EP-DT
Detector Technologies

Detectors and electronics for neutron detection in the NMX instrument of European Spallation Source
(BrightnESS T4.1)

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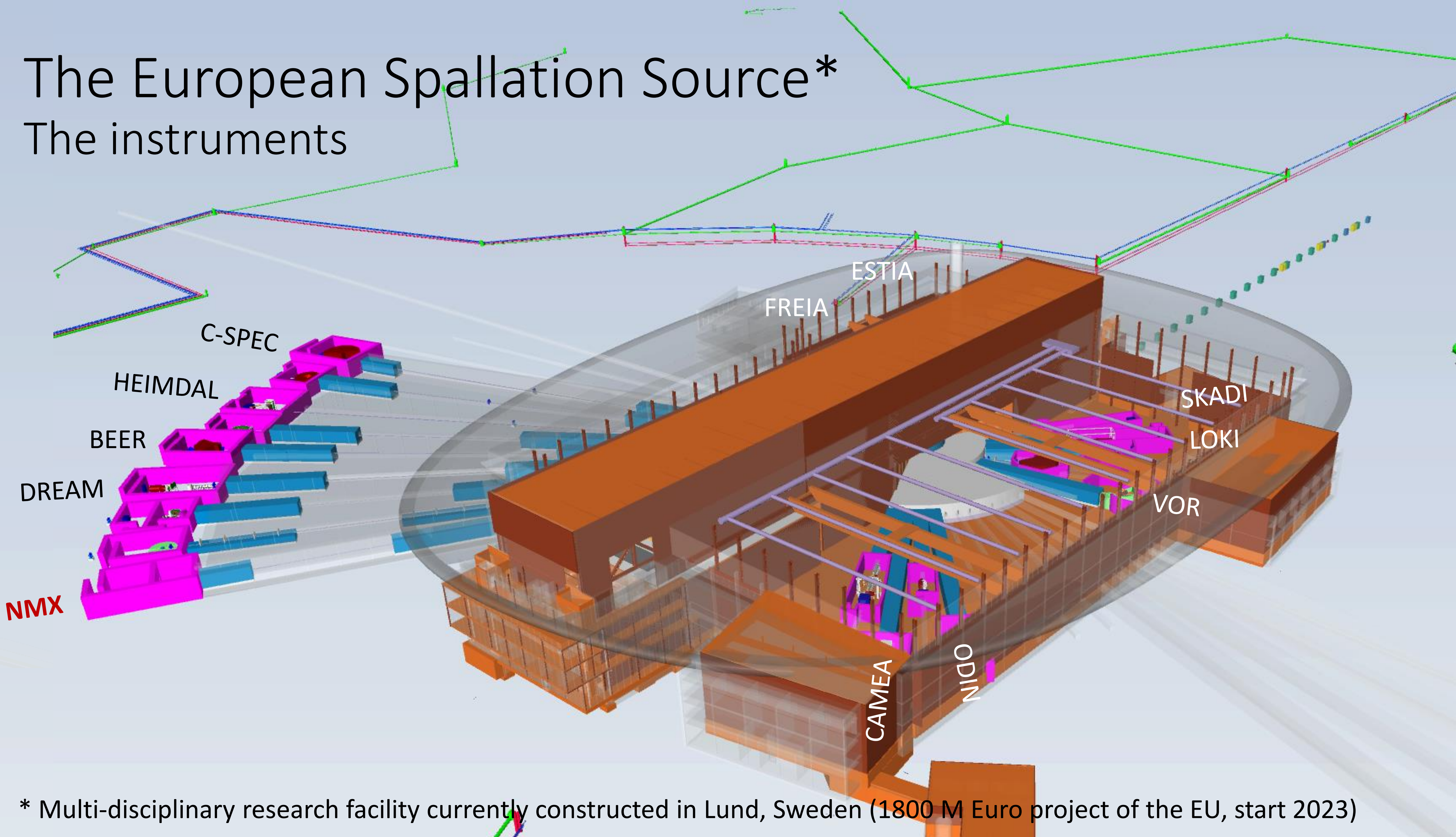
The European Spallation Source*

The instruments



* Multi-disciplinary research facility currently constructed in Lund, Sweden (1800 M Euro project of the EU, start 2023)


BMS

Outline

BrightnESS task 4.1

The NMX instrument

Detector demonstrator prototype

Detector read-out chain and electronics

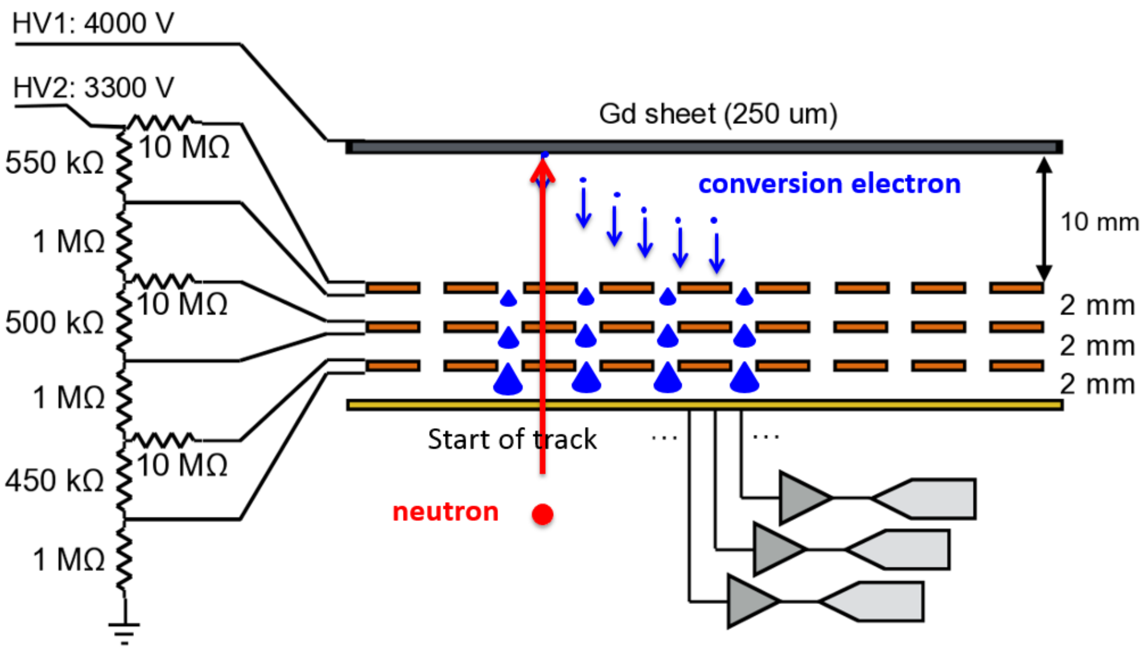
Conclusions

BrightnESS* task 4.1
The resolution challenge

Realize higher resolution detectors for ESS

NMX requires position resolution

of at least 200 µm



Development of detectors as “in-kind” contribution** from CERN

A) Neutron converter: Gadolinium

B) Detector technology: Gaseous Electron Multiplier (GEM)

C) Read-out technique: Micro Time Projection Chamber (µTPC)

*Horizon2020 project of the European Commission, budget ≈ 20 M Euro

** Two fellow positions in the GDD group

People in BrightnESS task 4.1

Filippo Resnati
CERN Fellow from March 2014
Coordination of WP 4.1
Since March 2017: CERN Staff
on CERN neutrino platform

Dorothea Pfeiffer
ESS Staff from Sept. 2013
Software development for
μ-TPC, simulation,
coordination with WP 5.1

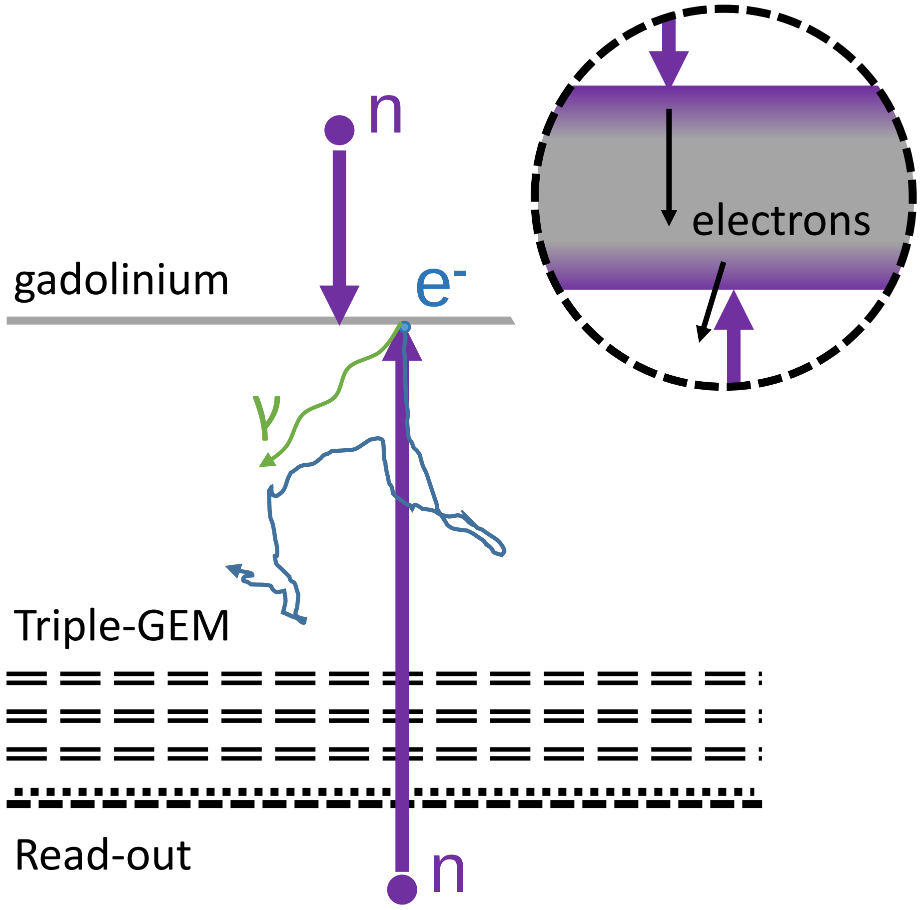
Patrik Thuiner
CERN Fellow from Feb. 2016
Detector construction: GEMs,
Gadolinium cathode, design &
optimisation for scattering

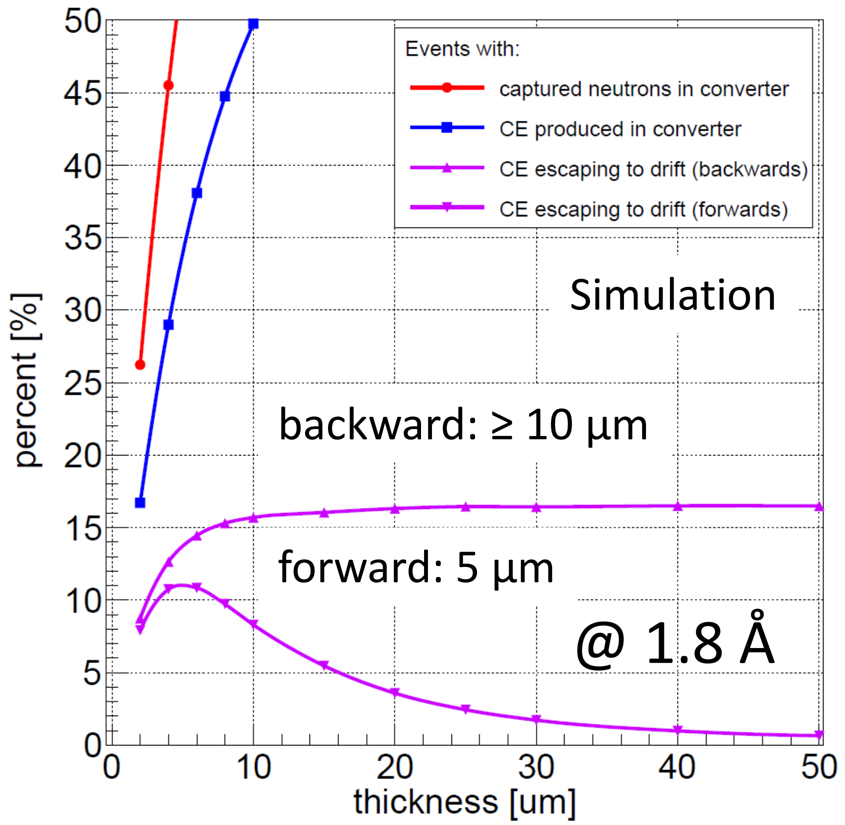
Michael lupberger
CERN Fellow from May 2016
Detector Readout: VMM ASIC
integration, readout electronics,
SRS firmware development, DAQ

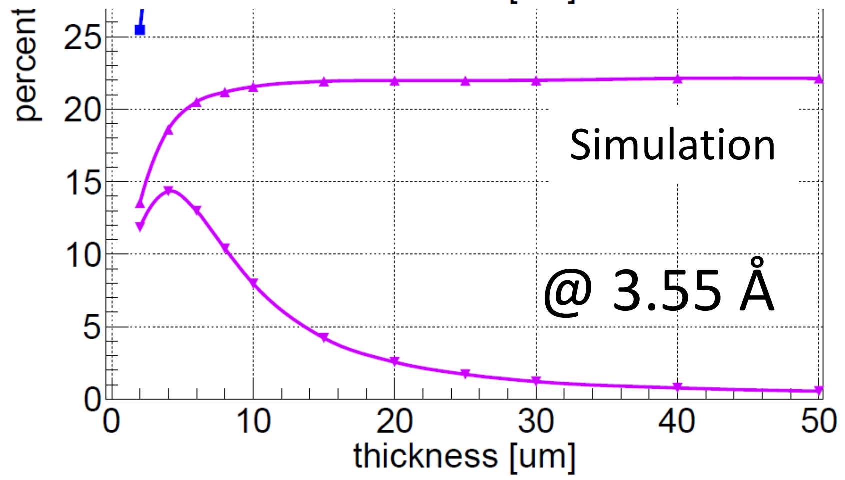
We are part of the CERN Gaseous detector group within the EP-DT-DD section lead by Leszek Ropelewski

