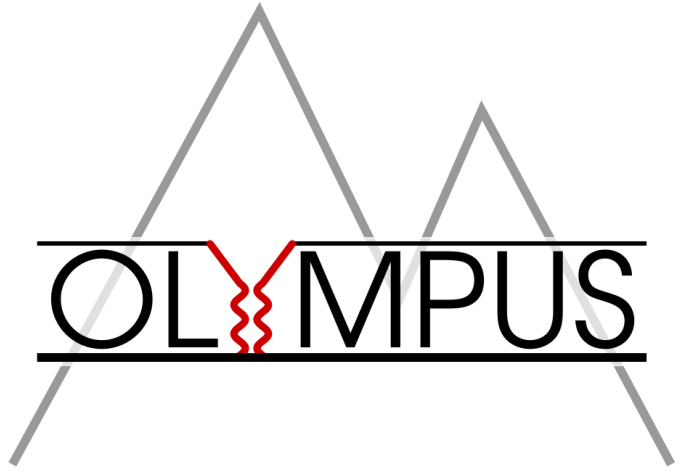
Overview of the Radiative Corrections Plan for



Rebecca Russell
Massachusetts Institute of Technology
for the Olympus Collaboration

October 7, 2013
IPN Orsay

Context for this talk

- OLYMPUS aims to measure a radiative correction to elastic *ep* scattering
  - Hard two photon exchange (TPE) contribution
  - Could solve G_E^p/G_M^p measurement discrepancy

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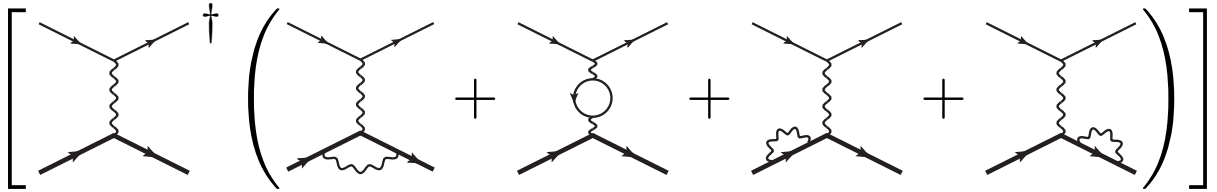
- Need to measure a quantity that's easy to apply to the question of the form factor discrepancy

Corrections to the elastic cross section

$$\frac{d\sigma}{d\Omega} = z^2 \left| \right|^2$$

Interference terms of order α^3

$$+ 2z^2\,\mathrm{Re}\left[\right]^\dagger \left(+ + + \right)$$



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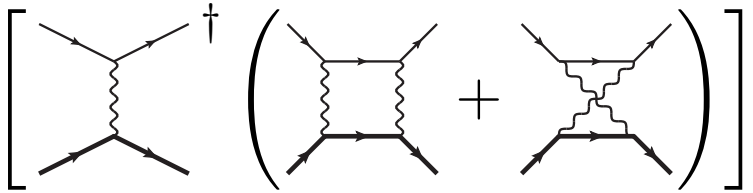

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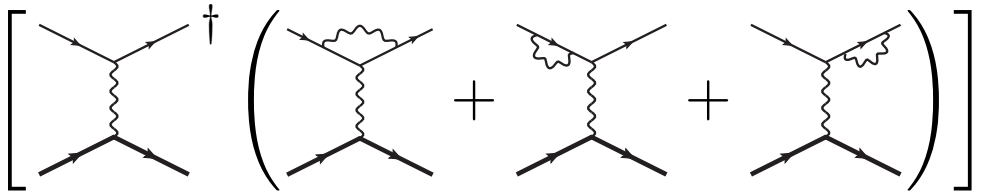

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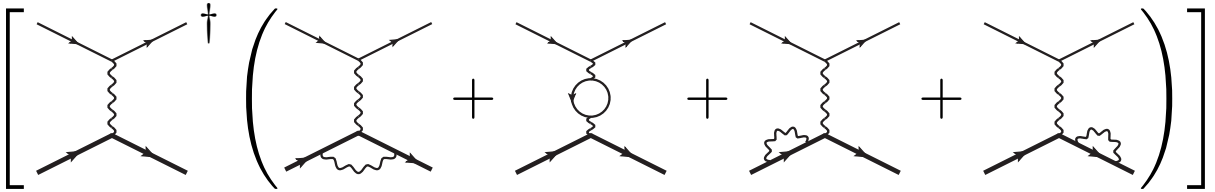

