Radiative Corrections from Medium to High Energy Experiments

Ethan Cline*, Andrei Afanasev, Jan C. Bernauer, Ron Gilman, Hubert Spiesberger

*ethan.cline@stonybrook.edu

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FONDAZIONE BRUNO KESSLER

ECT*
EUROPEAN CENTRE
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IN NUCLEAR PHYSICS AND RELATED AREAS

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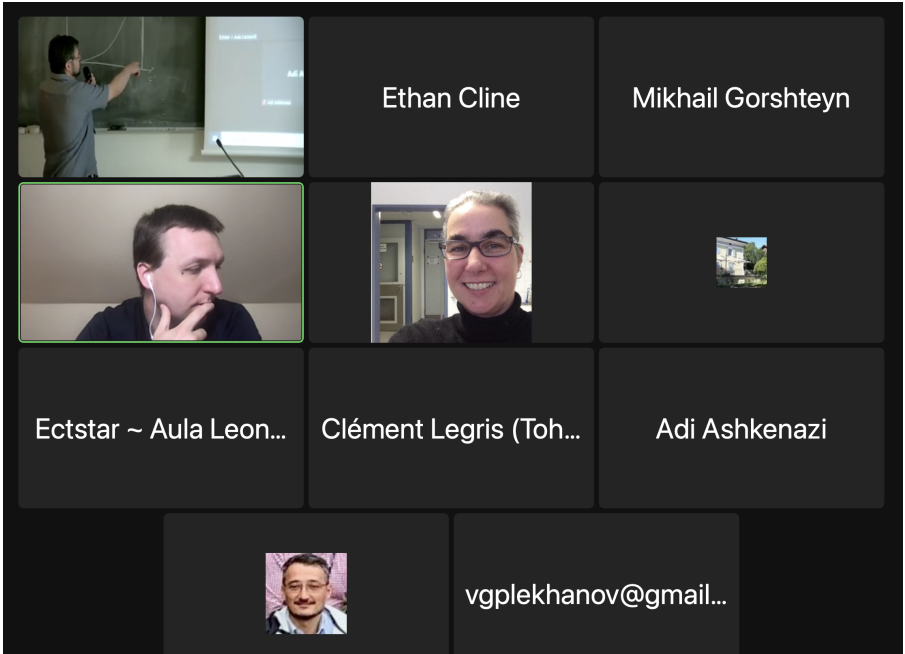
Thank **YOU**

Dinner

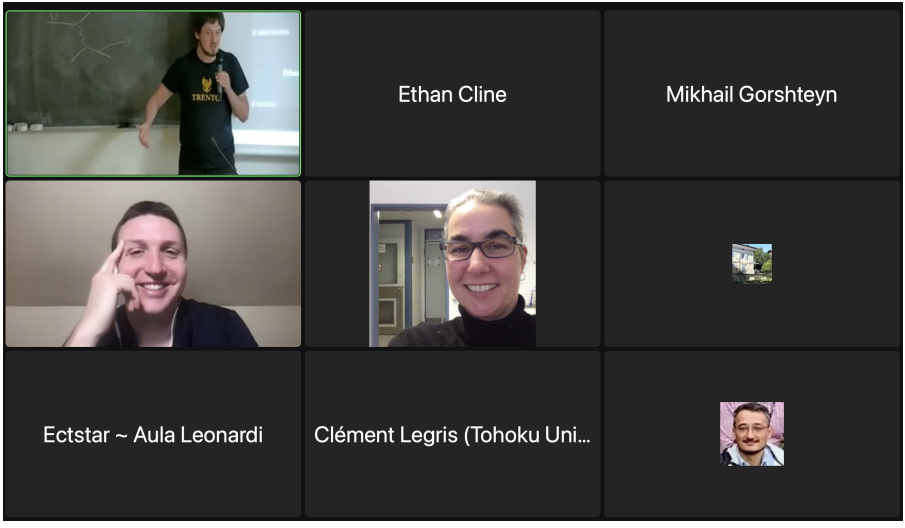
A Global Workshop

- From Detroit to Tohoku - separated in time by 13 hours
- Covering ep, νp, μp, e^+e^-, $\gamma\pi$, and meson decays
- LO to NNLO, 10 MeV to 10 GeV, elastic to (PV)DIS, theory to experiment
- Some pseudo-randomly selected highlights

