Results from the OLYMPUS Experiment at DESY

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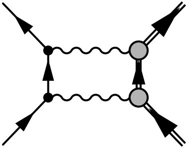
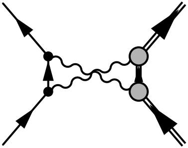
Laboratory for Nuclear Science
Massachusetts Institute of Technology

January 31, 2017

There is a discrepancy in measurements of the proton's form factors.

Possible culprit:  $+$ 

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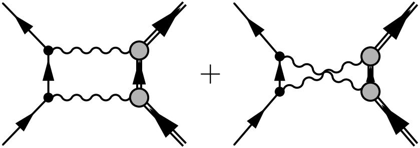
Possible culprit: 

OLYMPUS measured:

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

I will cover:

1. Form Factors
   - What can we learn from elastic scattering?
2. The discrepancy
   - Why should we measure $\sigma_{e^+p}/\sigma_{e^-p}$?
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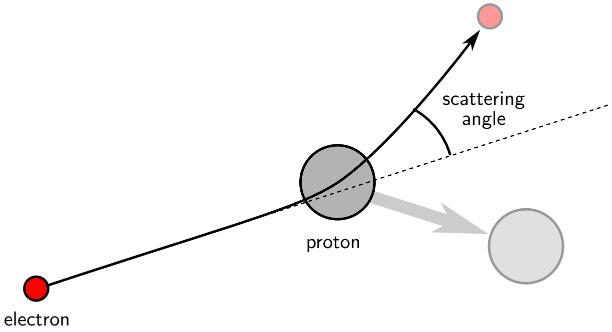
Elastic electron-proton scattering



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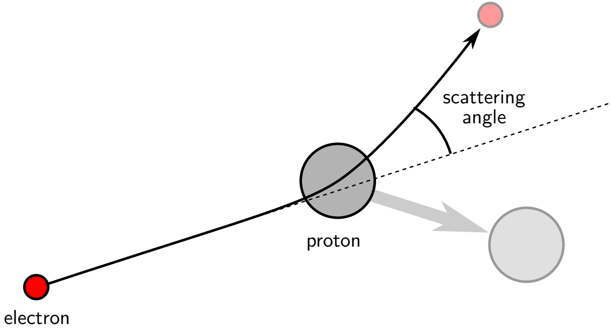

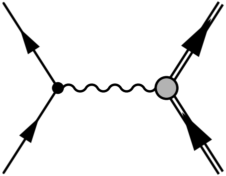

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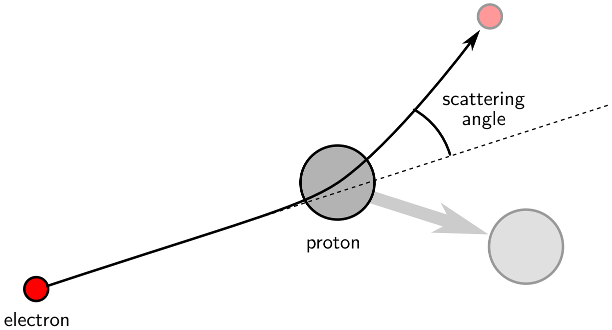
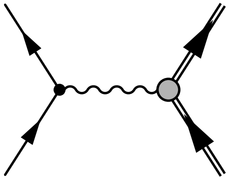
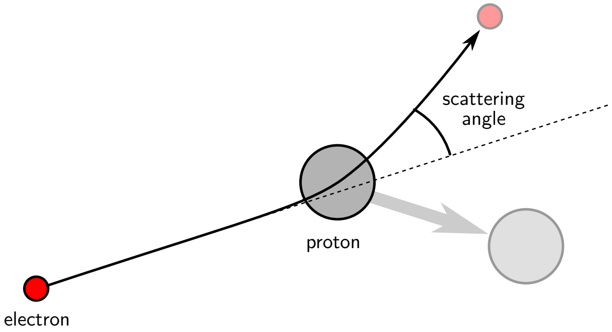


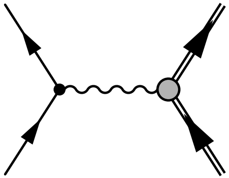


Free parameters:

1. Beam energy
2. Scattering angle

Elastic electron-proton scattering



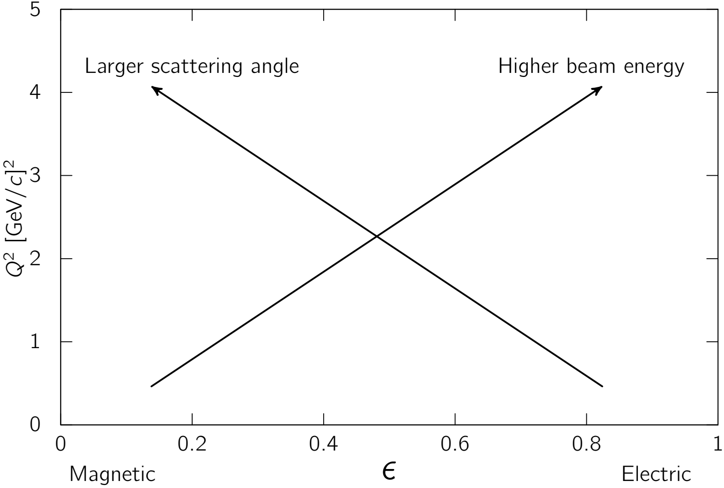


Free parameters:

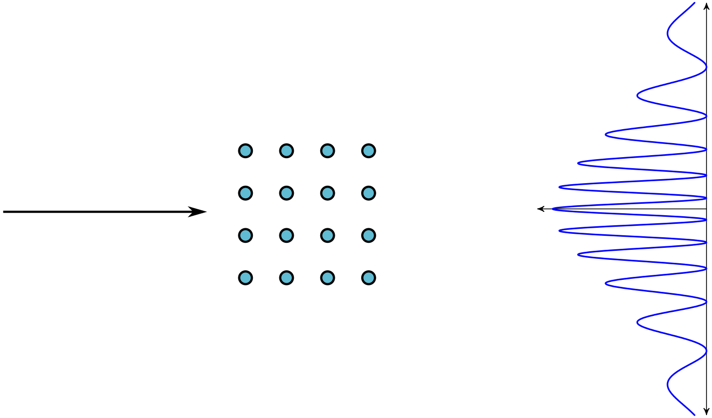
1. Beam energy
2. Scattering angle

1. Q^2: squared momentum transfer
2. ϵ: electric $\leftrightarrow$ magnetic

Elastic scattering kinematics are fixed by two parameters.



Form factors are analagous to structure factors in diffraction.



