SFB 1044

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

JG|U

P2 / Mainz
A new measurement of the weak charge of the proton

Dominik Becker

Institut für Kernphysik,
Johannes Gutenberg-Universität Mainz

The 5th International Symposium on Symmetries in Subatomic Physics,
Groningen / Netherlands, 2012

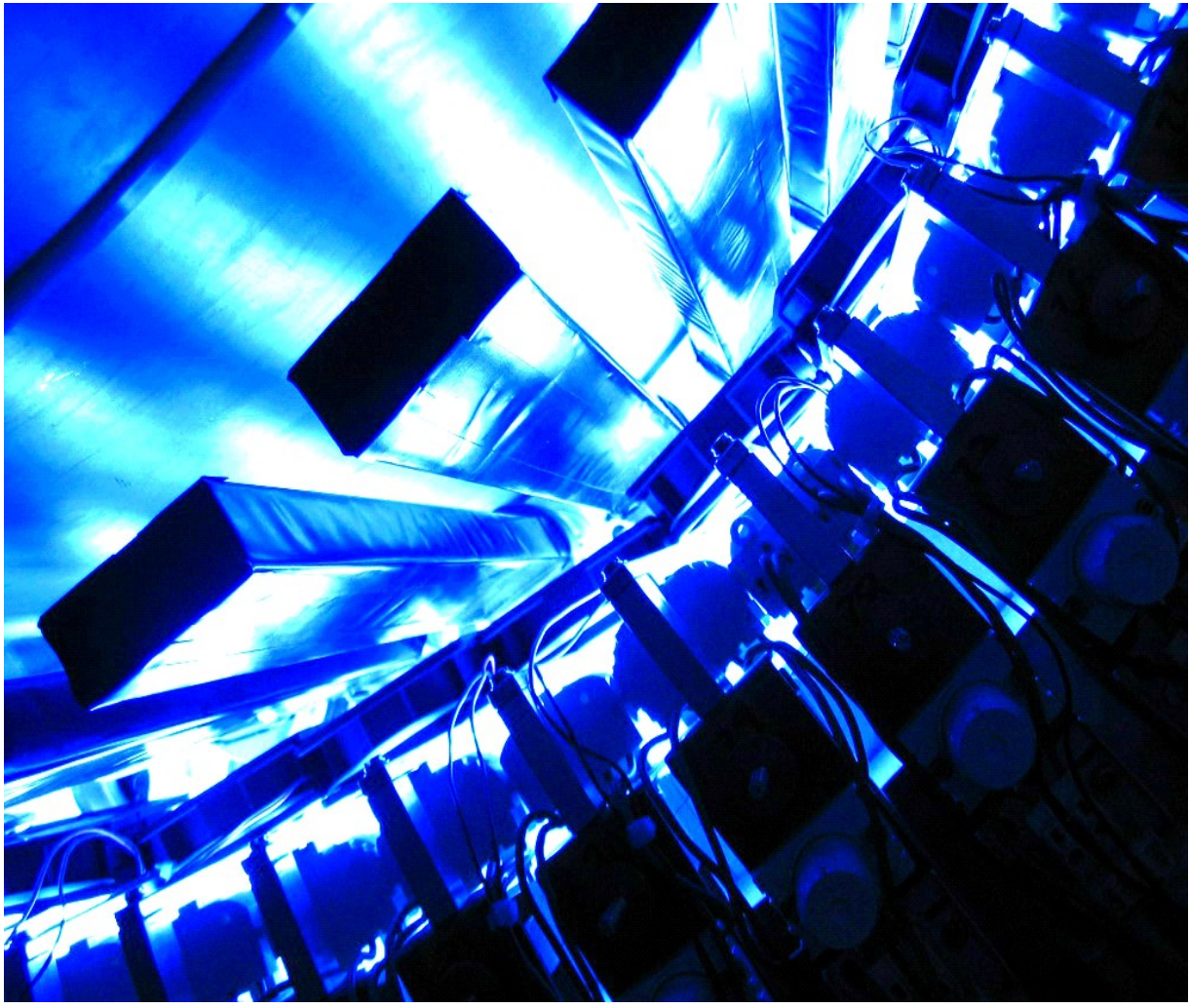
PRISMA

MAMI MAINZER MIKROTRON

HELMHOLTZ GEMEINSCHAFT
Helmholtz-Institut Mainz

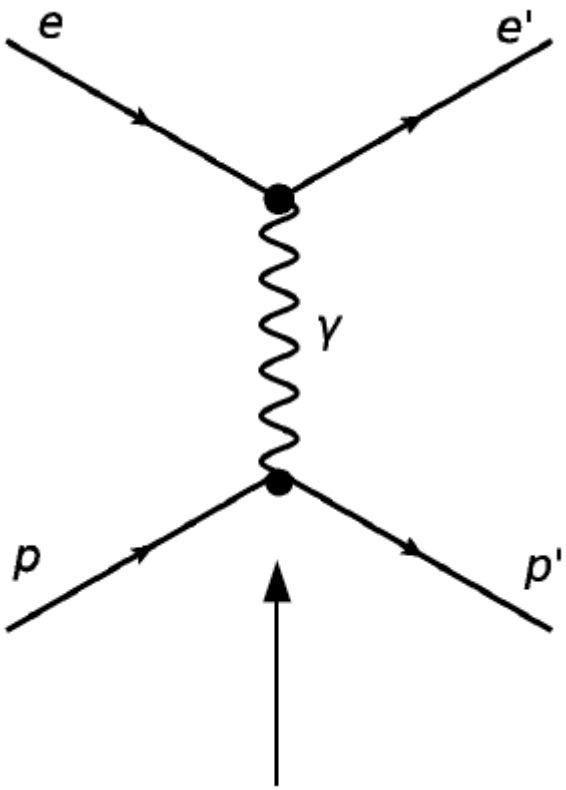
Outline

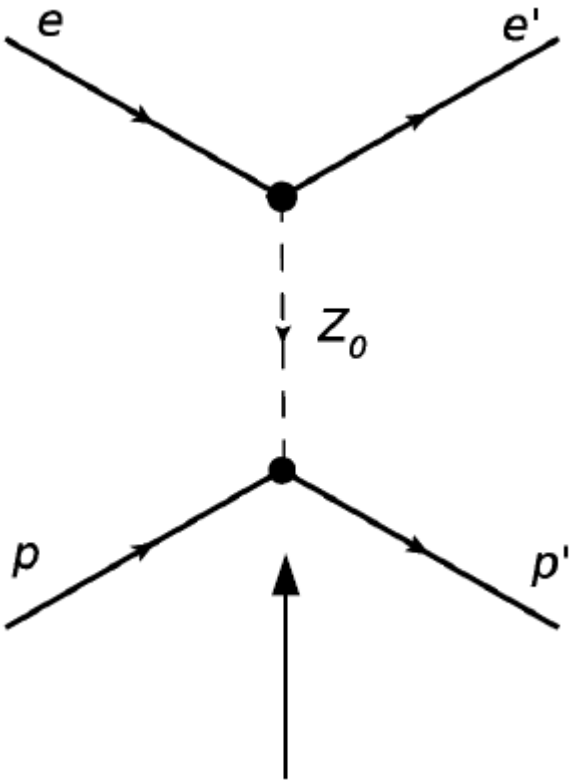
- The weak charge of the proton $Q_W(p)$ and the weak mixing angle
- Experimental access to $Q_W(p)$
- Concept studies for the Mainz P2 experiment



The weak charge of the proton and the weak mixing angle

The weak charge of the proton





$Q_e(p) = +e$

electric charge of the proton

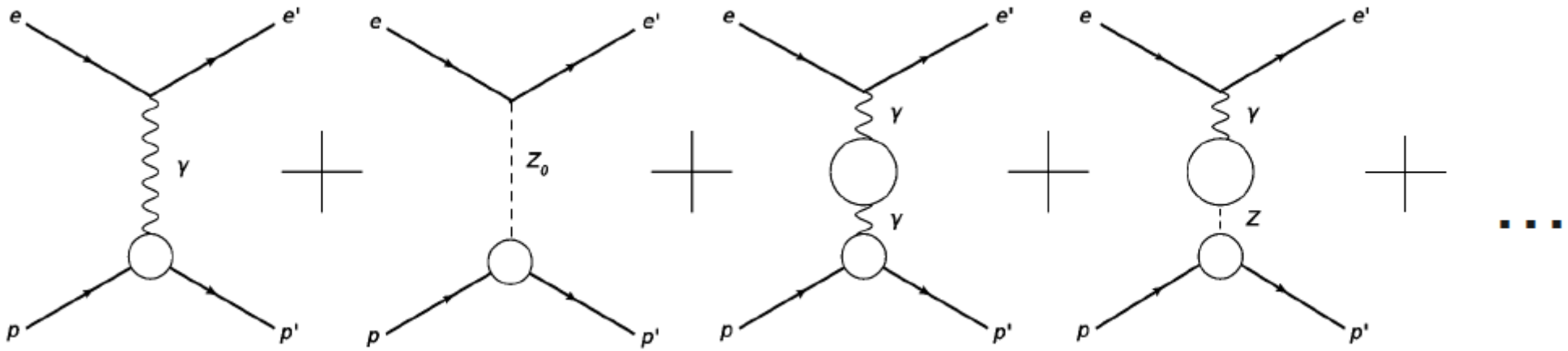
$$\boxed{Q_w(p) = 1 - 4\sin^2(\theta_W)}$$

weak charge of the proton

$\sin^2(\theta_W)$ is a central parameter of the standard model.

