A Tracking Detector for the P2 Experiment

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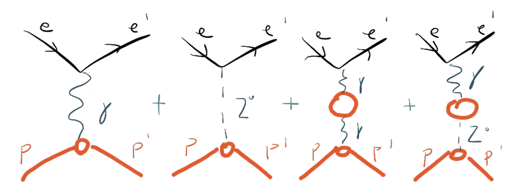
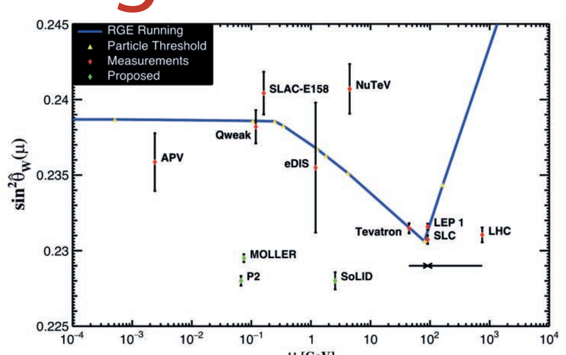
Abstract

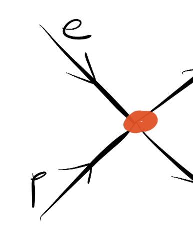
The P2 experiment at the new electron accelerator MESA in Mainz aims for a determination of the weak mixing angle at low momentum transfer with unprecedented precision. To this end, the parity violating asymmetry in electron proton scattering is studied with integrating Cherenkov detectors at very high rates of scattered electrons. In order to determine the average momentum transfer Q^2 and precisely study systematics effects which could lead to false asymmetries, a tracking detector is required. We present the design of such a detector based on high-voltage monolithic active pixel sensors (HV-MAPS), which are well suited to deal with the enormous rates of scattered electrons and photons and put a minimum amount of material into the particle path.

Weak mixing angle

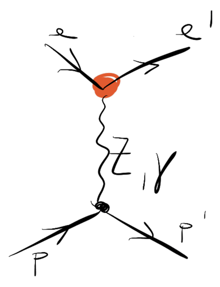


The interference of photon and Z exchange (and combinations involving fermion loops) leads to a running of the weak mixing angle.