BrightnESS task 4.1

A) Neutron converter: Gadolinium







BrightnESS task 4.1
B) Detector technology: Gaseous Electron Multiplier (GEM)

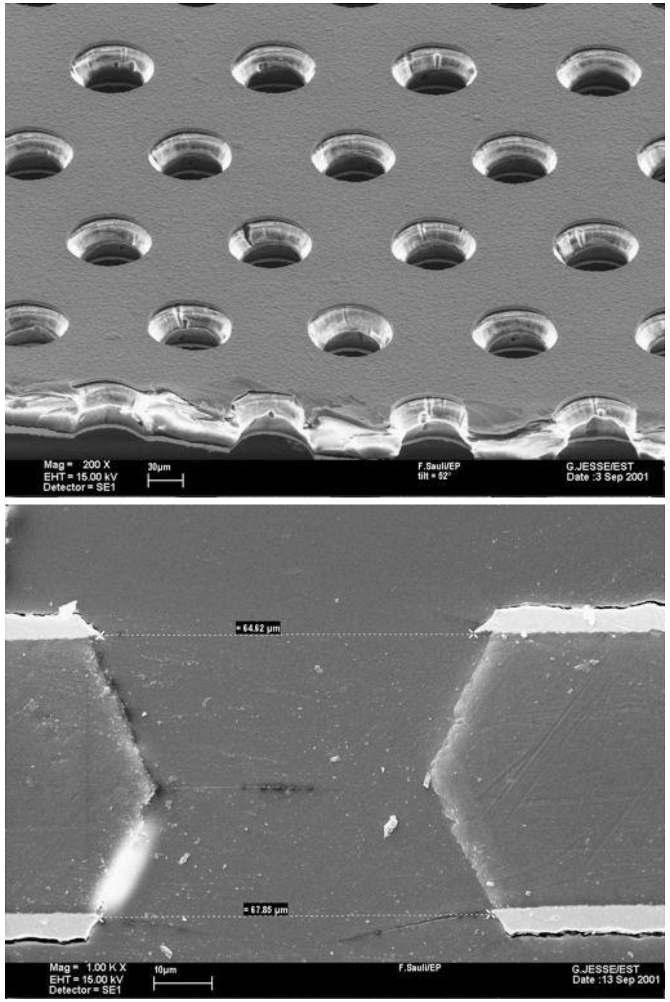
Metal-clad polyamide foil (usually 50 µm Kapton® with 5 µm Cu on both sides)

Perforated with **double-conical holes** in a honeycomb pattern (e.g. 70 µm diameter and 140 µm pitch)

Cathode on high negative potential with respect to GEM and anode

Potential difference applied between **top and bottom electrode** (typically in the order of 300-400 V)

Usually **more than one GEM used in series** to achieve stable operation at increased amplification

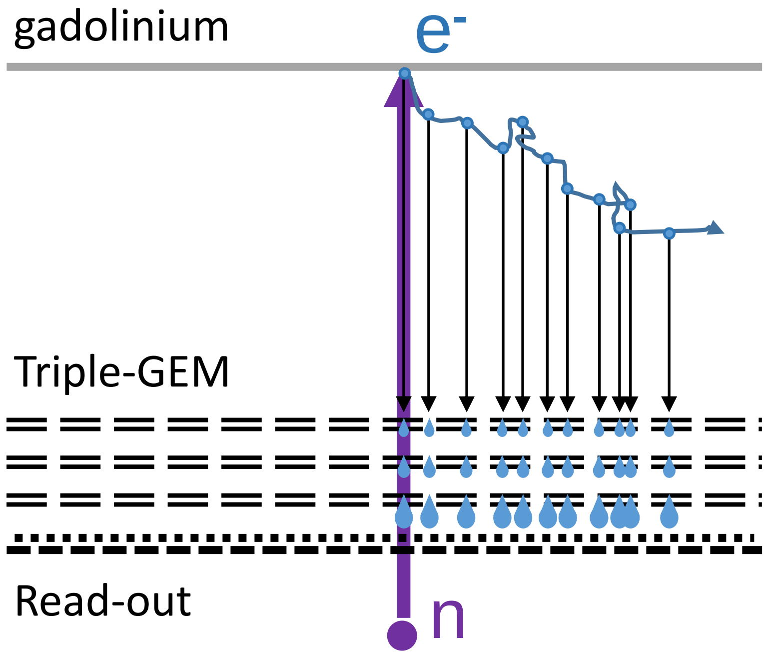


F. Sauli, *The gas electron multiplier (GEM): Operating principles and applications,* Nucl. Instr. Meth. A 805 (2016) 2-24

BrightnESS task 4.1

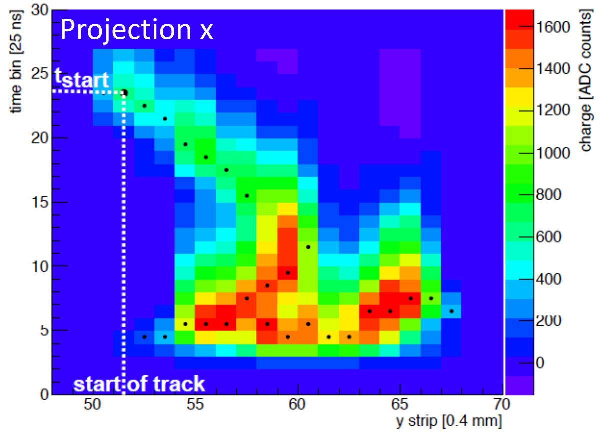
C) Read-out technique: Micro Time Projection Chamber (µTPC)

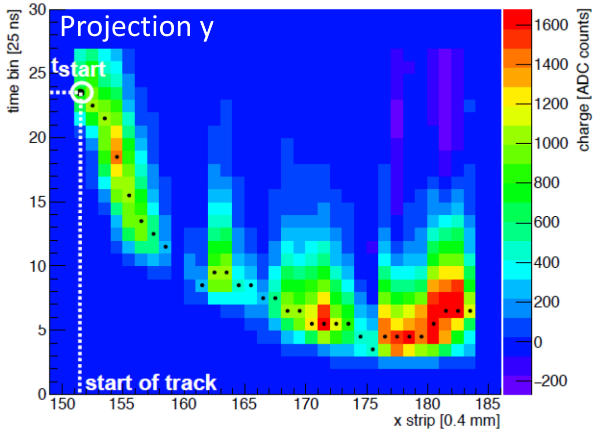
Already **working read-out technique** demonstrated for 10B† and Gd‡ neutron converters



position resolution of ***O*(200µm)** (strongly depending on read-out but generally improved by µTPC)

time resolution *O*(ns)





† D. Pfeiffer et al., JINST 10 (2015) 04, P04004 ‡ D. Pfeiffer et al, 2016 JINST 11 P05011 BrightnESS D4.3

The NMX instrument
Neutron macromolecular diffractometer

Determinate structures of proteins, location of hydrogen atoms

Optimised for small samples and large unit cells

Time-of-flight (TOF) quasi-Laue diffractometer

Wavelength band from 1.8 Å to 3.55 Å (6.49 to 25.25 meV)

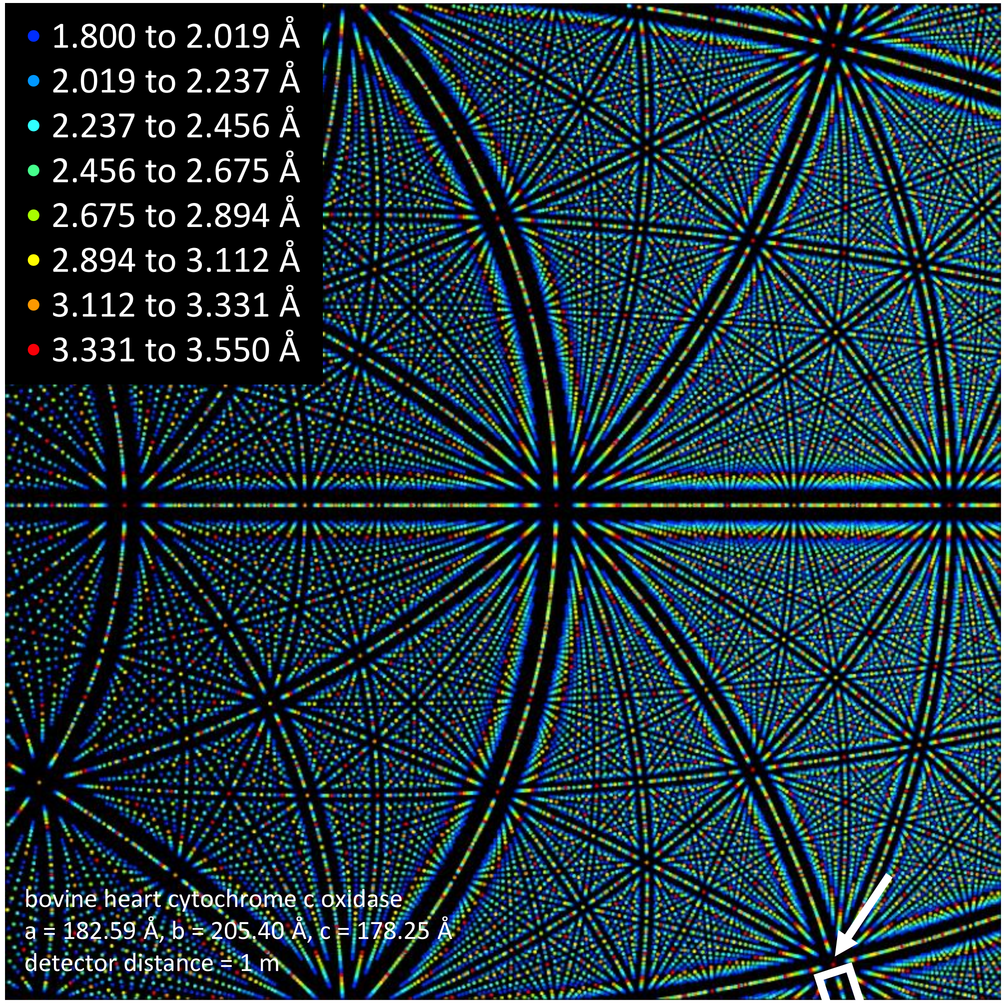
$2 \cdot 10^9$ n/s on 5×5 mm^2 sample (~ 4 kHz n/cm^2 on detector)

