MESA/P2:

A 2% precision measurement of the weak charge of the proton

PAVI11 From Parity Violation to Hadronic Structure and more..

Rome, September, 5 - 9, 2011
Mainz, IKP, May 19, 2011

Frank Maas, Johannes-Gutenberg Unversität Mainz und HIM/GSI

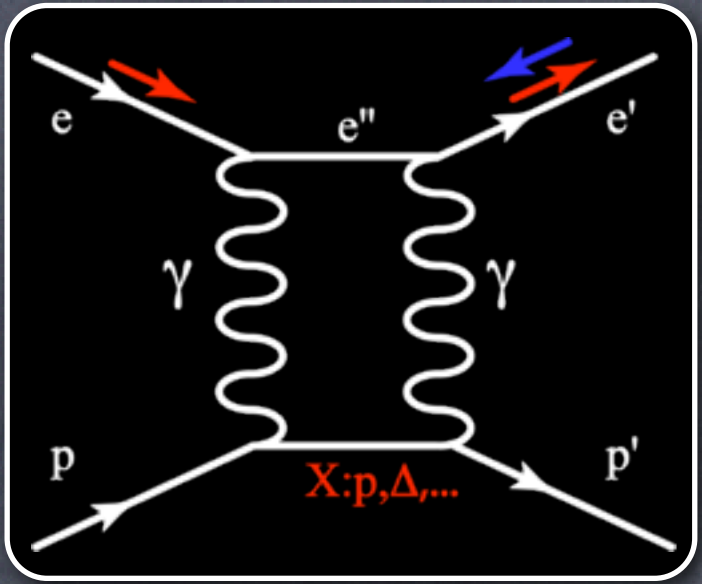
JG|U JOHANNES GUTENBERG UNIVERSITÄT MAINZ

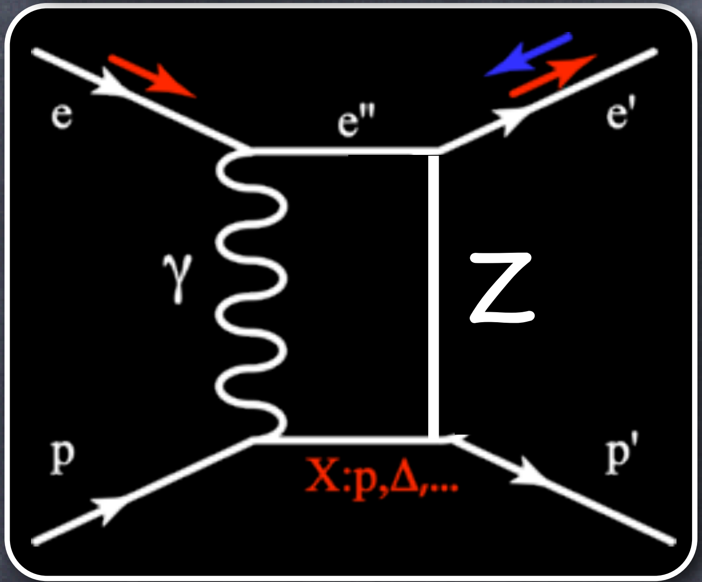
HELMHOLTZ | ASSOCIATION
Helmholtz Institute Mainz

