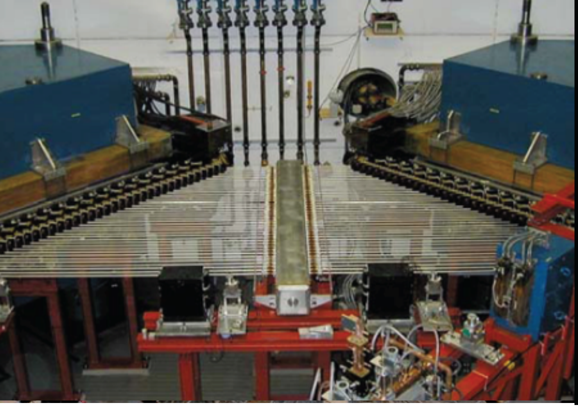
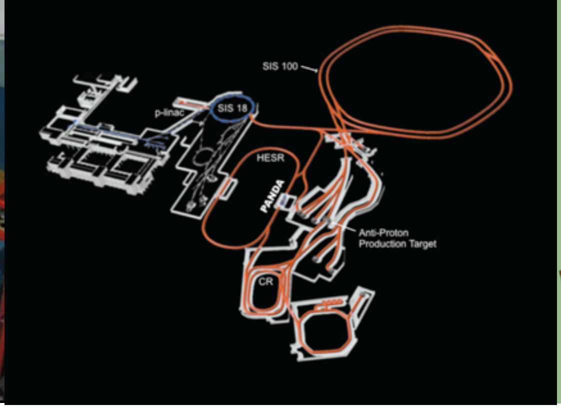
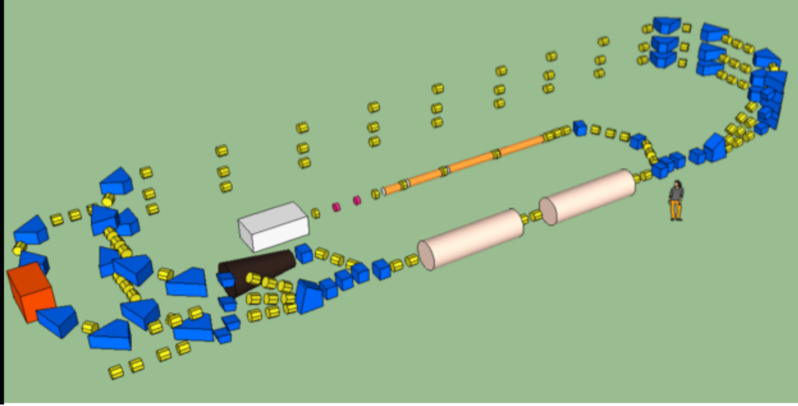






Low-energy precision physics

DIASTP HISS 2013
Dubna International Advanced School of Theoretical Physics
Helmholtz International Summer School:
Lattice QCD, Hadron Structure and Hadronic Matter

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

I:The Electromagnetic Form Factor (EM FF) of the Proton

- time like form factors (PANDA@FAIR, BESIII)
- transition distribution amplitudes (PANDA@FAIR)
- proton radius (MAMI, MESA)

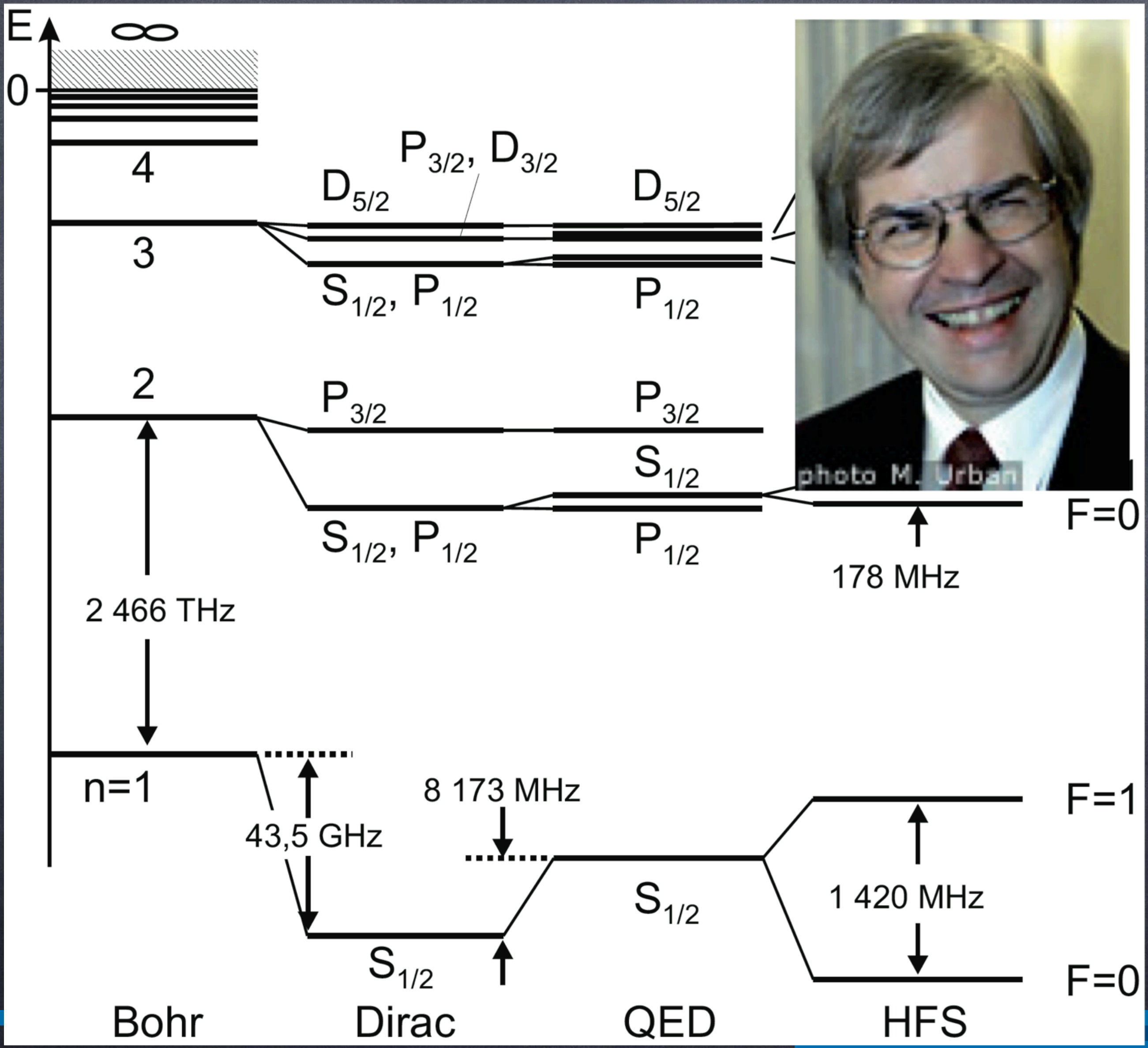
II: (Search for a Dark Photon at MESA)

Parity Violating Electron Scattering

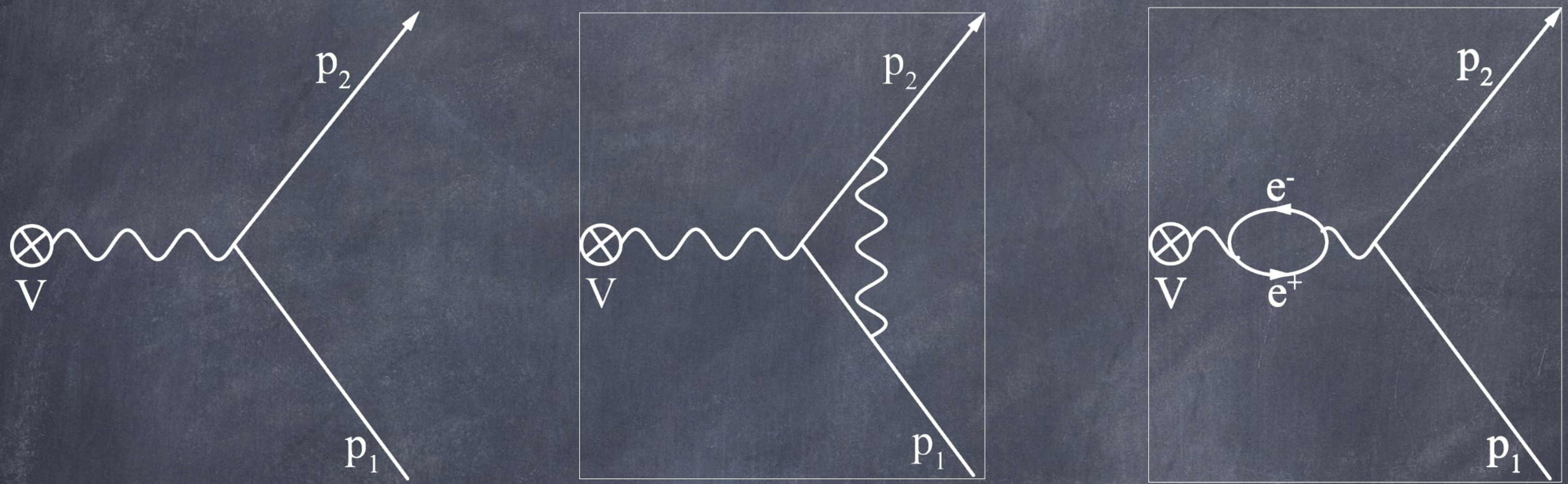
- Strangeness contribution to EM FF (MAMI)
- Precision measurement of the weak mixing angle (MESA)

Time-like Proton Form Factor

Hydrogen Atom, Electron (g-2)-factor, QED



Hydrogen Atom, Electron (g-2)-factor, QED

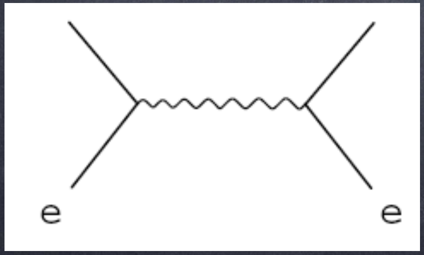


$$g_e = 2\,(\,1 + \alpha/2\pi - 0.328\,\alpha^2/\pi^2 + \ldots)$$

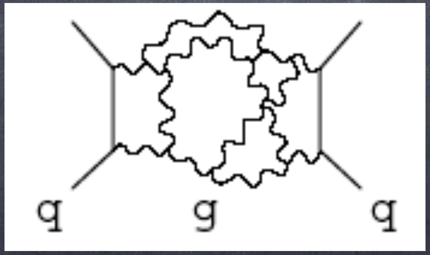
How do Hadrons arise from QCD?

- Fundamental differences relative to QED
  - Self-interacting: highly nonlinear
  - Interaction increases at large distance: Confinement
  - Interaction decreases at small distance: Asymptotic freedom

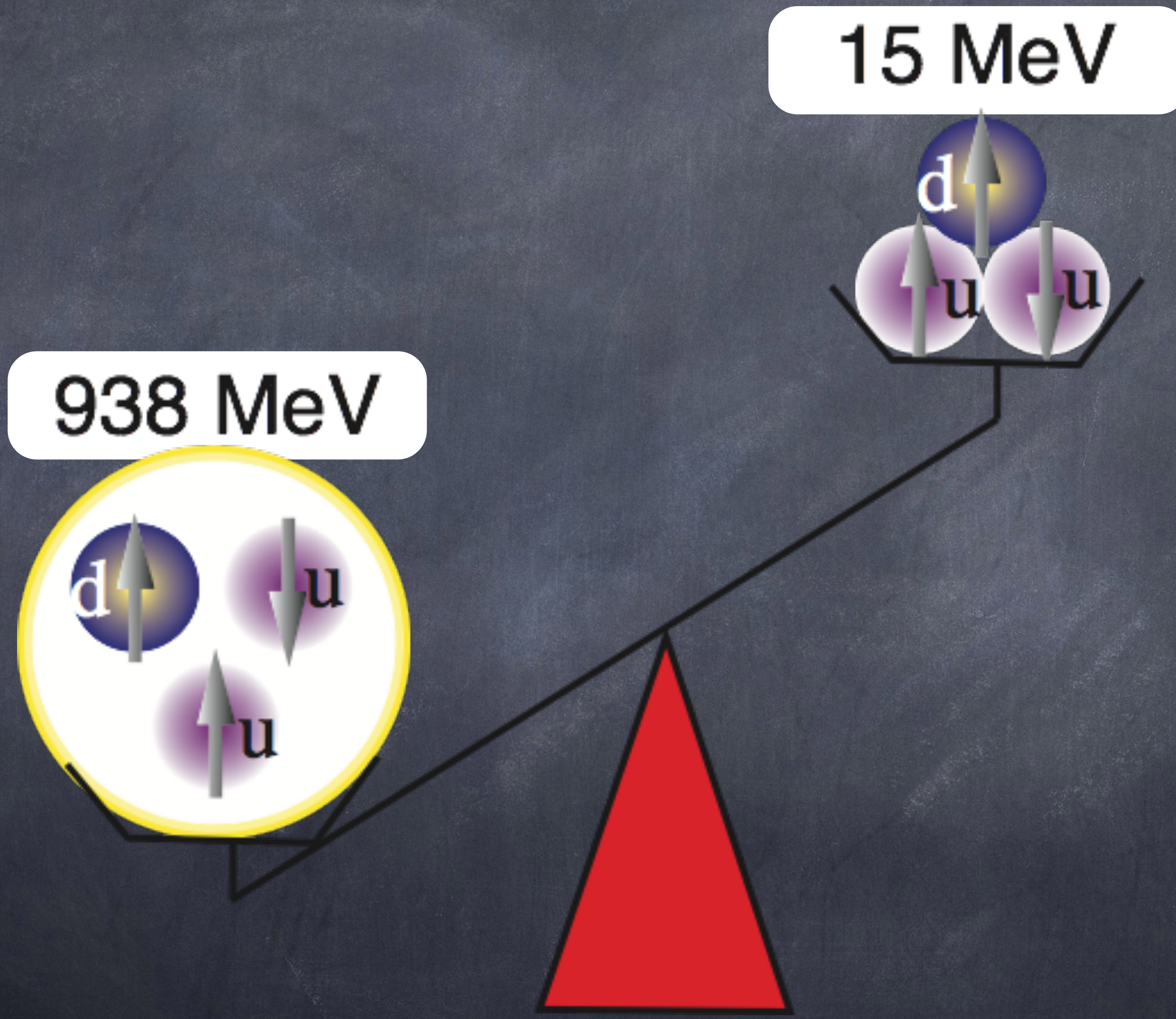
QED



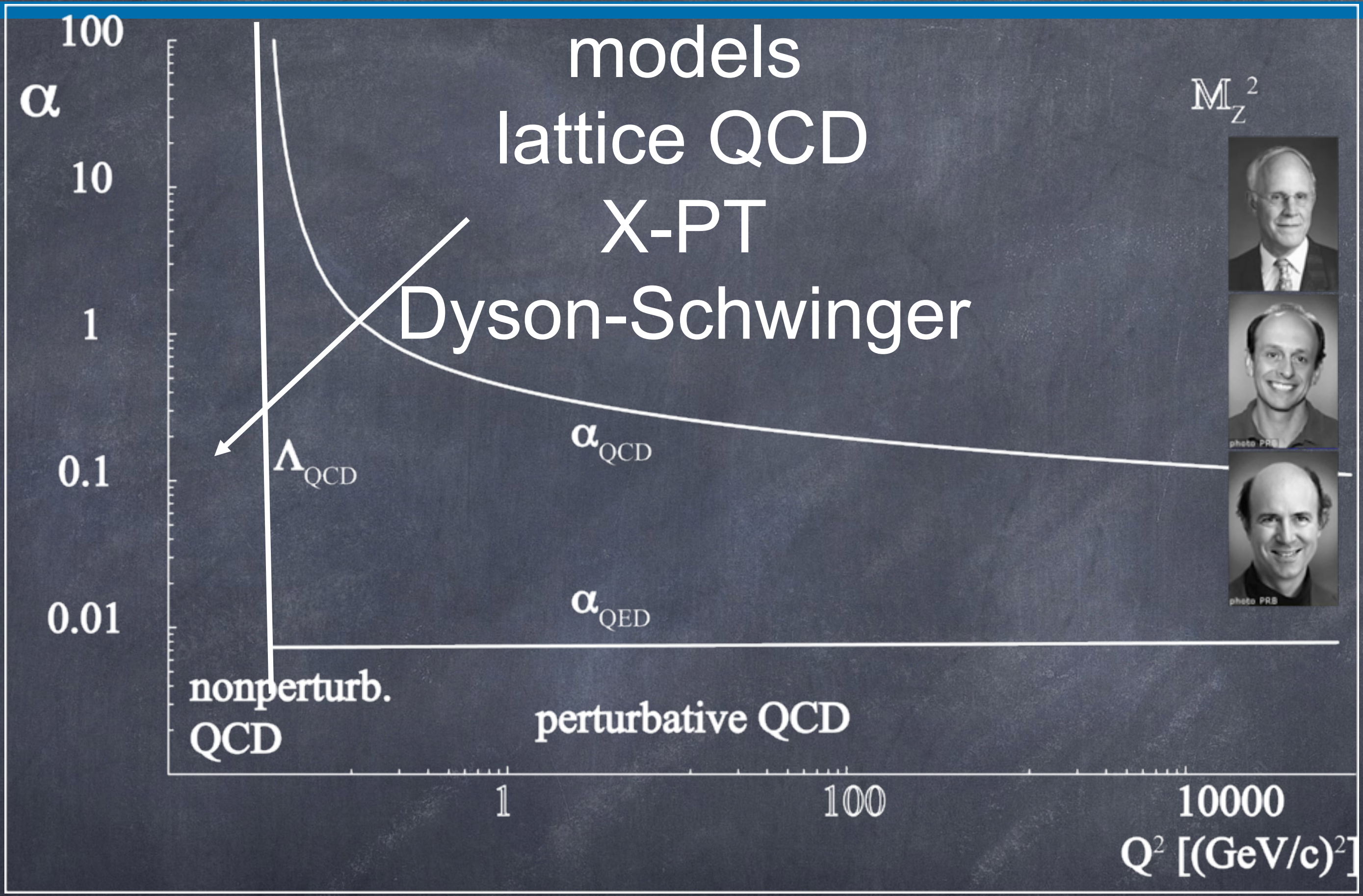
QCD



How do Hadrons arise from QCD?

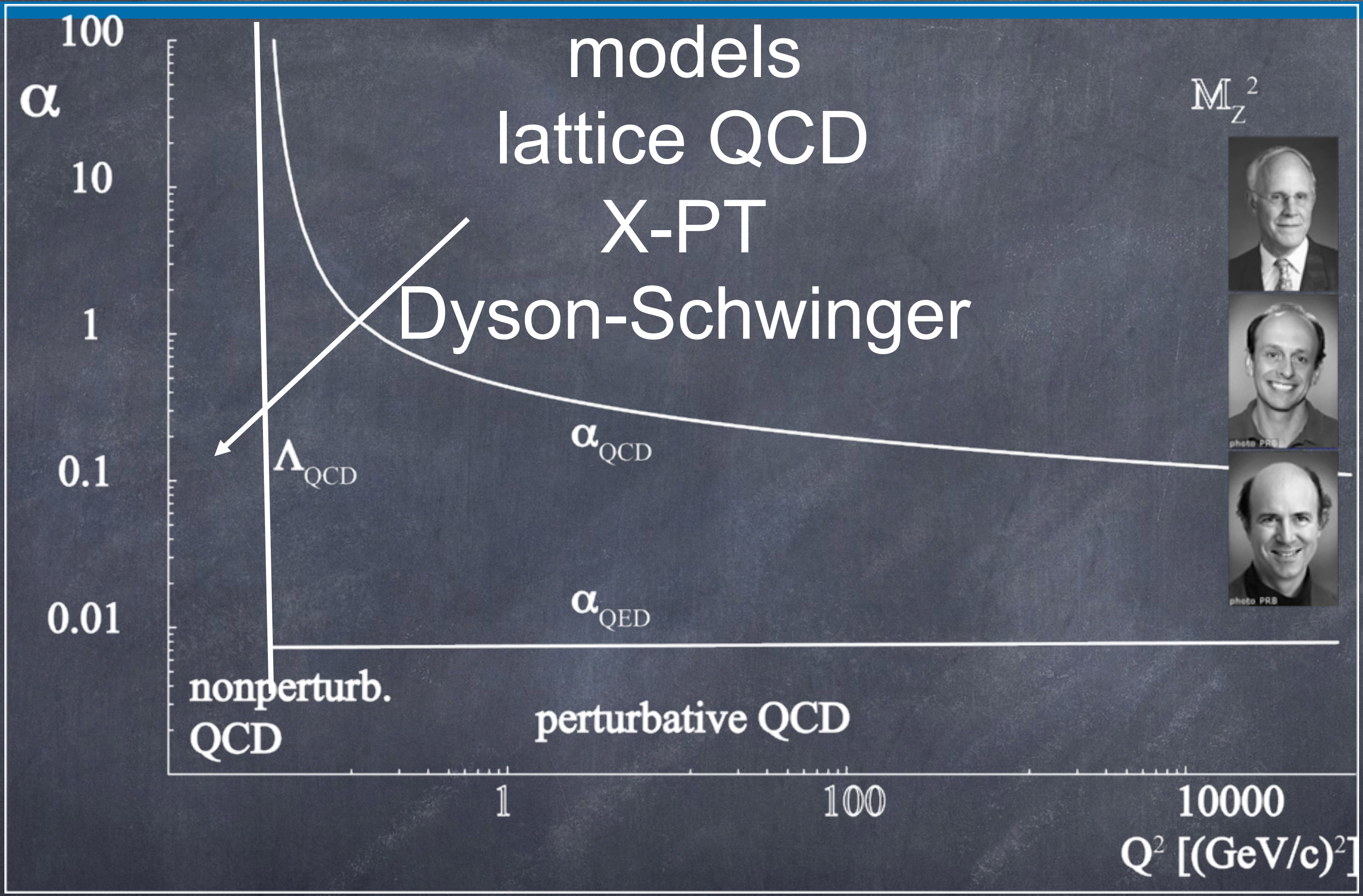


QCD-Renormalisation à la QED



- origin of nucleon mass
- quark and gluon condensates
- structure of the nucleon -> Form Factor

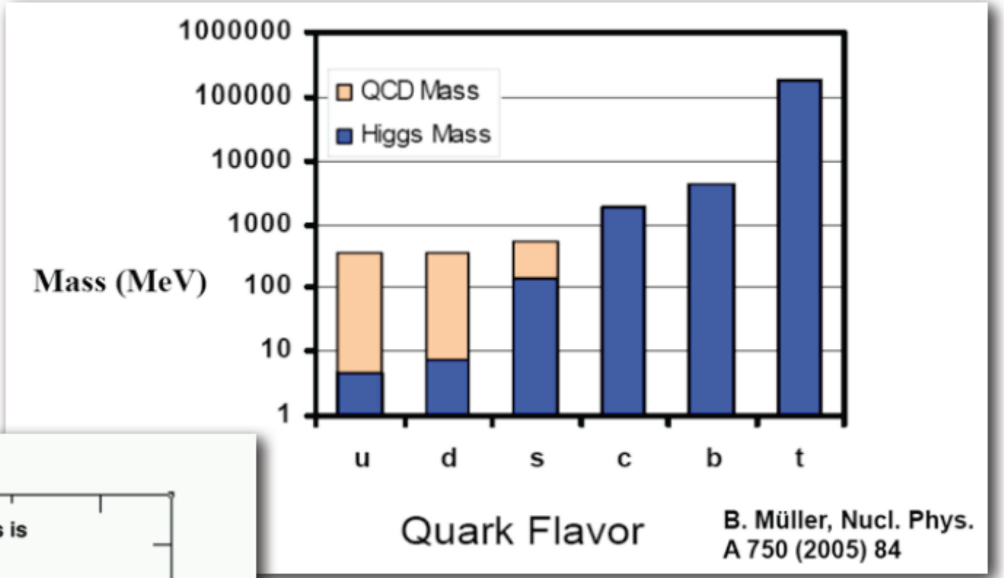
QCD-Renormalisation à la QED

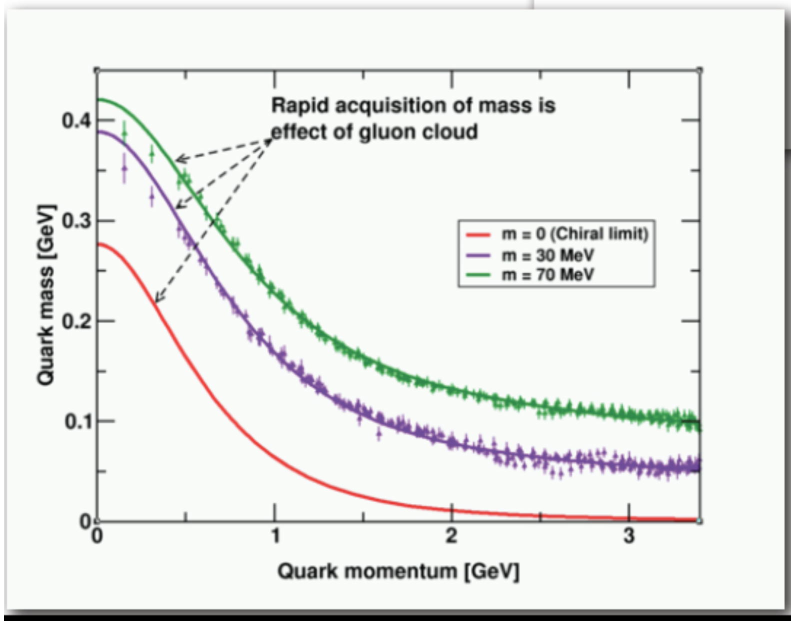


$m_u, m_d << m_s \approx \Lambda_{QCD} << m_c, m_b, m_t$

Strangeness as a Laboratory for Virtual Quarks

Visible Baryonic Mass Dominated by QCD





R. Hofstadter (1956), Proton Electromagnetic Form Factor

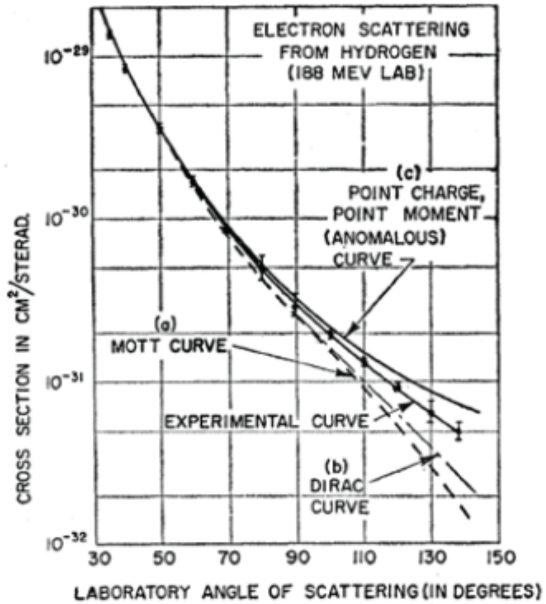


FIG. 24. Electron scattering from the proton at an incident energy of 188 Mev. The experimental points lie below the point-charge point-moment curve of Rosenbluth, indicating finite size effects.

Still today a hot topic of hadron physics. Electromagnetic form factors a testing ground for our understanding of QCD

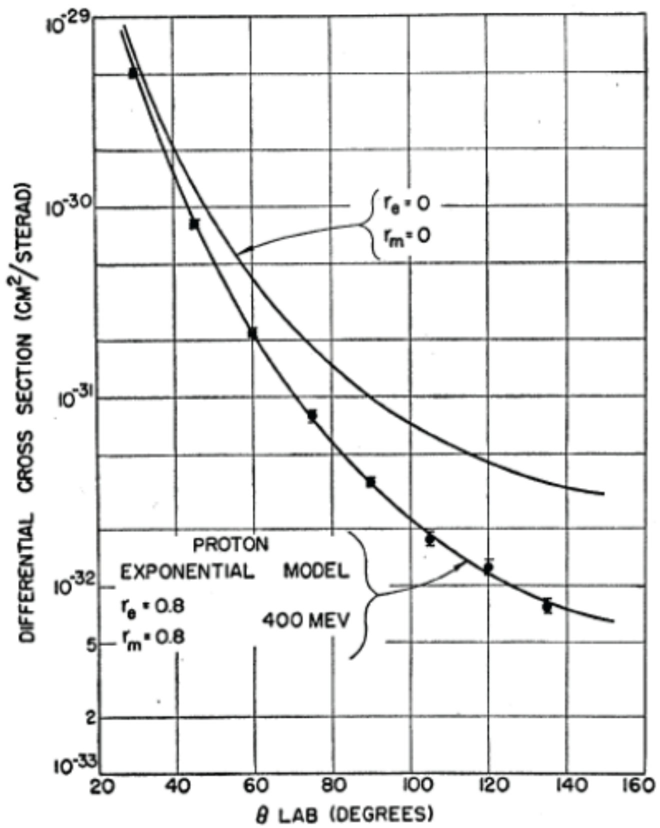
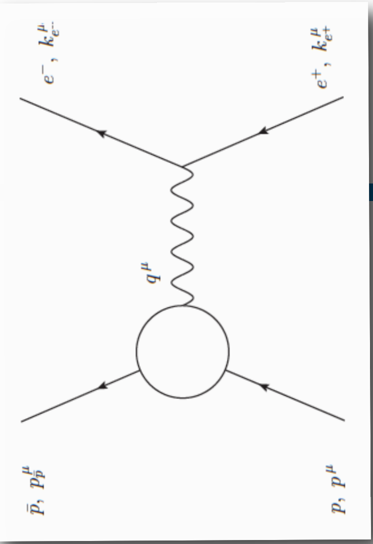


FIG. 26. Typical angular distribution for elastic scattering of 400-Mev electrons against protons. The solid line is a theoretical curve for a proton of finite extent. The model providing the theoretical curve is an exponential with rms radii $= 0.80 \times 10^{-13}$ cm.

R. Hofstadter, Rev. Mod. Phys. , 28 (1956), 243

Electromagnetic Form Factor (QED)



vector current of quarks

$$< \bar{N}(p')|q_u\bar{u}\gamma_\mu u + q_d\bar{d}\gamma_\mu d + \ldots |N(p) >$$

matrix element

$$\frac{e^2}{q^2} \; \bar{u}(k_2)\gamma_\mu u(k_1) \;\; \bar{u}(p_2)[F_1(q^2)\gamma_m u + i\kappa\frac{\sigma_{\mu\nu}q^\nu}{2m_p}F_2(q^2)]u(p_1)$$

Dirac

$G_E = F_1 + F_2$

$G_M = F_1 + \tau\, F_2$

Pauli

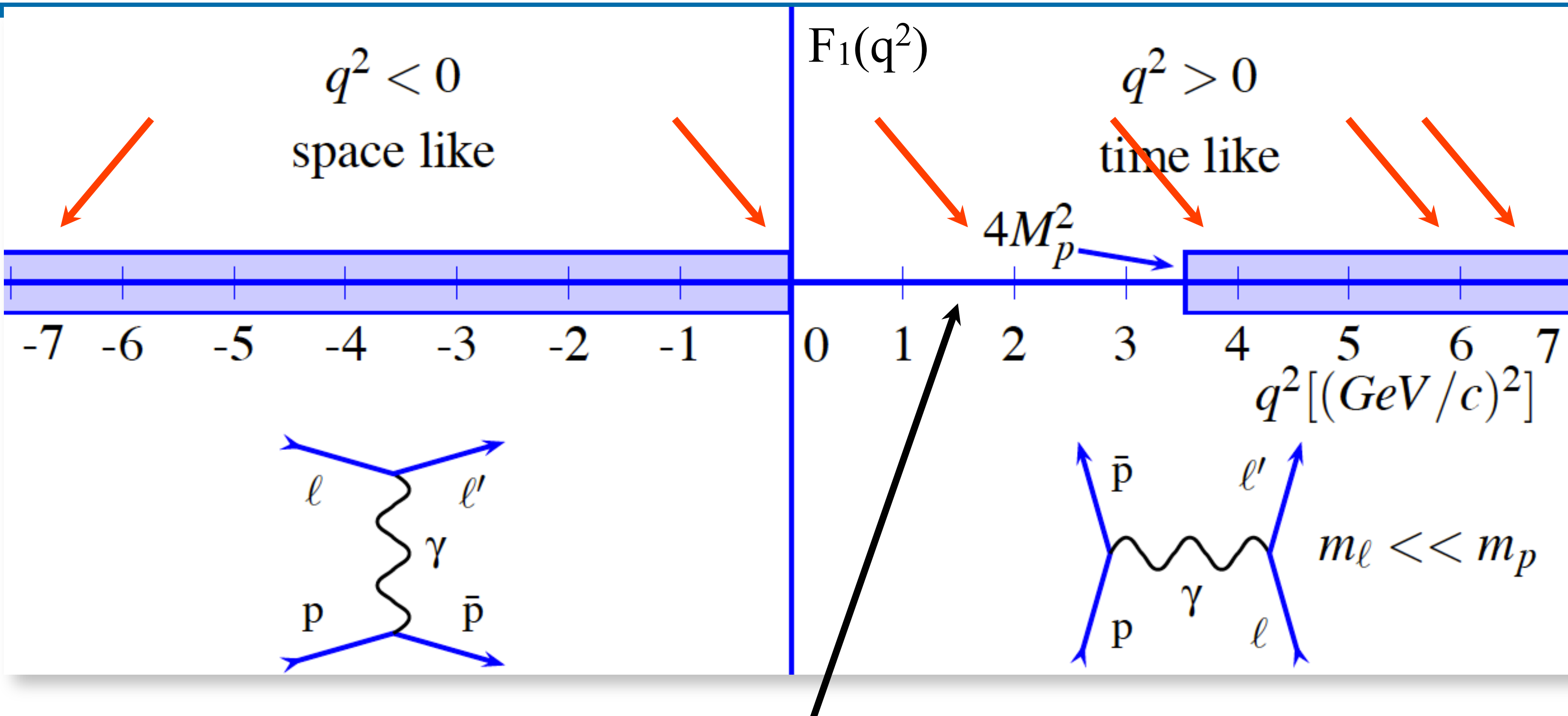
all hadronic structure and strong interaction in form factors, but subject to electromagnetic (QED) radiative corrections

hadronic vector current: two form factors (2 s + 1)

internal structure of hadron ground state

Dirac	Pauli
$F_1^p(q^2=0) = 1$	$F_2^p(q^2=0) = 1$
$F_1^n(q^2=0) = 0$	$F_2^n(q^2=0) = 1$

Electromagnetic Form factors of the Nucleon



Form Factor real

cross section (Rosenbluth)
no single spin observables
double spin observables

Form Factor complex

cross section (angular Distr.)
single spin observables (P_y)
double spin observables

connected by dispersion relations

Timelike Form Factors

QCD counting rules constrain asymptotic behavior

$$\begin{aligned} q^2 &\rightarrow -\infty \\ F_i(q^2) &\rightarrow (-q^2)^{-(i+1)} \\ i = 1 \ \text{Dirac FF} & \qquad i = 2 \ \text{Pauli FF} \\ G_{E,M} &\rightarrow (-q^2)^{-2} \end{aligned}$$

Analyticity

$$\begin{aligned} q^2 &\rightarrow \pm\infty \ \text{Phragmen Lindeloef} \\ G_{E,M}(-\infty) &= G_{E,M}(+\infty) \end{aligned}$$

(imaginary part must vanish for large q^2)

Observables

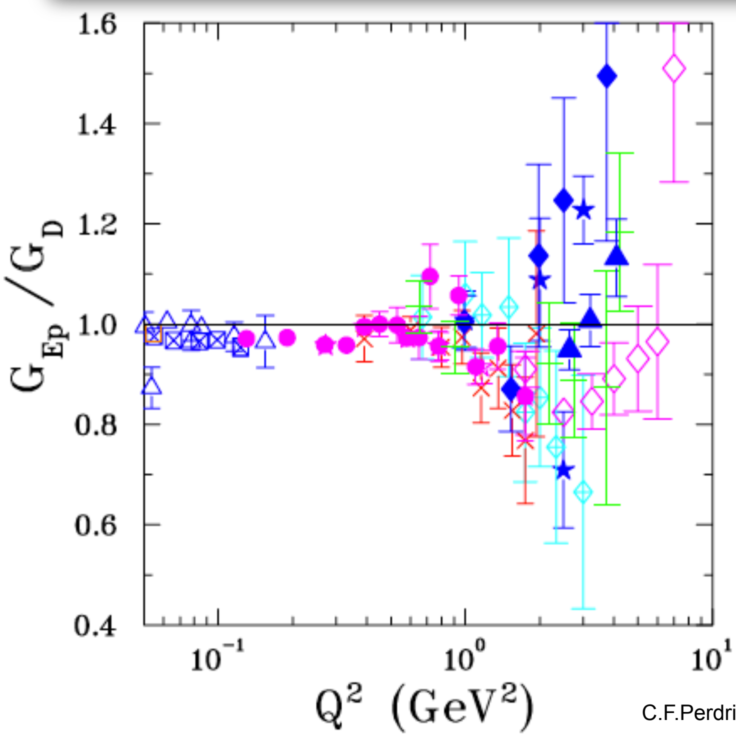
Cross Section (scattering) (Rosenbluth Separation)

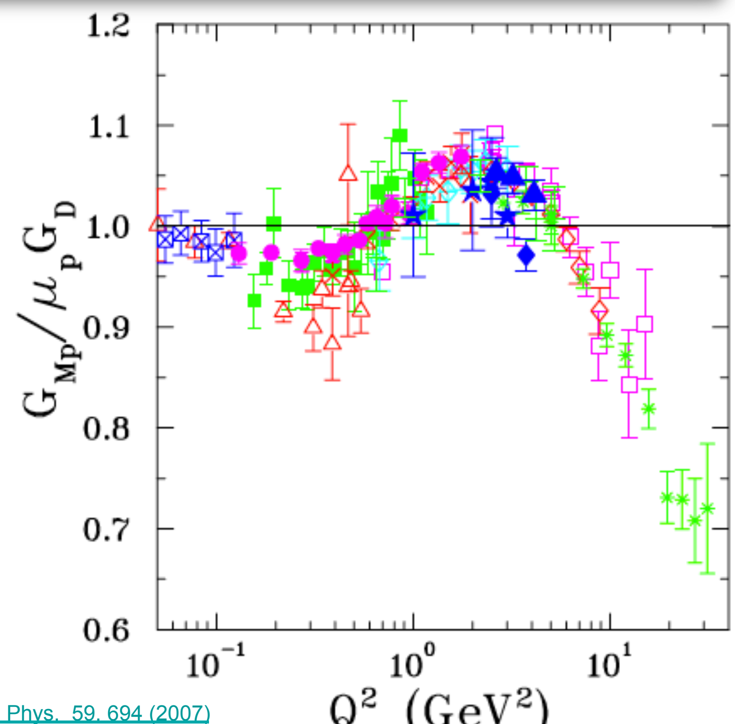
$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \times \left(G_E^2 + \tau \left[1 + 2(1+\tau)\tan^2\frac{\theta_e}{2}\right] G_M^2\right) / (1+\tau)$$

$$\tau = Q^2/4M^2$$

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

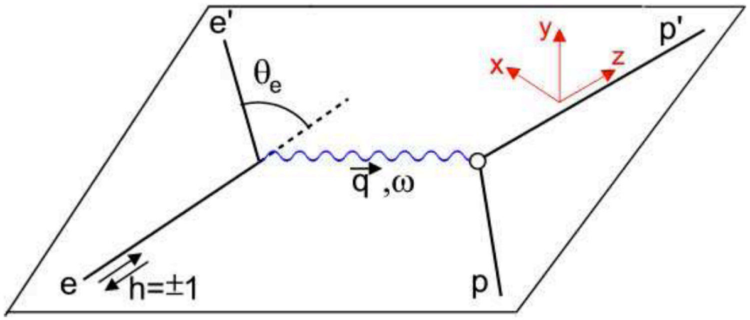
$$\left(\frac{d\sigma}{d\Omega}\right)_{reduced} = \frac{\epsilon(1+\tau)}{\tau} \left(\frac{d\sigma}{d\Omega}\right)_{exp} / \left(\frac{d\sigma}{d\Omega}\right)_{Mott} = G_M^2 + \frac{\epsilon}{\tau} G_E^2$$





C.F.Perdrisat et al., Prog. Part. Nucl. Phys. 59, 694 (2007)

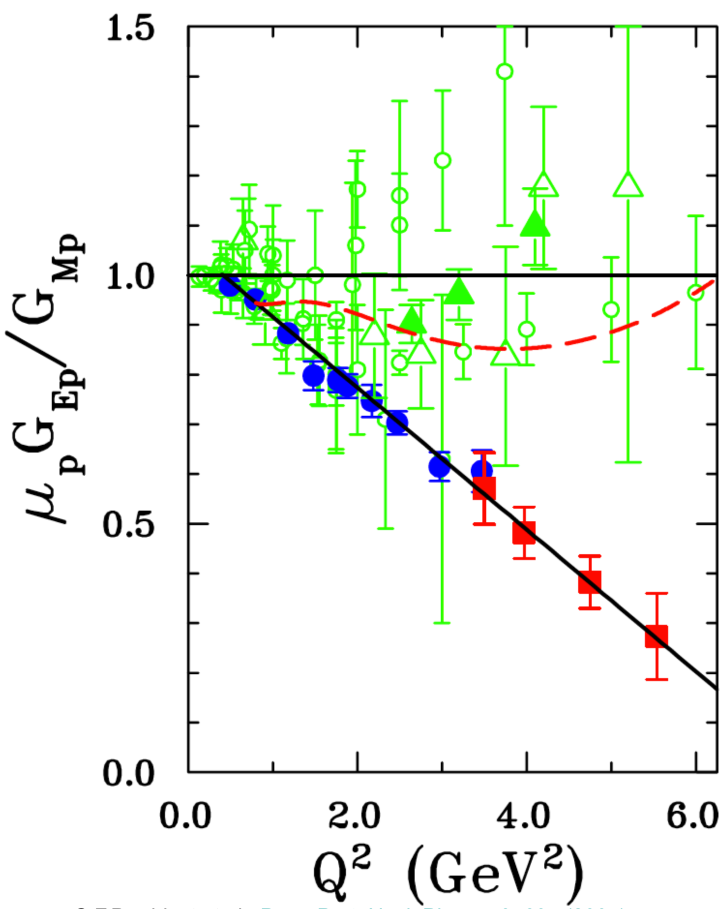
Polarisation Transfer (scattering)



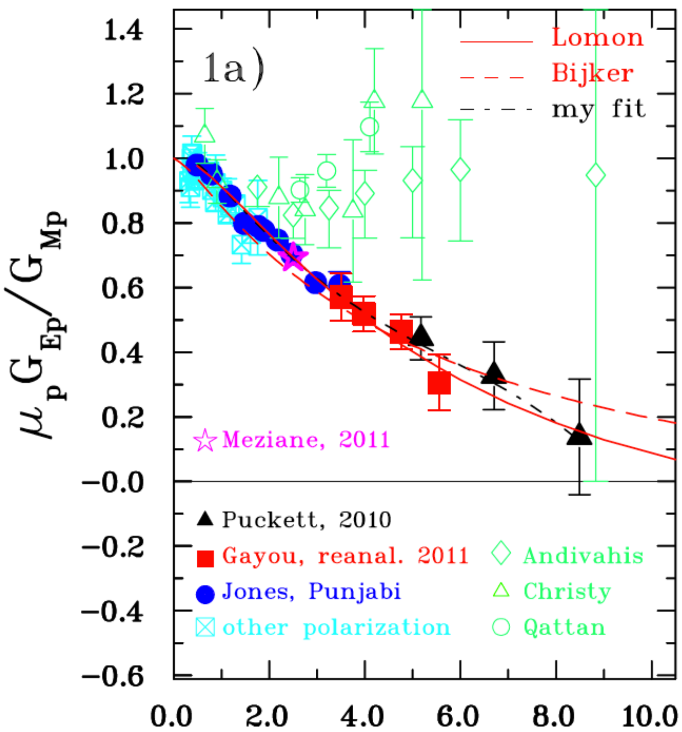
$$I_0 P_x = -2\sqrt{\tau(1+\tau)} G_E G_M \tan\frac{\theta_e}{2}$$

$$I_0 P_z = \frac{1}{M}(E_{beam} + E_e)\sqrt{\tau(1+\tau)} G_M^2 \tan^2\frac{\theta_e}{2}$$

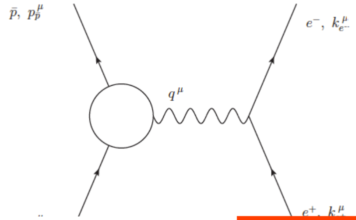
$$I_0 = G_E^2(Q^2) + \frac{\tau}{\epsilon} G_M^2(Q^2)$$



$$\frac{G_E}{G_M} = -\frac{P_x}{P_z}\frac{(E_{beam} + E_e)}{2M}\tan(\frac{\theta_e}{2})$$

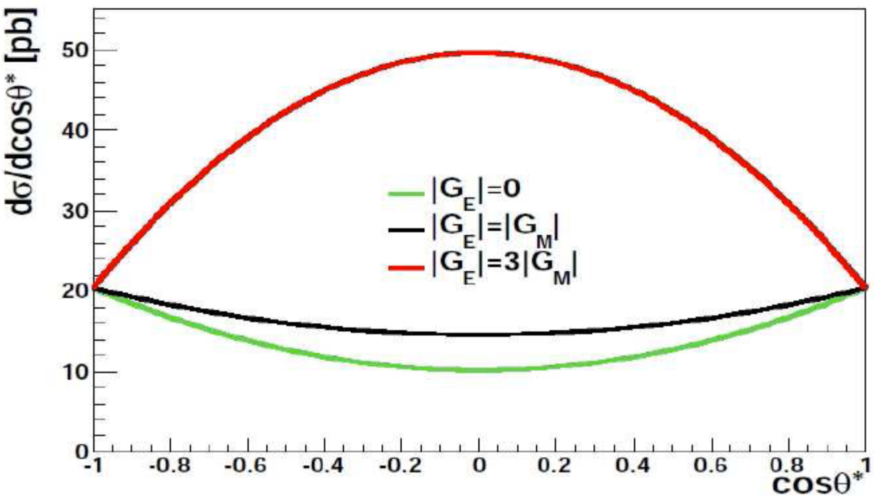


C.F.Perdrisat et al., Prog. Part. Nucl. Phys. 59, 694 (2007)



Cross Section (pbar annihilation) (Angular Distribution)

$$\frac{d\sigma}{d\cos\theta_{CM}} = \boxed{\frac{\pi\alpha^2}{8M_p\tau\sqrt{\tau(\tau-1)}}|G_M|^2}\left[\tau\left(1+\cos^2\theta_{CM}\right)+\frac{|G_E|^2}{|G_M|^2}\left(1-\cos^2\theta_{CM}\right)\right]$$



$G_E = F_1 + F_2$

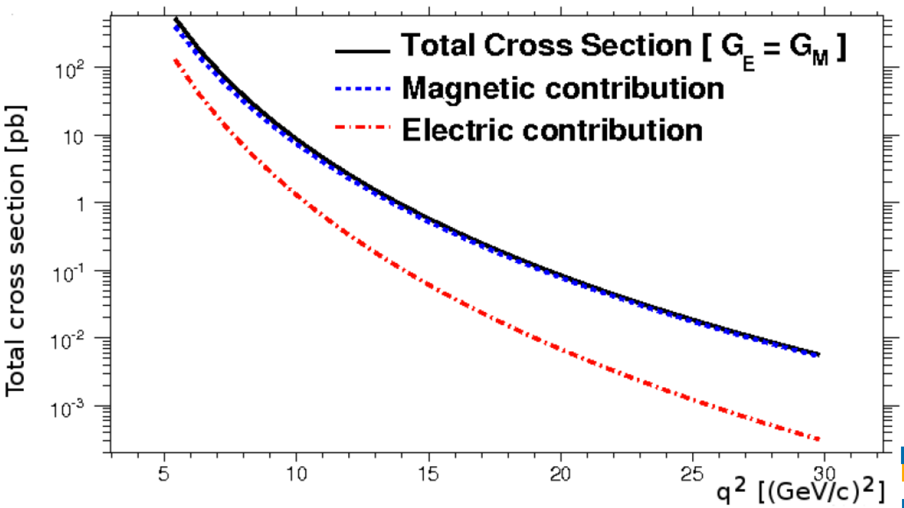
$G_M = F_1 + \tau F_2$

at threshold: $G_E = G_M$

two approaches:

assume G_E/G_M

extract G_E and G_M



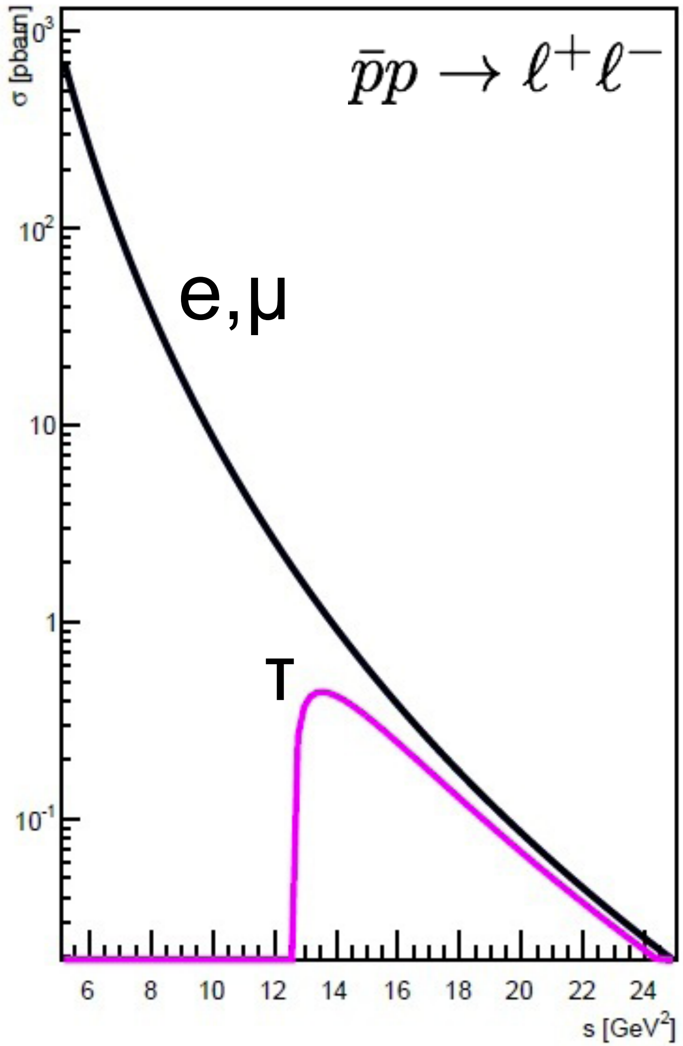
Integrated (Total) Cross Section:

$$\sigma = \frac{4\pi\alpha^2\beta C}{3q^2}\boxed{\left[|G_M|^2+\frac{1}{2\tau}|G_E|^2\right]}$$

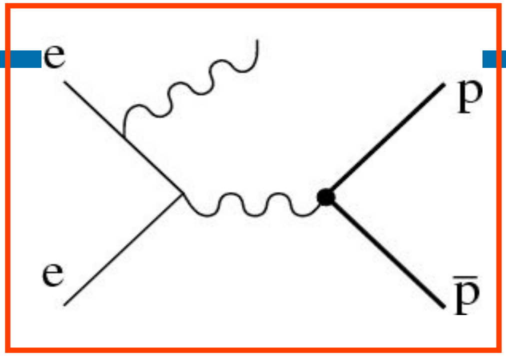
Effective FF

- Need Luminosity Measurement
- not on Resonance

Cross Section (pbar annihilation)
(total cross section)



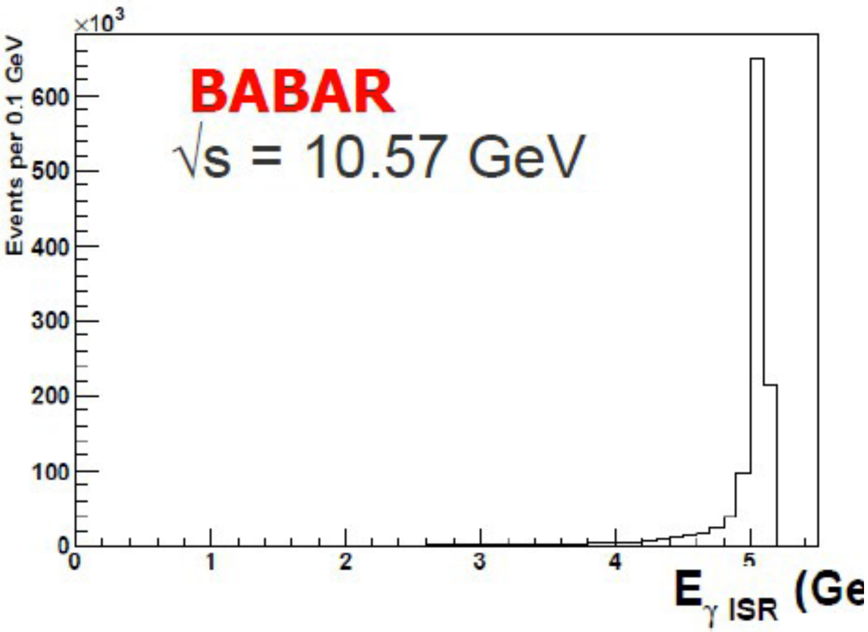
Cross Section (Initial State Radiation)

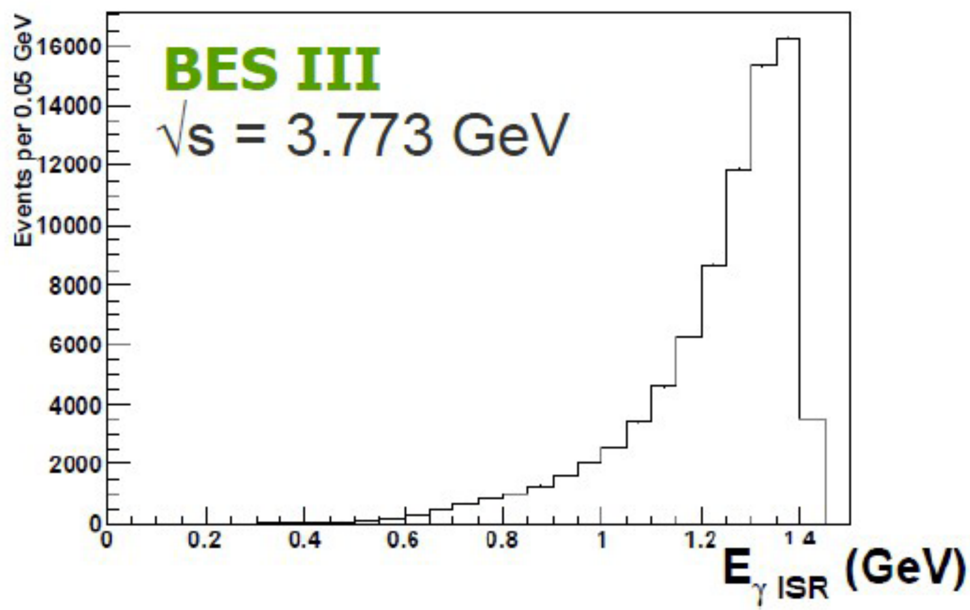


Mass spectrum of pp system in the $e^+e^- \to pp\gamma$ reaction is related to cross section of $e^+e^- \to pp$ reaction at E=m.

