

The OLYMPUS Experiment at DORIS Two Photon Exchange

Jürgen Diefenbach

Hampton University

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- 1 Motivation
- 2 OLYMPUS – Setup and First Data Taking
- 3 Summary

The Proton Electromagnetic Form Factors

The *proton*...

- ① carries electric charge
- ② has a sub-structure (resonances, μ_p , ...)

The Proton Electromagnetic Form Factors

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How is charge (and magnetization) distributed inside the proton?

Use elastic electron proton scattering

The Proton Electromagnetic Form Factors

Elastic electron proton scattering:

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega} \right)_{\text{Mott}} \frac{1}{1 + \tau} \left(G_M^2 + \frac{\epsilon}{\tau} G_E^2 \right)$$

$$\tau = Q^2/(4M_p^2), \quad \epsilon = (1 + 2(1 + \tau) \tan^2(\theta/2))^{-1}$$

with $G_E(Q^2)$ the electric and $G_M(Q^2)$ the magnetic form factor (FF) of the proton.

The Proton Electromagnetic Form Factors

First measurements: in 1950s (Hofstadter, SLAC)

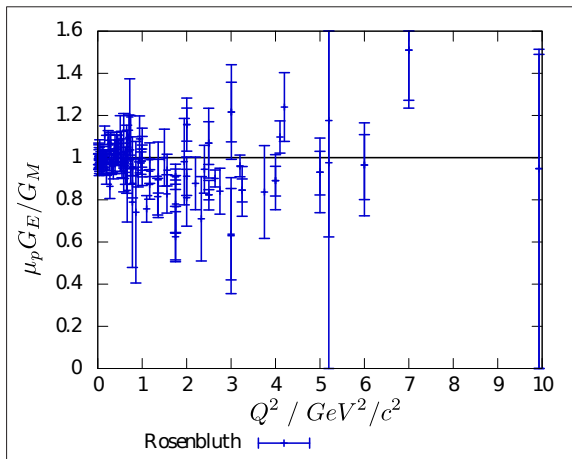
Separation of electric and magnetic FF:

- measurements at same Q^2 , different ϵ, τ
- different linear combinations of G_E^2, G_M^2
- separation of G_E^2, G_M^2 for one value of Q^2

Rosenbluth separation: >50 years of form factor measurements

Form Factor Ratio

Electric and magnetic FF seem to have same shape: (normalized)
ratio consistent with 1



Form Factor Ratio

Cross section is dominated by G_M^2 for high Q^2

Large uncertainty of ratio for high Q^2

$$\frac{1}{1 + \tau} \left(G_M^2 + \frac{\epsilon}{\tau} G_E^2 \right)$$

G_E^2 suppressed by $1/\tau \sim 1/Q^2$

Polarization Transfer I

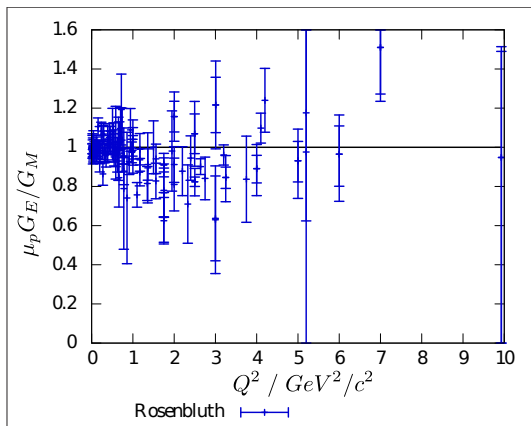
New technique used at Jefferson Lab in the 1990s:

- scattering of polarized electrons off unpolarized protons
- measure polarization of recoil protons
- transverse vs. longitudinal component $\sim$ FF ratio:

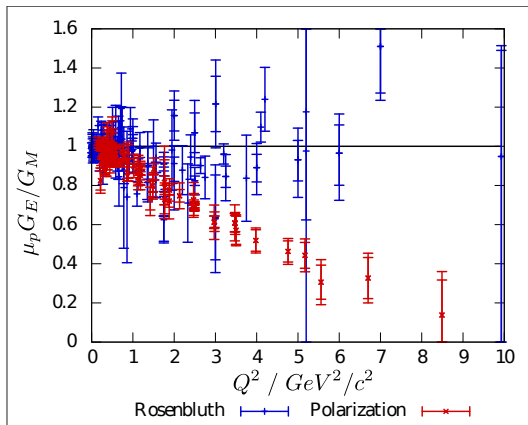
$$\frac{P_{\text{trans}}}{P_{\text{long}}} \sim \frac{G_E}{G_M}$$

► G_E no longer discriminated against G_M at higher Q^2

Polarization Transfer II

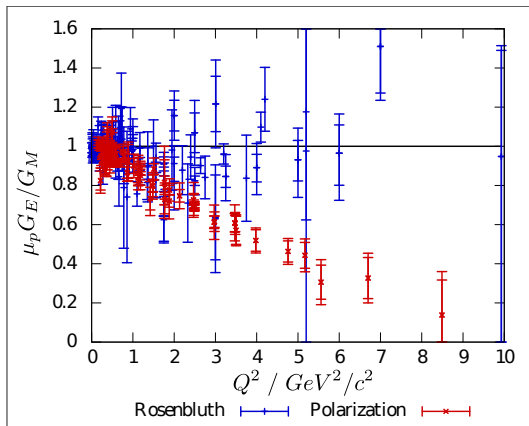


Polarization Transfer II



Discrepancy between Rosenbluth and Polarization Transfer!

Polarization Transfer II

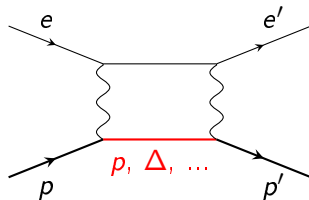
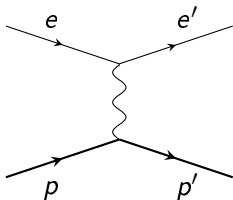


Discrepancy between Rosenbluth and Polarization Transfer!

Possible explanation: *Two Photon Exchange*

Two Photon Exchange

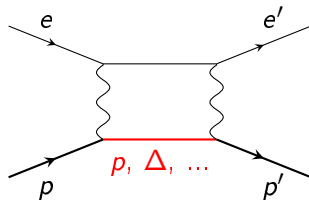
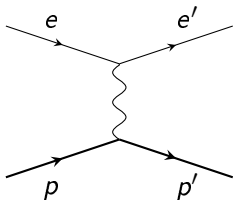
Rosenbluth method takes into account only single photon exchange...



... but two (multiple) photon exchange can contribute!

Two Photon Exchange

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... but two (multiple) photon exchange can contribute!

Direct access to two photon exchange amplitude?

Accessing the Two Photon Exchange Amplitude

Interference between single and two photon exchange

Sign depends on sign of lepton charge!

$$\sigma(e^- p) = |M_{1\gamma}|^2 \alpha^2 - 2 |M_{1\gamma}| |M_{2\gamma}| \alpha^3 + \dots$$

$$\sigma(e^+ p) = |M_{1\gamma}|^2 \alpha^2 + 2 |M_{1\gamma}| |M_{2\gamma}| \alpha^3 + \dots$$

Cross section ratio for elastic e^+ and e^- proton scattering:

$$R = \frac{\sigma(e^+ p)}{\sigma(e^- p)} = 1 + \frac{4 \Re(M_{1\gamma}^\dagger M_{2\gamma})}{|M_{1\gamma}|^2}$$

Measurement of Two Photon Contribution

Ingredients to determine two photon contribution:

- proton target
- electron / positron beam (switchable)
- detector to identify and count elastic events

