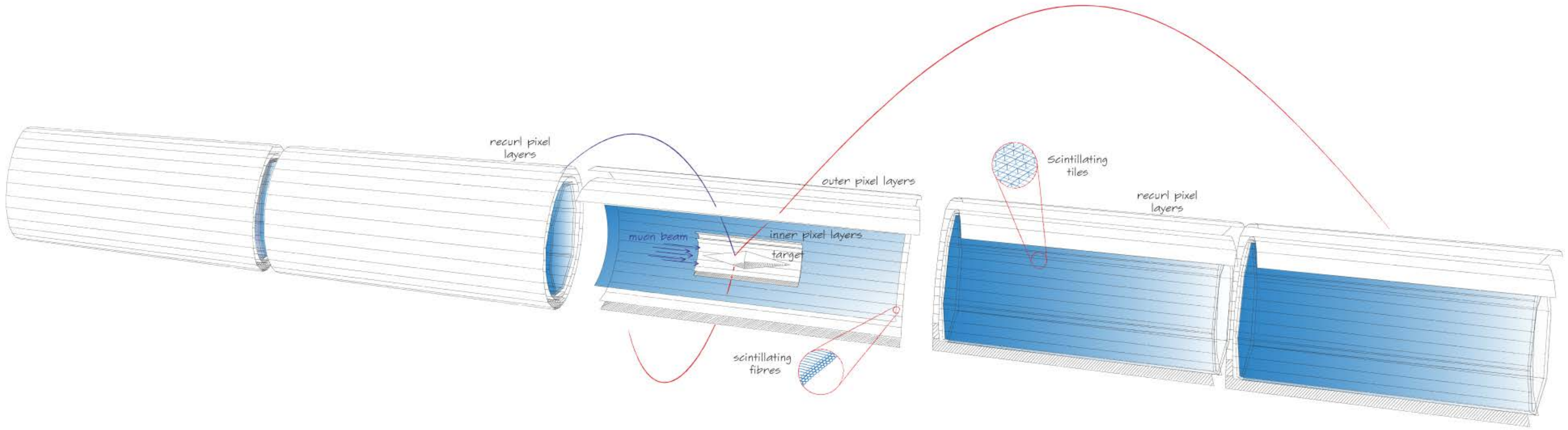
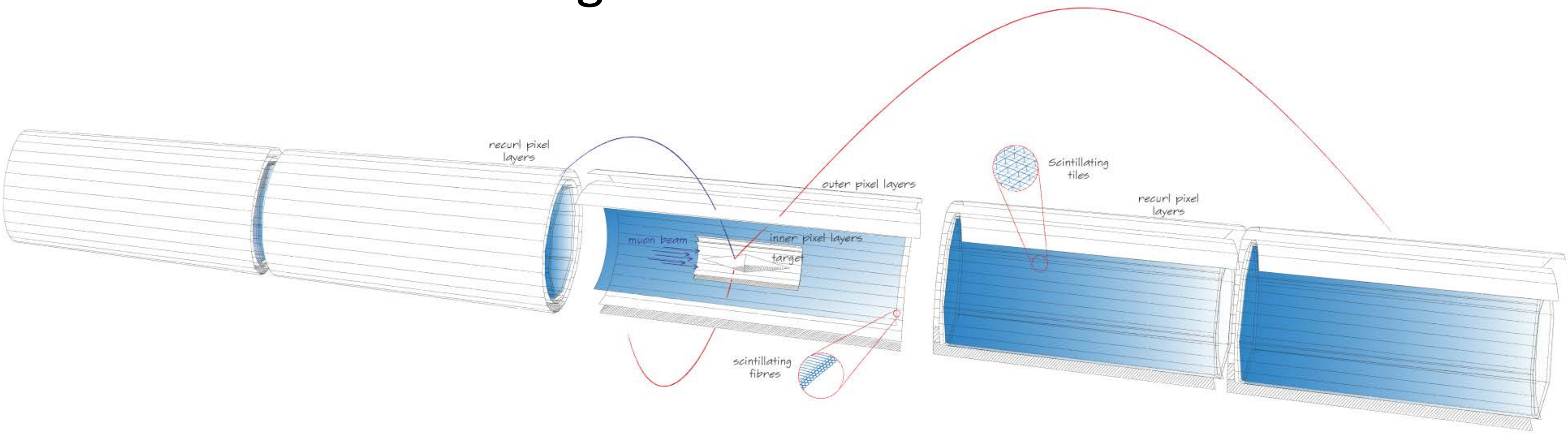
Ultra-Light Weight Mechanics and Cooling of the Mu3e Experiment

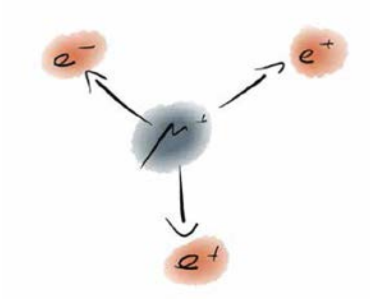


Bernd Windelband, University of Heidelberg, Germany
on behalf of the Mu3e collaboration

- Overview of the experiment
- Mechanical structure
- Cooling concept
- Integration



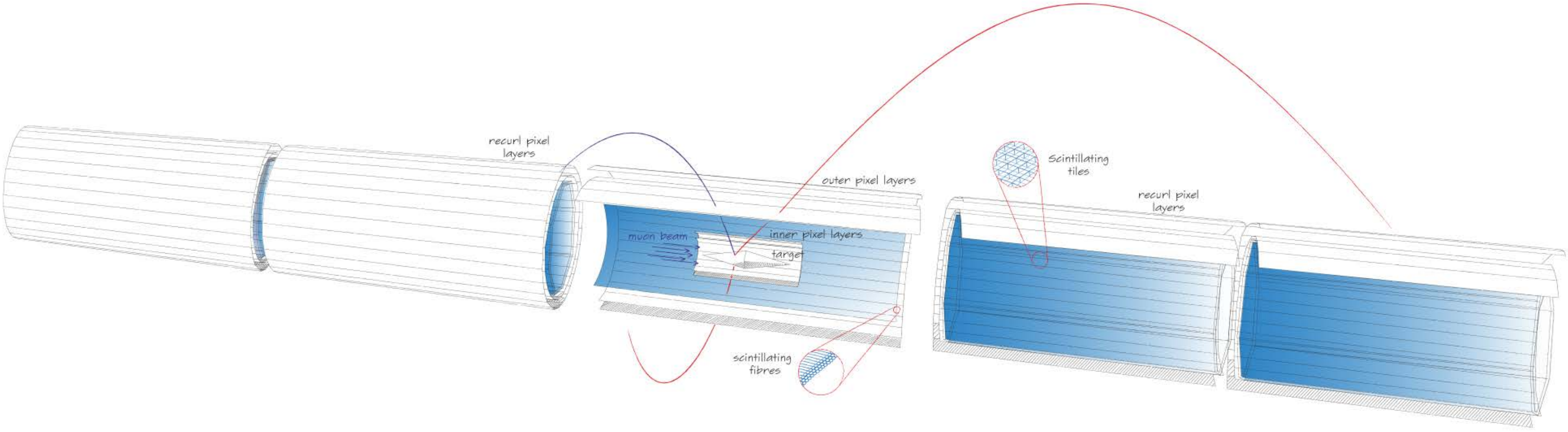
Goal of the Experiment



$\mu^+ \rightarrow e^+e^-e^+$

Observation of this decay points to physical processes

-> so far not described in the standard model



The Mu3e Collaboration

- DPNC, Geneva University
- Physics Institute, Heidelberg University
- KIP, Heidelberg University
- IPE, Karlsruhe Institute of Technology
- Paul Scherrer Institute
- Physics Institute, Zürich University
- Institute for Particle Physics, ETH Zürich
- Institute for Nuclear Physics, JGU Mainz

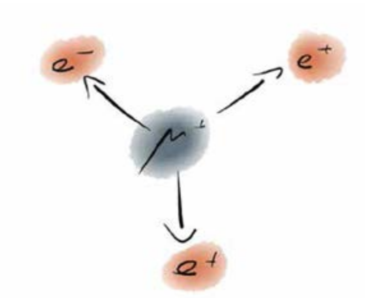
Muons from PSI

Paul Scherrer Institute in Villigen, Switzerland

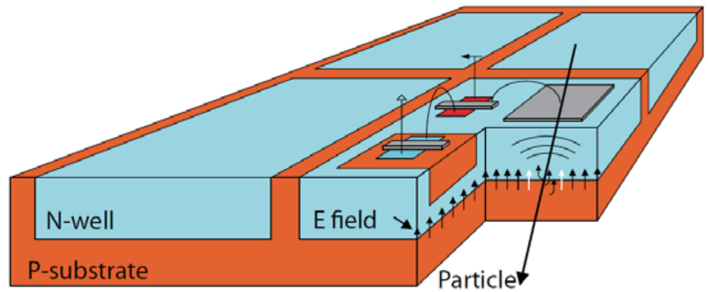
Mu3e Experiment

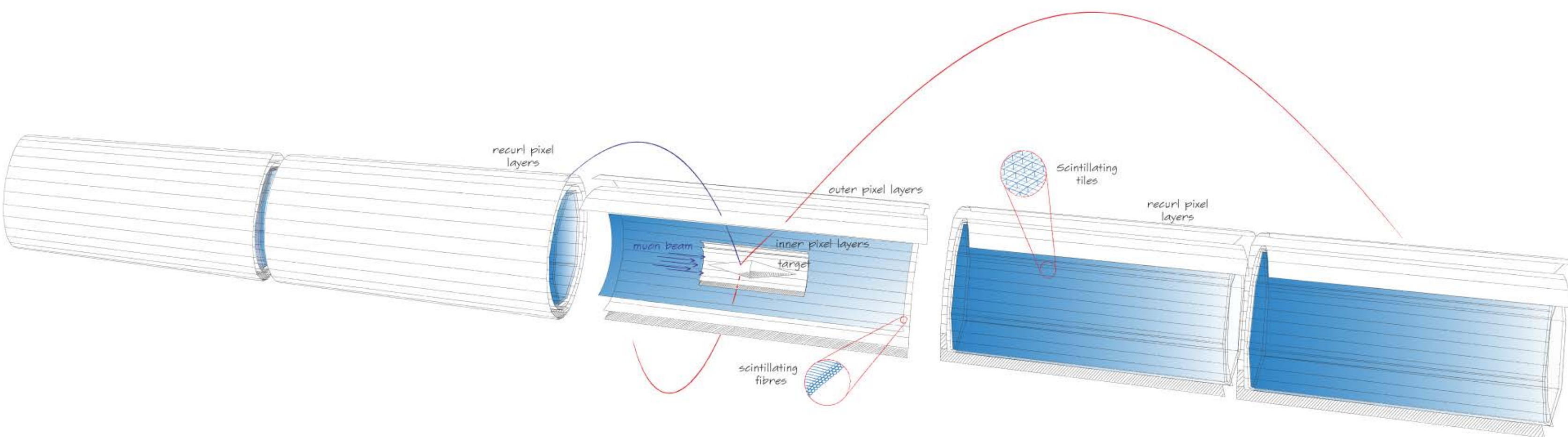
-> Combination of three detector technologies

-> High **V**oltage-**M**onolithic **A**ctive **P**ixel **S**ensor (HV-MAPS)



$\mu^+ \rightarrow e^+e^-e^+$

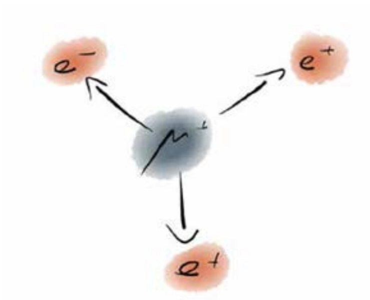




Mu3e Experiment

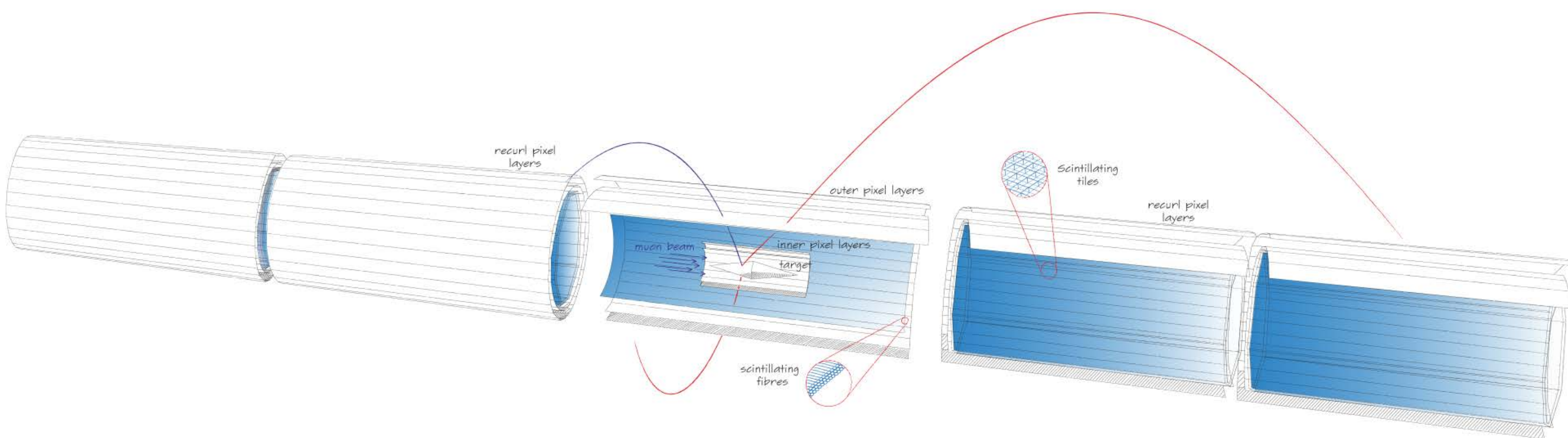
-> Combination of three detector technologies

- High Voltage-Monolithic Active Pixel Sensor (HV-MAPS)
- **Sci**ntillating **Fi**ber Tracker



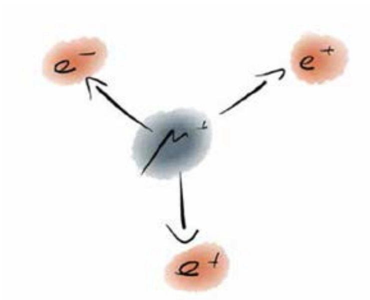
$\mu^+ \rightarrow e^+e^-e^+$

3-5 Layers of 250 µm SciFi
Read-out by SiPM‘s



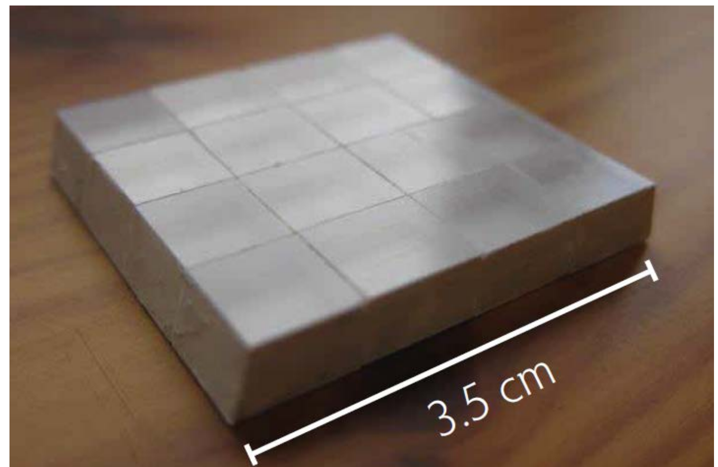
Mu3e Experiment

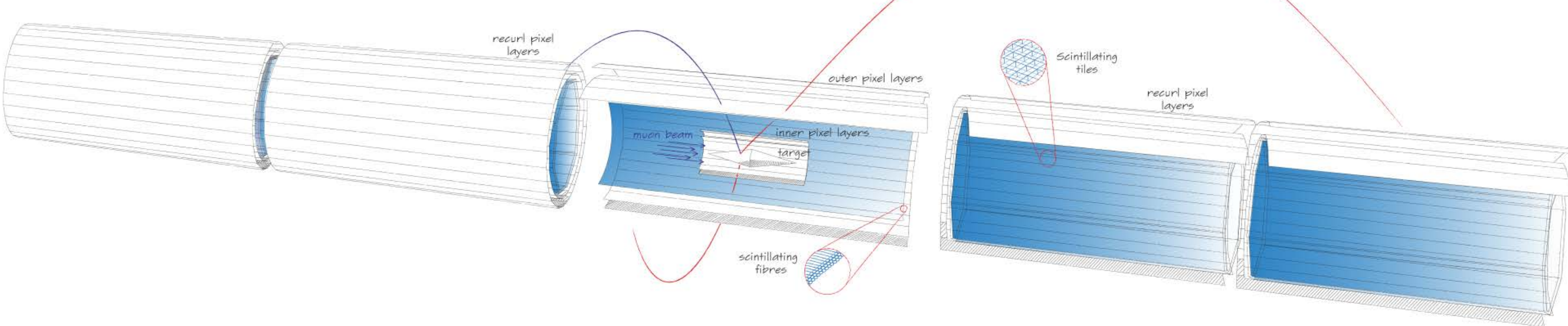
-> Combination of three detector technologies



$\mu^+ \rightarrow e^+e^-e^+$

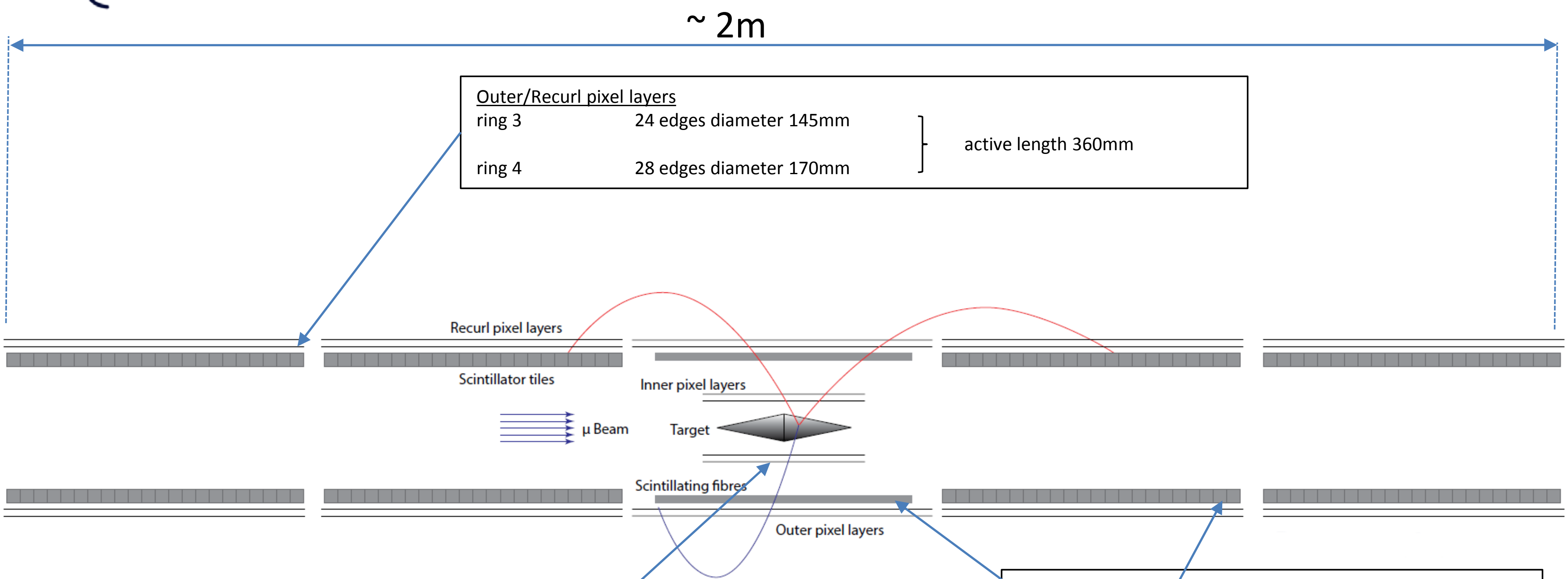
- High Voltage-Monolithic Active Pixel Sensor (HV-MAPS)
- Scintillating Fiber Tracker
- Scintillating Tile Detector





