Momentum transfer reconstruction for the P2 Experiment

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

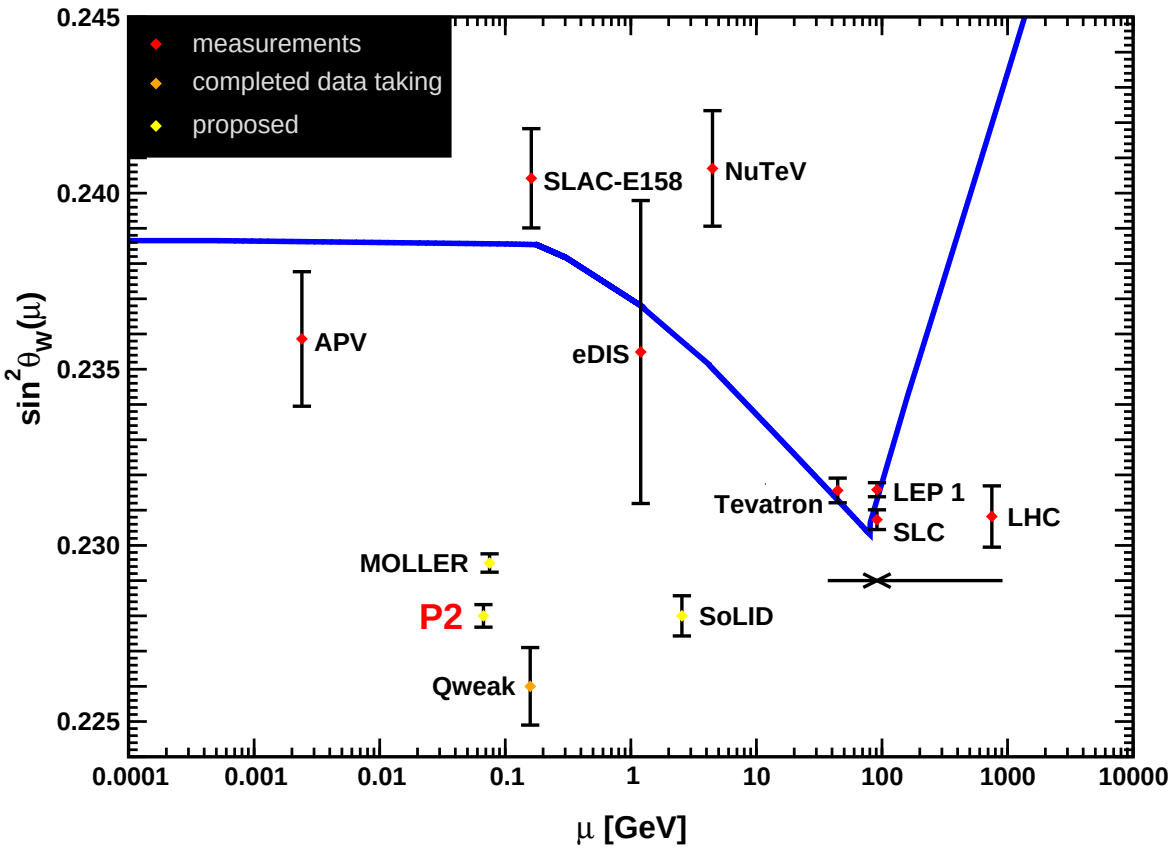
PRISMA

SFB 1044

THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

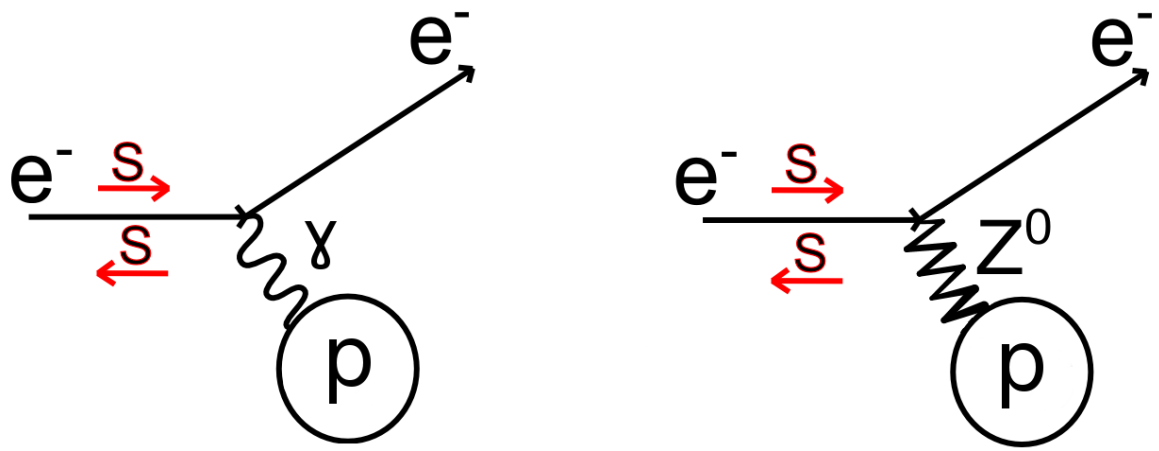
Motivation for measuring θ_W at low Q^2

- The Weak Mixing angle is a fundamental parameter of theory of electroweak unification
- $\sin^2(\theta_W) = g_e^2/g_w^2 \approx 0.2314$ with $\theta_W \approx 28.75^\circ$
- Running of $\sin^2(\theta_W)$ due to radiative corrections
- Measure precise $\sin^2(\theta_W)$ at $\mu < 1GeV \Rightarrow$ SM test or BSM physics



- P2 Experiment : Parity violating e^- scattering

Parity violating electron scattering

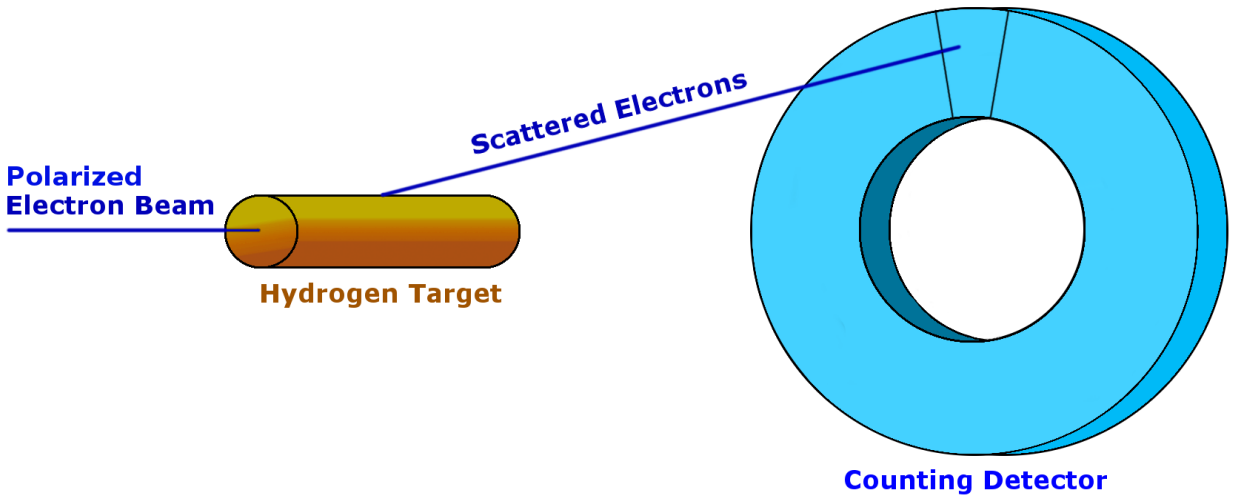


- Scattering of longitudinally polarized electrons on a proton target.
- EM-cross section dominates: $\sigma_\gamma \gg \sigma_Z$.
- Z^0 cross section depends on helicity of electron: $\sigma_Z^R \neq \sigma_Z^L$.
- Parity-violating asymmetry:

