Project P2
The weak charge of the proton

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PS1C: Kathrin Gerz: “Measurement of Weinberg Angle via electron scattering from 12C-nuclei within the P2-experiment”

PS4C: David Balaguer Rios: “Measurement of the parity violating asymmetry on deuterium and the axial form factor”
Outline

- Brief introduction: A new high precision determination of the electroweak mixing angle

- Access to the weak mixing angle

- Achievable precision within P2

- Concept studies for the P2 experiment
The electroweak mixing angle

At tree level: \( Q_W (p) = 1 - 4 \cdot \sin^2(\theta_W) \)

\[
\Delta \sin^2(\theta_W) = 0.15 \%
\]
Access to the weak mixing angle
Elastic scattering of longitudinally polarized electrons off protons

Cross section: \( \sigma_{ep} \sim \frac{\vec{s} \cdot \vec{p}}{|\vec{s} \cdot \vec{p}|} \)

The weak interaction is parity violating:

\[ \sigma_{ep}^+ \neq \sigma_{ep}^- \]

Define parity violating asymmetry:

\[ A_{PV} = \frac{\sigma_{ep}^+ - \sigma_{ep}^-}{\sigma_{ep}^+ + \sigma_{ep}^-} \]
The parity violating asymmetry in elastic e-p-scattering

\[ A_{PV} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{-G_F Q^2}{4 \sqrt{2} \pi \alpha} (Q_W(p) - F(Q^2)) \]

Proton structure: \( F(Q^2) = F_{EM}(Q^2) + F_{Axial}(Q^2) + F_{Strange}(Q^2) \)

Weak charge of the proton: \( Q_W(p) = 1 - 4 \sin^2(\theta_W)(\mu) \)

Measuring \( A_{PV} \) at low momentum transfer \( Q^2 \) gives access to \( Q_W(p) \).
Why measure at low beam energies?

\[ Q^2 = 4E E' \sin^2(\theta_{lab}/2) \]

Low \( Q^2 \): Lower beam energy and larger angle or vice versa?

At low energies, the uncertainties of Gamma-Z-boxgraph contributions to \( \sin^2(\theta_W) \) are negligible.
Achievable precision within P2
Achievable precision @ P2

Proposed experimental conditions:
- Beam energy: 200 MeV
- Beam current: 150 μA
- Polarization: 85 % ± 0.5 %
- $\theta_{lab} = 20^\circ \pm 10^\circ$
- $\Delta \Phi = 2\pi$
- Target: 60 cm liquid hydrogen
- Measuring time: 10000 h

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q^2$</td>
<td>0.0029 GeV$^2$</td>
</tr>
<tr>
<td>$A_{phys}$</td>
<td>-20.25 ppb</td>
</tr>
<tr>
<td>$\Delta A_{tot}$</td>
<td>0.34 ppb (1.7 %)</td>
</tr>
<tr>
<td>$\Delta A_{stat}$</td>
<td>0.25 ppb (1.2 %)</td>
</tr>
<tr>
<td>$\Delta A_{sys}$</td>
<td>0.19 ppb (0.9 %)</td>
</tr>
<tr>
<td>Rate</td>
<td>$0.44 \times 10^{12}$ Hz</td>
</tr>
<tr>
<td>$\Delta \sin^2 \theta_W$ stat</td>
<td>$2.8 \times 10^{-4}$</td>
</tr>
<tr>
<td>$\Delta \sin^2 \theta_W$ tot</td>
<td>$3.6 \times 10^{-4}$ (0.15 %)</td>
</tr>
</tbody>
</table>
Achievable precision @ P2

Systematic variation of experimental conditions:

- Beam energy
- Central scattering angle
- Solid angle

All in all: 763 plots!
Achievable precision @ P2

Systematic variation of experimental conditions:

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Achievable precision @ P2

Systematic variation of experimental conditions:

- Beam energy
- Central scattering angle
- Solid angle

All in all: 763 plots!

