Radiative Corrections in Super-Rosenbluth Experiments

Axel Schmidt

ECT Workshop on "Radiative corrections from medium to high energy experiment"

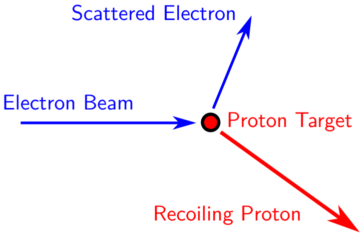
July 19, 2022

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

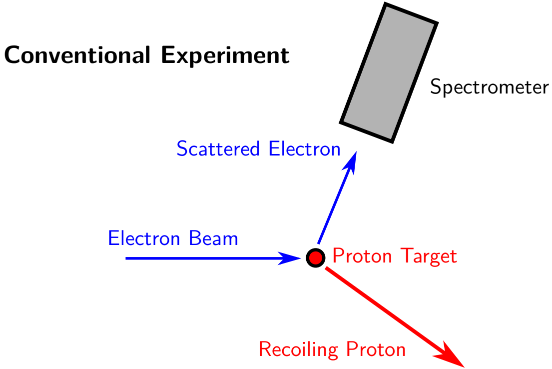
Claim: Radiative corrections are smaller/simpler in Super-Rosenbluth experiments.

Claim: Radiative corrections are smaller/simpler in Super-Rosenbluth experiments.

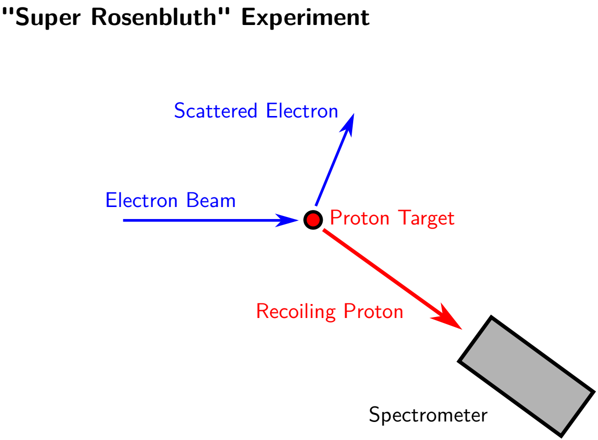
Electron-Proton Elastic Scattering



Claim: Radiative corrections are smaller/simpler in Super-Rosenbluth experiments.



Claim: Radiative corrections are smaller/simpler in Super-Rosenbluth experiments.

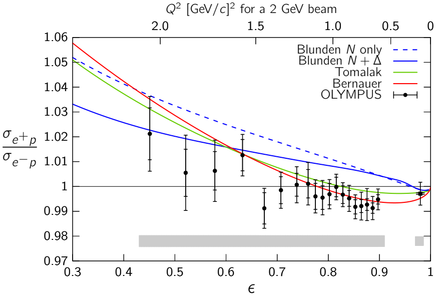


A little bit about myself

- PhD on OLYMPUS
  - Two-photon exchange in elastic *ep*, via e^+p/e^-p
  - Developed radiative generator with J. C. Bernauer, R. Russell

A little bit about myself

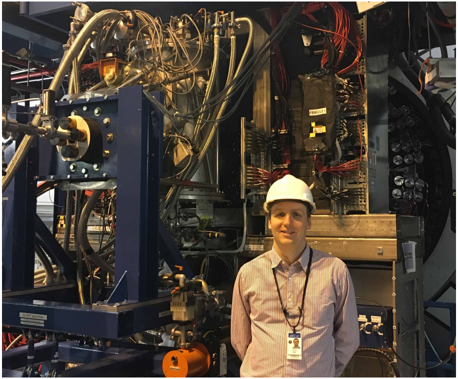
- PhD on OLYMPUS
  - Two-photon exchange in elastic *ep*, via e^+p/e^-p
  - Developed radiative generator with J. C. Bernauer, R. Russell



Phys.Rev.Lett. 118, 092501 (2017)

A little bit about myself

- PhD on OLYMPUS
    - Two-photon exchange in elastic *ep*, via e^+p/e^-p
    - Developed radiative generator with J. C. Bernauer, R. Russell
- Currently working on JLab experiments
    - Member of CLAS and GlueX
    - Studying role of nucleon-nucleon correlations



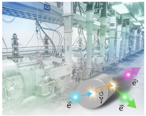
CLAS12 Backward Angle Neutron Detector

A little bit about myself

- PhD on OLYMPUS
  - Two-photon exchange in elastic *ep*, via e^+p/e^-p
  - Developed radiative generator with J. C. Bernauer, R. Russell
- Currently working on JLab experiments
  - Member of CLAS and GlueX
  - Studying role of nucleon-nucleon correlations
- JLab Positron Working Group
  - See recent white paper

EPJ A Topical Issue: An Experimental Program with Positron Beams at Jefferson Lab

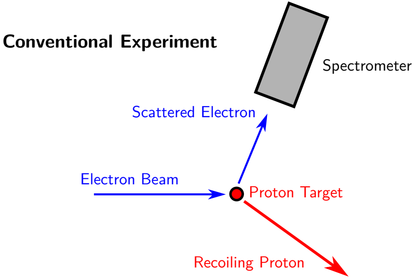
Published on 14 April 2022



The perspective of high energy and high duty cycle polarized positron beams in complement to the existing CEBAF (Continuous Electron Beam Accelerator Facility) electron beams is attracting a lot of interest. Following the proof-of-principle PEPPo (Polarized Electrons for Polarized Positrons)

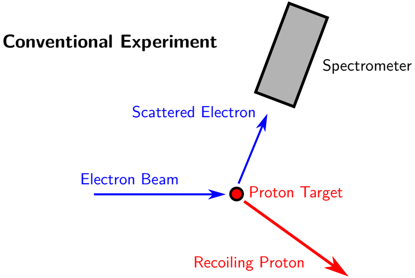
Eur. Phys. J. A (2022)

Measuring absolute electron-proton cross sections to determine proton form factors.



