CASCADE, neutron detectors for highest count rates in combination with ASIC/FPGA based readout electronics

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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)
- 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

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The Scaleable CASCADE Detector Concept

Disentangled Detection-Mechanism

1. Neutrons are converted by a **solid converter**, no pressure vessel
   - Imagine a large area detector that you can lift with one hand
2. Fragmentation products deposit energy in **low-cost counting gas at ambient pressure**
   - continuous purge of counting gas gives long term stability
   - detector can be serviced within a few hours, no UHV cleaning needed
3. **GEM-amplifier** raises Signal/Noise beyond needs
4. **Simple readout structures:** charges are collected by simple conducting structures of macroscopic size (e.g. strips, pads, circular patterns, etc.)
5. **Highly integrated ASIC/FPGA readout electronics**

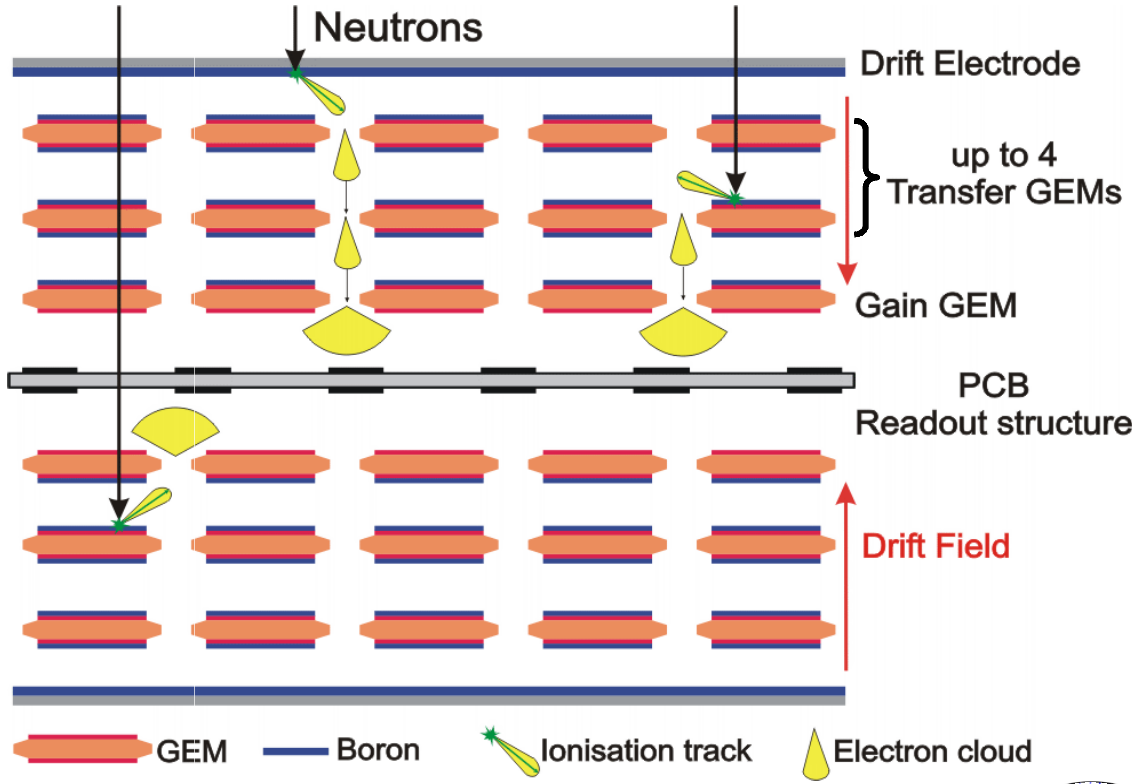
CASCADE: Multiple Boron Layers on GEMs

$^{10}B + n \rightarrow {}^{7}Li + \alpha + 2.79\ MeV$ (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.



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

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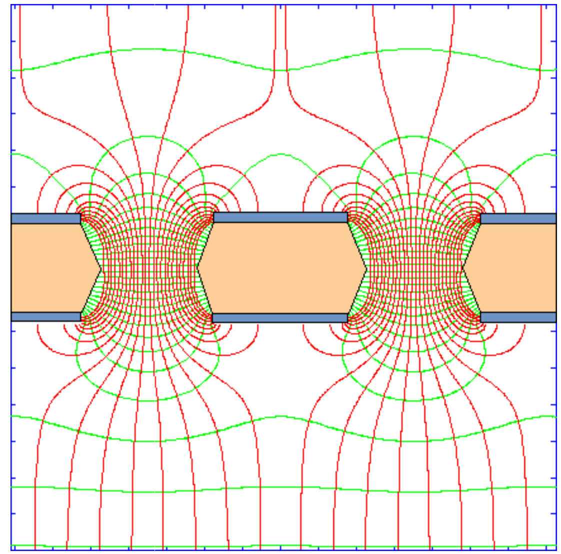
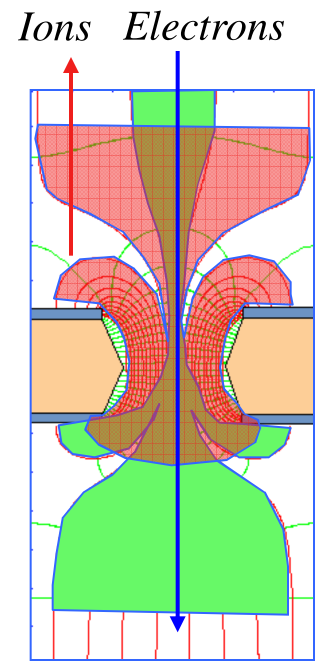
The Gas Electron Multiplier (GEM)

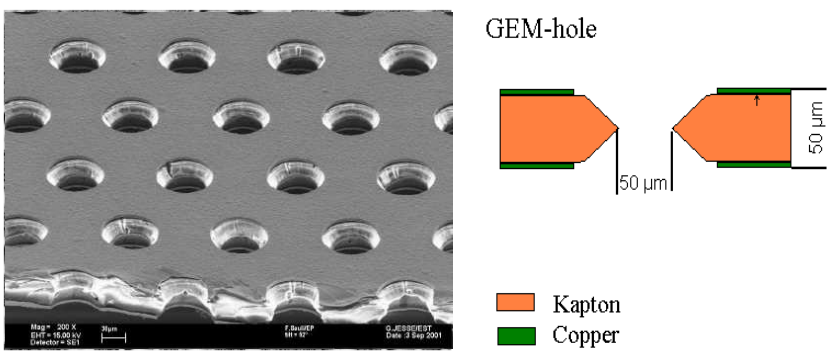
Amplifier Mode

- In hole high fields allow
  Gas amplification 1 - 400





pictures from Sauli



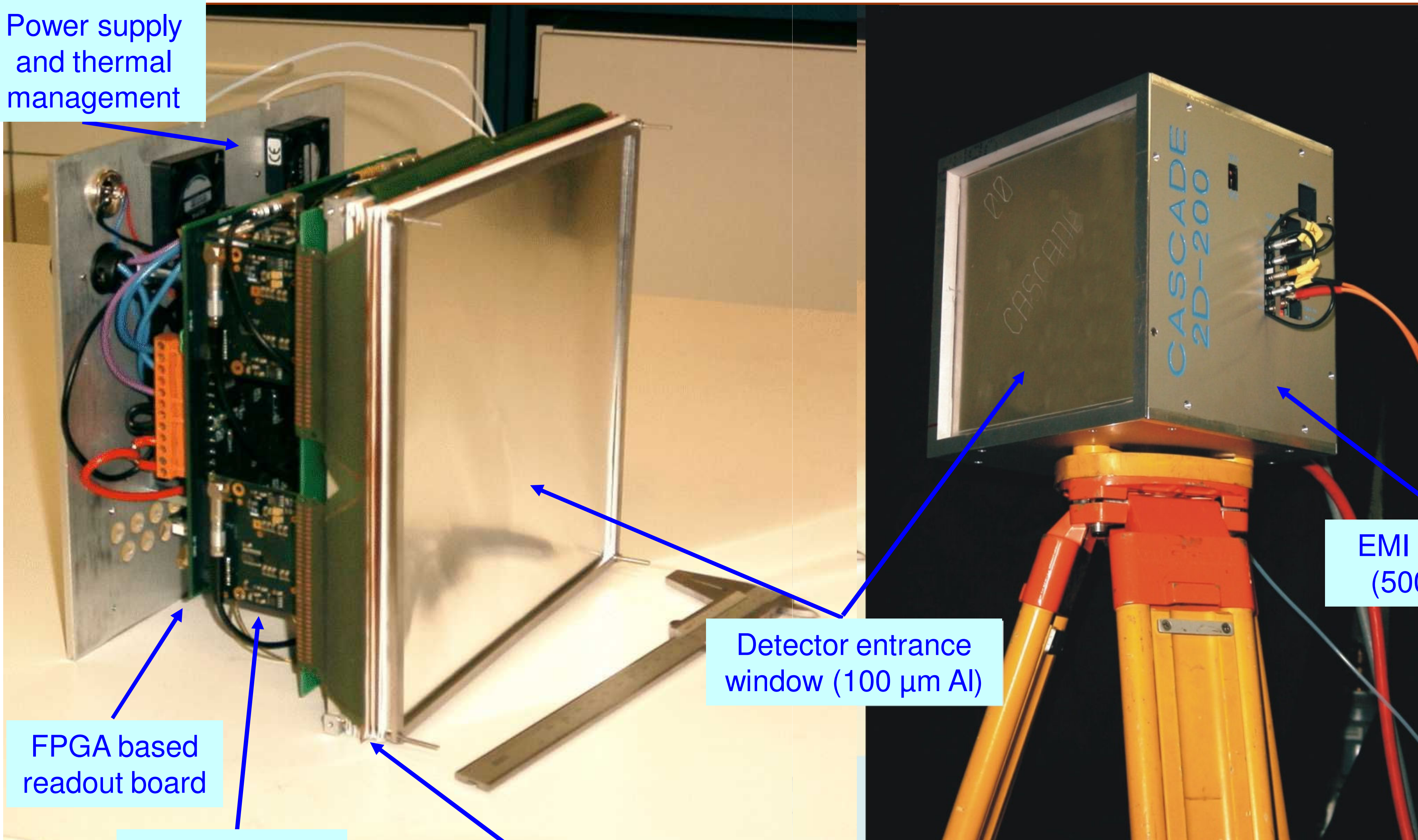
Transparent Mode

- 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



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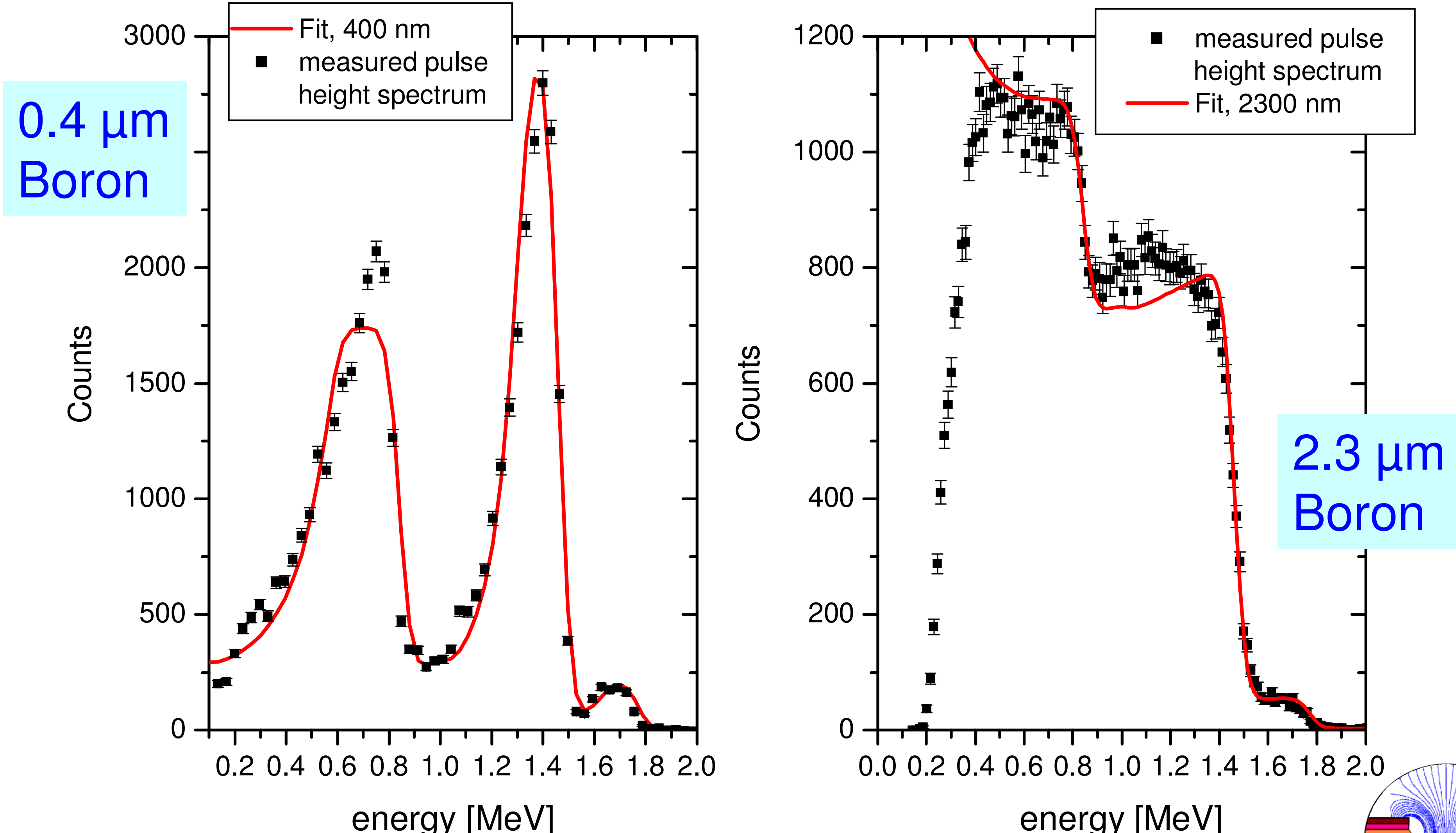
Pulse Height Spectra for a single Boron Layer



