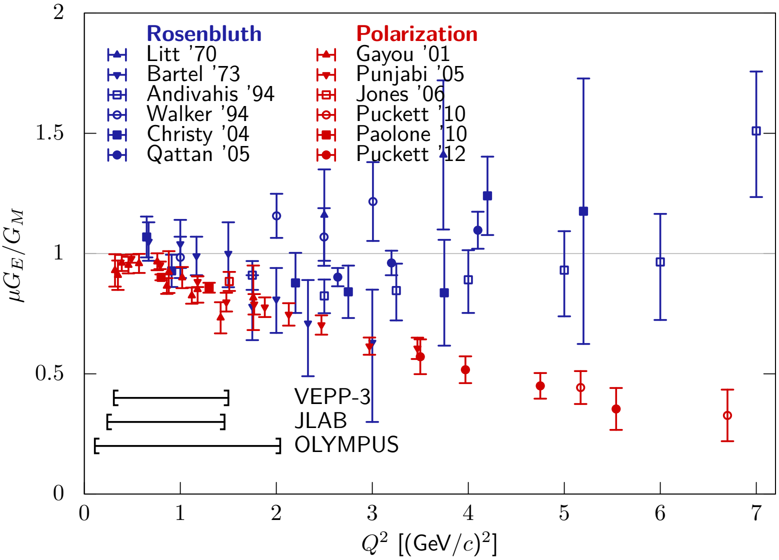
Two photon exchange: What to measure next

Jan C. Bernauer

ACFI workshop "The Electroweak Box" – September 2017

Massachusetts Institute of Technology

Phenomenology



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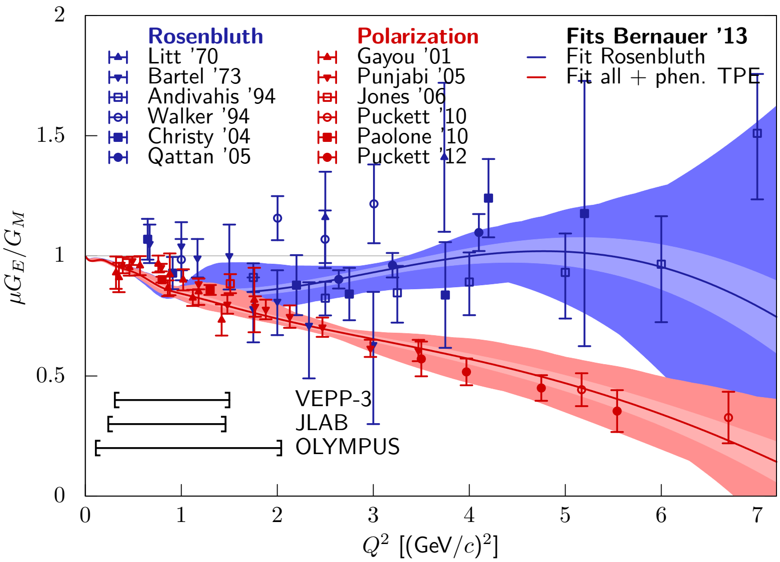


Direct measurement: Three modern experiments

CLAS

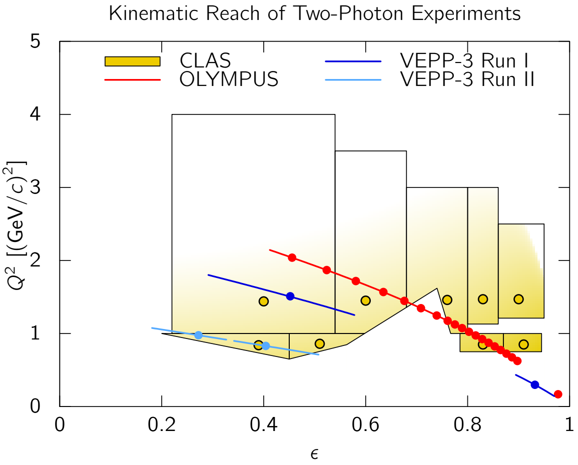
- e^- to γ to $e^{+/-}$ -beam
- Phys. Rev. C 95, 065201 (2017)
- PRL 114, 062003