- Peak position given by $d \sin \theta = n\lambda$

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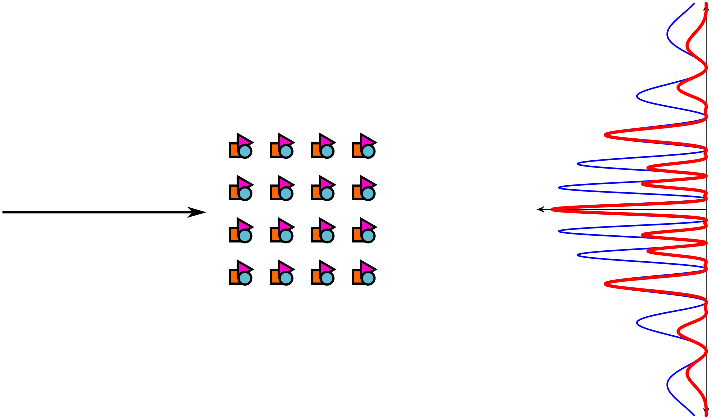

- Itensity modulated by $|f(\vec{q})^2|$

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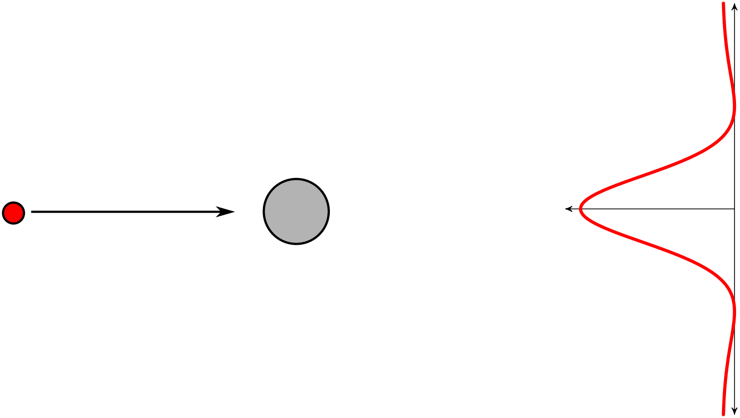
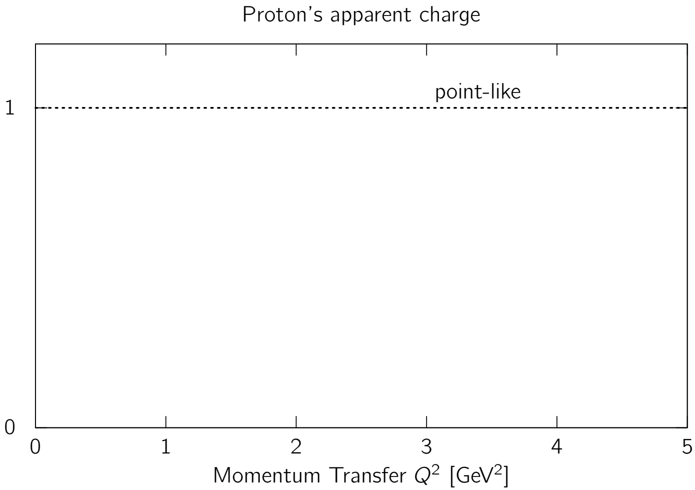


- Itensity modulated by $G_E^2(Q^2)$, $G_M^2(Q^2)$

Elastic scattering has told us about the proton's charge and magnetism.



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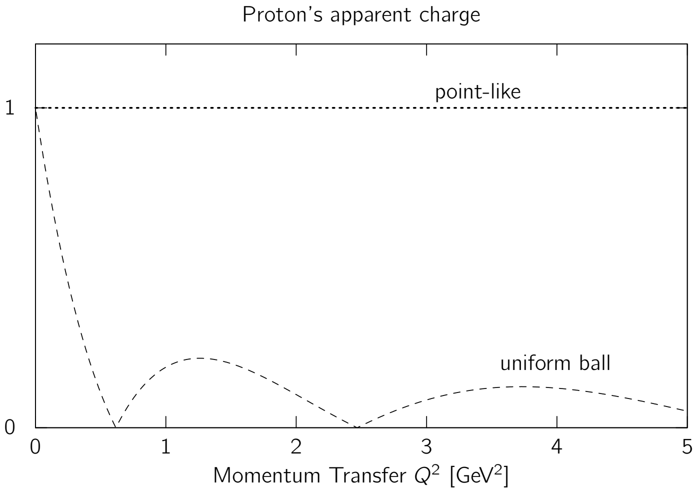

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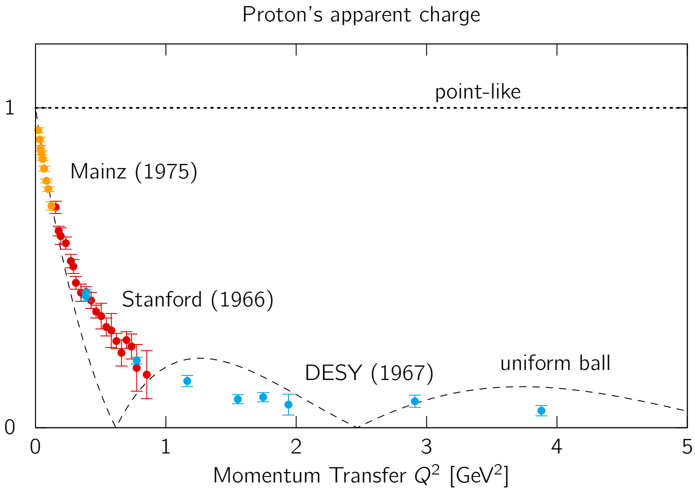

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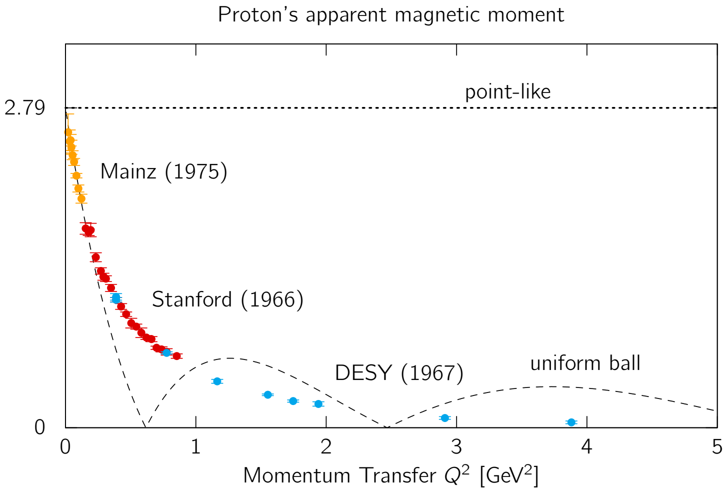
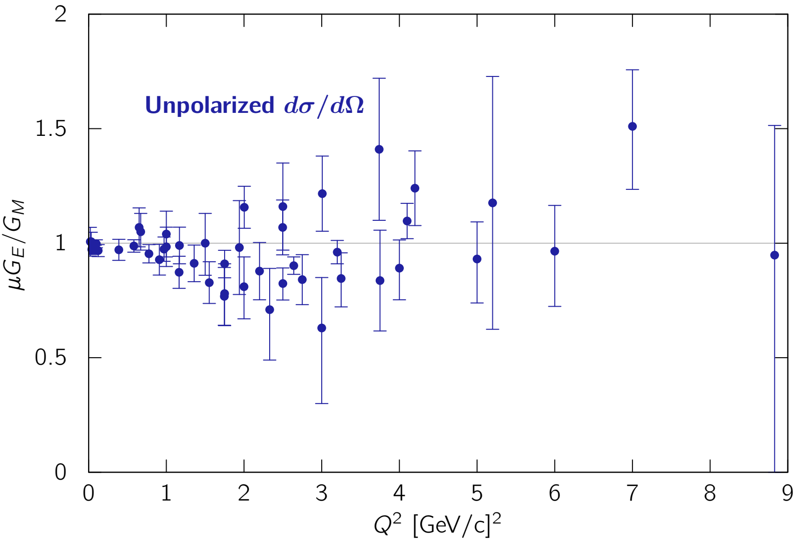


The form factor ratio is consistent with 1.



