The OLYMPUS Experiment at DORIS
Two Photon Exchange

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The Proton Electromagnetic Form Factors

The *proton*...

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

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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:

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

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

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)

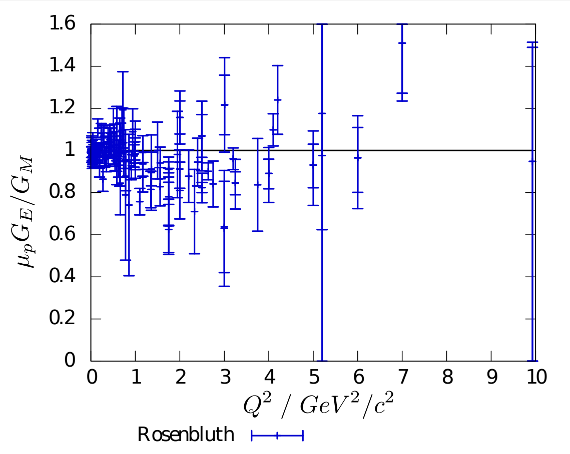
Separation of electric and magnetic FF:

- 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 supressed by $1/\tau \sim 1/Q^2$

Polarization Transfer I

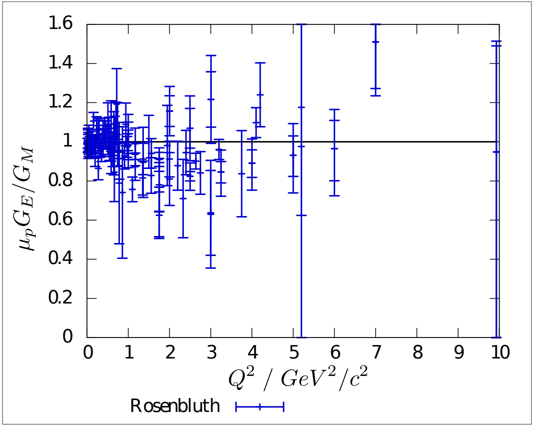
New technique used at Jefferson Lab in the 1990s:

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

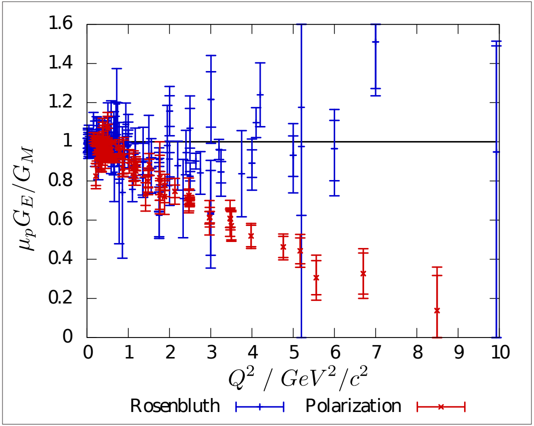
$$\frac{P_{\text{trans}}}{P_{\text{long}}} \sim \frac{G_E}{G_M}$$

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

Polarization Transfer II

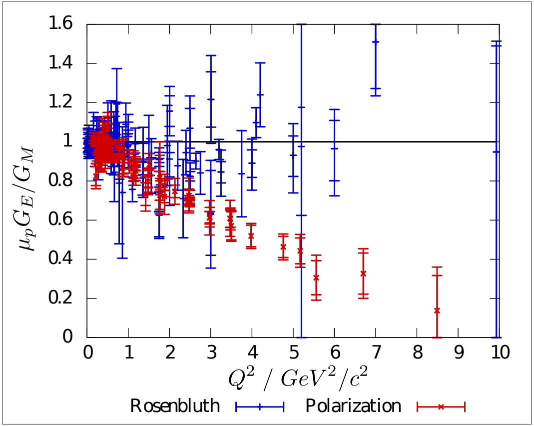


Polarization Transfer II



Discrepancy between Rosenbluth and Polarization Transfer!

Polarization Transfer II

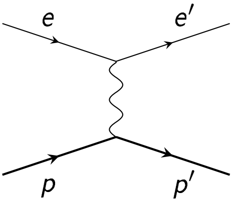


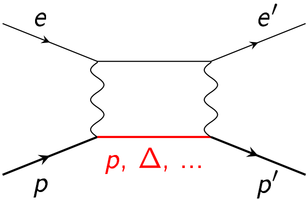
Discrepancy between Rosenbluth and Polarization Transfer!

