2011 - 2014 — PhD in theoretical physics
under supervision of Prof. Dr. Marc Vanderhaeghen
at Johannes Gutenberg University Mainz.
Thesis title ***"Light-by-light scattering and the muon's anomalous magnetic moment"***

2014 - 2015 — Postdoc at the Institute of Nuclear Physics in Mainz
Project: ***Lepton universality test in the photoproduction of e^-e^+ versus $\mu^-\mu^+$ pairs on a proton target***

JLab Director's Theory Seminar, December 2, 2015

Lepton universality test in the photoproduction of e^-e^+ versus $\mu^-\mu^+$ pairs on a proton target

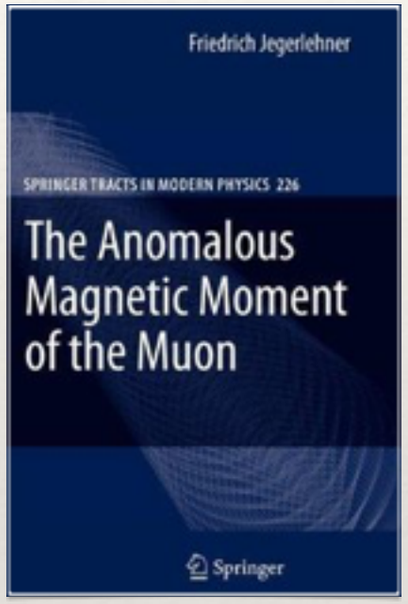
Vladiszlav Pauk
Thomas Jefferson
National Accelerator Facility
Newport News, VA, USA

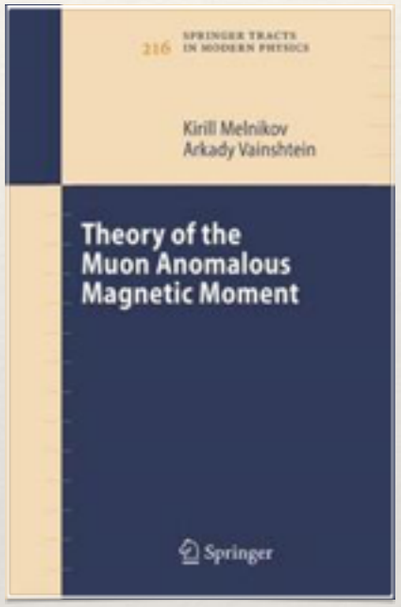
Summary of research activity

Electromagnetic properties of hadrons and their role in precision observables and searches for New Physics.

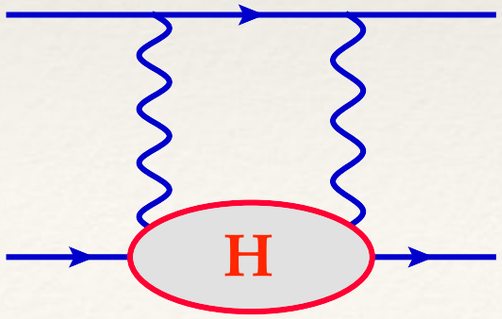
large **discrepancy** between theory and experiment

sign of **New Physics!**



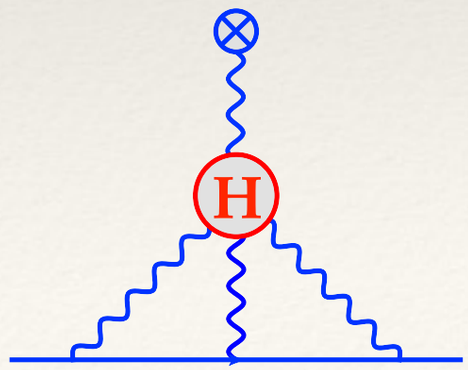


~ 7σ discrepancy



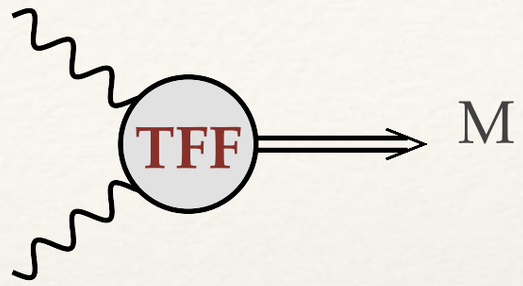
large **uncertainties** from unconstrained **hadronic corrections**

