JG|U

SFB 1044
Institut für Kernphysik

$\sin^2\theta_W = 0.238$
$\theta_W = 29{,}2°$

A new, high precision measurement of the weak mixing angle $\sin^2\theta_W$

Frank Maas
(Helmholtz Institute Mainz,
Institute for Nuclear Phyiscs,
PRISMA cluster of excellence
Johannes Gutenberg University Mainz)

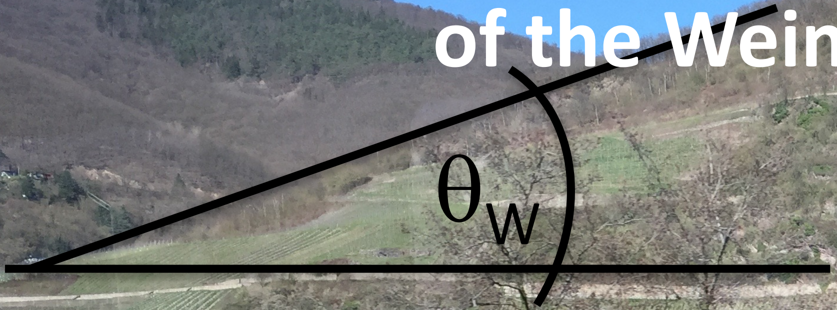
CEA Saclay, January 14, 2019

SFB 1044 HIM PRISMA

$\mathrm{Sin}^2\,\theta_W = 0.238$

$\theta_W = 29{,}2^\circ$

A new, high precision measurement of the Weinberg angle $\sin^2\theta_W$



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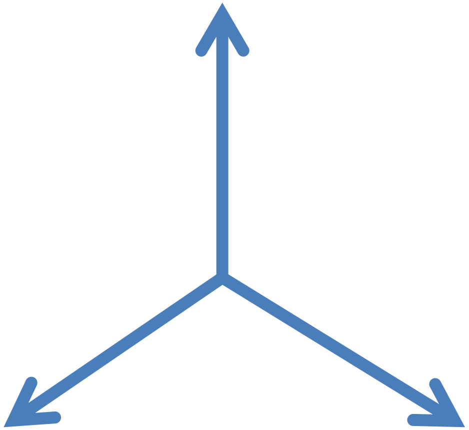
50 Jahre Beschleunigerphysik in Mainz, 15./16. Februar 2018

Search for New Physics: Various Methods



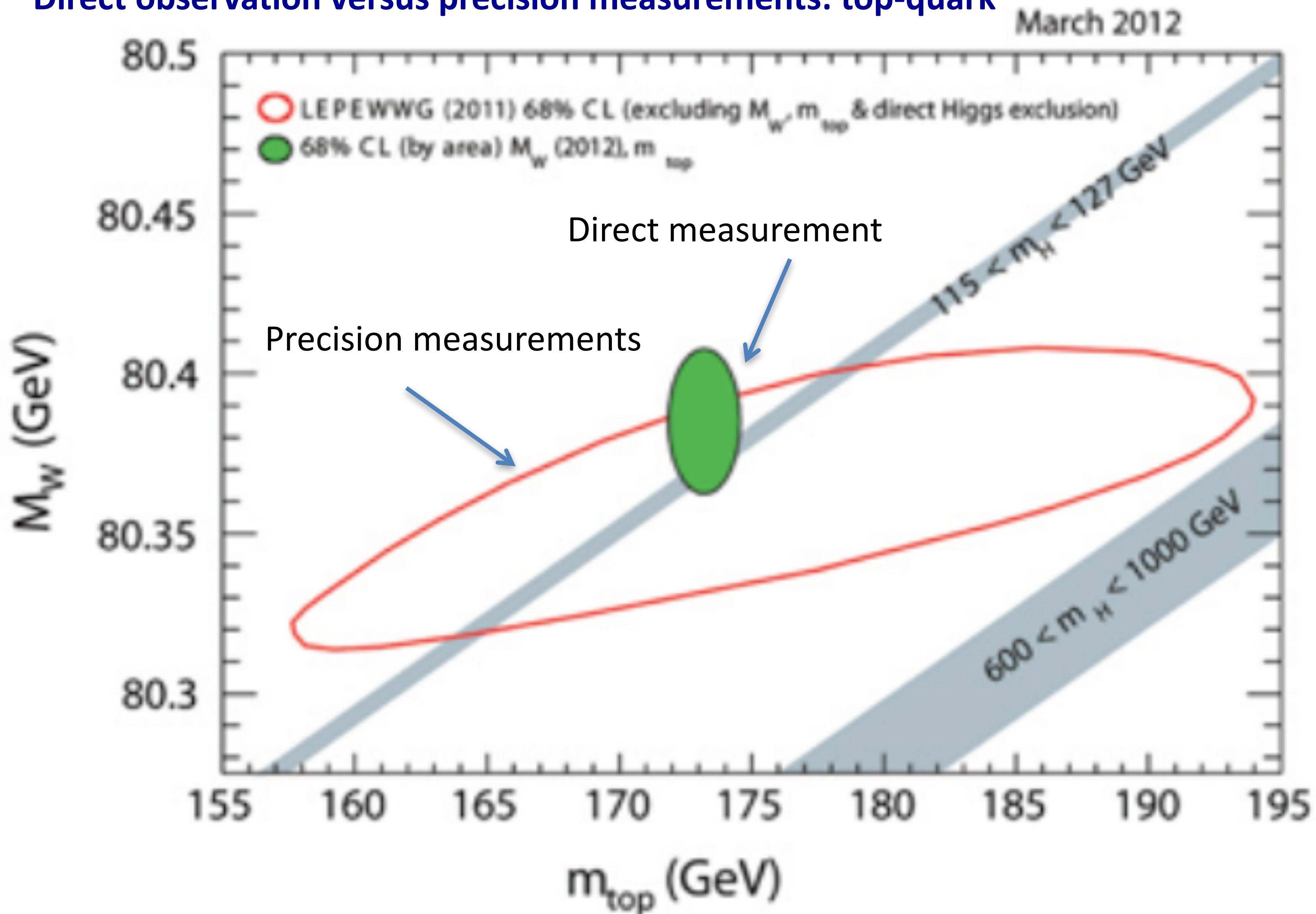
High Energy (LHC)

High Intensity
(B-decays)

High Precision
($(g-2)_\mu$, EDM, $\sin^2\theta_W$, …)

(at low energy)

Direct observation versus precision measurements: top-quark

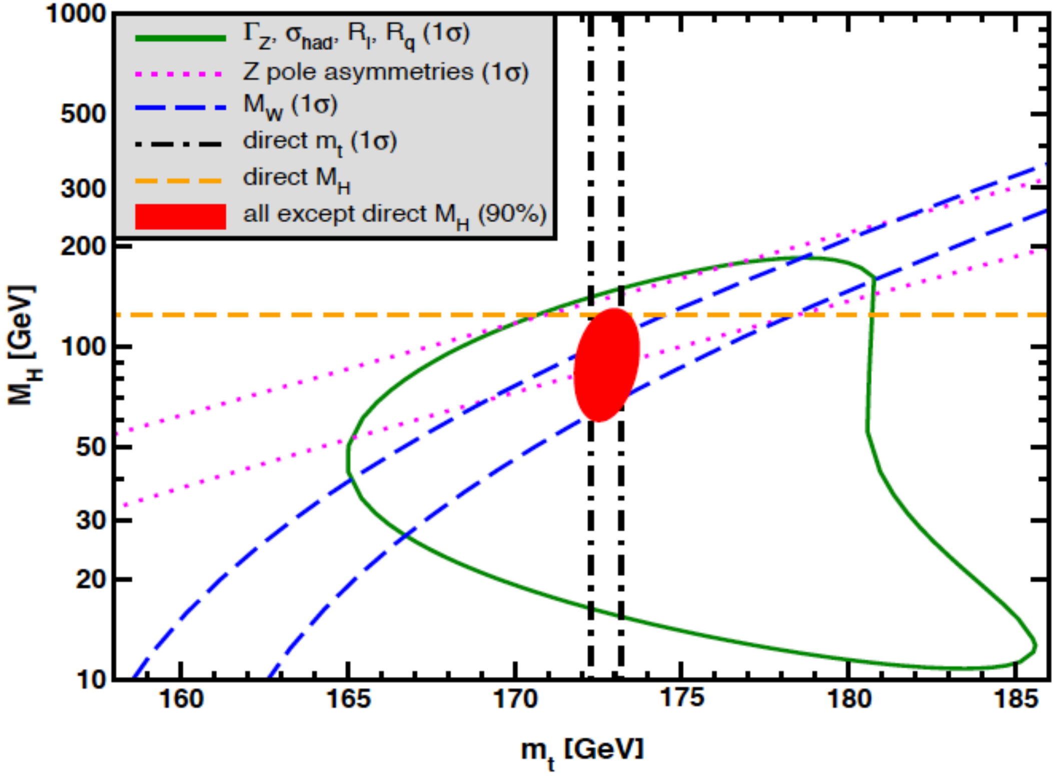


March 2012

Direct measurement

Precision measurements

Direct observation versus precision measurements: top-quark, Higgs



Erler '18

Direct measurements:

$$M_H = 125.14 \pm 0.15 \text{ GeV}$$

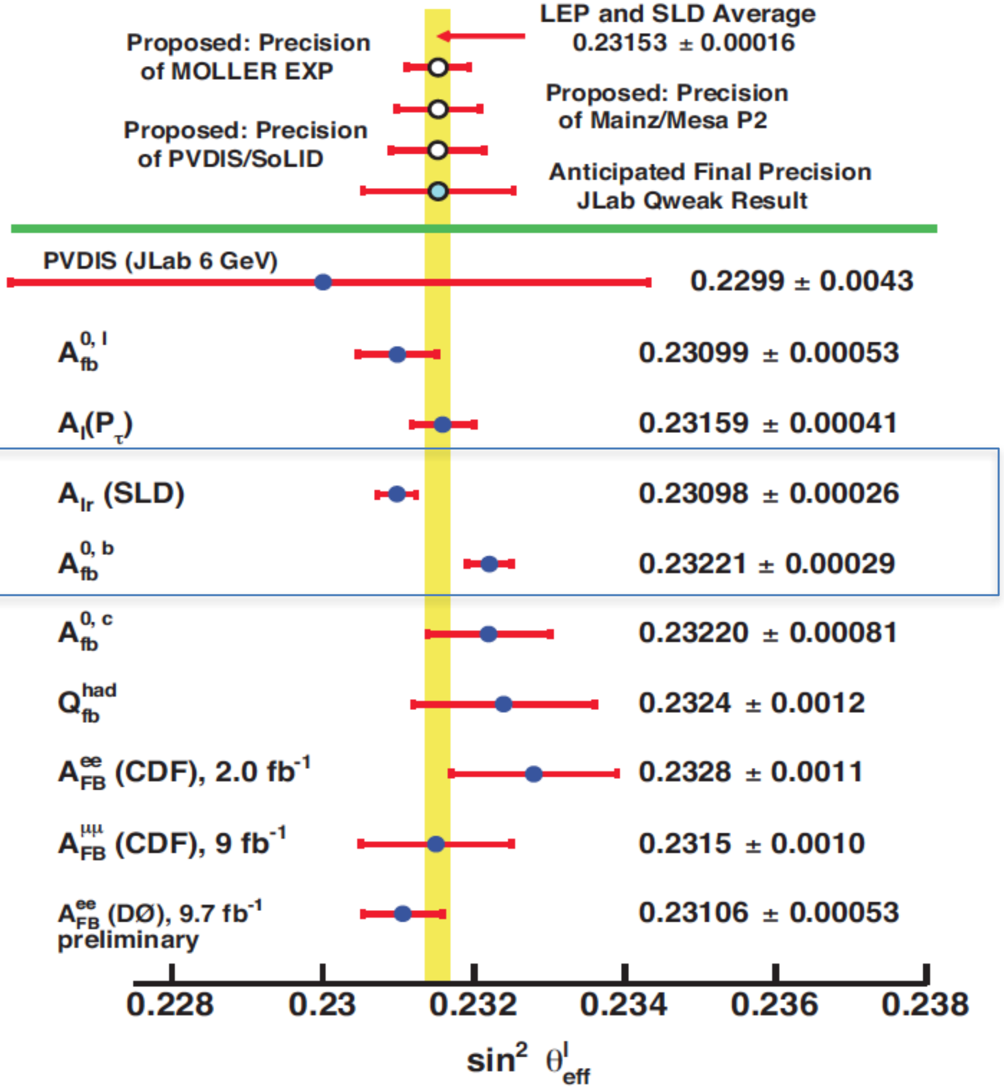
$$m_t = 172.74 \pm 0.46 \text{ GeV}$$

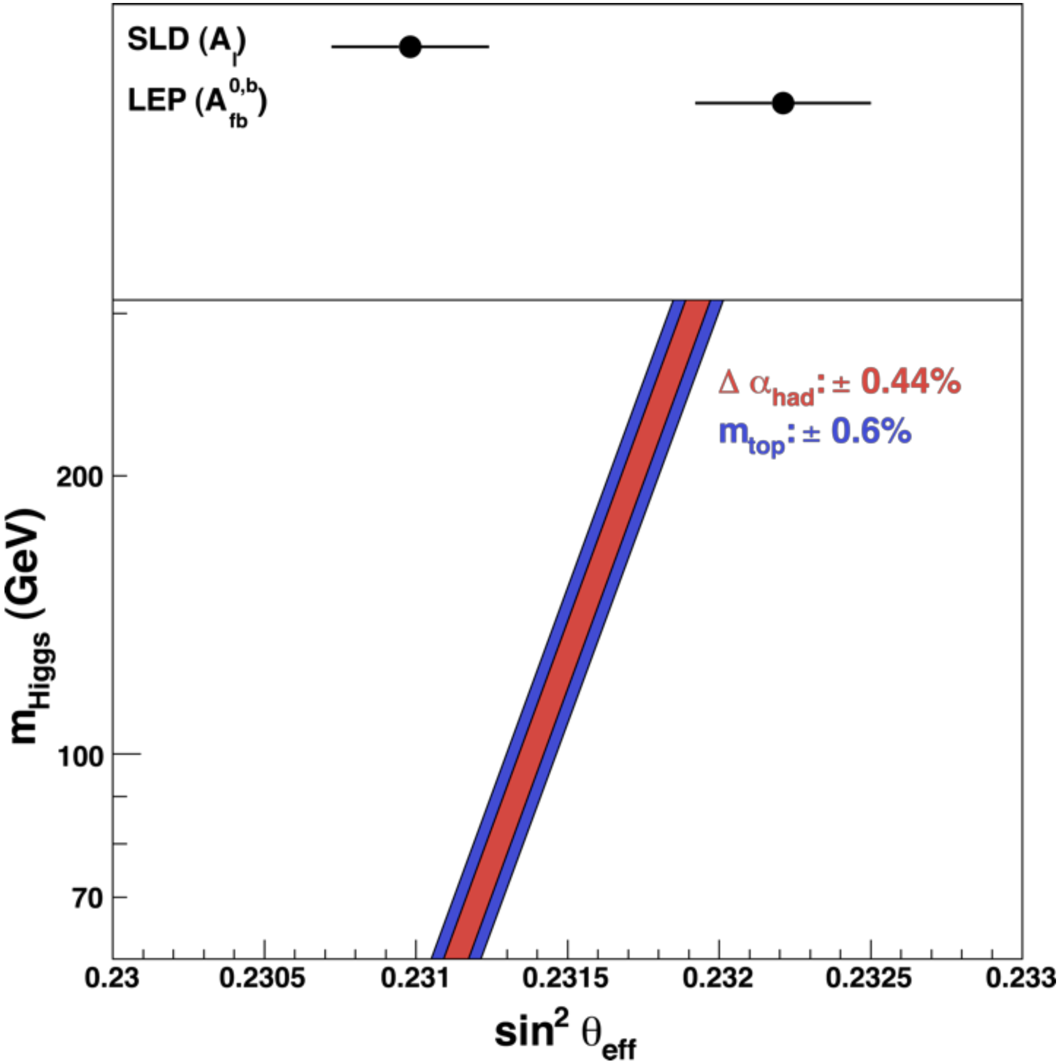
Indirect prediction:

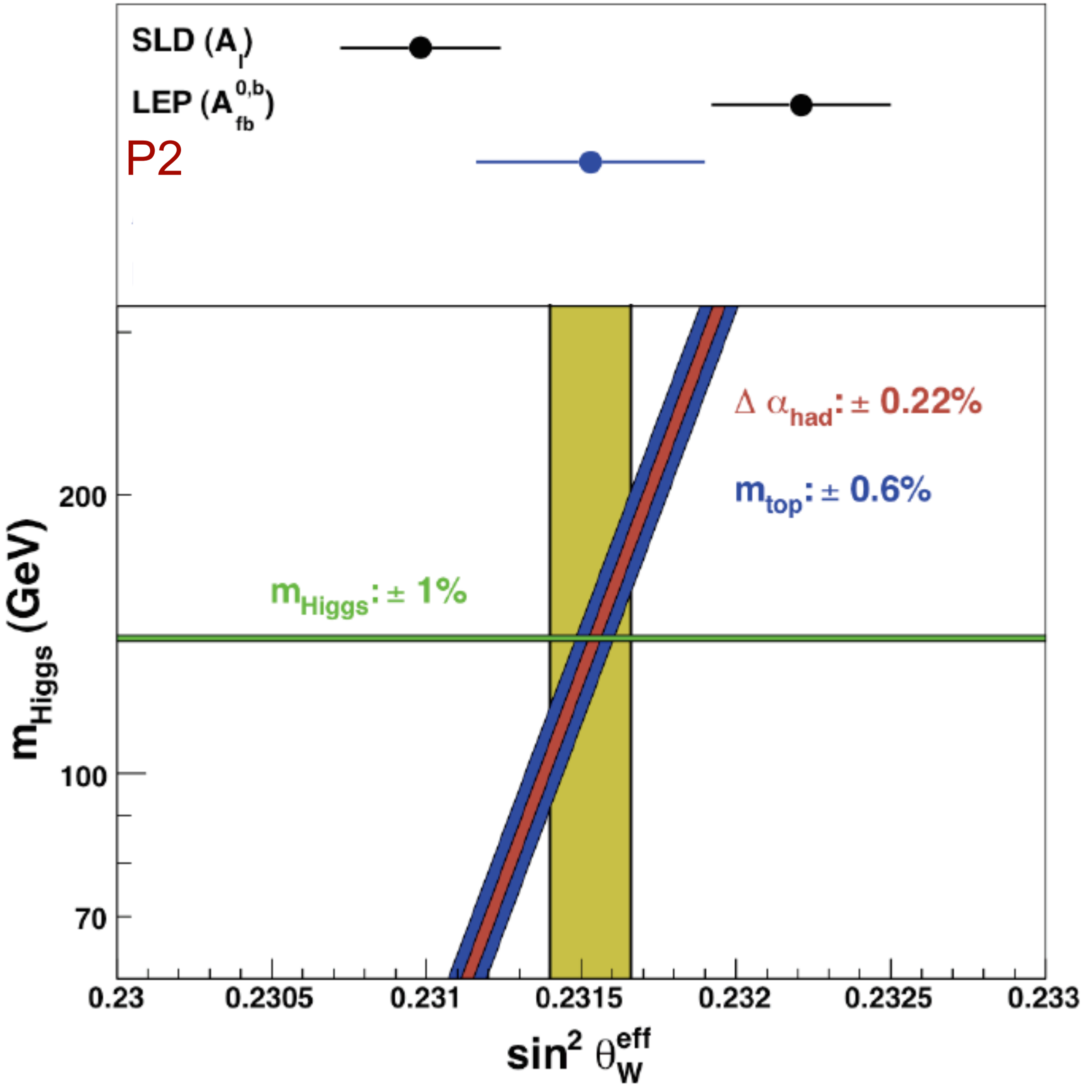
$$M_H = 90^{+17}_{-16} \text{ GeV}$$

$$m_t = 176.4 \pm 1.8 \text{ GeV}$$

Summary: Measurements of $\sin^2\theta_{W(\text{effective})}$

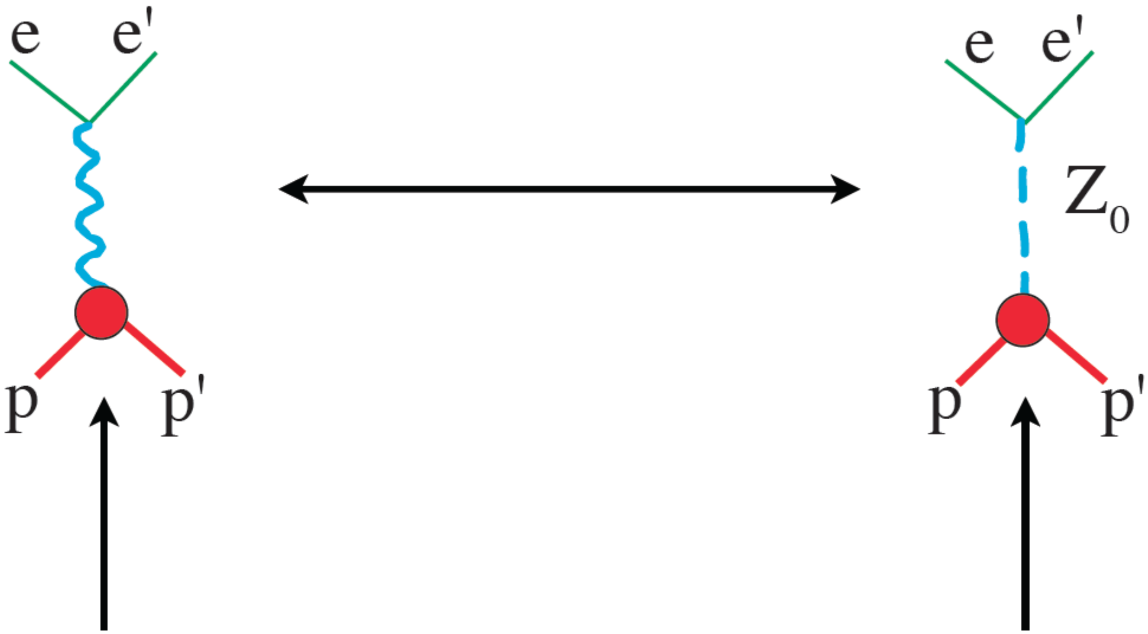



SLD (A_l)
LEP ($A_{fb}^{0,b}$)
$\Delta\,\alpha_{had}$: ± 0.44%
m_{top}: ± 0.6%
m_{Higgs} (GeV)
200
100
70
0.23
0.2305
0.231
0.2315
0.232
0.2325
0.233
$\sin^2\theta_{eff}$


SLD (A_l)
LEP ($A_{fb}^{0,b}$)
P2
$\Delta\ \alpha_{had}$: ± 0.22%
m_{top}: ± 0.6%
m_{Higgs}: ± 1%
m_{Higgs} (GeV)
200
100
70
0.23
0.2305
0.231
0.2315
0.232
0.2325
0.233
$\sin^2 \theta_W^{eff}$

The role of the weak mixing angle

The relative strength between the weak and electromagnetic interaction is determined by the weak mixing angle: $\sin^2(\theta_W)$

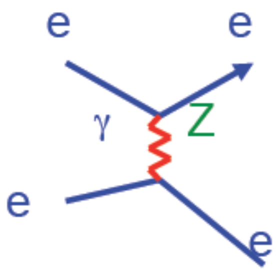


$Q_e(p) = +e$
electric charge of the proton

$Q_W(p) = 1 - 4\sin^2\theta_W$
weak charge of the proton

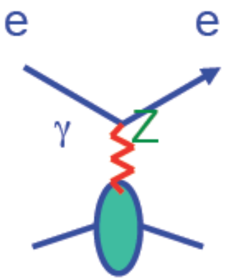
$\sin^2\theta_W$: a central parameter of the standard model

Møller Scattering



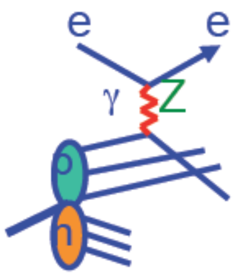
- Purely Leptonic

Q-Weak (JLab)
P2 (Mainz/MESA)



