



Detector Integration

Dirk Wiedner on behalf of Mu3e

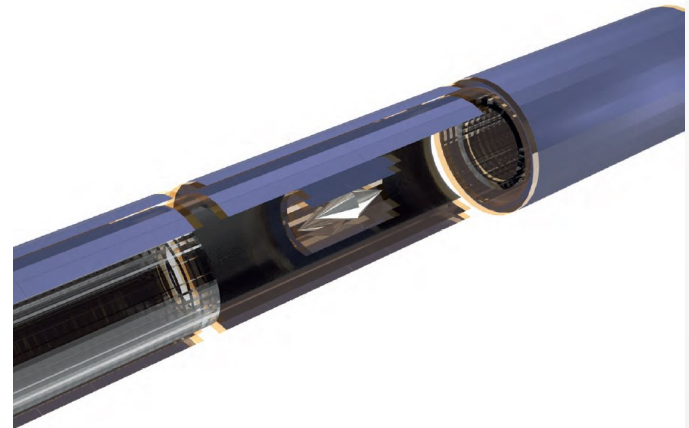
February 2018

Introduction

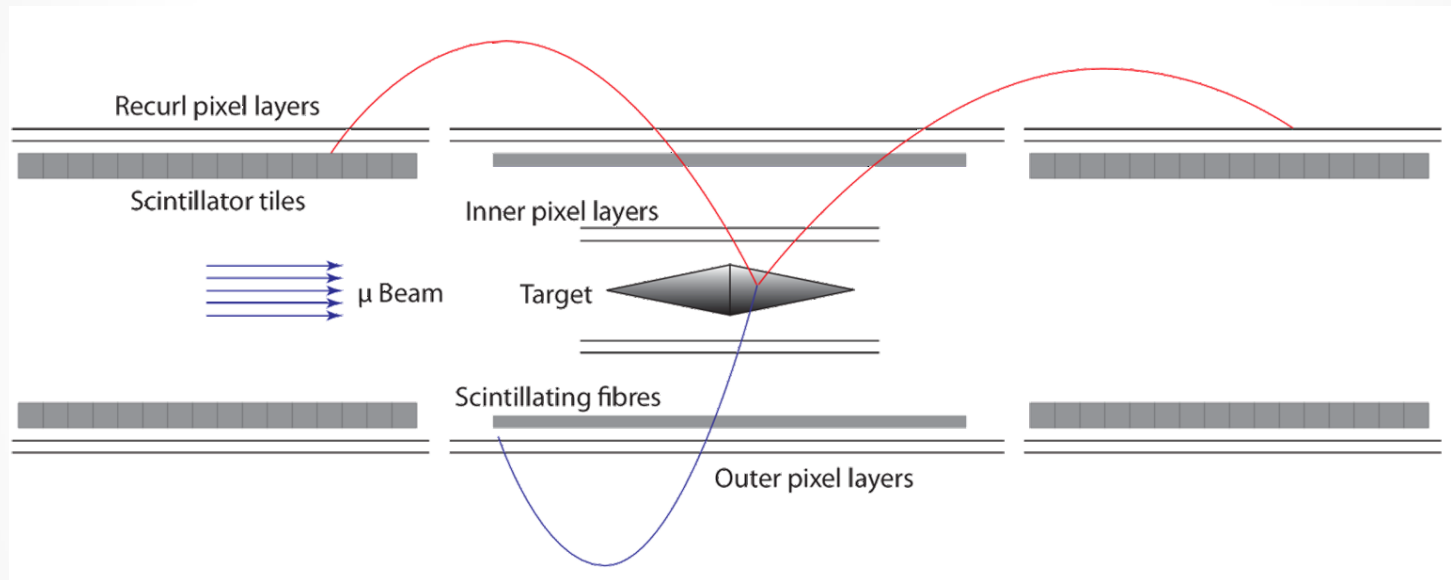
- Mu3e experiment
 - Pixel detector
 - Scintillating fibre detector
 - Tile detector
 - Target
- But also:
 - Solenoid magnet
 - Mechanics
 - Cooling
 - Cabling
 - Electronics...



Technical design of the Phase I
Mu3e Experiment



Phase I Experiment



- Muon beam $O(10^8/s)$
- Helium atmosphere
- 1 T B-field

- Target double hollow cone
- Silicon pixel tracker
- Scintillating Fiber detector
- Tile detector

Integration Challenges

Subsystem

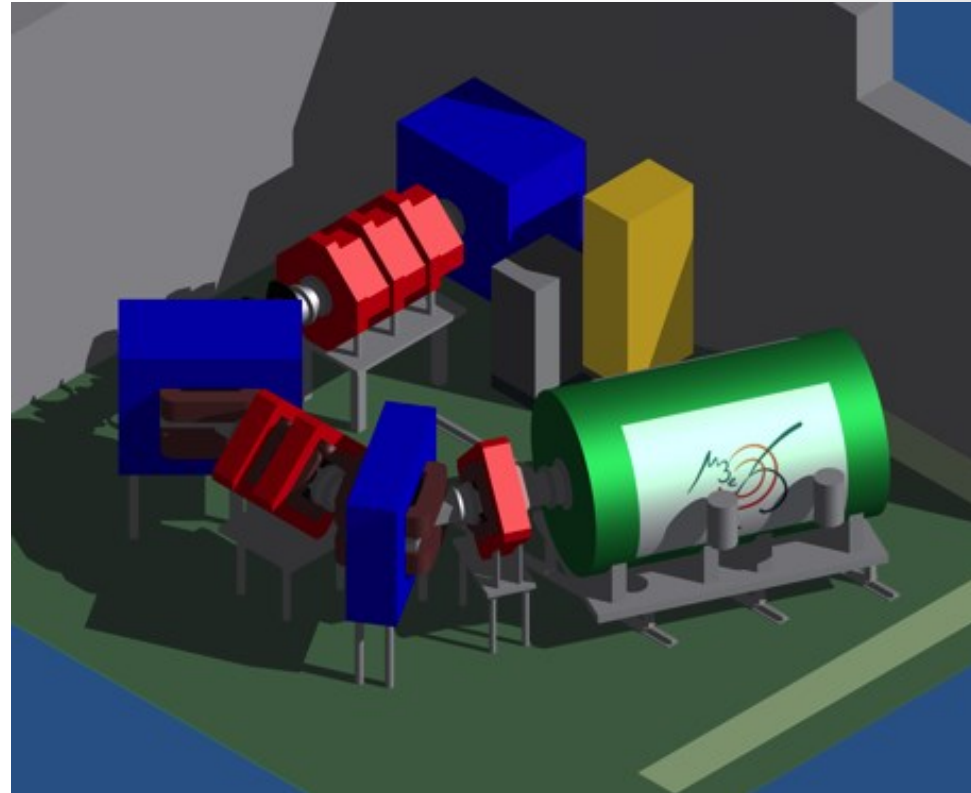
- 1 T Solenoid
- Power and cabling
- Readout

Challenges

- piE5 limited space
- >5kW overall power
 - Tight space
- Trigger less system
 - High bandwidth >Tbit/s
 - Three sub-detectors
 - Two different front end chips

Mu3e Solenoid

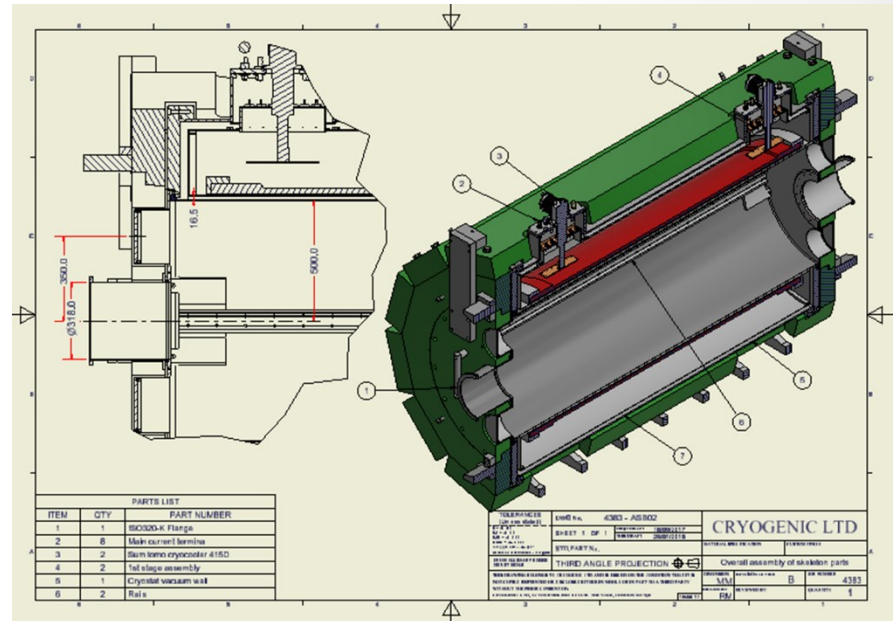
- Very limited space in piE5
- Solenoid under balcony
- Procedure for detector access lengthy- but well thought trough



Mu3e magnet

Mu3e Solenoid

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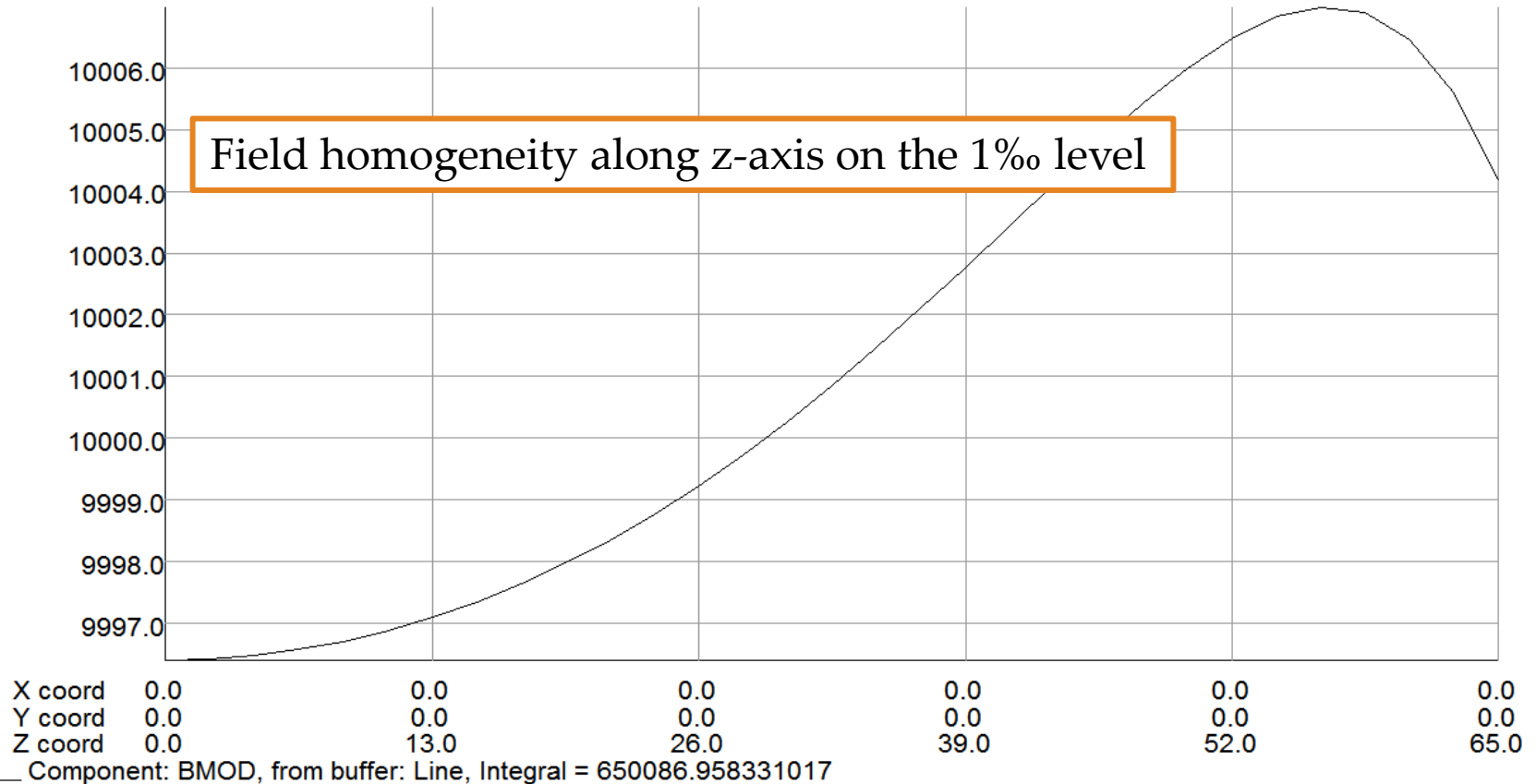


Mu3e magnet

Mu3e Solenoid

Field modulus along axis over 65cm (at 1T) ; +0.105%, -0%

30/Jan/2018 11:21:27

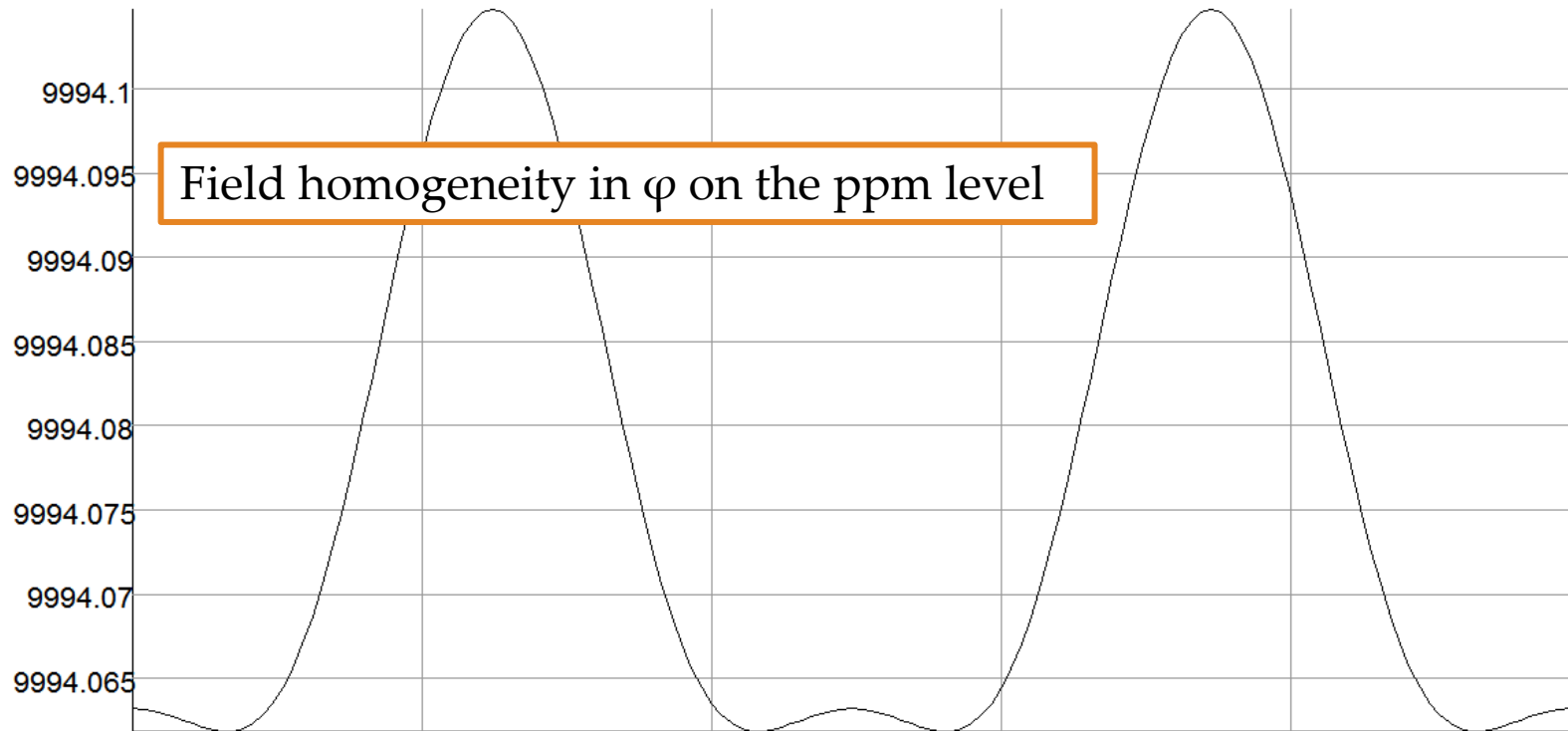


Opera

Mu3e Solenoid

Modulus field around a R35cm circle centred at Z=0 (Variation ~ 0.0003%)

30/Jan/2018 12:04:06



X coord	35.0	10.524703	-28.670322	-27.767367	11.970705
Y coord	0.0	33.3800933	20.0751753	-21.30665	-32.889242
Z coord	0.0	0.0	0.0	0.0	0.0

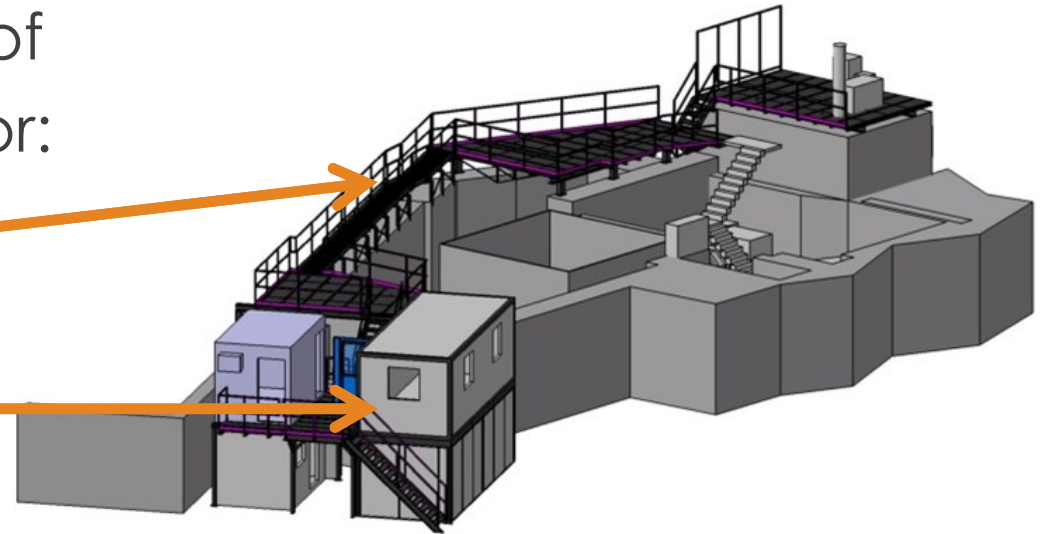
Component: BMOD, from buffer: Circle, Integral = 2.19763785399395E+06

Opera

Area Planning

Good progress in terms of CAD, civil engineering for:

- ✓ Platforms
- ✓ Access ways
- ✓ Counting containers
- ✓ Power
- Cooling



Remark:

- Space in area **extremely** limited

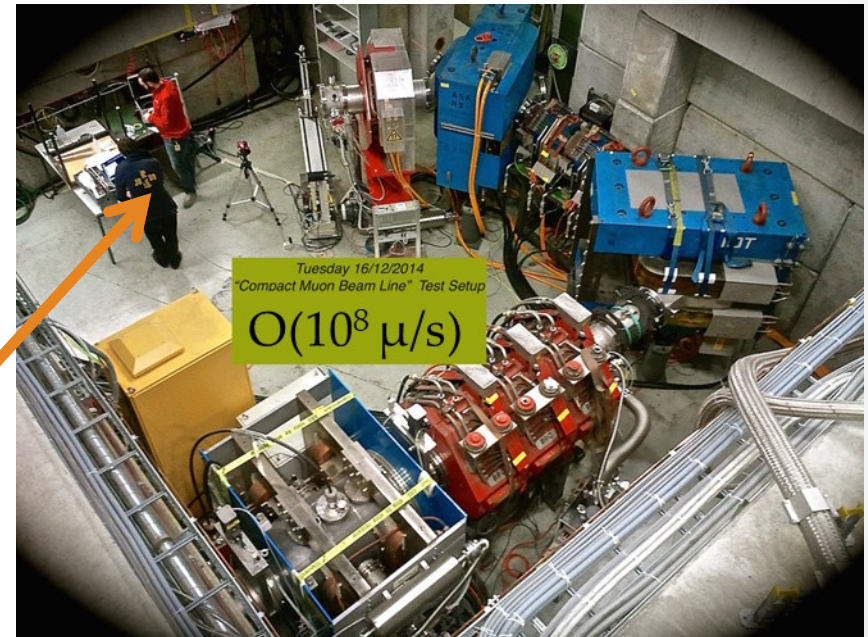
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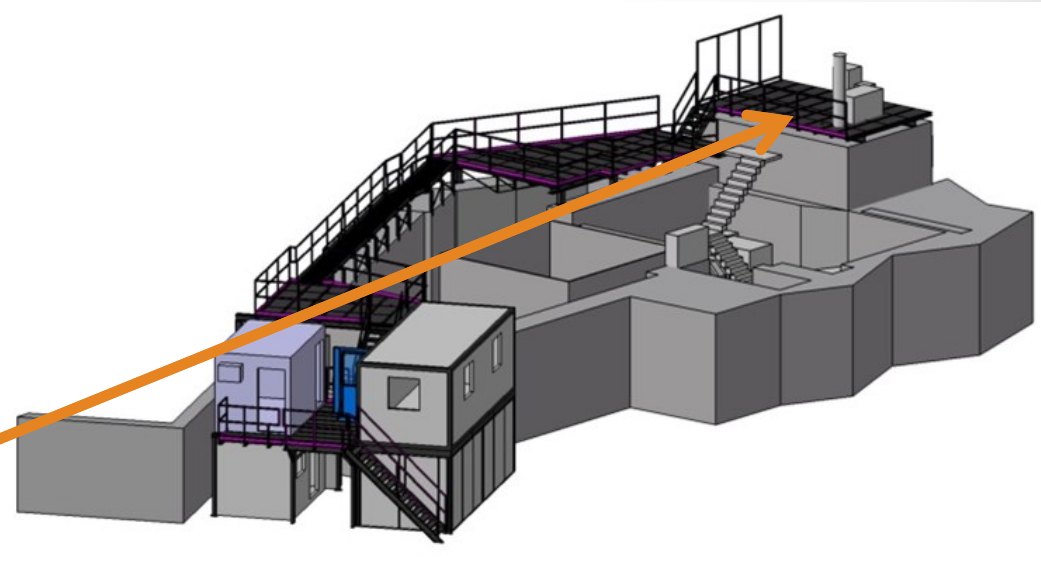
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Racks

- piE5
 - Low Voltage rack
 - Commissioning rack
- Skywalk platforms
 - Magnet power rack
 - Magnet compressor rack
 - Magnet control rack
 - Helium cooling rack
- Counting house
 - Filter farm racks
 - Clock and pixel slow control rack
 - Midas slow control rack

Sufficient rack space on skywalk platforms
and in counting house

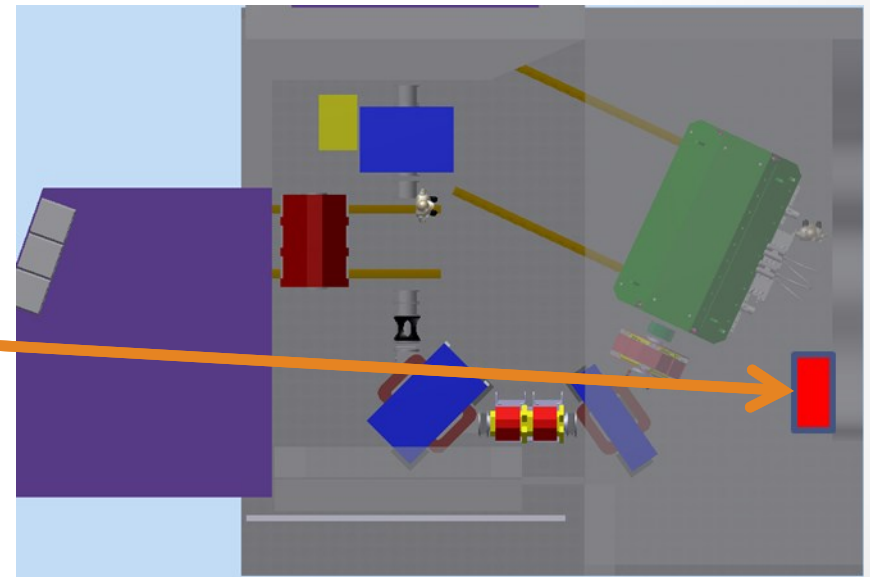
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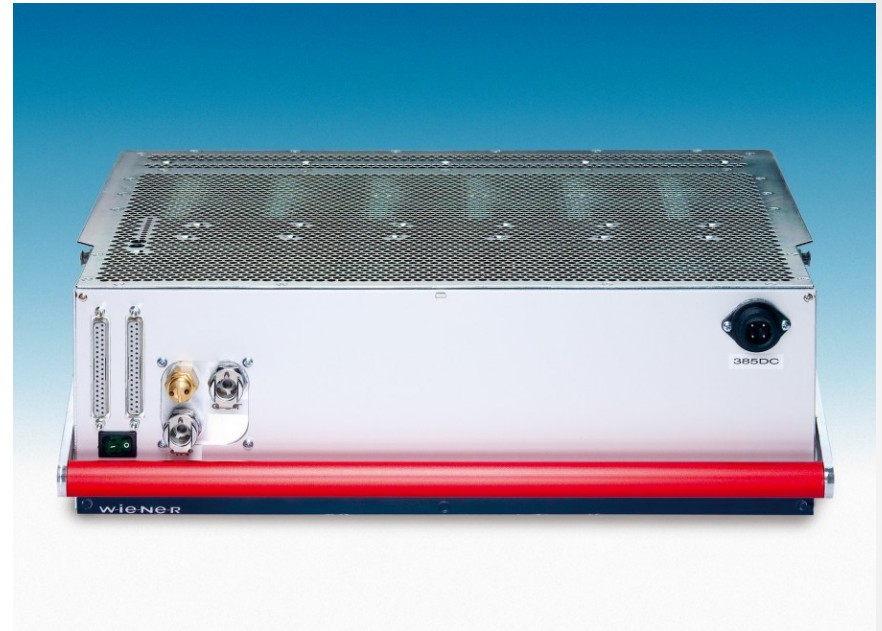
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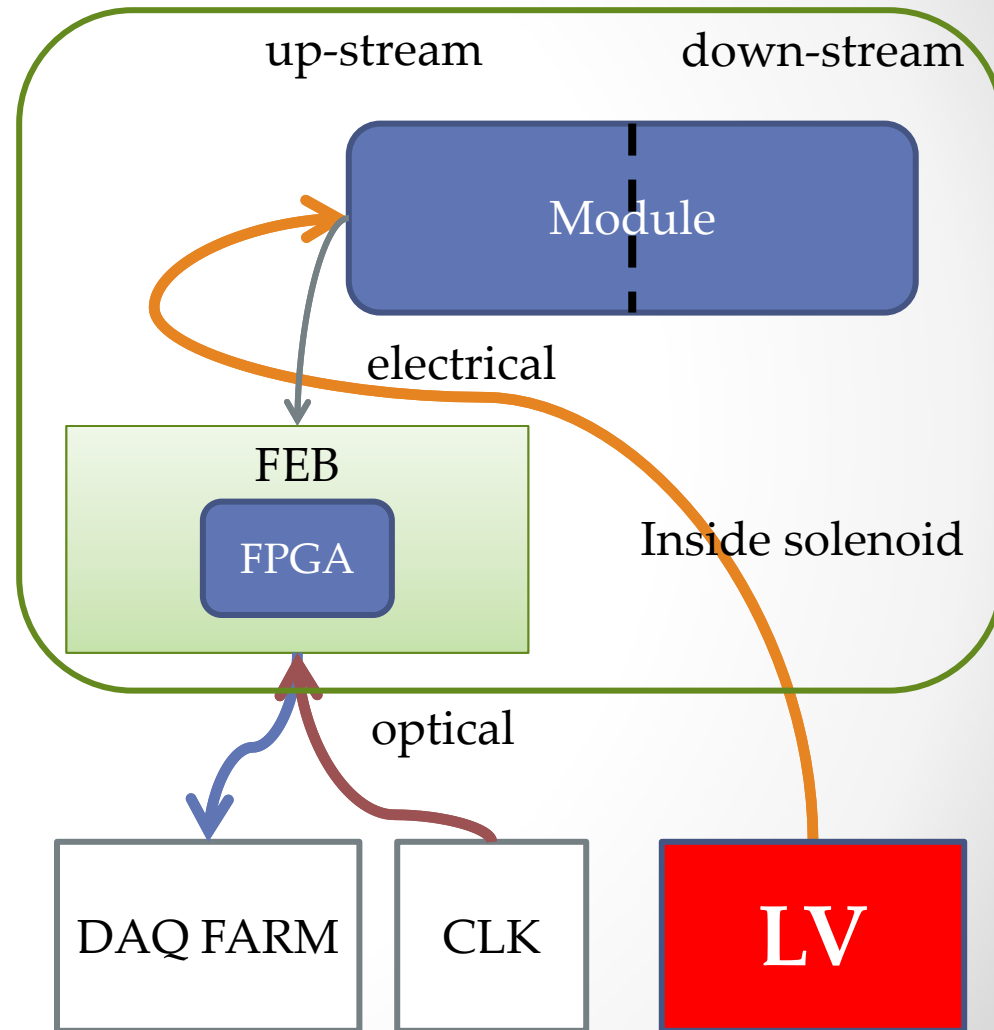
Power Supplies

- Wiener Maraton
- 10 crates
- 12 channels each
- Each channel:
 - 230W
 - 20V
 - 11.5A
 - Other versions available



Detector Partitions

- Half module corresponds to partition
- Modules read-out on both ends
- One front end board (FEB) per partition
- One low voltage per partition
- One high voltage per partition
- 112 partitions in total
 - +8 spares

