# The P2 Experiment

**DISCRETE 2022, Kongresshaus Baden-Baden - High Intensity Frontier**

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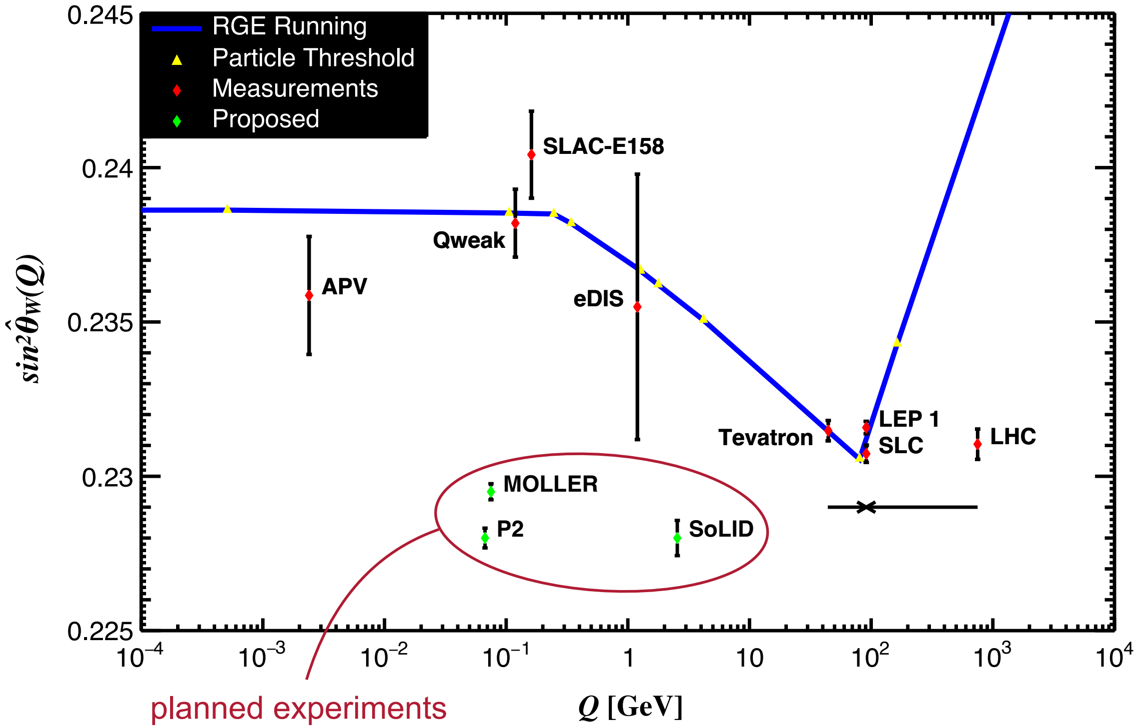
# PHYSICS GOAL AND MOTIVATION

- **Goal:** Determination of electroweak mixing angle $sin^2\theta_w$ ($s_w^2$) with high precision at low four-momentum transfer $Q^2 = 4.5 \cdot 10^{-3}$ $(\mathrm{GeV/c})^2$
- Standard Model (SM) prediction of running of $s_w^2$ fixed by Z-pole with high precision (SLAC, LEP, etc.)
  - ⇒ P2 will match precision of Z-pole measurements
  - ⇒ SM precision test
- Deviations from running hint towards new physics beyond the SM



planned experiments

# EXPERIMENTAL SETUP

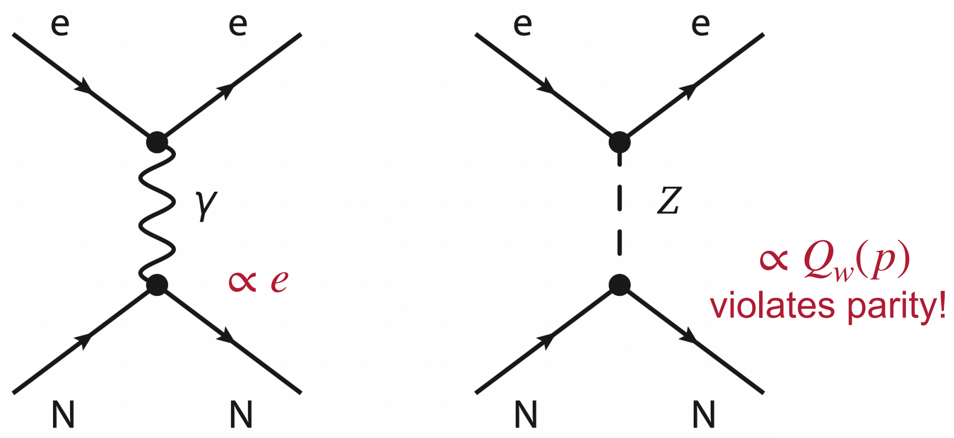
- Measurement of parity-violating asymmetry $A^{PV}$ in electron-proton scattering (at low $Q^2$)
- $A^{PV}$ caused by Z-exchange coupled to protons weak charge $Q_W(p)$:

$$A^{PV} = \frac{G_F Q^2}{4\pi\alpha_{em}\sqrt{2}}\left(Q_W(p) - F(E_i, Q^2)\right)$$

- Form factor $F(E_i,Q^2)$ accounts for proton's structure:

