Momentum transfer reconstruction for the P2 Experiment

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DPG Tagung 2017 Muenster

29.03.2017

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Cluster of Excellence Precision Physics, Fundamental Interactions and Structure of Matter

PRISMA

SFB 1044

THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

Motivation for measuring θ_W at low Q^2

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

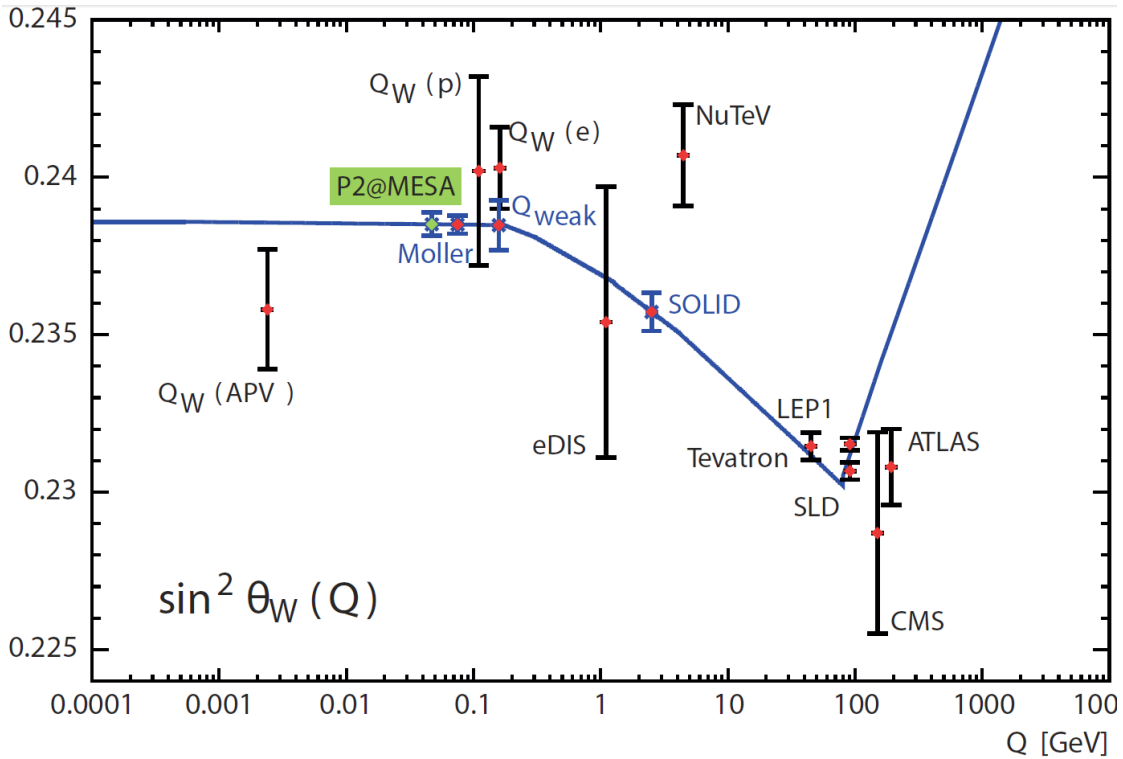
$$\begin{pmatrix} \gamma \\ Z^0 \end{pmatrix} = \begin{pmatrix} \cos(\theta_W) & \sin(\theta_W) \\ -\sin(\theta_W) & \cos(\theta_W) \end{pmatrix} \cdot \begin{pmatrix} B^0 \\ W^0 \end{pmatrix}$$

$$\sin^2(\theta_W) = \frac{g_e^2}{g_w^2} \approx 0.2314$$

- 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
- Inconsistent results of previous measurements must be resolved

