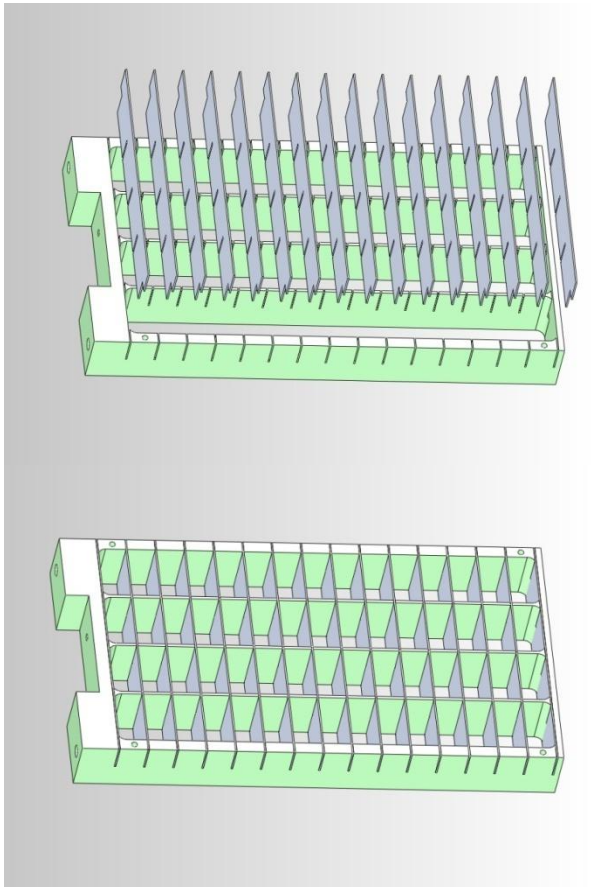


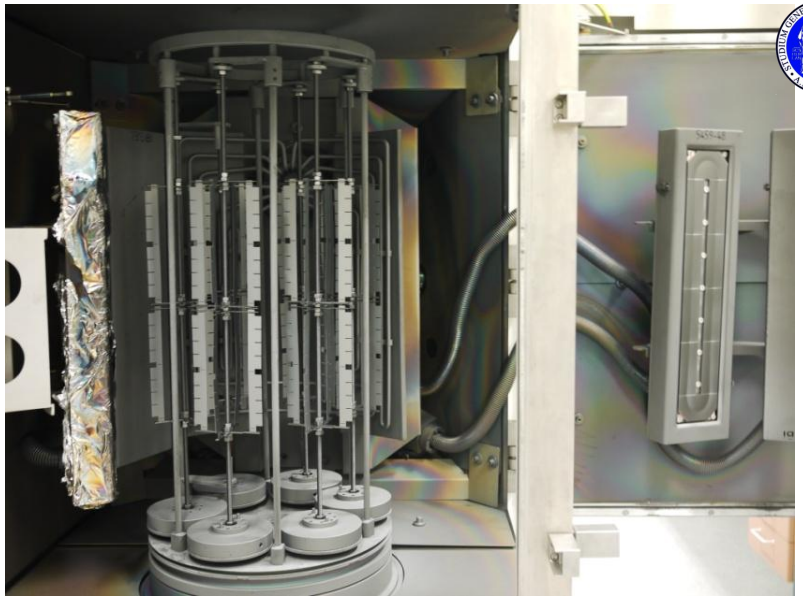
J. Correa et al., IEEE TNS, Volume PP, Issue 99, 17 January 2013, Pages 1-8, 10.1109/TNS.2012.2227798

Multi-Grid



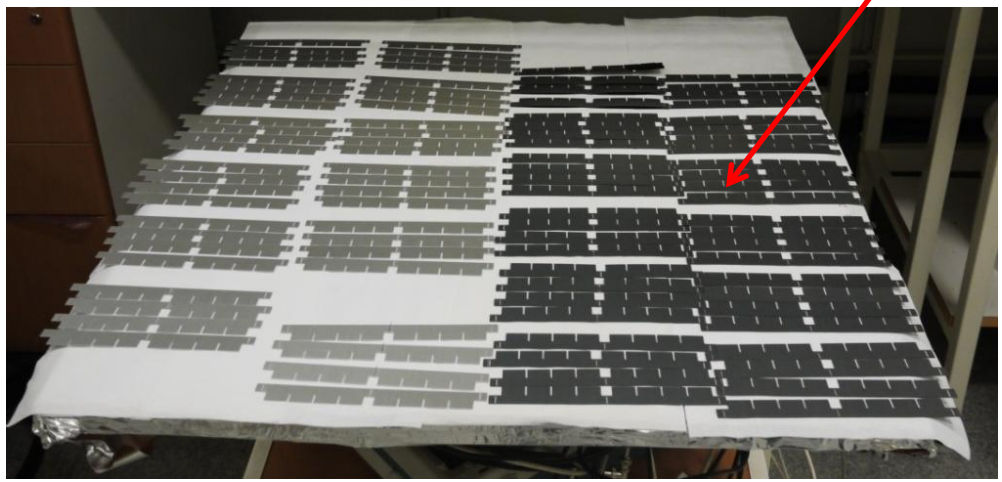
Multi-Grid





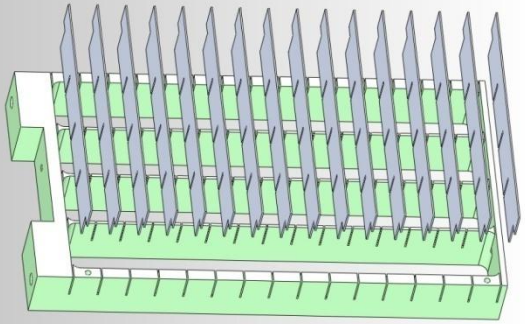
Linköping University

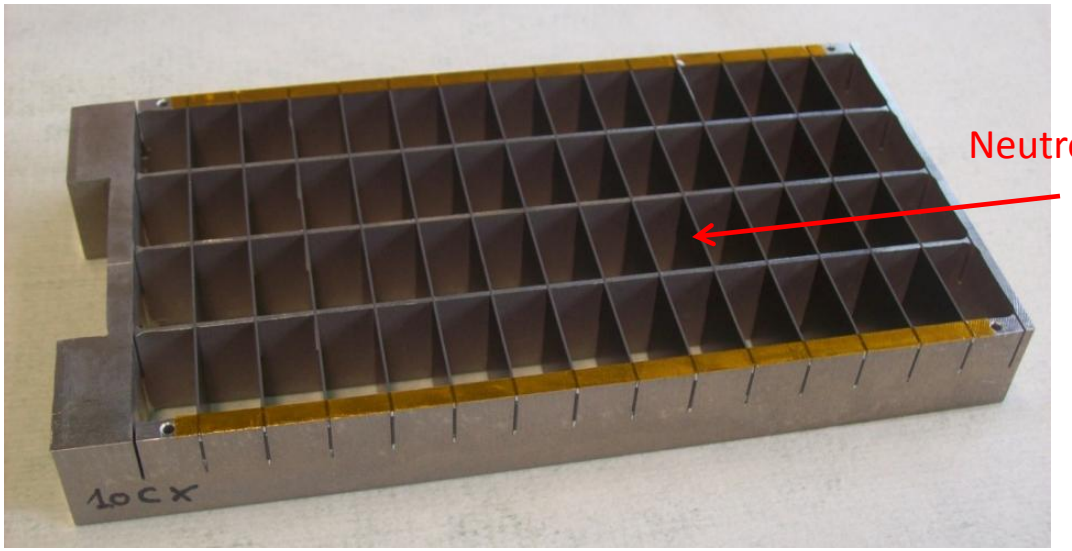
Sputtered $^{10}B_4C$ coatings

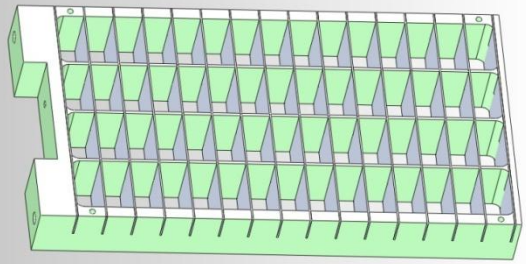


C. Höglund et a., J. Appl. Phys. **111**, 104908 (2012)

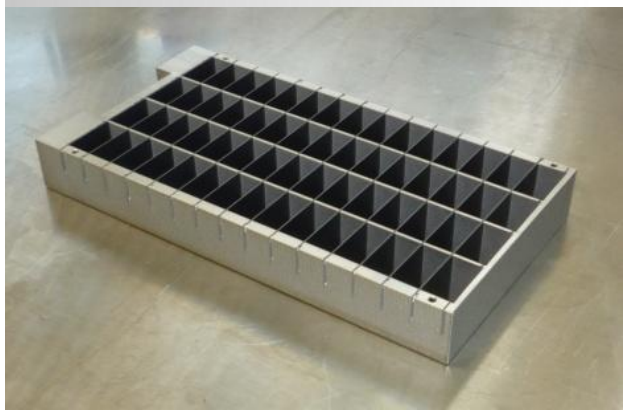
Multi-Grid

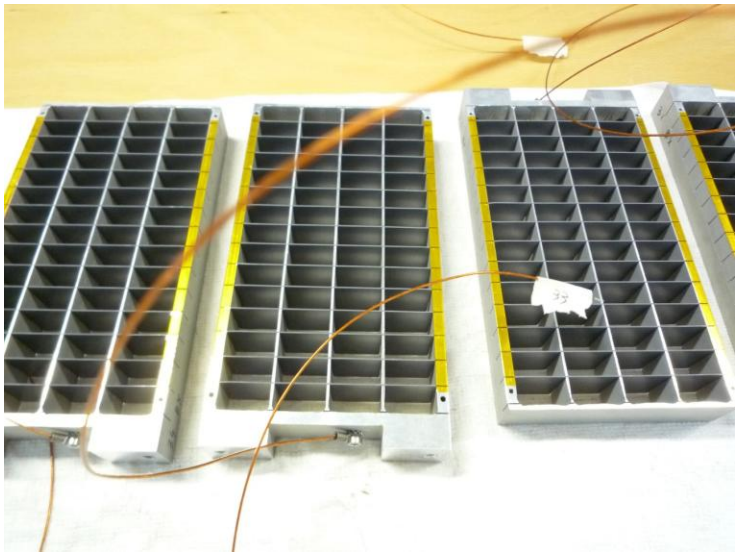




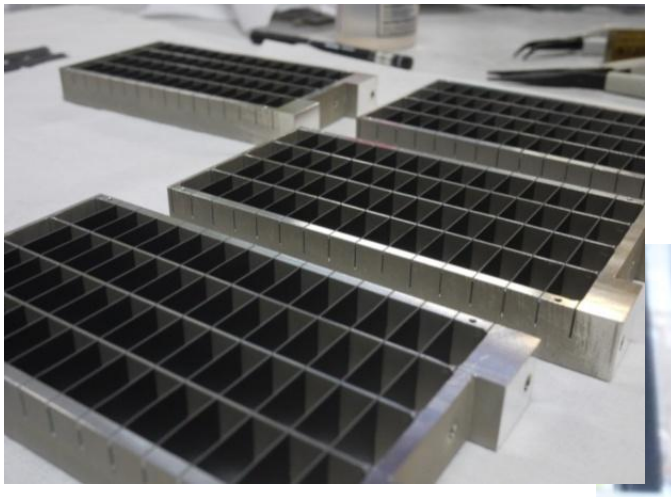


Voxel 2cm x 2cm x 1cm

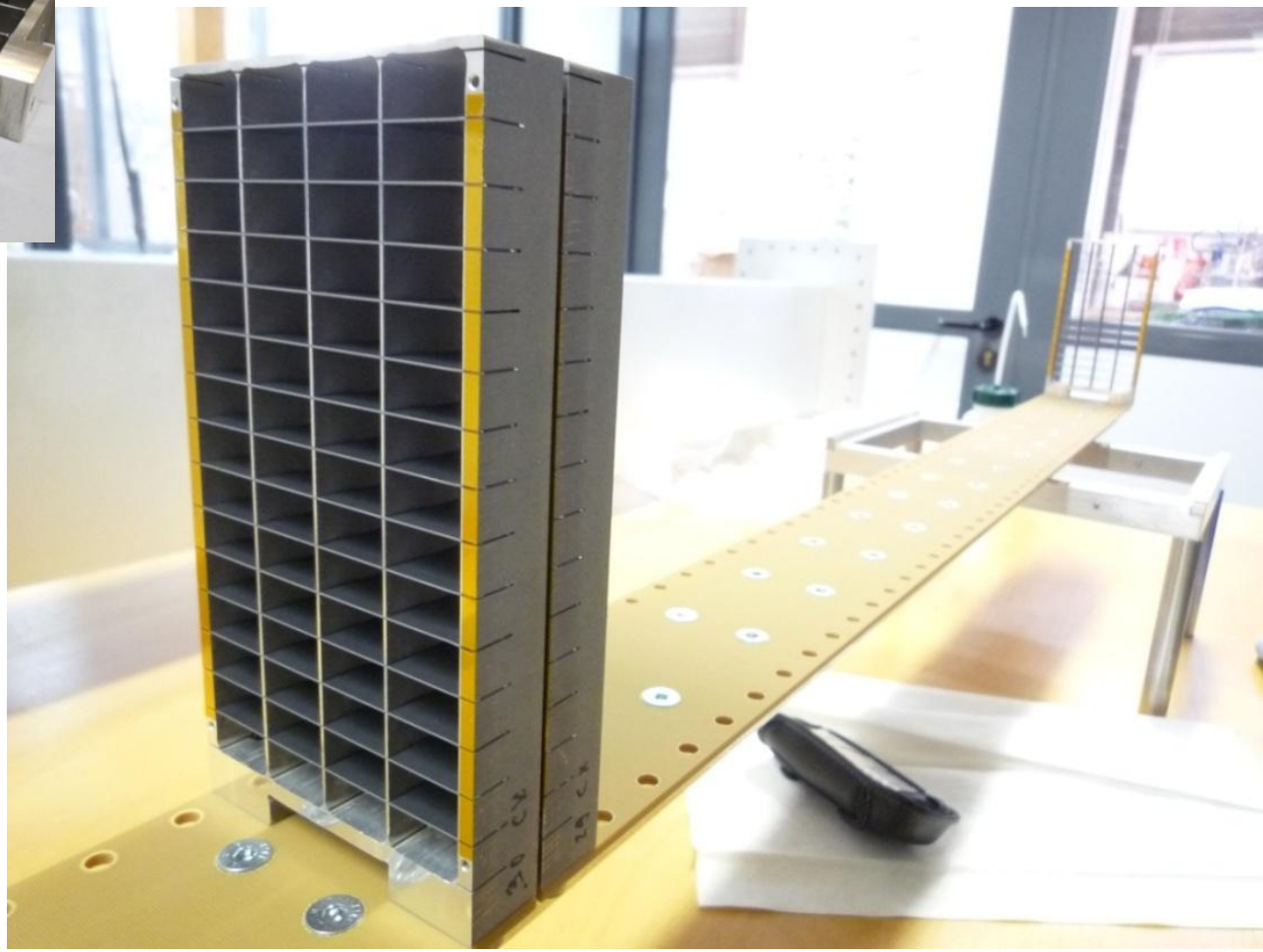




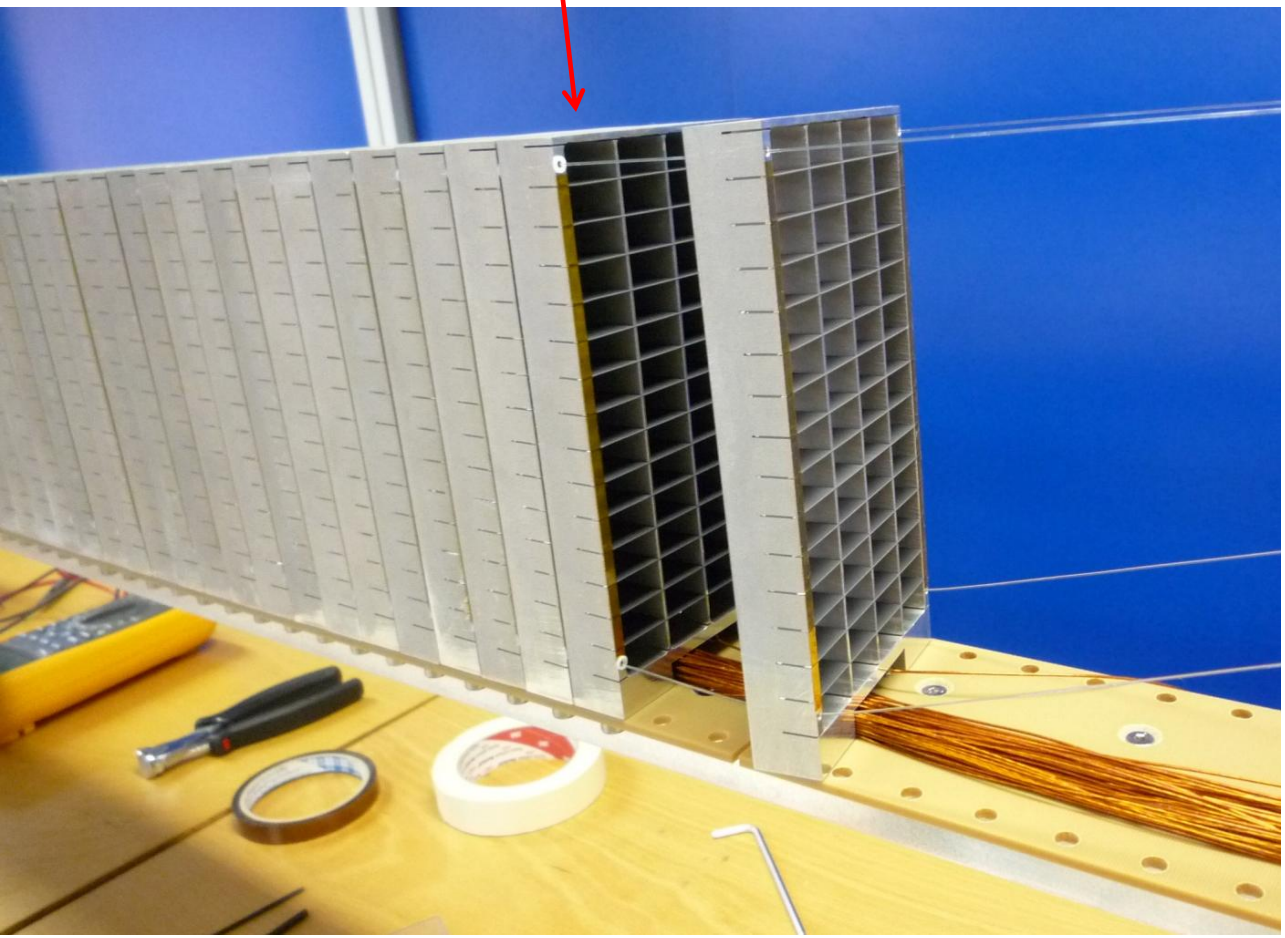
Multi-Grid



Neutron beam



Multi-Grid



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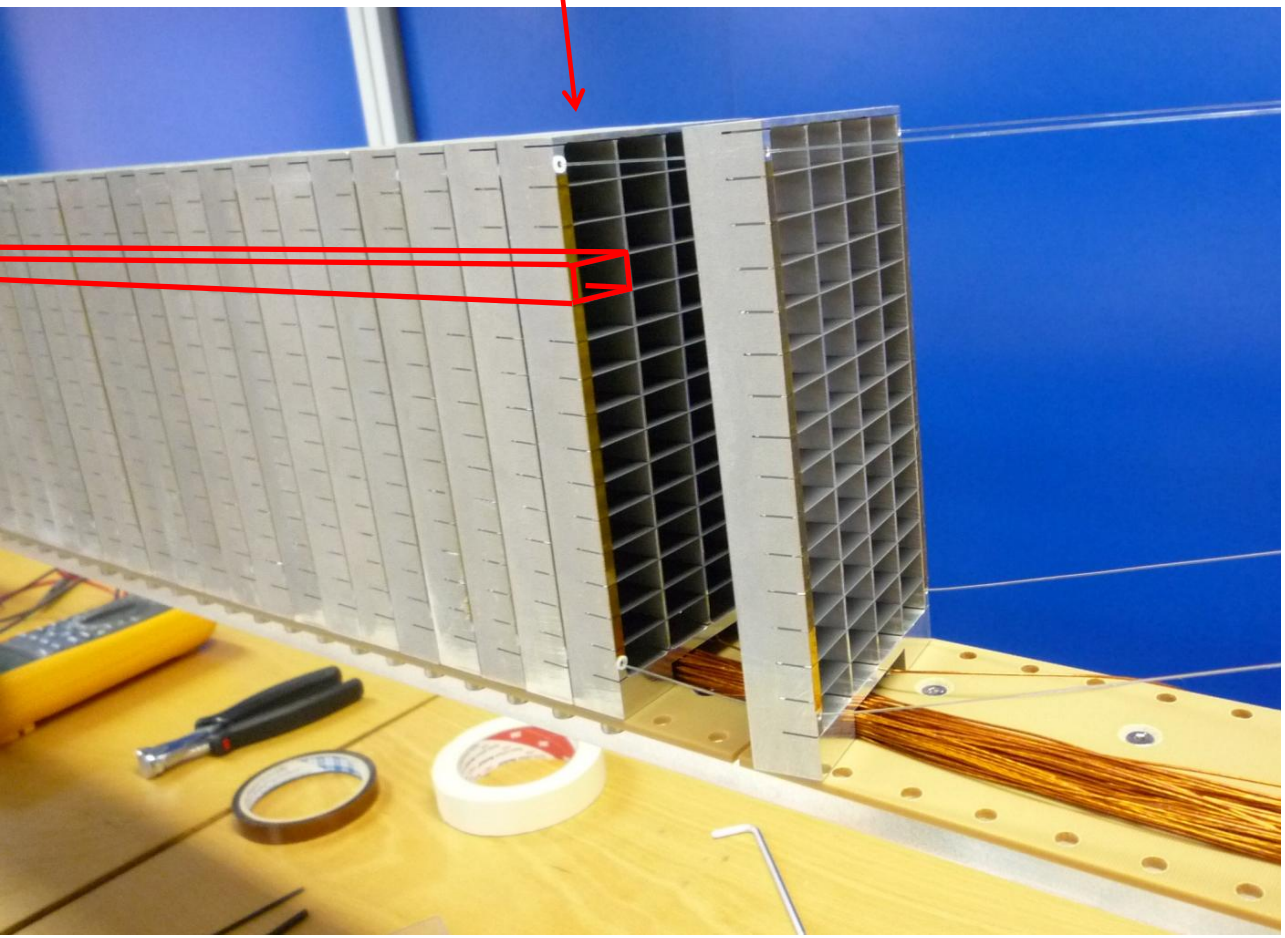

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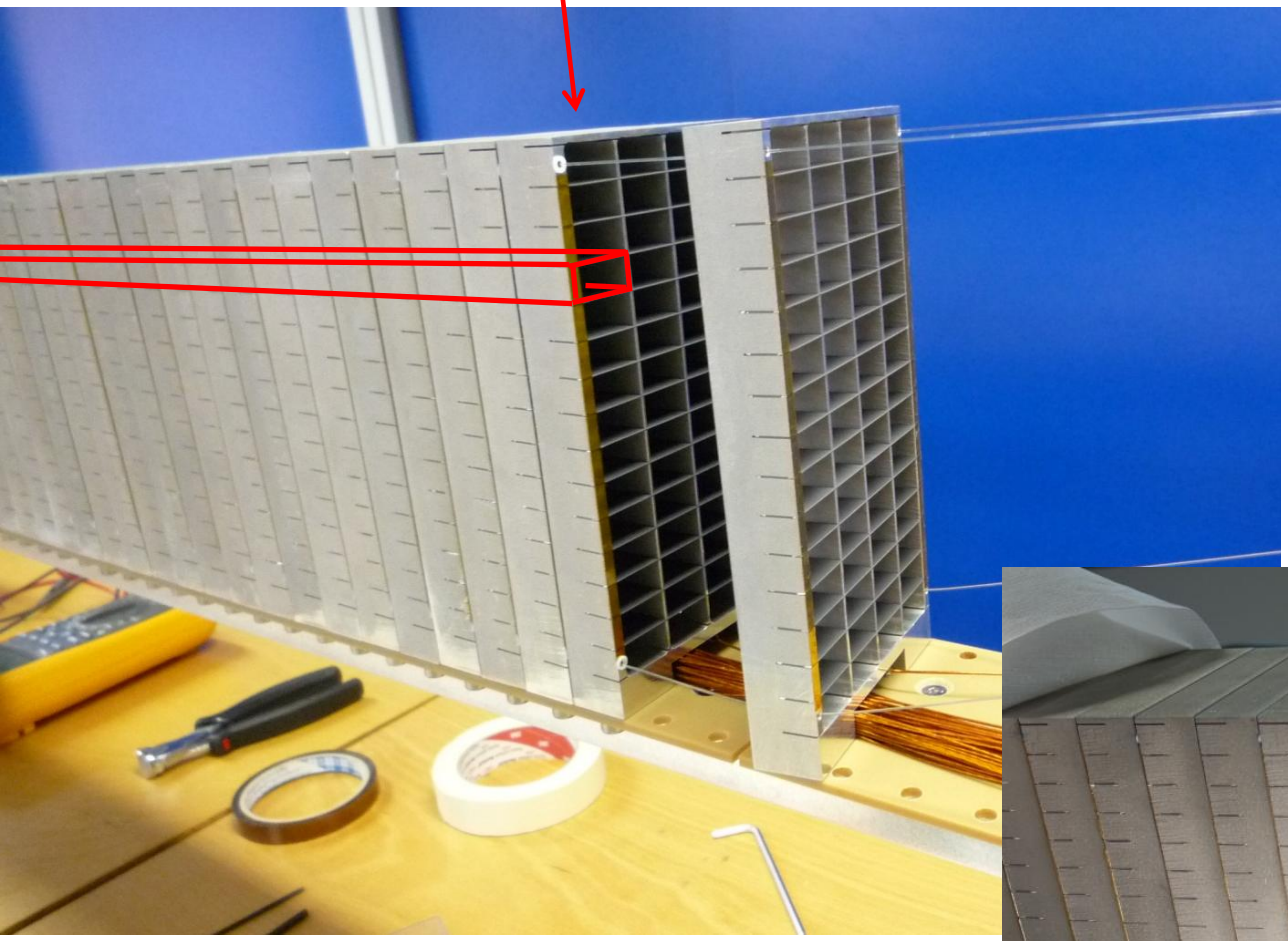