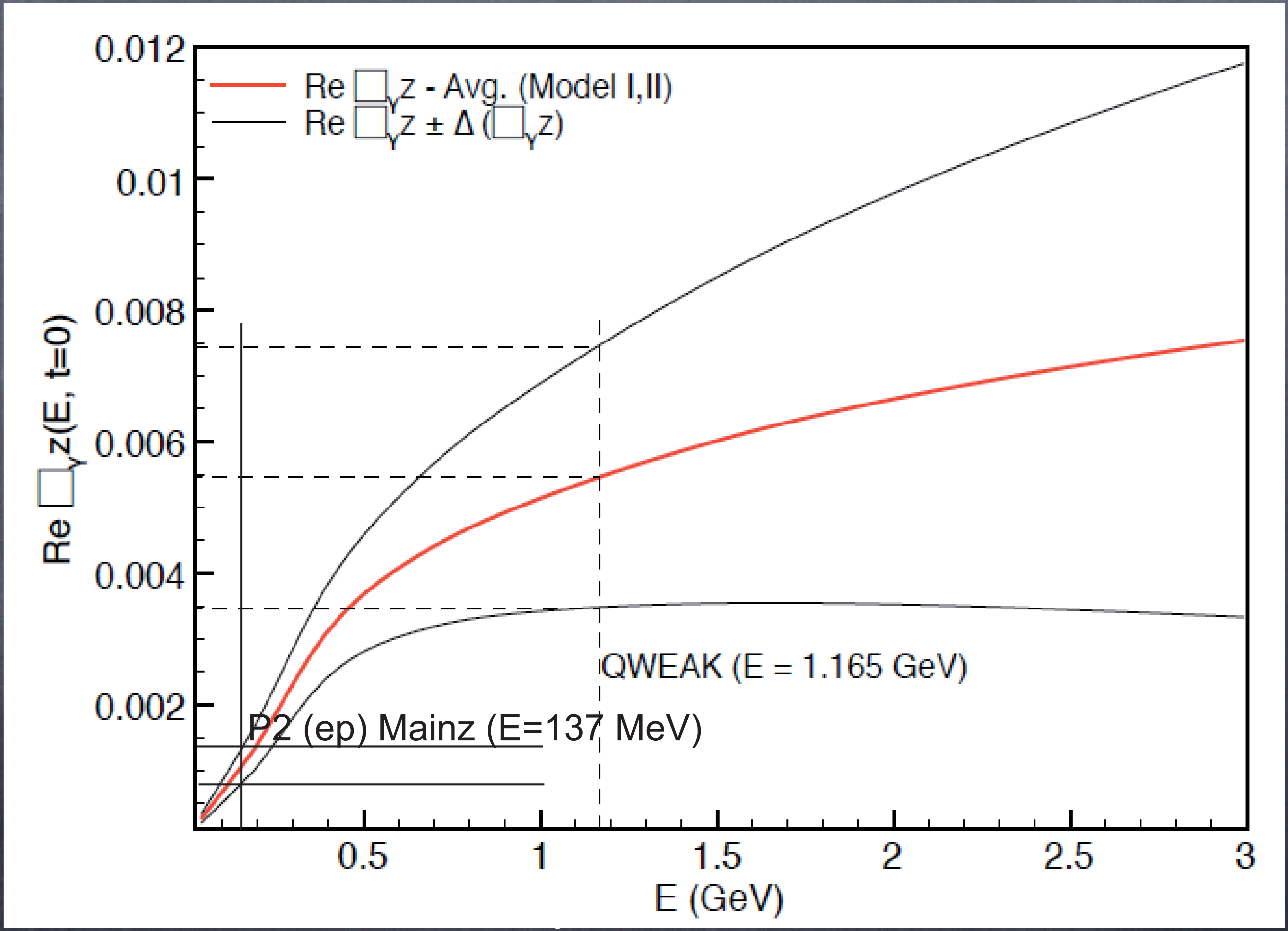
Outline

- Introduction
- P2: Precision
- P2: Technical aspects
- Summary

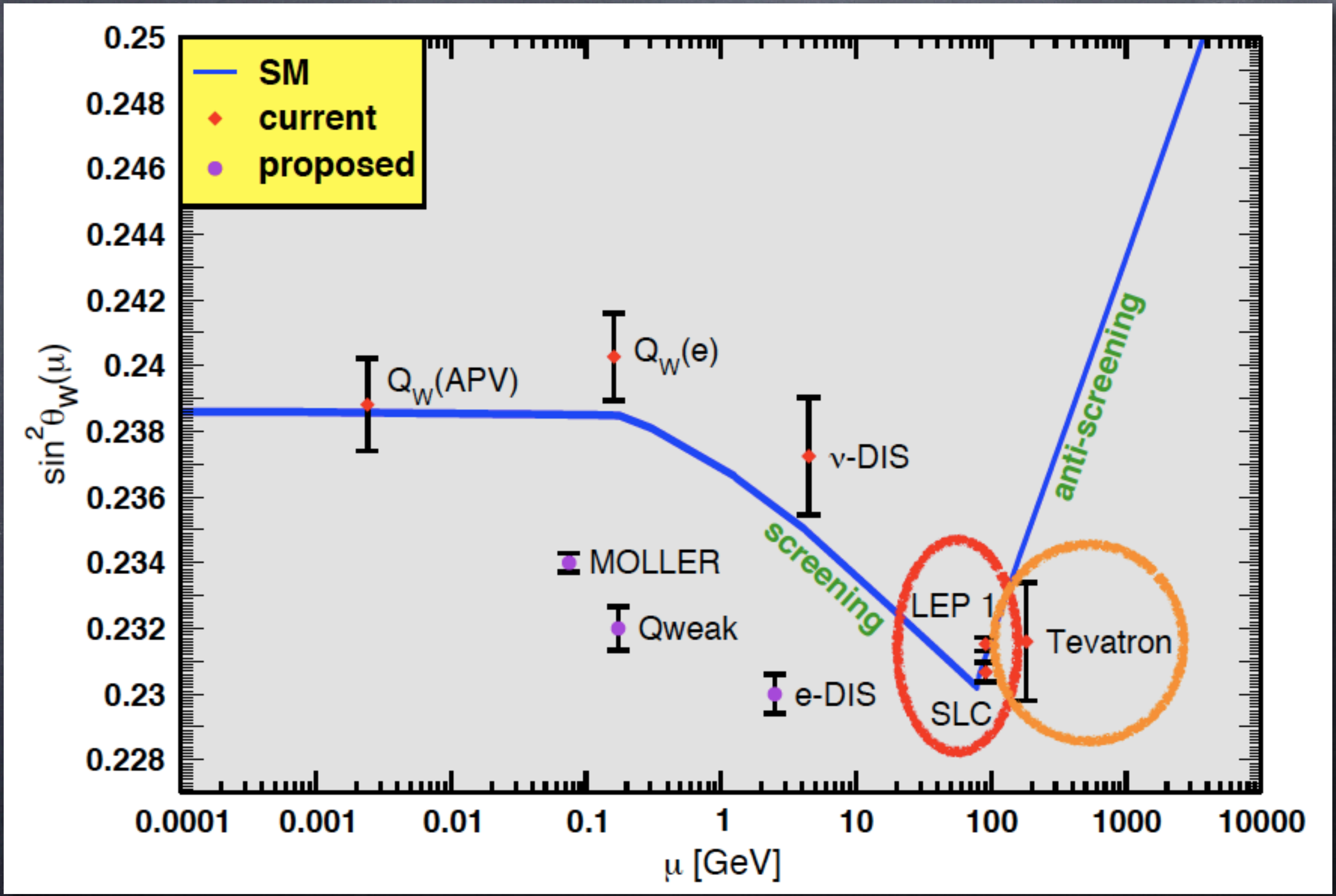
The „Gorchtein-Horrowitz“ Problem





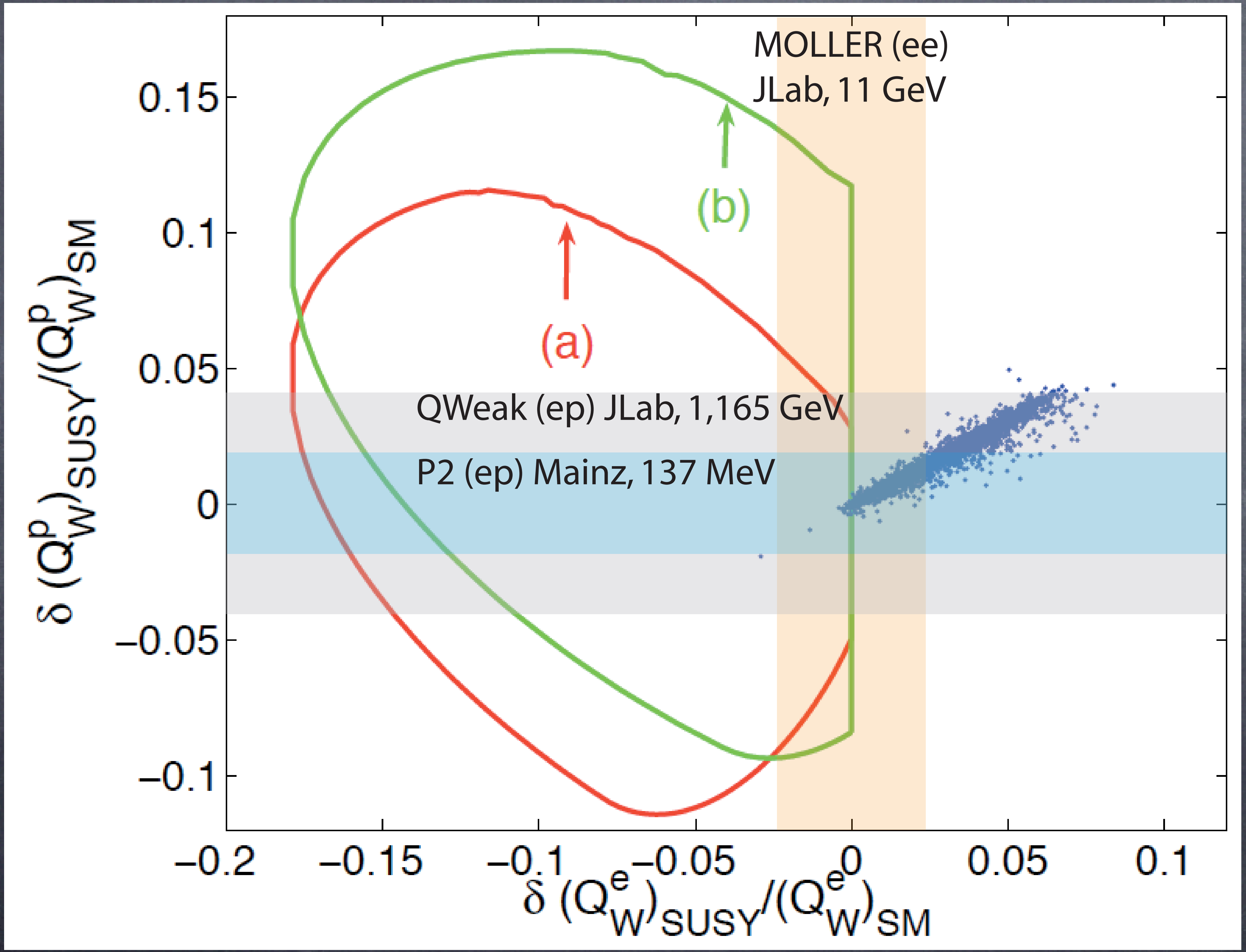


Weak Neutral Currents: Parity Violation



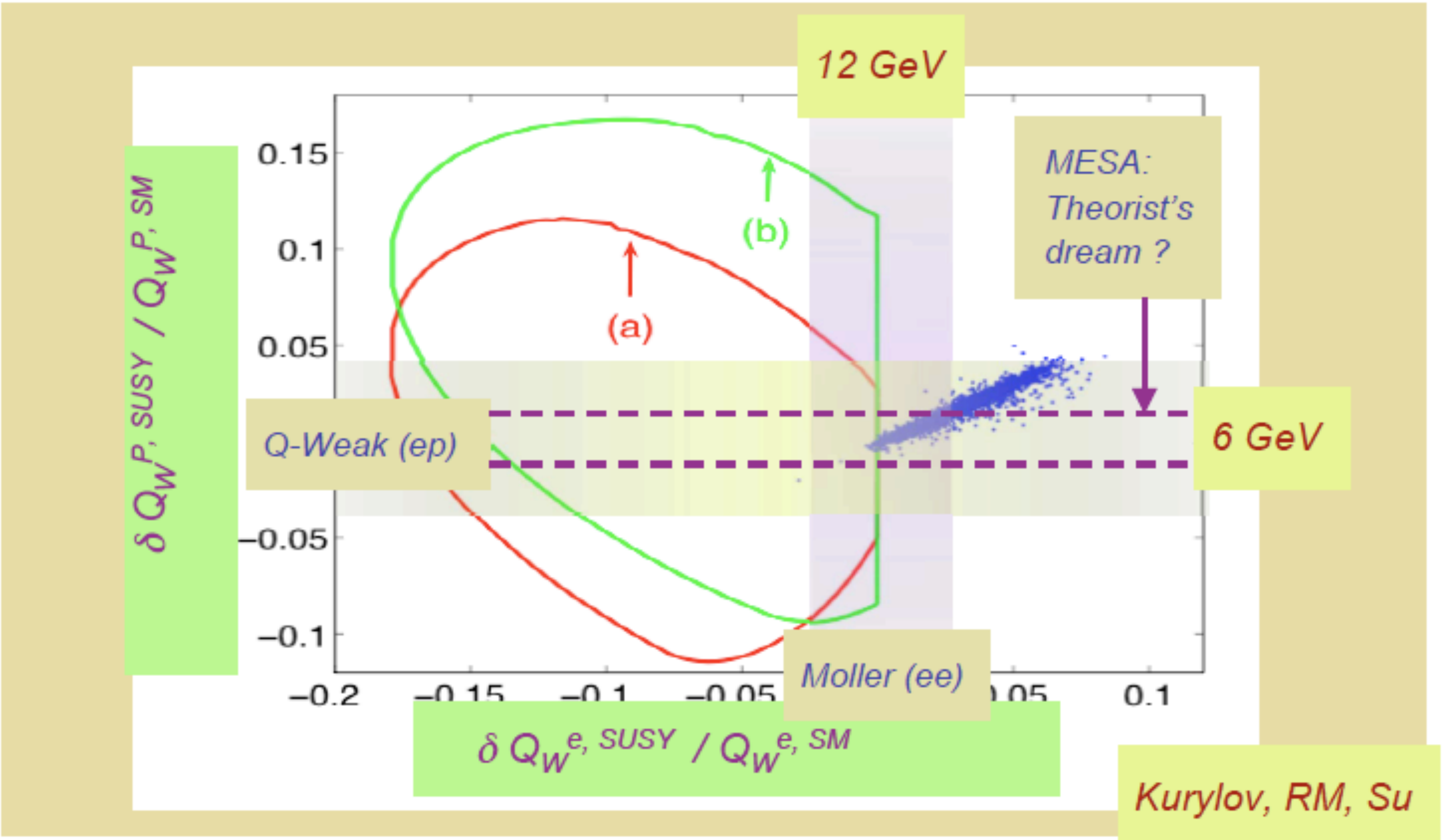
curtesy of Jens Erler

Weak Neutral Currents: Parity Violation

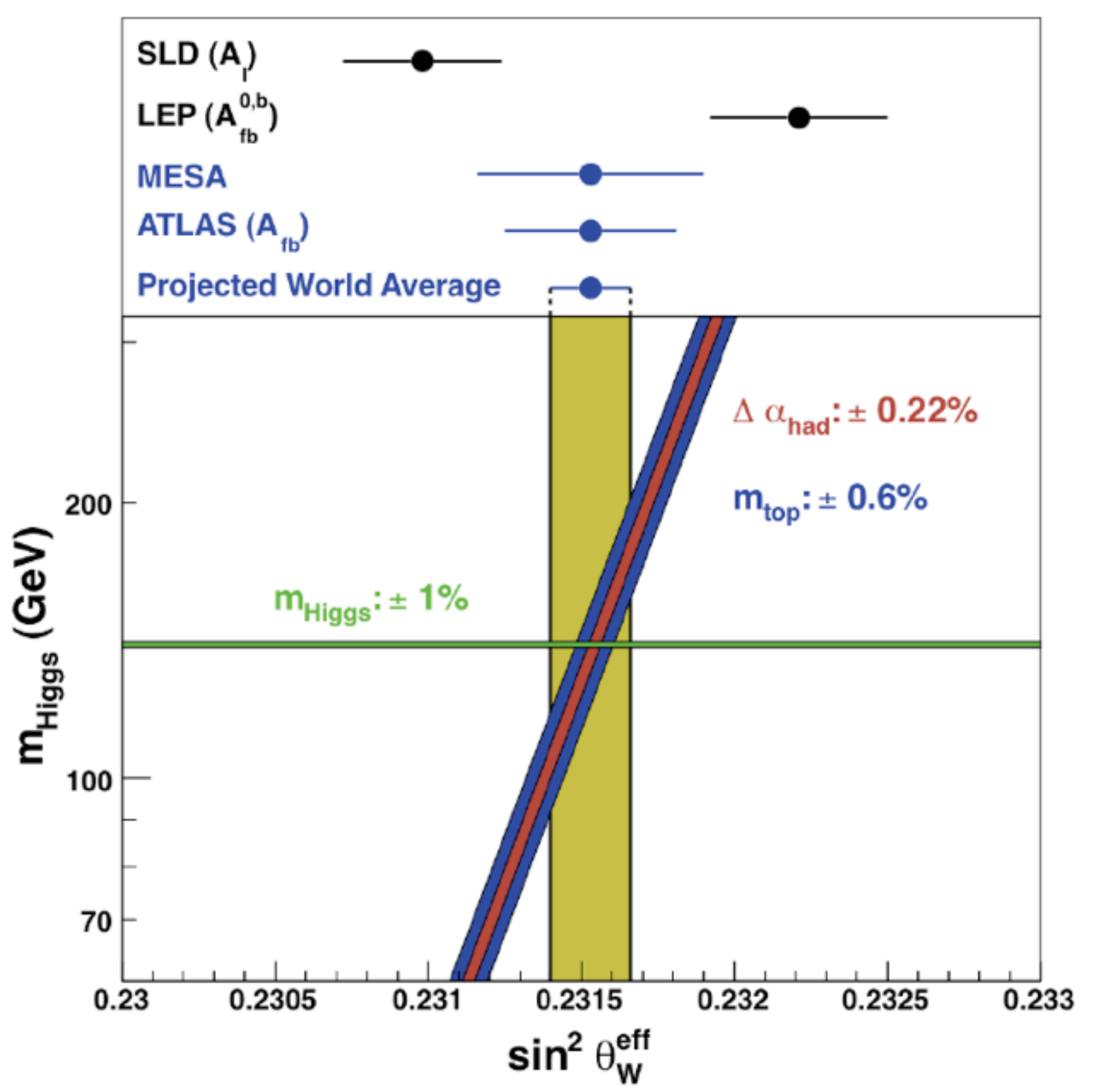


curtesy of Jens Erler

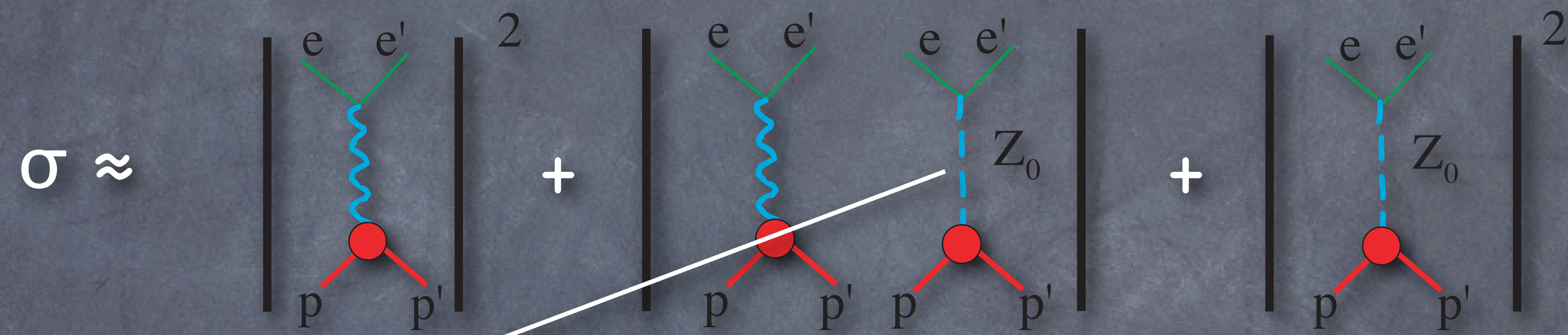
PVES & APV Probes of SUSY



Weak Neutral Currents: Parity Violation



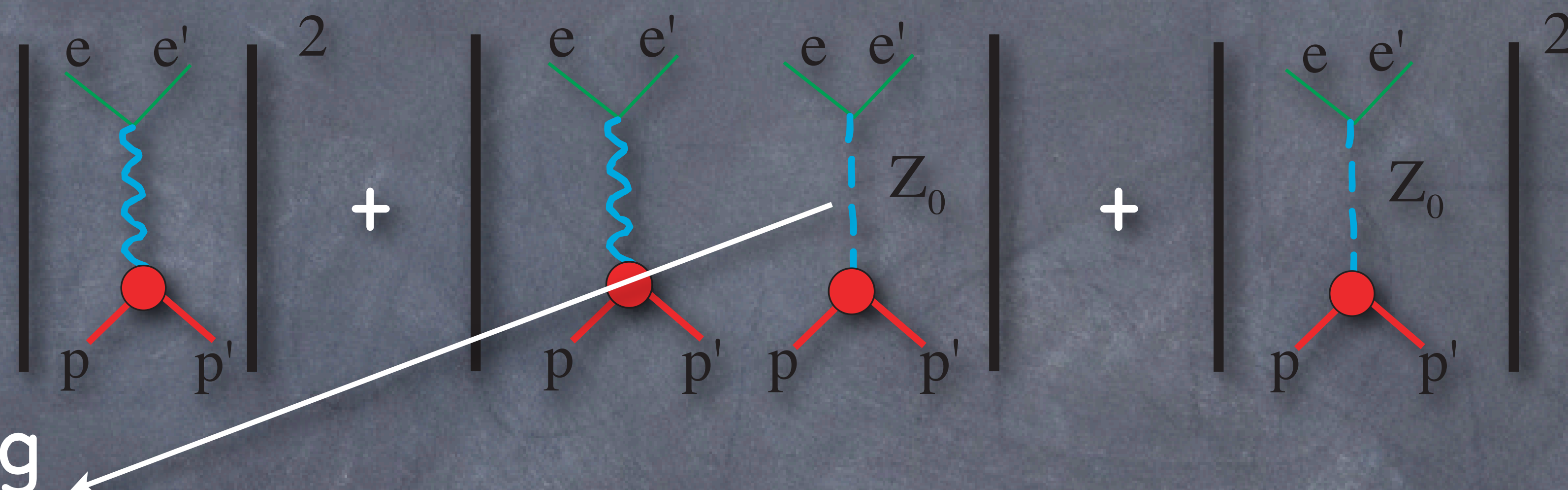
Search for New Physics Beyond the Standard Model: Parity Violating Electron Scattering



V-A Coupling

Search for New Physics Beyond the Standard Model: Parity Violating Electron Scattering

$\sigma \approx$

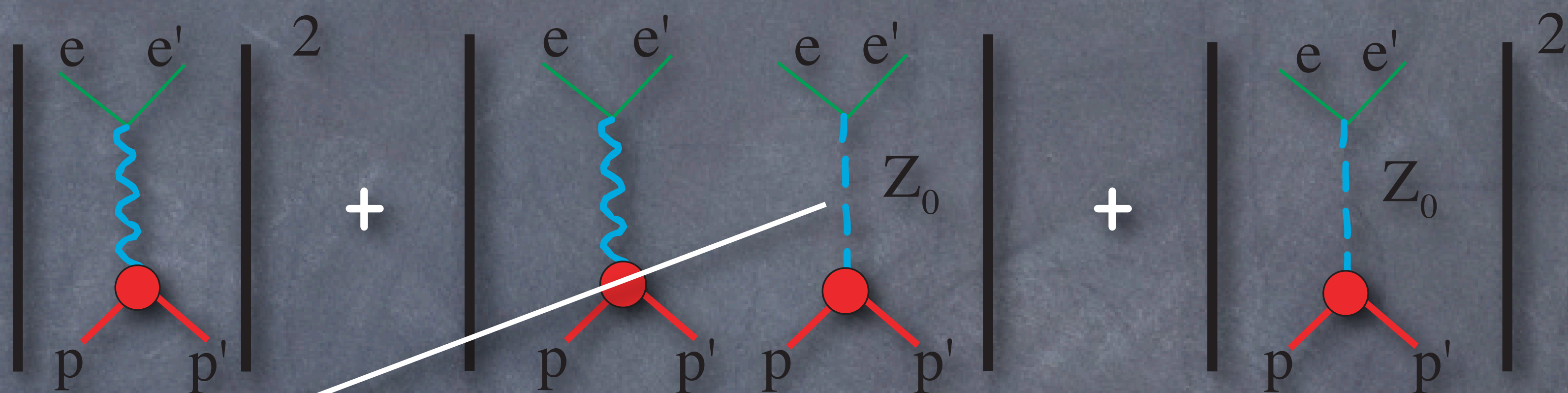


V-A Coupling

$$A = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$

long. polarised electrons
unpolarised protons

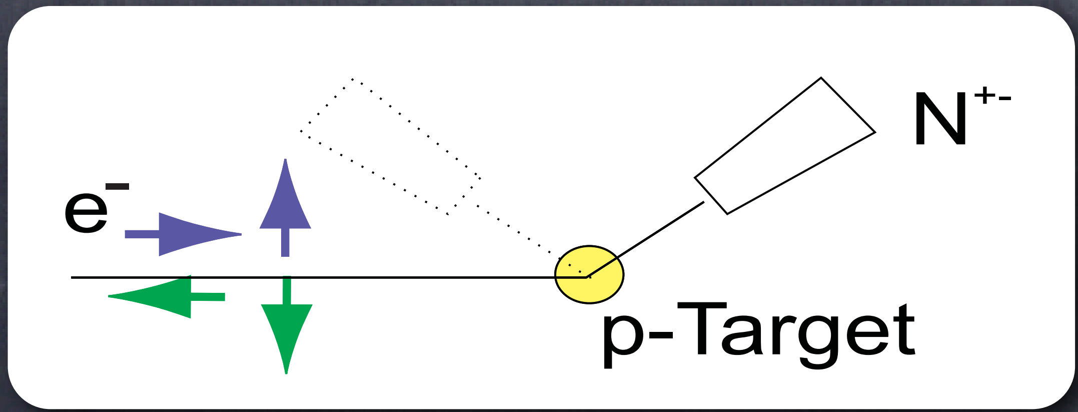
Search for New Physics Beyond the Standard Model: Parity Violating Electron Scattering

