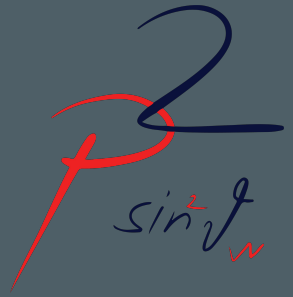


Building Tracking Detector Modules for P2

...

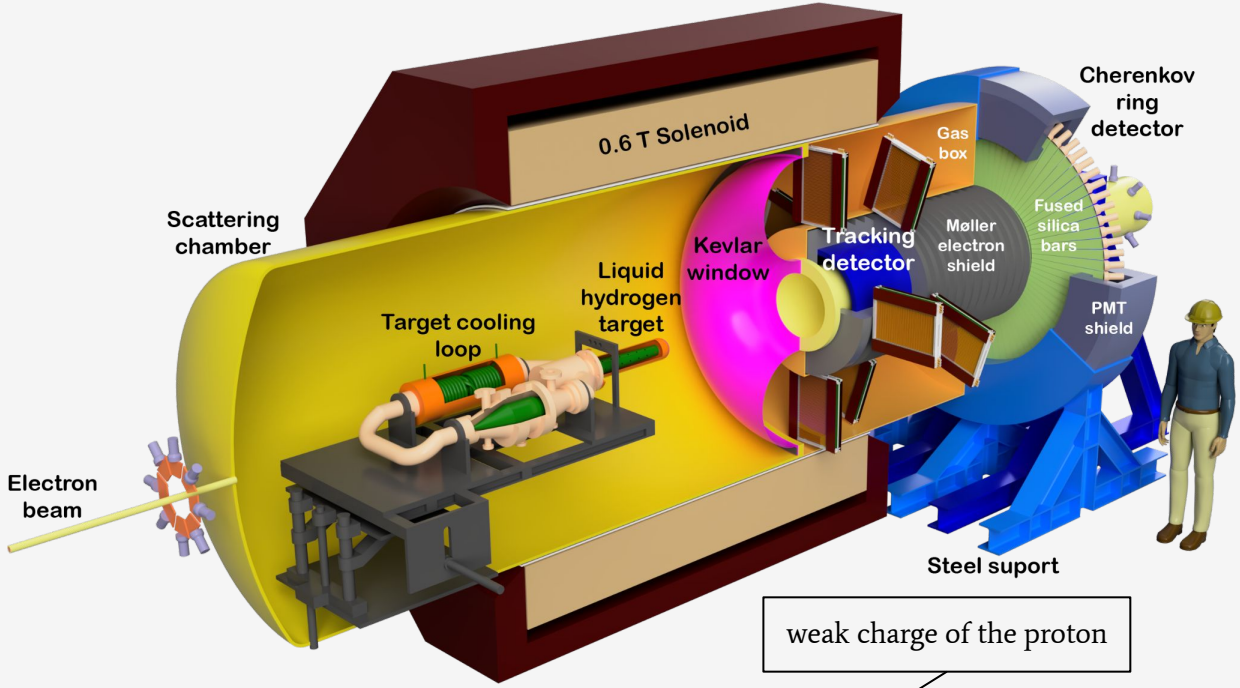
KPH-Meet-up 09-05-2023

Lucas Sebastian Binn
AG Berger
Niklaus Berger, Philipp Kern,
Michail Kravchenko, Lars Steffen Weinstock

JG|U

PRISMA+ DETECTOR LAB

P2 Experiment



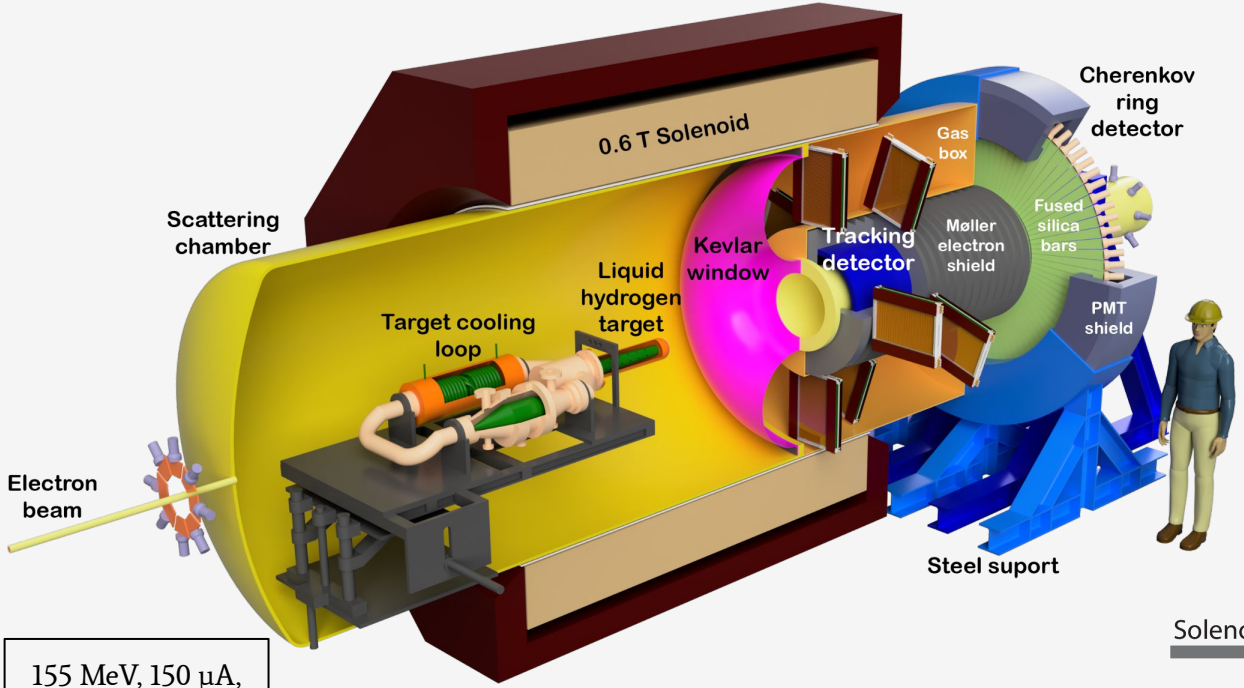
- Located @ MESA
- Determination of weak mixing angle at low momentum transfer
- Measure parity violating asymmetry in elastic electron-proton scattering

weak charge of the proton

$$A_{PV} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \frac{G_F Q^2}{4\sqrt{2}\pi\alpha}(Q_W + F(Q^2))$$

$$Q_W = 1 - 4\sin^2\theta_W$$

P2 Experiment

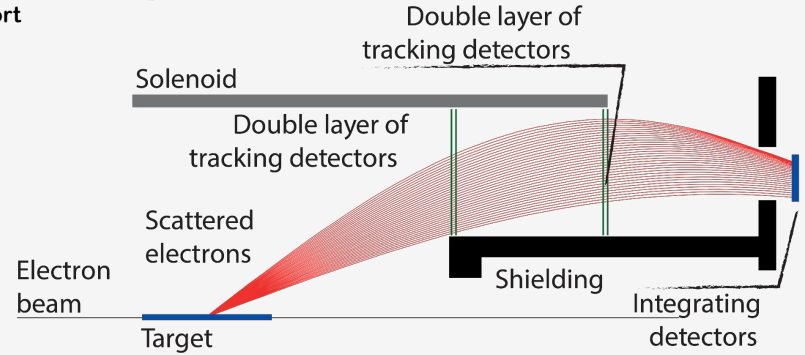


- Located @ MESA
- Determination of weak mixing angle at low momentum transfer
- Measure parity violating asymmetry in elastic electron-proton scattering
- Tracking Detector
  - Determination of average momentum transfer Q^2
  - Study of systematic effects

155 MeV, 150 μA,
f_{sw} = 1 kHz

$$A_{PV} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \frac{G_F Q^2}{4\sqrt{2}\pi\alpha}(Q_W + F(Q^2))$$