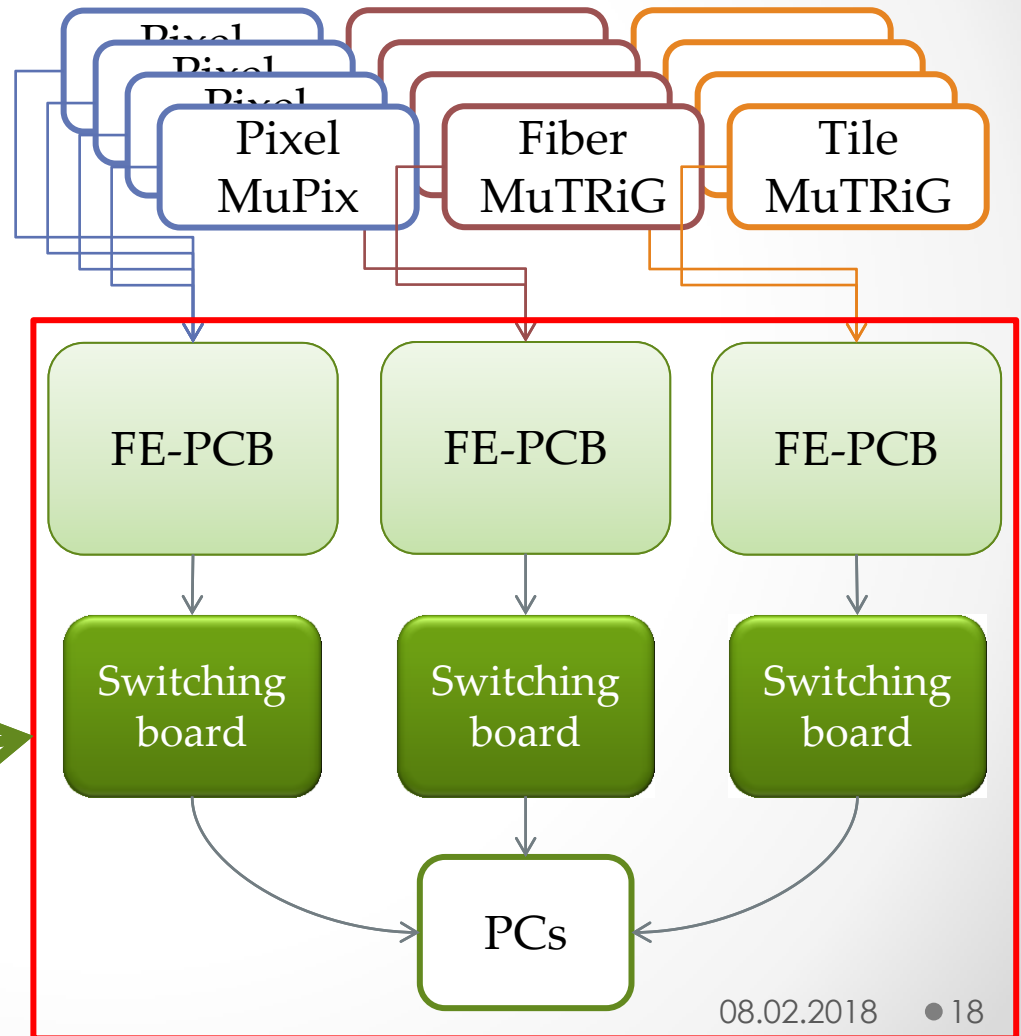


Detector Power

Detector	ASIC	#partitions	#ASICS/ partition	Power ASICs [W]	Power others [W]	Sum [W]	DC-DC [W]	Total power [W]
Pixel Layer 1	MuPix	4	12	19.2	20.9	40.1	69	229
Pixel Layer 2	MuPix	4	15	24	22.7	46.7	80.1	267
Pixel Layer 3	MuPix	3x12	32, 36	51.2, 57.6	20.9	72.1, 78.5	1162	3873
Pixel Layer 4	MuPix	3x14	36	57.6	20.9	78.5	1413	4710
Fibre	MuTRiG	12	16	17.6	17.9	35.5	182.6	609
Tile	MuTRiG	14	14	15.4	17.9	33.3	199.8	666
Total	MuTRiG	112						10354

Readout System

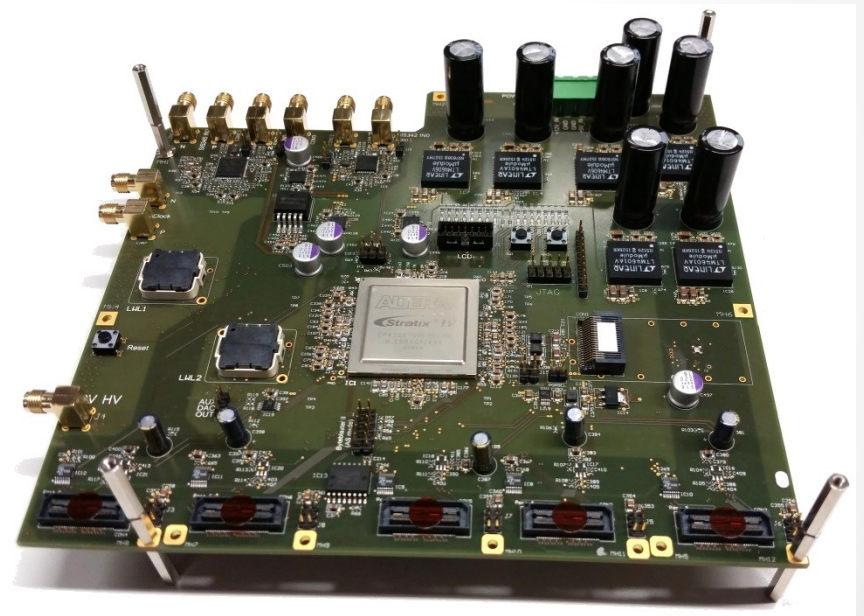
- Pixel detector
 - HV-MAPS (MuPix)
 - ✓ Pixel detector system on one chip
 - ✓ Zero-suppressed serialized data
- Timing detectors
 - SiPMs plus MuTRiG
 - ✓ TDC system
 - ✓ Zero-suppressed serialized data
- **Common read-out system**



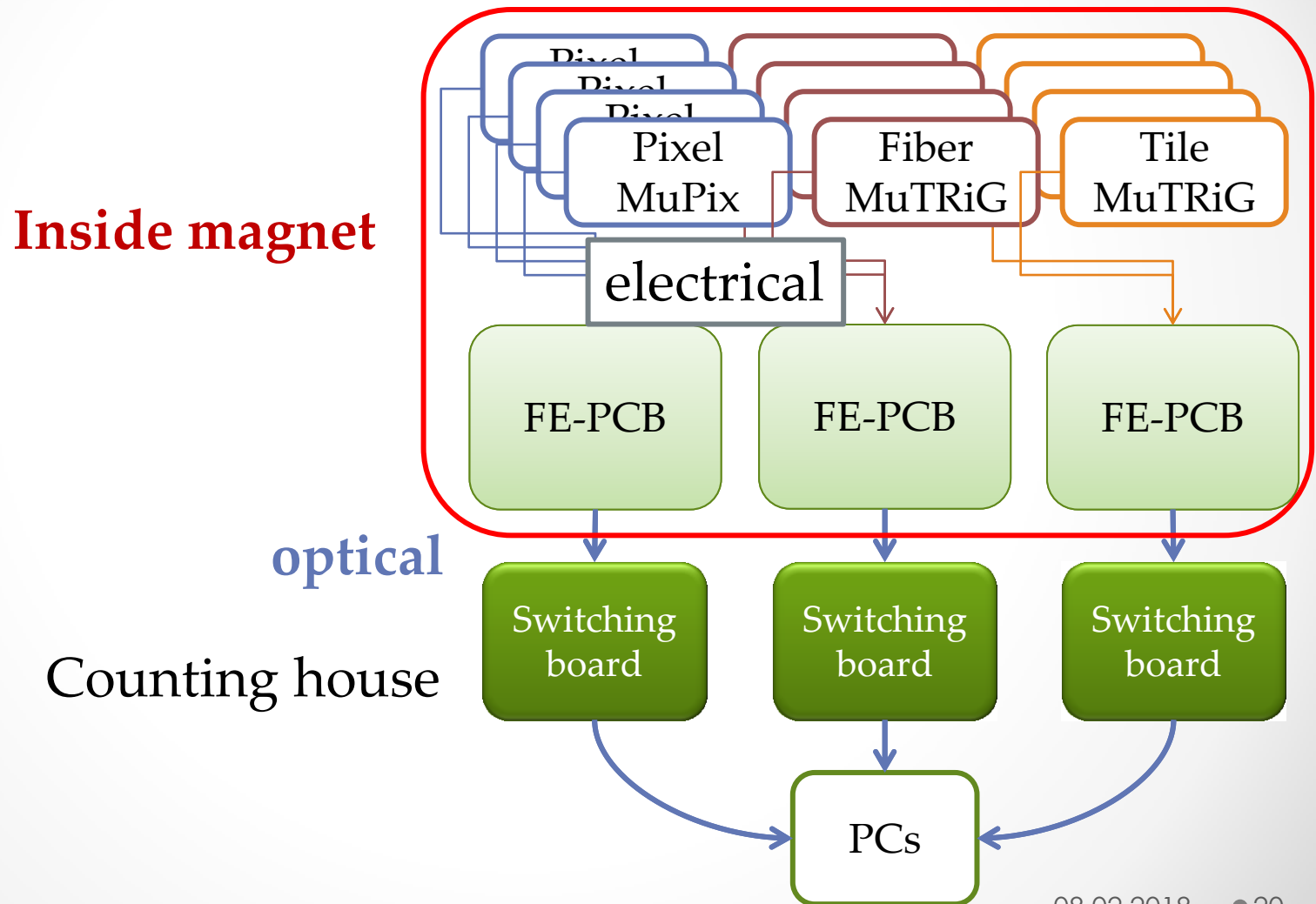
Common Read-out PCB

✓ Front-end PCB

- Common for pixel, fibre and tile detector
 - ✓ Data acquisition
 - ✓ Clock distribution
 - ✓ Slow control distribution
- ✓ Prototype **functional**

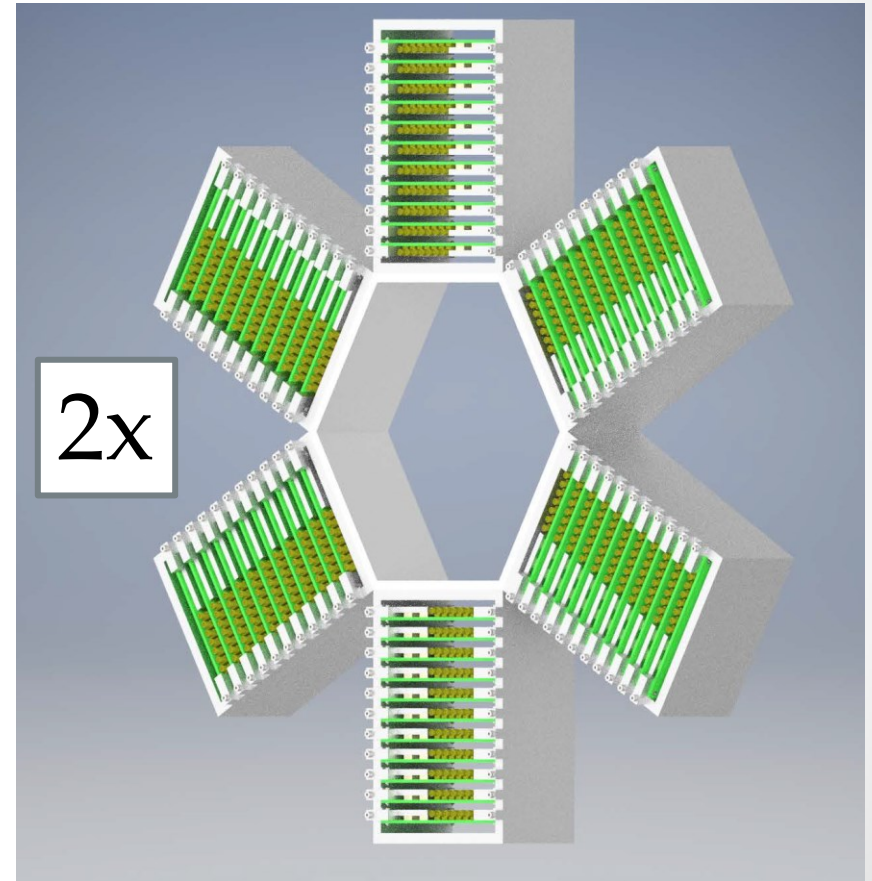


Readout System

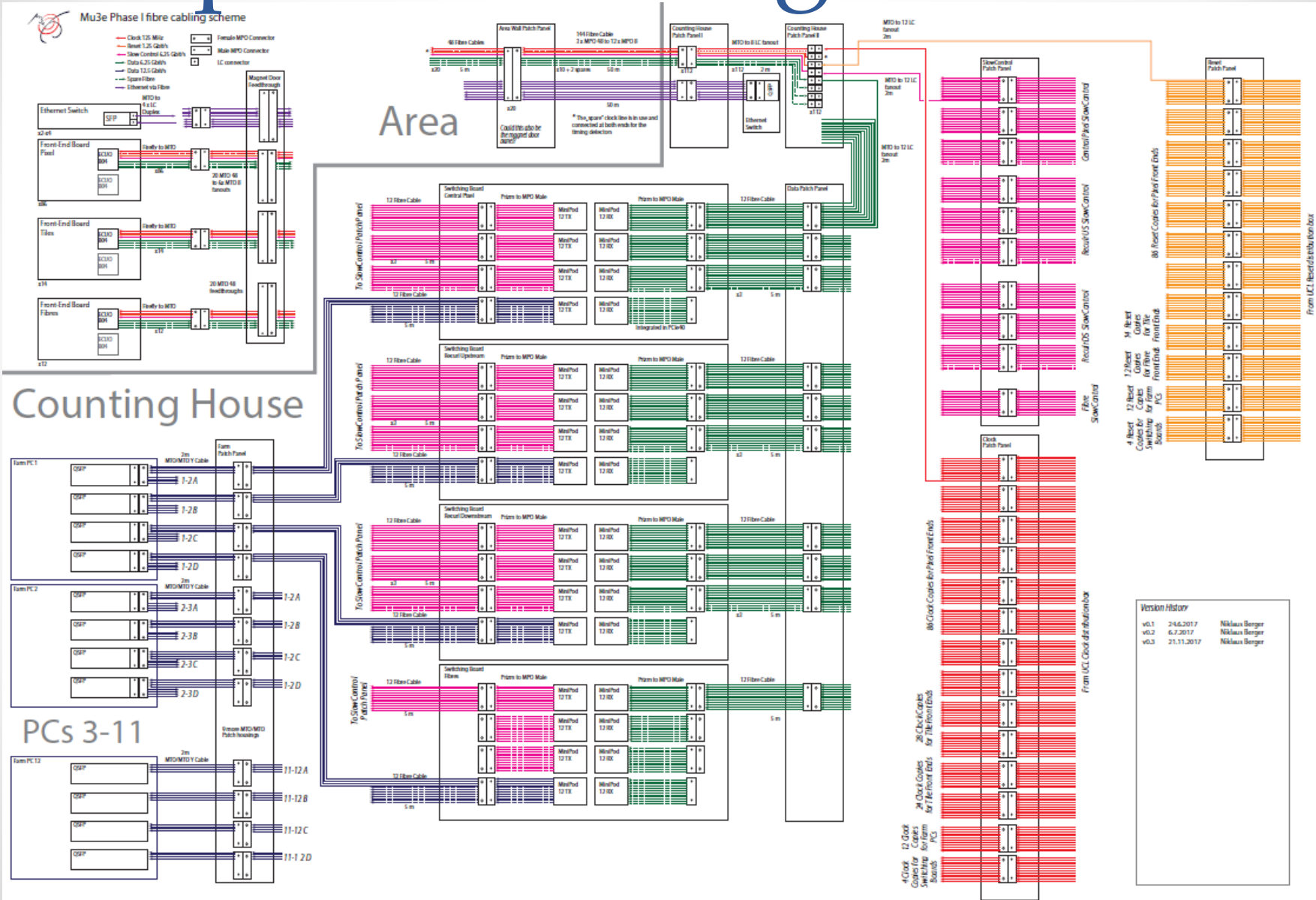


FEB Crates

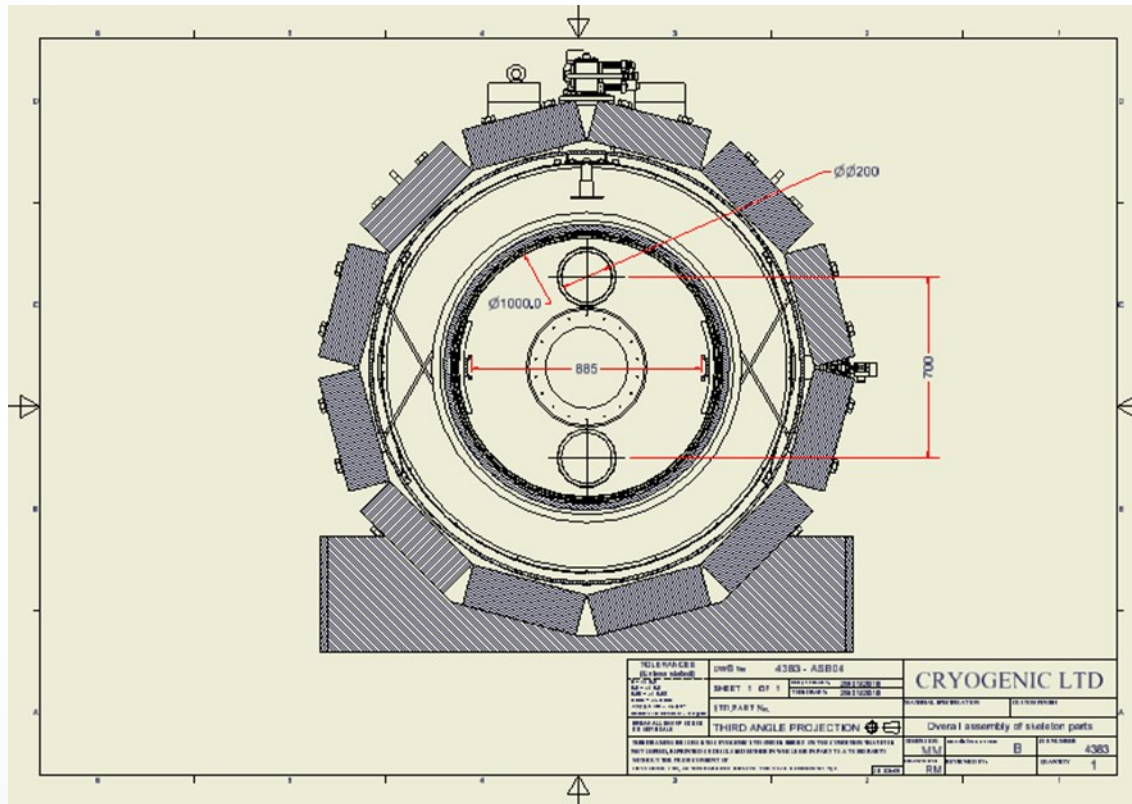
- Front end boards inside magnet
- 120 FEBs in total
- Mounted in mini crates
- Star of crates
 - Upstream +
 - Downstream



Optical cabling scheme

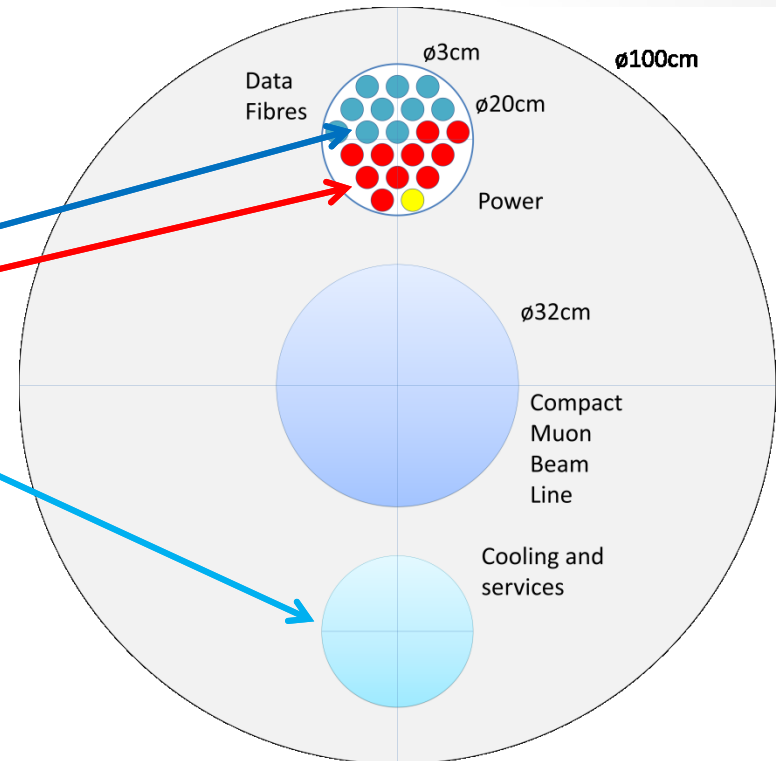


Magnet End Plate Feed-through



Magnet End Plate Feed-through

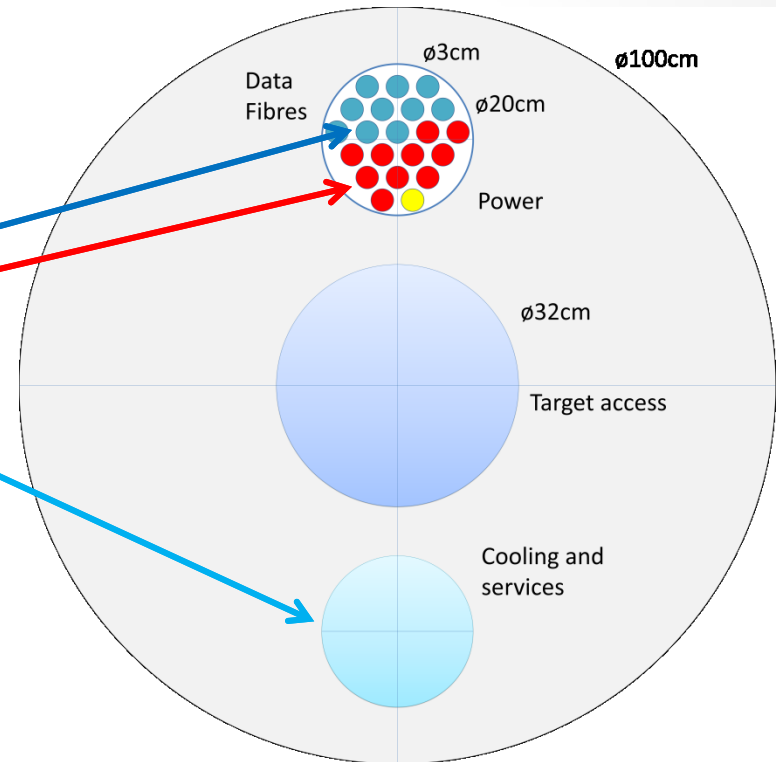
- He Atmosphere inside magnet
- Endplate feed troughs:
 - Optical data connectors
 - Power connectors
 - Cooling and services



Upstream

Magnet End Plate Feed-through

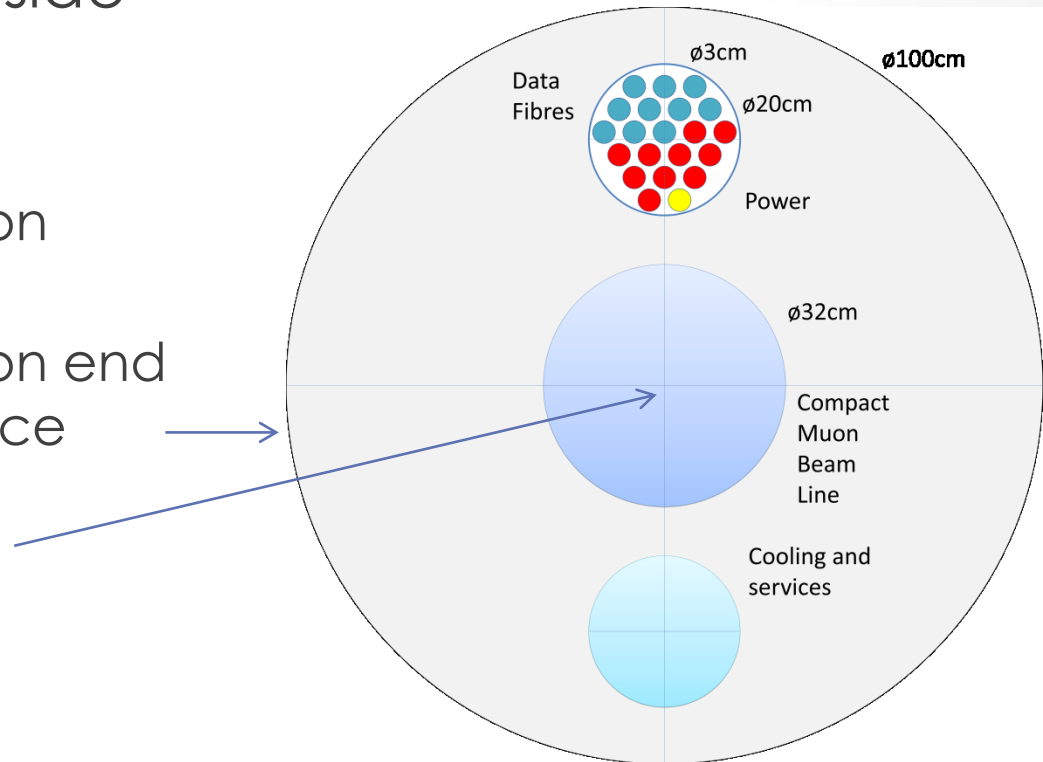
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Downstream

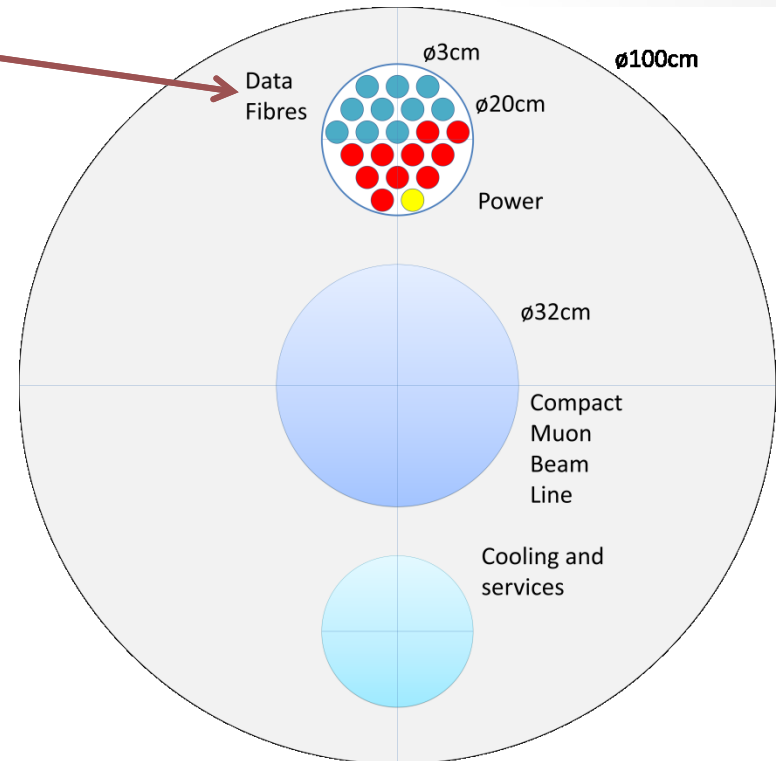
End plate design

- He Atmosphere inside magnet:
 - He tight design
 - Precision surface on magnet end rings
 - Precision surface on end plate circumference
- Beam pipe under vacuum
- Data and power connectors
 - Gas tight



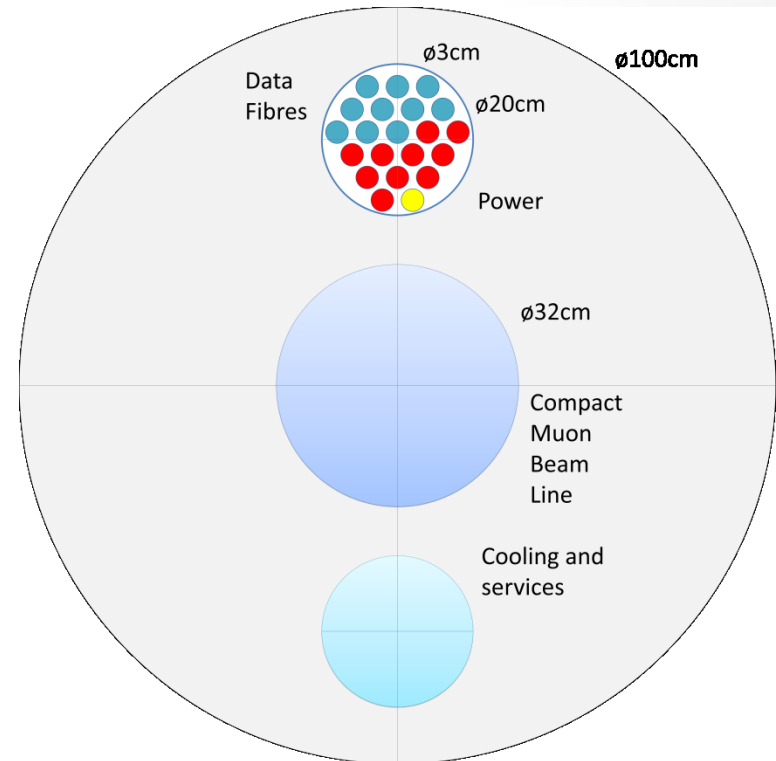
End plate design

- Data and power connectors
 - Gas tight
 - 120 detector partitions
 - One connector per 6 partitions
 - Each connector 3 cm diameter