$\sigma \approx$ 

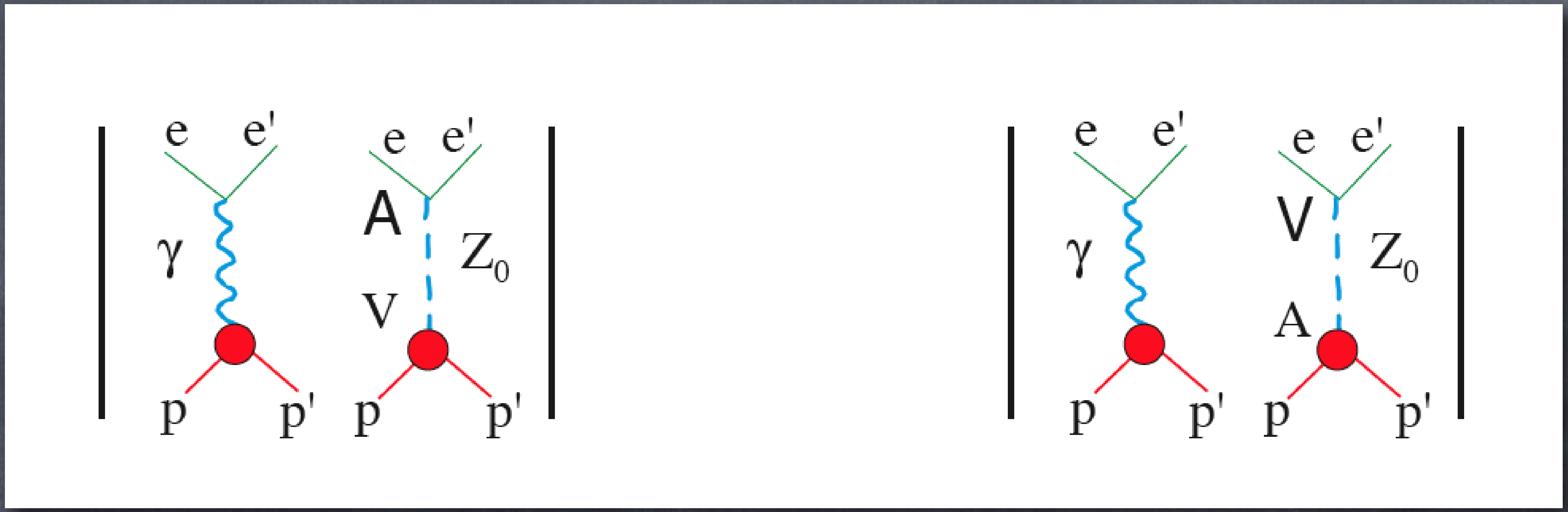
V-A Coupling

$$A = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$

long. polarised electrons
unpolarised protons



Parity Violation in Electroweak Interaction



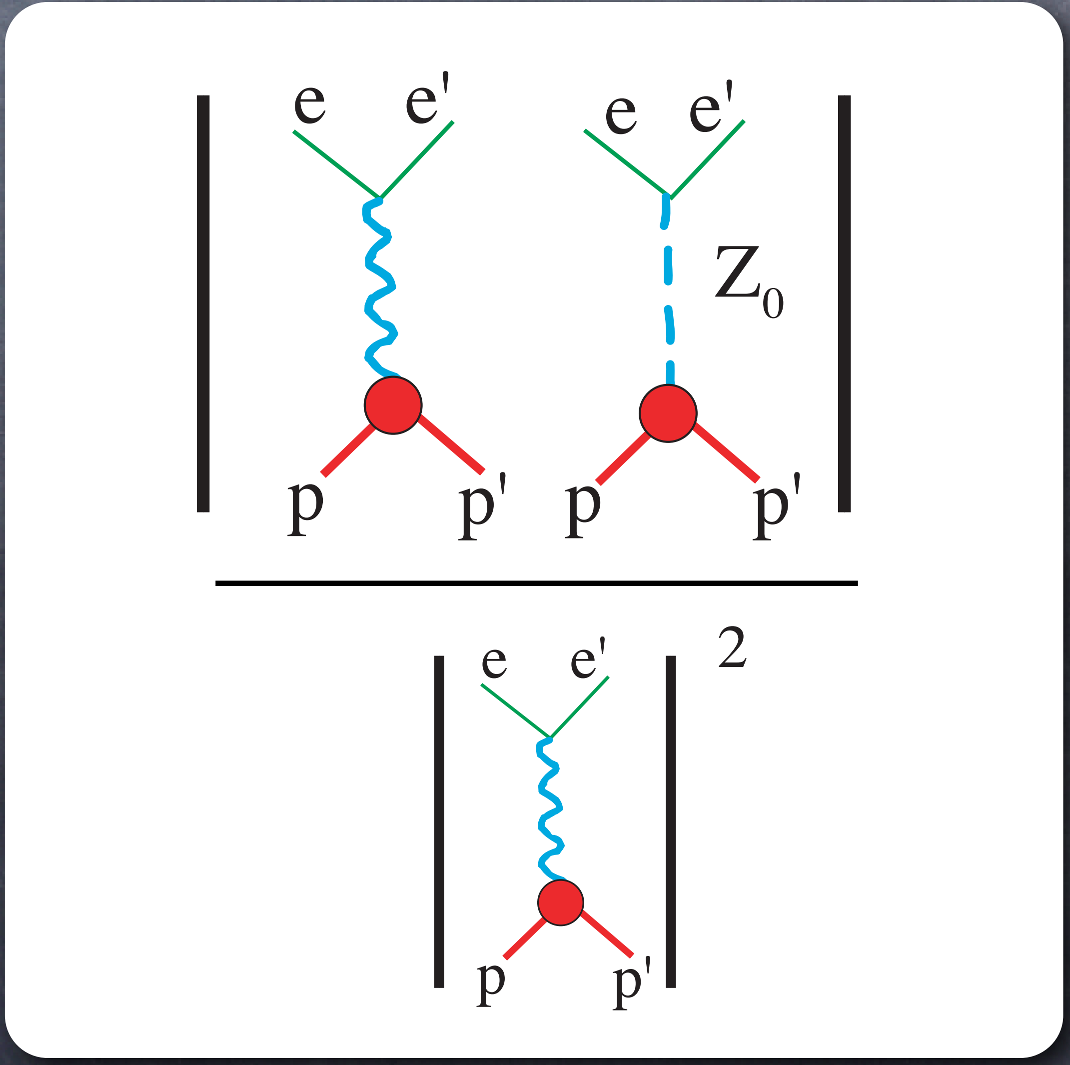
$C_{2u} = g_A{}^u g_V{}^e$

$Q_W{}^p = g_V{}^p g_A{}^e = \rho` (1 - 4\ \kappa`\ \sin^2\theta_W)$

$C_{1u} = g_V{}^u g_A{}^e$

Parity Violation in Electroweak Interaction

$$A^{PV} = -\frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}} \cdot \frac{\varepsilon G_E^p \tilde{G}_E^p + \tau G_M^p \tilde{G}_M^p - (1 - 4\sin^2\Theta_W)\varepsilon' G_M^p \tilde{G}_A^p}{\varepsilon\left(G_E^p\right)^2 + \tau\left(G_M^p\right)^2}$$



Parity Violation in Electroweak Interaction + Isospin Symetry

$$A_V = -\frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}}\rho'_{eq}\left\{\left(1-4\hat{\kappa}'_{eq}\hat{s}_Z^2\right) - \frac{\varepsilon G_E^p G_E^n + \tau G_M^p G_M^n}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2}\right\}$$

$$A_S = \frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}}\rho'_{eq}\left\{\frac{\varepsilon G_E^p G_E^s + \tau G_M^p G_M^s}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2}\right\}$$

$$A_A = \frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}}\left\{\frac{(1-4\hat{s}_Z^2)\sqrt{1-\varepsilon^2}\sqrt{\tau(1+\tau)}G_M^p \tilde{G}_A^p}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2}\right\}$$

Parity Violation in Electroweak Interaction + Isospin Symetry

Q_{weak}

$$A_V = -\frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}}\rho'_{eq}\left\{\left(1 - 4\hat{\kappa}'_{eq}\hat{s}^2_Z\right) - \frac{\varepsilon G^p_E G^n_E + \tau G^p_M G^n_M}{\varepsilon (G^p_E)^2 + \tau (G^p_M)^2}\right\}$$

$$A_S = \frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}}\rho'_{eq}\left\{\frac{\varepsilon G^p_E G^s_E + \tau G^p_M G^s_M}{\varepsilon (G^p_E)^2 + \tau (G^p_M)^2}\right\}$$

$$A_A = \frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}}\left\{\frac{(1 - 4\hat{s}^2_Z)\sqrt{1-\varepsilon^2}\sqrt{\tau(1+\tau)}G^p_M \tilde{G}^p_A}{\varepsilon (G^p_E)^2 + \tau (G^p_M)^2}\right\}$$

Parity Violation in Electroweak Interaction + Isospin Symetry

Q_{weak} EM-Form Factors

$$A_V = -\frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}}\rho'_{eq}\left\{\left(1-4\hat{\kappa}'_{eq}\hat{s}_Z^2\right)-\frac{\varepsilon G_E^p G_E^n+\tau G_M^p G_M^n}{\varepsilon (G_E^p)^2+\tau (G_M^p)^2}\right\}$$

$$A_S = \frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}}\rho'_{eq}\left\{\frac{\varepsilon G_E^p G_E^s+\tau G_M^p G_M^s}{\varepsilon (G_E^p)^2+\tau (G_M^p)^2}\right\}$$

$$A_A = \frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}}\left\{\frac{(1-4\hat{s}_Z^2)\sqrt{1-\varepsilon^2}\sqrt{\tau(1+\tau)}G_M^p\tilde{G}_A^p}{\varepsilon (G_E^p)^2+\tau (G_M^p)^2}\right\}$$

Parity Violation in Electroweak Interaction + Isospin Symetry

Q_{weak}

EM-Form Factors

$$A_V = -\frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}}\rho'_{eq}\left\{\left(1-4\hat{\kappa}'_{eq}\hat{s}^2_Z\right)-\frac{\varepsilon G^p_E G^n_E+\tau G^p_M G^n_M}{\varepsilon(G^p_E)^2+\tau(G^p_M)^2}\right\}$$

$$A_S = \frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}}\rho'_{eq}\left\{\frac{\varepsilon G^p_E G^s_E+\tau G^p_M G^s_M}{\varepsilon(G^p_E)^2+\tau(G^p_M)^2}\right\}$$

$$A_A = \frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}}\left\{\frac{(1-4\hat{s}^2_Z)\sqrt{1-\varepsilon^2}\sqrt{\tau(1+\tau)}G^p_M\tilde{G}^p_A}{\varepsilon(G^p_E)^2+\tau(G^p_M)^2}\right\}$$

EM-Form Factors

Parity Violation in Electroweak Interaction + Isospin Symetry

Q_{weak}

EM-Form Factors

$$A_V = -\frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}}\rho'_{eq}\left\{\left(1-4\hat{\kappa}'_{eq}\hat{s}^2_Z\right) - \frac{\varepsilon G_E^p G_E^n + \tau G_M^p G_M^n}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2}\right\}$$

$$A_S = \frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}}\rho'_{eq}\left\{\frac{\varepsilon G_E^p G_E^s + \tau G_M^p G_M^s}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2}\right\}$$

$$A_A = \frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}}\left\{\frac{(1-4\hat{s}^2_Z)\sqrt{1-\varepsilon^2}\sqrt{\tau(1+\tau)}G_M^p \tilde{G}_A^p}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2}\right\}$$

EM-Form Factors

Axial Form Factor

Parity Violation in Electroweak Interaction + Isospin Symetry

Qweak

EM-Form Factors

$$A_V = -\frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}}\rho'_{eq}\left\{\left(1 - 4\hat{\kappa}'_{eq}\hat{s}^2_Z\right) - \frac{\varepsilon G_E^p G_E^n + \tau G_M^p G_M^n}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2}\right\}$$

$$A_S = \frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}}\rho'_{eq}\left\{\frac{\varepsilon G_E^p G_E^s + \tau G_M^p G_M^s}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2}\right\}$$

$$A_A = \frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}}\left\{\frac{(1 - 4\hat{s}^2_Z)\sqrt{1-\varepsilon^2}\sqrt{\tau(1+\tau)}G_M^p \tilde{G}_A^p}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2}\right\}$$

EM-Form Factors

Axial Form Factor

Choose Kinematics so that Terms are Emphasized

Parity Violation in Electroweak Interaction + Isospin Breaking

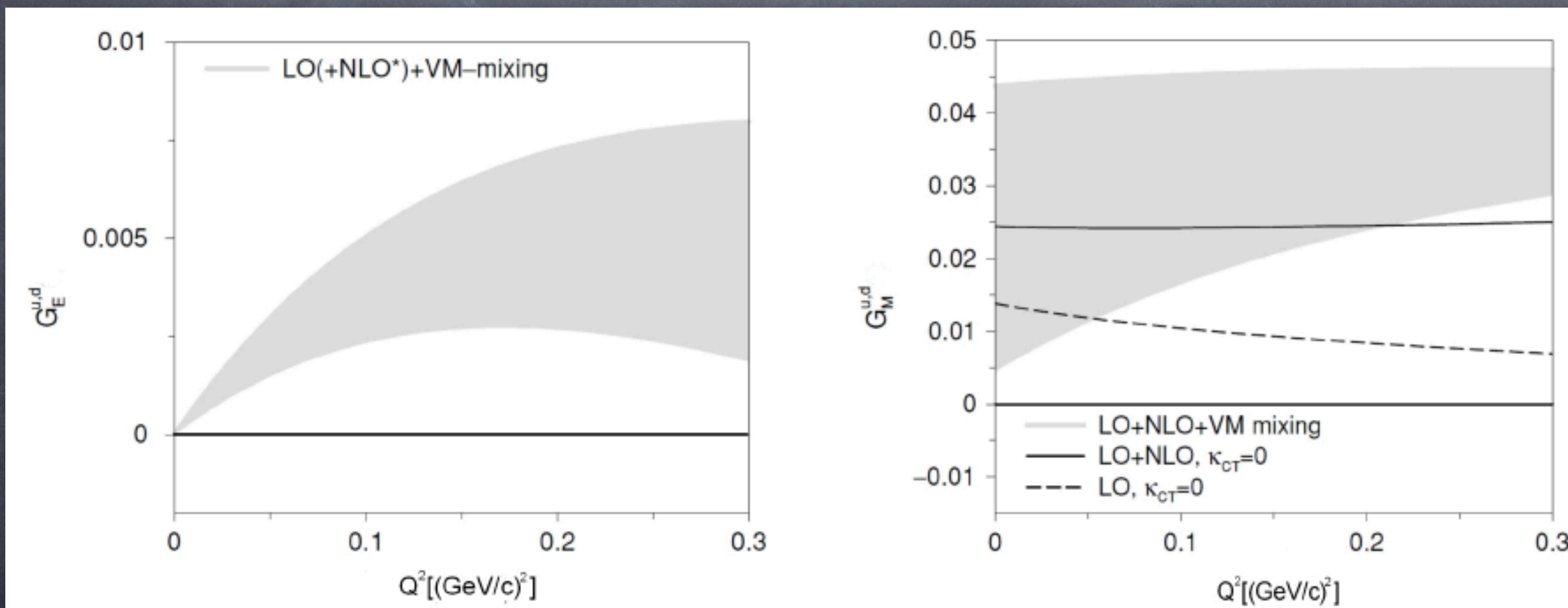
$$\frac{A^{exp}}{P} \stackrel{!}{=} A^{phys} = -a\Bigg\{\rho'_{eq}\left(1 - 4\hat{\kappa}'_{eq}\hat{s}_Z^2\right) - \rho'_{eq}\frac{\varepsilon G_E^p G_E^n + \tau G_M^p G_M^n}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2}$$

$$- \rho'_{eq}\frac{\varepsilon G_E^p G_E^s + \tau G_M^p G_M^s}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2} - \rho'_{eq}\frac{\varepsilon G_E^p G_E^{u,d} + \tau G_M^p G_M^{u,d}}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2}$$

$$- \frac{(1 - 4\hat{s}_Z^2)\sqrt{1-\varepsilon^2}\sqrt{\tau(1+\tau)}G_M^p \tilde{G}_A^p}{\varepsilon (G_E^p)^2 + \tau (G_M^p)^2}\Bigg\}$$