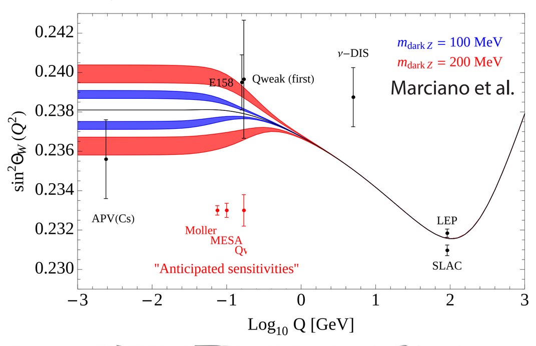


Sensitive to contact interactions up to a scale of 49 TeV

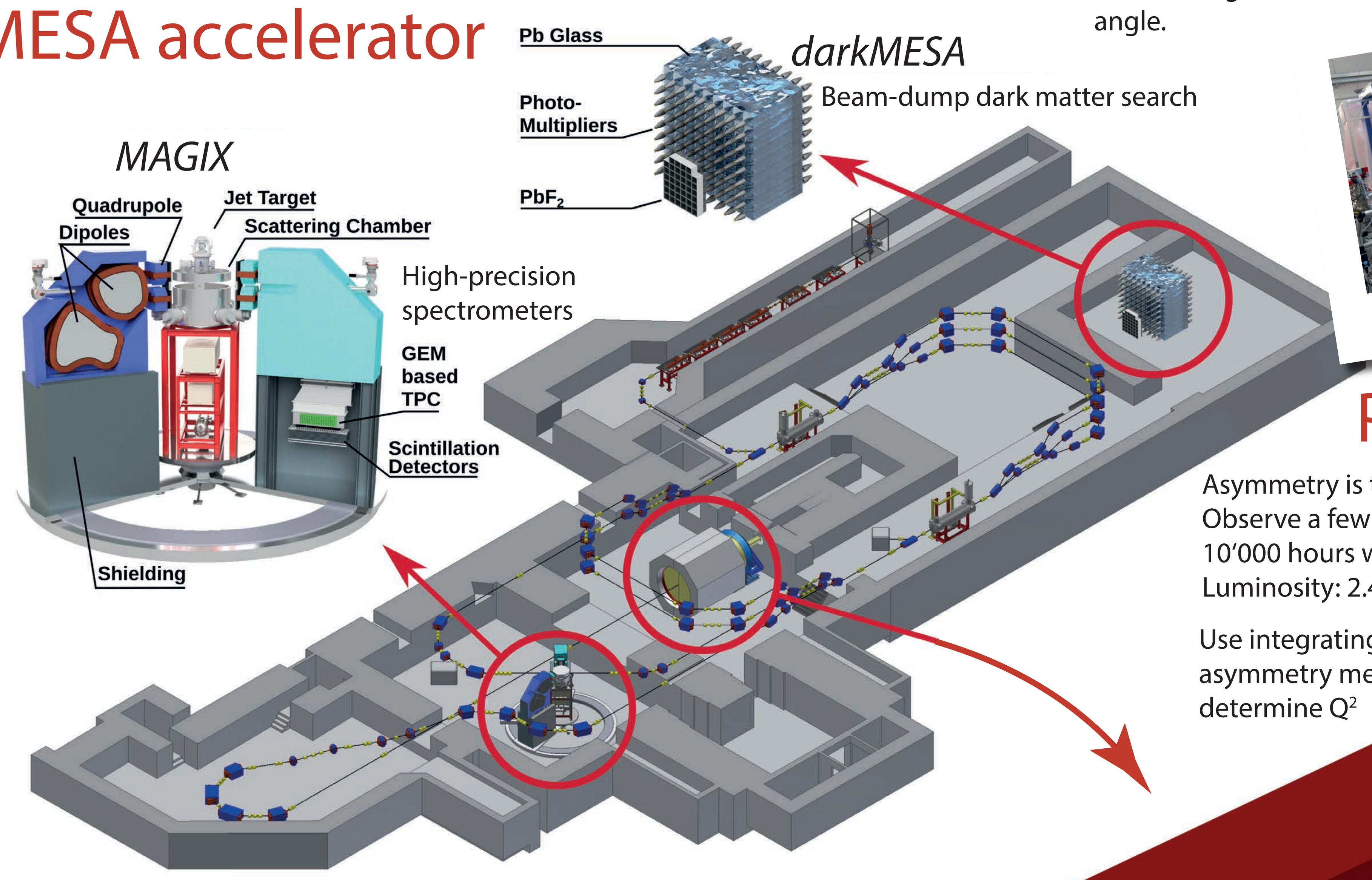


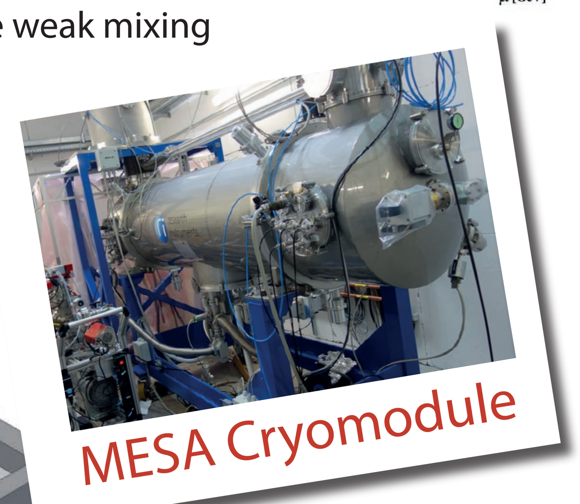
Dark Z mixing

New physics can modify the running and thus $\sin^2\theta_W$ far away from the Z pole.



