OLYMPUS Experiment at DORIS

R. Beck
for the
OLYMPUS- collaboration

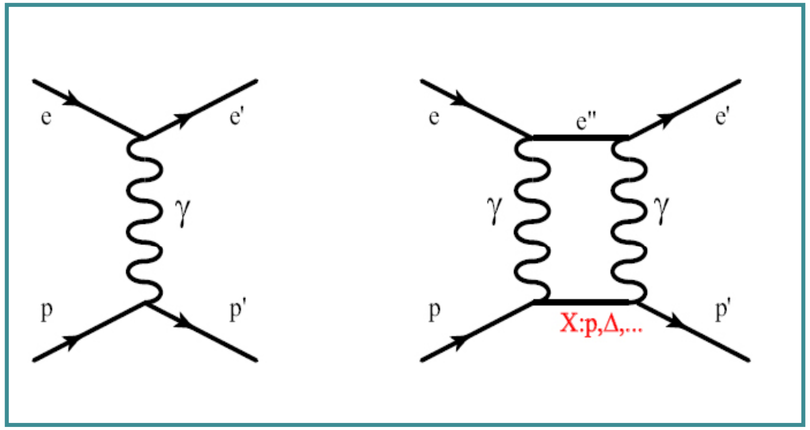
From Quarks and Gluons to Hadrons and Nuclei
Erice-Sicily, September 16-24, 2011

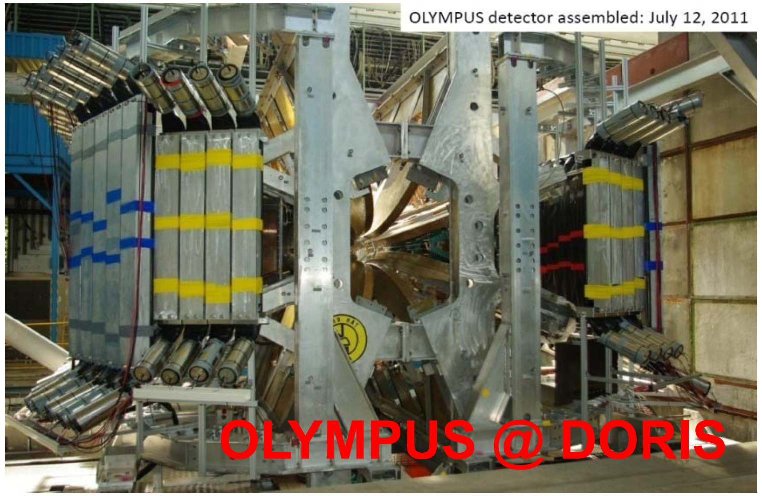
Outline of the talk

Two photon contributions in elastic electron nucleon scattering

- Introduction
- OLYMPUS experiment at DORIS

  $e^+ p$ / $e^- p$ elastic cross section ratio
- Recent Results
- Summary





OLYMPUS

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

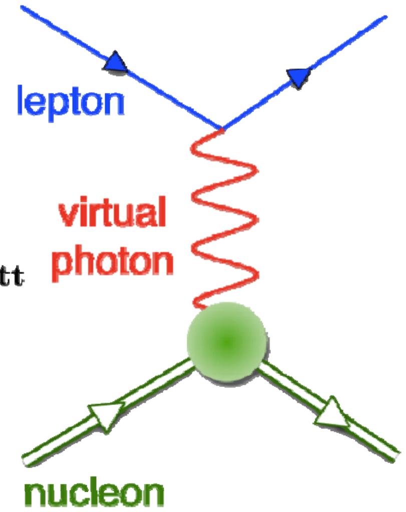
2007 – Letter of Intent
2008 – Full proposal
2009/10 – Funding and Approval
2010/11 – Transfer of BLAST detector
Installation and commissioning
2012 – OLYMPUS Running