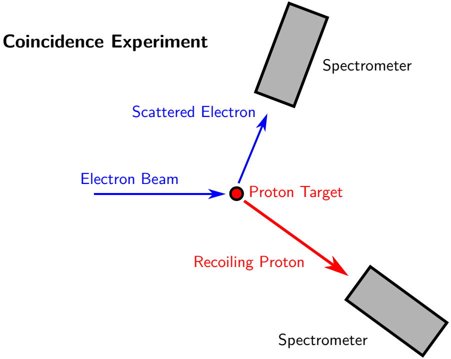
- Conventional (e^- only)
  - e.g., Stanford . . . Mainz A1

Measuring absolute electron-proton cross sections to determine proton form factors.



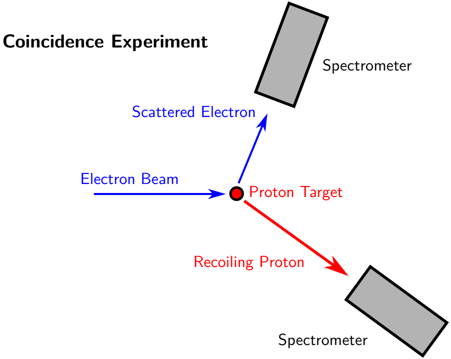
- Conventional (e^- only)
  - e.g., Stanford . . . Mainz A1
  - RC formulae, e.g. Mo+Tsai
  - Improvements beyond SPA

Measuring absolute electron-proton cross sections to determine proton form factors.



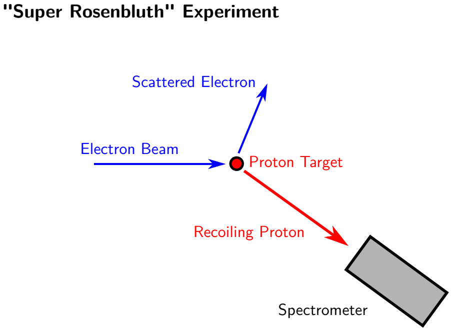
- Conventional (e^- only)
  - e.g., Stanford . . . Mainz A1
  - RC formulae, e.g. Mo+Tsai
  - Improvements beyond SPA
- Coincidence
  - e.g., OLYMPUS

Measuring absolute electron-proton cross sections to determine proton form factors.



- Conventional (e^{-} only)
  - e.g., Stanford . . . Mainz A1
  - RC formulae, e.g. Mo+Tsai
  - Improvements beyond SPA
- Coincidence
  - e.g., OLYMPUS
  - Radiative generator + coincidence cuts

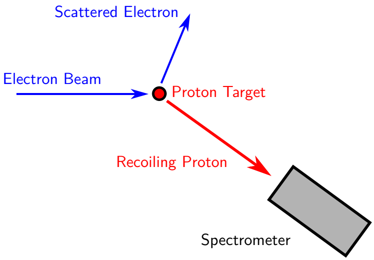
Measuring absolute electron-proton cross sections to determine proton form factors.



- Conventional (e^- only)
  - e.g., Stanford . . . Mainz A1
  - RC formulae, e.g. Mo+Tsai
  - Improvements beyond SPA
- Coincidence
  - e.g., OLYMPUS
  - Radiative generator + coincidence cuts
- Super-Rosenbluth
  - e.g., JLab Hall A Qattan et al., (2005)

Measuring absolute electron-proton cross sections to determine proton form factors.

"Super Rosenbluth" Experiment



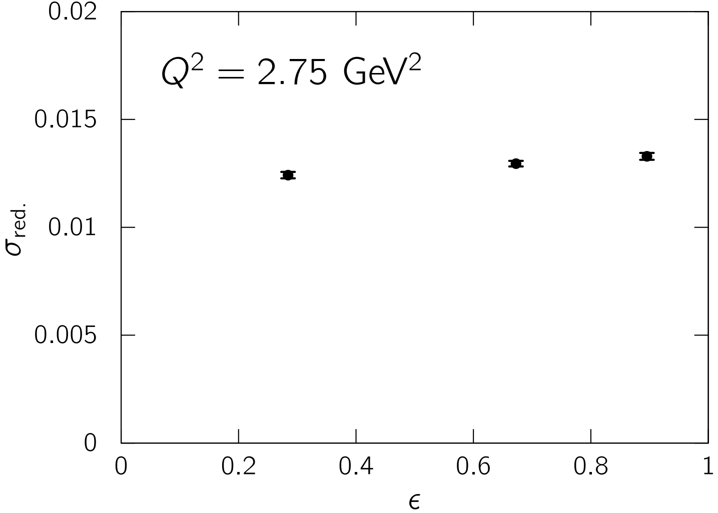
- Conventional (e^- only)
  - e.g., Stanford ... Mainz A1
  - RC formulae, e.g. Mo+Tsai
  - Improvements beyond SPA
- Coincidence
  - e.g., OLYMPUS
  - Radiative generator + coincidence cuts
- Super-Rosenbluth
  - e.g., JLab Hall A Qattan et al., (2005)
  - RC Formulae?
  - Simulate + integrate over all e^- phase space?