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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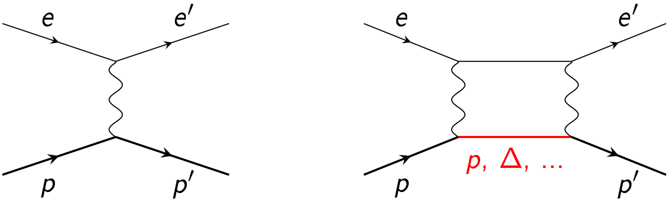

... but two (multiple) photon exchange can contribute!

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!

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

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

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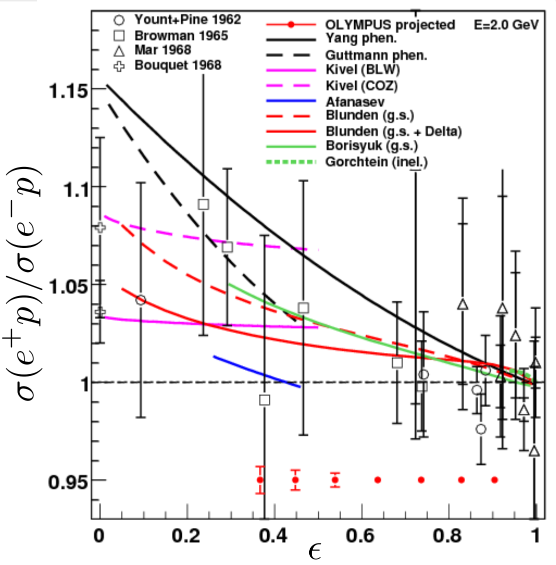
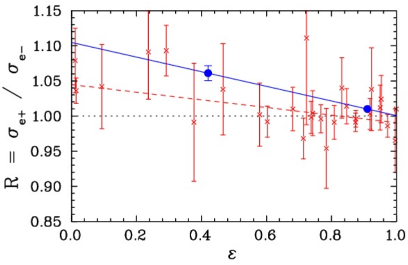
BLAST detector available since MIT Bates shutdown
DORIS storage ring for e^+, could store e^- as well

Measurement of Two Photon Contribution

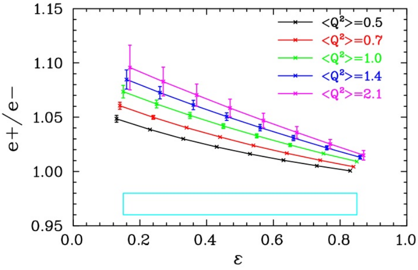


Measurement of Two Photon Contribution

Other Experiments (projected accuracies)



Novosibirsk experiment, VEPP-3

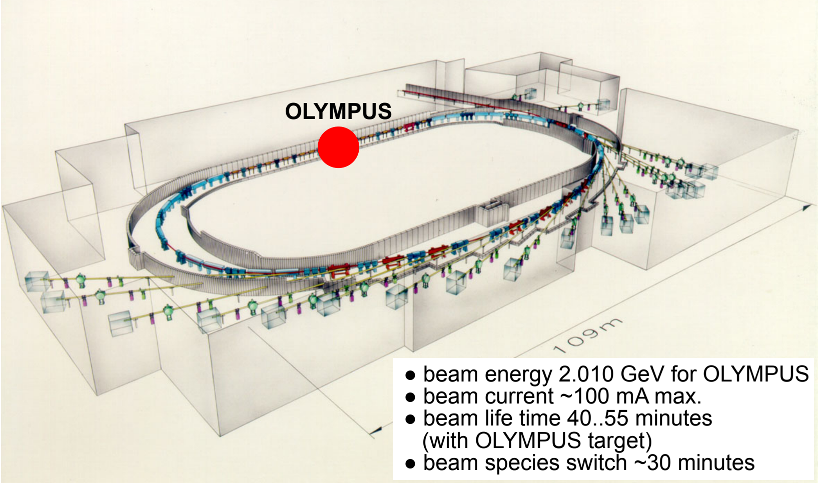


CLAS at Jefferson Lab

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

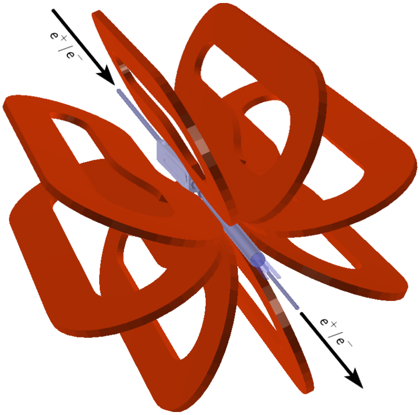


- beam energy 2.010 GeV for OLYMPUS
- beam current ~100 mA max.
- beam life time 40..55 minutes (with OLYMPUS target)
- beam species switch ~30 minutes