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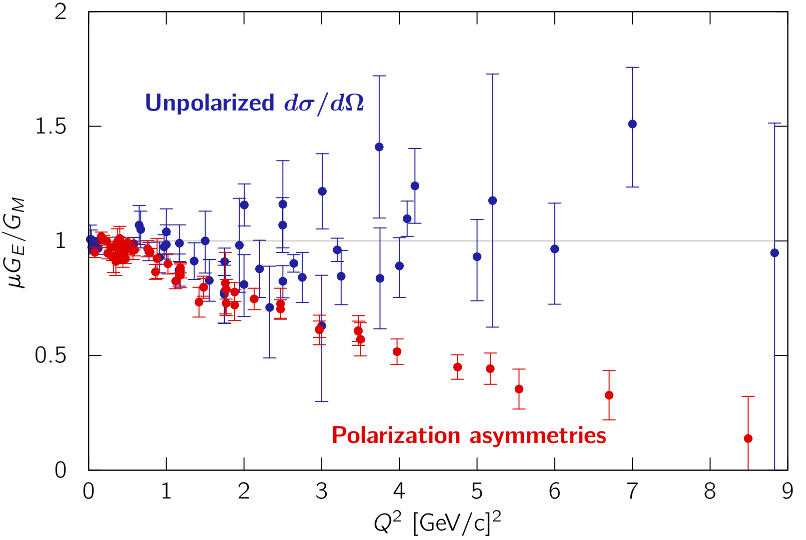
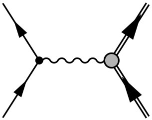
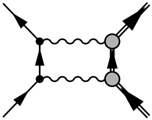
Polarized measurements do not agree.



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

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

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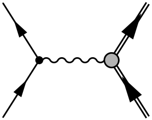
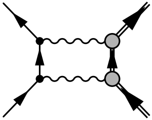
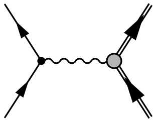
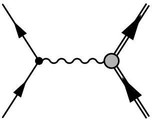
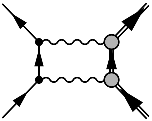
$\mathcal{M} =$  $+$  $+\,\mathcal{O}(\alpha^3)$

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

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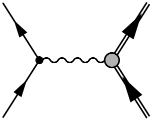
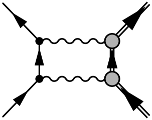
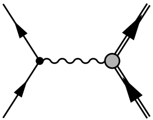
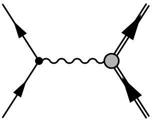
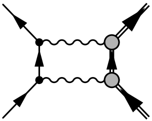
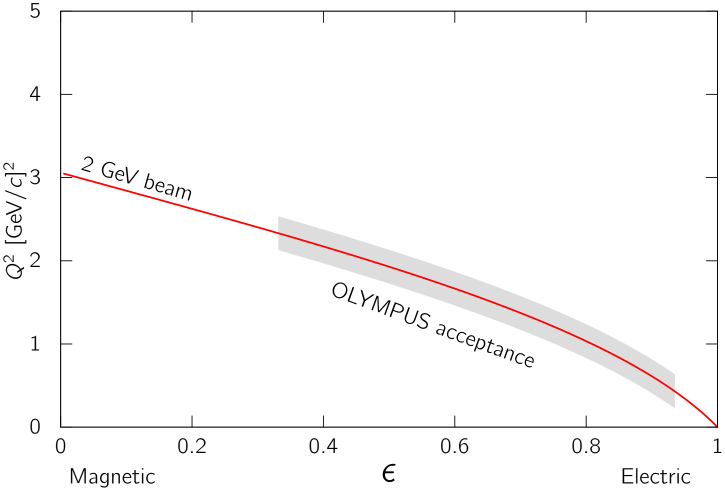
$\mathcal{M} =$  $+$  $+\,\mathcal{O}(\alpha^3)$

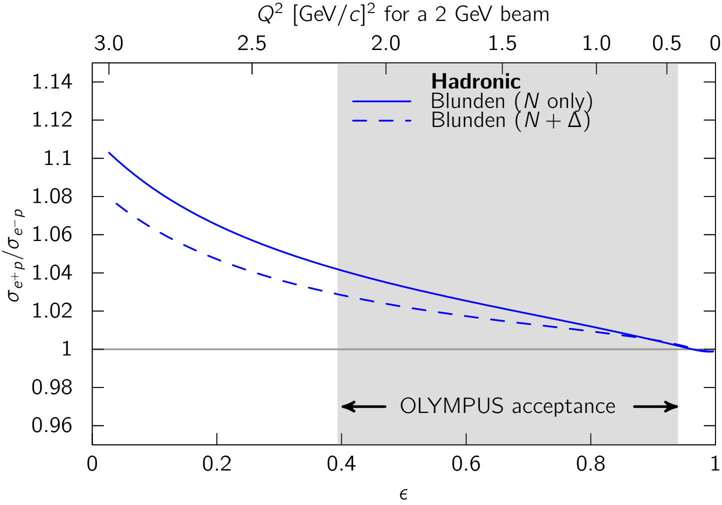
$\sigma \approx |\mathcal{M}|^2 = \Big|$  $\Big|^2 \pm 2\mathrm{Re}\Big[$   $\Big] + \mathcal{O}(\alpha^4)$

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

Upcoming plots show this contour.



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



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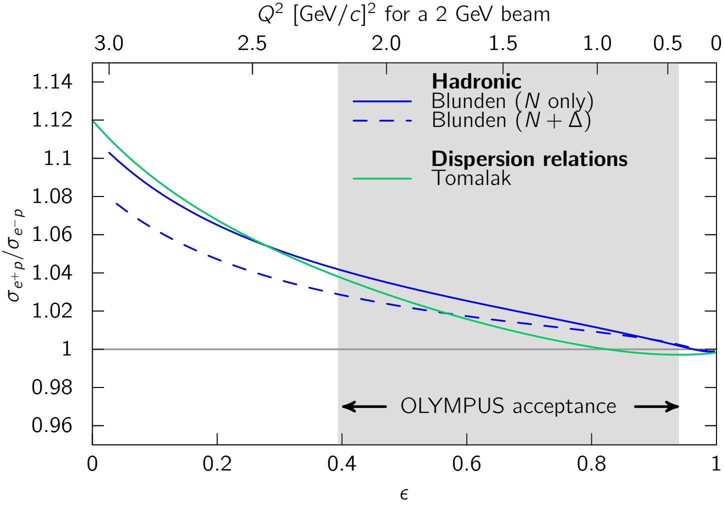

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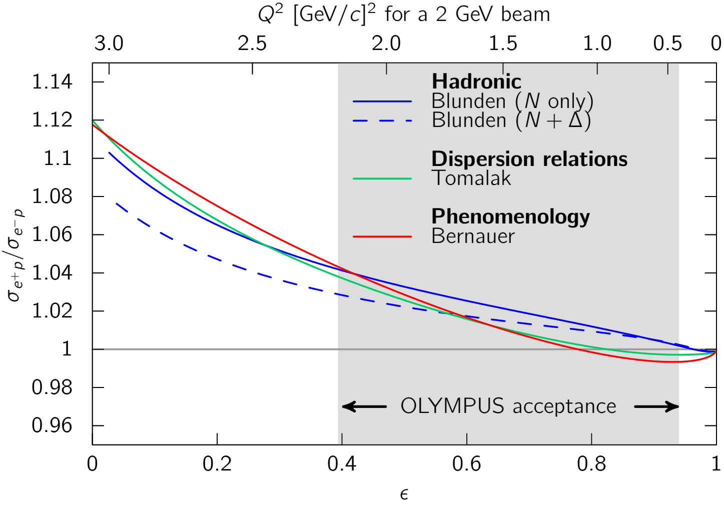