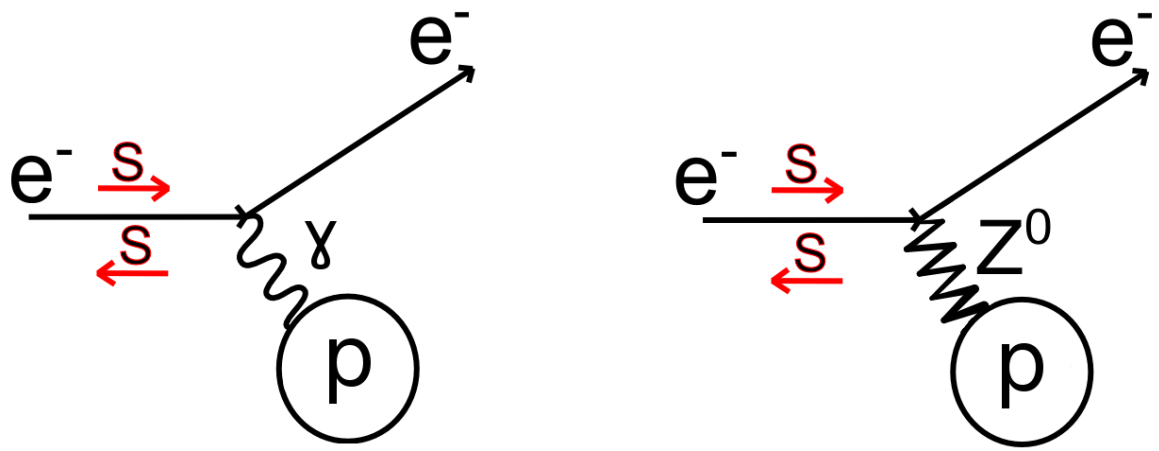
Measurements of $\sin^2(\theta_W)$

- 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

Parity violating electron scattering

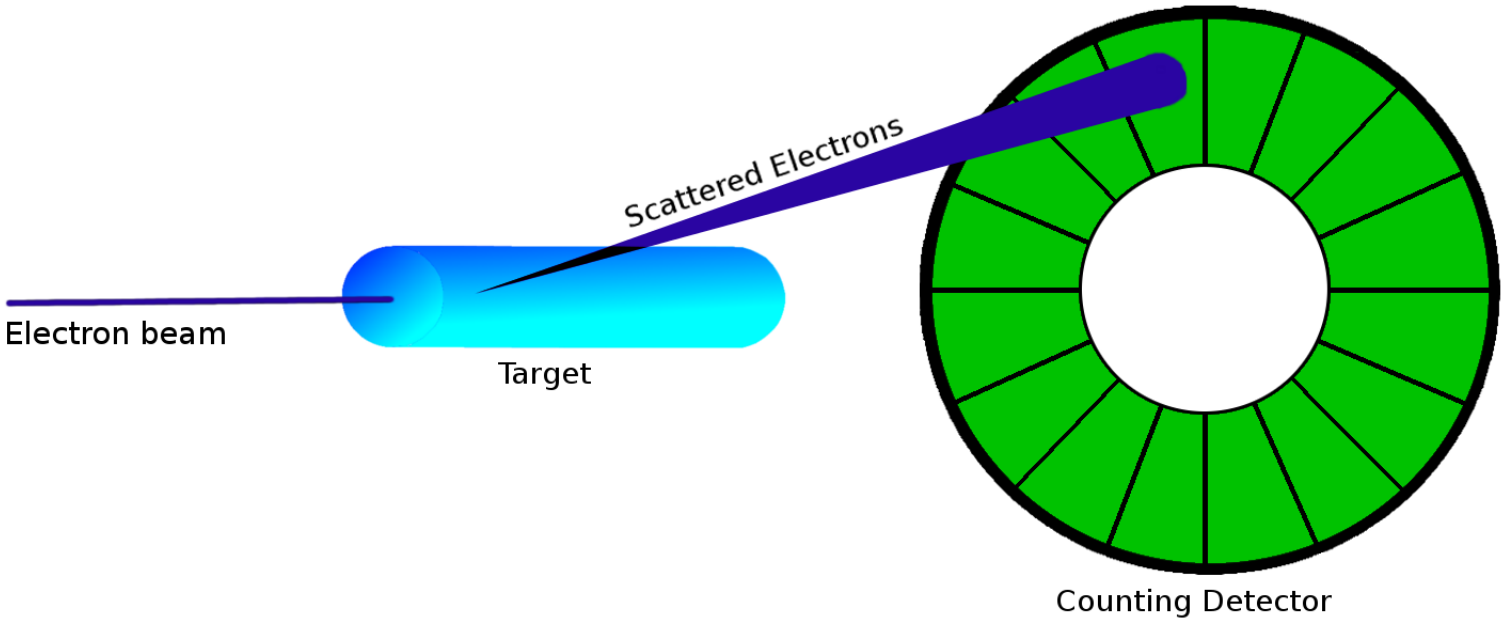


- Scattering of longitudinally polarized electrons on a proton target.
- EM-cross section dominates: $\sigma_\gamma \gg \sigma_Z$.
- Z^0 cross section depends on helicity of electron: $\sigma_Z^R \neq \sigma_Z^L$.
- Parity-violating asymmetry can be calculated from scattering rates:

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

Kinematics

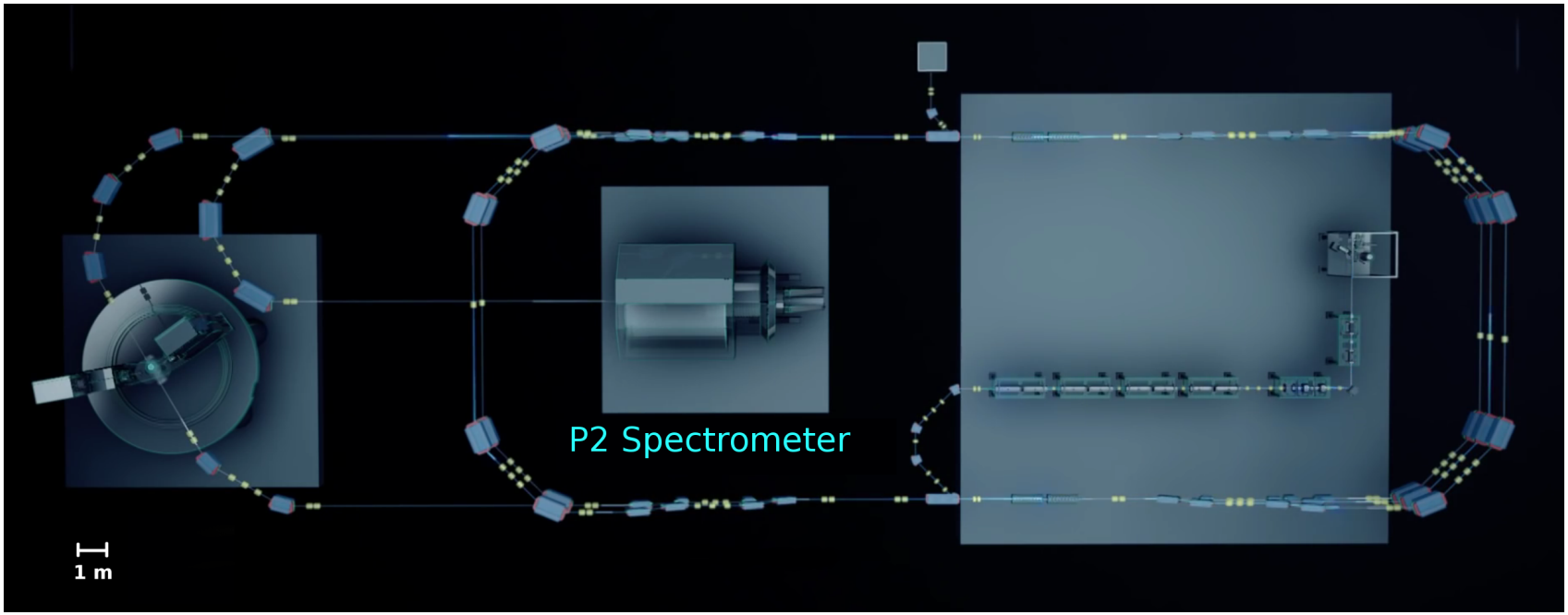
Choice of energy and scattering angle to minimize $\Delta \sin^2(\theta_W)$:
At lower Q^2 cross section gets higher, but asymmetry smaller



Beam	:	$E_{beam} = 155\,\text{MeV}, \quad I_{beam} = 150\,\mu\text{A} = 10^{15}\,e^-/s,$
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	:	$\Delta \sin^2(\theta_W) = 0.13\%$ after 10000 h