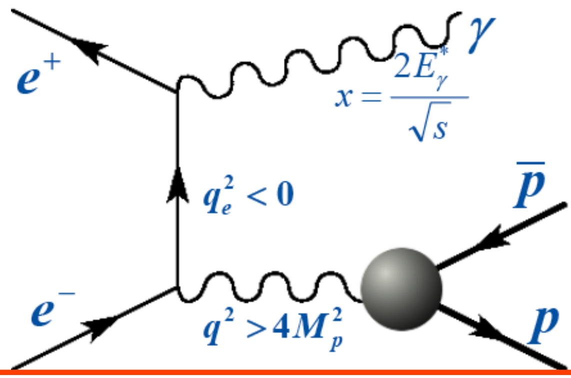
$$\frac{d\sigma(e^+e^- \to p\bar{p}\gamma)}{dm\, d\cos\theta} = \frac{2m}{s} W(s,x,\theta)\sigma(e^+e^- \to p\bar{p})(m), \quad x = \frac{2E_\gamma}{\sqrt{s}} = 1 - \frac{m^2}{s},$$

$$W(s,x,\theta) = \frac{\alpha}{\pi x}\left(\frac{2-2x+x^2}{\sin^2\theta} - \frac{x^2}{2}\right), \quad \theta >> \frac{m_e}{\sqrt{s}}.$$

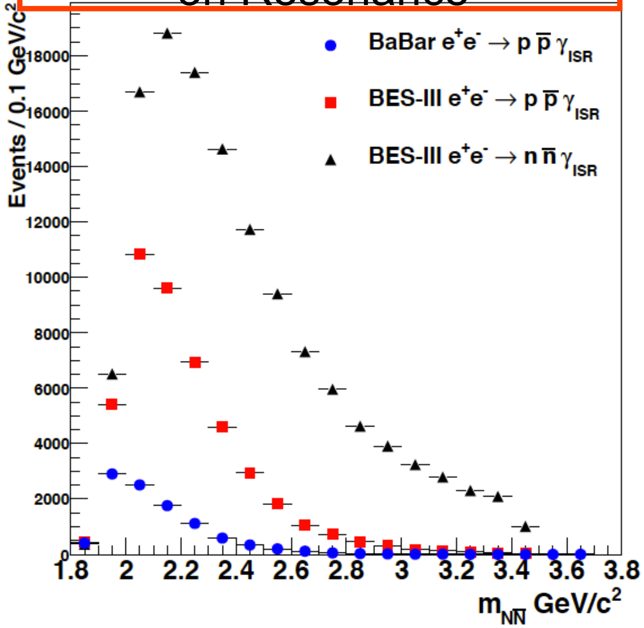




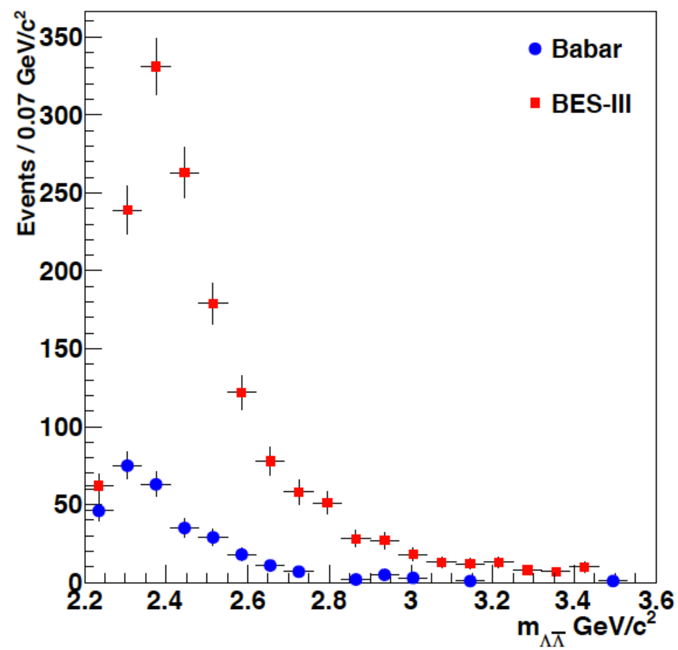
EM form factor ($q^2 > 0$)



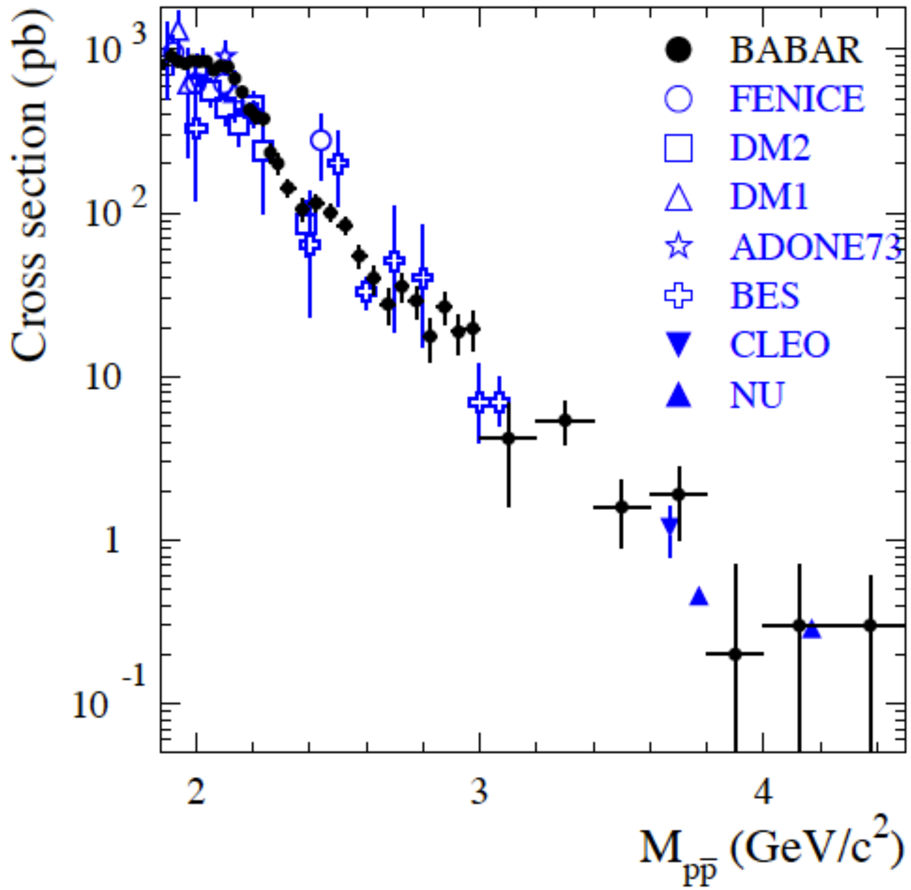
BaBar, BESIII: Measurement on Resonance



Babar, BESIII: Initial state radiation (ISR),
radiative return



Cross section ($q^2 > 0$)



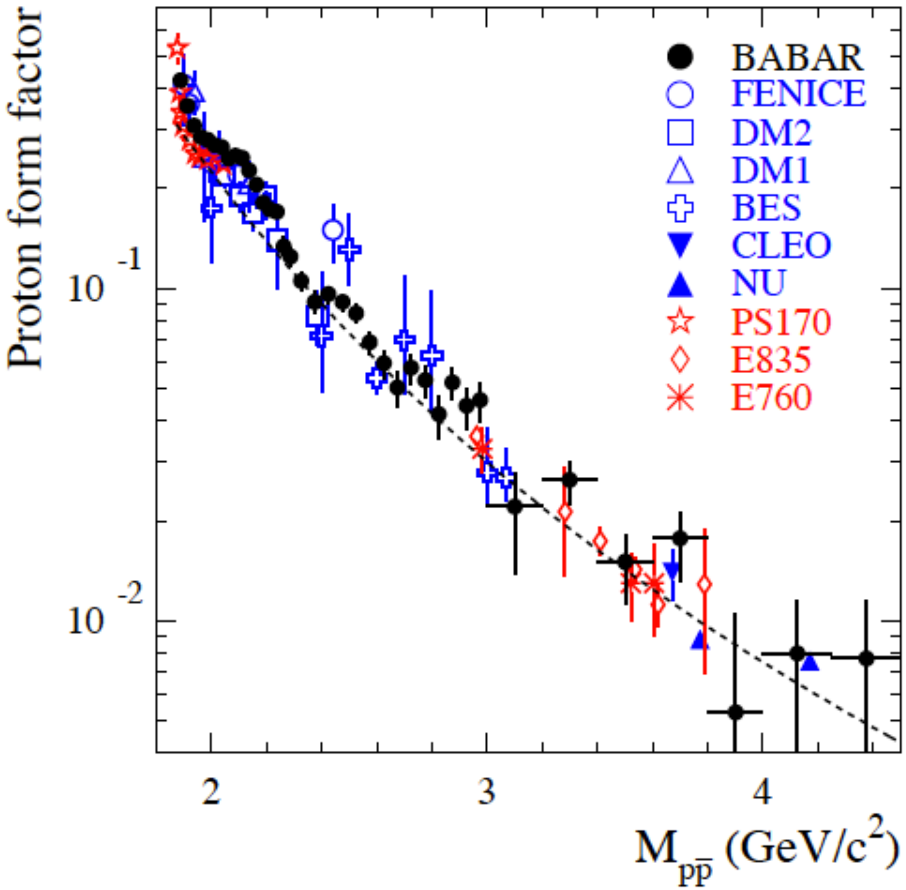
Adone e^+e^-: 25, 69 ev.
ELPAR $\bar{p}p$: 34 ev.
DM1,2 e^+e^-: 63, 172 ev.
 $|G_E|/|G_M| = 0.34$
PS170 $\bar{p}p$: 3667 ev.
 $|G_E|/|G_M| \approx 1$
E760 $\bar{p}p$: 29 ev.
E835 $\bar{p}p$: 206 ev.

CLEO e^+e^-: 14 ev.
BES e^+e^-: higher stat
BaBar e^+e^-: high stat

All data: Measure integrated cross section

new BABAR-Analysis: arxiv:1302.005

EM form factor ($q^2 > 0$)



Adone e^+e^-: 25, 69 ev.
ELPAR $\bar{p}p$: 34 ev.
DM1,2 e^+e^-: 63, 172 ev.
$|G_E|/|G_M| = 0.34$
PS170 $\bar{p}p$: 3667 ev.
$|G_E|/|G_M| \approx 1$
E760 $\bar{p}p$: 29 ev.
E835 $\bar{p}p$: 206 ev.

CLEO e^+e^-: 14 ev.
BES e^+e^-: higher stat
BaBar e^+e^-: high stat

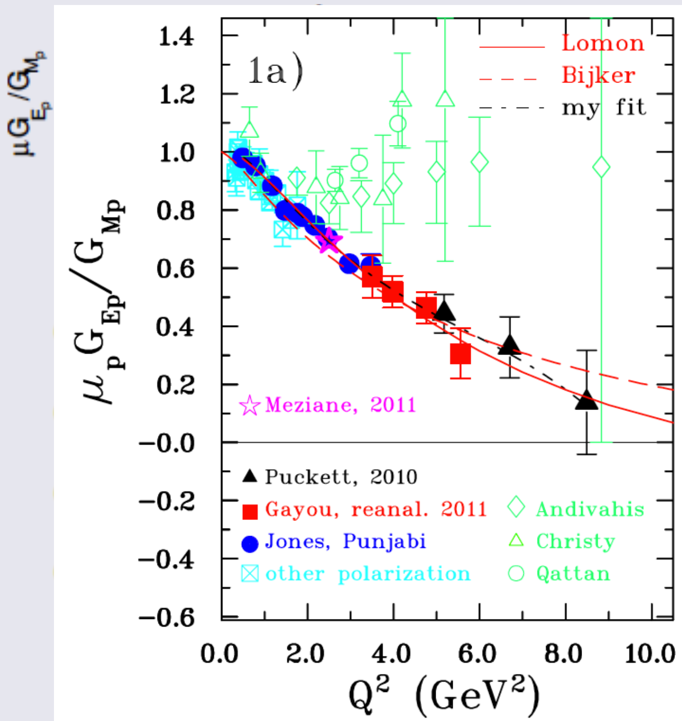
All data: Measure integrated cross section

assume: $G_E = G_M$, or $F = (\sigma)^{0.5}$

new BABAR-Analysis: arxiv:1302.005

EM form factor

Rossenbluth separation Space-like

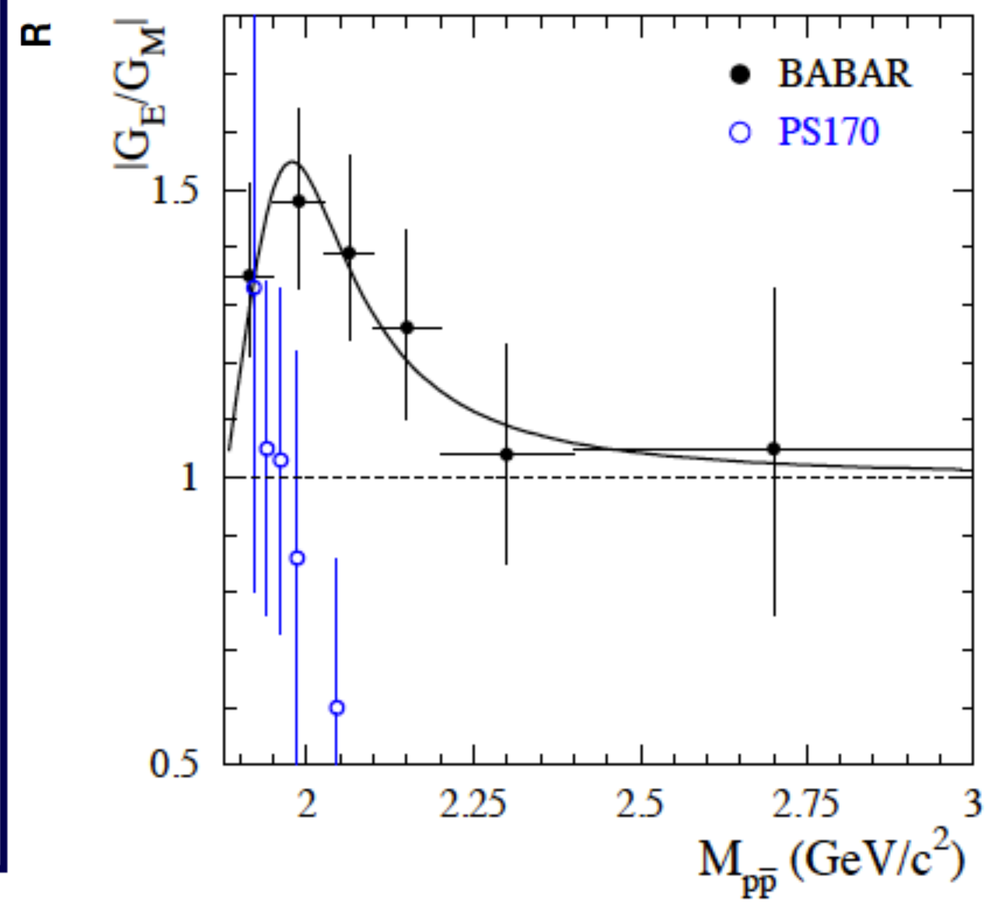


Polarization transfer experiments

$\rightarrow G_E \neq G_M$

$(q^2 < 0)$

From Angular Distribution:



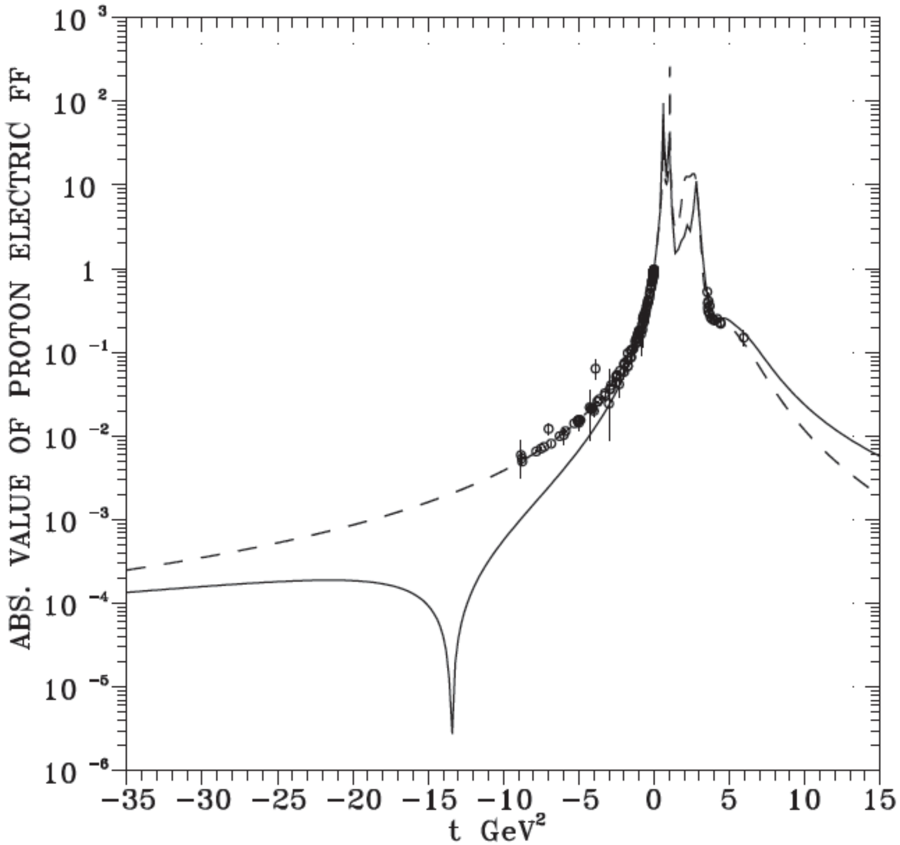
$(q^2 > 0)$

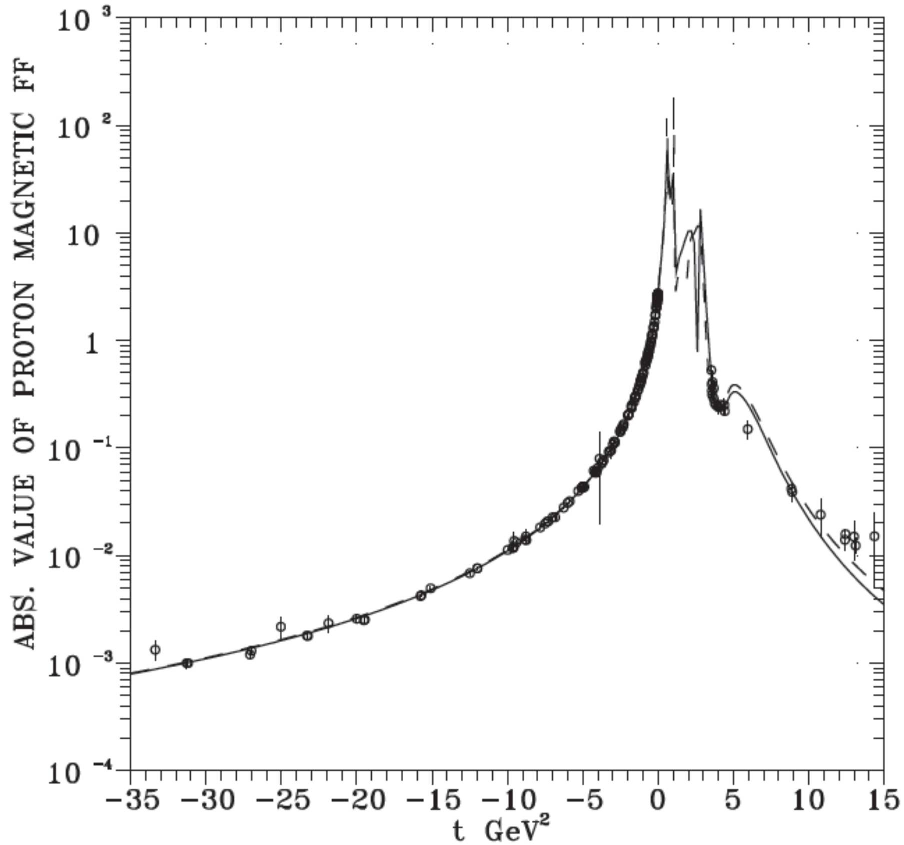
recent GEP-III results

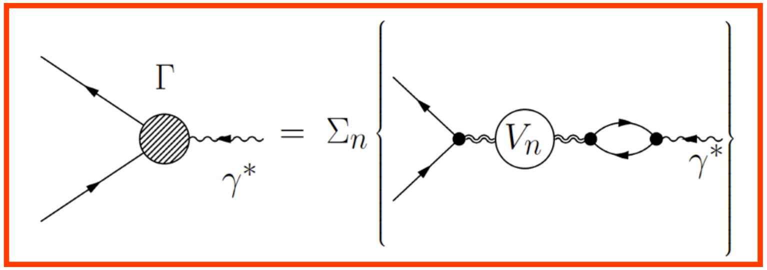
new BABAR-Analysis: arxiv:1302.005

Unphysical Region

EM form factor ($q^2 > 0$) and Vector Meson Dominance (VMD)

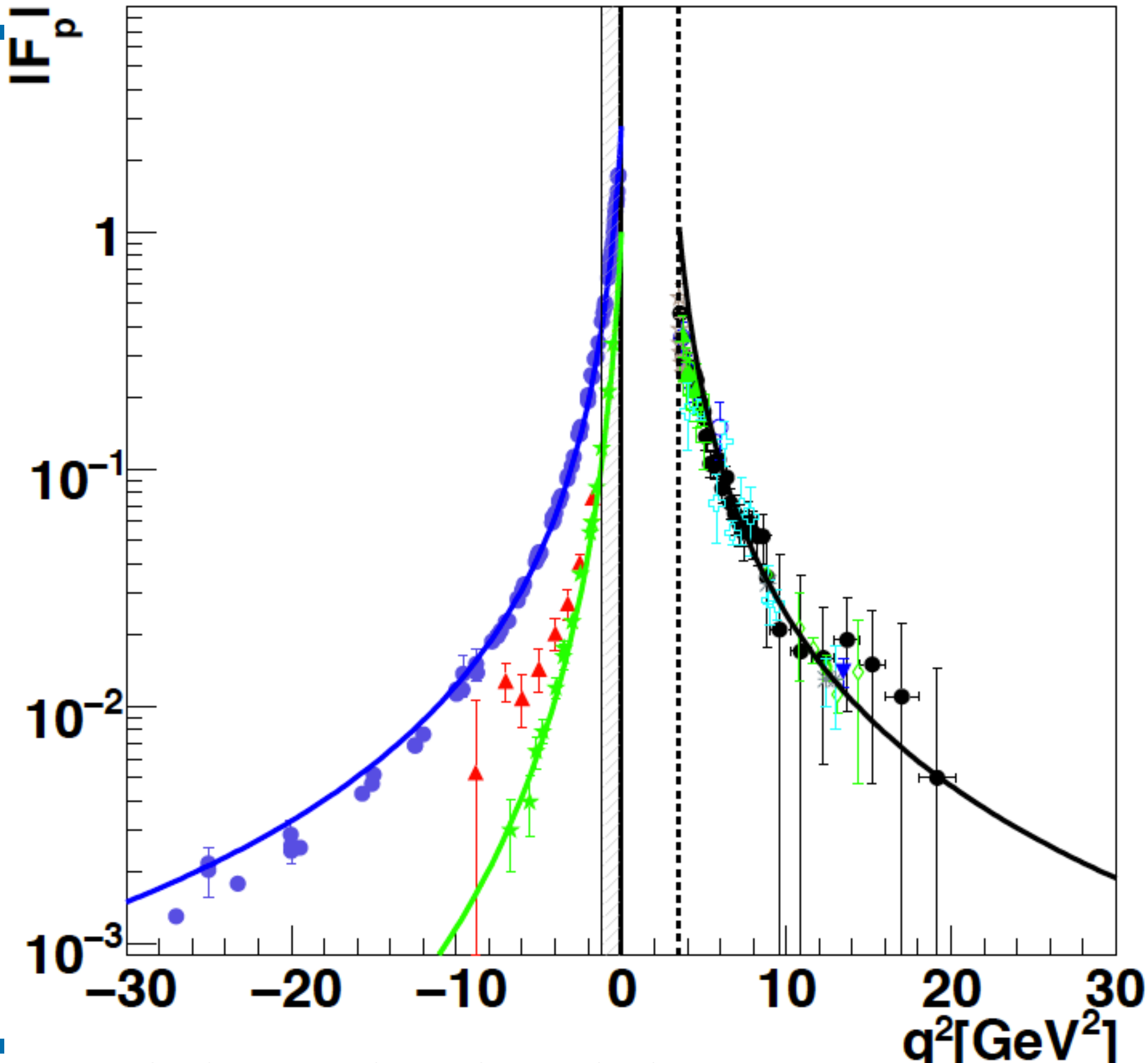






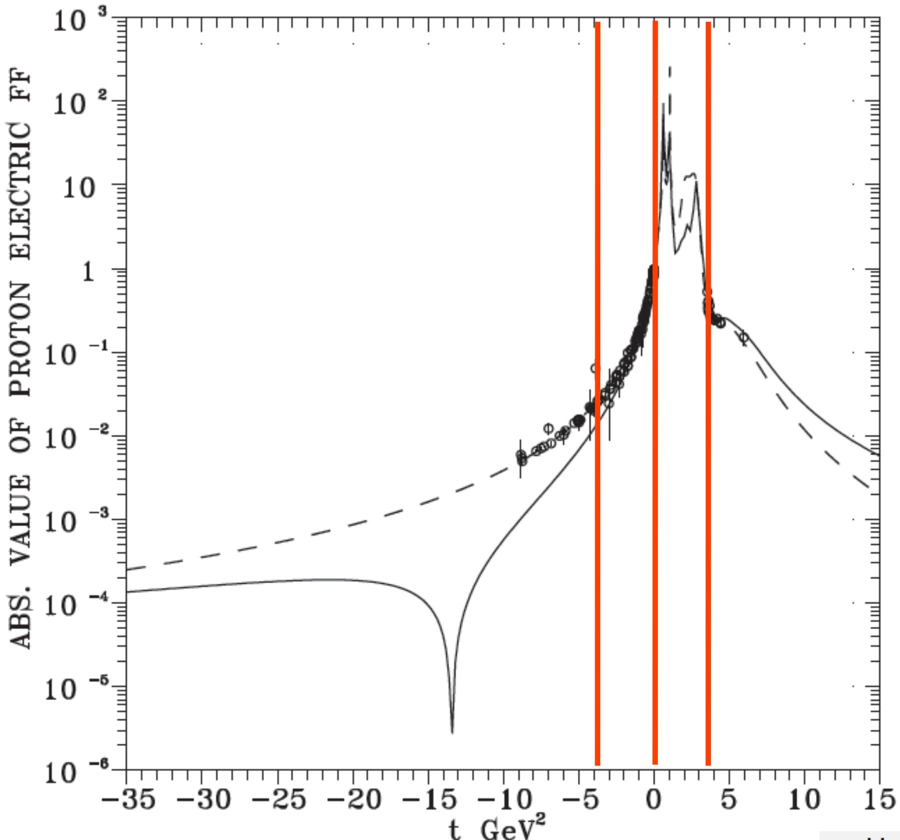
Vector Mesons

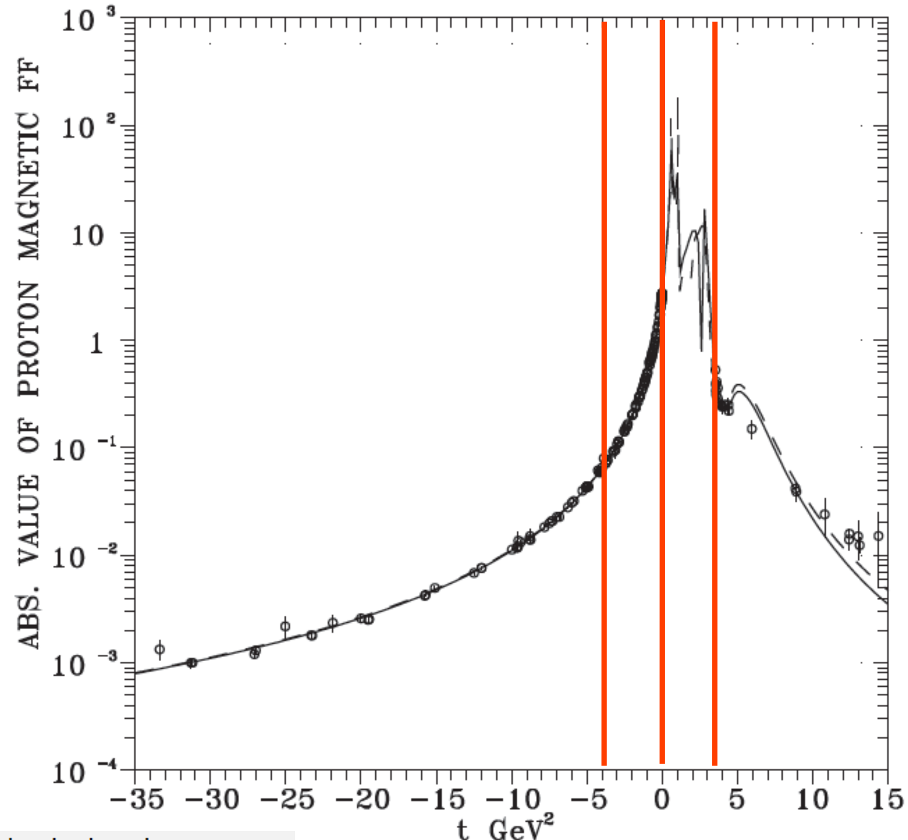
EM form factor ($q^2 > 0$)

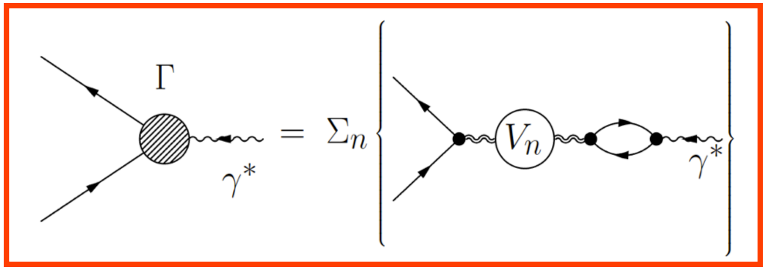


E.A.Kuraev, A.Dbeyssib, E. Tomasi-Gustafsson, Procedia Computer Science 00 (2012) 1–7

EM form factor ($q^2 > 0$) and Vector Meson Dominance (VMD) use pion-initial-state-radiation



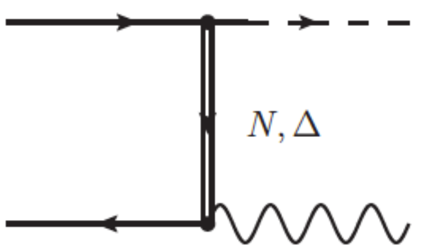




Vector Mesons

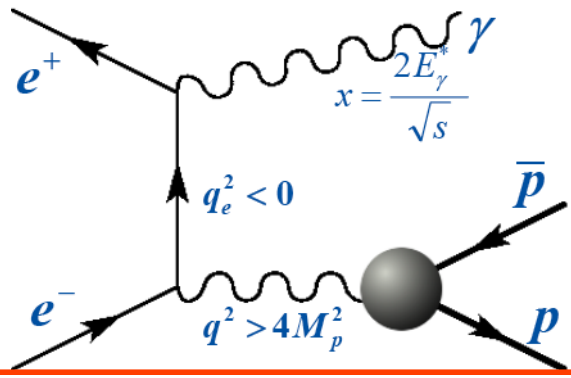
- Unphysical region: $0 < q^2 < 4m_N^2$
- Not accessible by process $p + \bar{p} \rightarrow e^+ + e^-$
- Idea: Consider process $p + \bar{p} \rightarrow \pi^0 + \gamma^* \rightarrow \pi^0 + e^+ + e^-$

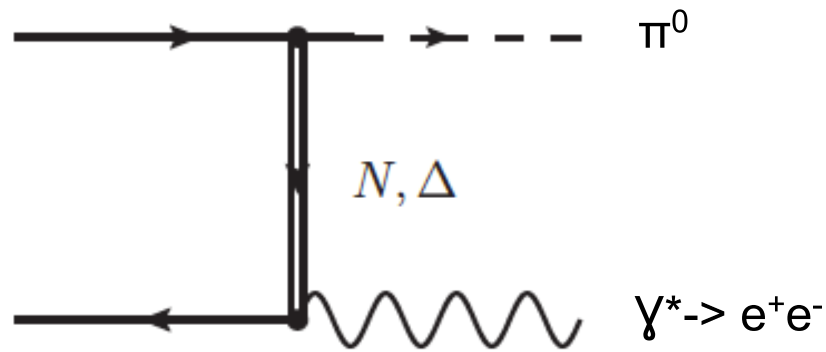
(Dubničková et al., ZPhys. (1996), Adamuščín et al., PRC (2007))



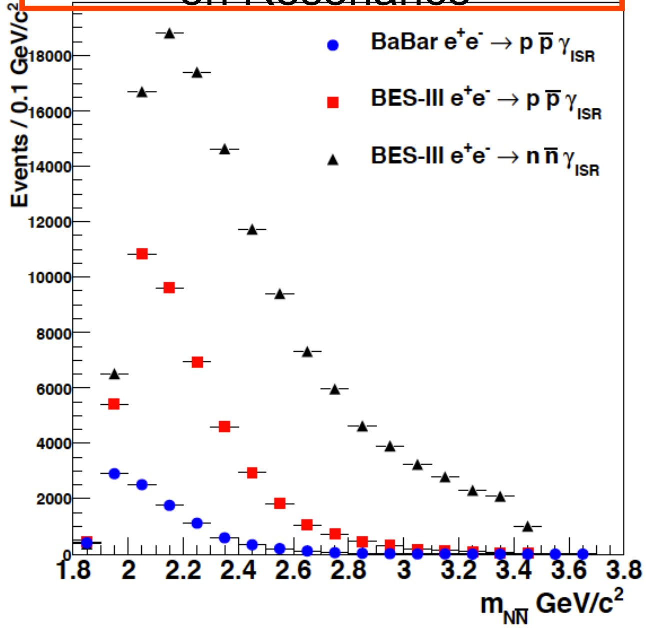
EM form factor in unphysical region($q^2 > 0$)

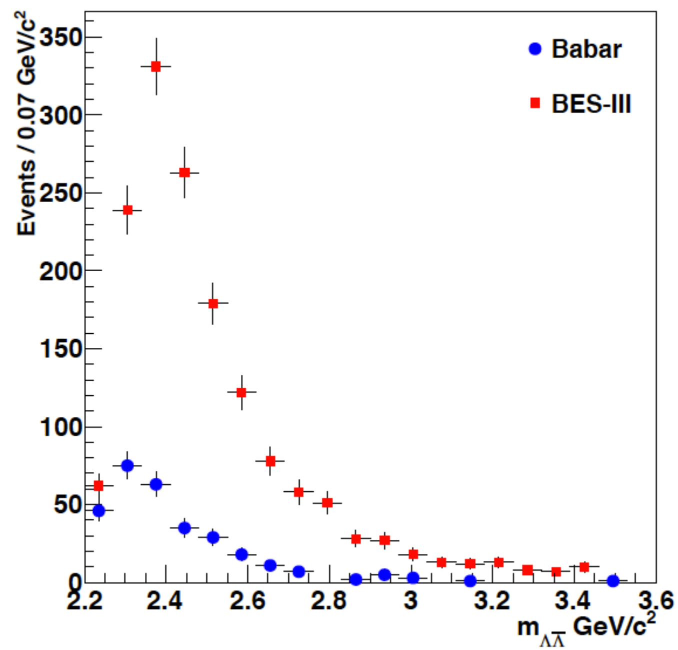
Babar, BESIII: Initial state radiation (ISR), radiative return





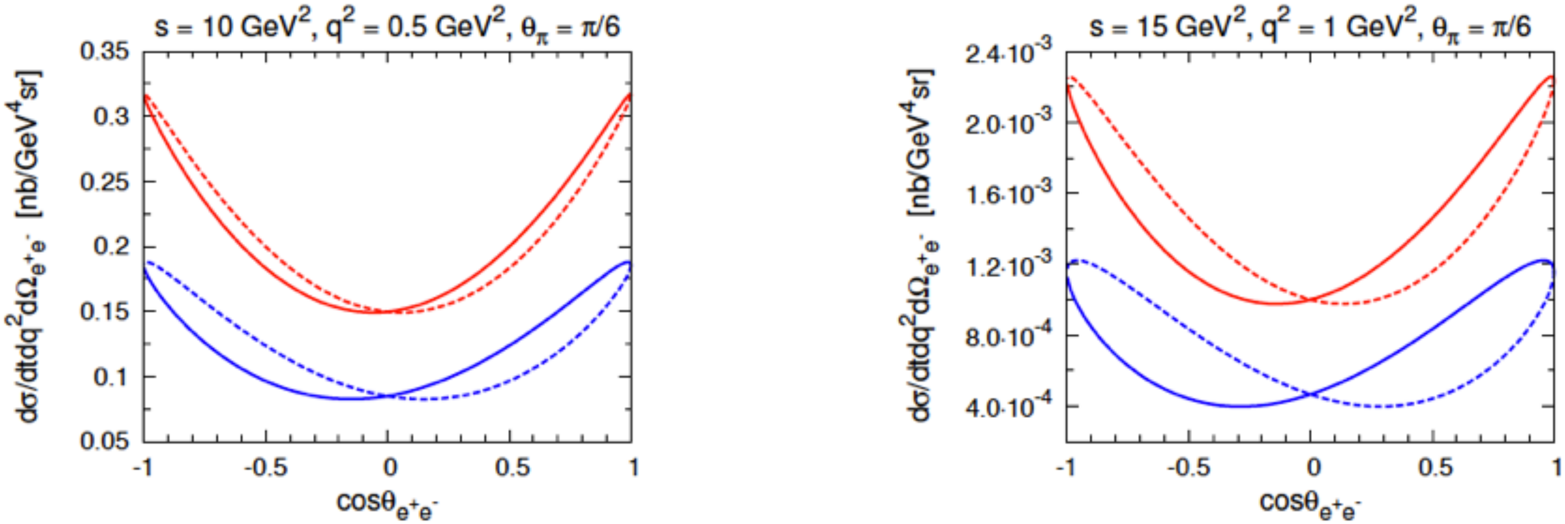
BaBar, BESIII: Measurement on Resonance





$p\bar{p} \to \pi^0 e^+ e^-$: Results in the Regge framework

Cross Section: $d\sigma/(dt\,dq^2 d\Omega_{e^+e^-})$ $\left[nb/GeV^4 sr\right]$



N-trajectory exchange: $\Phi_{e^+e^-} = 0$ (solid) and $\Phi_{e^+e^-} = \pi$ (dashed)

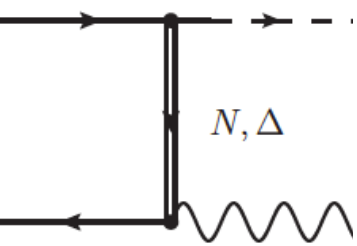
(N+Δ)-trajectory exchange: $\Phi_{e^+e^-} = 0$ (solid) and $\Phi_{e^+e^-} = \pi$ (dashed)

