Measuring Proton Form Factors and Two-Photon Exchange with the Future BDX Muon Beam

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BDX & Beyond

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Rosenbluth Form Factors

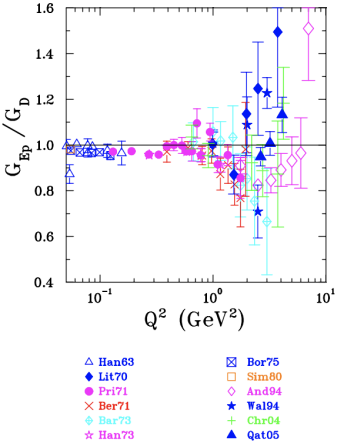


Figure 5: Data base for G_{Ep} obtained by the Rosenbluth method; the references are [Han63, Lit70, Pri71, Ber71, Bar73, Han73, Bor75, Sim80, And94, Wal94, Chr04, Qat05].

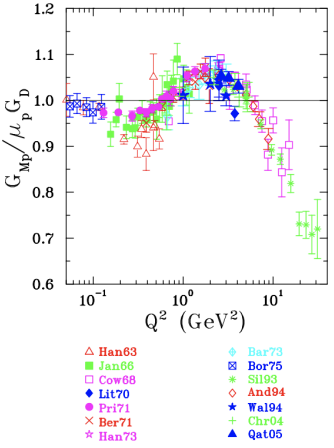
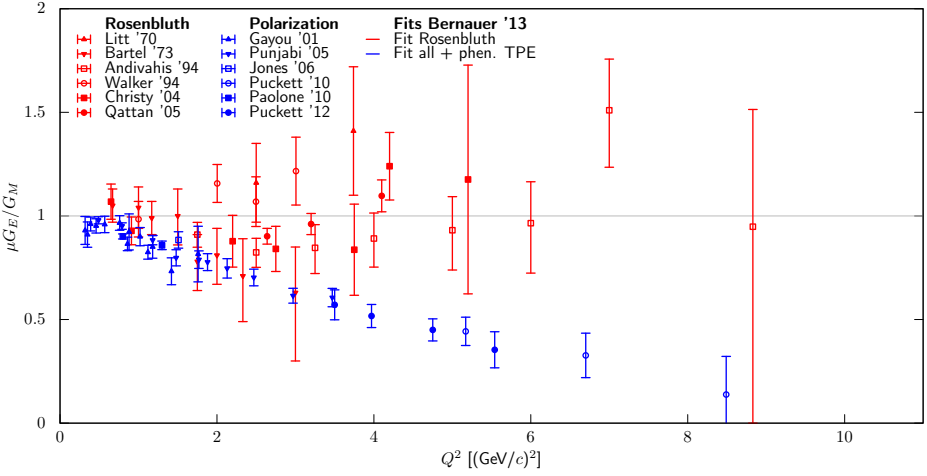


Figure 6: Data base for G_{Mp} obtained by the Rosenbluth method; the references are [Han63, Jan66, Cow68, Lit70, Pri71, Ber71, Han73, Bar73, Bor75, Sil93, And94, Wal94, Chr04, Qat05].

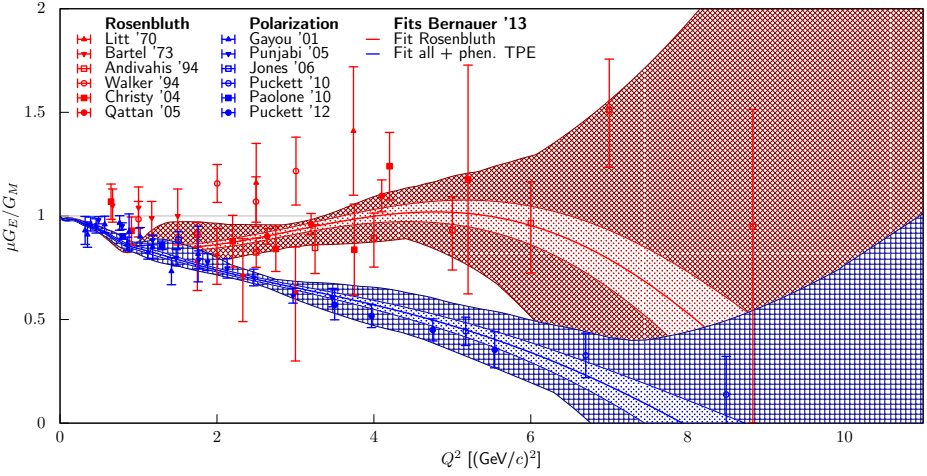
C. F. Perdrisat, *et al.*, https://arxiv.org/pdf/hep-ph/0612014.pdf (2007)

What's the Discrepancy?



