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The ^{10}B-based Jalousie Neutron Detector

DENIM 2015, Budapest, 8.09.2015

Christian J. Schmidt

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

RWTH AACHEN

JCNS
ZAT, ZEL

Texture analysis

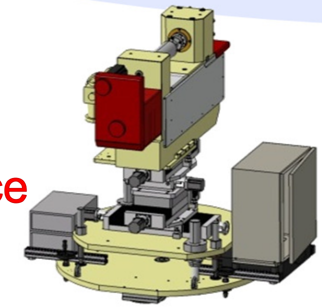
Solid state and quantum chemistry

High pressure station SAPHiR

Jens Walter
Christian Randau

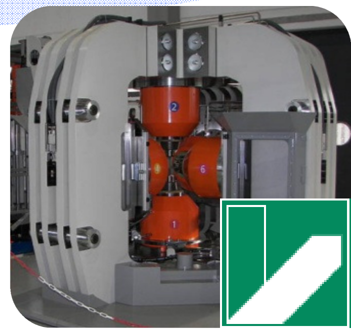
GZG Geowissenschaftliches Zentrum Göttingen

Geo-Science University Göttingen



Bundesministerium für Bildung und Forschung

Verbundforschung



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

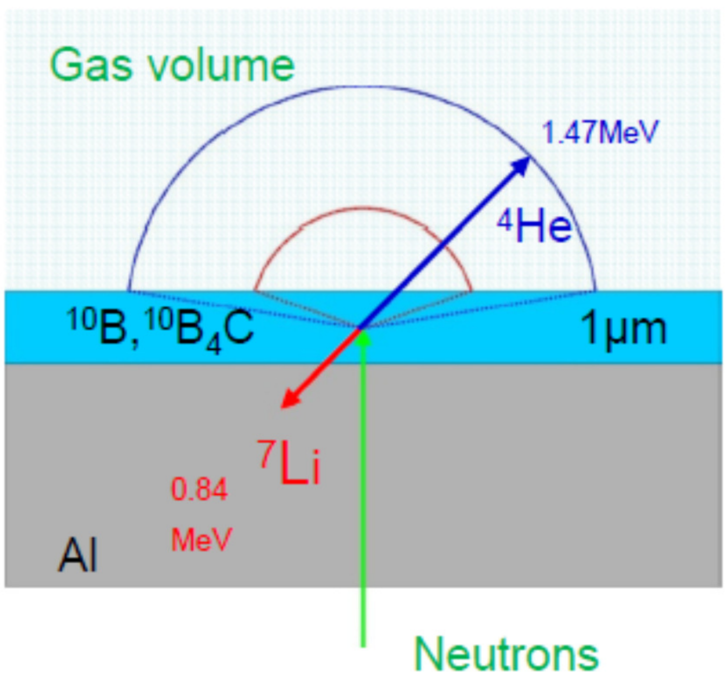
Neutron detection with ^{10}B converters

$^{10}B + n \rightarrow {}^{7}Li\ (1.02\ MeV) + \alpha\ (1.78\ MeV)$ (6%)

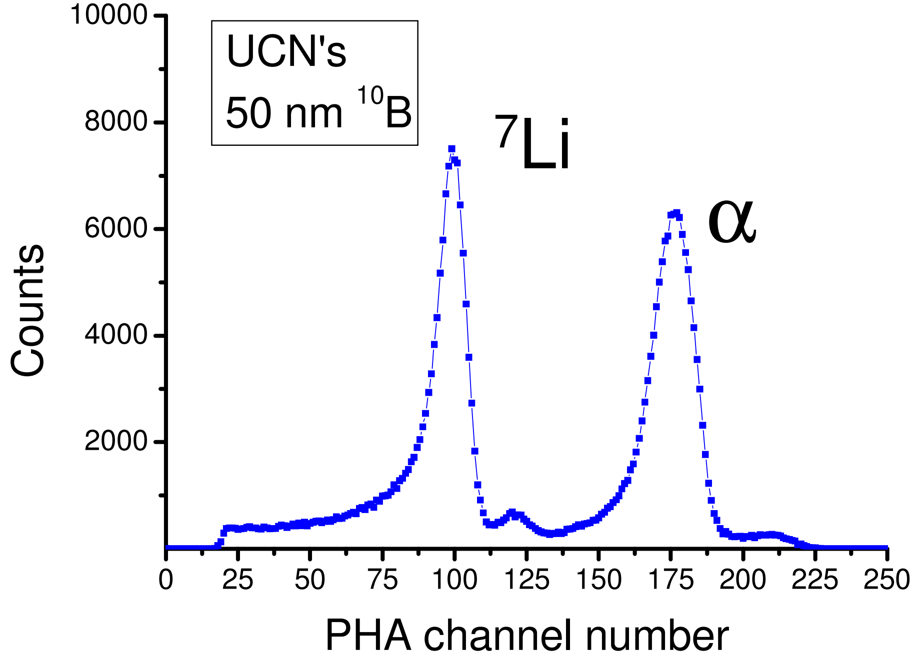
$\rightarrow {}^{7}Li\ (0.84 MeV) + \alpha\ (1.47\ MeV) + \gamma\ (0.48\ MeV)$ (94%)

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 (through 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

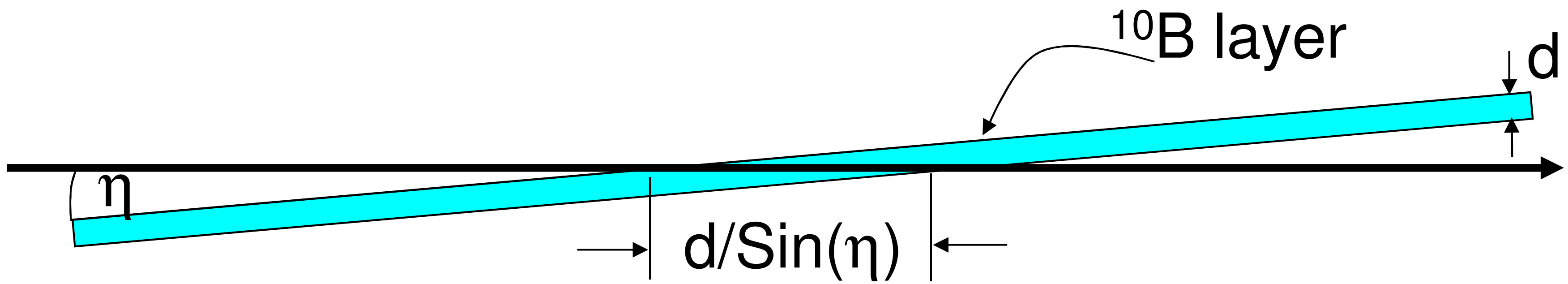


picture from K. Zeitelhack, FRM 2



Jalousie for POWTEX

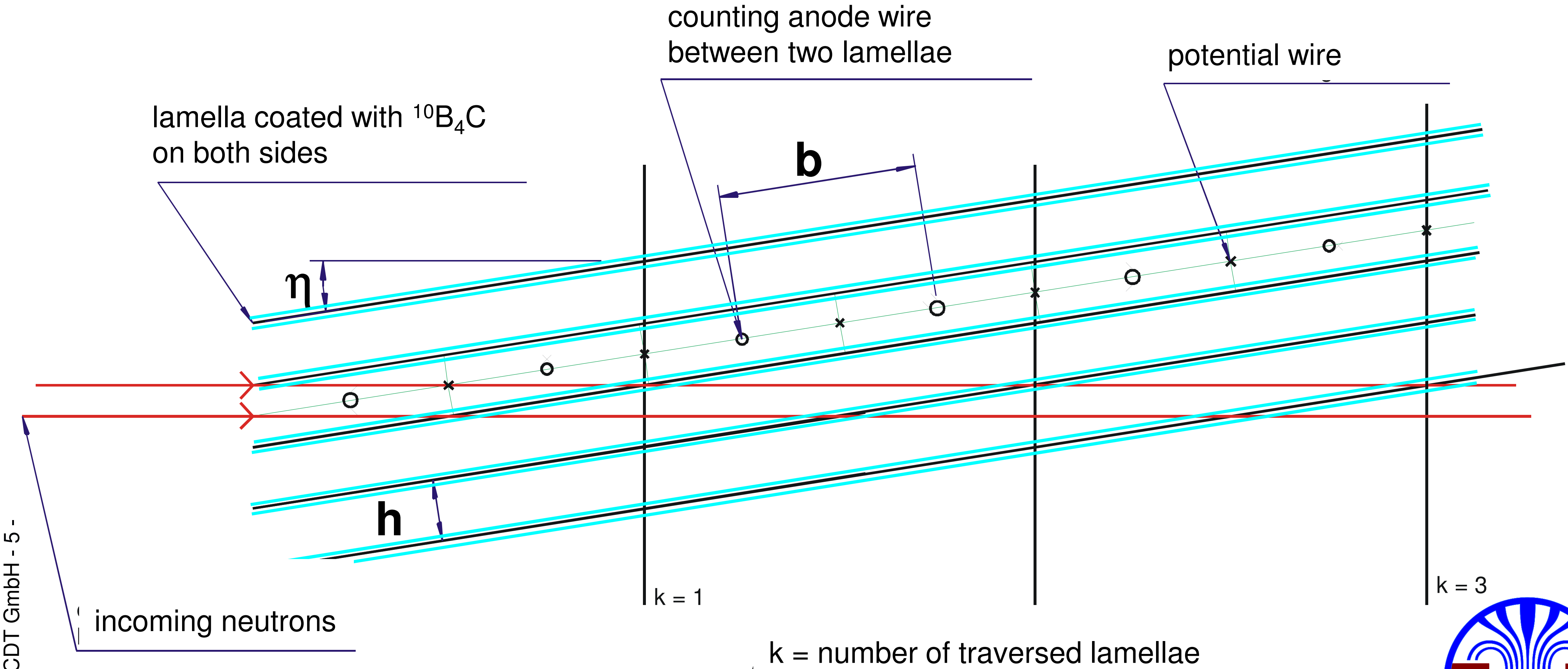
- Jalousie is a detector solution with inclined, solid ^{10}B or $^{10}B_4C$ converter layers.
  - Boron coatings are inclined to the neutron path to geometrically enhance converter depth,
  - while nuclear fragmentation products still enter the gas detector to deposit a large charge-signal.



- At η = 10° the effective converter depth is 5.75 times higher.

