Detector Development within the International Collaboration on Neutron Detectors

Karl Zeitelhack, Nigel Rhodes and members of ICND

ICANS-XXI Mito, Japan
02 October 2014

History

2009 working group set up to investigate prices increases and scarcity of 3He,

Three recommendations

- **Potential 3He requirements over next 5 years by neutron scattering community exceeded world supply**
- **More than 80% of 3He was in larger are detectors of inelastic neutron scattering.**
- **Three technologies deemed viable for investigation.**
    - **Scintillation detectors based on $ZnS{:}^{6}LiF$ or $ZnS{:}^{10}B_2O_3$**
    - **Gaseous detectors based on $^{10}BF_3$**
    - **Gaseous detectors based on solid ^{10}B**

ICND formed in 2010 at the request of the Facilities Directors

Collaboration is co-ordinated by Karl Zeitelhack, FRM II

There are 10 facilities contributing to the collaboration

There is a working group for each development area

Scintillator Working Group	ISIS, J-PARC, ORNL, JCNS, NIST + PSI
BF_3 Working Group	HZB, FRM II, ILL
^{10}B Working Group	ILL, ESS, FRM-2, HZB

Funding is from the individual facilities to their own working groups

ICND provides a forum for the exchange of knowledge.

Research and development is costly and time consuming.
Benefit greatly from the diverse expertise within the groups
Try and avoid unnecessary duplication of effort.

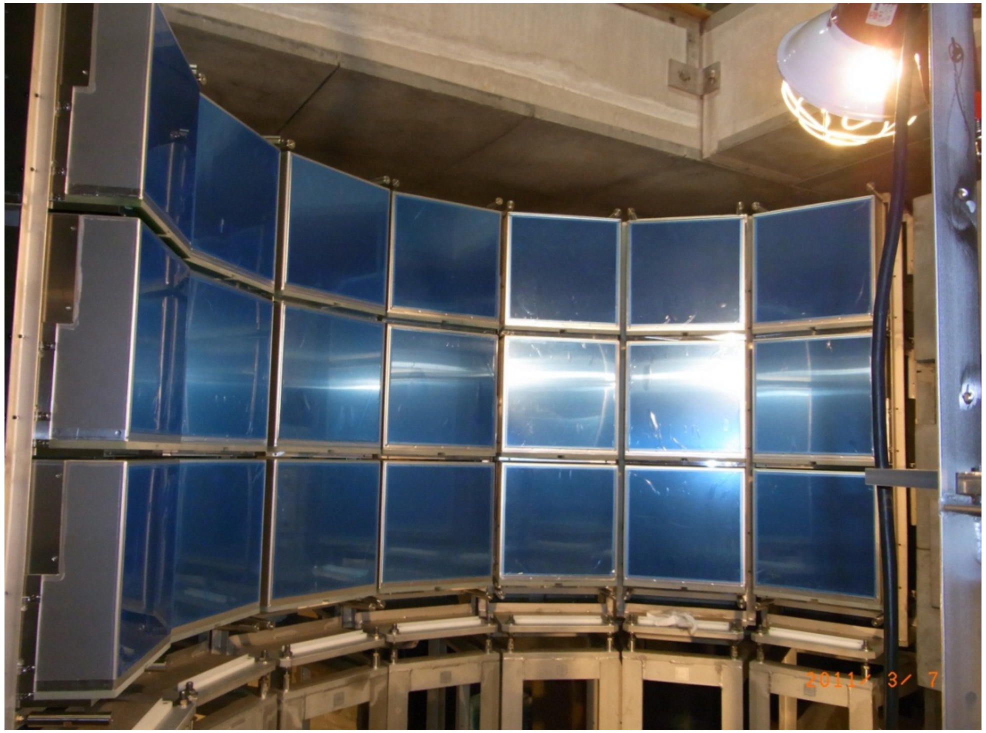
Requirements for large area detectors INS

Area	10 - 40+ m^2
Neutron Efficiency	70% at 1 Å
Gamma Sensitvity	10^{-6} at 1 MeV
Background	0.2 c hr^{-1} $pixel^{-1}$
Pixel size	20 x 20 mm^2
Local Count rate	50 kHz
Global Count Rate	50 kHz
Time resolution	1 µs
Environment	cryogenic vacuum

Misspositioning	
Multicount	
Dynamic Range	
COST	

Scintillation Detectors

SENJU
250 x 250 mm² detector with
4 x 4 mm² resolution



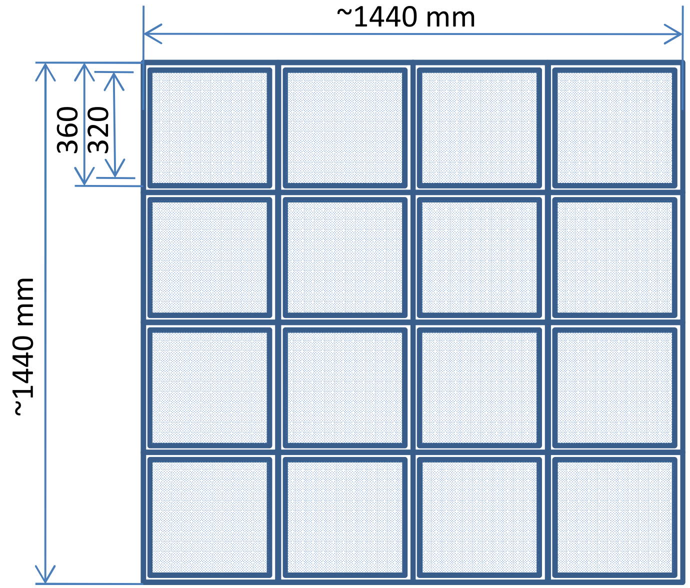
Conventional

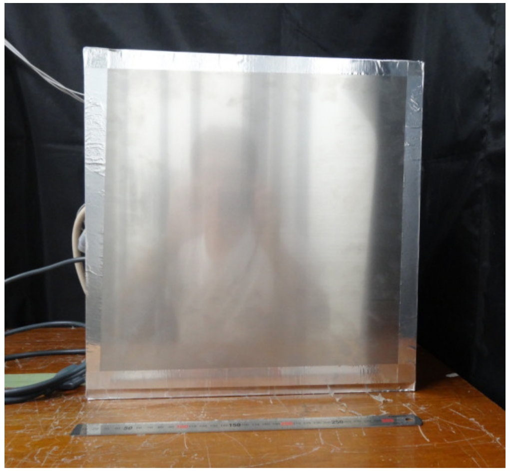
J-PARC

$ZnS/^{6}LiF$ → $ZnS/^{10}B_2O_3$

Neutron absorption of ^{10}B is four times larger than ^{6}Li.

