Track Reconstruction for the P2 Experiment

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- The Weinberg (Weak Mixing) angle $\theta_W \approx 28.75^\circ$ is a fundamental parameter of GWS theory of electroweak unification

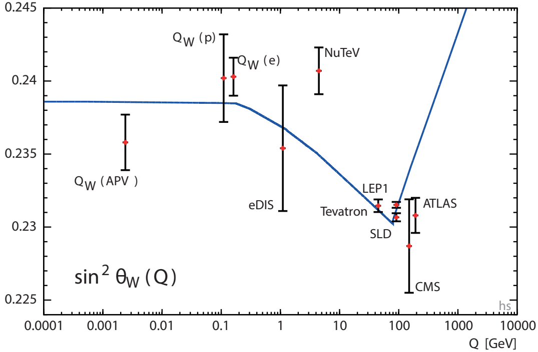
$$\begin{pmatrix} \gamma \\ Z^0 \end{pmatrix} = \begin{pmatrix} \cos(\theta_W) & \sin(\theta_W) \\ -\sin(\theta_W) & \cos(\theta_W) \end{pmatrix} \cdot \begin{pmatrix} B^0 \\ W^0 \end{pmatrix} \quad (1)$$

$$\sin^2(\theta_W) = \frac{g_e^2}{g_w^2} = 1 - \frac{M_W^2}{M_Z^2} \approx 0.2314 \quad (2)$$

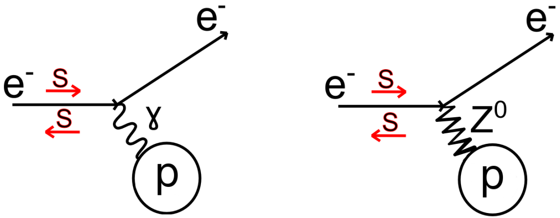
- θ_W is a free parameter of SM which is related to many other quantities
- Precise determination of $\sin^2(\theta_W)$ would verify SM or provide new physics
- Low and high energy scale is sensitive to different types of new physics
- Inconsistent results of previous measurements must be resolved

Measurements of $\sin^2(\theta_W)$

- Running of $\sin^2(\theta_W)$ due to radiative corrections
- From Z^0 pole at 91 GeV to low energies a 3% shift is expected
- P2 Experiment: at Q = 0.07 GeV with 0.13% precision



- Atomic Parity Violation
- Moeller scattering
- Neutrino scattering
- pp collisions
- e^+e^- collisions
- Deep inelastic e^- scattering
- Parity violating e^- scattering

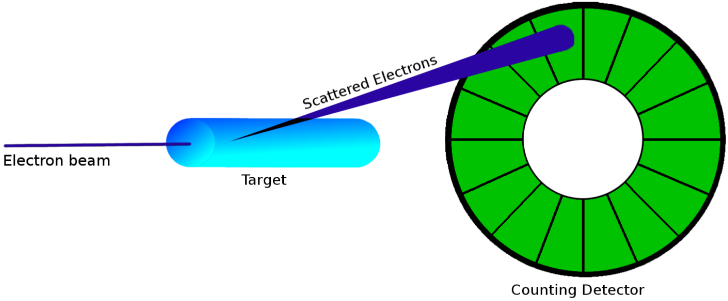


- Scattering of longitudinally polarized electrons on a proton target.
- EM-cross section dominates: $\sigma_\gamma \gg \sigma_Z$.
- Z^0 cross section depends on helicity of electron: $\sigma_Z^R \neq \sigma_Z^L$.
- Parity-violating asymmetry can be calculated from scattering rates:

$$A^{\mathrm{PV}} = \frac{\sigma^L - \sigma^R}{\sigma^L + \sigma^R} = \frac{G_f Q^2}{4\pi\alpha\sqrt{2}} \cdot \left(\underbrace{1 - 4\sin^2\theta_W}_{Q_W(p)} + F(Q^2) \right)$$

Kinematics

Choice of energy and scattering angle to minimize $\Delta \sin^2(\theta_W)$:
At lower Q^2 cross section gets higher, but asymmetry smaller



Beam : $E_{beam} = 150\,\text{MeV}, \quad I_{beam} = 150\,\mu\text{A} = 10^{15}\, e^- / s,$

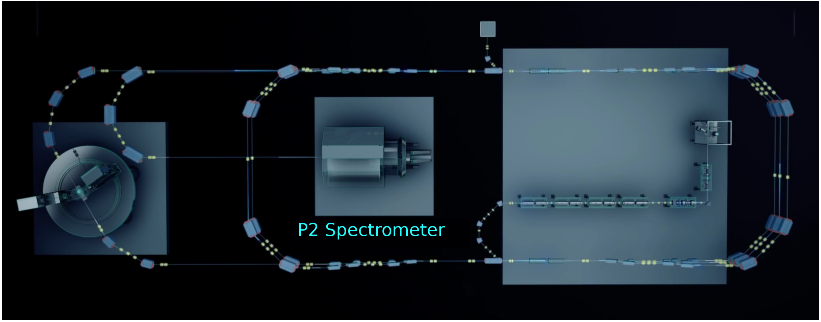
Target: 60 cm liquid hydrogen , $\quad L = 2.4 \cdot 10^{39} \text{s}^{-1} \text{cm}^{-2}$