Mu3e Experiment

Overall Dimensions - Side view



Outer/Recurl pixel layers

ring 3	24 edges diameter 145mm	active length 360mm
ring 4	28 edges diameter 170mm	

Scintillating fibres

edges 24	diameter 124mm	active length 312mm

Scintillator tiles

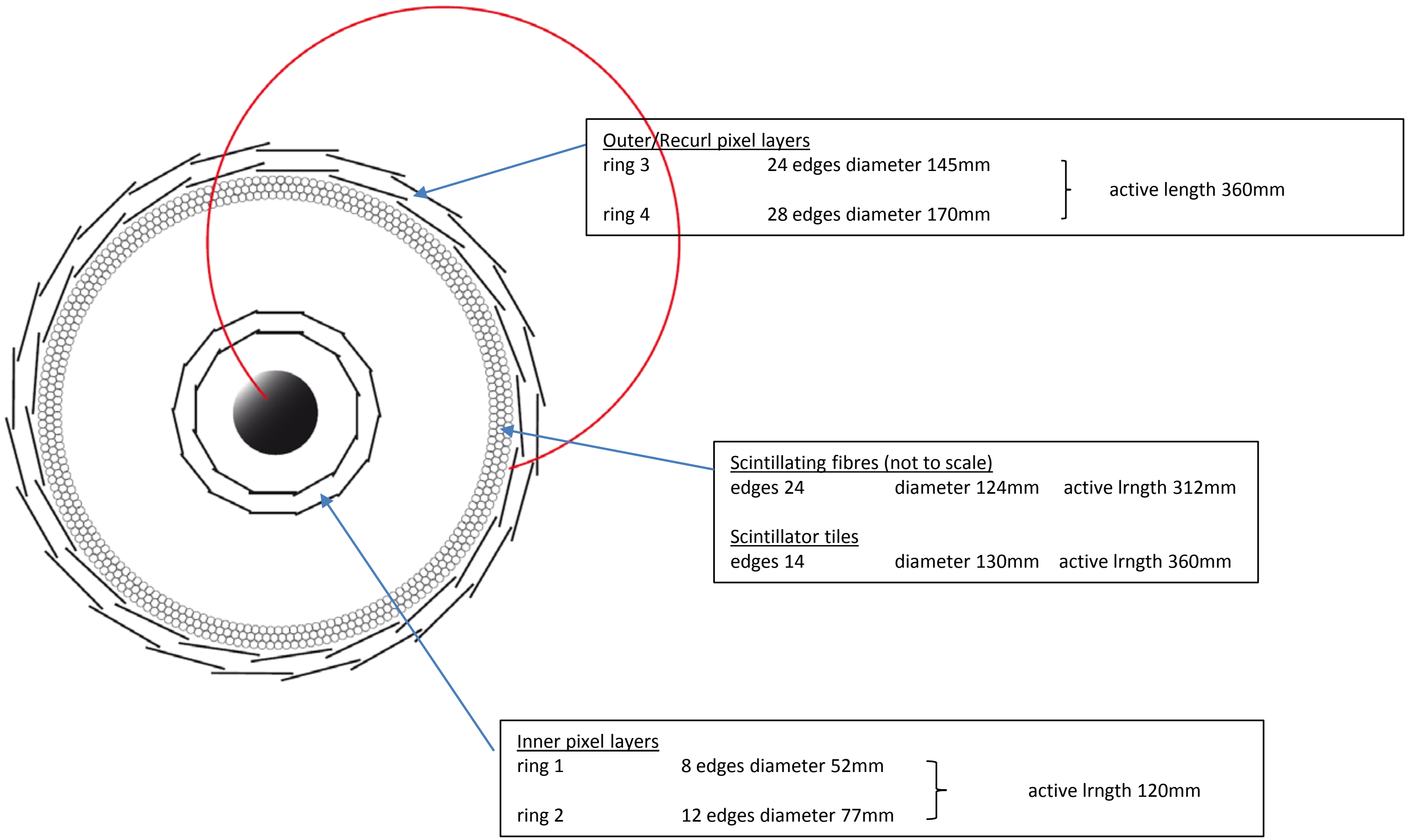
edges 14	diameter 130mm	active length 360mm

Inner pixel layers

ring 1	8 edges diameter 52mm	active length 120mm
ring 2	12 edges diameter 77mm	

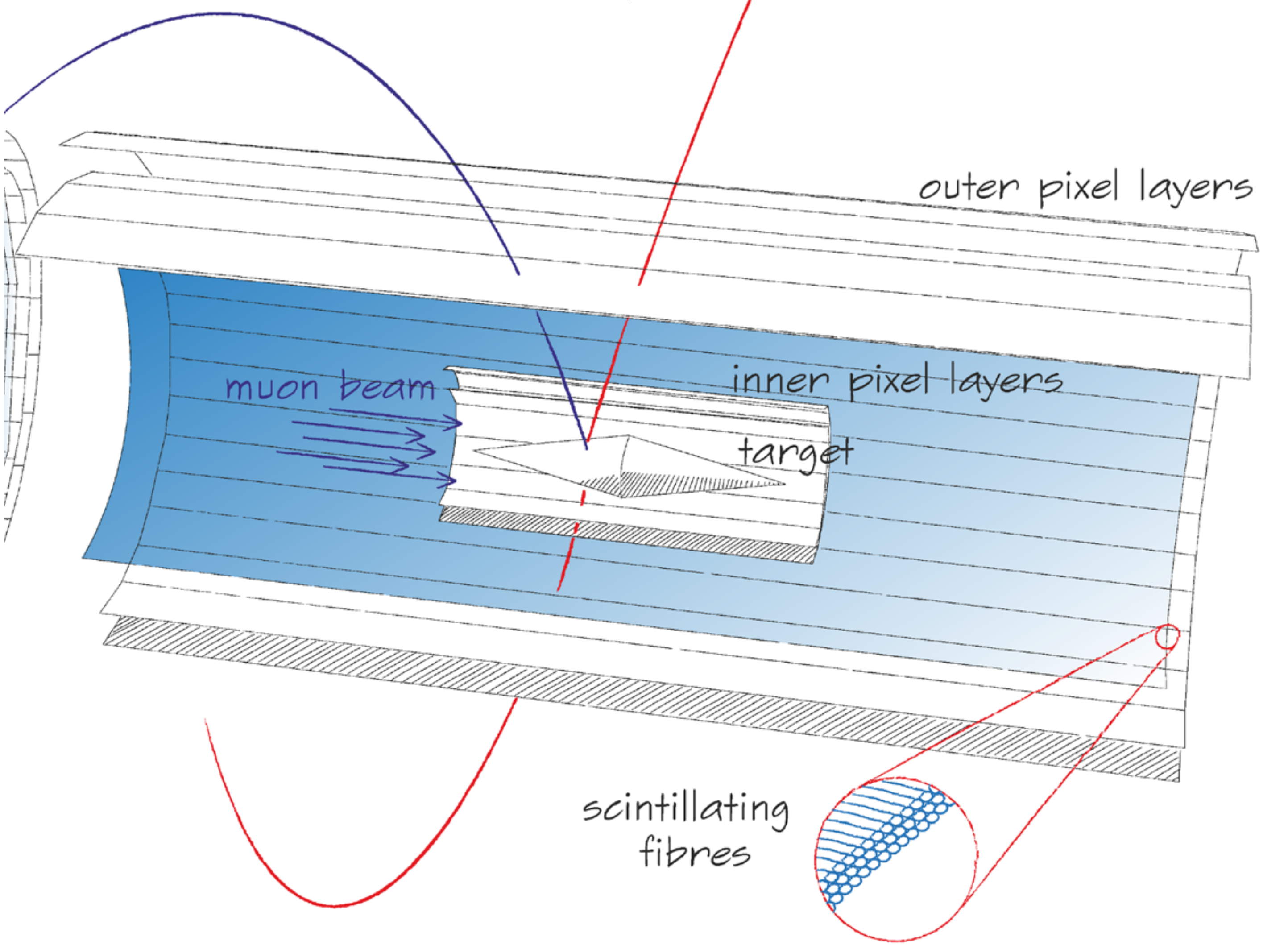
Mu3e Experiment

Overall dimensions - transverse cut to beam direction



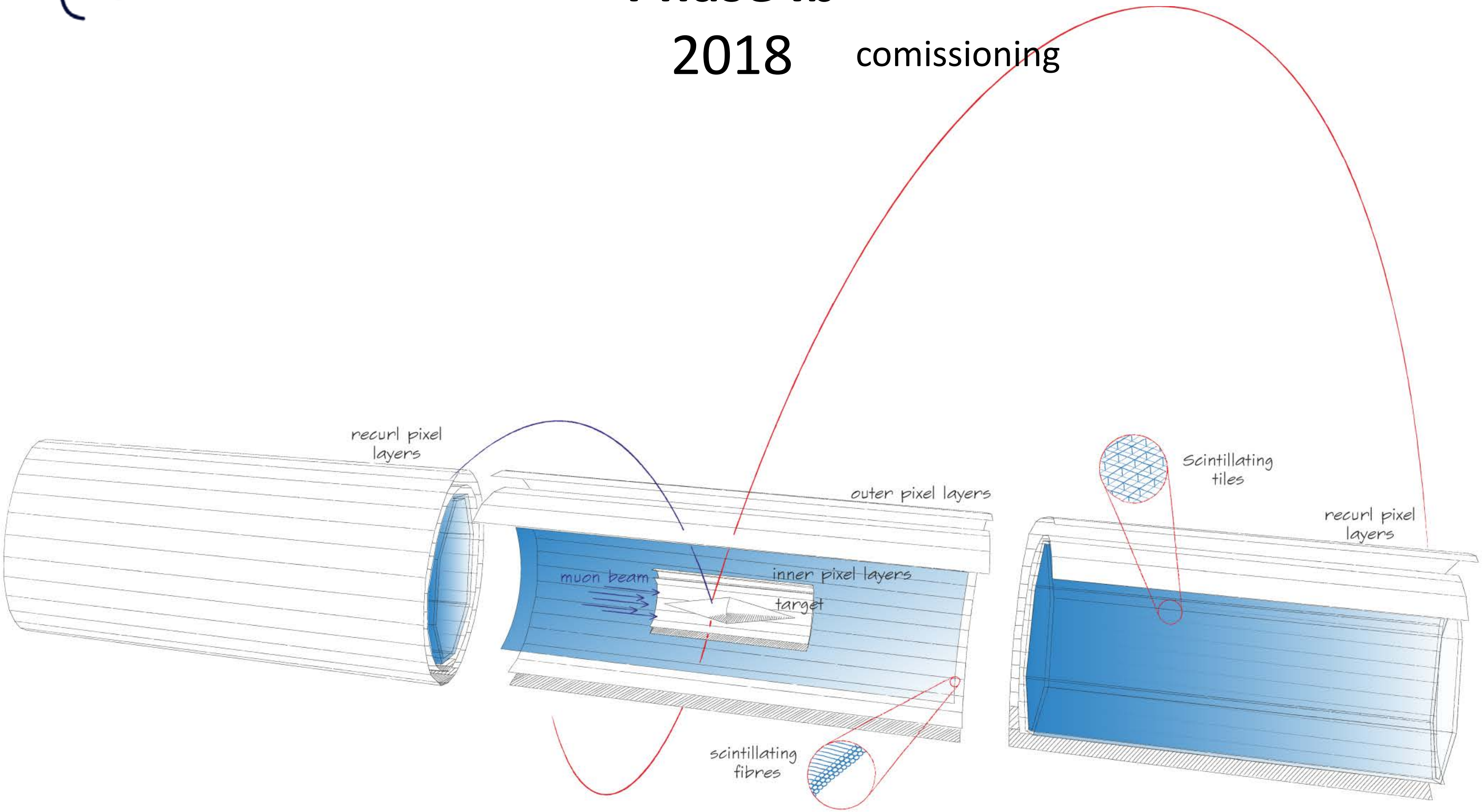
Phase Ia

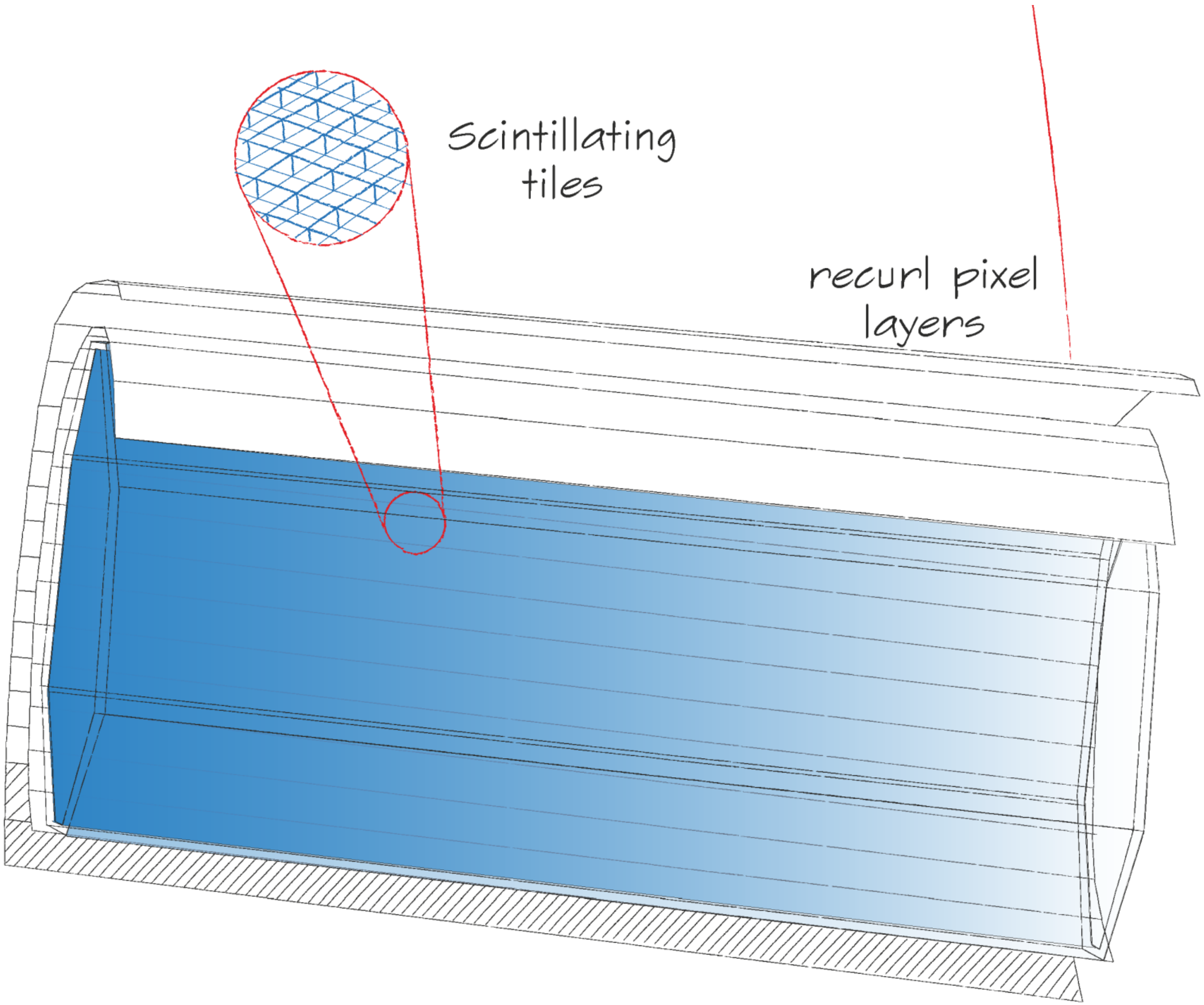
2017 comissioning



Phase Ib

2018 comissioning

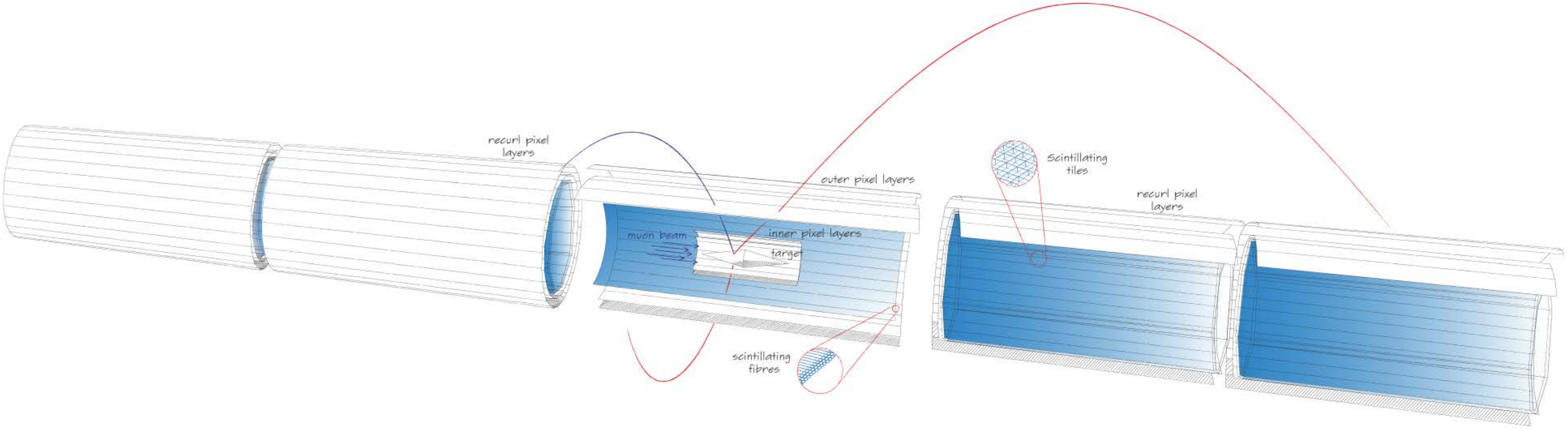



Scintillating
tiles
recurl pixel
layers

Phase II

Final Setup ~2020

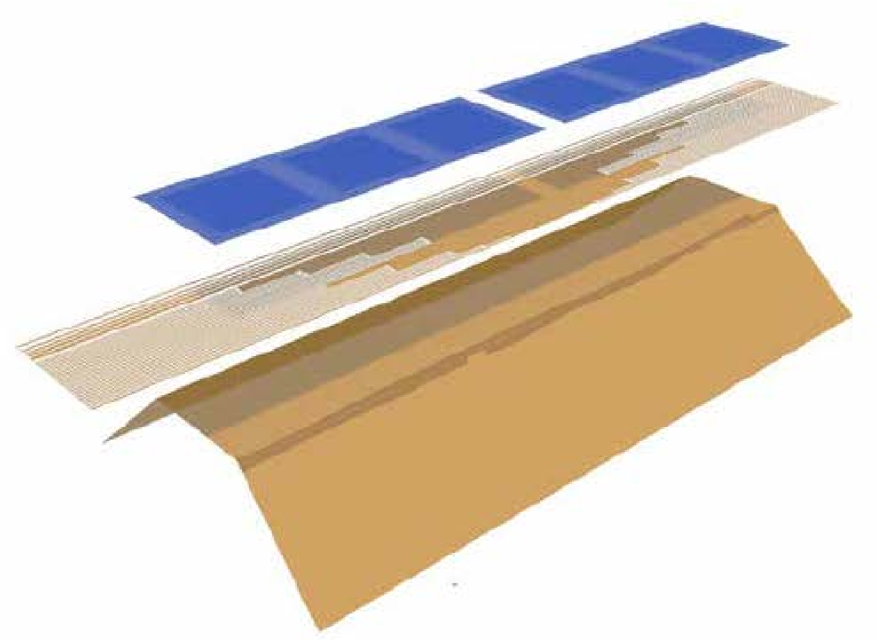
final beamline



Mechanical Structure

Mechanics

Maximum stiffness -> no material



- 50 µm silicon
- 25 µm Kapton™ flexprint with aluminium traces
- 25 µm Kapton™ frame as support
- Less than 1‰ of a radiation length per layer

