Radiative Corrections for E5

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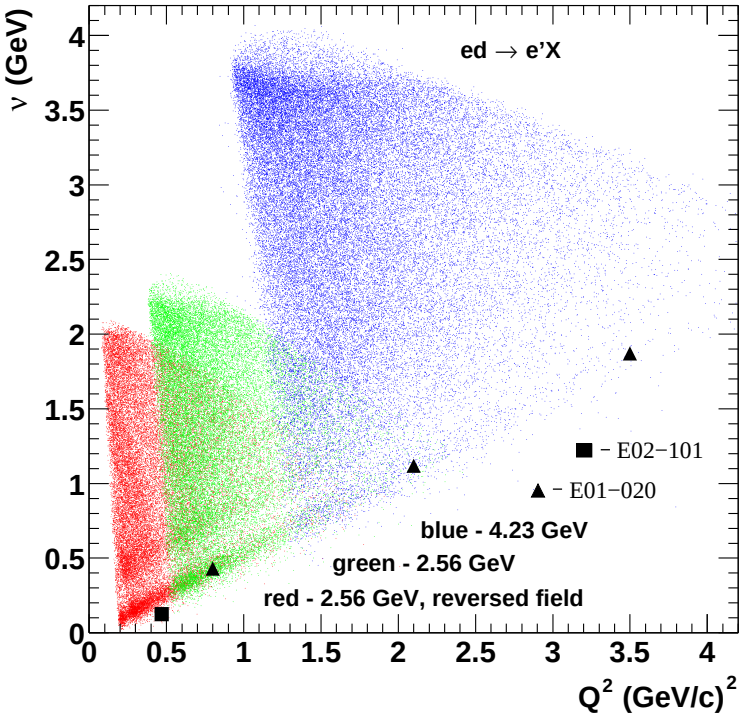
The E5 Data Set

- 2.3 billion electron triggers in the range $Q^2 = 0.2 - 5.0\ (GeV/c)^2$.
- Collected data under several running conditions.
  - 4.23 GeV, normal torus polarity.
  - 2.58 GeV, normal torus polarity.
  - 2.58 GeV, reversed torus polarity.
- Dual target cell containing deuterium (primary target) and hydrogen (for calibrations).
- Ongoing analyses of G_M^n, A'_{LT}, and others.

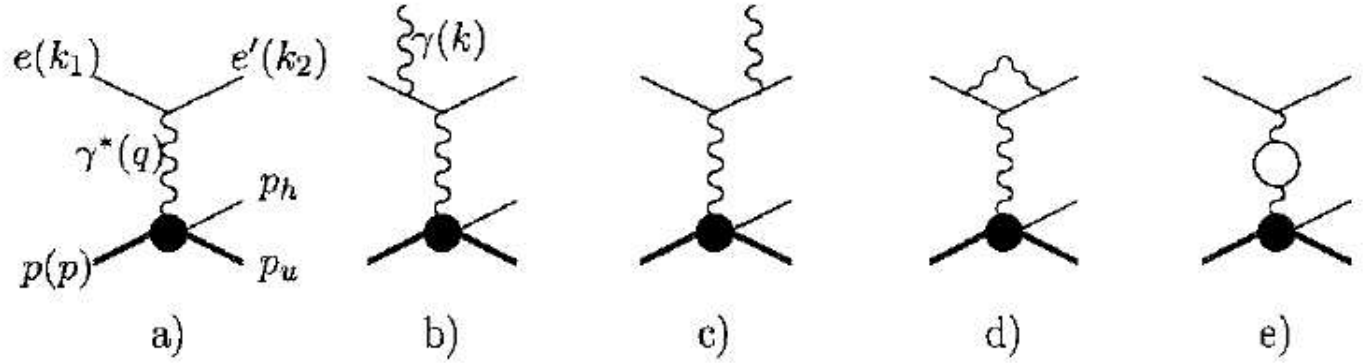


Radiative Corrections for Exclusive Reactions

- Radiative corrections (RC) are required for exclusive measurements of G_M^n and out-of-plane structure functions A'_{LT} using the E5 data set.
- The classical approach of Schwinger or Mo and Tsai cannot be directly applied here.
  - Detection of the ejected hadron alters the phase space allowed for the final radiated photon.
  - More structure functions contribute in these measurements.
  - Splitting of radiated photon phase space into hard and soft regions to avoid the infrared divergence.
- Recent work done by A.Afanasev, *et al.* to handle the exclusive case.