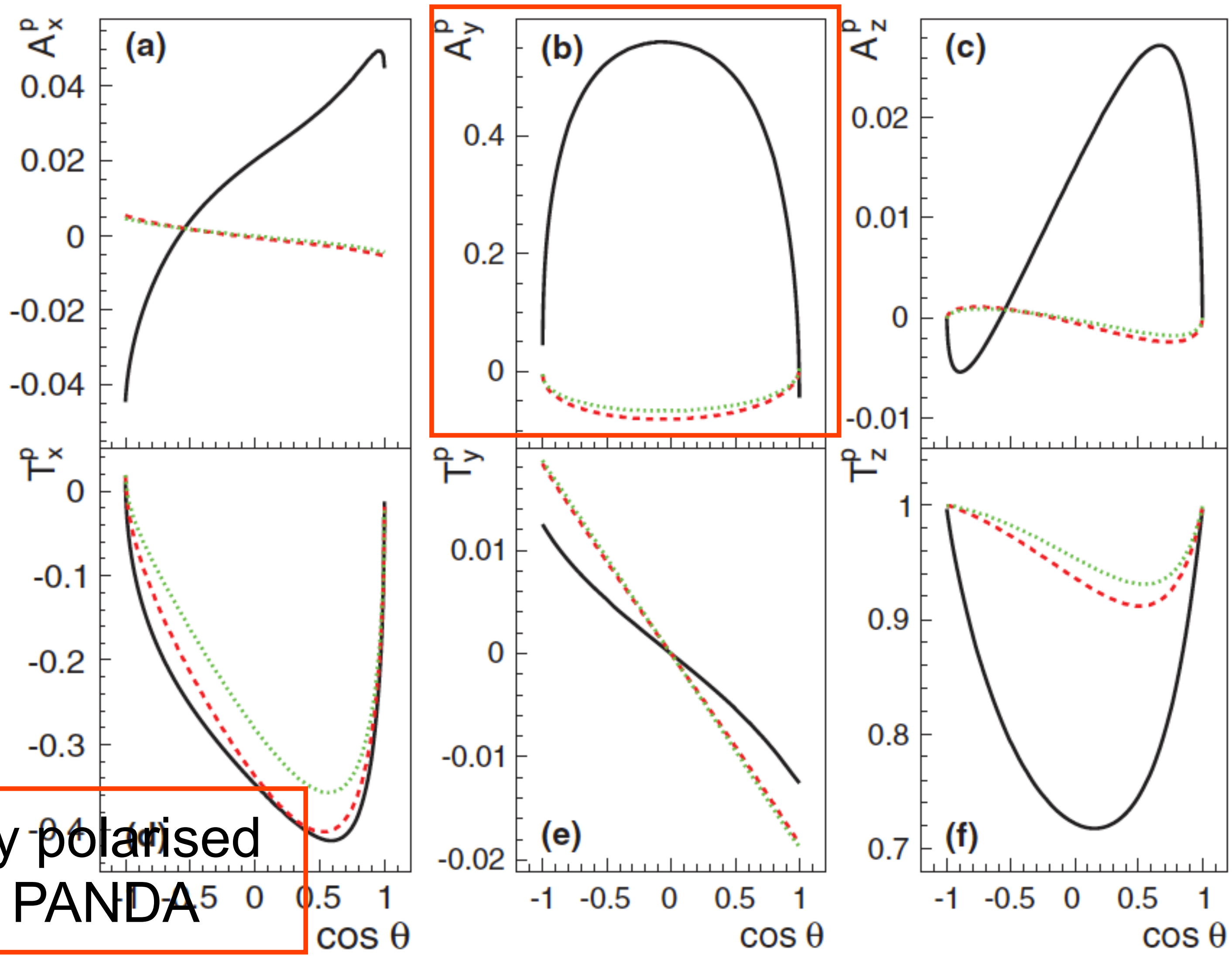
complementary approach to ff at and below threshold

interference terms (F_1F_2) in cross section

Target Asymmetry and Polarisation Transfer

$$\bar{p}p \rightarrow e^{+}e^{-}\pi^{0}$$

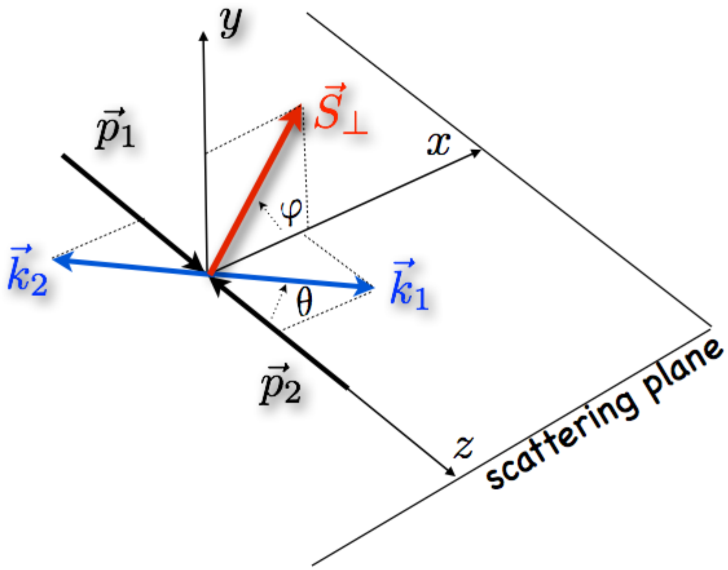




transversely polarised
Target in PANDA

G. I. Gakh, E. Tomasi-Gustafsson, A. Dbeyssi, A. G. Gakh, Phys. Rev. C 86, 025204 (2012)

Imaginary Part of Time Like FF
single spin target asymmetry



transversely polarised
Target in PANDA

$$\bar{p}p \to e^+e^-$$

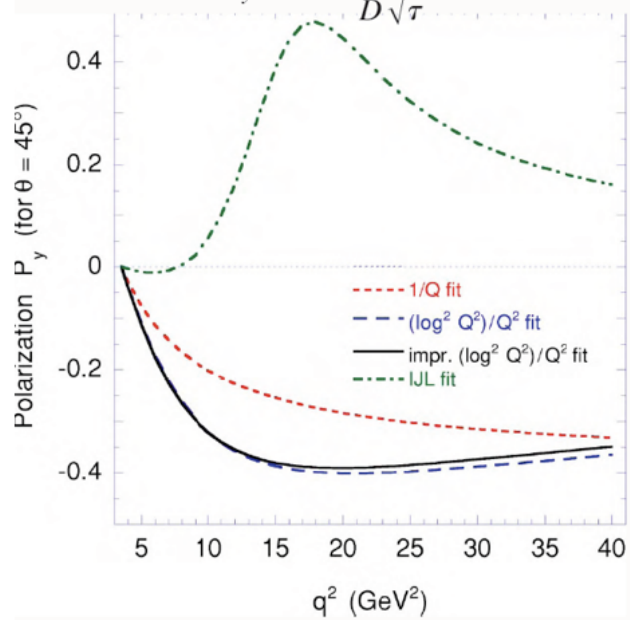
Single-spin polarization effects and the determination of timelike proton form factors

$$\mathcal{P}_y = \frac{\sin 2\theta \,\mathrm{Im}\, G_E^* G_M}{D\sqrt{\tau}} = \frac{(\tau-1)\sin 2\theta \,\mathrm{Im}\, F_2^* F_1}{D\sqrt{\tau}}$$

Carlson, Hiller, Hwang, sjb

$$D = |G_M|^2(1+\cos^2\theta) + \frac{1}{\tau}|G_E|^2 \sin^2\theta;$$

$$\tau \equiv q^2/4m_B^2$$

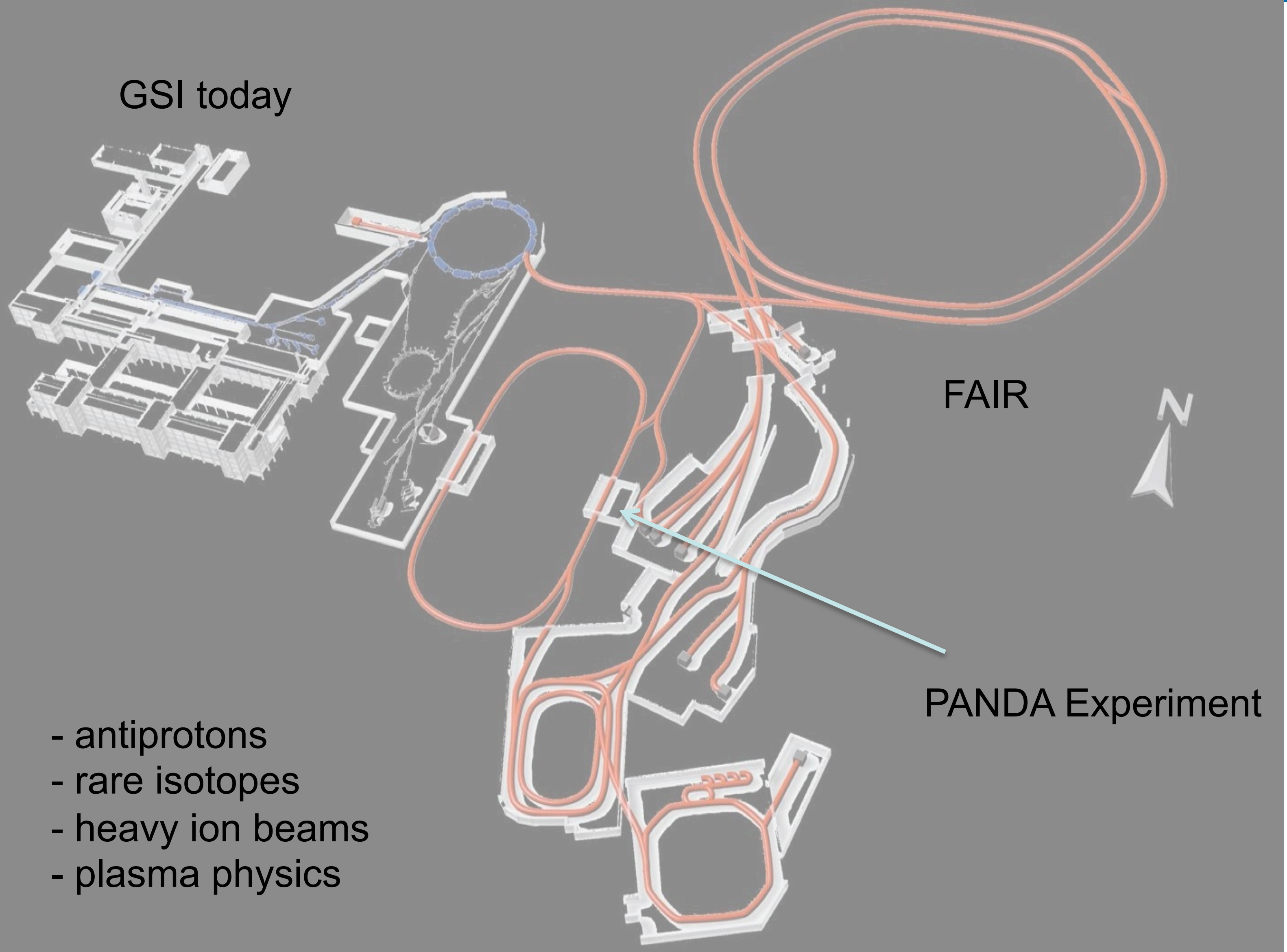


Measure relative phase of form factors

PANDA Experiment at FAIR

FAIR in 2017/2018

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 Collaboration

- At present a group of **500 physicists** from 62 institutions and 16 countries

Austria – Belaruz – China – France – Germany – India – Italy – The Netherlands – Poland – Romania – Russia – Spain – Sweden – Switzerland – U.K. – U.S.A.

AMU Aligarh, Basel, Beijing, BITS Pillani, Bochum, IIT Bombay, Bonn, Brescia, IFIN Bucharest, IIT Chicago, AGH-UST Cracow, JGU Cracow, IFJ PAN Cracow, Cracow UT, Edinburgh, Erlangen, Ferrara, Frankfurt, Gauhati, Genova, Giessen, Glasgow, GSI, FZ Jülich, JINR Dubna, Katowice, KVI Groningen, Lanzhou, Legnaro, LNF, Lund, Mainz, Minsk, ITEP Moscow, MPEI Moscow, TU München, Münster, BARC Mumbai, Northwestern, BINP Novosibirsk, IPN Orsay, Pavia, IHEP Protvino, PNPI St.Petersburg, South Gujarat University, SVNIT Surat, Sadar Patel University, KTH Stockholm, Stockholm, FH Südwestfalen, Suranaree University of Technology, Dep. A. Avogadro Torino, Dep. Fis. Sperimentale Torino, Torino Politecnico, Trieste, TSL Uppsala, Tübingen, Uppsala, Valencia, NCBJ Warsaw, TU Warsaw, AAS Wien

http://www.gsi.de/panda

PANDA Physics Program

Hadron Spectroscopy

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

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

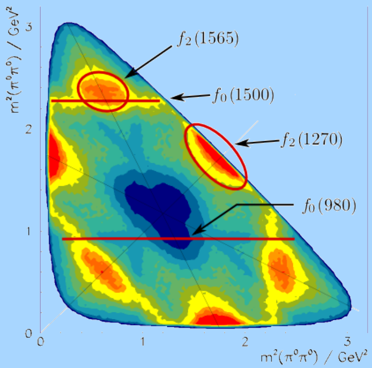
➔ Understand new XYZ states, $D_s(2317)$ and others

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

Spectroscopy with Antiprotons:

Production of states of all quantum numbers

Resonance scanning with high resolution



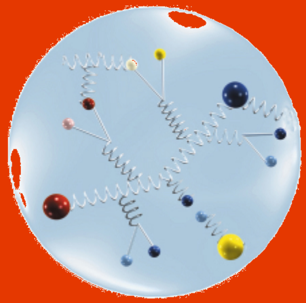
Hadron Structure

Generalized Parton Distributions

➔ Formfactors and structure functions, L_q

Timelike Nucleon Formfactors

Drell-Yan Process

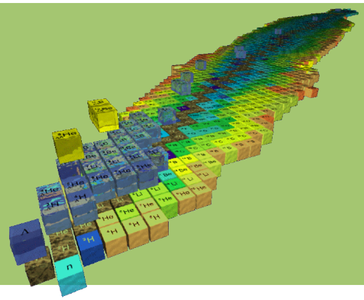


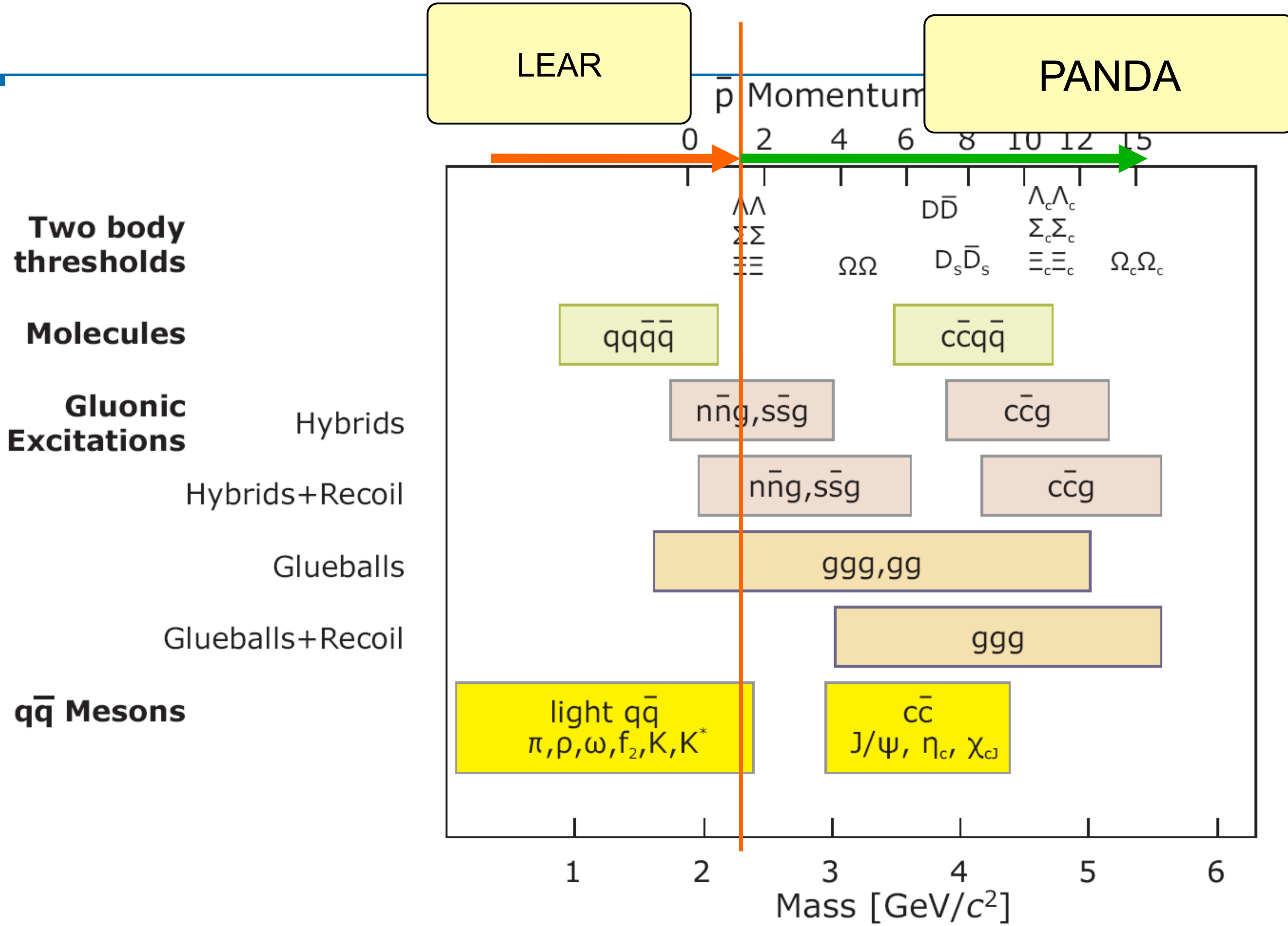
Nuclear Physics

Hypernuclei*:* Production of double Λ-hypernuclei

➔ γ-spectroscopy of hypernuclei, YY interaction

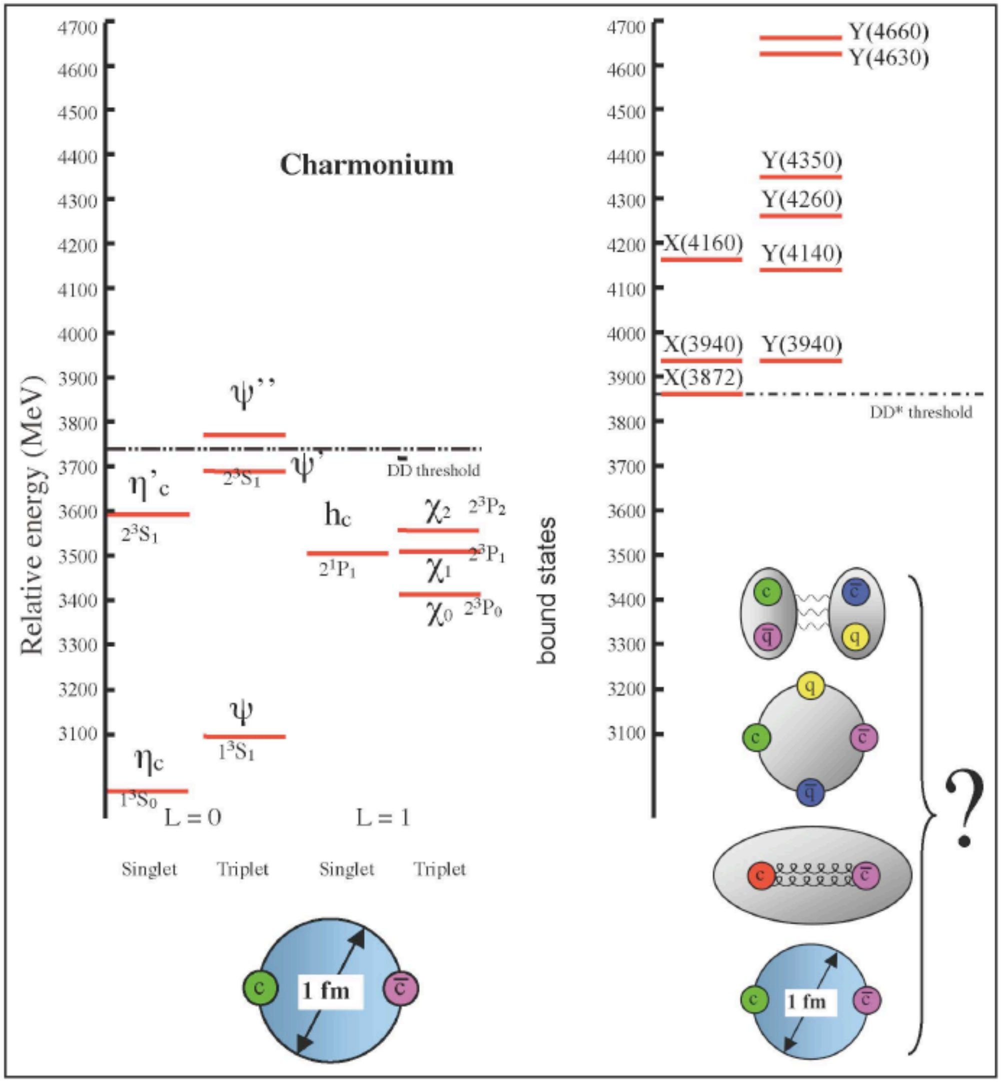
Hadrons in Nuclear Medium





Physics performance report: arXiv:0903.3905v1

Hadron Dynamics (spectroscopy)

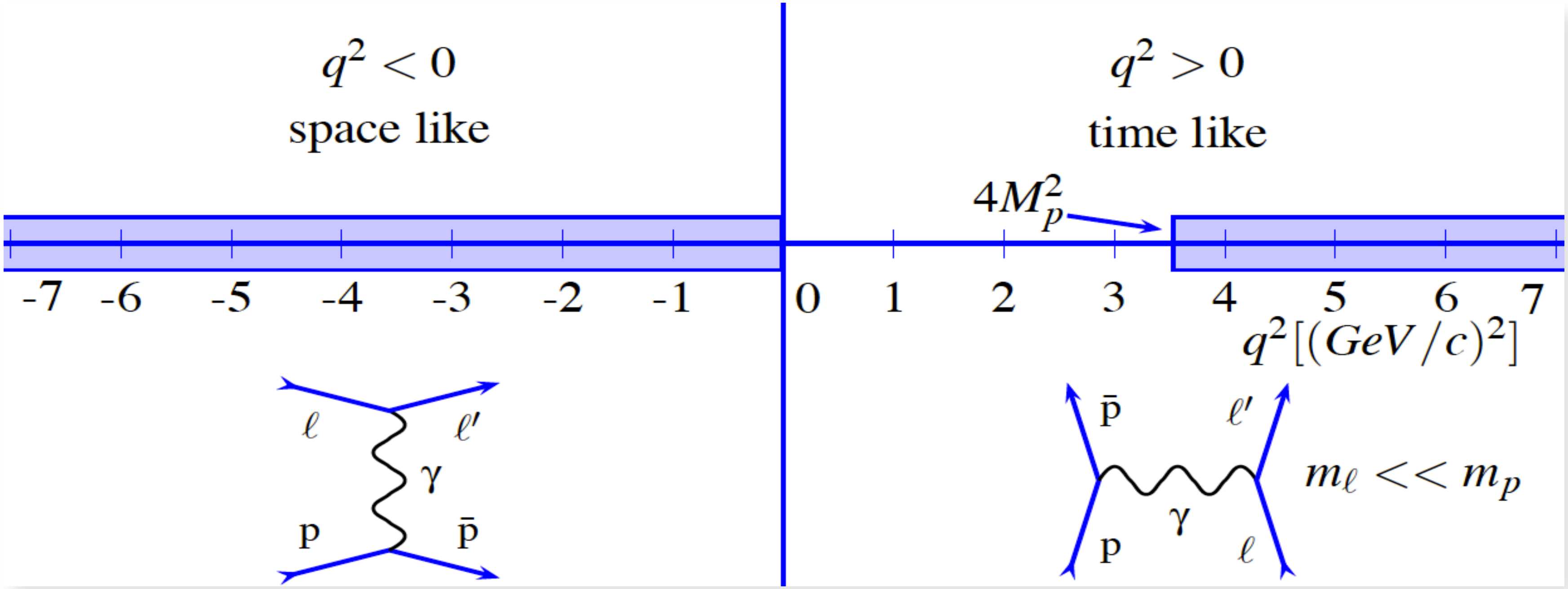


Revolution:
X,Y,Z – states: not understood,
new form of matter

Narrow, above open charm decay

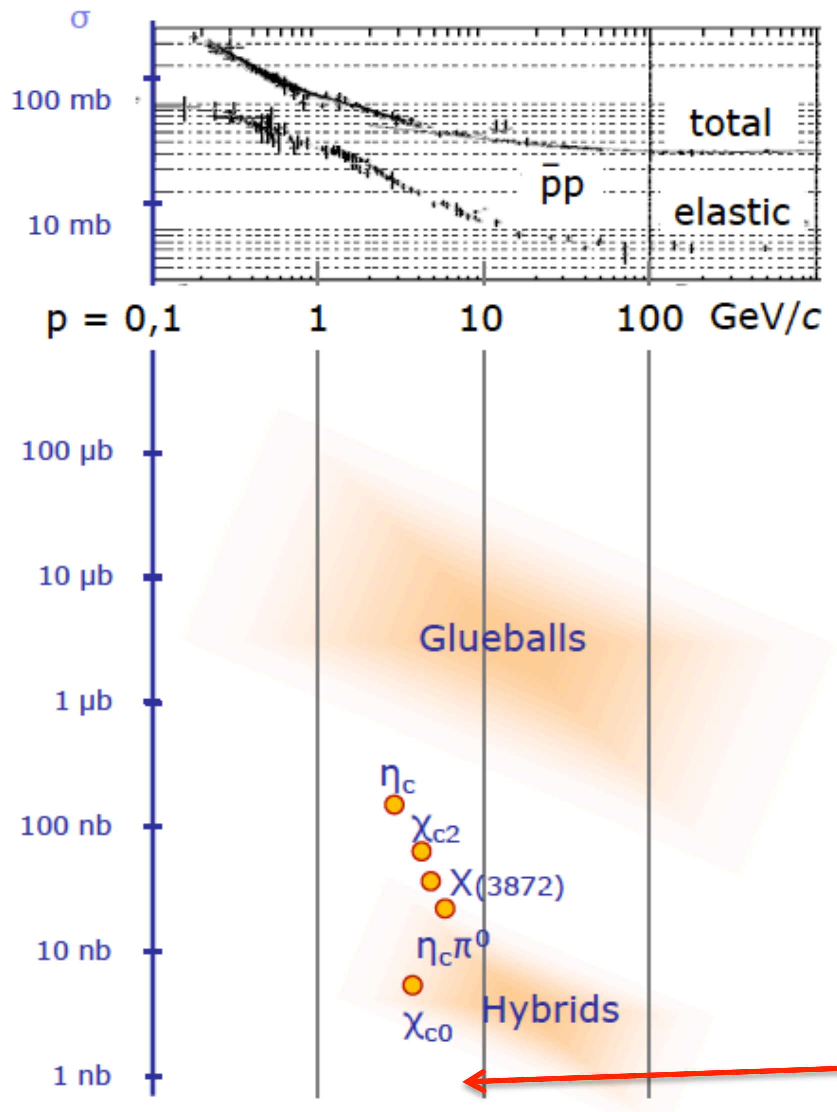
Decays not from two quark meson

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

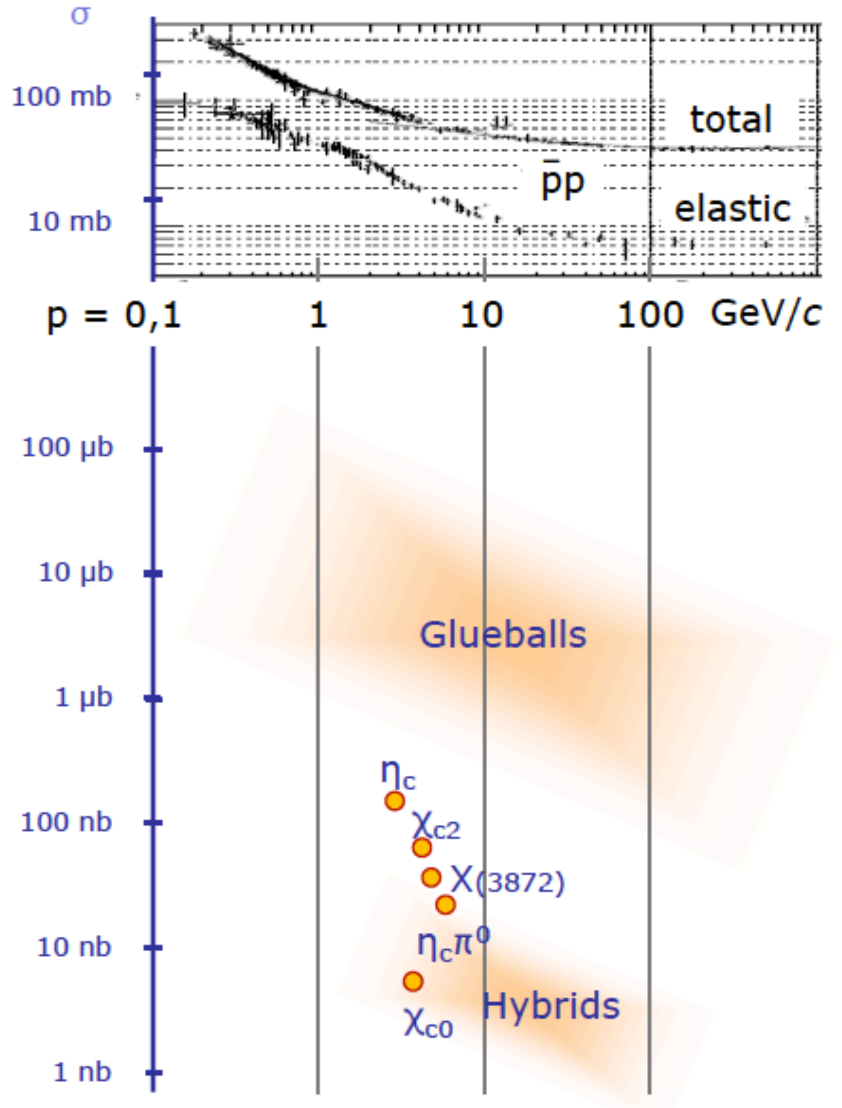
High rate capability, $2 \cdot 10^7\ s^{-1}$ interactions

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

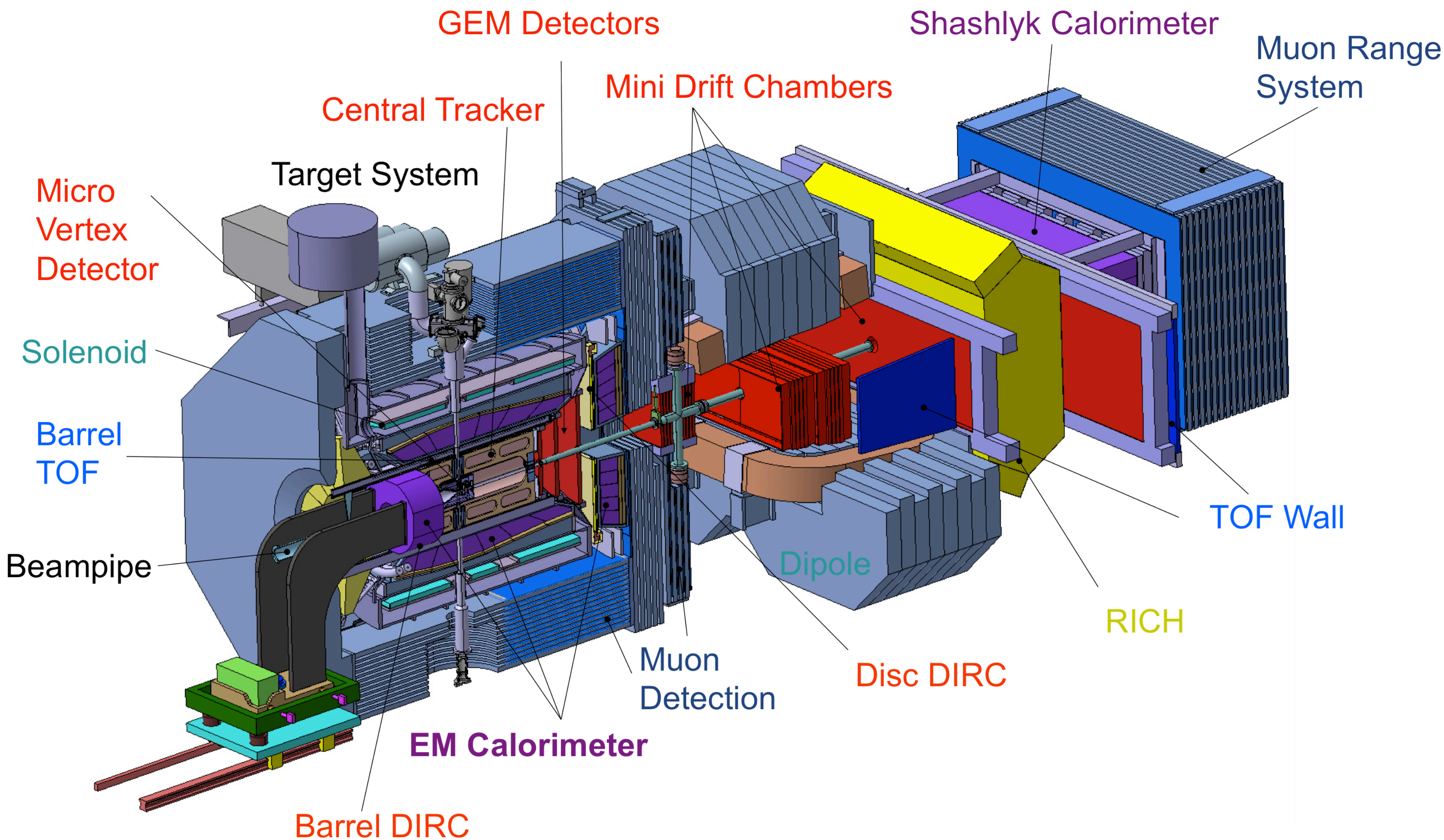
time of flight, dE/dx, muon counter

Displaced vertex info

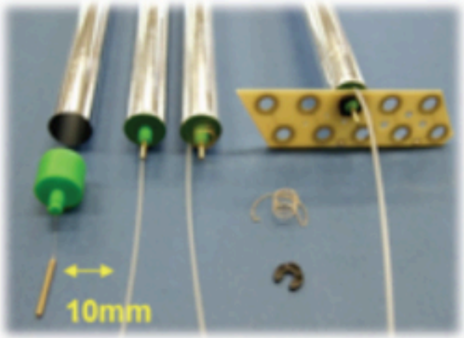
$c\tau$ = 317 μm for $D^{\pm}$

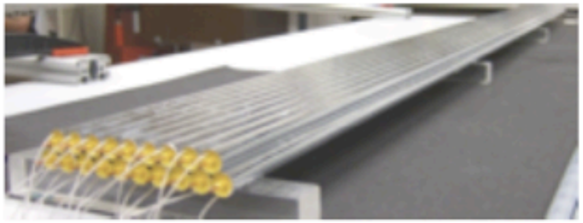
$\gamma\beta \approx 2$

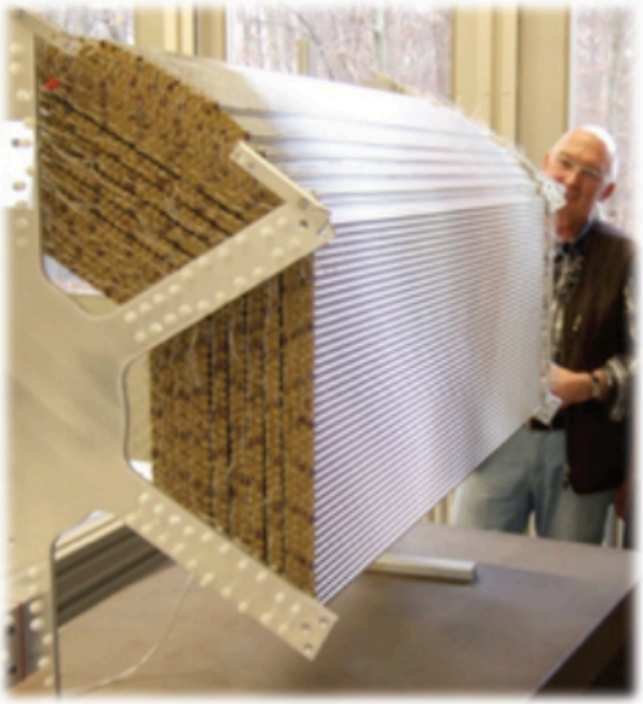
PANDA Detector

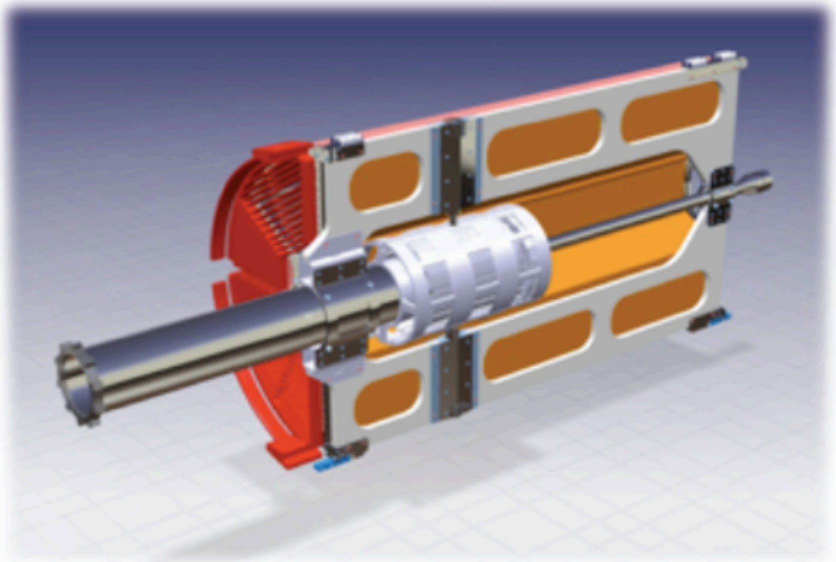


The PANDA Central Tracker

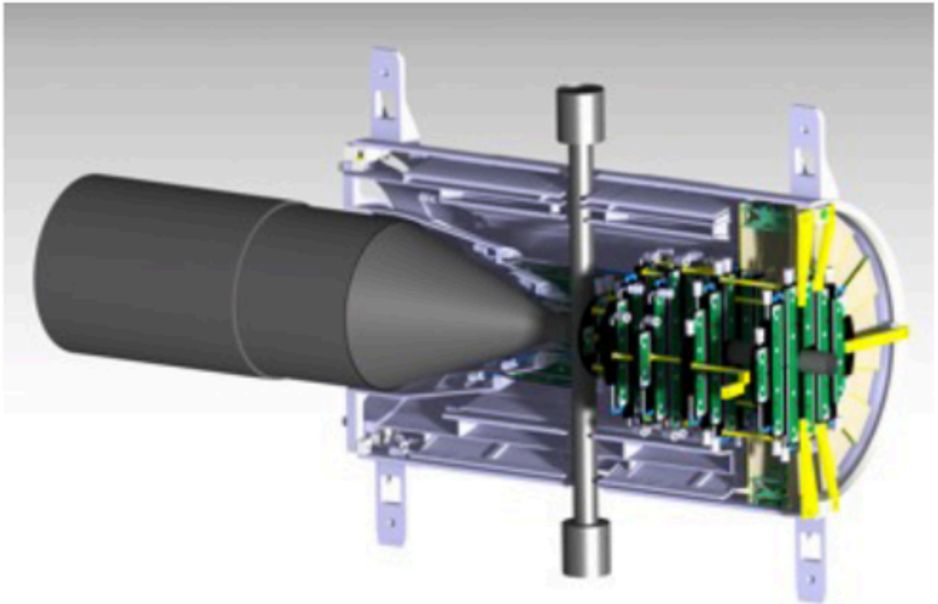




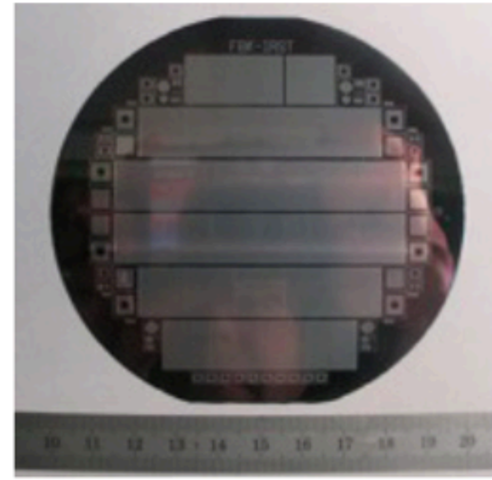




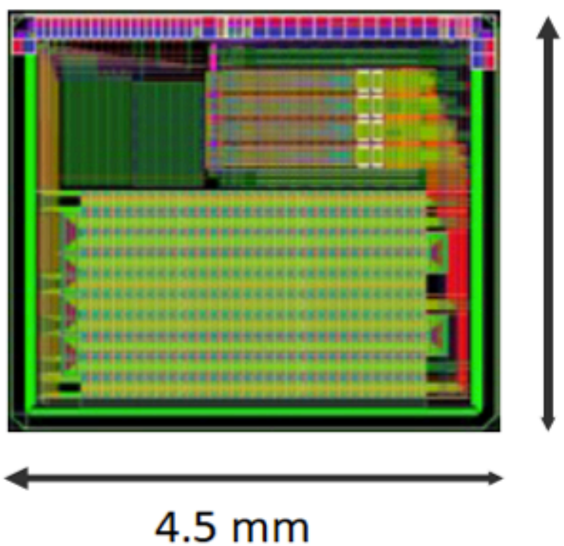
The PANDA MVD



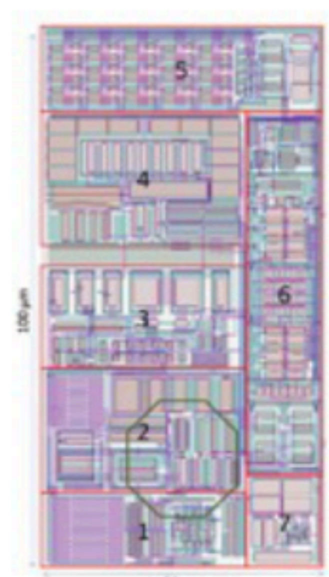
Full-Size Prototypes

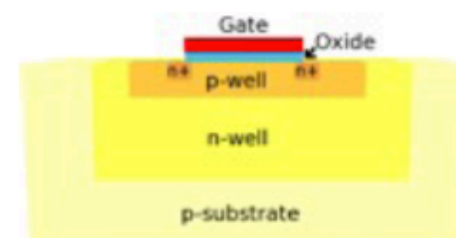


ASIC Prototypes

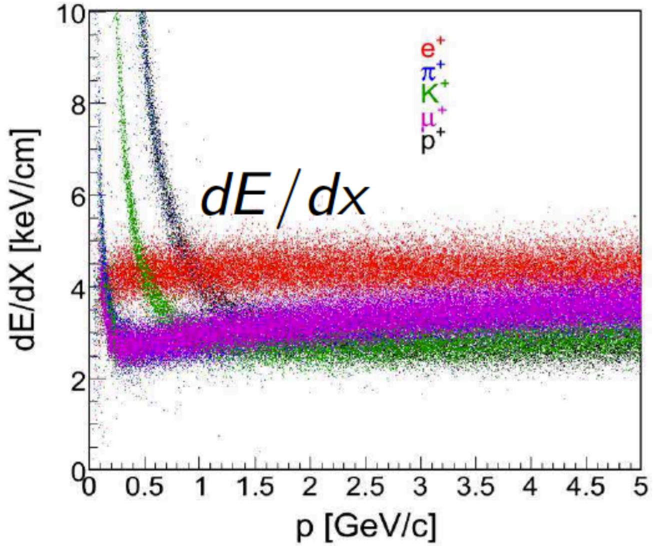


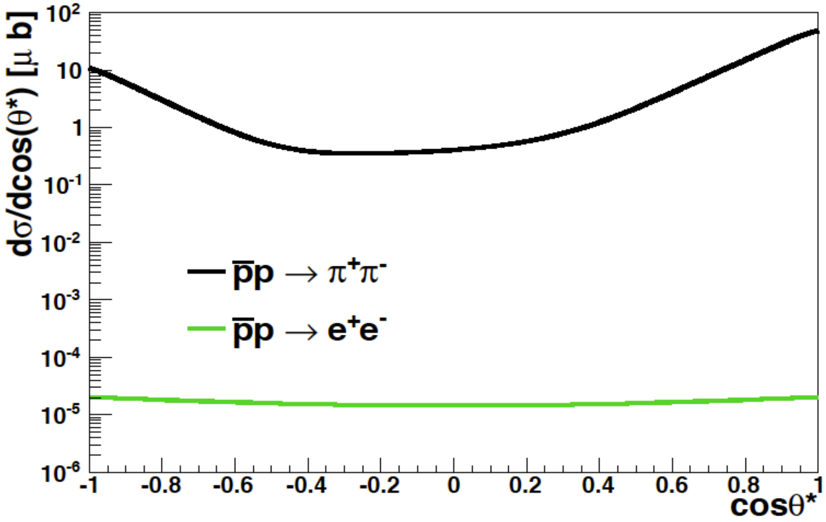
ToPix v3 Full-Feature Prototype

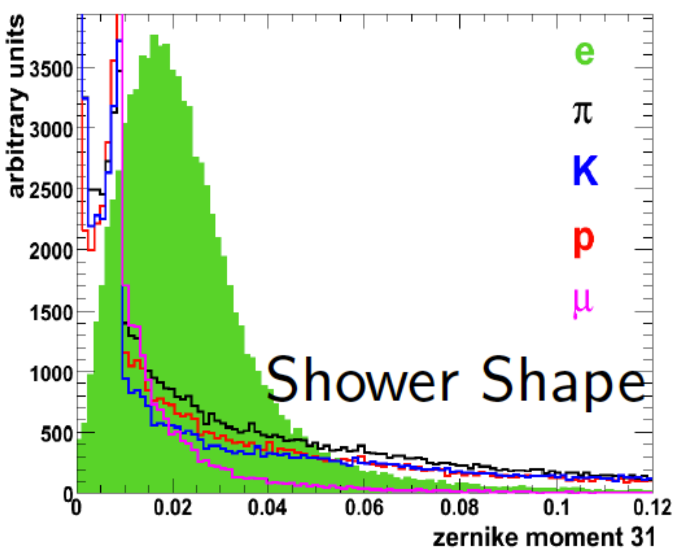


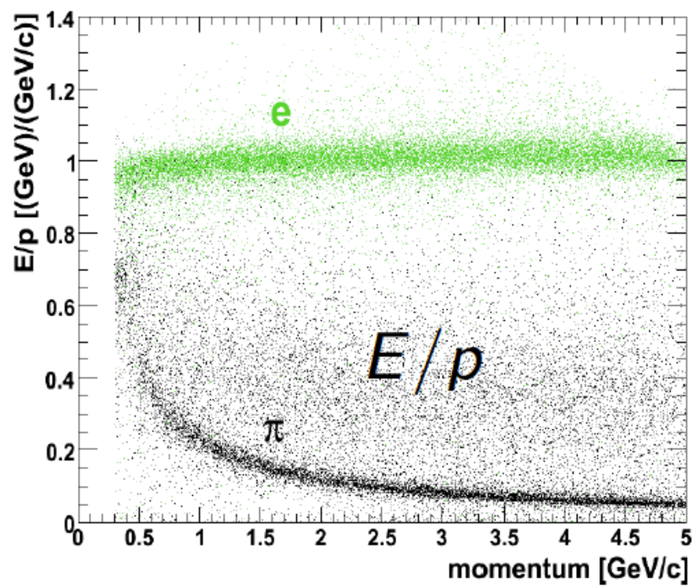


Particle Identification in PANDA

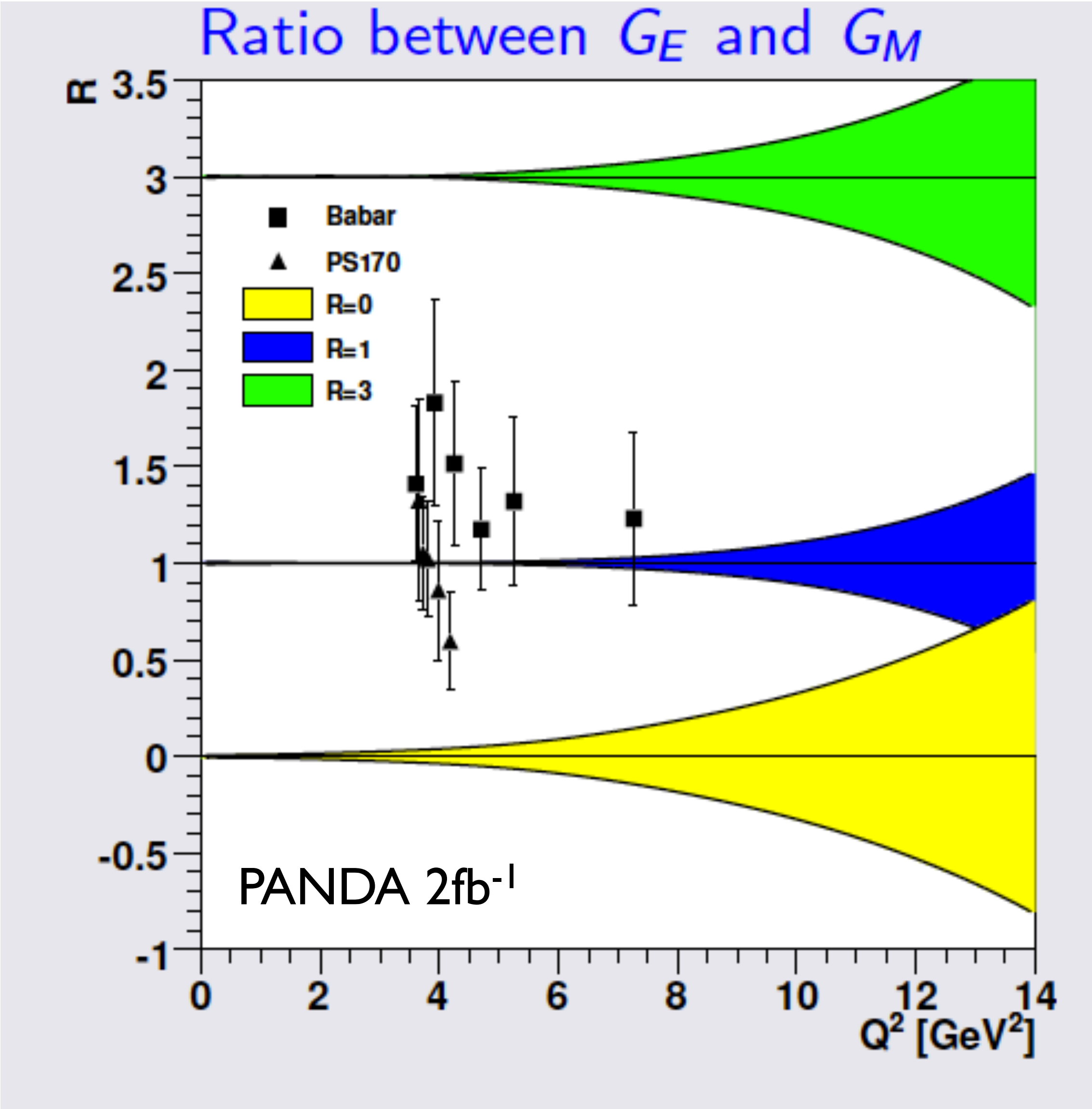








Time Like Electromagnetic Form Factors in PANDA



Extension to other Observables

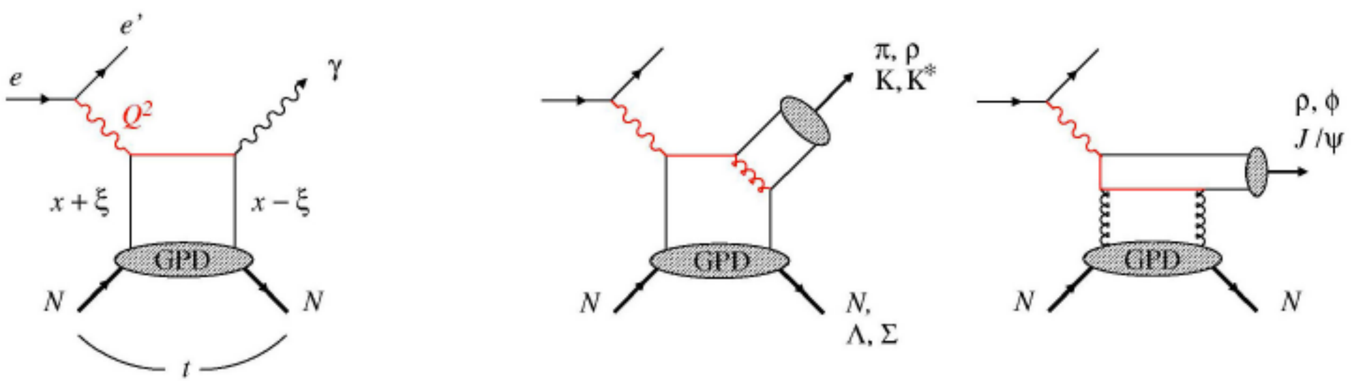
$$\bar{p}p \to e^+e^-\pi^0$$

Generalized Parton Distributions and Transition Distribution Amplitudes (scattering)