Energy scale dependency of the weak mixing angle

Elastic e-p-scattering: Quantum corrections



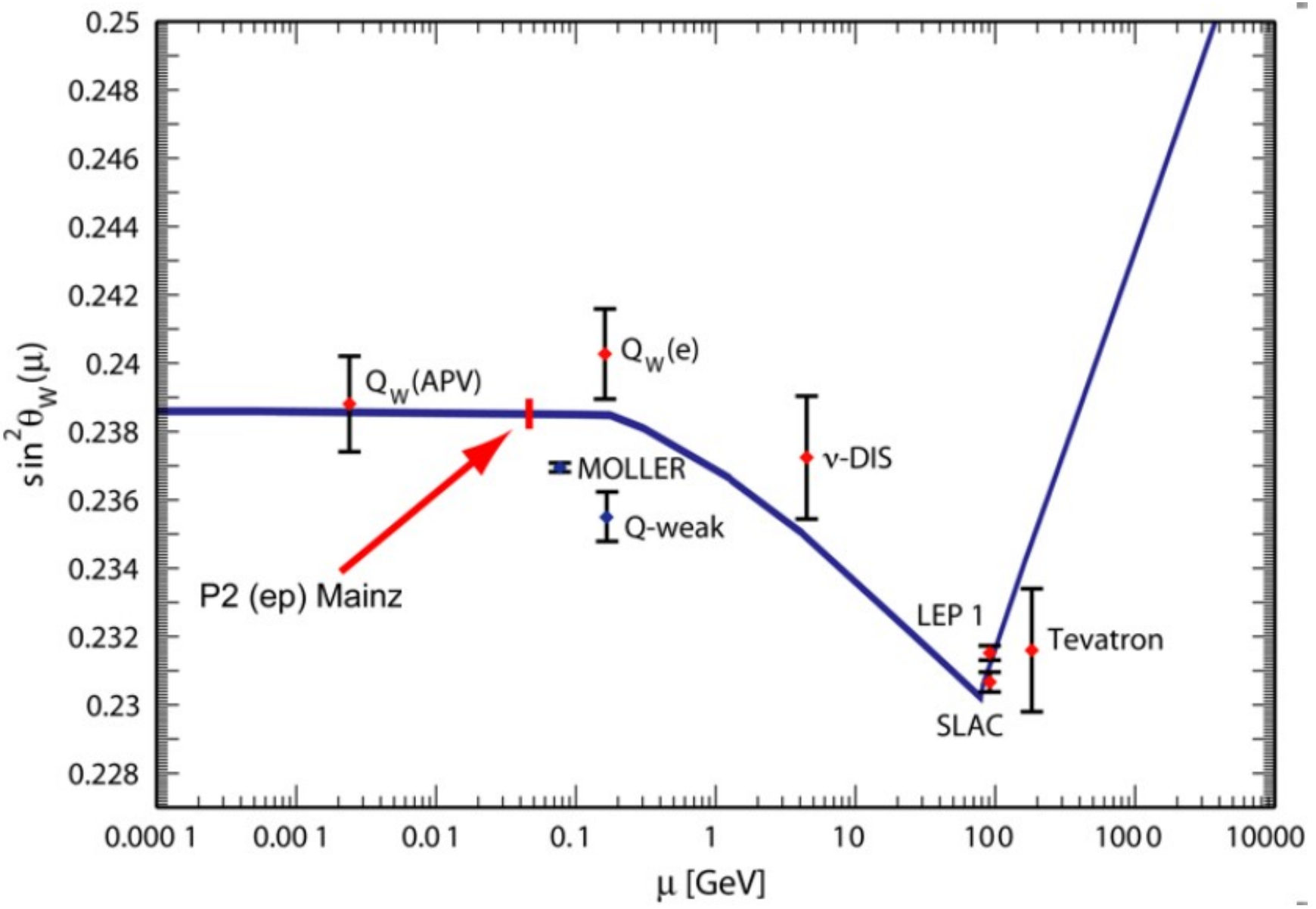
running of α

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

Quantum corrections can be absorbed into a
weak mixing angle depending on the transferred energy μ:

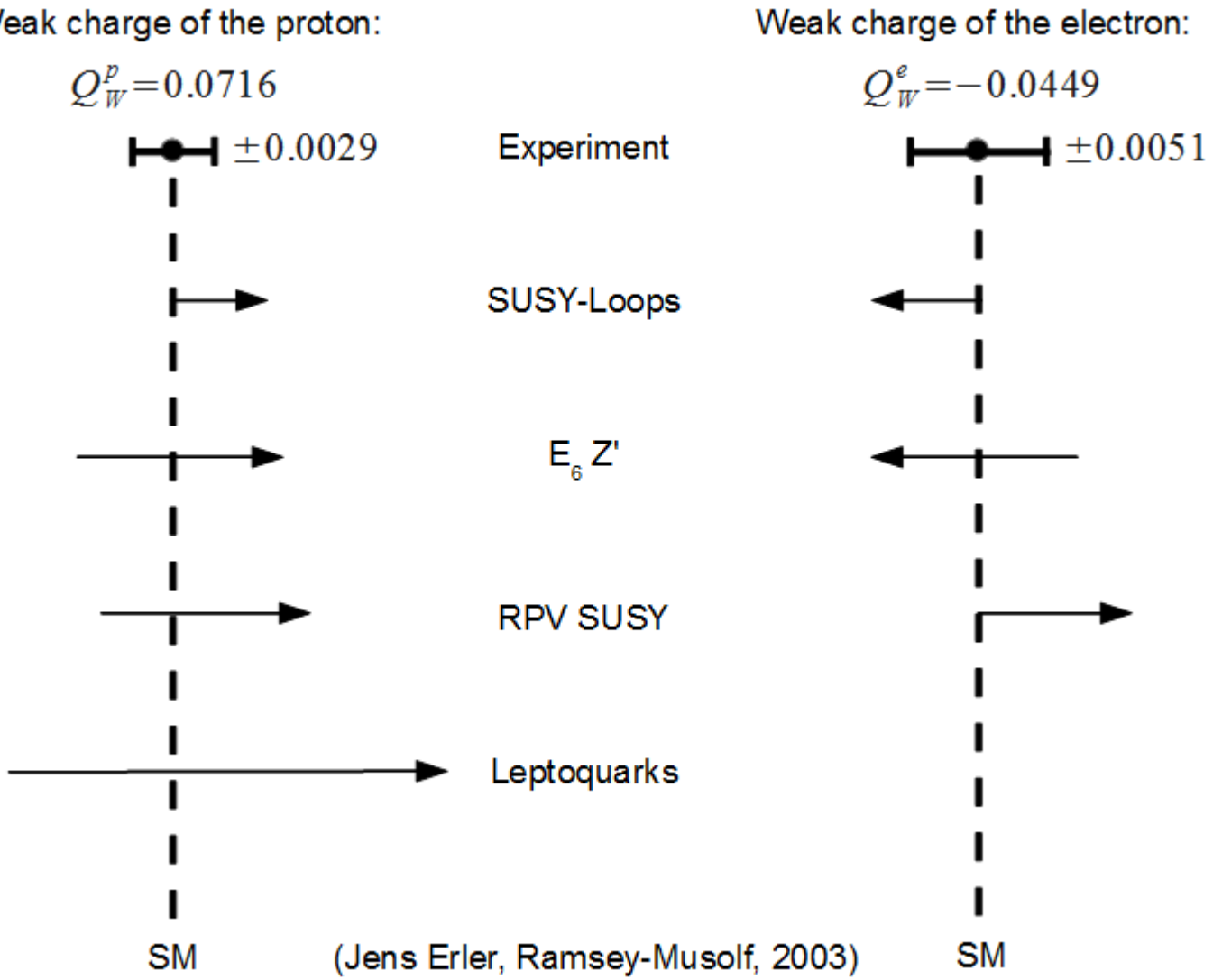
$$\sin^2(\theta_W) \rightarrow [\sin^2(\theta_W)](\mu)$$

Scale dependency of $\sin^2(\theta_W)$



Weak charges: Sensitivity to new physics

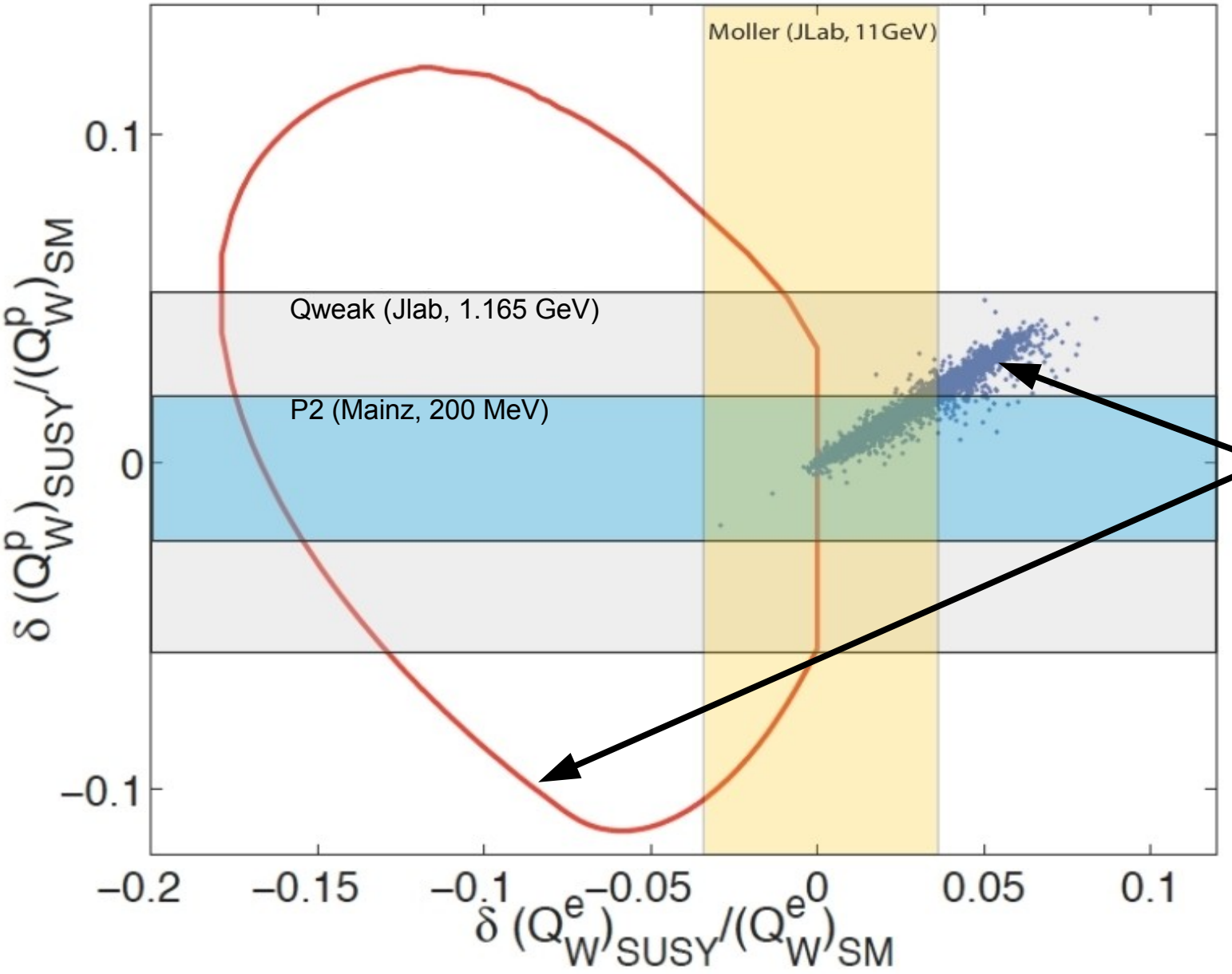
- Complementary access by weak charges of proton and electron



- Dark symmetries → Bill Marciano, this conference

Weak charges and SUSY

Experimental restriction of SUSY-parameters:



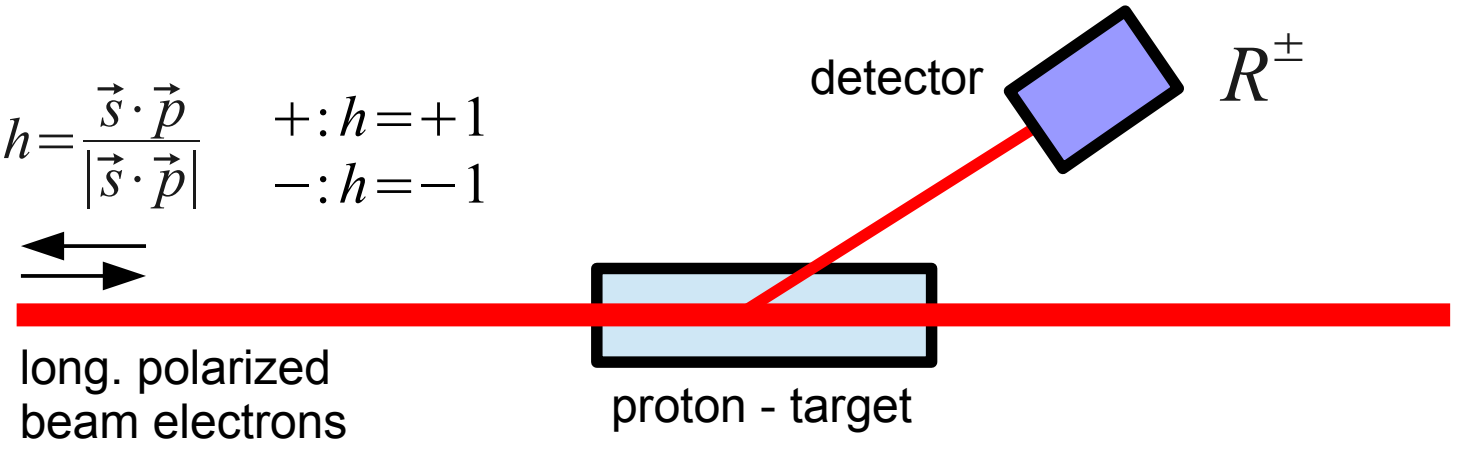
SUSY-predictions

(Ramsey-Musolf and Su, 2005)