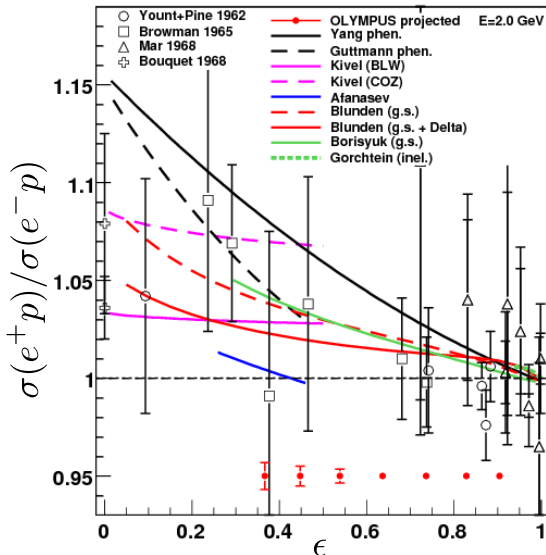
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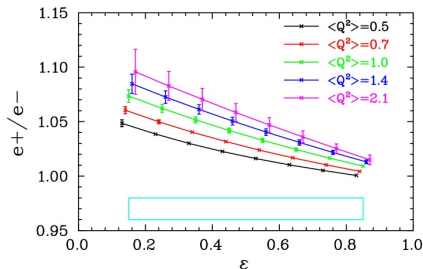
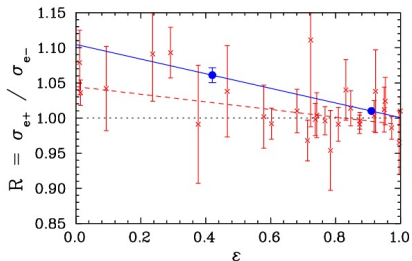
BLAST detector available since MIT Bates shutdown
DORIS storage ring for e^+ , could store e^- as well

Measurement of Two Photon Contribution



Measurement of Two Photon Contribution

Other Experiments (projected accuracies)



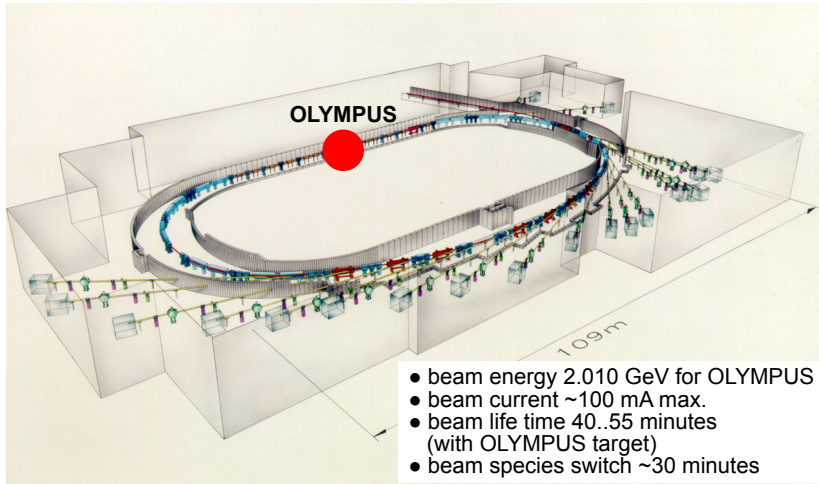
Novosibirsk experiment, VEPP-3

CLAS at Jefferson Lab

Timeline

- Proposal 09/2008
 - DOE funding 01/2010
 - BLAST shipped to DESY spring 2010
 - Modification of Interaction Region and
Test experiment @DORIS 02/2010
 - Detector assembly until 07/2011
 - Roll-in into DORIS 16.07.2011
 - OLYMPUS test beamtime in DORIS 08/2011
 - First data taking 01-02/2012
-
- Detector upgrades summer 2012
 - Second data taking 10-12/2012

