EP-DT
Detector Technologies

Gd-GEM detector development for the NMX instrument

(BrightnESS T4.1)

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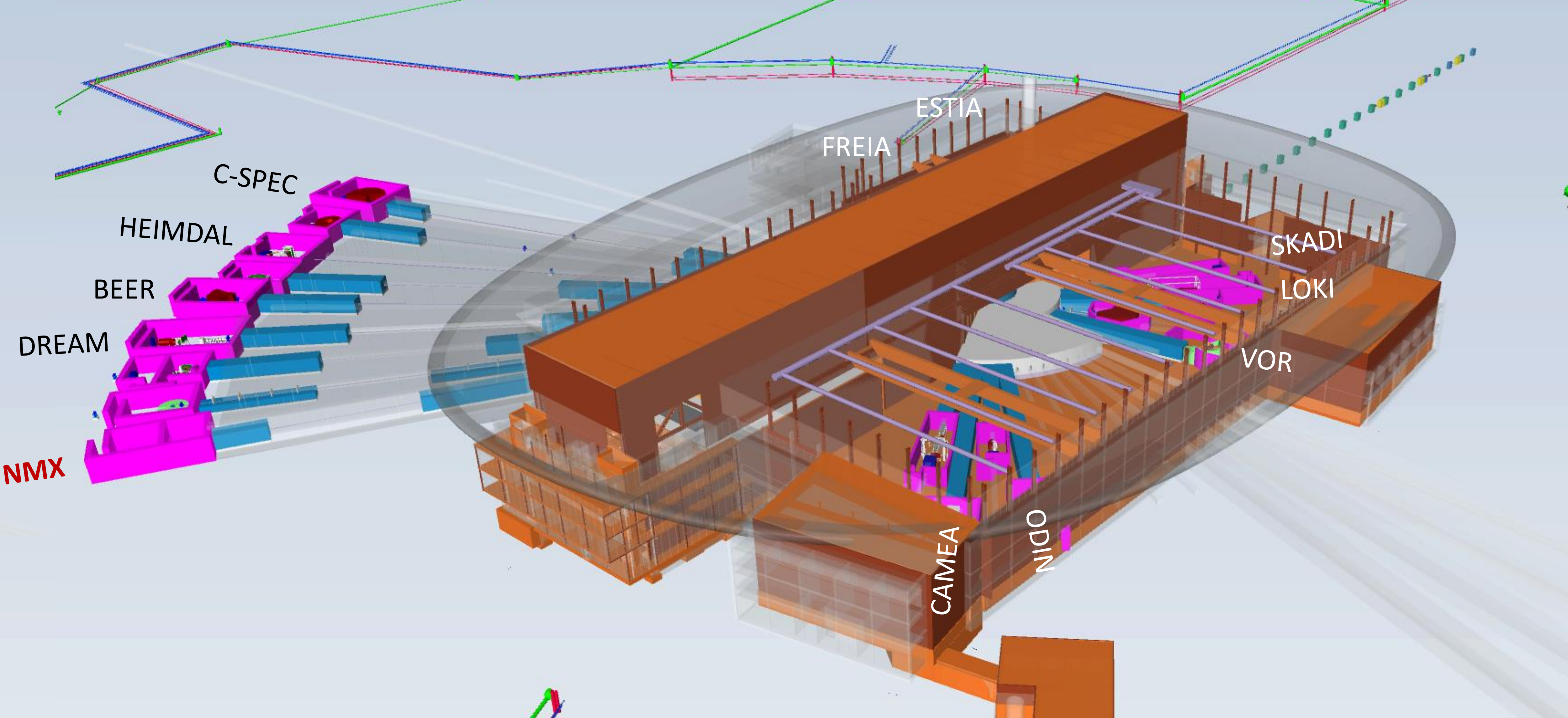
The European Spallation Source

The instruments



Outline

BrightnESS task 4.1

The NMX instrument

Detector demonstrator prototype

Detector read-out chain and electronics

Conclusions

Outlook

BrightnESS task 4.1
The resolution challenge

Realize higher resolution detectors for ESS

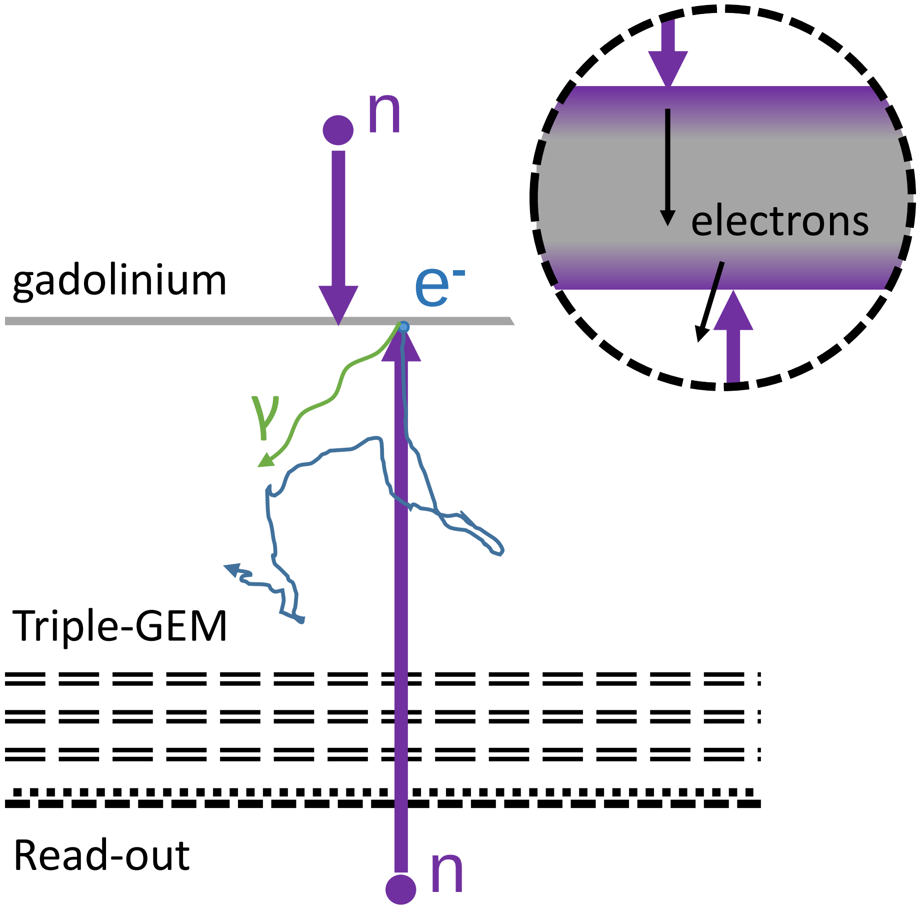
NMX requires position resolution of at least 200 µm

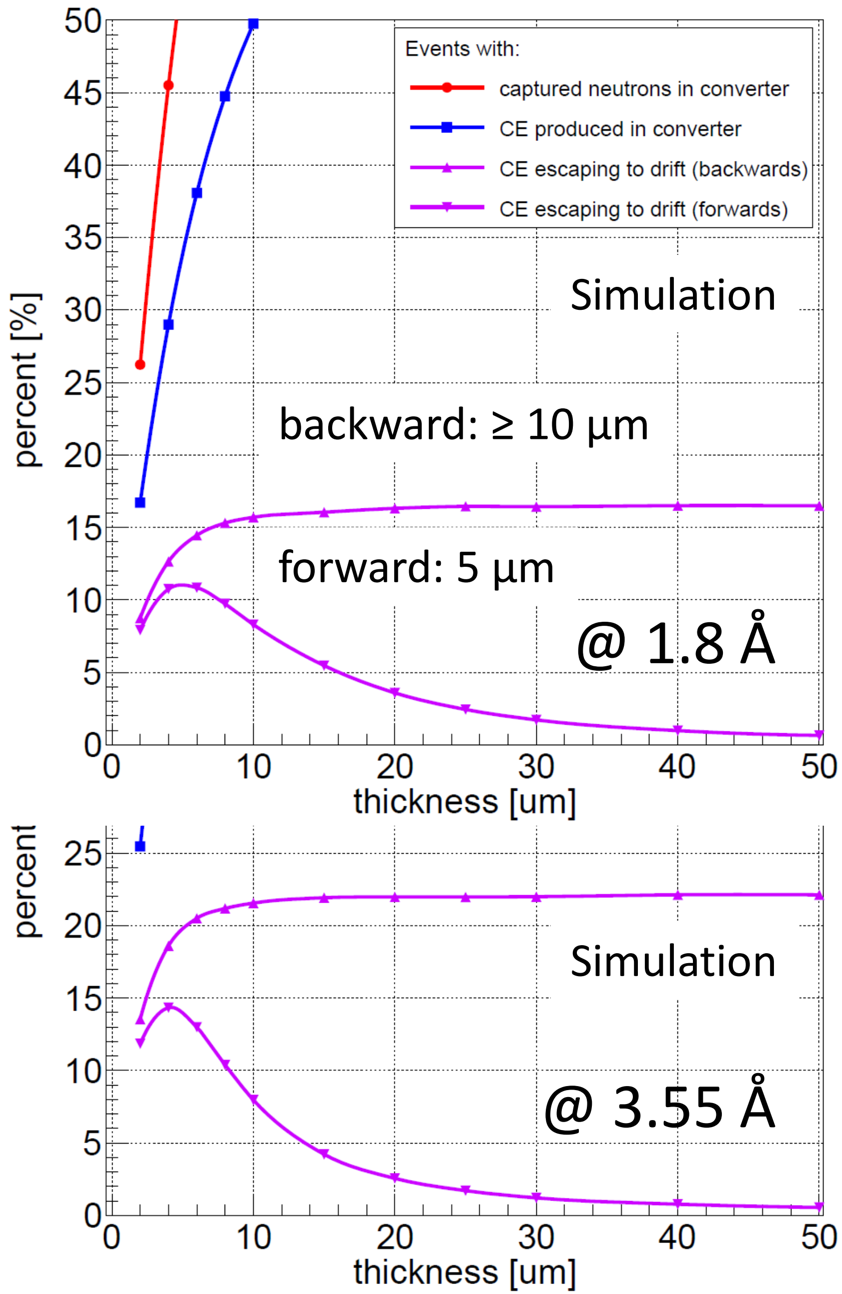
Development of detectors as “in-kind” contribution from CERN

A) Neutron converter: Gadolinium
B) Detector technology: Gaseous Electron Multiplier (GEM)
C) Read-out technique: Micro Time Projection Chamber (µTPC)

BrightnESS task 4.1

A) Neutron converter: Gadolinium





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

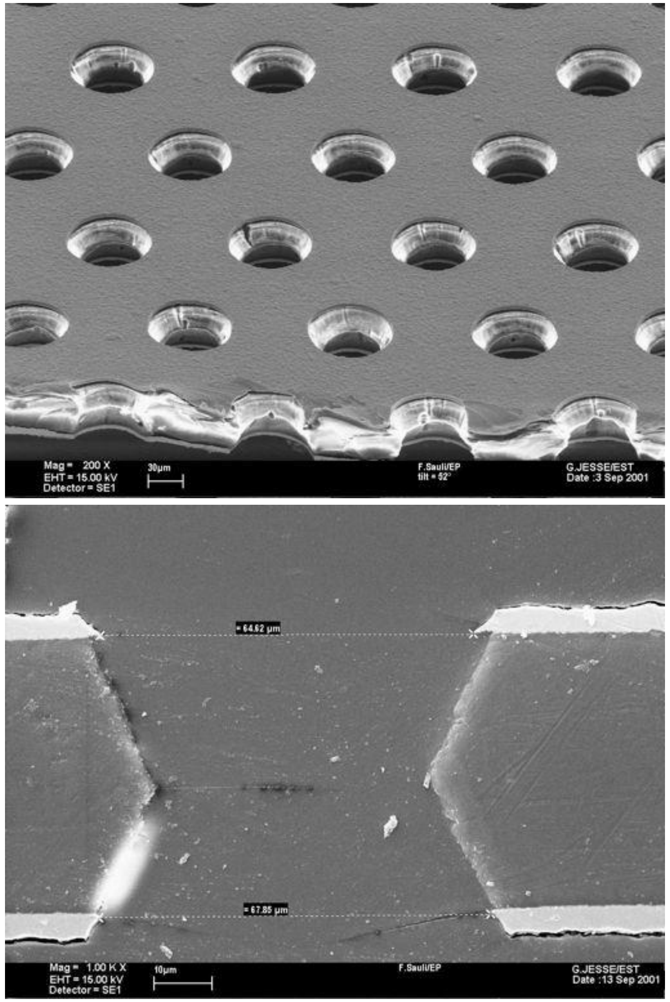
Metal-clad polyamide foil (usually 50 µm Kapton® with 5 µm Cu on both sides)

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

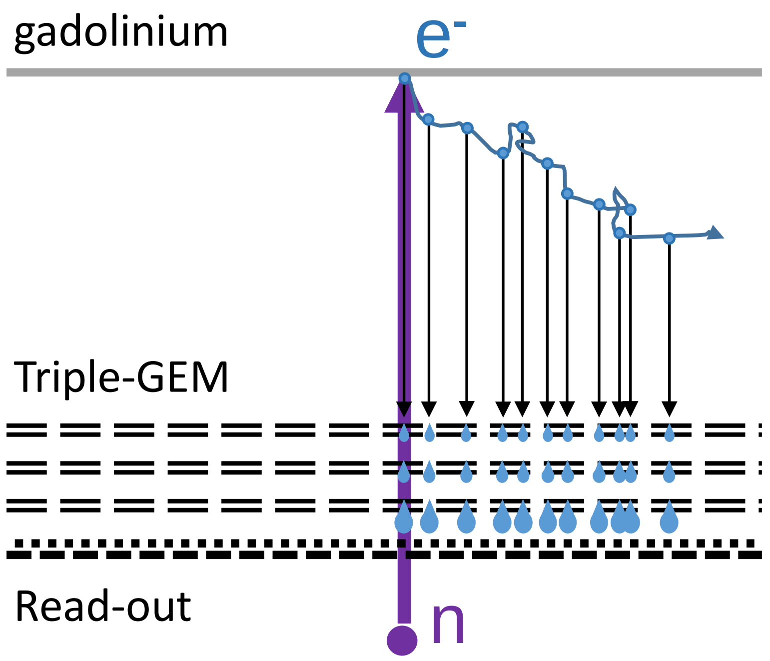


F. Sauli, *The gas electron multiplier (GEM): Operating principles and applications*, Nucl. Instr. Meth. A 805 (2016) 2-24

BrightnESS task 4.1

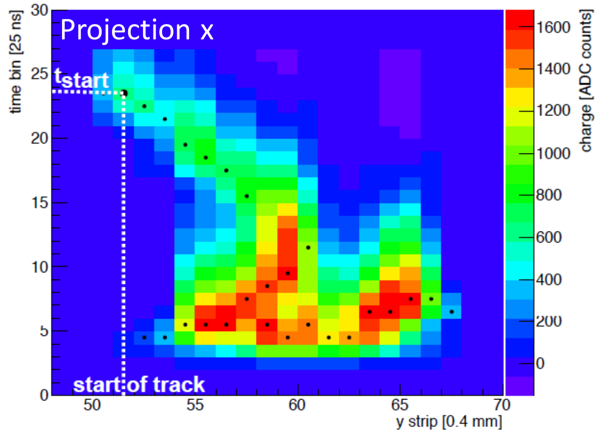
C) Read-out technique: Micro Time Projection Chamber (µTPC)

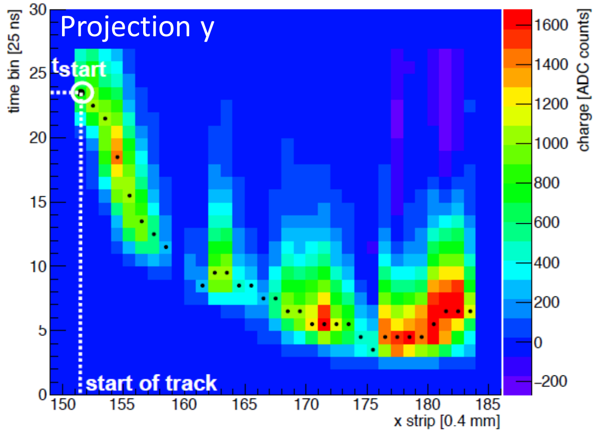
Already **working read-out technique** demonstrated for 10B† and Gd‡ neutron converters



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

time resolution *O*(ns)

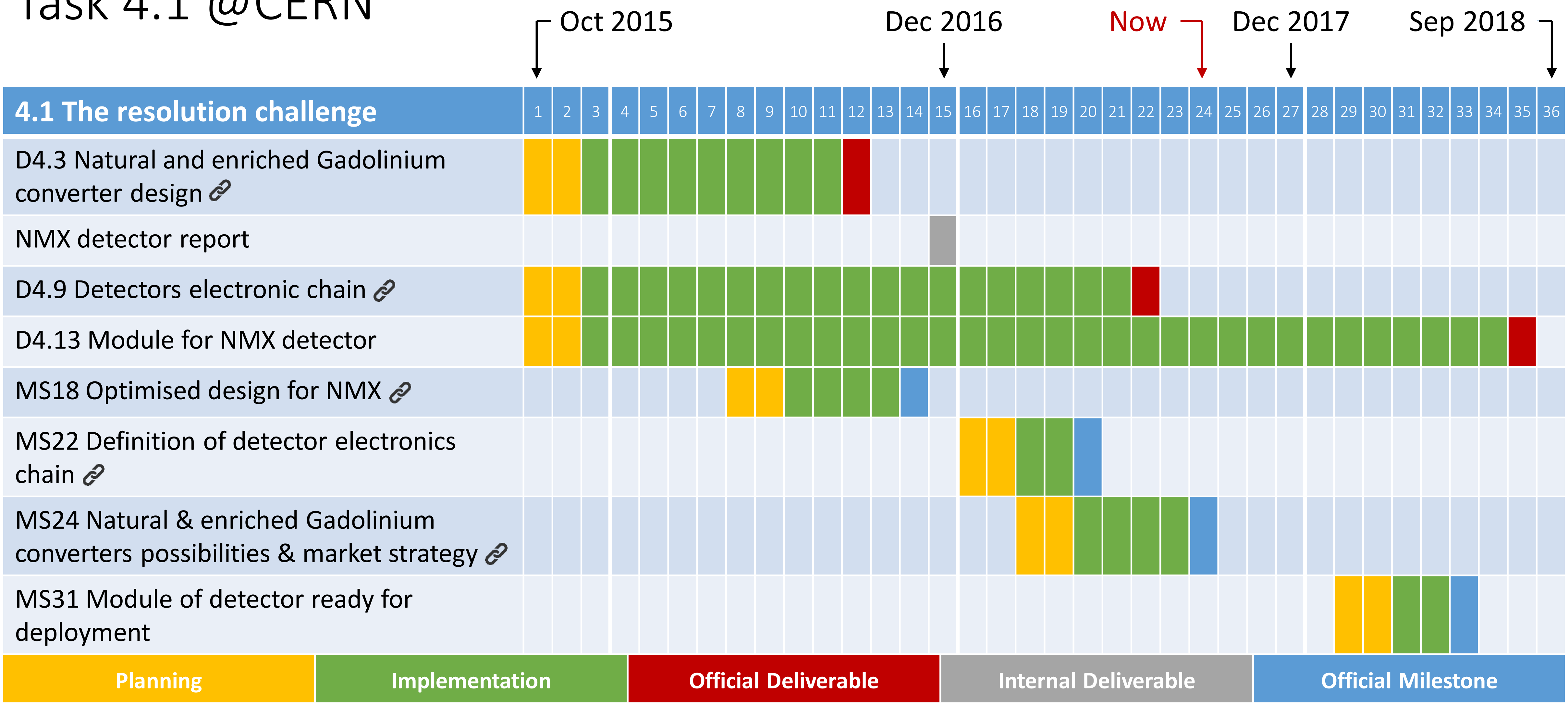




† D. Pfeiffer et al., JINST 10 (2015) 04, P04004 ‡ D. Pfeiffer et al, 2016 JINST 11 P05011 BrightnESS D4.3