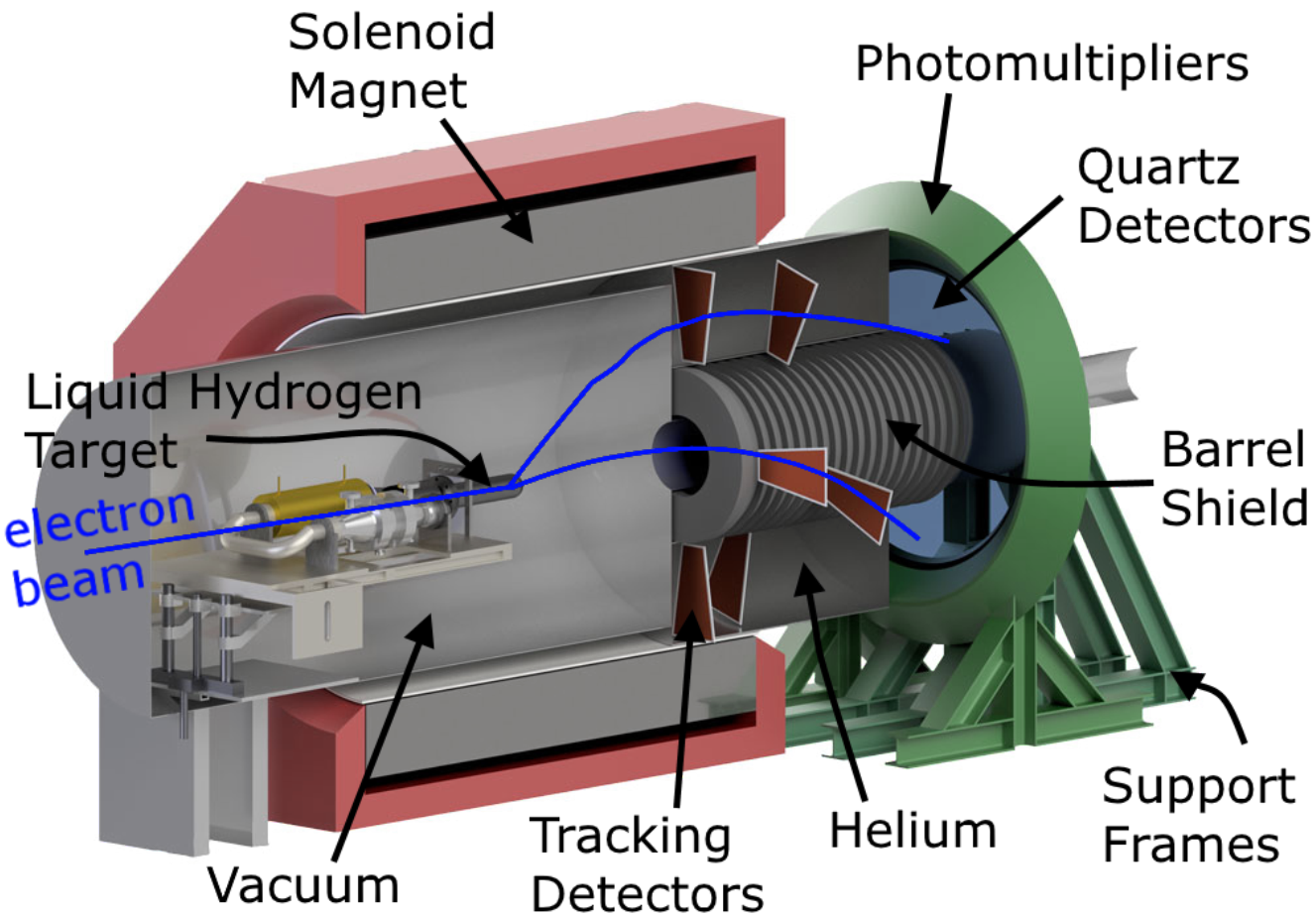
MESA - Mainz Energy-Recovering Superconducting Accelerator

A new electron accelerator is being built in Mainz which will allow a next generation parity violation experiment



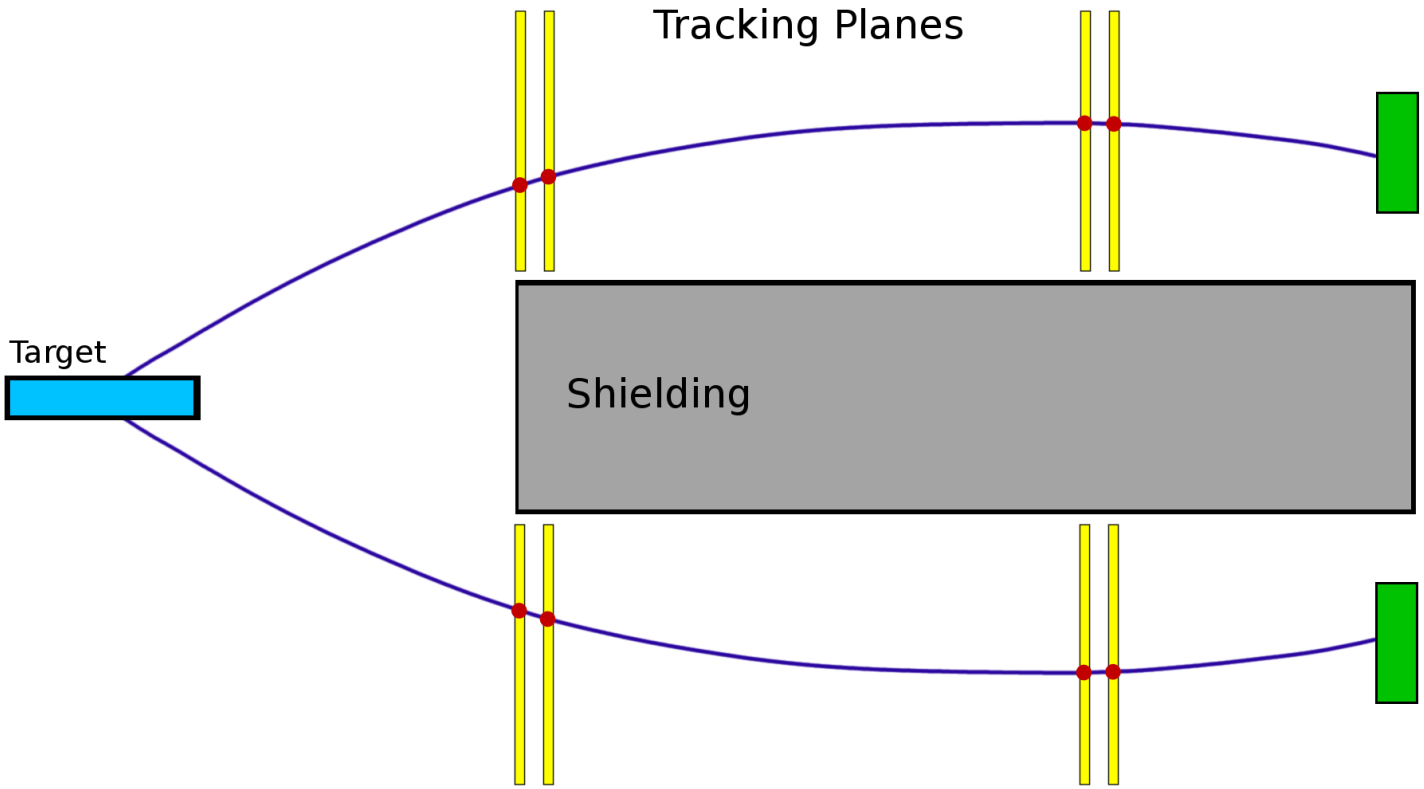
- High Intersity , 85% polarisation
- 155 MeV energy
- High stability of position, energy and intensity