OLYMPUS detector

- Large acceptance detector:
  $20^\circ < \theta < 80^\circ$ and $-15^\circ < \phi < 15^\circ$
  $0.37 < \epsilon < 0.9$ and $0.6 < Q^2 < 2.2$ ($\mathrm{GeV}^2/\mathrm{c}^2$)
- 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

OLYMPUS detector

Drift Chambers
MIT

Time-of-Flight Detectors
University of Glasgow,
University of New Hampshire,
Arizona State University

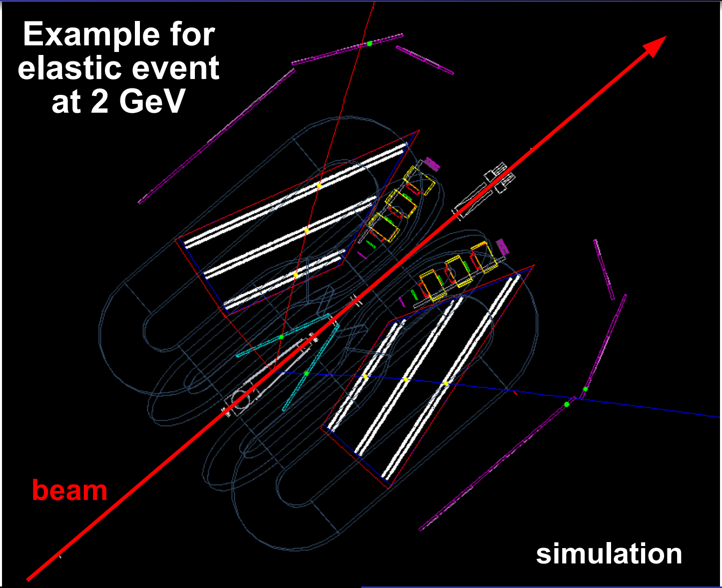
Internal HydrogenTarget
MIT, INFN Ferrara