Latest Deliverables and Milestones for BrightnESS

Task 4.1 @CERN



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

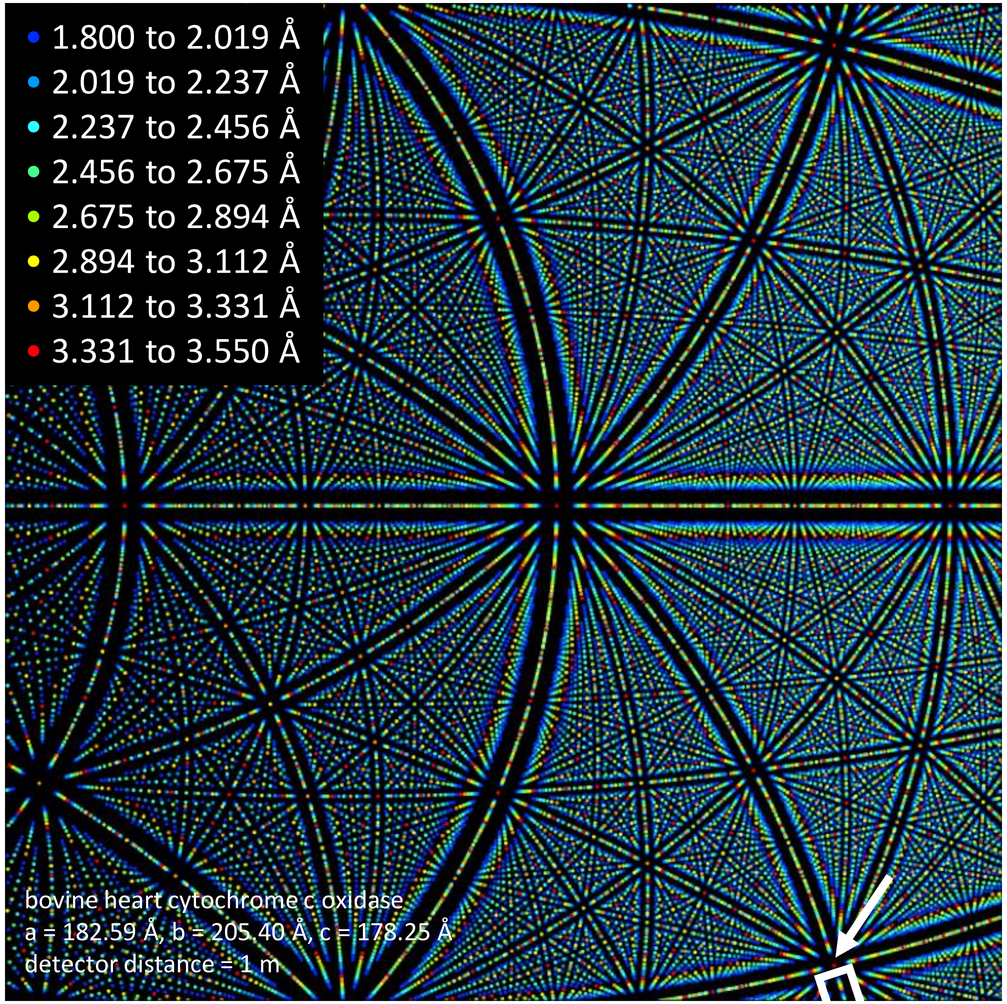
Wavelength band from 1.8 Å to 3.55 Å (6.49 to 25.25 meV)

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

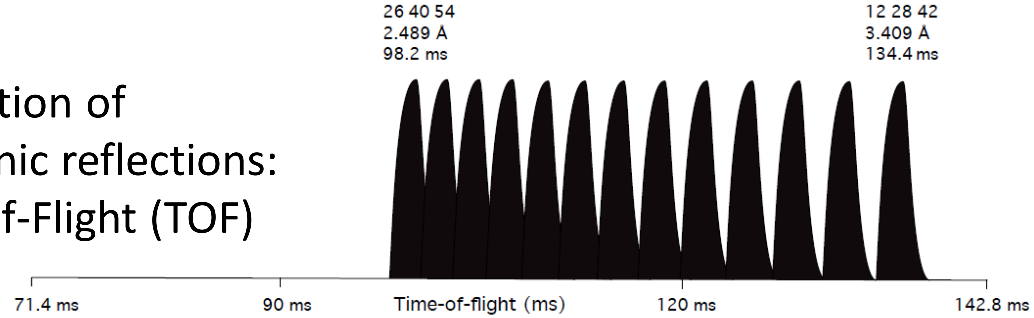
Approx. 0.8 m^2 detector active area

No fixed instrument geometry

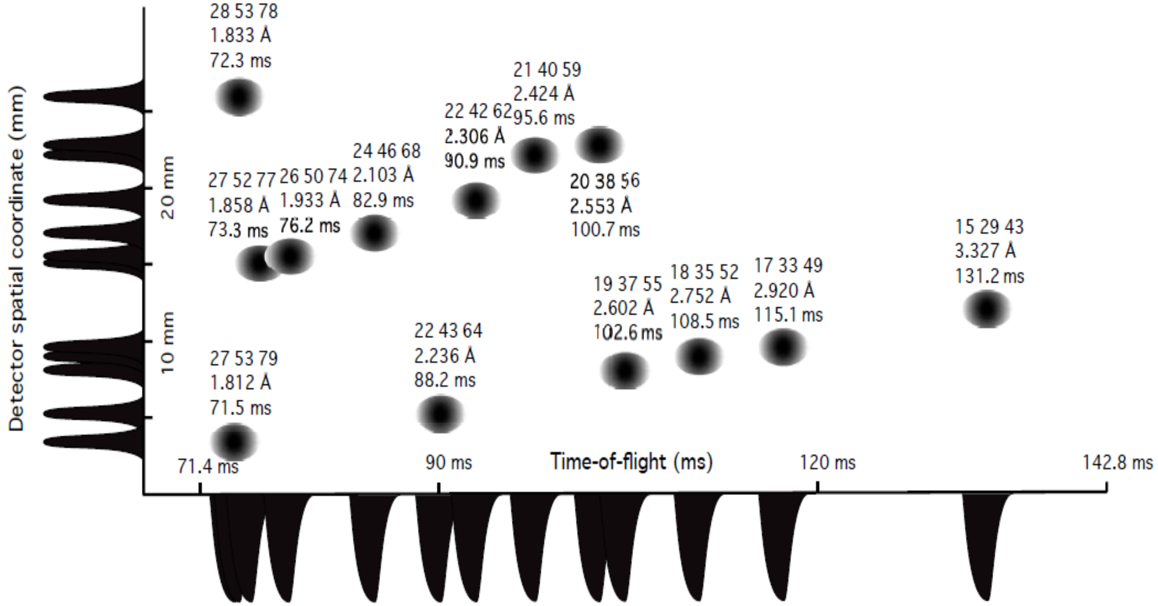
Quasi-Laue Time-Of-Flight Diffractometry
Example diffraction pattern



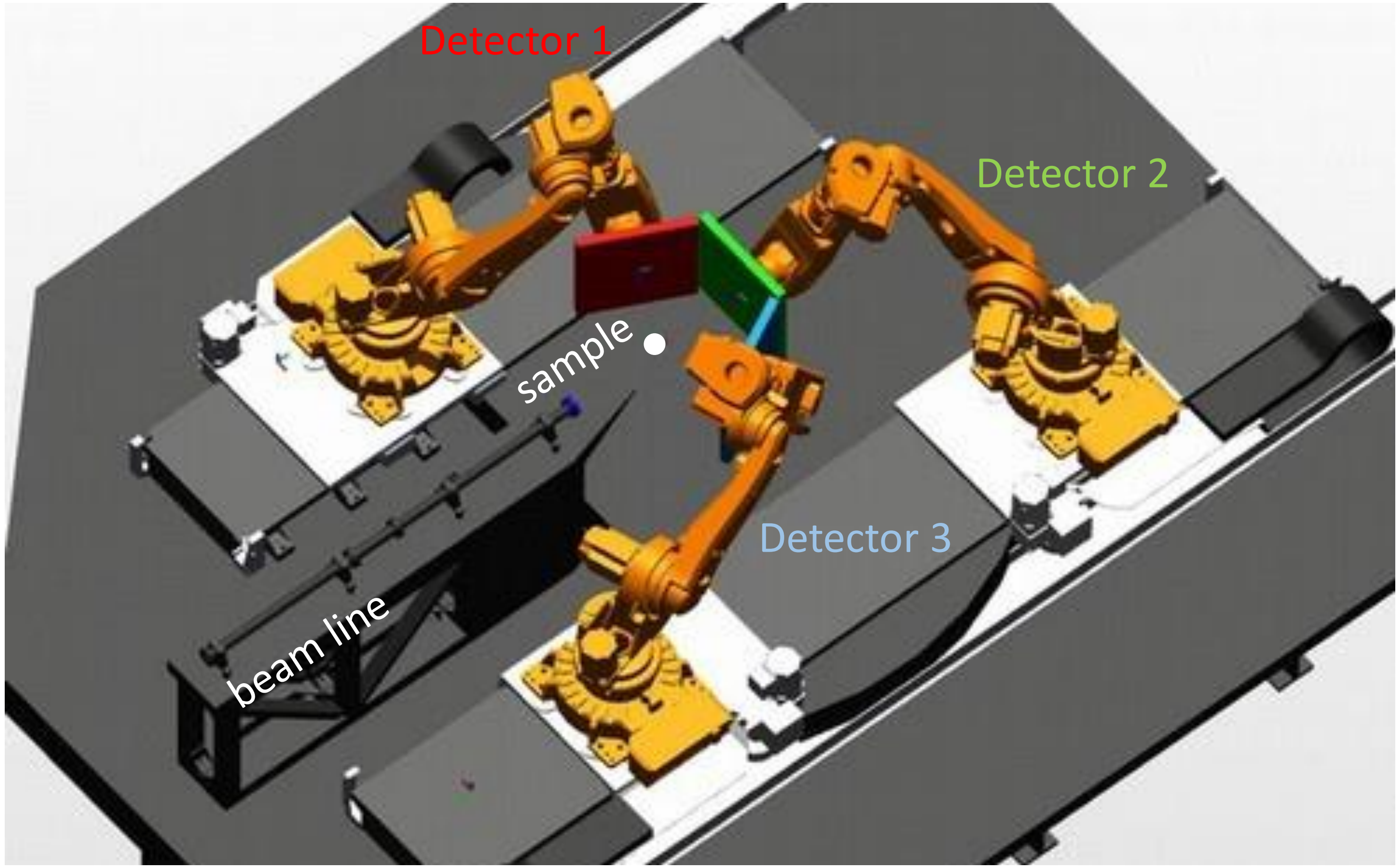
Separation of harmonic reflections: Time-of-Flight (TOF)



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

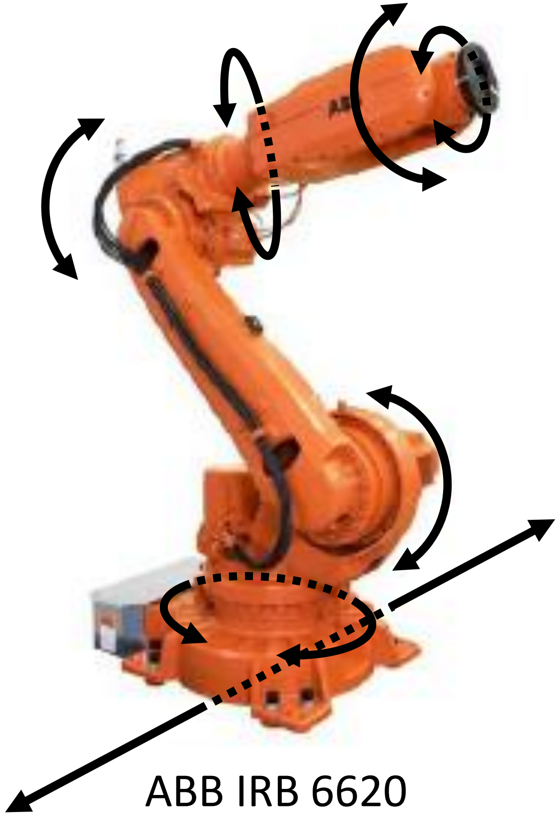
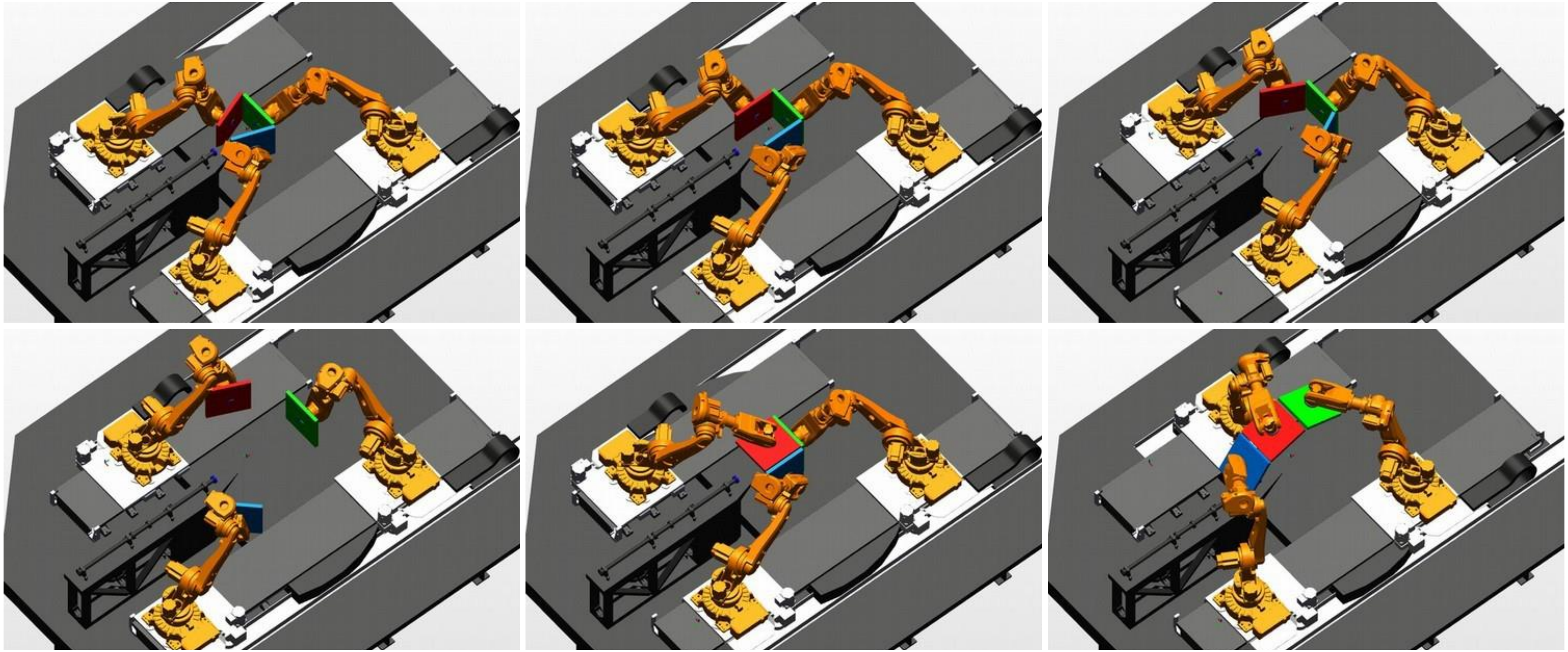
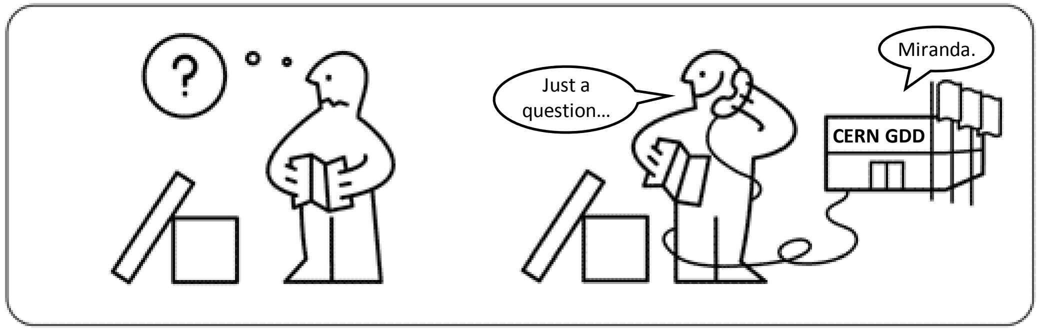


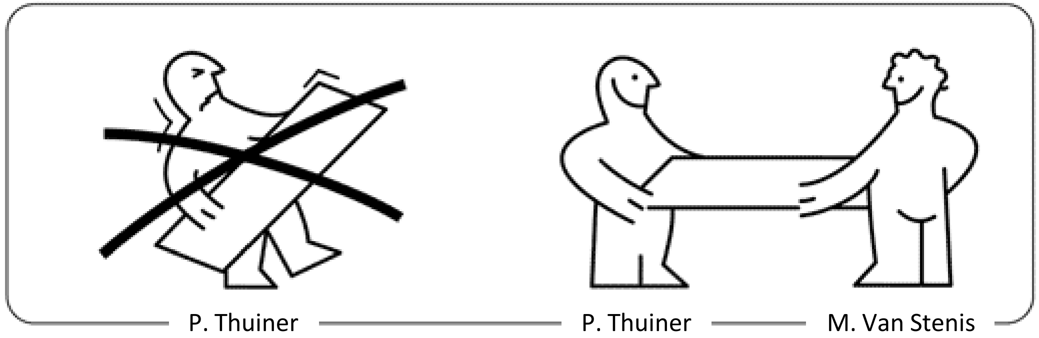
ABB IRB 6620
6 axes, 2.2 m reach
robotic arms on rails