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

Kinematics

Choice of energy and scattering angle to minimize $\Delta \sin^2(\theta_W)$:

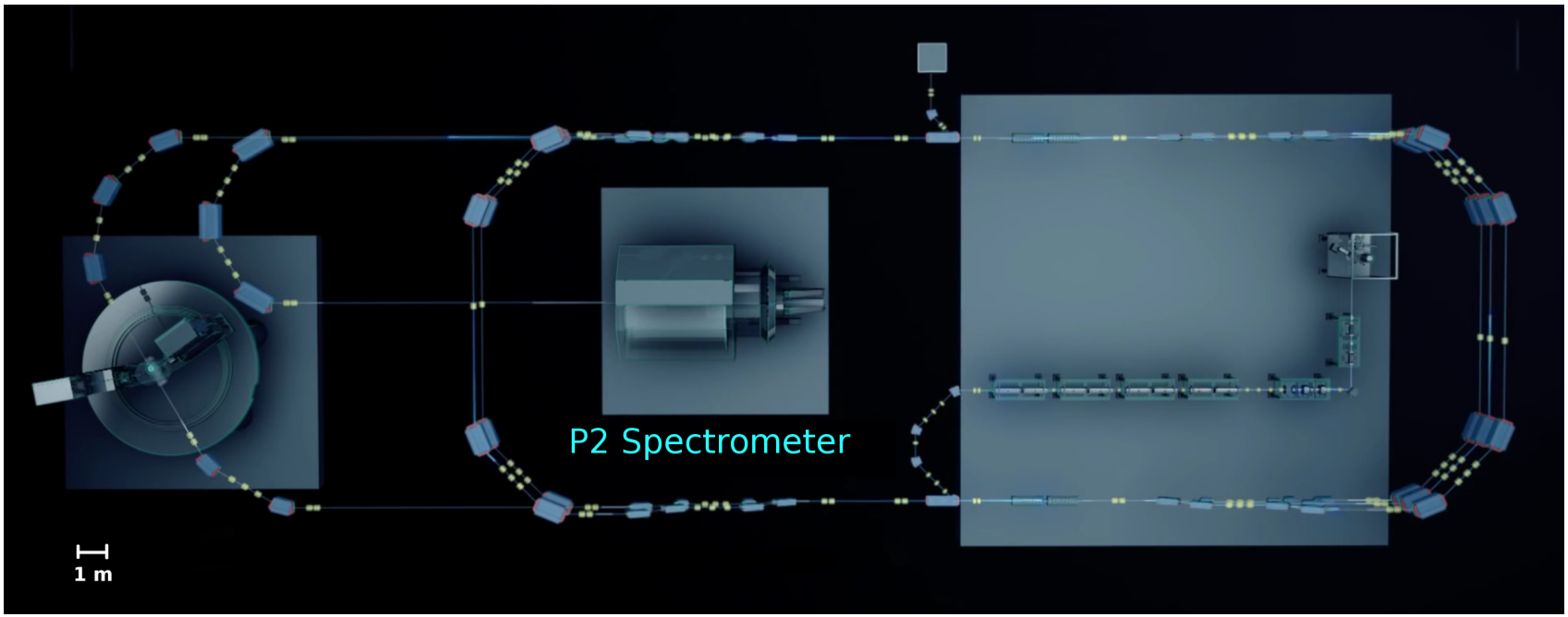


Beam	:	$E_{\text{beam}} = 155\,\text{MeV}, \quad I_{\text{beam}} = 150\,\mu\text{A} = 10^{15}\,e^-/s,$
Target	:	60 cm liquid hydrogen , $\quad L = 2.4 \cdot 10^{39}\text{s}^{-1}\text{cm}^{-2}$
Q^2	:	4.5×10^{-3} GeV^2
Experiment	:	10^{11} scattered electrons / sec for 11000 h
Asymmetry	:	$A_{PV} = 40\,\text{ppb}$, $\Delta A_{PV} = 0.57\,\text{ppb} = 1.4\%$

Weak mixing angle	:	$\Delta \sin^2(\theta_W) = 0.15\%$

MESA - Mainz Energy-Recovering Superconducting Accelerator

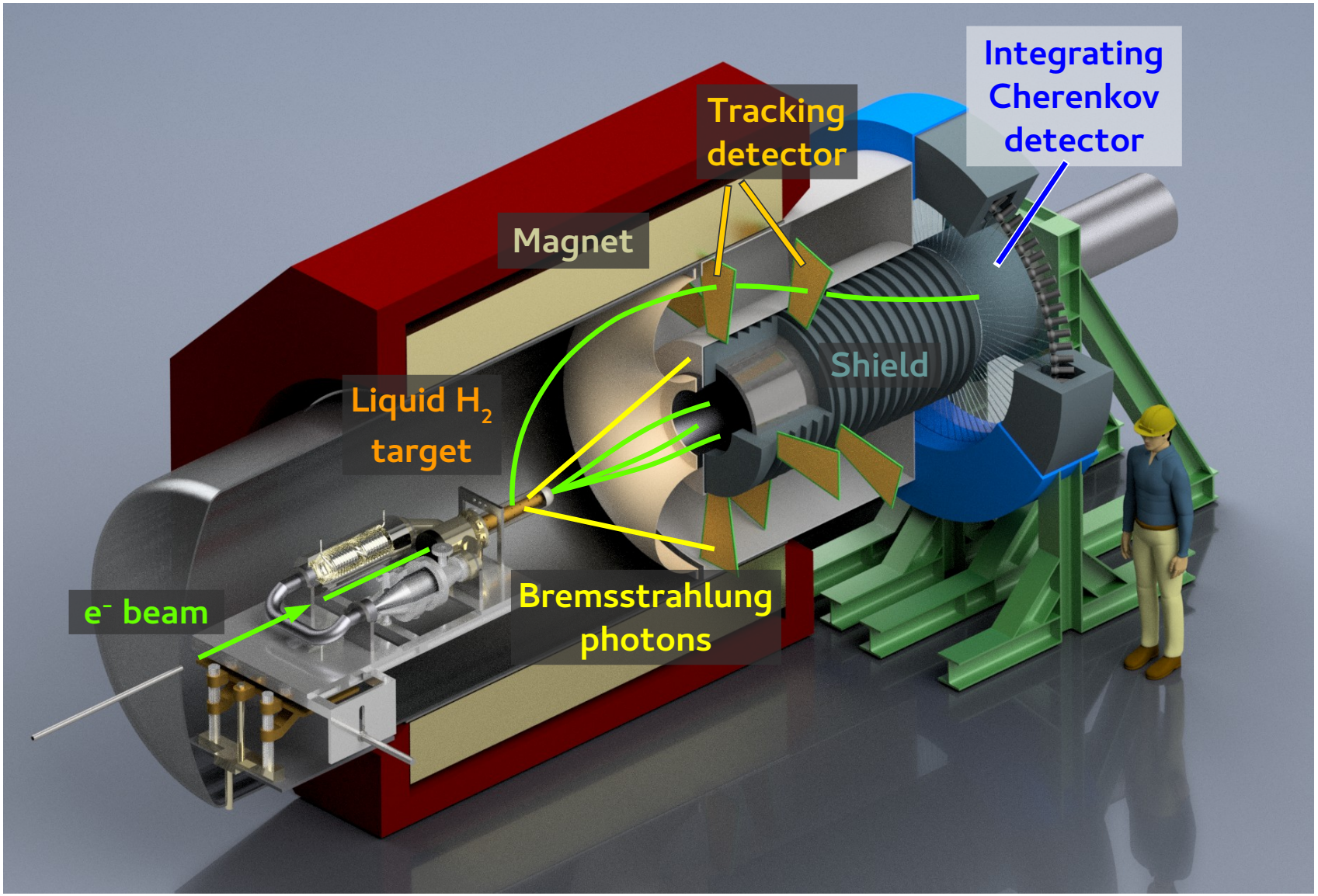
A new accelerator is being built in Mainz which will allow a next generation parity violation experiment



