OLYMPUS

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June 29, 2016

The OLYMPUS Experiment

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Elastic scattering cross section ratio:

$$\frac{e^+p \longrightarrow e^+p}{e^-p \longrightarrow e^-p}$$

The important points:

1. Motivation:
   - Why the discrepancy calls for a measurement of $\sigma_{e^+p}/\sigma_{e^-p}$
2. Experiment:
   - The advantages OLYMPUS has in making this measurement
3. Analysis:
   - How to guarantee an accurate result

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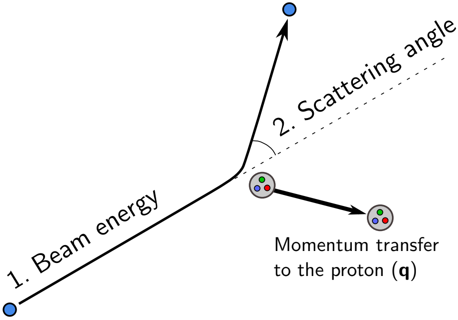
Elastic scattering kinematics are fixed by two parameters.

Experiment



Theory

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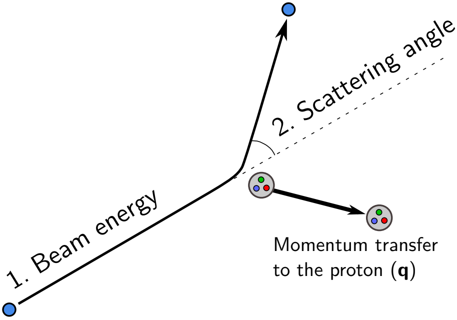

Theory

1. $Q^2 = -q_\mu q^\mu$

2. $\epsilon = \left[1 + 2\left(1 + \frac{Q^2}{4m_p^2}\right)\tan^2\frac{\theta}{2}\right]^{-1}$

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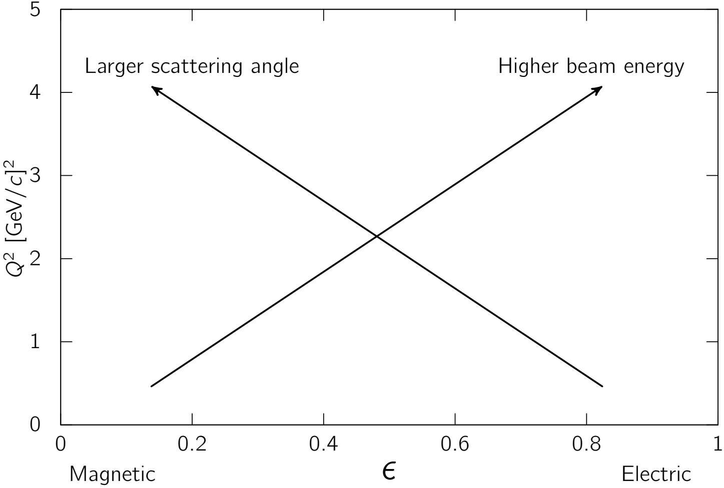

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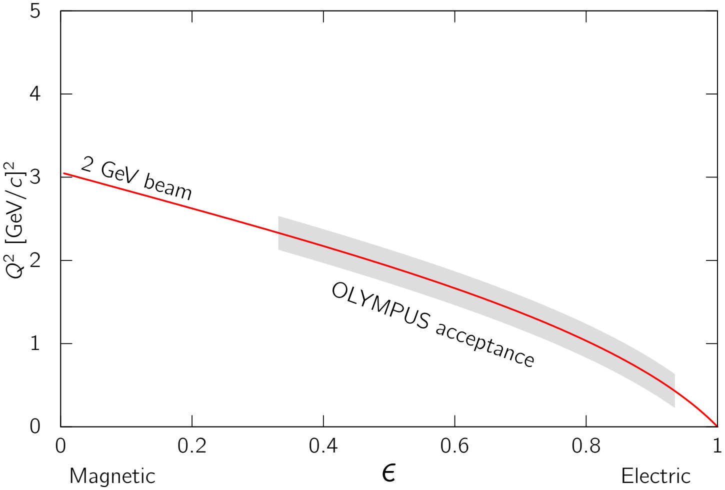
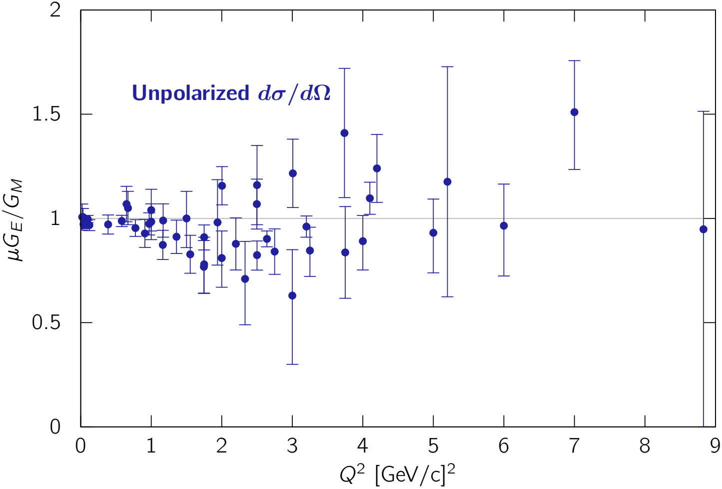


The two form factor extraction methods disagree.



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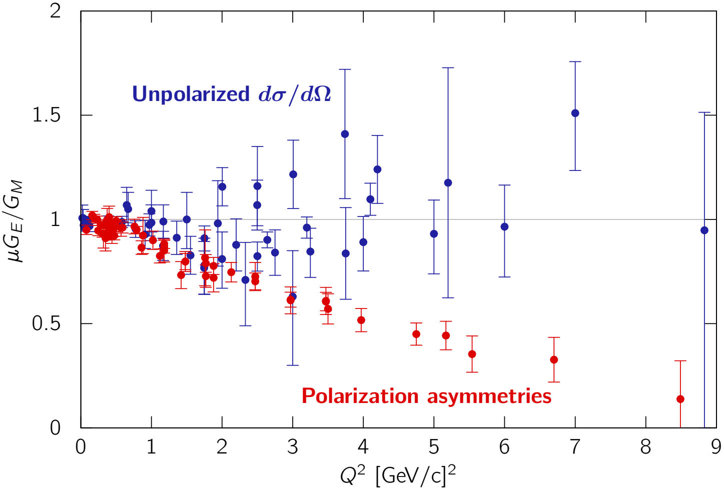
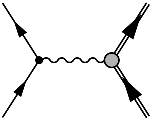
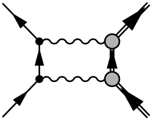


$\sigma_{e^+p}/\sigma_{e^-p}$ is sensitive to two-photon exchange.