- Factorization theorems for DVCS and HMP: amplitude can be presented as convolution of parton level amplitudes and GPDs

Generalized Bjorken limit:

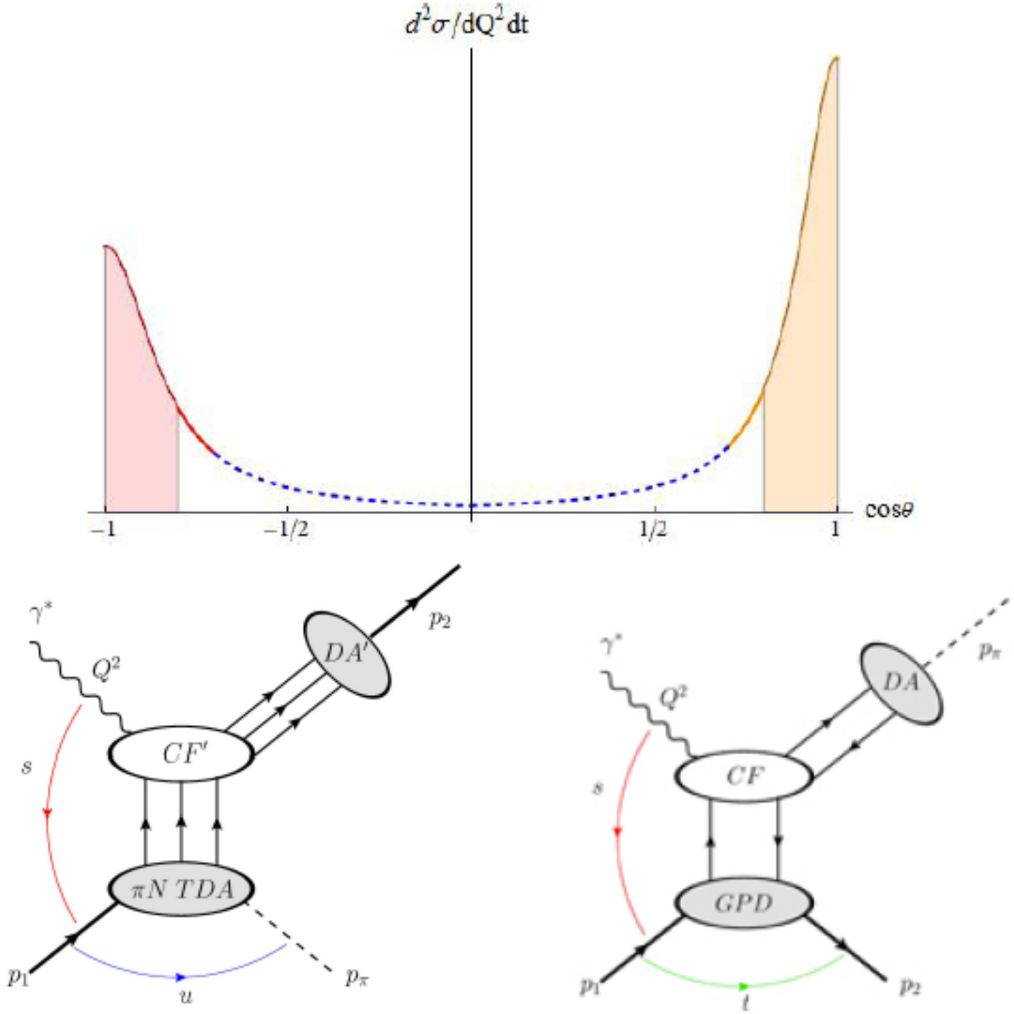
Q^2, W^2 – large x_B – fixed ;
$-t \equiv -(p' - p)^2$ – small
(compared to Q^2 and W^2)



Generalized Bjorken limit ($-q^2 = Q^2$, W^2 – large; $x_B = \frac{Q^2}{2p \cdot q}$ – fixed)

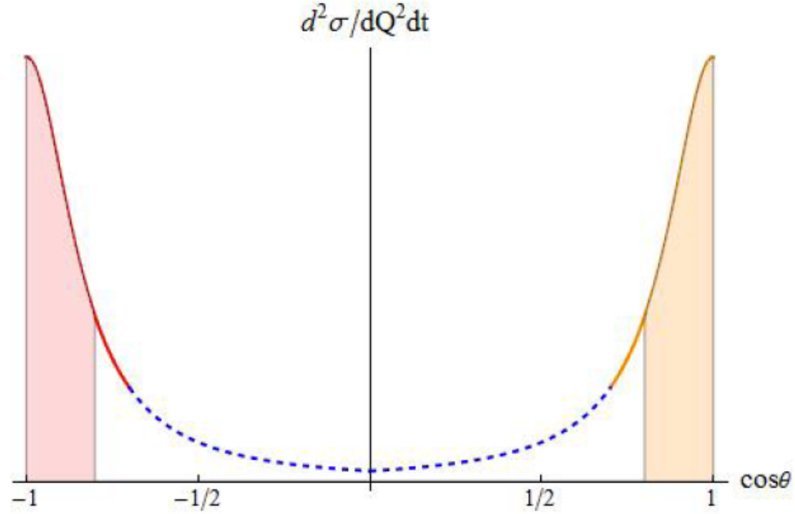
- $t \sim 0$ (forward peak) factorized description in terms of GPDs
- $u \sim 0$ (backward peak) factorized description in terms of TDAs (L. Frankfurt, M. V. Polyakov, M. Strikman et al.'02; B. Pire, L. Szymanowski'05)

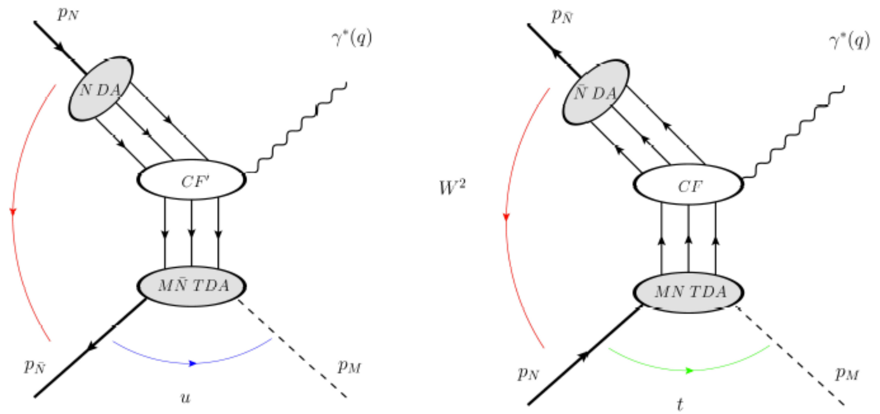
Generalized Parton Distributions and Transition Distribution Amplitudes (scattering)



Generalized Parton Distributions and Transition Distribution Amplitudes (annihilation)

- Factorized description of $\bar{N}N \to \ell^+\ell^- M$ in terms of MN TDAs for near forward ($q^2 = Q^2$, W^2 – large, $\frac{q^2}{2p_N \cdot q}$ – fixed, $t \sim 0$) and near backward ($q^2 = Q^2$, W^2 – large, $\frac{q^2}{2p_{\bar{N}} \cdot q}$ – fixed, $u \sim 0$) regimes (Lansberg et al.'07)



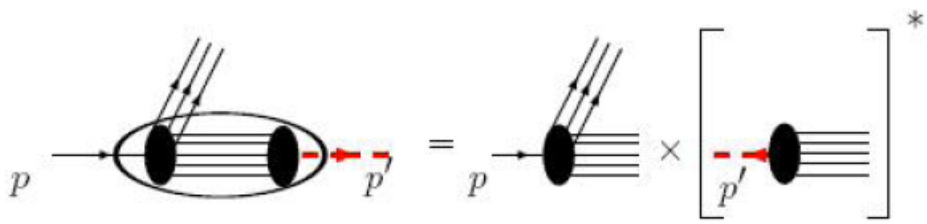


Generalized Parton Distributions and Transition Distribution Amplitudes (annihilation)

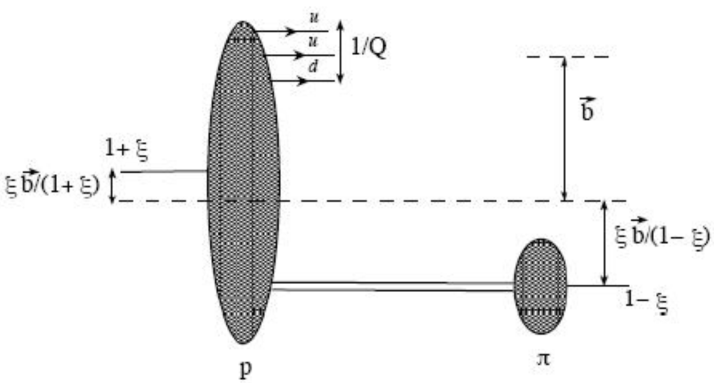
- develop the proton wave function as:

$$\underbrace{|qqq\rangle}_{\text{Described by nucleon DA}} \qquad + |qqq\,\pi\rangle + \ldots$$

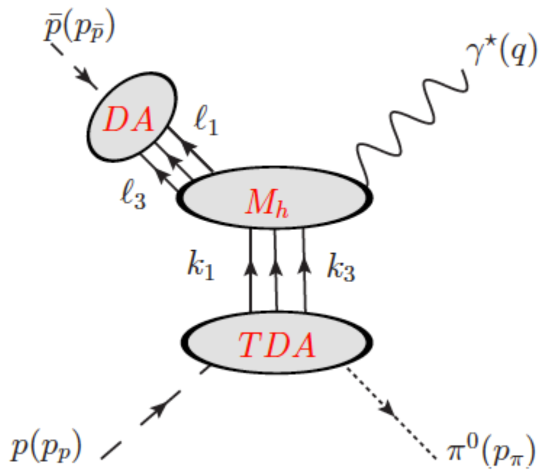
- πN TDAs provides information on the next to minimal Fock state in the baryon;



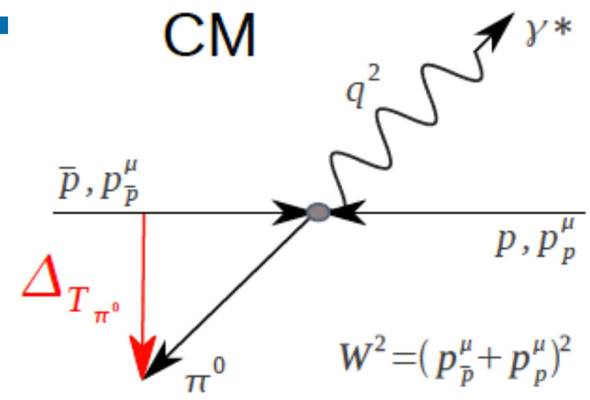
- Impact parameter space interpretation: the Fourier transform $\Delta_T \to b_T \Rightarrow$ transverse picture of pion cloud in the proton



Transition Distribution Amplitudes

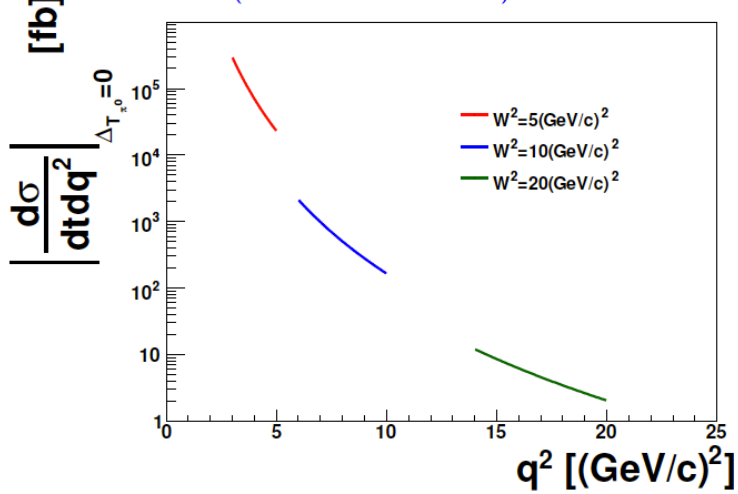


$\bar{p}p \rightarrow e^+e^-\pi^0$



Input for the Event Generator

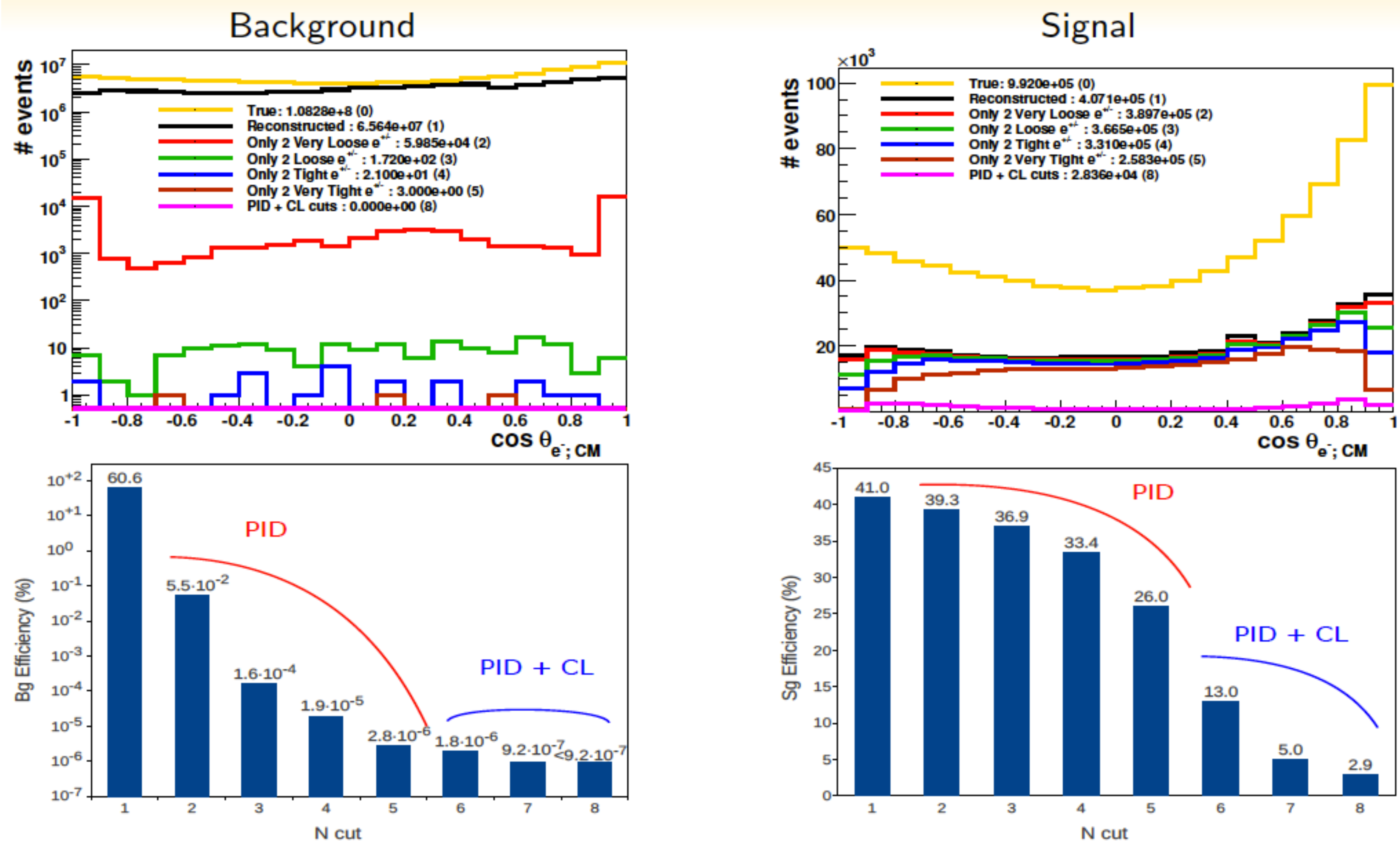
(for Babar-like framework)



Background: $\bar{p}p \rightarrow \pi^+\pi^-\pi^0$

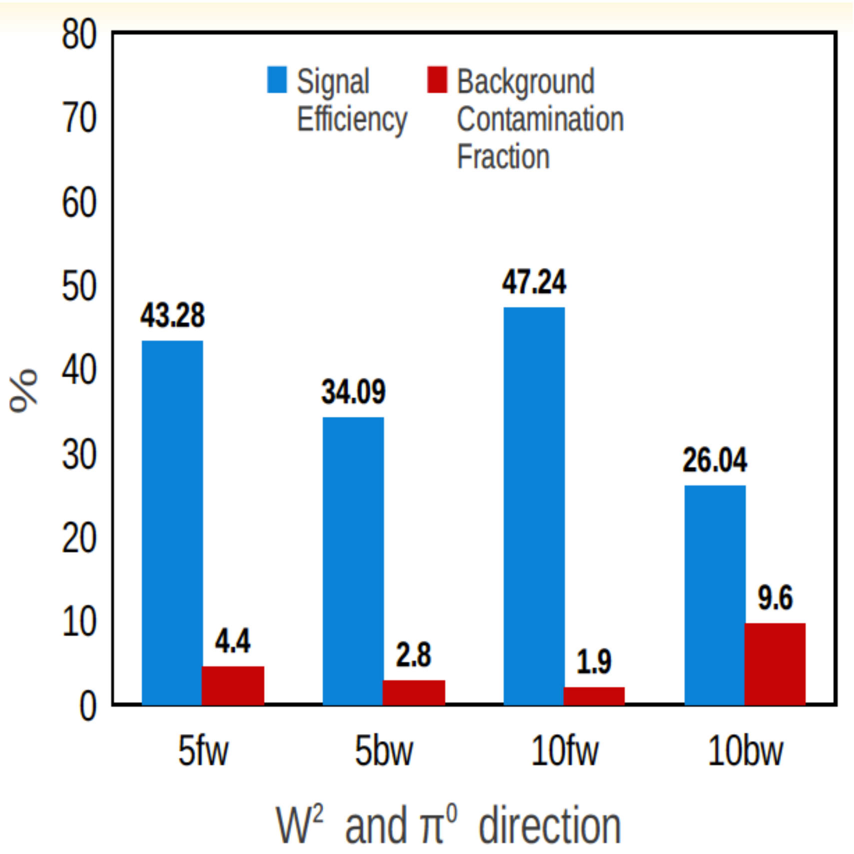
- No data
- The same angular distribution as the signal
- 10^6 times higher

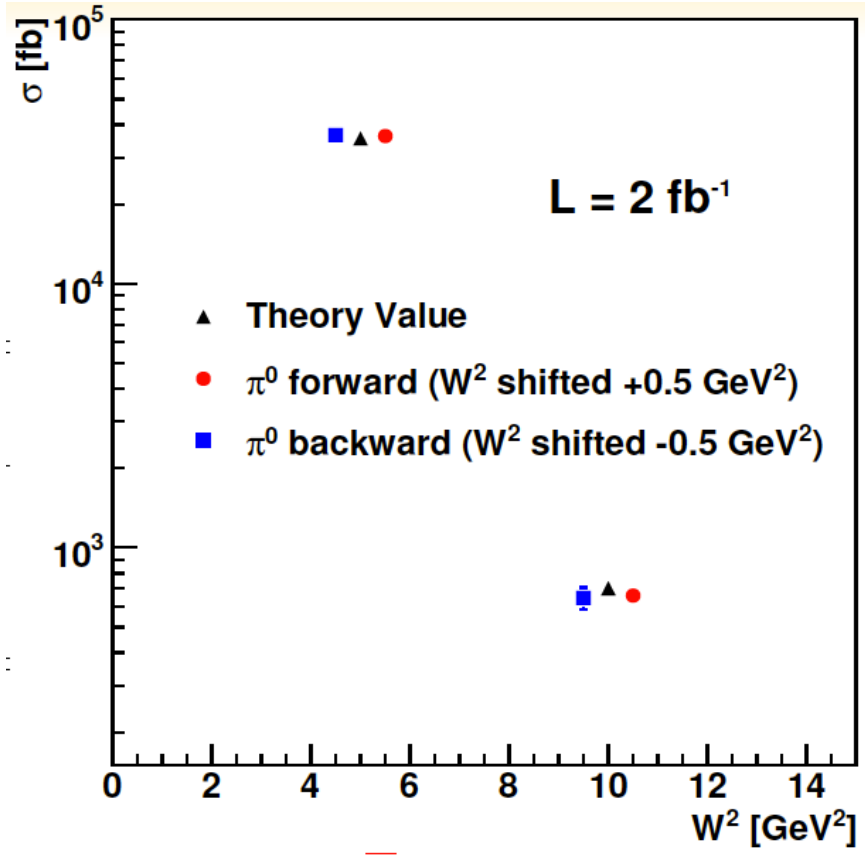
Transition Distribution Amplitudes



PID+CL: Only 2 Very Loose $e^{+/-}$ + $CL(e) > 10^{-3}$ + $CL(e) > 3 \cdot CL(\pi)$

Transition Distribution Amplitudes





Summary: Perspectives are Excellent

FAIR will be the main national laboratory for strong interaction Studies at all length scales: PANDA-experiment 1 of 4 Pillars

New at GSI: Antiproton beams for spectroscopy

Explore electromagnetic probe in antiproton annihilation

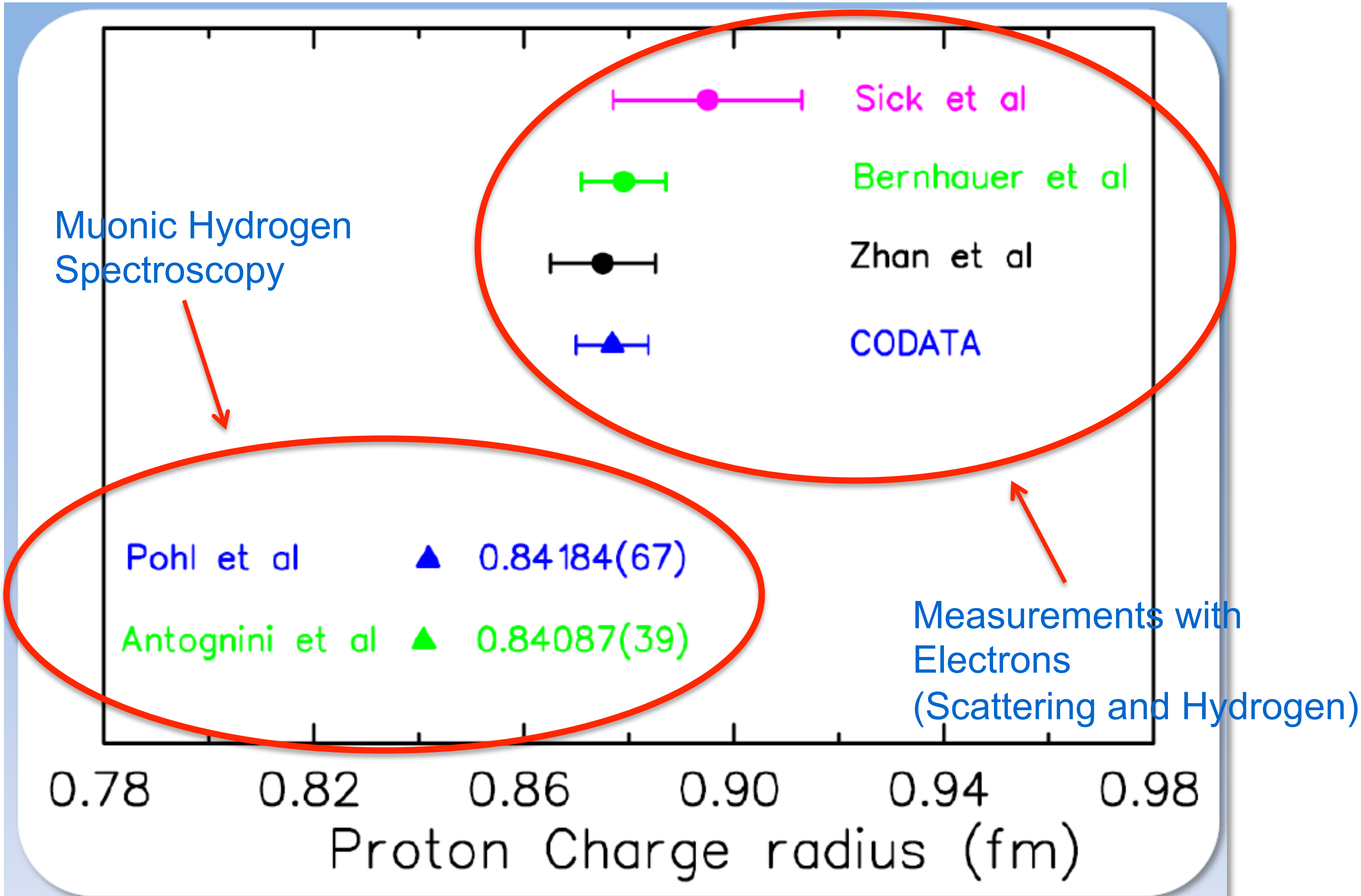
PANDA will deliver data for time like form factors with unprecedented accuracy

Electromagnetic probe accessible at PANDA due to particle id.

Can be used in many other channels

Proton Radius

Proton Radius Puzzle



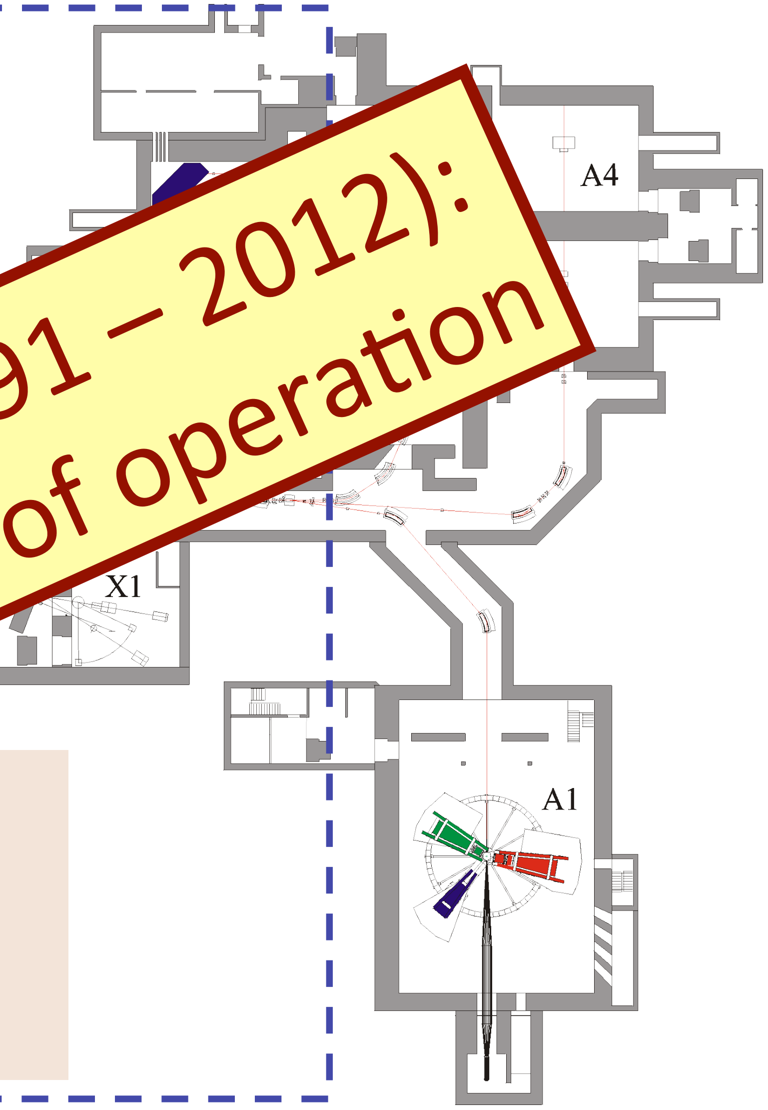
The Mainz Microtron MAMI (Operated by IKP Mainz)

MAINZER MIKROTRON

MAMI-C:

since 2007 in routine operation

→ Beam energy E_{γ}^{max} = 1.604 GeV



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

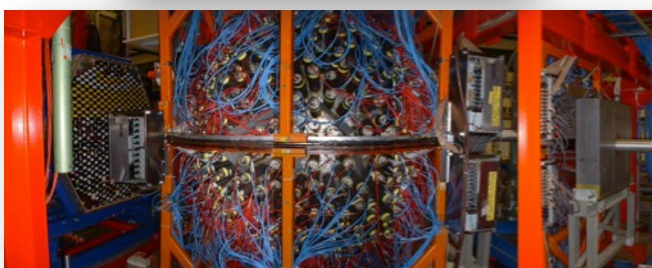
HIGH Intens... µA)
HIGH Resolu... (σ_E<0.100MeV)
HIGH Polarization (ca. 80% Polarization)
HIGH Reliability

Instrumentation at MAMI

A4: Parity violation in elastic ep scattering

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

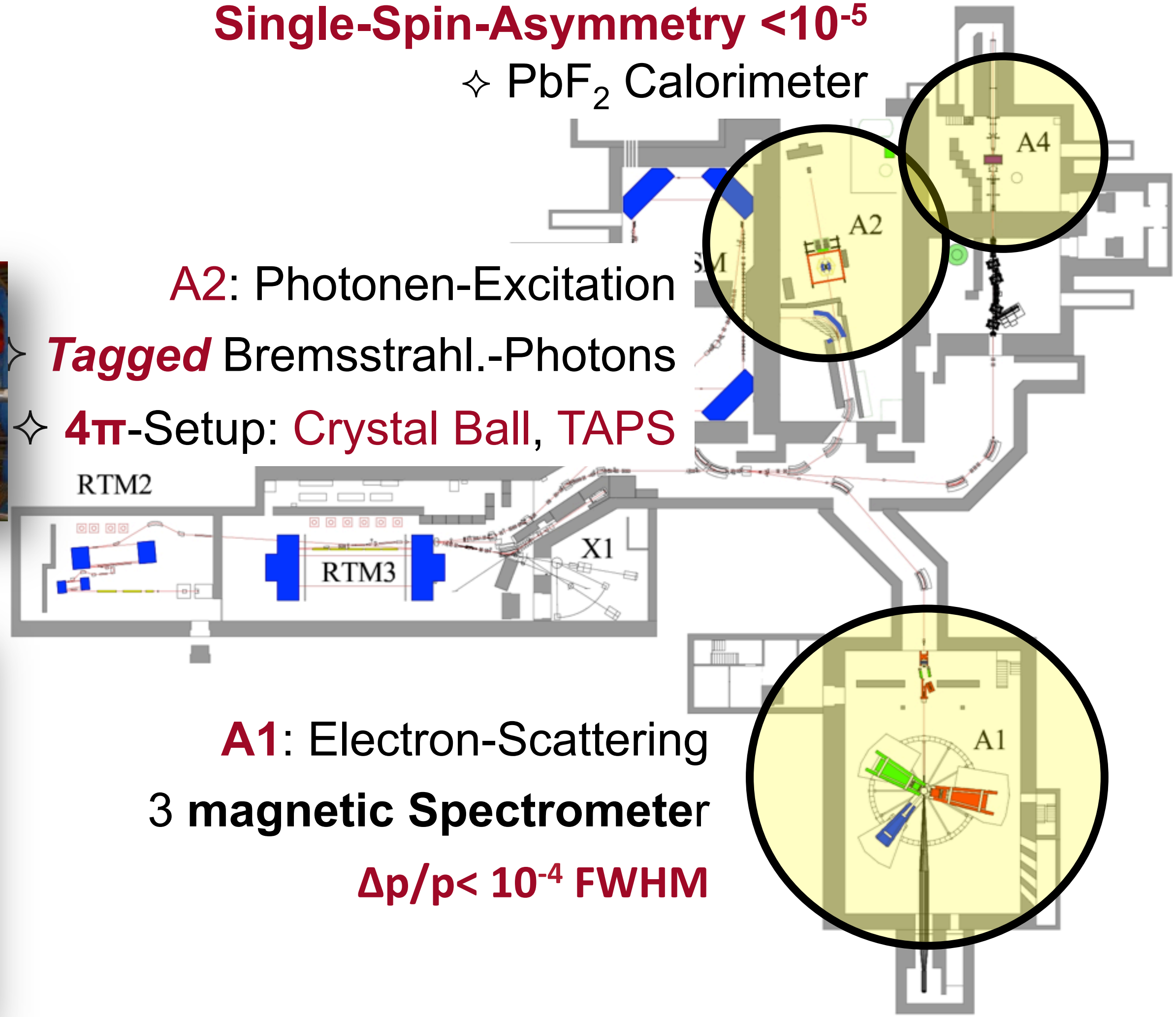
✧ PbF_2 Calorimeter



A2: Photonen-Excitation

✧ ***Tagged*** Bremsstrahl.-Photons

✧ **4π**-Setup: Crystal Ball, TAPS



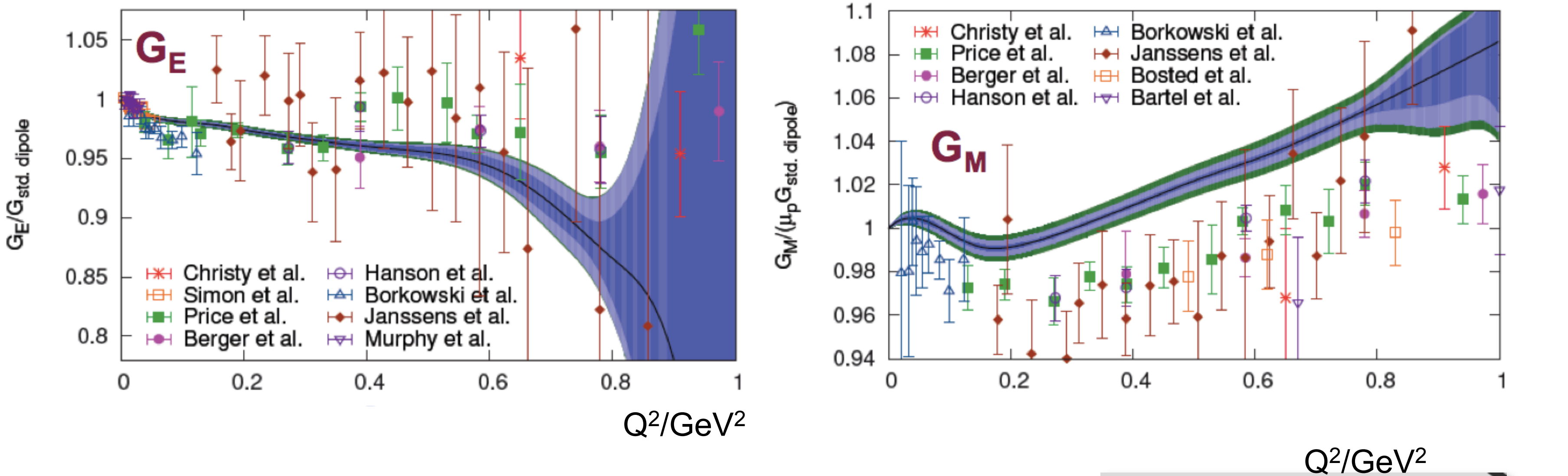
A1: Electron-Scattering

3 **magnetic Spectromete**r

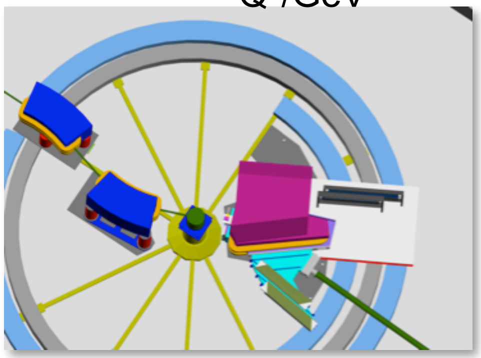
Δp/p< 10^{-4} FWHM

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



- **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:

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

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

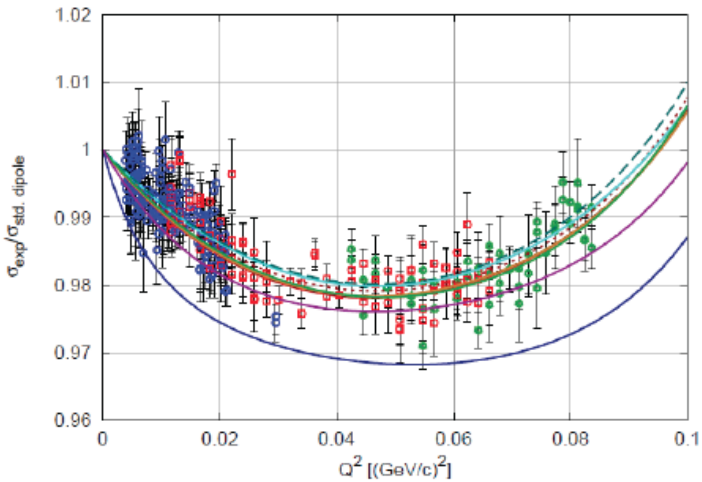
- Extraction of FF via Rosenbluth, Super-Rosenbluth Separation:

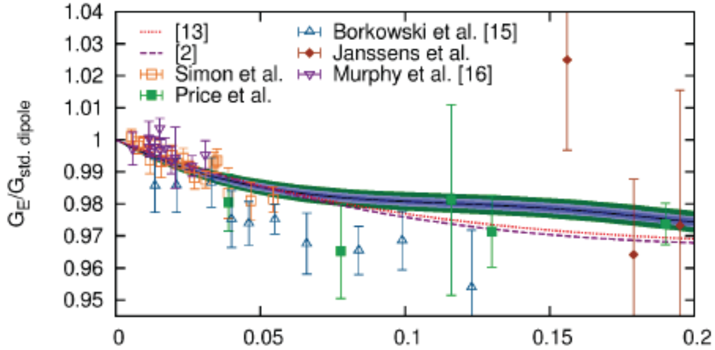
$$G_E(Q^2) \approx G^{Dipole}(Q^2) = \left(1 + \frac{Q^2}{0.71}\right)^{-2}$$

- Best estimate for radius:

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

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

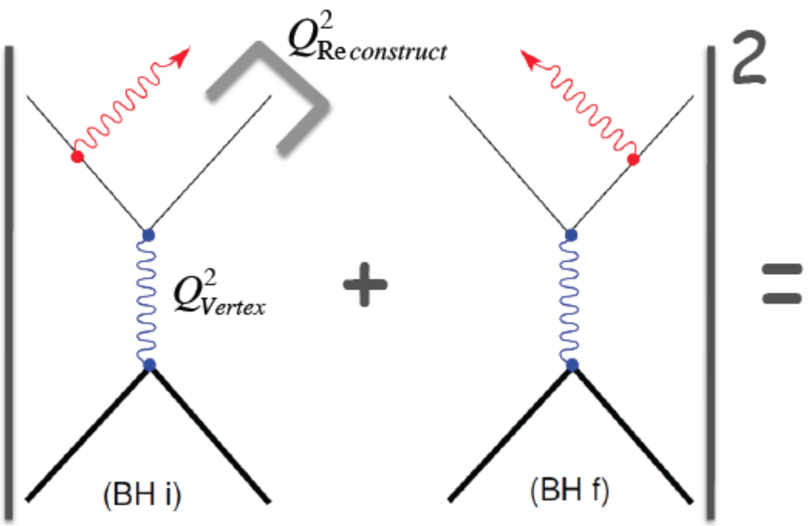


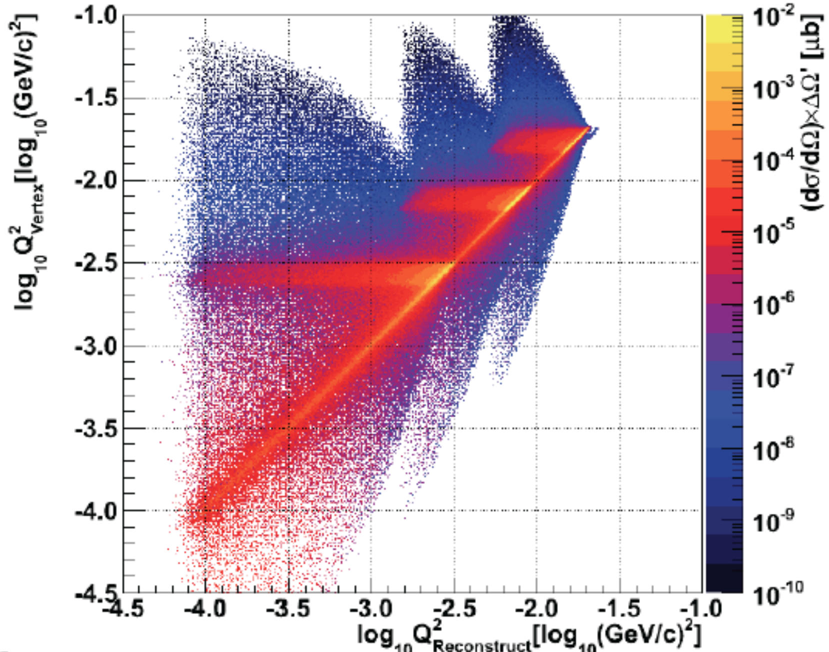


No data at lowest Q^2. Determination of proton radius depends on the slope of FF (Q^2->0).

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.

