



Introduction to CRC 1044:

The Low-Energy Frontier of the Standard Model

From Quarks and Gluons to Hadrons and Nuclei

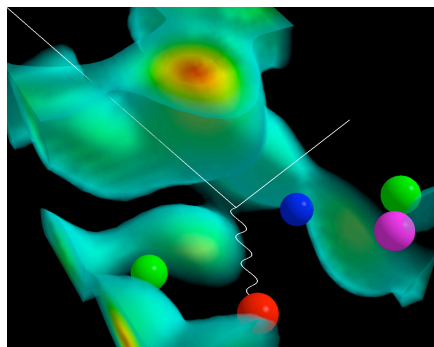


Speakers: Achim Denig , experiment
Marc Vanderhaeghen, theory

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



Hadrons and Nuclei



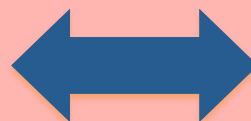
$$\sin^2 \theta_W$$

$$(g-2)_\mu$$

R_E
Proton charge
radius

Quarks and Gluons

Strong interactions
Hadron structure
Hadron spectroscopy



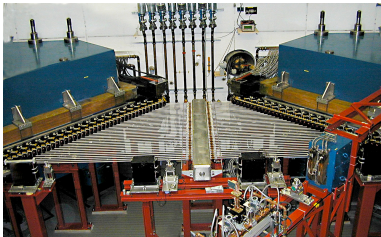
Particle physics
Atomic physics
Astro(particle) physics



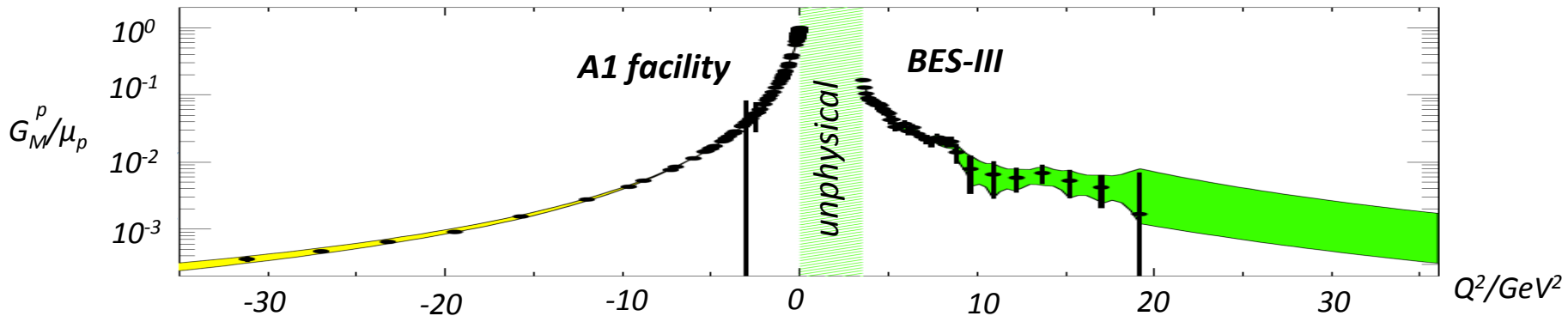
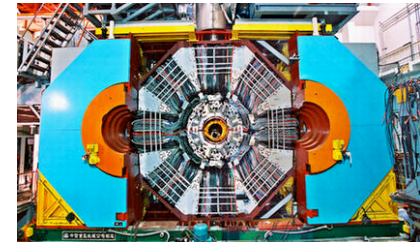
Low-Energy Frontier of the Standard Model

Novel concept of CRC1044:
Interplay btw. Spacelike and Timelike Measurements
Insights into Hadron Structure

MAMI
e⁻ Fixed Target



BES-III @ BEPC-II
e⁺e⁻ Collider





P=Precision Physics, **S**=Hadron Structure, **M**=Internal Symmetries & Structure of Mesons, **N**=Nuclear Physics