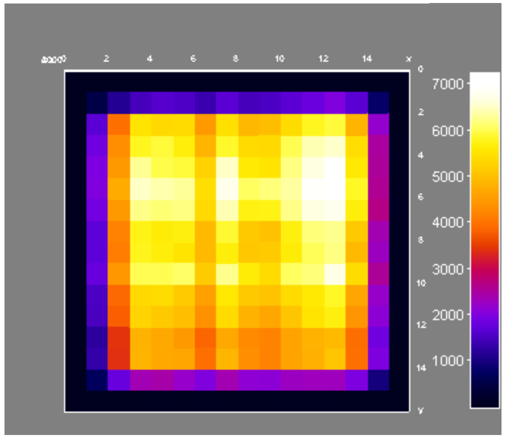
A higher neutron absorption and lower afterglow than the commercial product





Neutron-sensitive area	:	320 x 320 mm
Pixel size	:	20 x 20 mm
Detector efficiency	:	40% for 1.8 A
Gamma sensitivity	:	~1 x 10^6
Background count	:	4 x 10^{-4} cps/cm^2
Count uniformity	:	15 ± 2%
Physical size	:	360 x 360 x 250 mm
Weight	:	12 kg
Power dissipation	:	13 W

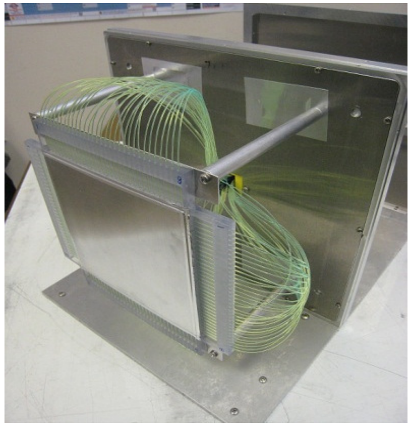
(ii) Flood neutron illumination

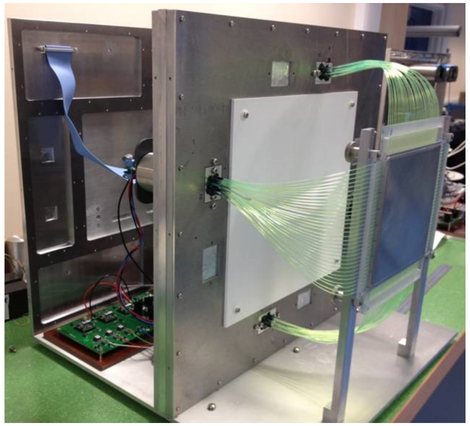


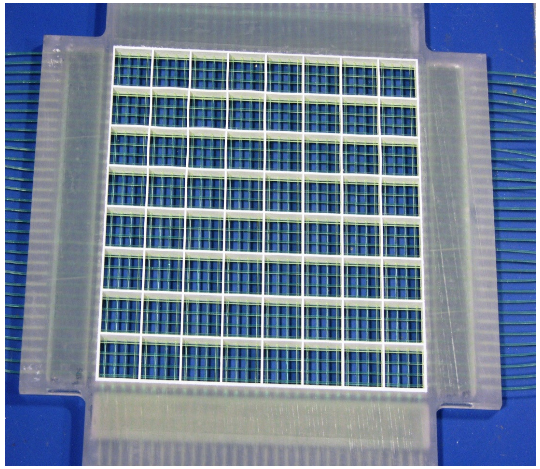
Count uniformity ~15 ± 2%

A first prototype detector exhibited designed detector performances.

A background count, still an order larger than ^3He tube, to be improved.



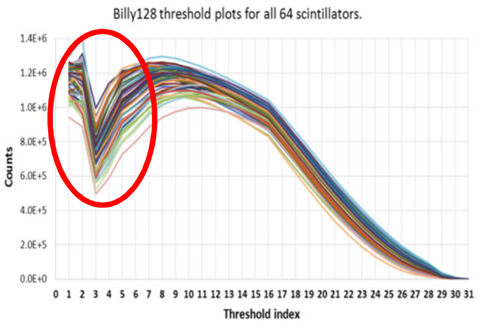


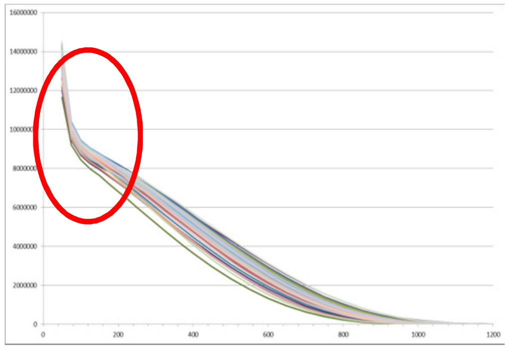


ISIS 16 x 16 cm^2 64 fibres - pair coded detector

ISIS 16 x 16 cm^2 64 fibres - quad coded detector

Printed reflector grid to reduce cross talk





Pattern recognition algorithm used for position reconstruction

Continuing to improve position algorithm

Next steps:
Double sandwich to improve efficiency
Intrinsic background too high for INS

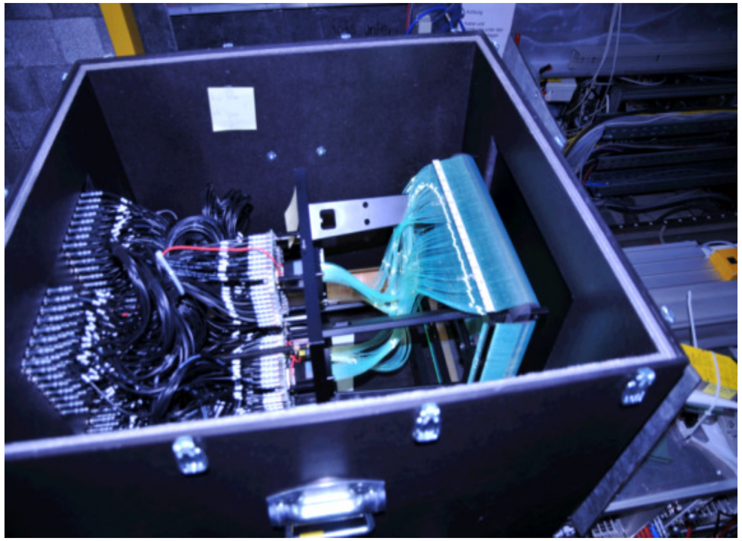
european spallation source

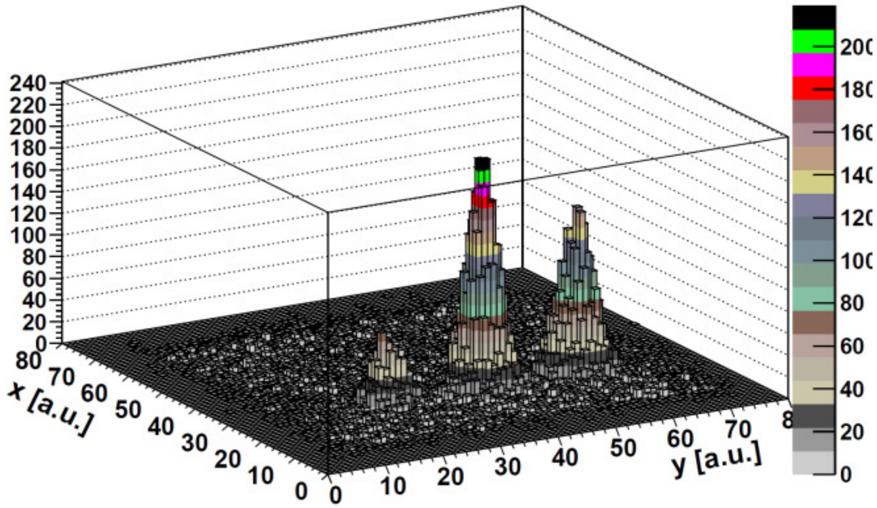
FRM II Forschungs-Neutronenquelle Heinz Maier-Leibnitz