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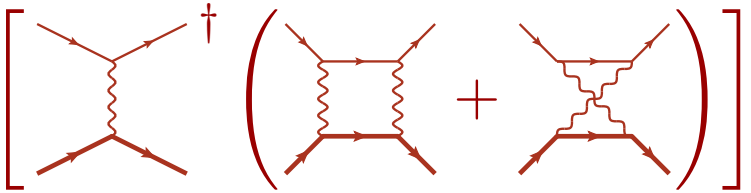

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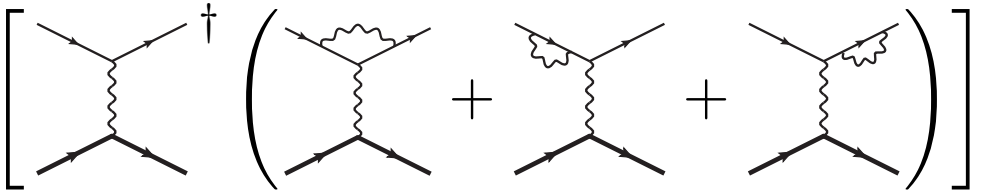

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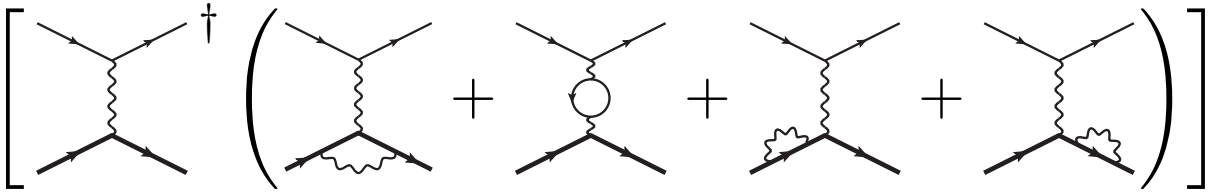

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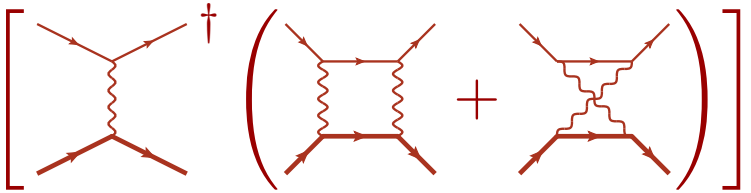

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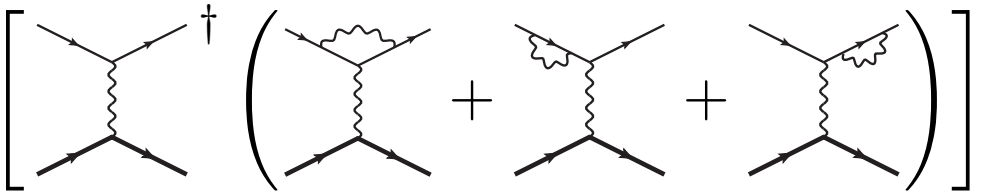


$$+ \mathcal{O}(\alpha^4)$$

However, almost all terms are IR divergent...

Corrections from inelastic (bremsstrahlung) processes

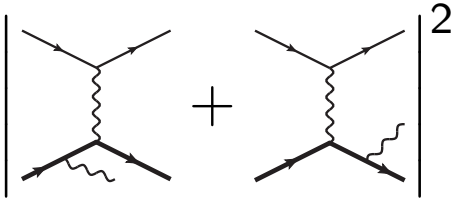
- Cancel exactly with divergences from the elastic cross section

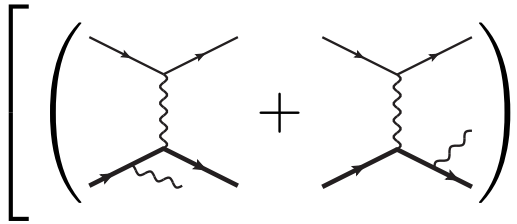
$$\frac{d\sigma_{\text{inel}}}{d\Omega} = z^2 \left| \quad + \quad \right|^2$$

