Status of the OLYMPUS Experiment

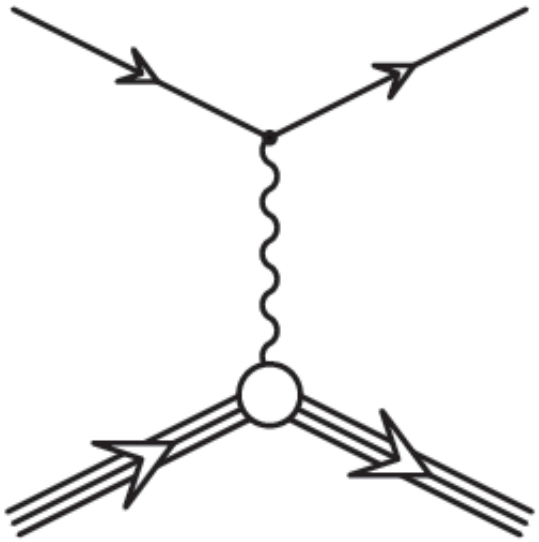
- Motivation (two-photon exchange)
- The OLYMPUS Experiment
- Data Analysis Status
- Summary

Ricardo Alarcon, CD2015, Pisa

Nucleon Elastic Form Factors

- One photon exchange approximation

$$\gamma^\mu F_1^N(Q^2) + i\sigma^{\mu\nu} q_\nu \frac{\kappa}{2M} F_2^N(Q^2)$$



- **Electric and Magnetic Form Factors**

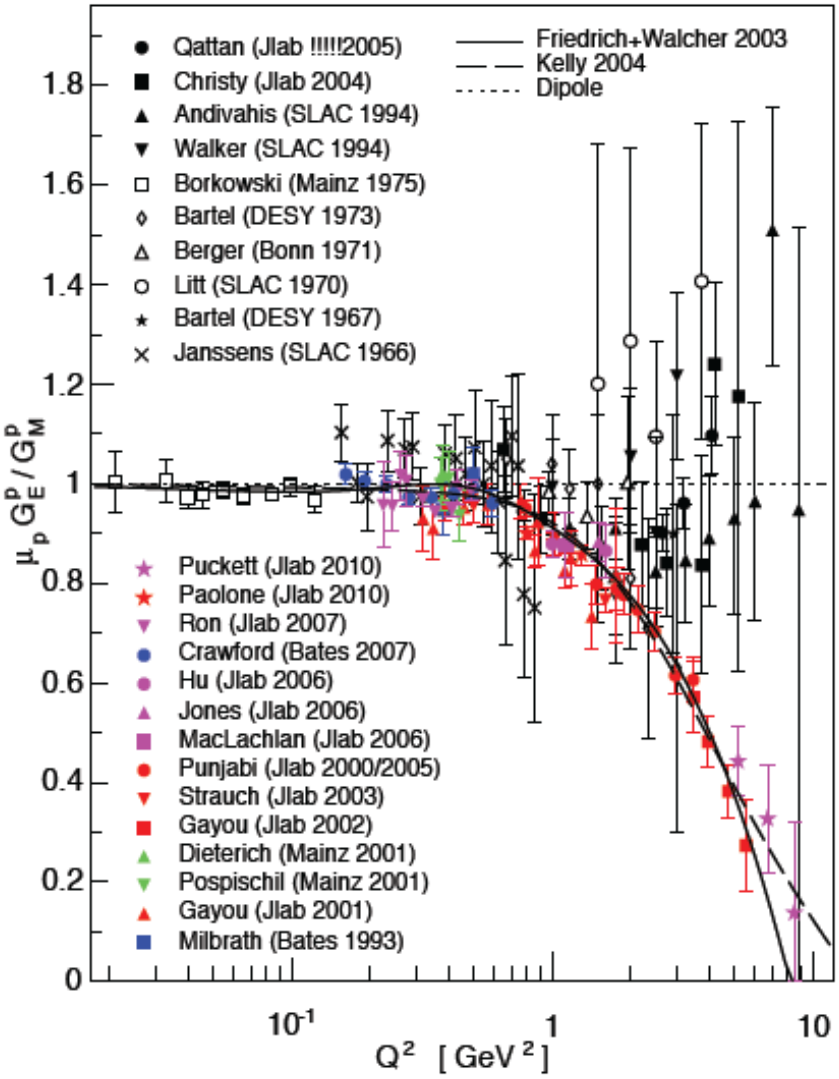
$$G_E^N = F_1^N - \tau\kappa F_2^N; \qquad G_M^N = F_1^N + \kappa F_2^N$$

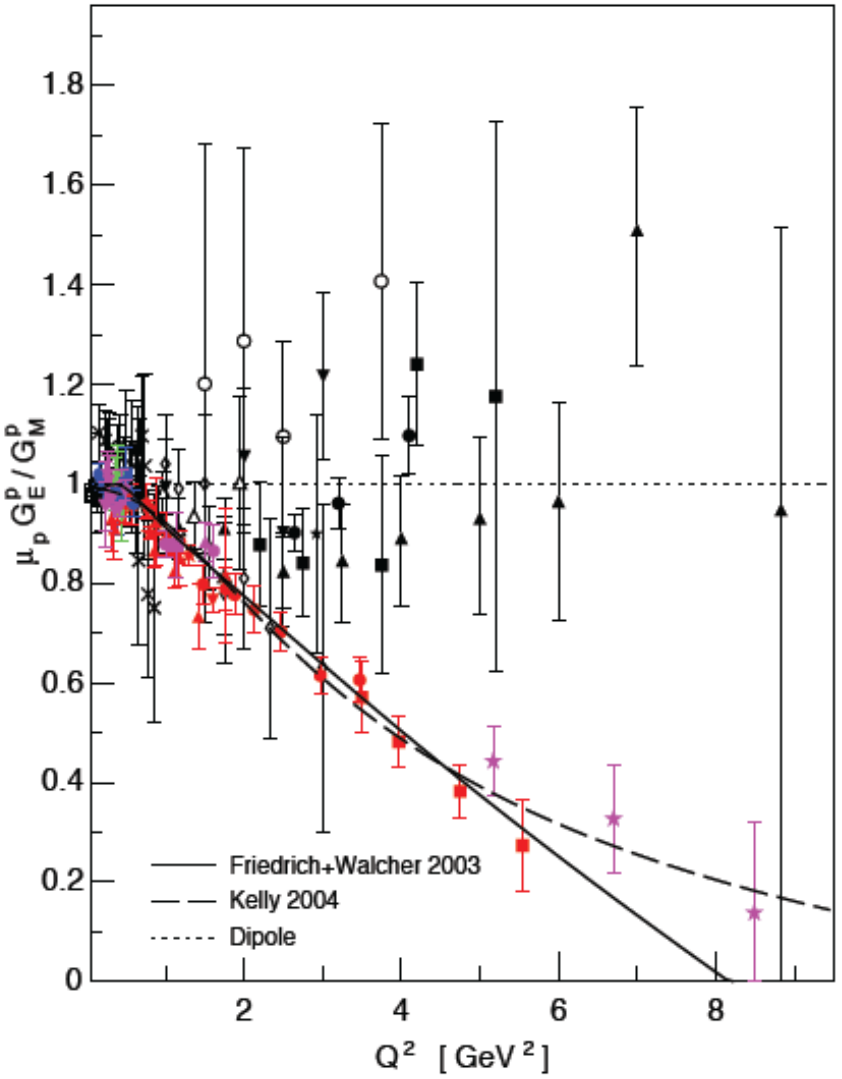
- **Elastic Cross Section (Rosenbluth separation)**

$$\left(\frac{d\sigma}{d\Omega}\right)_{Mott} \left[\left(\frac{G_E^{N\,2} + \tau G_M^{N\,2}}{1+\tau} \right) + 2\tau G_M^{N\,2} \tan^2 \frac{\theta}{2} \right]$$

$$G_E^p \approx \frac{1}{\mu_p} G_M^p \approx \frac{1}{\mu_n} G_M^n \approx G_D \sim \left(1 + \frac{Q^2}{0.71}\right)^{-2}$$