MESA accelerator





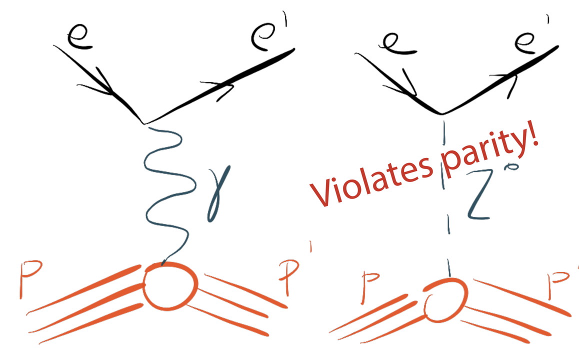
The Mainz energy recovery superconducting accelerator will deliver first beam in 2021. Two beam modes are availalbe: The extracted beam for P2 with 150 MeV, 150 μA and 85% polarisation and the energy recovery beam for the internal target experiment MAGIX with 100 MeV and 1 mA current.

Parity violation

Count/integrate scattered electrons for each electron beam helicity (R/L)

$$A_{PV} = \frac{N_R - N_L}{N_R + N_L} = \frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\left(Q_W - F(Q^2)\right)$$

parity violating assymmetry — electron counts — momentum transfer: sets scale — weak charge: what we want — proton structure small nuisance at small Q^2



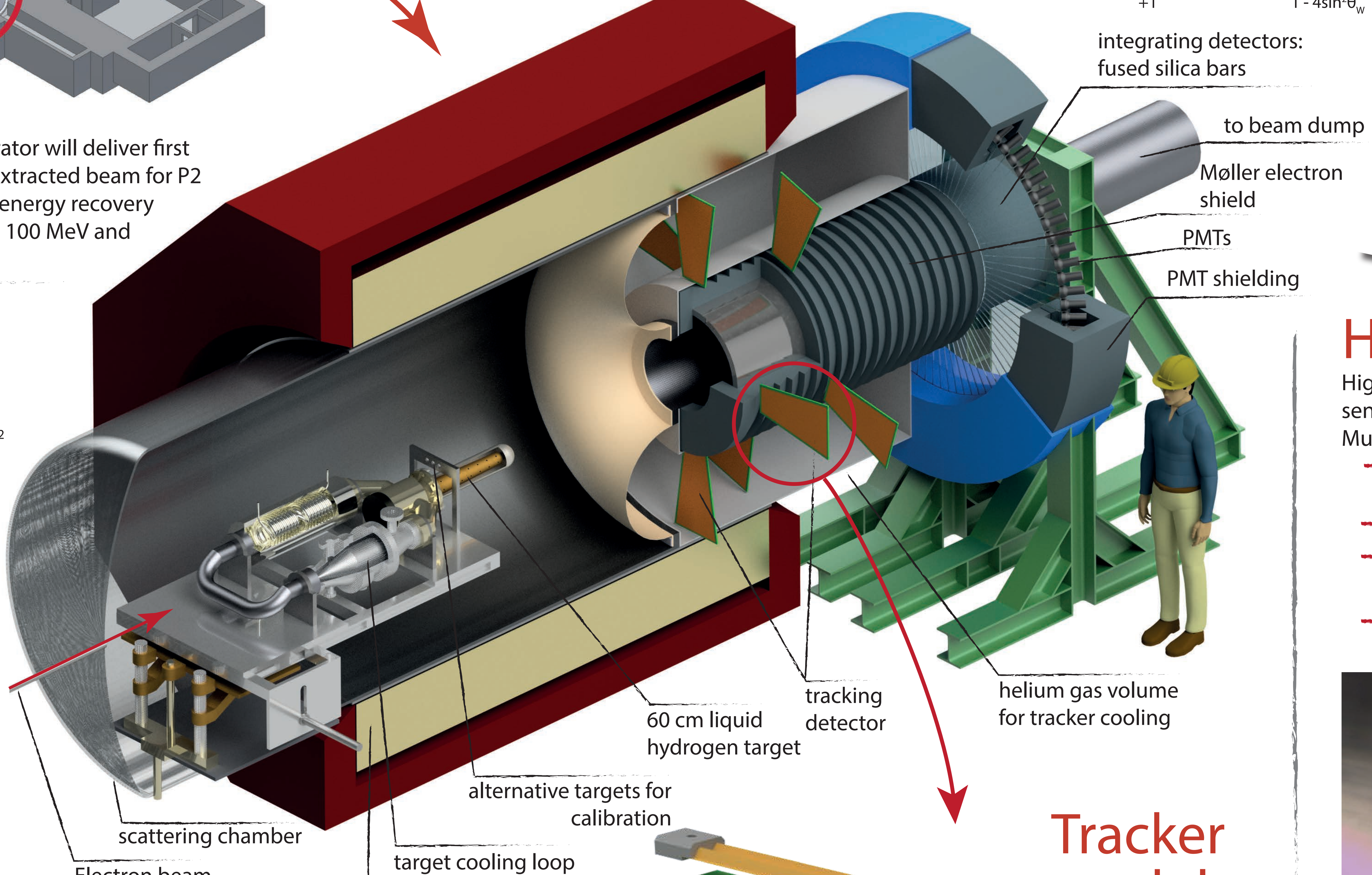
Obtain the weak mixing angle from the weak charge