<u>Special Thanks to the Post-docs of OLYMPUS:</u>

J. Bernauer, J. Diefenbach, C. Funke, P. Hoffmeister, R.F. Perez-Benito, A. Winnebeck,

Unpolarized Elastic e-N Scattering

- Rosenbluth cross section
  - single photon exchange – Born approximation



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

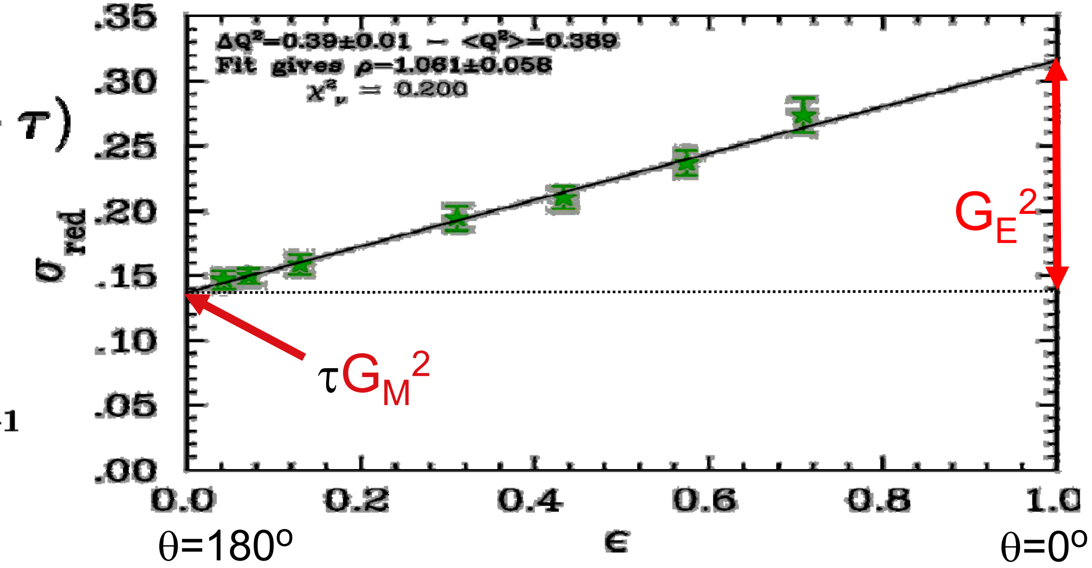
$$\tau = \frac{Q^2}{4M_p^2} \qquad \left(\frac{d\sigma}{d\Omega}\right)_{\text{Mott}} = \frac{\alpha^2}{4E^2}\frac{\cos^2\frac{\theta}{2}}{\sin^4\frac{\theta}{2}}\frac{E'}{E}$$

- Extract G_E and G_M

$$\sigma_{\text{red}} = \frac{\left(\frac{d\sigma}{d\Omega}\right)_{\text{Rosenbluth}}}{\left(\frac{d\sigma}{d\Omega}\right)_{\text{Mott}}}\,\epsilon\,(1+\tau)$$

$$= \epsilon|G_E|^2 + \tau|G_M|^2$$

$$\epsilon = \left[1 + 2(1+\tau)\tan^2\frac{\theta}{2}\right]^{-1}$$



Polarized Elastic e-N Scattering

- Double polarization transfer measurements in elastic ep-scattering
  - Polarized beam and recoil polarization or polarized proton target

$^{1}H(\vec{e},e'\vec{p})$, $^{1}\vec{H}(\vec{e},e'p)$

- Polarized cross section

$$\sigma = \sigma_0 \left(1 + P_e \vec{P}_p \cdot \vec{A}\right)$$

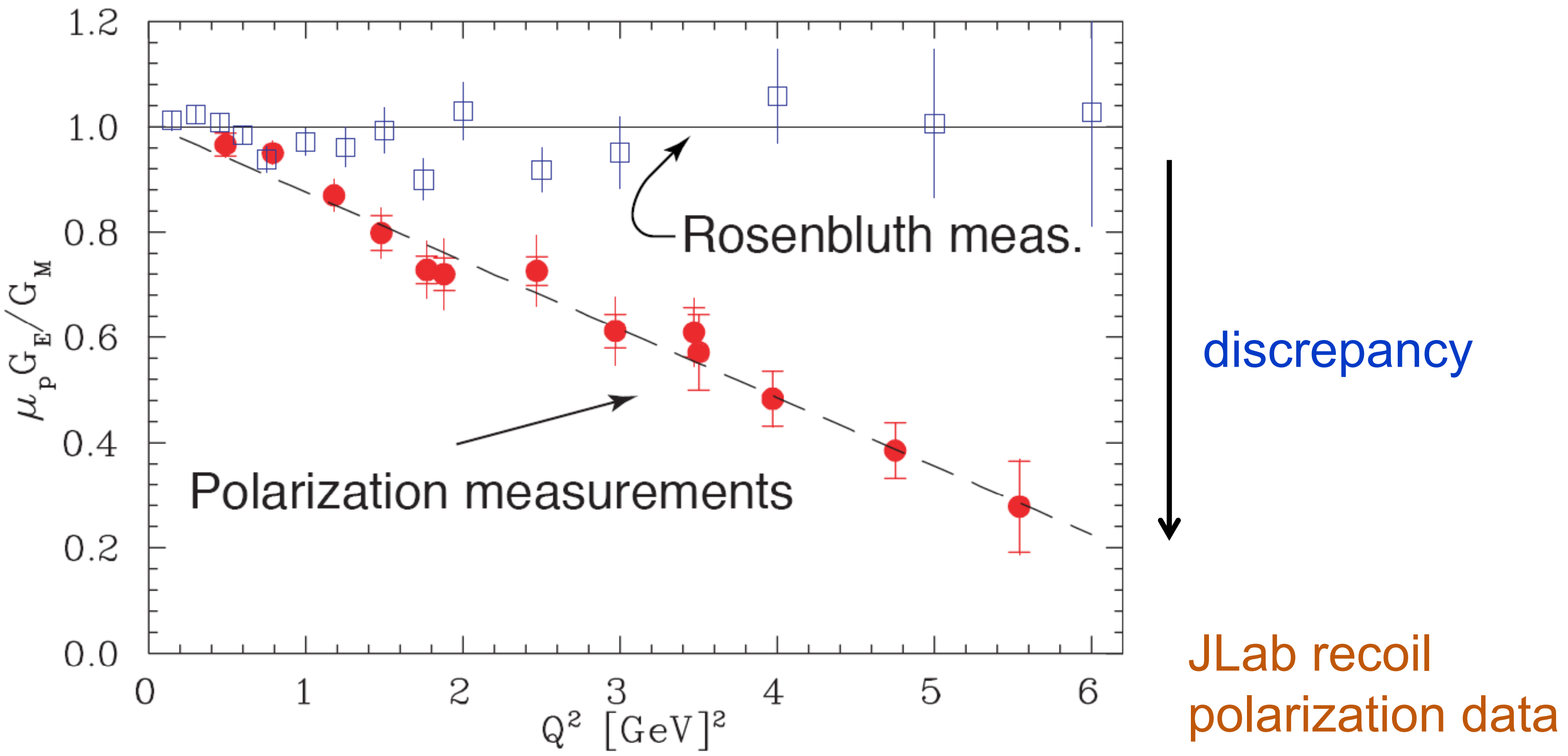
$$-\sigma_0 \vec{P}_p \cdot \vec{A} = \sqrt{2\tau\epsilon(1-\epsilon)} G_E G_M \sin\theta^* \cos\phi^* + \tau\sqrt{1-\epsilon^2} G_M{}^2 \cos\theta^*$$