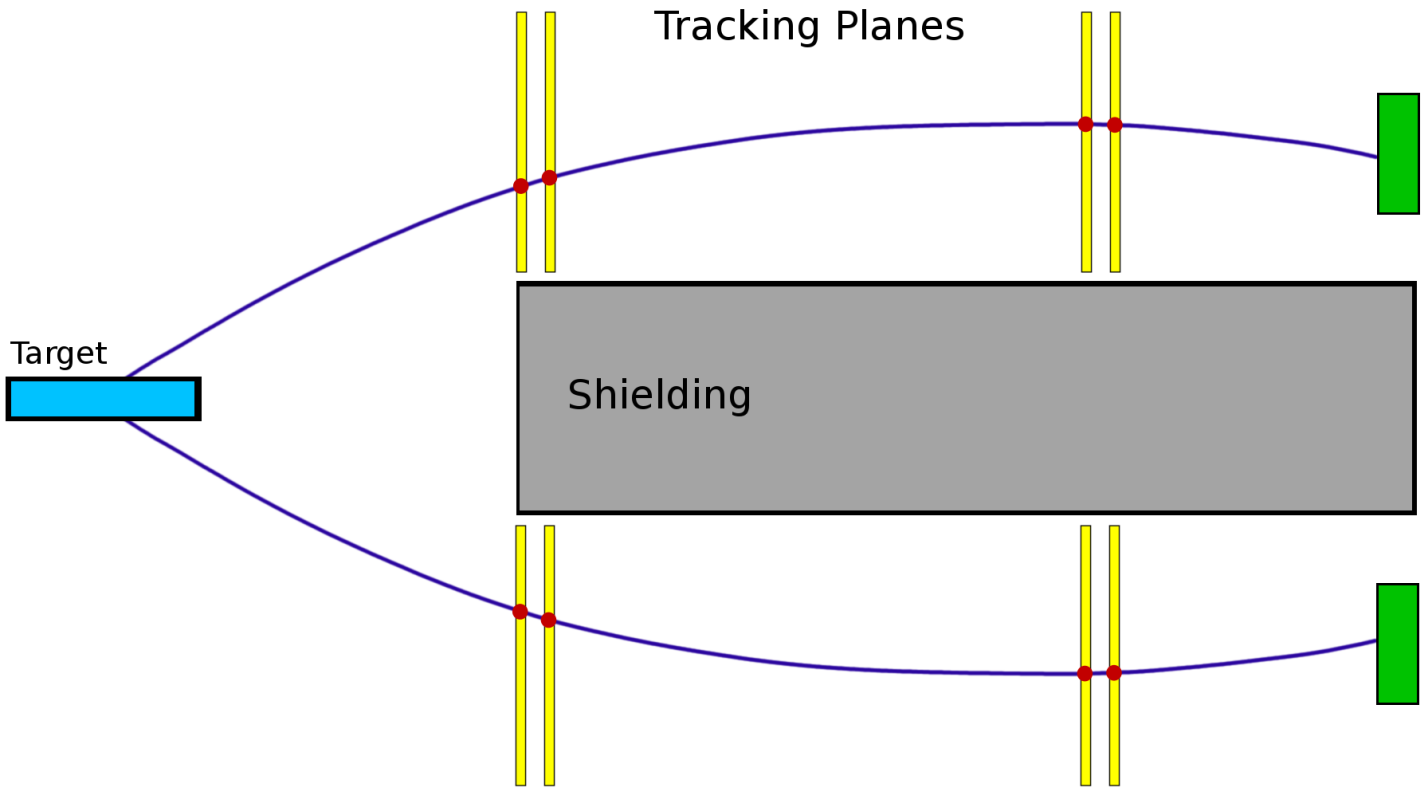
- High Intersity , 85% polarisation with 1 kHz helicity switching
- High stability of position, energy and intensity to minimize error of A^{PV}

P2 Spectrometer

- Magnetic field of solenoid bends electrons around a lead shield which protects the counting detector from background:



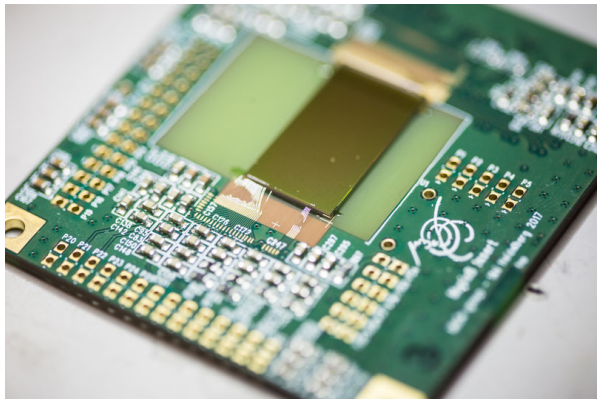
Tracking Planes

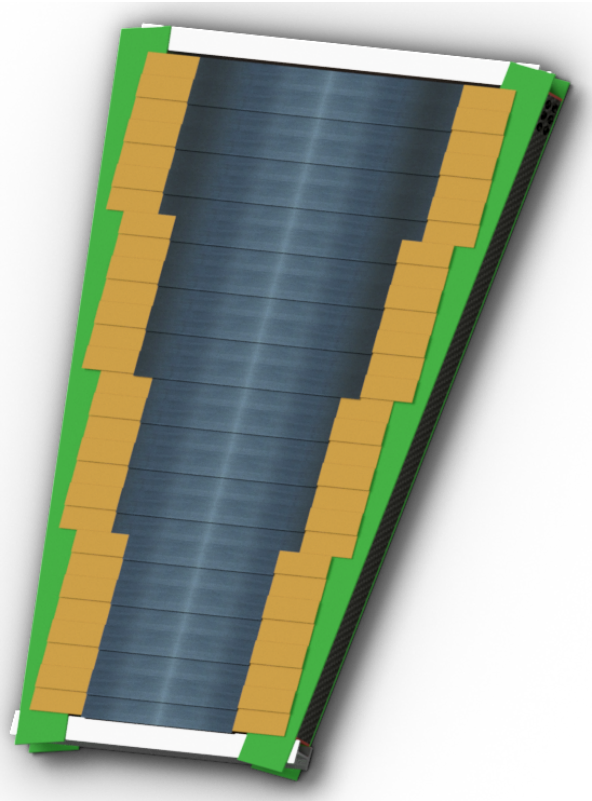


- Four tracking planes inside the magnetic field
- Tracking planes partially not shielded from photons
- No full azimuthal coverage necessary, very high electron rates

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

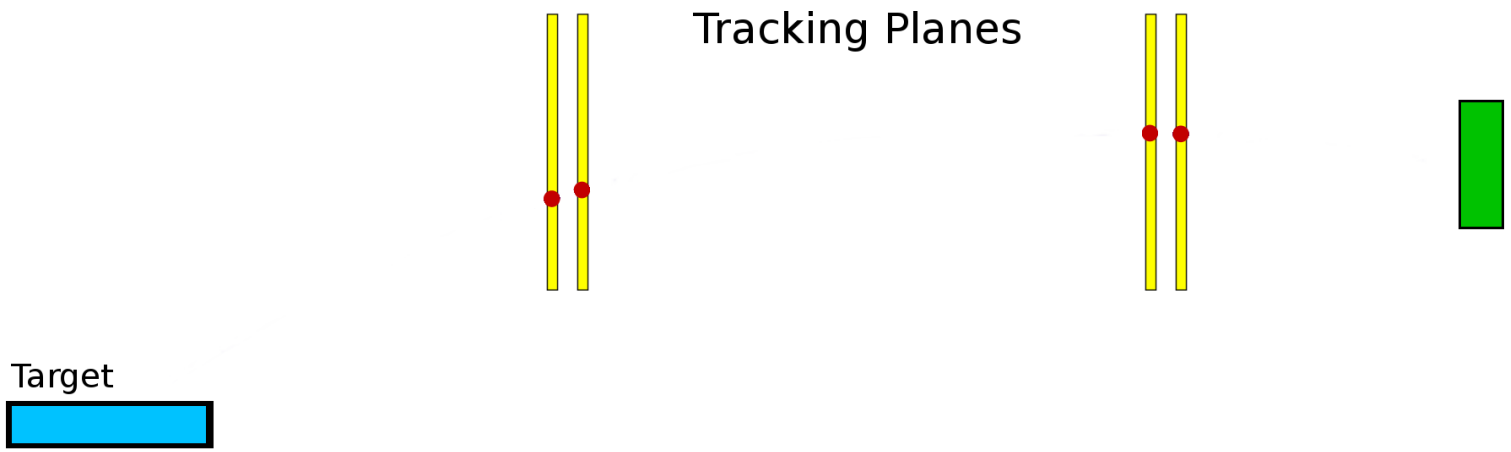




- 8 modules covering large area (15° each)
- Double layers of >300 MuPix chips
- Operation in high background environment
- Cooling (gaseous helium) required

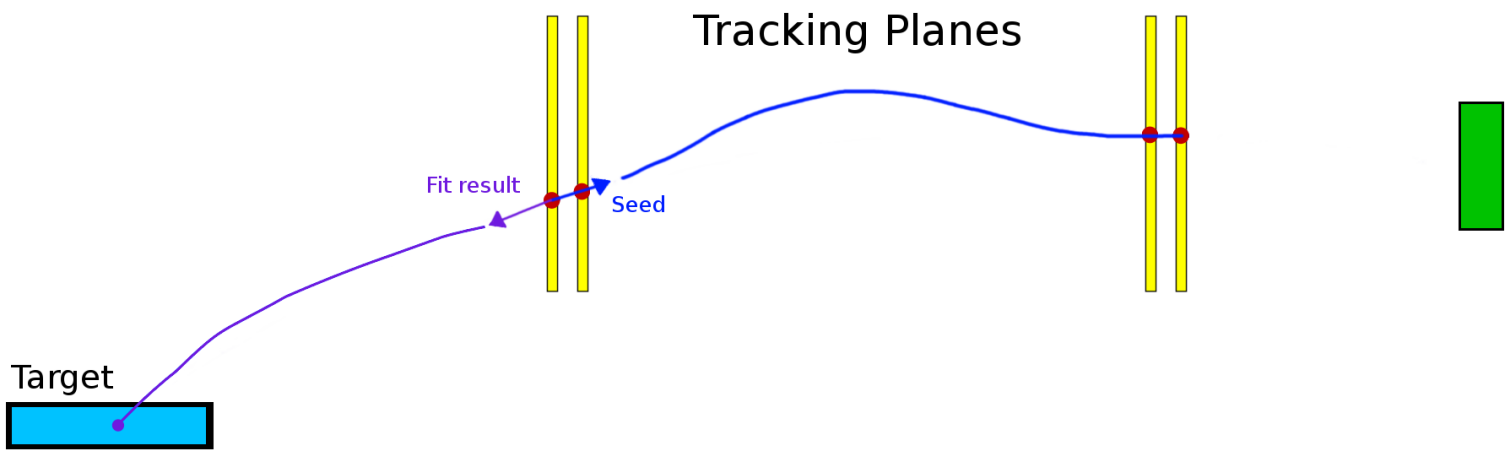
Track reconstruction

- Track finding: which 4 hits were created by the same track?
  many electrons + background photons $\Rightarrow$ combinatorics problem
- Track fitting : reconstruct track from 4 hits, one on each detection plane
- Inhomogeneous magnetic field and helium gas between planes
- Energy loss and scattering in planes



