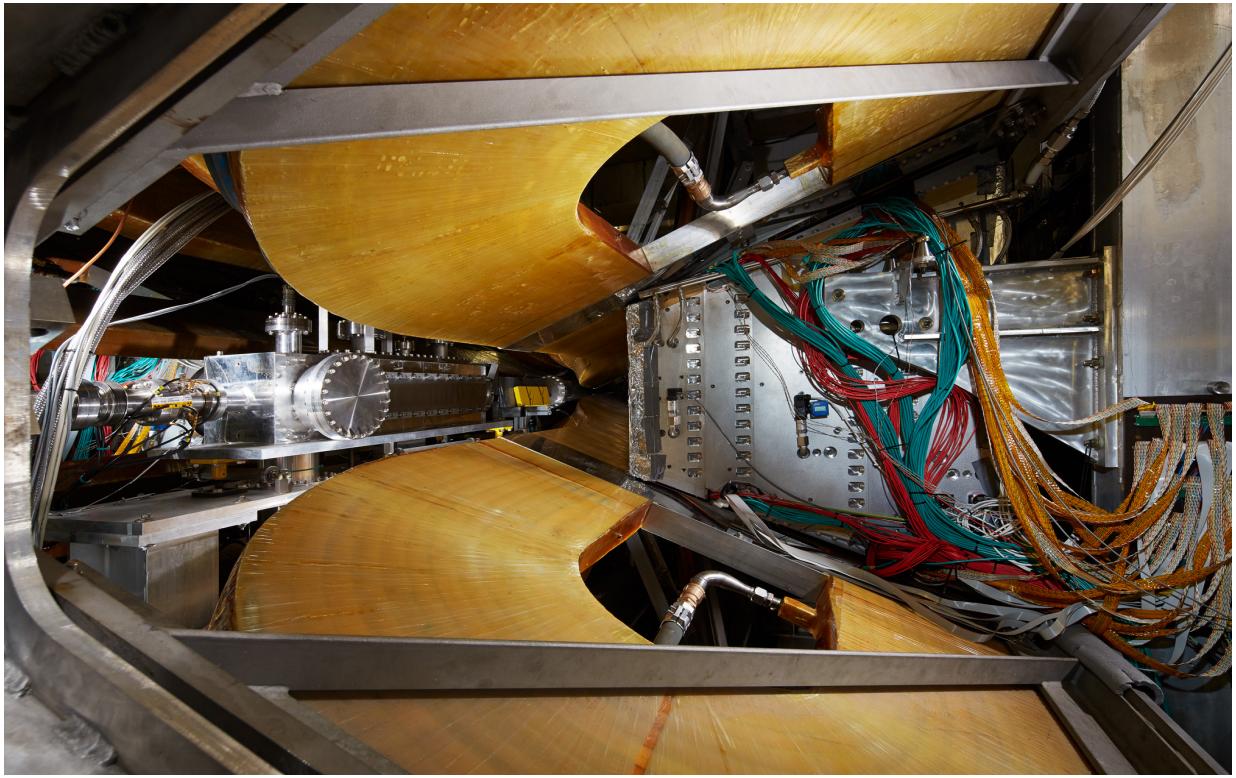
Two-Photon Exchange in Electron Proton Scattering - Status of OLYMPUS Experiment at DESY



PHOTON 2015
Novosibirsk

Uwe Schneekloth, DESY

on behalf of the
OLYMPUS Collaboration

HELMHOLTZ ASSOCIATION

DESY

Outline

- Introduction and Motivation
- Overview of the Experiment
- Schedule
- Data Taking Periods
- Performance
- Radiative Corrections
- Status of Analysis
- Conclusions

Elastic e N Scattering/Form Factors

Nucleon elastic form factors: electric G_E and magnetic G_M

- Fundamental observables describing distribution of charge and magnetism in proton and neutron
- Described by quark structure of proton
- Will be calculable in lattice QCD
- For ~ 50 years unpolarized cross section measurements have determined G^p_E and G^p_M using the Rosenbluth separation

$$\frac{d\sigma/d\Omega}{(d\sigma/d\Omega)_{Mott}} = \frac{\sigma}{\sigma_0} = A(Q^2) + B(Q^2)\tan^2\frac{\theta}{2}$$

$$= \frac{G_E^2(Q^2) + \tau G_M^2(Q^2)}{1+\tau} + 2\tau G_M^2(Q^2)\tan^2\frac{\theta}{2}$$

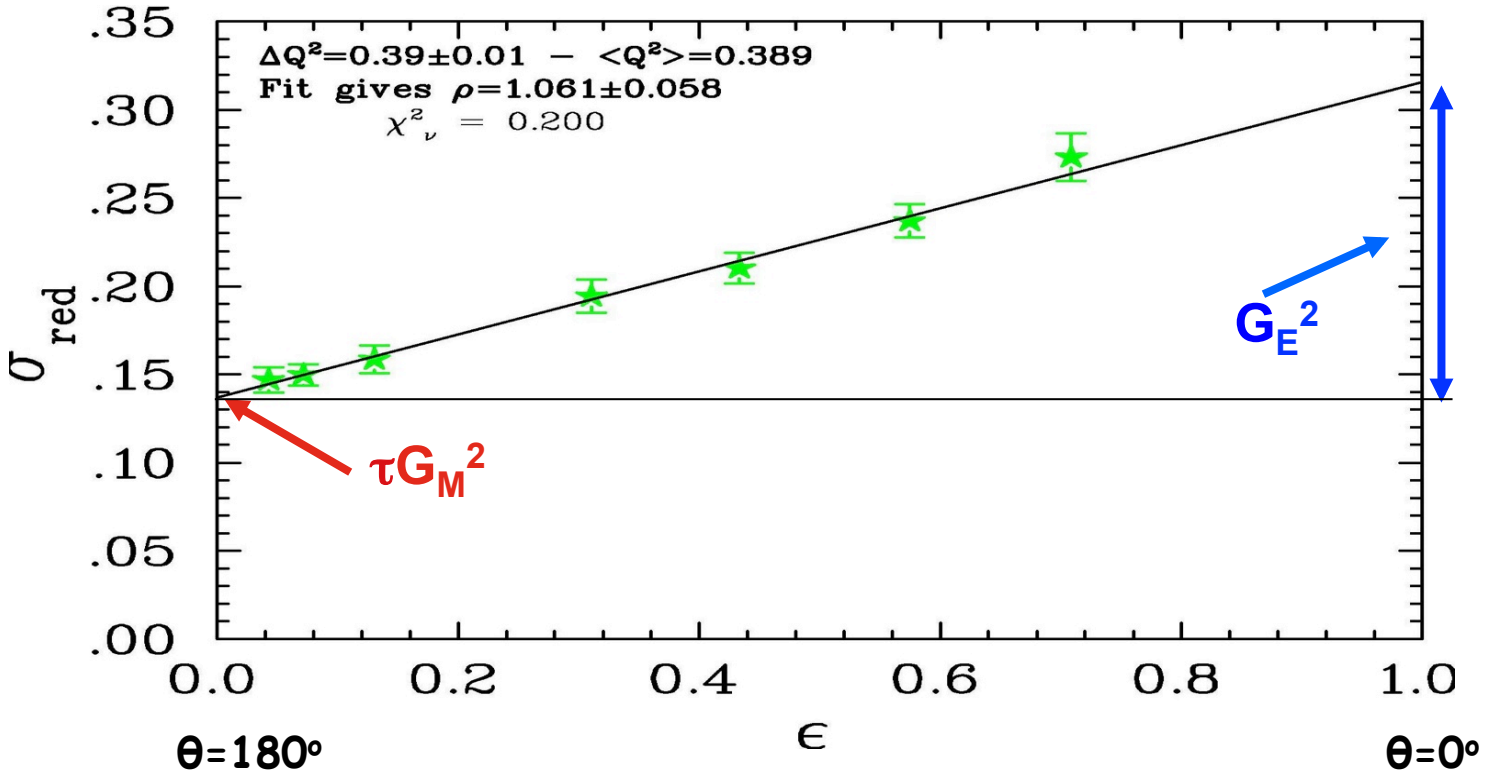
$$\sigma_{red} = \frac{d\sigma}{d\Omega}\frac{\varepsilon(1+\tau)}{\sigma_{Mott}} = \tau G_M^2 + \varepsilon G_E^2$$

$$\tau = Q^2/4M_p^2 \qquad \varepsilon = \left[1 + 2(1+\tau)\tan^2\theta/2\right]^{-1}$$

(ε transverse virtual photon polarization)

