The Quest of Building a Precise TPC Field Cage

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

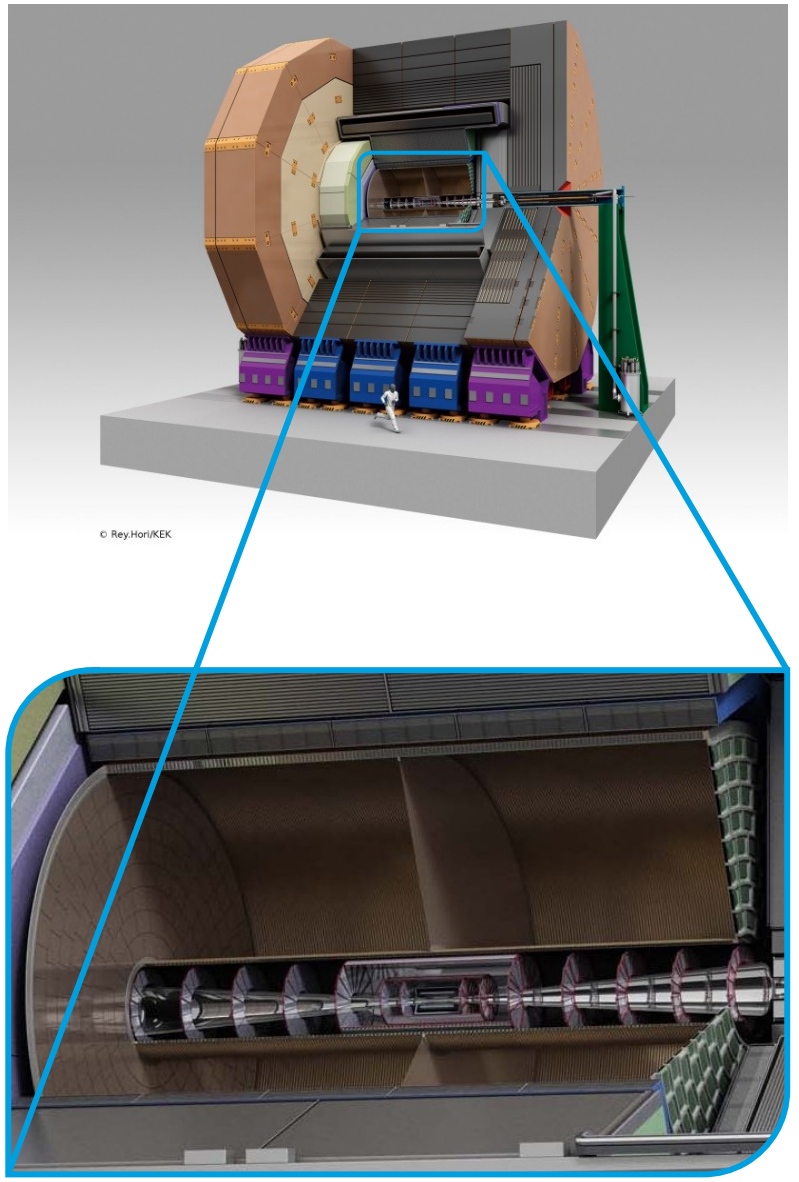
Overview

- R&D towards a Time Projection Chamber at the ILC
- Large Prototype TPC Field Cage V2 Motivation and Strategy
- What actually happened ...

The International Large Detector

ILD

- Developed for precision measurements at ILC
- Optimized for particle flow reconstruction
- **TPC with MPGD readout as main tracking detector**
  - ≈ 220 track points → continuous tracking & high redundancy
  - Near 100% tracking efficiency even for low momentum particles
  - Minimal material: 5% X_0 in barrel, 25% X_0 in endcaps
  - 3.5 T solenoid field
  - Momentum resolution required: 10^{-4} GeV^{-1} (TPC only)
    → point resolution in transverse direction: 100 µm
  - ≈ 5% dE/dX resolution allowing good particle identification



The LCTPC Setup at the DESY II Test Beam Facility

DESY II

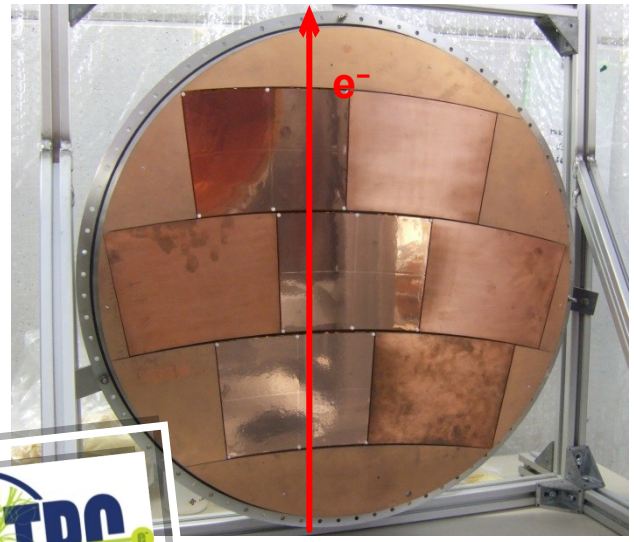
- 1 GeV to 6 GeV electrons

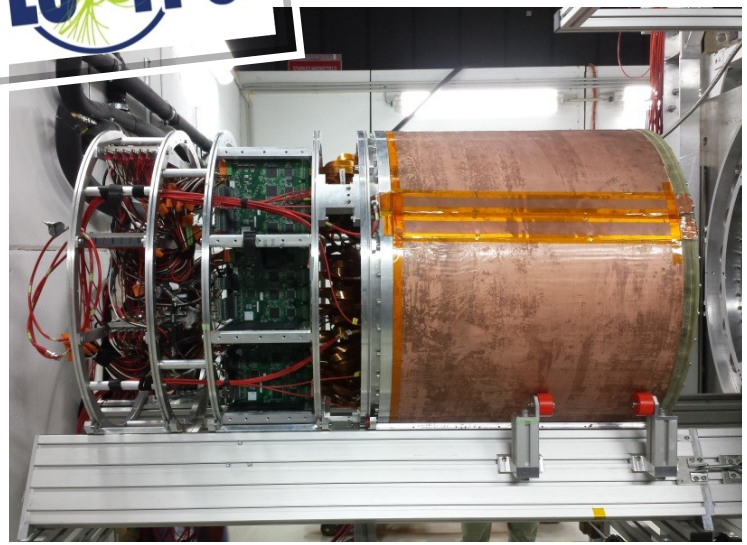
PCMag

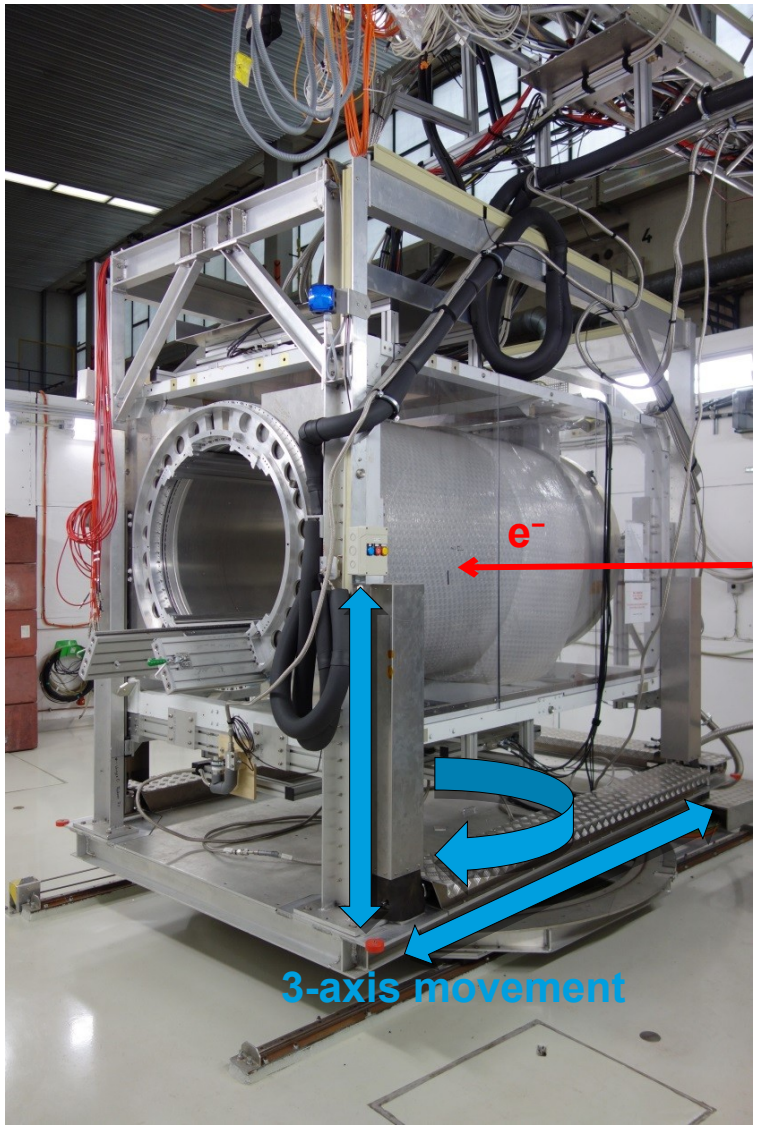
- 1 T superconducting solenoid
- 3-axis moveable stage
- 20% X_0 wall thickness
- 85 cm usable inner diameter