Jalousie: Detector Concept – neutrons at scraping incidence

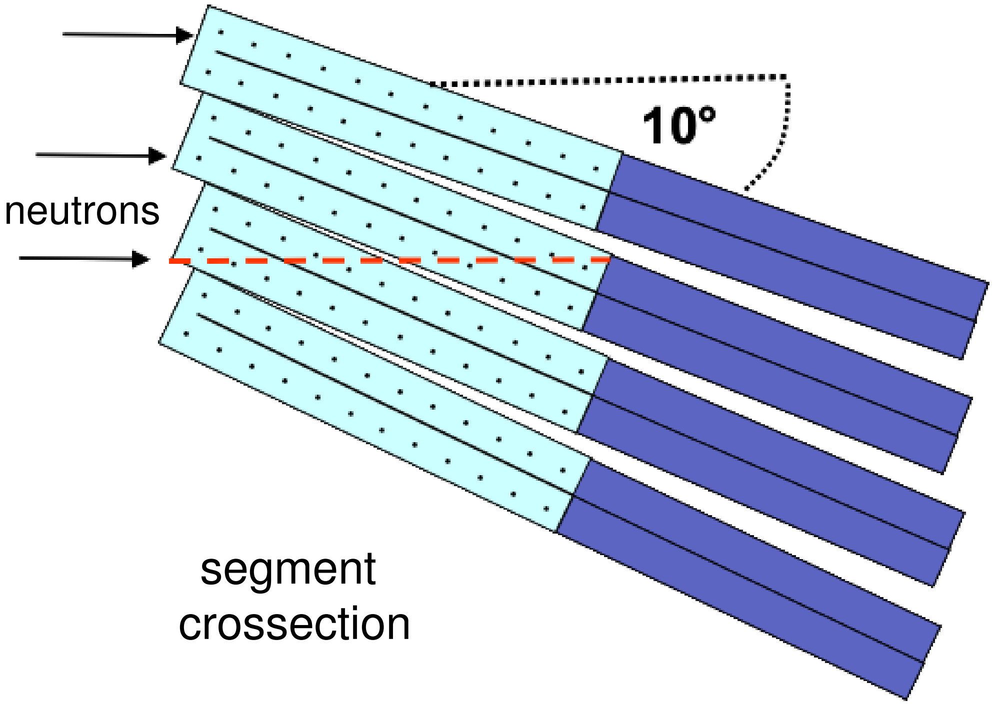
^{10}B-coated lamellae are inclined to the incoming neutron intensity at an angle of η = 10°

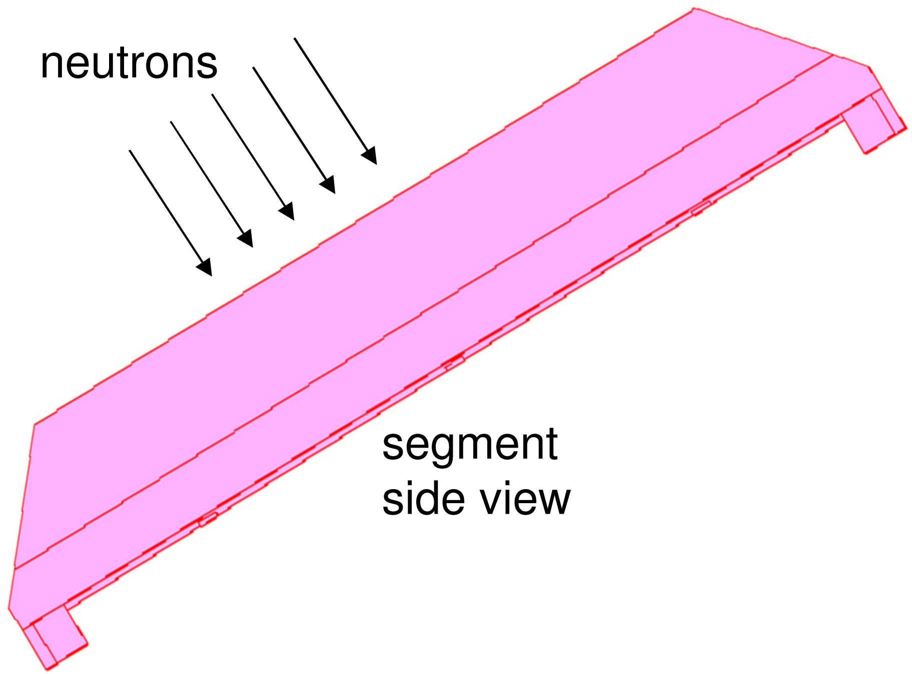


projected depth k = 4 (corresponds to 8 Boron layers)

Jalousie: Modular and Segmented

- Any neutron will pass 8 layers of Boron (1,1µm) under 10°, overall 46µm of ^{10}B
- In-depth detection as well as resolution to achieve TOF resolution



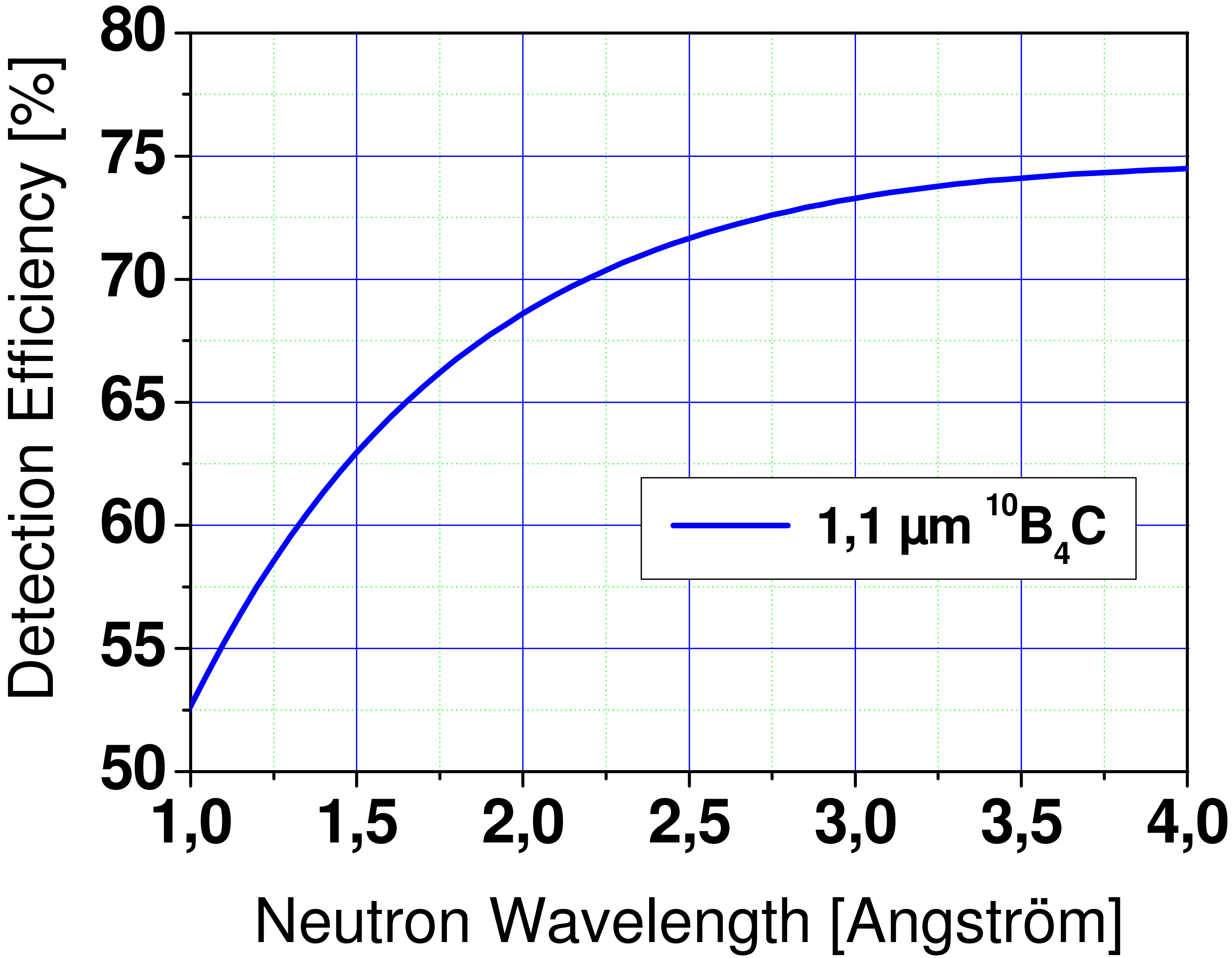


- Modular detector segments as individually operating proportional gas detectors with two anode planes each that may be assembled to cover large areas

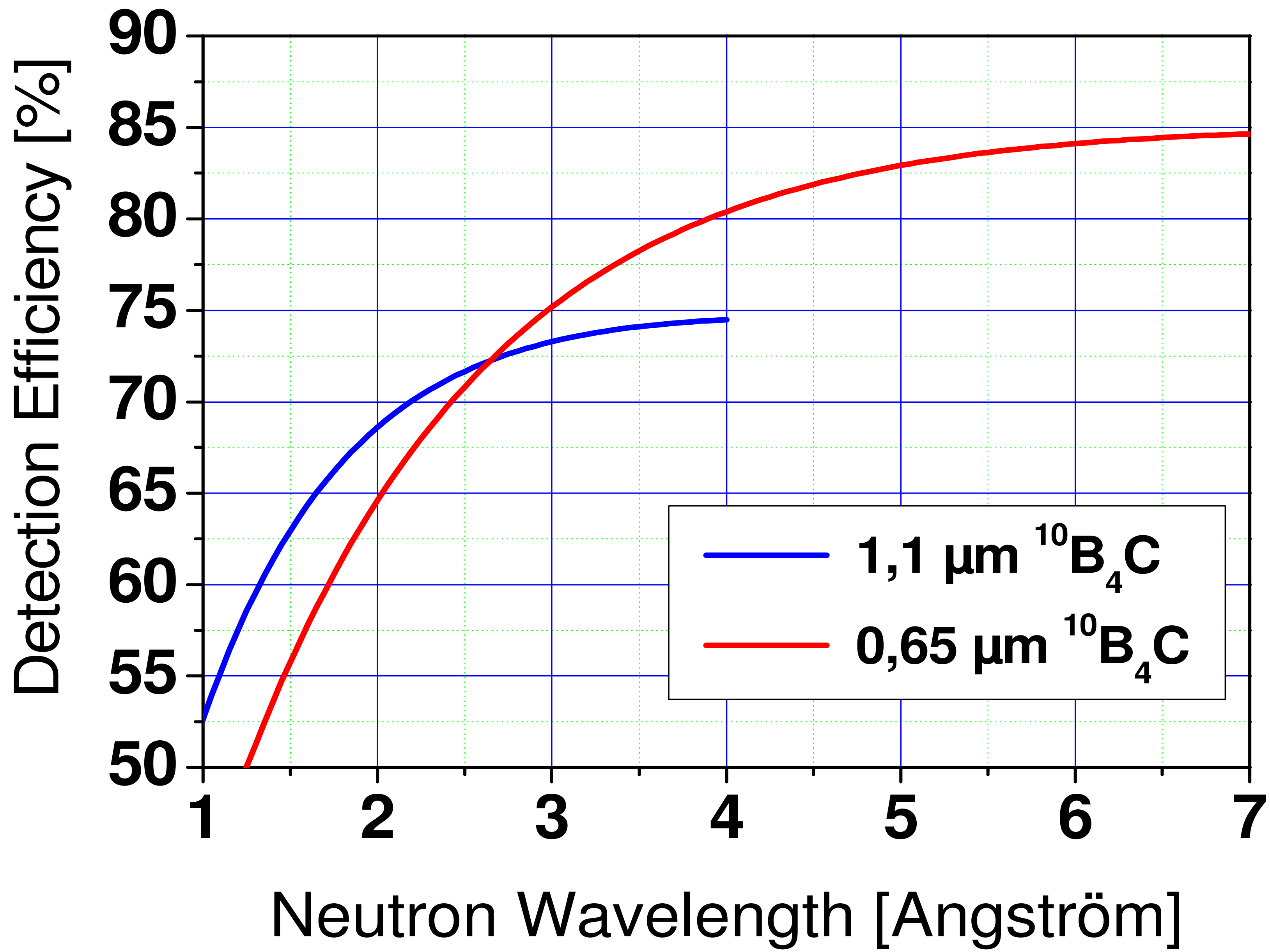
From point of view of incoming neutrons:
the stack of inclined lamellae looks like a „Jalousie“ or Venetian blind.