- Asymmetry ratio
  independent of polarization and analysis power

$$\frac{P_\perp}{P_\parallel} = \frac{A_\perp}{A_\parallel} \propto \frac{G_E}{G_M}$$

single photon exchange – Born approximation

Rosenbluth and Recoil Polarization

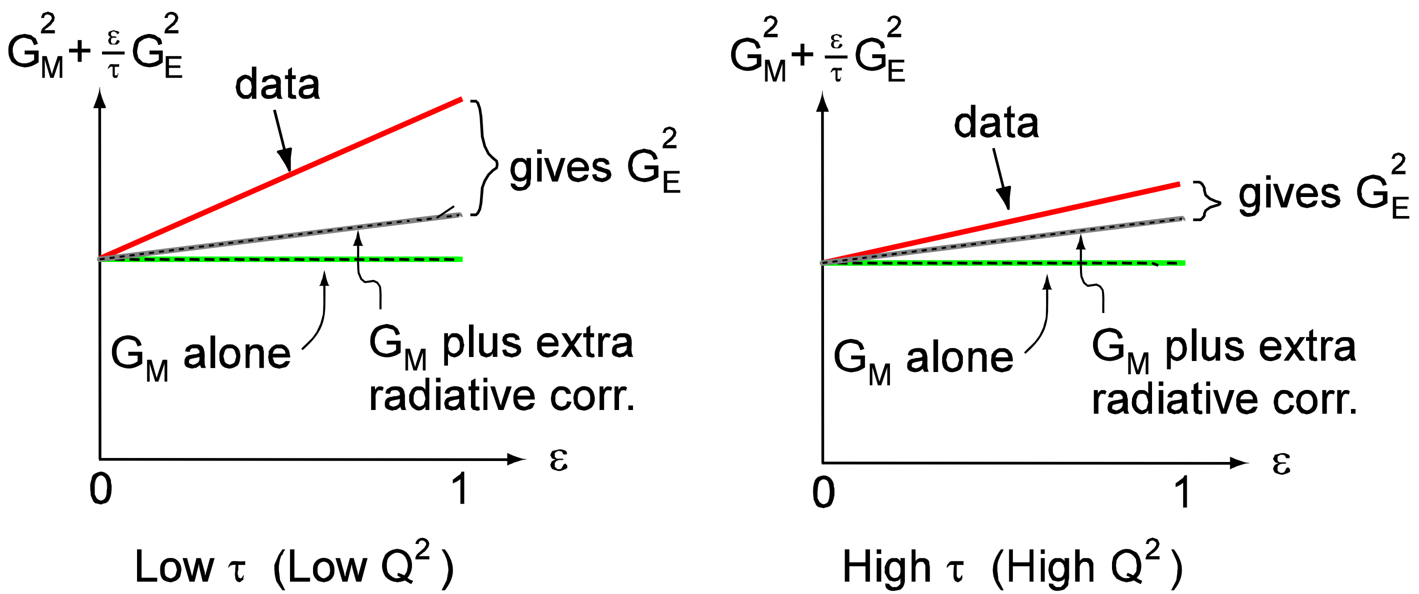


- Dramatic discrepancy between Rosenbluth and recoil polarization data
- All Rosenbluth data from SLAC and JLab in agreement
- Speculation: two photon exchange (TPE) could explain discrepancy

