CDT
CASCADE Detector Technologies GmbH

- Neutron Detectors
- Readout Electronics
- Complete Systems
  - ^{10}B Coatings

CDT

since 2006

a university spin-off dedicated to neutron detector technology

CDT GmbH
Hans-Bunte-Str. 8-10
69123 Heidelberg
Germany

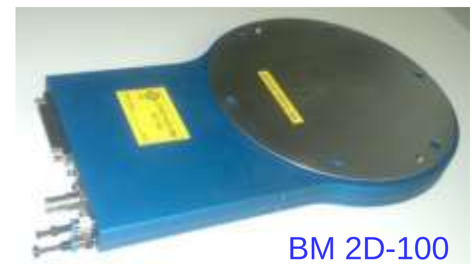
www.n-cdt.com

CDT CASCADE Detector Technologies GmbH

- Founded in 2006 as spin-off of Physikalisches Institut Heidelberg
- Current work: **^{10}B based area detectors for thermal and cold neutrons as complete system solutions with electronics, firmware and software**
- More generally: We consider ourselves as experts for
  - neutron detector systems,
  - the related specialized engineering and 3D-CAD and
  - the realization of high quality and cost effective serial manufacturing.
- Customers: FRM-II, FZJ, ESS, PSI, ILL, KIT (IBR-II), IHEP (CSNS, China), KEK & JAEA (Japan) via REPIC, KACST (Saudi Arabia) and others

Current Products

- JALOUSIE detector, the alternative for ^{3}He PSDs
  → large areas, medium resolution
  → POWTEX, DREAM, …
- CASCADE 2D-200 – a high rates GEM-based solution with extraordenary contrast of 10^5
  → expansion to 2D-300 (300 x 300mm^2)
- CASCADE-MIEZE – a special variation to resolve 1MHz intensity variations
- CASCADE-BM position sensitive Beam Monitors
- CASCADE-IBM neutron ionization beam monitoring of extreme robustness
- UCN detectors
- ASIC and FPGA-based multi-channel readout electronics



BM 2D-100

IBM

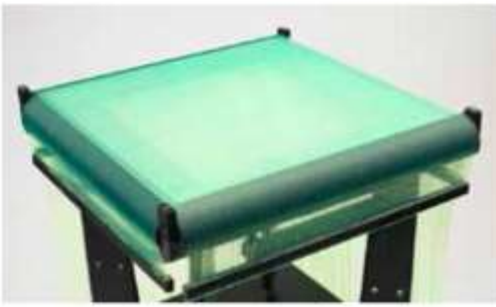
recently also WLSF-Detectors - Cooperation with FZJ ZEA-2

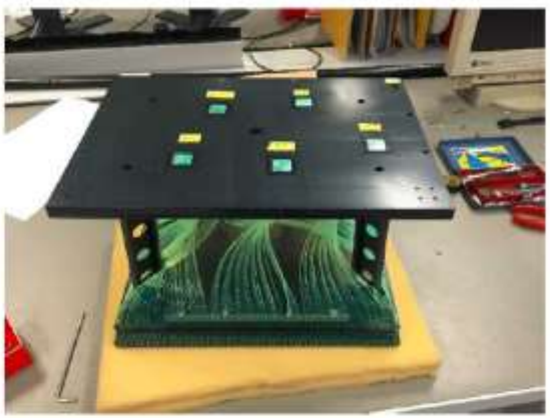
Technologies Portfolio: Developments

JÜLICH FORSCHUNGSZENTRUM

Wavelength Shifting Fiber based Scintillation Detector Prototype for the SAPHIR Instrument at FRM II

Special requirements: high spatial resolution, high neutron count rates for the entire detector, detector area >> 1 m², > 10 year life-time





Specification	Value (Goal Specifications)
Developer: Project time	ZEA-2: 2013 - 2016
Detector Main Technology	A grid of 192 x 128 WLSF yielding 2 mm pitch (1 mm thickness), sandwiched between 2 scintillator plates. Each WLSF is connected to an anode (64 anodes per module) of one of the five H7546 multi-anode PMTs per detector. Four detector modules have been built and partially characterized in a beam of thermal neutrons.
Scintillator	500 µm thick ZnS-Ag/^{6}LiF
Prototype active area	390 x 260 mm²
Number of output channels	320
Number of detector spatial units (pixels)	192 x 128
Max. spatial resolution	4 x 4 mm²
Max. count-rate	Tbd
Neutron Det. Efficiency	> 62 % (λ_n = 1.1 Å)
n-γ Discrimination	10^{-5}
Max. Magnetic Field	Not an issue
Power Consumption	Approx. 120 W per segment
Project status ZEA-2	Available and proven for development

CDT prepared for Contract Manufacturing

- With our expertise and experience on mechanics in the neutron detector field we do have interest in manufacturing detectors along third party designs.

- Such engagement allows us to equilibrate occupancy of personnel more efficiently

- If desired, we may add our readout electronics and system competence.

CDT Business Resources

- Equity capital:
  currently ~ (200 + 100) TEuro
- Current human resources:
  12 FTE with additional ext. engineering capacities.
- Company premises: 840 m^2
  lab-, production- and office space,
  additional new clean-room in preparation (20 m x 8 m)
- High throughput, large area $^{10}B_4C$ coating facility at hand (~ 3,5 m^2/day) (in cooperation with S-DH and recently Movatec), metallic Boron coating
- More than 5000 pre-ampflifier ASIC-dies (320k r/o channels) on stock to give long-term support to several instruments in parallel.

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The ^{10}B-based Jalousie Neutron Detector

CDT

Our solution for POWTEX (FRM-II) as alternative for ^{3}He-filled PSD counter tubes

POWTEX

Project leader:
Andreas Houben
RWTH Aachen

JARA Jülich Aachen Research Alliance

JÜLICH FORSCHUNGSZENTRUM

JCNS
ZAT, ZEL

RWTH AACHEN

Solid state and
quantum chemistry

Texture analysis

Bundesministerium für Bildung und Forschung

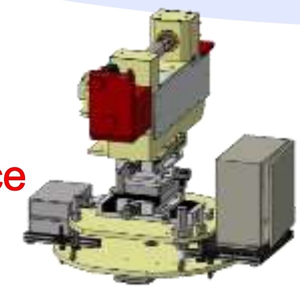
Verbundforschung

High pressure station SAPHiR

Jens Walter
Christian Randau

GZG Geowissenschaftliches Zentrum Göttingen

Geo-Science
University
Göttingen



Nico Walte

UNIVERSITÄT BAYREUTH

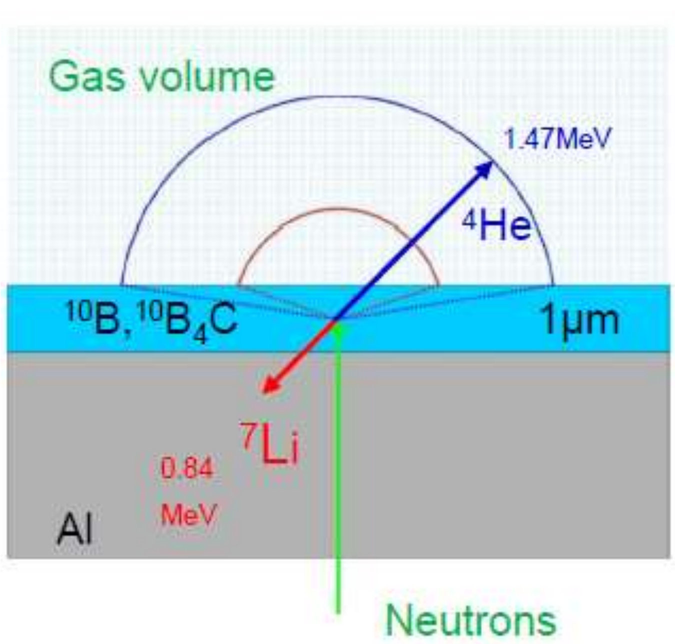
H. Conrad, Th. Brückel, W. Schäfer, J. Voigt, *J. Appl. Cryst*. **41**., 836 (2008).
A. Houben, W. Schweika, Th. Brückel, R. Dronskowski, *Nucl. Instr. and Meth. A* **680**, 124 (2012).

CDT GmbH contracted by RWTH Aachen for concept, design and realization at FRM II, cooperation with FZJ/JCNS through JARA

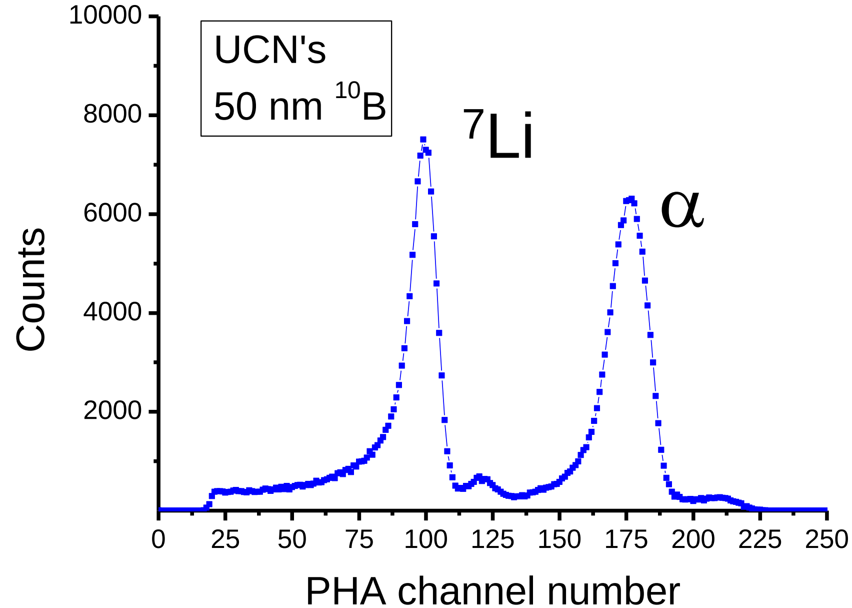
Neutron detection with ^{10}B converters

$$^{10}B + n \rightarrow {}^{7}Li\ (1.02\ MeV) + \alpha\ (1.78\ MeV) \qquad (\ \ 6\%)$$
$$\rightarrow {}^{7}Li\ (0.84 MeV) + \alpha\ (1.47\ MeV) + \gamma\ (0.48\ MeV) \qquad (94\%)$$
$$3838\ b\ (1.8\ A)$$

- ^{10}B and $^{10}B_4C$ are stable, inert (compared to BF_3) and non hygroscopic (as e.g. Li, BF_3)
- > 96% enriched ^{10}B available (large industrial demands for ^{11}B)
- large charge-signal inside detector
- Ranges of α (3.14 µm) and ^{7}Li (1.53 µm) limit single layer detection efficiency to ~ 5% for thermal neutrons at vertical incidence