Large TPC prototype

- 75 cm diameter
- 57 cm maximum drift length
- Endplate with space for 7 modules in 3 rows



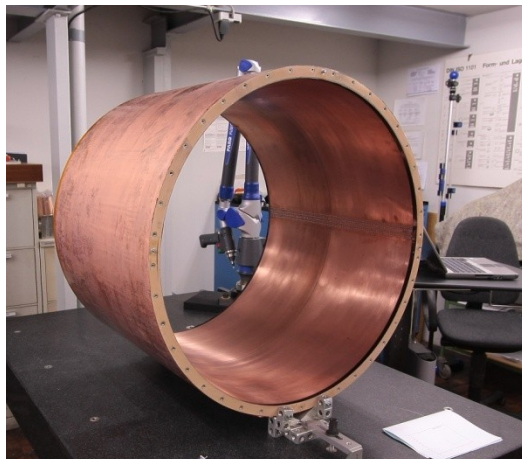


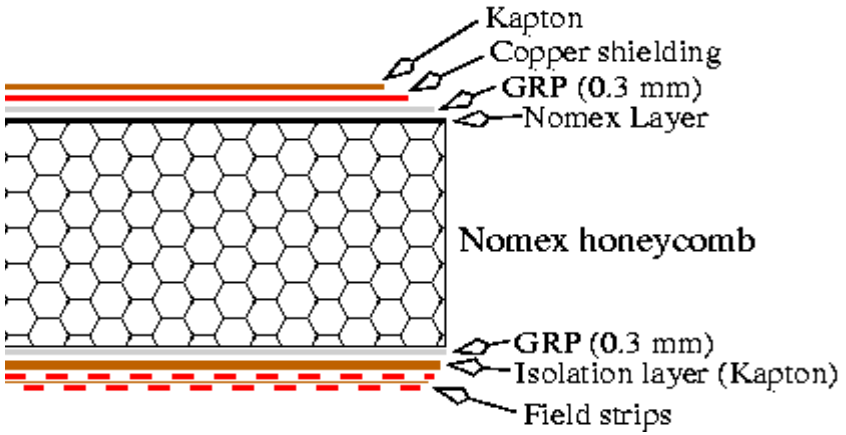


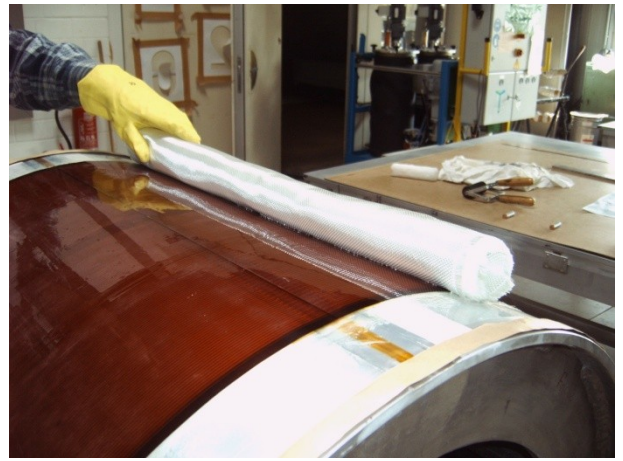
Large Prototype TPC Field Cage - V2

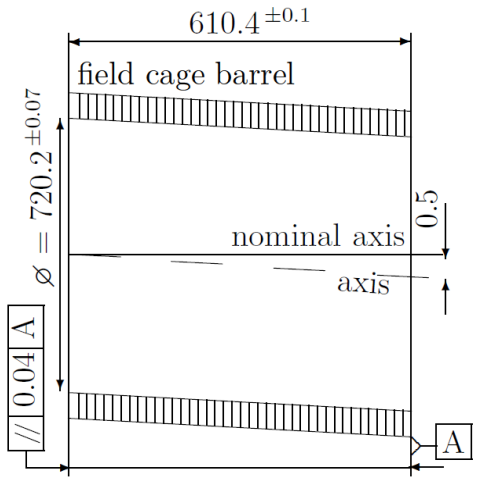
State of October 2019

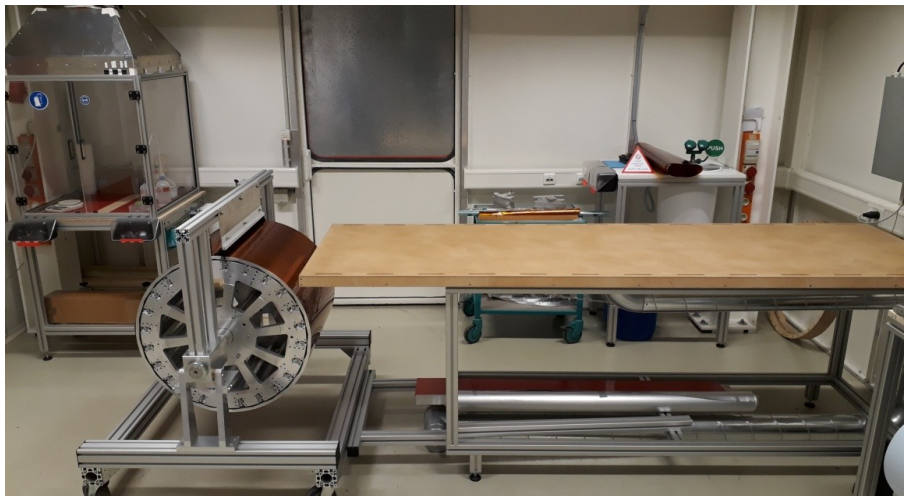
- Challenge of a high-precision TPC field cage:
  - Low material, high HV stability, high mechanical precision
- Why a new TPC prototype field cage?
  - Current field cage built by external company:
    Skewed by about factor 10 too much
    → field homogeneity not within specs
  - Want to gain more in-house experience for building the big ILD TPC
  - Verifiable material budget
- New workshop at DESY with precision mandrel for construction including vacuum bag ready







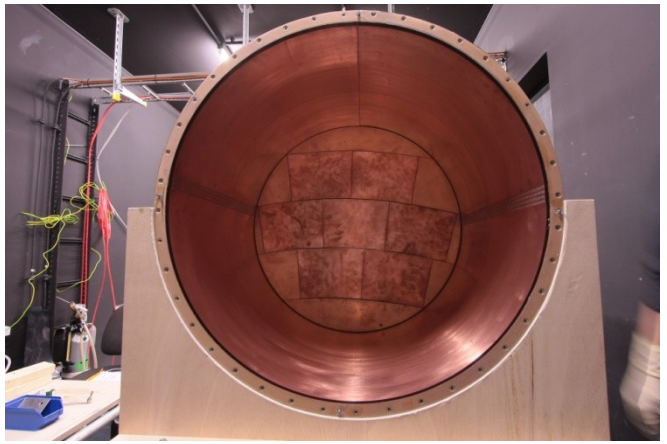


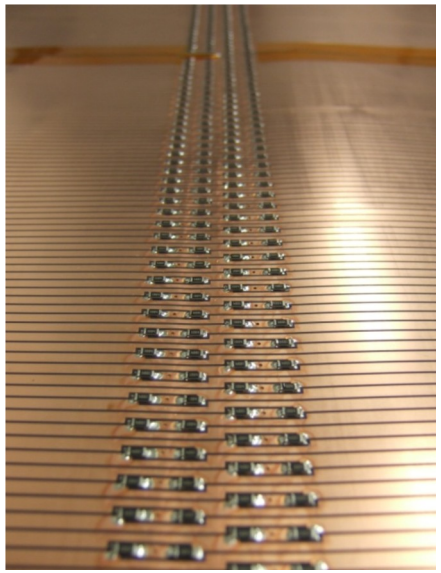


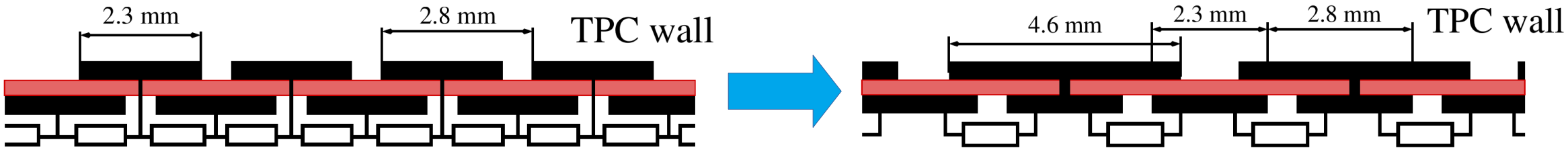
Large Prototype TPC Field Cage - V2

State of October 2019

- Detailed work procedure being finalized
- Last missing material being procured
- Final HV test of sample walls ongoing
- First field cage: No production site could do a two sided field strip foil of the required size (61 cm x ≈226 cm)
- Meanwhile: full size possible @CERN
- Expected to arrive end of this month
- New foil with a simpler field strip pattern → negligible impact on field homogeneity: distortion reach ≈7 mm instead of ≈5 mm from wall