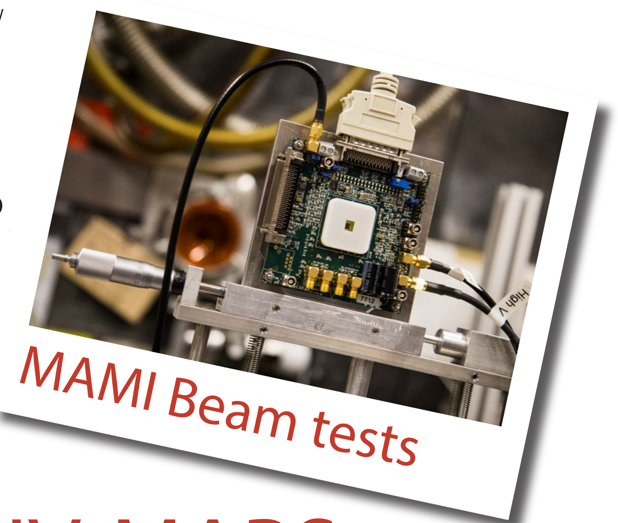
$$\sin^2\theta_W = \frac{1 - Q_W}{4}$$

P2 Experiment

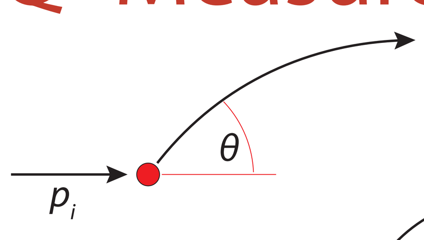
Asymmetry is tiny: 40 ppb; 1.5% measuremnt is 0.6 ppb
Observe a few 10^{18} scattered electrons
10'000 hours with 100 GHz
Luminosity: 2.4 10^{39} $s^{-1}cm^{-2}$, integrate 8.6 ab^{-1}

Use integrating fused silica Cherenkov detectors for asymmetry measurement; need a tracking detector to determine Q^2

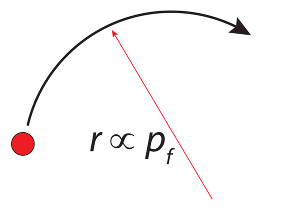




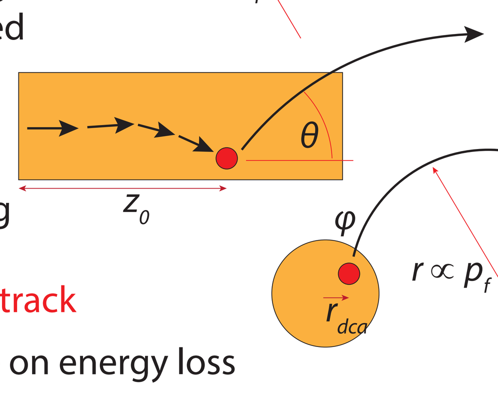
Q^2 Measurement



Elastic scattering: One free variable
θ or p each determine Q^2



Elastic scattering from an extended target:
Initial momentum unknown due to scattering and energy loss:
Reconstruct full track