	Projects	
<i>Project area P</i>	P1	Precision hadron physics : $(g-2)_\mu$ and $\alpha_{em}(M_Z^2)$
	P2	The weak charge of the proton @ MESA
<i>Project area S</i>	S1	Baryon form factors
	S2	Polarizabilities
	S3	Low-energy excitations of light hadrons
<i>Project area M</i>	M1	$\gamma\gamma$ physics and meson structure
	M2	Light meson dynamics (e.g. η , η' decays)
<i>Project area N</i>	N	Interactions in few-baryon systems



A new cluster of excellence within the German excellence initiative

- Mainz and Munich (TU and LMU) only successful proposals in our field
- PRISMA: group application of Institute of Nuclear Physics and Mainz HEP group (and related fields: atomic physics, UCN group, mathematics)


Total Budget: 32 M€

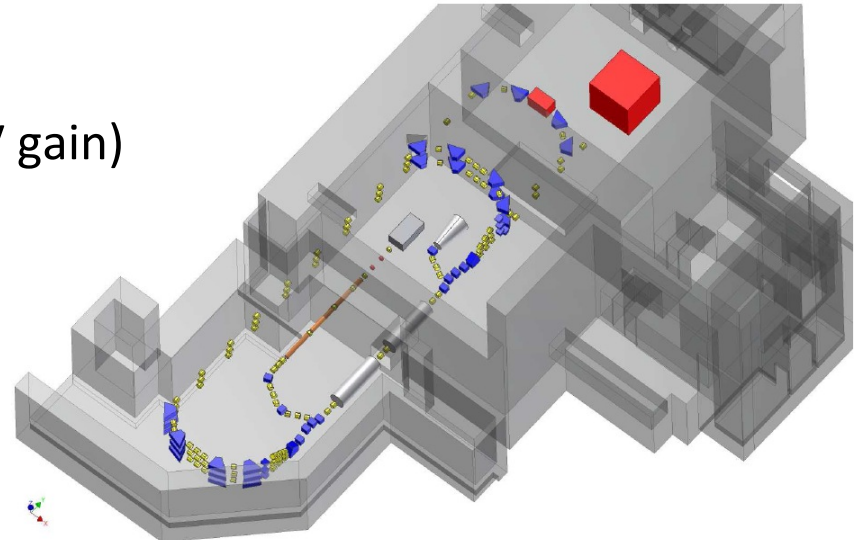
(Funding Period Nov. 2012 – Oct. 2017)

- 9 new professorships
(**W3-Exp: Precision Hadron Physics**, W2-Theory: Virtual Analysis Centre)
- Foundation of Mainz Institute for Theoretical Physics (**MITP**)
(Workshop Programs, Guest Scientists)
- Structural initiatives
(**MESA accelerator**, TRIGA upgrade, Detector laboratory)



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**
 - P2: Precision measurement of $\sin^2\Theta_w$
→ extracted beam mode 
 - High Resolution Spectrometers
→ ERL mode
 - **Frontier projects in Particle, Hadron, Nuclear Physics**





Selected Highlights from 2012-2013



$$\sin^2 \theta_W$$

$$(g-2)_\mu$$

R_E
Proton charge
radius

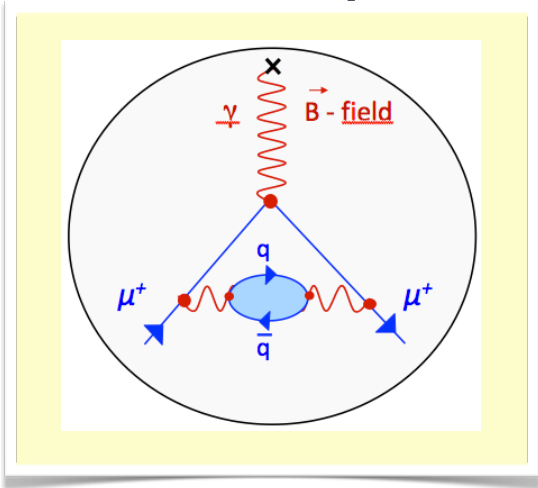


Hadron physics impact on new physics searches: magnetic moment of muon $a_\mu = (g - 2)_\mu / 2$

$a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = (24.9 \pm 8.7) \cdot 10^{-10} \quad (3 \sigma)$