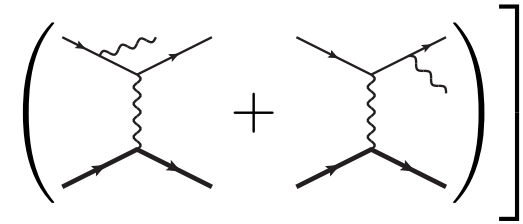
$$+ 2z^3 \,\text{Re}\left[\left(\quad + \quad \right)^{\dagger} \left(\quad + \quad \right) \right]$$

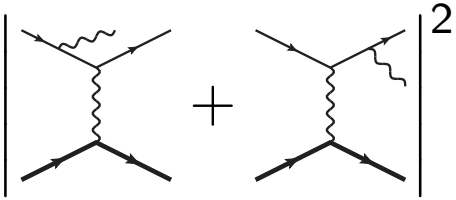
$$+ z^4 \left| \quad + \quad \right|^2$$

$$+ \mathcal{O}(\alpha^4)$$









We cannot separate inelastic *ep* events from elastic *ep* when very little energy is carried away by photons

Standard corrections for *ep* scattering

- Mo and Tsai did the first full calculation of the size of these corrections to elastic *ep* scattering
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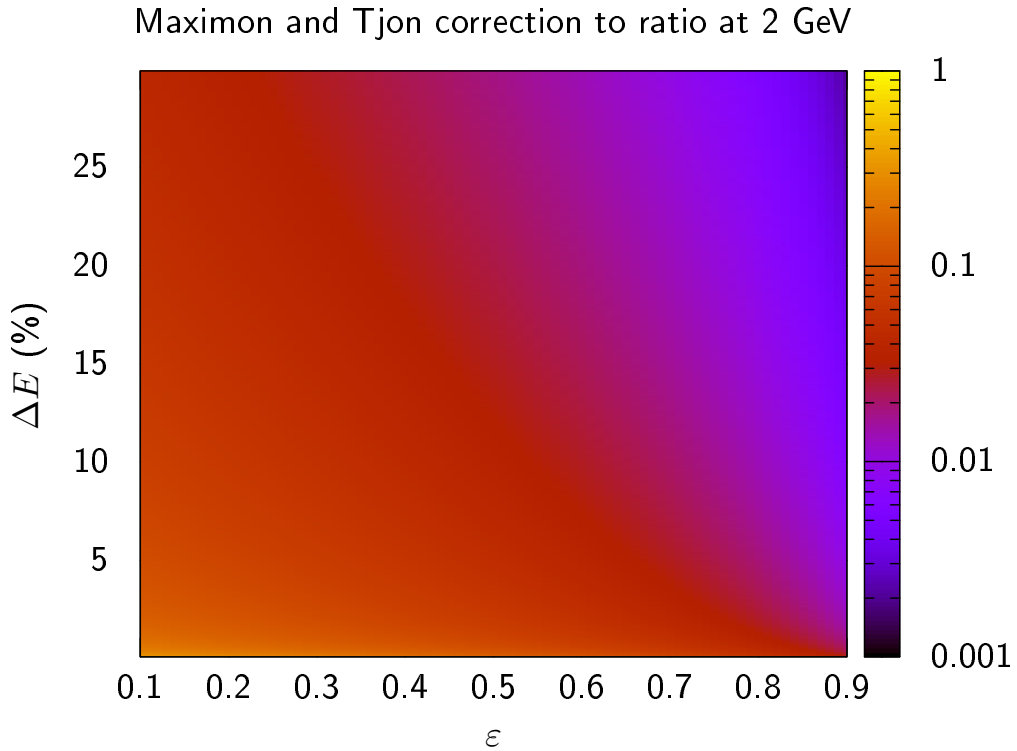
  - Used for the radiative corrections in most older measurements
- More recently, Maximon and Tjon improved upon the calculations of Mo and Tsai
  - L. C. Maximon and J. A. Tjon, Phys. Rev. C **62**, 054320 (2000)
  - Form for bremsstrahlung given in the soft photon limit without additional approximation
  - Less-severe soft photon approximation in calculation of TPE amplitudes
  - Full calculation of proton vertex

