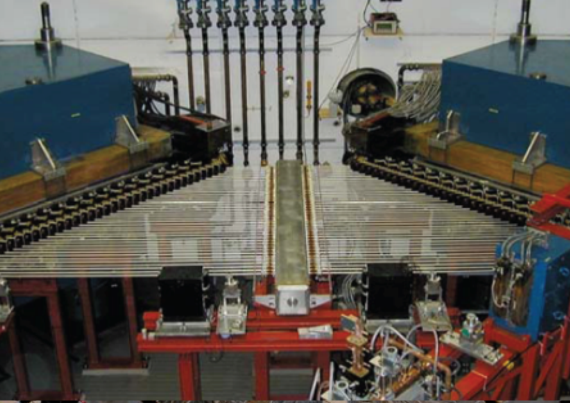
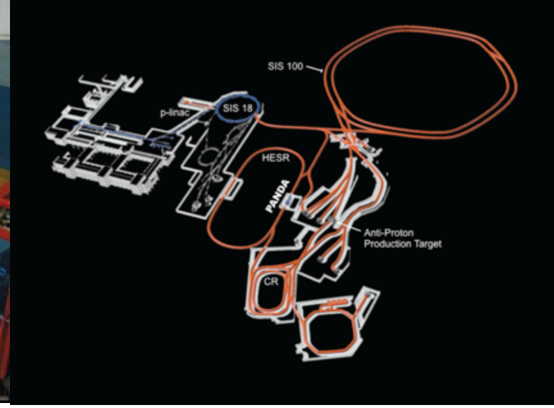
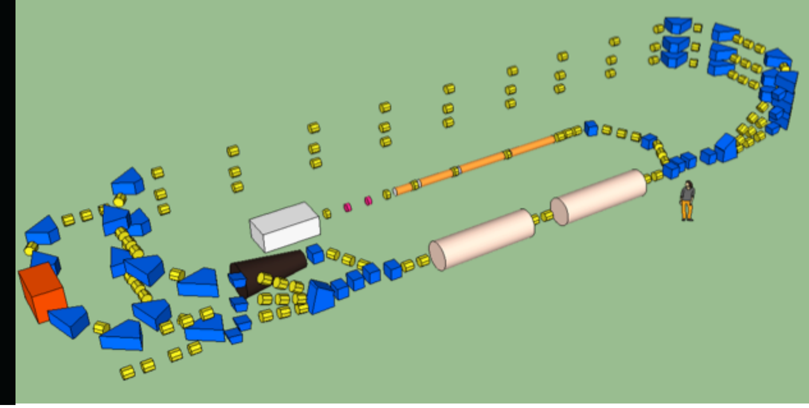






Low-energy precision physics

LATTICE 2013

31st International Symposium on Lattice Field Theory

July 29 – August 03, 2013, Mainz, Germany

Frank Maas

GSI / HIM / U Mainz

PRiSMA

SFB 1044 THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

HELMHOLTZ GEMEINSCHAFT Helmholtz-Institut Mainz

JG|U JOHANNES GUTENBERG UNIVERSITÄT MAINZ

GSI

Outline

New (Infra)structures in Mainz

Proton Form Factor and Proton Radius

Search for a Dark Photon

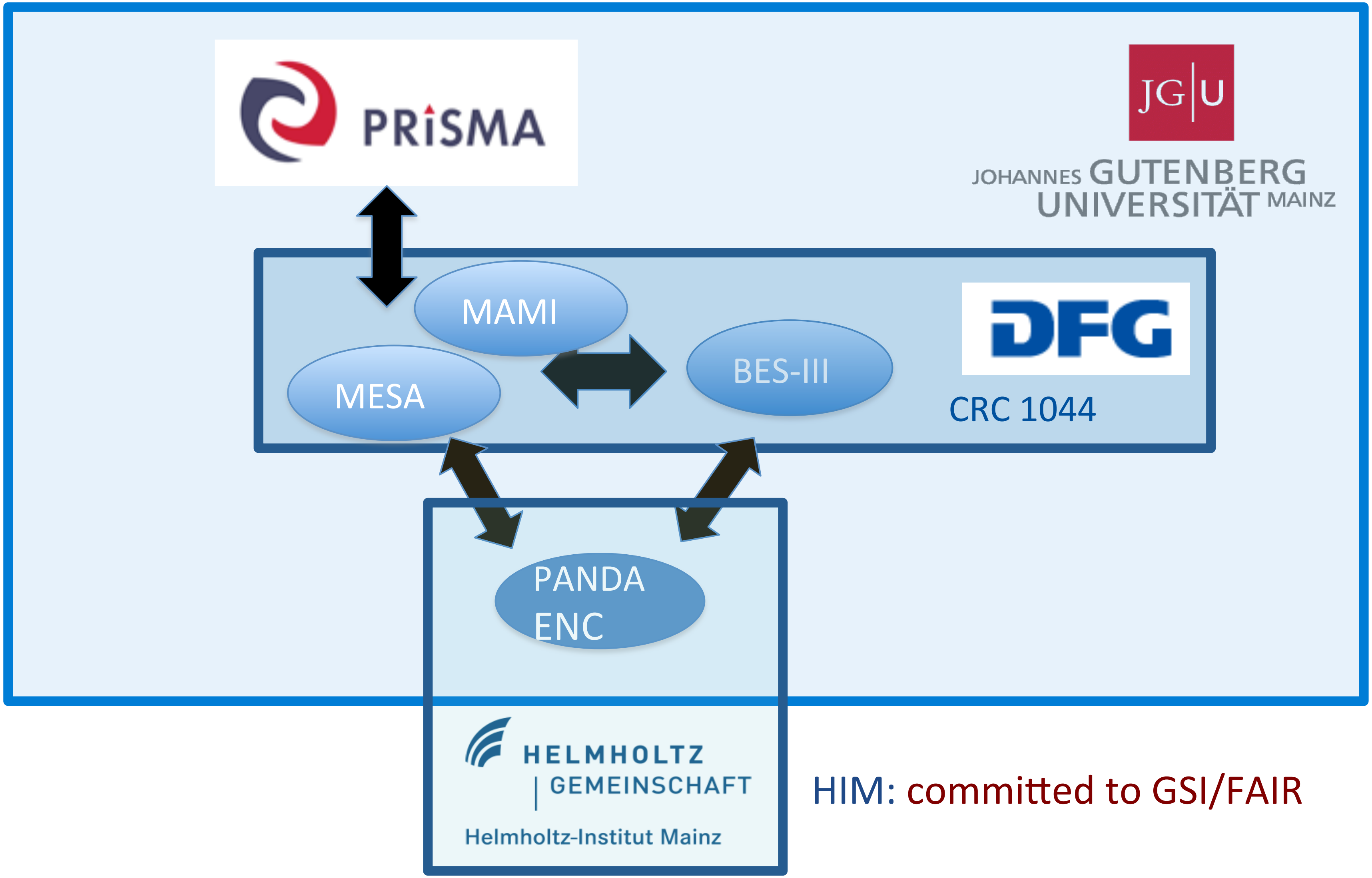
Parity Violating Electron Scattering

New (Infra) Structures in Mainz

Structures

Location	Institutes	Facilities	Physics	Group-Applications
Mainz	IKP (University)	MAMI (Mainz) MESA (Mainz) BES-III (Beijing)	Nucleon/Meson Structure and Spectroscopy Particle Physics	CRC1044 PRISMA
Mainz	HIM (new) GSI/ University	FAIR-accelerator GSI-accelerator BES-III (Beijing)	Hadron Physics Particle Physics	PRISMA
Darmstadt	GSI (National Lab.)	FAIR-accelerator	Nuclear Physics Atomic Physics Hadron Physics	

Structures in Mainz



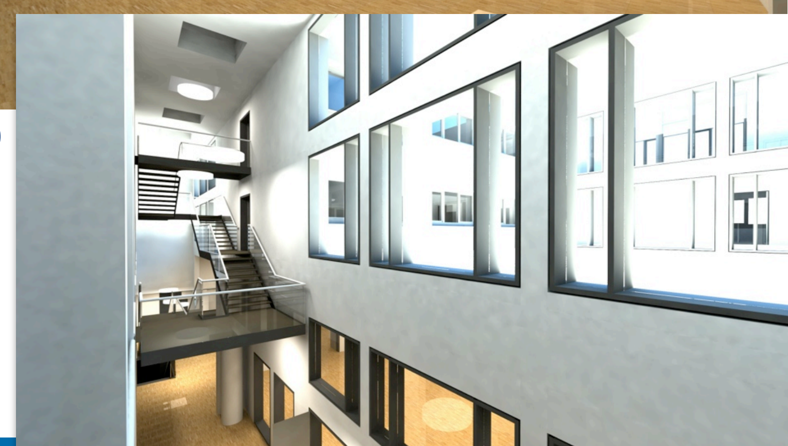
Helmholtz-Institute Mainz

First Institute of this kind in Germany

- Founded in 2009 as joint institution of GSI and JGU Mainz
- Participation of JGU Institutes of Physics, Nuclear Physics, Nucl. Chemistry
- Budget (5.5 M€ p.a.) from Helmholtz Association + same amount from JGU
- 6 Research sections:
  - EMP (Electromagnetic processes at PANDA)
  - SPECF (Spectroscopy and Flavour at PADA)
  - MAM (Atomic Physics with antiprotons)
  - SHE (Synthesis of Superheavy Elements)
  - ACID (Accelerator Technology)
  - Theory Floor (QCD Lattice and QCD Phenomenology)

High Performance Cluster HIMster

- HIM: committed to GSI/FAIR physics



New research building on JGU campus: 28M€ + 8M€
(financed by state of RLP and federal state)

Helmholtz-Institute Mainz (start of constr. 2013)

CRC-1044: The Low-Energy Frontier of the SM

Novel concept of CRC1044:
Hadron physics (= The Low-Energy Frontier of the Standard Model) plays a central and connecting role in interpretation of measurements at the precision frontier of the Standard Model

$\sin^2\theta_W$

$(g-2)_\mu$

R_E
Proton charge radius

Hadrons and Nuclei

Quarks and Gluons

Strong interactions
Hadron structure
Hadron spectroscopy

↔

Particle physics
Atomic physics
Astro(particle) physics

CRC-1044: The Low-Energy Frontier of the SM

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$\sin^2\theta_W$

$(g-2)_\mu$

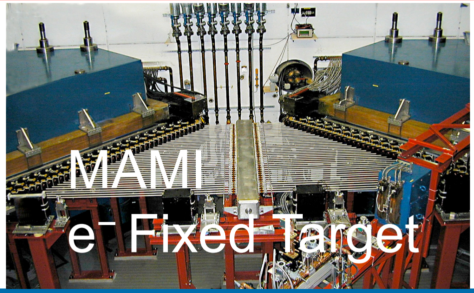
R_E
Proton charge radius

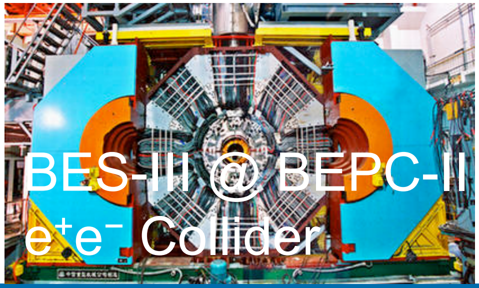
Hadrons and Nuclei

Quarks and Gluons

Space like measurements

Time like measurements

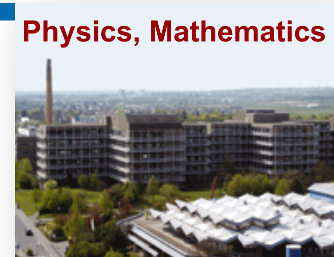


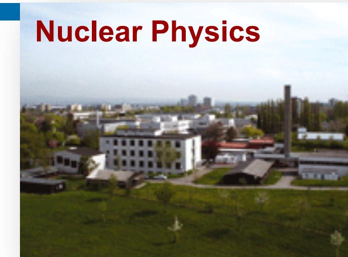


The PRISMA† Excellence Cluster

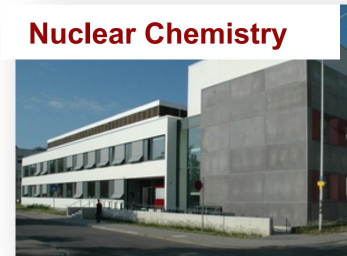
Participating Institutes:

- Institute for Nuclear Physics
- Institute for Physics
- Institute for Nuclear Chemistry
- Institute for Mathematics
- Helmholtz Institute Mainz



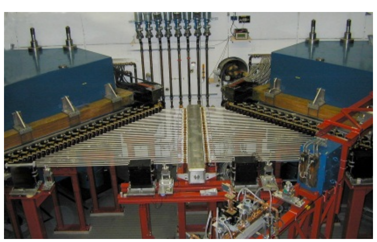


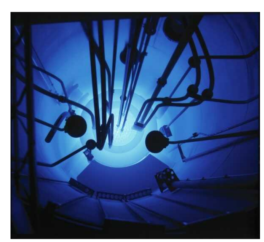
HELMHOLTZ ASSOCIATION
Helmholtz Institute Mainz



Local research infrastructure:

- Electron accelerator MAMI
- TRIGA research reactor
- High-Performance Cluster WILSON





†Precision Physics, Fundamental Interactions and Structure of Matter

The PRISMA† Excellence Cluster

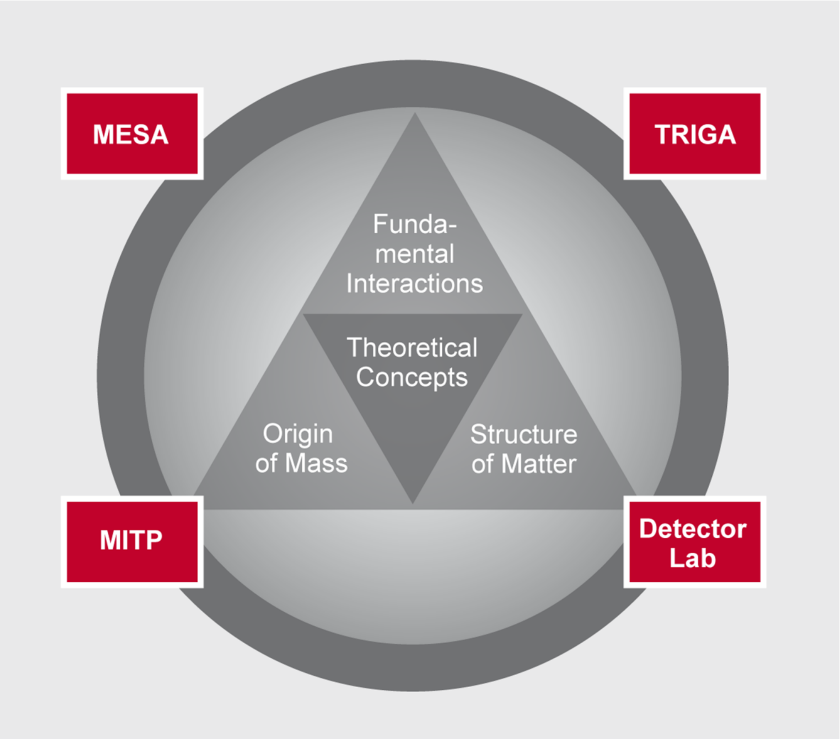
Research Areas:

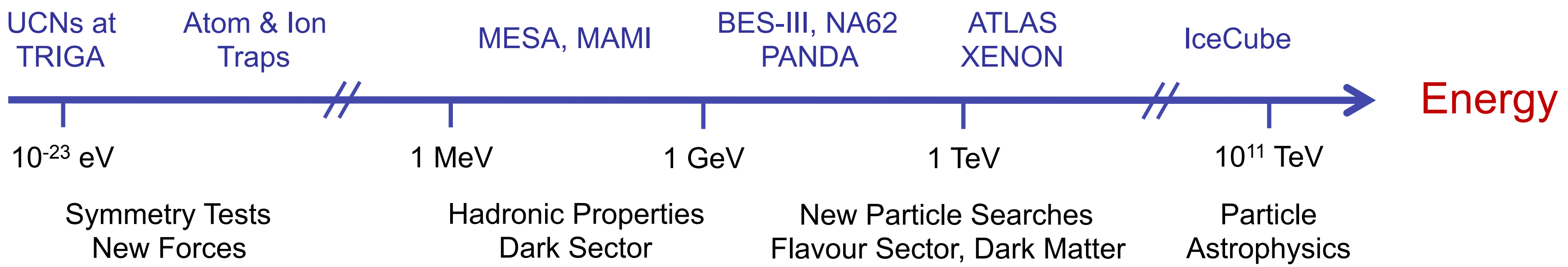
A: Fundamental Interactions

B: Origin of Mass and Physics beyond the Standard Model

C: Structure of Matter

D: Theoretical Concepts & Mathematical Foundations

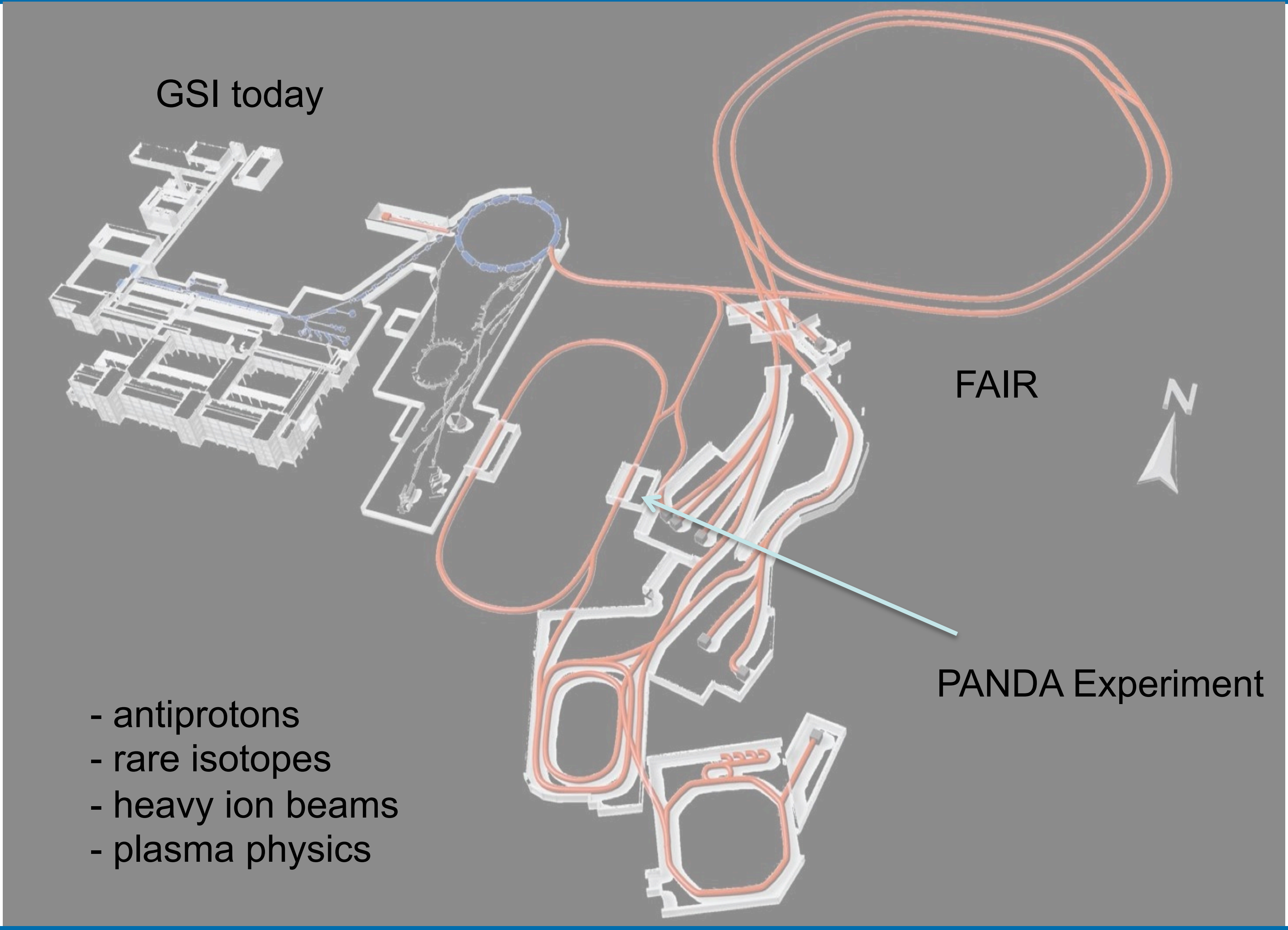




Time-like Proton Form Factor (at FAIR)

FAIR

FAIR Facility Darmstadt



- antiprotons
- rare isotopes
- heavy ion beams
- plasma physics

Timelines FAIR Modularised Start Version

- 6 Submission building permits
- 7 Site preparation
- 8 Civil construction contracts
- 9 Building of accelerator & detector components
- 10 Completion of civil construction work
- 11 Installation & commissioning of accelerators and detectors
- 12 Data taking

PANDA Physics Program

Hadron Spectroscopy

Experimental Goals: *mass, width & quantum numbers J^{PC} of resonances*

Charm Hadrons*: charmonia, D-mesons, charm baryons*

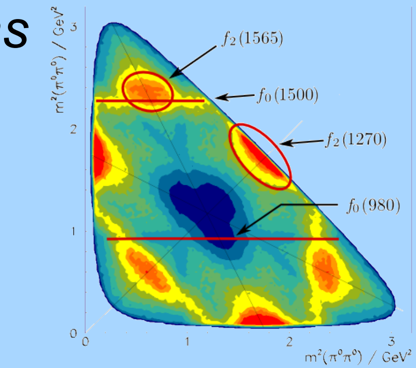
➔ Understand new XYZ states, $D_s(2317)$ and others

Exotic QCD States*: glueballs, hybrids, multi-quarks*

Spectroscopy with Antiprotons:

Production of states of all quantum numbers

Resonance scanning with high resolution



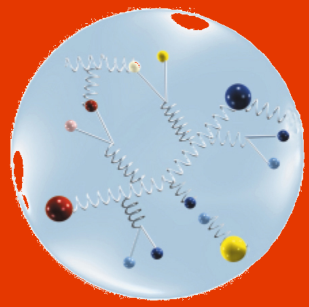
Hadron Structure

Generalized Parton Distributions

➔ Formfactors and structure functions, L_q

Timelike Nucleon Formfactors

Drell-Yan Process

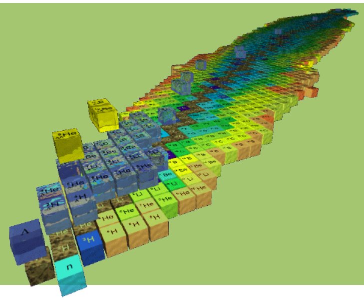


Nuclear Physics

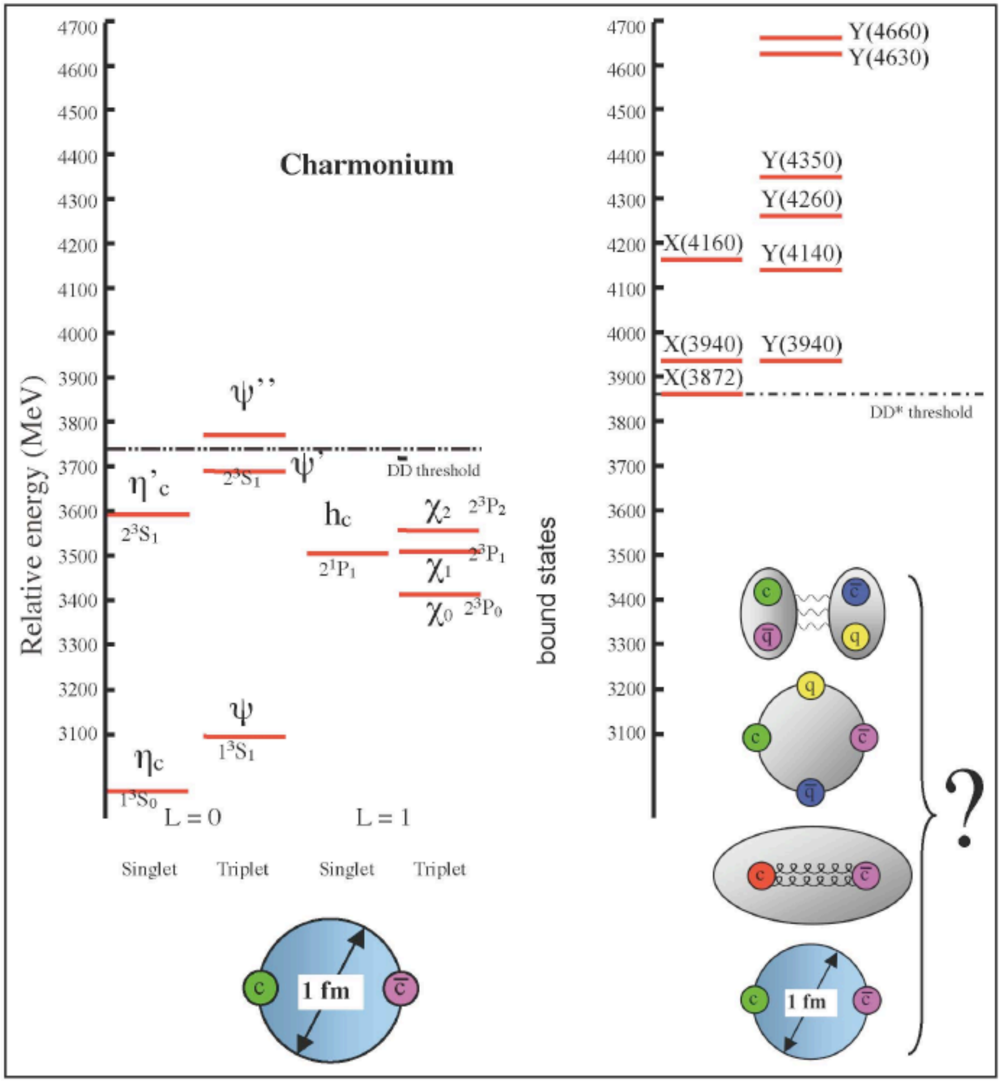
Hypernuclei*:* Production of double Λ-hypernuclei

➔ γ-spectroscopy of hypernuclei, YY interaction

Hadrons in Nuclear Medium



Hadron Dynamics (spectroscopy)

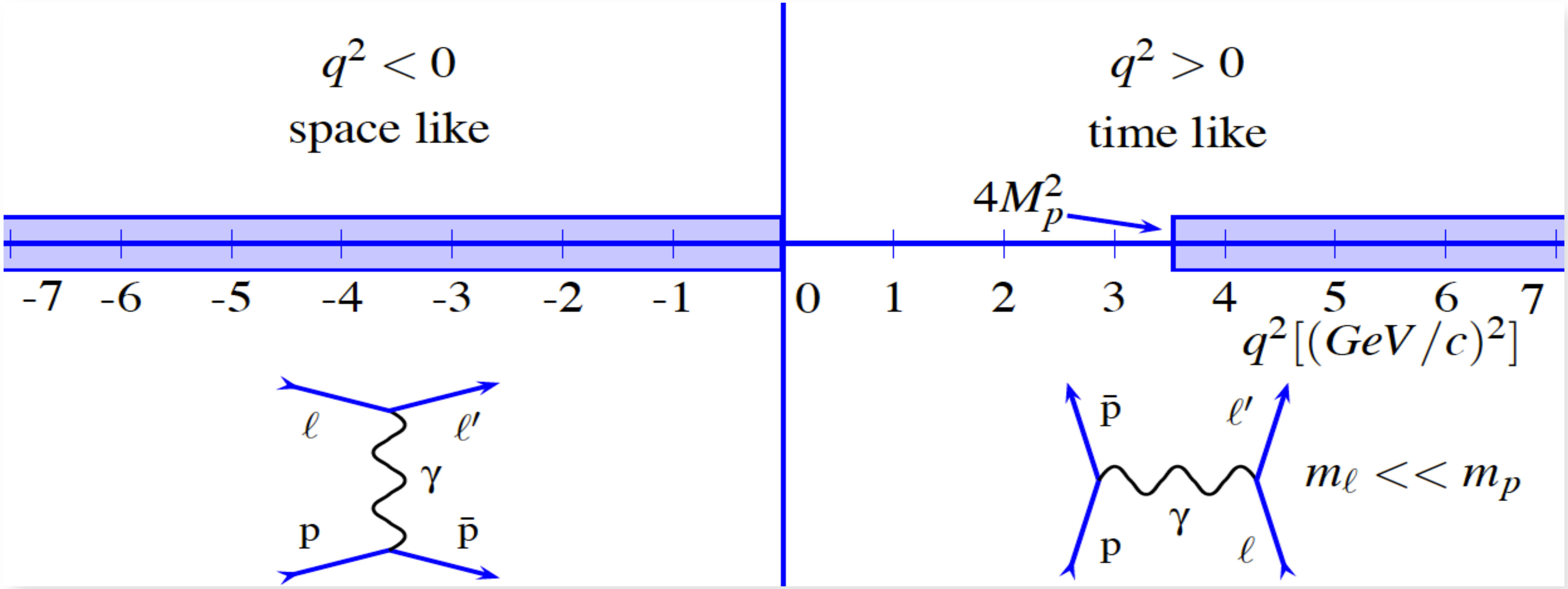


Revolution:
X,Y,Z – states: not understood,
new form of matter

Narrow, above open charm decay

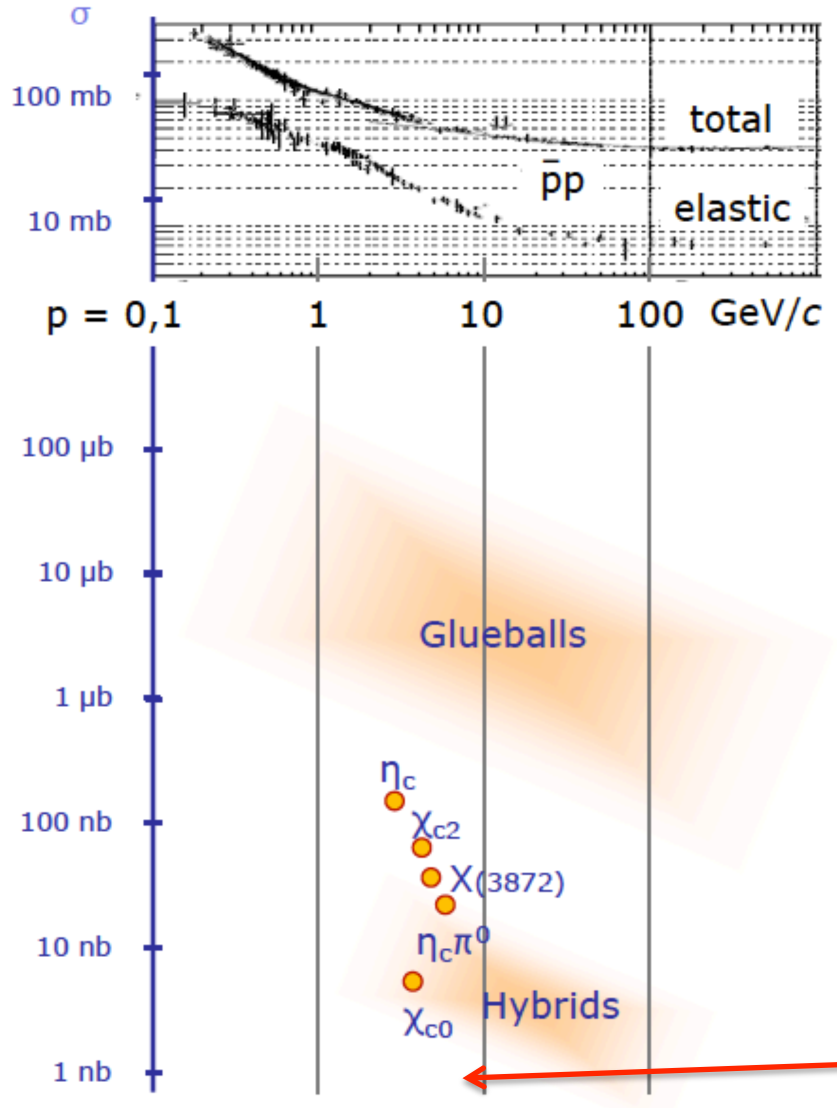
Decays not from two quark meson

Hadron Structure (Nucleon Form Factors)



- Hot Topics in Form Factor Research (Radius, Threshold, Large Q^2, Unphys. Region)
- Time Like Domain: Hadronic processes 10^6 times larger

Detector Requirements from Physics Case



High luminosity and hadronic cross sections

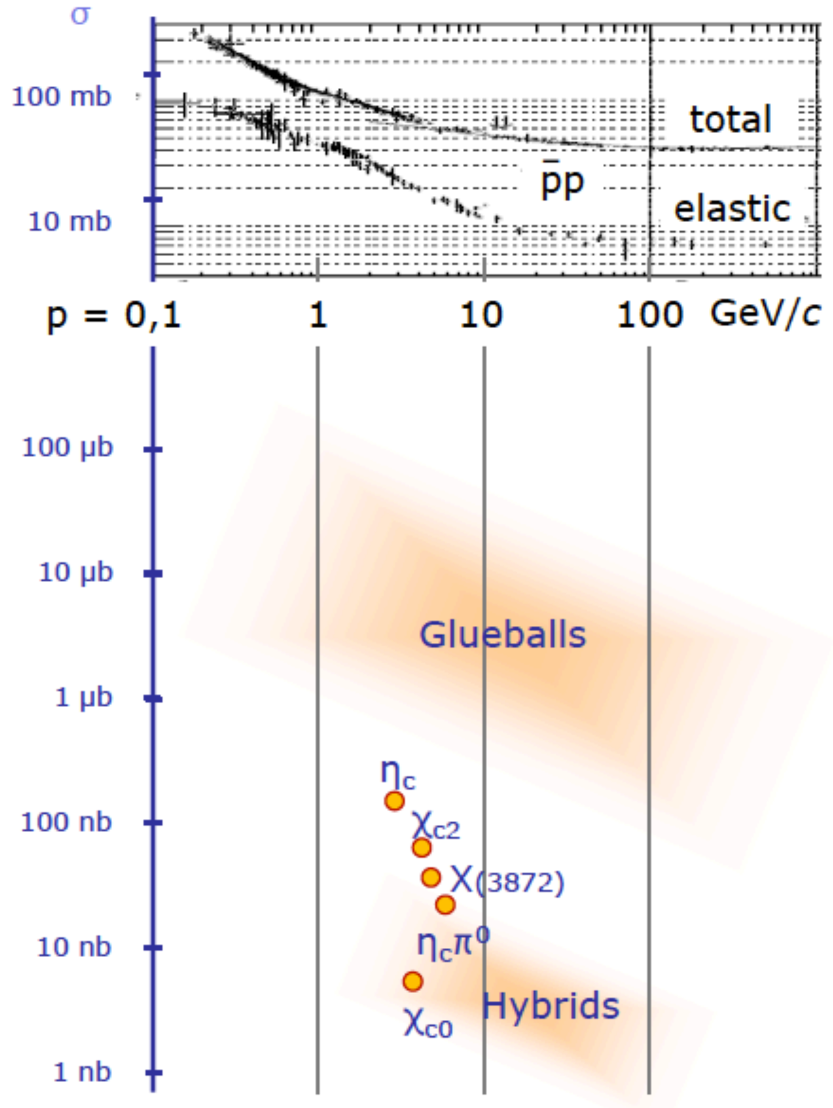
High rate capability, $2 \cdot 10^7\ s^{-1}$ interactions