Approx. 0.8 m^2 detector active area

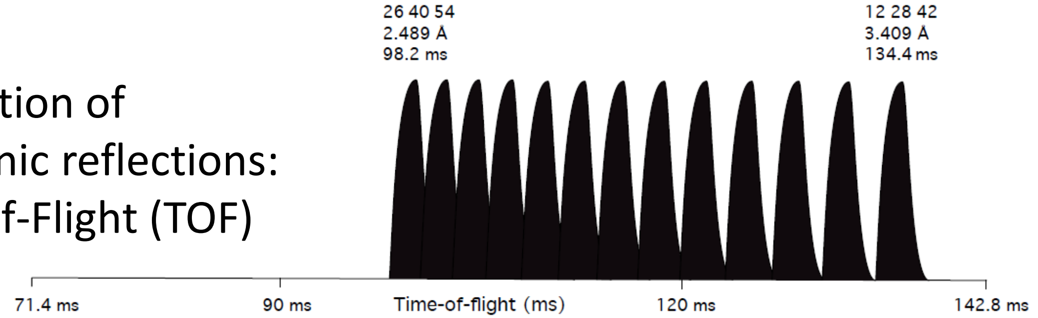
No fixed instrument geometry

Quasi-Laue Time-Of-Flight Diffractometry

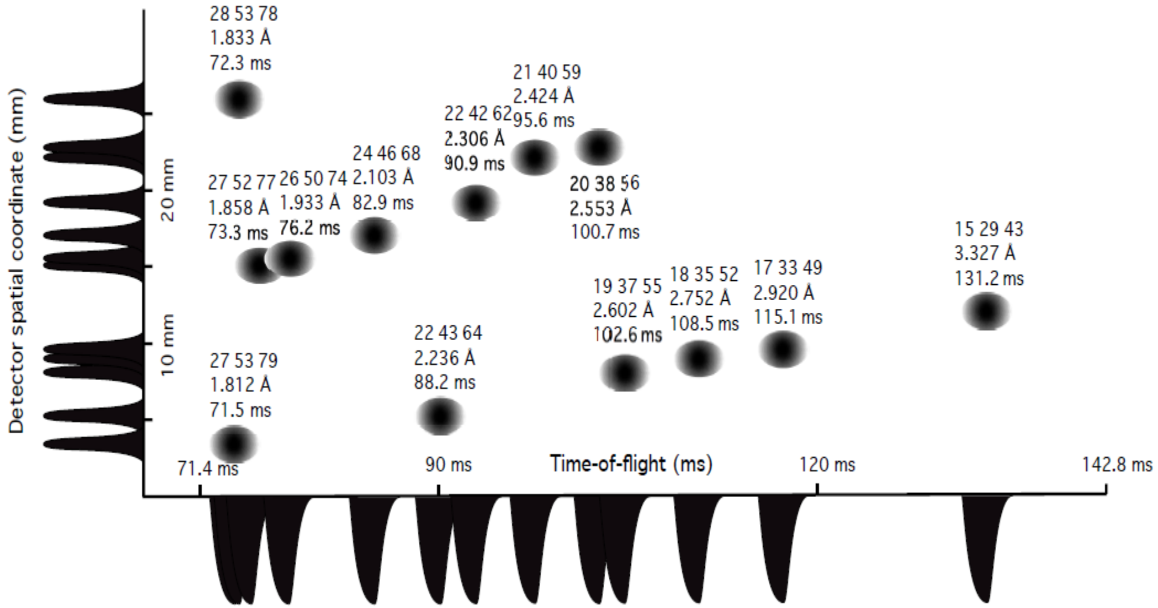
Example diffraction pattern



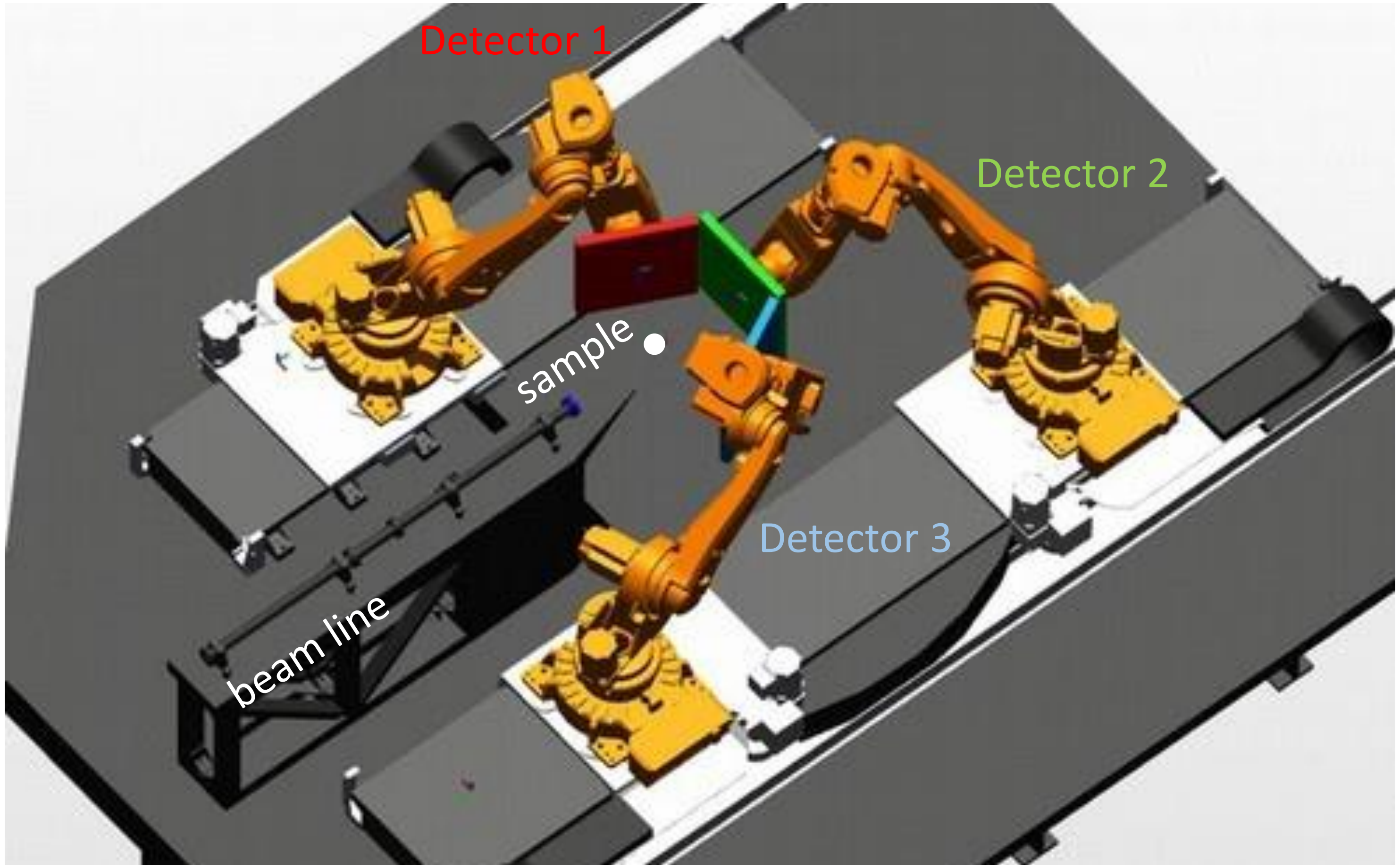
Separation of harmonic reflections: Time-of-Flight (TOF)



Separation of spatial reflections: TOF and superior position resolution



The NMX instrument
No fixed detector geometry



Detector Positioning System for ESS NMX, Final Design Report, J.-L. Ferrer

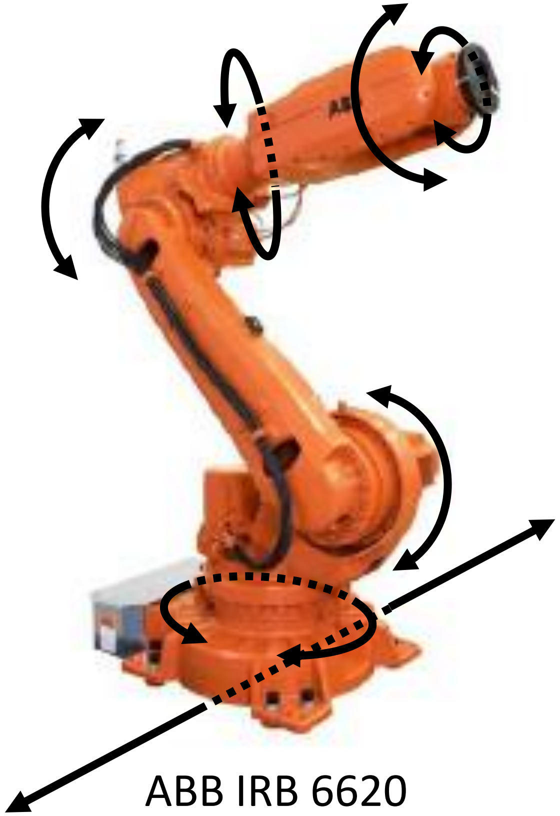
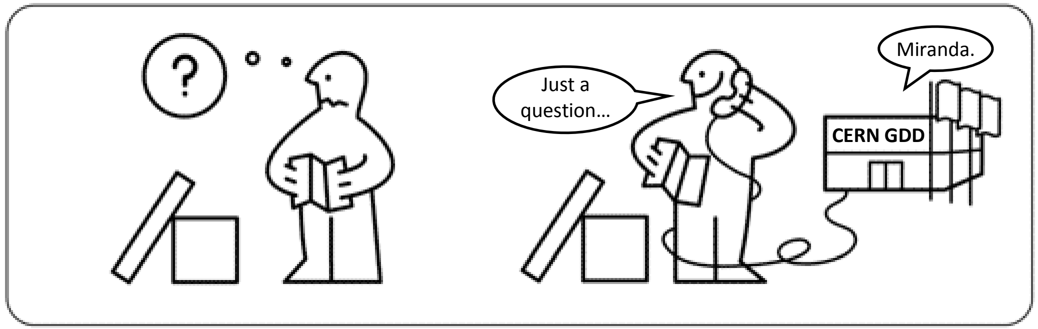
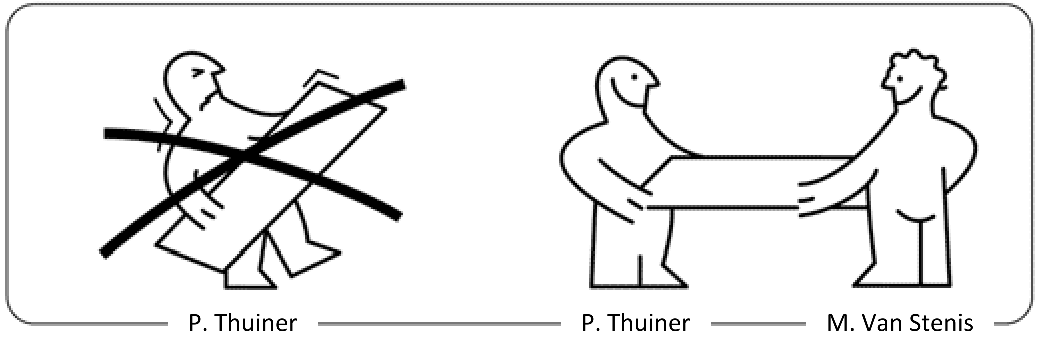


ABB IRB 6620
6 axes, 2.2 m reach
robotic arms on rails

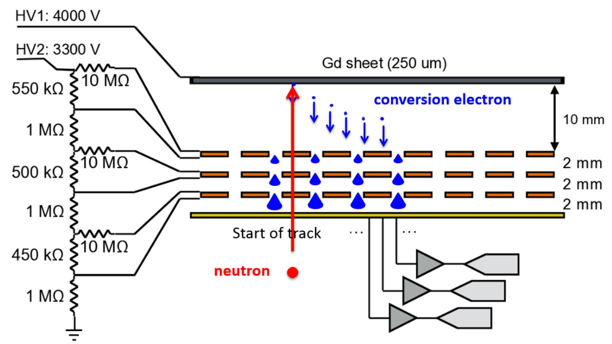


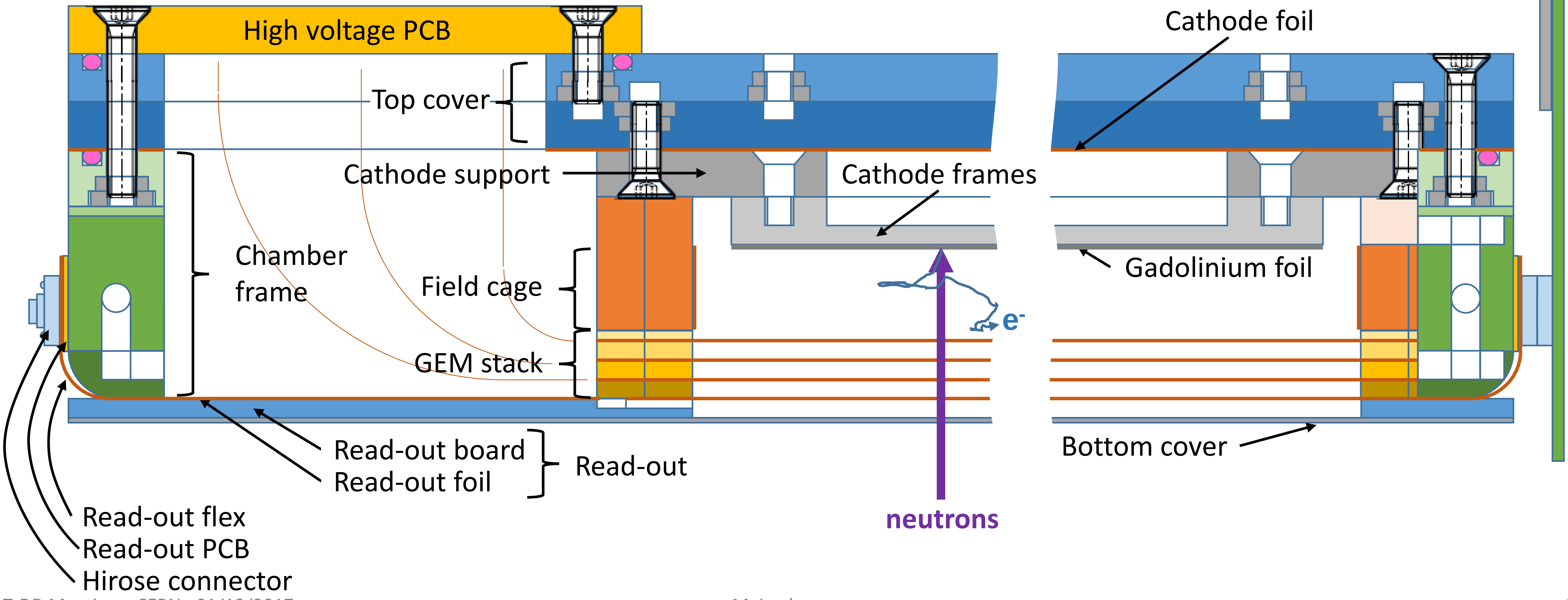
Detectör demonstrator prototype



The NMX demonstrator cross-section

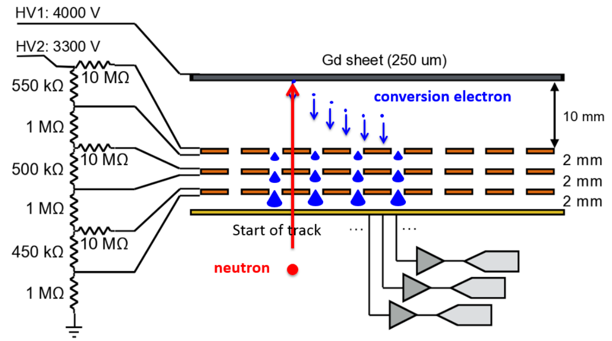
Detector prototype v0 “Zita”