New FNAL $(g-2)_\mu$ expt. (2016):
 $\delta a_\mu^{\text{exp}} = 1.6 \times 10^{-10}$

hadronic vacuum polarization

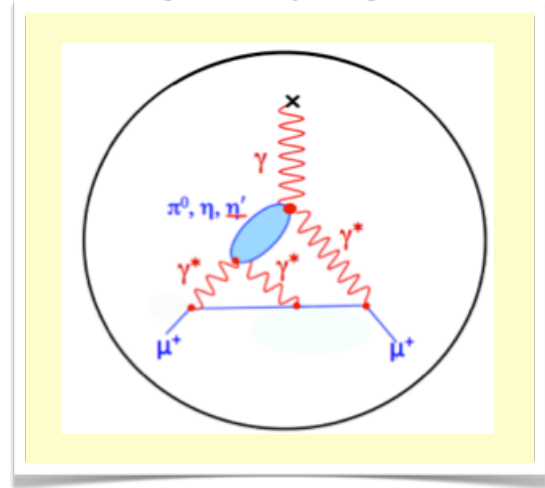


$a_\mu^{\text{had, VP}} = (692.3 \pm 4.2) \times 10^{-10}$

will be improved by cross section
measurements of $e^+ e^- \rightarrow$ hadrons

US "Snowmass"
white paper
arXiv:1311:2198

hadronic light-by-light scattering



$a_\mu^{\text{had, LbL}} = (11.6 \pm 4.0) \times 10^{-10}$

meson transition FF measurements
and theory developments



First results at BES-III

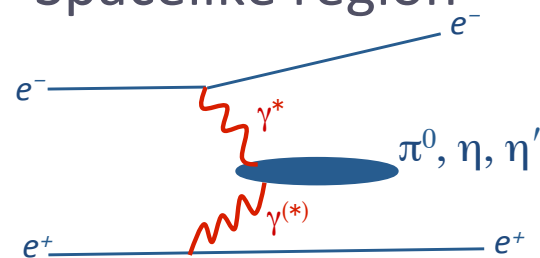
Timelike region



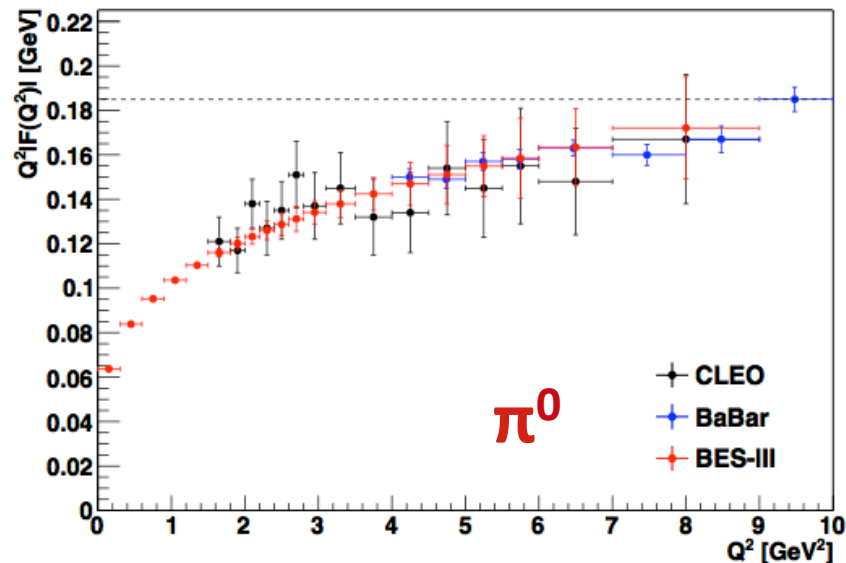
Preliminary



Spacelike region



$Q^2|F(Q^2)|$ vs. Q^2

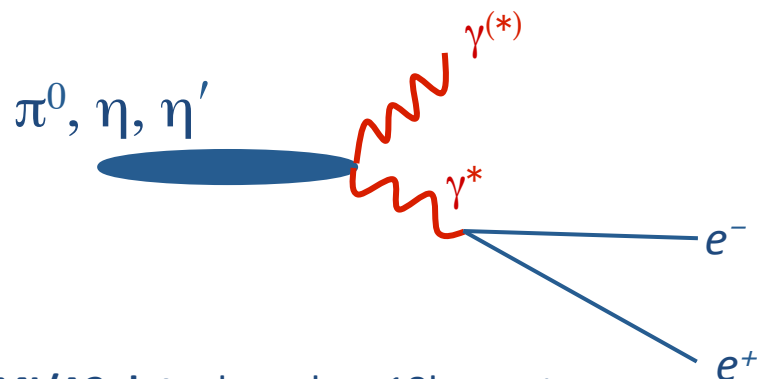


cross section precision 1.4 % (goal 1 %)

simulations for 1y running at BES-III (10 fb⁻¹)