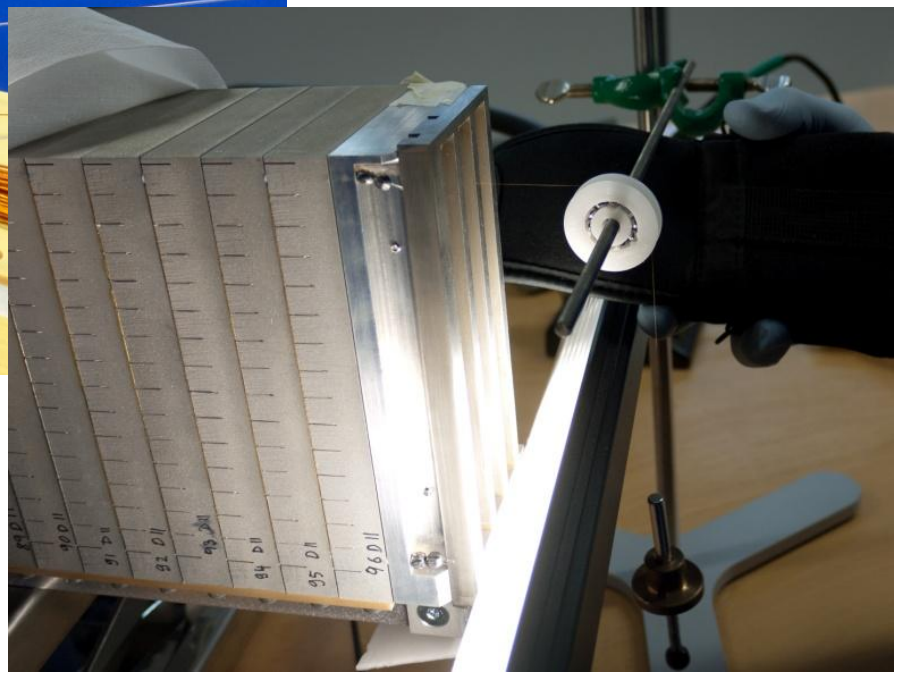

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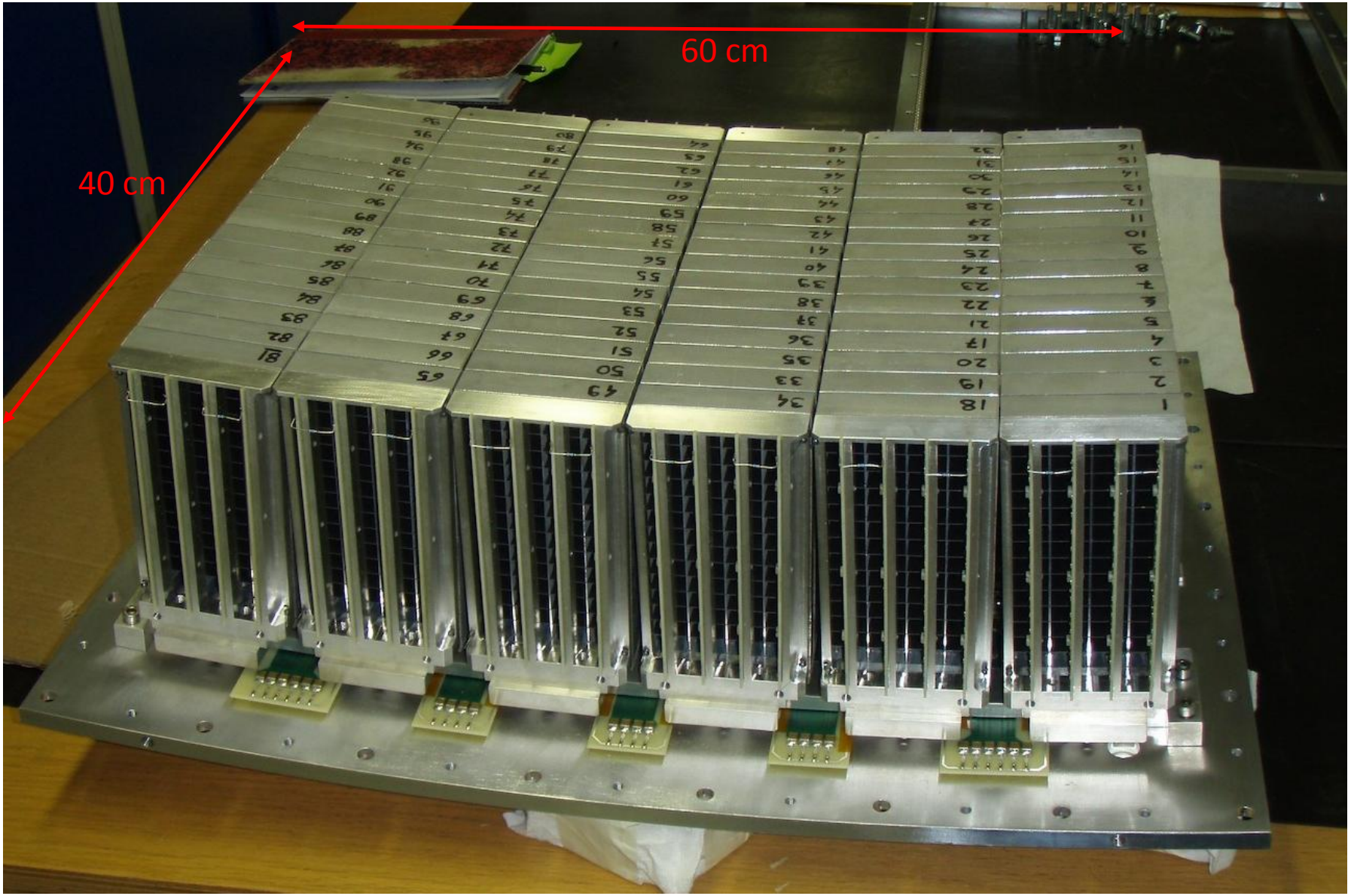

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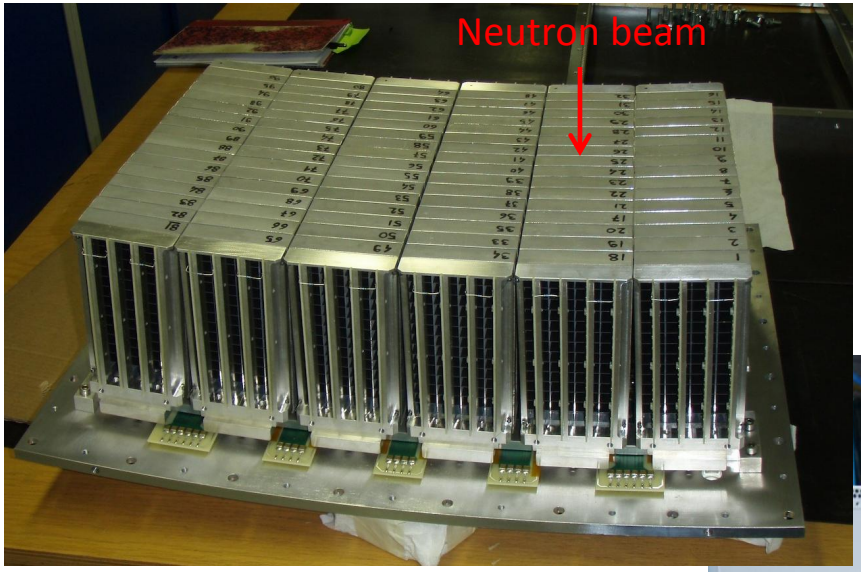
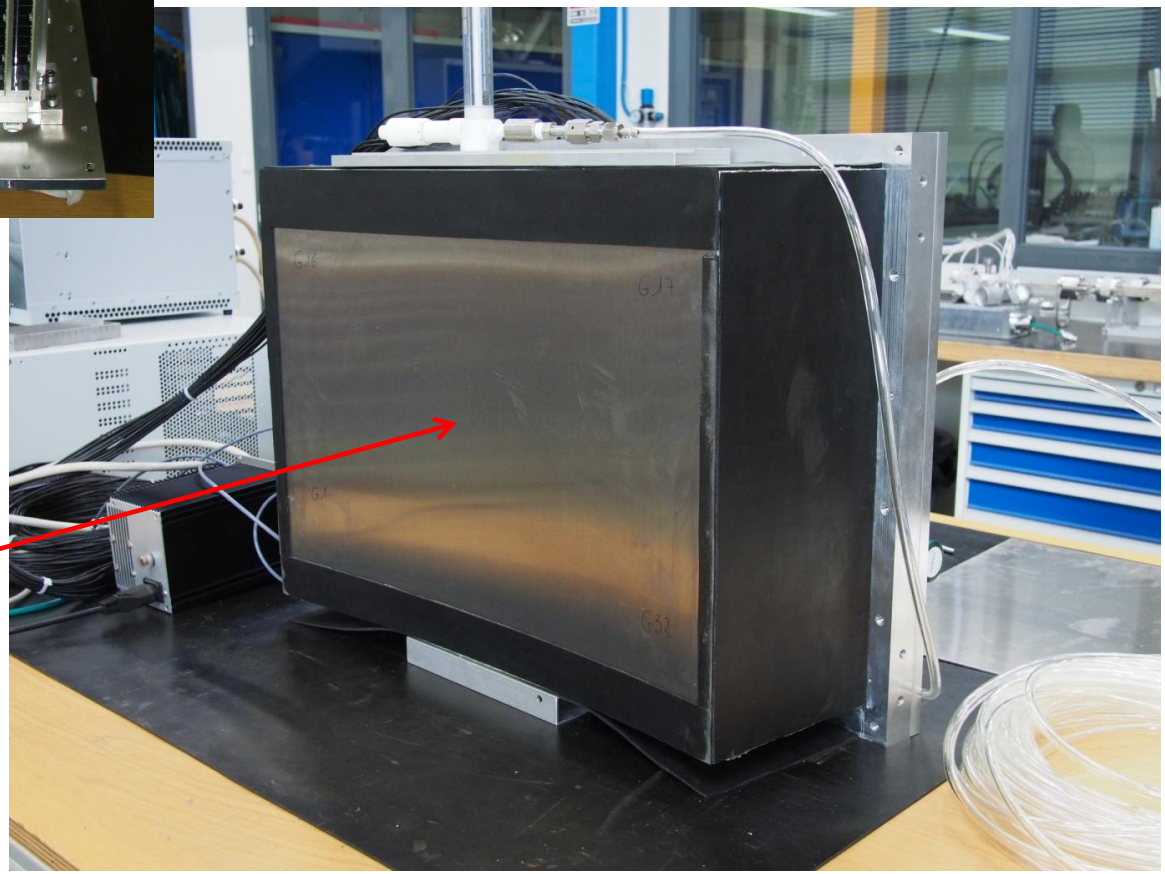
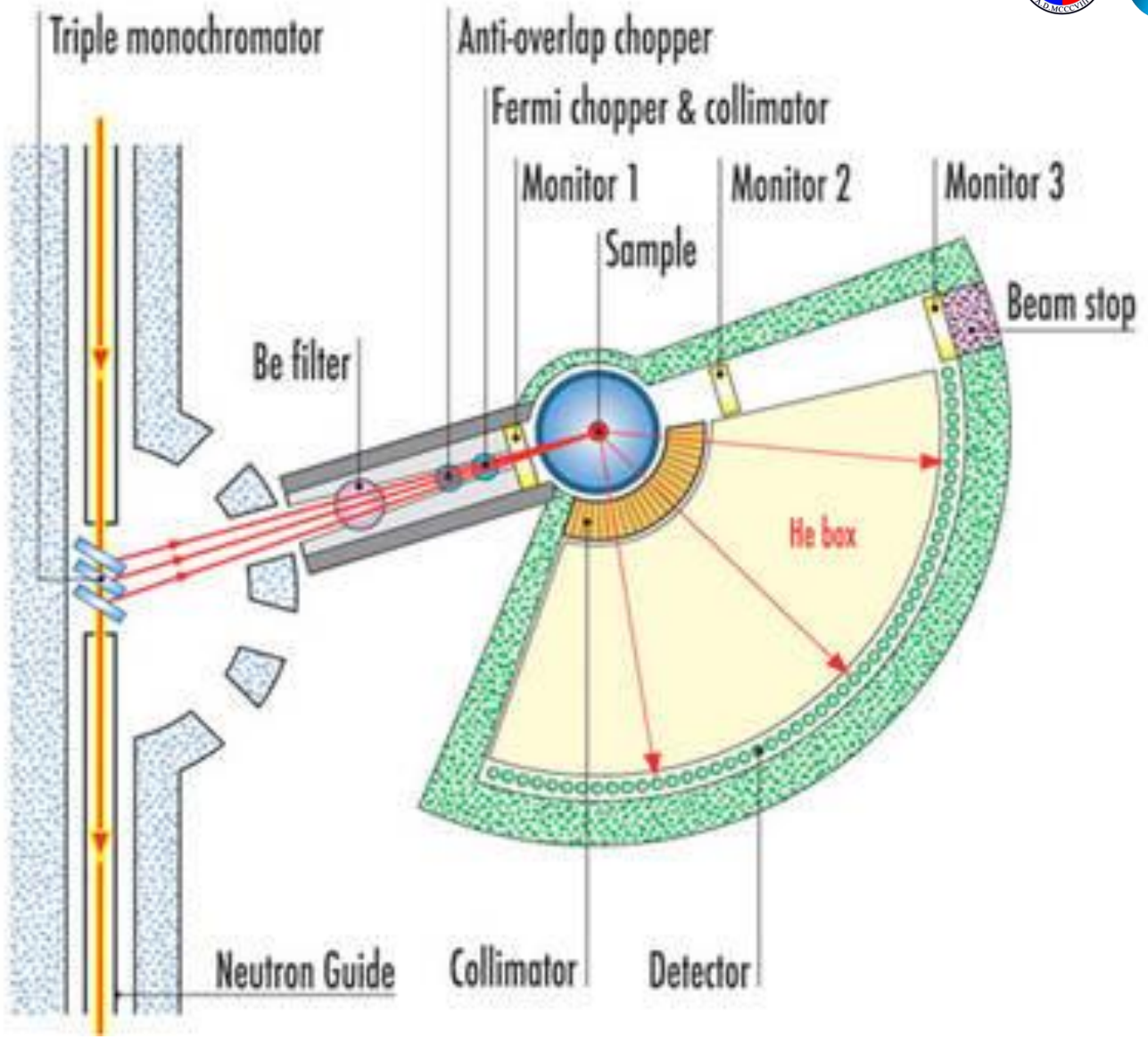


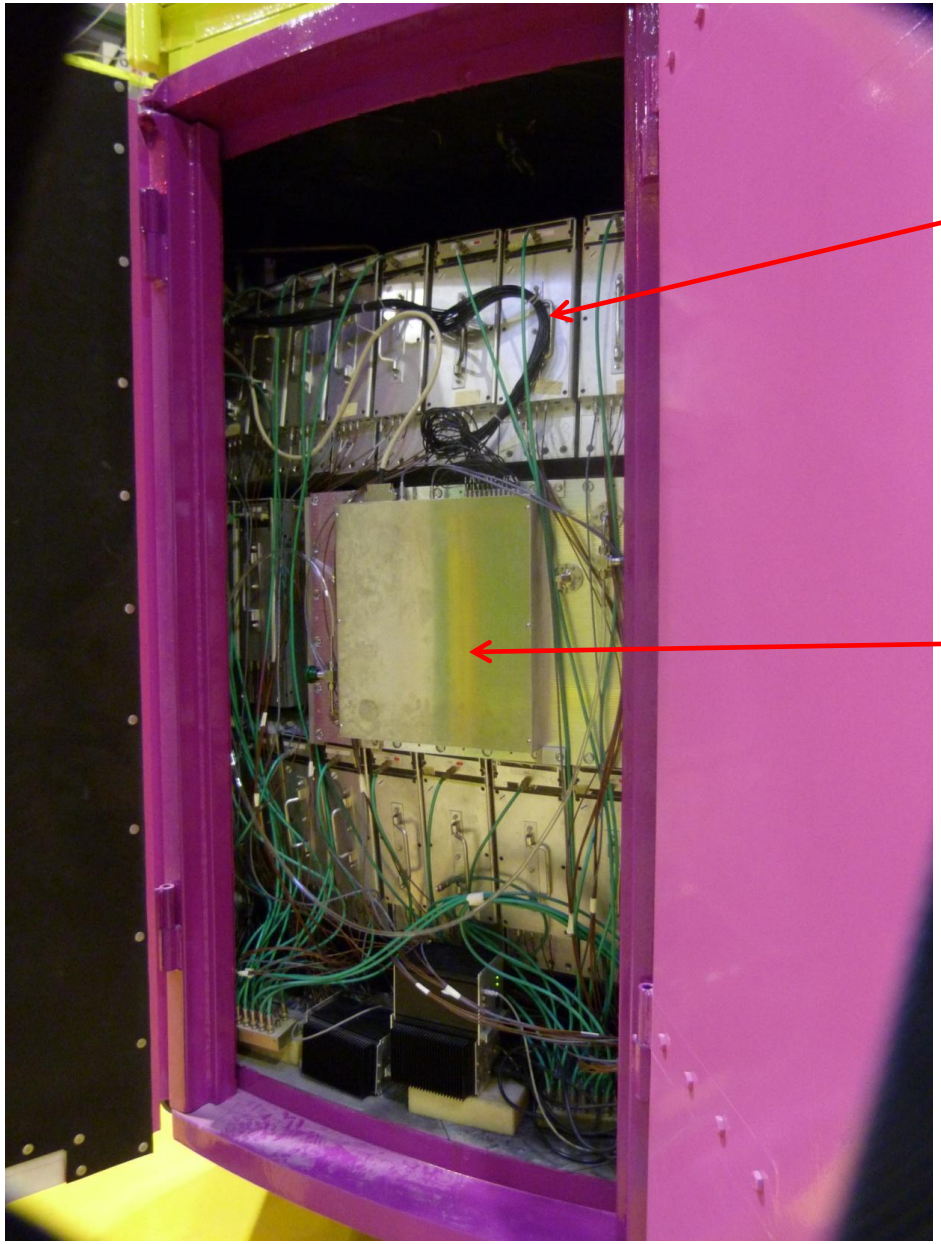


IN6 @ ILL

IN6 @ ILL


Triple monochromator
Anti-overlap chopper
Fermi chopper & collimator
Monitor 1
Monitor 2
Monitor 3
Sample
Beam stop
Be filter
He box
Neutron Guide
Collimator
Detector

Multi-Grid

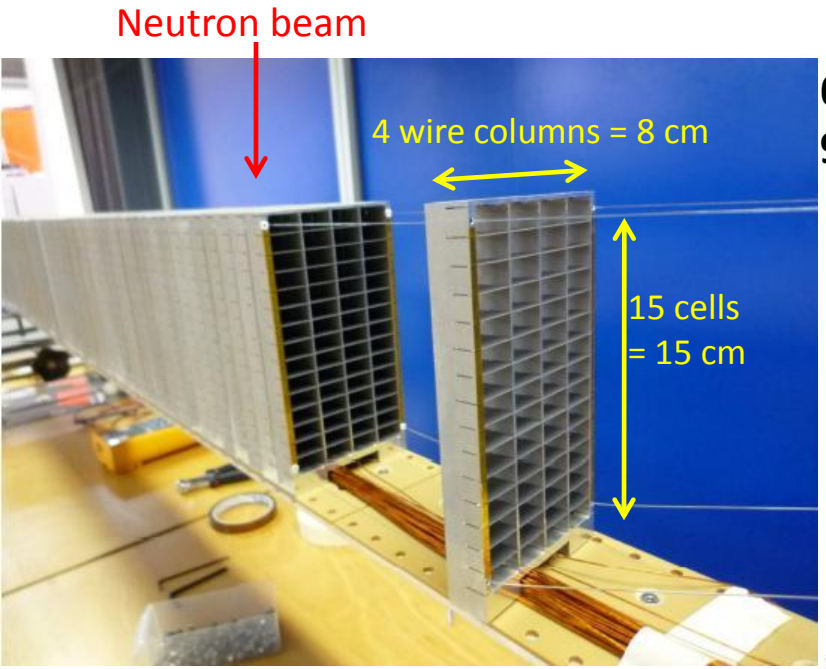


^{3}He - tubes

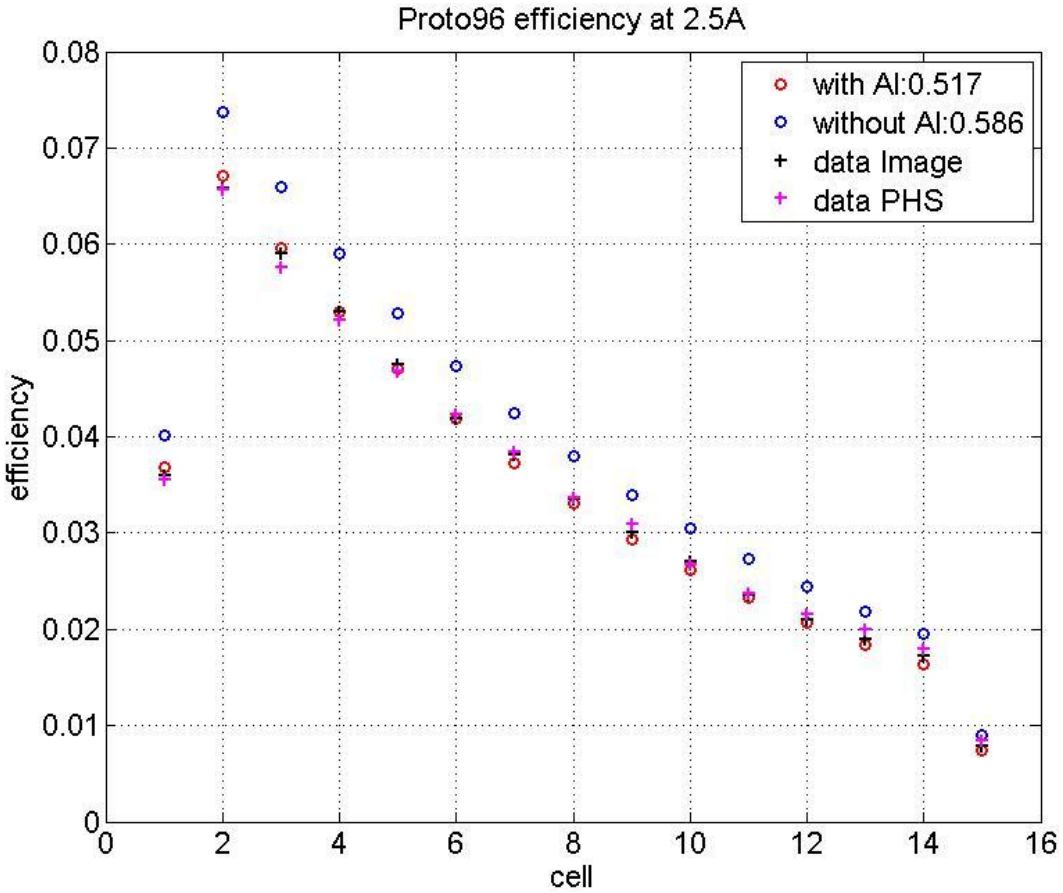
Multi-Grid

Results

Multi-Grid: efficiency



60 anodes
96 cathodes



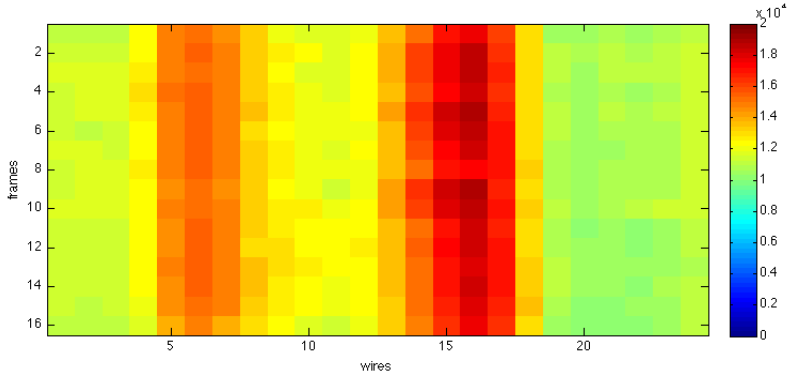
Measured efficiency @ 2.5Å:

$$\varepsilon = (51.4 \pm 0.2)\%$$

J. Correa et al., IEEE TNS, Volume PP, Issue 99, 17 January 2013, Pages 1-8, 10.1109/TNS.2012.2227798

Multi-Grid: efficiency VS ^{3}He tubes

(Courtesy of A. Khaplanov)



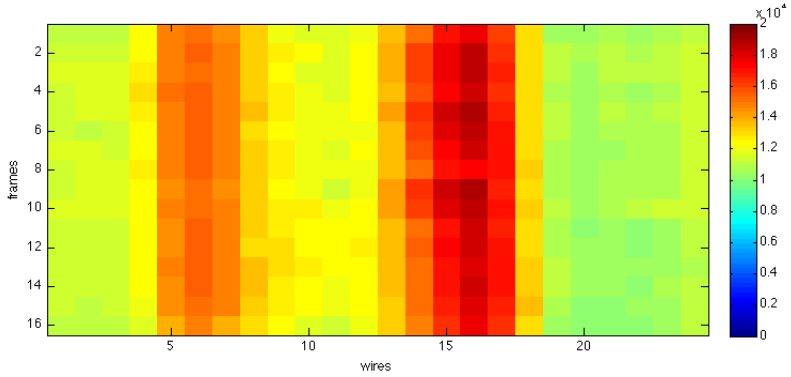
Bragg peaks in the detector

-> position spectra match ^{3}He tubes' (average on top and bottom ^{3}He tubes rows)

-> better position resolution in the prototype (higher granularity)

Multi-Grid: efficiency VS ^{3}He tubes

(Courtesy of A. Khaplanov)



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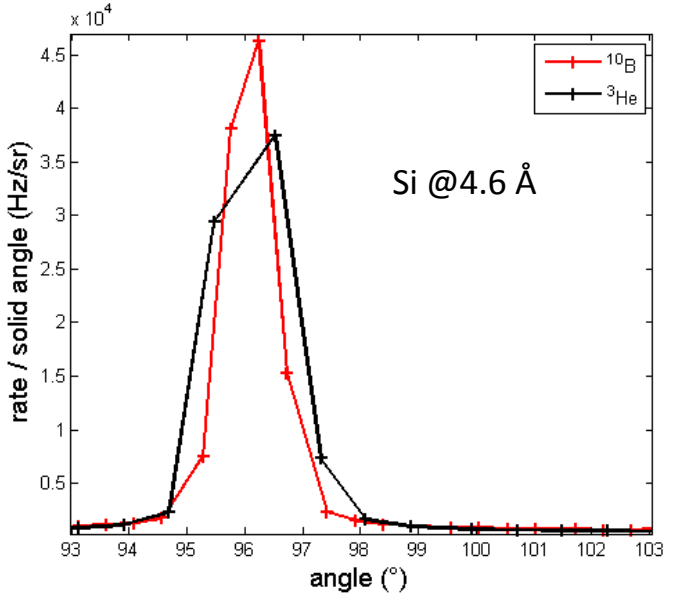
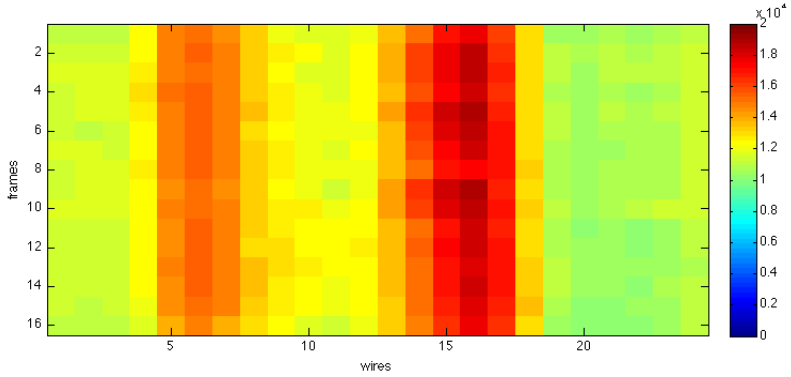
Ratio of integrated rates in Bragg peaks :

- 4.1 Å : rate(^{10}B) / rate(^{3}He) = 1.08
- 4.6 Å : rate(^{10}B) / rate(^{3}He) = 0.97



Multi-Grid: efficiency VS ^{3}He tubes

(Courtesy of A. Khaplanov)



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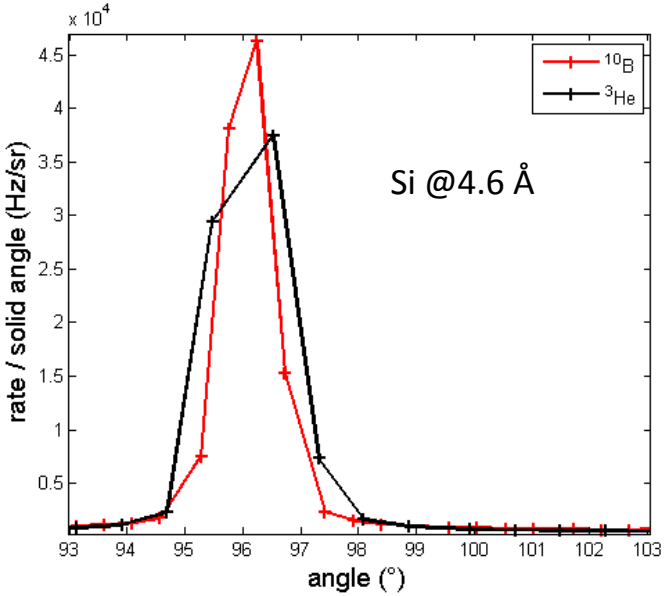
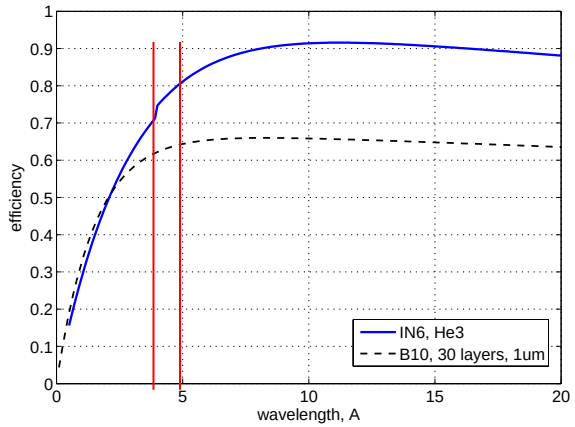
-> **measured efficiencies are similar** in both detectors @4.1 and 4.6 Å



