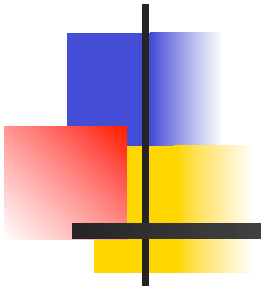
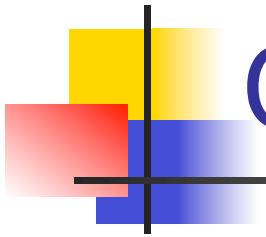


Two-Photon Exchange in Electron Proton Scattering - Status of OLYMPUS Experiment at DESY

Uwe Schneekloth, DESY
for the OLYMPUS Collaboration

28.08.2013
Lomonosov Conference



Outline

- Introduction and Motivation
- Overview of the Experiment
- Schedule
- Data Taking Periods
- Performance
- 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

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

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

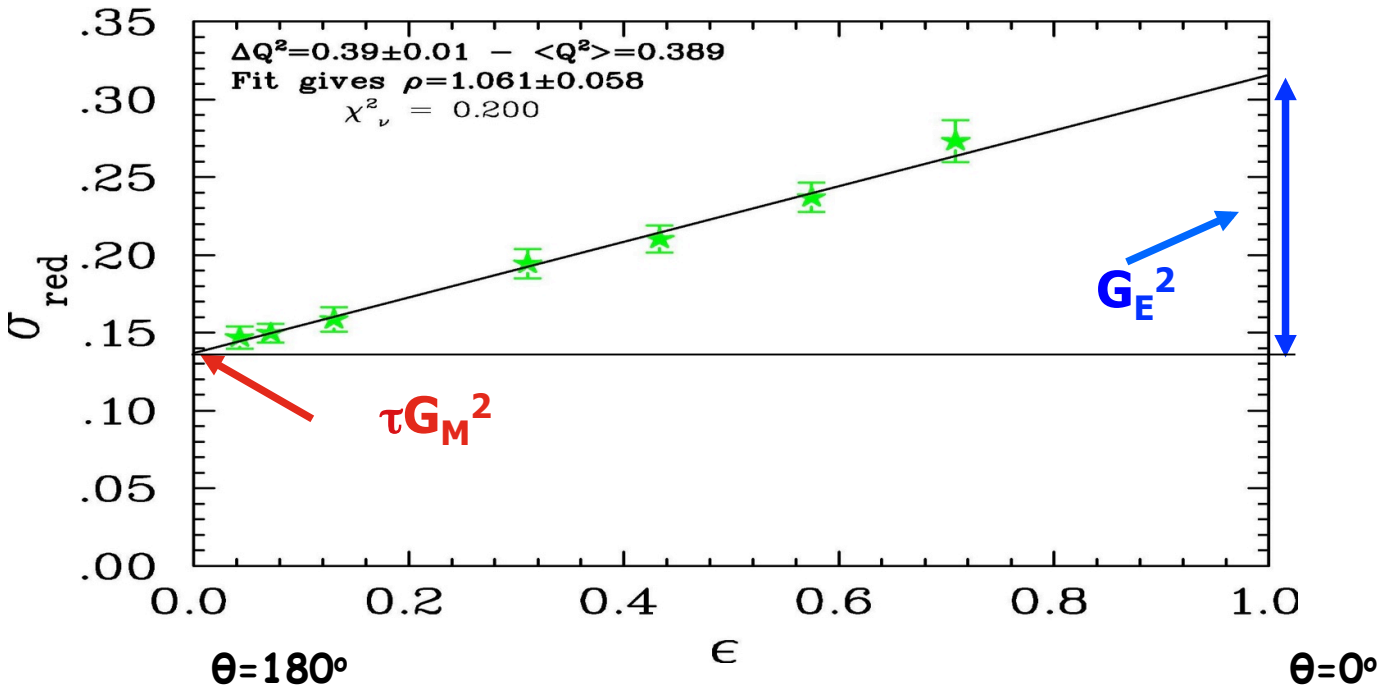
$$\sigma_{red} = \frac{d\sigma}{d\Omega}\frac{\varepsilon(1+\tau)}{\sigma_{Mott}} = \tau G_M^2 + \varepsilon G_E^2$$

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

(ε transverse virtual photon polarization)

Form Factors Rosenbluth Method

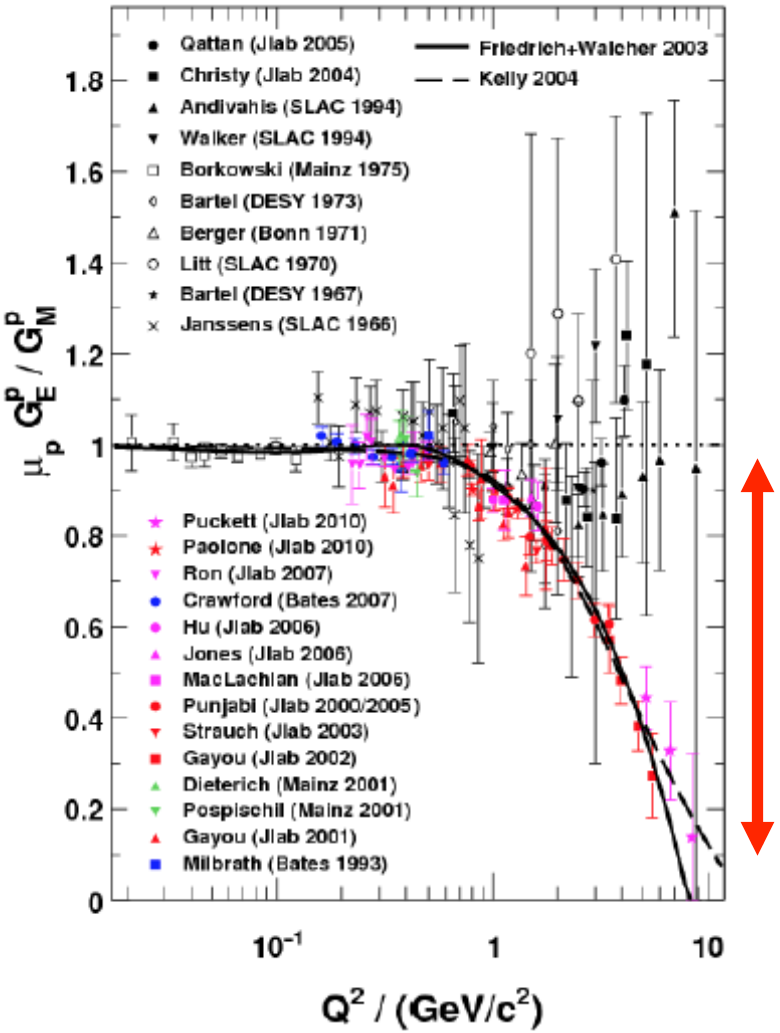
Reduced cross section $\sigma_{red} = \varepsilon G_E^2 + \tau G_M^2$



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

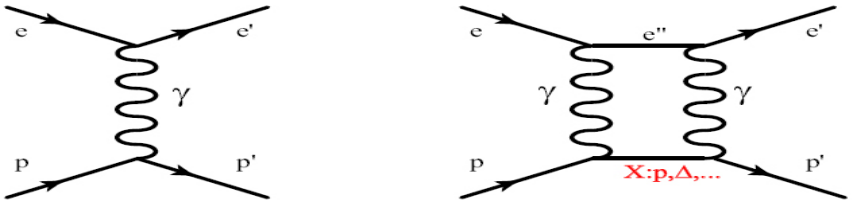
Motivation of OLYMPUS Experiment

Proton Form Factor Ratio

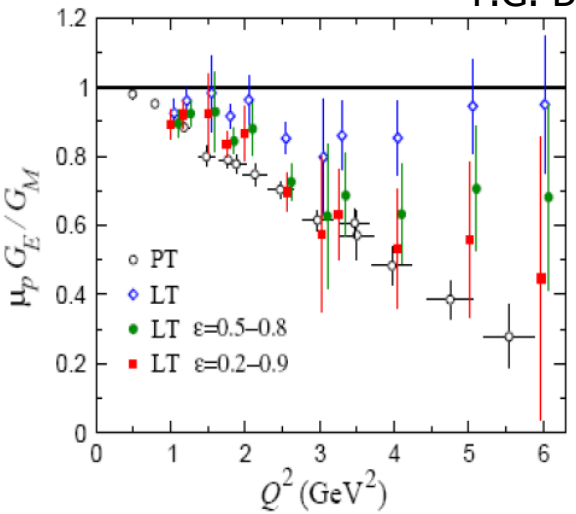


- All Rosenbluth data in agreement
- Dramatic discrepancy between Rosenbluth and recoil polarization technique
  - Jefferson Lab data(>800 citations) polarized beams and target
- Interpreted as evidence for two photon exchange

Two Photon Exchange



P.G. Blunden et al.