12° Tracking Telescopes
Hampton University
INFN Rome, Genova
PNPI St. Petersburg

Symmetric Moeller/ Bhabha Monitor
University of Mainz

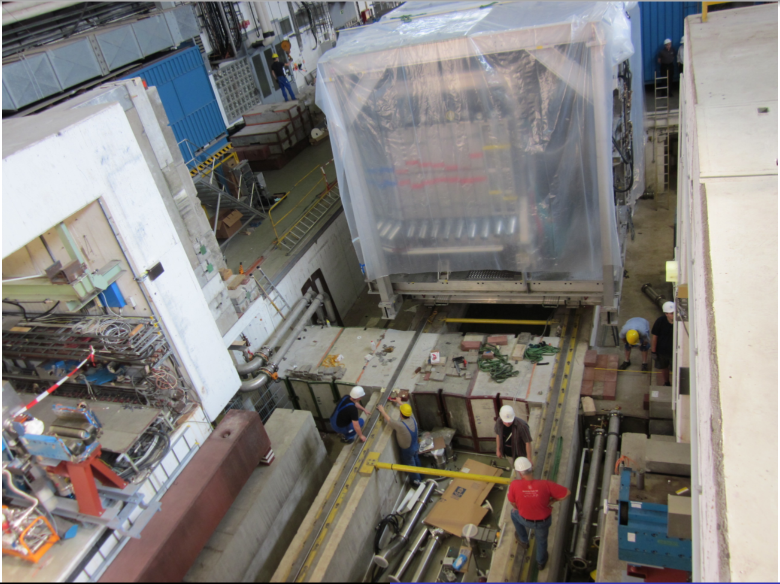
based on a figure by R. Russell

OLYMPUS detector

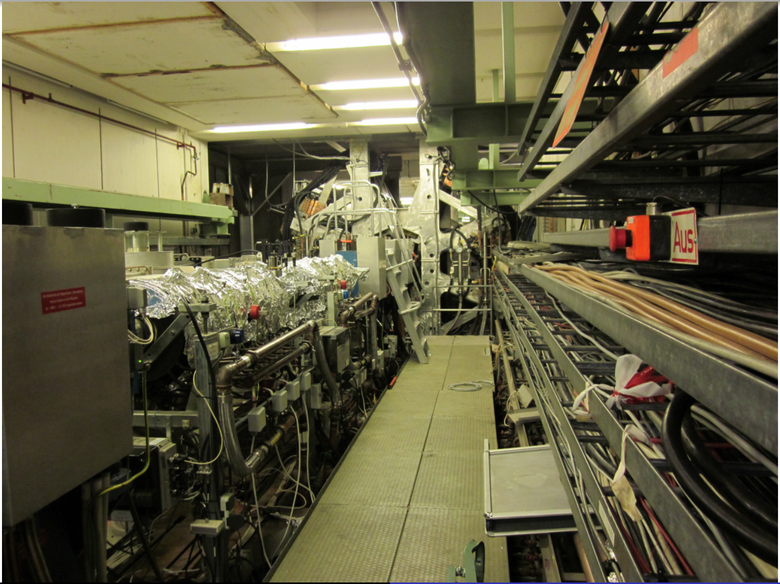


Roll-in I

Roll-in II

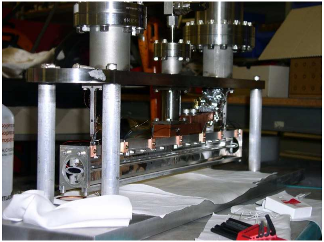


Roll-in III

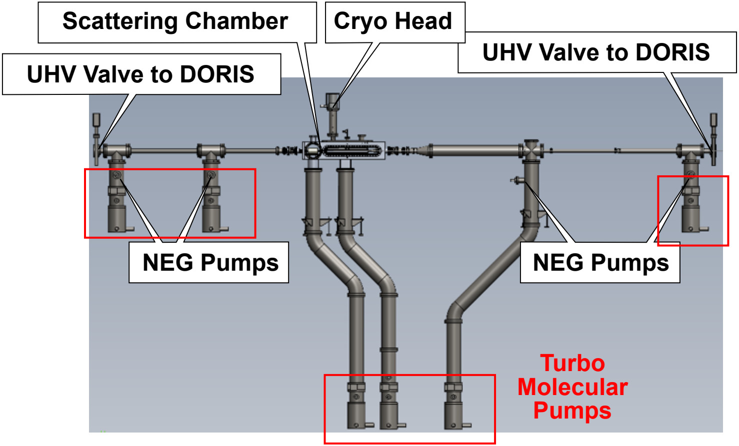


Target

- internal, windowless target
- 60 cm long storage cell
- elliptical cross section 27mm×9mm
- 100μm aluminum
- flows up to 1.0 sccm H_2
- $3 \cdot 10^{15}$ atoms/cm^2
- cryo-cooled to 40K
- MIT, INFN Ferrara
- hydrogen generator (electrolysis)



Target


Scattering Chamber
Cryo Head
UHV Valve to DORIS
UHV Valve to DORIS
NEG Pumps
NEG Pumps
Turbo Molecular Pumps

Drift Chambers

- jet style drift cells
  3 chambers per sector
- ~10000 wires in total
- 954 sense wires
- work well with $ArCO_2$ 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
$\longrightarrow$ second level trigger to be implemented, open up first level trigger

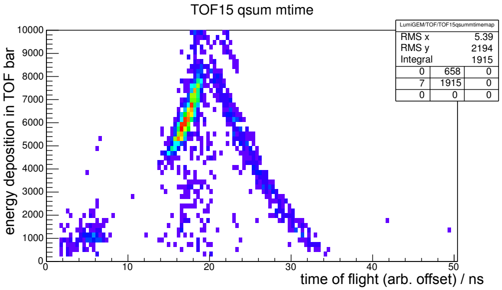
Time of Flight Counters and Trigger

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)

