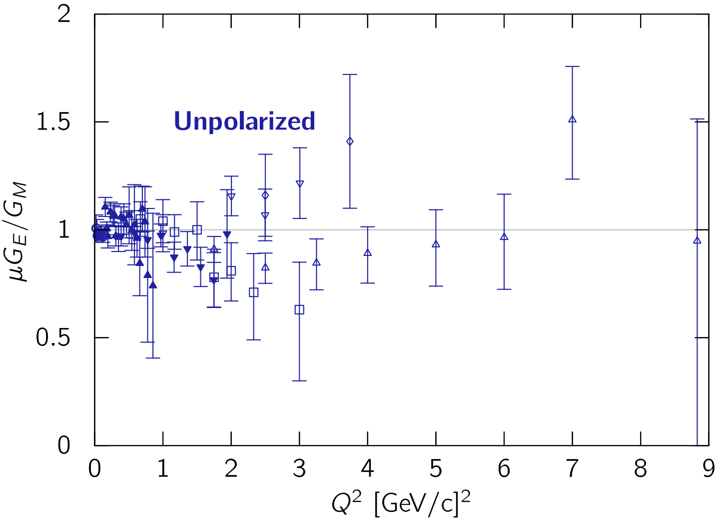
Modeling Radiative Processes for the OLYMPUS Experiment

Axel Schmidt

CFNS Ad-Hoc Meeting on Radiative Corrections

July 9, 2020

Polarized and unpolarized measurements of $\mu G_E / G_M$ disagree.



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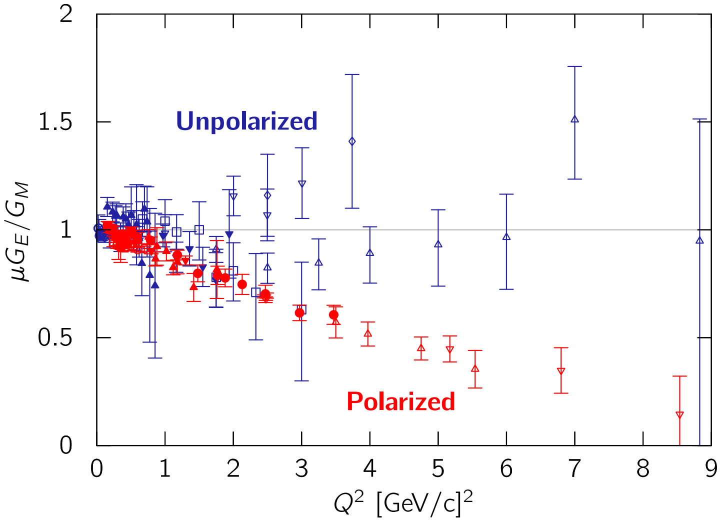

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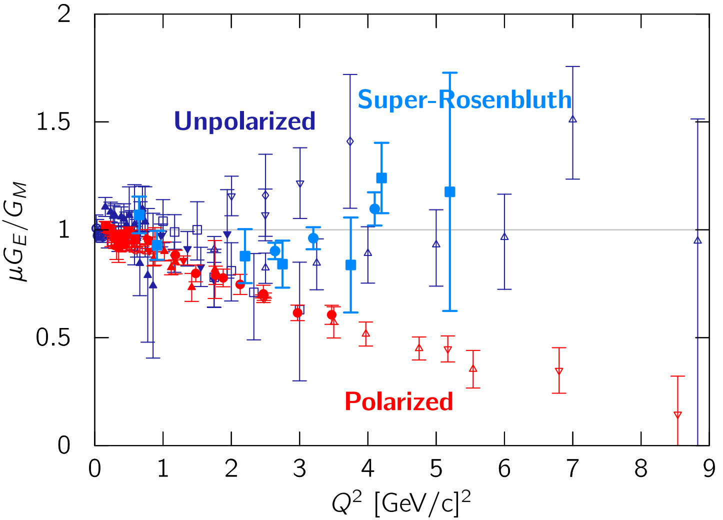

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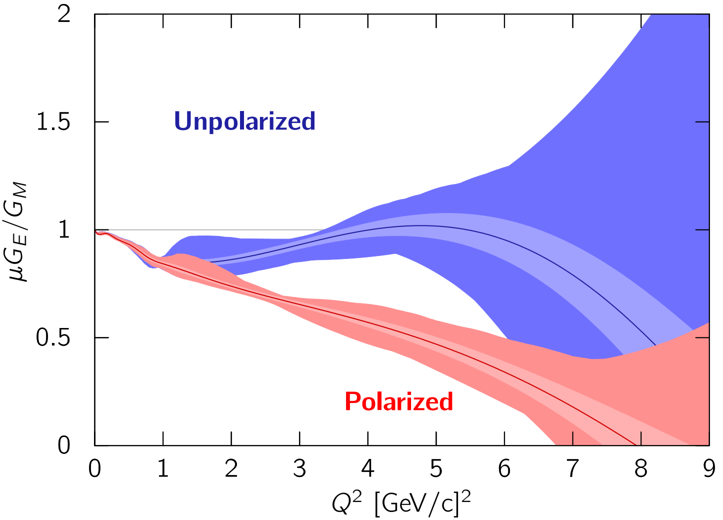
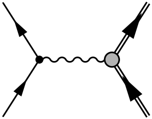
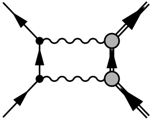


Hard TPE would cause asymmetry between e^+p and e^-p cross sections.