- Large theoretical (model) uncertainties
- Only experiment can definitively resolve the contributions beyond single photon exchange

→ Measure ratio of positron proton/ electron proton rates

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

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

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

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

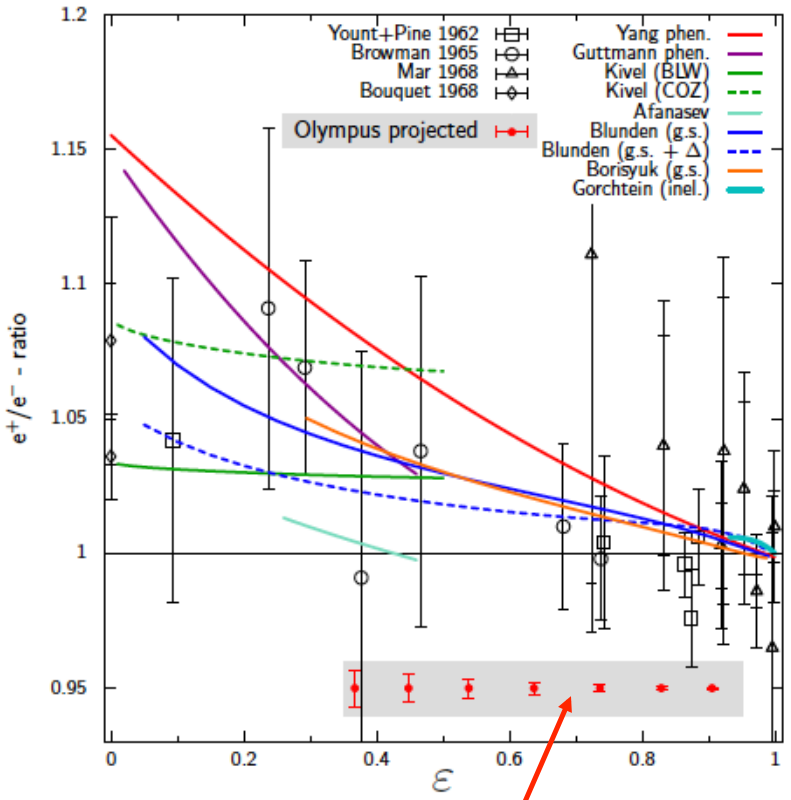
$$\frac{\sigma(e^+p)}{\sigma(e^-p)} = 1 + (2\alpha)\frac{2\gamma}{1\gamma}$$

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 100mA $e^+(e^-)$ 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 measurement of luminosity
- Using former BLAST detector from MIT/Bates. Ideally suited.

Comparison data and theory

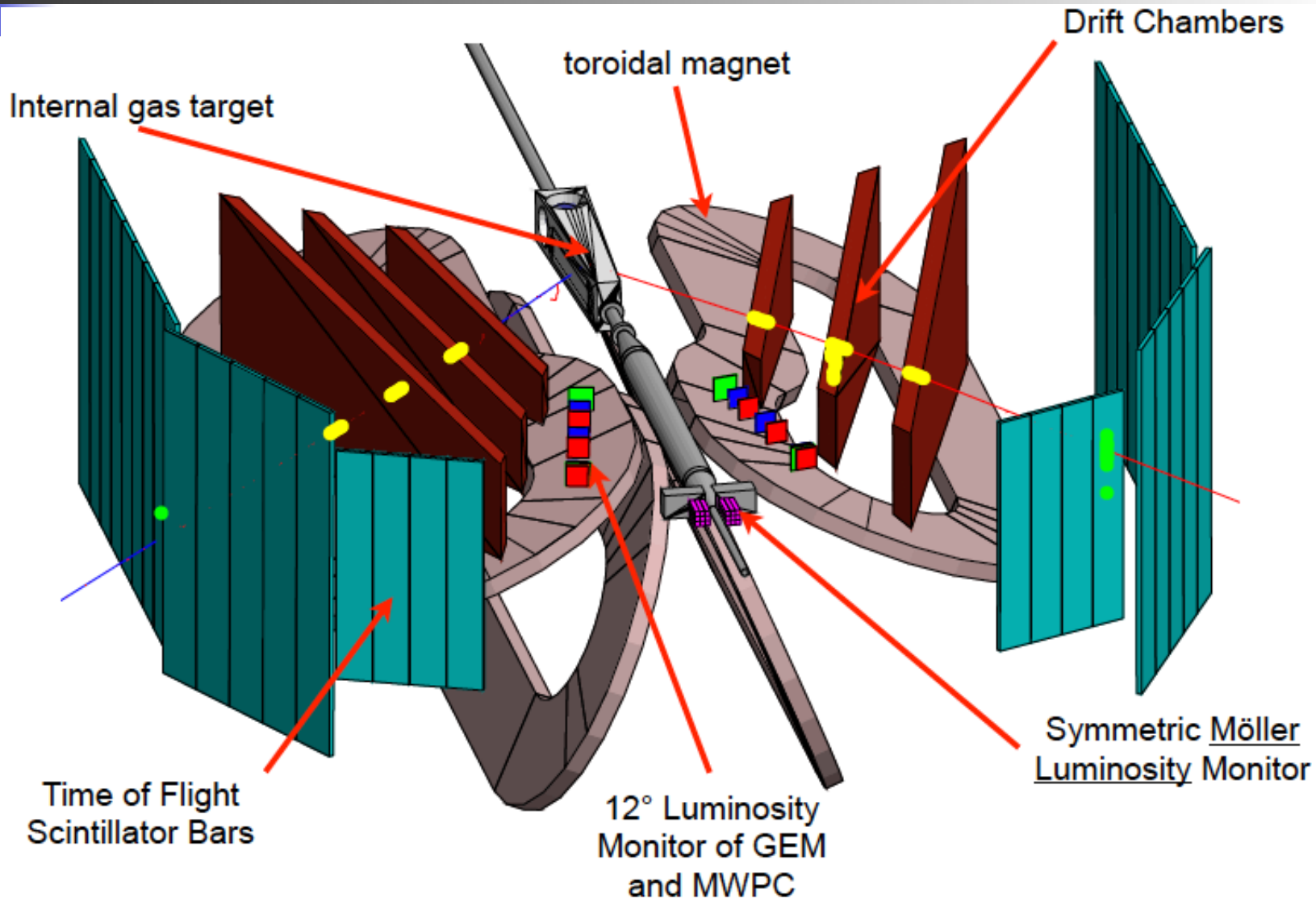


expected sensitivity

Schedule and Progress

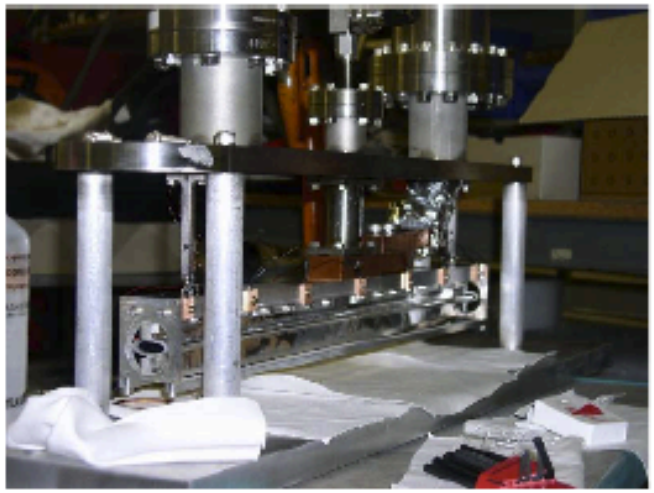
- 2008/2009
  - Proposal in PRC, technical review, final approval of DESY directorate
- 2010
  - Blast detector shipped from MIT to DESY, assembled in parking position
- 2011
  - Winter shut-down: interaction region modified
  - Feb.: one week of 2 GeV operation, test experiment
  - Summer shut-down: detector moved into beam position
  - Service weeks: some beam time (detector commissioning)
- 2012
  - February: first data taking period
  - Fall: second data taking period (22.10. – 2.01.2013)
- 2013
  - One month cosmic run
  - Optical survey and extensive magnet field measurements
  - Concentrating on reconstruction and analysis

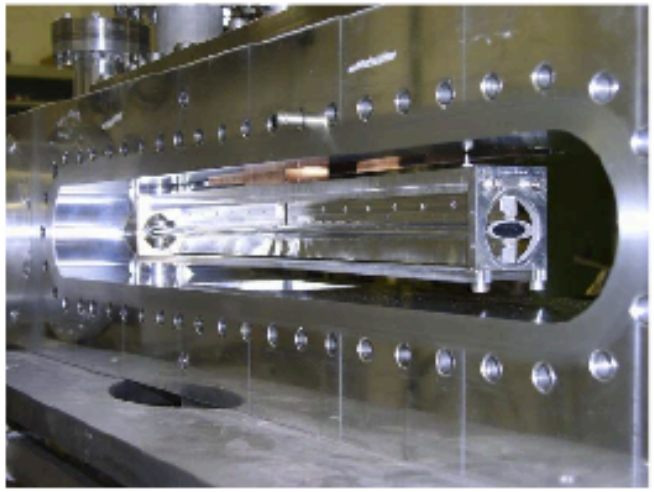
Detector Overview



Target System

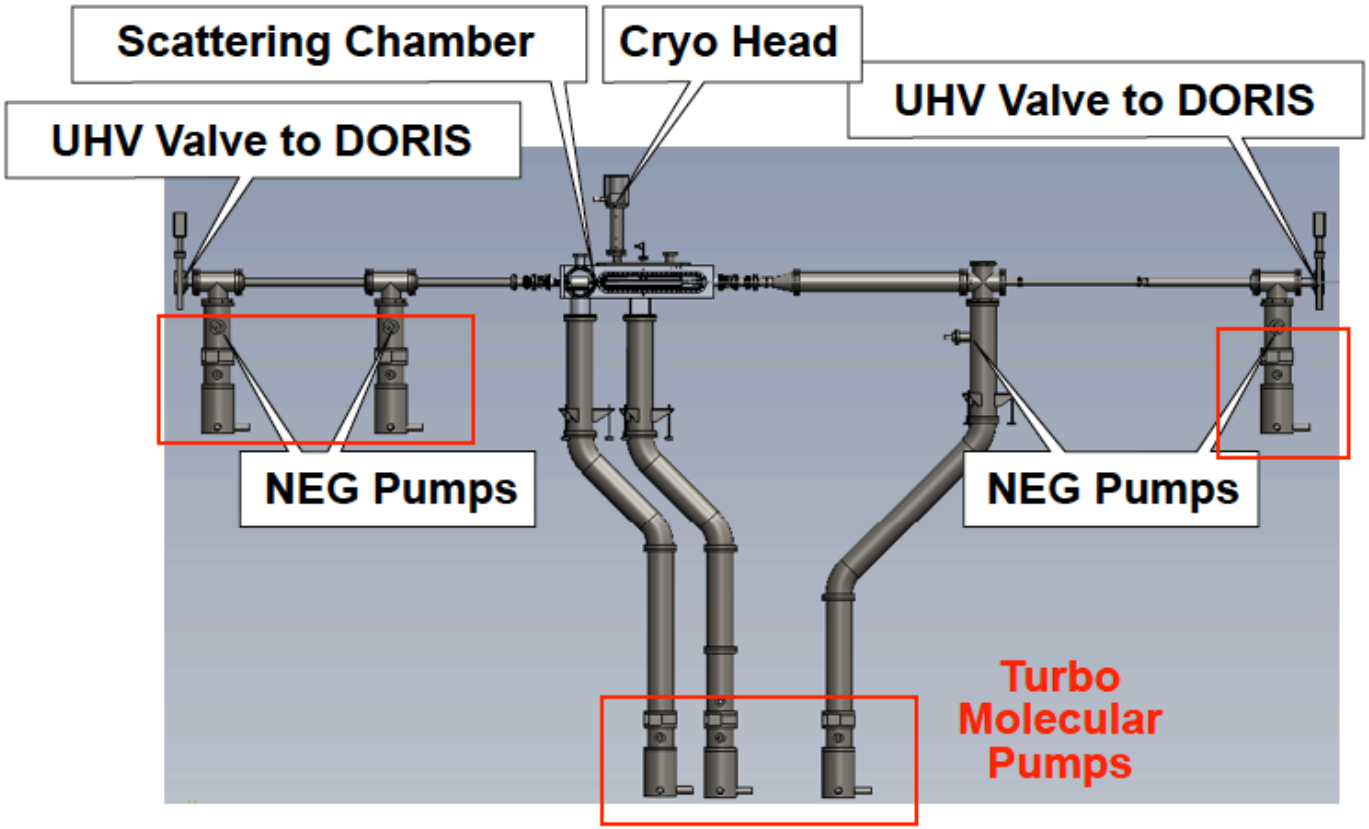
- Windowless internal gas target
- 60 cm long storage cell
- Elliptical cross section (27 mm x 9 mm)
- 100 μm thick aluminum wall
- Cryo cooled (43.5$\pm$1 K)
- $\mathcal{O}(10^{15})$ atoms/cm^2
- Hydrogen generator (electrolysis)