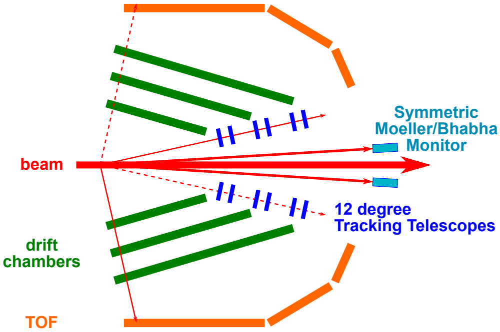


Luminosity Monitoring

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



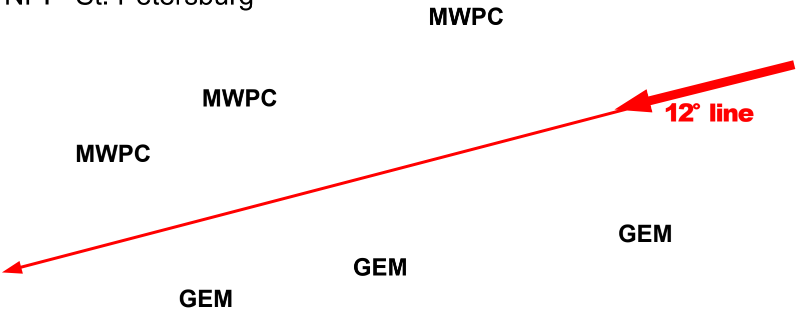
12 degree Tracking Telescopes

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

- 12° corresponds to high ϵ
  $\rightarrow$ 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

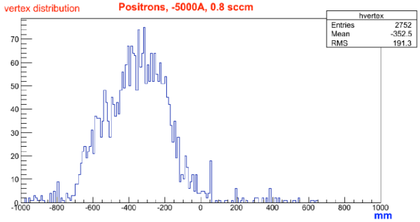
MWPCs (multi wire proprotional chambers)
PNPI - St. Petersburg



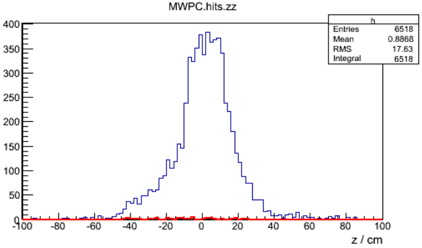
GEMs (gas electron multipliers)
Hampton University/MIT
INFN Rome, Genova

12 degree Tracking Telescopes

- GEM data first data taking period
- straight line tracks (ignoring magnetic field) preliminary!



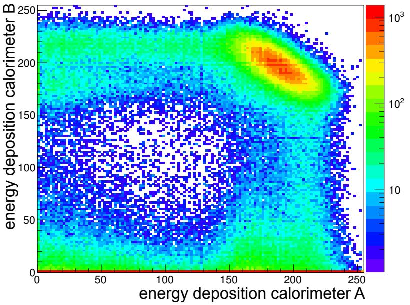
- MWPC data first data taking period
- Reconstructed vertex distribution
- Monte Carlo lookup table
- red: empty target run preliminary!



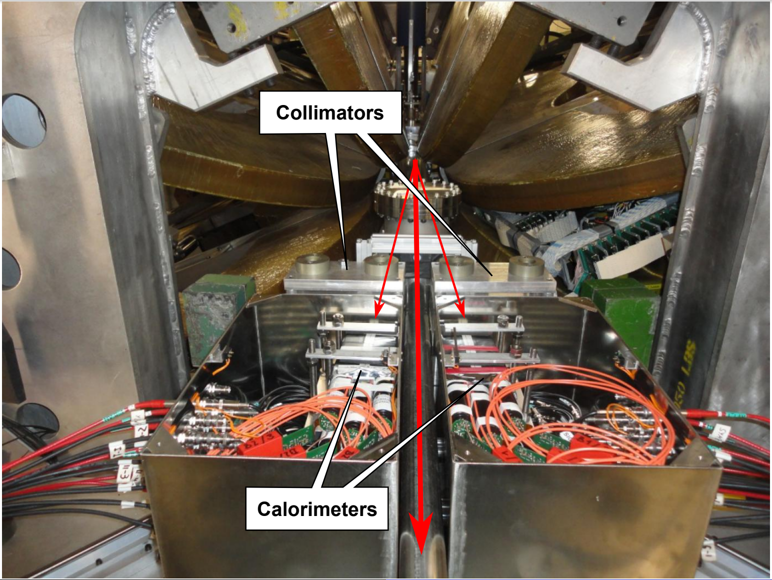
Symmetric Møller/Bhabha Monitor

Symmetric Møller and Bhabha scattering (and annihilation)

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



Symmetric Møller/Bhabha Monitor



First Data Taking January, Februrary 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 (+livetime, +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× statistics of 1st run

OLYMPUS Collaboration

- Arizone 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