~ 3σ discrepancy



Summary of research activity

Two-photon production
and meson **transition form factors**



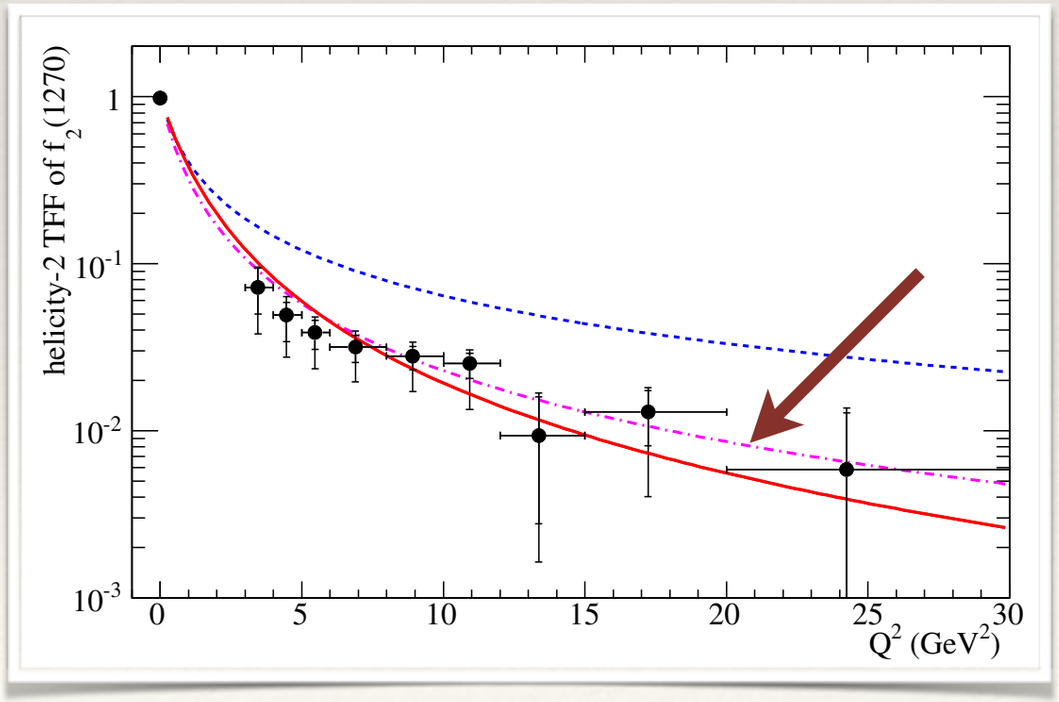
analyticity

unitarity

gauge symmetry

→ **Sum rules:**

$$\int_{s_0}^{\infty} \frac{\sigma_0 - \sigma_2}{s + Q^2} = 0$$



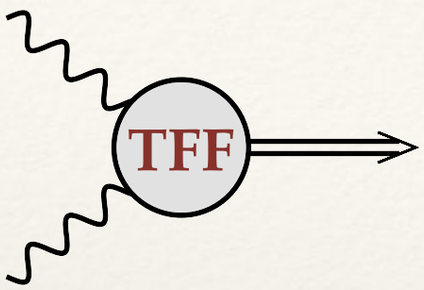
Belle (2015)

Phys. Rev. D 85, 116001
Phys.Lett. B725, 504-509

predictions for the TFF for **$f_2(1270)$**
as a function of the photon virtuality

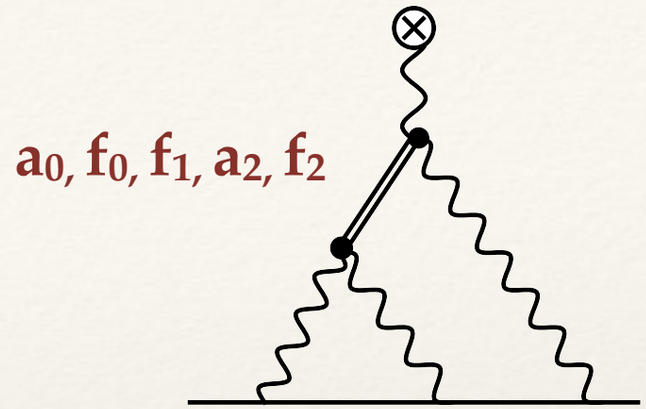
Next: update of the analysis using **new data**

Summary of research activity



$(g\text{-}2)_\mu$

Eur.Phys.J. C74 3008



FNAL expected accuracy:

$$\delta a_\mu \approx 16 \times 10^{-11}$$

Total contribution of single meson exchanges beyond pseudo scalars:

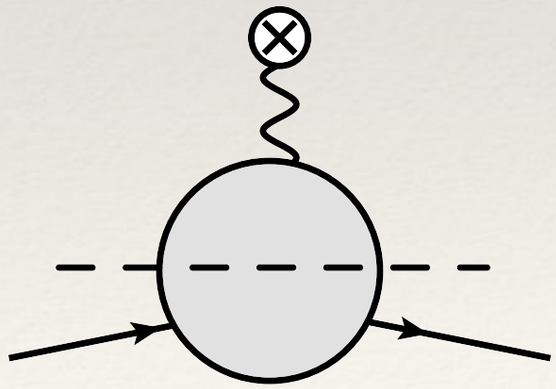
$$a_\mu(a_0, f_0, f_1, a_2, f_2) \approx 6 \times 10^{-11}$$

model independent approach needed for the **systematic account** of the hadronic uncertainties

new dispersive framework

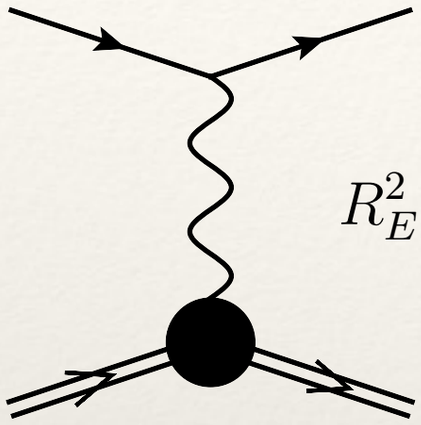
Phys.Rev. D90, 113012

relate $(g\text{-}2)_\mu$ to the absorptive part of the Pauli form factor in the **time-like region**



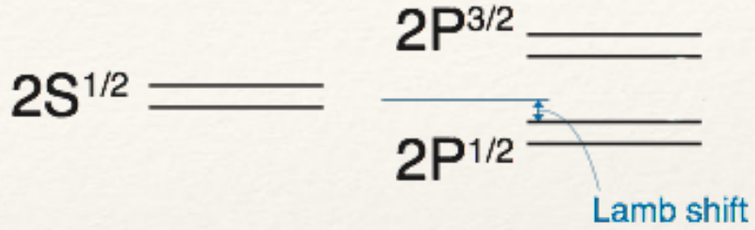
Next: realistic estimate of the contributions of the **single-** and **two-pion** thresholds