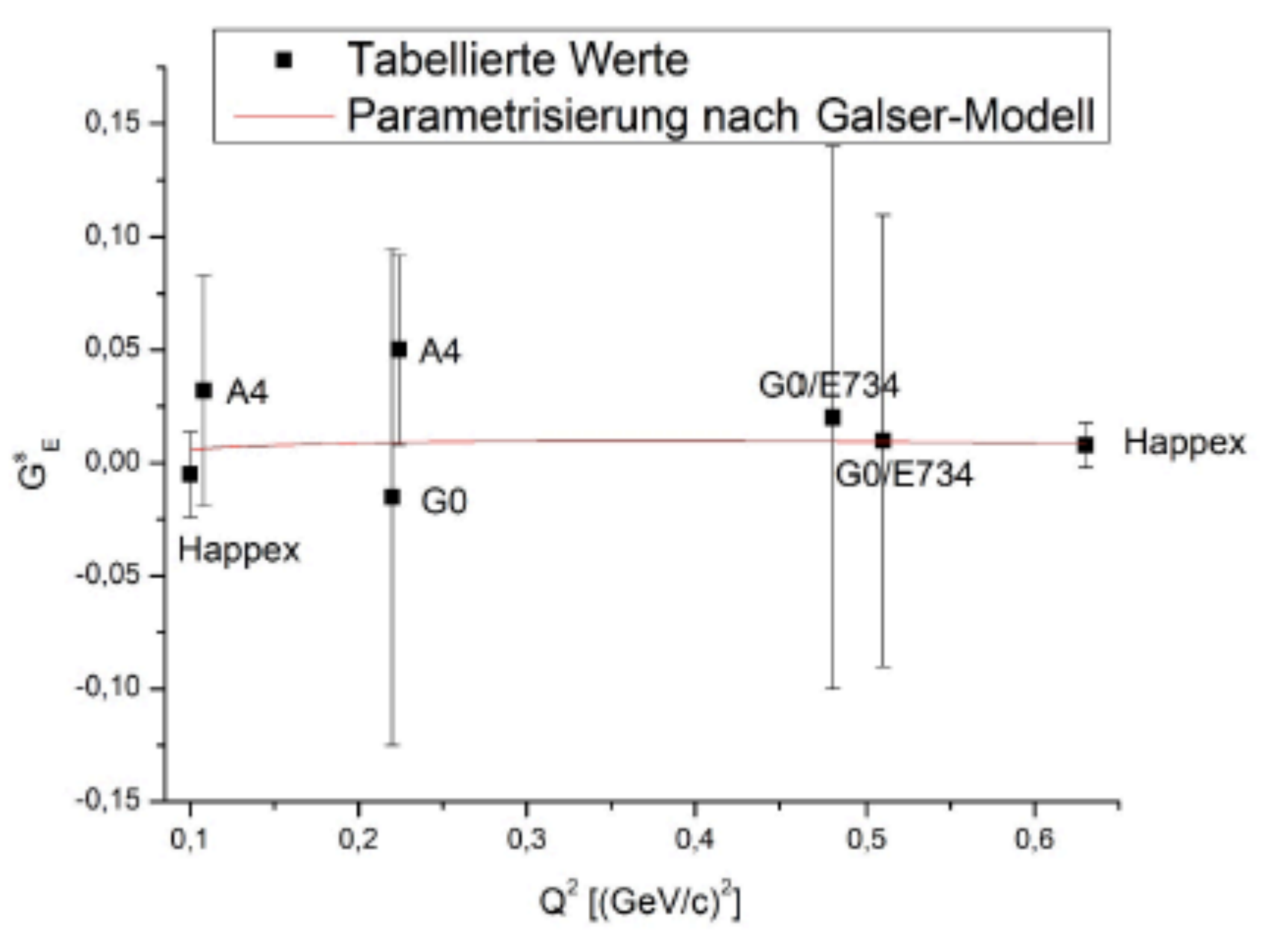
$$A_{LR} = \frac{\sigma(e_\downarrow) - \sigma(e_\uparrow)}{\sigma(e_\downarrow) + \sigma(e_\uparrow)} = -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\left(Q_W(\mathcal{N}) - F(Q^2)\right)$$

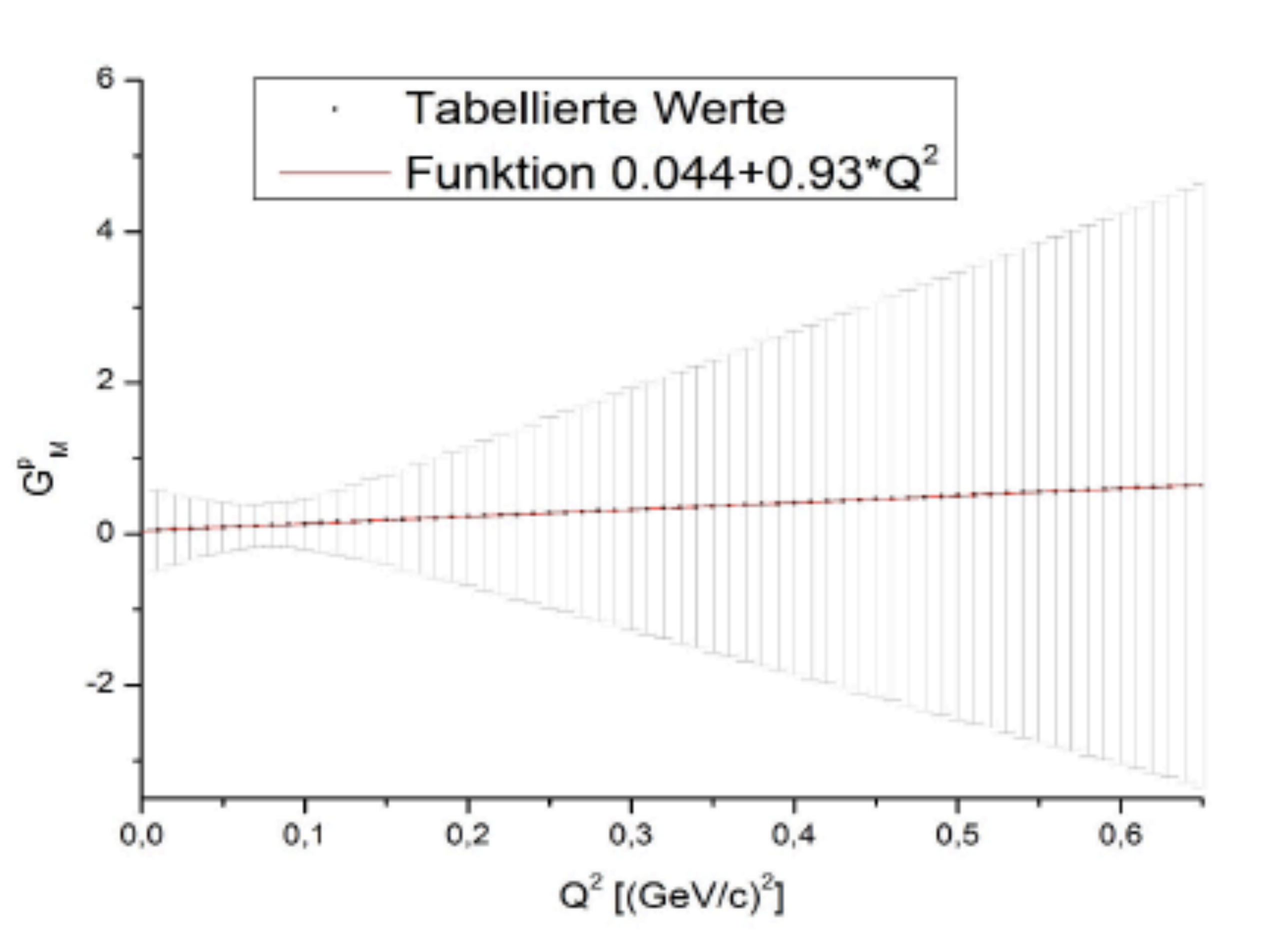
Parity Violation in Electroweak Interaction + Isospin Breaking



Bastian Kubis and Randy Lewis

Strangeness Form Factors





present A4: reduce old SAMPLE error in G_M^s and G_A^e by factor 2

Axial Form Factor

$G_A^p(Q^2 = 0\ GeV^2/c^2) = -\ 1.135(411)$
36% Error
includes Δs and RC (Anapole Moment)

$G_A^p(Q^2) = G_A^p(Q^2{=}0)\ G_A^D(Q^2)$
Standard Dipole with Axial Mass M_A

Relation between Q_{Weak} and $\sin^2 \theta_W$

$Q_{Weak} = 1 - 4 \sin^2 \theta_W$ (Tree Level)

$Q_{Weak} = 0.075$

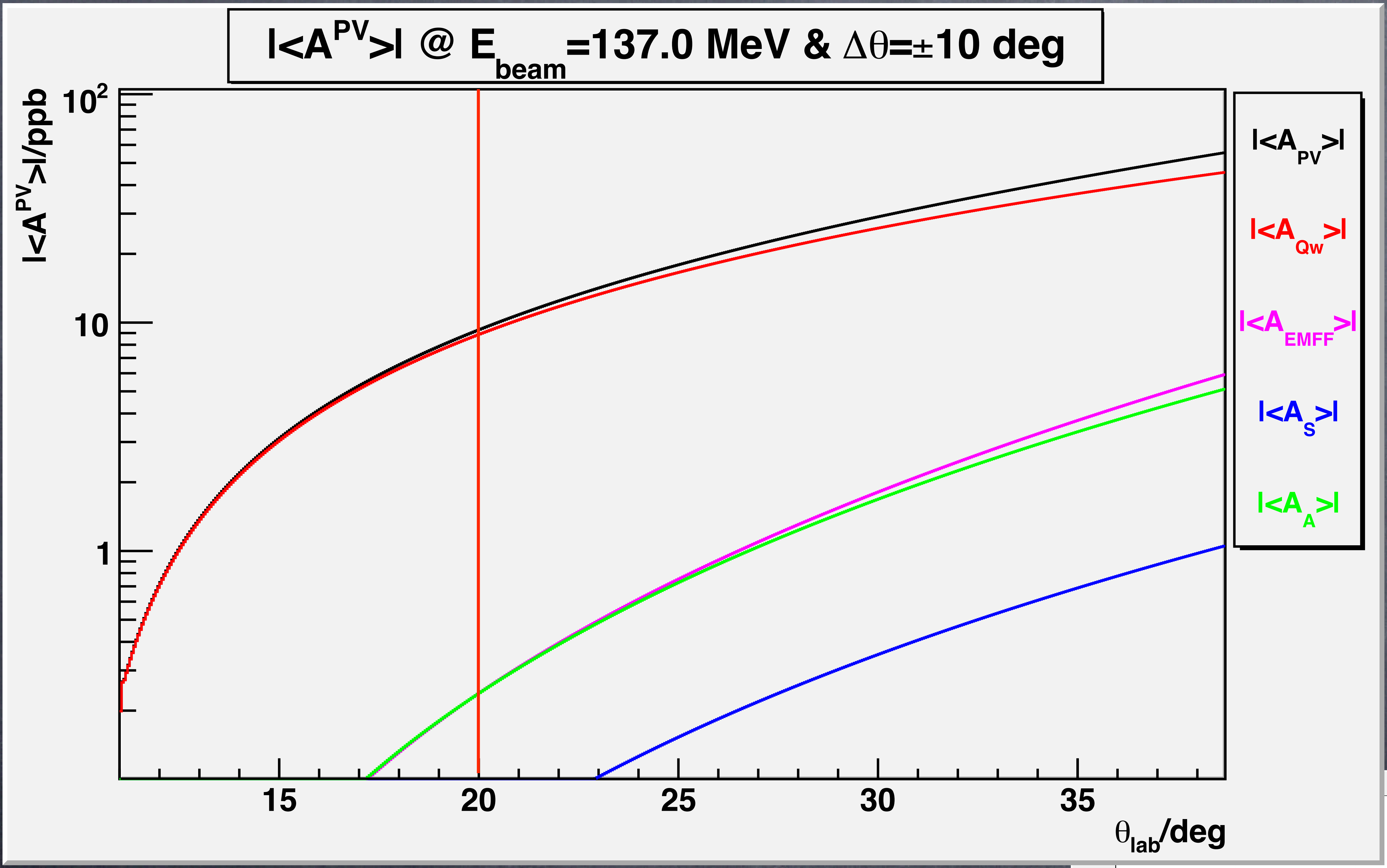
$Q_{Weak} = \rho` (1 - 4 \kappa` \sin^2 \theta_W)$ (Radiative Corrections)