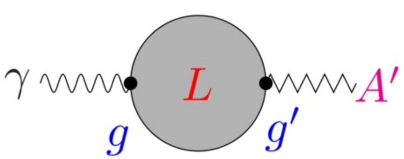
Search for a Dark Photon

"Dark Photon"

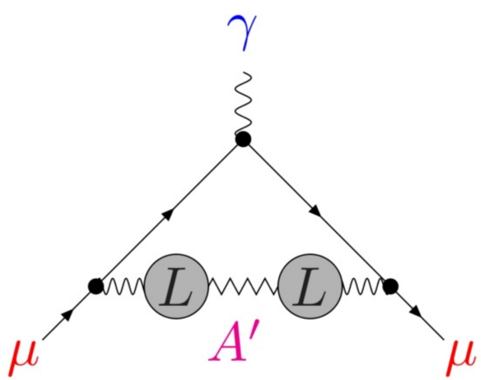
- "Dark Photons":
  - Gauge bosons of additional gauge groups in SM extensions
  - Couple to heavy fermions in dark matter models – **"messengers"**
  - Dark photon masses in MeV range can explain astrophysical anomalies

- Kinetic mixing mechanism couples dark sector to SM fermions

$\varepsilon = g'/g$



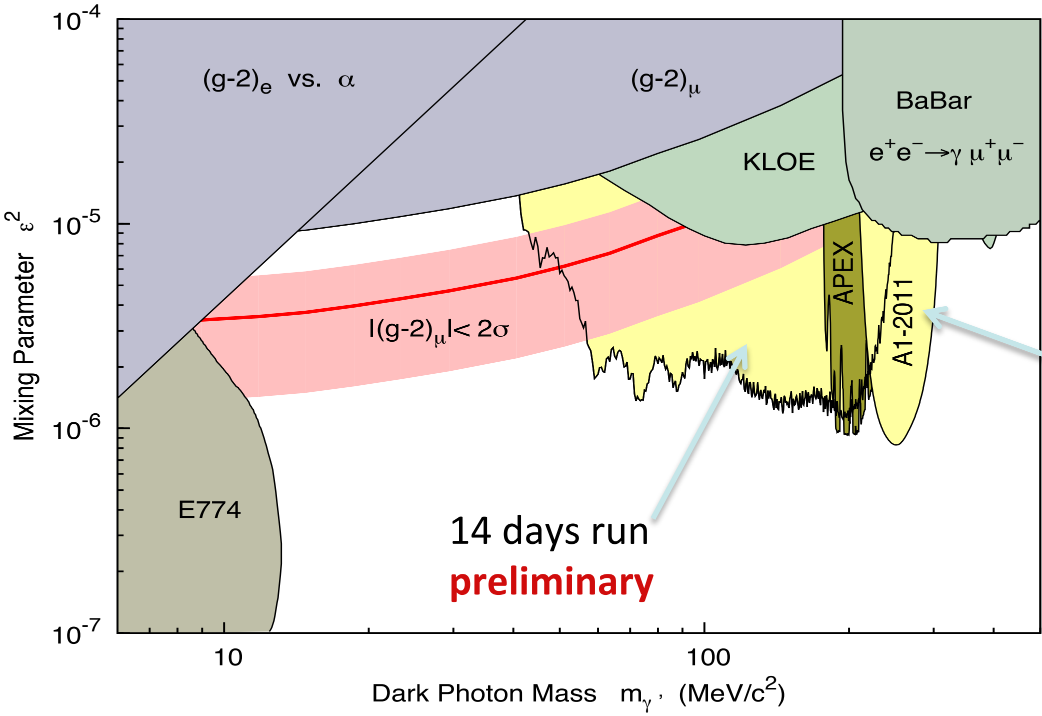
- Dark photons may explain the tension in a_μ



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 $(g-2)_\mu$

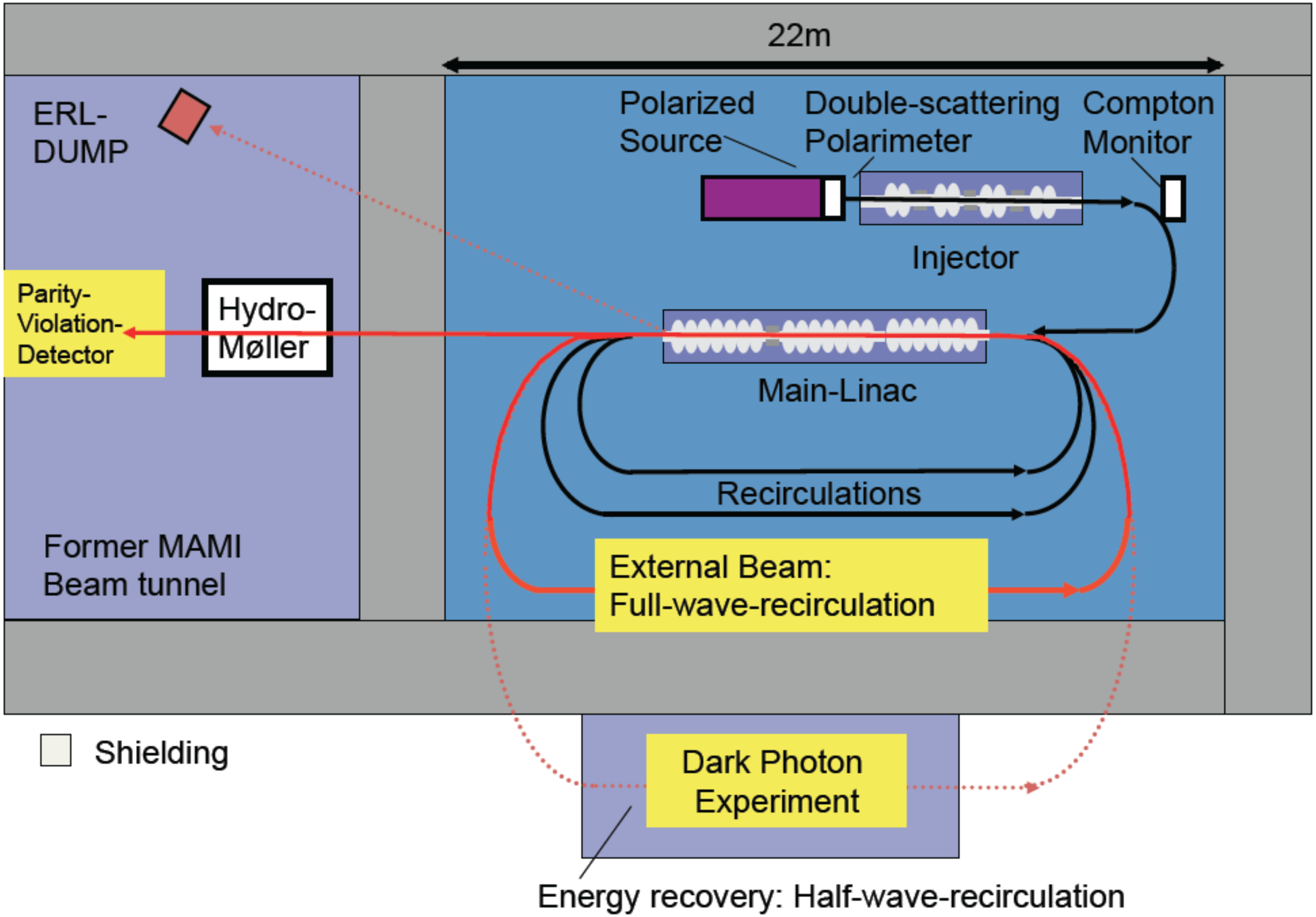


Exclusion range from **MAMI / A1 spectrometers** during **4-day pilot run**

A1/MAMI
Merkel et al. PRL 2011

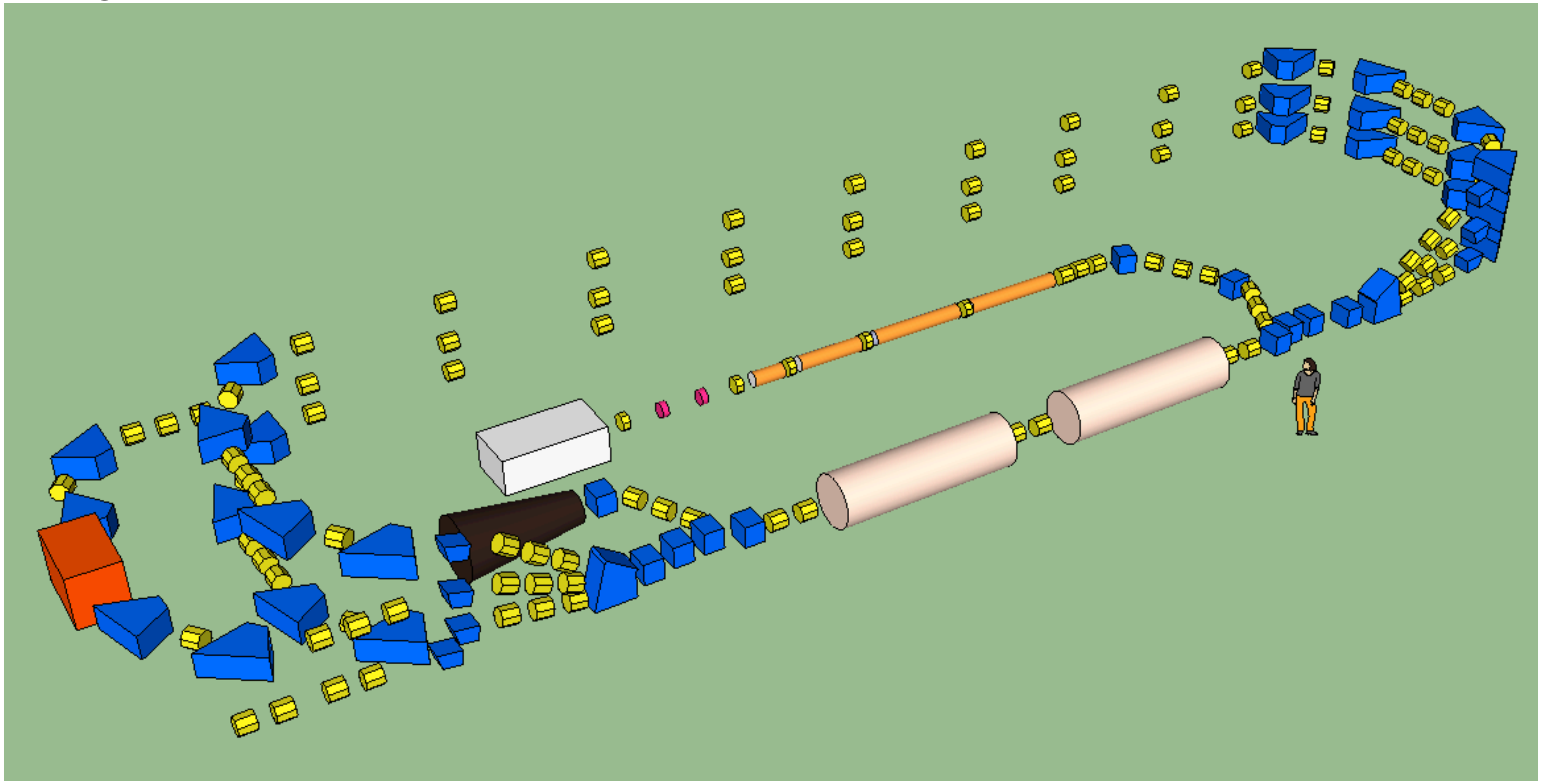
- Future: Low mass region <50 MeV/c^2 and small dark photon coupling ε^2

Mainz Energy-recovering Superconducting Accelerator (MESA)



Mainz Energy-recovering Superconducting Accelerator (MESA)

Design: Ralf Eichhorn

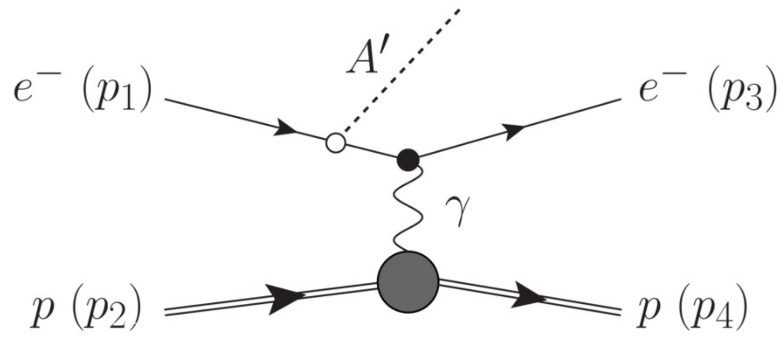


"A must-do facility … for the price of an experiment"

(W.J. Marciano, 2011 MESA workshop)

Experimental searches for Dark Photons

- Production of dark photons in scattering



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

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

  [Merkel et al. , 2011]

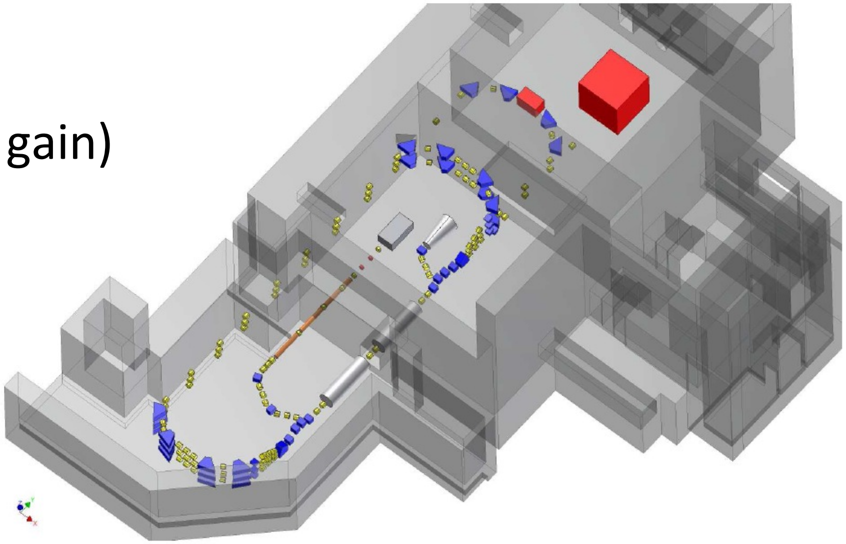
- Flagship experiment at MESA: Very thin hydrogen target, large current

- Other efforts: APEX experiment / DarkLight Proposal @ JLab

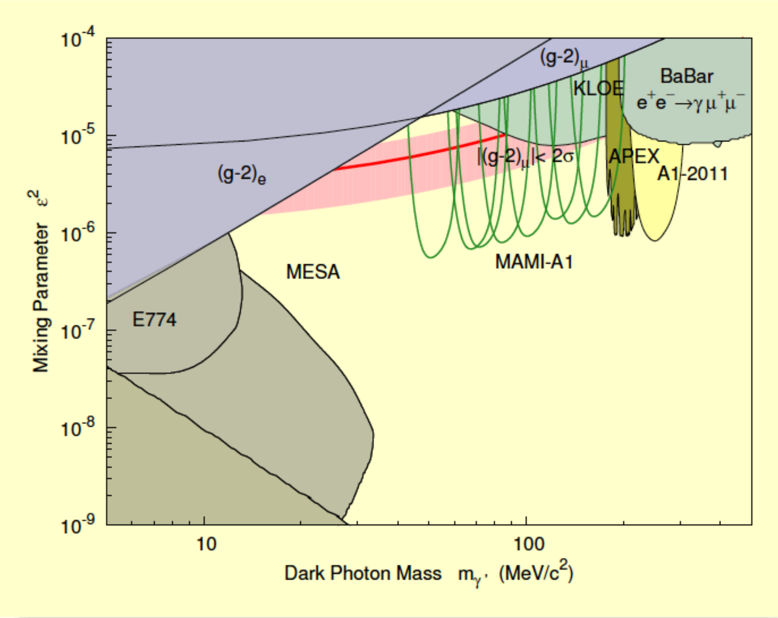
Accelerator MESA: key initiative in PRISMA

<u>M</u>ainz <u>E</u>nergy-Recovering <u>S</u>uperconducting <u>A</u>ccelerator
High-Intensity Electron Accelerator: 200 MeV @ >1 mA current

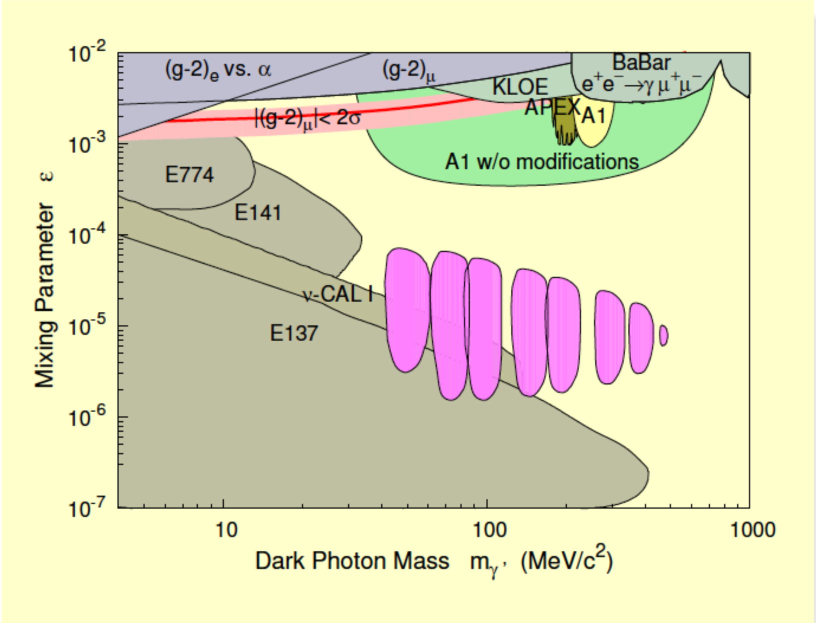
- **Location: existing halls of Institute** (former A4 hall)
- **Challenging accelerator project**
  → superconducting technology (50 MeV gain)
  → Energy-Recovering (ERL) technology
- **Frontier experiments**
  - Precision measurement of $\sin^2\Theta_W$
    → extracted beam mode
  - Search for the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



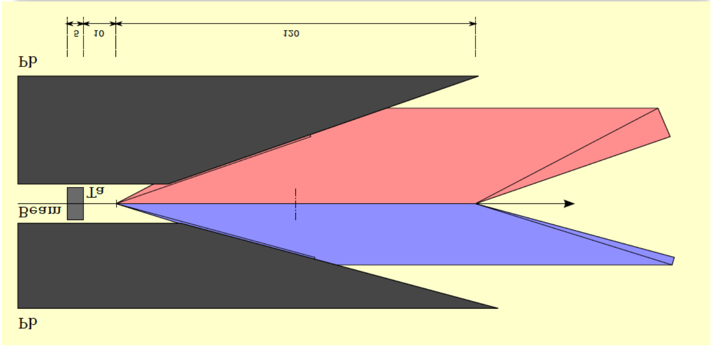
Experimental searches for Dark Photons at MAMI



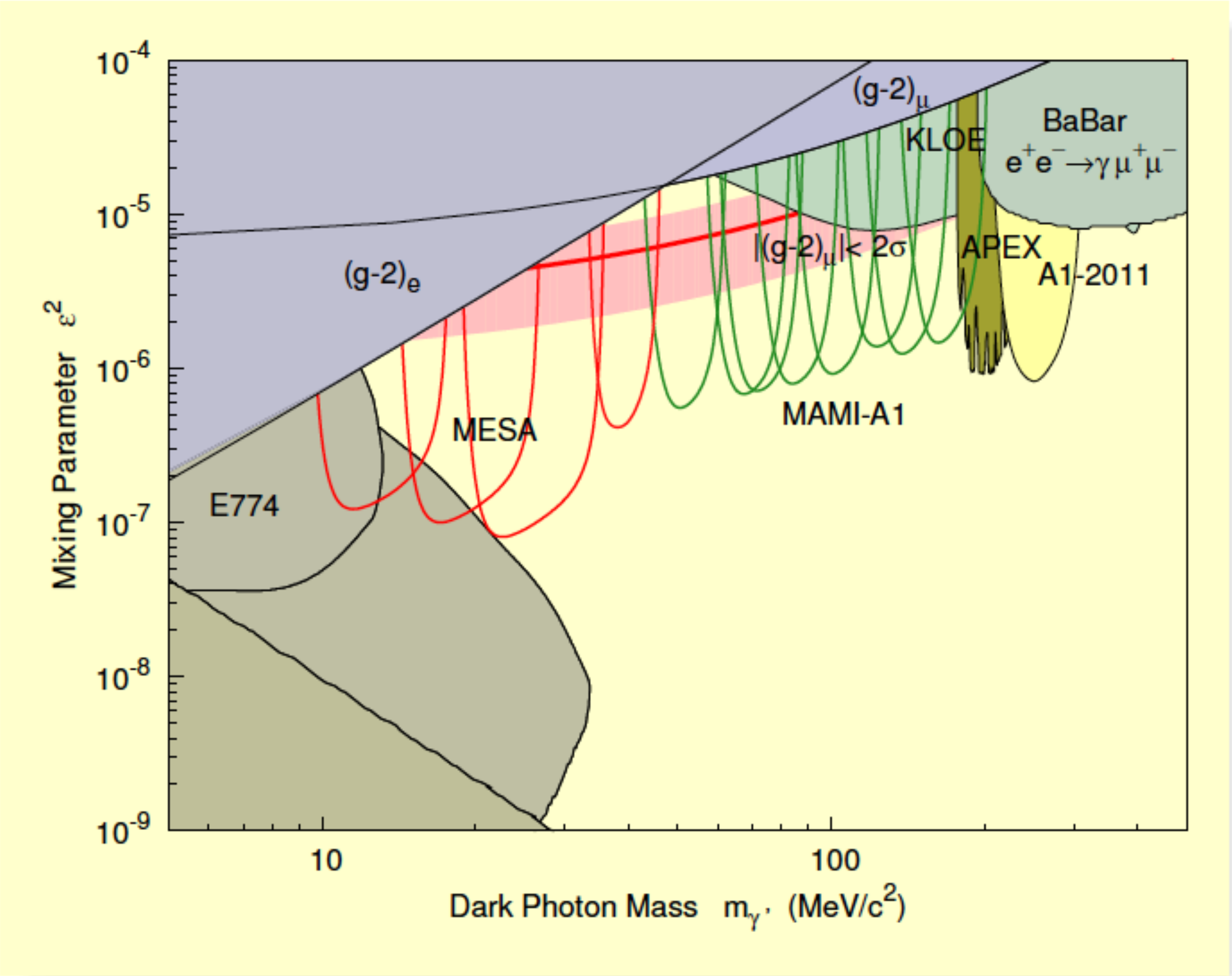
Data taken



Displaced vertex: future Experiment



Experimental searches for Dark Photons with MESA

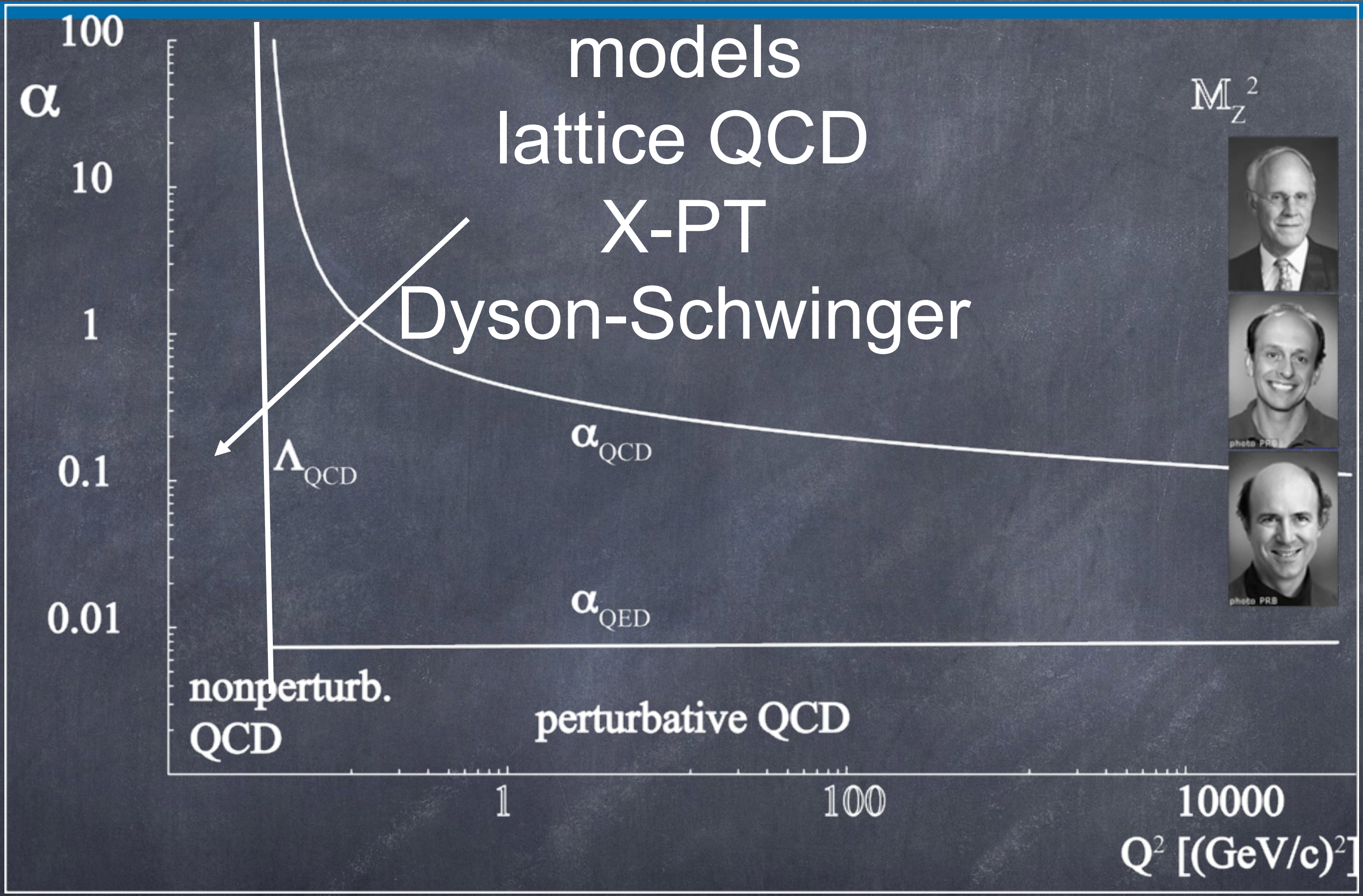


Parity violating electron scattering

a) strangeness in the nucleon

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

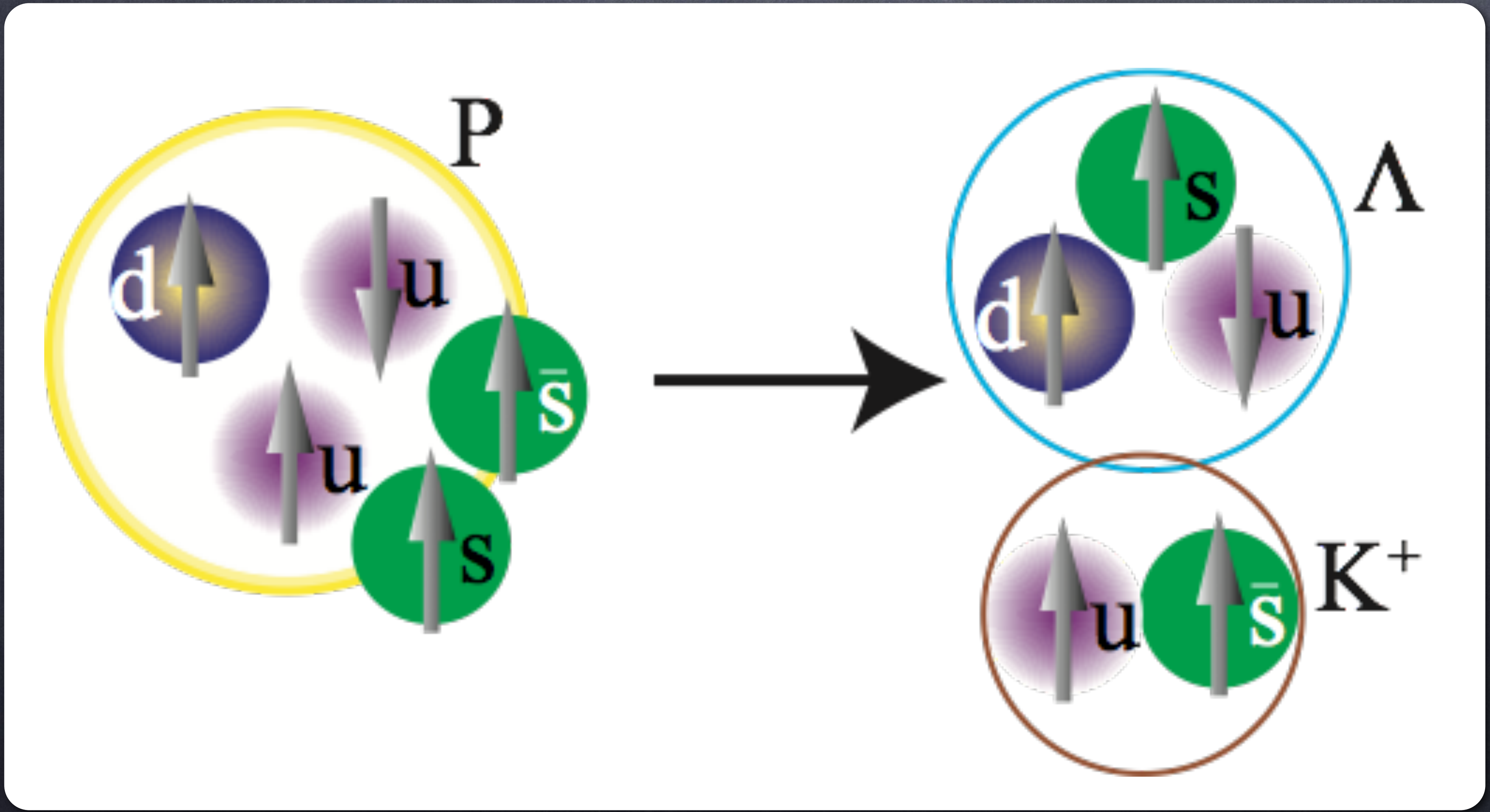
QCD-Renormalisation à la QED



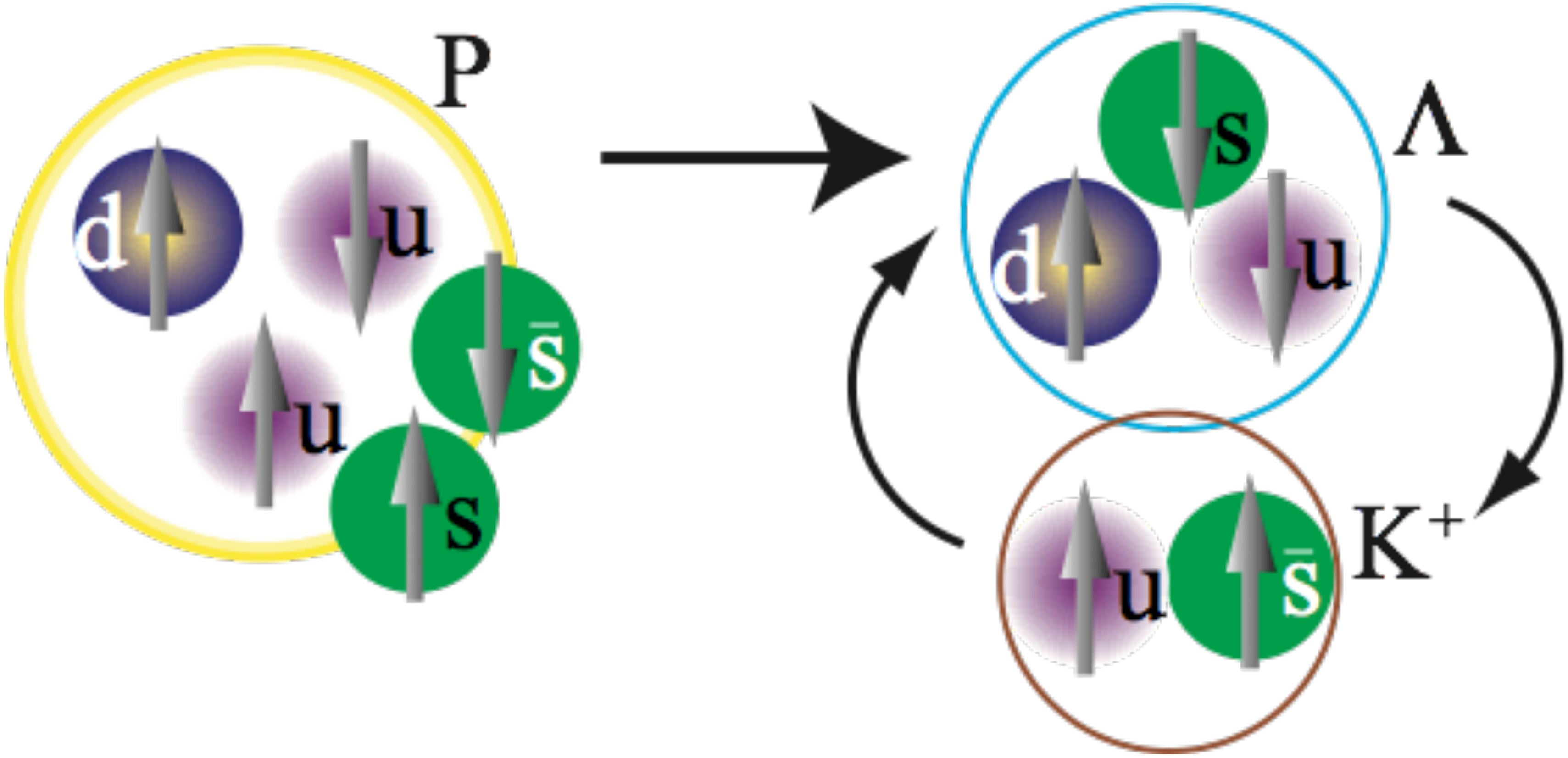
$m_u, m_d << m_s \approx \Lambda_{QCD} << m_c, m_b, m_t$

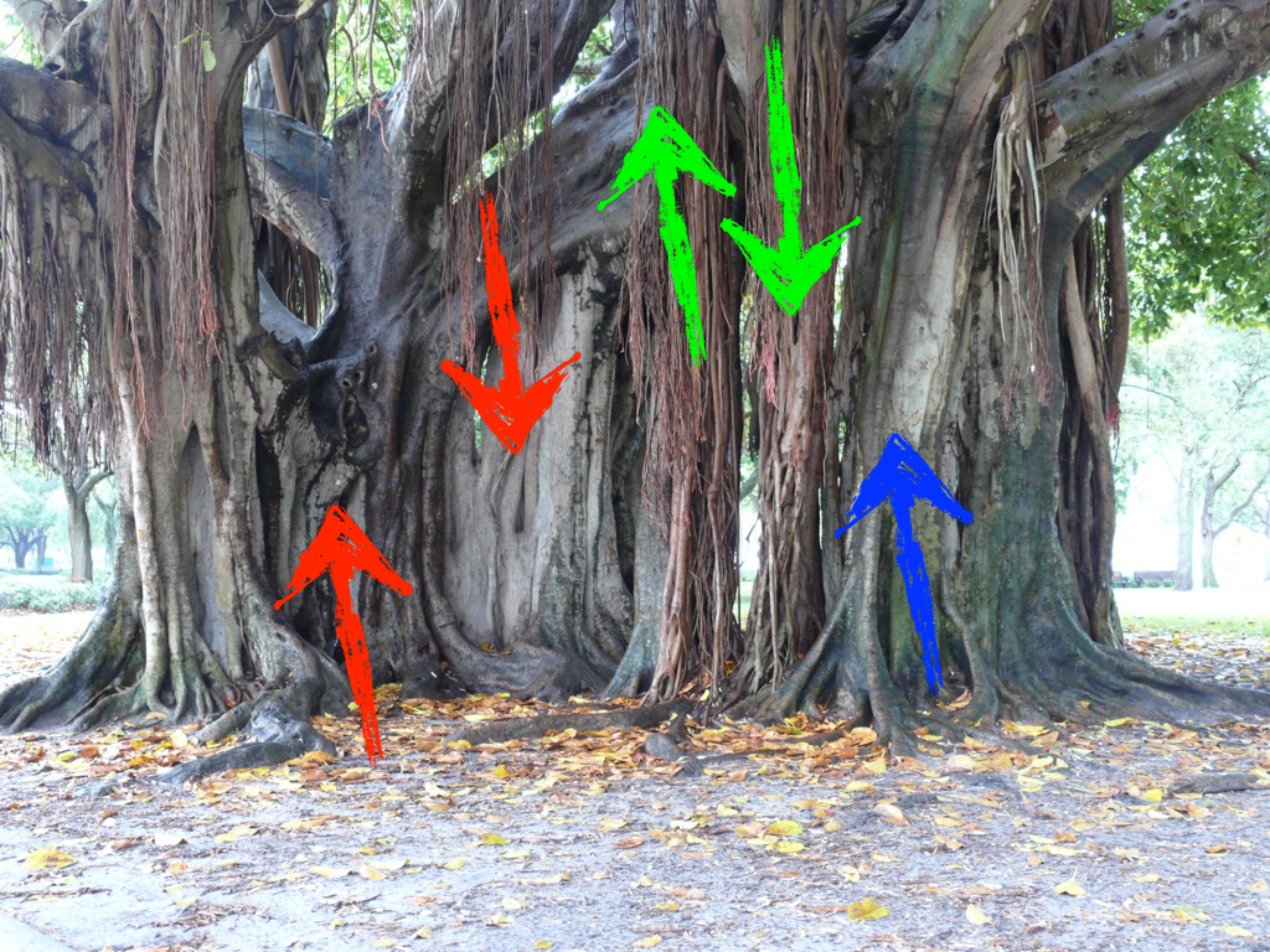
Strangeness as a Laboratory for Virtual Quarks

Contribution to CHARGE distribution (G_E^s)



Contribution to MAGNETISATION distribution (G_M^s)

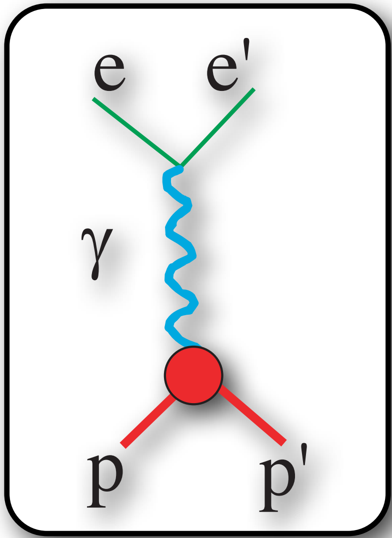




Strangeness in the Nucleon

Vacuum	$\langle 0 \vert \bar{s}s \vert 0 \rangle$	(0.8 ± 0.1) $\langle 0 \vert \bar{q}q \vert 0 \rangle$	QCD sum rules
Momentum	$\int x(\bar{s}+s)dx$	2-4%	DIS ν,μ,e
Mass	$m_s \langle N \vert \bar{s}s \vert N \rangle$	220 MeV	πN-scatt. $\Sigma_{\pi N}$-Term
Spin	$\langle N \vert \bar{s}\gamma_\mu \gamma^5 s \vert N \rangle$	- 10 %	pol. DIS
EM FF G_E^s, G_M^s	$\langle N \vert \bar{s}\gamma_\mu s \vert N \rangle$	???	PVelectron scattering

Elastic Electron Proton Scattering: Born

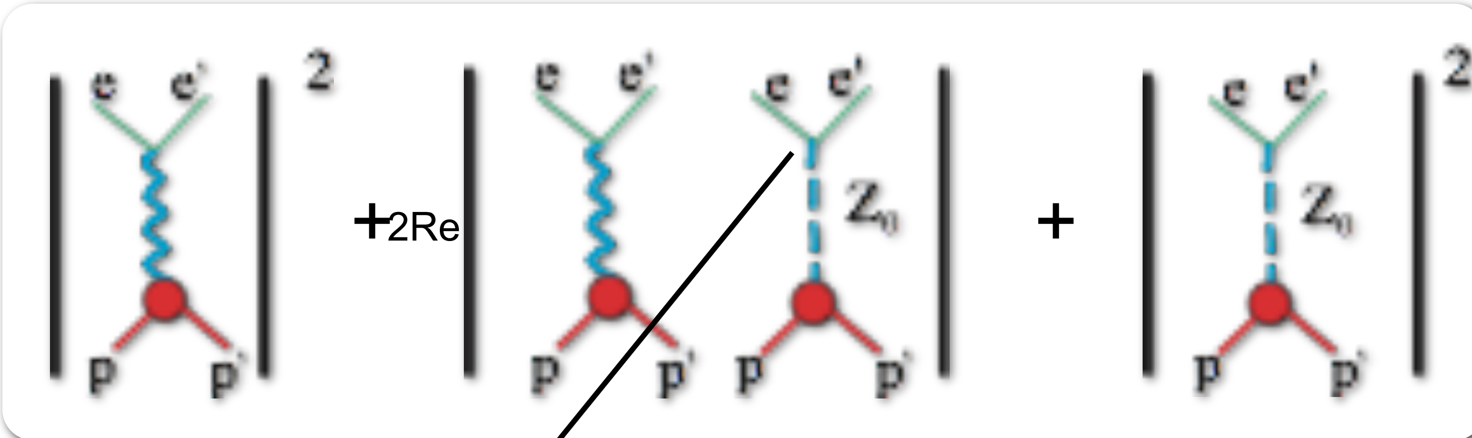


$$\sigma \sim \mathcal{M}\,\mathcal{M}^*$$
$$\sim \left(j_\mu \frac{1}{Q^2} J^\mu\right)\left(j_\mu \frac{1}{Q^2} J^\mu\right)^*$$
$$j_\mu \sim \bar{e}\,\gamma_\mu\, e \quad \text{Vector Current}$$

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

Parity Violation in Electroweak Interaction

$\sigma \approx$



$1 \quad + \quad 10^{-5} \quad + \quad 10^{-10}$

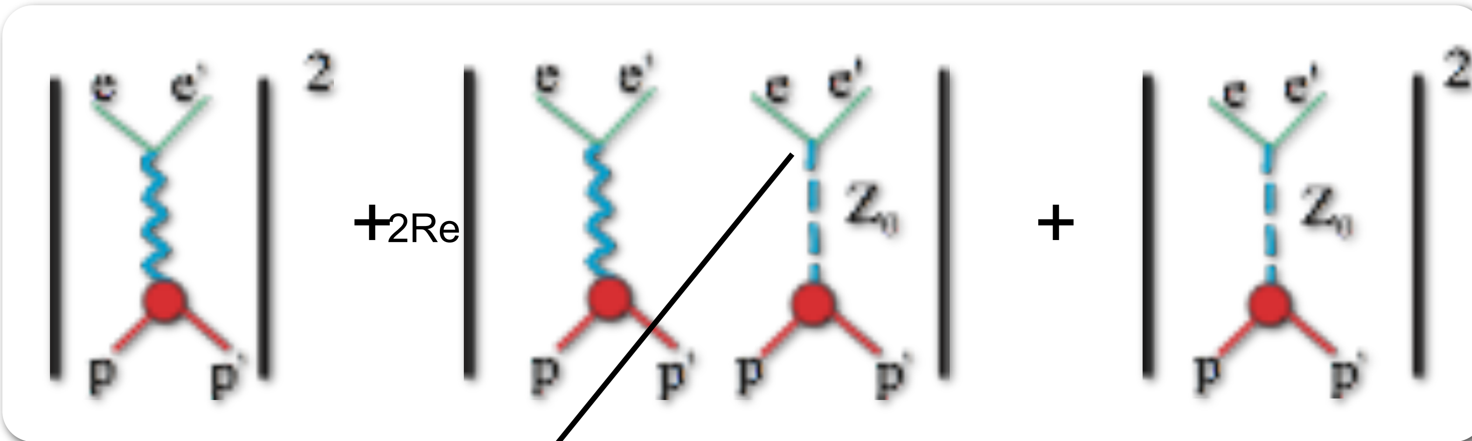
V-A Coupling

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

long. polarised electrons
unpolarised protons

Parity Violation in Electroweak Interaction

$\sigma \approx$

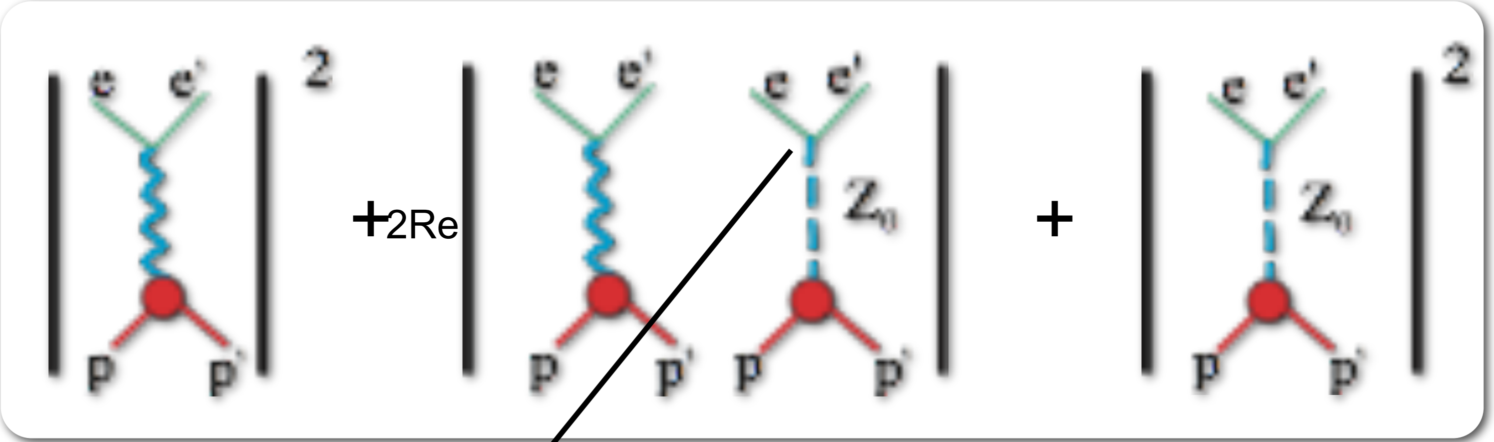


$1 \quad + \quad 10^{-5} \quad + \quad 10^{-10}$

$$A^{PV} \approx \frac{Re(\mathcal{M}_{\gamma}[\mathcal{M}_{Z,R} - \mathcal{M}_{Z,L}]^{*})}{|\mathcal{M}_{\gamma}|^{2}}$$

Parity Violation in Electroweak Interaction

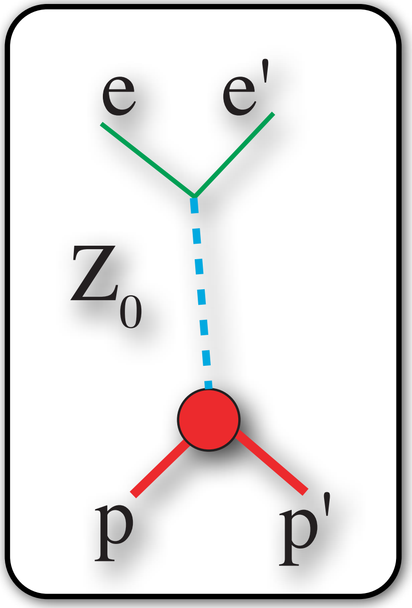
$\sigma \approx$



1 + 10^{-5} + 10^{-10}

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

Electroweak Elastic Electron Proton Scattering: Born



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

weak vector charge

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

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

Parity Violation in Electroweak Interaction + Isospin Symetry

Q_{weak}

EM-Form Factors

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

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

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

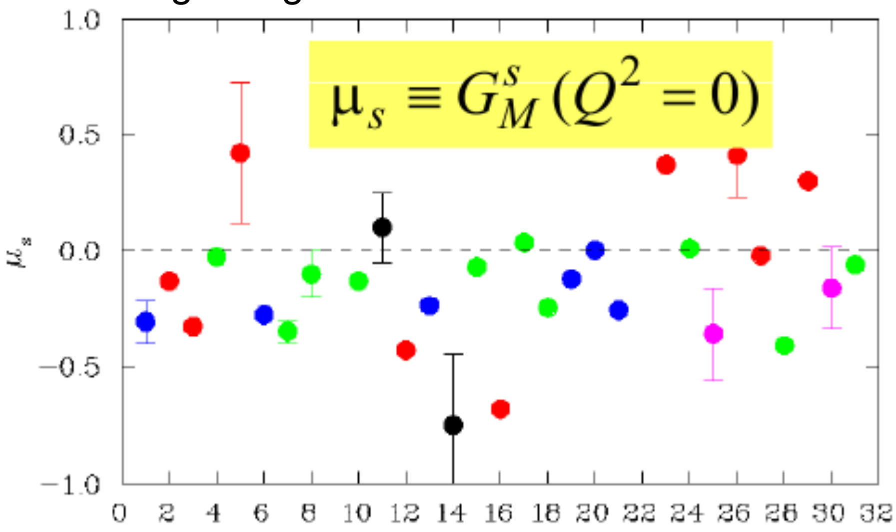
strangeness EM-Form Factors

Axial Form Factor

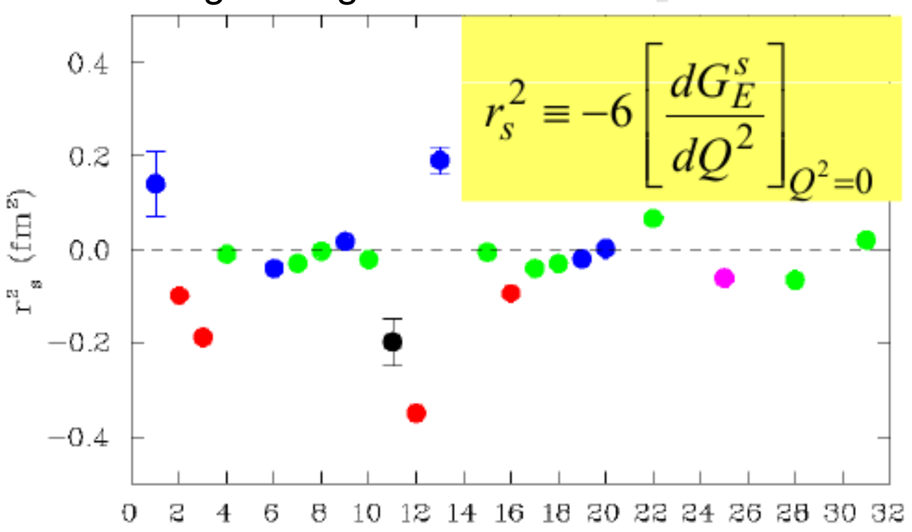
Choose Kinematics so that Terms are Emphasized