$\mathcal{M} =$  $+$  $+\,\mathcal{O}(\alpha^3)$

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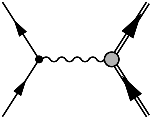
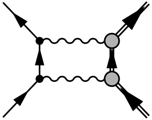
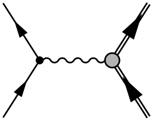
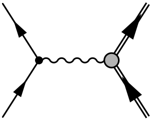
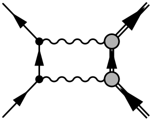
$\mathcal{M} =$  $+$  $+\,\mathcal{O}(\alpha^3)$

$\sigma \approx |\mathcal{M}|^2 = \Bigg|$  $\Bigg|^2 \pm 2\mathrm{Re}\Bigg[$   $\Bigg] + \mathcal{O}(\alpha^4)$

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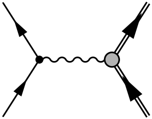
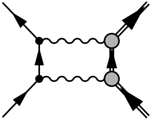
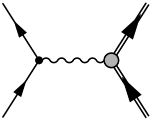
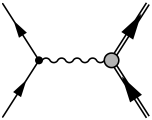
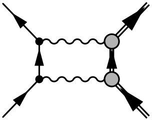
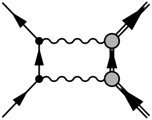
$\mathcal{M} =$  $+$  $+\, \mathcal{O}(\alpha^3)$

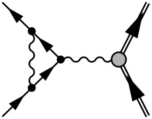
$\sigma \approx |\mathcal{M}|^2 = \Big|$  $\Big|^2 \pm 2\mathrm{Re}\Big[$   $\Big] + \mathcal{O}(\alpha^4)$

$$\frac{\sigma_{e^+p}}{\sigma_{e^-p}} \approx 1 + \frac{4\mathrm{Re}\{\mathcal{M}_{2\gamma}\mathcal{M}_{1\gamma}\}}{|\mathcal{M}_{1\gamma}|^2}$$

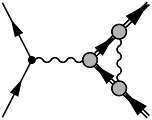
Other higher-order processes also contribute.



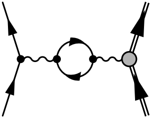
Soft TPE



e-vertex correction



p-vertex correction



Vacuum polarization

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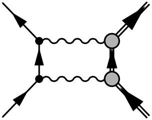

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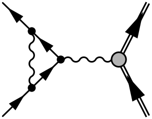

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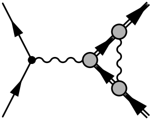

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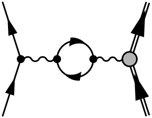
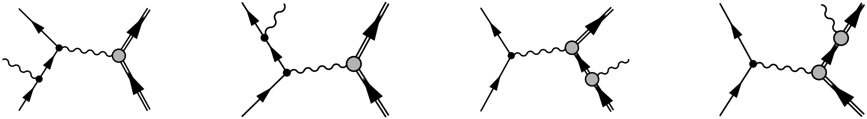


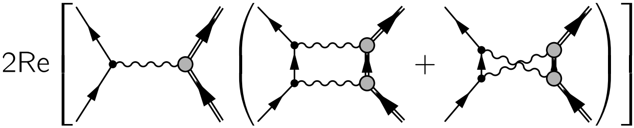
Vacuum polarization

Soft Bremsstrahlung

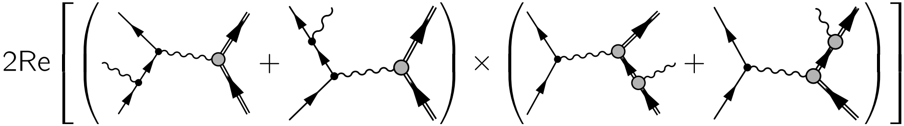


Charge-odd radiative corrections

Soft two-photon exchange



Bremsstrahlung interference



In my talk today:

- Review of the OLYMPUS Results
- Radiative Corrections in OLYMPUS
- New Charge-Averaged Cross Section Analysis

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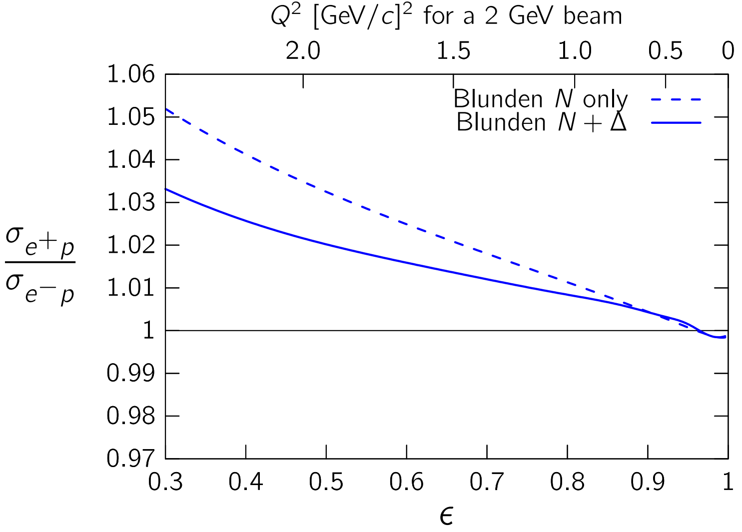

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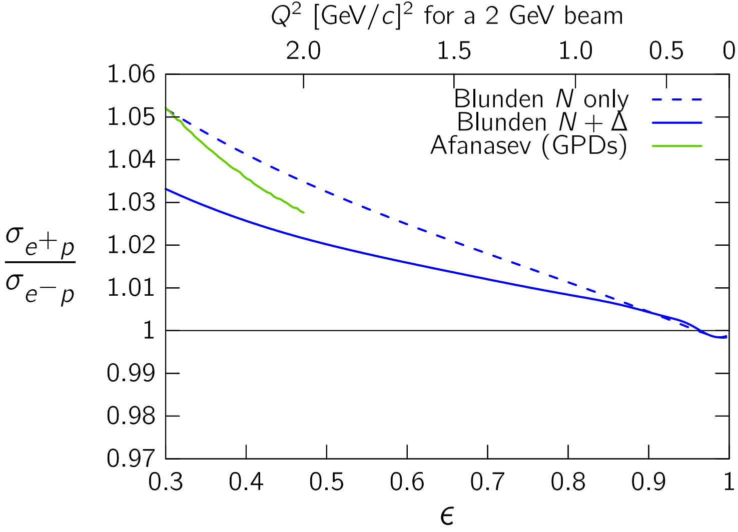