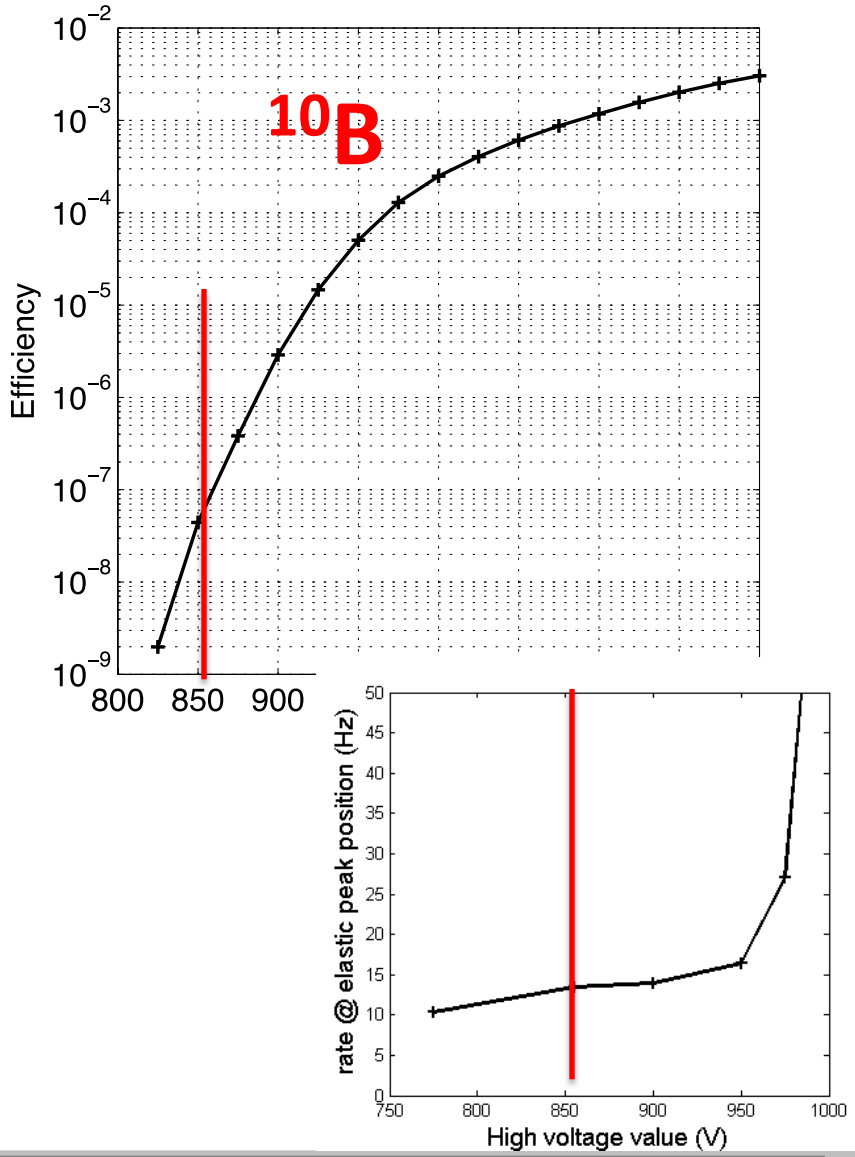


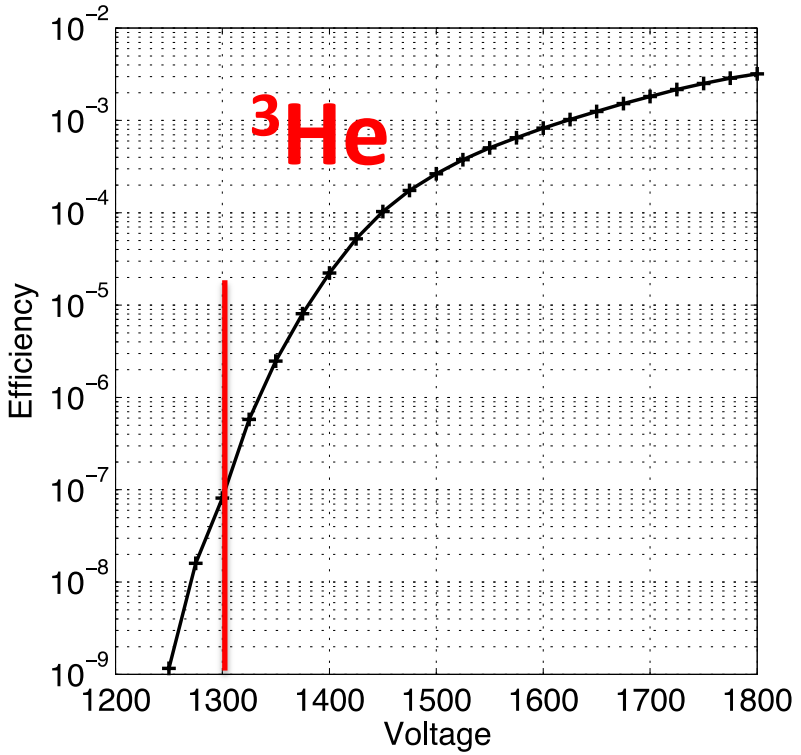
^{3}He tubes : higher intrinsic efficiency (see theoretical curves)

^{10}B Multi-Grid : less dead spaces

Multi-Grid: gamma sensitivity

(Courtesy of A. Khaplanov) 164 MBq 137Cs source, γ (662 keV)

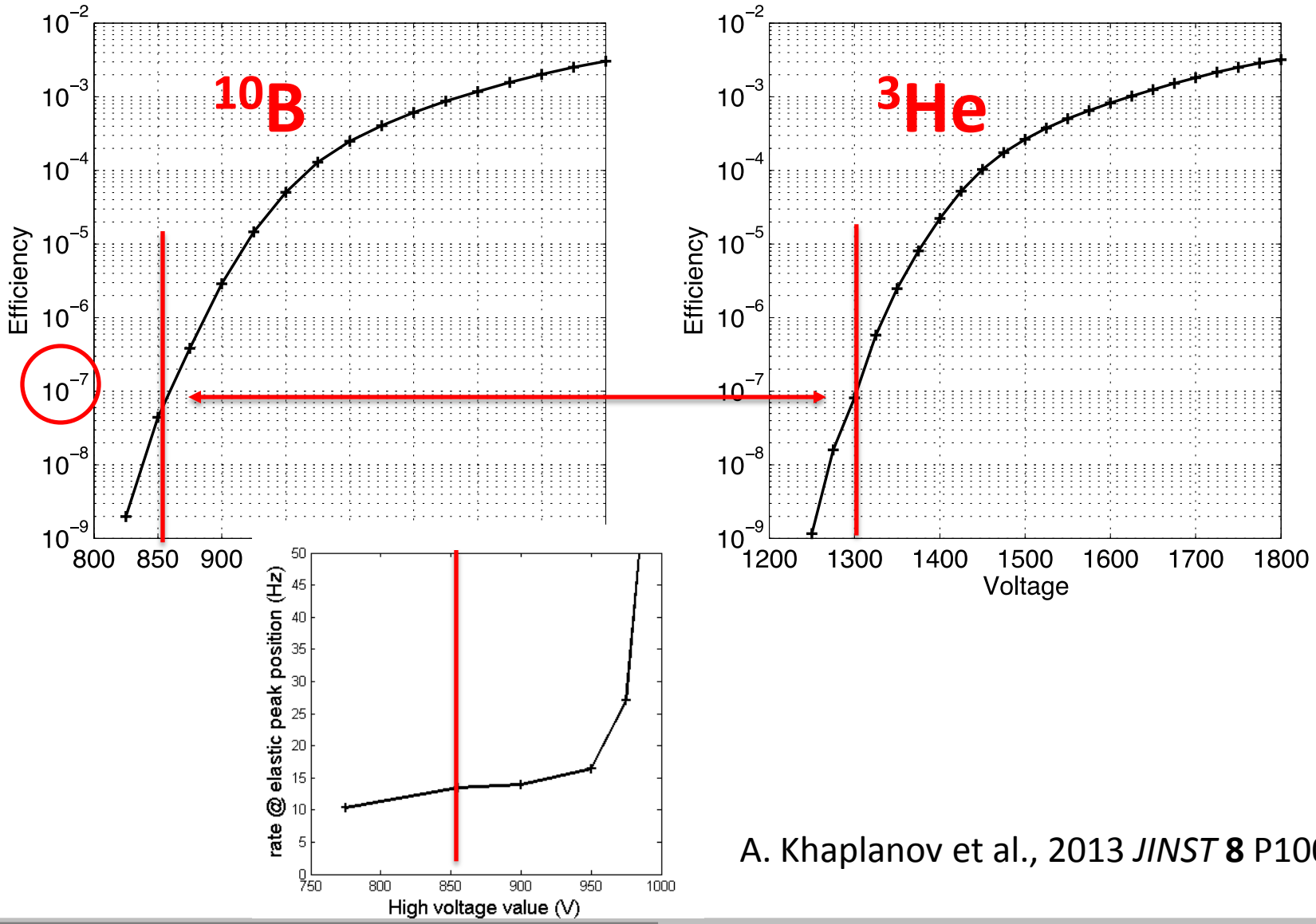




A. Khaplanov et al., 2013 *JINST* **8** P10025

Multi-Grid: gamma sensitivity

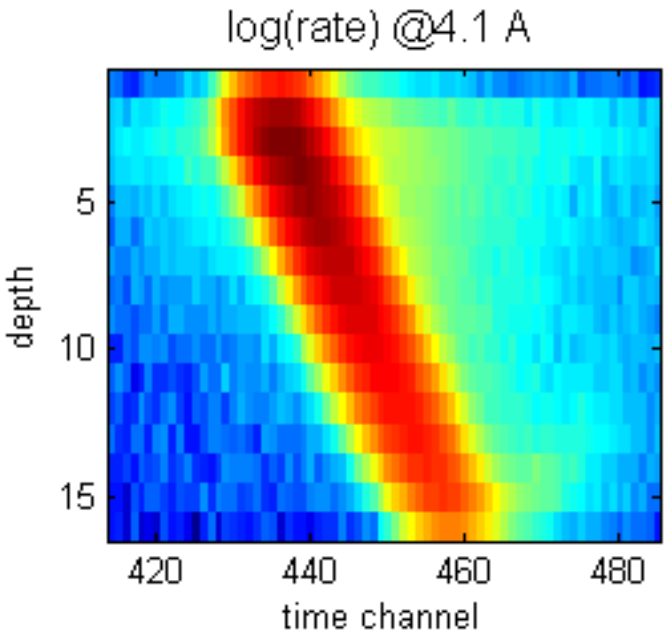
(Courtesy of A. Khaplanov) 164 MBq 137Cs source, γ (662 keV)



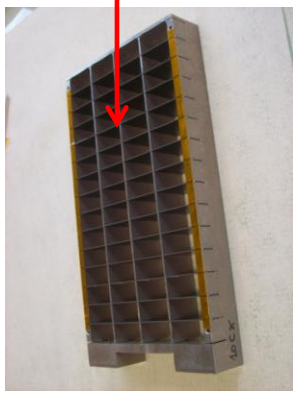
A. Khaplanov et al., 2013 *JINST* **8** P10025

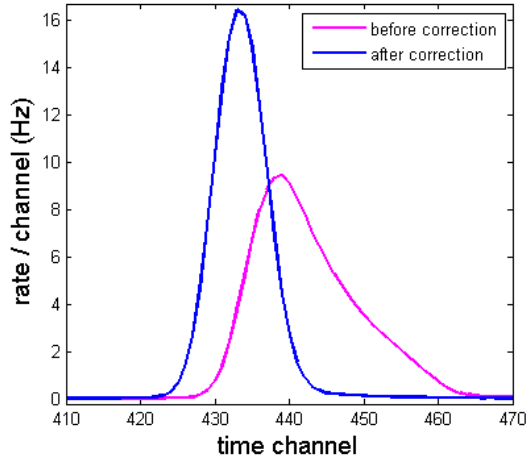
Multi-Grid: ToF resolution

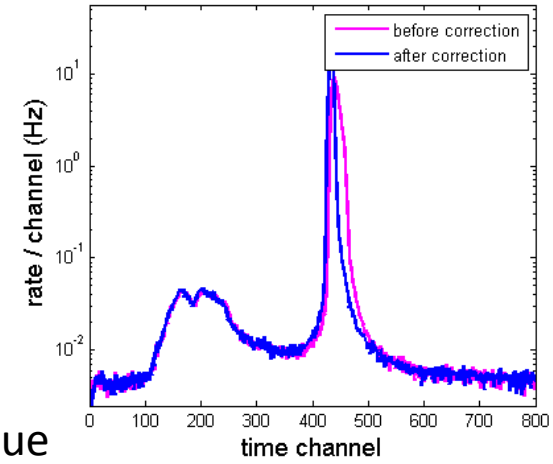
(Courtesy of A. Khaplanov)



Neutron beam







Time of Flight corrected for the depth of the detector

Resolution given by depth of the unit cell

δ_{depth} = 1cm → δ_{ToF} = 8.6 µs (@4.6 Å)

Detector/electronics resolution much higher

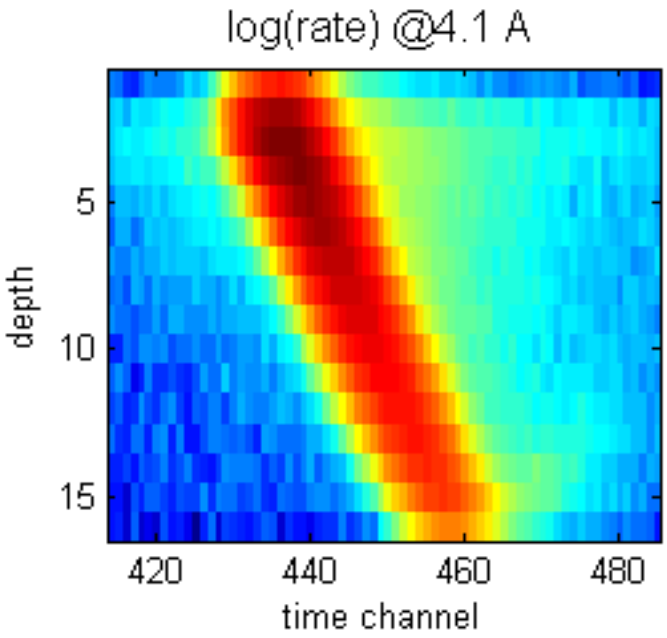
lambda	FWHM (µs)		(^{10}B -^{3}He) / ^{3}He
	^{3}He	^{10}B	
4,1	45,3	50,7	12,0%
4,6	45,9	53,0	15,5%
5,1	57,3	65,2	13,7%

Some loss of time resolution due to charge division readout (30 tubes together)

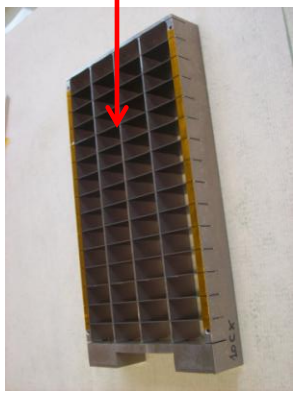
solved by individual readout

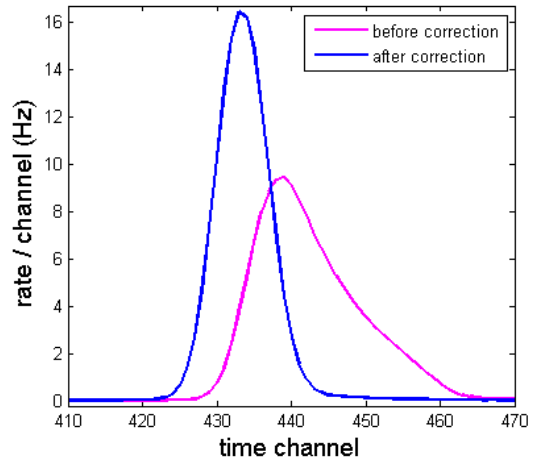
Multi-Grid: ToF resolution

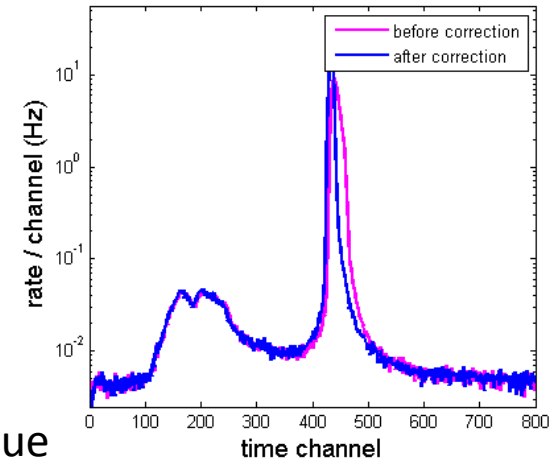
(Courtesy of A. Khaplanov)



Neutron beam







Electronics not optimized yet

Time of Flight corrected for the depth of the detector

Resolution given by depth of the unit cell

δ_{depth} = 1cm → δ_{ToF} = 8.6 µs (@4.1Å)

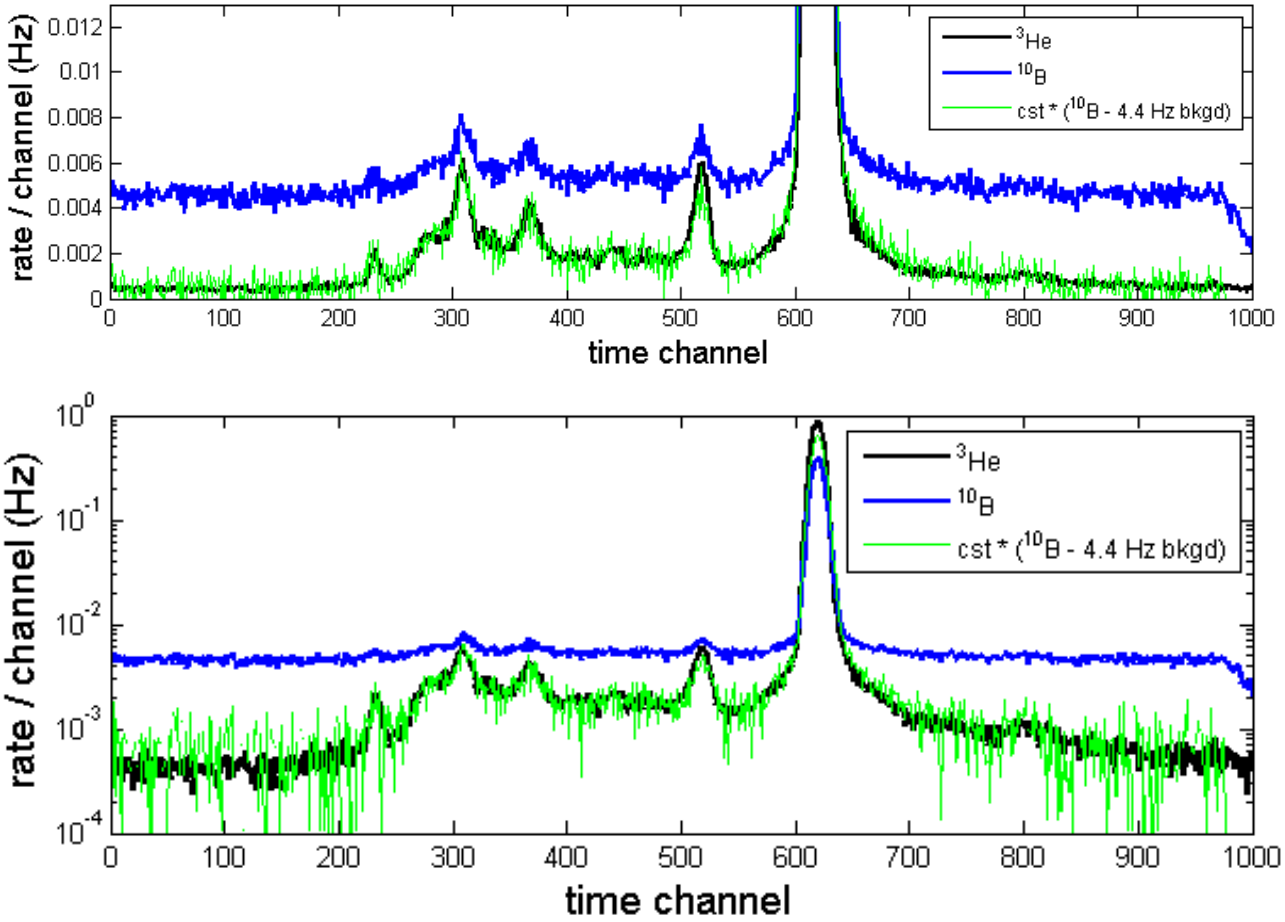
Detector/electronics resolution much higher

lambda	FWHM (µs)		(^{10}B -^{3}He) / ^{3}He
	^{3}He	^{10}B	
4,1	45,3	50,7	12,0%
4,6	45,9	53,0	15,5%
5,1	57,3	65,2	13,7%

Some loss of time resolution due to charge division readout (30 tubes together)

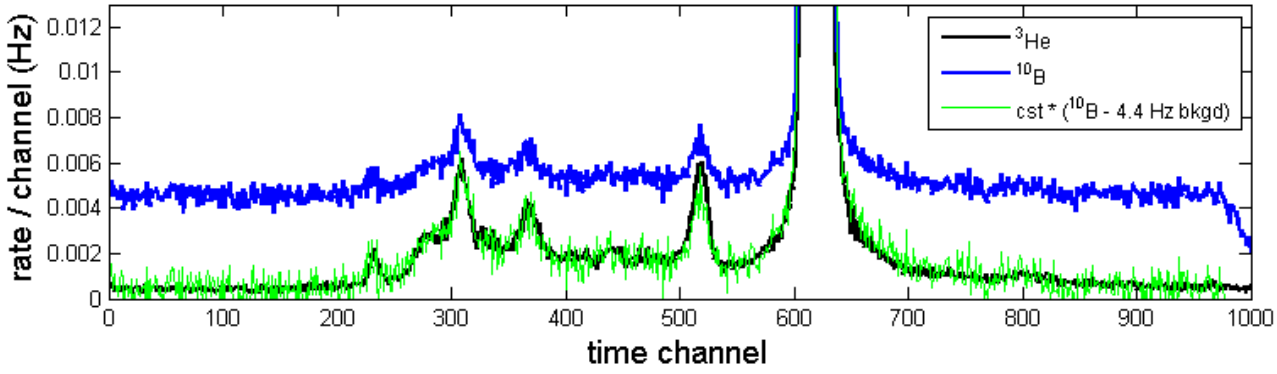
solved by individual readout

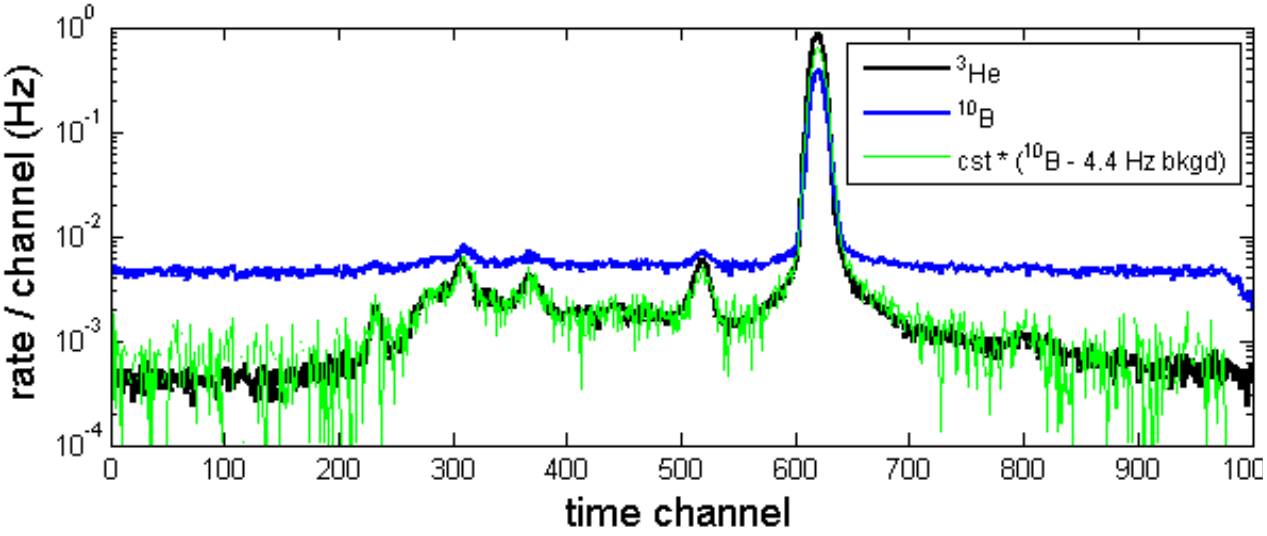
Multi-Grid: background issue

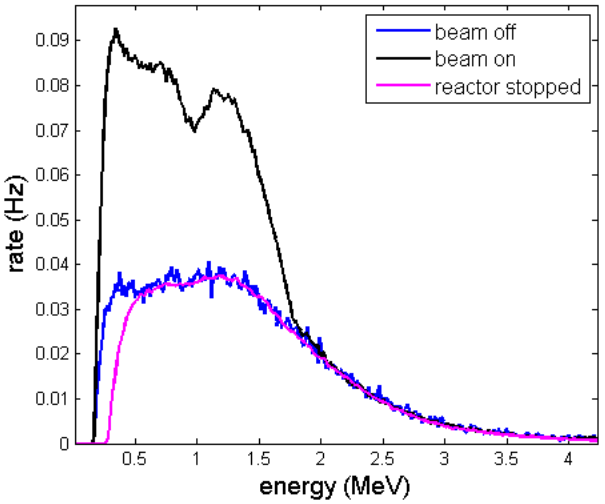


- **4.4 Hz flat background** was observed (**no time structure**)
  - → independent of the IN6 instrument / reactor
  - → uniform throughout detector