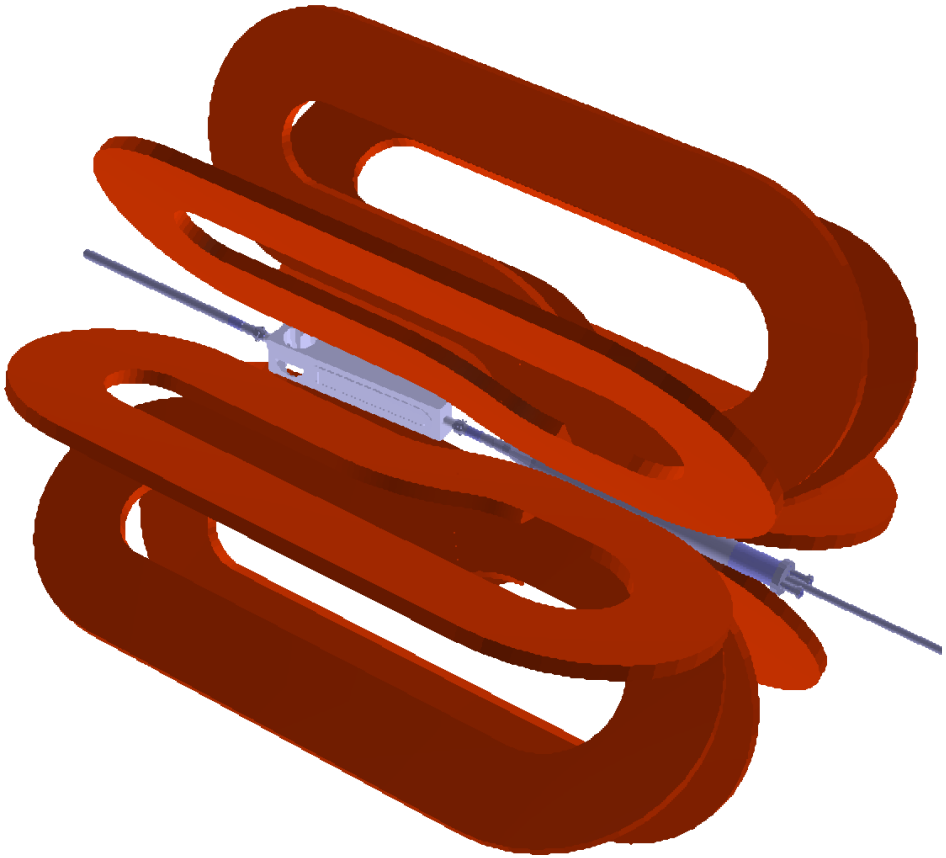
INFN Ferrara, MIT

OLYMPUS Vacuum System



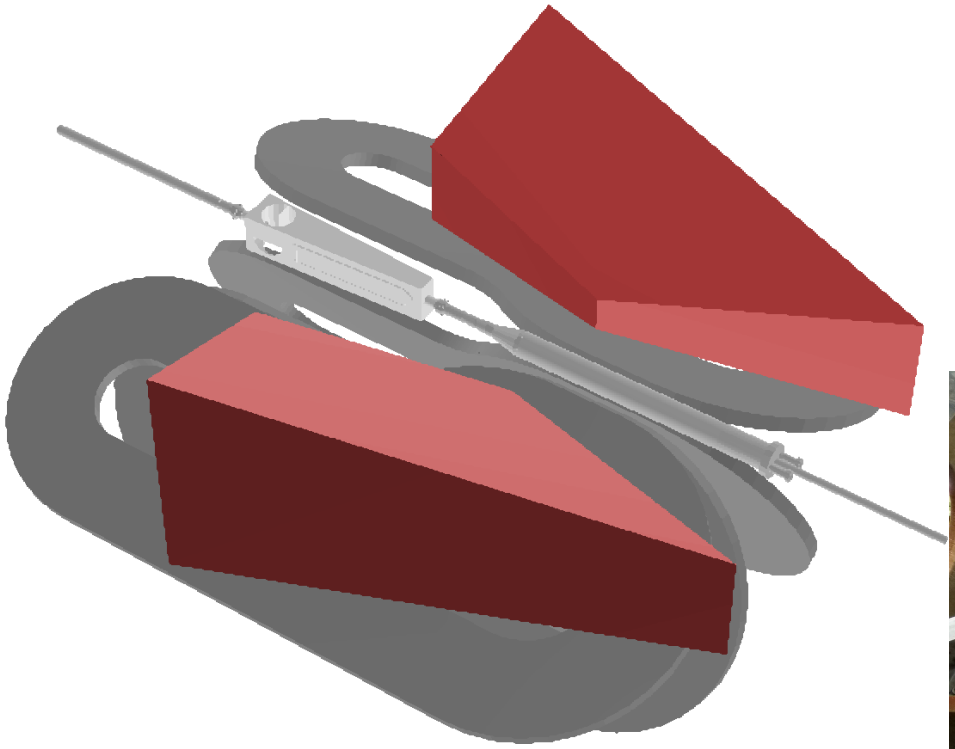
- Hydrogen flow: 0.8 instead of 0.4 sccm (factor 2 higher than proposed)
- Pressure outside experiment: 2 10^{-10} mbar no flow, 7 10^{-8} mbar with H_2
- Beam life time: ≈ 6 h no flow, ≈ 20 or 45 min with H_2

Toroidal Magnet



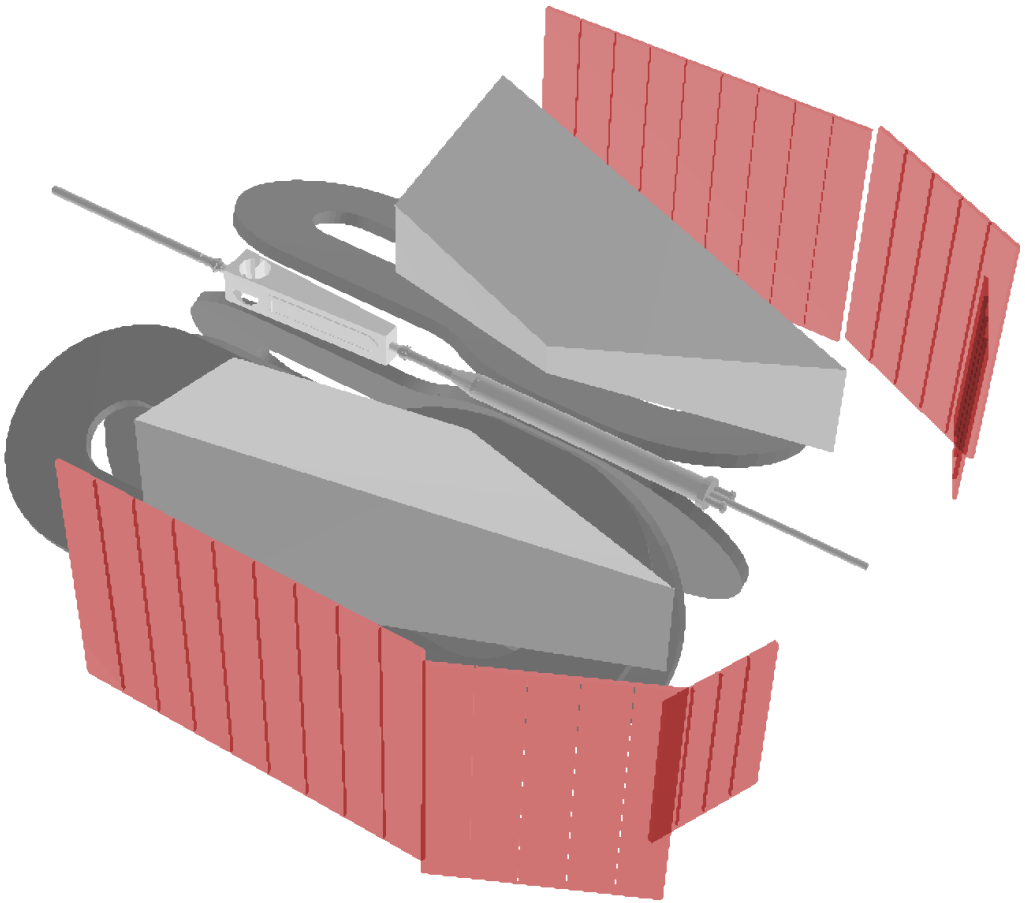
- 8 air coils from BLAST
- Operating at reduced field
- Positive and negative positive polarity
- Maximum field 0.28 T