Experiment: $\theta_{\text{scattering}} = 35^\circ$, observing 10^{11} electrons per second

Asymmetry: $A_{PV} = 33\,\text{ppb}$, $\Delta A_{PV} = 1.5\% = 0.44\,\text{ppb}$

Weinberg angle error: $\Delta \sin^2(\theta_W) = 0.13\%$ after 10000 h

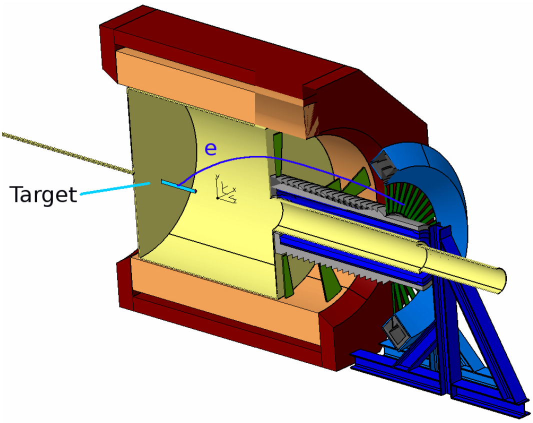
A new accelerator is being built in Mainz which will allow a next generation PV-Experiment



- 85% polarisation
- High position, intensity and energy stability
- Minimization of false asymmetries

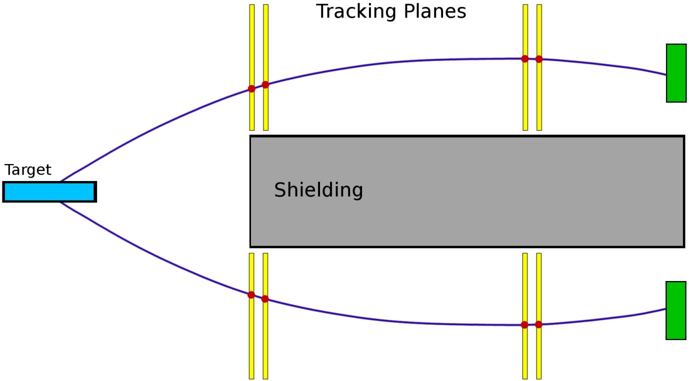
P2 Spectrometer

Counting 100 GHz of elastically scattered signal electrons while suppressing most of the background:



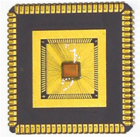
- 60 cm lH_2 target
- Solenoid magnet focusing scattered e^-
- Tracking Planes
- Integrating cherenkov counters
- Shield against photons and Moeller-electrons

Tracking Planes



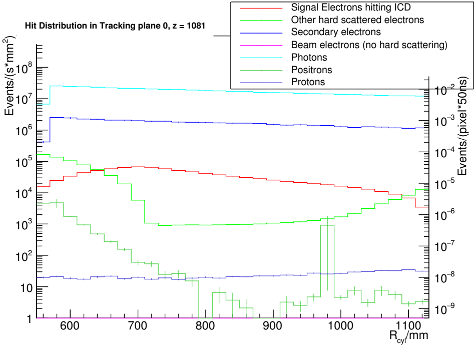
- Four tracking planes in 2 pairs inside the magnet
- Track the electrons before they reach the counting detector
- Tracking planes partially not shielded from photons
- No full azimuthal coverage necessary, very high electron rates

Tracking planes built out of silicon pixel chips (HV-MAPS, designed for Mu3e Experiment) :



- Pixel size 80 x 80 μm, chip size up to 2x2 cm^2
- Only 50 μm thickness, fast response, radiation hard

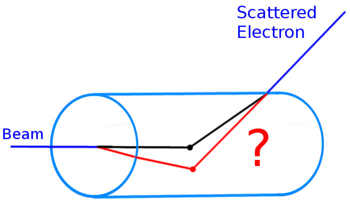
Backgrounds of an unshielded detector plane:



- Bremsstrahlung photons dominate
- Far more hits from background than from signal
- Definitive solution: reduce beam current for Q^2 measurement

Challenges:

- Inhomogeneous magnetic field
- Planes cause multiple scattering
- Vertex position not known
- Energy loss in Target
- Online tracking



Assuming 4 hits belong to a track:

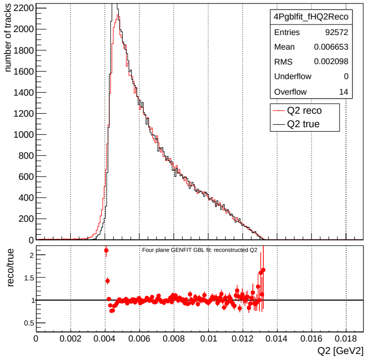
- Find a track which minizes χ^2
- Reconstruct momentum vector e.g. at first plane
- Propagate back to target
- Set point of closest approach to target center as vertex
- Reconstruct scattering angle

Solution:

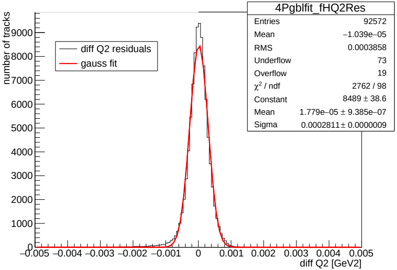
- **Runge-Kutta-Nystroem** propagator and **General Broken Lines** (C.Kleinwort) fit.

Momentum transfer Q^2 reconstruction

Reconstructed Q^2



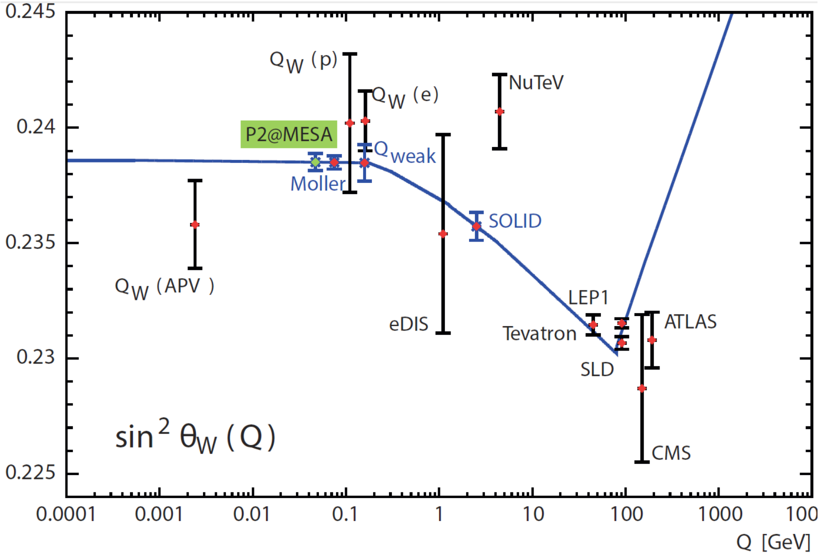
Reconstructed Q^2 Residual



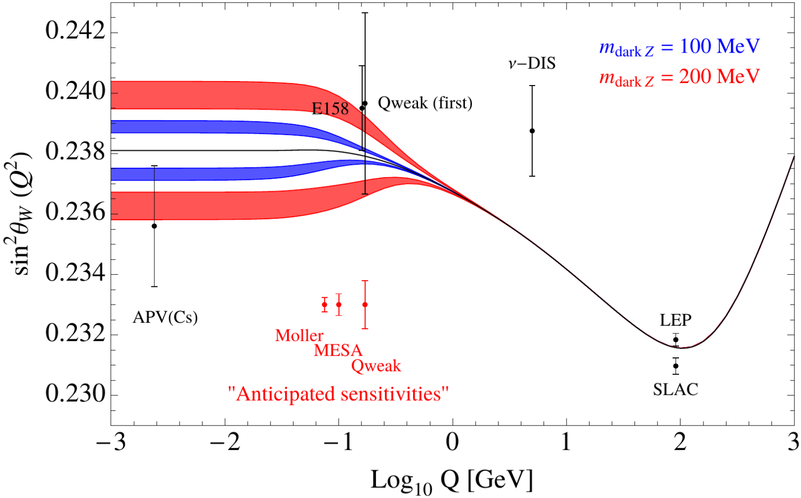
- Get reconstruction quality by comparing with Monte-Carlo simulation value
- Residual width of 0.00028 GeV^2/c^2 is an average of 4.2% resolution.