$E = 200 \text{ MeV}, \Delta \theta = 6^\circ$

$\min(\Delta \sin^2(\theta_w))$
Achievable precision @ P2

Systematic variation of experimental conditions:

- Beam energy
- Central scattering angle
- Solid angle

All in all: 763 plots!

$E = 200\text{ MeV}, \Delta \theta = 8^\circ$

$\sigma(\sin^2(\theta_W))_{\text{min}}$
Achievable precision @ P2

Systematic variation of experimental conditions:

- Beam energy
- Central scattering angle
- Solid angle

All in all: 763 plots!
Achievable precision @ P2

Systematic variation of experimental conditions:

- Beam energy
- Central scattering angle
- Solid angle

All in all: 763 plots!
Achievable precision @ P2

Systematic variation of experimental conditions:

- Beam energy
- Central scattering angle
- Solid angle

All in all: 763 plots!

\[ E = 200 \text{ MeV}, \Delta \theta = 14^\circ \]
Achievable precision @ P2

Systematic variation of experimental conditions:

- Beam energy
- Central scattering angle
- Solid angle

All in all: 763 plots!

$E = 200\text{ MeV}, \Delta \theta = 16^\circ$

$\sigma(\sin^2(\theta_W))$
Achievable precision @ P2

Systematic variation of experimental conditions:

- Beam energy
- Central scattering angle
- Solid angle

All in all: 763 plots!
Achievable precision @ P2

Systematic variation of experimental conditions:

- Beam energy
- Central scattering angle
- Solid angle

\[ \sigma(\sin^2(\theta_W)) \]

\[ E = 250 \text{ MeV}, \Delta \theta = 20^\circ \]

All in all: 763 plots!
Extensive scan of $\Delta \left( \sin^2(\theta_W) \right)$ in $(E, \theta, \Delta \theta)$

Broad energy region with $3 \cdot 10^{-4} \leq \Delta \left( \sin^2(\theta_W) \right) \leq 4 \cdot 10^{-4}$

$(E=150 \text{ MeV}, \theta=24^\circ) \Leftrightarrow (E=200 \text{ MeV}, \theta=20^\circ)$

"Analyzing power not averaged over solid angle"
"Analyzing power averaged over solid angle"

Influence of detector segmentation

Possible gain of factor 0.8 in precision!
Concept studies for the P2 experiment with Geant4 & ROOT
MESA and P2: Setup in the MAMI accelerator facility

New PV experiment: P2

New superconducting accelerator: MESA

Beam current: 150 µA, target length: 60 cm liquid hydrogen

- dealing with high rates ~ 0.5 THz (el. e-p scattering)
- integrating measurement
- good separation from background (Moeller, Bremsstrahlung) needed
Weapon of choice: Solenoid or Toroid?

**Solenoid:**
- Full azimuthal coverage
- Compact setup
- Superconducting coils

**Toroid:**
- Loss of ~50% solid angle → double measurement time
- Larger setup
- Copper coils

Feasibility study with Geant4 and ROOT

Beam-target-interaction: Initial state generators

Initial state analysis:
- Particle types
- Process
- Position
- Energy
- Momentum direction

Density distribution of elastic vertices with electron energies between 180 MeV and 200 MeV

Calculate realistic vertex distributions:
- el. e-p-scattering
- Moeller-scattering
- e-Bremsstrahlung

E = 200 MeV
Target length = 60 cm

Energy distribution of elastic vertices
For detector simulation: Validation of final state generators

Event generators for detector simulation:

- el. e-p scattering
- Moeller scattering
- e-Bremsstrahlung

- Can use vertex distributions
- Generate events w.r.t preset solid angle
Magnetic fieldmaps

**ZEUS-like solenoid:**
- Biot-Savart calculation
- Coil radius ~ 1 m
- Coil length ~ 2.4 m
- $B = 1.8 \, \text{T}$

**QTOR-like toroid:**
- Biot-Savart calculation
- 8 coils
- Coil length ~ 3.6 m
- $B = 0.4 \, \text{T}$
Systematic raytrace scans