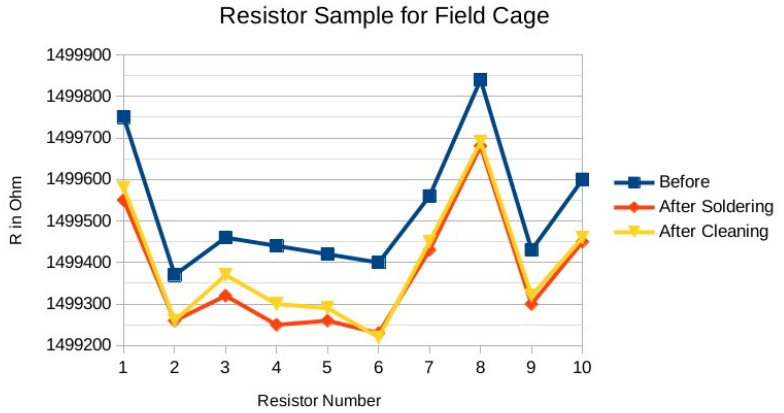


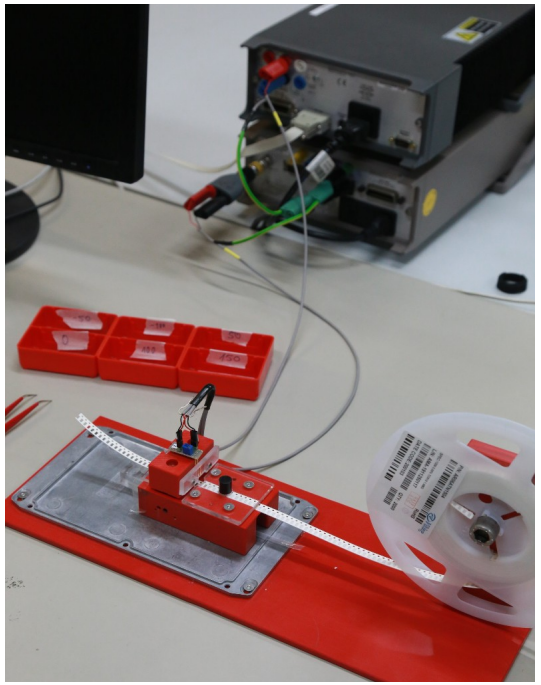


Field Cage V2 in 2020

High Precision Resistors

- January: High precision 1.5 MΩ resistors arrived
  - Testing the tools to select 0.005 % precision out of the purchased resistors with 0.05 % precision (HP3458A)
- March: Tests of resistance change after soldering
  → resistances change, but all in the same direction and range
- April: Design / construction of SMD resistor measurement station started
- June/July: Changed to a resistor comparison station with a Wheatstone bridge
  - Calibration of Keithley electrometer
- October: Resistor measurements
  - Noticed (before soldering): offset in some of the measured resistors
  - Improved setup including “online” analysis to find such effects
  - Re-did measurements and sorting in daily batches
- November: Soldering on field strip foil by DESY ZE group





Field Cage V2 in 2020

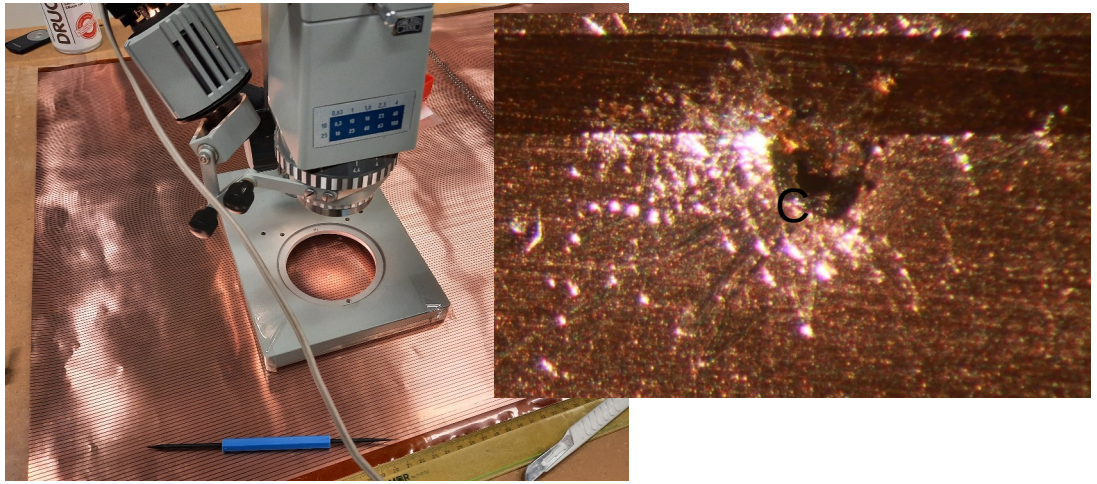
Field Strip Foil

- February: field strip foil production at CERN started
  - New, simpler mirror strip layout (distortion reach from wall ≈7 mm instead of ≈5 mm)
  - New material: 50µm Kapton with 17µm copper on both sides (before 35 µm Cu): saving ≈ 0.25% X_0
- June: Foil arrived
  - cutting investigated in more detail:
  - We need precise dimensions; goal: gap after wrapping around ≈ 100 µm
- July: Cutting test at external company, in September more tests at DESY
- October: Final cutting and trimming of the edges
- November
  - After soldering resistors found a field strip pair with 650 kΩ instead of 750 kΩ resistance

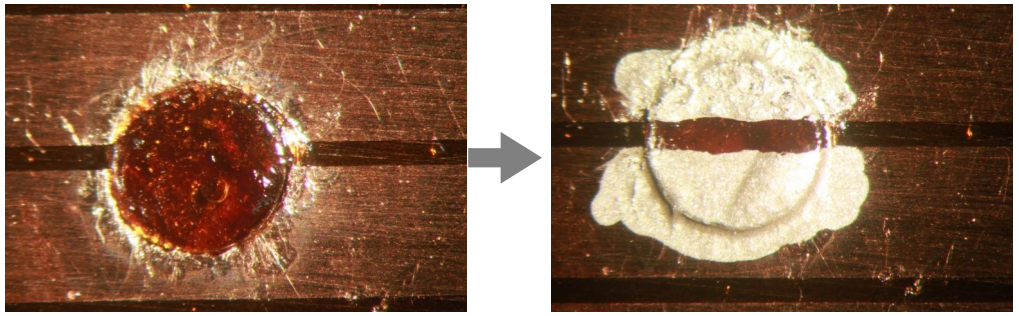
Field Cage V2 in 2020

Field Strip Foil

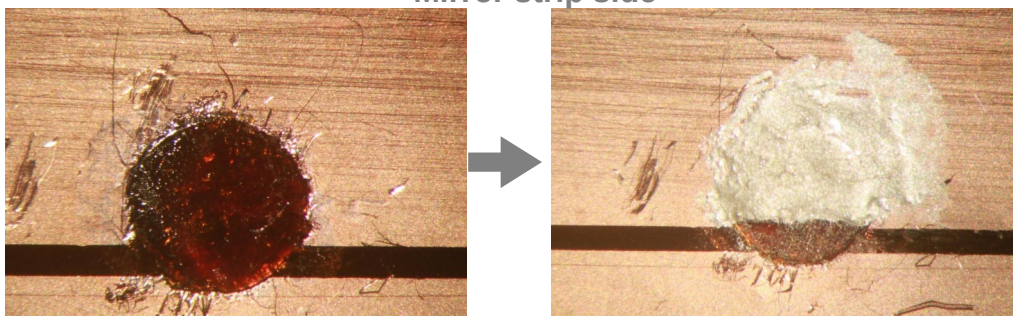
- December: Investigating and fixing resistance mismatch
  - Signal runtime measurements (reflectometry) lead to find a tiny hole to the mirror strip side
  - Recorded the growth of that hole by interplay of electrical discharges and thermal decomposition (see separate video)
  - Carefully “cleaned” hole borders and removed copper
  - Closed by gluing in a polyimide patch
  - Re-painted conducting pattern on top
  - Resistance after repair roughly as expected
- December 16th: "We stay at home" rule
  - HV test of the repaired place planned
  - Final gluing delayed, no activity in workshop since



