^{10}B based neutron detectors as technological alternative to ^{3}He based neutron detectors

CDT

Martin Klein

CDT GmbH
Hans-Bunte-Str. 8-10
69123 Heidelberg
Germany
www.n-cdt.com

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Outline

1. CDT CASCADE Detector Technologies GmbH
2. Neutron scattering and thermal neutron detection
3. Jalousie: Large scale (10 m^2 and more), medium count rate (10-100 kHz), low position resolution (5 mm FWHM and less)
4. CASCADE: Medium scale (~1 m^2), high count rate (2-100 MHz), medium position resolution (2,6 mm FWHM and less)
5. ASIC front-end paired with adaptable integrated FPGA data processing units
6. GEM based beam monitors
7. Summary and Outlook

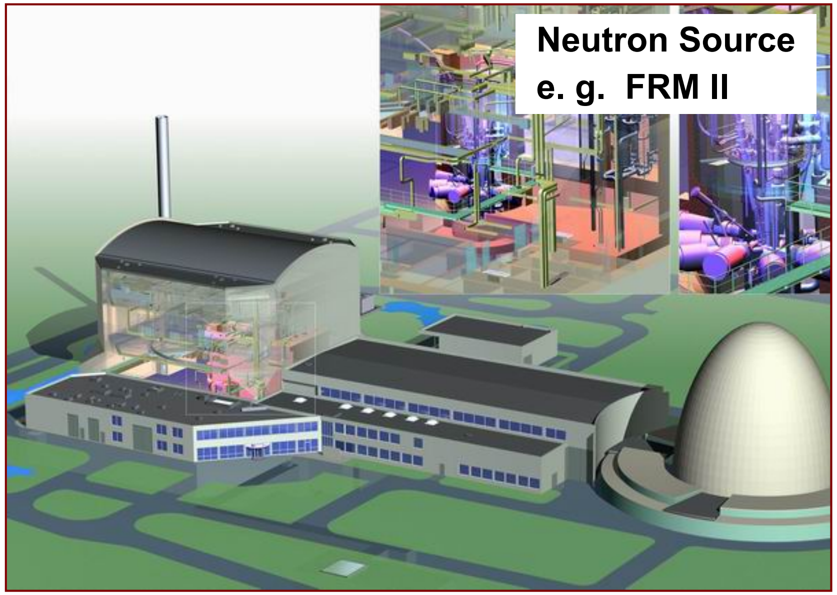
CDT CASCADE Detector Technologies GmbH

- Since 2006: university spin-off dedicated to (neutron) detector technology
- Based on know how from the Physikalische Institut Heidelberg:
  - Long tradition developing gas detectors for High Energy Physics experiments.
  - Success with technology transfer from the neutron physics research group of Prof. Dubbers:
    - S-DH GmbH: Development and Production of Neutron Supermirror Guides
  - ASIC-Laboratory: Development and test of highly integrated readout-electronic (ASIC-Chips) for various experiments and detector systems.

ASIC Labor Heidelberg

- Experience in building gas detector systems based on:
  - classical wire technology
  - modern GEM detectors for highest count rates
  - highly integrated readout electronics using ASIC/FPGA

Neutron scattering: large User Facilities for Big Science



SNS in the USA

Reactor Sources:

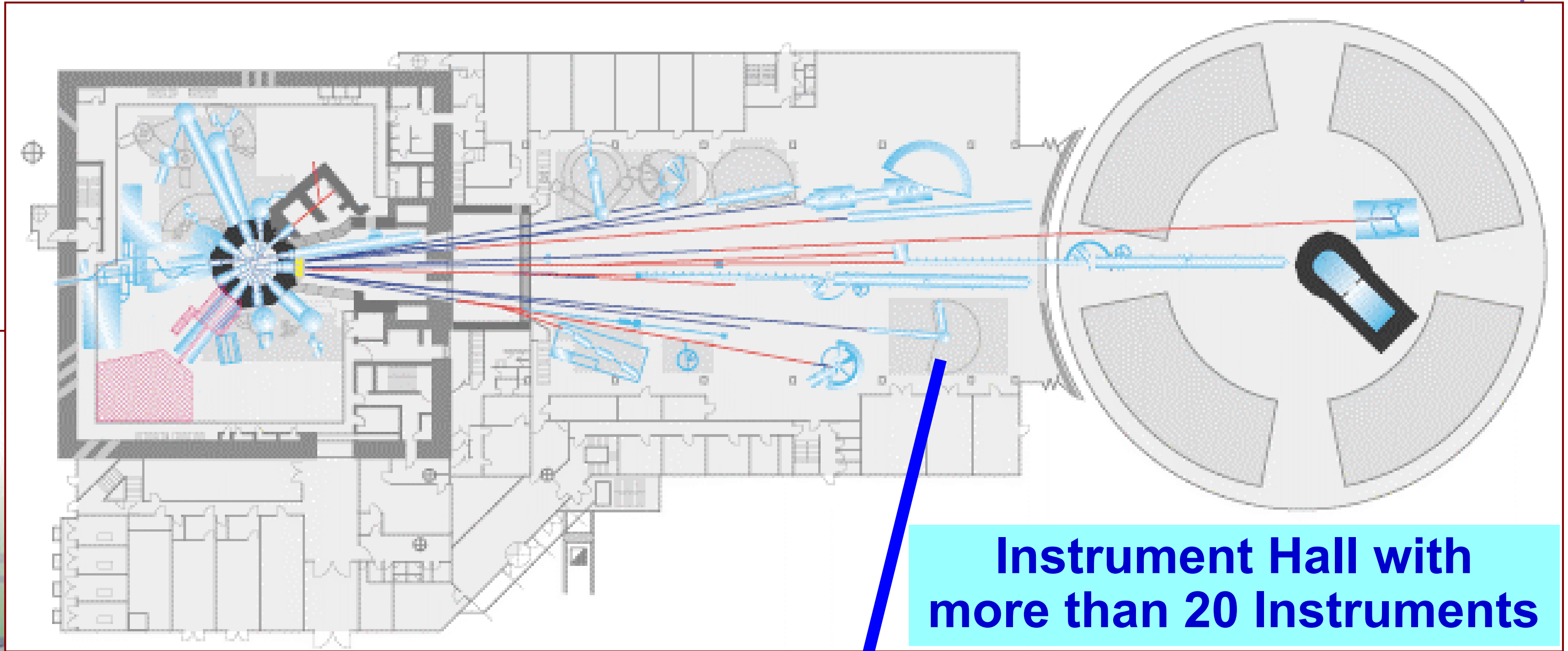
- ILL / Grenoble
- FRM II / München
- HMI / Berlin
- HIFAR / Australien
- IBR / Rußland
- more than 20 other Sources

Spallation Sources:

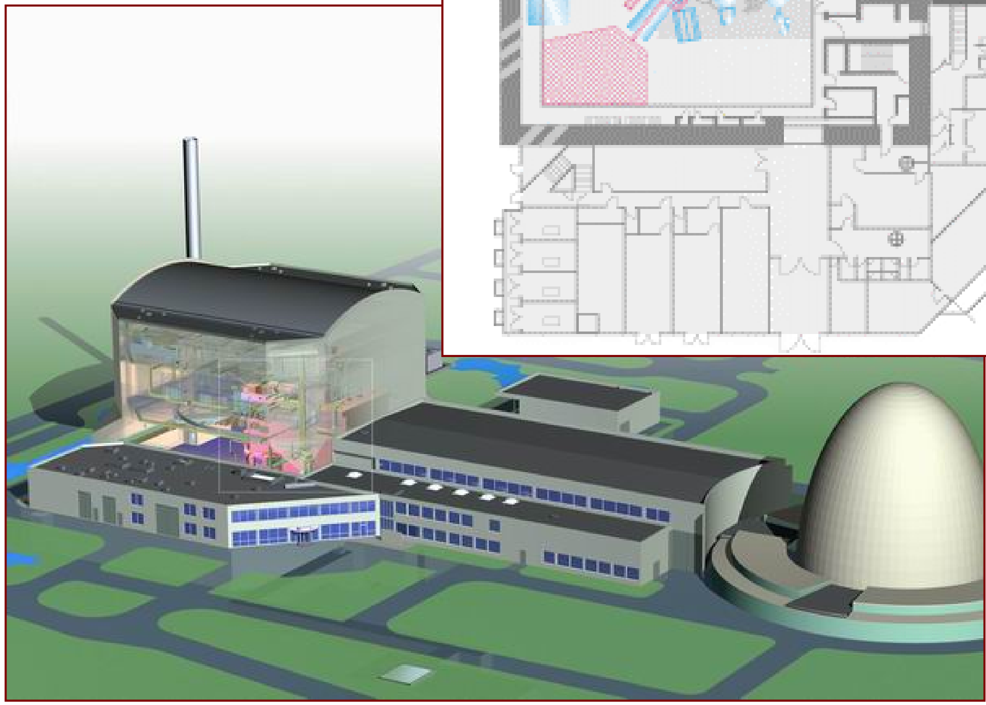
- ISIS / England
- PSI / Schweiz
- IPNS / USA
- SNS / USA
- J-PARC / Japan
- ESS (2018)

Infrastructure for research with Neutrons

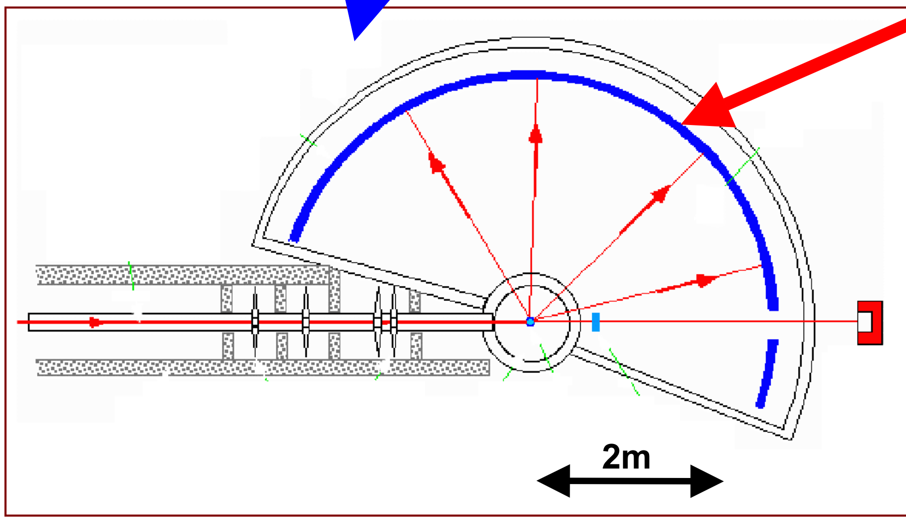
Neutron Source
e. g. FRM II



Instrument Hall with
more than 20 Instruments



Detector Array



Inelastic Scattering Spectrometer
IN5 at ILL / Grenoble

Modern Neutron Detector Needs

- Large position sensitive detector areas, no blind areas: 0.1 m^2 to several 10 m^2 with ~ 50.000 pixels per system
- Pixel size 1 mm^2 to 1 cm^2
- Detection efficiency 50% to 100% for thermal neutrons
- Rate capability far beyond 100 kHz (10^8 Hz over detector system)
- Time resolution better 1 µs for TOF-experiments
- Negligible sensitivity to gamma radiation
- Robust technology
- Serviceability

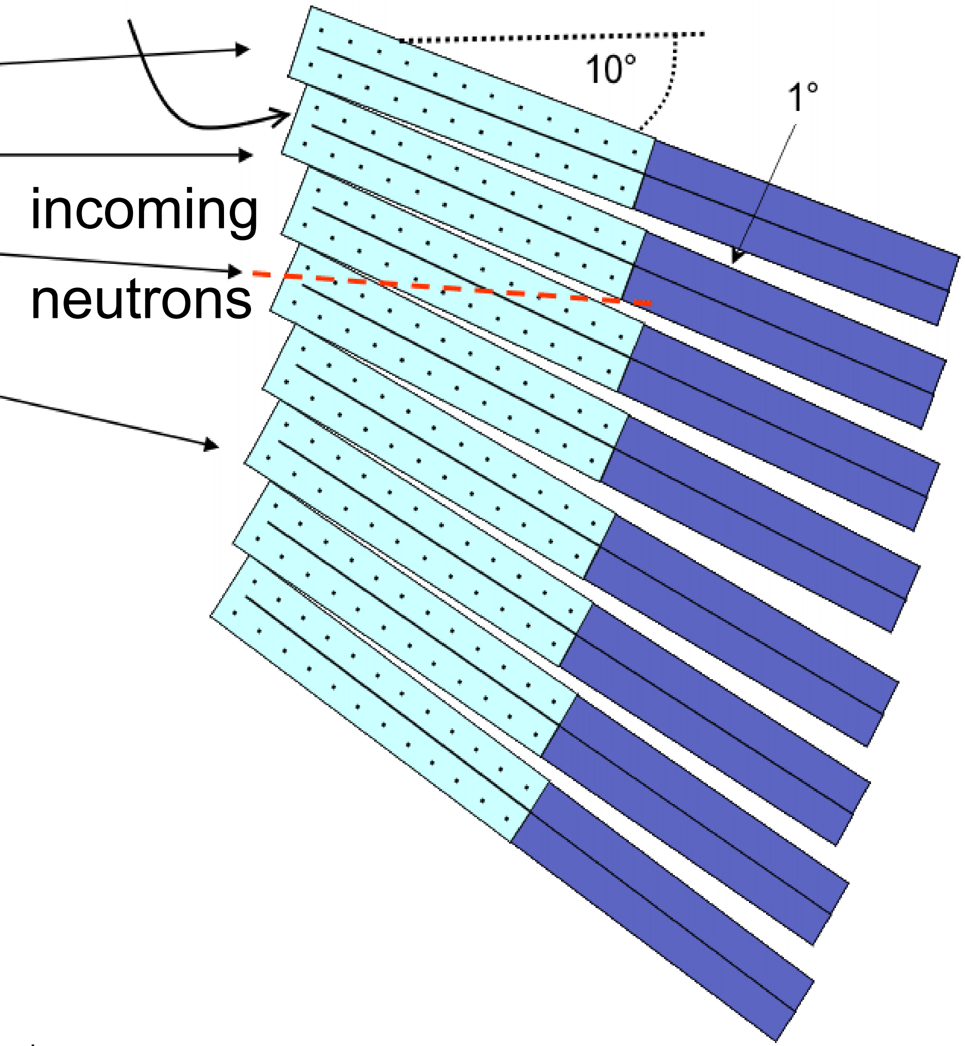
Maximize detector up-time!

- Large scale manufacturability

A prototype is not enough!

- A technological alternative to ^3He based neutron detectors, that suffer the severe crisis in supply of ^3He

The Jalousie Detector Concept



The concept:

- Neutrons pass 8 layers of ^{10}B coated on 4 lamellae.
- Lamellae are inclined (~10°) to reach high detection efficiency.
- Suitable to cover large areas.
- TOF capable through depth information.
- Low-cost counting gas at ambient pressure, no pressure vessel.