VEPP-3

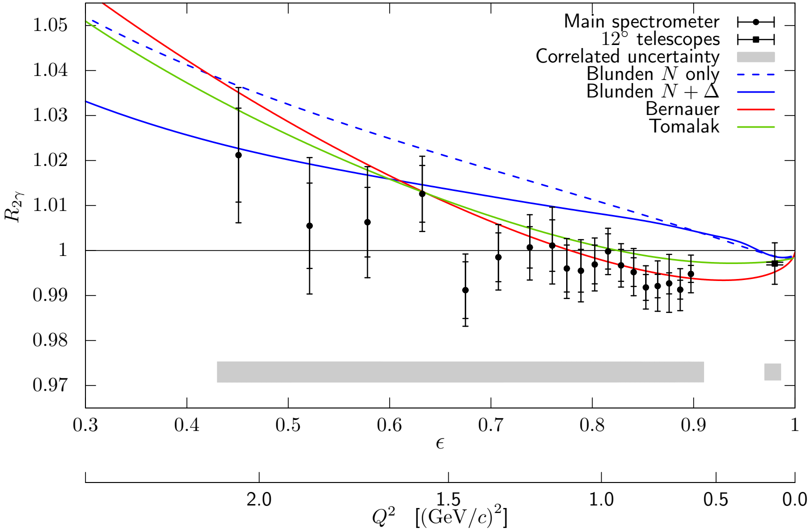
- 1.6/1 GeV beam
- no field
- Phys. Rev. Lett. 114, 062005 (2015)

OLYMPUS

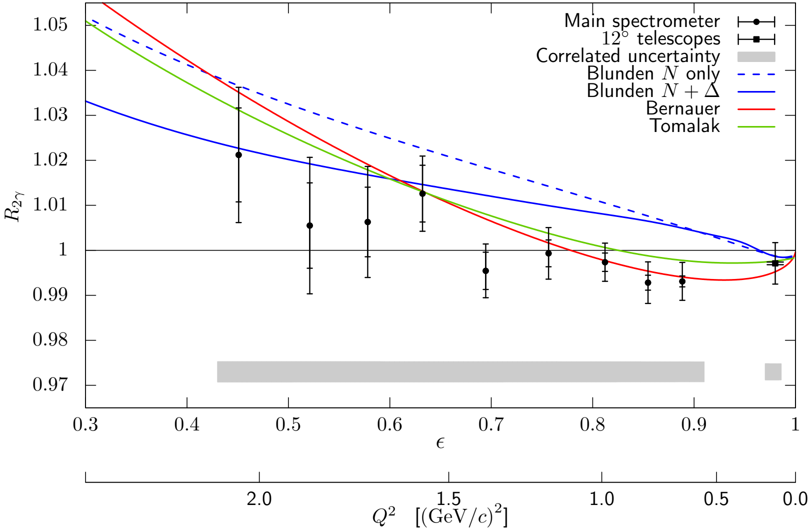
- DORIS @ DESY
- 2 GeV beam
- Phys. Rev. Lett. 118, 092501 (2017)