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

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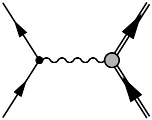
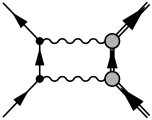
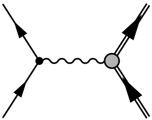
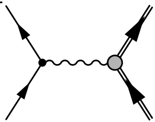
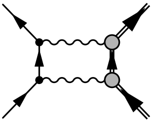
$\mathcal{M} =$  $+$  $+ \mathcal{O}(\alpha^3)$

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

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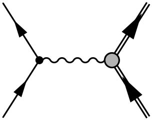
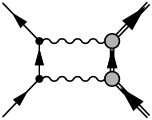
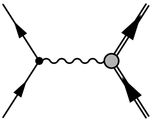
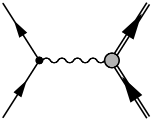
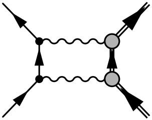
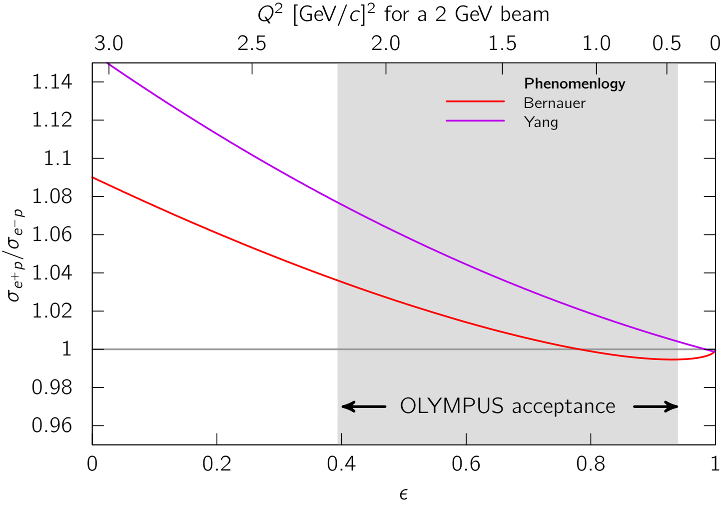
$\mathcal{M} =$  $+$  $+ \mathcal{O}(\alpha^3)$

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

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

A few percent effect is large enough to resolve the discrepancy.



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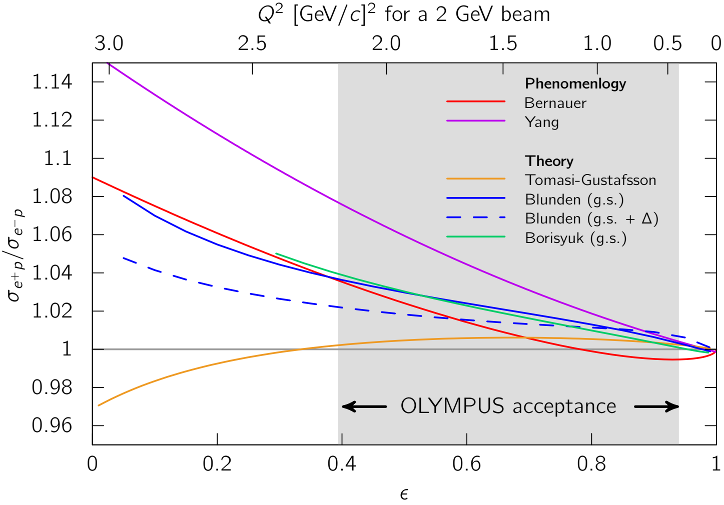

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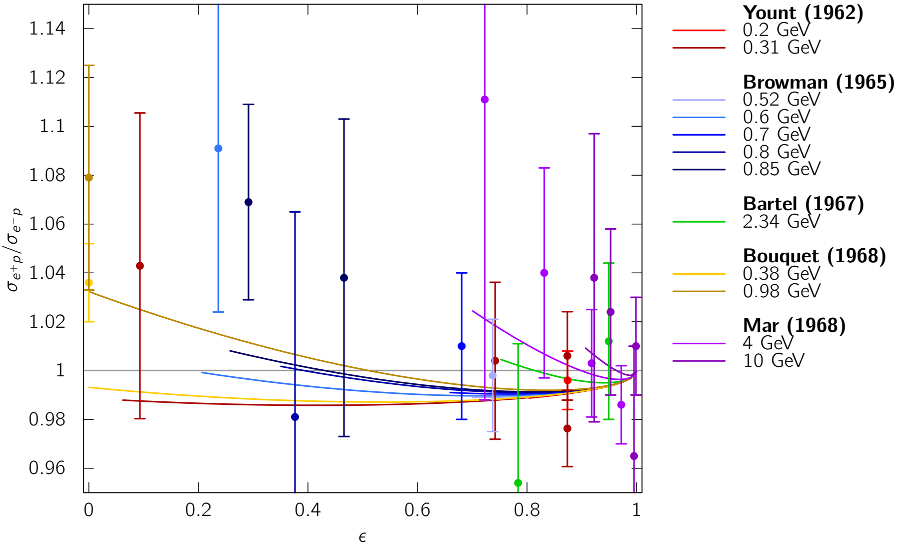

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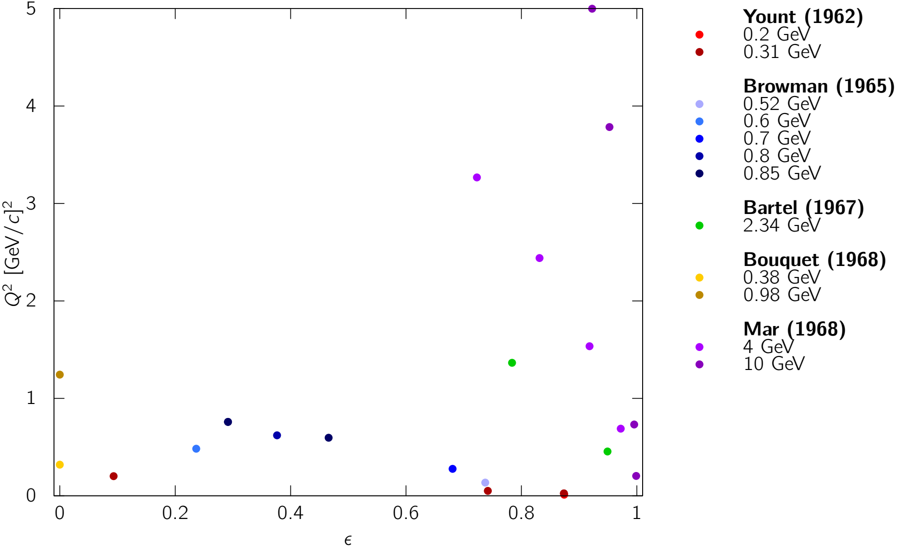

Three new experiments have taken data in the last few years.

OLYMPUS

CLAS **VEPP-3**

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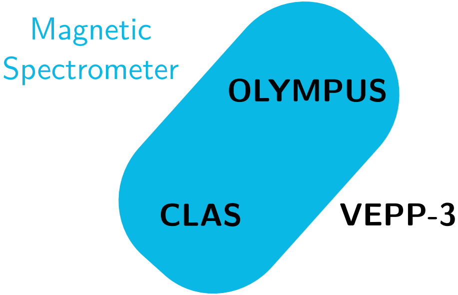

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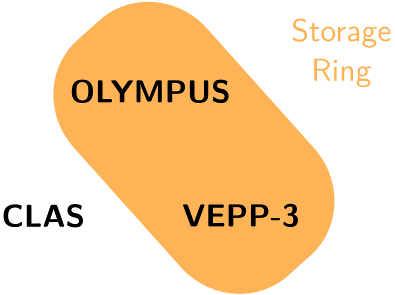
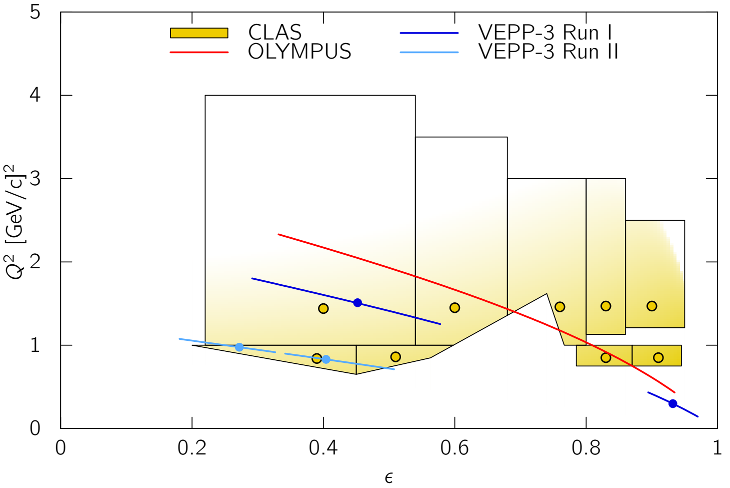


All three probe the relevant, low ϵ, high Q^2 phase space.