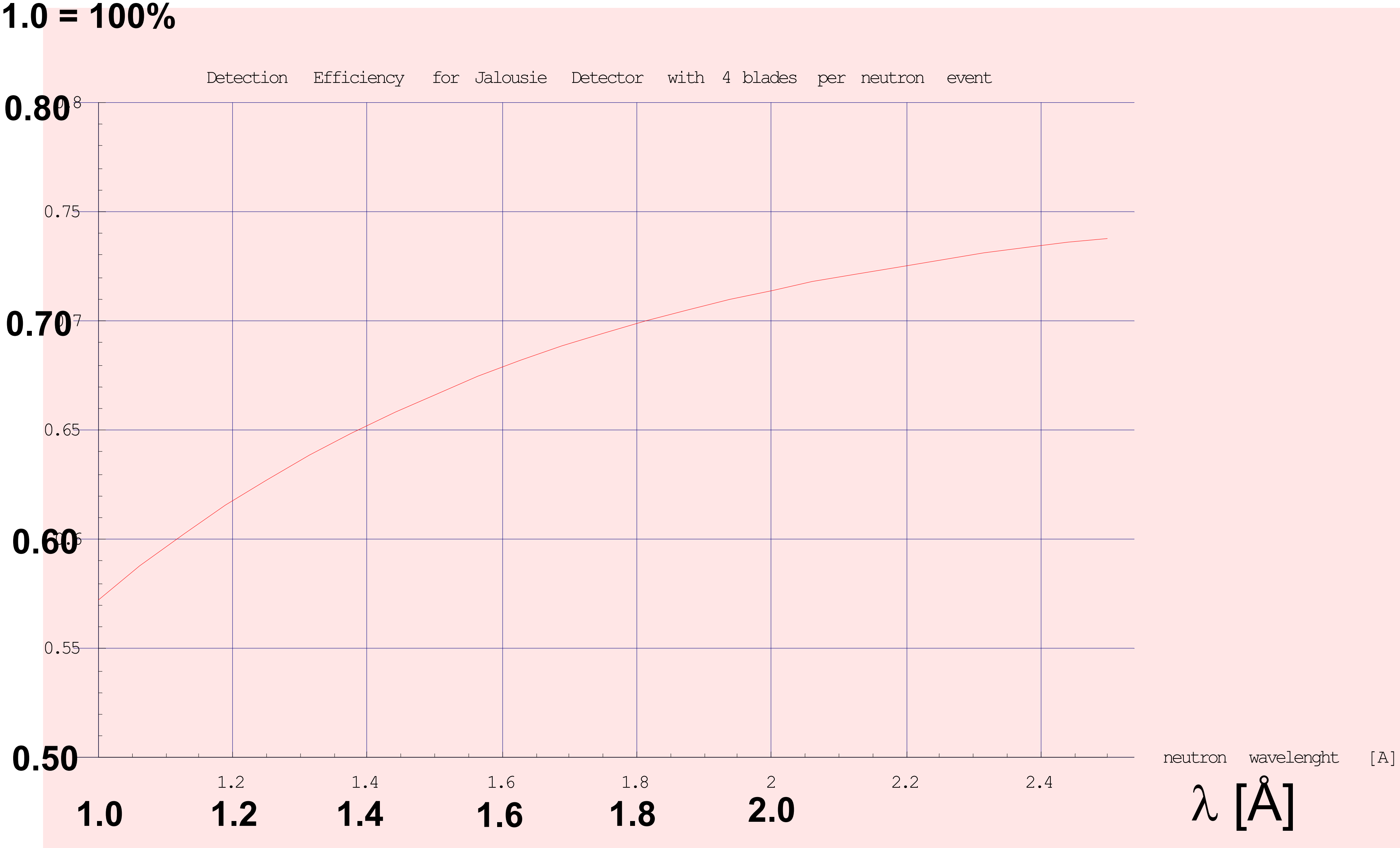
Actual design:

- 2 lamellae build one gas detector segment:
  - 2 anode wire planes and 3 cathode planes.
  - Segment can be shaped like a cake without blind area (not shown here).

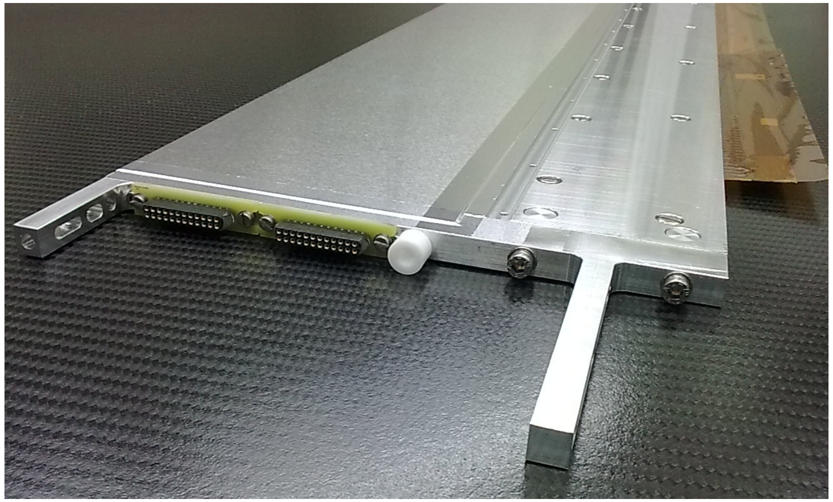
From point of view of incoming neutrons: the stack of inclined lamellae will look like a „Jalousie“ or Venetian blind.

Projected Detection Efficiency

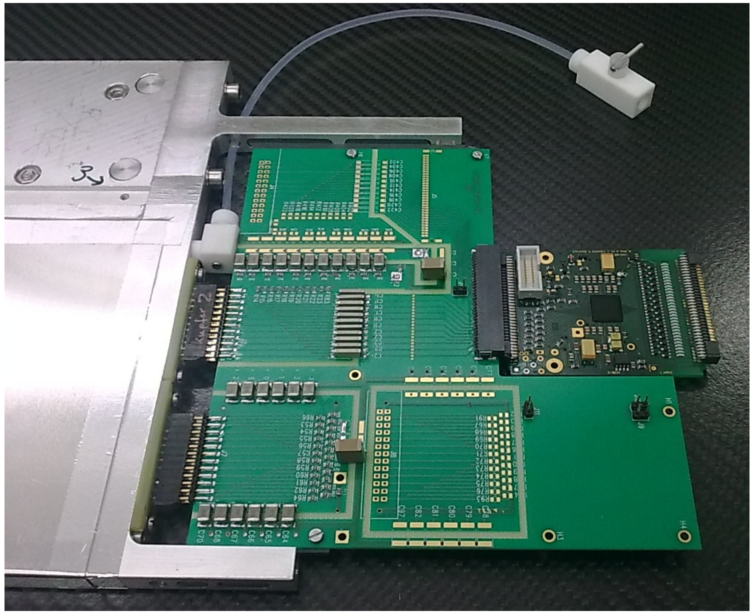
Efficiency as a function of wavelength λ [Å]
(8 layers of ^{10}B, η = 10°)



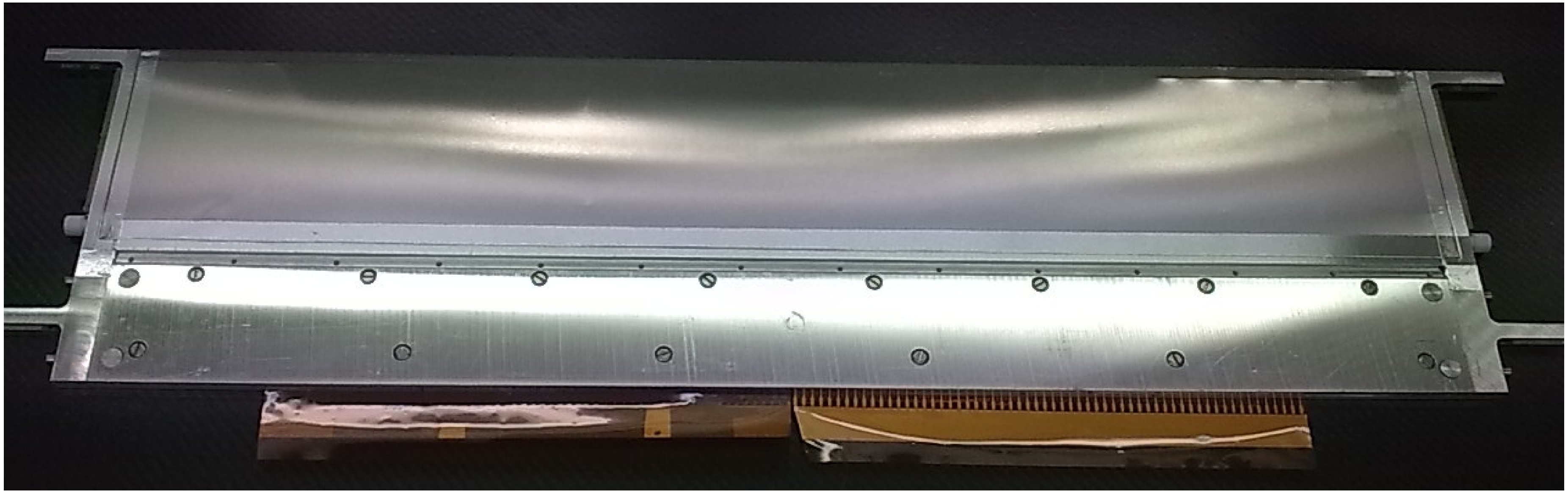
Pre-Prototype: detector housing, HV supply and ASIC readout



HV/signal and gas feed through



HV supply (anode wires) and signal readout



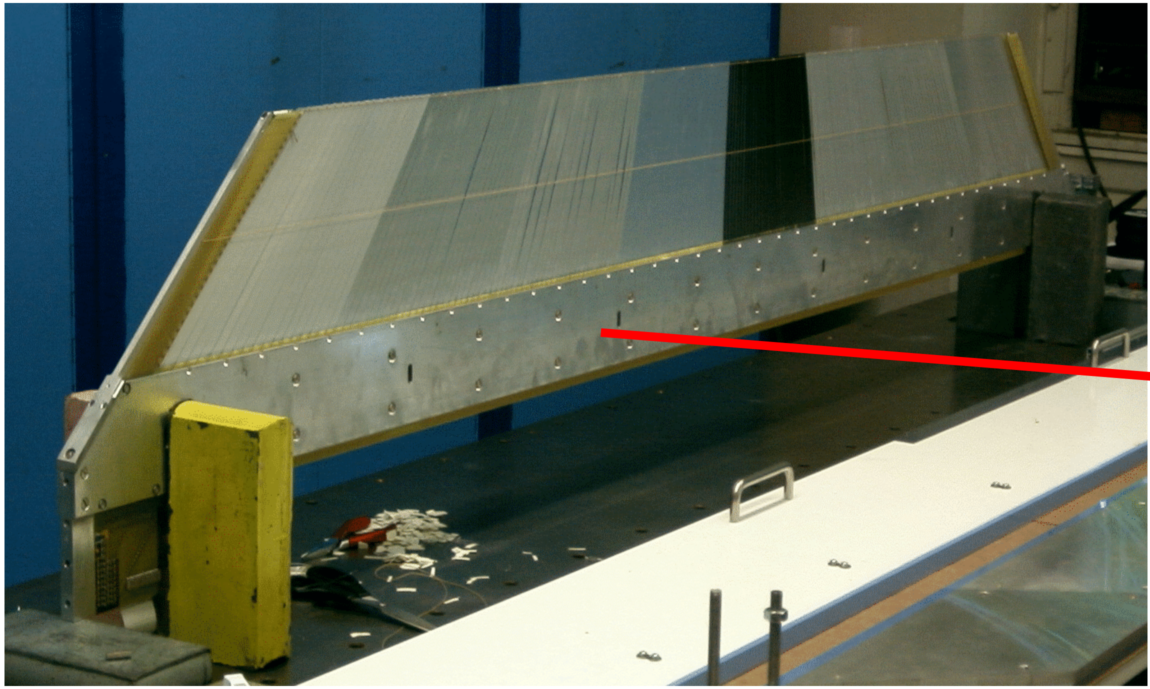
complete detector segment

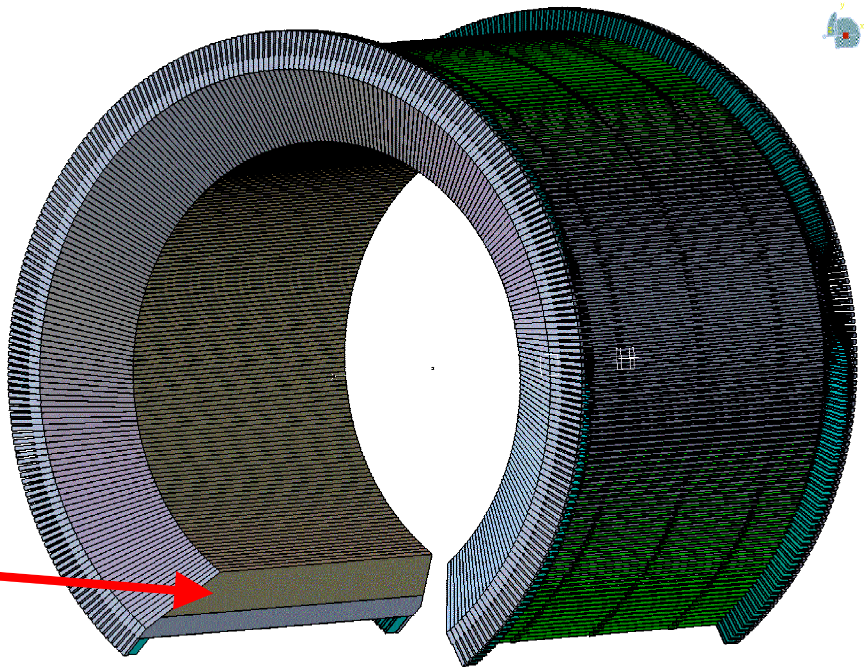
Final Prototype for POWTEX

- Active length l = 1,60 m.
- Distance to the scattering probe r = 80 cm.
- 45° design at the end to fit the front- and back-cup of the detector with minmal blind area.
- Stripes of central readout cathode are konfokal oriented to the scattering probe (integration of scattering intensity per θ).