EXCLURAD

- Method used by A.Afanasev, *et al.* for pion electroproduction on the proton in the program EXCLURAD (A.Afanasev, I.Akushevich, V.Burkert, K.Joo, Phys. Rev. D **66**, 074004 (2002)).
- Diagrams used here.
  - QED processes for undetected, radiated photon (b and c).
  - Vacuum polarization.
  - Lepton-photon vertex corrections.



- Generates the ratio of the cross section at a given Q^2, W, $\cos\theta_{pq}$, ϕ_{pq} to the PWIA result.

Modifying EXCLURAD for E5

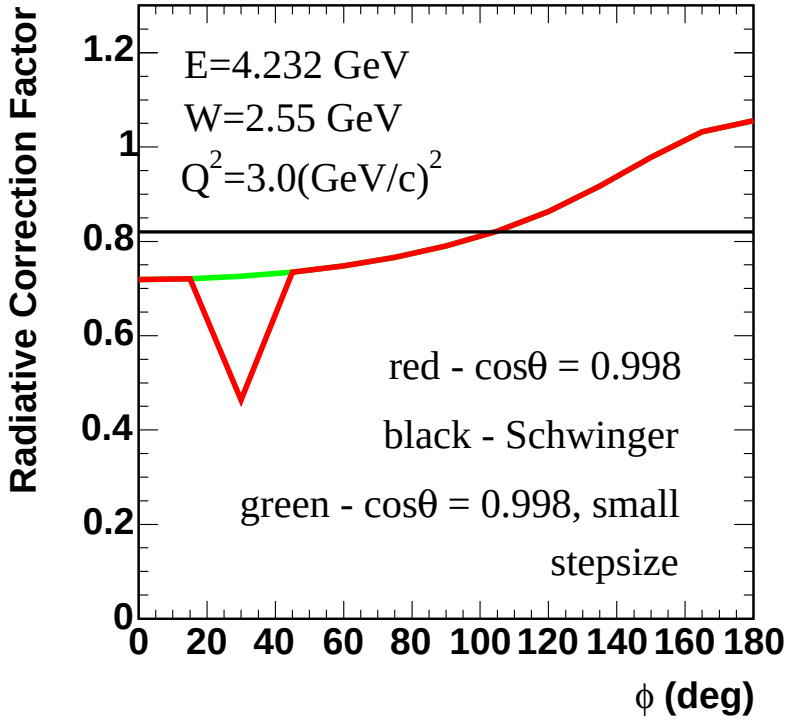
- The reactions of interest are $d(e,e'p)n$, $d(e,e'n)p$, and $d(\vec{e},e'p)n$.
- Changed masses of target and detected and undetected hadrons in routine SETCON.
- Installed new physics models for calculating response functions for $d(e,e'p)n$.
  - Using the DEEP program of Van Orden, *et al.* to calculate response functions using the relativistic impulse approximation.
  - Modified DEEP so it could be called as a subroutine.
  - Converted the output to be consistent with formalism used in EXCLURAD.

Modifying EXCLURAD for E5 - part 2

- Installed new physics models for calculating response functions for $d(e, e'n)p$.
  - Changed the masses in the routine SETCON so the proton is now the undetected hadron.
  - Modified DEEP to be called as a subroutine.
  - DEEP generates the response functions in the center-of-mass of the struck deuteron so $\theta_{neutron} = \pi - \theta_{proton}$.
- These changes work for G_M^n analysis, but DEEP does not include final-state interactions that are the focus of the out-of-plane structure function analysis. Will use code of S.Jeschonnek, *et al.* for that analysis (to be done).