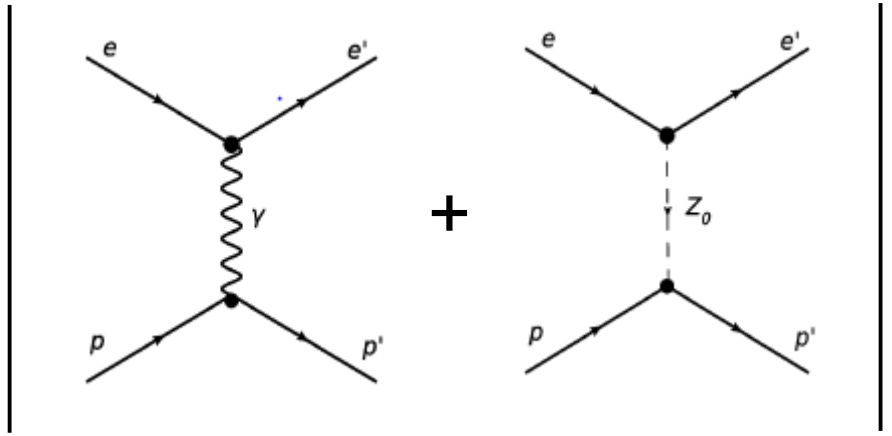
Experimental access to $Q_W(p)$

Elastic scattering of longitudinally polarized electrons off the proton

$$h = \frac{\vec{s}\cdot\vec{p}}{|\vec{s}\cdot\vec{p}|} \qquad +: h = +1 \qquad -: h = -1$$



Cross section: $\sigma_{ep} \sim$



^{2}

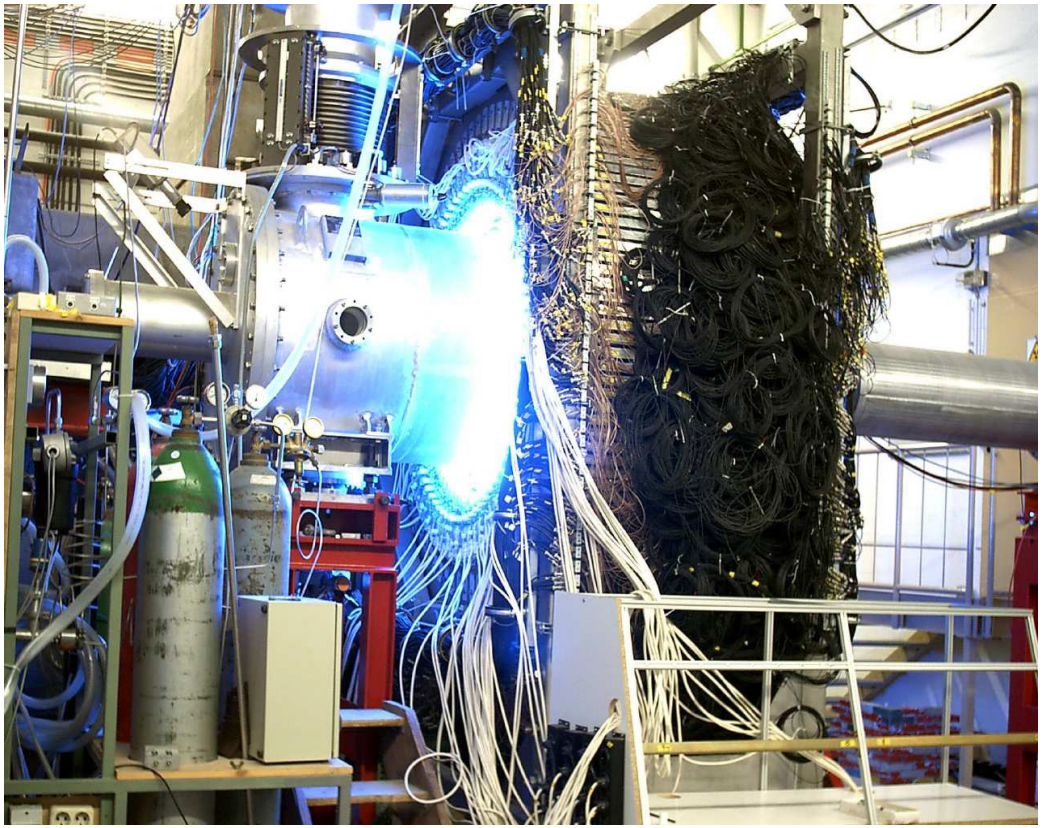
$\sim |M_\gamma + M_Z|^2$

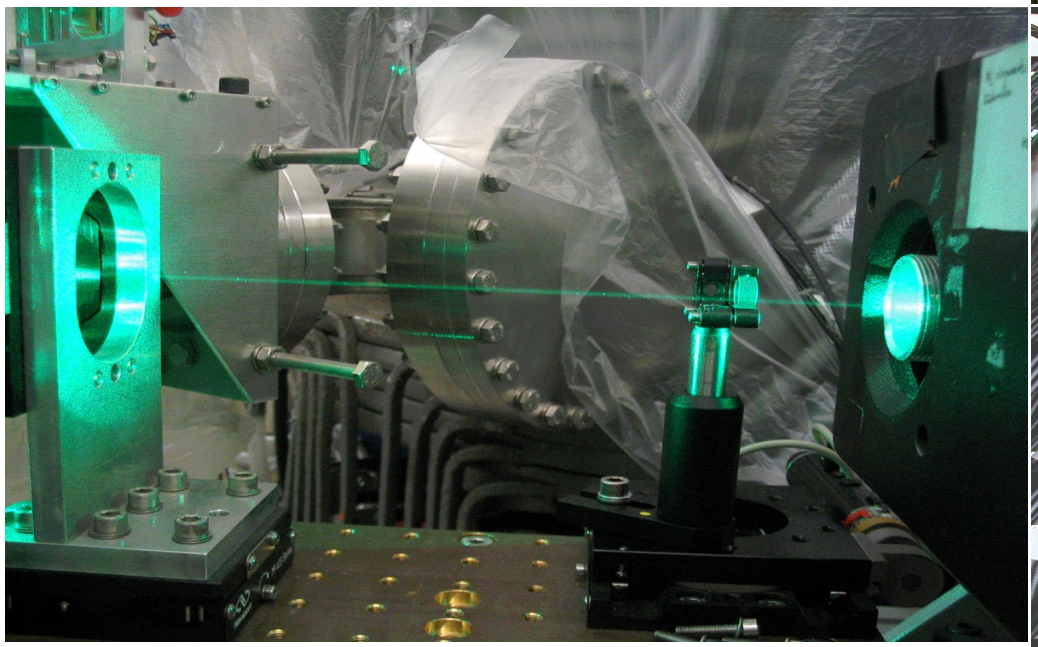
The weak interaction is **parity violating** : $M_Z^+ \neq M_Z^-$ $\longrightarrow$ $|M_\gamma + M_Z^+|^2 \neq |M_\gamma + M_Z^-|^2$

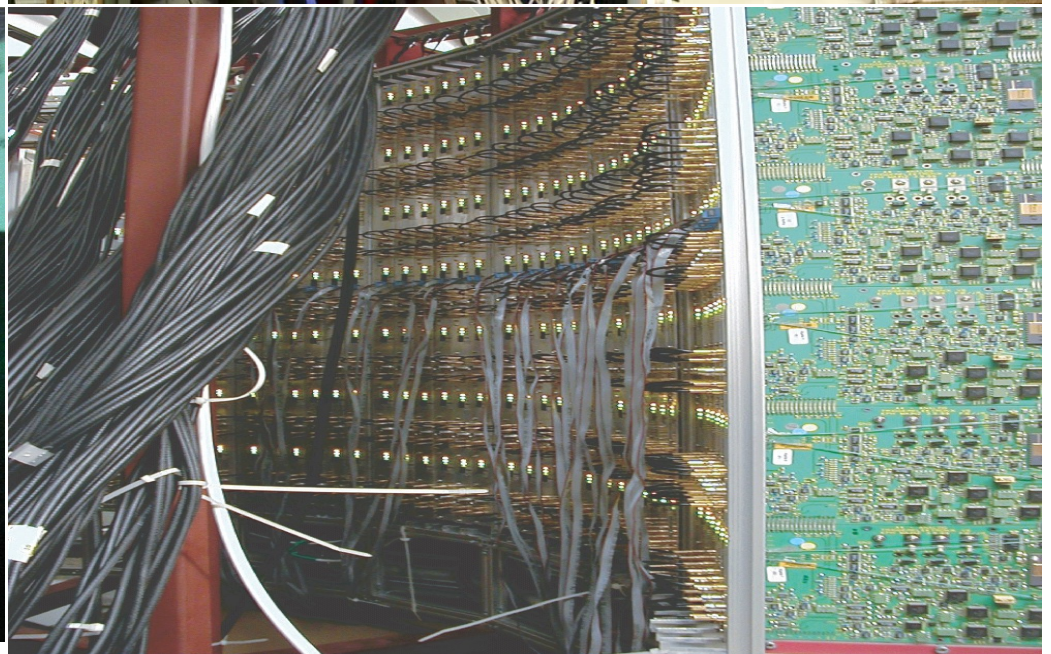
$\longrightarrow$ $\boxed{\sigma_{ep}^+ \neq \sigma_{ep}^-}$

A4 Experiment at MAMI

- 10 years of experience in parity violating electron scattering in Mainz
- Strangeness in the nucleon
- Asymmetries of the order 10^{-6}







The parity violating asymmetry in elastic e-p-scattering

Definition: $$A_{PV} = \frac{\sigma^{+}_{ep} - \sigma^{-}_{ep}}{\sigma^{+}_{ep} + \sigma^{-}_{ep}}$$

Structure: $$A_{PV} = \frac{-G_F Q^2}{4\sqrt{2}\pi\alpha}\left(Q_W(p) - F(Q^2)\right)$$