Proton Form Factor Ratio Discrepancy



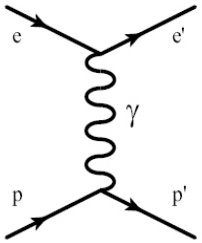


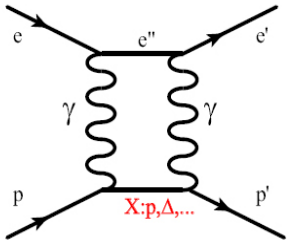
Rosenbluth re-analyzed with TPE

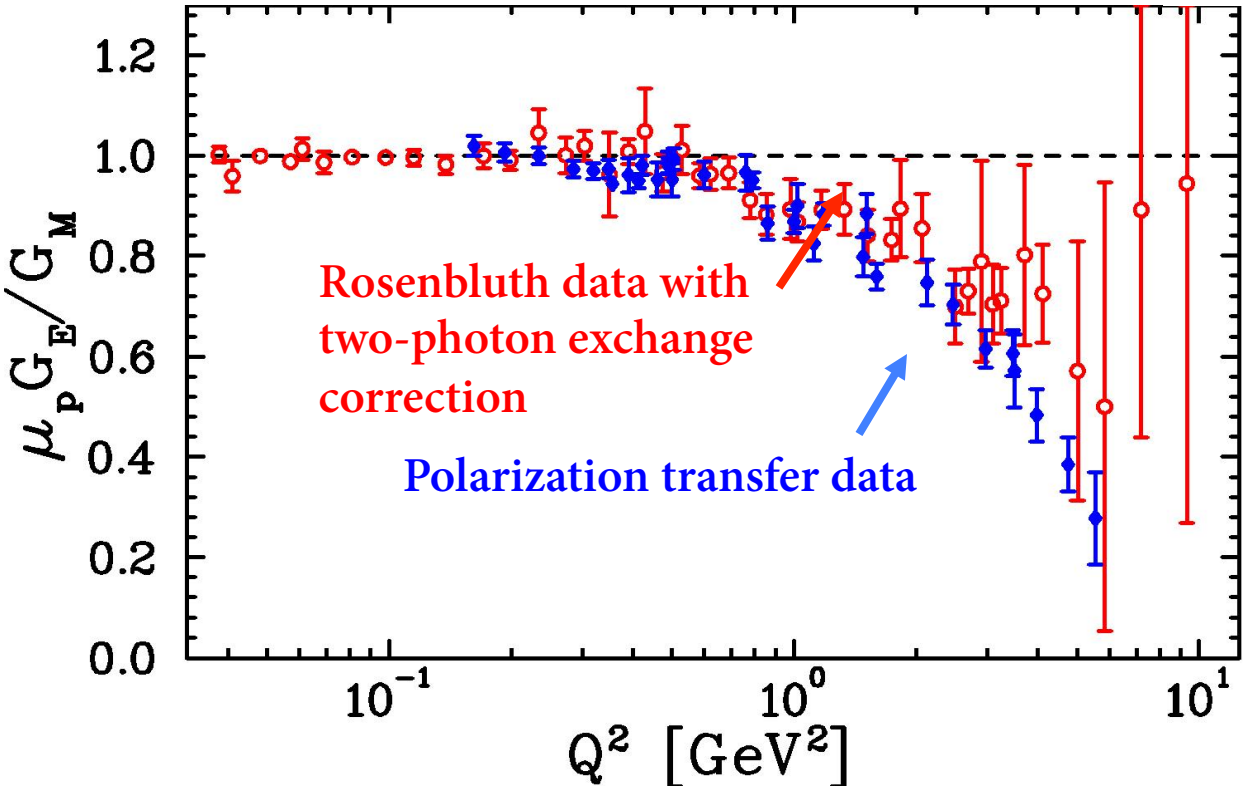
Two-photon exchange theoretically suggested

TPE can explain form factor discrepancy

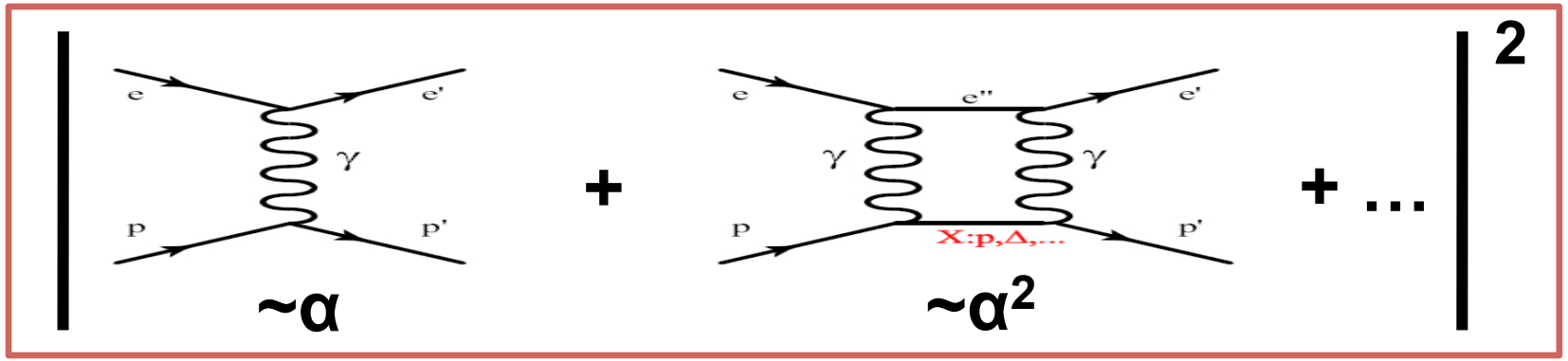
J. Arrington, W. Melnitchouk, J.A. Tjon,
Phys. Rev. C 76 (2007) 035205







Lepton-Proton Elastic Scattering



$$\sigma = (1\gamma)^2\alpha^2 + (1\gamma)(2\gamma)\alpha^3 + ...$$

$$e^- \Longleftrightarrow e^+ \Rightarrow \alpha \Longleftrightarrow -\alpha$$

$$\sigma(\text{electron-proton}) = (1\gamma)^2\alpha^2 - (1\gamma)(2\gamma)\alpha^3 + ..$$

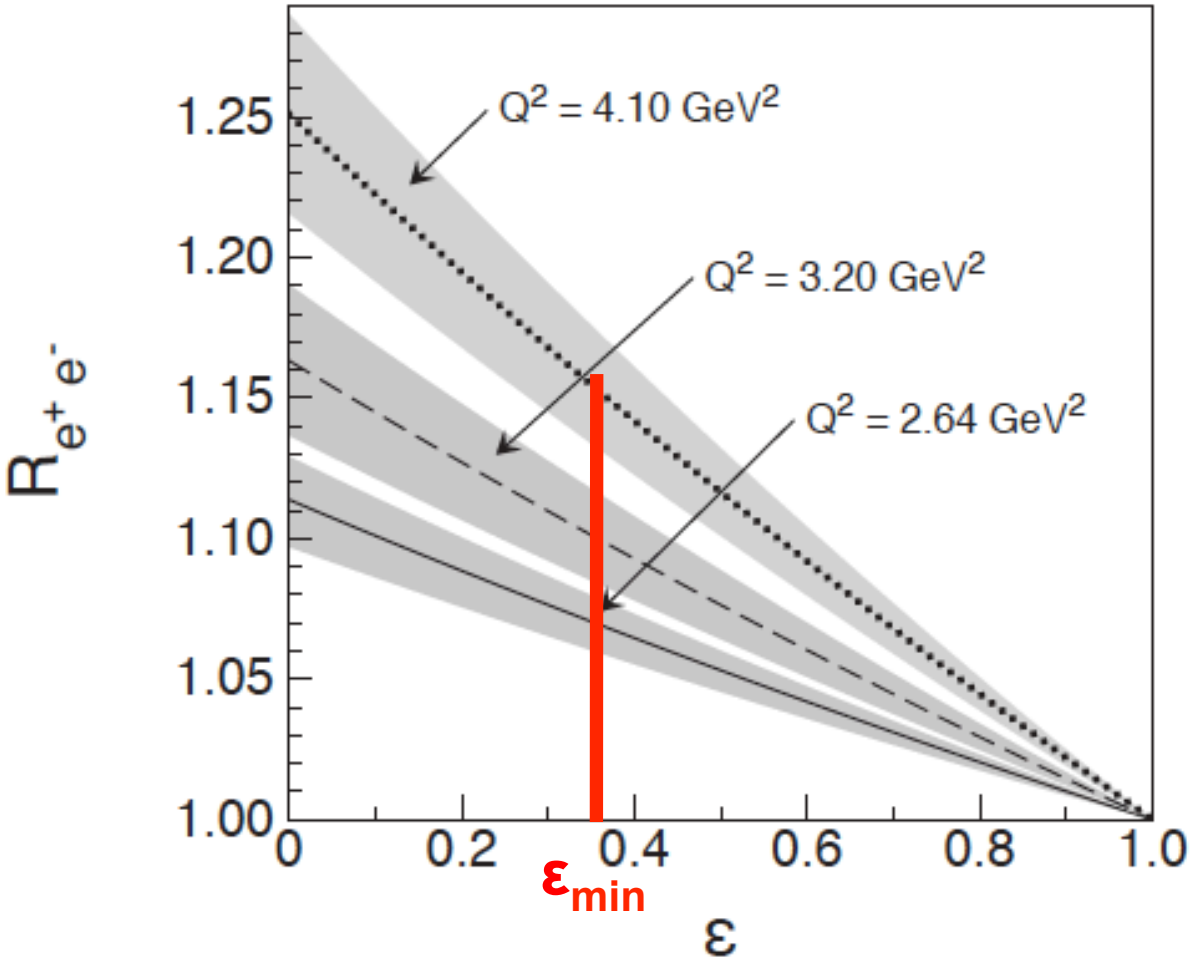
$$\sigma(\text{positron-proton}) = (1\gamma)^2\alpha^2 + (1\gamma)(2\gamma)\alpha^3 + ..$$