HZB Helmholtz Zentrum Berlin

NEUTRONS FOR SCIENCE

Science & Technology Facilities Council ISIS





Julich 30 x 30 cm^2 detector 256 fibres

		Absorption				Theo. Abs.	Absorption (Single)	Absorption (Double)	He-3
	#Probe	Density	ZnS	Dicke	1,1695 Å	1,1695 Å	1,1695 Å	1,1695 Å	Ereignisse
AST	Leermessung								3003601
	Off Reflection								12079
	23166	Normal	2	200	17,69%		17,31%	17,54%	
	23168	Normal	2	300	25,74%		24,81%	25,27%	
	23173	Normal	2	400	29,70%		28,80%	29,07%	
	23174	Normal	3	200	15,38%		15,18%	----	
	23178	Normal	3	300	19,92%		19,50%	19,88%	
	23182	Normal	3	400	25,23%		24,37%	24,92%	
Elien	4318-01-01	EJ-426-1	3.2	320	21,41%		20,59%	21,08%	
	4318-02-01	EJ-426-1	3.2	500	30,57%		29,47%	27,65%	
	4318-03-01	EJ-426HD2	2	320	27,96%		27,47%	26,56%	
	4318-04-01	EJ-426HD2	2	500	39,69%		37,91%	38,48%	
	4318-07-01	EJ-426HD2A (1-1)	1	320	33,33%		32,24%	32,47%	
	4318-08-01	EJ-426HD2A (1-1)	1	500	46,73%		43,01%	46,20%	
	4085-02-01	EJ-426HD	3.2	1000	31,51%	52,45%	49,86%	51,44%	
	4318-02-01	EJ-426-1			30,57%				
	4085-04-01	EJ-426HD	2	1000	38,17%	62,71%	60,91%	60,72%	
	4318-04-01	EJ-426HD	2		39,69%				
	3862-08-01	EJ-426HD2A	1	1000	51,25%	74,03%	72,64%	73,61%	
	4318-08-01	EJ-426HD2A (1-1)	1		46,73%				
	4085-03-01	EJ-426HD2	2	640	27,73%	47,94%	46,50%	46,81%	
	4318-03-01	EJ-426HD2	2		27,96%				

At Julich Center-of-Gravity Method is used for position reconstruction

B_4C-diaphram with 4mm holes and 10mm spacing accurately reproduced in detector

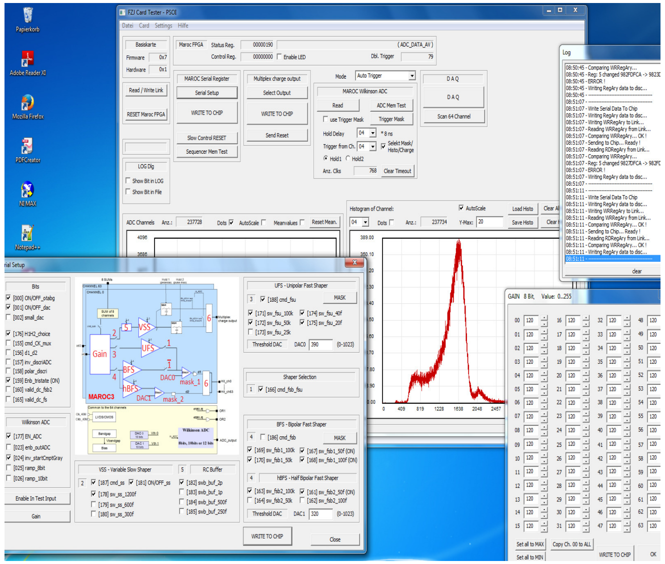
J-PARC

Jülich Centre for Neutron Science

PAUL SCHERRER INSTITUT PSI

OAK RIDGE National Laboratory

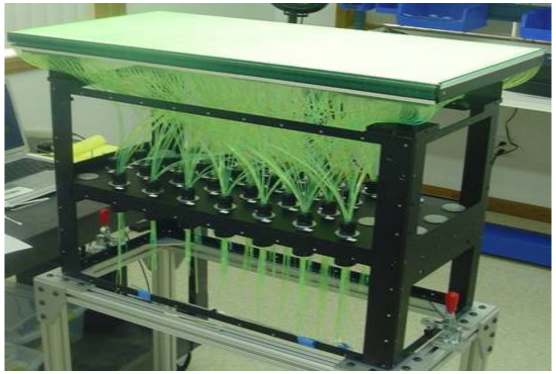
NIST Center for Neutron Research



Julich electronics

64 channel ASIC, FPGA, Optical link to PC
Board design and fabrication for a 64 ch MaPMT complete
FPGA board and MAROC 3 board tested
ASIC control and readout programme developed
Pulse simulator developed and is being commissioned

Wavelength-Shifting Fiber Neutron Scintillator Detector



Module in fabrication.

Eight modules installed on POWGEN stands

30 units installed in two SNS diffractometers, POWGEN and VULCAN

Fabrication is transferred to GE, Twinsburg, Ohio

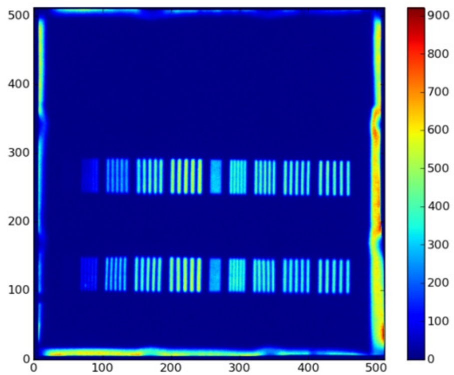
Focusing on improvement in light coupling into fibers and larger number of phototube elements using multi-anode PMTs.

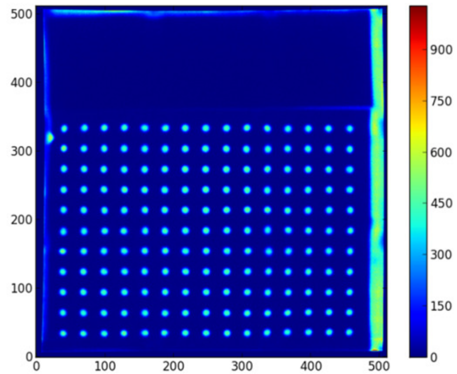
Expected to further improve uniformity and eliminate ghosting artifacts.