Design study for POWTEX

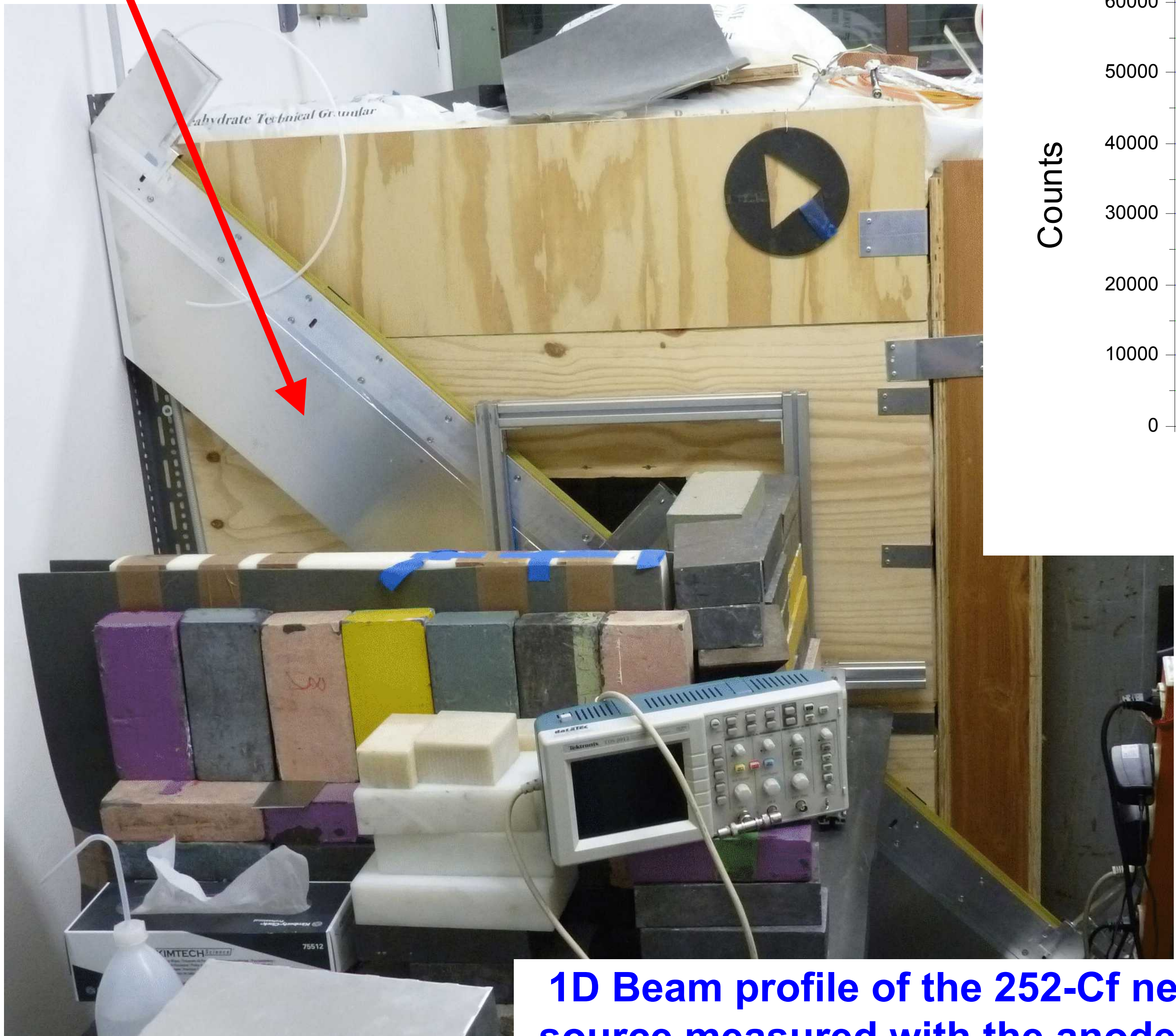
9m² sensitive area,
250 lamella segments,
front- and back-cup
are not shown here



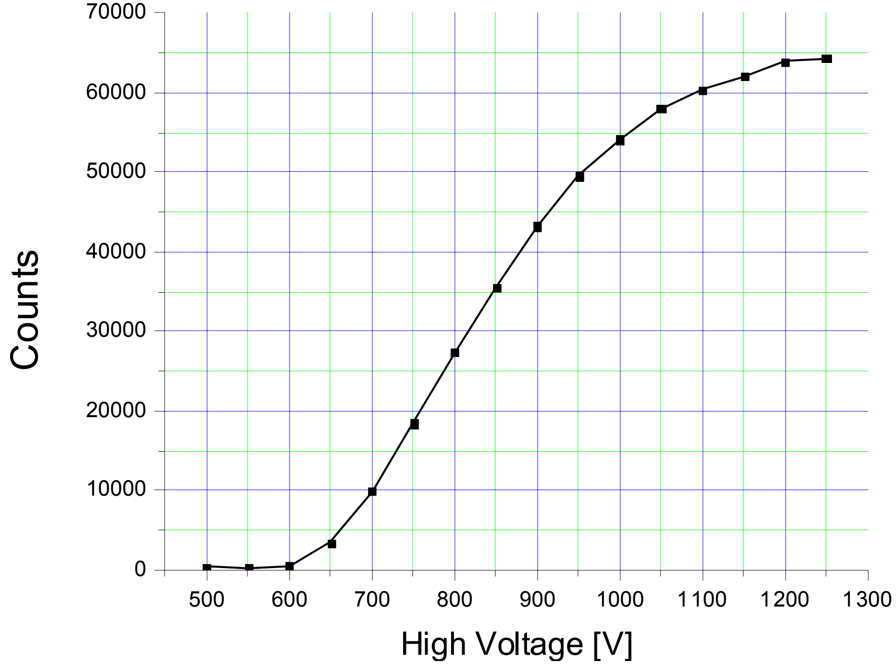


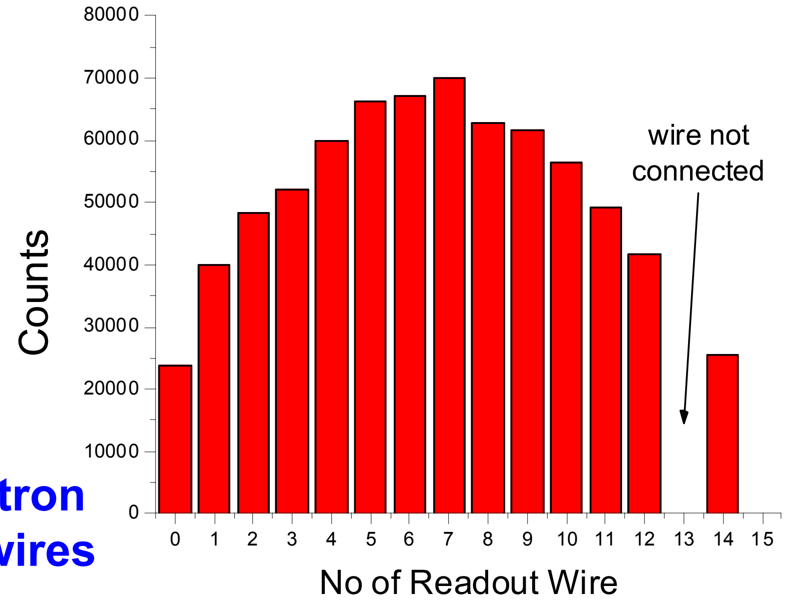
First measurement results

Final Prototype exposed to Cf-252 neutron source at the Physikalische Institut



Counts from the anode wires





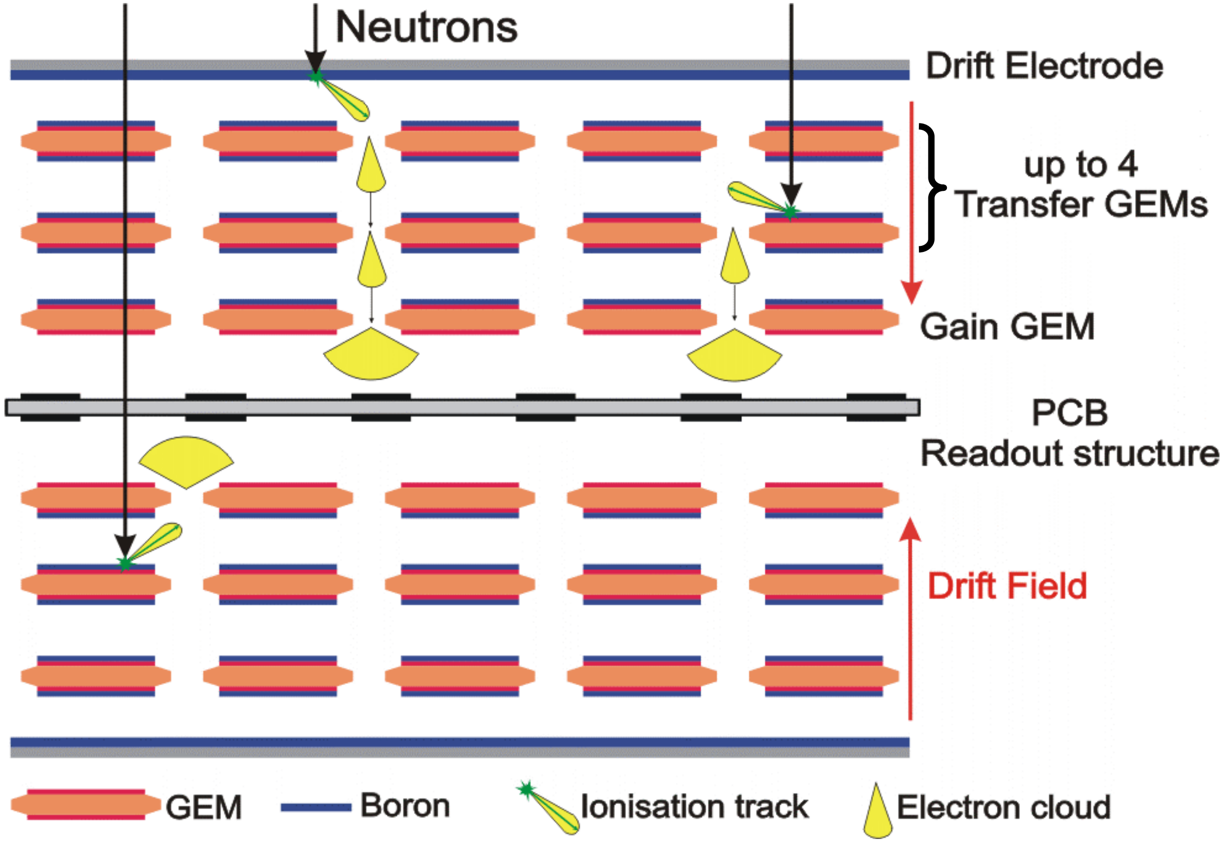
1D Beam profile of the 252-Cf neutron source measured with the anode wires

CASCADE: Multiple Boron Layers on GEMs (patented)

$^{10}B + n \rightarrow {}^{7}Li + \alpha + 2.79\ MeV$ (6%) 3838 b
$\hookrightarrow {}^{7}Li^{*} + \alpha + 2.31\ MeV$ (94%)

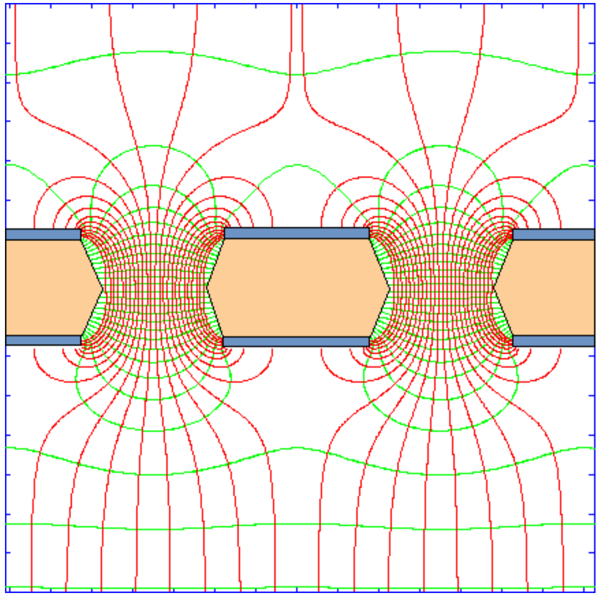
- GEMs can be operated to be transparent for charges!

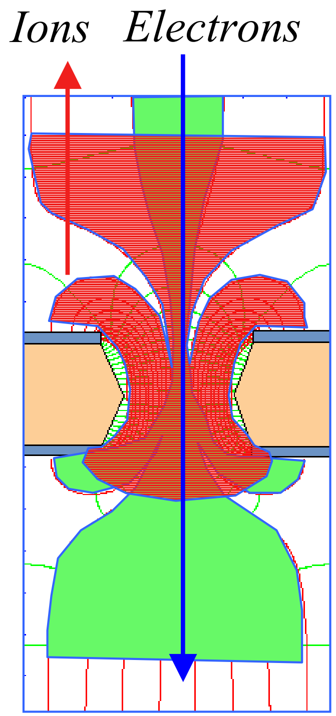
  → **they can be "cascaded"!**
- Each one can carry two Boron layers.
- Last one operated as amplifier.