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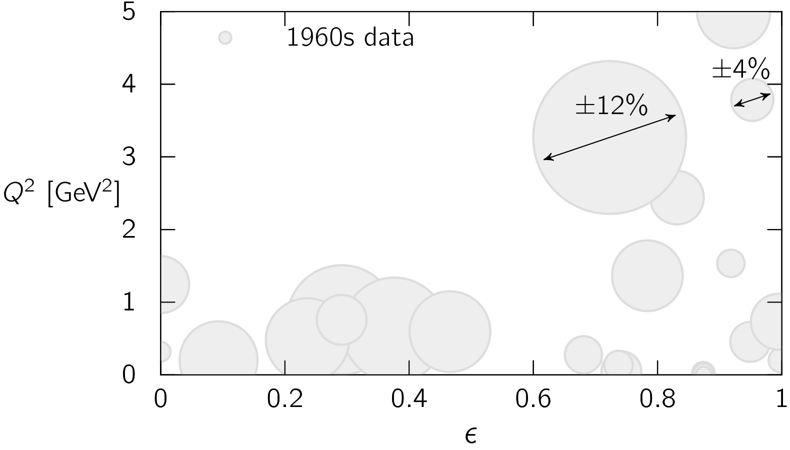

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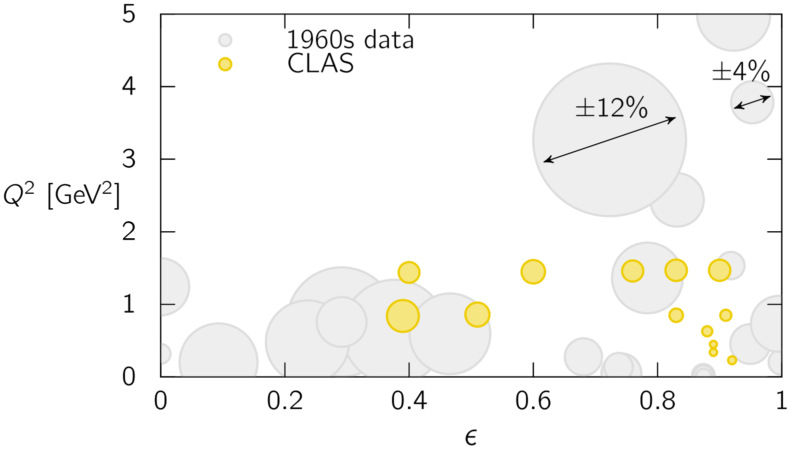

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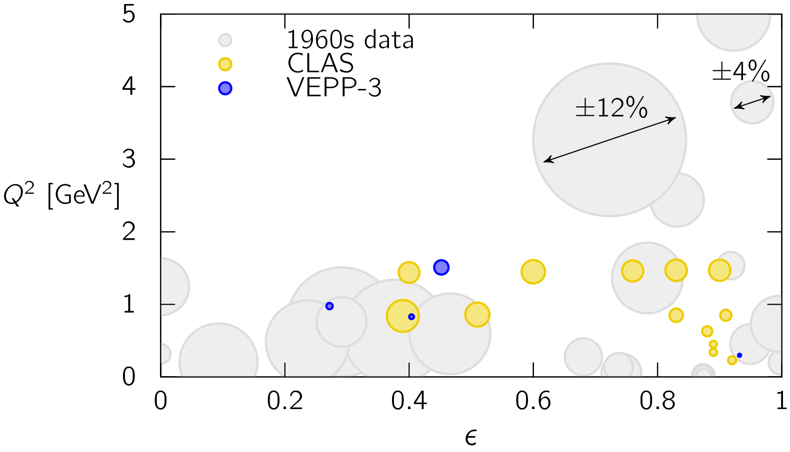
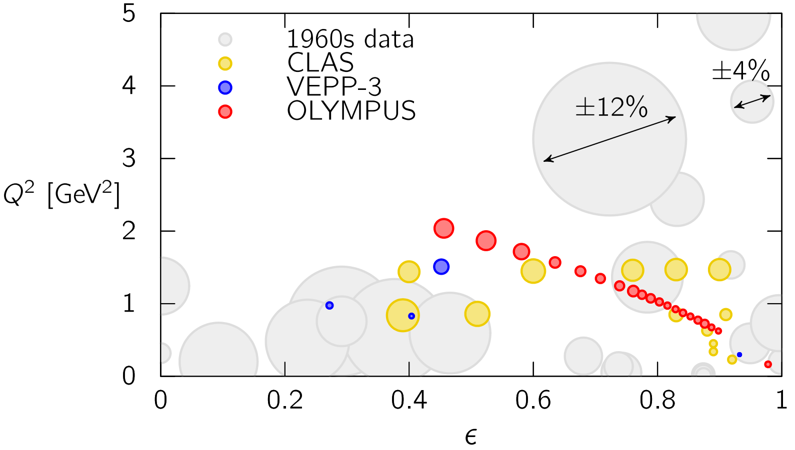


OLYMPUS has made the highest precision measurement so far.



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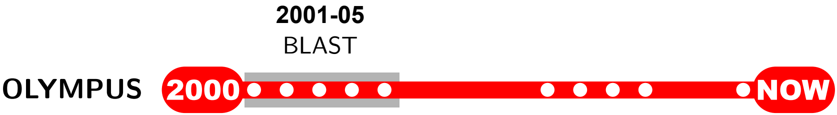
OLYMPUS ran on a short timeline.



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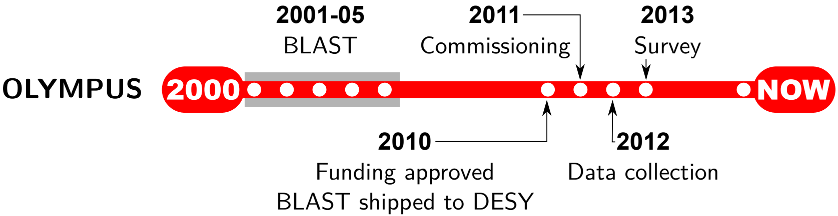