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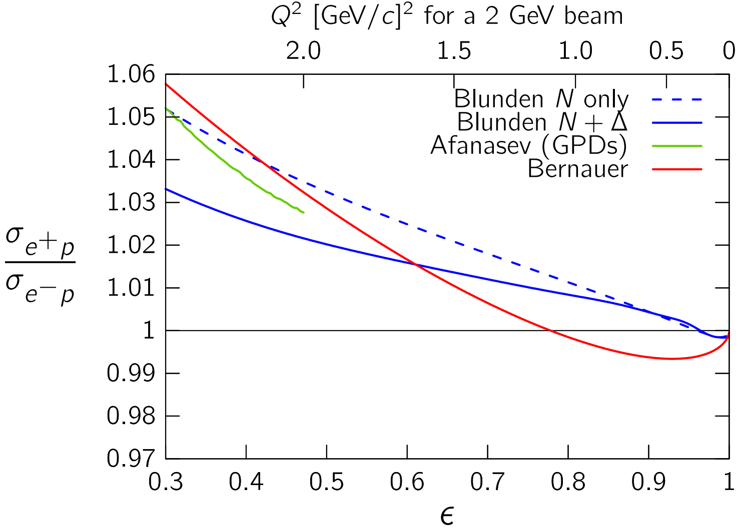
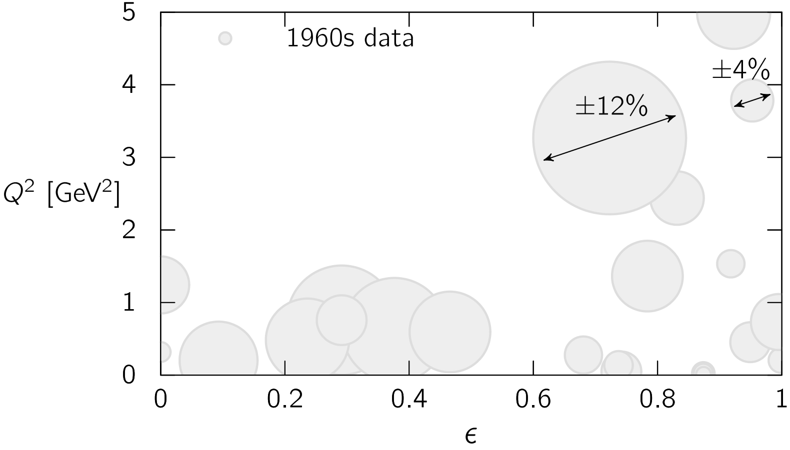


1960s data lack the coverage and precision to make strong claims about TPE.



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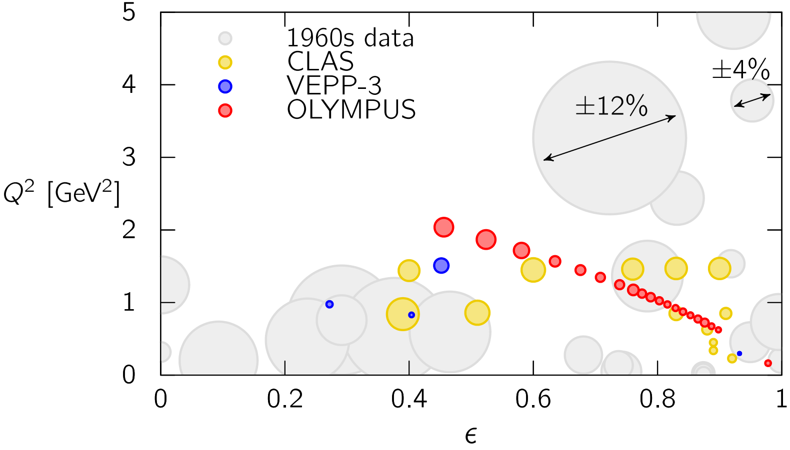


OLYMPUS was one of three new experiments to measure the e^+p/e^-p cross section ratio.

VEPP-3 TPE Experiment

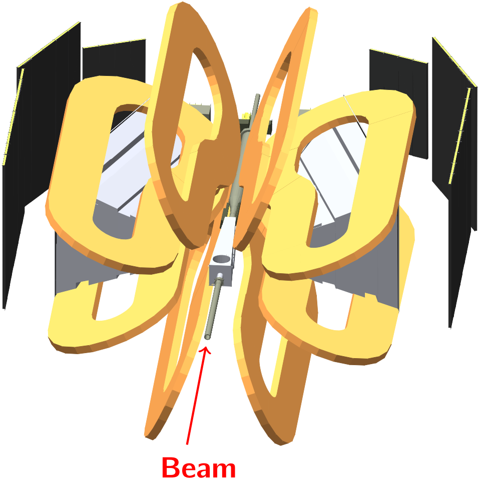
Институт ядерной физики
имени Г. И. Будкера СО РАН

CLAS TPE Experiment

The OLYMPUS Experiment at DESY

The OLYMPUS Experiment at DESY

- Alternating 2 GeV e^+ and e^- stored beams
- Window-less hydrogen target
- Former BLAST Spectrometer