High data rate

High degree of radiation resistance

Cross section for electromagnetic Processes

Detector Requirements from Physics Case



4π acceptance

Momentum resolution: 1%

central tracker in magnetic field

Photon detection: 1 MeV - 10 GeV

high dynamic range

good energy resolution

Particle identification: γ, e, μ, π, K, p

Cherenkov detector

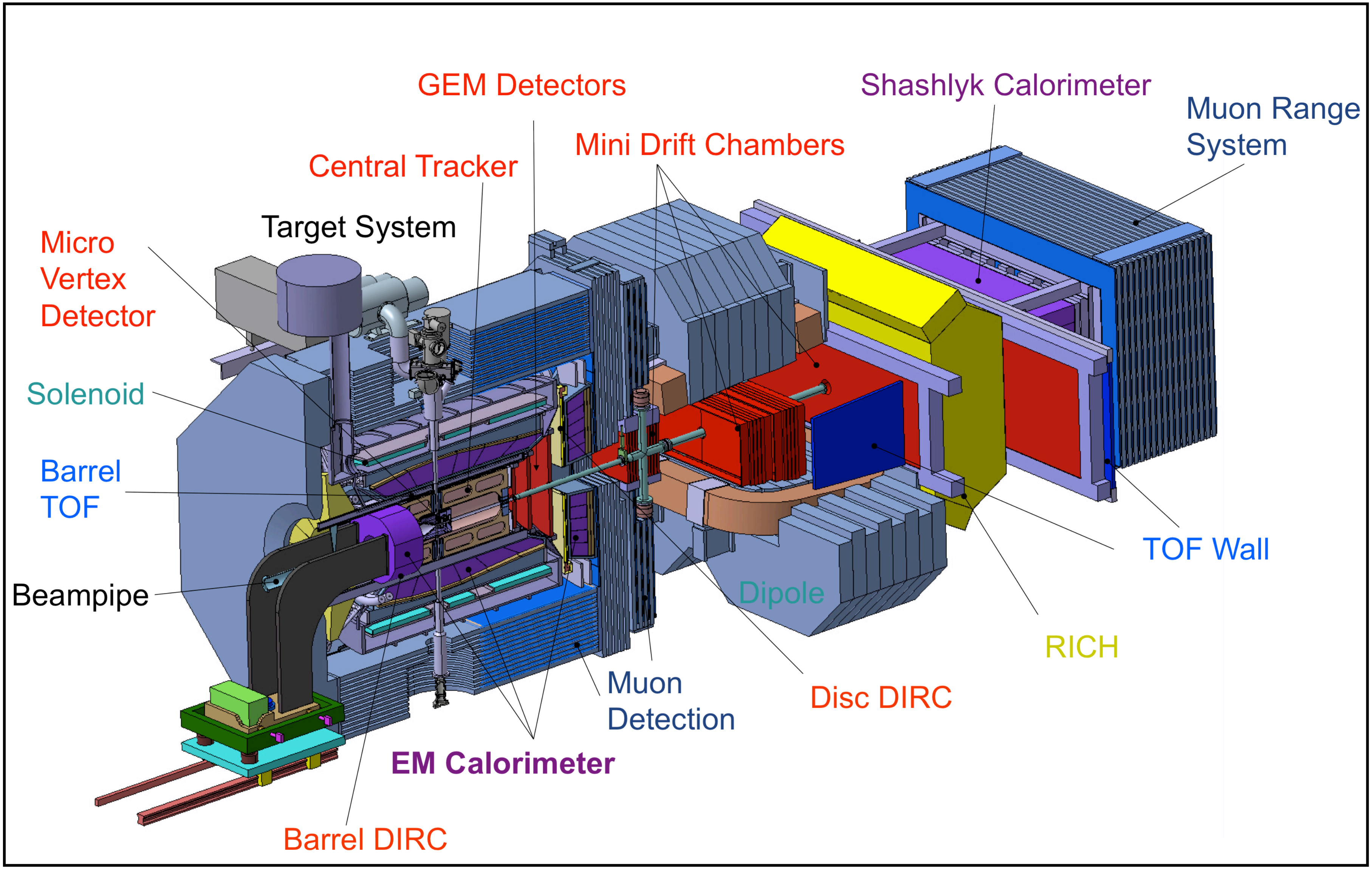
time of flight, dE/dx, muon counter

Displaced vertex info

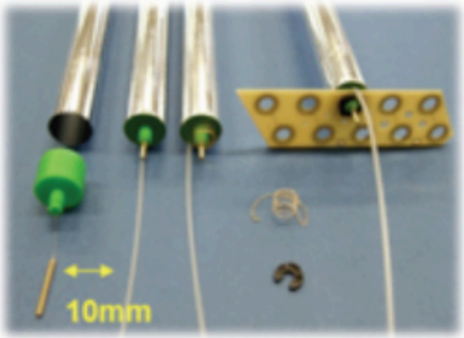
$c\tau = 317\ \mu m$ *for* $D^{\pm}$

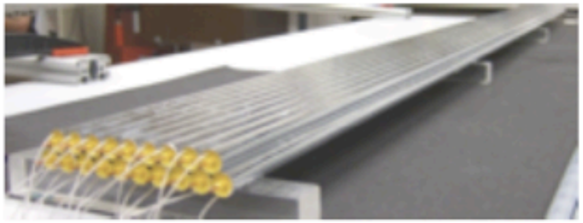
$\gamma\beta \approx 2$

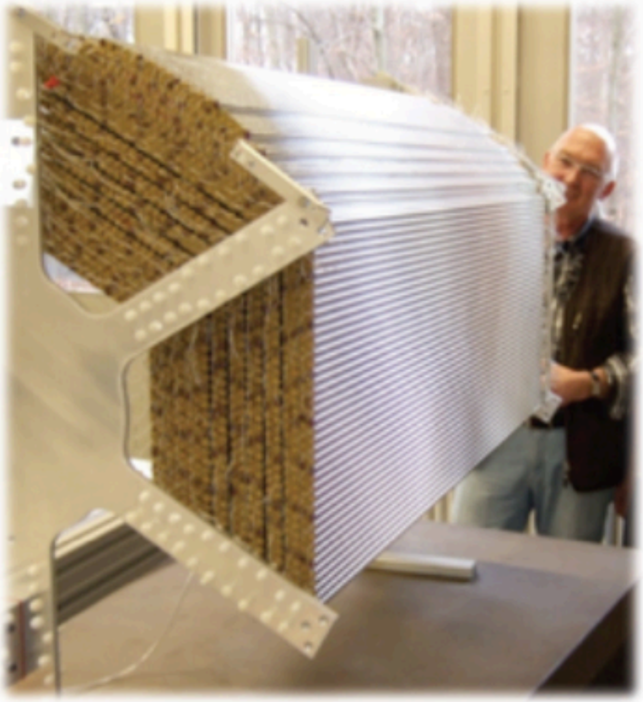
PANDA Detector

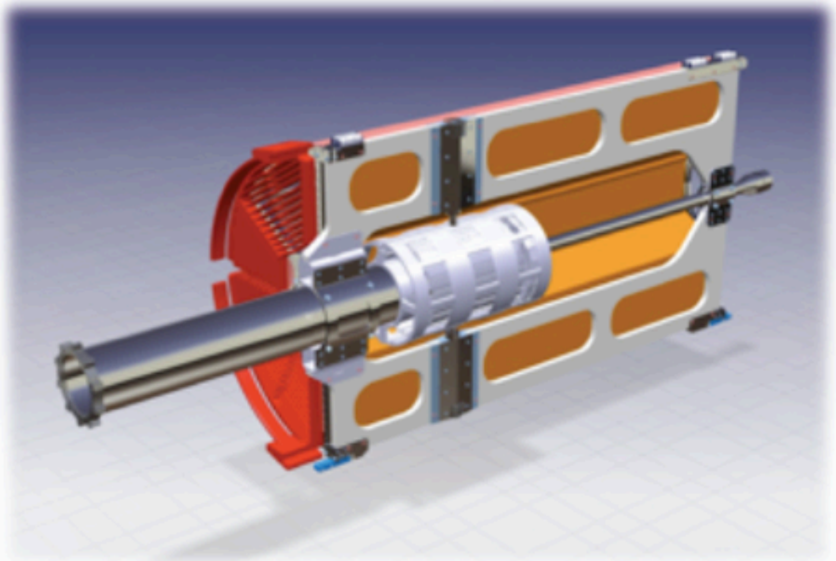


The PANDA Central Tracker

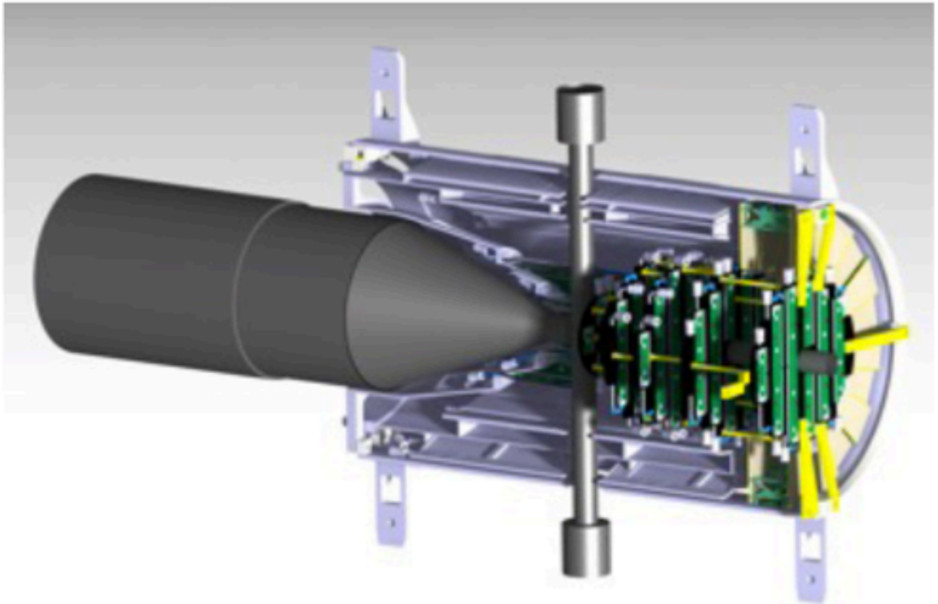




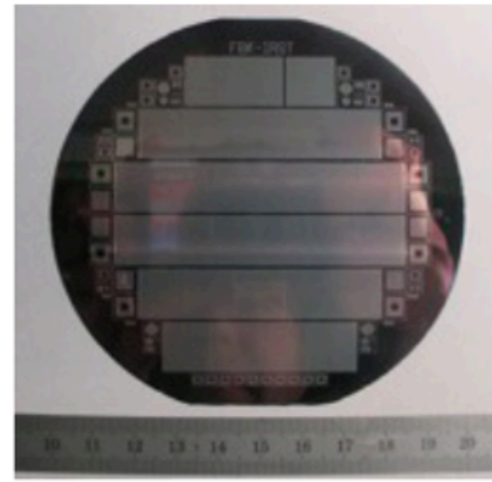




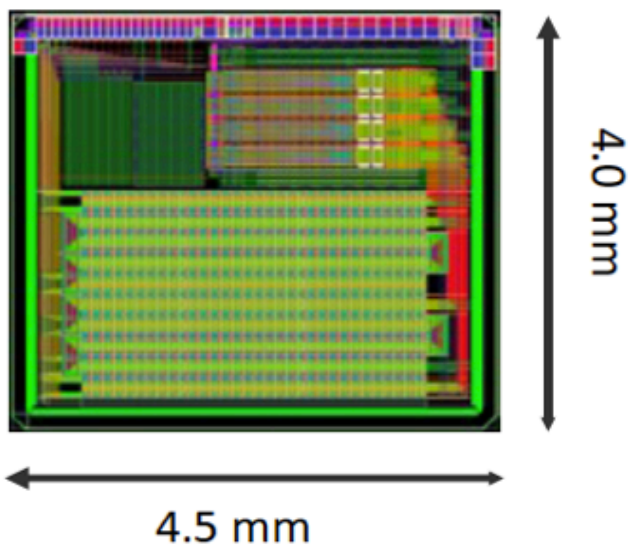
The PANDA MVD



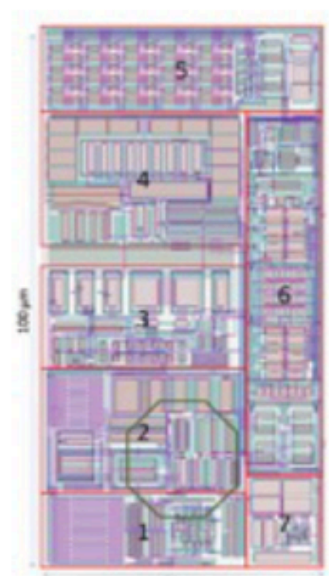
Full-Size Prototypes

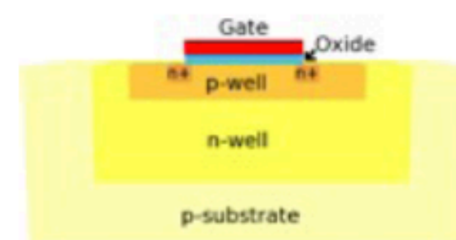


ASIC Prototypes

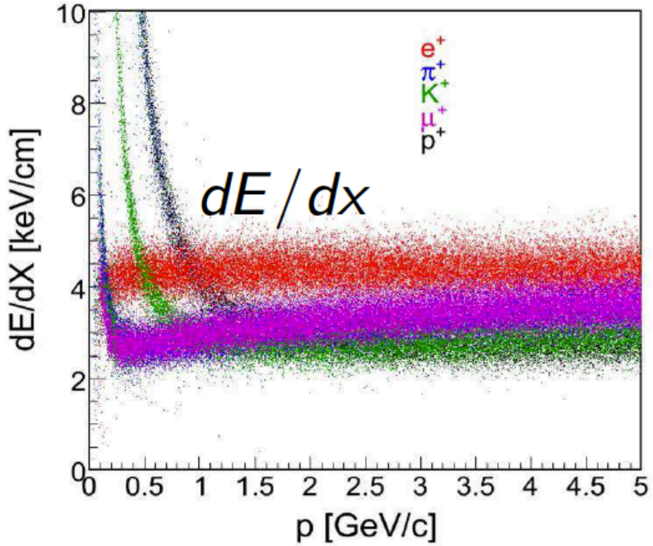


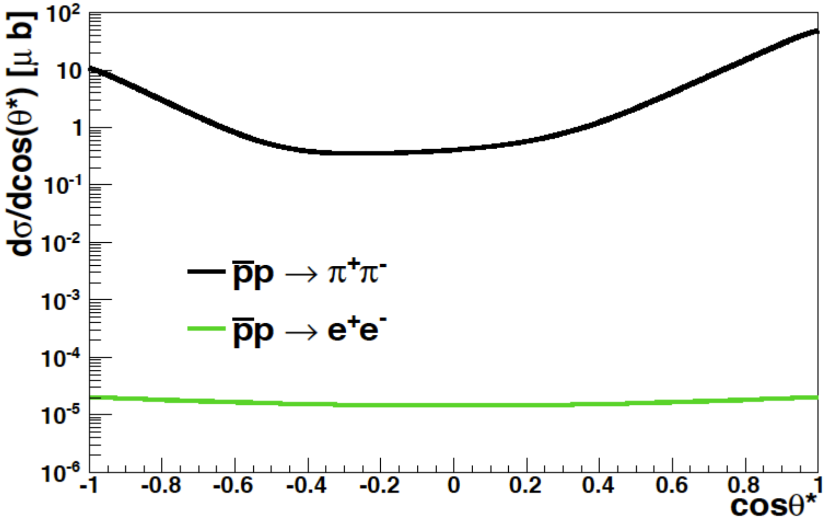
ToPix v3 Full-Feature Prototype

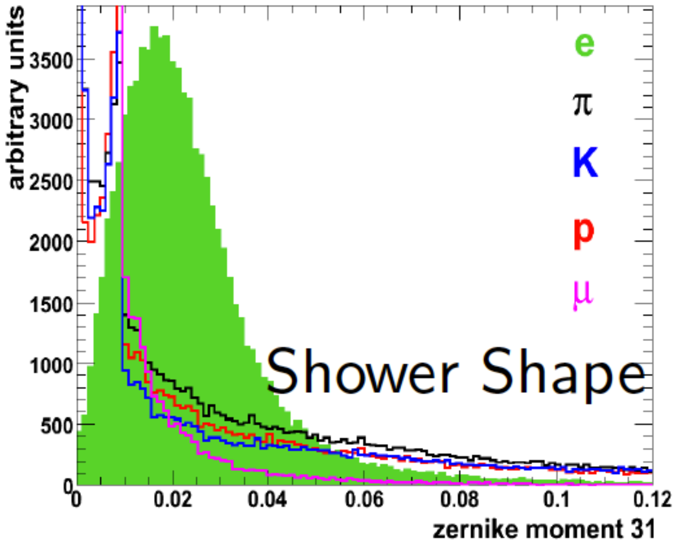


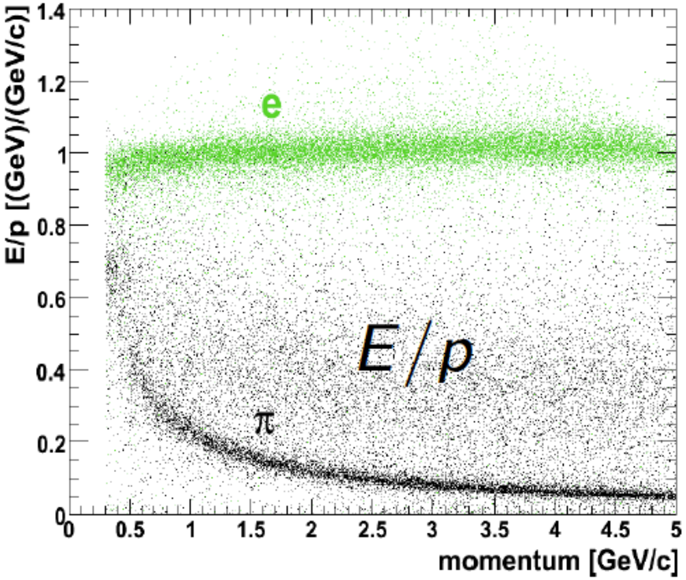


Particle Identification in PANDA

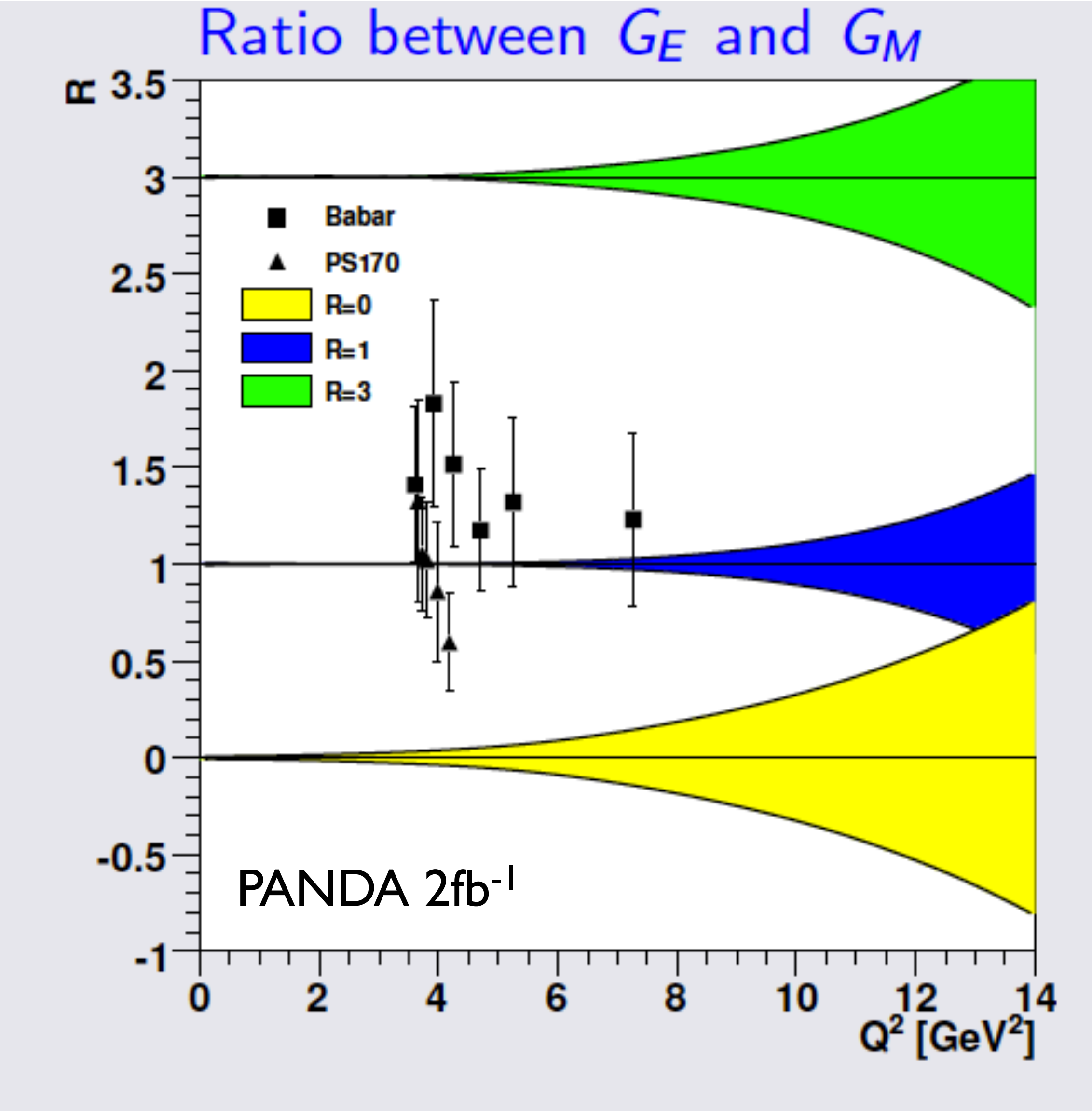






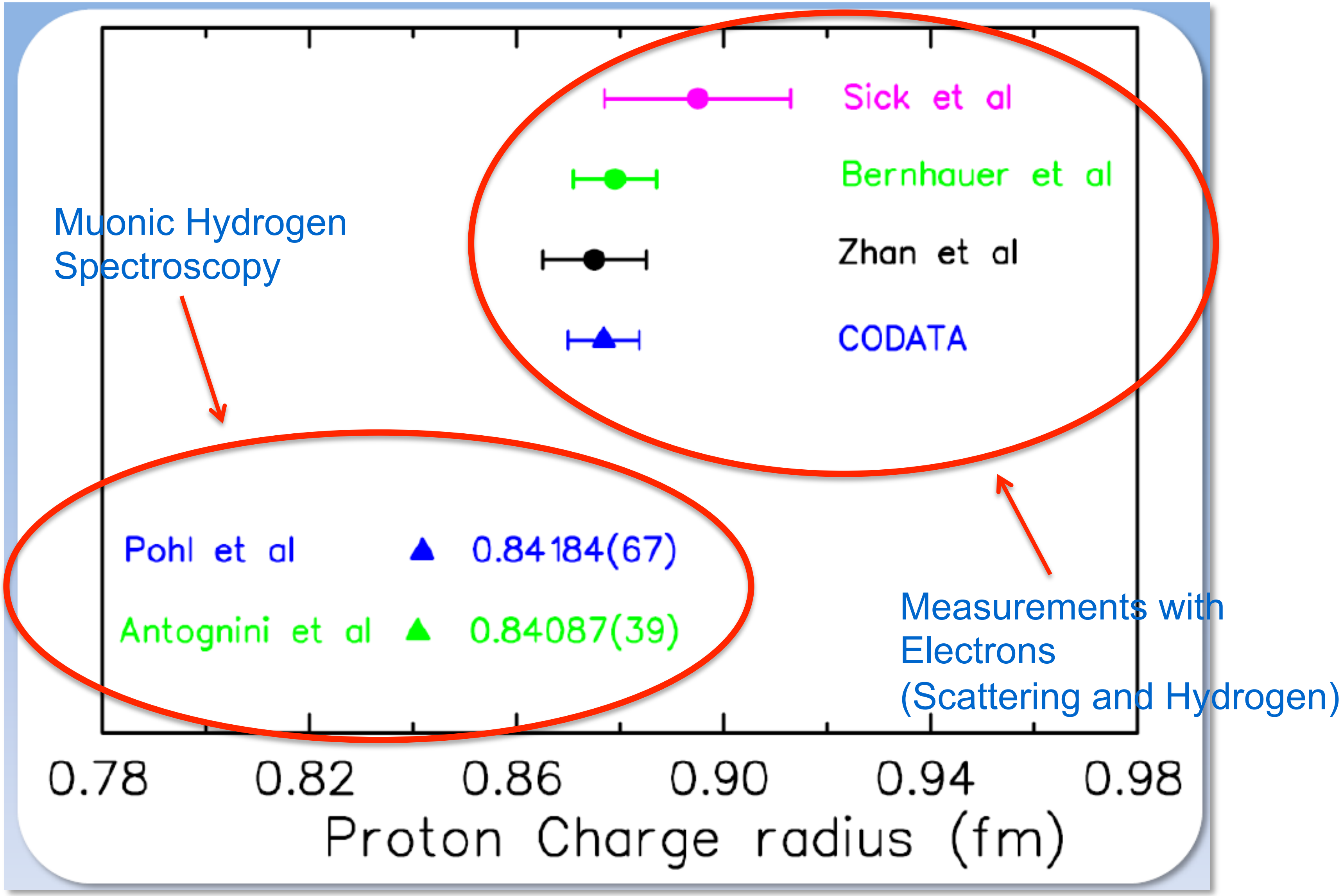


Time Like Electromagnetic Form Factors in PANDA



Proton Radius (at MAMI)

Proton Radius Puzzle

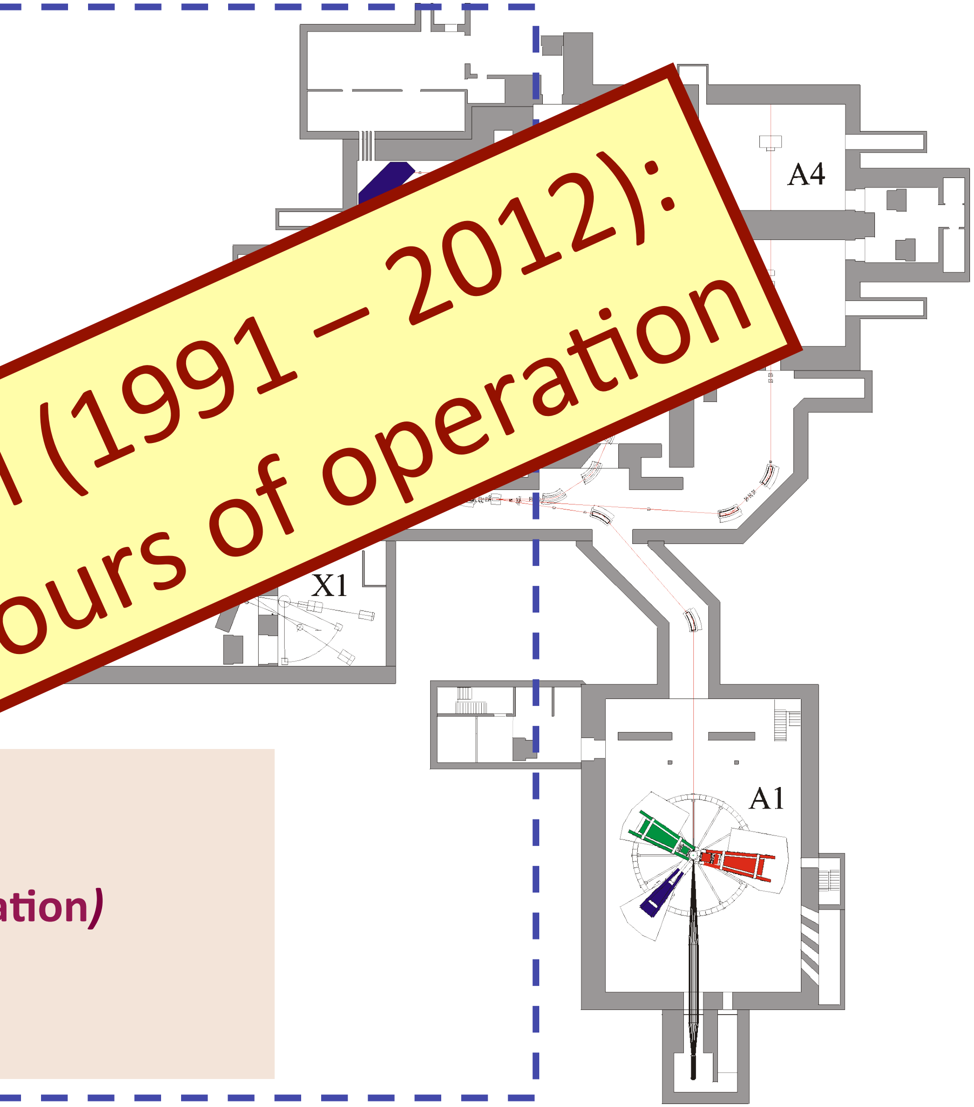


The Mainz Microtron MAMI (Operated by IKP Mainz)

MAMI-C:

since 2007 in routine operation

→ Beam energy E_γ^{max} = 1.604 GeV



MAMI total (1991 – 2012): 129,592 hours of operation

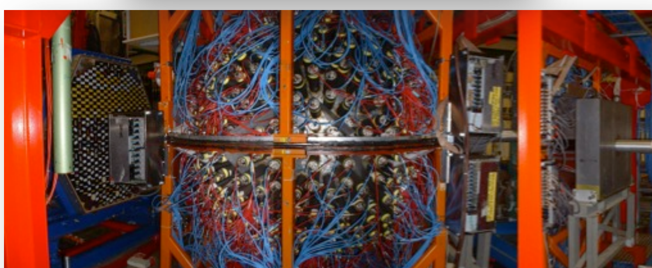
HIGH Inten… µA)

HIGH Resolu… σ_E<0.100MeV)

HIGH Polarization (ca. 80% Polarization)