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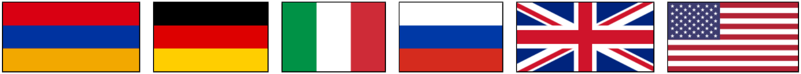
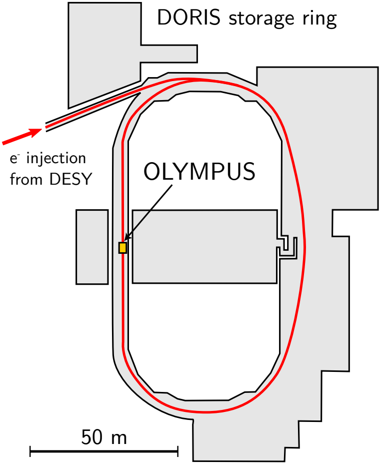
The OLYMPUS Experiment



- 60 scientists from 13 institutions in 6 countries
- Detector previously used in the BLAST experiment at MIT
- Collected data at DESY, Hamburg, Germany

Advantage I: High luminosity



- Alternate $e^- \leftrightarrow e^+$ daily

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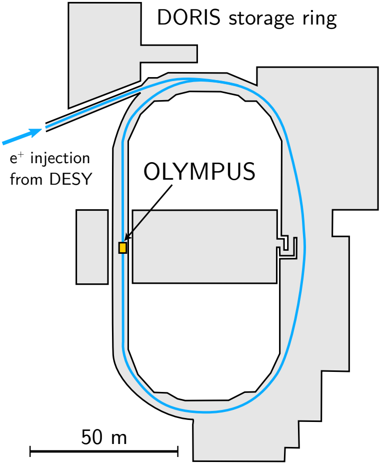

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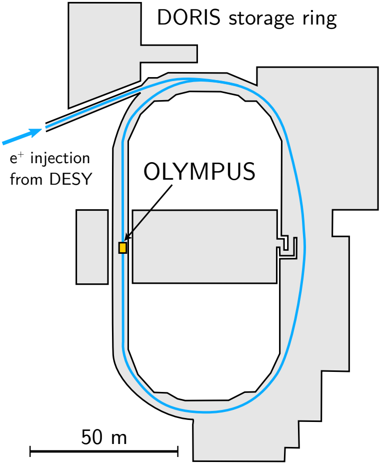

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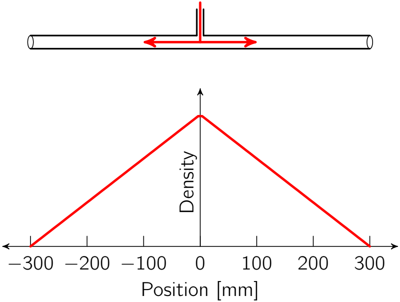

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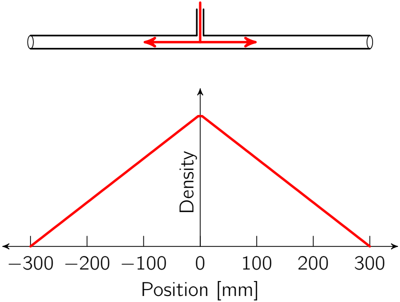

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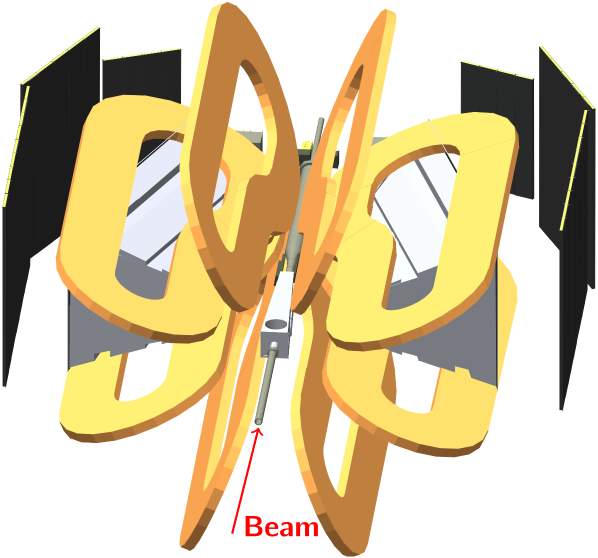
- Typical current: 50–70 mA
- Windowless hydrogen target
- $2 \times 10^{33} \mathrm{cm}^{-2}\mathrm{s}^{-1}$
  - Over 4 fb^{-1} recorded!

Advantage II: large acceptance spectrometer



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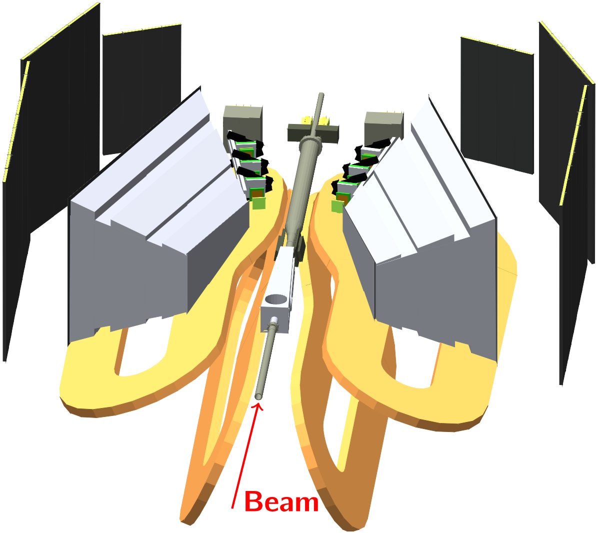

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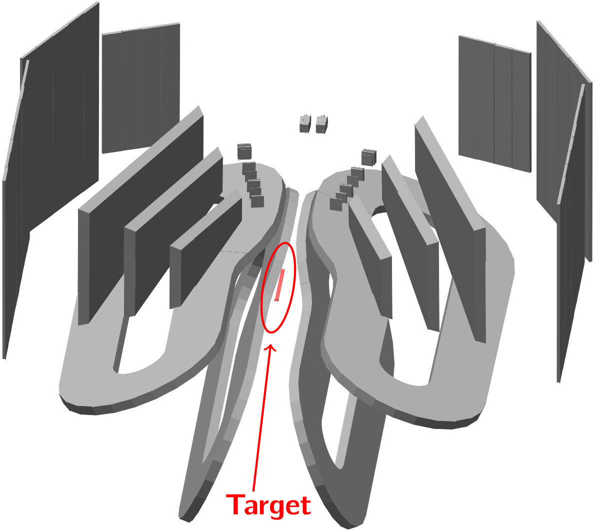