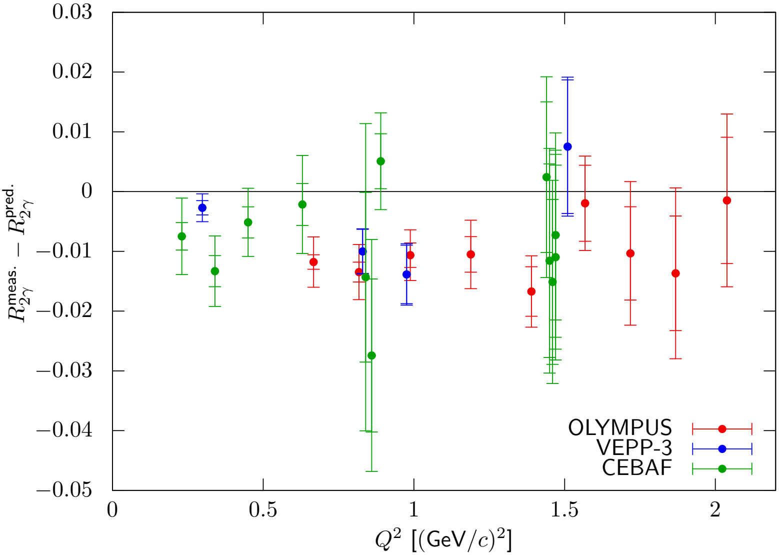
OLYMPUS results (B. Henderson et al., Phys. Rev. Lett. 118, 092501 (2017))



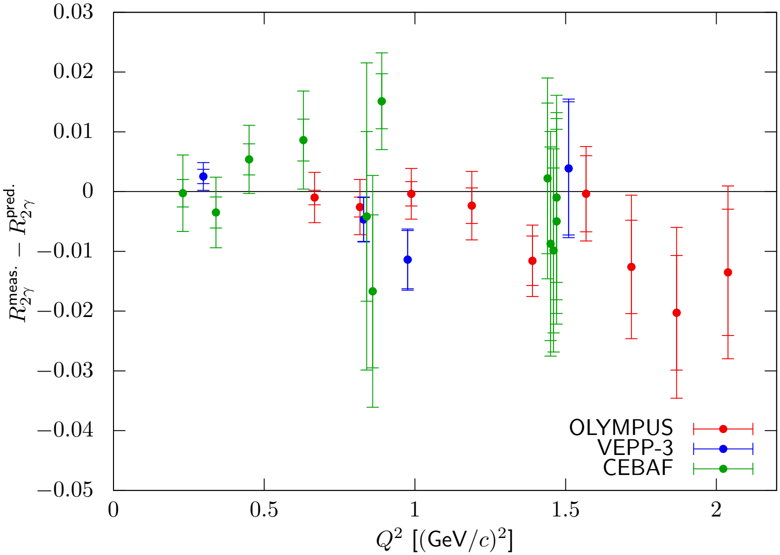
OLYMPUS results re-binned



Difference of data to prediction: Blunden's hadronic calculation



Difference of data to prediction: Bernauer et al. phenomenological prediction



χ^2 of the world data set

	VEPP-3	CLAS		OLYMPUS		World
	$\frac{\chi^2}{n_{d.f.}}$	$\frac{\chi^2}{n_{d.f.}}$	N.	$\frac{\chi^2}{n_{d.f.}}$	N.	$\frac{\chi^2}{n_{d.f.}}$
No hard TPE	7.97	0.84	0.43σ	0.65	0.75σ	1.53
Blunden	4.01	0.70	1.23σ	0.73	2.14σ	1.088
Bernauer	1.95	0.58	-0.40σ	0.49	0.45σ	0.679

- CLAS and OLYMPUS have too large errors
- Vepp-3 rules out no hard TPE
- Blunden et al get slope right, but large normalization shifts.
  - Probability for worse shift in same direction: $< 0.4\%$
- Phenomenological fit clearly preferred by all three experiments