HIGH Reliability

Instrumentation at MAMI



A4: Parity violation in elastic ep scattering

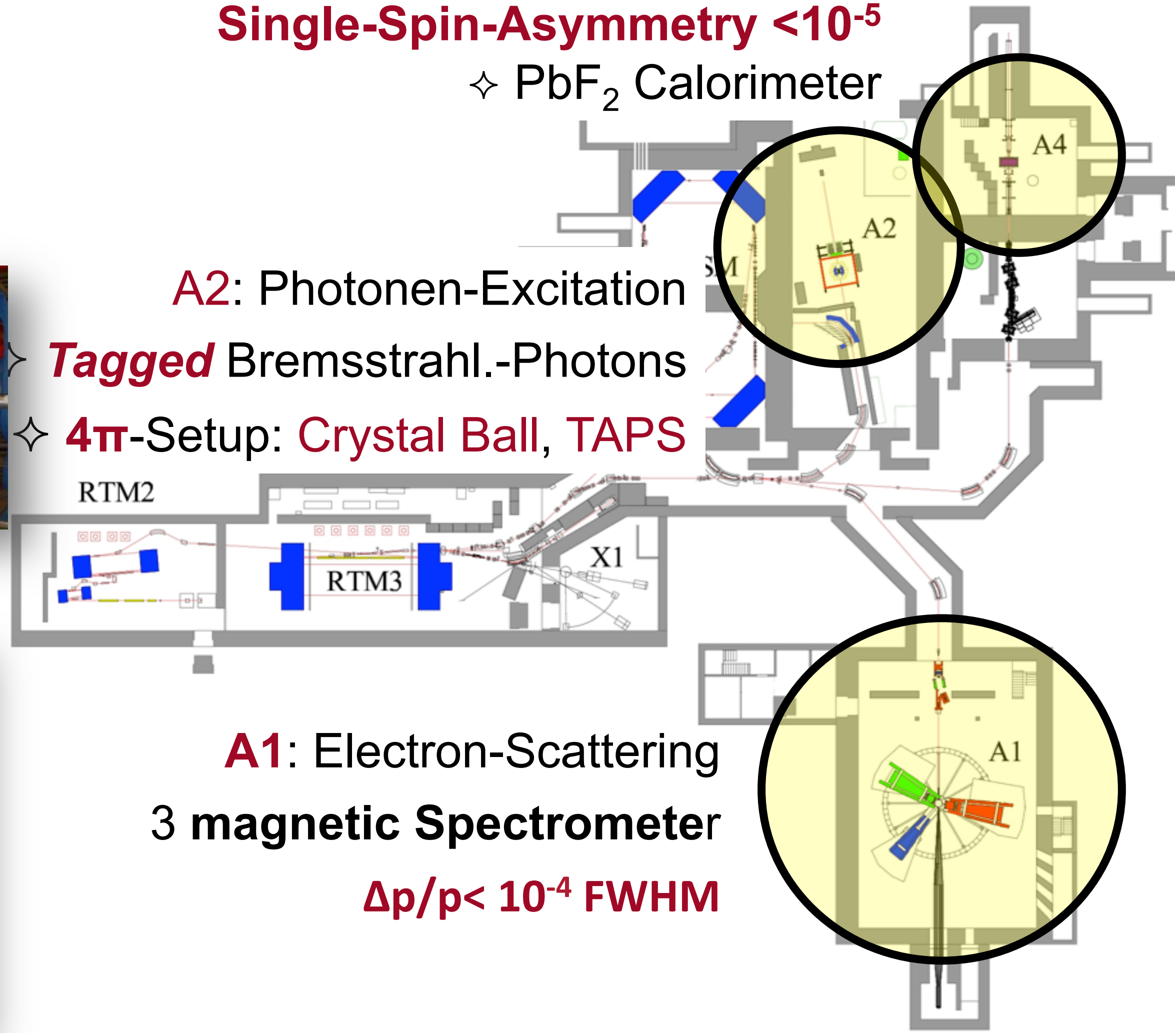
Single-Spin-Asymmetry <10^{-5}

✧ PbF_2 Calorimeter

A2: Photonen-Excitation

✧ ***Tagged*** Bremsstrahl.-Photons

✧ **4π**-Setup: Crystal Ball, TAPS



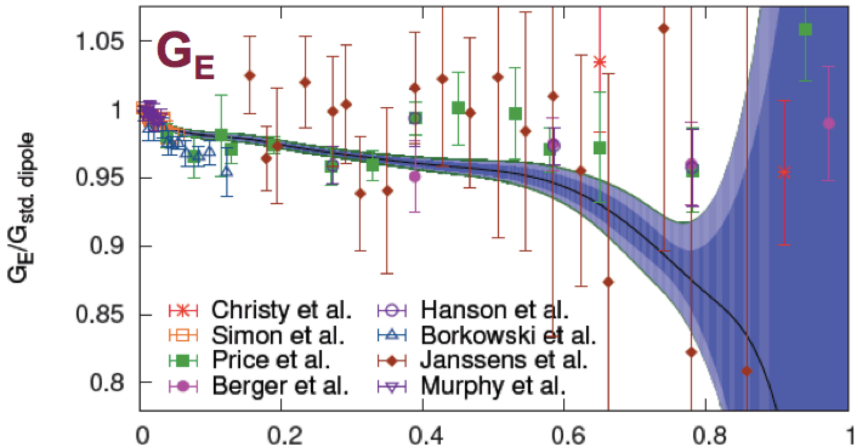
A1: Electron-Scattering

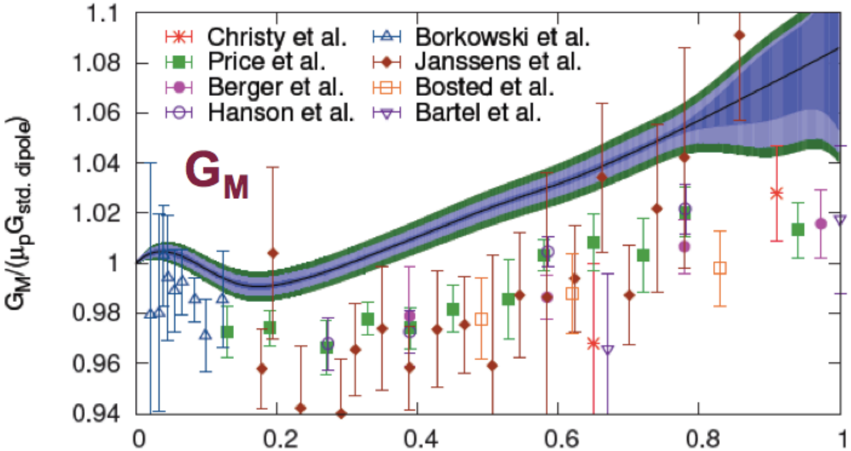
3 **magnetic Spectromete**r

Δp/p< 10^{-4} FWHM

Selected Highlights at MAMI: Proton Radius

- **High-precision determination of the electric and magnetic proton form factors**
  → Super-Rosenblugh fit → extraction of proton radius to ~1% precision

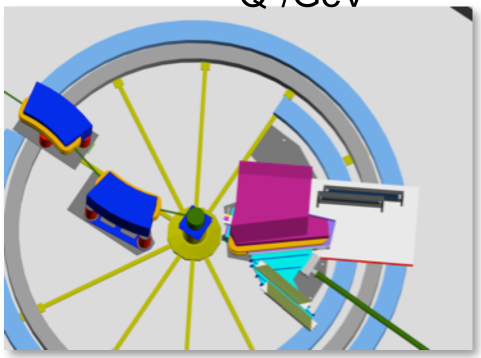




Q^2/GeV^2

Q^2/GeV^2

- **Successful installation of beam line chicane for 0° operation of KAOS**



- Elementary kaon production
- Start of hypernuclei programme (missing mass & π decay spectroscopy)

New Measurement of Proton Radius

- Radius can be obtained by measuring cross section of H(e,e')p:

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \frac{1}{1+\tau}\left[G_E^2(Q^2) + \frac{\tau}{\varepsilon} G_M^2(Q^2)\right]$$

$$\varepsilon = \left[1 + 2(1+\tau)\tan^2\frac{\vartheta_e}{2}\right]^{-1} \qquad \tau = \frac{Q^2}{4m_p^2},$$

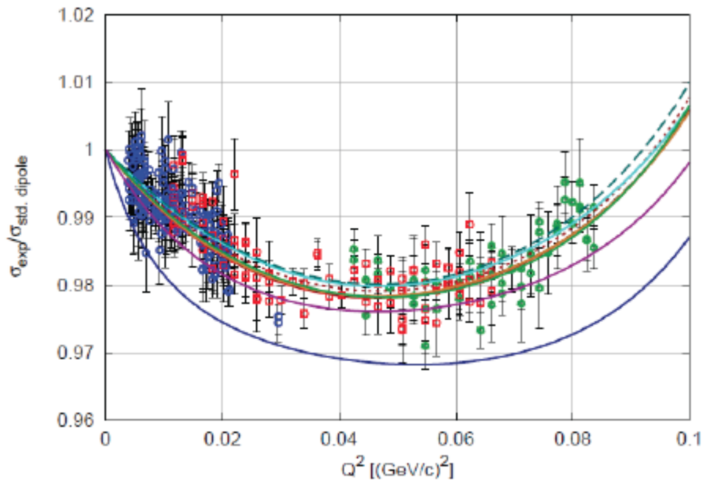
- Extraction of FF via Rosenbluth, Super-Rosenbluth Separation:

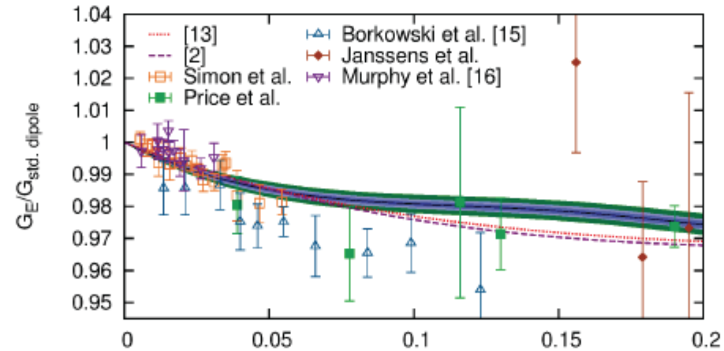
$$G_E(Q^2) \approx G^{Dipole}(Q^2) = \left(1 + \frac{Q^2}{0.71}\right)^{-2}$$

- Best estimate for radius:

$$\left\langle r_E^2 \right\rangle = -6\hbar^2 \frac{d}{dQ^2} G_E(Q^2)\Big|_{Q^2=0}$$

$$\rho_{Dipole}(r) = \frac{1}{8\pi}\left(\frac{12}{\left\langle r_E^2\right\rangle}\right)^{\frac{3}{2}} \exp\left(-r\sqrt{\frac{12}{\left\langle r_E^2\right\rangle}}\right)$$

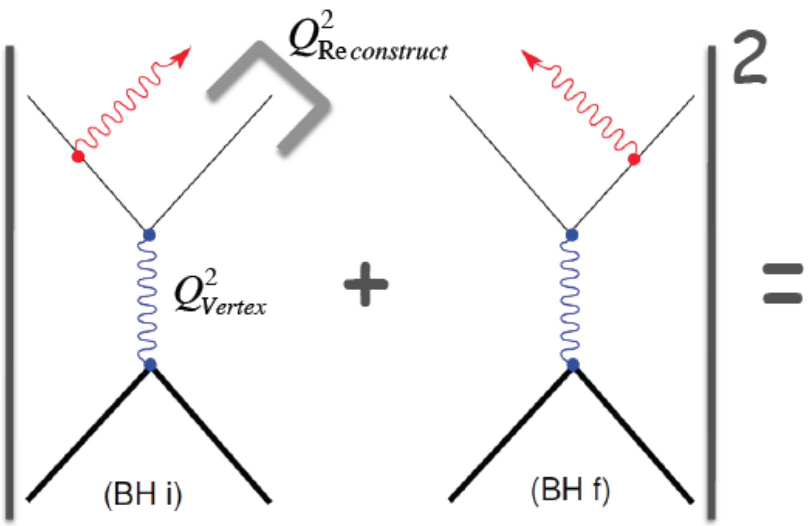


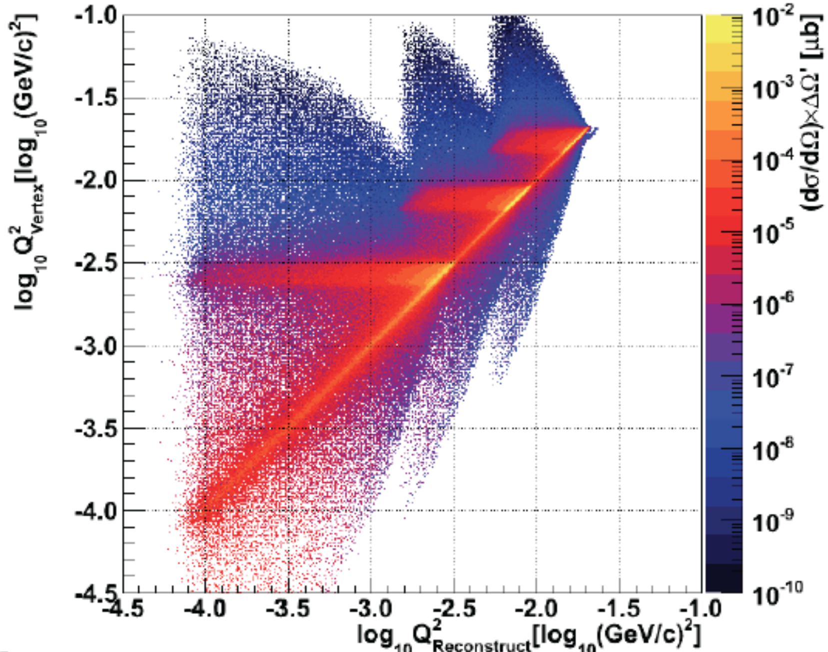


No data at lowest Q^2. Determination of proton radius depends on the slope of FF (Q^2->0).

New Measurement of Proton Radius

- Radiative tail dominated by coherent sum of two Bethe-Heitler diagrams.





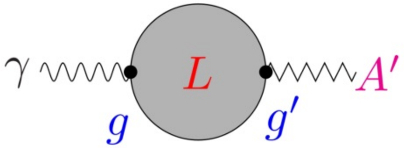
- In data ISR can not be distinguished from FSR.
- **Combining data to the Simulation, ISR information can be reached.**
- Idea behind new MAMI experiment to extract G_e^p at $Q^2 \sim 10^{-4}\ (GeV/c)^2$
- Redundancy measurements at higher Q^2 for testing this approach in a region, where FFs are well known.

Search for a Dark Photon

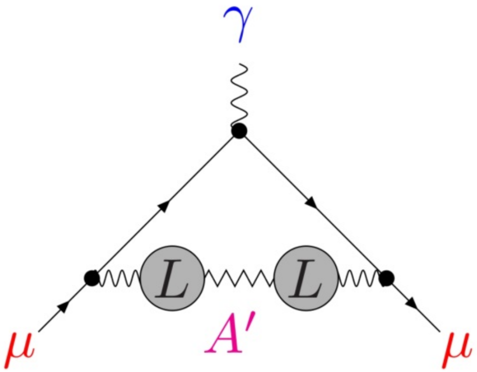
"Dark Photon"

- "Dark Photons":
  - Gauge bosons of additional $U(1)$ gauge groups in SM extensions
  - Couple to heavy fermions in dark matter models – **"messengers"**
  - Dark photon masses in MeV range can explain astrophysical anomalies
- Kinetic mixing mechanism couples dark sector to SM fermions

$\varepsilon = g'/g$



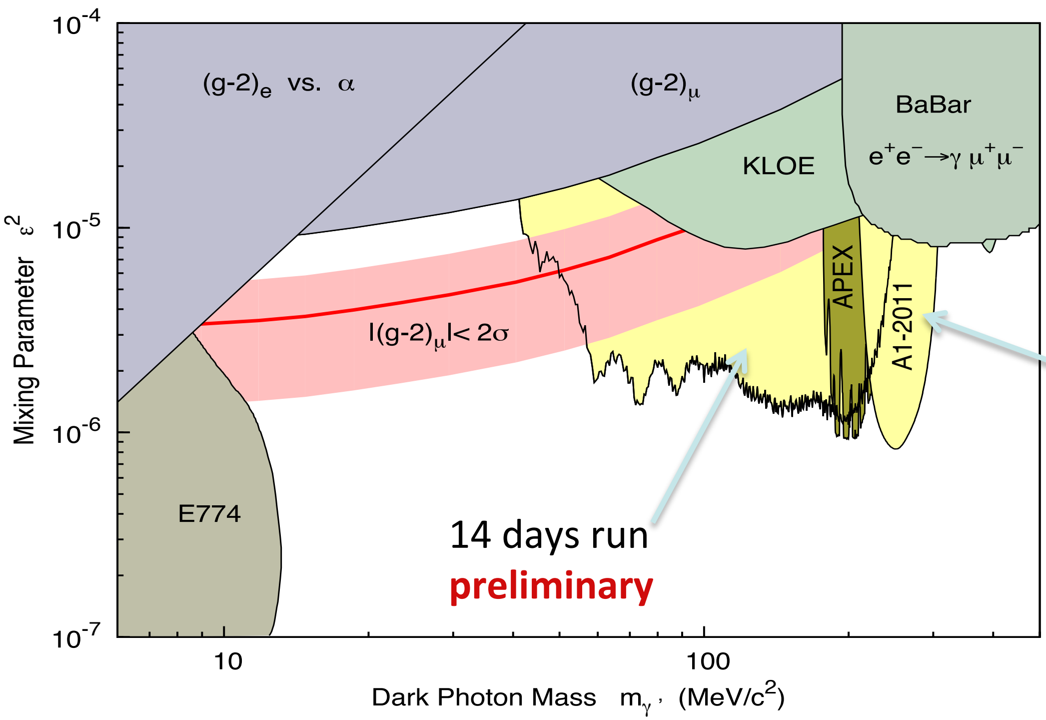
- Dark photons may explain the tension in a_μ



Selected Highlights at MAMI: Search for Dark Photon

➤ **Search for a new massive force carrier of extra $U(1)_d$: Dark Photon**

- Could explain large number of astrophysical anomalies
- Could explain deviation of 3.6σ btw. SM value and direct measurement of $(g-2)_\mu$

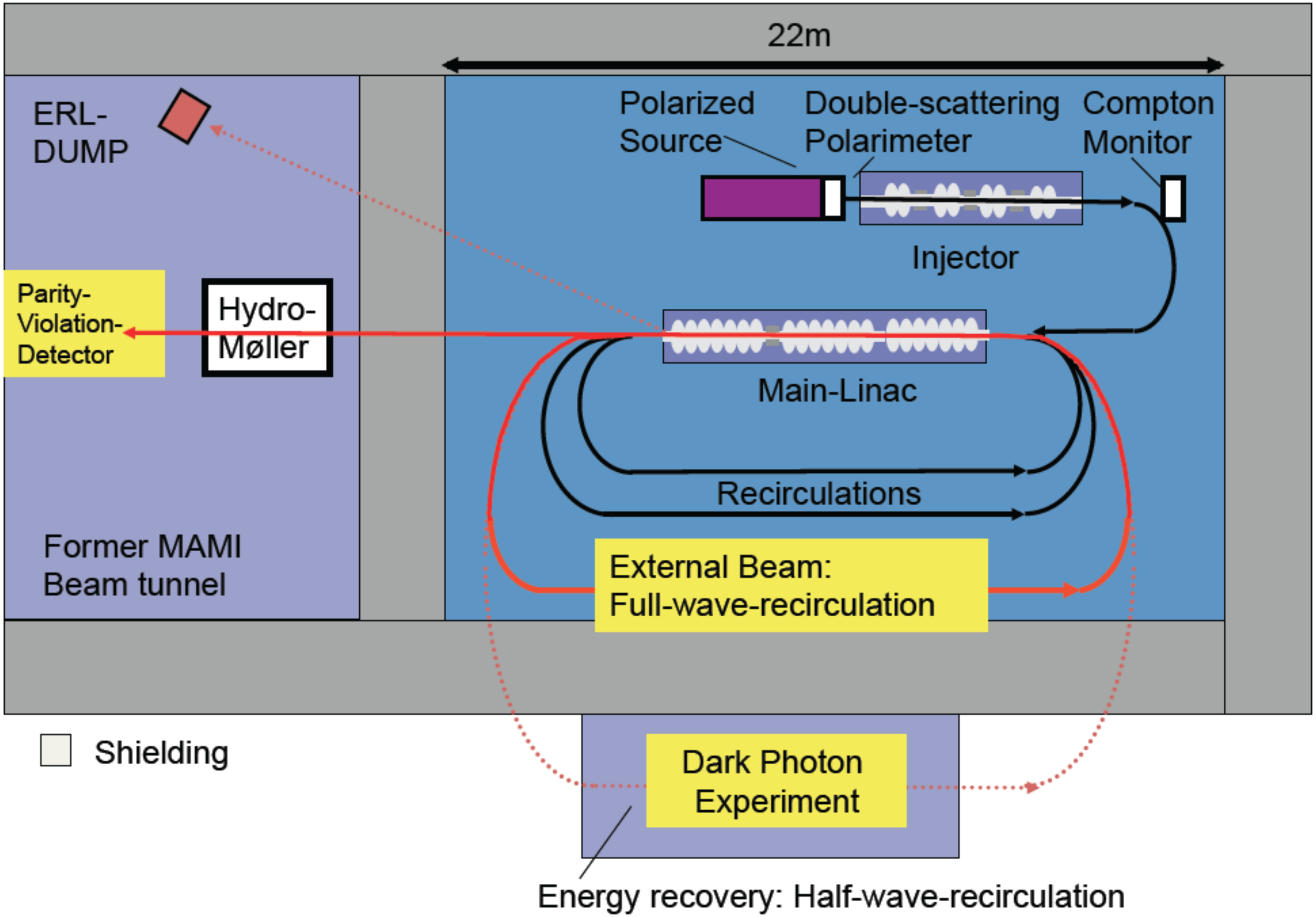


Exclusion range from **MAMI / A1 spectrometers** during **4-day pilot run**

A1/MAMI
Merkel et al. PRL 2011

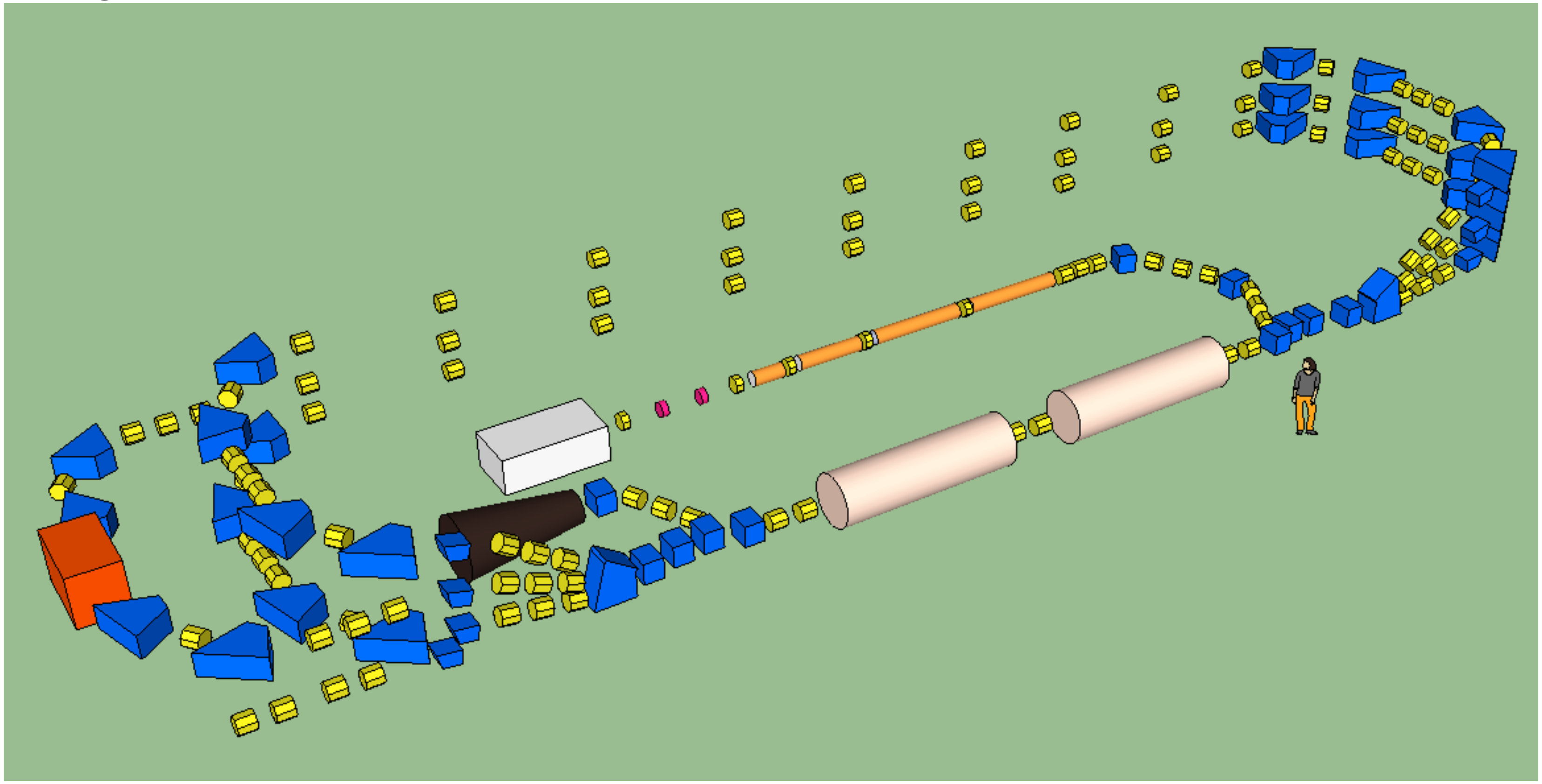
- Future: Low mass region <50 MeV/c^2 and small dark photon coupling ε^2