Field strip side



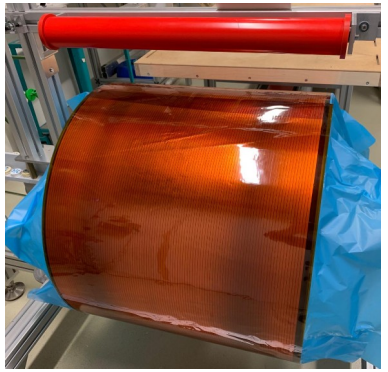
Mirror strip side



Field Cage V2 in 2020

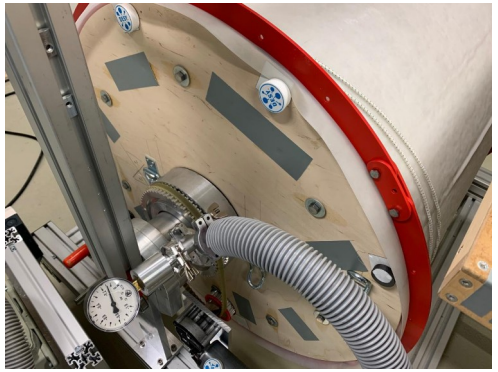
Construction, Gluing, HV and Shielding

- June: Investigating options for outer shielding foil
  - Previous: 10 µm Cu + 50 µm Kapton ≈ 0.09 % X_0
  - New: 2 samples PET/Al 23µm/25µm and 25µm/12µm, results in ≈ 0.03 % X_0 , foils arrived in July
- September: First dry run for gluing → a few small improvements on tooling and processes
- October:
  - Last missing material arrived
  - HV test of some components
    - Complete wall sample holds 30 kV
    - Kapton significantly less HV stable than expected in long term tests
    - For better gluing Nomex layer replaced by Kapton: more HV stability at same X_0
  - November: First gluing test on mandrel



Field strip + Kapton foil
(in blue: release film)

… + peel ply + suction fleece

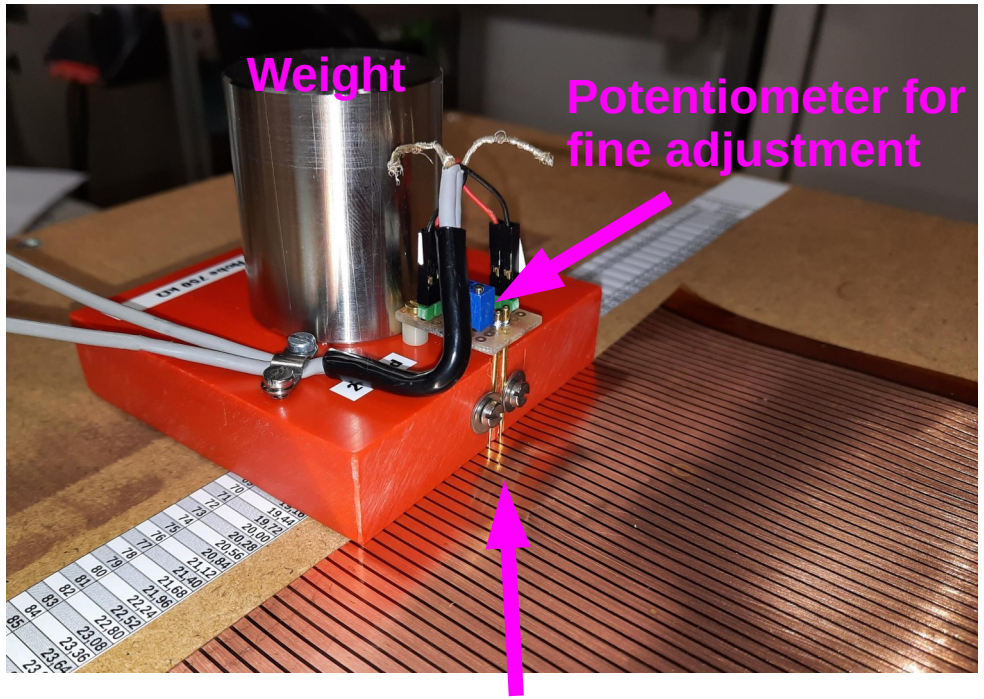


... put into vacum bag → pumping

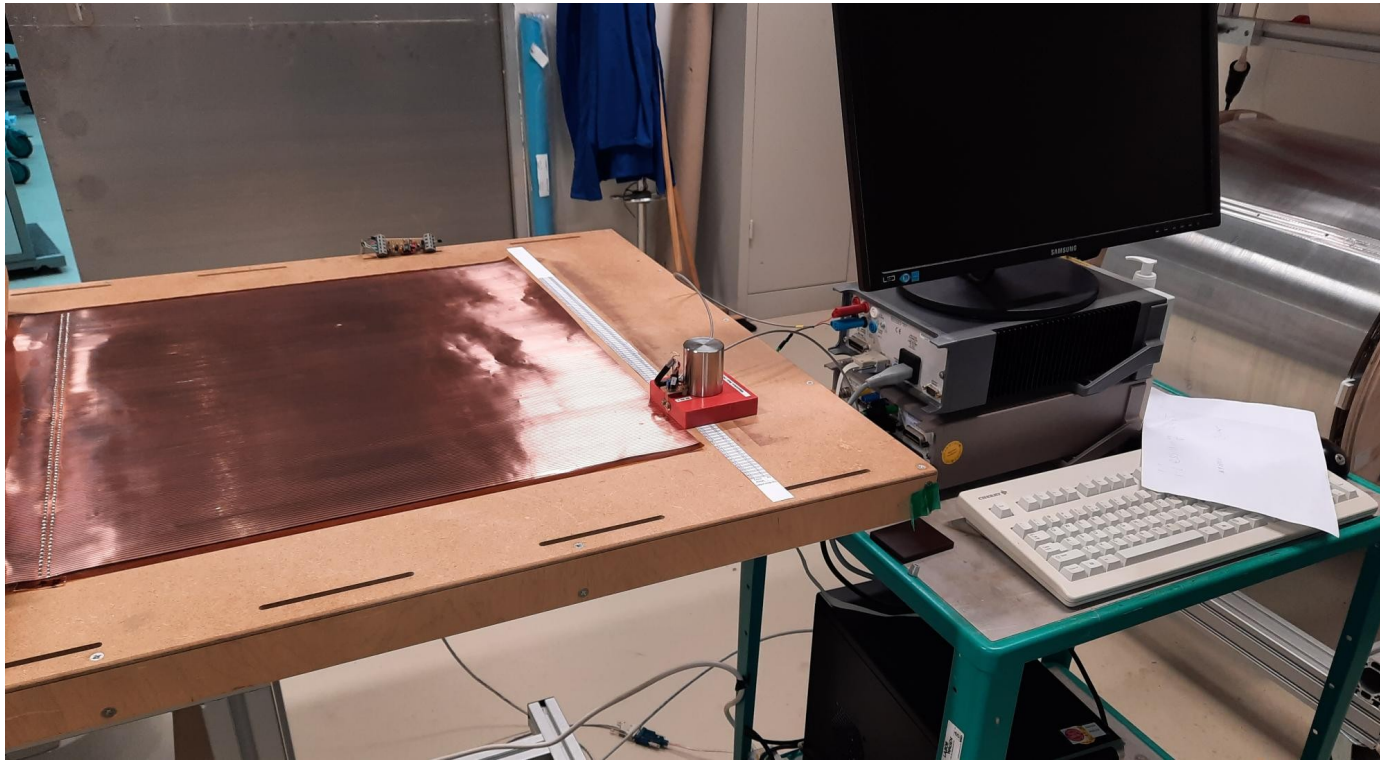
Field Cage V2 in 2021

Precision Measurement of the Resistor Chain

- All resistors need to be in a bin of 50 Ω width to fulfill our requirement on the field homogeneity
- September:modified the measurement equipment we used to select/sort the resistors before soldering, so it can be used on the field strip foil (same Wheatstone bridge design); includes a temperature sensor
  - Measurement done with respect to a default resistor