Multi-Grid: background issue



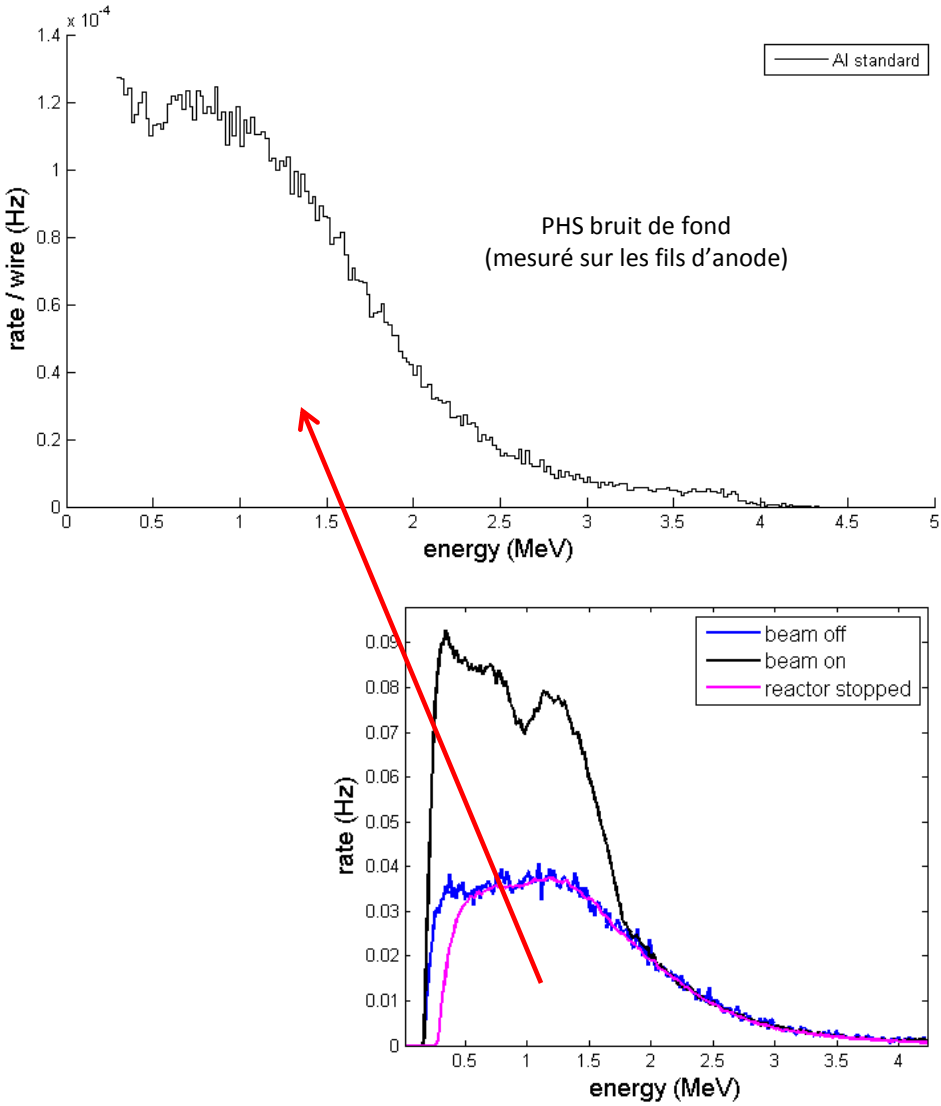




- **4.4 Hz flat background** was observed (**no time structure**)
  → independent of the IN6 instrument / reactor
  → uniform throughout detector

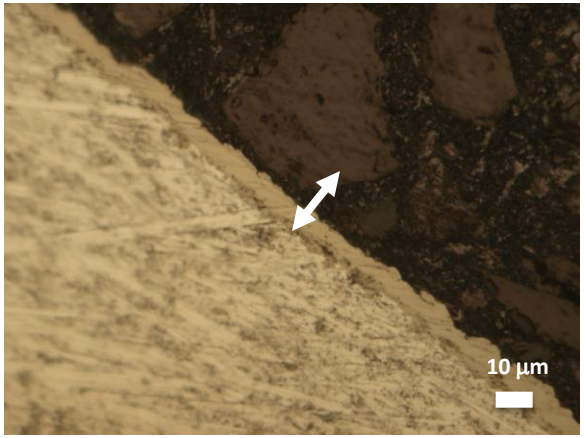
Multi-Grid: background suppression

(Courtesy of M. Ferraton)

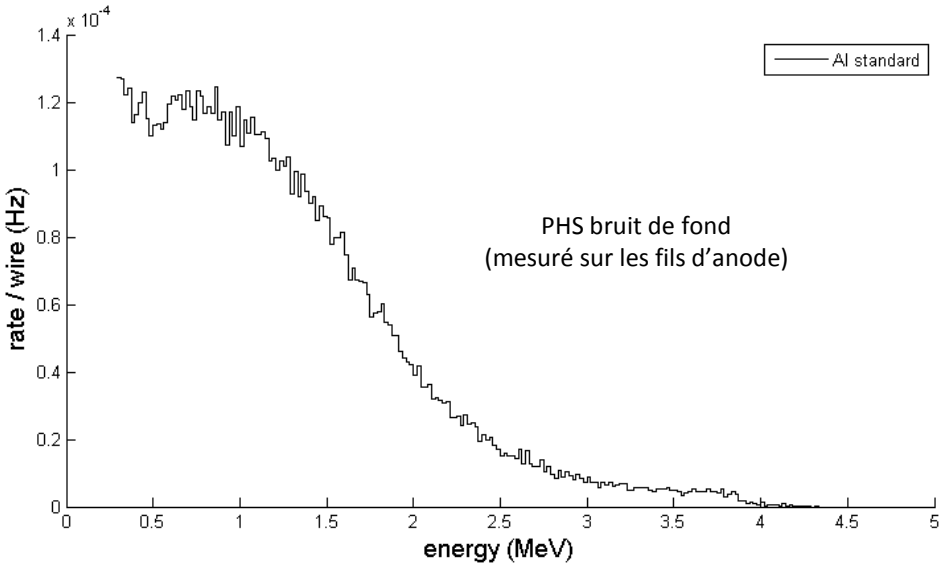


Multi-Grid: background suppression

(Courtesy of M. Ferraton)

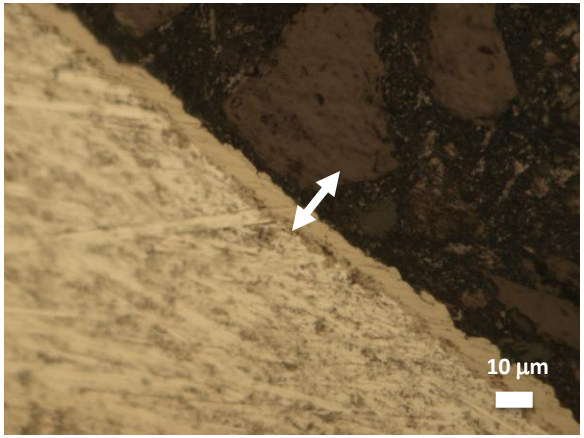


1. Ni layer Electrolytic deposition
2. Ni layer Chemical deposition
3. Al pure



Multi-Grid: background suppression

(Courtesy of M. Ferraton)



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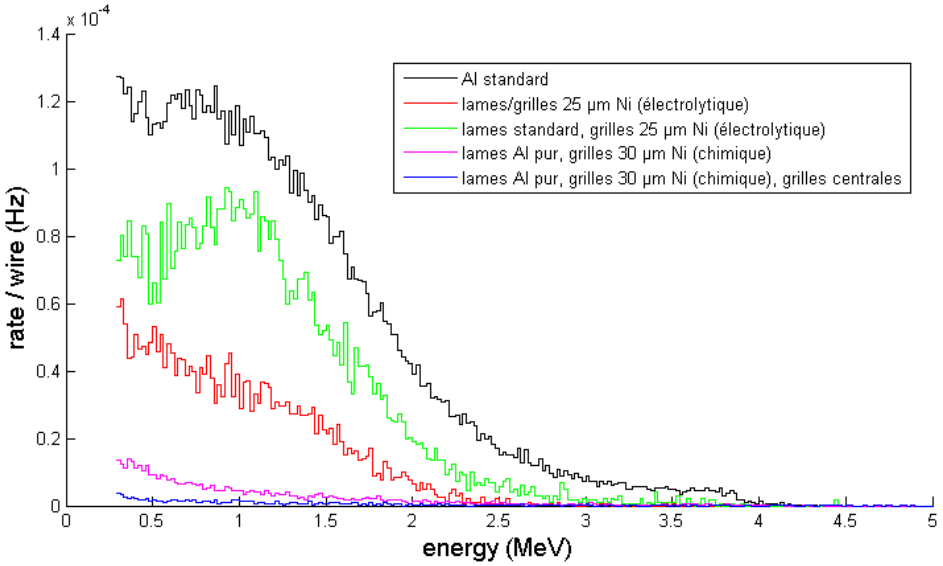
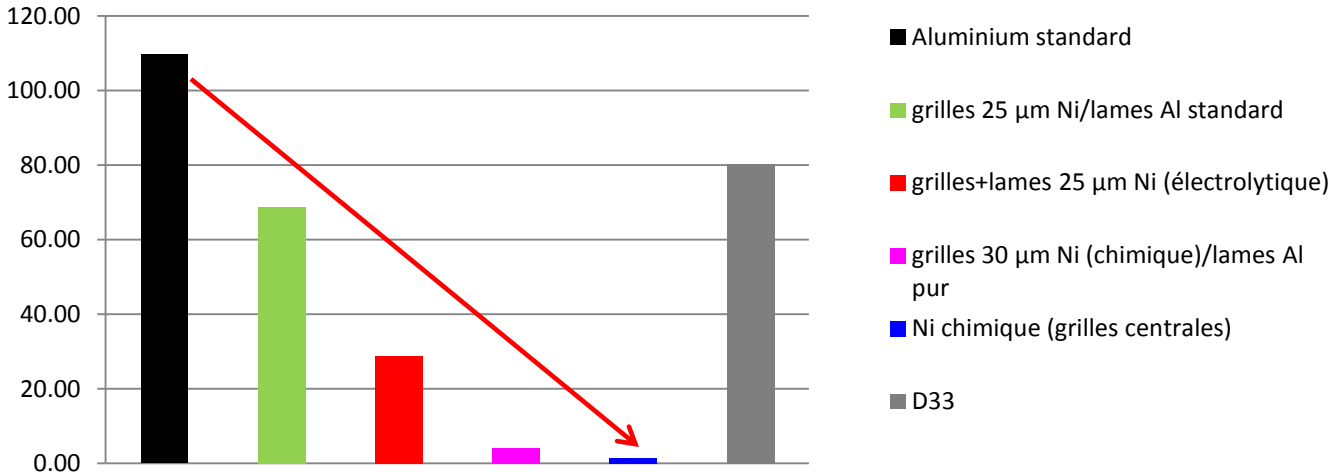


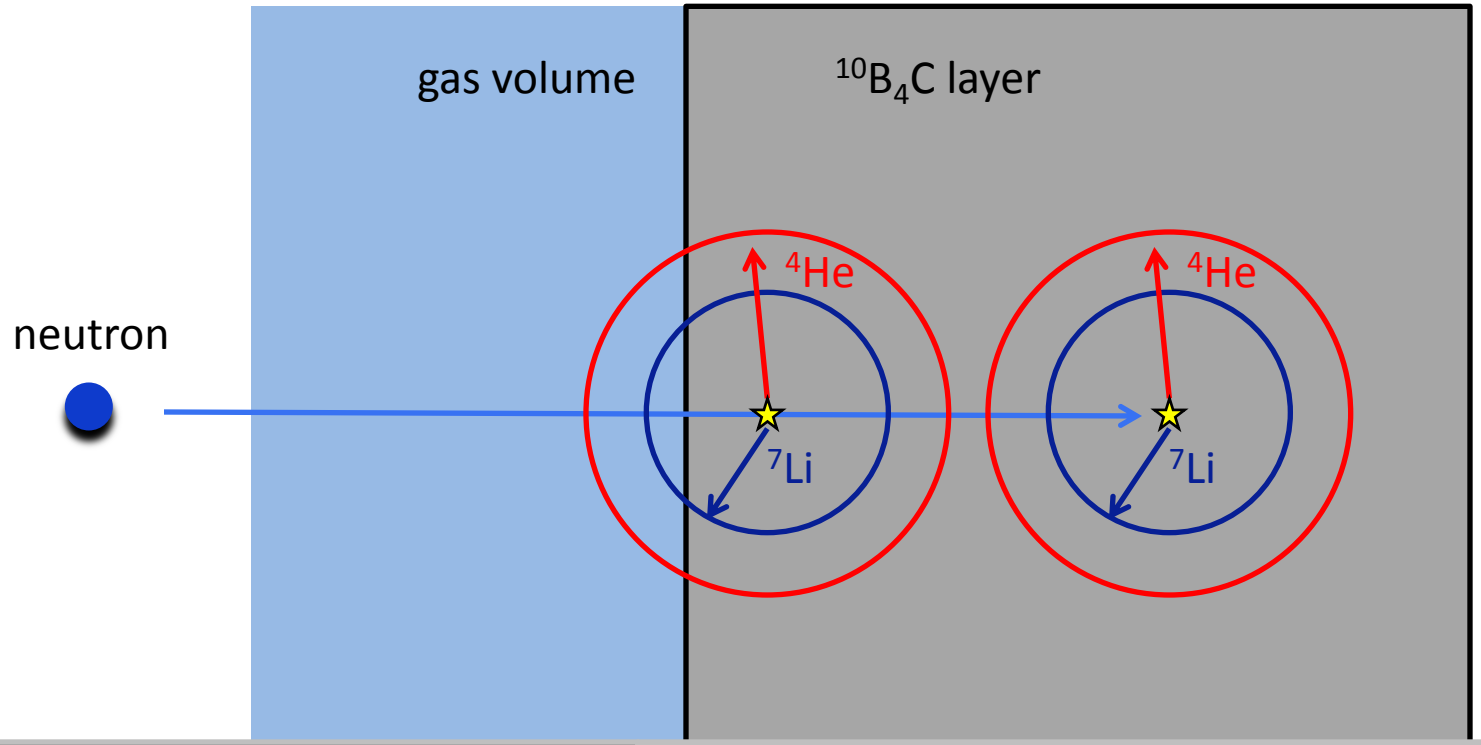


Multi-Blade

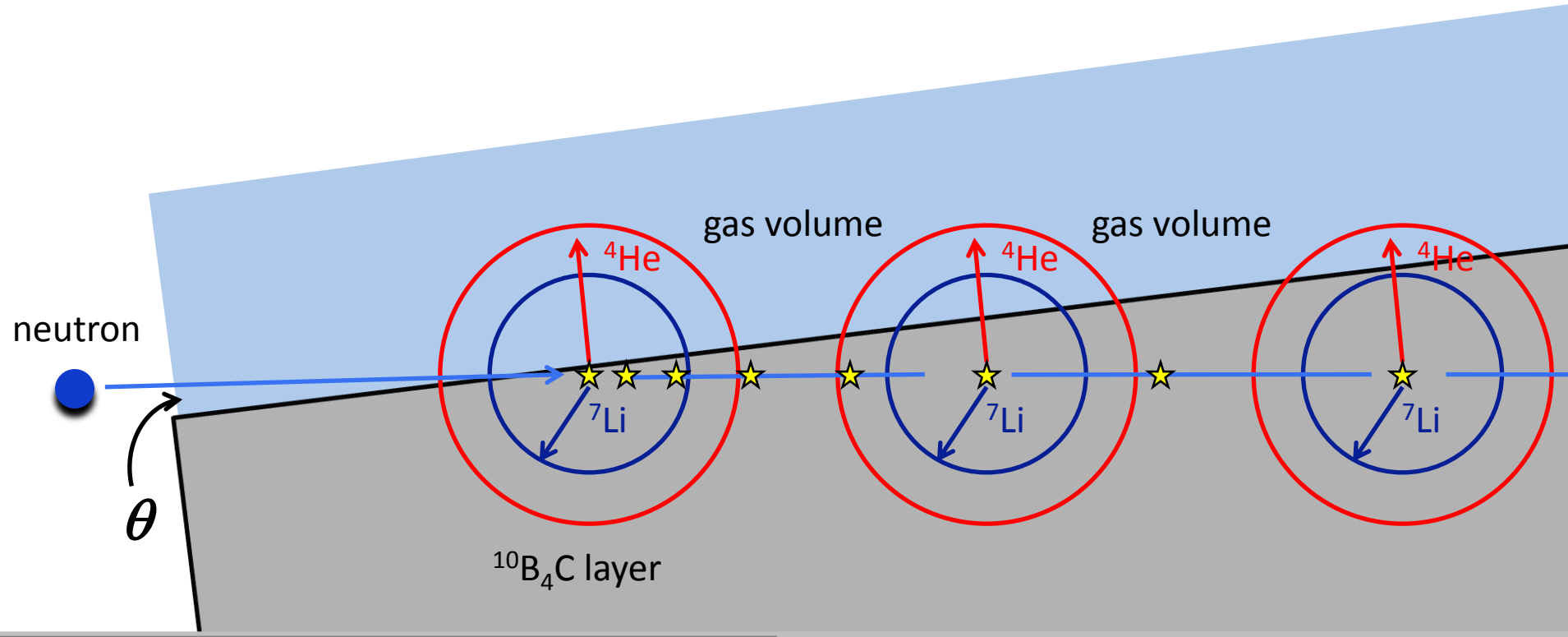
Multi-Blade: Principle

$$^{10}B + n \rightarrow {}^{7}Li^{*} + {}^{4}He \rightarrow {}^{7}Li + {}^{4}He + 0.48MeV\,\gamma\text{-ray} + 2.3\ MeV \quad (94\%)$$
$$\rightarrow {}^{7}Li + {}^{4}He \qquad + 2.79\,MeV \quad (6\%)$$

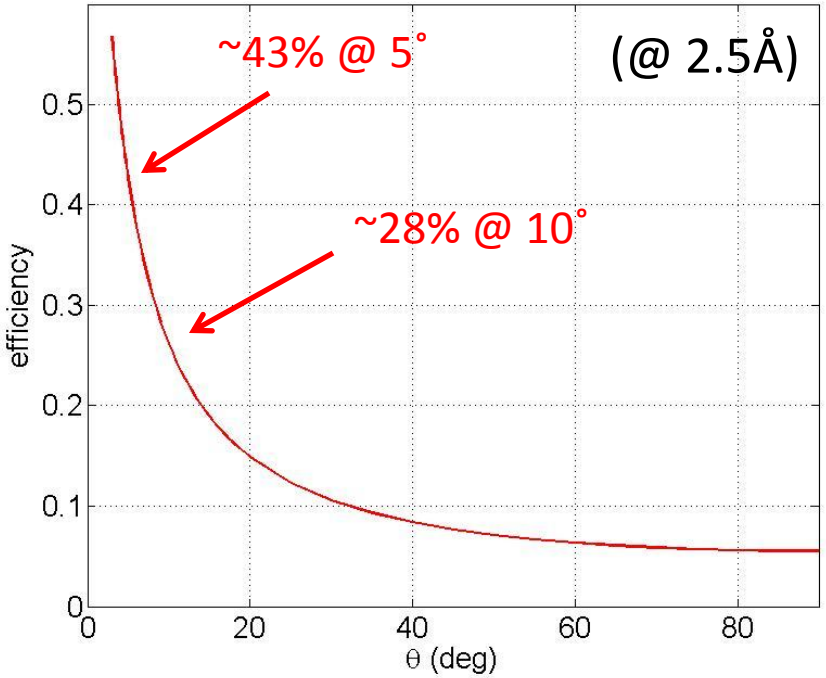
Efficiency 5% @ 2.5Å (saturated)



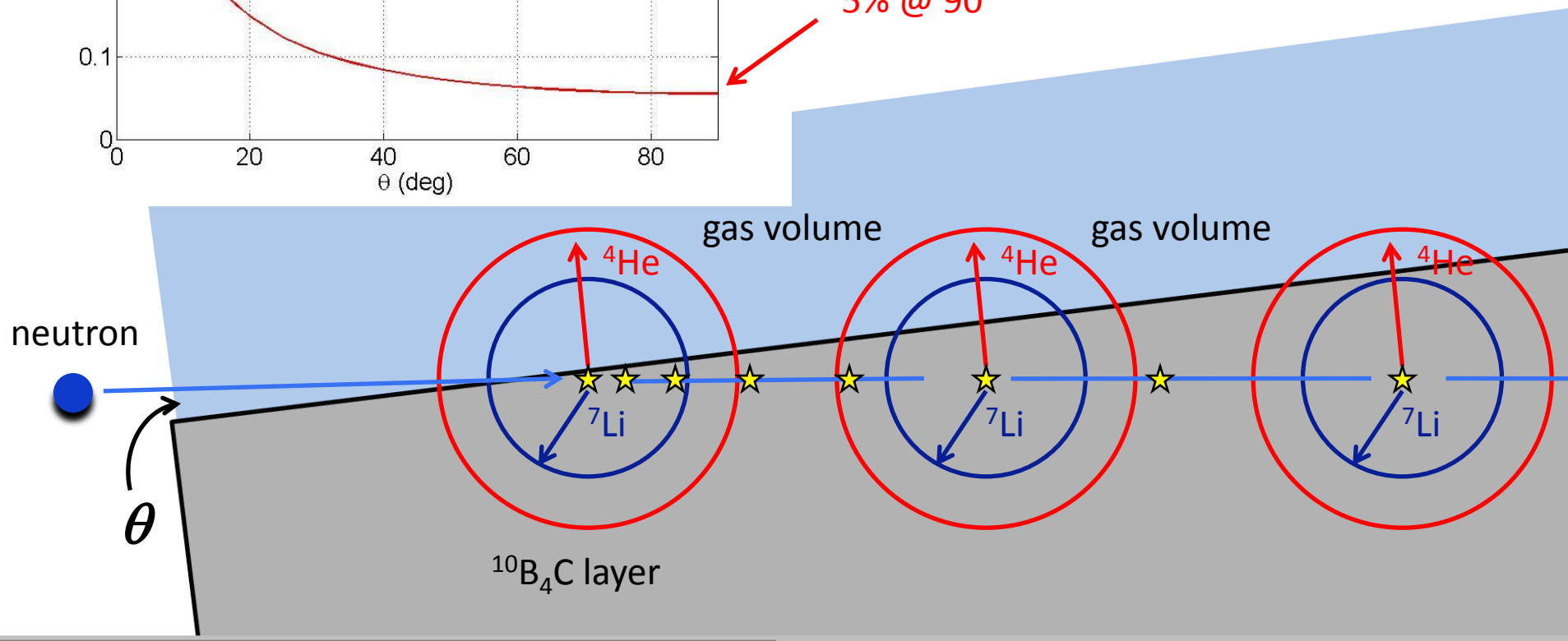
Multi-Blade: Principle



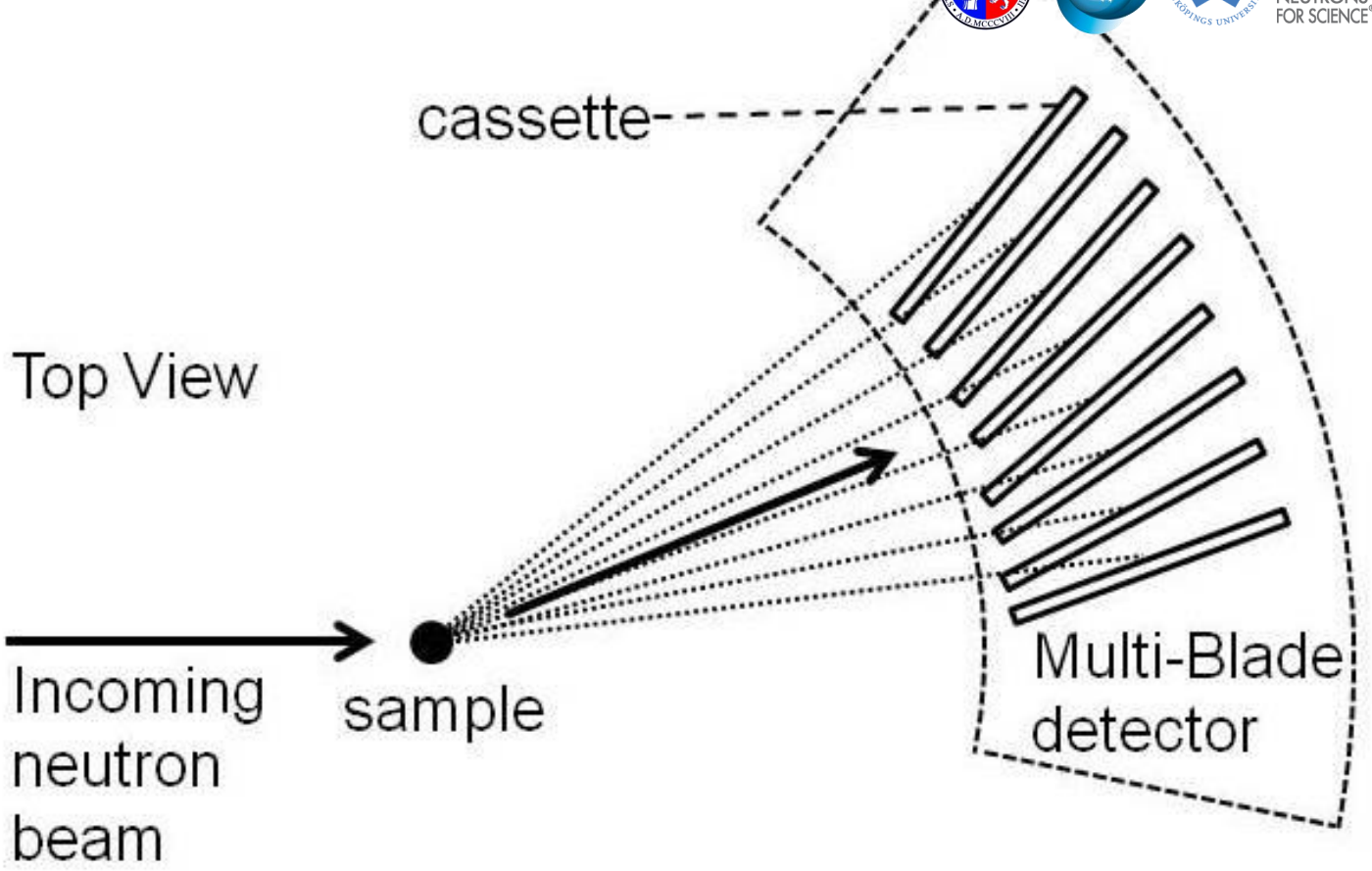
Multi-Blade: Principle



For single back-scattering layer.