The disagreement

What's the Discrepancy?



The disagreement with fits

What's Going On?

- Two-photon exchange
- Radiative correction with strong ε dependence, causes G_E to fall quickly

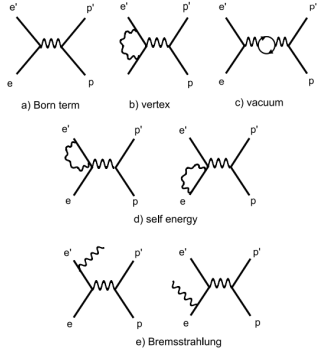


Figure 24: Born term and lowest order radiative correction graphs for the electron in elastic ep.

- Effect Rosenbluth more than polarization
- Soft TPE typically considered in existing analysis

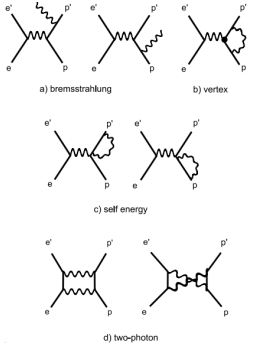
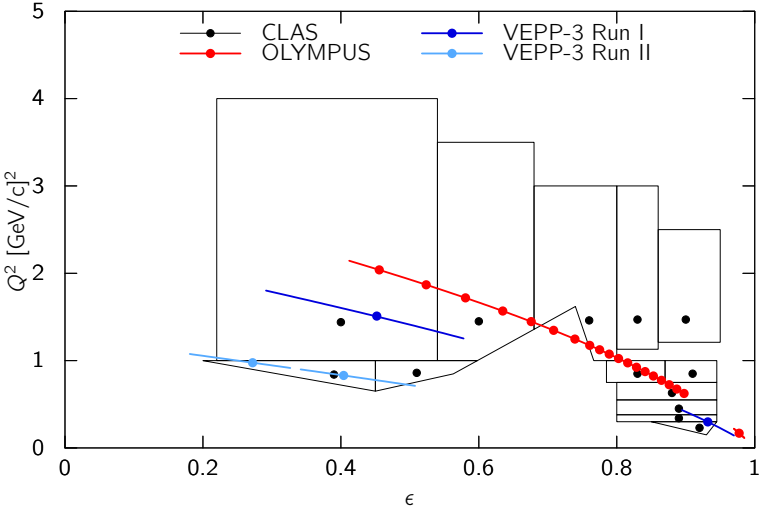


Figure 25: Lowest order radiative correction for the proton side in elastic ep scattering.

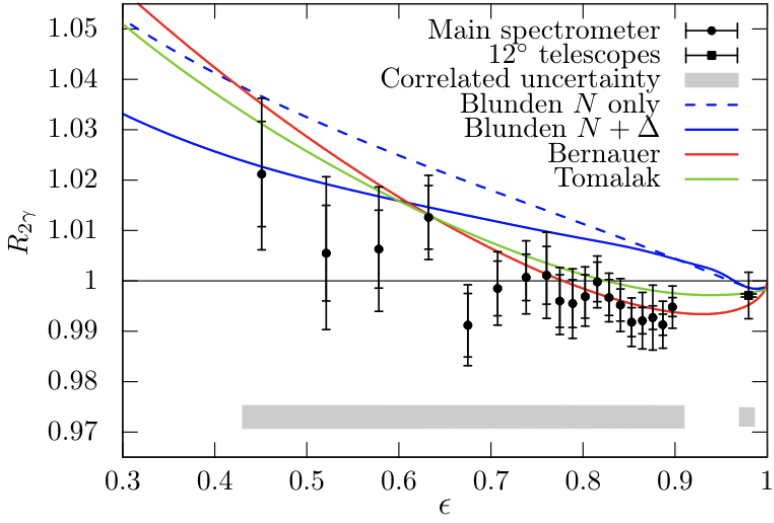
C. F. Perdrisat, *et al.*, https://arxiv.org/pdf/hep-ph/0612014.pdf (2007)