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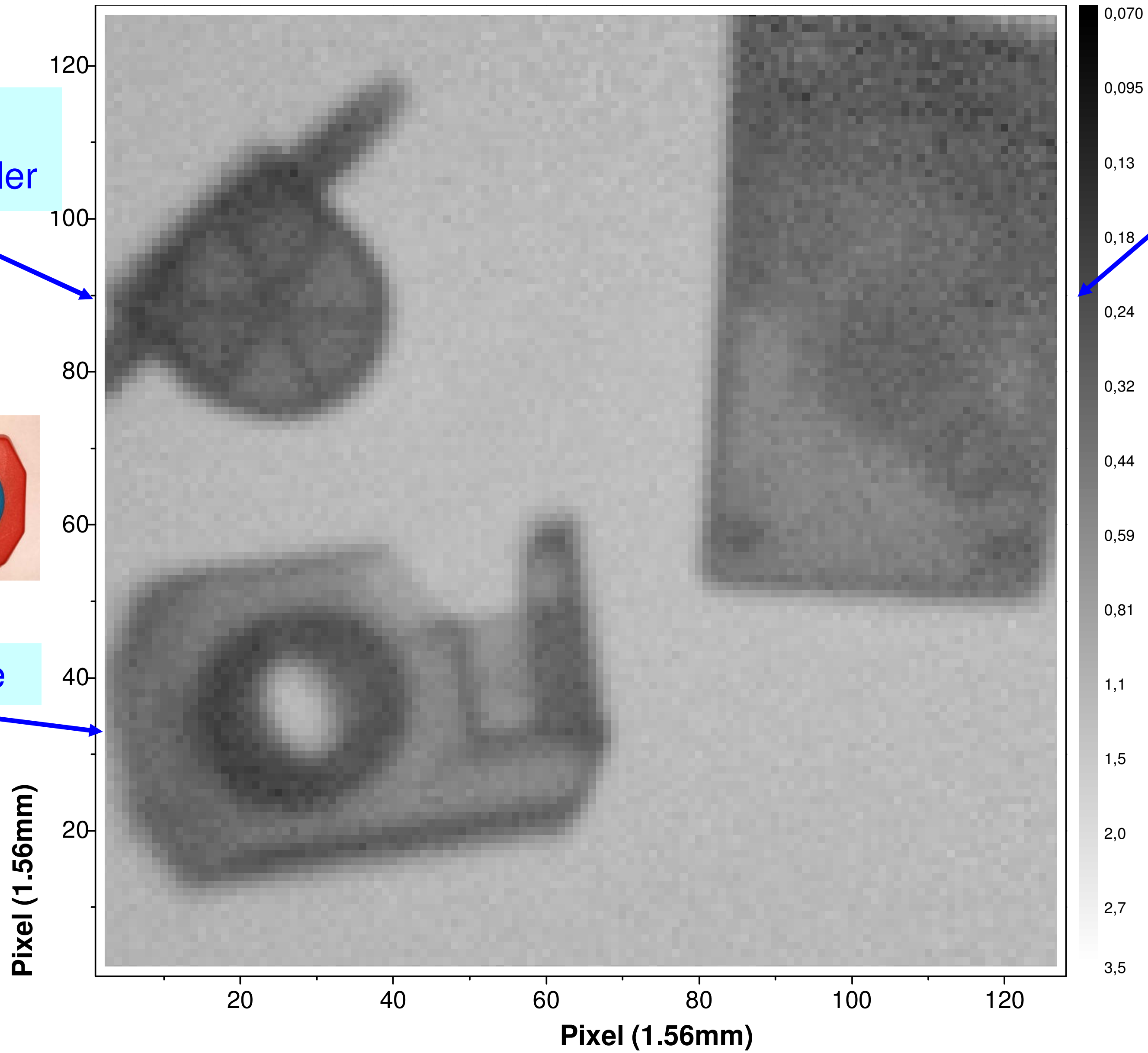
Neutron-Pictures with the 2D-200 CASCADE Detector System



measured at instrument EKN at FZ Jülich

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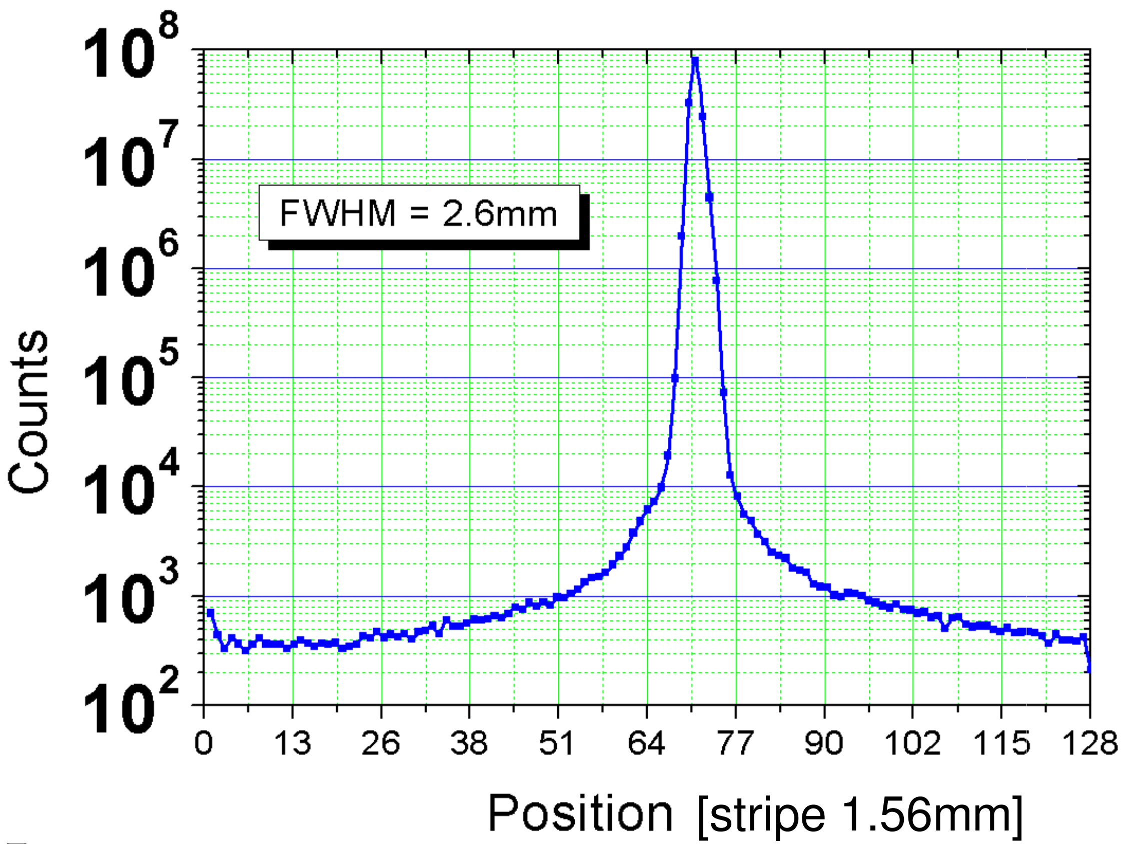
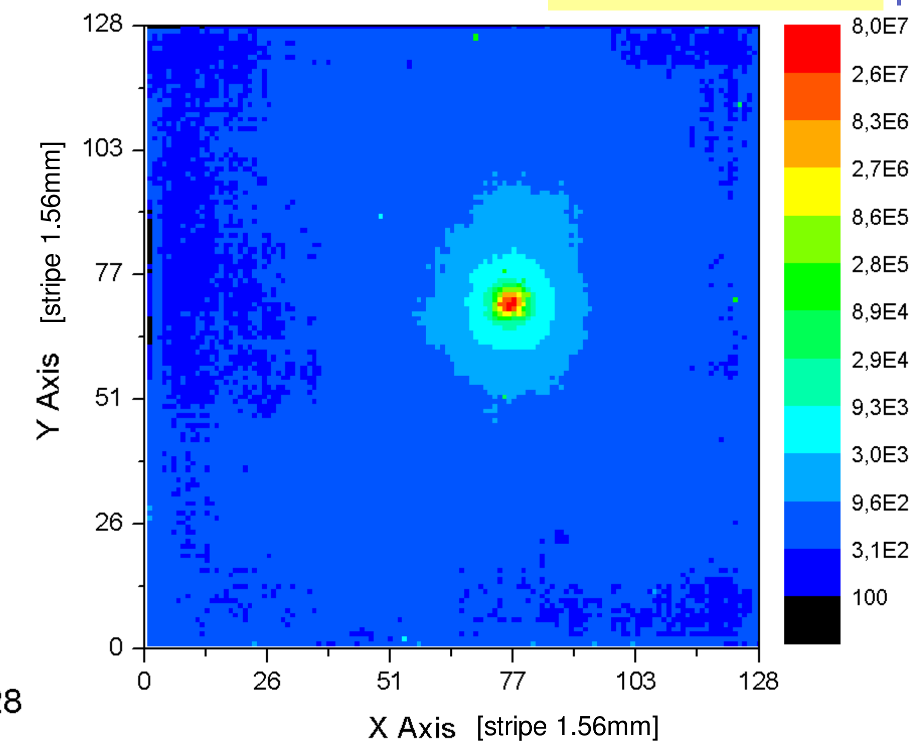
Position Resolution and Contrast with Neutrons

PSF measured using a beam of 0.57mm diameter



Log- Scale!



measured at instrument EKN at FZ Jülich

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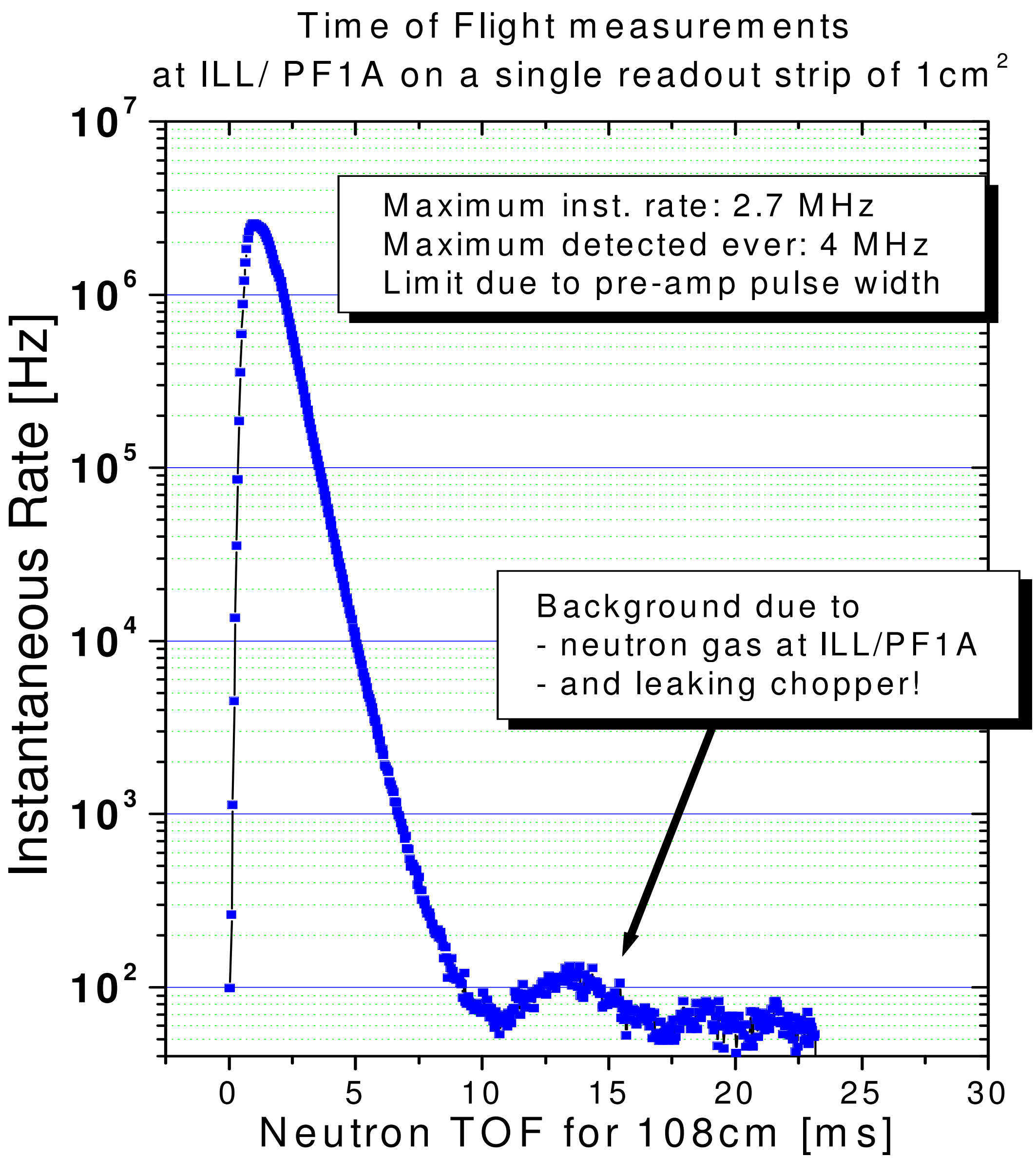
TOF Dynamics Achieved 2003 at PF1A/ILL



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

ClPix Readout ASIC

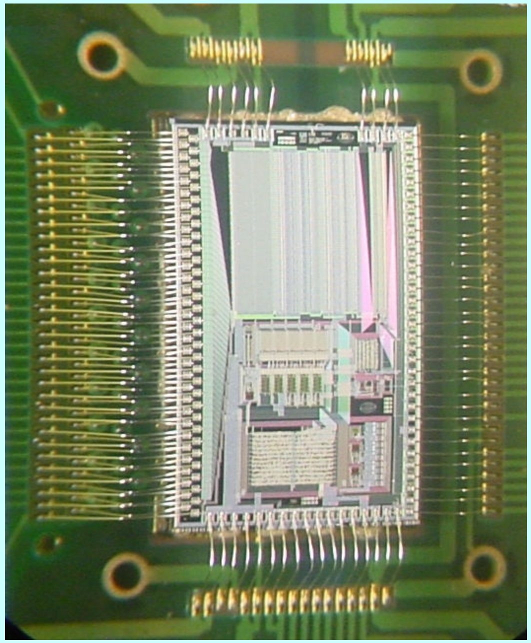
The GEM based CASCADE detector concept shifts High-Rates-Bottleneck to electronic readout !