$$\frac{\sigma(e^+p)}{\sigma(e^-p)} = 1 + (2\alpha)\frac{2\gamma}{1\gamma}$$

σ -ratio to deviate from 1 due to interference of 1 γ and 2 γ proportional to TPE

Empirical Extraction of TPE Amplitudes

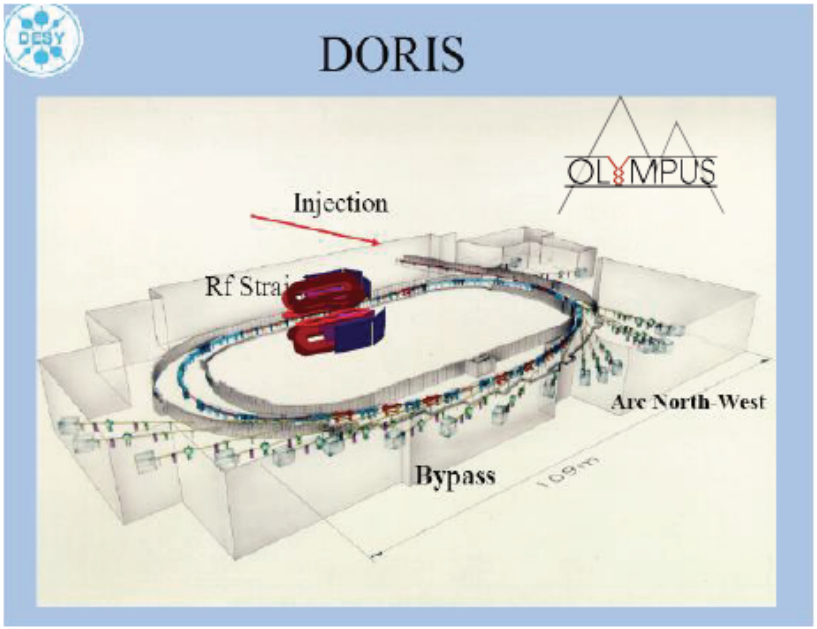
J. Guttmann, N. Kivel, M. Meziane, and M. Vanderhaeghen, EPJA 47 (2011) 77

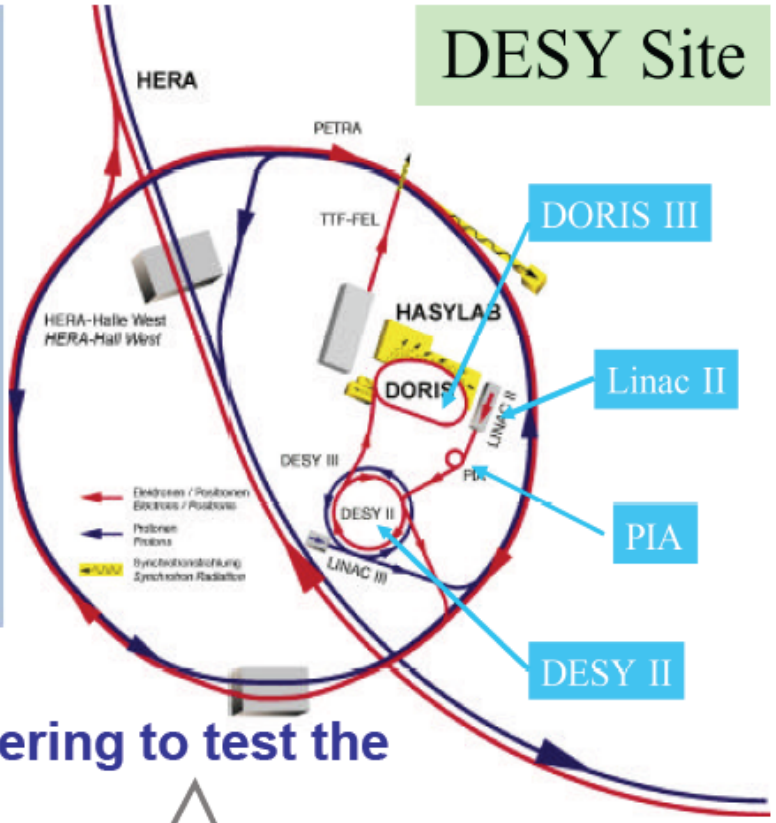


~6% effect for OLYMPUS@2.0GeV

grows with Q^2!

The OLYMPUS Experiment





pOsitron-proton and
eLectron-proton elastic scattering to test the
hYpothesis of
Multi-
Photon exchange
Using
DoriS

OLYMPUS

The OLYMPUS Experiment

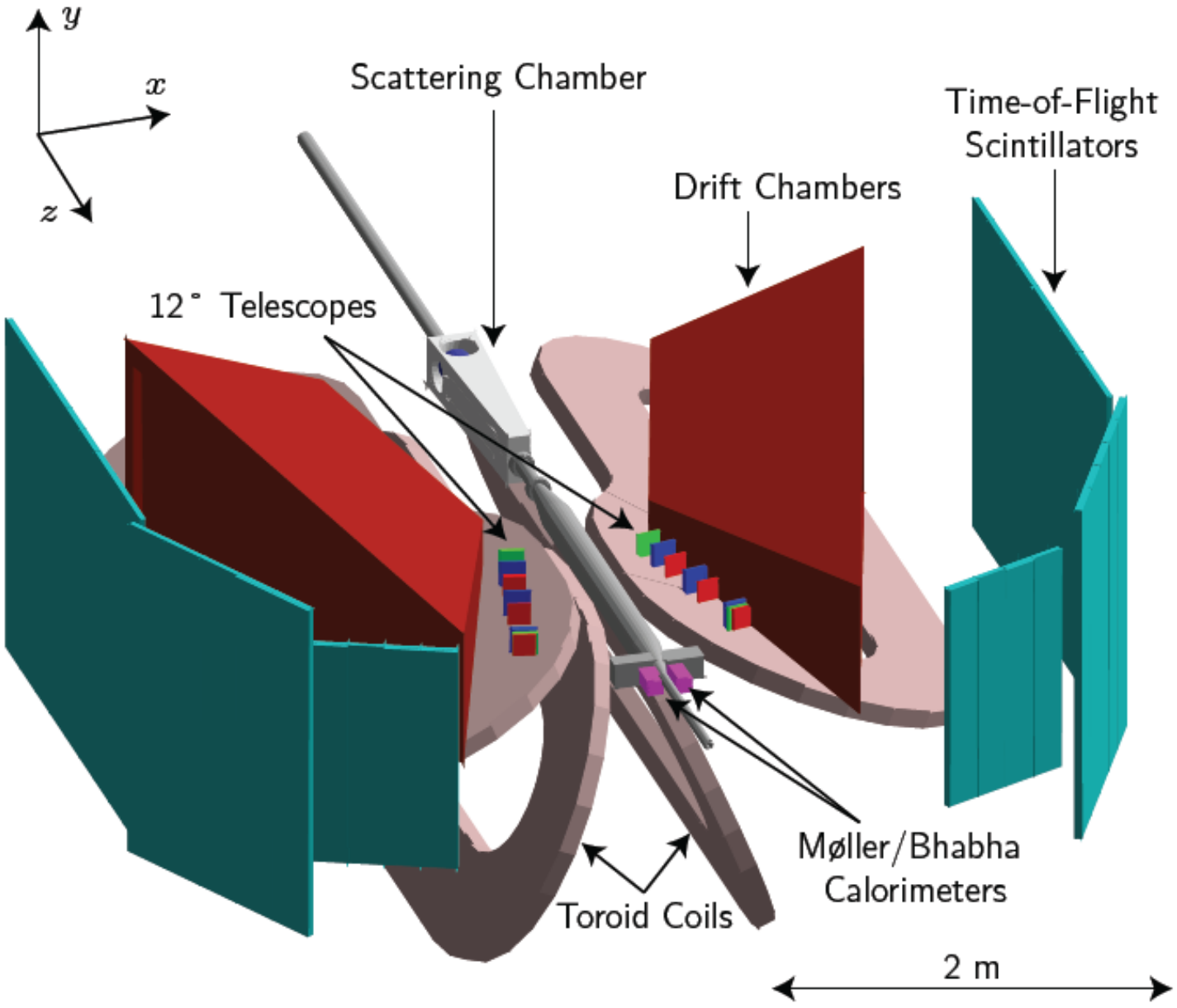
OLYMPUS Goal

Measure $\frac{\sigma(e^+p)}{\sigma(e^-p)}$ to within 1%
E = 2.0 GeV
$0.25 \leq Q^2 \leq 2.5$ (GeV/c)^2
$0.35 \leq \epsilon \leq 0.98$