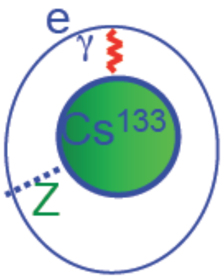
- Coherent quarks in p
- in operation now
- $2(2C_{1u}+C_{1d})$

e-DIS



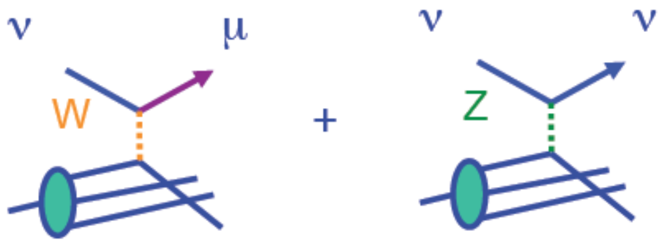
- Isoscaler quark scattering
- $(2C_{1u}-C_{1d})+Y(2C_{2u}-C_{2d})$

Atomic Parity Violation



- Coherent quarks in entire nucleus
- Nuclear structure uncertainties
- $-376\ C_{1u} - 422\ C_{1d}$

Neutrino Scattering

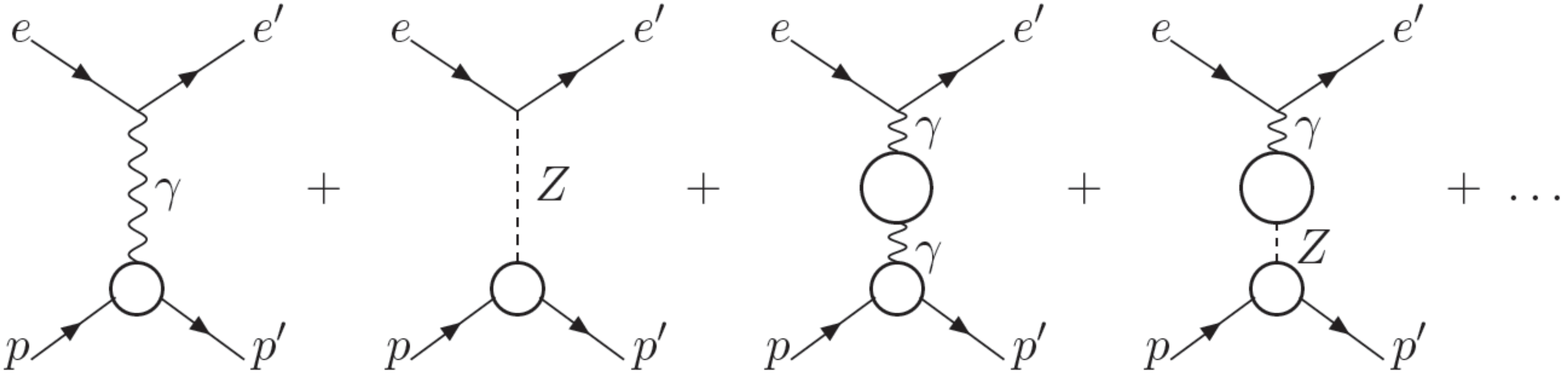


- Quark scattering (from nucleus)
- Weak charged and neutral current difference

Courtesy of P. Reimer and R. Arnold

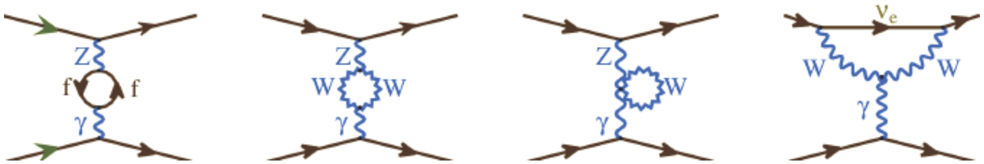
„running“ $\sin^2\theta_{eff}$ or $\sin^2\theta_W(\mu)$

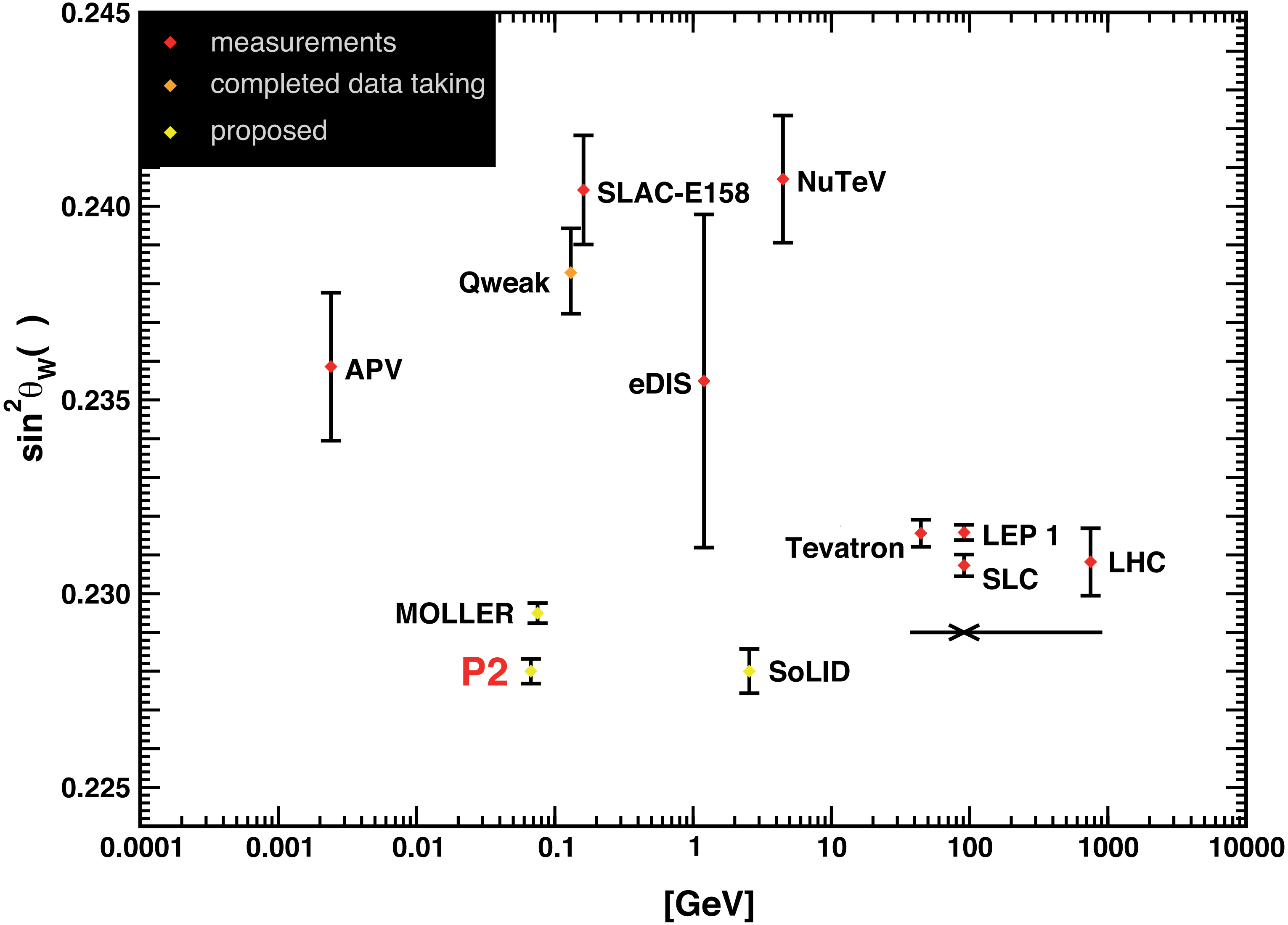
Precision measurements and quantum corrections:



running α running $\sin^2 \theta_W(\mu)$

Universal quantum corrections: can be absorbed into a scale dependent, „running" $\sin^2 \theta_{eff}$ or $\sin^2 \theta_W(\mu)$

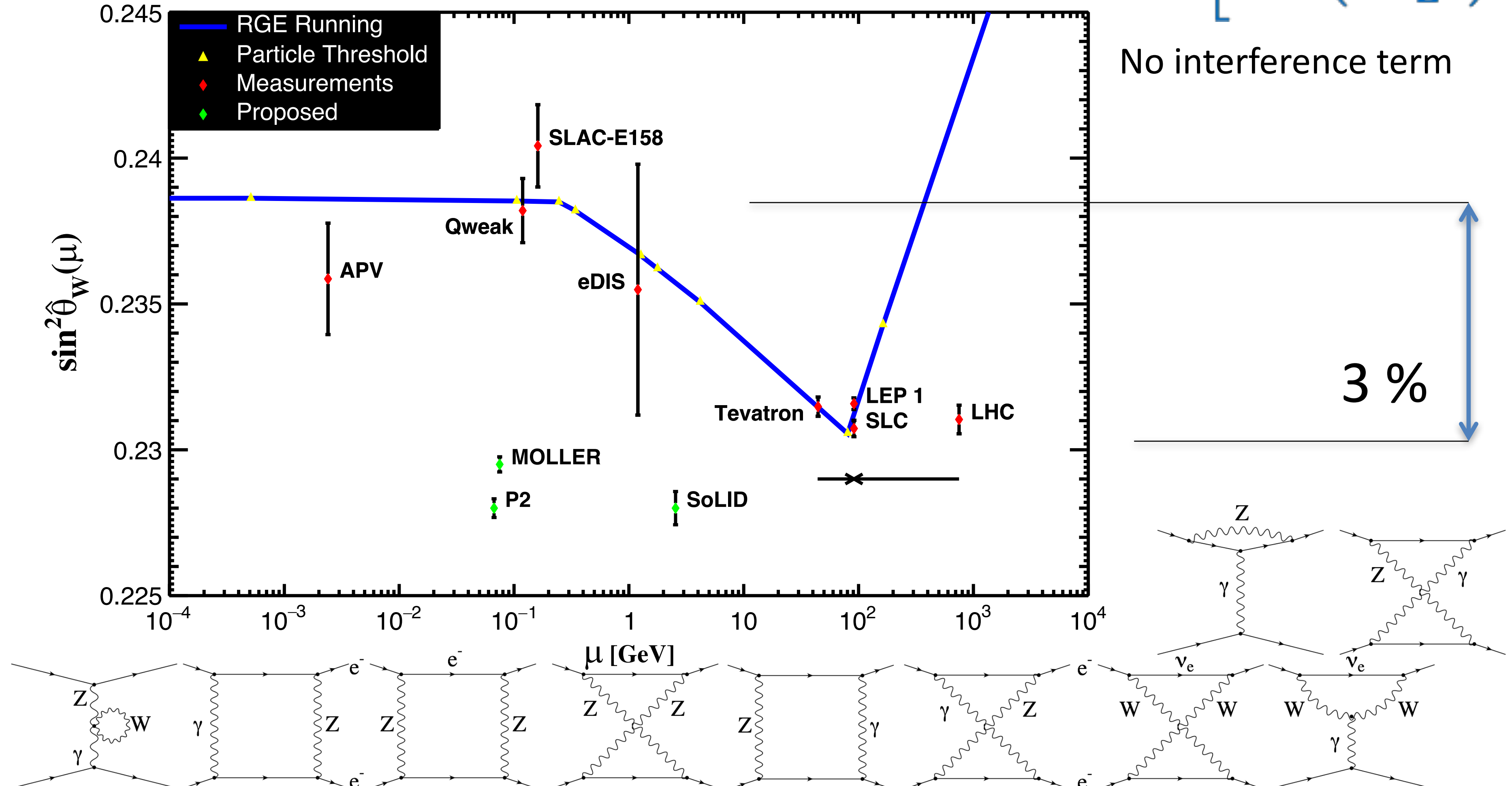



◆ measurements
◆ completed data taking
◆ proposed
$\sin^2\theta_W(\ )$
0.245
0.240
0.235
0.230
0.225
SLAC-E158
NuTeV
Qweak
APV
eDIS
Tevatron
LEP 1
SLC
LHC
MOLLER
P2
SoLID
0.0001
0.001
0.01
0.1
1
10
100
1000
10000
[GeV]

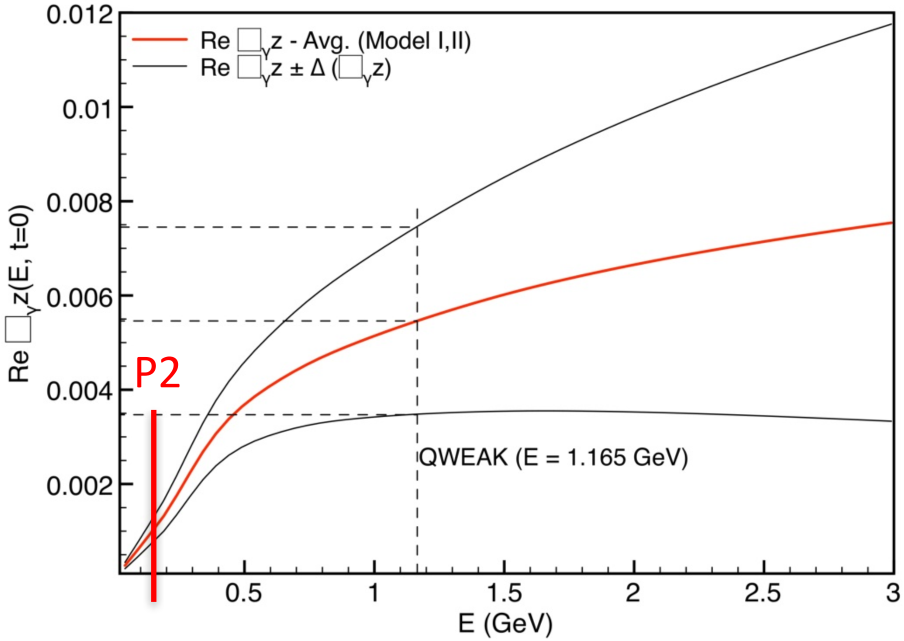
On Z resonance: A_Z is imaginary

$$\left|\mathbf{A_Z} + \mathbf{A_{new}}\right|^2 \rightarrow \mathbf{A_Z^2}\left[\mathbf{1}+\left(\frac{\mathbf{A_{new}}}{\mathbf{A_Z}}\right)^{\mathbf{2}}\right]$$

No interference term

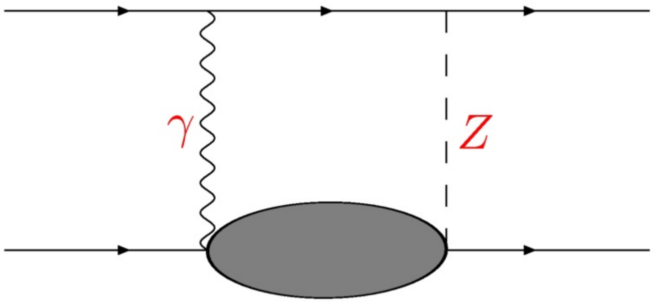


- γZ box graph contributions obtained by modelling hadronic effects:



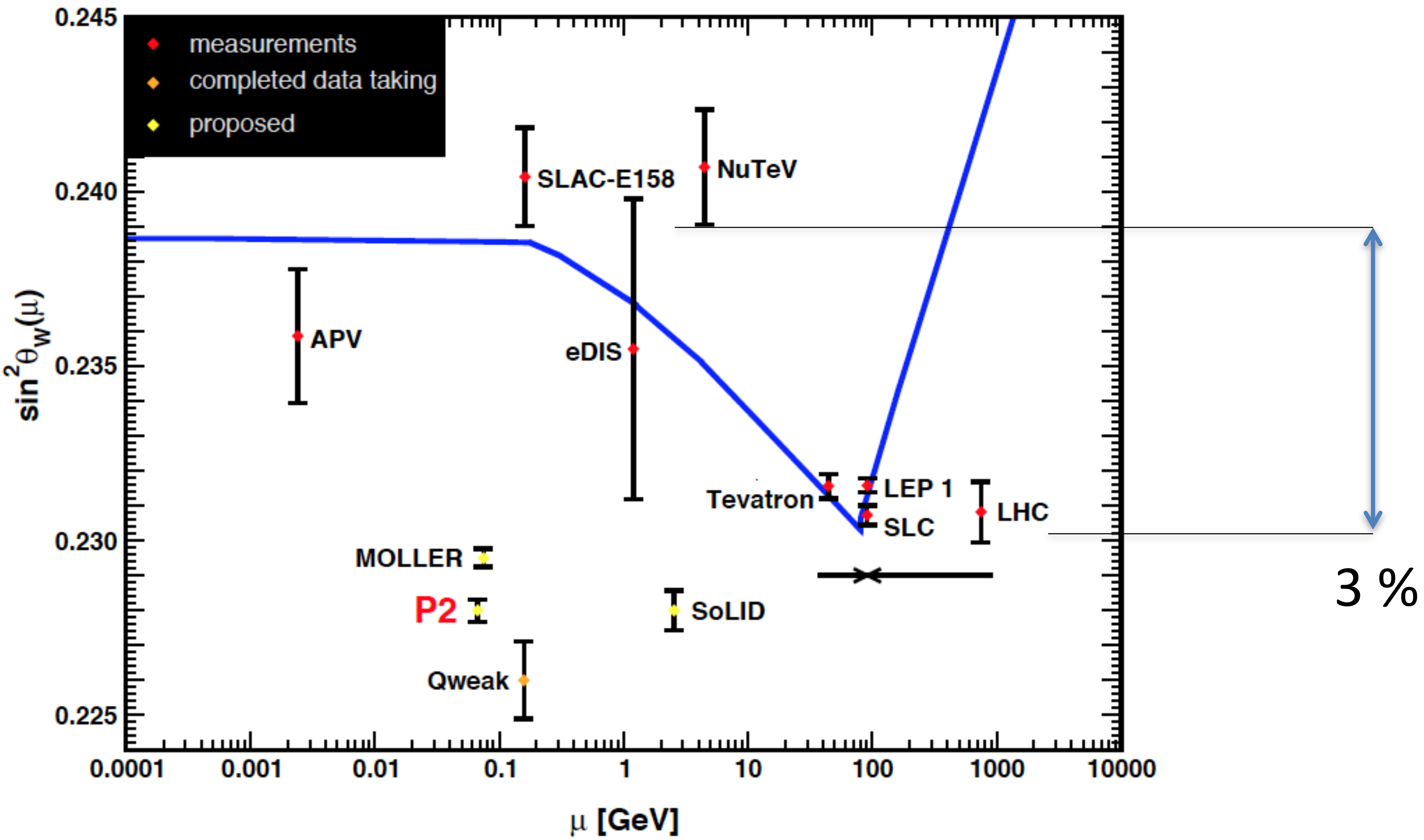
[Gorchstein, Horowitz & Ramsey-Musolf 2011]

- Hadronic uncertainties suppressed at lower energies
- Low beam energy experiment:
  P2 @ MESA



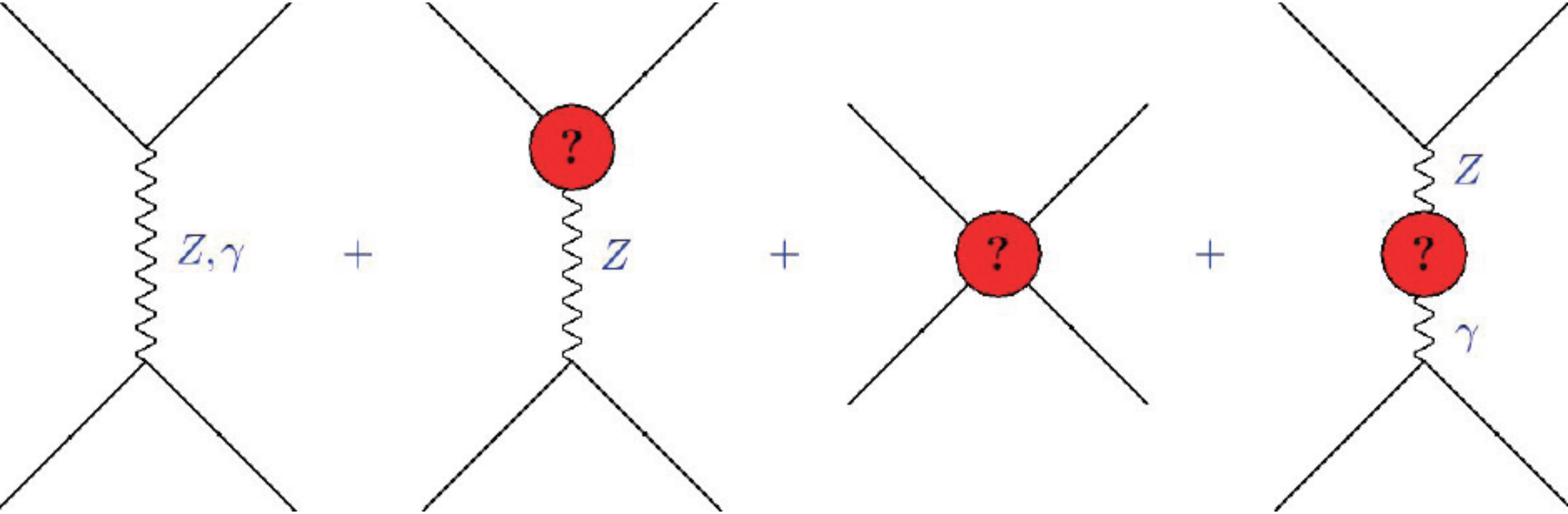
Progress in Theory

- Theory uncertainties in box diagrams
- 2 loop corrections
- Hadronic contributions in loops
- Auxiliary measurements
- PV-asymmetry in Carbon


measurements
completed data taking
proposed
0.245
0.240
0.235
0.230
0.225
$\sin^2\theta_W(\mu)$
0.0001
0.001
0.01
0.1
1
10
100
1000
10000
μ [GeV]
SLAC-E158
NuTeV
APV
eDIS
Tevatron
LEP 1
SLC
LHC
MOLLER
P2
SoLID
Qweak
3 %