Mechanical Structure

First design approach

Base support structure of innermost pixel layer

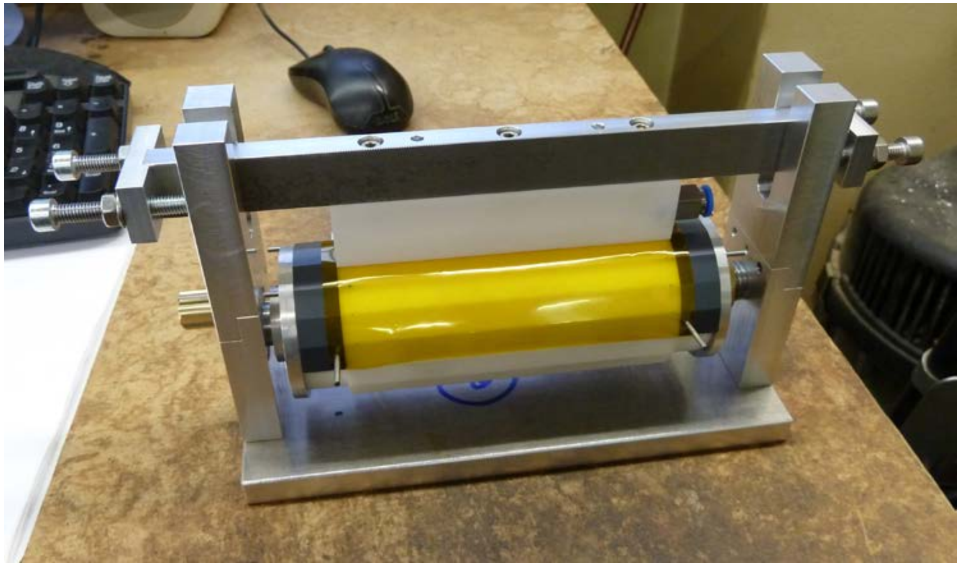
Half shell

Full cylinder
connected by front rings

Mechanical Structure

Inner pixel layers

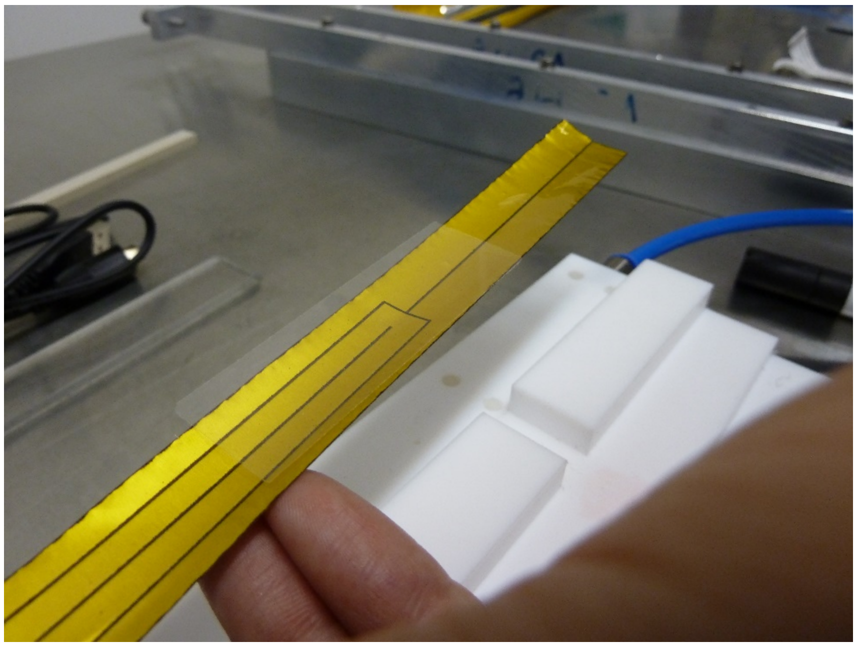
Inner pixel layers with dummy Si HV-MAPS and flexprint mounted to Al end wheels and PVC end rings

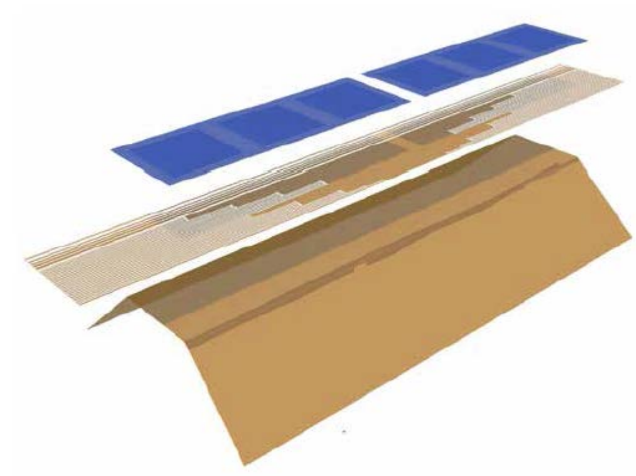


Mounting jig for layers 1 and 2

Mechanical Structure

First design approach

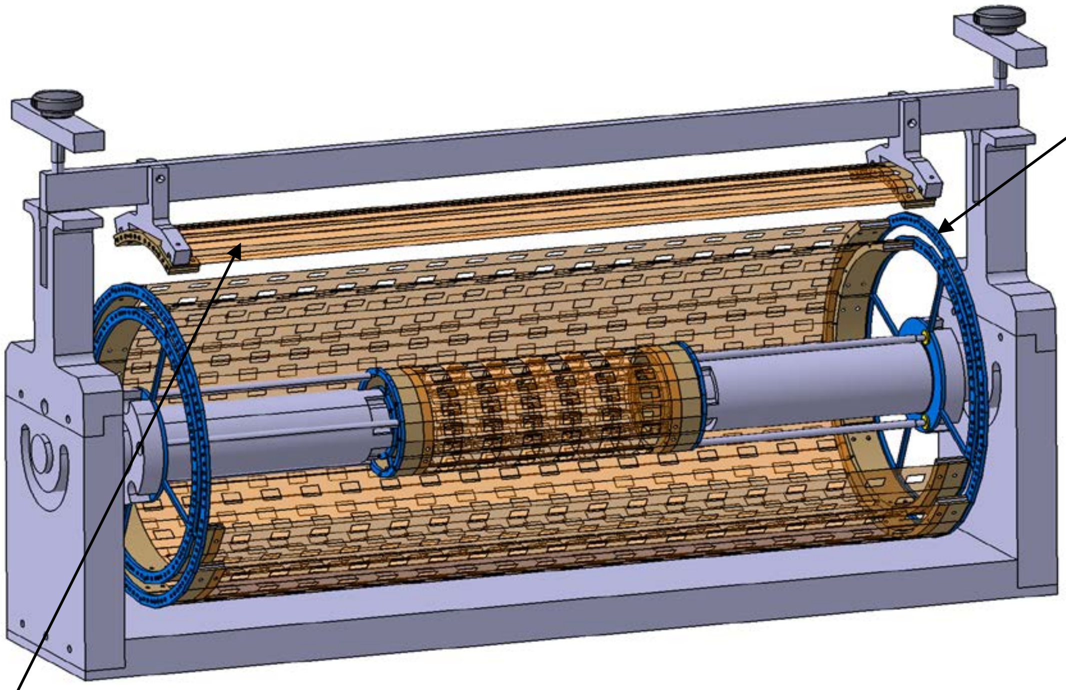




Aluminized Kapton foil	->	flexprint dummies
50 µm glass plates	->	Si HV-MAPS - dummies

Mechanical Structure

Basic design concept for central station (V0)



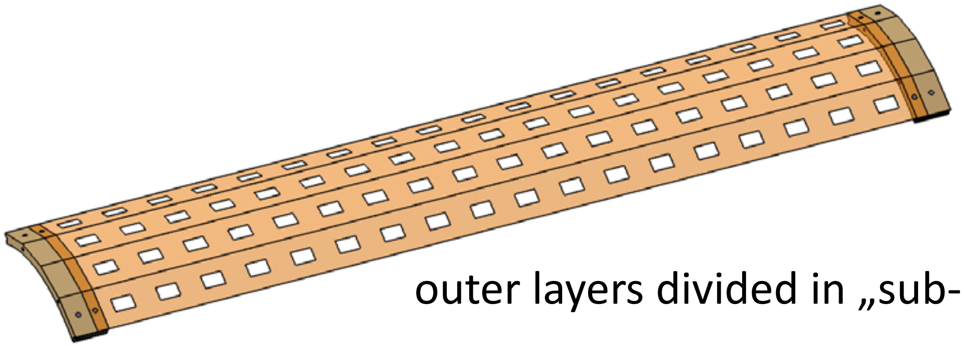
End wheel supports

-> pixel layers
-> inner pixel layers
-> cooling distribution system

subdivision because of
-> failure
-> handling (bonding)

Mechanical Structure

outer pixel layers

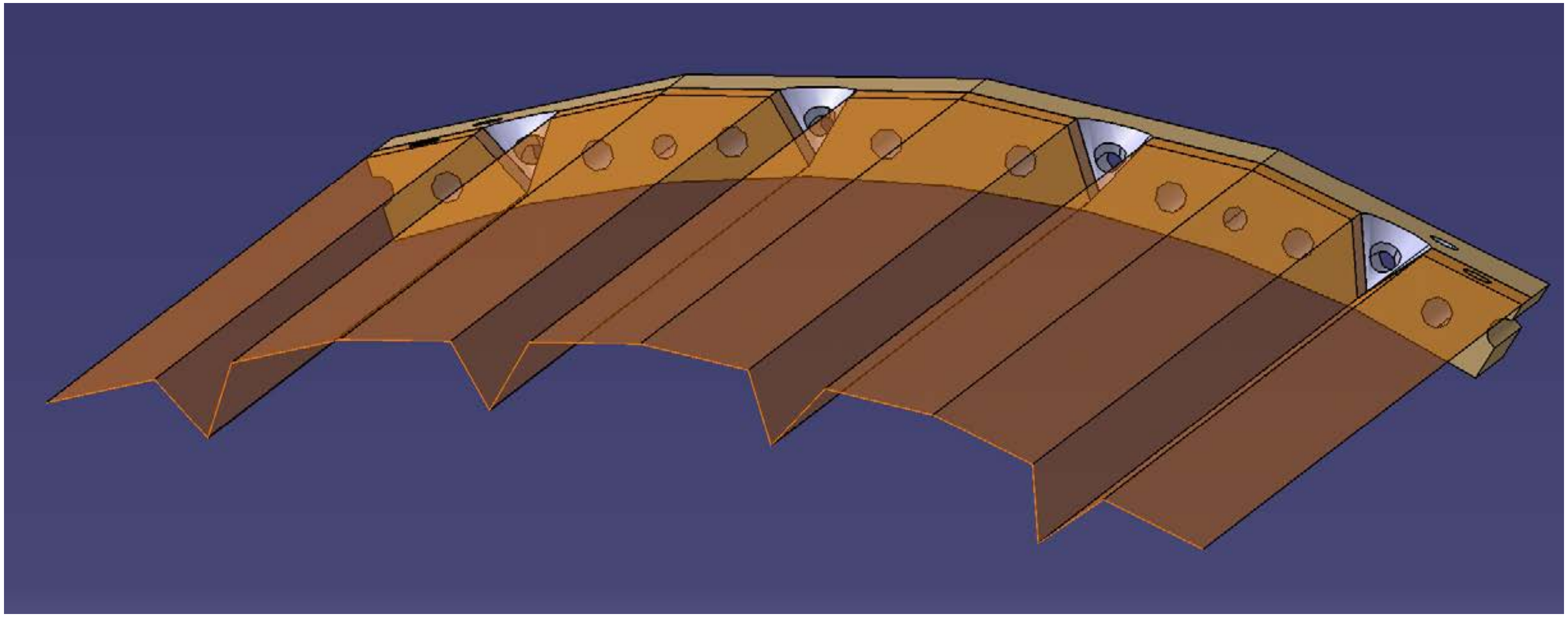


outer layers divided in „sub-layers“

no sufficient stability

Mechanical Structure

outer pixel layers

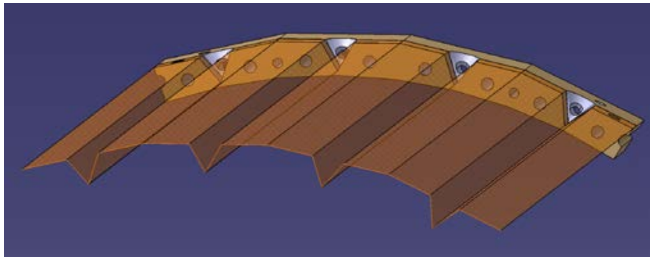


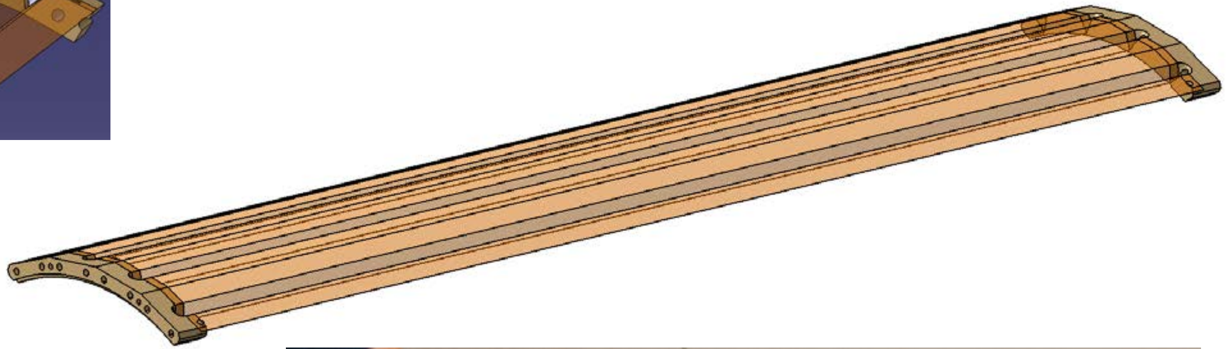
reinforcement of support by
„V“-shaped structure

-> provides sufficient stability
-> serves as local cooling supply line

Mechanical Structure

outer pixel layers



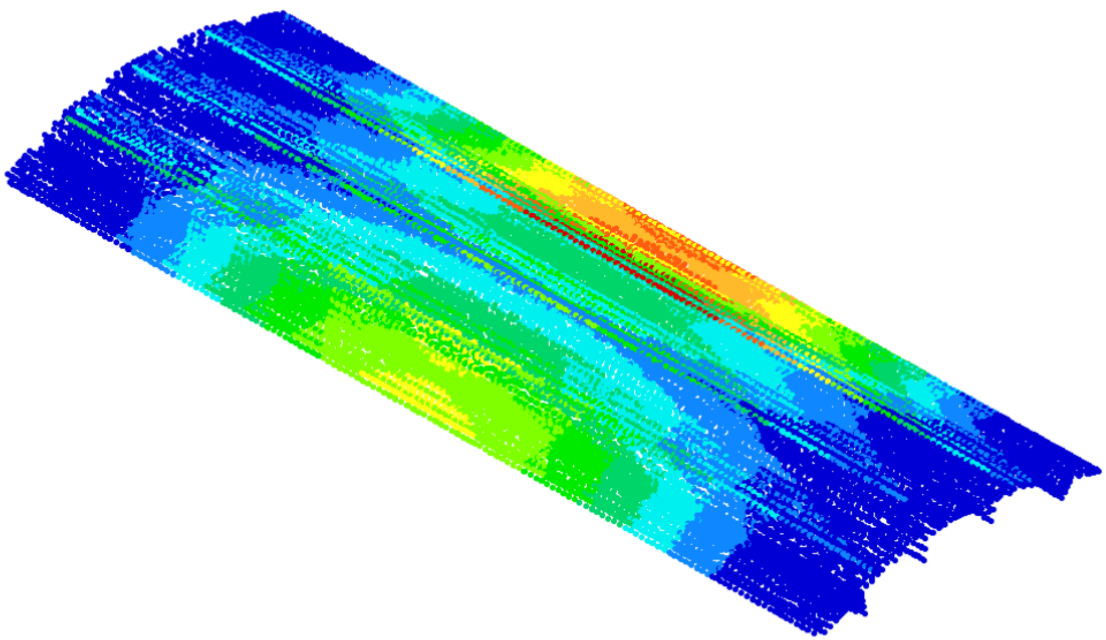


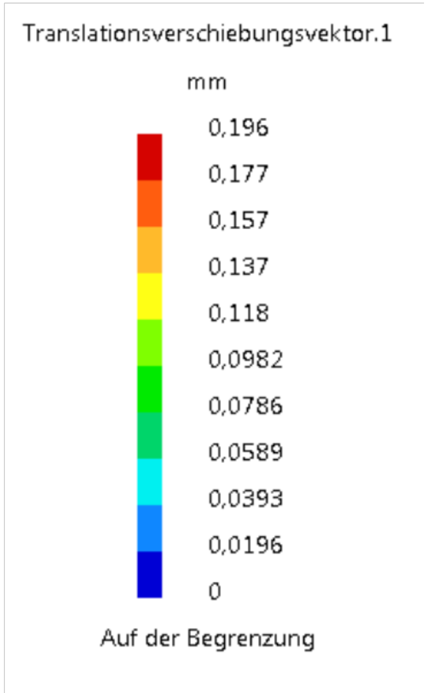
Reinforcement of support by „V“-shaped structure

-> provides sufficient stability
-> serves as local cooling supply line

Mechanical Structure

FE-calculations





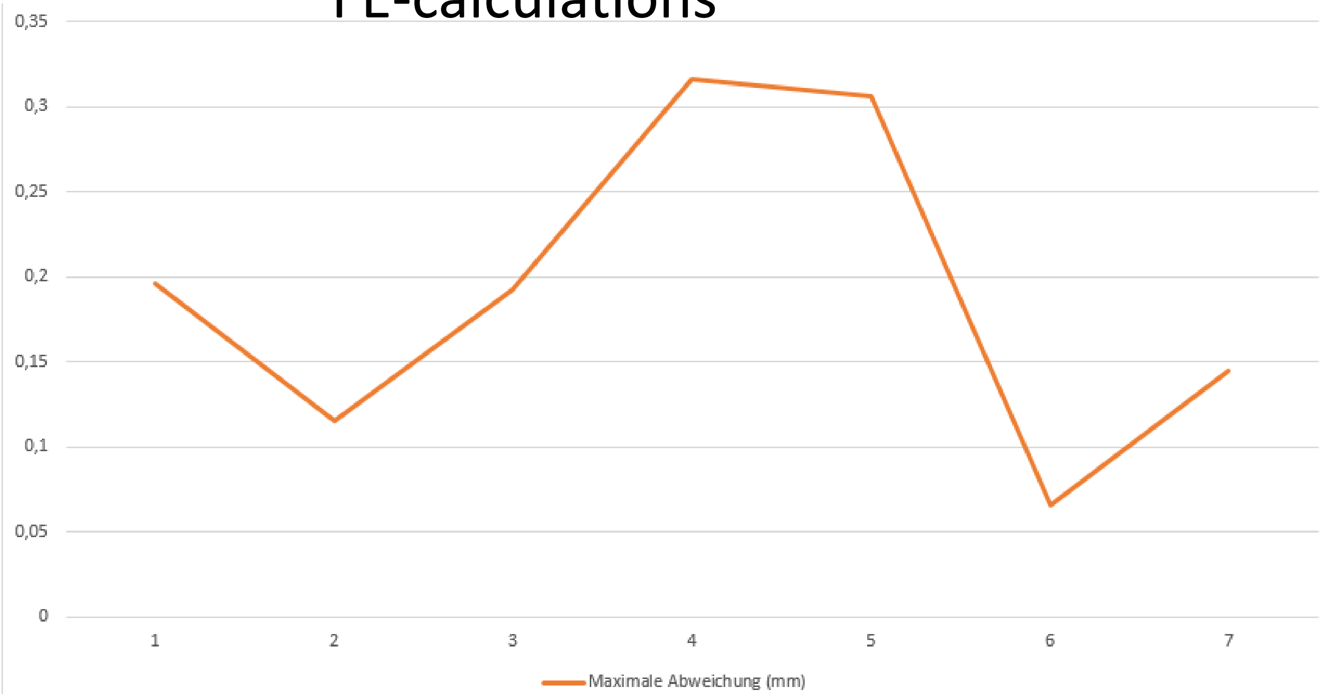
Results of position 1

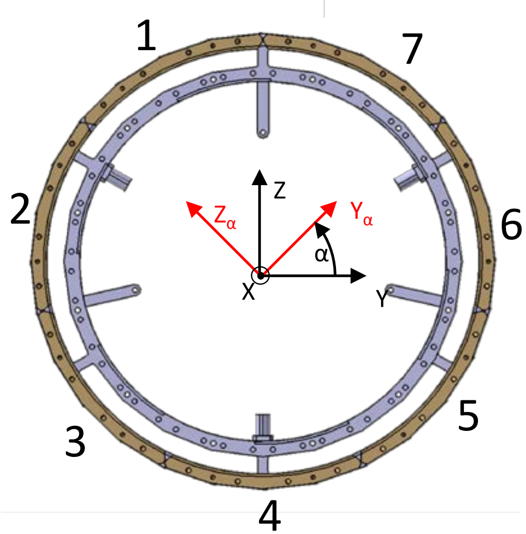
Simulations by
T. Mittelstaedt

Mechanical Structure

FE-calculations

Position	Maximale Abweichung (mm)
1	0,196
2	0,115
3	0,192
4	0,316
5	0,306
6	0,066
7	0,145