Wire Chambers



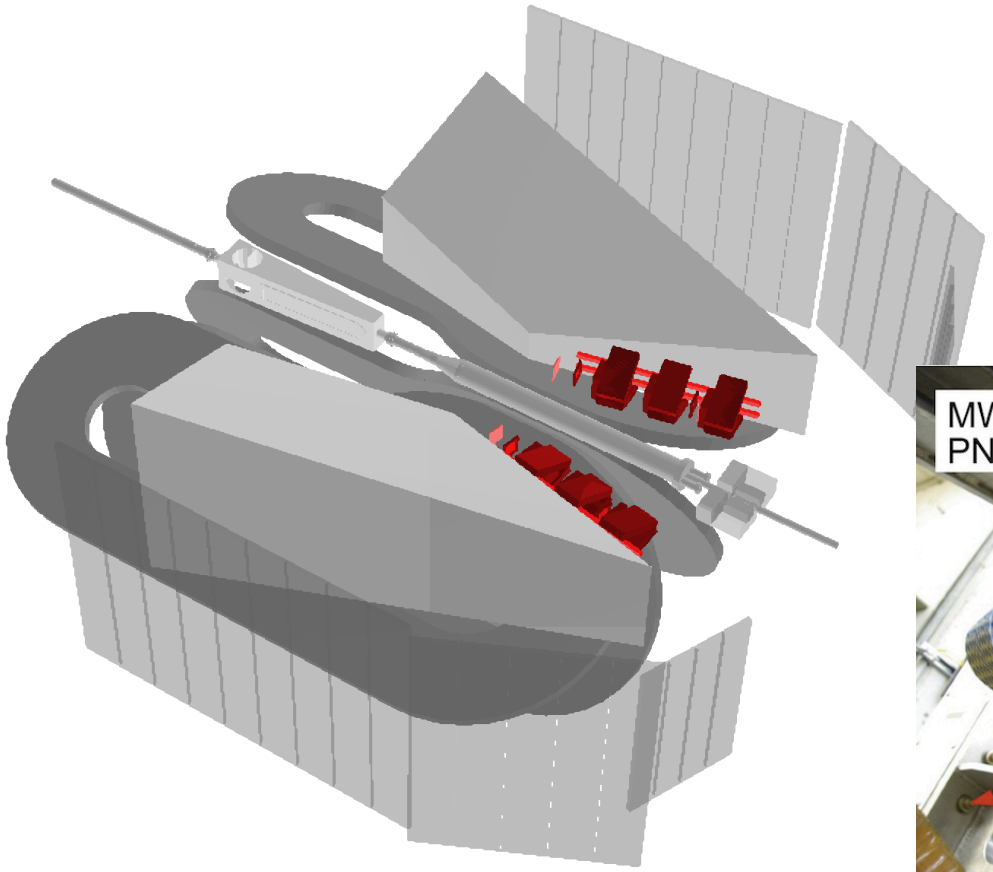
- Two chambers, trapezoidal shape
- Jet-style drift cells
- 5000 wires each
- Tracks with 18 hits
- 10^{o} stereo angle

Time-of-Flight Counters

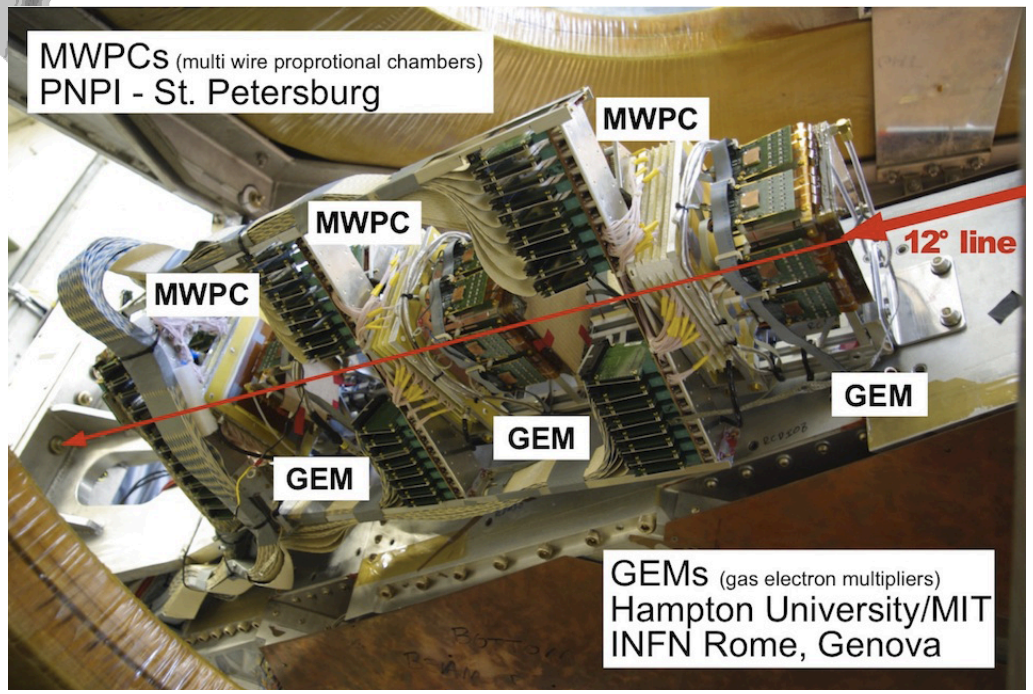


- Scintillation counters from BLAST
- Trigger
  - Top/bottom coincidence
  - Kinematic constraint
  - + 2nd level wire chamber
- Time-of-flight for particle ID

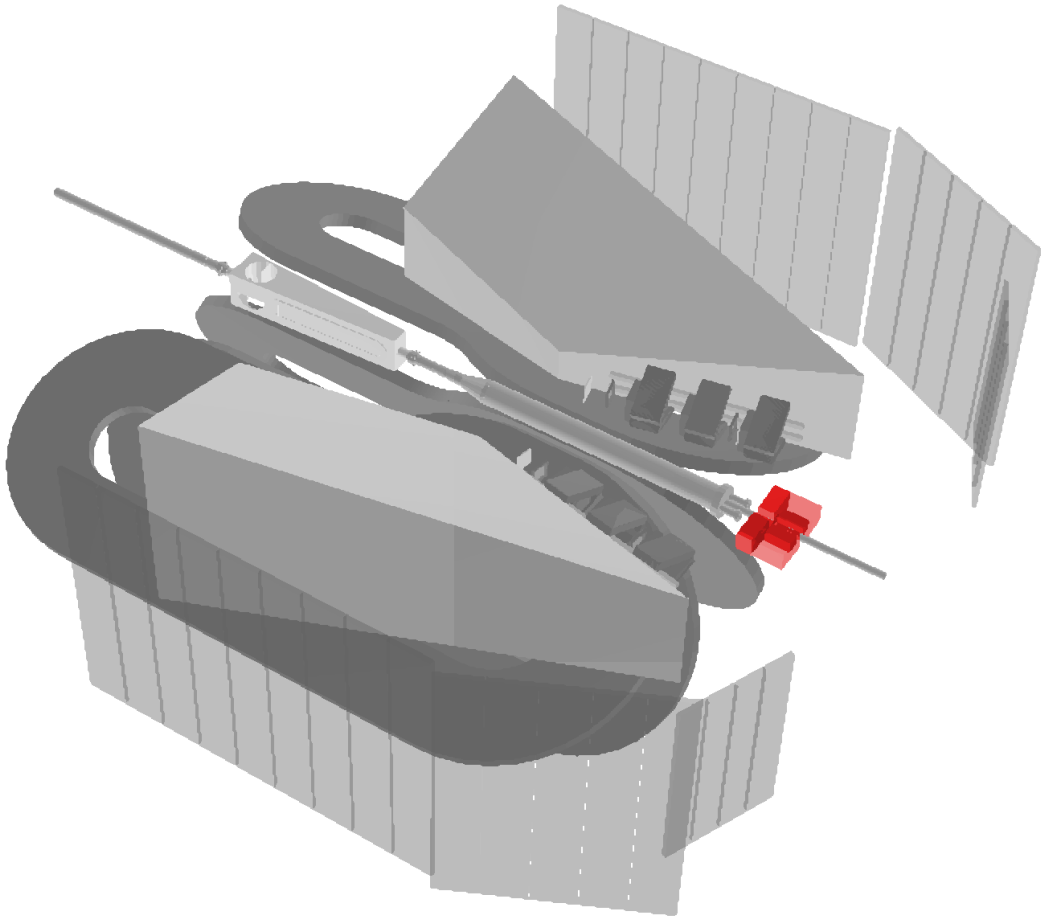
12^{o} Luminosity Monitor



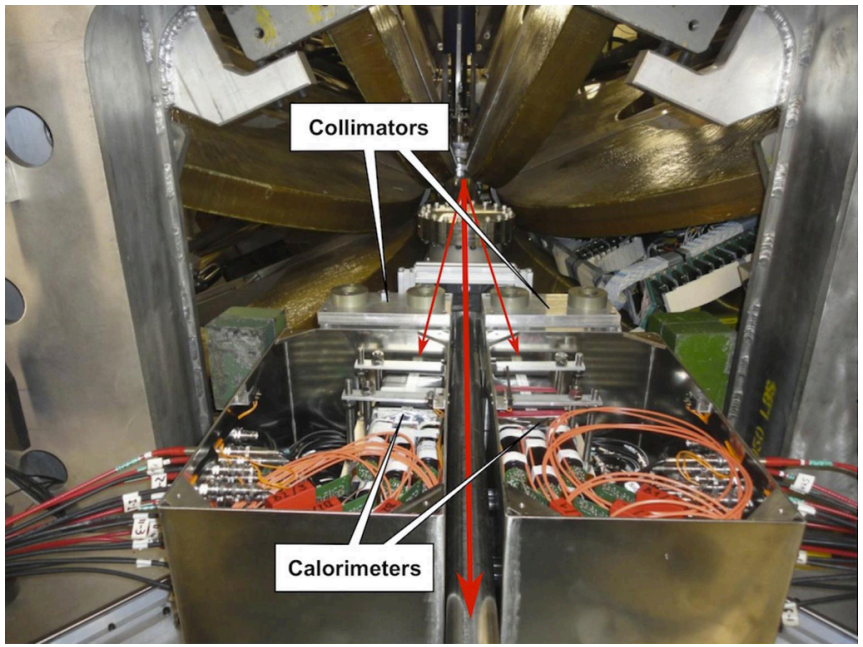
- Measure forward elastic ep scattering
- Two independent tracking systems
- 3 GEM and 3 MWPC detectors each side
- Scintillator trigger counters with SiPM readout