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



ASIC LABOR HEIDELBERG

Just read and digitise signals individually

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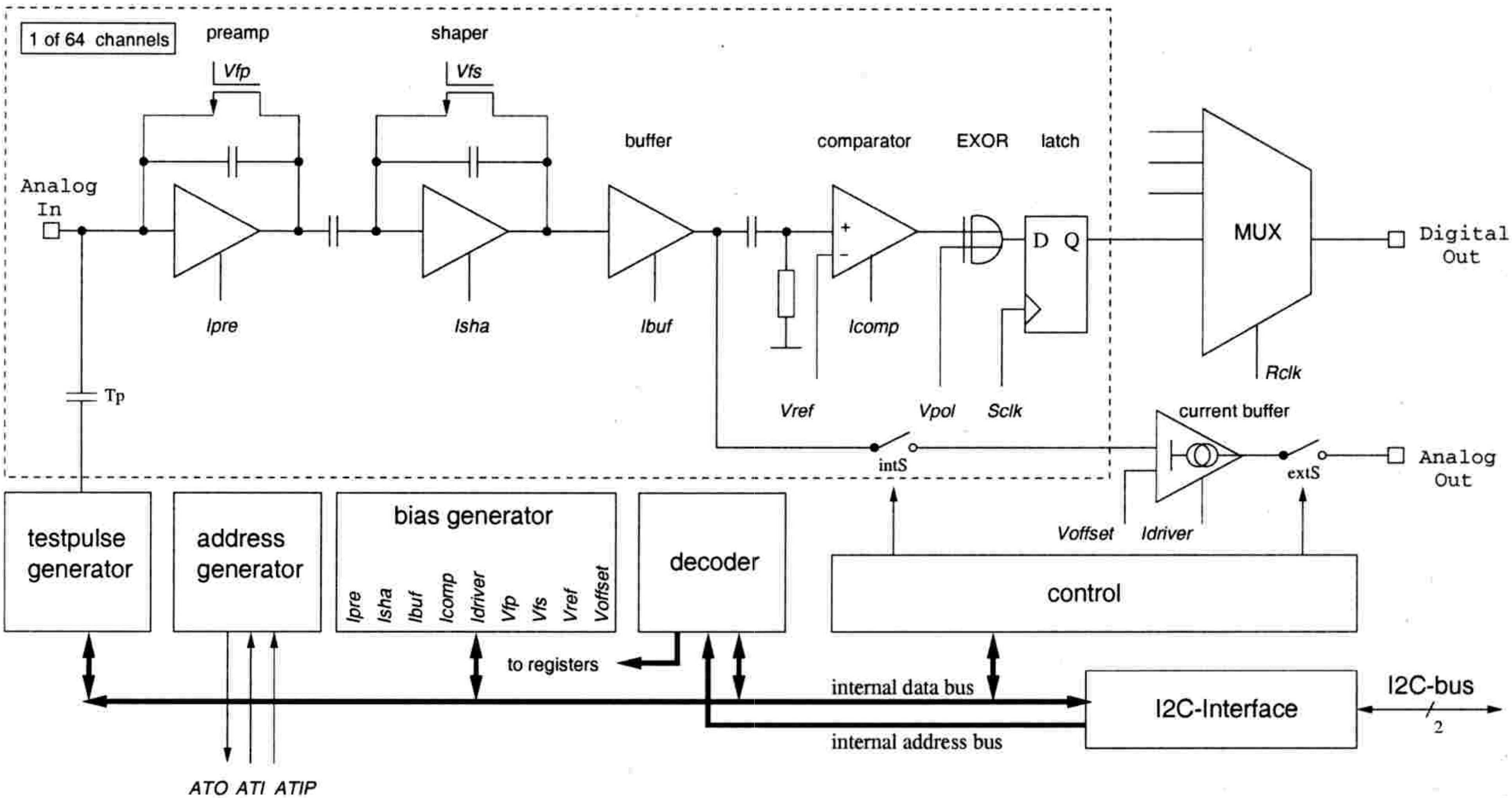
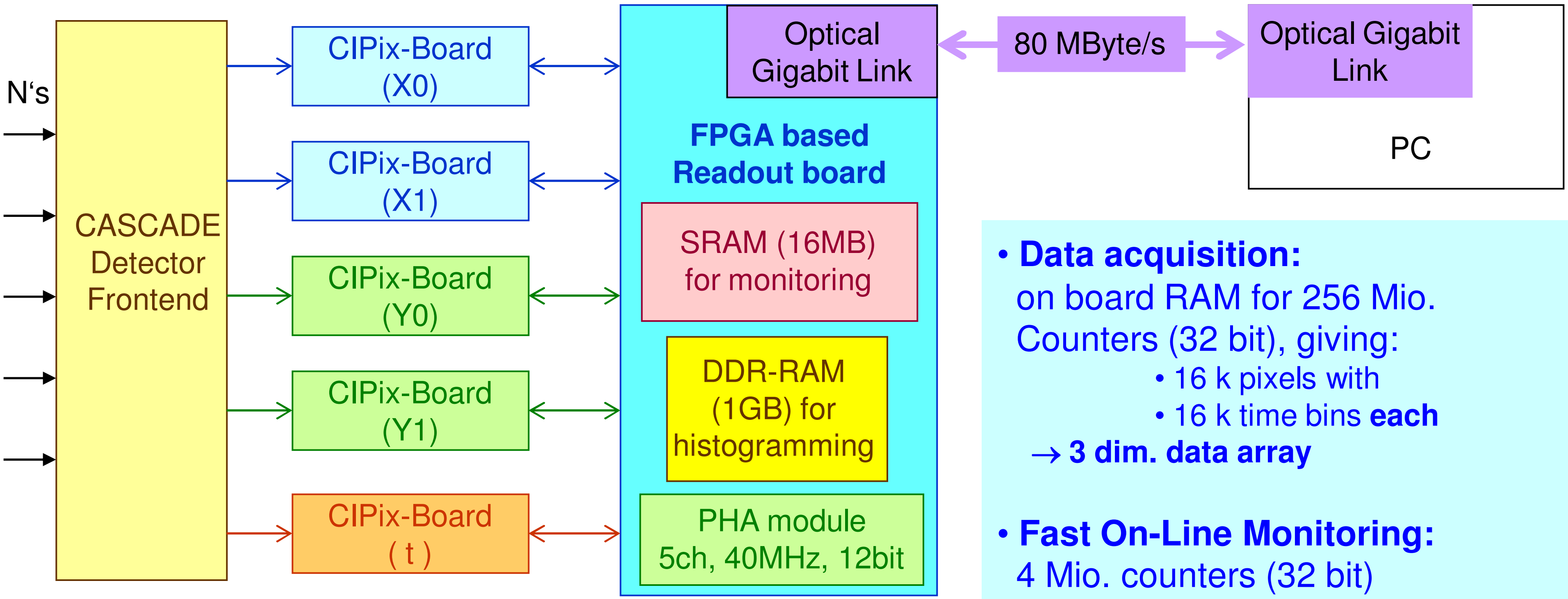
CIPix Schematic

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



CASCADE Detector Readout System



- **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

- **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 ch.**

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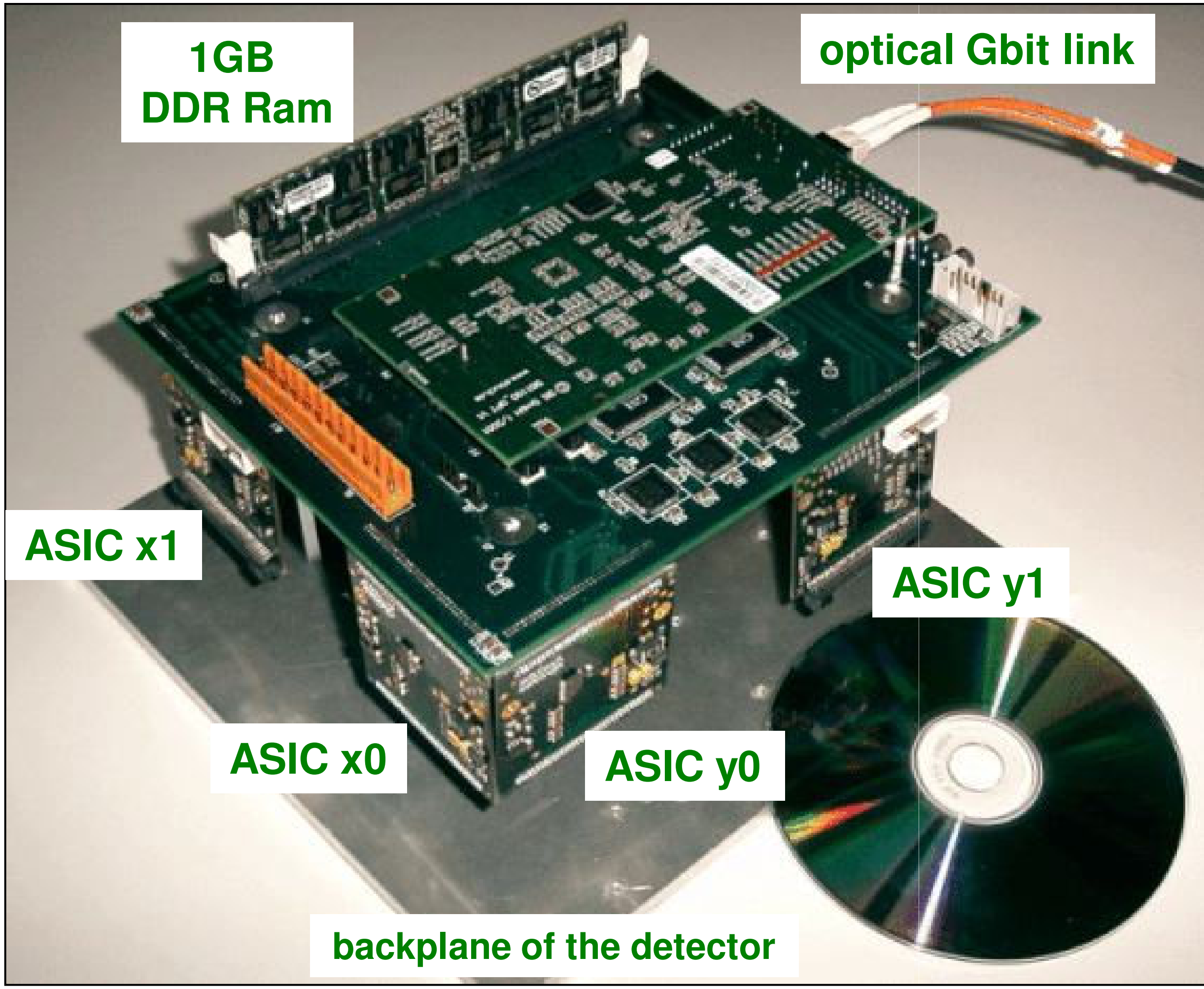
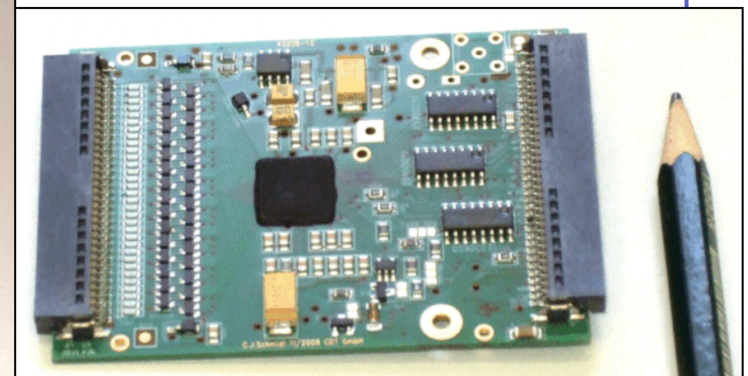
FPGA-based Readout of the 2D-200 Detector



CIPix PreAmp-Discr.
ASIC-board AS20B-1



size: 49mm x 75mm

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

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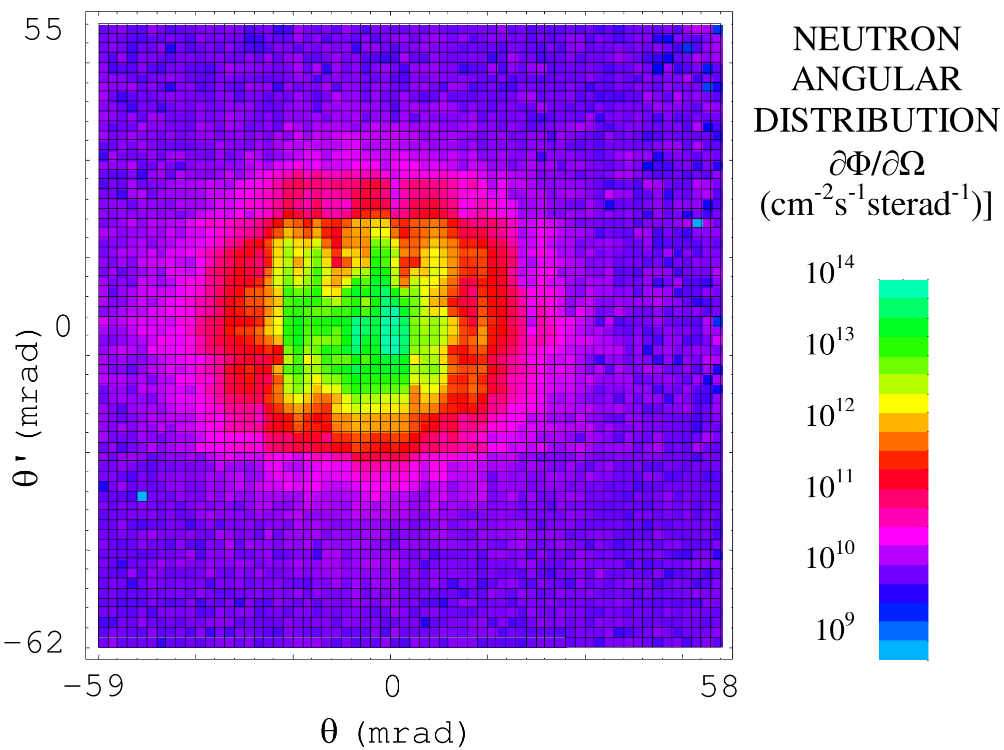
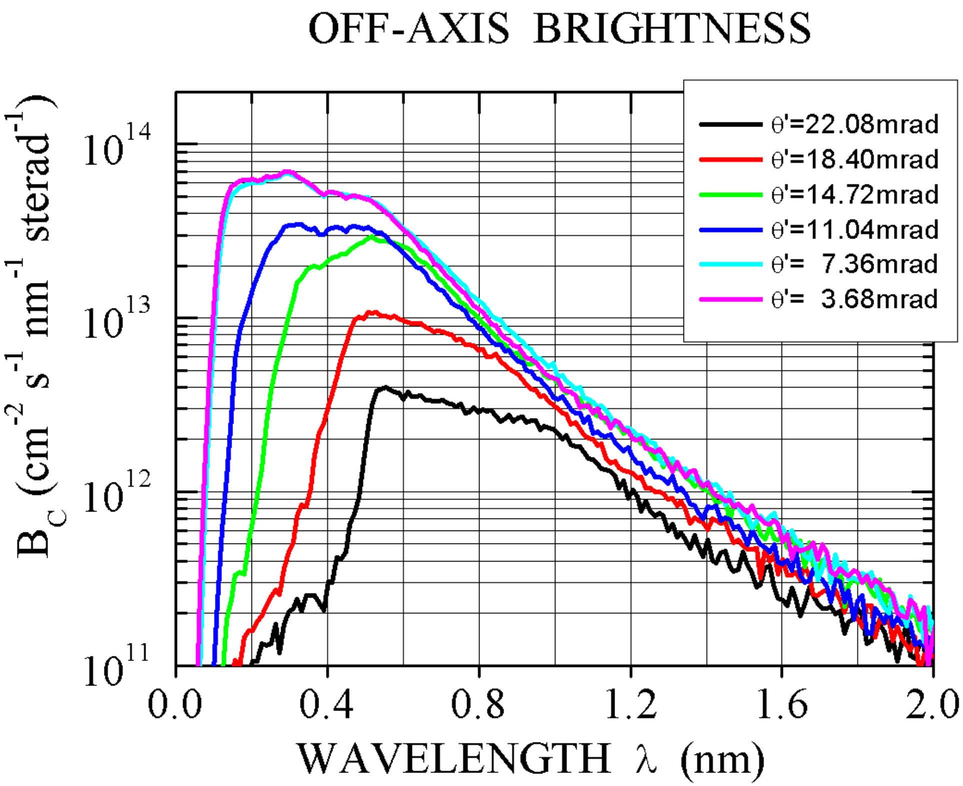
Neutron Time-Of-Flight Measurements

Measured absolute off-axis neutron capture-brightness spectrum $B_C(\lambda)$, at the centre of the exit window of guide H113 (06/2005, ILL): TOF on 64 x 64 pixels with 512 time bins each !