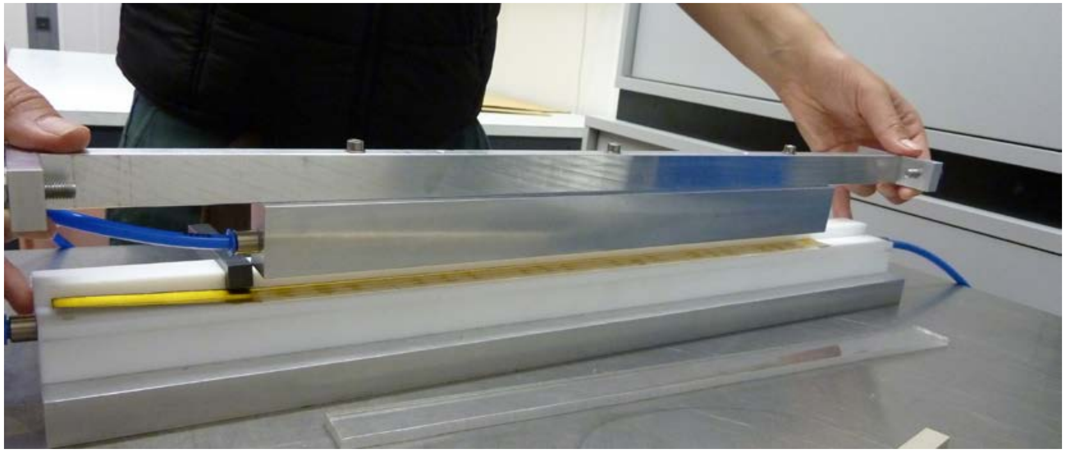


Deformation caused by gravity

7 different positions α (0°-360°)

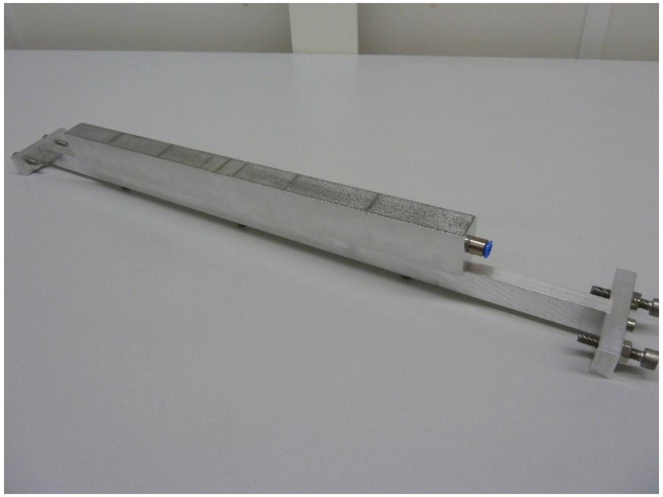
Simulations by
T. Mittelstaedt

Mechanical Structure
outer pixel layers - tooling

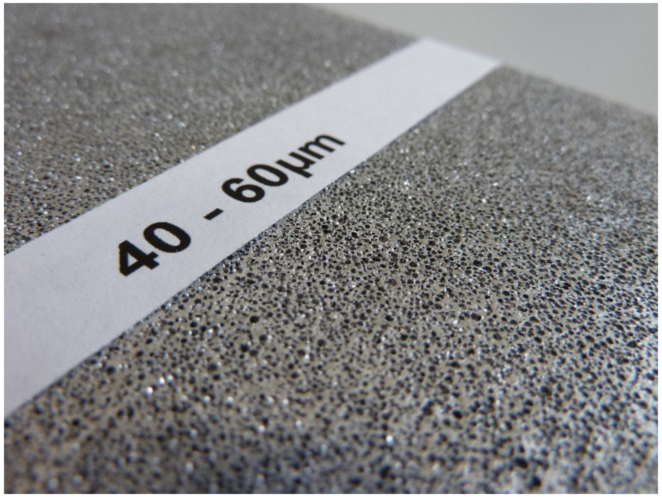


Vacuum jig gor glueing

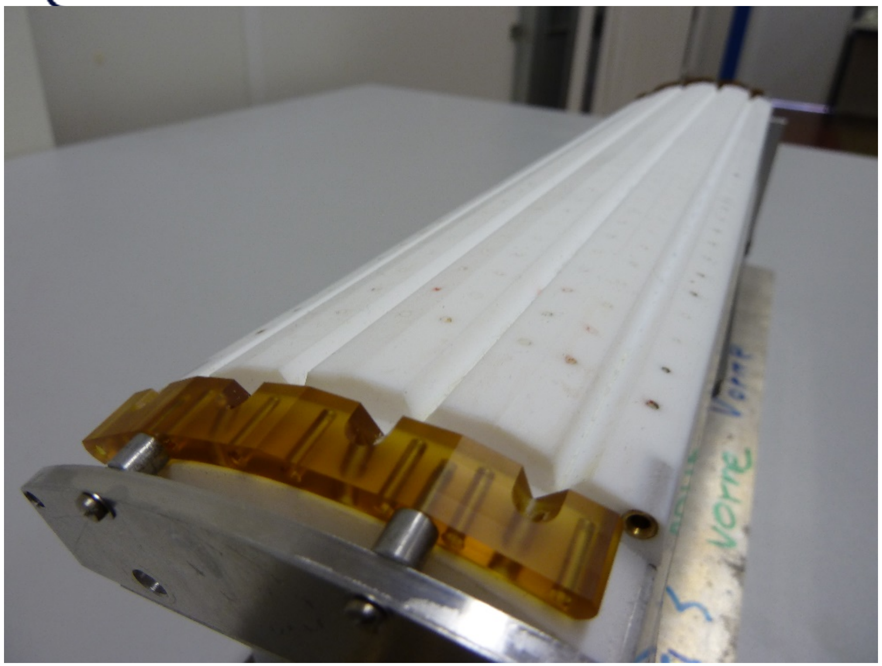
-> HV-MAPS to flexprint
-> unit to support structure



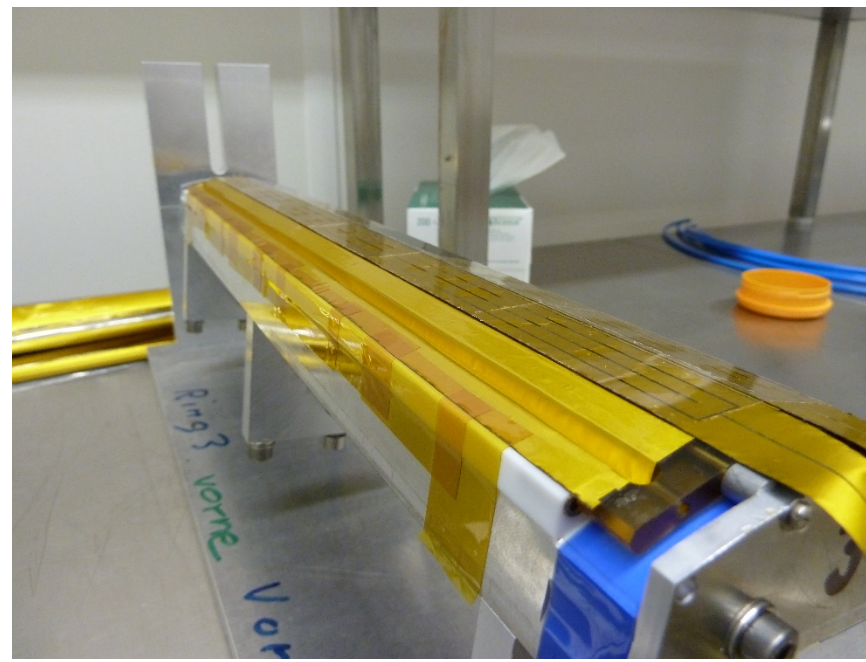
porose Al-plate provides uniform distribution of loads generated by the vacuum



Mechanical Structure
outer pixel layers - tooling



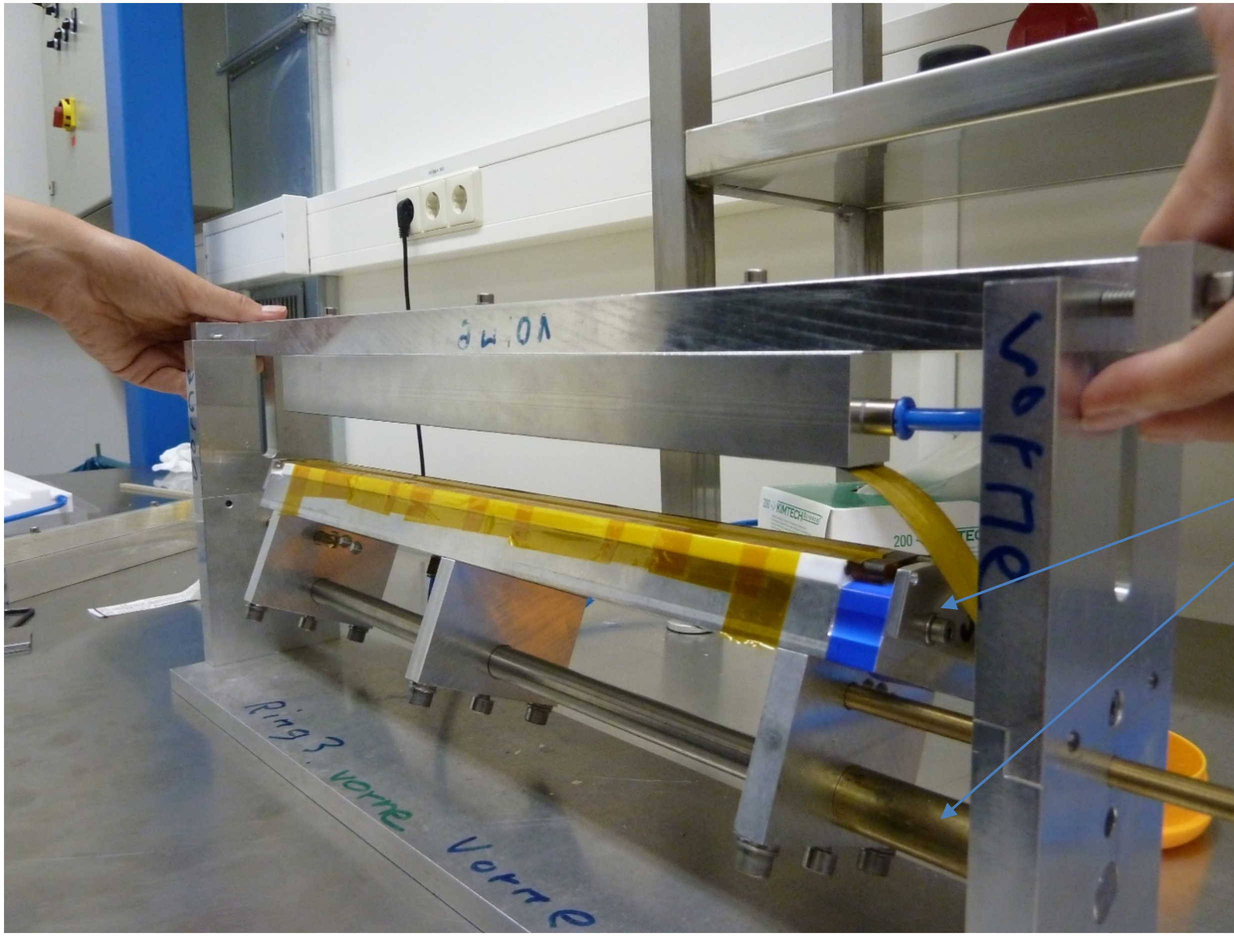
Glueing of HV-MAPS / flexprint unit
to support structure



Vacuum jig

-> to sugg Kapton support structure

Mechanical Structure
outer pixel layers - tooling



adjustable angle for mounting several units on one sub-layer

Mechanical Structure

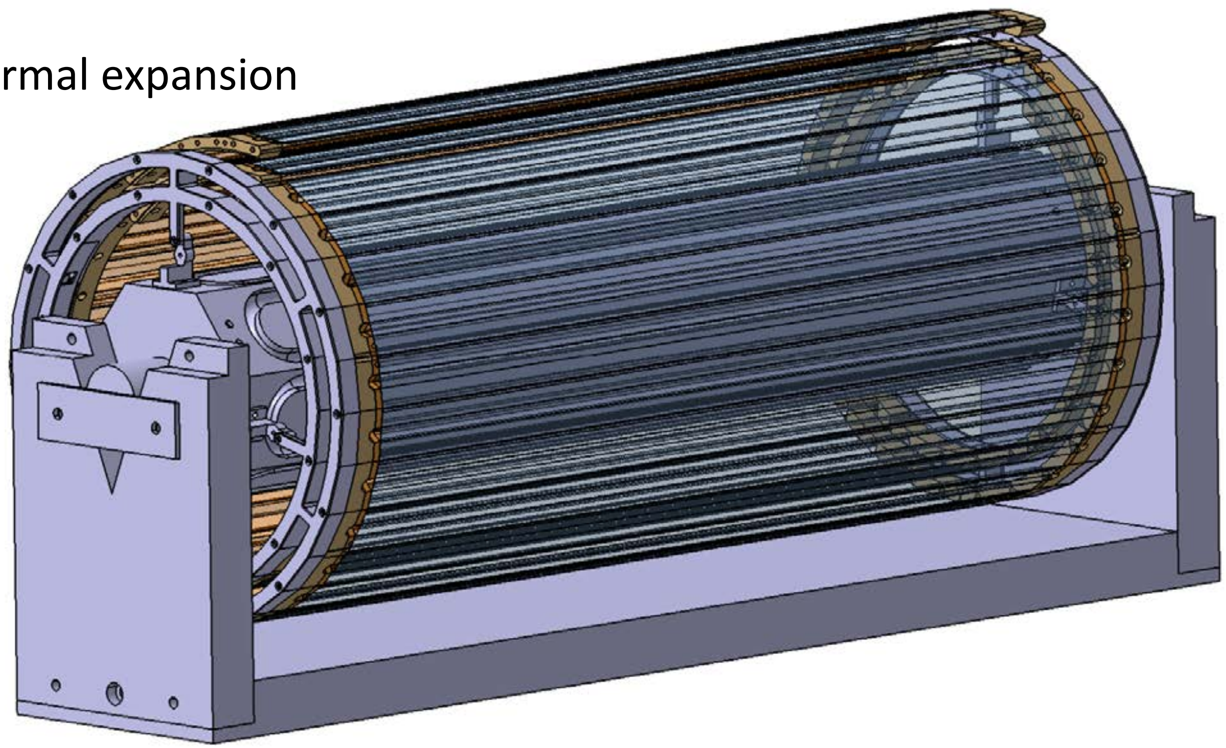
outer pixel layers

Mechanical Structure

Basic design concept for outer and recurl layers

Sub-layers assembeld
to full layer

-> connected by end wheels
-> fixed on beam pipe
-> compensation of thermal expansion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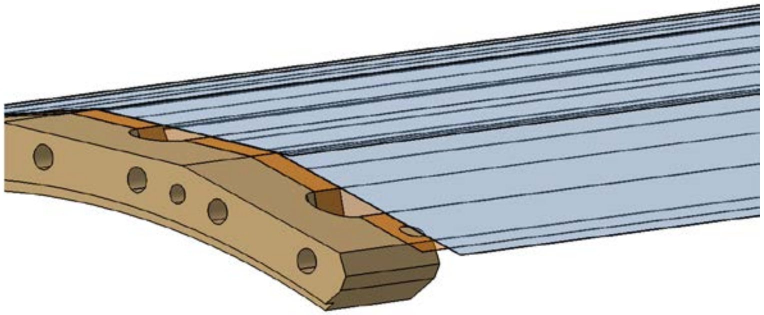
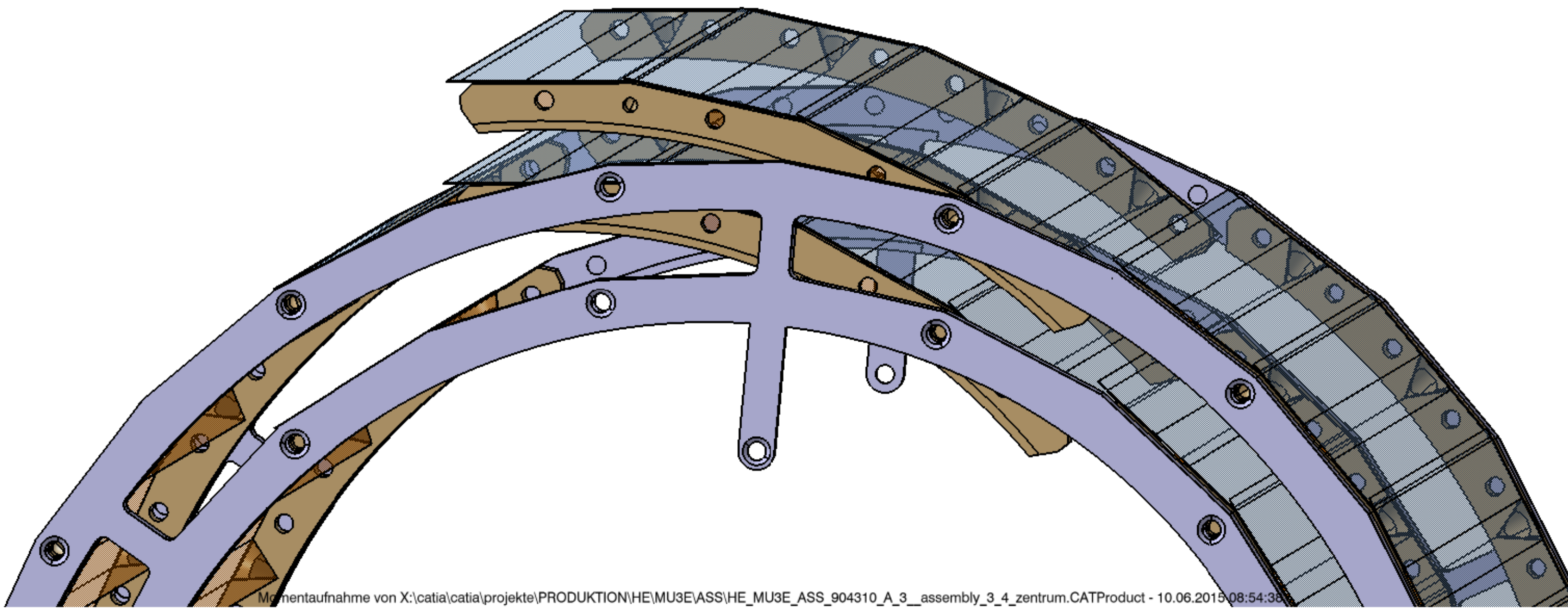
Mechanical Structure