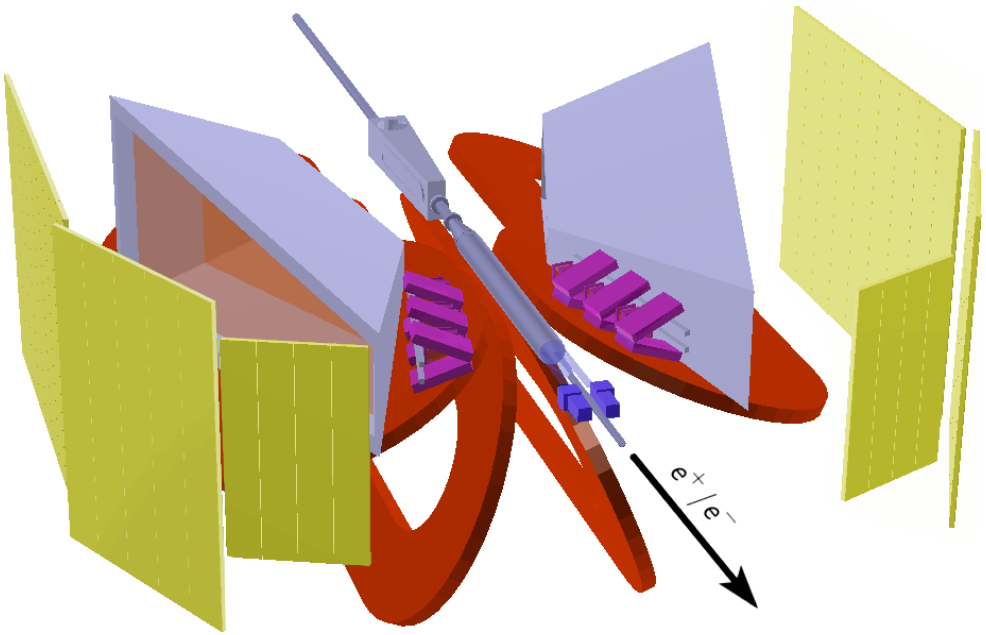
Standard corrections for *ep* scattering

- Both formulations express the correction to the cross section in terms of a parameter ΔE
  - ΔE is the maximum energy loss an inelastic electron can have and still be measured as elastic
  - Determined by detector resolution
- Size of correction increases with decreasing ΔE