Form Factors - Rosenbluth Method

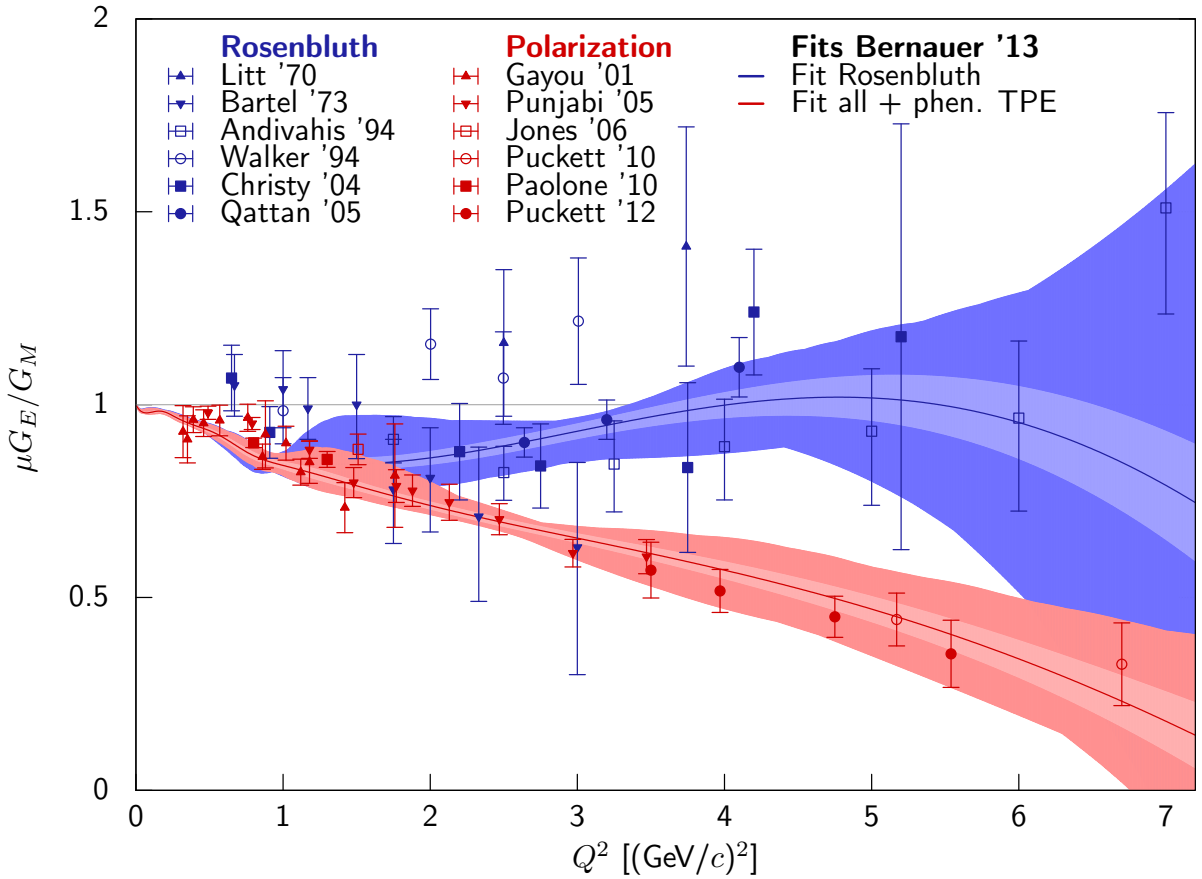
Reduced cross section $\sigma_{red} = \varepsilon G_E^2 + \tau G_M^2$



➔ Determine $|G_E|$, $|G_M|$,$|G_E/G_M|$

Motivation of OLYMPUS Experiment

Proton Form Factor Ratio

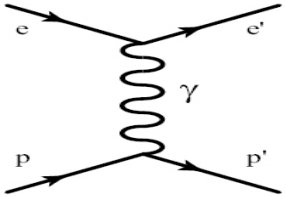


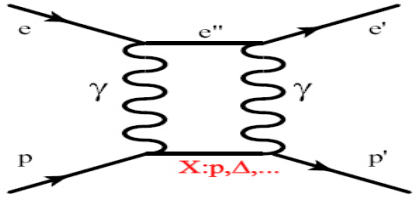
- All Rosenbluth data in agreement
- Dramatic discrepancy between Rosenbluth and recoil polarization technique
  - Jefferson Lab data (>800 citations) polarized beam and target
- Interpreted as evidence for two photon contribution to elastic scattering

Motivation of OLYMPUS Experiment

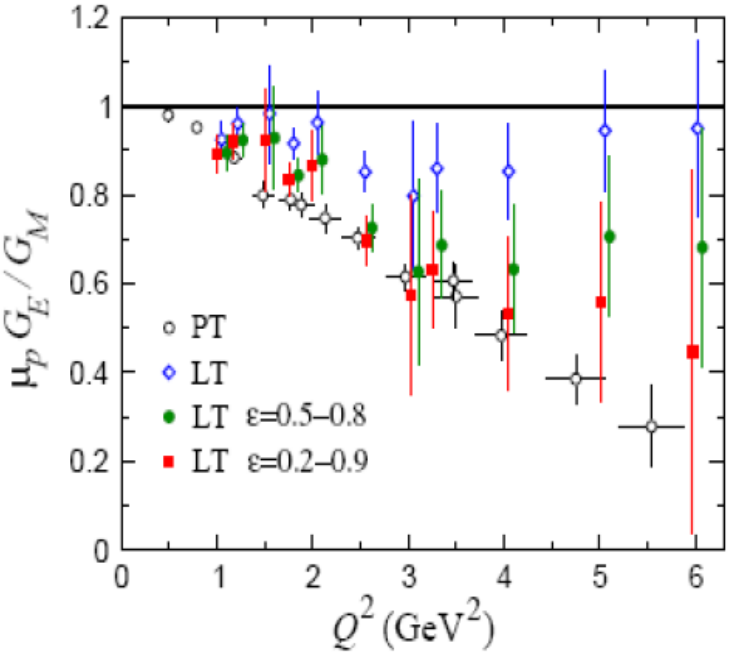
Two-Photon-Exchange

- Large theoretical model uncertainties
- Only experiment can definitively resolve the contributions beyond single photon exchange
- Determine TPE by measuring ratio of e^+p/e^-p, i.e. ratio of rates, no absolute cross section measurements





P.G. Blunden et al.



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

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

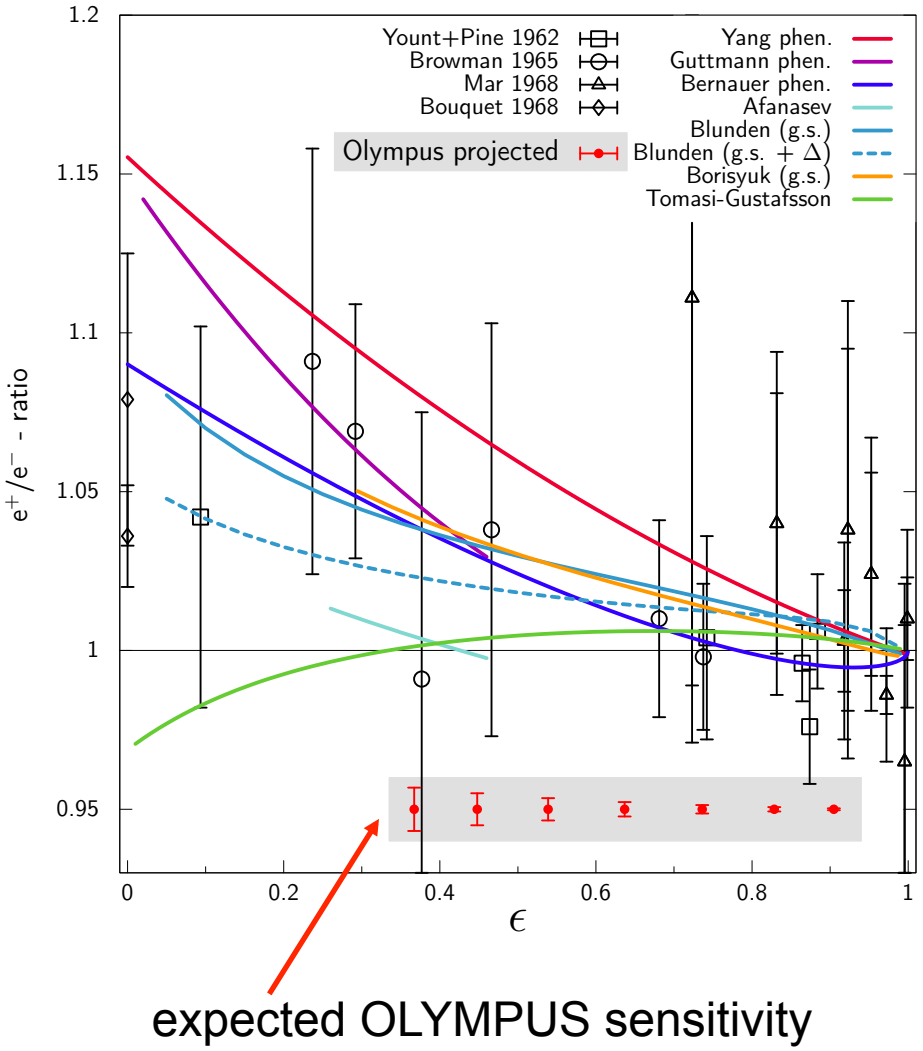
$$R = \frac{\sigma(e^+ p)}{\sigma(e^- p)} = 1 + \frac{4\,\Re(M_{1\gamma}^{\dagger} M_{2\gamma})}{|M_{1\gamma}|^2}$$

OLYMPUS Experiment at DORIS

Elastic $e^+(e^-)$ p scattering at 2 GeV beam energy

- Measure ratio of e^+p/e^-p rates with 1% precision
- DORIS 100 mA $e^+(e^-)$ beam
- Unpolarized internal hydrogen target, density 3 x 10^{15} at/cm^2
- Daily change of beam (e^+ or e^-) to minimize systematic error
- Redundant luminosity measurements
- Using former BLAST detector from MIT/ Bates. Ideally suited.