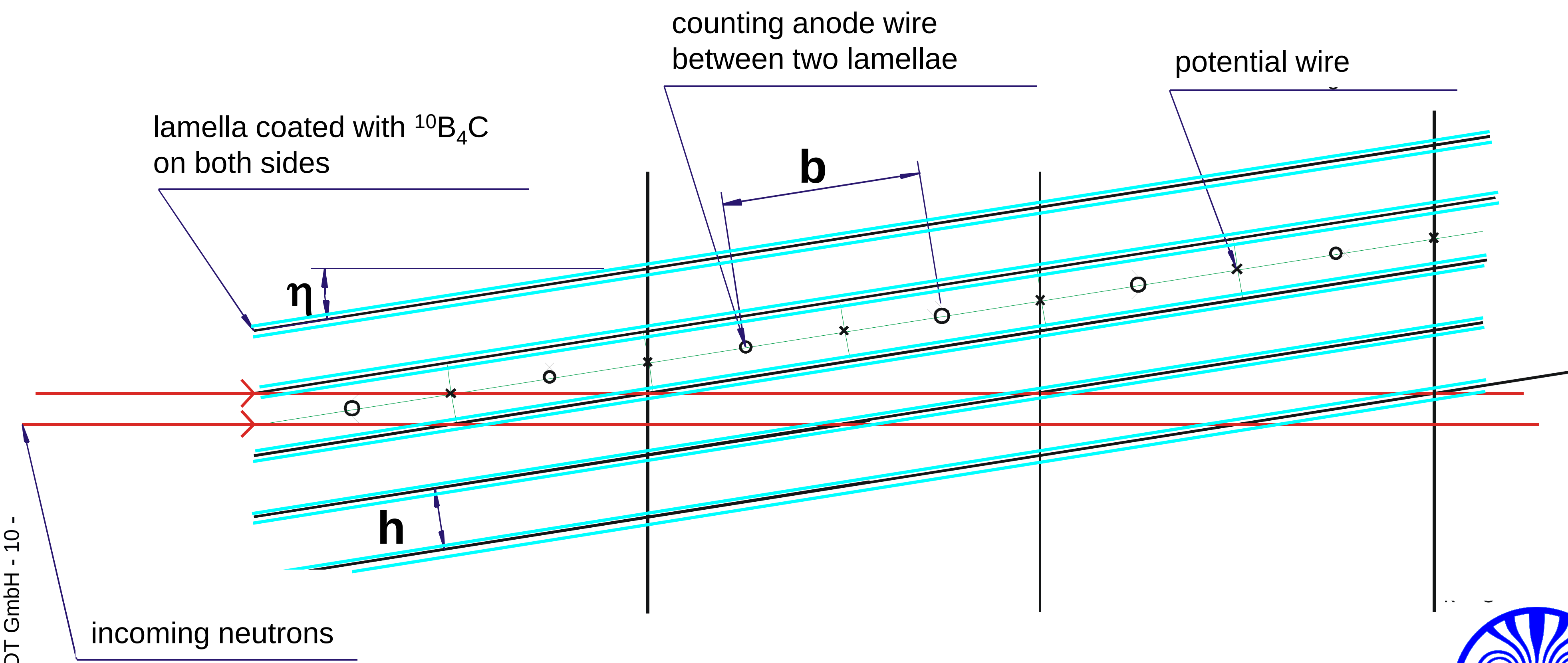


picture from K. Zeitelhack, FRM 2



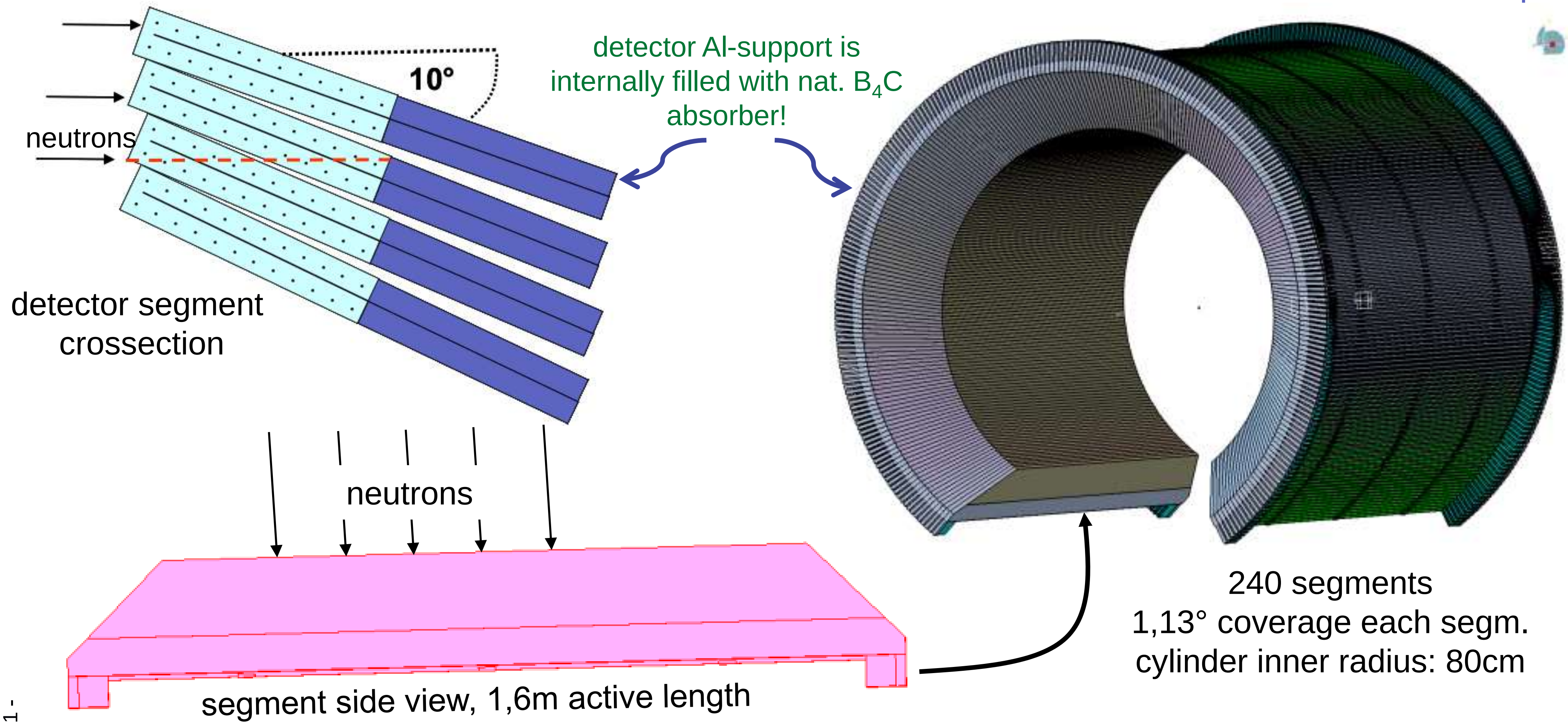
Jalousie: Detector Concept – neutrons at scraping incidence

^{10}B-coated lamellae inclined to incoming neutron intensity at an angle of η = 10°



realized depth: 8 Boron/B_4C layers

Jalousie: Modular and Segmented for POWTEX Cylinder



All-active detector entrance area, no blind areas !

And: Detector barrel acts as a tight neutron shield !

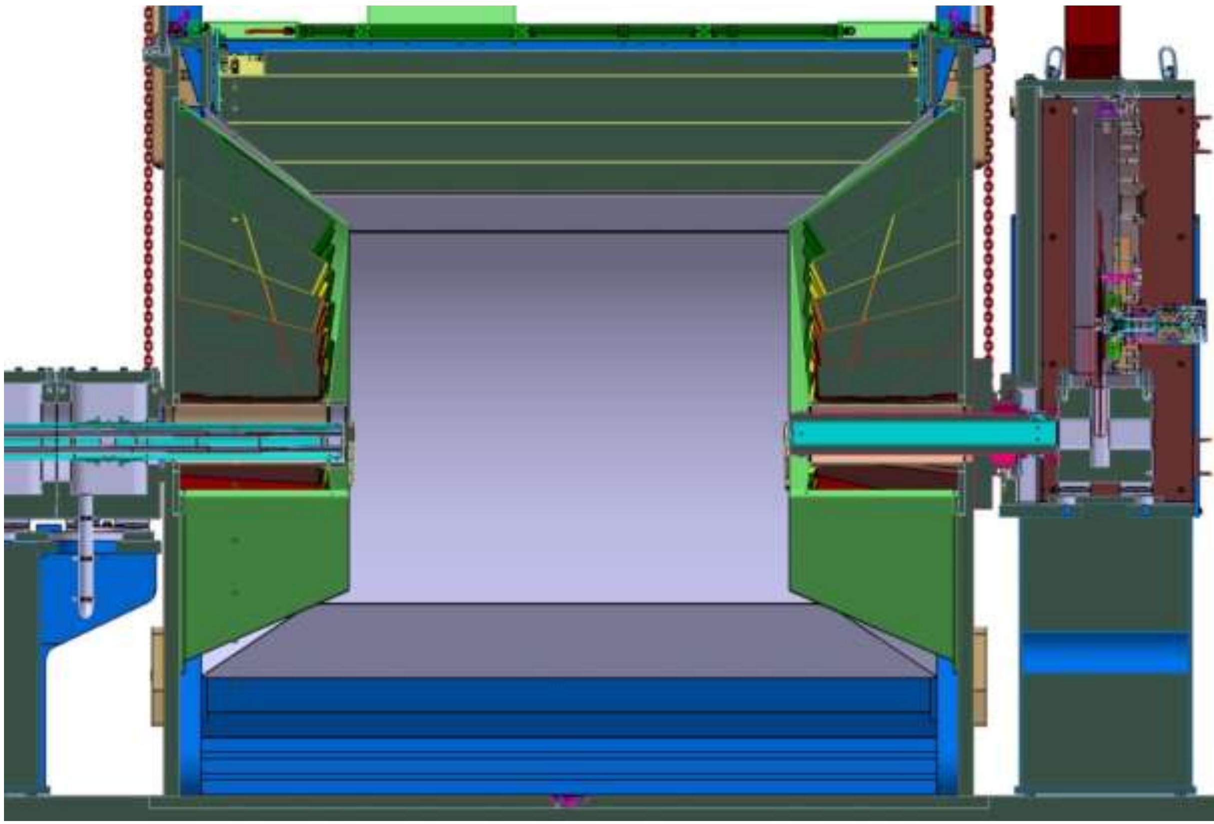
POWTEX Instrument, Towards 4π-Coverage

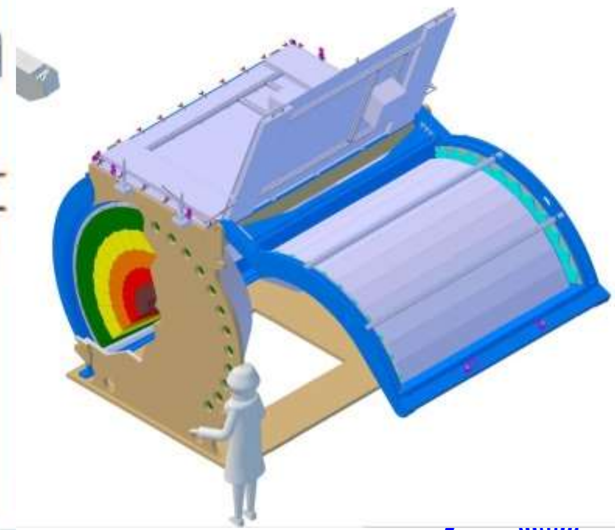
- Cylinder jacket coverage 274°, 240 segments
- Two end-caps, φ-coverage 276° each
- No coverage on bottom → sample instrumentation
- 2 Mio. active Voxels, 60.000 analog ASIC r/o channels