P2 Spectrometer



- 60 cm lH_2 target, magnetic field, 2 detector systems

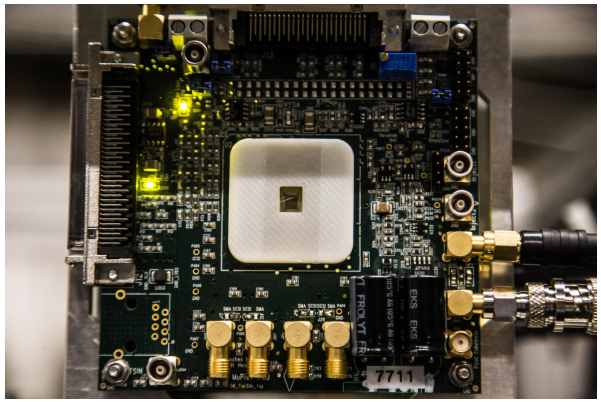
Tracking Planes

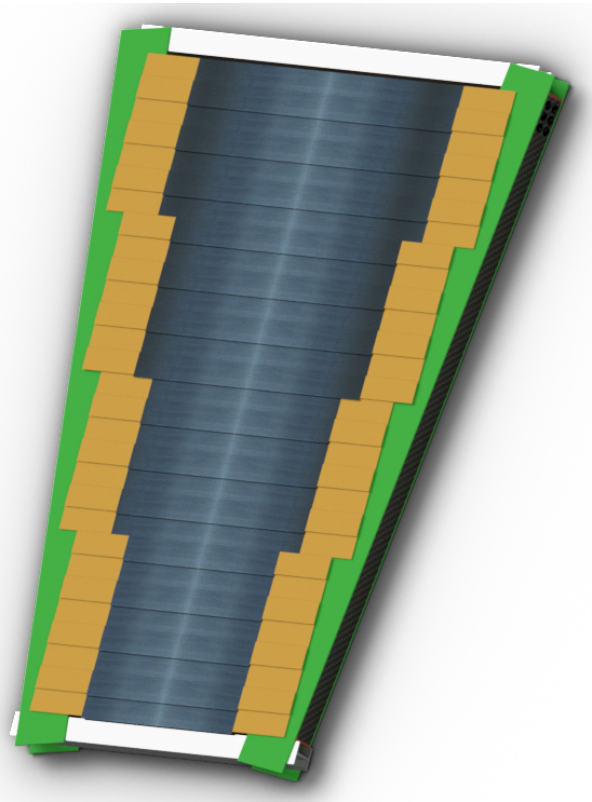


- Four tracking planes in 2 pairs inside the magnet
- Track the electrons before they reach the counting detector
- Tracking planes partially not shielded from photons
- No full azimuthal coverage necessary, very high electron rates

Tracking Planes

- MuPix chips
  (HV-MAPS, designed for Mu3e Experiment)
- Pixel size 80 x 80 μm, chip size 2x2 cm^2
- Only 50 μm thickness, fast response

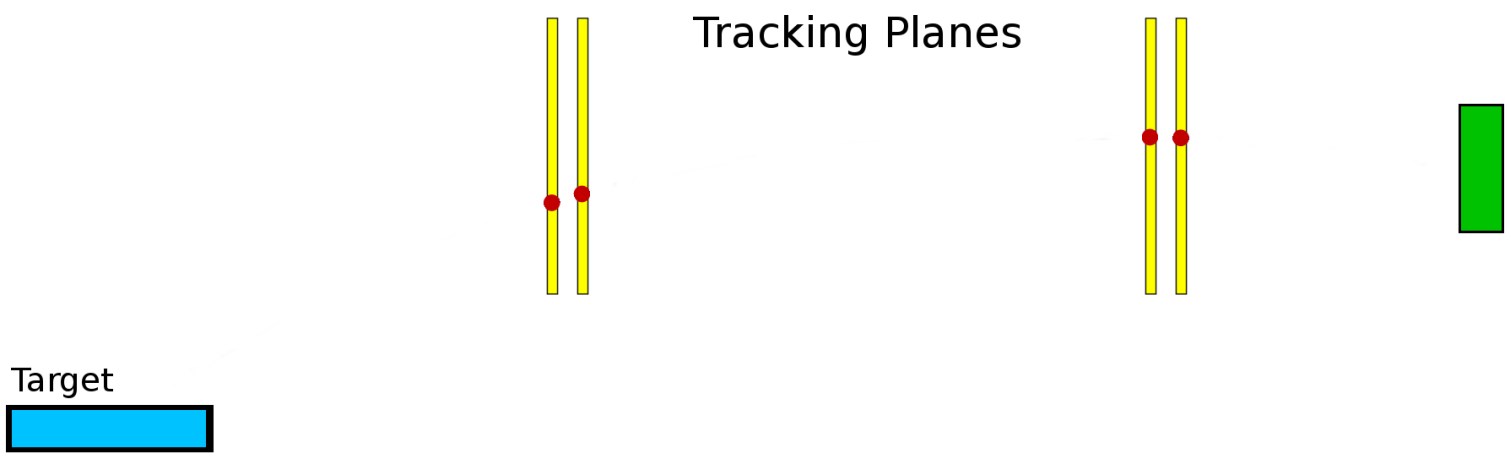




- 8 modules covering large area (15° each)
- Double layers of >300 MuPix chips
- Operation in high background environment
- Cooling required

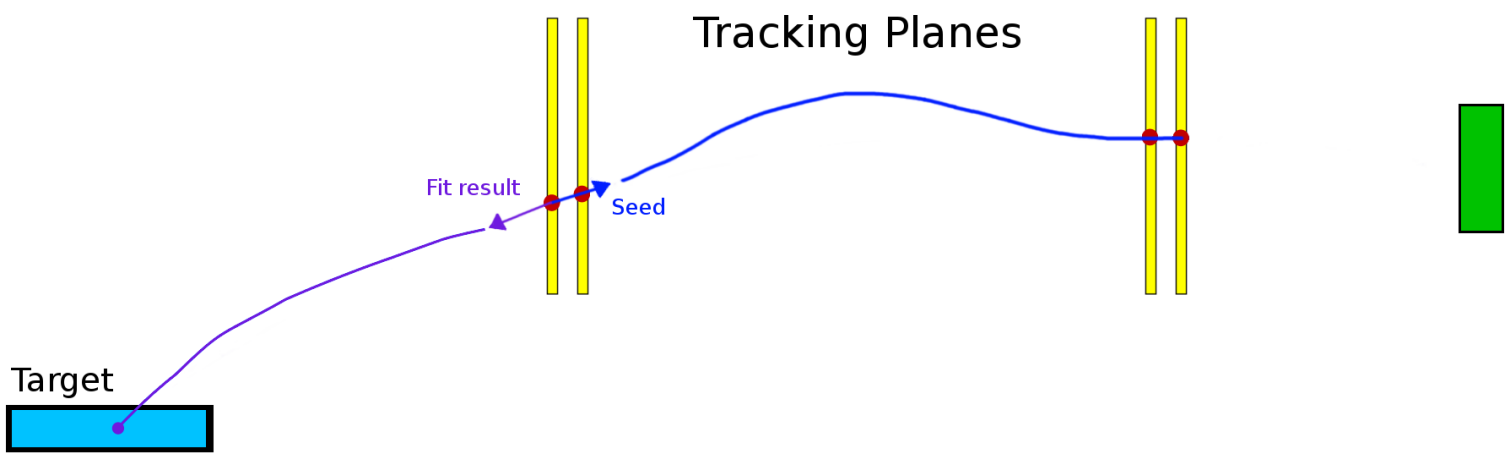
Track reconstruction

- Track finding (next talk) and track fitting problem
- Reconstruct track from one hit in each detection plane
- Approximate momentum transfer in target
- Inhomogeneous magnetic field and helium gas between planes
- Energy loss and scattering in planes



Track reconstruction - fitting

- Approximate seed momentum on the first plane
- Propagate seed momentum (Runge-Kutta-Nystroem)
- Calculate Jacobian matrix for the propagation (Bugge-Myrheim)
- Fit by minimizing the χ^2 (General Broken Lines , GBL)
- Refit until fit converges and extract the resulting fitted momentum