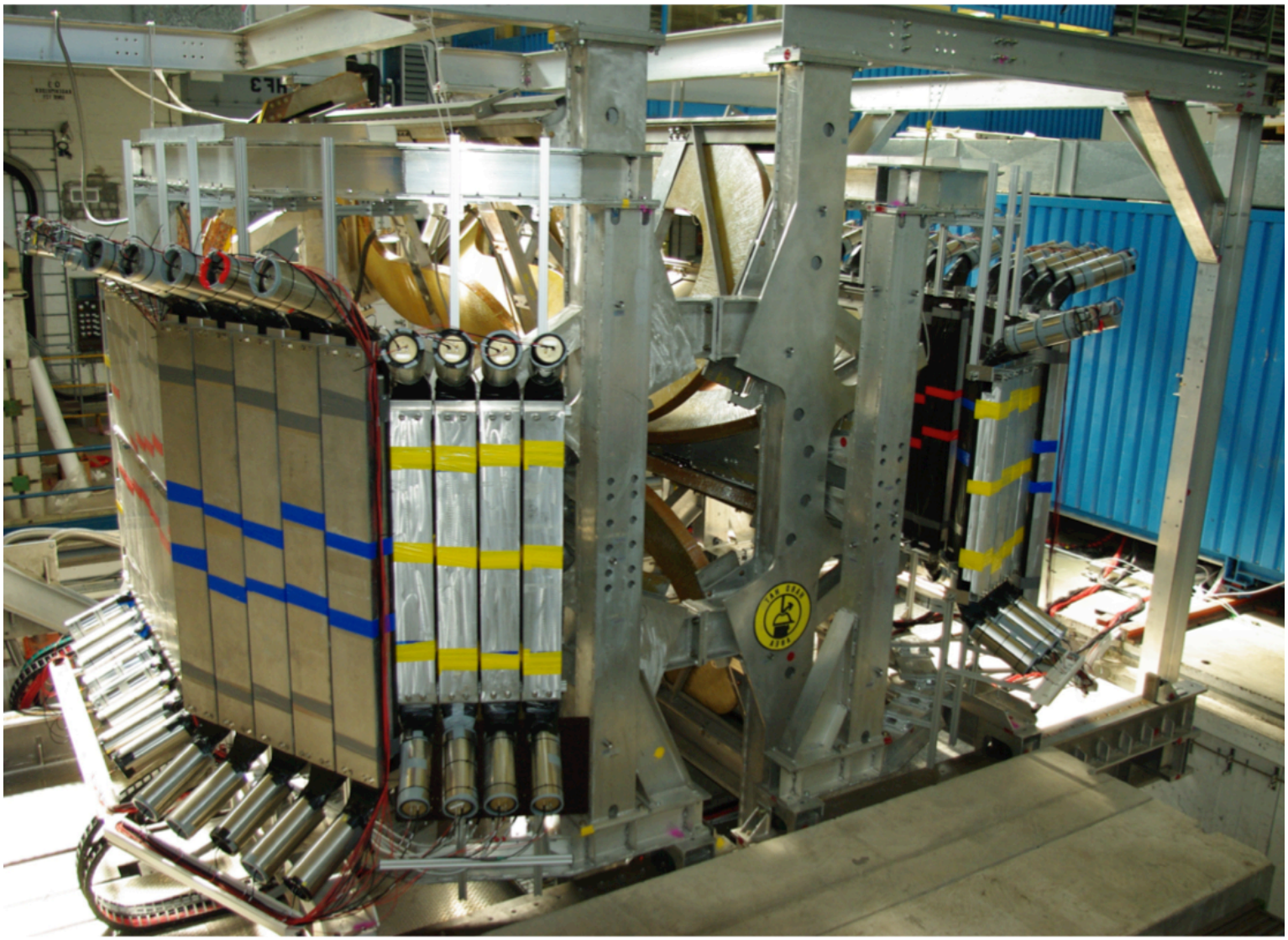
Moller/Bhabha Luminosity Monitor



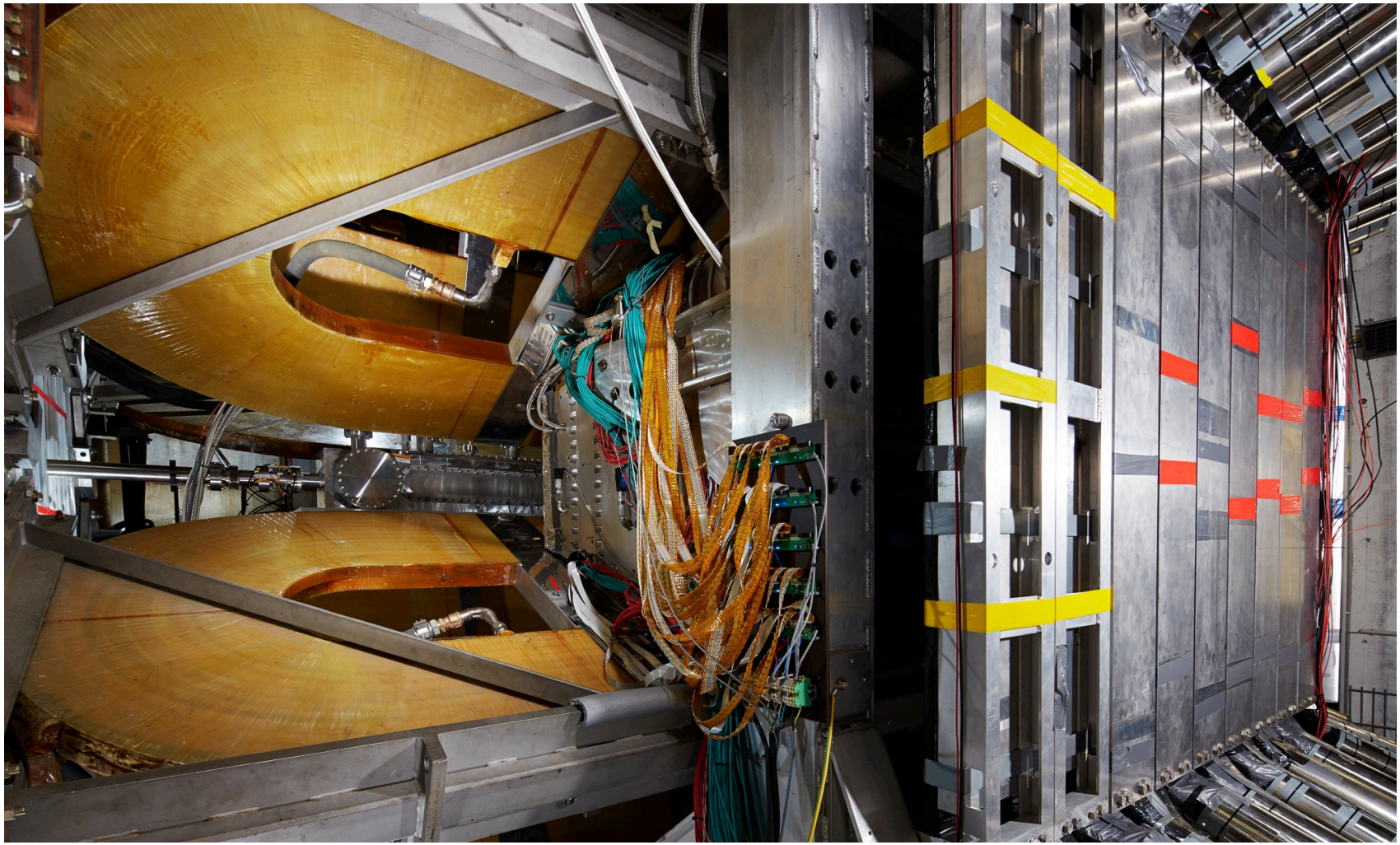
- Measure symmetric Moller/Bhabha events
- 3x3 PbF_2 crystals at 1.3^{o} each side
- High rate, no dead time
- Independent luminosity determination