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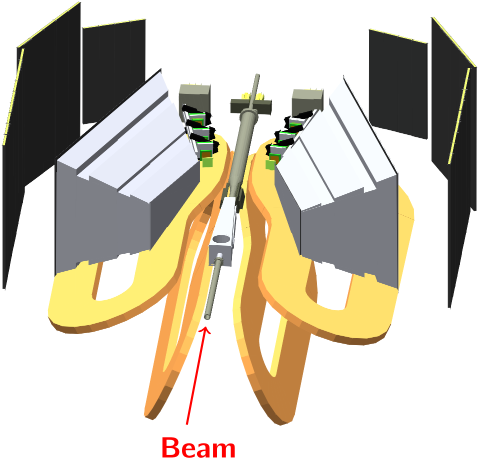
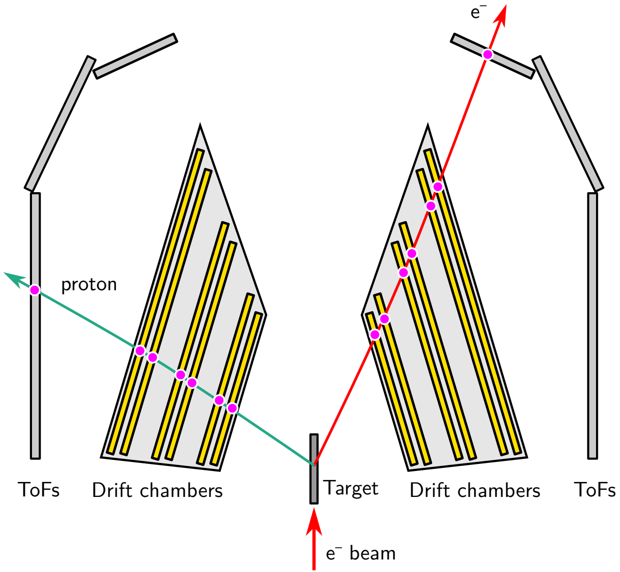


OLYMPUS relied on coincident detection.



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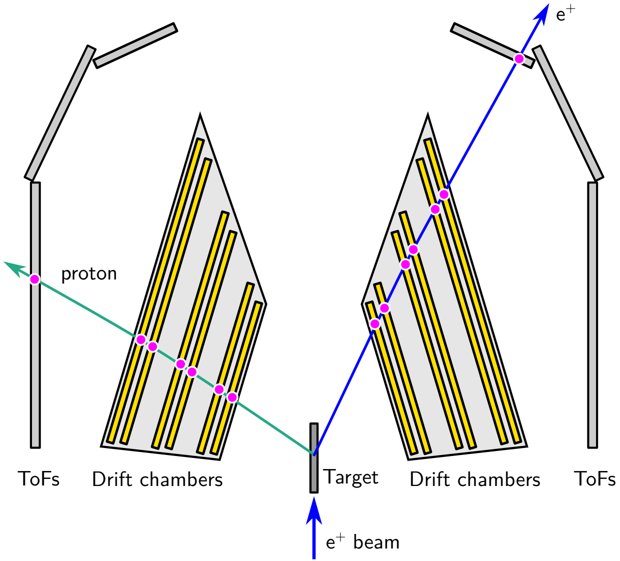
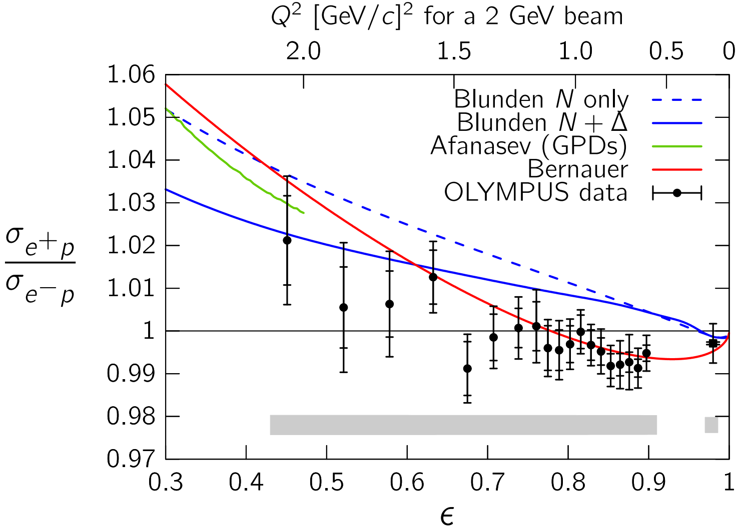
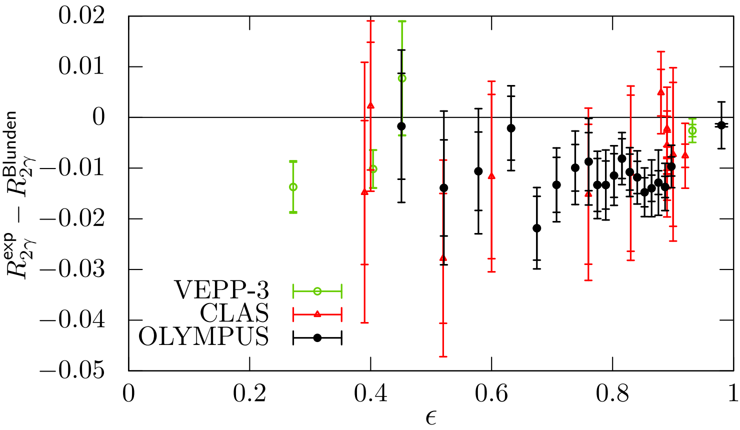


OLYMPUS Results



Henderson et al., PRL 118 092501 (2017)

The three experiments are consistent and slightly below Blunden.



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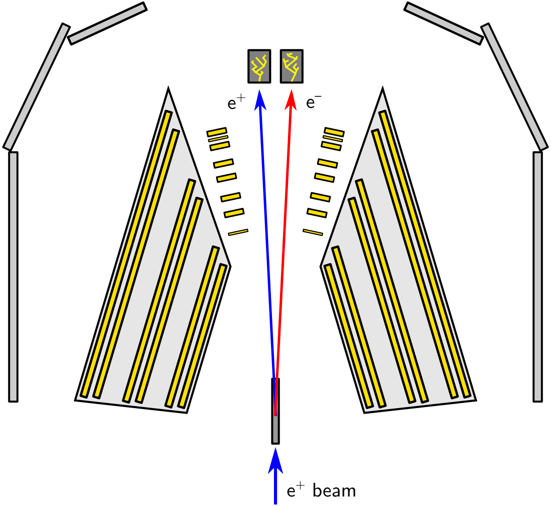
Forward calorimeters were designed to monitor the symmetric Møller/Bhabha rate.