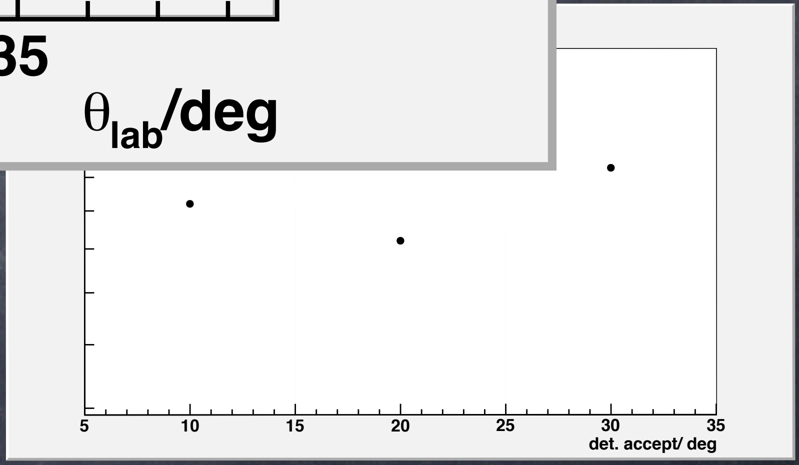
$Q_{Weak} = 0.0718$

$\Delta Q_{Weak} / Q_{Weak} = 4 \Delta \sin^2 \theta_W / Q_{Weak}$

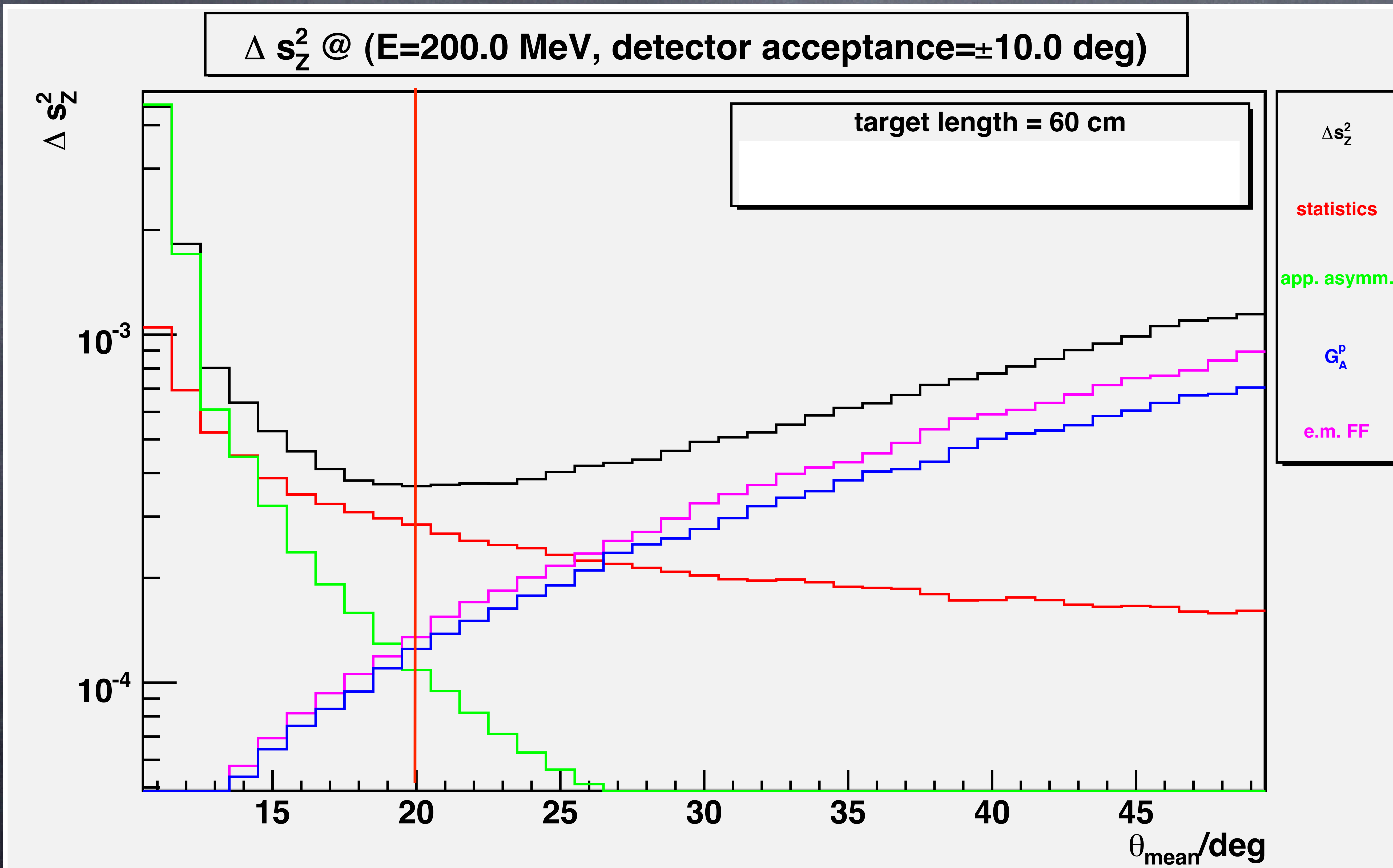
P2 Precision

Mean Asymmetry (acceptance 10°-20°)





Error on $\sin^2(\Theta_W)$ by Monte Carlo



P2-Parameters

Parameter	Q_{weak}	Error Q_{weak}	P2	Error P2
Beam Energy	1.165 GeV	1.165 MeV	137 MeV	150 keV
Polarisation	85 %	1%	80%	0.5%
Beam Current	180 μA	< 0.1%	150 μA	-
LH2 length	35 cm	-	30 cm	-
Run Time	2544 h	-	10000 h	-
Scattering Angle	7.9°	$5 \cdot 10^{-6\circ}$	20°	
Acceptance	±3°	-	±10°	-
Acceptance	49% von 2π	-	2π	-

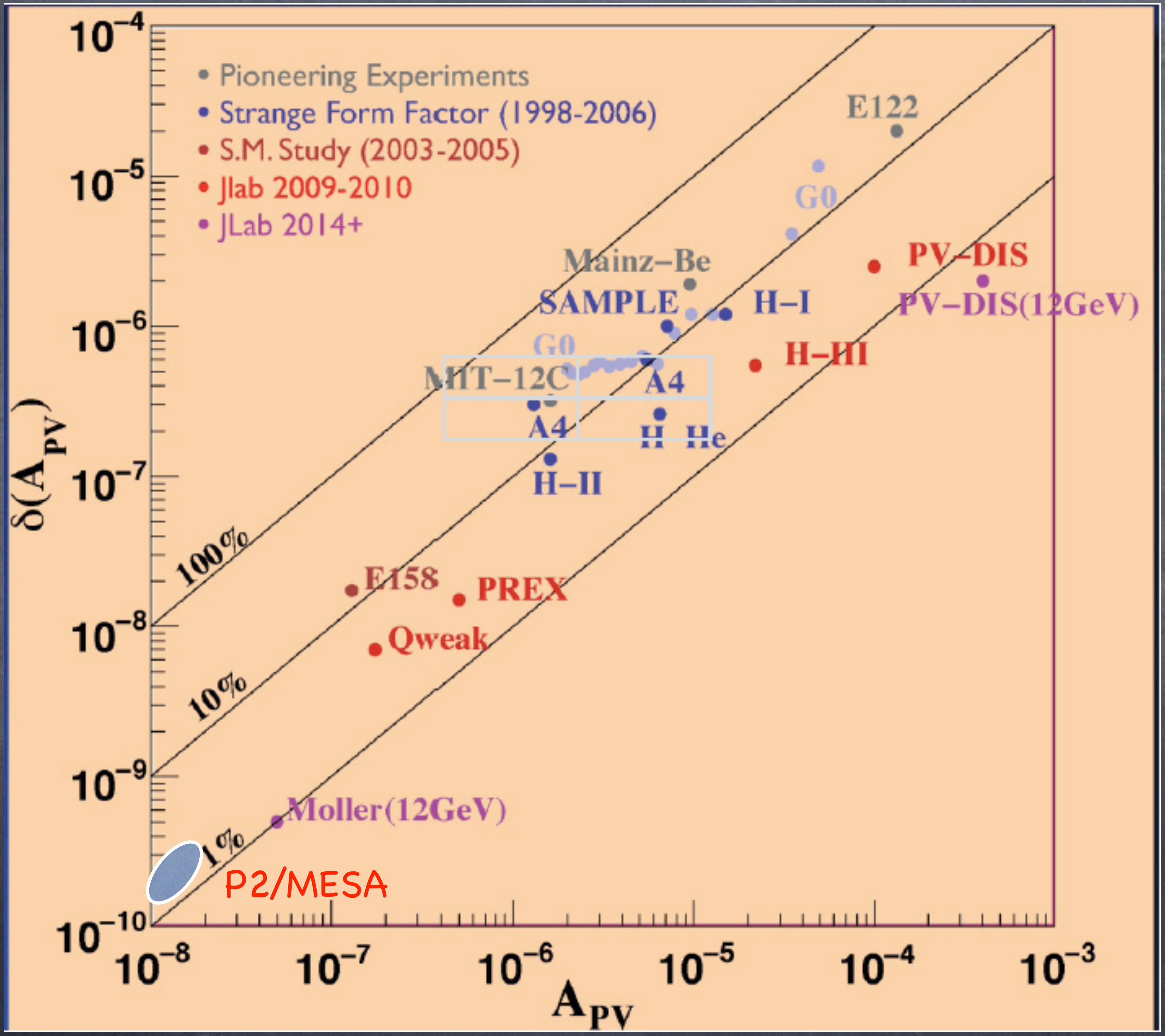
Beam energy and Luminosity will be further optimized

MESA/P2-Parameters

E_{Beam}	137 MeV	200 MeV	200 MeV
Q^2/θ_e	0,0022 GeV^2/20°	0,0048 GeV^2/20°	0,0048 GeV^2/20°
time/current/target	10000h/150μA/60cm	10000h/150μA/30cm	10000h/150μA/60cm
A_{phys}	-9.28 ppb	-20,25	-20,25
ΔA_{tot}	0,21 ppb (2.3%)	0,42 (2,1 %)	0,34 (1,7 %)
ΔA_{stat}	0,17	0,36	0,25
Rate	0,96 10^{12} Hz	0,21 10^{12} Hz	0,44 10^{12}Hz
ΔA_{sys}	0,11 (1,2%)	0,12 (0,6%)	0,19 (0,9%)
$\Delta s_Z{}^2{}_{tot}$	4,94 10^{-4} (0,21 %)	4,63 10^{-4} (0,2 %)	3,6 10^{-4} (0,15 %)
$\Delta s_Z{}^2{}_{stat}$	4,1 10^{-4}	3,9 10^{-4}	2,8 10^{-4}
P	85 %	85 %	85 %

High Rates: 200 GHz to 1 THz

Challenge



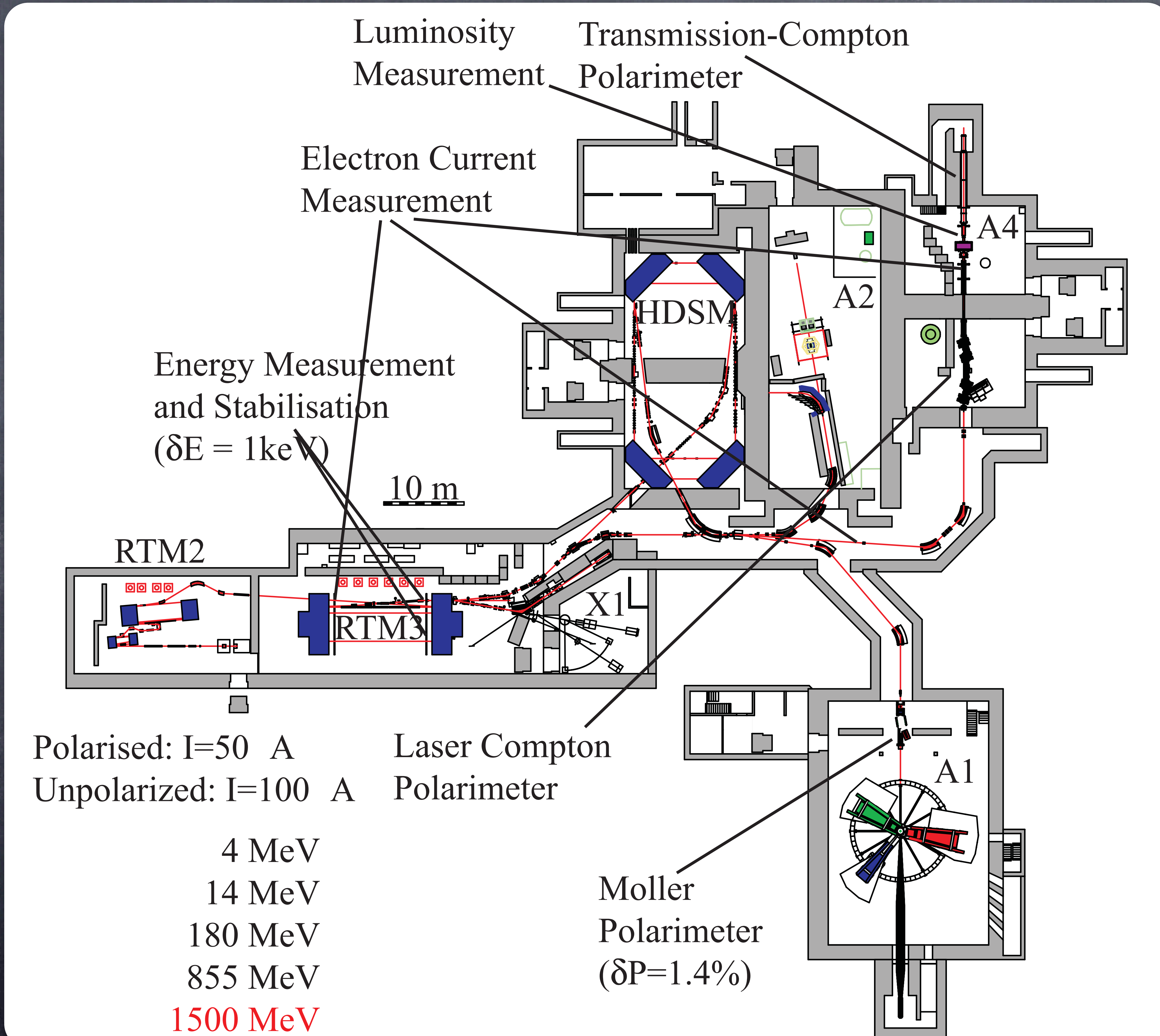
Pioneering Experiments
Strange Form Factor (1998-2006)
S.M. Study (2003-2005)
Jlab 2009-2010
JLab 2014+
E122
G0
Mainz–Be
SAMPLE
H–I
PV–DIS
PV–DIS(12GeV)
H–III
MIT–12C
A4
H
He
H–II
100%
10%
1%
E158
PREX
Qweak
Moller(12GeV)
P2/MESA
δ(A_PV)
A_PV

Summary

	A4	P2/MESA	
Asymmetry	1-15 ppm	10-10 ppb	HC beam fluct. by factor 10
Rates	100 MHz	0.2 - 1 THz	2kHz flipping
Polarimetry	1.5 % (4%)	5 %	Hydro-Möller
Electronics	Counting	Integrating	18 bit, 500 kHz ADCs
Spectrometer	Calorimeter	Magnetic Spectrometer	Solenoid versus toroid
Target	120 W	2 kW	beam raster, new target cell
Regression	from beam fluctuation	coil pulsing	hc feed back