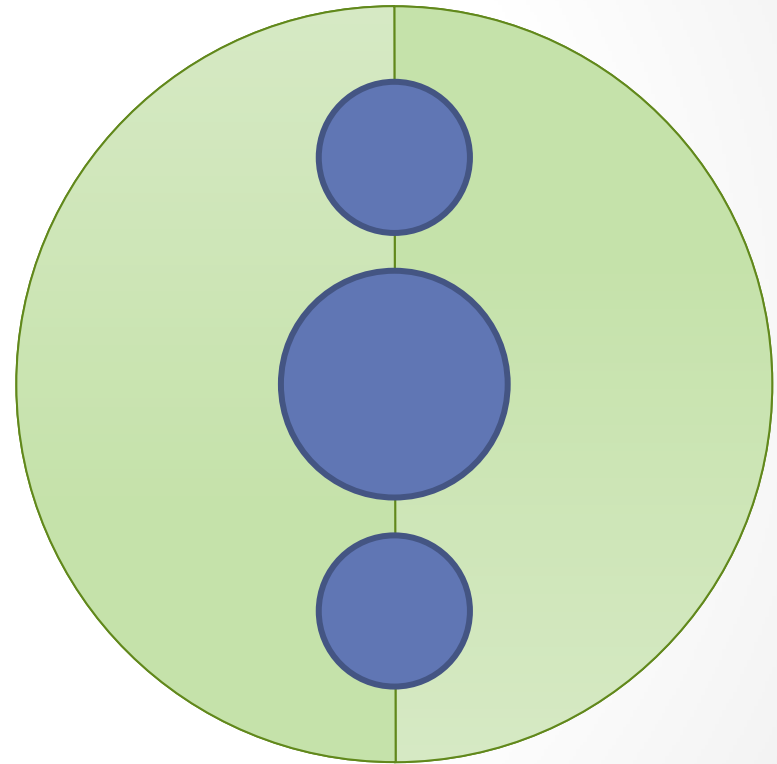
End plate design

- Data and power connectors
 - Gas tight
 - 120 detector partitions
 - 20 connectors of each type
 - Each connector 3 cm diameter
 - Requires 2 x 20 cm \varnothing
 - On plates



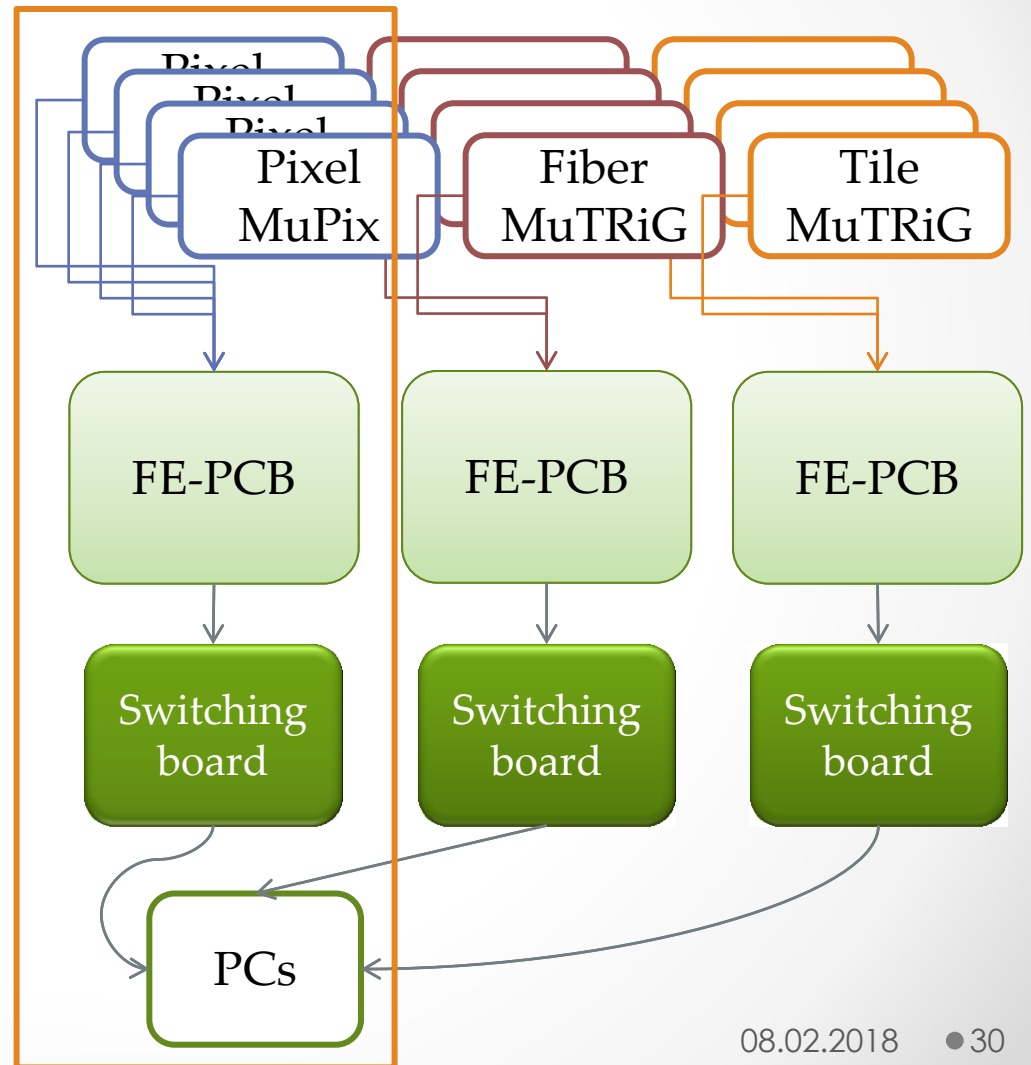
Magnetic shield doors

- Magnetic shield doors
 - Ca. 32 cm \varnothing cutout for beam
 - 2x 20 cm \varnothing cutout for signal/power/cooling
- Symmetrical upstream and downstream



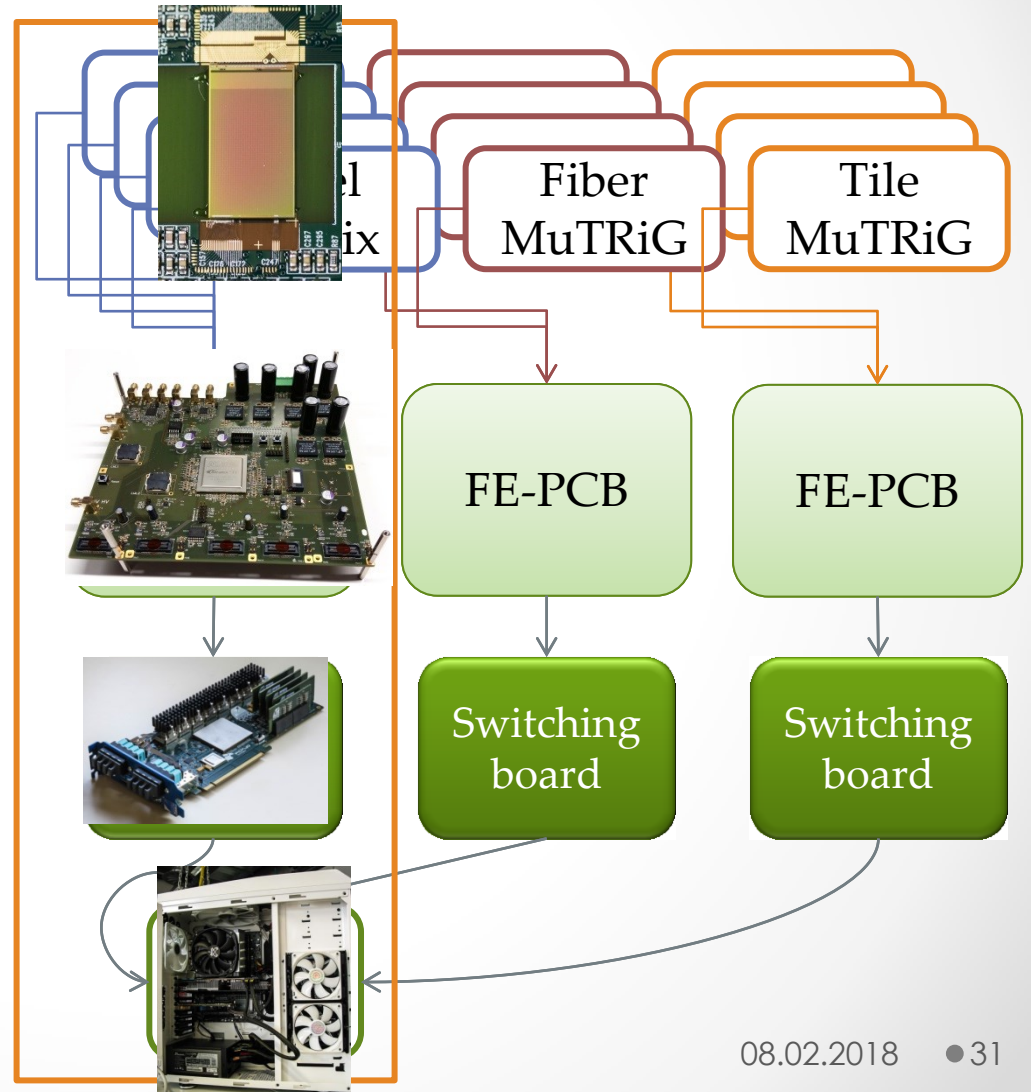
Readout Vertical Slice Test

- Pixel detector
 - HV-MAPS (MuPix8)
 - ✓ Large prototype
- Front end board
- Switching board
 - PCIe40
 - Delivery 2018
- PC



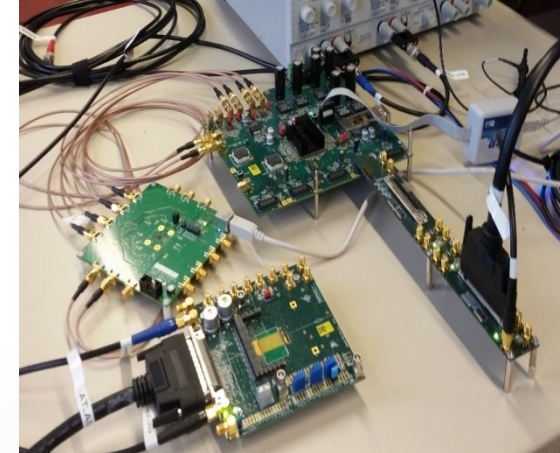
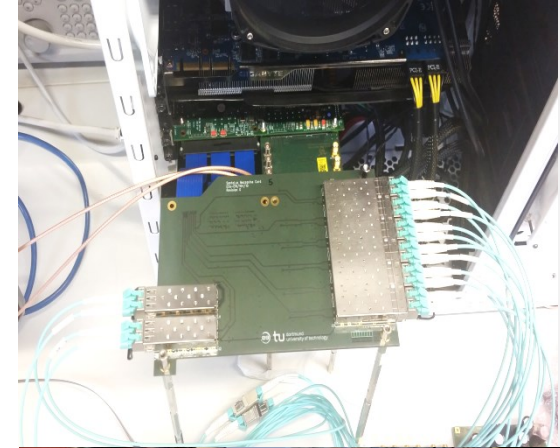
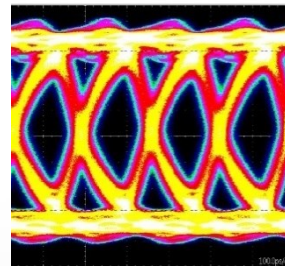
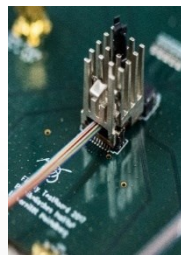
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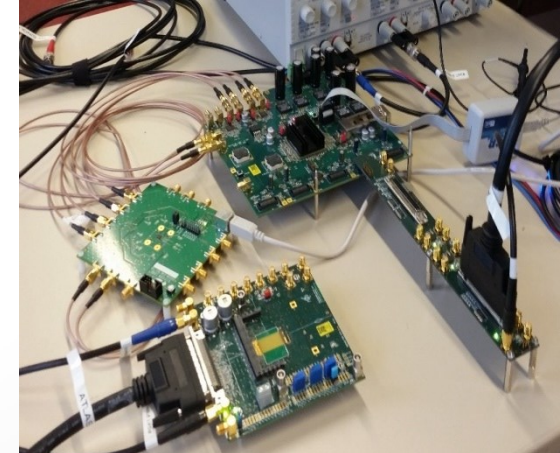
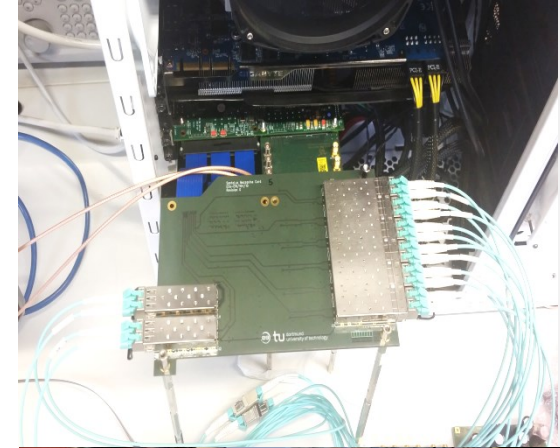
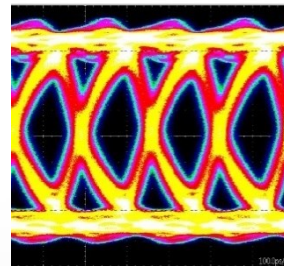
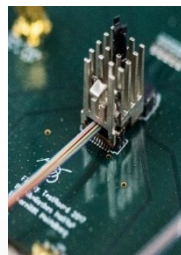
Readout Vertical Slice Test

- ✓ Control and readout firmware of MuPix sensors
- ✓ Optical links tested intensively: MiniPods, QSFP and Samtec Firefly
- ✓ Front end board to PC communication
- ✓ **Front end board MuPix8 readout**
NEW!
- ✓ Optical clock distribution



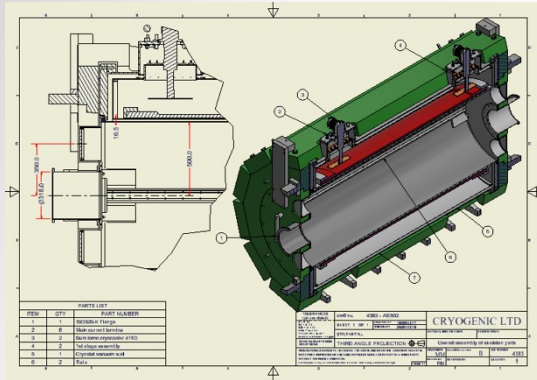
Readout Vertical Slice Test

- Test the system fully in the lab
 - Up to 8 MuPix8
- Use the vertical slice test system in DESY test-beam
- Include the tile detector readout prototype
- Include the SciFi readout

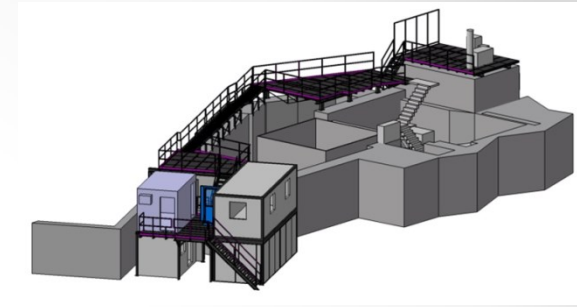


Milestones

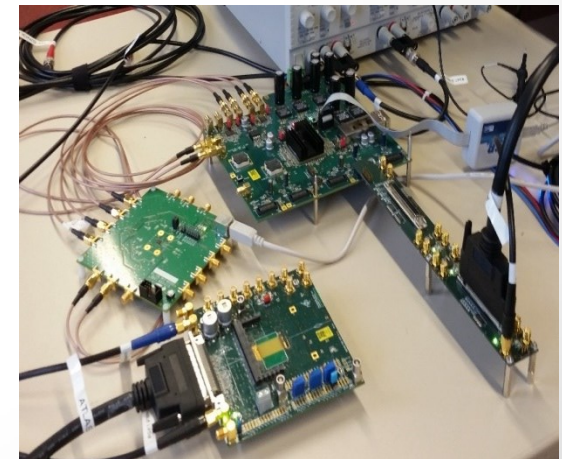
Milestone	
Vertical slice MuPix readout	Q1 2018
Magnet TDR	Q1 2018
Vertical slice Pixel + Tile detector	Q3 2018
Vertical slice Pixel + Tile + Fiber detector	Q1 2019



Summary



- Magnet technical design back on track
- Advanced area preparation
- Partitioning scheme for readout and power
- Vertical readout slice for pixel detector advanced



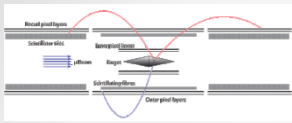
Outlook

- Magnet production this year
- Vertical slice tests for readout of all sub-detectors



Backup Slides

...

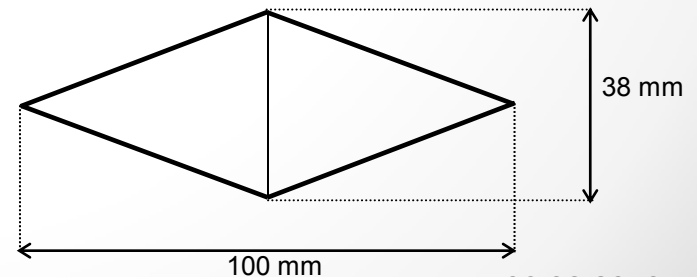
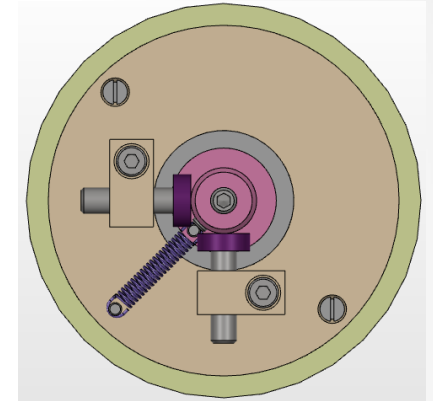


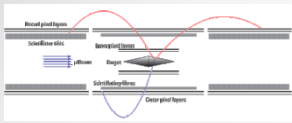
Muon Stopping Target

- Hollow double cone
- Mylar "sandwich" structure
- two/three rolled up foils glued with epoxy:

Upstream: $75\ \mu\text{m}$

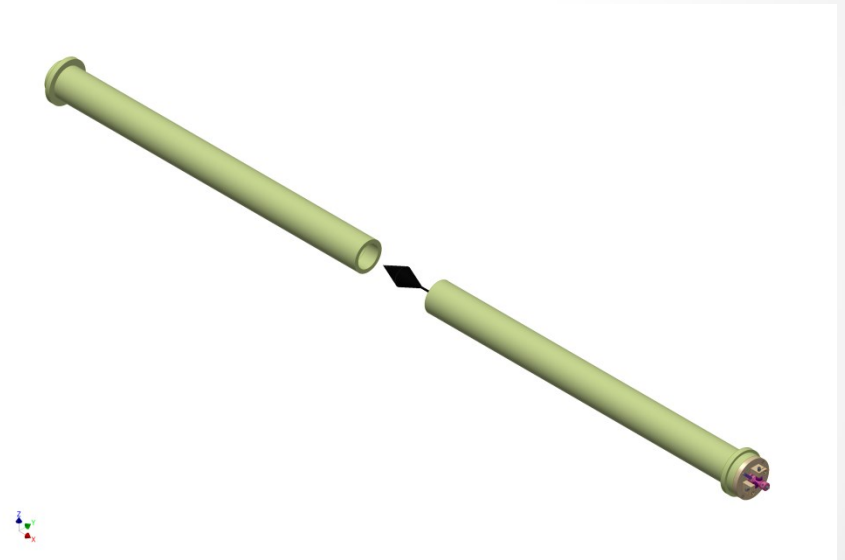
Downstream: $85\ \mu\text{m}$

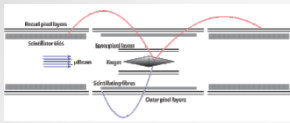




Muon Stopping Target

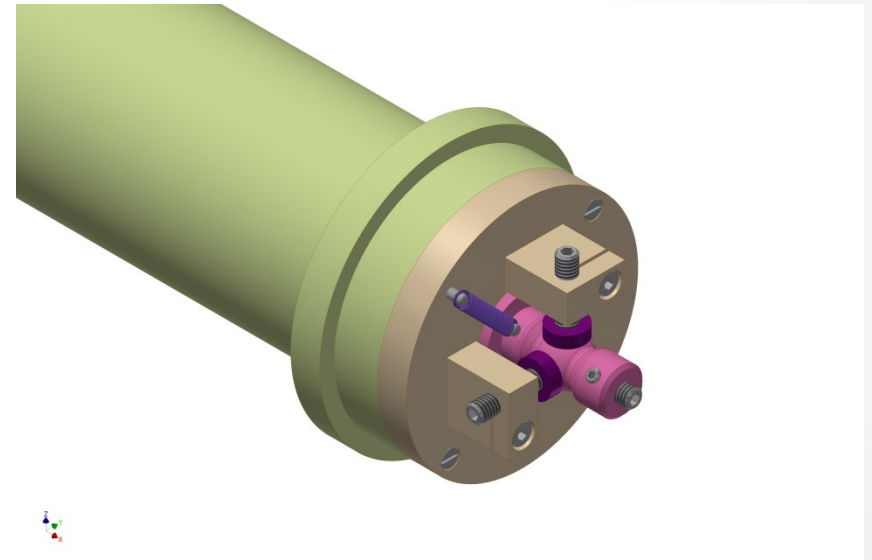
- Target position can be adjusted from the outside
- Target can be exchanged
- Pixel detector can stay during target exchange

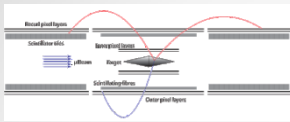




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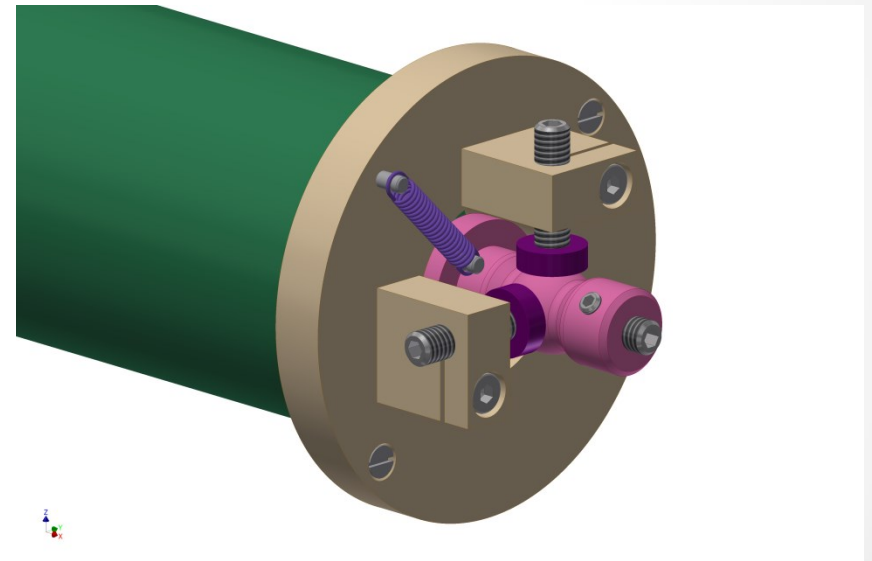
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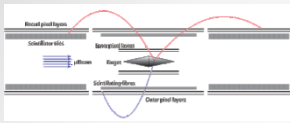




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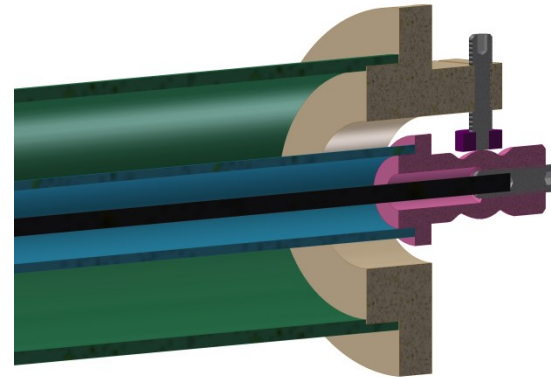
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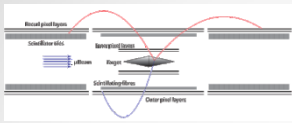




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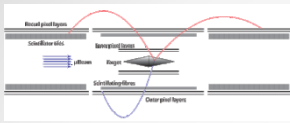




Muon Stopping Target

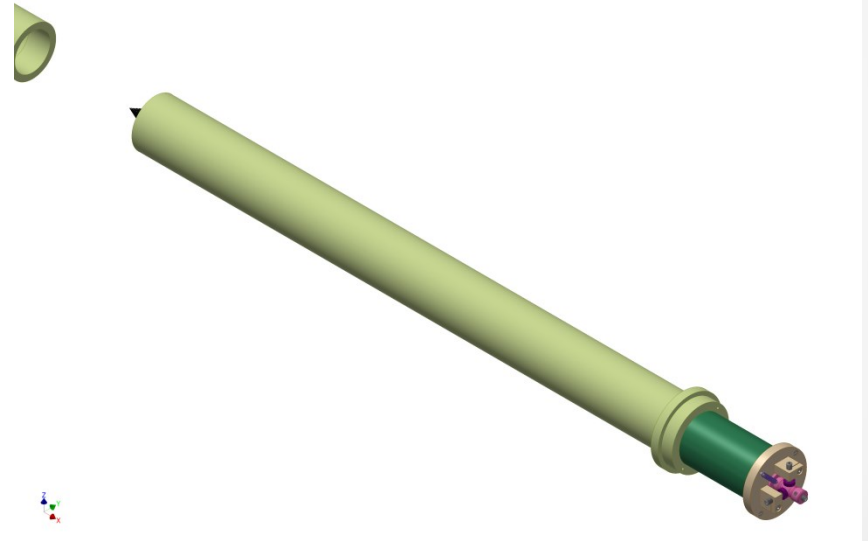
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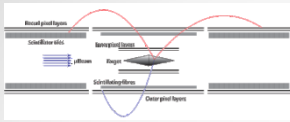




Muon Stopping Target

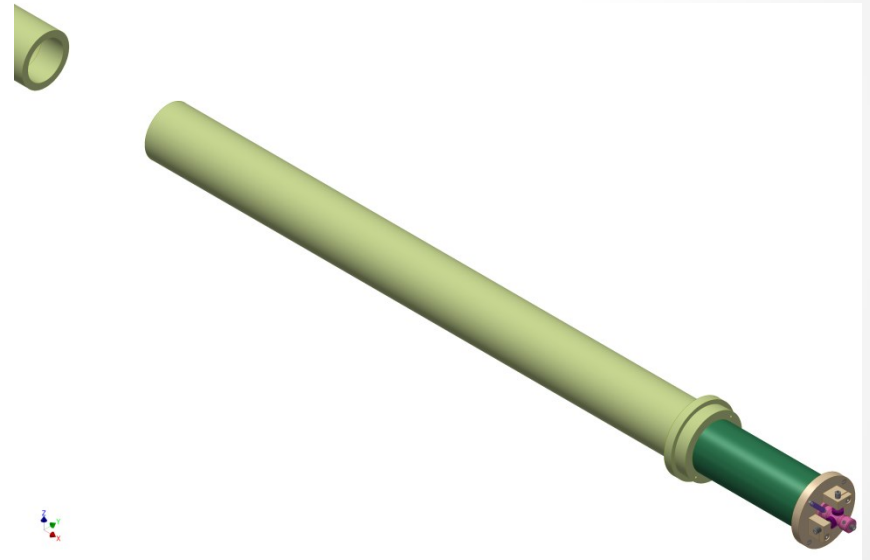
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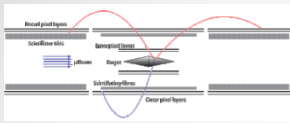




Muon Stopping Target

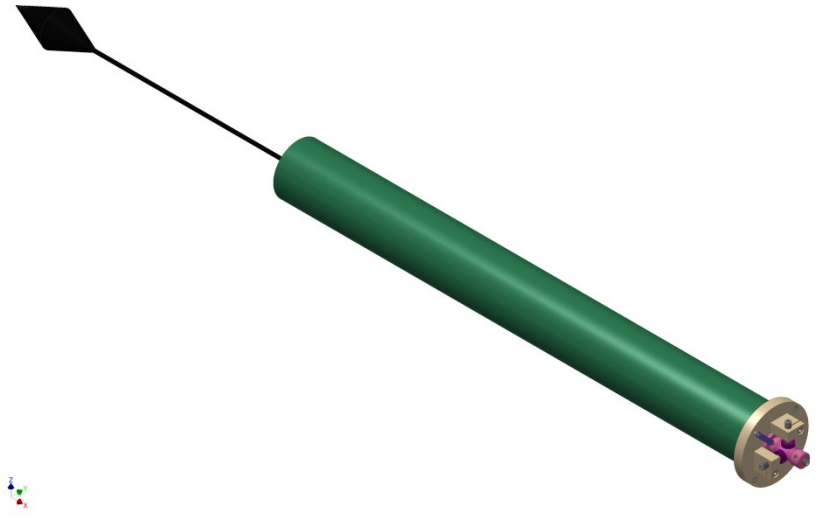
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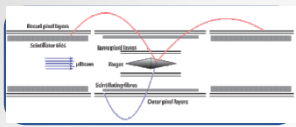