Comparison of data and theory

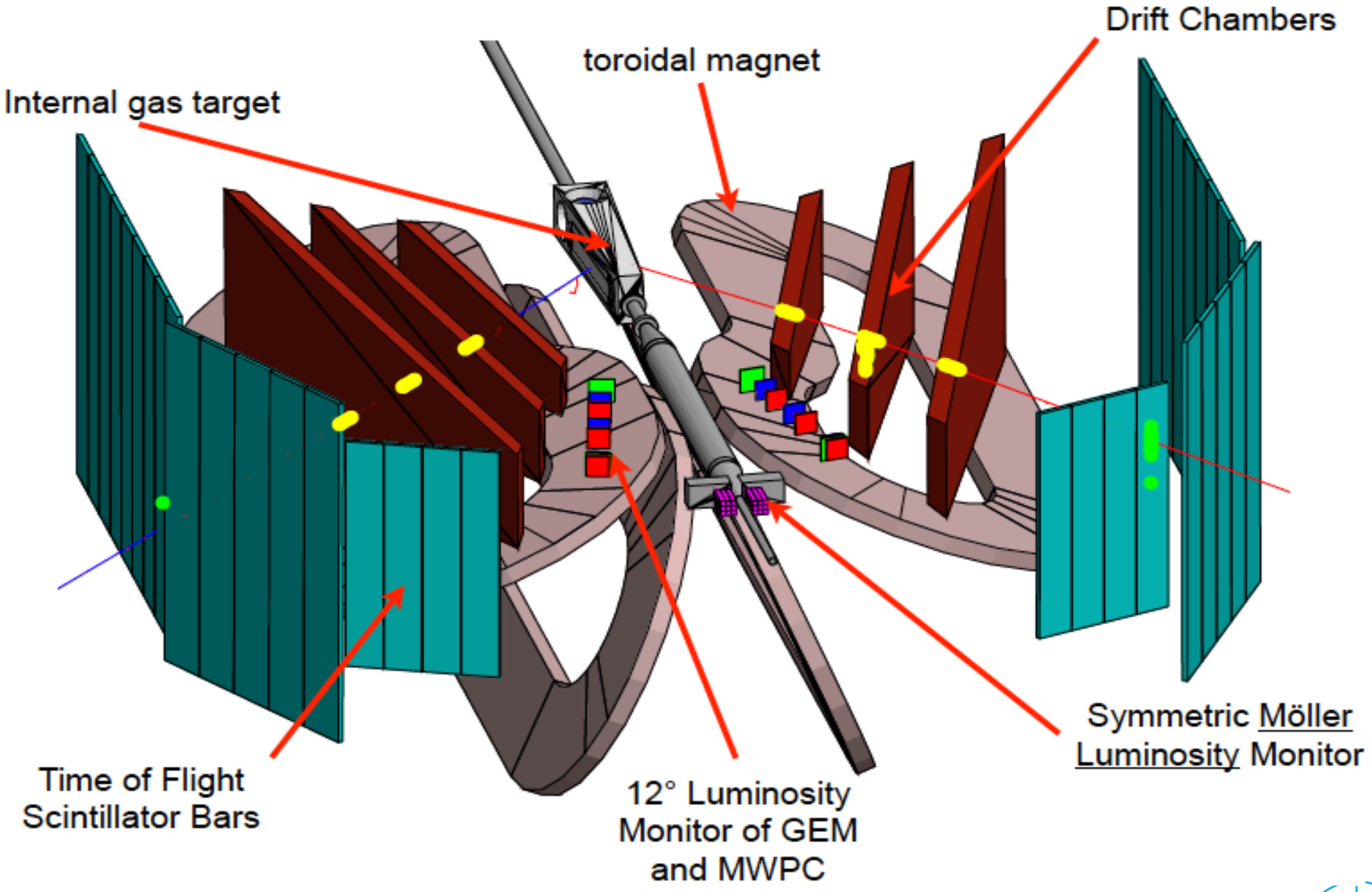


expected OLYMPUS sensitivity

Schedule and Progress

- 2010: Blast detector shipped from MIT to DESY, assembled in parking position
- 2011
  - February: Interaction region modified, test experiment
  - Summer: Detector moved in to beam position
- 2012 data taking
  - February: first data taking period
  - Fall: second data taking period 22.10.2012 – 2.01.2013
  - Exceeded integrated luminosity: design 3.6 fb^{-1}, achieved 4.45 fb^{-1}
- 2013
  - Cosmic ray run
  - Complete survey
  - New magnetic field map
  - Beam position monitor calibration
  - Reconstruction/data analysis
- 2014/15: Reconstruction/data analysis

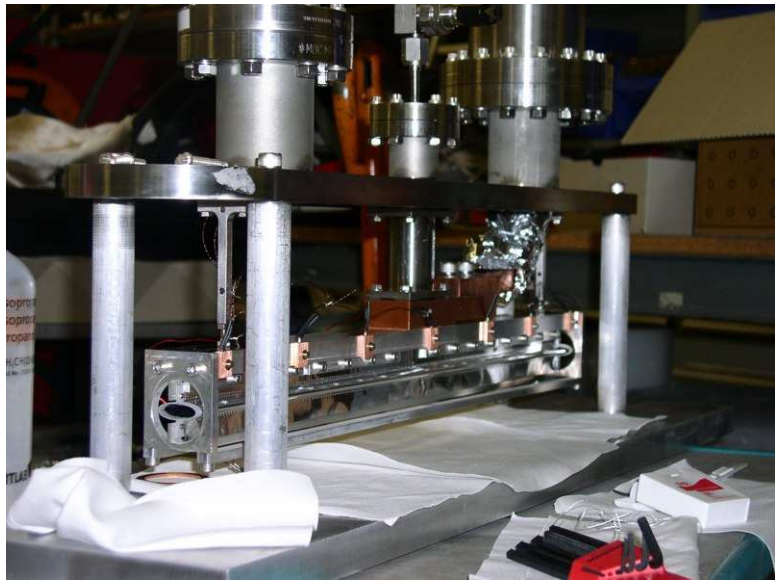
Detector Overview



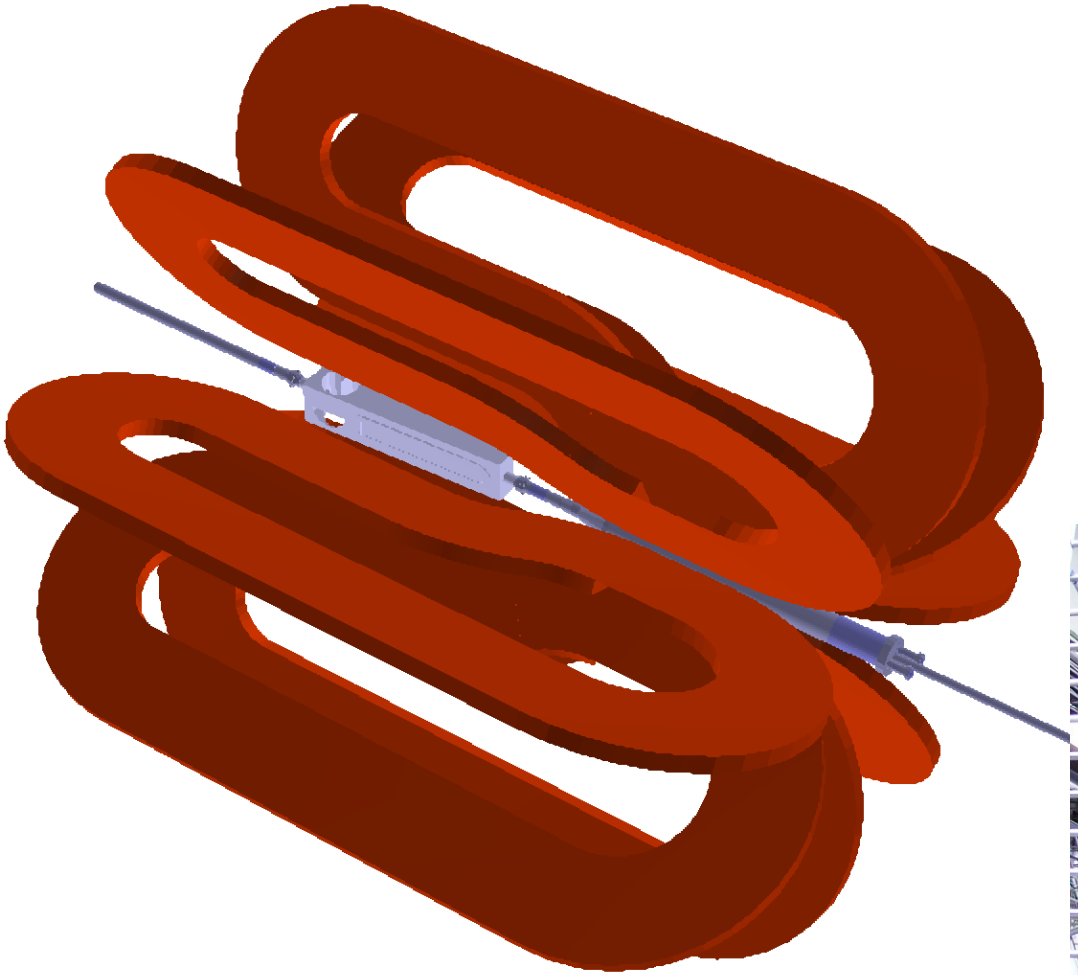
Target System

- Internal, windowless gas target
- 60 cm long storage cell
- Elliptical cross section (27 mm x 9 mm)
- 100 µm thick aluminum wall
- H_2 flows up to 1 sccm
- Cryo cooled ~45 K
- $O(10^{15})$ atoms/cm^2
- Hydrogen produced by generator (electrolysis)