D. Dubbers et al., “Characterization of a ballistic supermirror neutron guide”, Nuclear Instruments and Methods in Physics Research A 562 (2006) 407–417

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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:
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[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

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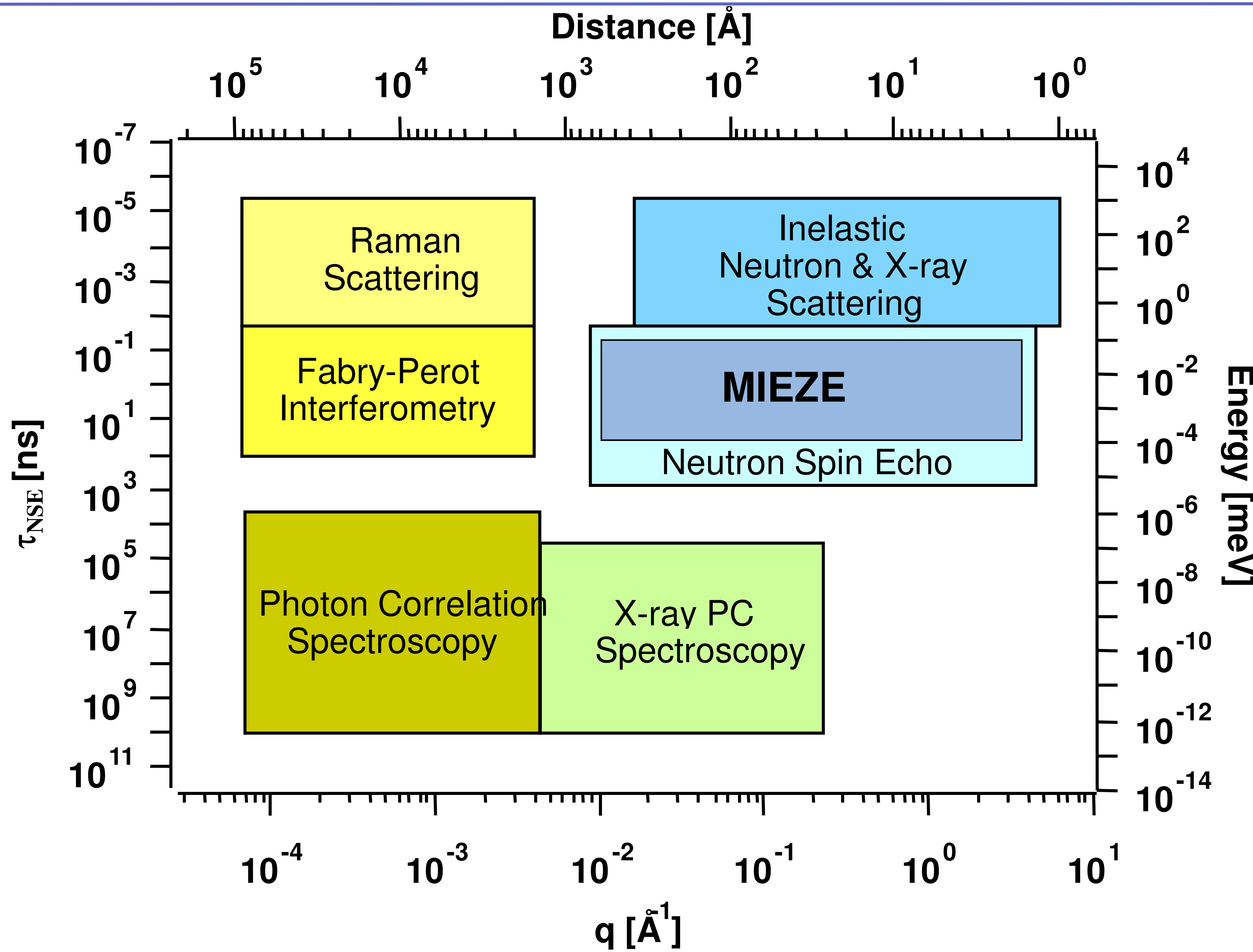
Application Map for Scattering Techniques



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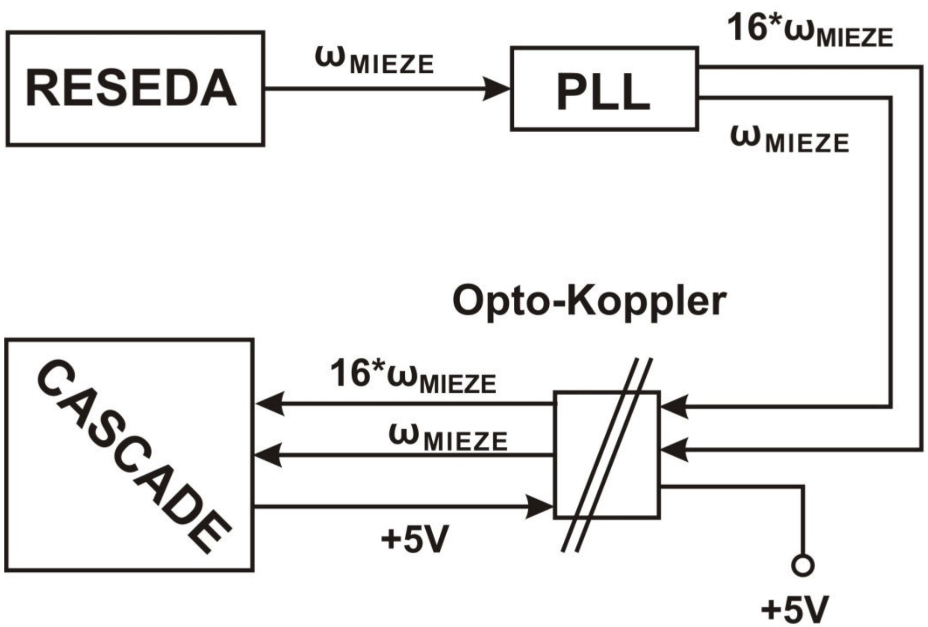
Synchronous Phase Sensitive Measurement Principle

Detector phase locked to RESEDA-RF

- Detector follows automatically RESEDA's radio-frequency
- Essential for tuning the instrument into spin-flip-resonance
- On-Line, phase sensitive Histogramming



Expect synchronous intensity modulation.
Signal detected in 16 phase bins.

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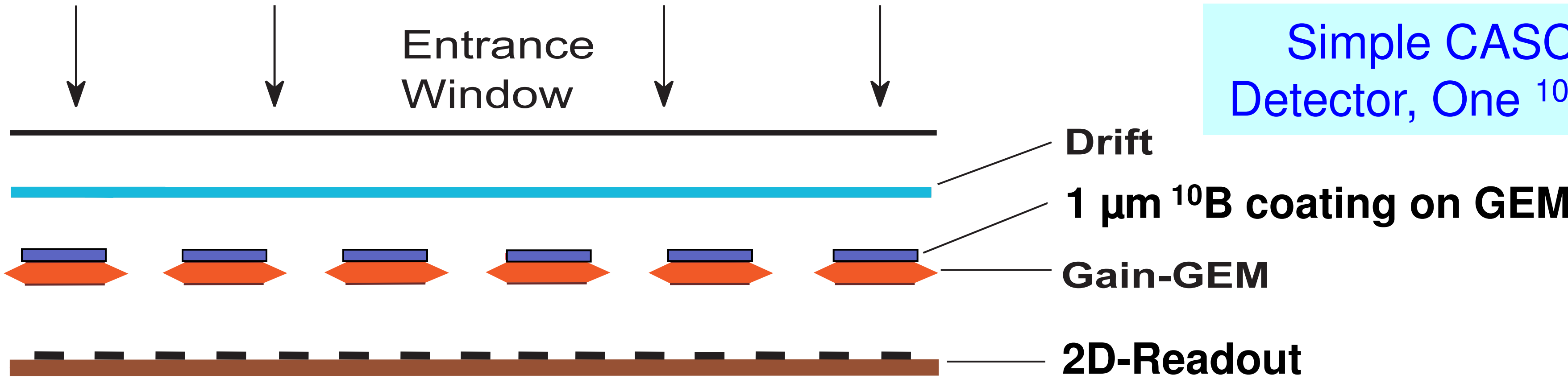
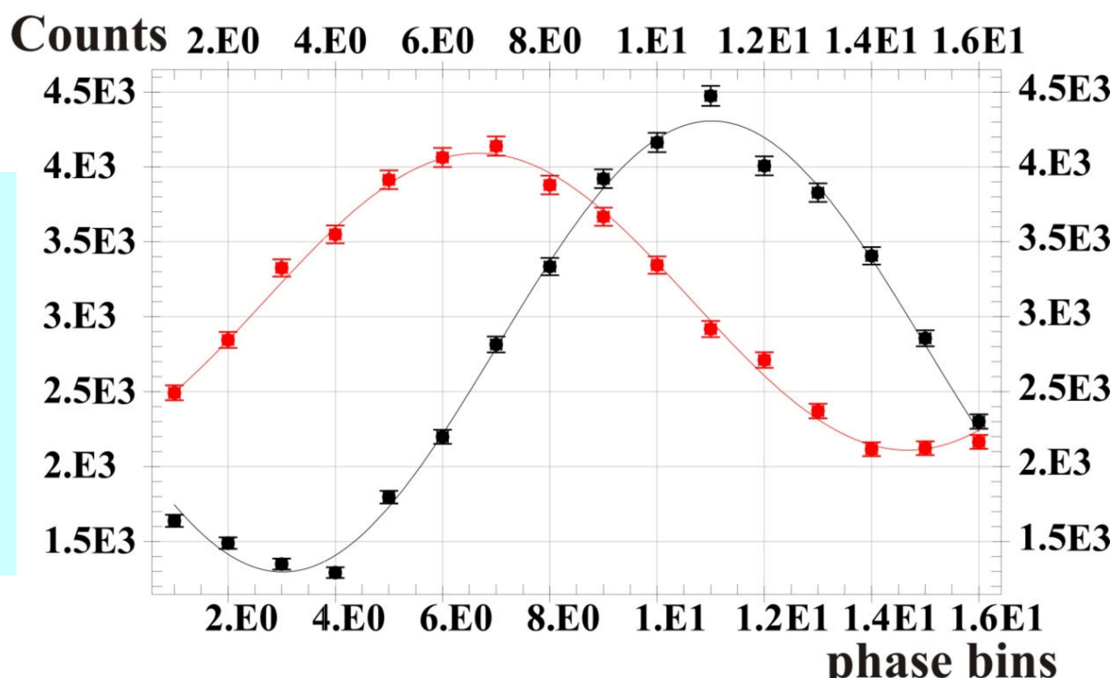
First MIEZE Test Experiment

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

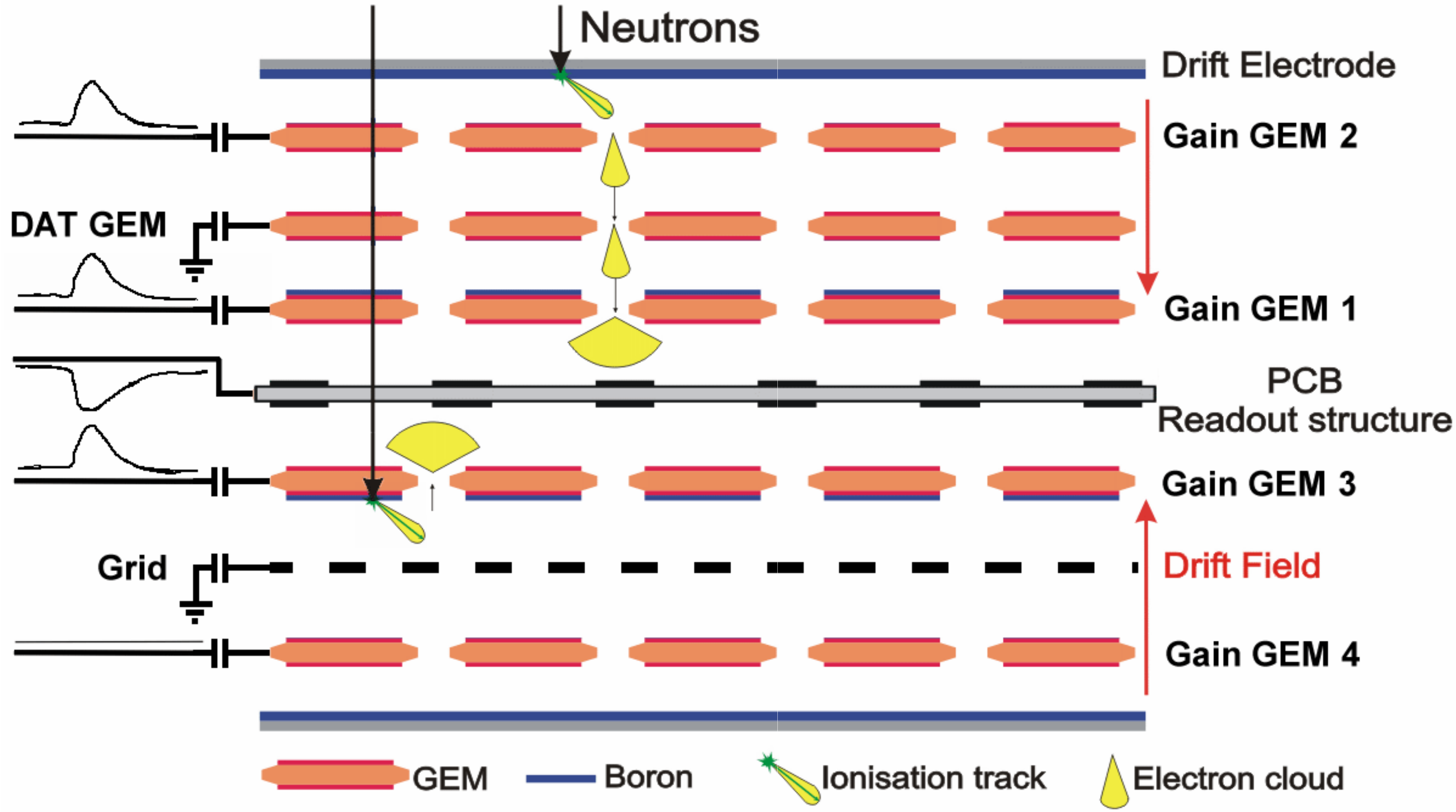


(dwell time 96 ns)

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)



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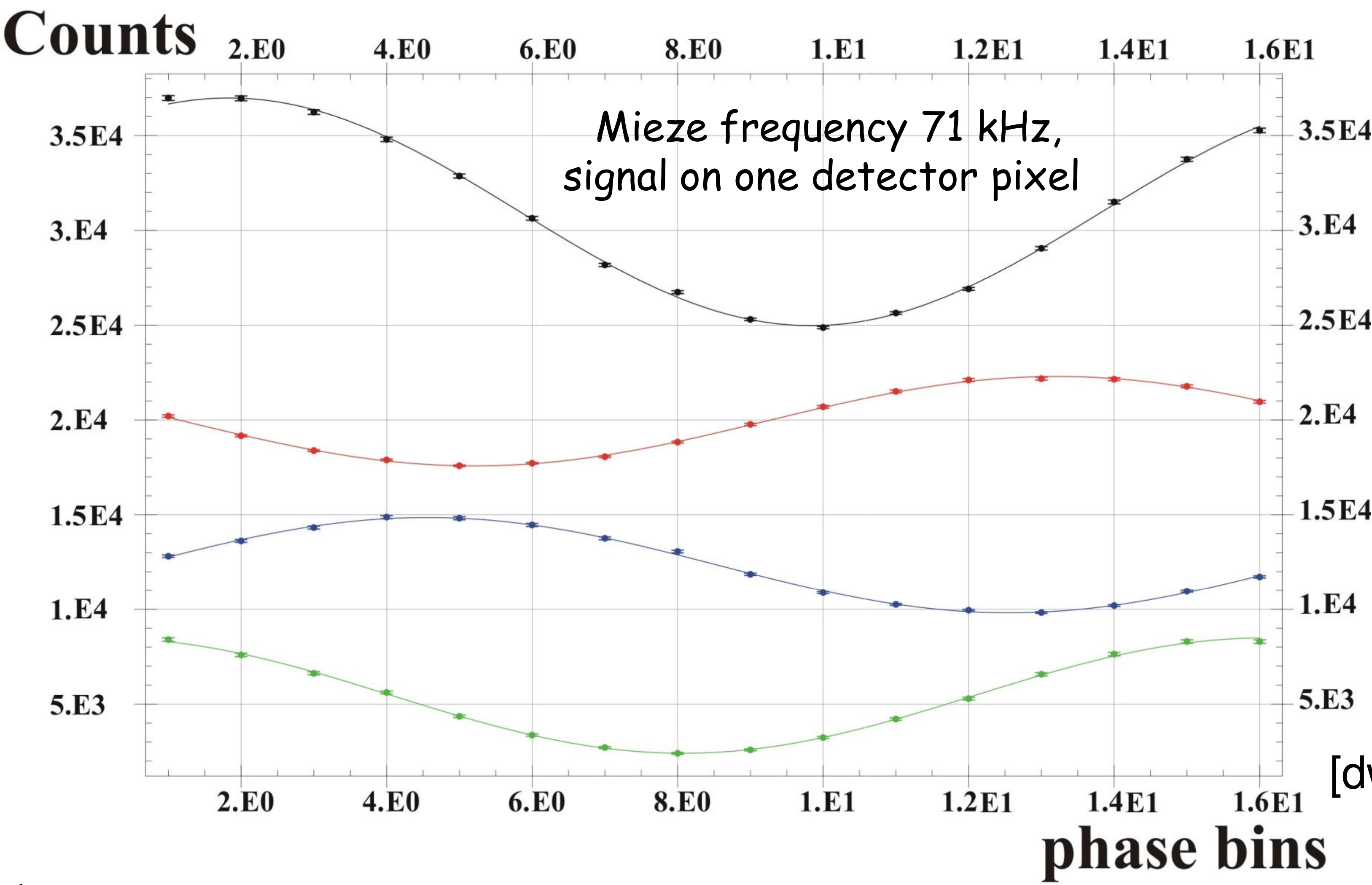
Modulation at Different Boron Layers