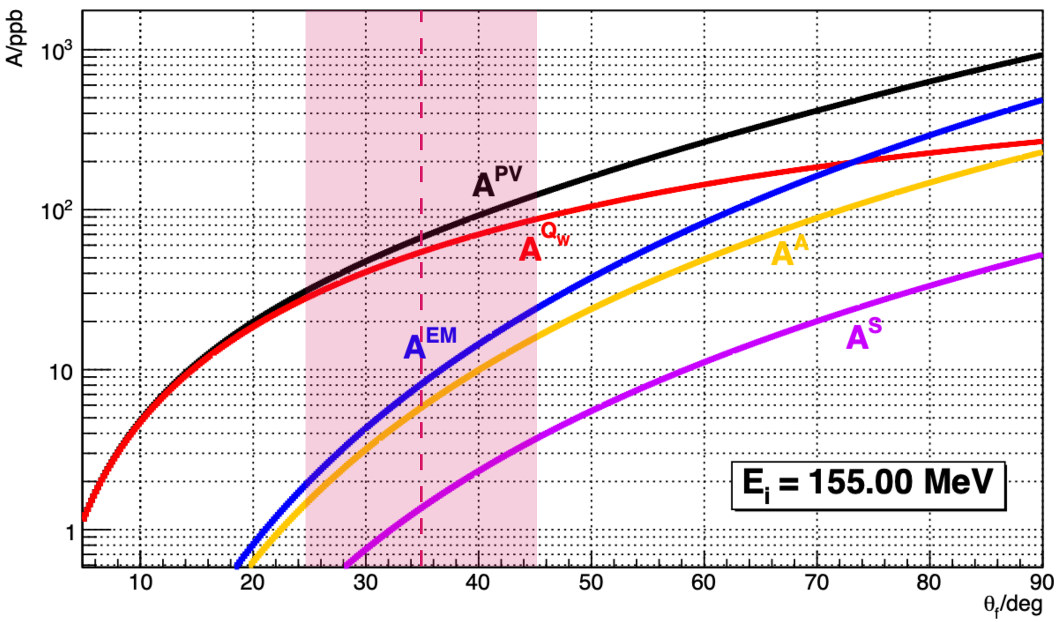
$$F(E_i, Q^2) = F^{EM}(E_i, Q^2) + F^{A}(E_i, Q^2) + F^{S}(E_i, Q^2)$$

- $A^{PV}$ dominated by $Q_W(p)$-contribution at at low $Q^2$ (i.e. low scattering angle $\theta_f$)



$\propto e$

$\propto Q_w(p)$
violates parity!



# PRECISION GOALS

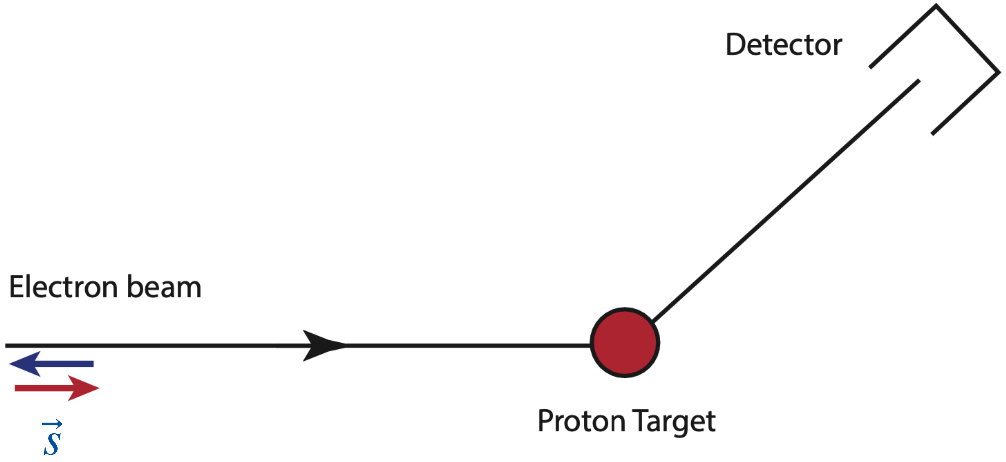
- Precision measurement of $A^{PV}$ gives precision $Q_W(p)$ and therefore precision $s_W^2$:

$$Q_W(p) = 1 - 4\, s_W^2 \quad \Rightarrow \quad \frac{\Delta s_W^2}{s_W^2} \approx 0.09\, \frac{\Delta Q_W(p)}{Q_W(p)}$$

- $A^{PV}$ is measured by *counting* electrons $N^+$ and $N^-$ with respect to beam helicity:

$$A^{PV} = \frac{N^+ - N^-}{N^+ + N^-}$$

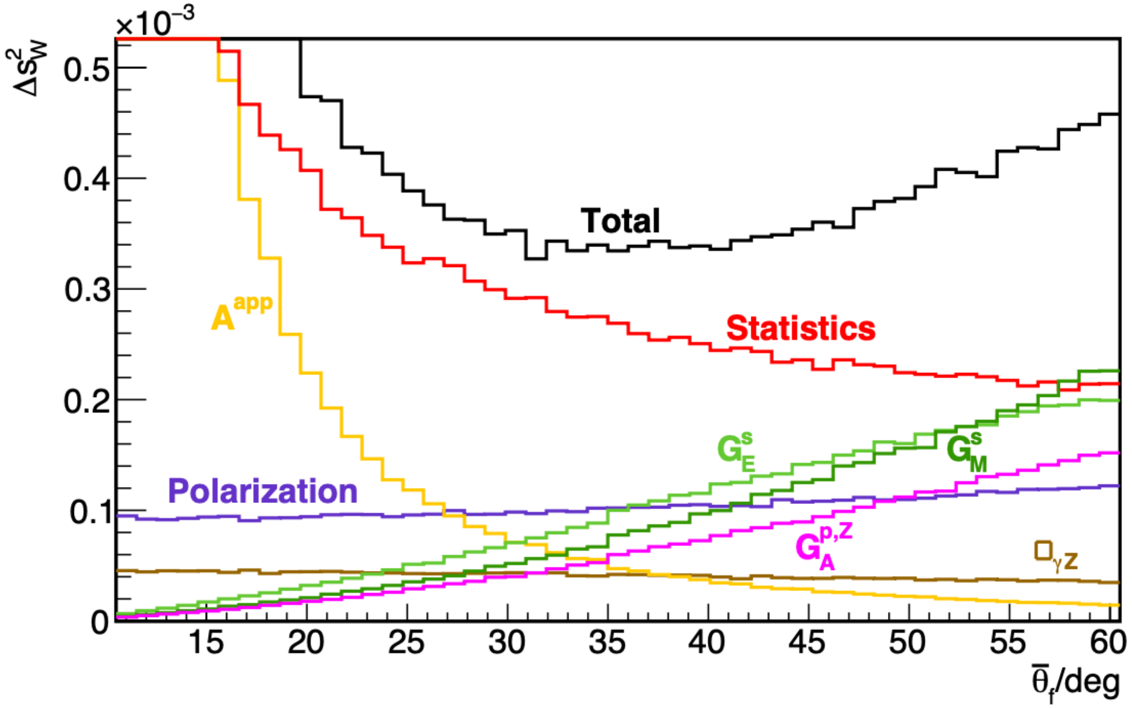
- To reach desired precision $\Delta s_W^2 / s_W^2 = 0.14\ \%$ need $A^{PV}$ at $1.5\ \%$
- Since $Q_W(p)$ is strongly suppressed in SM, $A^{PV}$ is very small ($A^{PV} \approx 40$ ppb $\Rightarrow \Delta A^{PV} \approx 0.6$ ppb)
- With $\Delta A^{PV} \sim 1/\sqrt{N} \Rightarrow$ Required number of scattered electrons: $N = \mathcal{O}(10^{18})$!