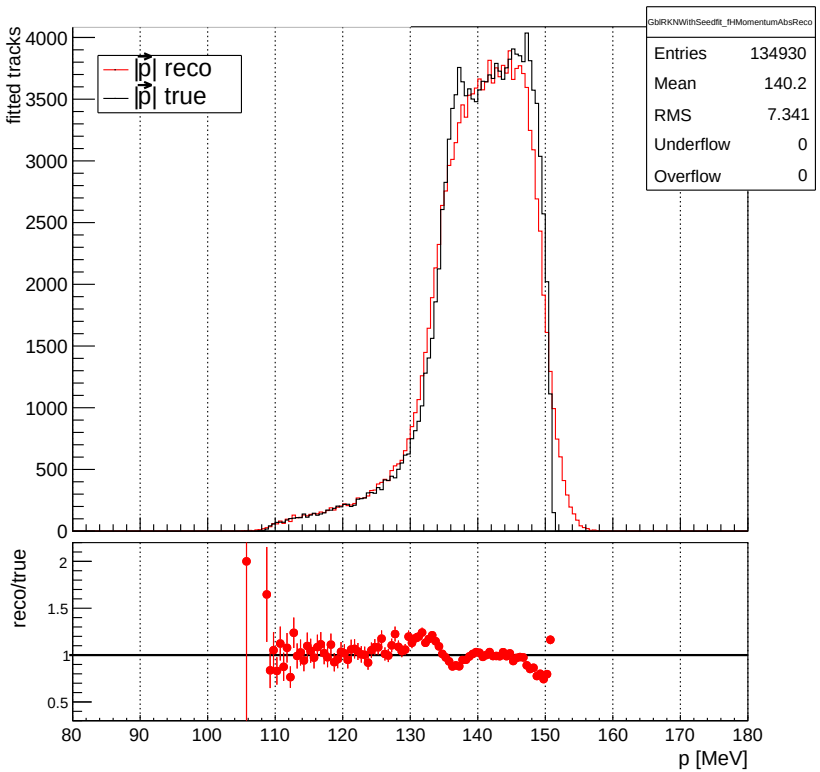


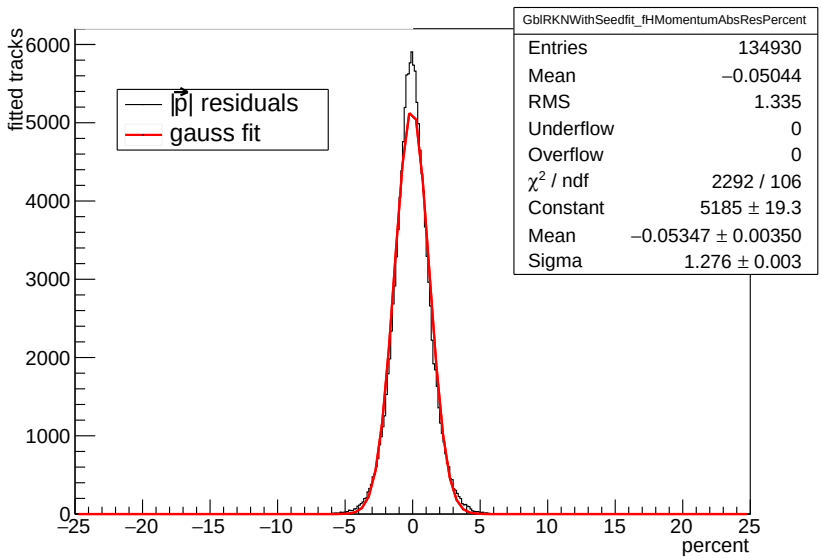
Track reconstruction - performance

Reconstruction of momentum magnitude from Geant4 simulation:

P_{reco} and P_{true} :

$$\frac{P_{reco} - P_{true}}{P_{true}} :$$



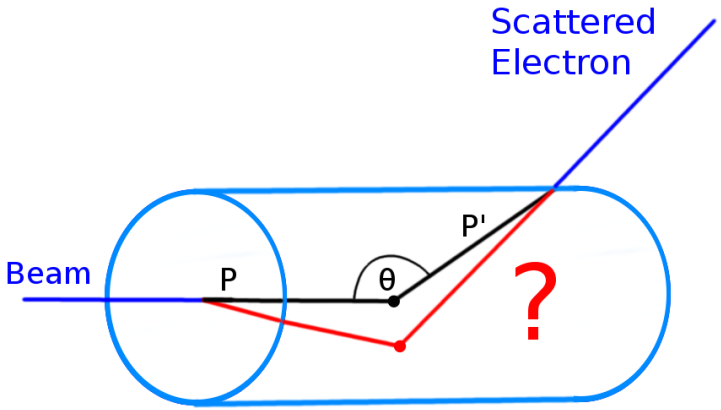


- The fit can never be perfect due to pixelsize, scattering, energy losses

Momentum transfer Q^2 reconstruction

Momentum transfer requires the kinematics of the event

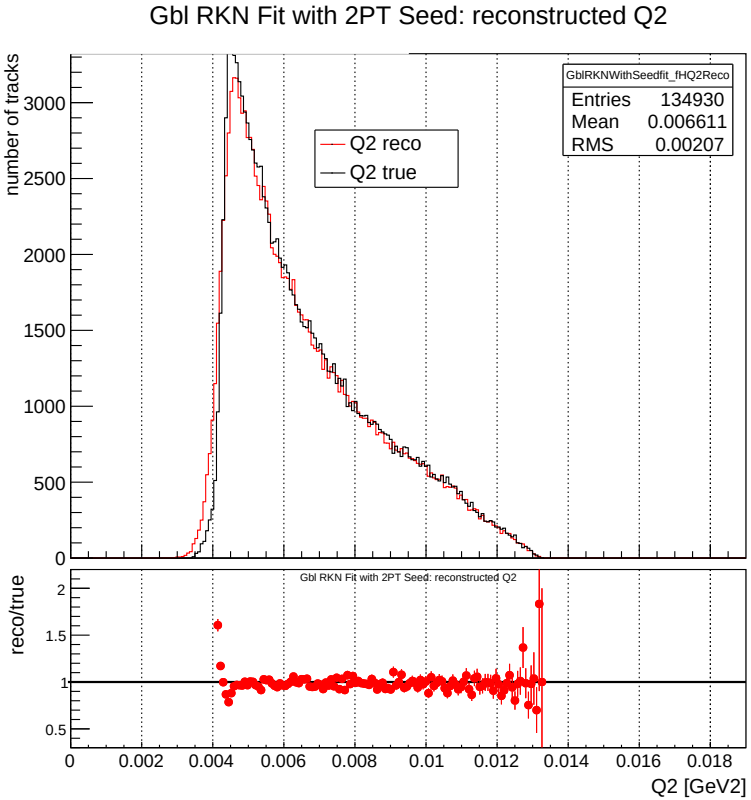
$$Q^2 = 4 \cdot P \cdot P' \cdot \sin^2(\theta/2)$$