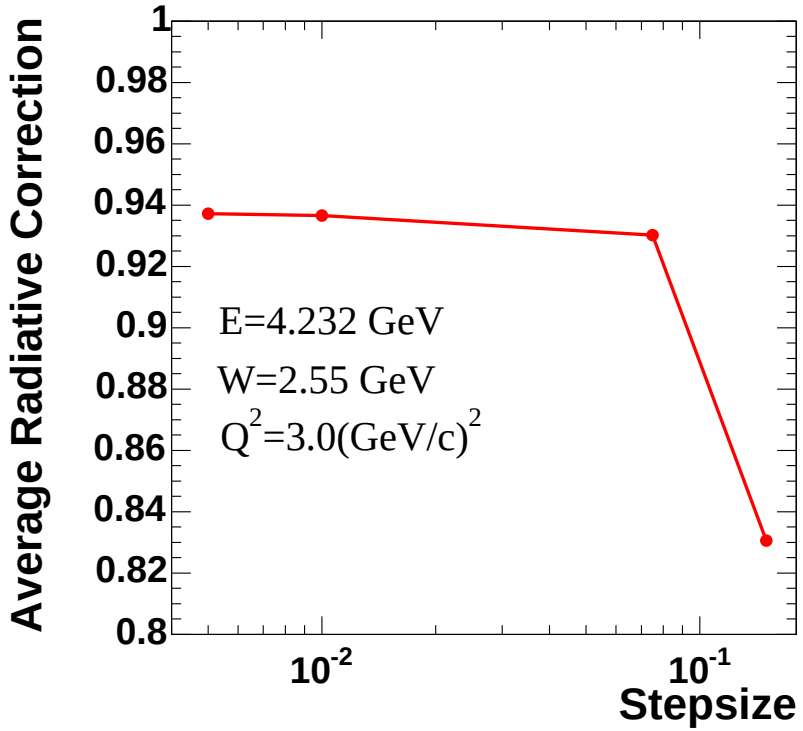
Tests and Comparisons

- Running the program.
  - Input: Q^2, W, $\cos\theta_{pq}$, and ϕ_{pq}.
  - Outputs: Ratio of the cross section with radiation included to the PWIA cross section.
  - EXCLURAD uses an adaptive subdivision strategy to perform a multi-dimensional integration so the compute time for each point can vary widely from less than a minute to 2-3 hours.
- A poor choice of the stepsize of the integration can produce unexpected results.



Tests and Comparisons - Part 2

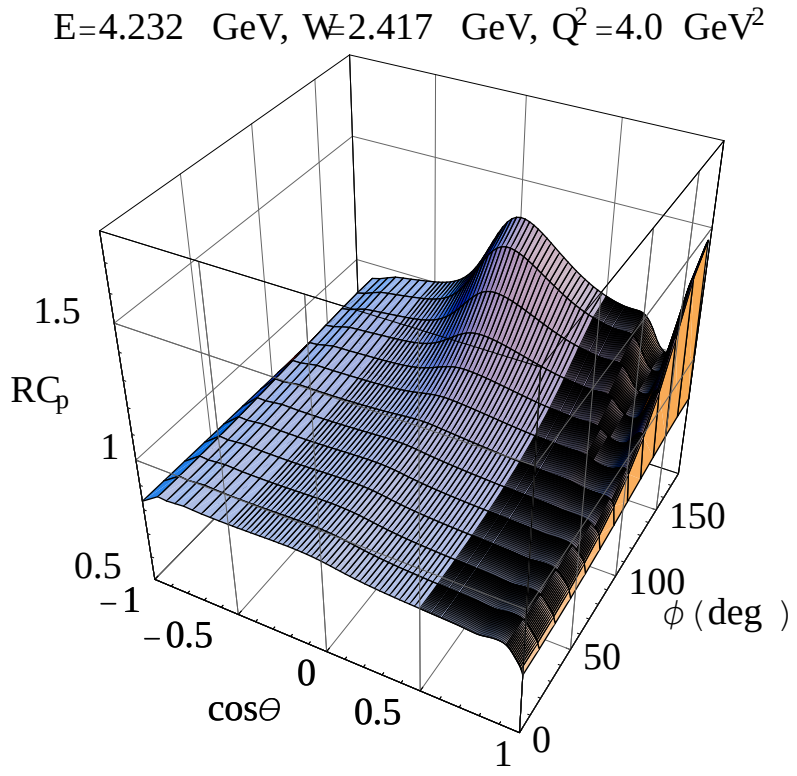
- Convergence behavior for equidistant bins in $\cos\theta_{pq}$.