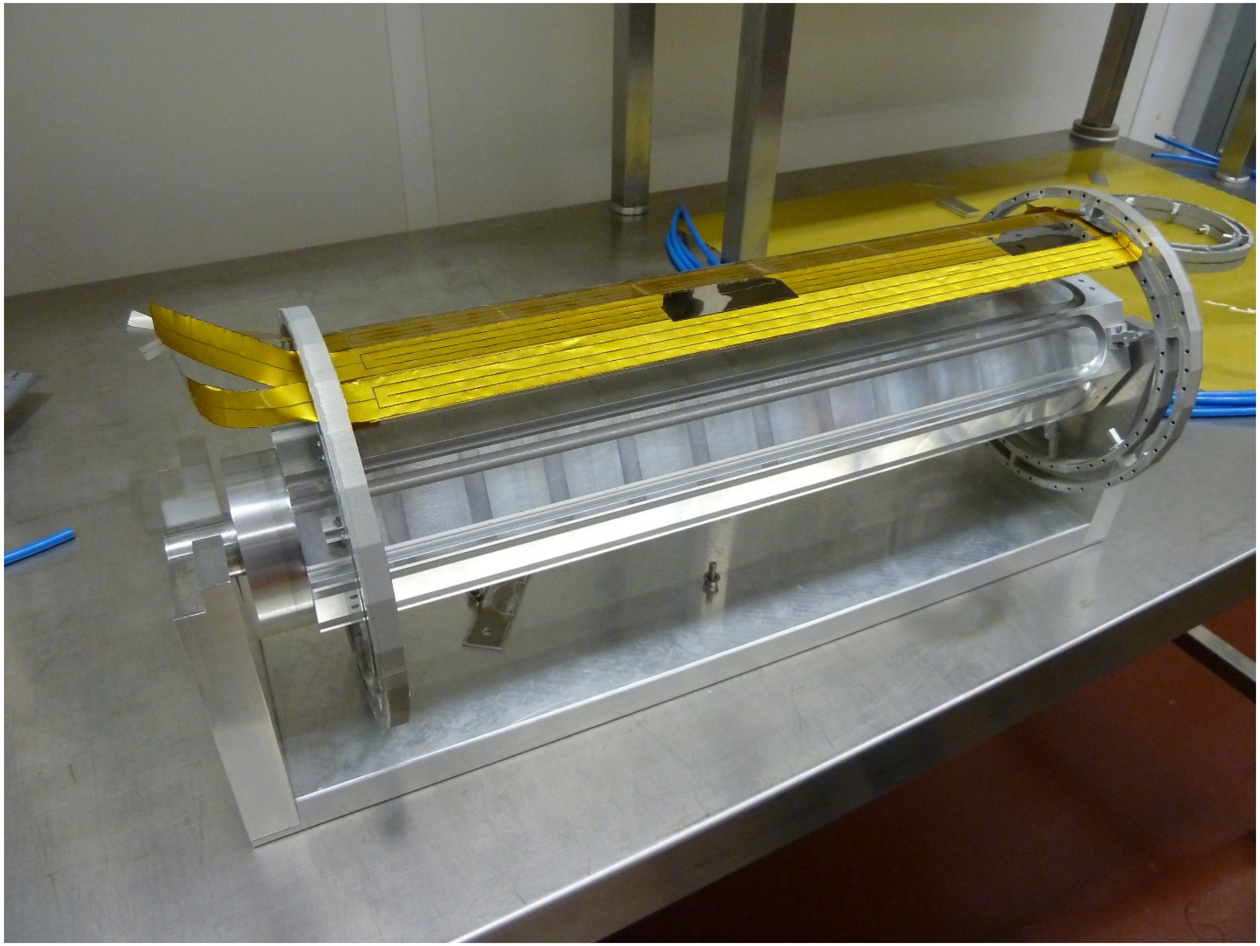
outer pixel layers – mounting of sub layers





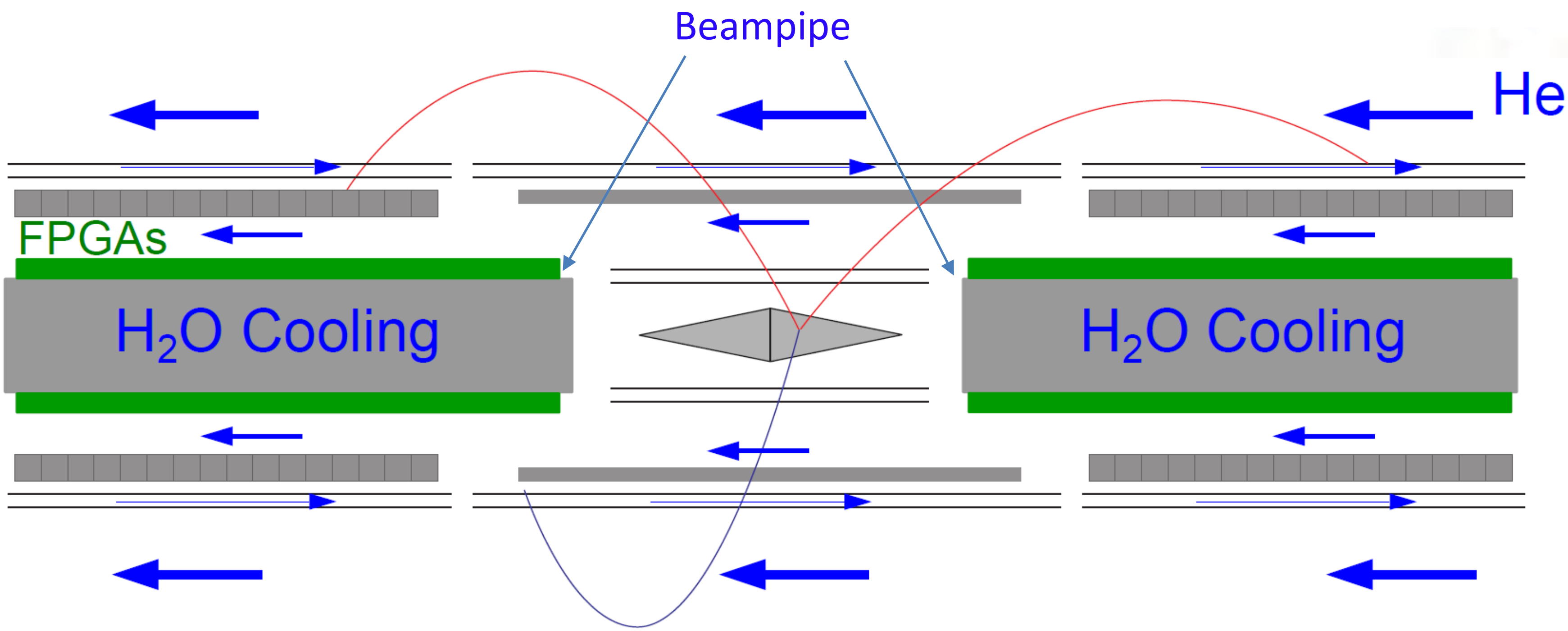
Mechanical Structure

Assembly of outer station



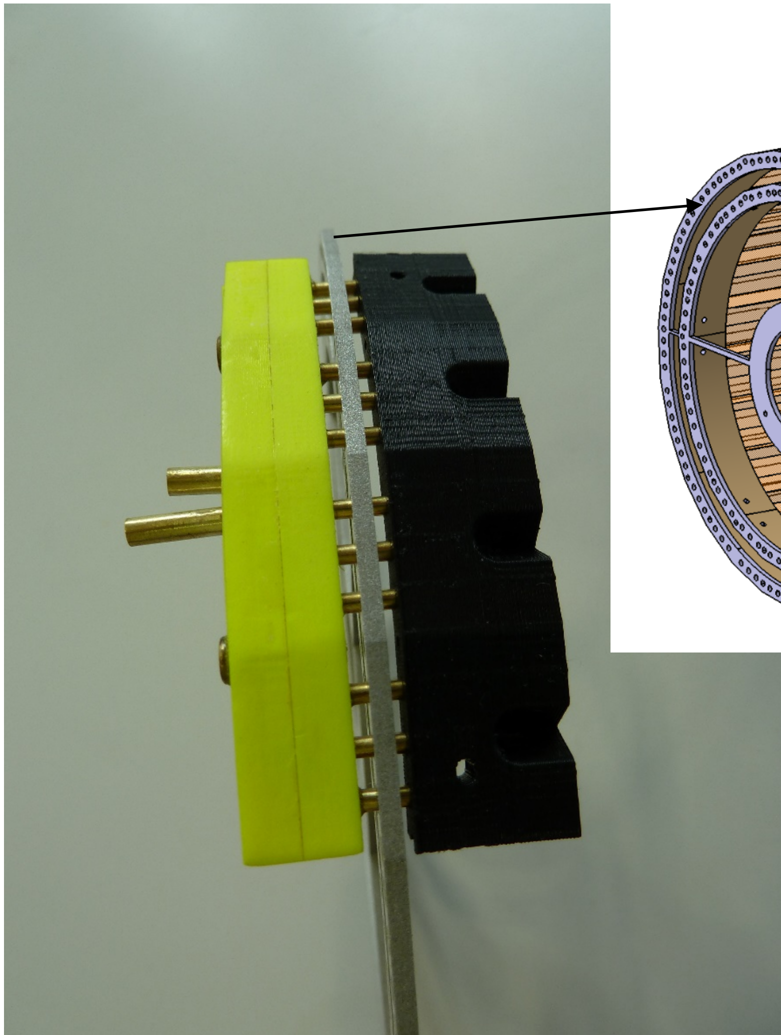
Mechanical Structure

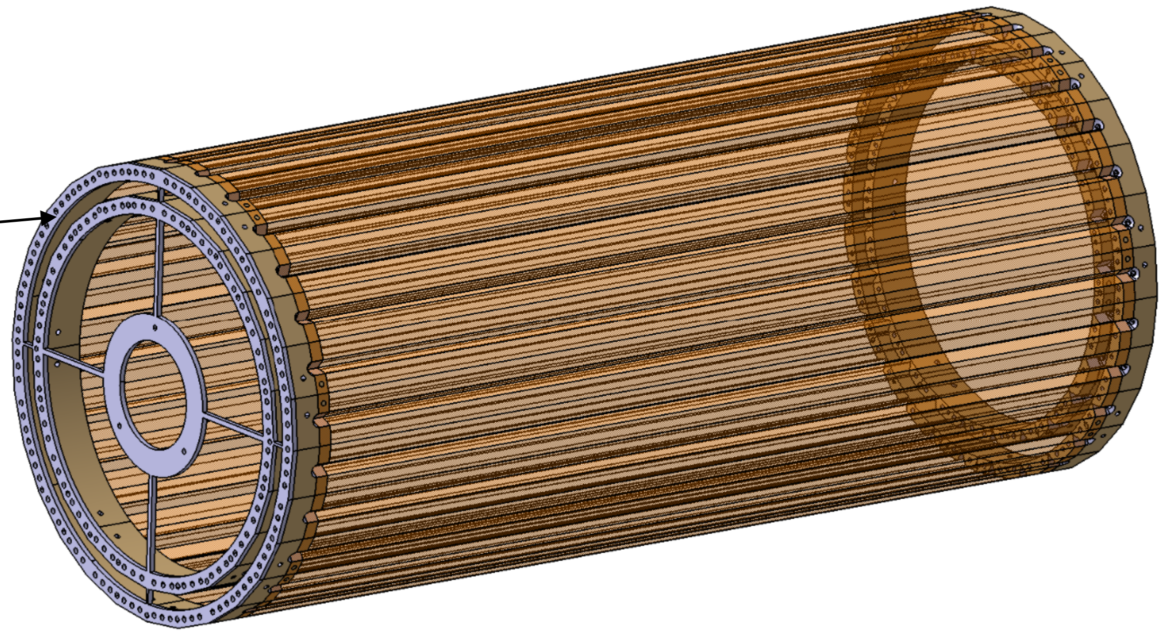
Overview of Cooling



Mechanical Structure

Cooling manifold – modular version





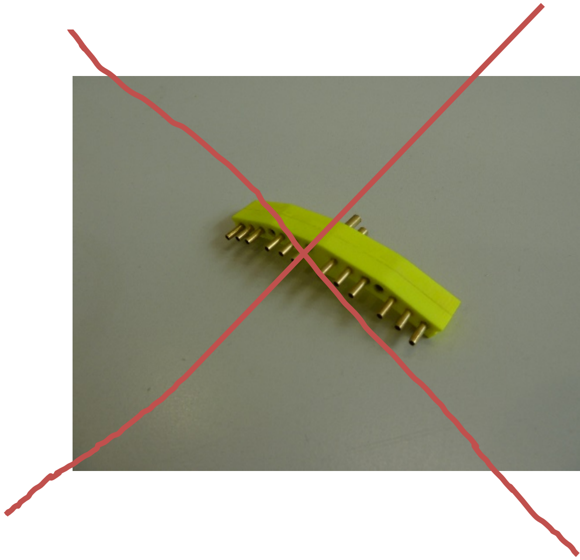
-> Identical sub division as sub-layers

-> different supply lines for local and global cooling

-> connection to sub-layer using brass pins

Mechanical Structure

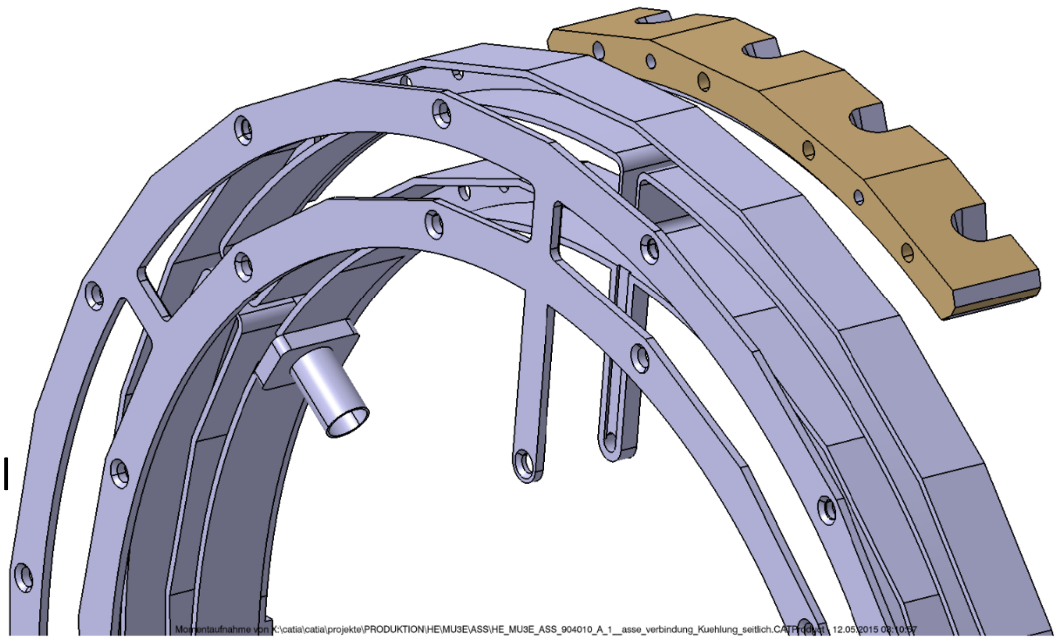
Cooling manifold



First test showed

-> very complicated handling

-> very high risk to damage sub-layers



Better solution

-> integration into support wheel

Mechanical Structure

End wheel

Prototype by 3D printing

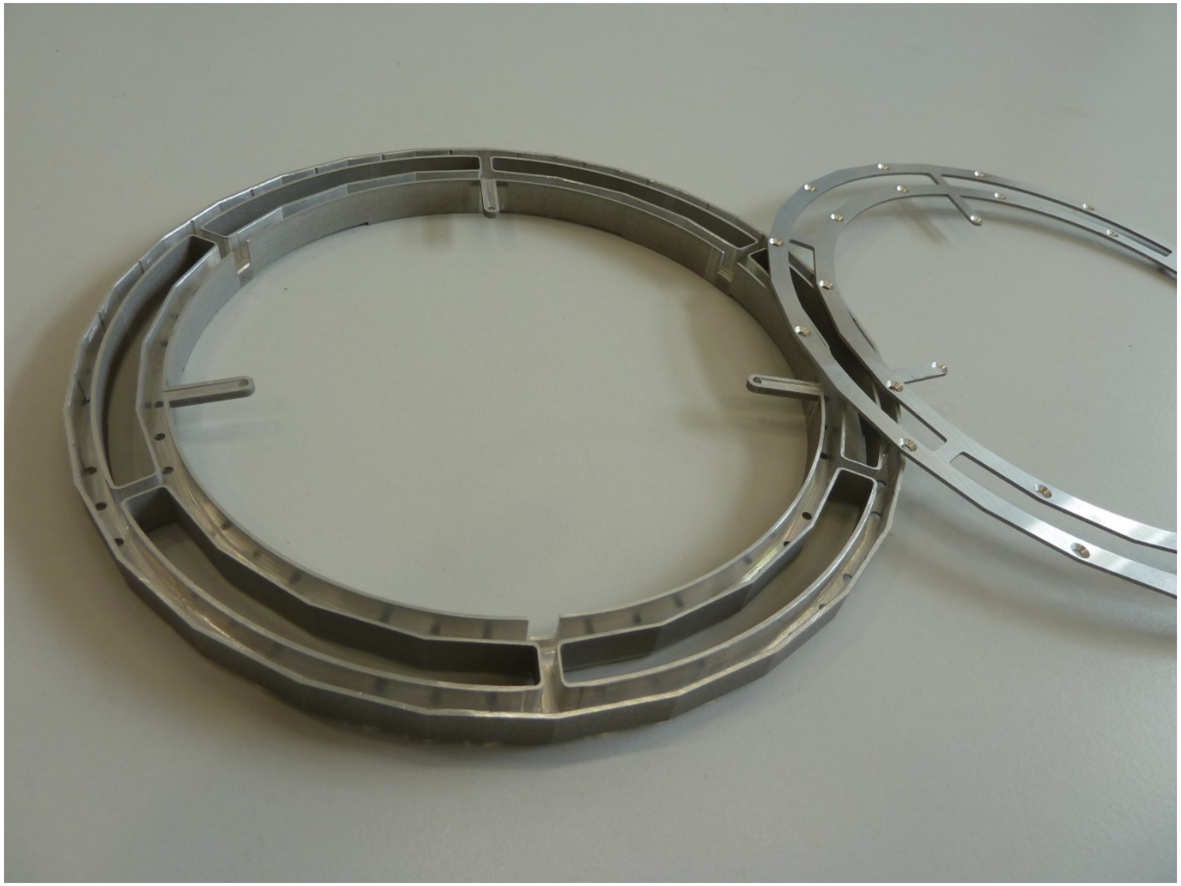
-> assembly tests
-> tests of cooling distribution

Very promising

-> first real prototype

Mechanical Structure

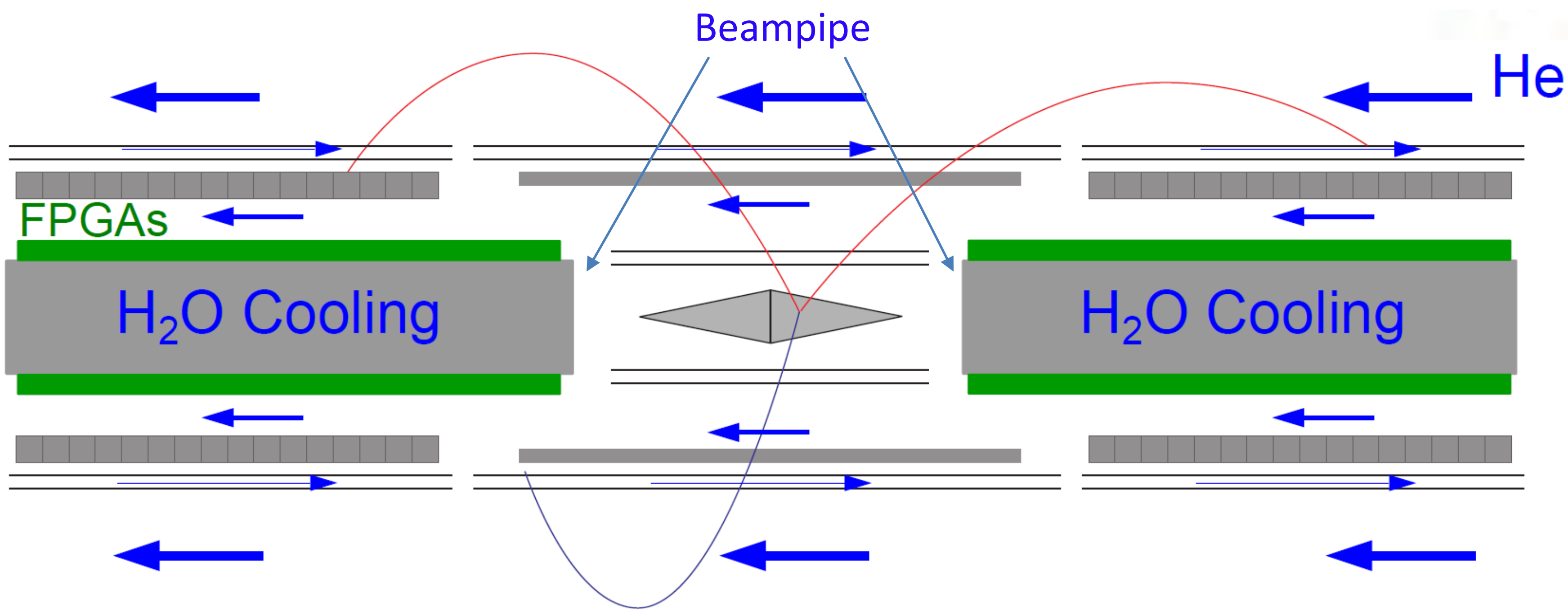
End wheel



-> Light Al structure produced by milling and wire erosion technique

-> Direct production of the NC-machining programm from CAD 3D-model using CAM workbench (CATIA V5)