Summary

- The P2 Experiment is planning a measurement of $\sin^2(\theta_W)$ with 0.13% precision
- A new accelerator will be built to make it possible
- The P2 Spectrometer will measure A_{PV} of 100 GHz elastically scattered electrons on liquid hydrogen
- Silicon pixel tracking planes will measure average Q^2

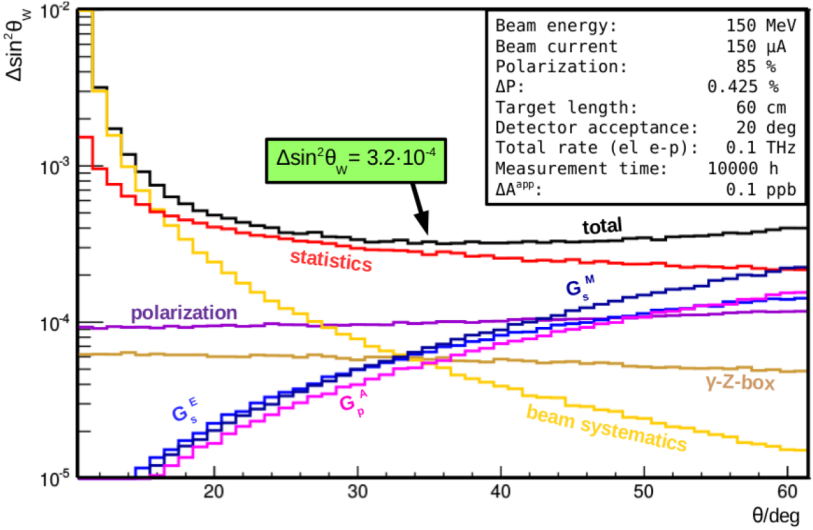


0.245
0.24
0.235
0.23
0.225
Q_W (p)
Q_W (e)
NuTeV
P2@MESA
Q_weak
Moller
SOLID
Q_W (APV)
eDIS
LEP1
Tevatron
SLD
ATLAS
CMS
sin²θ_W (Q)
0.0001
0.001
0.01
0.1
1
10
100
1000
100
Q [GeV]

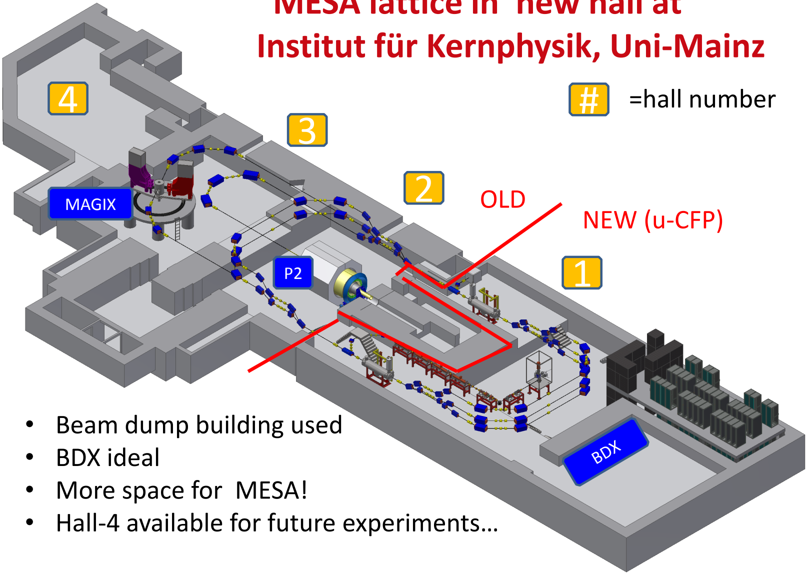


arXiv:1402.3620v2 , 21. Feb 2014

Backup: $\Delta \sin^2(\theta_W)$ optimiziation

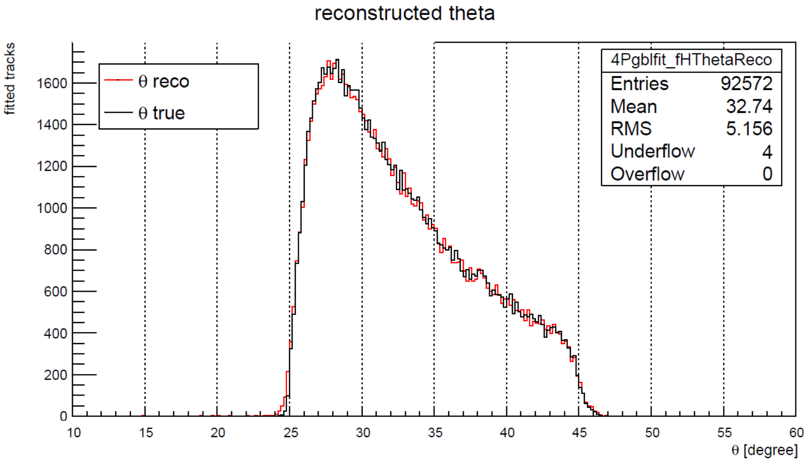


MESA lattice in new hall at Institut für Kernphysik, Uni-Mainz



- Beam dump building used
- BDX ideal
- More space for MESA!
- Hall-4 available for future experiments…

Backup: Angle reconstruction



Backup: Momentum reconstruction