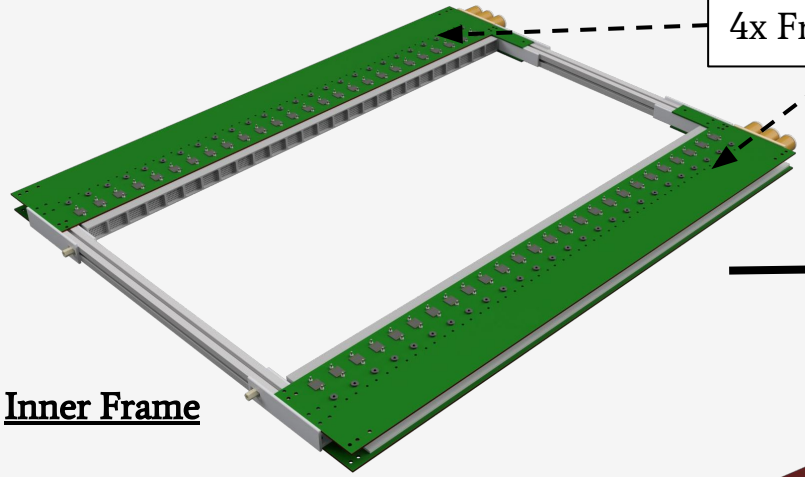
$$Q_W = 1 - 4\sin^2\theta_W$$



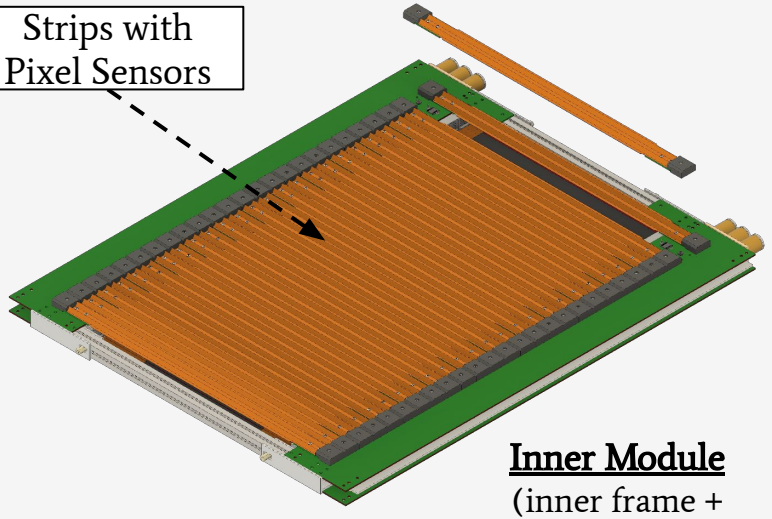
Tracking Detector Module

4x Frame PCBs

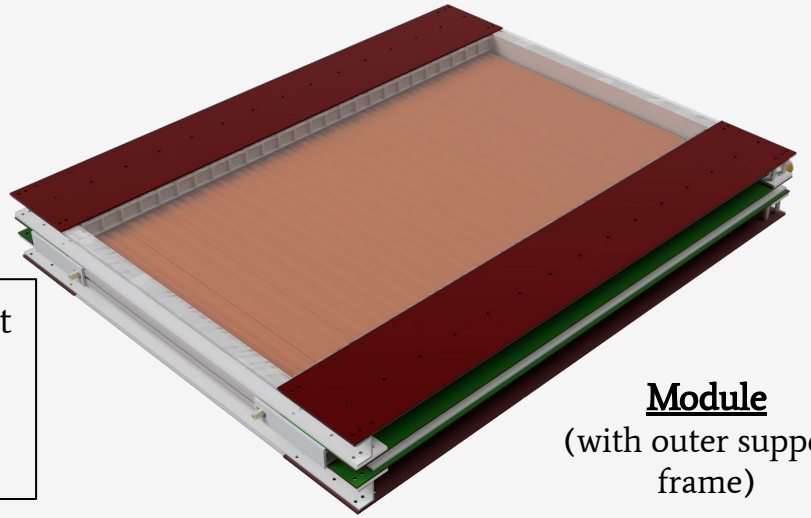
Strips with Pixel Sensors



Inner Frame



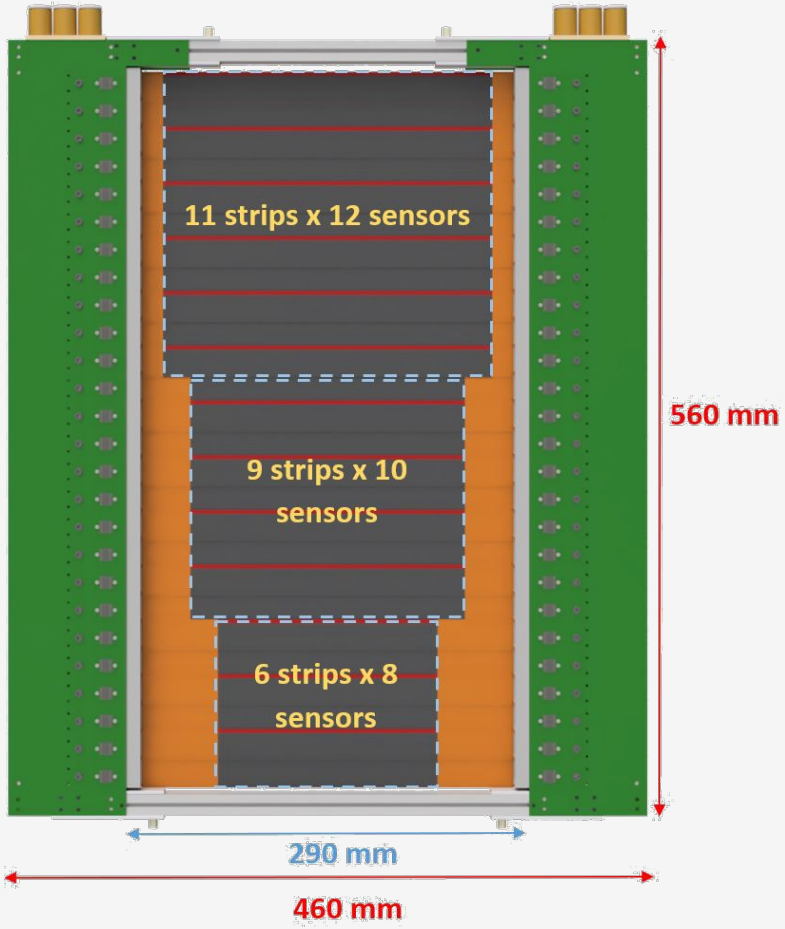
Inner Module
(inner frame + 2x sensor planes)



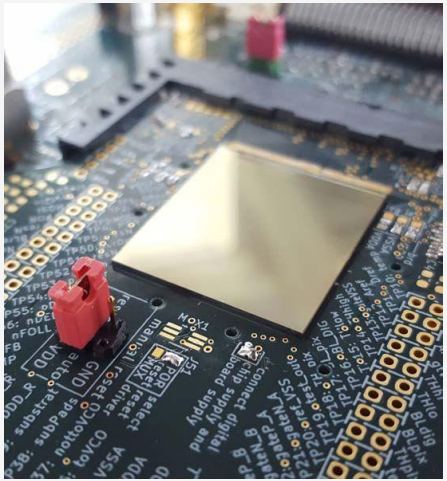
Module
(with outer support frame)

Design driven by requirement of low multiple Coulomb scattering
→ low material budget

Strip Configurations & Sensors

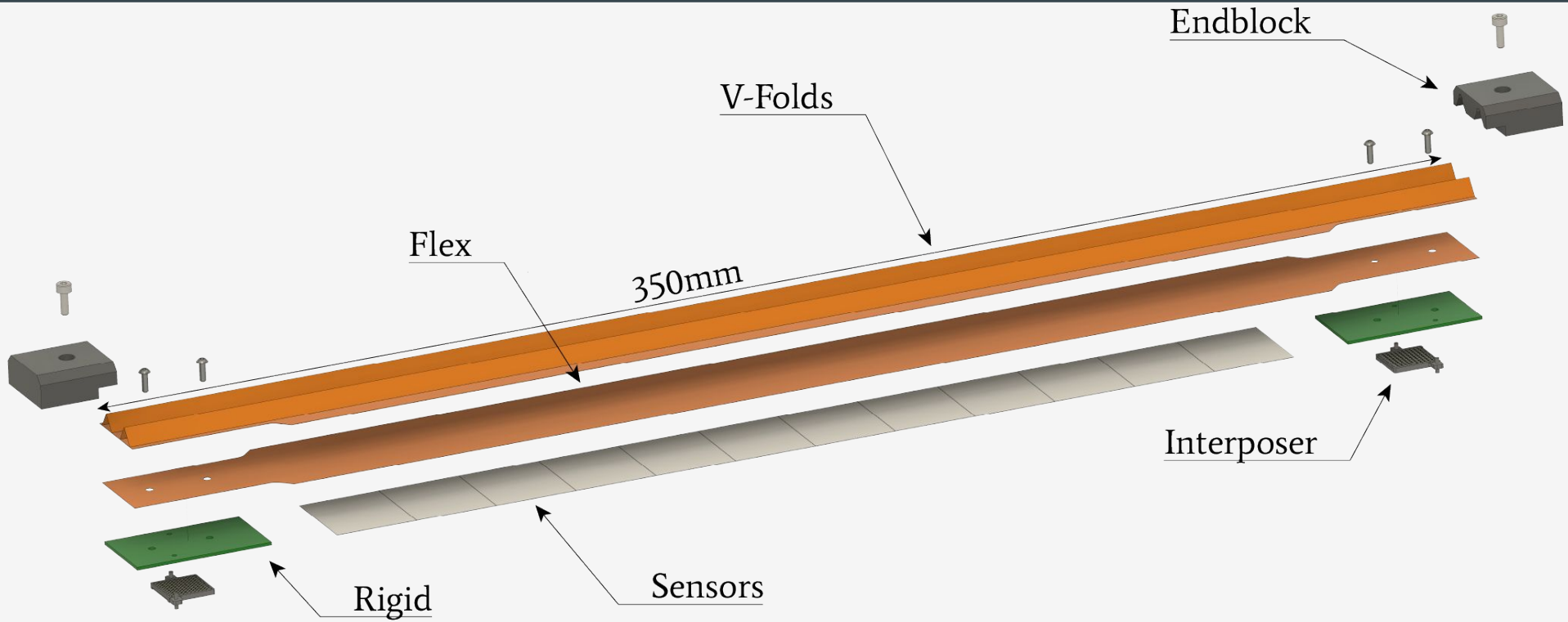


- 540 pixel sensors per module
- Similar pixel sensors as used in the Mu3e experiment
  → knowledge in group
- Monolithic, 70 µm thickness
  → reduced material budget
  → reduced multiple Coulomb scattering