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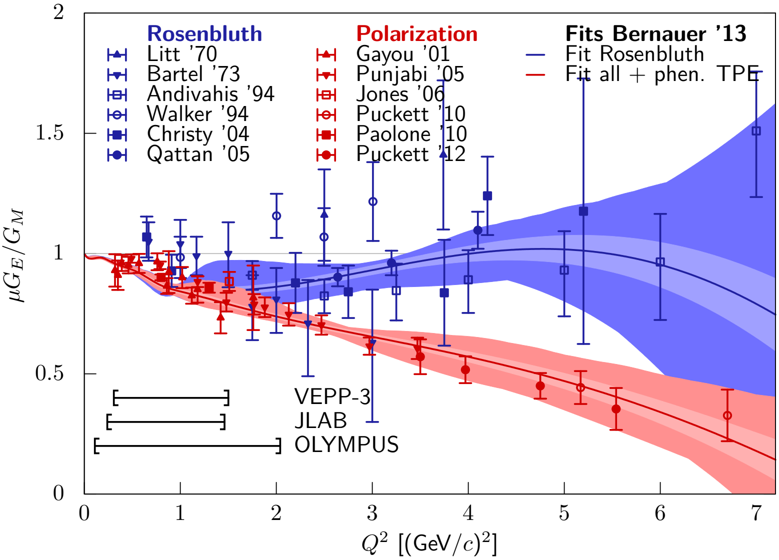
Need new measurements at relevant kinematics

Phenomenology



Effect size

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$$\Longrightarrow \frac{G_E}{G_M} \sim 1 - \alpha\tau f(Q^2)$$

  - We can only expect weak dependence on Q^2 $\Longrightarrow$Logarithmic dependence in Mainz fit, many calculations

Constructing a figure of merit

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- FOM is the deviation of $R_{2\gamma}$ from unity, measured in units of uncertainty:

$$FOM = \frac{|R_{2\gamma} - 1|}{\sqrt{\Delta^2_{stat} + \Delta^2_{syst}}}$$

- Statistical error: $\Delta_{stat} = \sqrt{\frac{2}{\sigma \times L \times t \times A}}$
- Systematical error: $\Delta_{syst} = 1\%$

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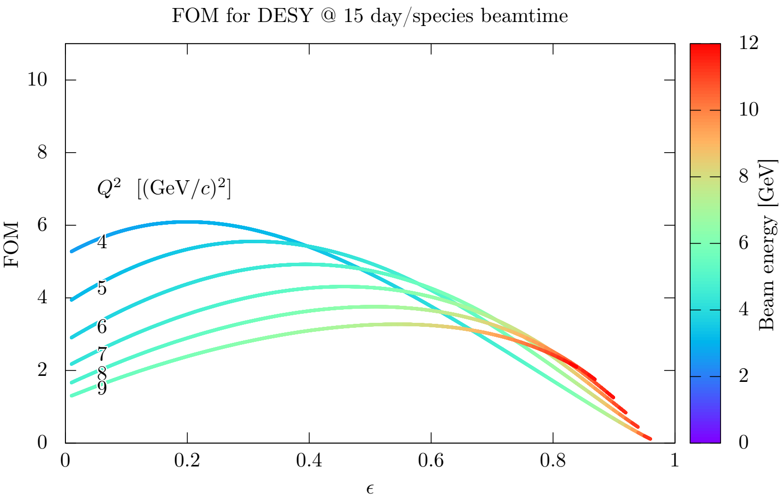
- DESY
  - Has no detectors, but beam
  - However: small time window: PETRA 3 will run with electrons only!

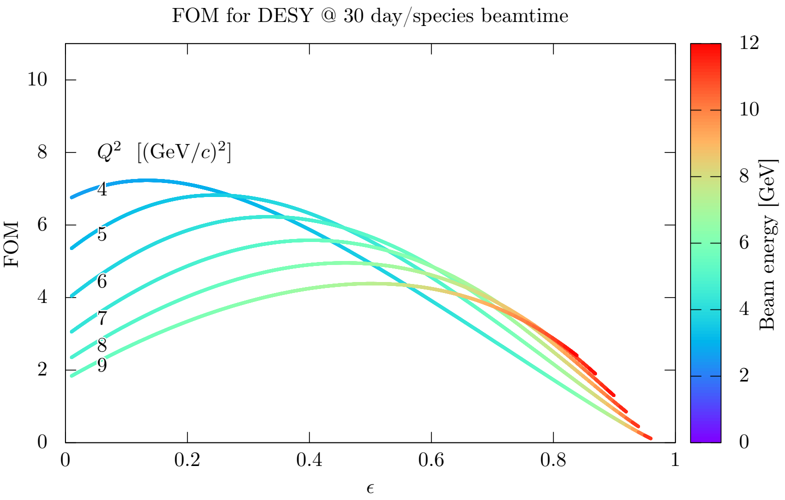
DESY

- DESY might have a test beam facility with positron/electron beams.
- Current: 60 nA (single bunch, maybe can do more?)
- Short window of opportunity: PETRA 3 might stop positron running.
- Target: Borrow from Mainz?
- Detector: Borrow something developed for Panda? Calorimeter? Assume 10 msr

