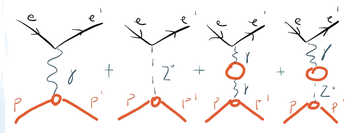
Tracking and Q^2 determination for the P2 experiment

Niklaus Berger, Iurii Sorokin, Alexey Tyukin and Marco Zimmermann for the P2 Collaboration
PRISMA Cluster of Excellence and Institute of Nuclear Physics, Johannes Gutenberg University Mainz

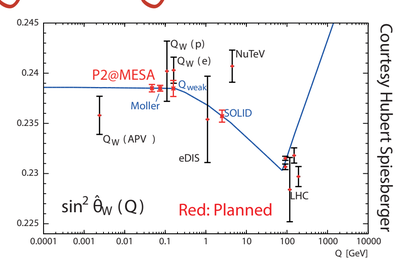
Abstract

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 propose to build such a detector from 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 beam path.

Weak mixing angle

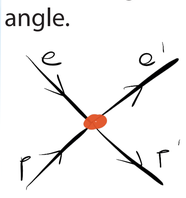


The interference of photon and Z exchange (and combinations involving fermion loops) leads to a running of the weak mixing angle.



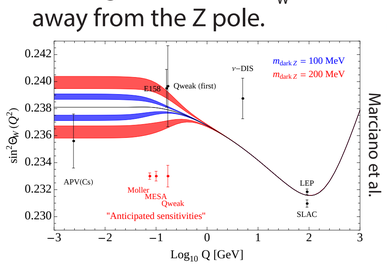
Courtesy Hubert Spiesberger

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



Sensitive to contact interactions up to a scale of 49 TeV

Dark Z mixing



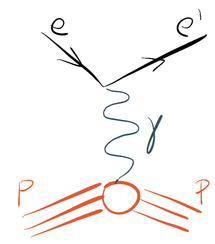
Marciano et al.

Parity violation

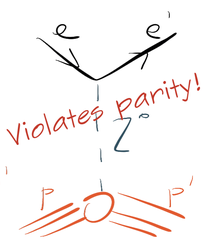
Count/integrate scattered electrons for each electron beam helicity

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

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



Proton electric charge: +1



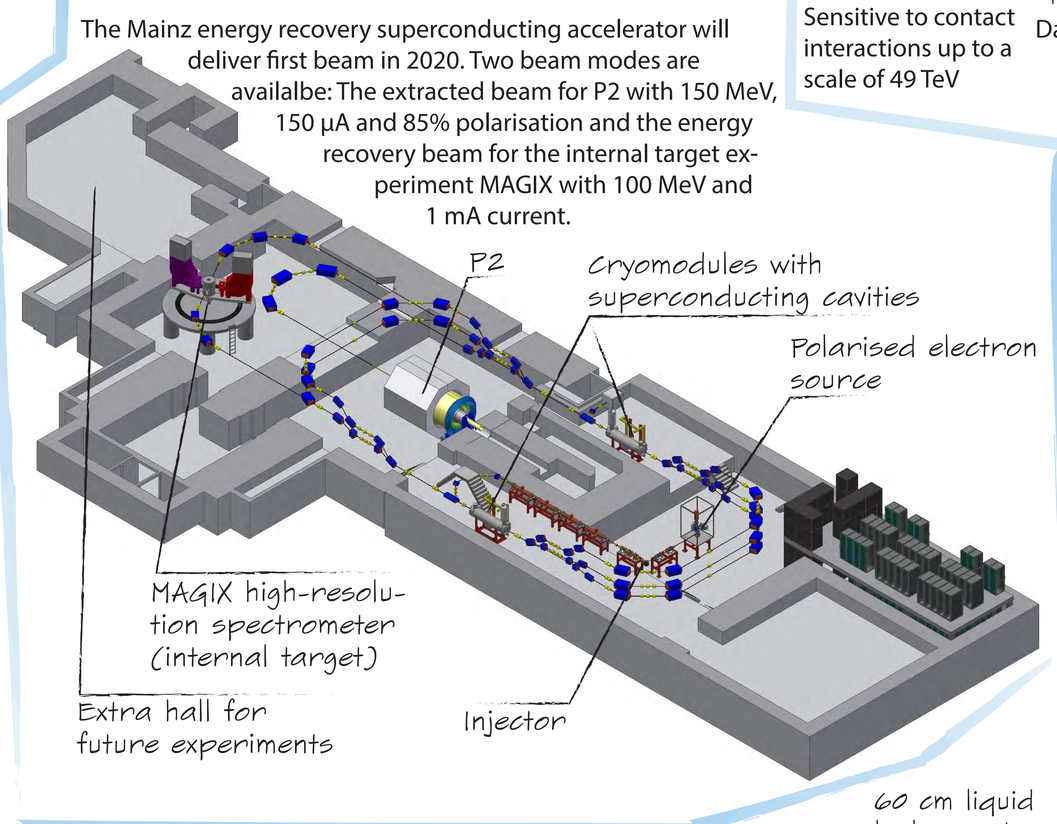
Proton weak charge: $1 - 4\sin^2\theta_W$

Obtain the weak mixing angle from the weak charge

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

MESA accelerator

The Mainz energy recovery superconducting accelerator will deliver first beam in 2020. 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.