Sensitivity to new physics beyond the Standard Model

Sensitivity to new physics beyond the Standard Model



Extra Z

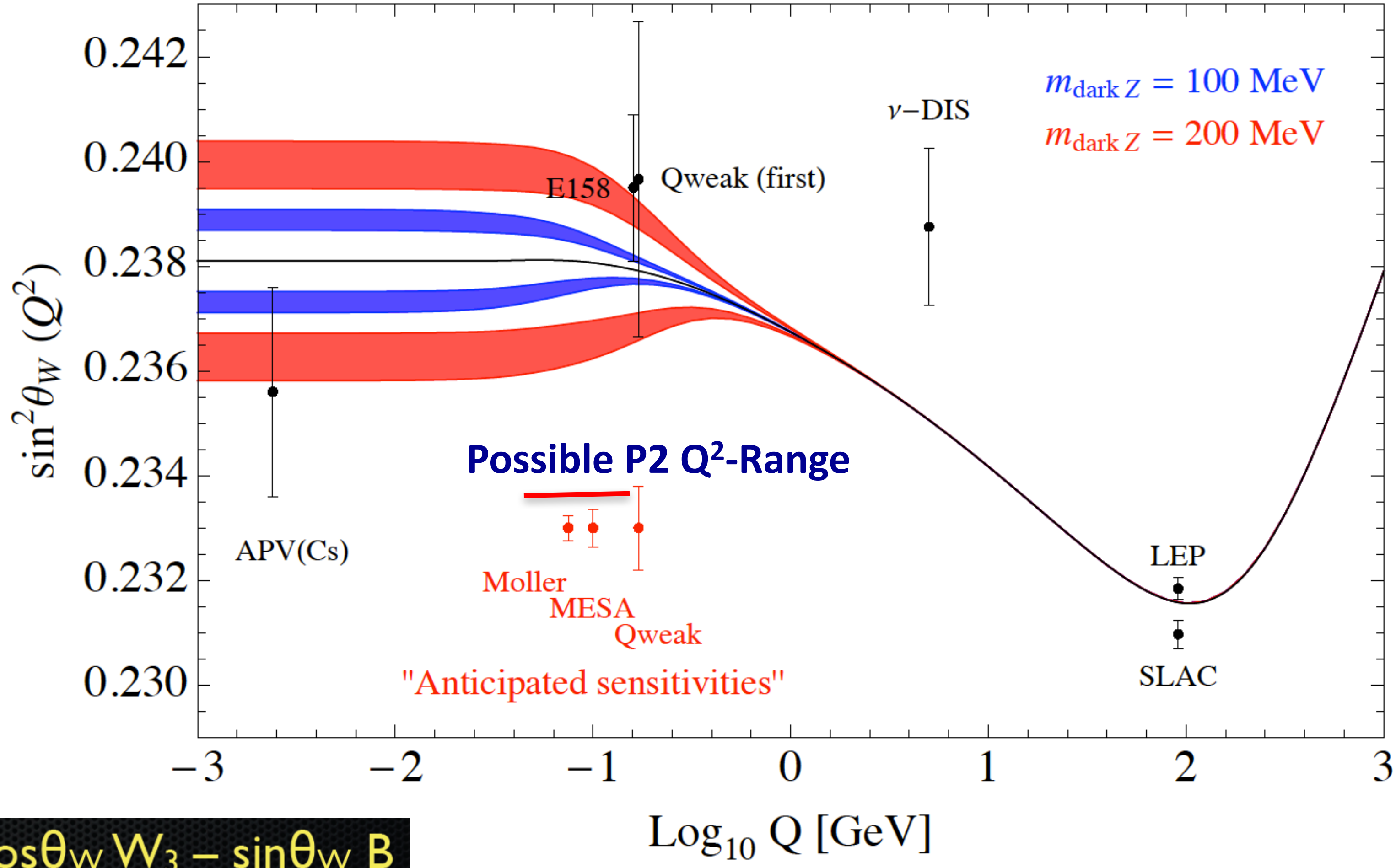
Mixing with
Dark photon or
Dark Z

Contact interaction

New
Fermions

Dark Photon, Z-Boson

Running $\sin^2\theta_W$ and Dark Parity Violation



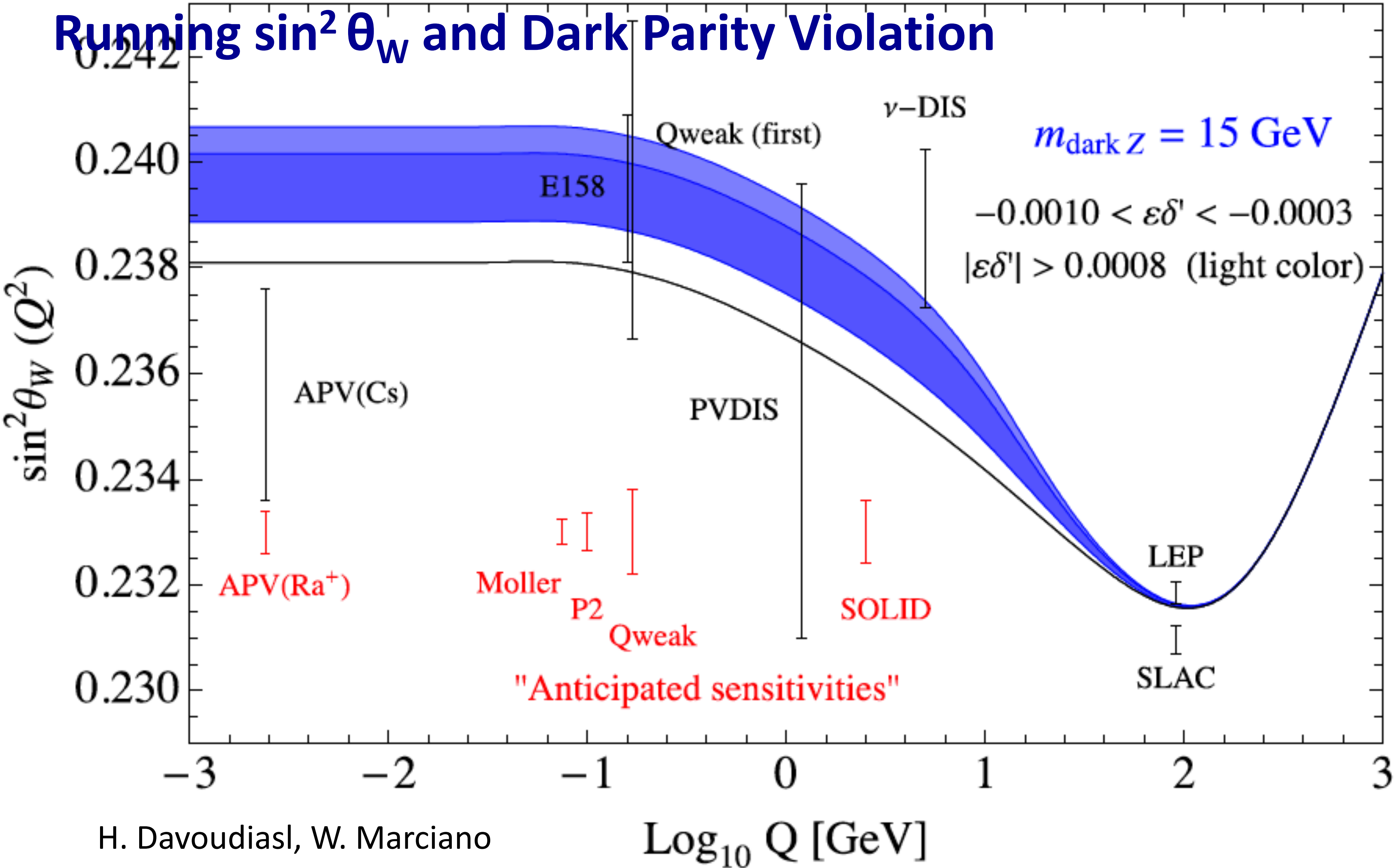
Possible P2 Q^2-Range

$Z = \cos\theta_W W_3 - \sin\theta_W B$

$A = \sin\theta_W W_3 + \cos\theta_W B$

Bill Marciano

Running $\sin^2 \theta_W$ and Dark Parity Violation

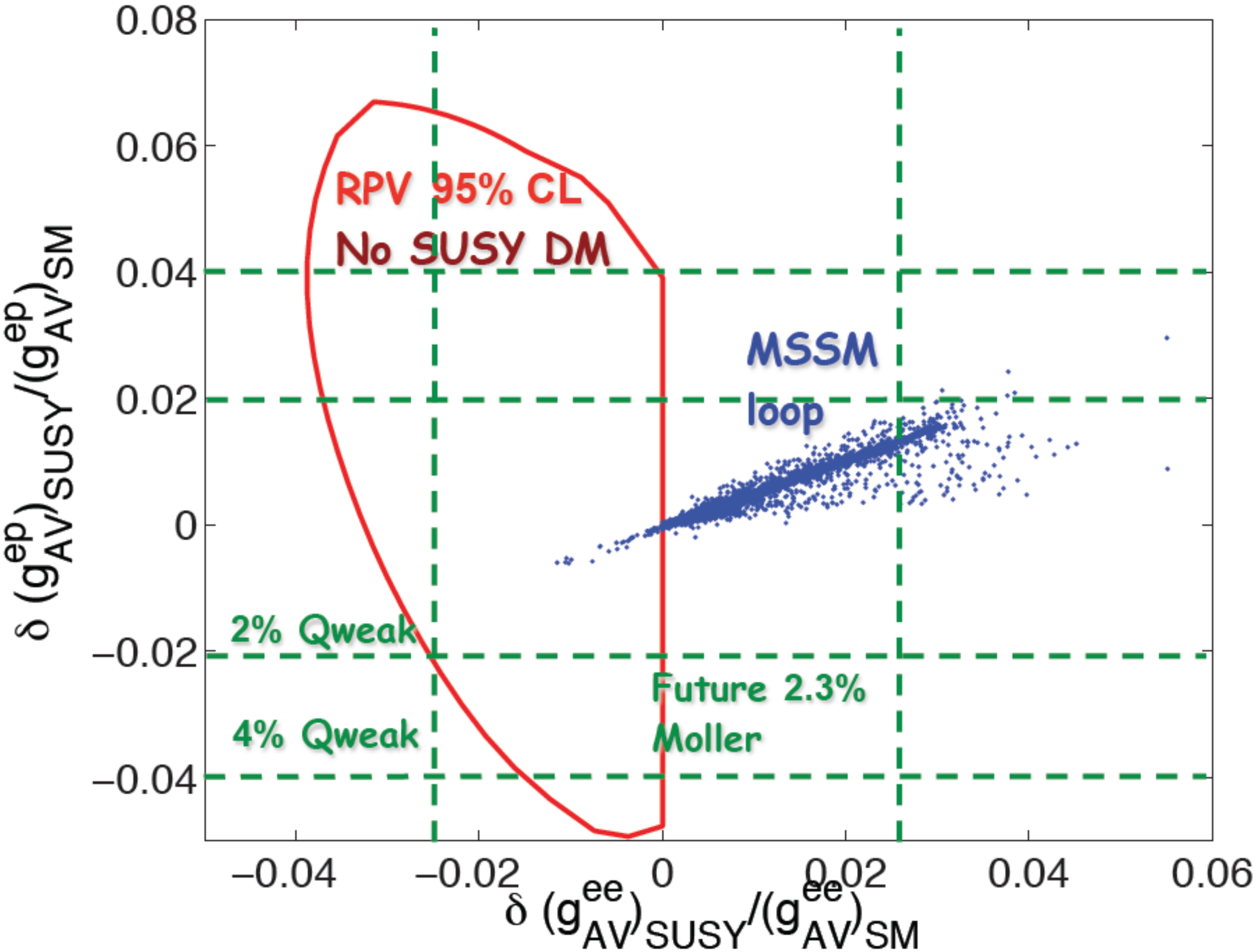


H. Davoudiasl, W. Marciano

Supersymmetry

Example: Supersymmetric standard model extensions

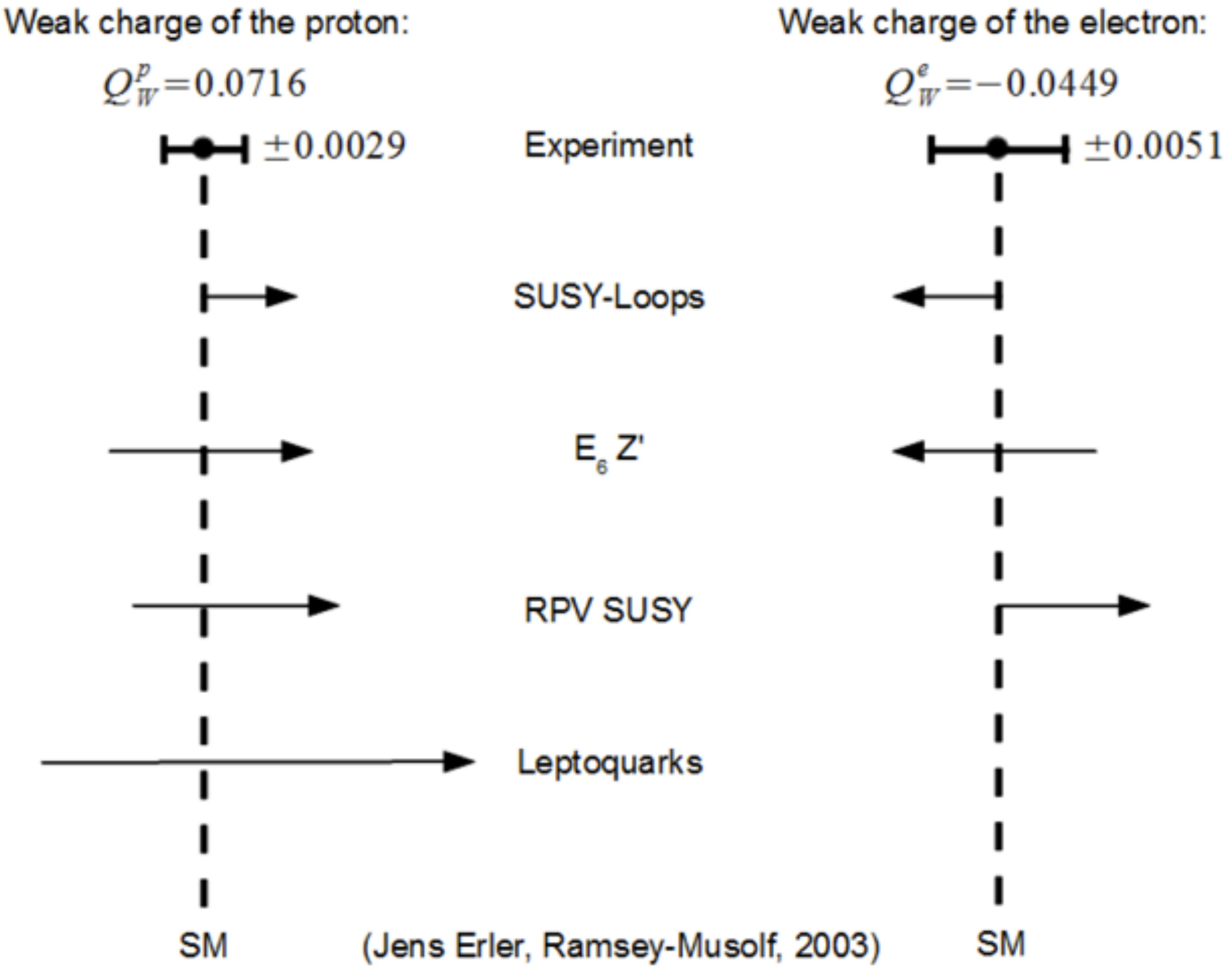
Kurylov, Ramsey-Musolf, Su (2003), updated



After LHC
Run 1

X. Su

- Complementary access by weak charges of proton and electron



Weak charge of the proton:

$Q_W^p = 0.0716$

Weak charge of the electron:

$Q_W^e = -0.0449$

± 0.0029 Experiment ± 0.0051

SUSY-Loops

E_6 Z'

RPV SUSY

Leptoquarks

SM (Jens Erler, Ramsey-Musolf, 2003) SM

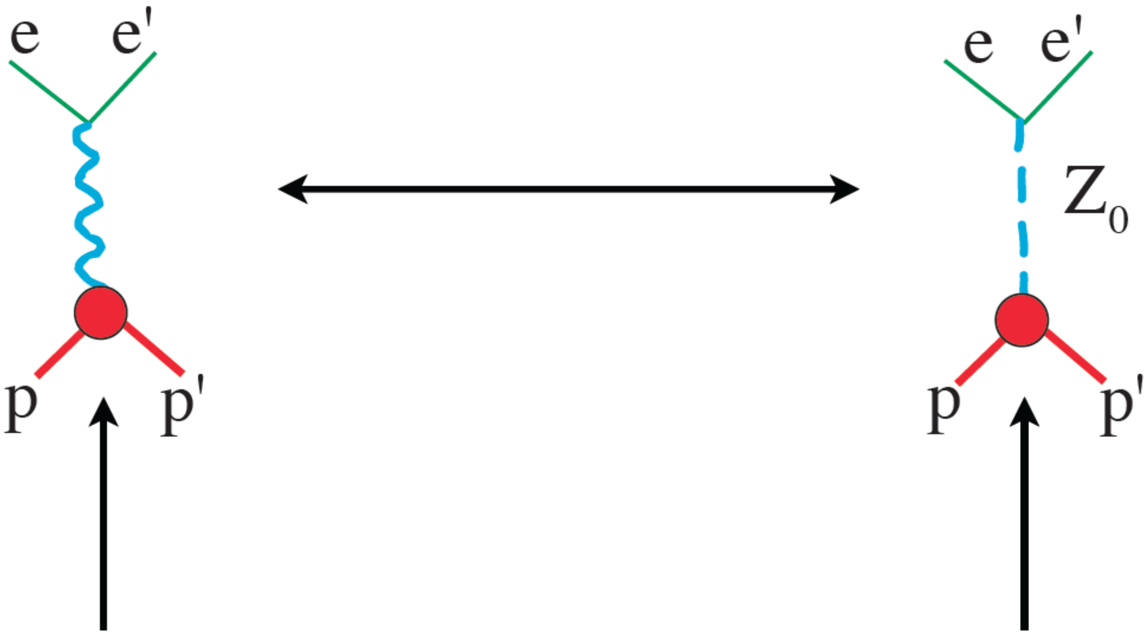
Weak
Charge
Of
Proton:
Qweak (Jlab),
P2 (MESA)

Weak
Charge
Of
Electron:
MOELLER
(JLAB)

Weak
Charge
Of
Quarks:
SOLID
(PVDIS)
(JLAB)

The role of the weak mixing angle

The relative strength between the weak and electromagnetic interaction is determined by the weak mixing angle: $\sin^2(\theta_W)$



$Q_e(p) = +e$
electric charge of the proton

$Q_W(p) = 1 - 4\sin^2\theta_W$
weak charge of the proton

$\sin^2\theta_W$: a central parameter of the standard model

Proton: special case

Proton Weak charge: $Q_W(p) = 1 - 4\sin^2\theta_W$

Error: $\Delta Q_W(p) = 4\,\Delta\sin^2\theta_W$

Rel. error: $\Delta Q_W(p)/Q_W(p) = 4/\left((1/\sin^2\theta_W) - 4 \right) \; (\Delta\sin^2\theta_W/\sin^2\theta_W)$

Rel. error $\Delta\sin^2\theta_W/\sin^2\theta_W = \left((1/\sin^2\theta_W) - 4 \right)/4 \;\; \Delta Q_W(p)/Q_W(p)$

Example: $\sin^2\theta_W\,(50\text{ MeV}) = 0.238$

$4/\left((1/\sin^2\theta_W) - 4 \right) \sim 20$

$\Delta Q_W(p)/Q_W(p) = 2\%$ from Experiment

$\Delta\sin^2\theta_W/\sin^2\theta_W = 0.1\,\%$ same precision as LEP, SLAC

Neutron Weak charge:

$\Delta Q_W(p)/Q_W(n) = \Delta\sin^2\theta_W/\sin^2\theta_W$

Future wEFT constraints from APV and PVES

Adam Falkowski at Mainz MITP workshop: Impact on low energy measurements

Current QWEAK, PVDIS, and APV cesium experiments:

$$\begin{pmatrix} \delta g^{eu}_{AV} \\ \delta g^{ed}_{AV} \\ 2\delta g^{eu}_{VA} - \delta g^{ed}_{VA} \end{pmatrix} = \begin{pmatrix} 0.74 \pm 2.2 \\ -2.1 \pm 2.5 \\ -39 \pm 54 \end{pmatrix} \times 10^{-3}$$

Projections from combined P2, SoLID, and APV radium experiments:

$$\begin{pmatrix} \delta g^{eu}_{AV} \\ \delta g^{ed}_{AV} \\ 2\delta g^{eu}_{VA} - \delta g^{ed}_{VA} \end{pmatrix} = \begin{pmatrix} 0 \pm 0.70 \\ 0 \pm 0.97 \\ 0 \pm 7.4 \end{pmatrix} \times 10^{-3}$$

$$\mathcal{L}_{\rm wEFT} \supset -\frac{1}{2v^2} \sum_{q=u,d} g^{eq}_{AV} (\bar{e}\,\bar{\sigma}_\rho e - e^c \sigma_\rho \bar{e}^c)(\bar{q}\,\bar{\sigma}^\rho q + q^c \sigma^\rho \bar{q}^c)$$

$$-\frac{1}{2v^2} \sum_{q=u,d} g^{eq}_{VA} (\bar{e}\,\bar{\sigma}_\rho e + e^c \sigma_\rho \bar{e}^c)(\bar{q}\,\bar{\sigma}^\rho q - q^c \sigma^\rho \bar{q}^c)$$

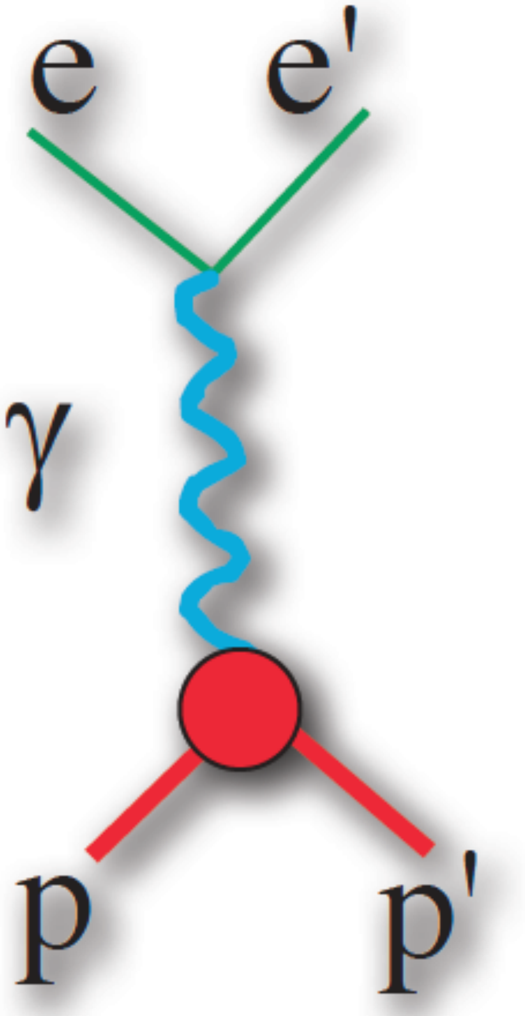
AA, Grilli Di Cortona, Tabrizi
1802.08296

AA, Gonzalez-Alonso
in progress

Physics sensitivity from contact interaction (LEP2 convention, $g^2 = 4\text{pi}$)

	precision	$\Delta \sin^2\bar{\theta}_W(0)$	Λ_{new} (expected)
APV Cs	0.58 %	0.0019	32.3 TeV
E158	14 %	0.0013	17.0 TeV
Qweak I	19 %	0.0030	17.0 TeV
Qweak final	4.5 %	0.0008	33 TeV
PVDIS	4.5 %	0.0050	7.6 TeV
SoLID	0.6 %	0.00057	22 TeV
MOLLER	2.3 %	0.00026	39 TeV
P2	2.0 %	0.00036	49 TeV
PVES ^{12}C	0.3 %	0.0007	49 TeV

Experimental Method:
Parity Violating Electron Scattering



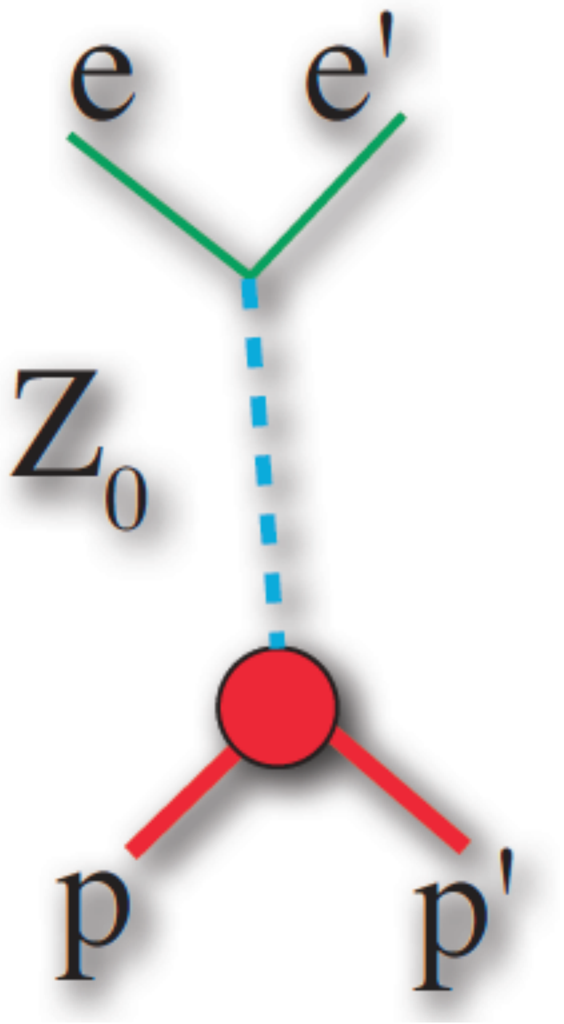
$$\sigma \sim \mathcal{M}\,\mathcal{M}^{*}\ \text{Phasespace}$$

$$\sim \left(j_\mu \frac{1}{Q^2} J^\mu\right)\left(j_\mu \frac{1}{Q^2} J^\mu\right)^{*}$$

$$j_\mu \sim \overline{e}\,\gamma_\mu\, e\ \ \text{Vector Current}$$

$$J^\mu_\gamma \sim \left\langle N \middle| q^u \overline{u}\,\gamma_\mu\, u + q^d \overline{d}\,\gamma_\mu d + q^s \overline{s}\,\gamma_\mu s \middle| N' \right\rangle$$