The NMX instrument
No fixed detector geometry



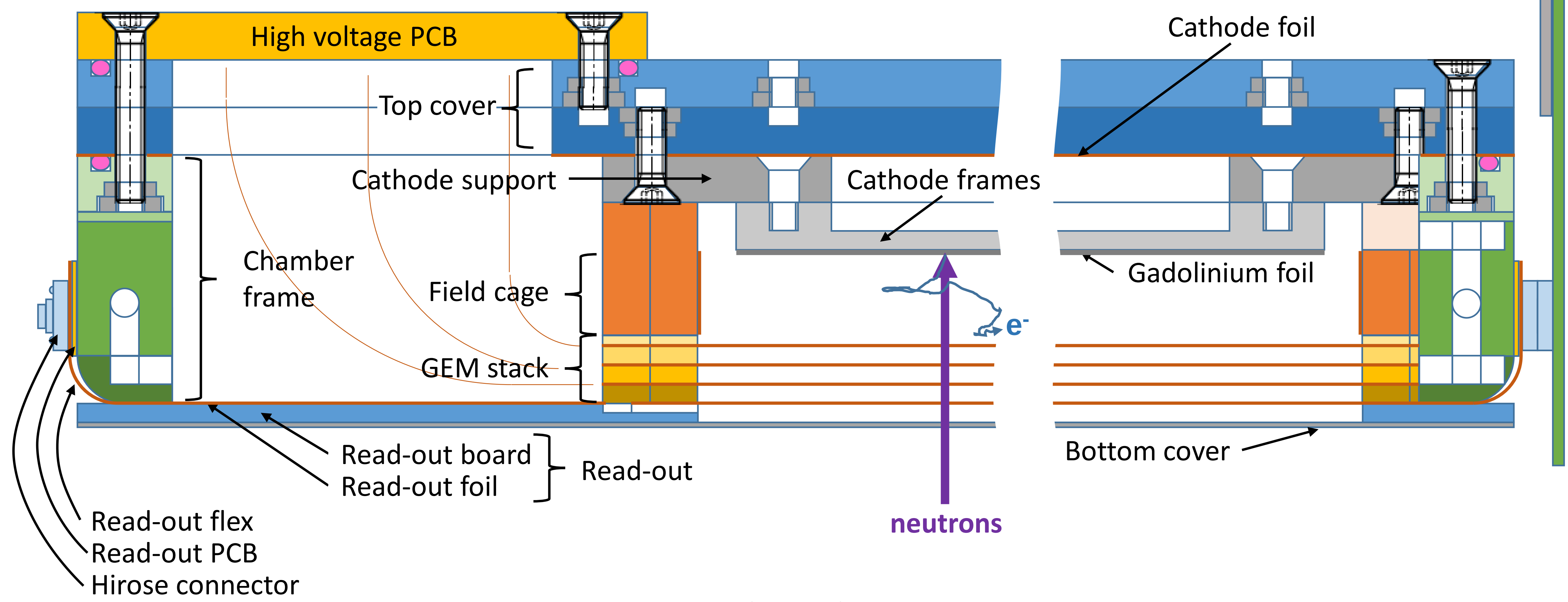


Detectör demonstrator prototype



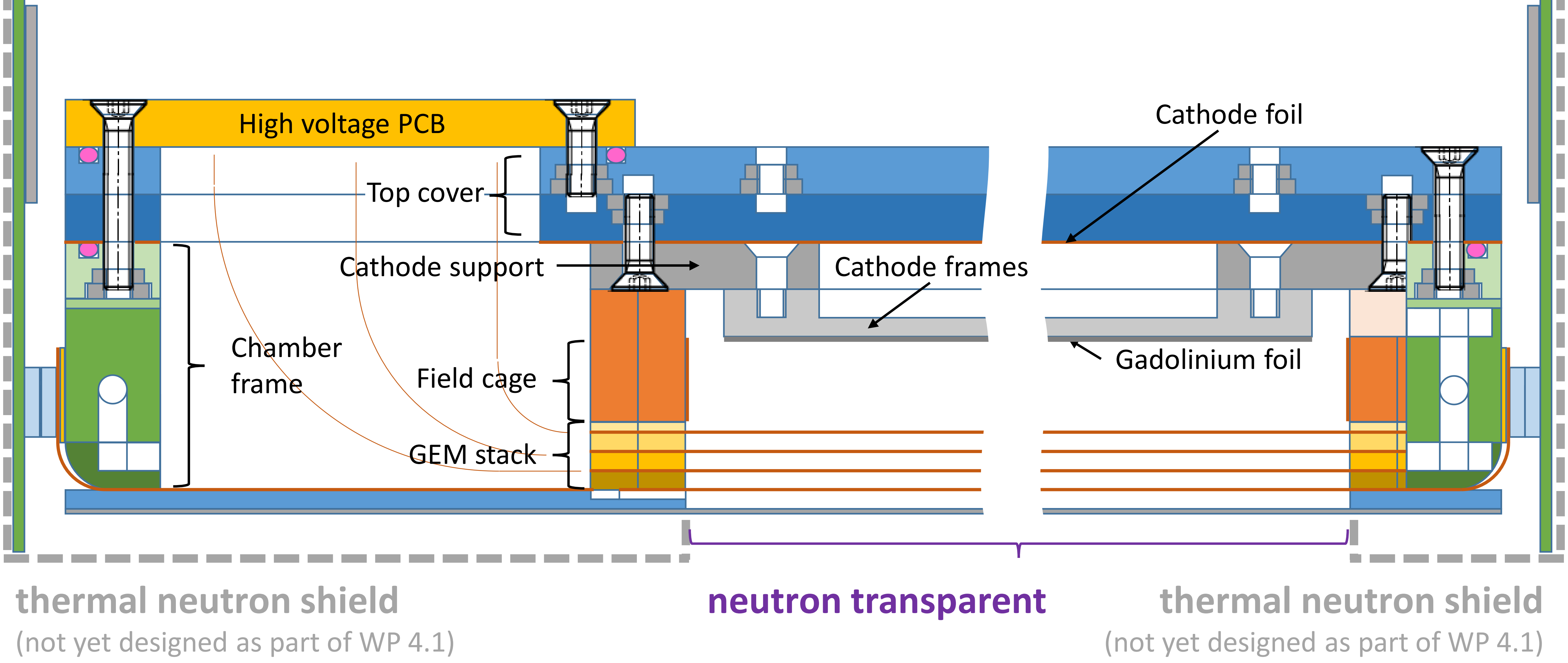
The NMX demonstrator cross-section

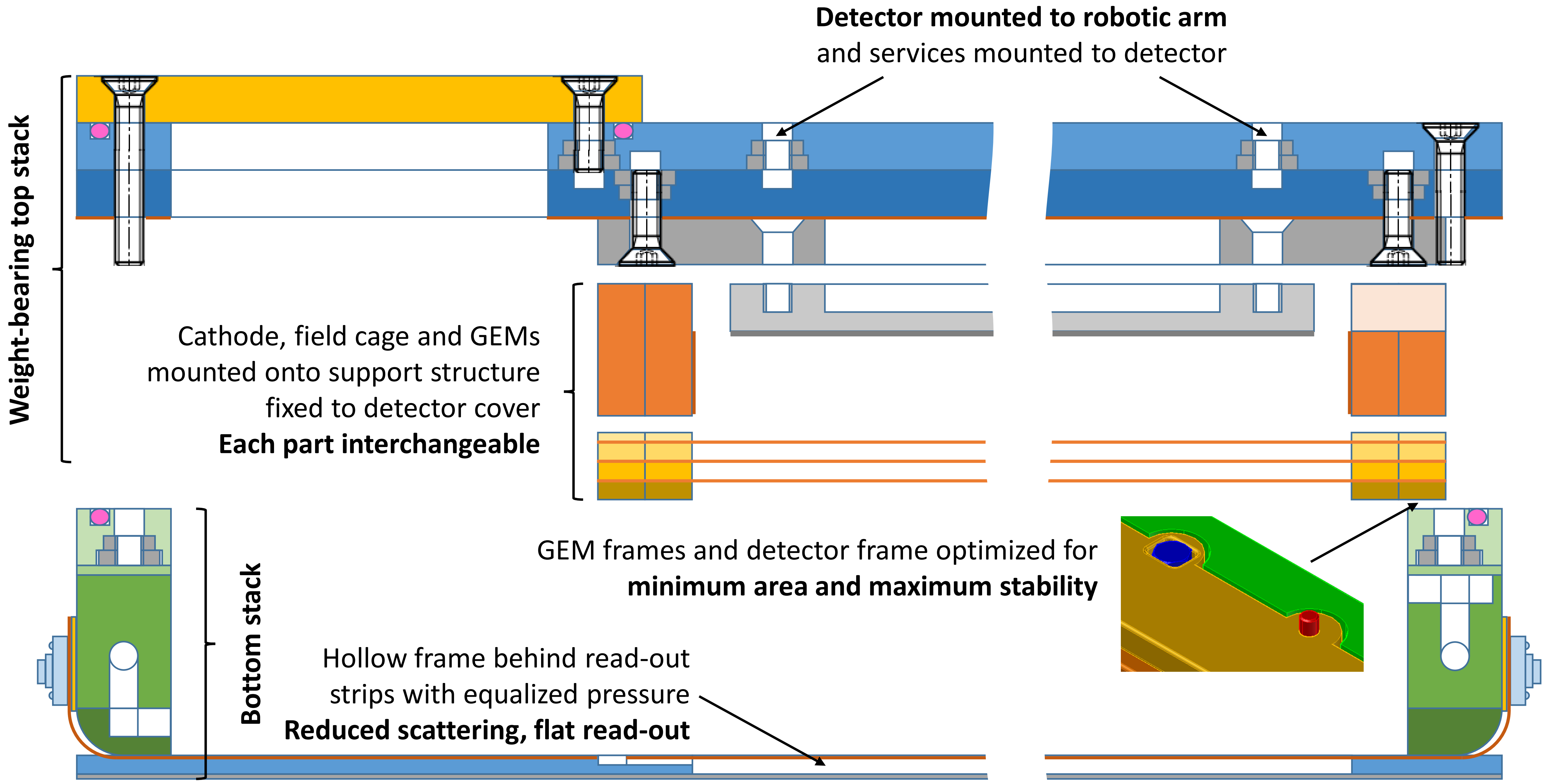
Detector prototype v0 “Zita”



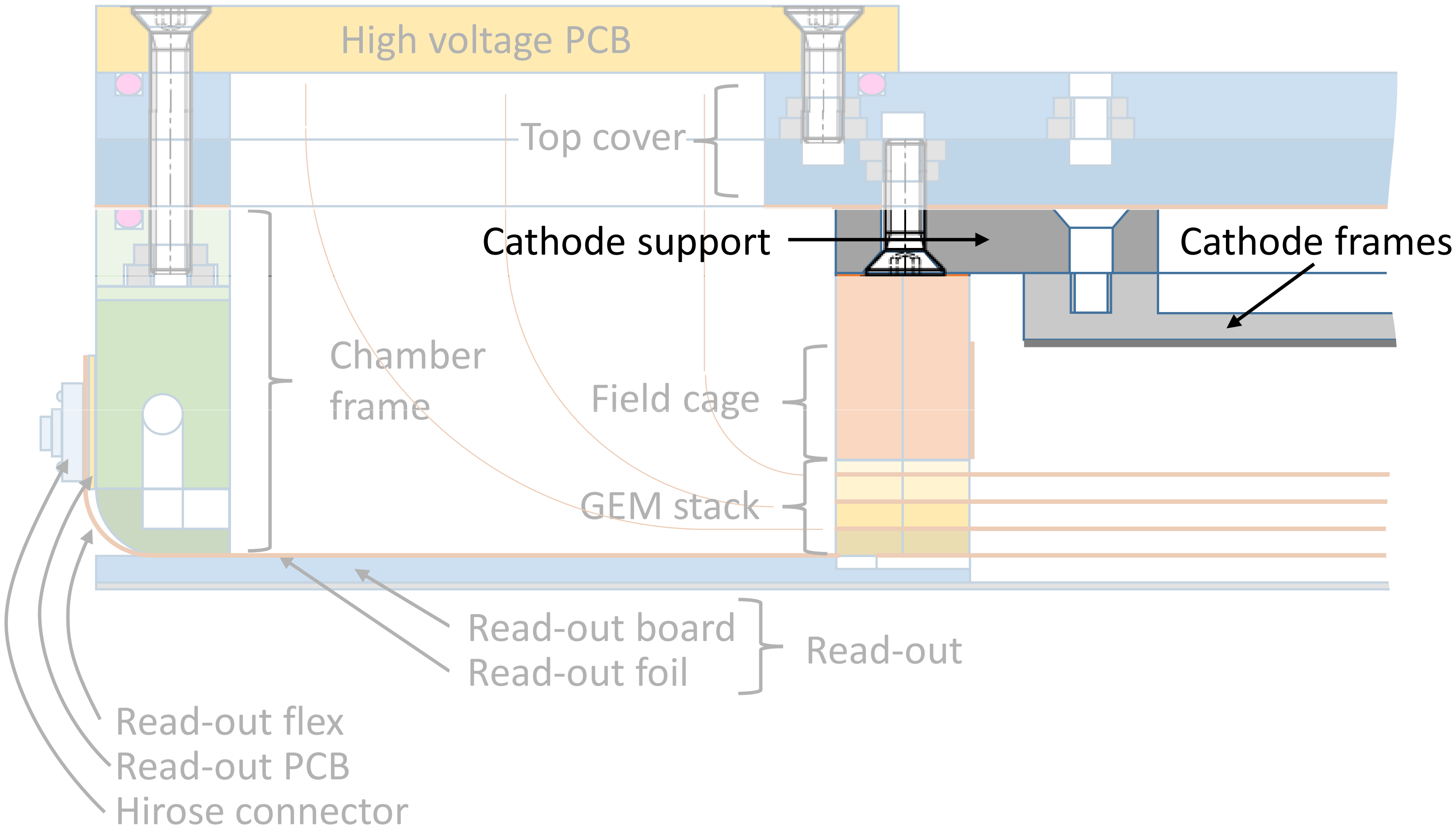
The NMX demonstrator cross-section

Detector prototype v0 “Zita”




Detector mounted to robotic arm
and services mounted to detector
Weight-bearing top stack
Cathode, field cage and GEMs
mounted onto support structure
fixed to detector cover
Each part interchangeable
GEM frames and detector frame optimized for
minimum area and maximum stability
Bottom stack
Hollow frame behind read-out
strips with equalized pressure
Reduced scattering, flat read-out

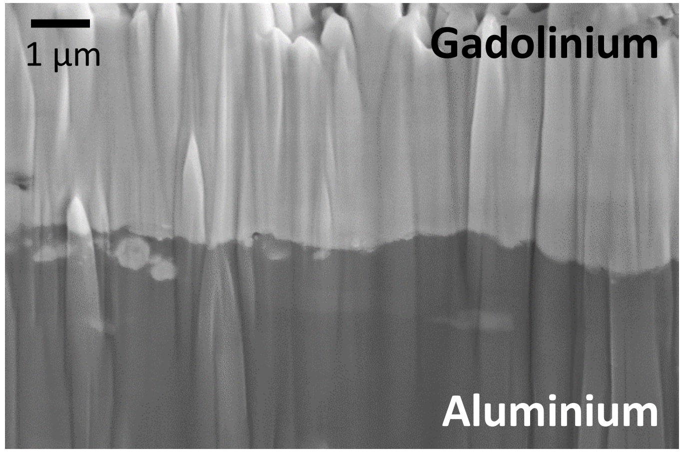
Assembly of gadolinium cathode

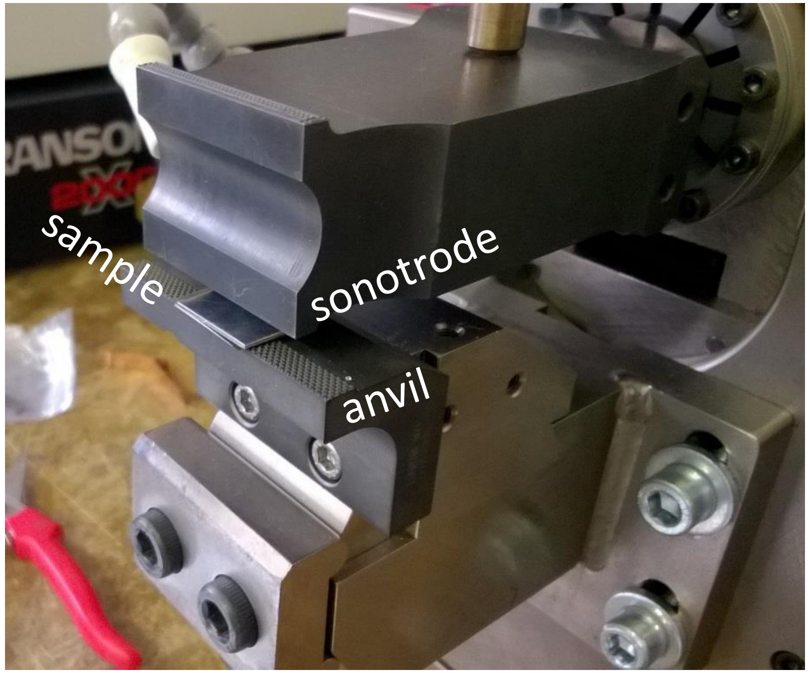


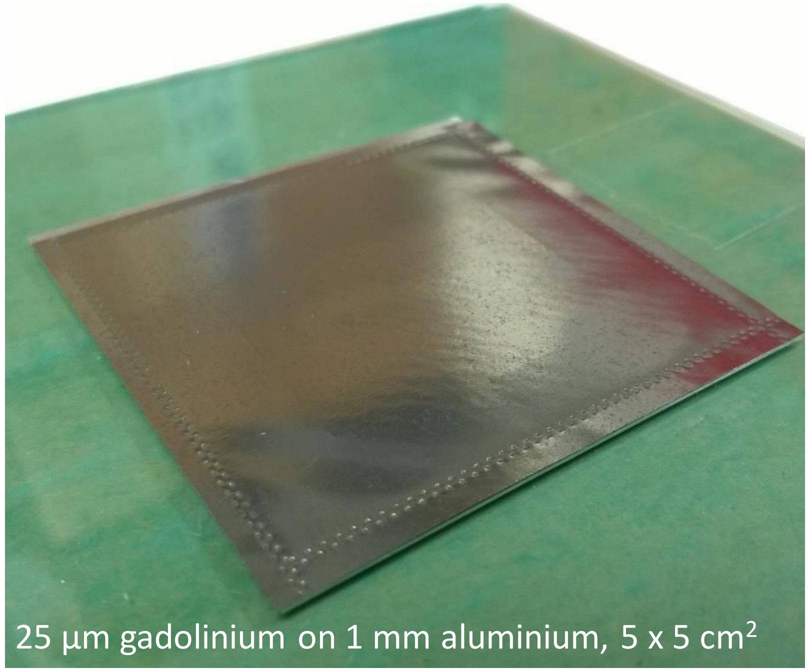
Cathode assembly due to maximum foil size

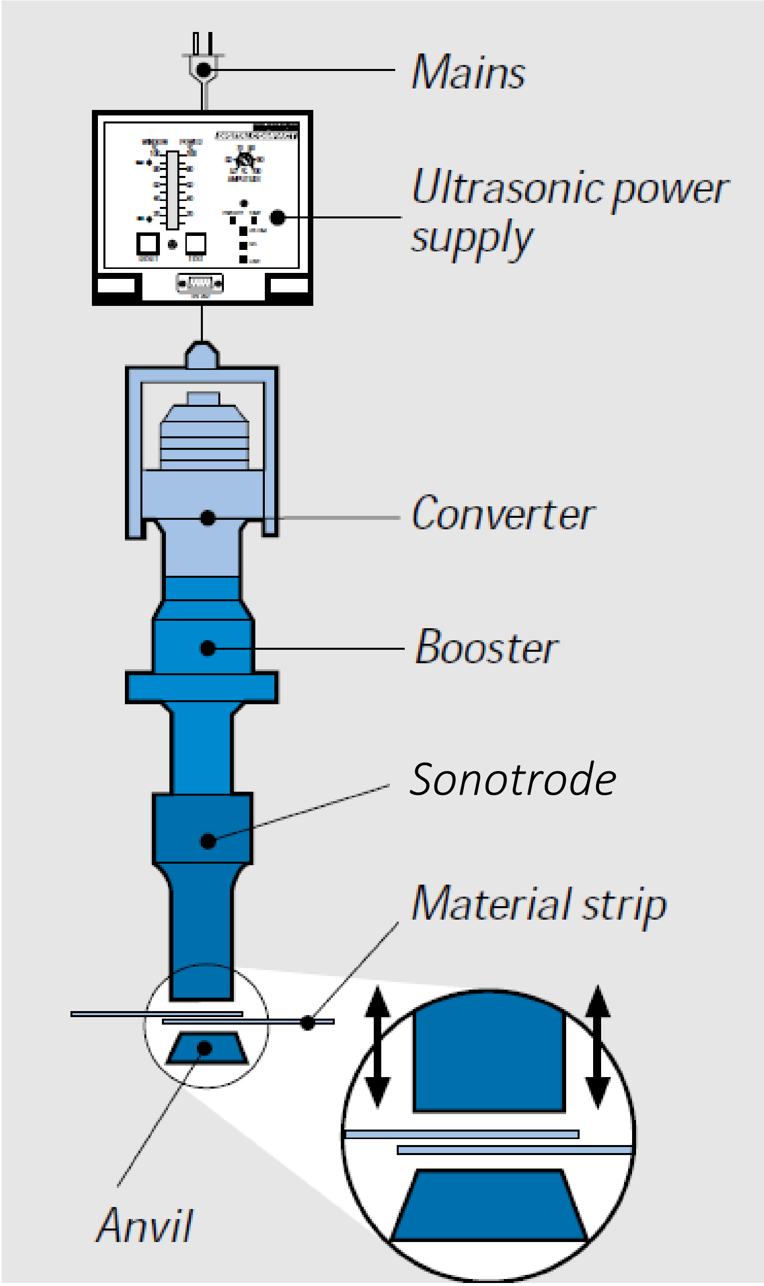
Ultrasonic welding for mechanical and electrical connection with