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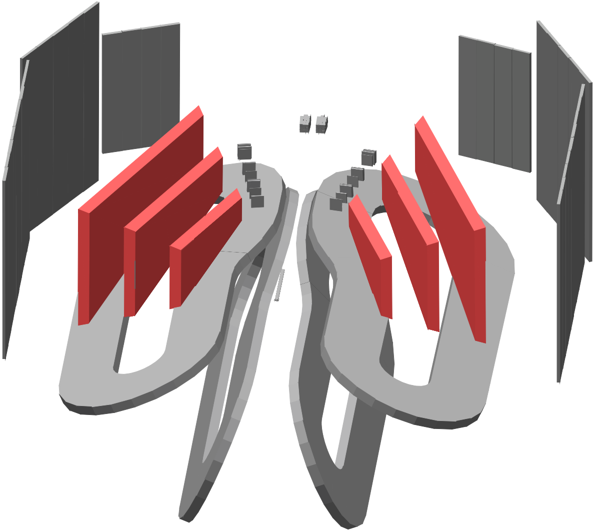

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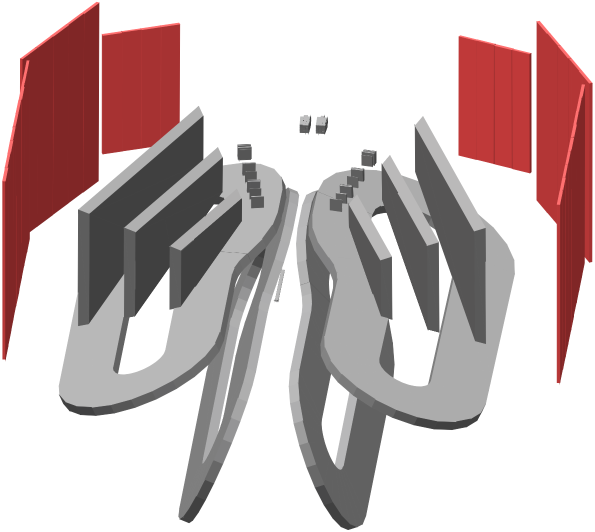

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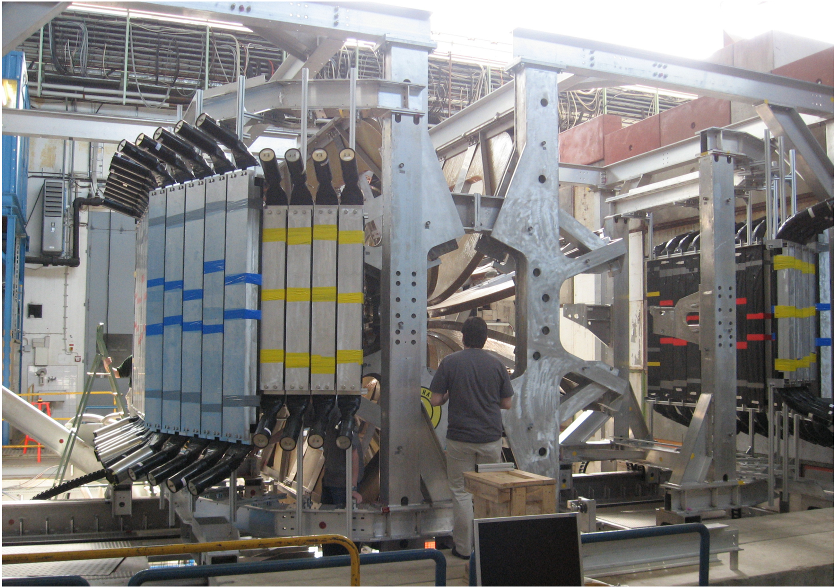

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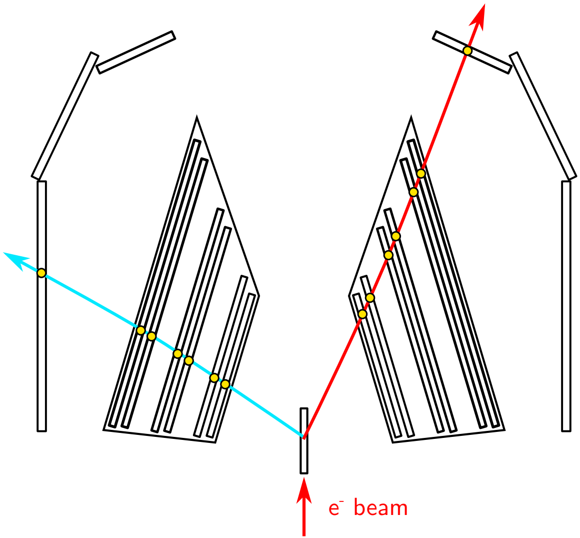

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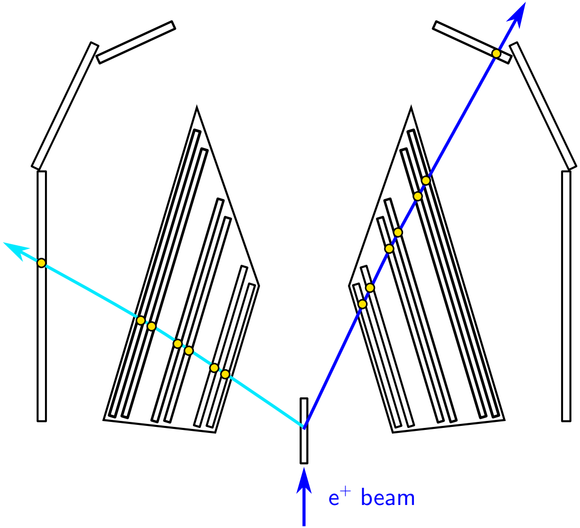

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Ways to determine the relative luminosity between e^+ and e^- running:

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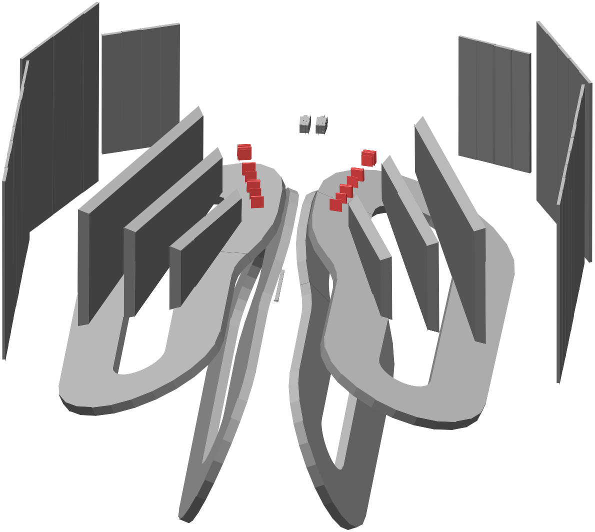
Forward telescopes monitor the elastic *ep* rate.