Cooling Concept

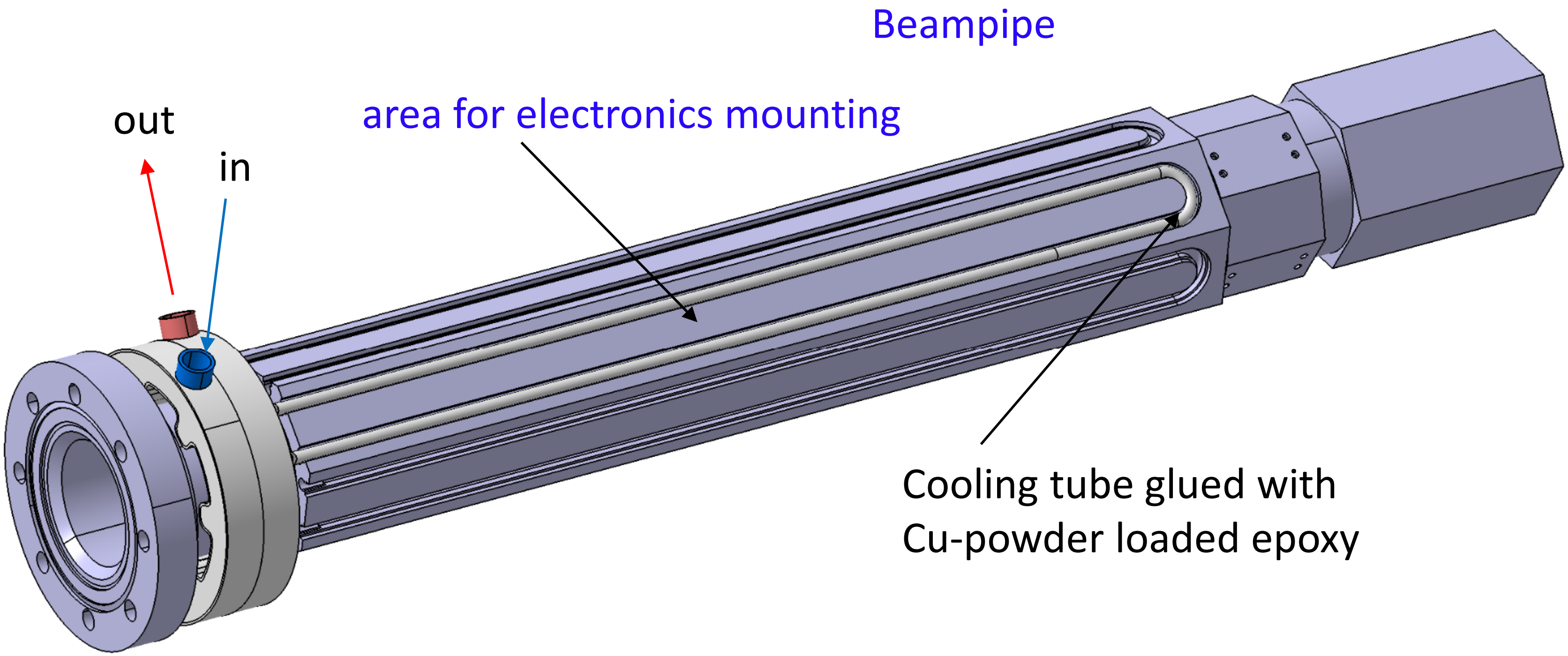


Water cooling -> integrated into beampipe (inactive area)

Gaseous helium cooling -> local and global (active area) -> $\frac{P}{A} = 100\ - 750\ mW/cm^2$

Cooling Concept

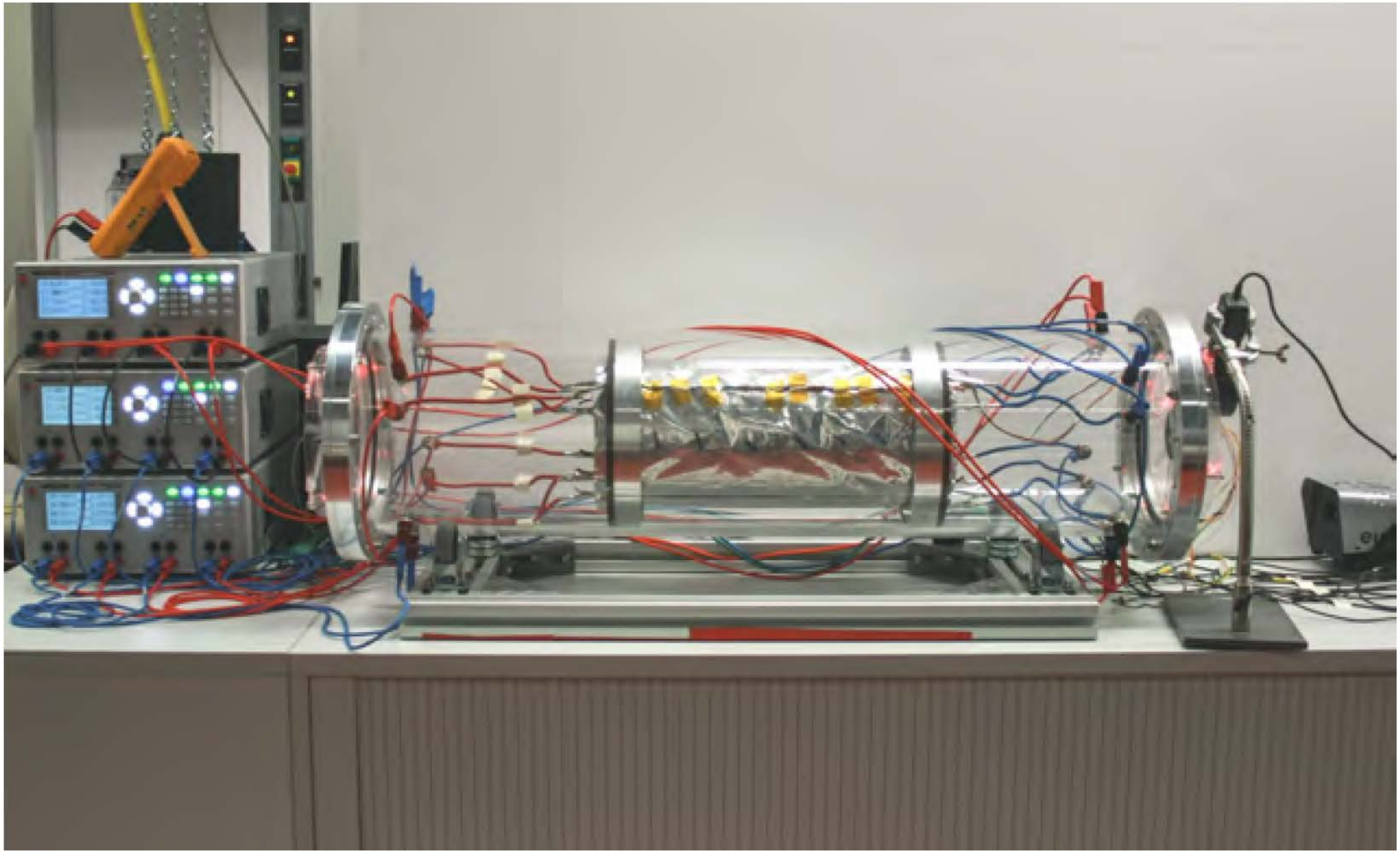
Water cooling of electronics



Water cooling -> integrated into beampipe (inactive area)