The proton radius



$$R_E^2 \overset{def}{=} -6 \left. \frac{dG_E}{dQ^2} \right|_{Q^2=0}$$

proton radius extraction



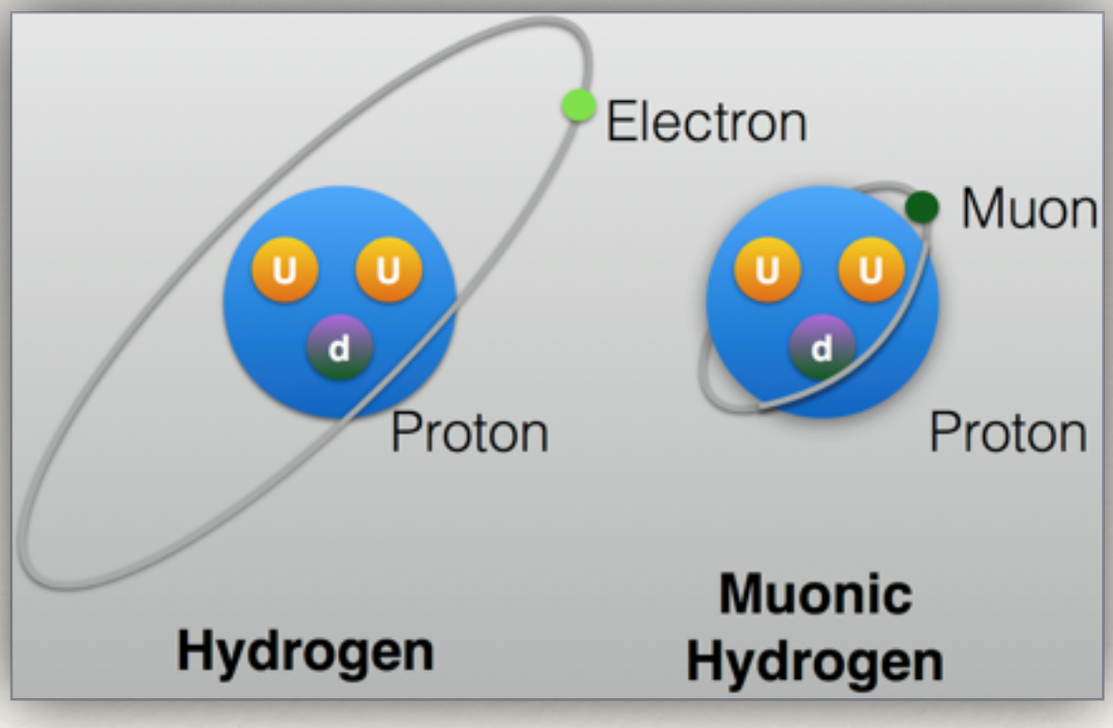
agree for the electron

(uncertainty ~0.6%)

$$\Delta E_L = \frac{2\pi\alpha}{3} |\phi(0)|^2 R_E^2$$

elastic scattering

atomic spectroscopy



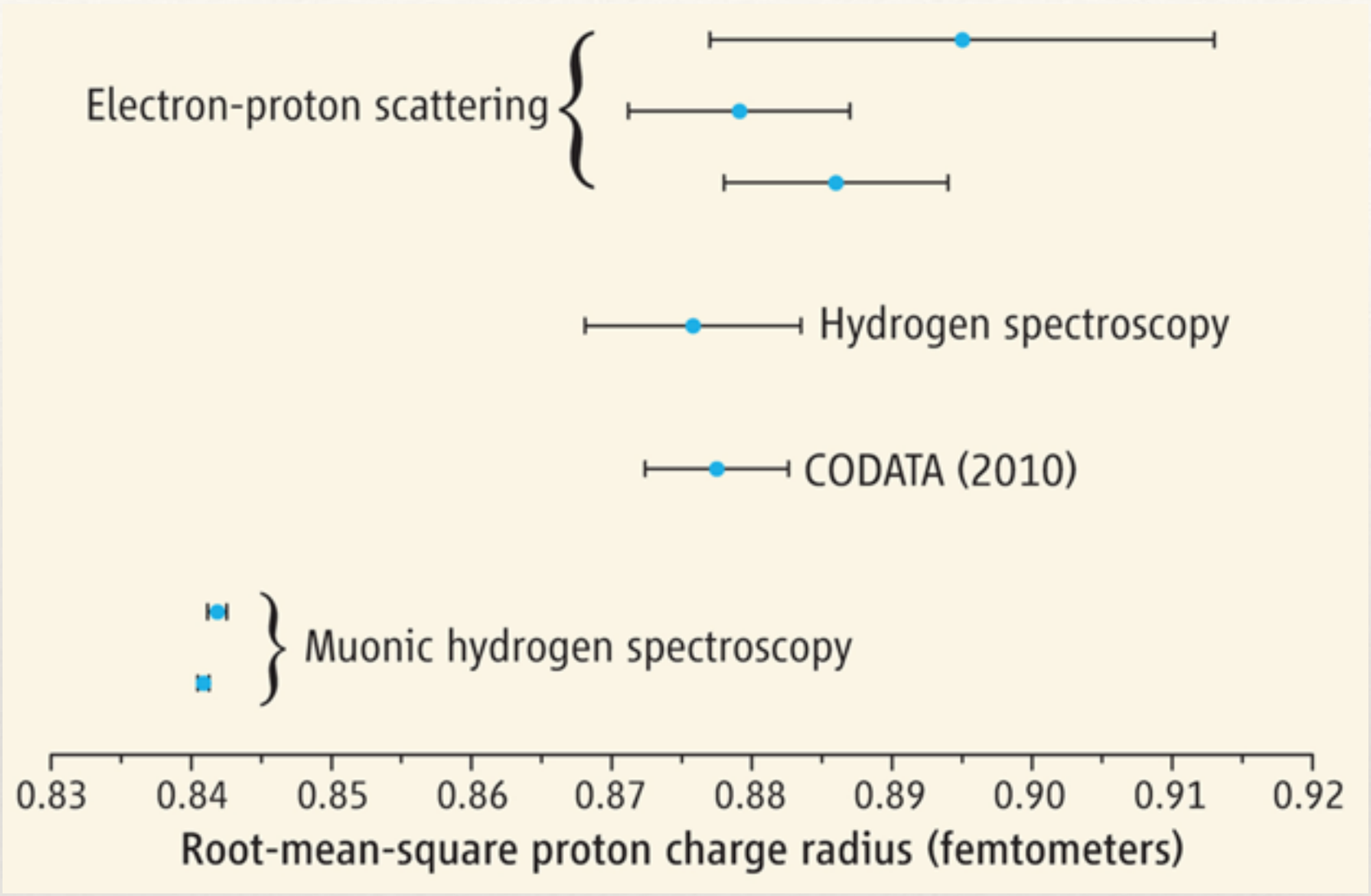
muon vs electron $m_\mu \sim 200\, m_e$

$$a_0 = \frac{\hbar^2}{m_e e^2}$$

Bohr radius

stronger effect from the proton size → 10x better precision

The puzzle



μH data:

$R_E = 0.8409 \pm 0.0004$ fm

Antognini et al.(2013)

Pohl et al.(2010)

7 σ difference !?

ep/eH data:

$R_E = 0.8775 \pm 0.0051$ fm

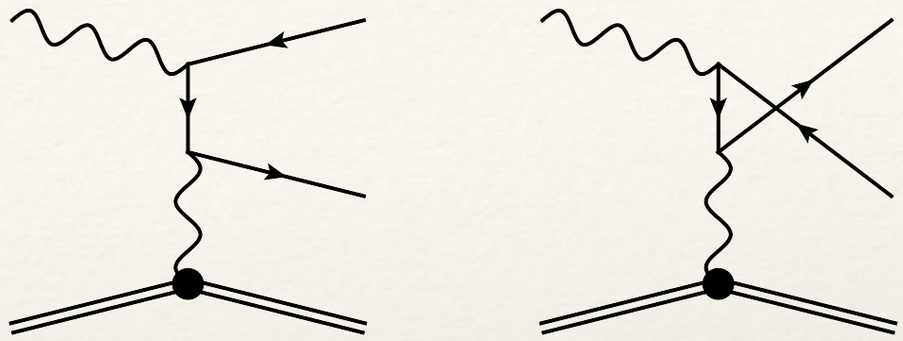
CODATA(2012)

Lepton pair production on a proton target

Measure the **ratio of the e vs μ** cross sections

$$R_{\mu/e} \equiv \frac{d\sigma(\mu^-\mu^+ + e^-e^+)}{d\sigma(e^-e^+)} - 1$$

Phys. Rev. Lett. 115, 221804



Bethe-Heitler process

Two-fold differential cross section of the **Bethe-Heitler** production to **leading order**

$$\frac{d\sigma^{BH}}{dt\,dM_{ll}^2} = \frac{\alpha^3}{(s-M^2)^2} \cdot \frac{4\beta}{t^2(M_{ll}^2-t)^4} \cdot \frac{1}{1+\tau} \left\{ C_E\, G_{Ep}^2 + C_M\, \tau\, G_{Mp}^2 \right\}$$

at **small t** the ratio $\mathbf{R_{\mu/e}}$ gives direct access to the ratio of the proton electric form factor in the **μp versus ep** scattering

the deviation from the unity will be a sign of violation of the lepton universality

Lepton pair production on a proton target

Bethe-Heitler is **highly peaked**
in the lepton **forward region**

Detect the proton
integrate over the lepton phase space

increase the **count rates**
the same systematics
no lepton acceptance corrections needed
large **cancellation** of radiative corrections