Projected Detection Efficiency

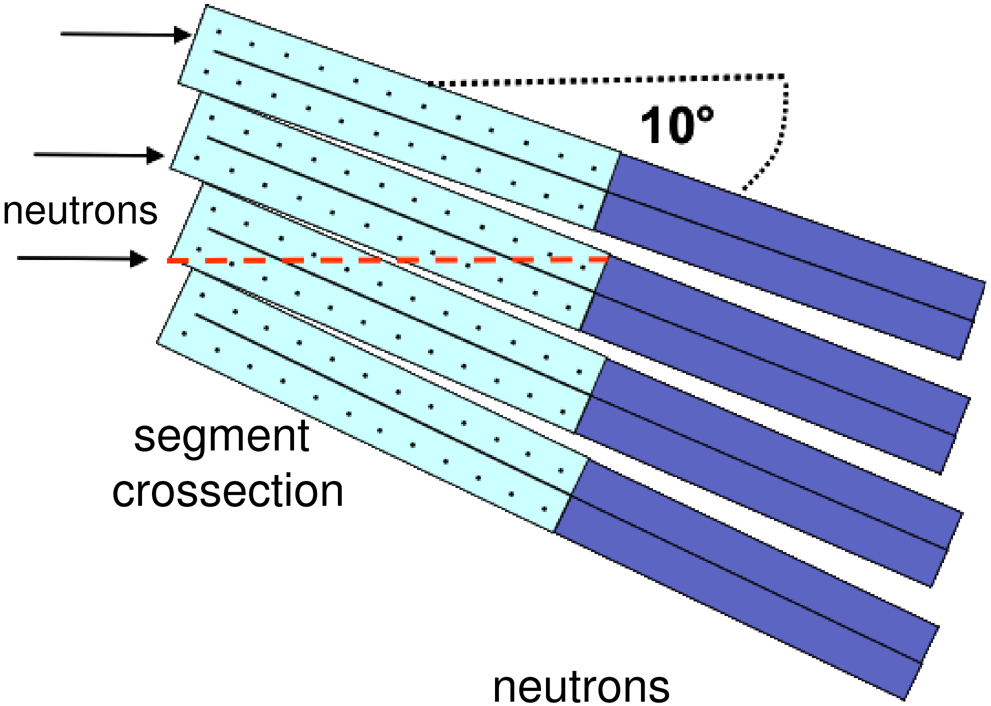
Efficiency as function of wavelength, η = 10°, 8 $^{10}B_4C$ layers

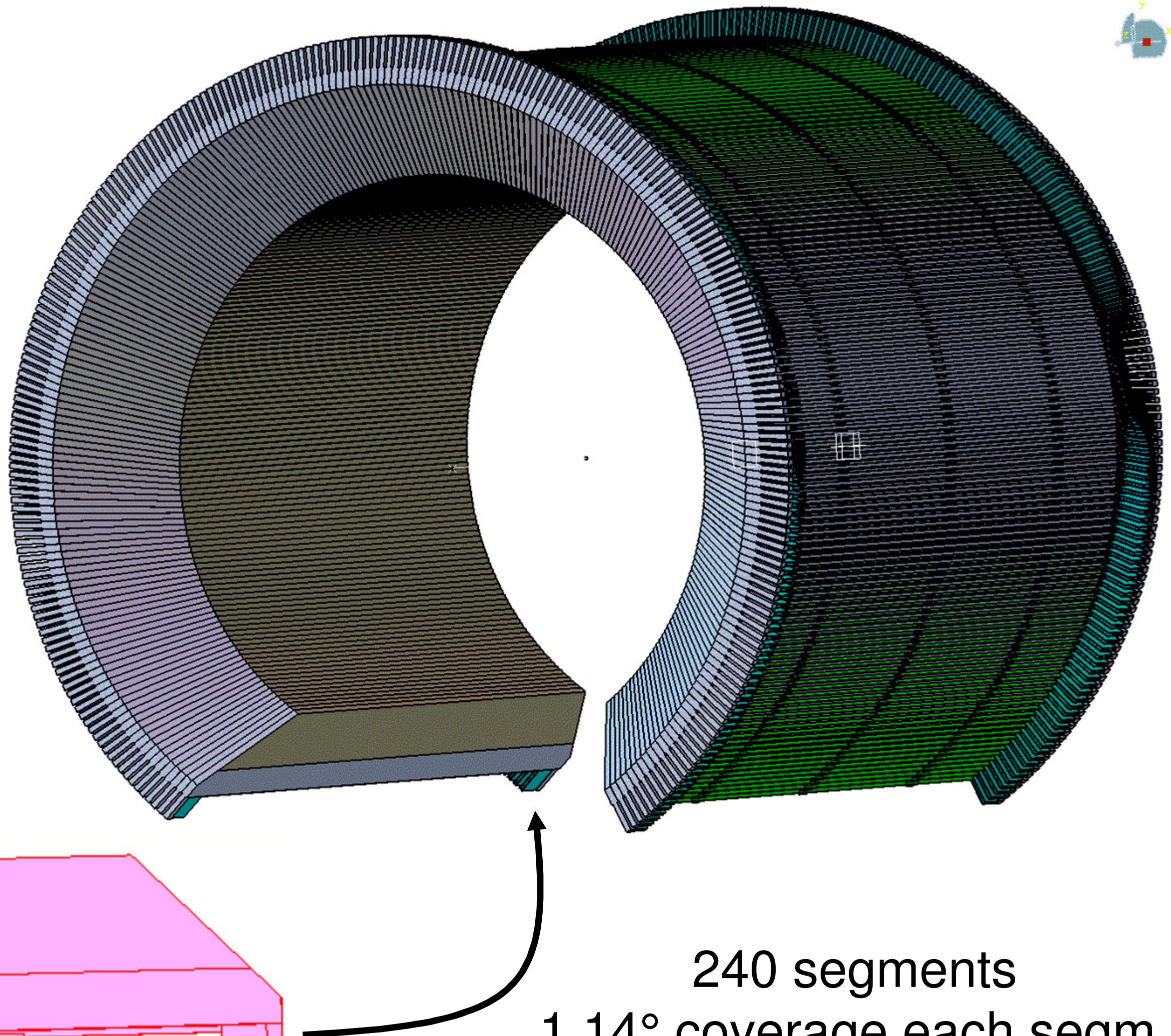


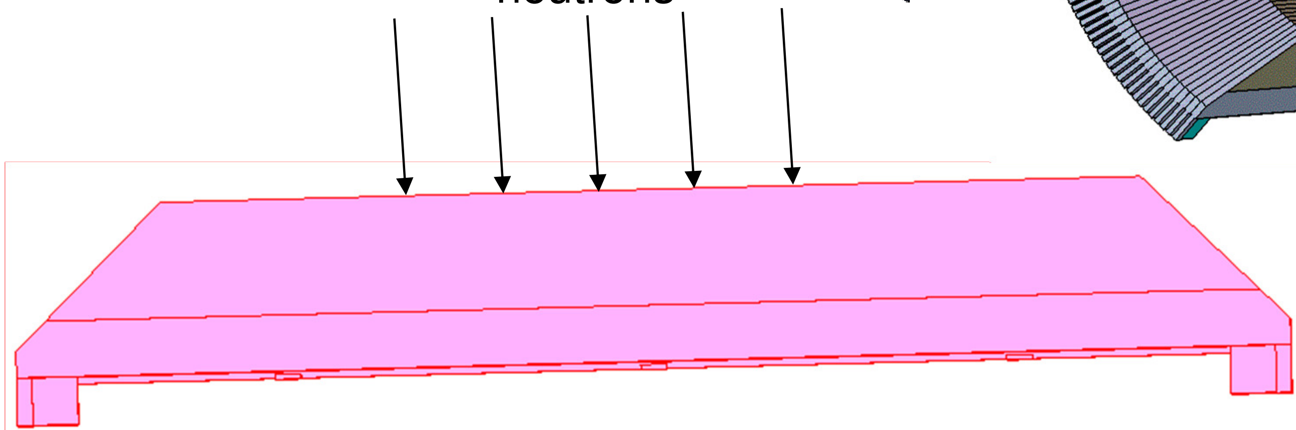
Efficiency may be optimized for the application