A. Afanasev sent me his paper on Super-Rosenbluth RCs yesterday.

"QED radiative corrections to asymmetries of elastic *ep* scattering in hadronic variables"
A. V. Afanasev et al., Phys.Lett.B 514, pp. 269-278 (2001)

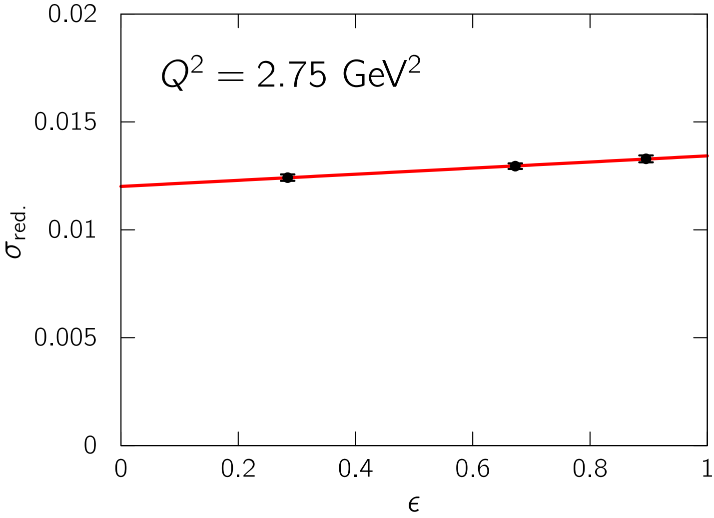
- Appears to answer many of the questions I raise today.
- I have not coded up the analytic expressions yet
  but I will!

Super-Rosenbluth has experimental advantages.



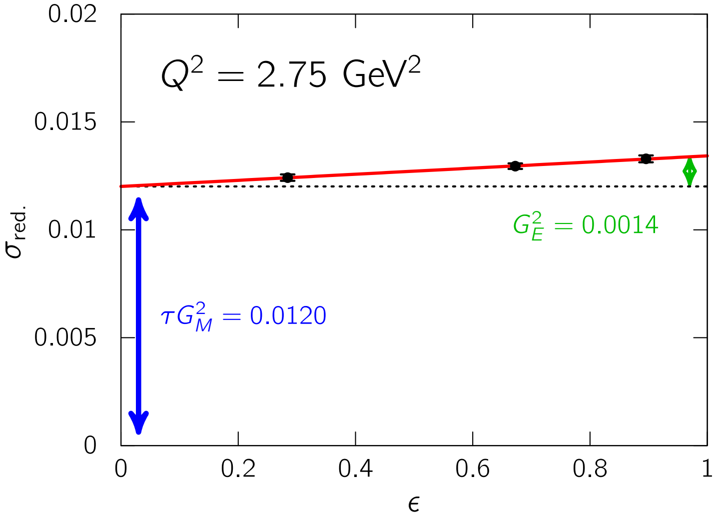
M. E. Christy et al. (JLab Hall C), PRC 70, 015206 (2004)

Super-Rosenbluth has experimental advantages.



M. E. Christy et al. (JLab Hall C), PRC 70, 015206 (2004)

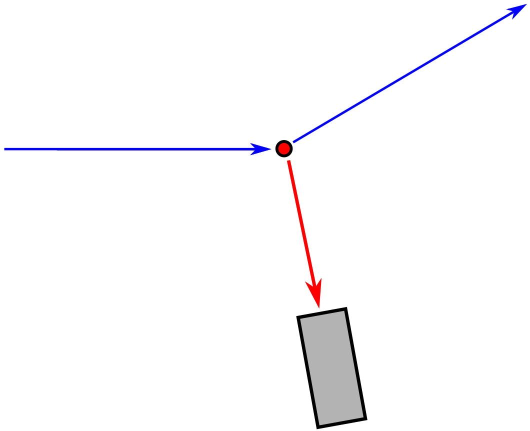
Super-Rosenbluth has experimental advantages.



M. E. Christy et al. (JLab Hall C), PRC 70, 015206 (2004)

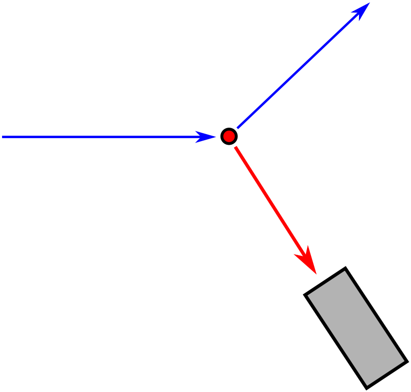
Super-Rosenbluth has experimental advantages.

For fixed Q^2, out-going proton momentum is fixed.



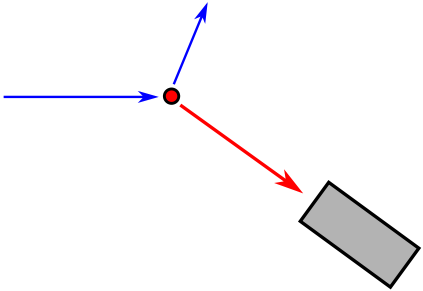
Super-Rosenbluth has experimental advantages.

For fixed Q^2, out-going proton momentum is fixed.



Super-Rosenbluth has experimental advantages.

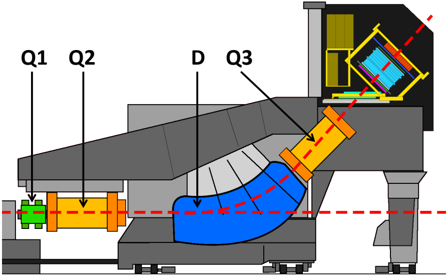
For fixed Q^2, out-going proton momentum is fixed.