# PRECISION GOALS

- Additional sources of uncertainty: experimental setup, beam polarisation, form factors …
- Numeric, Monte-Carlo driven error analysis:
    - Beam energy $E_{beam} = 155\,\mathrm{MeV}$
    - Central scattering angle $\bar{\theta}_f = 35°$
    - Detector acceptance $\delta\theta_f = 20°$
    - Measurement time $T = 11000\,\mathrm{h}$

      ⇒ Achievable precision: $\underline{\Delta s_W^2 = 3.3 \cdot 10^{-4}\ (0.14\ \%)}$

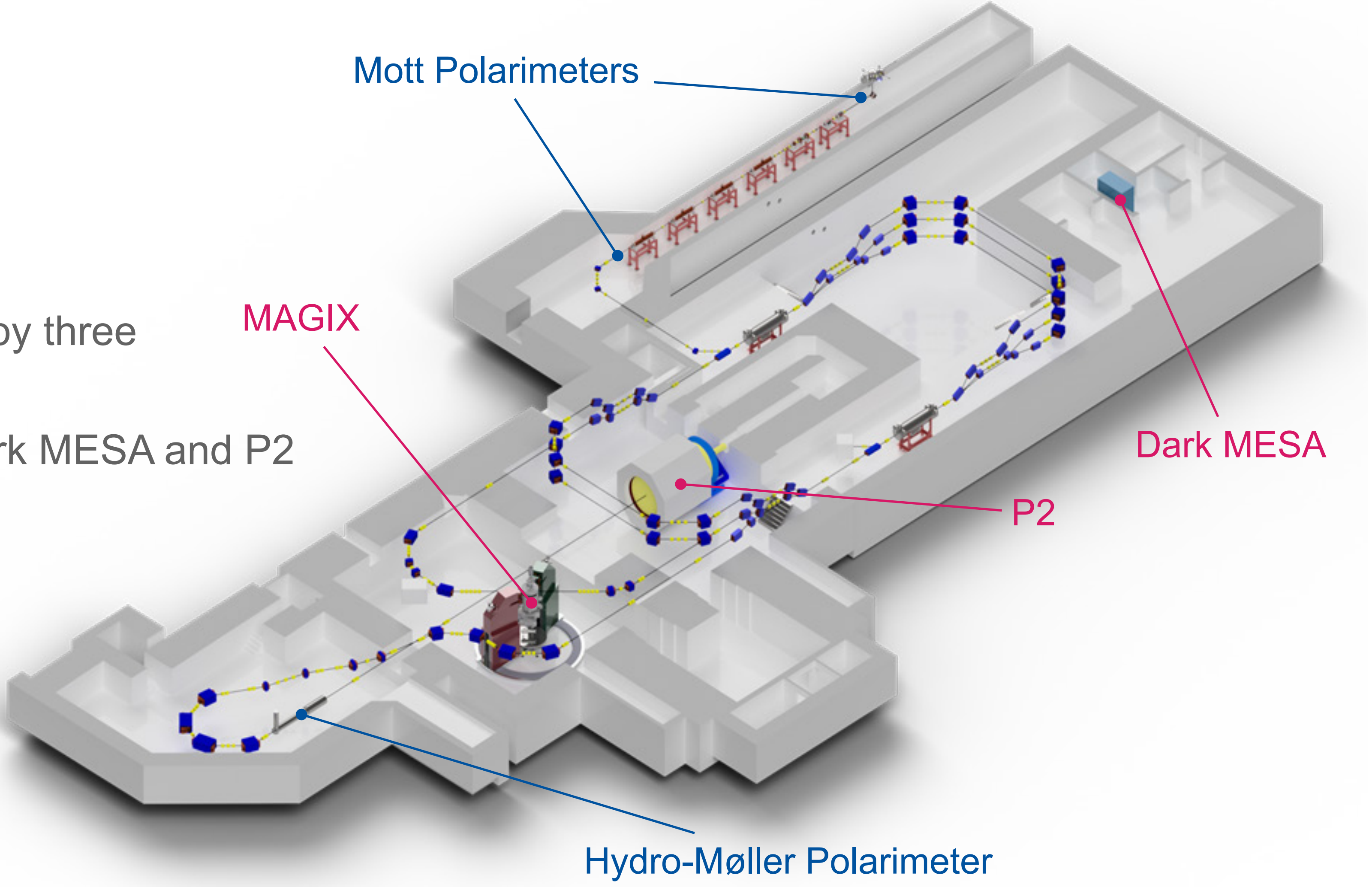


- With $N = \mathcal{O}(10^{18})$ electrons in $T = 11000\,\mathrm{h}$ ⇒ Expected electron rate $\mathcal{O}(0.1\,\mathrm{THz})$