Jalousie Configuration for the POWTEX cylinder







segment side view, 1,6m active length

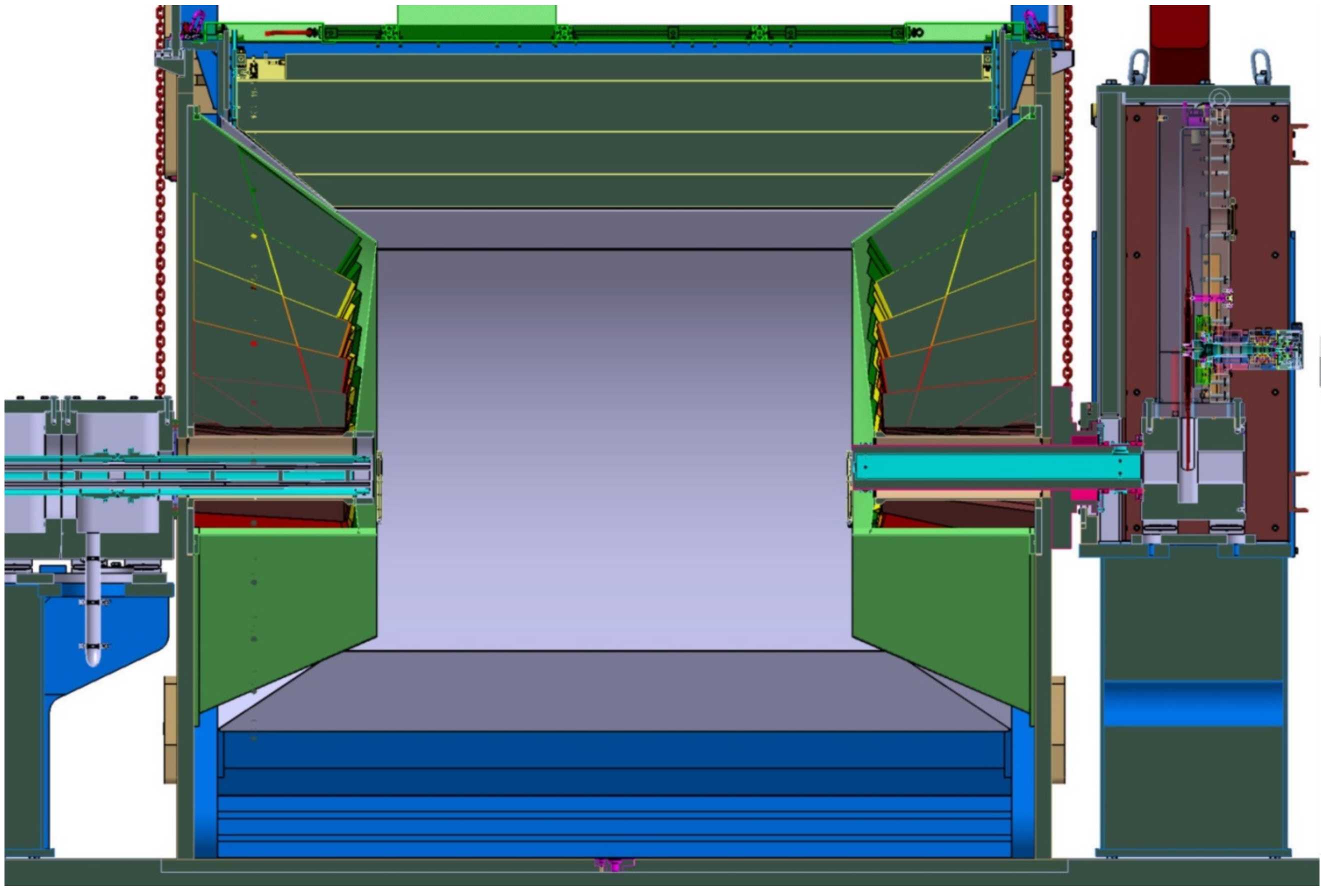
240 segments
1,14° coverage each segm.
cylinder inner radius: 80cm

All-active detector entrance area, no blind areas !

POWTEX Instrument, towards 4π-Coverage

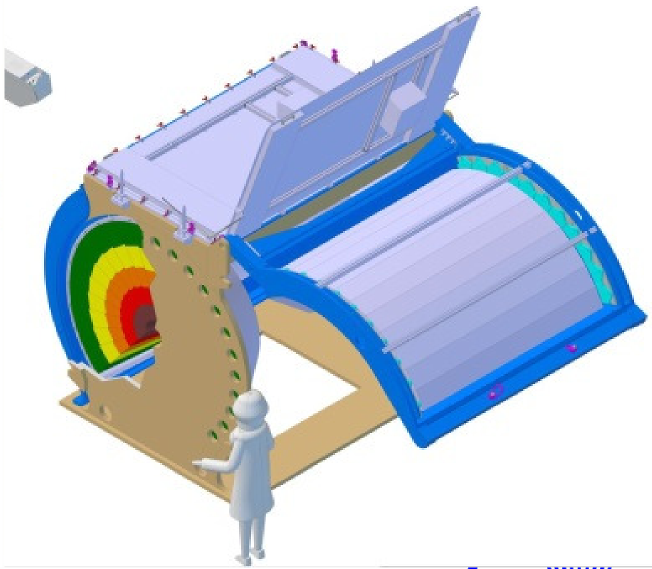
- Cylinder jacket coverage 274°, 240 segments
- Two end-caps, φ-coverage 276° each
- No coverage on bottom → space for instrumentation
- 2 Mio. active Voxels, 60.000 analog ASIC r/o channels

POWTEX



9 sqm detector area

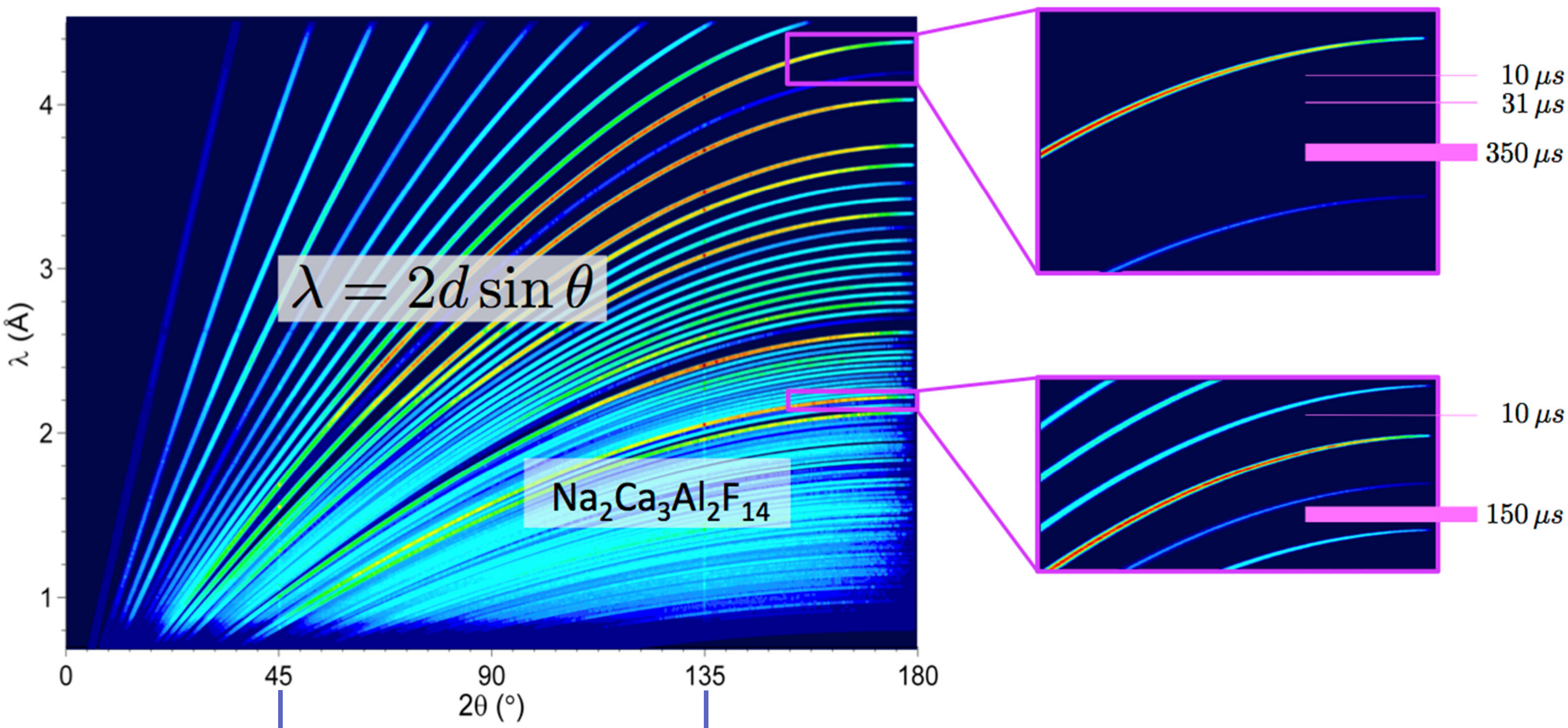
overall blind area < 5,8%



Neutron Powder Diffractometer POWTEX

example: NAC standard

with pulsed beam, ToF ~ λ

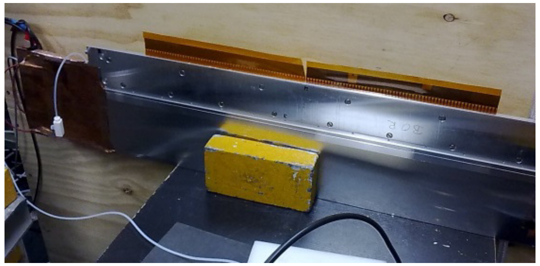


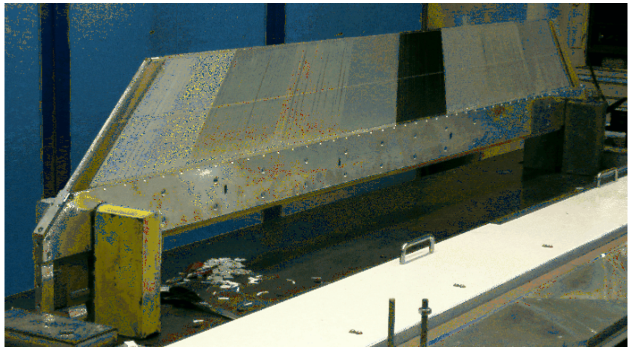
forward endcap	barrel jacket	backward endcap

calculation thanks to Dr. Werner Schweika, FZJ

Realization of POWTEX-Jalousie at FRM II

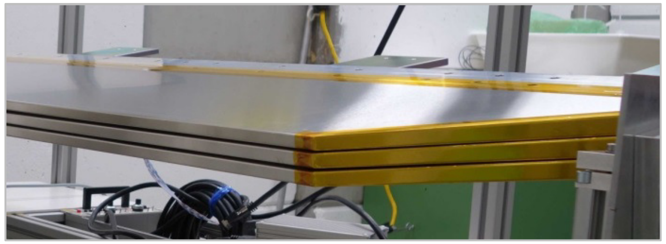
- **Jalousie was elaborated in two prototyping iterations.**