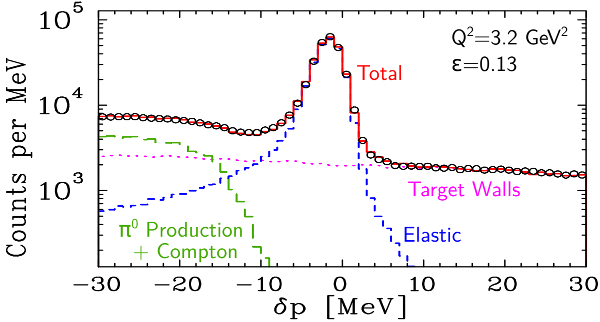
Jefferson Lab Hall A
Super-Rosenbluth Measurement

I. A. Qattan et al., PRL 94, 142301 (2005)

- Experiment E01-001
- Beam energies: 1.91, 2.62, 2.84, 3.77, 4.70 GeV
- 4 cm liquid hydrogen target
- $Q^2 = 2.64, 3.20, 4.10 \text{ GeV}^2$
- Hall A High-Resolution Spectrometer (HRS)
  - ≈ 6 msr acceptance
  - $\delta p/p \approx 10^{-4}$



Jefferson Lab Hall A
Super-Rosenbluth Measurement



Jefferson Lab Hall A
Super-Rosenbluth Measurement

"Finally, radiative corrections (mainly electron bremsstrahlung) . . .
have smaller ϵ-dependence when the proton is detected."

Jefferson Lab Hall A
Super-Rosenbluth Measurement

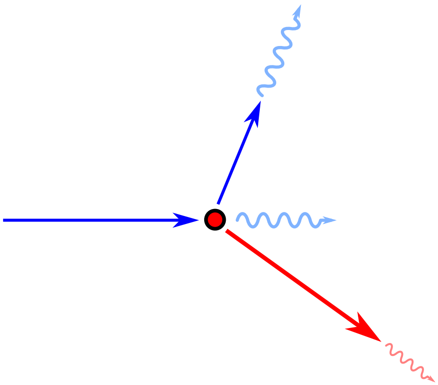
"Finally, radiative corrections (mainly electron bremsstrahlung) . . . have smaller ϵ-dependence when the proton is detected."

"Radiative corrections to the cross section are 20%, with a 5%–10% ϵ-dependence, smaller than in previous Rosenbluth separations where the electron was detected."

NE-18 Radiative Monte Carlo Generator

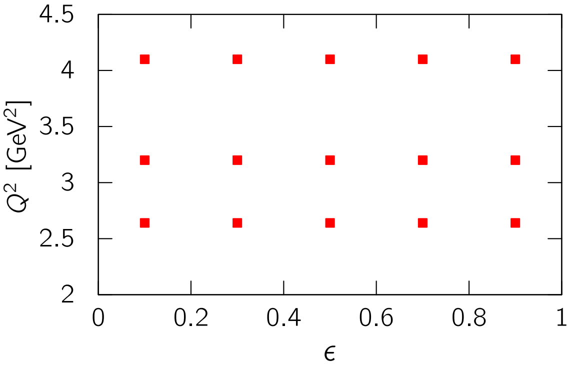
R. Ent et al., Phys. Rev. C 64, 054610 (2001)

- Adapted into SIMC, widely used at JLab
- Multi-photon (exponentiated), pure peaking approximation
- Loop corrections to α^3 (*non-exponentiated*)
- Randomly sample radiation from each particle, update kinematics

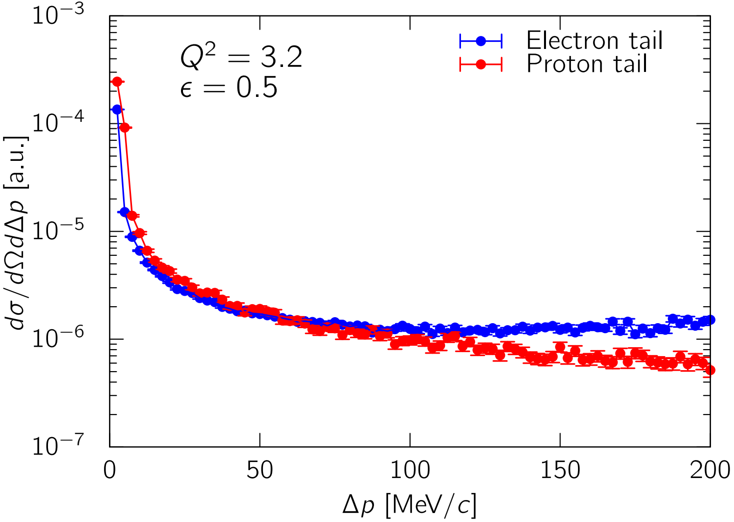


My simulated pseudo experiment

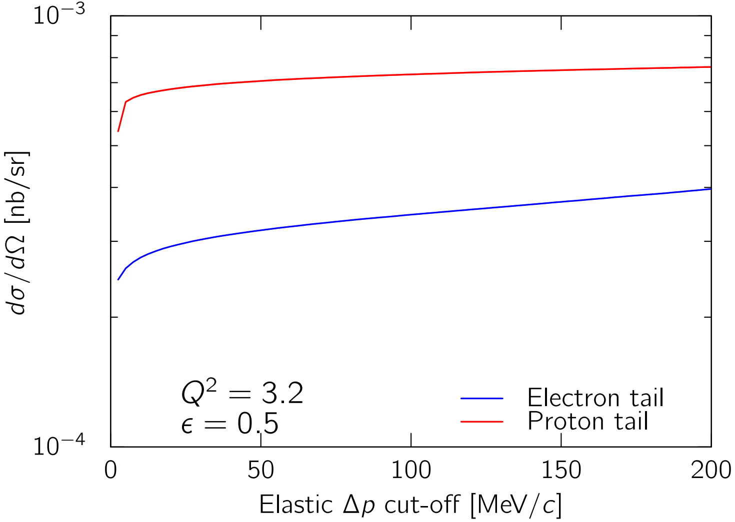
- Rosenbluth separations at 2.64, 3.20, and 4.10 GeV
  (same as Hall A)
- In-plane acceptance of $\pm 1 mrad$
  (much smaller than Hall A)
- Assume std. dipole form factors