Mainz Energy-recovering Superconducting Accelerator (MESA)



Mainz Energy-recovering Superconducting Accelerator (MESA)

Design: Ralf Eichhorn

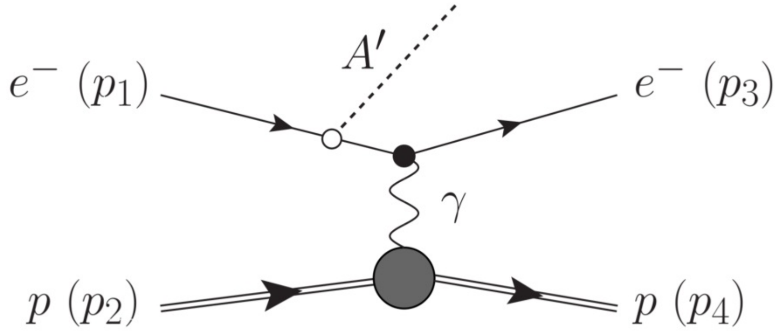


"A must-do facility … for the price of an experiment"

(W.J. Marciano, 2011 MESA workshop)

Experimental searches for Dark Photons

- Production of dark photons in *ep* scattering



- A' -> l+ l-, search for sharp peak in invariant mass distribution

- First results (exclusion limits): A1 spectrometer @ MAMI

[Merkel et al. , 2011]

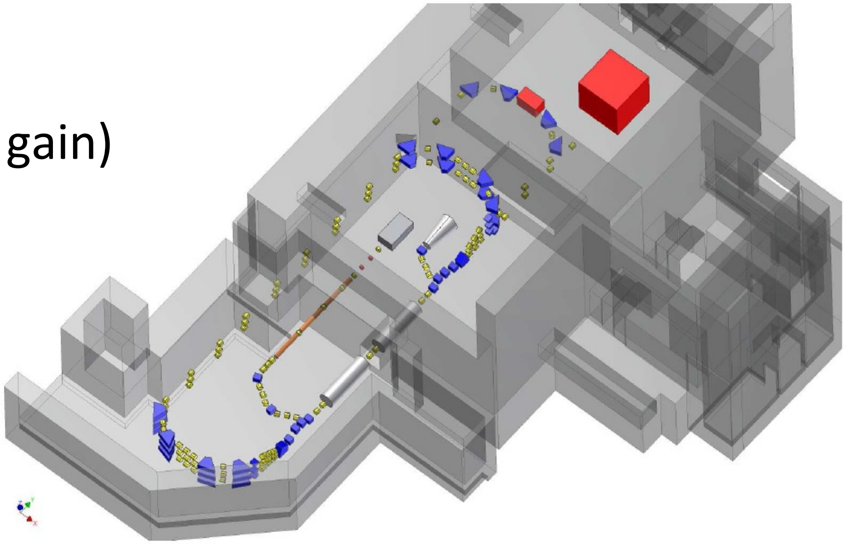
- Flagship experiment at MESA: Very thin hydrogen target, large current

- Other efforts: APEX experiment / DarkLight Proposal @ JLab

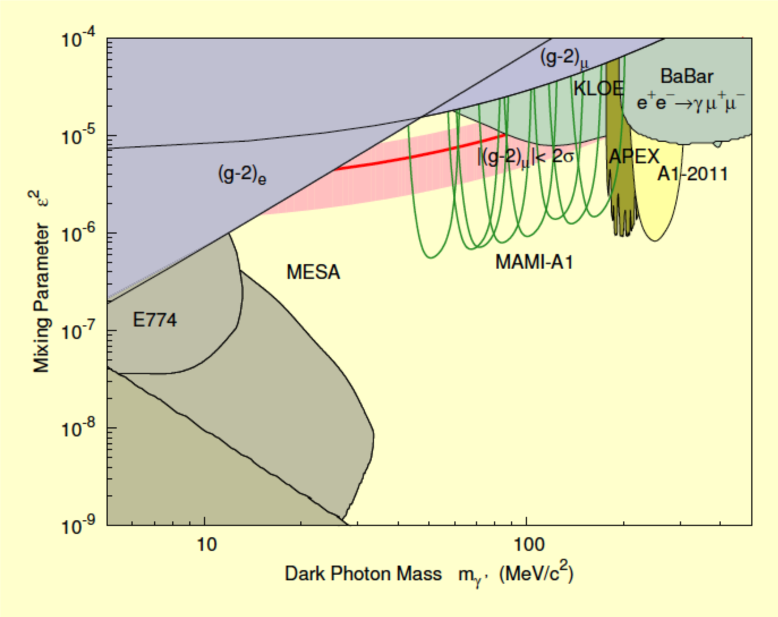
Accelerator MESA: key initiative in PRISMA

Mainz Energy-Recovering Superconducting Accelerator
High-Intensity Electron Accelerator: 200 MeV @ >1 mA current

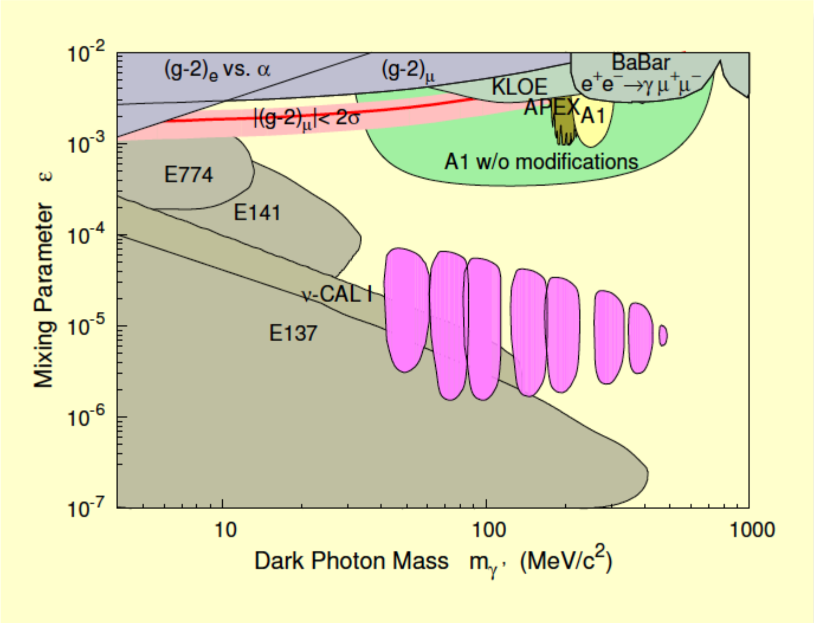
- **Location: existing halls of Institute** (former A4 hall)
- **Challenging accelerator project**
  → superconducting technology (50 MeV gain)
  → Energy-Recovering (ERL) technology
- **Frontier experiments**
  - Precision measurement of $\sin^2\Theta_W$
    → extracted beam mode
  - Search for the Dark Photon
    → ERL mode
  - Frontier projects in Particle, Hadron, Nuclear Physics ….



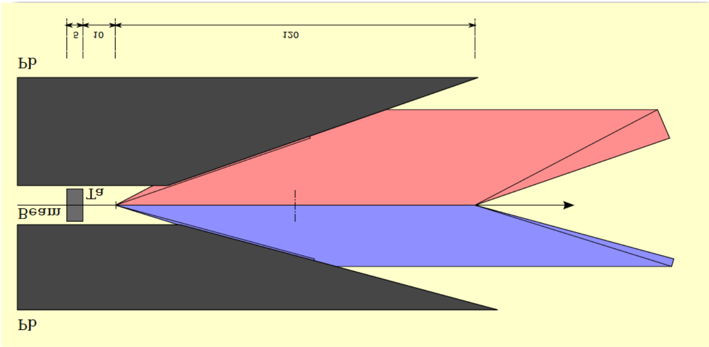
Experimental searches for Dark Photons at MAMI



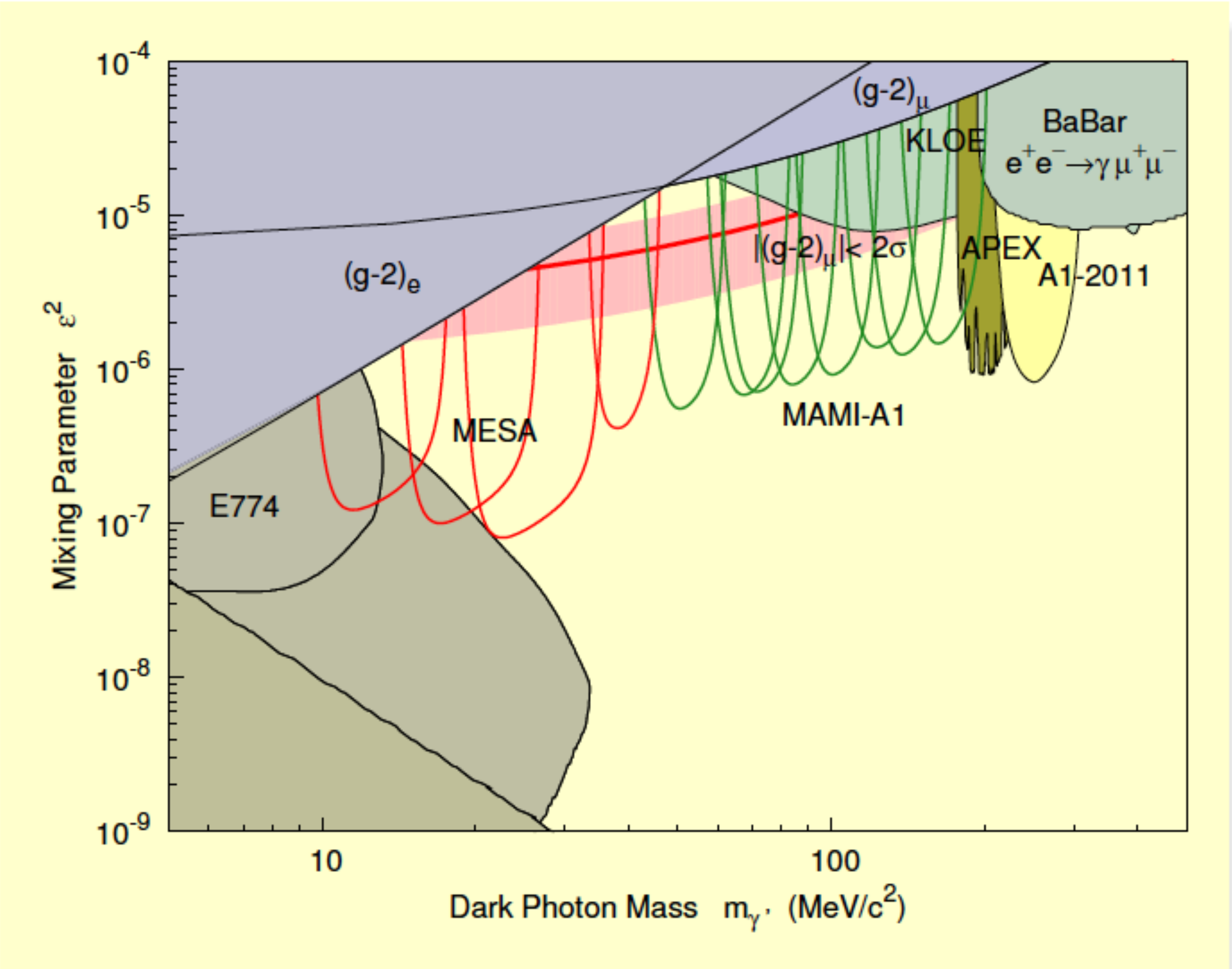
Data taken



Displaced vertex: future Experiment



Experimental searches for Dark Photons with MESA

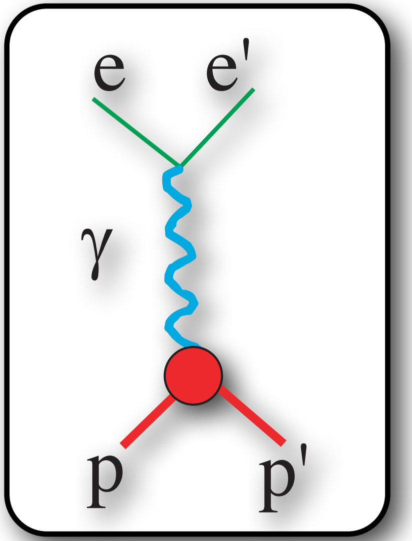


Parity violating electron scattering

a) strangeness in the nucleon

b) weak charge of the proton for a precise determination of $\sin^2(\theta_W)_{eff}$

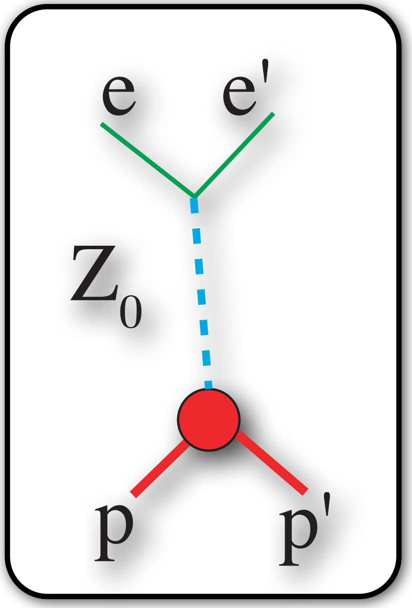
Elastic Electron Proton Scattering: Born



$$\sigma \sim \mathcal{M}\,\mathcal{M}^*$$
$$\sim \left(j_\mu \frac{1}{Q^2} J^\mu\right)\left(j_\mu \frac{1}{Q^2} J^\mu\right)^*$$
$$j_\mu \sim \bar{e}\,\gamma_\mu\, e \quad \text{Vector Current}$$

$$J^\mu_\gamma \sim \left\langle N \middle| q^u \bar{u}\,\gamma_\mu\, u + q^d \bar{d}\,\gamma_\mu d + q^s \bar{s}\,\gamma_\mu s \middle| N' \right\rangle$$
$$= \bar{\mathcal{P}}\left[\gamma^\mu F_1 - i\sigma^{\mu\nu} q_\nu \frac{\kappa_p}{2M_N} F_2\right]\mathcal{P}$$

Electroweak Elastic Electron Proton Scattering: Born



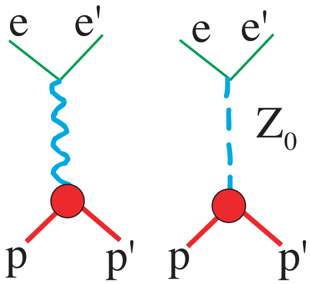
$$\tilde{q}^{d}{}_{V} = \tau_3 - 2q^{d}\sin^2(\theta_W)$$

weak vector charge

$$\tilde{J}^{\mu}_{Z} \sim \left\langle N\left|\tilde{q}^{u}\bar{u}\,\gamma_\mu\, u + \tilde{q}^{d}\bar{d}\,\gamma_\mu d + \tilde{q}^{s}\bar{s}\,\gamma_\mu s\right|N'\right\rangle$$

$$= \bar{\mathcal{P}}\left[\gamma^\mu \tilde{F}_1 - i\sigma^{\mu\nu} q_\nu \frac{\kappa_p}{2M_N}\tilde{F}_2\right]\mathcal{P}$$

Parity Violating Asymmetry in Elastic Scattering



$$A_{\mathrm{RL}} = \frac{\sigma_{\mathrm{R}} - \sigma_{\mathrm{L}}}{\sigma_{\mathrm{R}} + \sigma_{\mathrm{L}}} \qquad q^2 \ll M_Z^2$$

$$= \frac{q^2}{M_Z^2} \frac{2 j_{\gamma,\mu} \langle J_\gamma^\mu \rangle \left(a_\mu \langle V_Z^\mu \rangle + v_\mu \langle A_Z^\mu \rangle \right)}{\left| j_{\gamma,\mu} \langle J_\gamma^\mu \rangle \right|^2} \sim 10^{-5}$$

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

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

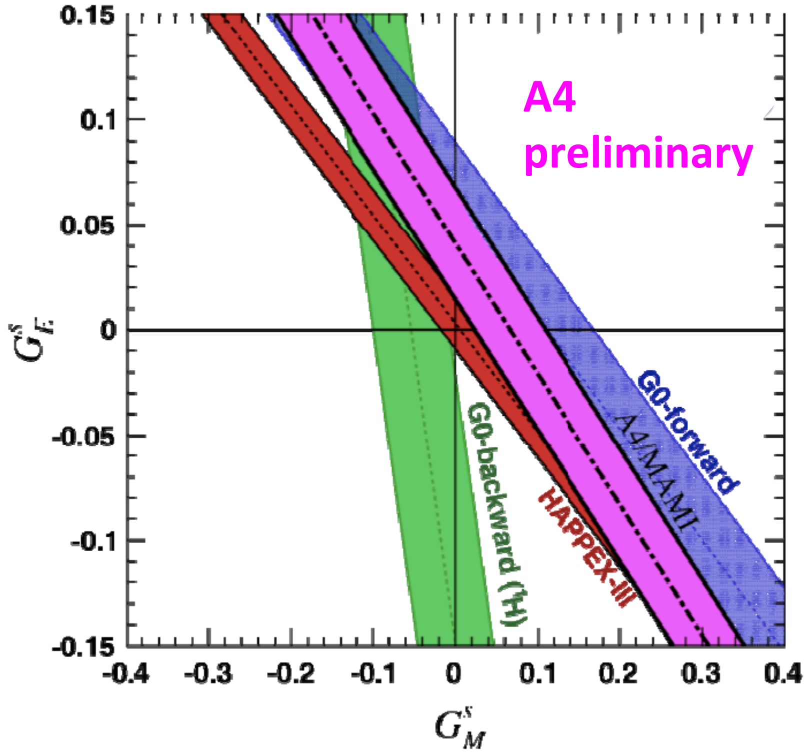
Selected Highlights at MAMI: Parity Violation

- **Measurement of parity-violating cross section asymmetry @ Q^2=0.62 GeV^2**
  → EM strangeness form factors

$$\mathbf{G_E^s + 0.62 \cdot G_M^s = 0.042 \pm 0.029}$$

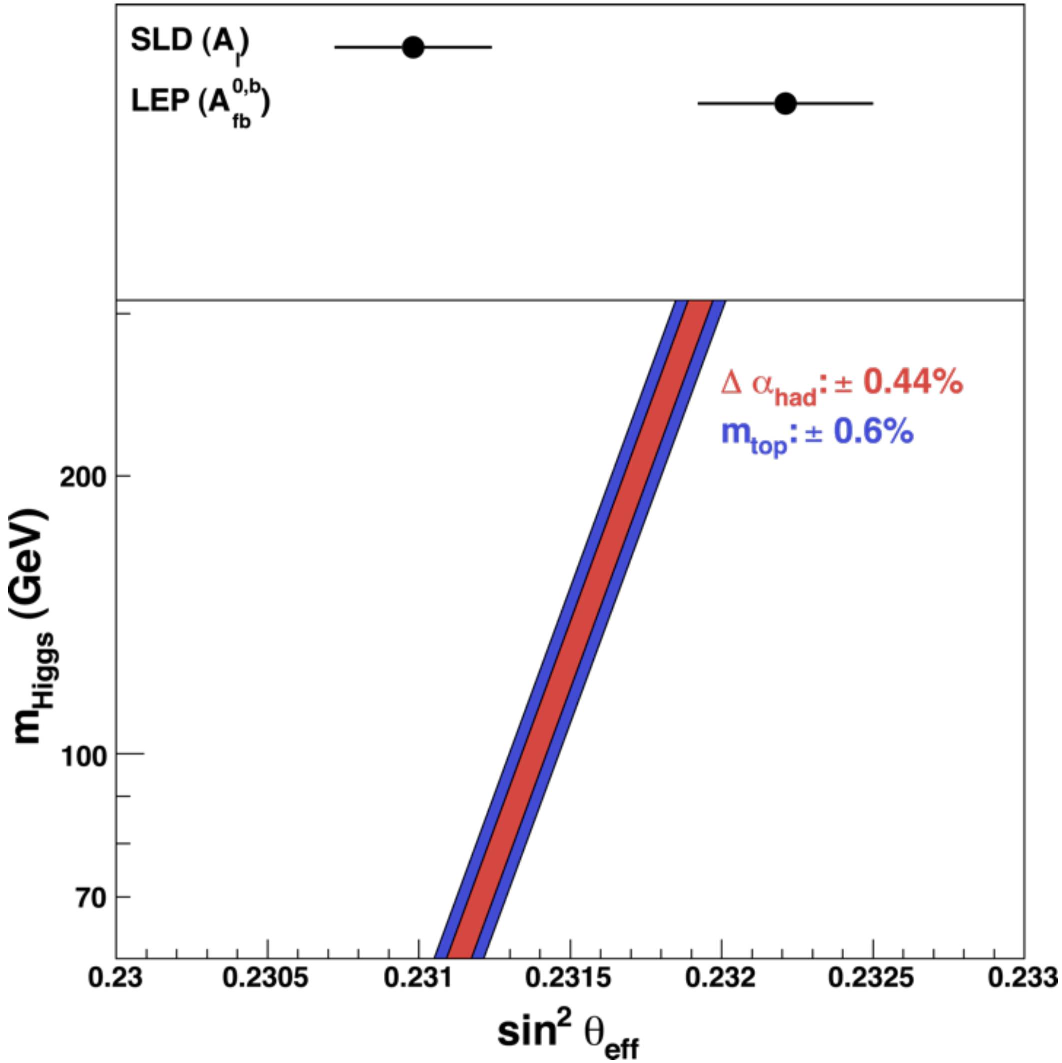
(preliminary)

- **Recent measurement @ Q^2=0.1 GeV^2**
  → extrapolation to $Q^2 \to 0$



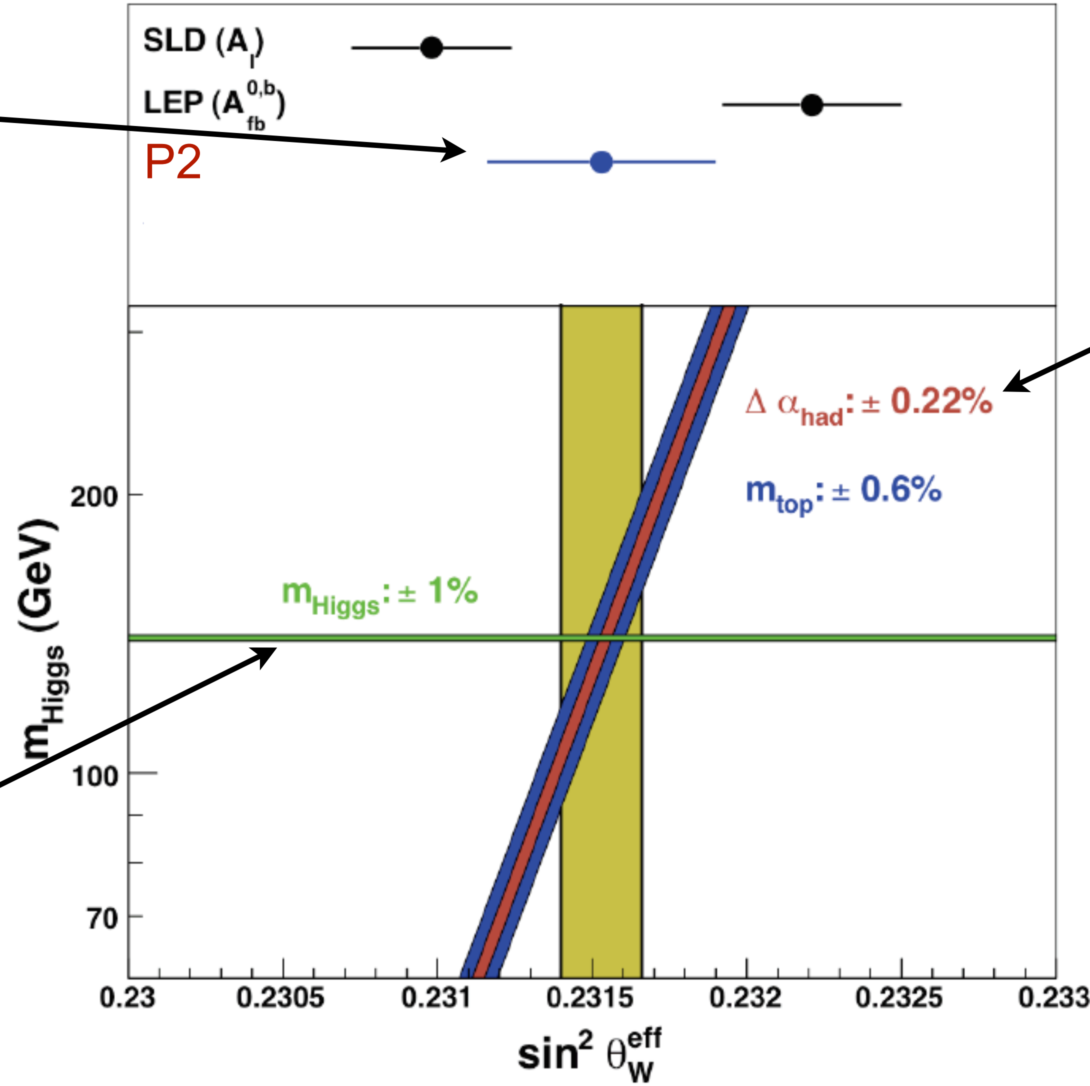
A4 experiment has successfully completed physics programme
→ Preparation for a new experiment P2 to measure $\sin^2\theta_W$ at low Q^2 with unprecedented precision
→ Project within CRC-1044 (personnel) and PRISMA (MESA accel.)