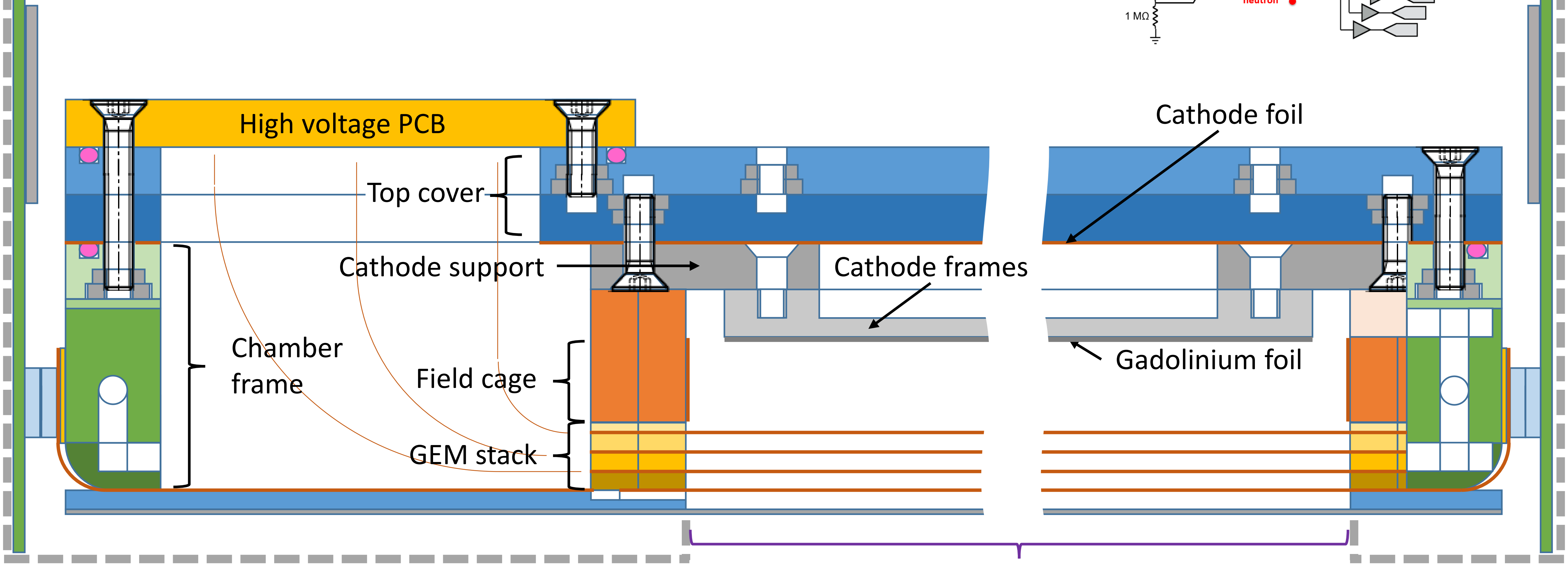




The NMX demonstrator cross-section

Detector prototype v0 “Zita”





thermal neutron shield
(not yet designed as part of WP 4.1)

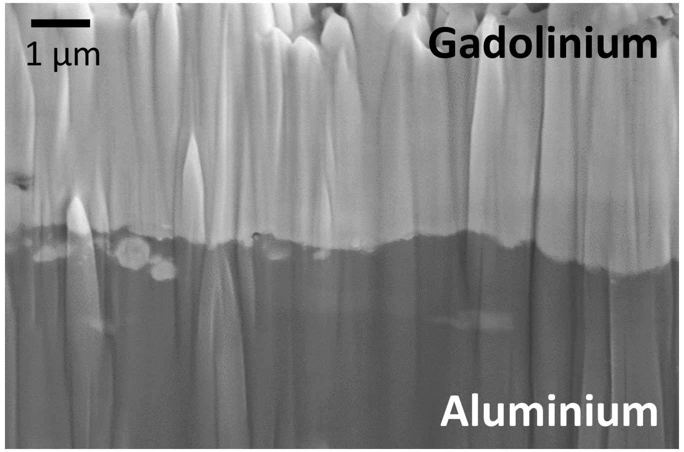
neutron transparent

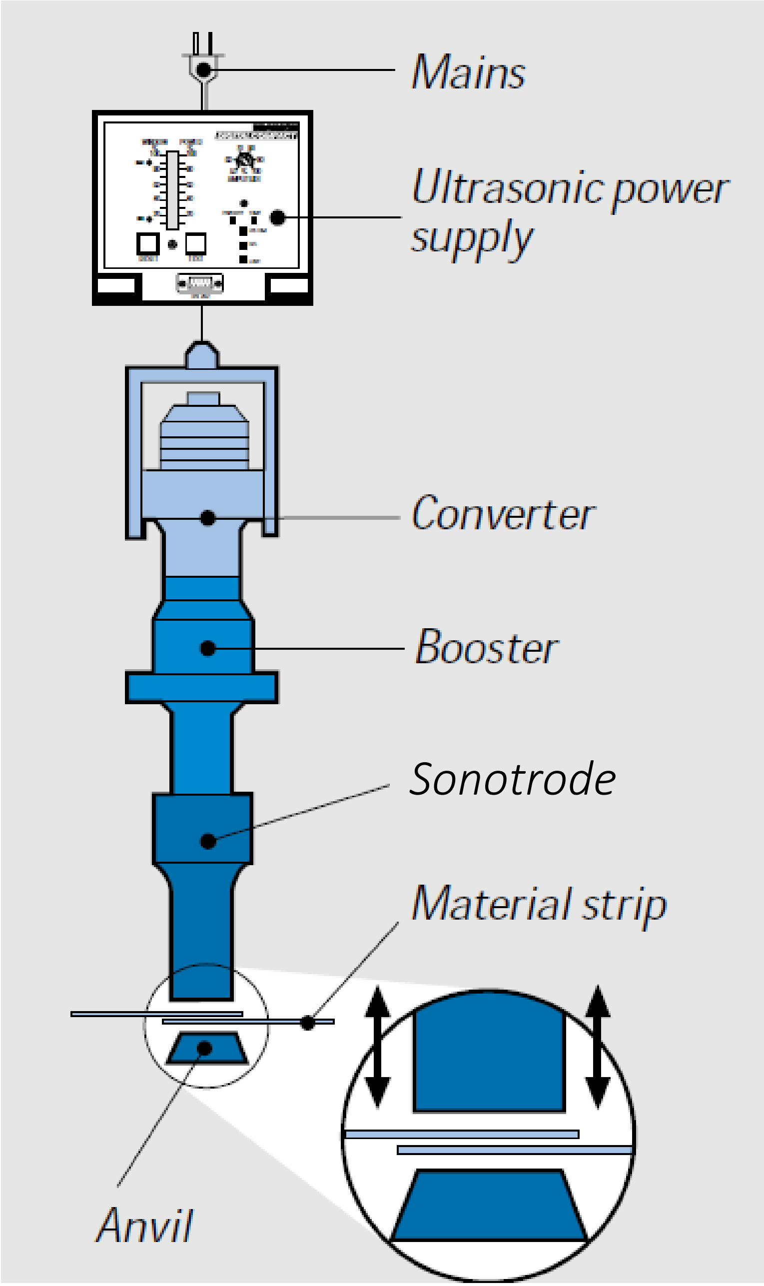
thermal neutron shield
(not yet designed as part of WP 4.1)

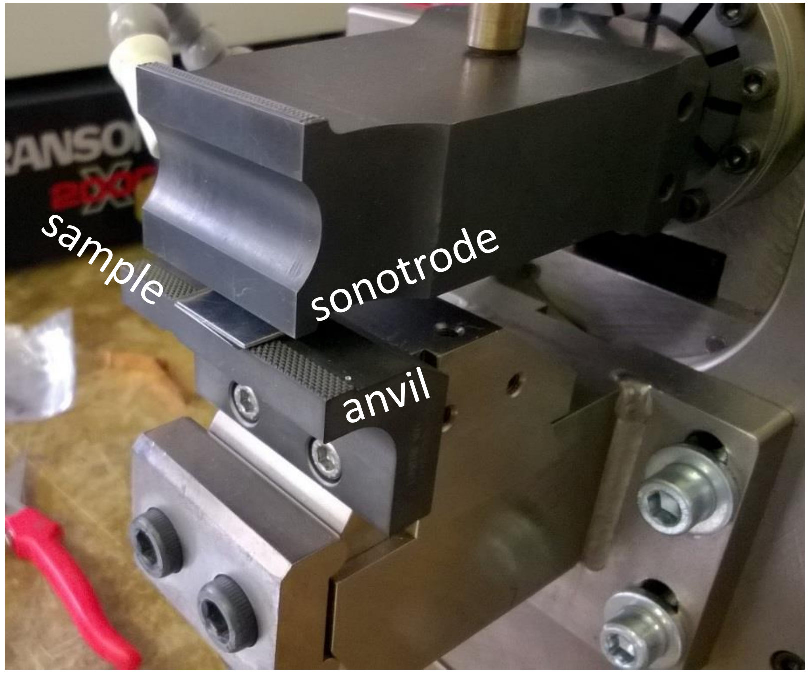
Cathode assembly due to maximum foil size

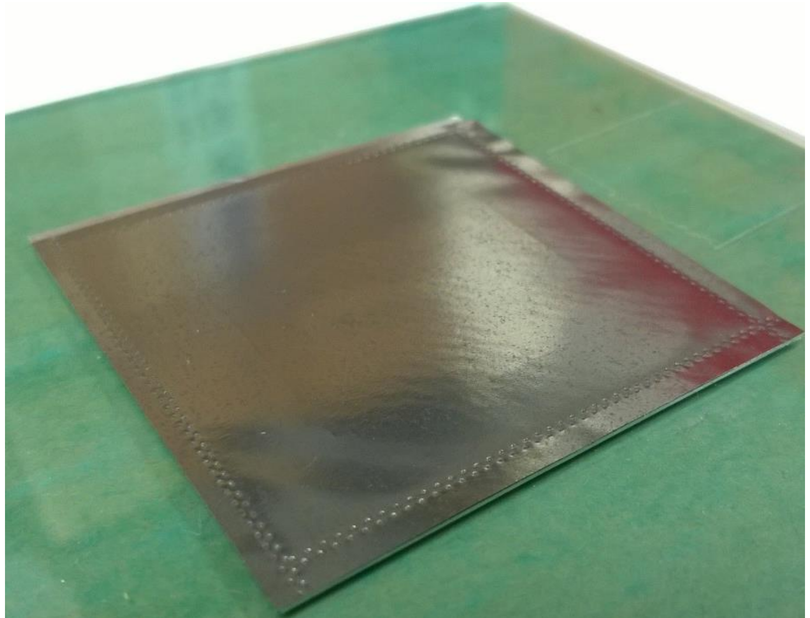
Ultrasonic welding for mechanical and electrical connection with

No dead area








25 µm gadolinium on 1 mm aluminium, 5 x 5 cm^2

Conclusions

Detector demonstrator prototype

NMX instrument will be first instrument without fixed geometry
Three **fully integrated and moveable detector units**

Testing and **assembly** has started **early October**

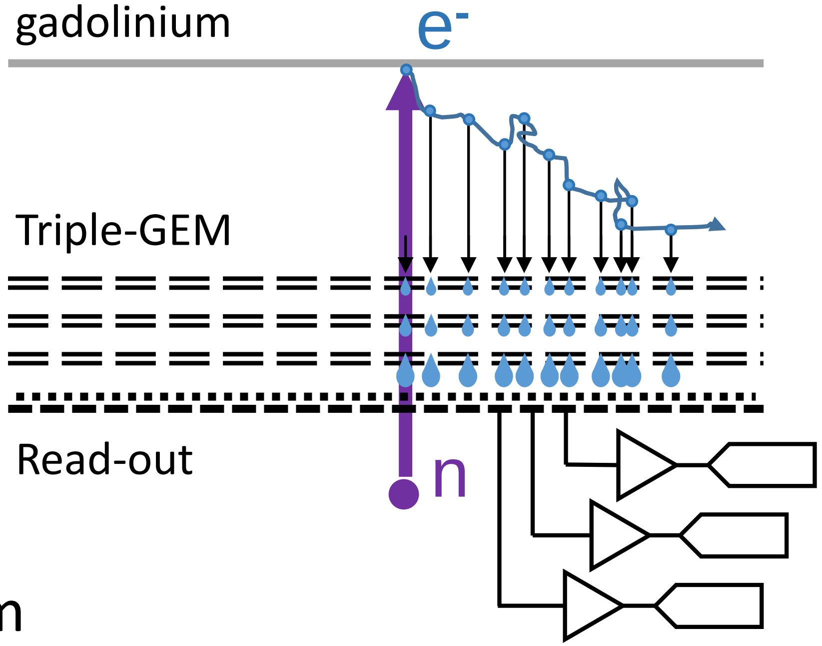
Close to requirement of **200 µm** spatial resolution

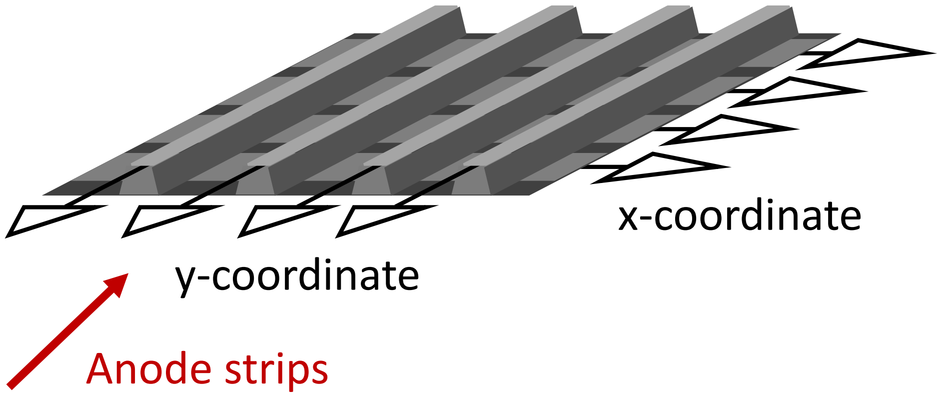
First gadolinium cathodes produced with ultrasonic welding

Possibility to upgrade to **enriched Gd-157** studied
and is **viable future upgrade path**

Detector read-out chain and electronics

Electronics
Reminder





Anode strip pitch: 400 μm

NMX prototype: 5120 strips w/ 4 kHz hits per strip
→ fast dense electronics needed to process charge signal: integrated circuit