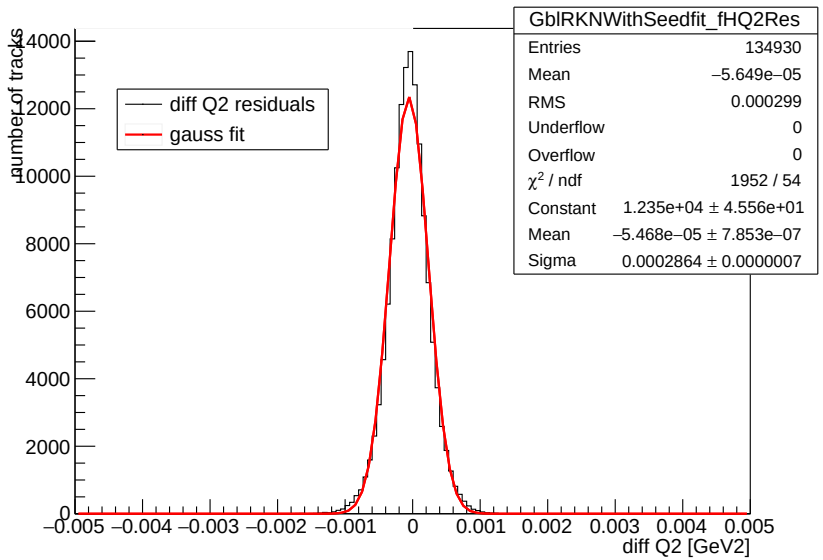
- Need to estimate P,P', θ
- Propagate fit result back to the target
- Estimate vertex as point of closest approach to target center
- Energy loss in target before and after scattering

Momentum transfer Q^2 reconstruction

Reconstructed Q^2



Reconstructed Q^2 Residual

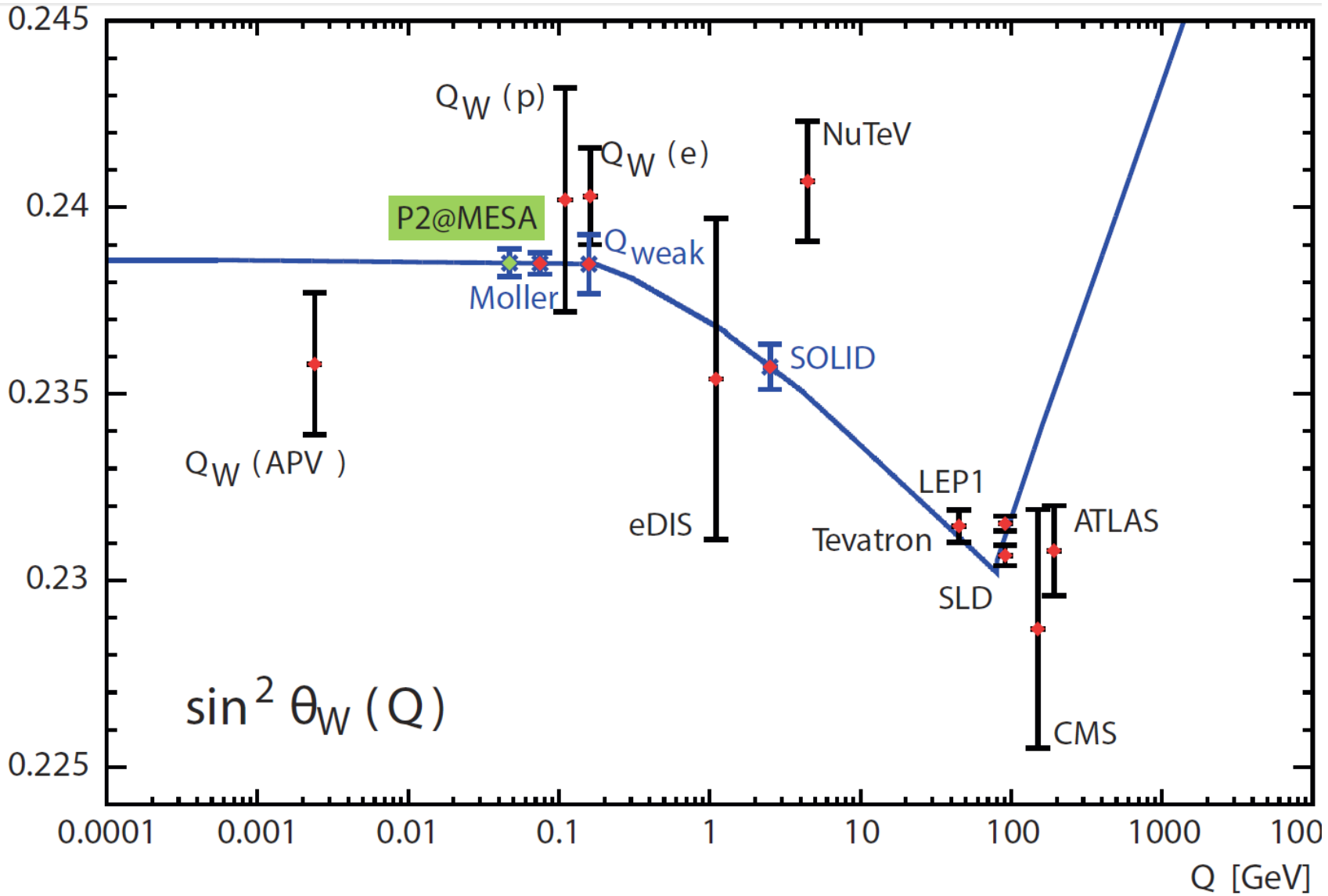


- Get reconstruction quality by comparing with Monte-Carlo simulation value
- Residual width of 0.00028 GeV^2/c^2 is an average resolution of 4.2%.