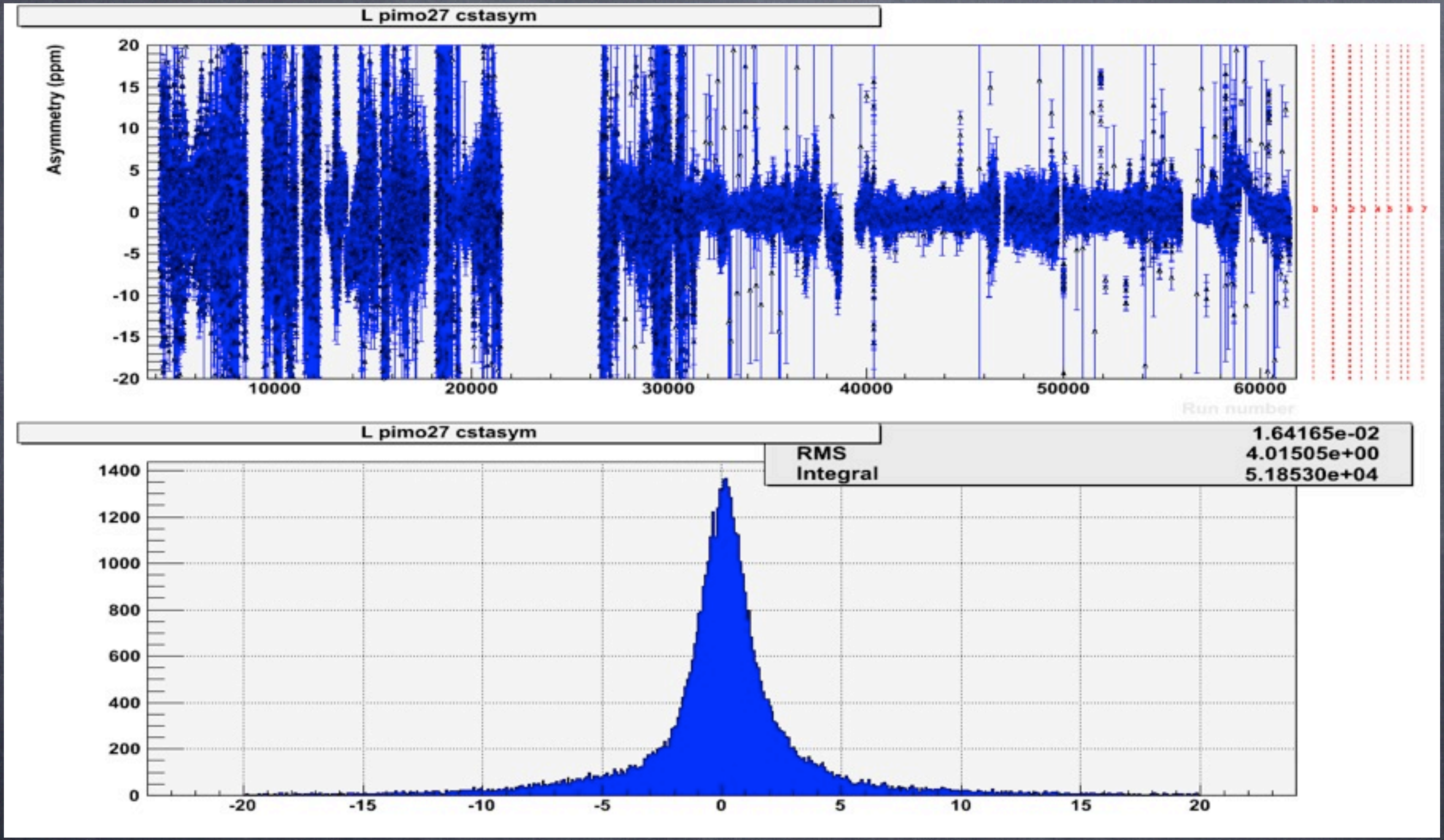
P2 technical Aspects

Stabilisation of Beam Parameters



37 stab. systems, ΔT=0.1 K

Polarized Source: Current



Mean: <50 ppb

False Asymmetries

Paramter	±1% f.A: P2 137 MeV	±1% f.A: P2 200 MeV	A4/MAMI Precision 5000h	A4/MAMI Mean 5000H
Intensity	0,15 pb	0,36 ppb	16 ppb	50 ppb
Position	0,06 nm	0,13 nm	1 nm	10 nm
Anglr	0,03 nrad	0,06 nrad	0,8 nrad	7 nrad
Energy	0,02 eV	0,07 eV	0,05 eV	0,05

so far (A4): no Helicity Correlated Feedback Loops

MAMI Running Extremely Well

Improvement by Large Factors possible

Have designed special „Lock-In“ Amplifier

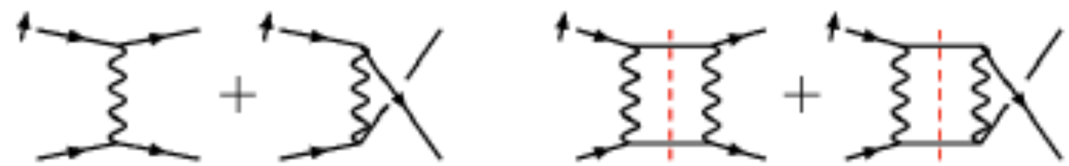
Polarimetry Goal: $\Delta P = 0.5$ %

see talk by K. Aulenbacher

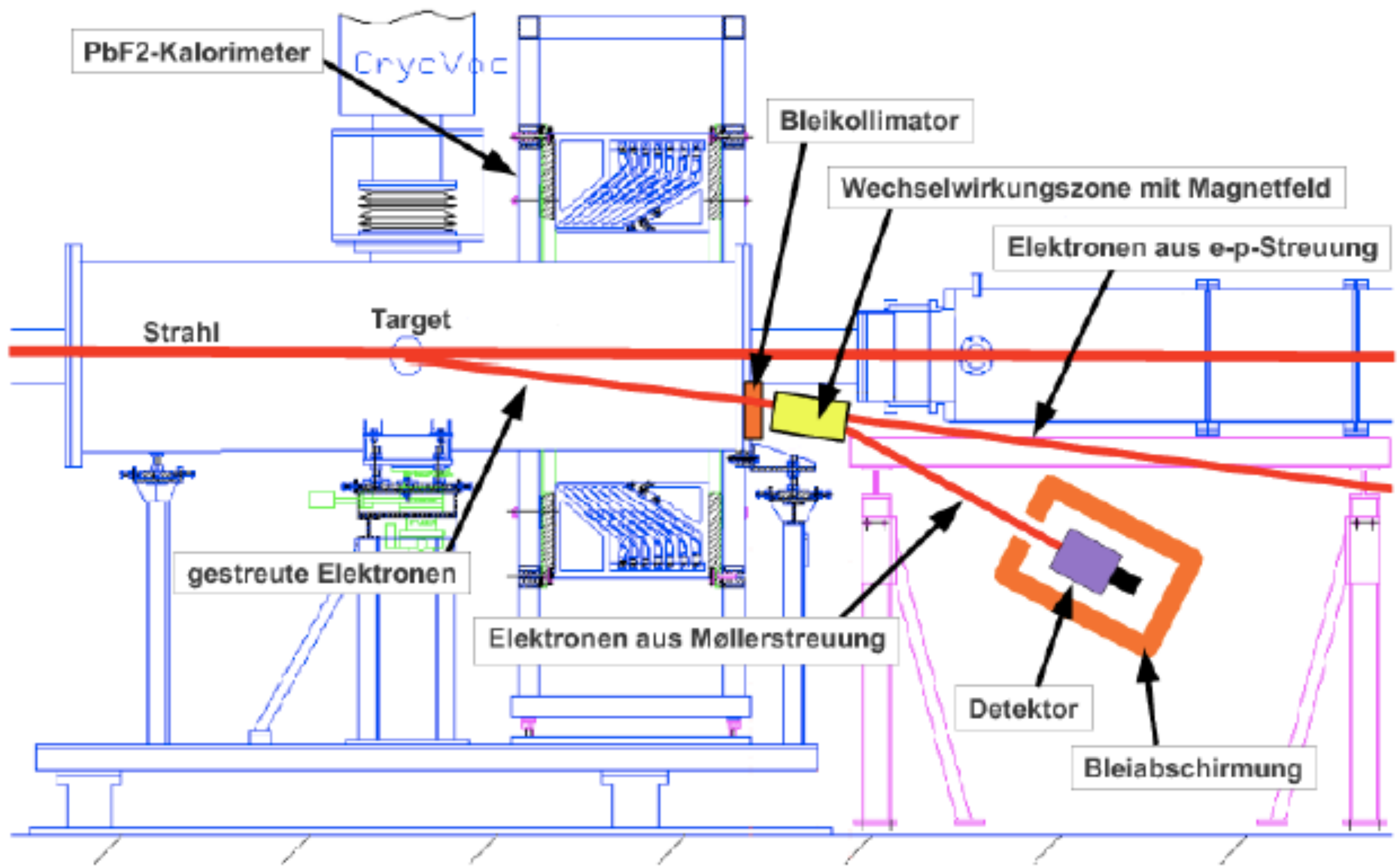
- Double Mott (<0.3 %, invasive, at Low Energy)
- Brute Force Atomic HYDRO-Moeller in Magnetic Trap
(0.5%, noninvasive, at Beam Energy)
- Single Spin Moeller Polarimeter (SAMS)
(0.5%, noninvasive, at Beam Energy, transverse Polarisation)
- Laser-Compton Backscatter Difficult at Low Energy
- Transmission Compton: Fast Relative Value.

S.A.M.S. - Measurement of transverse beam polarization

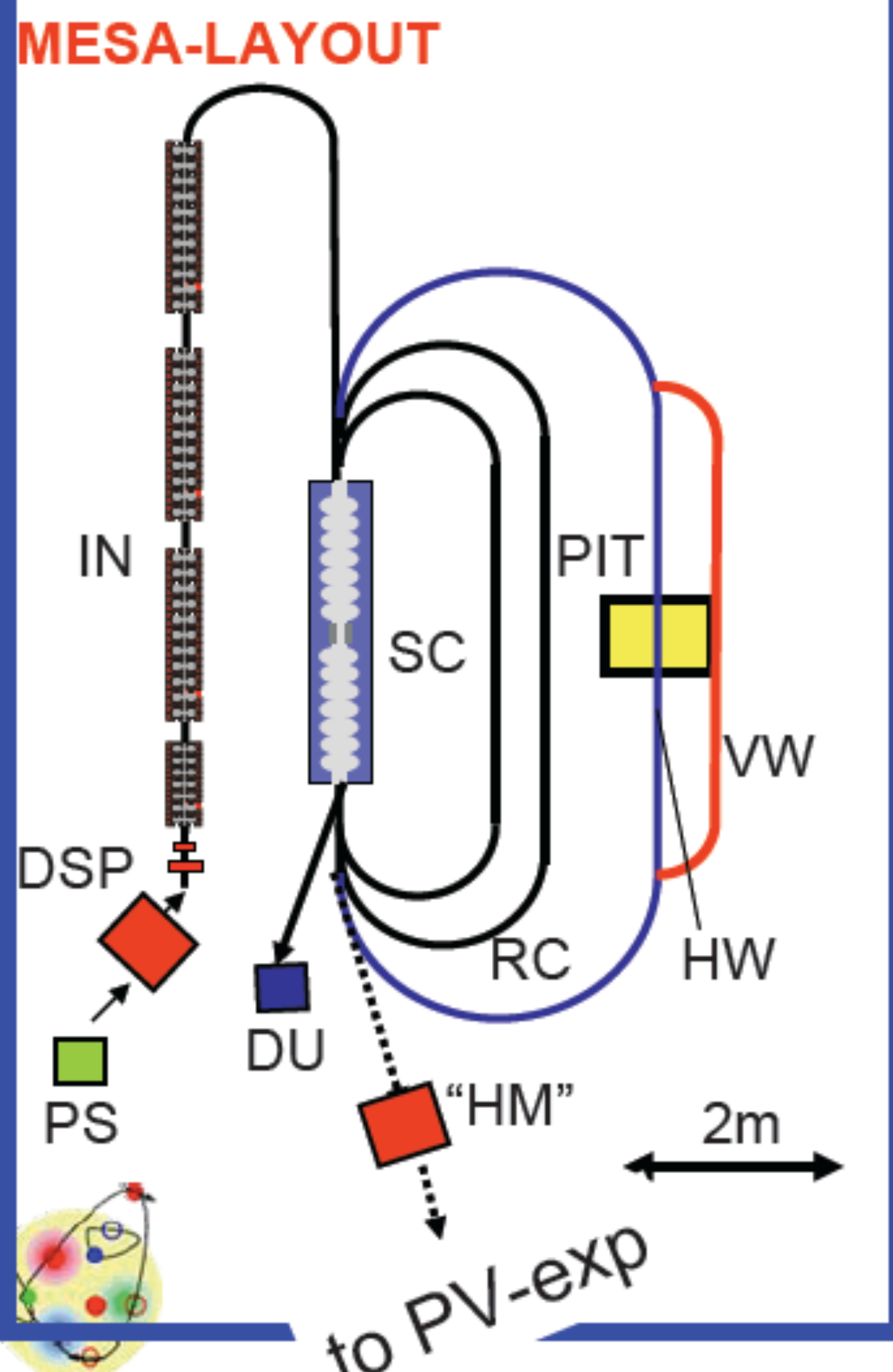
- Two-Photon exchange in Moller scattering



- Clean QED process



P2 technical Aspects

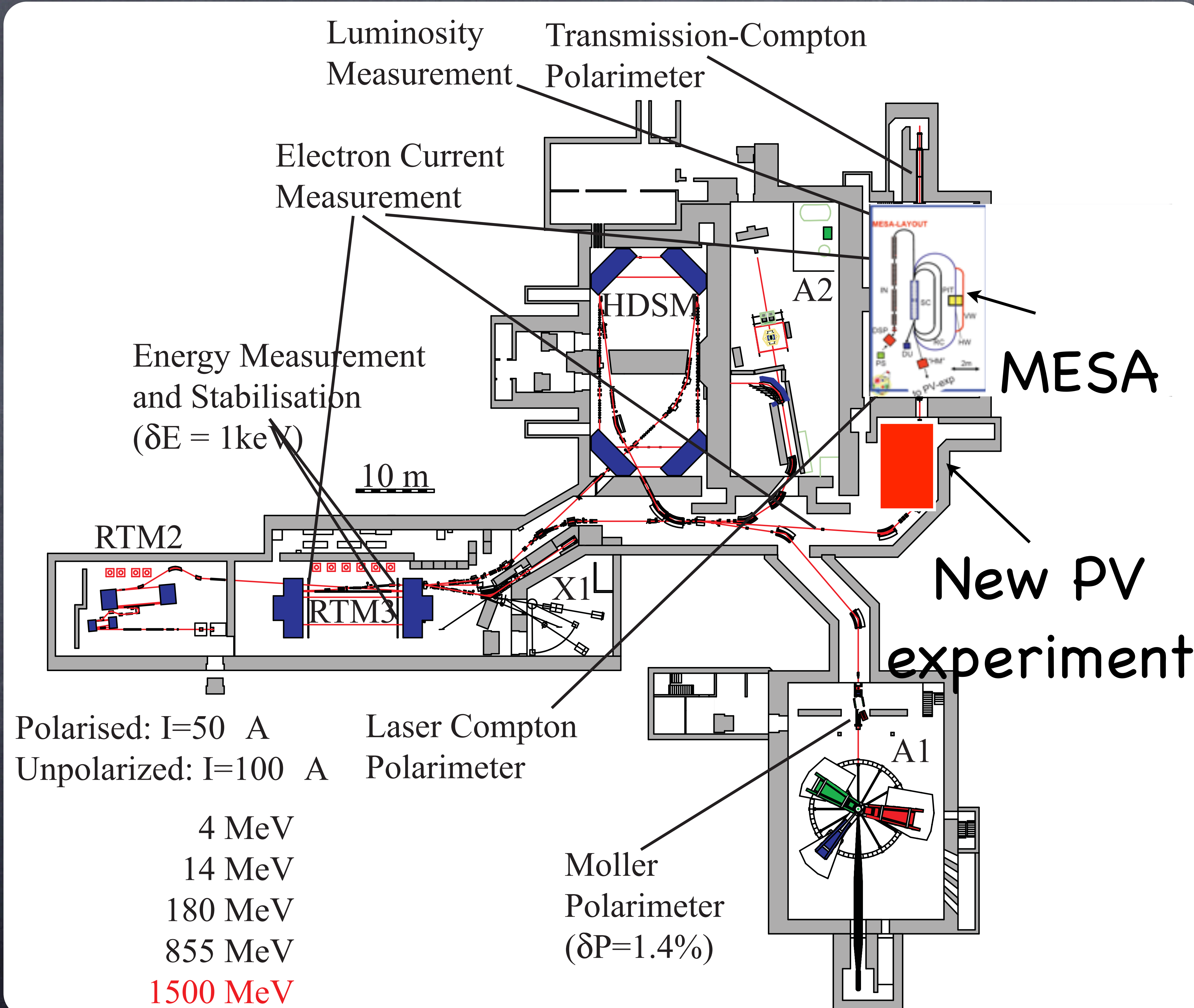


Machine gadgets:
PS: Photosource (pol. and unpol. Beaml)
IN: 5MeV NC Injektor
SC: 2 SRF Cavities
RC: Recirculation (3 times)
HW,FW:100MeVERL-mode, 137MeV ext. beam
PIT: Pseudo Internal Target (ERL Mode)
PV: PV-experiment(EB-Mode)
DU: 5 MeV beam dump in ERL-Mode