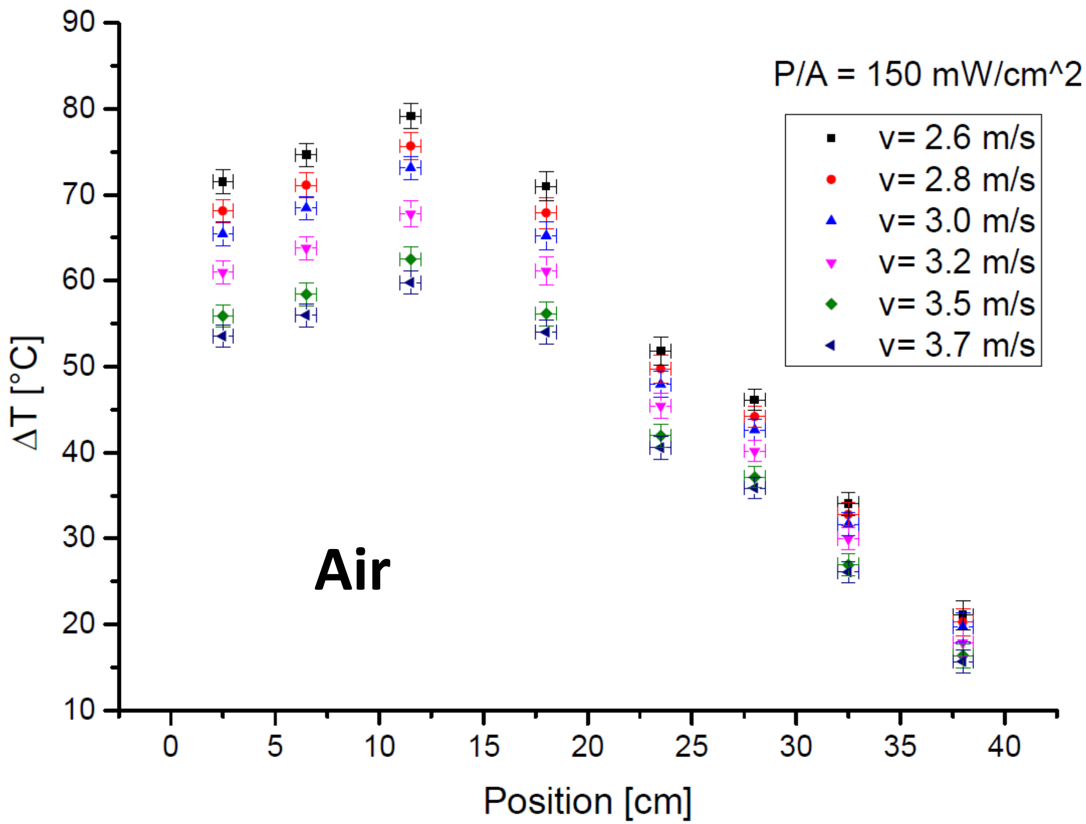
Cooling Concept

Cooling Tests – Global Gas Flow



Cooling Concept

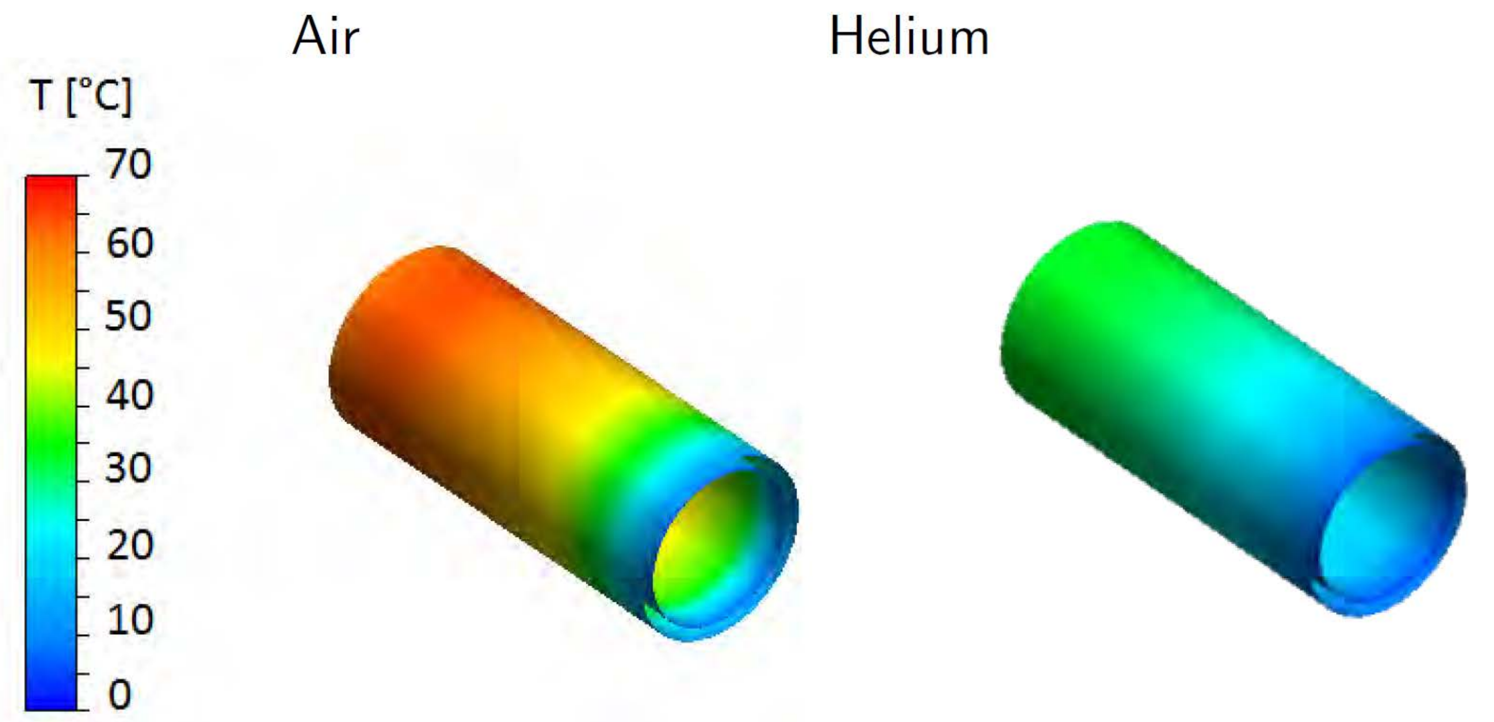
Cooling Tests – Global Gas Flow



Tests and simulations by
A. Herkert

Cooling Concept

CFD Simulations – Global Gas Flow



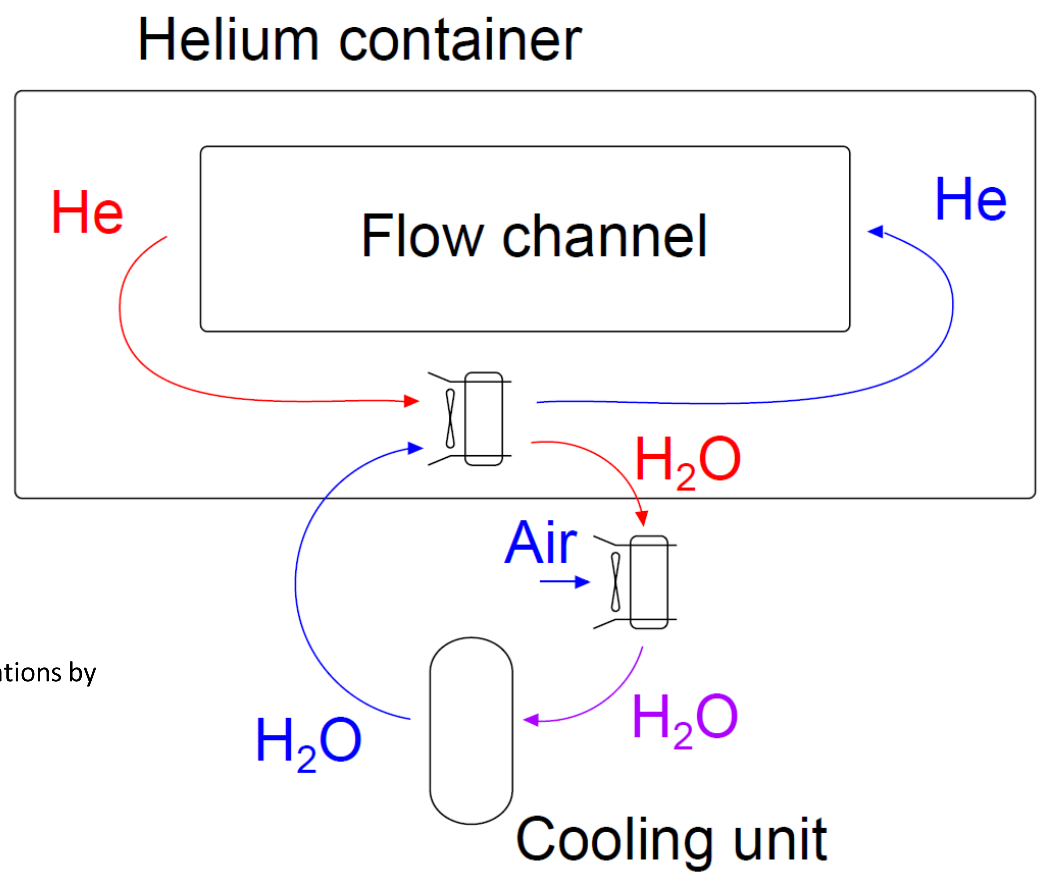
Tests and simulations by
A. Herkert

- $P/A = 150\,\mathrm{mW/cm^2}$
- $v = 3\,\mathrm{m/s}$

Cooling Concept

Cooling Tests – Global Gas Flow

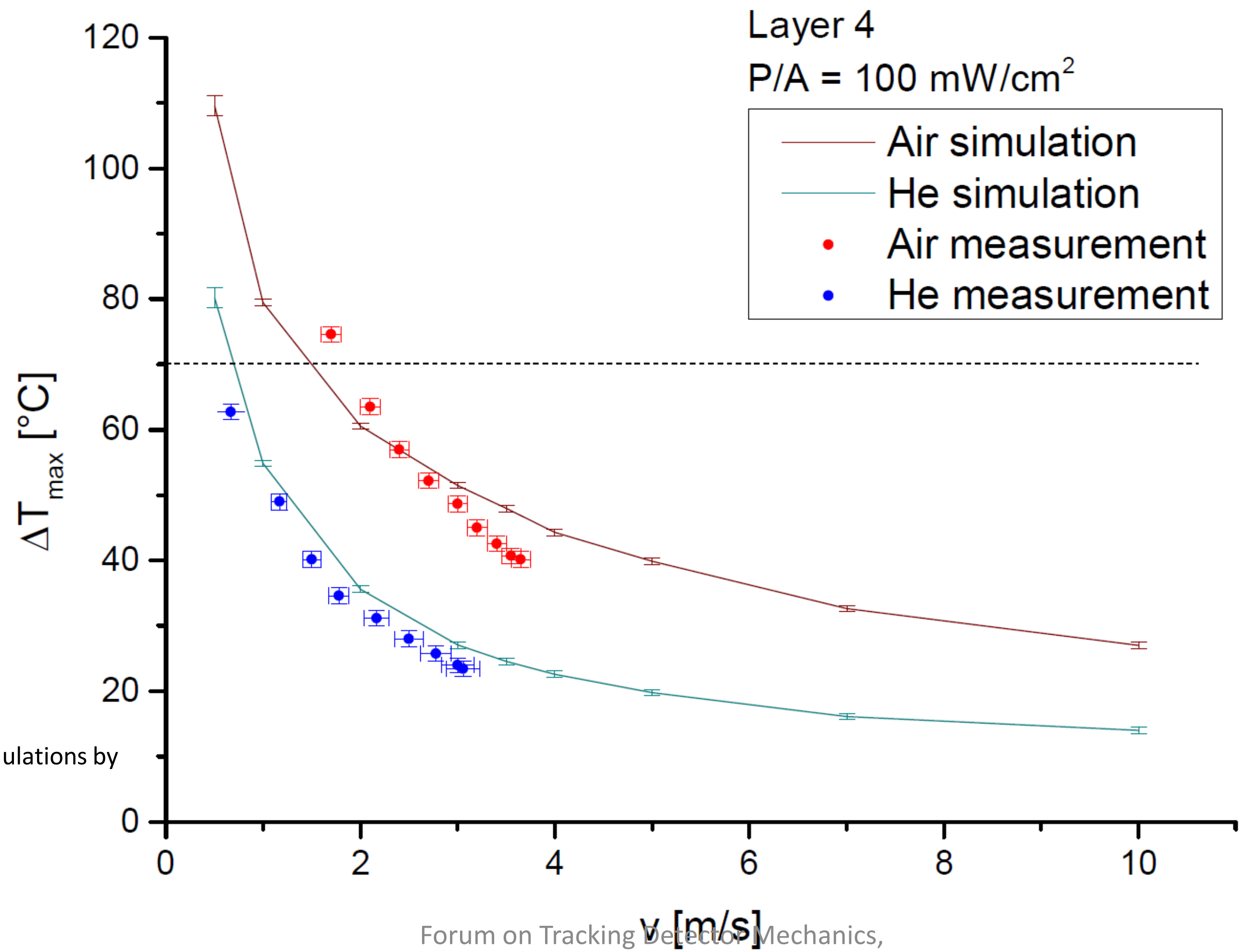
Helium



Tests and simulations by
A. Herkert

Cooling Concept

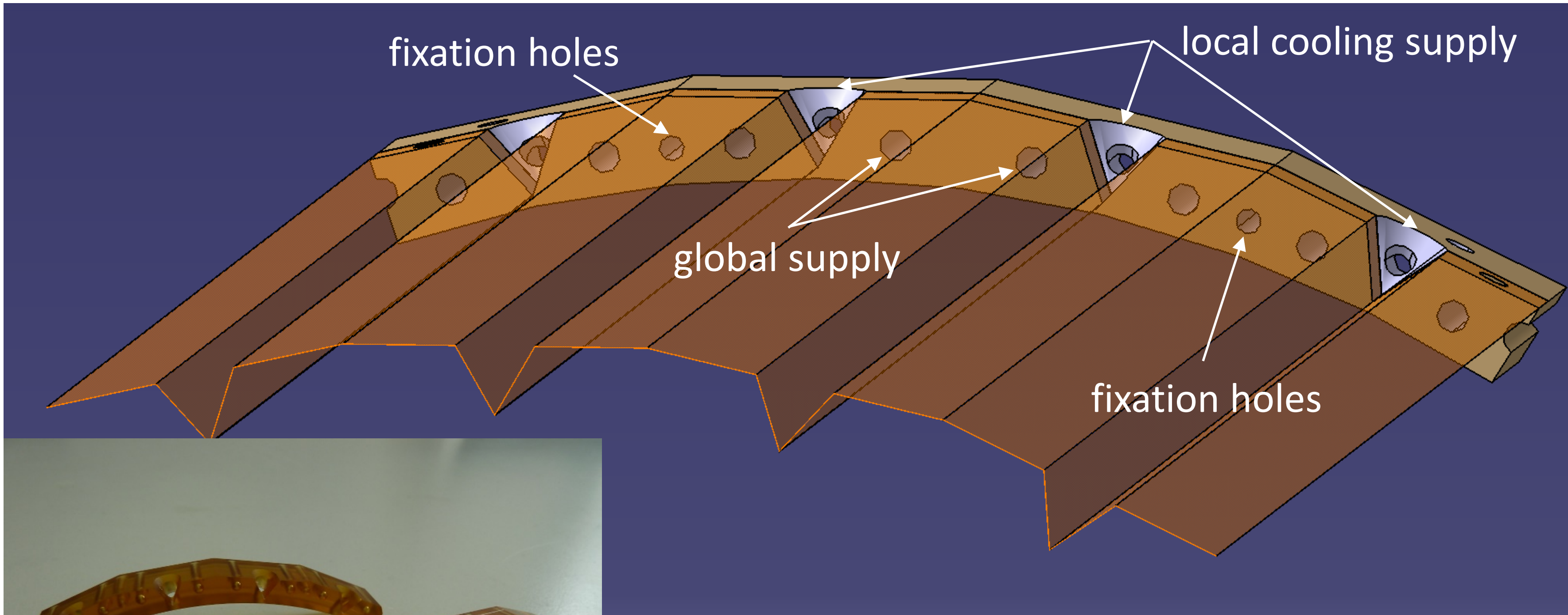
Global Gas Flow - Summary



Tests and simulations by
A. Herkert

Cooling Concept

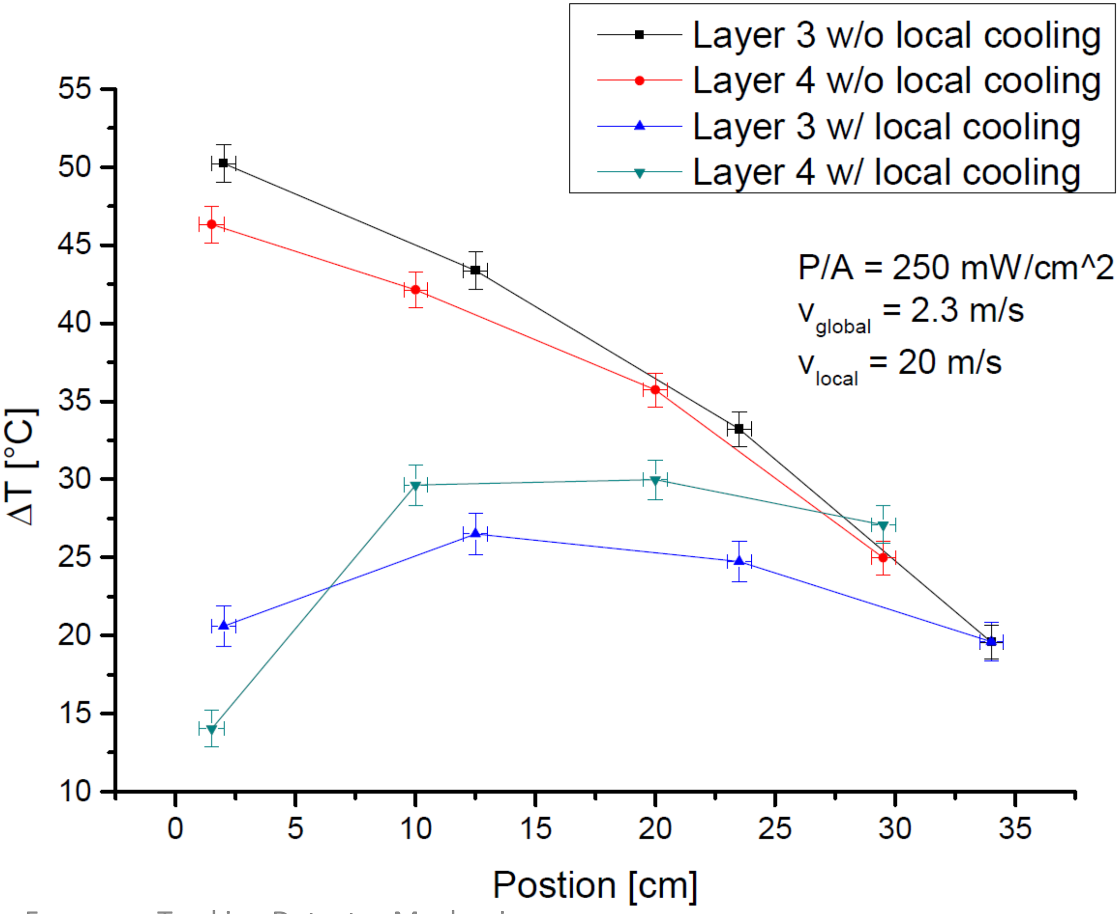
Global and local cooling supply



Cooling Concept

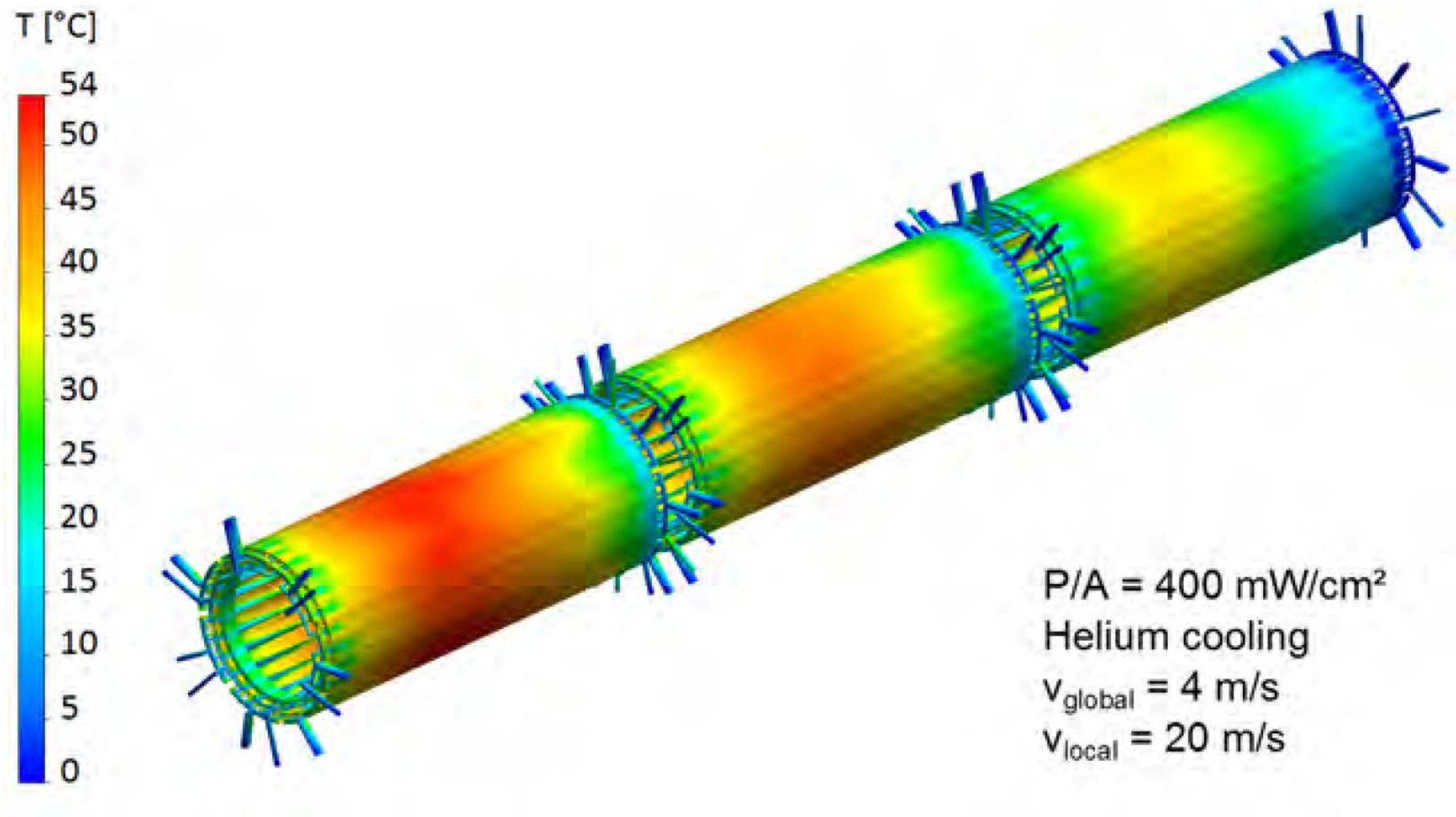
Global and local Gas Flow – Tests with Helium