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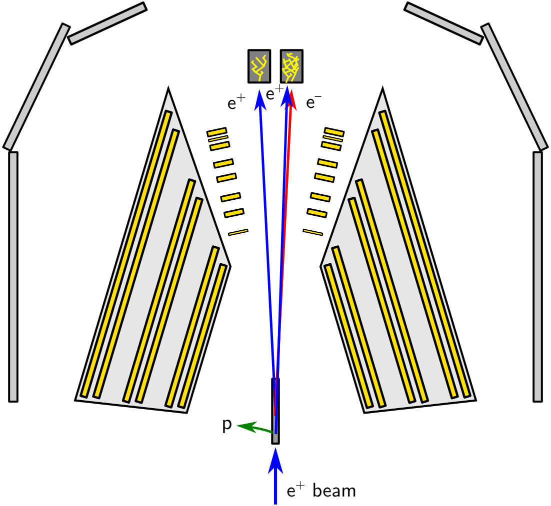
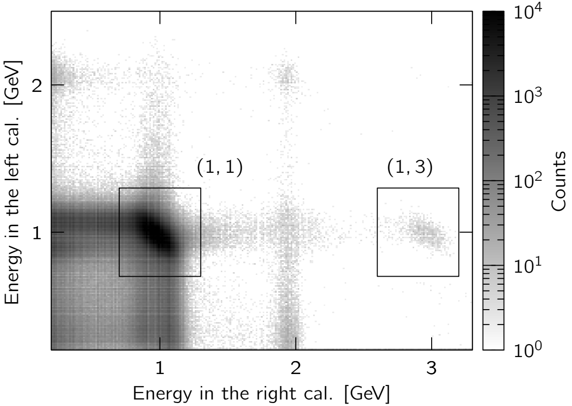


The luminosity normalization method in OLYMPUS was highly robust.

$$\mathcal{L} = \frac{N_{\text{multi}} \times N_{\text{bunches}}}{N_{\text{Møller}} \times \sigma_{ep}} + \ldots \text{corrections}$$



Method is immune to:

- Simulation error
- Inefficiency
- Beam alignment

NIM A 877 p. 112 (2018)

How do the OLYMPUS results compare with the size of the discrepancy?

Assumptions about hard TPE:

- Preserves the linearity (in ϵ) of reduced cross section.
- Has negligible impact on polarization transfer measurements.
- Zero as $\epsilon \to 1$.

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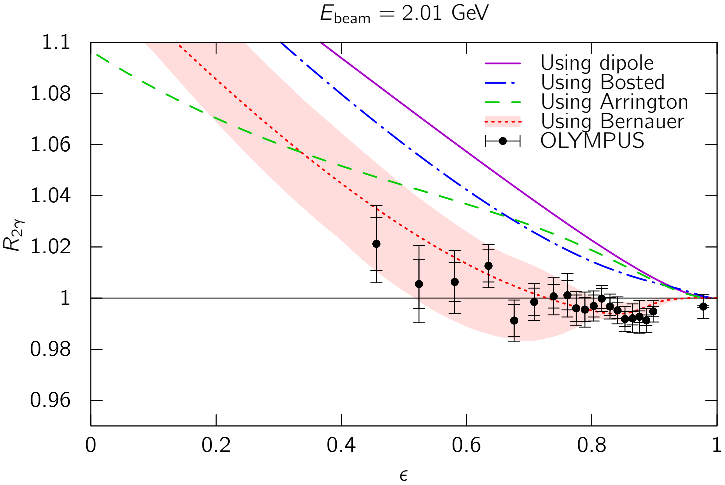
Inputs:

- Global fits to G_E and G_M (unpolarized).
- Assume true $\mu G_E/G_M = 1 - 0.12Q^2$ (polarized)

OLYMPUS data match the size of the discrepancy, assuming Bernauer FFs.



A. Schmidt, J. Phys. G 47 055109 (2020)

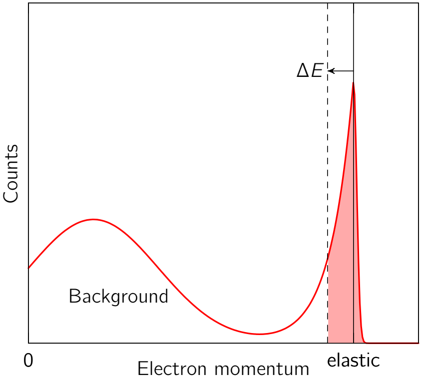
In my talk today:

- Review of the OLYMPUS Results
- **Radiative Corrections in OLYMPUS**
- New Charge-Averaged Cross Section Analysis

The "standard" approach to radiative corrections:

$$\frac{d\sigma}{d\Omega}_{\text{meas.}} = \frac{d\sigma}{d\Omega}_{\text{Born}} \times [1 + \delta(\Delta E)]$$

- Inclusive measurement
  - Soft bremsstrahlung defined by e^- ΔE
- Good resolution
  - Small ΔE, set by detector resolution