μTPC requires time resolution *O*(ns)
→ high time resolution required

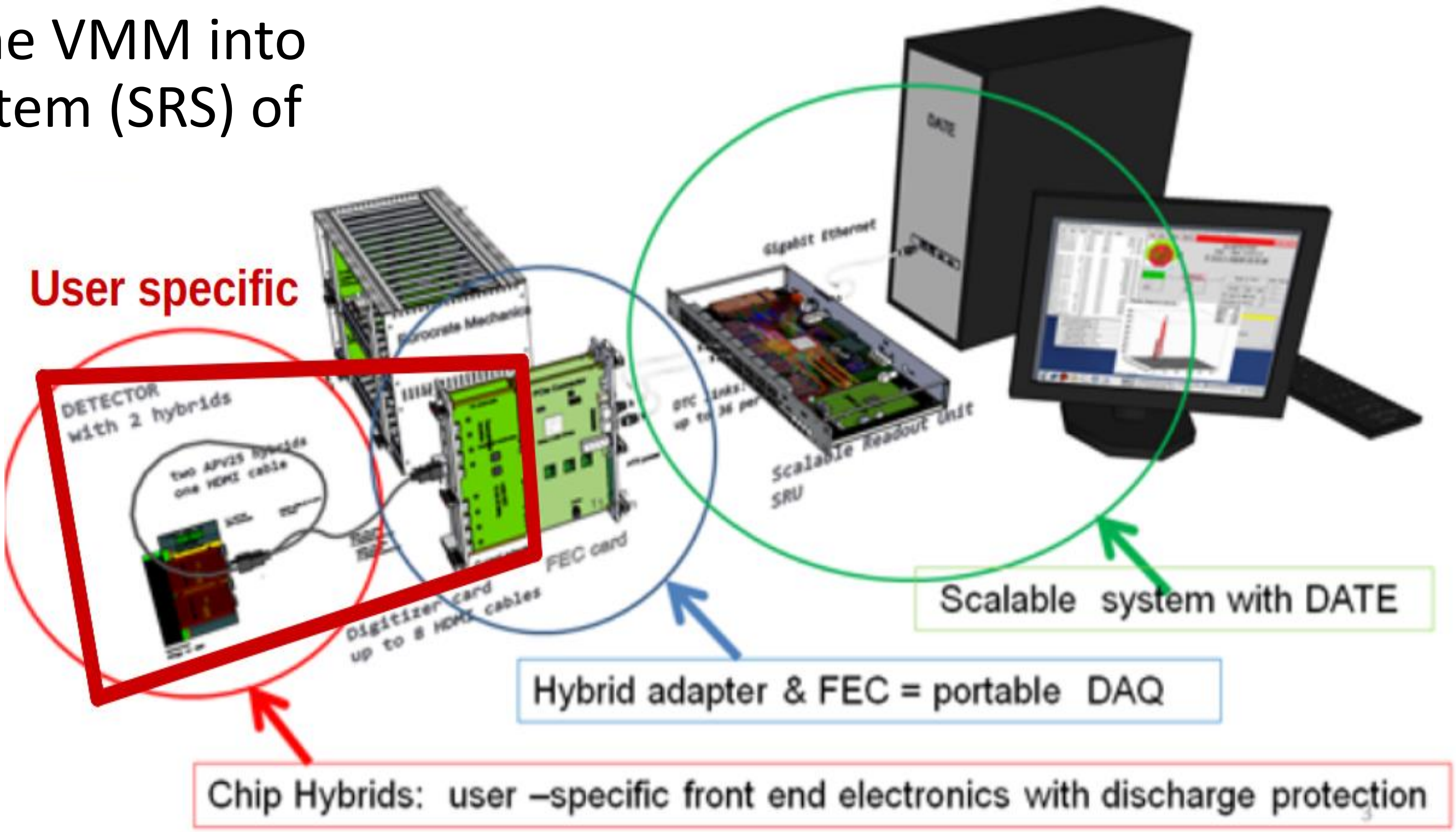
Robotic arms restrict number of cables from detector to back-end

→digitise data on detector

Use VMM ASIC from ATLAS New Small Wheel project

Electronics
The Scalable Readout System

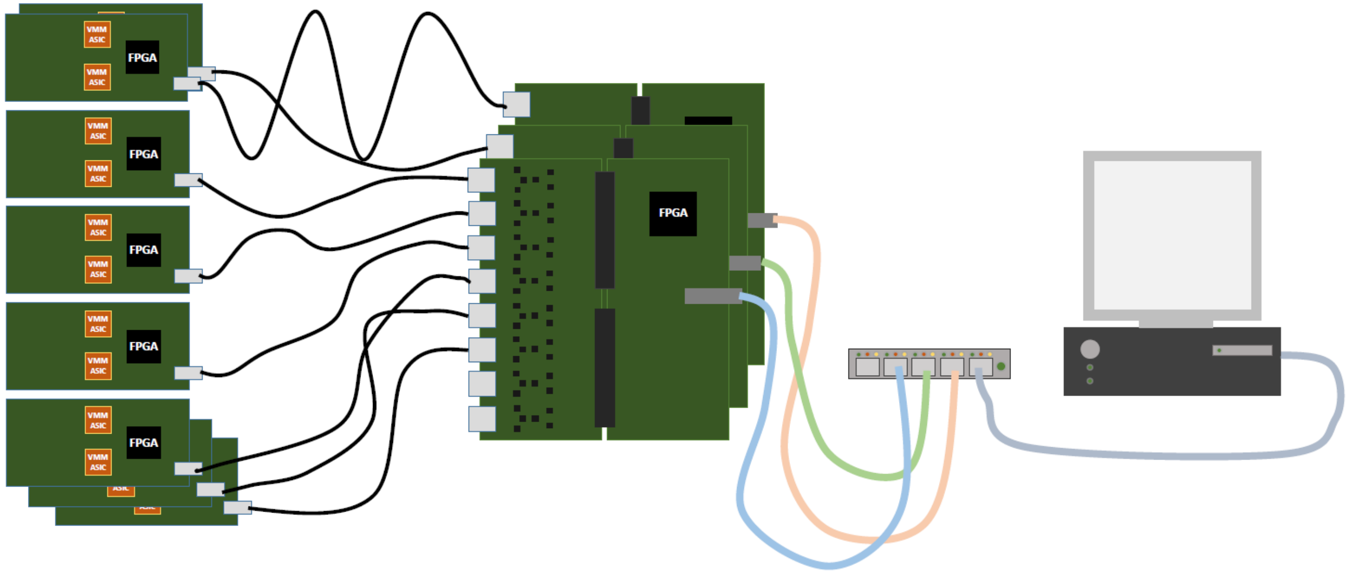
Implementation of the VMM into Scalable Readout System (SRS) of RD51 Collaboration



Electronics

Readout chain and components

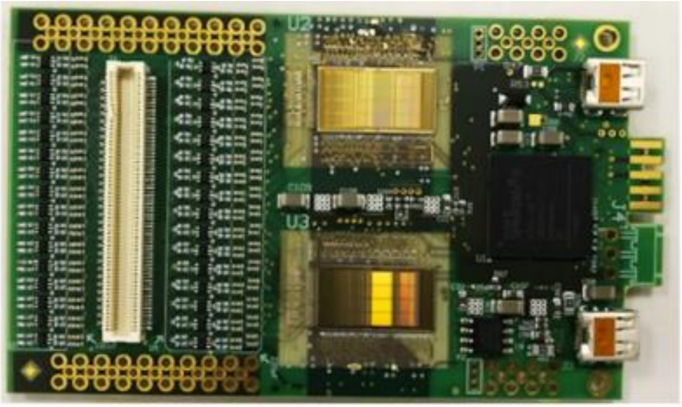
New hybrid and adapter card, FPGA firmware, and PC software has been designed to implement VMM in SRS



VMM Hybrid → HDMI cable → Adapter card + FEC → Ethernet → Switch →Ethernet → PC

Scalability: up to 8 VMM hybrids/FEC, many FECs/PC

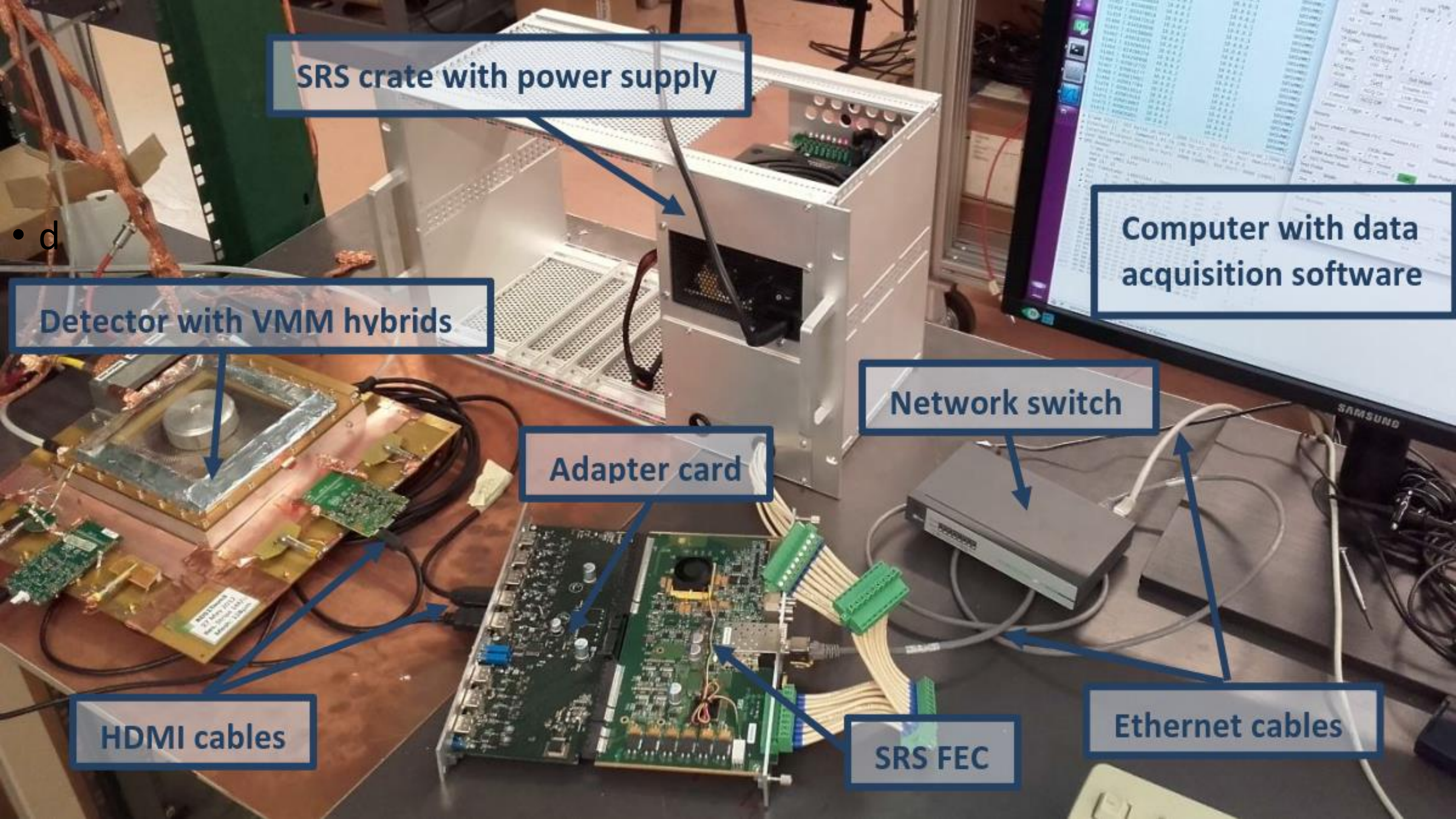
→ system scalable from one to 64 hybrids and more



VMM hybrid

SRS FEC and adapter card for VMMs

• d

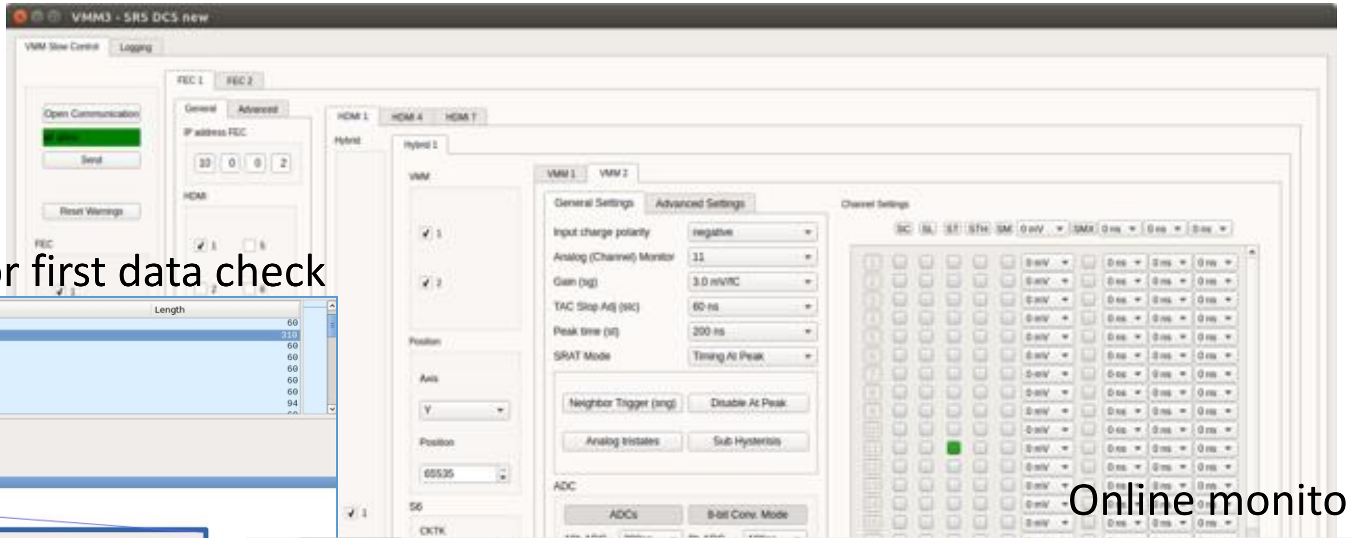


SRS crate with power supply
Computer with data acquisition software
Detector with VMM hybrids
Network switch
Adapter card
HDMI cables
Ethernet cables
SRS FEC