Theory Predictions

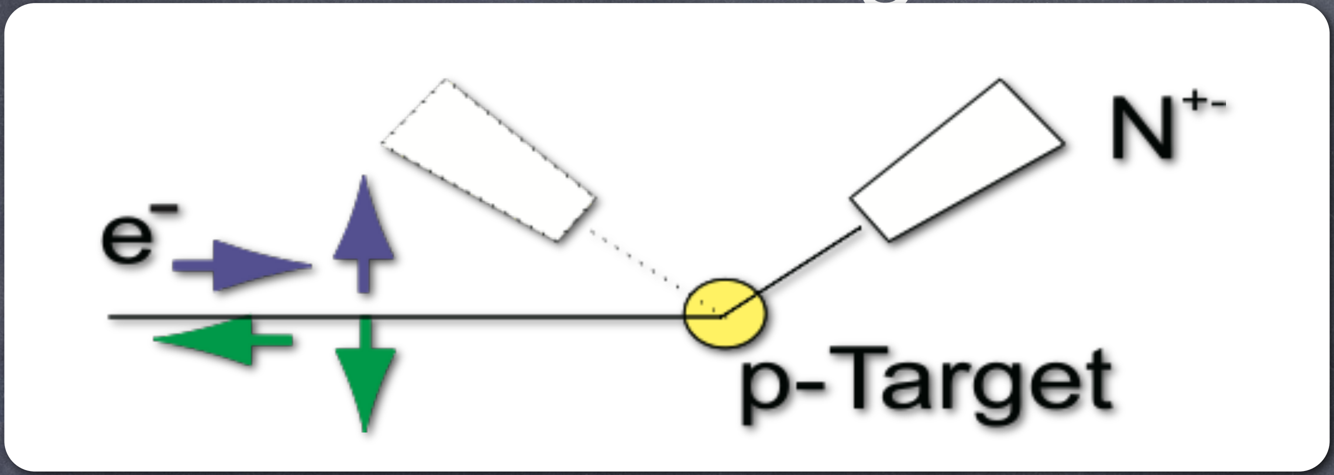
strange magnetic moment



strange charge radius



Statistics: Parity Violating Electron Scattering



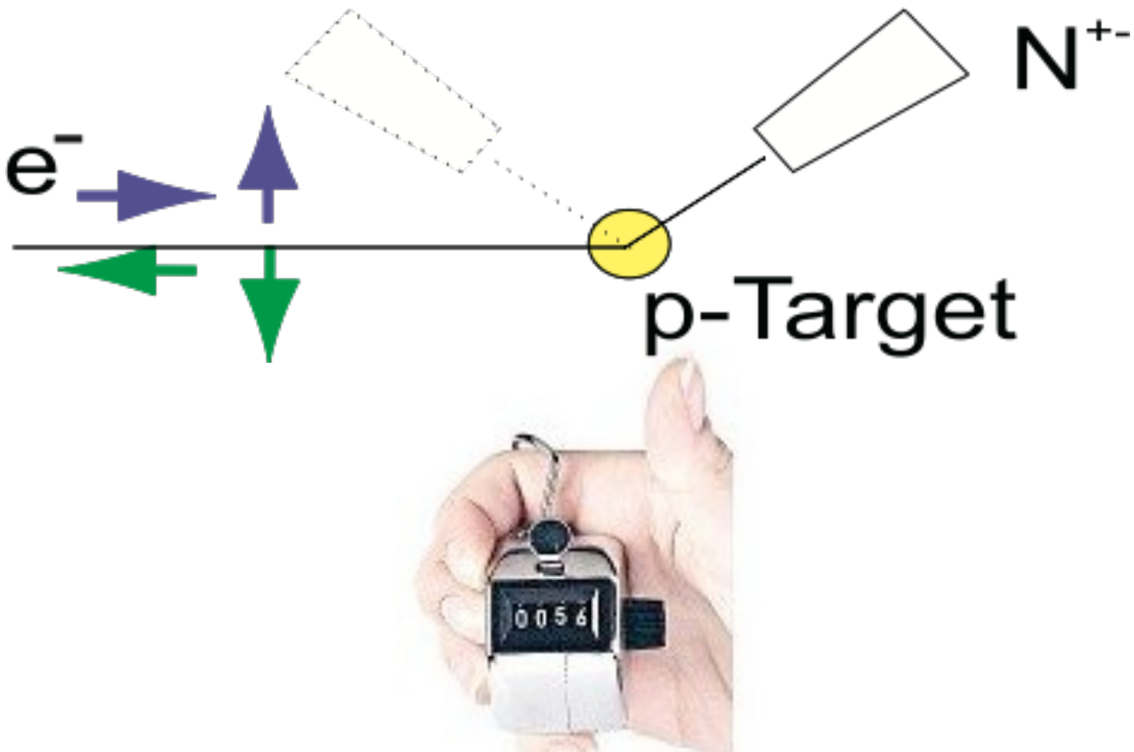
$$A = \frac{N^+ - N^-}{N^+ + N^-}$$

$$\delta A = 1/N^{1/2}$$

Example: $A = 10^{-6}$ Goal: 10% measurement

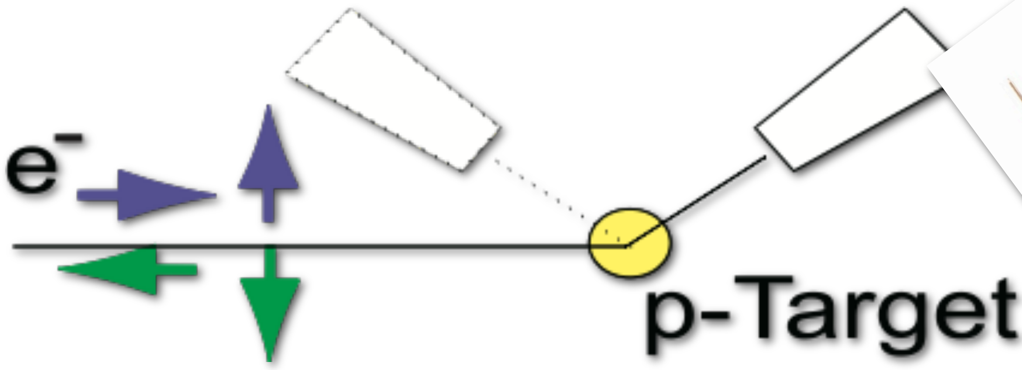
$\delta A = 10^{-7}$ -> $N = 10^{14}$ events

High Statistics: Counting Technique



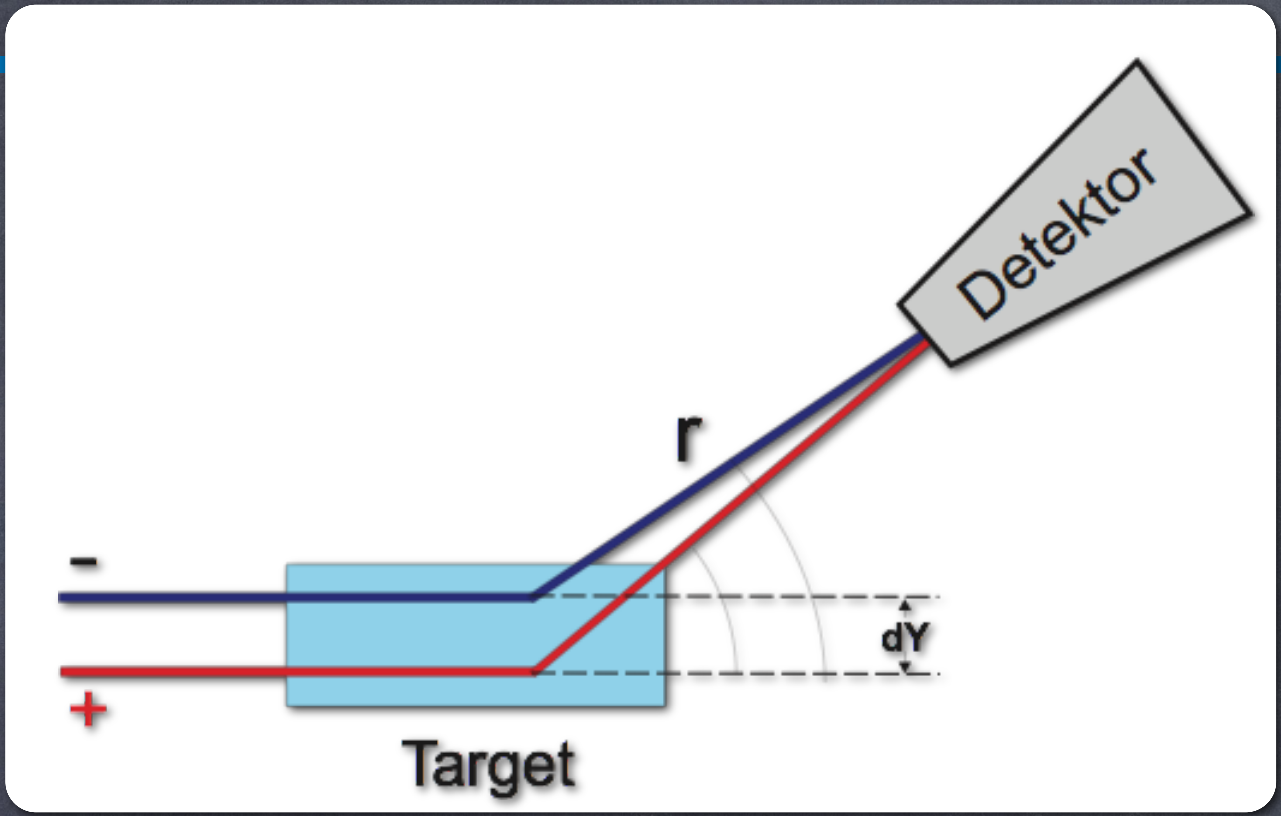
Count scattered electrons:
- pile-up (double count losses)
- Background Asymmetry
- Very Fast Counting (MHz)
- Measure TOF or Energy

High Statistics: Integrating Technique



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

False (Detector) Asymmetries



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

Fluctuations of Beam Parameters

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

Experiments

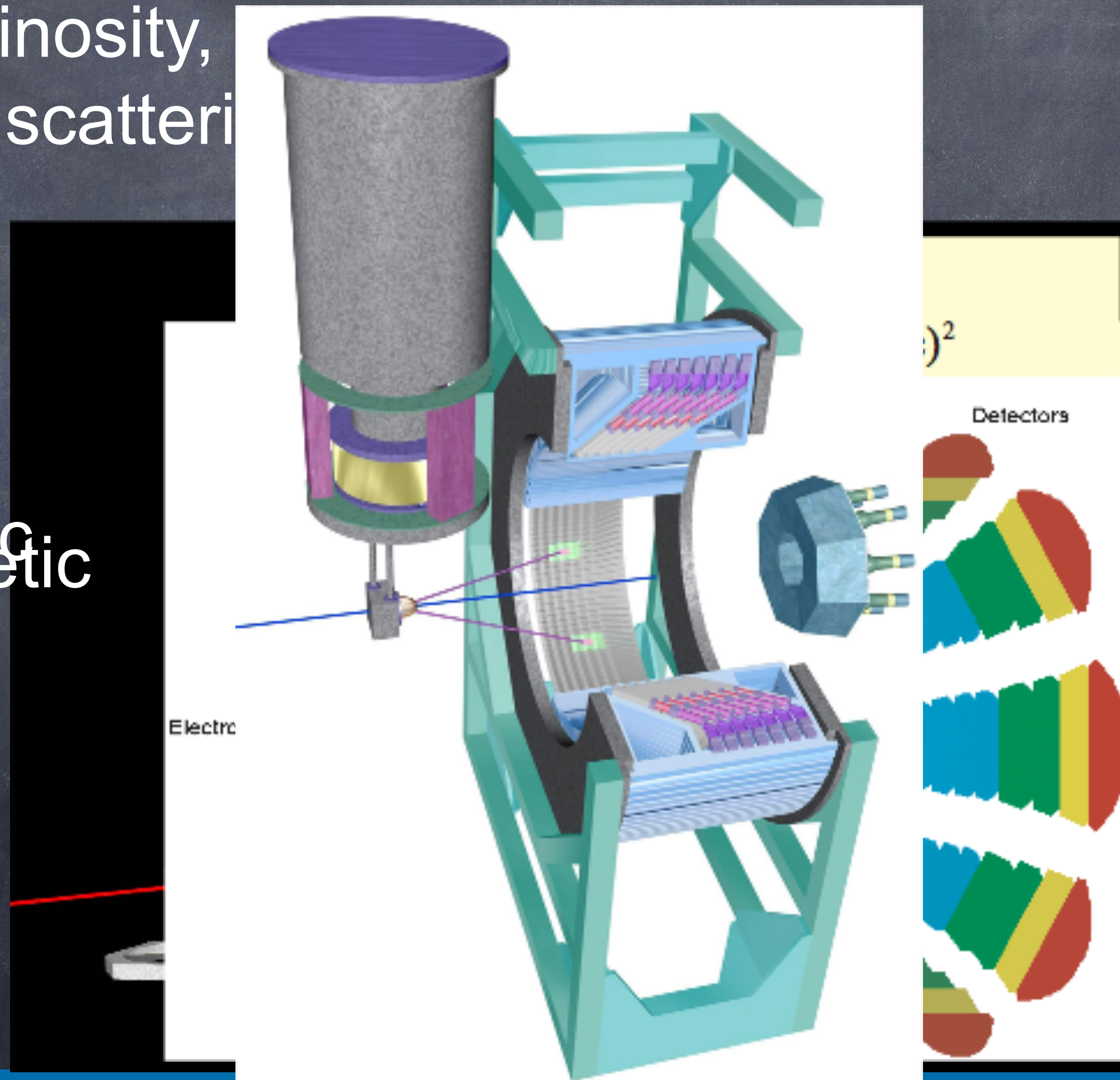
Asymmetries: 10^{-6} -> 10^{14} events

high luminosity,

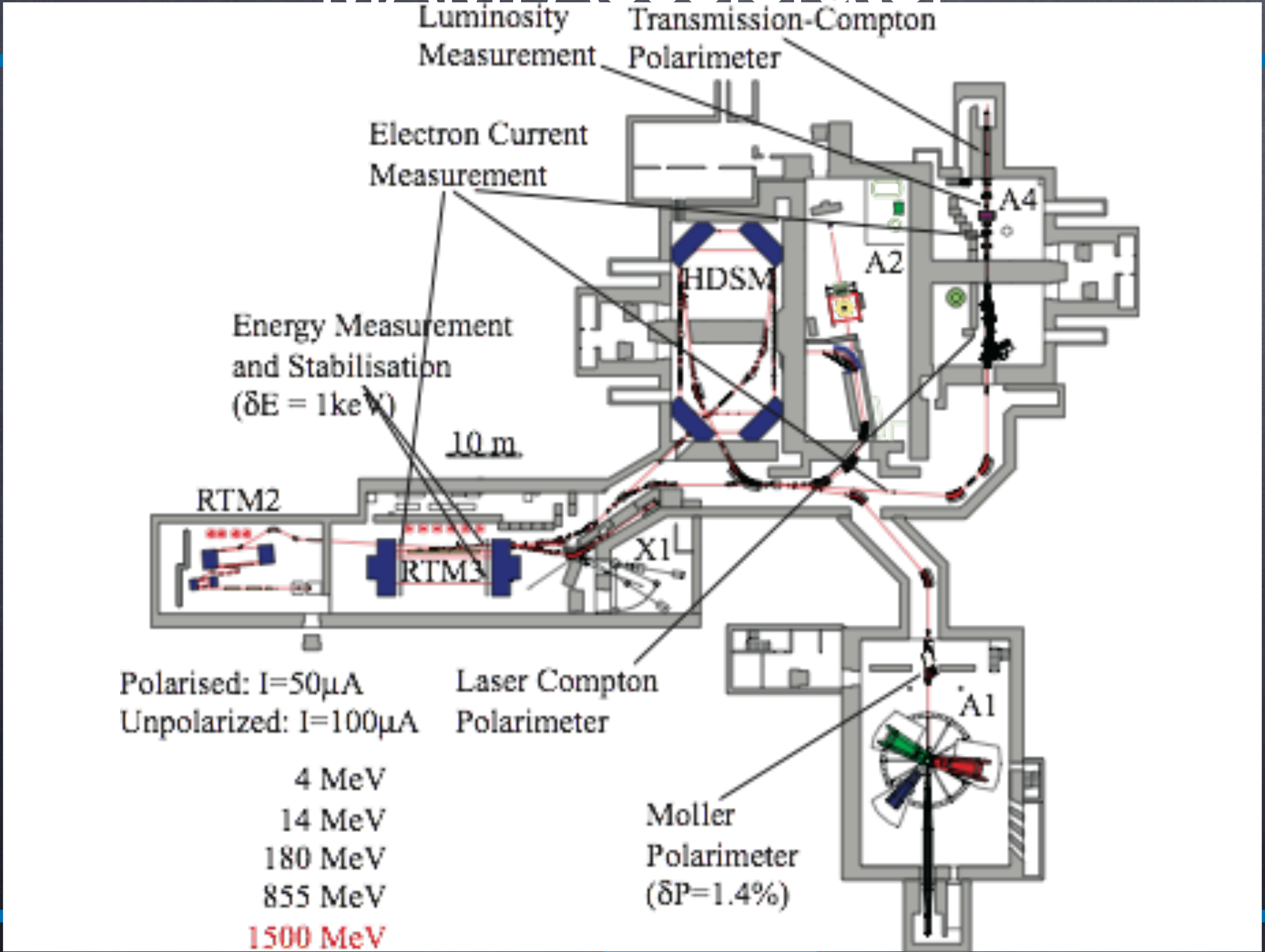
inelastic scatteri

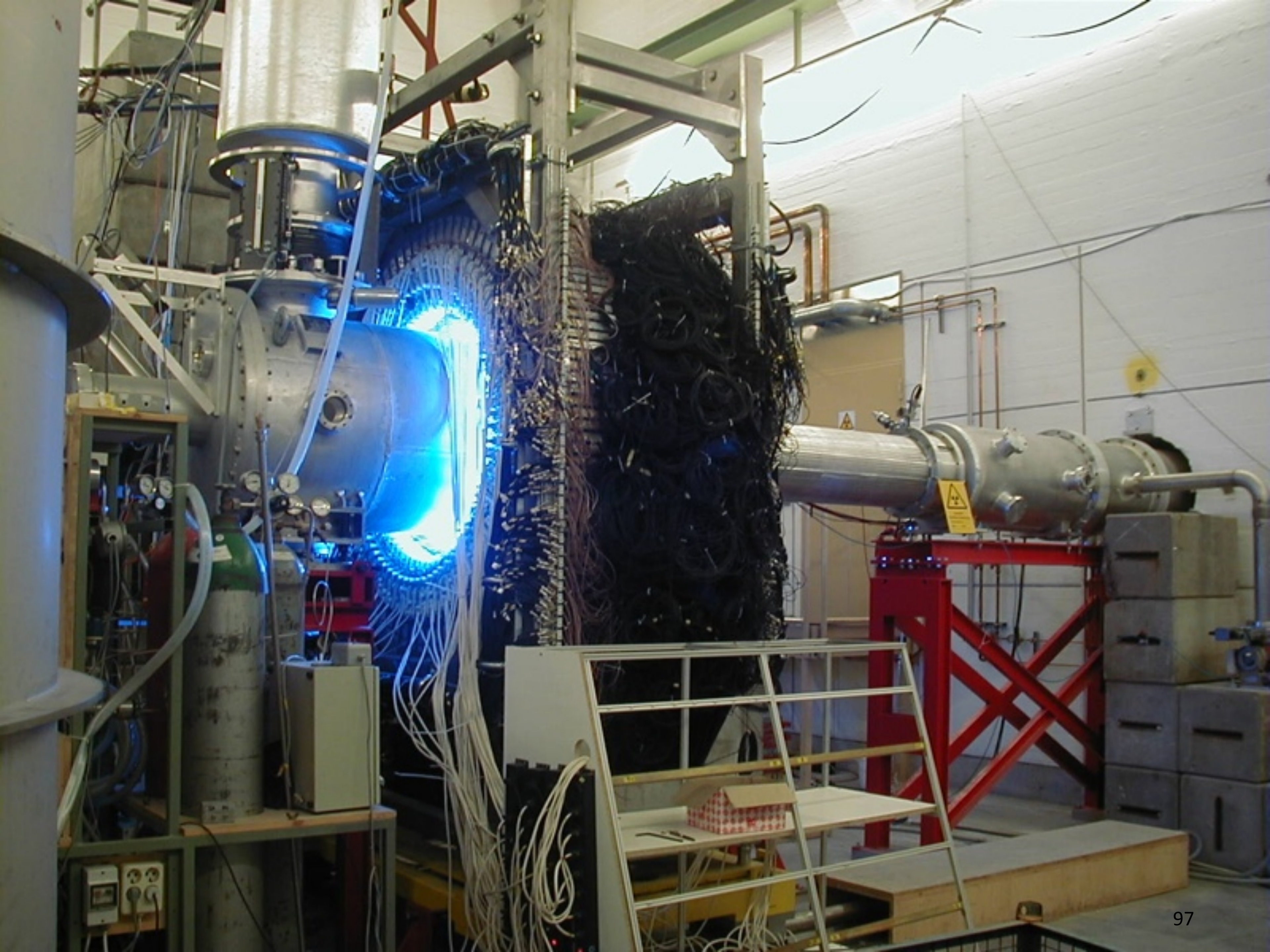
G0
HAPPEX
SAMPLE
Hall C
MAMI (Mainz)
Jefferson Lab
Electromagnetic
Magnetic
Calorimeter
Spectrometer
Integrating
Forward
Backward
Counting

ToF

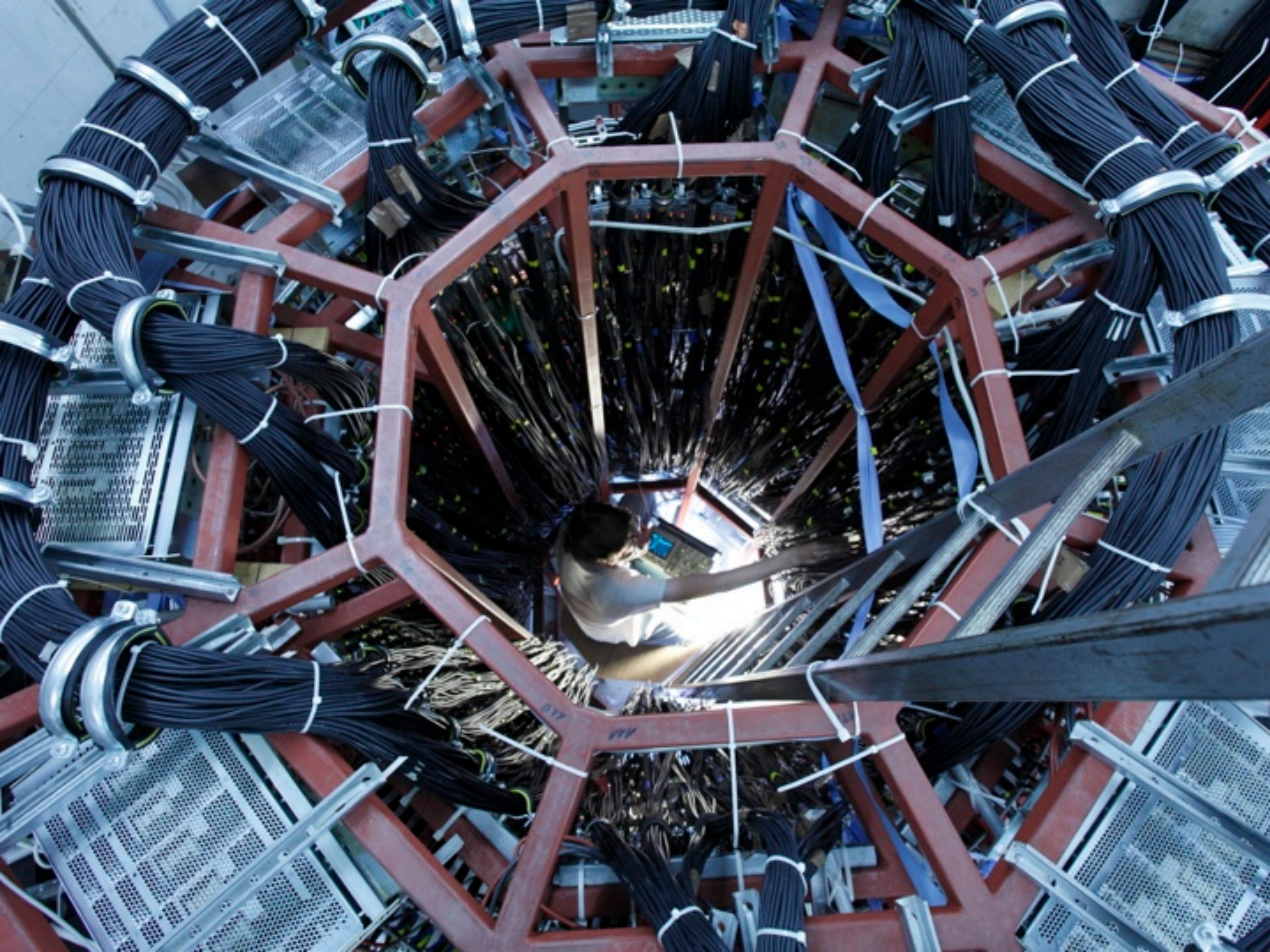


MAMI Accelerator



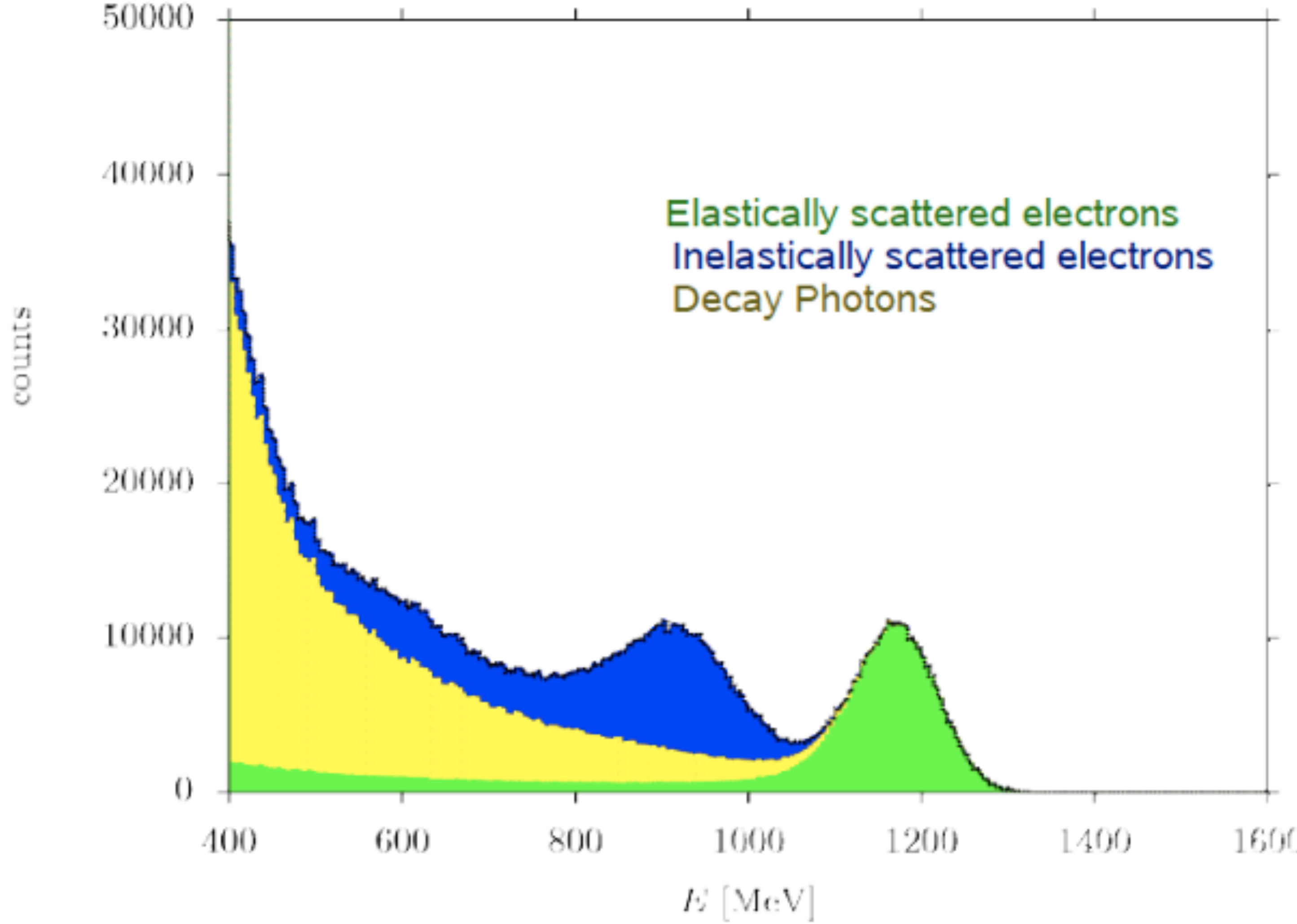


Readout Electronics



A4 at 1.5 GeV

Energy spectra: MC Study



A4: Data Taking Since 2001

D~ 20 measurements, ~6.000 h data taking, 84219 runs

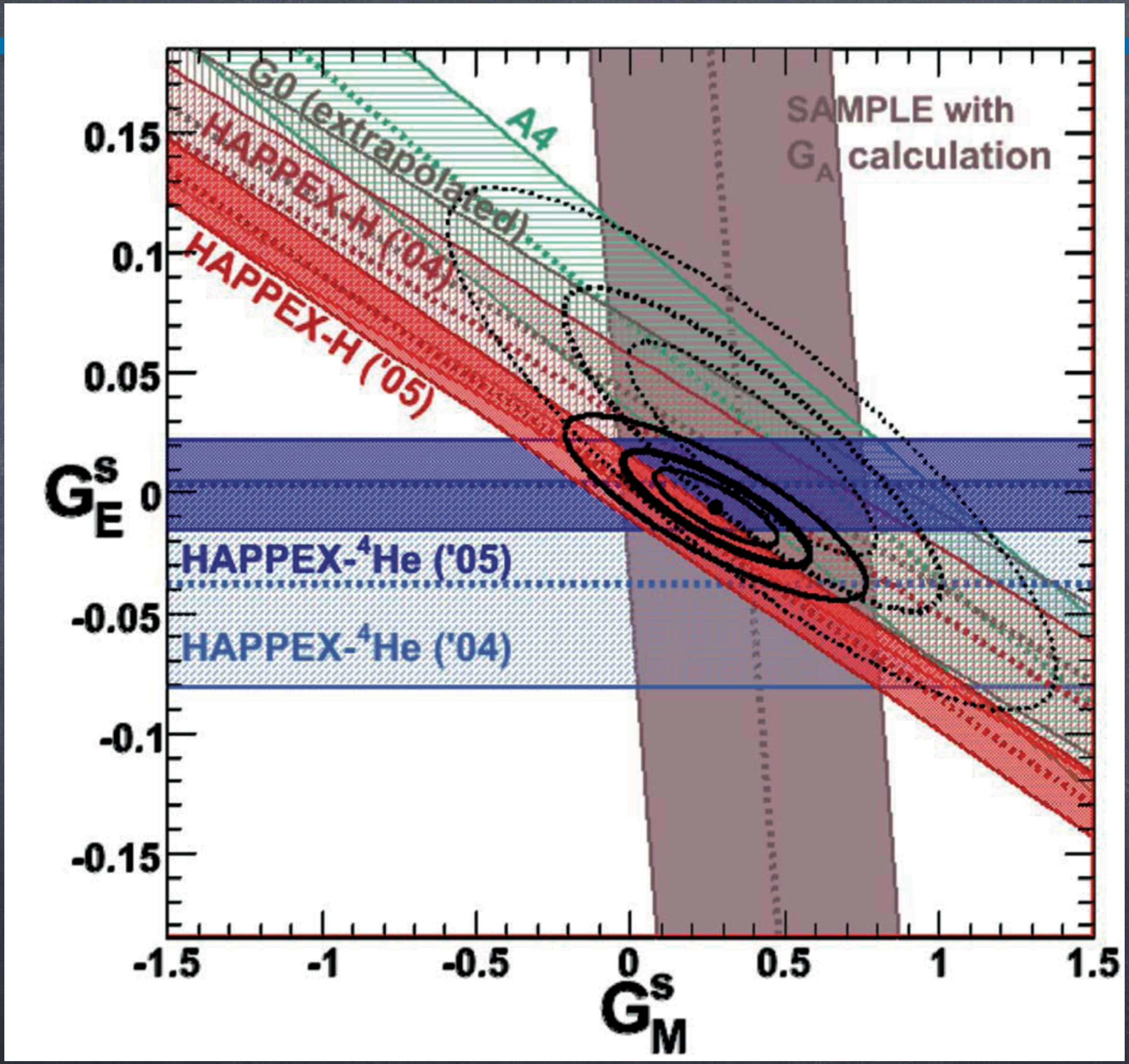
	Longitudinal	Transverse
Forward angle	➢ E= 855 MeV, Θ=35°, H_2 ➢ E= 570 MeV, Θ=35°, H_2 ➢ E=1508 MeV, Θ=35°, H_2	➢ E= 855 MeV, Θ=35°, H_2 ➢ E= 570 MeV, Θ=35°, H_2 ➢ E=1508 MeV, Θ=35°, H_2 ➢ E= 510 MeV, Θ=35°, H_2 ➢ E= 420 MeV, Θ=35°, H_2 ➢ E= 315 MeV, Θ=35°, H_2
Backward angle	➢ **E= 315 MeV, Θ=145°, H_2** ➢ **E= 315 MeV, Θ=145°, D_2** ➢ E= 210 MeV, Θ=145°, H_2 ➢ E= 210 MeV, Θ=145°, D_2	➢ **E= 315 MeV, Θ=145°, H_2** ➢ **E= 315 MeV, Θ=145°, D_2** ➢ **E= 420 MeV, Θ=145°, H_2** ➢ **E= 420 MeV, Θ=145°, D_2** ➢ E= 210 MeV, Θ=145°, H_2 ➢ E= 210 MeV, Θ=145°, D_2

Strangenes Form Factors: World Data

Strangeness Parity Experiments

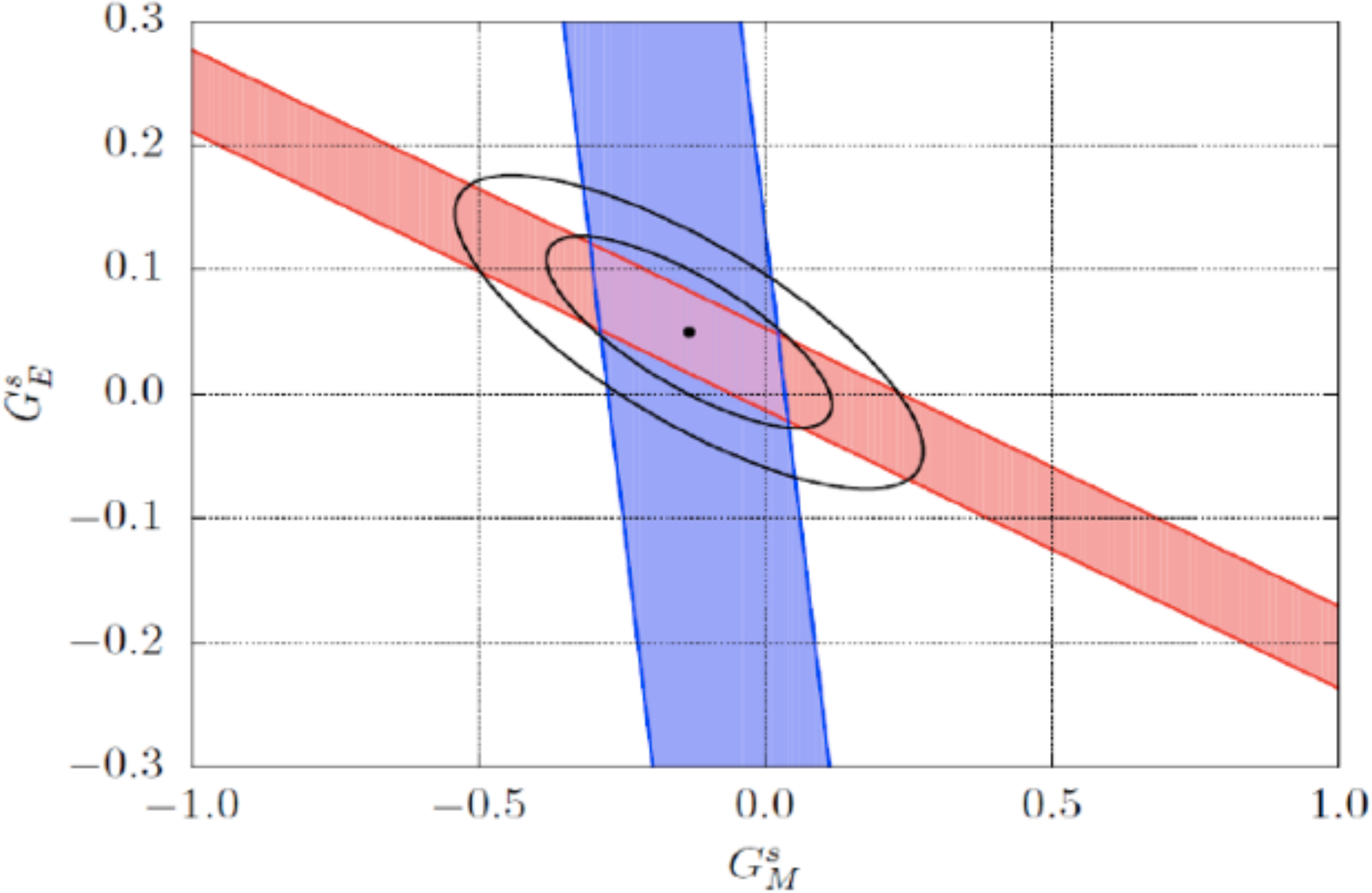
	e+p forward	e+p backward	e+^{4}He forward	e+d backward
Sample		0.10 (GeV/c)^2		0.04 (GeV/c)^2 0.1 (GeV/c)^2
Happex	0.10 (GeV/c)^2 0.48 (GeV/c)^2 0.62 (GeV/c)^2		0.10 (GeV/c)^2	
A4	0.11 (GeV/c)^2 0.23 (GeV/c)^2 0.62 (GeV/c)^2	0.23 (GeV/c)^2 *0.11 (GeV/c)^2*		0.23 (GeV/c)^2 *0.11 (GeV/c)^2*
G^0	(0.12... 1.0) (GeV/c)^2	0.23 (GeV/c)^2 0.62 (GeV/c)^2		0.23 (GeV/c)^2 0.62 (GeV/c)^2

World Data at 0.1 $(GeV/c)^2$



$G_M^s = 0.28 \pm 0.20$ $G_E^s = -0.006 \pm 0.016$

A4: Strange FF at Q^2=0.23 GeV^2



G_E^s = 0.050 ± 0.042 (± 0.038_{exp} ± 0.019_{FF})

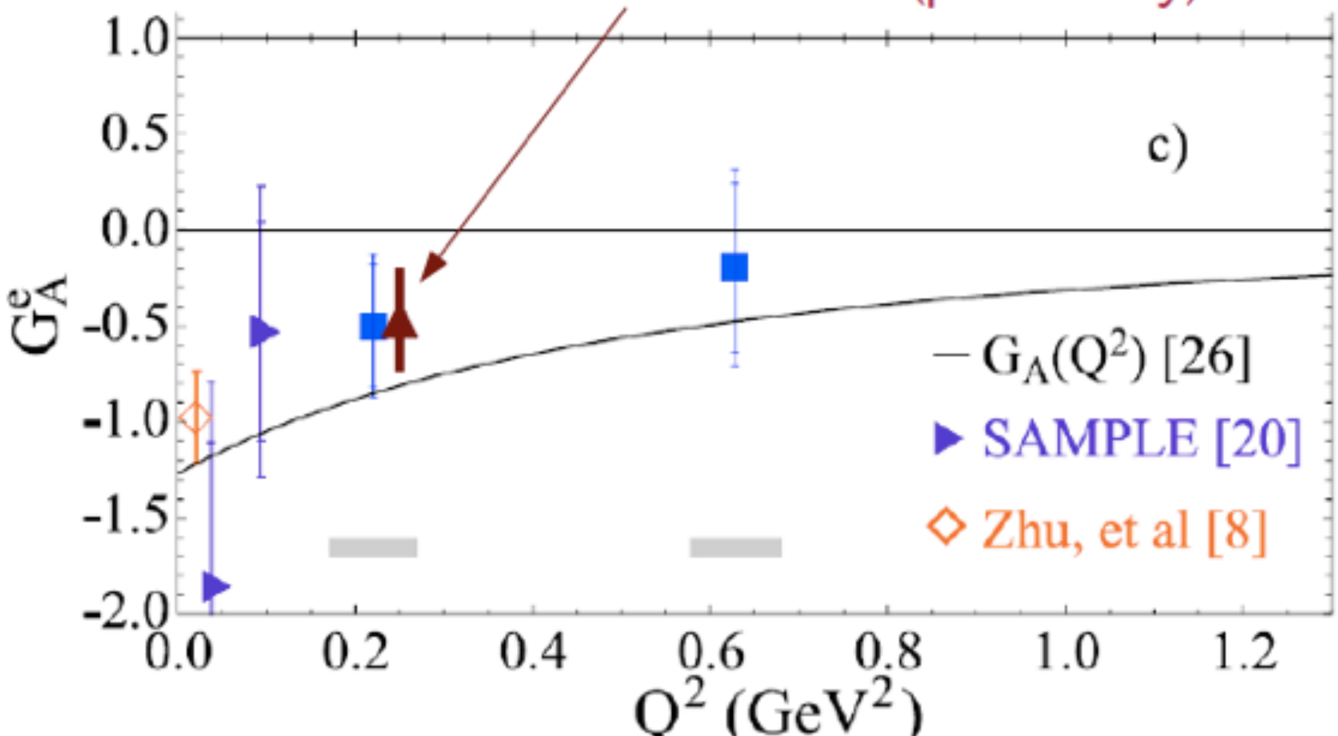
G_M^s = -0.14 ± 0.16 (± 0.11_{exp} ± 0.11_{FF})

S. Baunack et al.,
Phys Rev. Lett. 102, 15803 (2009)

A4 backward results (H_2 / D_2)

Comparison with G0 backward angle measurement:

MAMI result (preliminary)



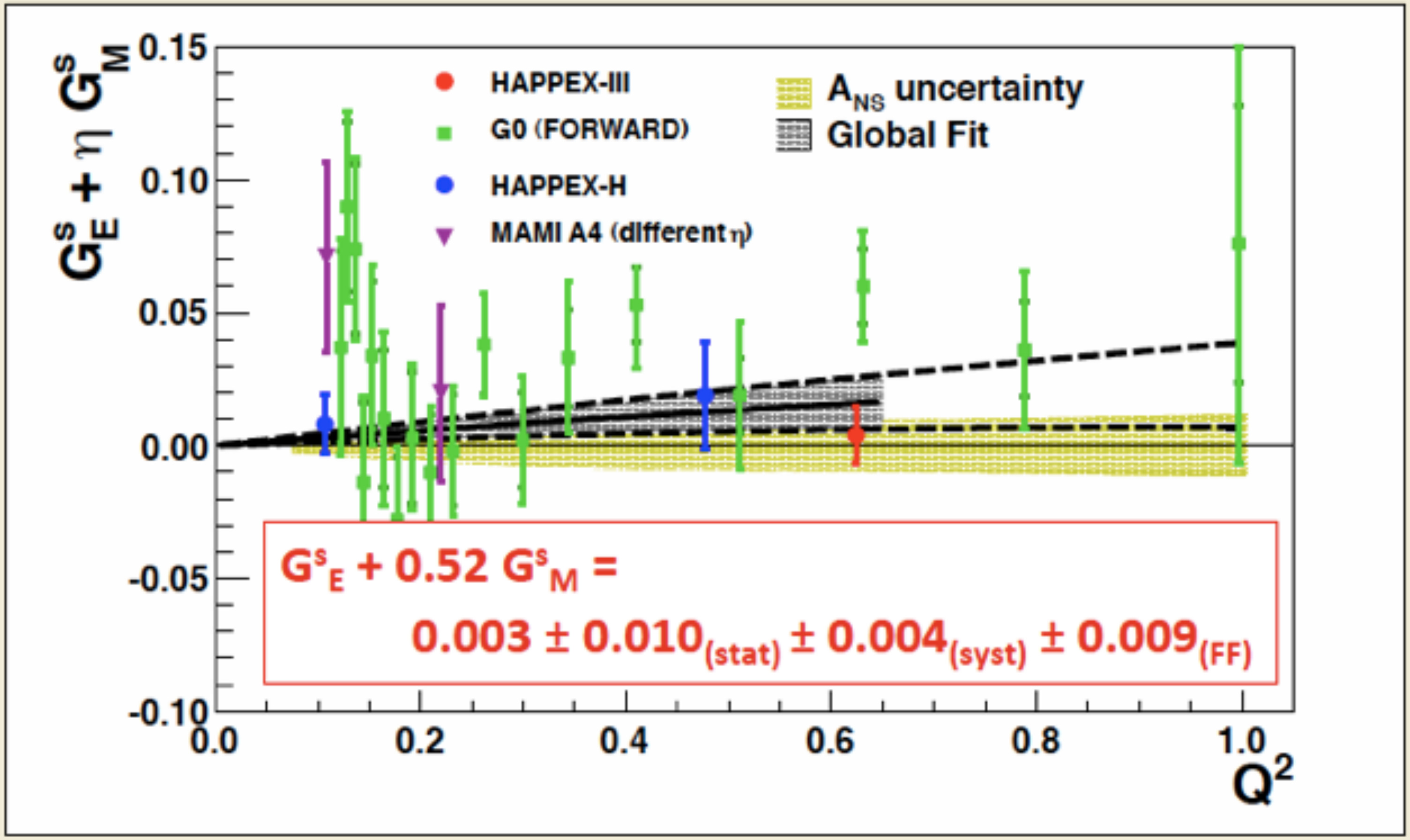
Phys.Rev.Lett. 104 (2010) 012001

HAPPEX-III Result

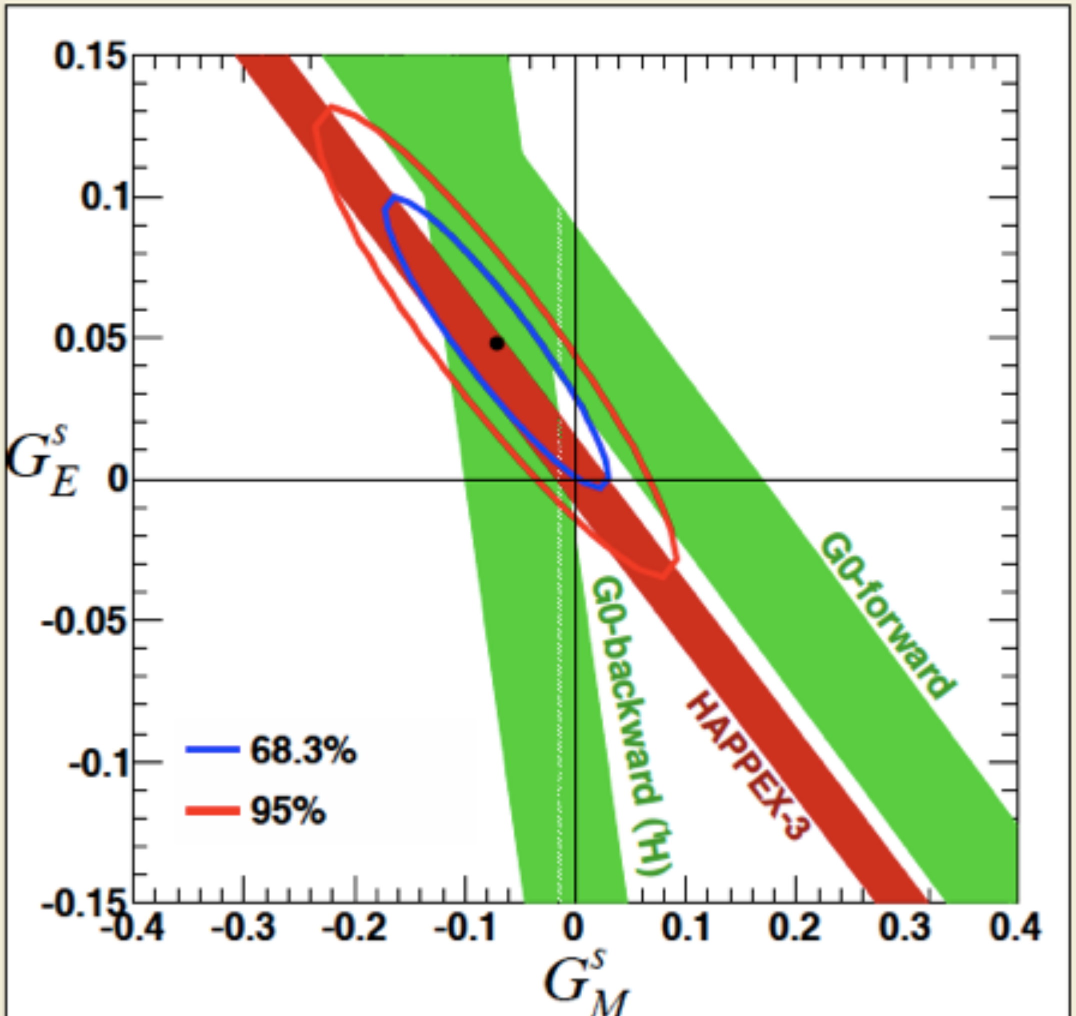
$$A_{PV} = -23.803 \pm 0.778\ (stat) \pm 0.359\ (syst)\ ppm$$

$$Q^2 = 0.6241 \pm 0.0032\ (GeV/c)^2$$

$A(G^s=0) = -24.062$ ppm $\pm$ 0.734 ppm



$Q^2 = 0.62\ GeV^2$ in combination

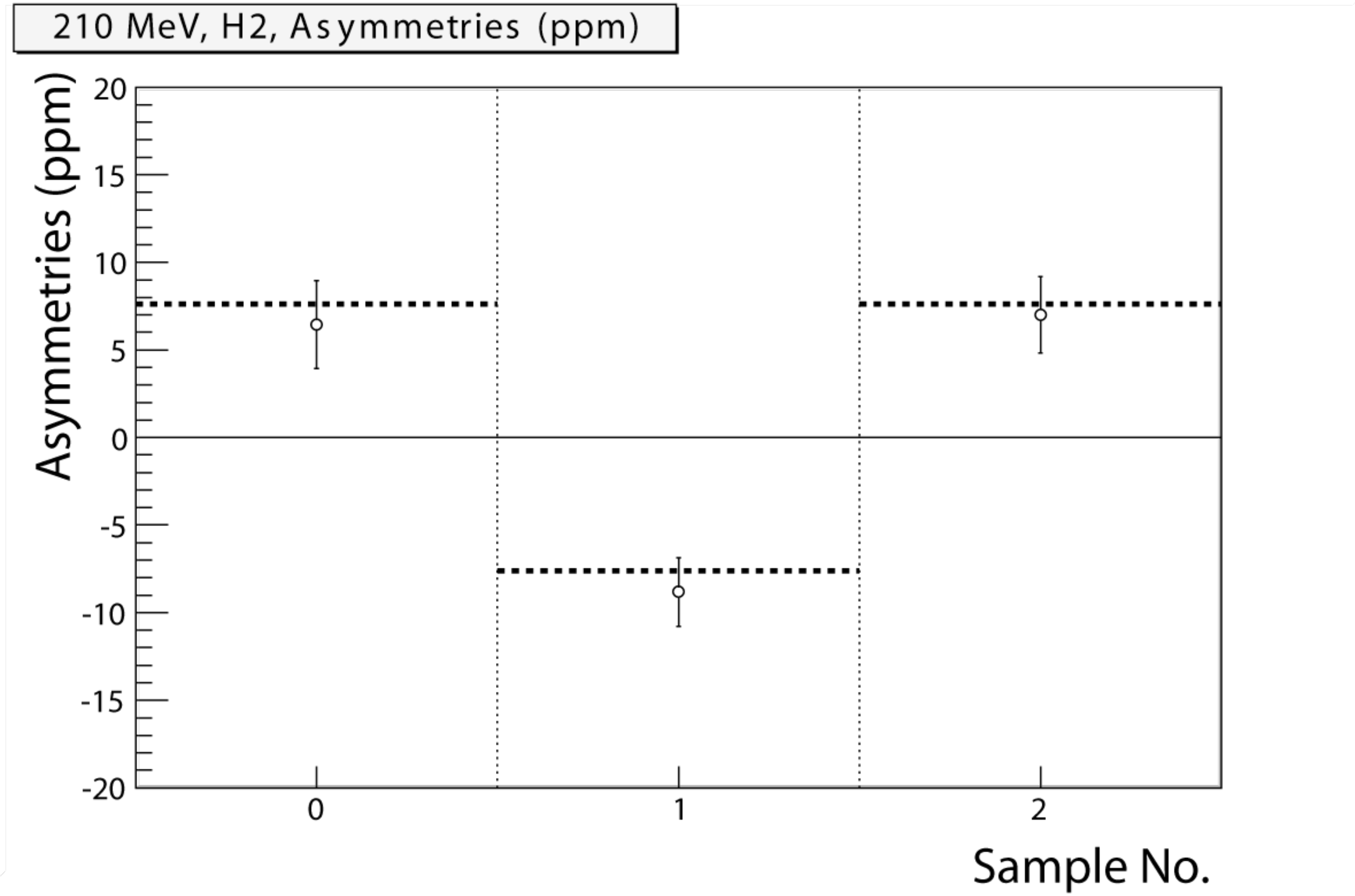


Zhu constraint is used for axial form-factor

Combined fit includes form-factor uncertainties, experimental bands do not

"A4-IV"