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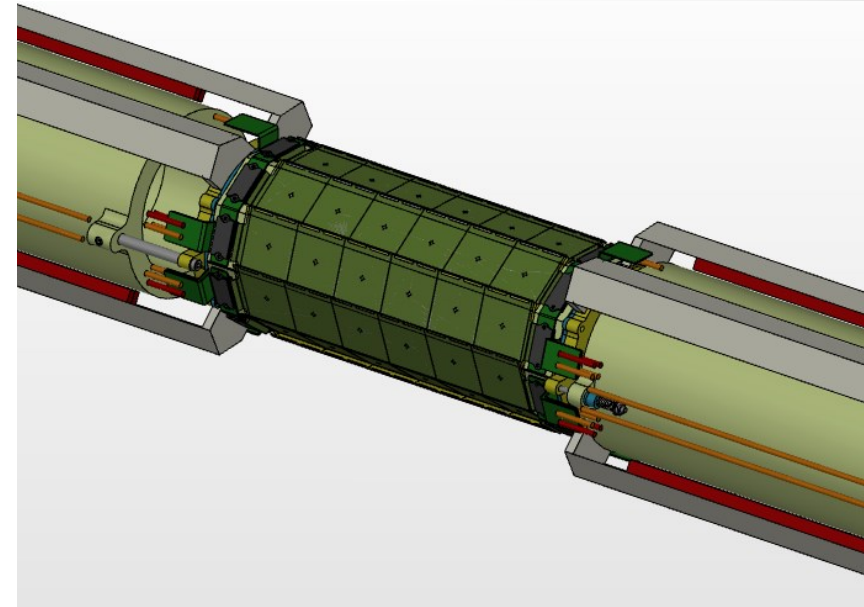


Pixel Tracker

- ✓ Successful **feasibility** studies for:
 - ✓ Module mechanics
 - ✓ He-cooling with low vibration
 - ✓ Ultrathin Flexible circuit boards
 - ✓ HV-CMOS large prototype
 - ✓ Readout board prototypes
- ✓ Ongoing re-design of pixel detector services
 - ✓ He distribution
 - ✓ Power and cabling
 - Effects all surrounding systems

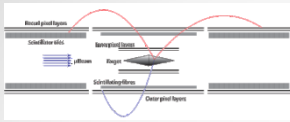
To be done:

- **1st operational detector module**
- Qualification of optimized module design



Pixel Tracker
Rendering of CAD study
Re-optimized pixel tracker

See talk:
Pixel Detector
Frank Meier Aeschbacher



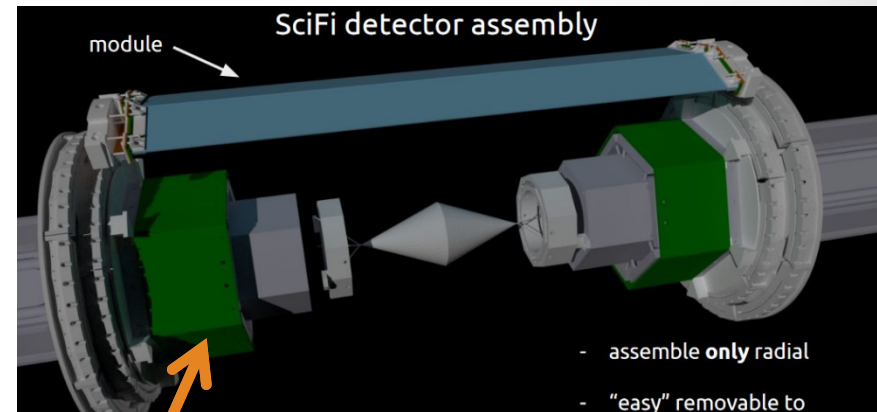
Fibre Detector

Accomplished:

- ✓ Characterization of fibres
- ✓ **Proof of concept** including
 - ✓ Simulation of fibre response
 - ✓ Identification of working point

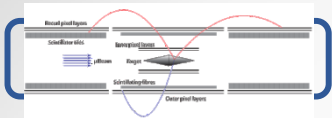
To be done:

- Choice of fibre type
- 1st operational detector module
- **Ultra compact front end electronics**
 - **critical**
 - **Integrate** new MuTRiG TDC chip



Fibre Detector
Rendering of CAD study

See talk:
SciFi
Antoaneta Damyanova



Tile Detector

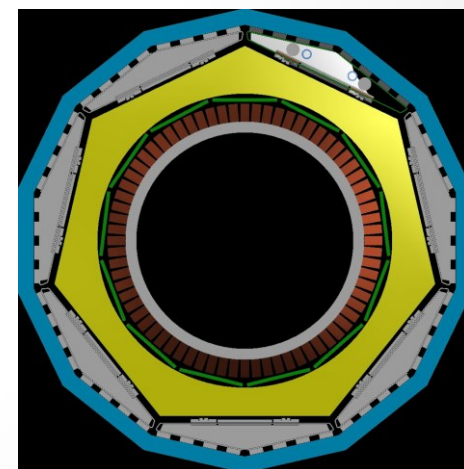
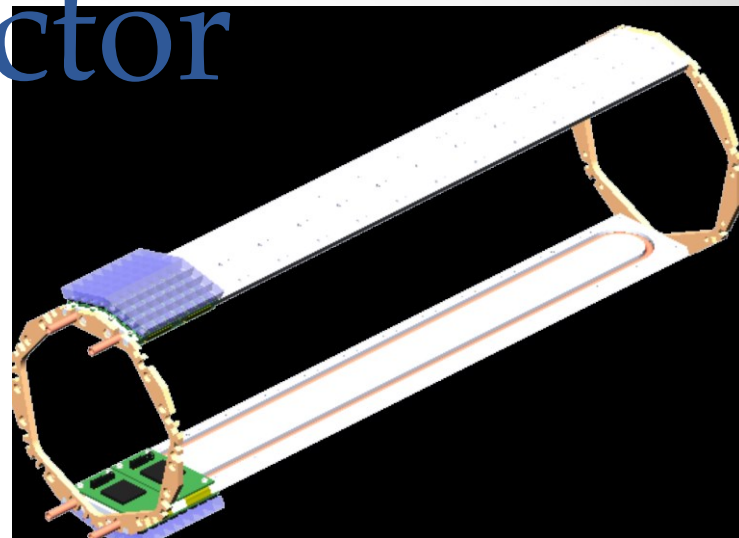
Accomplished:

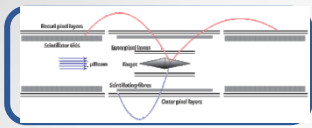
- ✓ Characterization of submodule
- ✓ **Proof of concept** including
 - ✓ Production of similar system
- ✓ Development of TDC ASIC
MuTRiG

To be done:

- 1st operational detector module
 - Prototypes in production
- **Share space with He lines and cables**

See talk:
Timing Detectors
Yonathan Munwes





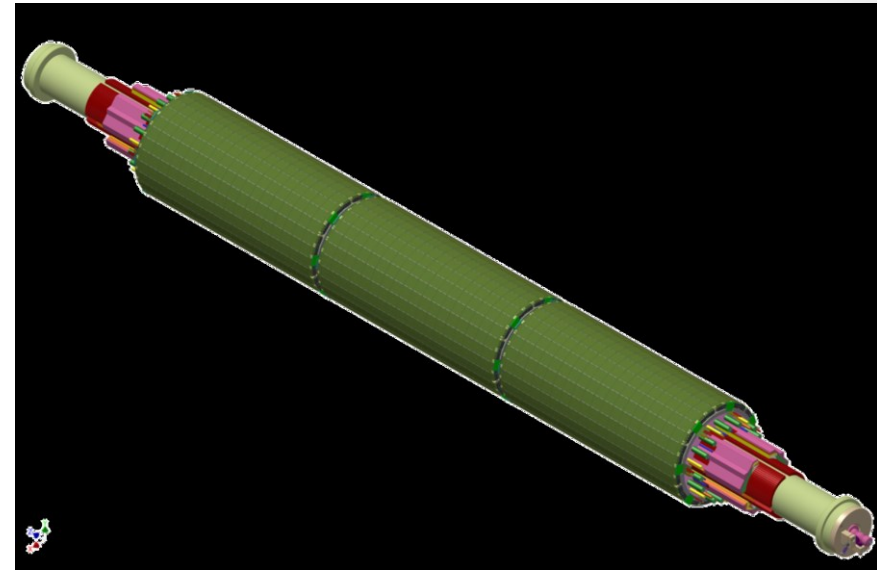
Mechanical Integration

Accomplished:

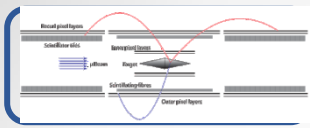
- ✓ CAD of modules
- ✓ Mechanical prototypes

To be done:

- Integration of cooling and cables
 - **advancing well**
- Re-distribution of space
- **Remark:**
- **Space inside detector extremely limited**
- **Extreme power and cooling requirements (pixel detector)**



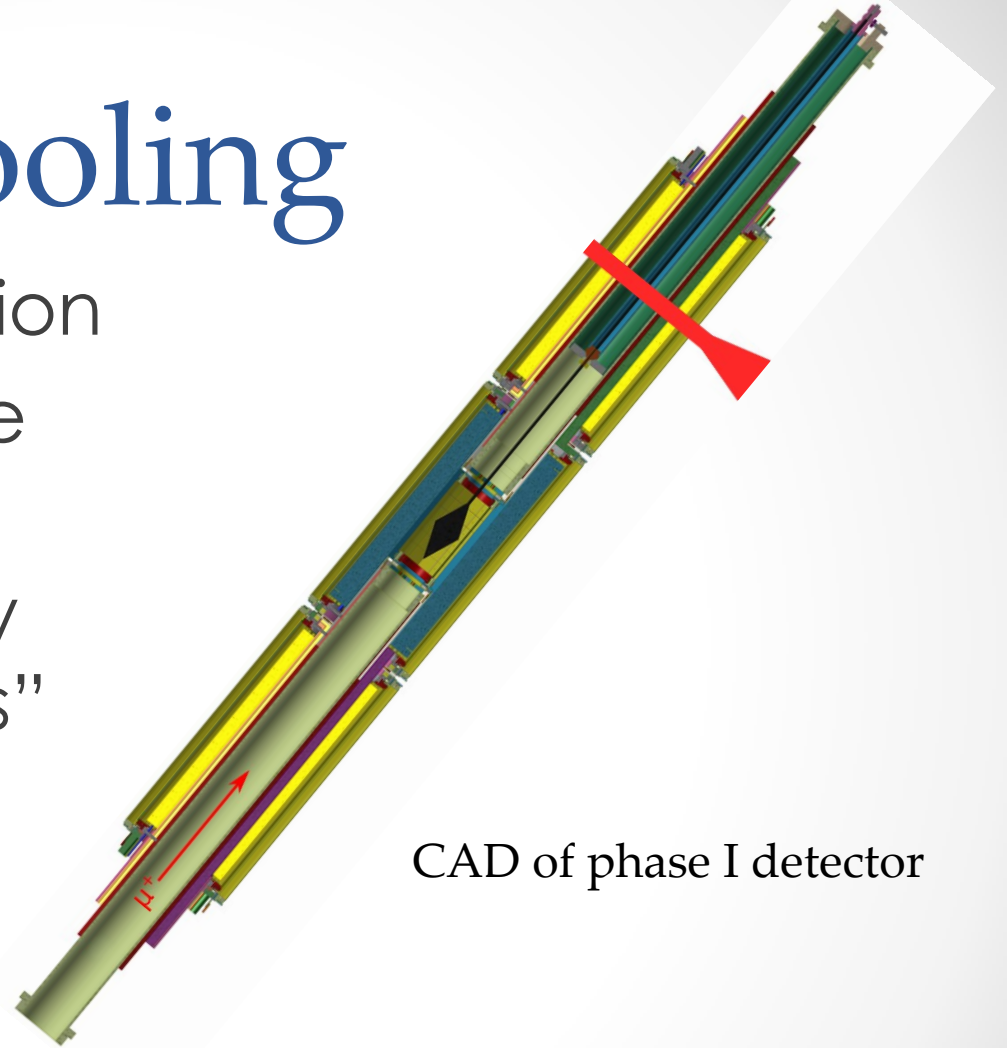
CAD of phase I detector



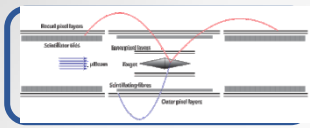
Cooling

5 + 5KW heat dissipation

- He cooling in active area
- Inside detector only few “classical pipes”
- **He distribution**
 - ✓ integrated in mechanical structures of pixel detector



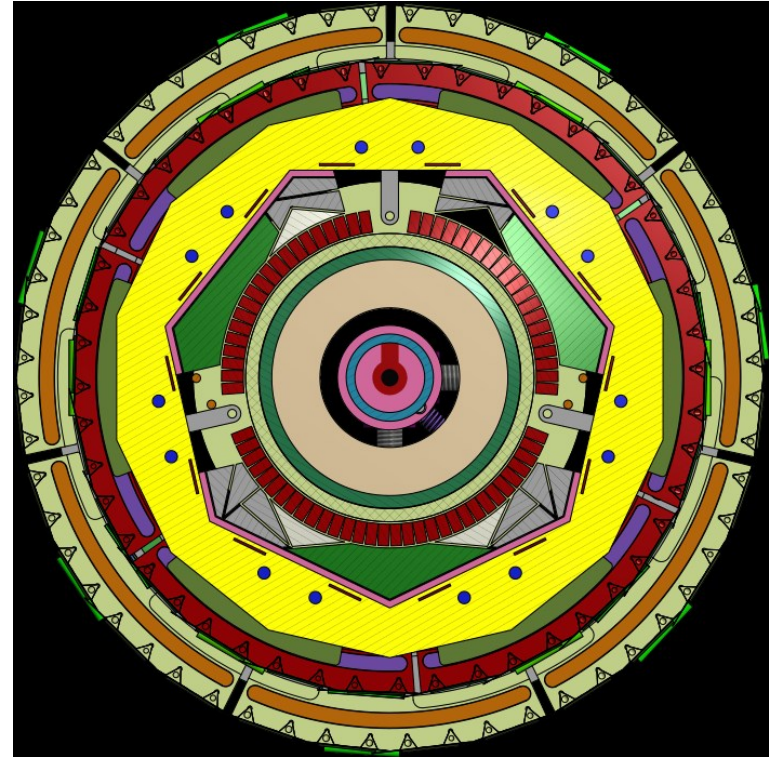
CAD of phase I detector



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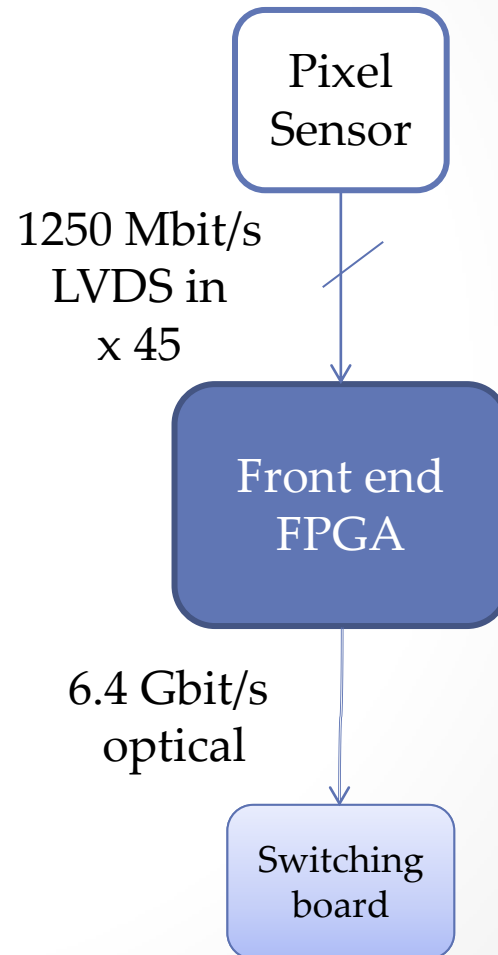


CAD of phase I detector

DAQ Backup ...

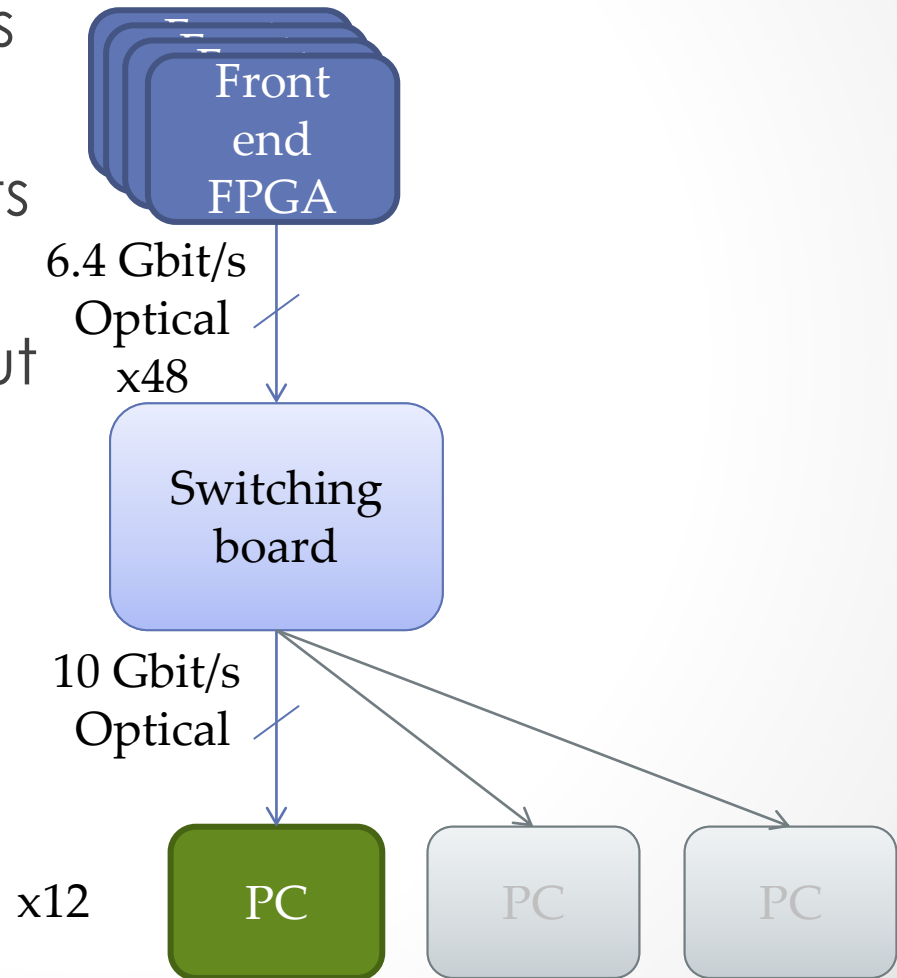
Front End FPGAs

- FPGAs in magnet volume
 - 112 pieces
- Receive sensor data
 - 36-45 LVDS inputs
- 6.4 Gbit/s outputs
 - 8 optical links
 - ... to counting house



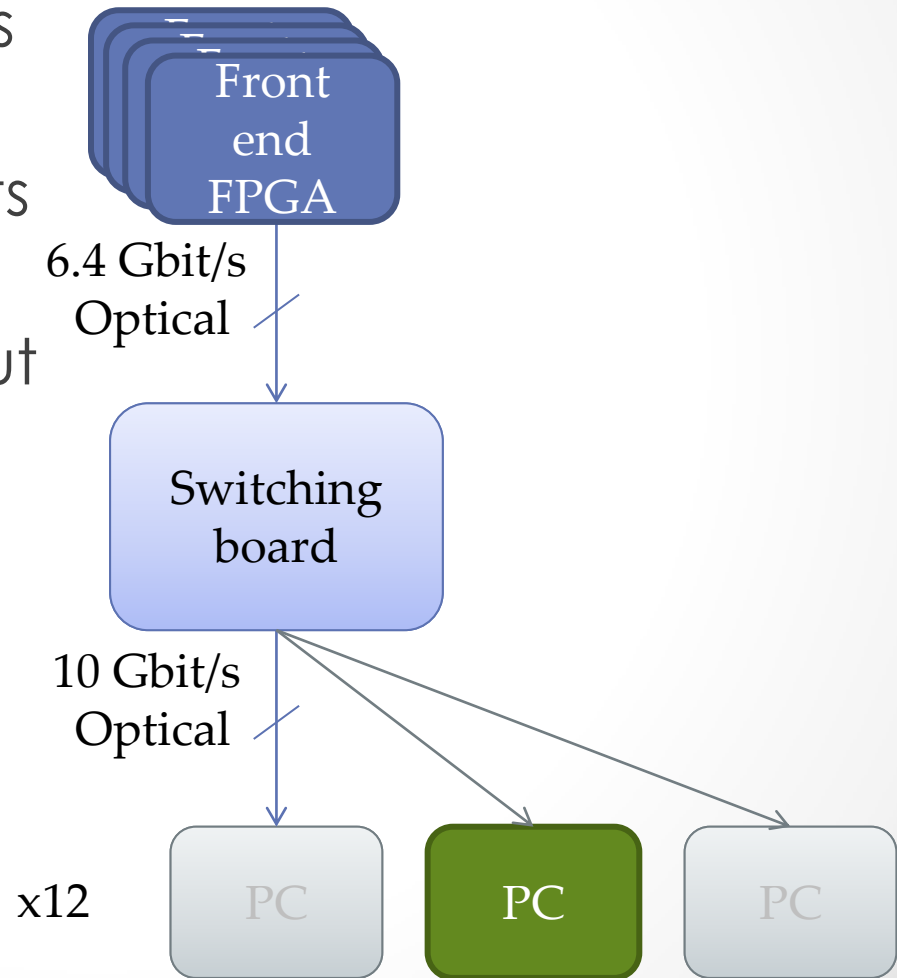
Switching Board

- FPGA switching boards
 - per sub-detector
- 6.4 Gbit/s optical inputs
 - 16-48 inputs
- 10 Gbit/s optical output
 - 12 outputs to PCs
- Switching network
 - One output per PC



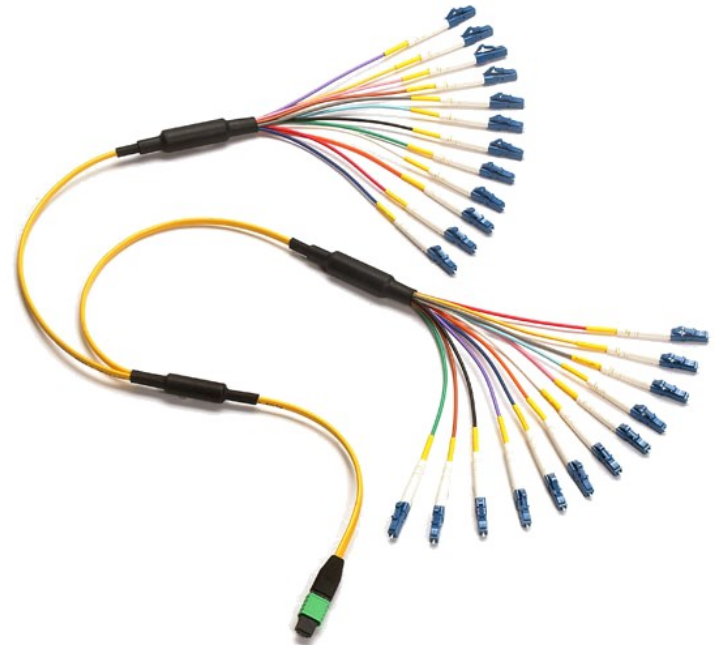
Switching Board

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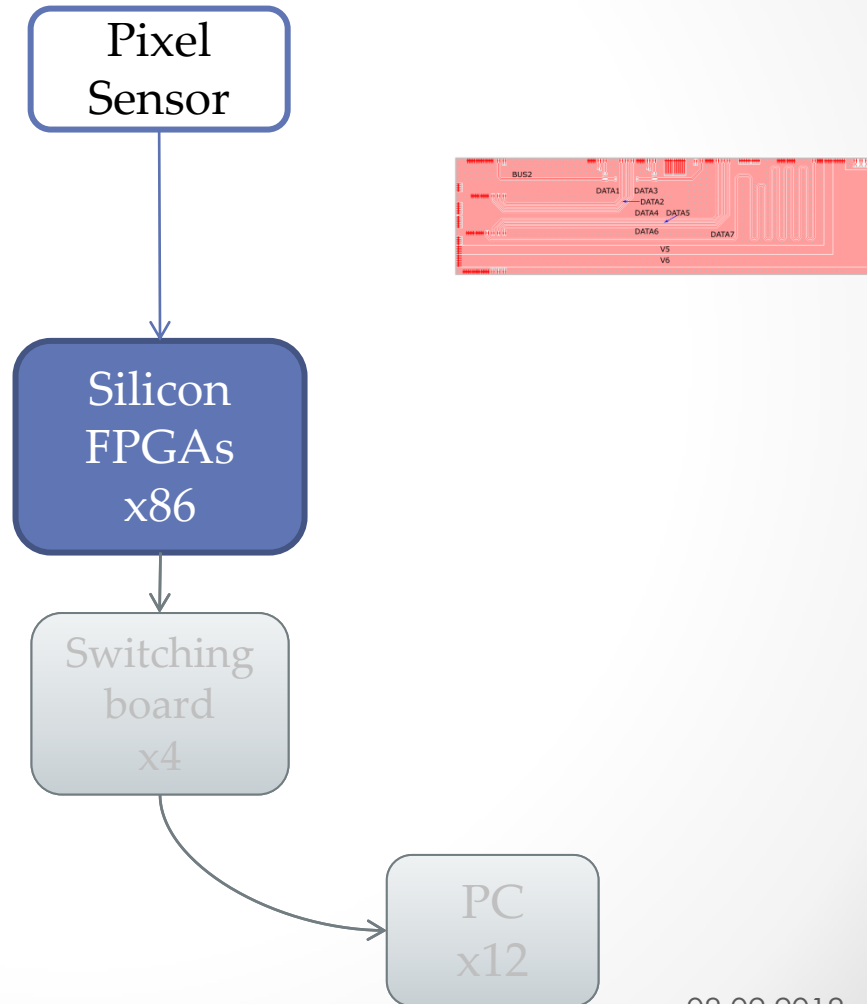
Trigger-less DAQ

- Front end links
 - Pixel sensor to on-detector FPGA
 - 1250 Mbit/s
 - LVDS
 - Timing detector readout
- Optical links from detector
 - Front end FPGAs
 - ... to switching boards
 - 6.4 Gbit/s
- Optical links in counting room
 - Off-detector read out boards
 - ...to PC Farm



