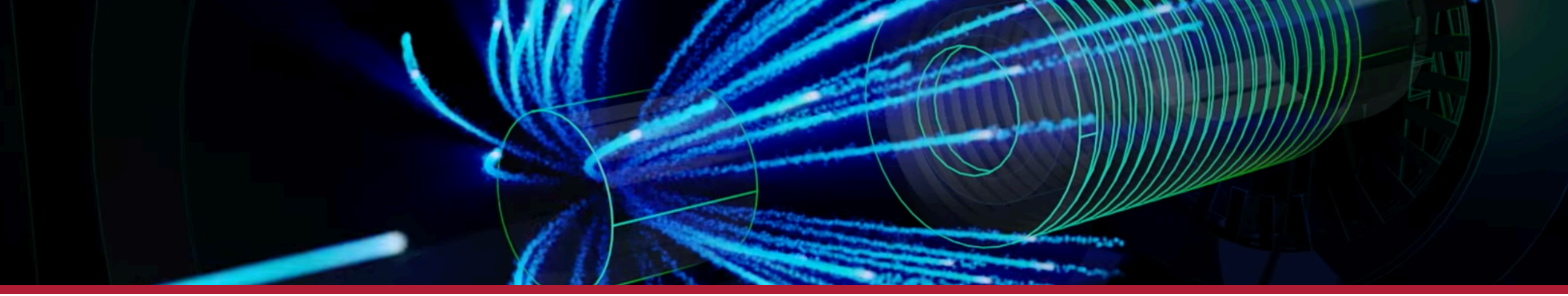

The Tracking Detector of the P2 Experiment at the MESA Accelerator

DPG Dortmund 2021 - T 64.2 Pixel Detectors III

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MOTIVATION

- **Goal:** Determination of protons weak charge $Q_w(p)$ through parity violating asymmetry A^{PV} in electron-proton scattering at low momentum

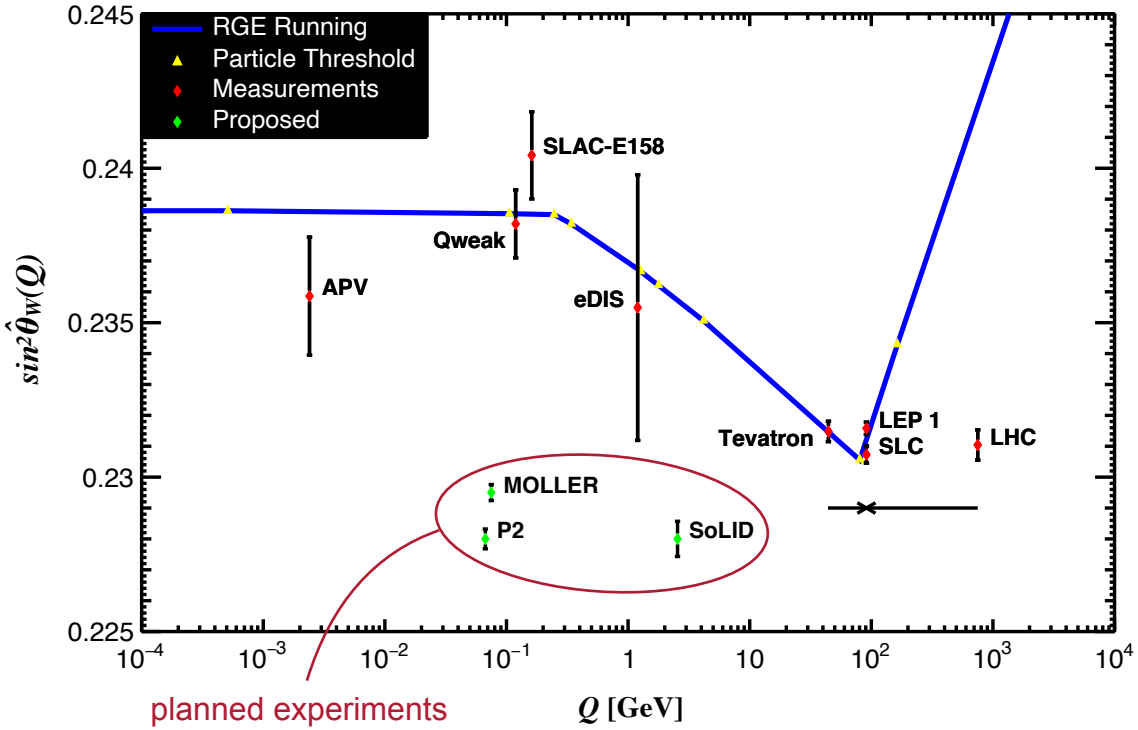
$$A^{PV} = \frac{G_F Q^2}{4\pi\alpha_{em}\sqrt{2}} \left(Q_W(p) - F(E_i, Q^2)\right)$$