POWTEX

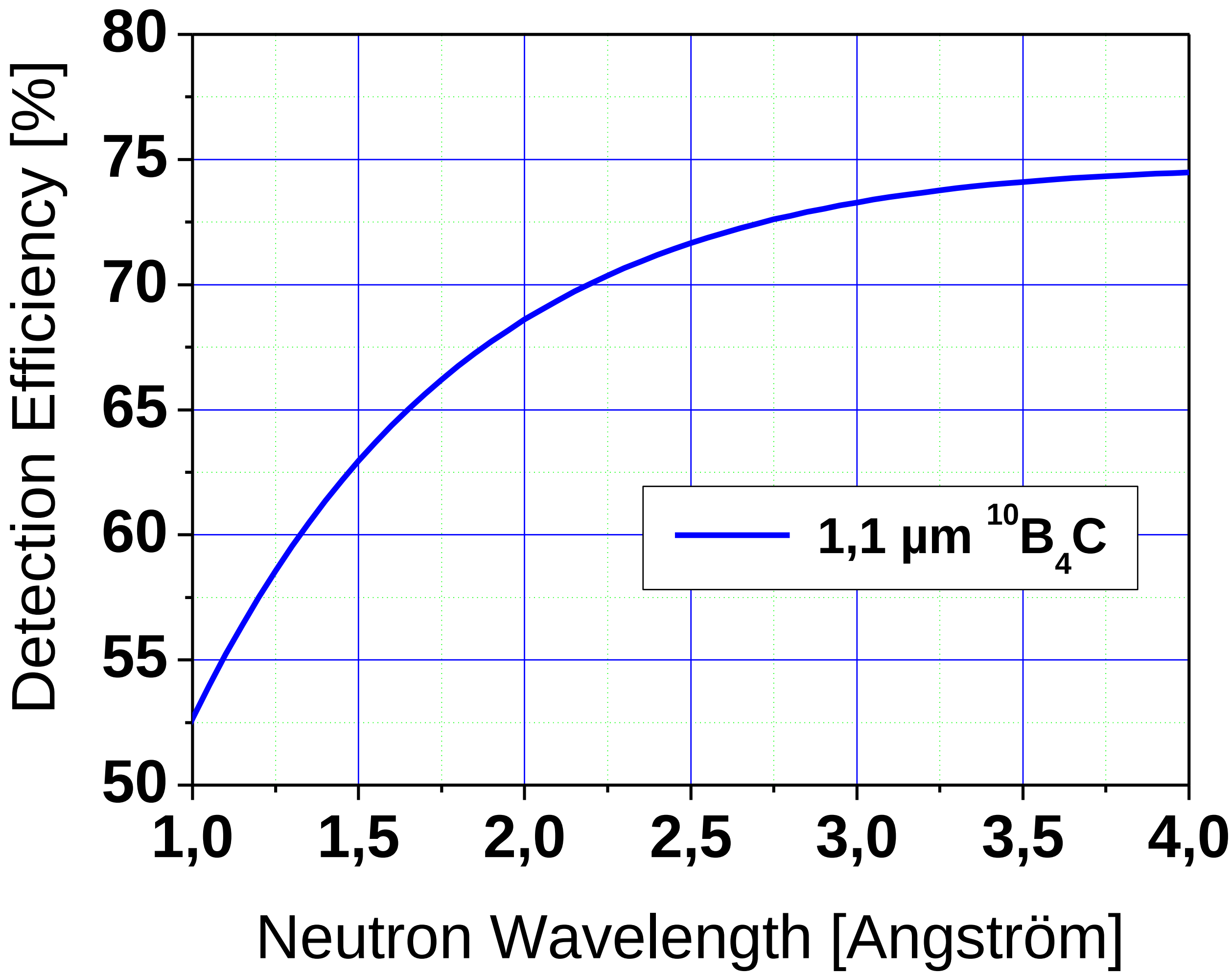
9 sqm detector area

overall blind area < 5,8%





Projected Detection Efficiency



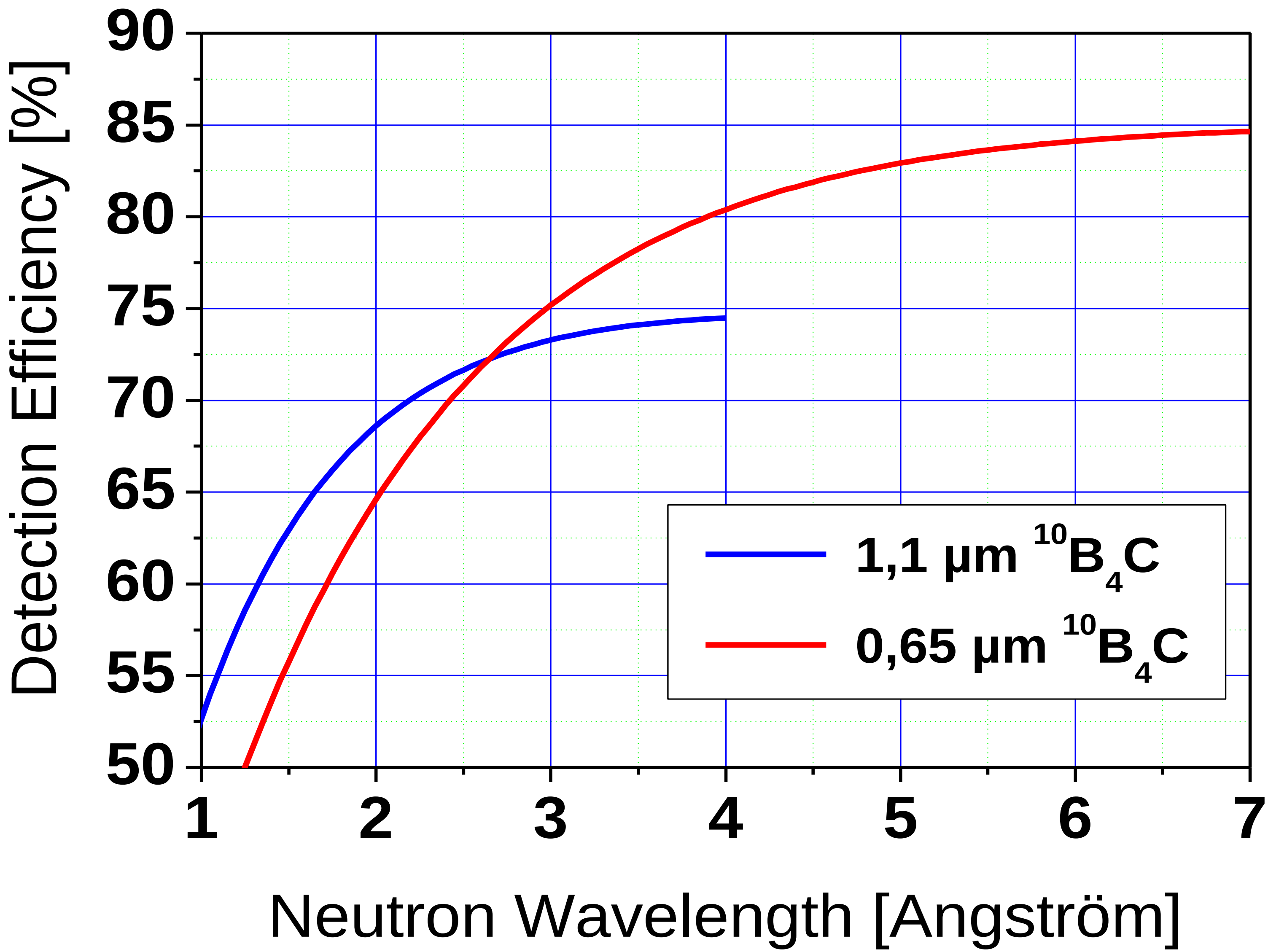
Efficiency as function of wavelength:

- inclination 10°
- 8 $^{10}B_4C$ layers

"The ^{10}B based Jalousie neutron detector – An alternative for ^{3}He filled position sensitive counter tubes", M. Henske et. al., Nucl. Instr. and Meth. A 686 (2012) 151–155.

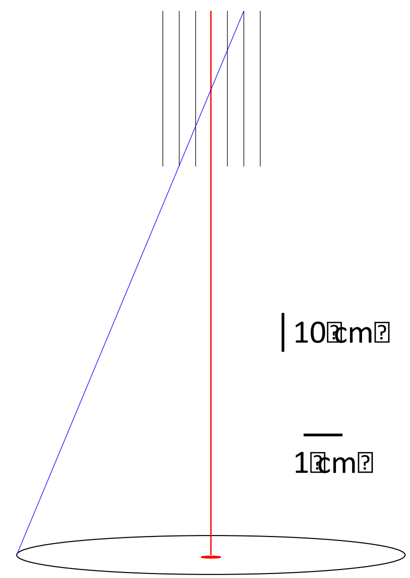
"Absolute efficiency measurements with the ^{10}B based Jalousie detector", G. Modzel et. al., Nucl. Instr. and Meth. A 743 (2014) 90–95.

Efficiency may be optimized for the application



From Area- to Volume-Sensitivity

- POWTEX → Volume detector with VOXELs
  - born to cumulate detection efficiency → competitive to ^{3}He
  - enhancement in rate capability even with wire-chamber tech.
  - operation at ambient pressure → close to complete coverage, no pressure tanks
  - enhancement in point density → in depth, voxels not aligned!
  - advanced options in background analysis
    → e.g. stray reflected rays
    → ***intrinsic collimation***



picture from W. Schweika, FZJ

Realization of POWTEX-Jalousie at FRM II

- **Jalousie was elaborated in two prototyping iterations.**

module pair
at HEIDI
(FRM II)

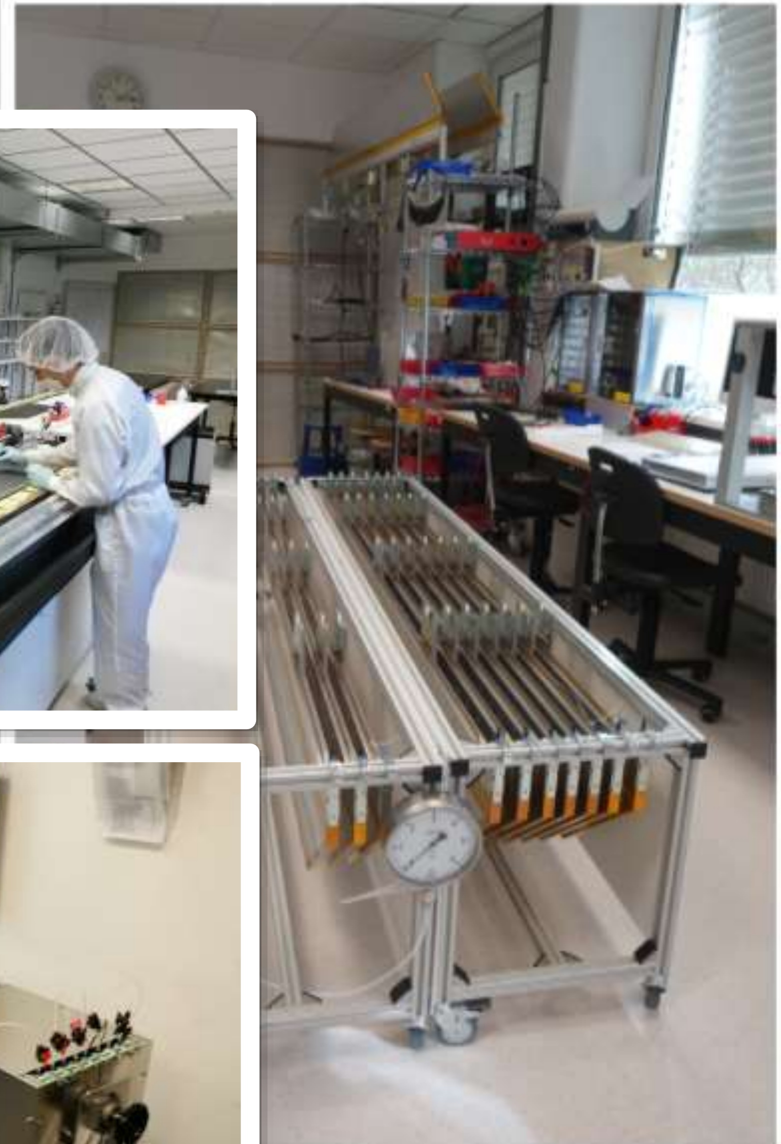
- **Third iteration: Production pre-series (12 segments).**
- **Serial Production ongoing:**
  - **240 cylinder segments assembled 100%**
  - **71% coating done (~500 m^2).**
  - **all electronics manufactured.**
  - **3 to 4 segments per week.**

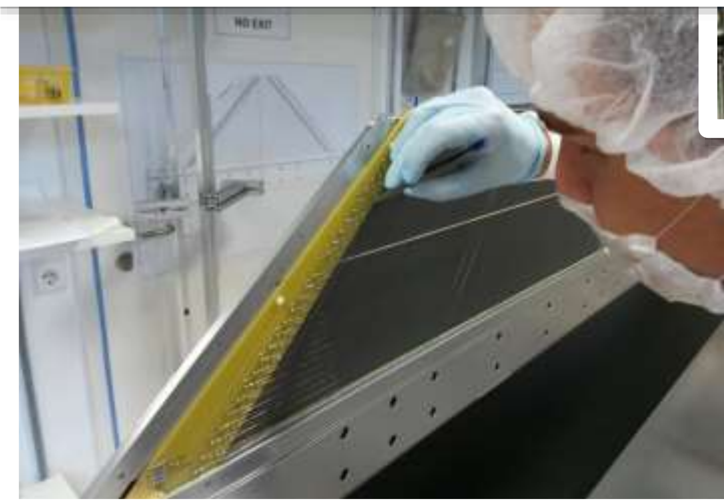
storage shelf

detector tests

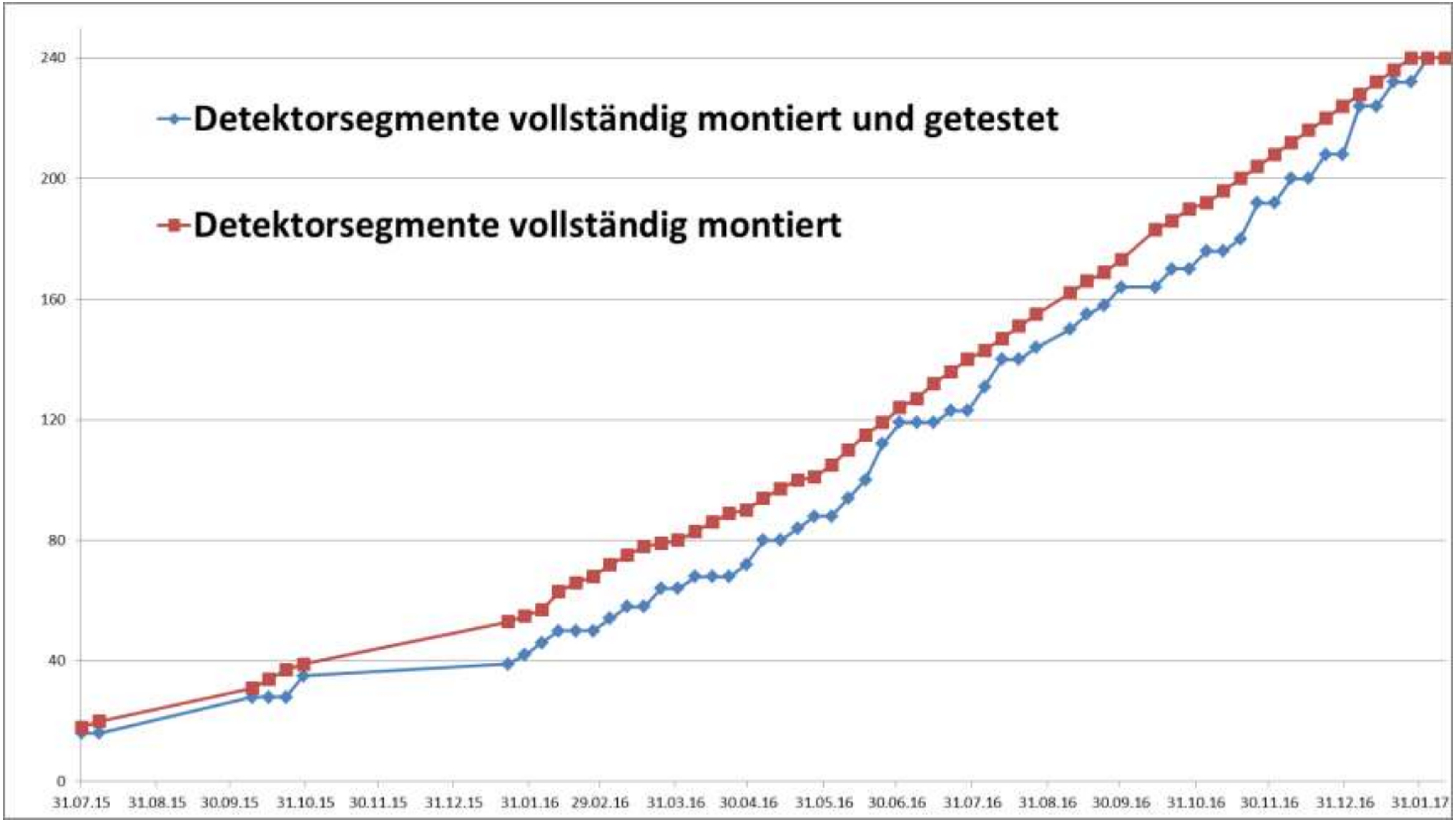
Detector Segments in Production at CDT GmbH