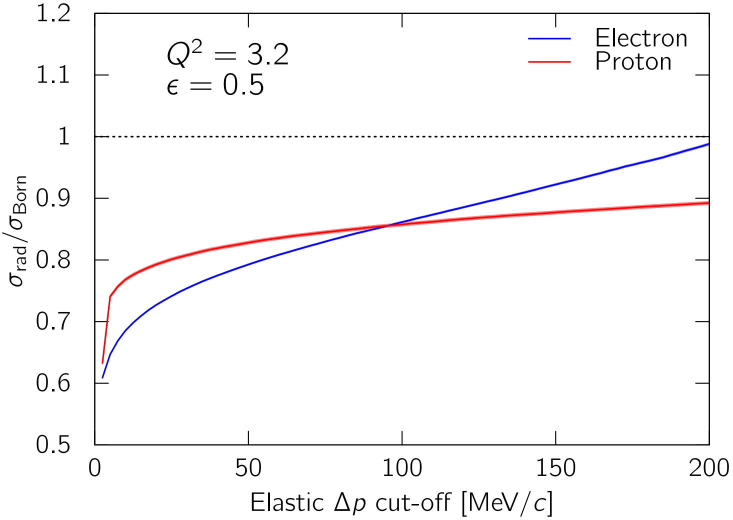
Tail-shape in simulation



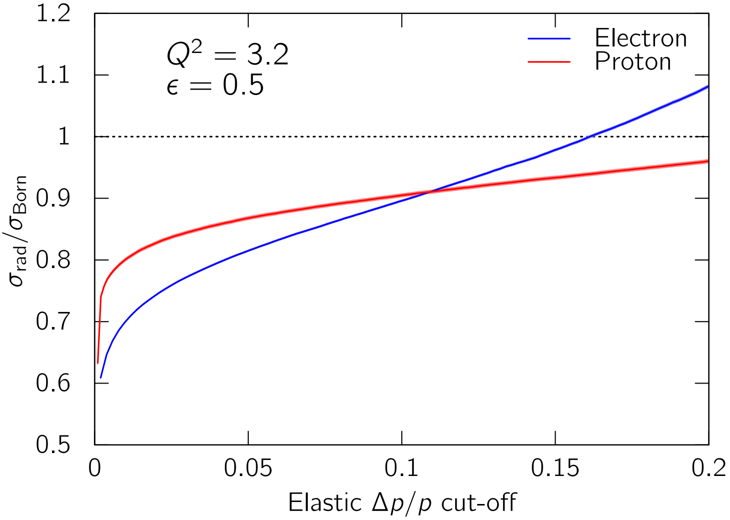
Tail-shape in simulation



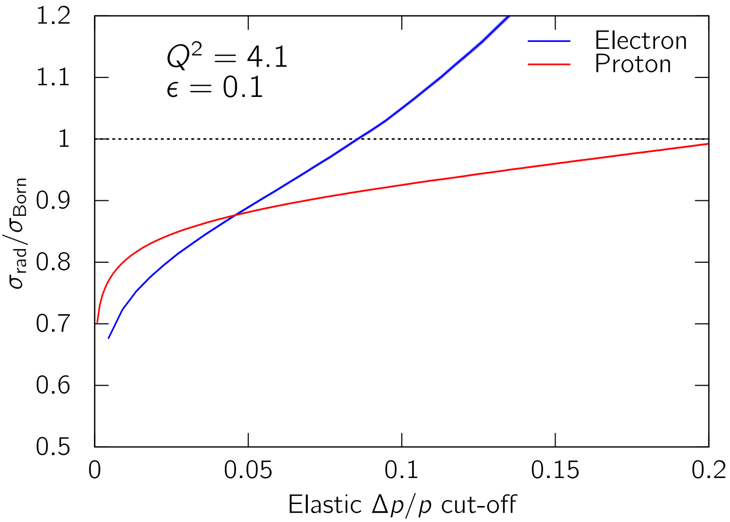
Radiative correction in simulation



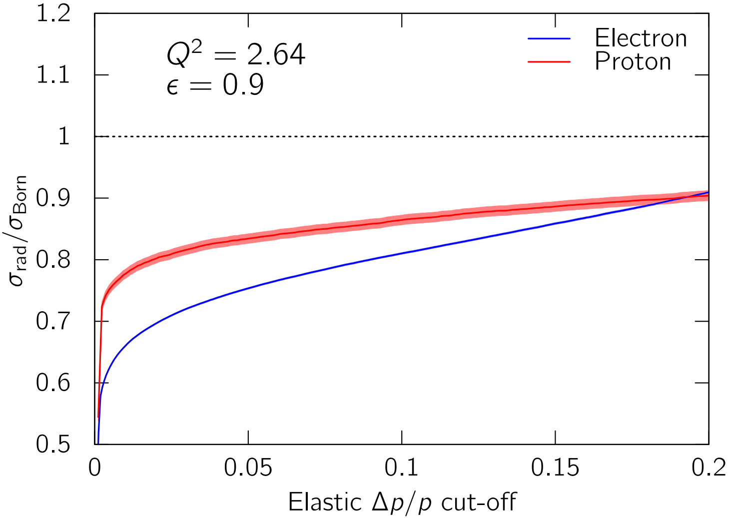
Radiative correction in simulation



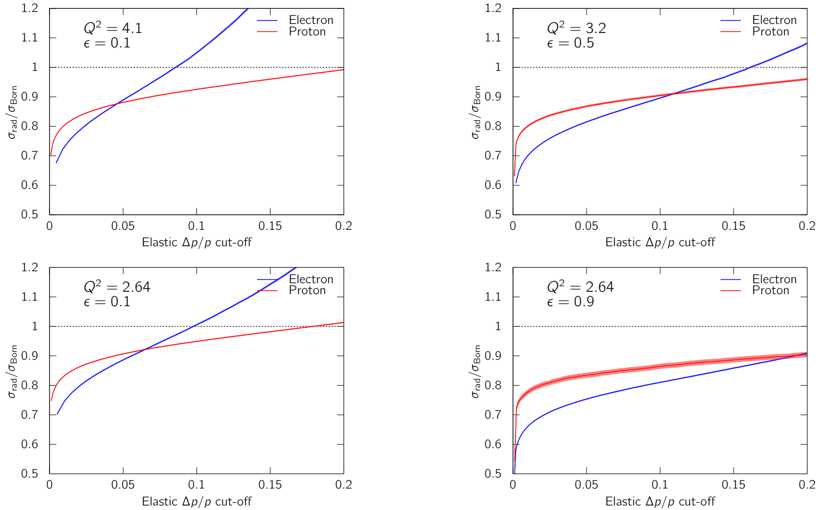