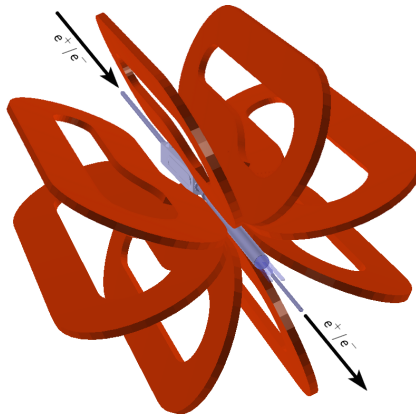
DORIS



OLYMPUS detector

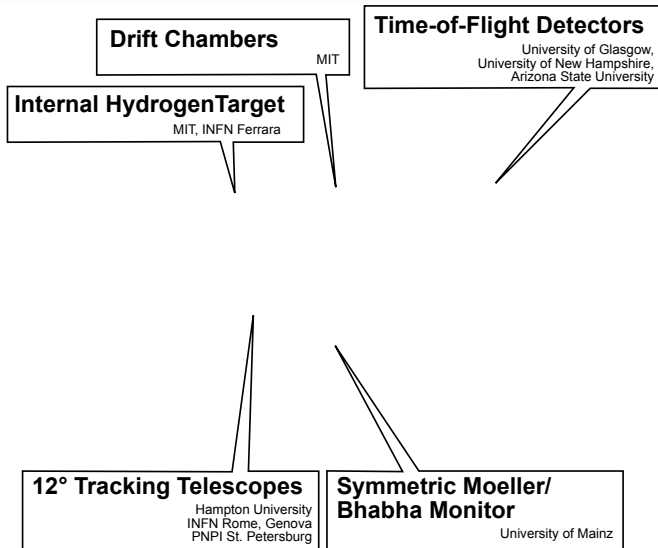
- Large acceptance detector:
 $20^\circ < \theta < 80^\circ$ and $-15^\circ < \phi < 15^\circ$
 $0.37 < \epsilon < 0.9$ and $0.6 < Q^2 < 2.2 \text{ (GeV}^2/\text{c}^2)$
- Toroidal magnetic field
- Left/right symmetric (two sectors)
- Time of flight scintillator walls
- Drift chambers for lepton and proton tracking
- Luminosity monitoring:
two independent systems:
 - 12° forward tracking telescopes (ep)
internally redundant (GEMs + MWPCs)
 - 1.2° very forward calorimeters (ee)

OLYMPUS detector



based on a figure by R. Russell

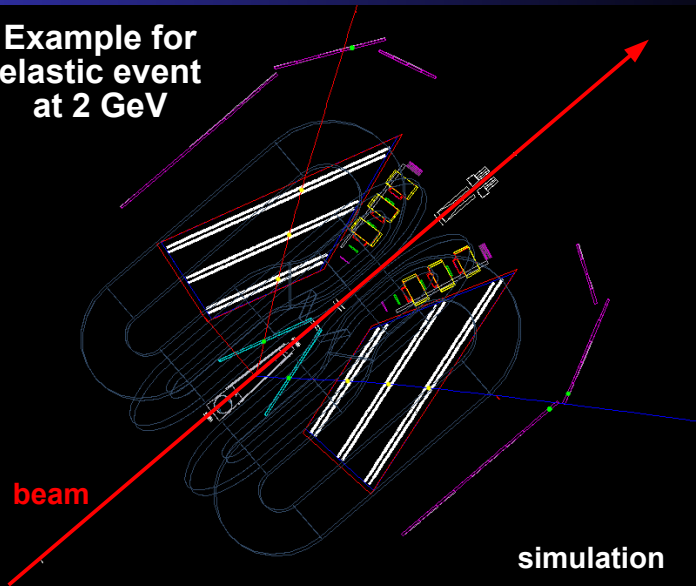
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OLYMPUS detector