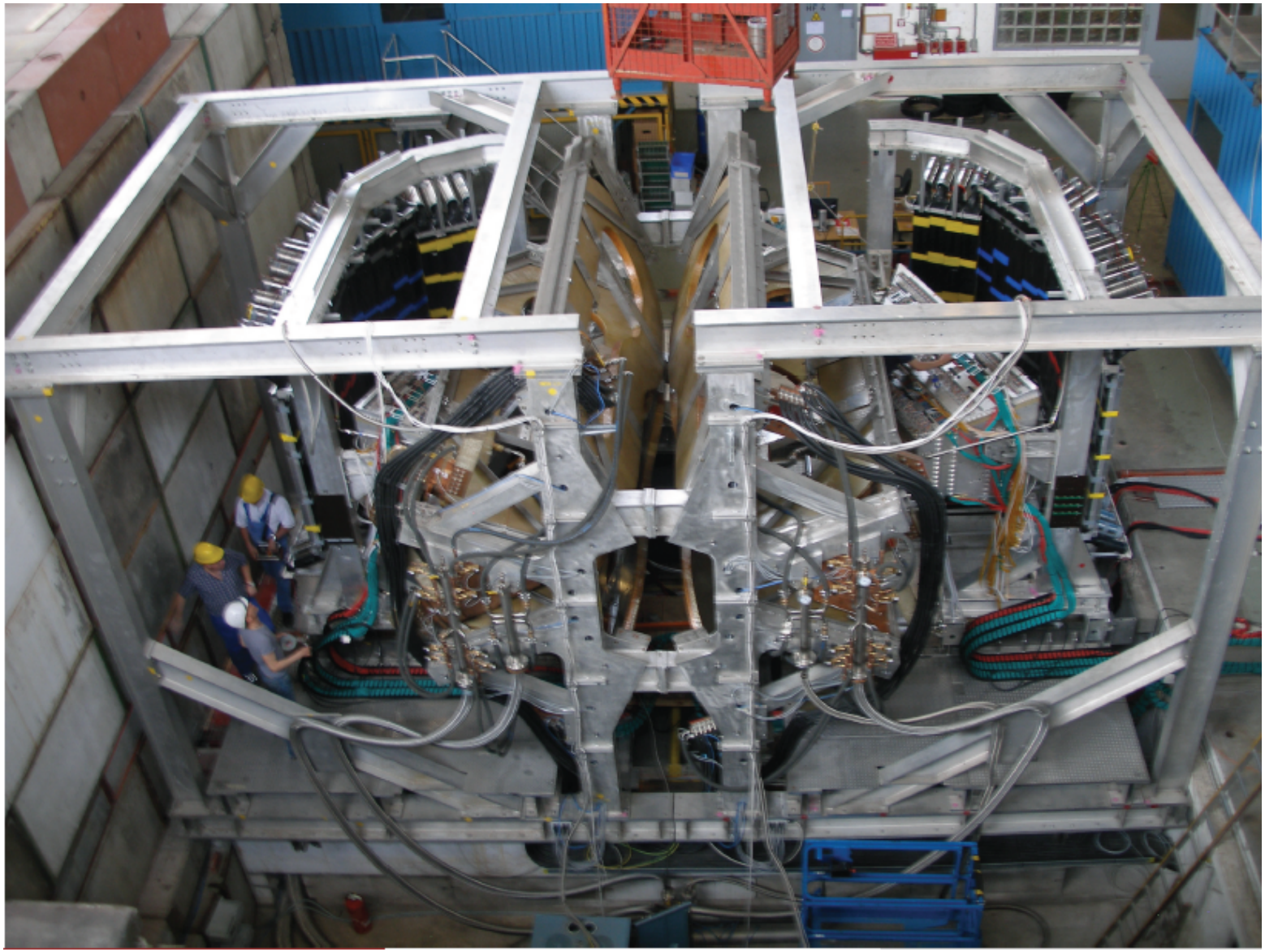
Other Experiments

- VEPP-3 Novosibirsk
  - E = 1.6 and 1 GeV
  - No magnetic field
  - I.A. Rachek, et al., Phys. Rev. Lett. 114, 062005 (2015)
- CLAS
  - E $<$ 5.5 GeV
  - Large Q^2 and ϵ range
  - D. Adikaram, et al., Phys. Rev. Lett. 114, 062003 (2015)

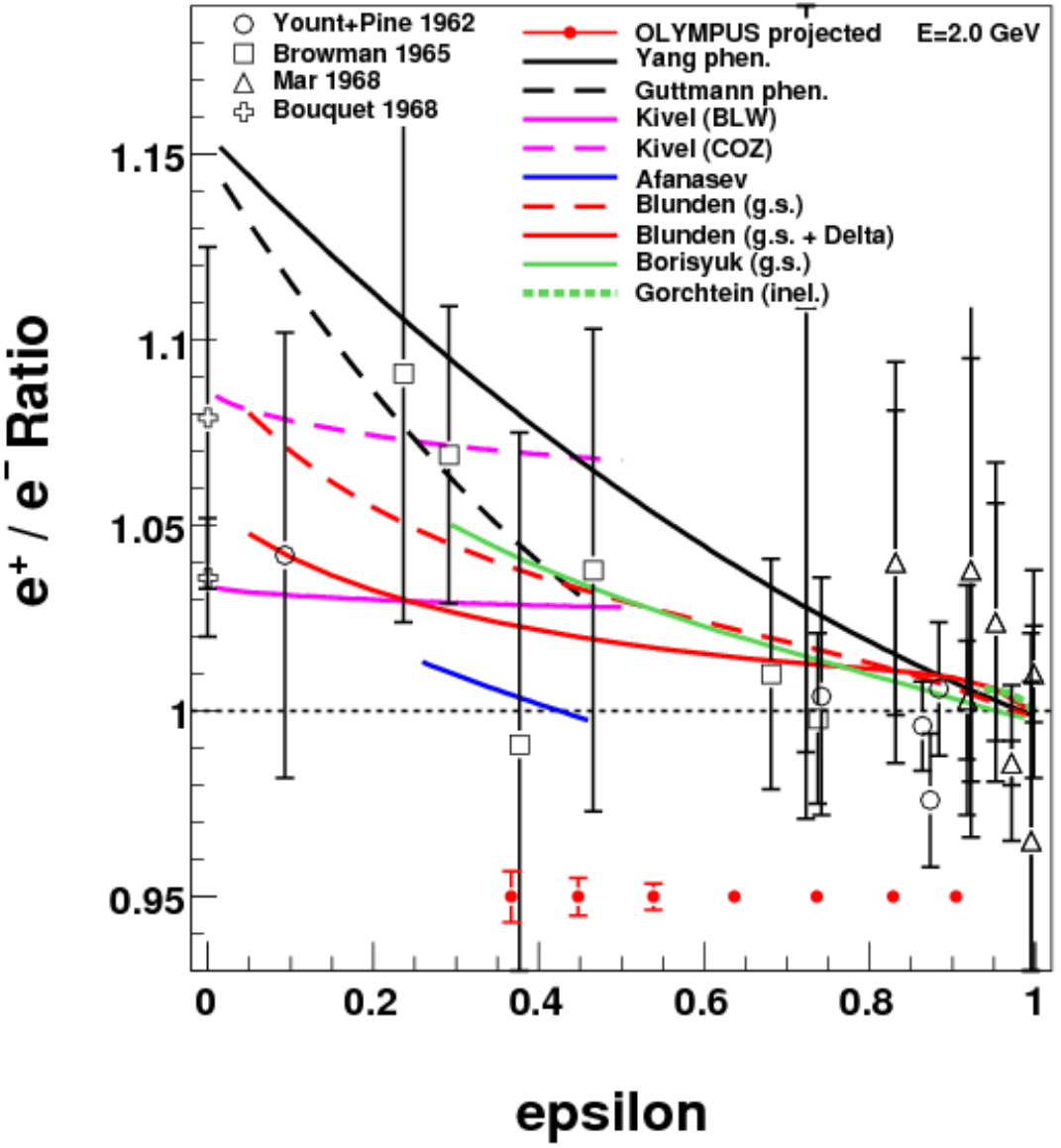
The OLYMPUS Detector



The OLYMPUS Detector



Projected Results for OLYMPUS



Data from 1960's

Many theoretical predictions with little constraint

OLYMPUS:

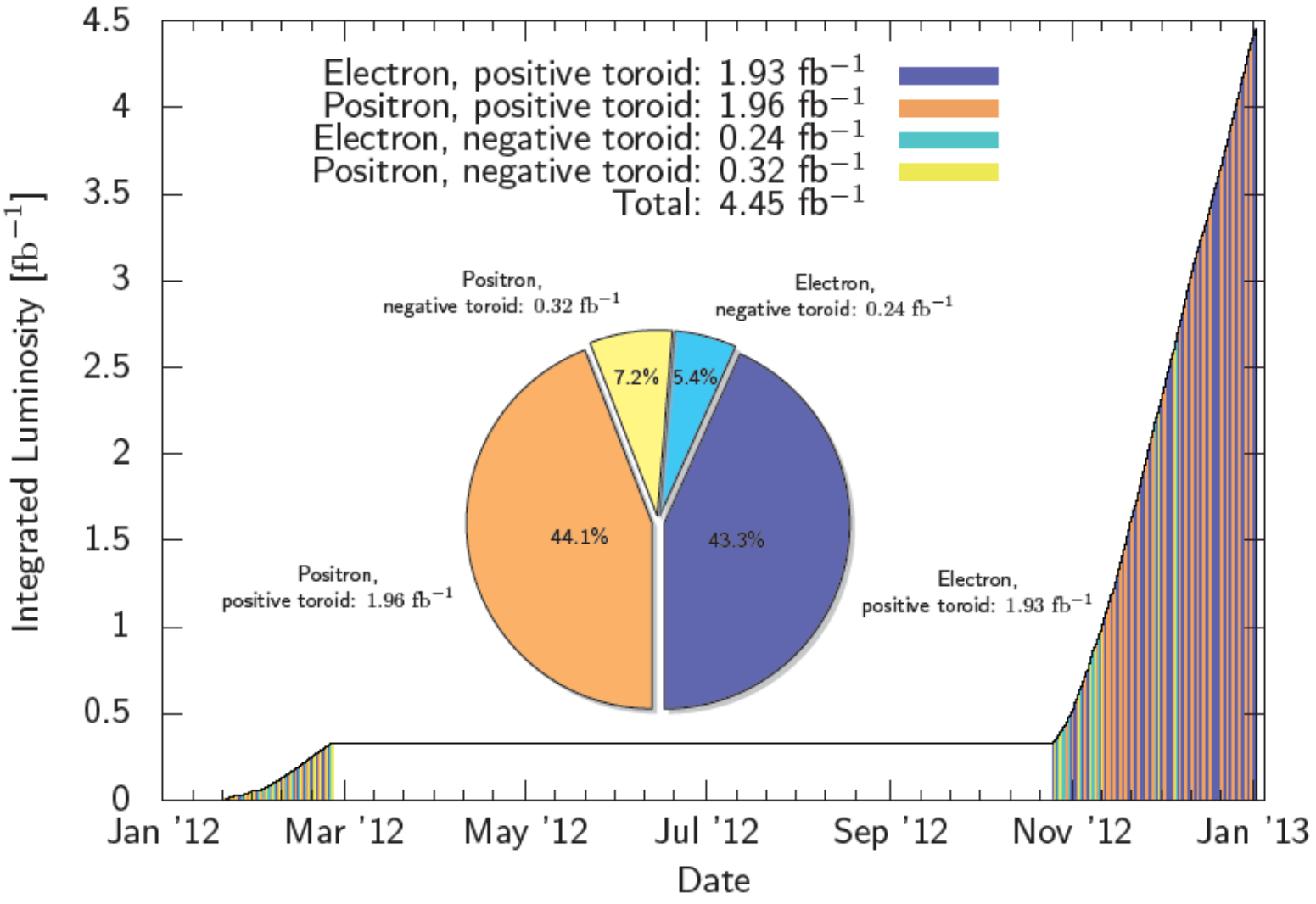
E = 2 GeV, ε = 0.37-0.9

Q^2 = 0.6-2.2 $(GeV/c)^2$

<1% projected uncertainties

500h @ $2x10^{33}$ / cm^2s e^+,e^-

Luminosity: Statistical Precision



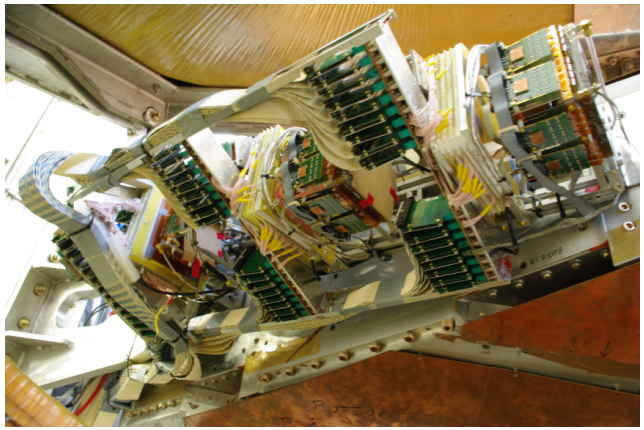
Luminosity Determination

The **relative** luminosity between e^+p and e^-p must be precisely known.

Three **independent** Luminosity Monitoring Systems

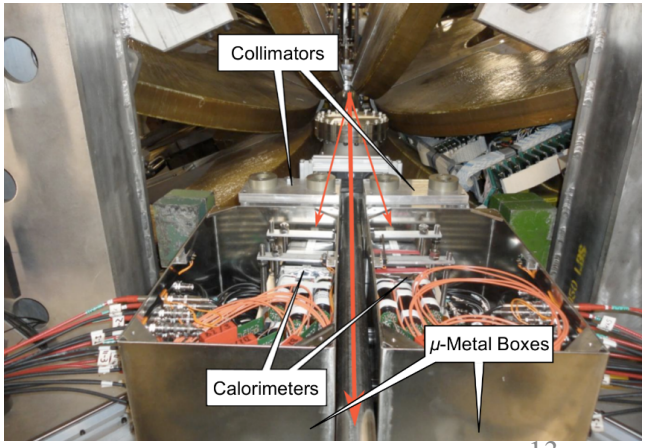
- Slow control: beam and target information
- Elastic scattering $e^{\pm}p$ at 12°

  - Interleaved telescope GEMs and MWPCs.
  - Redundancy of six detector planes.
  - Statistical precision of approximately 1% per hour



- Symmetric Moller and Bhabha Calorimeters

  - Detected Møller, Bhabha, and pair annihilation coincidence events at very forward angles (1.3°)
  - Arrays of nine PbF_2 crystals in each sector
  - Very high statistical precision