  ⇒ Challenge for detector design; require integrating measurements

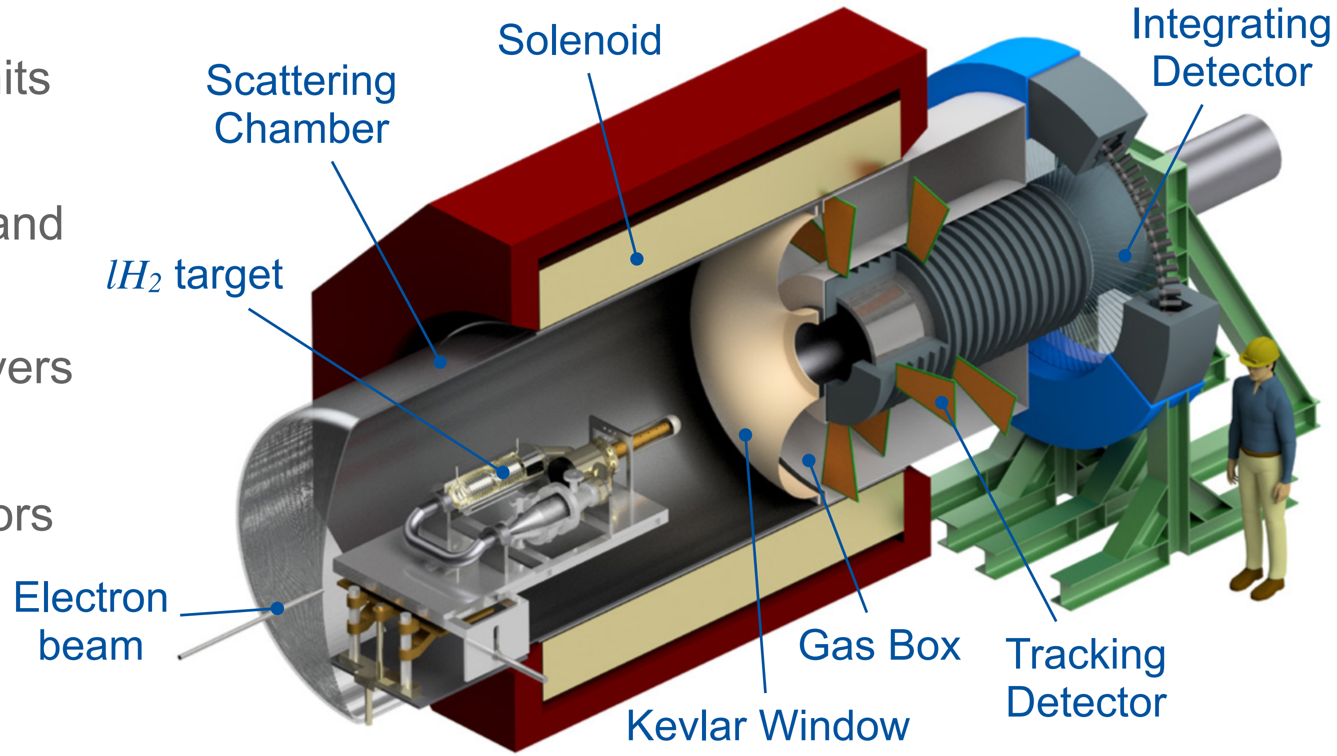
# MAINZ ENERGY-RECOVERY SUPERCONDUCTING ACCELERATOR (MESA)

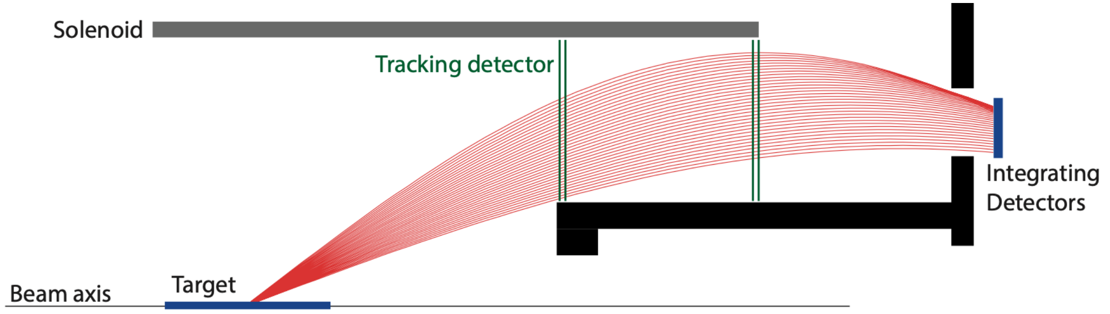
- Currently under construction in Mainz
- Provides polarised electron beam
    - $E_{beam} = 155$ MeV, $I_{beam} = 150$ μA
    - Helicity switched at $f_{sw} \sim 1$ kHz
- Beam polarisation closely monitored by three independent measurements
- Hosts three experiments: MAGIX, Dark MESA and P2
- Additional mode; energy recovery