Impromptu Classes

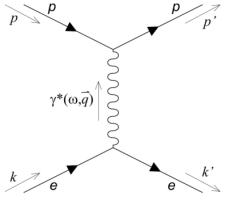


Impromptu Classes



Background 1

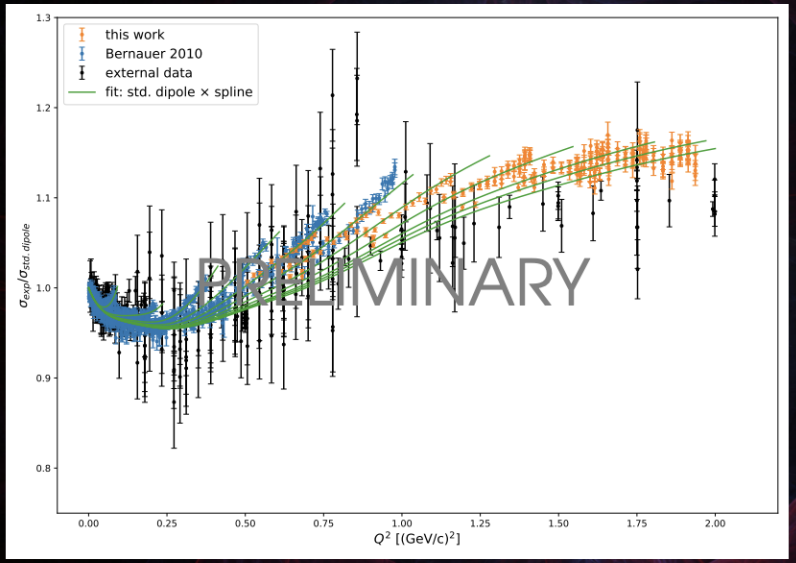
- I grew up in pion scattering, etc., then moved to electromagnetic scattering as a postdoc
- I learned that electron scattering was well understood, with some small, well-understood, "radiative correction" hardly worth discussing



Lowest order perturbation theory in QED (single photon exchange)

Results from our speakers - Bernauer

Mainz large Q^2 ff (PhD. thesis Julian Mueller)

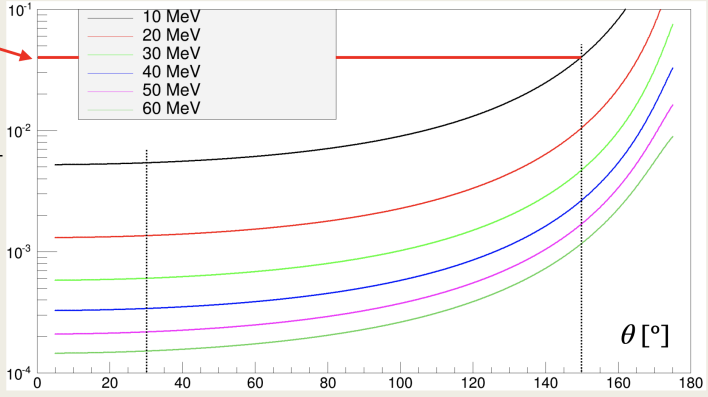


Electron mass

Up to 4 % at 10 MeV!

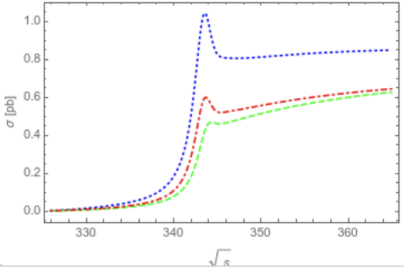
$$\frac{\left|\left(\frac{d\sigma}{d\Omega}\right)_{real} - \left(\frac{d\sigma}{d\Omega}\right)_{URL}\right|}{\left(\frac{d\sigma}{d\Omega}\right)_{real}}$$

(with PWBA and standard-dipole form factors)