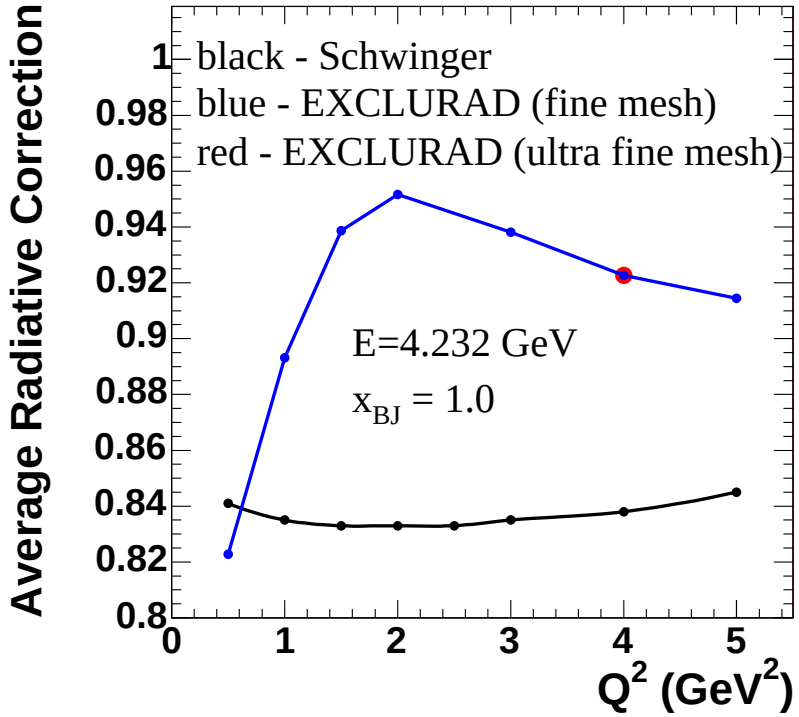


- To be sure a particular calculation has converged we can either vary the stepsize (very time consuming) or calculate an angular distribution (probably had to do this anyway).

Tests and Comparisons - Part 3

- Investigate the systematic behavior of $\langle RC \rangle$.