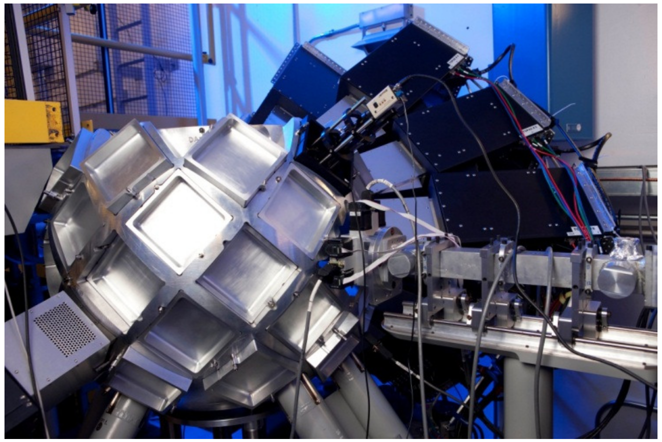
Anger Camera Is Now In wide use at SNS

Resolution about 1.0mm (FWHM)

Distortion < 0.5mm



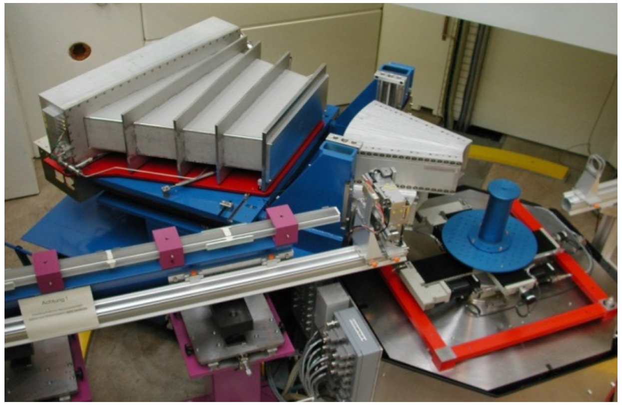


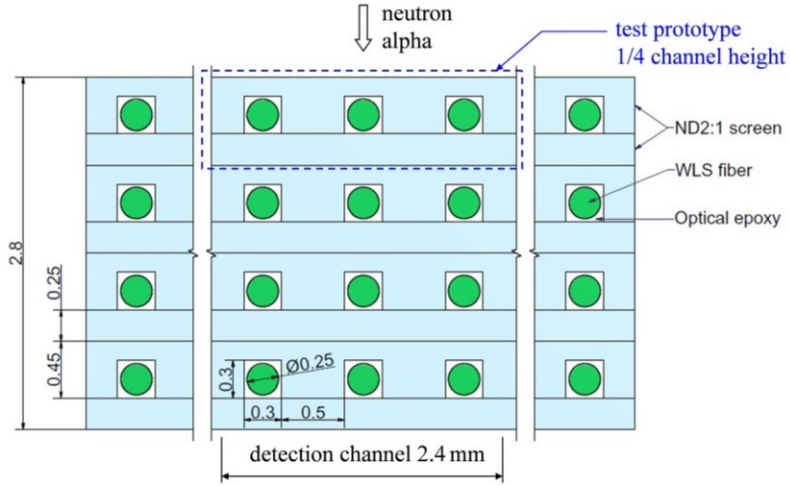


23 Anger Cameras Installed at TOPAZ,
70 planned or installed on other Instruments

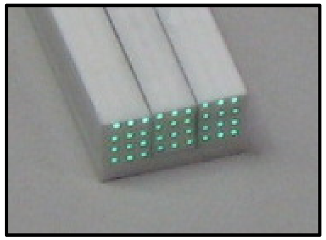
Efforts are focused on finding higher light yield scintillators

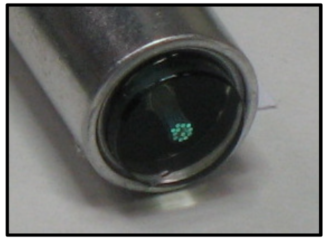
PSI - POLDI beam line at SINQ





ToF diffractometer for strain measurements
4 modules
400 pixels per module
Each pixel 2.5 x 200 mm

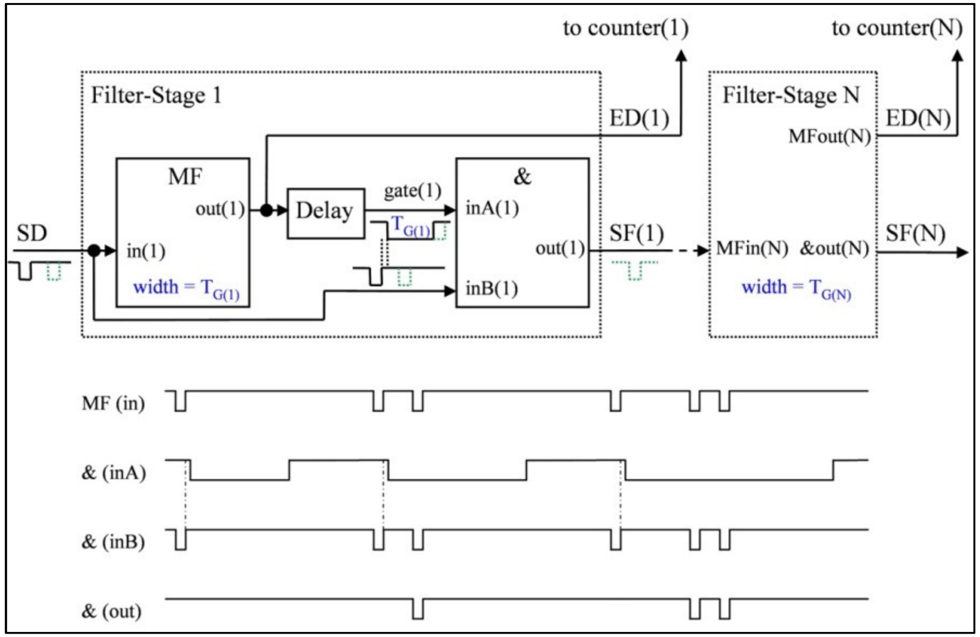




Limited space
High local count rate 4 kHz per pixel
Magnetic fields present

SiPM readout

Layered machined scintillator 2.8 mm thick
Each pixel twelve 0.25 mm dia fibres
Each coupled to single SiPM
Signal processing system to supress dark counts



en-abs >80% @ 1.2 Å
trigger efficiency ≈ 80%

Gamma sensitivity ≤ 10-6 for 10 filter stages and up to 2 MHz SiPM dark count rate