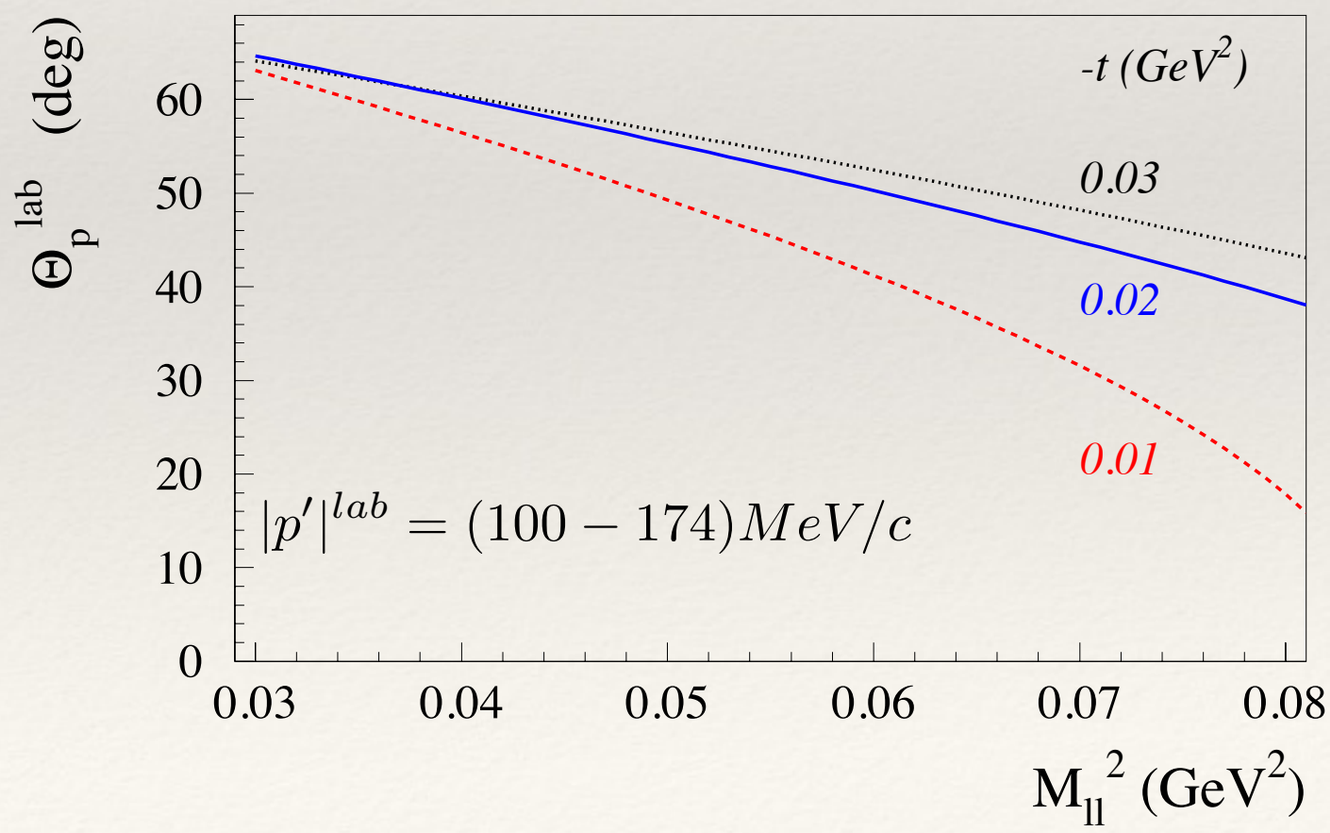
recoil proton Lab angle

$$\cos\Theta_p^{lab} = \frac{M_{ll}^2 + 2(s+M^2)\tau}{2(s-M^2)\sqrt{\tau(1+\tau)}}$$