current capacity:
4 segments per week





Cylinder Segment History of Production

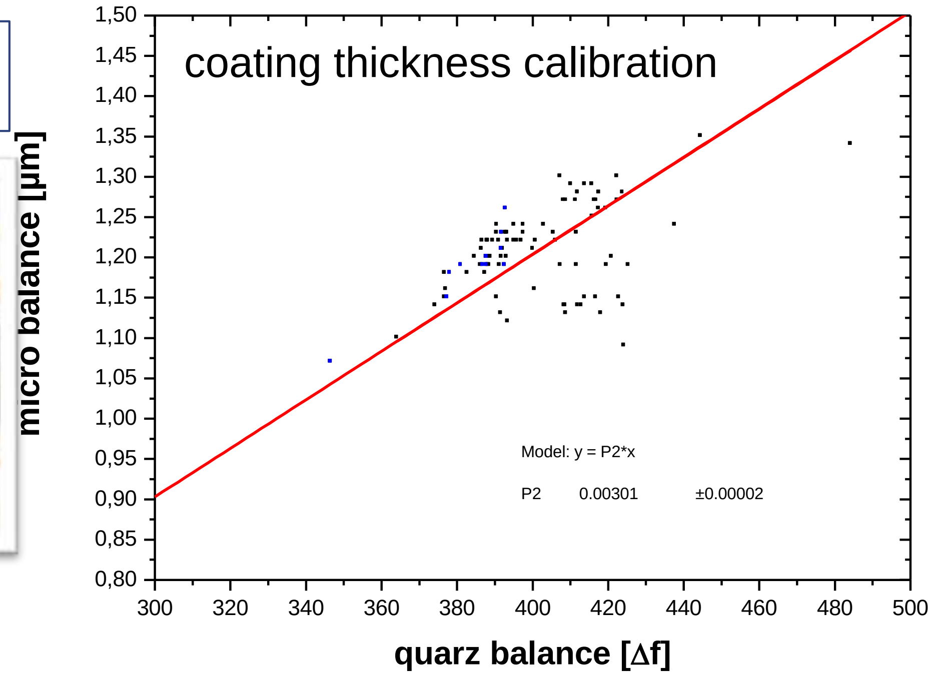


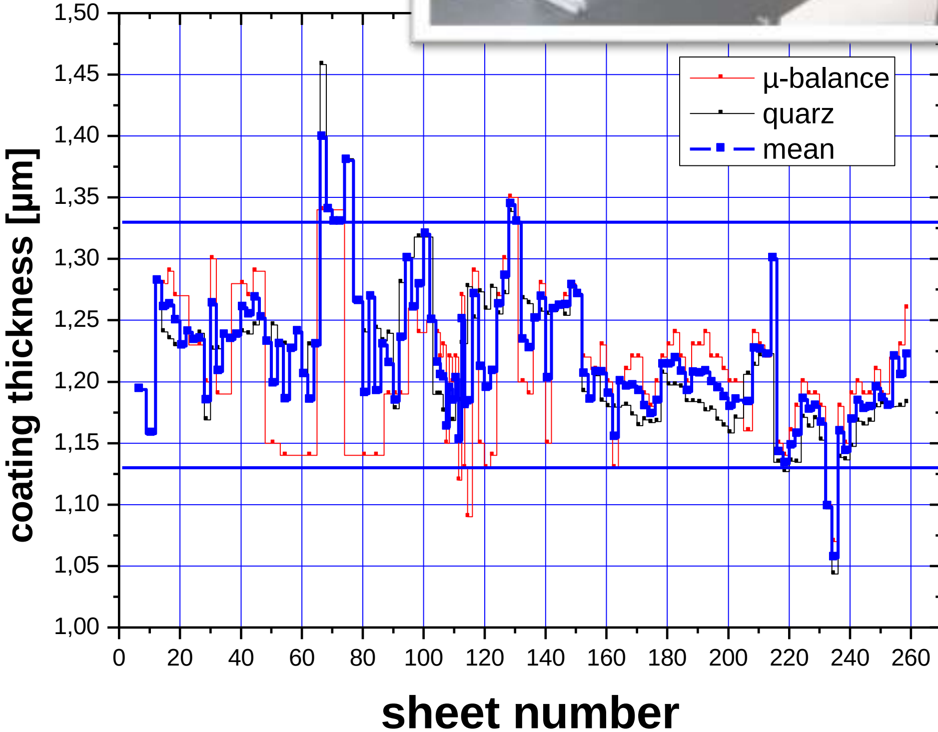
consolidated rate of assembly: 3,8 segments/week

$^{10}B_4C$ Coating for POWTEX

500 m² coated ~ 71% of total area (700 m²)

cathodes coated by
Fraunhofer Institut IST



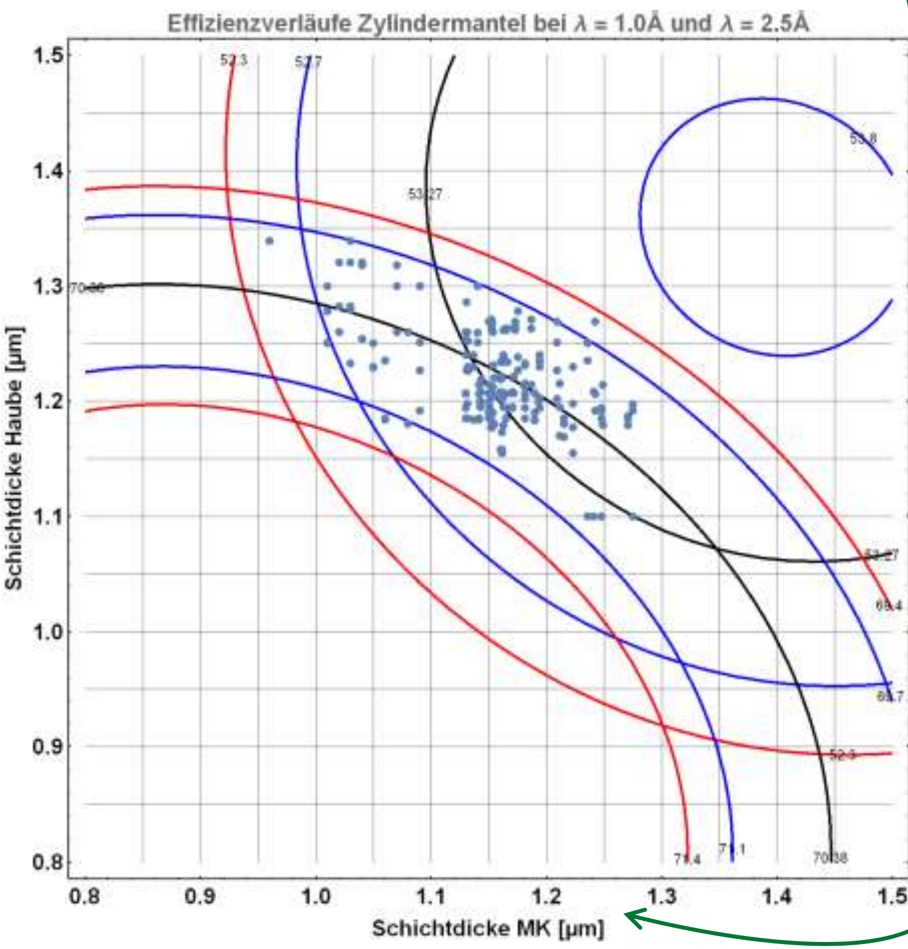


Coating at S-DH
our neighbor and expert in
neutron guides

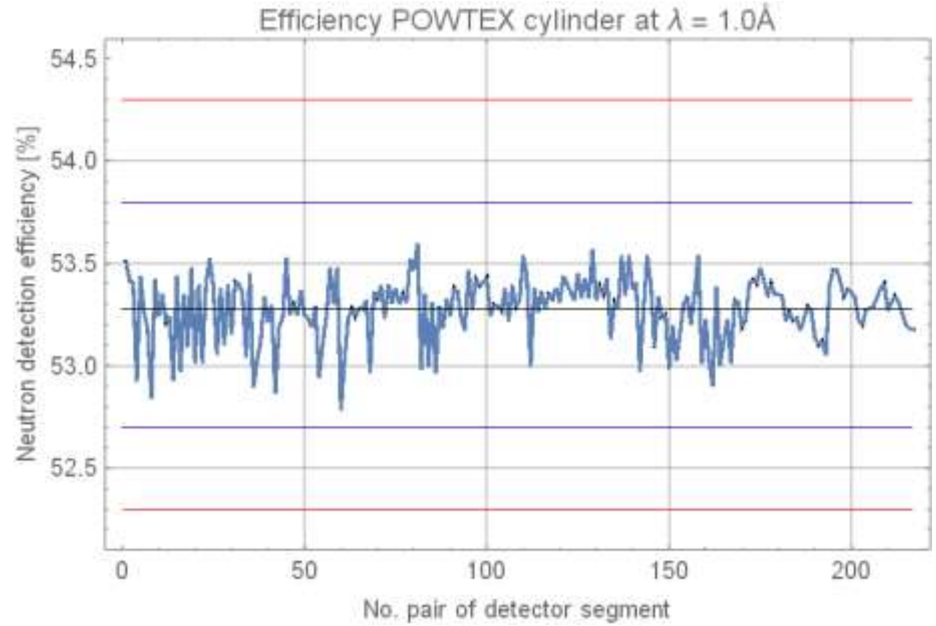
$^{10}B_4C$ Coating for POWTEX

Figure of merrit „homogenous detection efficiency“

1. Realized through matching the boron layer thickness of the different cathode layers per detector segment.



2. Realized through matching detection efficiencies of different detector segments within the barrel sequence.

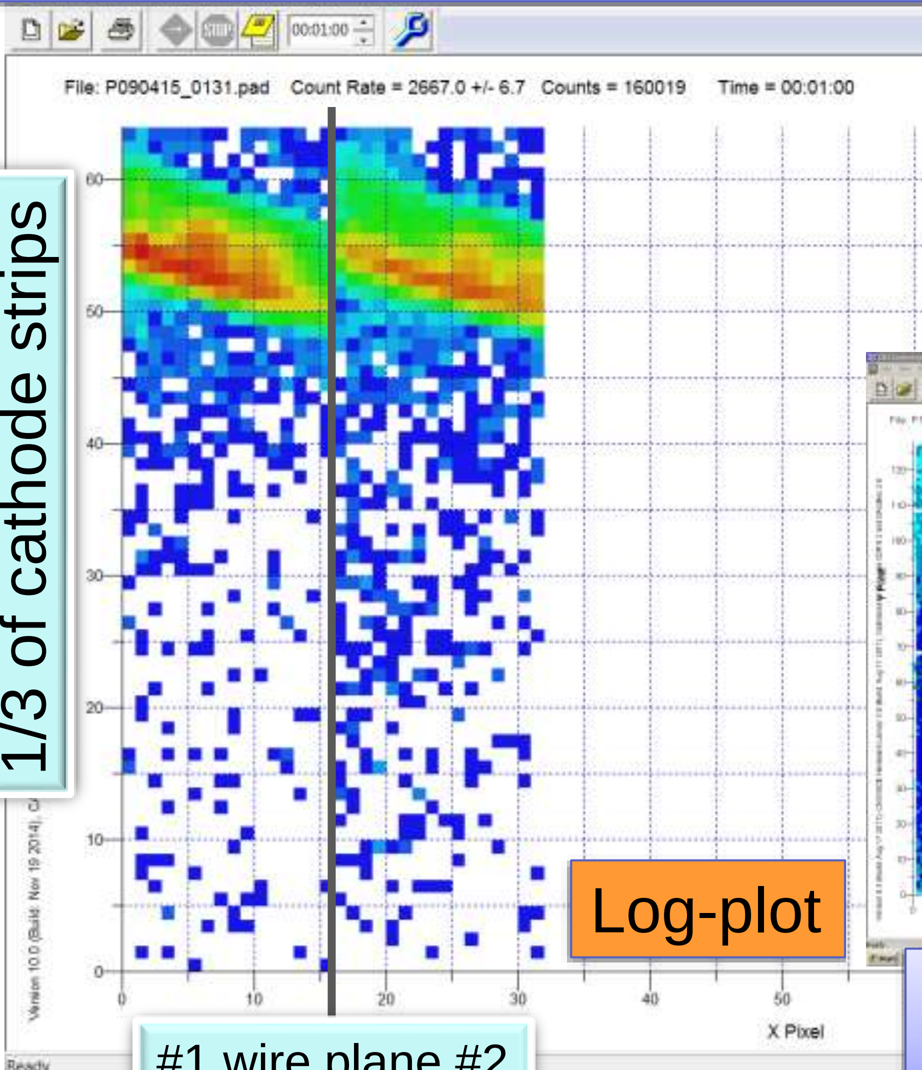


+/- 1% variation from mean

+/- 1% absolute variation (POWTEX)