For both solenoid and toroid: Raytrace scans varying

- Target position
- Target length (30 cm & 60 cm)
- Magnetic field strength
- Beam energy
- Solid angle

Projection of electron trajectories
Toroid simulation: Raytraces

- $B = 0.04\ T$
- $E = 200\ MeV$
- Target length = 60 cm
- Target center @ -3250 mm
Toroid simulation: Raytraces

- $B = 0.08 \, T$
- $E = 200 \, MeV$
- Target length = 60 cm
- Target center @ -3250 mm

QTOR
$I = 0.20 * I_{QTOR}$
Target center @ $z = -3250 \, mm$
$E_{beam} = 200 \, MeV$

e-p$-scattering: $\theta \in [10 \, deg, 30 \, deg]$
Moeller-scattering: $\theta \in [0 \, deg, 5 \, deg]$
Moeller-scattering: $\theta \in [10 \, deg, 30 \, deg]$
$B = 0.12 \text{T}$

$E = 200 \text{ MeV}$

Target length = 60 cm

Target center @ -3250 mm

Toroid simulation: Raytraces

- $I = 0.30 I_{\text{QTOR}}$
- Target center @ $z = -3250 \text{ mm}$
- $E_{\text{beam}} = 200 \text{ MeV}$
- $e-p$-scattering: $\theta \in [10 \text{ deg}, 30 \text{ deg}]$
- Moeller-scattering: $\theta \in [0 \text{ deg}, 5 \text{ deg}]$
- Moeller-scattering: $\theta \in [10 \text{ deg}, 30 \text{ deg}]$
Toroid simulation: Raytraces

- $B = 0.16 \, \text{T}$
- $E = 200 \, \text{MeV}$
- Target length = 60 cm
- Target center @ -3250 mm

QTOR

$I = 0.40 \cdot I_{\text{QTOR}}$

- $E_{\text{beam}} = 200 \, \text{MeV}$
- e-p-scattering: $\theta \in [10 \, \text{deg}, 30 \, \text{deg}]$
- Möller-scattering: $\theta \in [0 \, \text{deg}, 5 \, \text{deg}]$
- Möller-scattering: $\theta \in [10 \, \text{deg}, 30 \, \text{deg}]$
Toroid simulation: Raytraces

- $B = 0.20 \, T$
- $E = 200 \, MeV$
- Target length = 60 cm
- Target center @ -3250 mm

QTOR

- $l = 0.50 \cdot l_{QTOR}$
- Target center @ $z = -3250 \, mm$
- $E_{beam} = 200 \, MeV$
- $e$-$p$-scattering: $\theta \in [10 \, \text{deg}, 30 \, \text{deg}]$
- Moeller-scattering: $\theta \in [0 \, \text{deg}, 5 \, \text{deg}]$
- Moeller-scattering: $\theta \in [10 \, \text{deg}, 30 \, \text{deg}]$
Toroid simulation: Raytraces

- $B = 0.24 \, \text{T}$
- $E = 200 \, \text{MeV}$
- Target length = 60 cm
- Target center @ -3250 mm

QTOR

$I = 0.60 \cdot I_{\text{QTOR}}$

Target center @ $z = -3250 \, \text{mm}$

$E_{\text{beam}} = 200 \, \text{MeV}$

e-p-scattering: $\theta \in [10 \, \text{deg}, 30 \, \text{deg}]$

Moeller-scattering: $\theta \in [0 \, \text{deg}, 5 \, \text{deg}]$

Moeller-scattering: $\theta \in [10 \, \text{deg}, 30 \, \text{deg}]$
Toroid simulation: Raytraces

- $B = 0.28 \, \text{T}$
- $E = 200 \, \text{MeV}$
- Target length = 60 cm
- Target center @ -3250 mm