Rosenbluth and Recoil Polarization

- <u>Speculation</u>: There are radiative corrections to Rosenbluth experiments that are not included
- At high Q^2 electric form factor G_E is small,
- Missing radiative corrections will affect G_E extraction

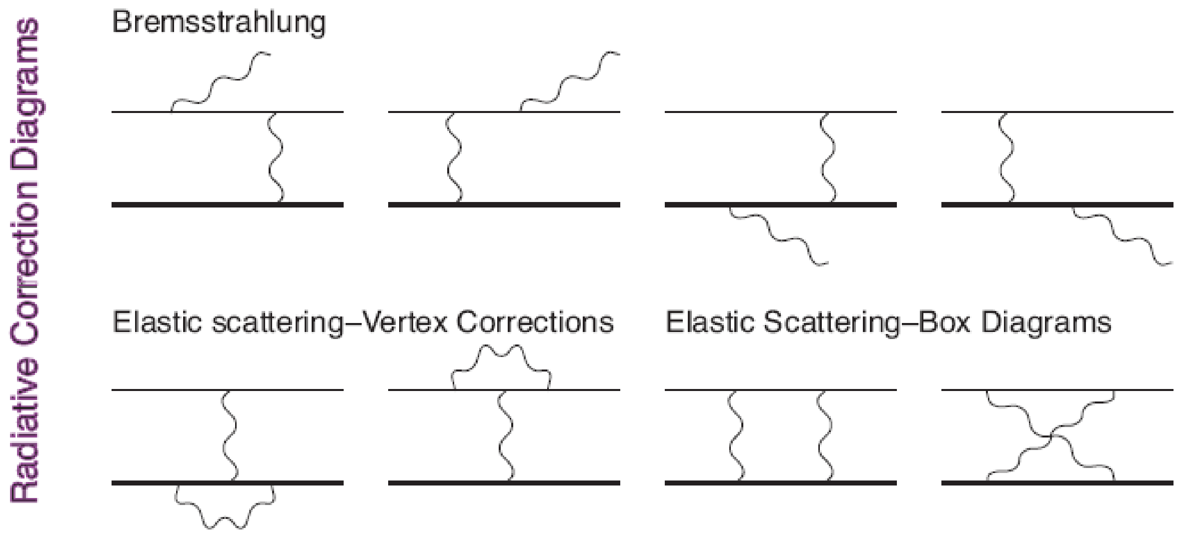
missing correction : linear in ε, not strongly Q^2 dependent



effect more visible at large Q^2

Radiative Corrections

- Since the Rosenbluth separation involves a small term, G_E , need to consider the corrections, specifically radiative corrections



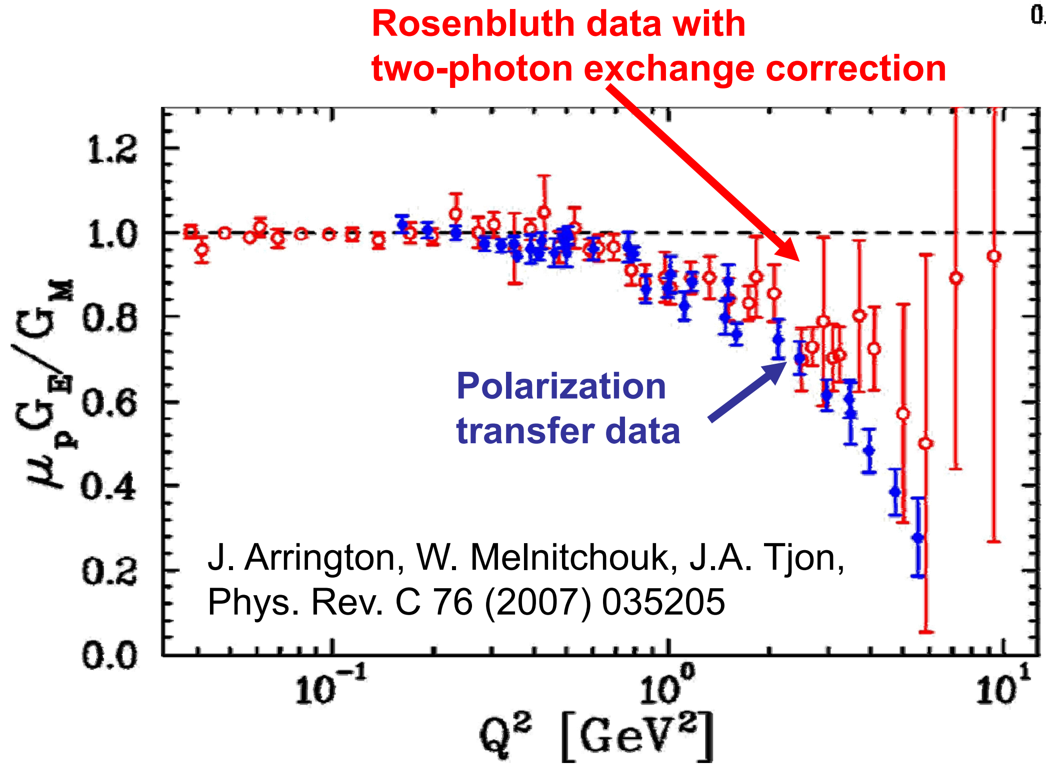
- Mostly well done in the past:

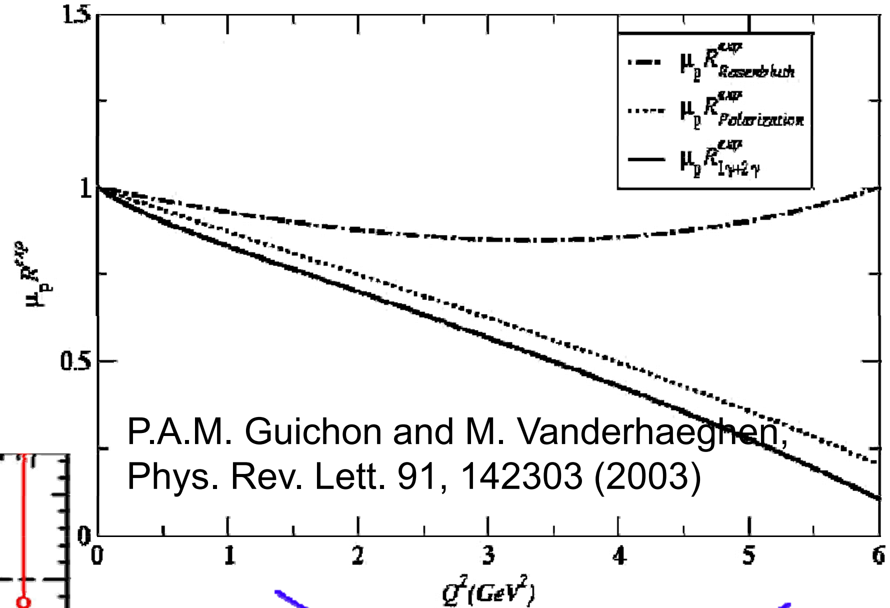
  - Meister and Yennie (1963)
  - Mo and Tsai (1961 and 1969)
  - Maximon and Tjon (2000)

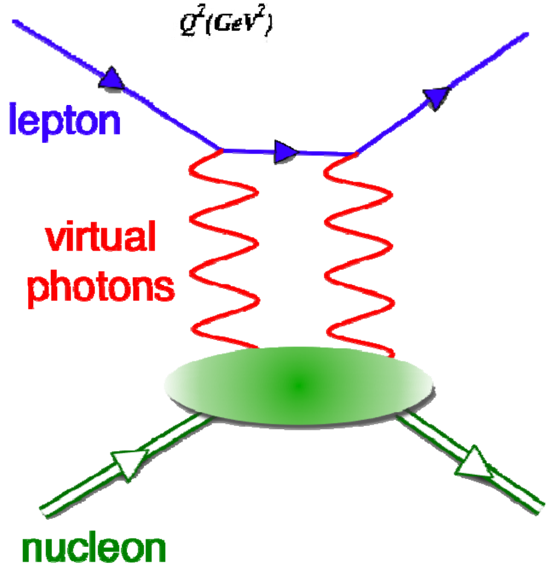
- But clear incompleteness in two photon exchange diagrams

Radiative Corrections

- Observed effect
  - mostly explicable by 2-photon exchange
  - experimental proof missing