Let's Measure TPE

$$R_{2\gamma} = \frac{\sigma_{e^+}}{\sigma_{e^-}} = 1 - 2\delta_{2\gamma} \tag{1}$$

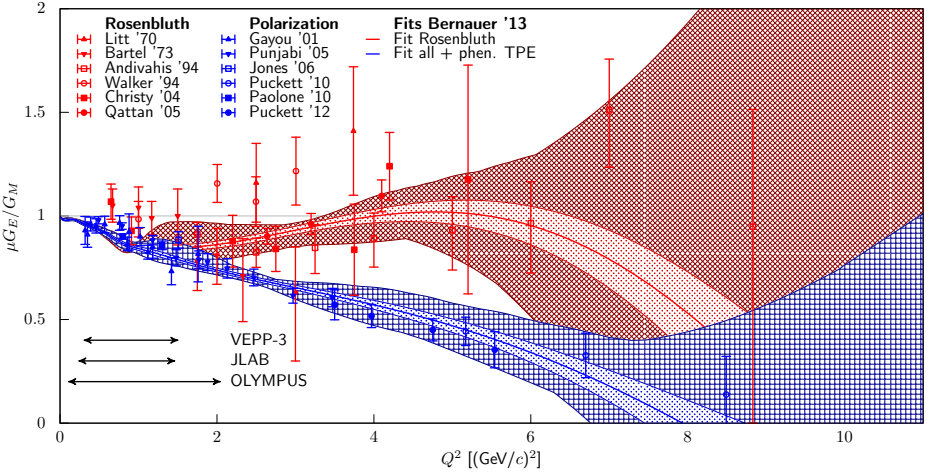


Let's Measure TPE



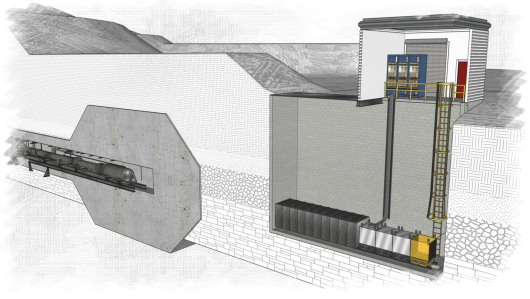
Disagreement with existing theory at larger ε, but small TPE in measured range.
B. Henderson, *et al.*, doi.org/10.1103/PhysRevLett.118.092501 (2017)

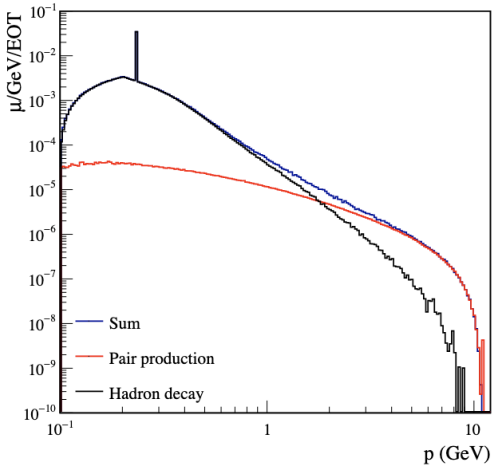
Existing Two-Photon Reach



Not covering region of largest discrepancy.