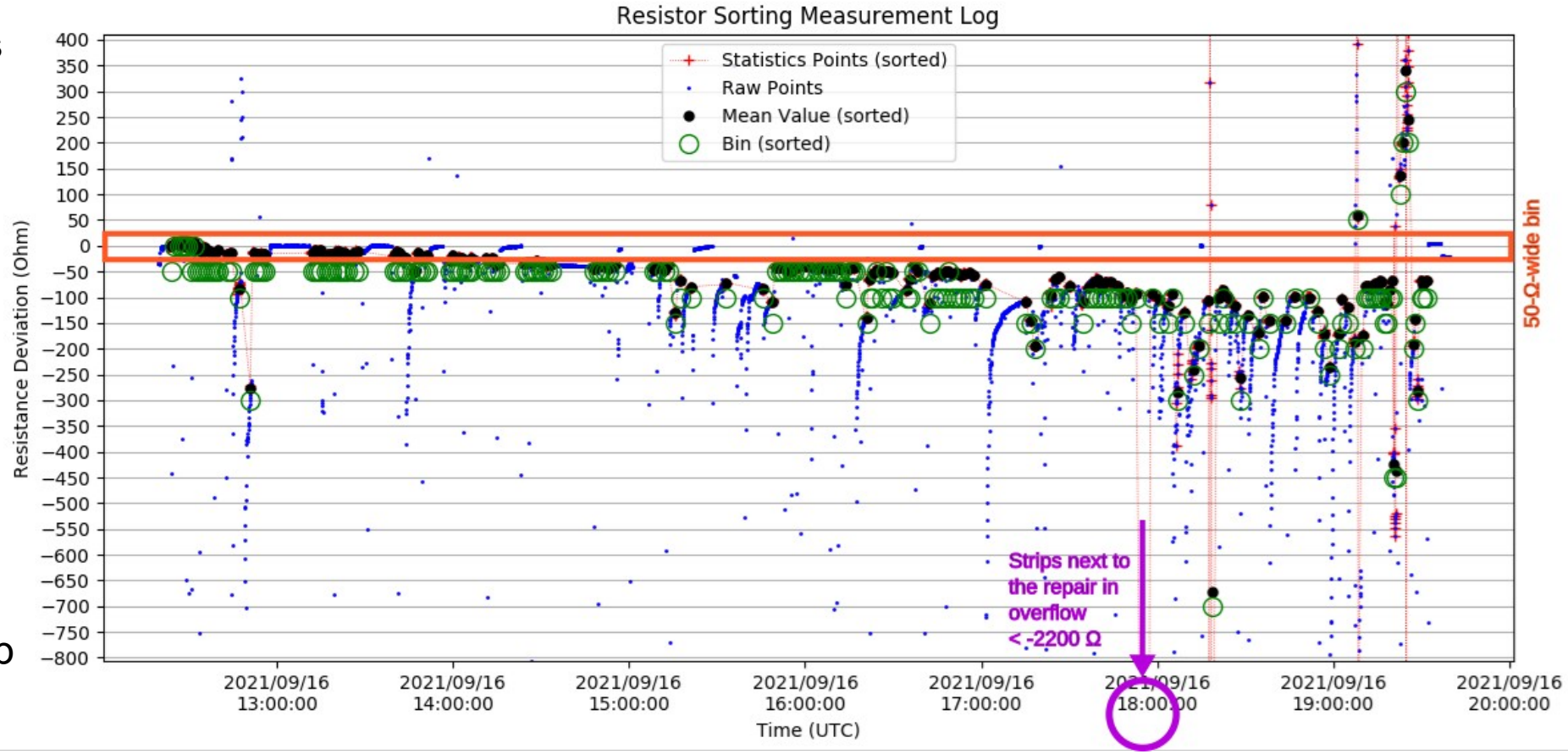
2 spring loaded measurement pins



Field Cage V2 in 2021

Precision Measurement of the Resistor Chain

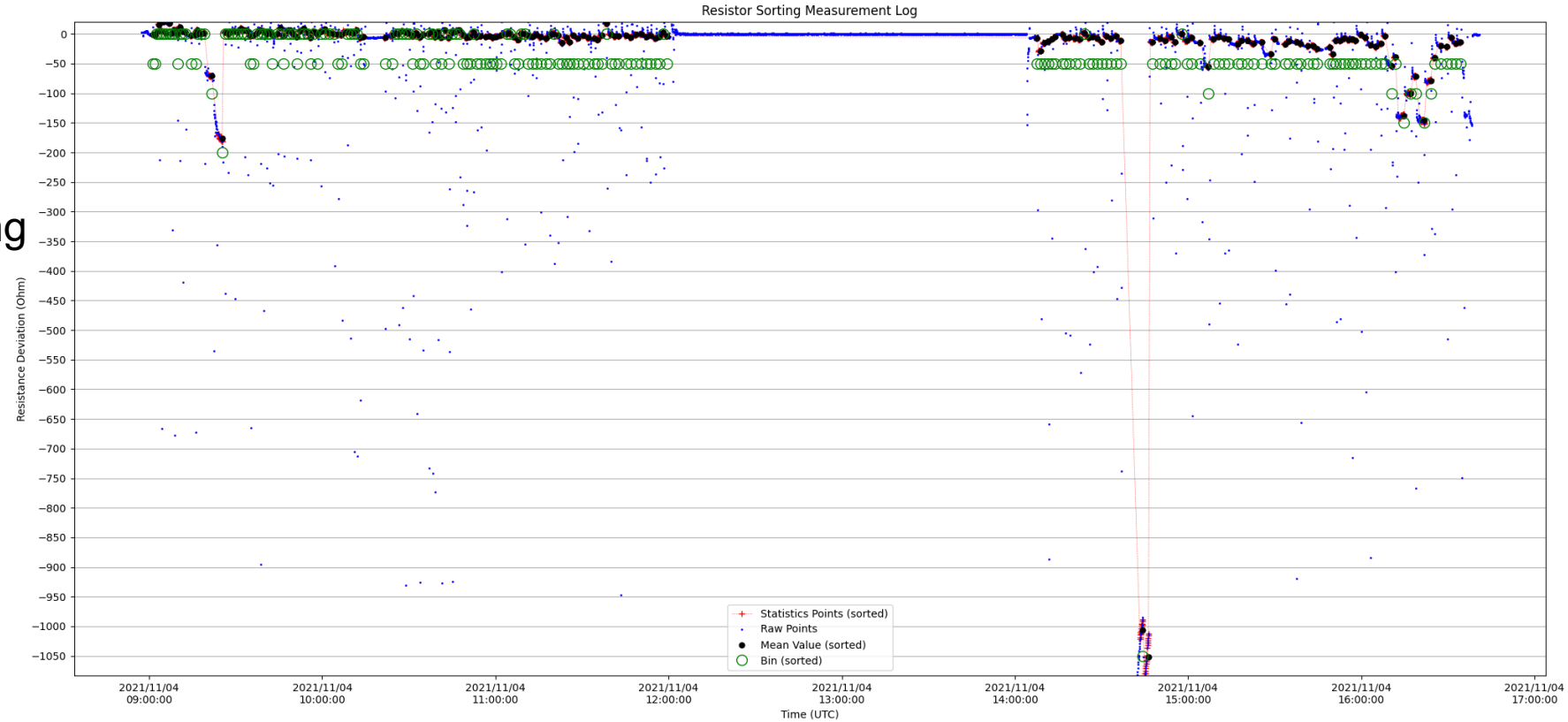
- Measurement from 16.Sep.2021
  - Field strip foil lying on protection foil, temperature sensor and lamp mounted on the table
  - Observed charge-up as well as discharge behavior and fluctuations
  - Impact of the foil beneath?
    - Tried ESD protection mat → didn't work, resistance too low
  - Impact of mounted lamp and temp sensor?



Field Cage V2 in 2021

Precision Measurement of the Resistor Chain

- Measurement from 04.Nov.2021
  - Field strip foil lying on bare table, temperature sensor and lamp mounted on the table
- Directly measuring on the wooden table working, but:
  - Some outliers at beginning and versus the end
  - Large deviation of ≈1kΩ next to the repair



Field Cage V2 in 2021

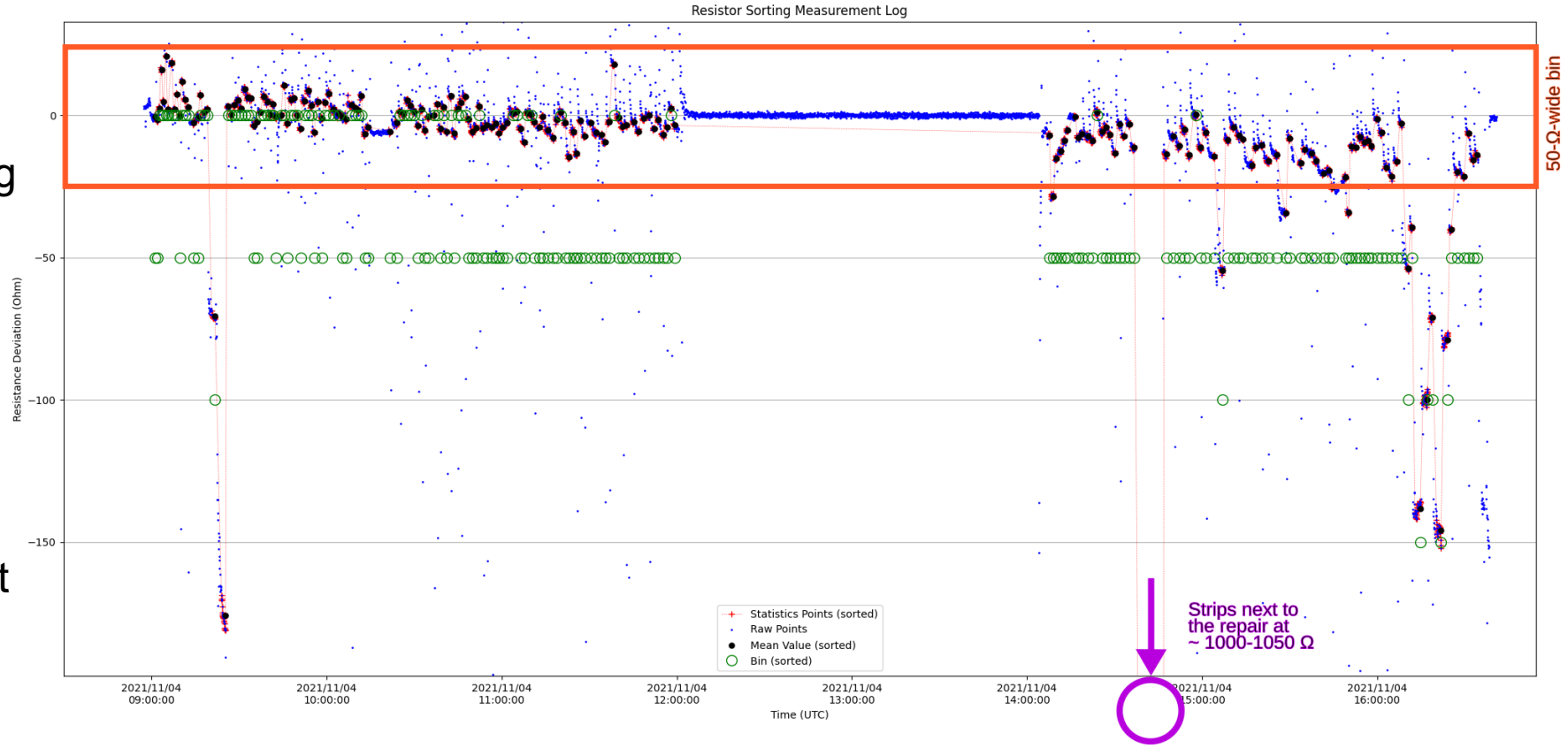
Precision Measurement of the Resistor Chain