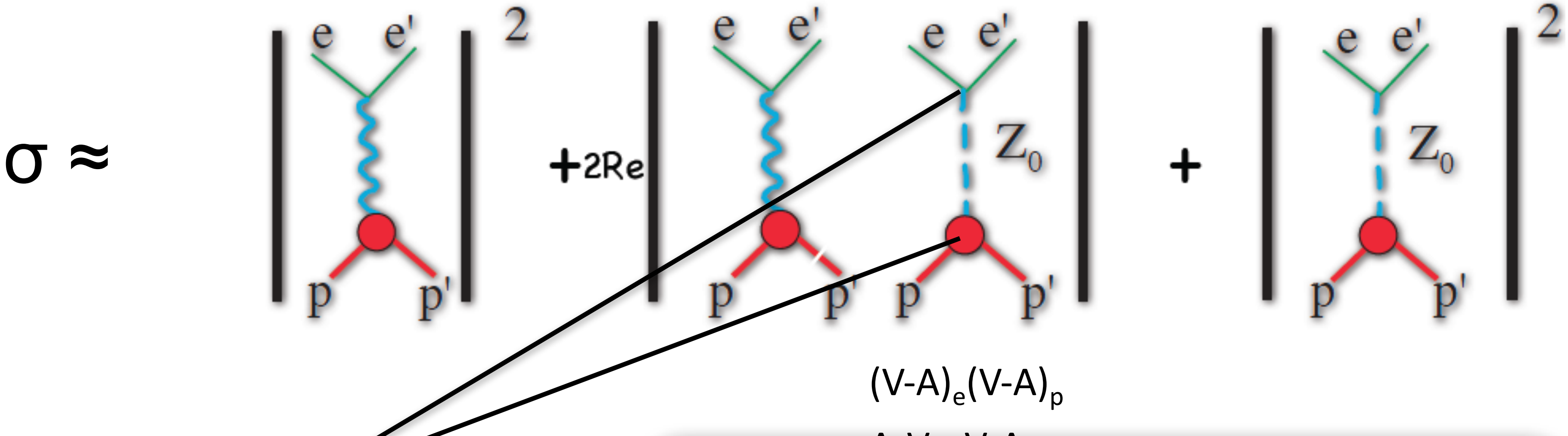
$$= \overline{\mathcal{P}}\left[\gamma^\mu F_1 - i\sigma^{\mu\nu} q_\nu \frac{\kappa_p}{2M_N} F_2\right]\mathcal{P}$$



$$\tilde{q}^{d}{}_{V} \quad = \quad \tau_3 - 2q^{d} sin^2(\theta_W)$$

$$\begin{aligned} \tilde{J}^{\mu}_{Z} \;&\sim\; \left\langle N|\tilde{q}^{u}\overline{u}\,\gamma_\mu\, u + \tilde{q}^{d}\overline{d}\,\gamma_\mu d + \tilde{q}^{s}\overline{s}\,\gamma_\mu s|N'\right\rangle \\ &=\; \overline{\mathcal{P}}[\gamma^{\mu}\tilde{F}_1 - i\sigma^{\mu\nu}q_\nu \frac{\kappa_p}{2M_N}\tilde{F}_2]\mathcal{P} \end{aligned}$$

Parity Violating Asymmetry in elastic electron proton scattering



$(V\text{-}A)_e(V\text{-}A)_p$

$A_eV_p+V_eA_p$

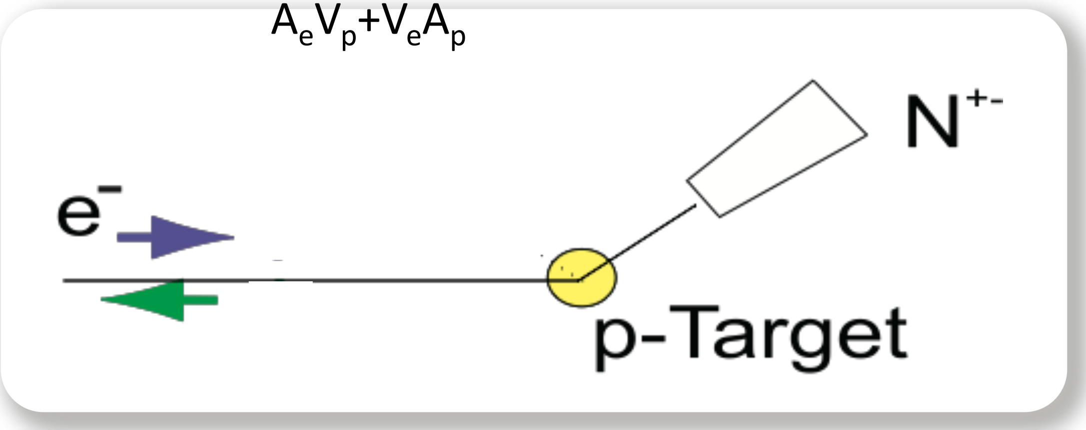
V-A coupling:

parity-violating

cross section asymmetry A_{LR}

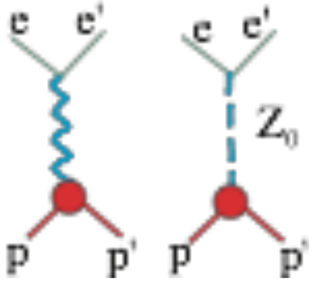
longitudinally pol. electrons

unpolarised protons



Parity violating cross section asymmetry

$$A_{ep} = \left[\frac{G_F\, Q^2}{4\pi\alpha\sqrt{2}}\right] \frac{\epsilon G_E^{\gamma} G_E^{Z} + \tau G_M^{\gamma} G_M^{Z} - (1-4\sin^2\theta_W)\epsilon' G_M^{\gamma} G_A^{Z}}{\varepsilon (G_E^{\gamma})^2 + \tau (G_M^{\gamma})^2}$$



$$A_{\mathrm{RL}} = \underbrace{A_{\mathrm{V}} + A_{\mathrm{A}}}_{= A_0} + A_{\mathrm{S}} \begin{cases} A_{\mathrm{V}} = -a\rho'_{eq}\left[(1-4\sin^2\theta_W) - \dfrac{\epsilon G_E^p G_E^n + \tau G_M^p G_M^n}{\epsilon (G_E^p)^2 + \tau (G_M^p)^2}\right] \\ A_{\mathrm{A}} = a\dfrac{(1-4\sin^2\theta_W)\sqrt{1-\epsilon^2}\sqrt{\tau(1+\tau)}G_M^p \tilde{G}_A^p}{\epsilon (G_E^p)^2 + \tau (G_M^p)^2} \\ A_{\mathrm{S}} = a\rho'_{eq}\dfrac{\epsilon G_E^p G_E^s + \tau G_M^p G_M^s}{\epsilon (G_E^p)^2 + \tau (G_M^p)^2} \end{cases}$$

e

$$a = -G_F q^2/4\pi\alpha\sqrt{2}, \quad \tau = -q^2/4M_{\mathrm{p}}^2, \quad \epsilon = [1 + 2(1+\tau)\tan^2\theta/2]^{-1}$$

P2 back angle measurement

Proton structure: Parameterized by form factors

$$F_{EM}\left(Q^2\right)=\frac{\varepsilon G_E^p G_E^n+\tau G_M^p G_M^n}{\varepsilon\left(G_E^p\right)^2+\tau\left(G_M^p\right)^2}$$

sufficiently enough known

$$F_{axial}\left(Q^2\right)=\frac{\left(1-4s_z^2\right)\sqrt{1-\varepsilon^2}\sqrt{\tau(1+\tau)}G_M^p G_A}{\varepsilon\left(G_E^p\right)^2+\tau\left(G_M^p\right)^2}$$

suppressed by weak charge

vanishes for Θ $\theta\to$

but large uncertainty for G_A

$$F_{Strange}\left(Q^2\right)=\frac{\varepsilon G_E^p G_E^s+\tau G_M^p G_M^s}{\varepsilon\left(G_E^p\right)^2+\tau\left(G_M^p\right)^2}$$

G_E^s sufficiently enough known

but large uncertainty for G_M^s

where $\tau=\frac{Q^2}{4M_p^2}$ and $\varepsilon=\frac{1}{1+2(1+\tau)\tan^2\frac{\theta}{2}}$

P2 Backward angle measurement

Beam energy: 155 MeV
Scattering angle: 140° < Θ < 150°

	Hydrogen	Deuterium
Rate	77.3 MHz	104.3 MHz
Asymmetry	-4.6 ppm	-5.2 ppm

P2 Backward angle measurement

Beam energy: 105 MeV
Scattering angle: 140° < Θ < 150°

	Hydrogen	Deuterium
Rate	135 MHz	174 MHz
Asymmetry	-2.1 ppm	-2.3 ppm

Possible back angle measurements

- **Option A:**
  Back angle measurement on hydrogen parallel to P2 main experiment

Advantage: - Very precise determination of A_{PV}
Disadvantages: - Gives only a linear combination of G_M^s and G_A
- Momentum transfer Q^2=0.1 GeV^2 does not match the main experiment's $Q^2 \approx 0.0049$ GeV^2

- **Option B:**
  Dedicated back angle measurements on hydrogen and deuterium with lower beam energy E = 105 MeV

Advantage: - Separate determination of G_M^s and G_A with better matching Q^2
- Back angle setup alone requires less space in ExHall 4

Disadvantage: - Requires additional beam time, assume here 1000h each

Parity violating cross section asymmetry

tracking system

weak charge

$$A_{LR} = \frac{\sigma(e\uparrow)-\sigma(e\downarrow)}{\sigma(e\uparrow)+\sigma(e\downarrow)} = -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\left(Q_W - F(Q^2)\right)$$

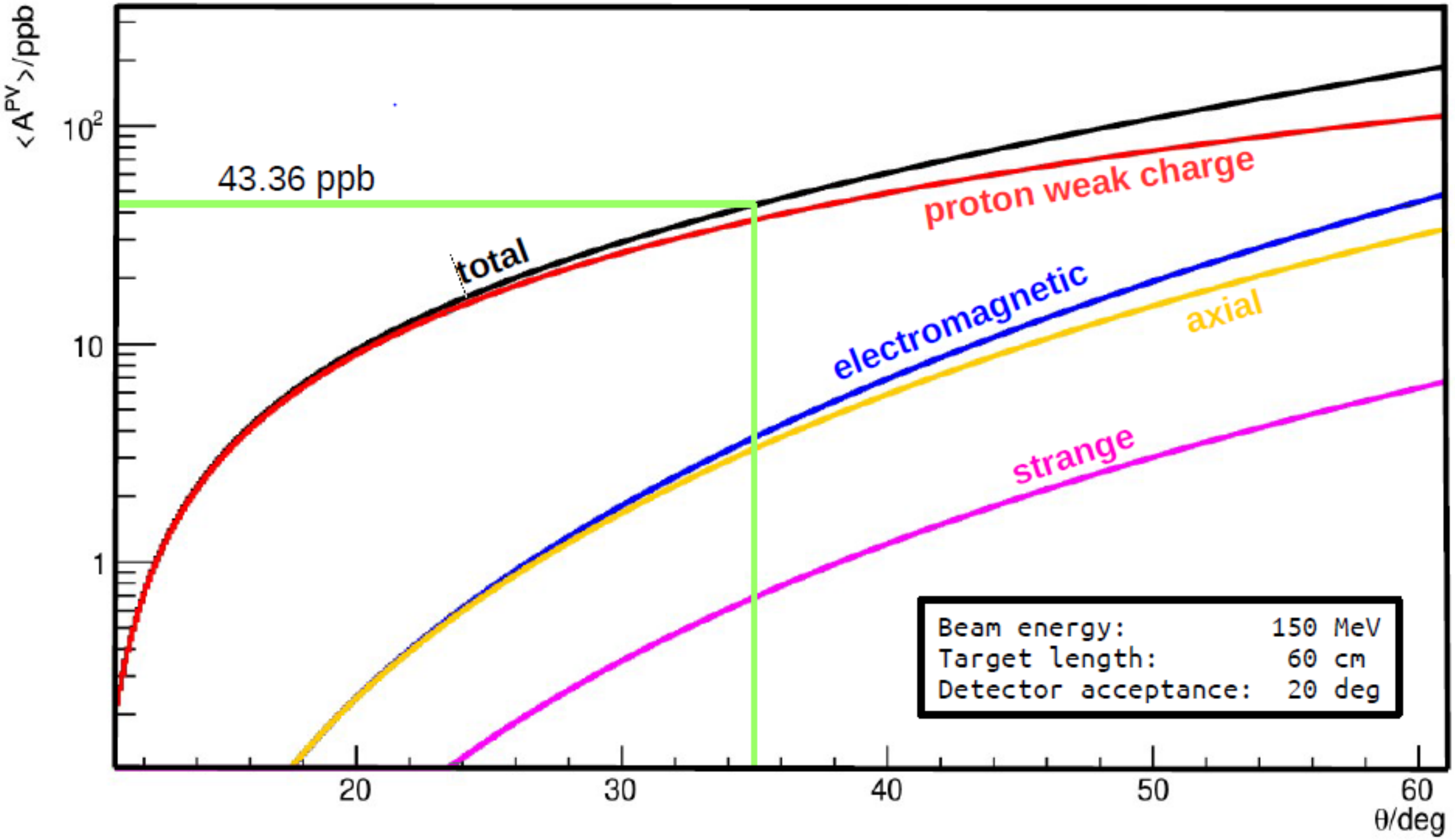
polarisation measurement

hadron structure

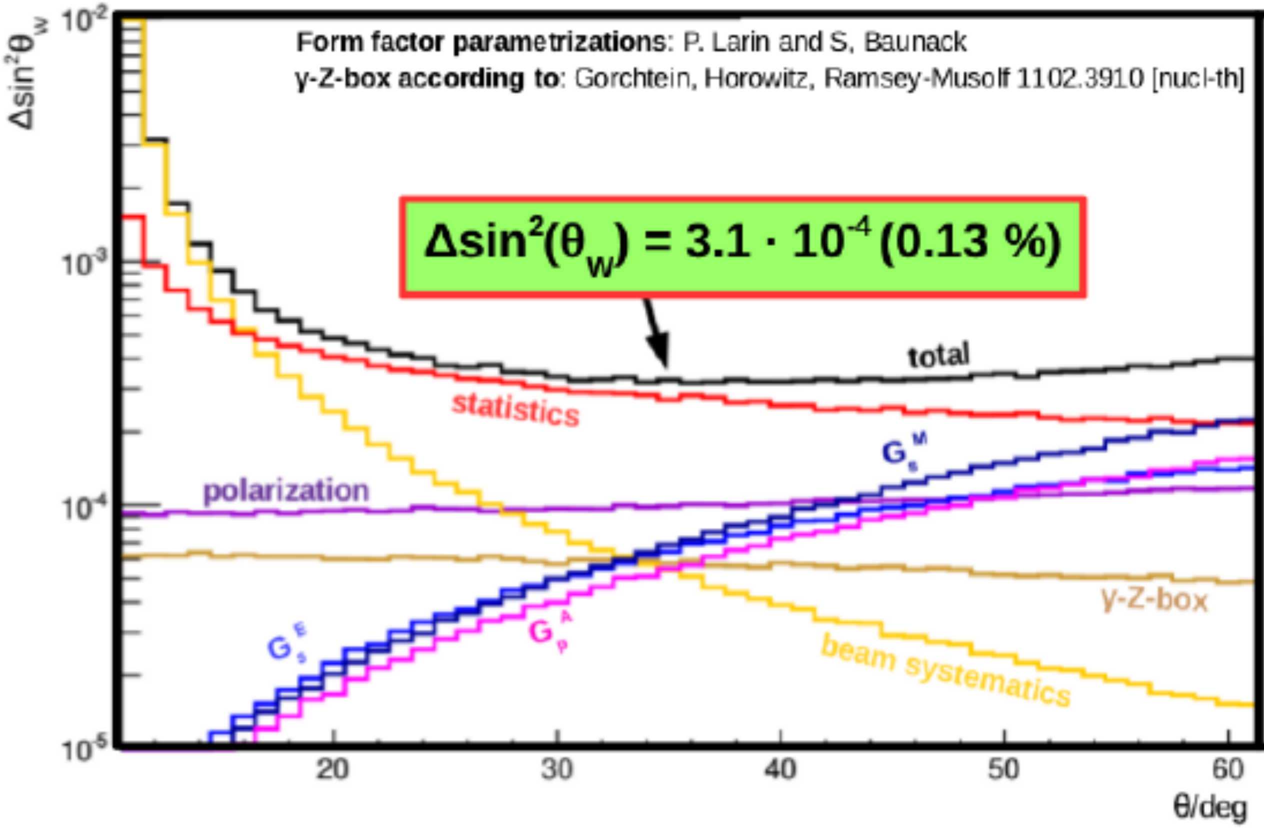
$$Q_W = 1-4\sin^2\theta_W(\mu)$$

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

- Contributions to $\Delta\sin^2\Theta_W$ for 35° central scattering angle, E=150 MeV, 10000 h of data taking



P2-Precision in $\sin^2\theta_W$



Beam energy: 155 MeV

Beam current: 150 µA

Polarization: (85±0.5)%

Target: 60 cm lH2

Acceptance: 2π·(35°±10°)