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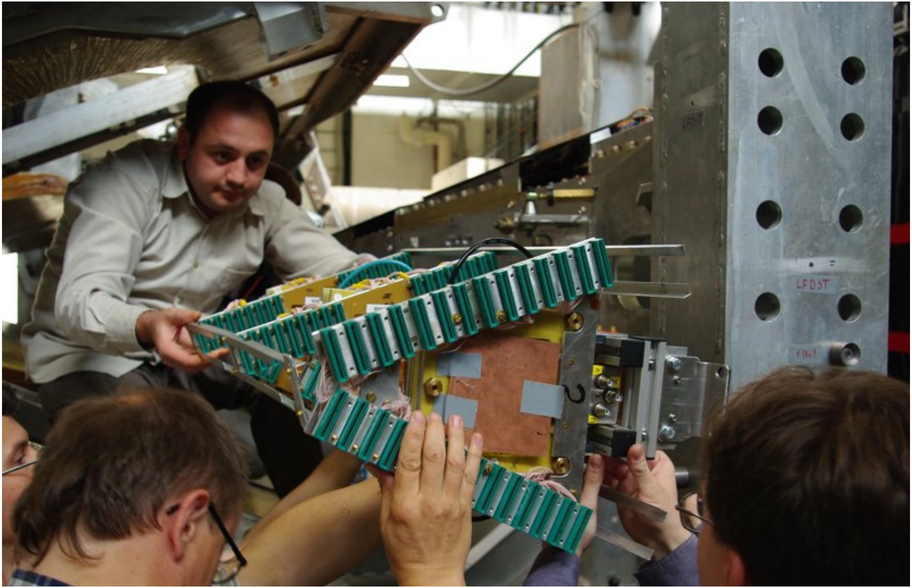

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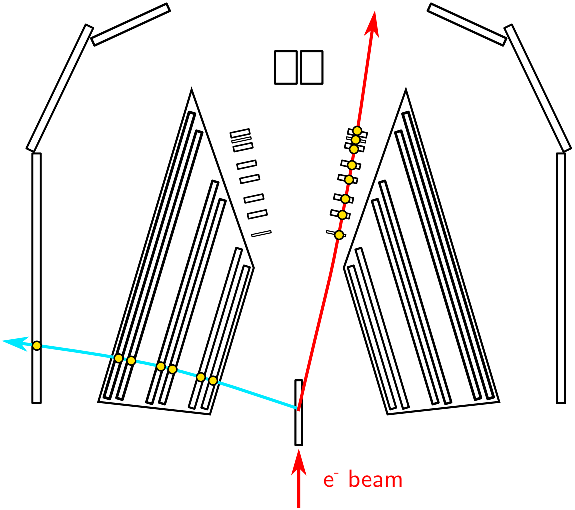

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Ways to determine the relative luminosity between e^+ and e^- running:

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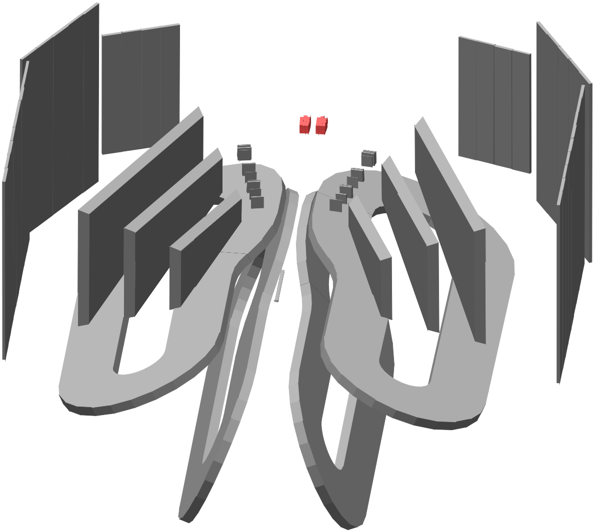
2. Forward tracking telescopes
3. Symmetric Møller/Bhabha Calorimeters

Calorimeters monitor the elastic *ee* rate.



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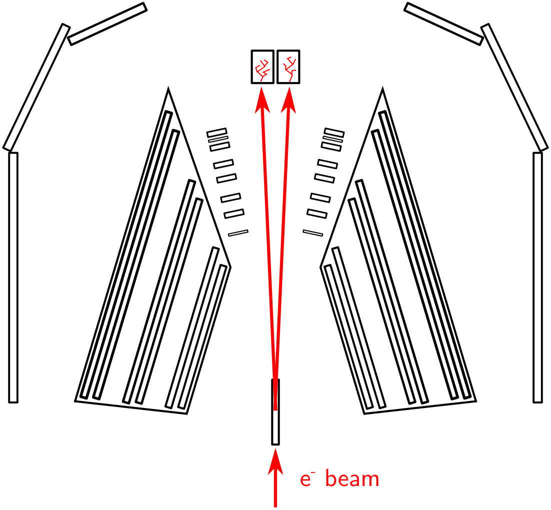
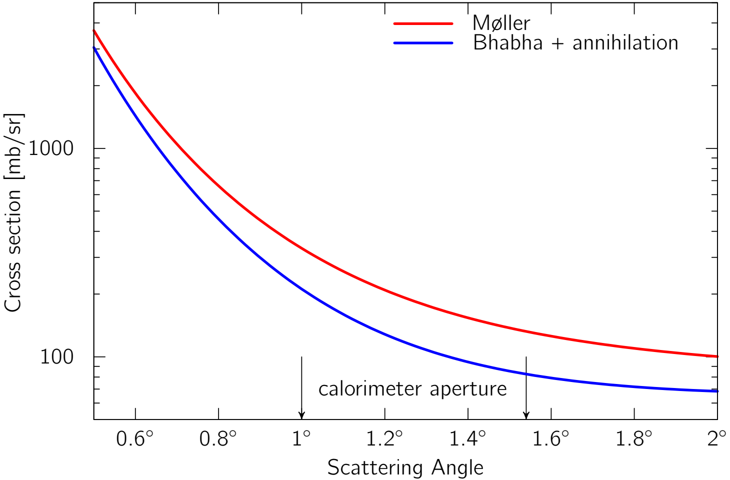
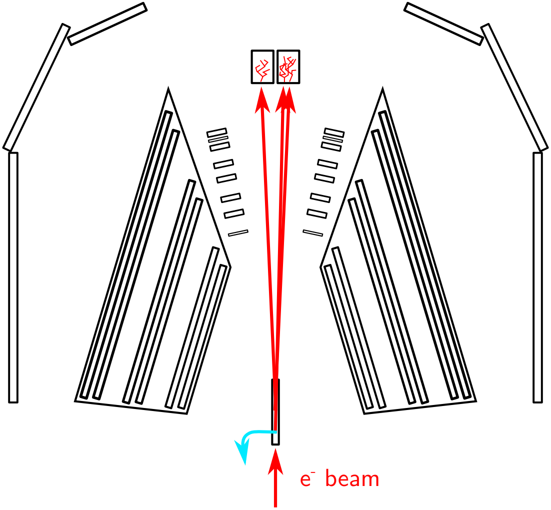


The Møller cross section is 60% larger than the Bhabha cross section.



A better method: multi-interaction events



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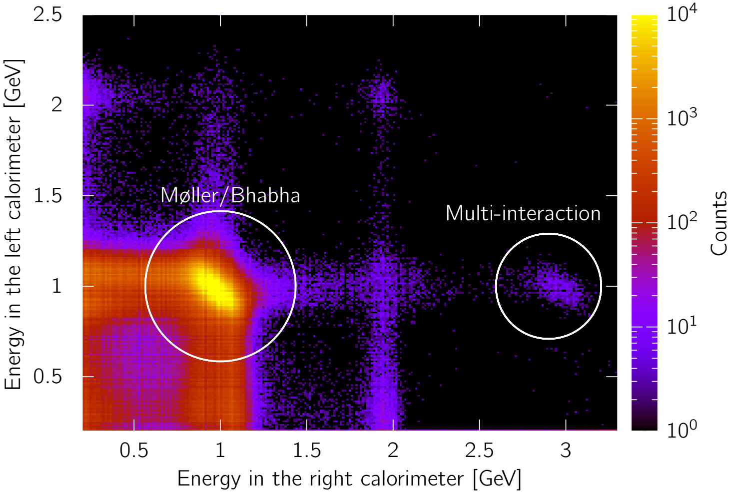

A better method: multi-interaction events

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

This is immune to:

- Møller/Bhabha simulation errors
- Detector/DAQ inefficiency
- Beam position errors

Accuracy better than 0.3%!