INFN Ferrara, MIT

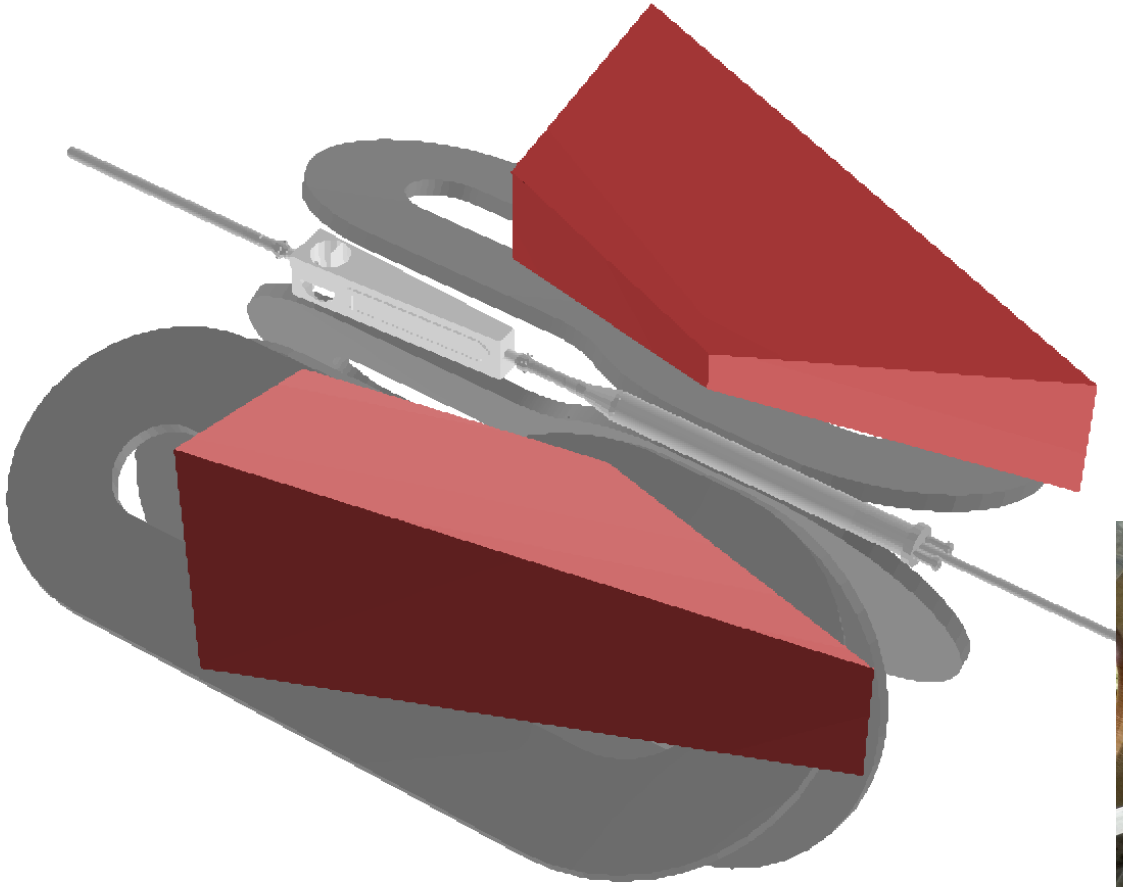


Toroidal Magnet



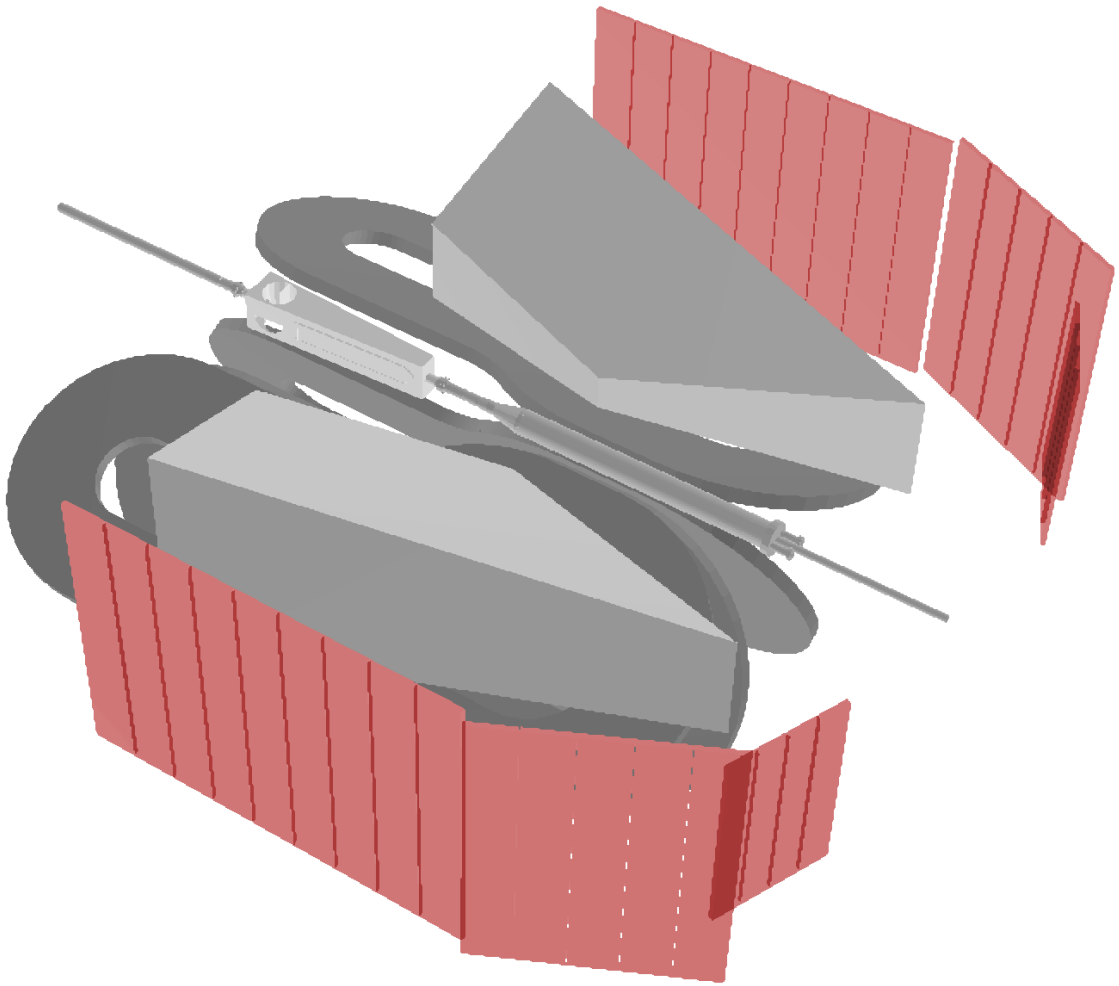
- 8 air coils from BLAST
- Operating at reduced field
- Positive and negative polarity
- Maximum field 0.28 T

Drift Chambers



- Two chambers, trapezoidal shape
- Jet-style drift cells
- 5000 wires each
- Tracks with 18 hits
- 10^{o} stereo angle

Time – of - Flight Counters



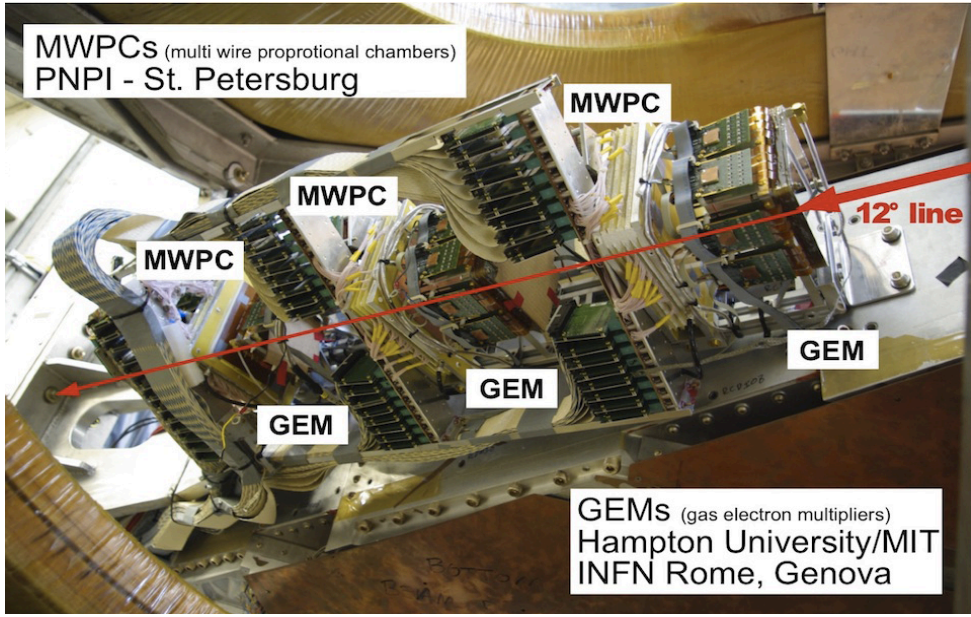
- Scintillation counters from BLAST
- Trigger
  - Top/bottom coincidence
  - Kinematic constraint
  - + 2nd level wire chamber
- Time-of-flight for particle ID