Radiative correction in simulation



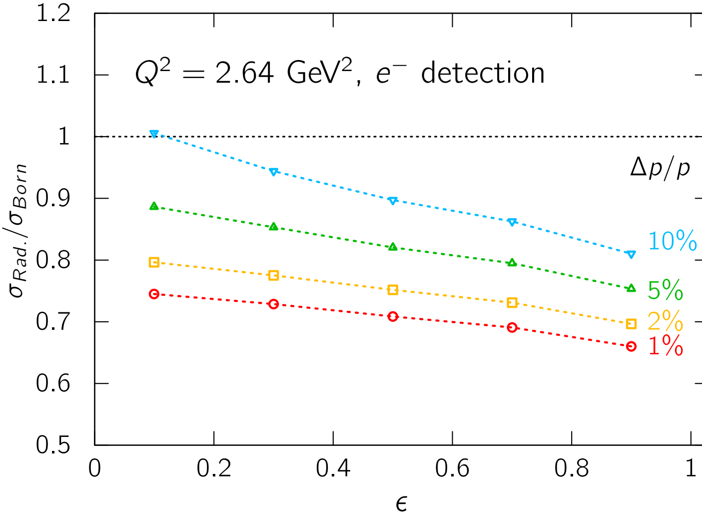
Radiative correction in simulation



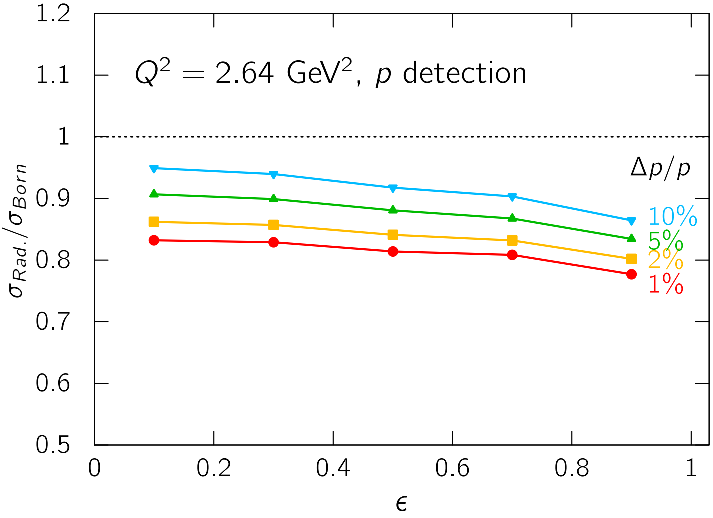
While magnitude depends on kinematics, proton RCs tend to be flatter in Δp.



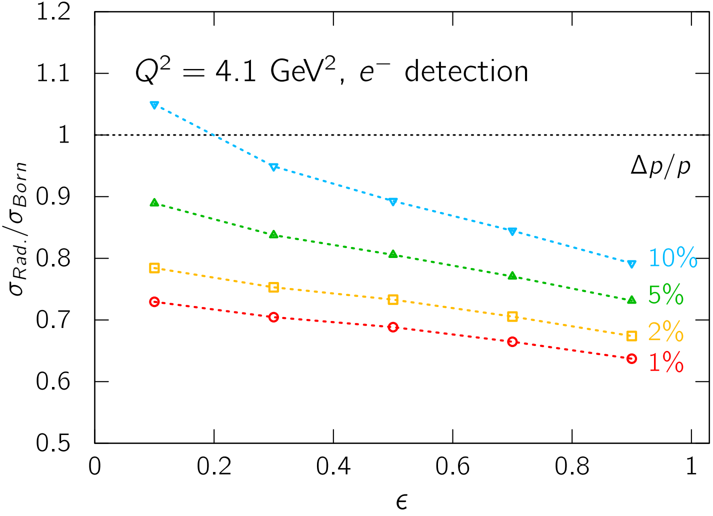
ϵ-dependence of the radiative correction