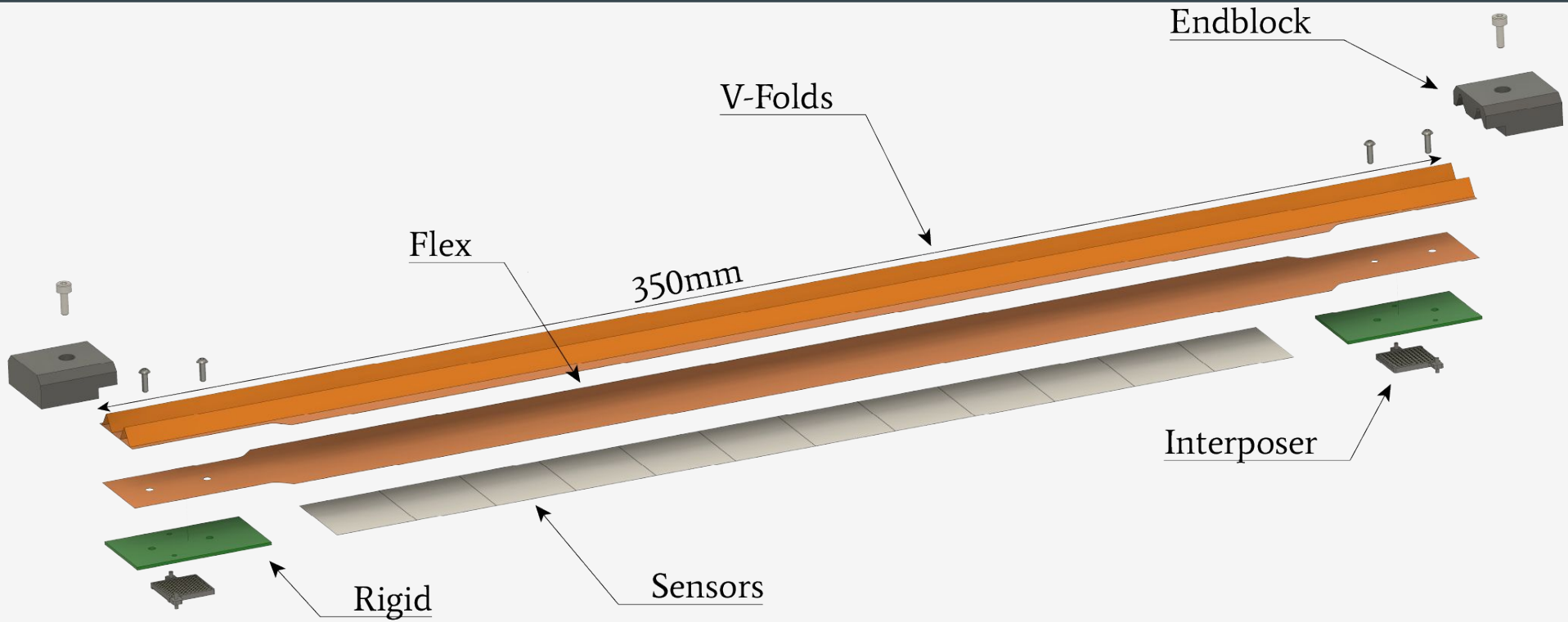


[MuPix 10]

Structure of the Strips



Structure of the Strips



- Two layer flex (with rigid parts at the ends)
- 9 µm copper thickness, 25 µm dielectric → X_0= 1.45‰

Development of Rigid-Flex

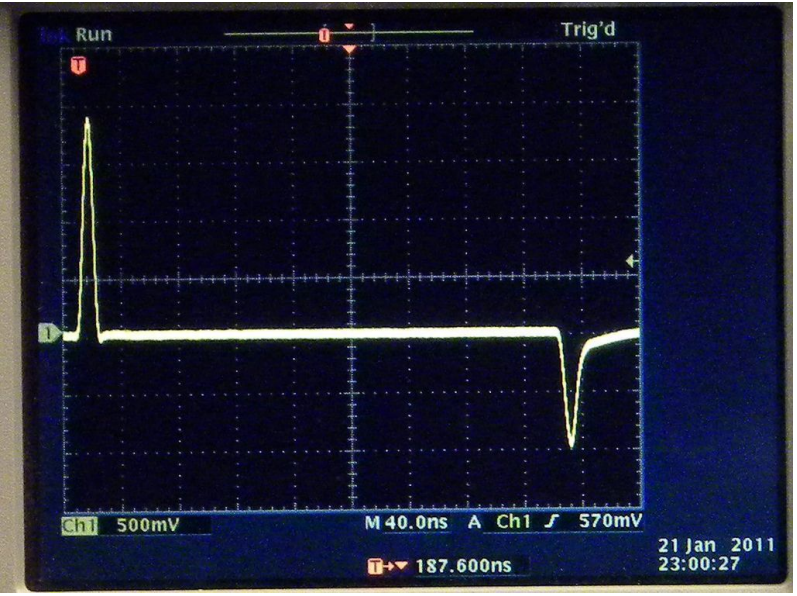
Soldered Rigid-Flex

Rigid-Flex

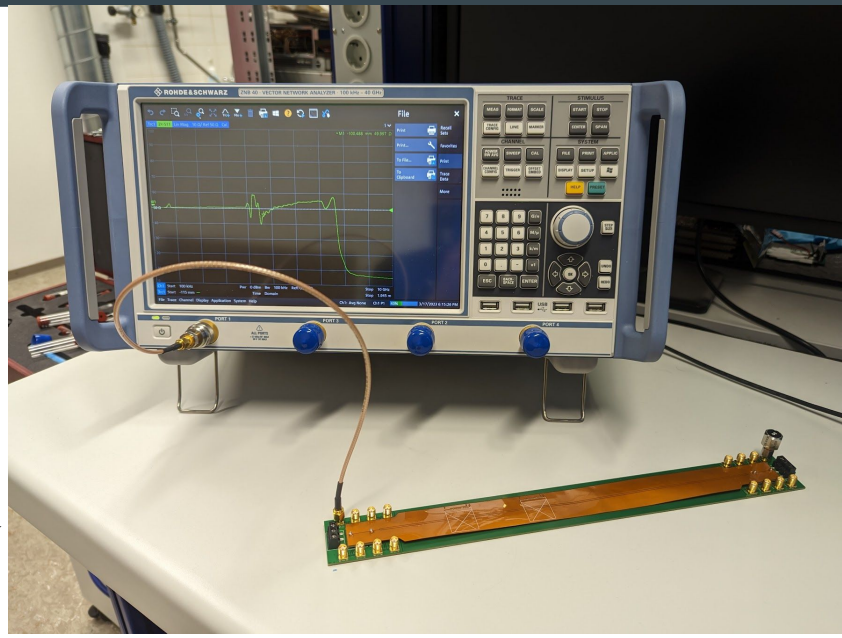
Test Jig (with mounted rigid-flex)

Time Domain Reflectometry

- Measure characteristic impedance along conductor
- Verify differential line impedance (constant)
  (signal integrity @ 1.25 Gbit/s)
- Reflection of signal at change of characteristic impedance



[Oscilloscope]