Detector before Roll-in July 2011



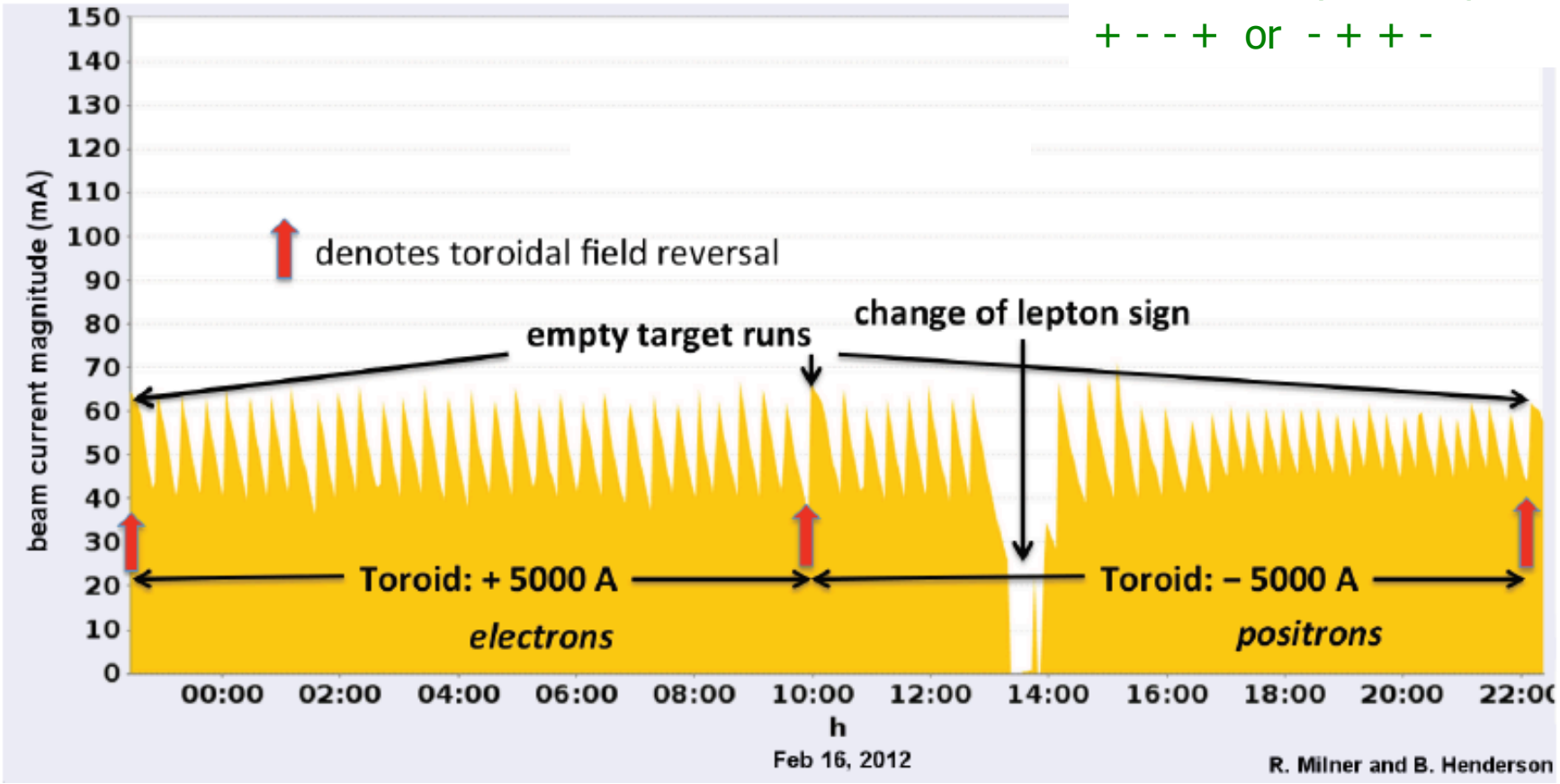
Detector in Beam Position



DORIS Operation – February Run

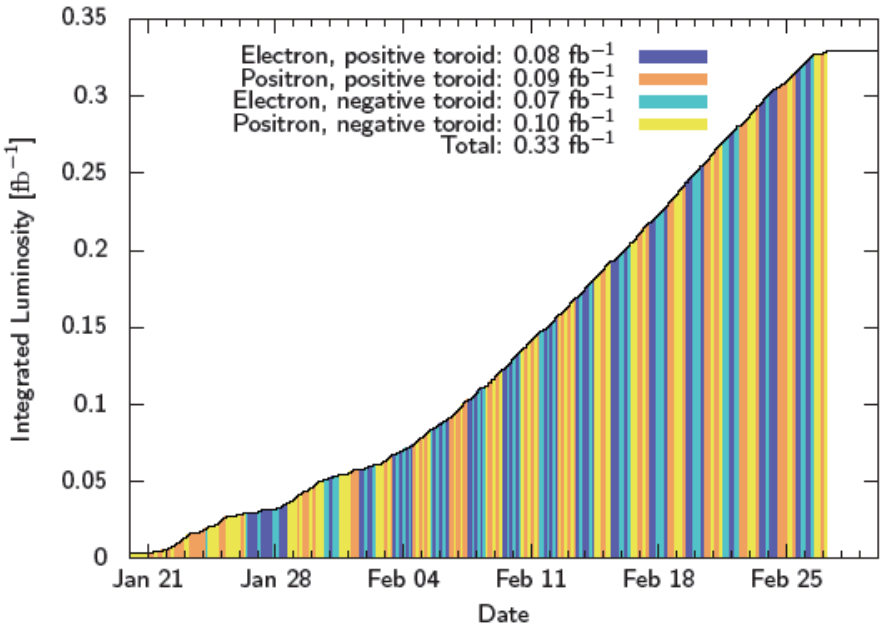
Random daily toroid polarity

+ - - + or - + + -



Very stable operation

February Run



Run Summary

In principle, very good performance

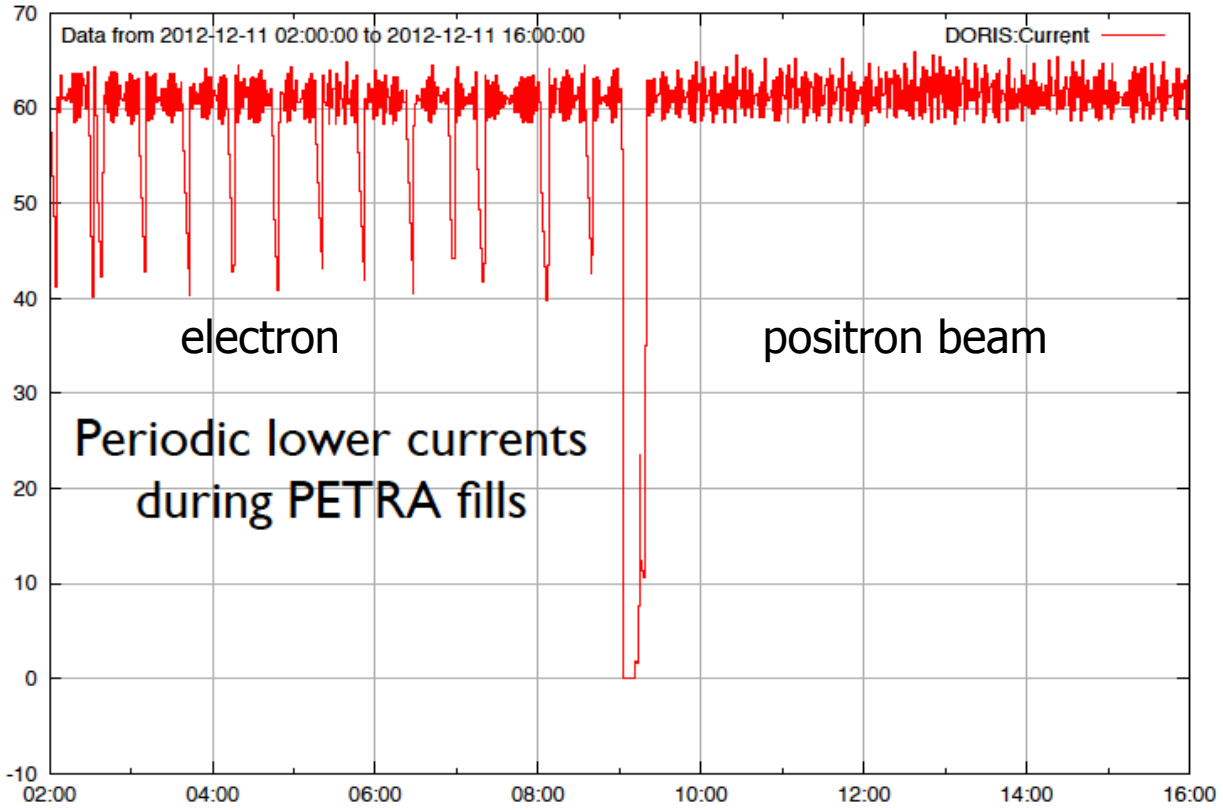
- All four settings (beam, mag. field)
- Very stable operation
- Target density however reduced due to internal hydrogen leak

Improvements/modifications for fall run

- Gas inlet to target cell improved -> much higher H_2 density possible
- 2nd level track trigger to allow for higher trigger rate
- DORIS operation in top-up injection mode