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

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

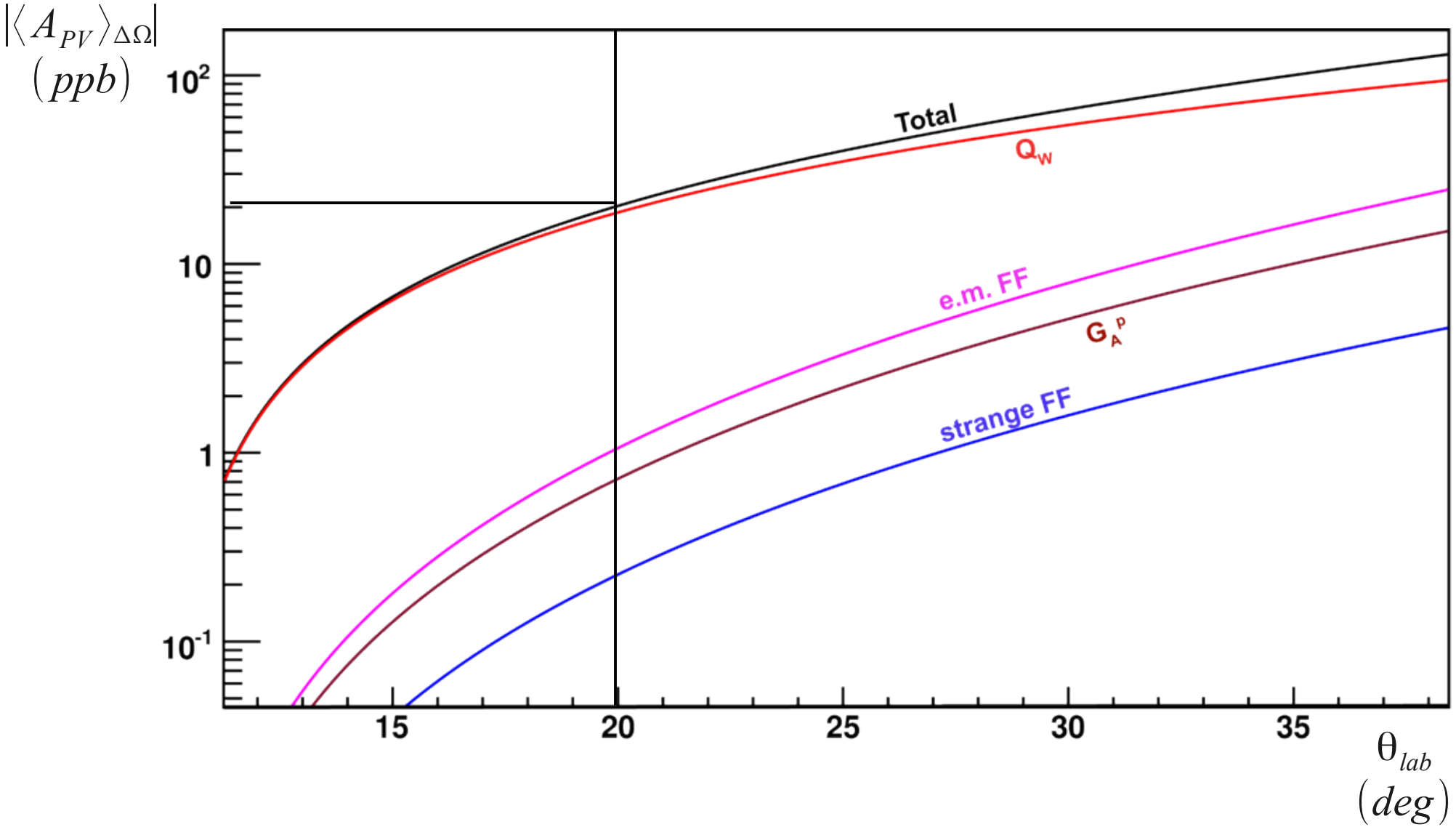
→ Measuring A_{PV} at low momentum transfer Q^2 gives access to $Q_W(p)$.

The asymmetry at P2-conditions

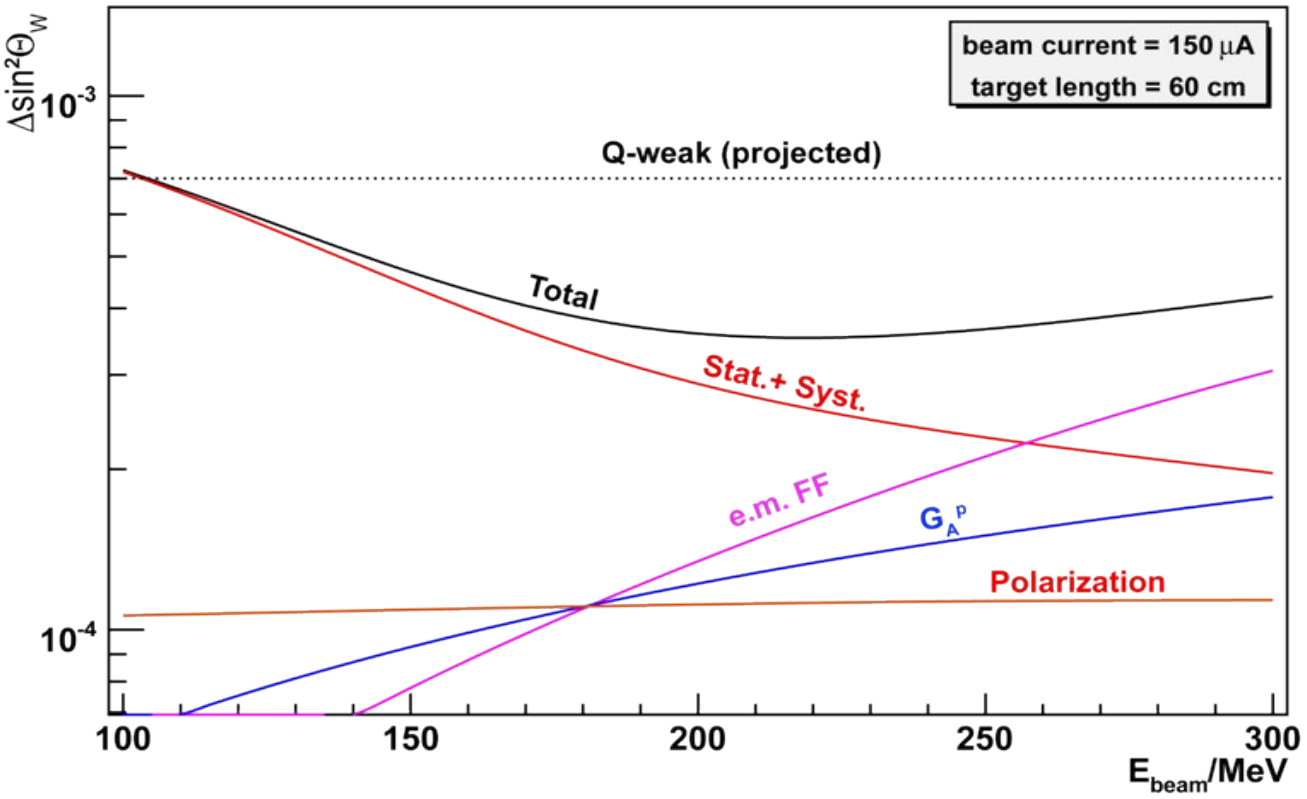
Beam energy: $E_{beam} = 200\,\mathrm{MeV}$

Polar acceptance: $\Delta\theta = 20^\circ$

$|\langle A_{PV}\rangle_{\Delta\Omega}| = 20\ ppb$



Precision of P2: Monte-Carlo-Studies

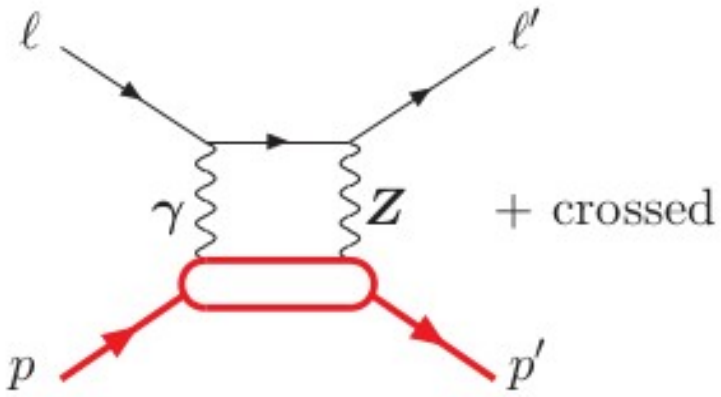


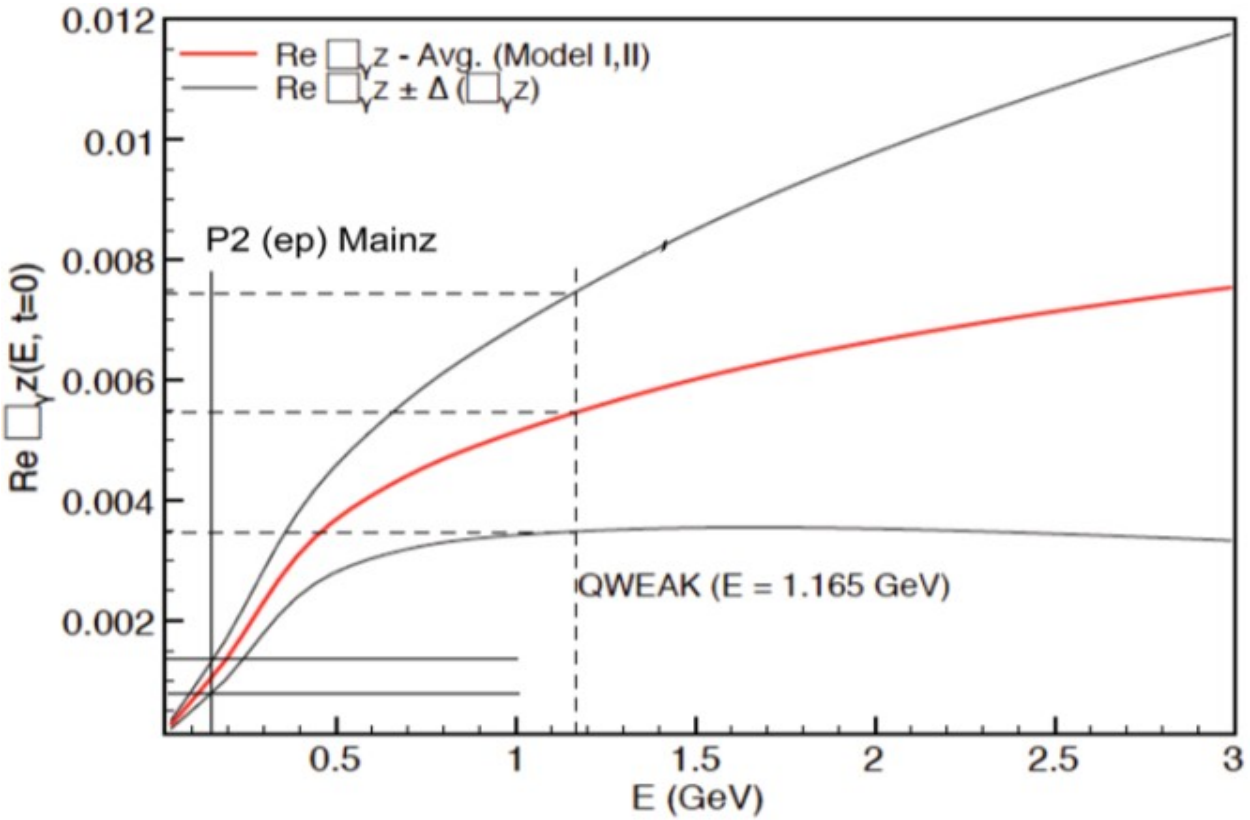
Proposed experimental conditions:

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

Q^2	0.0048 GeV^2
A_{phys}	-20.25 ppb
ΔA_{tot}	0.34 ppb (1.7 %)
ΔA_{stat}	0.25 ppb
ΔA_{sys}	0.19 ppb (0.9%)
Rate	0.44 10^{12} Hz
$\Delta\sin^2\theta_{W\ stat}$	2.8 10^{-4}
$\Delta\sin^2\theta_{W\ tot}$	3.6 10^{-4} (0.15 %)

Gamma-Z-Box graph contributions to the uncertainty





Gorchtein, Horowitz, Ramsey-Musolf 1102.3910 [nucl-th]