MAMI/A2 results on η, η' decays



MAMI/A2 data: based on 18k events

S. Prakhov, M. Unverzagt, et al. (2013)

Theory: Pade-approximant prediction from spacelike

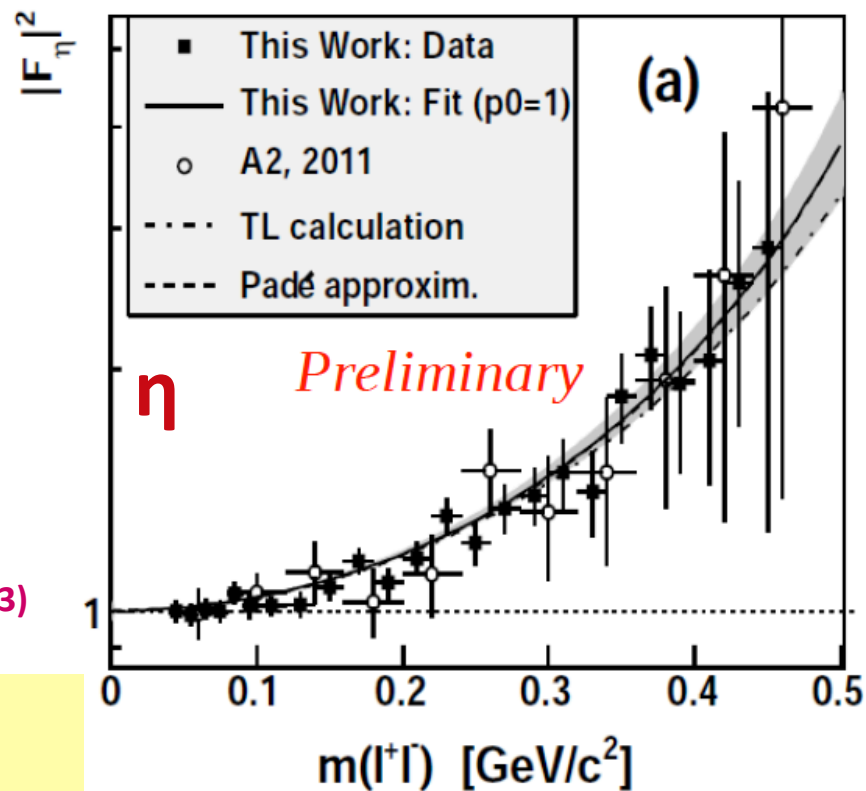
data: **R. Escribano, P. Masjuan, P. Sanchez-Puertas (2013)**

Workshops sponsored/organized by CRC1044 on hadronic light-by-light contribution to $(g-2)_\mu$:

→ ECT* Coll. Meeting (Trento/Italy, April 2013)

→ EINN 2013 (Pafos/Cyprus, Oct 28 – Nov 2, 2013)

→ MITP workshop (Mainz, April 2014)