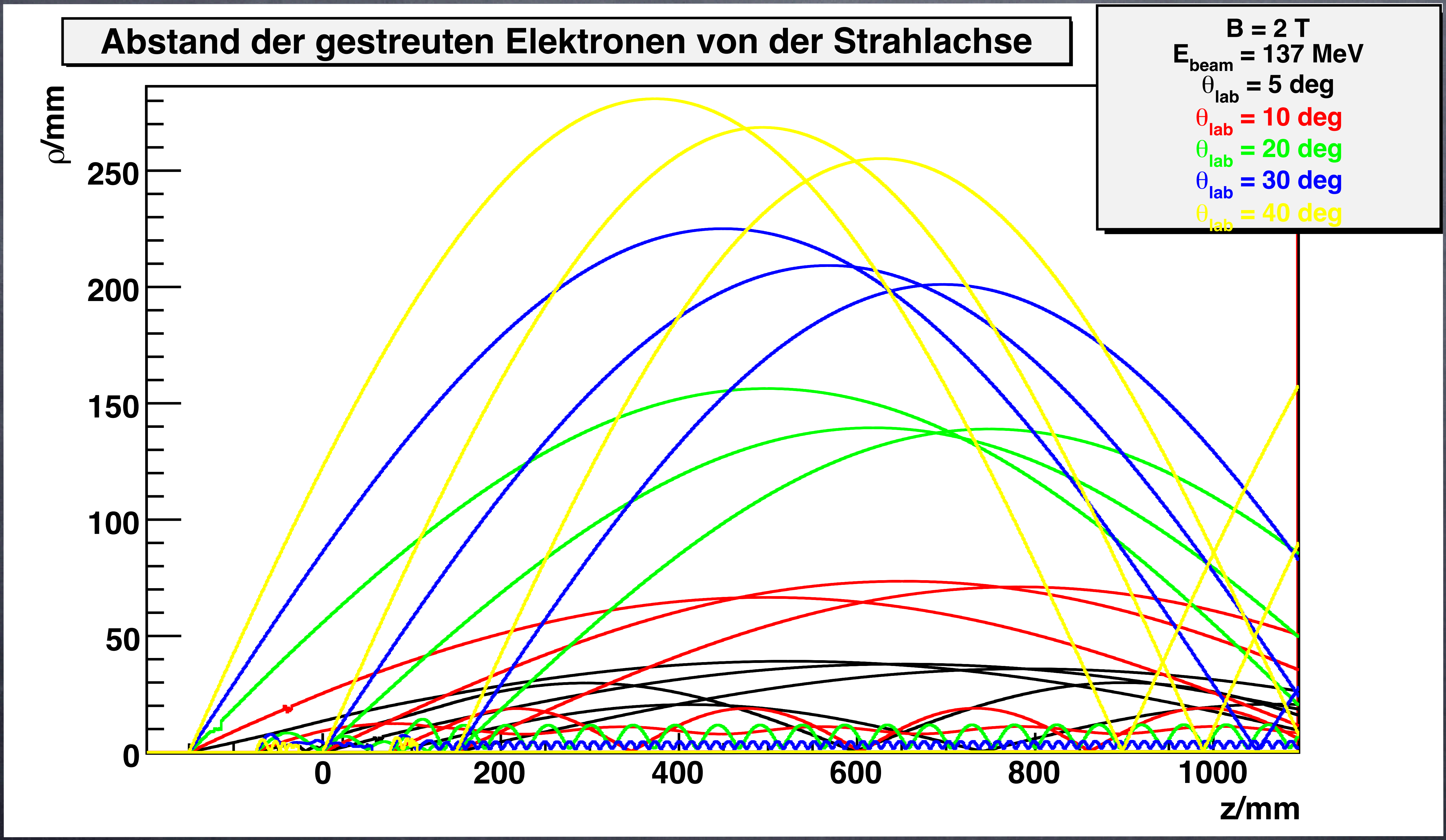
Polarimetry:
DSP: Double scattering polarimeter:
Probably best known accuracy for effective analyzing power: <0.3%@100keV (invasive device)
A. Gellrich, J. Kessler: Phys. Rev. A. 43, 204 (1991)
HM: "Hydro Möller": (online measurement)
Full polarization of electrons in H-Atoms
8T magnetic trap
(E. Chudakov V. Luppov: IEEE Trans. Nucl. Sci 54, 1533 (2004))

PV-Spectrometer: Solenoid,
Toroid (like G0, Q_{Weak})

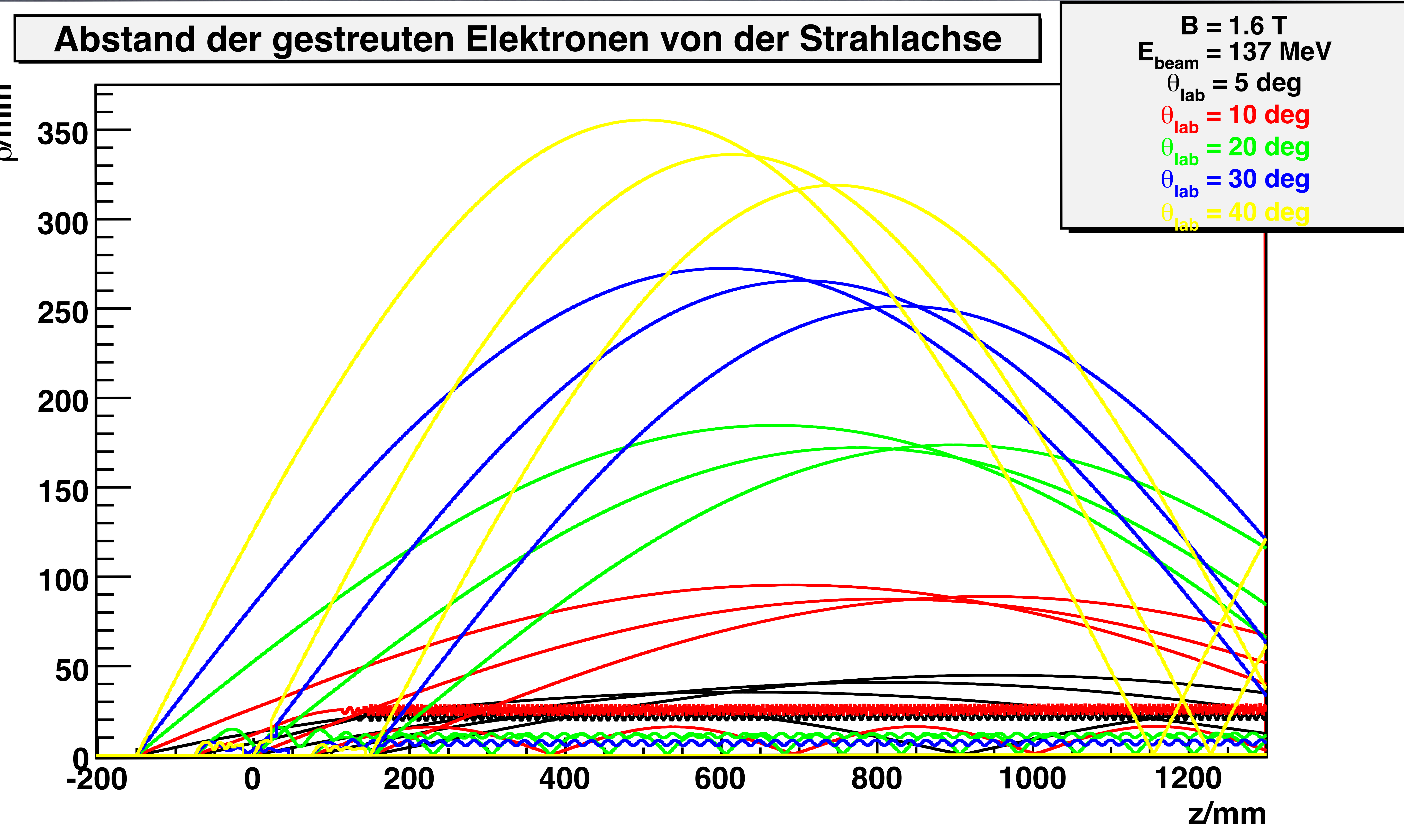
Stabilisation of Beam Parameters



Solenoid

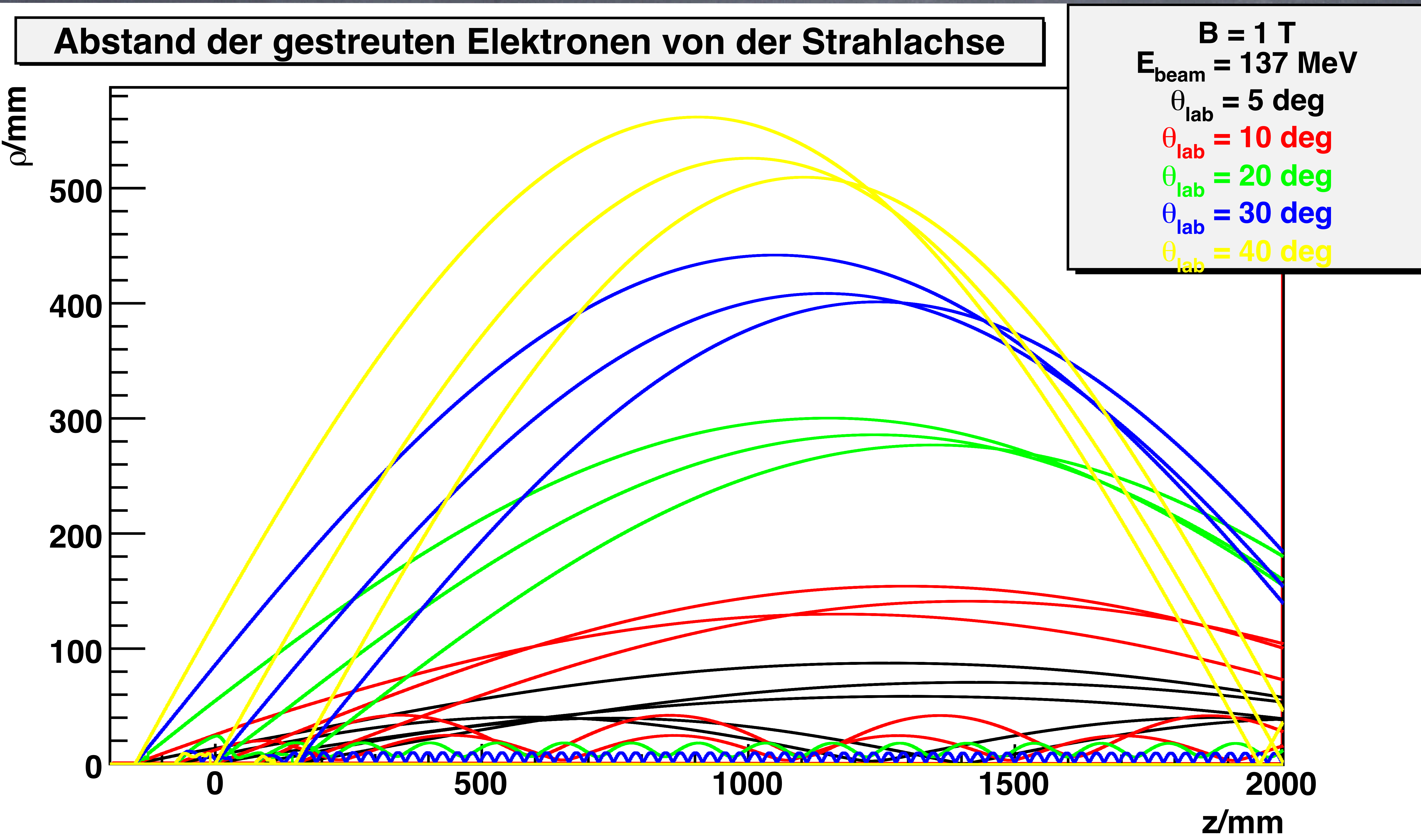

Abstand der gestreuten Elektronen von der Strahlachse
B = 2 T
E_beam = 137 MeV
θ_lab = 5 deg
θ_lab = 10 deg
θ_lab = 20 deg
θ_lab = 30 deg
θ_lab = 40 deg
ρ/mm
250
200
150
100
50
0
0
200
400
600
800
1000
z/mm

Solenoid



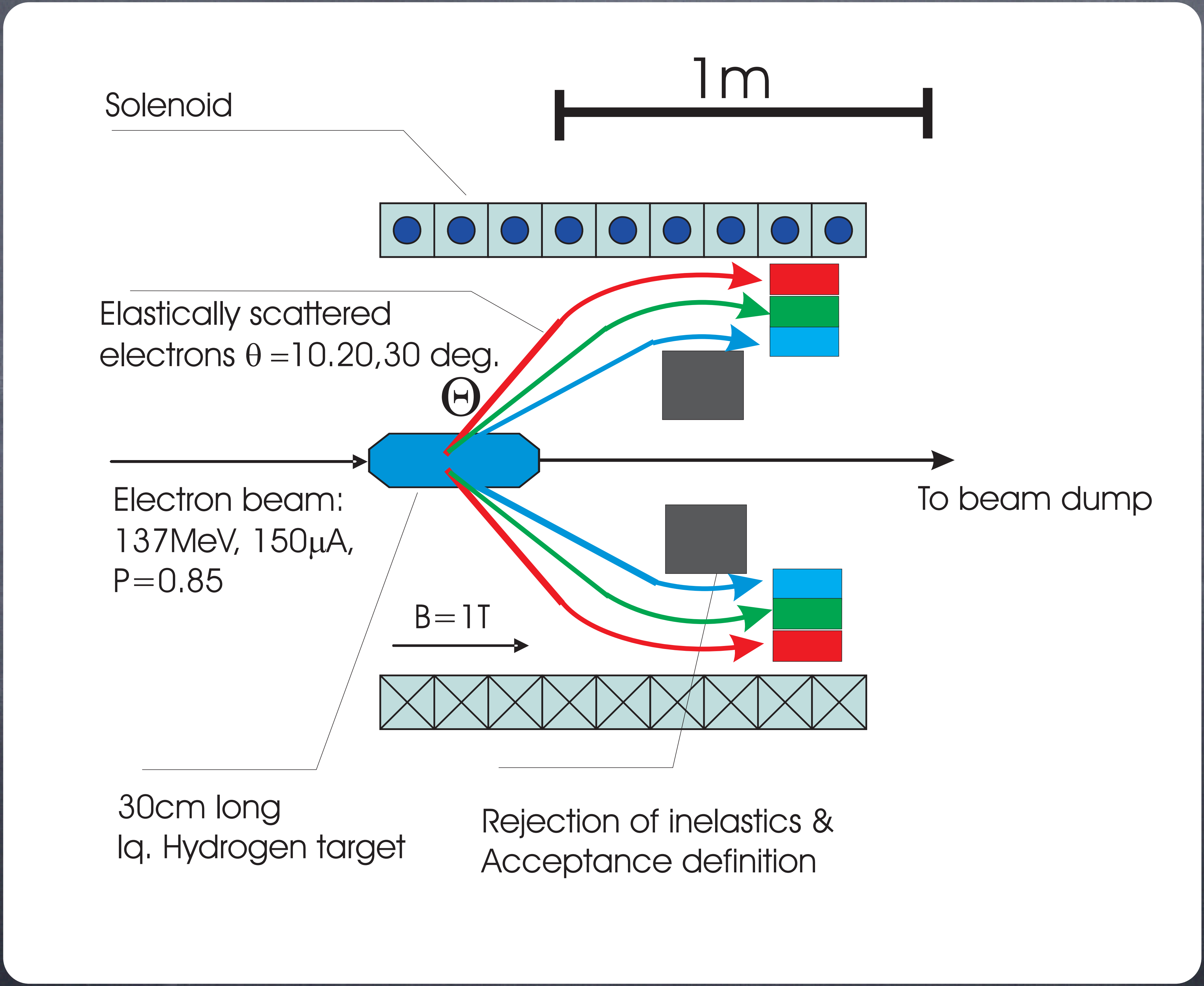
Abstand der gestreuten Elektronen von der Strahlachse
B = 1.6 T
E beam = 137 MeV
θ lab = 5 deg
θ lab = 10 deg
θ lab = 20 deg
θ lab = 30 deg
θ lab = 40 deg
350
300
250
200
150
100
50
0
-200
0
200
400
600
800
1000
1200
z/mm