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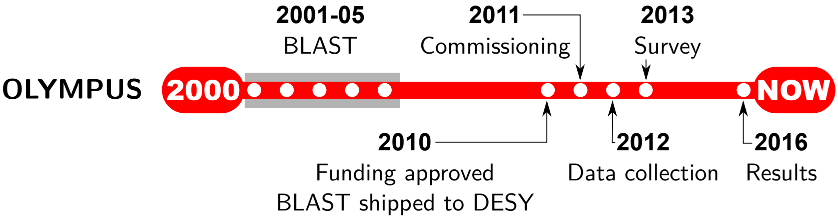
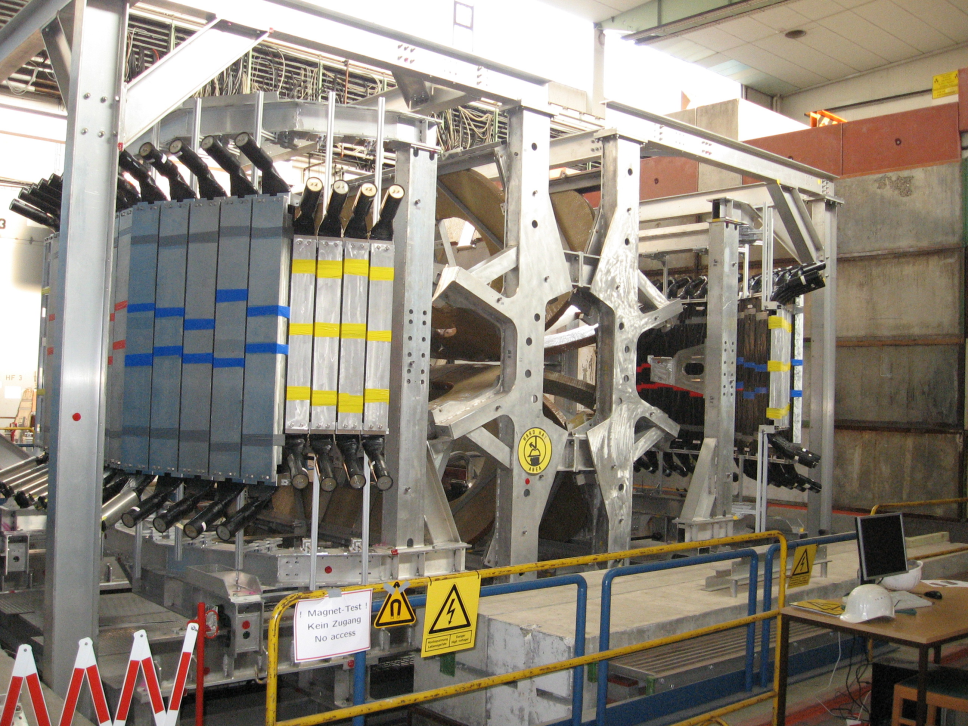
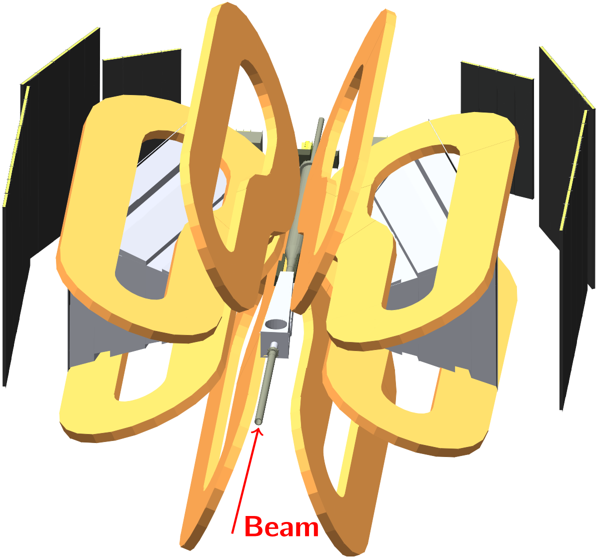



DANGER


! Magnet-Test !
Kein Zugang
No access
HARD HAT AREA
Hochspannung Lebensgefahr
Danger High voltage!
HF 3

The OLYMPUS experiment



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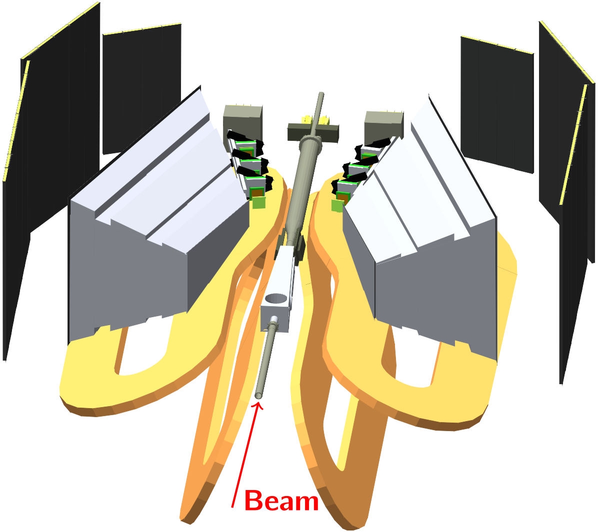
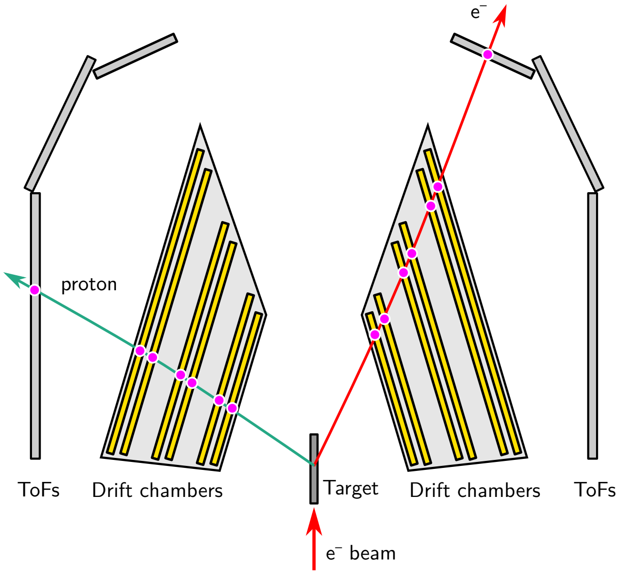


e^+ and e^- beams were alternated once per day.