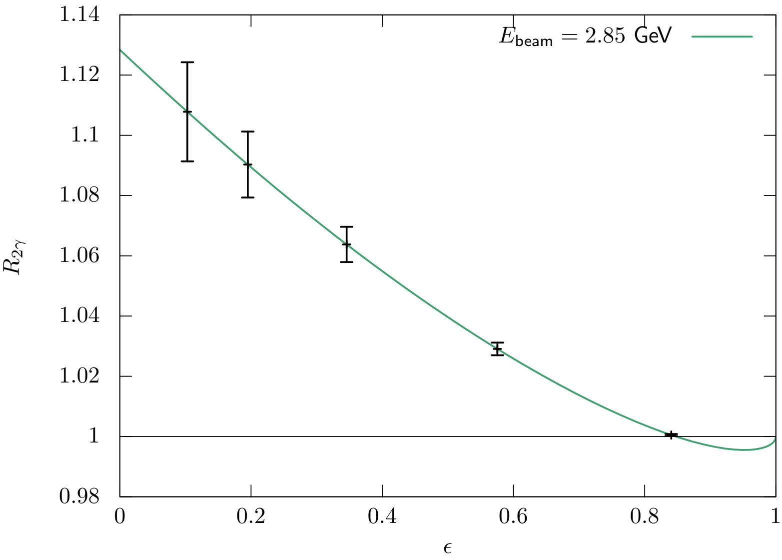
DESY @ 15 days per species



DESY @ 30 days per species

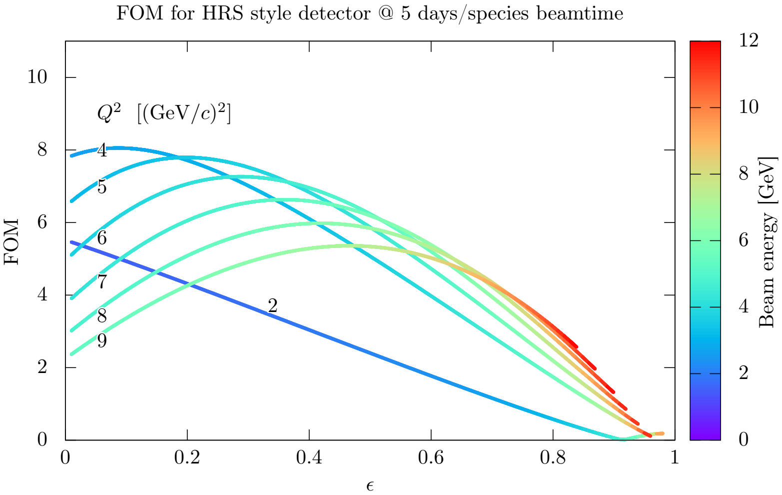


DESY projected errors (15 days per species)