Solenoid



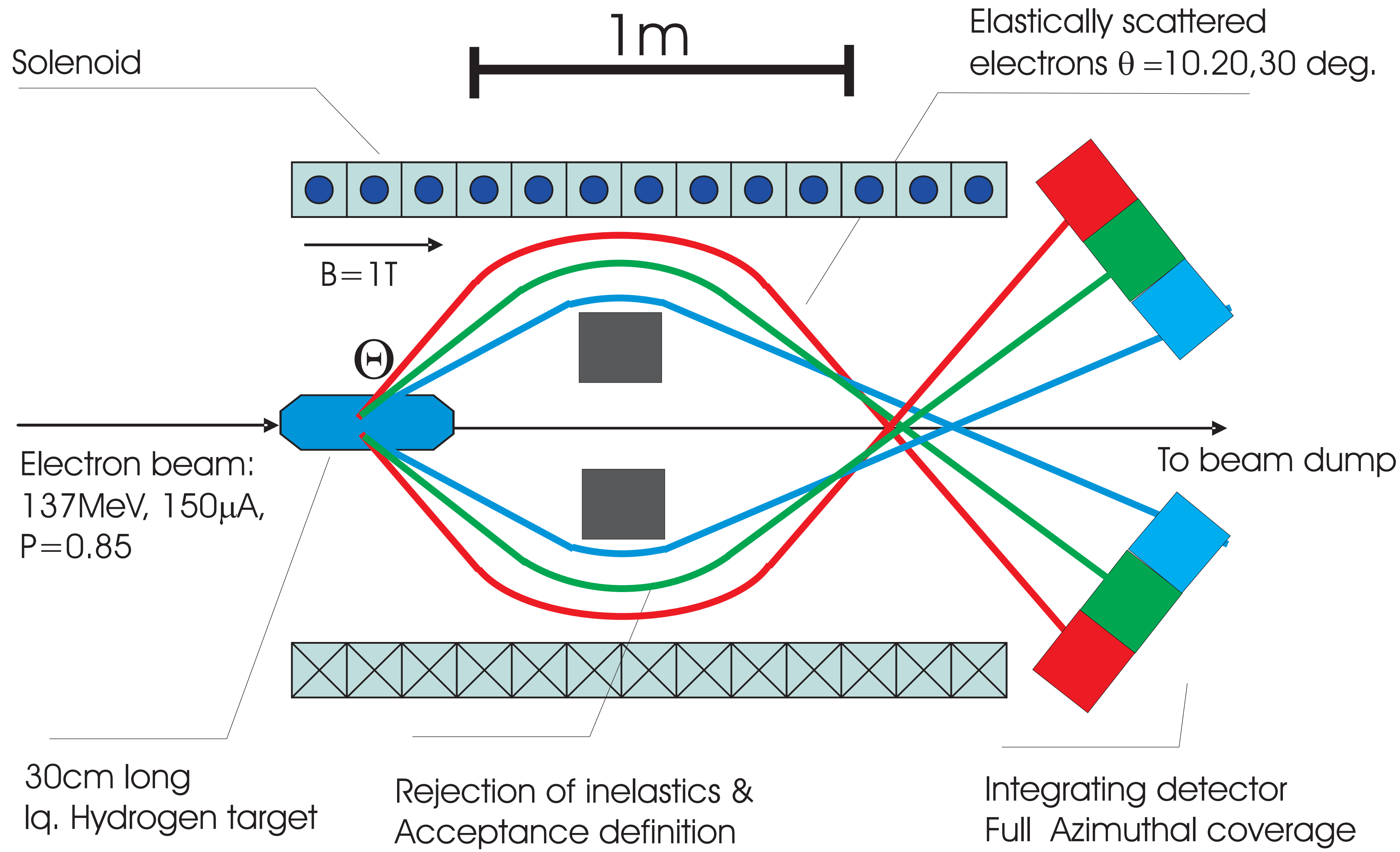
Abstand der gestreuten Elektronen von der Strahlachse
B = 1 T
E_{beam} = 137 MeV
θ_{lab} = 5 deg
θ_{lab} = 10 deg
θ_{lab} = 20 deg
θ_{lab} = 30 deg
θ_{lab} = 40 deg
ρ/mm
0
100
200
300
400
500
0
500
1000
1500
2000
z/mm

P2-Setup



1m
Solenoid
Elastically scattered
electrons θ =10.20,30 deg.
Θ
Electron beam:
137MeV, 150μA,
P=0.85
To beam dump
B=1T
30cm long
lq. Hydrogen target
Rejection of inelastics &
Acceptance definition

P2-Setup



1m
Solenoid
Elastically scattered
electrons θ =10.20,30 deg.
B=1T
Θ
Electron beam:
137MeV, 150μA,
P=0.85
To beam dump
30cm long
lq. Hydrogen target
Rejection of inelastics &
Acceptance definition
Integrating detector
Full Azimuthal coverage

next Steps

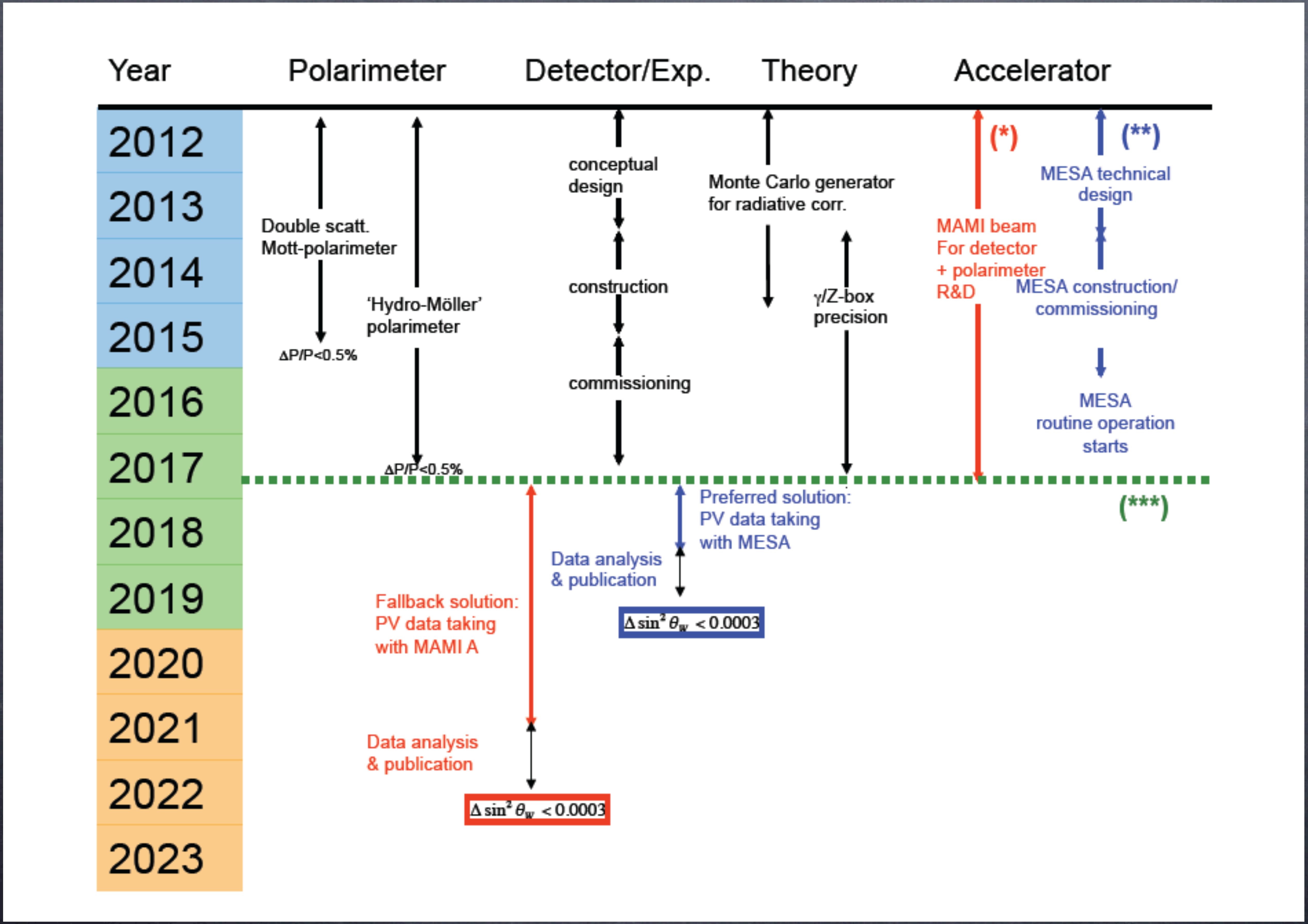
- Study Helicity Correlated Beam Fluctuations
(defines the kinematics together with statistical error)

- Study Spectrometer
- can we extend to Carbon Target
(Neutron Skin Measurement)

- Found/Create International Collaboration
- Common Interest with Moeller and SOLID
- Offer from Q_{Weak} to use Toroid
- Polarimetry
- Electronics, Detectors, Target

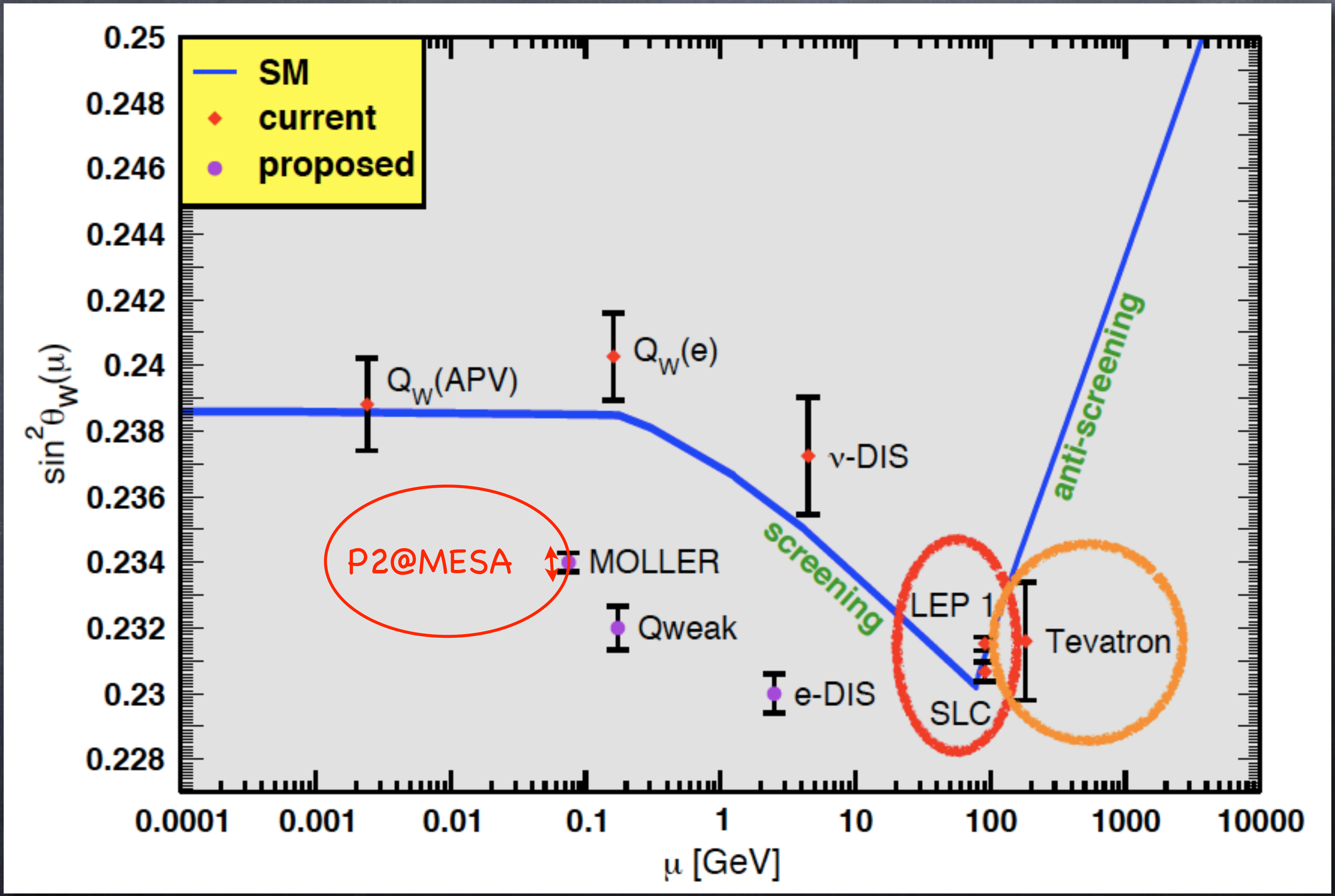
- Get Funding for MESA, Polarimeter, Spectrometer

Time Line



Year
Polarimeter
Detector/Exp.
Theory
Accelerator
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
Double scatt. Mott-polarimeter
ΔP/P<0.5%
'Hydro-Möller' polarimeter
ΔP/P<0.5%
conceptual design
construction
commissioning
Monte Carlo generator for radiative corr.
γ/Z-box precision
(*)
MAMI beam For detector + polarimeter R&D
(**)
MESA technical design
MESA construction/ commissioning
MESA routine operation starts
(***)
Preferred solution: PV data taking with MESA
Data analysis & publication
$\Delta \sin^2 \theta_W < 0.0003$
Fallback solution: PV data taking with MAMI A
Data analysis & publication
$\Delta \sin^2 \theta_W < 0.0003$

Summary



SM
current
proposed
0.25
0.248
0.246
0.244
0.242
0.24
0.238
0.236
0.234
0.232
0.23
0.228
$\sin^2\theta_W(\mu)$
Q_W(APV)
Q_W(e)
ν-DIS
P2@MESA
MOLLER
Qweak
e-DIS
screening
anti-screening
LEP 1
SLC
Tevatron
0.0001
0.001
0.01
0.1
1
10
100
1000
10000
μ [GeV]

Summary

- P2: New Mainz Parity Violation Experiment
- Technically Very Challenging
- Decrease Errors on Axial and Strangeness Contribution
- New Highest Precision Measurement of Q_{weak} is feasible with an Error of $\Delta Q_{Weak}/Q_{weak}$=2.1% yielding $\Delta \sin^2(\theta_W)$ = 0.00037 (0.16%)
- If you want to join this Challenge: Collaborators are Highly Welcome