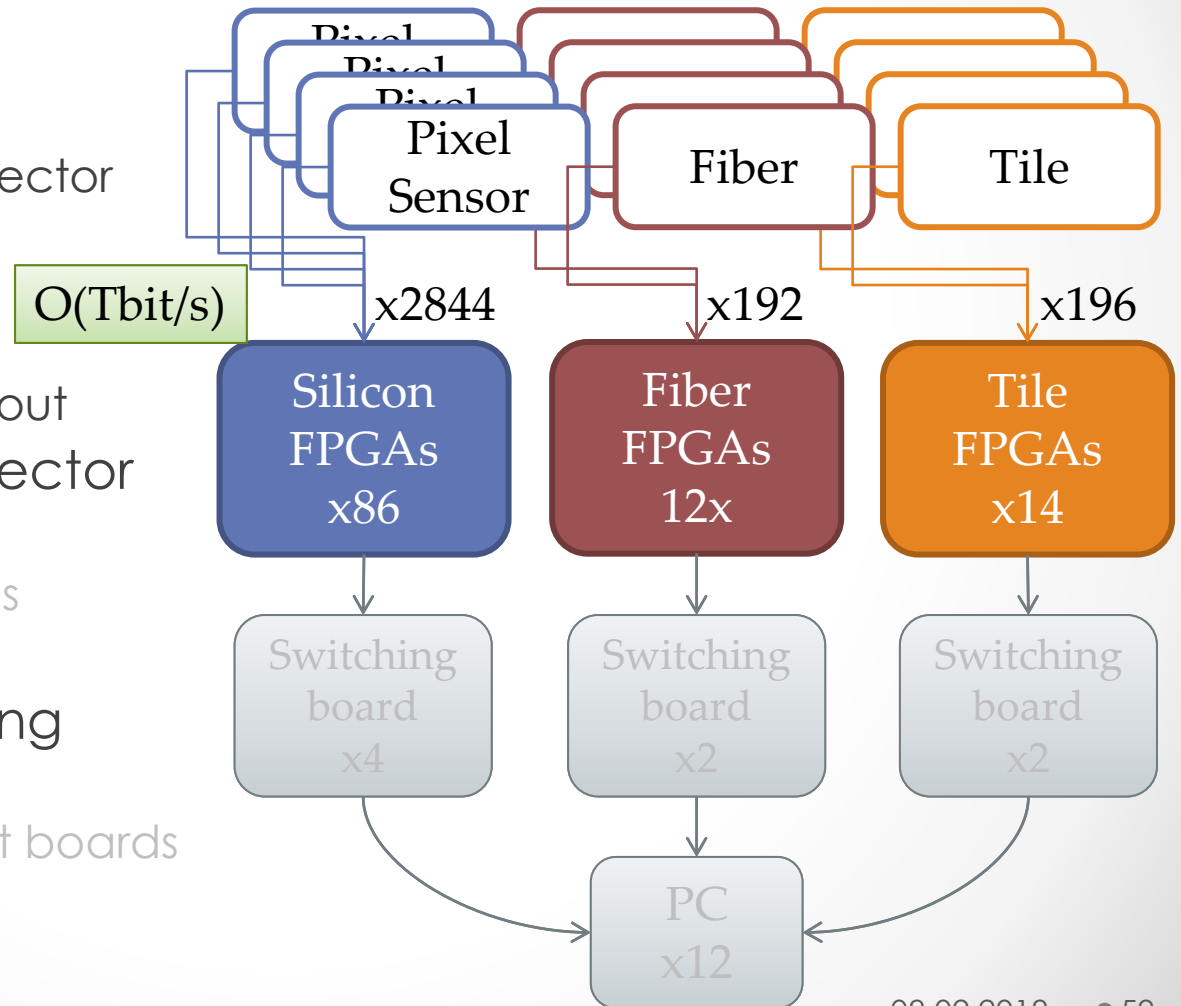
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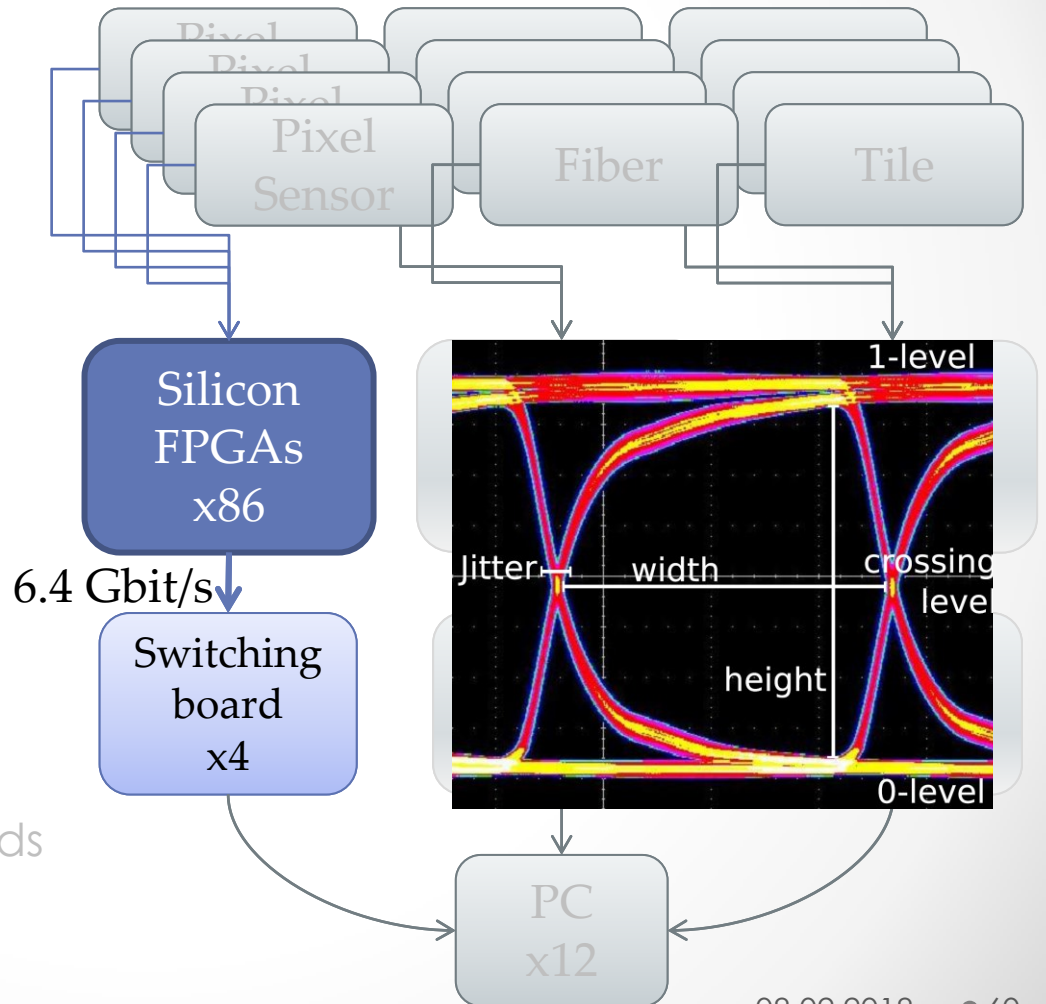
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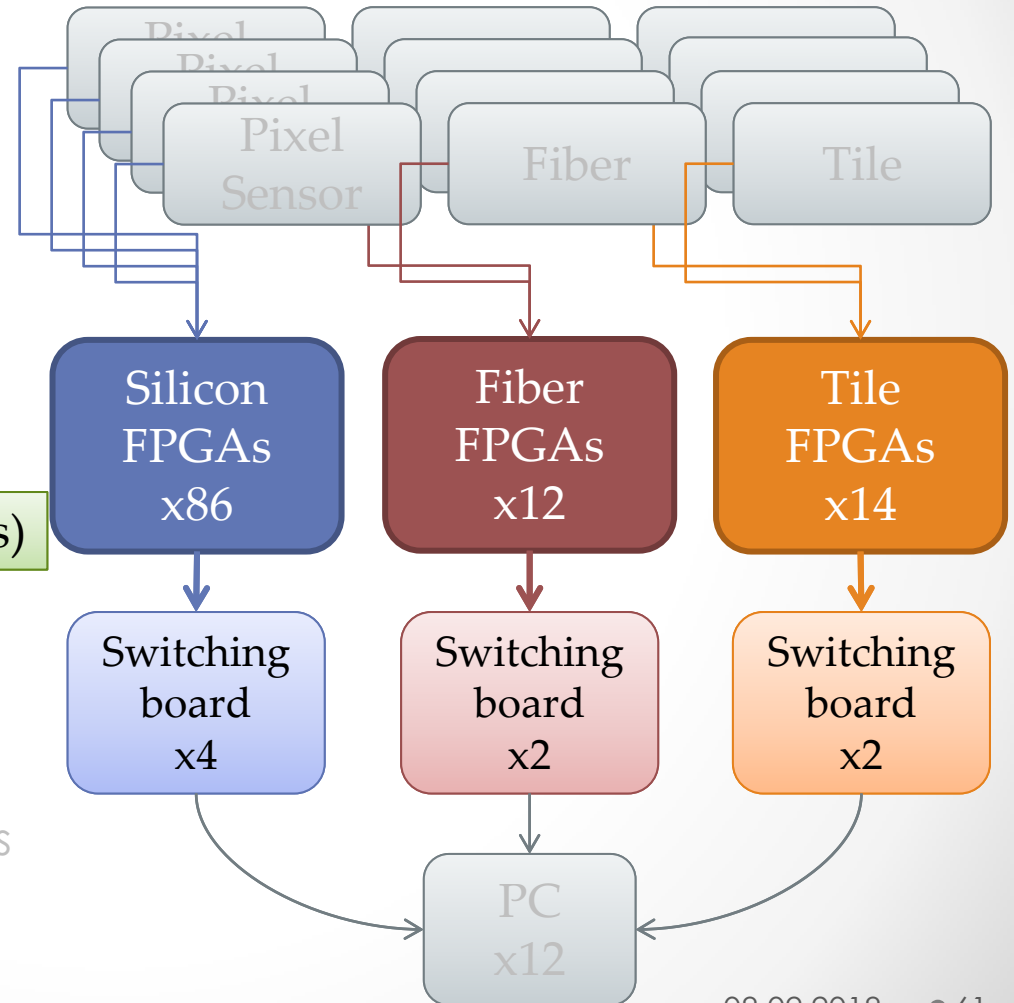
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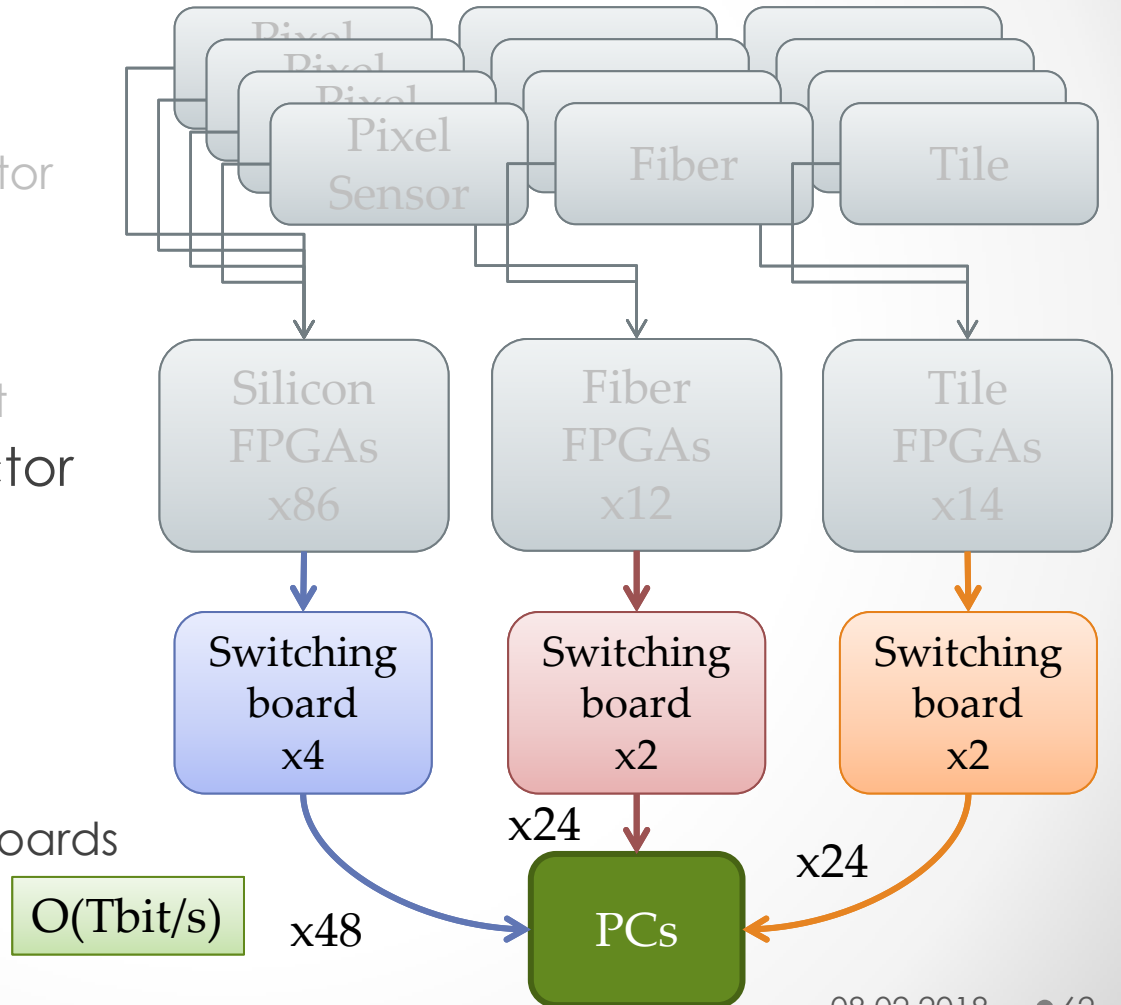
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 - ... to readout boards
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 - Off-detector read out boards
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Trigger-less DAQ

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GPU-PC

- PC with GPU
- 10 Gbit/s Fiber input
 - 8 inputs from sub-detectors
- Data filtering
 - Timing Filter on FPGA
 - Track filter on GPU
 - Data to tape < 100 MB/s



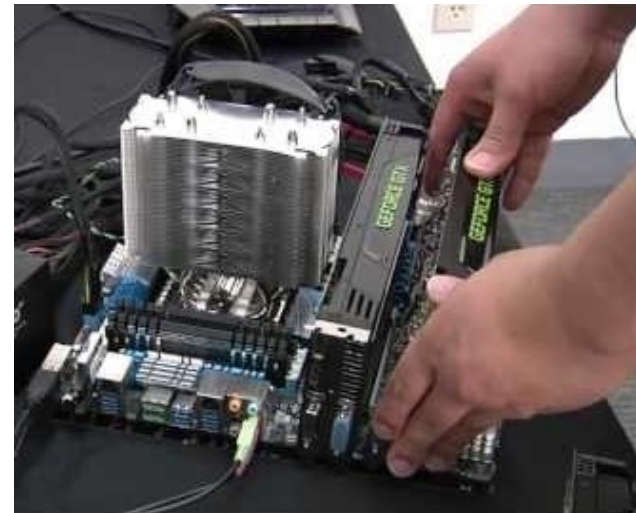
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Optical mezzanine connectors



FPGA PCIe board

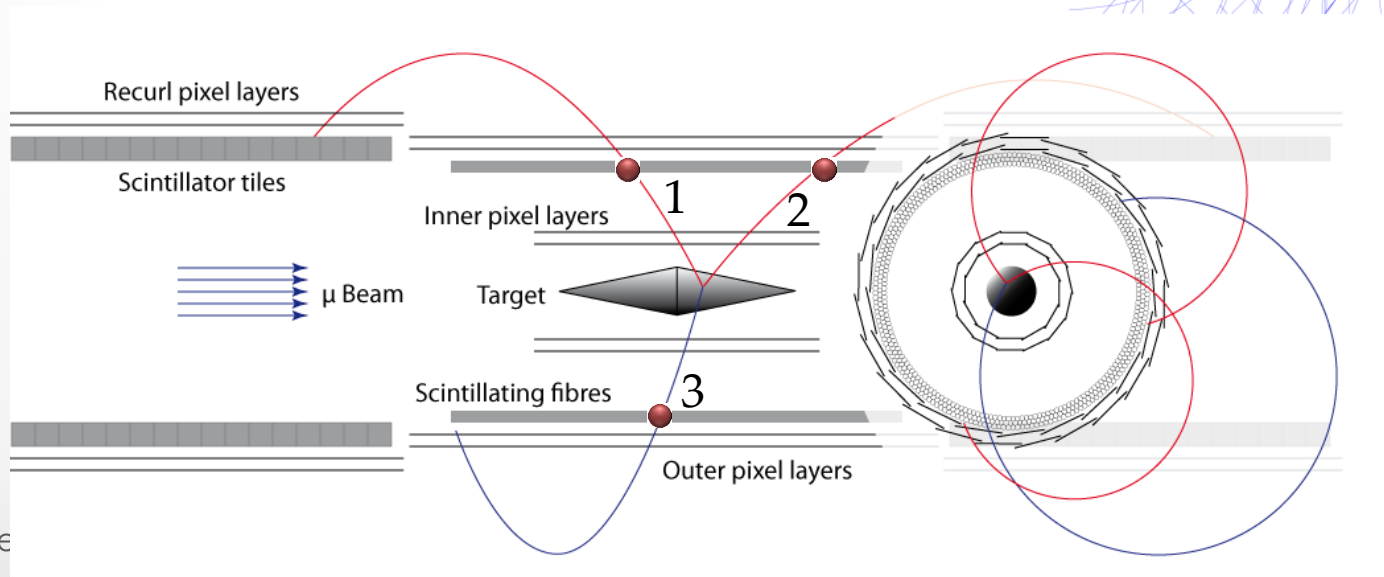
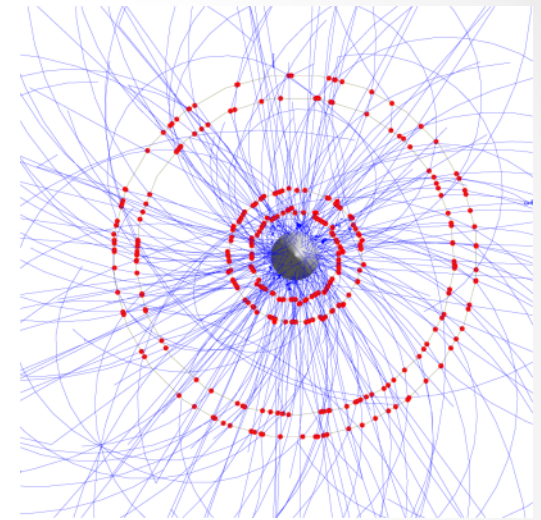


GPU computer

Timing Filter

Under discussion

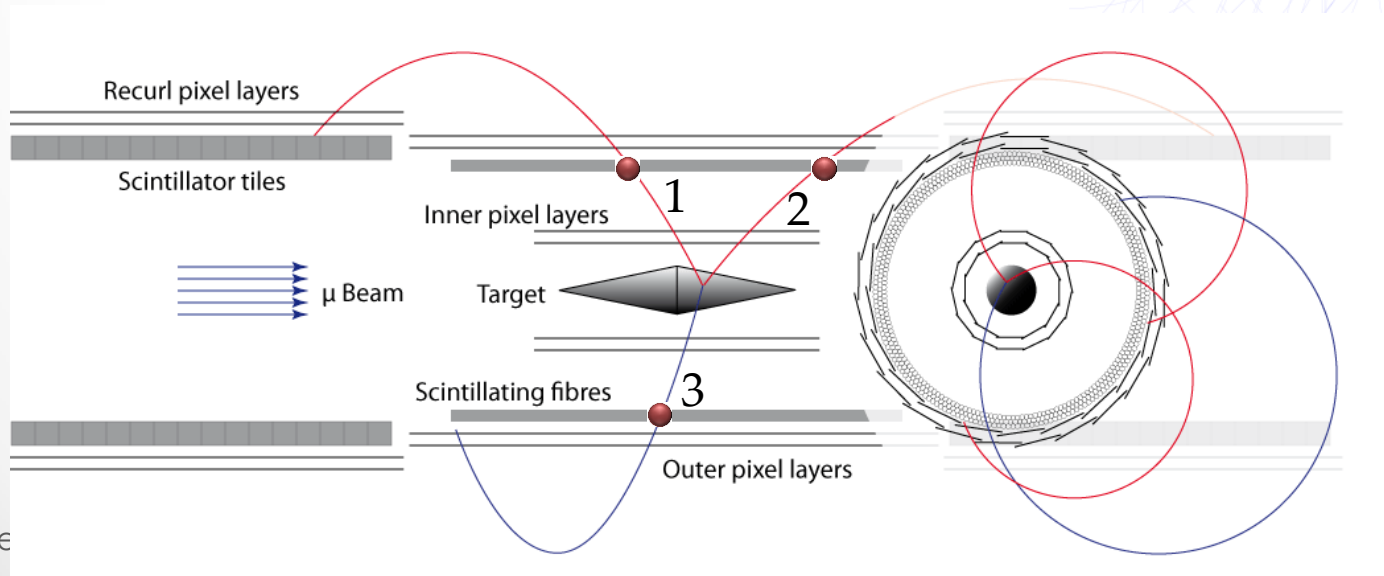
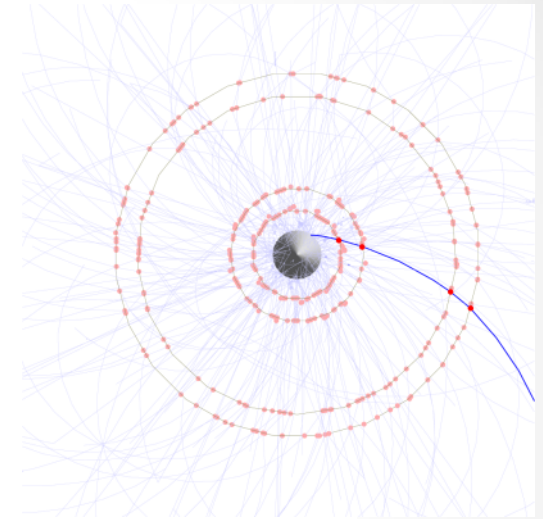
- Entire event on PCIe FPGA
- Tile and Fiber data
 - Easy to match
 - Look for three tracks
- Reject data without three hits
 - ... inside time interval



Timing Filter

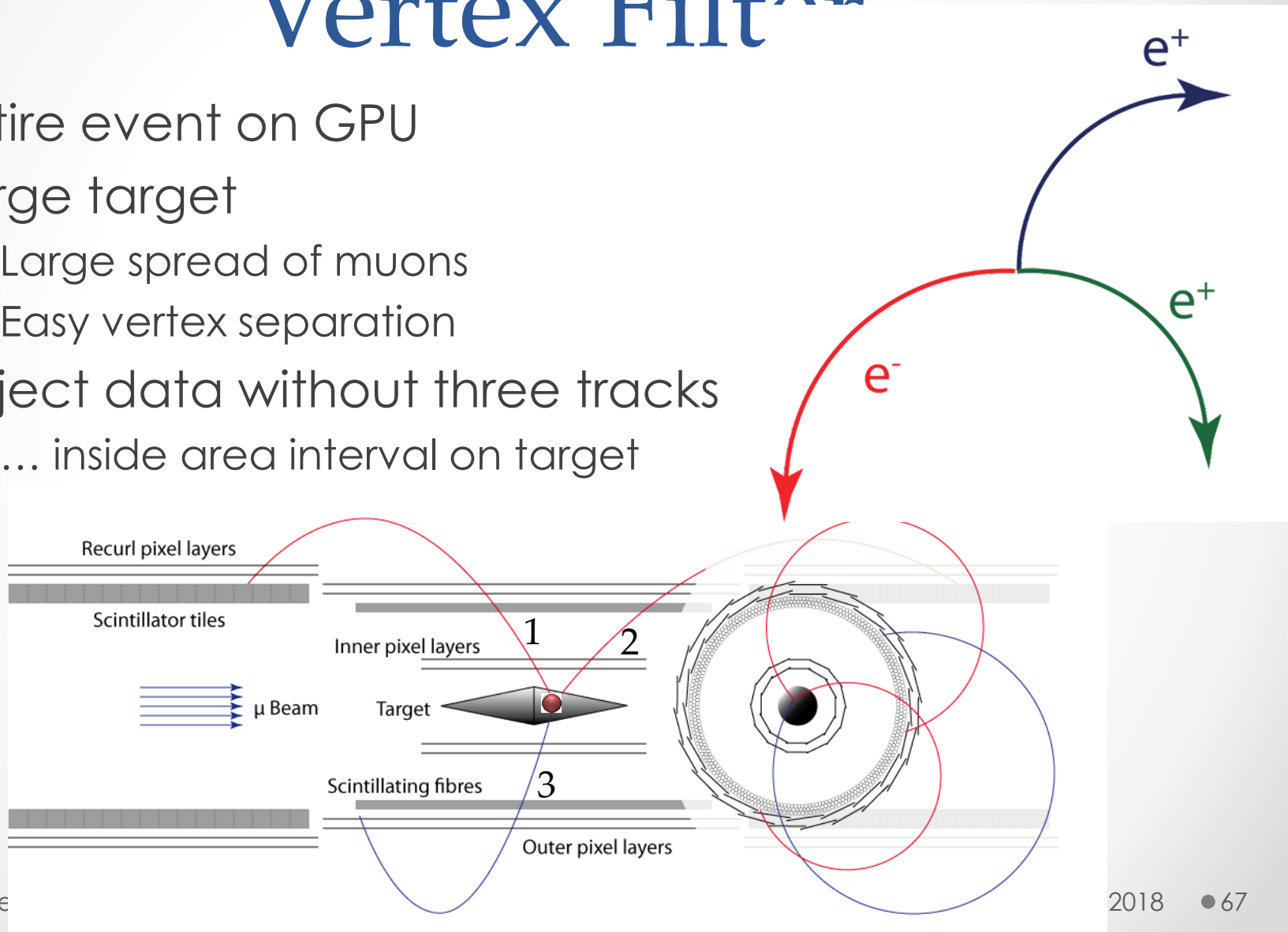
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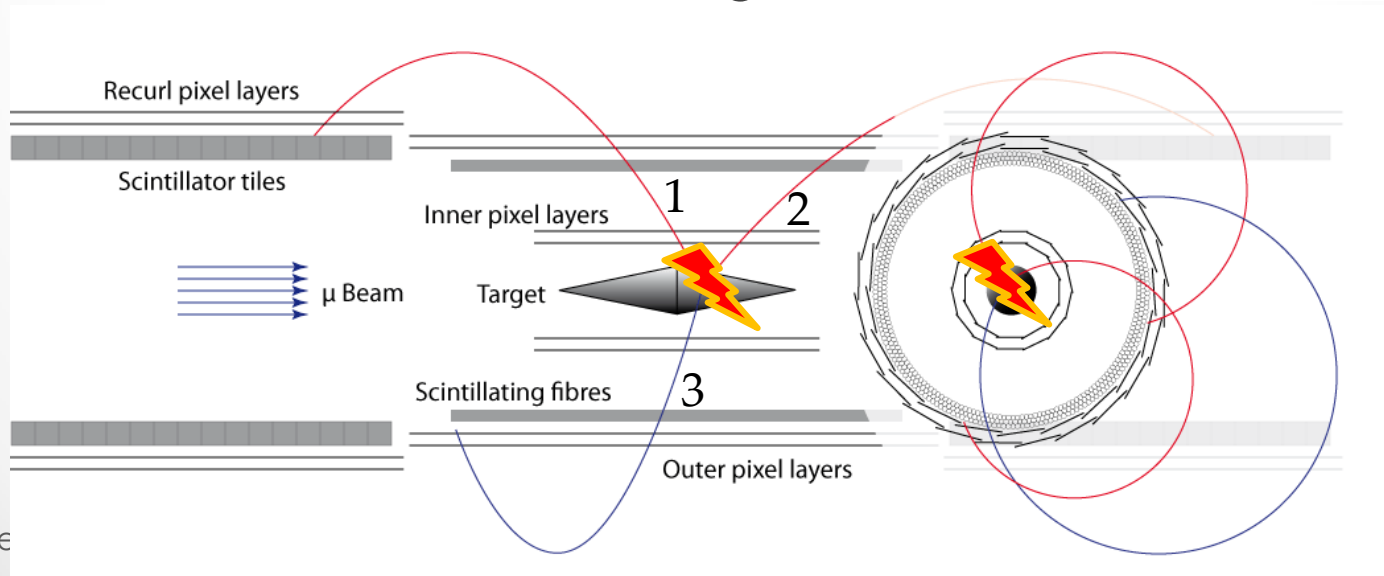
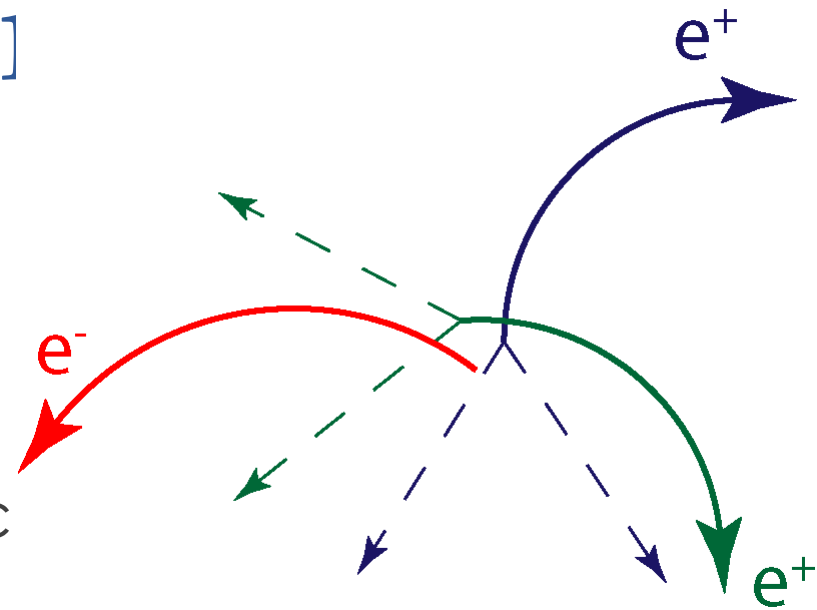
Vertex Filter

- Entire event on GPU
- Large target
 - Large spread of muons
 - Easy vertex separation
- Reject data without three tracks
 - ... inside area interval on target



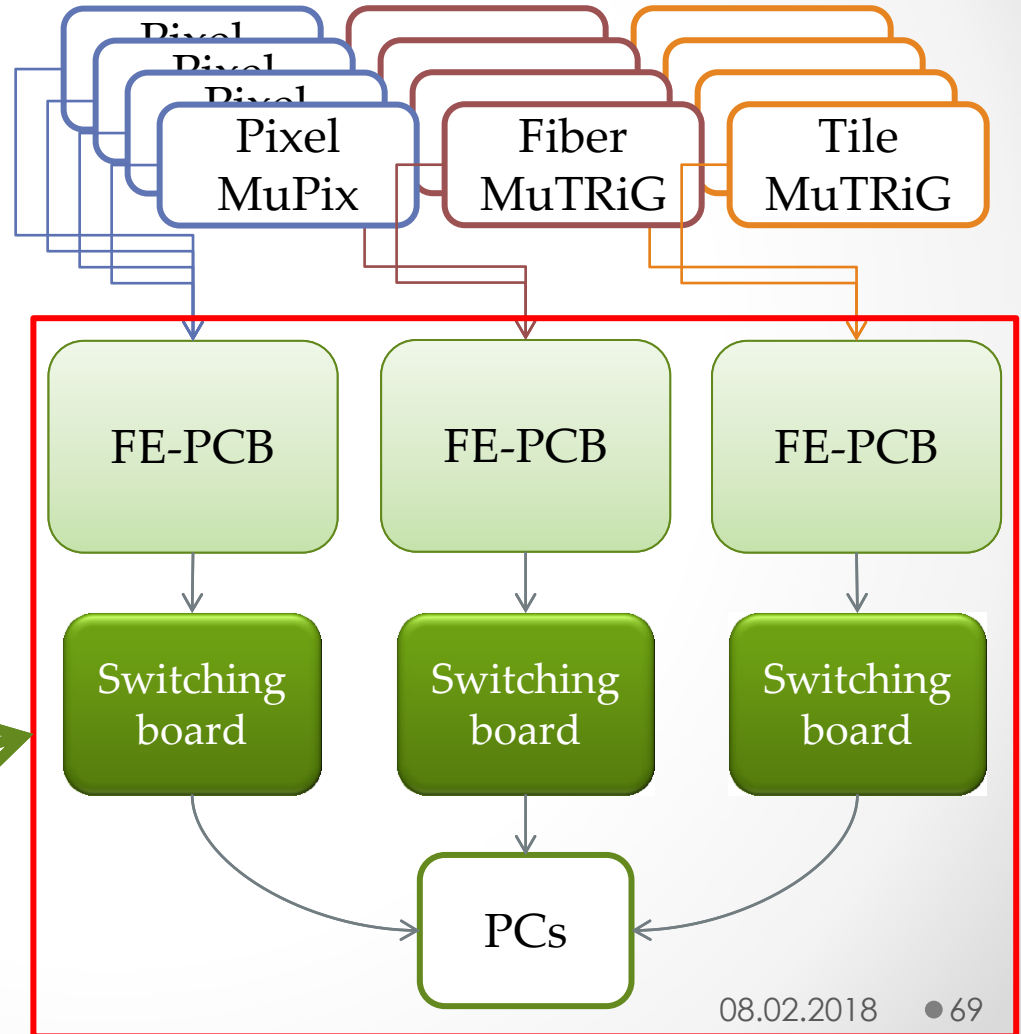
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Readout system