0.8 MHz overall detection rate

[dwell time 880ns]

Added offsets for clarity, measured polarization 65%

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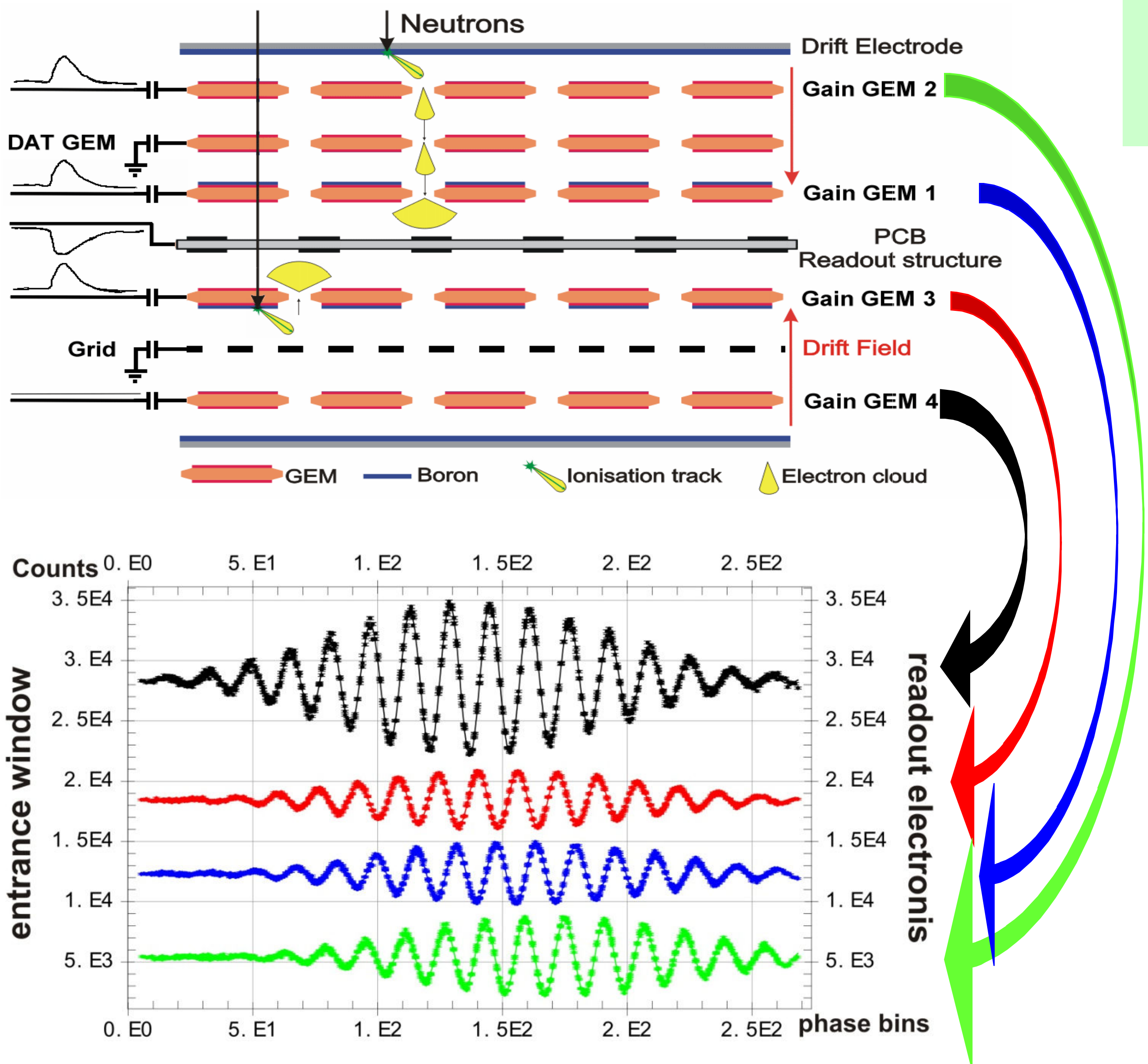
Measured Spin-Echo-Group used for high resolution scattering



Current overall detection efficiency at 5.3 Å with four boron layers ~ 18 %

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

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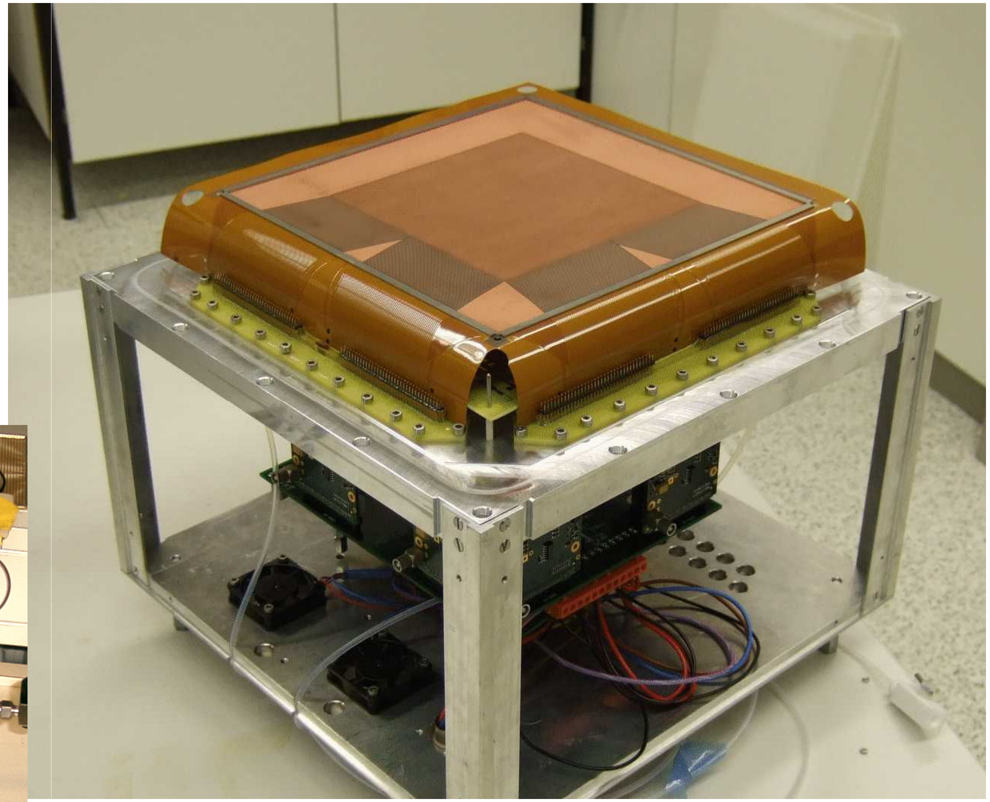
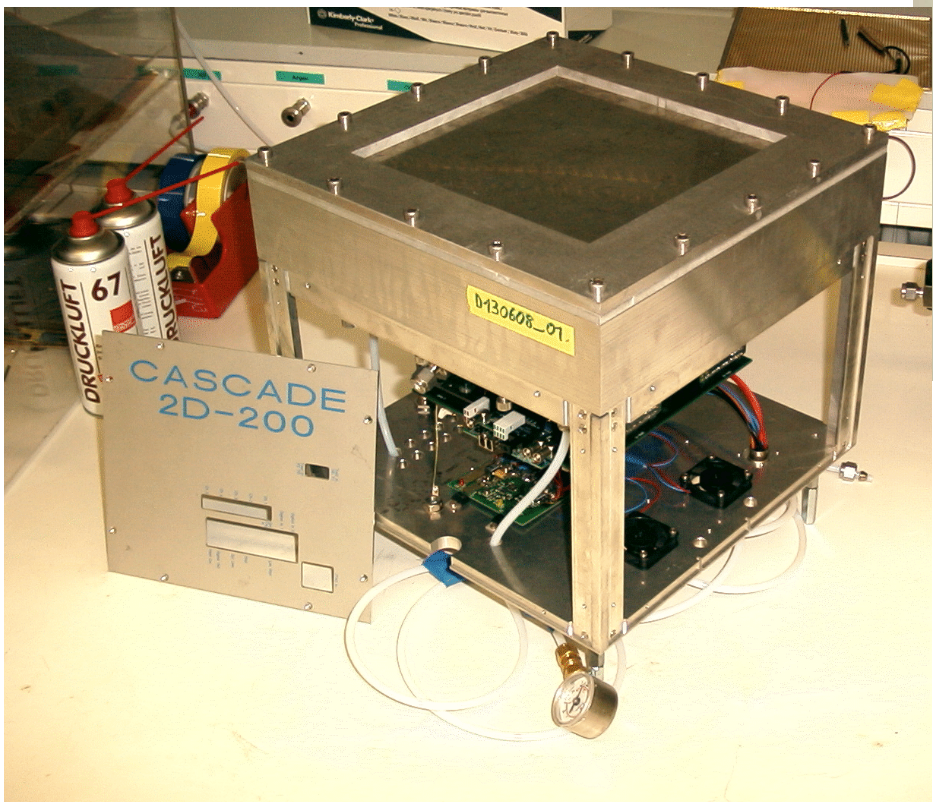
CASCADE Detector with 1mm Resolution

- 5 bar pressure chamber
- prototyping 2D-readout with 1mm pitch integrated
- Neutron beam tests at our lab ^{252}Cf-source





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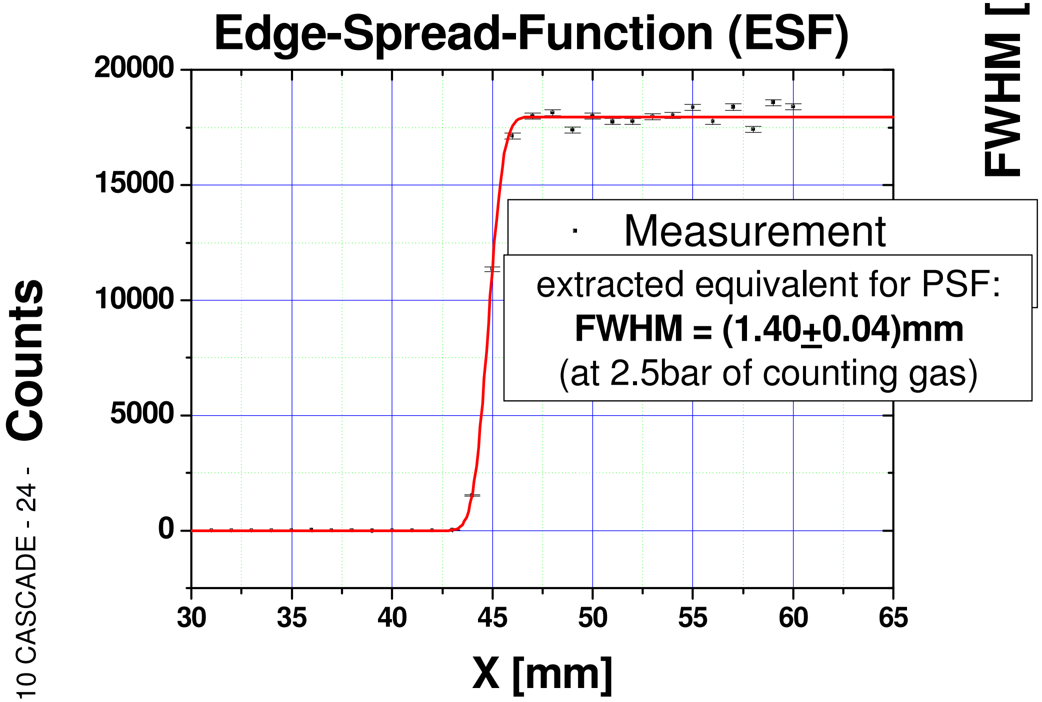
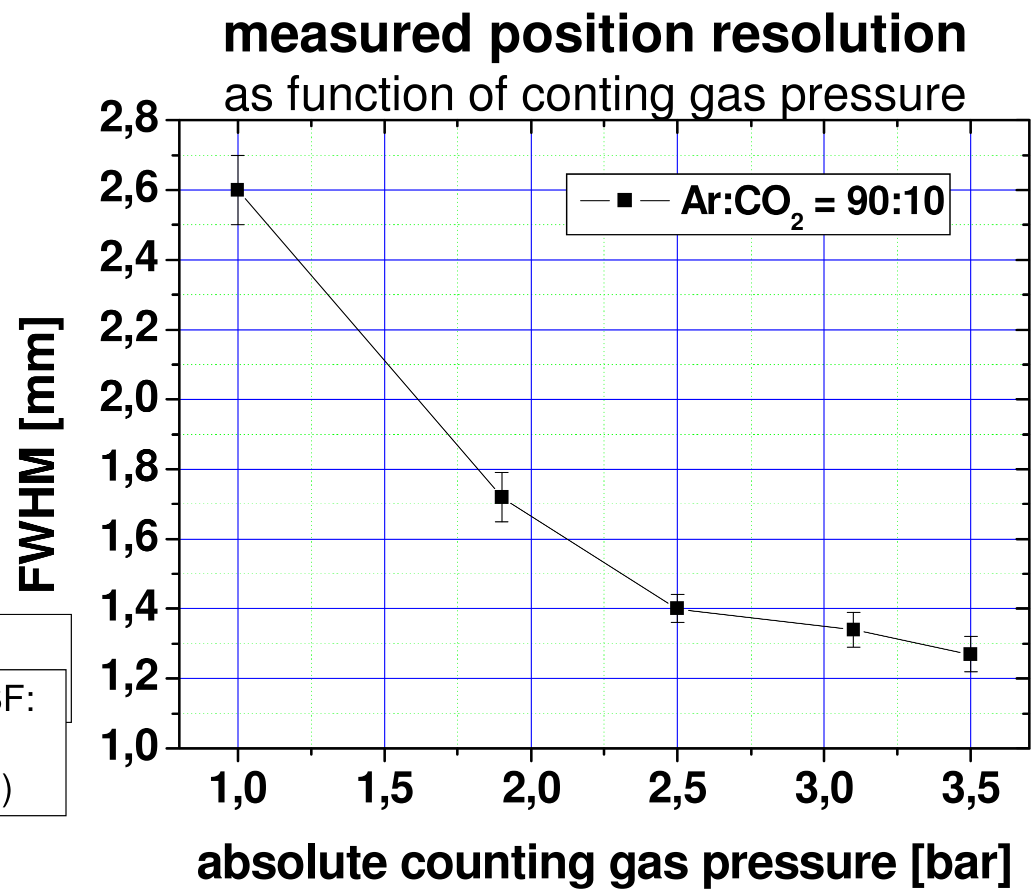
Position Resolution versus Gas Pressure