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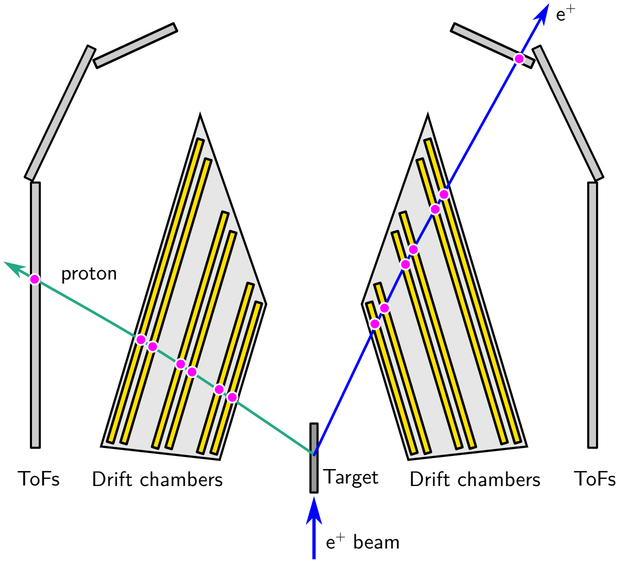
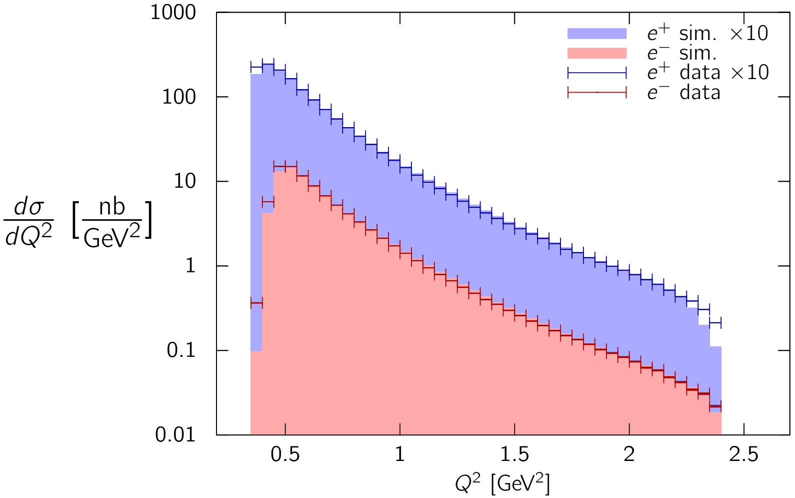
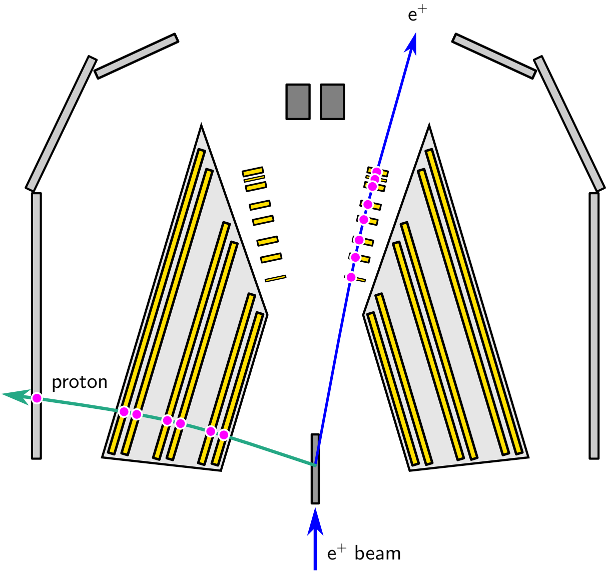
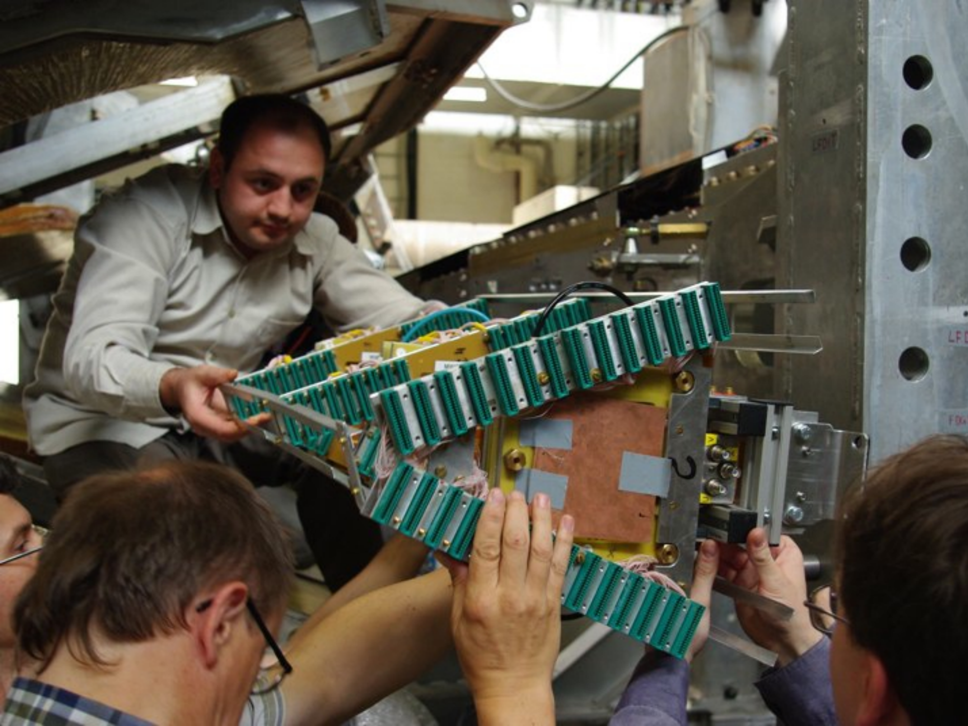


We effectively collected two data sets.

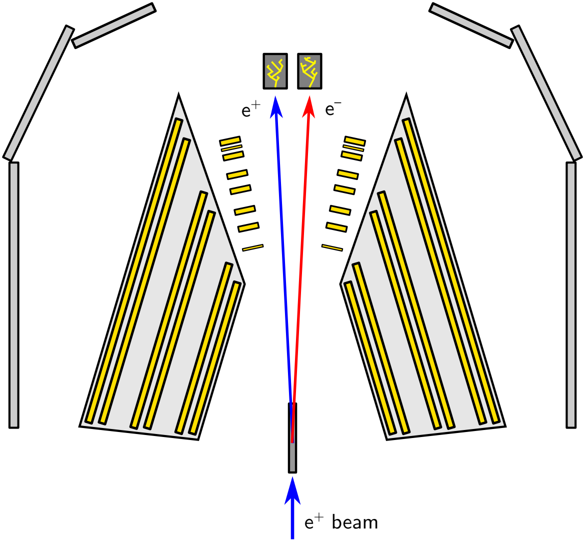


Forward telescopes monitored the elastic *ep* rate.





Symmetric calorimeters monitored the *ee* rate.



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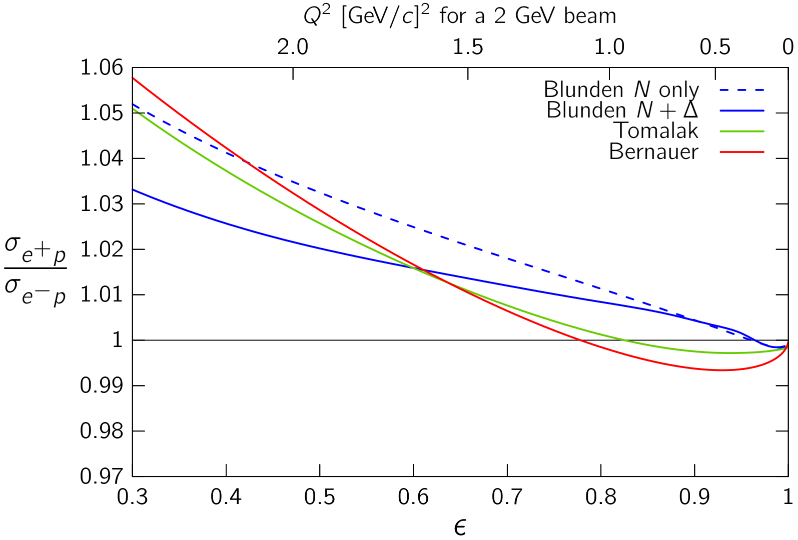
OLYMPUS results