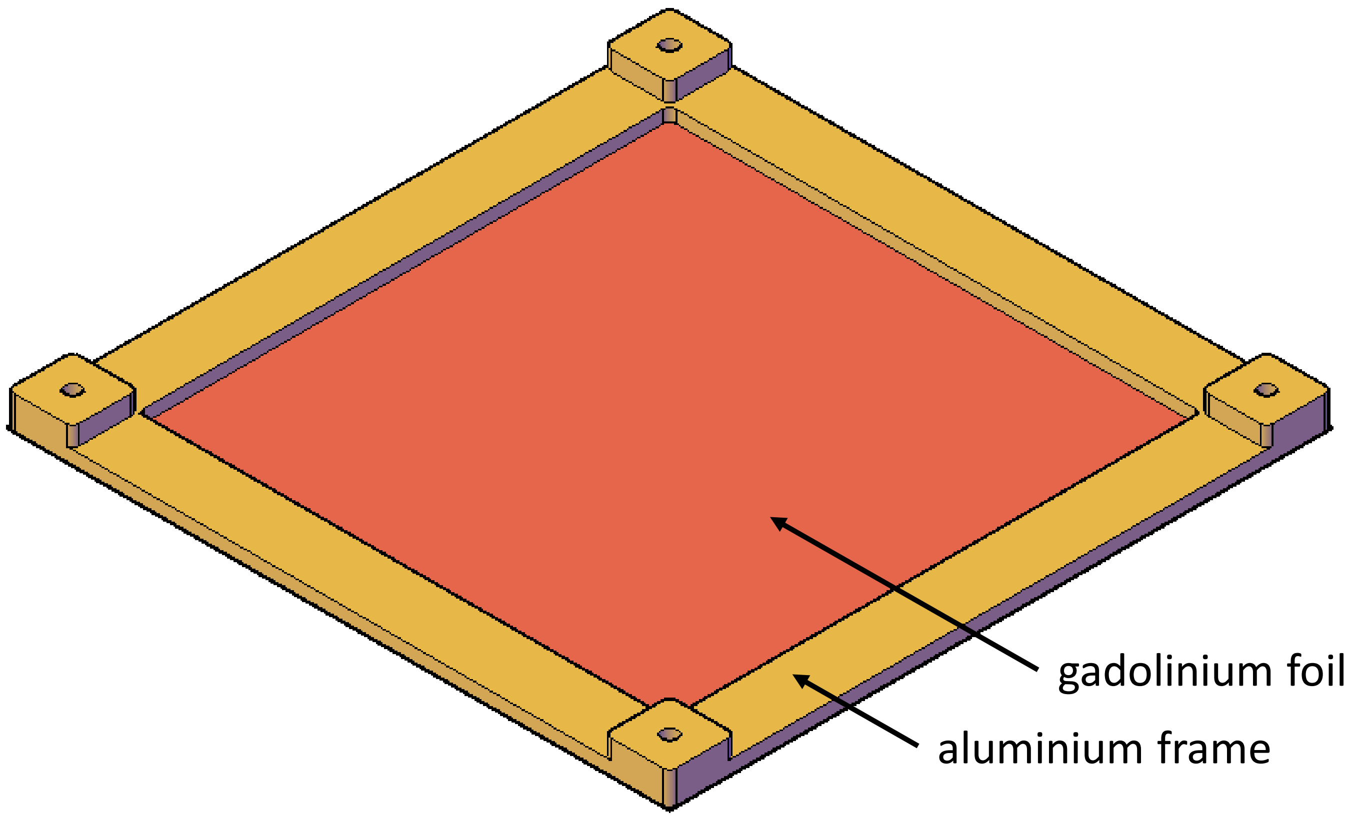
No dead area

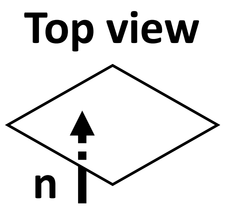








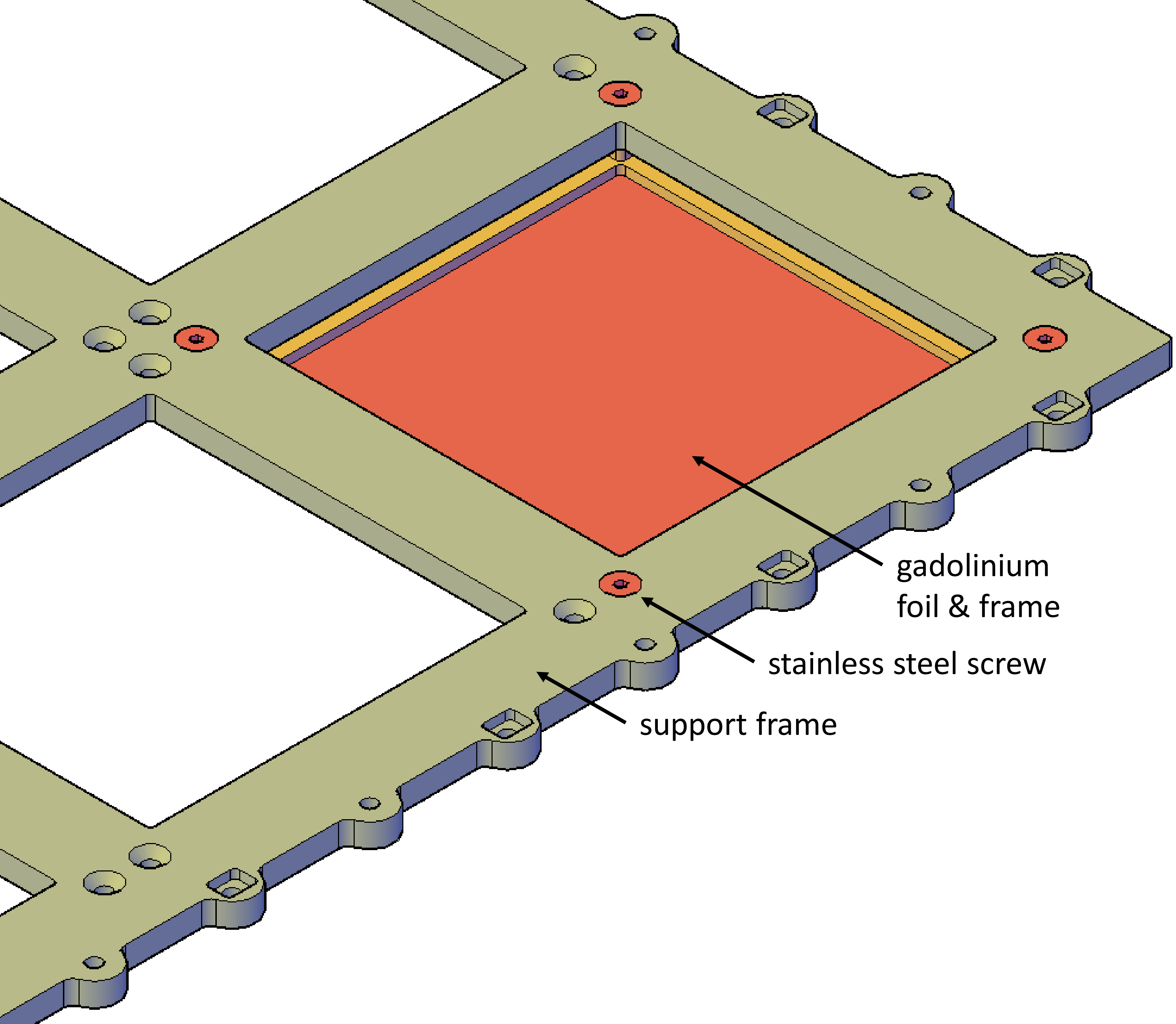




25 individual gadolinium foils ultrasonically welded onto aluminium frame

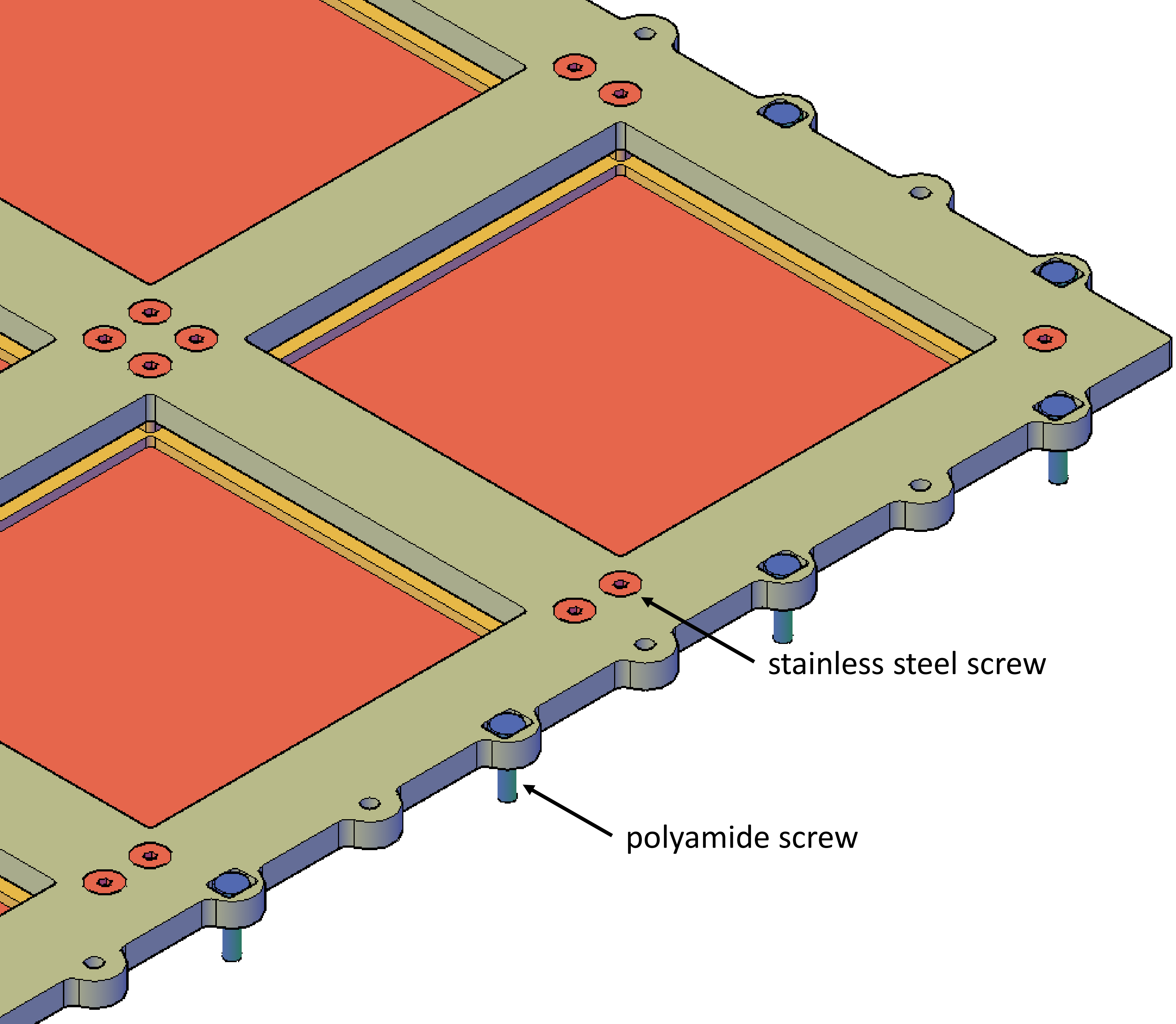
Gadolinium foil
- Natural gadolinium
- thickness 25 µm
- area 10.24 x 10.24 cm²
  (about maximum size produced by supplier)

Total active area
- 51.22 x 51.22 cm²



Gadolinium frame screwed onto aluminium support frame

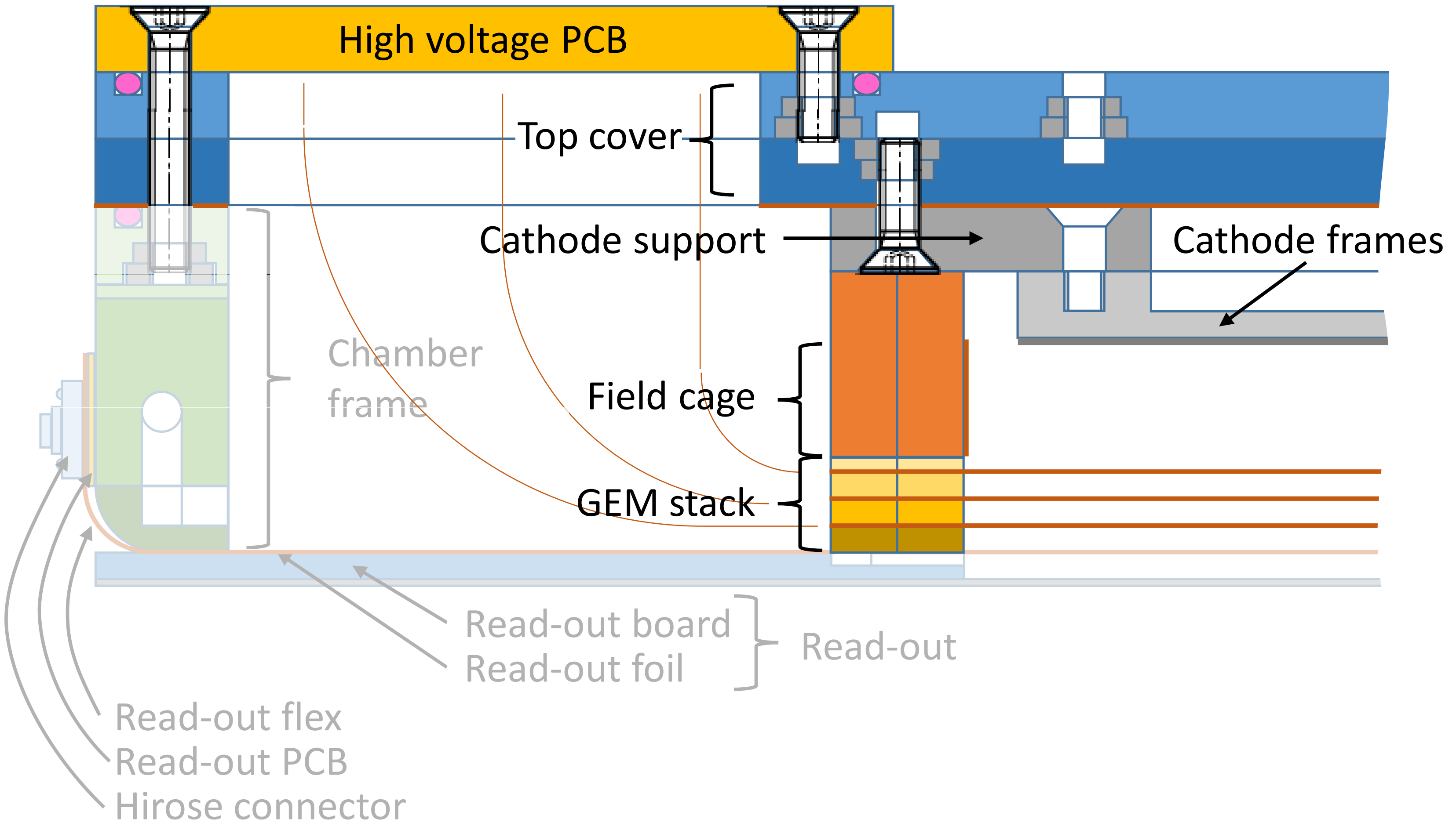
Electrical contact between frame and support on four corners

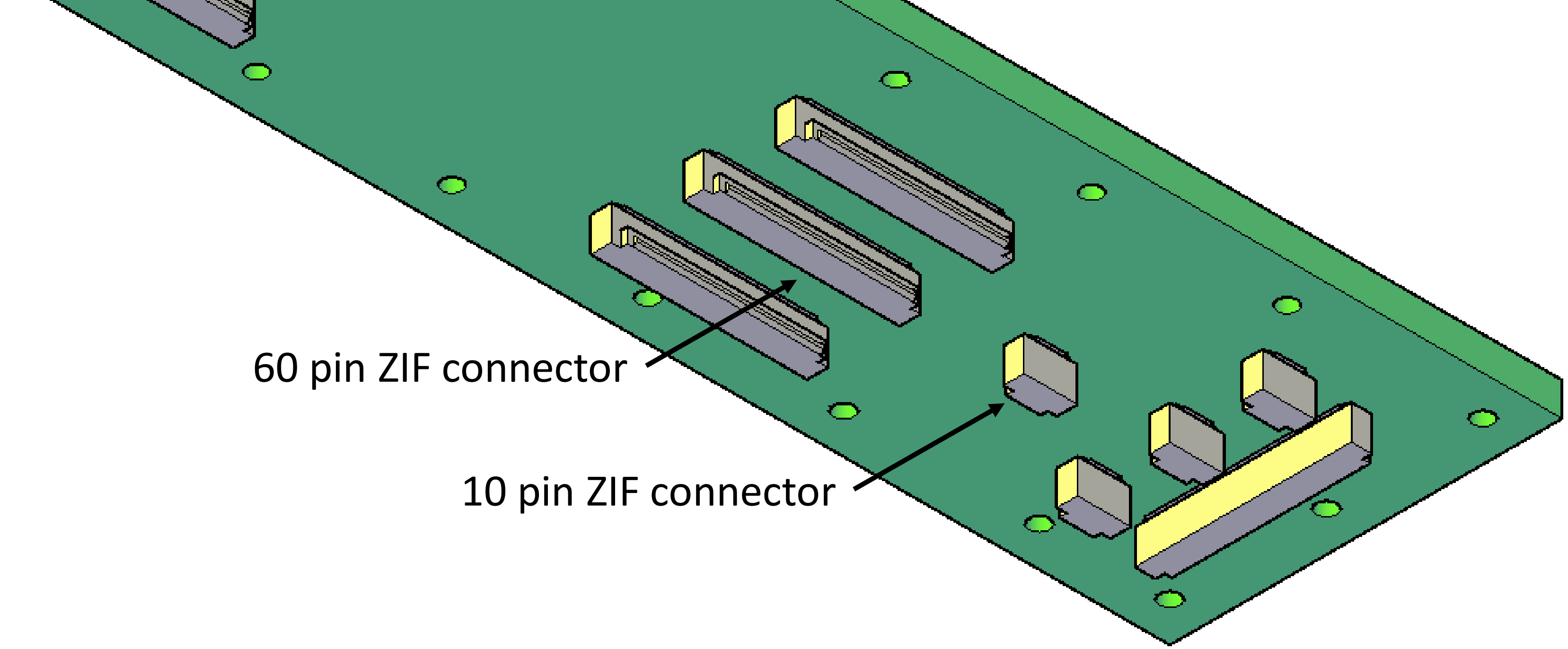


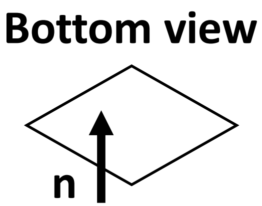
Gadolinium frames screwed onto aluminium support frame

w/ polyimide screws for field cage assembly already inserted

Assembly of top stack







High voltage PCB w/

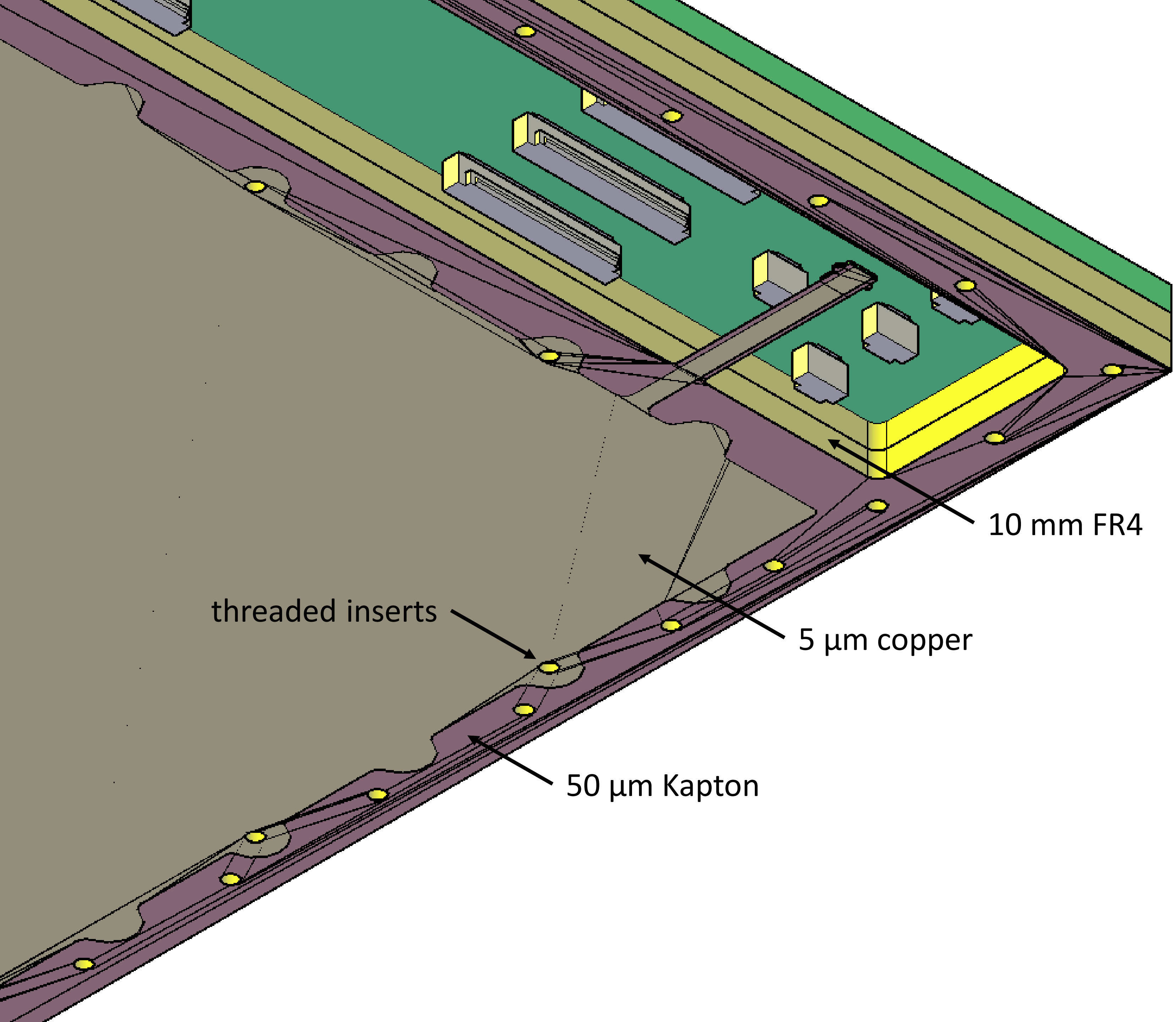
- HV connector
- resistor divider and
- protection resistors

on top side and

- ZIF connectors

on bottom side

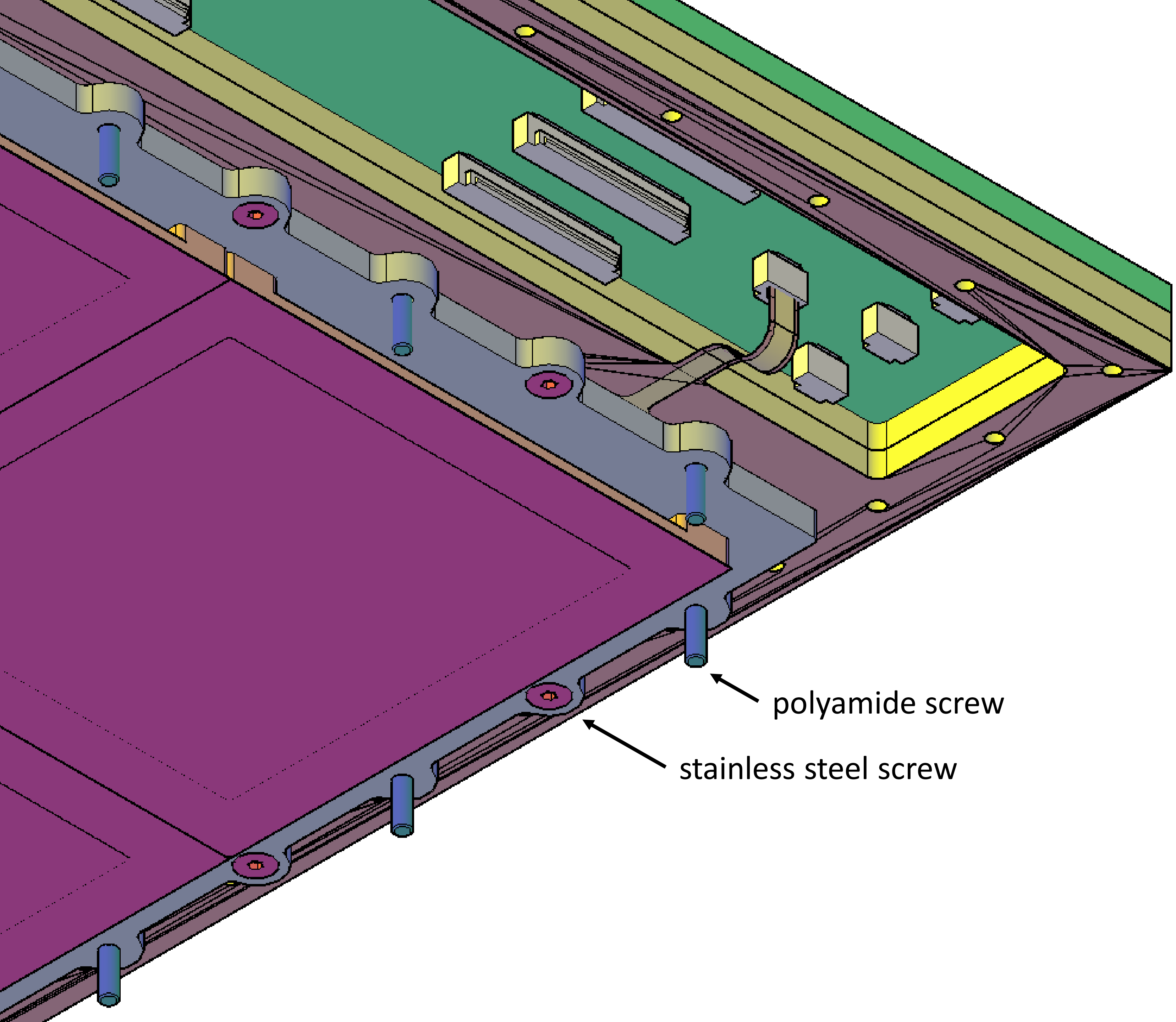
Cleaned after soldering of resistors and connectors