multi count ratio

< 1% with blocking time of 15 ms

background rate

- **≤ 10-3 Hz up to 2 MHz SiPM dark count rate**

<u>outlook:</u>

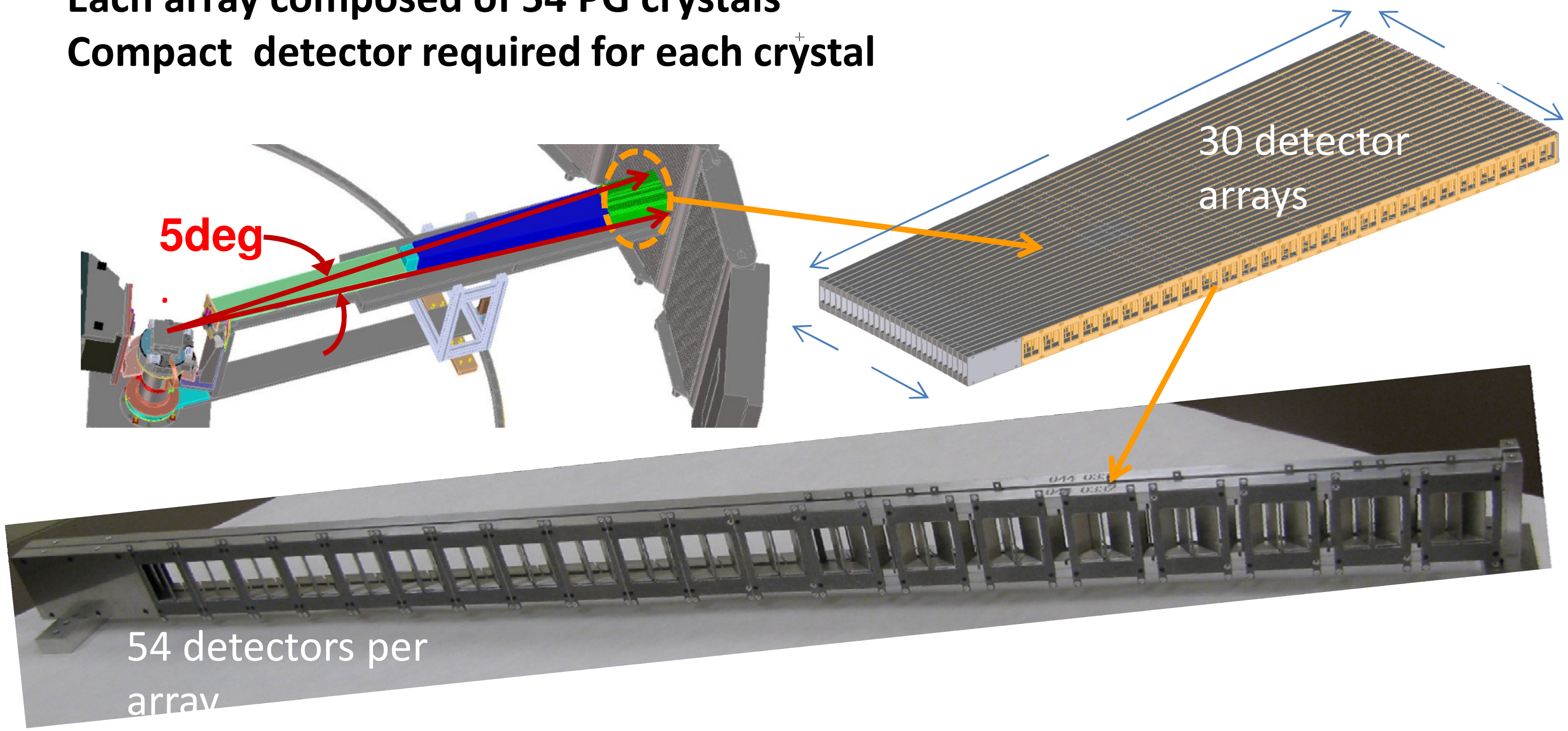
- **manufactoring procedure for full length detection units (200 mm), 20-channel prototype**
- **further optimization of geometry of detection unit**
- **further optimization of signal processing system (parameters, principle)**

acknowledgement: J.-B. Mosset, A. Stoykov, Malte Hidelbrandt

NIST are developing the CANDOR instrument

Chromatically Analysing Neutron Diffractometer or Reflectometer

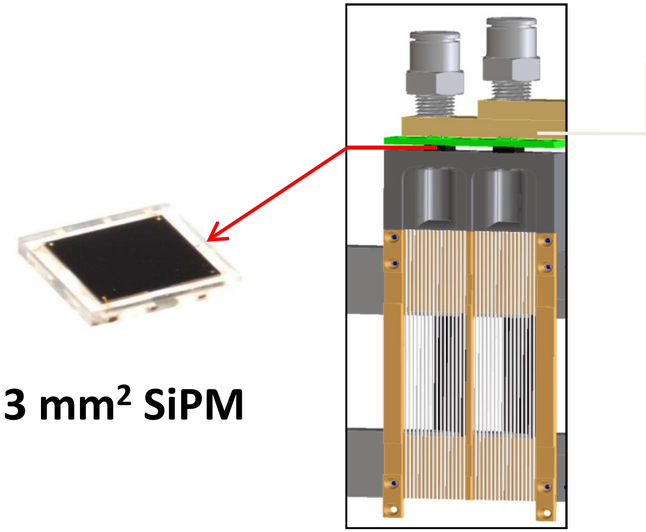
- Polychromatic beam (4 to 6 Angstroms) on sample
- Scatters into 30 detector arrays
- Each array composed of 54 PG crystals
- Compact detector required for each crystal



Very Limited space
Magnetic fields present

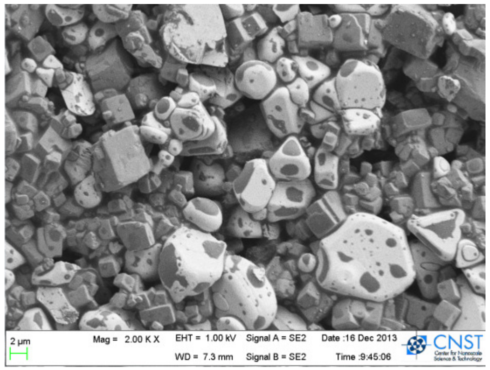
Solutiion
ZnS:Ag/6LiF scintillation detector
0.5 mm dia WLS fibre

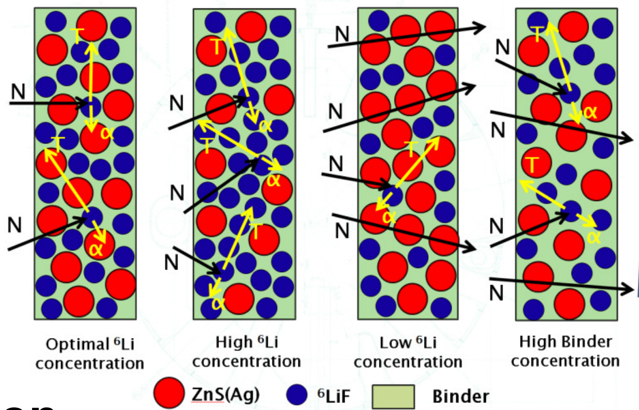
SiPM readout



3 x 3 mm^2 SiPM

Need to maximize the light content
Working with Eljen to optimise scintillator light output





Particle size and distribution

$^{10}BF_3$ Proportional Counters

Study of BF_3-filled IN5-prototype module at ILL

- *Study influence of pressure on detector performance*

Study of small size PSDs at HZB, ILL, BARC (India)