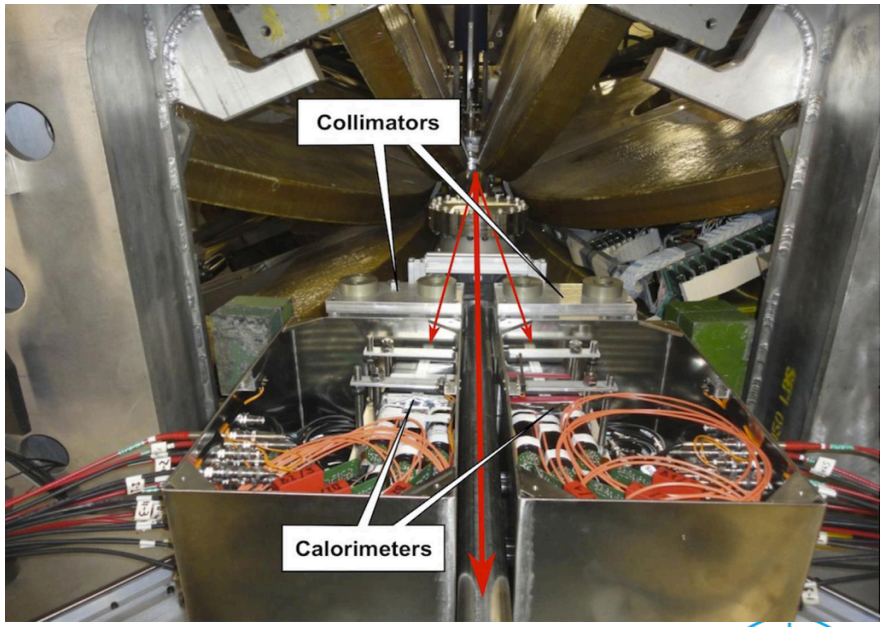
Luminosity Determination

Three independent measurements

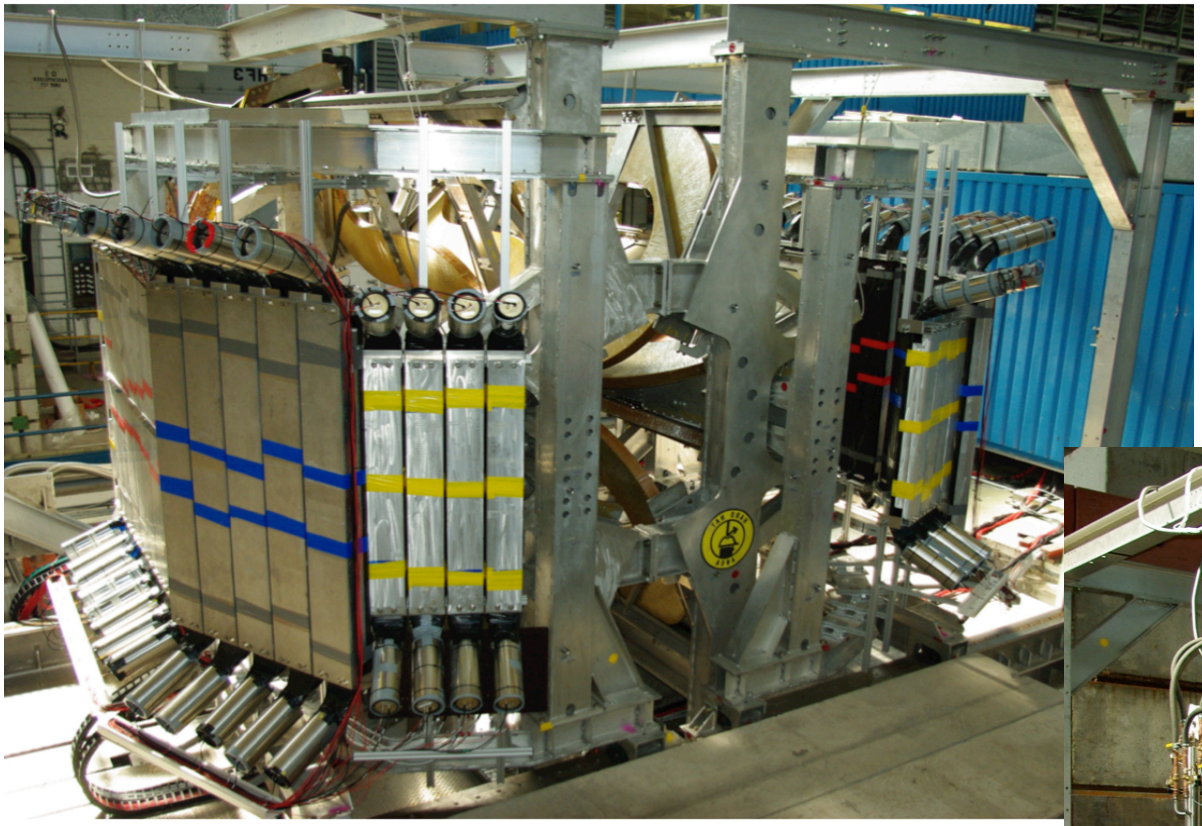
- Slow Control
  - Beam current and target density
  - 15 - 20% absolute uncertainty, relative <5%
- Tracking telescopes at 12°
  - Elastic ep scattering at small angles
  - Two independent sectors with independent tracking systems: MWPCs and GEMs
  - Use combined information or separately for cross checks
- Møller/Bhabha monitor at 1.3°
  - High statistics measurement, no dead time

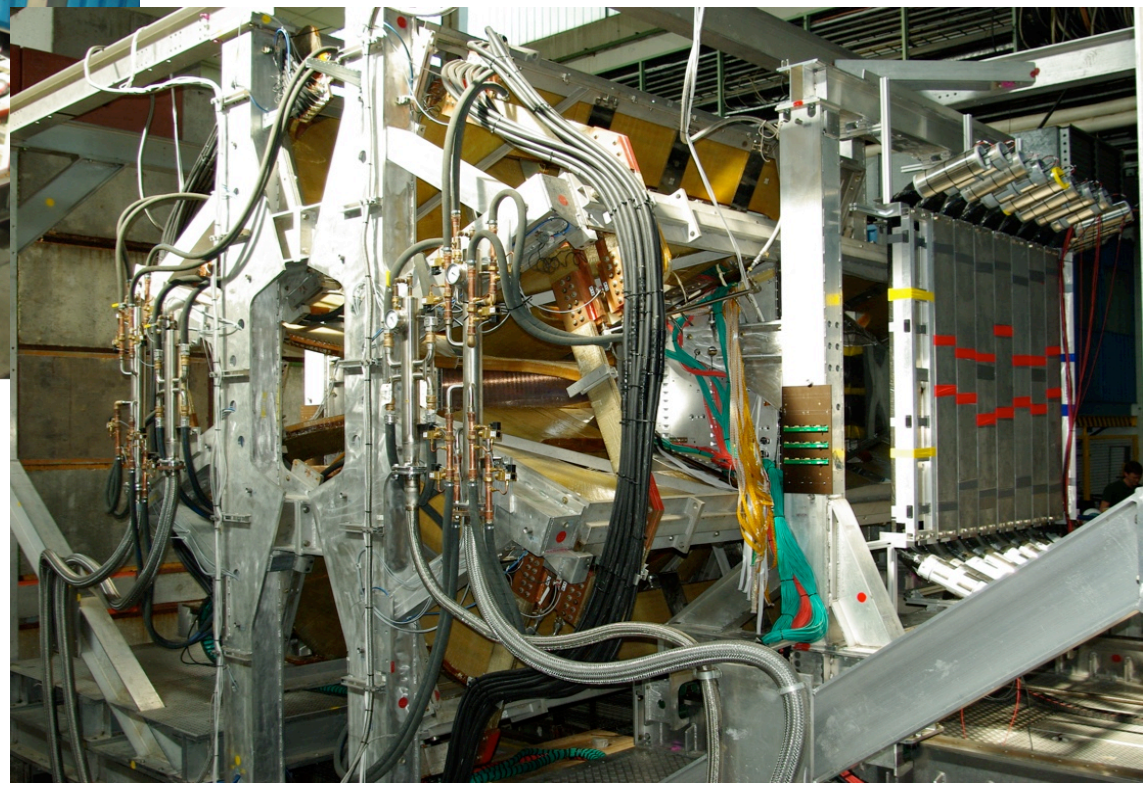
Need e^+p/e^-p luminosity ratio, not precise absolute luminosity