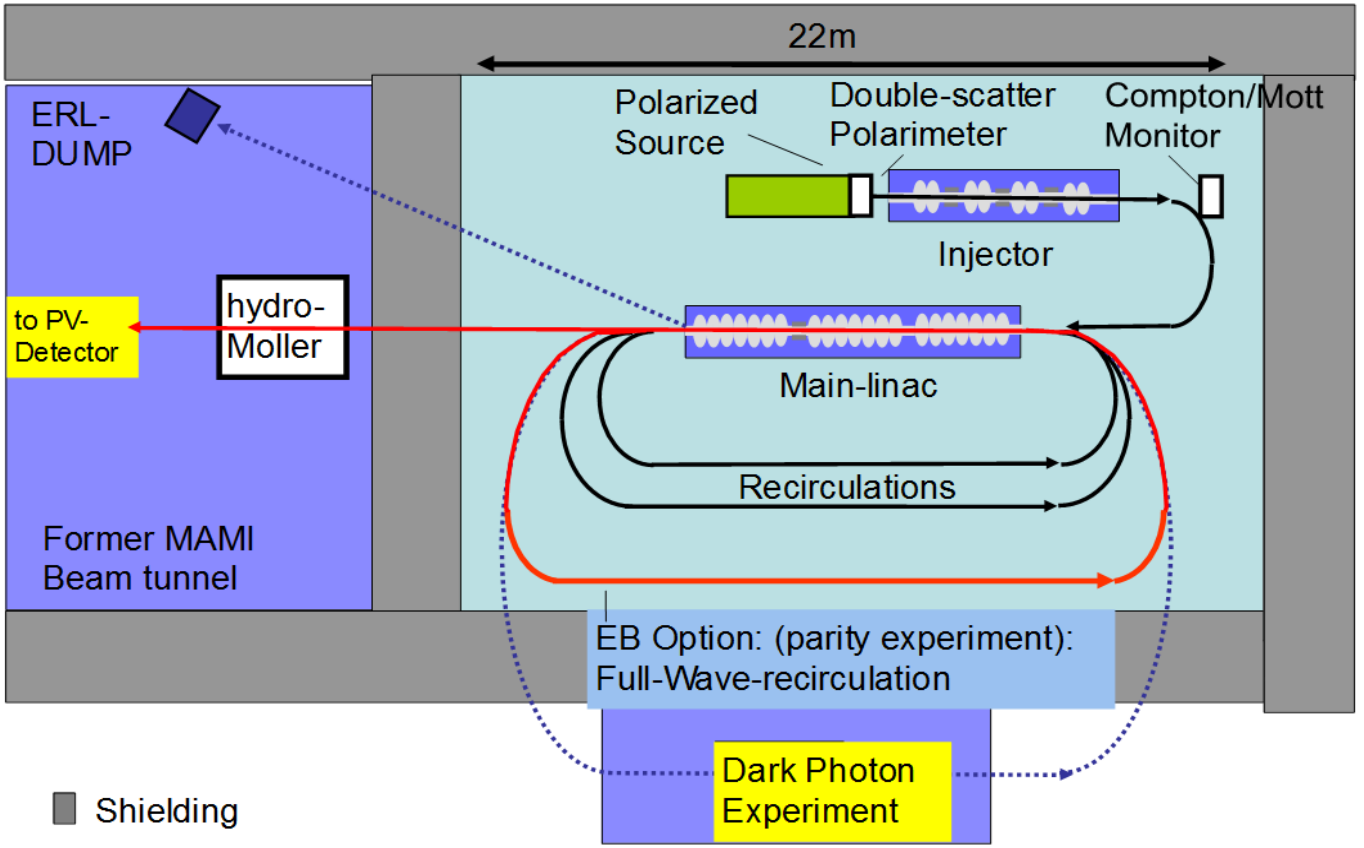
Radiative corrections:

- Gamma-Z-box contributions: included in the Monte-Carlo
- Higher-order radiative effects due to one and two photon emission
- General theory support for the interpretation of the measurement

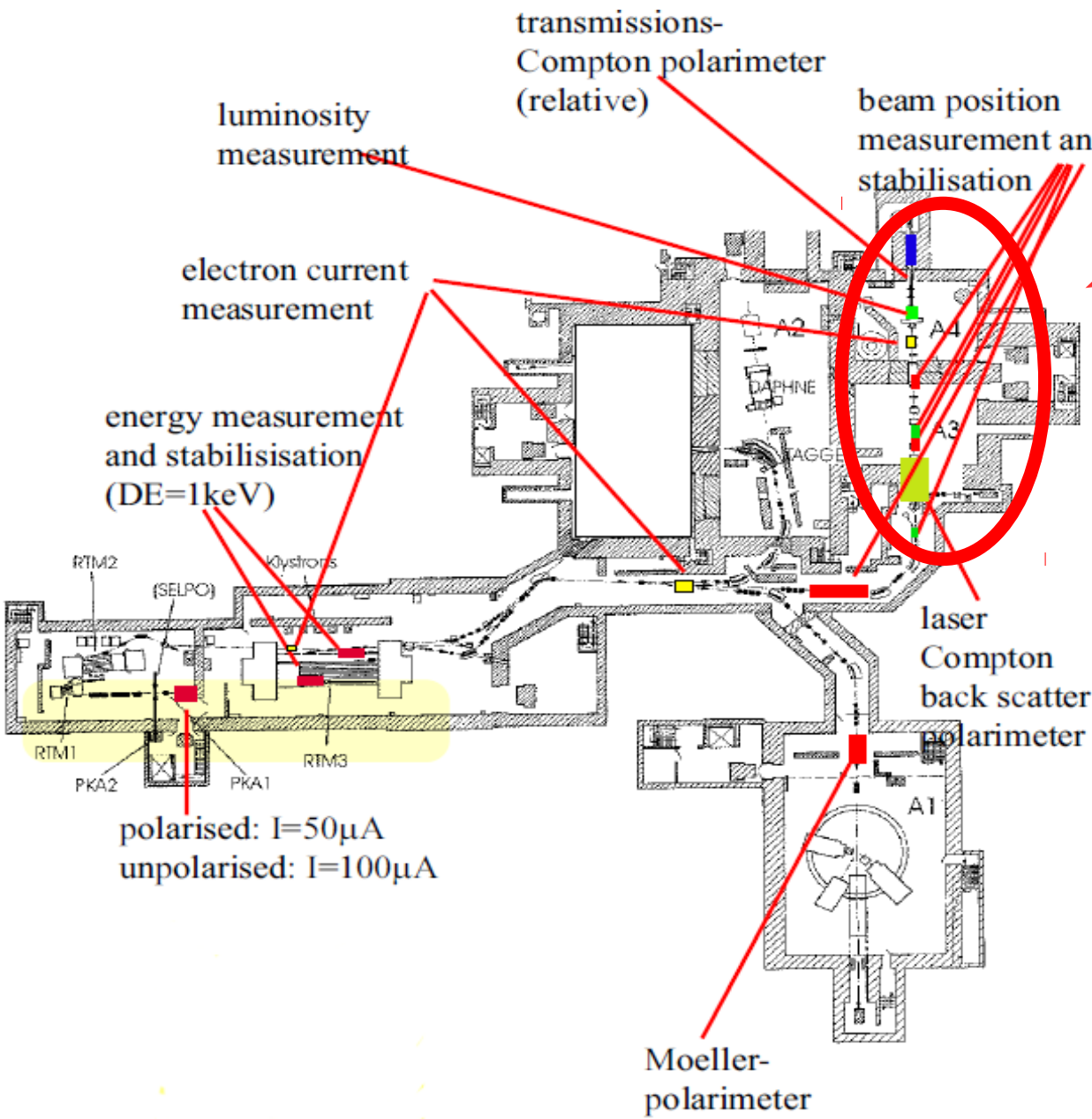
Concept studies
for the P2 experiment

New superconducting accelerator in Mainz: MESA

Granted by the
German Excellence Initiative
15.06.2012, 3:45 ppm



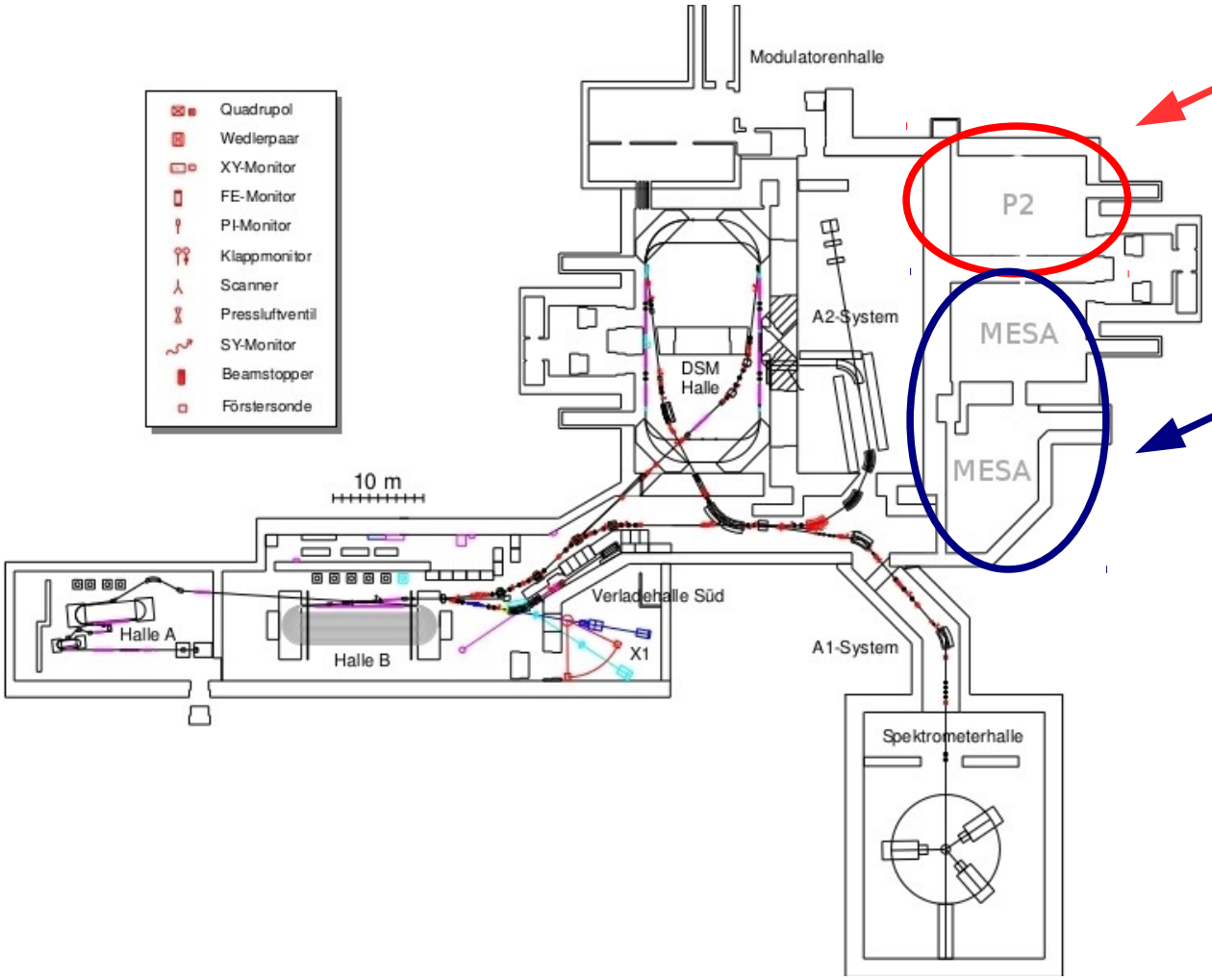
MAMI accelerator facility: Current setup for PV measurements



Location of present A4 PV experiment

- Several stabilization systems (position, current, energy)
- Several polarimeters

MESA and P2: Setup in the MAMI accelerator facility



New PV experiment: P2

New superconducting accelerator: MESA

Experimental challenges

MESA:

- Beam current I = 150 μA
- Beam energy E = 200 MeV
- Polarization P = 85 % $\pm$ 0.5 %