Muon Beam at BDX

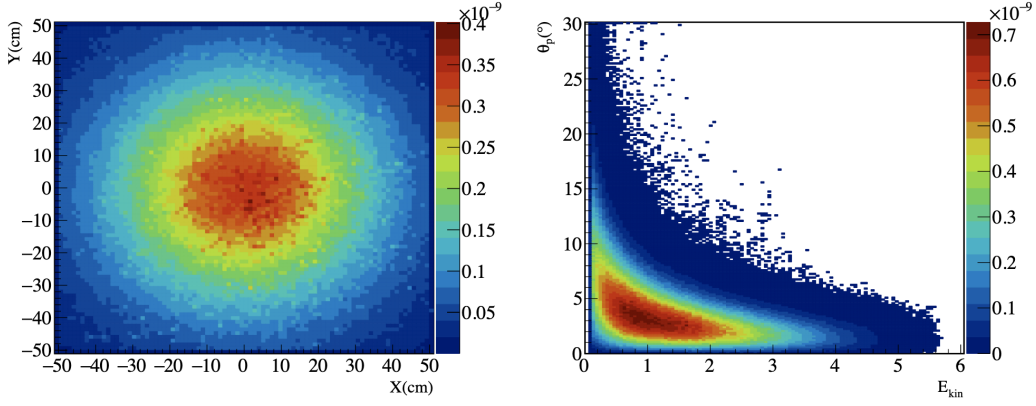




$\mu^{\pm}$ available in the BDX vault.

M. Battaglieri, *et al.*, https://www.mdpi.com/2410-390X/8/1/1

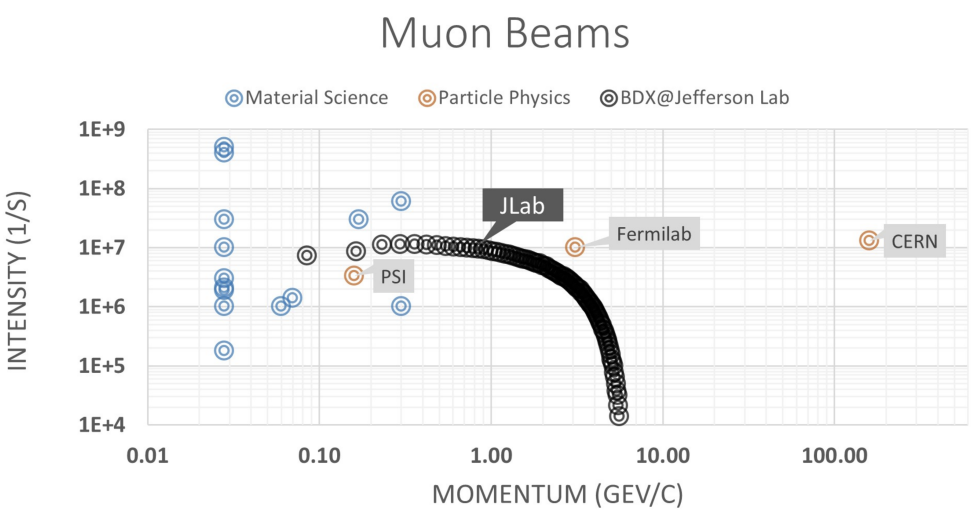
Muon Beam at BDX



Left: Muon spatial distribution produced in the interaction with the Hall A beam dump. Right: Muon angular distribution as a function of energy.

M. Battaglieri, *et al.*, https://www.mdpi.com/2410-390X/8/1/1

Muon Flux at BDX



Flux of produced muons as a function of muon momentum.

https://indico.jlab.org/event/951/page/493-secondary-beam-information

The Muon Beamline

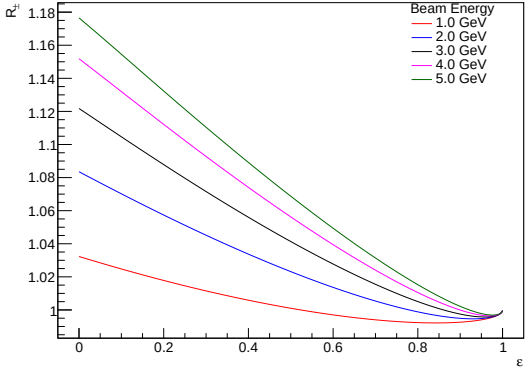
Advantages

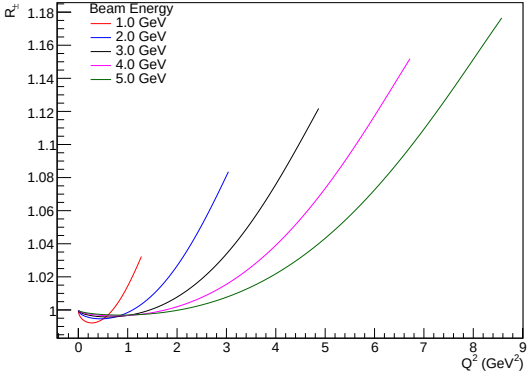
- Produced muons have a large range of momenta!
- Mixed $\mu^{\pm}$ beam enables broad physics program!
- Fairly pure beam after passing through beam dump
- Beam containing *all* momenta and both charges provides unique challenges and opportunities
- Specifically, a TPE measurement becomes possible through $\mu^{\pm}p$ scattering