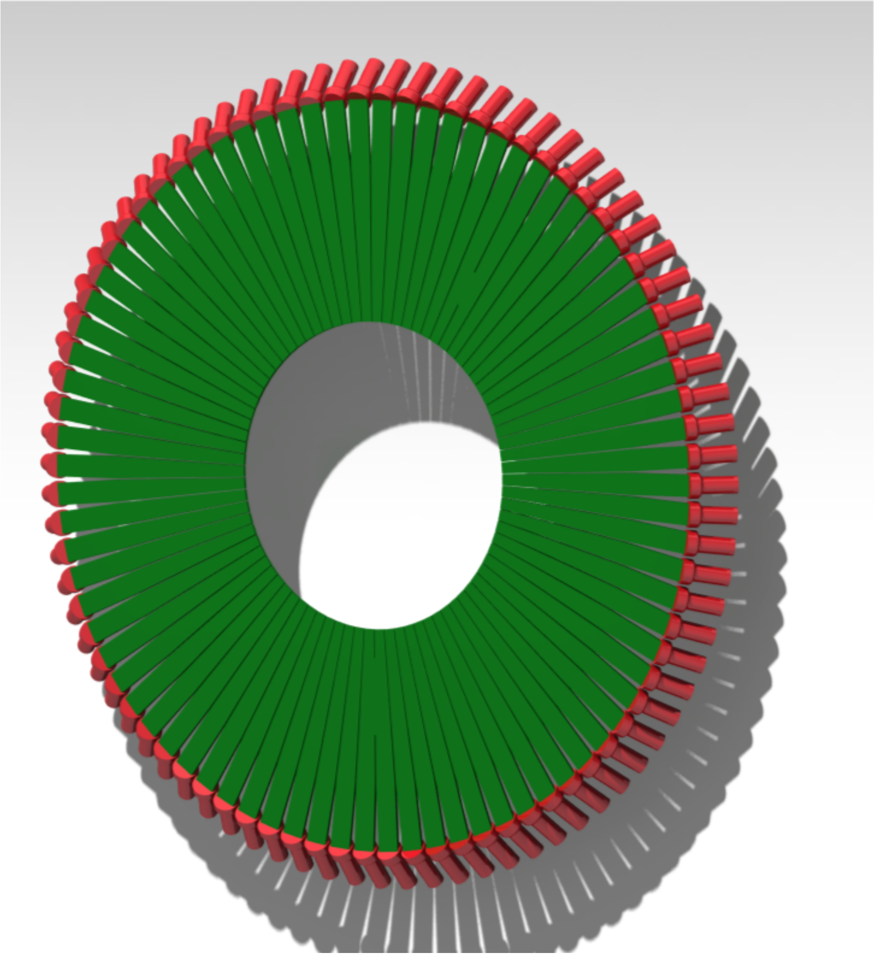
# THE P2 SPECTROMETER

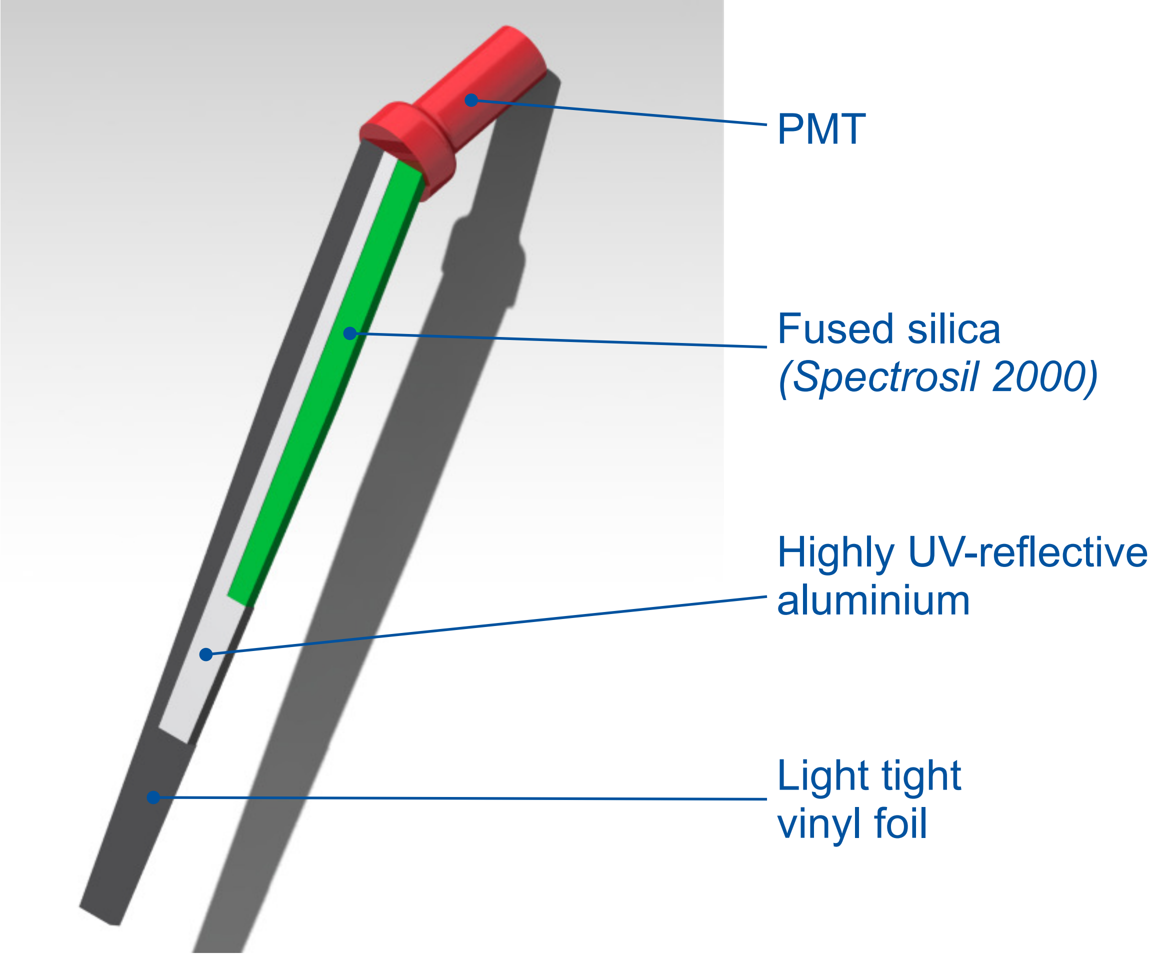
- Electron beam enters Scattering Chamber and hits $600\,\mathrm{mm}$ liquid Hydrogen target ($lH_2$)
- Kevlar Window separating Scattering Chamber and Helium-filled Gas Box
- Tracking detector: $8$ modules arranged in two layers each covering $15^\circ$ (no full azimuthal covering)
  - Each module has two layers of pixel detectors $\Rightarrow 4$ hits per track for track-fitting
- Enclosed by solenoid $\Rightarrow 0.6\,\mathrm{T}$ along beam axis
- Integrating Detectors: $82$ wedged silica bars read out by PMTs $\Rightarrow$ photocurrent $\propto$ no. of electrons