suppressed at low Q^2

- $Q_w(p)$ suppressed in SM → sensitive for hypothetical new physics effects!
- With $Q_w(p) \propto 1 - 4 \cdot \sin^2\theta_W$ → P2 gives electroweak mixing angle $\sin^2\theta_W$ at low energy scale

  ⇒ Precision test for SM prediction of running $\sin^2\theta_W(Q)$

  ⇒ Hints to physics beyond SM?



EXPERIMENTAL SETUP

- Scattering experiment with longitudinally polarised electron beam and unpolarized liquid hydrogen target

  ⇒ Measurement of Q^2 and N^+/N^-

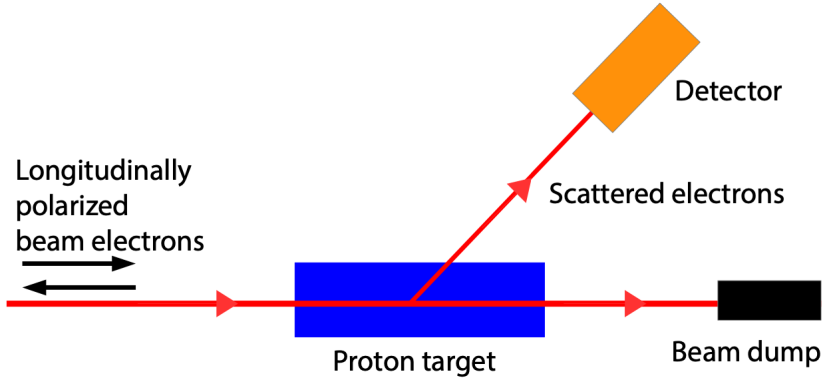
- Asymmetry A^{PV} defined as difference in scattering cross section for left- and right-handed electrons

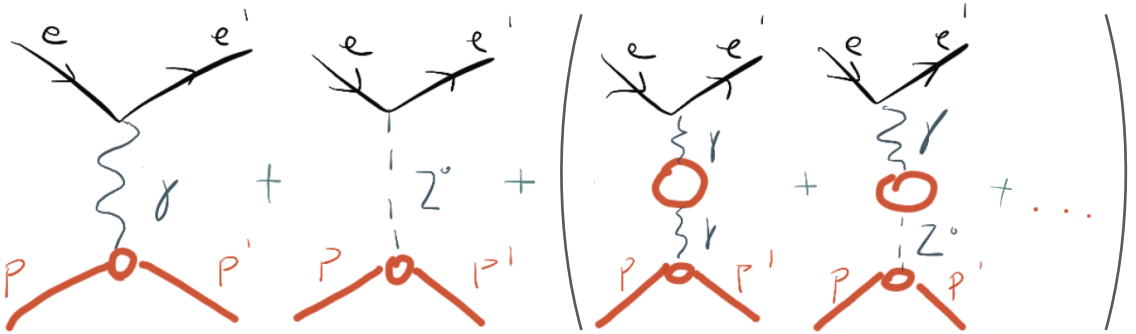
$$A^{PV} = \frac{d\sigma_{ep}^{+} - d\sigma_{ep}^{-}}{d\sigma_{ep}^{+} + d\sigma_{ep}^{-}} \propto \frac{N^{+} - N^{-}}{N^{+} + N^{-}}$$

- Challenge: A^{PV} is **very** small (≈ 40 ppb)

  ⇒ **Huge** amount of events required → high intensity beam + long measurement time

- With measurement time $10000\ h$ expected precision of $\Delta s_w^2/s_w^2 = 0.14\ \%$ and $\Delta Q_w(p)/Q_w(p) = 1.83\ \%$





$\propto e$ $\propto Q_w(p)$
parity violating!