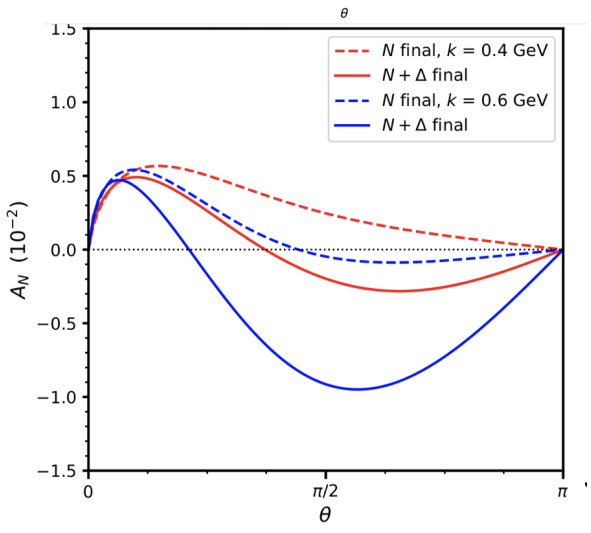
Conclusions

- We calculated the ISR corrections to the process $e^+e^- \to \gamma^*/Z^*$ up to $O(\alpha^6 L^5)$.
- This includes the first (up to) three logarithmic terms at lower orders.
- We calculated the leading logarithmic ISR corrections to the forward-backward asymmetry up to $O(\alpha^6 L^6)$.
- The corrections can become important at future e^+e^- machines running at high luminosities.
- The radiators can be used for various processes like $e^+e^- \to t\bar{t}$ and $e^+e^- \to Z\,H$.



blue: O(α^0), obtained with `QQbarThreshold` [Beneke, Kiyo, Maier, Piclum (Comp. Phys. Com. (2009))] ; green: O(α^1); red: O(α^2)

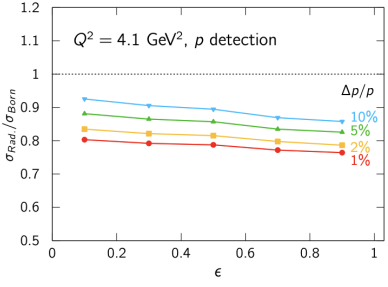
Results from our speakers - Goity



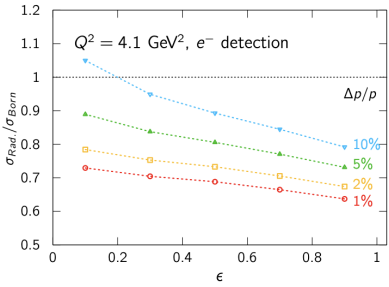
Goity, Weiss, Willemyns arXiv:2207.07588
transverse target SSA- approach based on the 1/Nc expansion

Results from our speakers - Schmidt

ϵ-dependence of the radiative correction



ϵ-dependence of the radiative correction

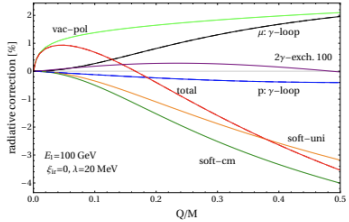


"Finally, radiative corrections (mainly electron bremsstrahlung) . . . have smaller ε-dependence when the proton is detected."
"Credit to A. Afanasev for already solving this back in 2001 (and thank you for sending me the paper!)."

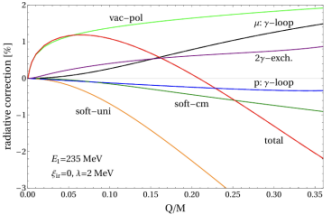
Results from our speakers - Kaiser

Pattern of radiative corrections for AMBER and MUSE

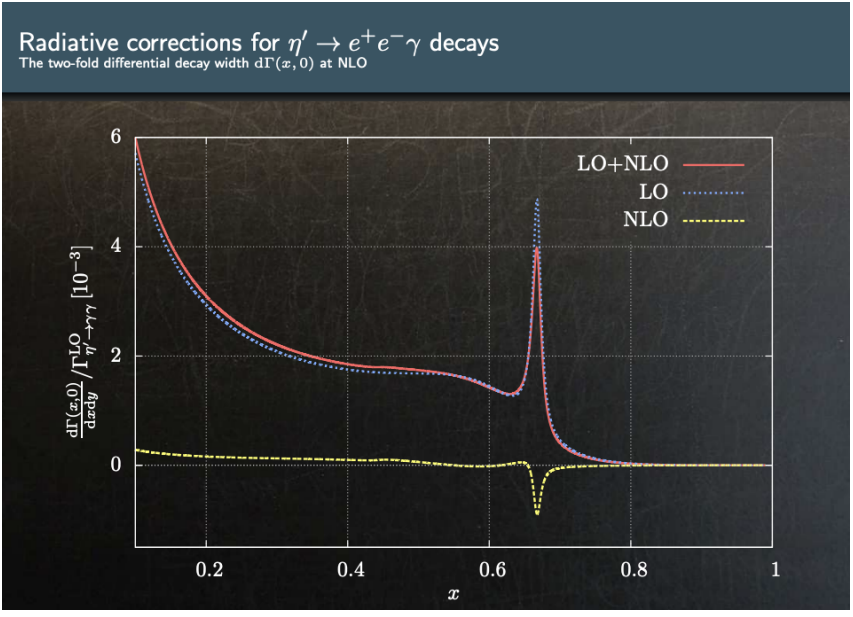
- Individual radiative corrections to $\mu^- p \to \mu^- p$ including proton structure