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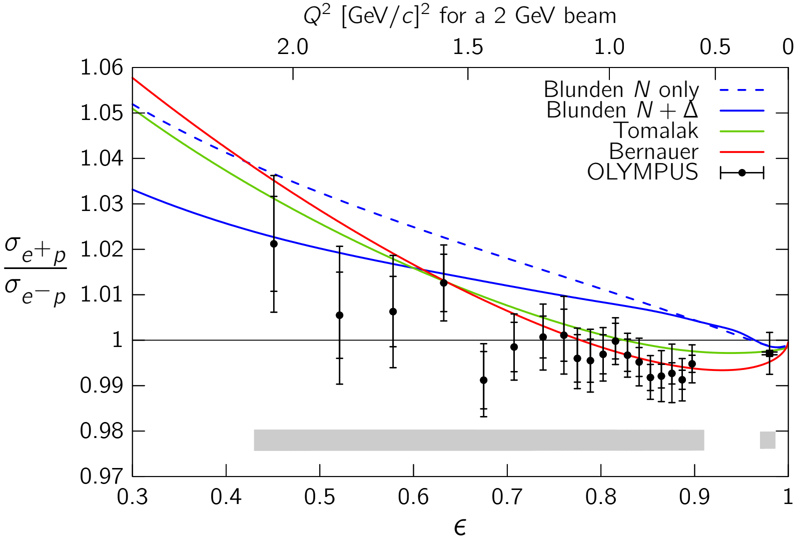
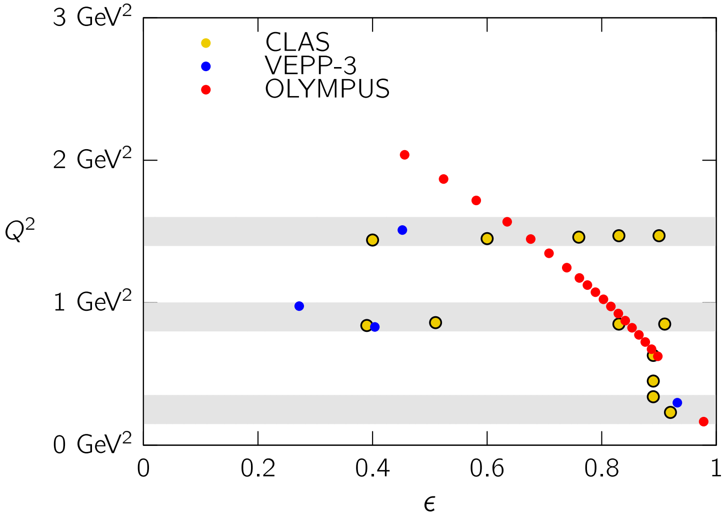
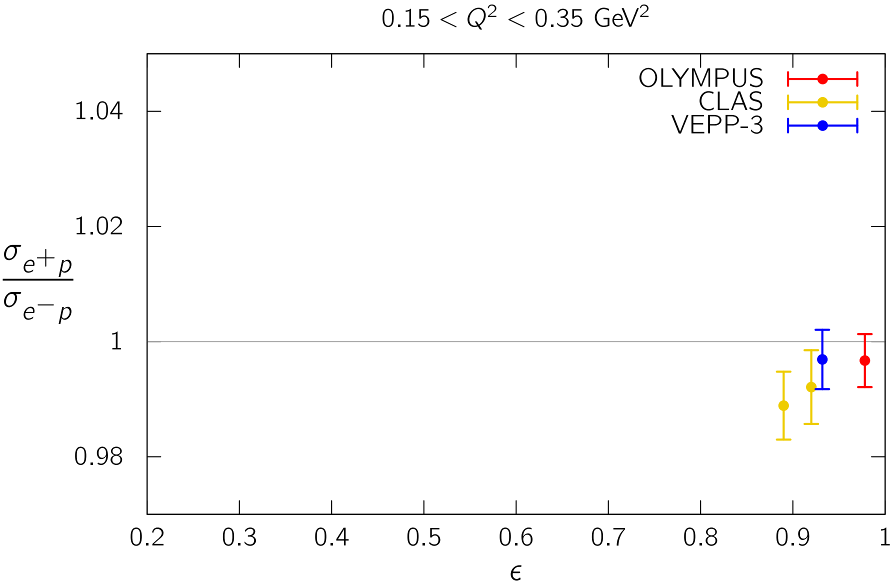


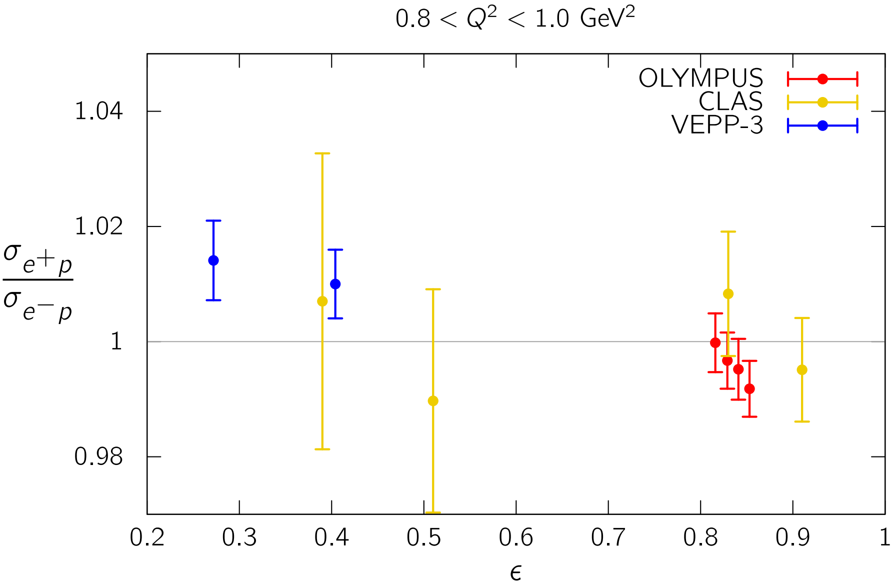
Comparing experiments is not straight-forward.