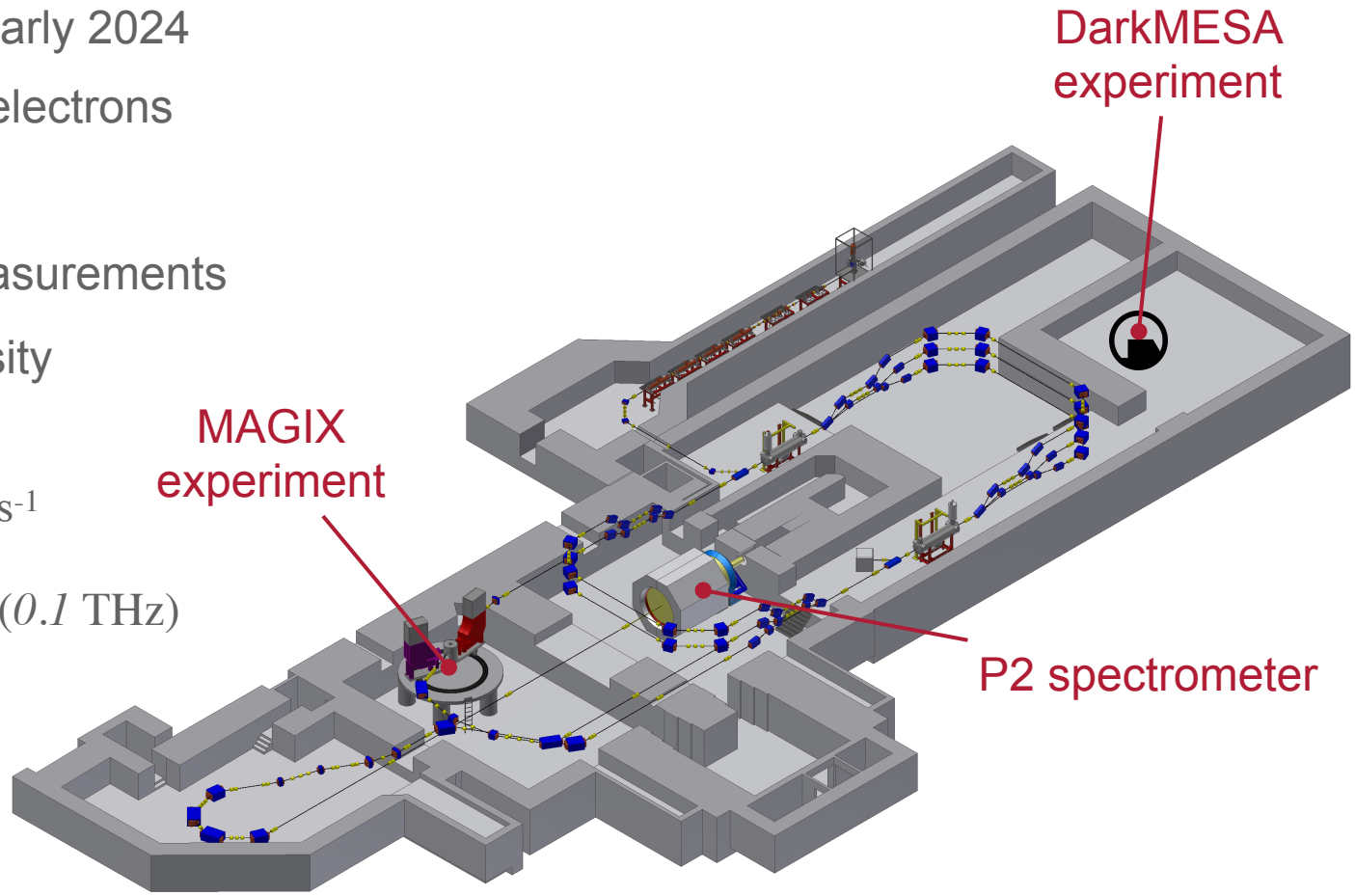
[Dominik Becker et al., *The P2 Experiment - A future high-precision measurement of the electroweak mixing angle at low momentum transfer*, DOI: 10.1140/epja/i2018-12611-6]