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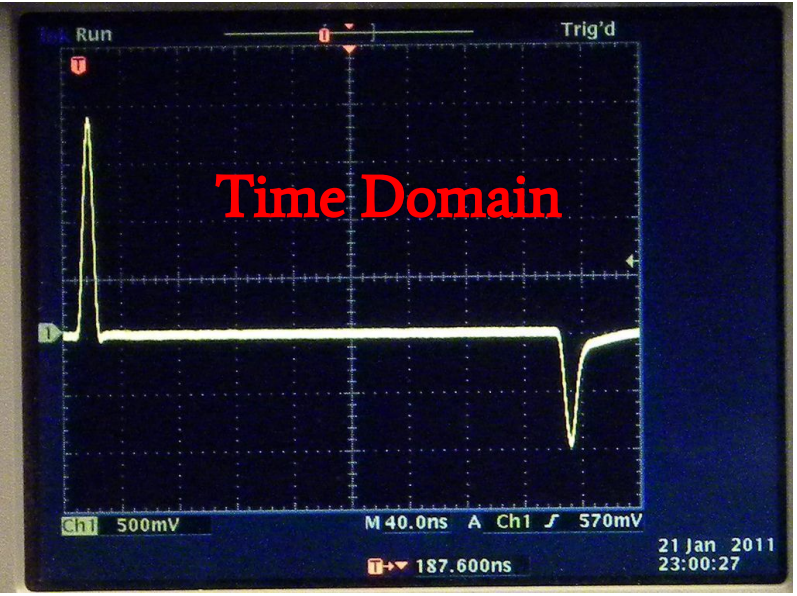
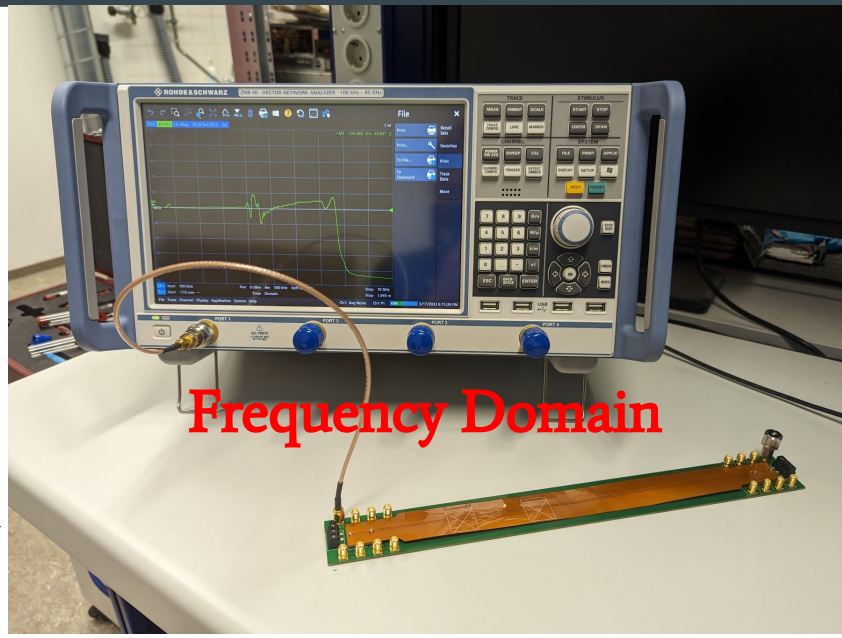


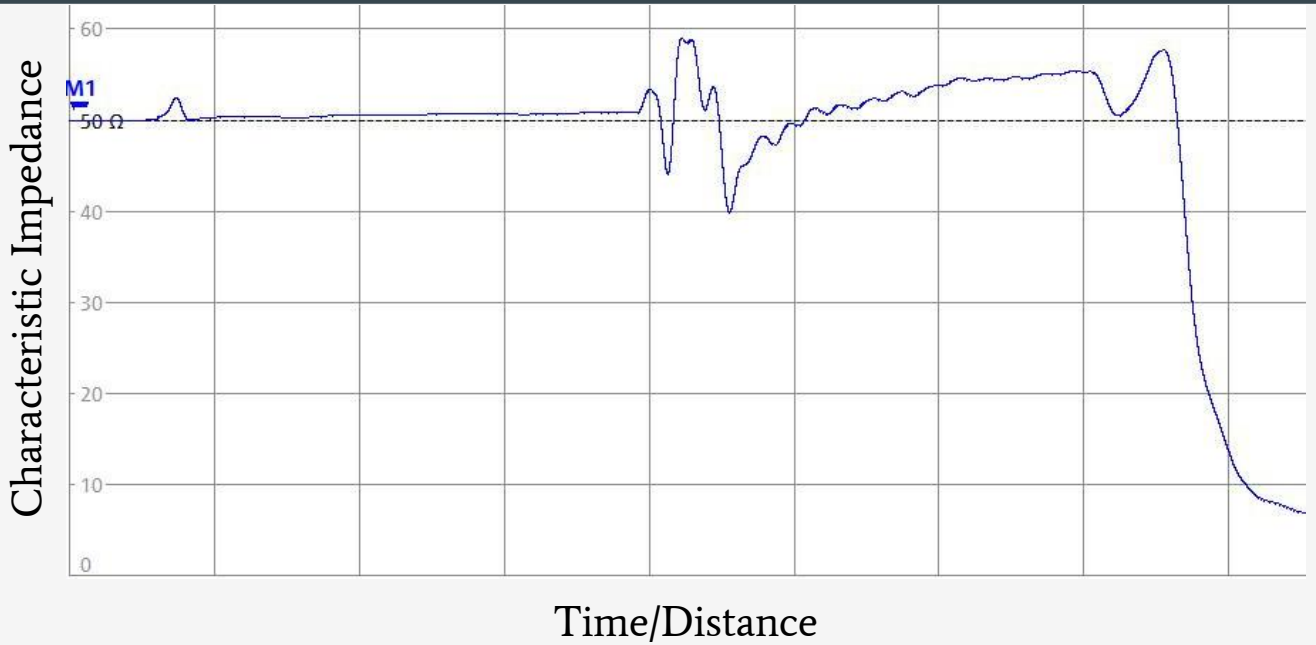
[Oscilloscope]

DFT

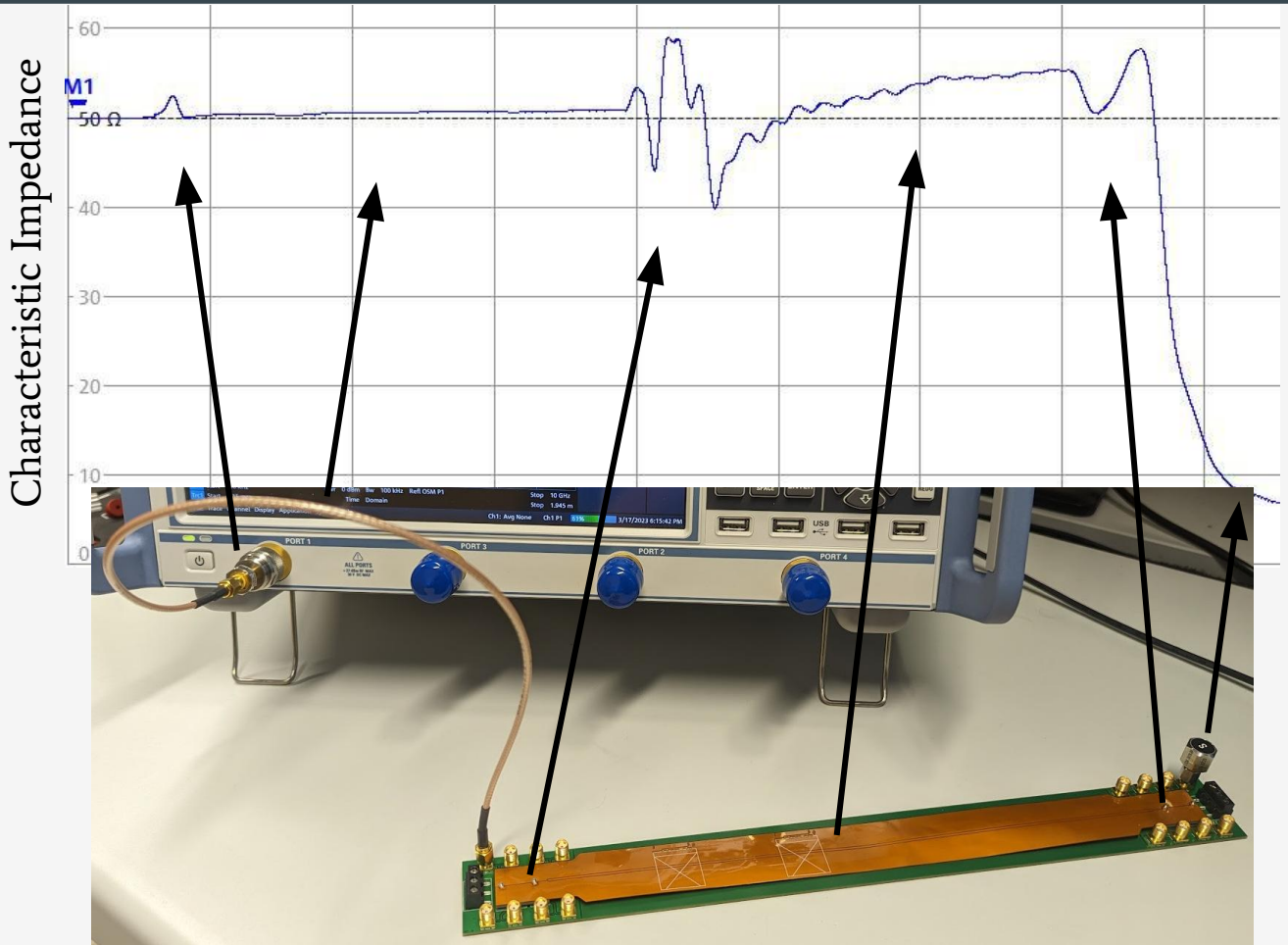


[Vector Network Analyser]