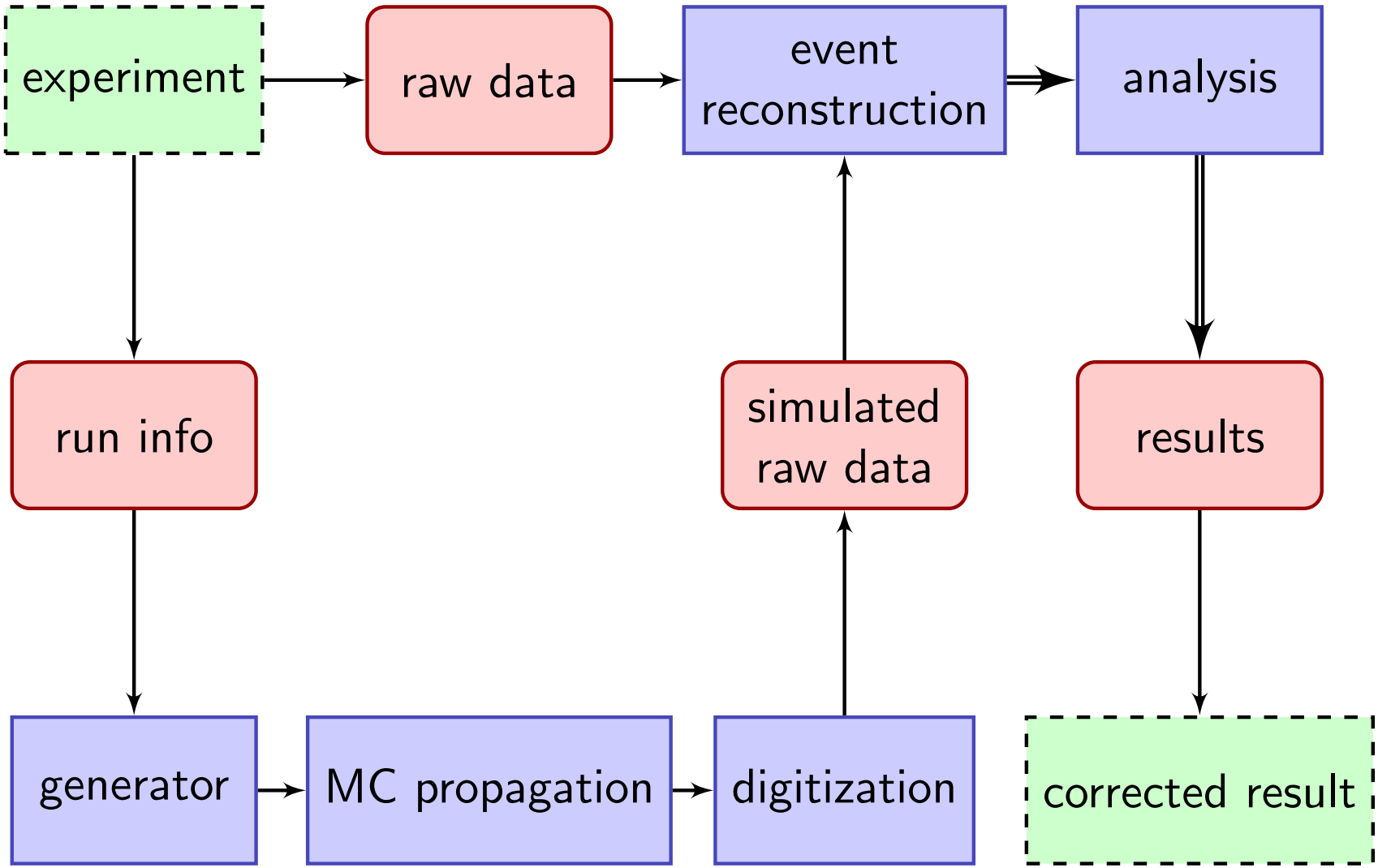
$$\varepsilon = [1 + 2(1 + Q^2/4M^2)\tan^2(\theta/2)]^{-1}$$

Monte Carlo



- ΔE far too crude of a quantization of our ability to separate elastic and inelastic events
- Need to take into account efficiencies, cuts, and acceptances of the detectors
- Monte Carlo is the clear solution
  - Allows us to go beyond Maximon and Tjon
  - Can do a full calculation of bremsstrahlung with no soft-photon approximation

Analysis plan



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- 12° $ep \to ep$ luminosity monitors
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- Symmetric Møller/Bhabha luminosity monitor
  - Currently using tree level generator
  - Need a radiative one for the final result
  - $e^- + e^- \to e^- + e^-$
    $e^+ + e^- \to e^+ + e^-$
    $e^+ + e^- \to 2\gamma$

OLYMPUS generator plugin

- Outer "interfacing" part:
  - Gets the beam position, slope, charge, and energy from run info
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  - Gets the beam position, slope, charge, and energy from run info
  - Passes the beam charge (e^+ or e^-) and energy to the inner part
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- Inner "physics" part:
  - Contains the differential cross section and event generation
  - Easy to swap in and out
  - Born, isotropic, pion, Novosibirsk radiative, OLYMPUS radiative (testing)
    - Pion: MAID2007 (`http://wwwkph.kph.uni-mainz.de/MAID/maid2007/`)
    - Novosibirsk radiative: ESEPP by Alexander Gramolin (`http://www.inp.nsk.su/~gramolin/esepp/`)
  - Can add other radiative generators...