MAINZ ENERGY-RECOVERING SUPERCONDUCTING ACCELERATOR (MESA)

- Construction in progress → first beam time early 2024
- Provides beam with longitudinally polarized electrons
- Beam helicity flipped with $f_{sw} \sim 1$ kHz
- Polarity monitored by three independent measurements
- Low energy ($E_{beam} = 155$ MeV) but high intensity ($I_{beam} = 150$ µA)

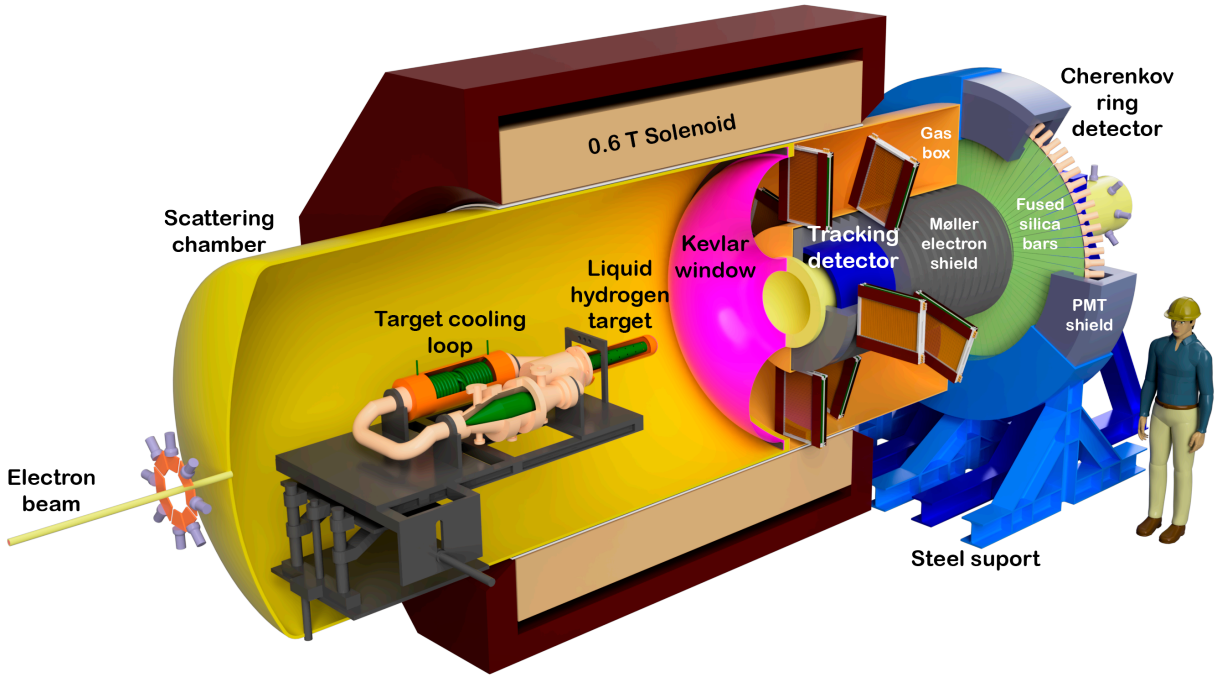
  ⇒ Expected luminosity $\mathscr{L} = 2.38 \cdot 10^{39}$ cm^{-2}s^{-1}