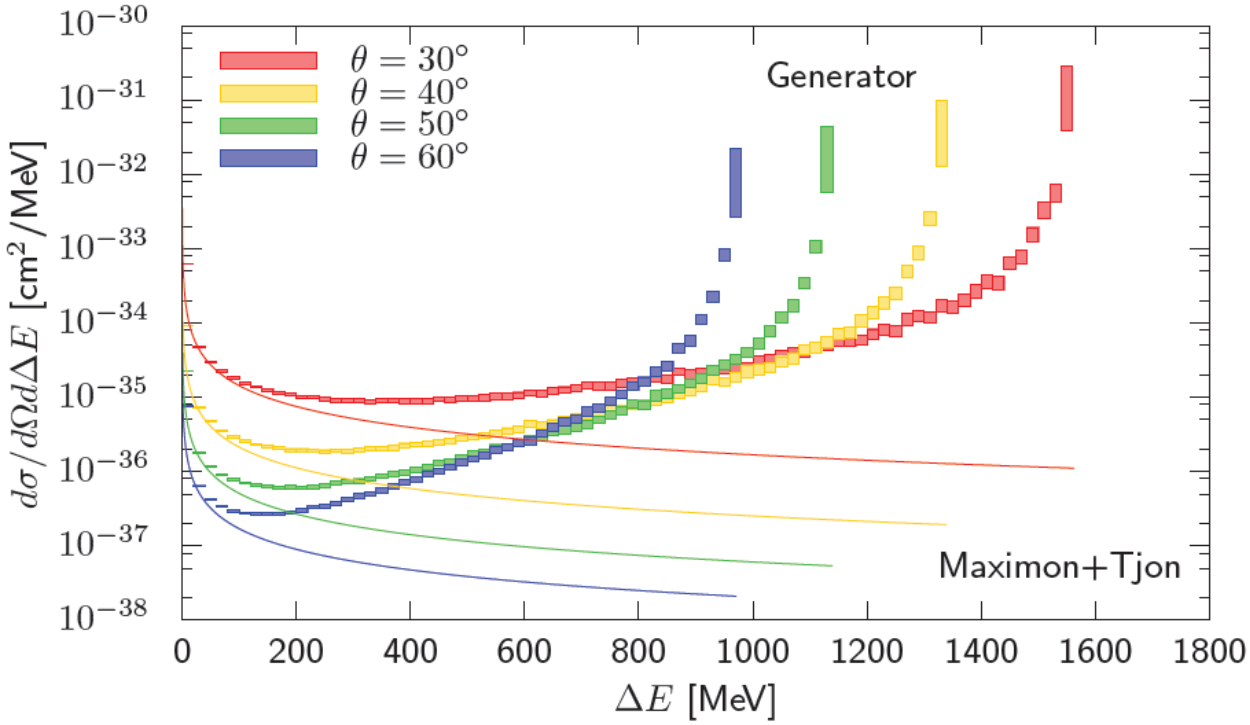
Radiative Corrections

OLYMPUS radiative corrections approach

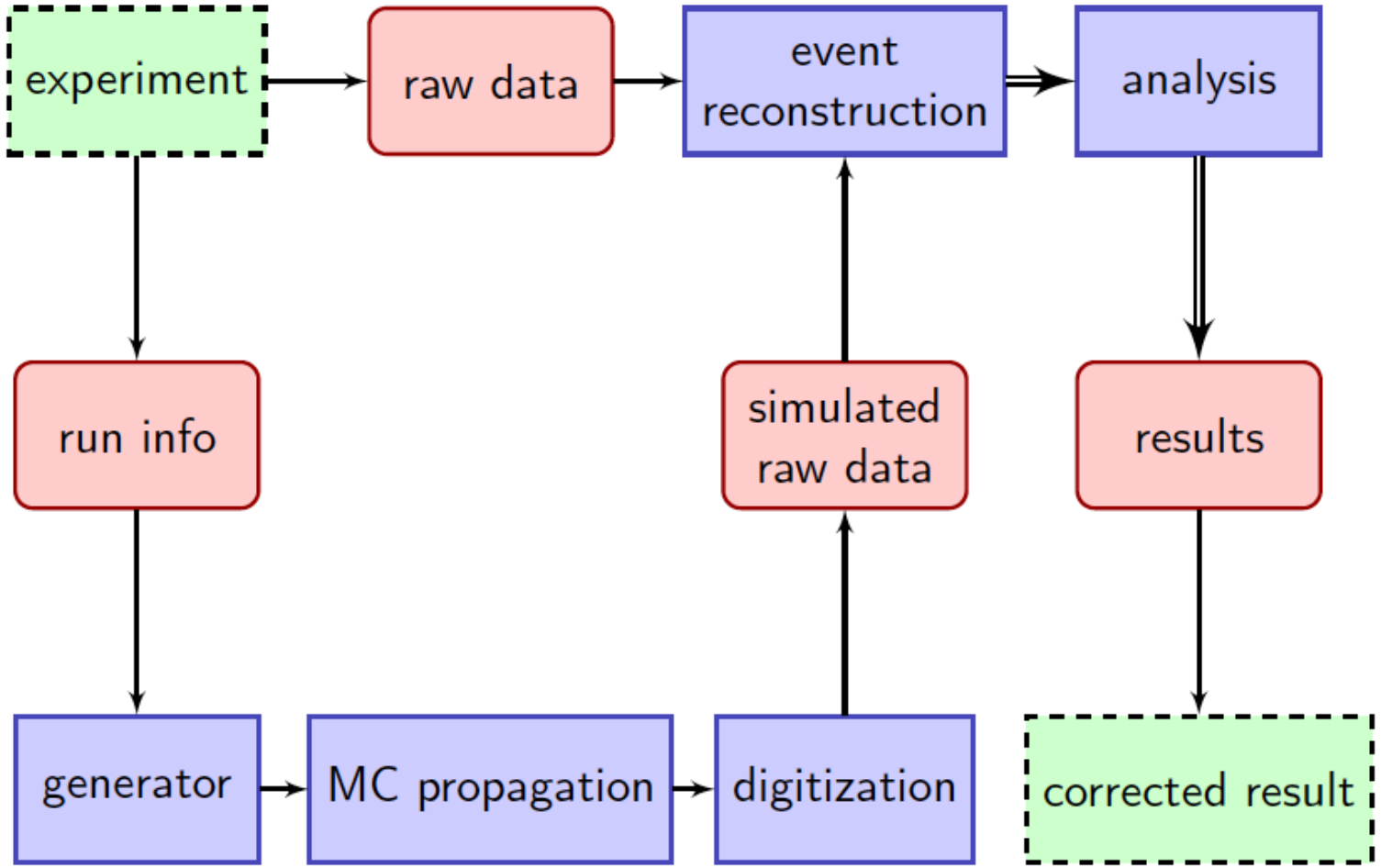
- Custom radiative generator which uses event info Monte Carlo and digitization
- Propagate radiative effects through whole analysis chain

The MIT generator

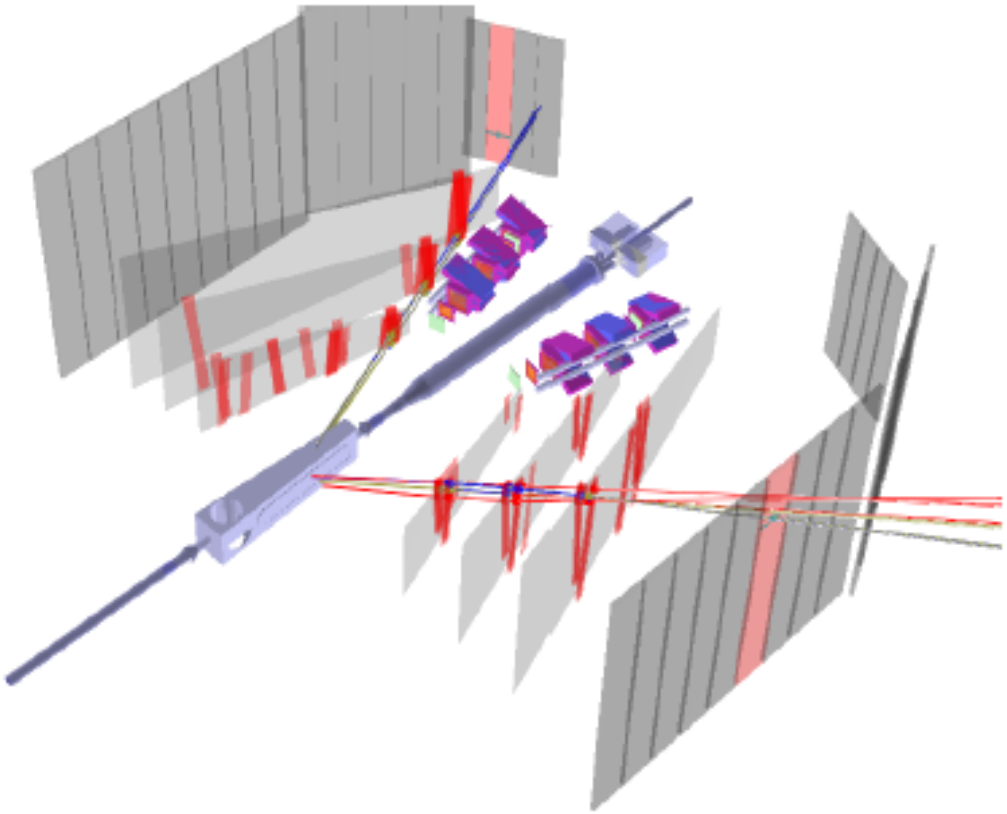
- Full α^3 radiative corrections including bremsstrahlung without approximation
- Extensive options that can be propagated in parallel through use of weights