Track reconstruction - fitting

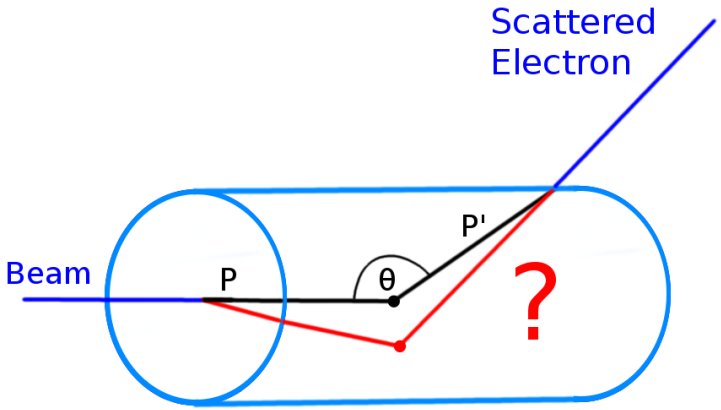
- Approximate seed momentum on the first plane
- Propagate seed momentum (Runge-Kutta-Nystroem)
- Calculate Jacobian matrix for the propagation (Bugge-Myrheim)
- Fit by minimizing the χ^2 (General Broken Lines , GBL)



Momentum transfer Q^2 reconstruction

Simple method for example:
Momentum transfer requires the kinematics of the event

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



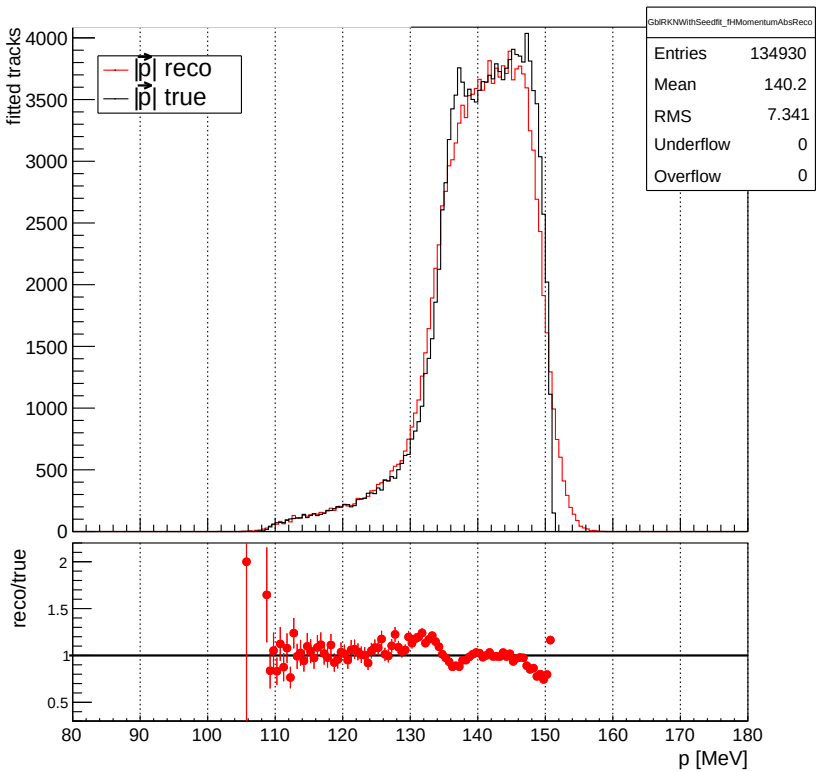
- Need to estimate P,P', θ
- Propagate fit result back to the target
- Estimate vertex as point of closest approach to target center
- Energy loss in target before and after scattering

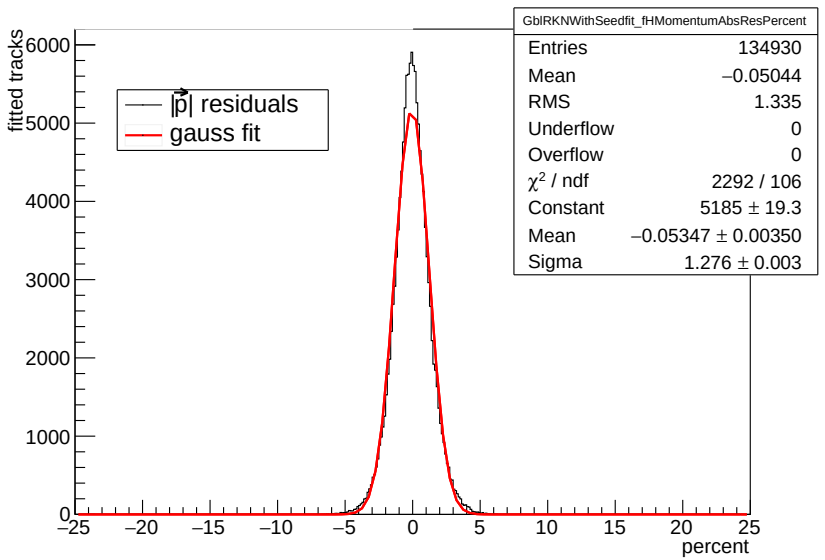
Track reconstruction performance

Reconstruction of momentum magnitude from Geant4 simulation:

P_{reco} and P_{true} :

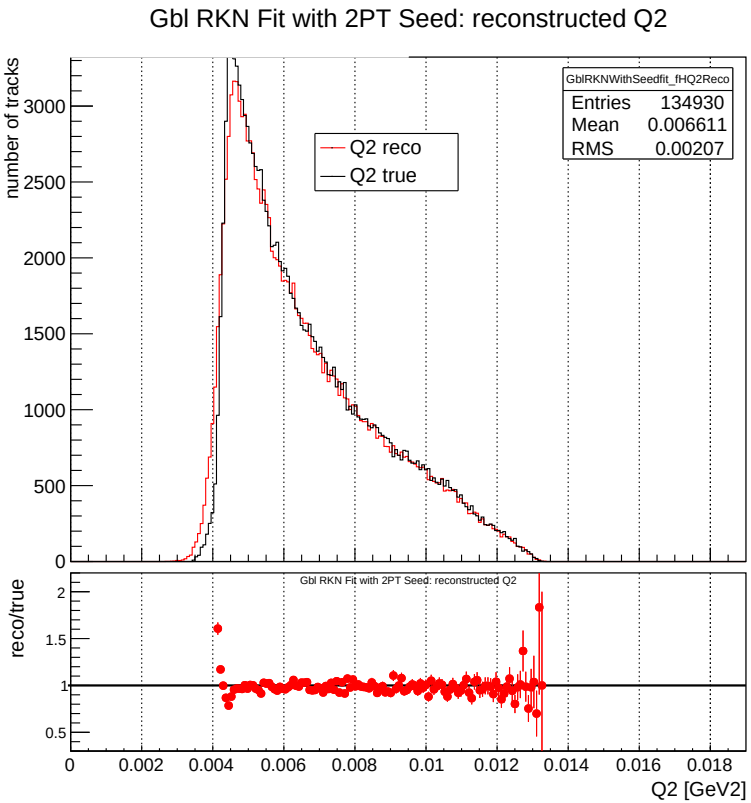
$$\frac{P_{reco} - P_{true}}{P_{true}} :$$