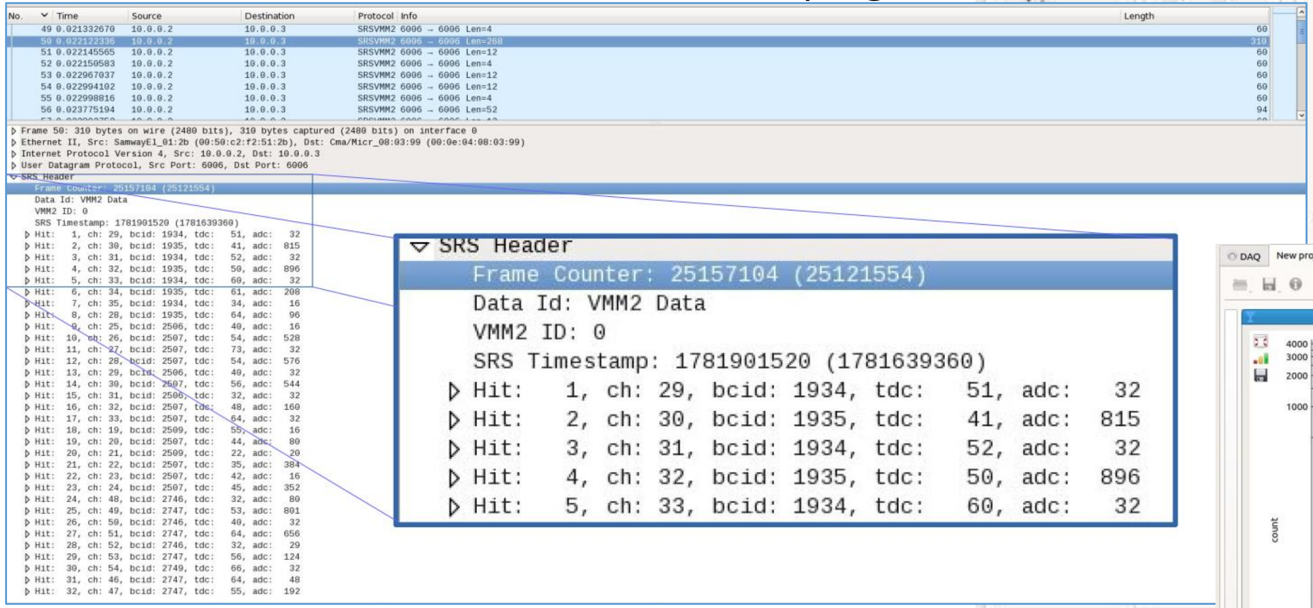
Electronics

Data from SRS

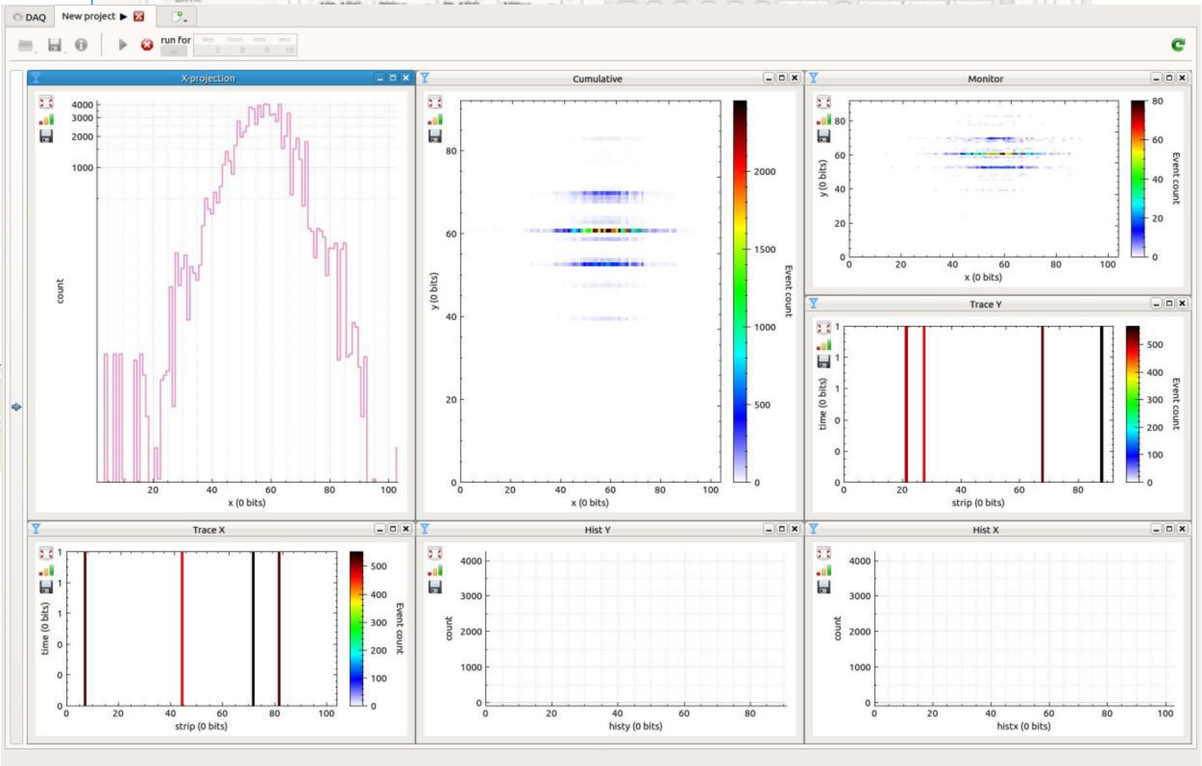
Slow control



Wireshark & plugin for first data check



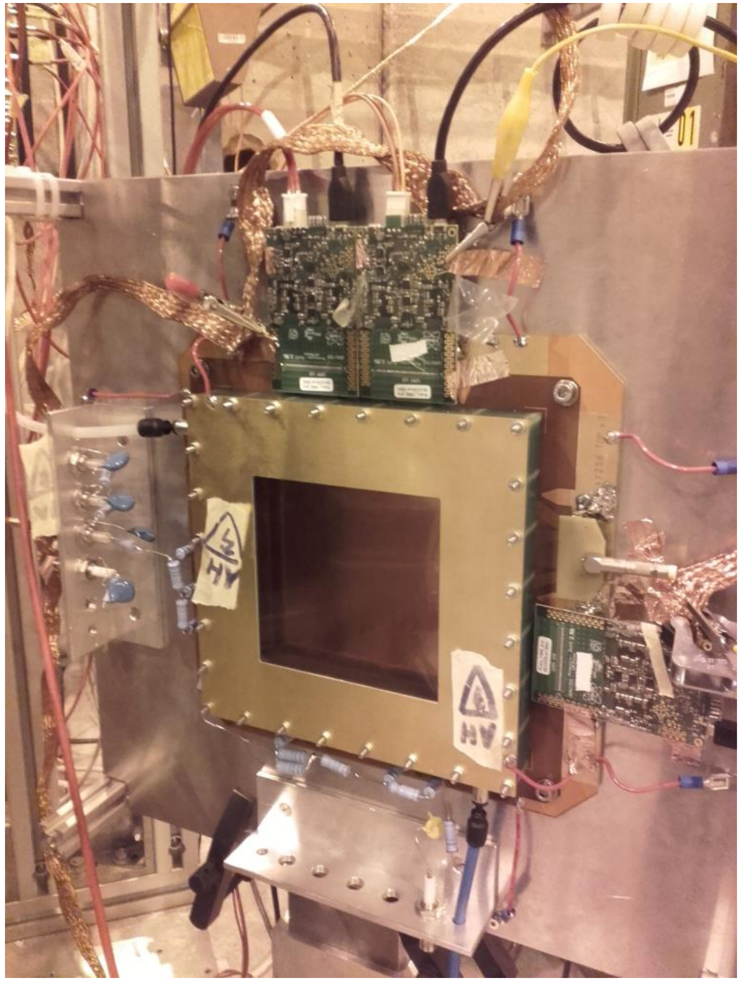
Online monitoring



Help from BrightnESS WP5.1, DMSC for online data monitoring and fast data acquisition

Electronics

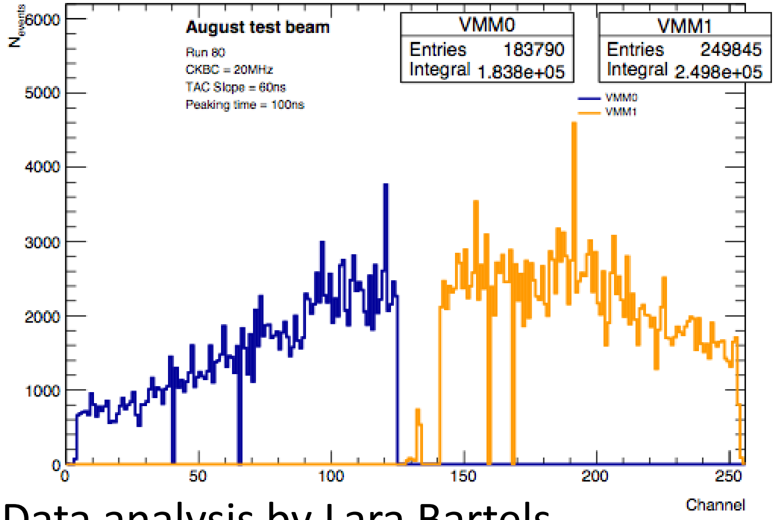
Latest test beam at CERN North area with beam from SPS

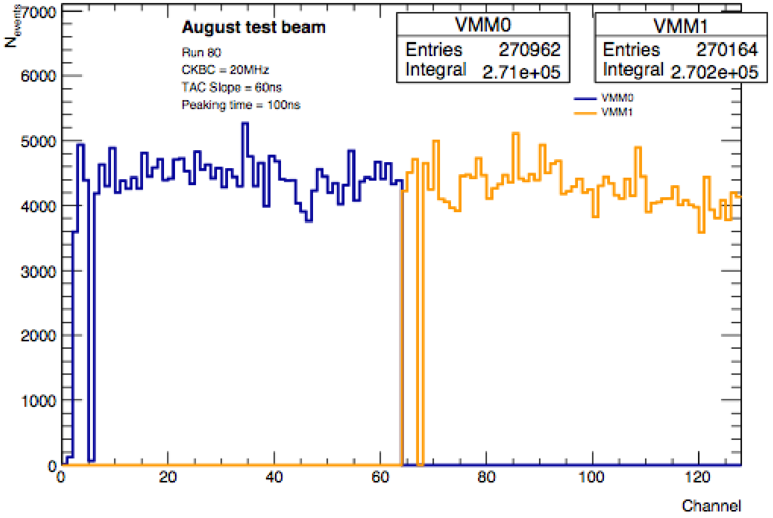


Triple-GEM detector with copper cathode (no gadolinium for muons and pions)

Three VMM3 hybrids (2 on x-axis, 1 on y-axis)

- Continuous data in self-triggered mode at 5kHz readout frequency
- Goal of test: operate electronics and test different settings

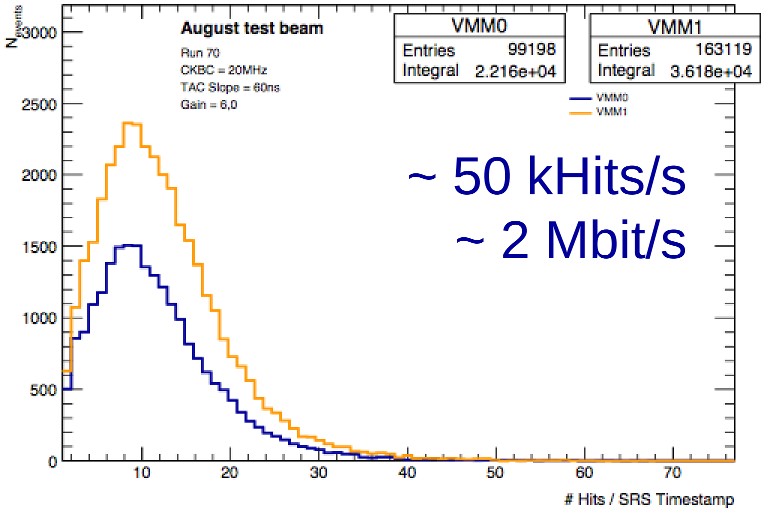


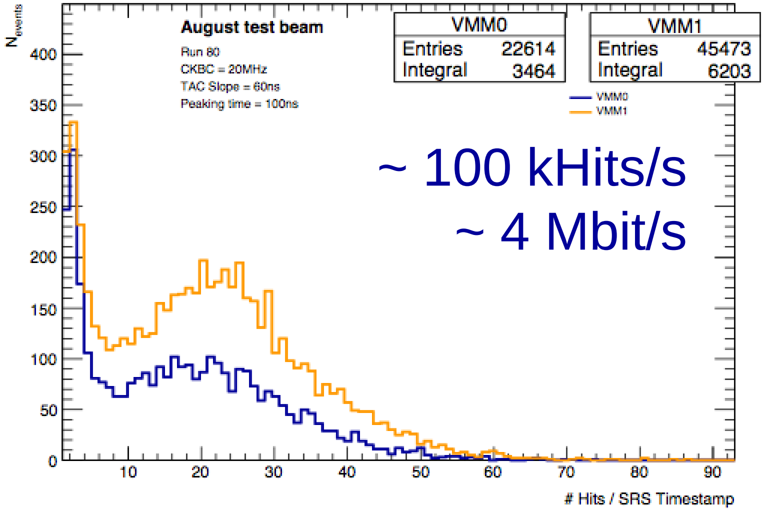


Data analysis by Lara Bartels

Electronics

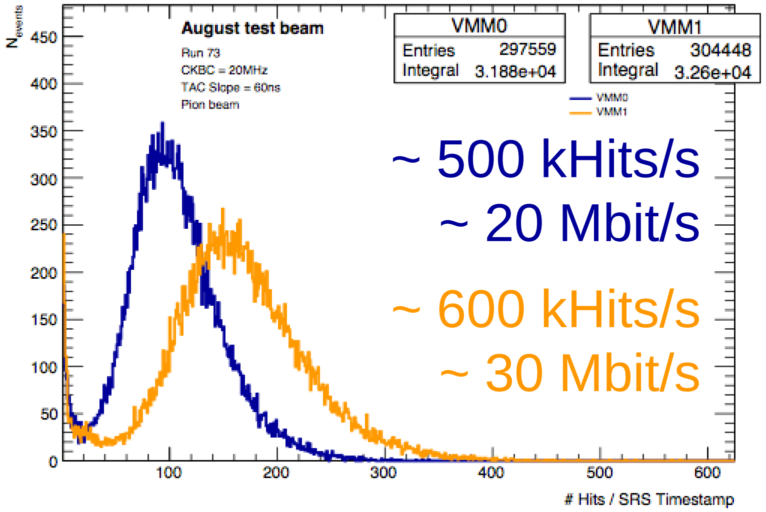
Latest test beam at CERN North area with beam from SPS