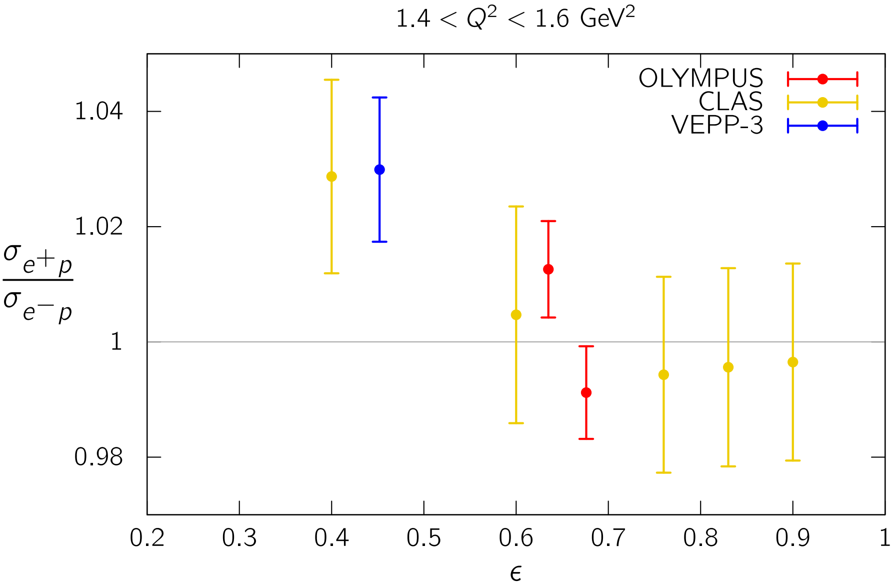
Comparison at low Q^2



Comparison at mid Q^2



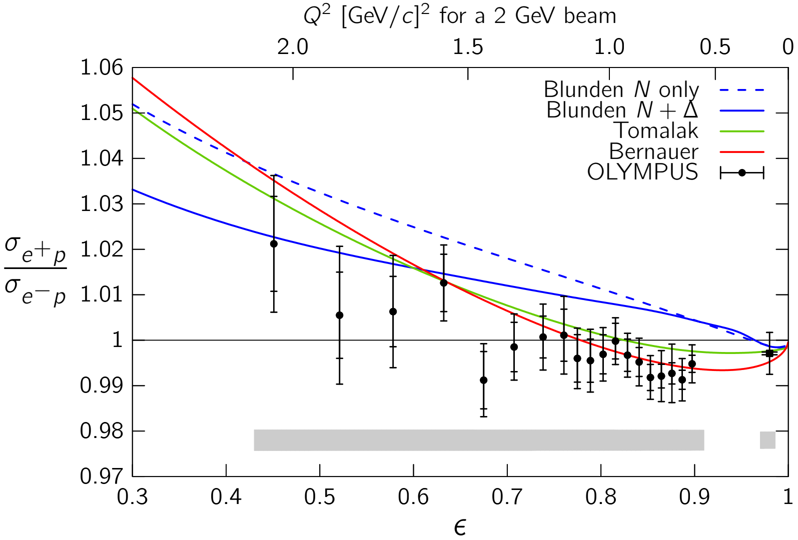
Comparison at high Q^2



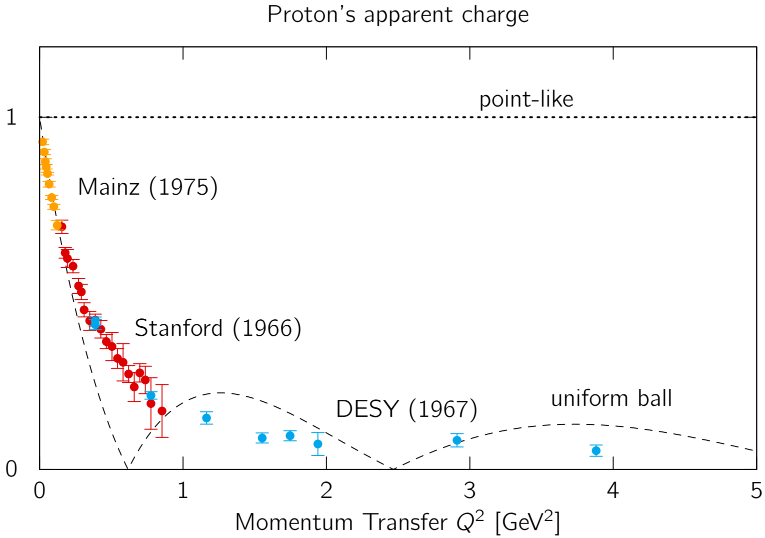
What have we learned?

- All three experiments are painting a consistent picture.
- Two-photon exchange is smaller than theory predicts.
- Phenomenological predictions match better.
- The ratio dips below unity at high ϵ!

The ratio dips below unity at high ϵ.

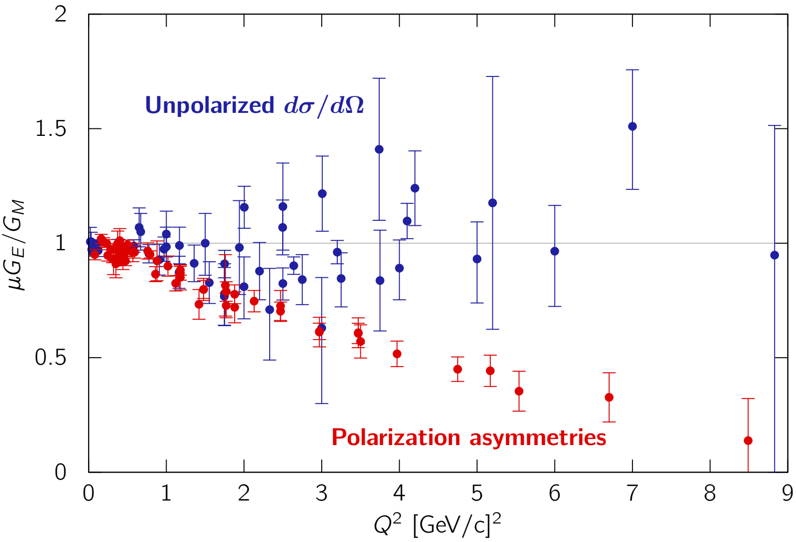


To recap:



Proton's apparent charge
point-like
Mainz (1975)
Stanford (1966)
DESY (1967)
uniform ball
1
0
0
1
2
3
4
5
Momentum Transfer Q^2 [GeV^2]

To recap:


Unpolarized $d\sigma/d\Omega$
Polarization asymmetries
$\mu G_E/G_M$
Q^2 [GeV/c]^2
0
0.5
1
1.5
2
0 1 2 3 4 5 6 7 8 9

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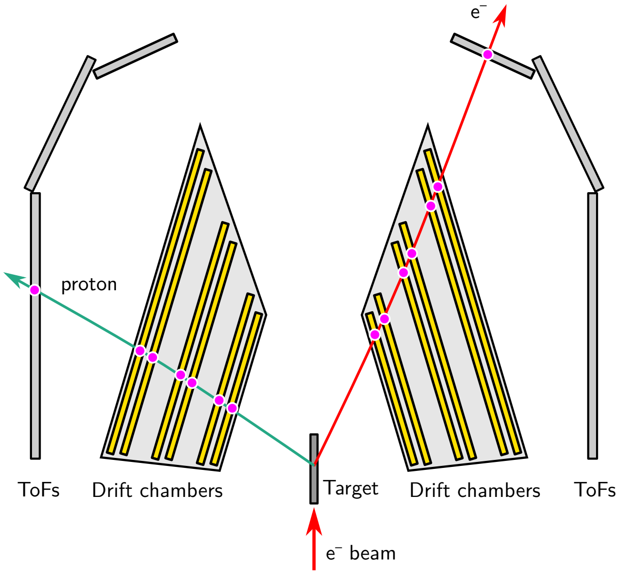

e⁻
proton
ToFs
Drift chambers
Target
Drift chambers
ToFs
e⁻ beam

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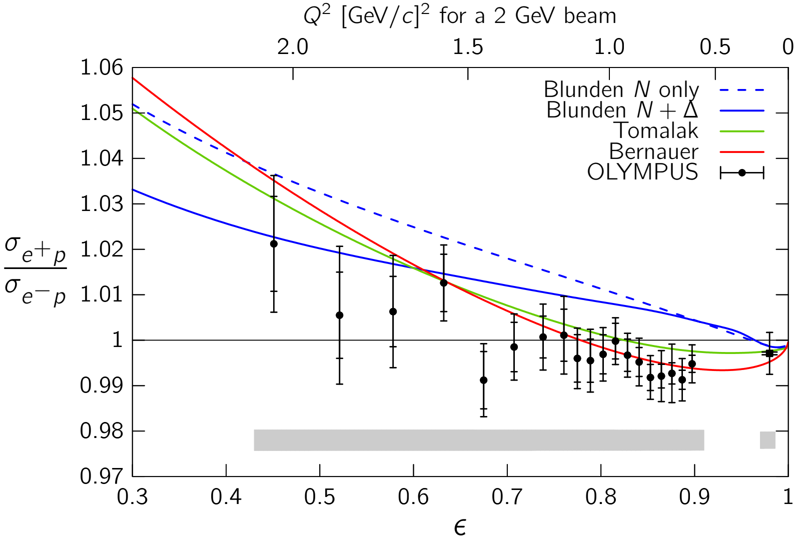

Q^2 [GeV/c]^2 for a 2 GeV beam
2.0
1.5
1.0
0.5
0
1.06
1.05
1.04
1.03
1.02
1.01
1
0.99
0.98
0.97
$\frac{\sigma_{e^+p}}{\sigma_{e^-p}}$
Blunden N only
Blunden $N + \Delta$
Tomalak
Bernauer
OLYMPUS
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
ϵ

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3. I think a test at higher Q^2 is worth while.