High voltage PCB screwed onto top cover

Top cover w/

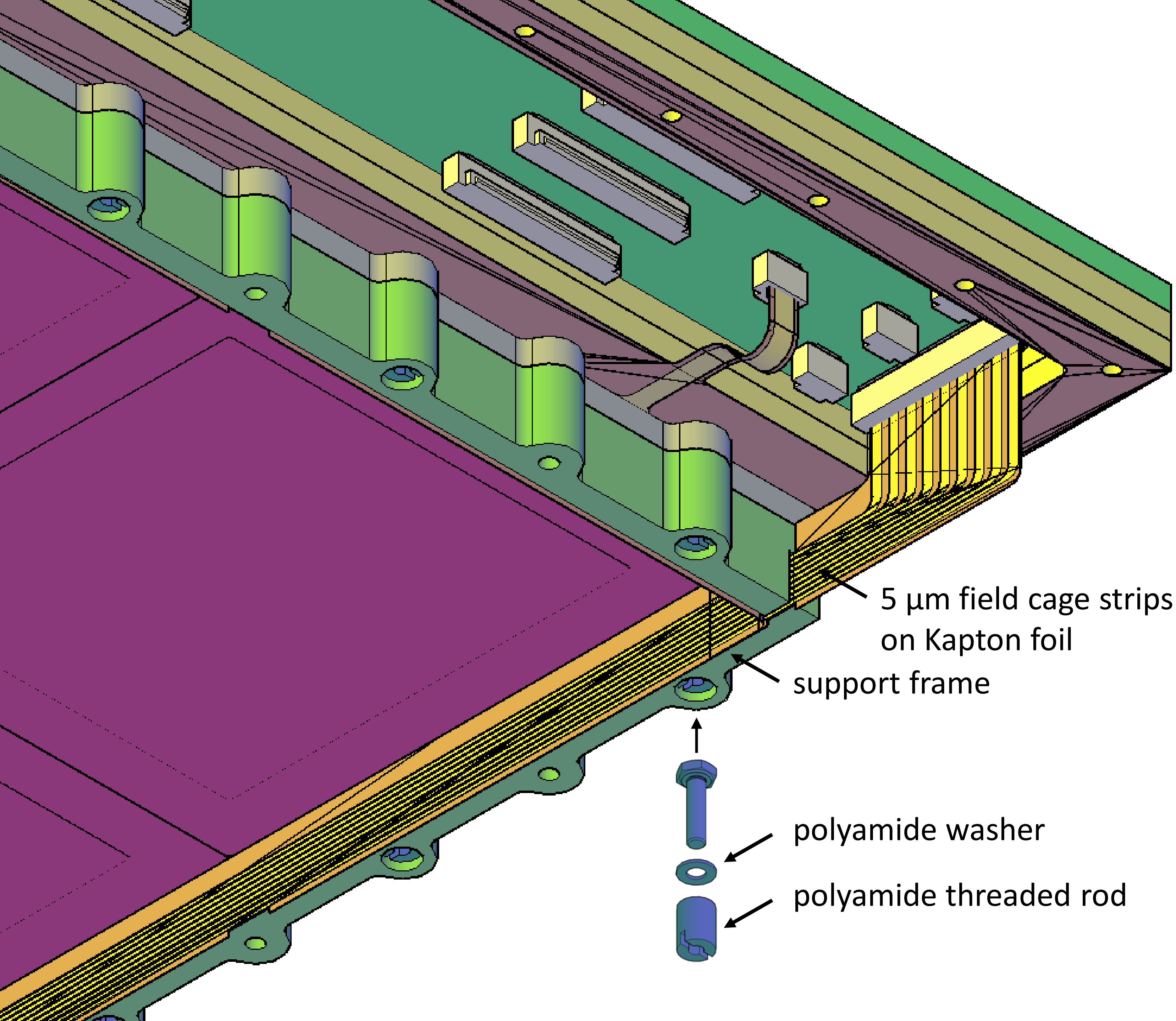
- Copper cathode
- Inserts for screws
- O-ring for gas-tightness



Cathode plugged in and tested

Gadolinium support screwed onto cathode w/ 32 screws

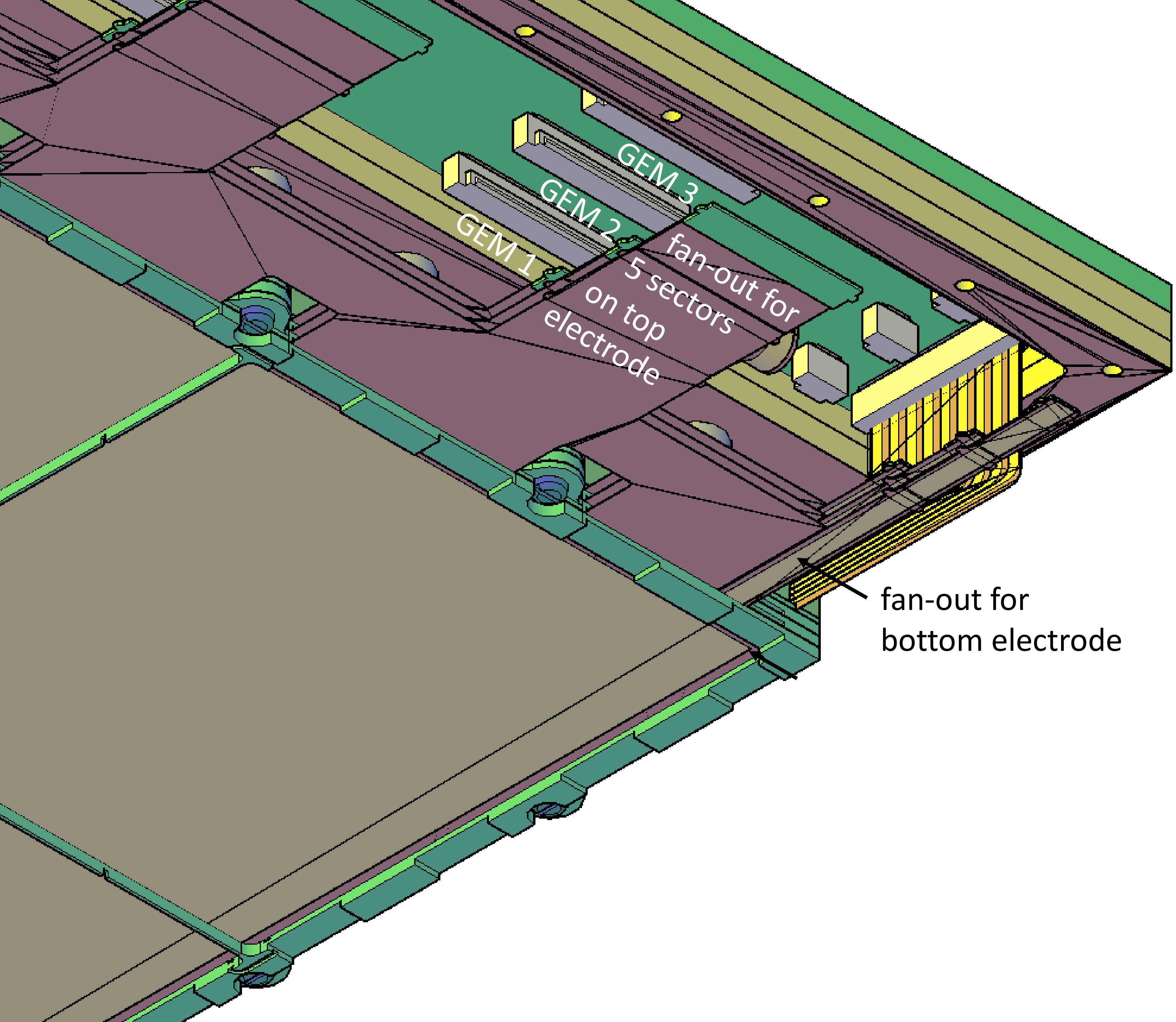
Electrical contact to cathode along surface of frame



Field cage screwed onto support frame w/ 36 threaded rods

Field cage

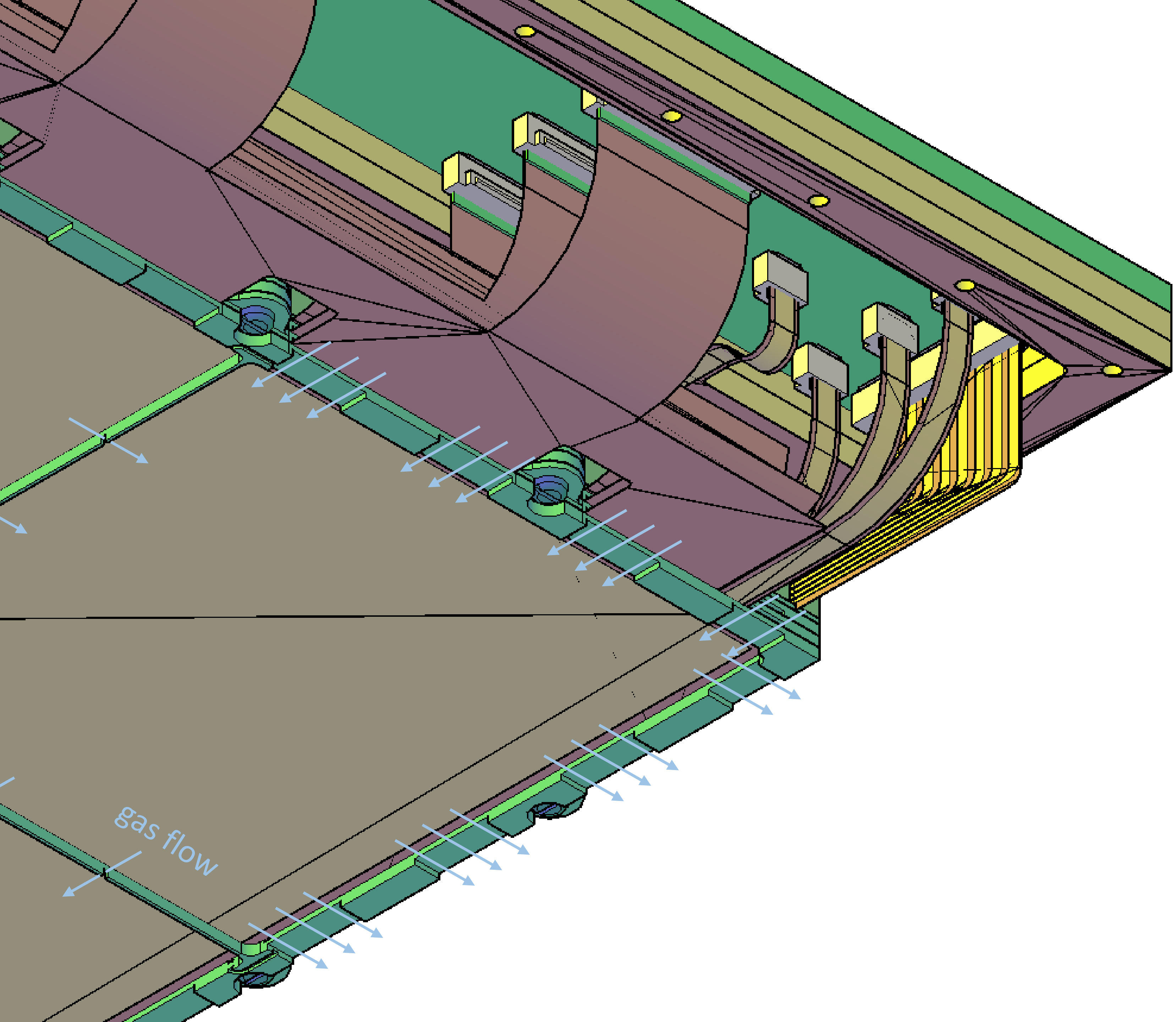
- 9 individual copper strips
- on Kapton foil
- glued into support frame
- connected to voltage divider with ZIF connector



Triple-GEM stack crewed onto field cage frame w/ 32 screws

Each GEM with

- 5x5 sectors on top electrode
- one common bottom electrode
- spacer grid to keep distance between stages

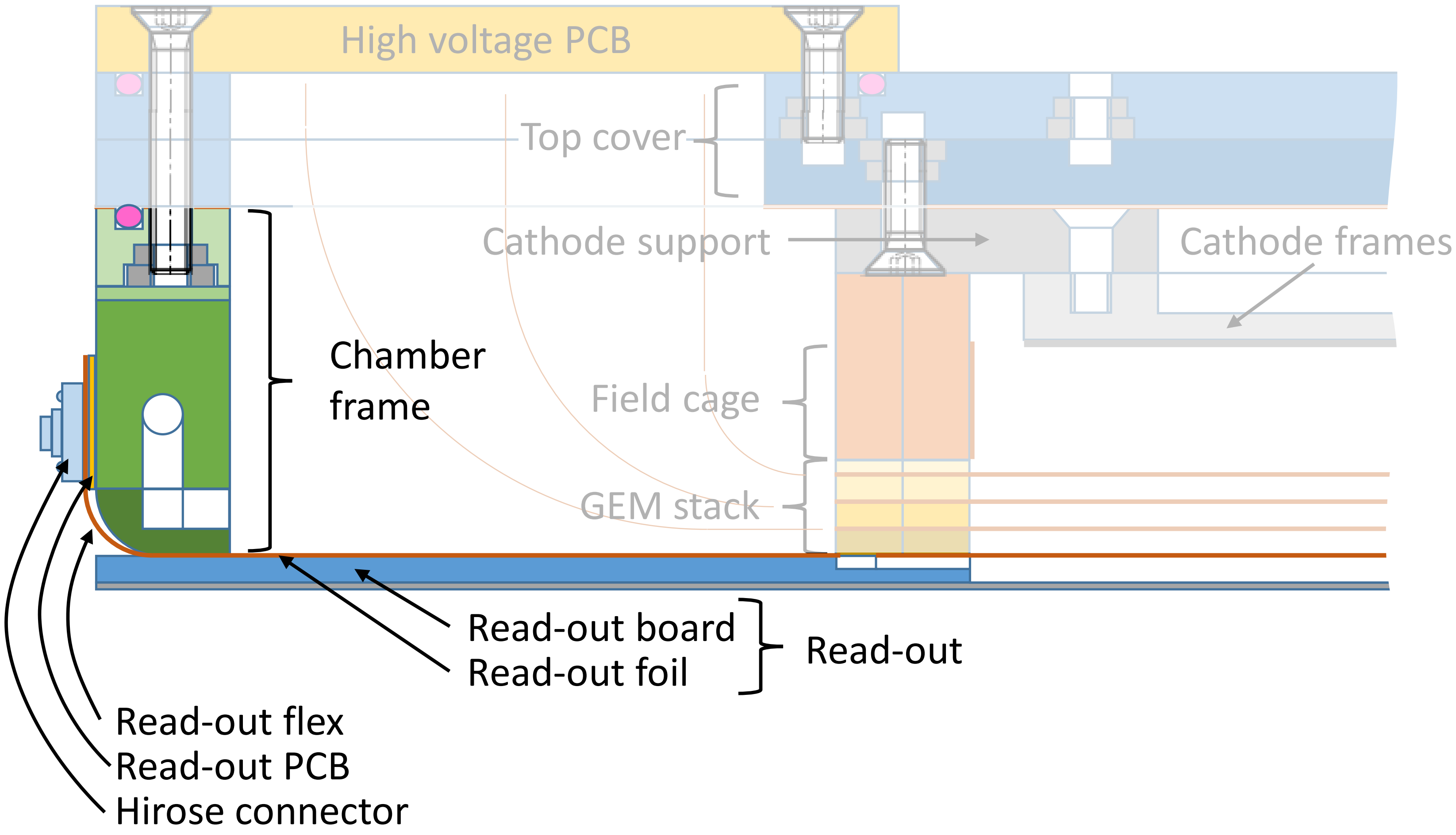


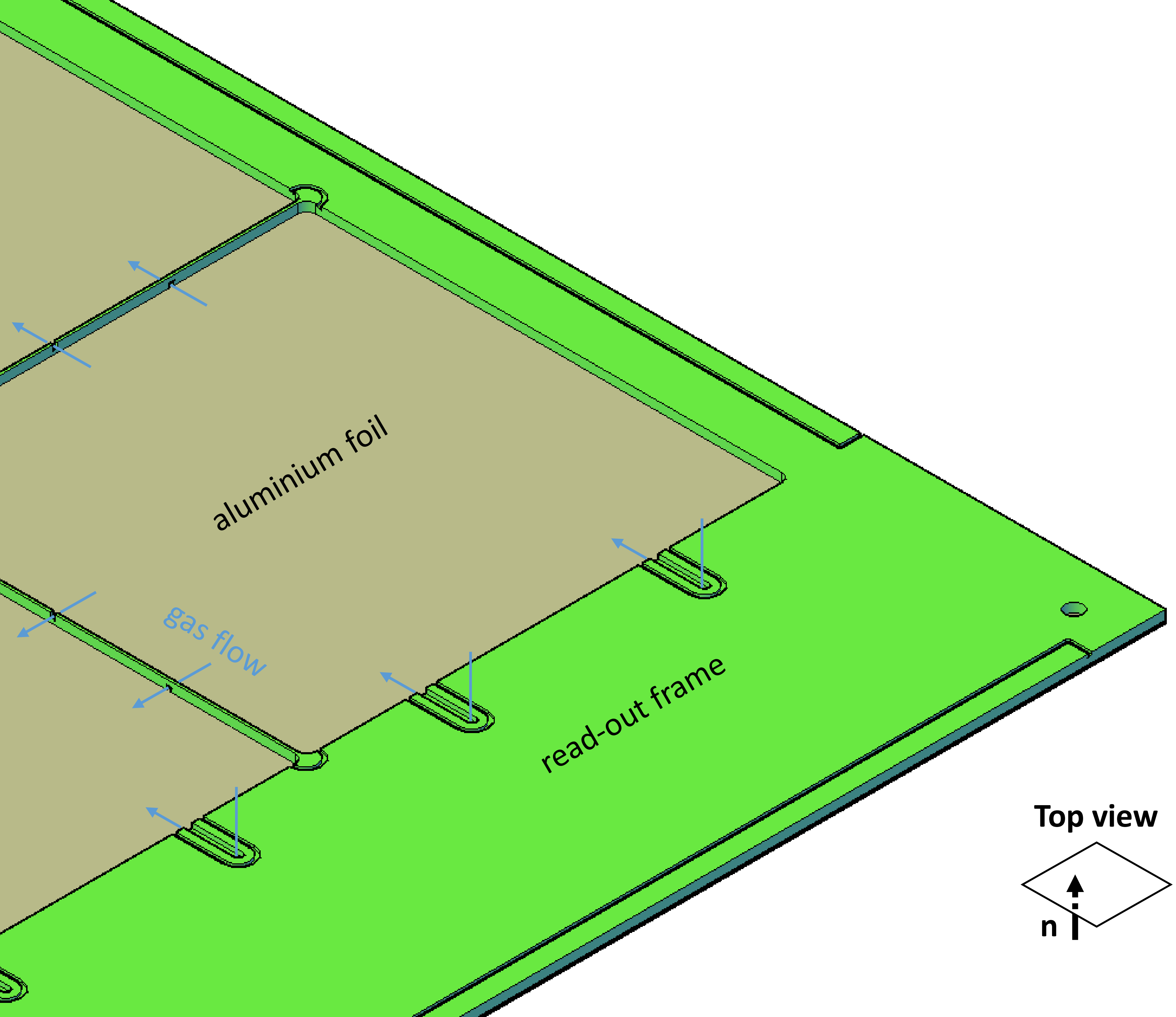
Top stack fully assembled

All connectors plugged in

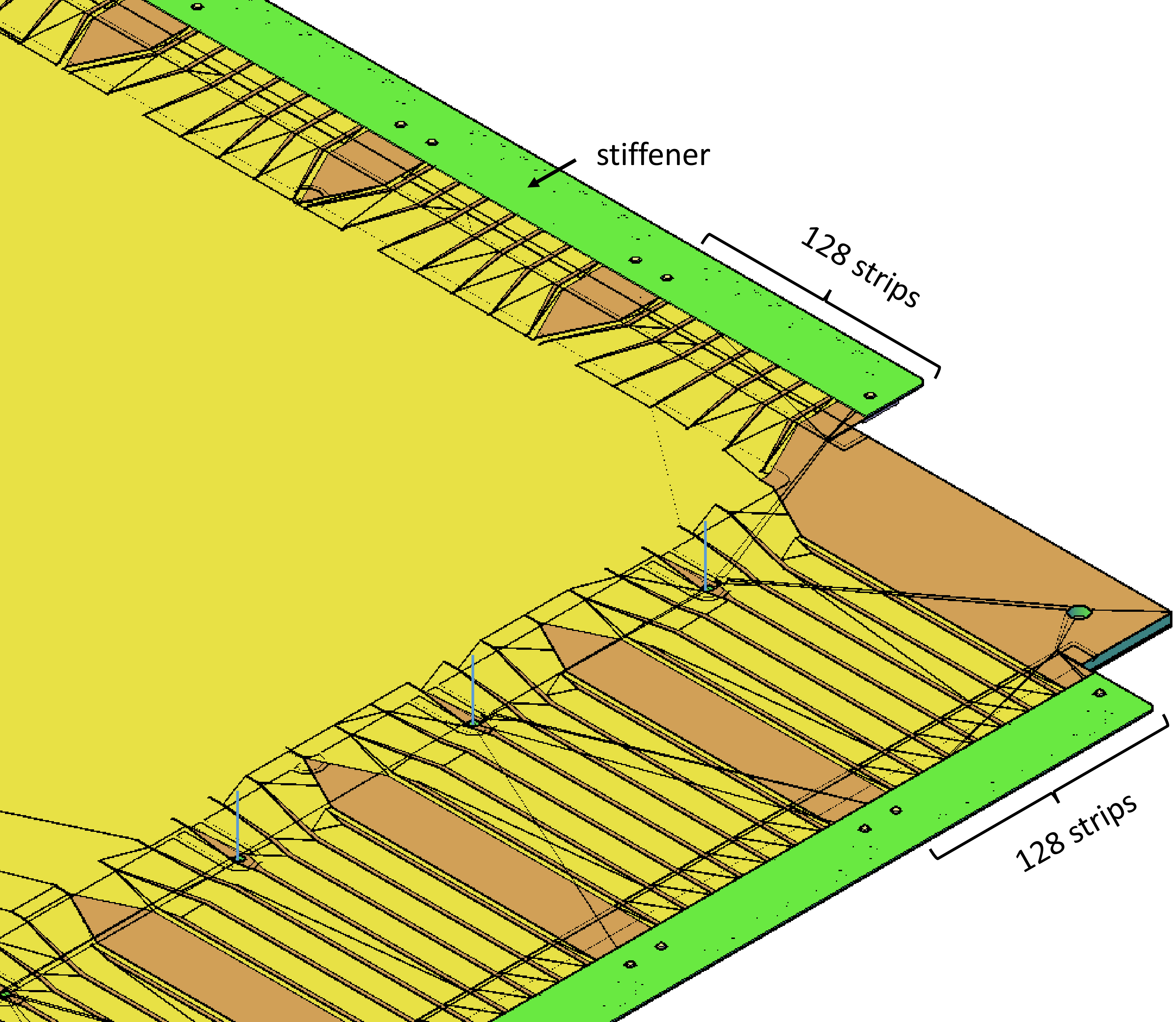
Ready to be screwed onto bottom assembly