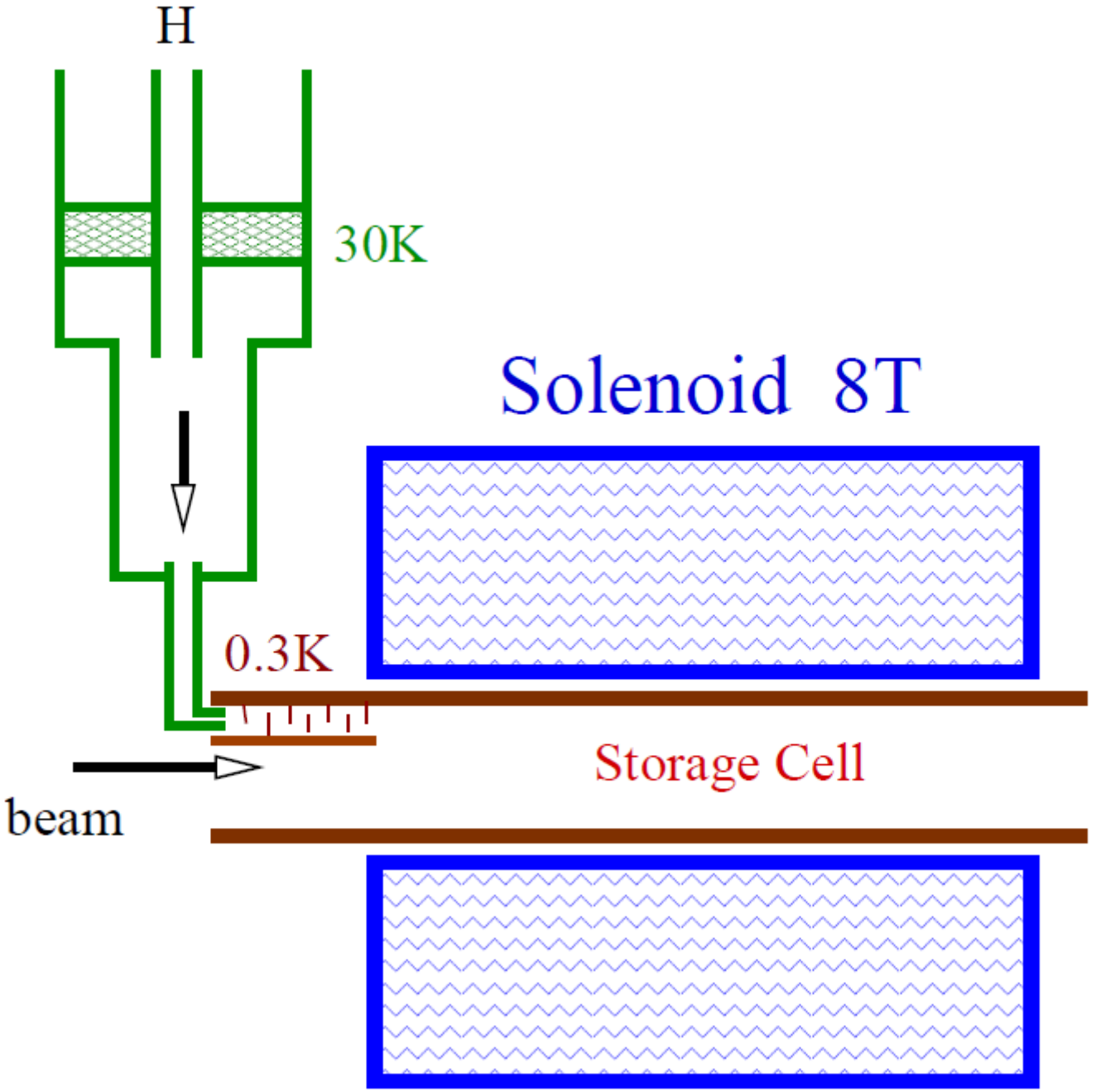
P2:

- 60 cm liquid-hydrogen target
- $\theta_{Lab} \in [10°, 30°]$, $\Delta\phi = 2\pi$
- Elastic e-p-scattering: Rate = 0.22 THz

→ Dealing with high rates

→ Background suppression

High precision polarimetry: Hydro-Moeller

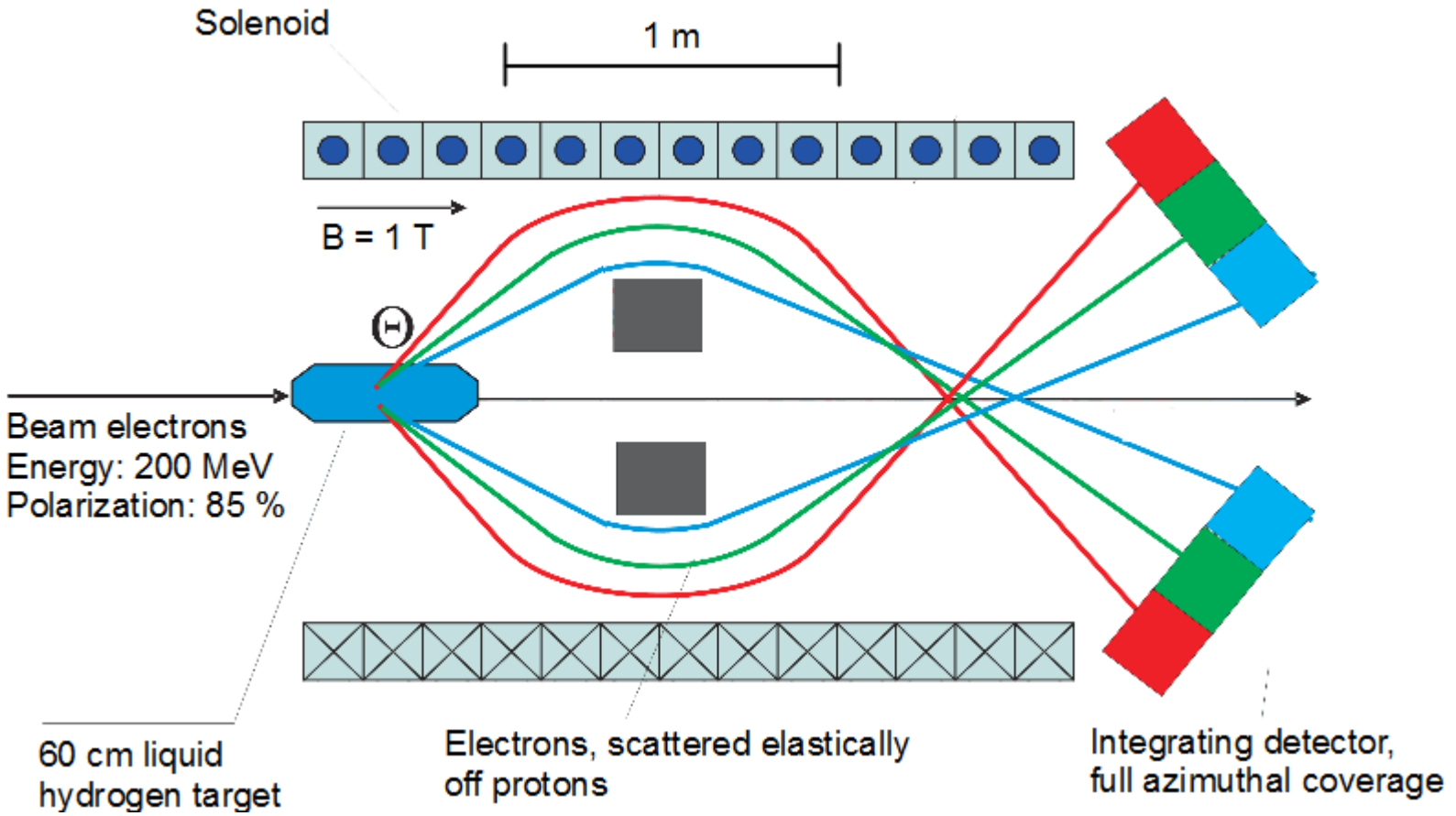


- Strong magnetic field:
- B=8 T
- Low temperature T=0.3 K
- Magnetic trap
- → 100% polarization of the electrons
- Precision goal: $\Delta P=0.5\%$

Concept by E.A. Chudakov and V.G. Luppov

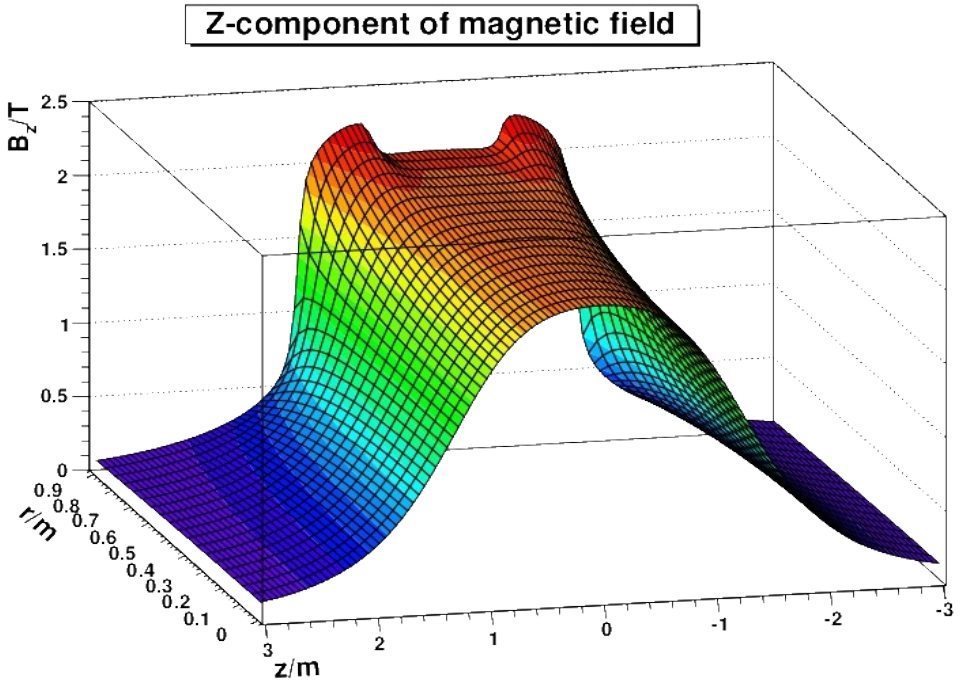
P2: Possible design of spectrometer

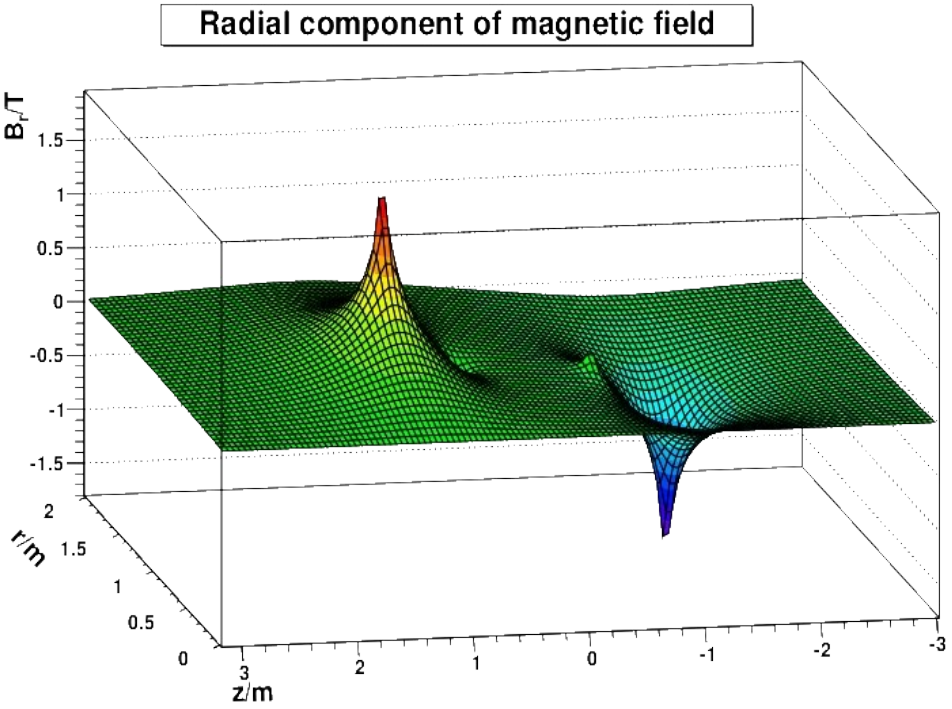
- Solenoid design:

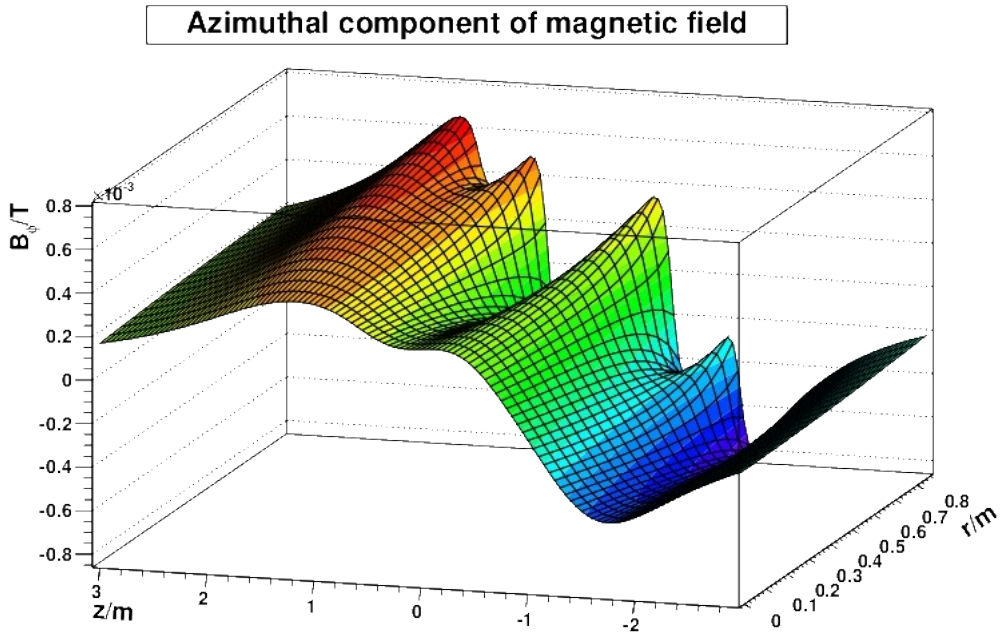


- Other option: Qweak-line toroid

Superconducting solenoid

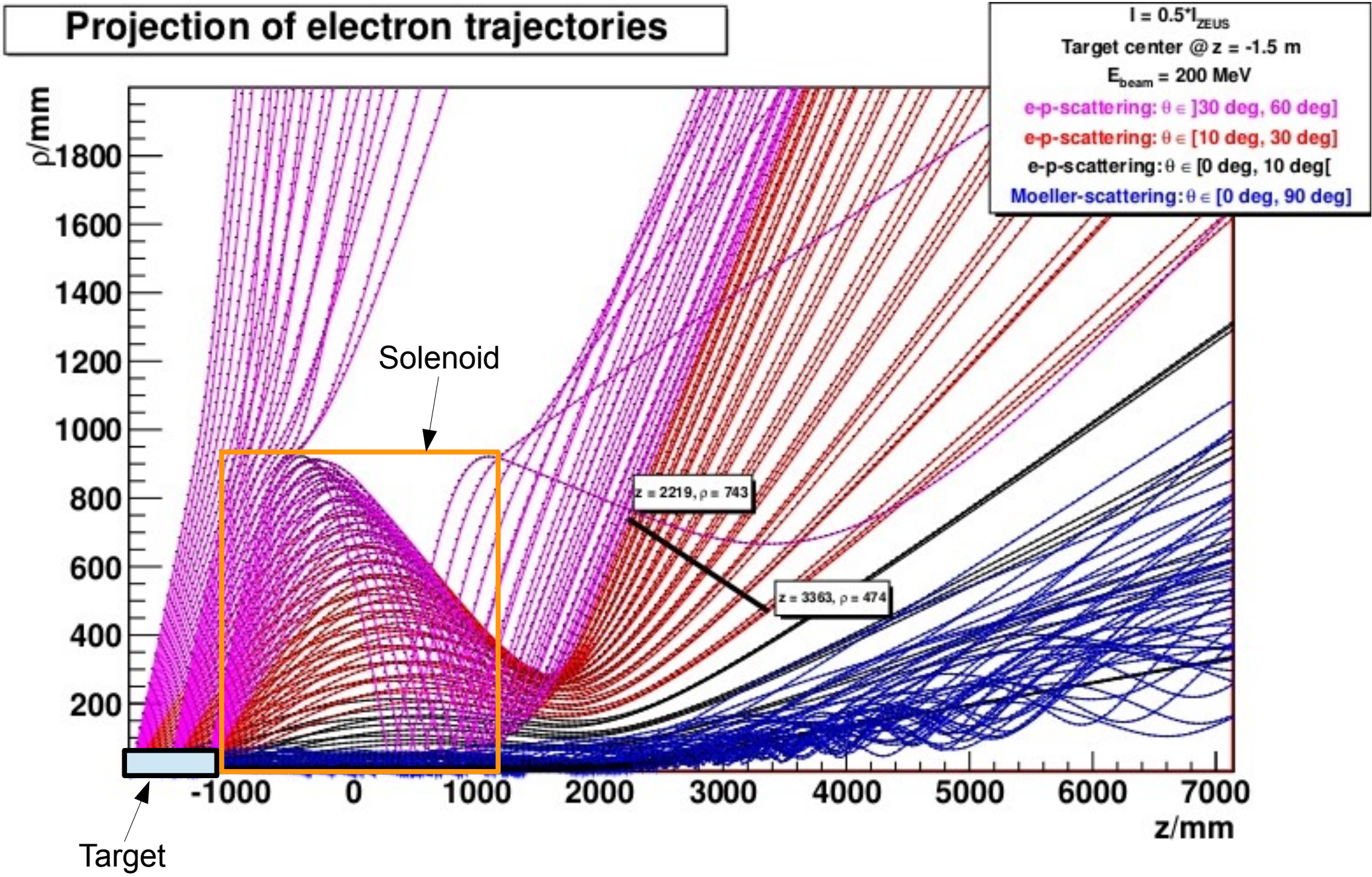






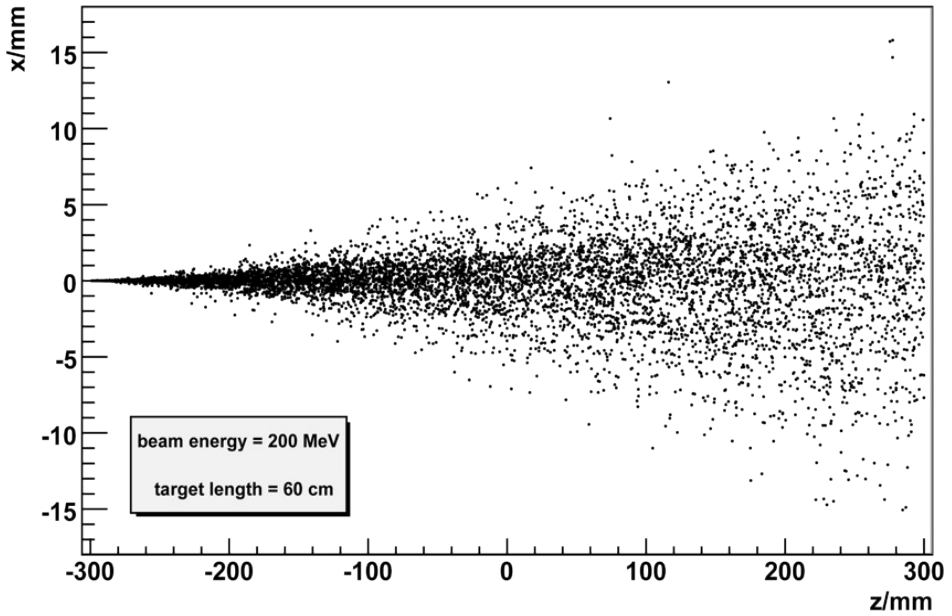
- Radius = 1 m
- Length = 2.5 m
- Current = 5 kA
- 1000 windings

Studies with ROOT & Geant4: Tracking

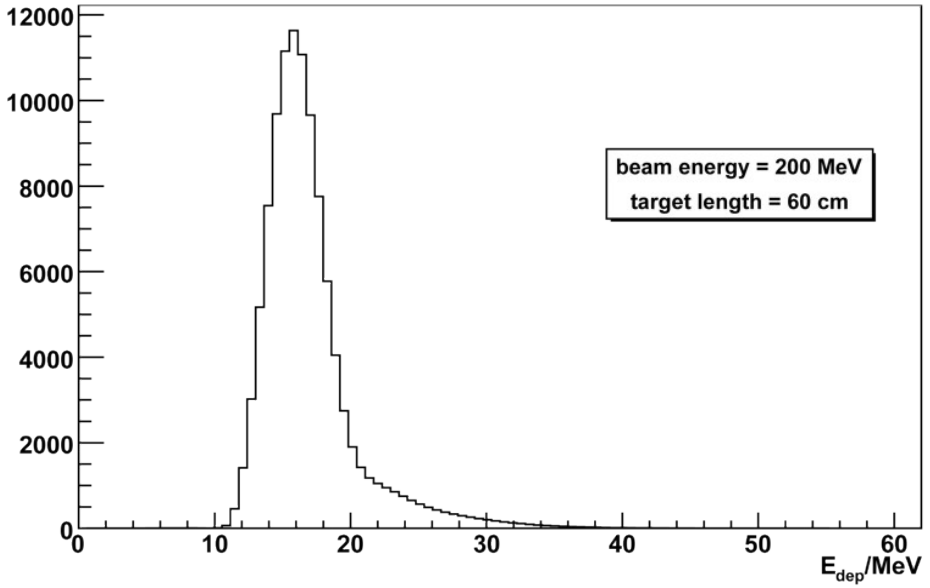


Energy loss in liquid H2 target

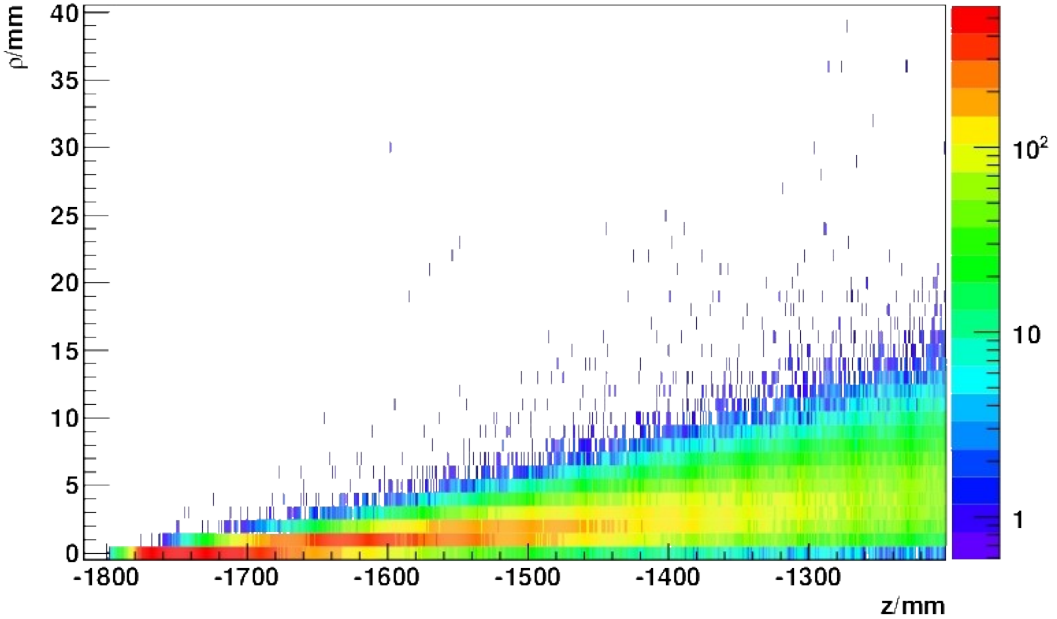
Vertex distribution in the target volume