The $\sin^2 \theta_W$ - m_{Higgs} Connection



The $\sin^2\theta_W$ - m_{Higgs} Connection

Projection for project P2

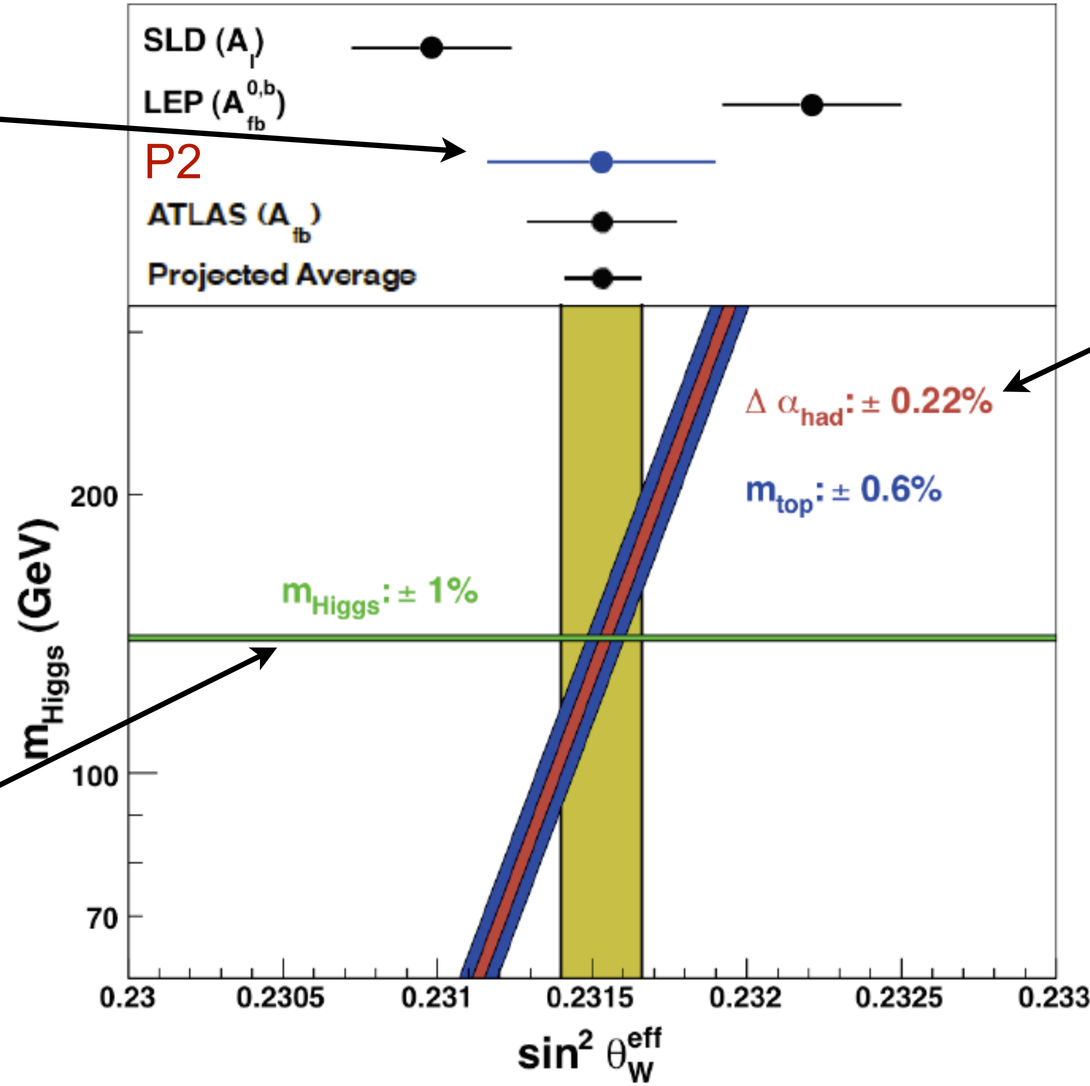


Projection for project P1

Expectation from LHC

The $\sin^2\theta_W$ - m_{Higgs} Connection

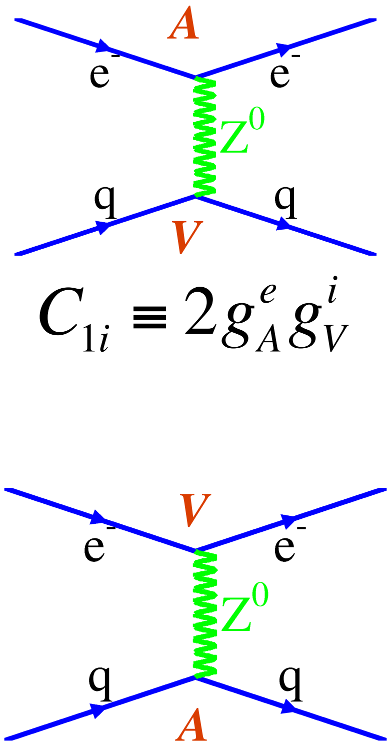
Projection for project P2



Projection for project P1

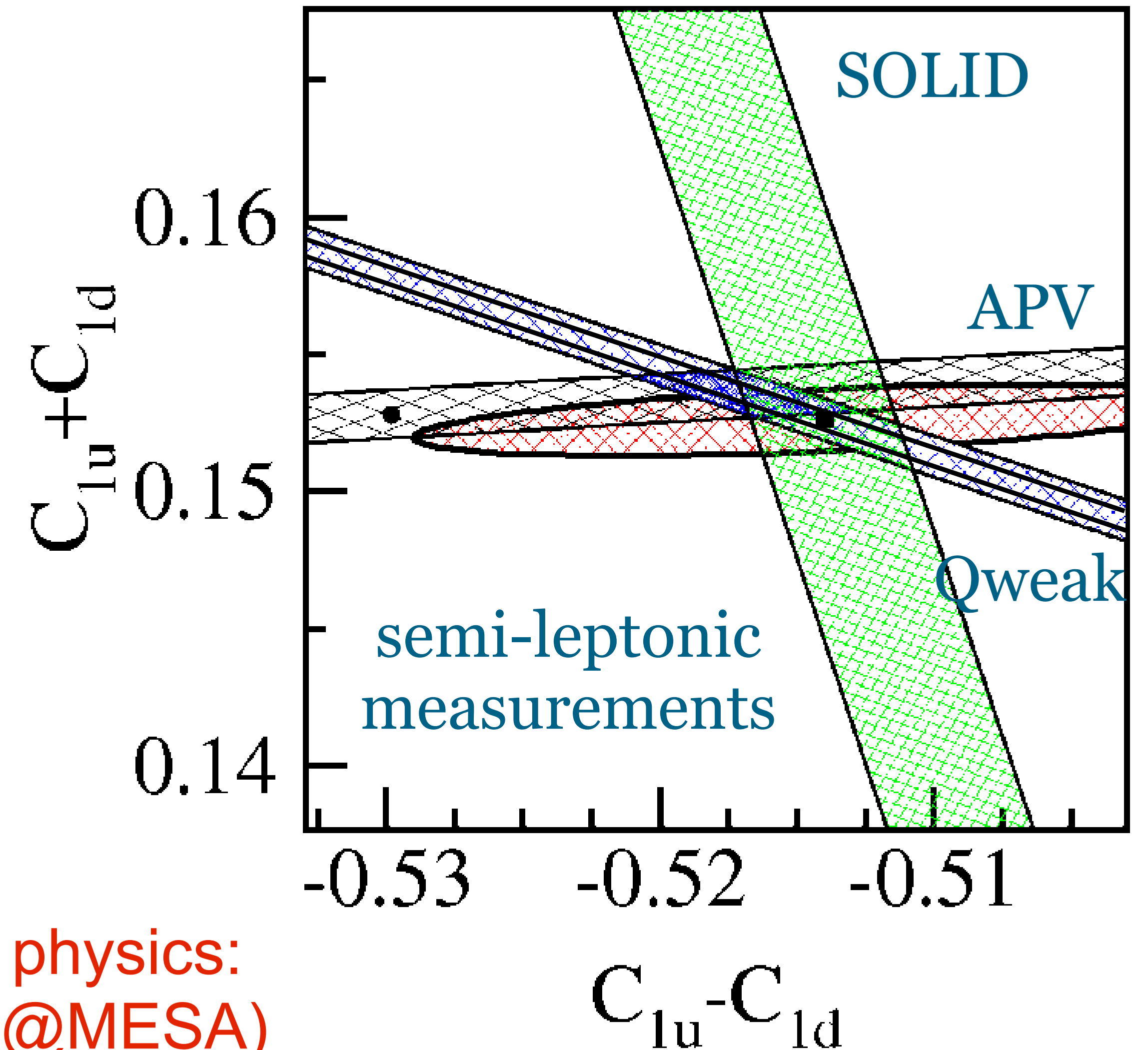
Expectation from LHC

Semi-Leptonic Electroweak Couplings



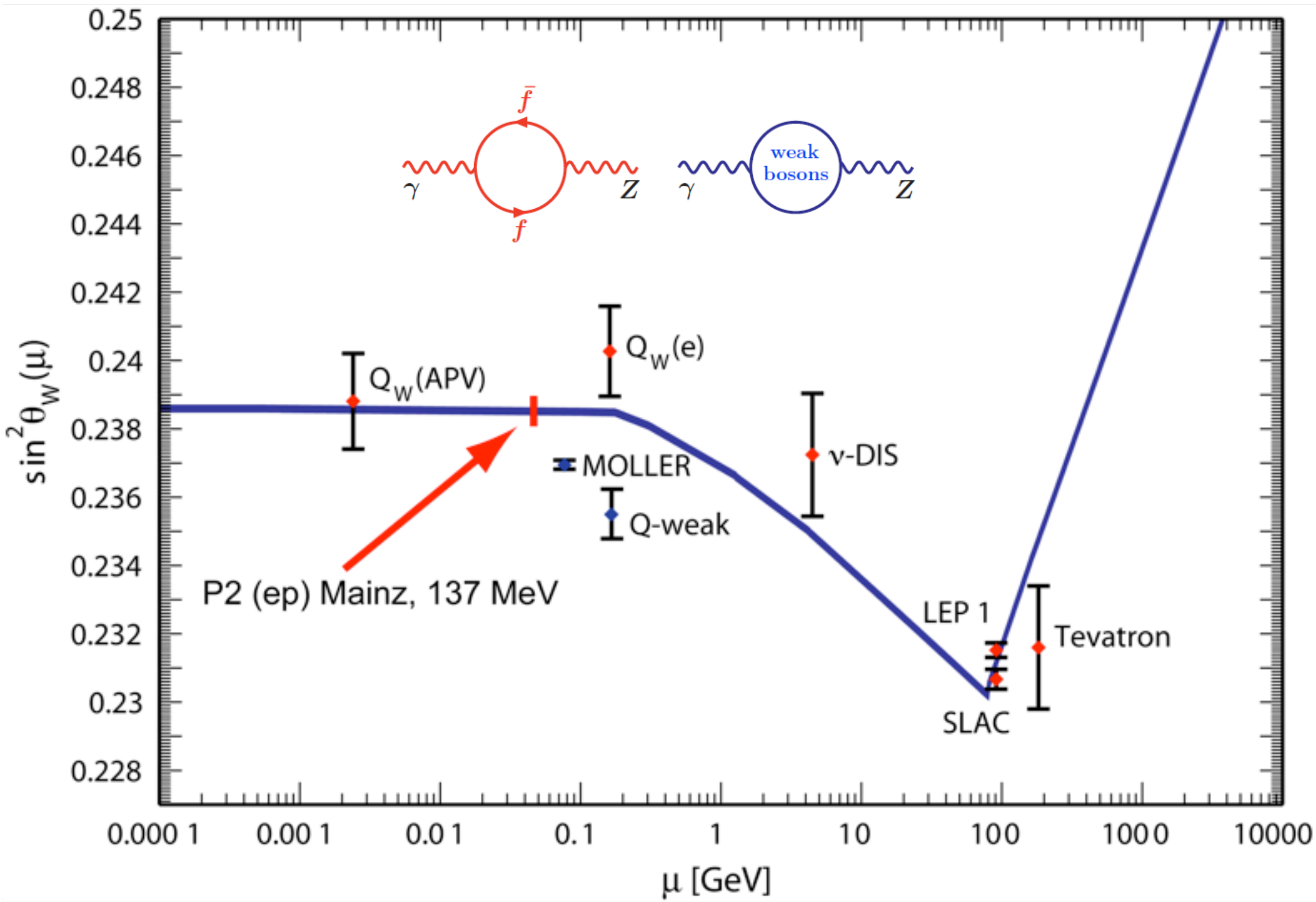
$C_{1i} \equiv 2g_A^e g_V^i$

$C_{2i} \equiv 2g_V^e g_A^i$



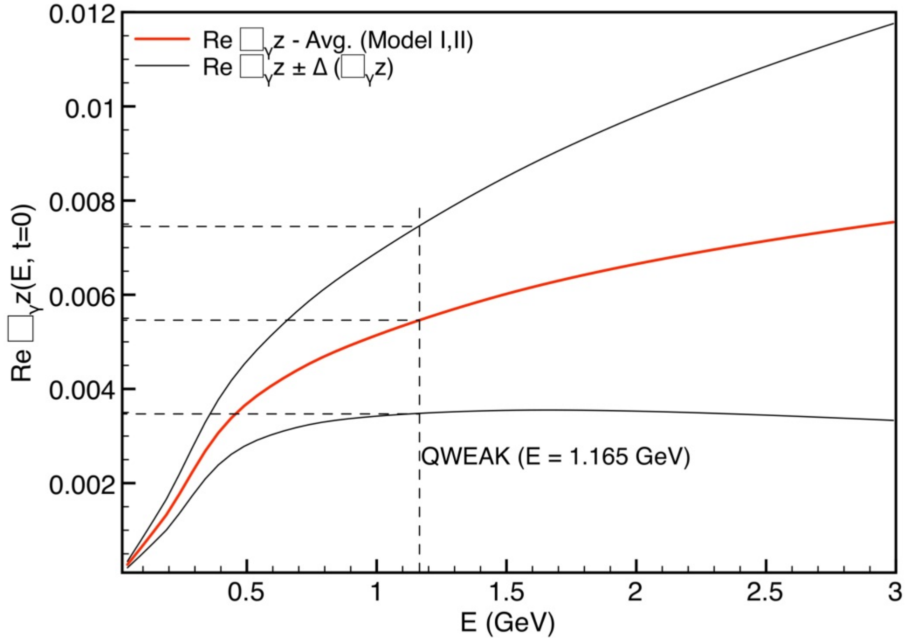
Sensitivity to new physics:
$\Lambda_{new} \simeq 6.4$ TeV (P2@MESA)

Determination of $\sin^2 \theta_W(\mu)$



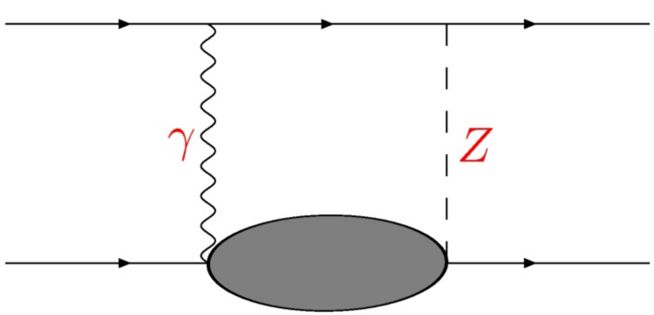
Hadron Structure Contributions vanish at low Q

- γZ box graph contributions obtained by modelling hadronic effects:



[Gorchtein, Horowitz & Ramsey-Musolf

- Hadronic uncertainties suppressed at lower energies
- Planned experiment: **P2 @ MESA**



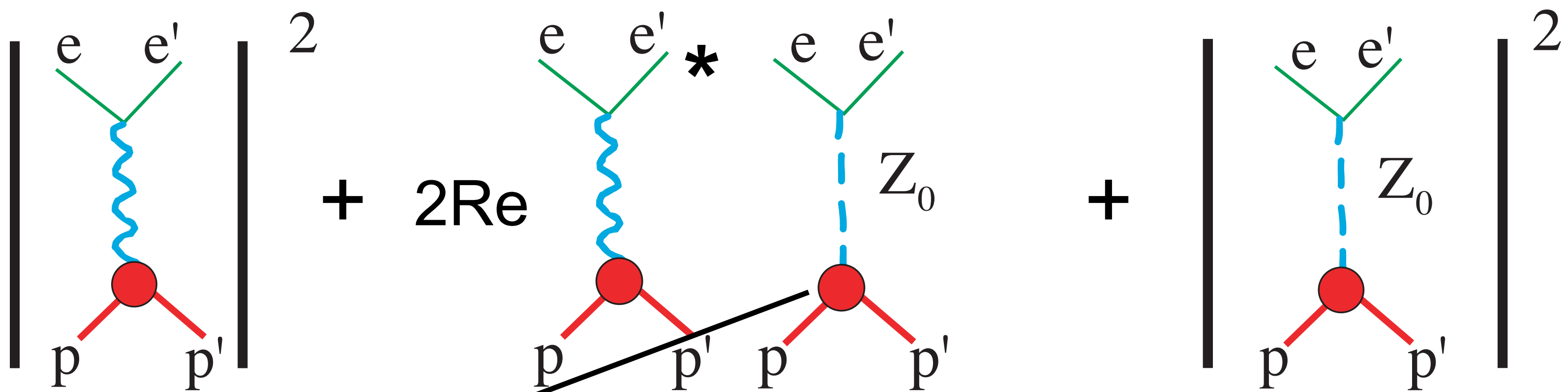
Dominant theoretical uncertainty:

γZ box graphs, $\Box_{\gamma Z}$

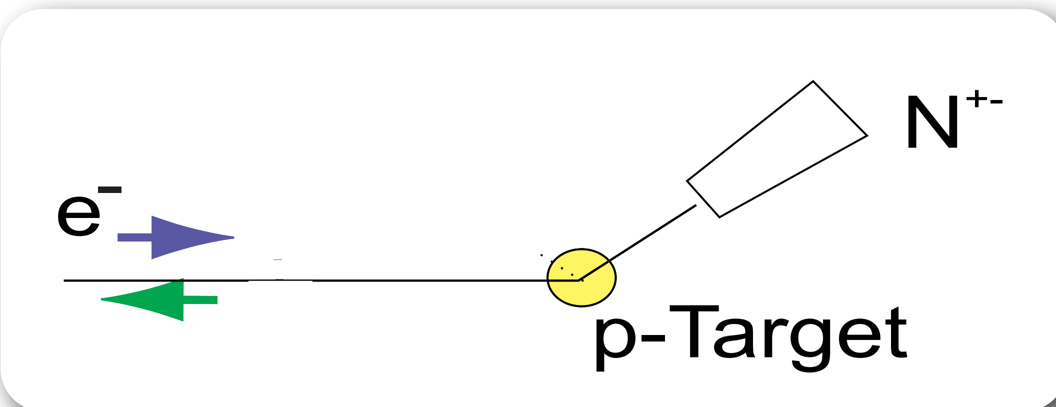
Sensitive to hadronic effects

Method: Parity-Violating Electron-Proton Scattering

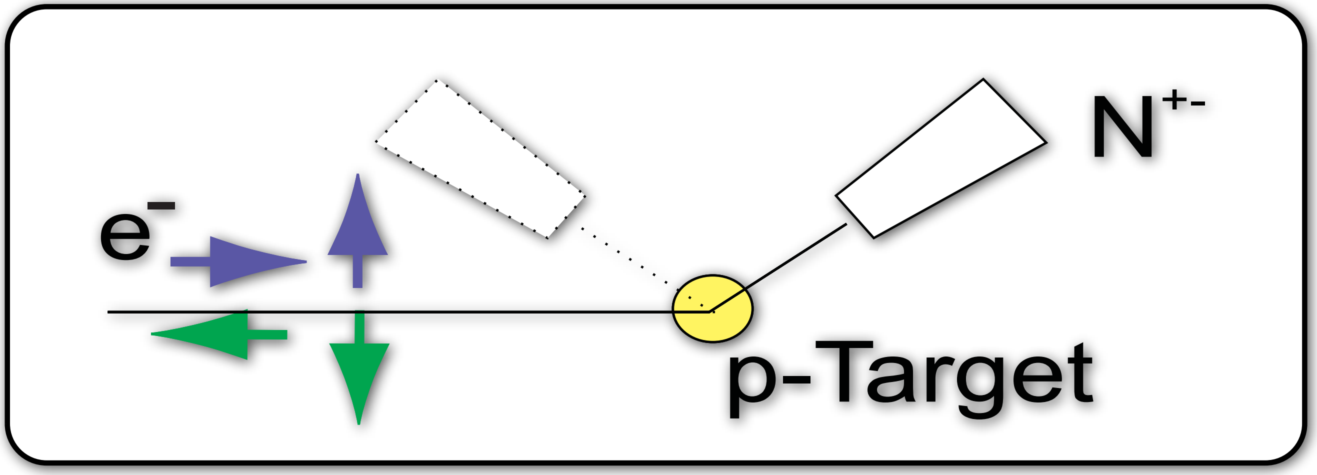
$\sigma \approx$



V-A coupling:
parity-violating
cross section asymmetry A_{LR}
longitudinally pol. electrons
unpolarised protons