Measurements at Triga Reactor Mainz

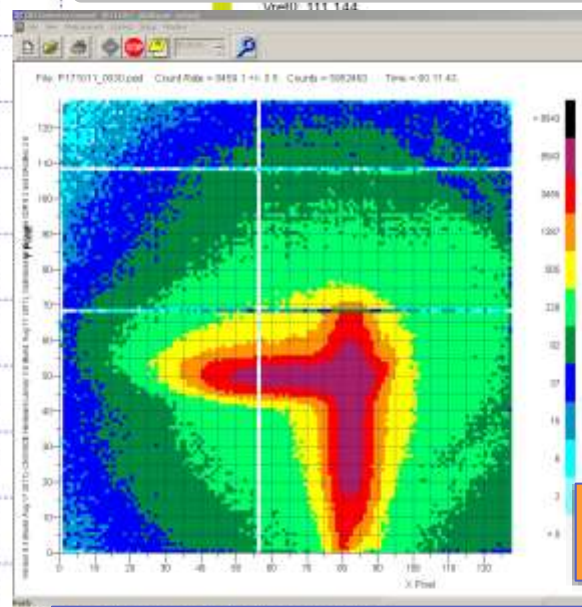
Slit-collimated Beam onto Jalousie segment at 10°
(both wire planes shown side by side)



1/3 of cathode strips

#1 wire plane #2

Log-plot



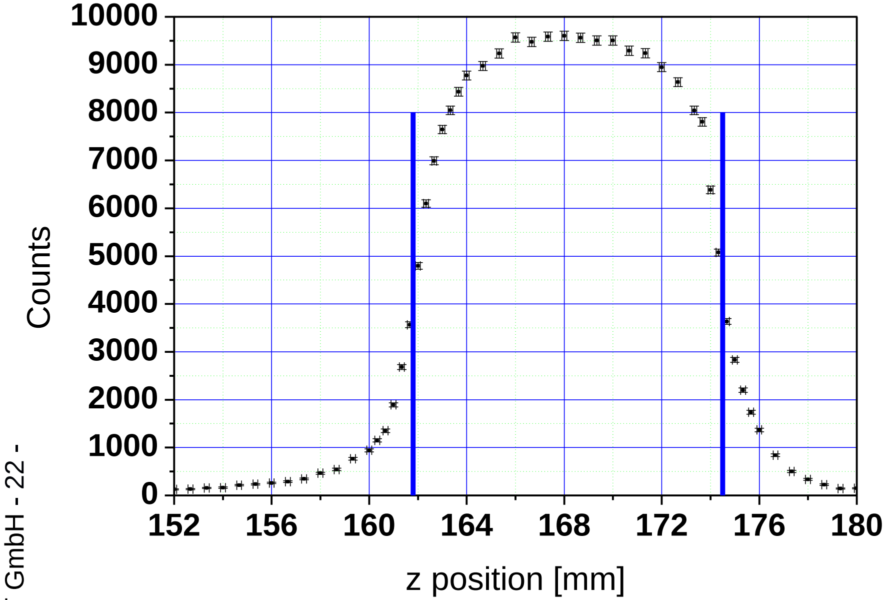
Log-plot

Uncollimated beam profile measured with CASCADE 2D-200

Measurements at Triga Reactor Mainz, Prototype II

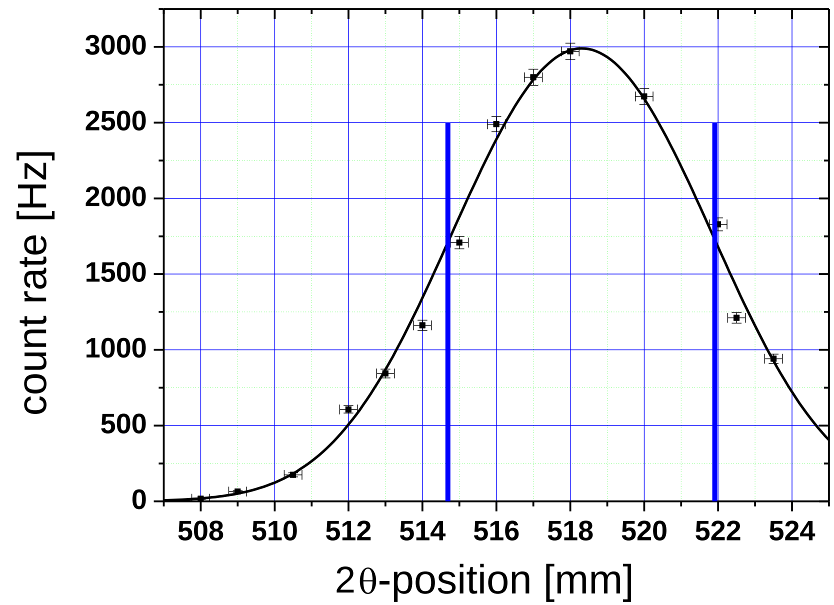
collimated beam:
width 0,5mm in detector

Resolution scan across anode wires



provides TOF-resolution: $\Delta\tau$ = 2,7-6,9 µs
FWHM for 1.0-2.5 Å wavelength

Resolution scan across cathode strips



measured resolution: $\Delta 2\theta$ = 0,38° FWHM

Delivery in Mounting Units of 8 Segments

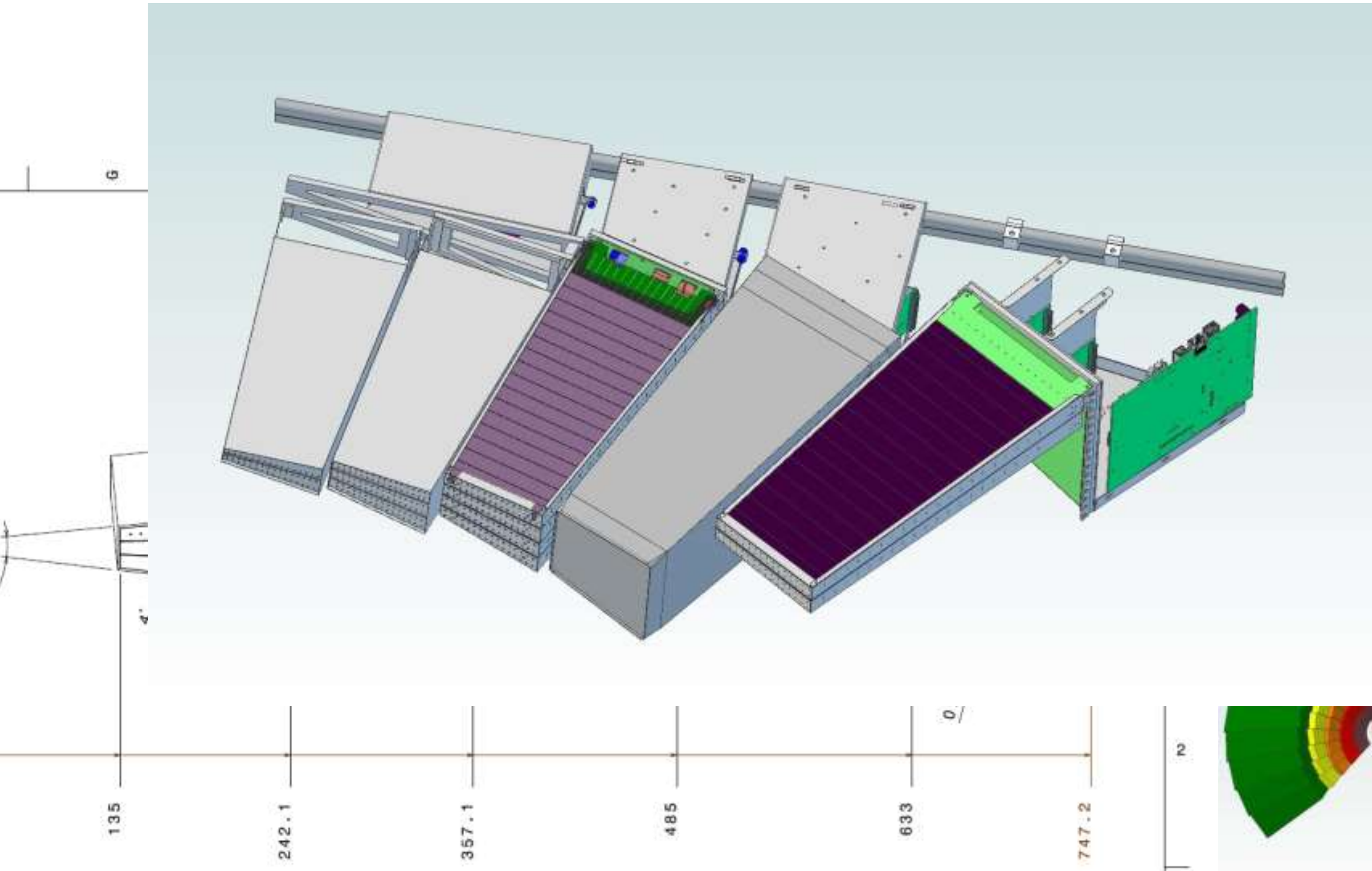
Jalousie Specifications to meet POWTEX Needs

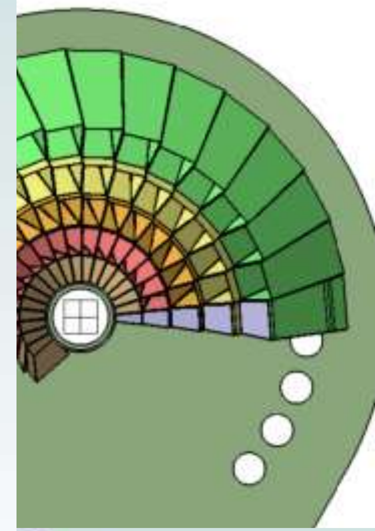
Parameter	Design	Value
Accumulated detection efficiency	■ 8 boron layers ■ inclined at 10°	**> 52% (1.0 Å)** **> 65% (1.8 Å)** **> 72% (2.5 Å)**
spatial resolution (2D) (at ambient counting gas pressure) 3D in depth → TOF	■ width of cathode readout strip $\Delta 2\theta = 0{,}469°$ ~ 6 mm ■ lamellae height h = 7,9 mm at window corresp. to $\Delta\varphi = 0{,}566°$	**resolution in 2θ:** **0,38° (FWHM)** **resolution in φ:** **0,665° (FWHM)**
TOF resolution	Anode spacing b = 15,6 mm	**2,7 – 6,9 µs (FWHM)**
Count rate per segment	limited by coincident read-out of cathode and anode	**1 MHz @ 10% dead time**
Count rate per readout ch	limited by ASIC shaping time constant	**333 kHz @ 10% dead time**

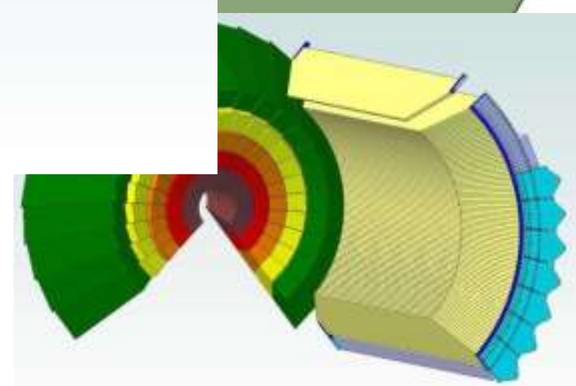
- **Very low γ-background:** Low-Z converter material ^{10}B, alpha versus e-ionization density
- **Long term stability** due to continuous purge of cheap counting gas through detector.

POWTEX End-Cap, anode-wires oriented to sample

- End-cap engineering design and prototyping ongoing
  - 12°-Segment sub-structured in 5 submodules

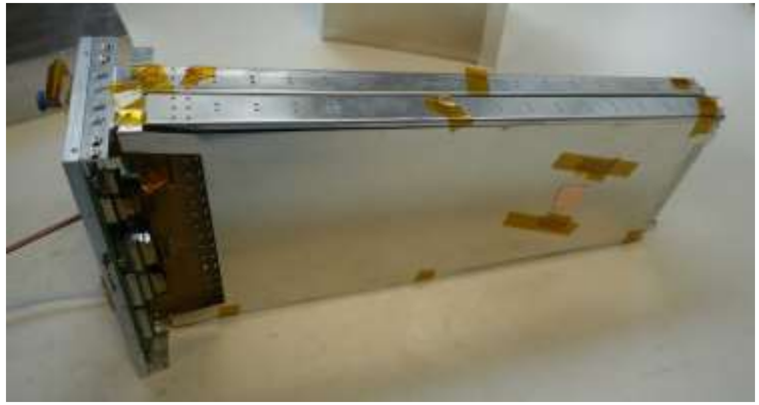




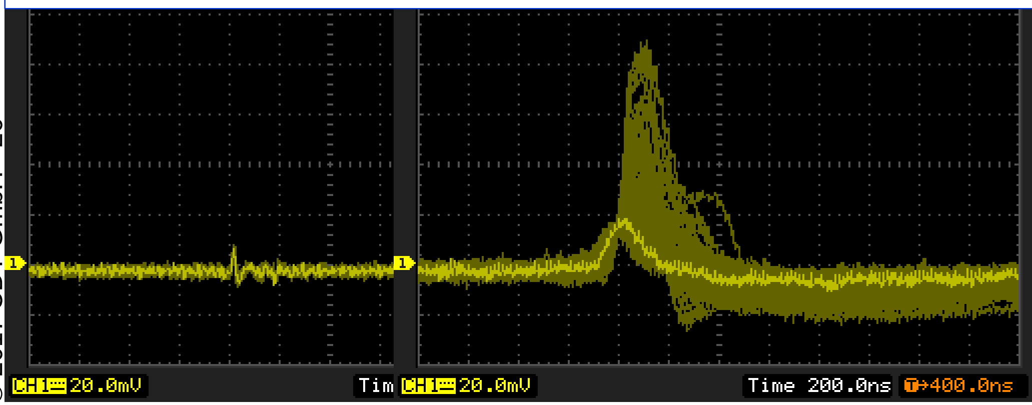


POWTEX Endcap Prototype

- First prototype of SUMO3 (not yet coated) has passed all tests successfully.
- Second prototype of SUMO3 is under construction: now also coated with $^{10}B_4C$.
- Test at TRIGA Reaktor Mainz soon.
- Production pre-series (four 12°-segments) sheduled for Q2/2017
- Serial production from Q3/2017 (additional 42 segments)
- **POWTEX project finalization mid 2018.**