- Measurement from 04.Nov.2021
  - Field strip foil lying on bare table, temperature sensor and lamp mounted on the table

- Directly measuring on the wooden table working, but:
  - Some outliers at beginning and versus the end
  - Large deviation of ≈1kΩ next to the repair

→ Not good enough for our requirement

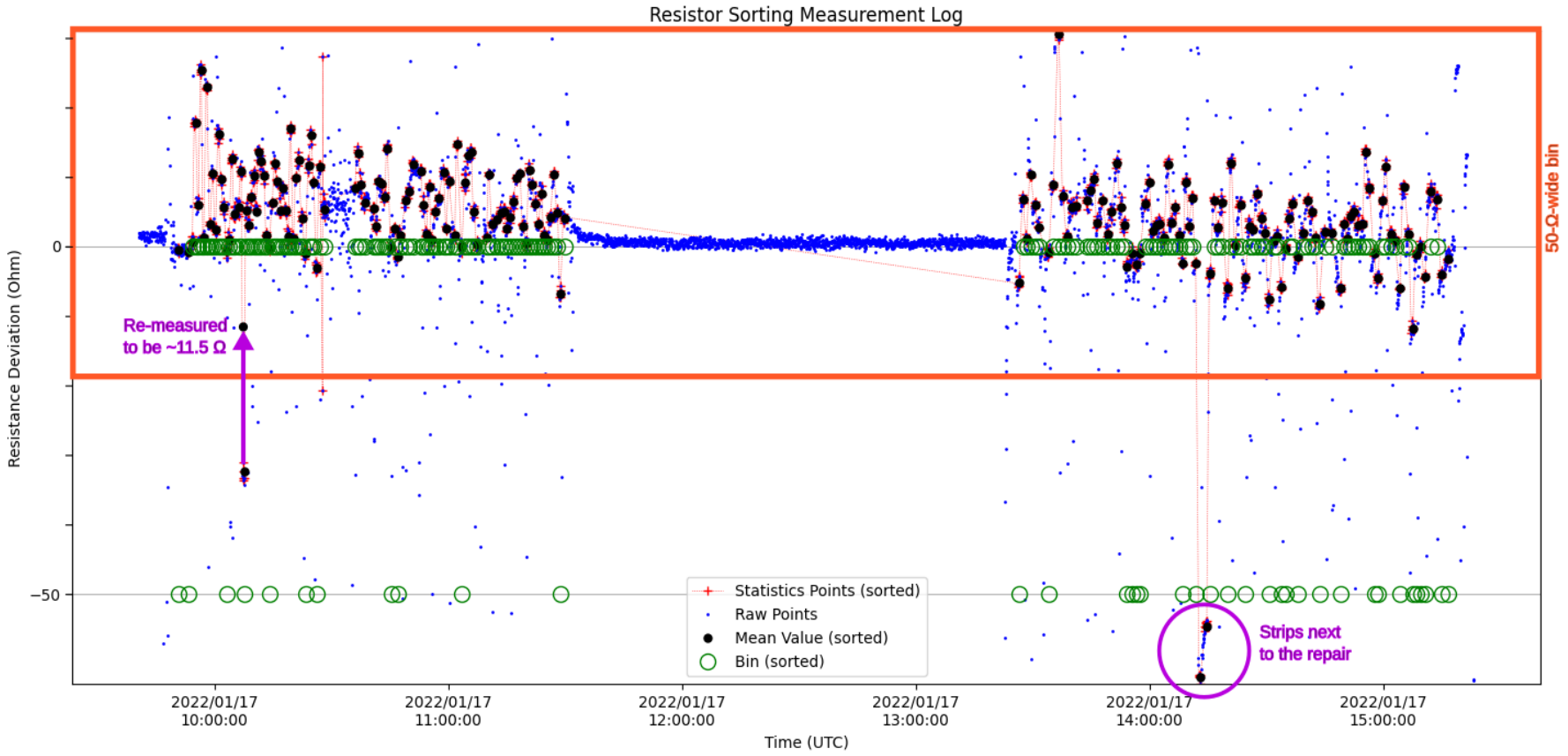
→ Try measuring at different location on table, and without lamp and temperature sensor



Field Cage V2 in 2022

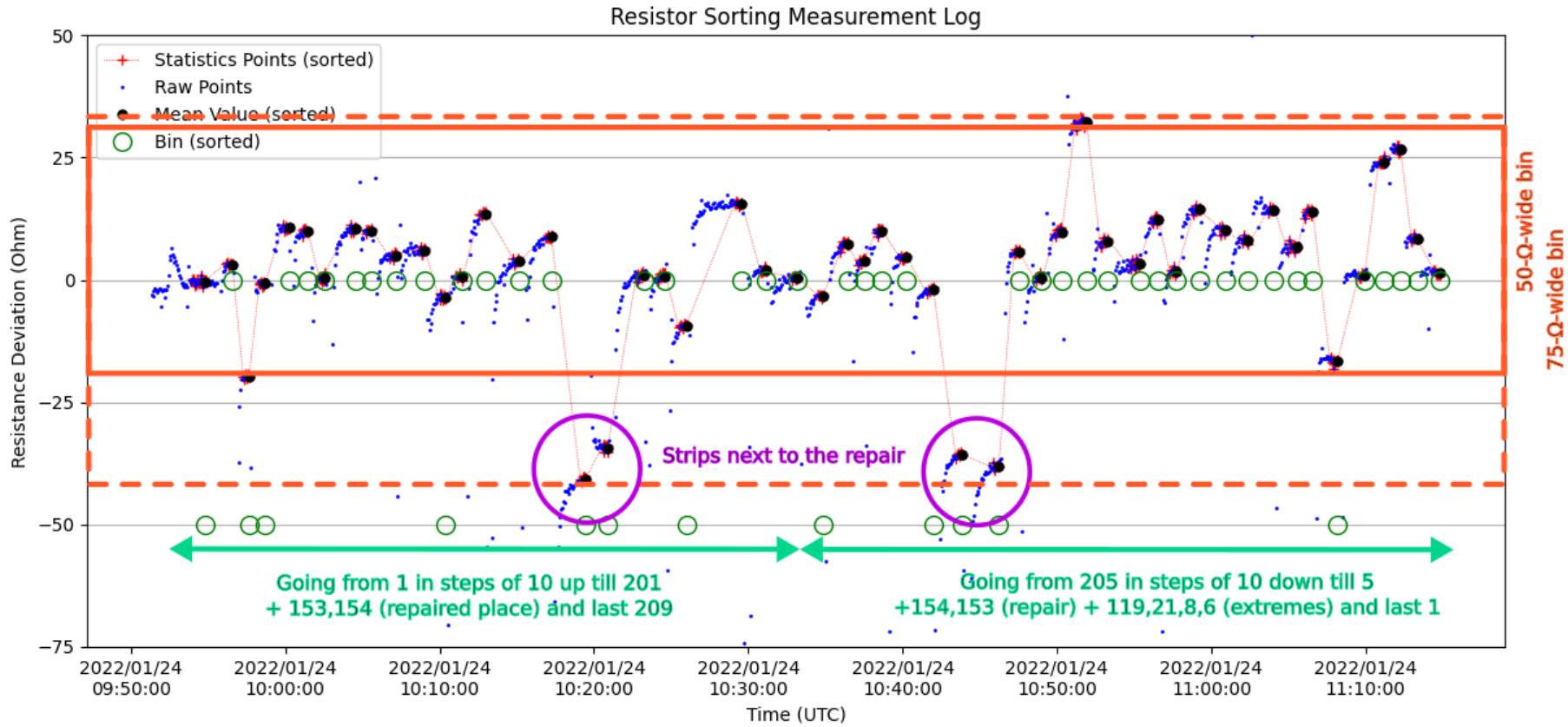
Precision Measurement of the Resistor Chain

- Measurement from 17.Jan.2022
  - Field strip foil lying on bare table, temperature sensor and lamp removed
- Nearly all strips in a 50-Ω-wide bin
- resistance next to repair: only small deviation (-50 Ω > R > -60 Ω)
  - repair needed?
- Should be confirmed by a measurement of at least a few samples