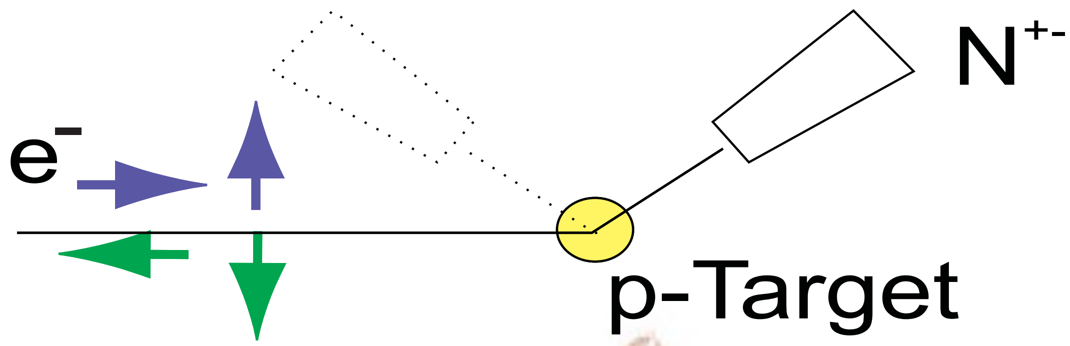
Statistics: Parity-Violating Electron-Proton Scattering



$$A = \frac{N^+ - N^-}{N^+ + N^-} \qquad \delta A = 1/N^{1/2}$$

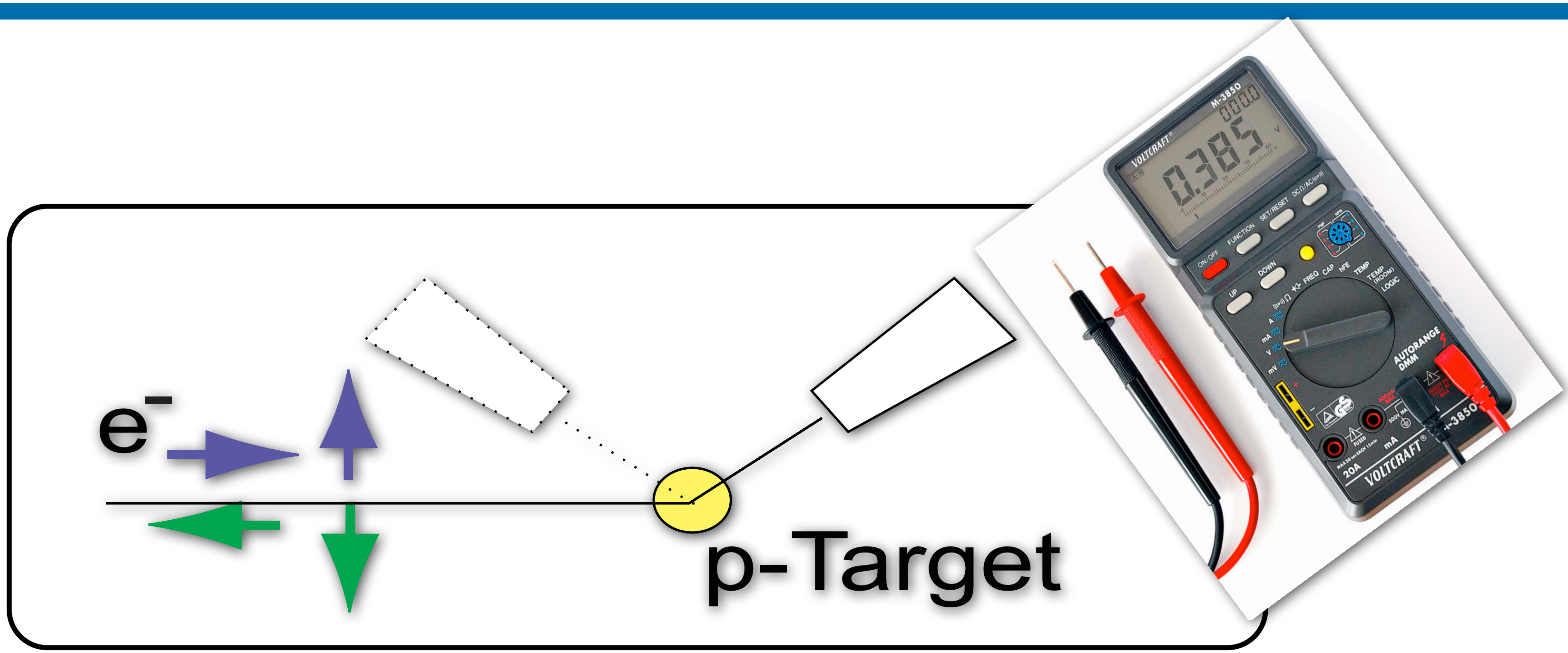
Example: $A = 10^{-6}$ Goal: 10% measurement
$\delta A = 10^{-7}$ -> $N = 10^{14}$ events

High Statistics: Counting Technique



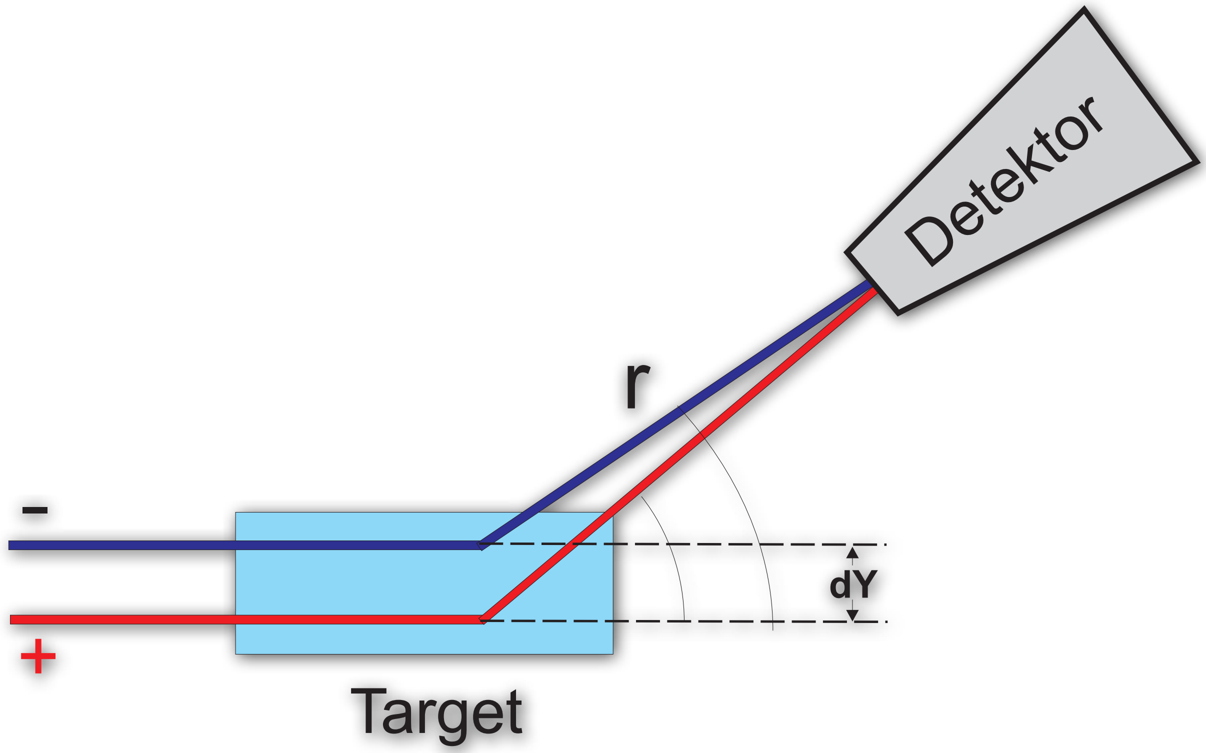
Count scattered electrons:
- pile-up (double count losses)
- Background Asymmetry
- Very Fast Counting (MHz)
- Measure TOF or Energy

High Statistics: Counting Technique

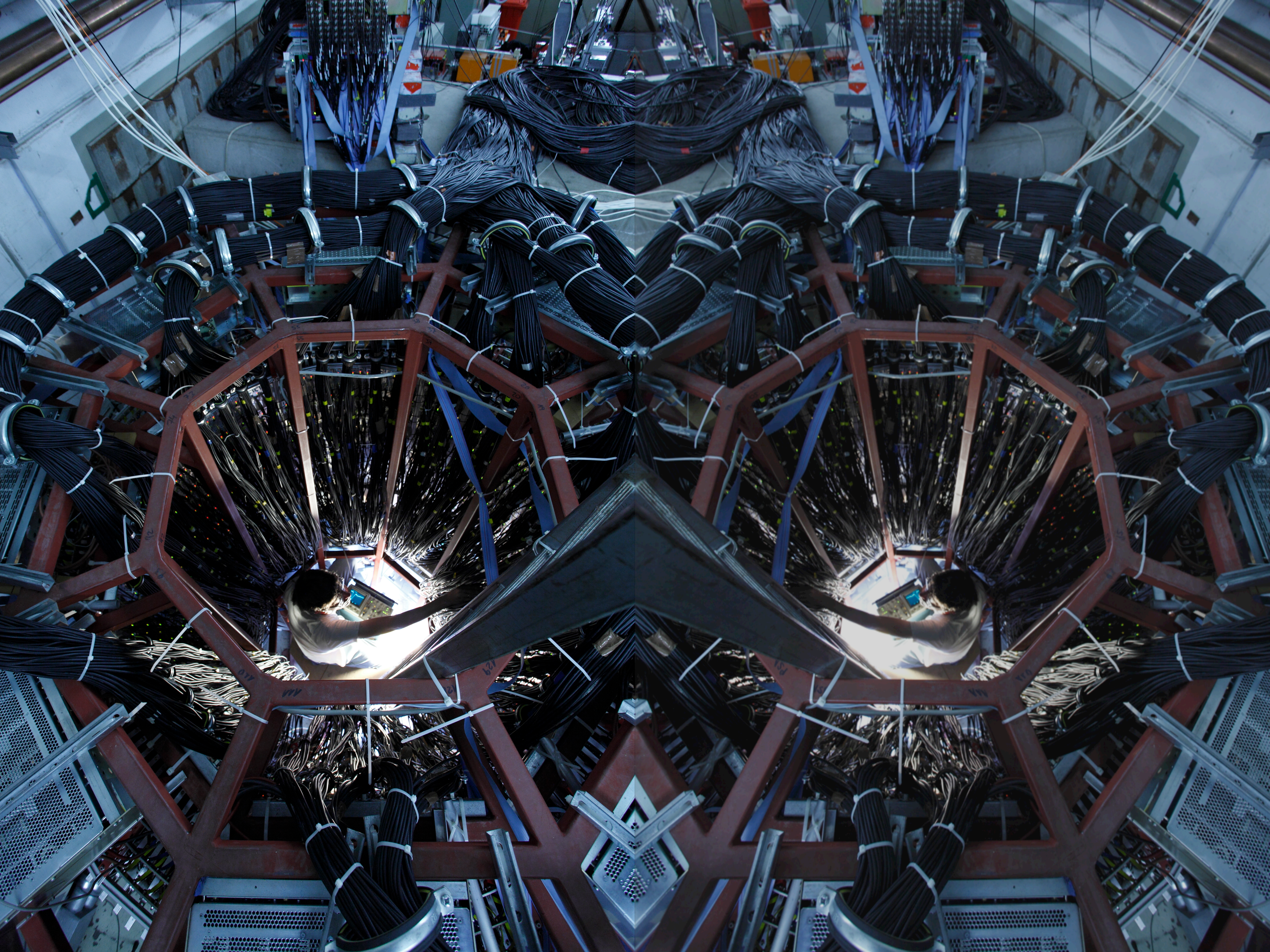


Measure Flux of Scattered electrons:
- no pile-up (double count losses)
- sensitive to small electr. fields.
- no separation of phys. process

“False” Asymmetries



$$A_{exp} = A_{PV} + A_f^{\theta}$$



Fluctuation of Beam Parameters (Past)

Parameter	1% Modification von A_{exp}
Current I_e	$6.2 \cdot 10^{-8}$
Energy E_e	32.0 eV
Position x	18.0 nm to 38.0 nm
Position y	18.0 nm to 38.0 nm
Angle x'	15.8 nrad to 35.5 nrad
Angle y'	15.8 nrad to 35.5 nrad

Parity-Violating Asymmetry in Electron-Proton Scattering

weak charge

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

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

hadron structure

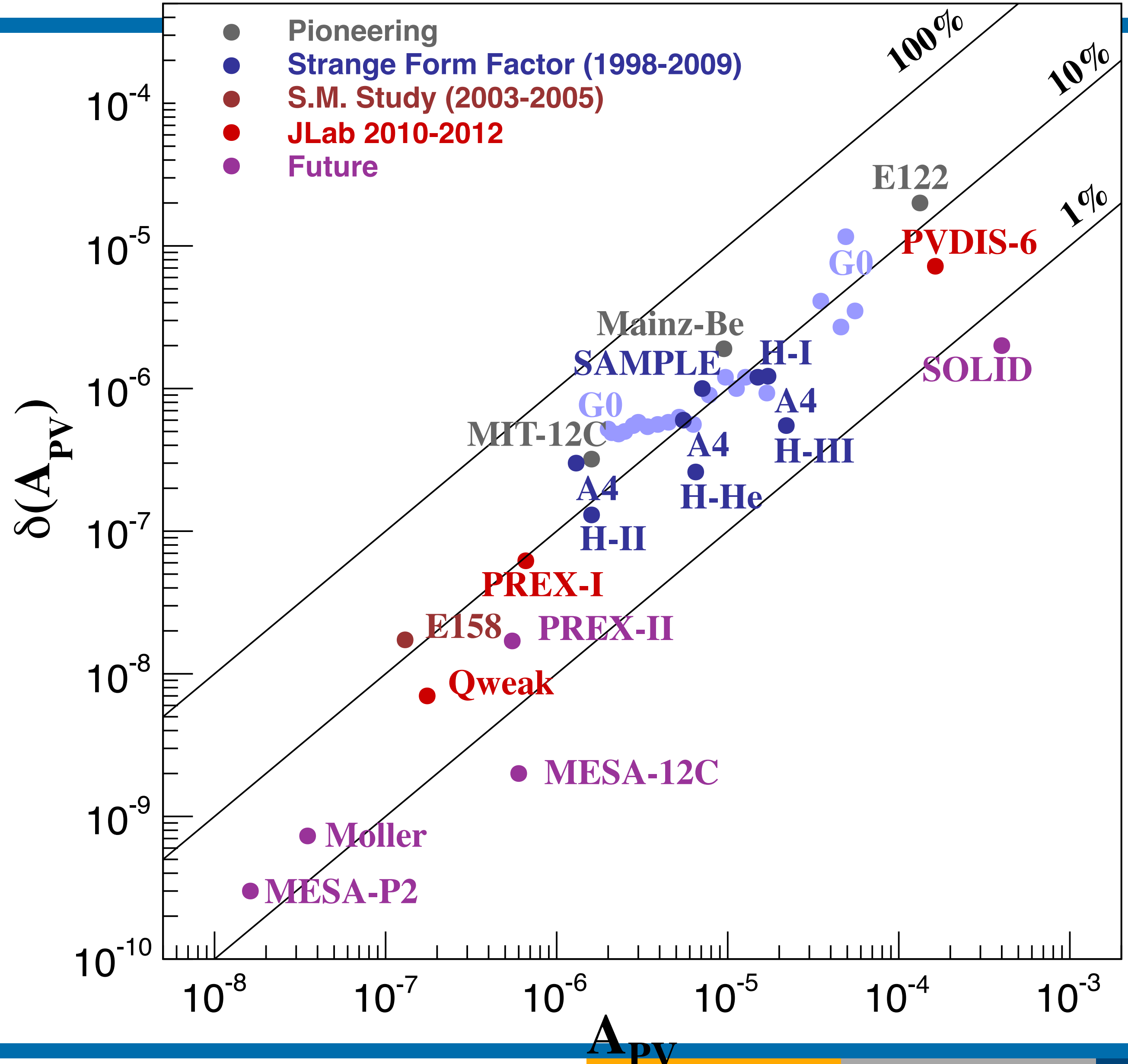
$$F(Q^2) = F_{EM}(Q^2) + F_{Axial}(Q^2) + F_{Strange}(Q^2)$$

Experimental Parameters

E_{Beam}	200 MeV
Q^2/θ_e	0.0048 GeV^2/20°
Time/current/target	10000h/150μA/60cm
A_{phys}	-20.25 ppb
ΔA_{tot}	0.34 ppb (1.7 %)
ΔA_{stat}	0.25 ppb
ΔA_{sys}	0.19 ppb (0.9%)
Polarization	(85 ± 0.5) %
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 %)

High rates: 440 GHz, polarization precision: 0.5 %

PVeS Experiment Summary



Method: Parity-Violating Electron-Proton Scattering

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

$Q_{Weak} = 0.075$

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

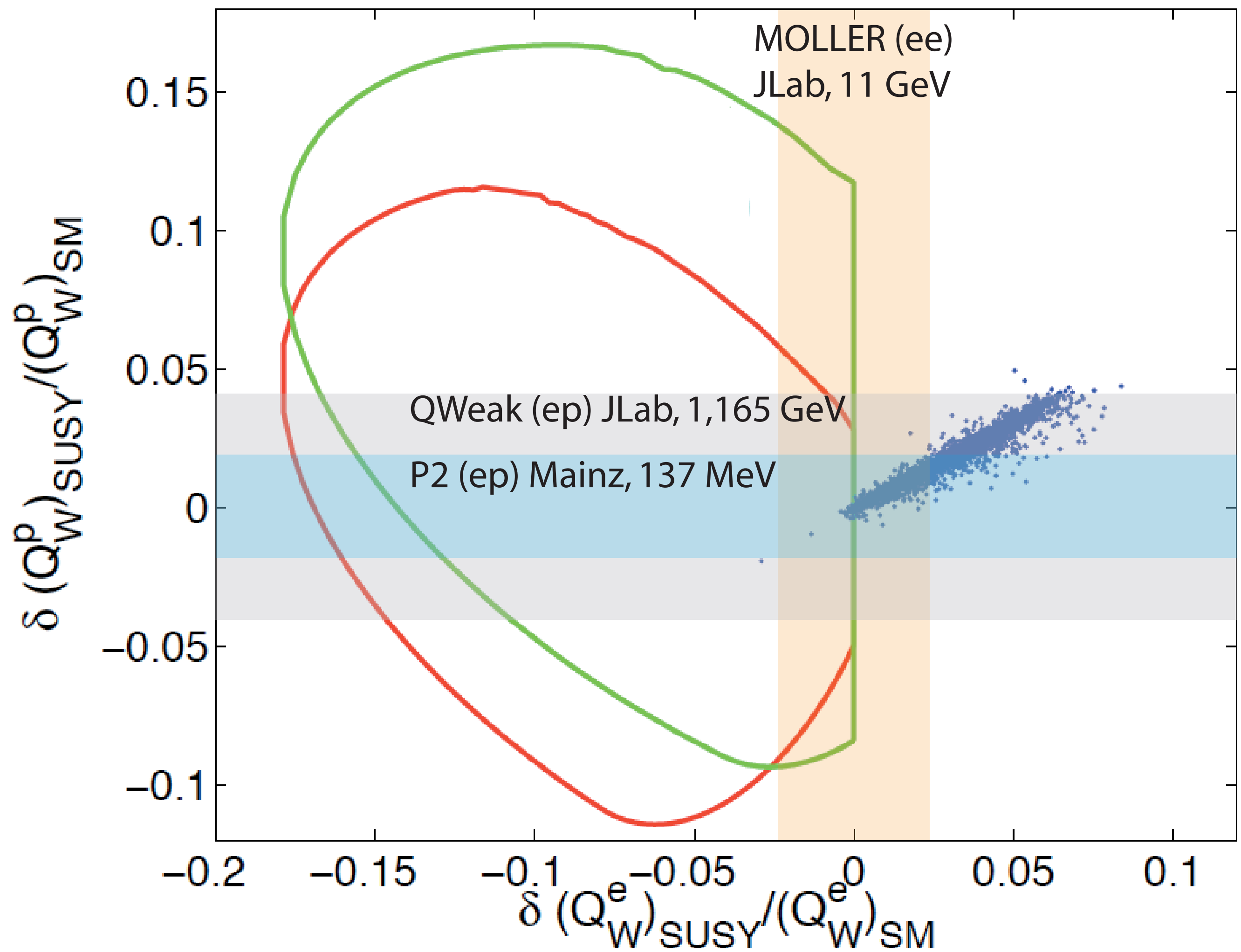
$Q_{Weak} = 0.0718$ (4% modification)