Multi-Blade: detector concept

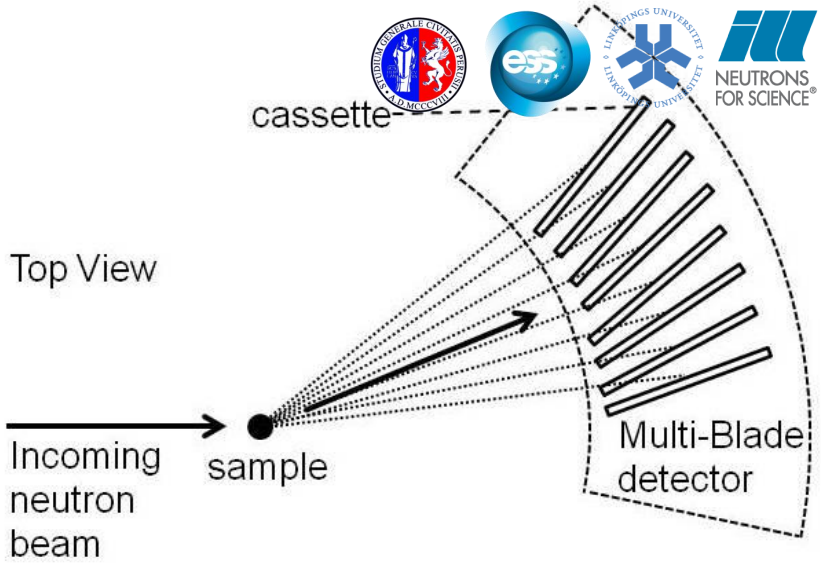


Introduced at ILL in 2005:

J.C. Buffet et al., NIM A 554, 1–3, 2005, 10.1016/j.nima.2005.08.018

Multi-Blade: detector concept

Suitable for Neutron Reflectometer
(for both monochromatic and ToF)



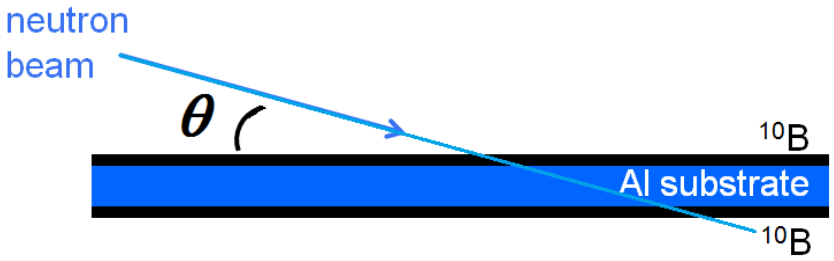
Figaro @ ILL

Gas fill	8 bar ^{3}He + 2 bar CF_4
Area	512 x 256 mm^2
Resolution	2 x 8 mm^2
Efficiency	60% @ 2.5Å

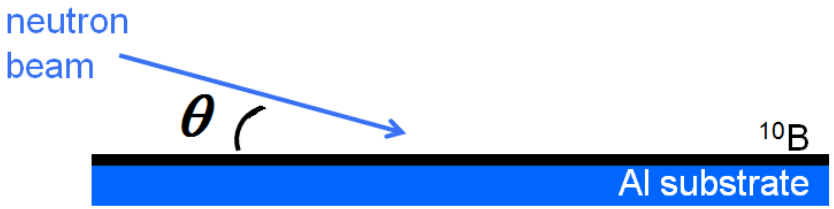
Introduced at ILL in 2005:

J.C. Buffet et al., NIM A 554, 1–3, 2005, 10.1016/j.nima.2005.08.018

Multi-Blade: detector concept



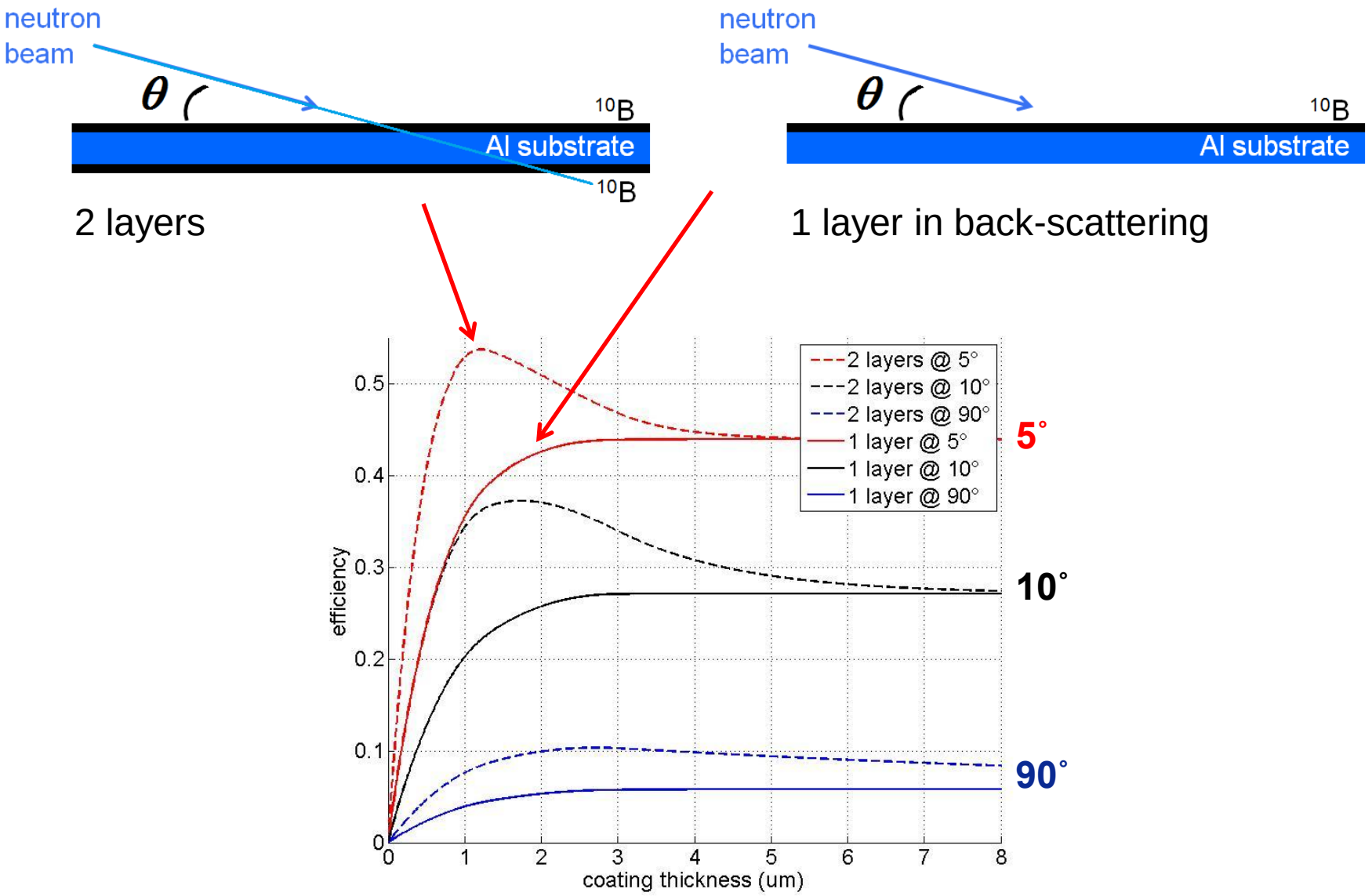
2 layers



1 layer in back-scattering

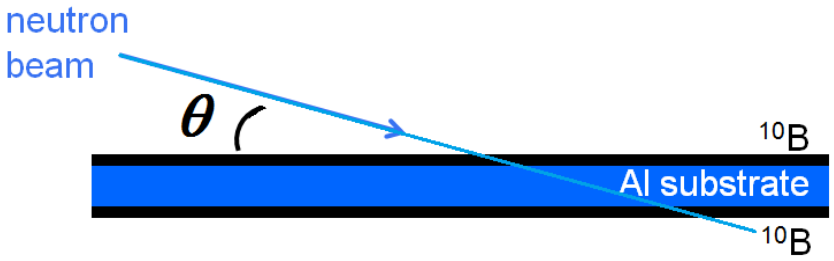
Multi-Blade: detector concept

(@ 2.5Å)

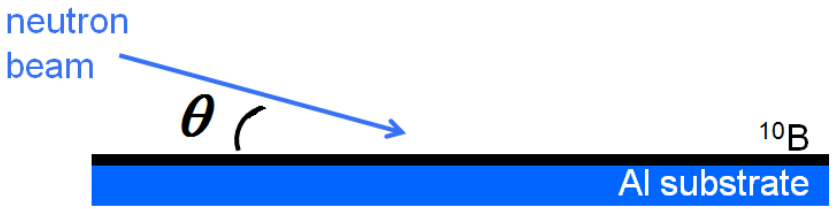


Multi-Blade: detector concept

(@ 2.5Å)



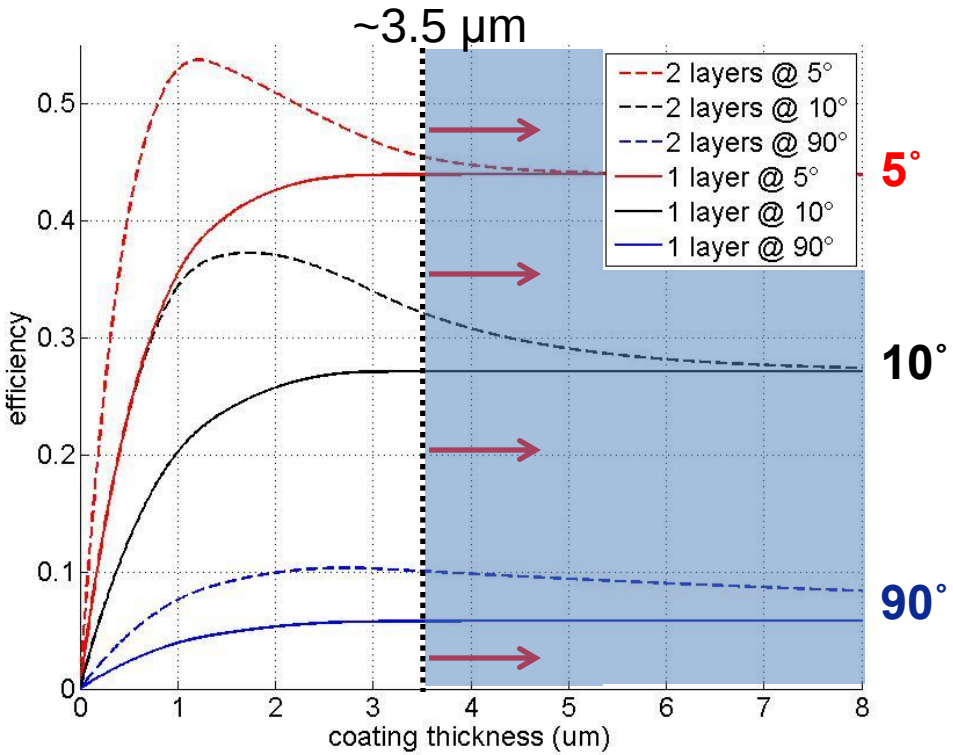
2 layers



1 layer in back-scattering

higher efficiency

substrate choice

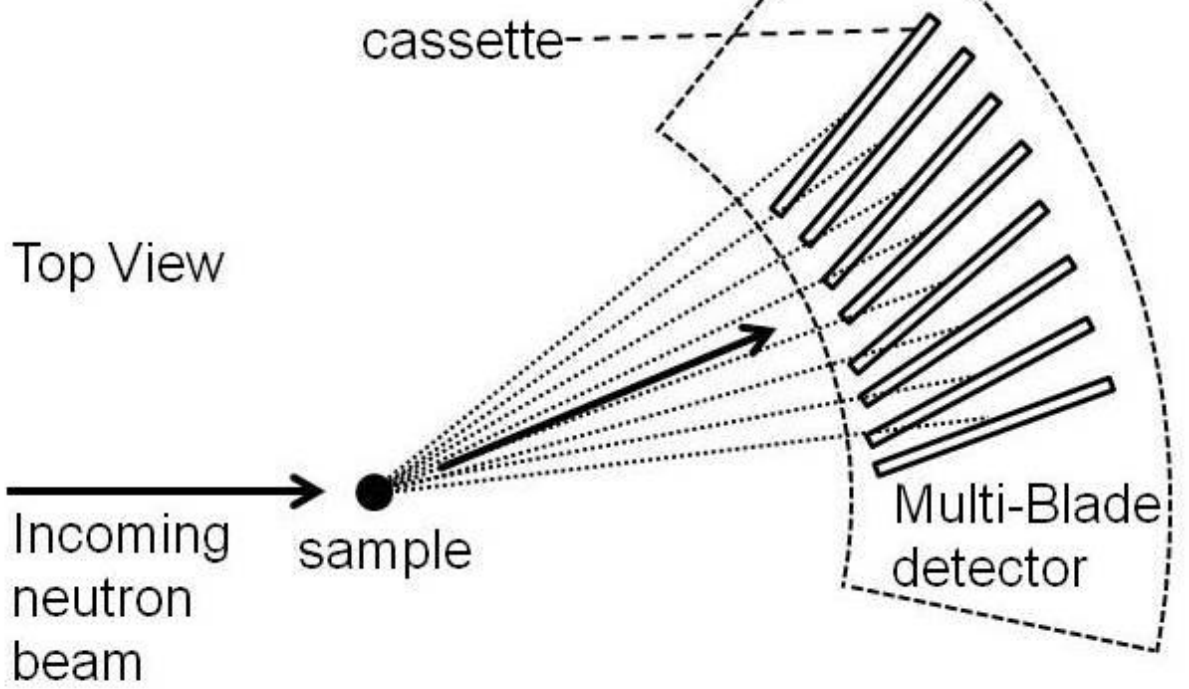


lower efficiency

but independent from layer thickness

no substrate problem

Multi-Blade: detector concept



Introduced at ILL in 2005:

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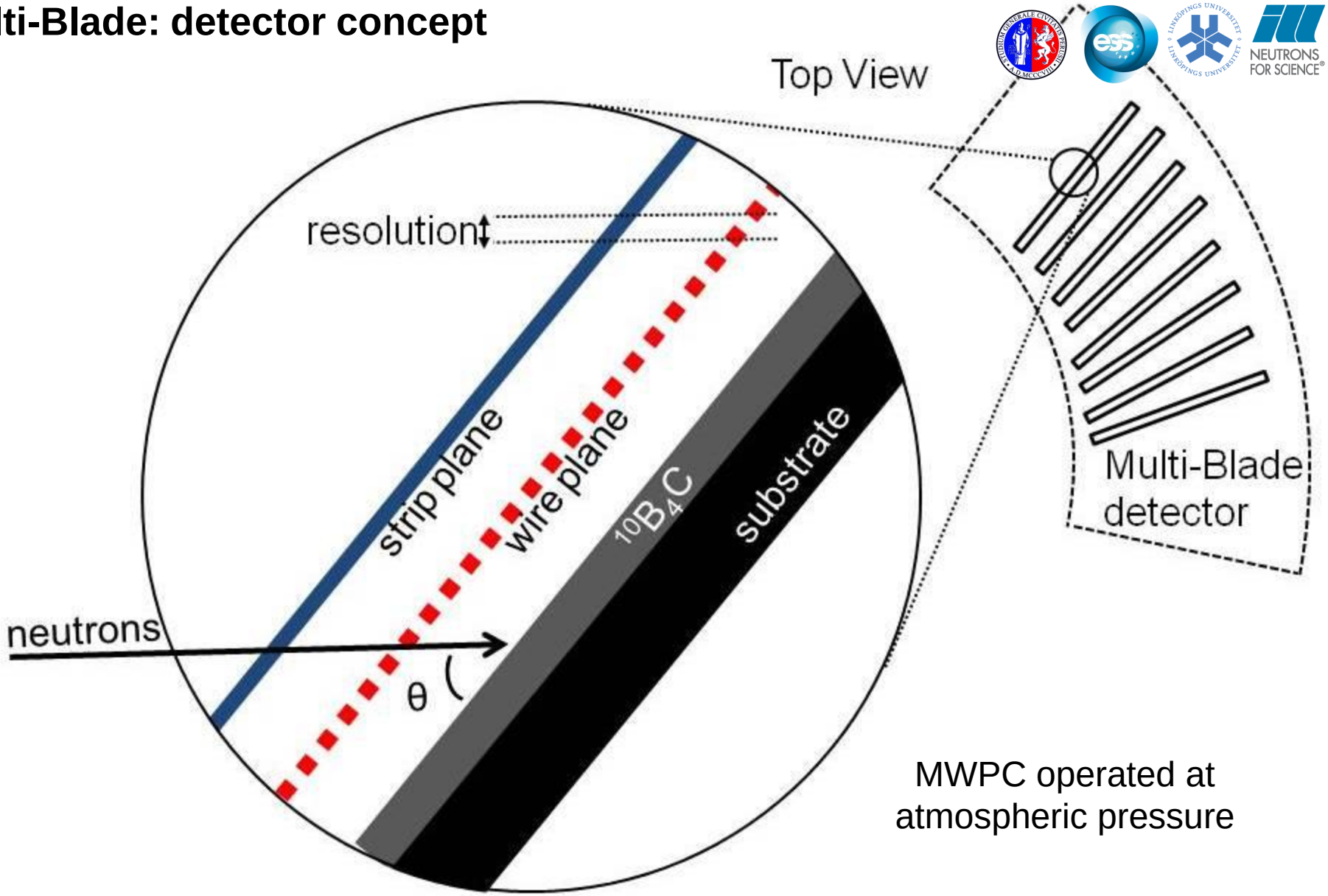
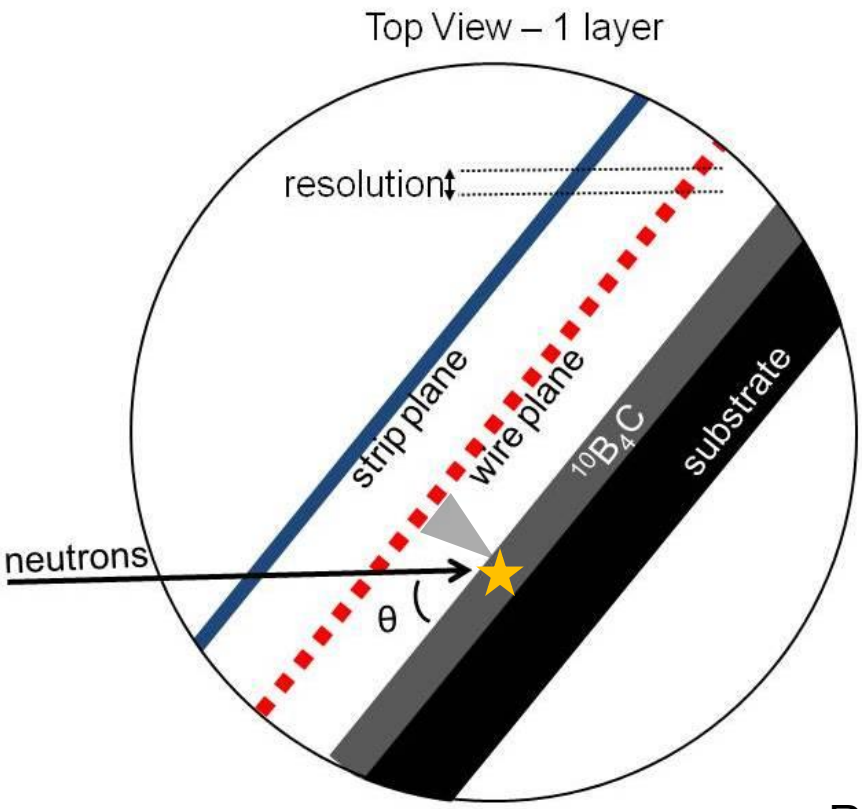
Multi-Blade: detector concept



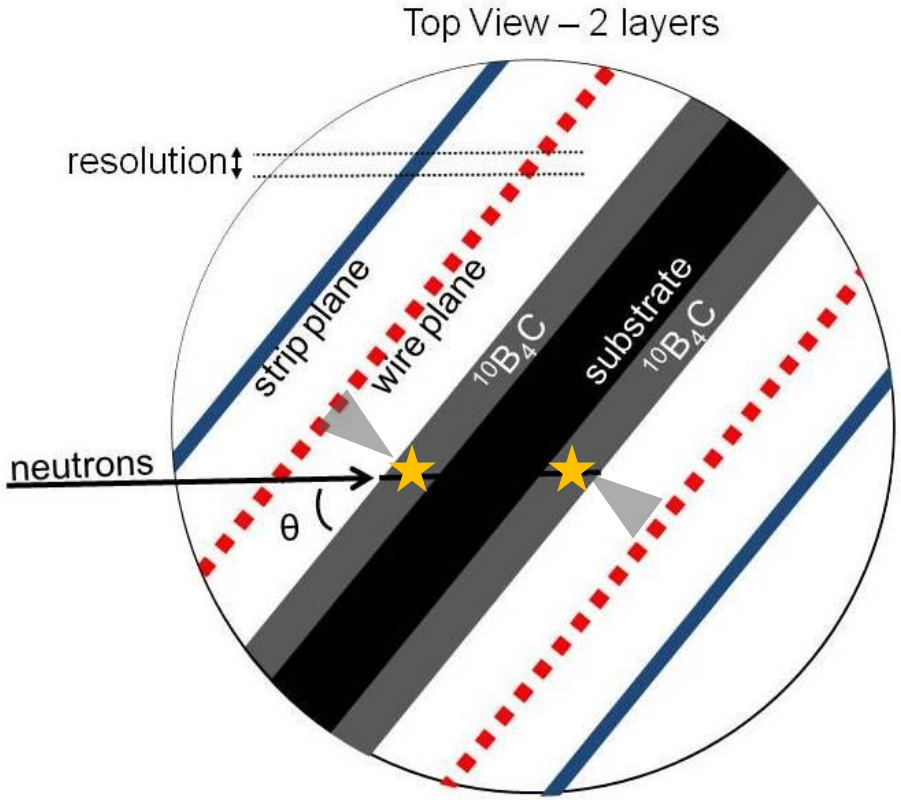
MWPC operated at atmospheric pressure

Multi-Blade: detector concept

A

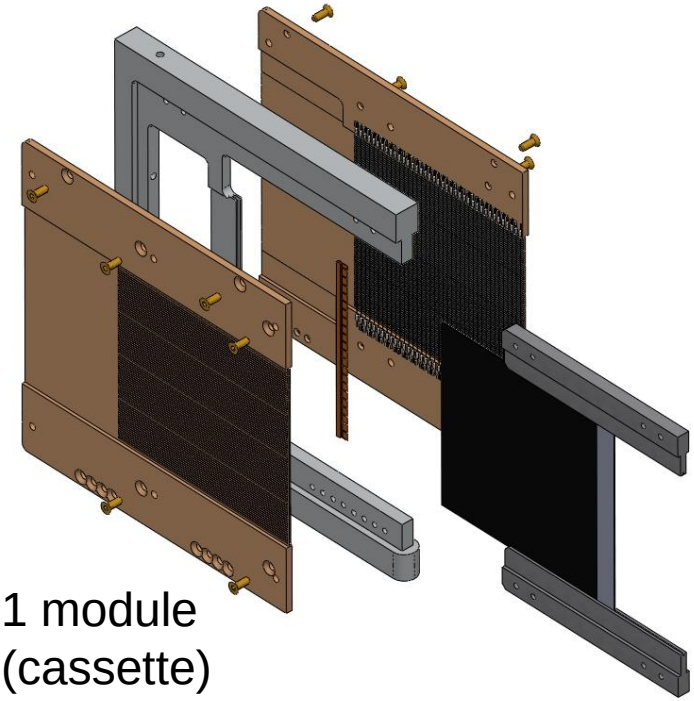


B

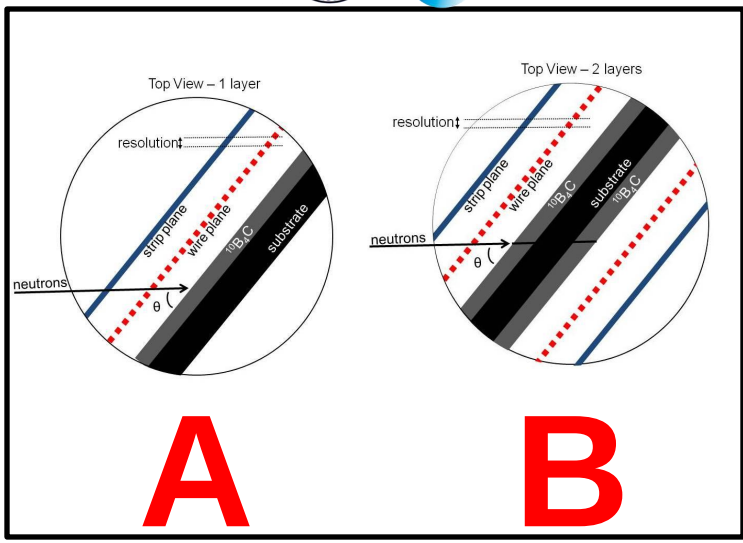


Resolution:
~Wire pitch x 5 at 10˚
(x10 at 5˚)

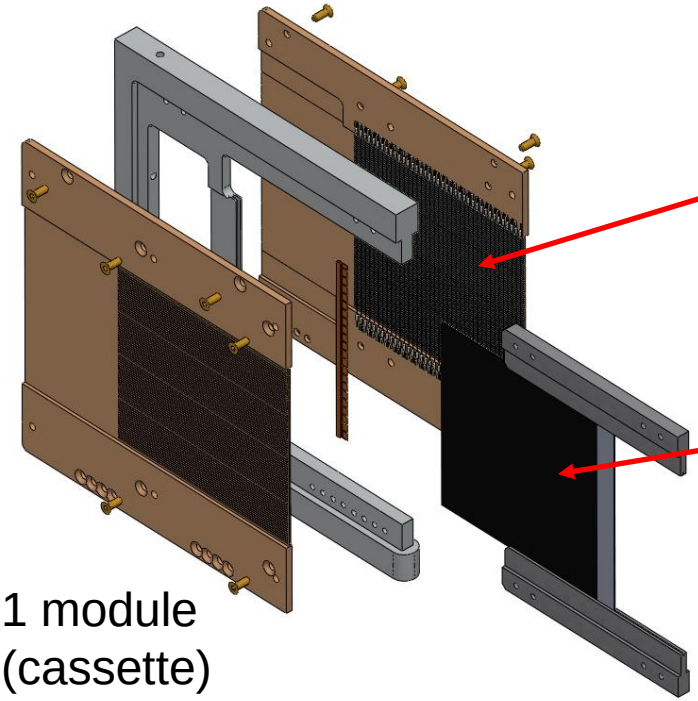
Multi-Blade: detector schematic



1 module
(cassette)



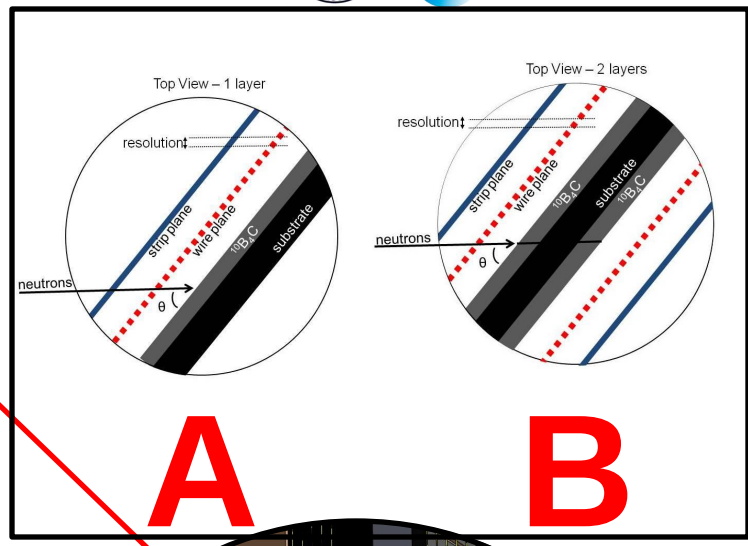
Multi-Blade: detector schematic

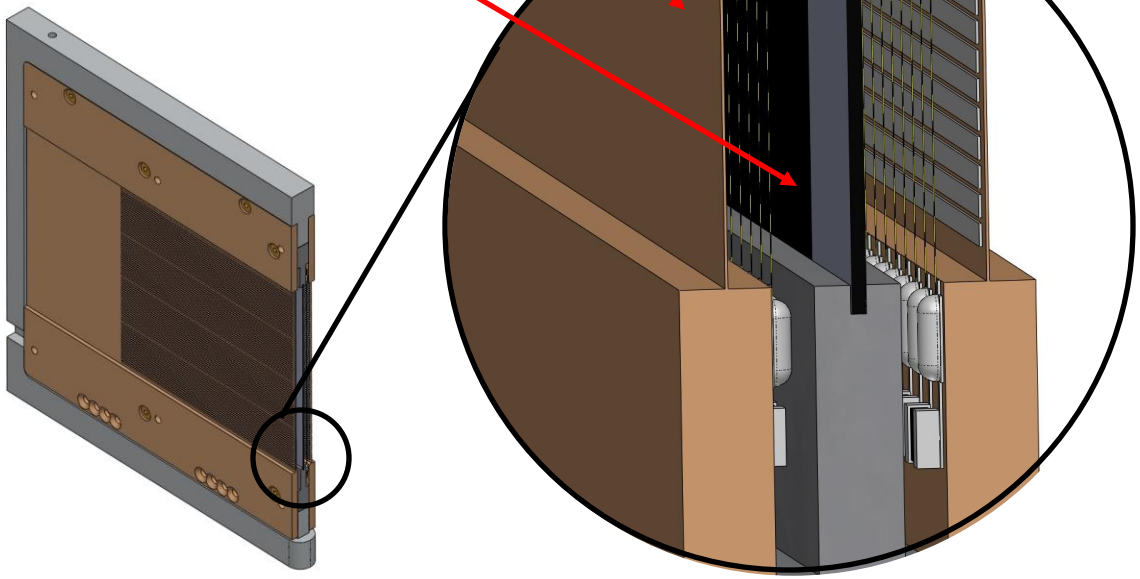


1 module
(cassette)