Lab measurements at ^{252}Cf-source





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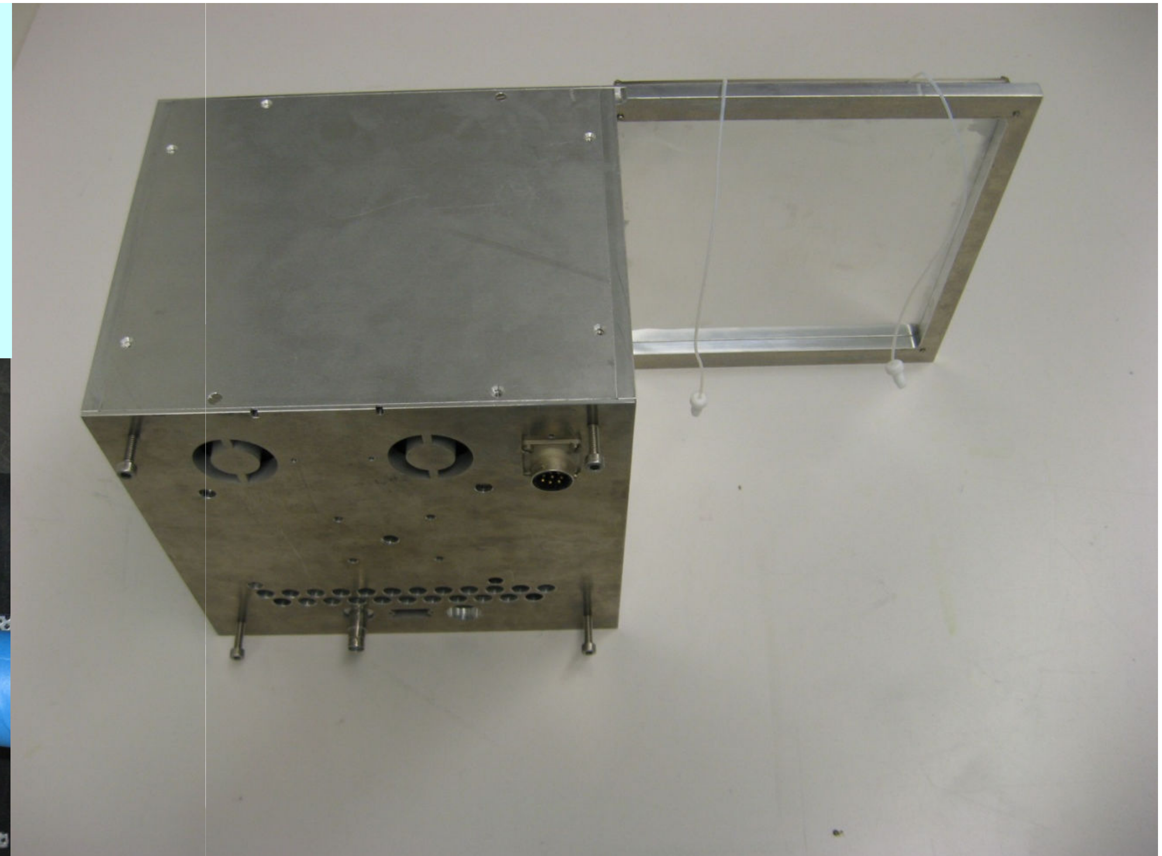
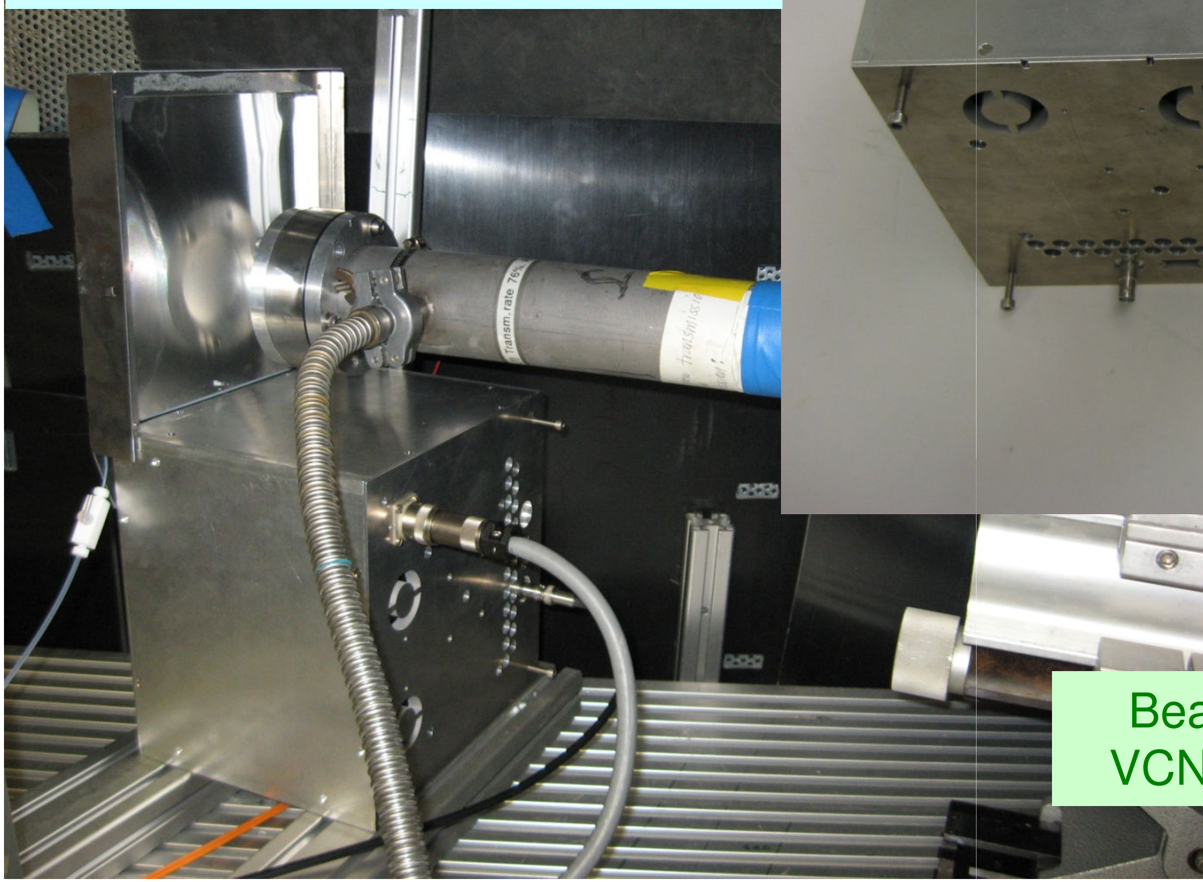
Beammonitor 200mm x 200mm

- actual: 1D readout with 128 stripes
- 20MHz count rate capability (up to 48MHz with reduced position resolution)





Beammonitor used for VCN on Niveau D at ILL

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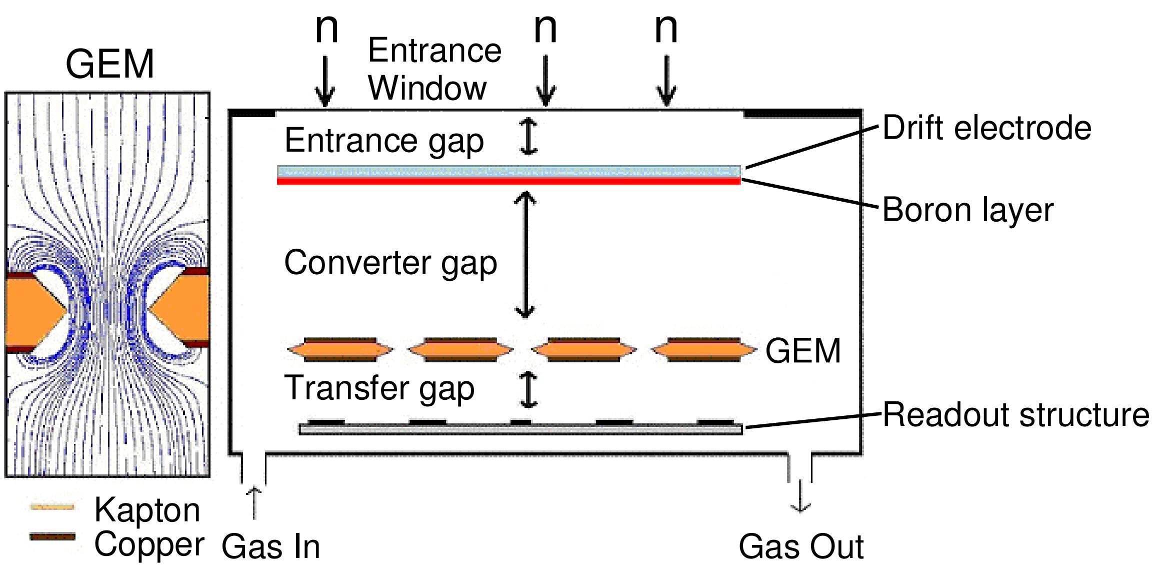
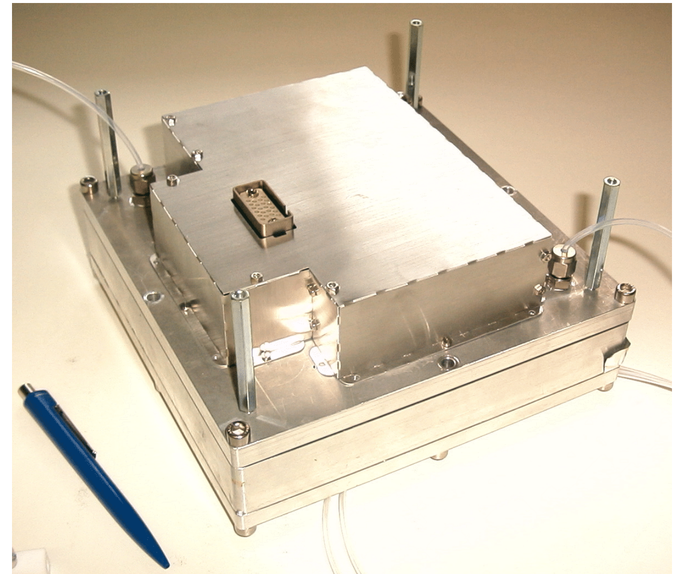
CASCADE-U for UCN and VCN Detection