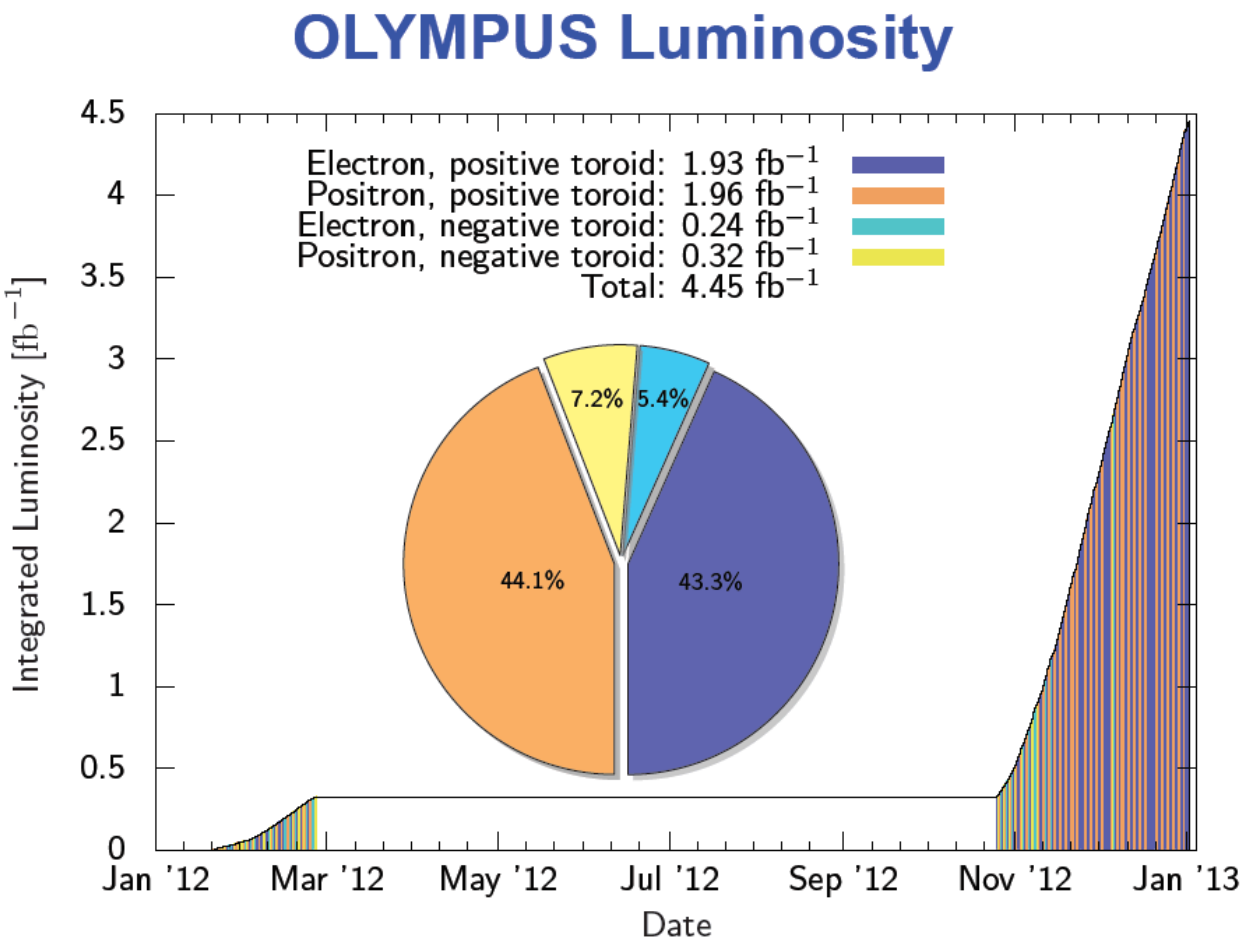


Detector before Roll-in July 2011





DataTaking in 2012

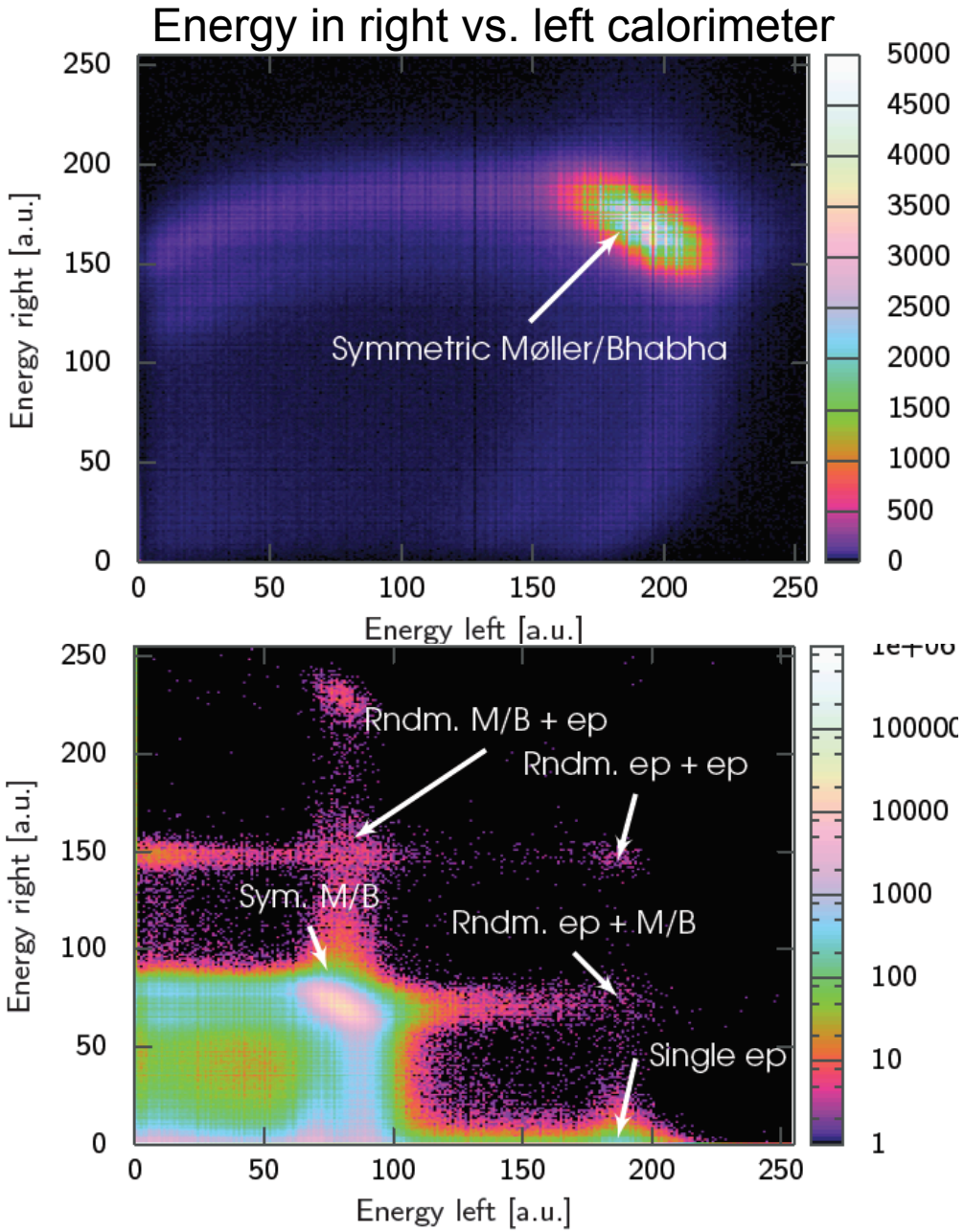


Limited flow and luminosity in Feb. run

Fall run

- Full hydrogen flow
- DORIS top-up mode
- Excellent performance
- Exceeded integrated luminosity:
  - Design 3.6fb^{-1}, achieved 4.45fb^{-1}
- Daily switch of beam species, good balance
- Mainly positive toroid polarity due to background
- Negative field for systematics checks

Møller/Bhabha Luminosity Monitor



- Independent luminosity measurement at 1.3°
- In addition, can detect lepton from e p scattering
- Cross check energy calibration and rate estimate
- Rates are corrected for beam positions and slopes

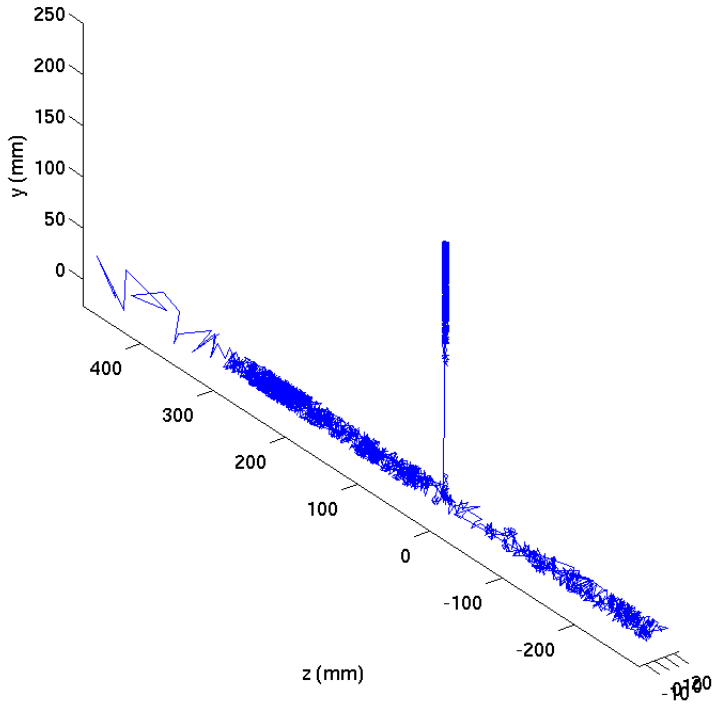
OLYMPUS

DESY

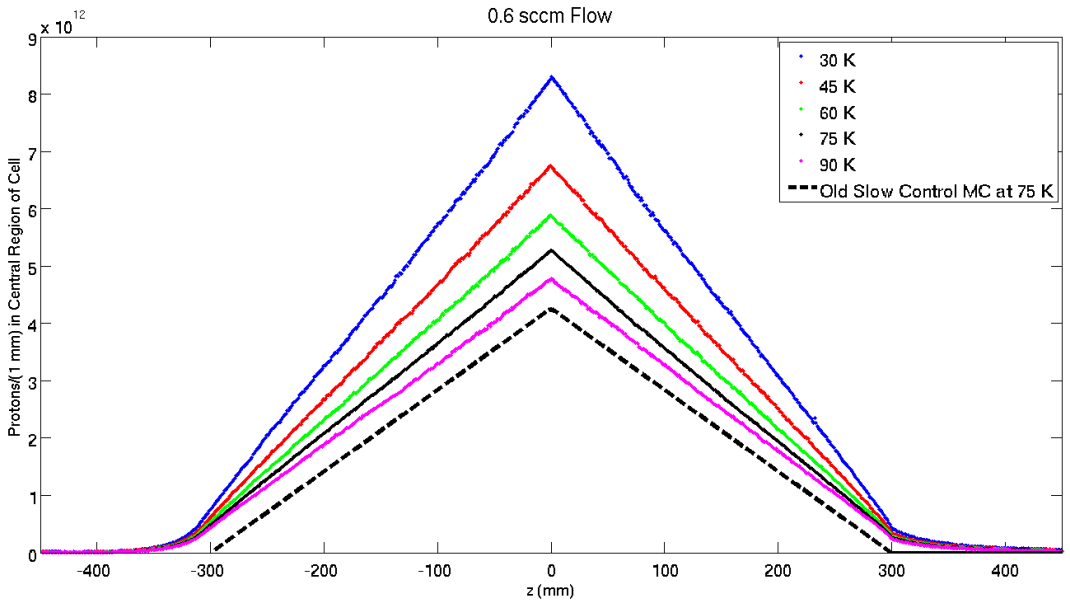
OLYMPUS Monte Carlo

- Utilizing advanced Monte Carlo simulation to account for:
  - Beam position/slope
  - Detector acceptance/geometry
  - Detector resolution and response
  - Detector efficiencies
  - Radiative corrections (radiative $e^{\pm}$ p and Møller/Bhabha generators developed)
- Recent improvements:
  - Refinement of detector geometry model
  - Implementation of multiple generator weights for radiative generator systematic studies
  - Molecular flow Monte Carlo simulation of target gas flow to improve MC target distribution