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Differences between e^- and e^+ running:

- Lepton curvature direction
  - Acceptance (as a function of angle)
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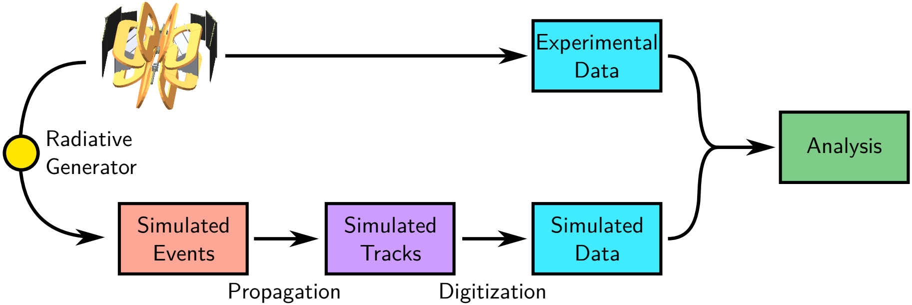
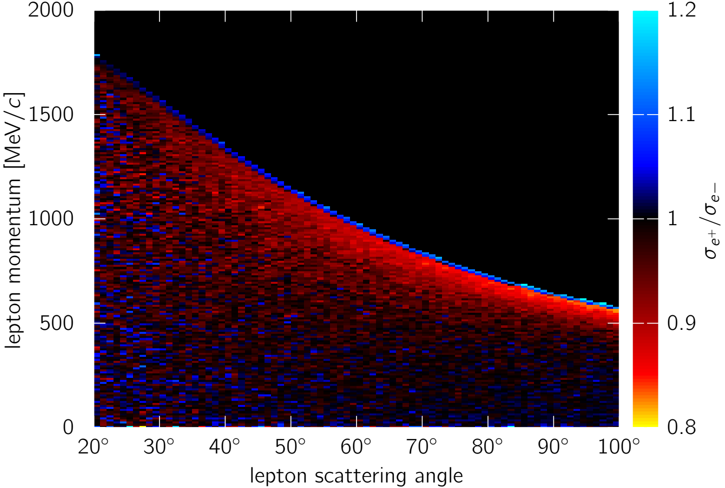
Simulate with Monte Carlo!

Experimental data and simulated data are analyzed with the same software.

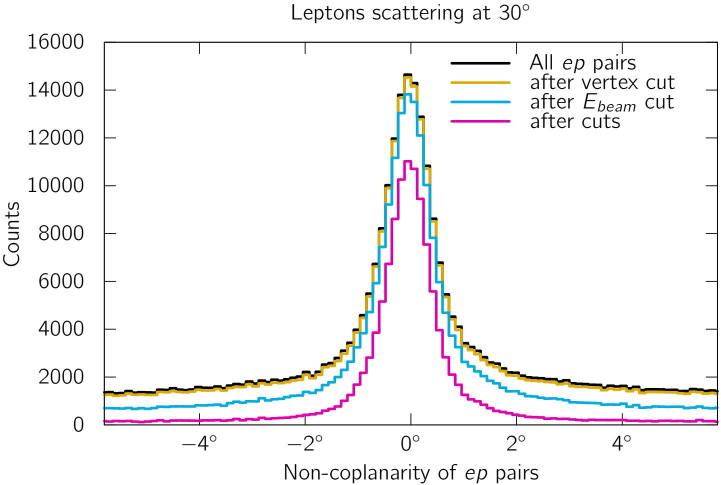


$$R_{2\gamma} = \frac{N^{exp.}_{e^+p}}{\sigma^{sim.}_{e^+p}\mathcal{L}_{e^+p}} \times \frac{\sigma^{sim.}_{e^-p}\mathcal{L}_{e^-p}}{N^{exp.}_{e^-p}}$$

Simulating radiative corrections give us freedom in our elastic selection.



Elastic events are easy to select.



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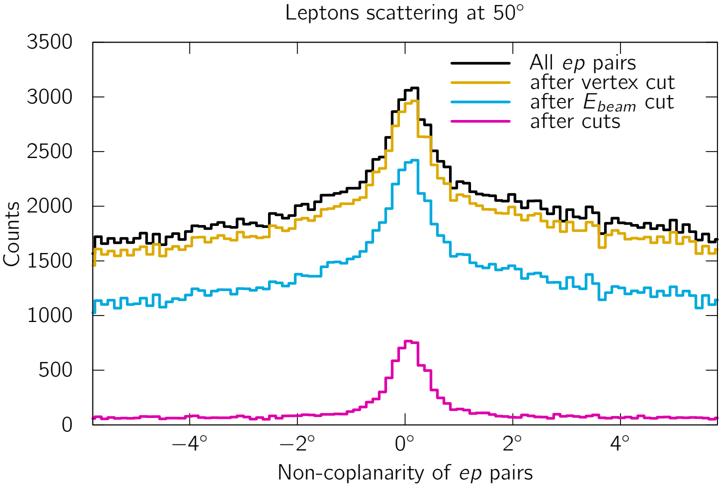
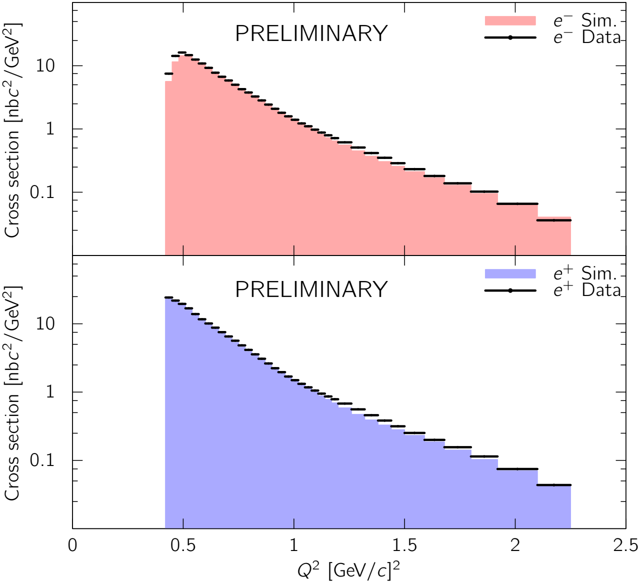


After background subtraction, we can form yields.



We can test our simulation without biasing the result.