# INTEGRATING DETECTORS





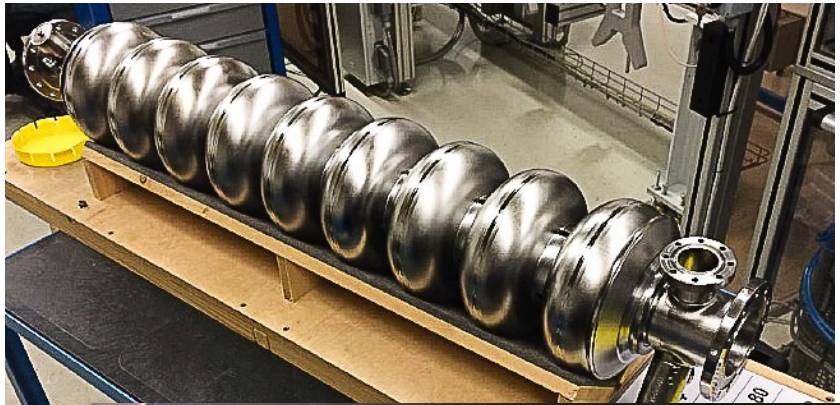
# SUMMARY AND OUTLOOK

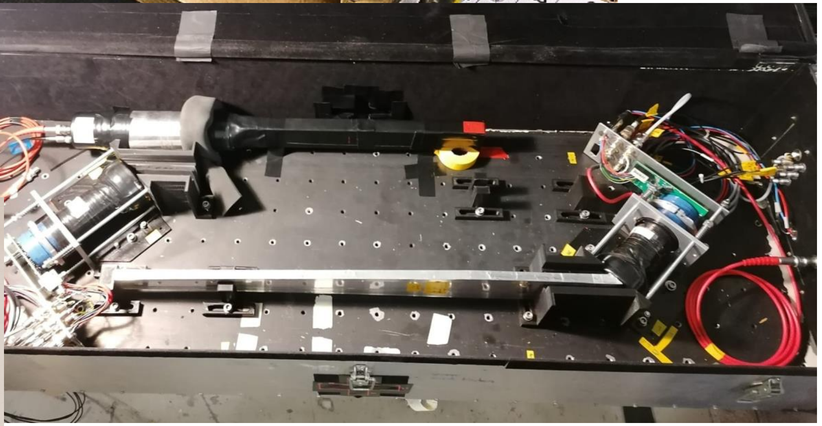
## SUMMARY

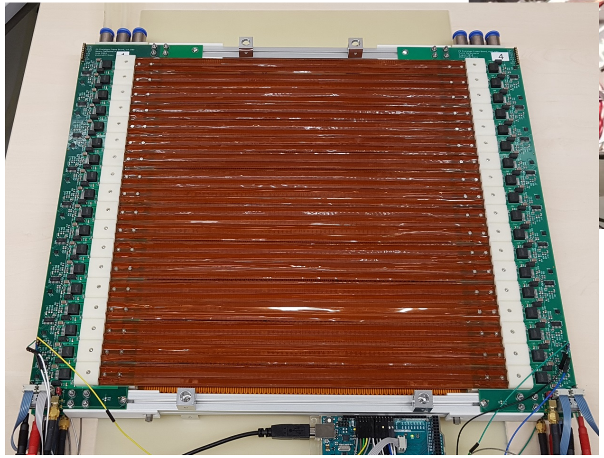
- P2 performs precision measurement of $s_w^2$ by measuring APV in $e^-p^+$ scattering
- $A^{PV}$ caused by protons weak charge $Q_w(p)$
- Require $11000\,\mathrm{h}$ measurement time with electron rate of $\mathcal{O}(10^{18})$

## OUTLOOK

- MESA civil engineering almost completed
- First accelerator cavities arrived
- Tracker and integrating detectors under development