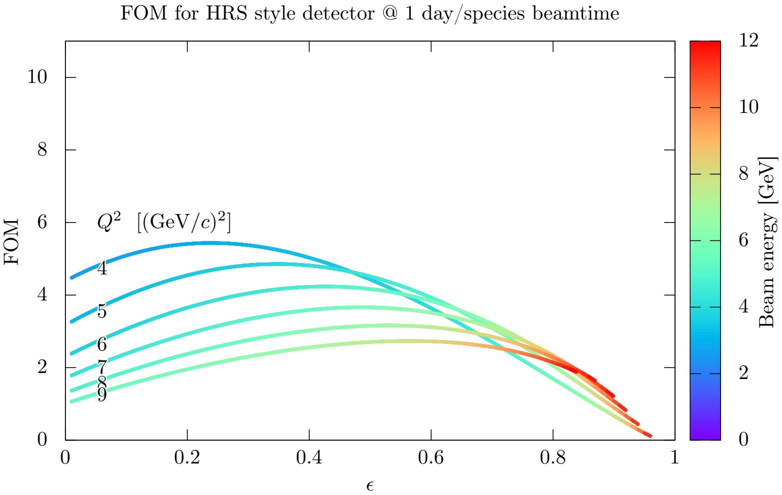


- Assume $1\mu A$ positron/electron beam on 10 cm target $\Longrightarrow L = 2.6 \cdot 10^{36}/(cm^2 s)$
- Acceptance: 6 msr

JLab @ 5 days per species



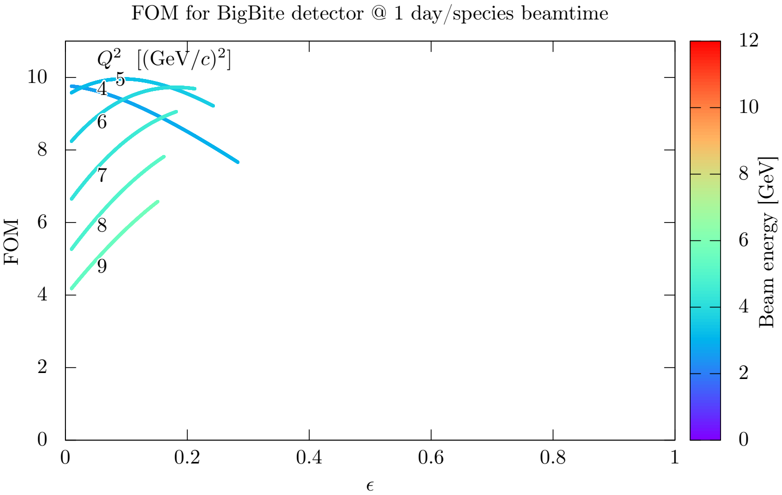
JLab @ 1 day per species



JLab BigBite

- 96 msr!
- But limited momentum acceptance.
- Limits angle $> 70 - 90^{\circ}$

JLab BigBite @ 1 day per species

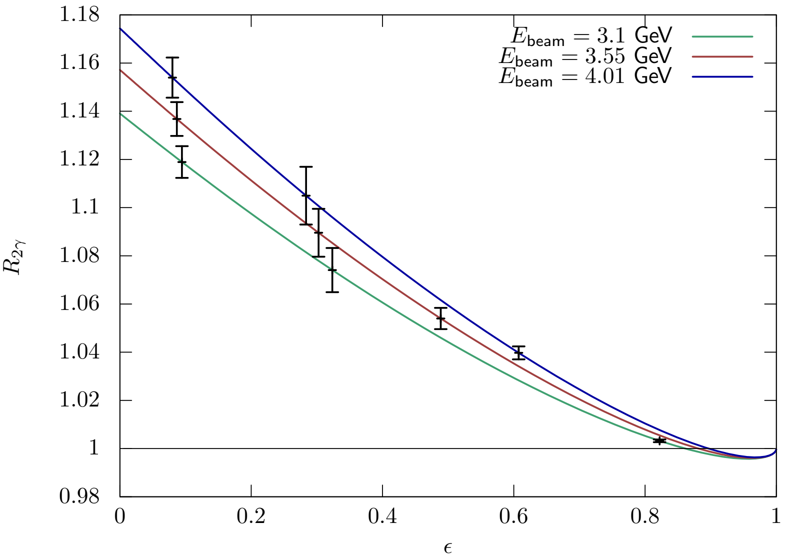


Hall A

- 10 cm target
- two spectrometers, 6.7 msr
- BigBite, 96 msr
- runtime with 100% efficiency