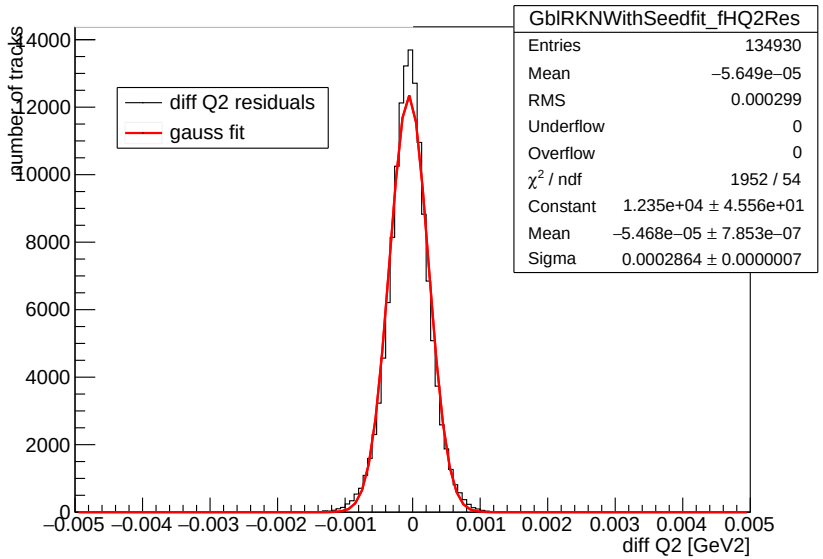


Momentum transfer Q^2 reconstruction performance

Reconstructed Q^2



Reconstructed Q^2 Residual

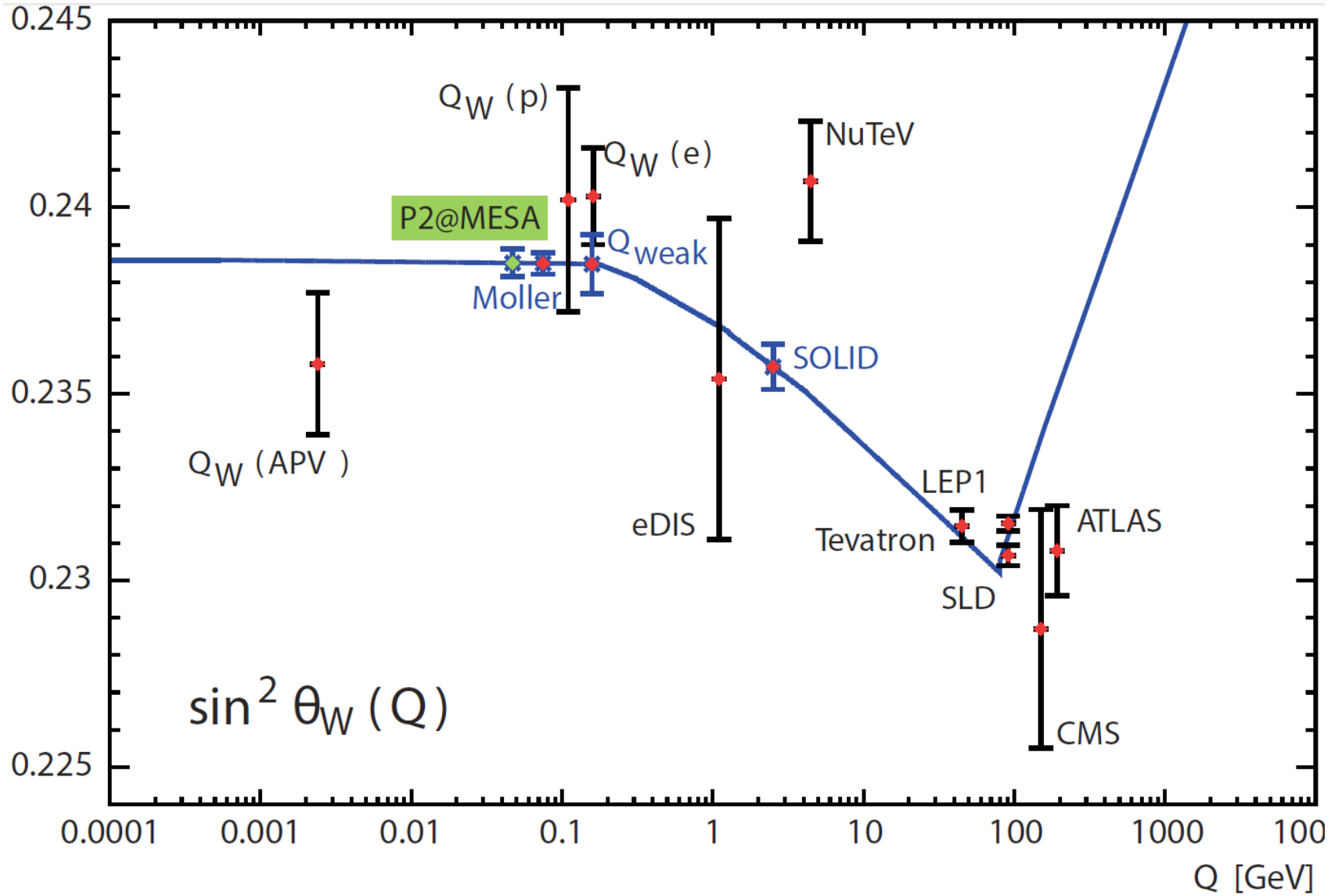


- Get reconstruction quality by comparing with Monte-Carlo simulation value
- Residual width of 0.00028 GeV$^2/c^2$ is an average resolution of 4.2%.
- True diffculty is in reconstructing Q^2 without bias on average.