- Photon-loop around proton and 2γ-exchange are suppressed
- Major role played by vacuum polarization and soft photon radiation
- Requires calculation of (hard) bremsstrahlung incl. detector acceptance

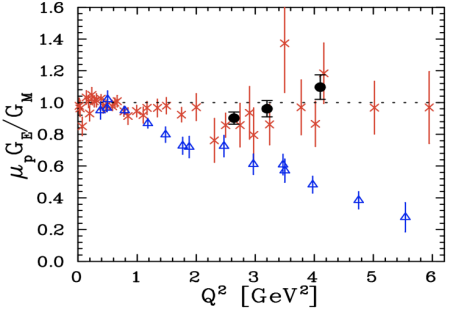


Results from our speakers - Husek

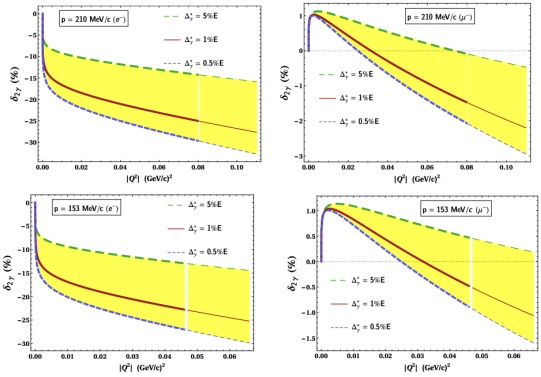


Discrepancy Reconfirmed

- (Skipping a little forward in time...) I. Qattan et al., PRL 94 (2005) 142301
  Rosenbluth separation measuring recoil protons rather than scattered electrons



Results from our speakers - Myrher

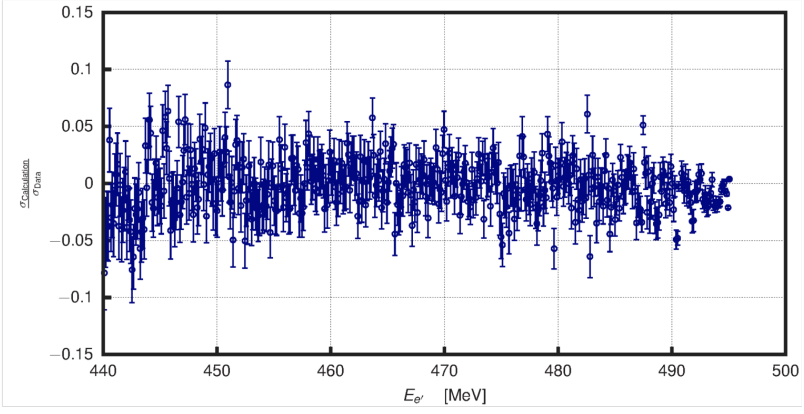


The lower limit of the photon energy detection $\sim \Delta_\gamma^*$.

Results are found in the soft photon approximation.

The (yellow) bands are the variation of the *lab*-frame detector resolution when $0.5\,\% < \Delta_\gamma^* < 5\,\%$ of the incident lepton energy E.

Experimental study of external corrections



- **The experiment confirmed the theoretical predictions.**
- The external radiative and collisional corrections impact the shape of the radiative tail.

SIDIS event generator on radiative corrections

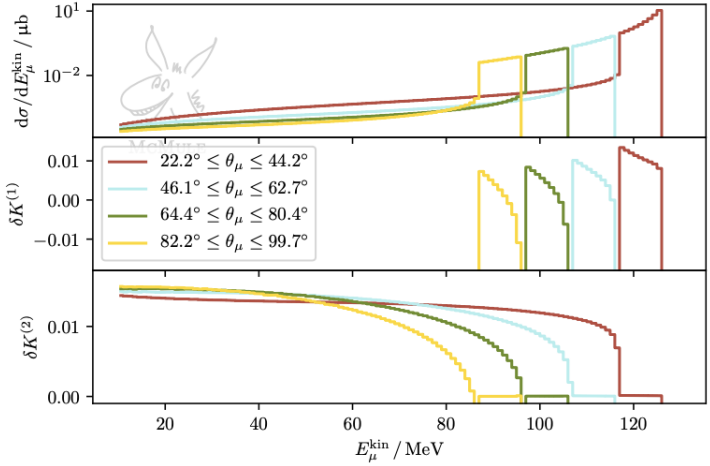
A Monte Carlo event generator created by Duane Byer from Duke University, based on the SIDIS RC paper: https://github.com/duanebyer/sidis