CASCADE-U Detection Principle





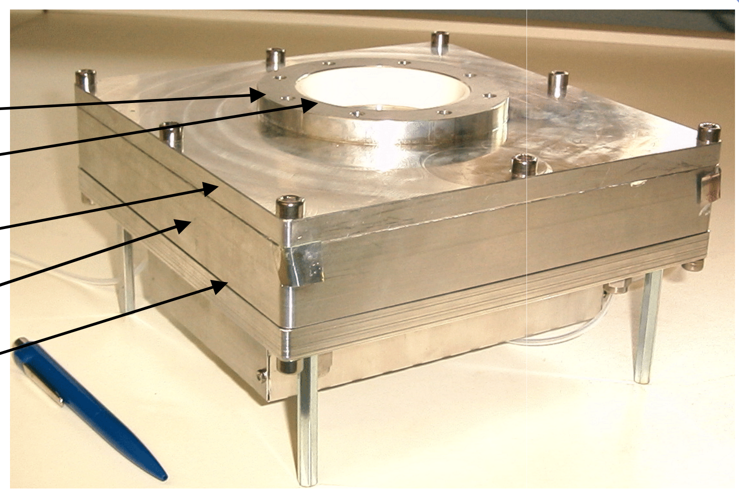
Adapter to Wilson-flange

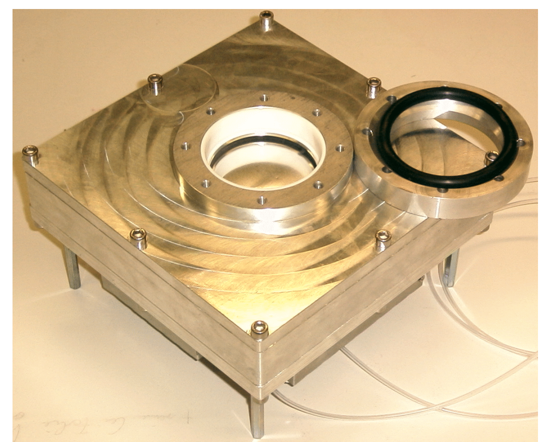
Teflon ring

Top-flange

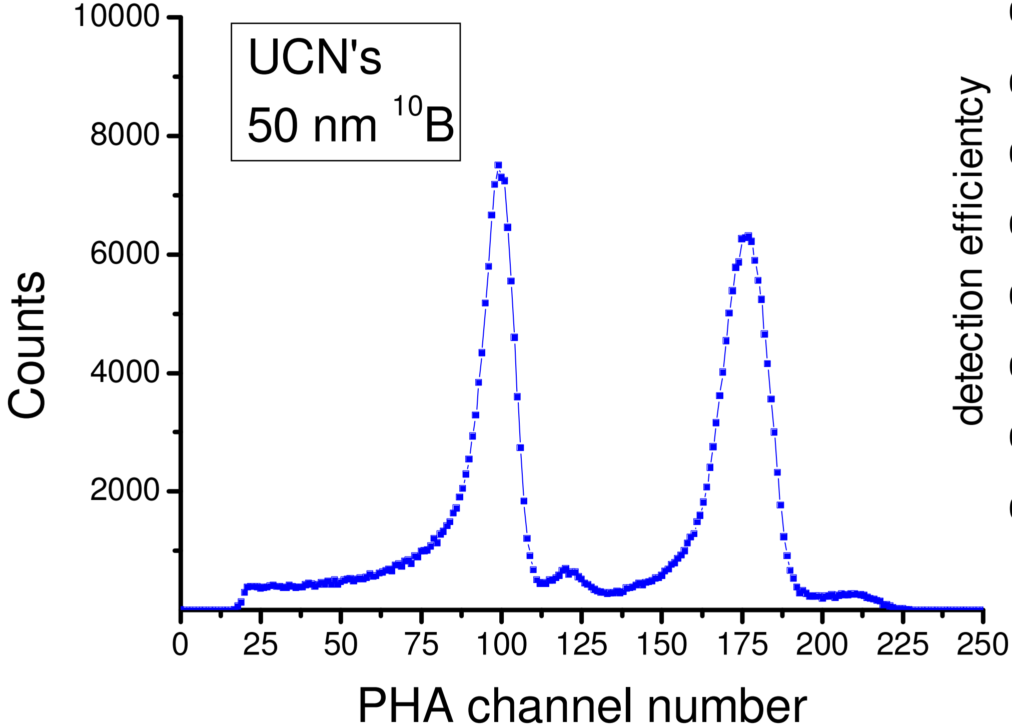
Sidewall-flange

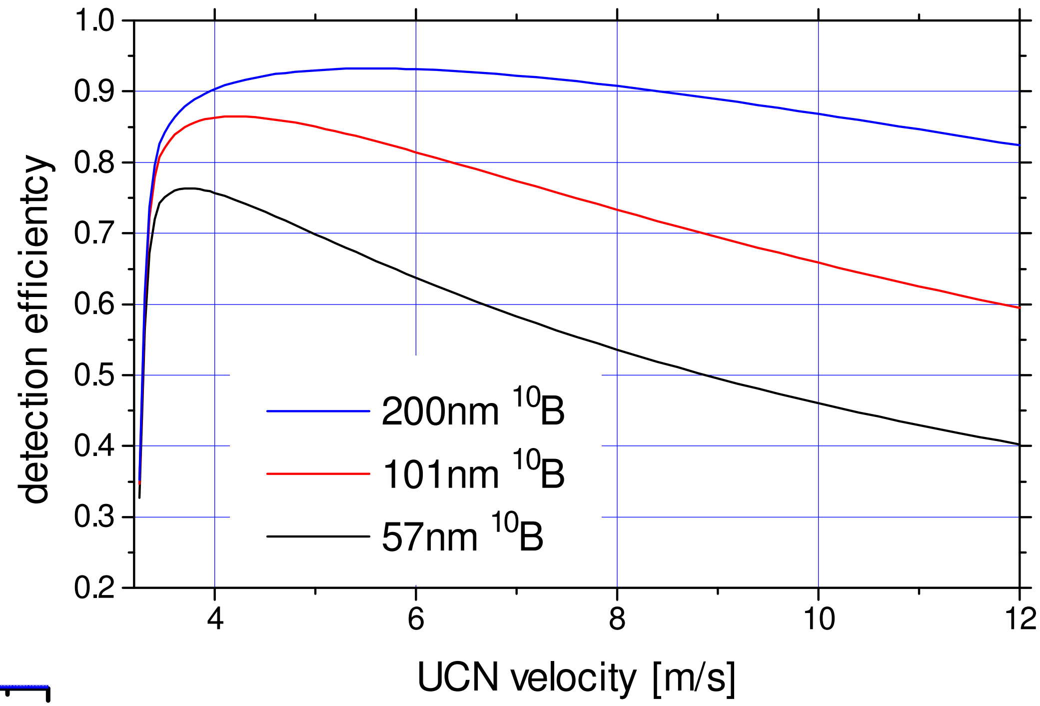
Bottom-flange





UCN-Results measured at ILL





- Very low background < 0.01Hz.
- In combination with the ASIC/FPGA readout electronics:
  - High count rate capability of up to 40MHz for single pixel readout.
- Polarization analysis through iron coated entrance window tested successfully

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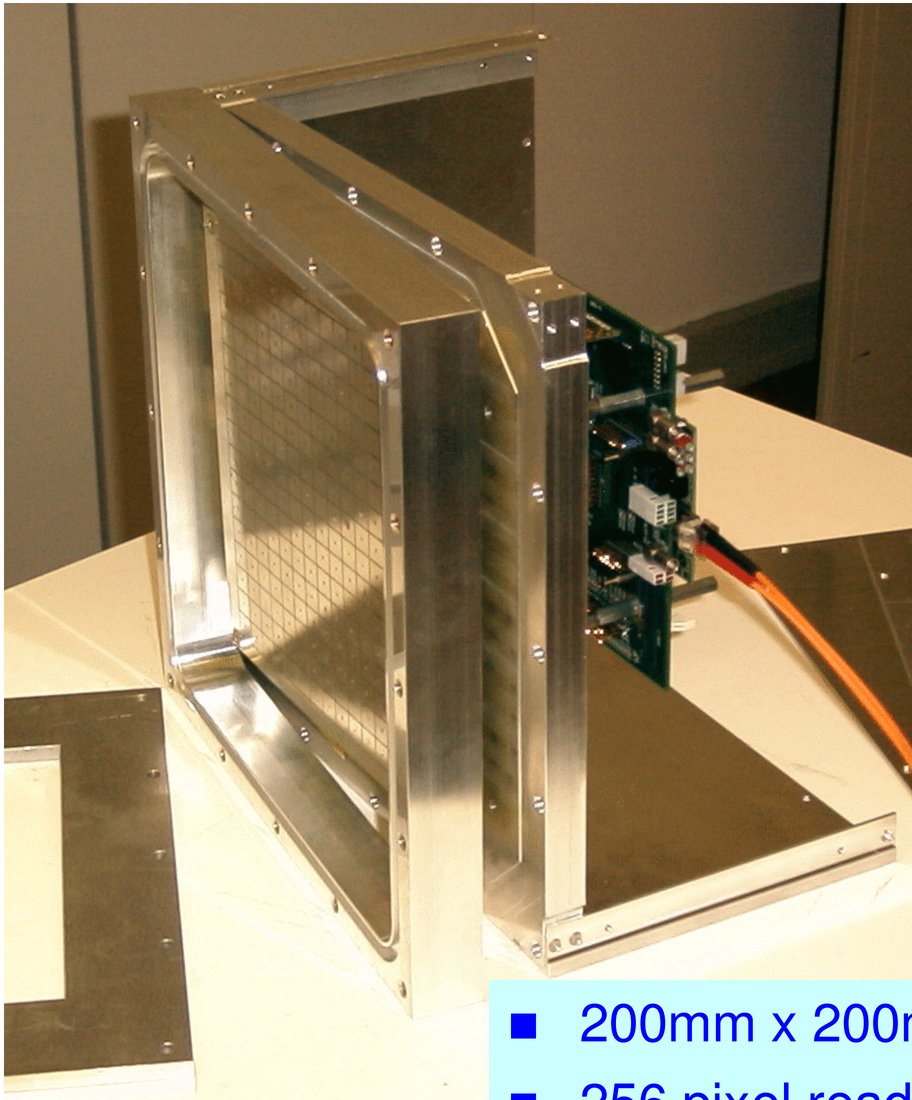
CASCADE-U 2D-200 delivered to UCN-project at PSI



- 200mm x 200mm sensitive area
- 256 pixel readout structure
- 20MHz rate capability

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Summary

- CASCADE has developed to be a real technological alternative to ^{3}He based neutron detectors, that suffer the severe crisis in supply of ^{3}He.
- It combines high count rate capability with a large dynamical range as well as very low background sensitivity.
- The detector can cope with SNS/JPARC-type source intensities and it can exploit their time structure.
- The concept is scaleable to many square meters and can be grouped to build up a large detector system.
- It can be easily adapted to special neutron applications:
  - resolving very fast neutron intensity modulations in MIEZE applications.
  - higher position resolution with higher gas pressure.
  - beam monitor detectors.
  - detection of very cold and ultra cold neutrons.

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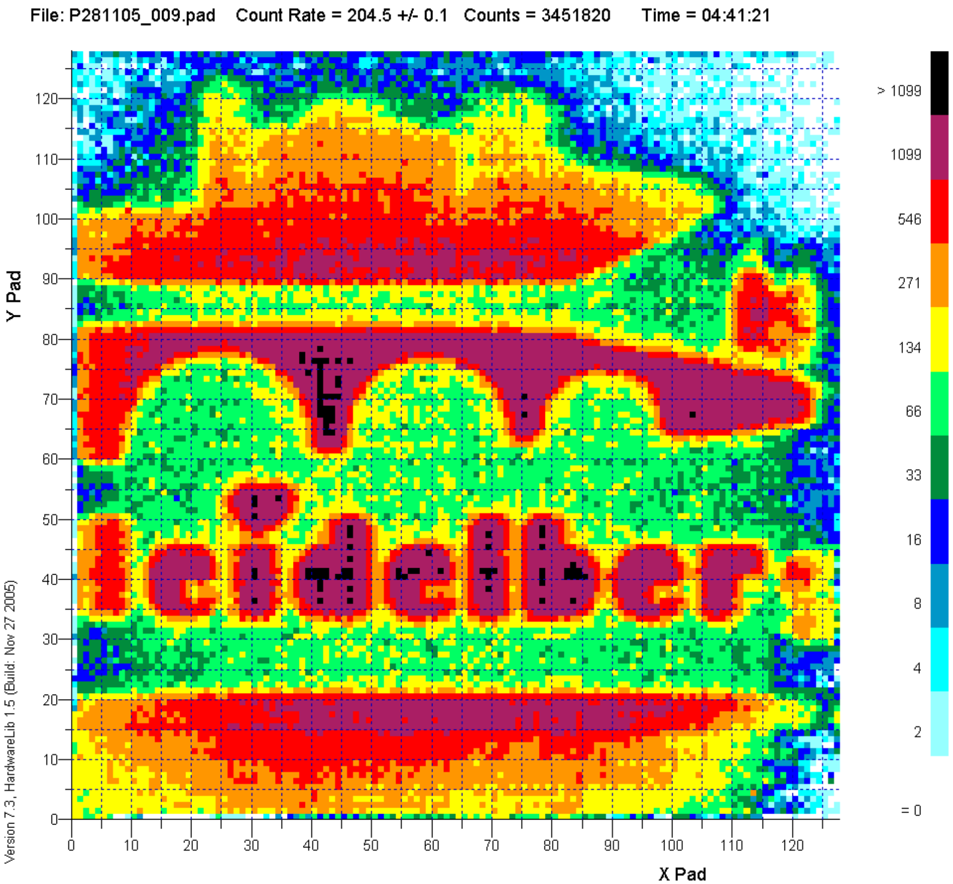
Thank you very much for your attention!



"The castle and the old bridge of Heidelberg"

Measured at our lab source through a mask of Cadmium

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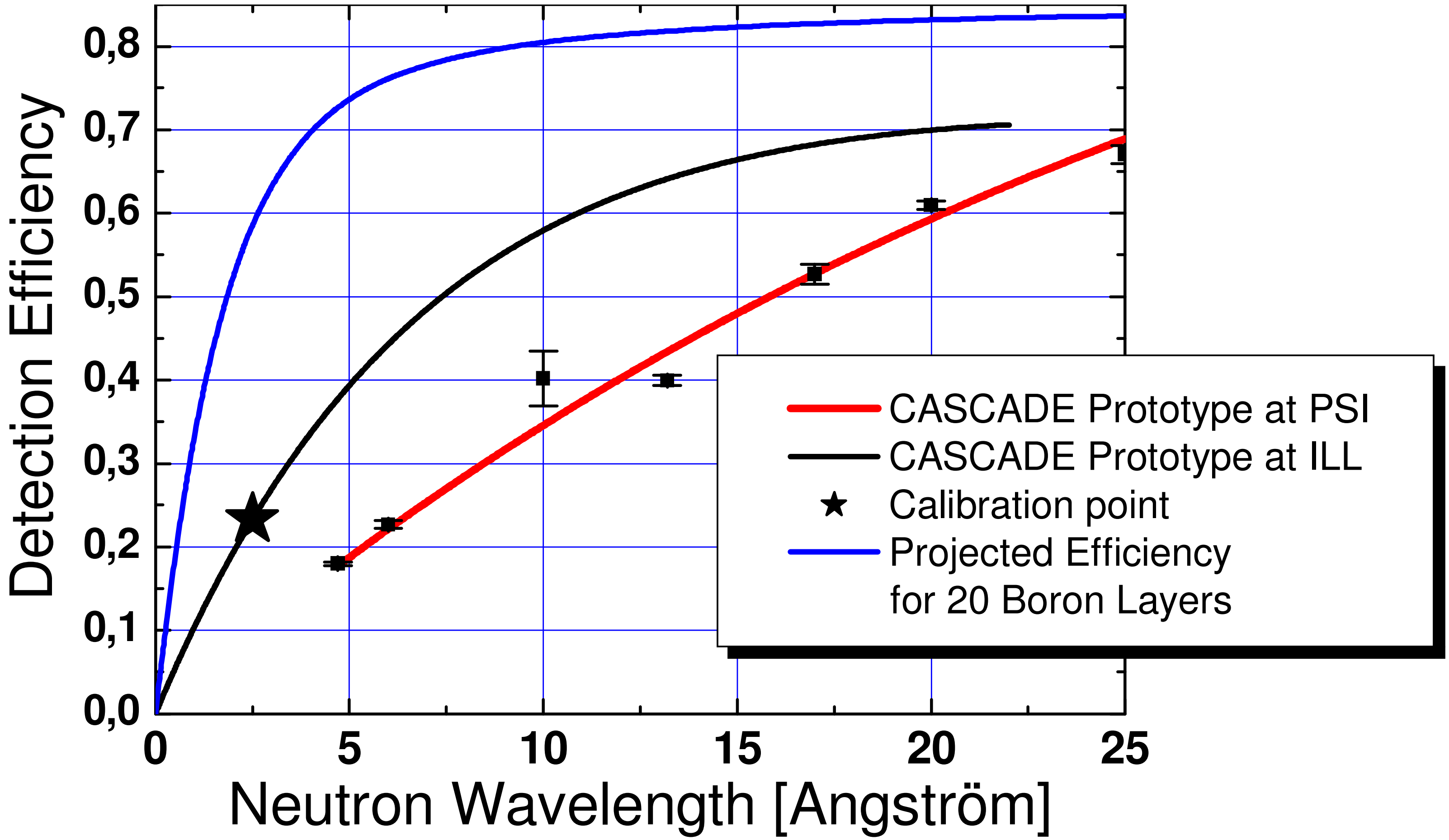
Experimental: Detection Efficiency

Three ^{10}Boron layers CASCADE at PSI-SANS.
Eight ^{10}Boron layers CASCADE at ILL-CT2 and PF1 A.