Tests and simulations by
A. Herkert



Cooling Concept

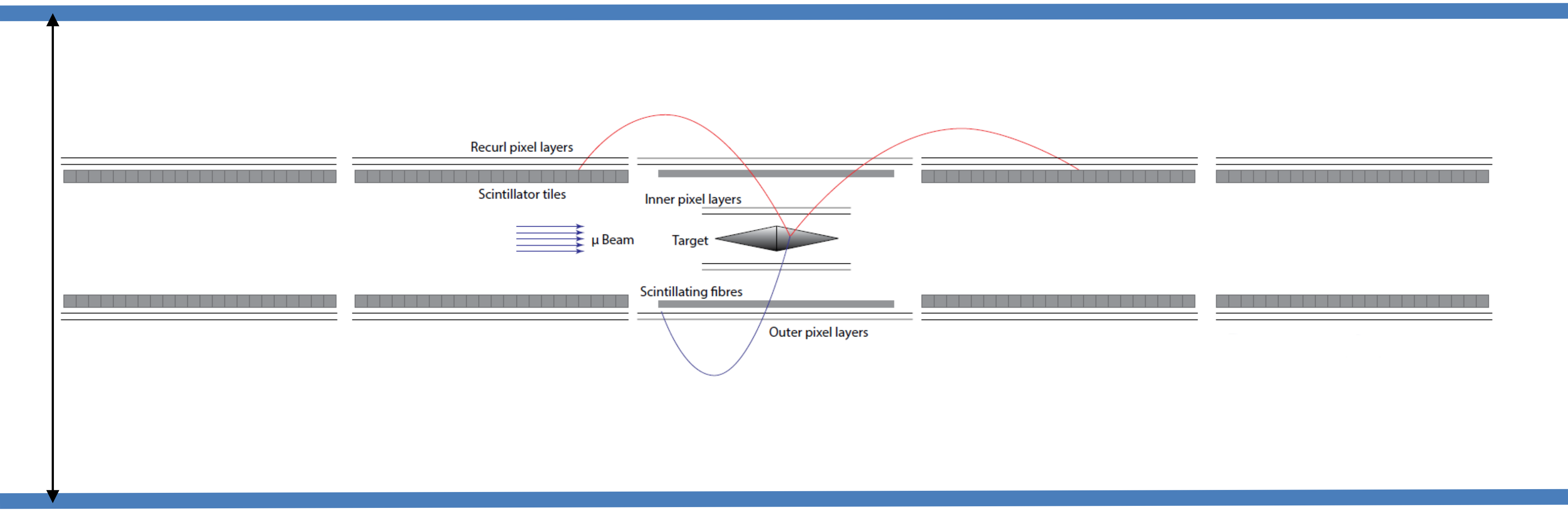
Further Simulations – Phase Ib Setup



Tests and simulations by
A. Herkert

Integration

Superconducting solenoid

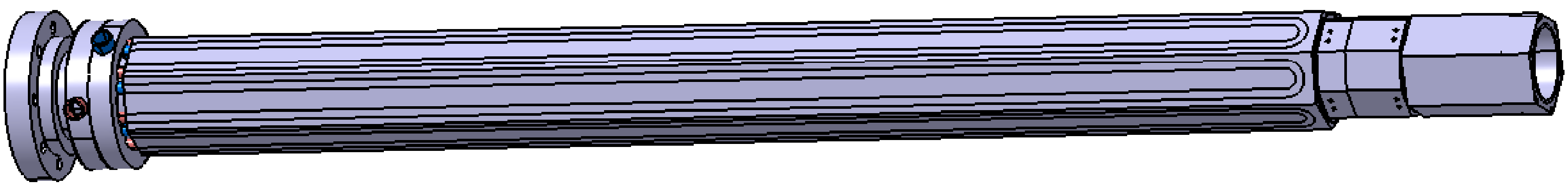


Warm bore ~ Ø 1m

Overall dimensions:
~ 3m length
~ 2m outer diameter
max. Field: 2 Tesla

Integration

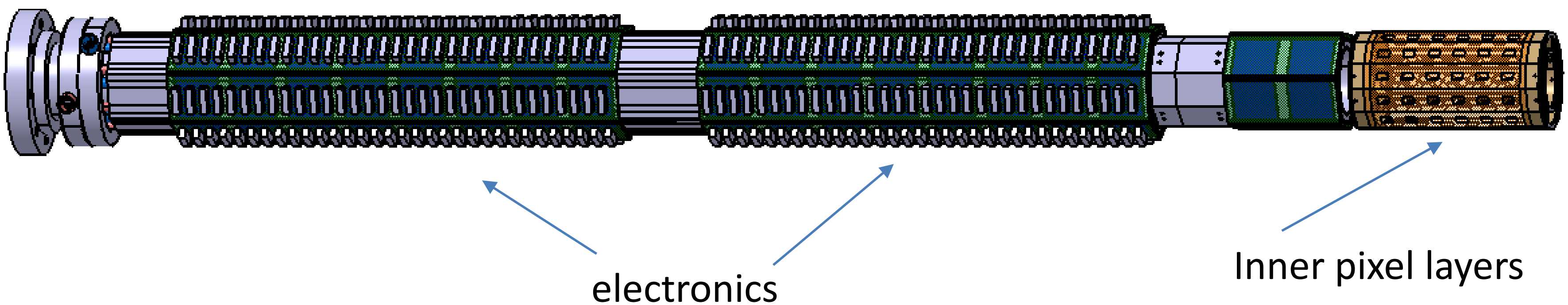
Assembly sequence



Beam pipe left side

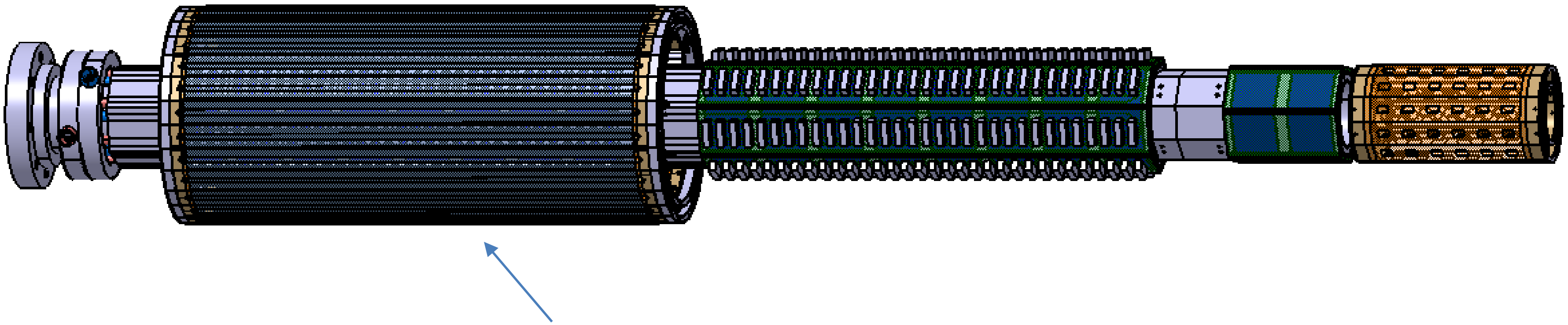
Integration

Assembly sequence



Integration

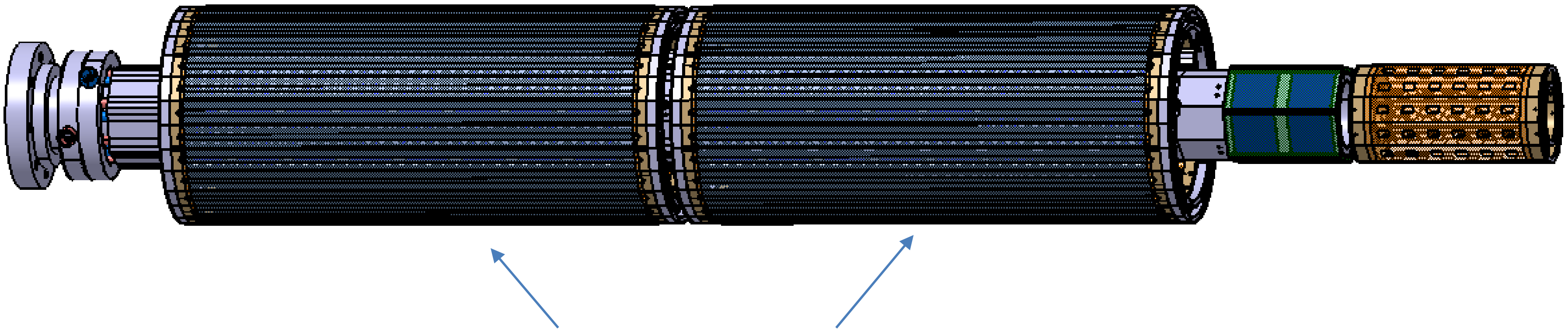
Assembly sequence



Outer stations with integrated tile detectors

Integration

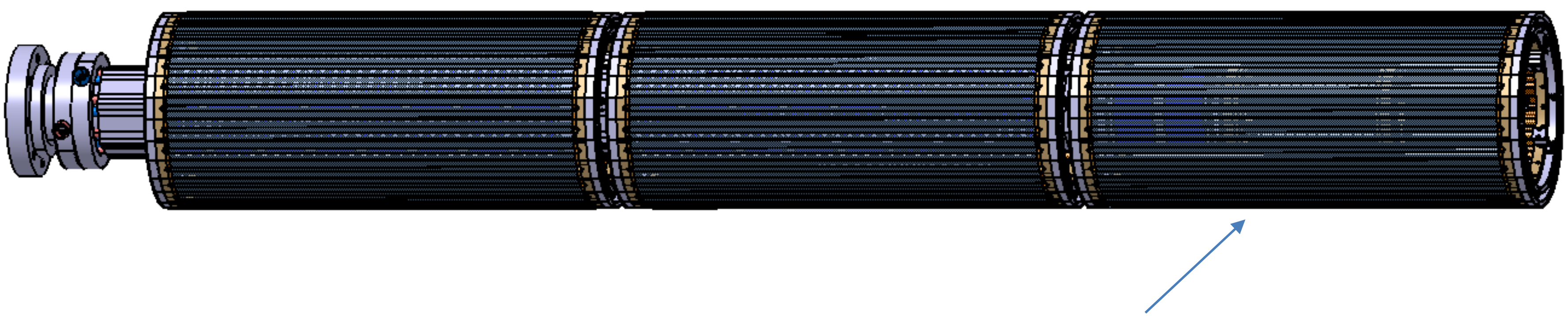
Assembly sequence



Outer stations with integrated tile detectors

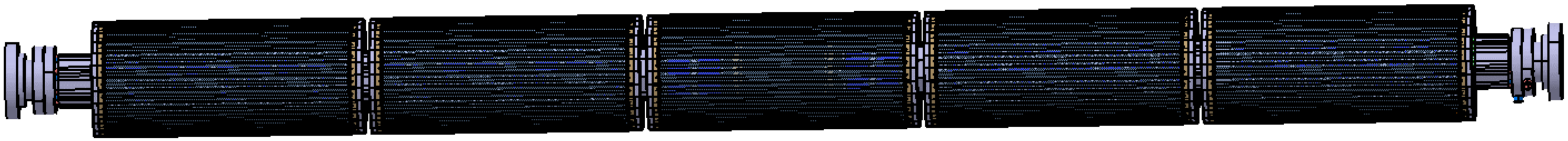
Integration

Assembly sequence



Integration

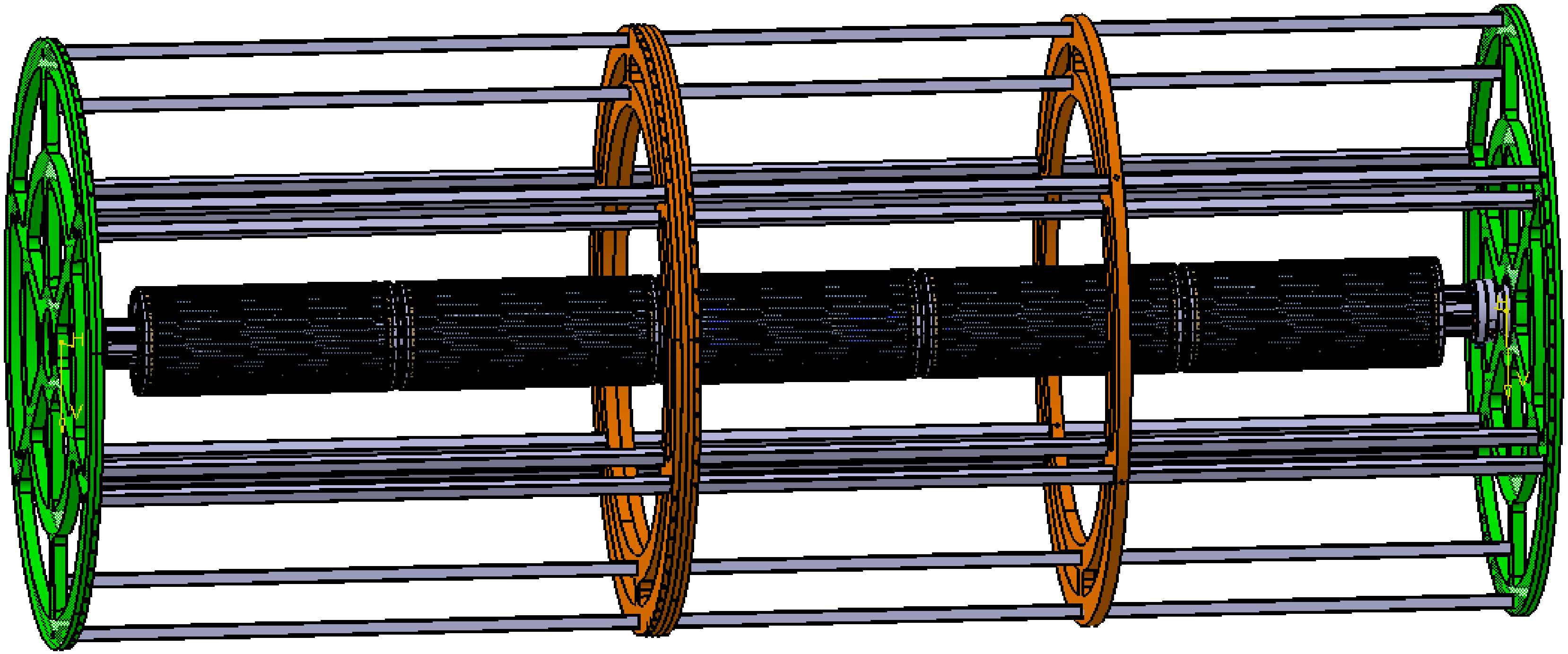
Assembly sequence



Full experimental setup (Phase II)

Integration

Assembly sequence

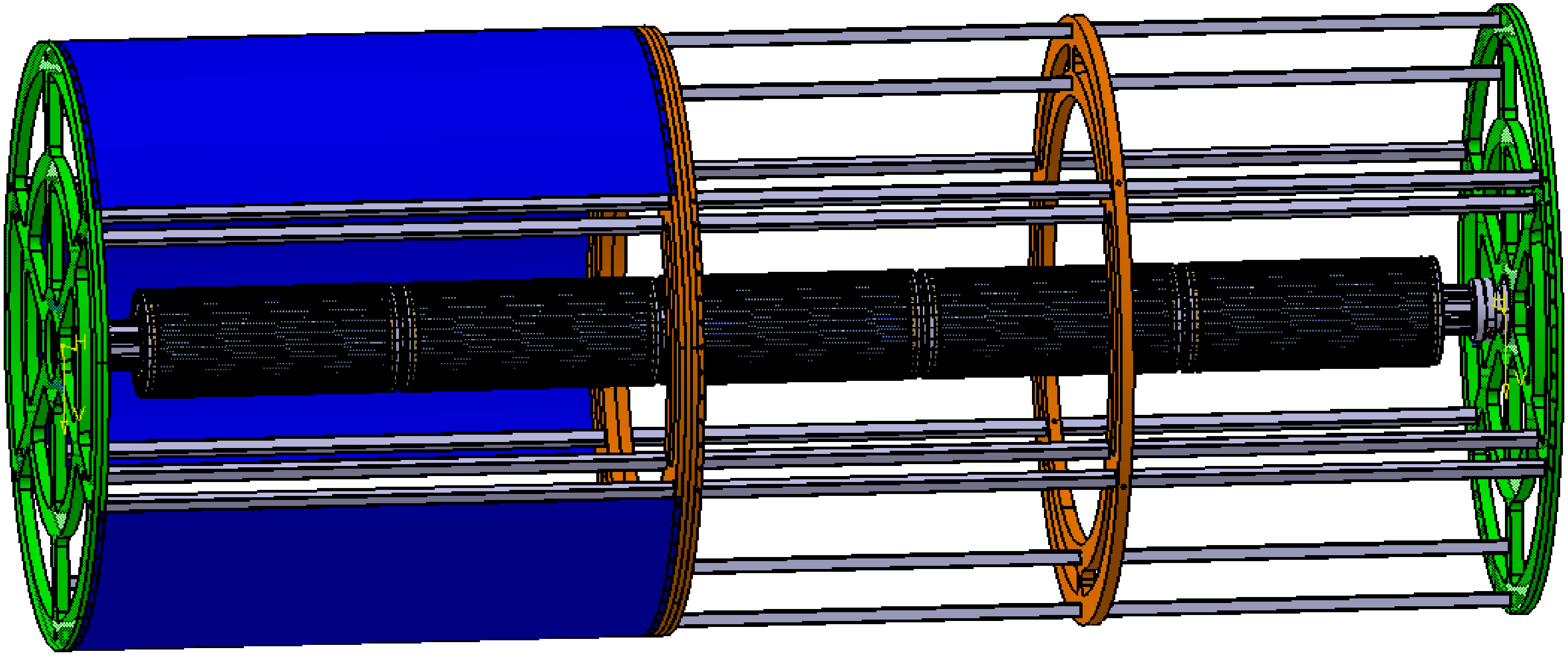


Outer support structure

Integration

Assembly sequence

Outer support structure

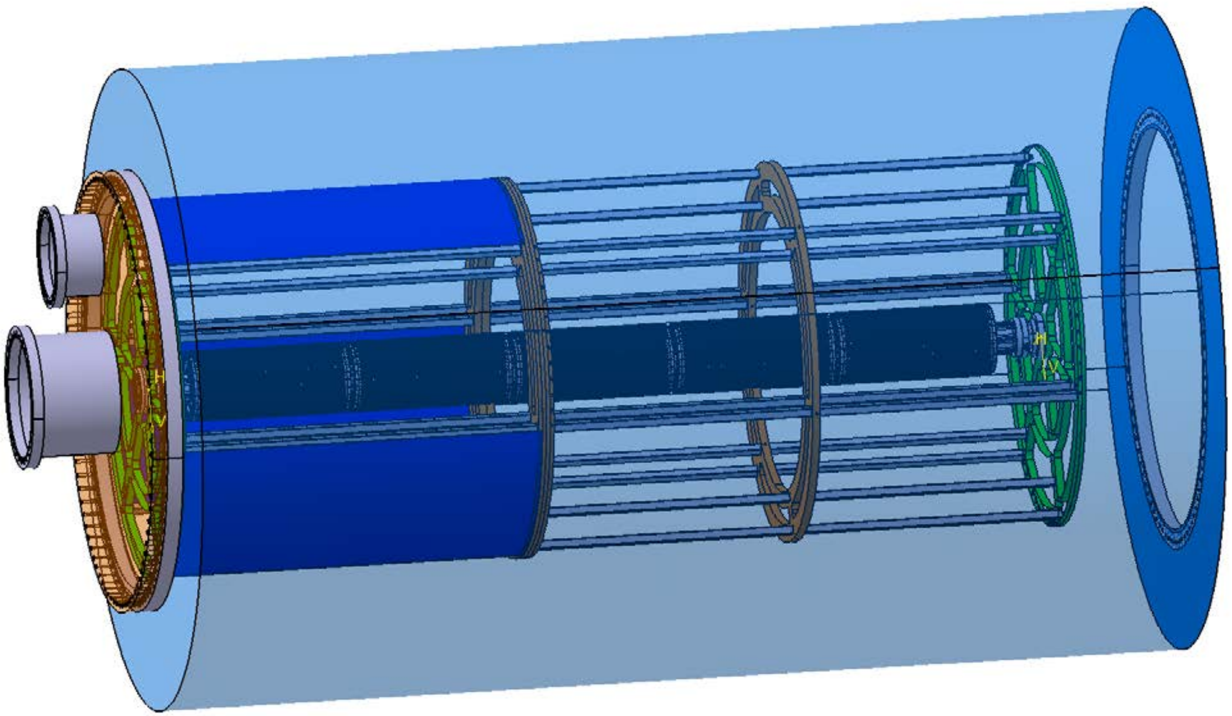


bending / torsion

Integrated into the assembly procedure

Integration

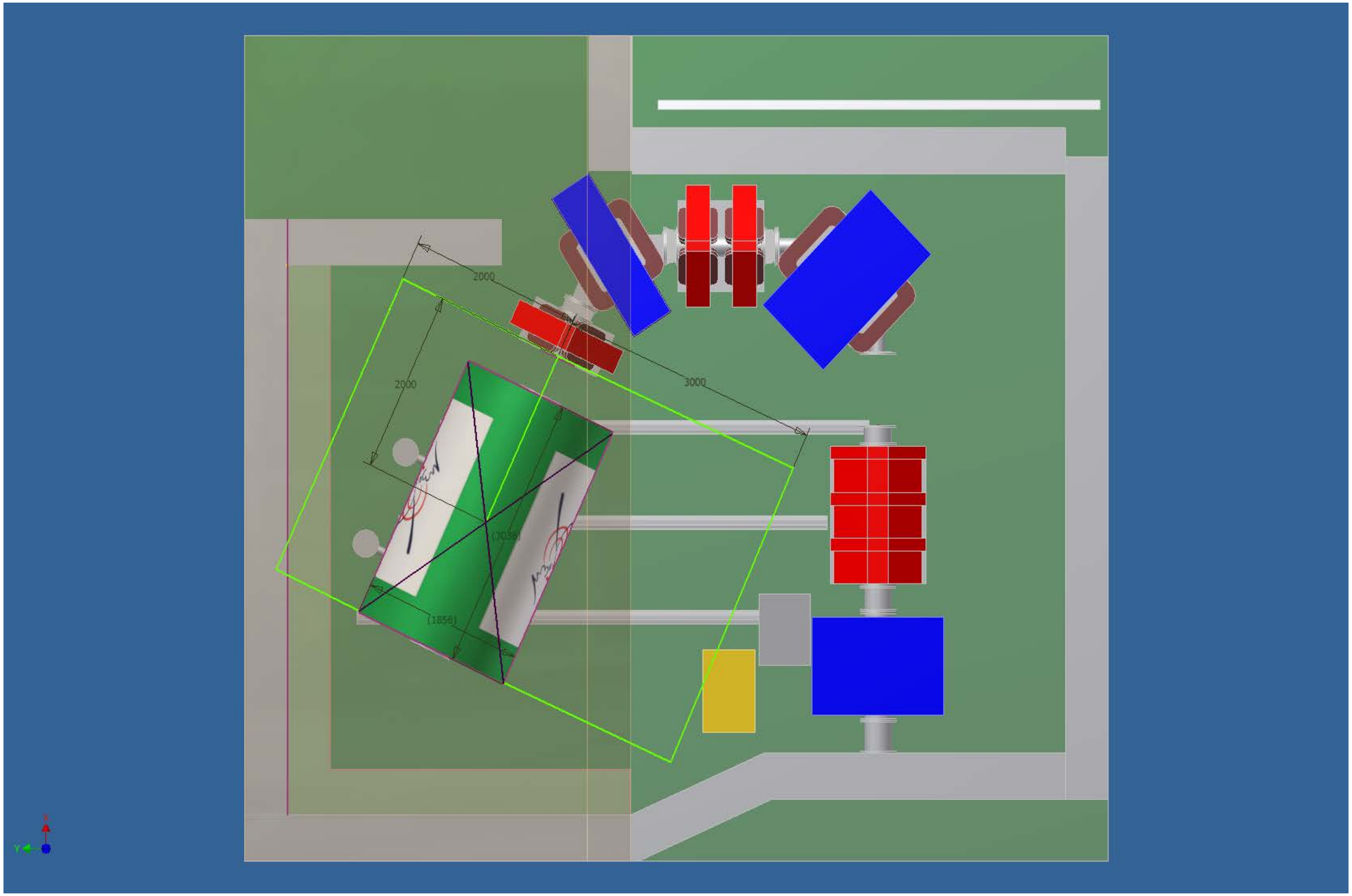
Assembly sequence



Integration into magnet using a rail system

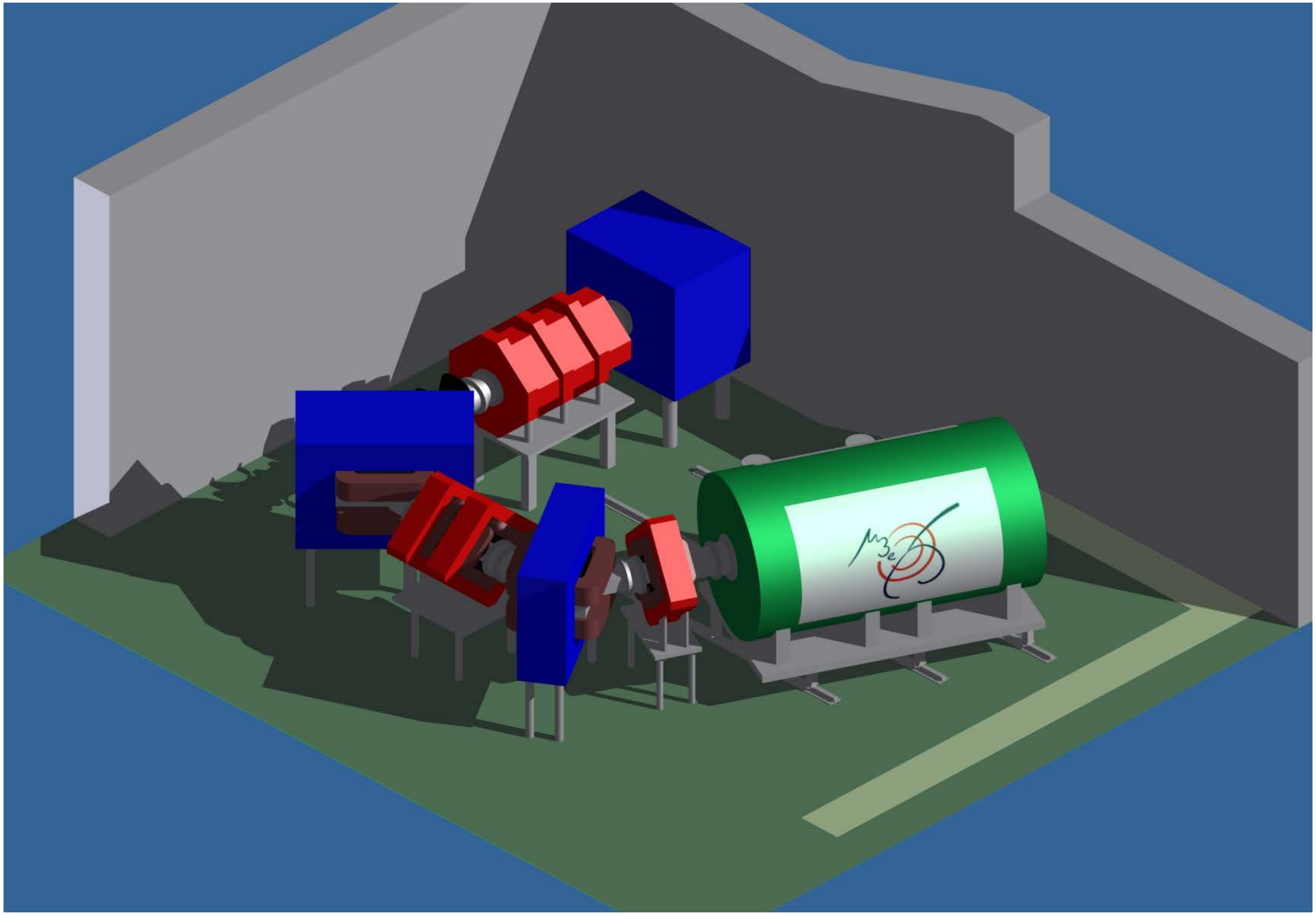
Integration

Experimental setup – top view



Integration

Experimental setup



Summary

Mechanical Structure

-> Kapton structure as base support

-> HV-MAPS glued and bonded to Kapton flexprints

-> HV-MAPS/felxprint units glued to Kapton support structure

-> configuration delivers ~0.1% X/X0

-> mechanical stability, max deformation 0,3mm

Summary

Cooling Concept

-> mock up for cooling tests

-> several measurements / simulatons with air and helium

-> local/global He-cooling suitable solution veryfied up to phase Ib setup

-> further tests and simulations necessary (full setup)

-> investigate potential flow induced vibrations of the system

Summary

Integration

-> assembly procedure worked out

-> to be synchronized with services connections

-> external support structure

-> supports experimental setup in the magnet

-> should als serve as support during assembly

-> integration into magnet by rail system

Summary

General still many „construction sites“

Thanks to all people involved

K. Stumpf, S. Rabenecker, J. Riedinger

backup

Component	Tickness [μm]	x/X_0 [%]
Support structure	25	0.018
Flex-print	25	0.018
Aluminum traces	12	0.013
HV-MAPS	50	0.053
Adhesive	10	0.003
Full layer	122	0.105