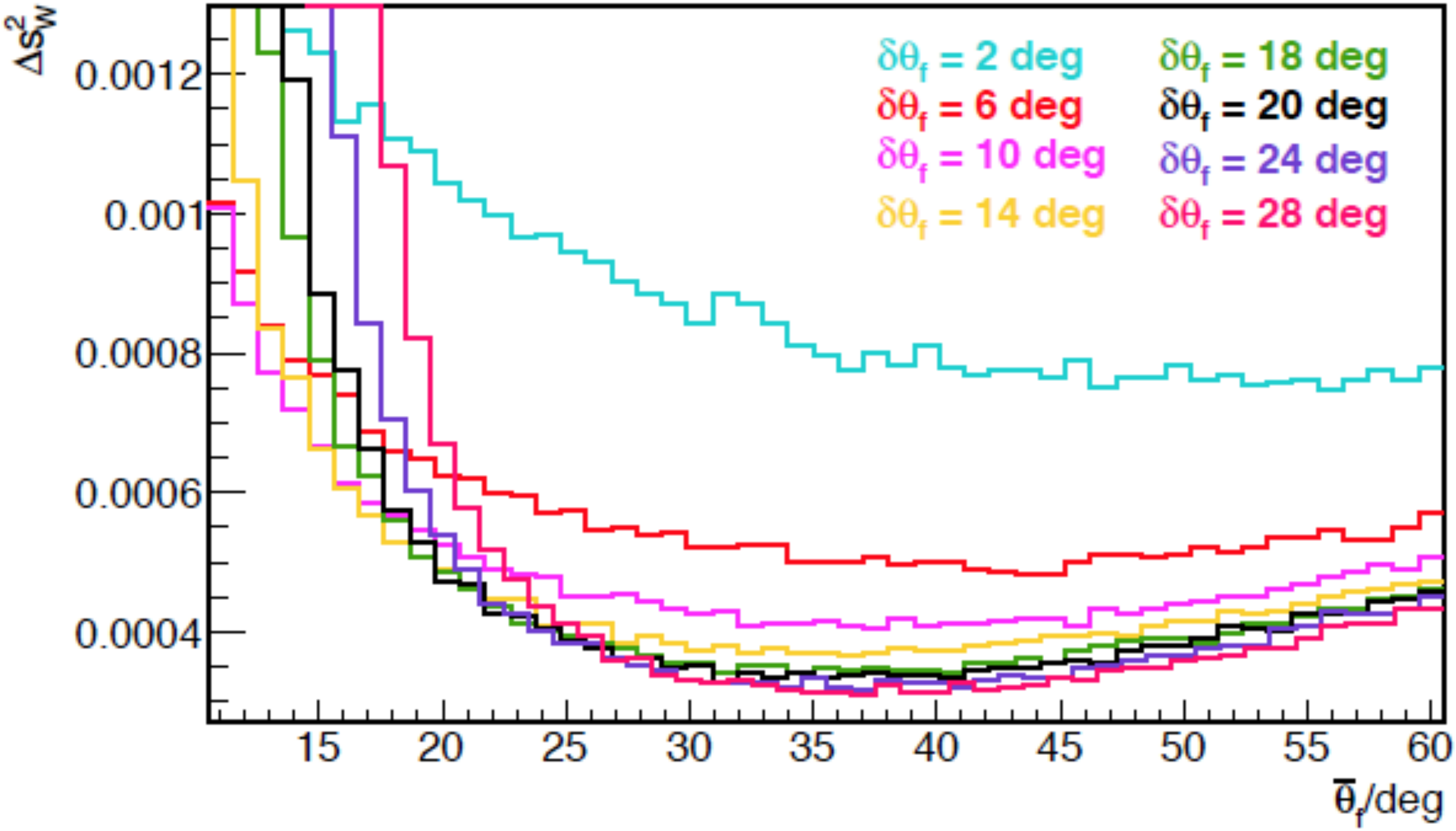
Rate: 0.5 THz

Runtime: 10000 h

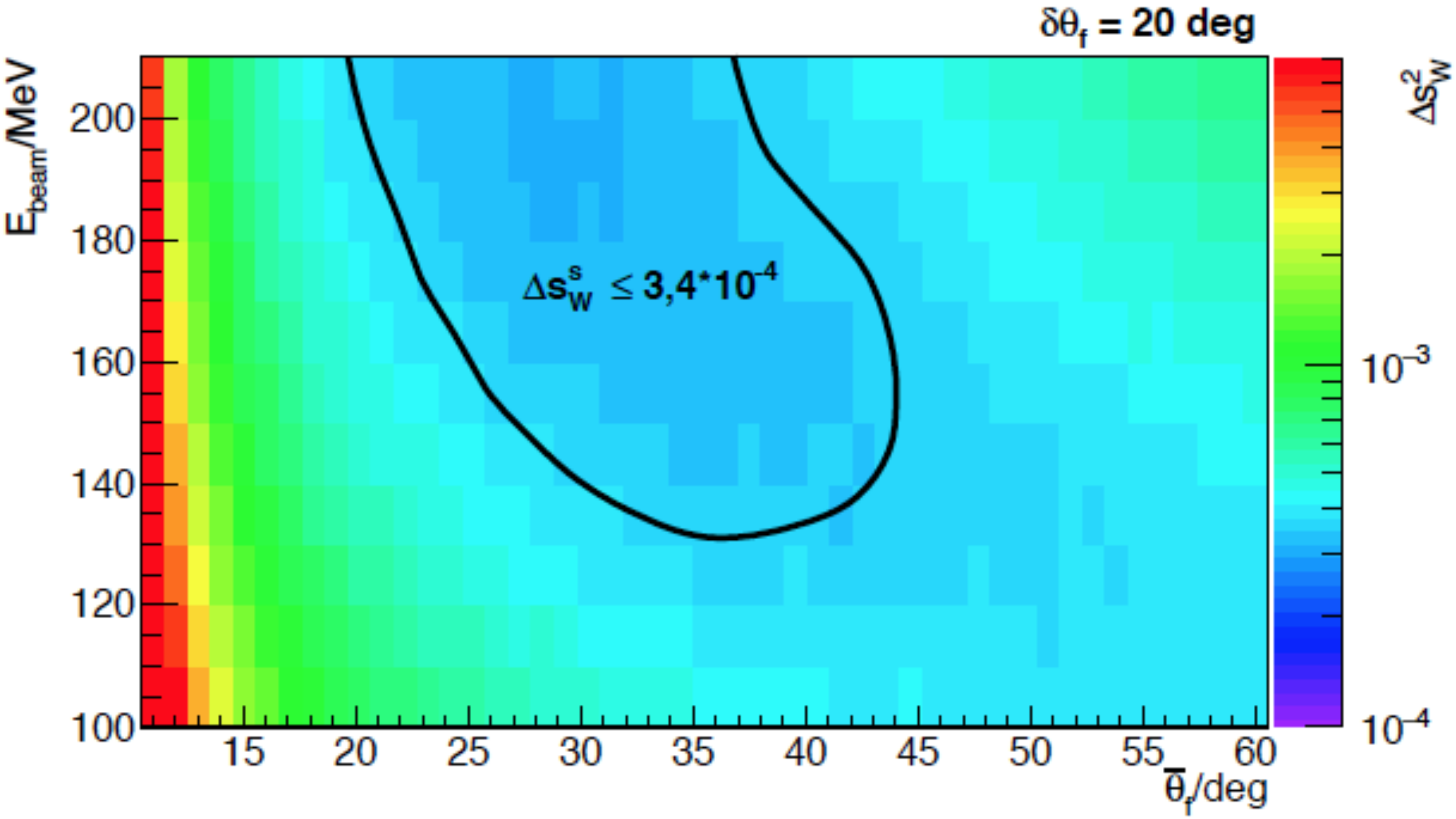
ΔA^{app}: 0.1 ppb

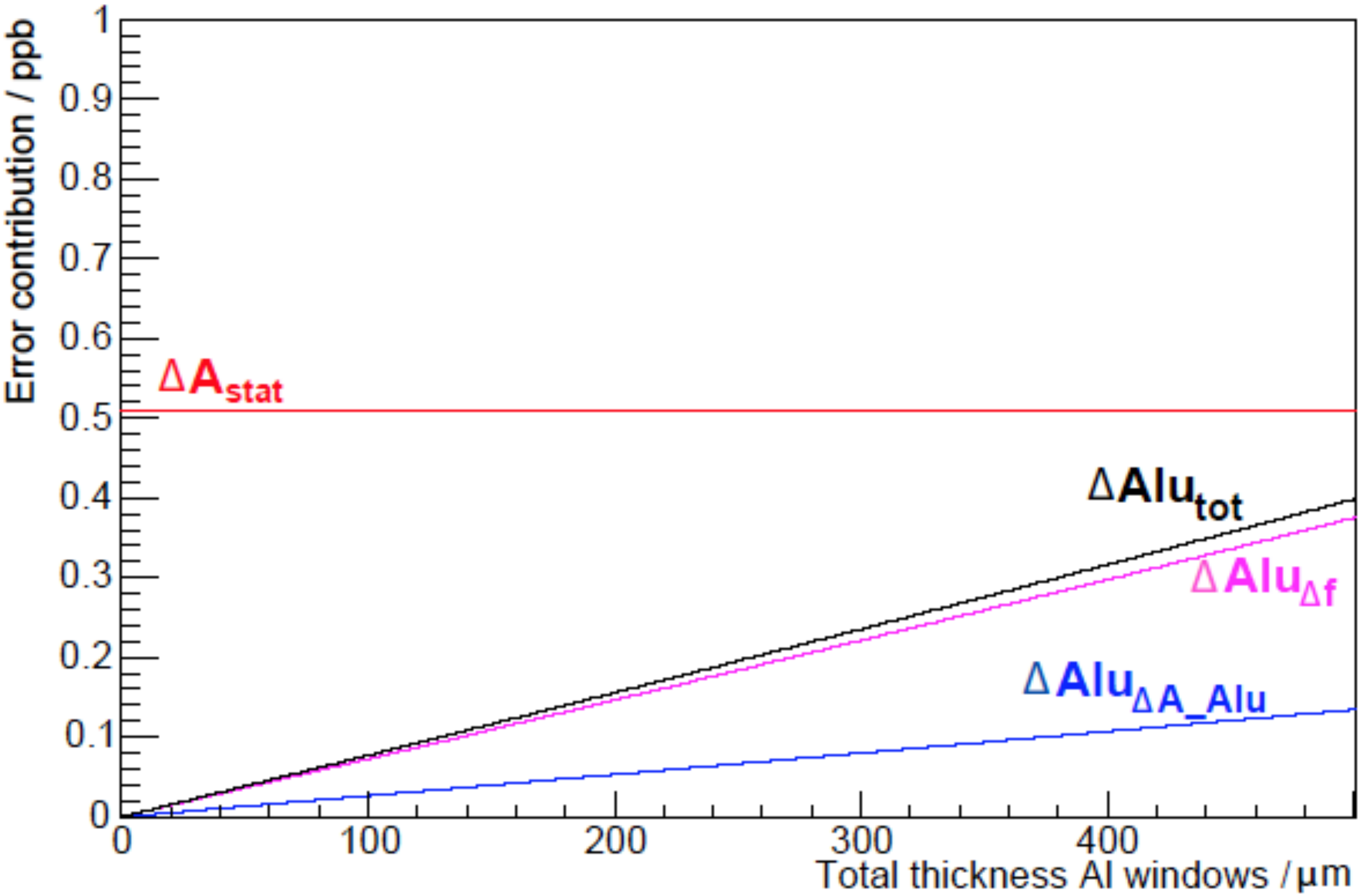
	Total	Statistics	Polarization	Apparative	FF	Re(□$_{\gamma ZA}$)
$\Delta\sin^2(\theta_W)$	3.1e-4 (0.13 %)	2.6e-4 (0.11 %)	9.7e-5 (0.04 %)	7.0e-5 (0.03 %)	1.4e-4 (0.04 %)	6e-5 (0.03 %)
ΔA^{exp}/ppb	0.44 (1.5 %)	0.38 (1.34 %)	0.14 (0.49 %)	0.10 (0.35 %)	0.11 (0.38 %)	0.09 (0.32 %)

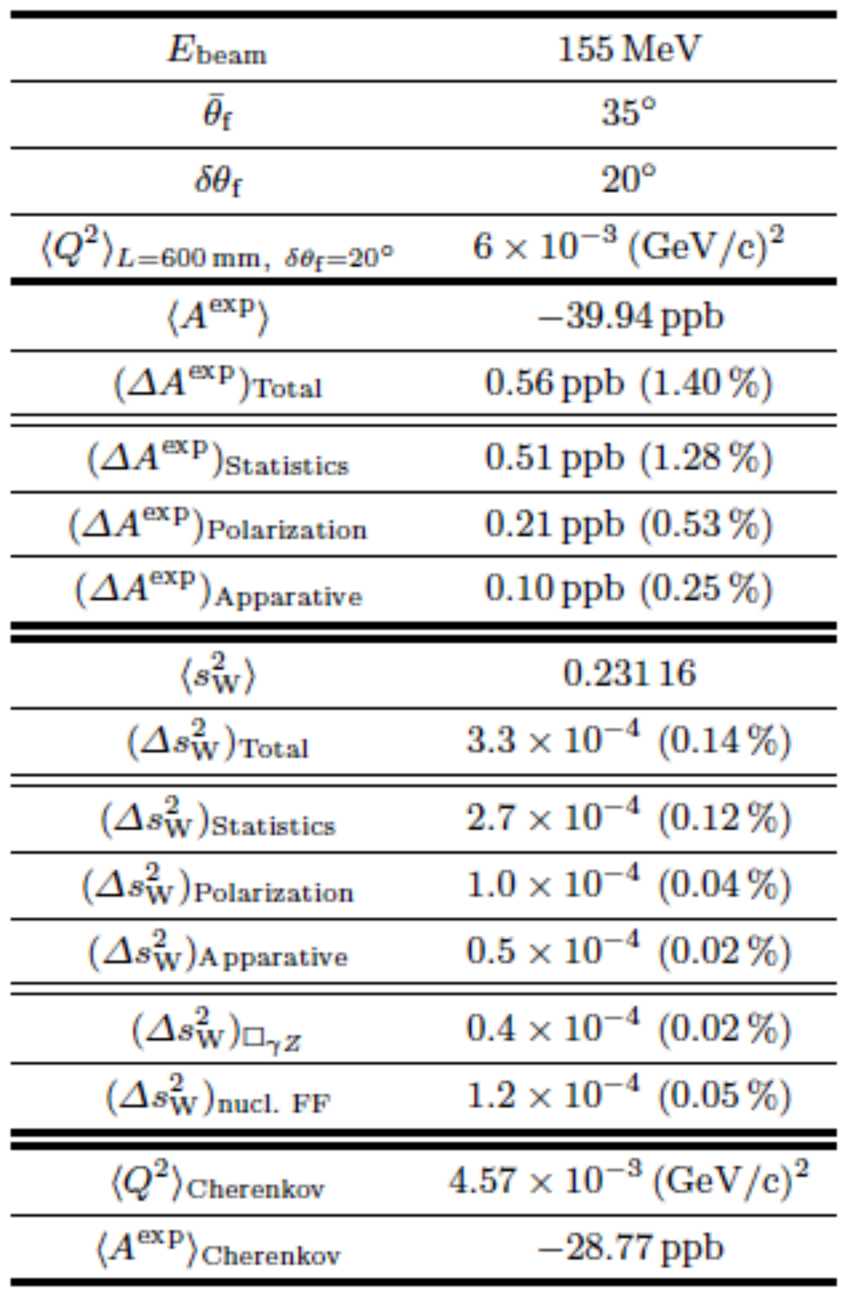
Optimization of acceptance in $\Delta\theta$



Optimization of beam energy and mean scattering angle θ

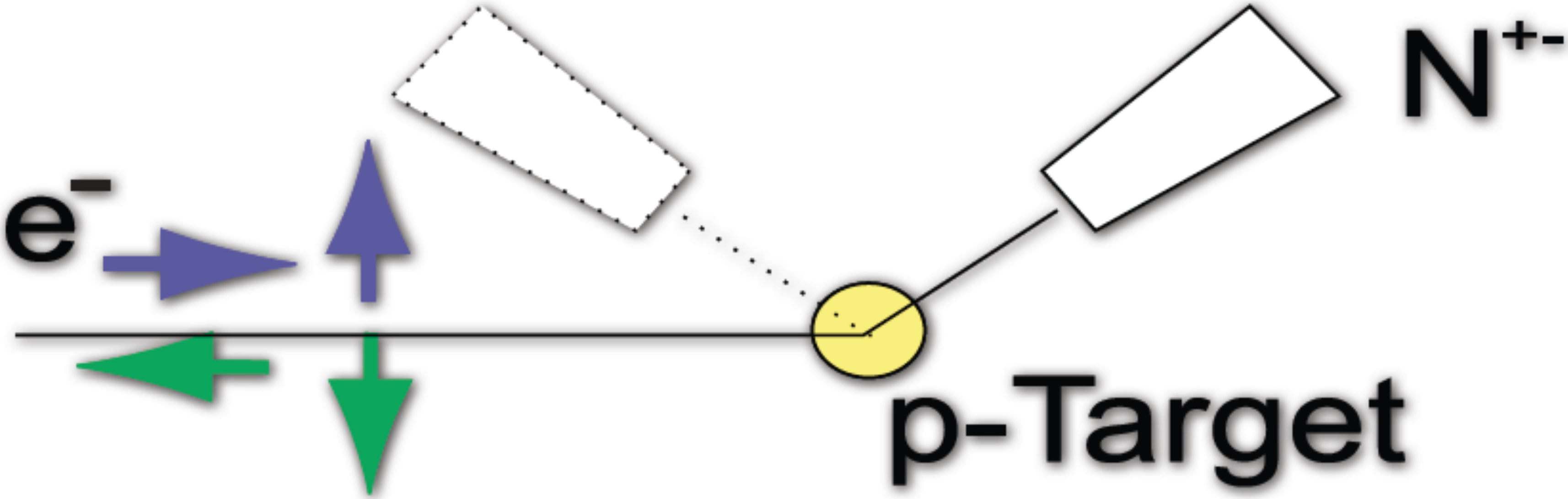



Error contribution / ppb
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
Total thickness Al windows / µm
ΔA_stat
ΔAlu_tot
ΔAlu_Δf
ΔAlu_ΔA_Alu



E_{beam}	155 MeV
$\bar{\theta}_{\mathrm{f}}$	35°
$\delta\theta_{\mathrm{f}}$	20°
$\langle Q^2 \rangle_{L=600\,\mathrm{mm},\ \delta\theta_{\mathrm{f}}=20^\circ}$	$6 \times 10^{-3}\,(\mathrm{GeV/c})^2$
$\langle A^{\mathrm{exp}} \rangle$	-39.94 ppb
$(\Delta A^{\mathrm{exp}})_{\mathrm{Total}}$	0.56 ppb (1.40 %)
$(\Delta A^{\mathrm{exp}})_{\mathrm{Statistics}}$	0.51 ppb (1.28 %)
$(\Delta A^{\mathrm{exp}})_{\mathrm{Polarization}}$	0.21 ppb (0.53 %)
$(\Delta A^{\mathrm{exp}})_{\mathrm{Apparative}}$	0.10 ppb (0.25 %)
$\langle s_{\mathrm{W}}^2 \rangle$	0.231 16
$(\Delta s_{\mathrm{W}}^2)_{\mathrm{Total}}$	3.3×10^{-4} (0.14 %)
$(\Delta s_{\mathrm{W}}^2)_{\mathrm{Statistics}}$	2.7×10^{-4} (0.12 %)
$(\Delta s_{\mathrm{W}}^2)_{\mathrm{Polarization}}$	1.0×10^{-4} (0.04 %)
$(\Delta s_{\mathrm{W}}^2)_{\mathrm{Apparative}}$	0.5×10^{-4} (0.02 %)
$(\Delta s_{\mathrm{W}}^2)_{\Box_{\gamma Z}}$	0.4×10^{-4} (0.02 %)
$(\Delta s_{\mathrm{W}}^2)_{\mathrm{nucl.\ FF}}$	1.2×10^{-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 ppb

Conceptually very simple experiments



$A = (N^{+}-N^{-})/(N^{+}+N^{-})$ $\Delta A = (N^{+}+N^{-})^{-1/2} = N^{-1/2}$

$A = 20 \times 10^{-9}$ 2% Measurement $N = 6.25 \times 10^{18}$ events

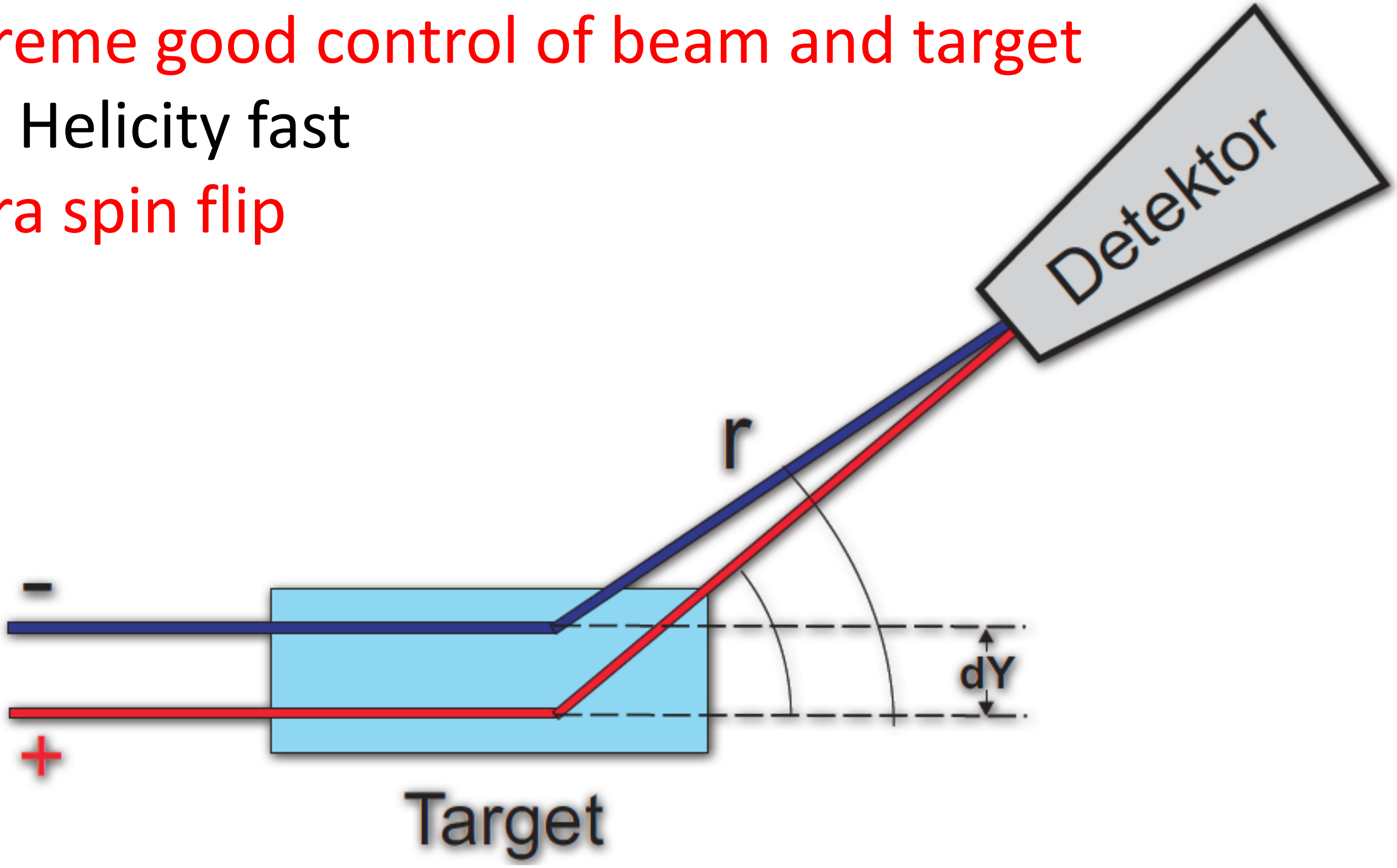
Highest rate, measure Q^2: Large Solid Angle Spectrometers

Apparative (false) asymmetries:

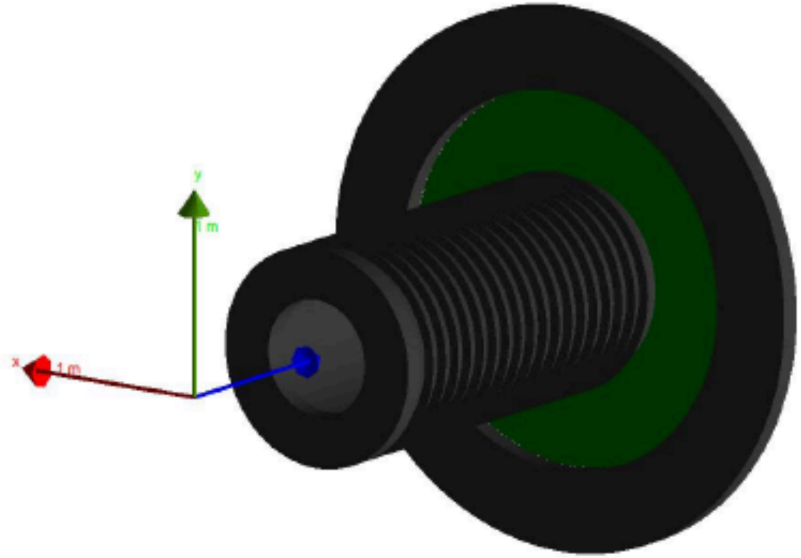
Extreme good control of beam and target

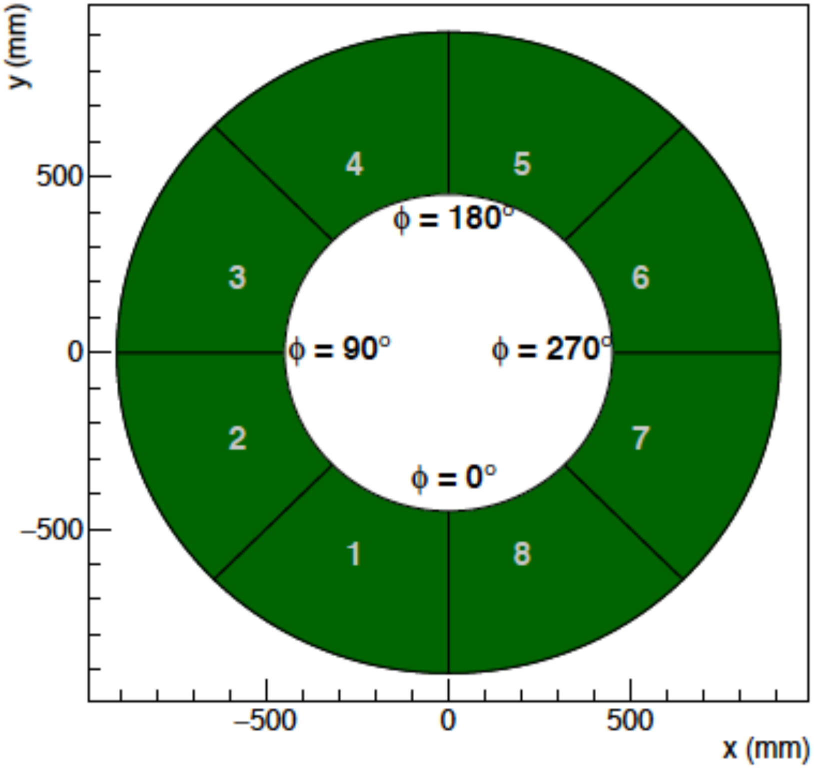
Flip Helicity fast

Extra spin flip



Coordinate system





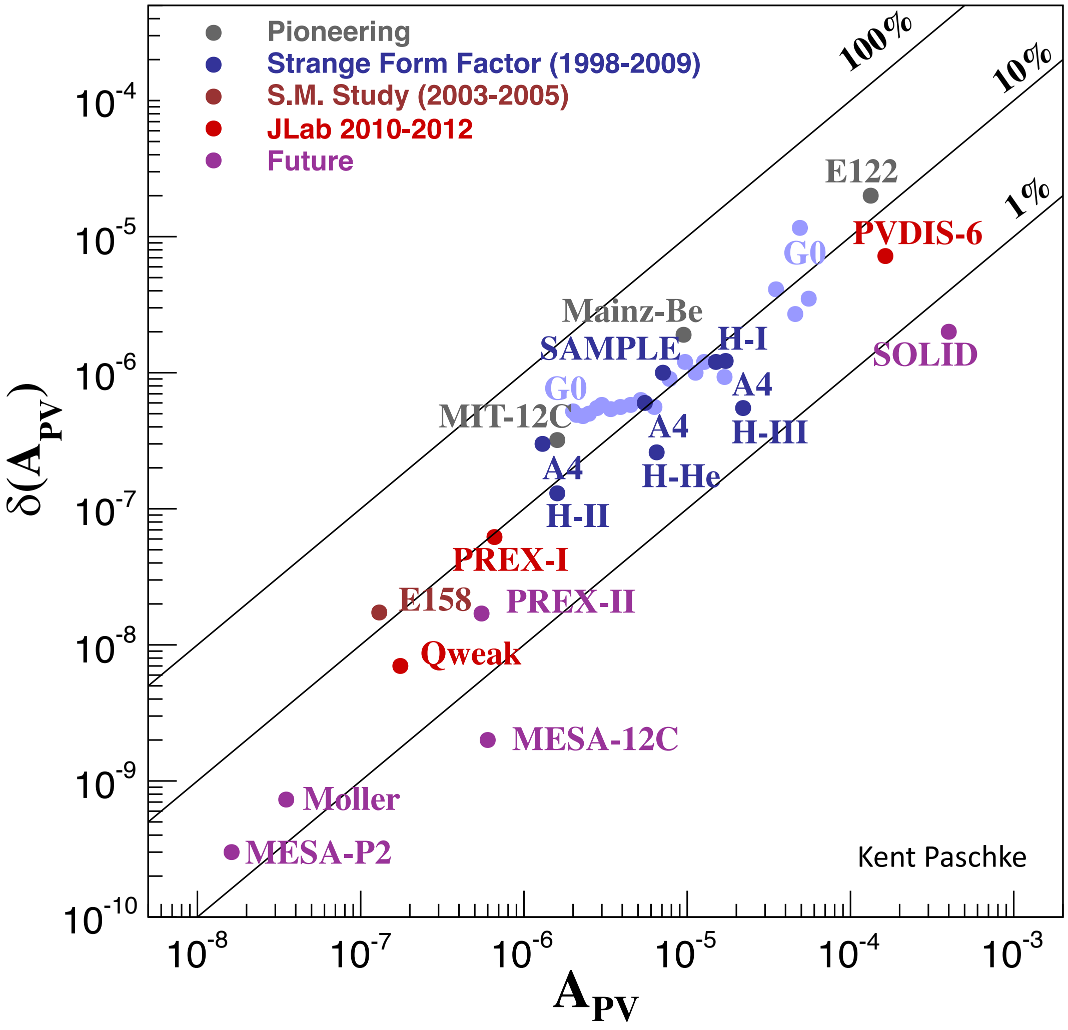
Energy shift

Sector	**False asymmetry** $(10^{-9}/\mathrm{eV})$
1	-2.69 ± 0.28
2	-2.43 ± 0.29
3	-2.70 ± 0.29
4	-2.36 ± 0.29
5	-2.46 ± 0.50
6	-2.21 ± 0.31
7	-2.05 ± 0.28
8	-2.19 ± 0.23
all	-2.3857 ± 0.0070