QTOR
$I = 0.70 \cdot I_{QTOR}$
Target center @ $z = -3250 \, \text{mm}$
$E_{\text{beam}} = 200 \, \text{MeV}$
e-p-scattering: $\theta \in [10 \, \text{deg}, 30 \, \text{deg}]$
Moeller-scattering: $\theta \in [0 \, \text{deg}, 5 \, \text{deg}]$
Moeller-scattering: $\theta \in [10 \, \text{deg}, 30 \, \text{deg}]$
Toroid simulation: Raytraces

- \( B = 0.32 \text{ T} \)
- \( E = 200 \text{ MeV} \)
- Target length = 60 cm
- Target center @ -3250 mm

\[ I = 0.80 \cdot I_{QTOR} \]

Target center \( z = -3250 \text{ mm} \)

\( E_{beam} = 200 \text{ MeV} \)

- e-p-scattering: \( \theta \in [10 \text{ deg}, 30 \text{ deg}] \)
- Moeller-scattering: \( \theta \in [0 \text{ deg}, 5 \text{ deg}] \)
- Moeller-scattering: \( \theta \in [10 \text{ deg}, 30 \text{ deg}] \)
Toroid simulation: Raytraces

- \( B = 0.36 \, T \)
- \( E = 200 \, \text{MeV} \)
- Target length = 60 cm
- Target center @ -3250 mm

\( I = 0.90I_{\text{QTOR}} \)
\[ \text{Target center @ } z = -3250 \, \text{mm} \]
\( E_{\text{beam}} = 200 \, \text{MeV} \)
\[ \text{e-p-scattering: } \theta \in [10 \, \text{deg}, 30 \, \text{deg}] \]
\[ \text{Moeller-scattering: } \theta \in [0 \, \text{deg}, 5 \, \text{deg}] \]
\[ \text{Moeller-scattering: } \theta \in [10 \, \text{deg}, 30 \, \text{deg}] \]
Toroid simulation: Raytraces

- $B = 0.40\ T$
- $E = 200\ MeV$
- Target length = 60 cm
- Target center @ -3250 mm

**QTOR**

$I = 1.00^*I_{QTOR}$

- Target center @ $z = -3250\ mm$
- $E_{\text{beam}} = 200\ MeV$

- e-p-scattering: $\theta \in [10\ deg, 30\ deg]$
- Moeller-scattering: $\theta \in [0\ deg, 5\ deg]$
- Moeller-scattering: $\theta \in [10\ deg, 30\ deg]$
Toroid simulation: Raytraces

- $B = 0.40$ T
- $E = 200$ MeV
- Target length = 60 cm
- Target center @ -3250 mm

QTOR
- $I = 1.00 I_{QTOR}$
- Target center @ $z = -3250$ mm
- $E_{beam} = 200$ MeV
- e-p-scattering: $\theta \in [10 \text{ deg}, 30 \text{ deg}]$
- Moeller-scattering: $\theta \in [0 \text{ deg}, 5 \text{ deg}]$
- Moeller-scattering: $\theta \in [10 \text{ deg}, 30 \text{ deg}]$
**Toroid full simulation**

- el. e-p scattering
- Moeller scattering in $[0^\circ, 5^\circ]$ (red)
- Moeller scattering in $[10^\circ, 30^\circ]$ (blue)

**Simple tracking detector:**
- Consists of vacuum
- Analyses particles that fly through

**Rate distribution of tracking detector**

- $E = 200$ MeV
- Beam current = 150 µA
- Target length = 60 cm

**Full simulation:**
- Flat vertex distribution
- Energy loss in target volume after event generation
- Flat polar angle distribution, weightening in histogram with cross section
**Simple tracking detector:**
- Consists of vacuum
- Analyses particles that fly through

**Toroid full simulation**

- **Flat vertex distribution**
- **Energy loss in target volume after event generation**
- **Flat polar angle distribution, weightening in histogram with cross section**

**Rate distribution of tracking detector**

- $E = 200$ MeV
- $B = 0.4$ T
- Beam current = $150 \mu A$
- Target length = $60$ cm
**Simple tracking detector:**
- Consists of vacuum
- Analyses particles that fly through