Data Analysis Strategy



Track Reconstruction



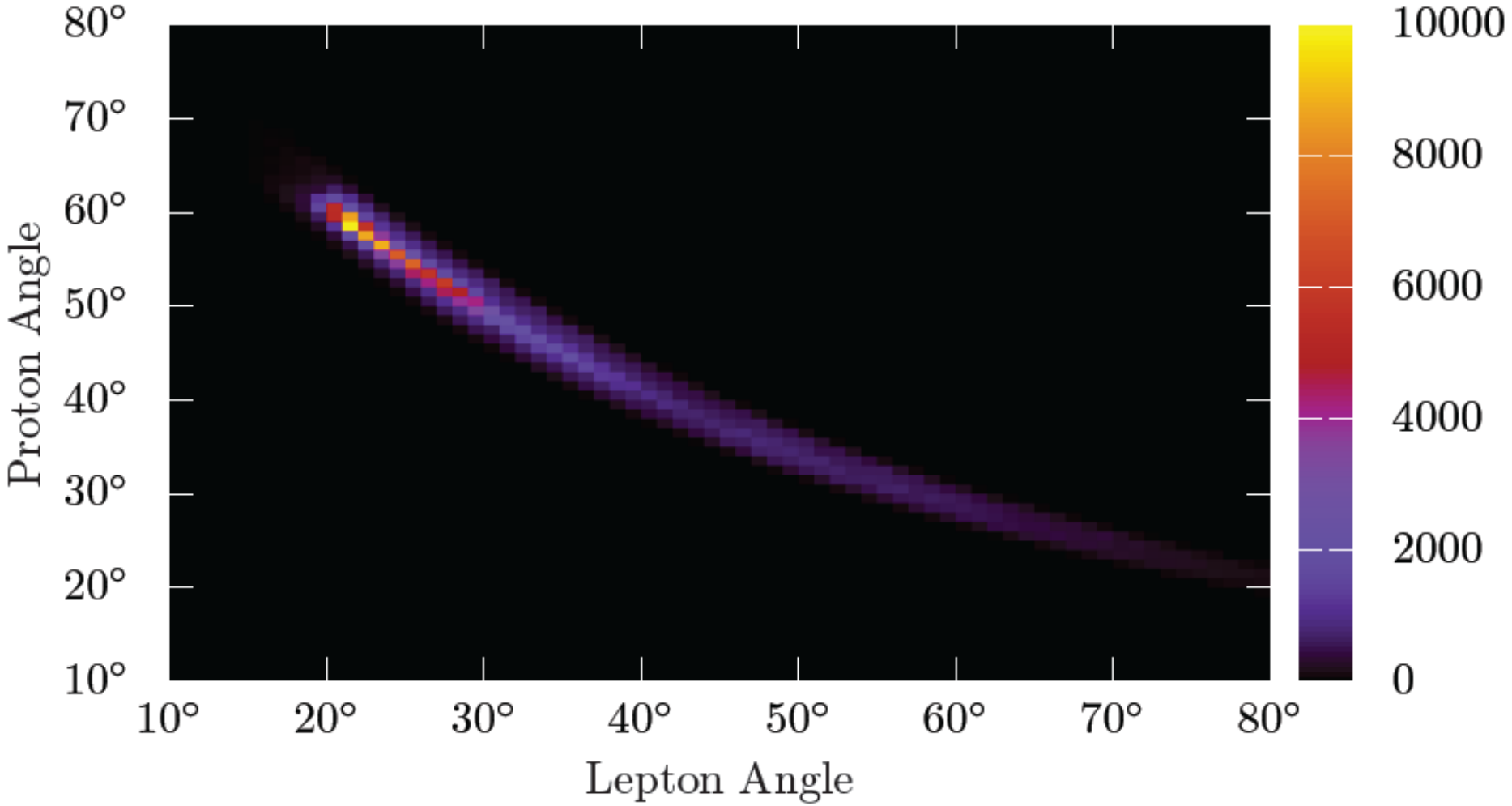
Track Finding

- Pattern matching: M. Dell'orso and L. Ristori (NIMA 287, 436 (1990))

Elastic Arm Approach

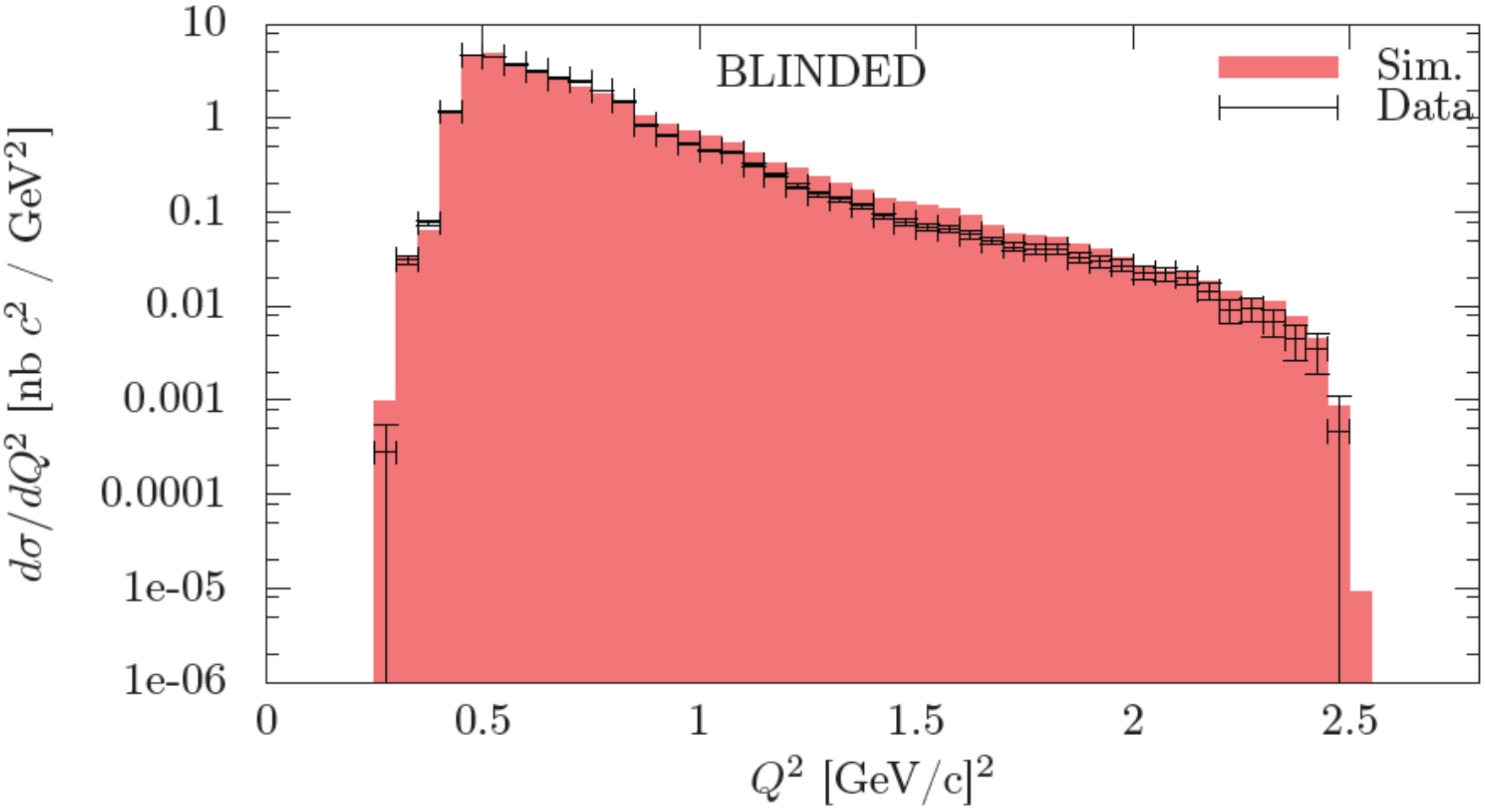
- Track reconstruction: M. Ohlsson and C. Peterson (CPC 71 (1992))
- Deformable templates
- Deterministic annealing