Shift in x

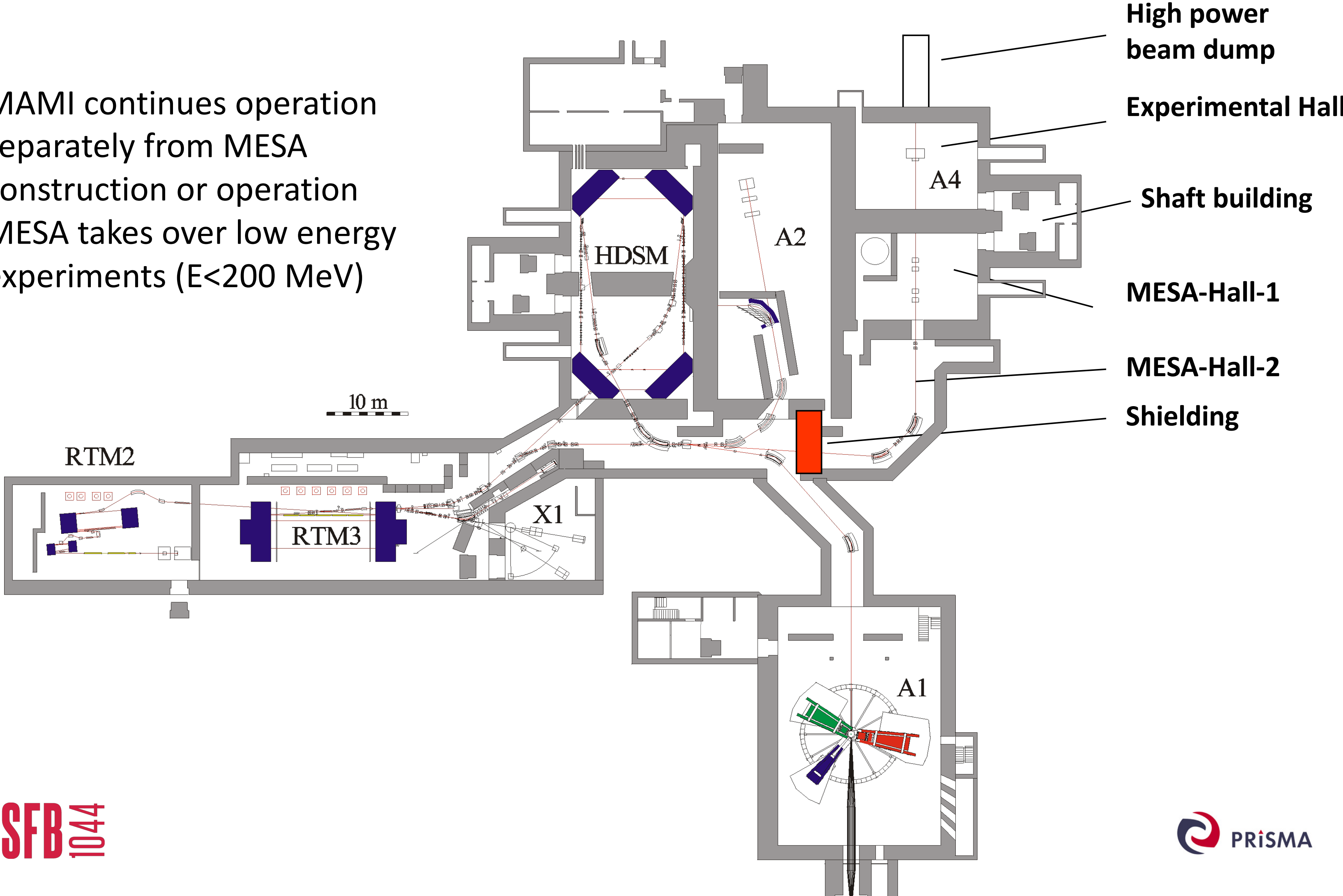
Sector	**False asymmetry** $(10^{-6}/\mu\mathrm{m})$
1	-2.446 ± 0.076
2	-2.973 ± 0.076
3	-1.707 ± 0.076
4	0.504 ± 0.076
5	2.590 ± 0.076
6	3.217 ± 0.076
7	1.849 ± 0.076
8	-0.676 ± 0.076
all	0.097 ± 0.027

PVeS Experiment Summary



Kent Paschke

- MAMI continues operation separately from MESA construction or operation
- MESA takes over low energy experiments (E<200 MeV)



High power beam dump

Experimental Hall

Shaft building

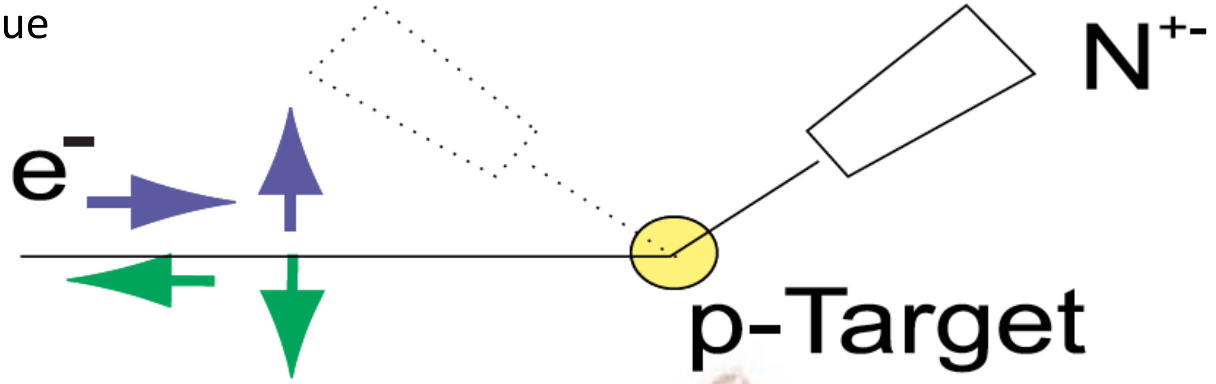
MESA-Hall-1

MESA-Hall-2

Shielding

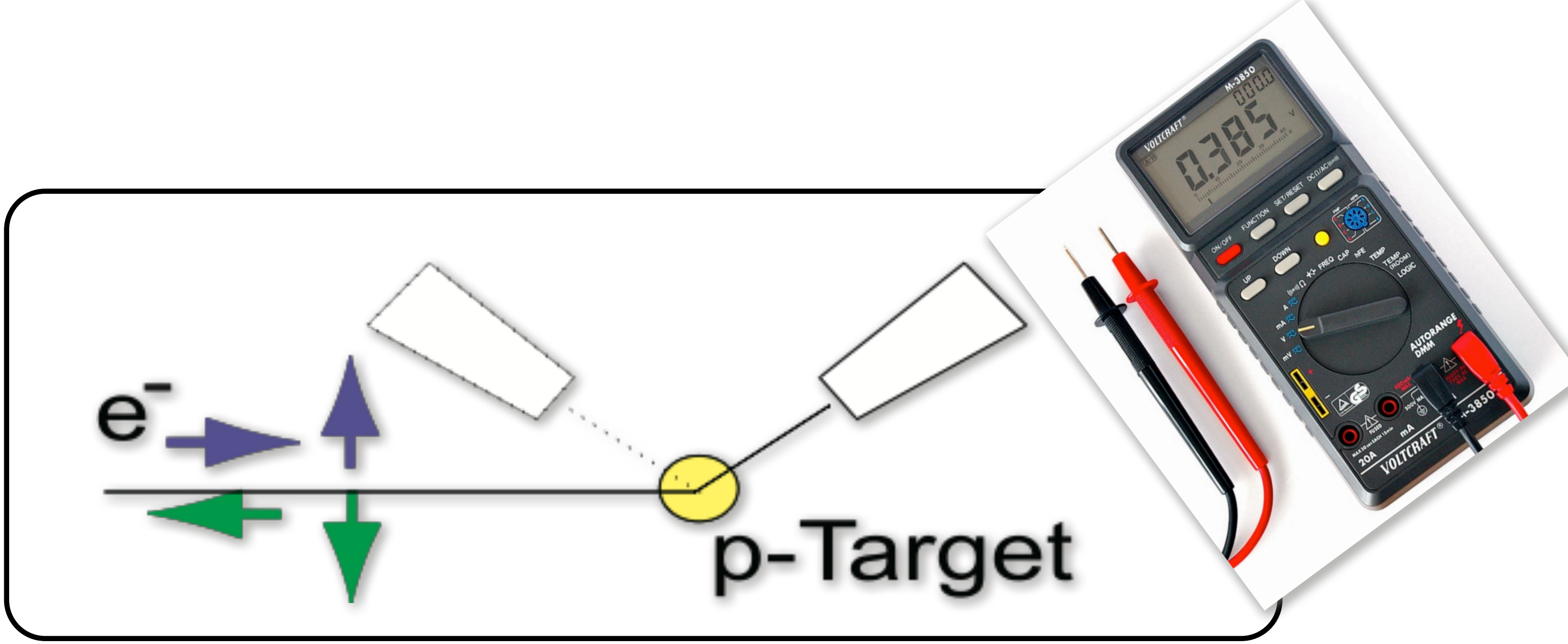
A4: Mainz, MIT, Orsay

Counting Technique



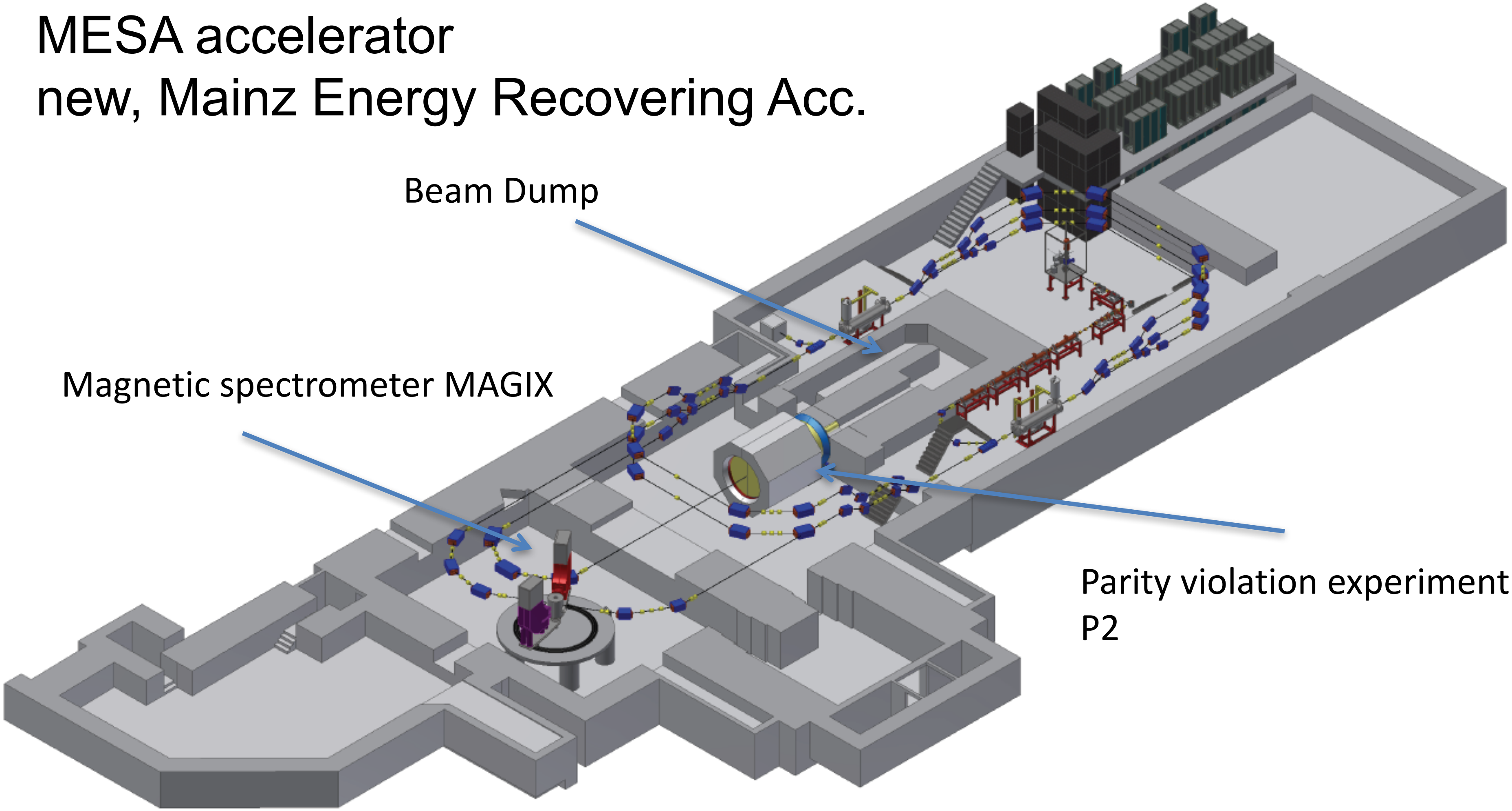
Count scattered electrons:
- pile-up (double count losses)
- Background Asymmetry
- Very Fast Counting (MHz)
- Measure TOF or Energy

Analogue Technique



Measure Flux of Scattered electrons:
- no pile-up (double count losses)
- sensitive to small electr. fields.
- no separation of phys. process

MESA accelerator
new, Mainz Energy Recovering Acc.

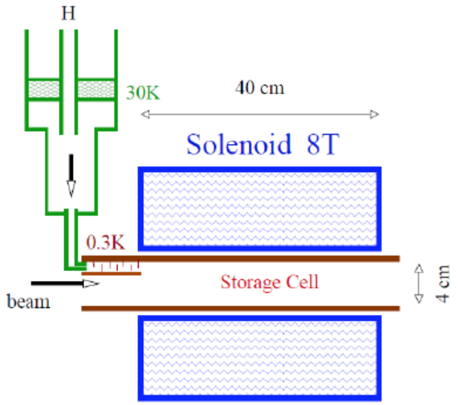


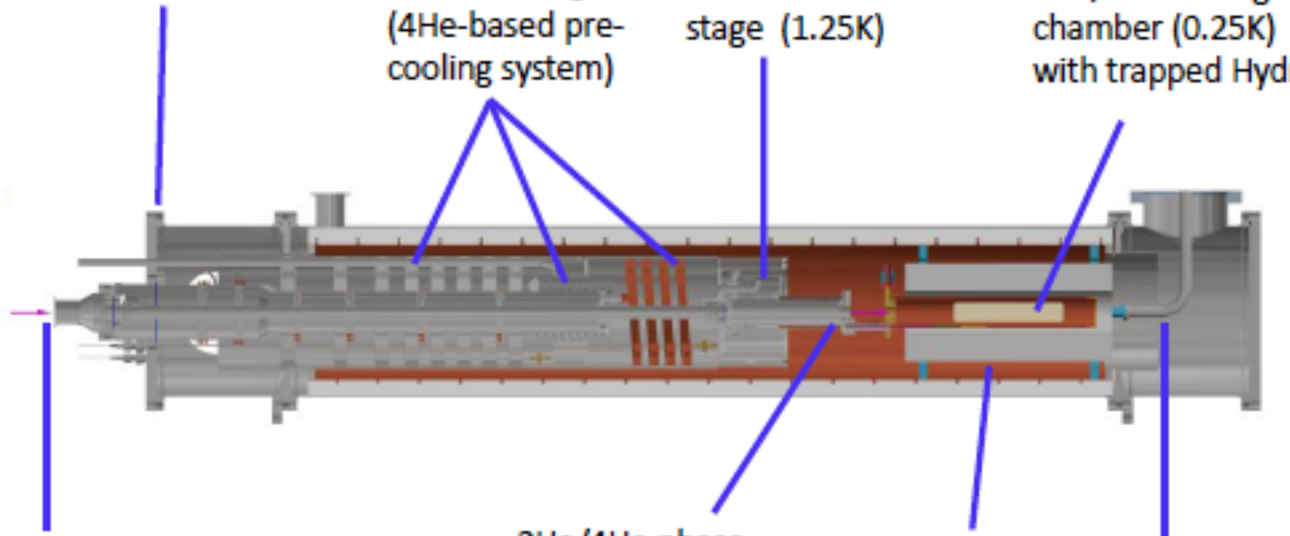
Beam Dump

Magnetic spectrometer MAGIX

Parity violation experiment
P2

Hydro-Möller Polarimeter





Carrier flange

Heat exchangers (4He-based pre-cooling system)

Pre-cooler final stage (1.25K)