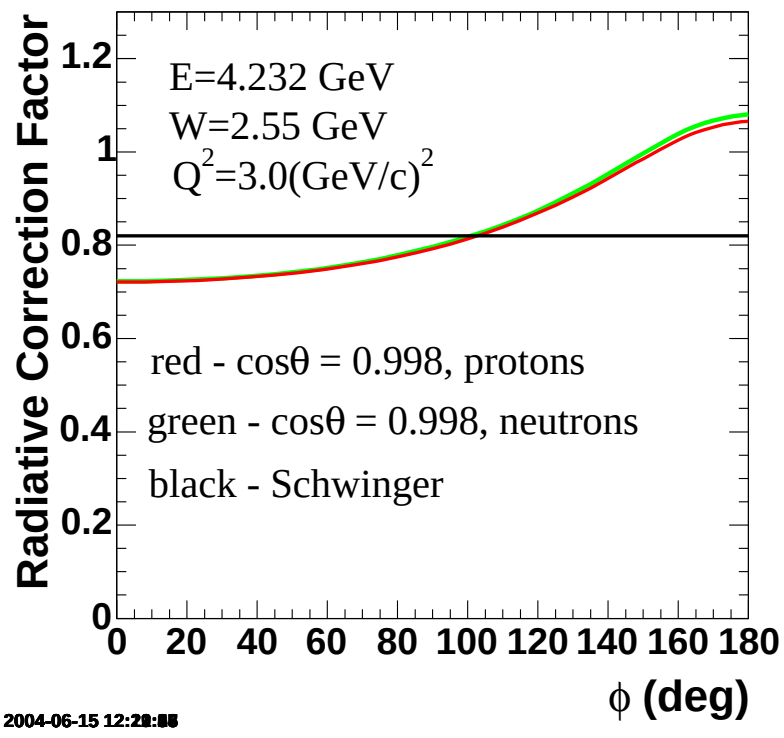


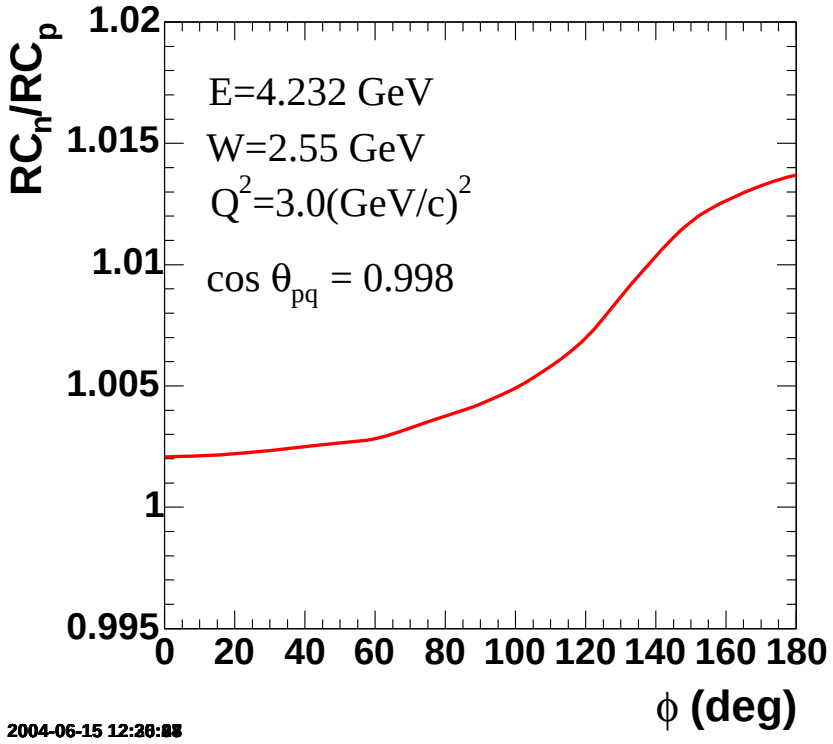
- Significant difference between the Schwinger* calculation and EXCLURAD can be attributed to the behavior of the response functions.

* K.Aniol, J.Cornejo, `http://www.calstatela.edu/academic/nuclear_physics/schwin12_extbrems.html`

Tests and Comparisons - Part 4

- Comparison of RC for $d(e,e'p)n$ and $d(e,e'n)p$ for G_m^n measurement.





- The effect of the radiative corrections on the n/p ratio is small.

Running E5 EXCLURAD

- The radiative corrections surface shown above required several hundred hours of CPU time to be calculated.
- Need a computing cluster to perform calculations in a reasonable time.
- Richmond cluster consists of 53 dual-CPU linux machines with about 4.5 TByte of space. It is available for use by CLAS collaborators.