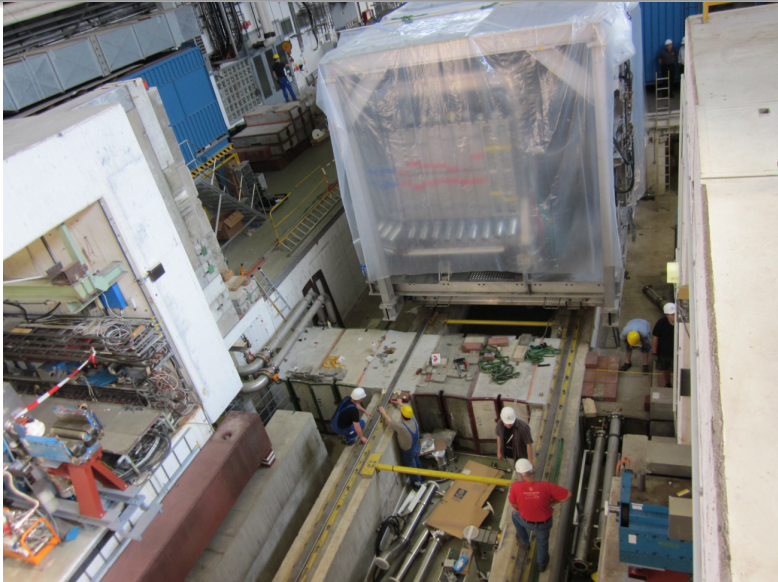
**Example for
 elastic event
 at 2 GeV**



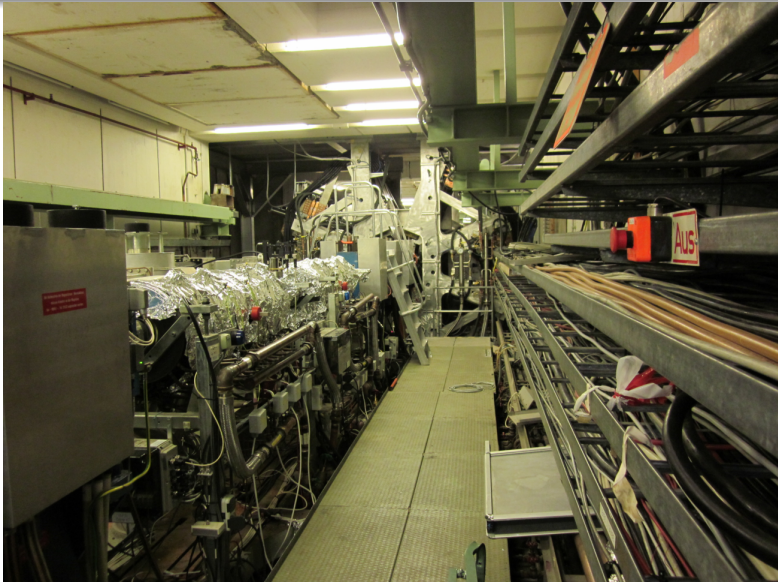
Roll-in I



Roll-in II

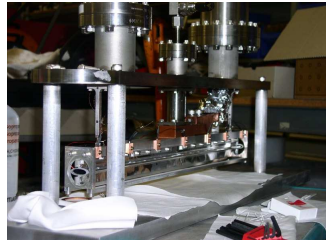


Roll-in III

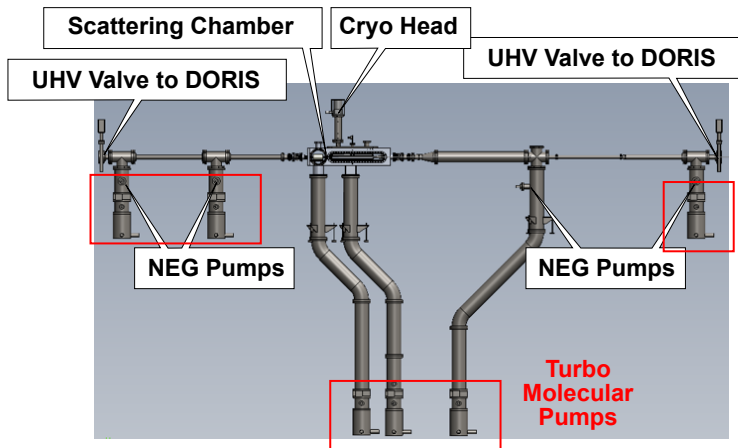


Target

- internal, windowless target
- 60 cm long storage cell
- elliptical cross section
27mm×9mm
- 100 μ m aluminum
- flows up to 1.0 sccm H₂
- $3 \cdot 10^{15}$ atoms/cm²
- cryo-cooled to 40K
- MIT, INFN Ferrara
- hydrogen generator
(electrolysis)