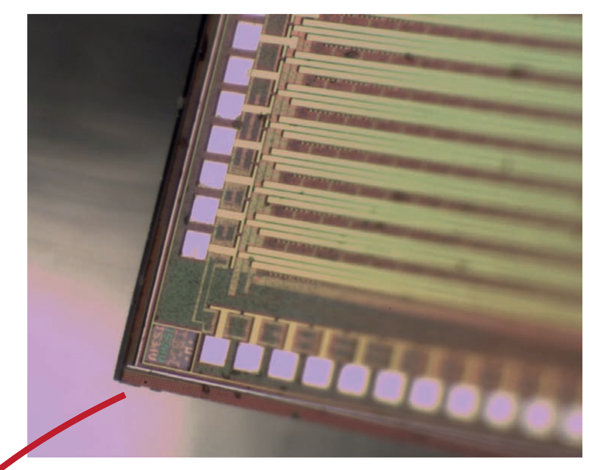


z_0 gives a handle on energy loss
r_{dca} gives a handle on scattering θ and p constrain Q^2

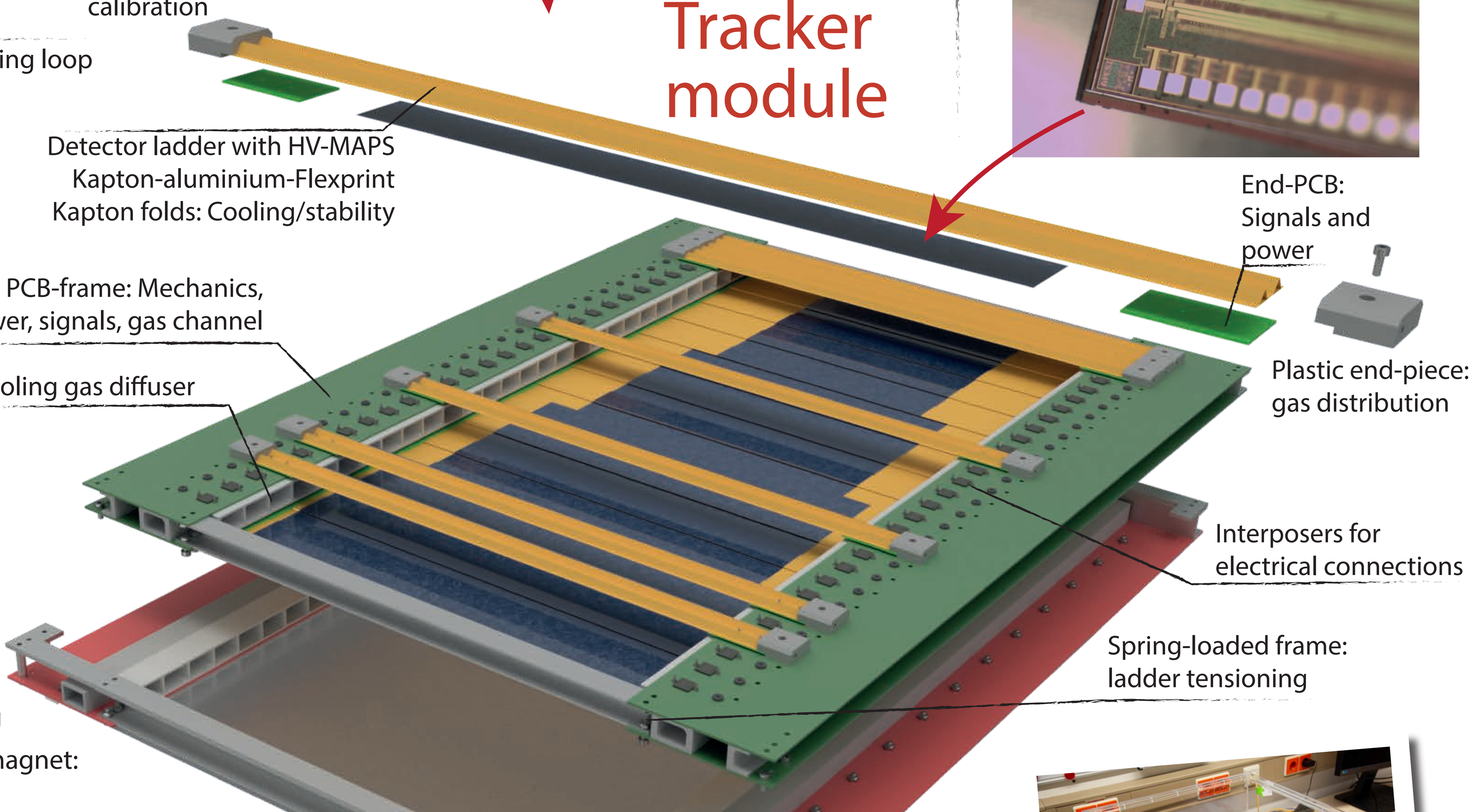
HV-MAPS

High-voltage monolithic active pixel sensors developed