module pair
at FRM II, HEIDI

- **Third iteration: Production pre-series (12 segments).**

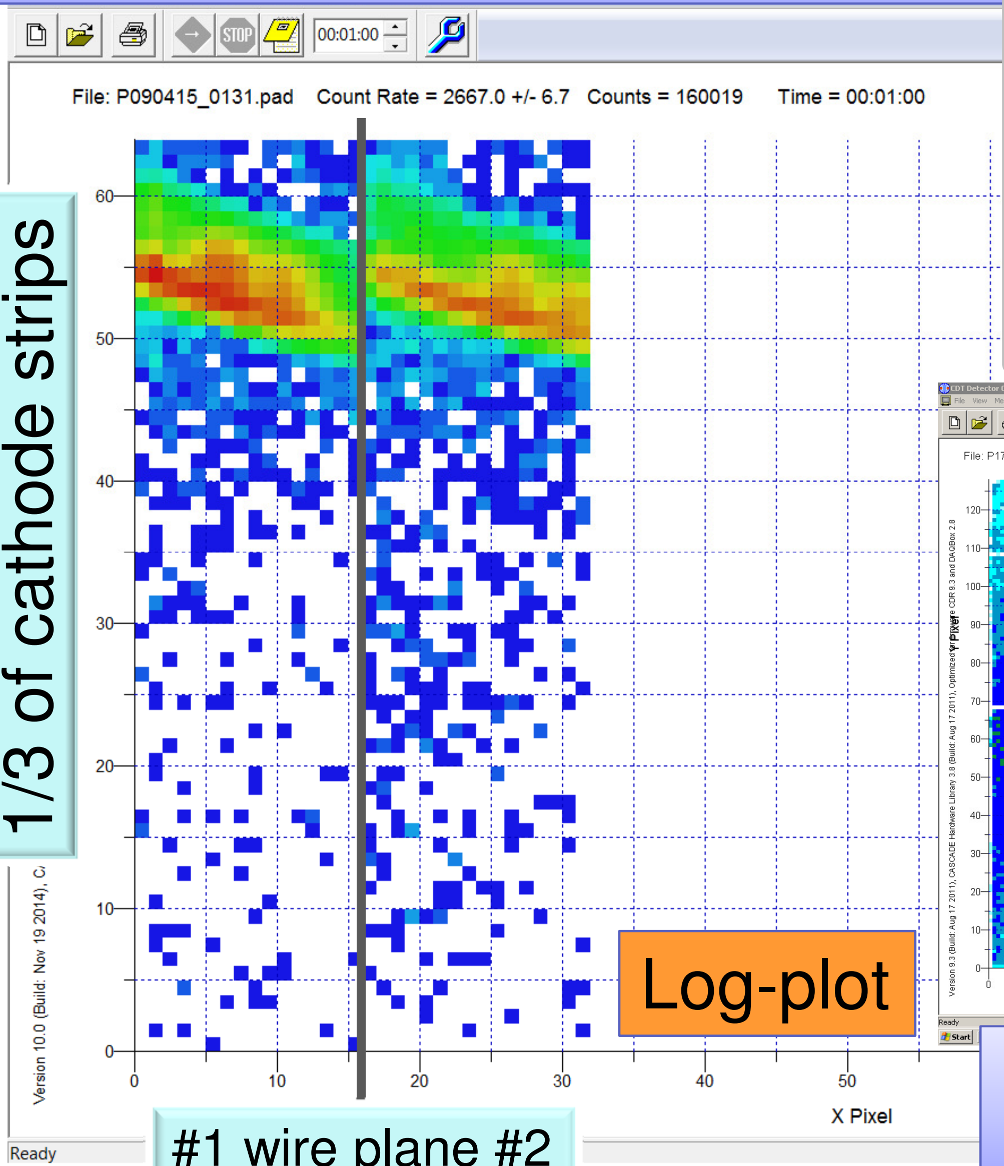


- **Serial Production started,**

26/240 segments assembled, ~40% coating done (~280 sqm),
all electronics manufactured
assembly capacity: ~3 segments per week

Measurements at Triga Reactor Mainz

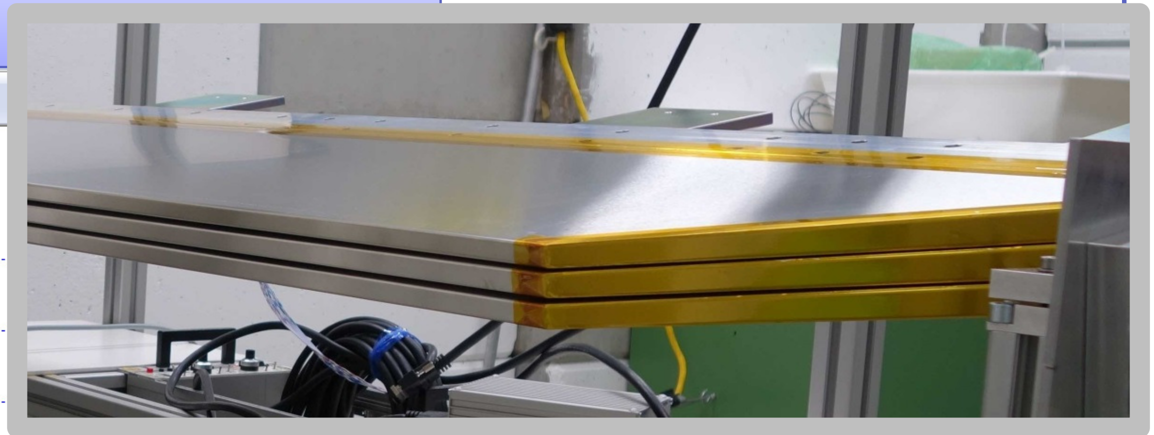
Beam from collimated slit onto Jalousie segment at 10°
(both wire planes shown side by side)

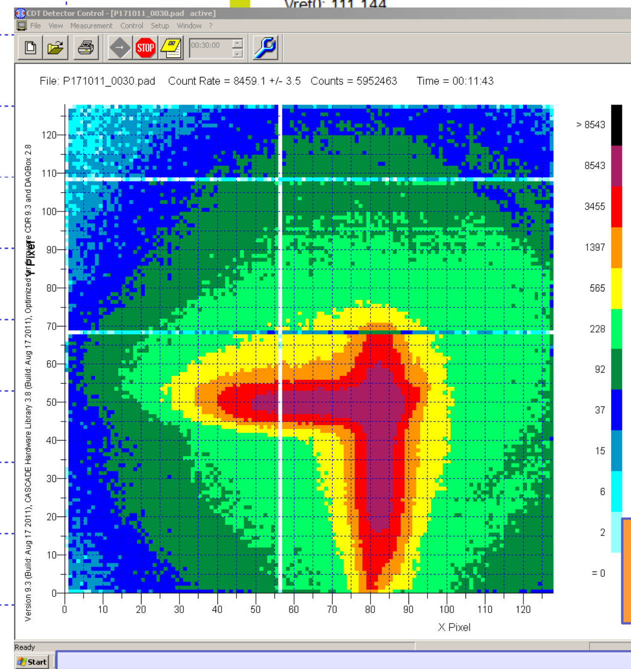


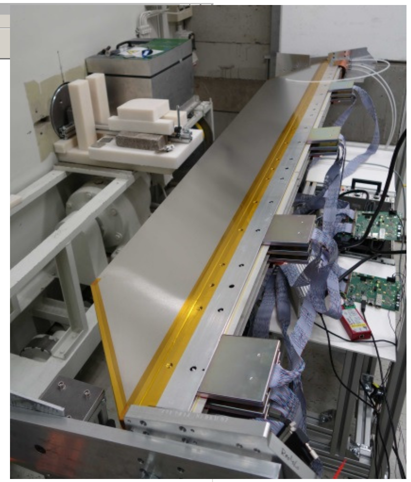
1/3 of cathode strips

#1 wire plane #2

Log-plot







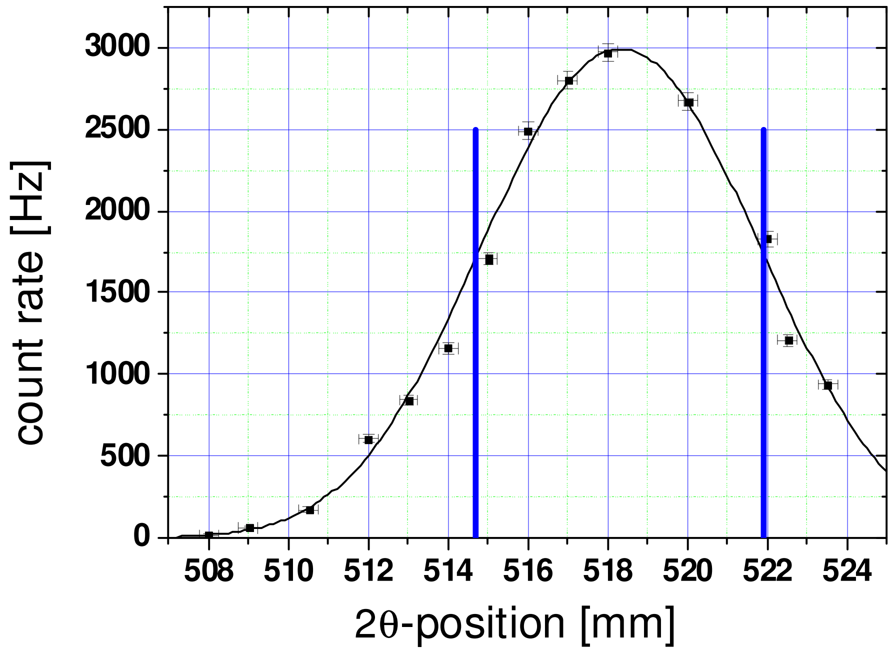
Log-plot

Uncollimated beam profile measured with CASCADE 2D-200

Measurements at Triga Reactor Mainz, Prototype II

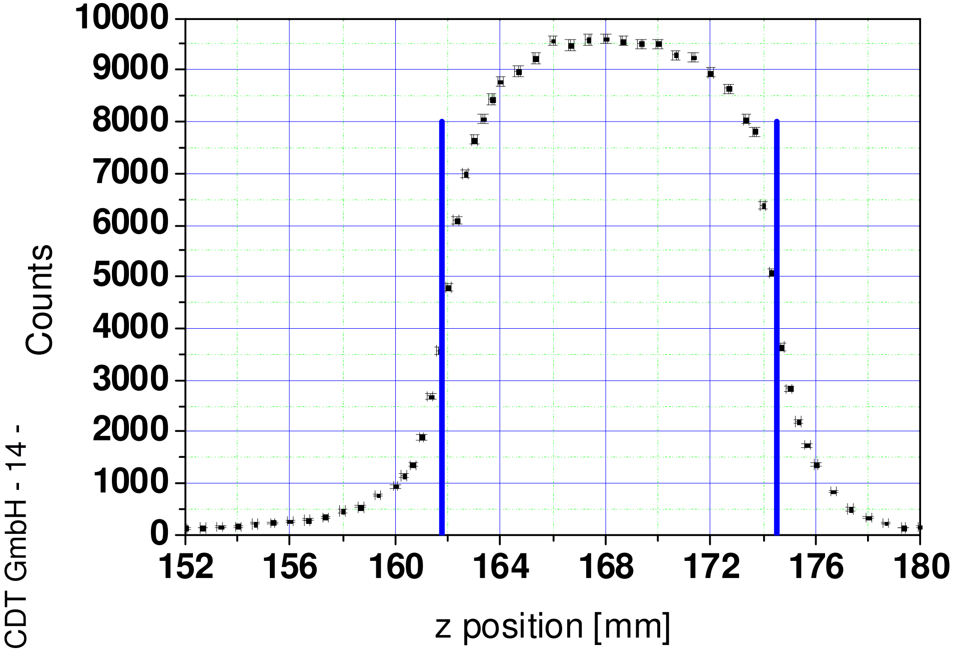
employing collimator:
beam width 0,5mm in detector