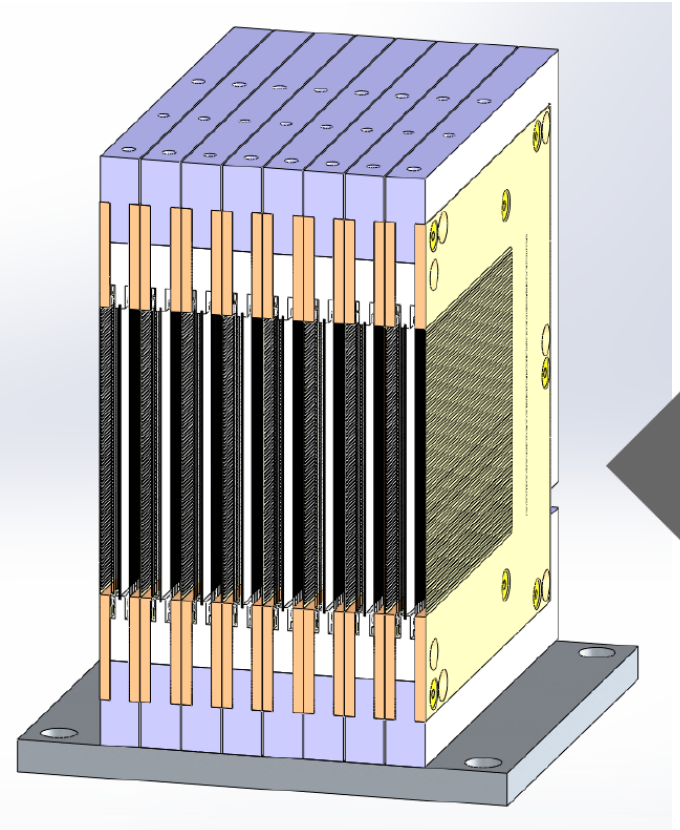
Kapton
read-out
system

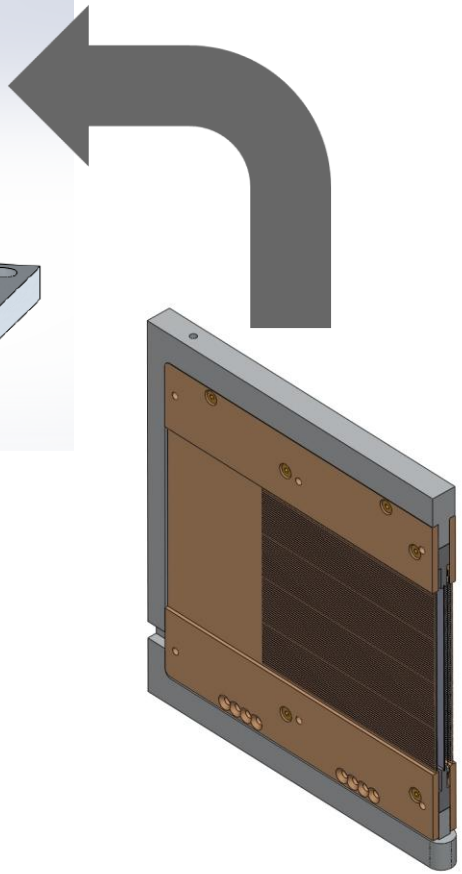
$^{10}B_4C$
layer

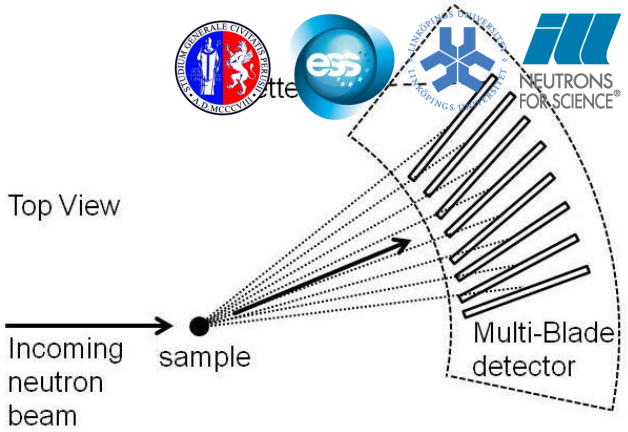




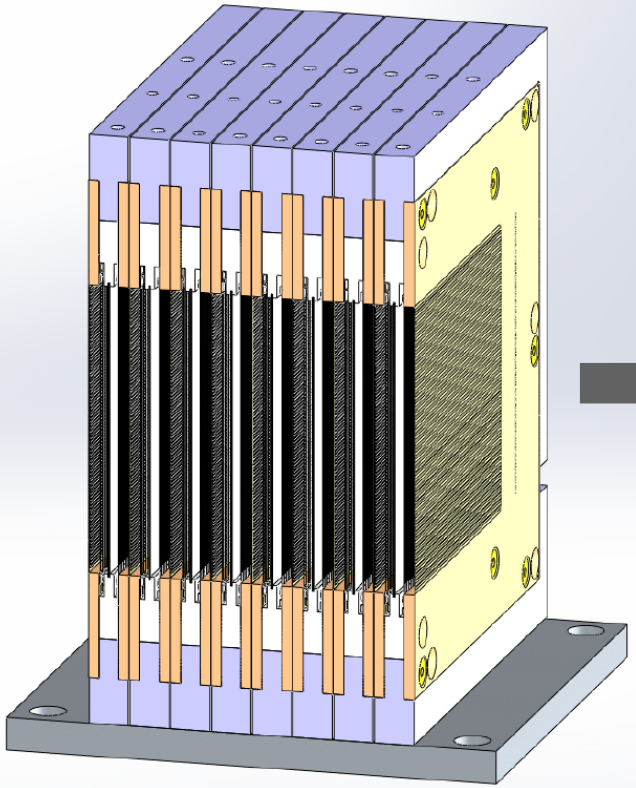
Multi-Blade: detector schematic

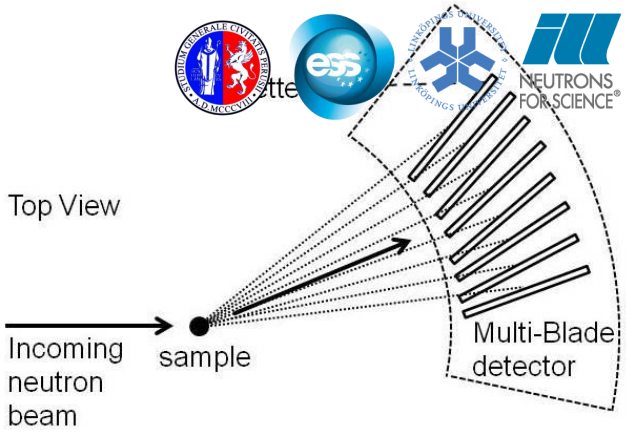


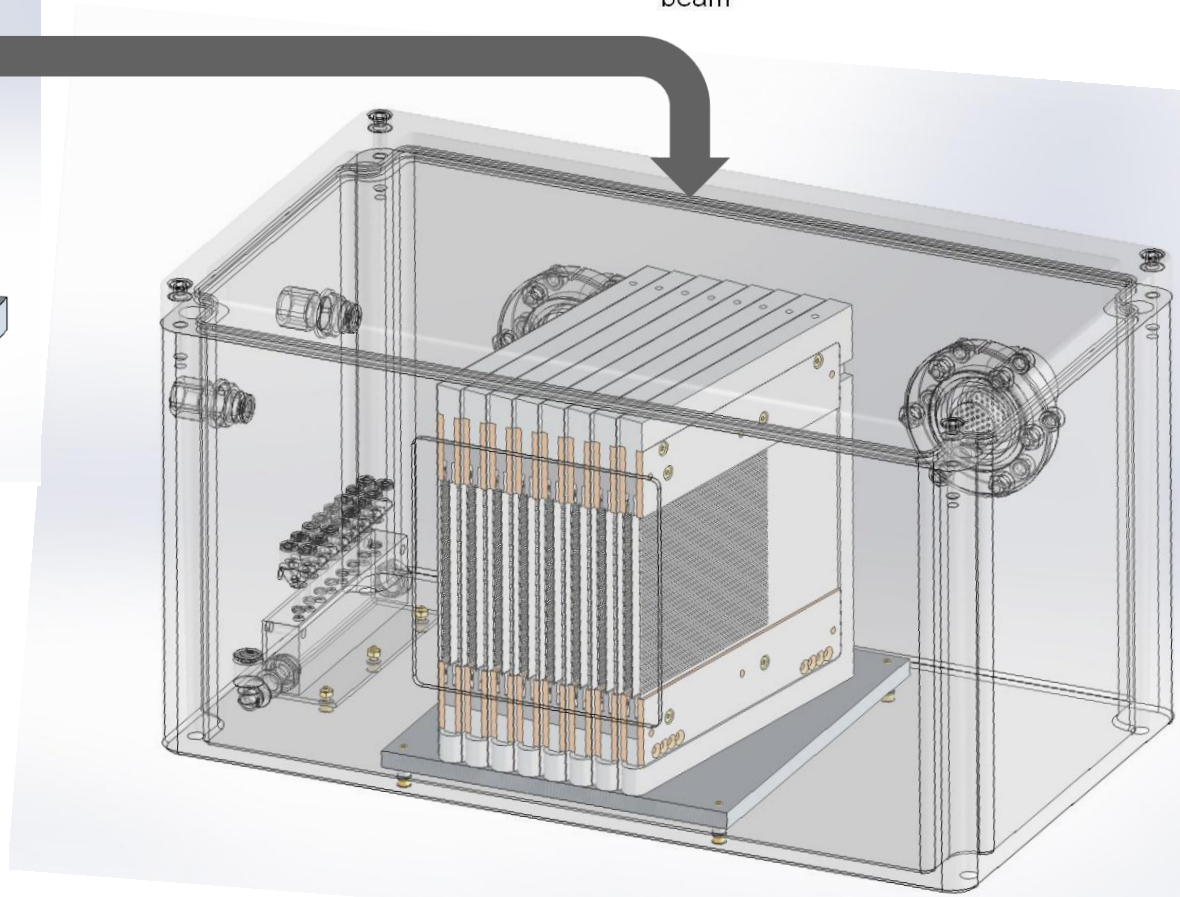




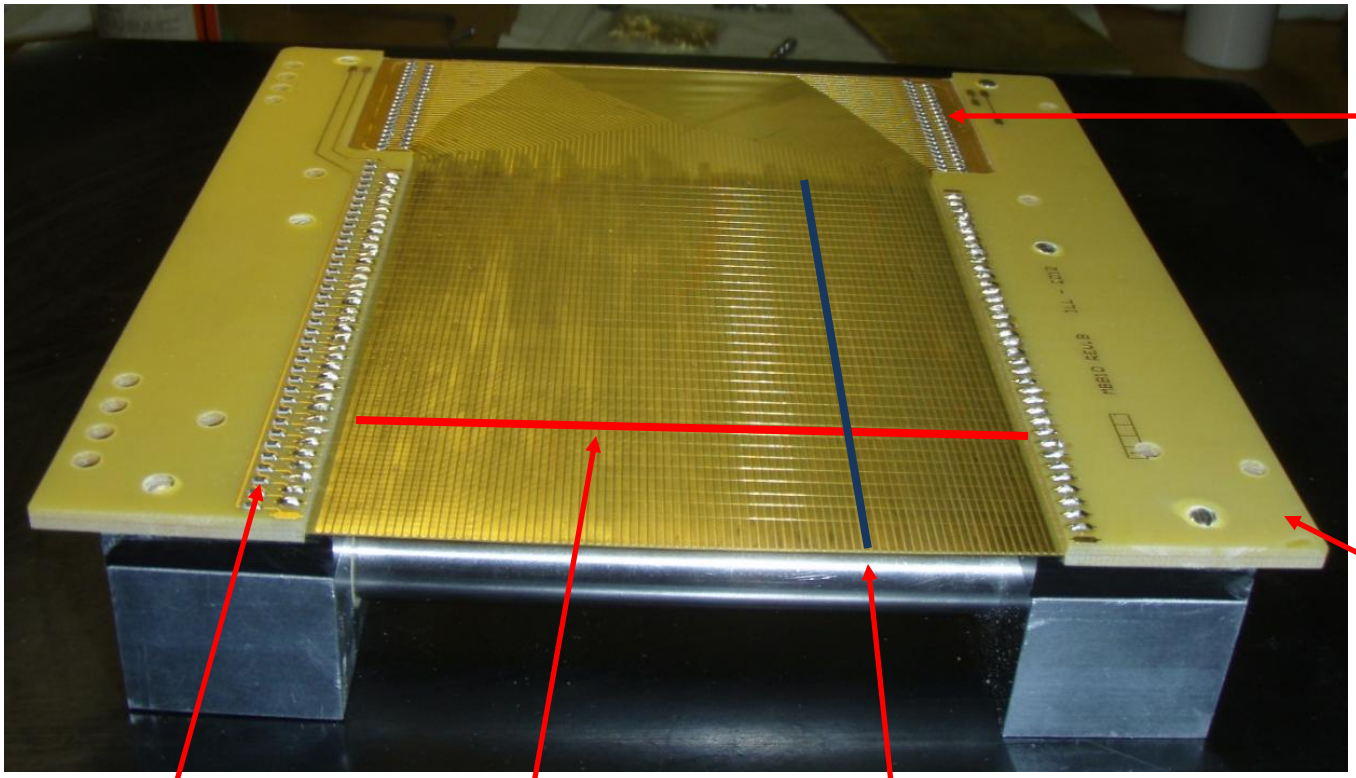
Multi-Blade: detector schematic







Multi-Blade



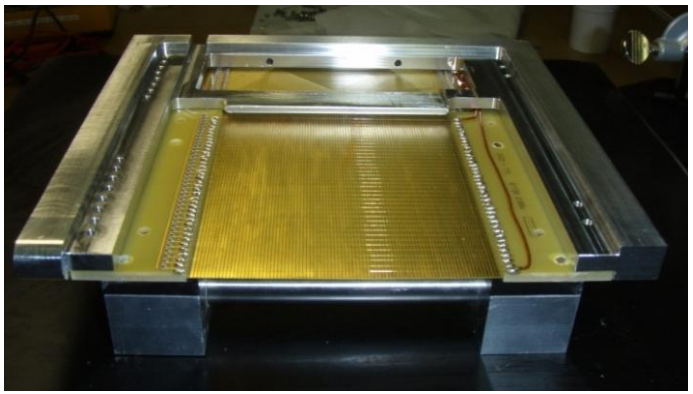
Strip resistive chain for read-out

Kapton read-out system

Wire resistive chain for read-out

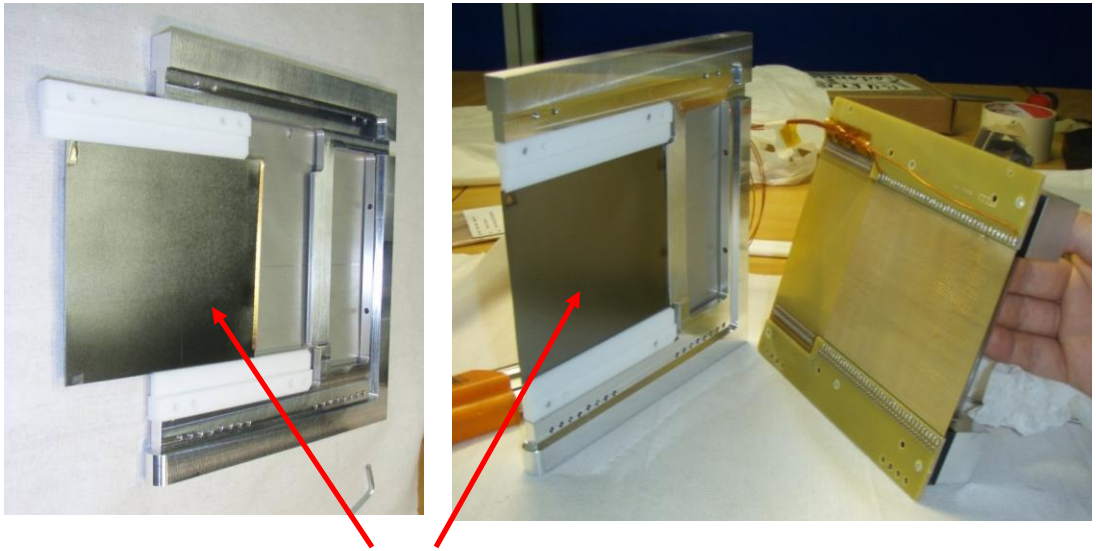
Wires (anodes) (Spacing 2.5mm)

Strips (cathodes)



Very thin Kapton substrate to do not affect neutron beam

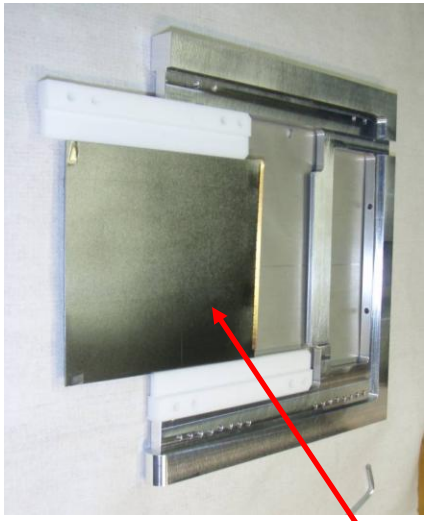
Multi-Blade

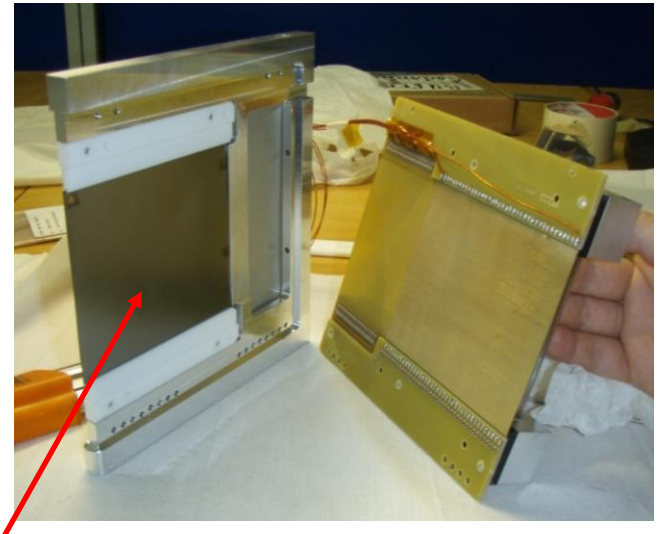


$^{10}B_4C$ layer*

*C. Höglund et a., J. Appl. Phys. **111**, 104908 (2012)

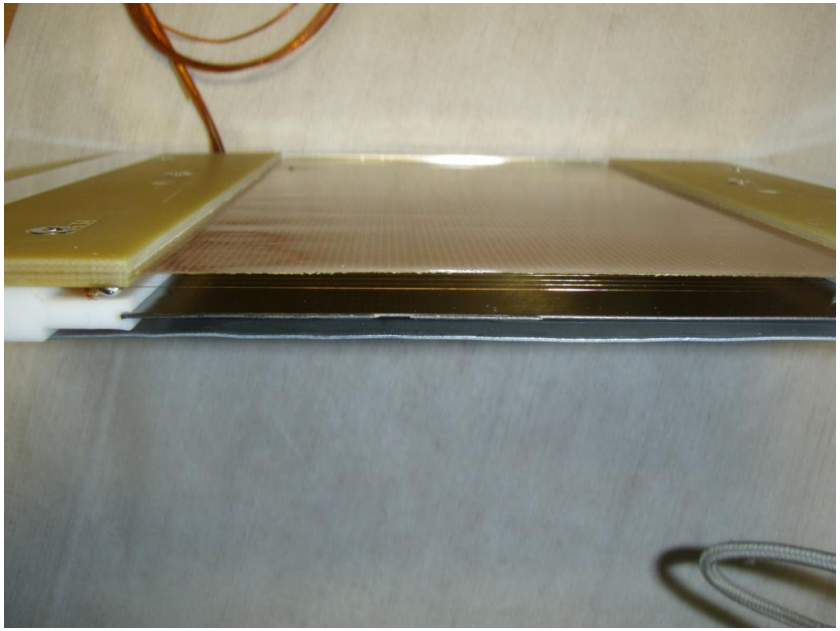
Multi-Blade

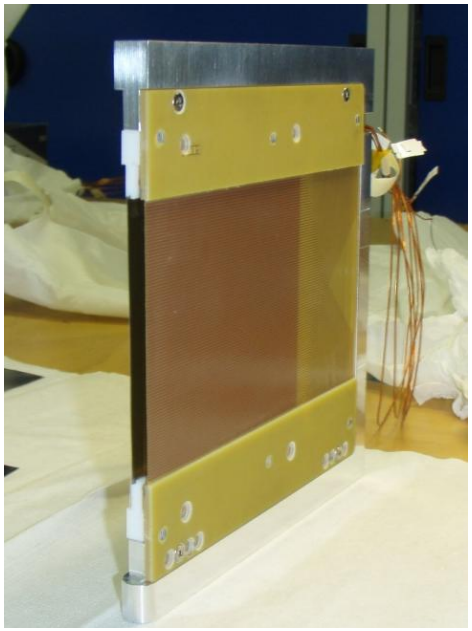




$^{10}B_4C$ layer*

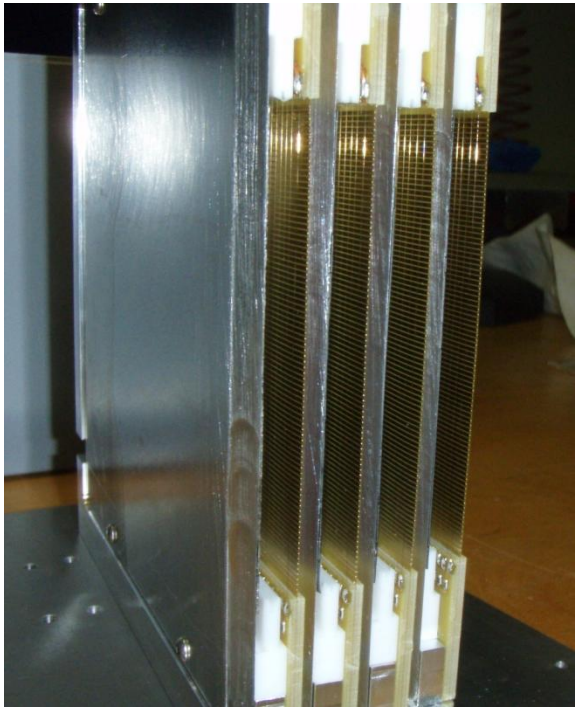
1 module (cassette)

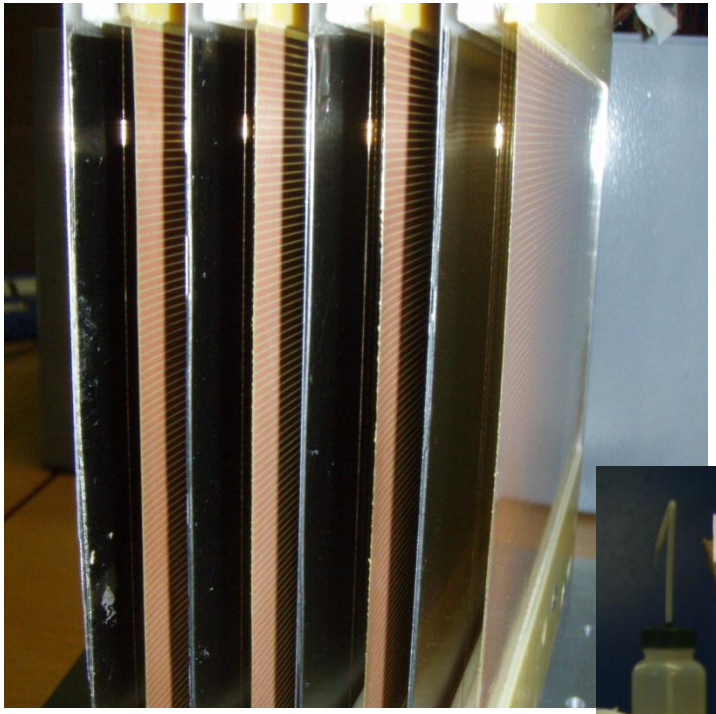




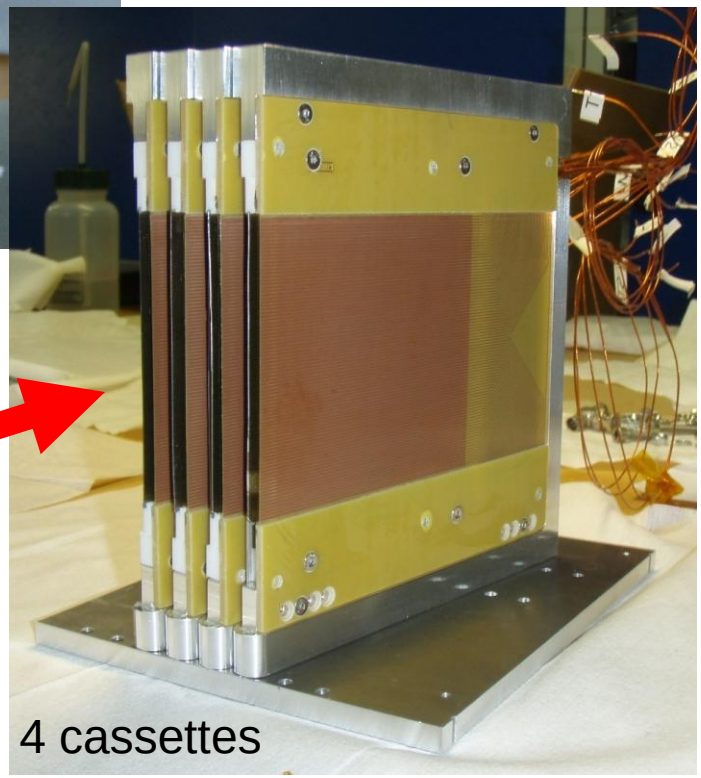
*C. Höglund et a., J. Appl. Phys. **111**, 104908 (2012)