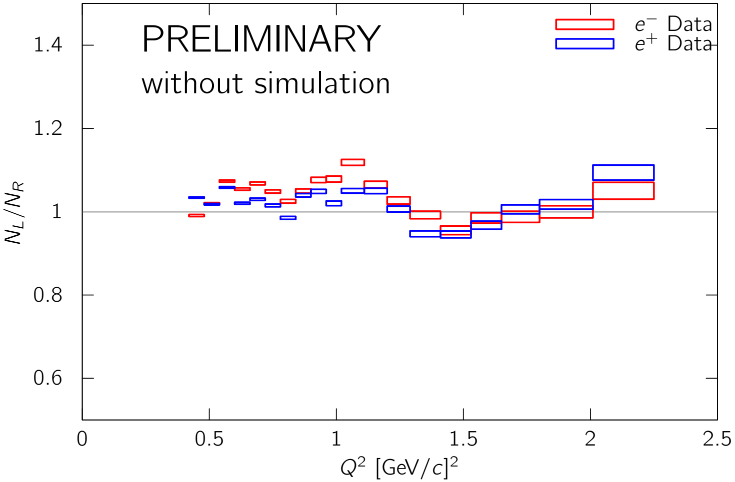
1. Left/right ratio:

$$\frac{R_L}{R_R} \equiv \left(\frac{\sigma^{exp.}}{\sigma^{sim.}} \right)_L \Big/ \left(\frac{\sigma^{exp.}}{\sigma^{sim.}} \right)_R$$

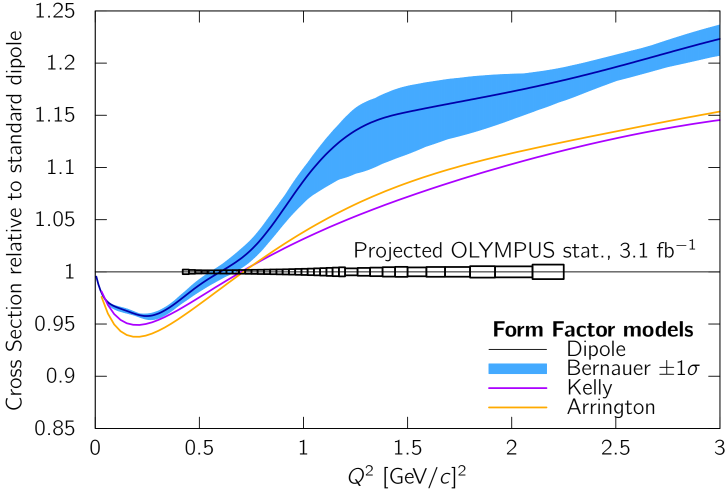
2. Lepton-averaged cross section ratio:

$$\frac{\bar{\sigma}^{exp.}}{\bar{\sigma}^{sim.}} \equiv \frac{\sigma^{exp.}_{e^+p} + \sigma^{exp.}_{e^-p}}{\sigma^{sim.}_{e^+p} + \sigma^{sim.}_{e^-p}}$$

Left/right comparisons can reveal deviations.



Lepton-averaged cross section is limited by knowedge of the form factors.



We exploit redundancy to control our systematics.

- Acceptance
  - $\longrightarrow$ Lepton-averaged cross section
  - $\longrightarrow$ Left-right ratio
- Luminosity
  - $\longrightarrow$ Two independent monitors
- Radiative corrections / form factors
  - $\longrightarrow$ Simulate multiple corrections, form factor models
- Tracking efficiency
  - $\longrightarrow$ Two independent track-reconstruction algorithms
- Event selection / background subtraction
  - $\longrightarrow$ Multiple independent analyses

Results will be released when we are confident
in all of our systematic checks.

In summary...

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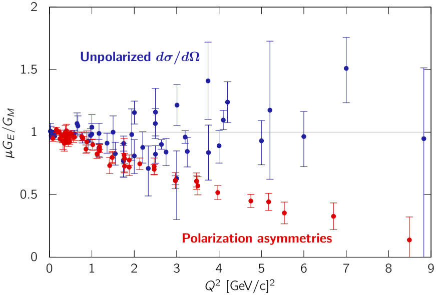

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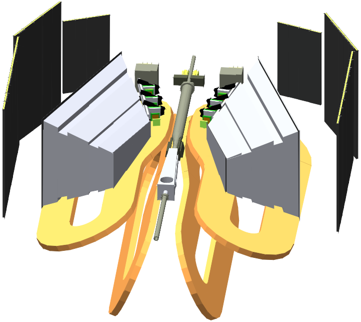
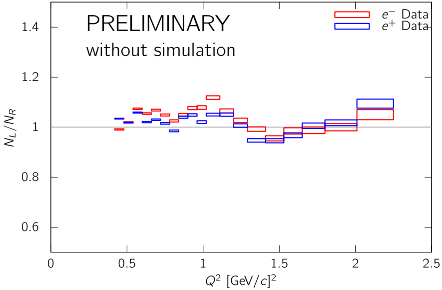
- OLYMPUS has advantages:
  - Excellent statistics
  - Large acceptance
  - Redundant luminosity monitors



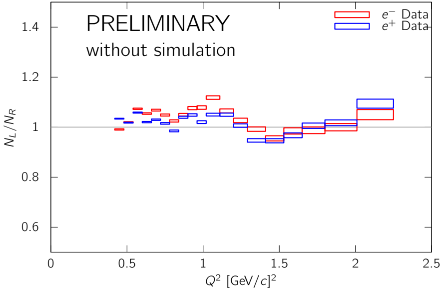
In summary...

- $\sigma_{e^+p}/\sigma_{e^-p}$ will say if two-photon exchange causes the form factor discrepancy.
- OLYMPUS has advantages:
  - Excellent statistics
  - Large acceptance
  - Redundant luminosity monitors
- Redundancy helps us guard against systematics.

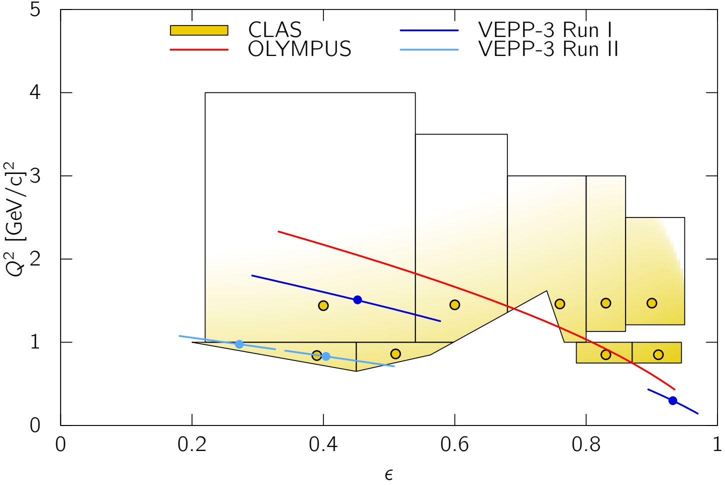


In summary...

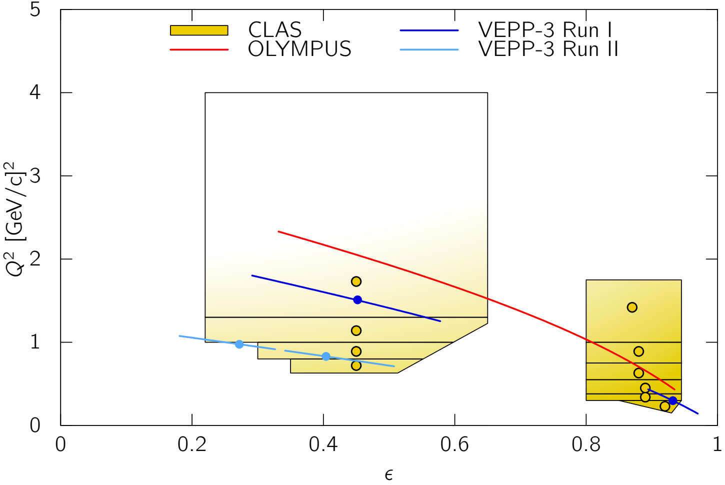
- $\sigma_{e^+p}/\sigma_{e^-p}$ will say if two-photon exchange causes the form factor discrepancy.
- OLYMPUS has advantages:
  - Excellent statistics
  - Large acceptance
  - Redundant luminosity monitors
- Redundancy helps us guard against systematics.
- Expect results soon.