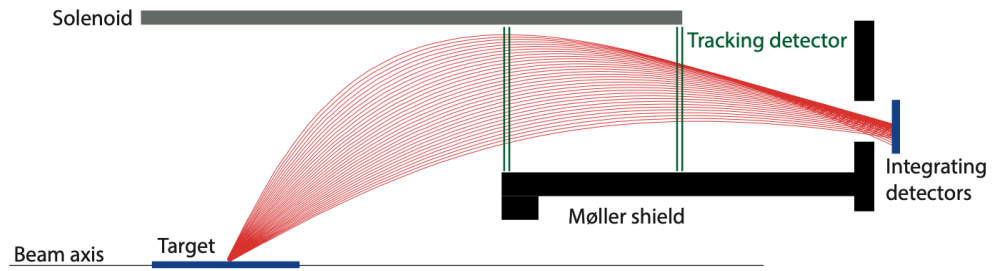
  ⇒ Expected event rate for P2 detector ~ $\mathcal{O}(0.1$ THz)



P2 SPECTROMETER

- Enclosed by solenoid ($B_z = 0.6$ T along beam axis)
- Electron beam enters scattering chamber and hits liquid hydrogen target (lH^2)
- Tracking detector in helium atmosphere (gas box)
  - 8 modules arranged in two layers
  - Each module covers 15°
    (no full azimuthal coverage!)
  - 4 hits per track → curve fit for Q^2
- Integrating Cherenkov ring detector → ~ N^+/N^-
  - 82 wedged silica bars read out by PMTs