"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

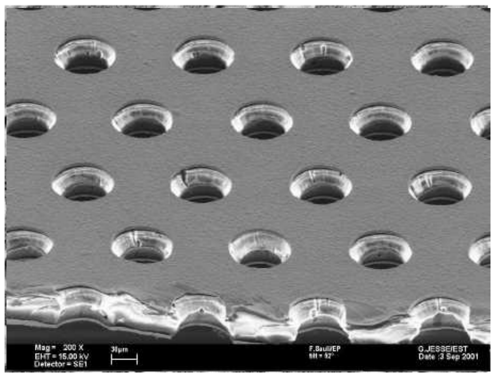
The Gas Electron Multiplier (GEM)

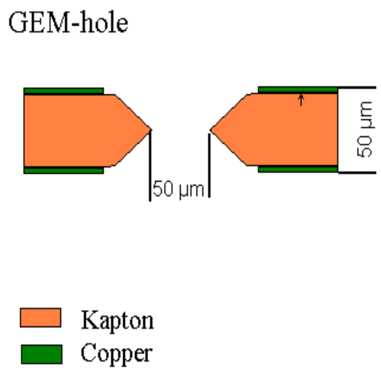




Amplifier Mode

- In hole high fields allow
  Gas amplification 1 - 400





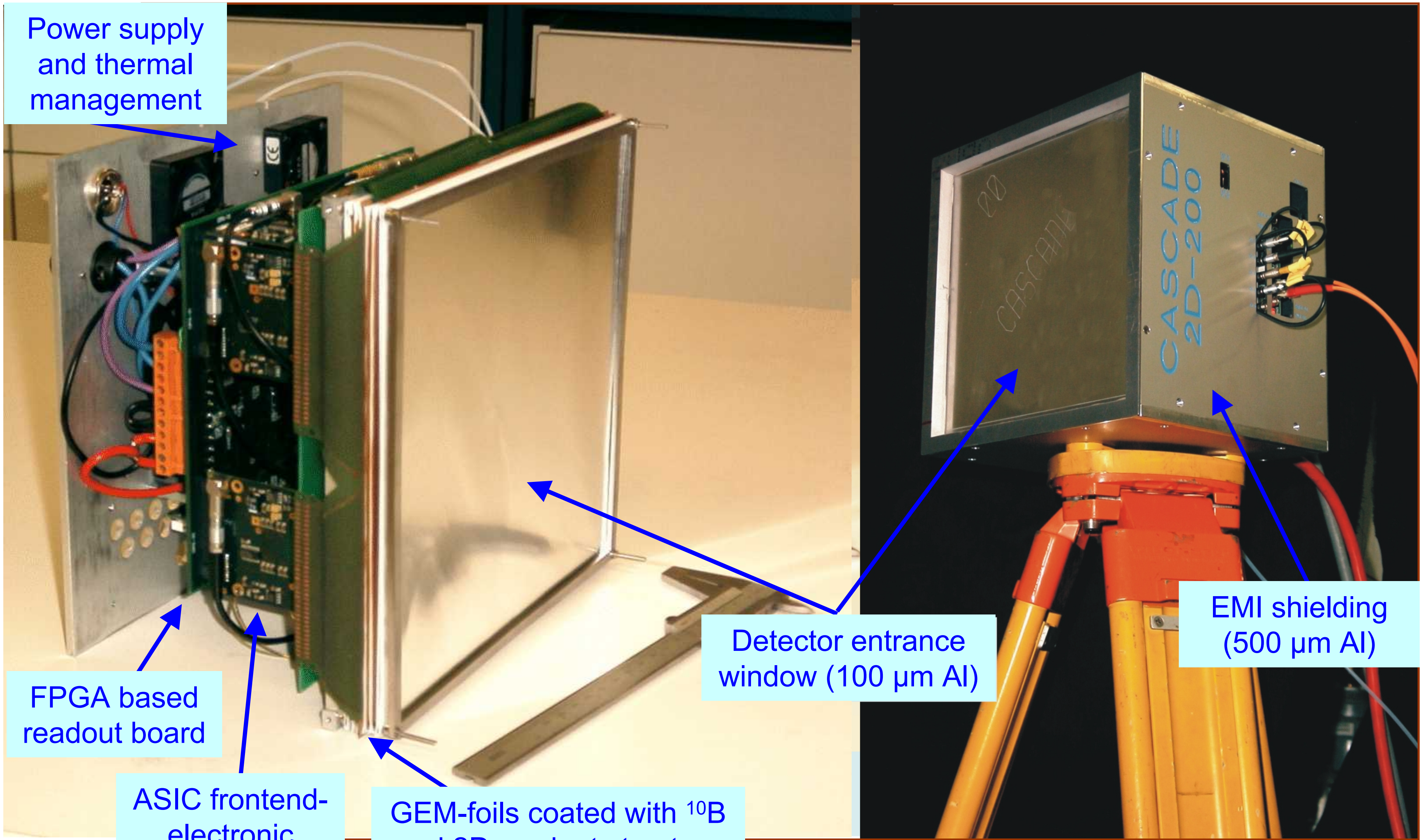
Transparent Mode

- At gain 1, electric fields transport charges through the holes

The GEM inherently introduces high rates capability of 10 MHz/cm^2 !

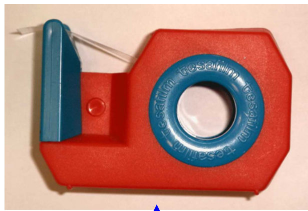
taken from Sauli et al.: http://www.cern.ch/GDD