Target Gas Simulation



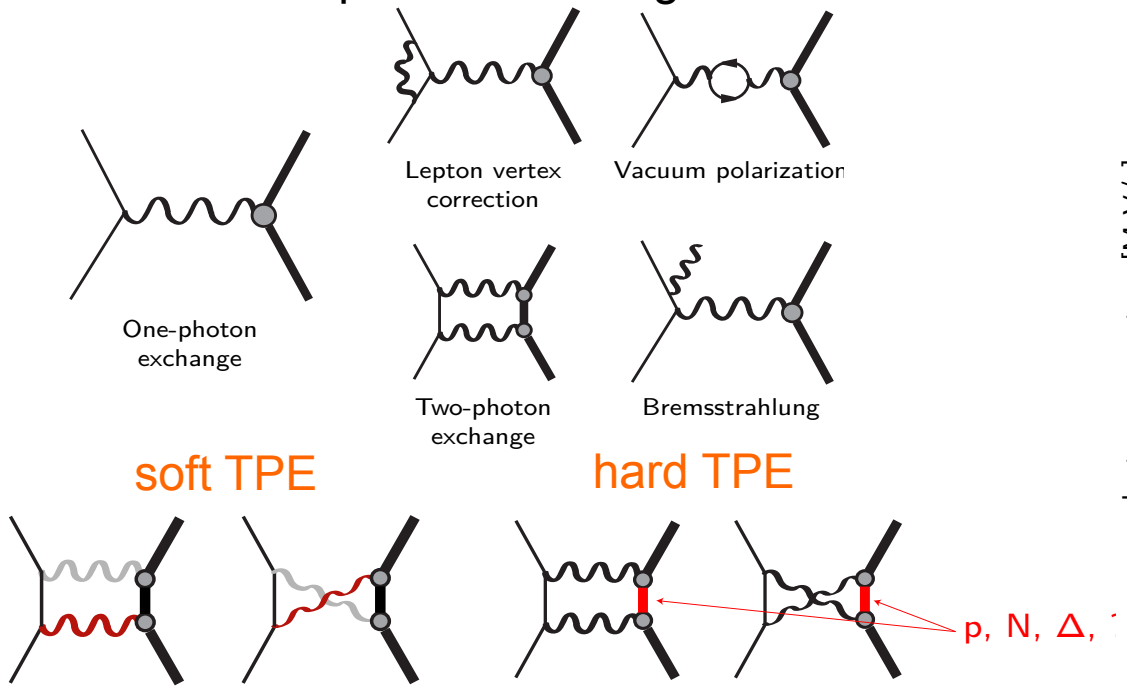
- Molecular flow Monte Carlo simulaton of target more realistic than conductance-based calculation
- Important to get shape of target distribution correct since $e^{\pm}$ acceptance can vary along target

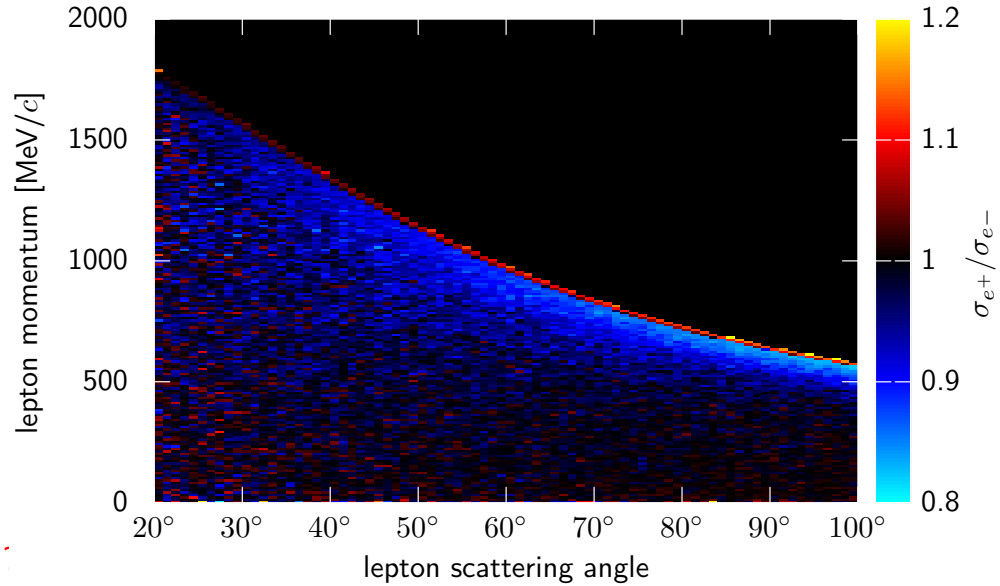


Radiative Corrections

Independent elastic $e^{\pm}p$ generators written at MIT (weighted)

- Radiative corrections include:
  - Initial and finale state beamsstrahlung for lepton and proton, vertex corrections, vacuum polarization and soft two photo exchange
  - Hard two photon exchange not included

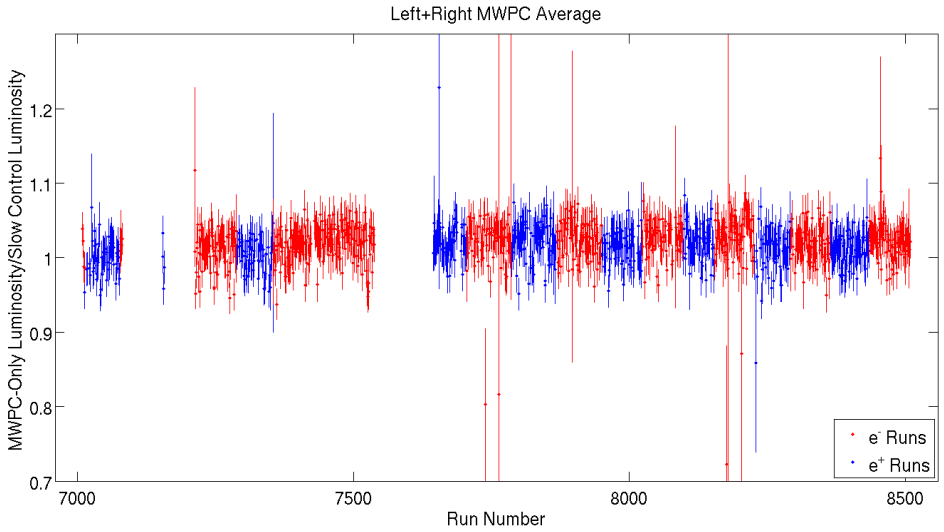


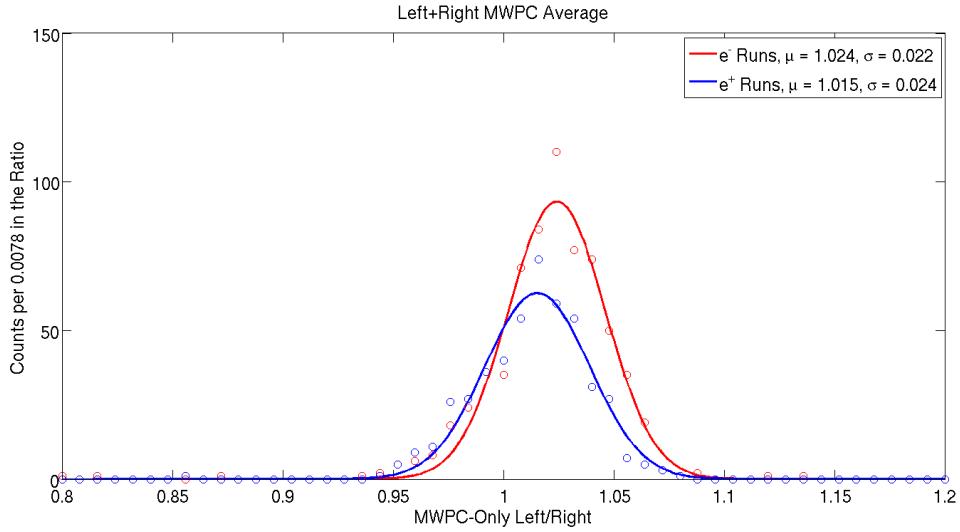


Møller/Bhabha generator with radiative corrections written at MIT

Luminosity Analysis

- Presently focusing on tracking of $e^{\pm}p$ events in 12^{o} luminosity telescopes
  - Detailed simulation of target distribution has significantly improved data/MC comparison
  - Geometry description improved
  - MWPC digitization re-written, including handling of defective wire and multi-wire hits
  - Tracking code improved
  - TOF meantime used to identify recoil proton

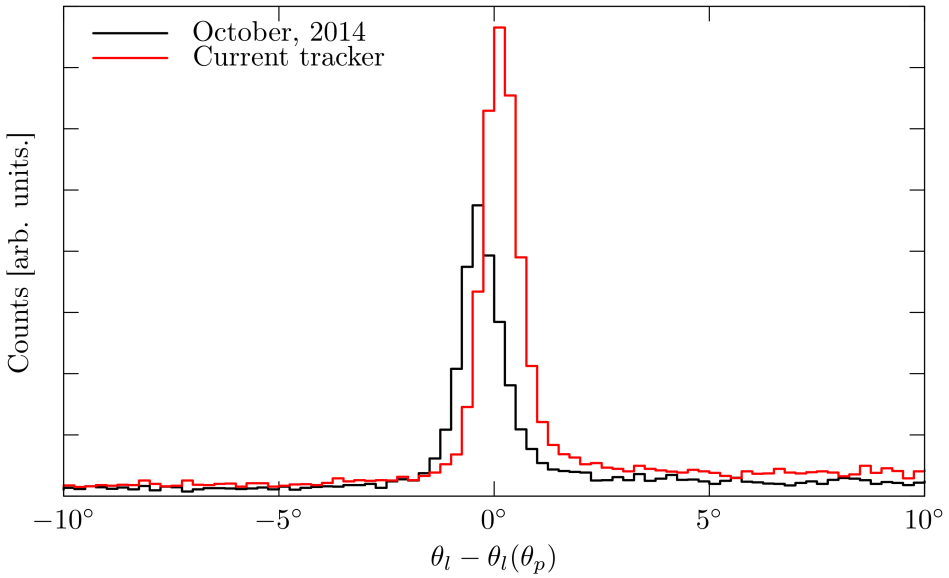




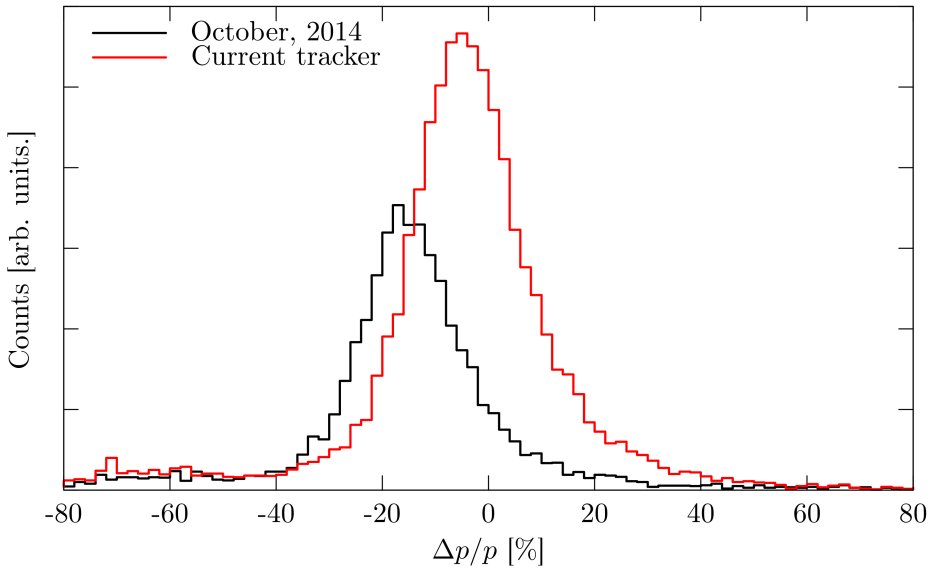
Very good agreement with “slow control” luminosity