Assembly of bottom stack





Read-out frame with aluminium foil glued onto bottom side



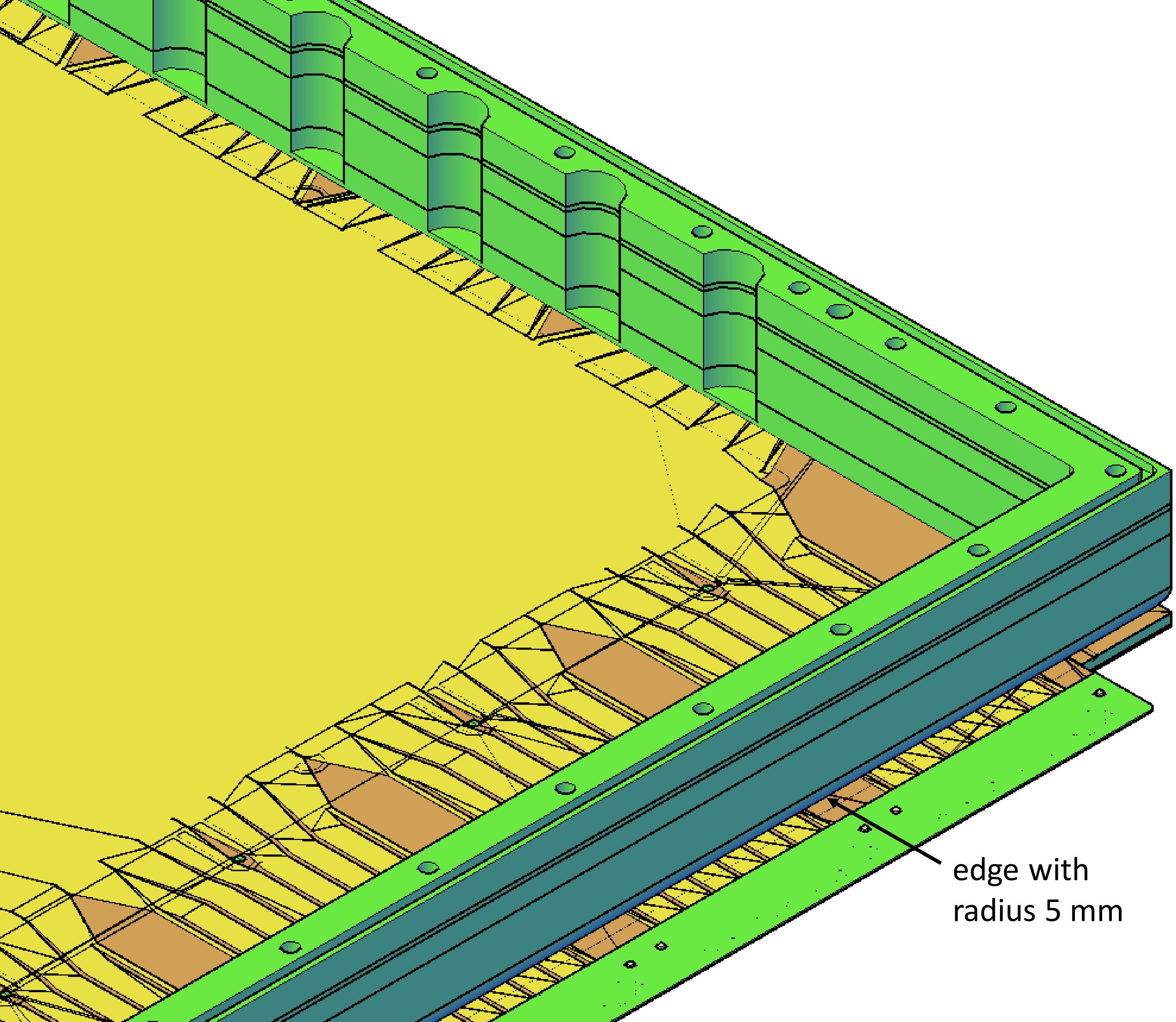
Cartesian strip read-out with 400 µm strip pitch

Split into four quarters w/ 640 strips per coordinate

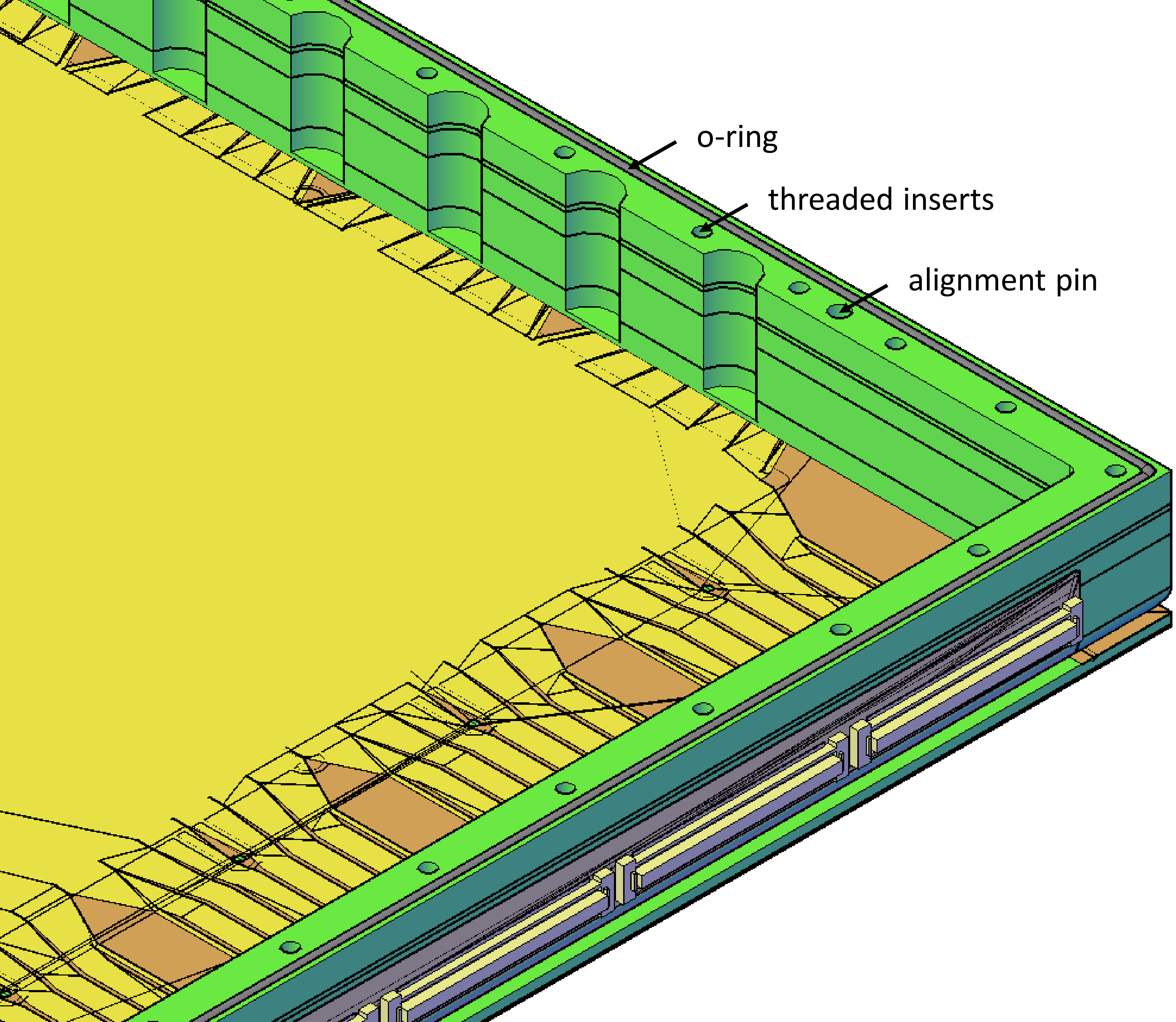
Read-out foil glued onto cathode frame

Stiffener glued onto top side of read-out foil

140 pin-connectors soldered onto bottom side

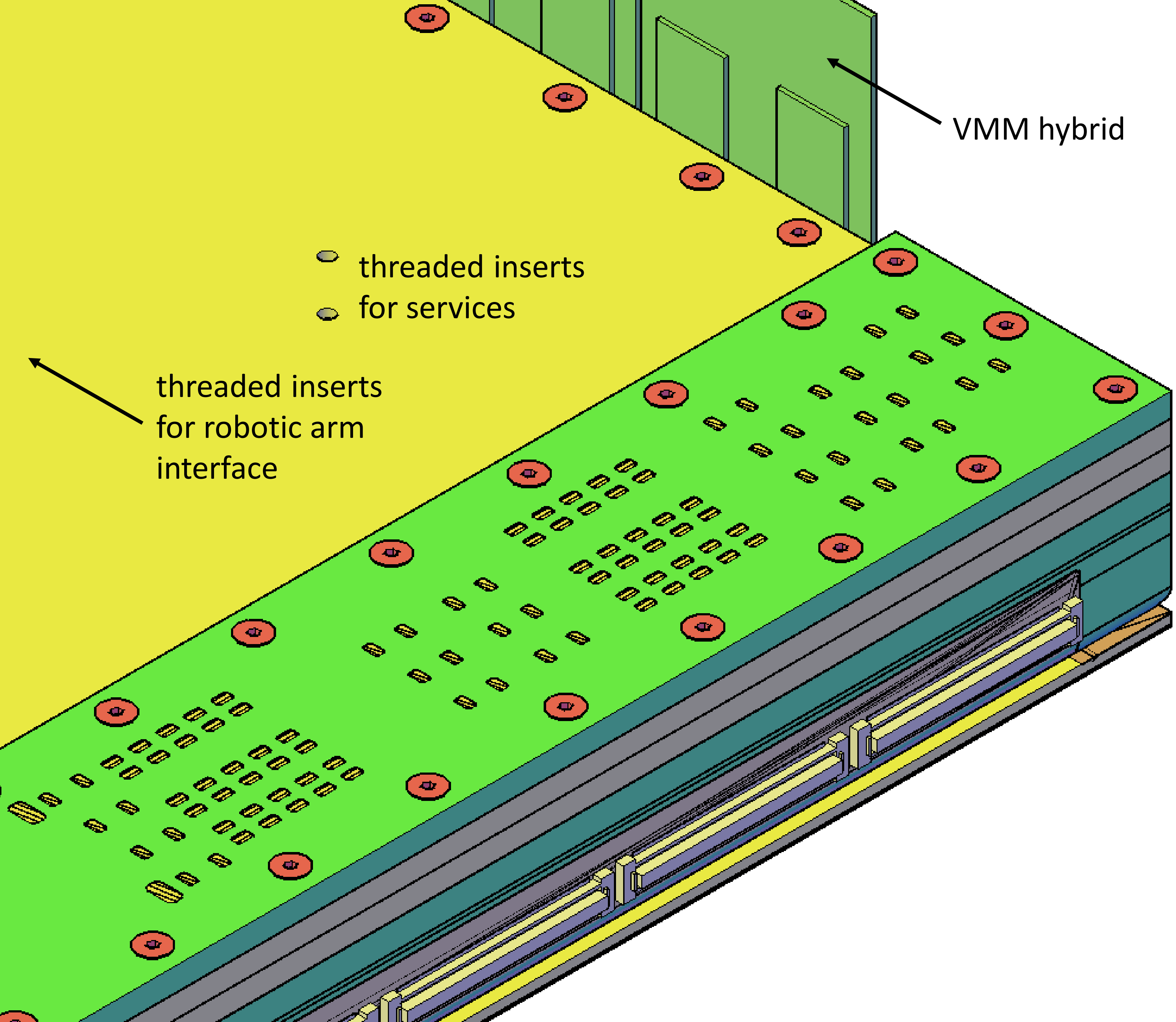


Chamber frame glued onto read-out



140-pin connectors folded onto side of chamber frame

O-ring inserted into groove on top of chamber



Top stack screwed onto bottom stack w/

screws and polyamide washers for gas tightness

VMM hybrids connected

Detector fully assembled

Flushed with Ar/CO2 70/30 and ready for testing

Conclusions
Detector demonstrator prototype

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

Testing and **assembly** will start **early October**

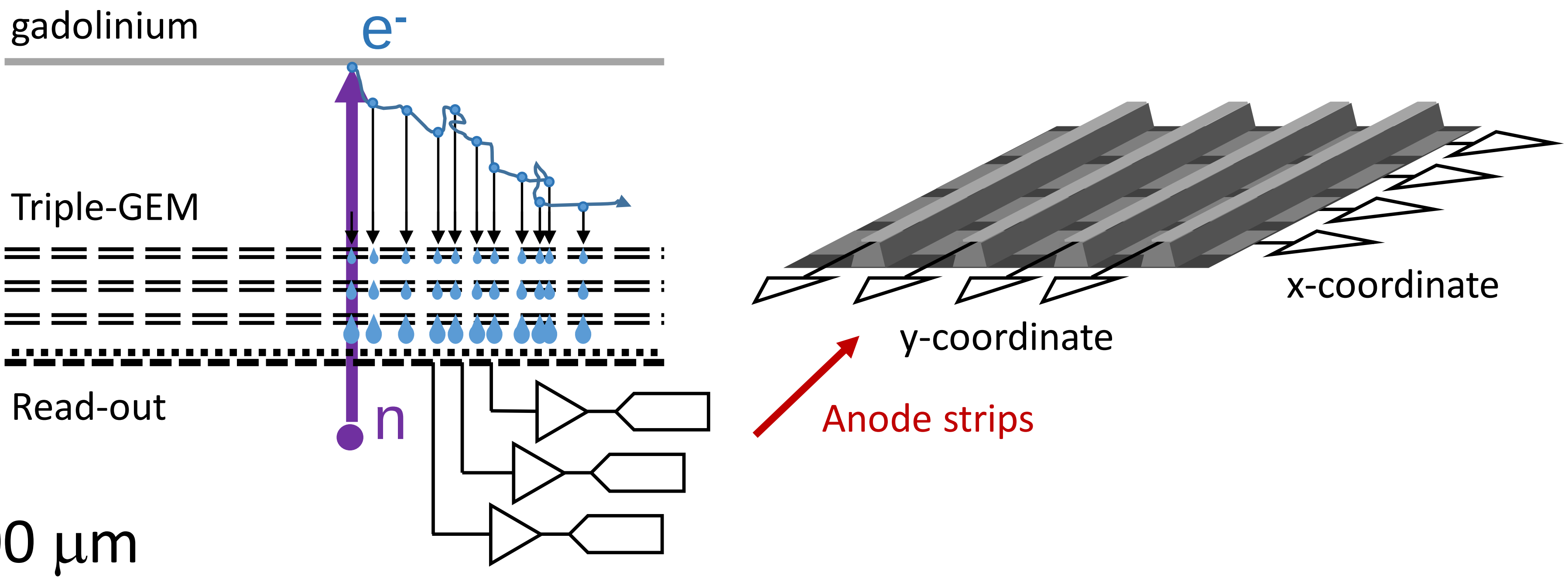
Close to requirement of **200 µm** spatial resolution

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

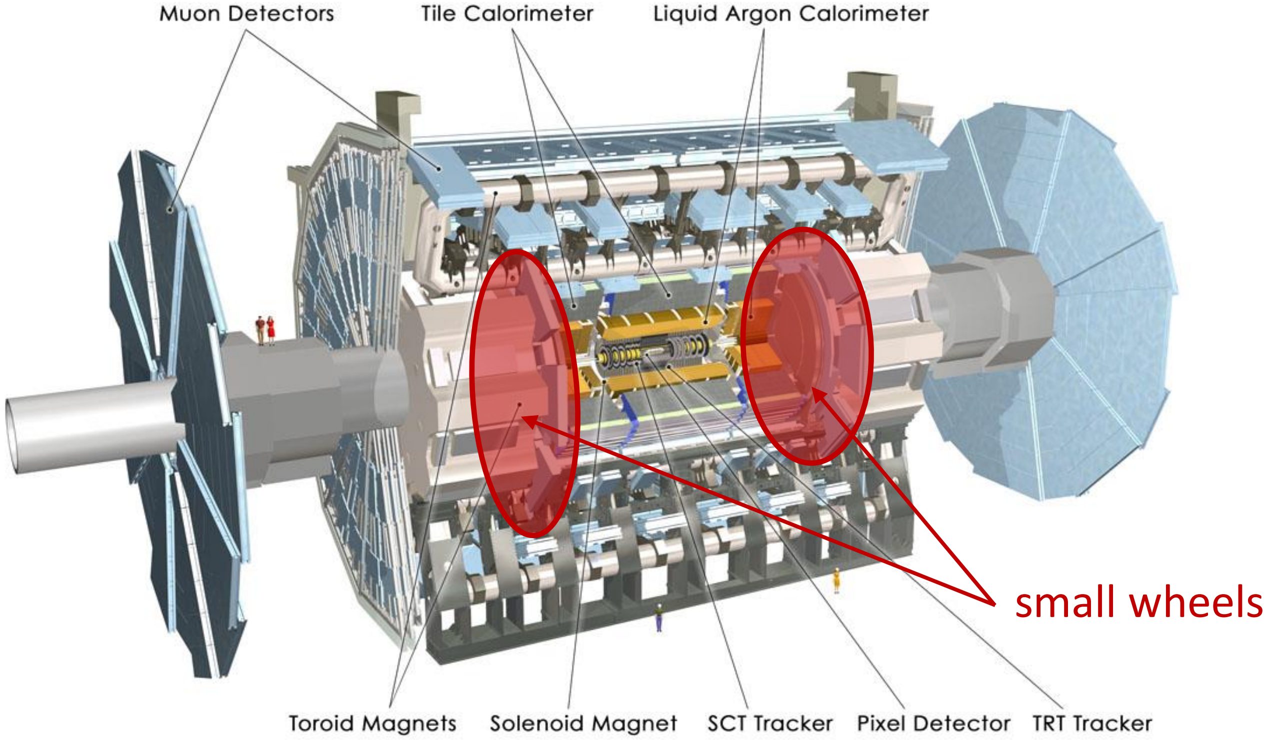
Robotic arms restrict number of cables from detector to back-end

→ digitise data on detector

Electronics

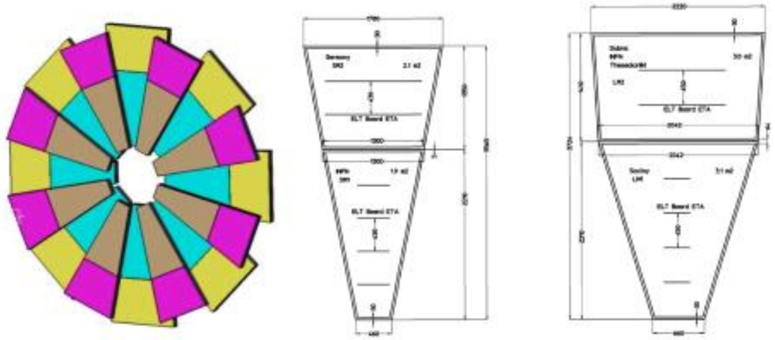
The ATLAS New Small Wheel Upgrade

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

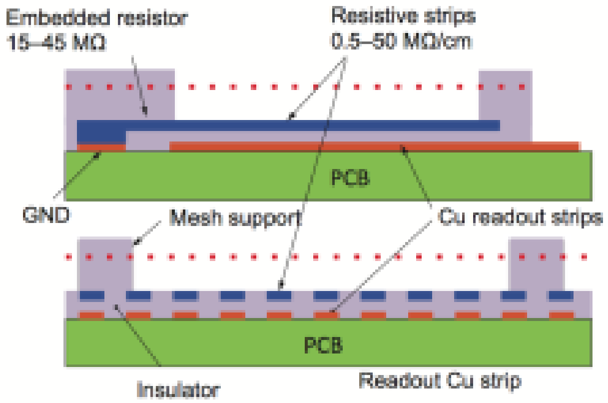


http://www.atlasexperiment.org

New fronted ASIC developed by Brookhaven National Lab.