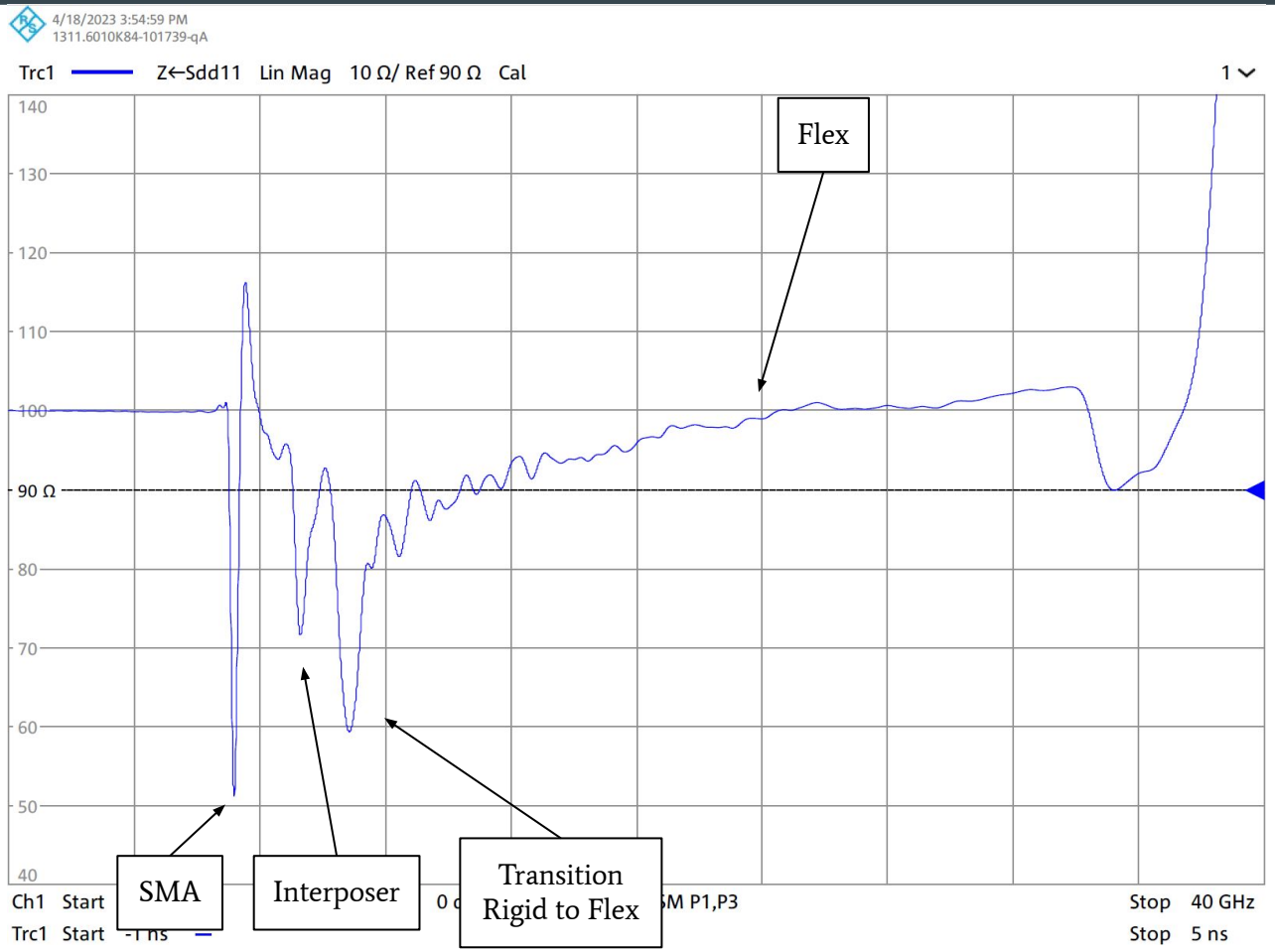
Time Domain Reflectometry

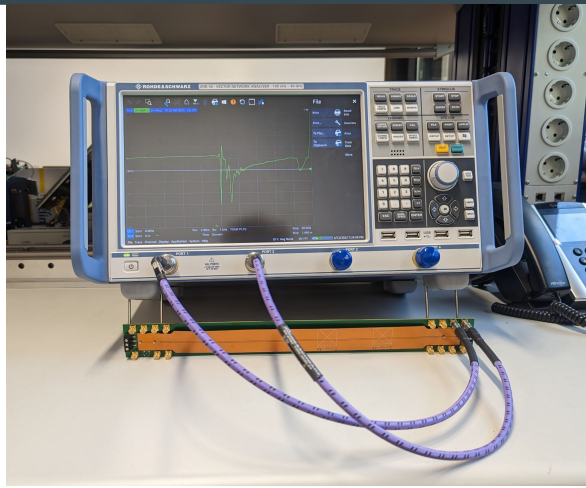


Time Domain Reflectometry



Time Domain Reflectometry

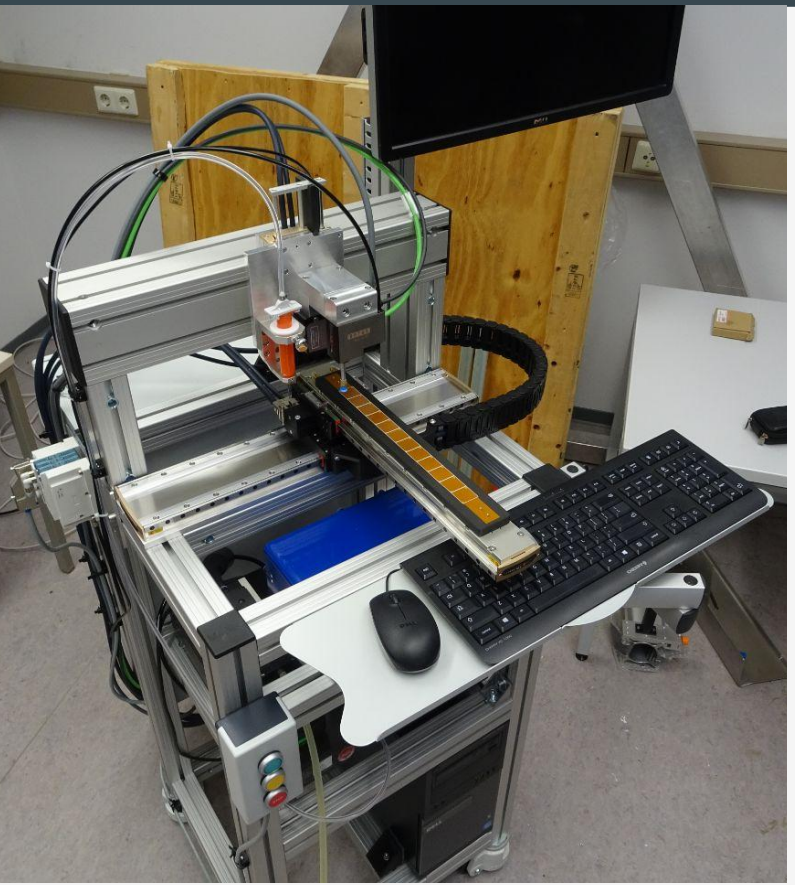




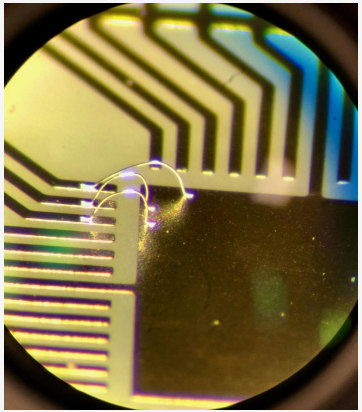
Next up
Bit **E**rror **R**ate **T**est
+ Eye Diagrams