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

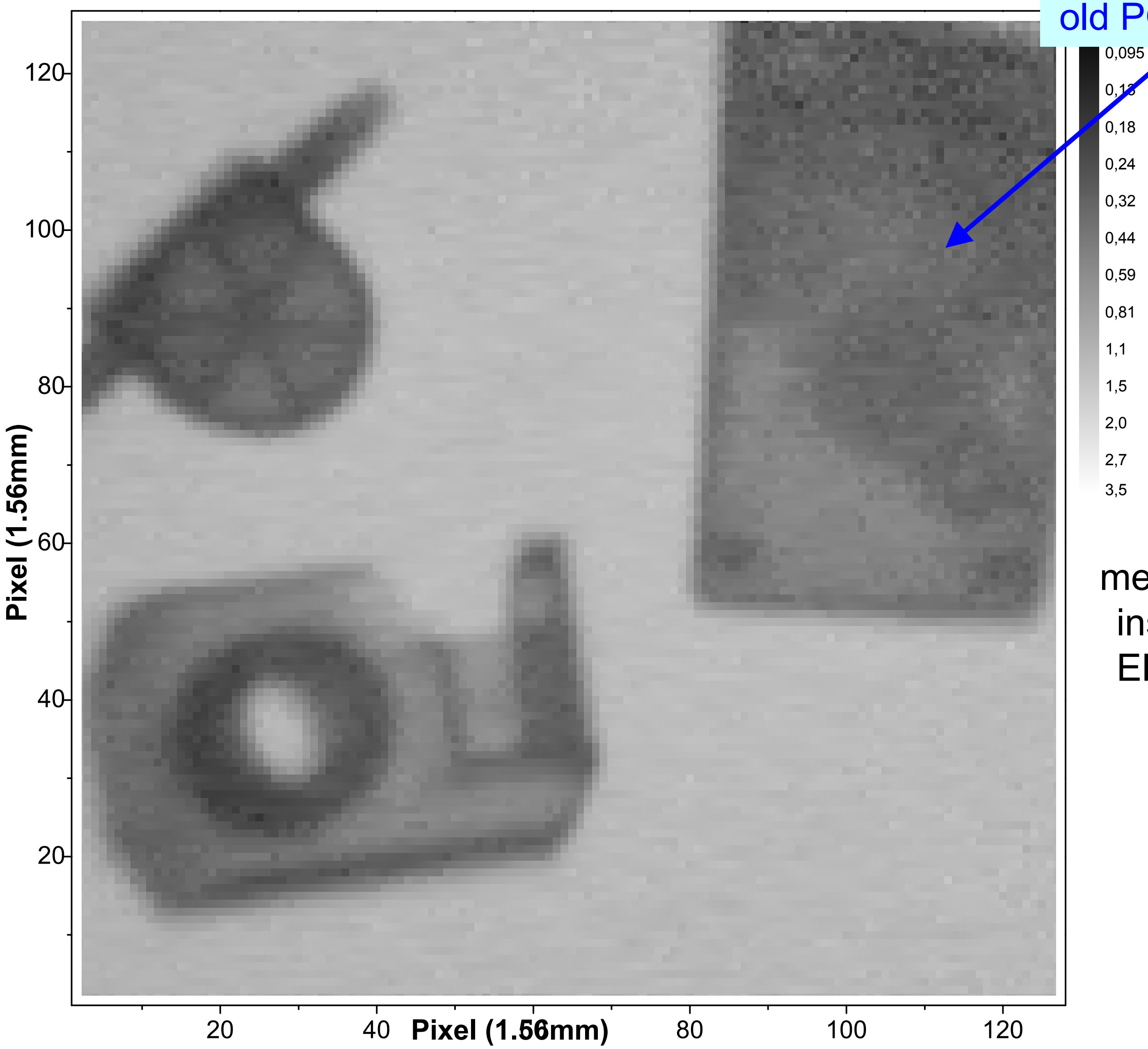


Neutron-Pictures with the 2D-200 CASCADE Detector System

Water Flow-Controller



Tesa-Tape



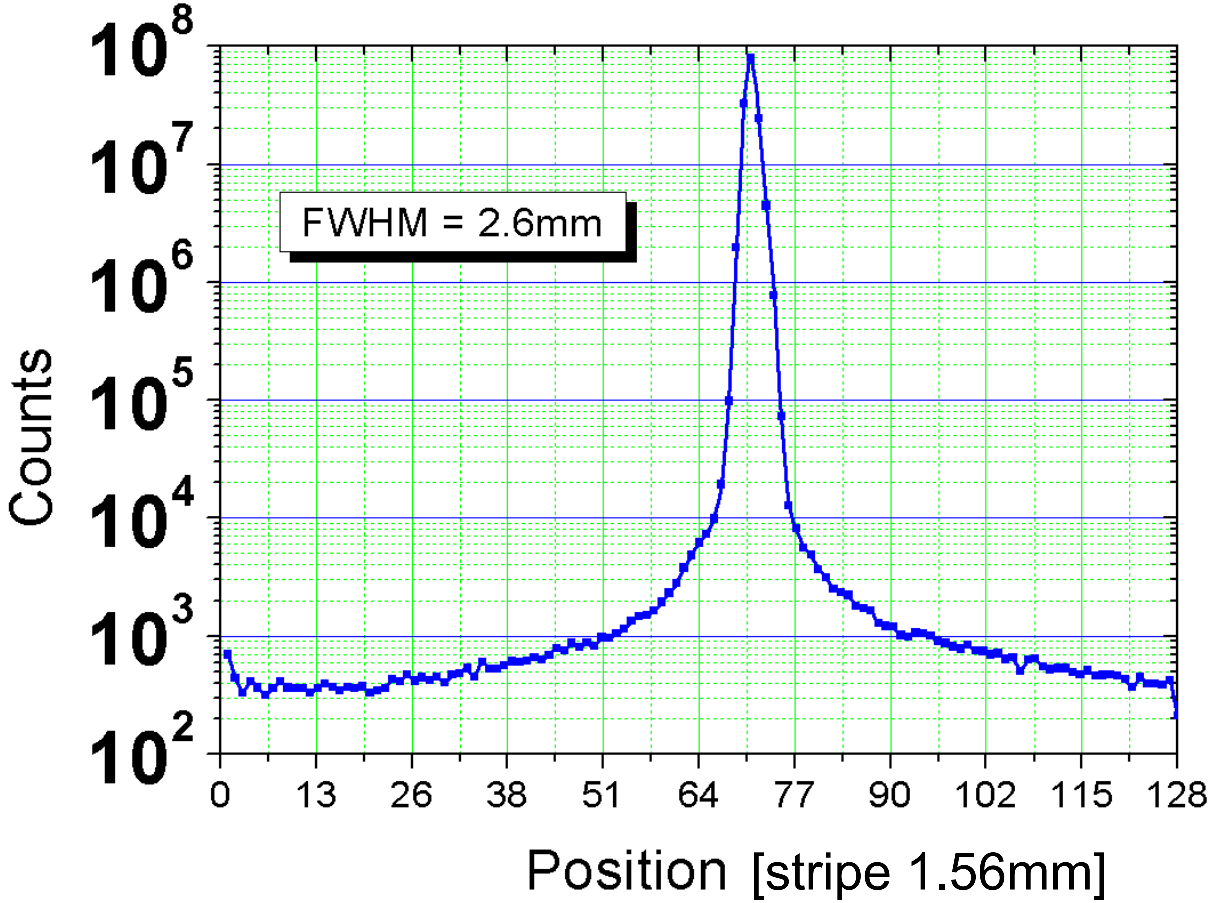
old PC-Mouse

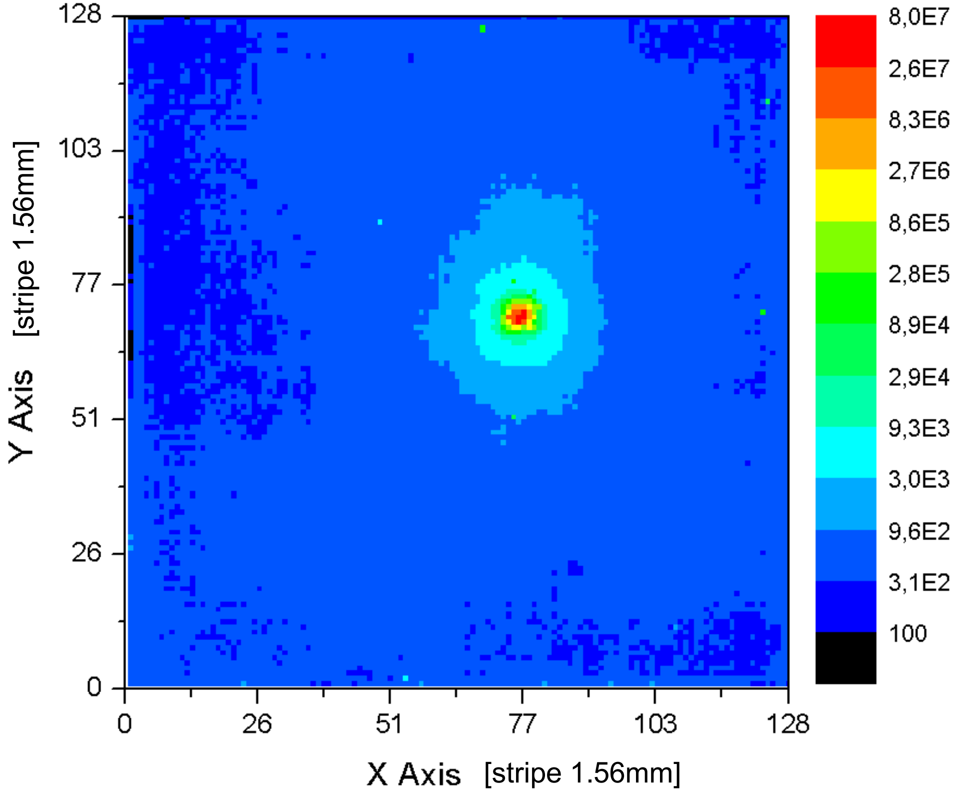
measured at instrument EKN at FZ Jülich

Position Resolution and Contrast with Neutrons

PSF measured using a beam of 0.57mm diameter

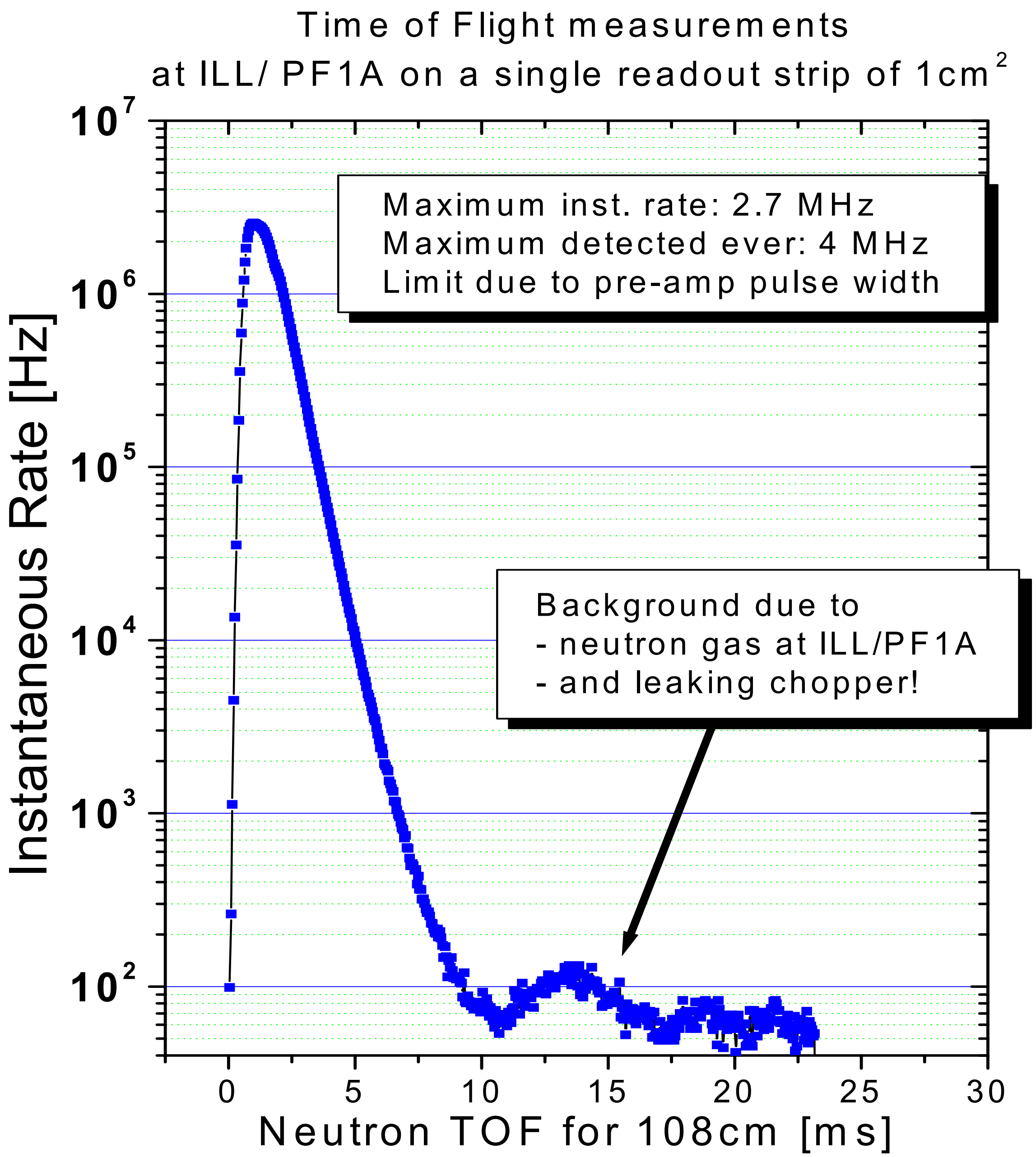
Log- Scale!





measured at former instrument EKN at FZ Jülich

TOF Dynamics Achieved 2003 at PF1A/ILL



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

Latest Detector App.: Modulated IntEnsity by Zero Effort (MIEZE)

MIEZE: Resonance Spin-Echo without the second Arm

- Fast Intensity Modulation Technique used in Quasielastic Neutron Scattering
- Large solid angle as no second spin-echo arm needed → multi-detector setup
- Polarized neutron Scattering on magnetic structures and objects with very high resolution
- Instrument Development at RESEDA / FRM II

Collaboration:
F. Groitl[1], J. Kindervater[3], W. Häußler[3 4], M. Klein[1], C.J. Schmidt[2], U. Schmidt[1]

[1]Physikalisches Institut, Universität Heidelberg
[2]GSI Detector Laboratory, Darmstadt
[3]Physik Department E21, Technische Universität München
[4]Research Neutron Source Heinz Maier-Leibnitz (FRM II)

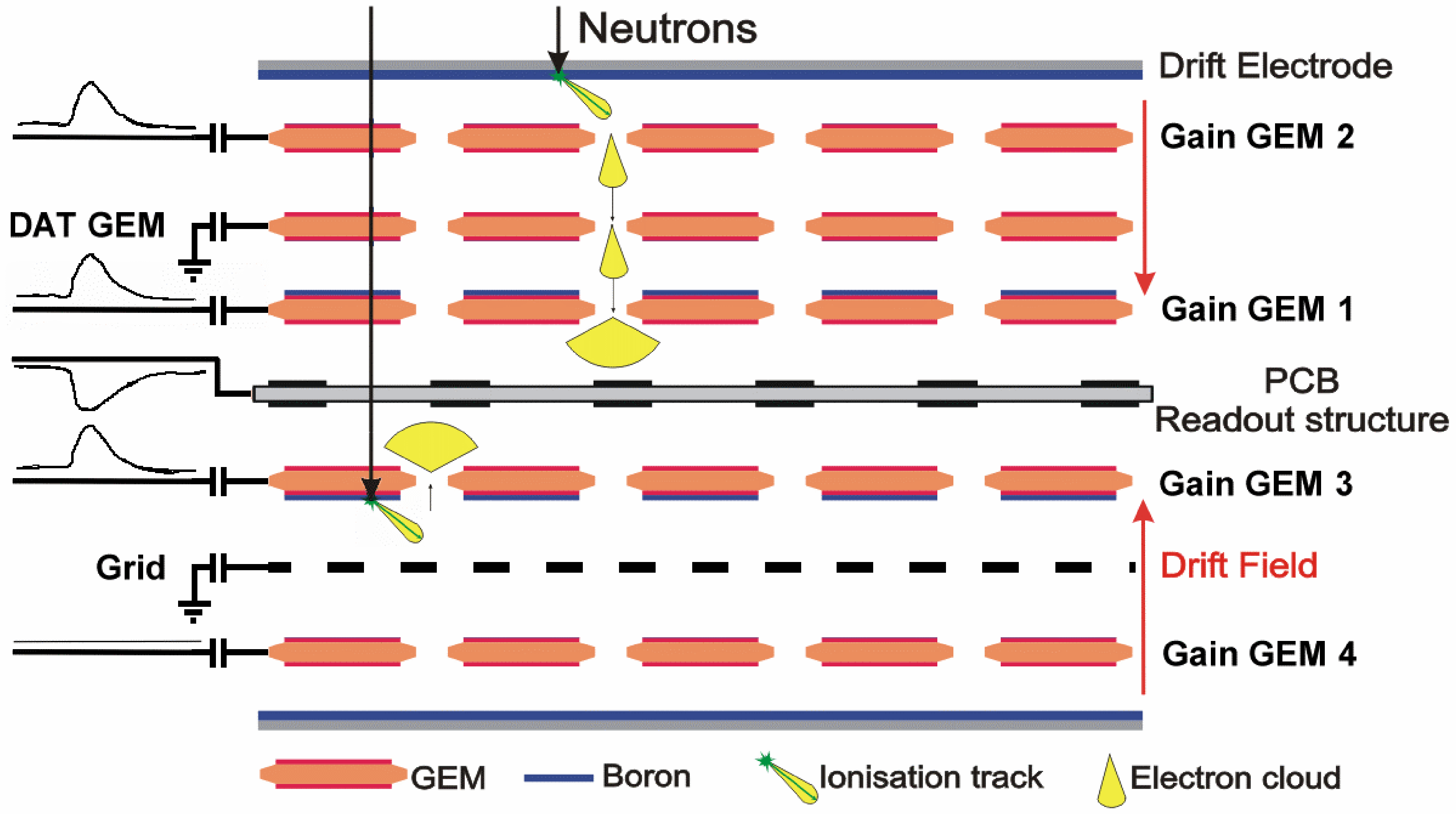
Challenges:

- Modulation freq. **(10kHz - 1MHz)** requires high intrinsic detector time resolution
- Long. signal period (25mm - 250µm) requires z-resolution up to 25 µm
- synchronous, phase sensitive detection at several MHz

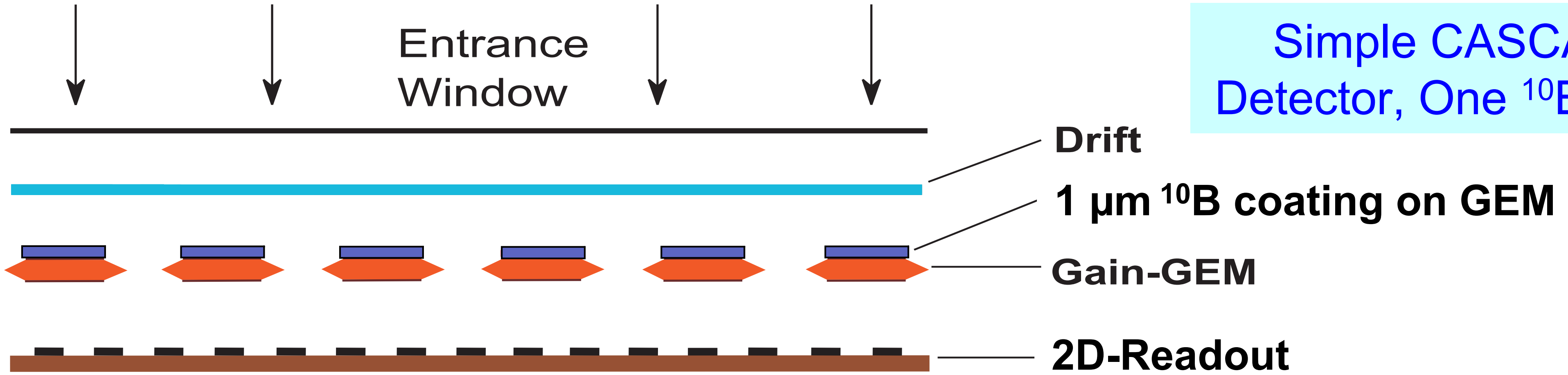
Second MIEZE Test Experiment

Succesfully tested: Detection of influenced charge signals at GEM's and **Inter-GEM signal decoupling reached through**

- a further, AC-grounded GEM (DAT-GEM)
- an AC-grounded Mesh (Grid, 30% open)



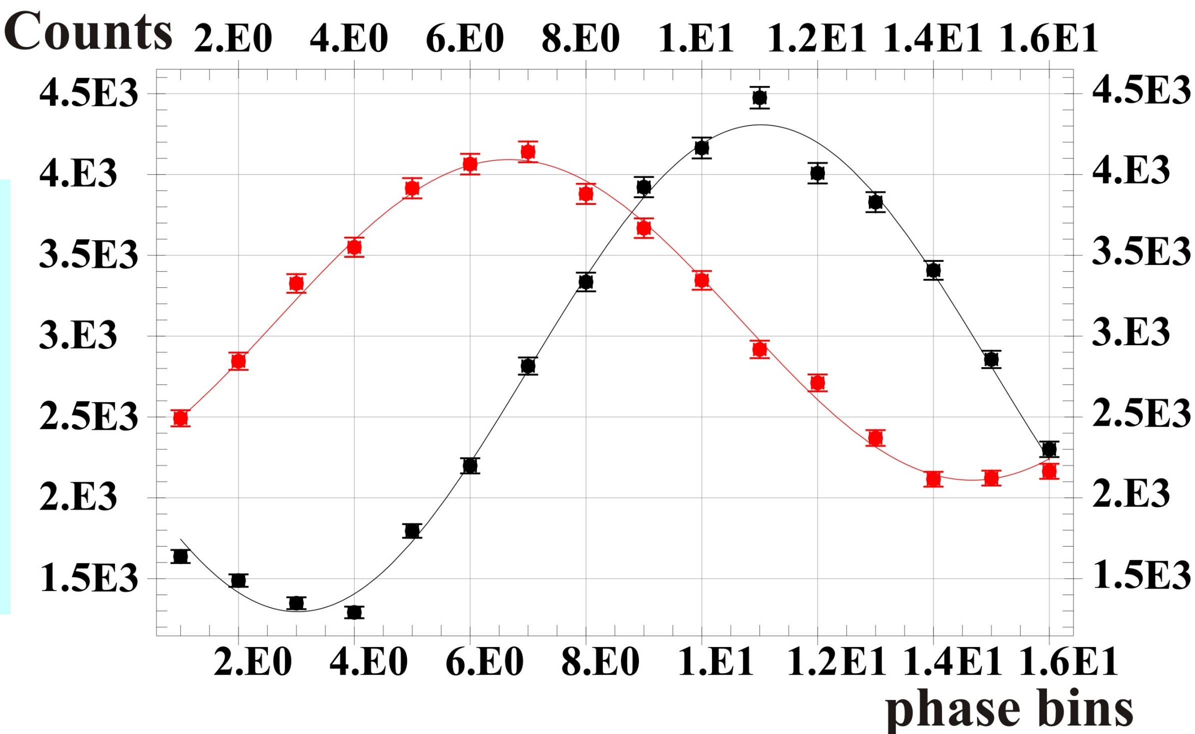
First MIEZE Test Experiment



Simple CASCADE Detector, One ^{10}B Layer

Intensity Modulation at 2 different Pixels on the Detector

MIEZE frequency 654 kHz at λ_n = 5.3 Angstrom



(dwell time 96 ns)

ClPix Readout ASIC

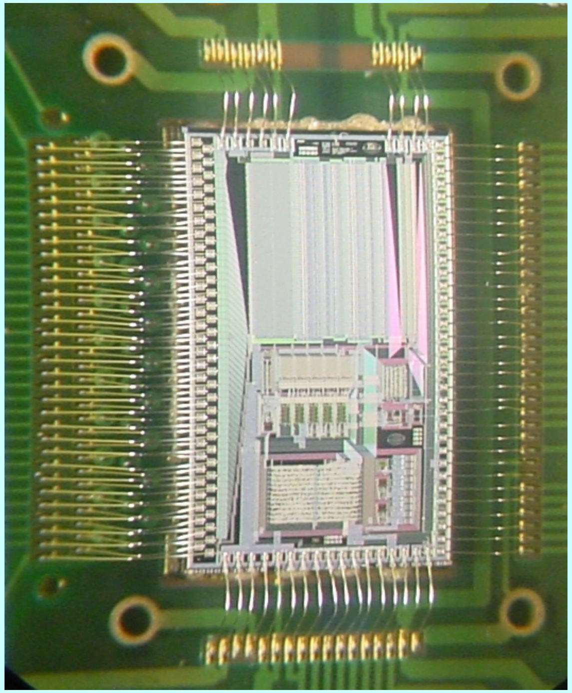
- High Energy Physics has been there! They provide solutions:

- Heidelberg ASIC Lab developed

  64 channel X 10 MHz

  ASIC pre-amp and discriminator

  on one chip: The ClPix for H1



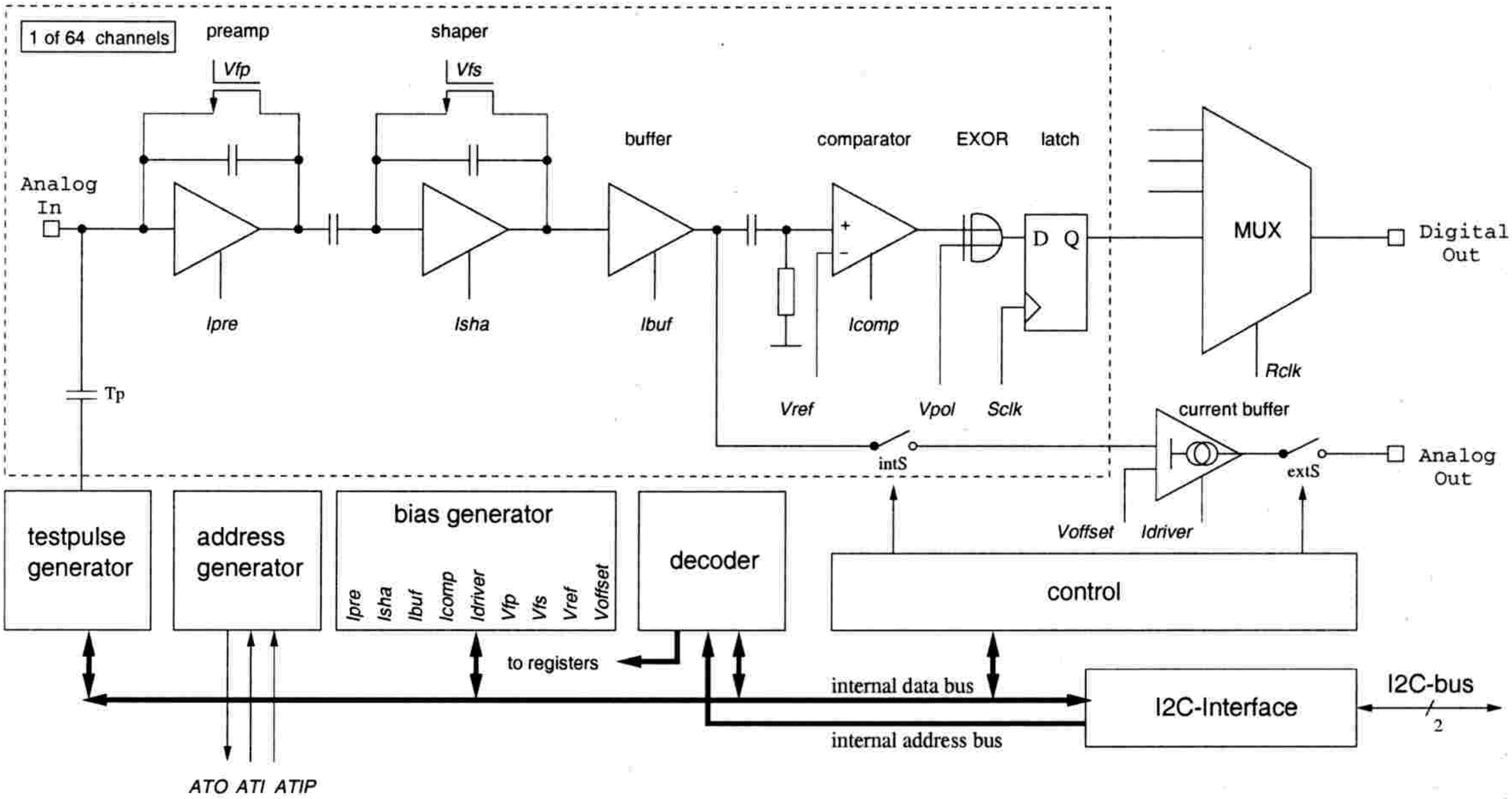
ASIC LABOR HEIDELBERG

- ClPix and supporting electronics will pump neutron data to the computer.
- No more analogue hf-simulations to cope with readout distortions….

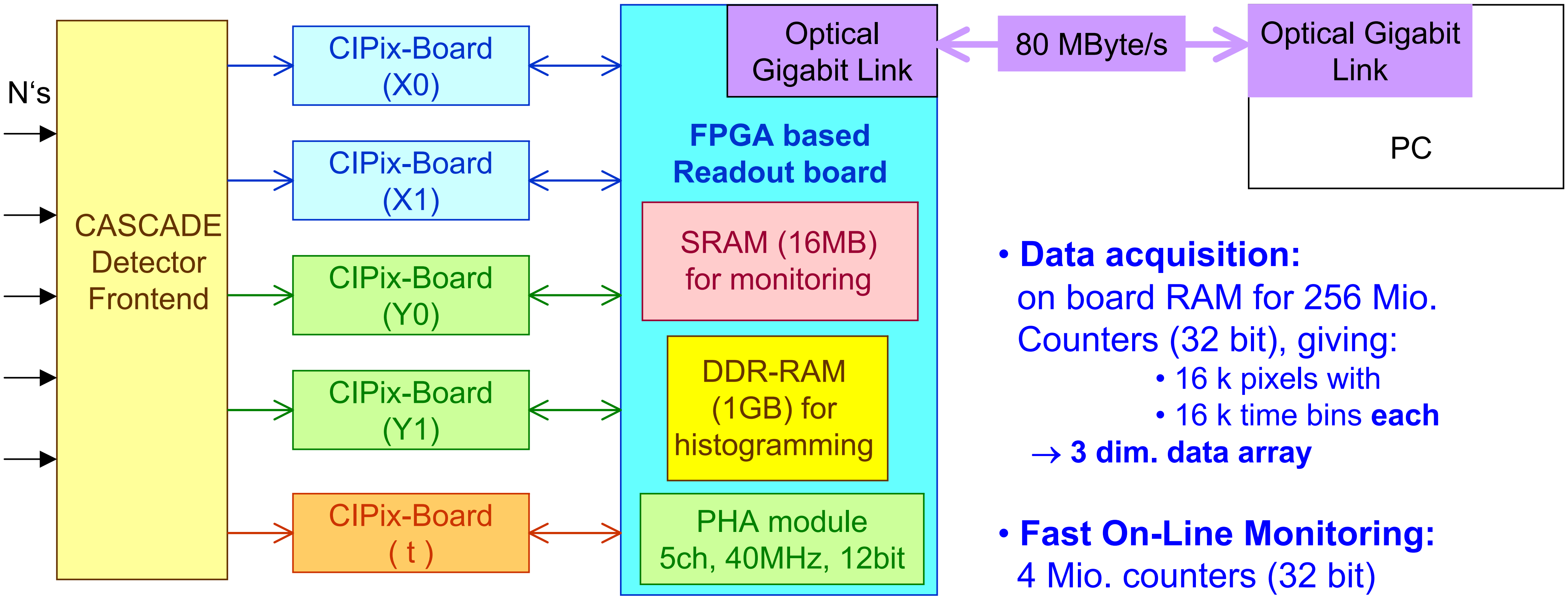
Just read and digitise signals individually

ClPix Schematic

64-Ch. Charge Sensitive Pre-Amp, Shaper, Discriminator



CASCADE Detector Readout System



- **Data acquisition:**
  on board RAM for 256 Mio. Counters (32 bit), giving:
  - 16 k pixels with
  - 16 k time bins **each**

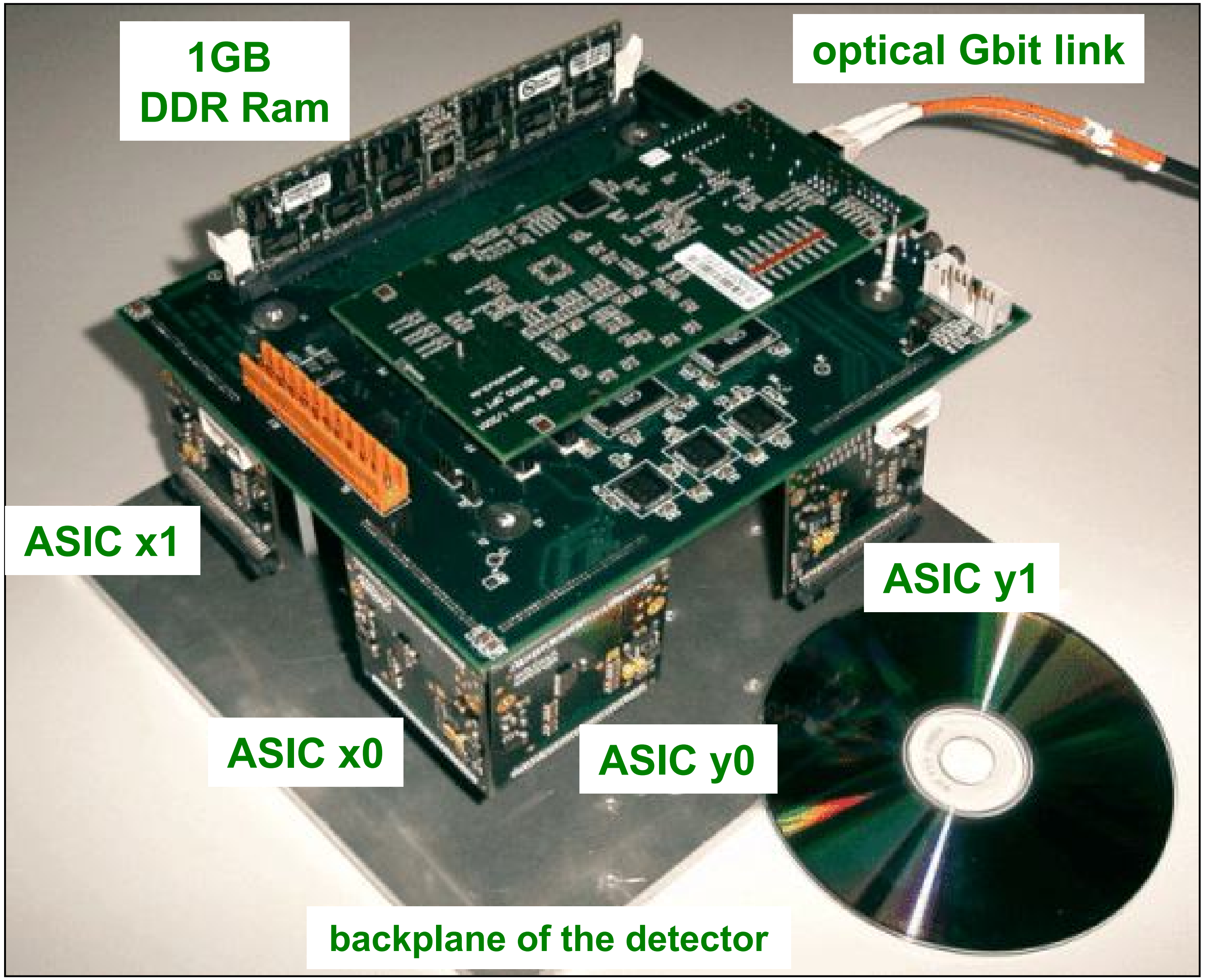
  → **3 dim. data array**

- **Fast On-Line Monitoring:**
  4 Mio. counters (32 bit)
  freely configurable: e.g.
  - 16 k pixels time integrated
  - 16 k pixels each realizing TOF in a window from e.g. 10ms to 11ms

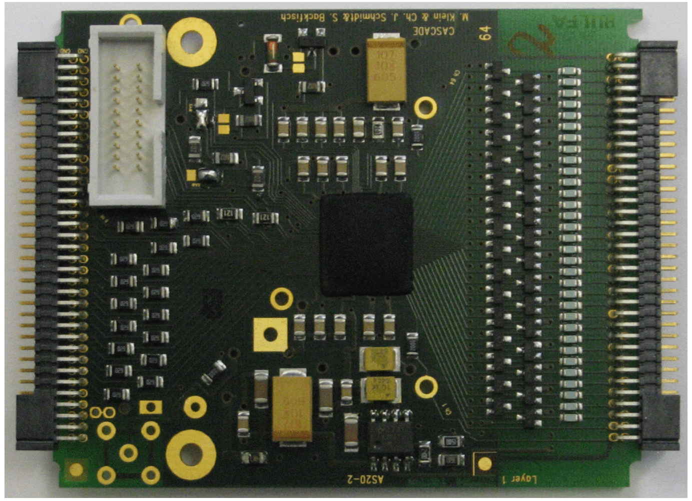
- **Programmable Pulse Height Analysis (PHA) on selected channels**

- **4 CIPix ASIC** reading **128x128** channels
- **1 CIPix ASIC** for TOF-resolution down to **100ns**
- **FPGA** based readout, control of CIPix, data-preprocessing and compression
- boards mounted directly on the rear of the detector
- electrically decoupled from host computer

FPGA-based Readout of the 2D-200 Detector

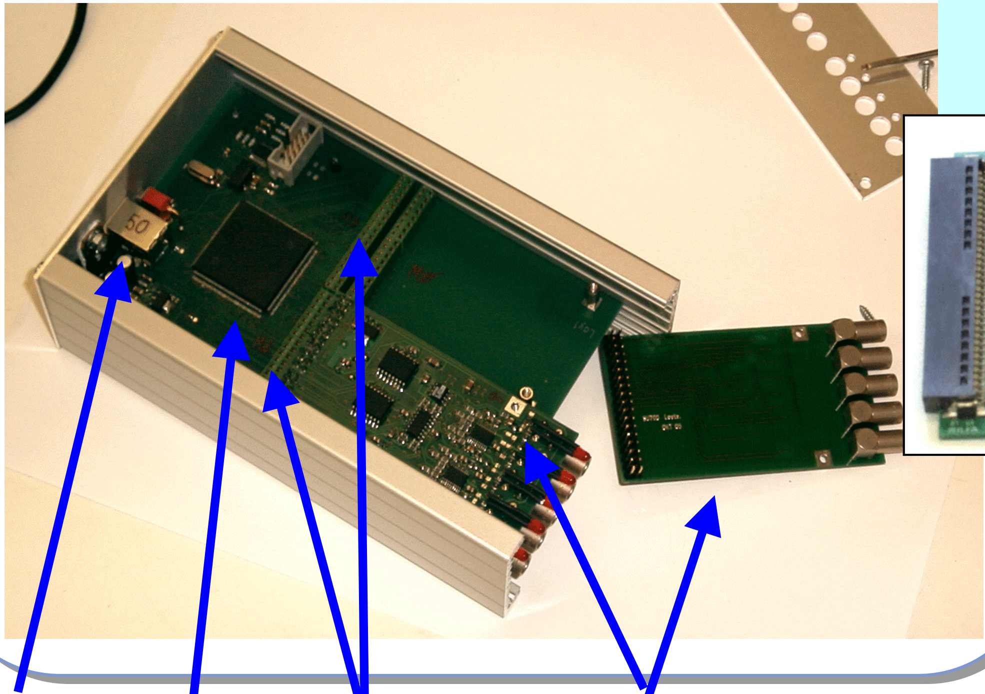


ASIC board AS20-3 with input spark protection



Integral Count Rate: 2MHz; local count rate: 333kHz (10% dead time)