3He/4He mixing chamber (0.25K) with trapped Hydrogen

Electron beam

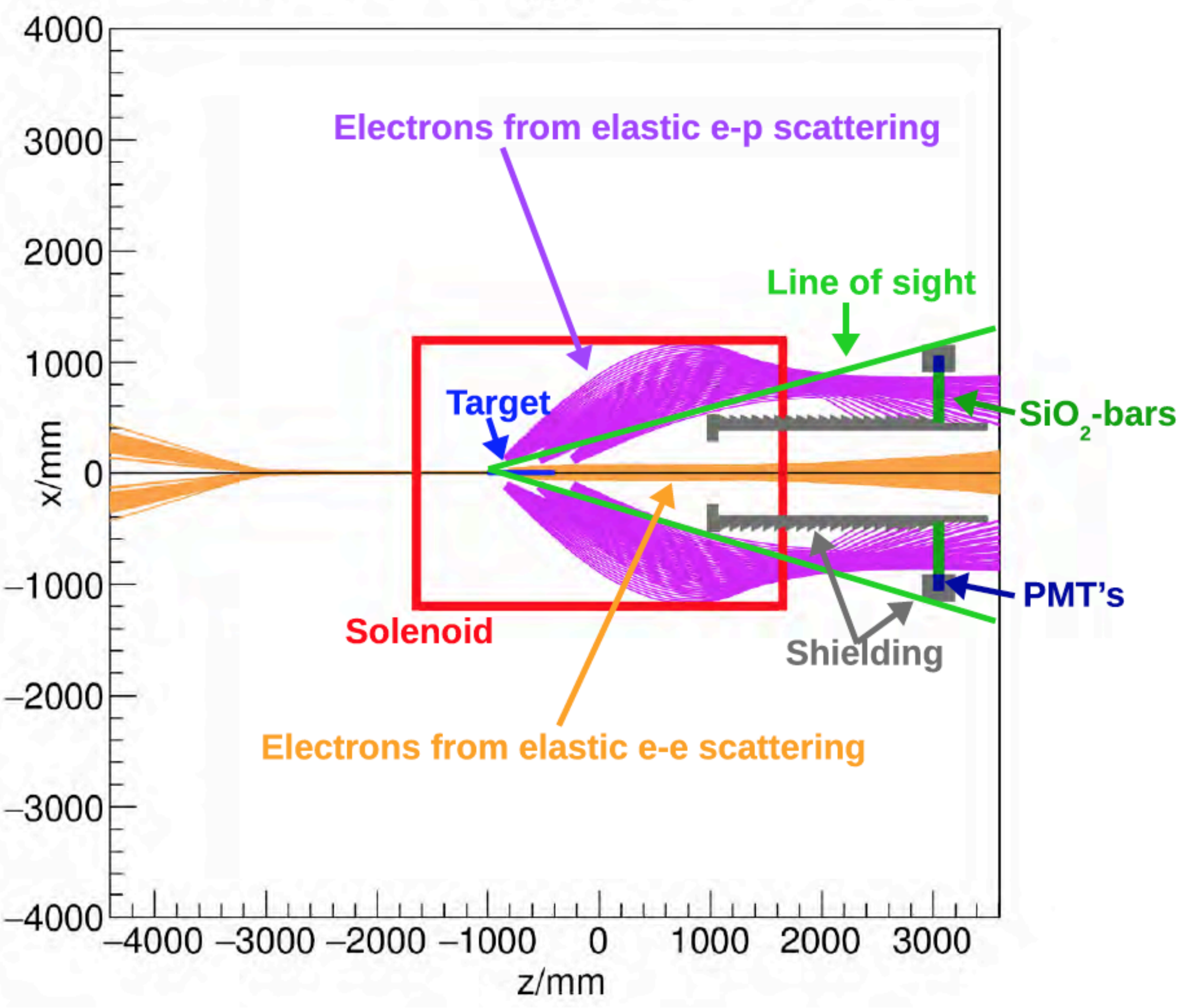
3He/4He phase separation (Still) 0.7K

Solenoid

Hydrogen injection

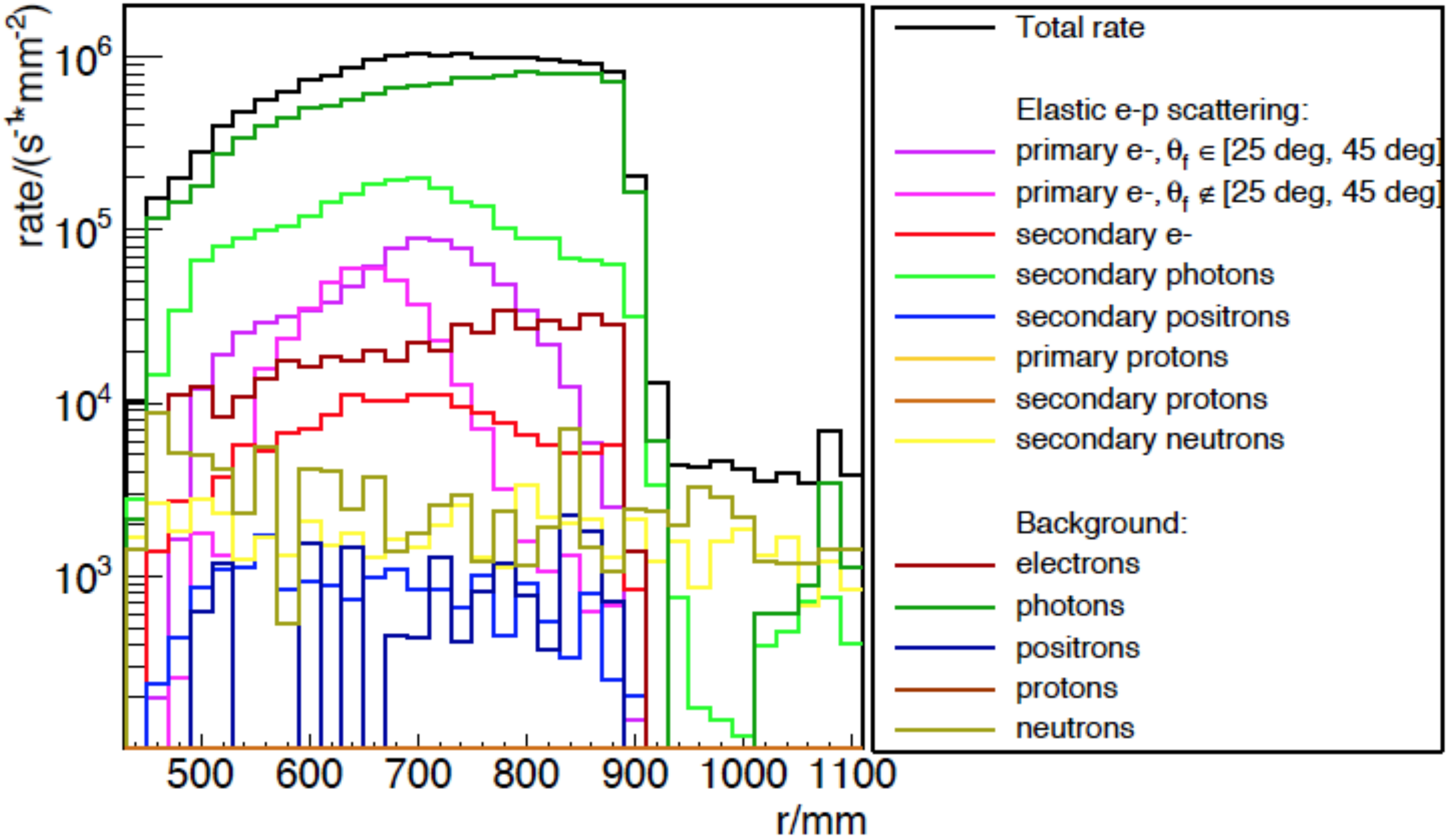
P2-experimental setup

Simple ray-tracing



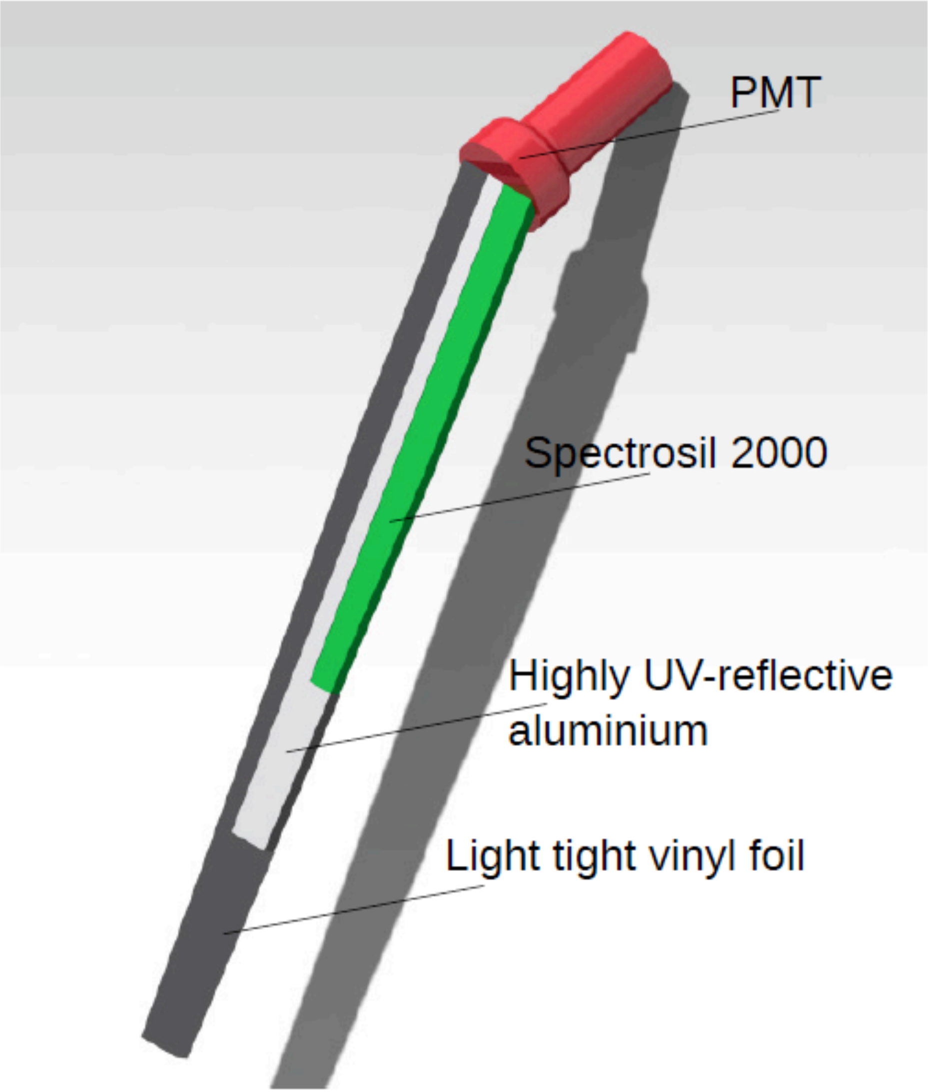
Particle rates

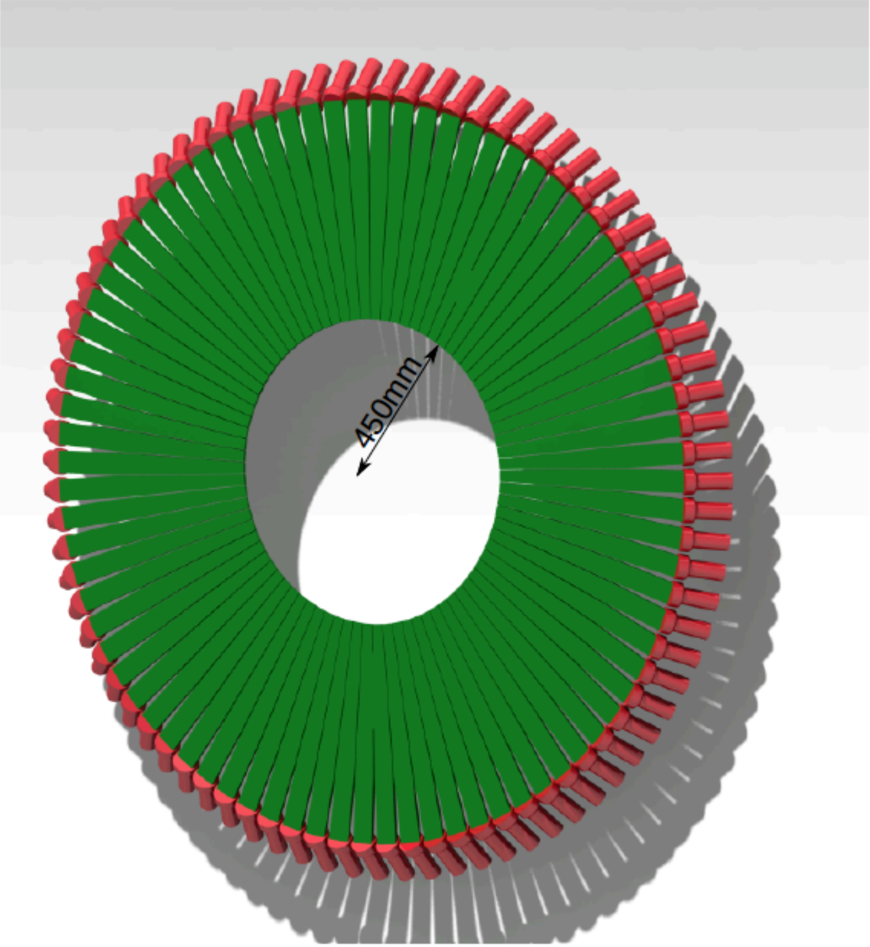
Full GEANT4 simulation



Cherenkov ”Quartz” detectors

Full GEANT4 simulation

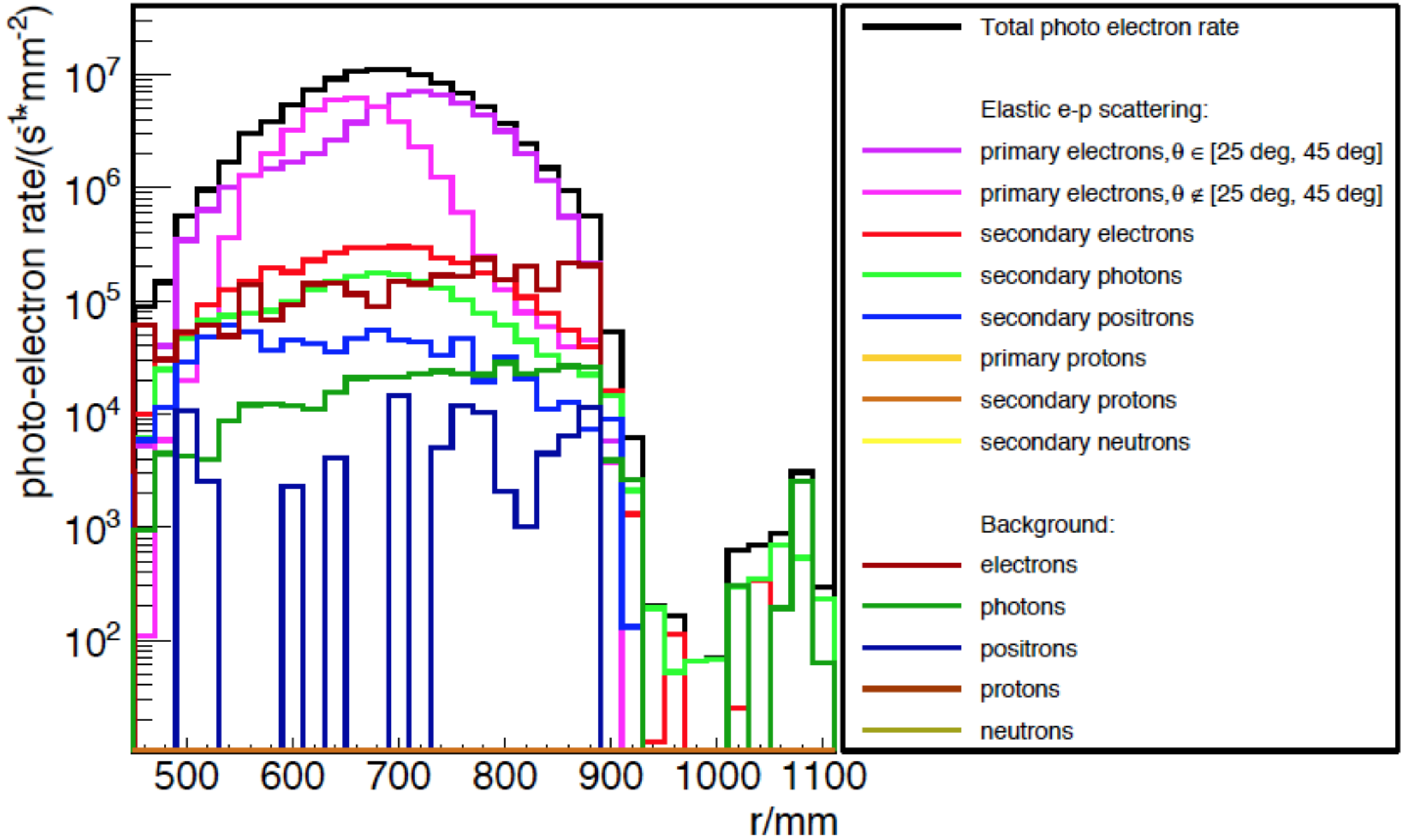




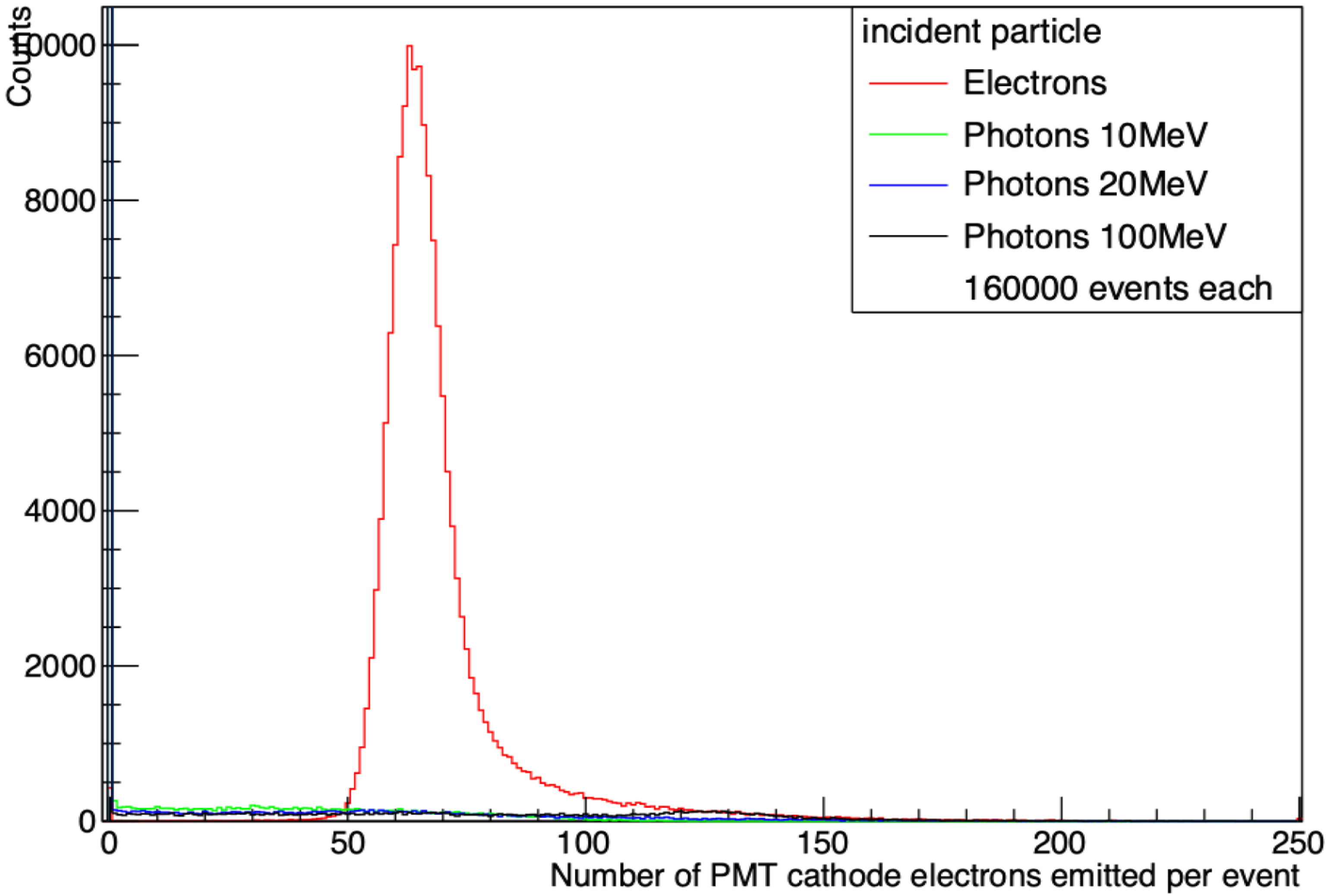
Kathrin Gerz

P2-Detector response

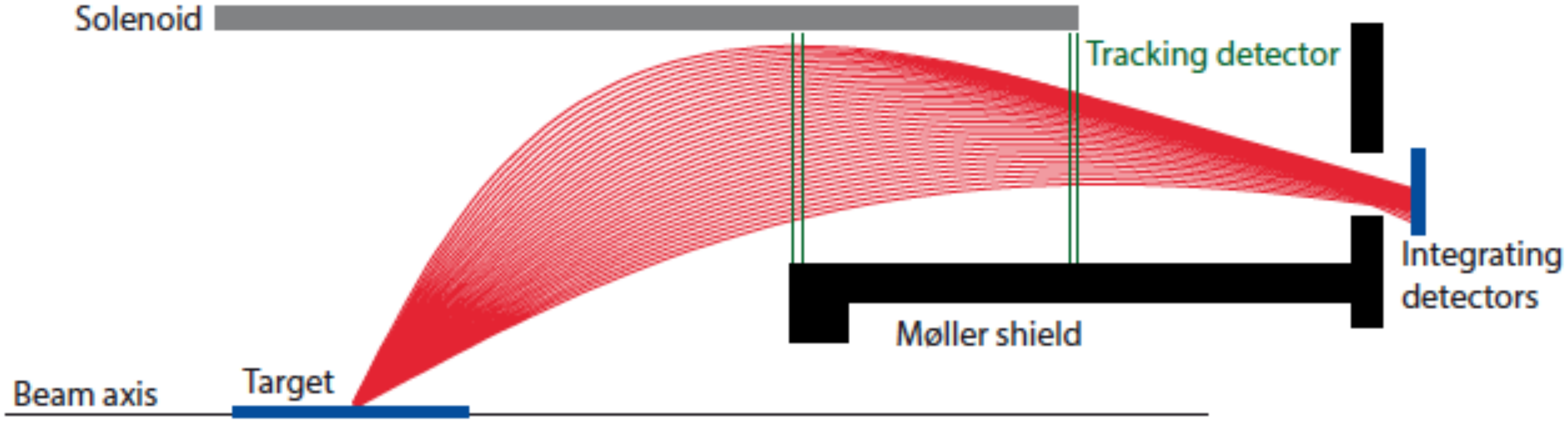
Full GEANT4 simulation

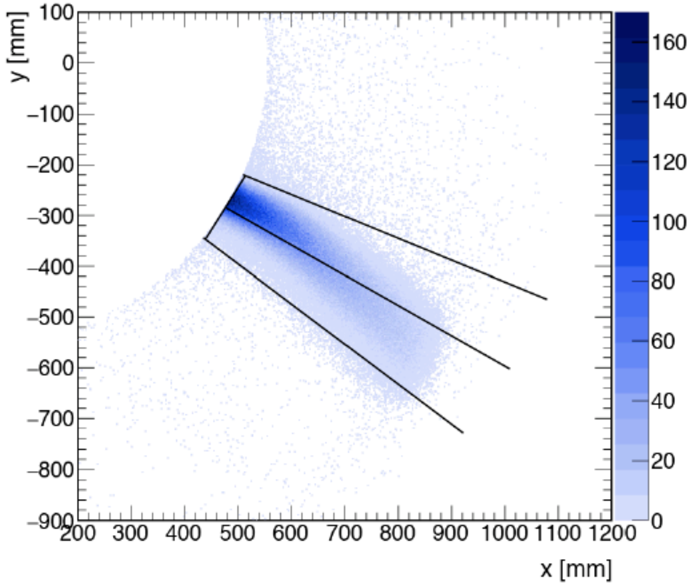


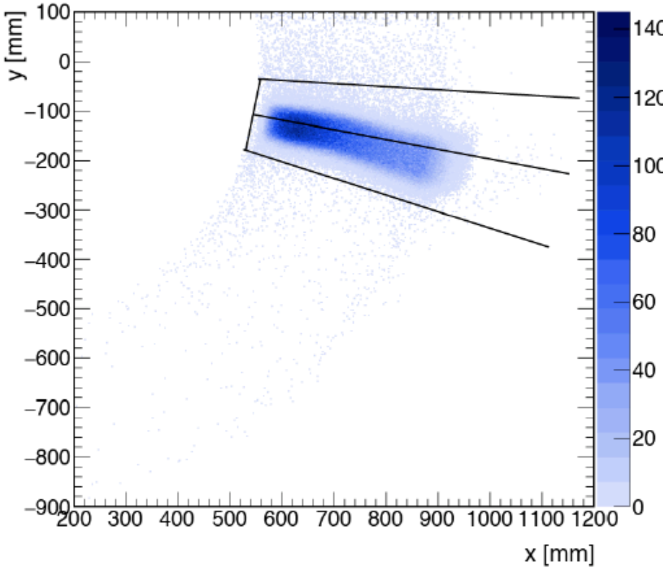
Number of PMT cathode electrons emitted per event