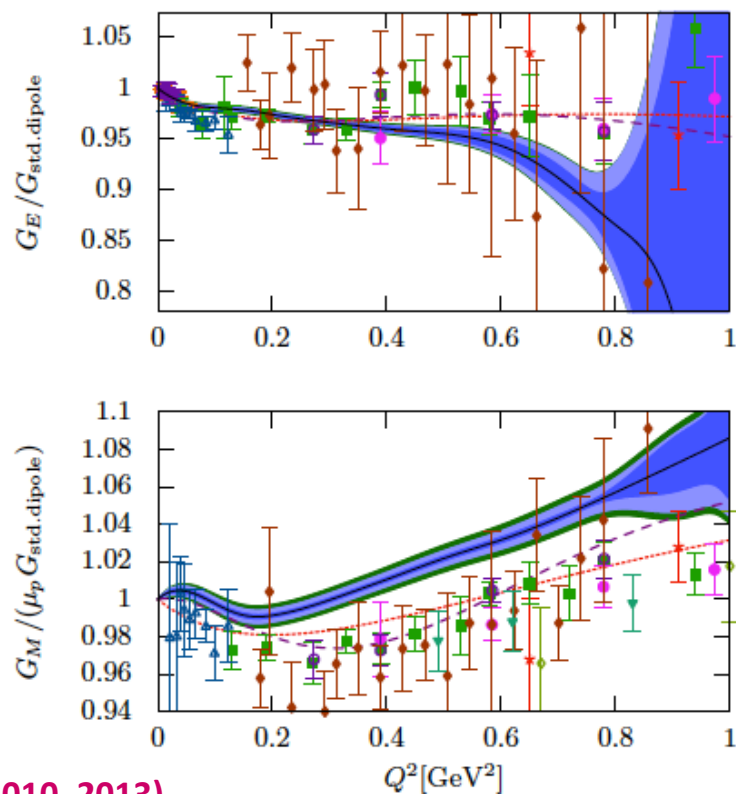
Proton charge radius

MAMI: uniquely positioned to deliver high-precision hadron data

High momentum resolution $\sim 10^{-4}$



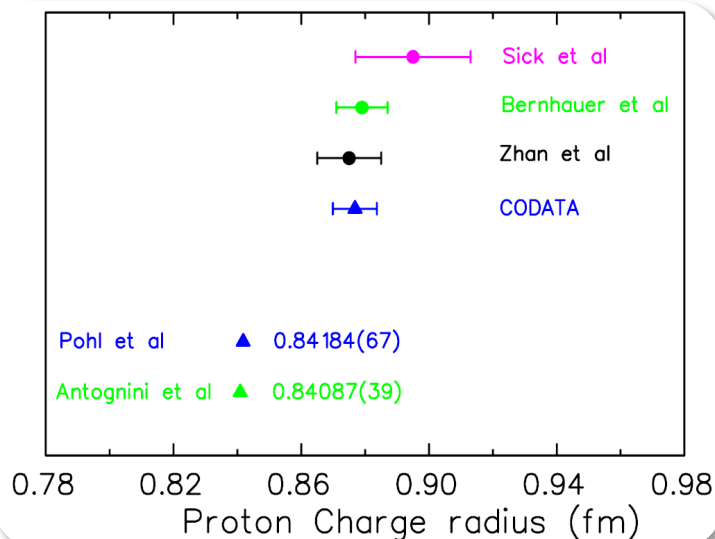
MAMI achieved 1% measurement of R_E



Bernauer et al. (2010, 2013)

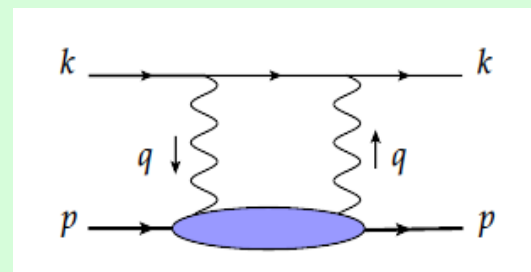


Proton radius puzzle



corrections to Lamb shift: **300 μeV below expectation**

proton structure corrections:



$$\Delta E = (-33 \pm 2) \mu\text{eV}$$

Carlson, Vdh (2011)

+ Birse, McGovern (2012)

μH data:

$$R_E = 0.8409 \pm 0.0004 \text{ fm}$$

Pohl et al. (2010)
Antognini et al. (2013)