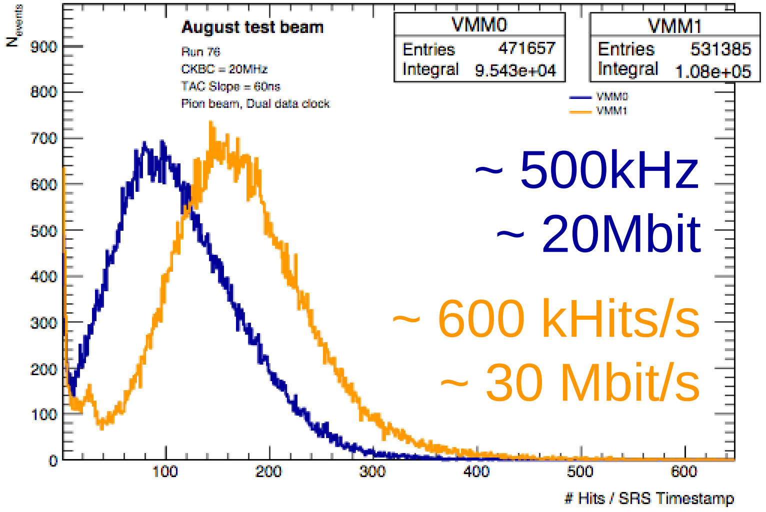




muon beam

pion beam



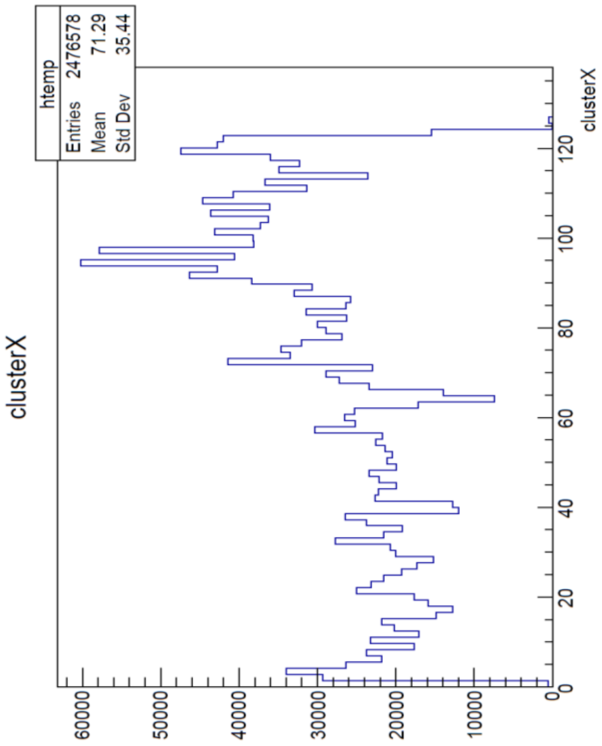


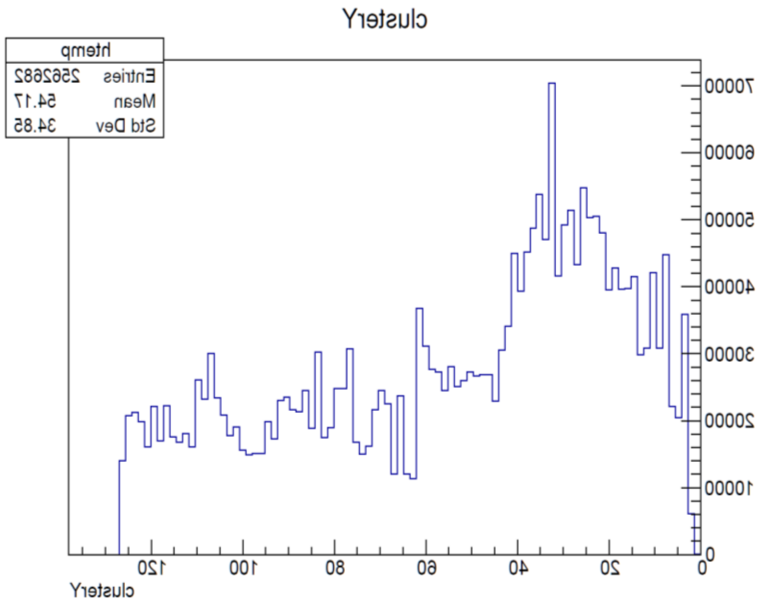
Electronics

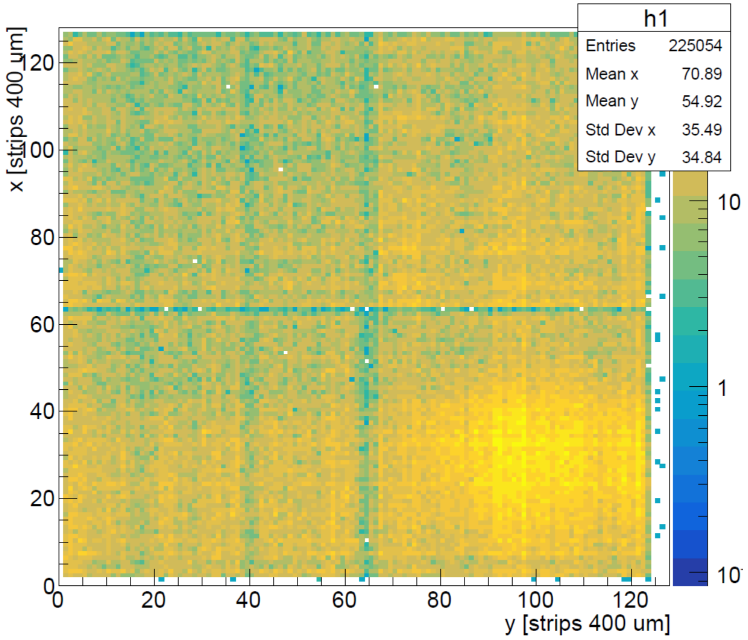
Latest test beam at CERN North area with

Clustered data from pion beam

VMM3 is working
and will also work with
all diffraction patterns!







Conclusion
Electronics

SRS + VMM readout still in prototype status with development ongoing

CERN test beam has shown that:

- Prototype system is operational and can read out signals from detector
- All hardware components work
- Software for slow control, online monitoring and data acquisition is available and allows for smooth operation of the system
- System can handle data rates up to about 50 Mbit/s/VMM for 6 VMMs (NMX prototype: 80 VMMs at equal data rates)
- Data analysis software available (Lara's Summer Student project)

Conclusions
NMX @CERN

Everything **running according to schedule**
Delivery of detector components, electronics,...

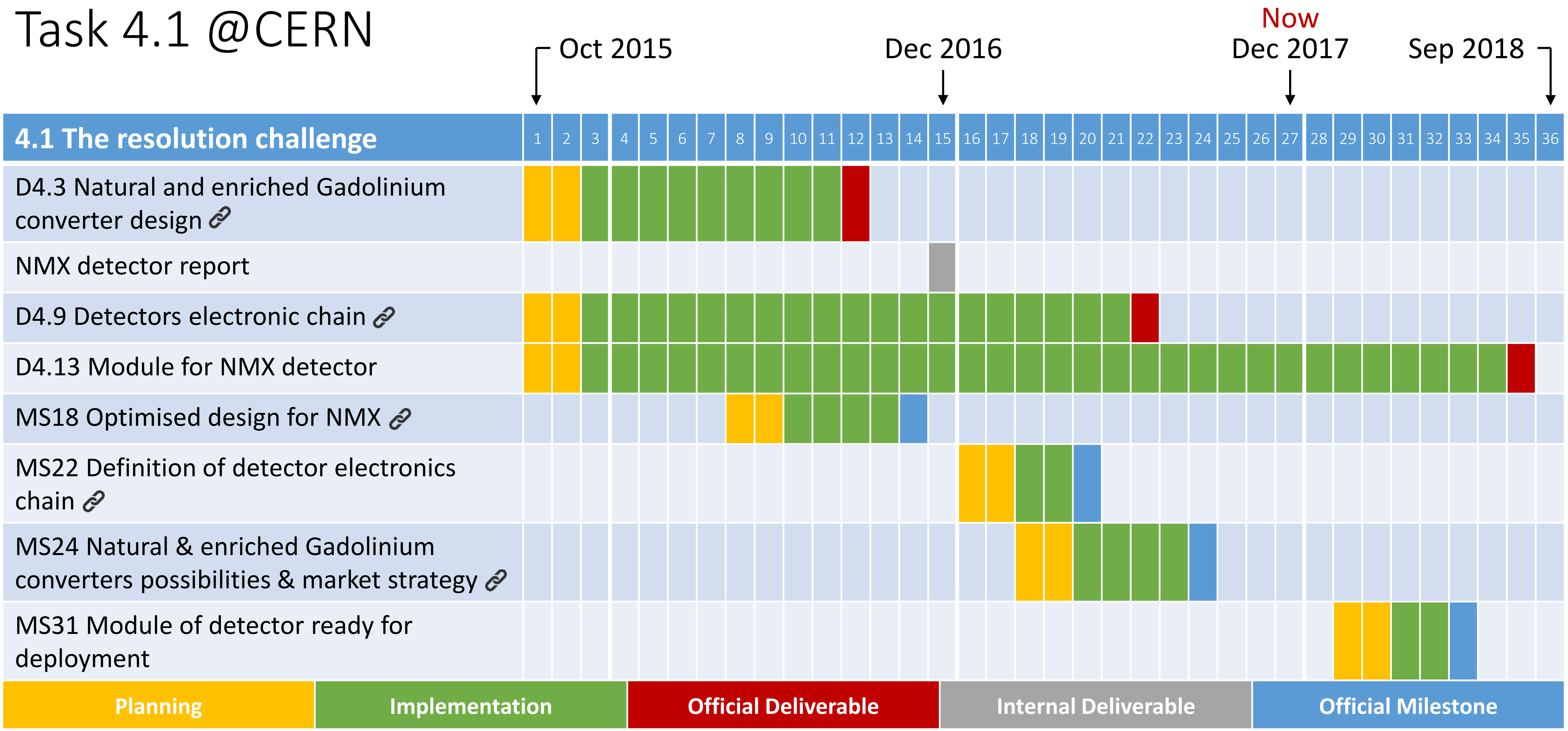
Concept for **detector** has been proven to work and **close to requirements**
Electronics are working like expected

Detailed engineering and **implementation has started**

Outlook: Test beam with neutrons at reactor in Norway next week with mockup of prototype detector and SRS + VMM electronics

Latest Deliverables and Milestones for BrightnESS

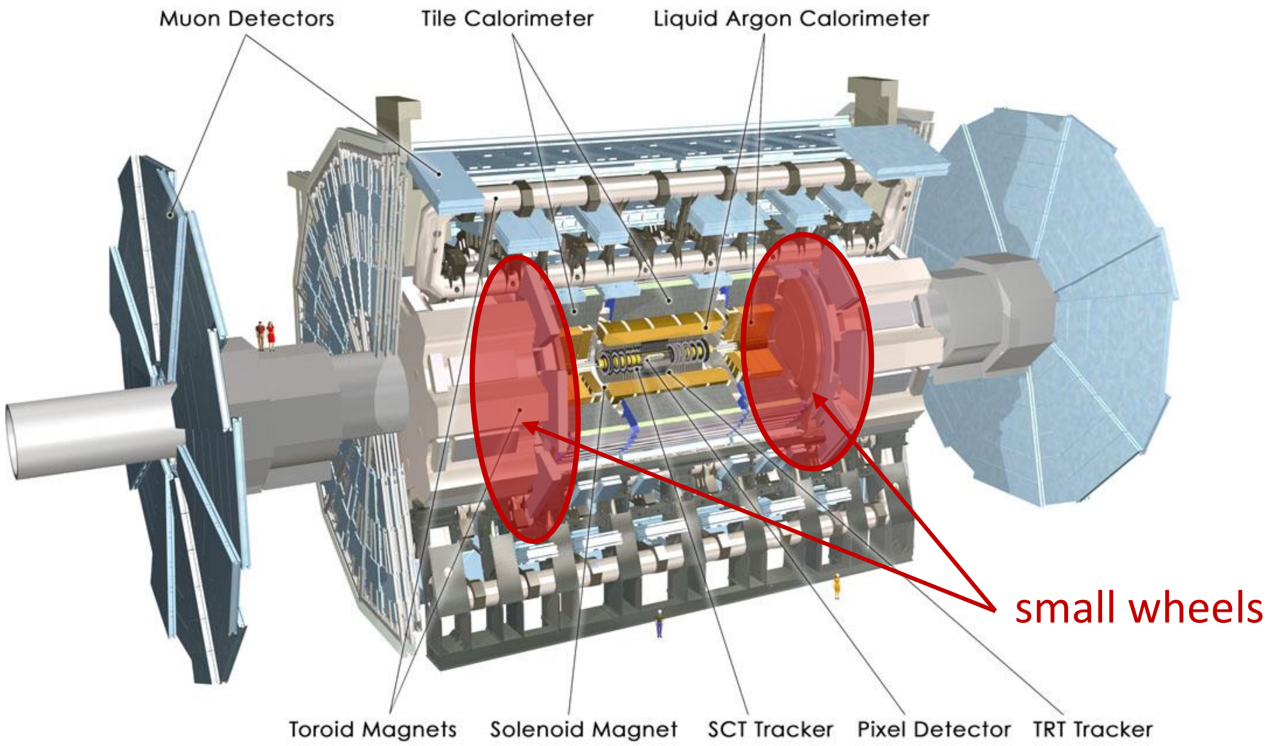
Task 4.1 @CERN



Electronics

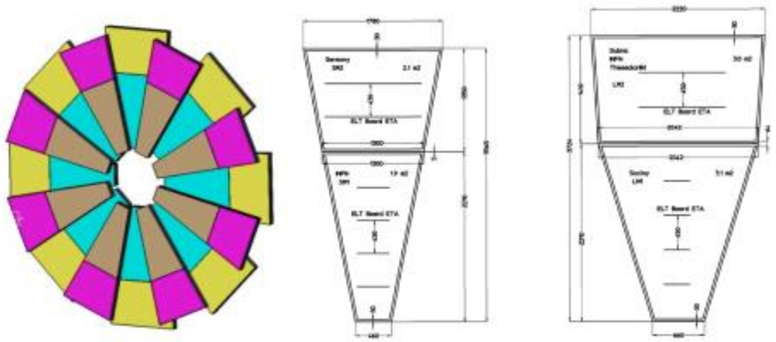
The ATLAS New Small Wheel Upgrade

In the scope of the high luminosity upgrade of the LHC at CERN, the ATLAS experiment replaces parts of its muon detectors