- Generates events for SIDIS six-fold cross sections computation
- All eighteen SIDIS structure functions implemented in Gaussian and Wandzura-Wilczek type approximations: S. Bastami et. al., JHEP06, 007 (2019)
- More fine tuning on the generator should be done for running it in the SoLID experiment's framework, including the neutron target
- In the meantime, the generator can be used for other experiments from medium to high energies, which also measure the SIDIS processes (CIAS12, COMPASS, etc.)

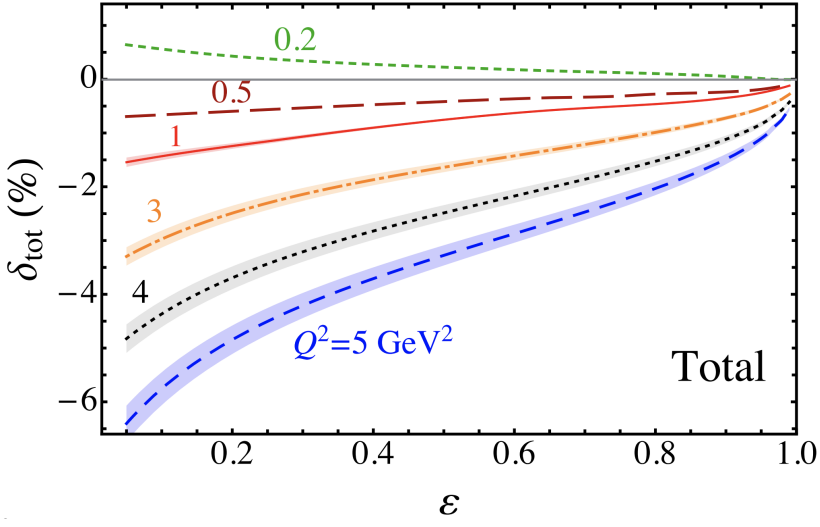
Results from our speakers - Ulrich

$p_\mu^{\text{in}} = 210\,\text{MeV},\ 20° < \theta_\mu < 100°$

mall mule-tools.gitlab.io/user-library/l-p-scattering/muse-legacy

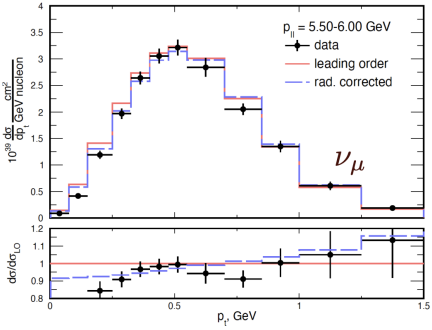


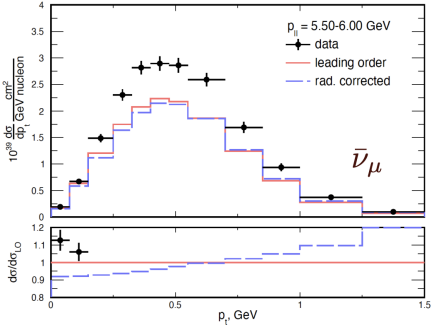
TPE corrections to cross section (CLAS resonances)



Comparison to data

- medium-energy flux data from MINERvA@FERMILAB





Lessons Learned

- Experimentalists must make it clear what corrections were applied!
- Theorists should provide equations experimentalists can understand (ratios and asymmetries are nice)!
- There are many excellent calculations, generators, and experiments out there!
- Radiative corrections are *important* for nuclear physics

Thoughts During the Workshop(revisited)

- Should we write a whitepaper?
  - NSAC charged the American DOE and NSF with recommending a new Long Range Plan by October 2023
  - EIC is on the distant horizon

Future Work

- Write something up on this workshop
  - At a minimum a list of relevant generators should be compiled and posted
  - Conveners for each subject?
  - Mailing list?
  - arXiv or journal?
- A database of cross sections would be very useful, along with details of radiative corrections that were applied
  - Give user ability to apply some prescription with minimal overhead
- Write a universal translator to interface generators and simulations
- Future workshop? ECT* or CFNS?

fin.

THANK **YOU**!