- Pixel detector
 - HV-MAPS (MuPix)
 - ✓ Sensor and read-out chip in one
 - ✓ Deliver zero-suppressed serialized data
- Timing detectors
 - SiPMs plus MuTRiG TDC
 - Deliver zero-suppressed serialized data
- **Common read-out system** →



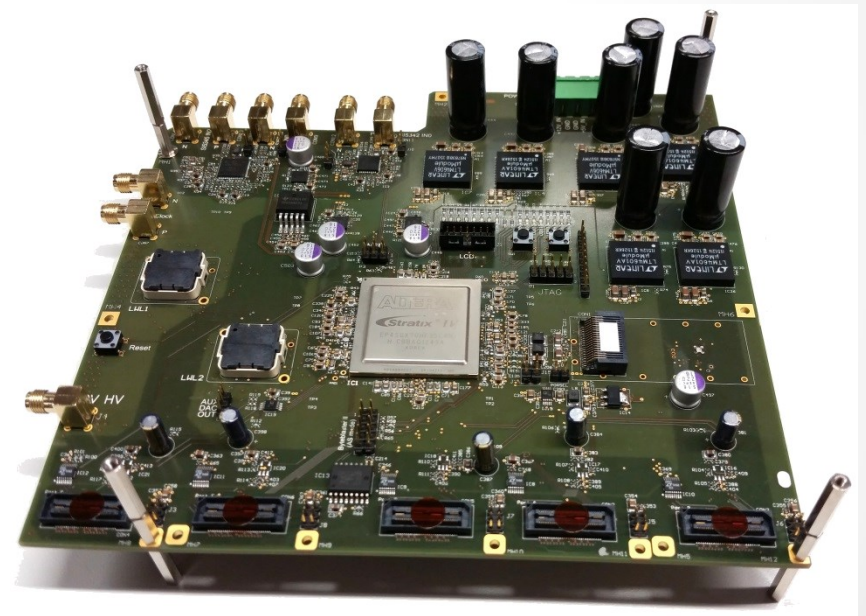
Common read-out PCB

✓ Front-end PCB

- Common for pixel, fibre and tile detector
- ✓ Data acquisition
- ✓ Clock distribution
- ✓ Slow control distribution

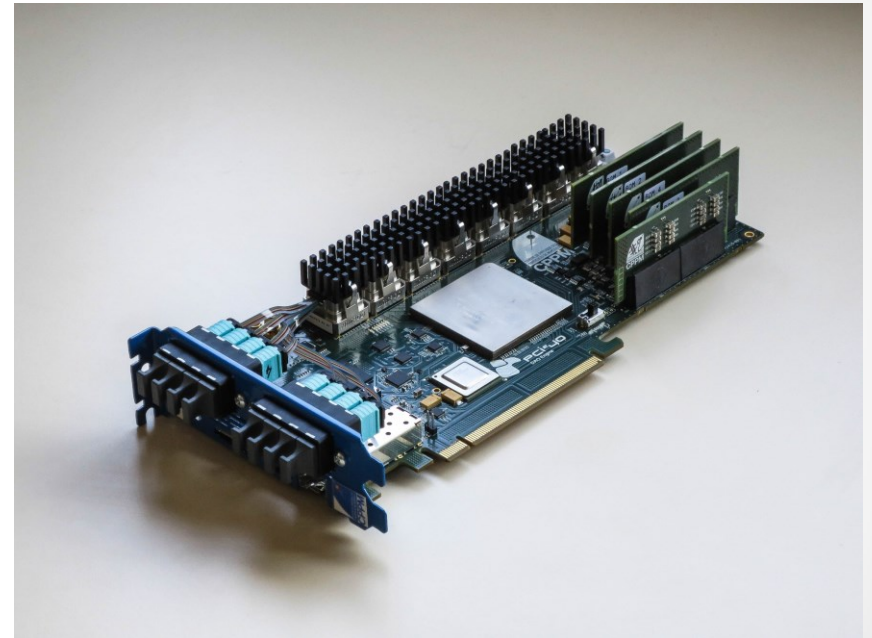
✓ Prototype **functional**

- Improved version for Q3/2017
- Next: Vertical slice test:
 - All electronics from (pixel) module to PC



Switching Board

- PCIe40
- Developed for LHCb and ALICE upgrade by CPPM (Marseille)
- 48 optical I/Os
- Optical network switch from Mu3e filter farm
- Mu3e will receive samples from the current production

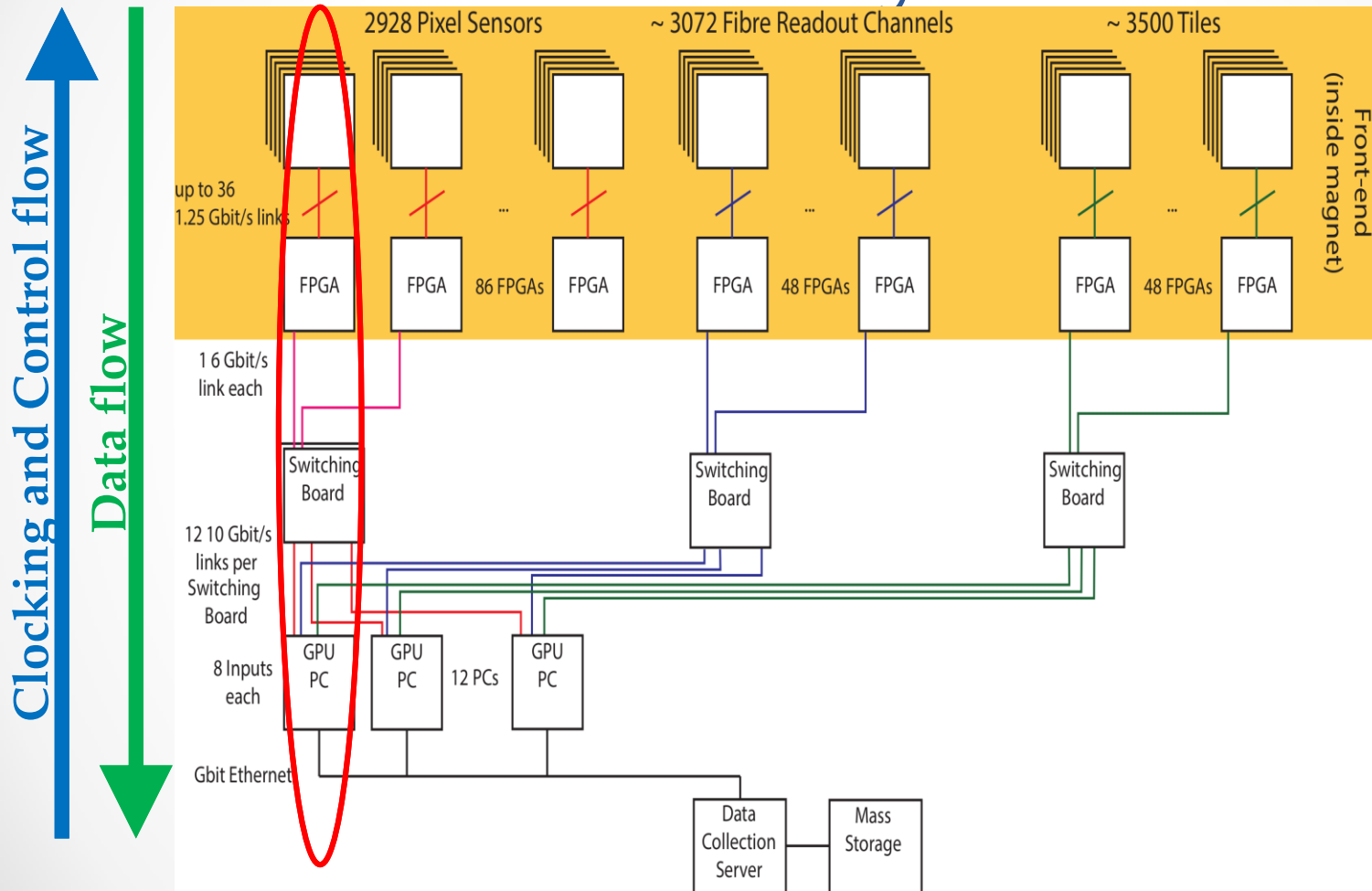


Receiving FPGA board PC side

- De5a-NET boards from Terasic
- Successfully tested at Mainz
- 8 out of 12 boards already acquired



Vertical slice of the Mu3e readout system

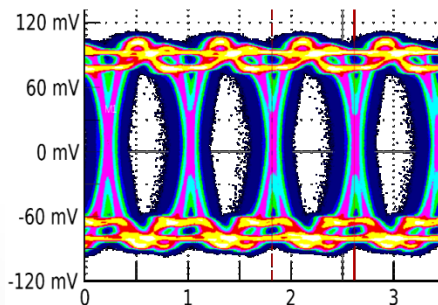
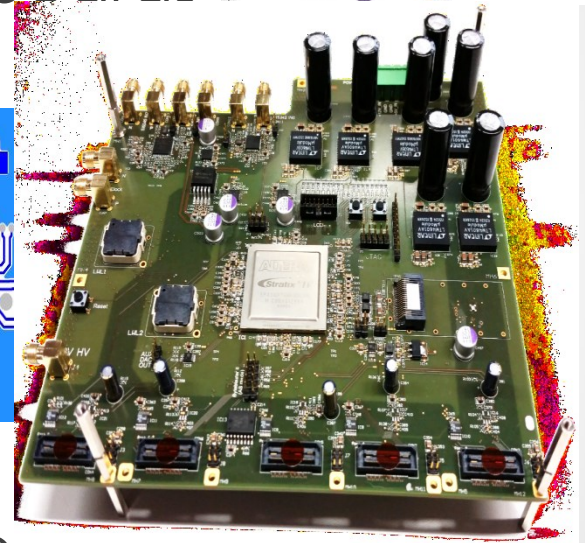
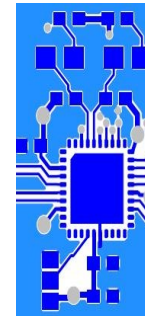


Tasks, problems, challenges

- Hard-, firm- and software developments
- Testing custom designed front-end boards and bringing them to operation
- Data transmission studies
 - Electrical links
 - Optical links
- **Data reduction at front-end:**
Up to 45×1.25 Gbps \rightarrow 1×6 Gbps with as little logic utilization as possible

```
write_process : process(clkin, reset_n)
begin
  if(reset_n = '0')then
    synfifo_wmem(0) <= '0';
```

```
void MudadqDevice::zero_wmem()
{
  uint32_t temp;
```



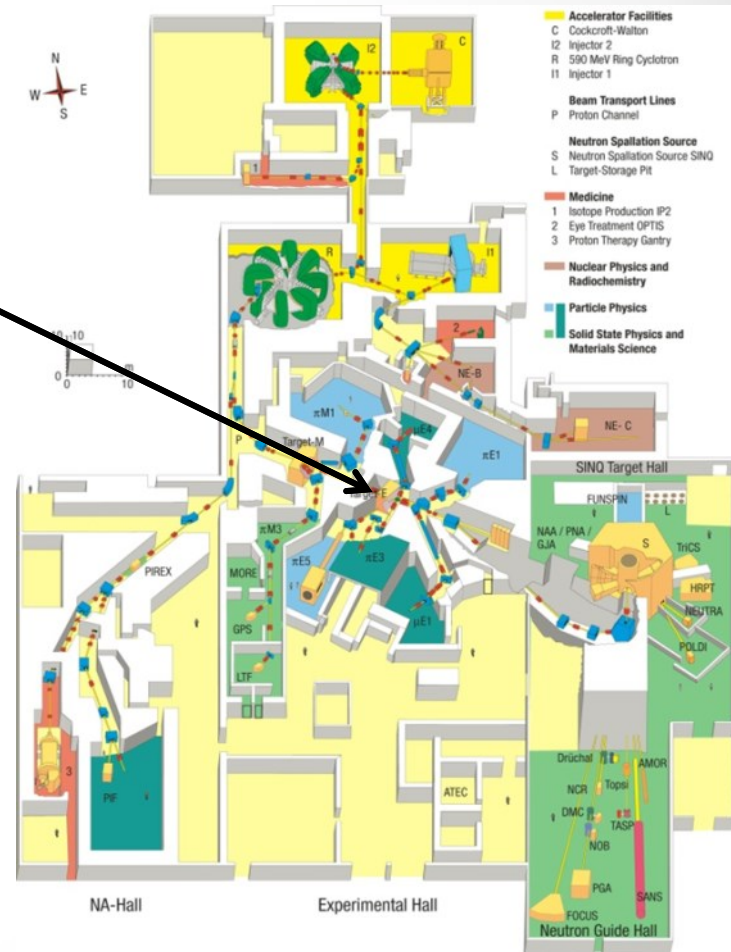
Backup Area Planning



PSI μ -Beam

Paul Scherrer Institute Switzerland:

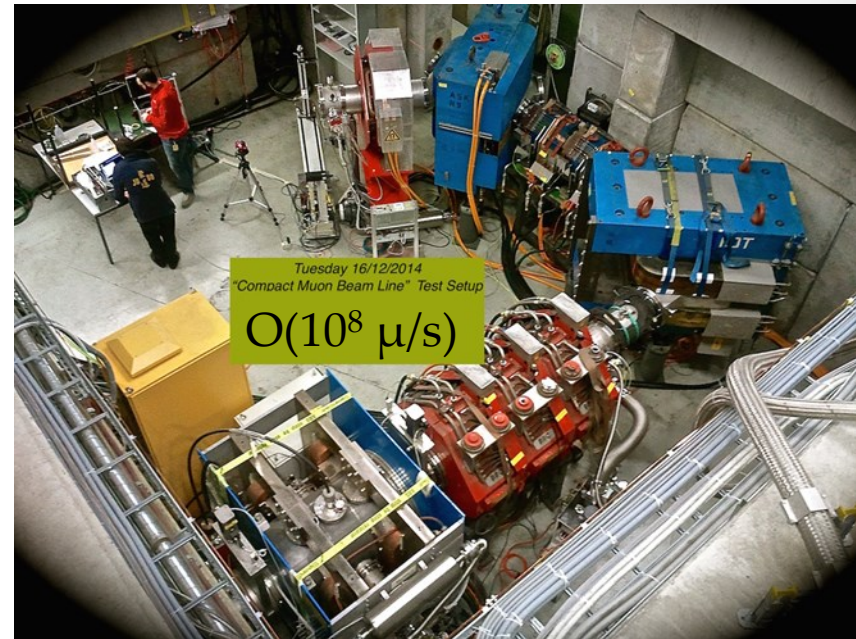
- 2.2 mA of 590 MeV/c protons
- Surface muons from target E
- Up to $\sim 10^8 \mu/s$
- $> 10^{15}$ muon decays per year



PSI μ -Beam

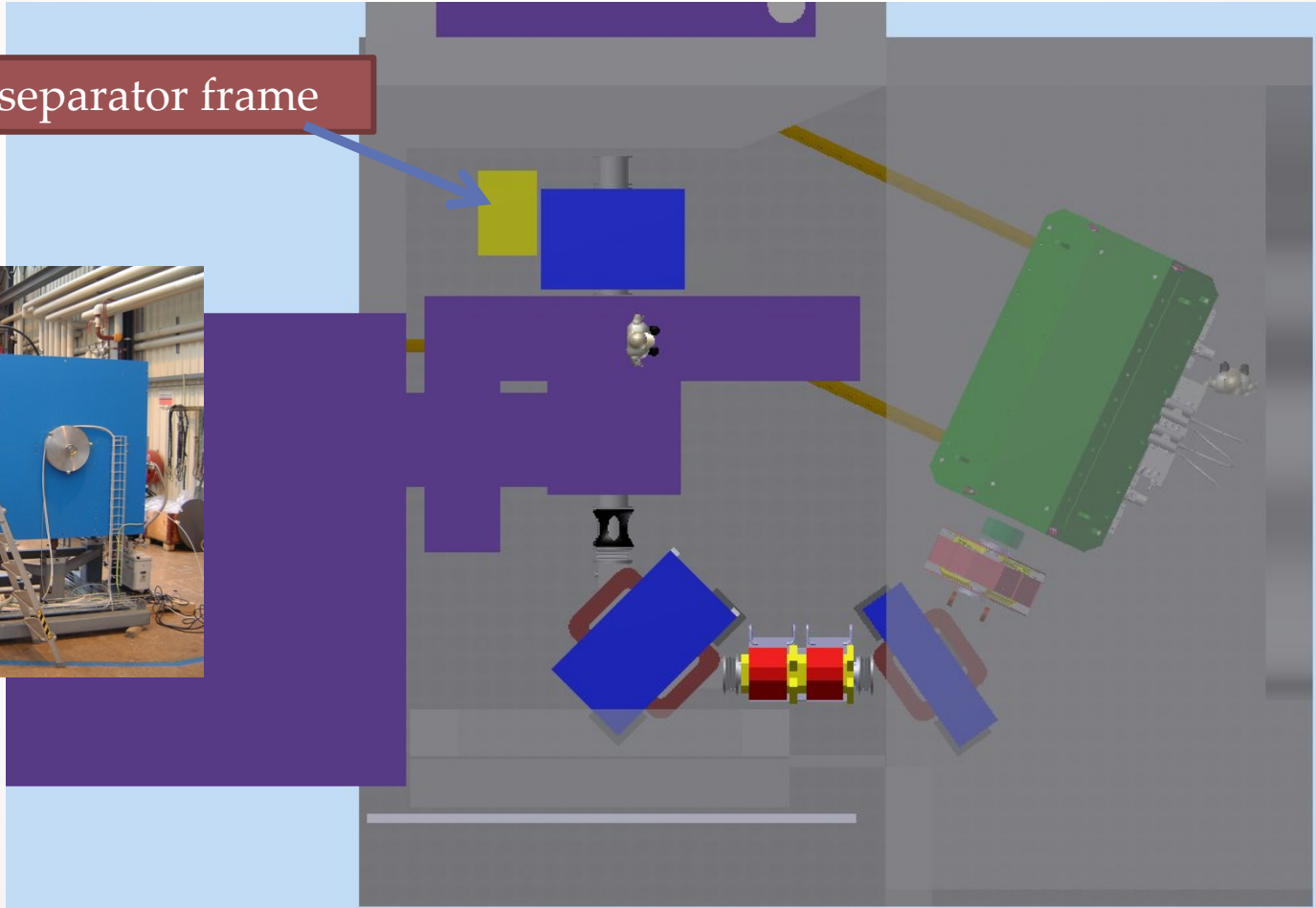
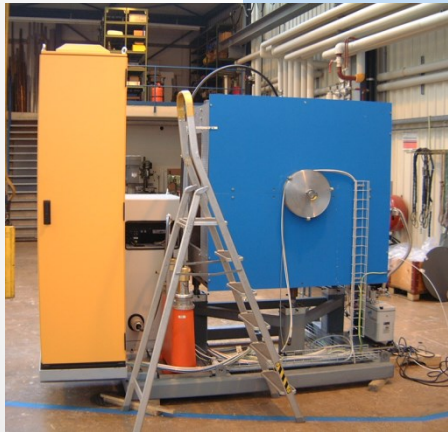
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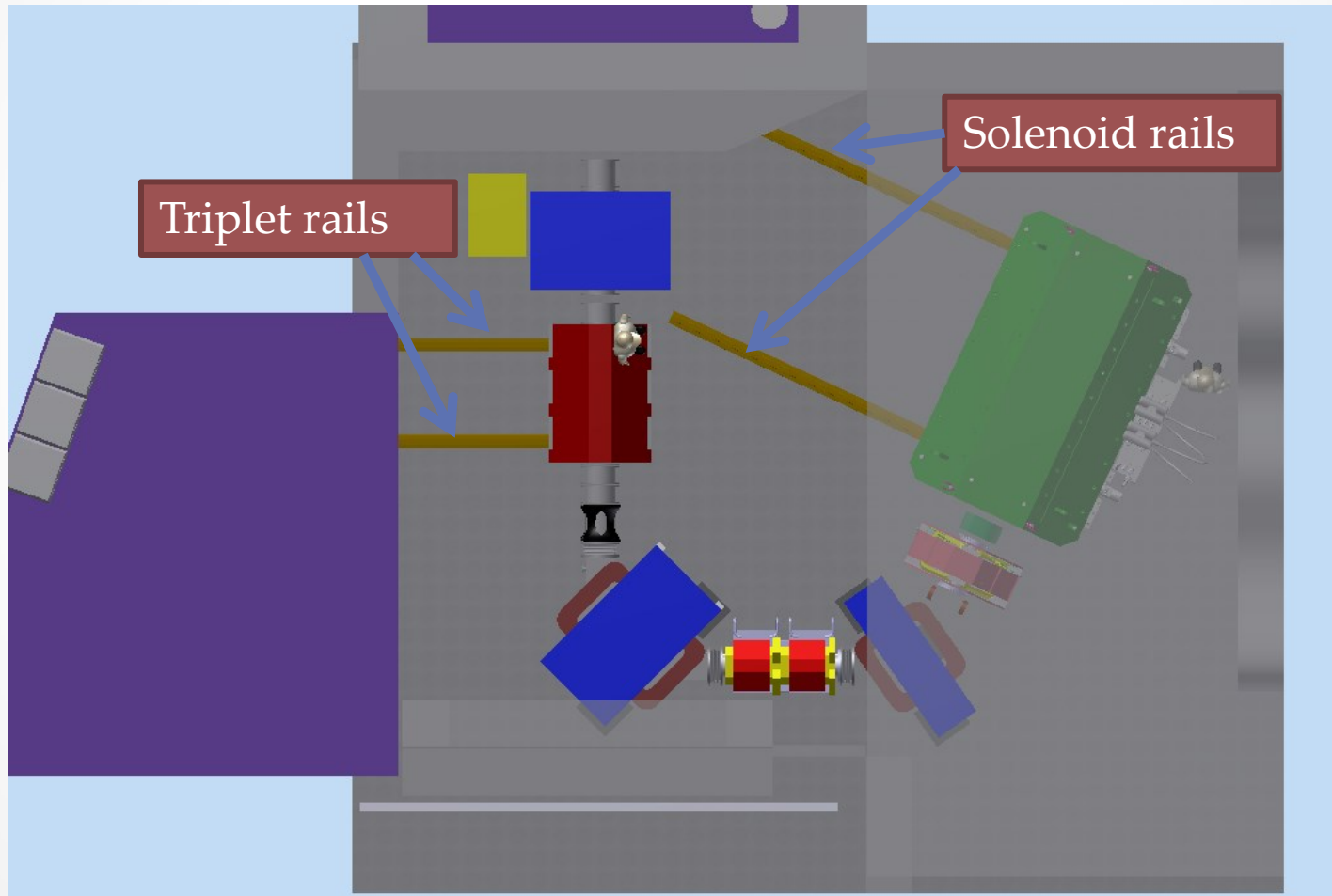


Area Layout

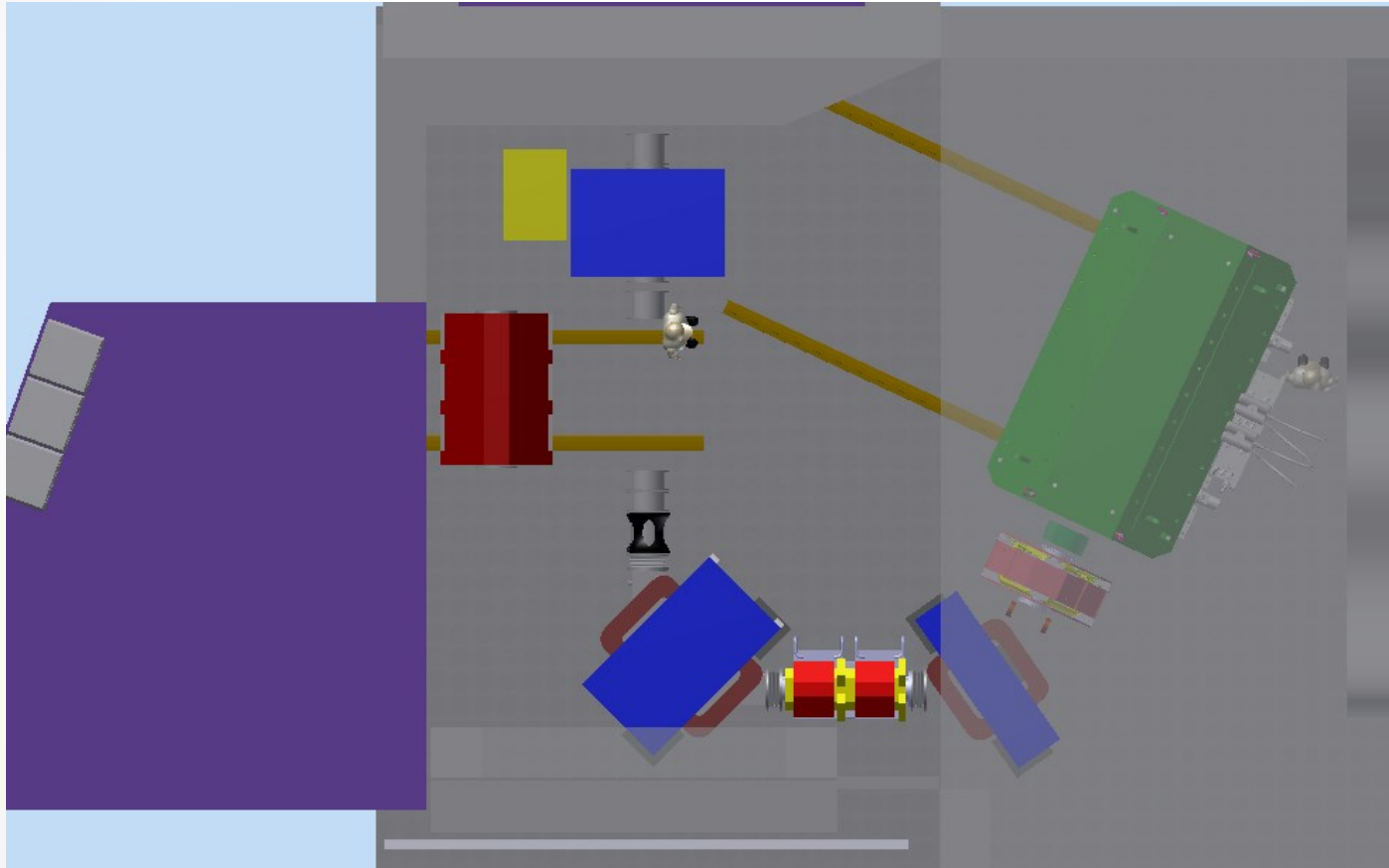
Modified separator frame



Remove Triplet platform and stairs

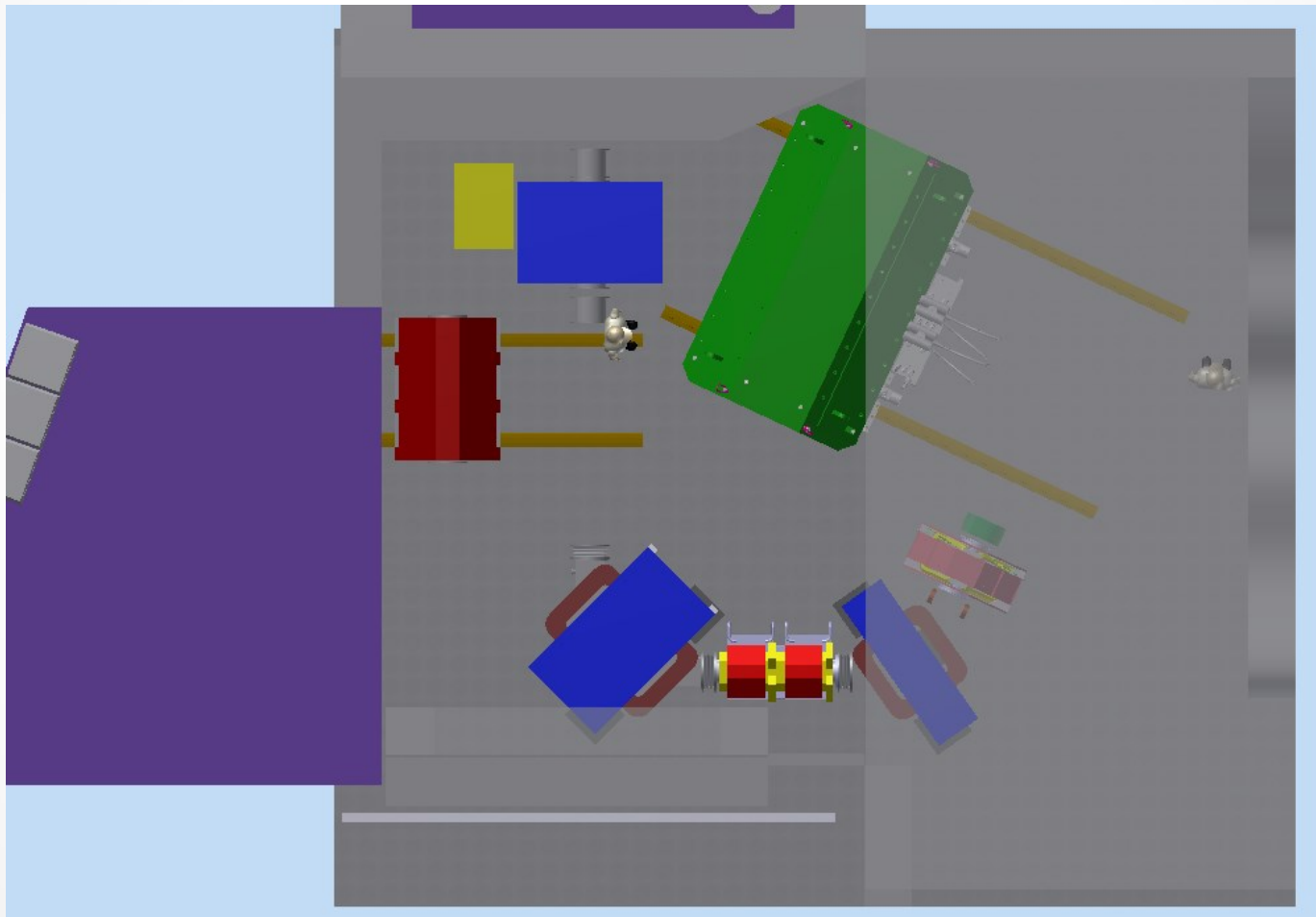


Move triplet II

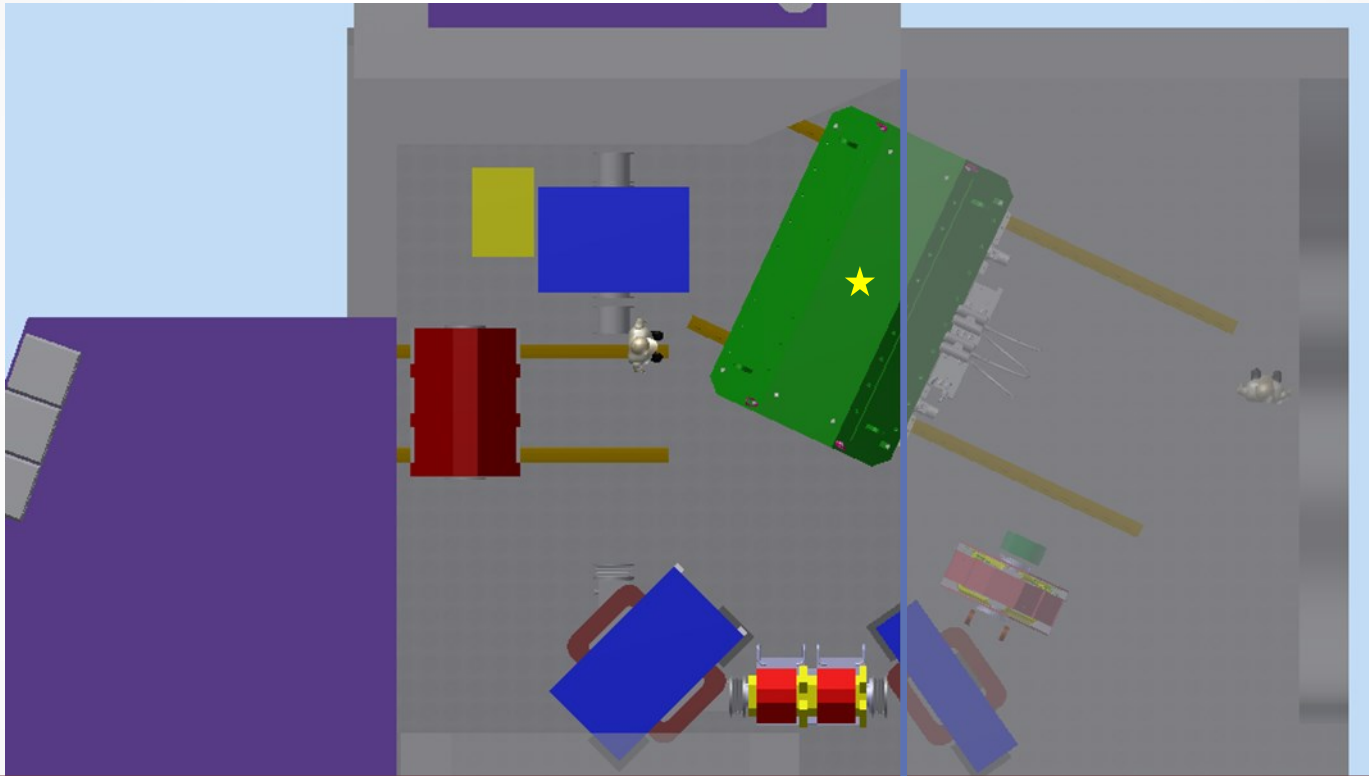


Optionally the beam pipe and collimator DS triplet II could be attached to triplet II frame and could be moved at once. Otherwise remove beam pipes and collimator.