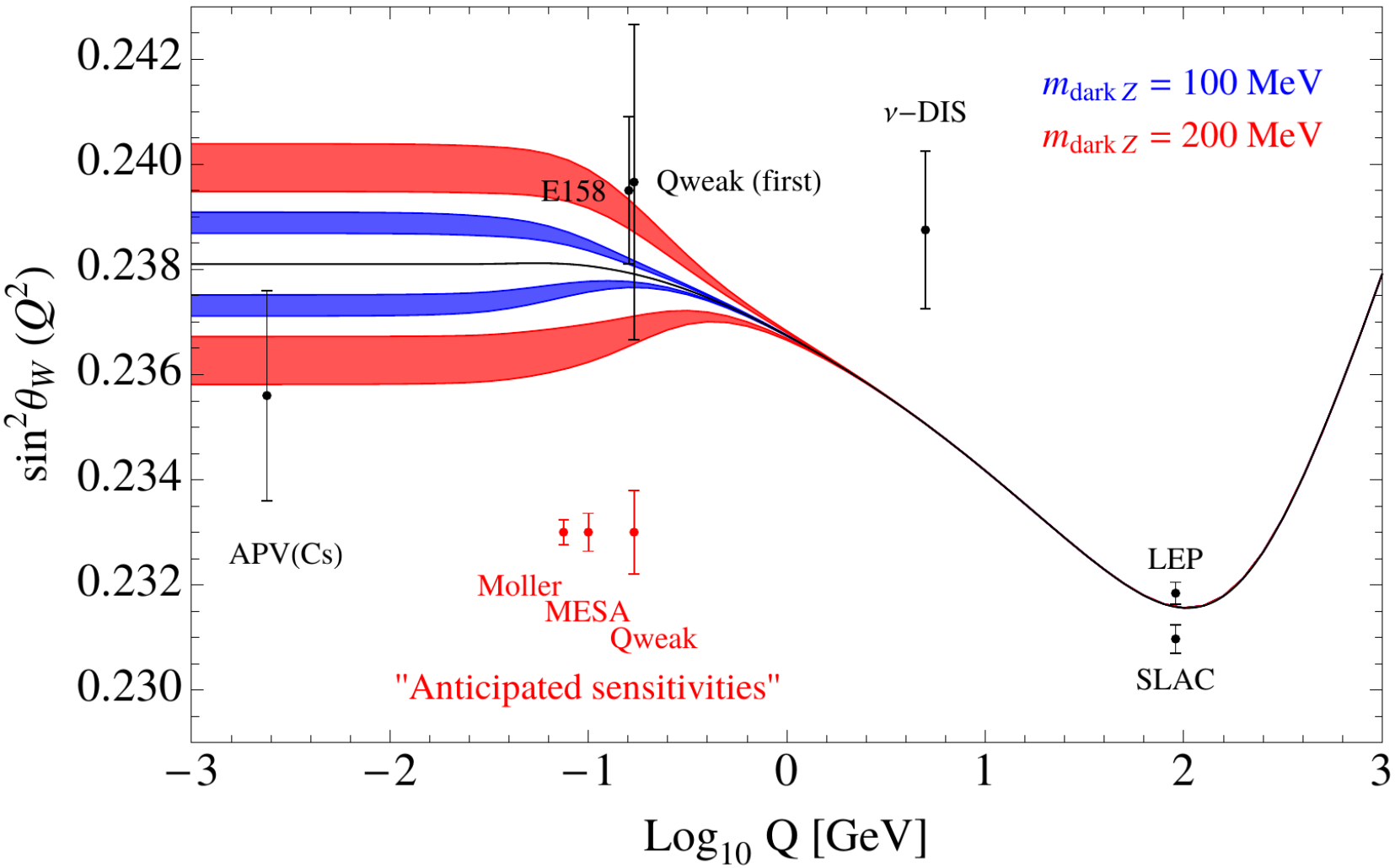
Summary

- 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

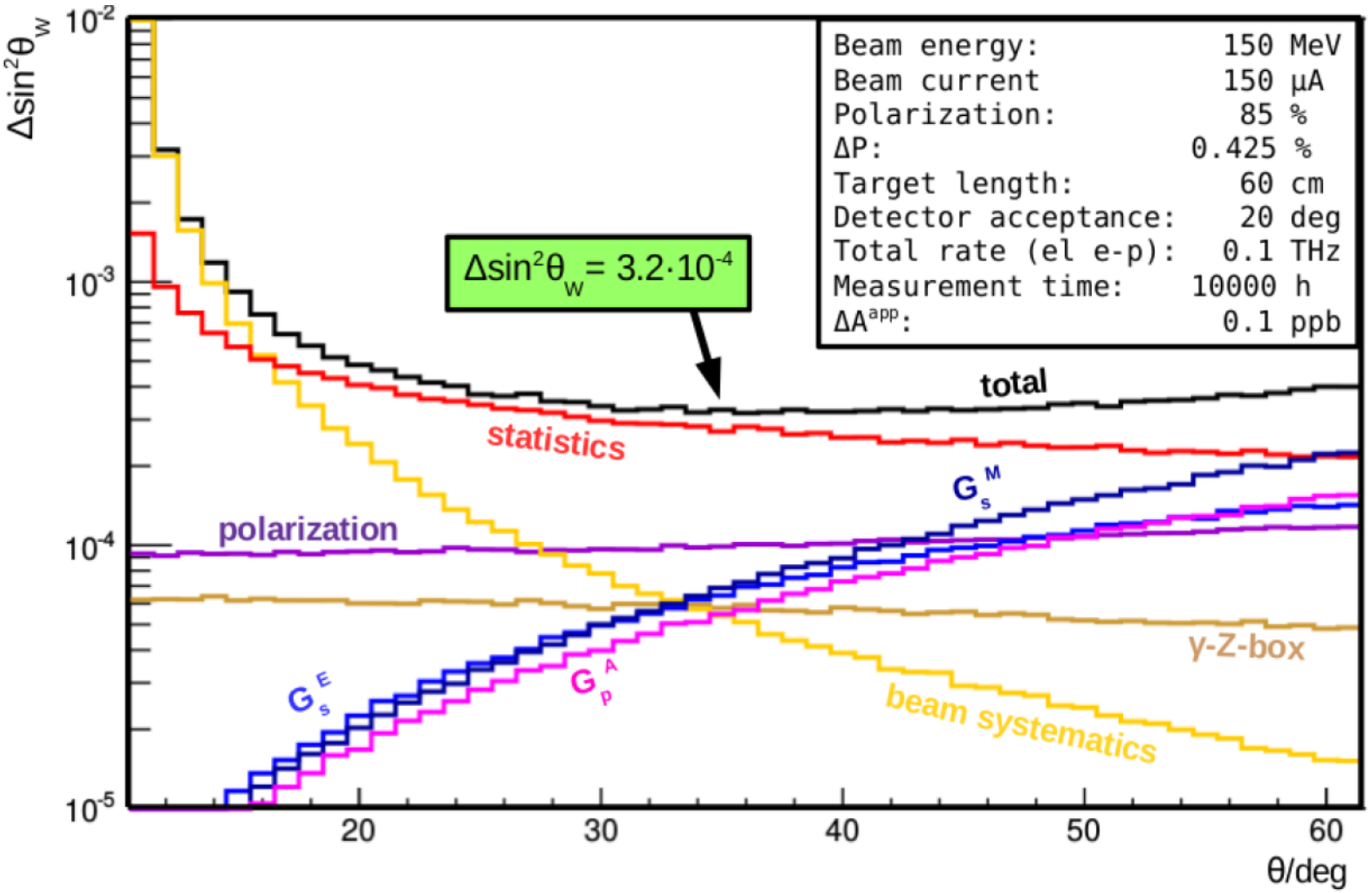


Backup:dark Z

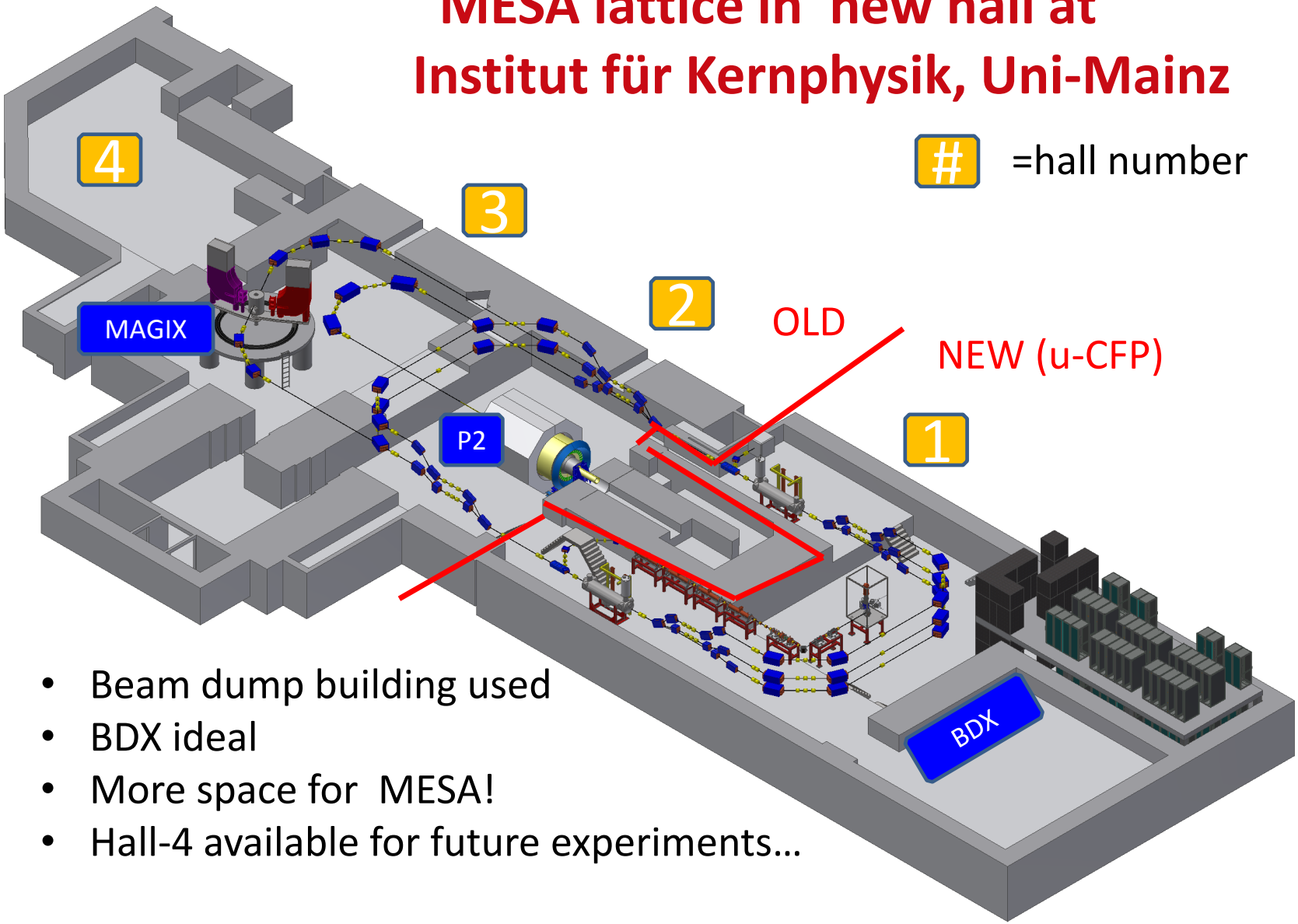


arXiv:1402.3620v2 , 21. Feb 2014