CASCADE DAQBox: one touch solution for a single ASIC



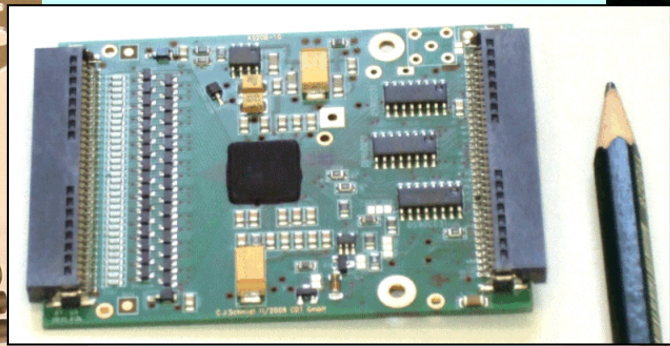
USB 2.0 interface

FPGA

Positions for up to 4 Sub-modules

Example for two Sub-modules

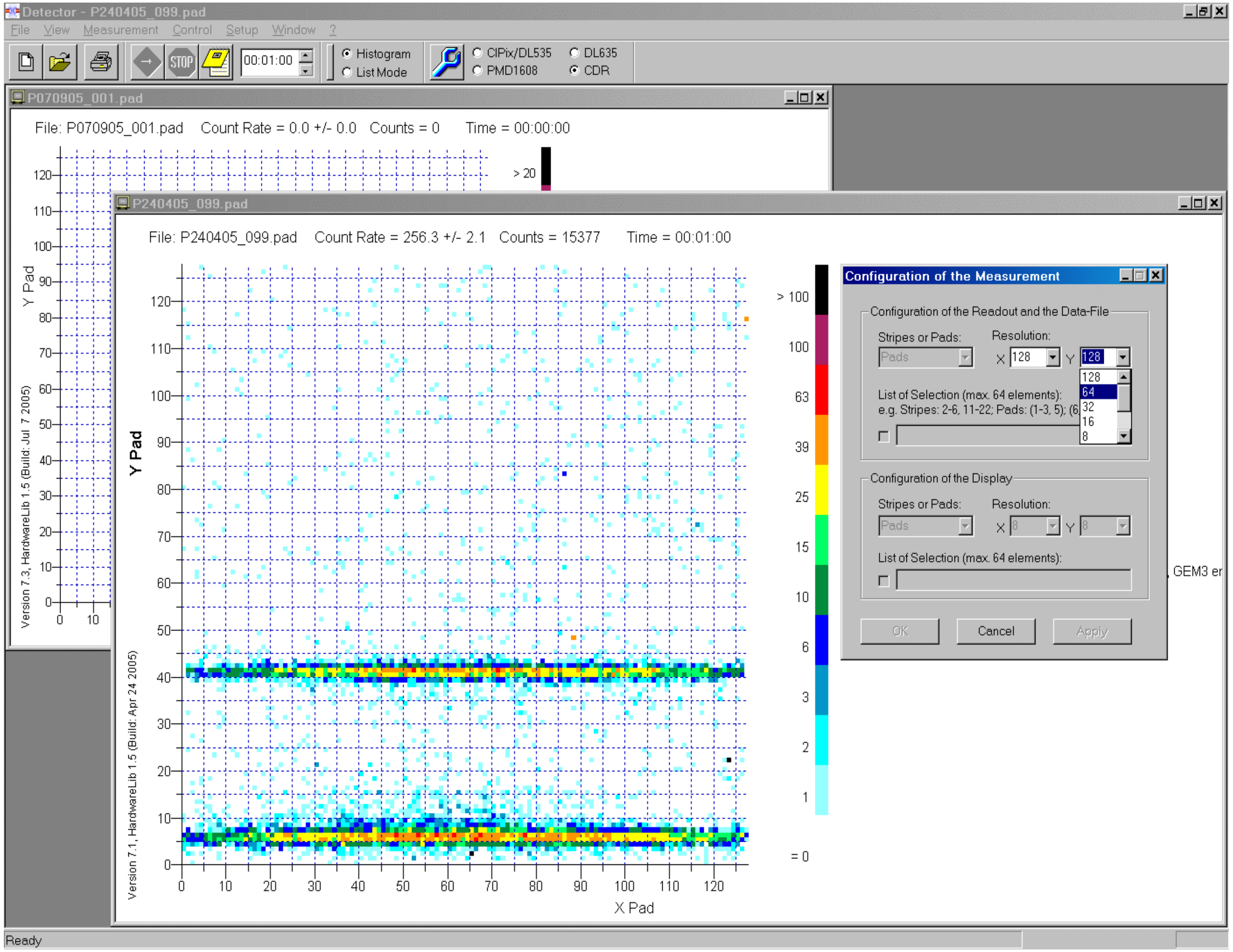
CIPix ASIC-board AS20B-1



size:
49mm x 75mm

- USB 2.0-Interface to PC, Software-Library and Windows Control Program.
- FPGA for event reconstruction, histograming and interface to ASIC.
- Memory sub-module (32 MB) to store data (histogram) on DAQBox.
- Interface to ASIC board (direct connection or via flat cable).
- Programmable PHA sub-module

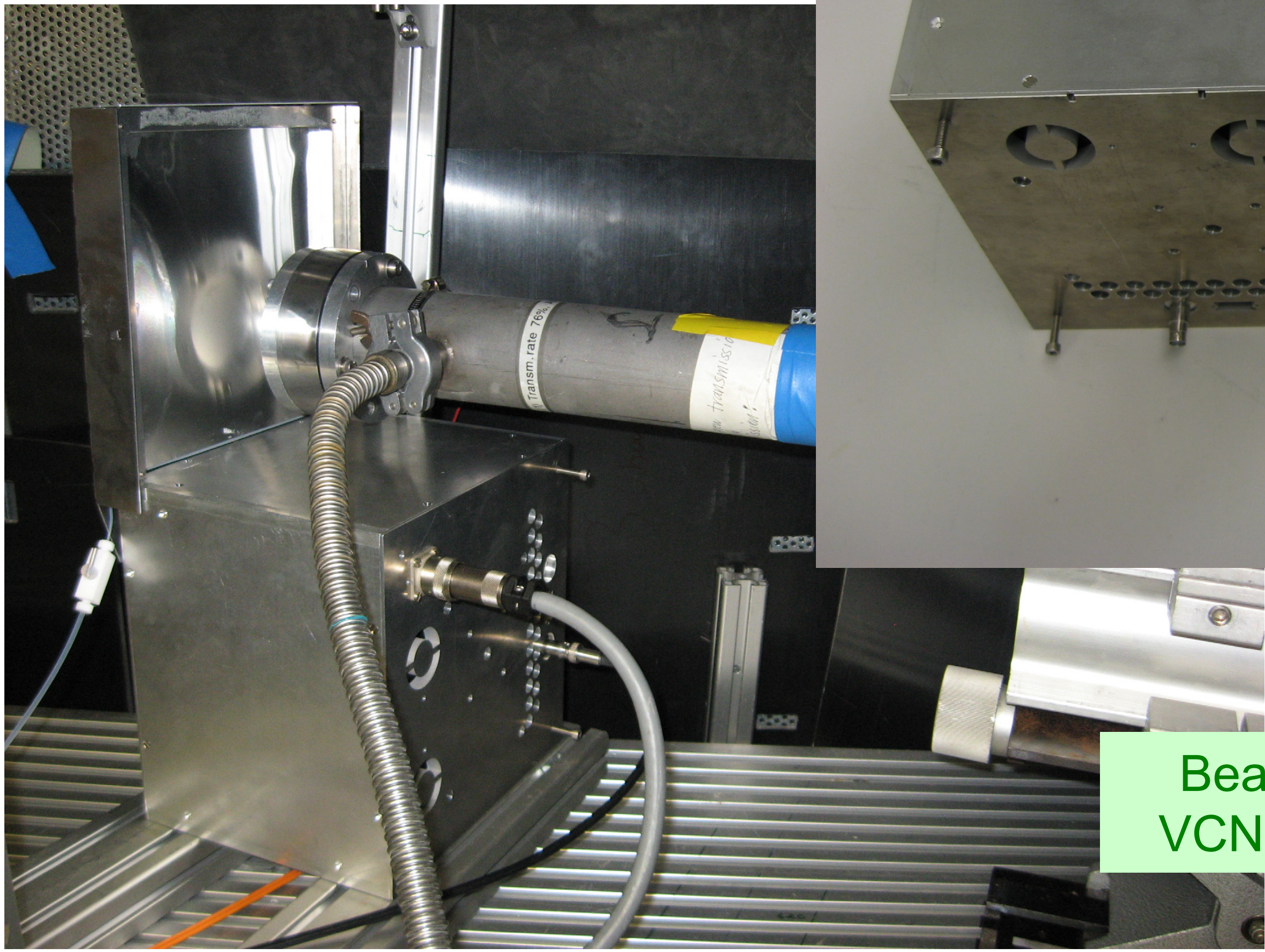
Detector Control Software

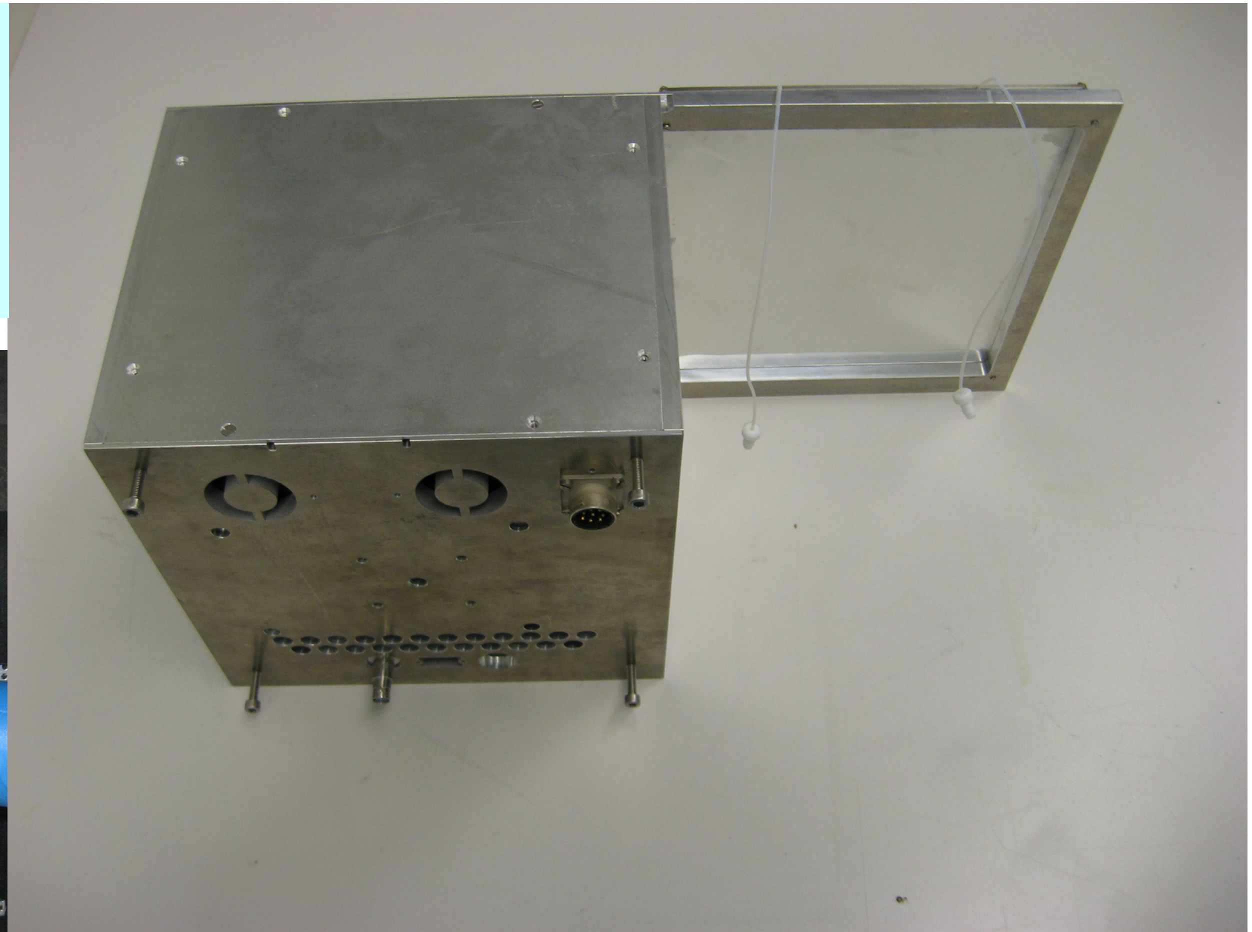


- Supports all types of CDT readout electronics
- Start measurement (Image, TOF, PHA, etc.) immediately
- CASCADE Hardware Library in C++
- Software drivers for Windows (NT/2000/ XP) and Linux (2.4.x and 2.6.x)

GEM based beam monitors 200mm x 200mm

- actual: 1D readout with 128 stripes
- 20 MHz count rate capability





Beammonitor used for VCN on Niveau D at ILL

Summary

- CDT developes and provides technological alternatives to ^{3}He based neutron detectors.
- Experienced in building gas detector systems based on:
  - classical wire technology
  - modern GEM detectors for highest count rates
  - highly integrated readout electronics using ASIC/FPGA
- The systems combine high count rate capability with a large dynamical range as well as very low background sensitivity.
- The detectors can cope with ESS/SNS/JPARC-type source intensities and they can exploit spallation source time structure.
- The Jalousie design addresses detector systems with many square meters and can be grouped to build up a large detector system.
  - Under development: final beam test of POWTEX prototype in Dez. 2011
- CASCADE detectors can be easily adapted to special (neutron) applications:
  - resolving very fast (neutron) intensity modulations (in MIEZE applications).
  - beam monitor detectors.