Challenges

- Beam is very diffuse, 50 % in 50 $\times$ 50 cm^2, strong position-momentum correlation
- Requires a muon capture beamline (See talk tomorrow by J. Benesch)
- Will require array of beamline detectors
- May need to excavate part of the vault to fit scattered particle spectrometers

TPE Reach at BDX





Size of the TPE effect at different muon energies.

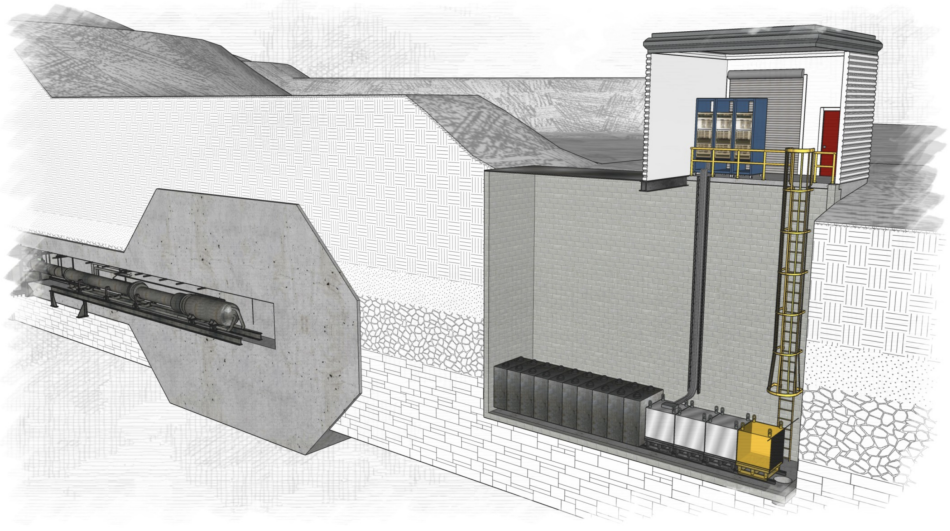
Rate Challenges

Scattering rates at fixed energies and angles assuming a one meter long liquid hydrogen target, and a constant beam flux of 1×10^7 Hz.

Beam Energy (GeV)	Scattering Angle (°)	Rate (Hz)
2	10	600
2	50	5×10^{-2}
2	100	2×10^{-3}
5	10	20
5	50	2×10^{-4}
5	100	2×10^{-5}

The extremely low rates means this will be a long-term experiment. A detector with the largest possible acceptance is required, and there must be a way to capture and focus the beam.

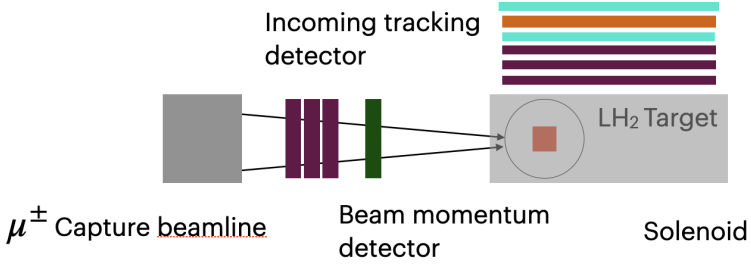
Space Limited



Shielding blocks are 5 feet wide.

Thoughts on Required Detectors

- Beamline tracking detector, GEM, μRWell, etc.
- Beamline momentum detector, maybe a RICH?
  - Might be able to get away without a dipole for momentum selection, allowing for simultaneous measurement of all momenta
- Solenoid magnet for better acceptance



Solenoid design. Not to scale.

Summary

- Exciting possibilities with BDX muon beam
- Technical challenges exist but can be overcome with careful design
- Require a muon capture beamline, beamline detector package, and magnetic spectrometers for scattered particles
- Can perform a competitive measurement of TPE

Backup