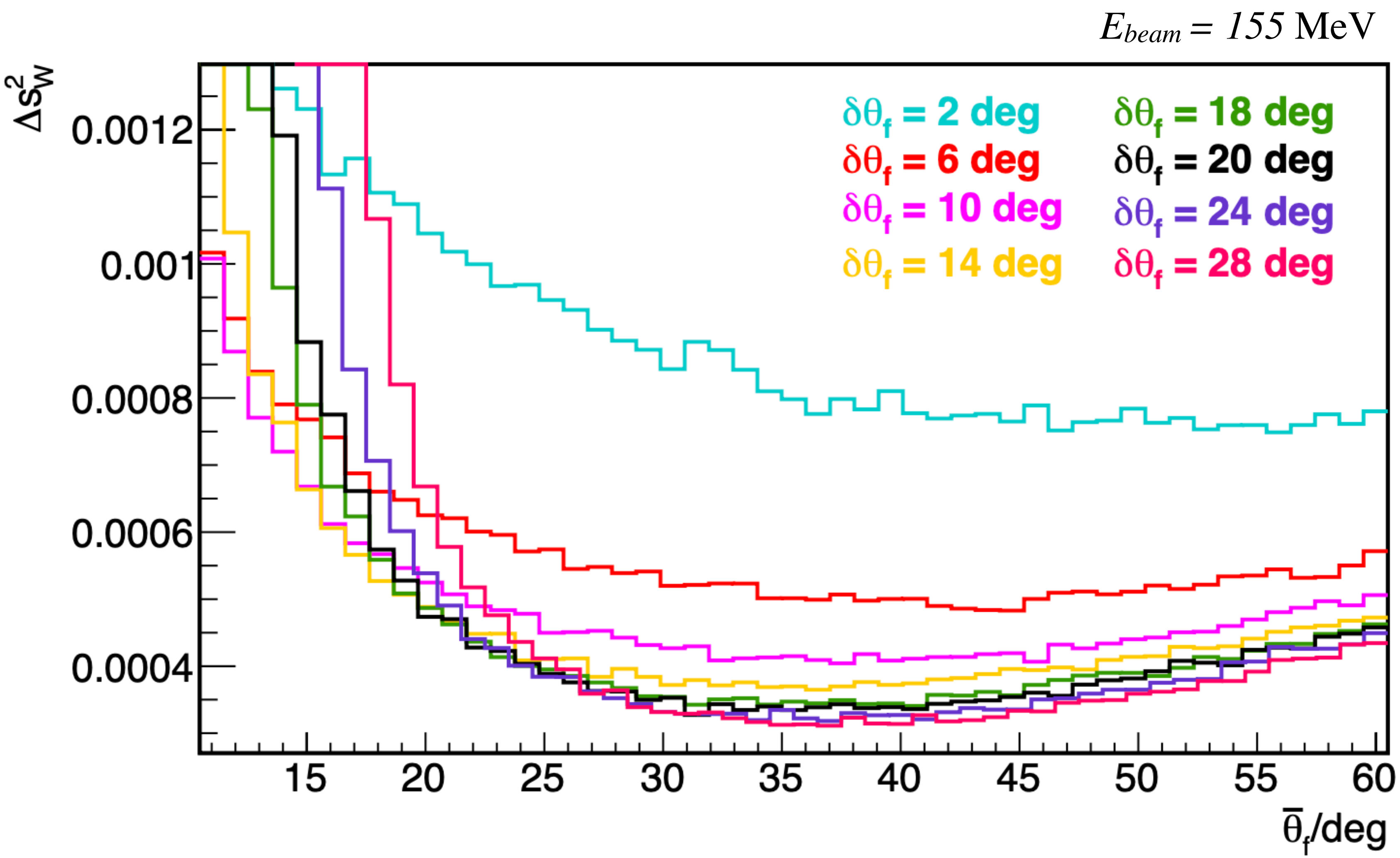




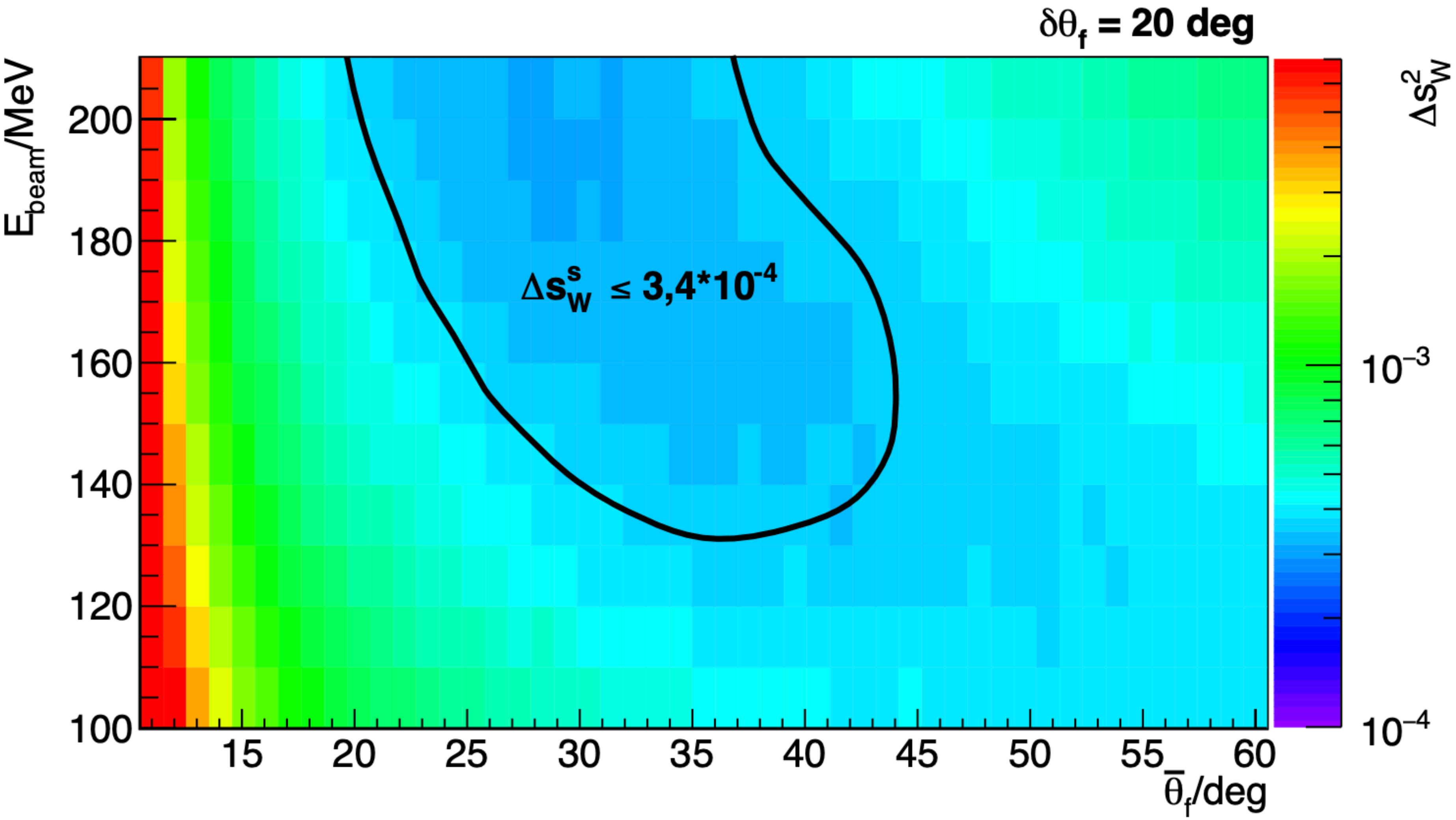
Thank you for your attention!