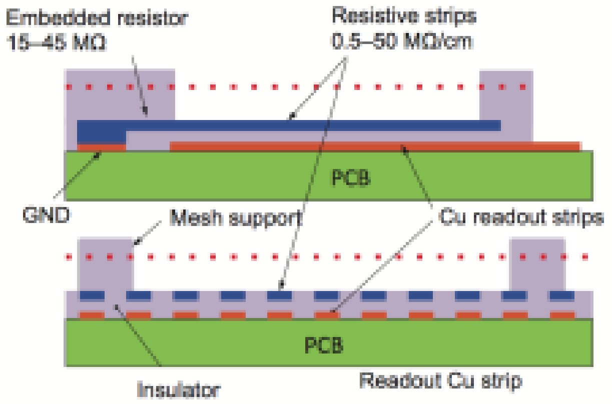


http://www.atlasexperiment.org

New fronted ASIC developed by Brookhaven National Lab.



One of the new detector types are Micromegas

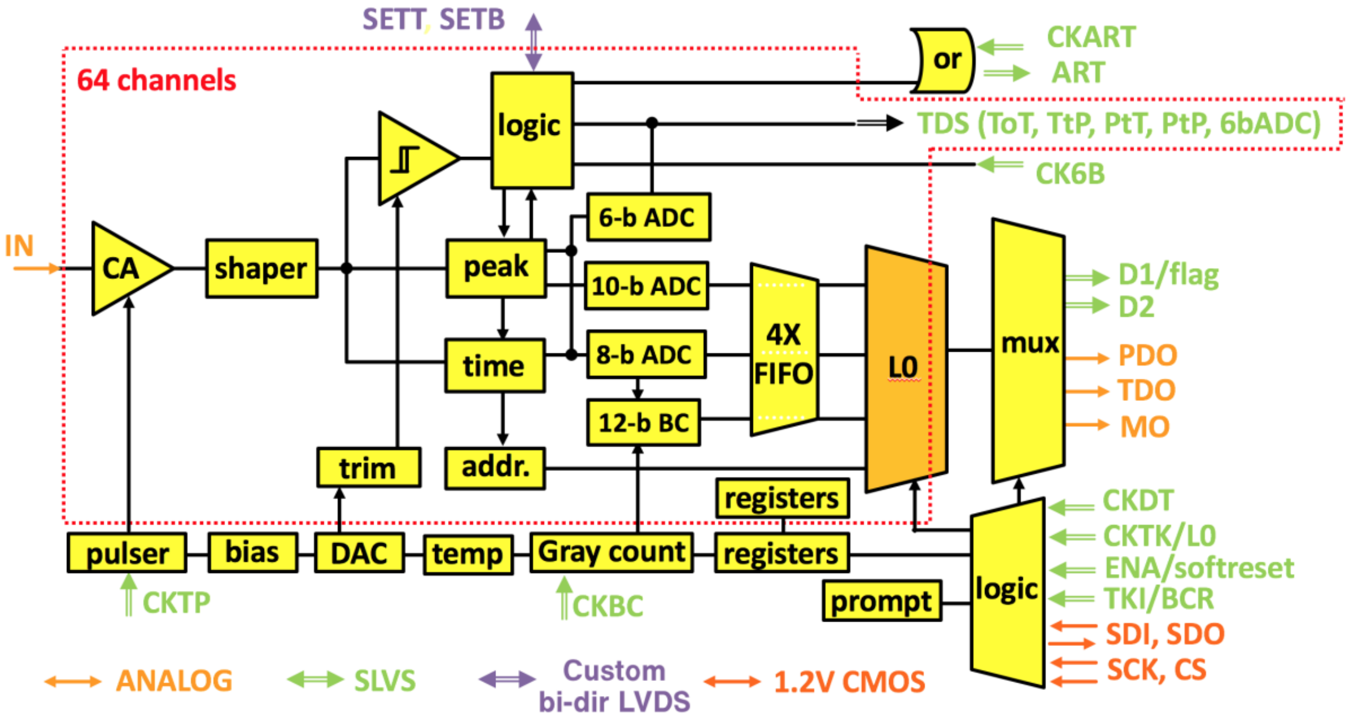


Anode strips read-out similar to our GEM detector

Iakovidis, Georgios. "The Micromegas project for the ATLAS upgrade." *Journal of Instrumentation* 8.12 (2013): C12007.

Electronics
The VMM ASIC – Features

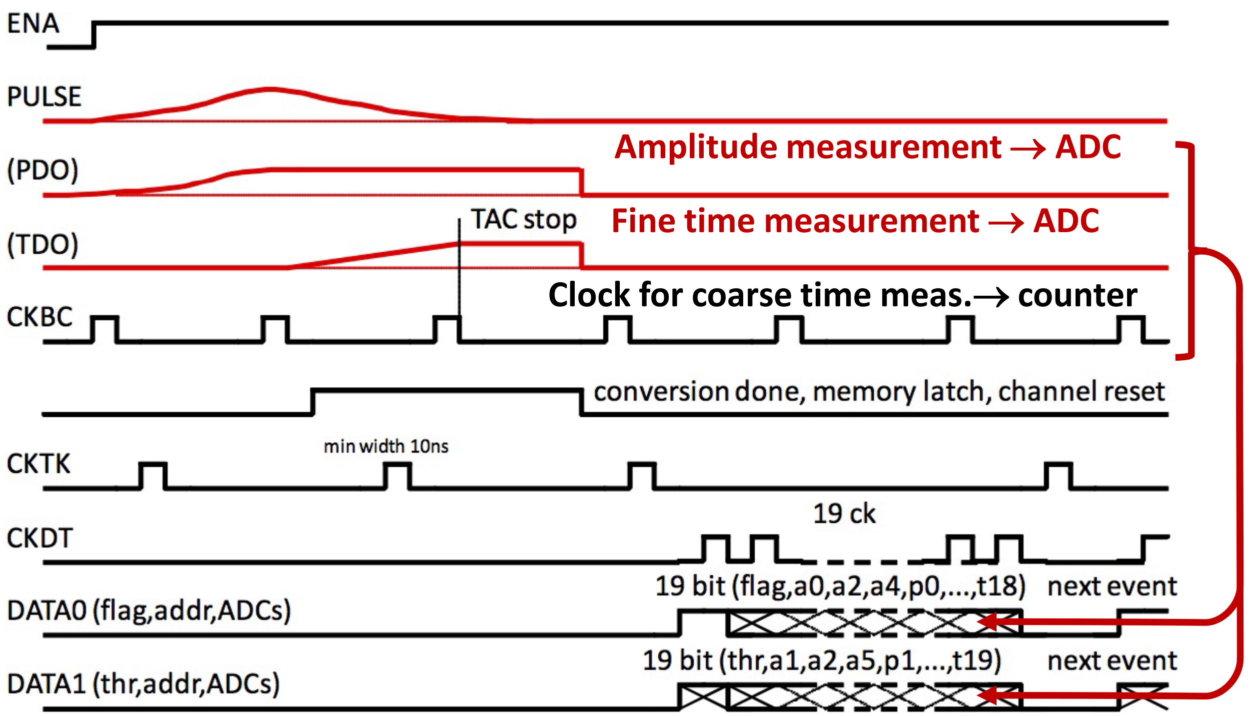
- 130 nm CMOS technology
- 64 input channels, each w/ preamplifier, shaper, peak detector, several ADCs
- Pos. & neg. polarity sensitive
- Digital block w/ neighbouring logic, FIFO, multiplexer
- Adjustable gain 0.5 – 16 mV/fC
- Adjustable shaping time from 25 ns – 200 ns
- Input capacitance from few pF – 1 nF



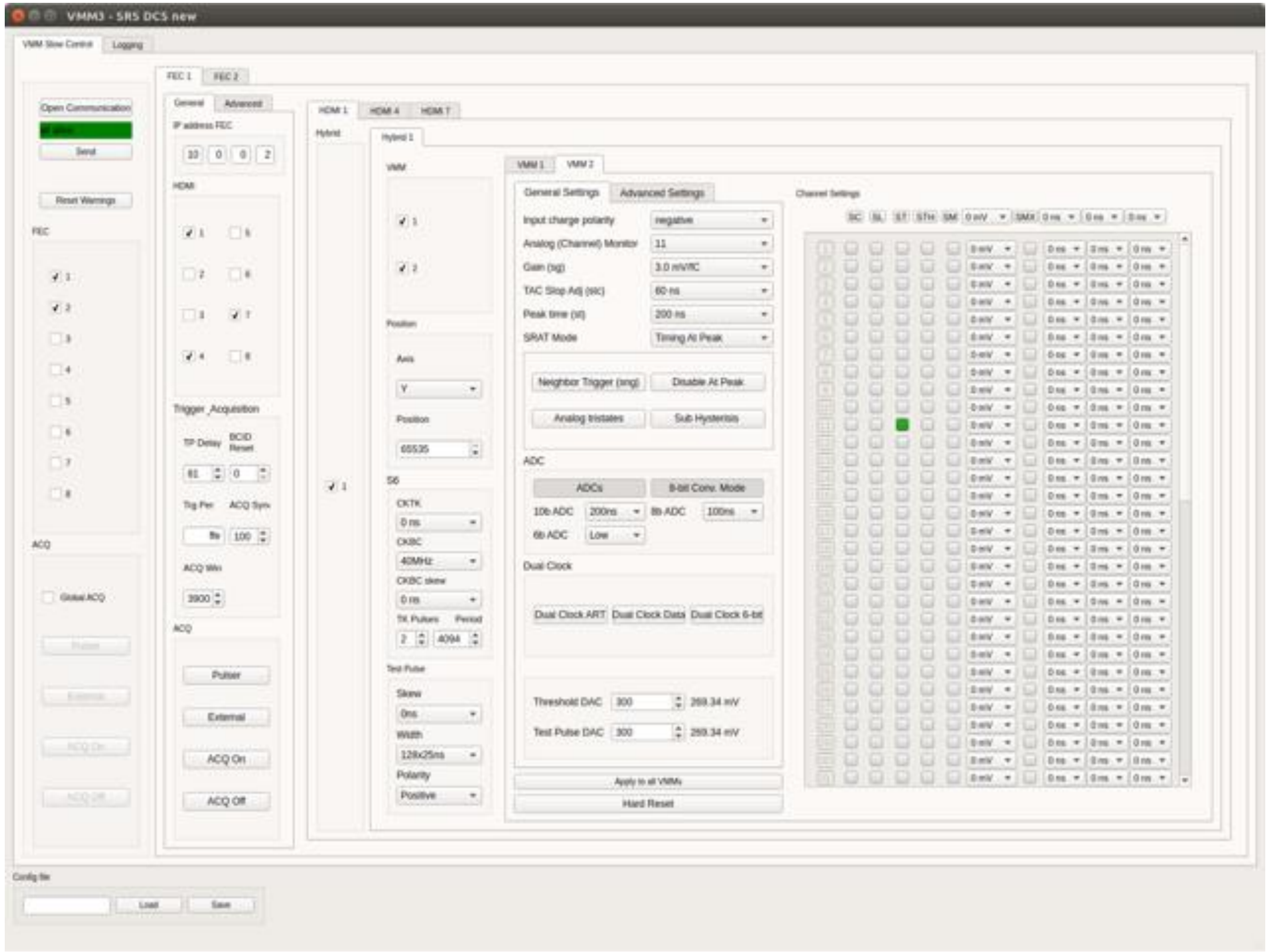
Electronics

The VMM ASIC – Features (continued)

- Internal test pulser with adjustable amplitude
- Global threshold & adjustment per channel
- Self-triggered, zero suppressed
- 38 bit per hit
  (if input charge goes over threshold)
  1. Event flag (1 bit)
  2. Over threshold flag (1 bit)
  3. Channel number (6 bit)
  4. Signal amplitude (10 bit)
  5. Arrival time (20 bit)



Electronics
Slow control for the readout system



CERN Summer student project of Manuel Guth