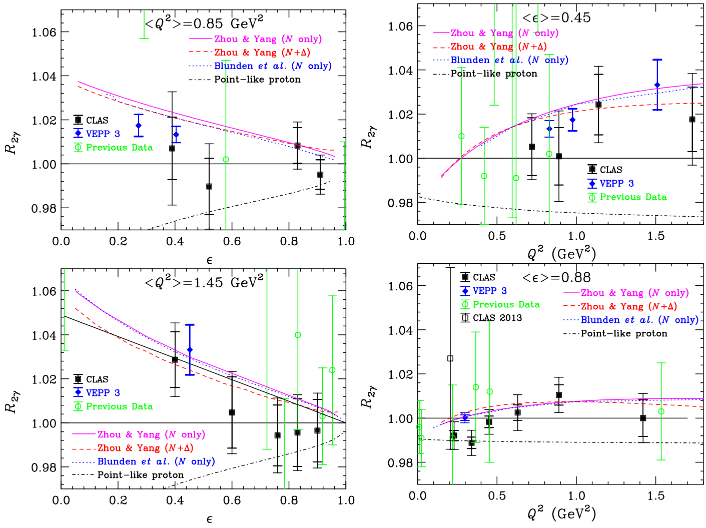
Results from VEPP-3, CLAS



Results from VEPP-3, CLAS

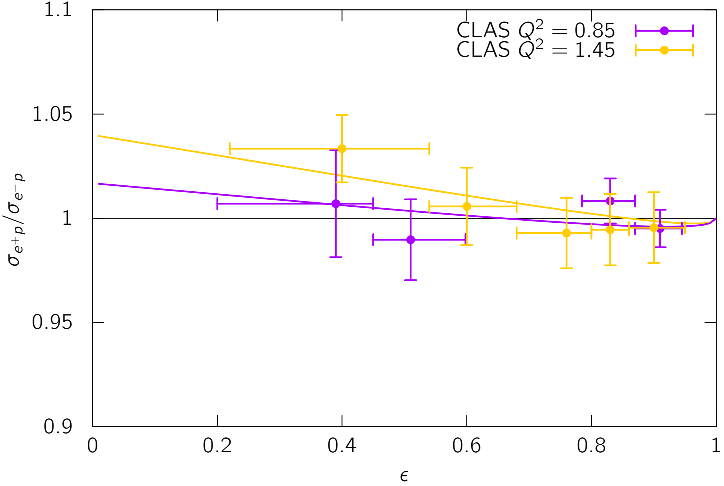


CLAS results

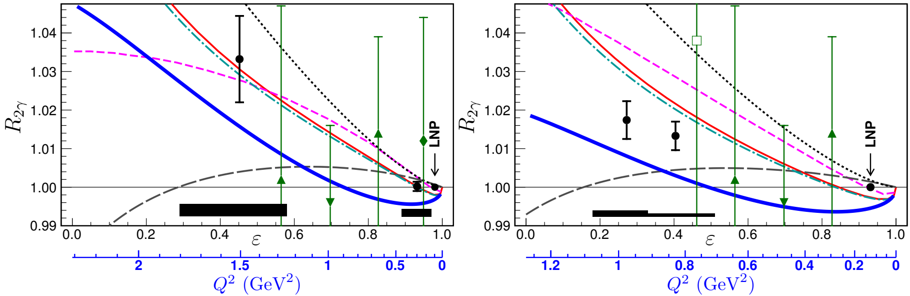


Figs. 18 and 19 from arXiv:1603.00315v1

CLAS results

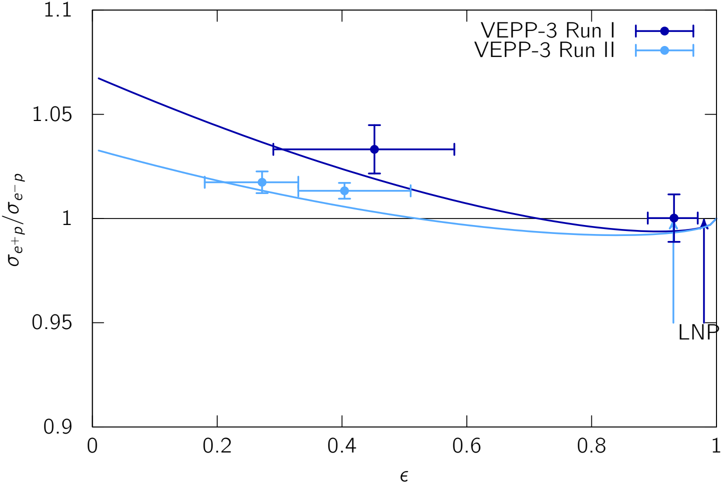


VEPP-3 results

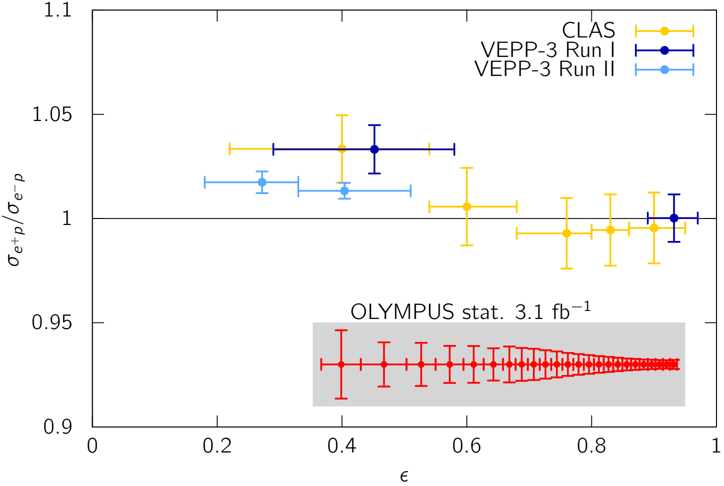


Figs. 1 and 2 from PRL **114**, 062005 (2015)

VEPP-3 results



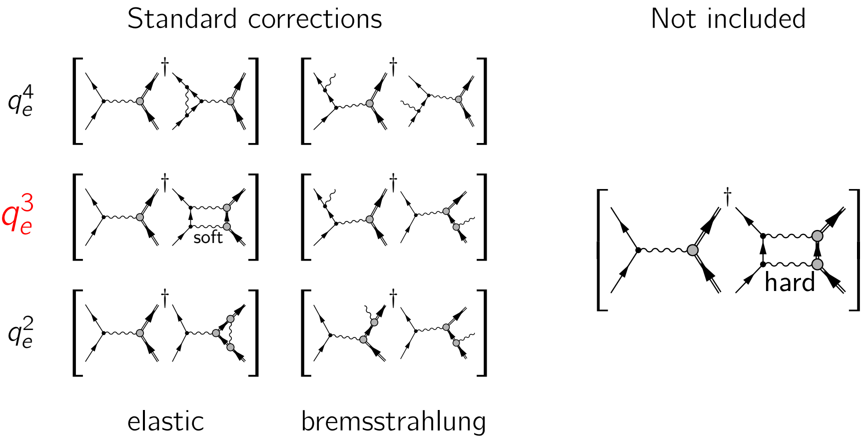
Results from CLAS and VEPP-3



Back-up Slides

OLYMPUS

Standard radiative corrections neglect hard two-photon exchange.



Multi-interaction analysis results