P2 Experiment

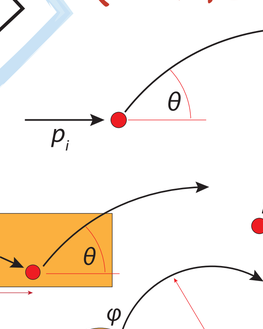
Asymmetry is tiny: 40 ppb - 1.5% measuremnt is 0.6 ppb
Observe a few 10^{18} scattered electrons
10'000 hours with 100 GHz
Luminosity: 2.4 10^{39} $s^{-1}cm^{-2}$, integrate 8.6 ab^{-1}

Detector: count

Electron beam: switch helicity → Hydrogen target: scatter

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

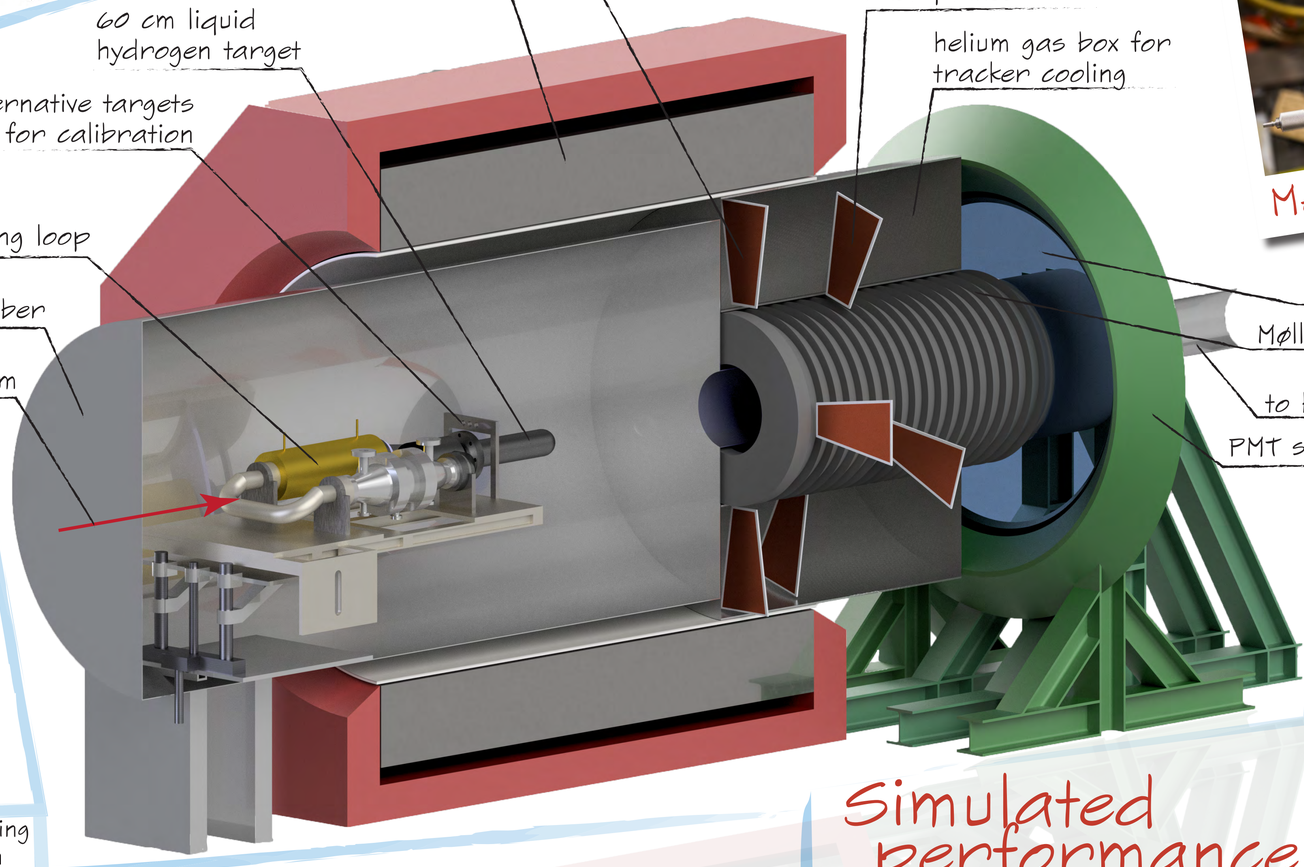
z_0 gives a handle on energy loss

r_{dca} gives a handle on scattering

θ and p constrain Q^2

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

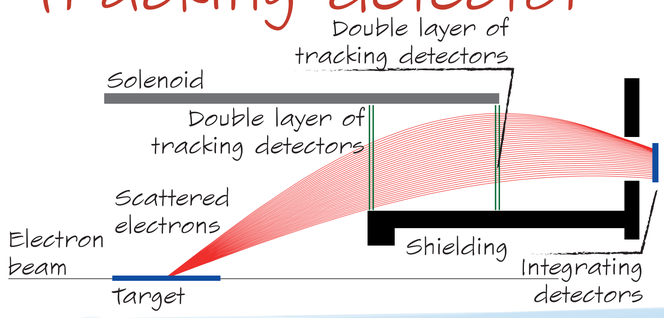
MAMI Beam tests

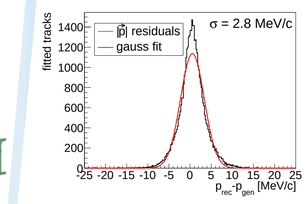