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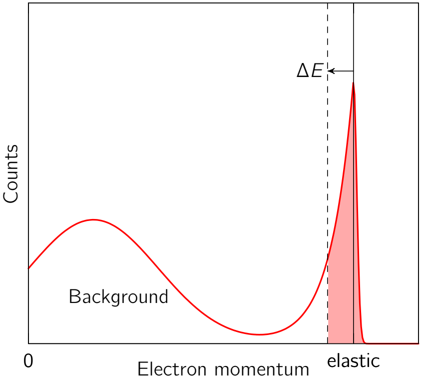
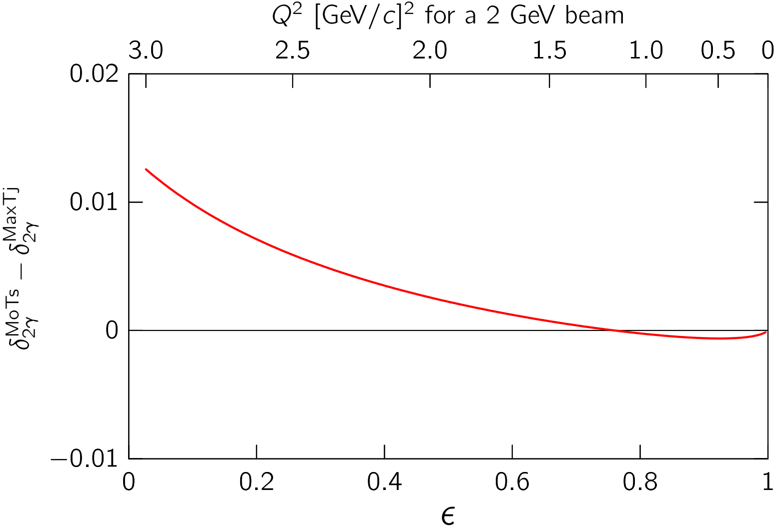


Mo-Tsai and Maximon-Tjon prescriptions have different definitions of soft TPE.



OLYMPUS had special RC needs.

- Coincidence Measurement
  - Soft bremsstrahlung defined by non-trivial exclusivity cuts on *both* $e^{\pm}$ and p.
- Not-so-great momentum resolution
  - Deep-tail contributions
  - Soft-photon approximations are bad!

$\longrightarrow$ Adopt peaking-approx. MC approach like that developed for NE18

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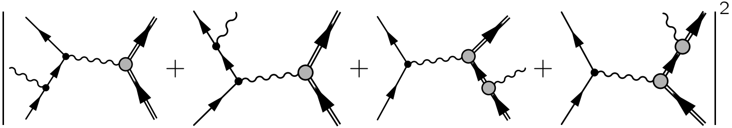
$\longrightarrow$ Adopt peaking-approx. MC approach like that developed for NE18

- Bremsstrahlung interference is a charge-odd correction!
  - Peaking approximations that fail to treat interferences are bad!

$\longrightarrow$ write a custom MC event 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



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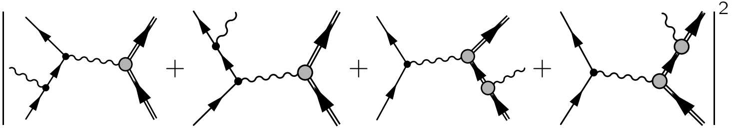


2. Exponentiated approach
   - Based on prev. work by J. M. Friedrich, J. C. Bernauer at Mainz A1

Exponentiated Approach

Assumptions:

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

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

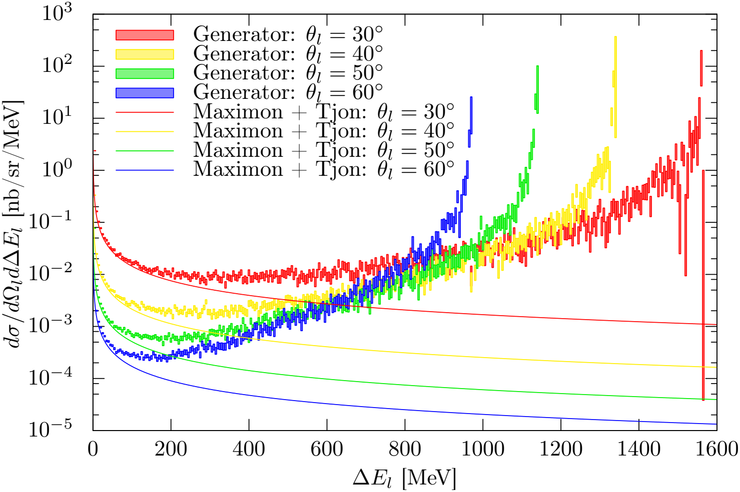
- The differential part of δ is well-approximated

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

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

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

Exponentiated approach matches standard correction at low E_γ.



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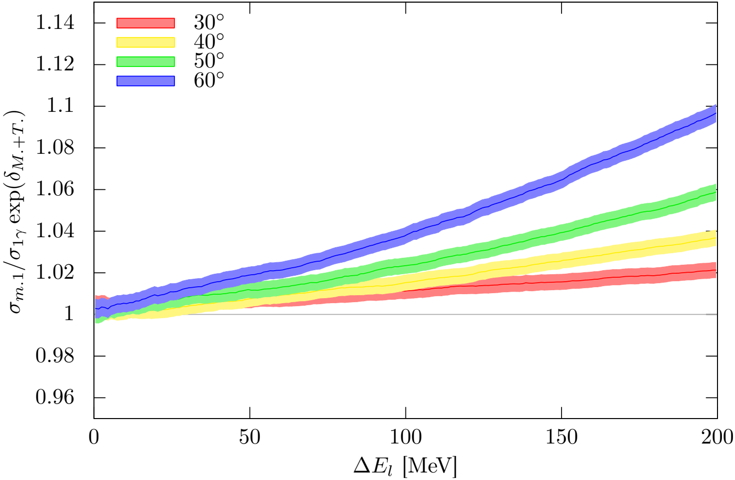
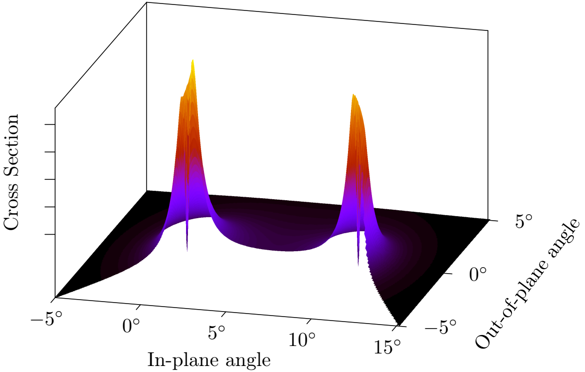