Move Solenoid



Access with crane

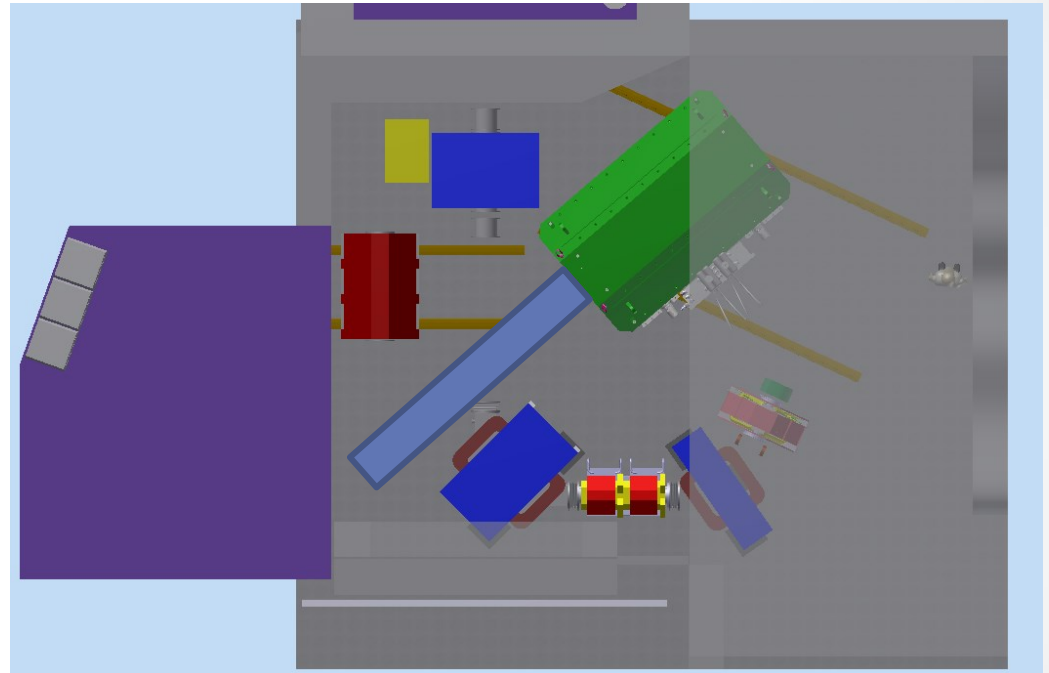
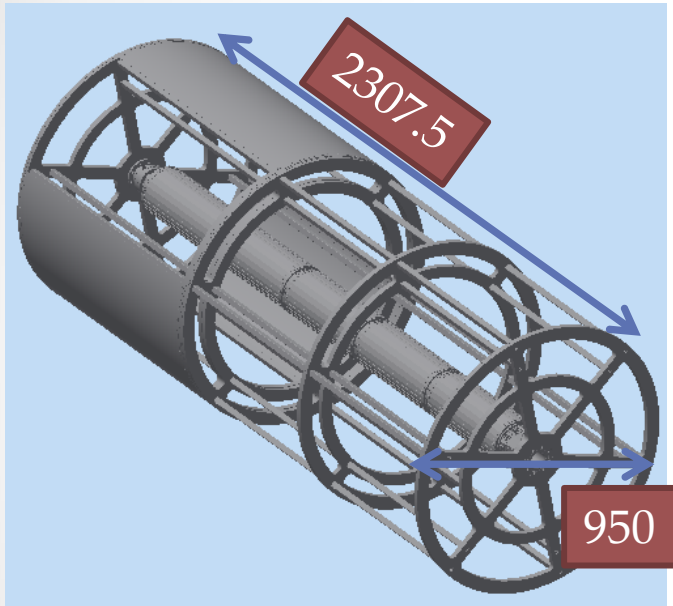


Center of solenoid is now not covered by ceiling anymore. Therefore the solenoid can now be moved with the crane (allows translation and rotation. Need frame of max 1m height on top of solenoid if frame stays attached to solenoid lifting eyes)

Crane in/out position

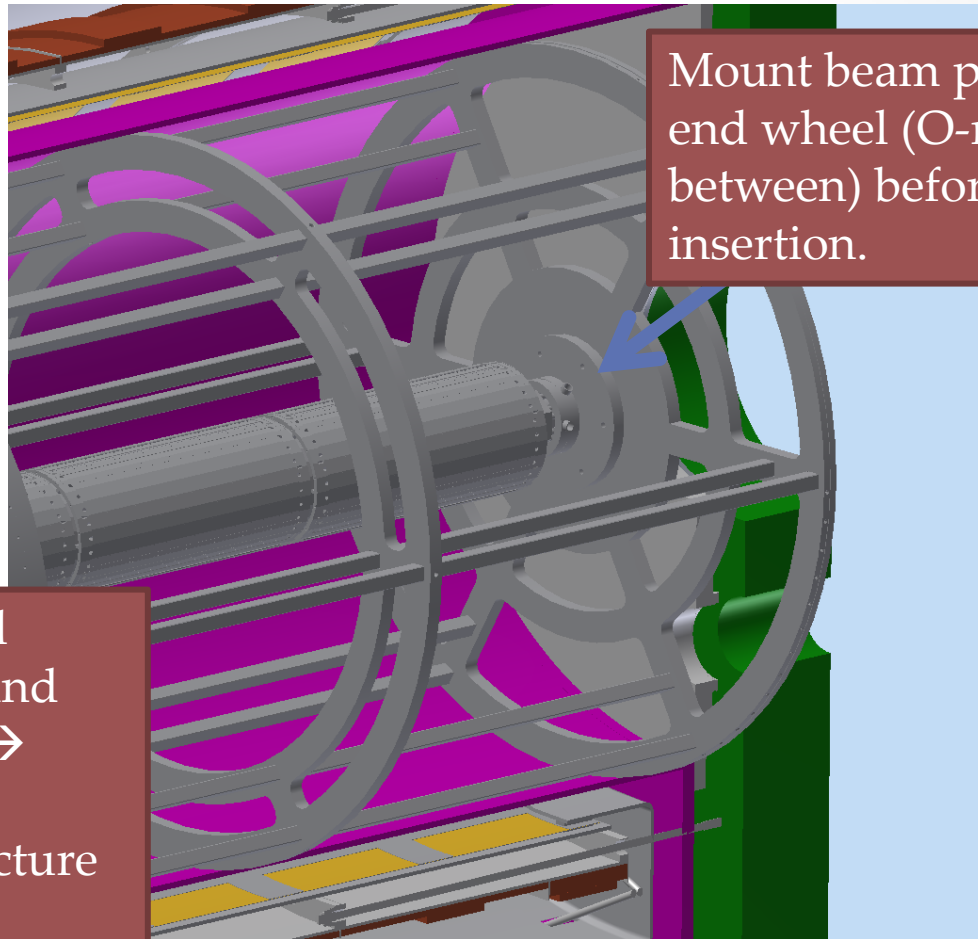
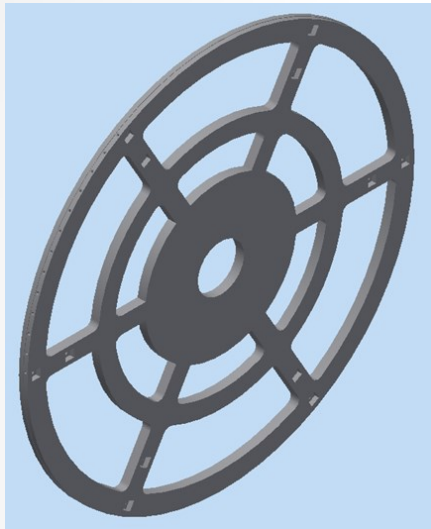


Insert / Extract Detector on railsystem



Enough space in front of Mu3e solenoid ✓

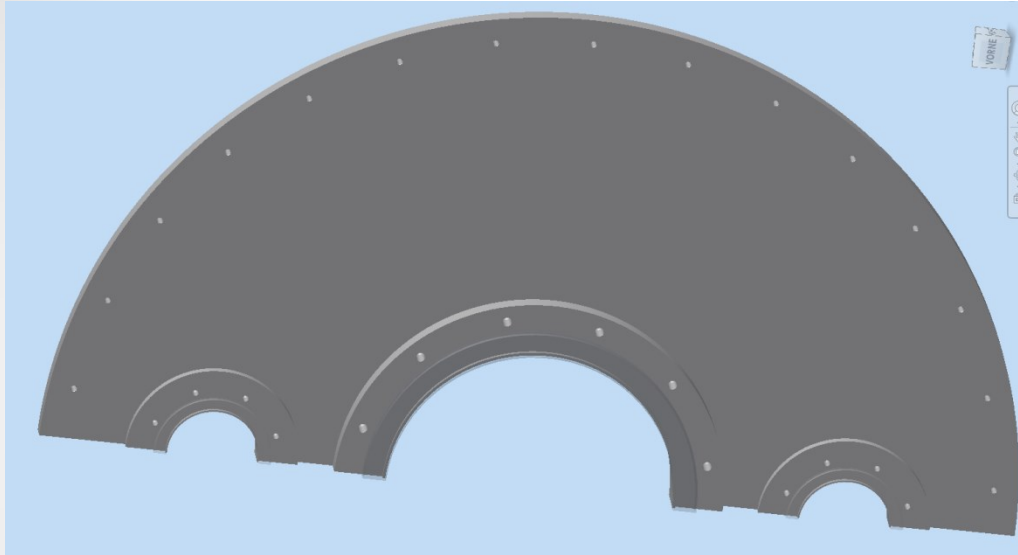
Inner Beam Pipe and End wheel modified



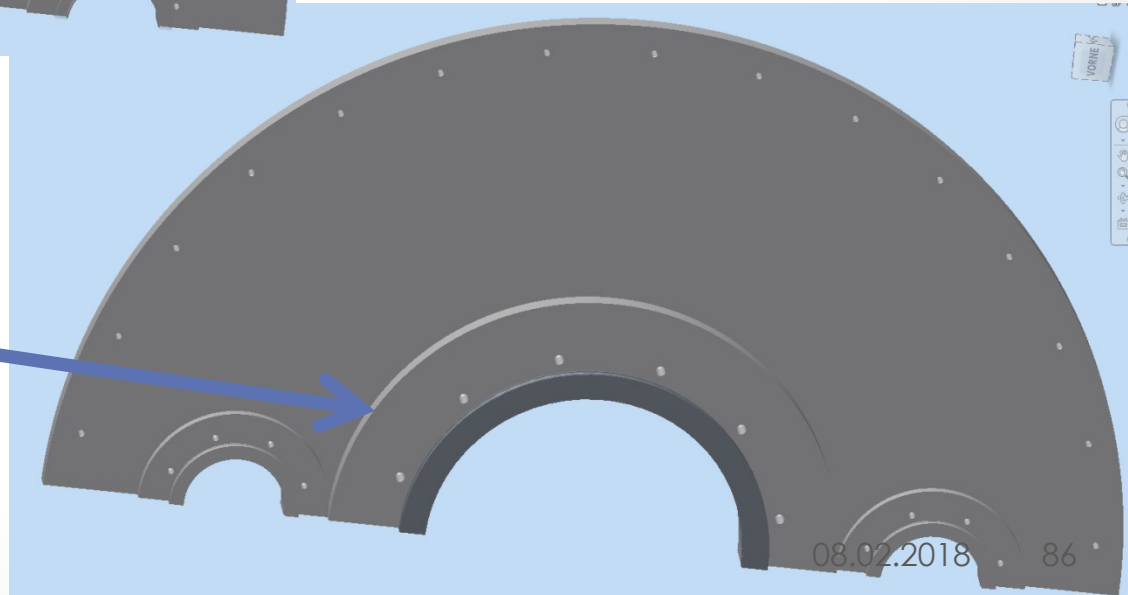
Mount beam pipe to end wheel (O-ring in-between) before insertion.

End wheel has a bigger radial surface with sealing surface and blind holes from both sides. → Mount beam pipe before implementation of inner structure to end wheel sealing surface

Helium lid modified (only half of the lid is shown)

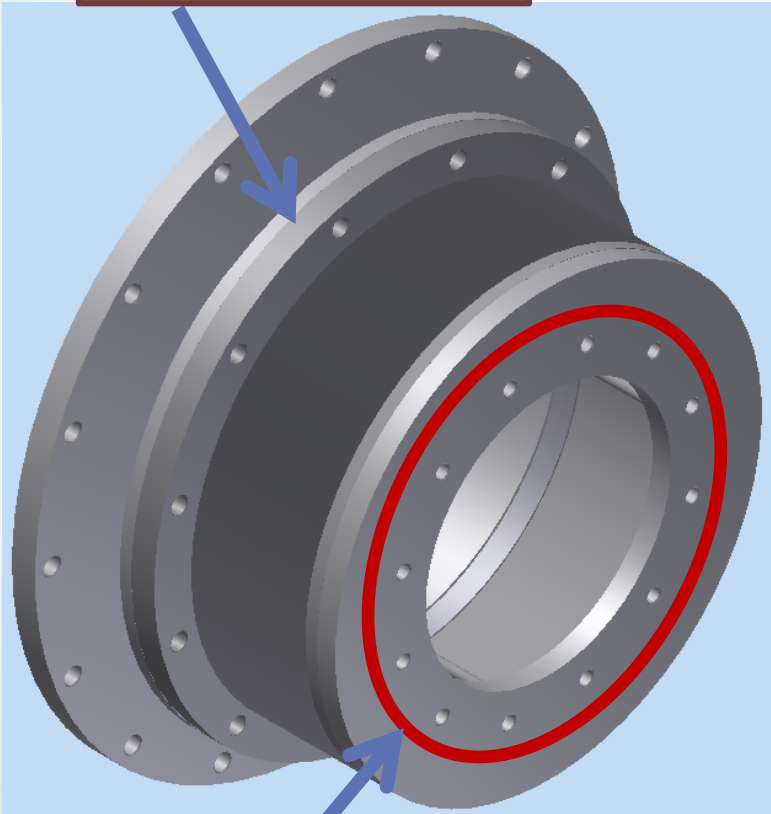


Need more material here to have blind holes from detector side

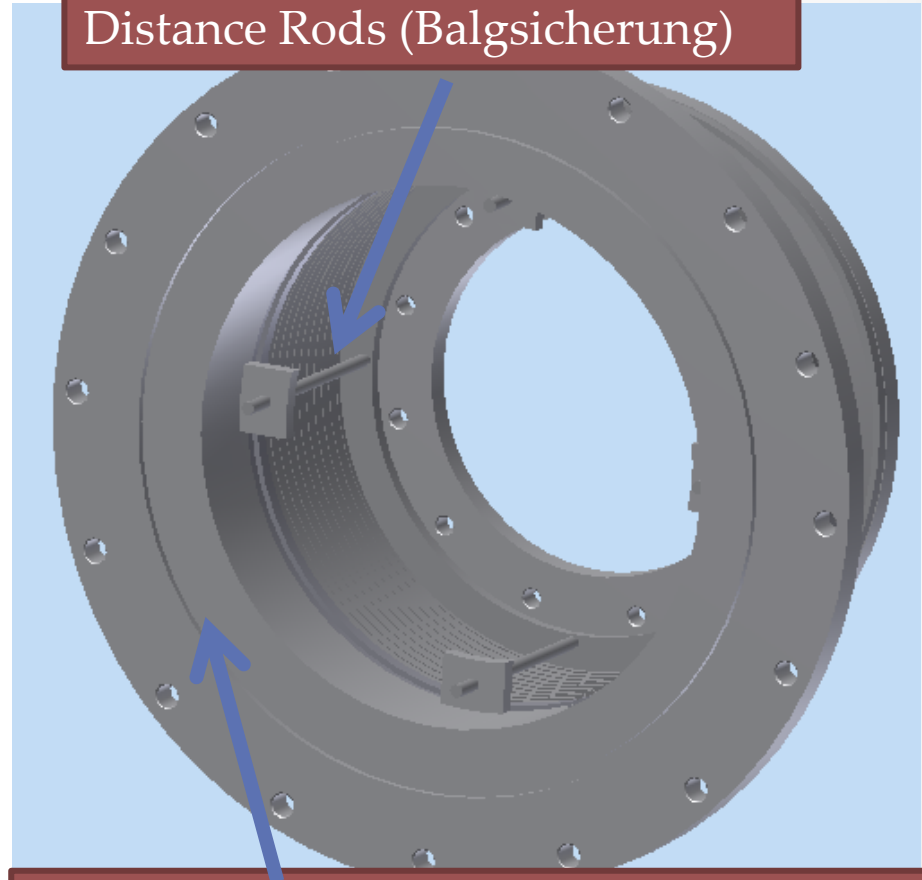


Inner Coupling Tube (Nose)

Welded connection



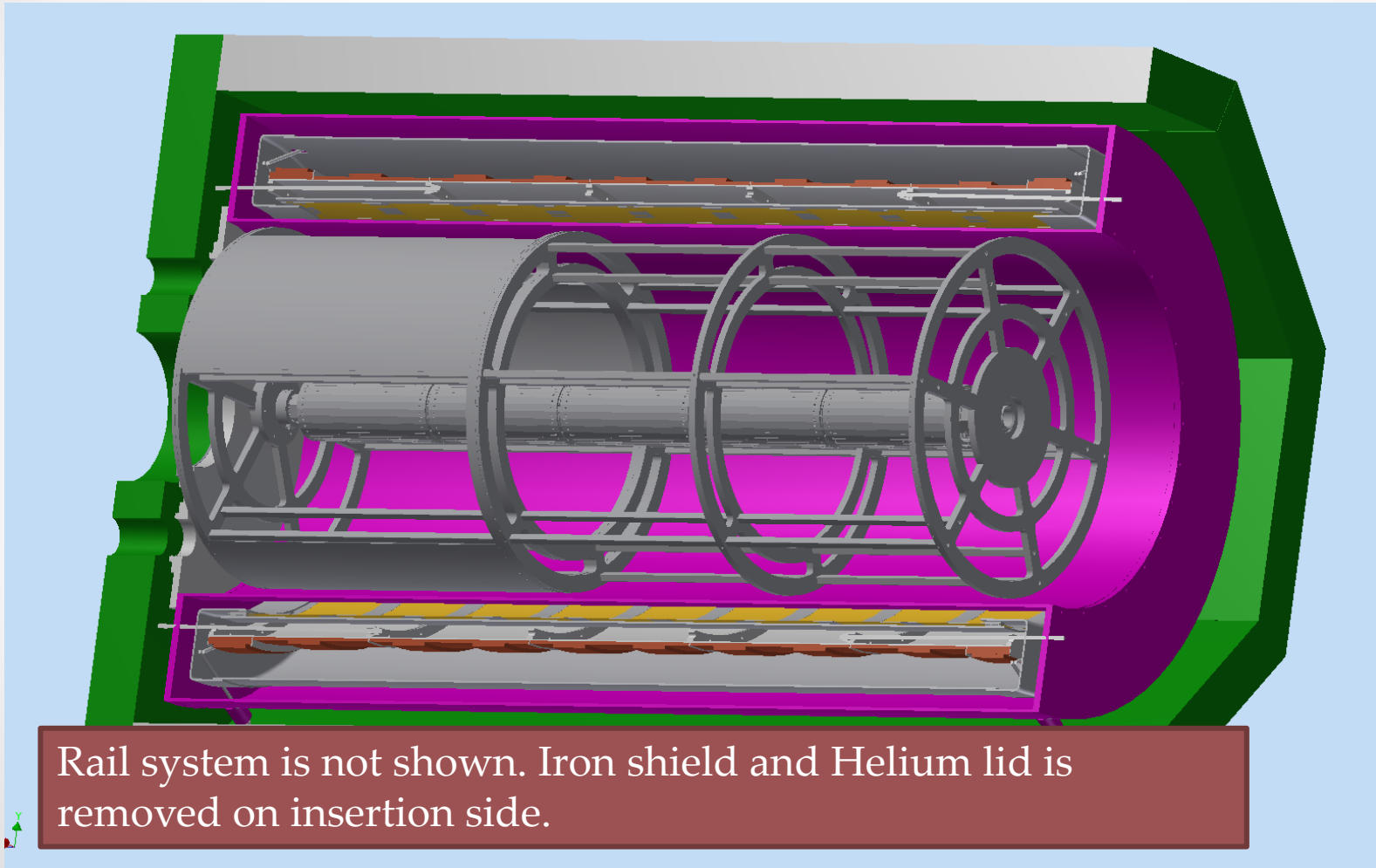
Distance Rods (Balgsicherung)



Sealing surface inside screws on area side

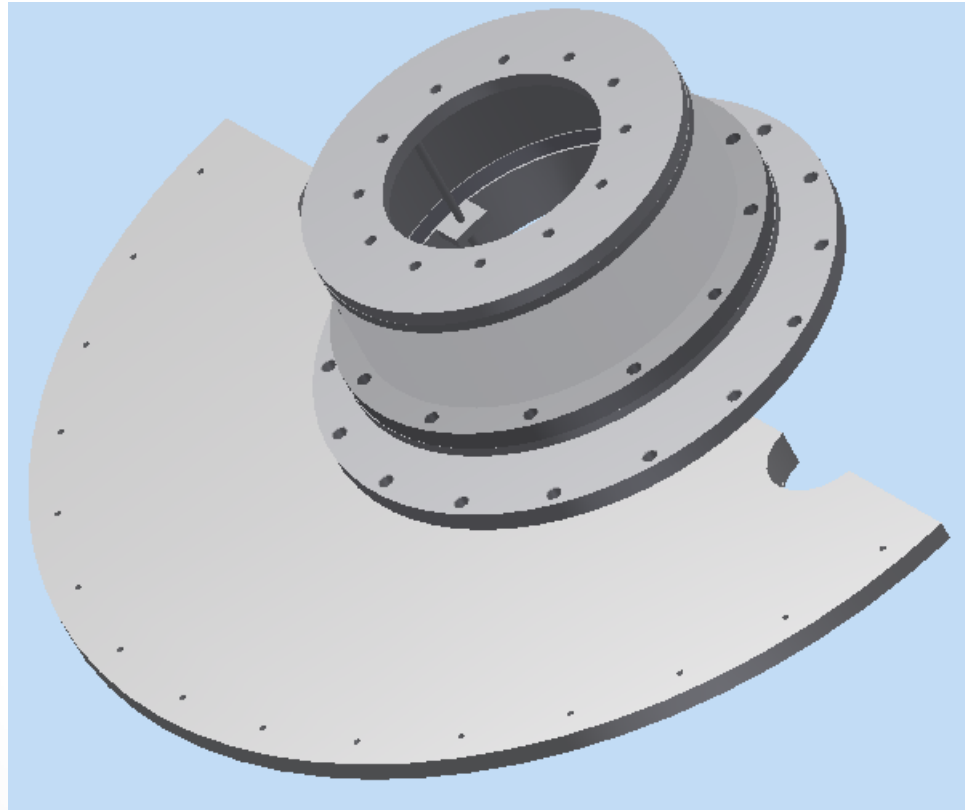
Sealing surface outside screws on detector side

Detector in solenoid



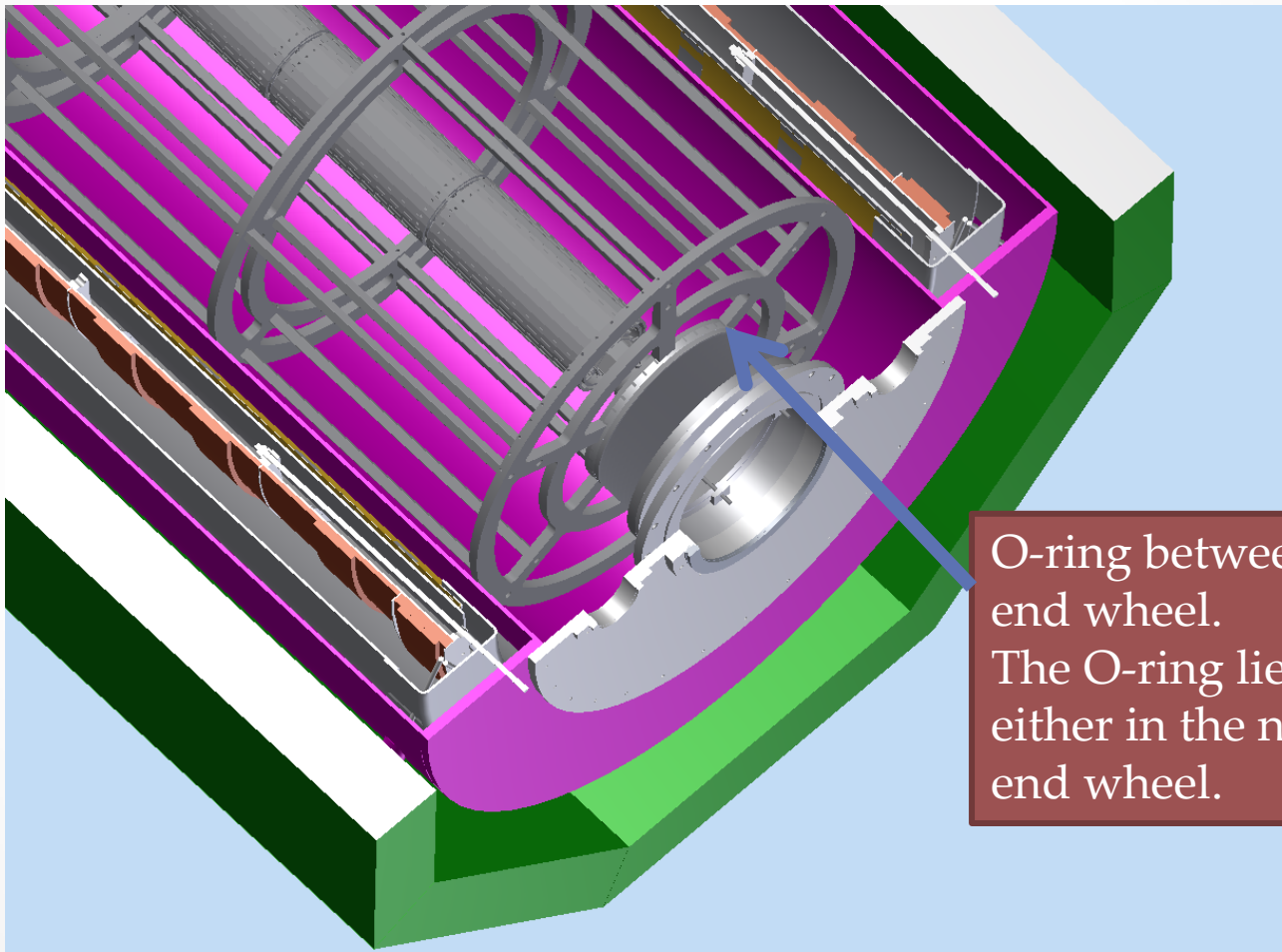
Rail system is not shown. Iron shield and Helium lid is removed on insertion side.