Analoge signales at oszi (800V operating voltage):
Sr (Beta-Emitter) Am (Alpha-Emitter)



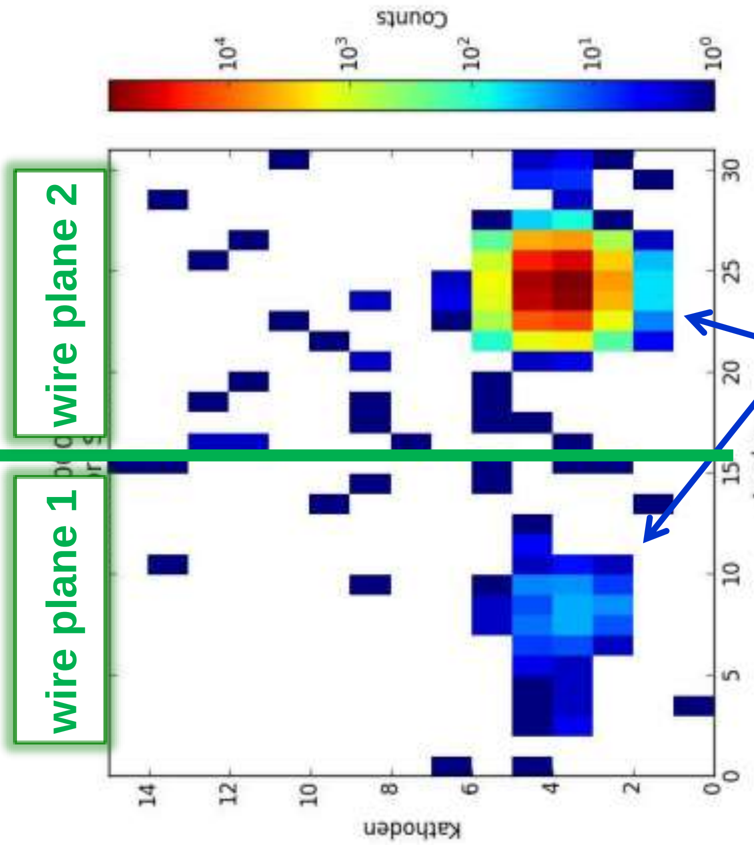


Image Am-source

Electronic Signal-Readout and DAQ

- 60.000 individual channels with CIPix-1.1 readout ASIC

- Position and event reconstruction via coincidence identification in local, module based FPGA, 2 Mio. volume elements (VOXELs)
- Data readout through daisy-chained GBit optical link (Struck SIS1104)
  - One GBit optical link transmits 12,8 Mio. **event mode data** elements per second (64 Bit per event defined for POWTEX).
  - Data aggregation onto few GBit links
  - Bandwidth focusing through Token Ring

CDRS: 256-channel read-out for POWTEX, 2D-200 or 2D-300 GEM detector

- Spartan-6 FPGA, future: Ultrascale
- opt. Gbit interface
- 4-fold CIPix-ASIC interface
- Clock recovery and synchronisation to global time
- 4ch ADC (60 MHz, 10 bit)
  → pulse height analysis
- DDR-RAM on board
- LVDS interface
- Avago opt. I/O interface
- Digital-IO diagnostic sensor interface
- 48V power distribution ring (galvanically decoupled)

System capability and scalability of CDRS

- Token-Ring readout along the daisy chain
  → distribute bandwidth where it is needed

- Star-shaped clock distribution and backup communications channel

- System precautionary previsions:
  - Twofold access concept for firmware in-system upgrade
  - Guaranteed access even with faulty firmware installed
  - Three-fold clocking means
  - Two-fold controls access

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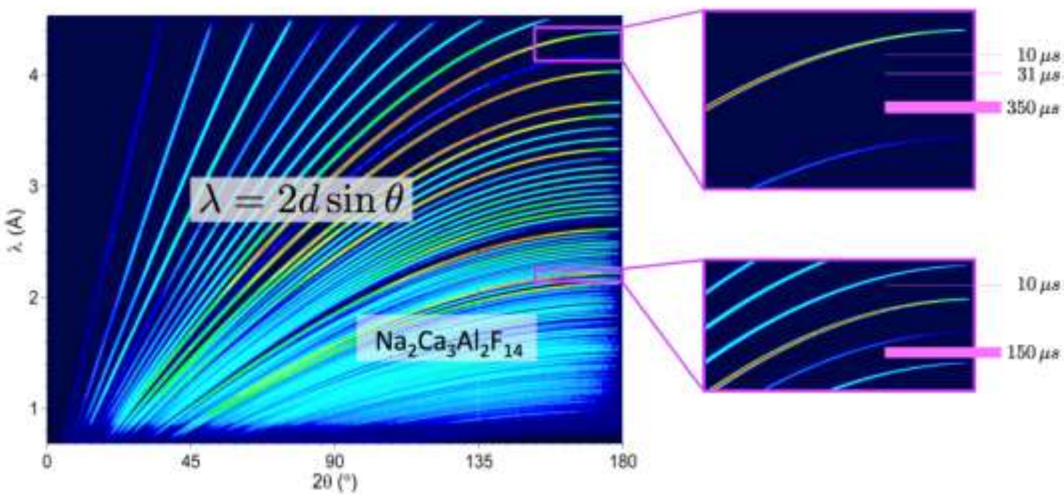
New projects in 2017/2018

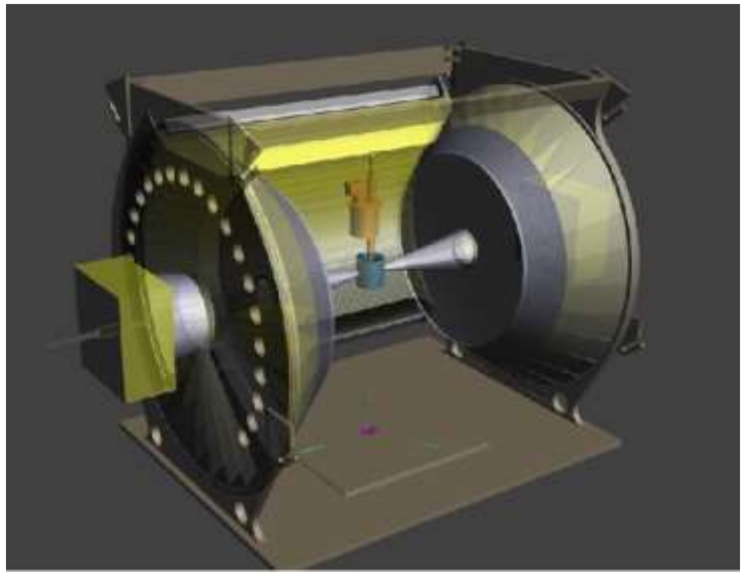
DREAM, …

CDT

The ESS-Instrument DREAM

- Perfect in timing for production-resources availability.
- Engineering, assembly and QA procedures are running smoothly.
- DREAM-like larger coating area needs are feasible.

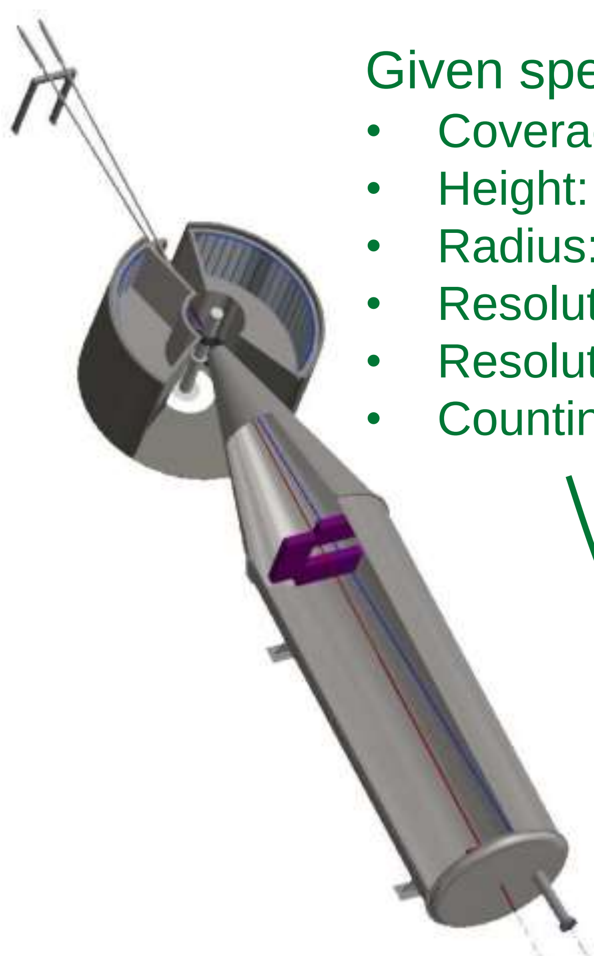




- CDT-team strives to get engaged !
- But production demand staged over many years !

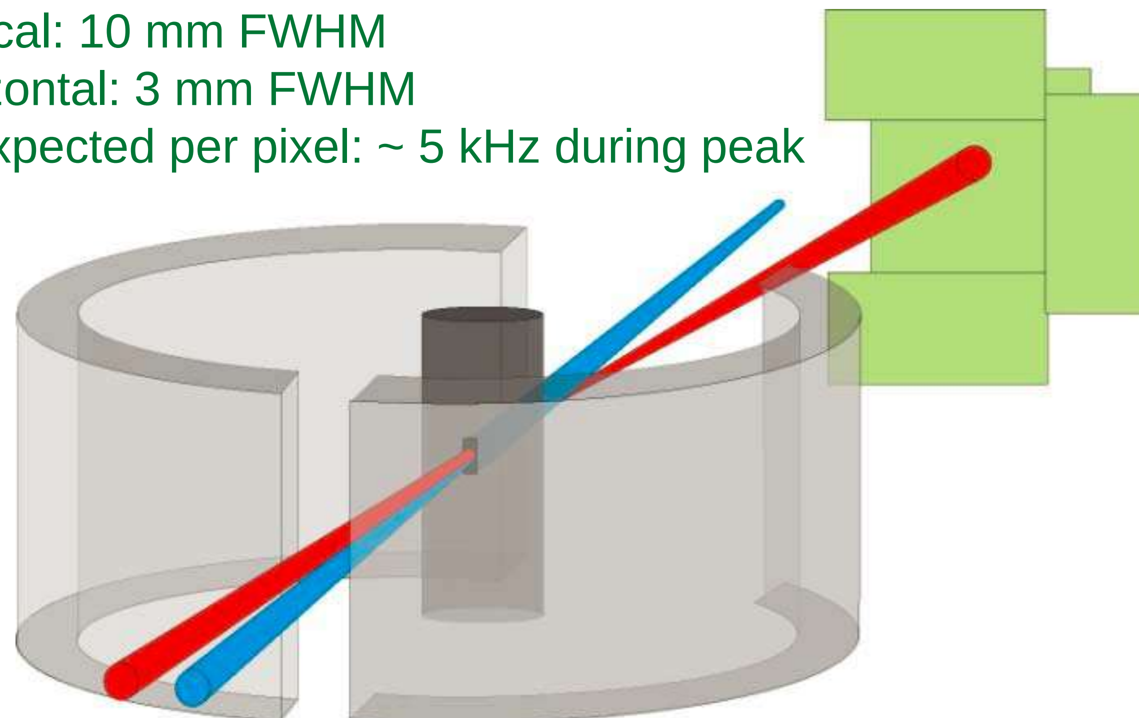
The ESS-Instrument HEIMDAL

HEIMDAL, an instrument, which combines neutron powder diffraction (NPD), small angle neutron scattering (SANS) and neutron imaging (NI) in a single instrumental setup.