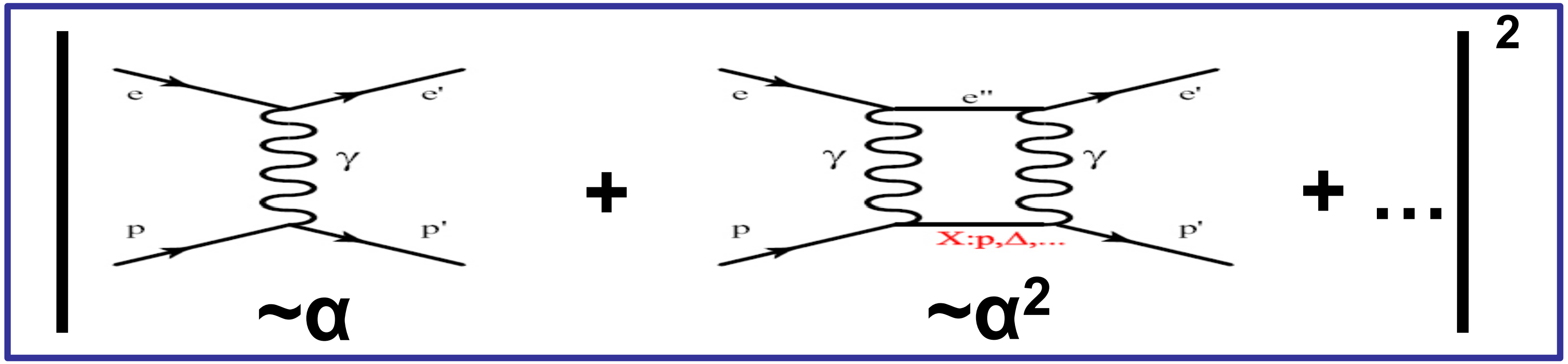






Two-Photon Contributions

- Most sensitive variable for two-photon effects: Cross section ratio e^+p / e^-p



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

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

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

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

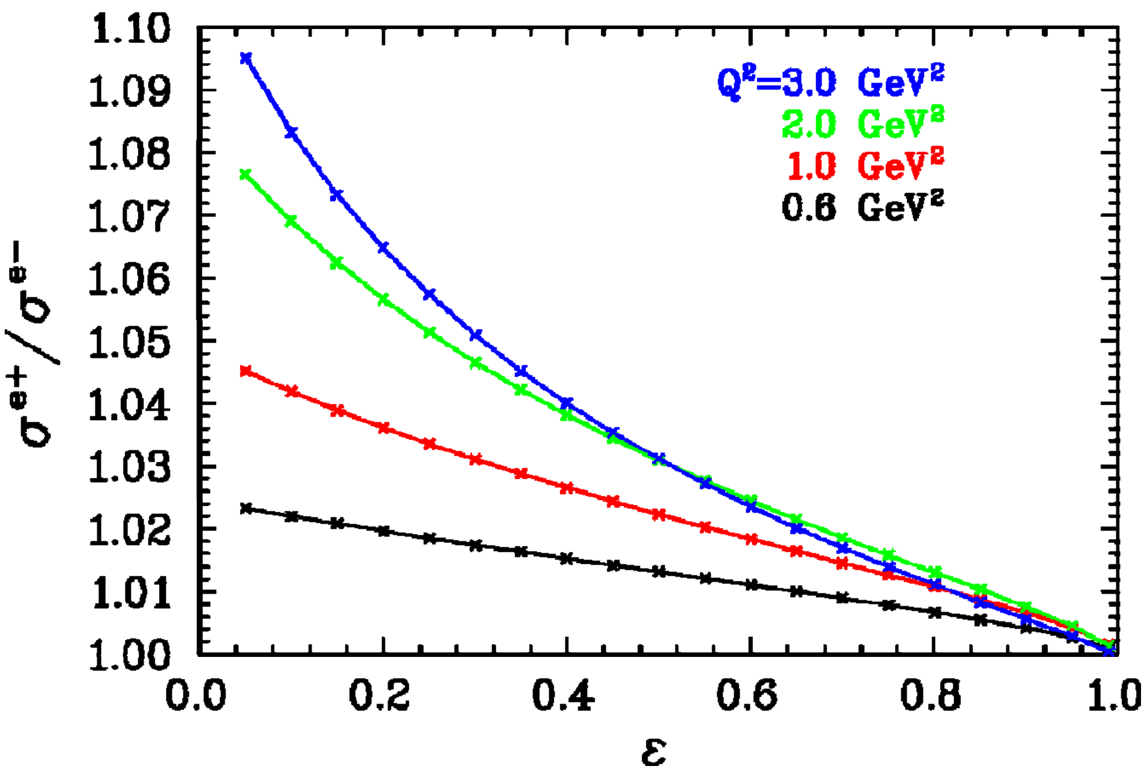
$$\frac{\sigma(e^+p)}{\sigma(e^-p)} = 1 + (2\alpha)\frac{2\gamma}{1\gamma}$$

Interference between
1γ and 2γ exchange

Different sign
for e+p or e-p

Two-Photon Contributions

- Most sensitive variable for two-photon effects
  - Cross section ratio e^+/e^-
    - exactly unity in1-photon exchange (Born approximation)
    - several percent effect at Q^2 ~ 2 GeV^2