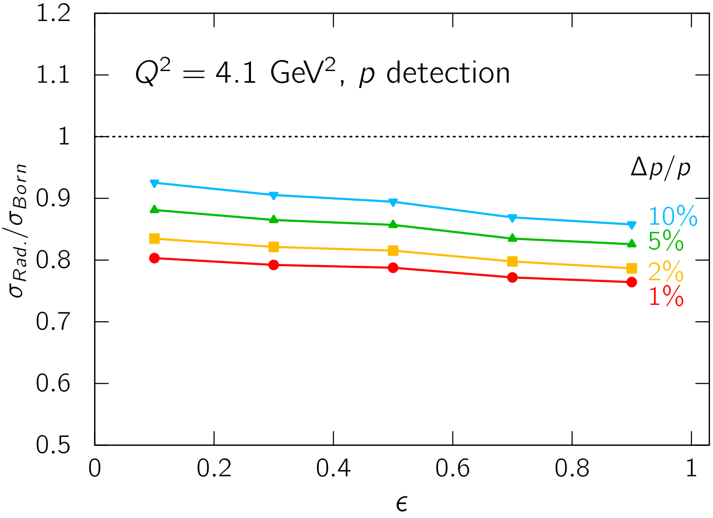
ϵ-dependence of the radiative correction



ϵ-dependence of the radiative correction



ϵ-dependence of the radiative correction



The claims in Qattan et al. are correct within their chosen prescription.

"Finally, radiative corrections (mainly electron bremsstrahlung) . . . have smaller ϵ-dependence when the proton is detected."

True

"Radiative corrections to the cross section are 20%, with a 5%–10% ϵ-dependence, smaller than in previous Rosenbluth separations where the electron was detected."

True

The claims in Qattan et al. are correct within their chosen prescription.

"Finally, radiative corrections (mainly electron bremsstrahlung) ... have smaller ϵ-dependence when the proton is detected."

True

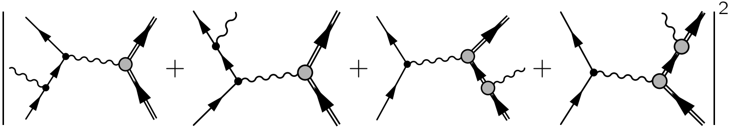
"Radiative corrections to the cross section are 20%, with a 5%–10% ϵ-dependence, smaller than in previous Rosenbluth separations where the electron was detected."

True

How about with the OLYMPUS generator?

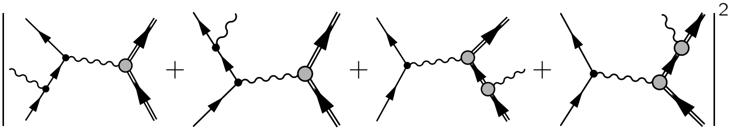
The OLYMPUS generator used two approaches.

1. Conventional $\mathcal{O}(\alpha^3)$ approach
   - Distinguish between near-elastic and tail.
   - near elastic: $\frac{d\sigma}{d\Omega}_{\text{meas.}} = \frac{d\sigma}{d\Omega}_{\text{Born}} \times [1 + \delta(\Delta E)]$
   - tail: tree-level bremsstrahlung cross section



The OLYMPUS generator used two approaches.

1. Conventional $\mathcal{O}(\alpha^3)$ approach
   - Distinguish between near-elastic and tail.
   - near elastic: $\frac{d\sigma}{d\Omega}_{\text{meas.}} = \frac{d\sigma}{d\Omega}_{\text{Born}} \times [1 + \delta(\Delta E)]$
   - tail: tree-level bremsstrahlung cross section



2. Exponentiated approach
   - Based on prev. work by J. M. Friedrich, J. C. Bernauer at Mainz A1

Exponentiated Approach

Assumptions:

- Multi-photon kinematics can be well-approximated by single-photon bremsstrahlung kinematics
- Differential cross section takes an exponentiated form:

$$d^5\sigma = \frac{d\sigma}{d\Omega}_{\text{Born}} e^{\delta} \left(\partial_{\vec{p}_\gamma} \delta\right)$$

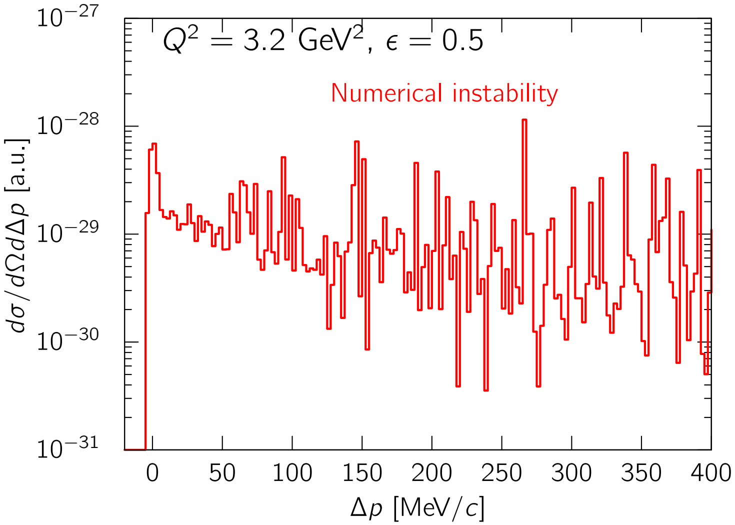
- The differential part of δ is well-approximated

$$\partial_{\vec{p}_\gamma} \delta \longrightarrow \frac{d^5\sigma}{d\Omega_e d\Omega_\gamma E_\gamma}_{\text{Brems.}} \Big/ \frac{d\sigma}{d\Omega}_{\text{Born}}$$