Premount nose on Helium lid (outside)



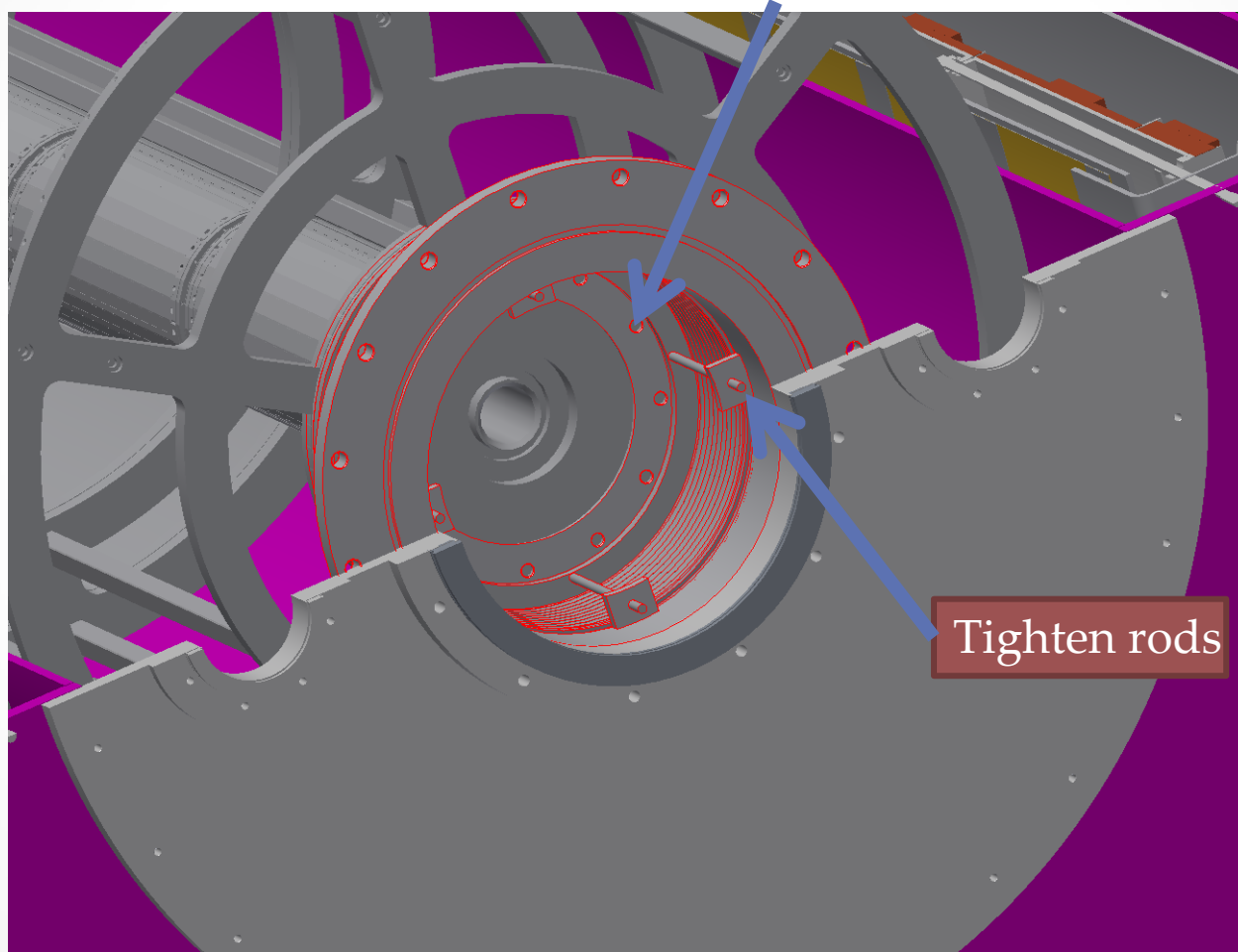
Before attaching the He lid inside attach cables to feedthroughs on the DN100's

Mount helium lid with attached nose

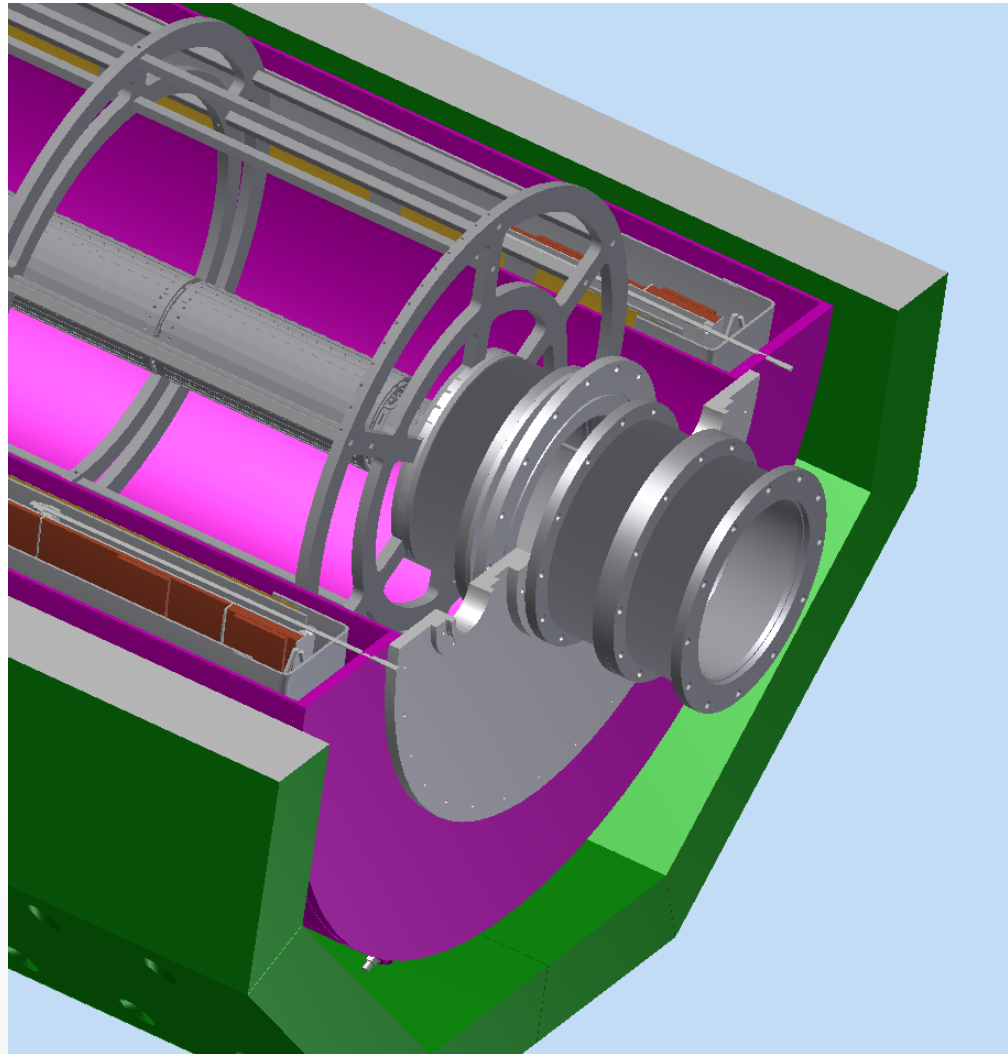


O-ring between nose and end wheel.
The O-ring lies in a groove either in the nose or the end wheel.

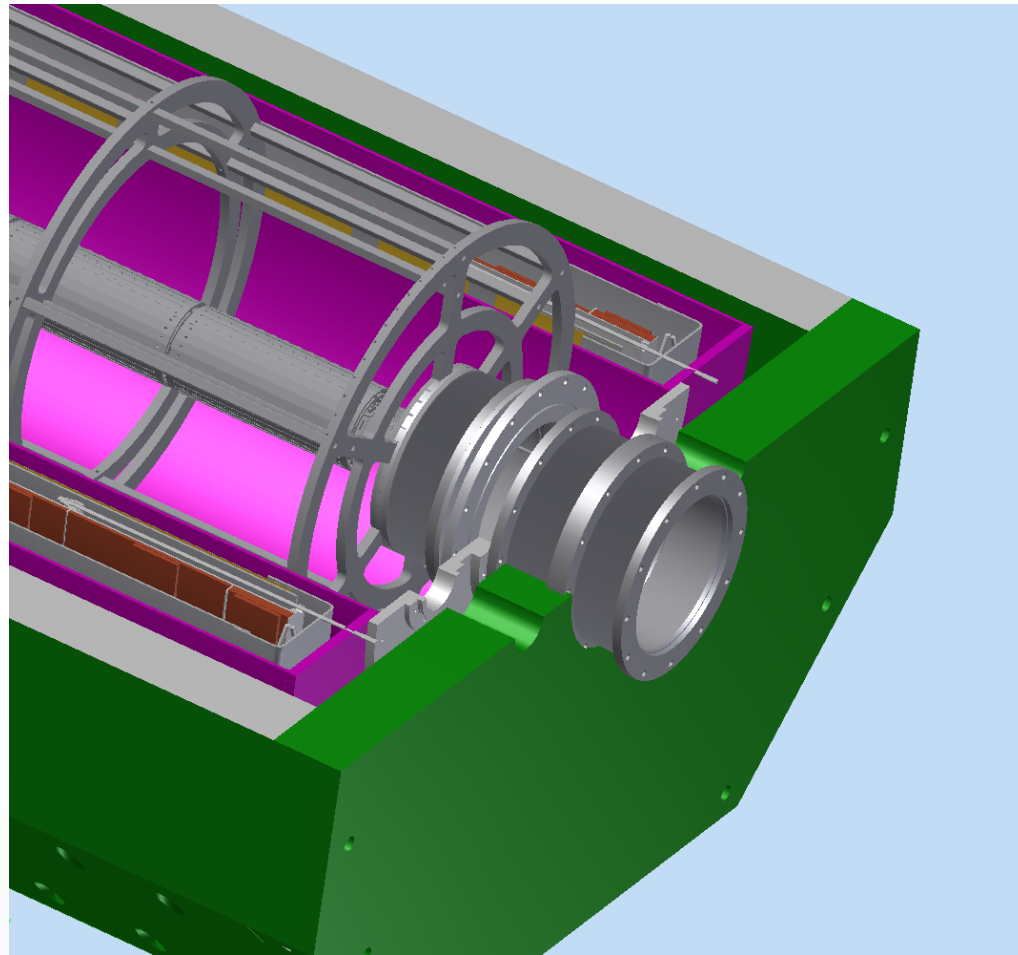
Tighten screws (nose to blind holes in end wheel)



Mount connection to outside (tube/bellow)

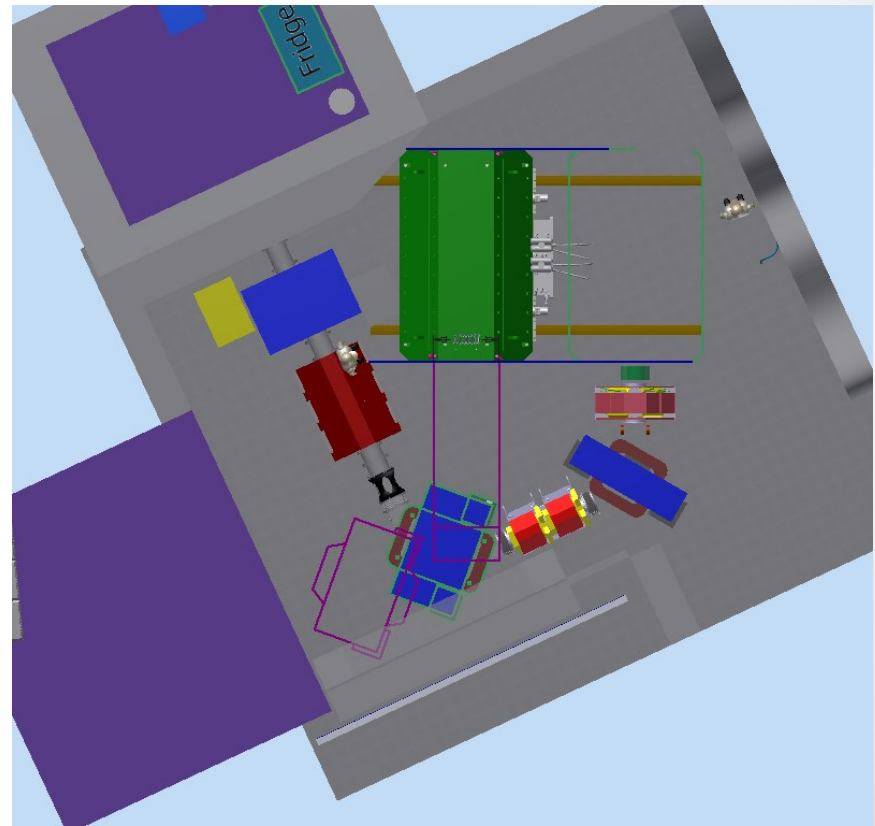
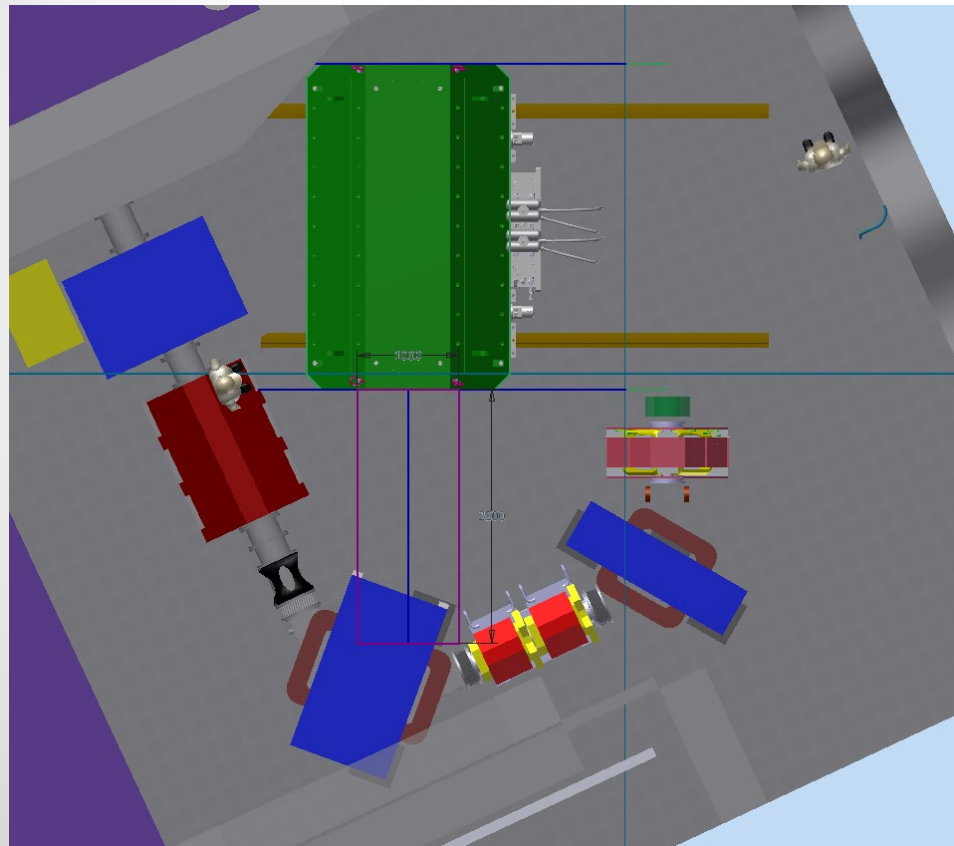


Mount iron shielding



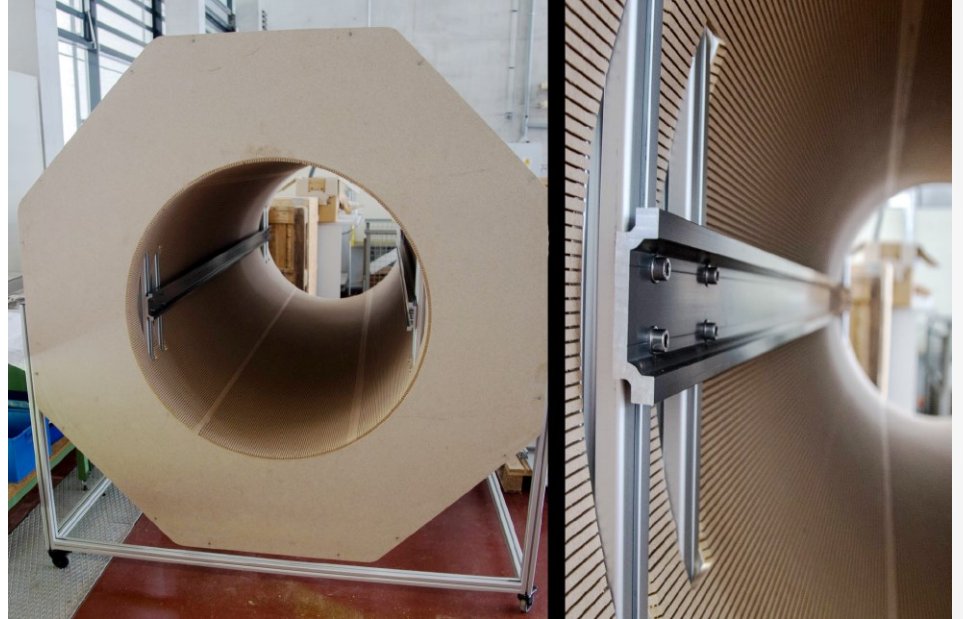
Feed cable through bores and mount iron shielding.

Move ASL → access one side w/o craning



Cage and rails in Magnet

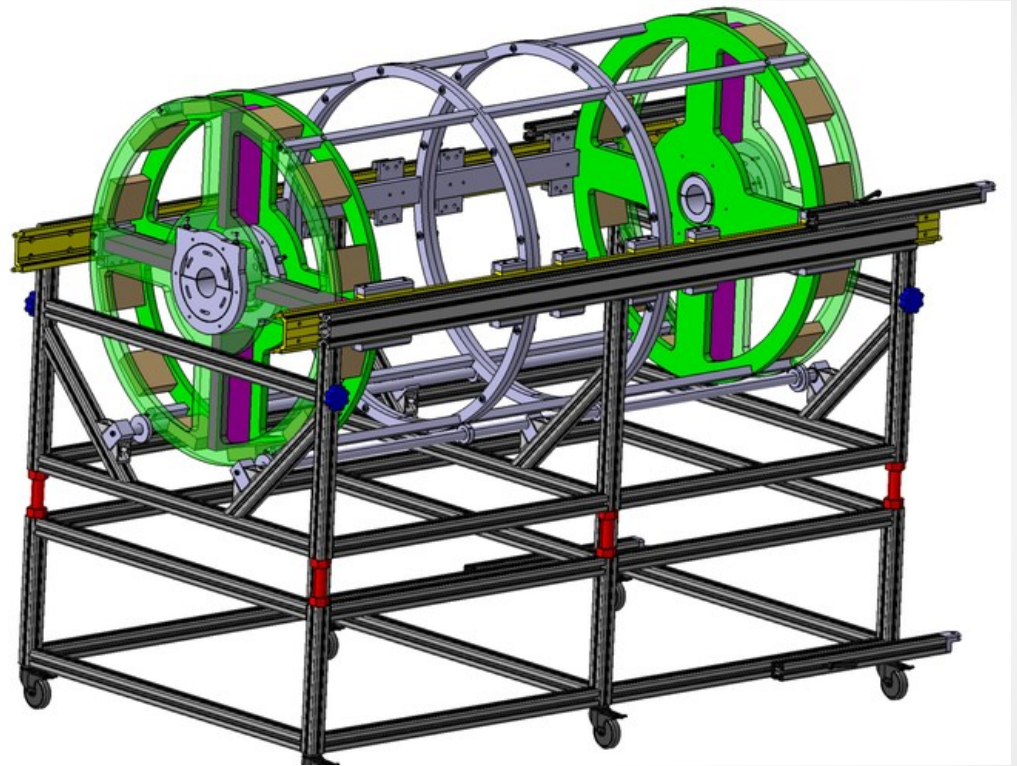
- ✓ Full-size mockup
 - ✓ Magnet
 - ✓ Rail system
 - ✓ Cage
 - ✓ Cart
 - Rotatable



Mockup of **magnet** and rail system

Cage and rails in Magnet

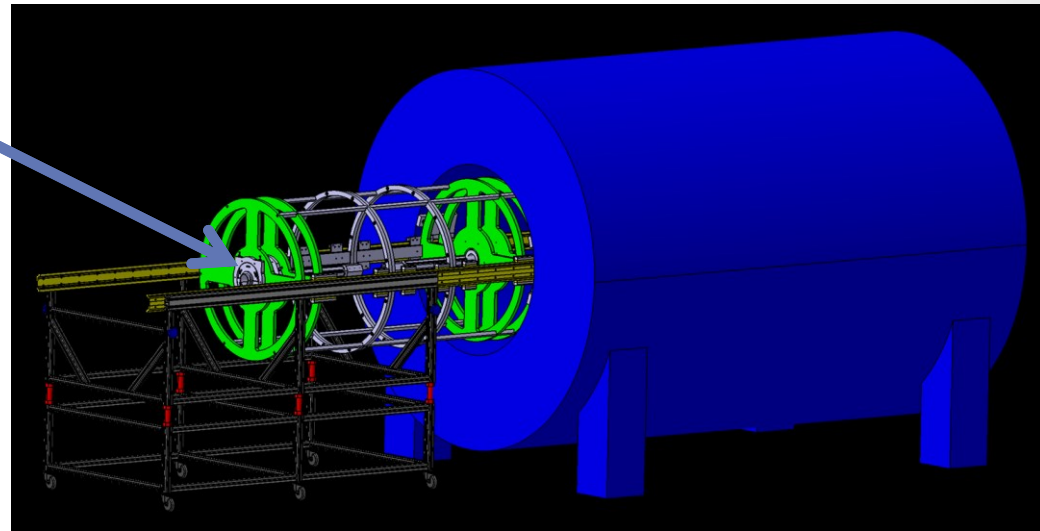
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Rotatable detector cart

Mu3e detector support

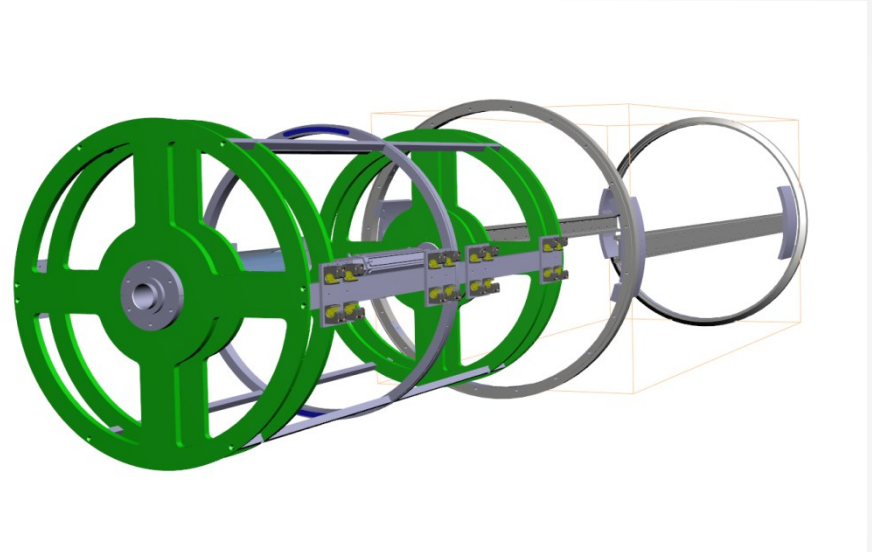
- Detector mounted in cage
 - Cage supports beam pipes
 - **Mechanical reinforcement studies ongoing**
 - **Simulation studies of beam pipe sag ongoing**
 - Cage is inserted on rails
- Rail system inside magnet
 - Mounted only to the magnet far ends



(Old) CAD of phase I detector

Mu3e rail system

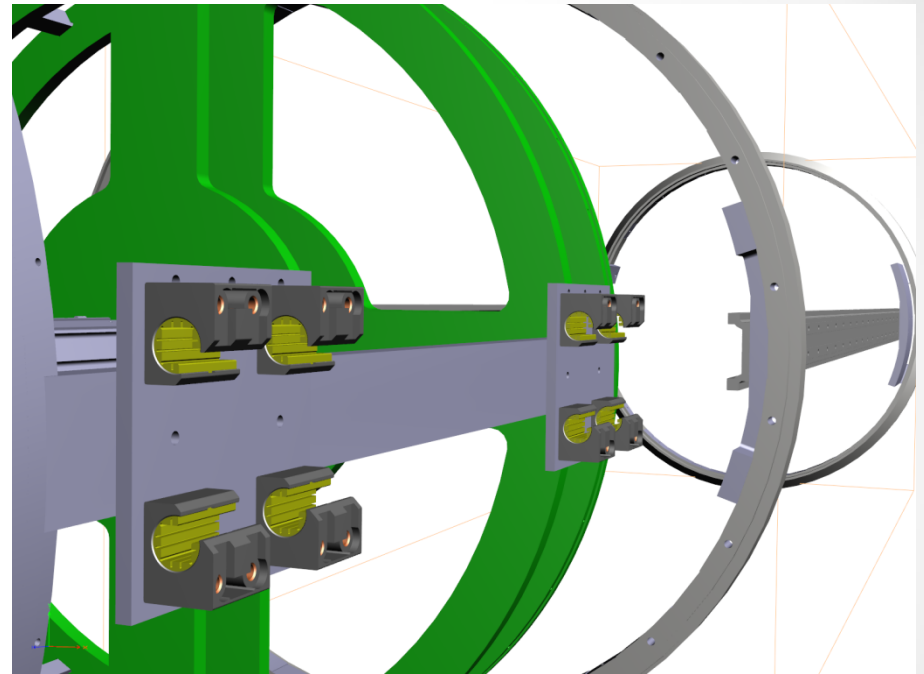
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- Rail system inside magnet
 - Mounted only to the magnet far ends
 - ...to avoid influence of thermal expansion etc.



(Old) CAD of rails inside magnet

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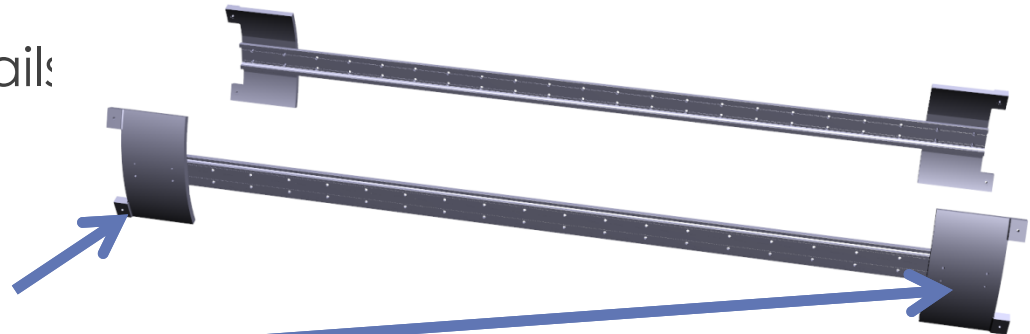
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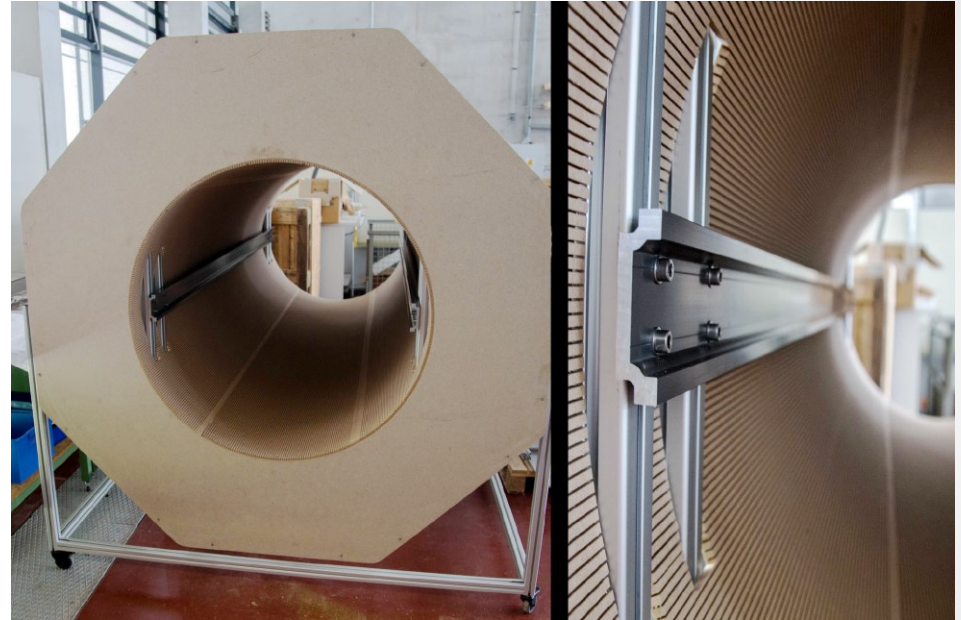
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Mockup of **magnet** and rail system

Summary

- Rail system
 - Healthy design
 - Prototype tested
- End plates
 - He enclosure
 - Beam pipe feedthrou
 - Signal and power feedthrough
- Magnet shield
 - Doors must respect feedthroughs