Given specs for the NPD detector:

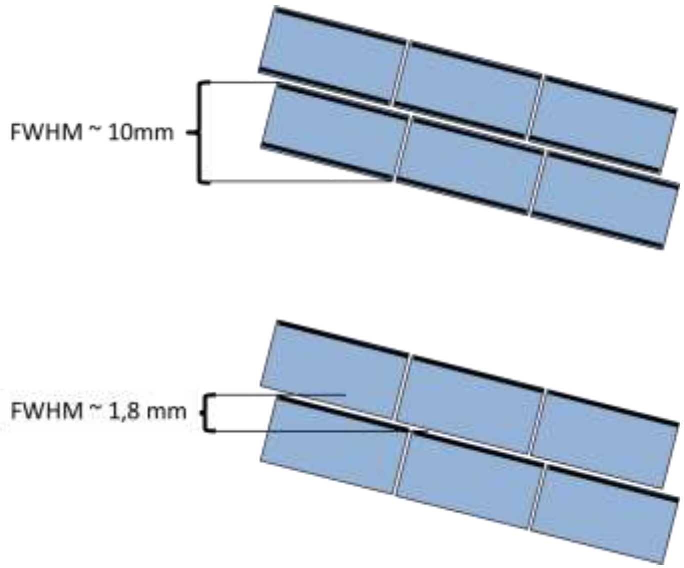
- Coverage: 130° (from 30° to 160° in 2Theta)
- Height: 1000 mm
- Radius: 1500 mm (zylinder axis: vertical)
- Resolution vertical: 10 mm FWHM
- Resolution horizontal: 3 mm FWHM
- Counting rate expected per pixel: ~ 5 kHz during peak

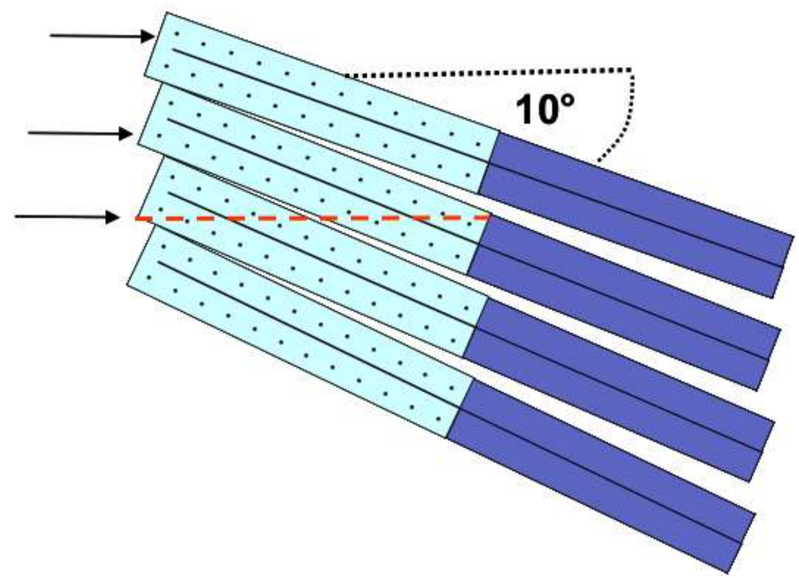


NPD of HEIMDAL can be realized by Jalousie detector segments

NPD: coverage in 2θ: 130° at R = 1500 mm
coverage in phi: +/- 18° ~ +/- 500 mm

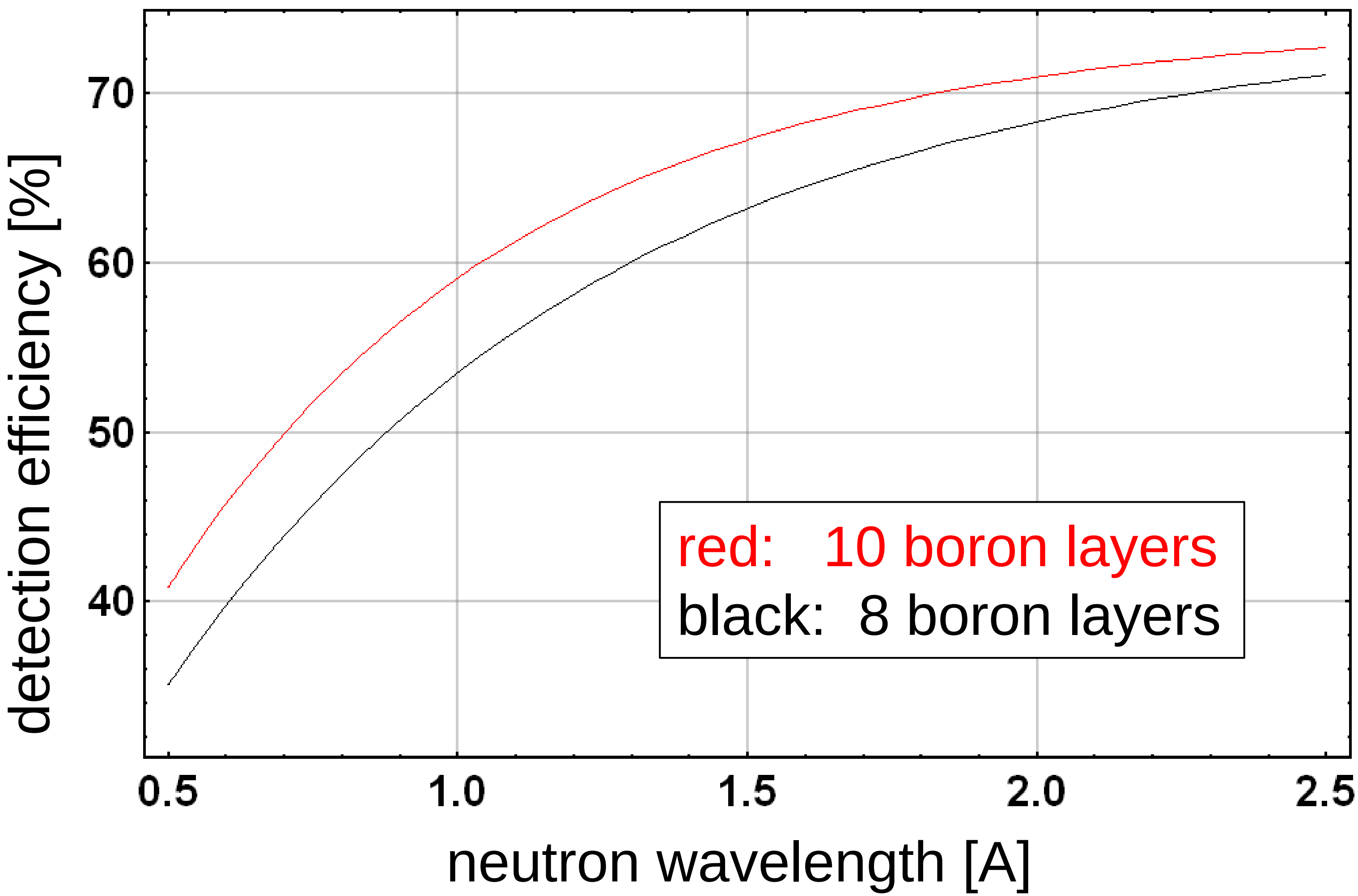
- Enhancement of resolution in 2θ with single sided coating: 1,8 mm FWHM





- 8 to 10 successive converter layers feasible

HEIMDAL NPD detection efficiency



CASCADE 2D-200 and 2D-300

GEM Based Detector

CDT

Christian J. Schmidt
Martin Klein

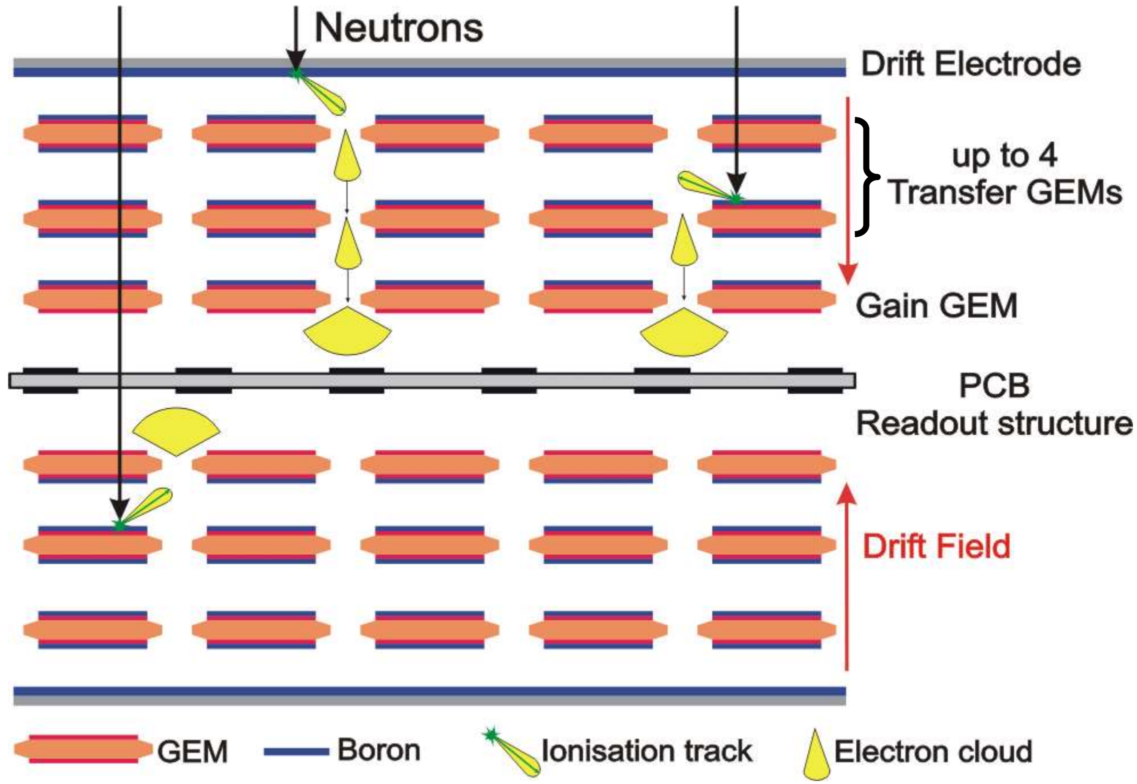
CASCADE: Multiple Boron Layers on GEMs

$^{10}B + n \rightarrow {}^{7}Li + \alpha + 2.79\ MeV$ (6%) 3838 b

$\rightarrow {}^{7}Li^{*} + \alpha + 2.31\ MeV$ (94%)

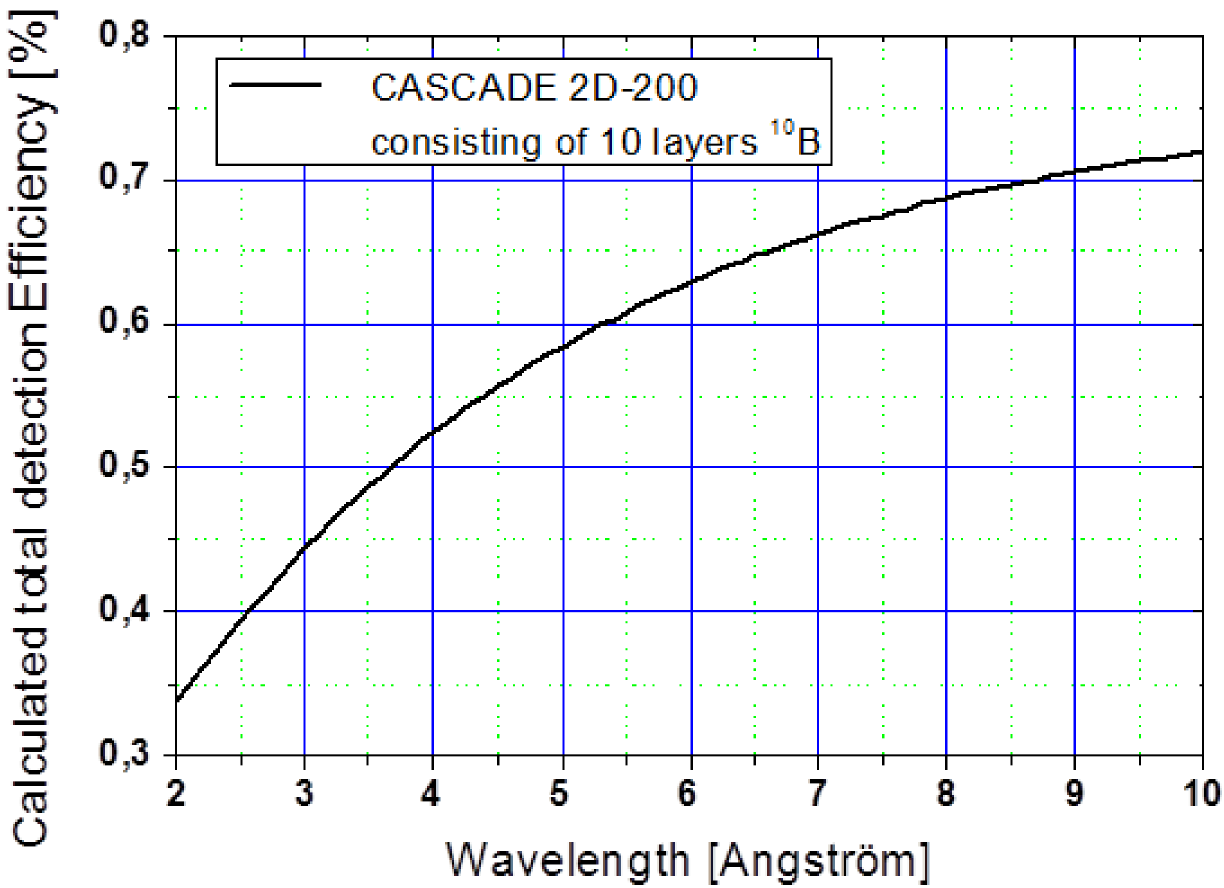
- GEMs can be operated to be transparent for charges!

  → **they can be "cascaded"!**
- Each one can carry two Boron layers.
- Last one operated as amplifier.