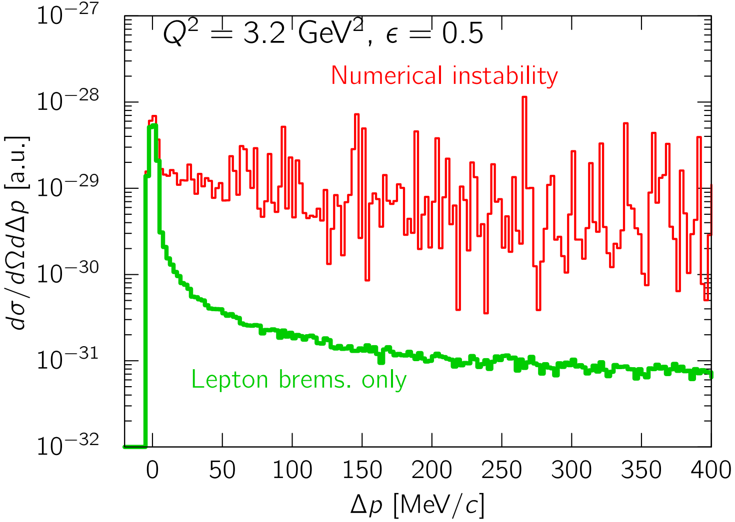
- δ given by standard prescription (e.g. Mo-Tsai)

$$d^5\sigma = \frac{d^5\sigma}{d\Omega_e d\Omega_\gamma E_\gamma}_{\text{Brems.}} e^{\delta(E_\gamma)}$$

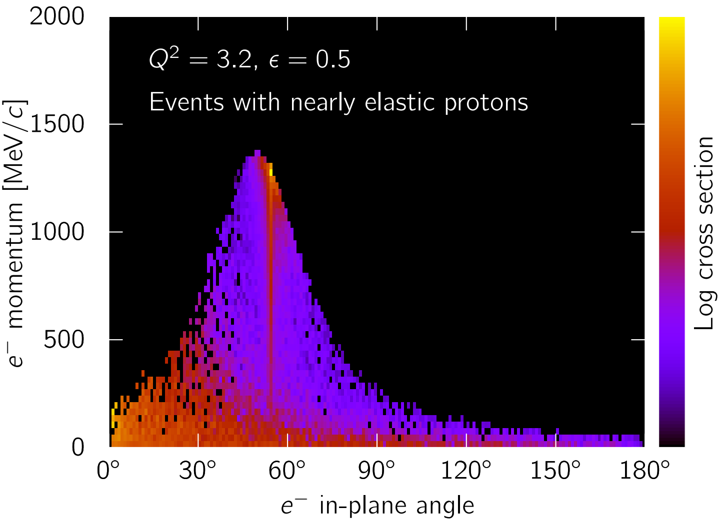
Proton spectrum within the OLYMPUS generator



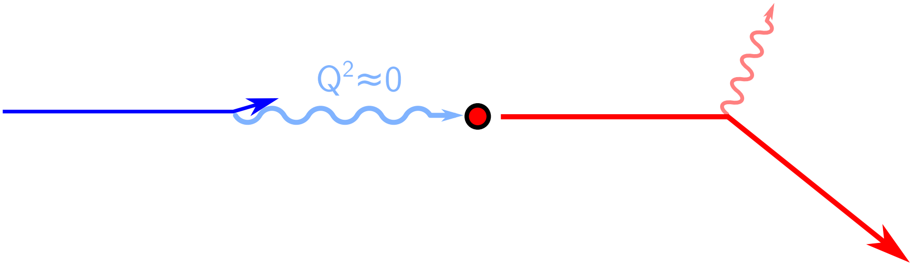
Proton spectrum within the OLYMPUS generator



Where are the electrons going?

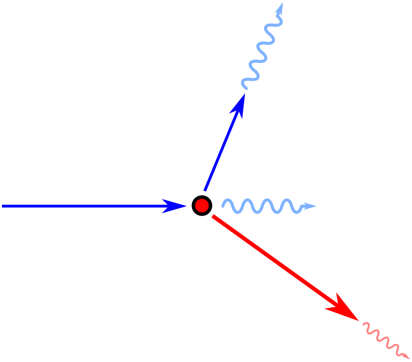


The problem seems to come from "barely virtual" Compton scattering



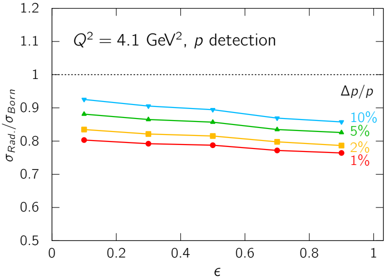
Recap

- Super-Rosenbluth RCs have the challenge of integrating radiation "all the way down to zero."



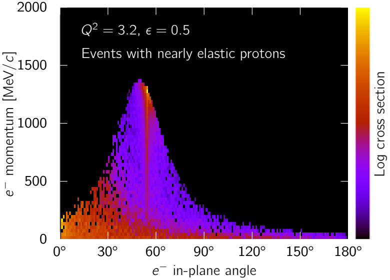
Recap

- Super-Rosenbluth RCs have the challenge of integrating radiation "all the way down to zero."
- Within peaking framework, Super-Rosenbluth RCs are smaller/flatter.



Recap

- Super-Rosenbluth RCs have the challenge of integrating radiation "all the way down to zero."
- Within peaking framework, Super-Rosenbluth RCs are smaller/flatter.
- Numerical pitfalls for full bremss. cross section.



Conclusions

- Until I get a second model working, no clue about the model dependence of SIMC approach in Qattan et al.

Conclusions

- Until I get a second model working, no clue about the model dependence of SIMC approach in Qattan et al.

- Credit to A. Afanasev for already solving this back in 2001 (*and thank you for sending me the paper!*).