E_{beam}	3.1	3.55	4.01
Angles	30/70/110	52.7/70/110	42.55/70/110
Q^2	1.79/3.99/4.75	3.99/4.75/5.56	3.99/5.55/6.4
ϵ	0.822/0.32/0.1	0.49/0.3/0.09	0.6/0.28/0.08
Time	1 day	2 days	3 days

Hall A projected errors

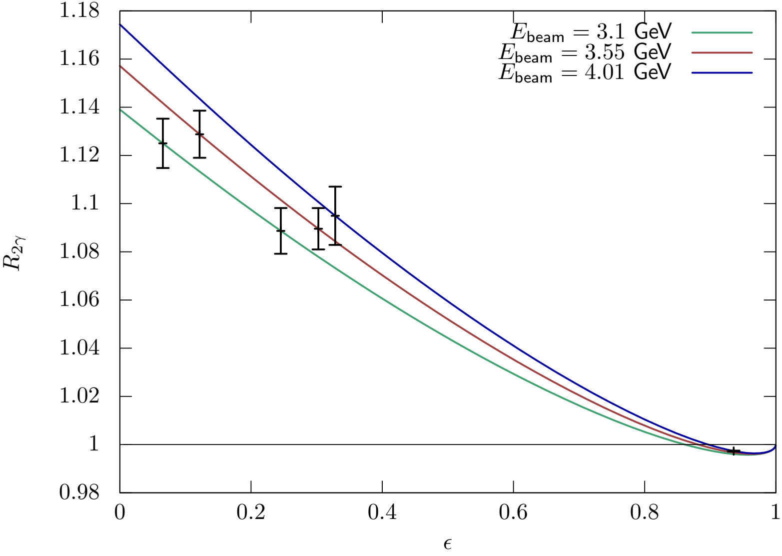


Hall C

- 10 cm target for HMS, SHMS
- HMS: 6 msr (e^-), SHMS 4 msr (proton)
- runtime with 100% efficiency

E_{beam}	3.1	3.55	4.01
Angles	79.7/7.64 (120)	70/9.95 (100)	18/16.57 (65)
Q^2	4.25/4.84	4.76/5.43	1.3/5.35
ϵ	0.244/0.06	0.302/0.122	0.935/0.33
Time	3 days	2 days	1 days

Hall C projected errors



What about the proton radius?

	r_e (fm)	r_m (fm)
(ours) McKinley/Feshbach	0.879	0.777
Borisyuk/Kobuskin	0.876	0.803
Arrington/Sick	0.875	0.769
Blunden et al.	0.875	0.799

more to come!

- Probably not important for electric radius.
- Very important for magnetic radius!

$\Longrightarrow$ Measure at low Q^2 too!

MUSE: The missing piece

r_E (fm)	ep	μp
Spectroscopy	0.8758 ± 0.077	0.84087 ± 0.00039
Scattering	0.8770 ± 0.060	????

Measure radius with muon-proton scattering

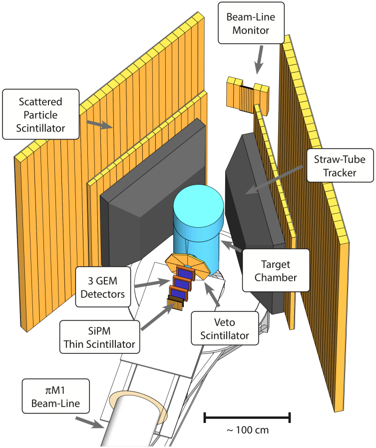
MUSE - Muon Scattering Experiment at PSI

World's most powerful low-energy $e/\pi/\mu$-beam:

Direct comparison of *ep* and μp!