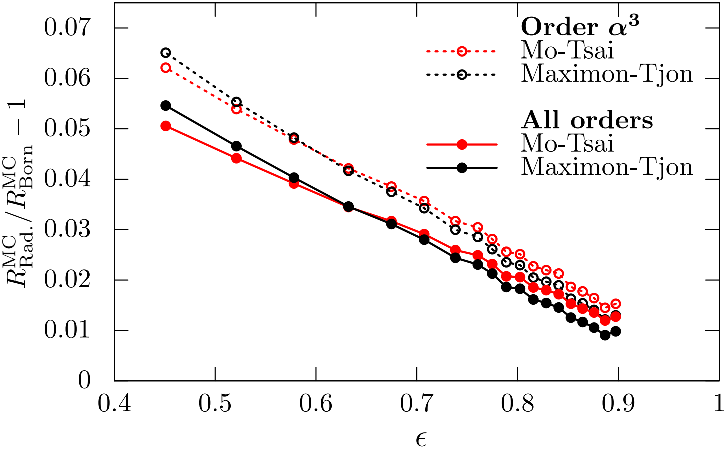
Sampling kinematics in MC generator is non-trivial.

See:

- A. Schmidt thesis, chapter 5 (arXiv:1711.09894)
- J. C. Bernauer thesis, section 5.2



The OLYMPUS radiative correction is significantly larger than the hard TPE effect.



What can be improved

- I need to document and publish.
- Use off-shell proton currents for calculating diagrams
- Add models of hard TPE

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- Radiative Corrections in OLYMPUS
- **New Charge-Averaged Cross Section Analysis**

In progress: charge-averaged cross sections

Effects of hard TPE cancel!

$$\left\langle \frac{d\sigma}{d\Omega} \right\rangle \equiv \frac{1}{2}\left[\frac{d\sigma}{d\Omega}_{e^+p} + \frac{d\sigma}{d\Omega}_{e^-p} \right]$$

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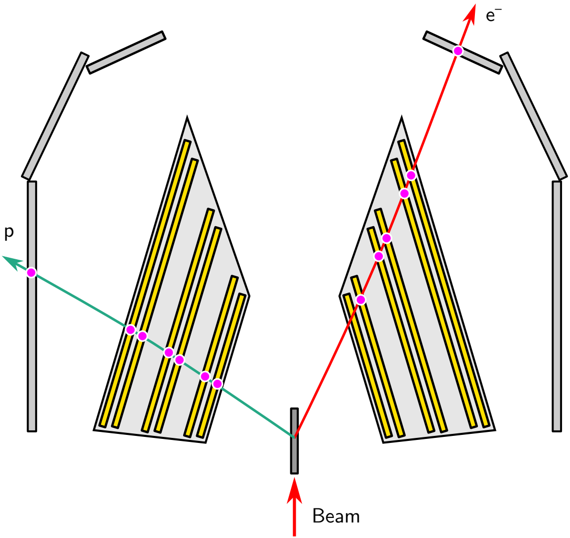
Challenges:

- Absolute efficiency
- Absolute track reconstruction efficiency
- Absolute luminosity

Absolute efficiency was studied by tracking while ignoring tracking planes.



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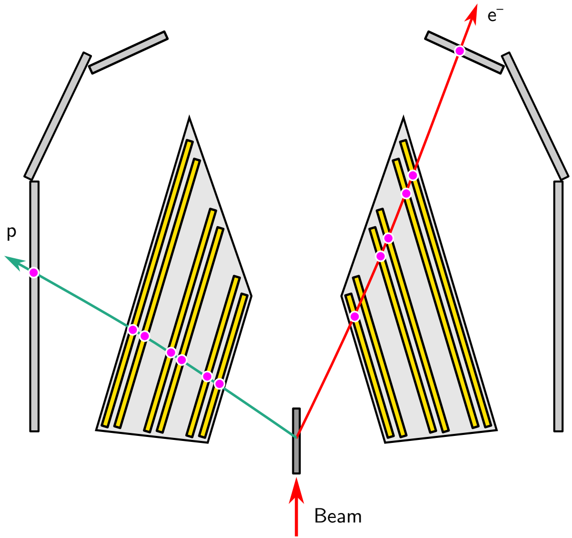

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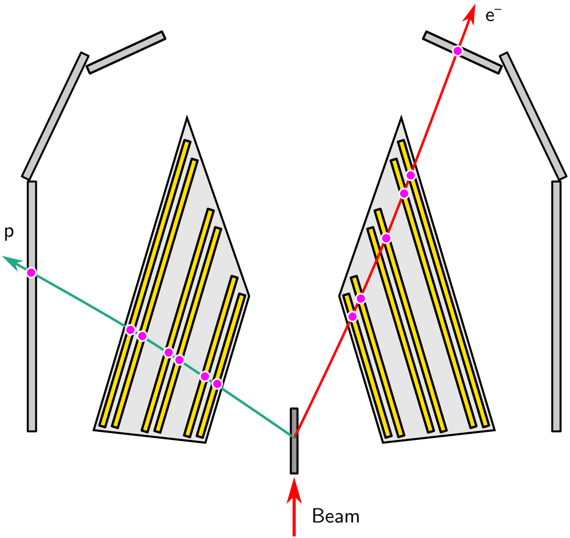