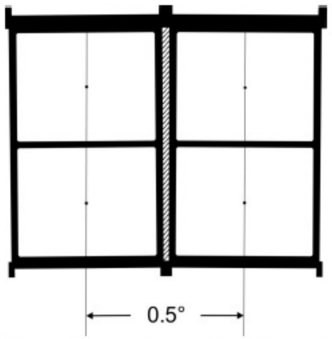
- *Study of efficiency, position resolution, rate capability,*
- *For a 1" PSD:*
  Max. pressure ~2bar, ε ~ 70% for 5.0Å
  Position resolution: $\Delta x/x$ ~ 0.5%

Development of 3m long "Twin-tube" PSD-modules for NEAT at HZB

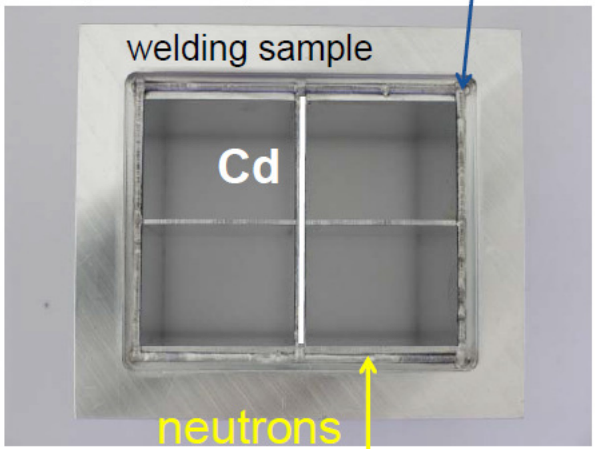
- *Installation of specific BF_3-Lab (~100m²)*
- *Dedicated BF_3 Gas handling system*
- *Safety problems intensively studied and solved*
- *Production of "Twin-tube" prototype detector*
- *Ageing solved by proper choice of material, purification of BF_3 and admixture of agent*

Optimized detector design for ToF Instruments

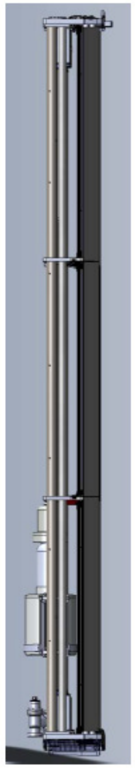
HZB Helmholtz Zentrum Berlin



Problems with tightness of welds
Solved 12/2012



Extruded Al6060
free geometry, wall 0.6-3.0 mm



side view

back side

Design in collaboration HZB - ILL

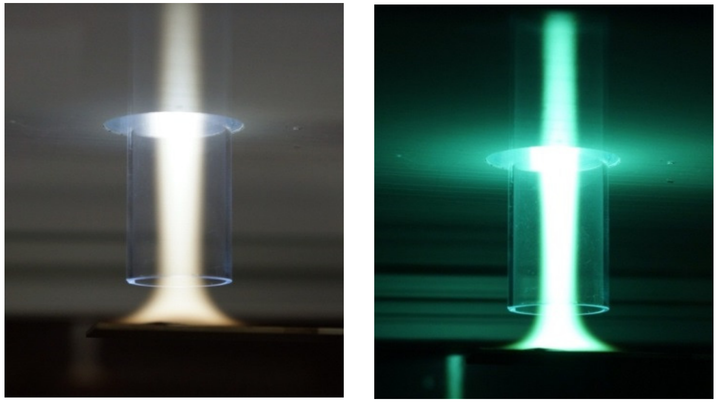
Infrastructure at HZB for BF_3 filled LPSD production

HZB Helmholtz Zentrum Berlin

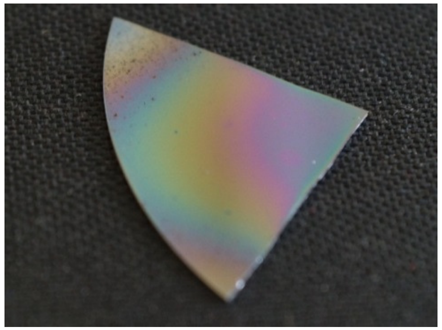
Solid 10B gaseous detectors

Exploration of alternative production techniques - HZB leading

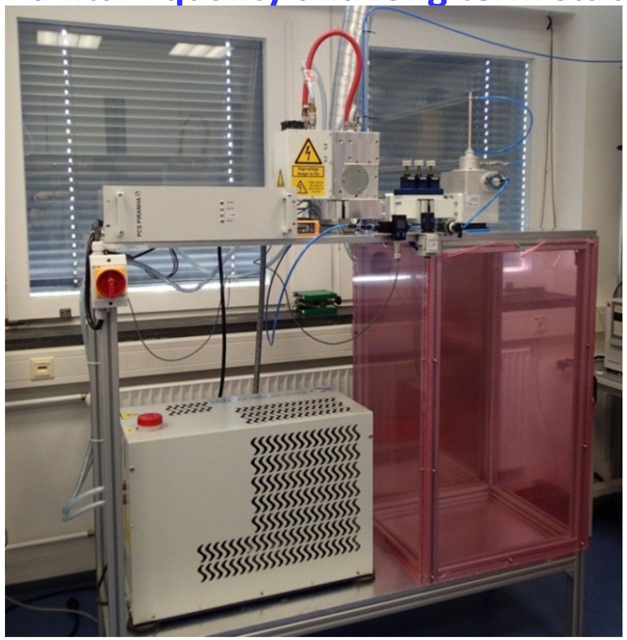
Drivers:
Increase boron layer production rate:
Reduce cost
Need to maintain quality and long term stability



The colour change signifies boron evaporation

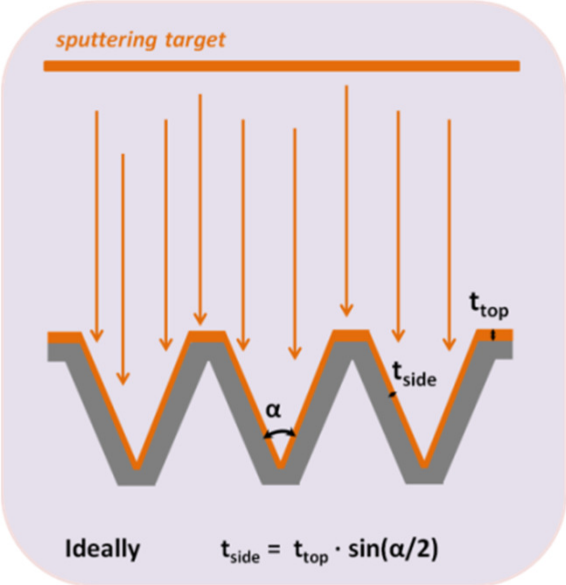


High deposition rate achieved on silicon substrate



Powder spraying with microwave atmospheric plasma selected as most promising technique

FRM II Developed Macro structured converter



GARFIELD simulations:

- ✓ Electric field inside a MWPC with macrostructured cathodes;
- ✓ Drift lines and times for electrons.