- Beam of $e^+/\pi^+/\mu^+$ or $e^-/\pi^-/\mu^-$ on liquid H_2 target
    - Species separated by ToF, charge by magnet
- Absolute cross sections for *ep* and μp
- Charge reversal: test TPE
- Momenta 115-210 MeV/c $\Rightarrow$ Rosenbluth G_E,G_M

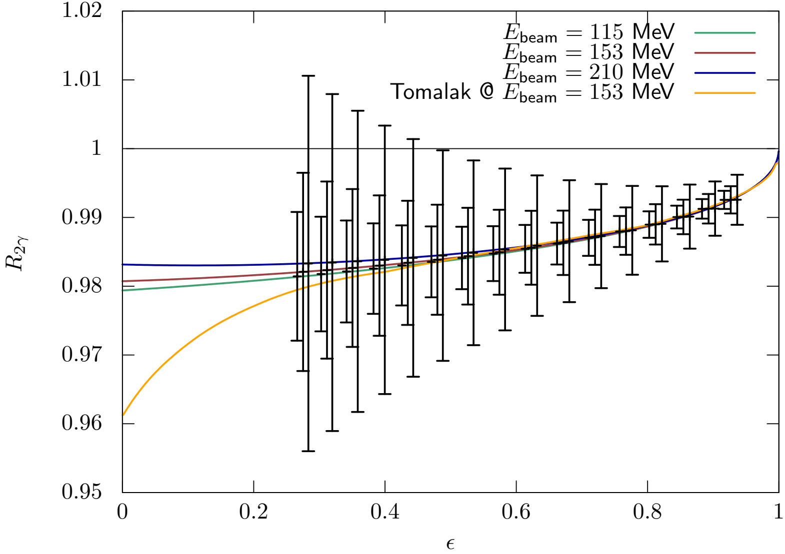
Experiment layout



R. Gilman et al., arXiv:1303.2160 (nucl-ex)

- Secondary beam $\Longrightarrow$ track beam particles
- Low flux (5 MHz)$\Longrightarrow$ large acceptance
- Mixed beam $\Longrightarrow$ identify particles in trigger

MUSE projected errors ($e^{\pm}$only)



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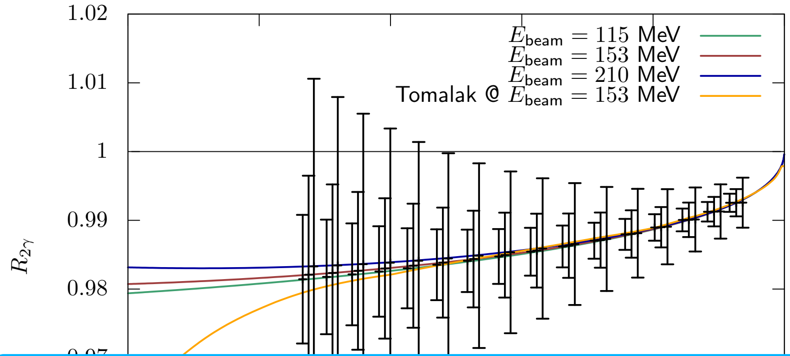

- Can test ϵ behavior important for electric radius
- Maybe test theory
- Cannot test ϵ behavior important for magnetic radius
- Low-ϵ experiment at PSI not feasible.

ϵ

How to get a good result: Systematic errors I

- Many systematics cancel if measured with same apparatus
- But: How same is same?
  - Have to reverse field?
  - Efficiency, dead time stable?
  - Same beam energy / same beam angle?

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Switch beam species often. If possible, multiple times a day!

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- Need beam-species-relative luminosity
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- Super forward elastic lepton-proton
  - High rates, but same process, so easier theory
- Look at random coincidences
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  - see: arxiv:1708.04616

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This is the trickiest part!

Conclusion

- New measurements crucial for understanding form factors at large Q^2
- Also crucial for magnetic radius
- Effect in G_E/G_M grows ~linearly $\rightarrow$ weak Q^2 dependence of TPE
- Ideal program for large Q^2
  - Pilot experiment at DESY
  - Full study at JLAB
- Some low-Q^2 data will come from MUSE. Probably not enough for magnetic radius.
- MUSE will also have pion data. Interesting?