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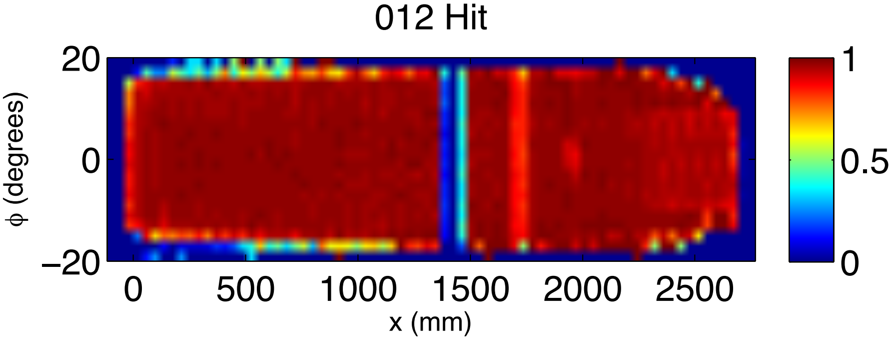
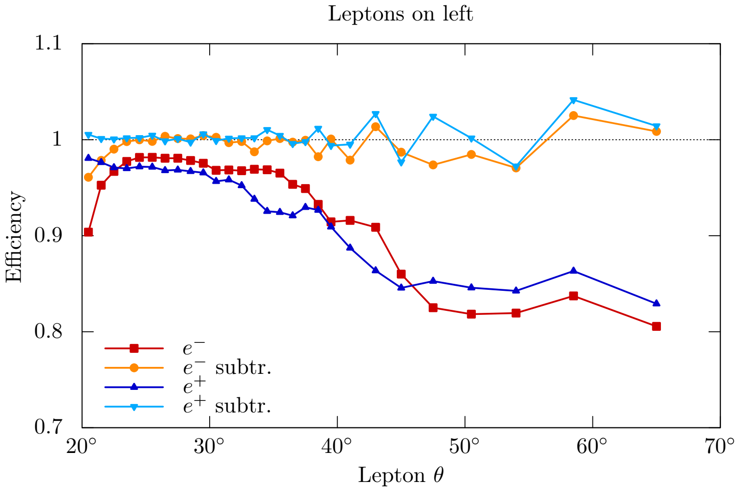


Brian Henderson Thesis (2016)

Track reconstruction was studied using single-arm event selection.



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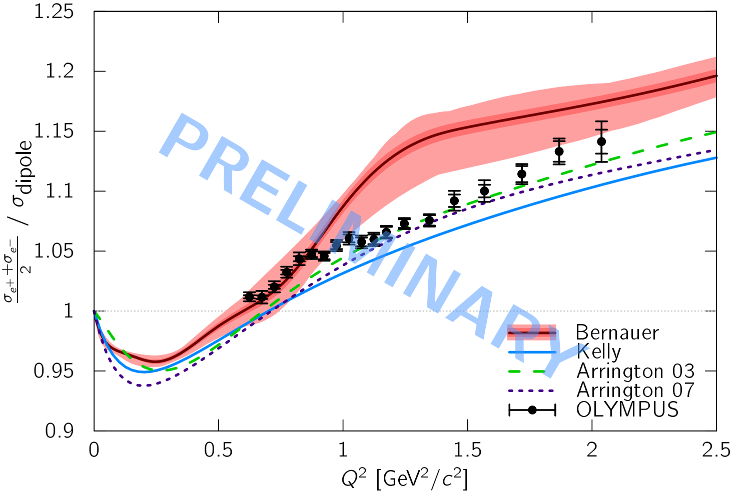
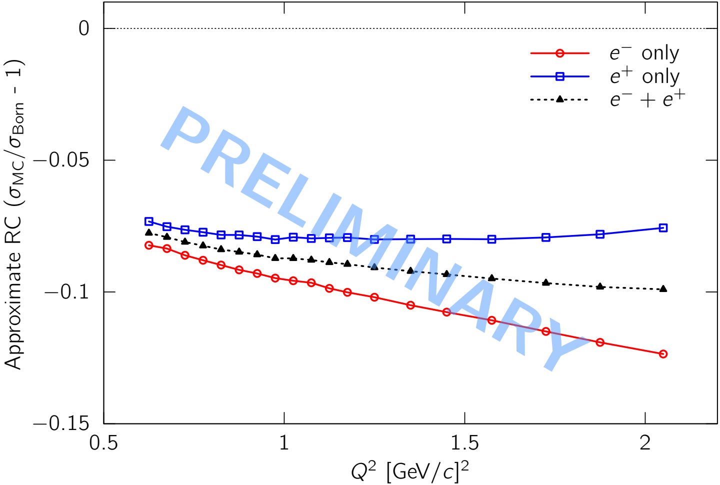
3. Multi-interaction effects in forward calorimeters
   - Extremeley sensitive to beam position, alignment
   - Effect can be estimated: 7% normalization uncertainty

Charge-averaged cross section



The charge-odd radiative correction is a significant fraction of the total.



To Recap:

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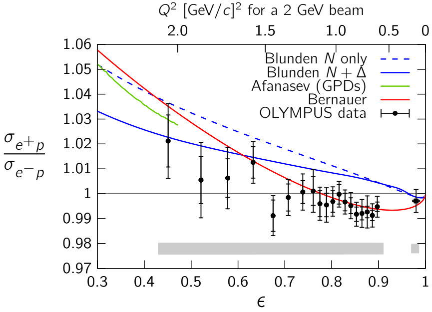

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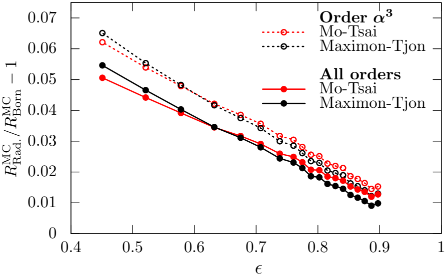

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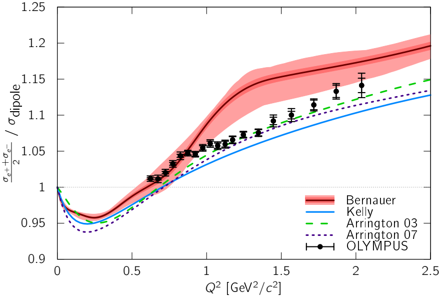
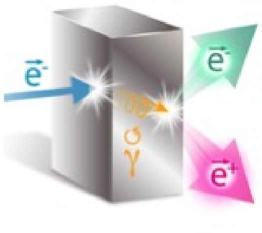


Hoping for interesting new data!

MUSE

TPEX @DESY



Positron Working Group at Jefferson Lab