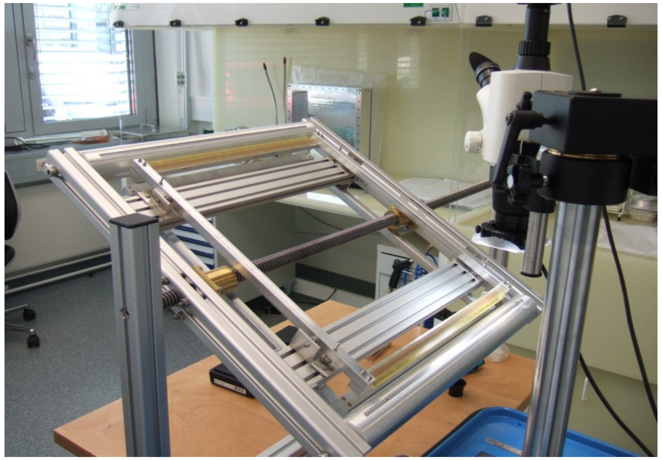
GEANT4 simulations:

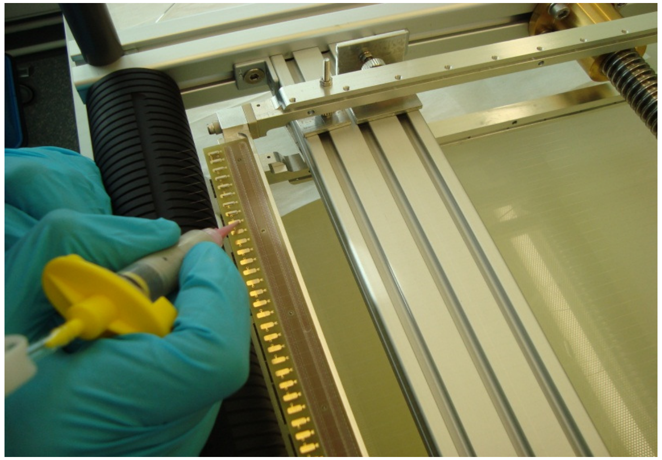
- ✓ Optimal geometry of the groove to maximize the detection efficiency of the coated plate;
- ✓ Effects of the conformality of the coating on the detection efficiency.

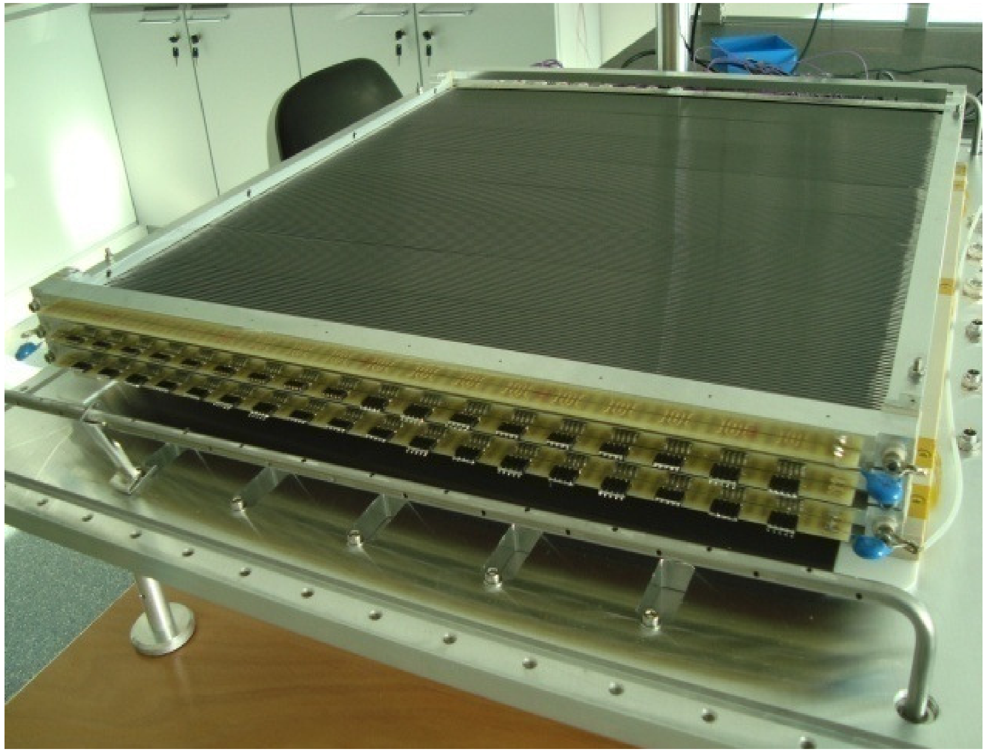
Gives 40% increase in efficiency cf flat layer

I. Stefanescu et al., Nuclear Instruments and Methods in Physics Research A727 (2013) 1

Macro grooved structure used in stacked MWPC concept study

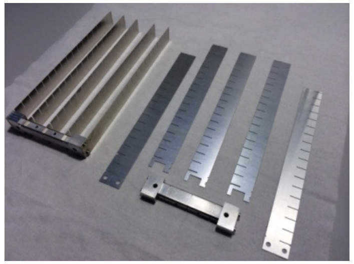
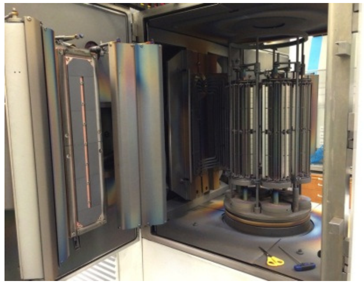
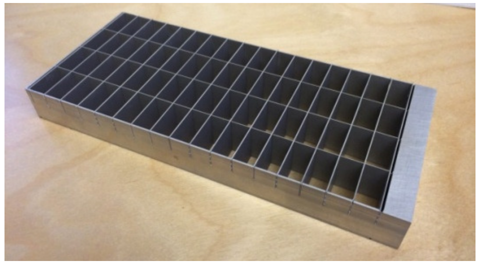






40 cm x 40 cm active area
2 MWPCs sandwiched between 3 layers of macrostructured planes each coated with 1.4 µm $^{10}B_4C$ by magnetron sputtering. Ar/CO_2 gas