One of the new detector types are Micromegas



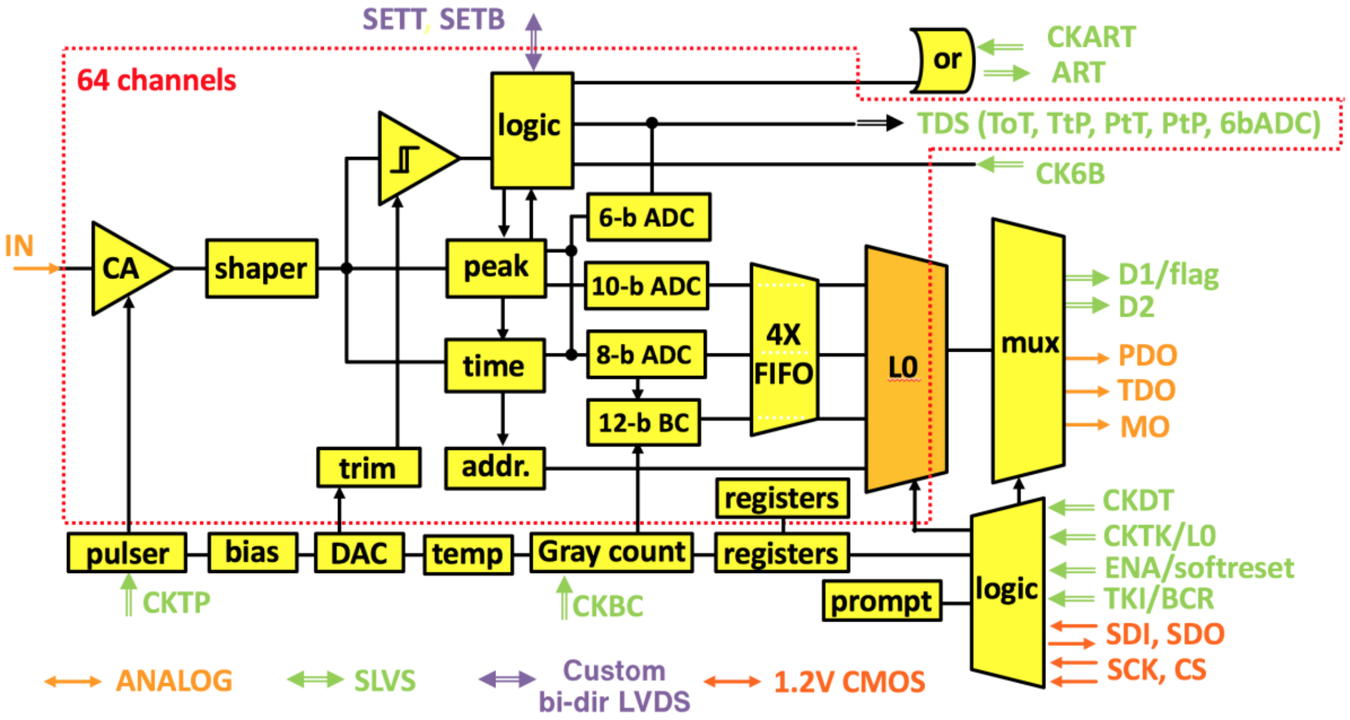
Anode strips read-out similar to our GEM detector

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

Electronics

The VMM ASIC – Features

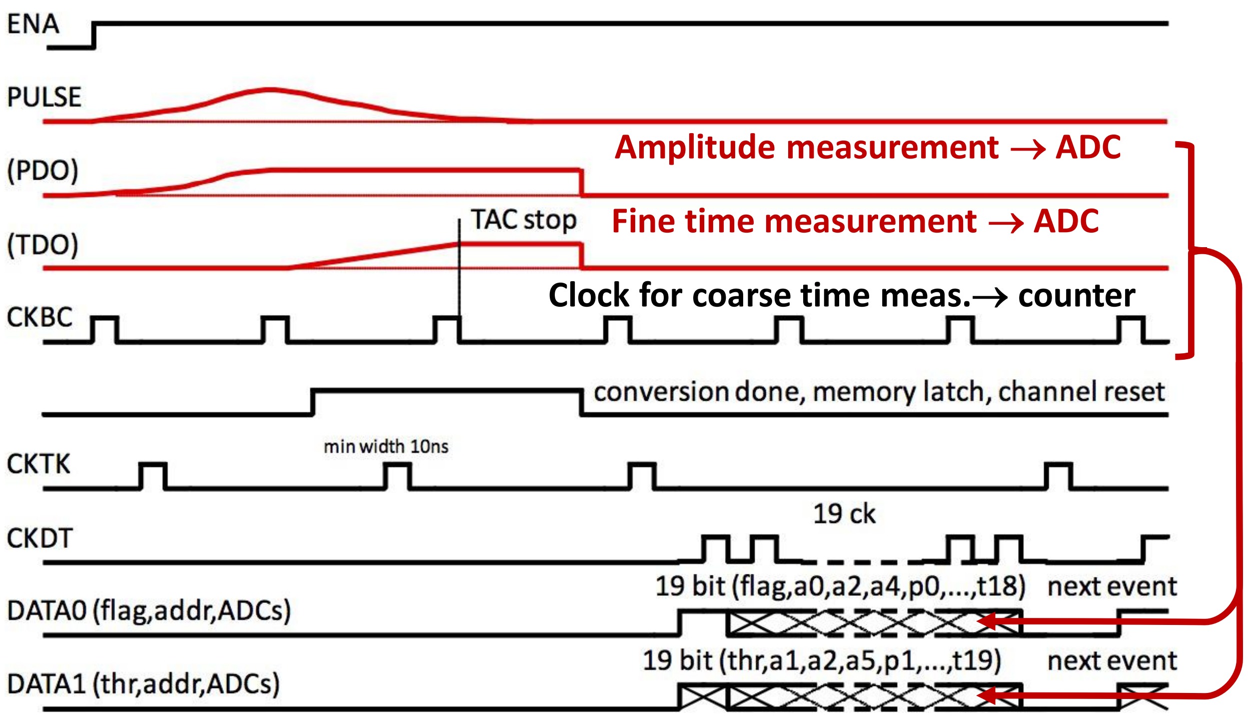
- 130 nm CMOS technology
- 64 input channels, each w/ preamplifier, shaper, peak detector, several ADCs
- Pos. & neg. polarity sensitive
- Digital block w/ neighbouring logic, FIFO, multiplexer
- Adjustable gain 0.5 – 16 mV/fC
- Adjustable shaping time from 25 ns – 200 ns
- Input capacitance from few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



Electronics

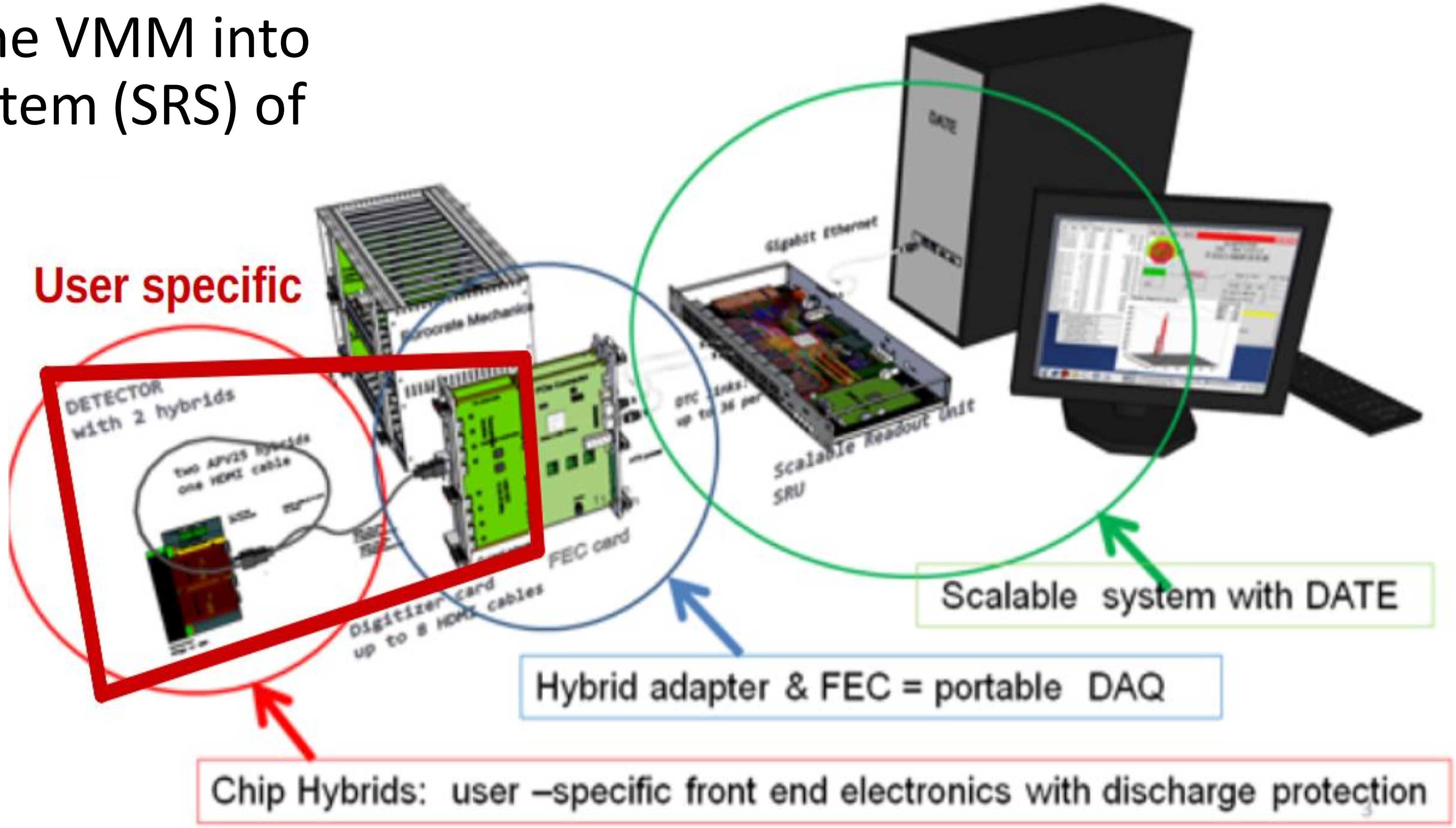
The VMM ASIC – Features (continued)

- 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
The Scalable Readout System

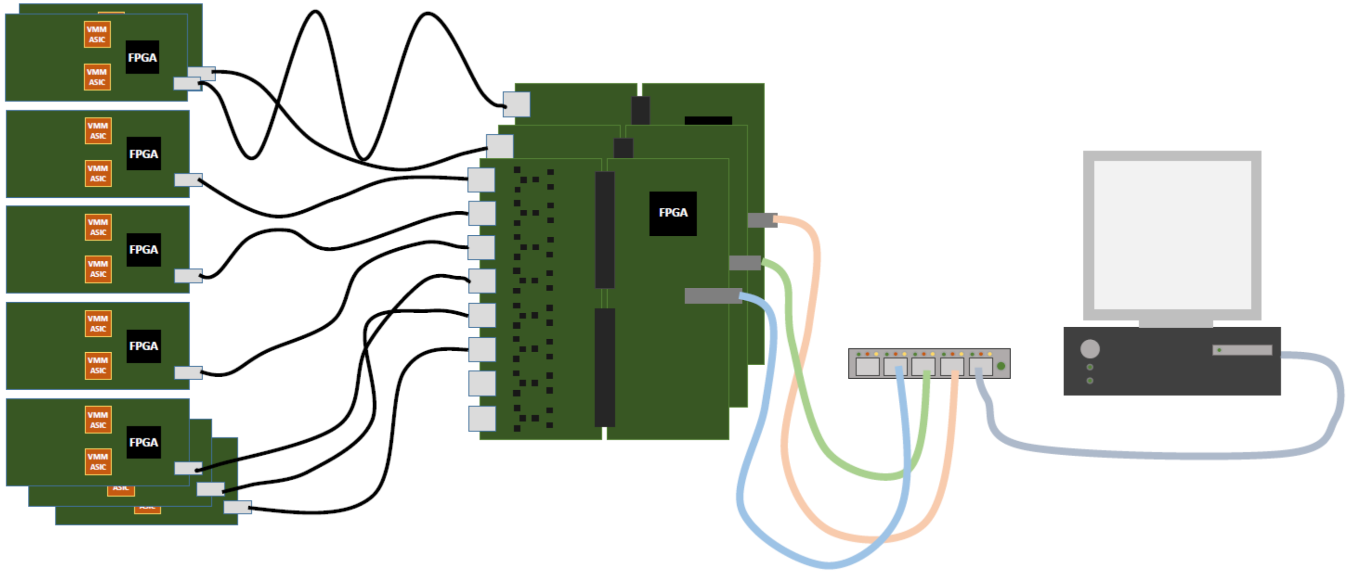
Implementation of the VMM into Scalable Readout System (SRS) of RD51 Collaboration



Electronics

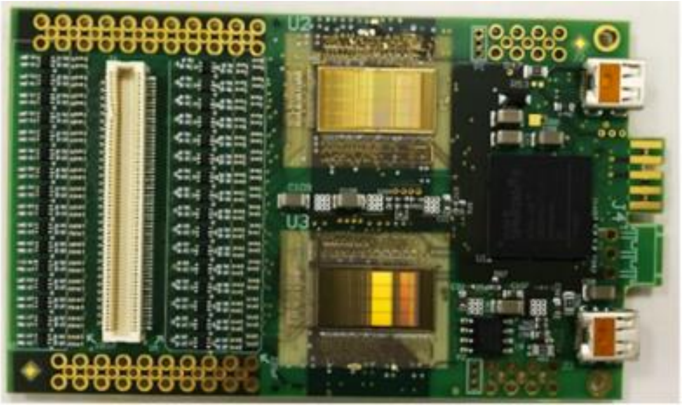
Readout chain and components

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



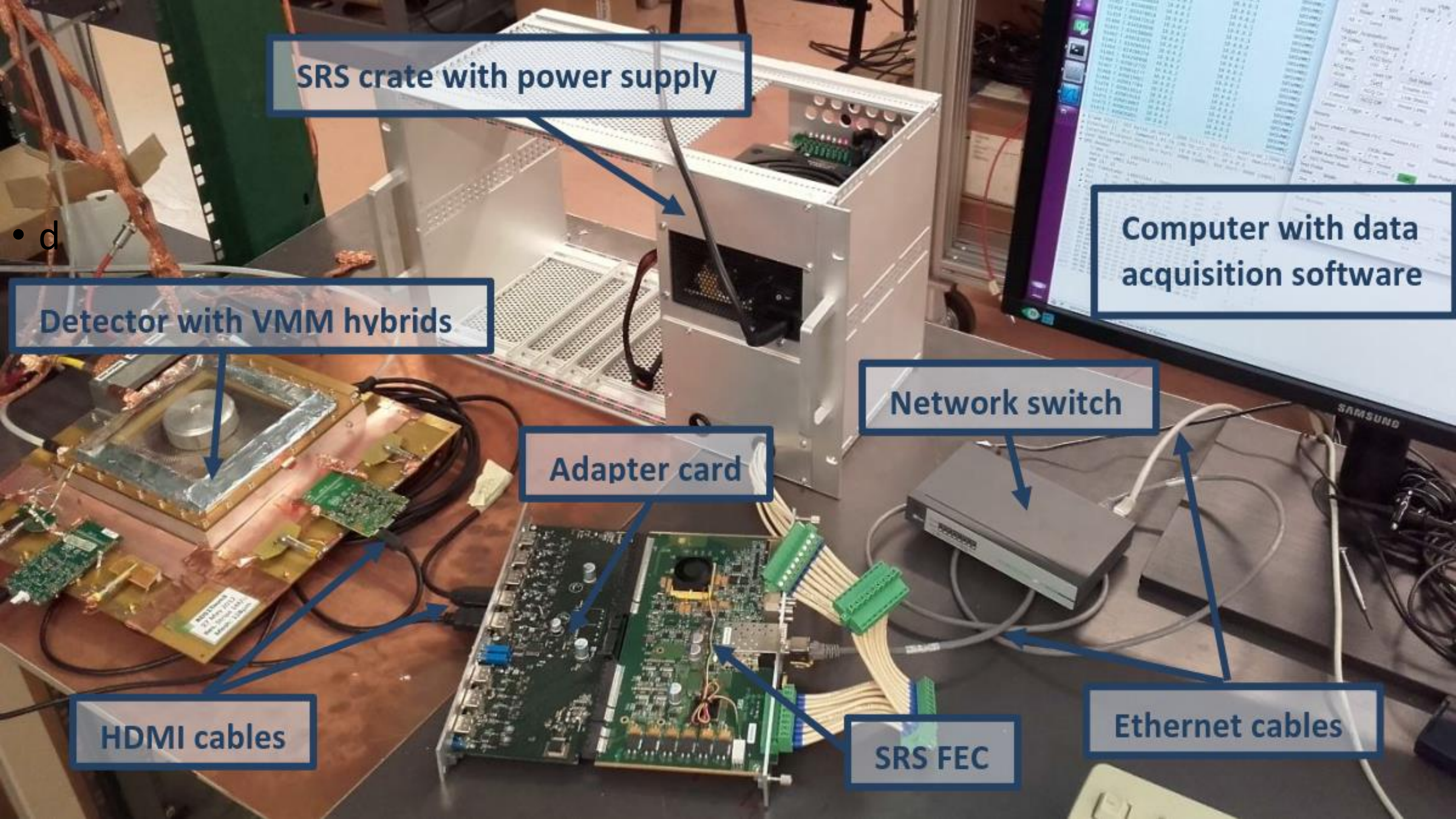
VMM Hybrid → HDMI cable → Adapter card + FEC → Ethernet → Switch →Ethernet → PC

Scalability: up to 8 VMM hybrids/FEC, many FECs/PC
→ system scalable from one to 64 hybrids and more

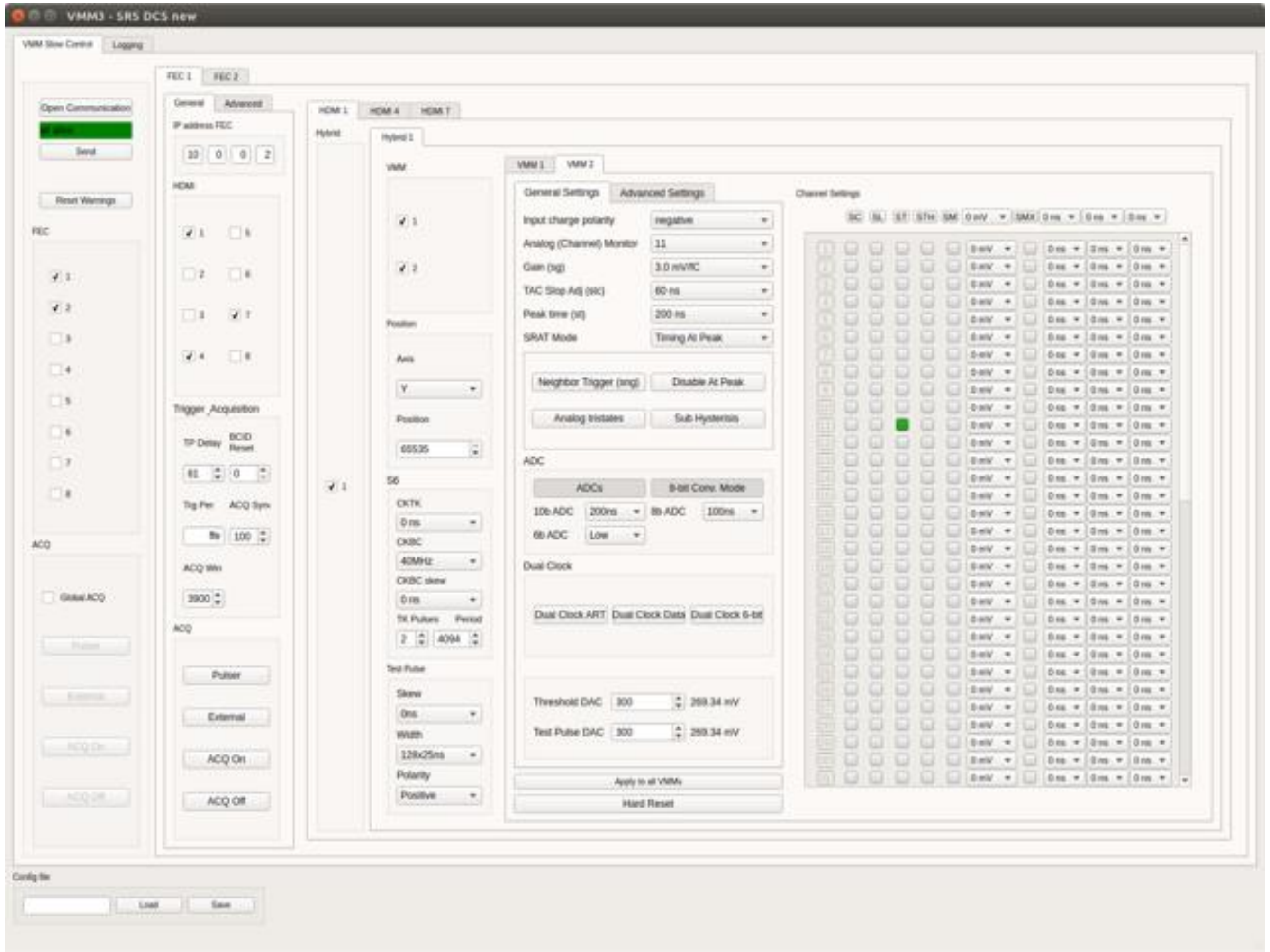


VMM hybrid

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
SAMSUNG

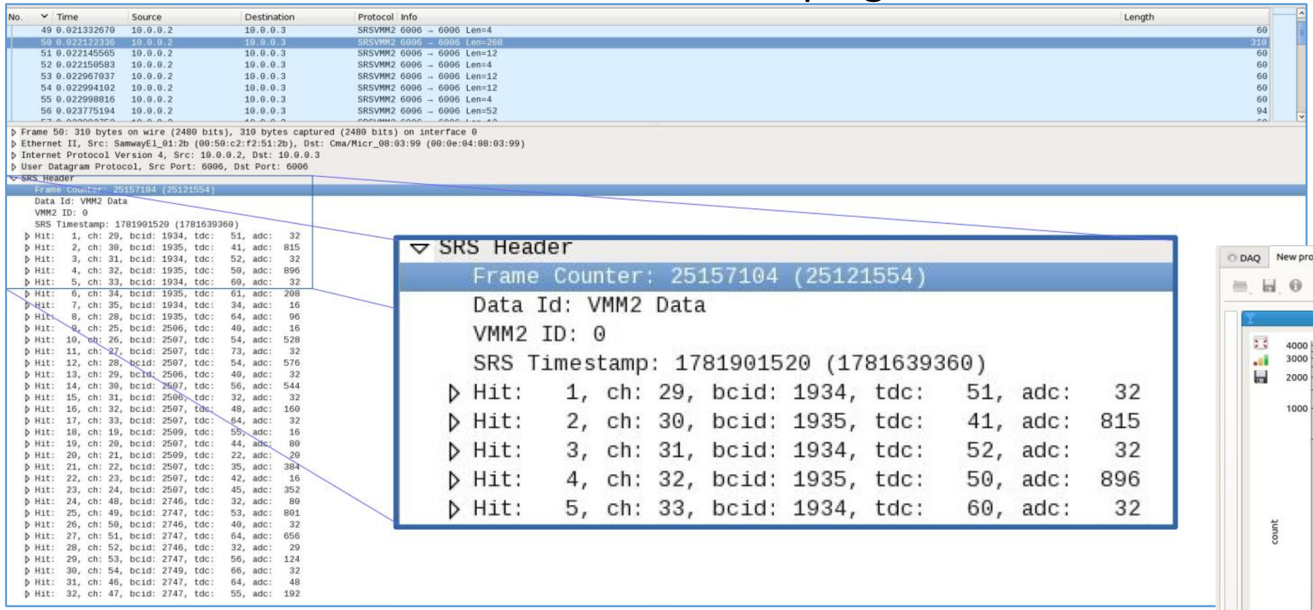
Electronics
Slow control for the readout system