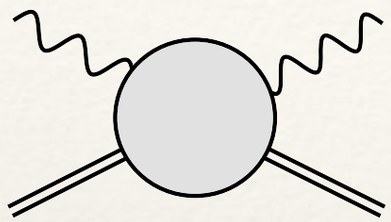
proton Lab momentum

$$|\vec{p}\,'|^{lab} = 2M\sqrt{\tau(1+\tau)}$$

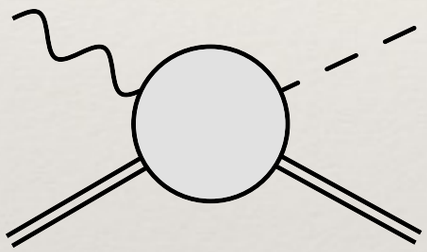
$$\tau = -t/(4M)^2$$



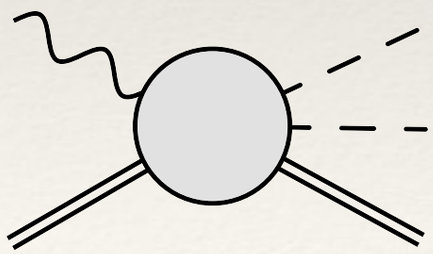
Experimental feasibility



Compton

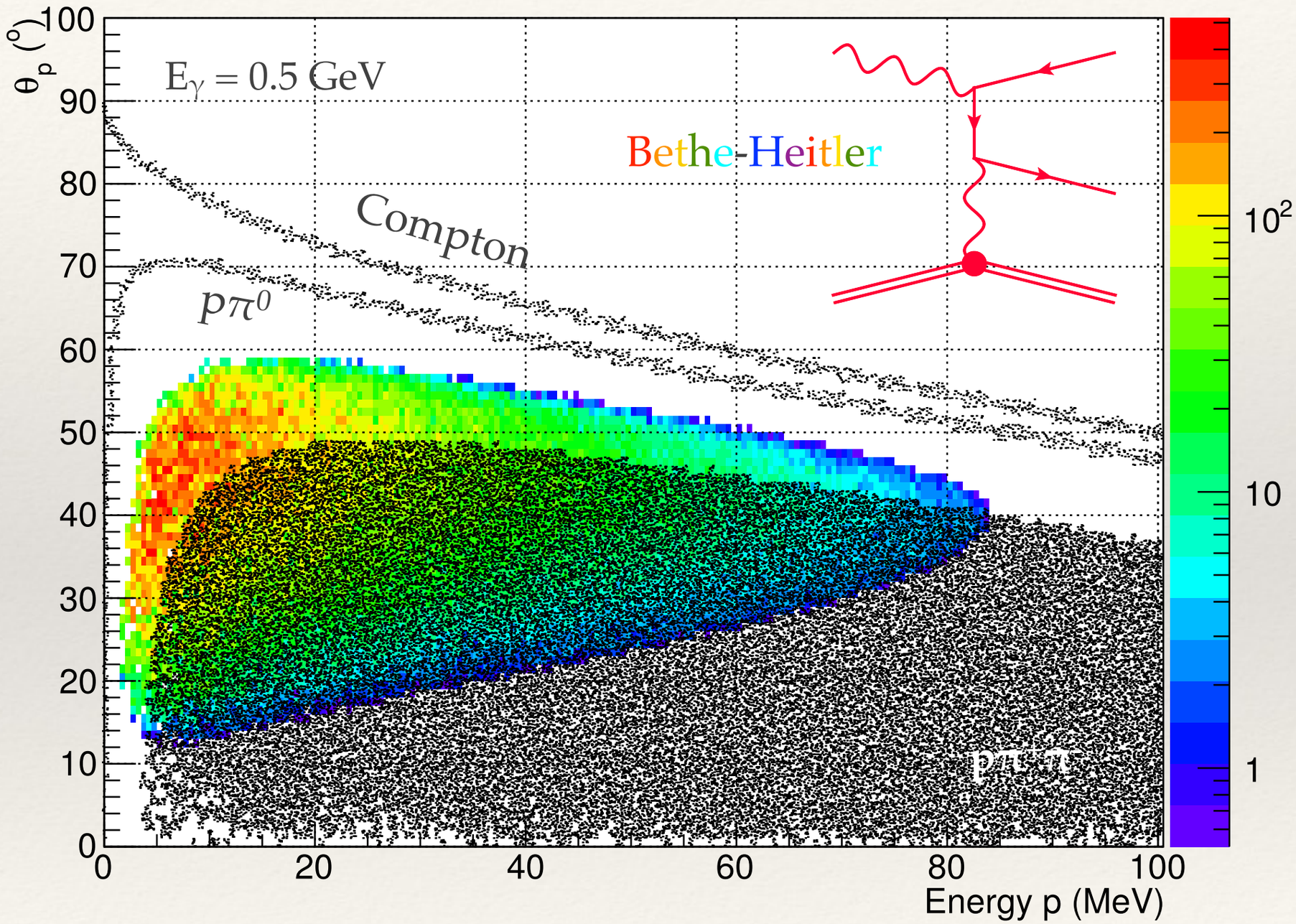


$p\pi^0$



$p\pi^+\pi^-$

$\gamma p \rightarrow \mu\text{-}\mu\text{+}\ p$: 200 000 events produced



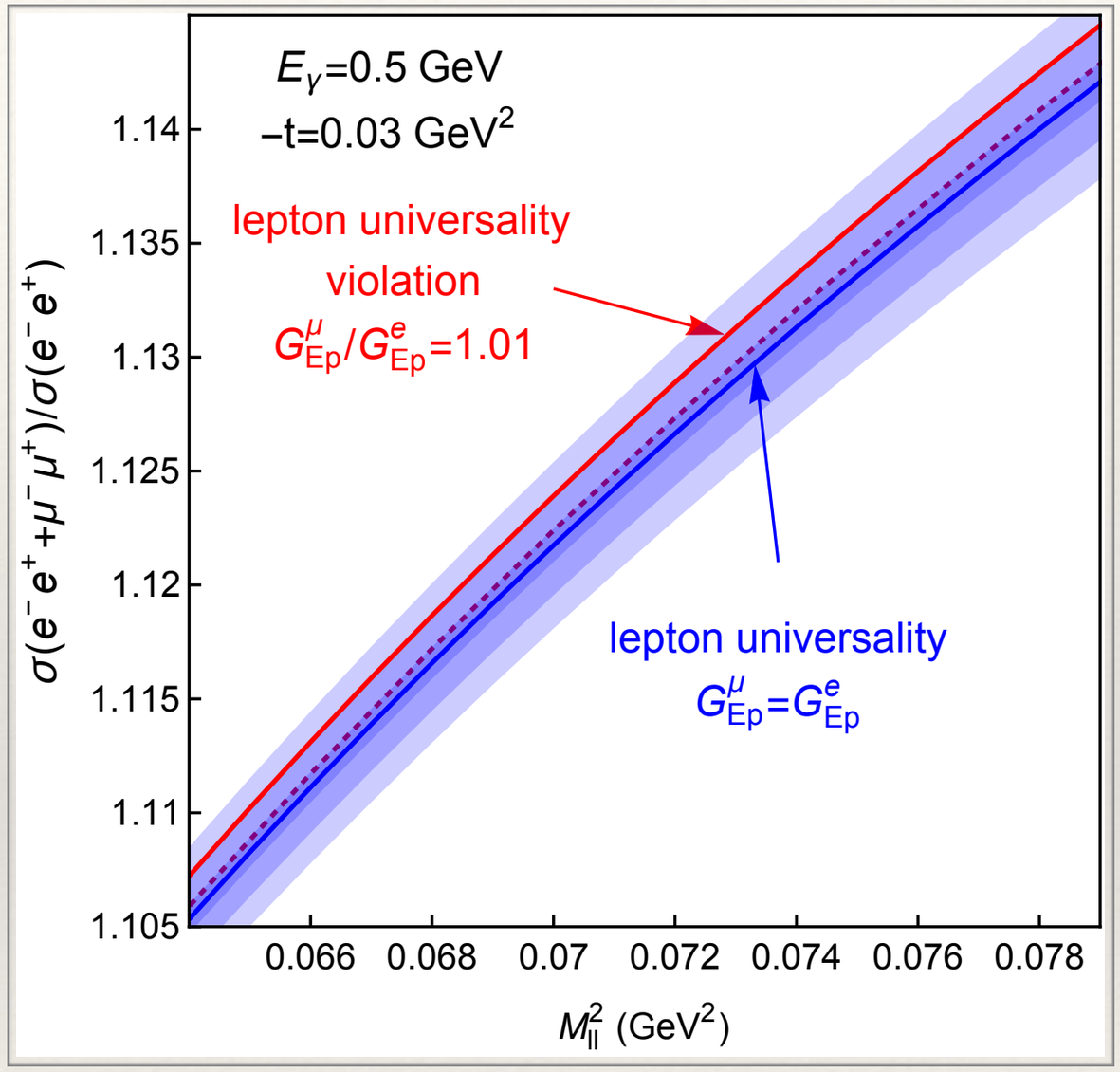
Adlarson (2015)

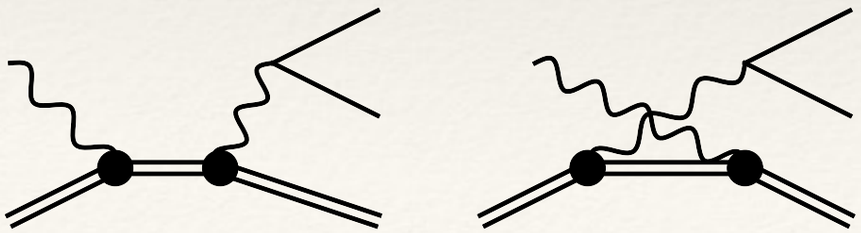
Lepton universality test

The cross section ratio

$$R_{\mu/e} \equiv \frac{d\sigma(\mu^-\mu^+ + e^-e^+)}{d\sigma(e^-e^+)} - 1$$

1% difference in measured proton charge FF in **electron vs muon** observables leads to a **0.2%** **absolute effect for $R_{\mu/e}$**





the contribution of the TVCS **~5x smaller** than the effect due to the 1% variation in the value of G^μ_{Ep}

JLab & JPAC

Double-Regge exchange model for

$\pi^- p \to \pi^- \eta' p$

at COMPASS
and explanation of $J^{PG}=1^{-+}$ **exotics**

Dilepton production
by detecting electrons and muons

Forward-backward asymmetries
and study of the **TVCS**

JPAC

Study the **double-Regge** limit of the
$2 \to 3$ process and connect to to the **resonance region** by the **finite energy sum rules**

JLab

access the **proton form factor** from the Bethe-Heitler process by analyzing **angular distributions of the lepton pairs**

direct measurement of the **interference between TVCS and BH** to extract the **information on the TVCS** (polarizabilities, high-energy behavior)