by Ivan Perić for Mu3e will be used:

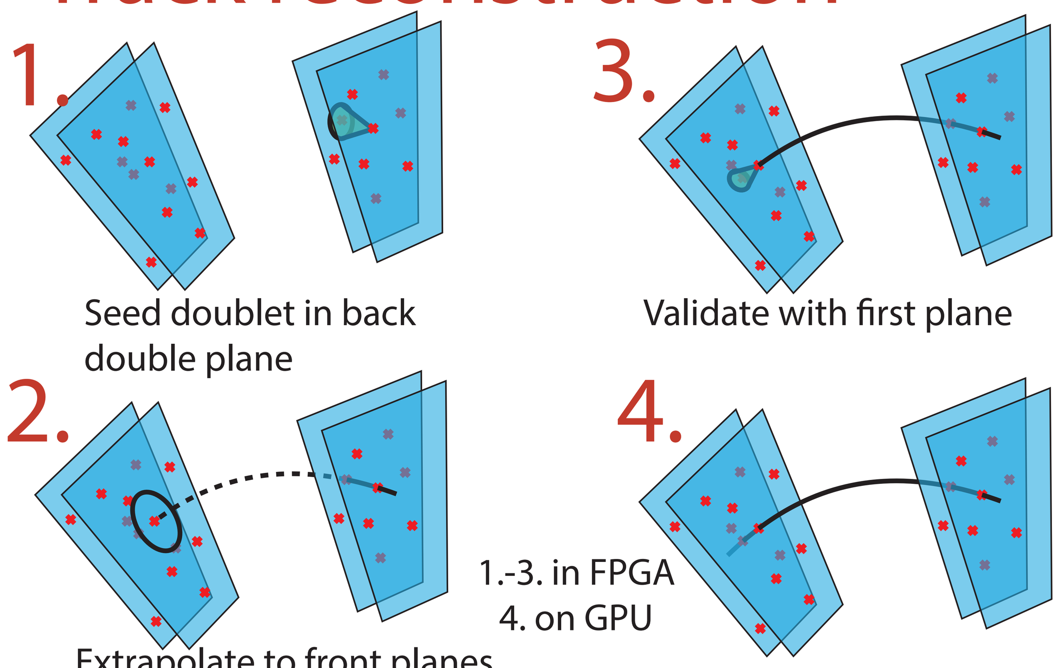
- 2 x 2 cm^2 sensors with 80 x 80 μm^2 pixels
- Thinned to 50 μm
- On chip zero-suppression and timestamping
- streaming digital readout of up to 7.8 Mhits/s/cm^2