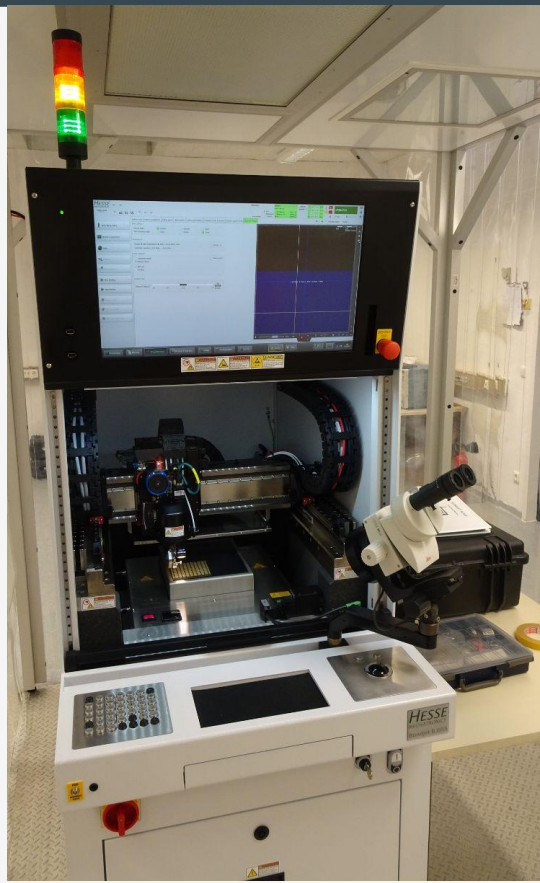
Gluing & Bonding of Sensors

Gluing & Bonding



Production of all 260 strips in Mainz
→ semi-automated processes

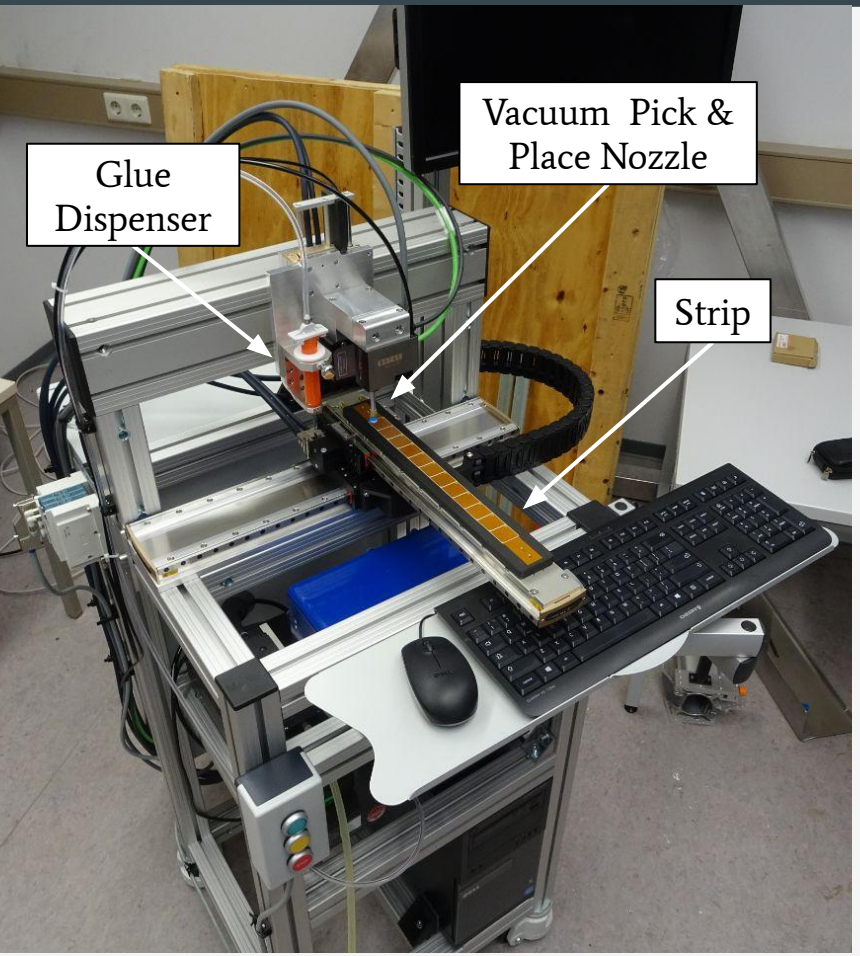




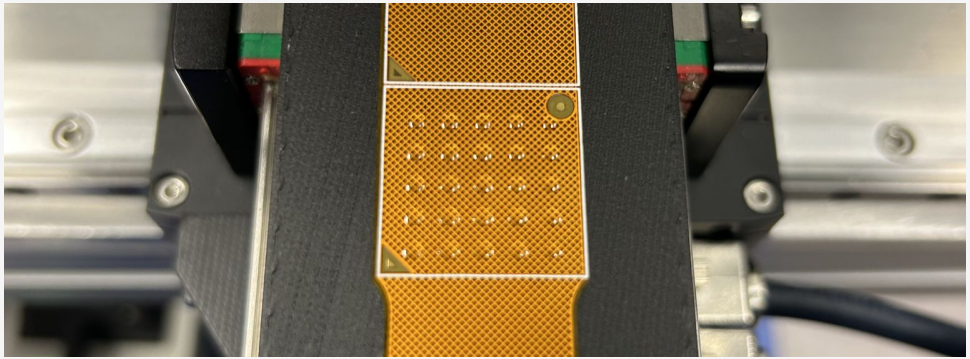
Gluebot

Wire-Bonding Machine

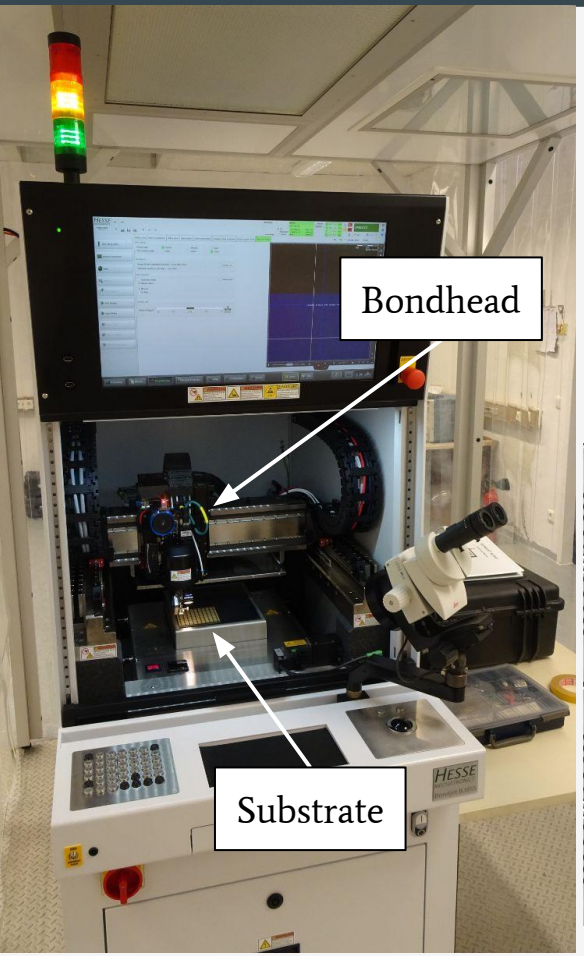
Gluebot



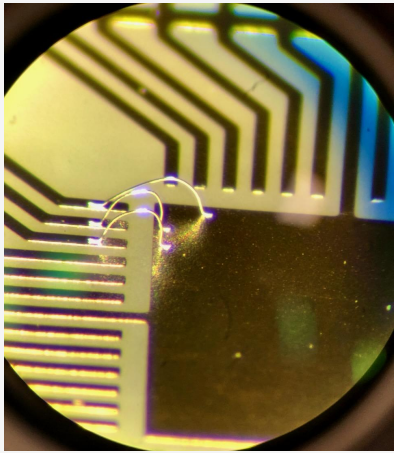
- Build & Developed by us
- Features
  - 4 Axes CNC Machine
  - Vacuum Table
  - Time Pressure Dispenser
  - Vacuum Pick & Place Nozzle
  - Microscopic Camera
  - Laser Distance Sensor
  - UV LEDs for Curing
- Sensor Placement Precision Goal ~10 µm

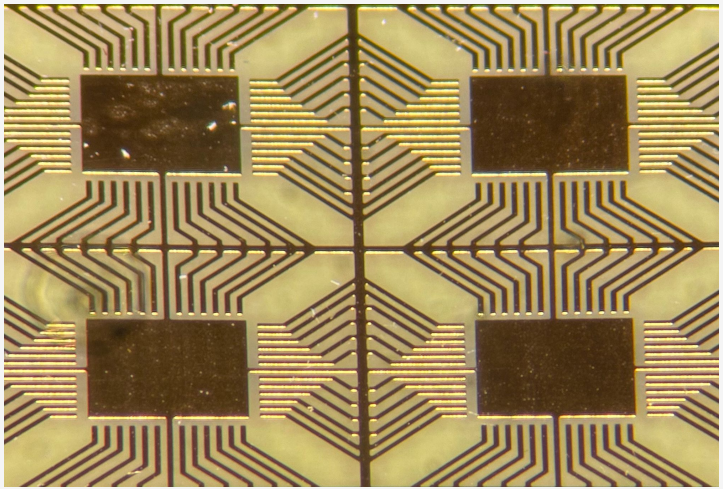


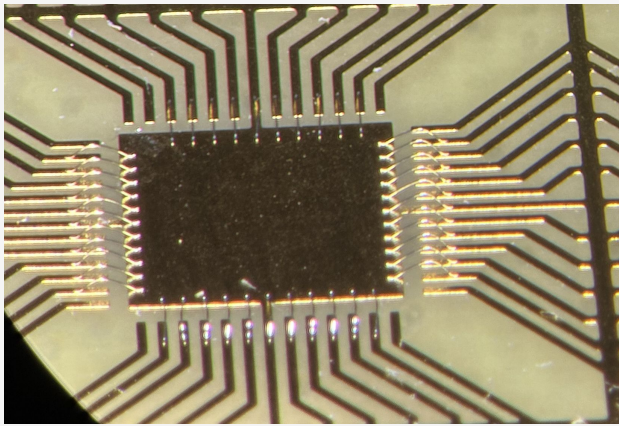
Wire Bonding Machine



- Commercial Machine
- Ultrasonic Wedge Bonding (cold welding)
- Aluminium Wire 25 µm
- Pattern Recognition
- Speed ~3 wire bonds / s