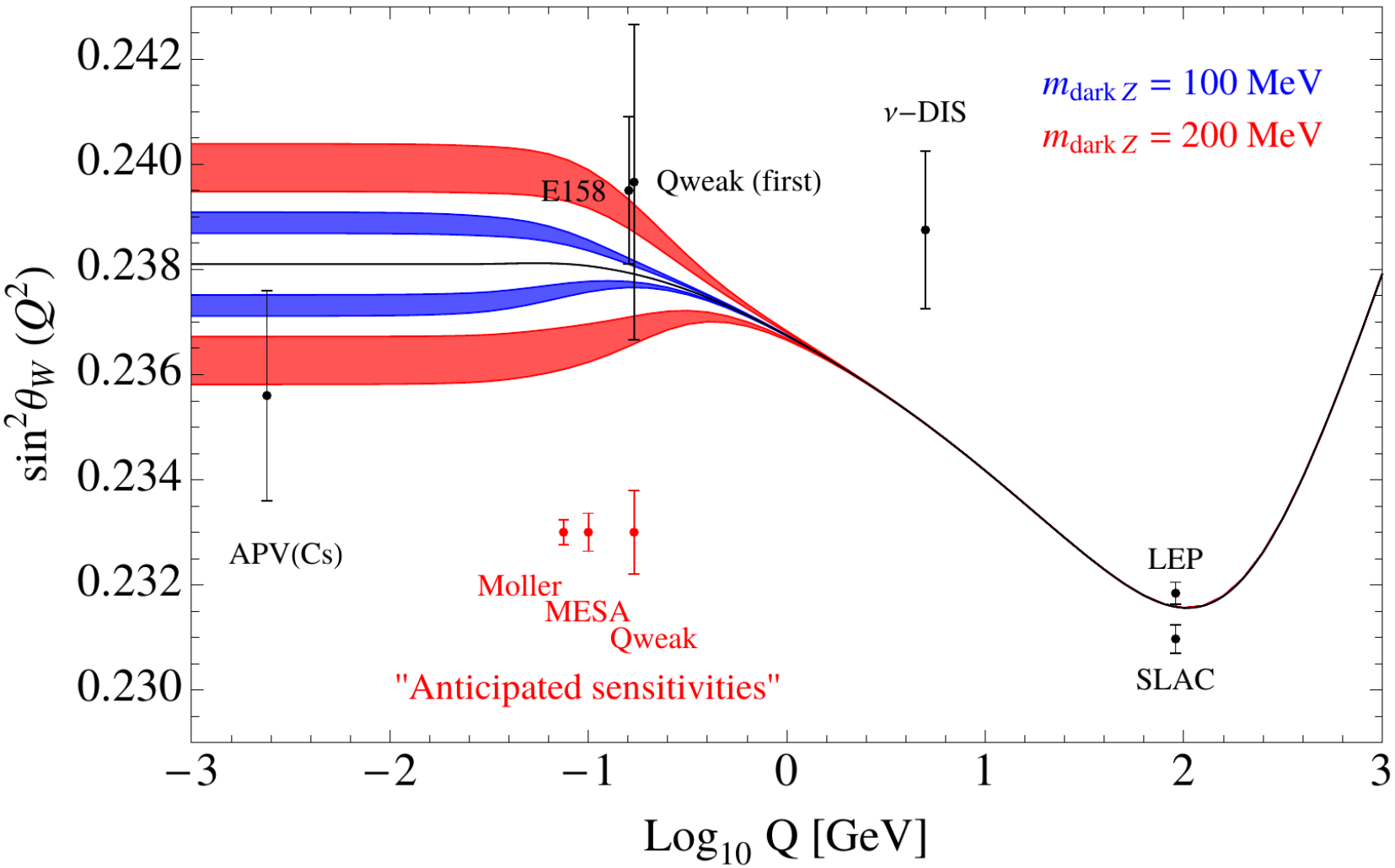
Summary

- 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

Backup: Future measurements

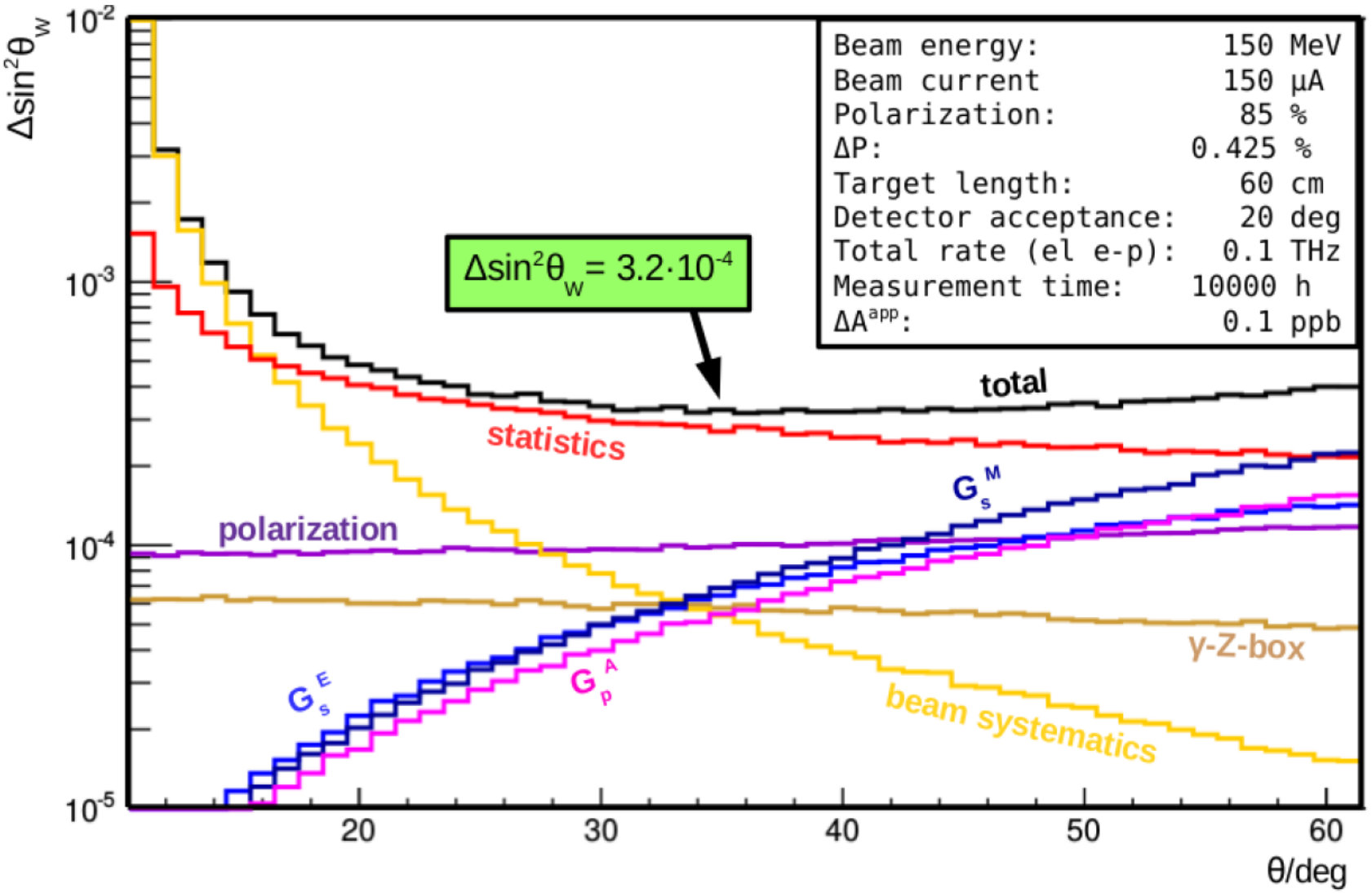


Backup:dark Z

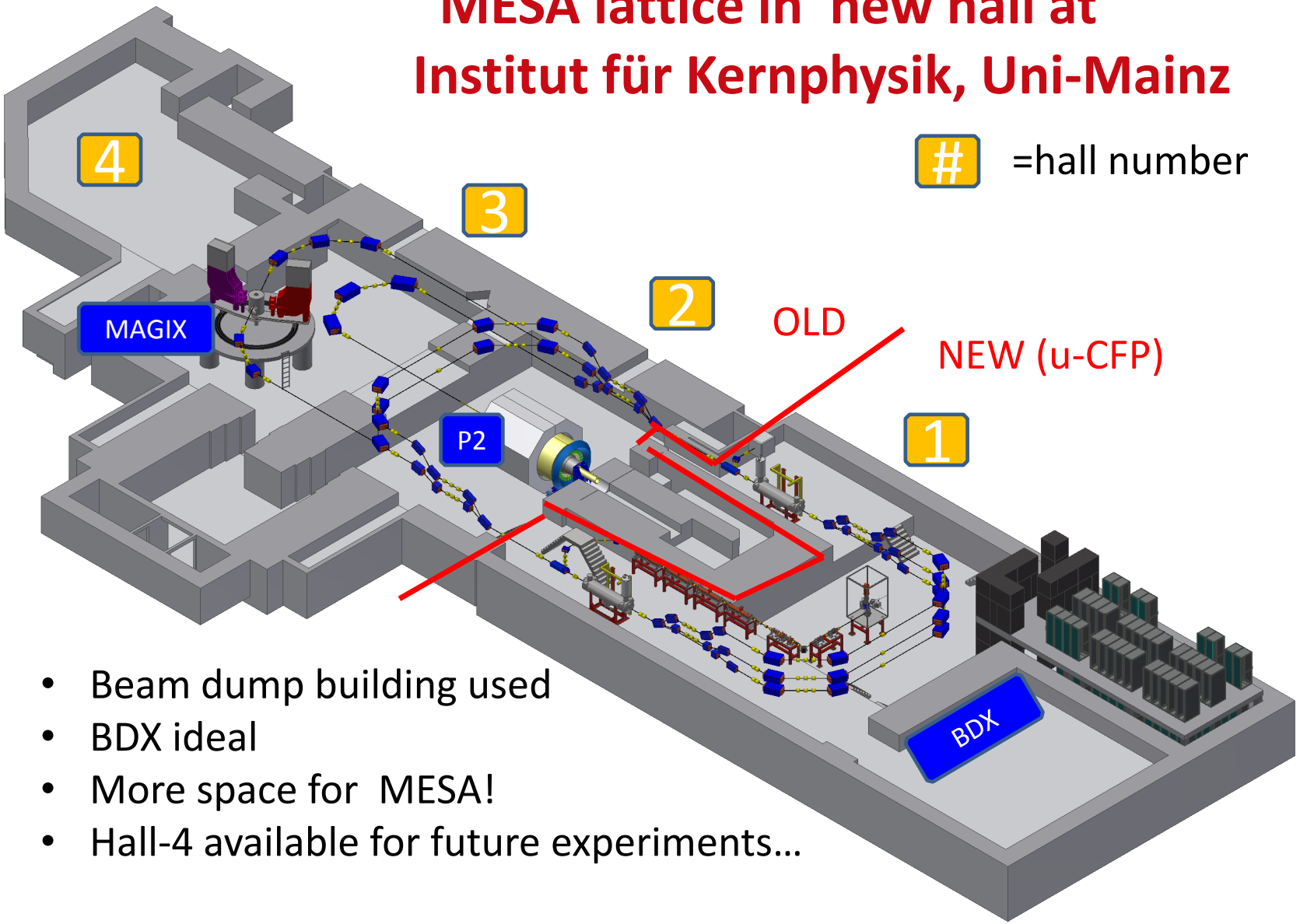


arXiv:1402.3620v2 , 21. Feb 2014