Target



Drift Chambers

- jet style drift cells
3 chambers per sector
- ~ 10000 wires in total
- 954 sense wires
- work well with ArCO₂ 90:10



Time of Flight Counters and Trigger

- 18 TOF bars per sector
- complete coverage of drift chamber acceptance
- ep elastic events: left & right coincidences
- top/bottom PMT readout for vertical impact position

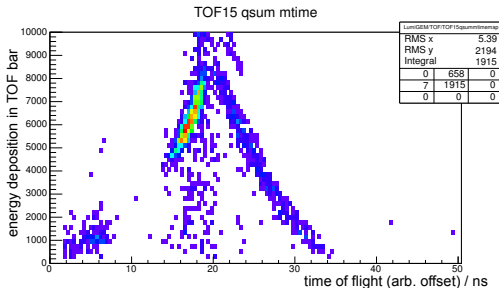
So far *kinematic trigger*: coincidence matrix for elastic ep kinematics
→ second level trigger to be implemented, open up first level trigger

Time of Flight Counters and Trigger

Example events with “lumi trigger” events (forward leptons):

Separation of fast (e^+, e^-)
and slow (**protons**)
particles by

- time of flight
 - energy deposition
- in a rear TOF bar (L15)



Luminosity Monitoring

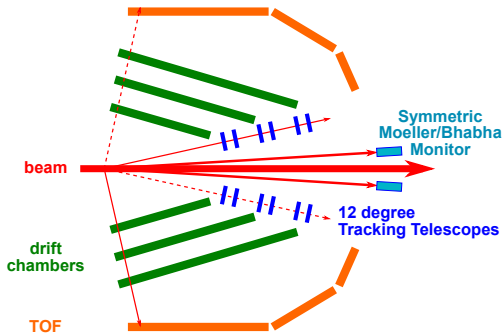
Cross section ratio

e^+/e^- switch once per day

Importance of (relative!) Luminosity Monitoring

Two independent systems:

- 12 degree tracking telescopes
- 1.2° symmetric Møller/Bhabha calorimeters



12 degree Tracking Telescopes

Detect leptons from elastic ep at 12° for luminosity monitoring:

- 12° corresponds to high ϵ
 → two photon contribution small
- proton in opposite sector drift chamber
- trigger: plastic scintillators on 12° arm (PNPI, DESY)
 efficiency monitoring by downstream lead glass detectors
 (alternative 12° trigger)
- tracking elements: 3 GEMs + 3 MWPCs per arm
 redundancy + efficiency monitoring

12 degree Tracking Telescopes

MWPCs (multi wire proportional chambers)
PNPI - St. Petersburg

MWPC

MWPC

MWPC

12° line

GEM

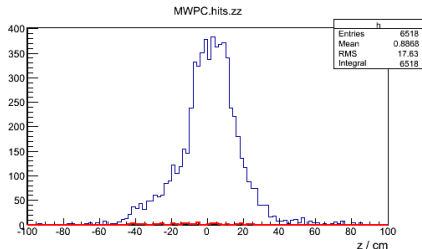
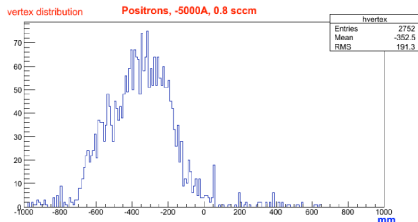
GEM

GEM

GEMs (gas electron multipliers)
Hampton University/MIT
INFN Rome, Genova

12 degree Tracking Telescopes

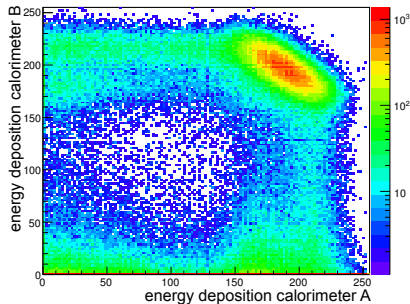
- GEM data first data taking period
- straight line tracks (ignoring magnetic field)
preliminary!
- MWPC data first data taking period
- Reconstructed vertex distribution
- Monte Carlo lookup table
- red: empty target run
preliminary!