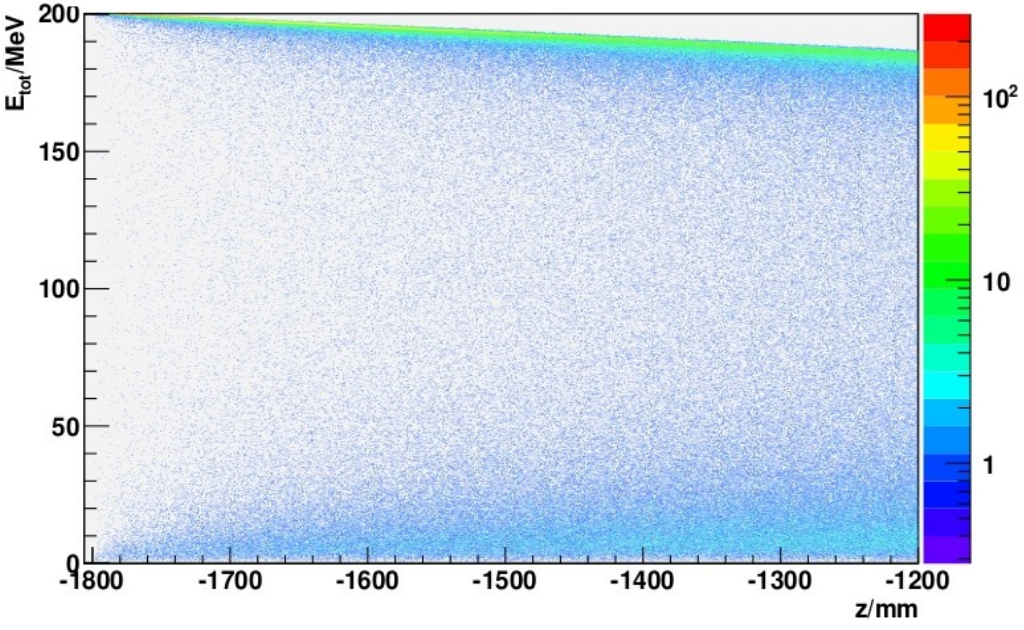
Energy deposition in the target volume



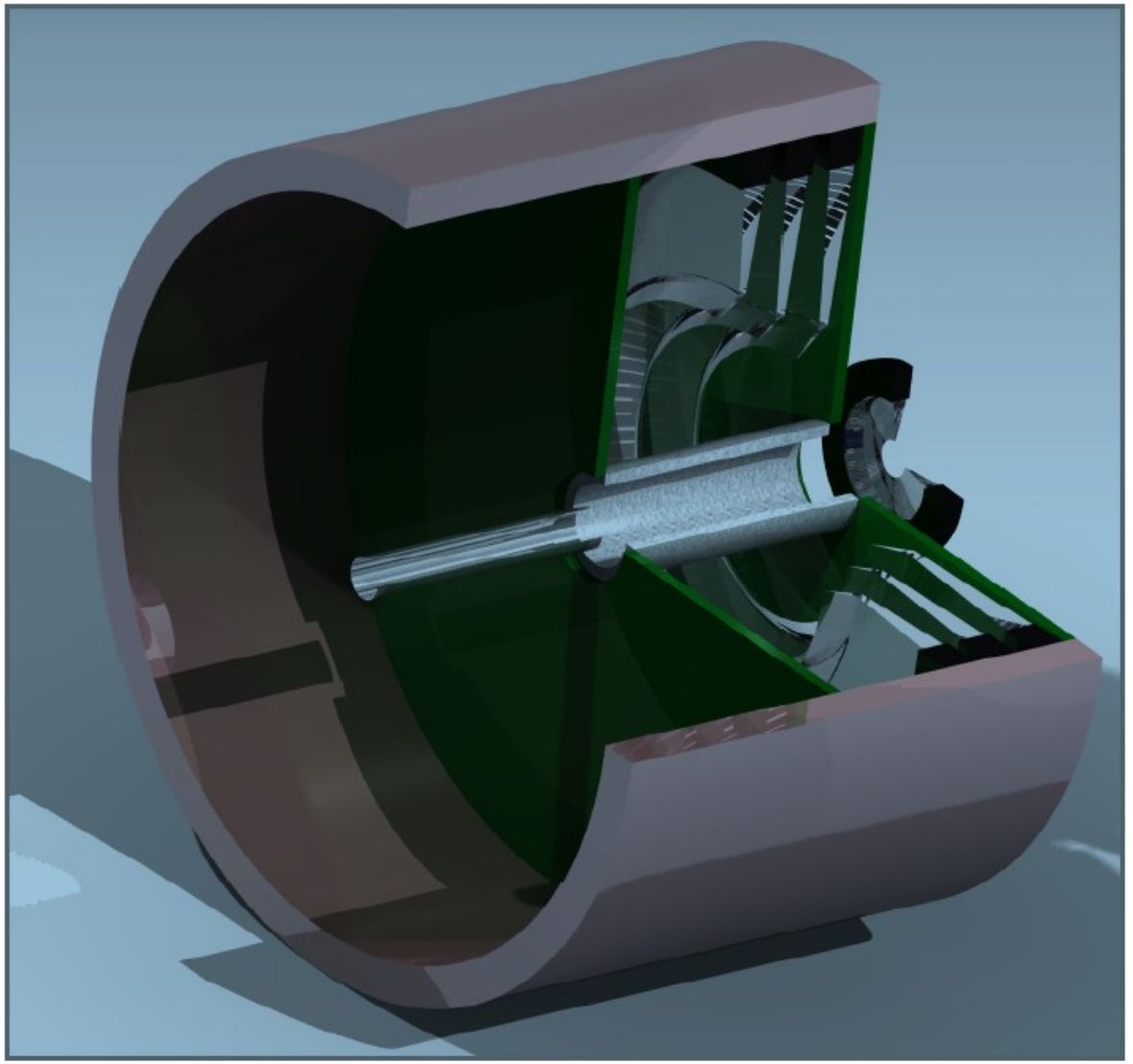
Density distribution of elastic vertices with electron energies between 180 MeV and 200 MeV



Energy distribution of elastic vertices



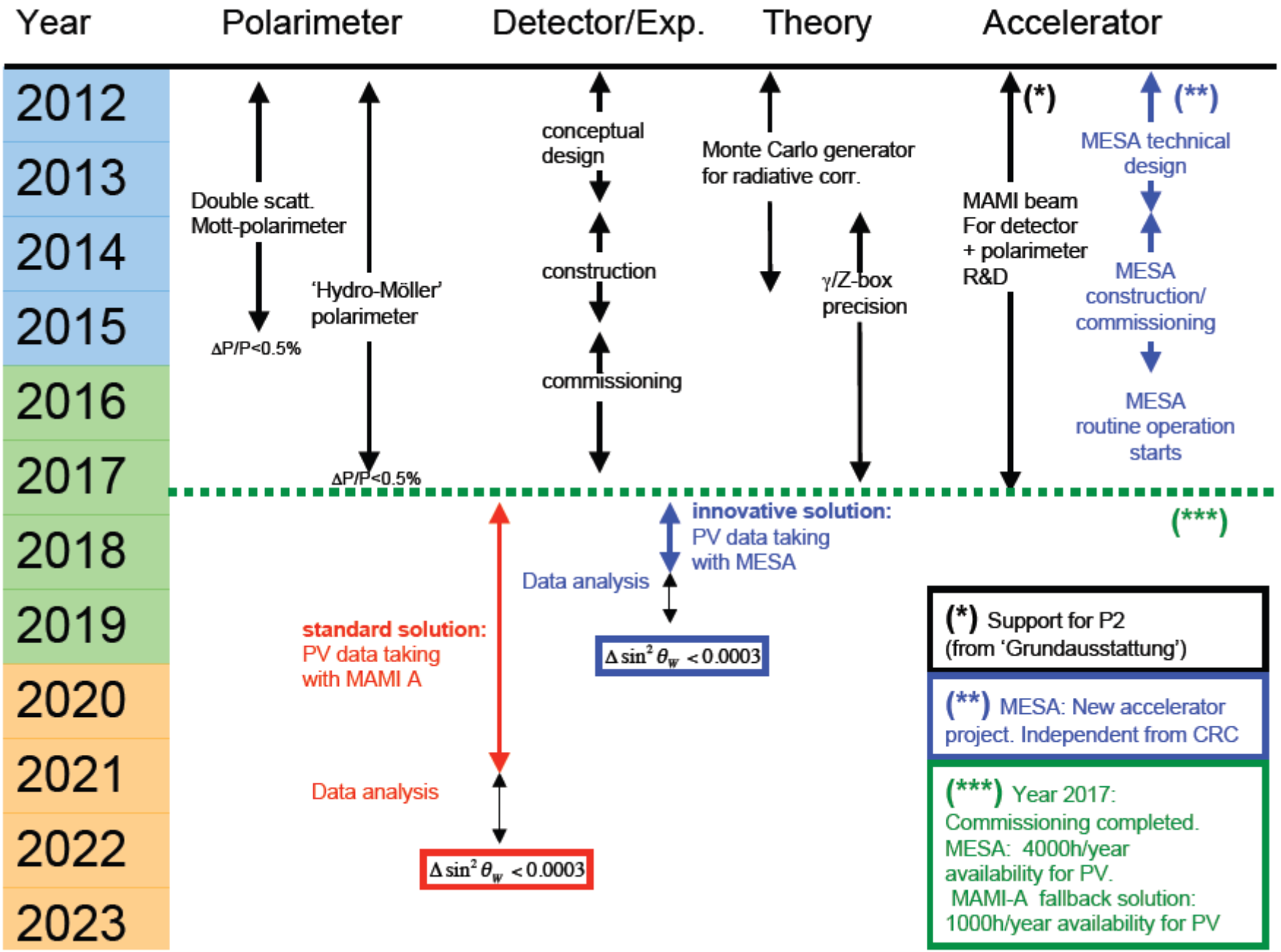
Solenoid setup



Design by D. Rodriguez Pineiro

- Other option: Qweak-line toroid

Timeline of project P2



Summary

- Measurement of the weak charge of the proton yields $\sin^2(\theta_W)$, a key parameter of the standard model
- High precision measurement: Search for new physics (SUSY, ...)
- P2: A new PV experiment in Mainz with precision goal $\Delta\sin^2(\theta_W) = 3.6 \cdot 10^{-4}$
- New superconducting accelerator at MAMI facility: MESA
  Granted since June 15, 2012
- After ten years of experiments with PVES, concept studies for the new P2 setup are in progress