7.7 σ difference

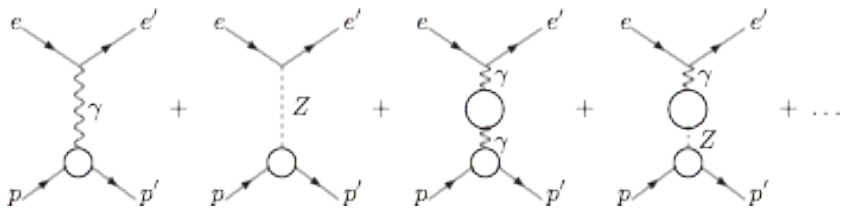
ep-data:

$$R_E = 0.8772 \pm 0.0046 \text{ fm}$$

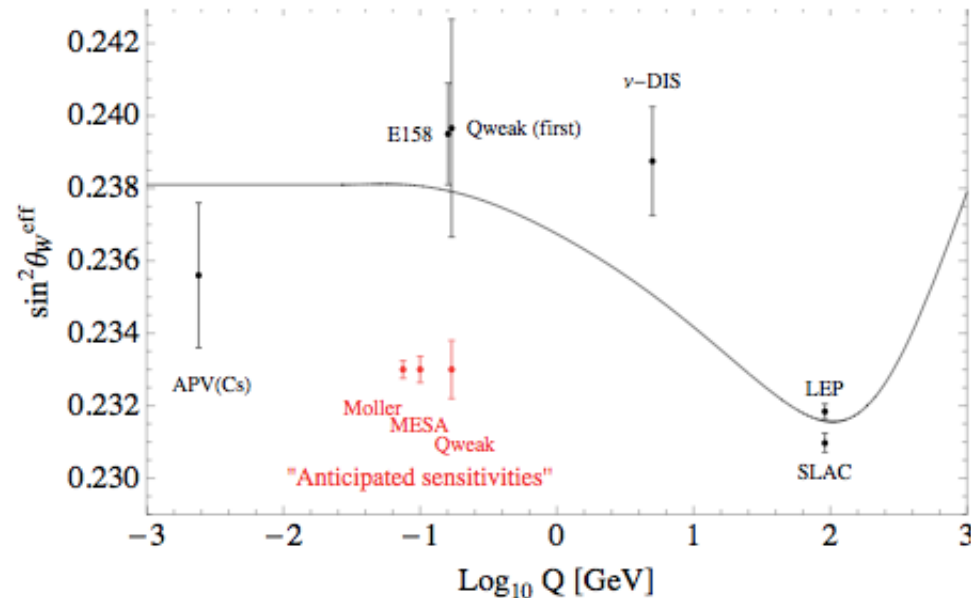
Bernauer et al. (2010, 2013)
Zhan et al. (2011)



Weak charge of proton



Universal quantum corrections: can be absorbed in a scale dependent, „running“ $\sin^2 \theta_W(Q)$



➤ Experiment at MESA: Feasibility studies of magnetic field configuration have been performed (both solenoid and toroid possible)

➤ first test beam measurements were taken

➤ Progress in theory: γZ box graphs

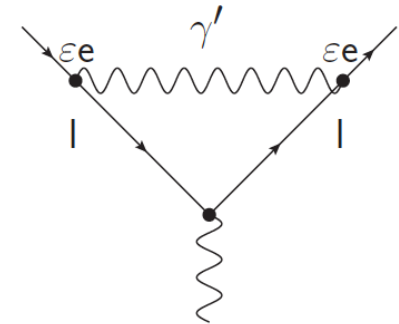
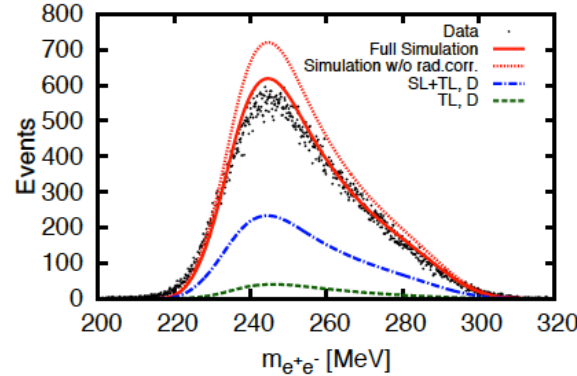
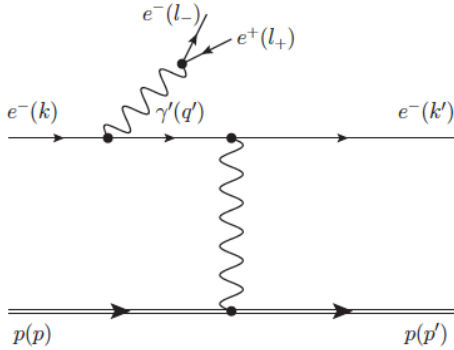
Workshops on low-energy precision physics:

→ MIT workshop (Cambridge/USA, March 2013)

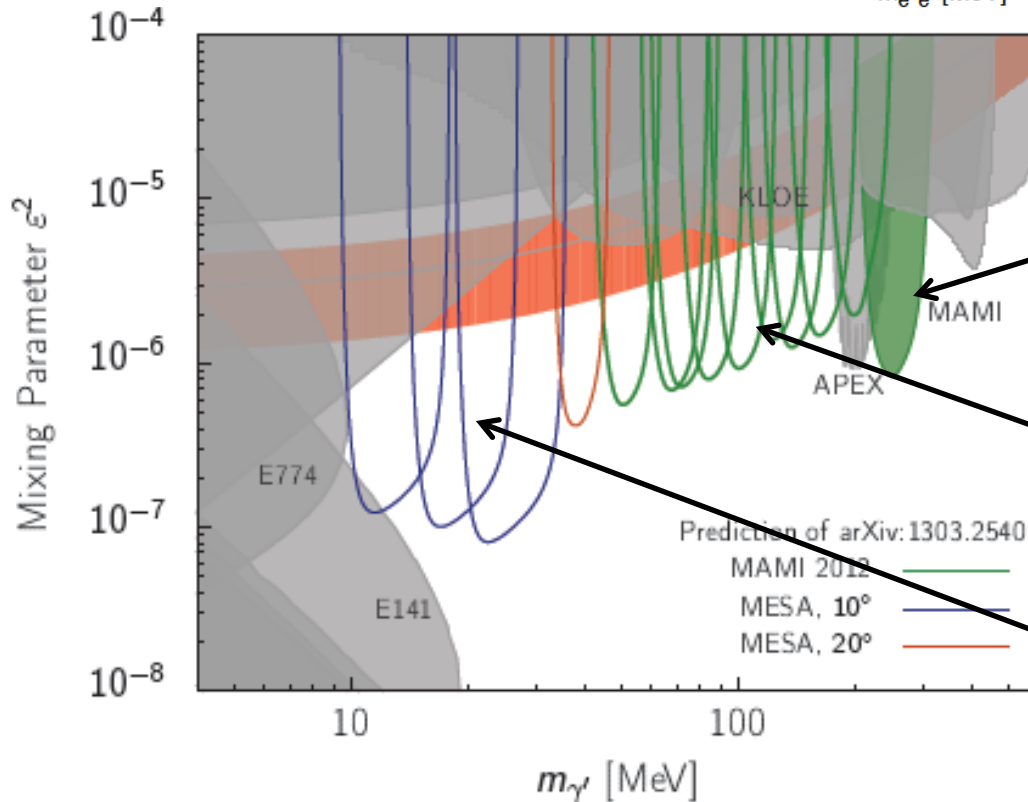
→ MITP workshop (Mainz, September/October 2013)



Dark photon limits



Red band: $(g-2)\mu$



Step1:

Published result from 2010 pilot run
→ PRL (2011)

Step2:

Expected exclusion range from 2012/2013 data sets (6 weeks)

Step3:

Low Mass range not accessible by MAMI
→ MESA



- CRC-1044: long term perspective (12y) for MAMI operation
- 1st funding period: Jan 2012 – Dec 2015
- outline projects 2nd funding period have to be sent to DFG in early 2015

full proposal for 2nd funding period (2016-2019) has to be submitted to DFG by mid 2015

- identify new, competitive research directions which strengthen the research program
- Light Meson Dynamics (M2 Project):
identify new research directions, impact on other physics questions
complementarities between different experiments



**Hadronic contributions to the muon (g-2):
strategies for improvements of the accuracy of
the theoretical prediction**

(org: T. Blum, S. Eidelman, F. Jegerlehner, D. Stöckinger + A. Denig, M. Vdh)

Mainz, April 1-5, 2014 : MITP workshop (TH)

+ April 7-11, 2014 : SFB workshop (EXP)