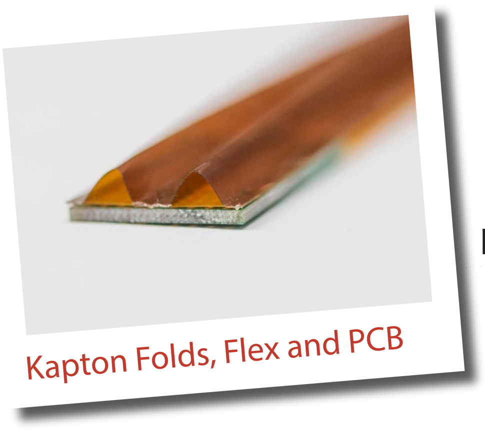


Tracker module



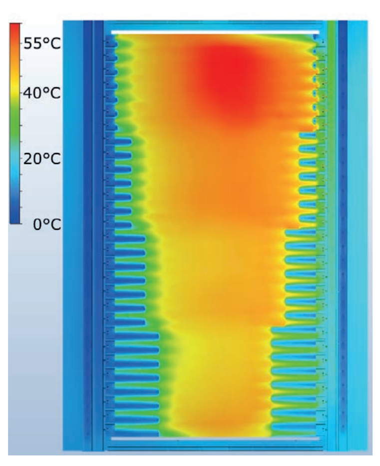
Track reconstruction



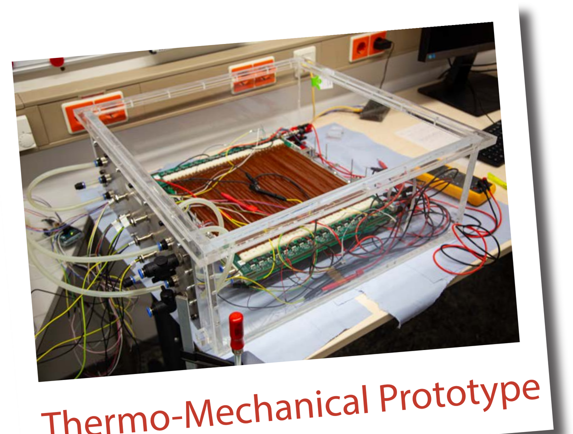


Challenges

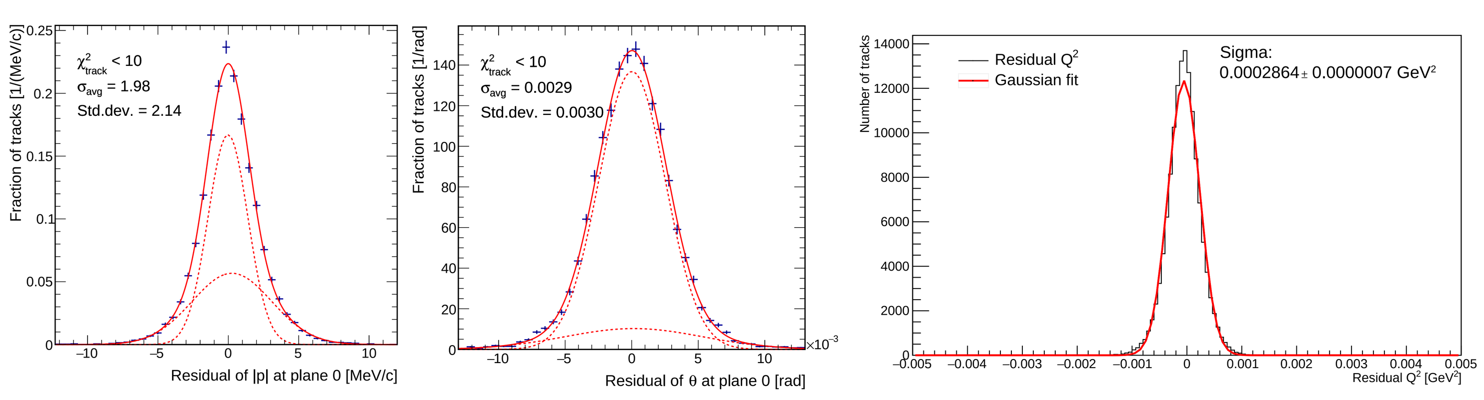
- Very high rates: 100 GHz of electrons, several THz Bremsstrahlung photons
- Low momentum: Lots of multiple Coulomb scattering
- Operate at the edge of the magnet: inhomogeneous field



Helium gas cooling simulated with CFD and tested with thermo-mechanical prototype



Simulated performance



Statistical accuracy for $\langle Q^2 \rangle$ sufficient after 16 tracks - systematics absolutely crucial

D. Becker et al. The P2 Experiment - A future high-precision measurement of the electroweak mixing angle at low momentum transfer, arxiv:1802.04759, Eur. Phys. J. A (2018) 54: 208.

SFB 1044 THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL
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