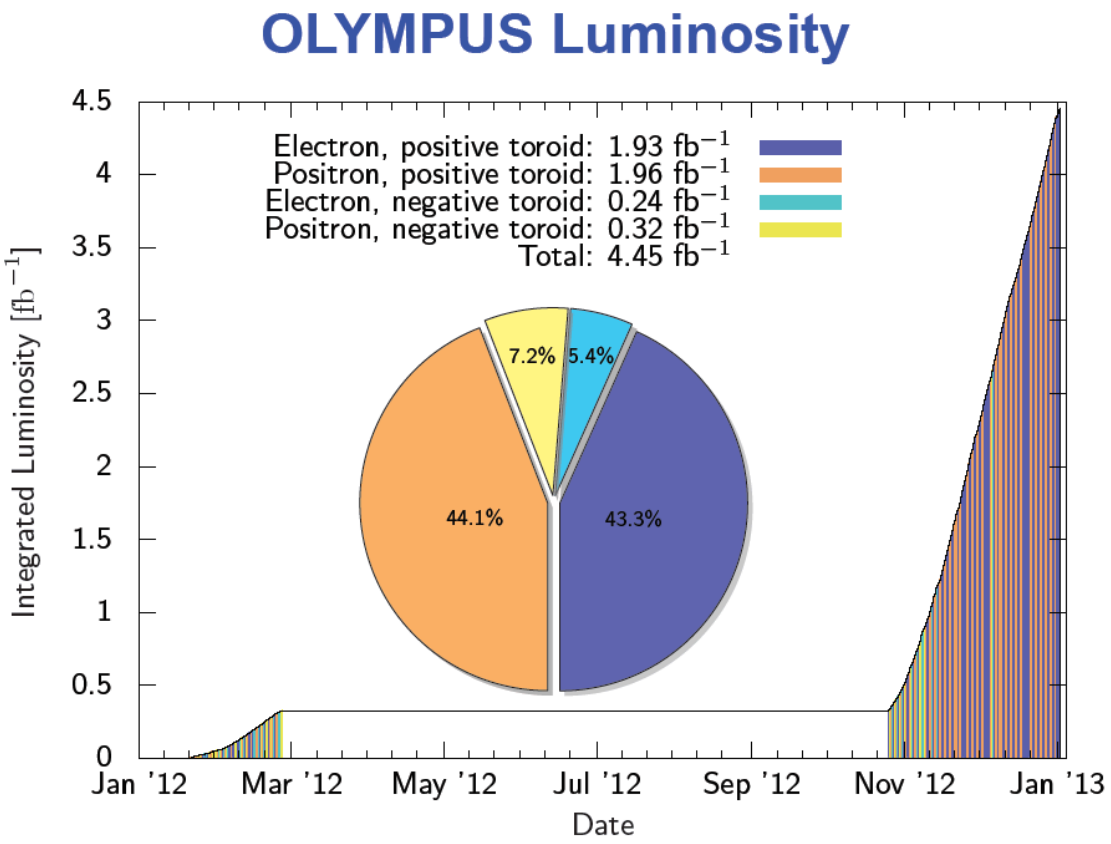
DORIS Operation - Top-Up Injection

DORIS beam current vs. time



Beam current almost constant

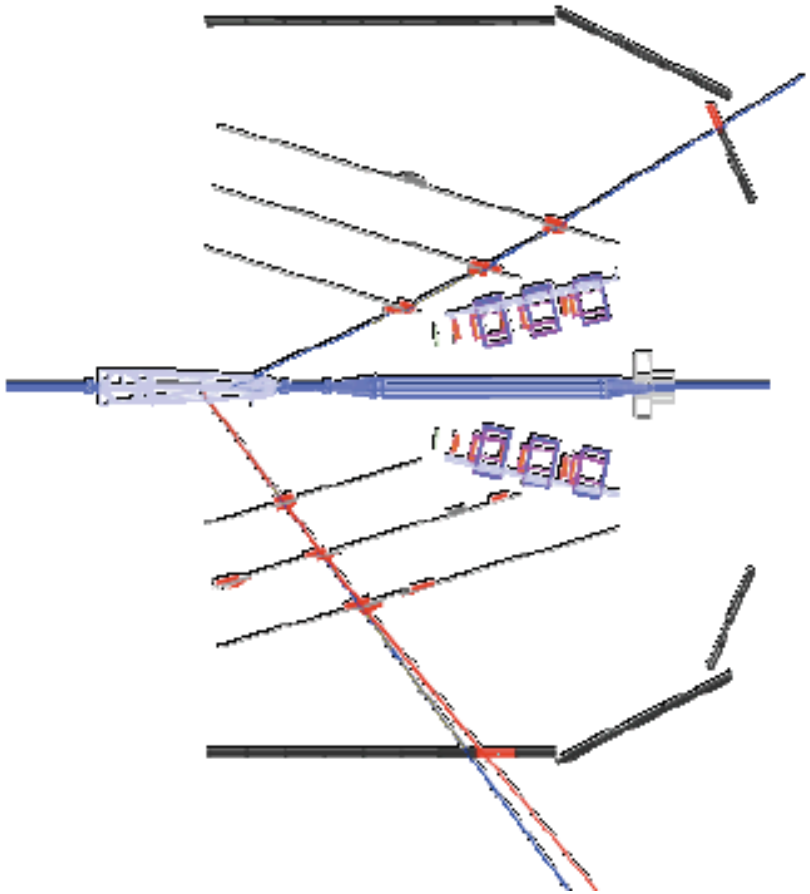
Fall Run

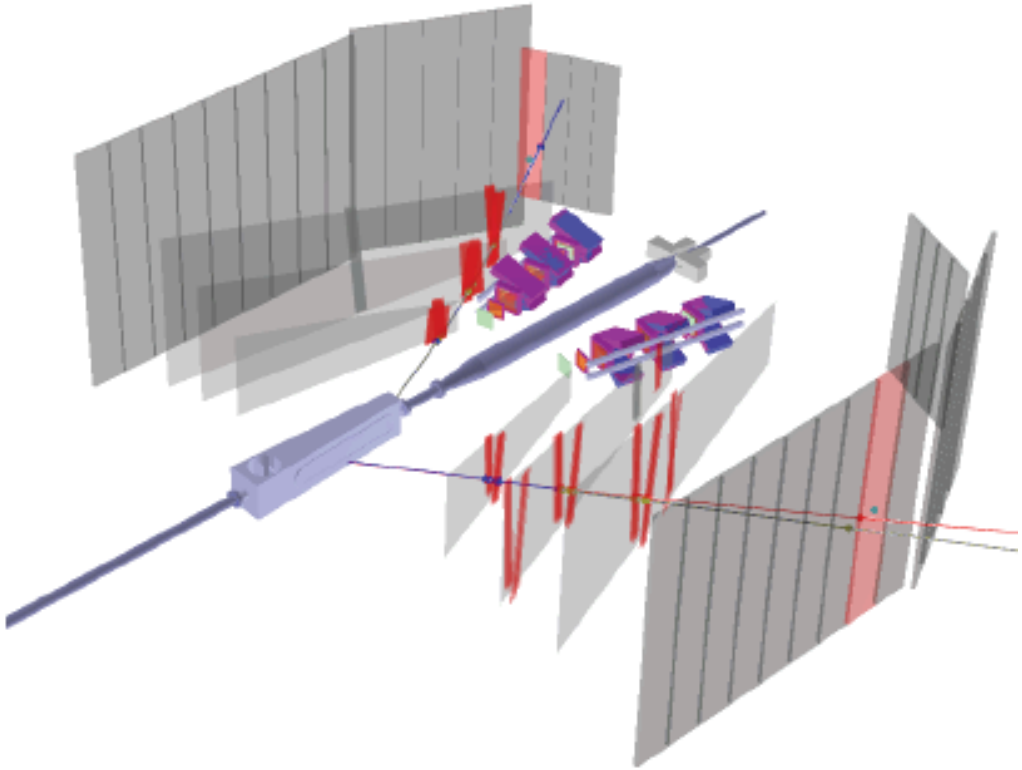


Run Summary

- 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
- Only positive toroid polarity due to background
- Negative field for systematics checks

Elastic ep Event

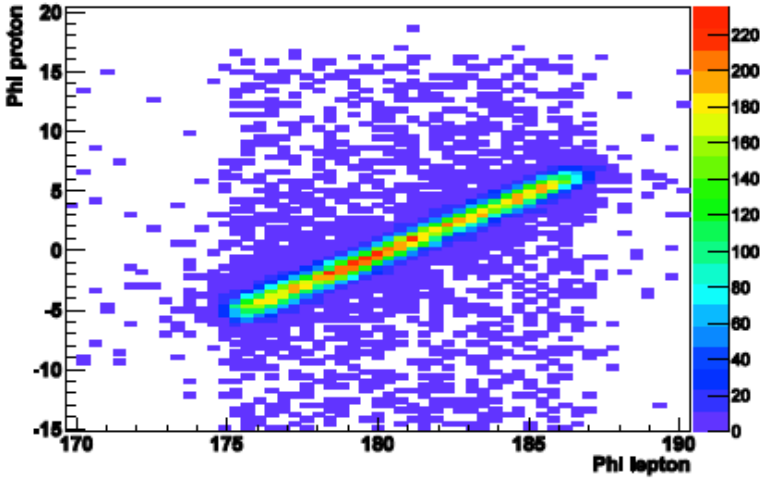




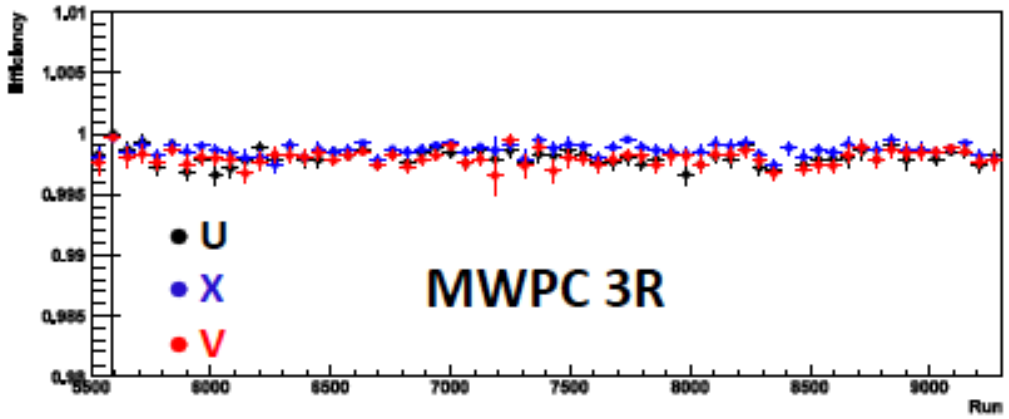
PRELIMINARY

Lumi MWPC Performance

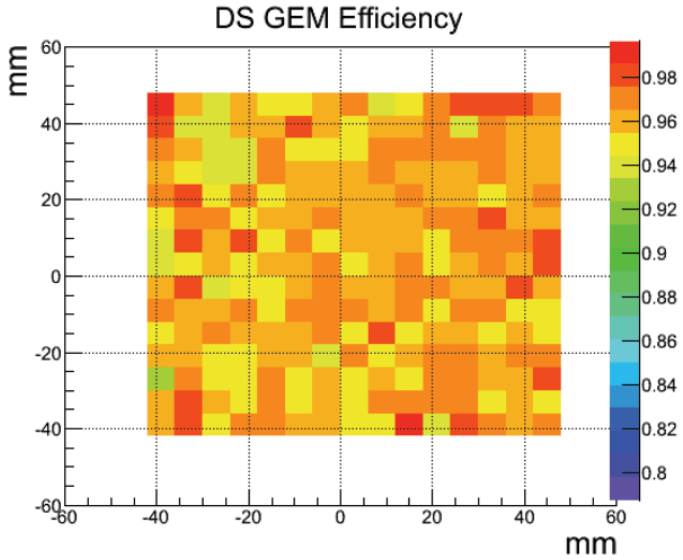
Phi angle correlation proton (WC) lepton (MWPC)