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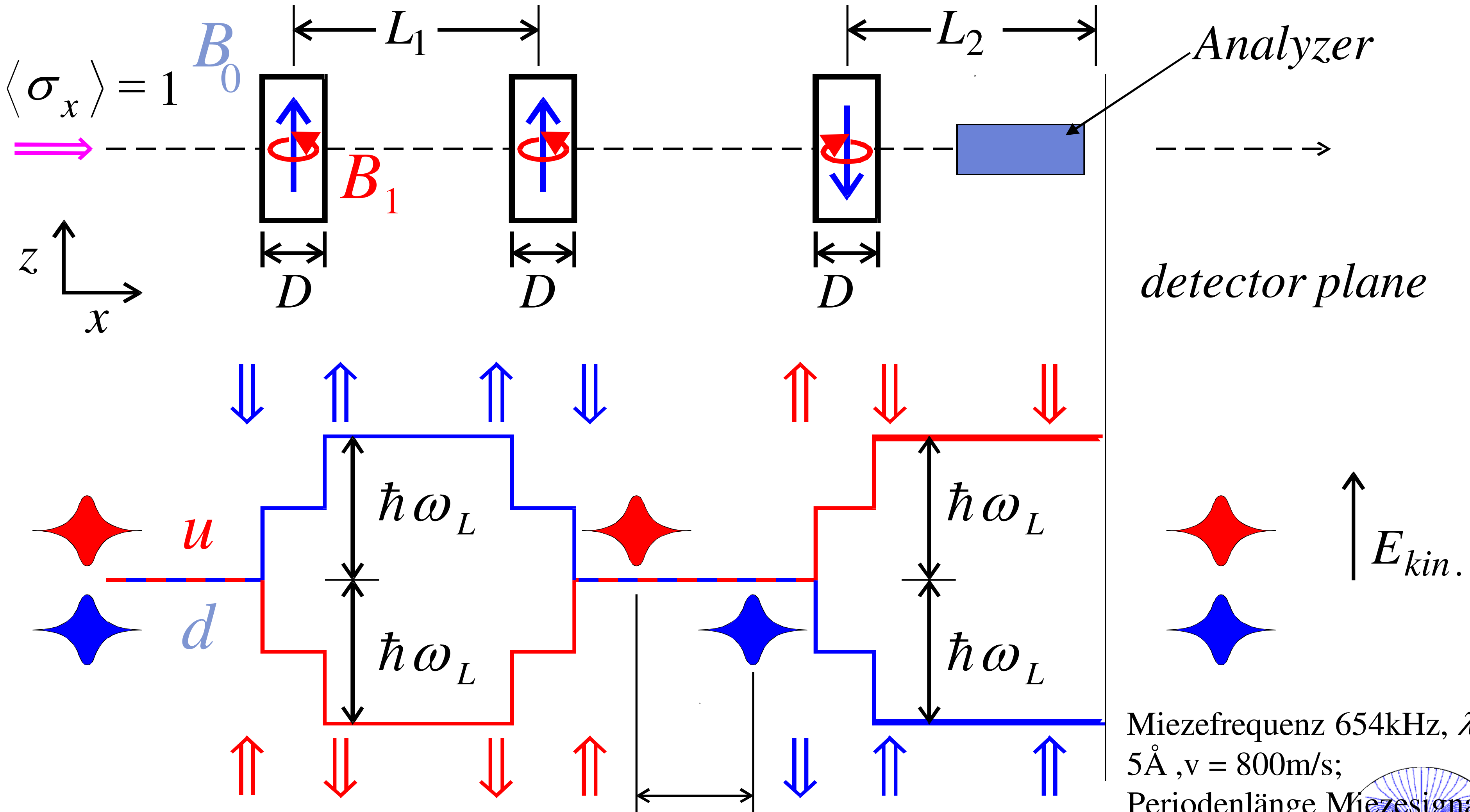
Principle Mieze II



$$v_0 \tau_{NRSE} = 2 v_0 \tau_{NSE}$$

Miezefrequenz 654kHz, λ_n= 5Å ,v = 800m/s; Periodenlänge Miezesignal 1.2 mm

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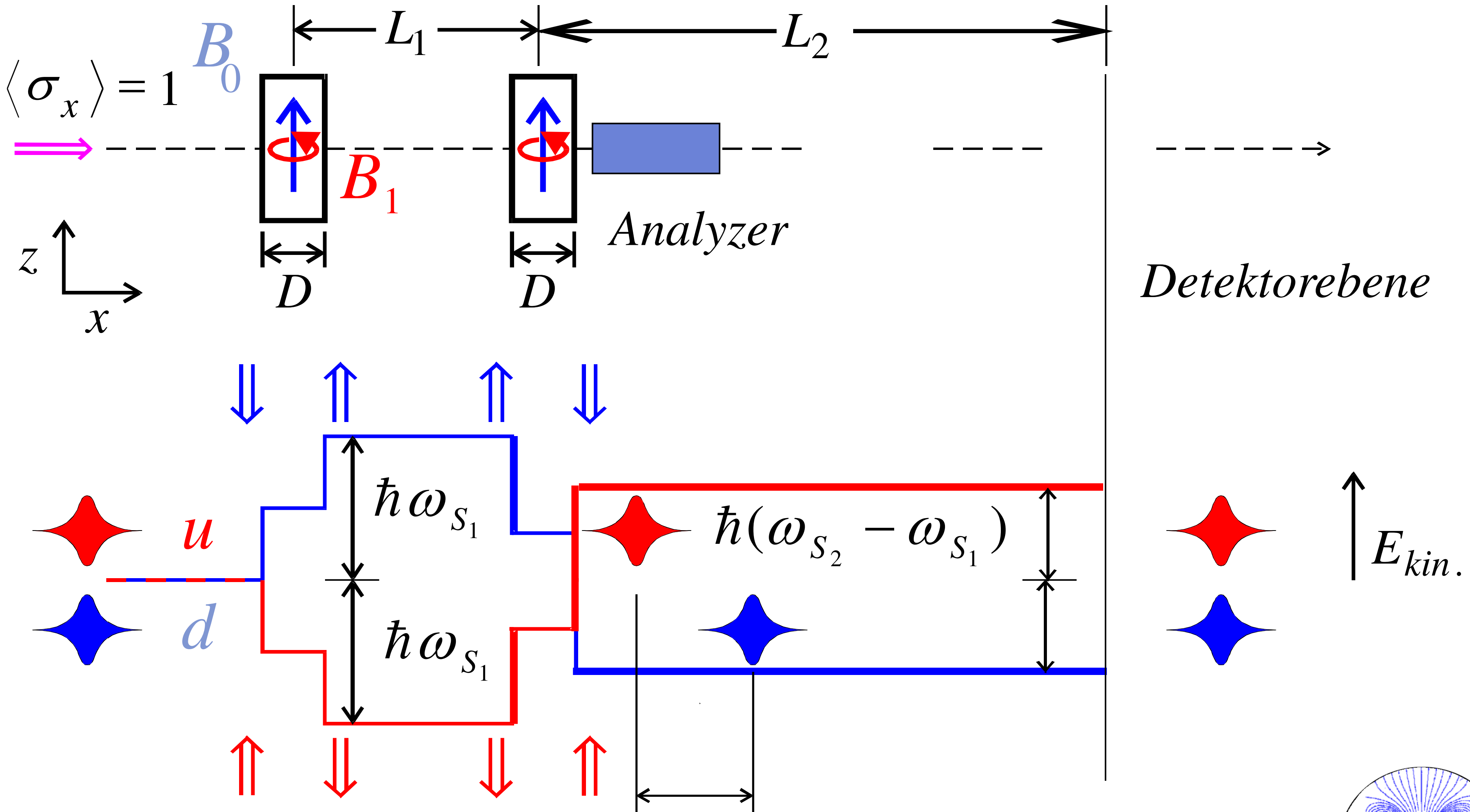
Principle Mieze I



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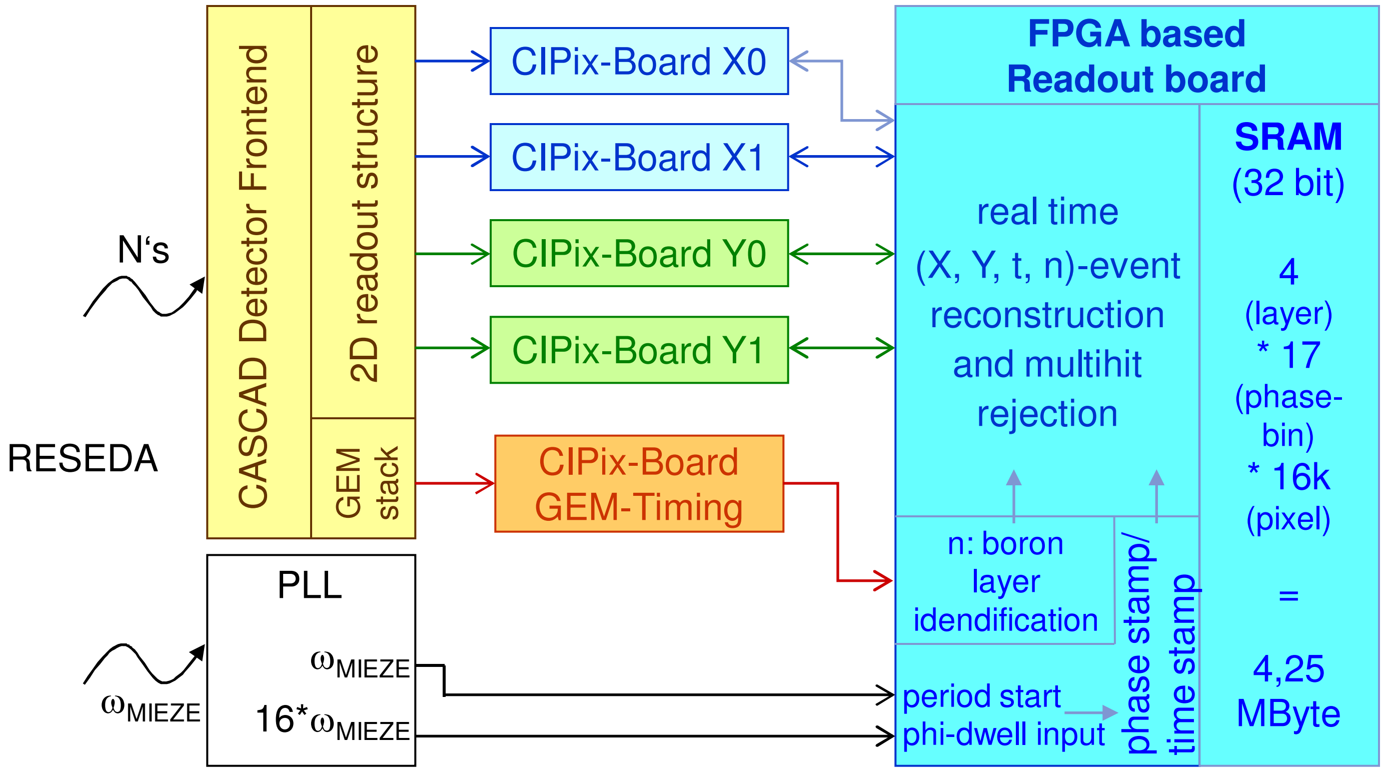
Schematic of the DAQ System



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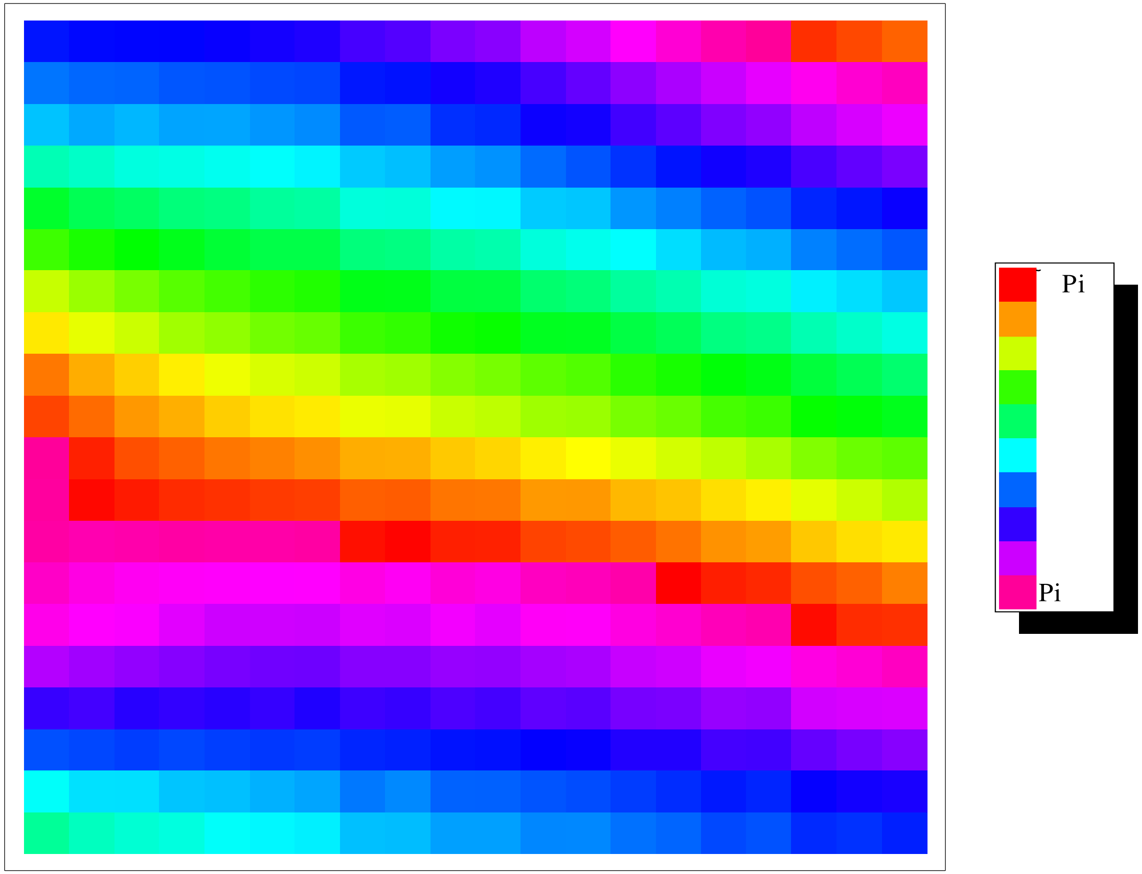
Accentuate distortion of the phase front

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 %

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

→ *acquisition robust to mechanical misalignments!*

CASCADE

CDT GmbH
CASCADE Detector Technologies

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

a university spin-off
dedicated to
neutron detector
technology

CASCADE

Dr. Christian J. Schmidt
and
Dr. Martin Klein

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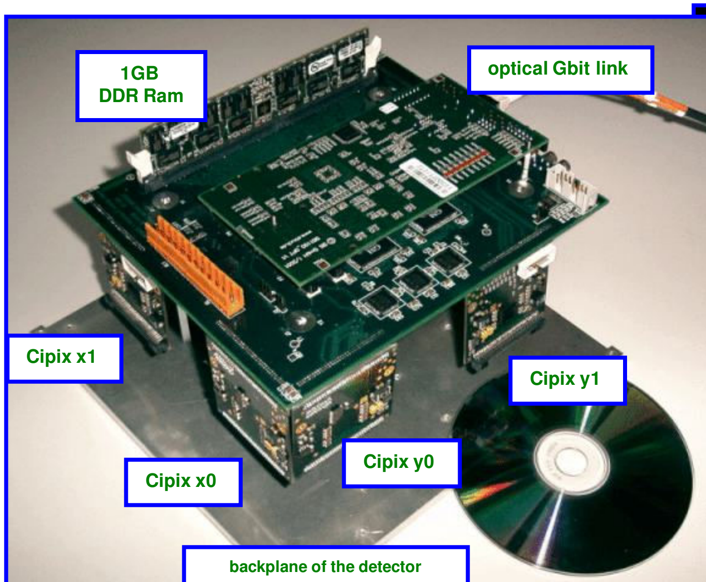
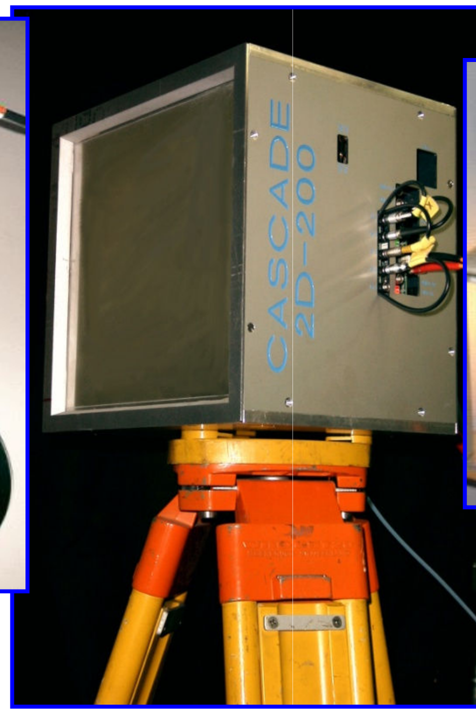
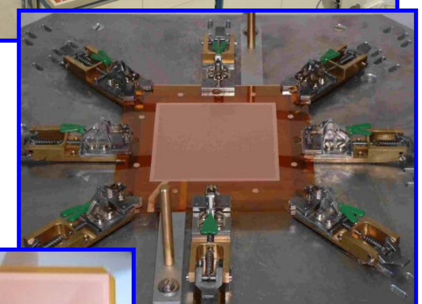
Germany
www.n-cdt.com

CDT: Development, Production and Sale

- Coating-Plants for ^{10}Boron
- Clean-Room for Detector-Production
- Development and Test of Readout Electronics
- Programming of Control Firmware and Software, Customized Solutions







CDT