**Rate distribution of tracking detector**

- \( E = 200 \text{ MeV} \)
- \( B = 0.4 \text{ T} \)
- Beam current = 150 \( \mu \text{A} \)
- Target length = 60 cm

**Full simulation:**
- Flat vertex distribution
- Energy loss in target volume after event generation
- Flat polar angle distribution, weightening in histogram with cross section
Simple tracking detector:
- Consists of vacuum
- Analyses particles that fly through

Rate distribution of tracking detector

- \( E = 200 \text{ MeV} \)
- \( B = 0.4 \text{ T} \)
- Beam current = 150 \( \mu \text{A} \)
- Target length = 60 cm

Full simulation:
- Flat vertex distribution
- Energy loss in target volume after event generation
- Flat polar angle distribution, weightening in histogram with cross section


Simple tracking detector:
- Consists of vacuum
- Analyses particles that fly through

**Toroid full simulation**

- Dominated by el. e-p scattering
- Moeller scattering in $[0^\circ, 5^\circ]$  
- Moeller scattering in $[10^\circ, 30^\circ]$

**Rate distribution of tracking detector**
- $E = 200$ MeV  
- Beam current = 150 µA  
- Target length = 60 cm

- e-, el. e-p scattering, $[10^\circ, 30^\circ]$  
- e-, el. e-p scattering, $[1^\circ, 75^\circ]$  
- e-, background  
- e+  
- γ  
- p

Dominated by el. e-p scattering $\theta \in [10^\circ, 30^\circ]$
Solenoid simulation: Raytraces

- **B = 0.00 T**
- **E = 200 MeV**
- **Target length = 30 cm**
- **Target center @ -1500 mm**

**ZEUS**

- $I = 0.00^\ast I_{ZEUS}$
- Target center @ $z = -1500$ mm
- $E_{\text{beam}} = 200$ MeV
- e-p-scattering: $\theta \in [10 \text{ deg}, 30 \text{ deg}]$
- Moeller-scattering: $\theta \in [0 \text{ deg}, 5 \text{ deg}]$
- Moeller-scattering: $\theta \in [10 \text{ deg}, 30 \text{ deg}]$
**Solenoid simulation: Raytraces**

- **B** = 0.18 T
- **E** = 200 MeV
- **Target length** = 30 cm
- **Target center** @ -1500 mm

**ZEUS**

\[ I = 0.10 \times I_{ZEUS} \]

Target center @ \( z = -1500 \) mm

- **E\_beam** = 200 MeV
- e-p-scattering: \( \theta \in [10 \text{ deg}, 30 \text{ deg}] \)
- Moeller-scattering: \( \theta \in [0 \text{ deg}, 5 \text{ deg}] \)
- Moeller-scattering: \( \theta \in [10 \text{ deg}, 30 \text{ deg}] \)
Solenoid simulation: Raytraces

- $B = 0.36$ T
- $E = 200$ MeV
- Target length = 30 cm
- Target center @ -1500 mm
Solenoid simulation: Raytraces

- $B = 0.54$ T
- $E = 200$ MeV
- Target length = 30 cm
- Target center @ -1500 mm
Solenoid simulation: Raytraces

- $B = 0.72\, \text{T}$
- $E = 200\, \text{MeV}$
- Target length = 30 cm
- Target center @ -1500 mm

**ZEUS**
- $I = 0.40 I_{\text{ZEUS}}$
- Target center @ $z = -1500\, \text{mm}$
- $E_{\text{beam}} = 200\, \text{MeV}$
- $\theta \in [10\, \text{deg}, 30\, \text{deg}]$
- Moeller-scattering: $\theta \in [0\, \text{deg}, 5\, \text{deg}]$
- Moeller-scattering: $\theta \in [10\, \text{deg}, 30\, \text{deg}]$
Solenoid simulation: Raytraces

- $B = 0.90$ T
- $E = 200$ MeV
- Target length = 30 cm
- Target center @ -1500 mm