Multigrid detector ILL-ESS-Linkoping collaboration – partially funded by CRISP

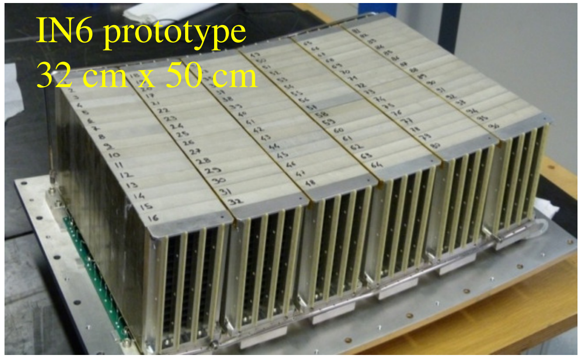




Huge amount of work has gone into this development

Aluminium blades are sputtered with ~1 µm $10B_4C$

Grids isolated from each other to form position sensitive cathodes

Wires run through grids the grids to form anodes

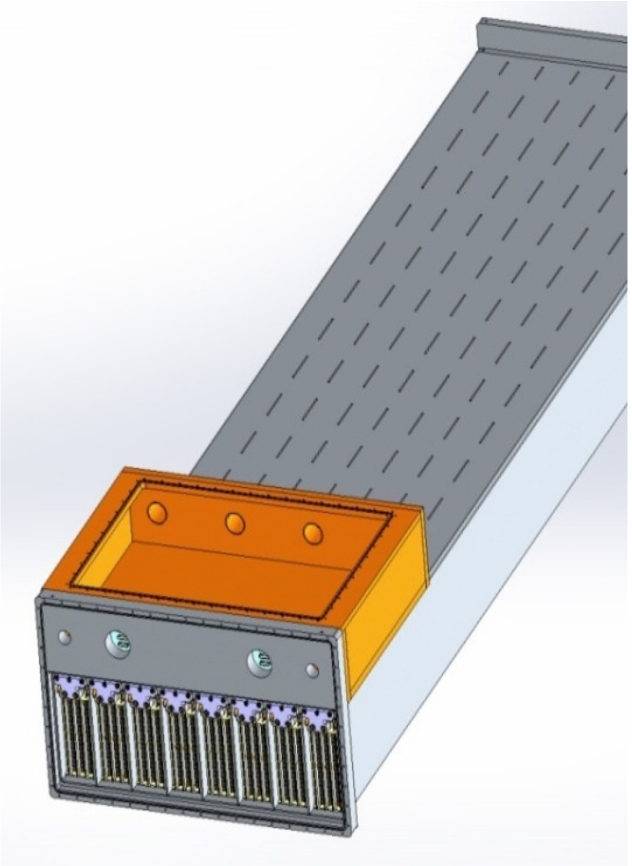


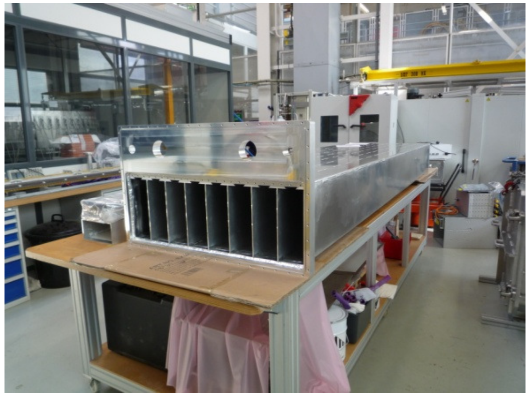
Tested on IN5 and In6

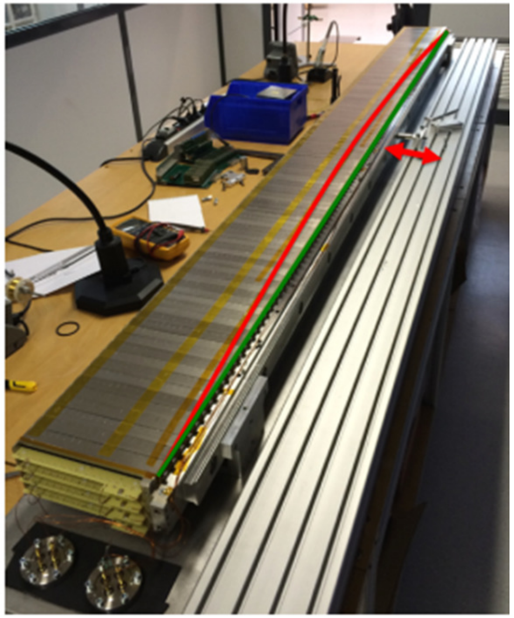
Problems in gamma sensitivity and intrinsic background overcome

Meets technical specification

Full scale demonstrator in construction







3m long 800 mm wide

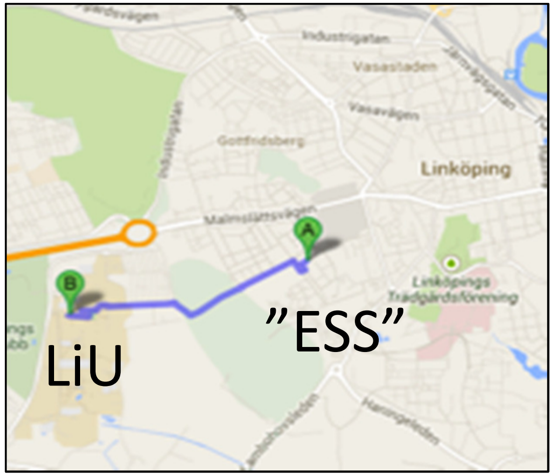
512 wires

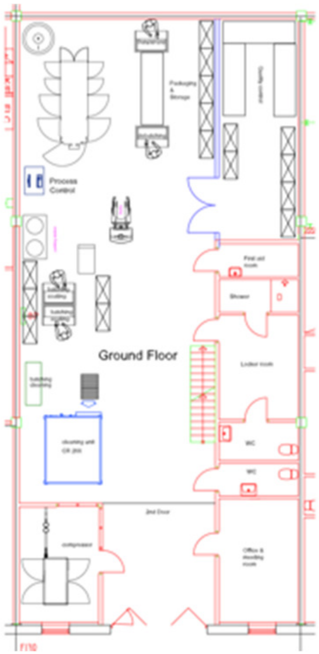
1024 grids

~18,000 blades all coated

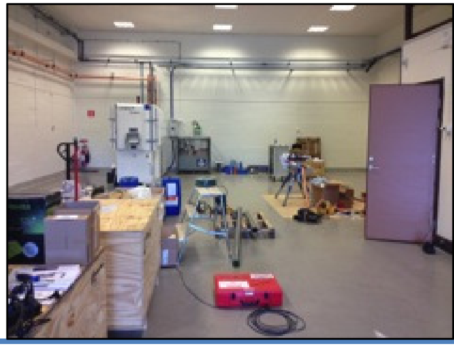
Nearing completion

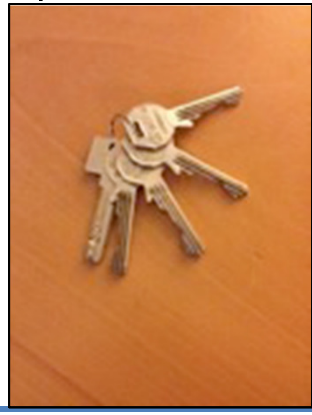
ess european spallation source
FRM II Forschungs-Neutronenquelle Heinz Maier-Leibnitz
HZB Helmholtz Zentrum Berlin
ill NEUTRONS FOR SCIENCE
Science & Technology Facilities Council ISIS





- New facility running
- New colleague - Linda
- Collaborative coating requests welcomed
- Capacity for >1000 m^2 of $^{10}B_4C$ per year
- (ESS needs ~6000 m2)





J-PARC
JCNS Jülich Centre for Neutron Science
PAUL SCHERRER INSTITUT PSI
OAK RIDGE National Laboratory
NIST Center for Neutron Research

Conclusions

We meet formally once a year as a complete group

Different partners meet much more frequently

ICND enables sharing of knowledge and expertise wrt a common goal

We are far more aware of each others knowledge and capabilities as a result of ICND

A lot of work has gone on since 2010

I believe this work has benefited from the existence of ICND

How can we improve it to meet future needs?