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

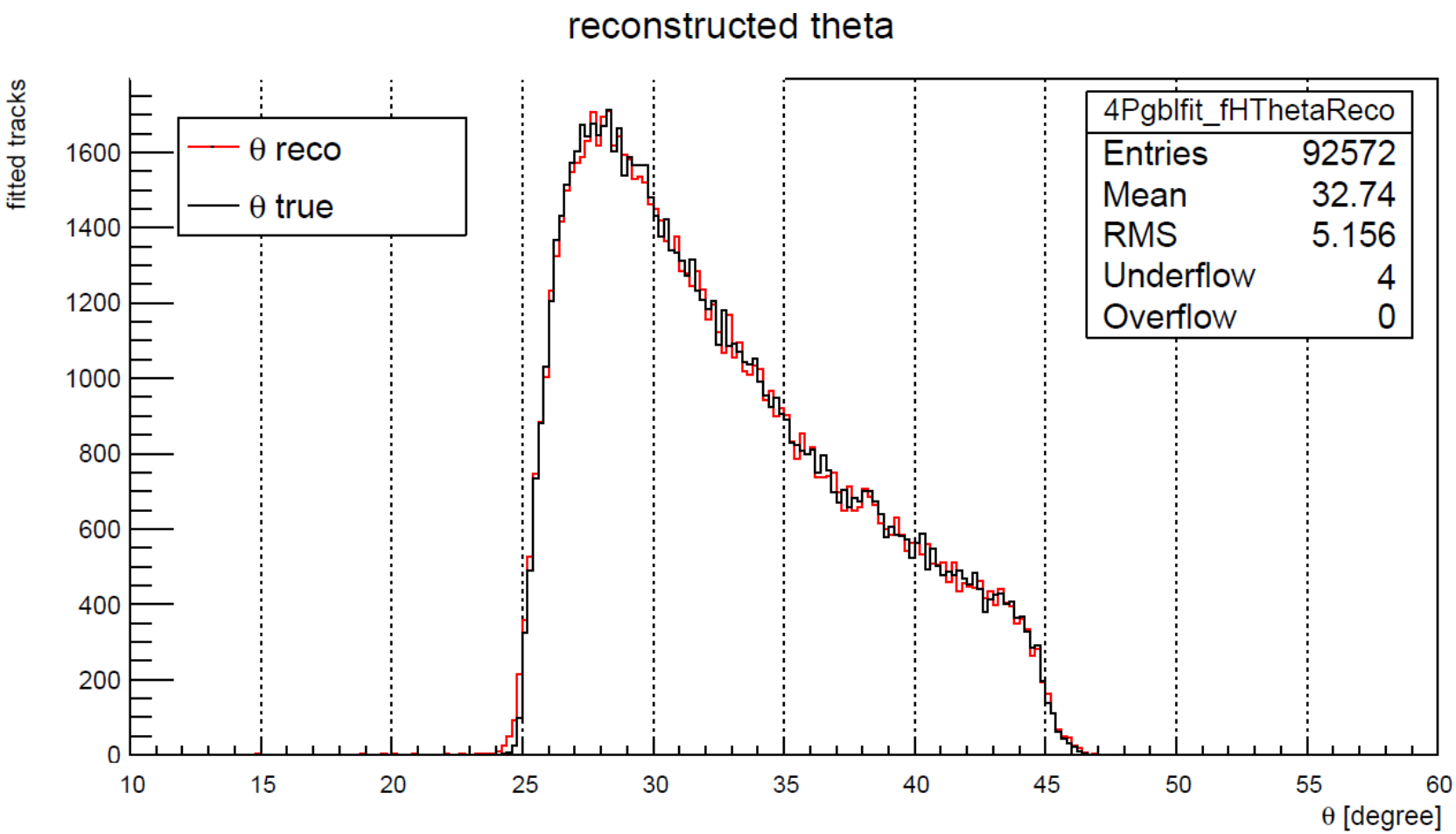


MESA lattice in new hall at Institut für Kernphysik, Uni-Mainz



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

Backup: Angle reconstruction



Backup: Momentum reconstruction