ZEUS
- $I = 0.50 I_{ZEUS}$
- Target center @ $z = -1500$ mm
- $E_{beam} = 200$ MeV
- e-p-scattering: $\theta \in [10$ deg, $30$ deg]
- Möller-scattering: $\theta \in [0$ deg, $5$ deg]
- Möller-scattering: $\theta \in [10$ deg, $30$ deg]
Solenoid simulation: Raytraces

- $B = 1.08$ T
- $E = 200$ MeV
- Target length = 30 cm
- Target center @ -1500 mm

ZEUS
$I = 0.60 I_{ZEUS}$
Target center @ $z = -1500$ mm
$E_{beam} = 200$ MeV
$e$-$p$-scattering: $\theta \in [10 \text{ deg}, 30 \text{ deg}]$
Moeller-scattering: $\theta \in [0 \text{ deg}, 5 \text{ deg}]$
Moeller-scattering: $\theta \in [10 \text{ deg}, 30 \text{ deg}]$
Solenoid simulation: Raytraces

- $B = 1.26 \, T$
- $E = 200 \, \text{MeV}$
- Target length = 30 cm
- Target center @ -1500 mm

ZEUS

$I = 0.70 \, I_{\text{ZEUS}}$

Target center @ $z = -1500 \, \text{mm}$

$E_{\text{beam}} = 200 \, \text{MeV}$

e-p-scattering: $\theta \in [10 \, \text{deg}, 30 \, \text{deg}]$

Moeller-scattering: $\theta \in [0 \, \text{deg}, 5 \, \text{deg}]$

Moeller-scattering: $\theta \in [10 \, \text{deg}, 30 \, \text{deg}]$
Solenoid simulation: Raytraces

- $B = 1.26 \, T$
- $E = 200 \, MeV$
- Target length = 30 cm
- Target center @ -1500 mm

ZEUS
- $I = 0.70 I_{ZEUS}$
- Target center @ $z = -1500 \, mm$
- $E_{beam} = 200 \, MeV$
- e-p-scattering: $\theta \in [10 \, deg, 30 \, deg]$
- Moeller-scattering: $\theta \in [0 \, deg, 5 \, deg]$
- Moeller-scattering: $\theta \in [10 \, deg, 30 \, deg]$

shielding
**Solenoid full simulation**

- **Flat vertex distribution**
- **Energy loss in target volume after event generation**
- **Flat polar angle distribution**, weightening in histogram with cross section

**Simple tracking detector:**
- Consists of vacuum
- Analyses particles that fly through

**Rate distribution in tracking detector**

- **E = 200 MeV**
- **B = 1.26 T**
- **Beam current = 150 µA**
- **Target length = 30 cm**

**Full simulation:**
- Flat vertex distribution
- Energy loss in target volume after event generation
- Flat polar angle distribution, weightening in histogram with cross section
Solenoid full simulation

- Rate distribution in tracking detector
  - $E = 200$ MeV
  - Beam current = 150 $\mu$A
  - $B = 1.26$ T
  - Target length = 30 cm

- Simple tracking detector:
  - Consists of vacuum
  - Analyses particles that fly through

- Full simulation:
  - Flat vertex distribution
  - Energy loss in target volume after event generation
  - Flat polar angle distribution, weightening in histogram with cross section
Solenoid full simulation

Simple tracking detector:
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Rate distribution in tracking detector

- E = 200 MeV
- B = 1.26 T
- Beam current = 150 µA
- Target length = 30 cm

Full simulation:
- Flat vertex distribution
- Energy loss in target volume after event generation
- Flat polar angle distribution, weightening in histogram with cross section
**Solenoid full simulation**

- el. e-p scattering
- Moeller scattering in [0°, 5°]
- Moeller scattering in [10°, 30°]

**Simple tracking detector:**
- Consists of vacuum
- Analyses particles that fly through

**Rate distribution in tracking detector**

| E = 200 MeV | Beam current = 150 µA |
| B = 1.26 T  | Target length = 30 cm |

**Full simulation:**
- Flat vertex distribution
- Energy loss in target volume after event generation
- Flat polar angle distribution, weightening in histogram with cross section
**Solenoid full simulation**

- Better shielding required.
- Better separation of Moeller-e- needed.