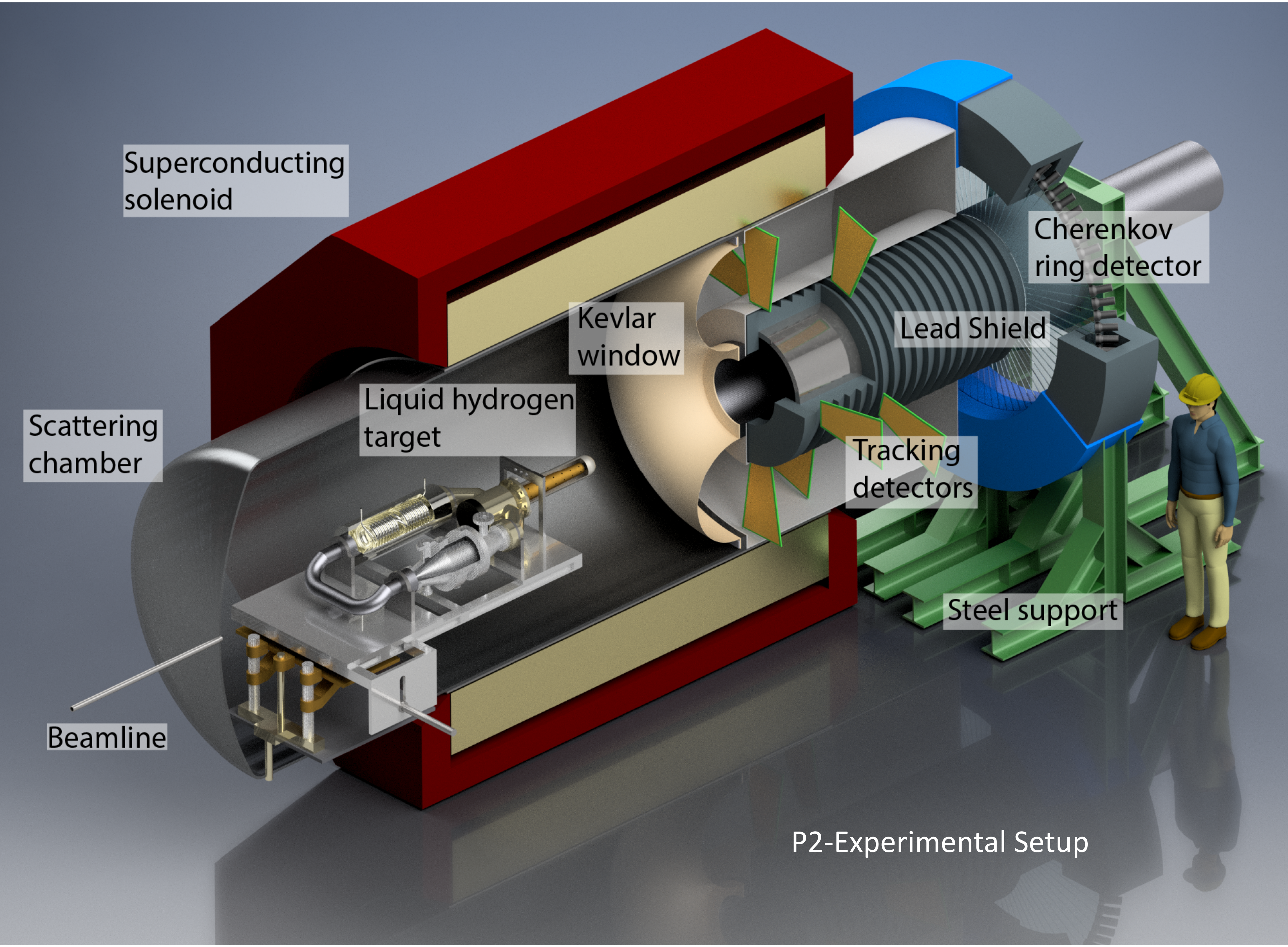


Q^2-Measurement



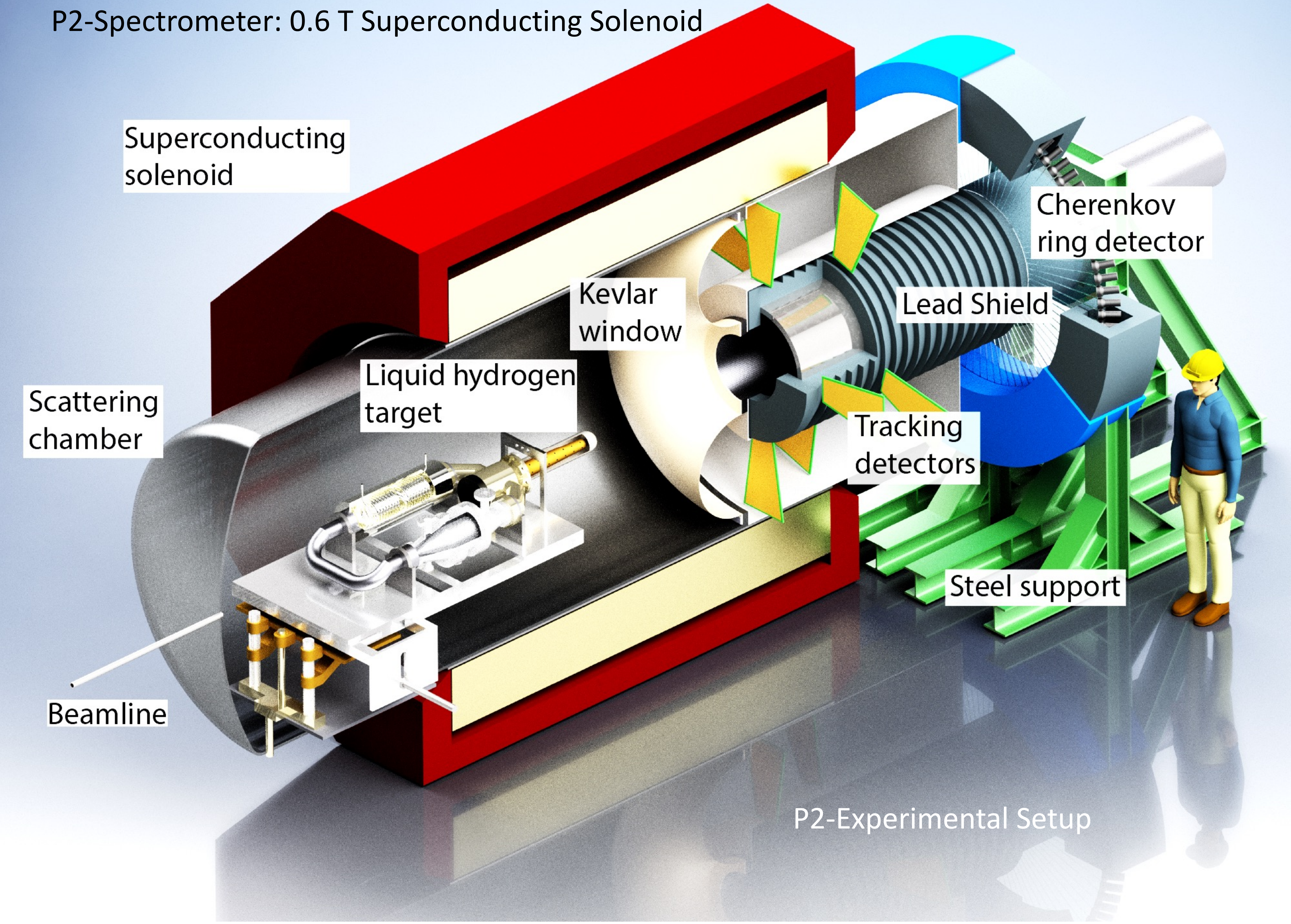




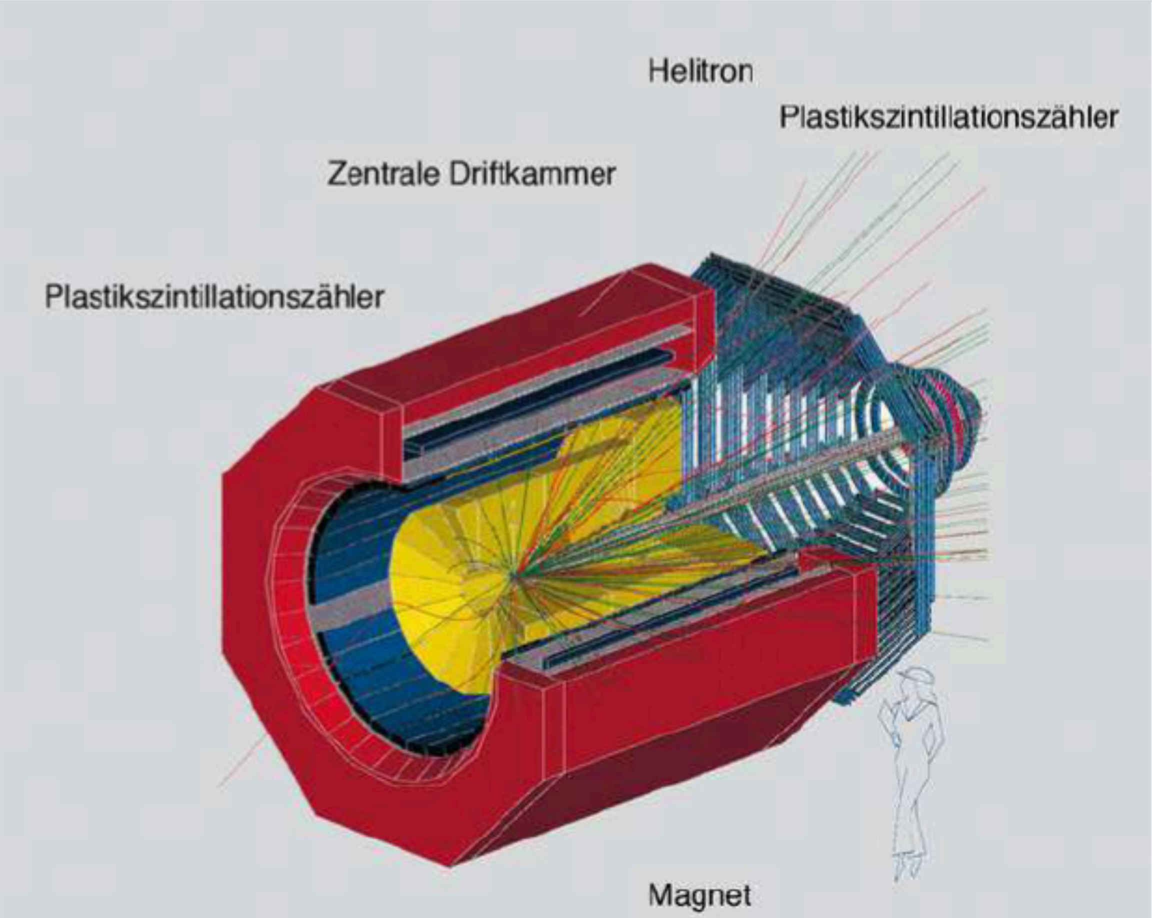


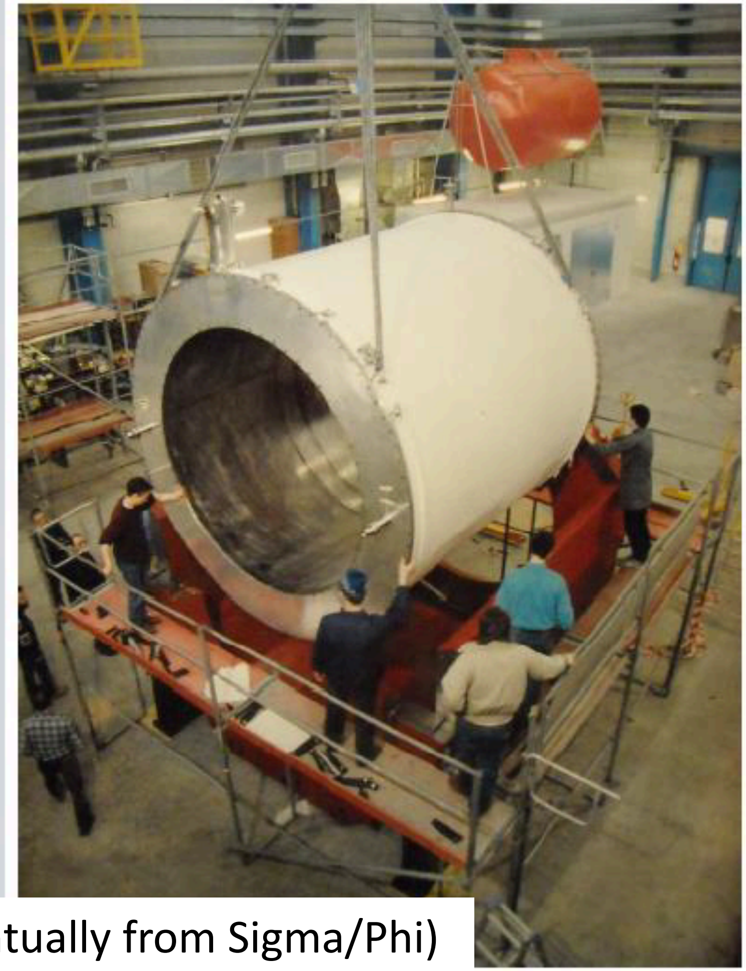
P2-Experimental Setup

P2-Spectrometer: 0.6 T Superconducting Solenoid



P2-Spectrometer: 0.6 T Superconducting Solenoid





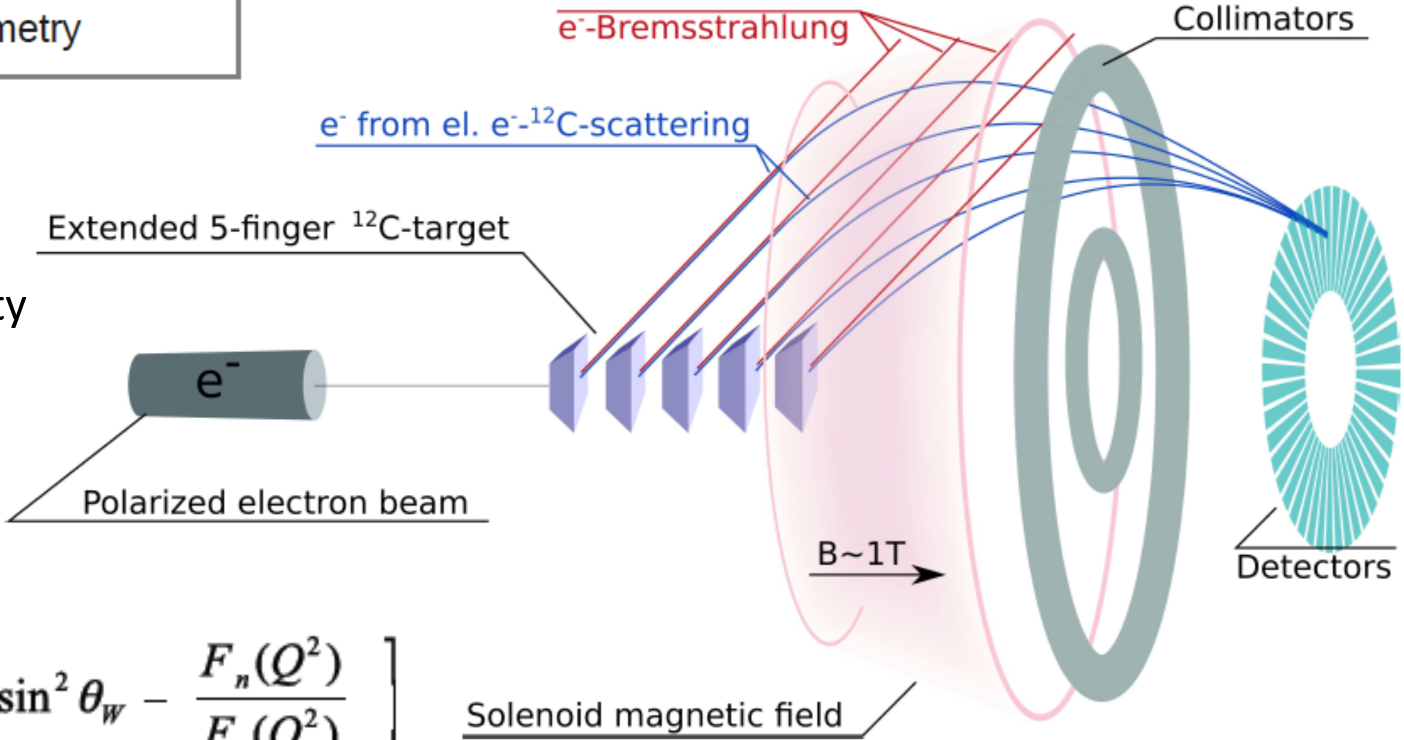
Former „FOPI“ Magnet yoke: new coil with cryostat (eventually from Sigma/Phi)

Other Measurements:
Carbon, Lead

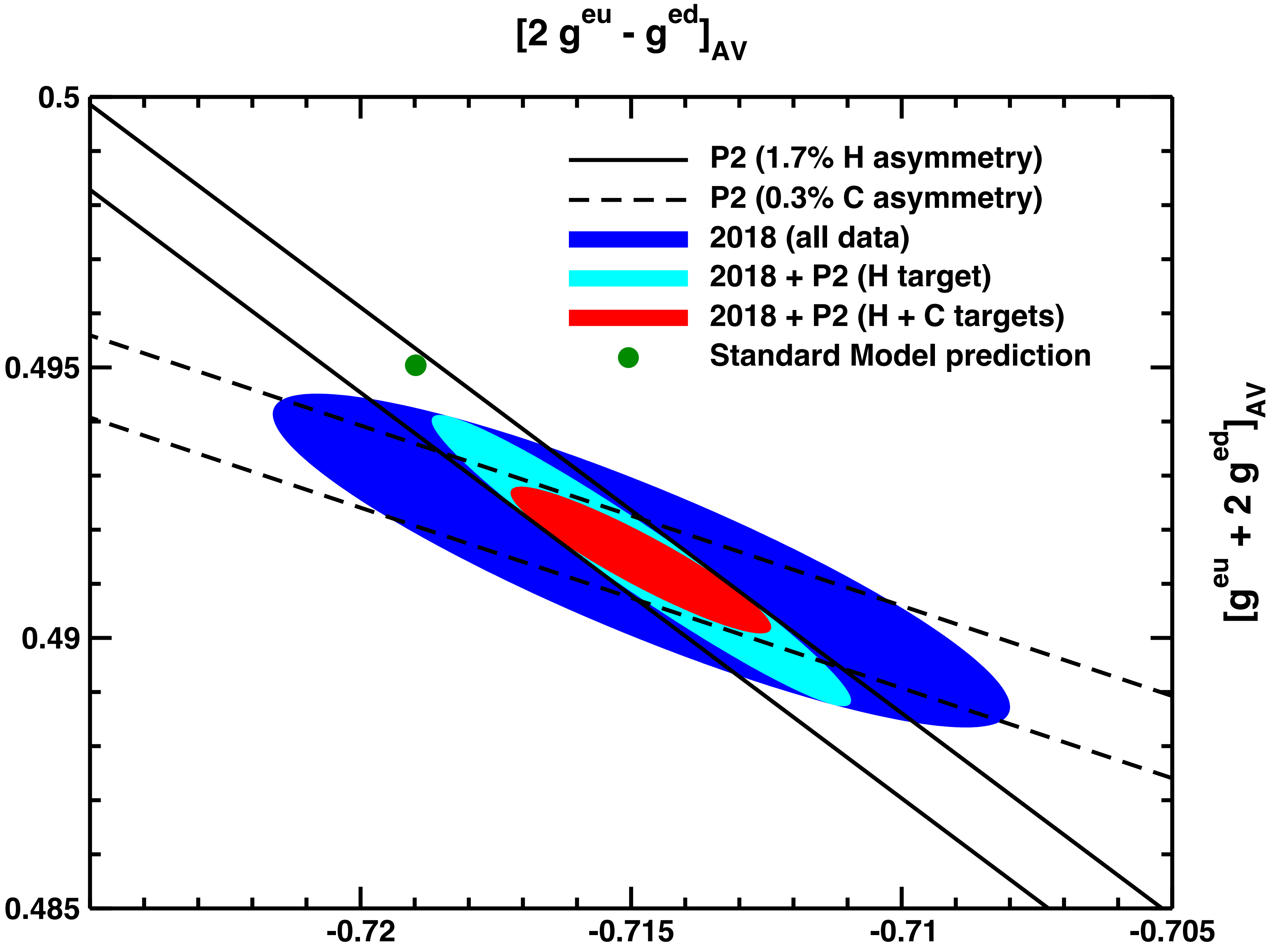
EXPERIMENTAL REALIZATION

MESA:
- 150µA
- 150MeV-200MeV
- Polarimetry

Enhanced sensitivity
To new physics

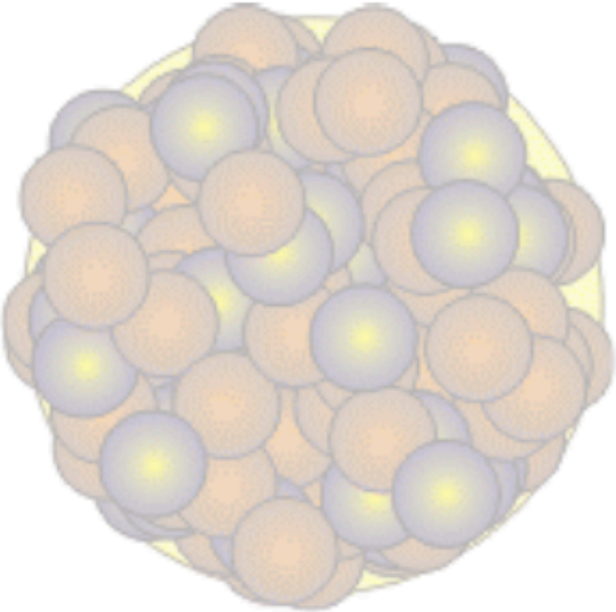


$$-N = \frac{G_F Q^2}{2\pi\alpha\sqrt{2}} \left[\underbrace{\sin^2\theta_W}_{\approx 0} - \frac{F_n(Q^2)}{F_p(Q^2)} \right]$$


[2 g^eu - g^ed]_AV
0.5
0.495
0.49
0.485
-0.72
-0.715
-0.71
-0.705
[g^eu + 2 g^ed]_AV
P2 (1.7% H asymmetry)
P2 (0.3% C asymmetry)
2018 (all data)
2018 + P2 (H target)
2018 + P2 (H + C targets)
Standard Model prediction

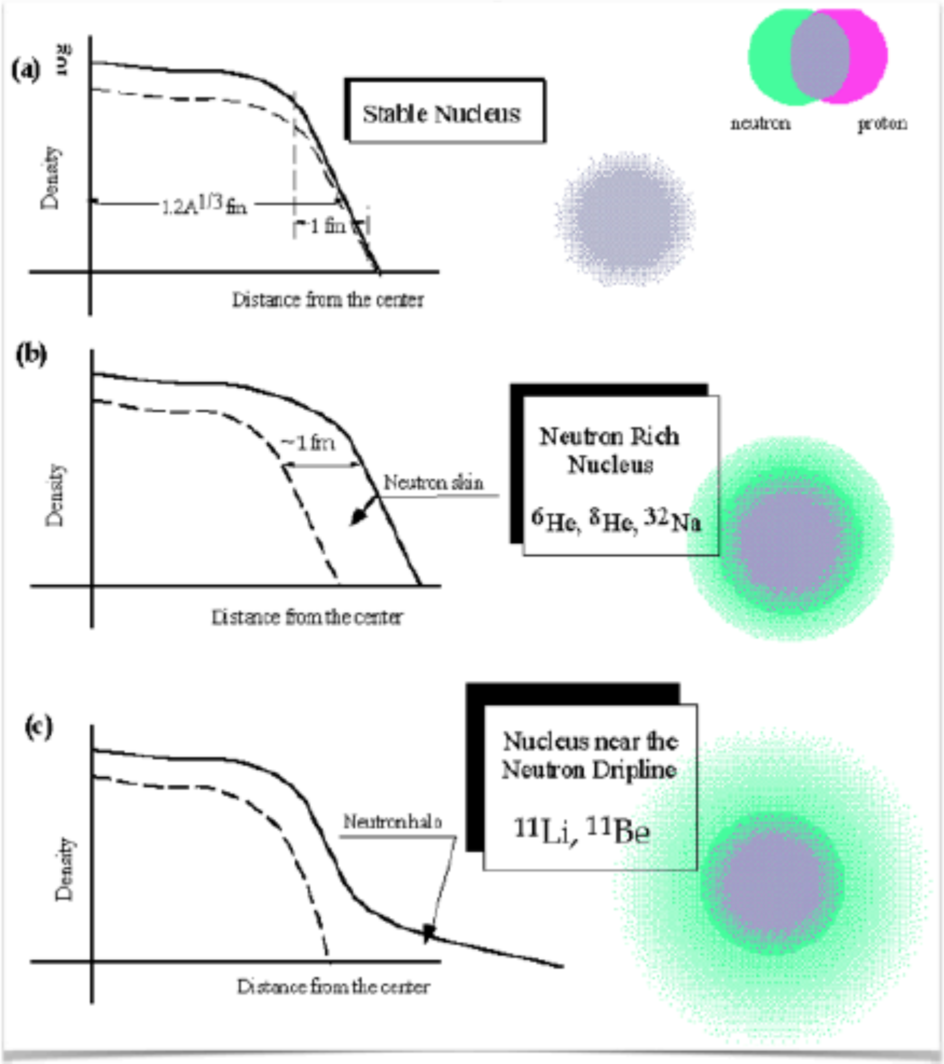
Neutron Skin for beginner

Where do the neutrons go?

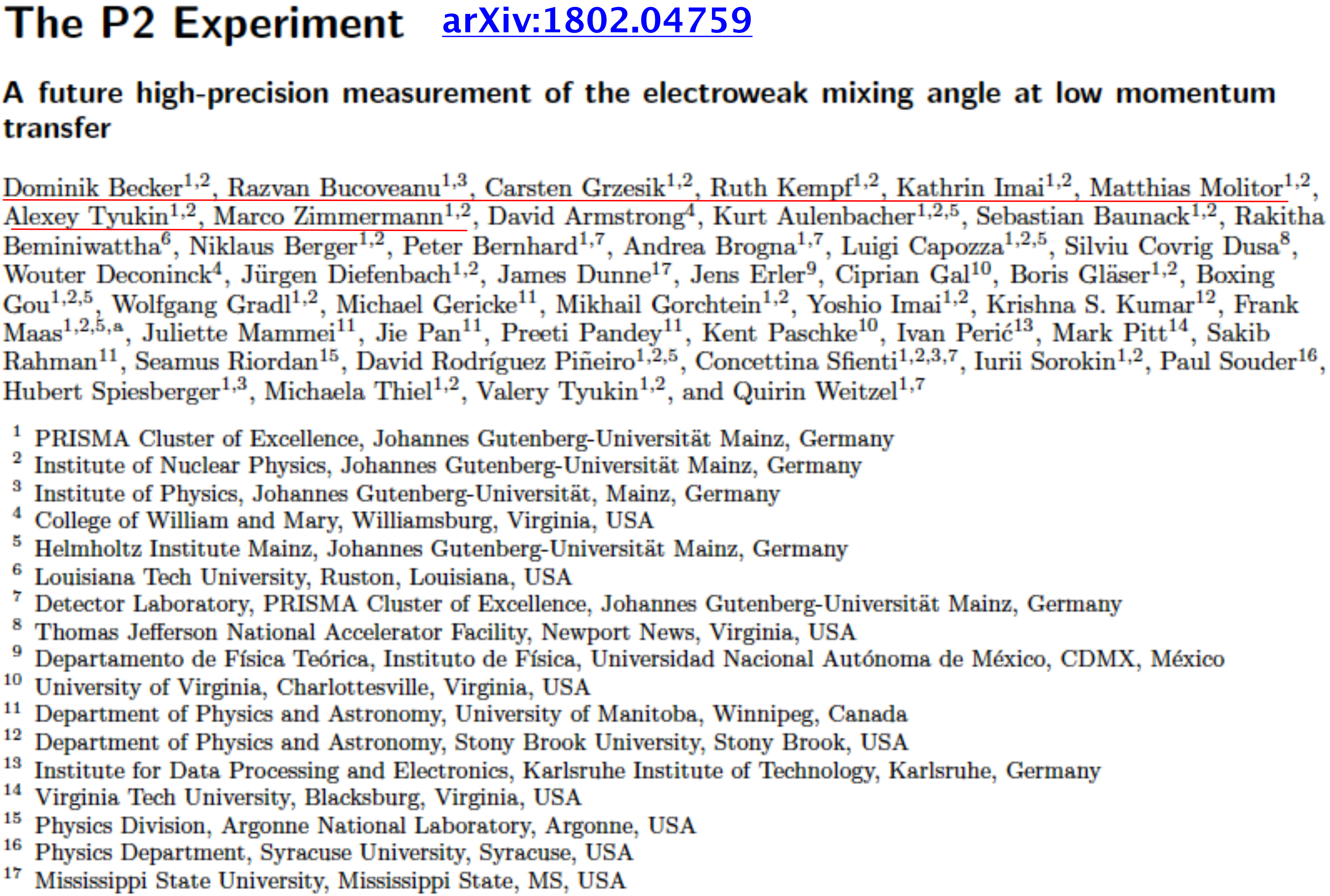


Pressure forces neutrons out against surface tension

→ **EOS**



P2: International Collaboration



The P2 Experiment

arXiv:1802.04759

A future high-precision measurement of the electroweak mixing angle at low momentum transfer

Dominik Becker[1,2], Razvan Bucoveanu[1,3], Carsten Grzesik[1,2], Ruth Kempf[1,2], Kathrin Imai[1,2], Matthias Molitor[1,2], Alexey Tyukin[1,2], Marco Zimmermann[1,2], David Armstrong[4], Kurt Aulenbacher[1,2,5], Sebastian Baunack[1,2], Rakitha Beminiwattha[6], Niklaus Berger[1,2], Peter Bernhard[1,7], Andrea Brogna[1,7], Luigi Capozza[1,2,5], Silviu Covrig Dusa[8], Wouter Deconinck[4], Jürgen Diefenbach[1,2], James Dunne[17], Jens Erler[9], Ciprian Gal[10], Boris Gläser[1,2], Boxing Gou[1,2,5], Wolfgang Gradl[1,2], Michael Gericke[11], Mikhail Gorchtein[1,2], Yoshio Imai[1,2], Krishna S. Kumar[12], Frank Maas[1,2,5,a], Juliette Mammei[11], Jie Pan[11], Preeti Pandey[11], Kent Paschke[10], Ivan Perić[13], Mark Pitt[14], Sakib Rahman[11], Seamus Riordan[15], David Rodríguez Piñeiro[1,2,5], Concettina Sfienti[1,2,3,7], Iurii Sorokin[1,2], Paul Souder[16], Hubert Spiesberger[1,3], Michaela Thiel[1,2], Valery Tyukin[1,2], and Quirin Weitzel[1,7]

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[13] Institute for Data Processing and Electronics, Karlsruhe Institute of Technology, Karlsruhe, Germany
[14] Virginia Tech University, Blacksburg, Virginia, USA
[15] Physics Division, Argonne National Laboratory, Argonne, USA
[16] Physics Department, Syracuse University, Syracuse, USA
[17] Mississippi State University, Mississippi State, MS, USA

- Parity violating electron scattering: “Low energy frontier” comprises a sensitive test of the standard model complementary to LHC
- 7 years of R&D in Mainz, many components are ready to be built
- P2-Experiment is funded to 90%, Q1/2021 building will be ready
- Determination of $\sin^2(\theta_W)$ with high precision (similar to Z-pole)
- P2-Experiment (proton weak charge) in Mainz under preparation

  New MESA energy recovering accelerator at 155 MeV, target precision is 2 % in weak proton charge i.e. 0.15% in $\sin^2(\theta_W)$, Sensitivity to new physics up to a scale of 50 MeV up to 50 TeV
- Much more physics from PV electron scattering
- Together with Moeller@Jlab (electron weak charge) and SOLID@Jlab (quark weak charge) very sensitive test of standard model and possibility to narrow in on Standard Model Extension