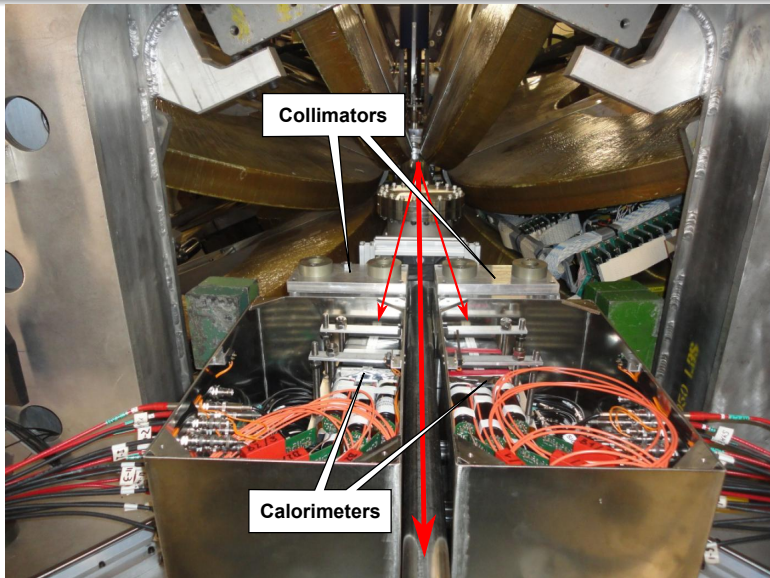
Symmetric Møller/Bhabha Monitor

Symmetric Møller and Bhabha scattering (and annihilation)

- pure QED $\rightarrow$ calculable
- completely independent from 12 degree monitors
- fast Cherenkov calorimeters with custom readout
20 ns dead time vs. 96 ns bunch spacing
 $\rightarrow$ quasi dead-time free
- left/right coincidence, 1 GeV each
- elastic ep, 2 GeV single arm for cross checks



Symmetric Møller/Bhabha Monitor



First Data Taking January, February 2012

- Routine switching between e^+ and e^-
- Routine switching of toroid polarity
- DORIS availability $\sim 90\%$

Integrated Luminosity / a.u.

average data taking
efficiency 50 %
(as anticipated)

J. Bernauer

Summary

Unique combination of OLYMPUS and DORIS:

- OLYMPUS aims to determine the contribution of two photon exchange to elastic ep scattering on the percent level

First data taking period in February successful:

- All detectors operational
- Routine switching of magnet and beam species established
- Anticipated data taking efficiency reached (although some commissioning was still done)

Data analysis ongoing

Detector upgrades for second production run (end of 2012)

Outlook

Planned upgrade and improvements:

- GEM tracker (+redundancy, +momentum resolution for tracking)
- Second level trigger (+lifetime, +statistics, +kinematic range)
- Lumi trigger upgrade (+efficiency monitoring, +stability, +redundancy)

Looking forward to second data taking period

Two months: November + December 2012
will give more than $2\times$ statistics of 1st run

OLYMPUS Collaboration

- Arizona State University, USA
- DESY, Deutschland
- Hampton University, USA
- INFN Bari, Ferrara, Rome, Italy
- MIT, USA
- Petersburg Nuclear Physics Institute, Russia
- Universität Bonn, Germany
- Universität Mainz, Germany
- University of Glasgow, UK
- University of New Hampshire, USA
- Yerevan Physics Institute, Armenia