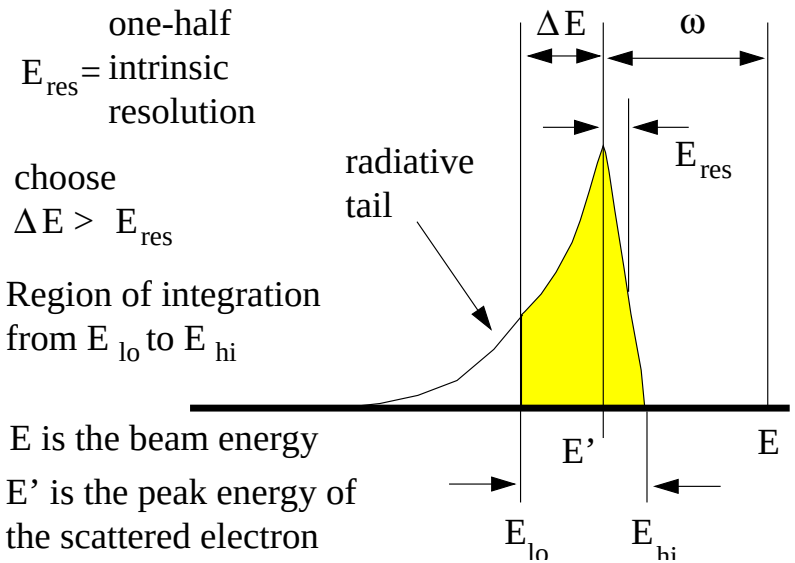
- Documentation, examples of scripts, *etc.* are available at

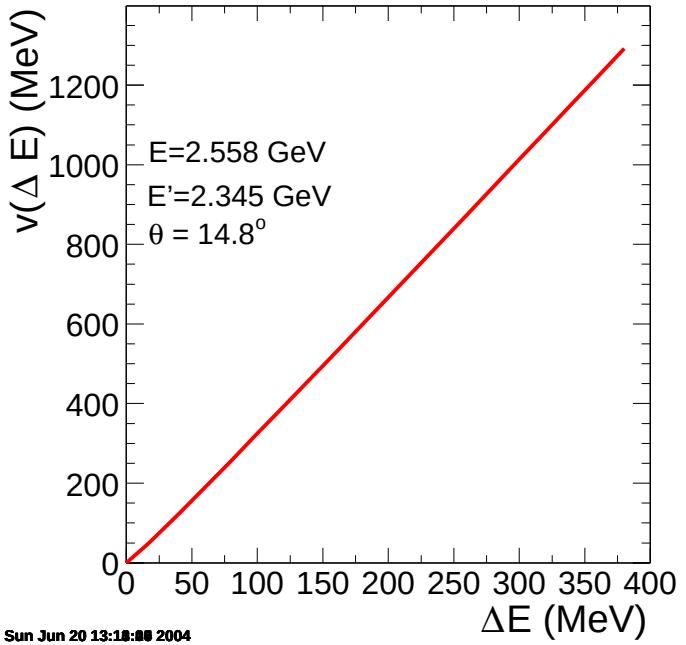
`www.richmond.edu/~ggilfoyl/research/spiderwulf/cluster_home.html`
`www.richmond.edu/~ggilfoyl/research/RC/wvo.html`

Running E5 EXCLURAD - Part 2

- Traditional radiative corrections require an integration interval ΔE.

- The code uses a parameter v defined as $v = \Lambda^2 - m_u^2$ where m_u is undetected hadron mass and Λ is the four-momentum of the undetected particle.





Conclusions

- We have successfully developed versions of EXCLURAD (originally written for pion electroproduction) for the $d(e,e'p)n$ and $d(e,e'n)p$ reactions.
- Effect of radiative corrections on the G_M^n measurements is small.
- Still need to develop a version that includes final-state interactions.
- Documentation and the codes are available at the following locations.

`www.richmond.edu/~ggilfoyl/research/RC/wvo.html`
`www.richmond.edu/~ggilfoyl/research/spiderwulf/cluster_home.html`

- Richmond cluster is available for calculating RC surfaces.
- Just starting to apply these calculations to E5 results.