**Simple tracking detector:**
- Consists of vacuum
- Analyses particles that fly through

**Rate distribution in tracking detector**

- $E = 200 \text{ MeV}$
- Beam current = 150 $\mu$A
- $B = 1.26 \text{ T}$
- Target length = 30 cm

- e-, el. e-p scattering, [1°, 30°]
- e-, el. e-p scattering, [10°, 30°]
- e-, background
- e+
- γ
- p

- Better shielding required.
- Better separation of Moeller-e-needed.
Conclusion & Outlook

• Measurement of the proton weak charge yields $\sin^2(\theta_W)$, a key parameter of the standard model.

• P2: A new PV experiment in Mainz with precision goal $\left(\frac{\Delta \sin^2(\theta_W)}{\sin^2(\theta_W)}\right) = 0.15\%$.

• $(E=150 \text{ MeV}, \theta = 24^\circ)$ equivalent to $(E=200 \text{ MeV}, \theta = 20^\circ)$ in terms of $\Delta \sin^2(\theta_W)$.

• Solenoid highly desirable, further investigation required
  → Add secondary solenoid to keep Moeller-e- attached to beamline
  → Model detector response for Cherenkov-counter (large reduction of gamma-contribution)

• Toroid: Feasible, fallback solution
Backup slides
\( \Delta A_{\text{tot}} = 0.25 \text{ ppb} \), \( T = 20 \text{ K} \), \( E_{\text{beam}} = 200.0 \text{ MeV} \), \( P = 85.0 \% \), \( \theta_{\text{mean}} = 20 \text{ deg} \), \( \Delta \theta = 20 \text{ deg} \)
Weak charges: Sensitivity to new physics

- Complementary access by weak charges of proton and electron

Weak charge of the proton: $Q_w^p = 0.0716$ ± 0.0029

Weak charge of the electron: $Q_w^e = -0.0449$ ± 0.0051

- Experiment
- SUSY-Loops
- $E_e Z'$
- RPV SUSY
- Leptoquarks

SM (Jens Erler, Ramsey-Musolf, 2003) SM
Sensitivity to new physics

For example: Experimental restriction of SUSY-parameters

\[ \delta (Q_{W}^{p})_{\text{SUSY}} / (Q_{W}^{p})_{\text{SM}} \]

\[ \delta (Q_{e}^{p})_{\text{SUSY}} / (Q_{e}^{p})_{\text{SM}} \]

Moller (JLab, 11 GeV)

Qweak (JLab, 1.165 GeV)

P2 (Mainz, 200 MeV)

SUSY-predictions

(Ramsey-Musolf and Su, 2005)
Achievable precision @ P2: Monte Carlo method

We are going to measure:

\[ A_{\text{exp}} = P \cdot \langle A_{PV} \rangle_{\Delta \Omega} + A_{\text{app}} \]

\[ A_{PV} = A_{PV}(E, \theta, \{FF\}, \sin^2(\theta_W)) \]

\[ \sin^2(\theta_W) = \sin^2(\theta_W)(E, P, \Delta \Omega, \{FF\}, A_{\text{exp}}, A_{\text{app}}, Q^y_{Wz}) \]

\[ = \{\xi_i'\} \]

Parameter uncertainties:

\[ \Delta A_{\text{exp}} = \frac{1}{\sqrt{N}} \]

To include counting statistics:
Achievable precision @ P2: Monte Carlo method

Sample the input parameters:

\[ \sin^2(\theta_W) + \delta(\sin^2(\theta_W)) = \sin^2(\theta_W)(\{\zeta_i' + \delta \zeta_i\}) \]

N iterations yield:

\[ \Delta(\sin^2(\theta_W))(\{\zeta_i'\}) \]
Energy distribution in tracker 40 @ z = 3030 mm