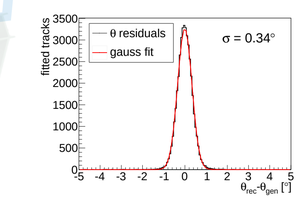
Challenges for the tracker

- 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

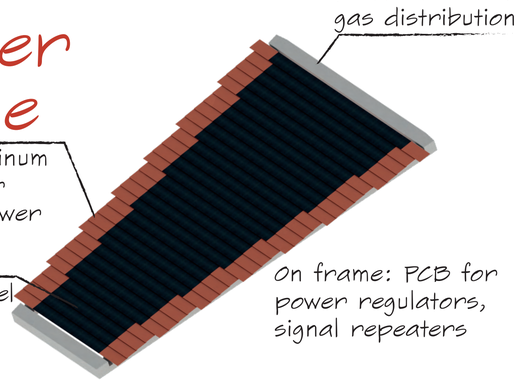
Tracking detector



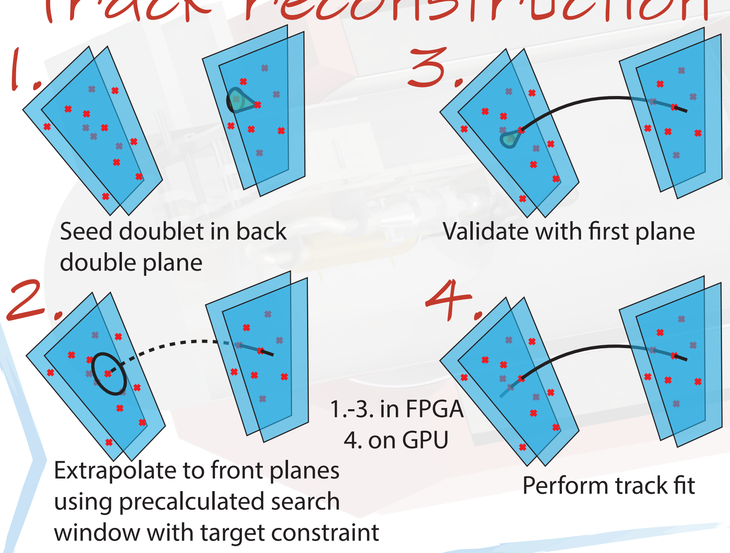




Tracker module

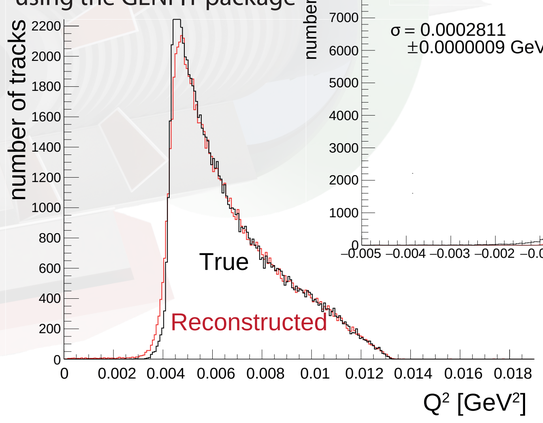


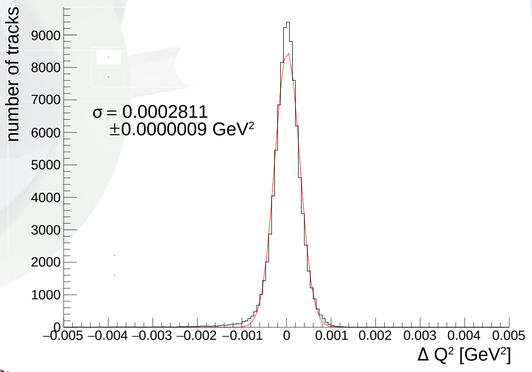
Track reconstruction



Simulated performance

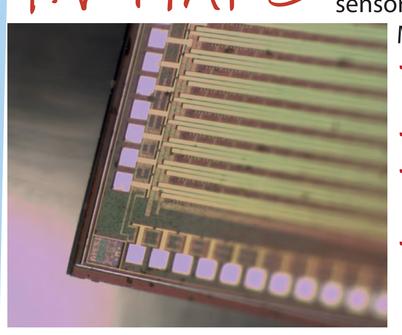
Full Geant4 detector simulation, broken line fit in inhomogeneous field using the GENFIT package





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

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

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