Drift Chamber Tracking Improvements

- Recent tracking improvements
  - Geometry description
  - Minimization routine
  - Including TOF hits as additional track points (resolves ambiguities)
  - Expansion of elastic pattern library used by tracker
  - Advanced methods to recover difficult tracks
  - Time-to-distance fits expanded to include all runs (so far using 1000 runs)



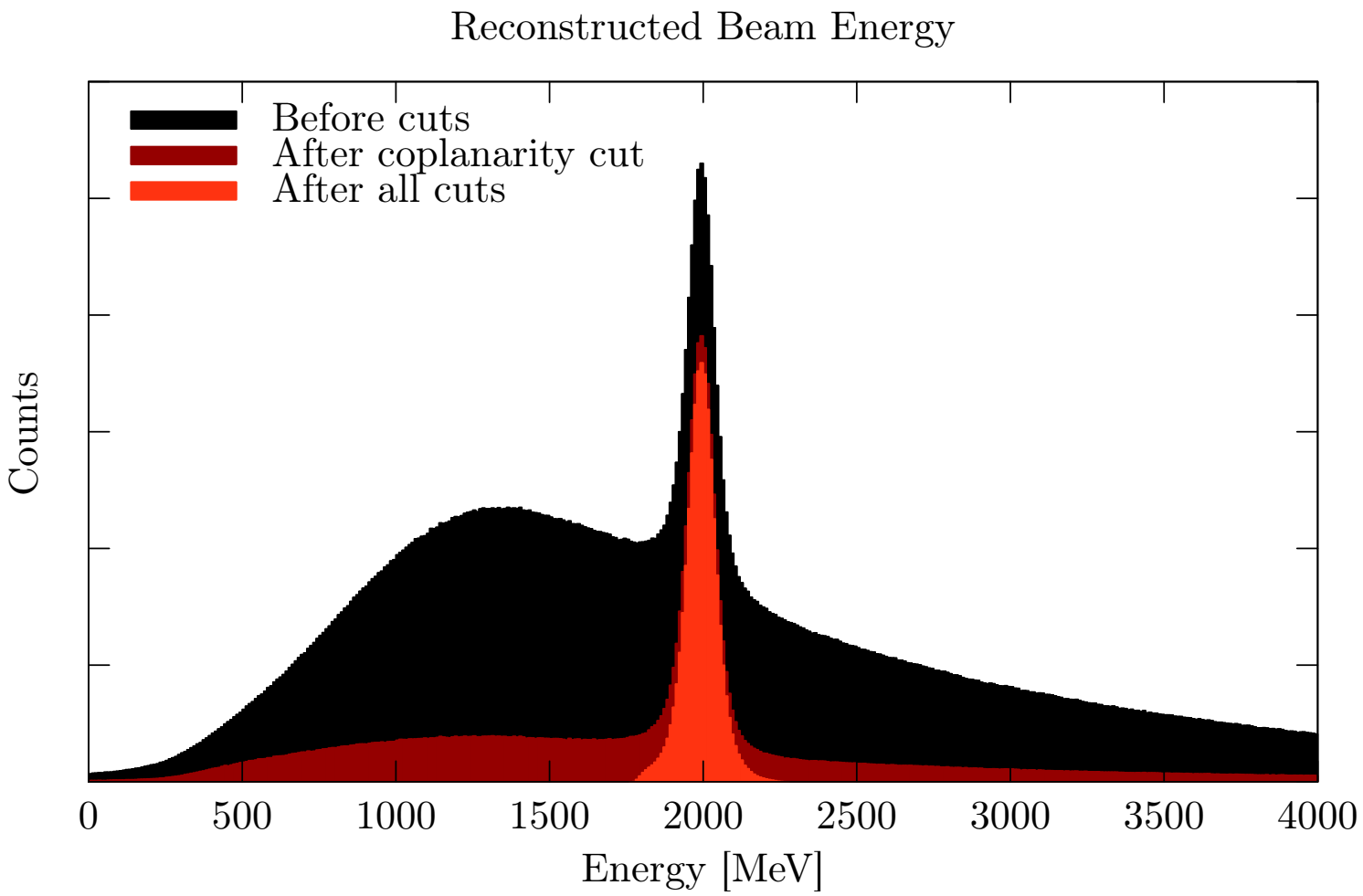
Status as of early May



Data Analysis

Selection cuts on

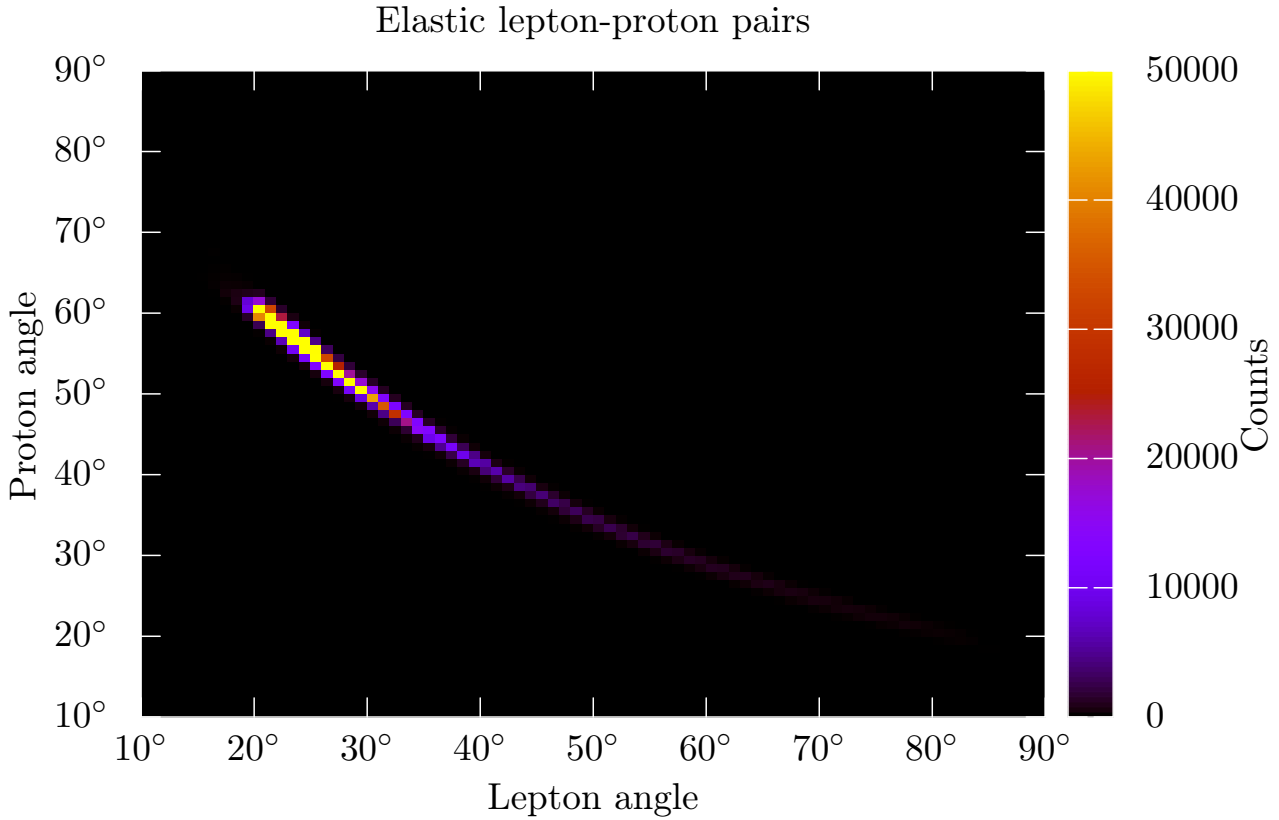
- Coplanarity
- Vertex correlation
- θ_e, θ_p correlation
- p, θ correlation
- Event time correlatio



Data Analysis

Selection cuts on

- Coplanarity
- Vertex correlation
- θ_e, θ_p correlation
- p, θ correlation
- Event time correlation



Systematic studies in progress

- In early May observed few percent left/right asymmetry
- Found and fixed a few problems with reconstruction
- Newly reconstructed data sample almost ready
- Aiming at < 1% systematic uncertainty on e^+/e^- ratio

OLYMPUS

DESY

Conclusions

- Study of two photon exchange important for understanding proton form factor ratio disagreement
  - Two other experiments at Novosibirsk and JLab
- Former BLAST detector moved from MIT/Bates to DORIS accelerator at DESY and reassembled
- Very successful data taking in 2012
- Data reconstruction and analysis well advanced
- Large effort to understand systematic uncertainties to achieve ratio measurement at 1% level
- Preliminary results on the full data set available fall this year

OLYMPUS Collaboration

Institutes

- Arizona State University, USA
- DESY
- Hampton University, USA
- INFN, Bari, Italy
- INFN, Ferrara, Italy
- INFN, Rome, Italy
- MIT, USA
- Petersburg Nucl. Phys. Inst.
- Universität Bonn, Germany
- University of Glasgow
- Universität Mainz, Germany
- Univ. of New Hampshire, USA
- Yerevan Physics Inst., Armenia

45 physicists