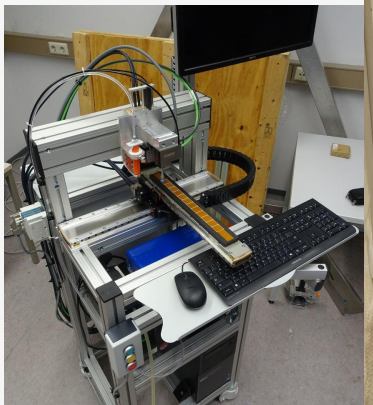
Conclusion & Outlook

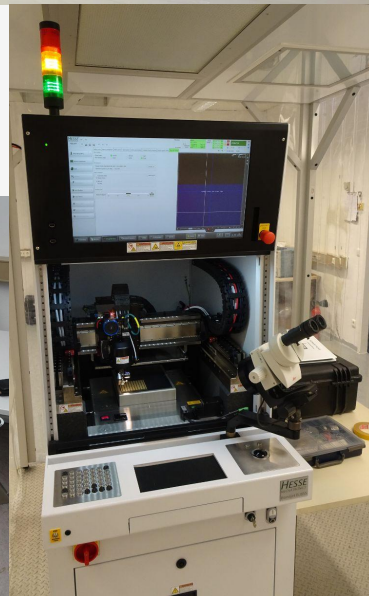
Rigid-Flex

- Developing Testing Methods
- Time Domain Reflectometry for understanding
- Bit Error Rate Test & Eye Diagram (signal integrity)

Gluing & Wire Bonding

- Glue Dispensing & Wire Bonding parameters
- Gluebot Picking & Placing of Sensors
- Semi-automation of processes (pattern recognition etc.)





Conclusion & Outlook

Thanks for your attention!

Rigid-Flex

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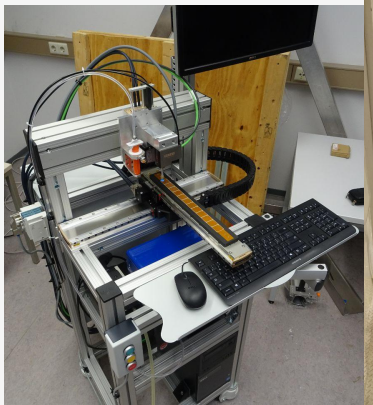
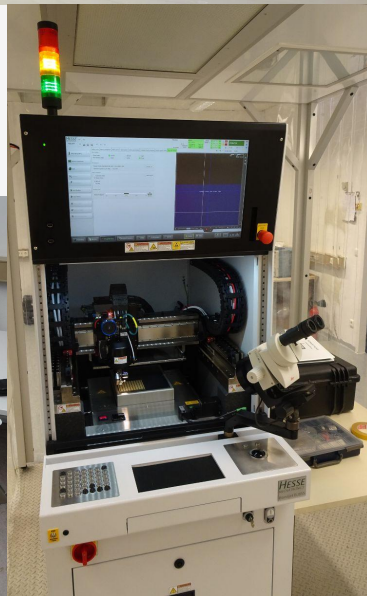
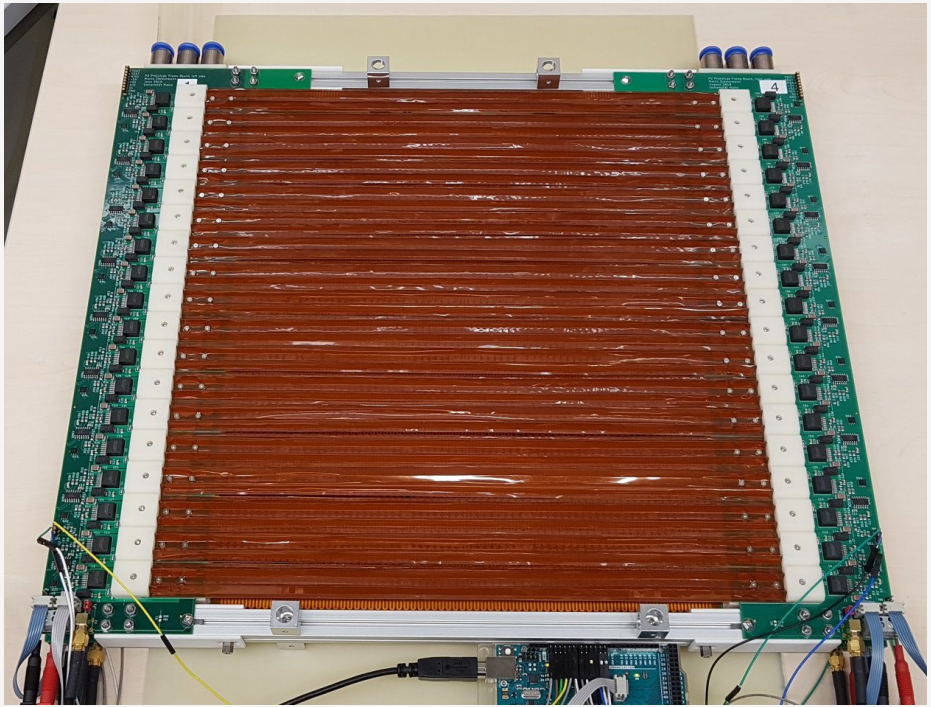
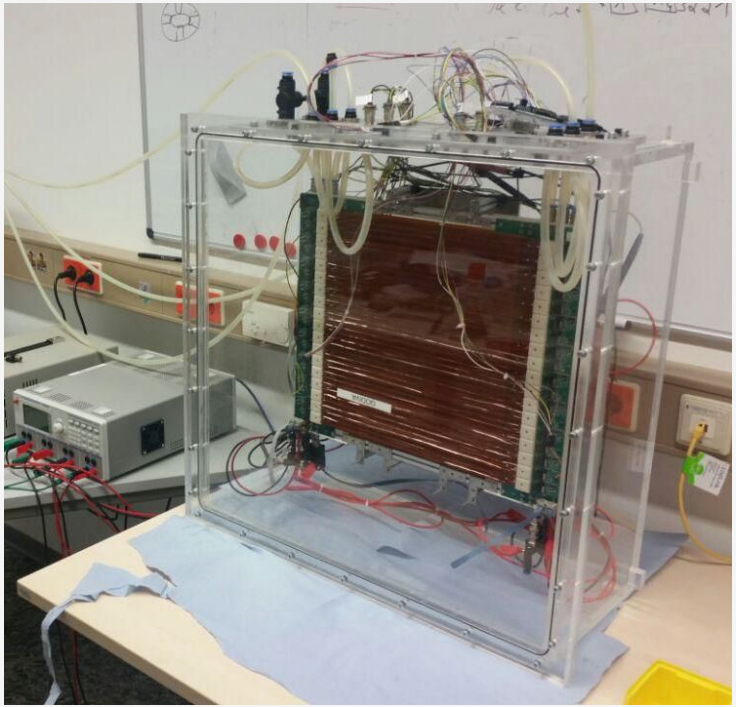




Backup

Thermo Mechanical Prototype

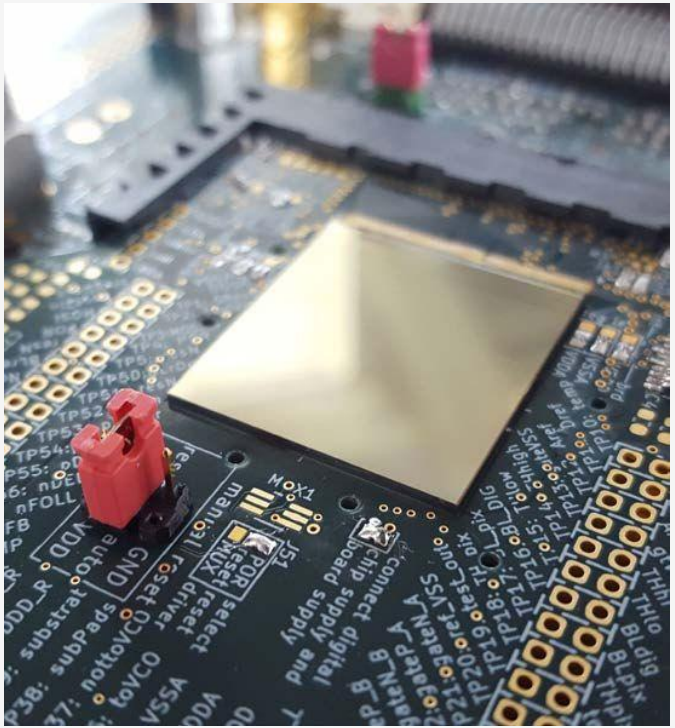




[Marco Zimmermann & Michail Kravchenko]