Field Cage V2 in 2022

Picking up from Collaboration Meeting 2022

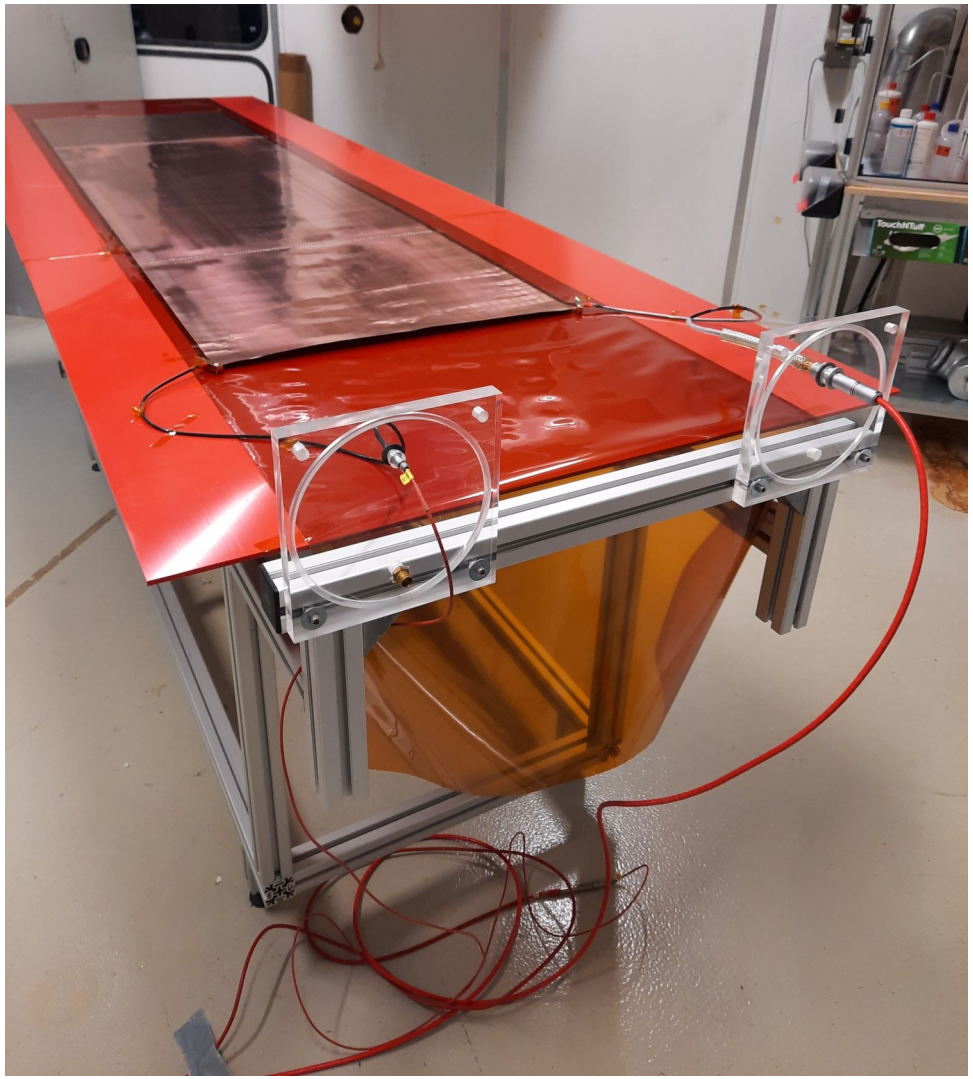


- Remeasured on 24th January 2022: all strips sufficiently within specs
- Assumption: epoxy resin took that long to fully cure and for moisture trapped in bubbles to diffuse out
  → Proceed with high voltage test

Field Cage V2 in 2022

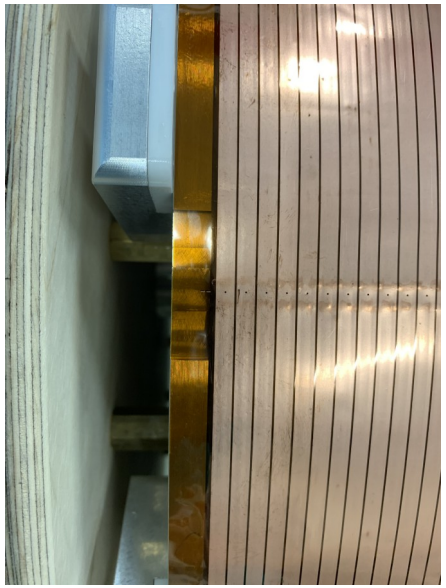
- From February: preparations for open HV test of field strip foil (many safety precautions)
- 26th / 27th April: HV test of field strip foil passed
  - Quick test with 30 kV
  - 24 hours at 25 kV without problems

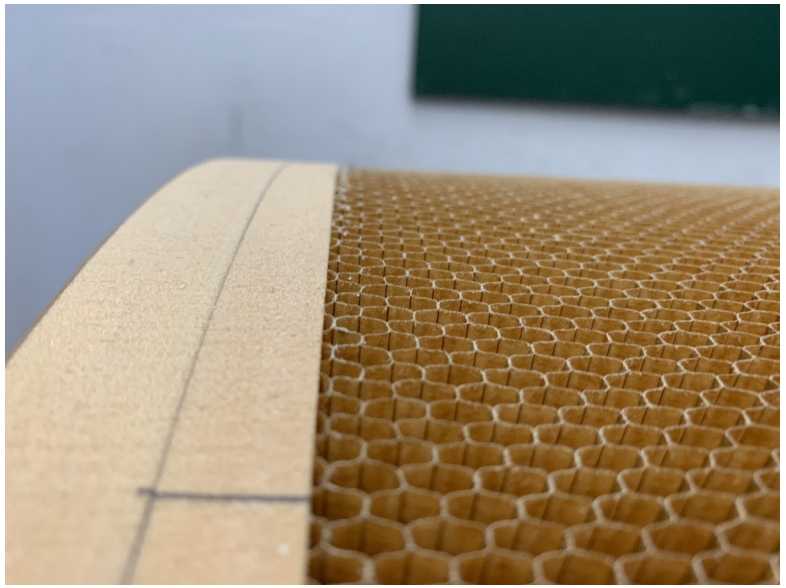
→ Proceed with field cage construction



Field Cage V2 in 2022

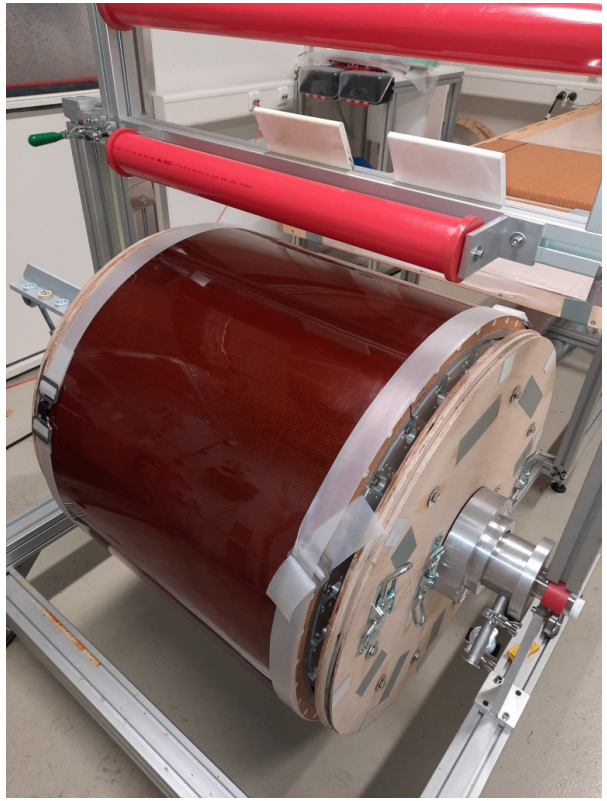
- June: lamination of field cage
  - Works well until a height difference between flange rings and honeycomb layer is noticed
  - Excess honeycomb is milled/routed down
  - Further complications with laminating subsequent layers, running out of material