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

$\sin^2 \theta_W = 0.2311$

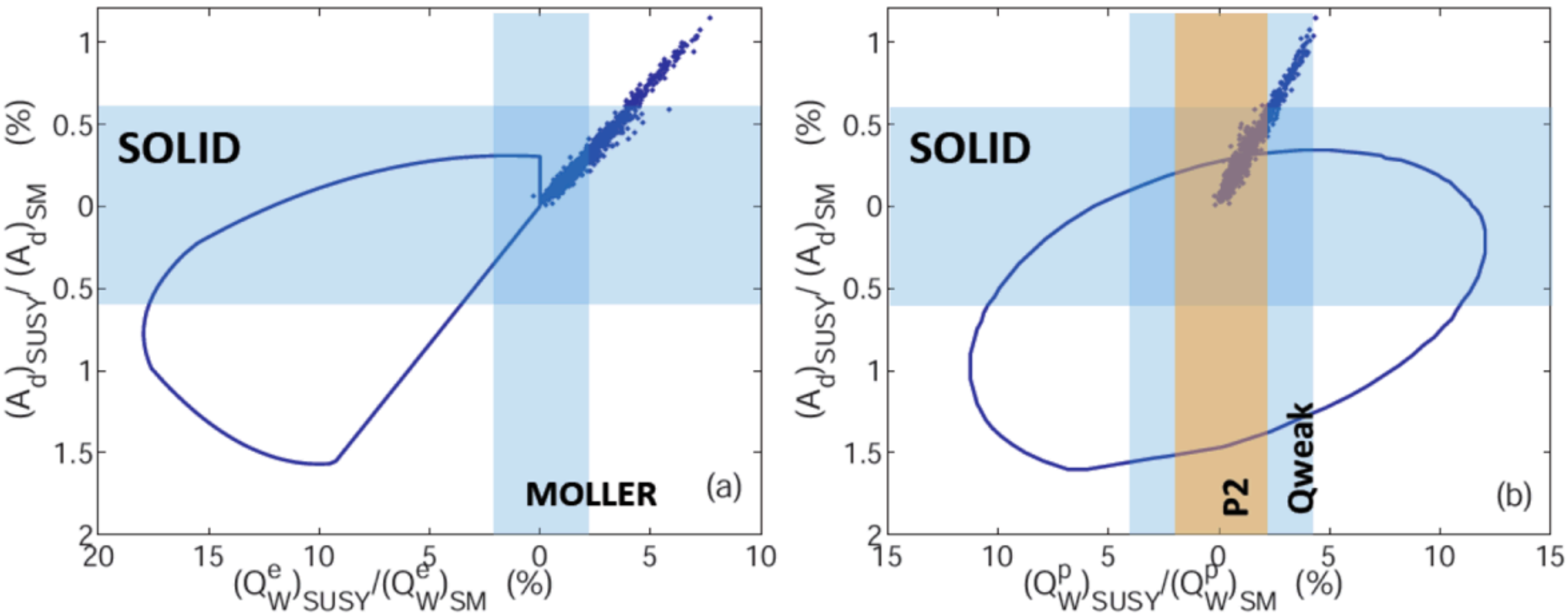
Sensitivity to new Physics

Example: supersymmetric Standard Model extensions

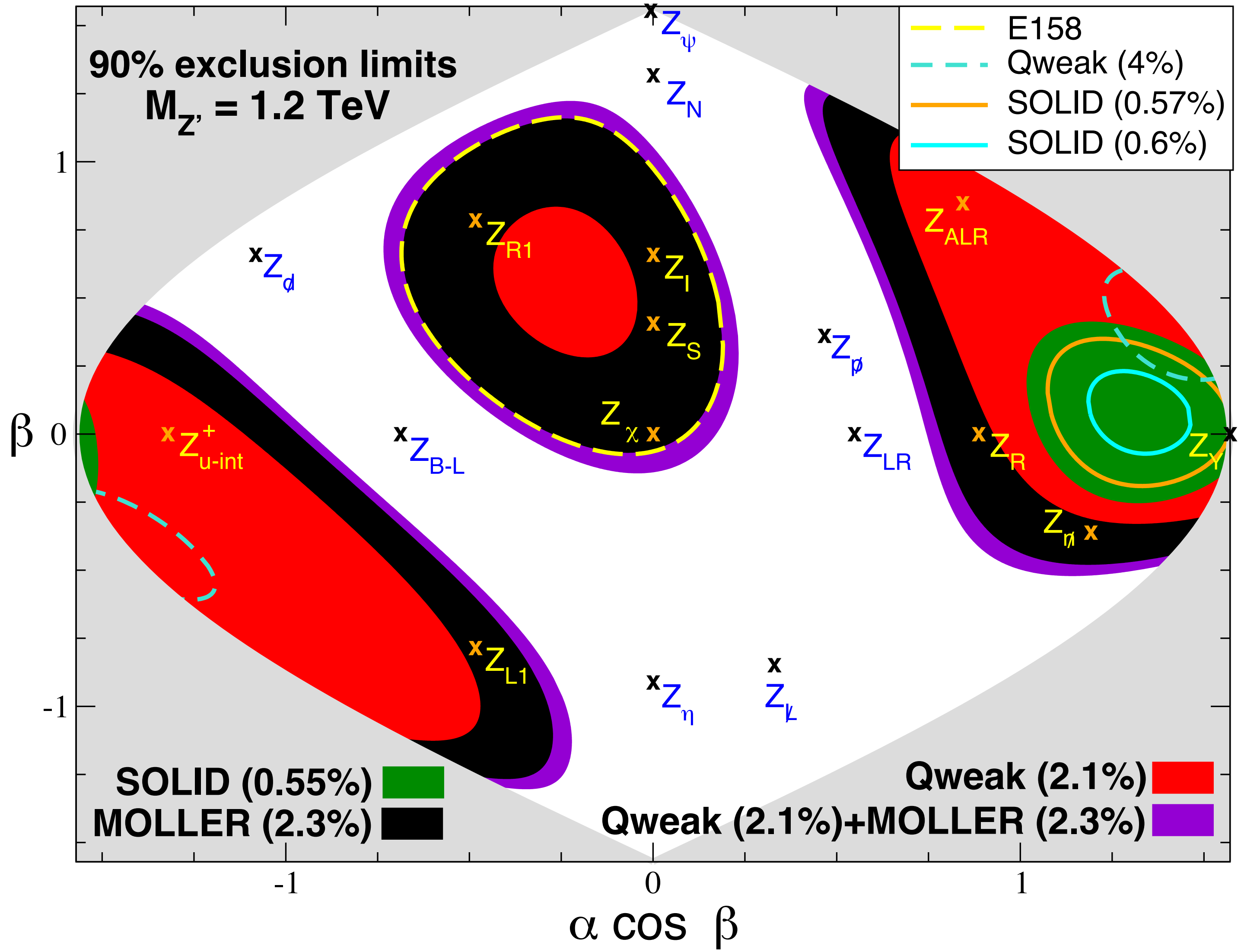


Sensitivity to new Physics

Ramsey-Musolf and Su, ***Phys. Rep. 456 (2008)***

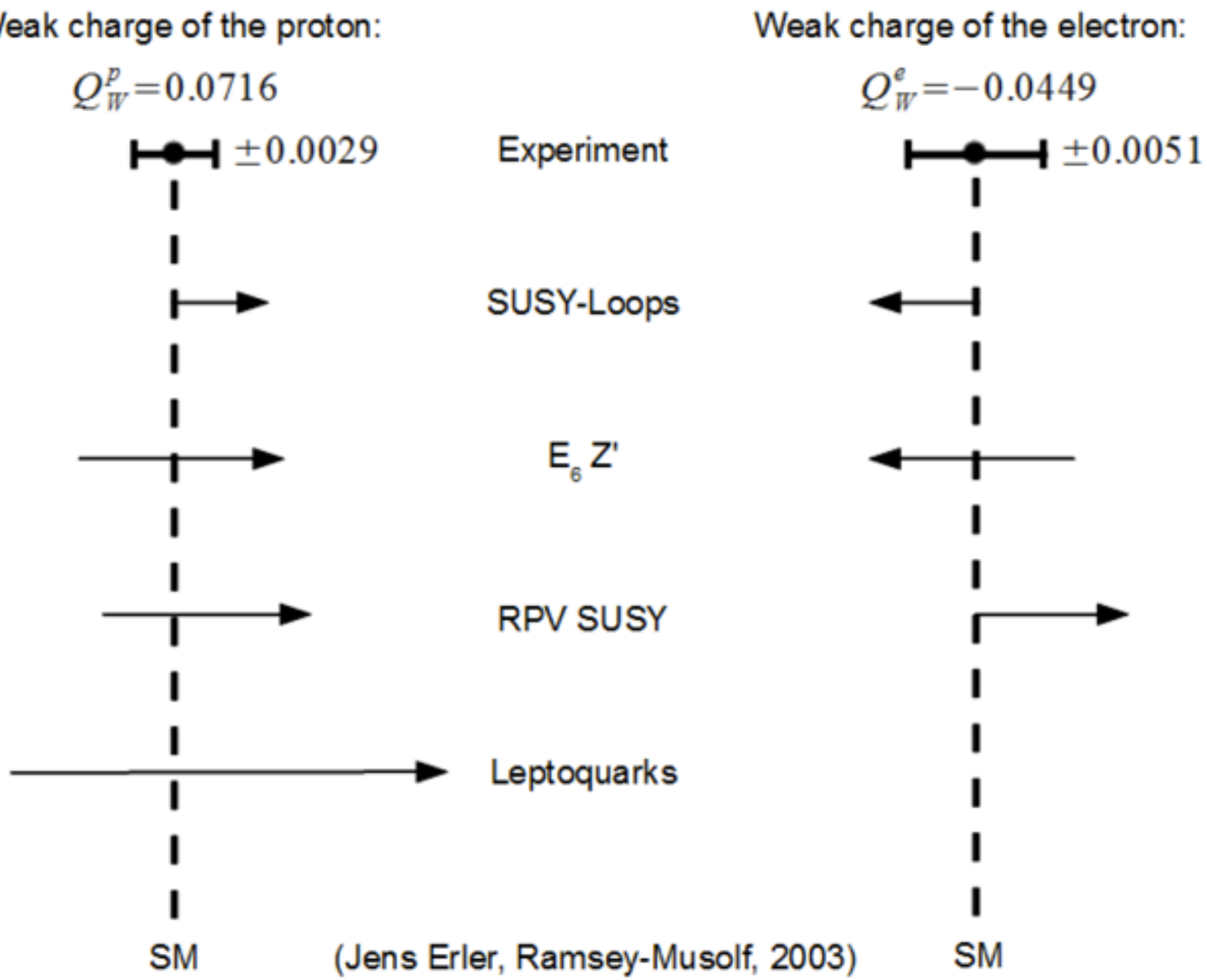


Sensitivity to new Physics



Sensitivity to new Physics

- Complementary access by weak charges of proton and electron



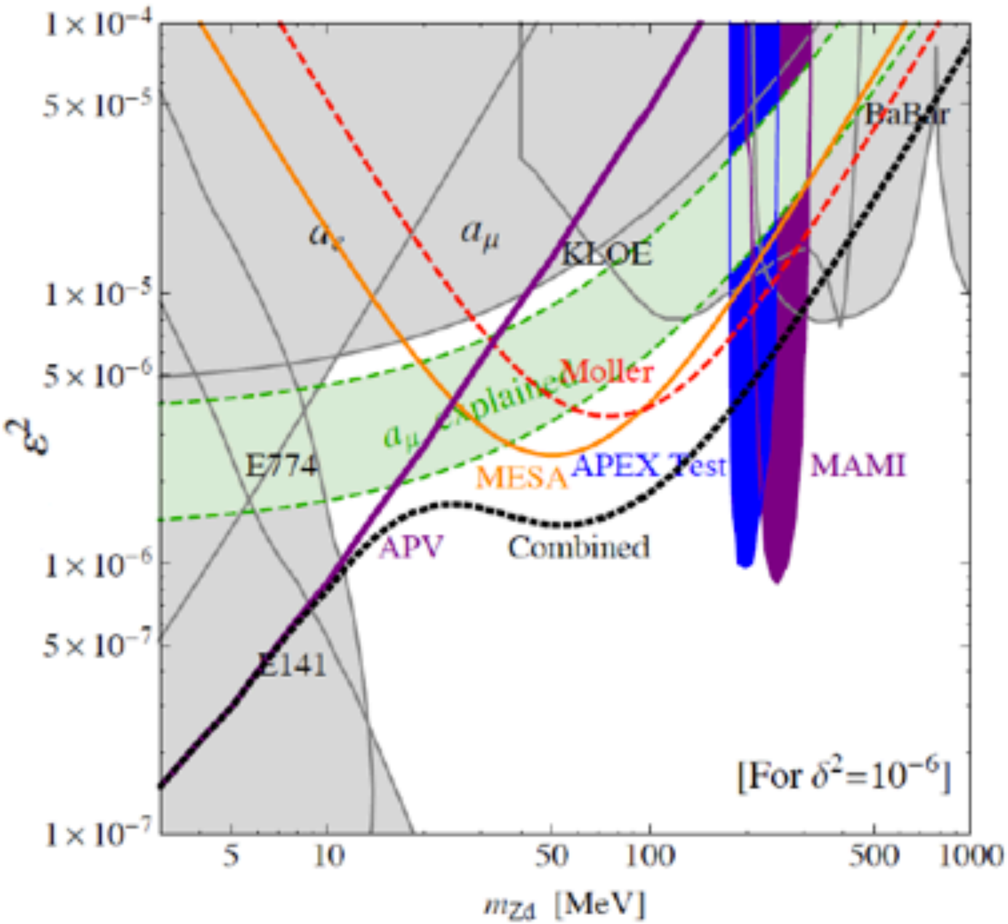
(Jens Erler, Ramsey-Musolf, 2003)

Sensitivity to new Physics

Davoudiasl, Lee, Marciano:
Phys.Rev. D85 (2012) 115019

Possible mass mixing between dark photon and dark Z:

$$\epsilon_Z = \frac{m_{Z_d}}{M_Z}\delta$$



Complementary to direct heavy photon searches:
Lifetime/branching ratio
Model dependence
vs. mass mixing assumption

Sensitivity to new Physics

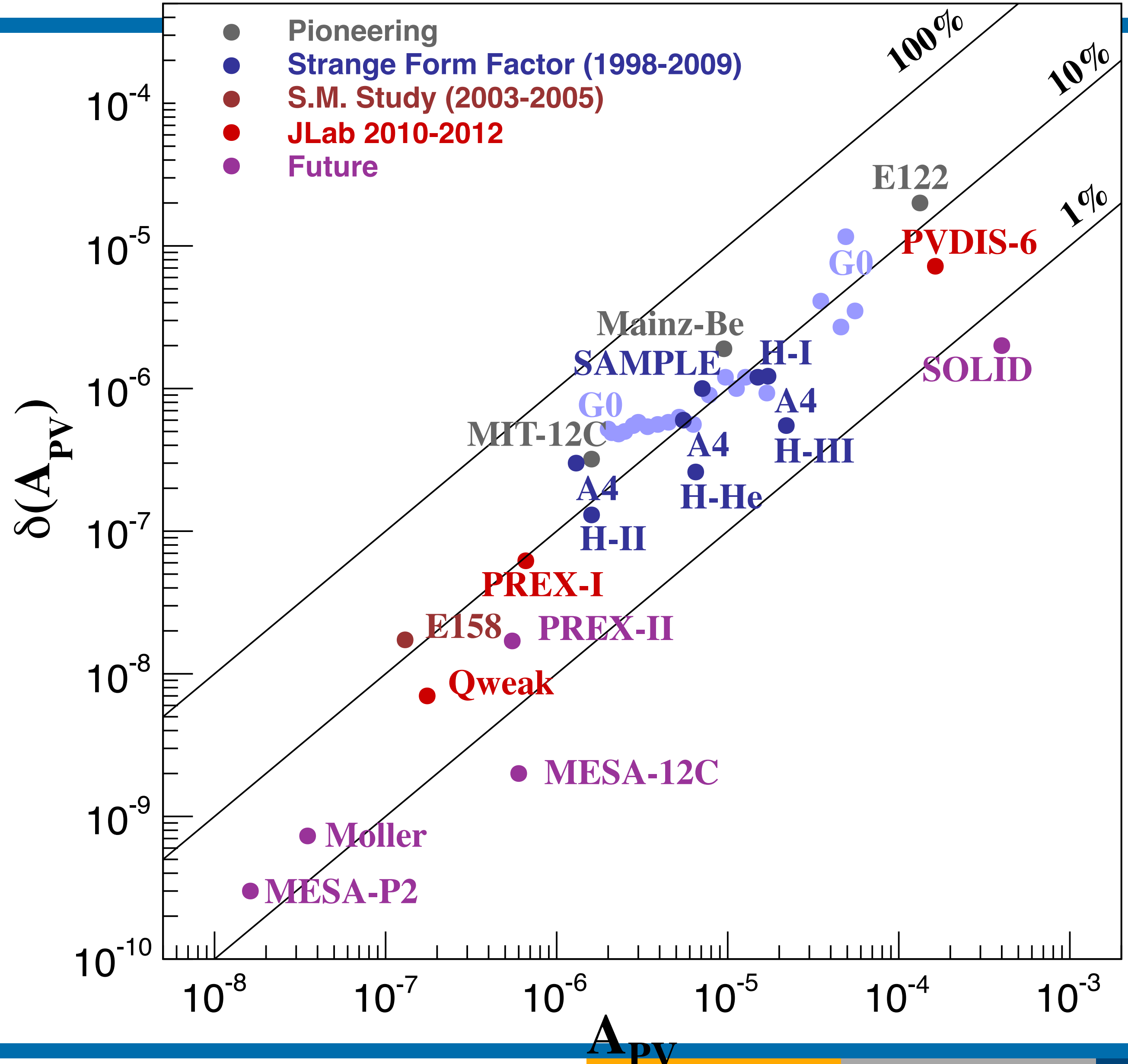
$\Lambda_{new} \simeq [\sqrt{2}\, G_F\, \Delta Q_W]^{-1/2} = 246.22\ \text{GeV}/\sqrt{\Delta QW}$

$\Lambda_{new} \simeq$ 3.4 TeV (E158@SLAC, published)
$\Lambda_{new} \simeq$ 4.6 TeV (Qweak@JLab, finished, under analysis)
$\Lambda_{new} \simeq$ 2.5 TeV (SOLID@JLab, planned)
$\Lambda_{new} \simeq$ 7.5 TeV (MOLLER@JLab, planned)

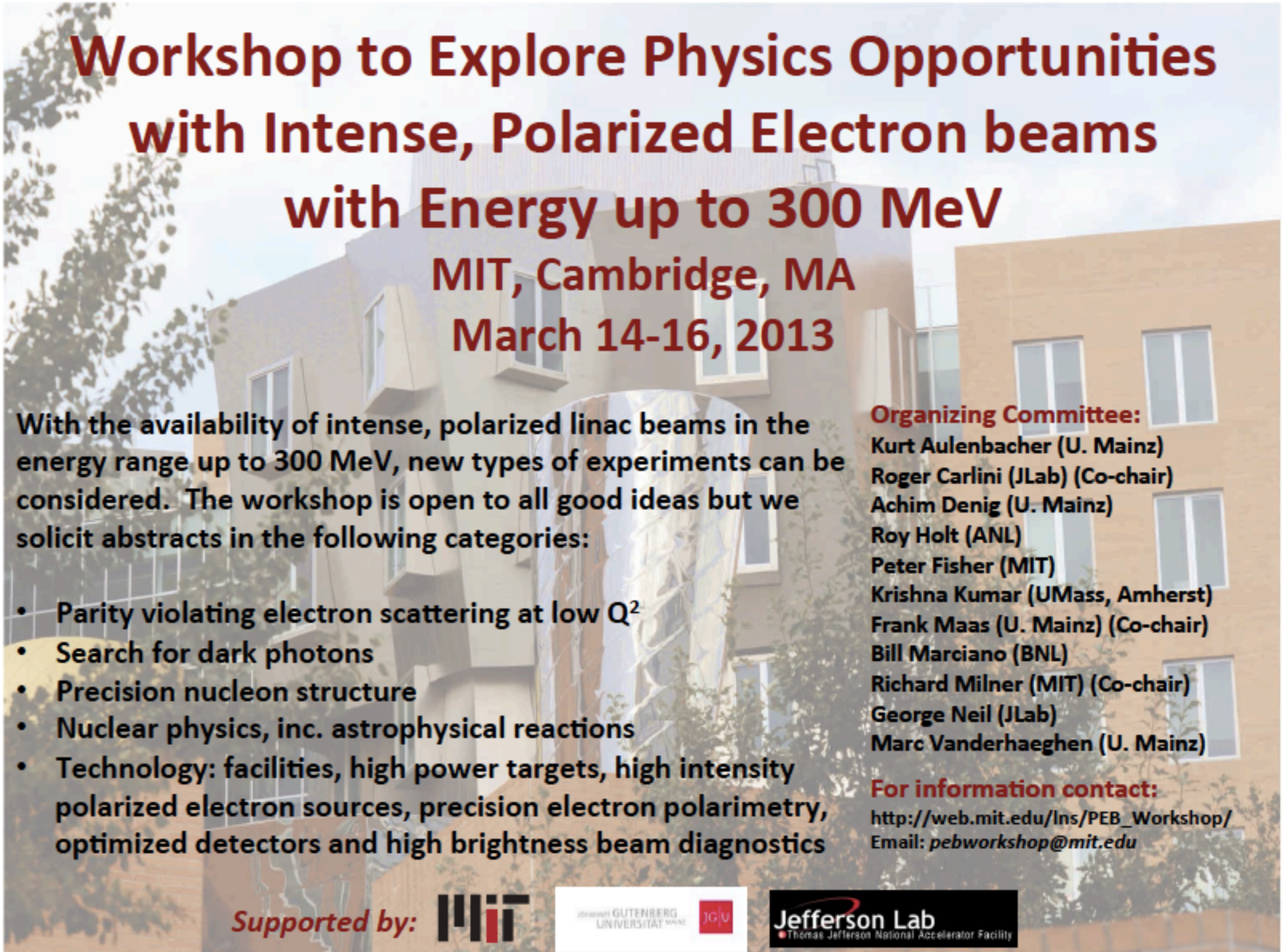
$\Lambda_{new} \simeq$ 6.4 TeV (P2@MESA, planned)

Method: Parity-Violating Electron-Proton Scattering

PVeS Experiment Summary



MESA as low energy electron accelerator facility



Summary: Perspectives are Excellent

Location	Institutes	Facilities	Physics	Group-Applications
Mainz	IKP (University)	MAMI MESA (new)	Nucleon/Meson Structure and Spectroscopy	CRC1044 (new) PRISMA (new)
Mainz	HIM (new) IKP (University)	FAIR-accelerator (new) GSI-accelerator MESA (new)	Hadron Physics Particle Physics	PRISMA (new)
Darmstadt	GSI (National Lab.)	FAIR-accelerator (new)	Nuclear Physics Atomic Physics Hadron Physics	
Bonn	HISKP IP (University)	ELSA	Nucleon/Meson Spectroscopy	

Summary: Perspectives are Excellent

Mainz has evolved to one of the main physics centers in hadron and particle physics in Germany

"Low energy frontier" comprises a sensitive test of the standard model complementary to LHC

MAMI and MESA: Key facilities for low energy precision hadron and particle physics

Could only show a small collection of the full program