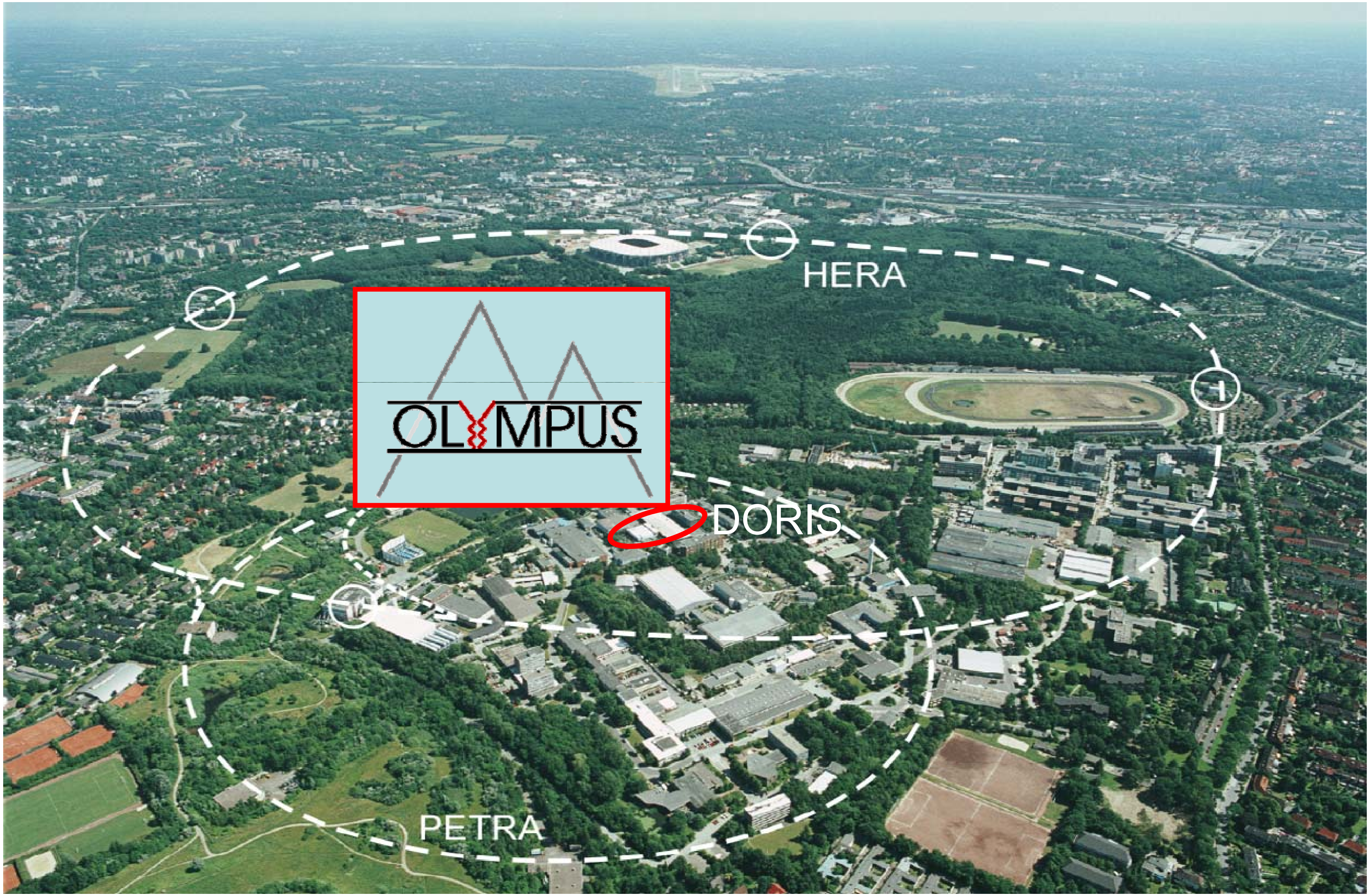
P.G. Blunden et al., Phys. Rev. C 72, 034612 (2005)