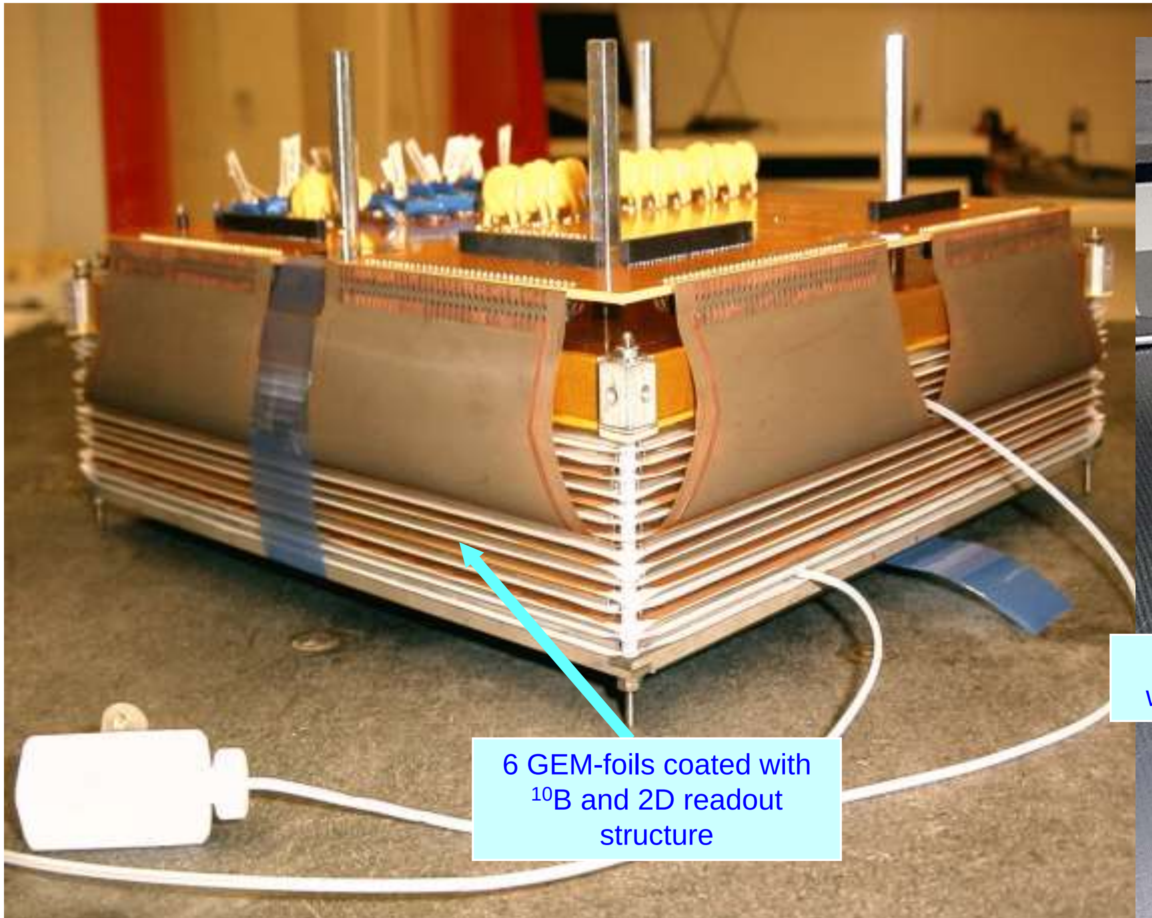


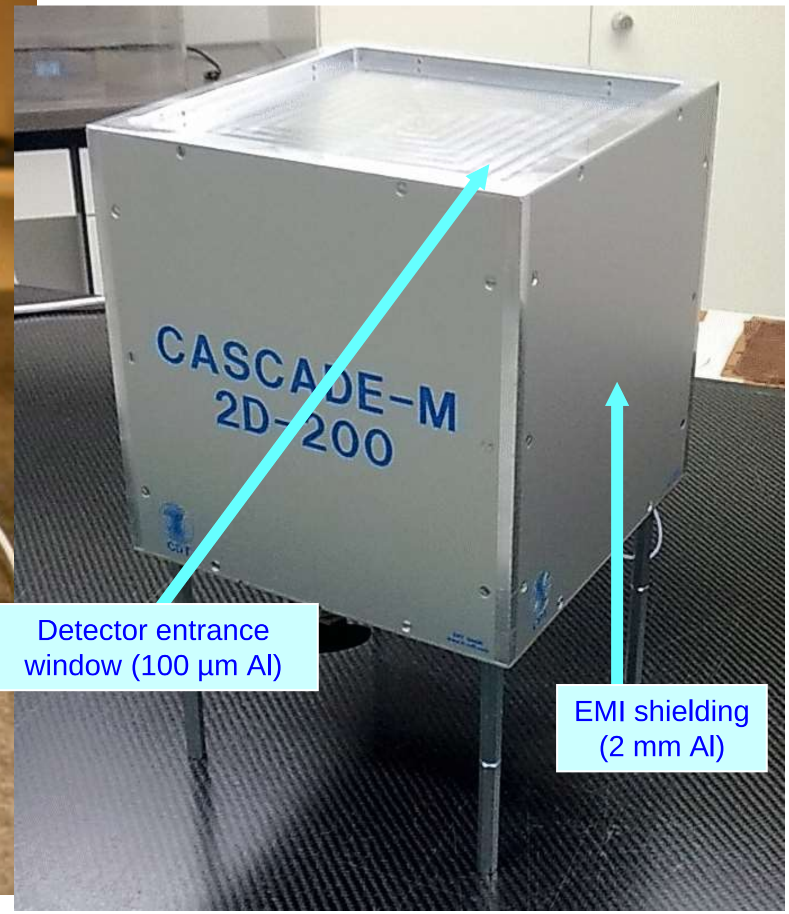
"CASCADE, neutron detectors for highest count rates in combination with ASIC/FPGA based readout electronics", M. Klein, C. J. Schmidt, Nucl. Instr. and Meth. A 628 (2011) 9-18

Typical Detection Efficiency of CASCADE 2D-200



CASCADE-Detector: 200x200 mm^2, 128x128 stripes



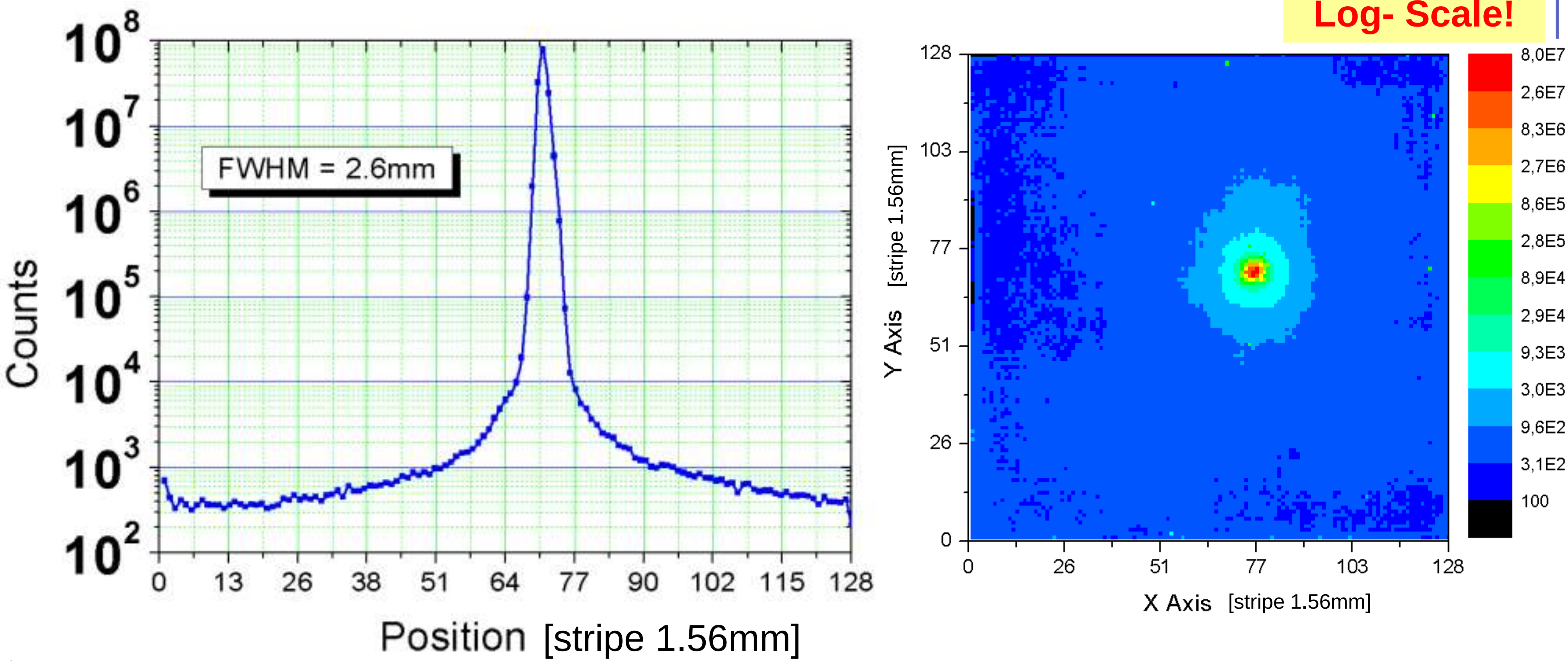


Development towards 300mm x 300mm ongoing

Position Resolution and Contrast with Neutrons

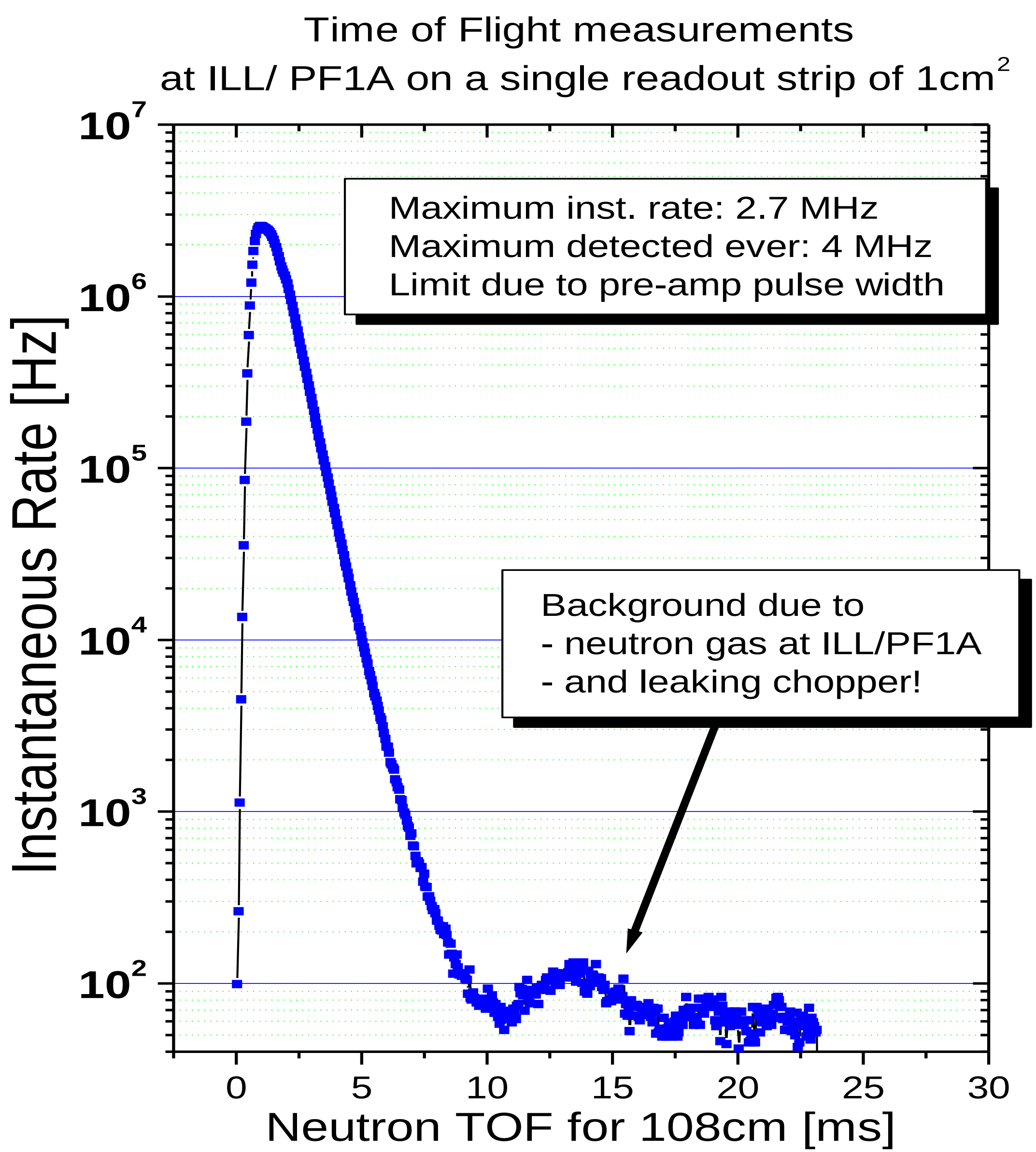
PSF measured using a beam of 0.57mm diameter

Log- Scale!



measured at former instrument EKN at FZ Jülich

TOF Dynamics at PF1A/ILL, 2003



- No saturation up to several MHz/cm^2 neutron conversion rate
- Dynamic range larger than 4 orders of magnitude

Conclusion

- CDT will move from POWTEX to ESS instruments in 2017/18.
- Any project requires a preceding engineering period.
- We are prepared to fully engage in supply of detector systems for ESS
- But we do also engage in contract manufacturing along third party designs.

- CDT maintains a broad portfolio of highly specialized detector systems for thermal neutron detection such as the GEM based detectors CASCADE 2D-200 and 2D-300 and position sensitive beam monitoring solutions.