# BACKUP

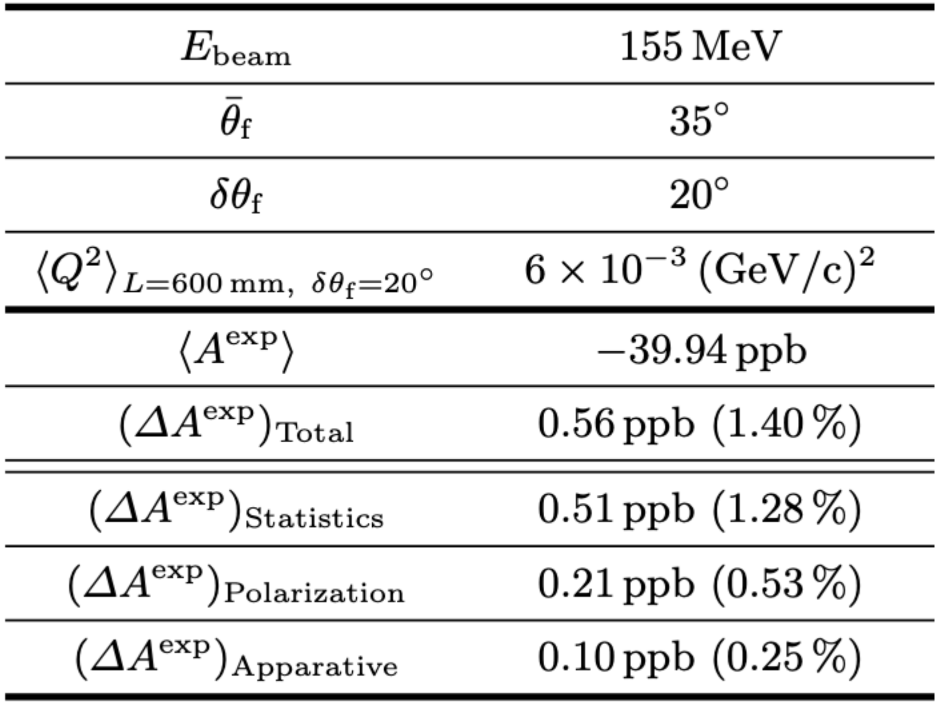
# CHOICE OF CENTRAL SCATTERING ANGLE



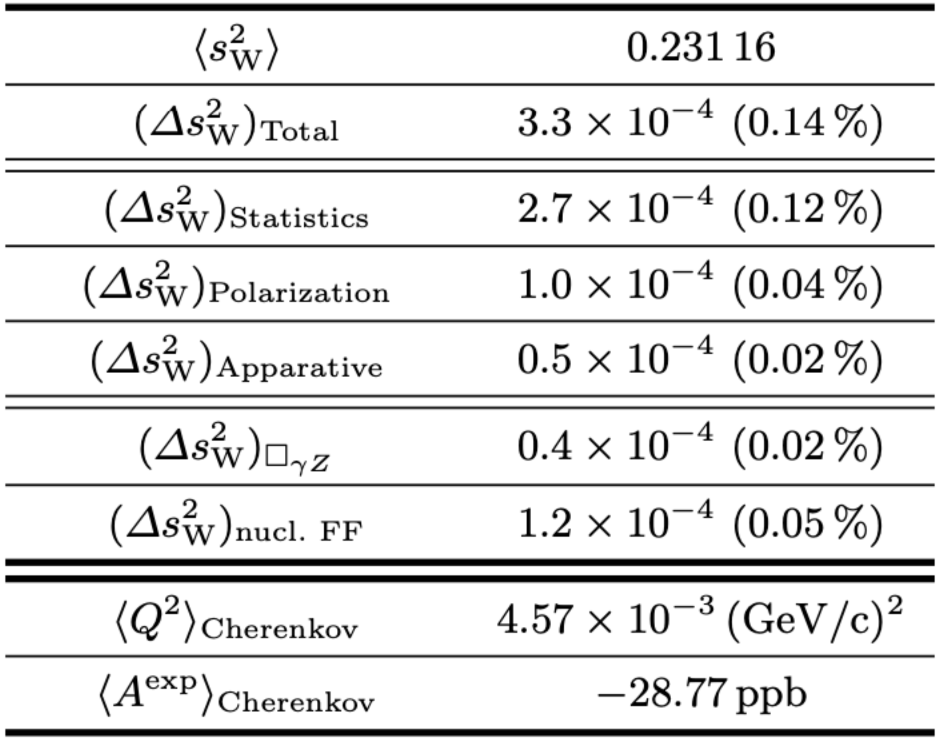
# CHOICE OF BEAM ENERGY



# P2 ERROR BUDGET



| | |
|---|---|
| $E_{\mathrm{beam}}$ | $155\,\mathrm{MeV}$ |
| $\bar{\theta}_{\mathrm{f}}$ | $35^\circ$ |
| $\delta\theta_{\mathrm{f}}$ | $20^\circ$ |
| $\langle Q^2 \rangle_{L=600\,\mathrm{mm},\ \delta\theta_{\mathrm{f}}=20^\circ}$ | $6 \times 10^{-3}\,(\mathrm{GeV/c})^2$ |
| $\langle A^{\mathrm{exp}} \rangle$ | $-39.94\,\mathrm{ppb}$ |
| $(\Delta A^{\mathrm{exp}})_{\mathrm{Total}}$ | $0.56\,\mathrm{ppb}\ (1.40\,\%)$ |
| $(\Delta A^{\mathrm{exp}})_{\mathrm{Statistics}}$ | $0.51\,\mathrm{ppb}\ (1.28\,\%)$ |
| $(\Delta A^{\mathrm{exp}})_{\mathrm{Polarization}}$ | $0.21\,\mathrm{ppb}\ (0.53\,\%)$ |
| $(\Delta A^{\mathrm{exp}})_{\mathrm{Apparative}}$ | $0.10\,\mathrm{ppb}\ (0.25\,\%)$ |



| | |
|---|---|
| $\langle s_{\mathrm{W}}^2 \rangle$ | $0.231\,16$ |
| $(\Delta s_{\mathrm{W}}^2)_{\mathrm{Total}}$ | $3.3 \times 10^{-4}\ (0.14\,\%)$ |
| $(\Delta s_{\mathrm{W}}^2)_{\mathrm{Statistics}}$ | $2.7 \times 10^{-4}\ (0.12\,\%)$ |
| $(\Delta s_{\mathrm{W}}^2)_{\mathrm{Polarization}}$ | $1.0 \times 10^{-4}\ (0.04\,\%)$ |
| $(\Delta s_{\mathrm{W}}^2)_{\mathrm{Apparative}}$ | $0.5 \times 10^{-4}\ (0.02\,\%)$ |
| $(\Delta s_{\mathrm{W}}^2)_{\square_{\gamma Z}}$ | $0.4 \times 10^{-4}\ (0.02\,\%)$ |
| $(\Delta s_{\mathrm{W}}^2)_{\mathrm{nucl.\ FF}}$ | $1.2 \times 10^{-4}\ (0.05\,\%)$ |
| $\langle Q^2 \rangle_{\mathrm{Cherenkov}}$ | $4.57 \times 10^{-3}\,(\mathrm{GeV/c})^2$ |
| $\langle A^{\mathrm{exp}} \rangle_{\mathrm{Cherenkov}}$ | $-28.77\,\mathrm{ppb}$ |