MuPix 10

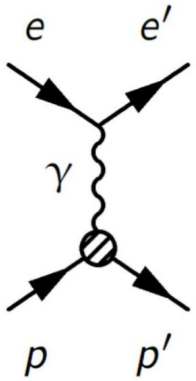
- HV-MAPS - High voltage monolithic active pixel sensors (Ivan Perić)
- Based on 180 nm HV-CMOS process
- Can be thinned down to 50 µm
- Pixel Matrix 256 x 250
- Pixel Size 80 µm x 80 µm
- Active Area 20.40 mm x 20 mm
- Efficiency > 99%
- Noise Rate < 2 Hz / Pixel
- Power Consumption < 200 mW / cm²

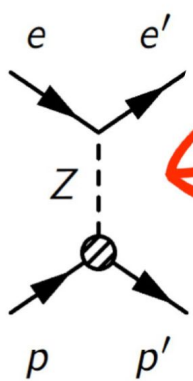


P2 - Theory

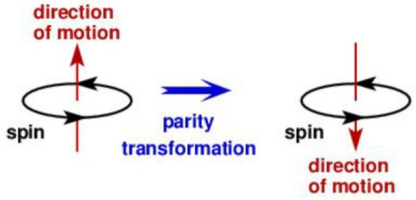
The weak mixing angle (Weinberg-angle):

$$\sin^2\theta_W = \frac{g'^2}{g^2+g'^2}$$





Violates parity!



Proton electric charge $+1$

Proton weak charge $1-4\sin^2\theta_W$

Parity violating asymmetry

momentum transfer

Asymmetry: $$A_{PV} = \frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\left(1 - 4\sin^2\theta_W - F(Q^2)\right)$$

proton form factor (small @ low Q^2)

P2 - Experiment

Measuring the parity violating asymmetry in e-p-scattering

polarization of the beam

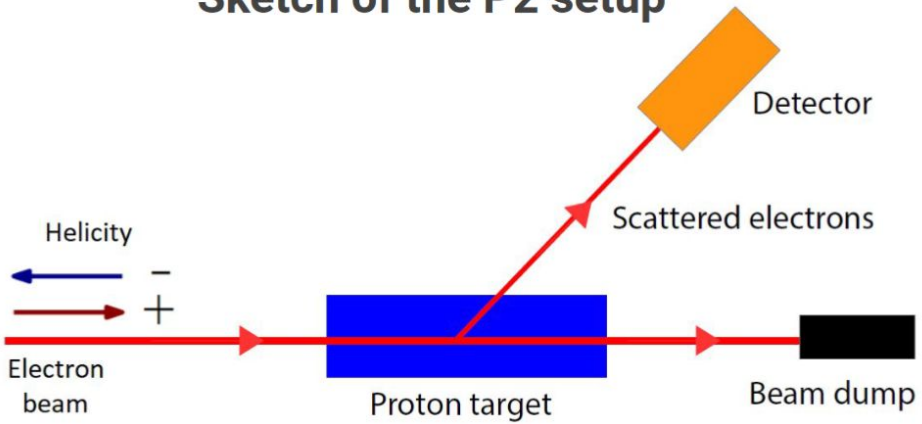
$$A_{exp} \equiv \frac{N^+ - N^-}{N^+ + N^-} = P_{beam} \cdot \langle A_{pv} \rangle + A_{app}$$

~ 30 ppb

averaged expected value

apparative asymmetry

Sketch of the P2 setup



Beam:

- Highly polarized (≥85%)
- Current: 150 μA = 10^{15} e^-/s
- L ≈ $2.4 \cdot 10^{39}$ $cm^{-2}s^{-1}$
- Energy: 155 MeV
- Flip helicity @ 1 kHz

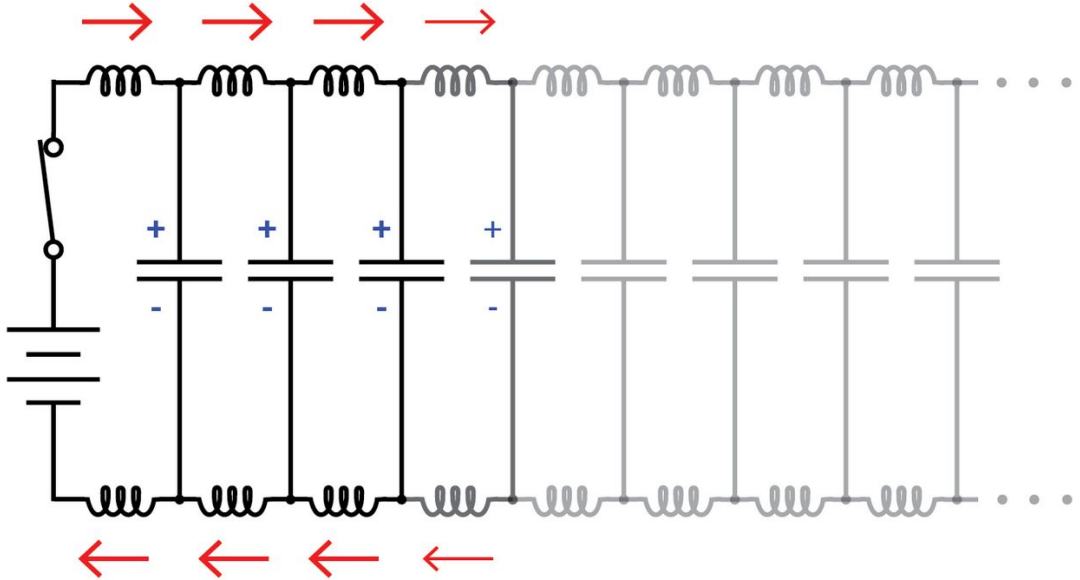
Additional requirement:

- Beam polarization: $\Delta P_b / P_b \leq 0.5\%$

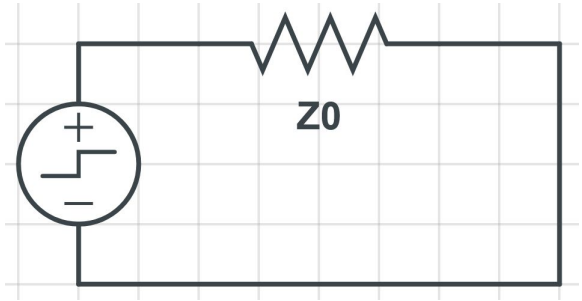
Characteristic Impedance

$$I = C \cdot \frac{dU}{dt}$$

$$U = L \cdot \frac{dI}{dt}$$

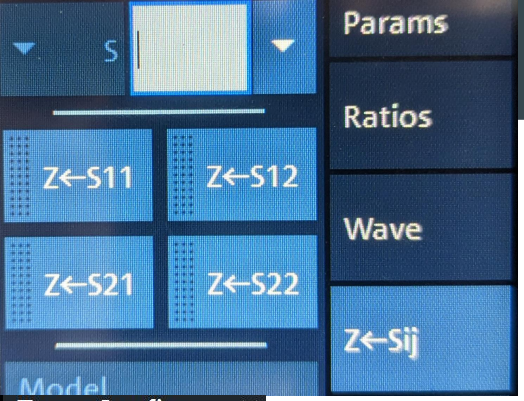


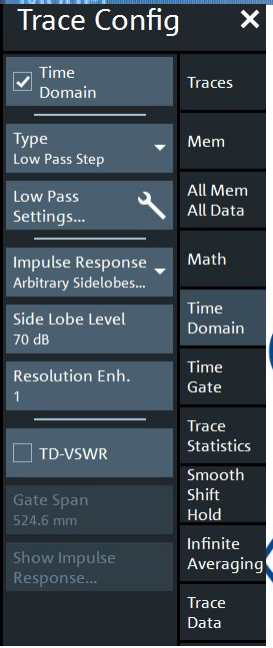
$$V = \frac{c}{\sqrt{L'C'}}$$



$$Z_0 = \frac{V}{I} = \sqrt{\frac{L'}{C'}}$$

2-Port VNA





$$\frac{V_{refl}}{V_{in}}$$

$$S_{11} = |S_{11}| \cdot e^{i\varphi}$$

phase delay

$$|S_{11}| = 20 \cdot \log\left(\left|\frac{V_{refl}}{V_{in}}\right|\right) = \frac{Z - Z_0}{Z + Z_0}$$

new impedance

reference impedance