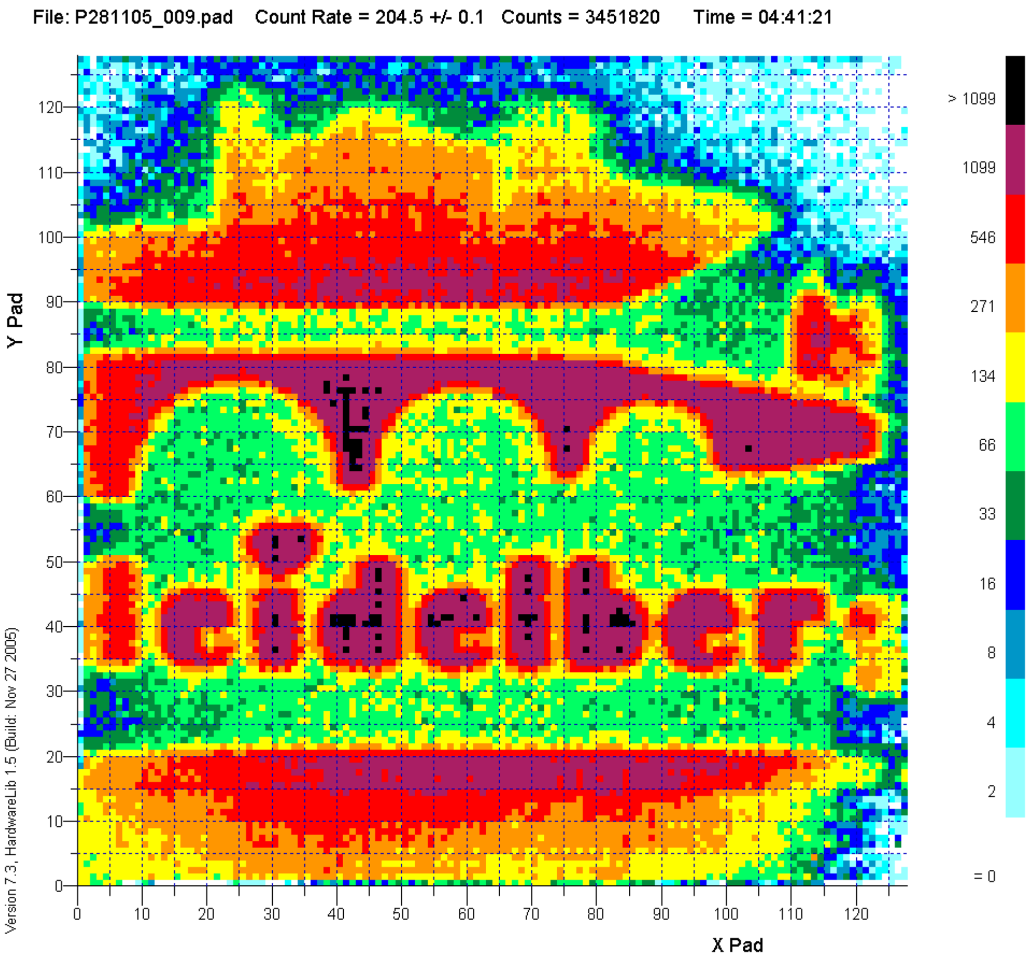
Outlook for new dimensions of count rate capability

- GEM based gas detectors (e.g. beam monitors)
- operated in real counting mode
- detecting GHz of single ionizing particles
- on detector areas of about 10cm x 10cm or more

→ GEM has shifted High-Rates-Bottleneck to electronic readout !

→ CDT has started development for multi-channel, position sensitive readout electronics with 100 MHz count rate capability as a first step.

Thank you very much for your attention!



"The castle and the old bridge of Heidelberg"

Measured with a CASCADE detector at our lab source through a mask of Cadmium

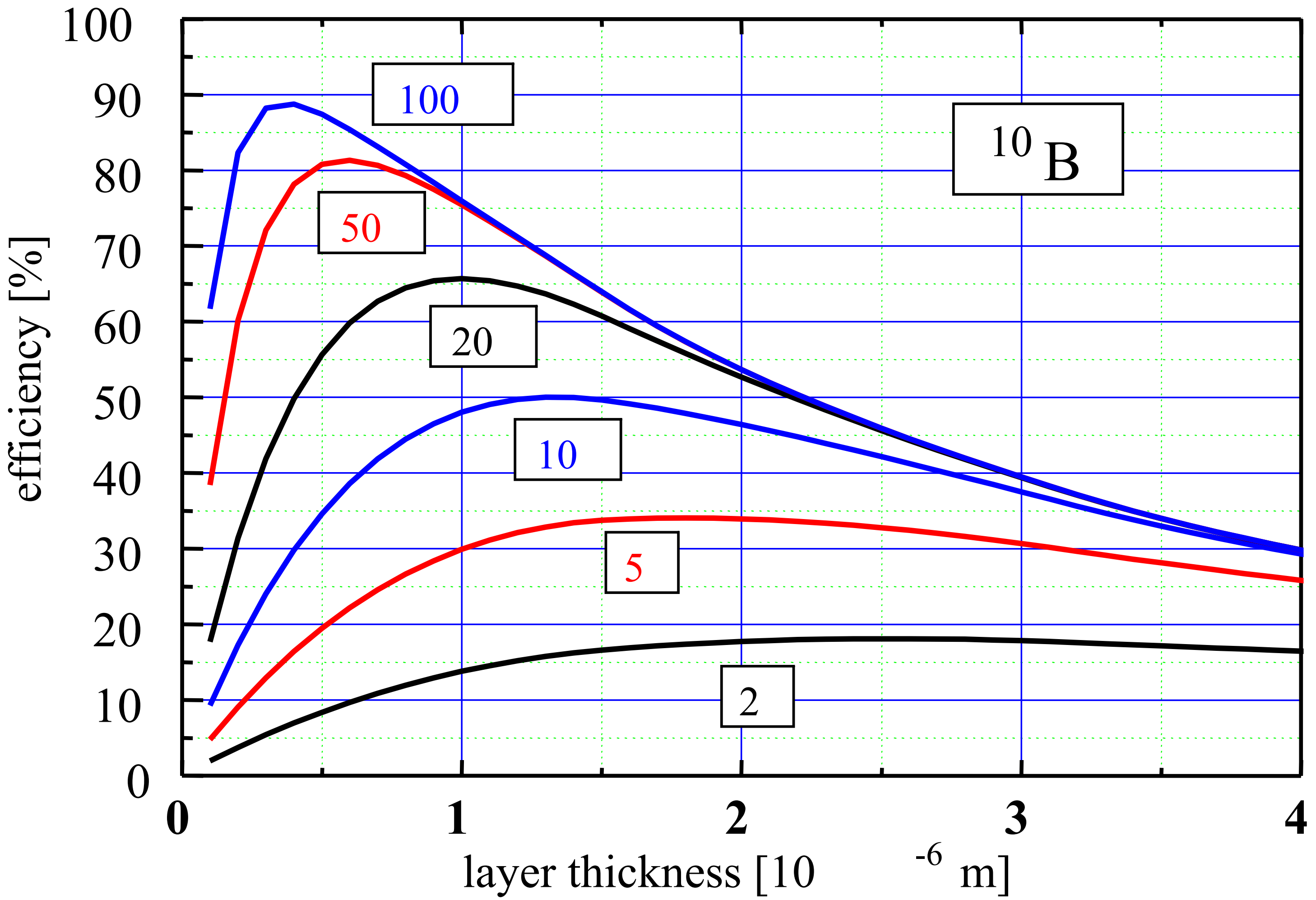
Actual specifications to meet POWTEX

Accumulated detection efficiency	■ 8 boron layers ■ inclined with 10°	**70% (1.8A)** **57% (1A)**
2D spatial resolution (at ambient counting gas pressure)	■ width of cathode readout stripe a = 6,25 mm ■ lamellae height h = 7,9 mm	**θ: 5,4mm (FWHM)** **φ: 9 mm (FWHM)**
TOF resolution (due to many folded anode readout wires within the depth of one lamella)	wire distance b = 12,7 mm	**2,5-5,5µs (FWHM)**
Count rate capacity per segment	due to the coincident read out of cathode and anode	**2MHz** **(10% dead time)**
Count rate per pixel	due to the segmented and individually read out cathode structure	**333kHz** **(10% dead time)**

- **Very low γ-background:** Low Z converter material ^{10}B, the high energy of the α can easily be detected and small drift gaps amplify the enormous difference in ionization density, a fast electron from gamma interaction creates in the counting gas as opposed to an alpha particle from neutron conversion.
- **Long term stability** due to continuous purge of cheap counting gas through detector.

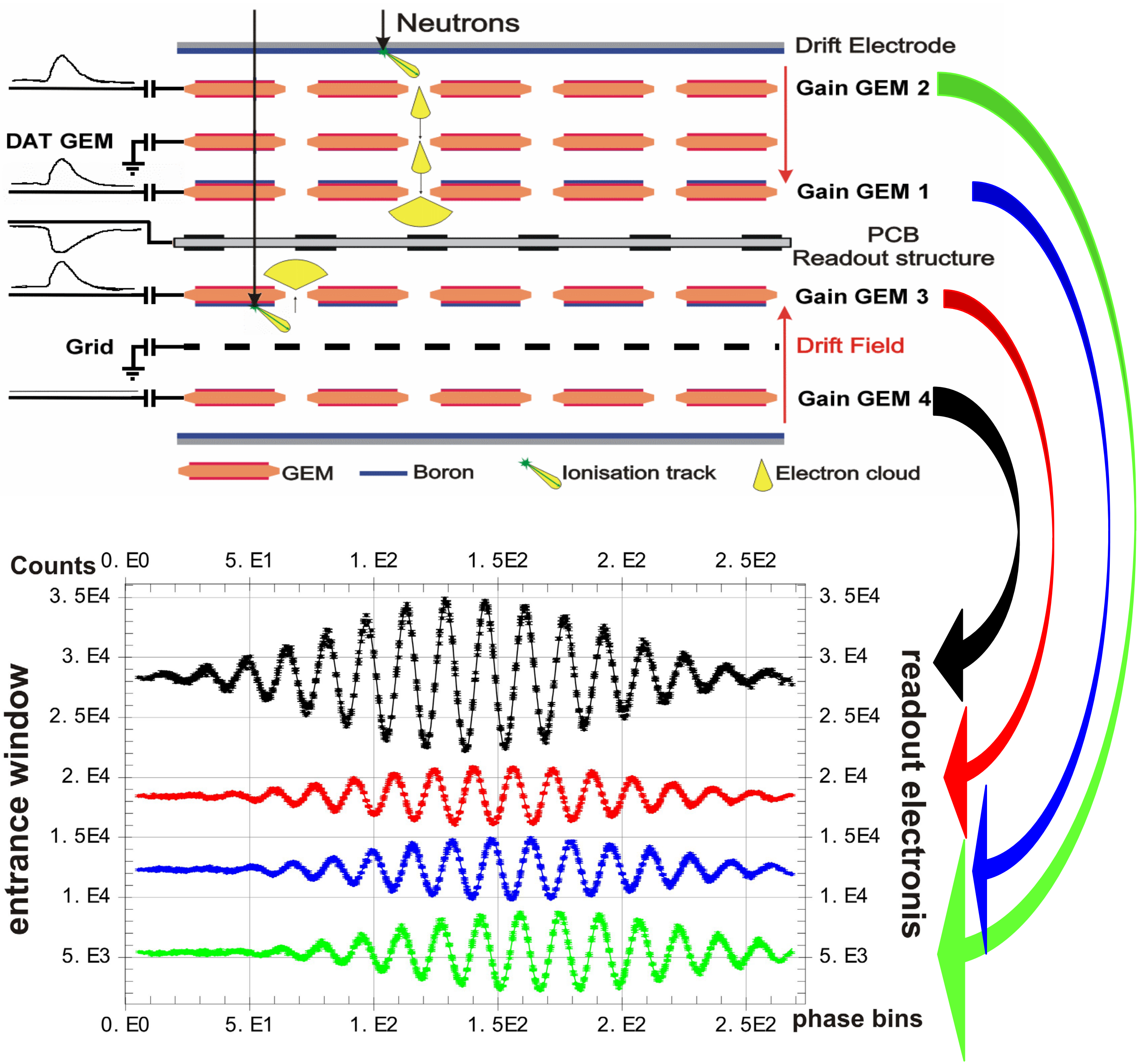
Cumulated detection efficiency for thermal neutrons (1.8 Å)

Accumulate single layer detection efficiency up to 50% for thermal neutrons (1.8Å) and up to 75% for cold neutrons (5Å).



Parameter: Number of doubly coated GEMs

Measured Spin-Echo-Group used for high resolution scattering

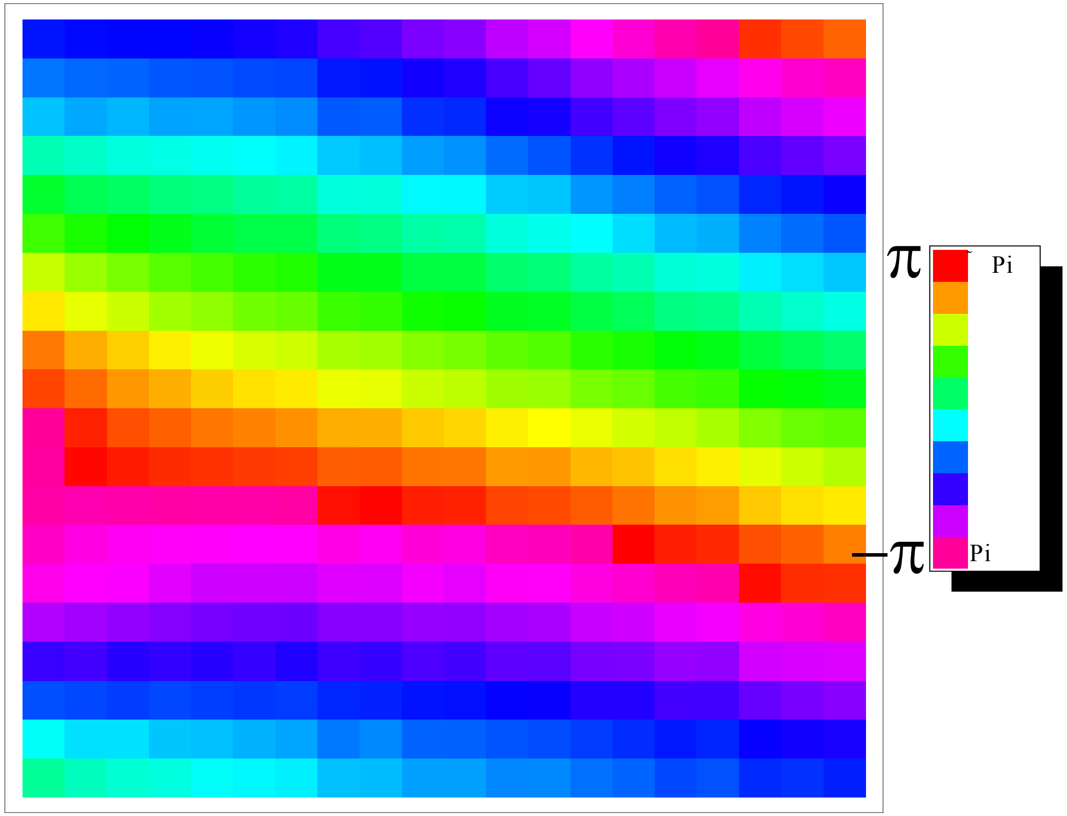


Shifting the Spin-Echo Group through the detector

- by moving the detector
- by means of an additional field coil (here employed)
- by detuning the synchronous frequency in coil 3

Follow the phase front, pixelwise determin. of Polarization

MIEZE neutron precession frequency: 654kHz, λ_n= 5Å , t_{se} = 0.76 ns



polarization seen w/o pos. resolution: 0.4%

Polarization with position sensitive phase correction: 36.90± 0.09 %

"CASCADE with NRSE: Fast Intensity Modulation Techniques used in Quasielastic Neutron Scattering", C.J. Schmidt, F. Groitl, M. Klein, U. Schmidt, W. Häussler, J. Phys.: Conf. Ser. 251 012067 (2010)

Last flipping coil tilted by 3.1°
→ more than 3π phase variation over detector plane

Two systems with 6 boron layers each operative at FRM II (RESEDA and MIRA)! Please look for Wolfgang Häußlers talk on Tuesday: „Experiments using NSE, NRSE and MIEZE-I at RESEDA"