Resolution scan across cathode strips



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

Resolution scan across anode wires



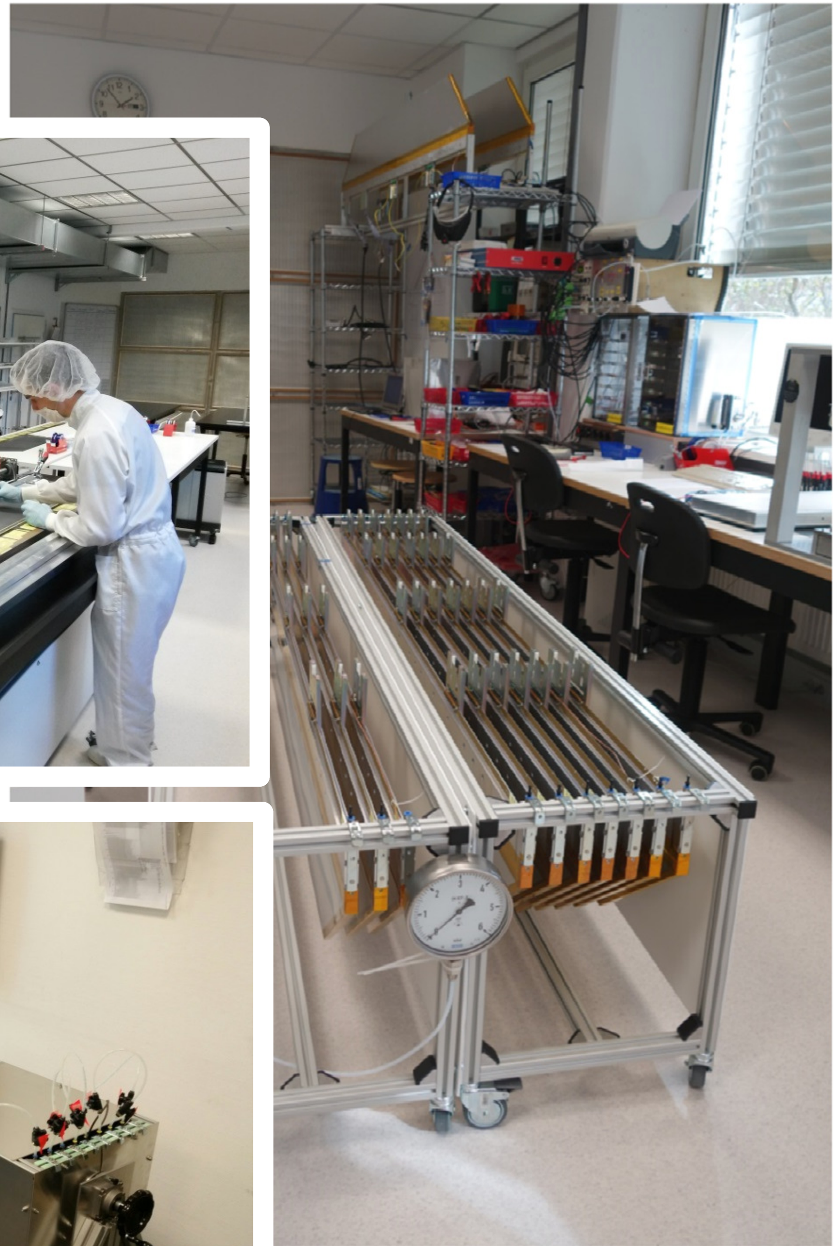
Jalousie Specifications to meet POWTEX Needs

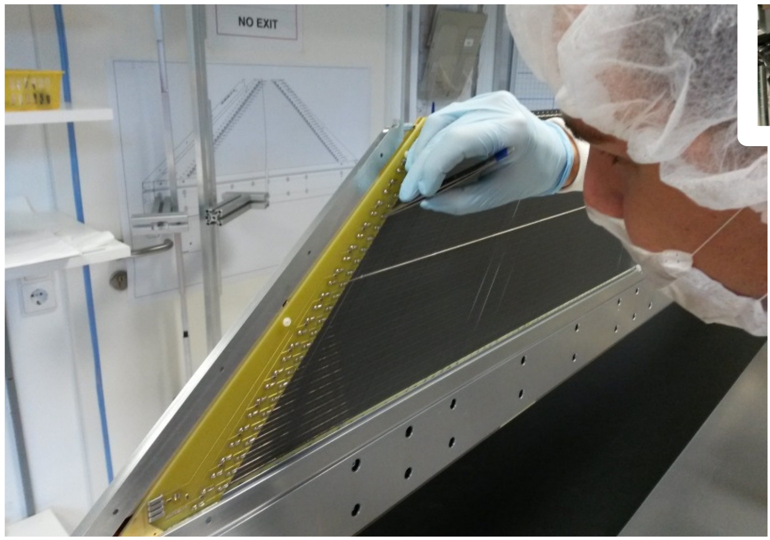
Parameter	Design	Value
Accumulated detection efficiency	■ 8 boron layers ■ inclined at 10°	> 52% (1.0 Å) > 65% (1.8 Å) > 72% (2.5 Å)
spatial resolution (2D) (at ambient counting gas pressure) 3D in depth → TOF	■ width of cathode readout strip $\Delta 2\theta = 0{,}469°$ ~ 6 mm ■ lamellae height h = 7,9 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	2MHz @ 10% dead time
Count rate per readout ch	limited by ASIC shaping time constant	333kHz @ 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.

Detector Segments in Production at CDT GmbH

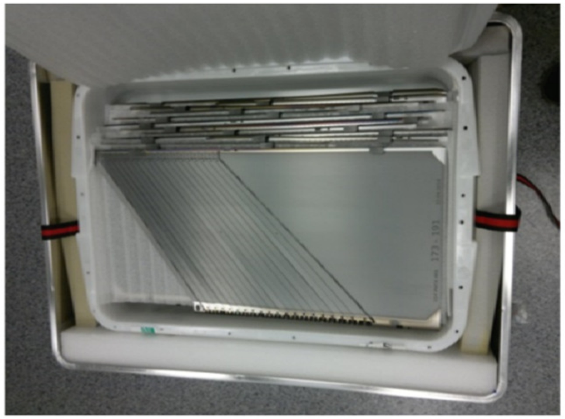
current capacity:
3 segments per week



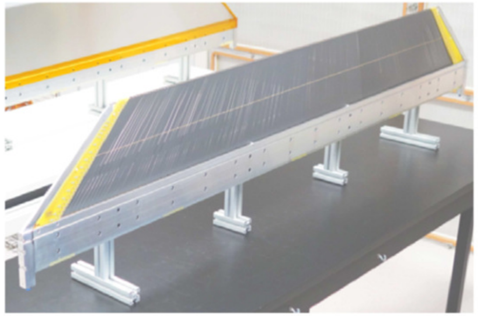


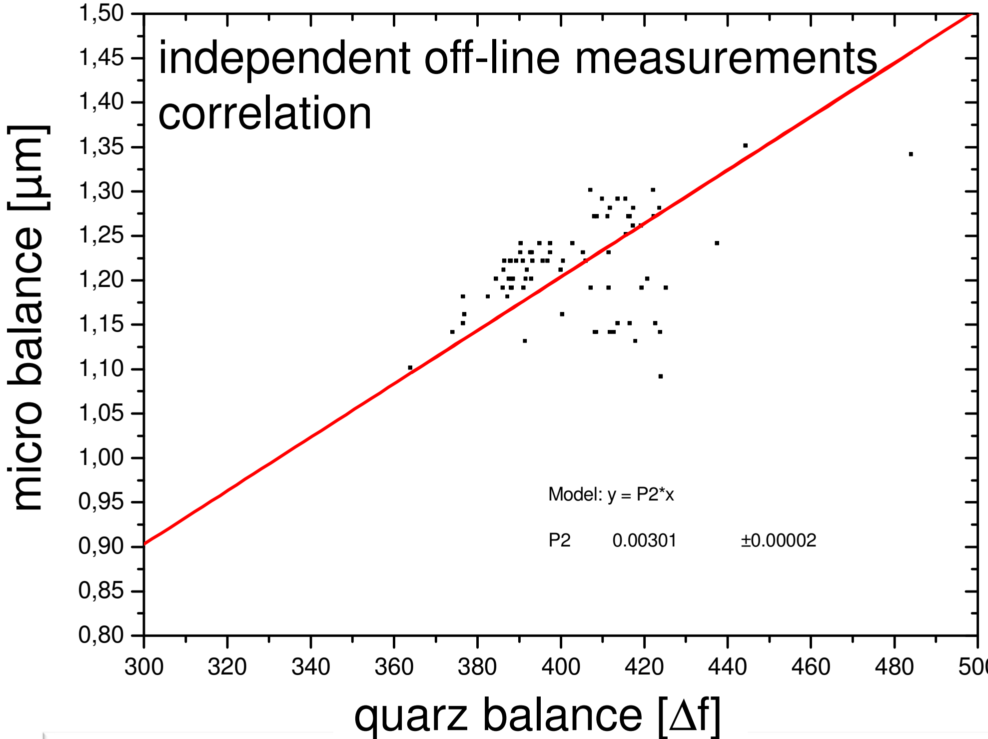
$^{10}B_4C$ Coating for POWTEX

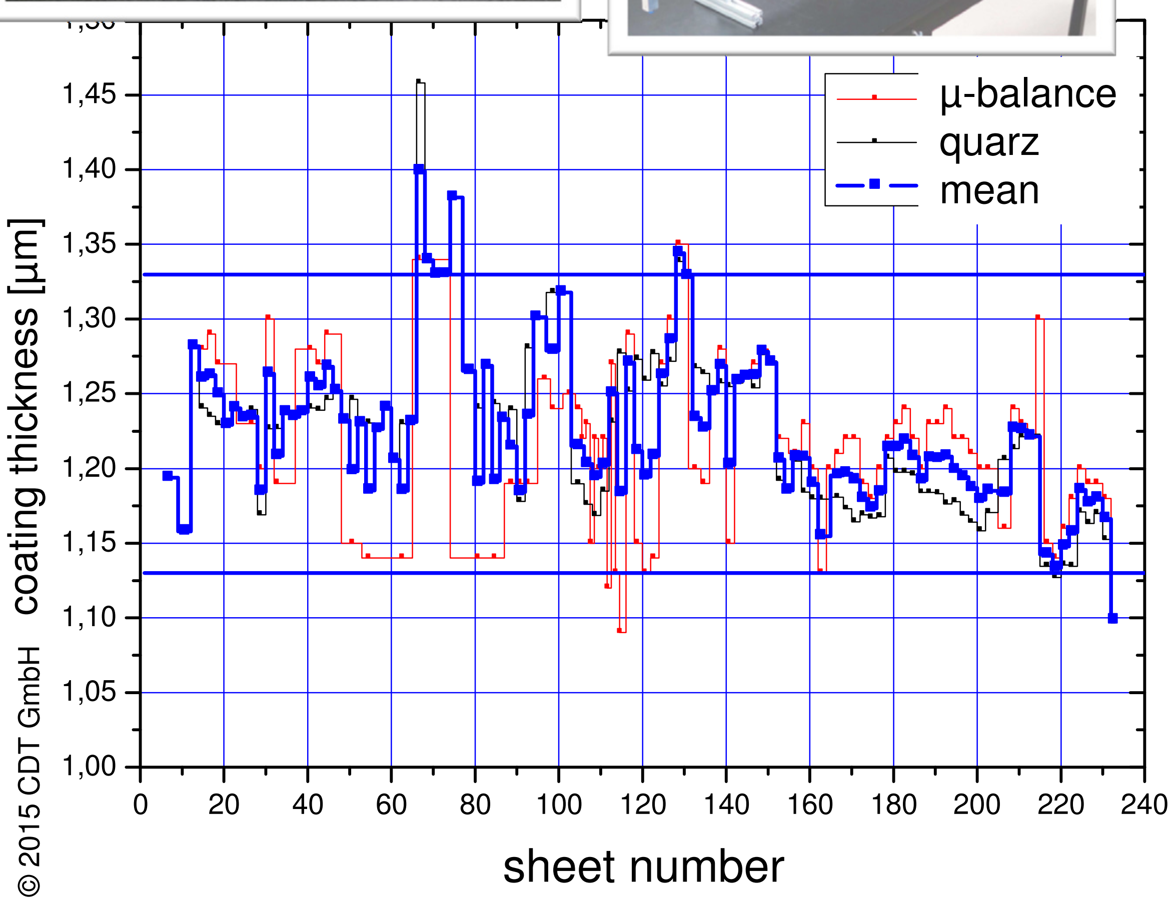
280 m² coated ~ 40% of total area (700 m²)