Efficiency of MWPC 99%

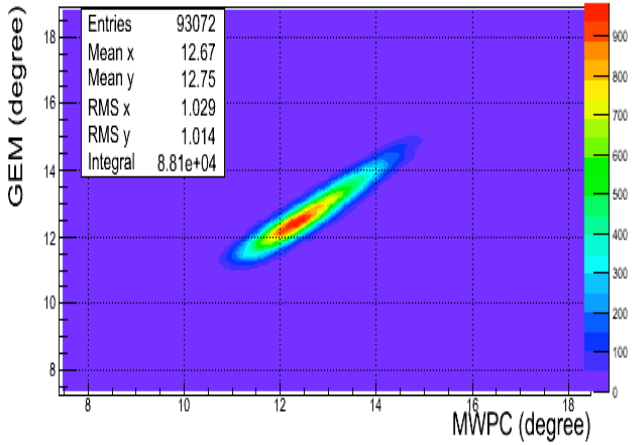


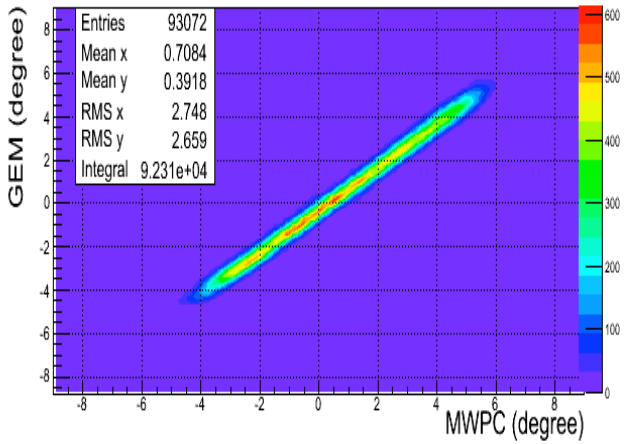
Lumi GEM Performance



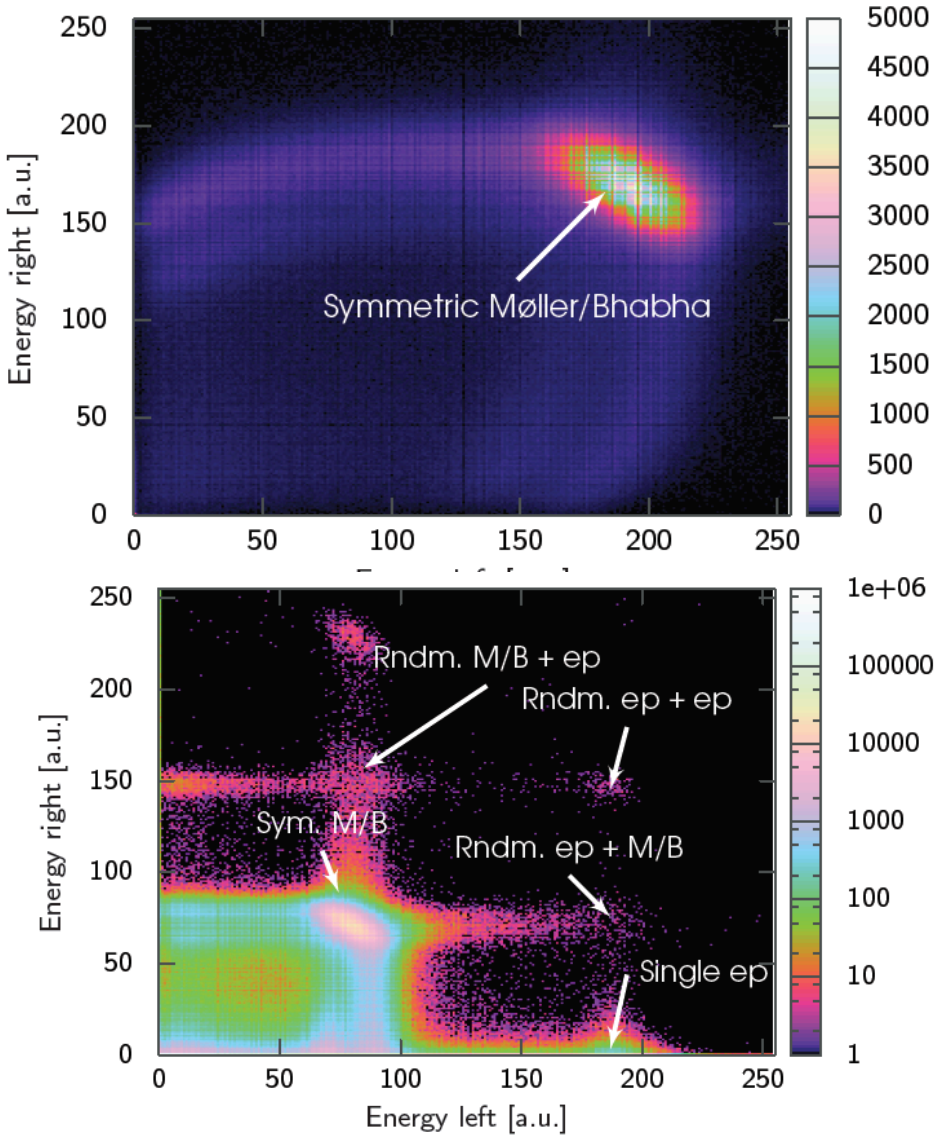
- efficiency ~96%
- resolution ~60 μ m

GEM MWPC correlations (ϕ and θ)





Symmetric Moller/Bhabha Lumi Monitor



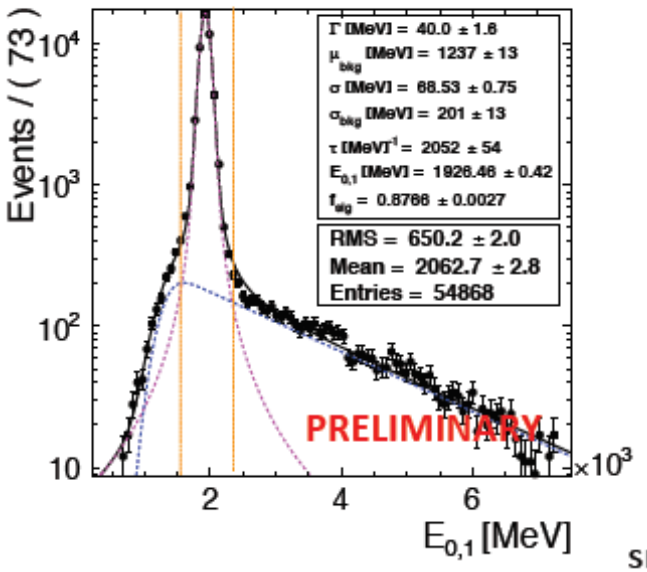
- Independent luminosity measurement at 1.3°
- In addition, can detect lepton from e p scattering
- Cross check energy calibration and rate estimate
- Rates to be corrected for beam positions and slopes

Beam Energy Reconstruction

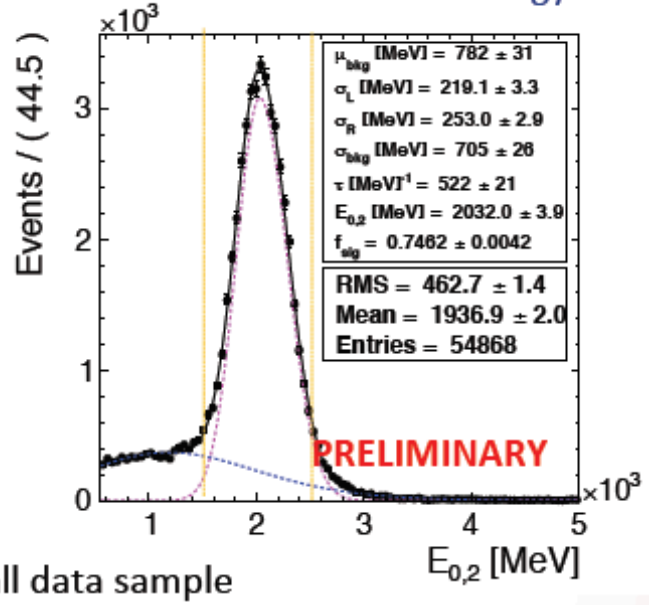
Kinematics is overconstrained

February data, few days with old tracking version

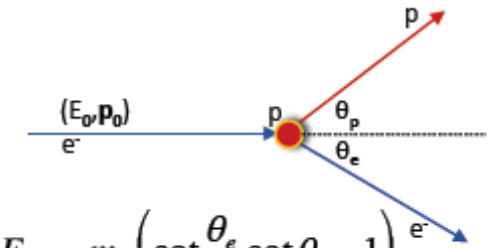
Reconstruction from angles



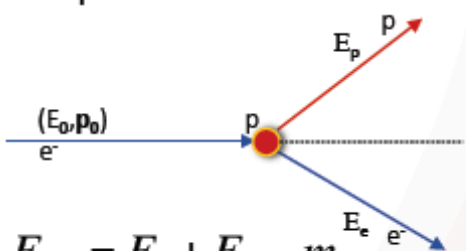
Reconstruction from energy



small data sample



$$E_{0,1} = m_p\left(\cot\frac{\theta_e}{2}\cot\theta_p - 1\right)$$



$$E_{0,2} = E_e + E_p - m_p$$

Conclusions

- Study of two photon exchange important for understanding proton form factor ratio disagreement
  - Two other experiments in progress 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 now in progress
- Large effort to understand systematic uncertainties to achieve ratio measurement at 1% level
- Preliminary results available next year

OLYMPUS Collaboration

OLYMPUS Collaboration:

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

50 physicists from 13 institutes