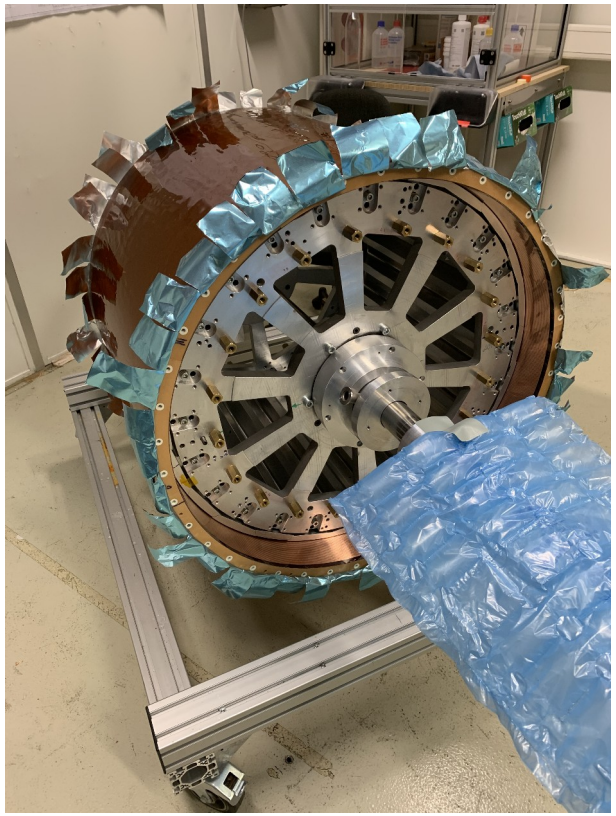


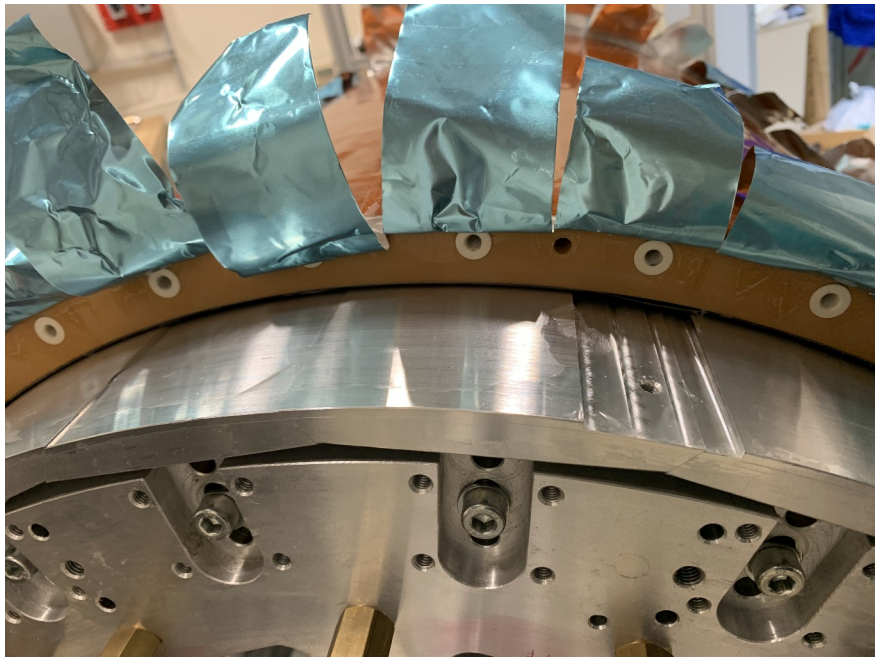


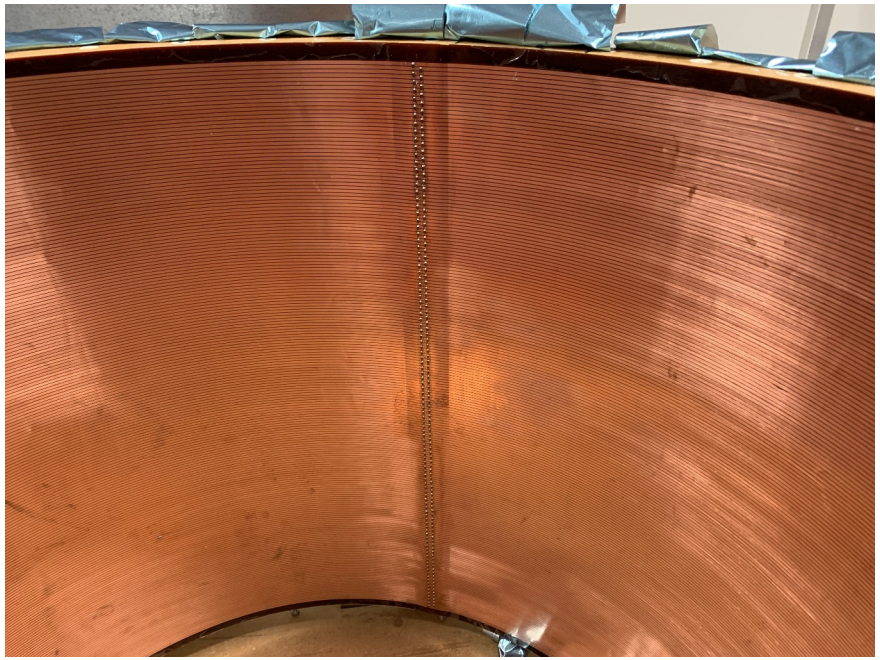
Field Cage V2 in 2023

- New material for field cage has finally arrived (delivery crisis)
- Completed field cage in April



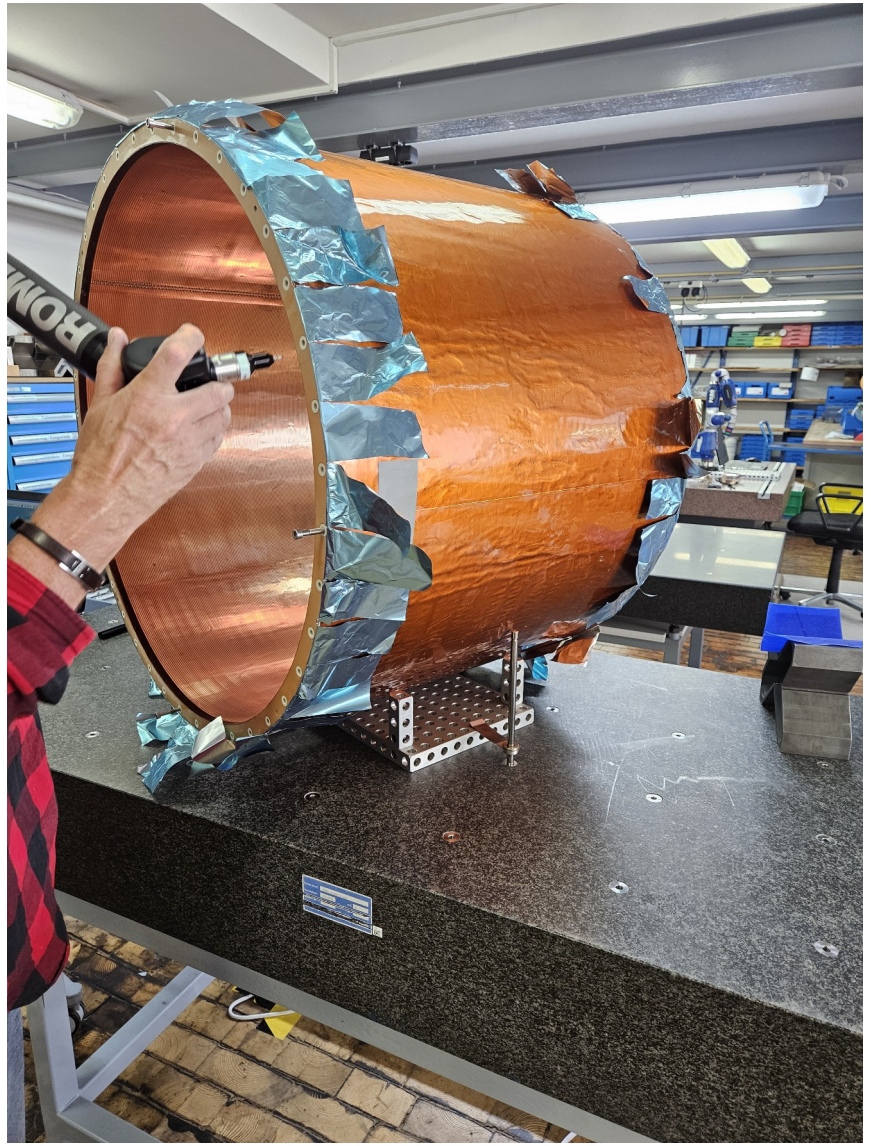






Field Cage V2 in 2024

- Currently evaluating results from a geometrical survey of the new field cage
- Still somewhat inconclusive
- New measurement equipment has different accuracy and reach than the one used for field cage V1 (>15 years ago)
- First preliminary results suggest:
  - some aspects (skew) could be improved with respect to field cage V1
  - others seem worse (tilted flange, field strip alignment to flanges and at seam) in spite of very precise alignment on mandrel
- Cause, impact and possible corrections need to be studied



Conclusion & Outlook

- A new, improved field cage for the Large Prototype TPC was foreseen to be ready in spring 2020
- COVID-19 and parallel priority workload of everyone involved caused extreme delays
- Thanks to the continued steady effort of the former TPC group at DESY and especially our technical staff Ole Bach, Bernd Beyer, Andreas Busch, Volker Prahl, and the support of DESY groups ZE and ZMQS field cage version 2 could finally be completed in April 2023
- Inhouse experience for such a construction was gained
- New methods for resistor sorting, fault detection and repair in flexible circuit boards were developed
- The propagation and growth of electrical insulation faults in copper-clad polyimide foil could be filmed which might give new insights for similar applications of such foils in MPGD (see separate video file)