cathodes coated by
Fraunhofer Institut IST





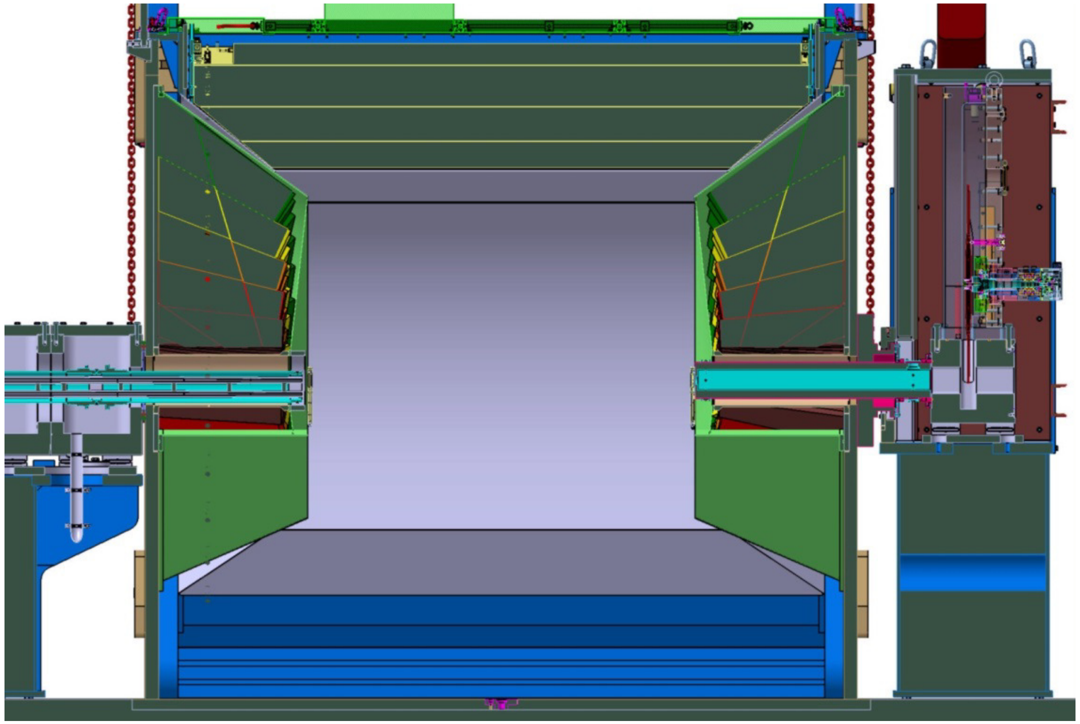


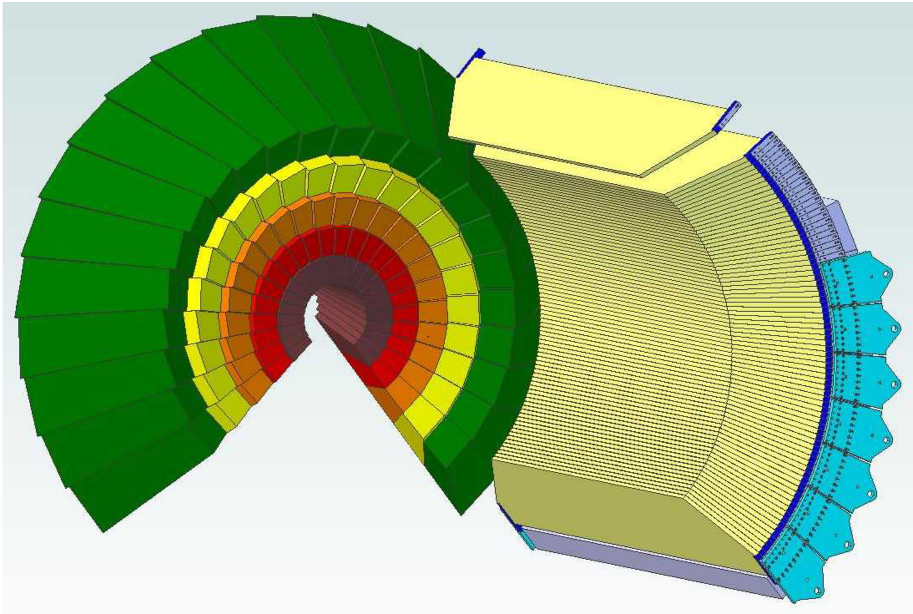
Coating at S-DH
our neighbor and expert in
neutron guides

POWTEX End-Cap Concept

- Two end-caps, covering 276° each
- 12°-segments with similar lamellae structure.
- Anode wires oriented in direction of the neutron path → avoid blind areas!

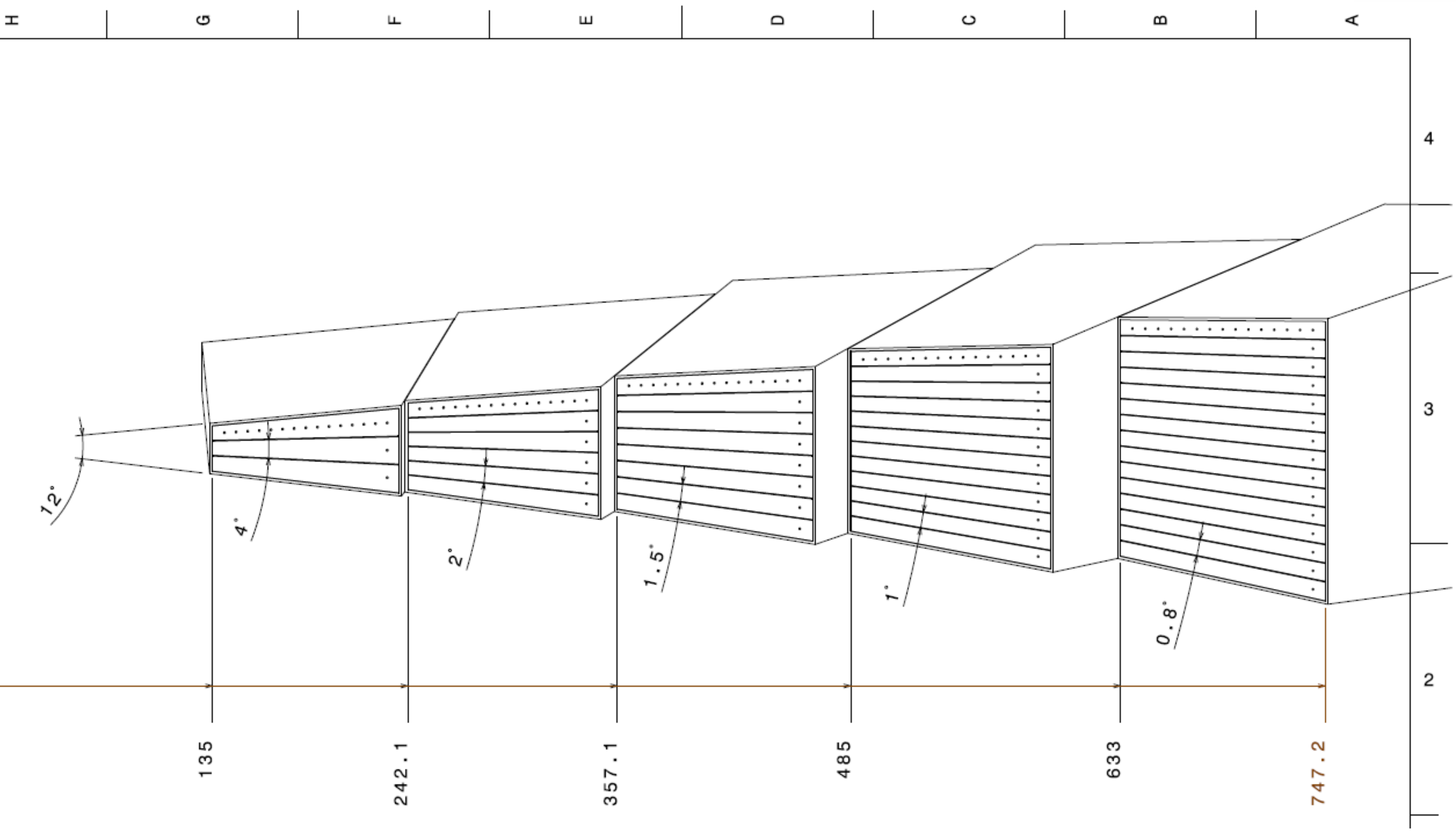
- Overall blind area < 5,8%

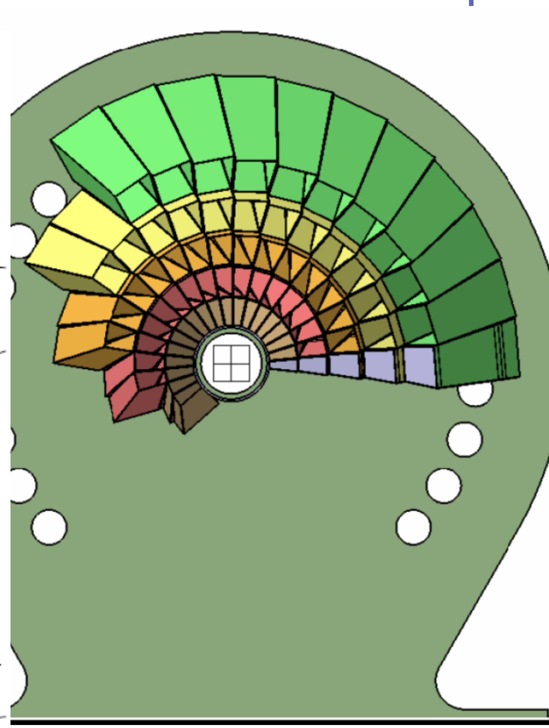




POWTEX End-Cap, anode-wires oriented to sample

- End-cap engineering design and prototyping ongoing
  - 12°-Segment substructured in 5 submodules
  - 10° inclination in φ → detection efficiency + avoid blind area!
  - 10° inclination in 2θ → avoid blind area between submodules!