Event Selection

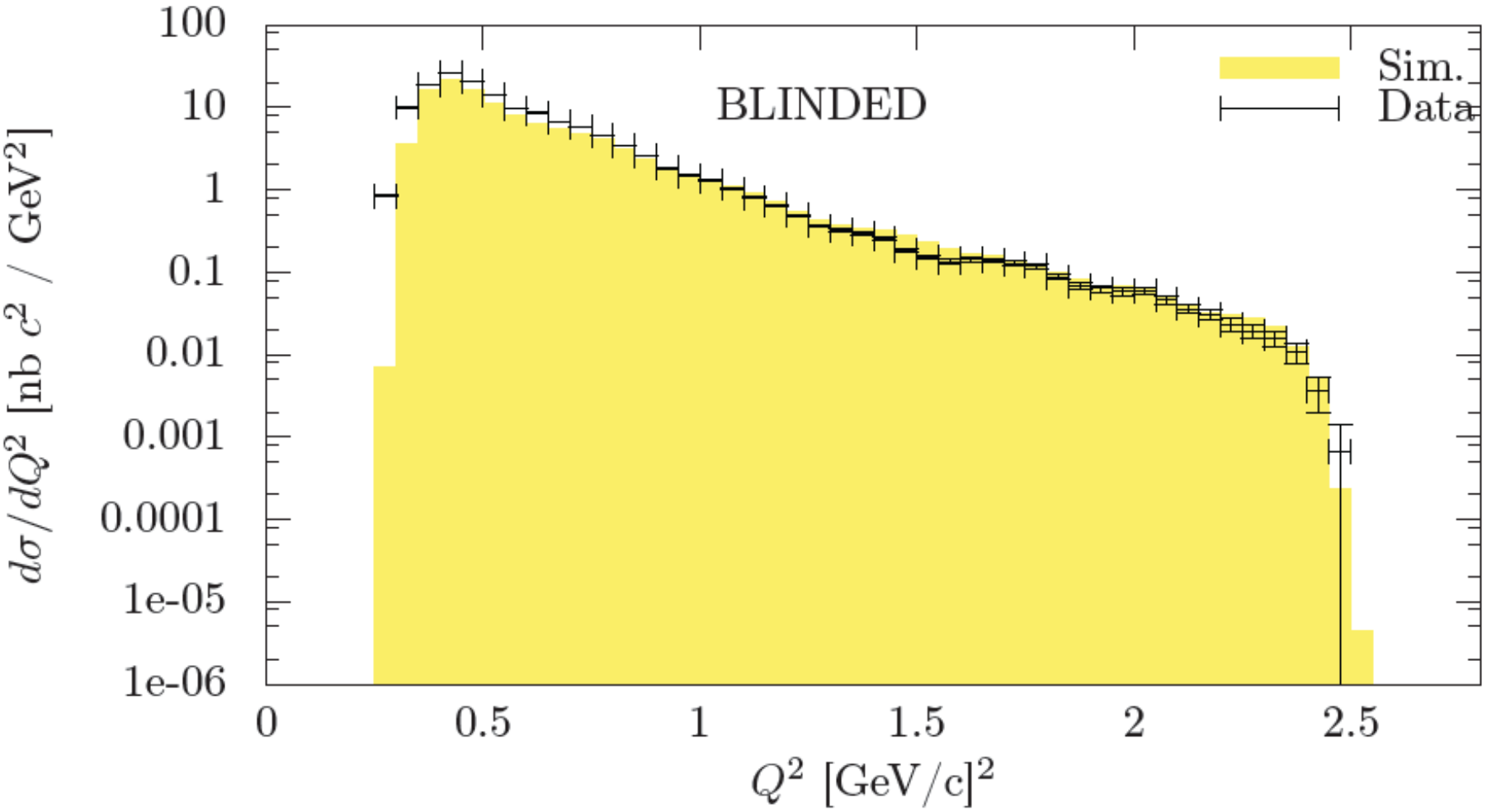


Cuts: Coplanarity, Vertex, Angular Correlation

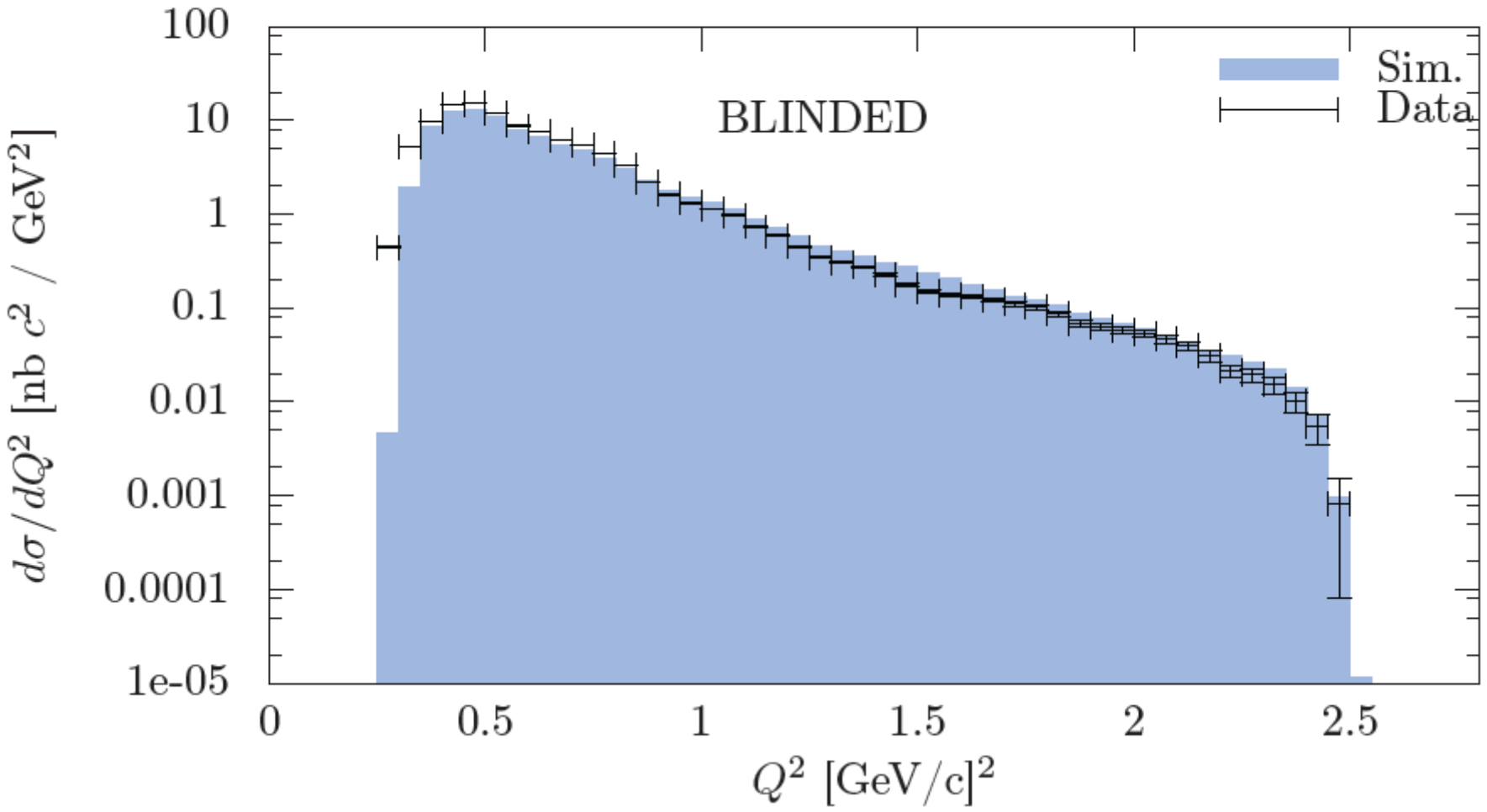
Analysis-Electron Yield ~2% of data



Analysis-Positron Yield ~2% of data



Electron + Positron Yield ~2% of data



Summary and Outlook

- Two-photon exchange most likely explanation for the discrepancy in the **proton form factor ratio**

- Results from JLab and Novosibirsk show two-photon effect
  - 2–4 % effect at $Q^2 < 1.5$ GeV^2 and small ε
  - some indication of $e^+p/e^-p < 1$ at large ε and small Q^2

- **OLYMPUS**
  - analysis being completed
  - data will span $0.35 < \varepsilon < 0.98$ and $0.25 < Q^2 < 2.5$ GeV^2
  - expect < 1 % uncertainty and absolute relative normalization
  - preliminary results by DNP 2015 meeting in Santa Fe

The OLYMPUS Collaboration

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MIT-Bates Linear Accelerator Center
St. Petersburg Nuclear Physics Institute
University of Bonn
University of Glasgow
University of Mainz
University of New Hampshire
Yerevan Physics Institute

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