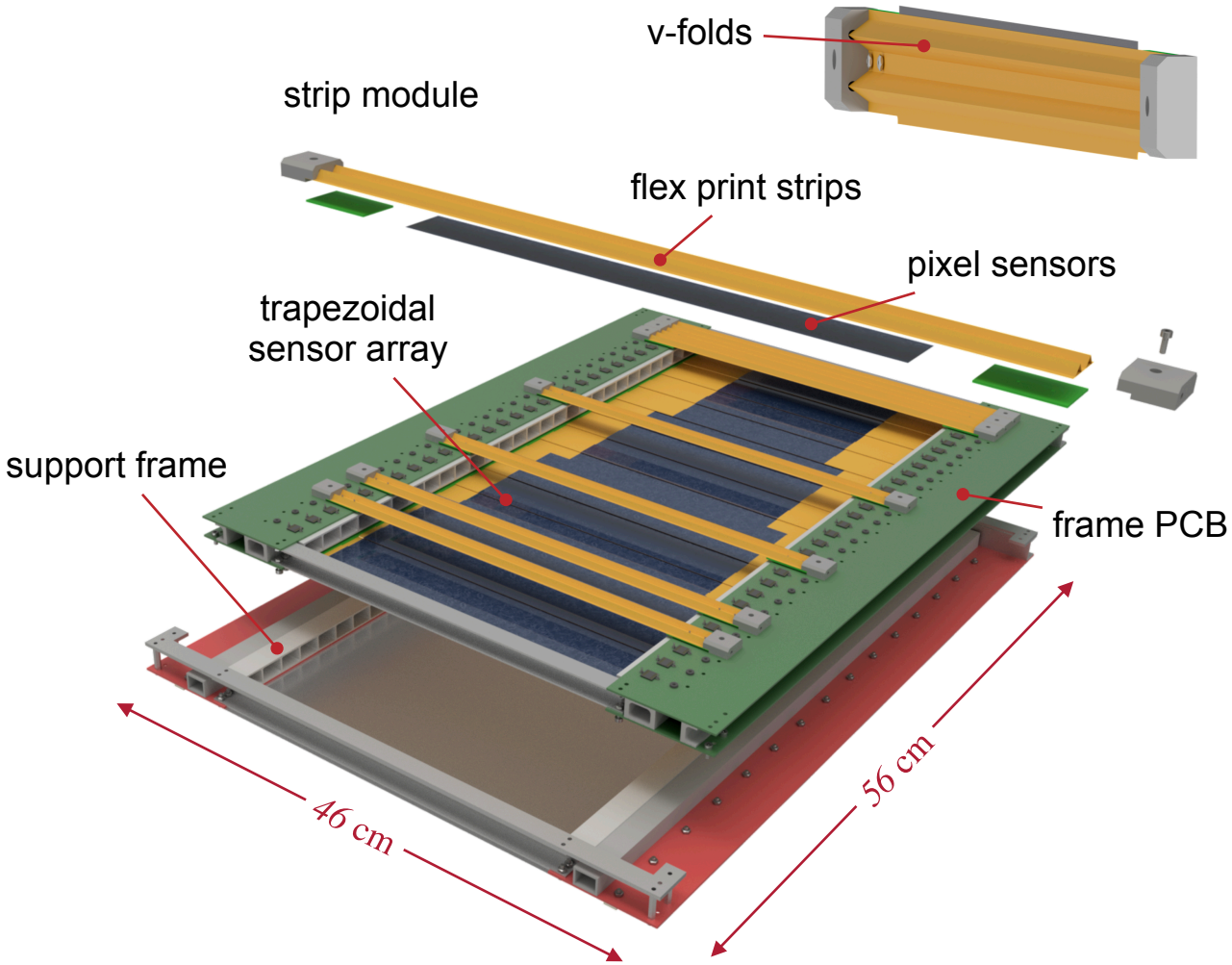




P2 TRACKER MODULE

- Two layers of pixel sensors (540 sensors in total)
- Pixel sensors mounted on strip submodules
  - Kapton strips with Aluminium traces (flex print)
  - Supported by structure of folded Kapton foil (v-folds) → allows direct He cooling
- Cooled by Helium distribution system*
- Strip submodules mounted on frame PCBs with radiation hard readout electronics and power

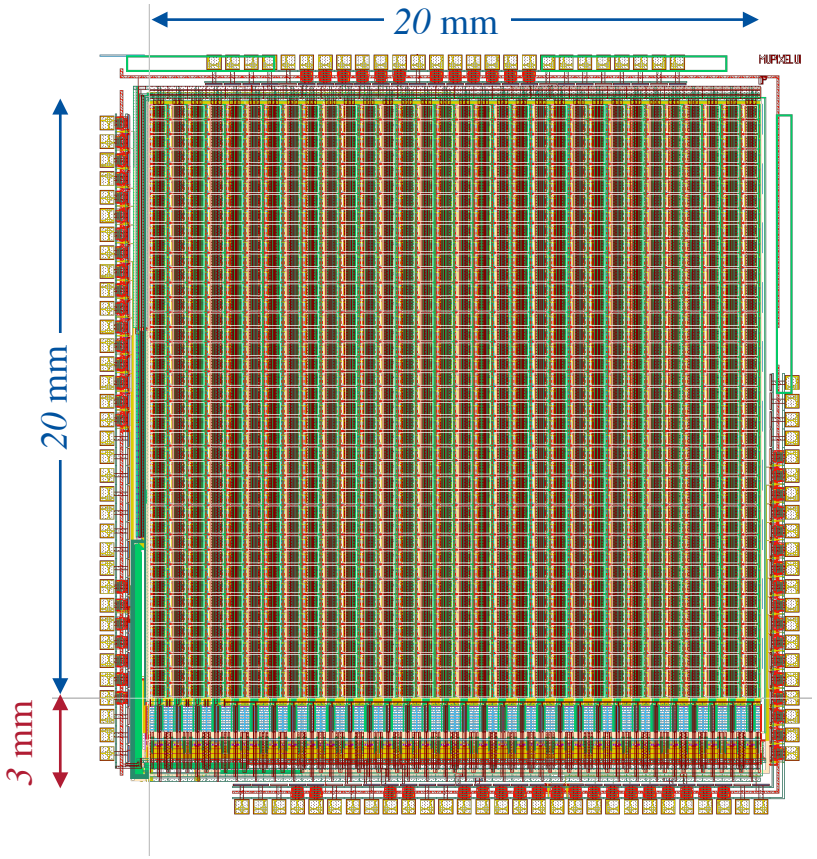
  ⇒ High radiation expected ($TID \sim 60$ Mrad)
- Support frame for rigidity and helium distribution



[*Michail Kravchenko, *Design and cooling of the tracking detector of the P2 experiment,* Pixel Detectors II T 39.6, DPG Talk]