Unweighted vs. Weighted

Different approaches to event generation:

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- Unweighted:
  - Can easily use regular counting statistics
  - Looks just like data
  - Non-trivial to generate from a high-dimensional distribution
- Weighted:
  - Easier to change energy on an event-to-event basis
  - Choice of what distribution to sample from
  - Can have multiple weights while propagating each event

Options with weighted generators

- Importance sampling
  - Choose a distribution that's easy to sample from
  - Should approximate cross section in range you care about
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  - For more: Talk tomorrow by Axel Schmidt

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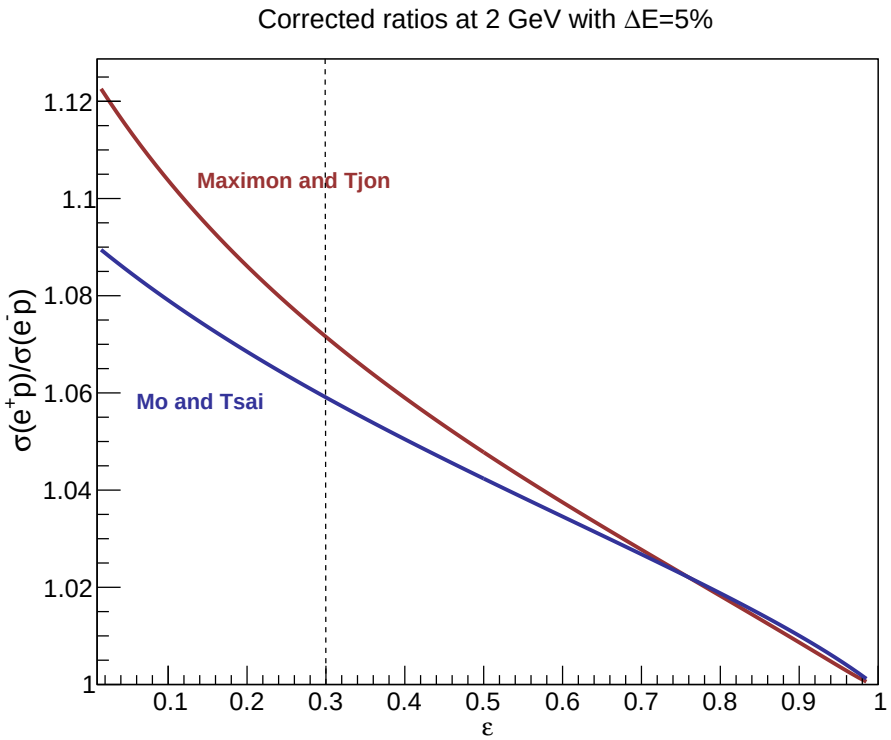
- Multiple weights
  - Slowest step of analysis is propagation of generated events through Monte Carlo
  - Want to propagate as few events as possible
  - Can carry weights from many different cross section calculations simultaneously
  - Allows us to break the final radiative correction into components

“Hard” vs “soft” two photon exchange

- Hard TPE has not been accounted for in Rosenbluth experiments
  - Mo and Tsai and Maximon and Tjon calculate “soft” two photon exchange differently
  - “Hard” two photon exchange is everything else...



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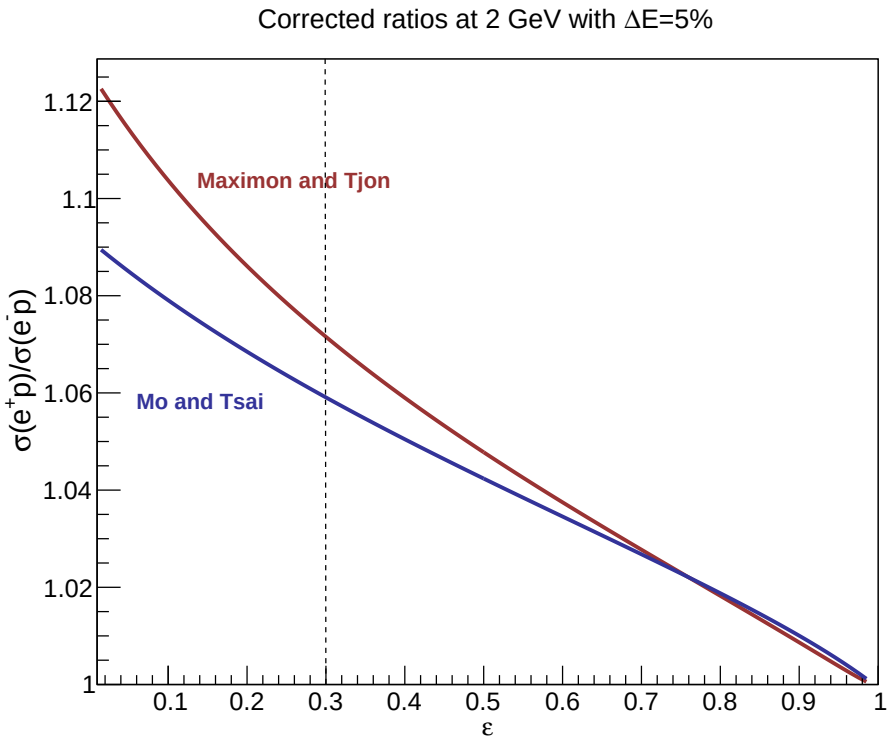