- ~ 250 hours of data, halfwave plate IN / OUT
- **Peliminary results**:



"A4-IV"

- Error estimation, based on data from this beamtime:

G_M^s (Q^2=0.1 GeV^2) = xxx +- 0.16 (preliminary!, G_A taken from calculation)

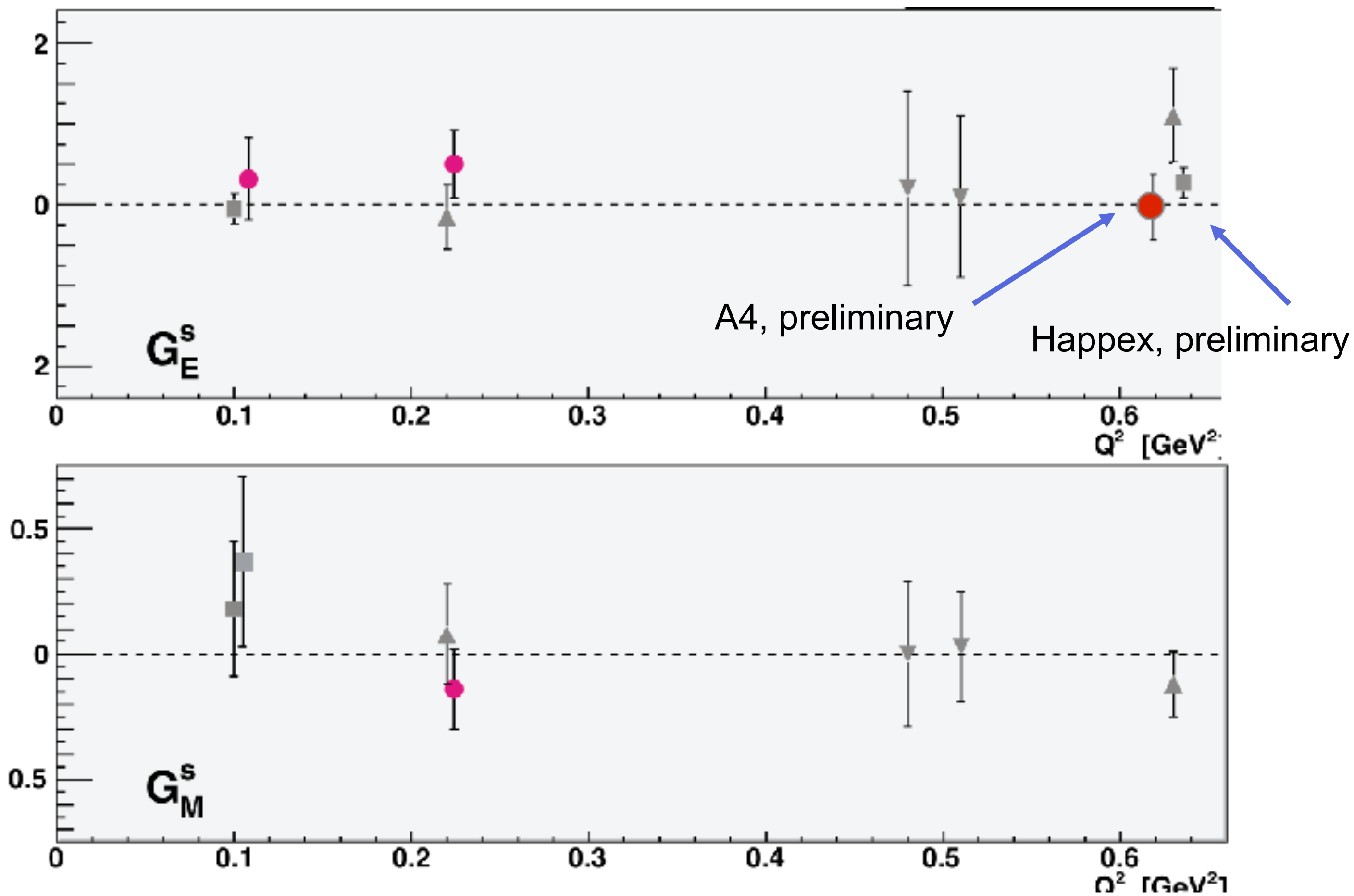
- Comparison with SAMPLE result (D.T. Spayde et al., Phys Lett. B583 (2004))

G_M^s (Q^2=0.1 GeV^2) = 0.37 +- 0.33 (G_A taken from calculation)

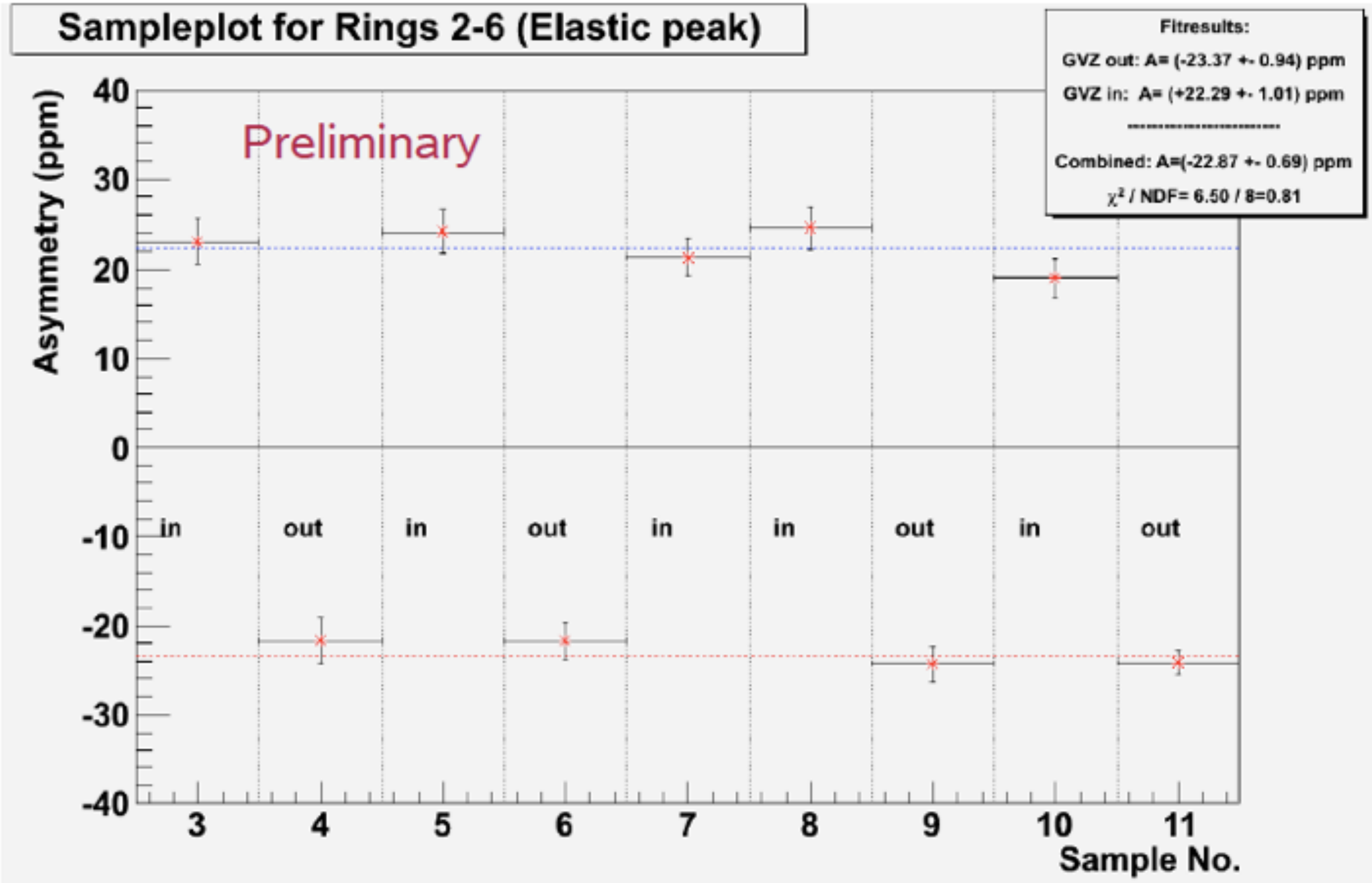
Next beamtimes will reduce the uncertainty.

"A4-III"

Preliminary result: $G_E^s + 0.628 * G_M^s = 0.067$ +- 0.030 *(all errors added in quadrature)*



A4 @ 1.5 GeV: Asymmetries



Selected Highlights at MAMI: Parity Violation

- **Measurement of parity-violating cross section asymmetry @ Q^2=0.62 GeV^2**

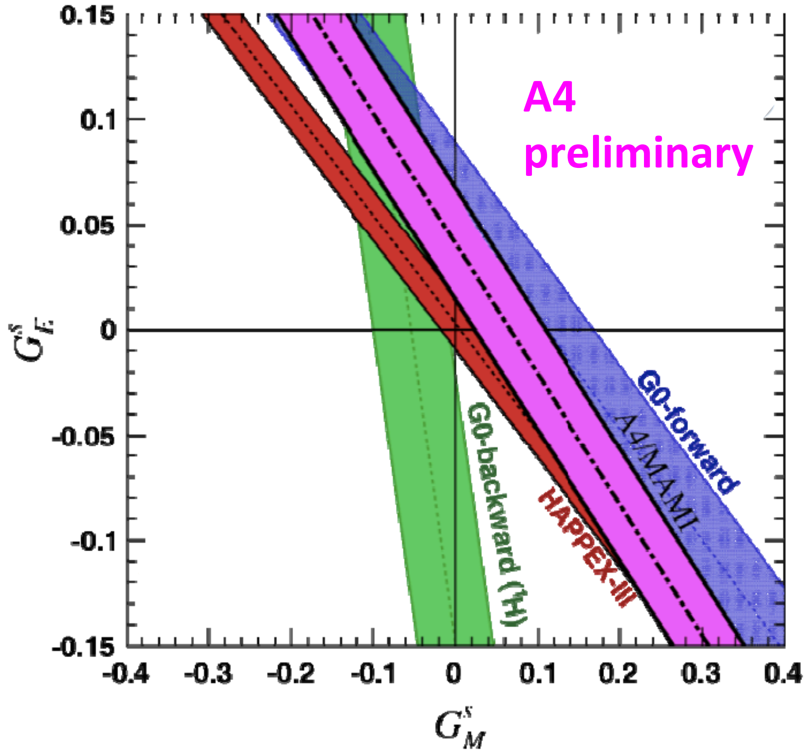
  → EM strangeness form factors

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

  (preliminary)

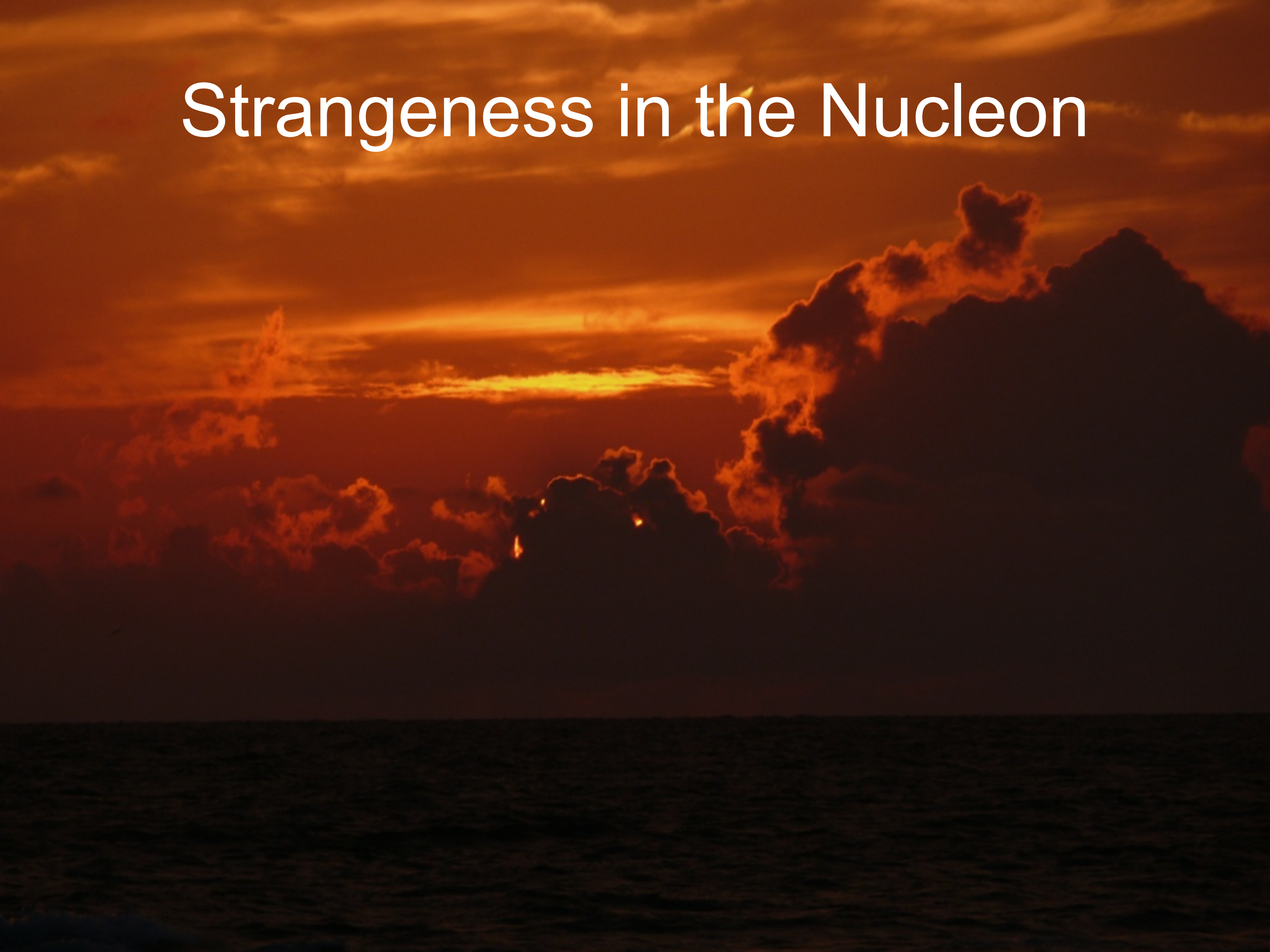
- **Recent measurement @ Q^2=0.1 GeV^2**

  → extrapolation to $Q^2 \to 0$

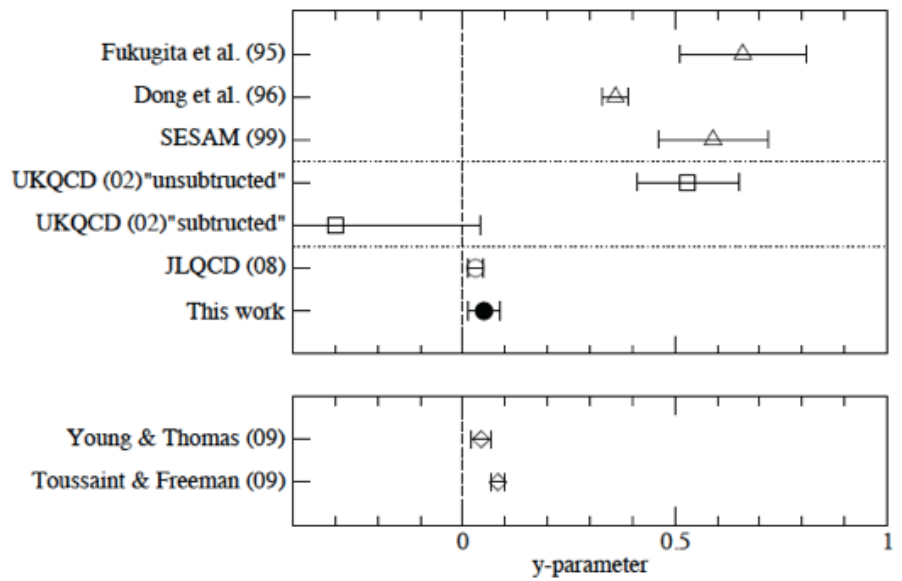


A4 experiment has successfully completed physics programme
→ Preparation for a new experiment P2 to measure $\sin^2\theta_W$ at low Q^2 with unprecedented precision
→ Project within CRC-1044 (personnel) and PRISMA (MESA accel.)

Strangeness in the Nucleon



Strangeness and the parameter $y = \frac{2\langle N|\bar{s}s|N\rangle}{\langle \bar{u}u + \bar{d}d\rangle}$



- JLQCD [1011.1964] find $m_s\langle N|\bar{s}s|N\rangle/M_N = 0.032(8)_{\text{stat}}(22)_{\text{syst}}$ and $y = 0.050(12)(34)$ JLQCD [1011.1964] ($N_f = 2$ calculation: strange quark is quenched)
- JLQCD [1012.1907] $m_s\langle N|\bar{s}s|N\rangle/M_N = 0.013(12)(16)$ $\quad (N_f = 2+1)$

ce QCD

y Meyer

J. Martin Camalich

University of Sussex, UK

We have critically analyzed the experimental situation using **baryon chiral perturbation theory**

CIPANP 2012, St. Petersburg Florida

$\sigma_{\pi N} = \mathbf{59(7)}$ **MeV** leads to a negligible strangeness of the nucleon

$\mathbf{y = 0.02(13)(10)}$

Δs puzzle persists

from DIS + SU(3):

$$\boxed{\Delta s = -0.08 \pm 0.01(\text{stat.}) \pm 0.02(\text{syst.})}$$

from SIDIS:

$$\boxed{\Delta s = -0.02 \pm 0.02(\text{stat.}) \pm 0.02(\text{syst.})}$$

A possible resolution of the strange quark polarization puzzle ?

Elliot Leader
Imperial College London
Prince Consort Road, London SW7 2BW, England

Alexander V. Sidorov
Bogoliubov Theoretical Laboratory
Joint Institute for Nuclear Research, 141980 Dubna, Russia

Dimiter B. Stamenov
Institute for Nuclear Research and Nuclear Energy
Bulgarian Academy of Sciences
Blvd. Tsarigradsko Chaussee 72, Sofia 1784, Bulgaria

Abstract

A possible resolution of the strange quark polarization puzzle is proposed. To this end the results of a new combined NLO QCD analysis of the polarized inclusive and semi-inclusive DIS data using the Hirai et. al. (HKNS) fragmentation functions are presented. It was demonstrated that the polarized strange quark density is very sensitive to the kaon fragmentation functions, and if the set of HKNS fragmentation functions is used, the polarized strange quark density is *negative* and well consistent with that obtained from the pure DIS analyses.

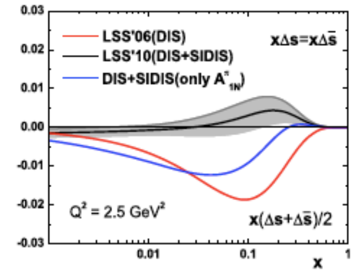
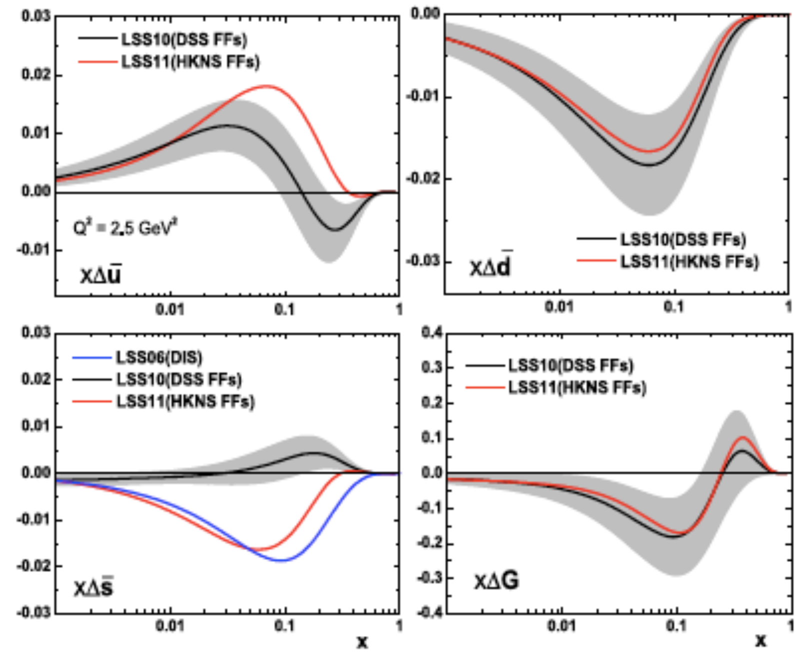
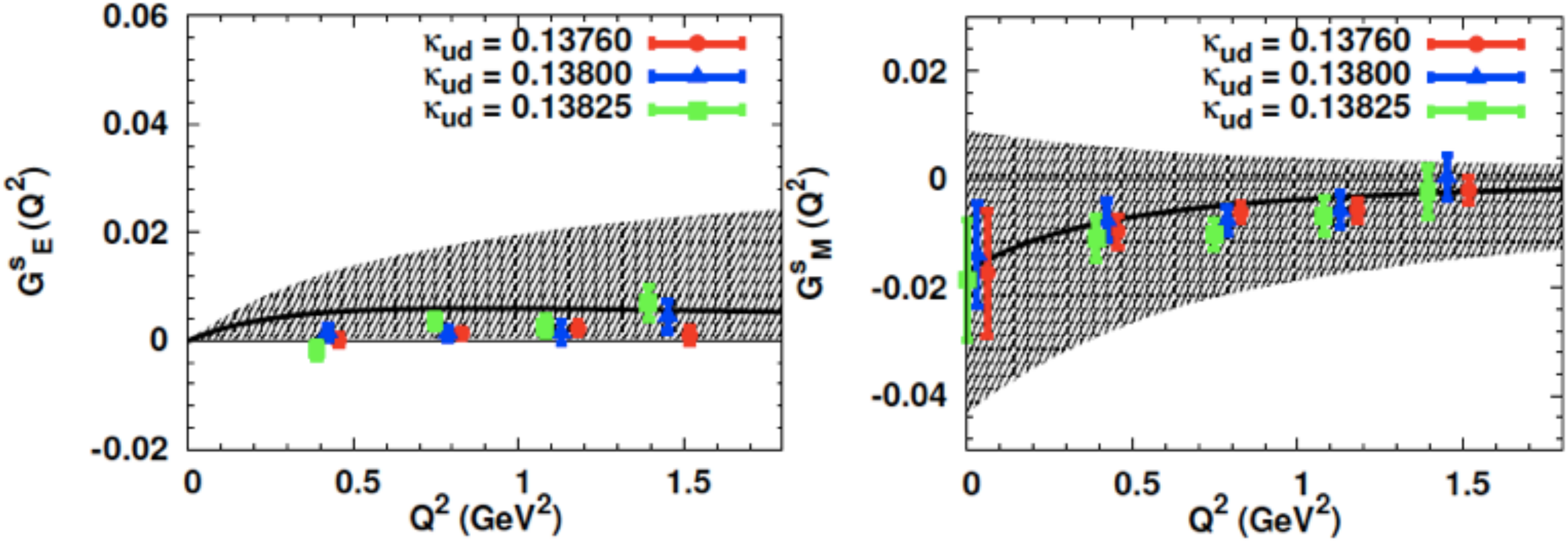


Figure 1: Comparison between polarized strange quark densities obtained from different kind of NLO QCD analyses (see the text).



Strangeness form factor on the lattice



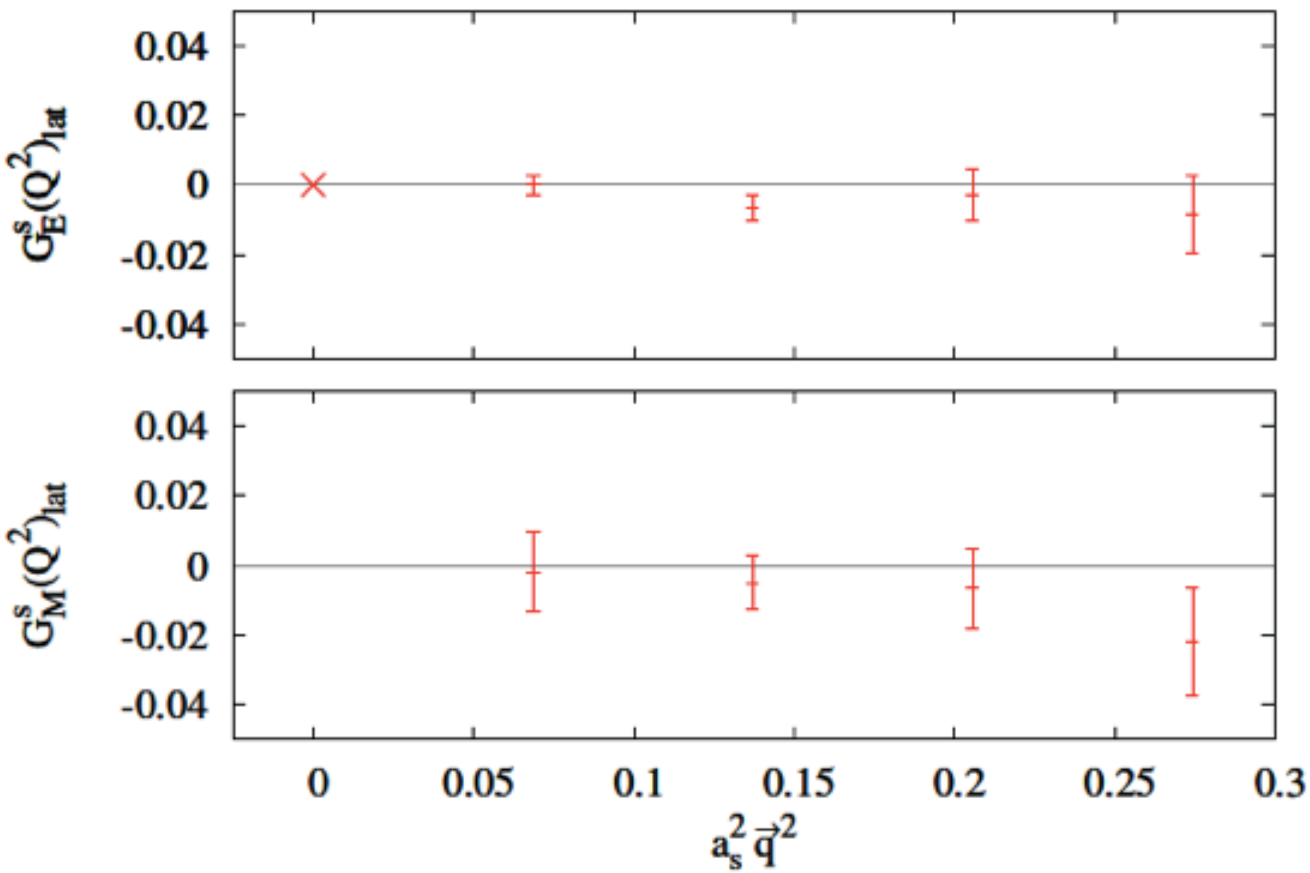
χQCD collaboration 0903.3232 $\quad N_f = 2+1 \quad a = 0.12\text{fm} \quad m_\pi \geq 600\text{MeV}$

Electromagnetic form factors of the proton: (NB. $G_E^u(0) = 2$)

$$G_{E,M} = \frac{2}{3}G^u - \frac{1}{3}G^d - \frac{1}{3}G^s = \frac{1}{2}G^{u-d} + \frac{1}{6}G^{u+d-2s} + 0 \cdot G^{u+d+s}$$
$$= \frac{1}{2}G^{u-d}_{\rm conn} + \frac{1}{6}G^{u+d}_{\rm conn} + \frac{1}{6}(G^{u+d}_{\rm disc} - 2G^s_{\rm disc})$$

These Figs suggest disconnected diagrams contribution $< 0.01 \Rightarrow$ negligible at low Q^2.

Strangeness form factor on the lattice (II)



[Babich et al 1012.0562] $a_s = 0.108(7)$fm, $m_\pi = 416(36)$MeV.

cf. PVA4 [0903.2733] $G^s_M(0.22\text{GeV}^2) = -0.14 \pm 0.11 \pm 0.11$.

Strangeness in the Nucleon

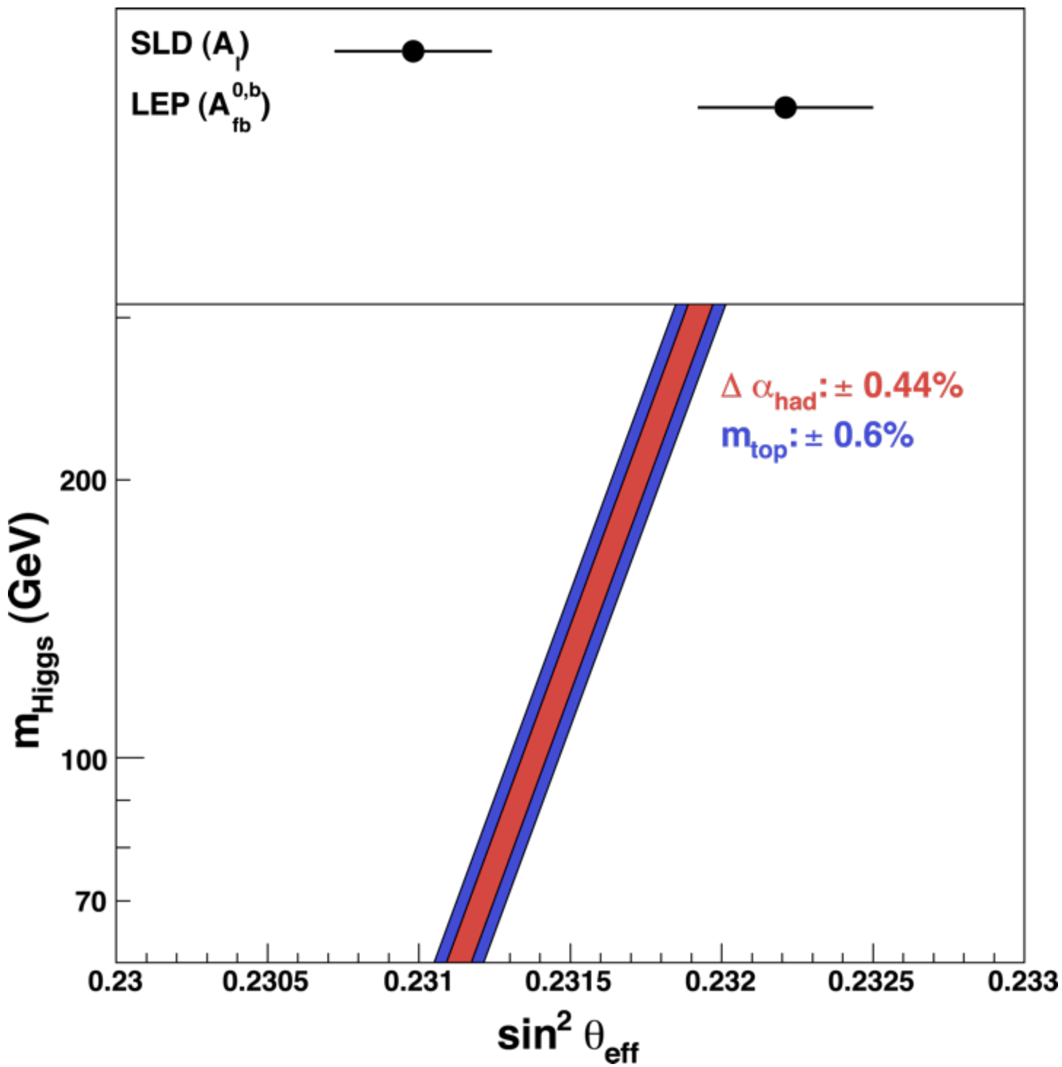
Vacuum	$\langle 0\|\bar{s}s\|0\rangle$	(0.8 ± 0.1) $\langle 0\|\bar{q}q\|0\rangle$	QCD sum rules	
Momentum	$\int x(\bar{s}+s)dx$	2-4%	DIS u,μ,e	from q^2-evolution
Mass	$m_s\langle N\|\bar{s}s\|N\rangle$	220 MeV	πN-scatt. $\Sigma_{\pi N}$-Term	14 MeV
Spin	$\langle N\|\bar{s}\gamma_\mu\gamma^5 s\|N\rangle$	- 10 %	pol. DIS	fragmentat. functions
EM FF G_E^s, G_M^s	$\langle N\|\bar{s}\gamma_\mu s\|N\rangle$	???	PVelectron scattering	$G_E^s<0.02$,$G_M^s<0.2$ compatible with 0

Parity violating electron scattering

a) strangeness in the nucleon

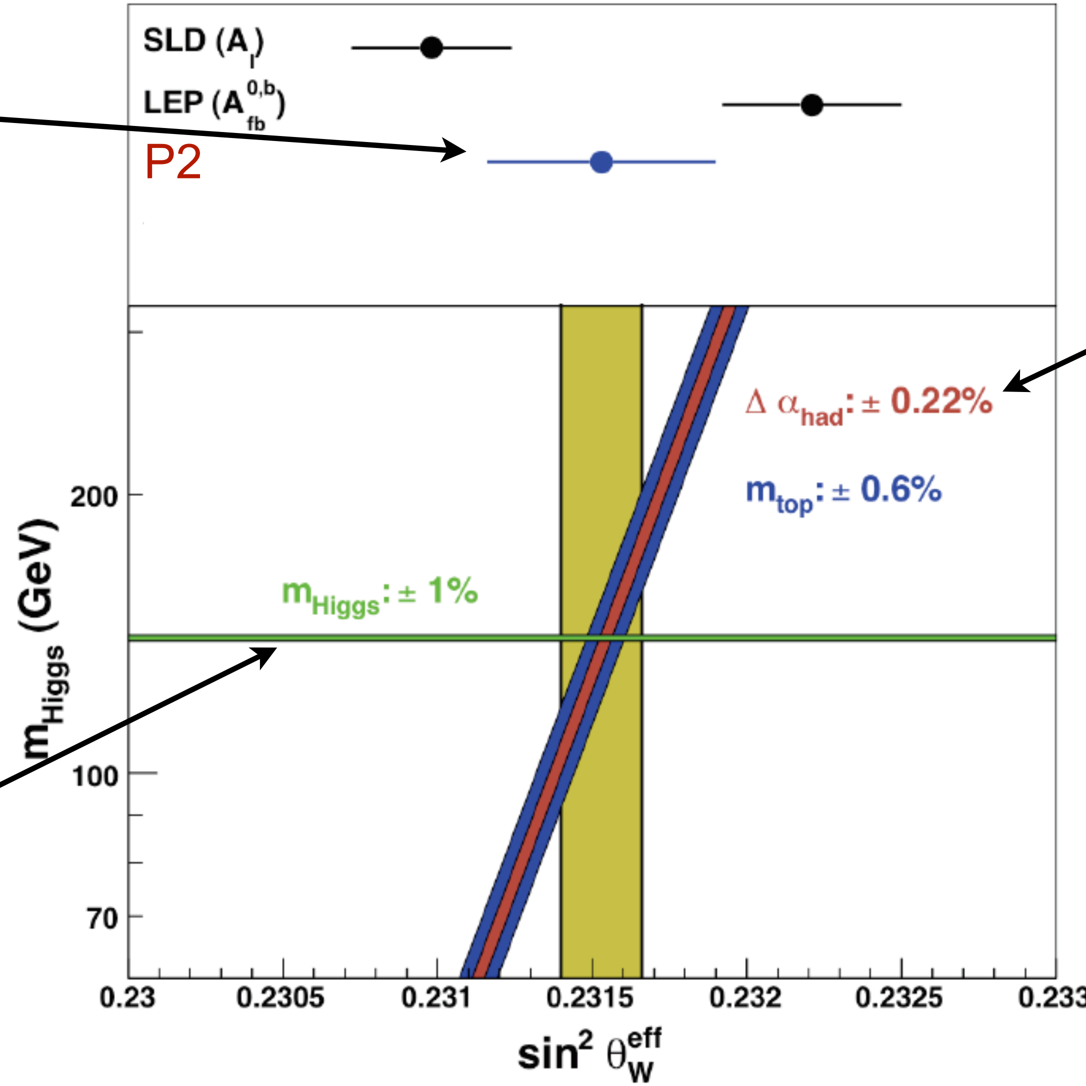
b) weak charge of the proton for a precise determination of $\sin^2(\theta_W)_{eff}$

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



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

Projection for project P2

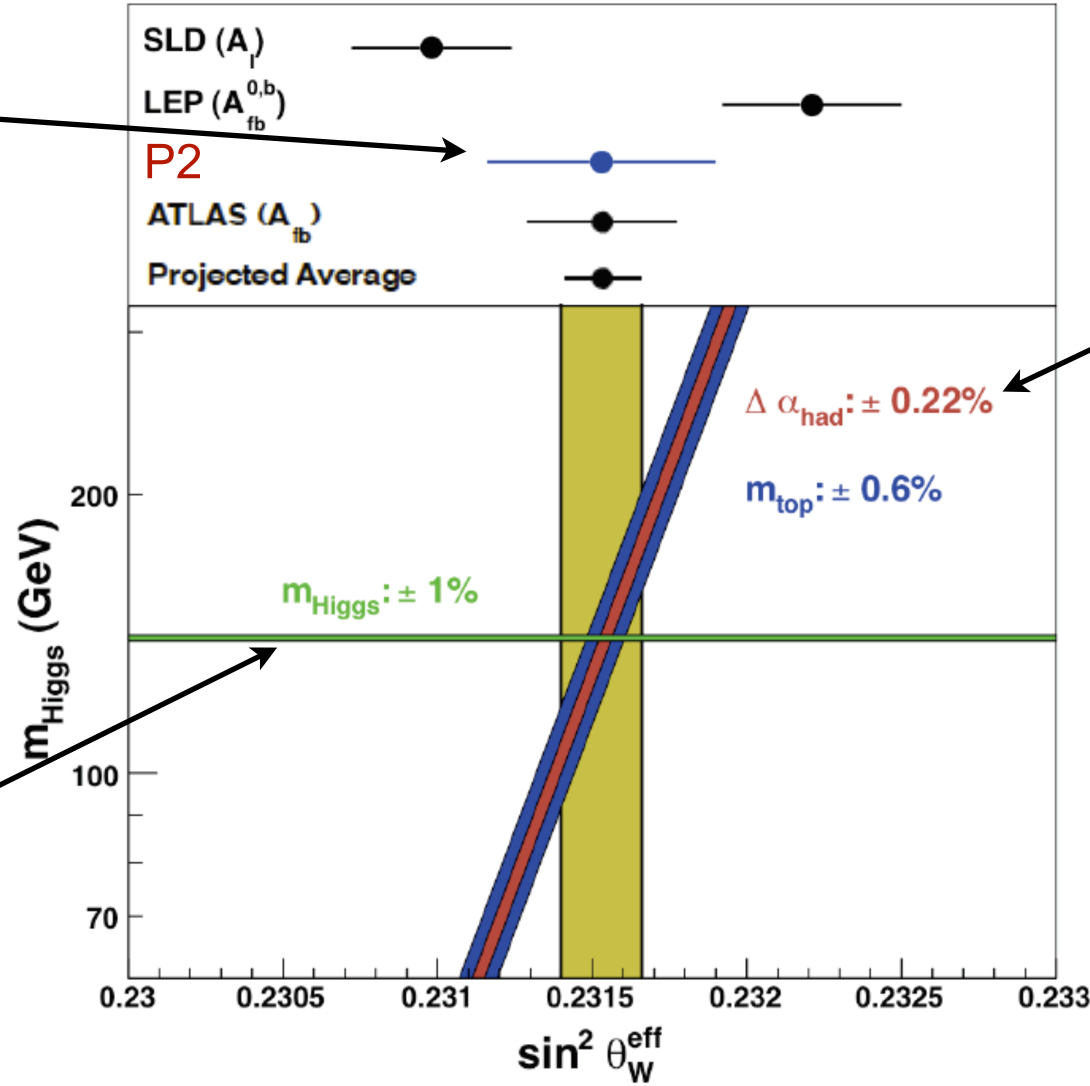


Projection for project P1

Expectation from LHC

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

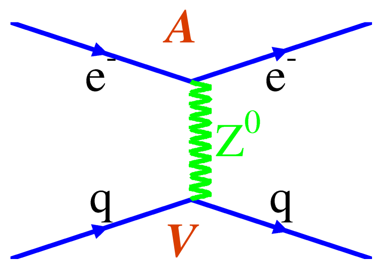
Projection for project P2



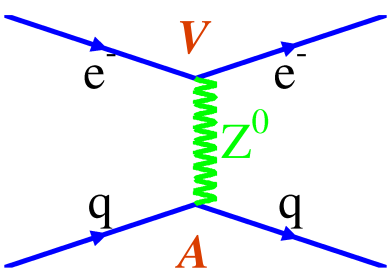
Projection for project P1

Expectation from LHC

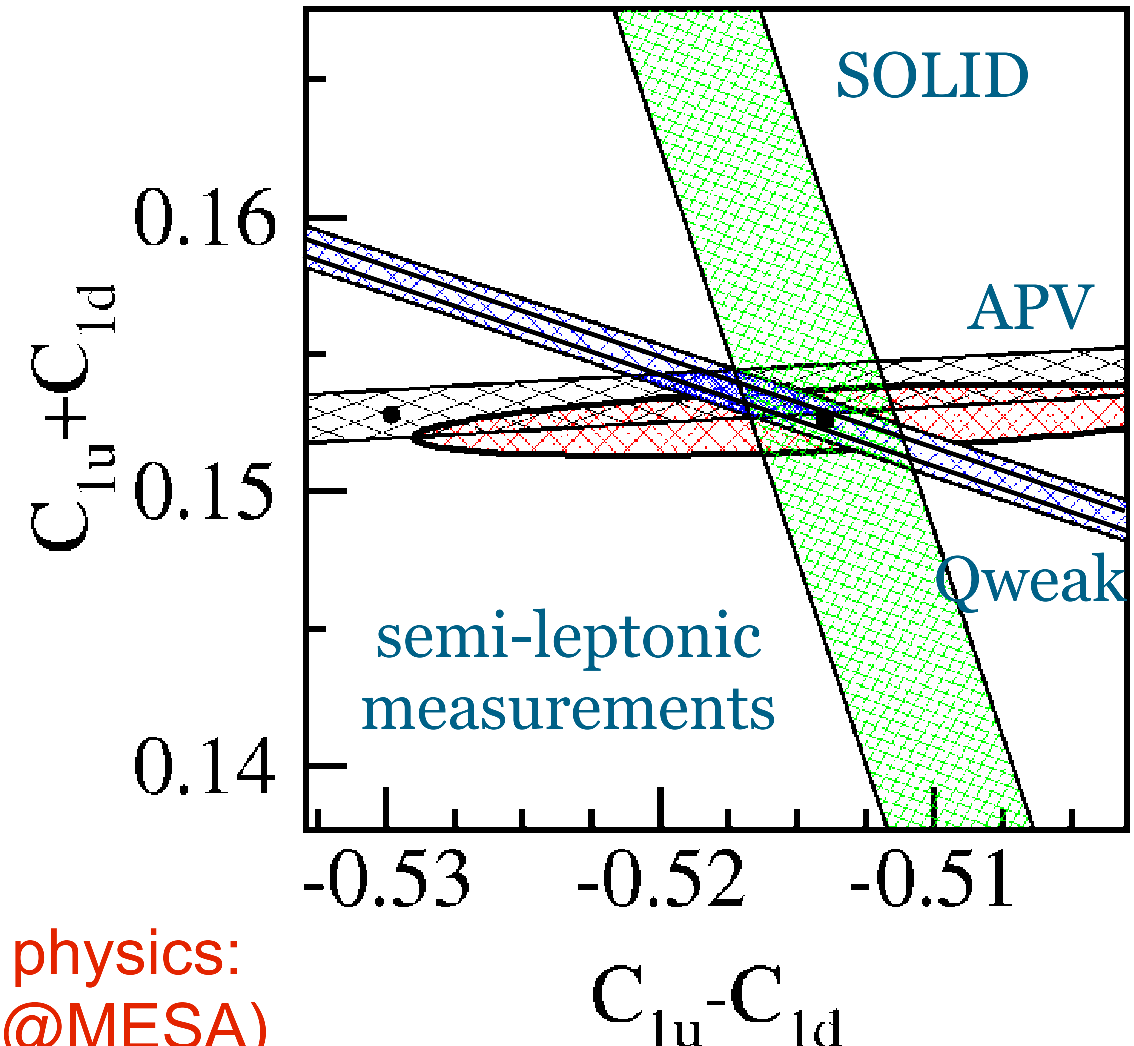
Semi-Leptonic Electroweak Couplings



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



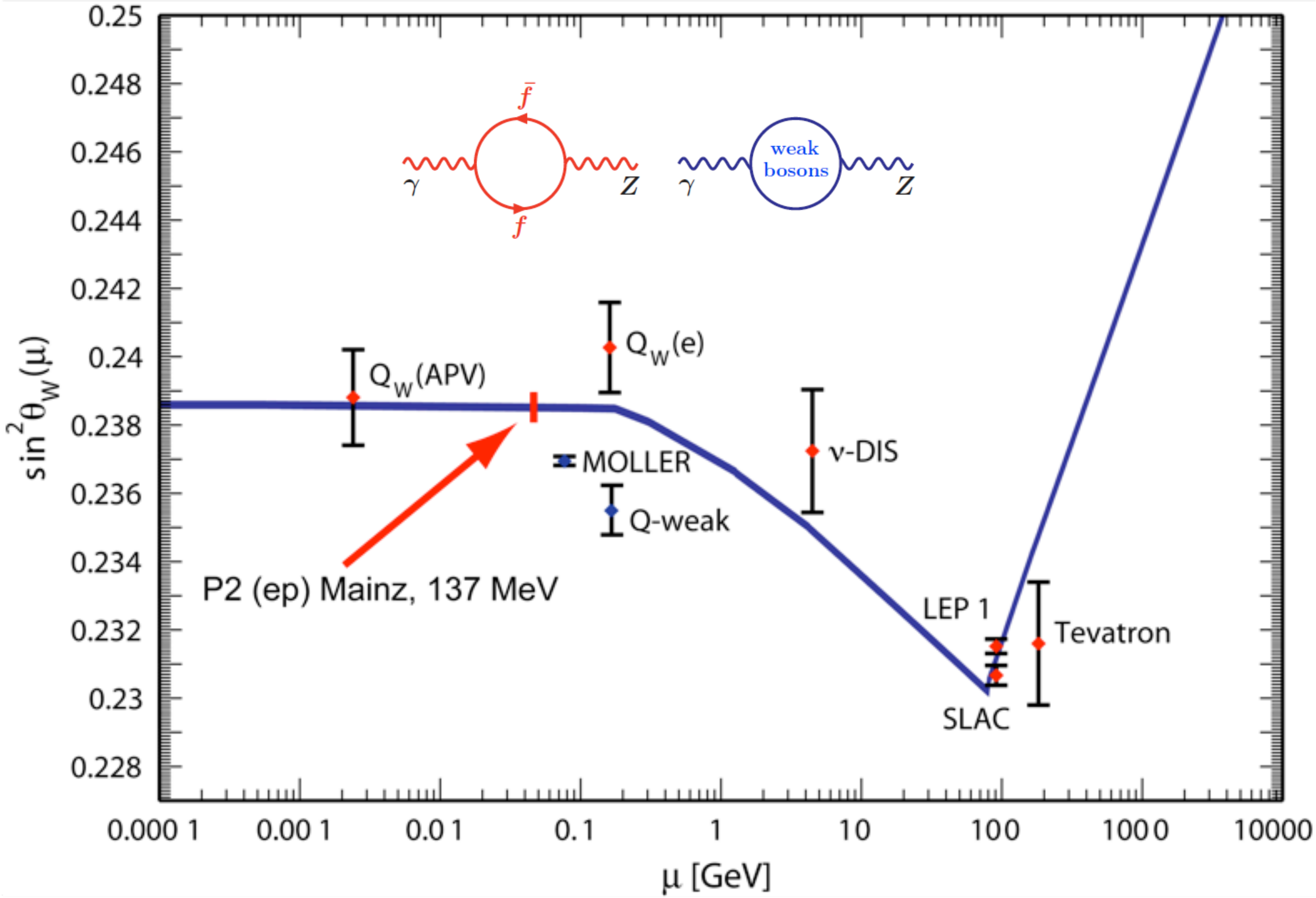
$$C_{2i} \equiv 2 g_V^e g_A^i$$



Sensitivity to new physics:

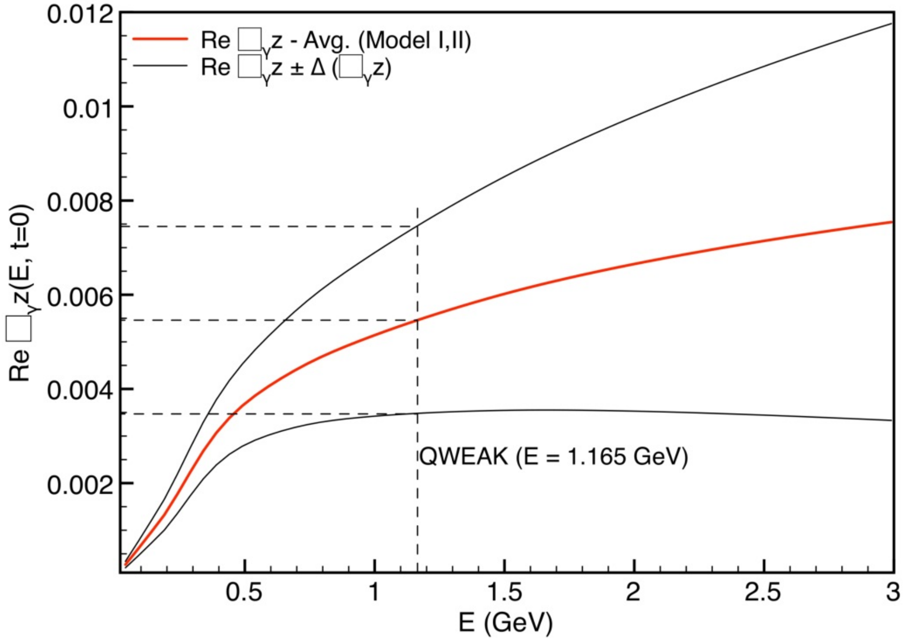
$\Lambda_{new} \simeq$ 6.4 TeV (P2@MESA)

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



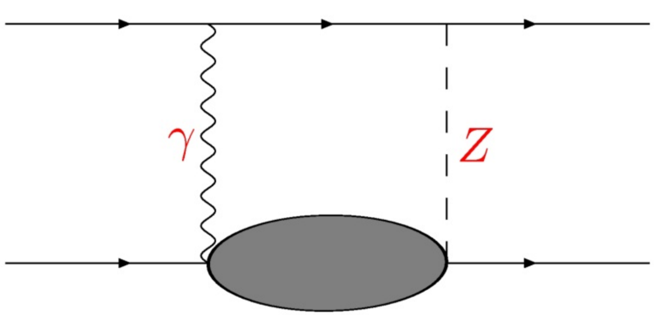
Hadron Structure Contributions vanish at low Q

- γZ box graph contributions obtained by modelling hadronic effects:



Musolf

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

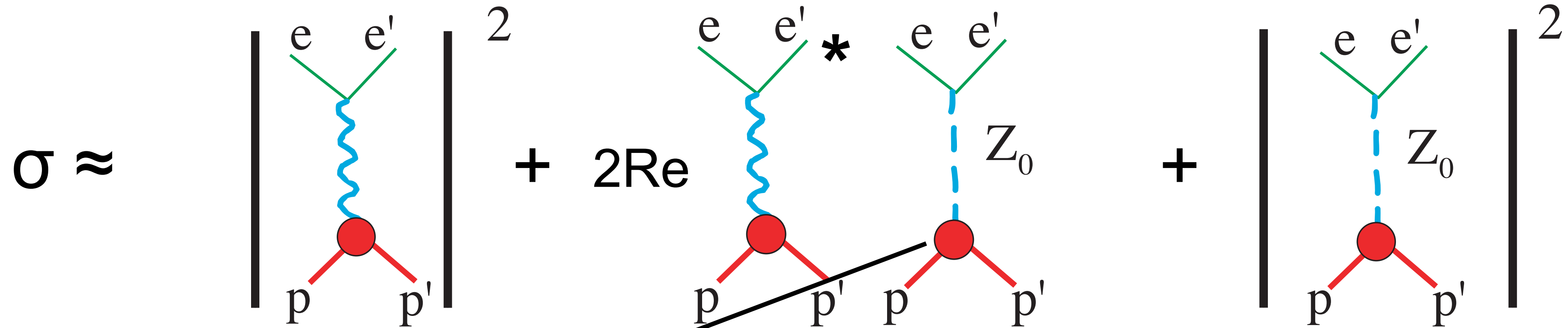


Dominant theoretical uncertainty:

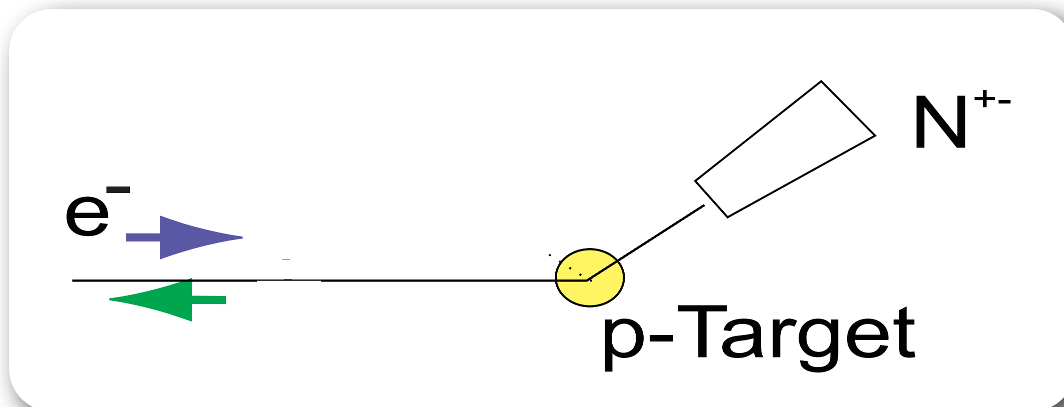
γZ box graphs, $\Box_{\gamma Z}$

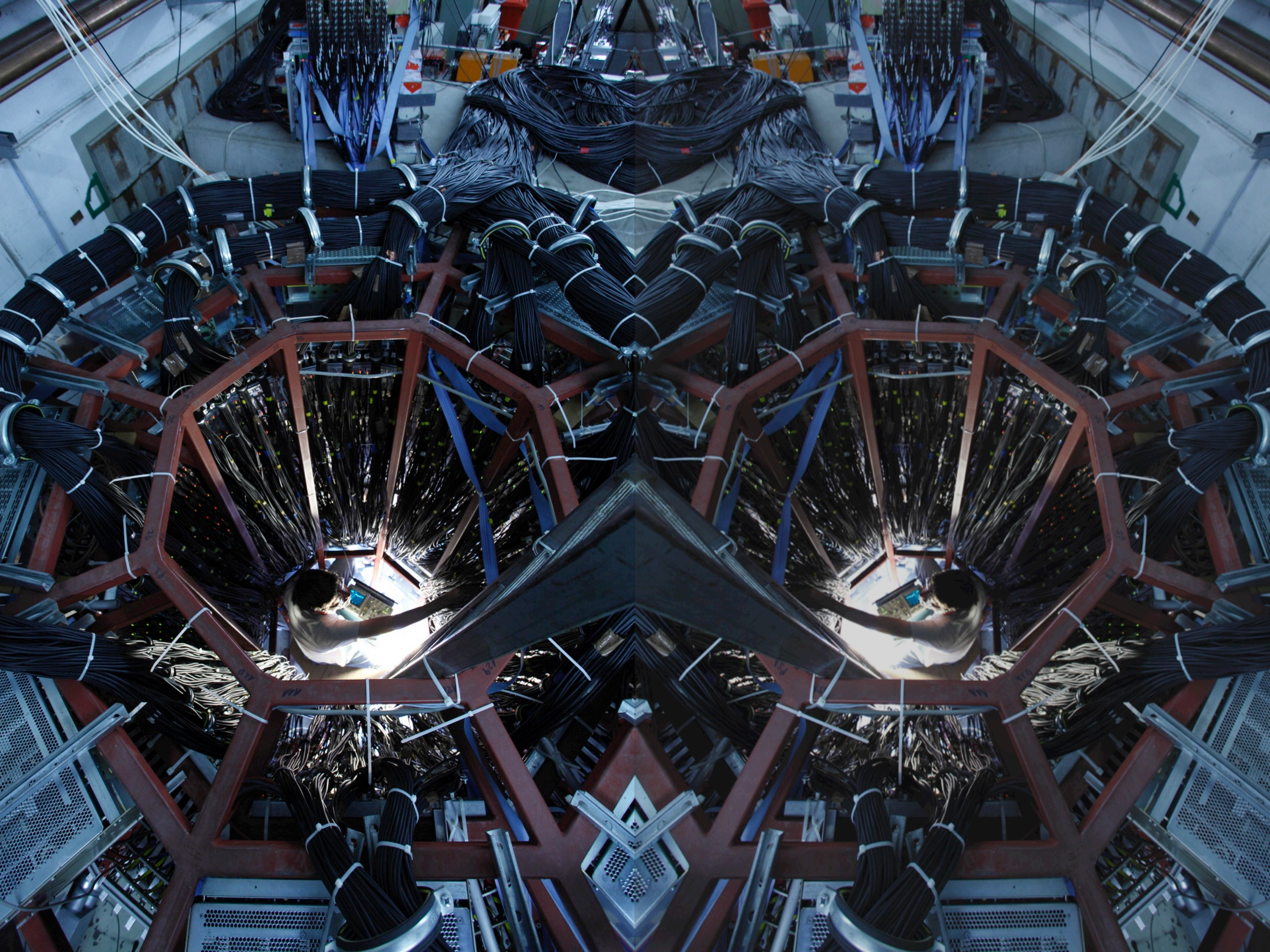
Sensitive to hadronic effects

Method: Parity-Violating Electron-Proton Scattering



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





Parity-Violating Asymmetry in Electron-Proton Scattering

weak charge

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

hadron structure

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

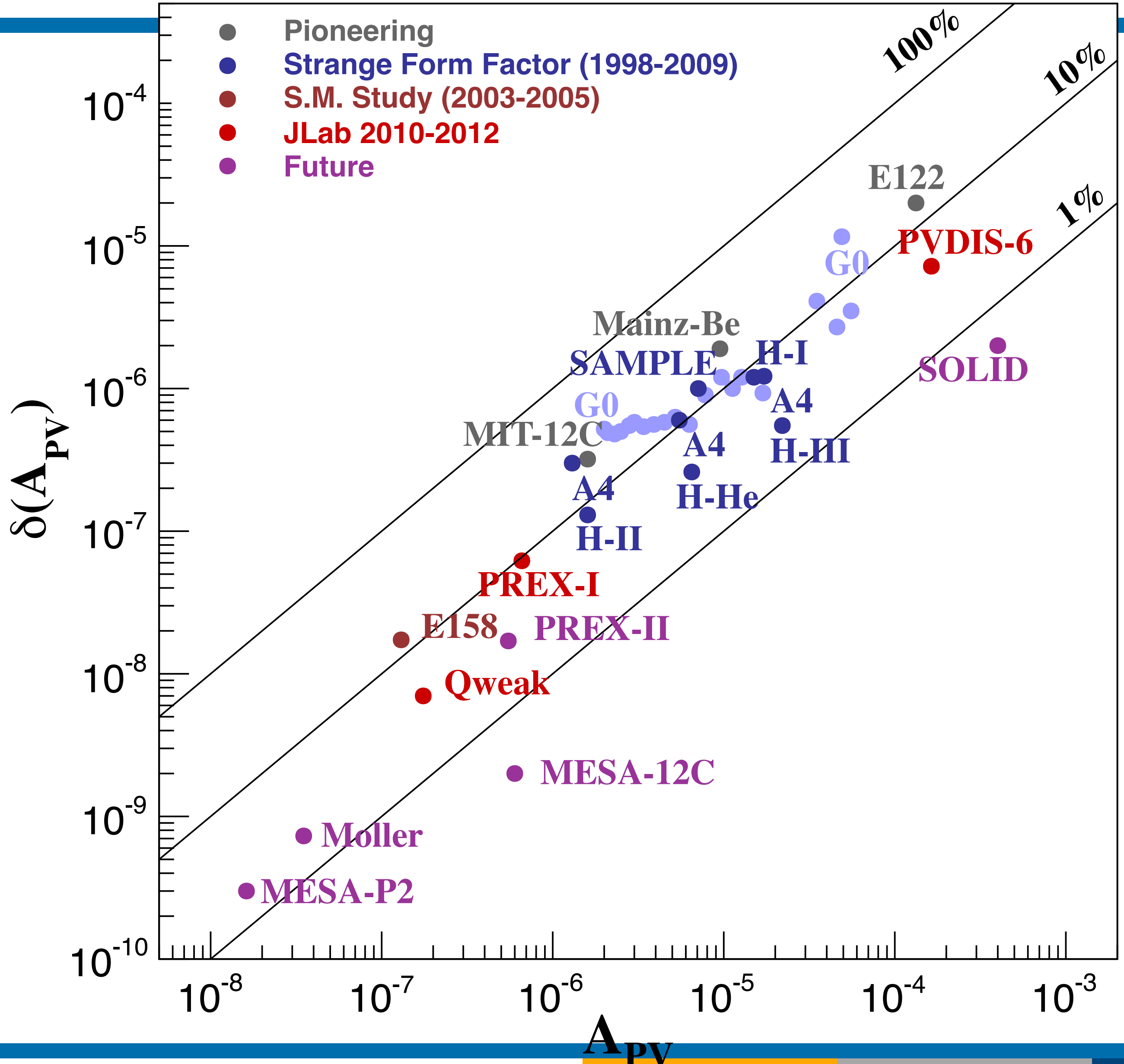
$$F(Q^2) = F_{EM}(Q^2) + F_{Axial}(Q^2) + F_{Strange}(Q^2)$$

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)

$Q_{Weak} = 0.075$

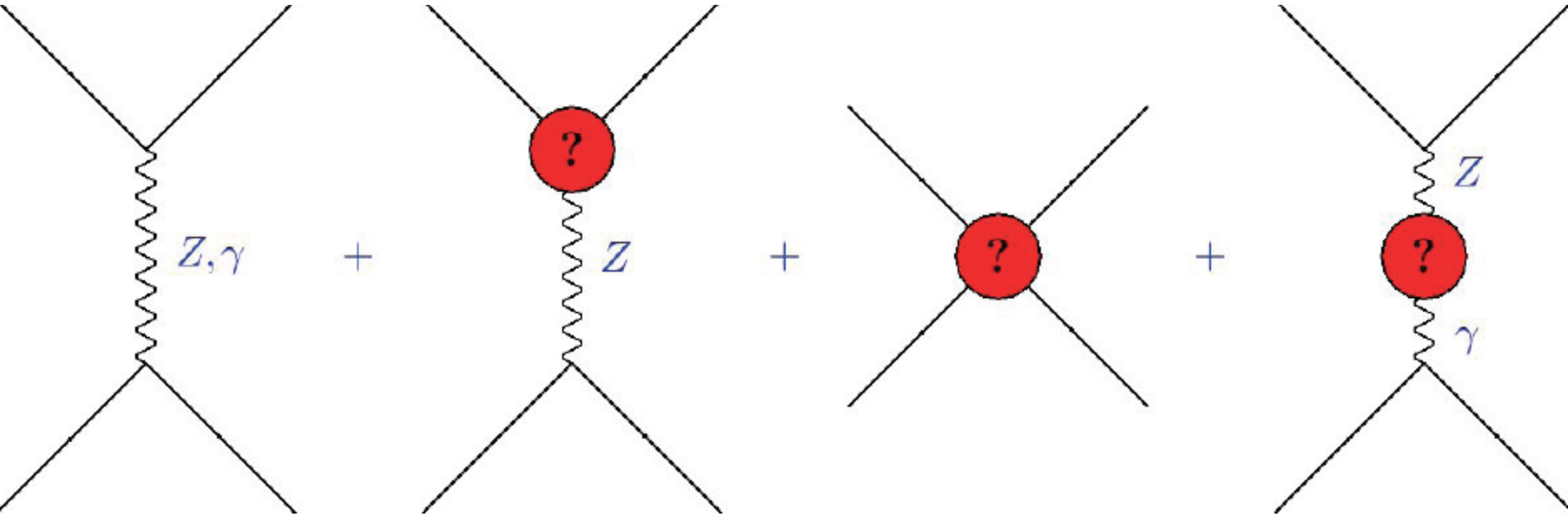
$Q_{Weak} = \rho' (1 - 4 \kappa' \sin^2 \theta_W)$ (Radiative Corrections)

$Q_{Weak} = 0.0718$ (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 beyond the Standard Model



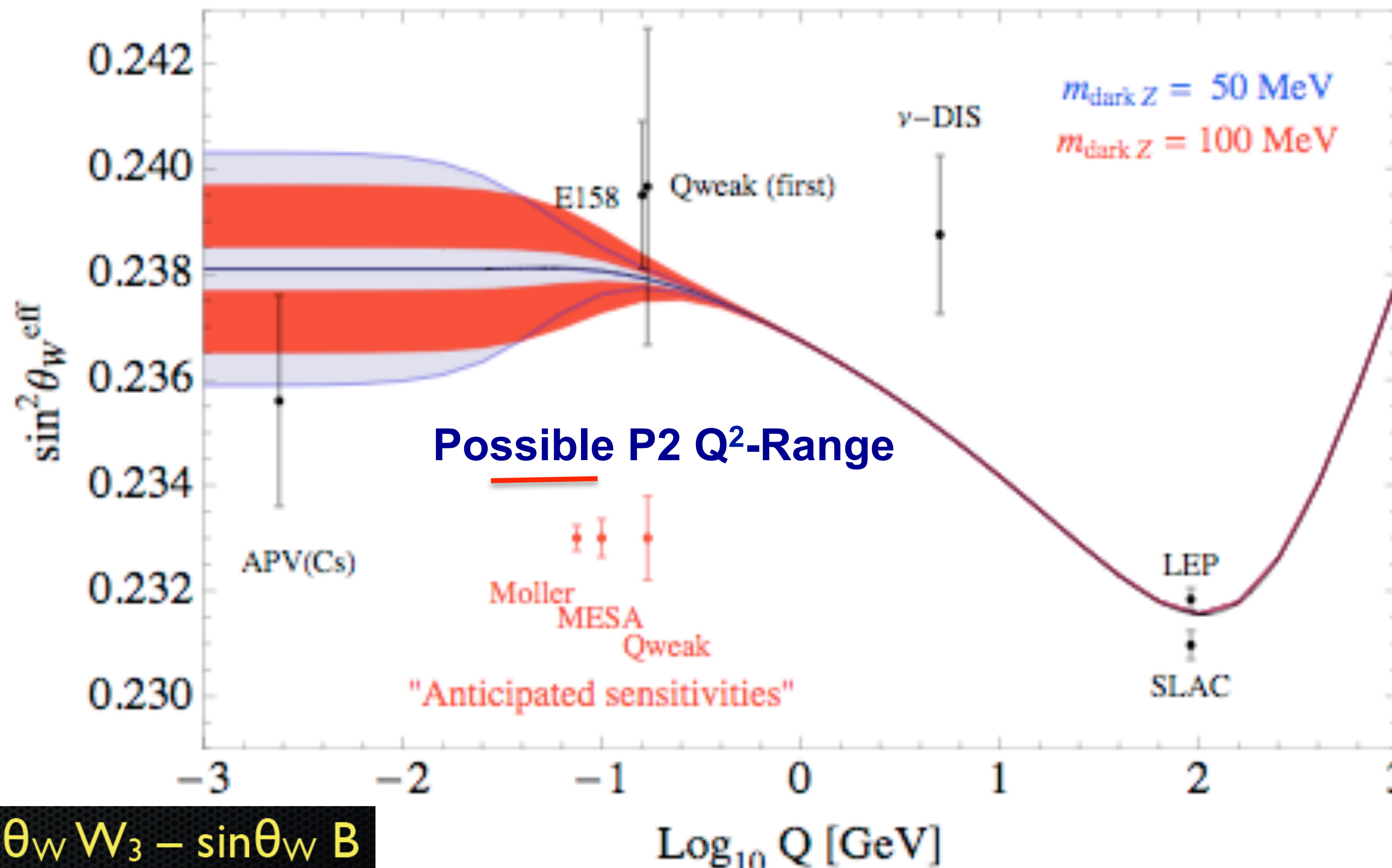
Extra Z

Mixing with Dark photon or Dark Z

Contact interaction

New Fermions

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



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

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

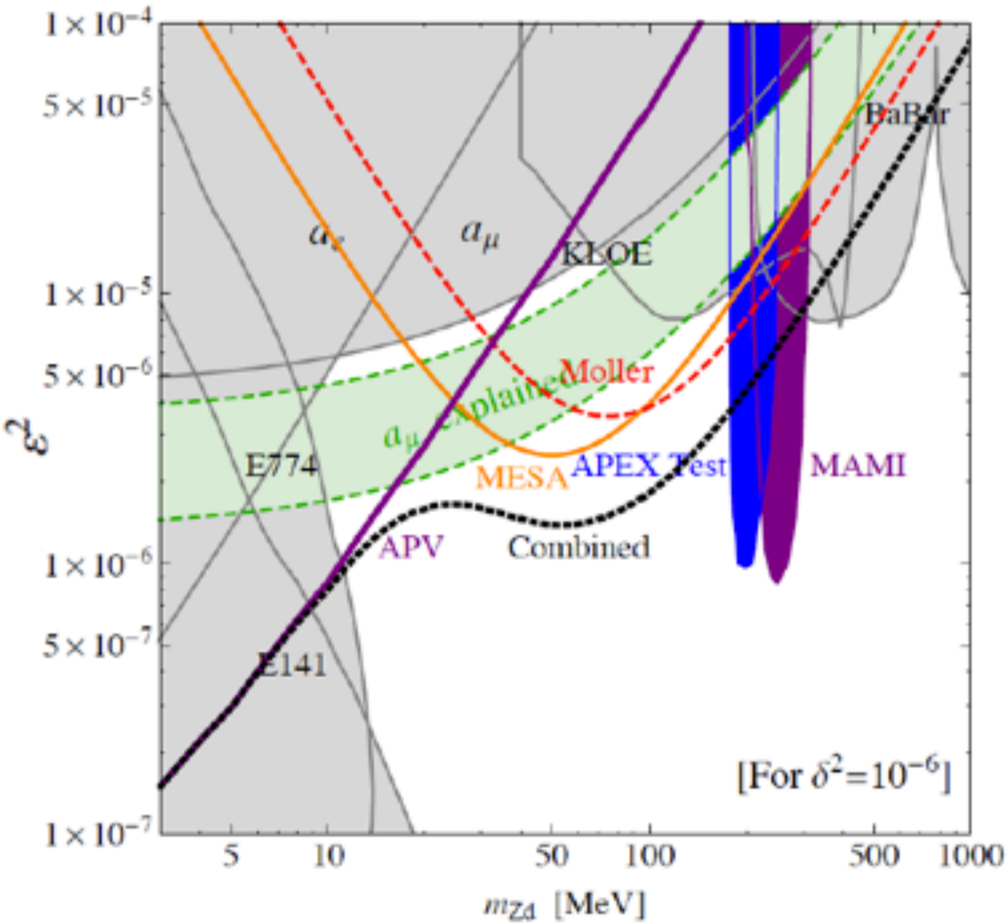
Bill Marciano

Sensitivity to new Physics

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

Possible mass mixing between dark photon and dark Z:

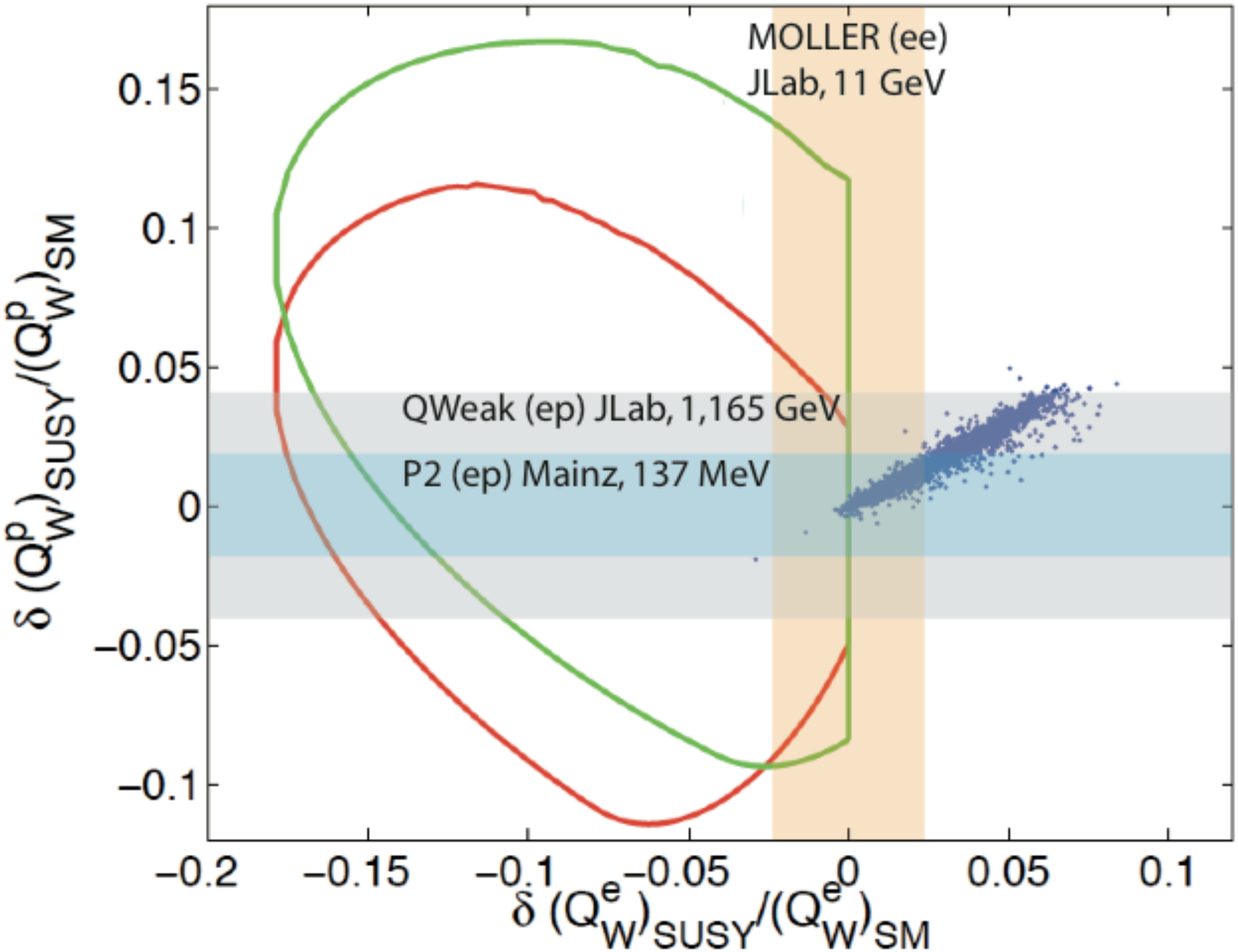
$$\epsilon_Z = \frac{m_{Z_d}}{M_Z}\delta$$



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

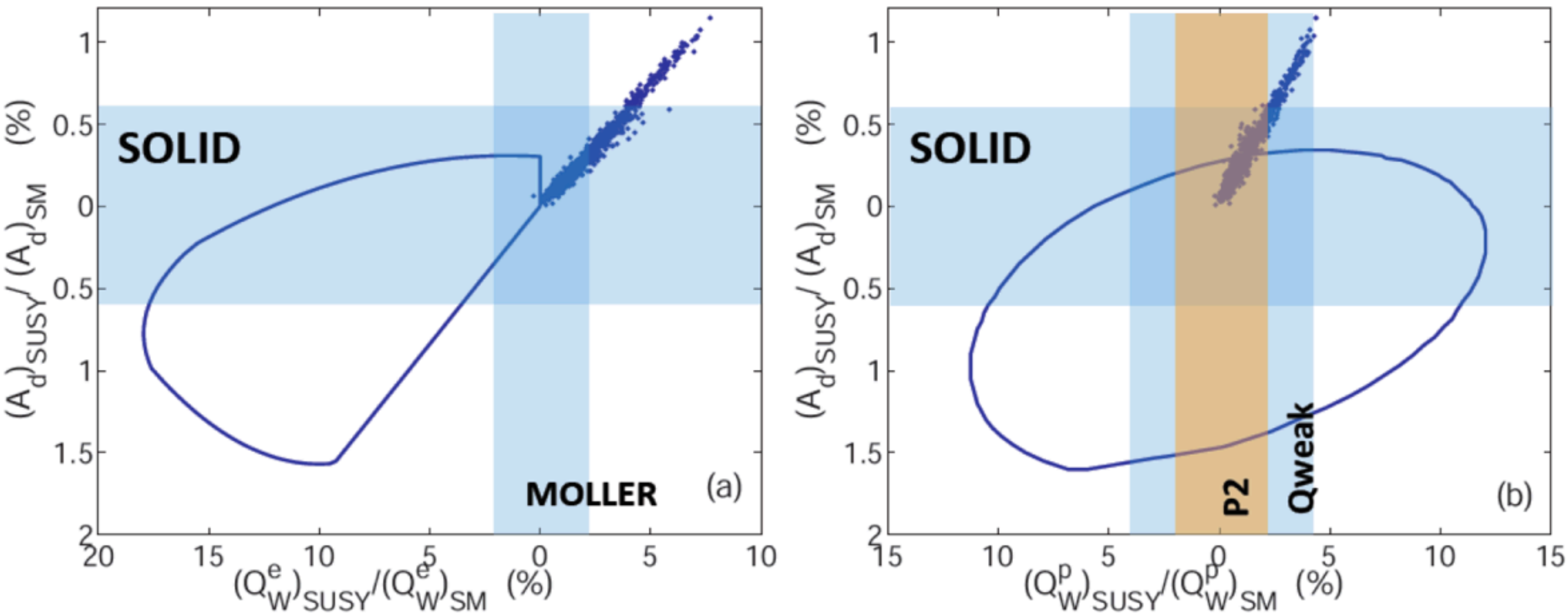
Sensitivity to new Physics

Example: supersymmetric Standard Model extensions

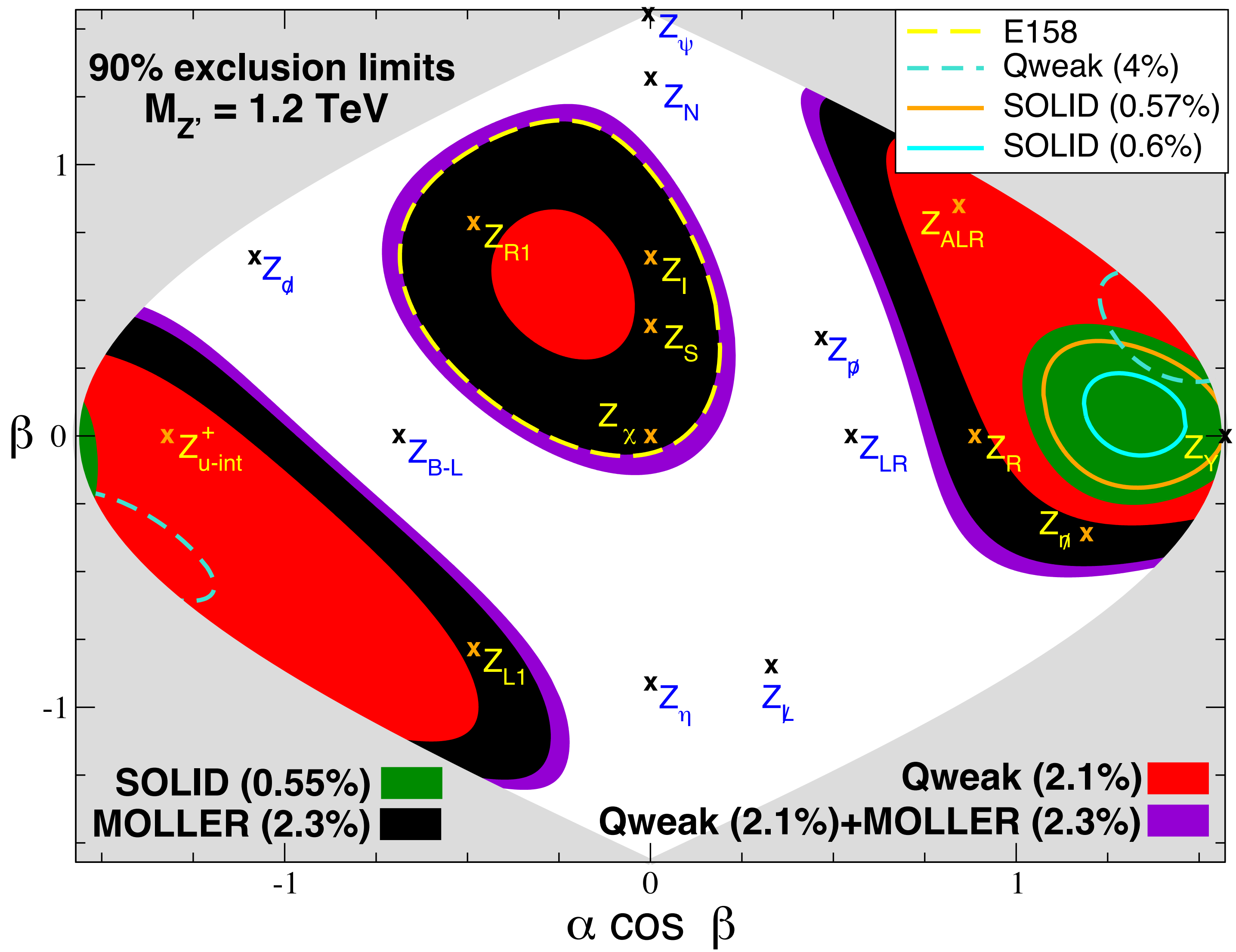


Sensitivity to new Physics

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

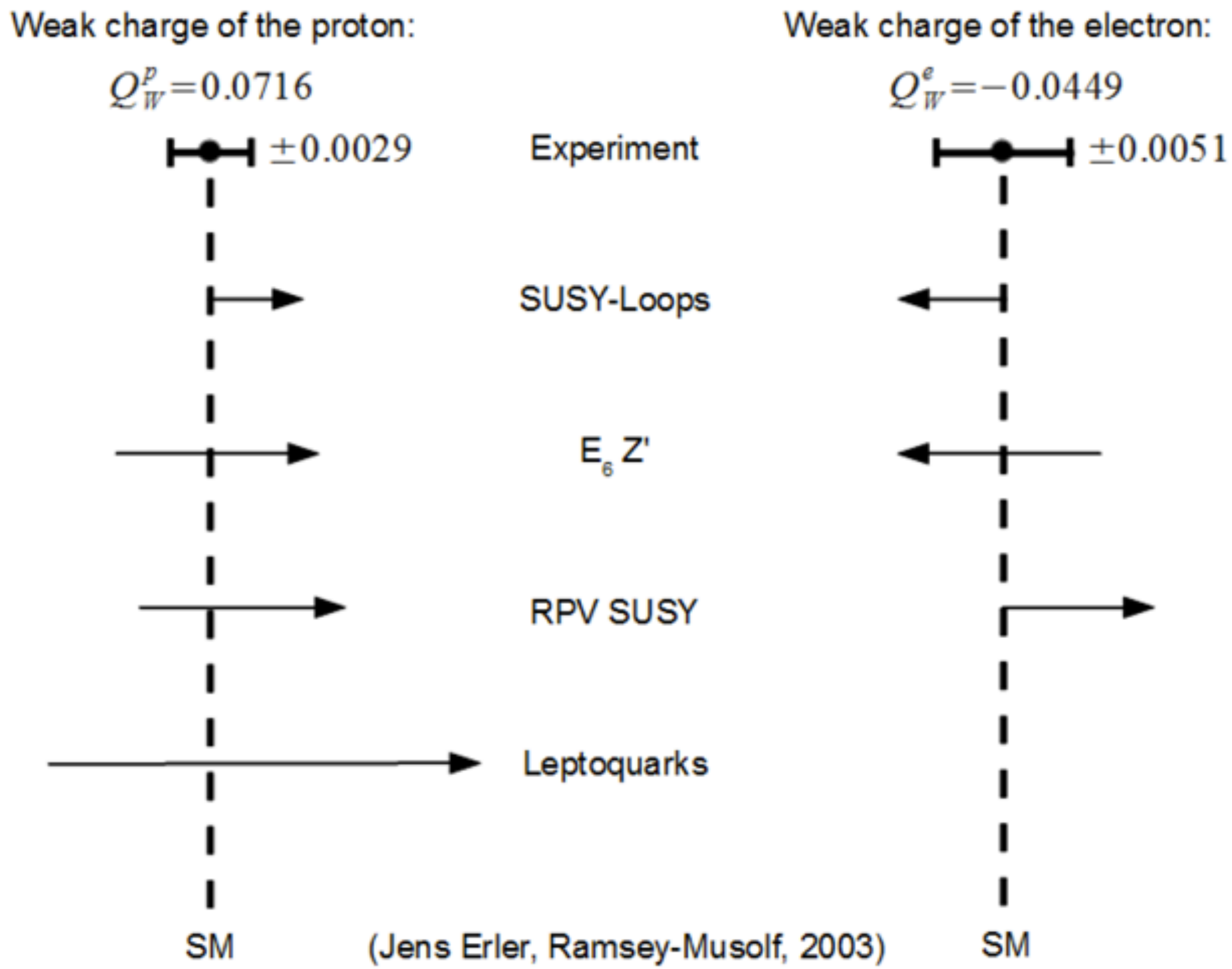


Sensitivity to new Physics



Sensitivity to new Physics

- Complementary access by weak charges of proton and electron



(Jens Erler, Ramsey-Musolf, 2003)

Sensitivity to new Physics

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

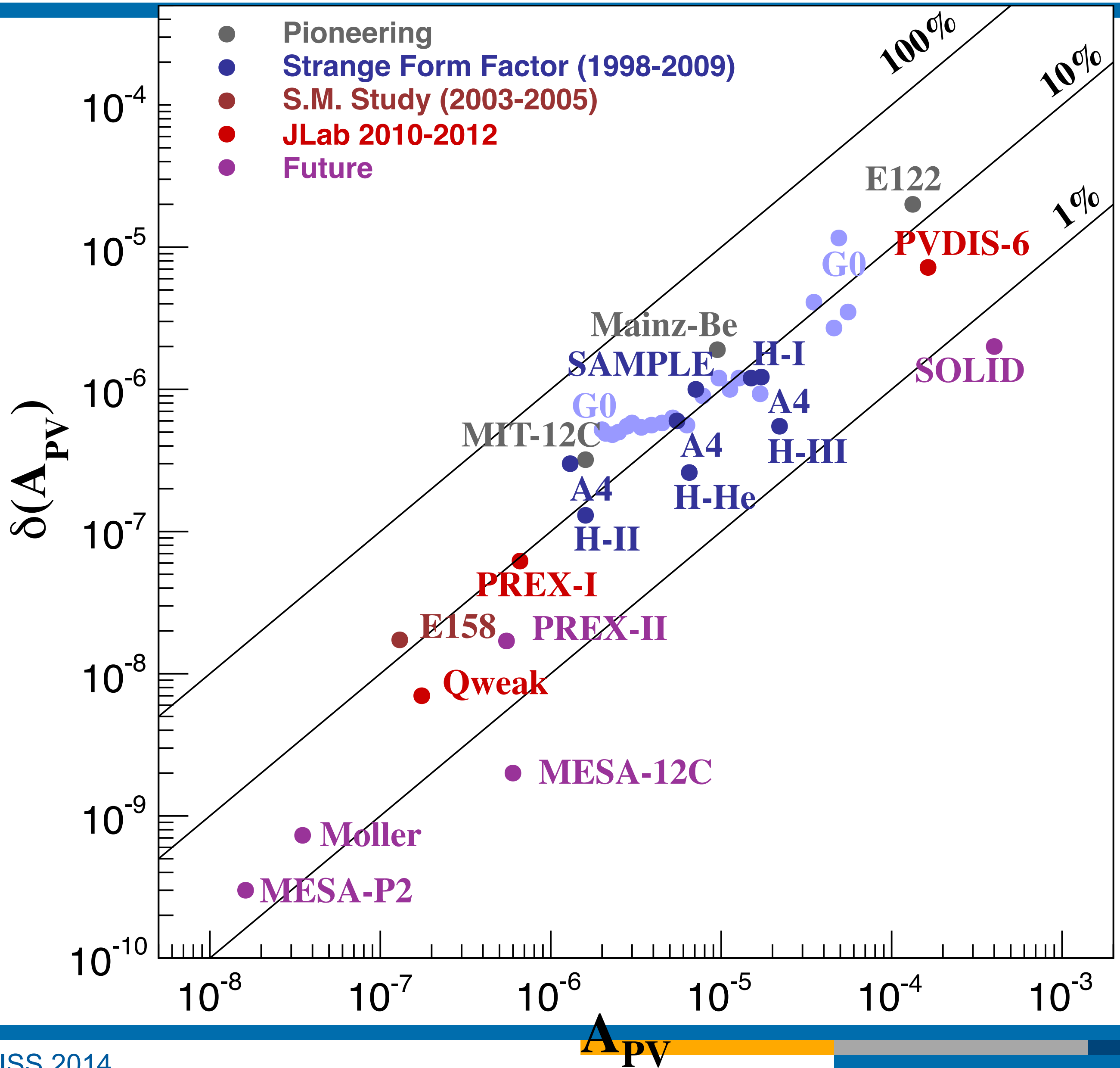
$\Lambda_{new} \simeq$ 3.4 TeV (E158@SLAC, published)
$\Lambda_{new} \simeq$ 4.6 TeV (Qweak@JLab, finished, under analysis)
$\Lambda_{new} \simeq$ 2.5 TeV (SOLID@JLab, planned)
$\Lambda_{new} \simeq$ 7.5 TeV (MOLLER@JLab, planned)

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

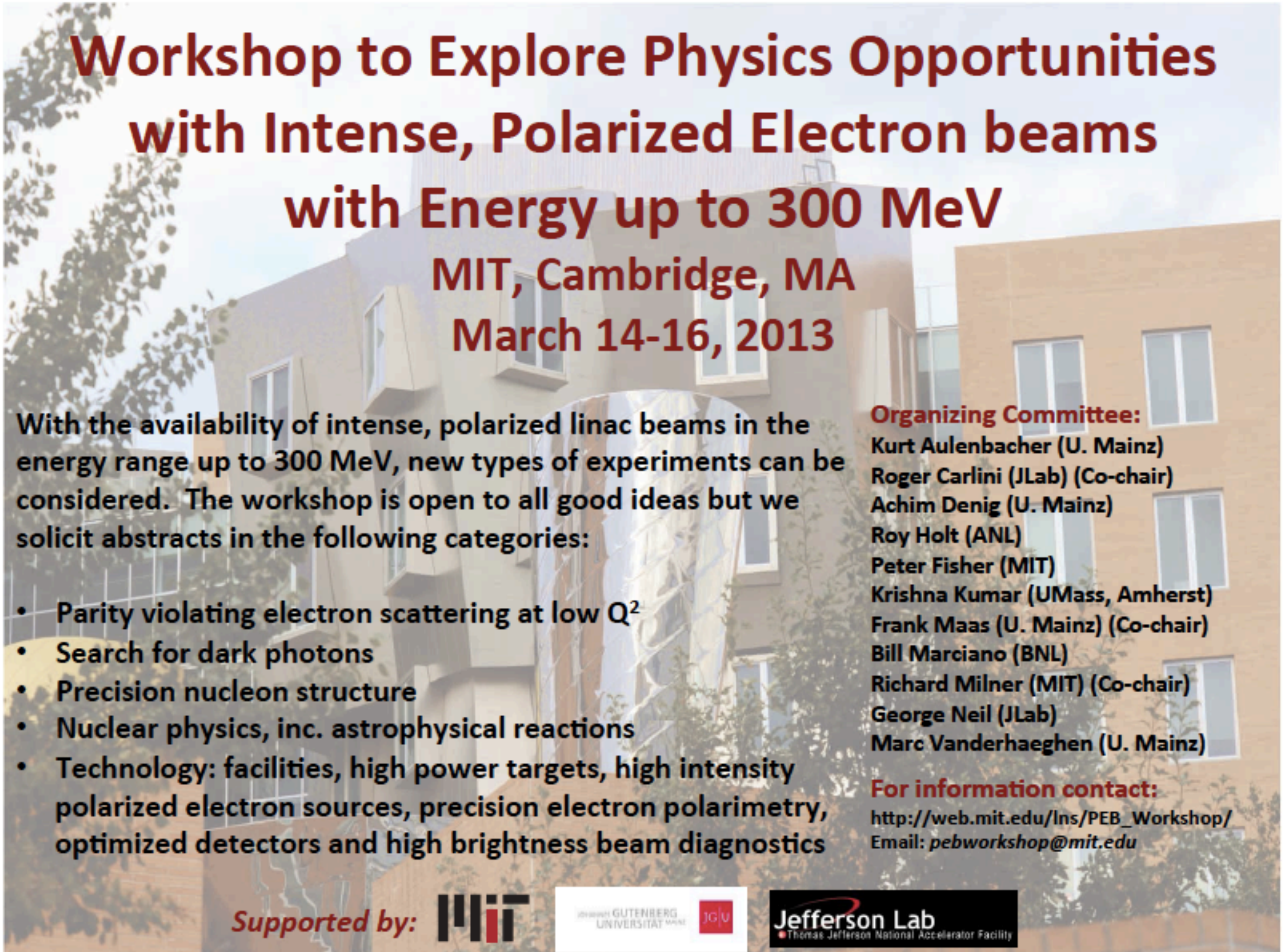
Physics sensitivity from contact interaction

	precision	$\Delta \sin^2\overline{\theta}_W(0)$	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

Method: Parity-Violating Electron-Proton Scattering



MESA as low energy electron accelerator facility



Summary: Perspectives are Excellent

FAIR will be the main national laboratory for strong interaction
Studies at all length scales: PANDA-experiment 1 of 4 Pillars

New at GSI: Antiproton beams for spectroscopy

Explore electromagnetic probe in antiproton annihilation

PANDA will deliver data for time like form factors with unprecedented accuracy

Electromagnetic probe accessible at PANDA due to particle id.

Can be used in many other channels

Summary: Perspectives are Excellent

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

1.6 Gev electron accelerator MAMI (normal conducting)

0.15 GeV electron accelerator MESA (supercond., energy recov.)

“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:

- dark photon
- weak mixing angle
- proton radius

Could only show a small collection of the full program