POWTEX End-Cap

- Prototyping of sub-module 3 in autum

Challenges:

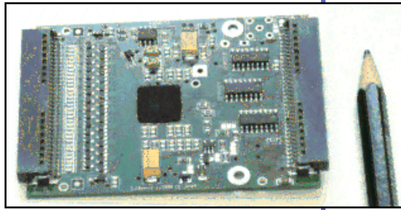
- 3D-Structure
- Sealed Aluminum housing
- Assembly procedures
- Contacting electrodes

- Production pre-series (four 12°-segments)
- Serial production in 2016 (full additional 42 segments)

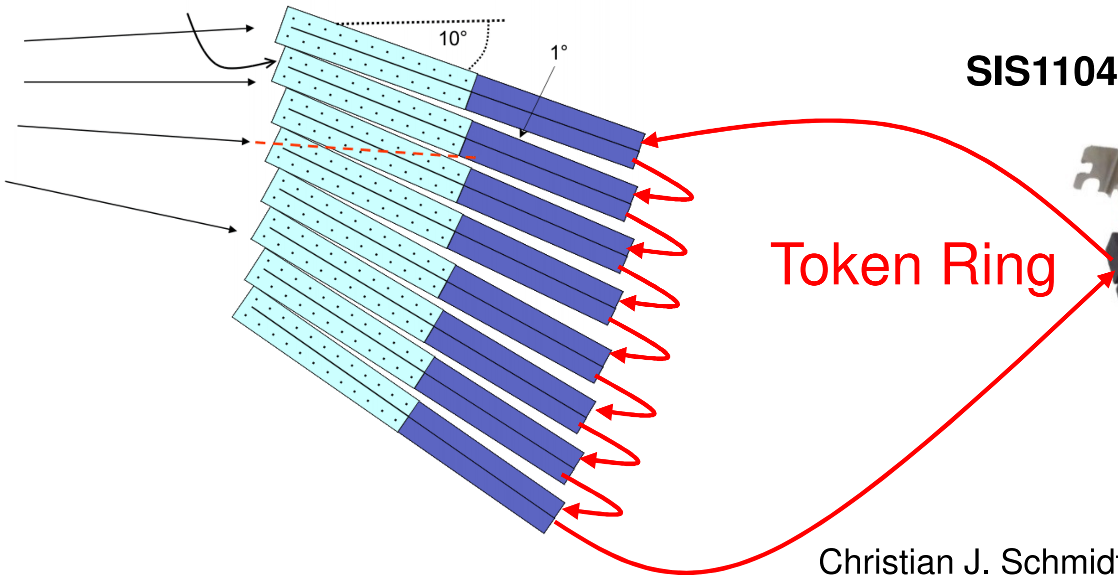
POWTEX project finalization in spring 2017

Electronic Signal Readout and DAQ

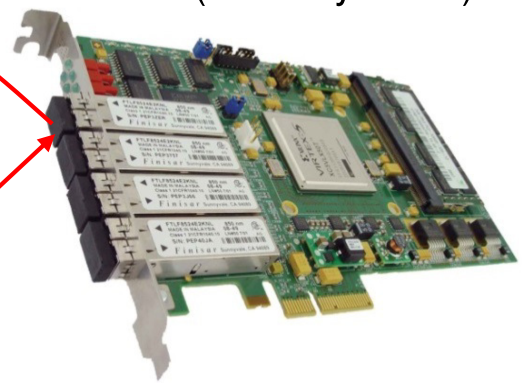
- Readout of individual channels through readout-ASIC CIPix-1.1, 60.000 ch



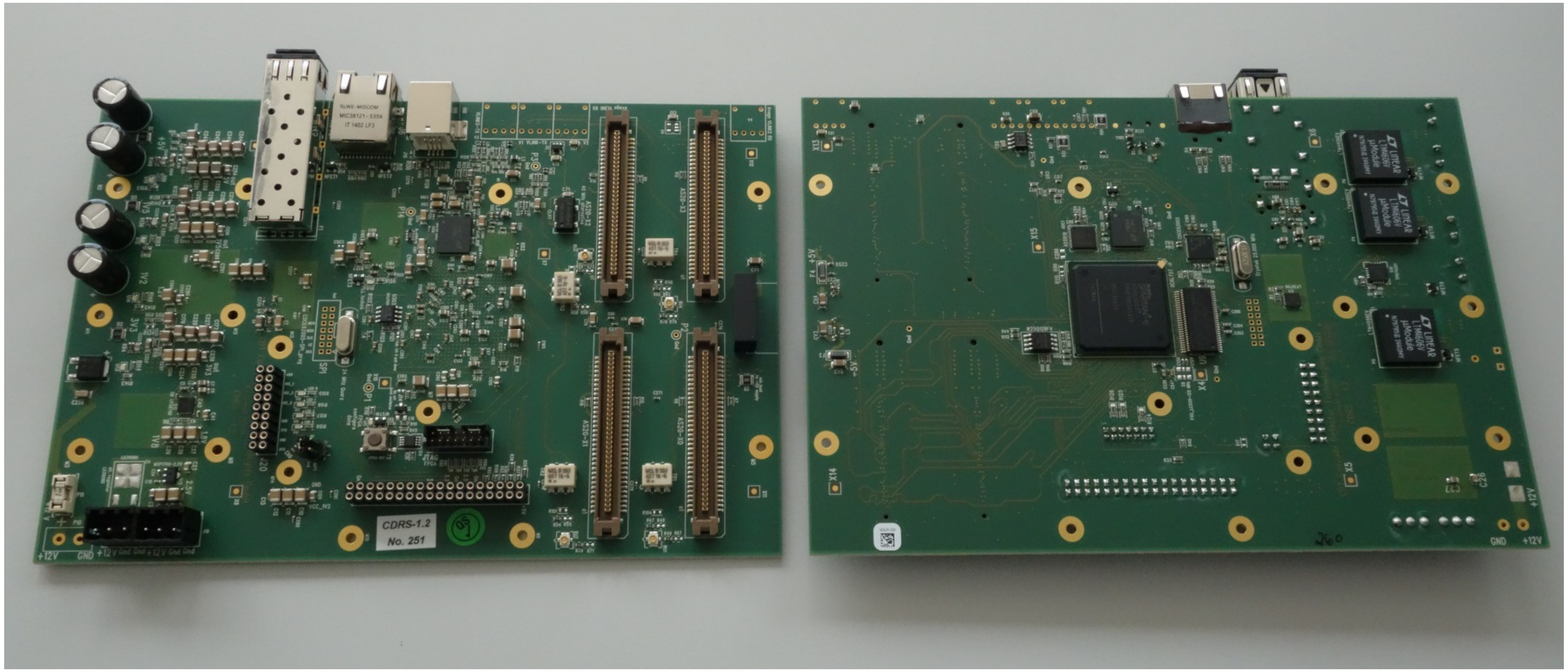
- Position identification and event reconstruction via coincidence identification in a local, module based FPGA, 2 Mio. volume elements (VOXELs)
- Data readout through Struck daisy-chained GBit optical link (SIS1104)
  - One GBit optical link transmits at least 12,8 Mio. event mode data elements per second (64 Bit per event defined for POWTEX).
  - More bandwith through segmentation into several readout areas



SIS1104 PCI Express Quad Optical Link Card
(640MByte/sec)



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



- Spartan-6 FPGA
- 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
- Powering via 48V/24V (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 safety previsions:
  - Three-fold concept to access for firmware upgrades
  - Guaranteed access even with faulty firmware installed
  - Three-fold clocking means
  - Two-fold controls access

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

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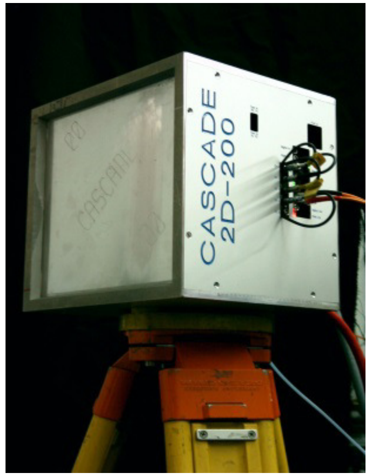
69123 Heidelberg
Germany

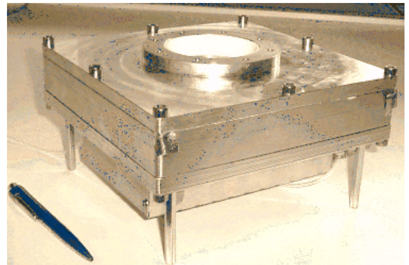
www.n-cdt.com

CDT CASCADE Detector Technologies GmbH

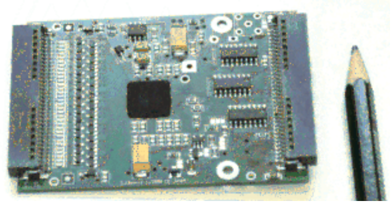
- Founded in 2006 as spin-off of Physikalisches Institut Heidelberg
- Focus: ^{10}**B based area detectors for thermal and cold neutrons as complete system solutions with electronics and software**



  - JALOUSIE detector, the alternative for ^{3}He PSDs
    large areas, medium resolution → POWTEX
  - CASCADE 2D-200 – high rates GEM-based solution with extraordenary contrast of 10^5. → expansion to 2D-300

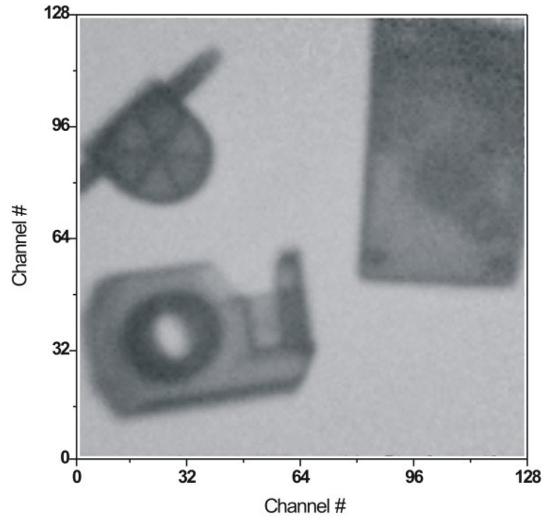


  - CASCADE-MIEZE – special variation to resolve 1MHz intensity variations
  - CASCADE-BM position sensitive Beam Monitors



  - UCN detectors
  - ASIC and FPGA-based multi-channel readout electronics
- Customers: FRM-II, FZJ, ESS, PSI, ILL, KIT (IBR-II), IHEP (CSNS, China), KEK & JAEA (Japan) via REPIC, KACST (Saudi Arabia),

CDT Business Resources



- Equity capital: currently ~ (190 + 100 + 100) TEuro
- Current human resources:

  10 FTE with additional ext. engineering capacities, further buildup ongoing
- Company premises: > 600m^2 for lab-, production- and office space,
- High throughput, large area $^{10}B_4C$ coating facility at hand (~ 2 m^2/day)

  (cooperation with S-DH), metallic Boron coating