Multi-Blade

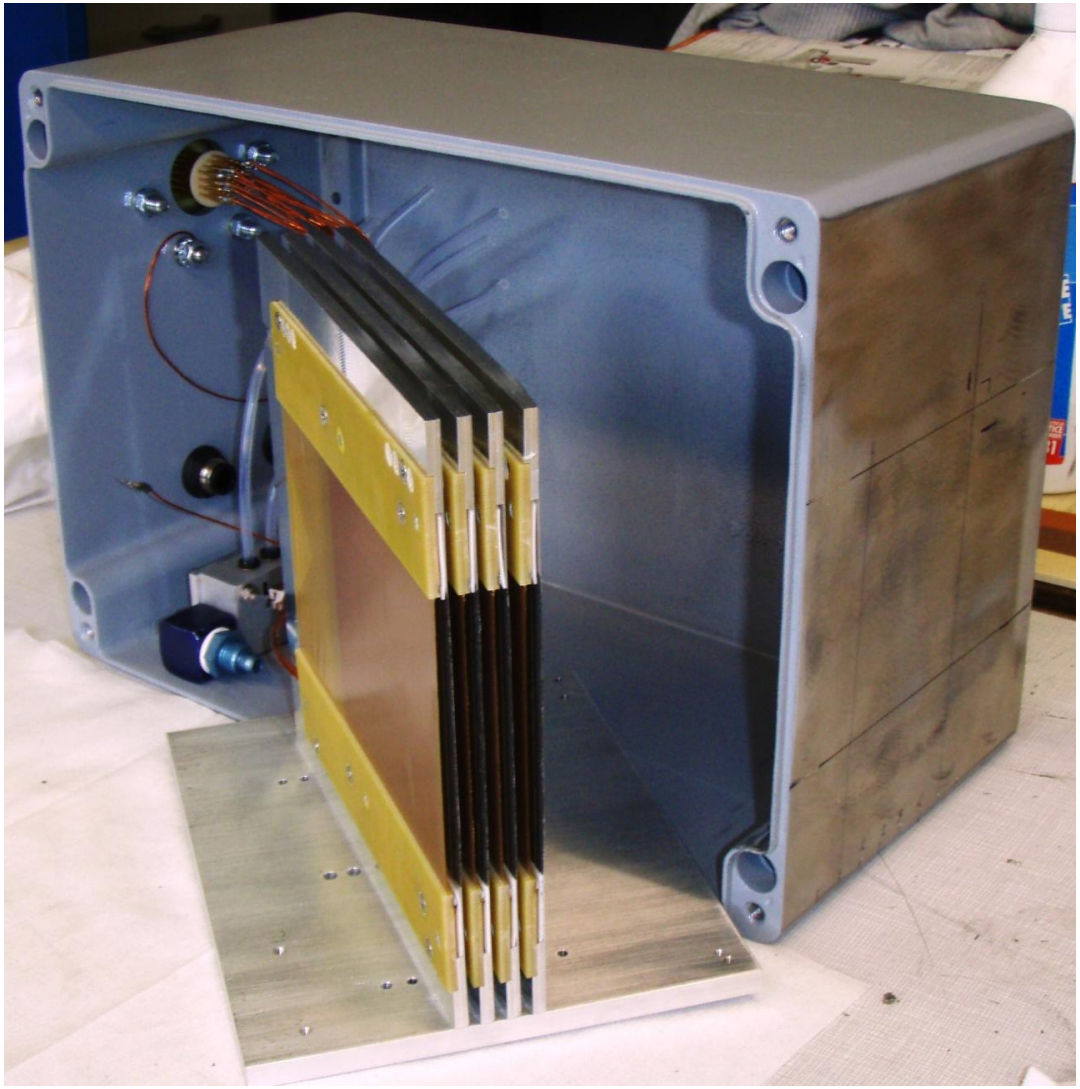


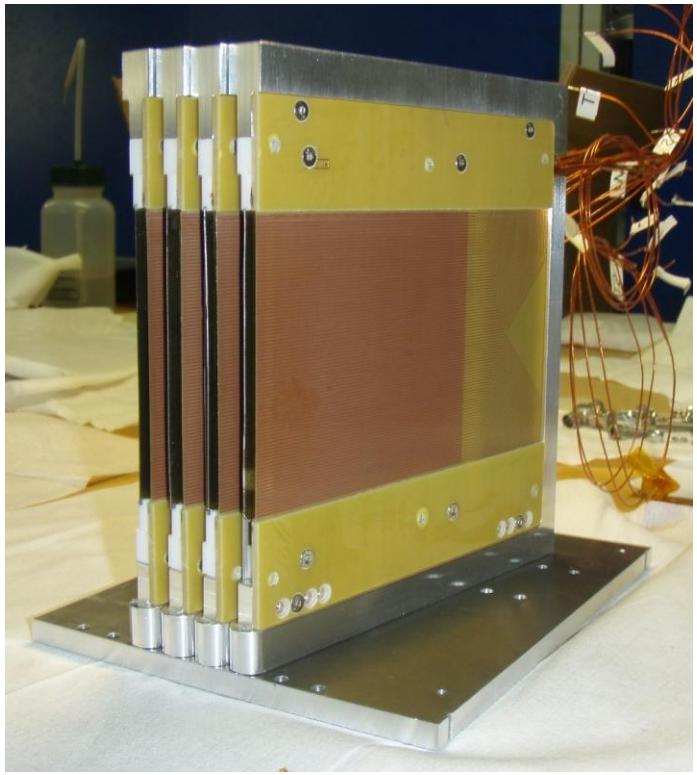


Neutron beam
hits the layers
at 10˚ or 5˚

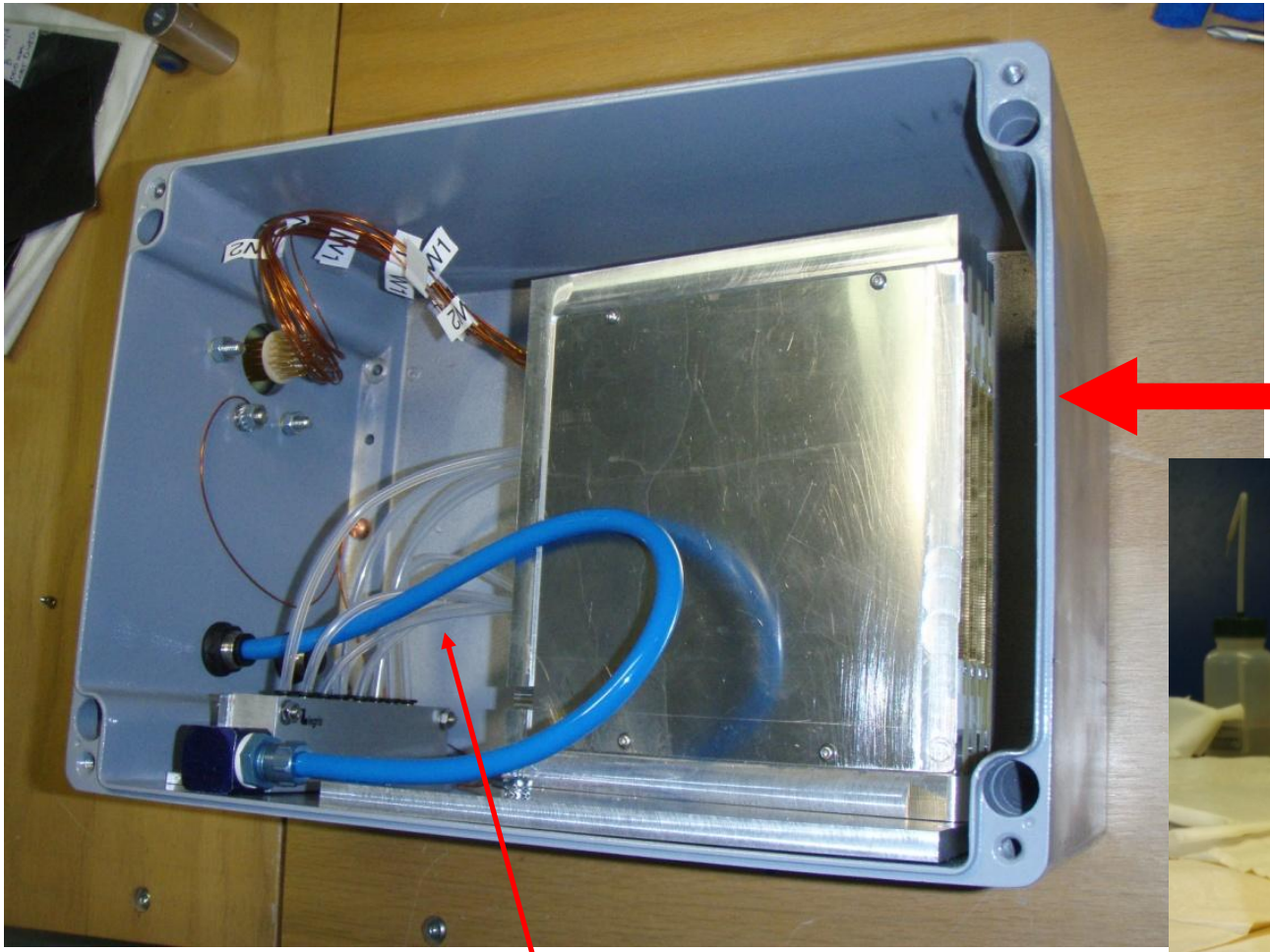


Multi-Blade



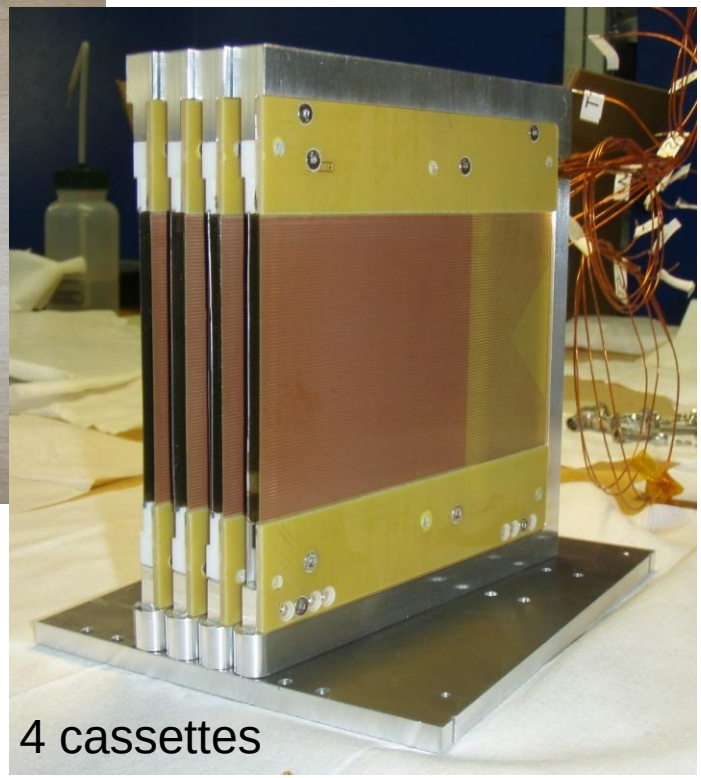


Multi-Blade



Detector
active surface
60mm x 90mm

Neutron beam



4 cassettes

Each cassette has its own gas inlet.

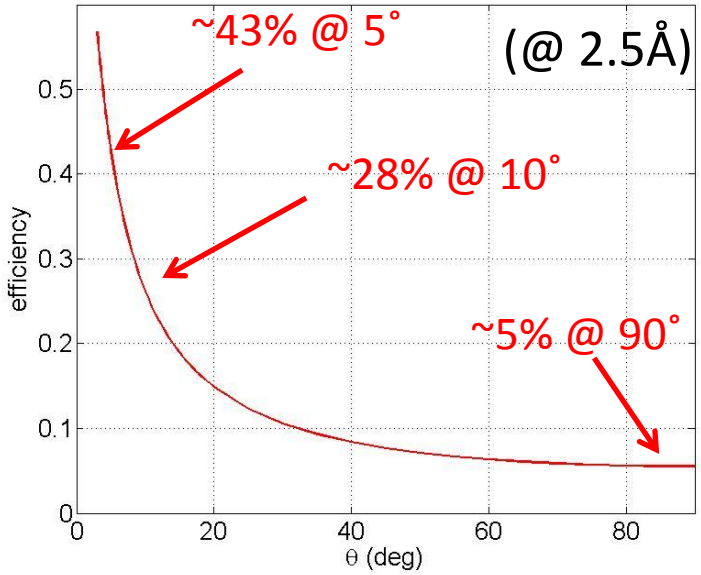
Atmospheric Ar/CO_2 continuous flux.

Results

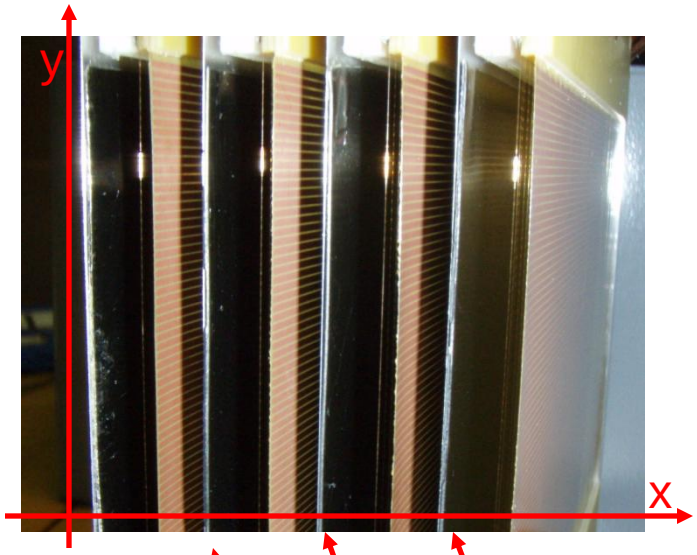
Results: efficiency

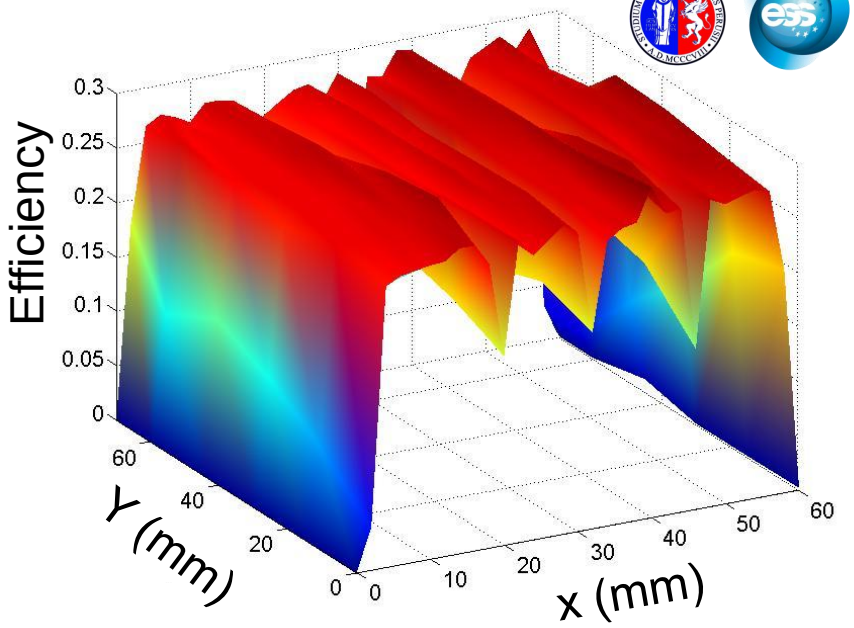
Average measured efficiency @ 2.5Å, 10˚:

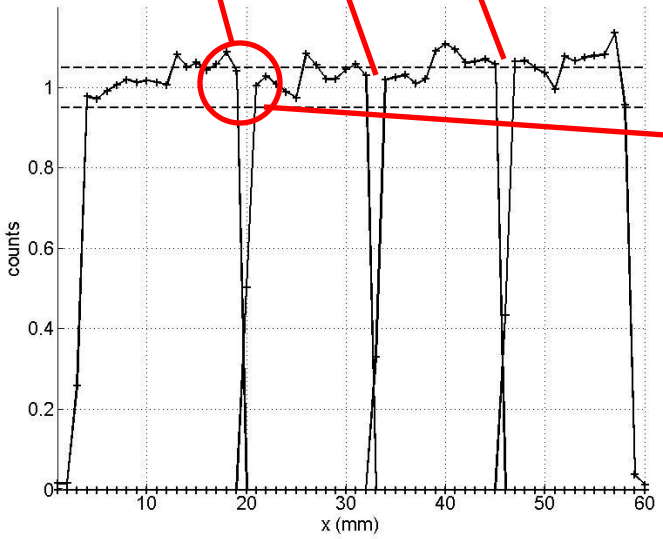
$$\varepsilon = (27.8 \pm 0.2)\%$$

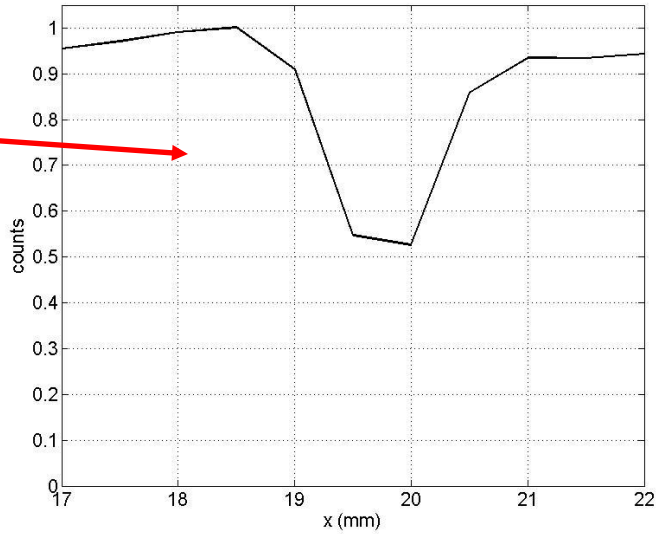


Results: uniformity



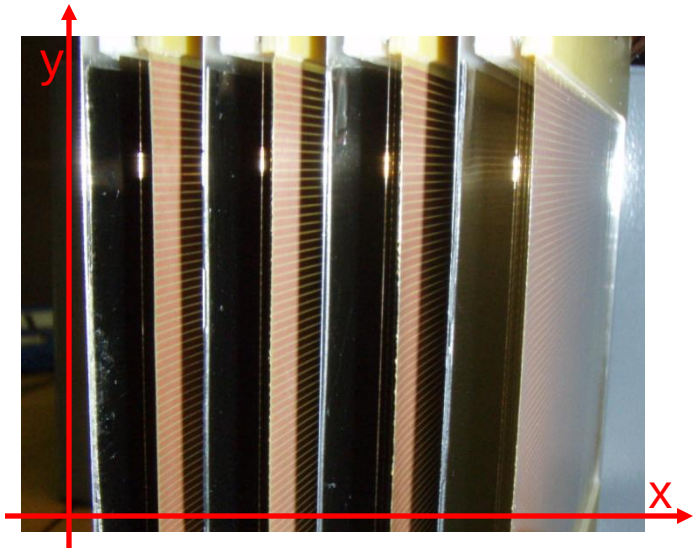


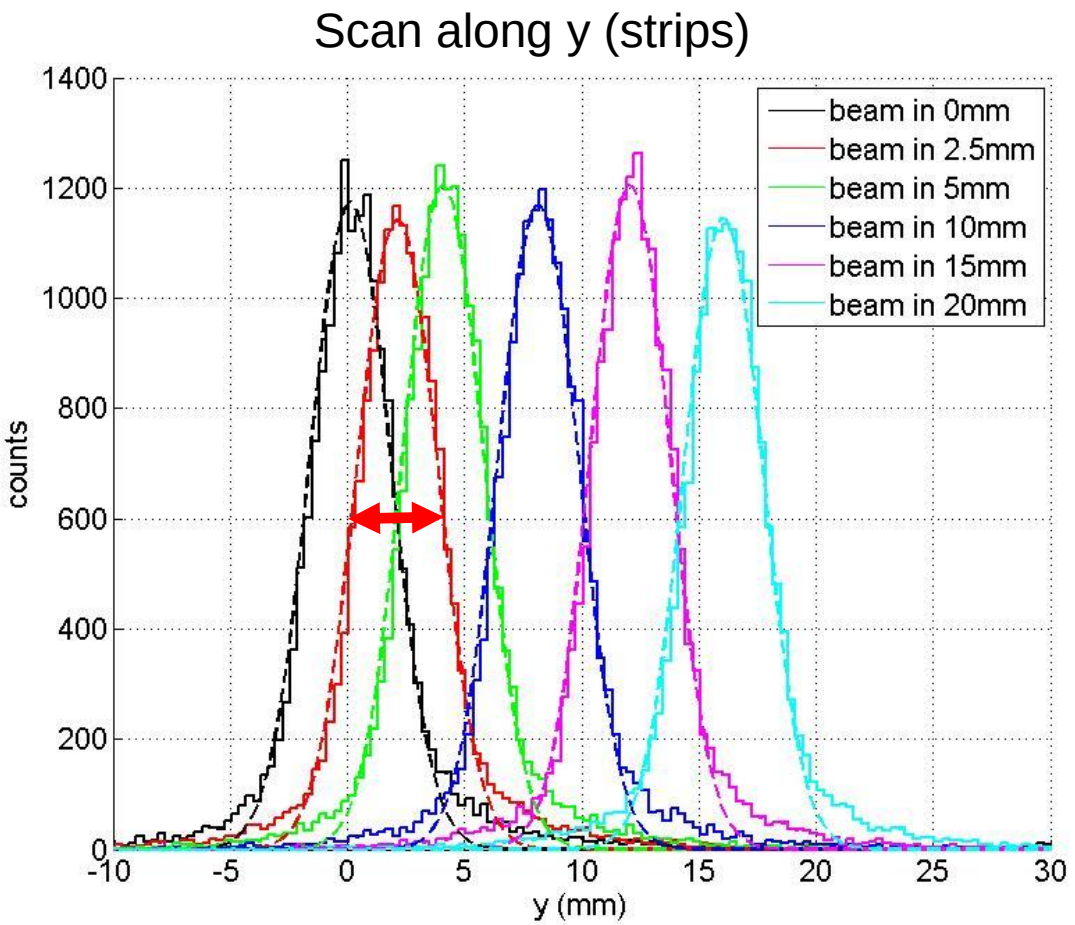




Active surface
60mm · 90mm

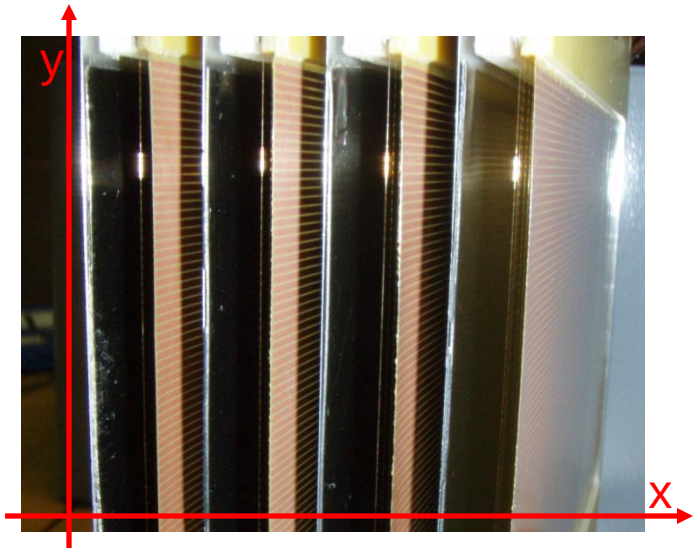
Results: spatial resolution y



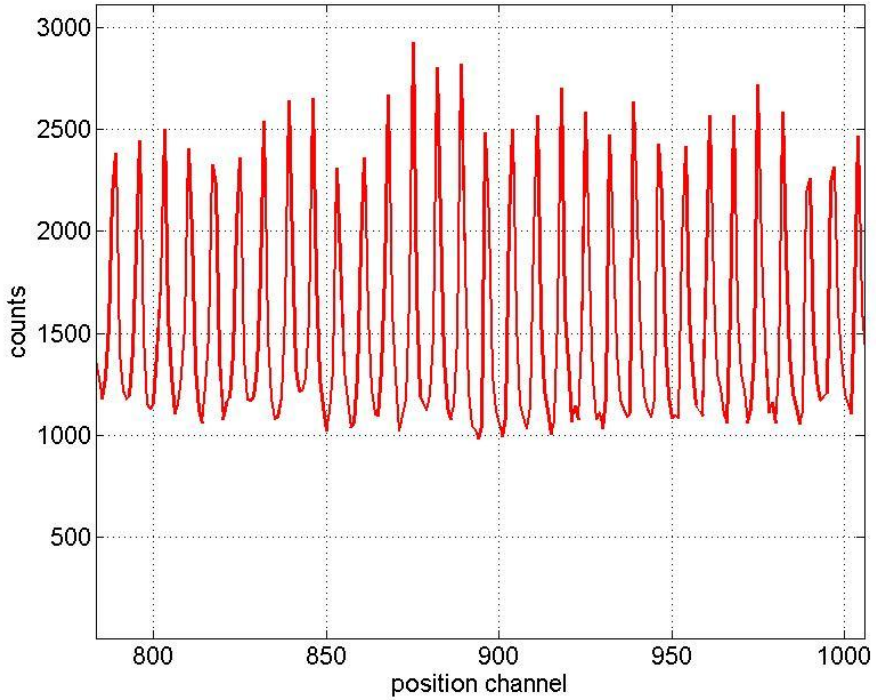


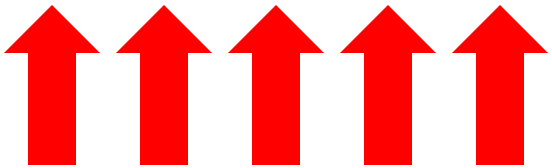
$\Delta y = 4mm$ (FWHM)