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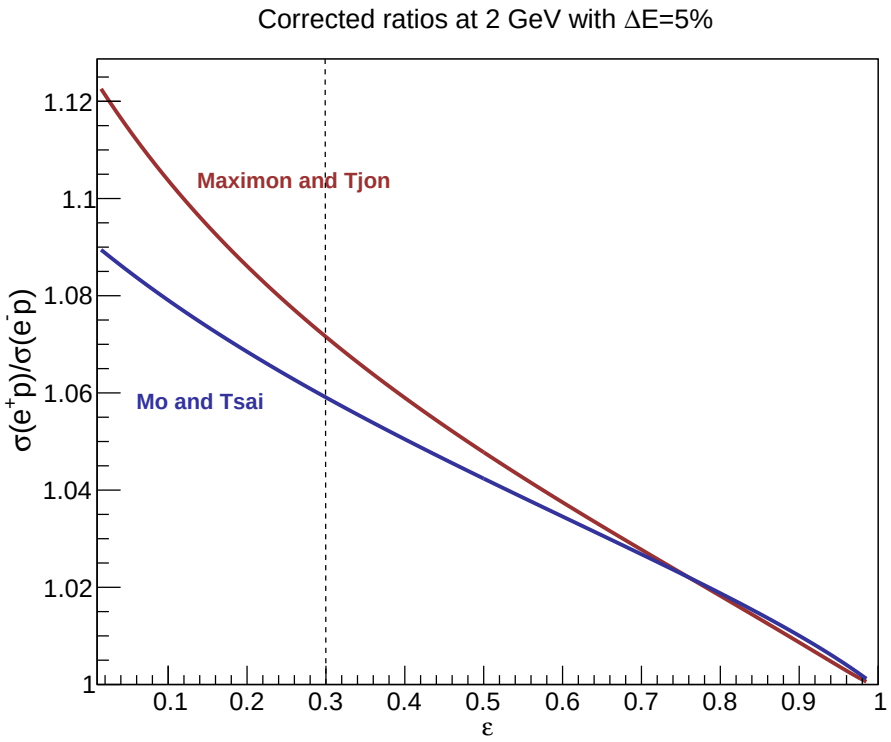
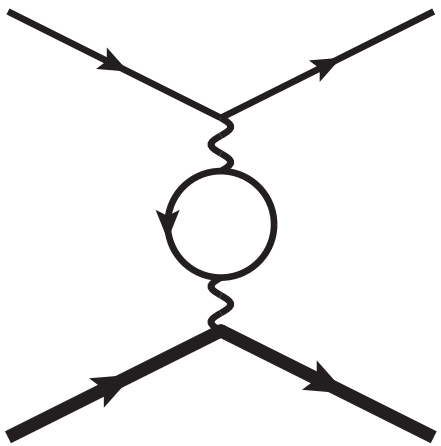
- Carry two weights for each simulated event, and easily generate two final results