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

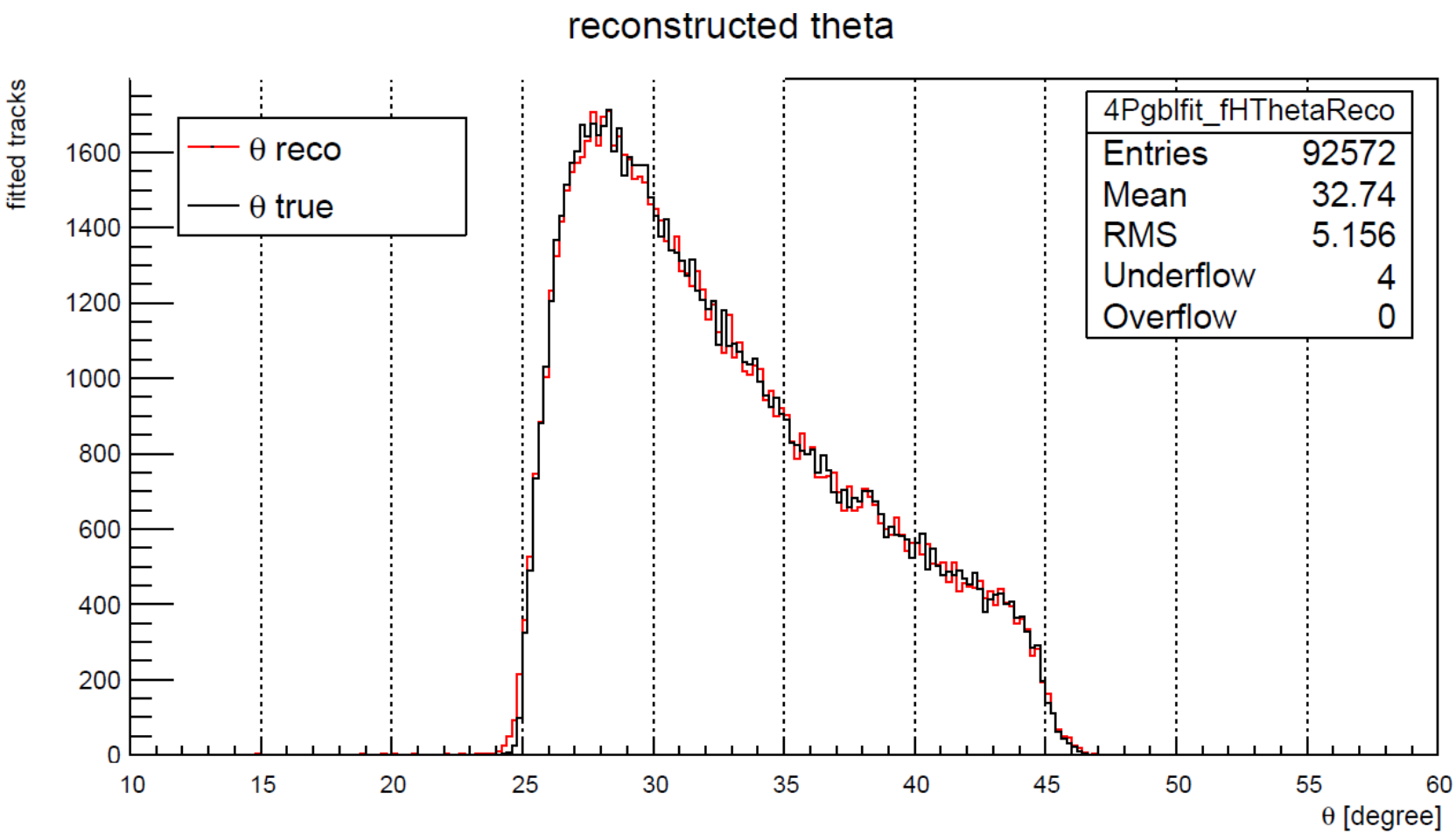


MESA lattice in new hall at Institut für Kernphysik, Uni-Mainz



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

Backup: Angle reconstruction



Backup: Momentum reconstruction