Results: spatial resolution x



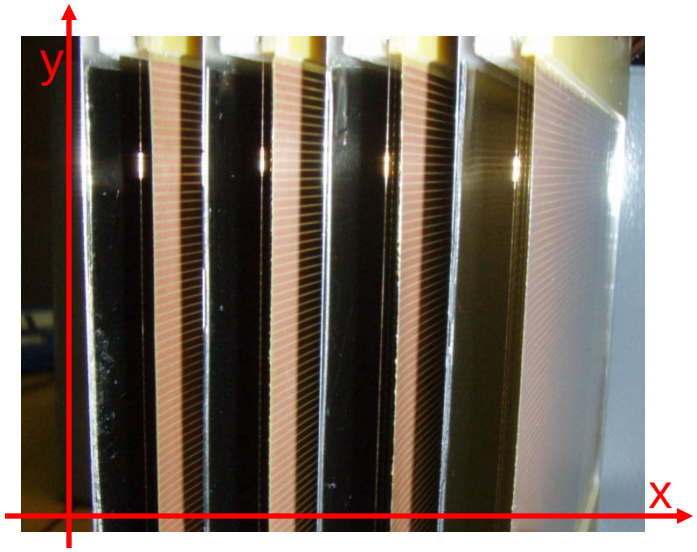
wire response for a collimated beam



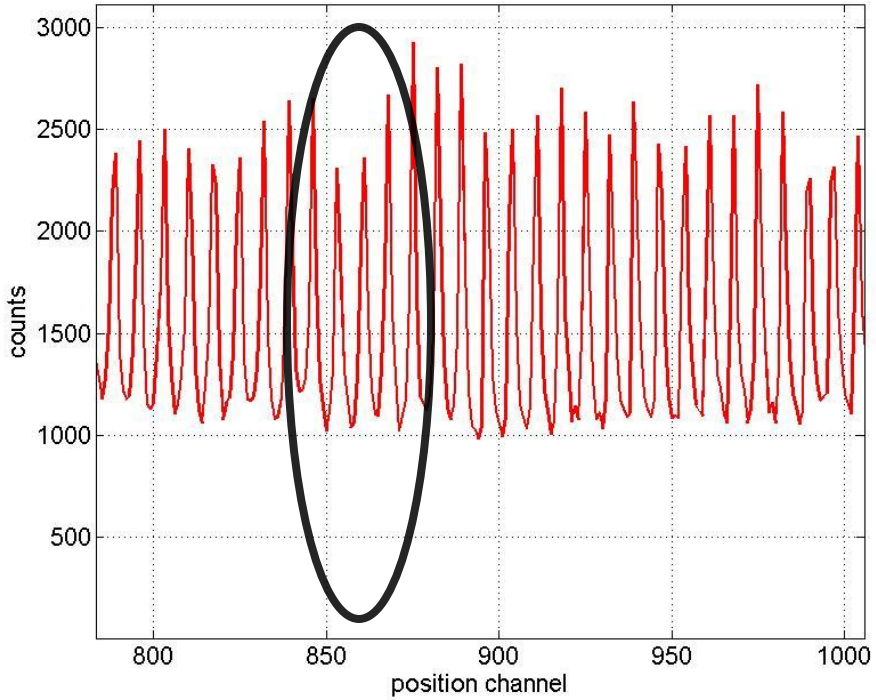


Neutron beam

Results: spatial resolution x

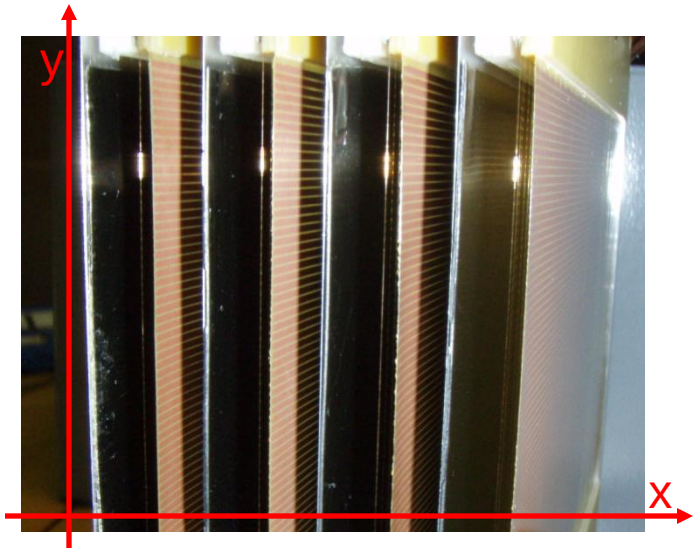


wire response for a collimated beam

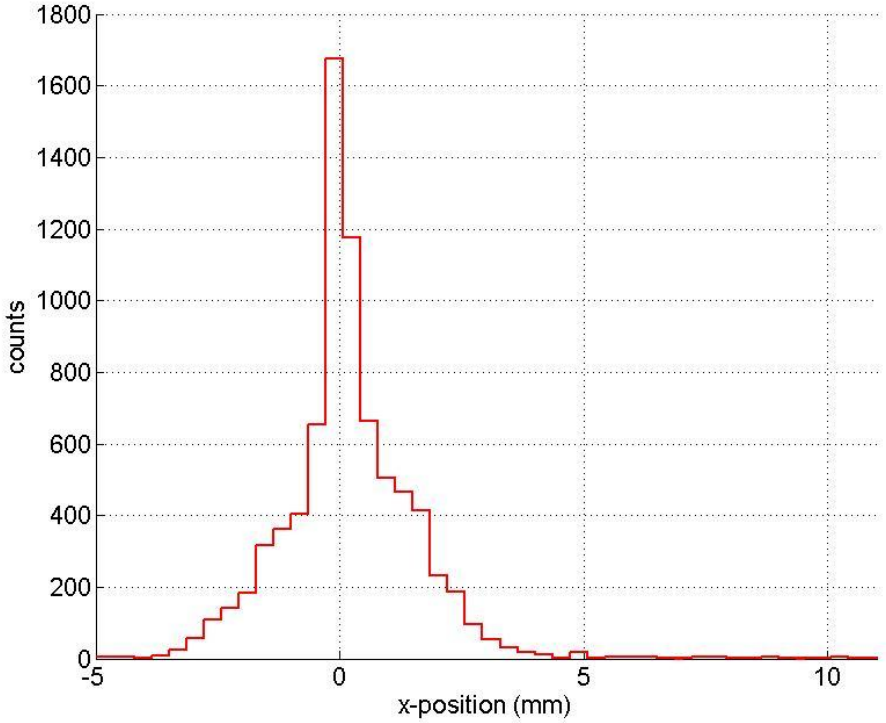


Neutron beam

Results: spatial resolution x

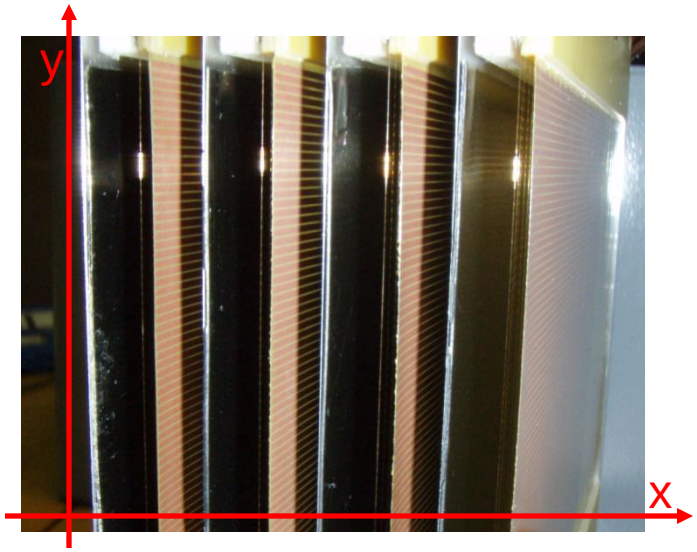


wire response for a collimated beam

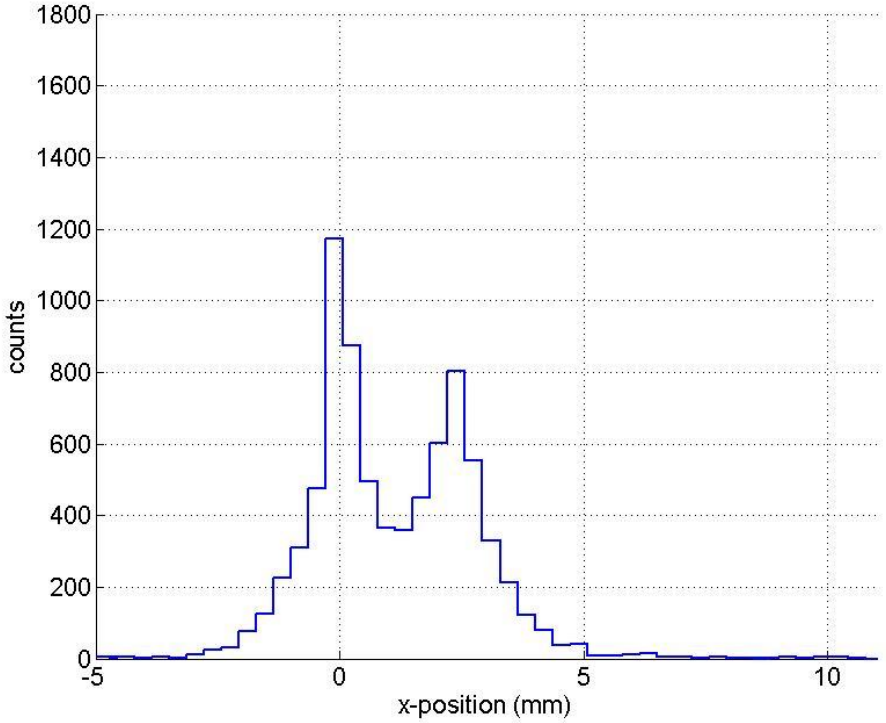


Neutron beam

Results: spatial resolution x

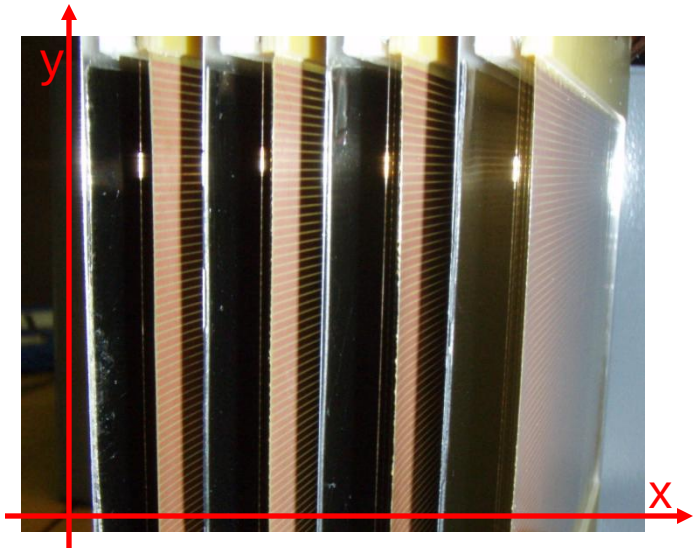


wire response for a collimated beam

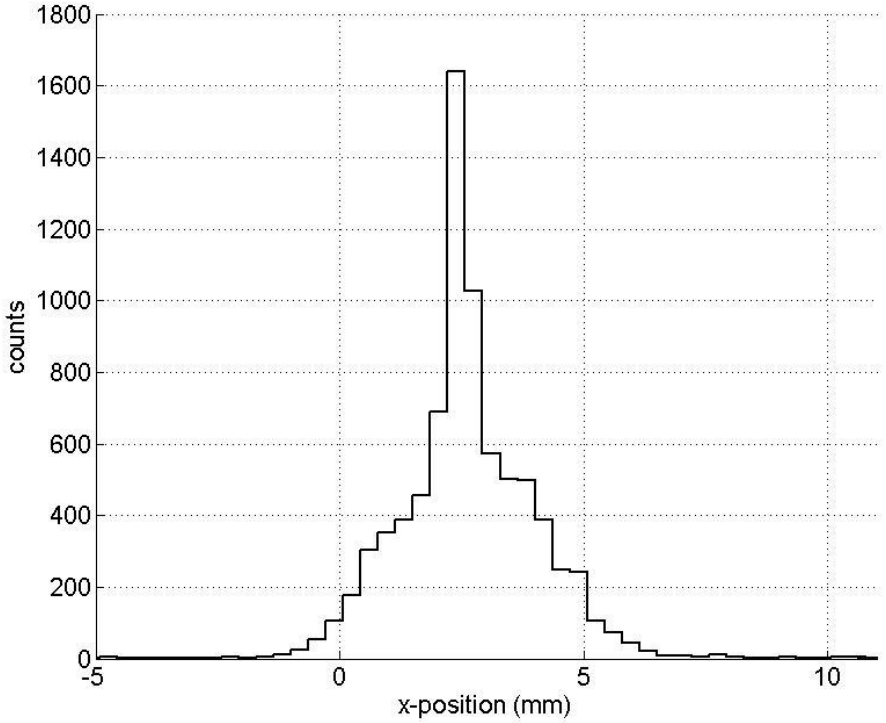


Neutron beam

Results: spatial resolution x

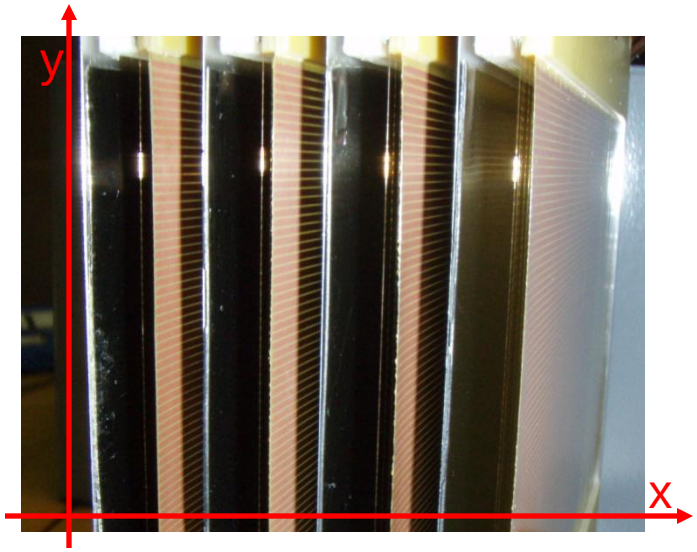


wire response for a collimated beam

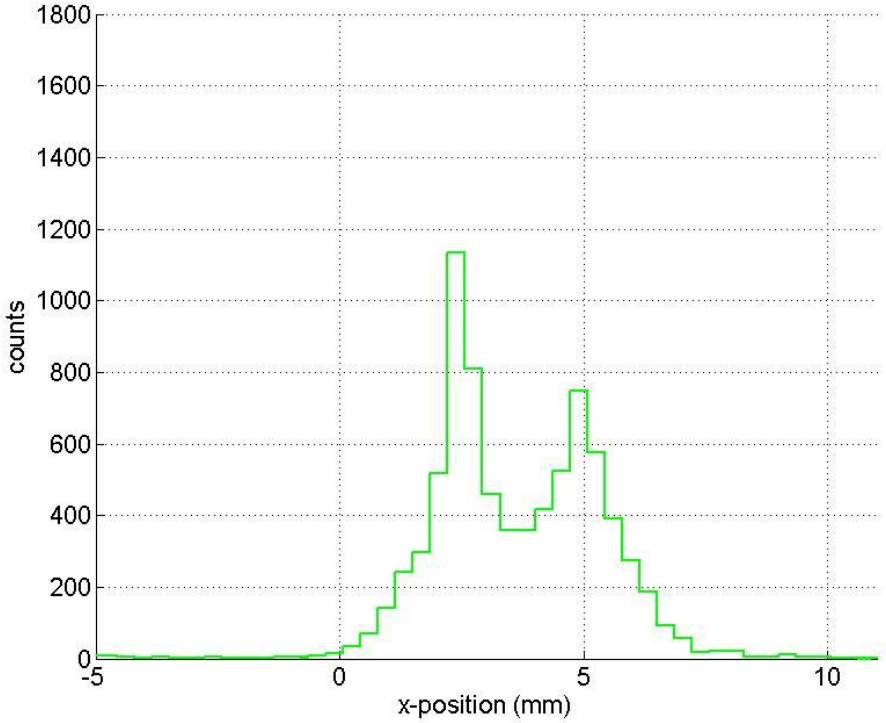


Neutron beam

Results: spatial resolution x

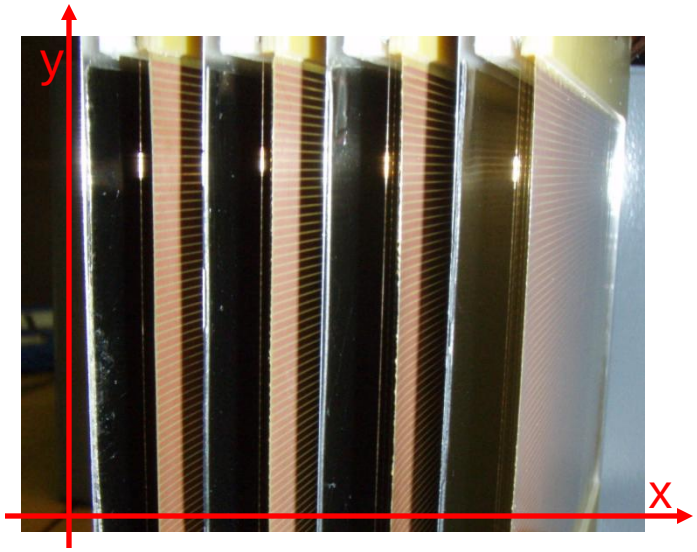


wire response for a collimated beam

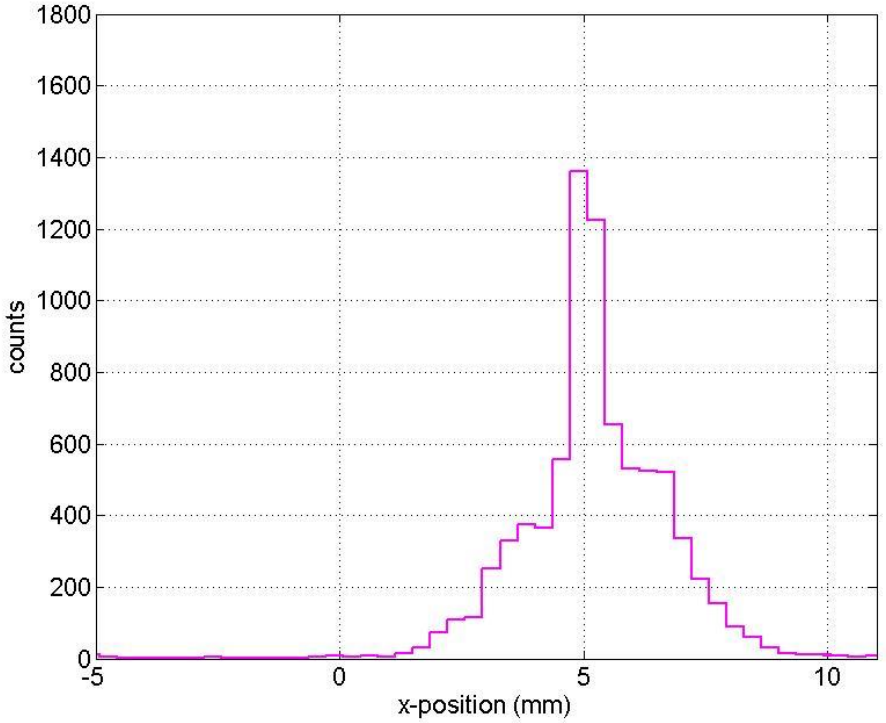


Neutron beam

Results: spatial resolution x

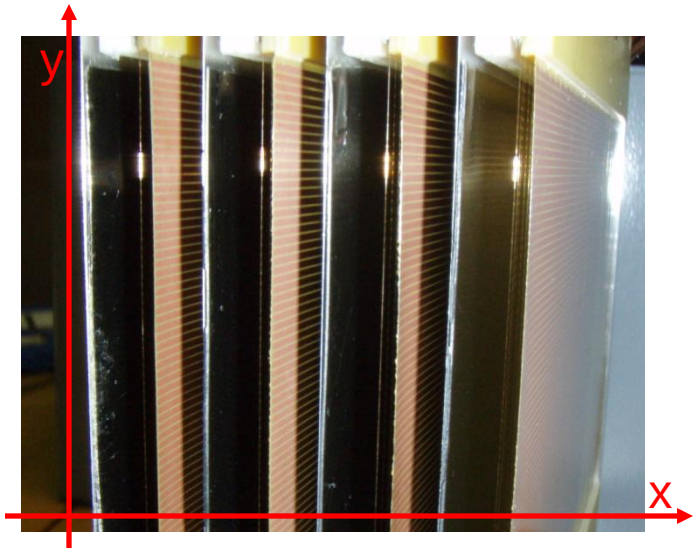


wire response for a collimated beam



Neutron beam

Results: spatial resolution x



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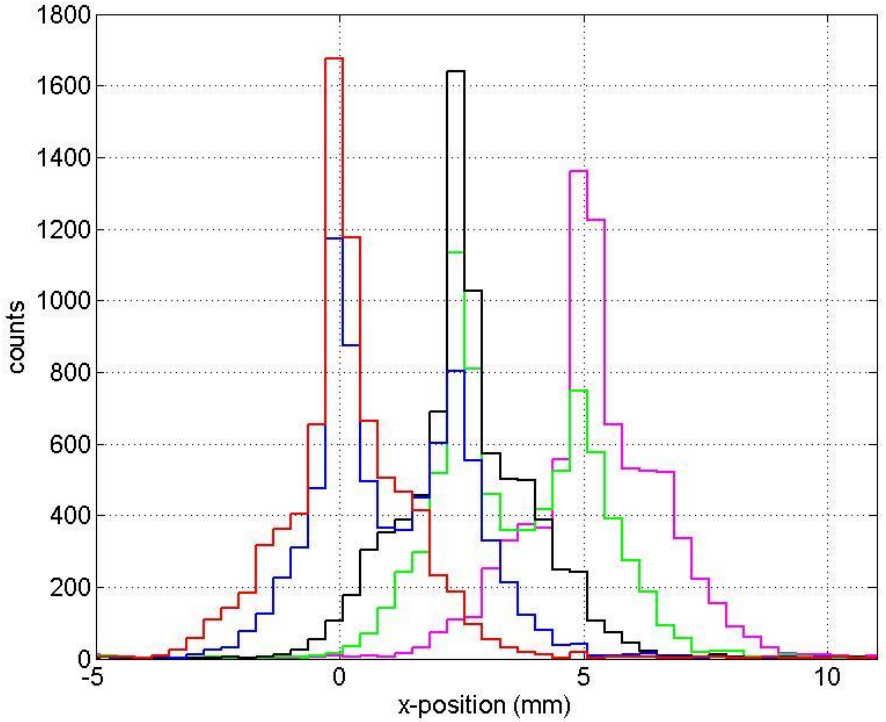


Inclination 10°

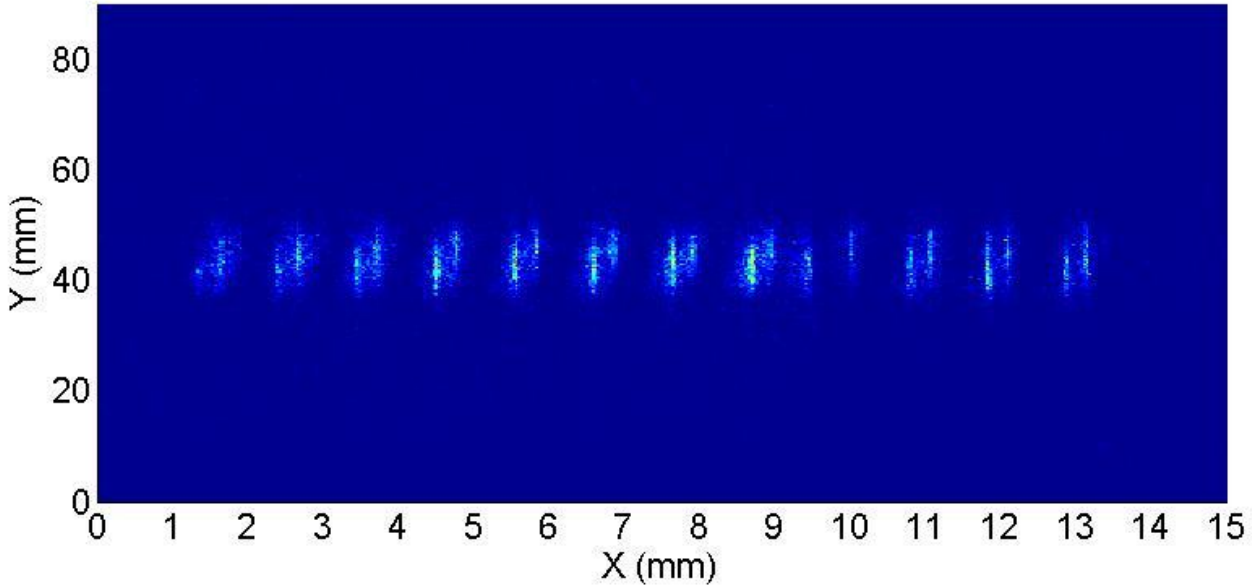
$\Delta x = \sim 0.6$ mm
(FWHM equivalent)
(3.4 mm before projection)

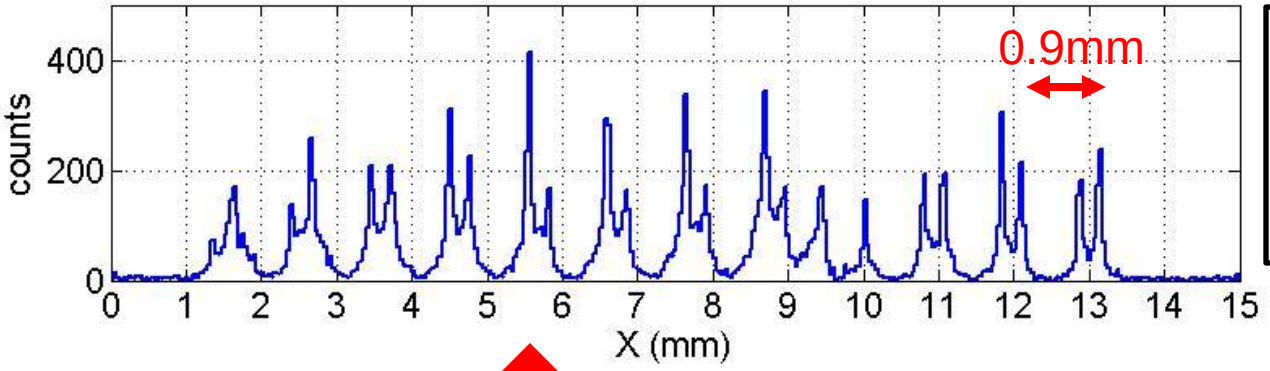
Inclination 5°

$\Delta x = \sim 0.28$ mm
(FWHM equivalent)
(3.2 mm before projection)

P. Van Esch et al., Proceeding of ANNIMA, 2013, arXiv:1307.7507

Results: spatial resolution x





Neutron beam (0.2mm)

$\Delta x = 0.28$ mm

(FWHM equivalent)

(3.16mm before projection)

Conclusions

Conclusions

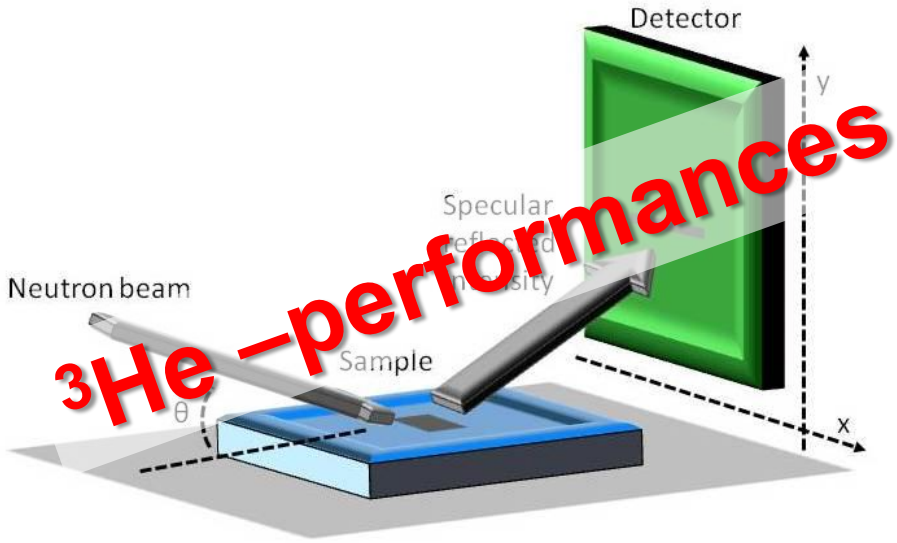
Figaro @ ILL

Gas fill	8 bar ^{3}He + 2 bar CF_4
Area	0.2 m^2
Resolution	2 x 8 mm^2
Efficiency	60% @ 2.5Å

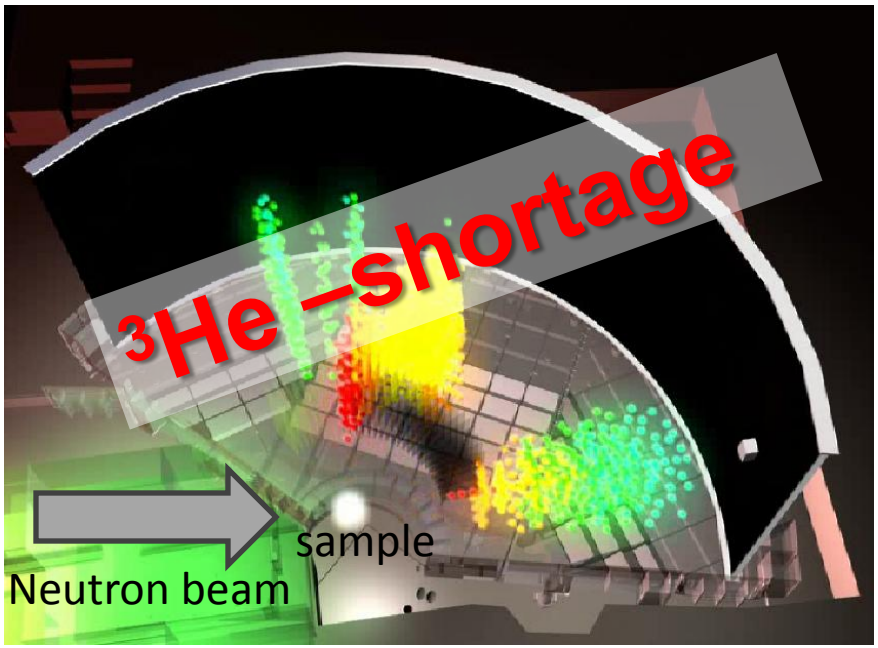
IN5 @ ILL

Gas fill	4.75 bar ^{3}He + 1.25 bar CF_4
Area	30 m^2
Resolution	2.6 x 2.6 cm^2
Efficiency	75% @ 2.5Å

Neutron reflectometry



Neutron spectroscopy - ToF



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Neutron reflectometry

^{3}He –performances

Multi-Blade

Neutron spectroscopy - ToF

^{3}He –shortage

Multi-Grid

Conclusions

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Neutron reflectometry

^{3}He –performances

Multi-Blade

Suitable efficiency
Spatial resolution 0.3 x 4 mm^2
High rate capability
Atmospheric pressure
Cost effective materials

Neutron spectroscopy - ToF

^{3}He –shortage

Multi-Grid

Conclusions

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Neutron spectroscopy - ToF

^{3}He –shortage

Multi-Grid

Lower efficiency 51%
(compensated by)
Better position resolution
Less dead space
Atmospheric pressure
Suitable gamma sensitivity
Suitable ToF resolution

Conclusions

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Neutron reflectometry

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Uniformity issue still opened…

Neutron spectroscopy - ToF

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Neutron reflectometry

^{3}He –performances

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Suitable gamma sensitivity
Suitable ToF resolution

Background issue solved!

University of Perugia

European Spallation Source

Linköping University

Institut Laue-Langevin

Thank you.

University of Perugia

European Spallation Source

Linköping University

Institut Laue-Langevin