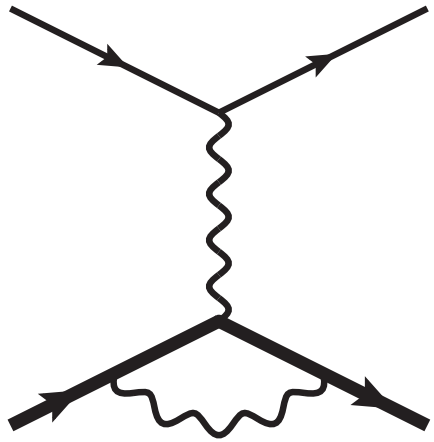
Vacuum polarization



- Maximon and Tjon and Mo and Tsai use just electrons/positrons in the loop
  - Easy to extend to more leptons
  - Detailed theoretical calculations exist
  - Can use experimental measurement
- Once again, we can carry a bunch of weights through our whole analysis to see how big of an effect this might have

Form factor dependence

- We're trying to solve a form-factor discrepancy



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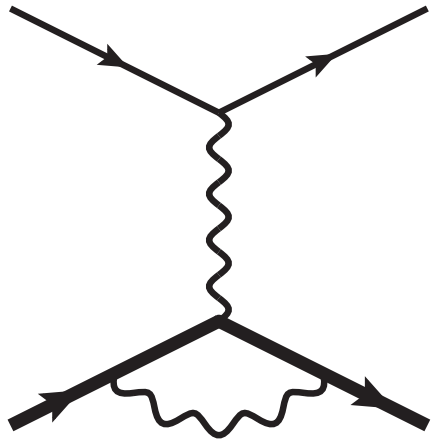

Form factor dependence

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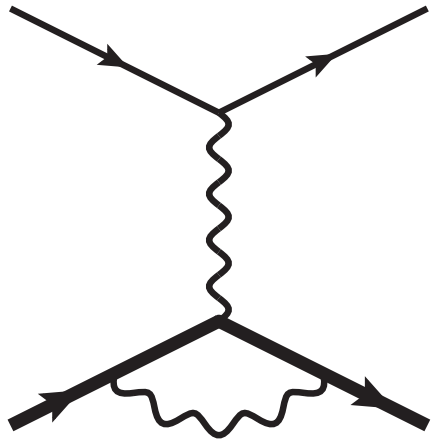
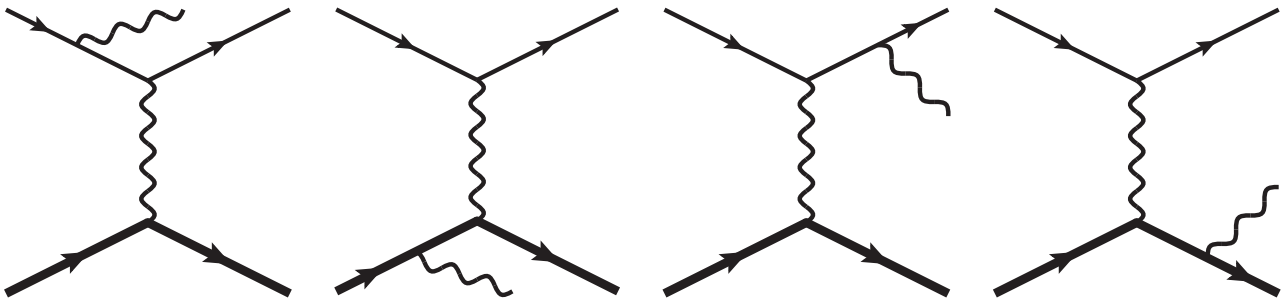
- Bremsstrahlung
  - Probably not totally negligible
  - Can use several choices: dipole, more sophisticated parameterizations
  - Can use different weights to see if choice makes a difference



Bremsstrahlung

The most challenging part of our radiative corrections



- Detailed calculation of bremsstrahlung to the order of α^3 without any soft photon approximation or peaking approximation for most of parameter space
- Use Maximon and Tjon formulation for cross section with elastic kinematics very close to the elastic curve
- See: Talk by Axel Schmidt tomorrow

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- Radiative generator is mostly written
  - Not yet well tested...
- Check to make sure it produces similar results to Novosibirsk generator
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- Geant4 Monte Carlo development is complete
  - Detectors and materials positioned by surveys done before and immediately after data taking
- Digitization is not yet completed for all detectors

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- OLYMPUS radiative corrections approach
  - Custom radiative generator which uses event info
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- Working with the other TPE experiments to ensure consistent radiative corrections