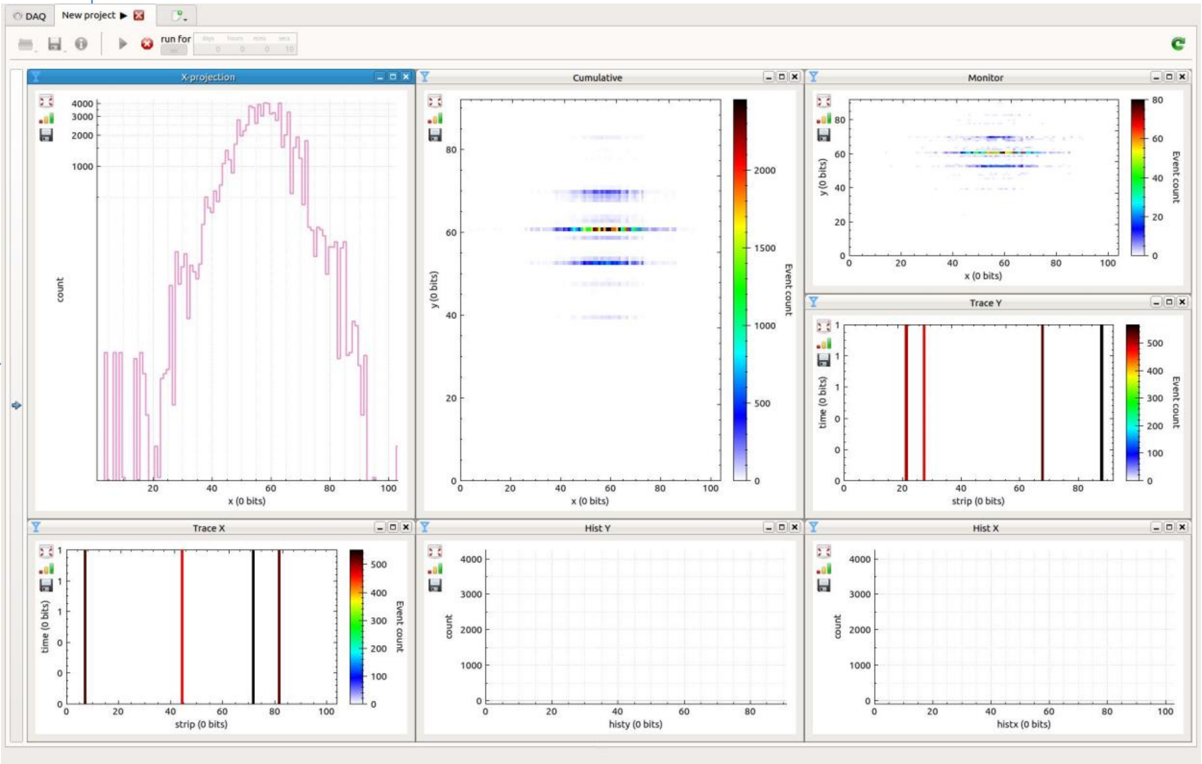
CERN Summer student project of Manuel Guth

Electronics
Data from SRS

Wireshark & plugin for first data check



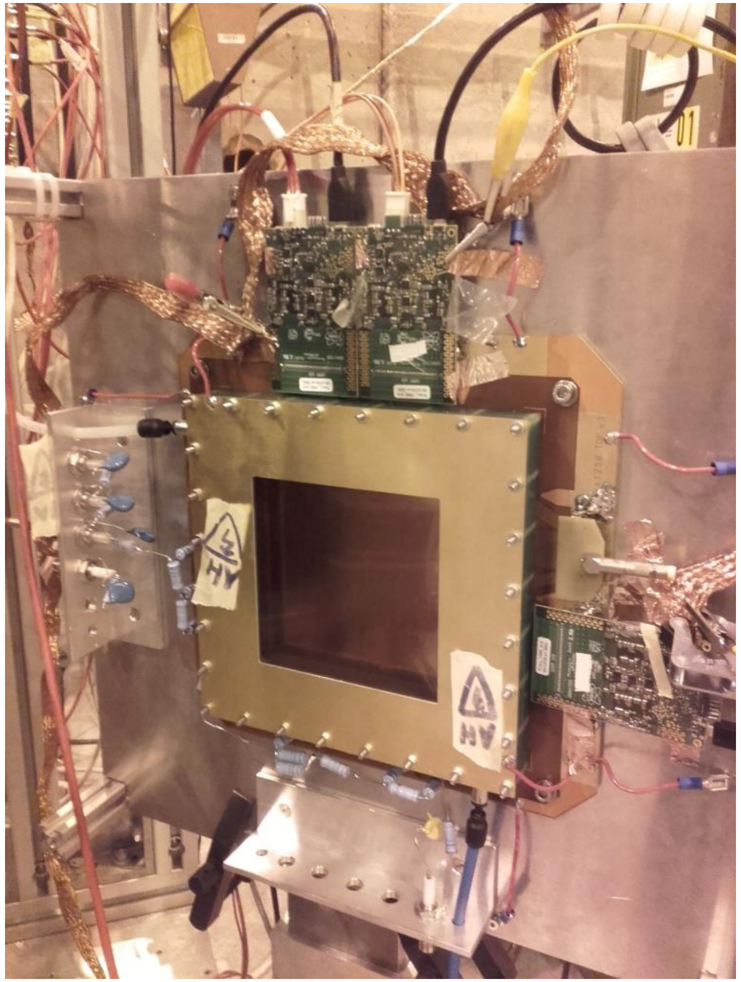
Online monitoring



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

Electronics

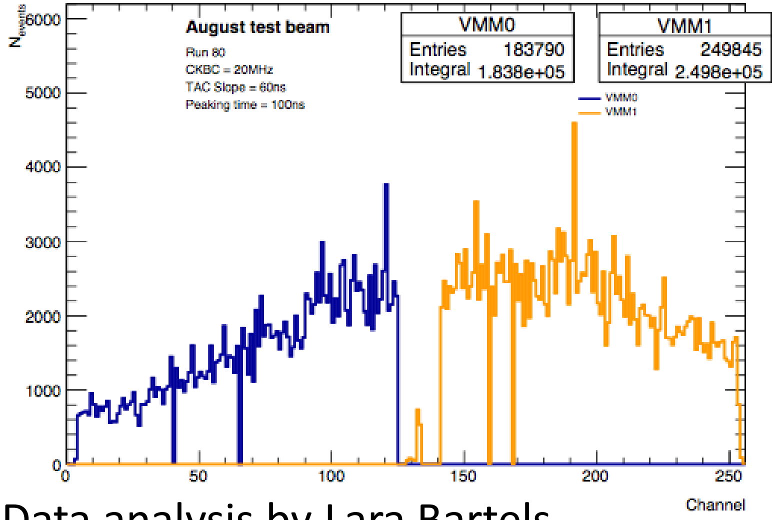
Latest test beam at CERN North area with beam from SPS

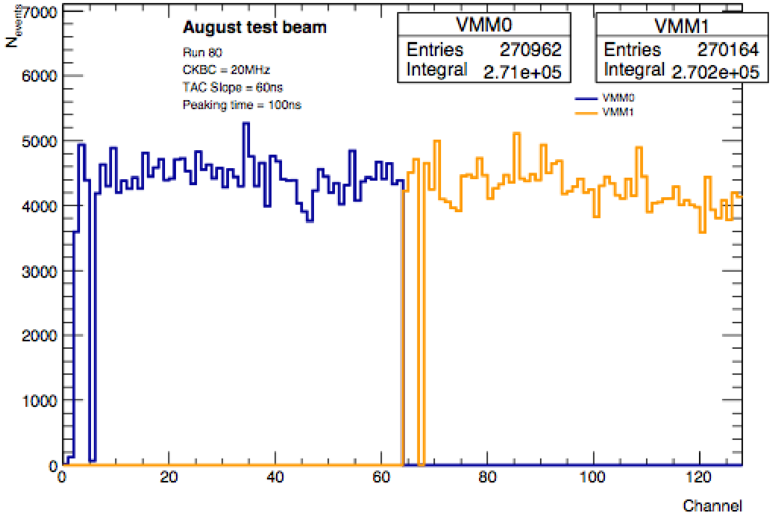


Triple-GEM detector with copper cathode (no gadolinium for muons and pions)

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

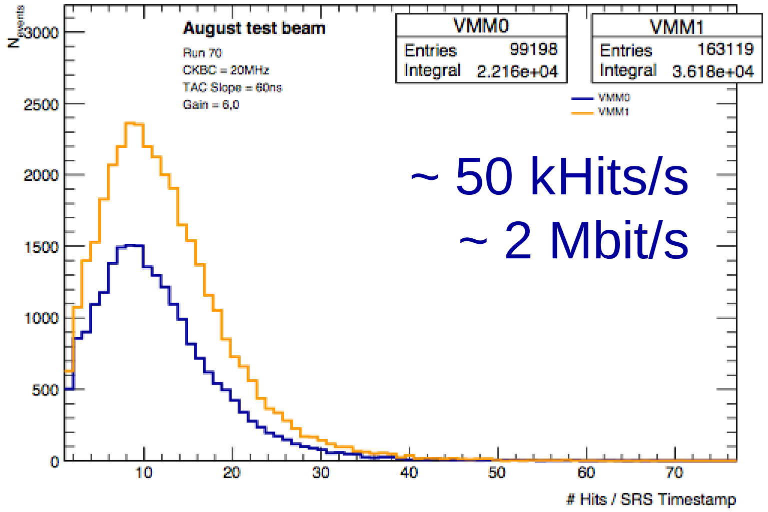


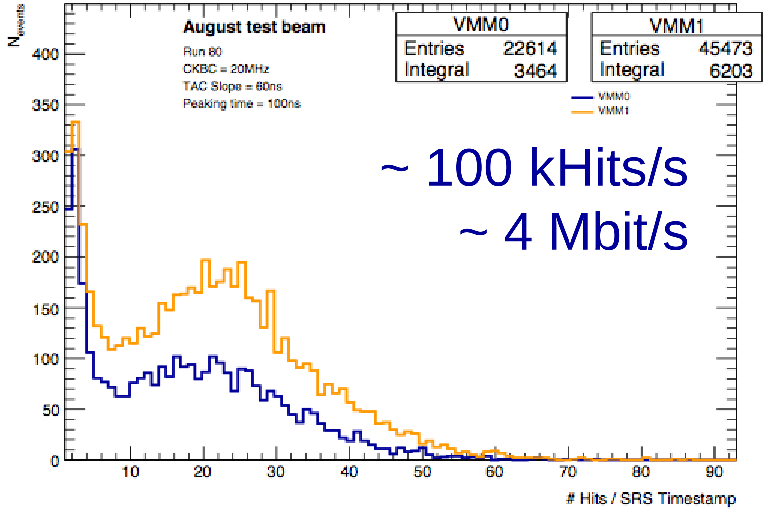


Data analysis by Lara Bartels

Electronics

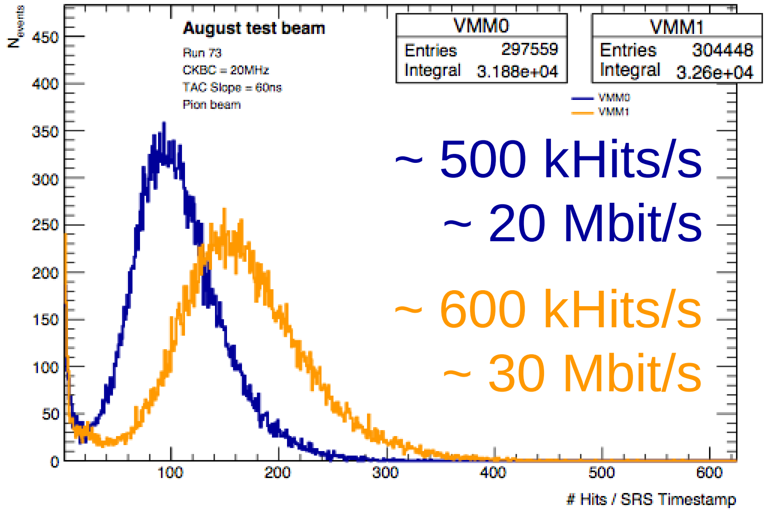
Latest test beam at CERN North area with beam from SPS

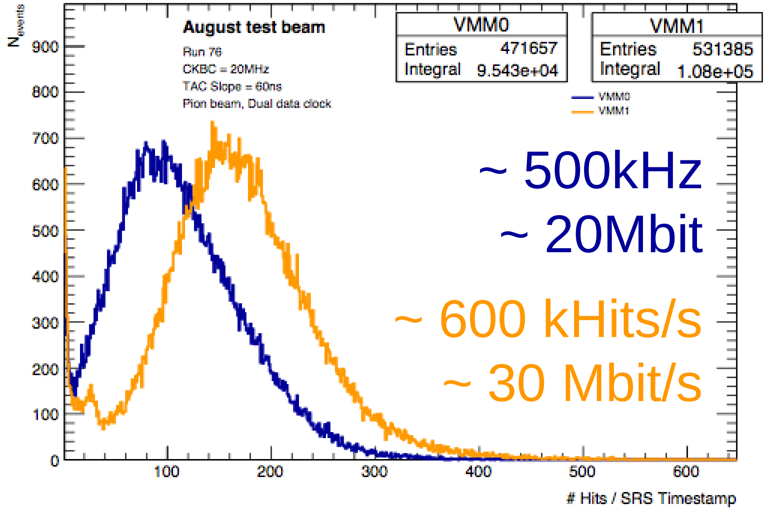




muon beam

pion beam



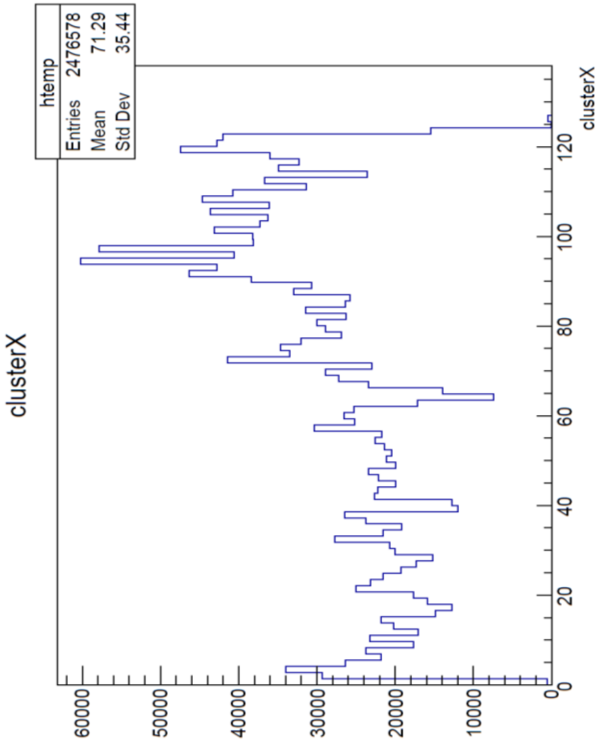


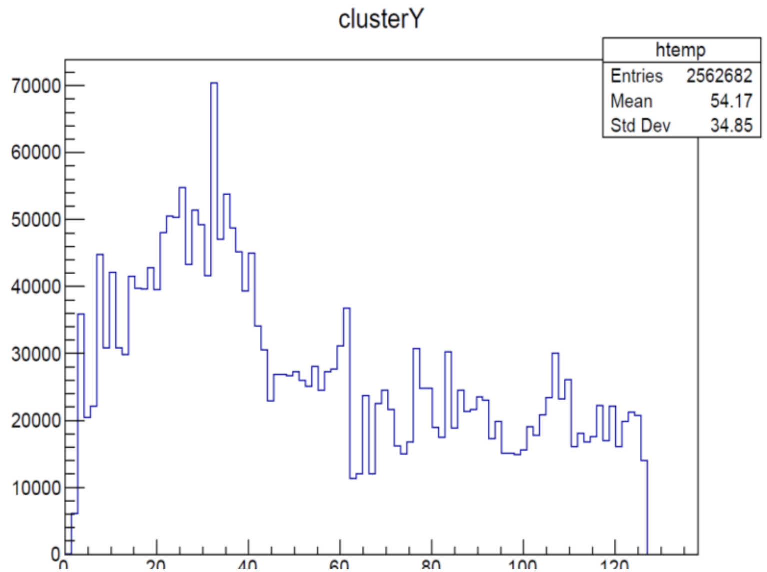
Electronics

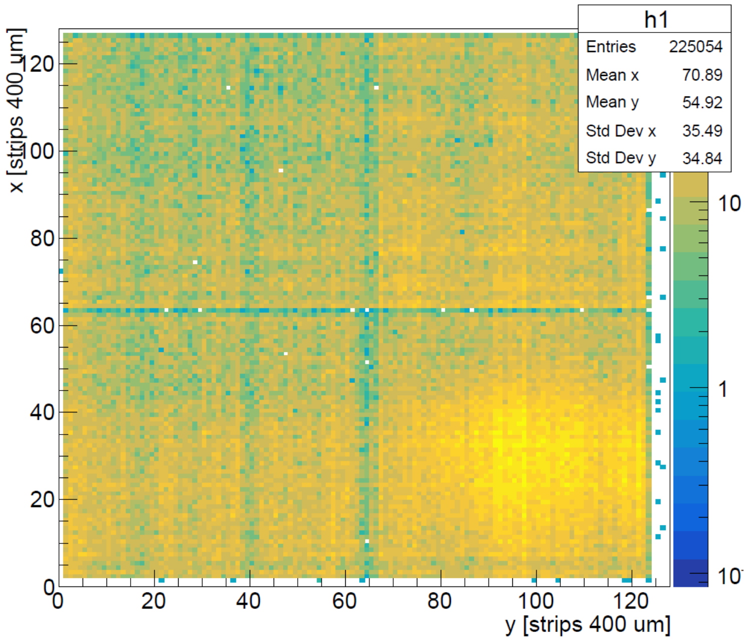
Latest test beam at CERN North area with

Clustered data from pion beam

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







Electronics
Current status

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)

Electronics
Outlook

Next CERN test beam at SPS from October 2nd. Improvements to previous one:

- New slow control
  - Allows for simpler operation of system with several hybrids
  - Includes routines for some calibrations already
- Improved online monitoring
  (ongoing development with BrightnESS WP5.1, DMSC)
- 4th VMM hybrid ready
  - Fully equipped 10 cm x 10 cm GEM detector (2 hybrids in x, 2 hybrids in y)
  - Higher data rate between SRS FEC and computer $\rightarrow$ try to reach current limits
- New student for two months, Summer Students have left

Electronics
Outlook

Next IFE Norway **test beam** at JEEP II start at 4^{th} December:
same electronics (4 hybrids for full detector read-out), but with neutron beam

Mid term: test of hardware improvements $\rightarrow$ go ahead for larger scale production of hybrids and adapter cards

Long (final) term: scale up of the system (multi FEC) for full prototype

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 starting in next few weeks**

Stay tuned for results at IKON 14!