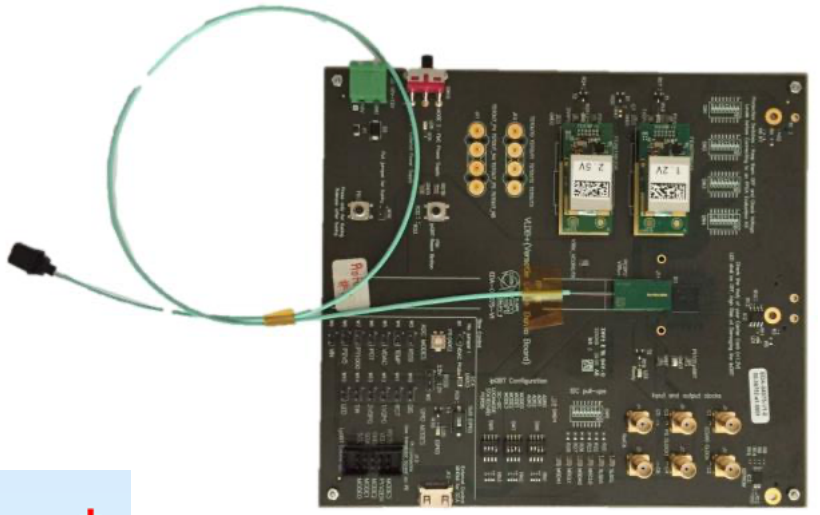
HIGH VOLTAGE MONOLITHIC ACTIVE PIXEL SENSORS (HV-MAPS)

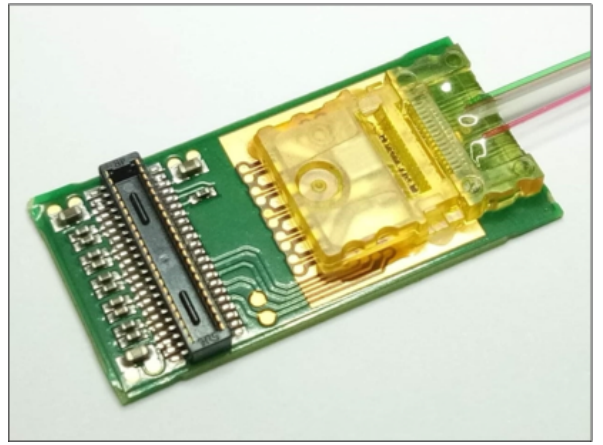
- Compact system on chip
  - 80×80 µm pixels with in-pixel amplifiers
  - Hits detected by on-chip tuneable comparators
  - Hit data sent out via 1.25 Gbit/s LVDS link
    (column & row address, time stamp, time over threshold)
  - Low material budged (50 µm thick)
- Based on muPix and AtlasPix design (KIT + Uni Heidelberg)
  - Detection efficiency $> 99\%$
  - Time resolution $\Delta t = 15$ ns @ $f_{noise} < 1$ Hz
  - Power dissipation ~ 200 - 300 mW/cm² → cooling!



TRACKER READOUT & CLOCK DISTRIBUTION

- Data readout and clock distribution using CERNs *Versatile Link+*
  - Low-power Gigabit Transceiver (lpGBT) Ser/Des ASIC
    - ⇒ 7 - 28 readout channels @ *320 - 1280* MBit/s
    - ⇒ Clock recovery from down link data stream
  - Versatile Transceiver Plus (VTRx+) optical readout module
    - ⇒ 1 RX + 4 TX fibres @ *2.56 - 10.28* Gbit/s
  - Radiation hard (*TID* ≈ *100* Mrad)
  - Low power consumption
- Back-end with commercial off-the-shelf components
  - SAMTEC FireFly™ optical transceivers
  - FPGA running custom firmware (GBT-FPGA)





SUMMARY AND OUTLOOK

- P2 aims for unmatched precision of $\Delta Q_w(p)/Q_w(p) = 1.83\ \%$ and $\Delta s_w^2/s_w^2 = 0.14\ \%$ at low momentum
  - ⇒ SM precision test
  - ⇒ Search for physics beyond SM
- New HV-MAPS chips under development for tracker
- State of the art radiation hard readout using CERNs lpGBT ASICs & VTRx+ modules
- First beam time planned for early 2024!