Saturation at Q^2 ~ 2-3 $(GeV/c)^2$

Experimental Requirements

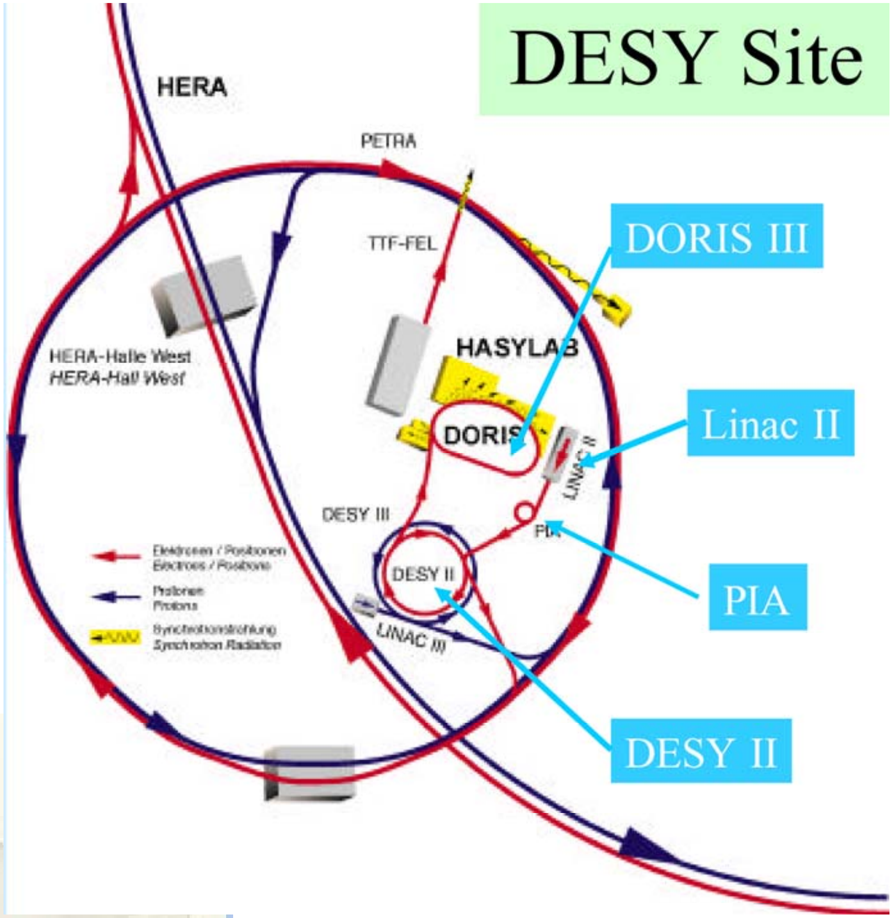
- Requirements: for cross section ratio e^+/e^-
  - electron and positron beams
    - E ~ 2 GeV
    - frequent switch
  - pure proton target
  - lepton-proton coincidence measurement
  - large theta coverage (epsilon range)
  - minimise systematic uncertainties
    - symmetric arrangement
    - precise relative luminosity

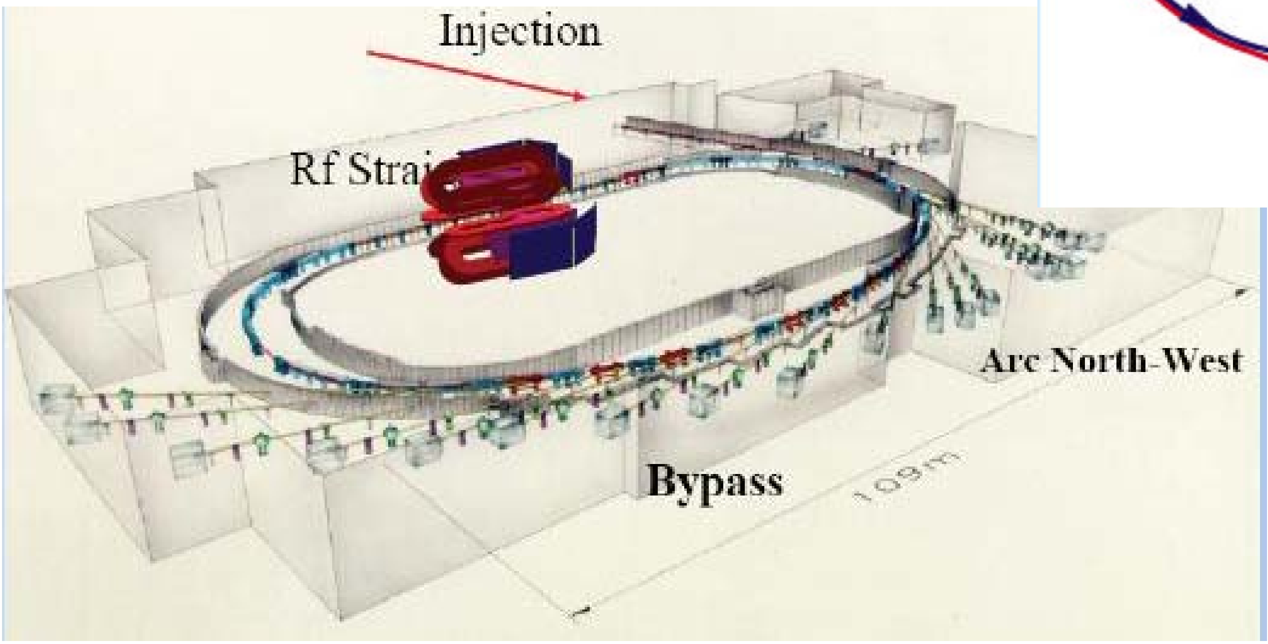
OLYMPUS at DESY



DORIS

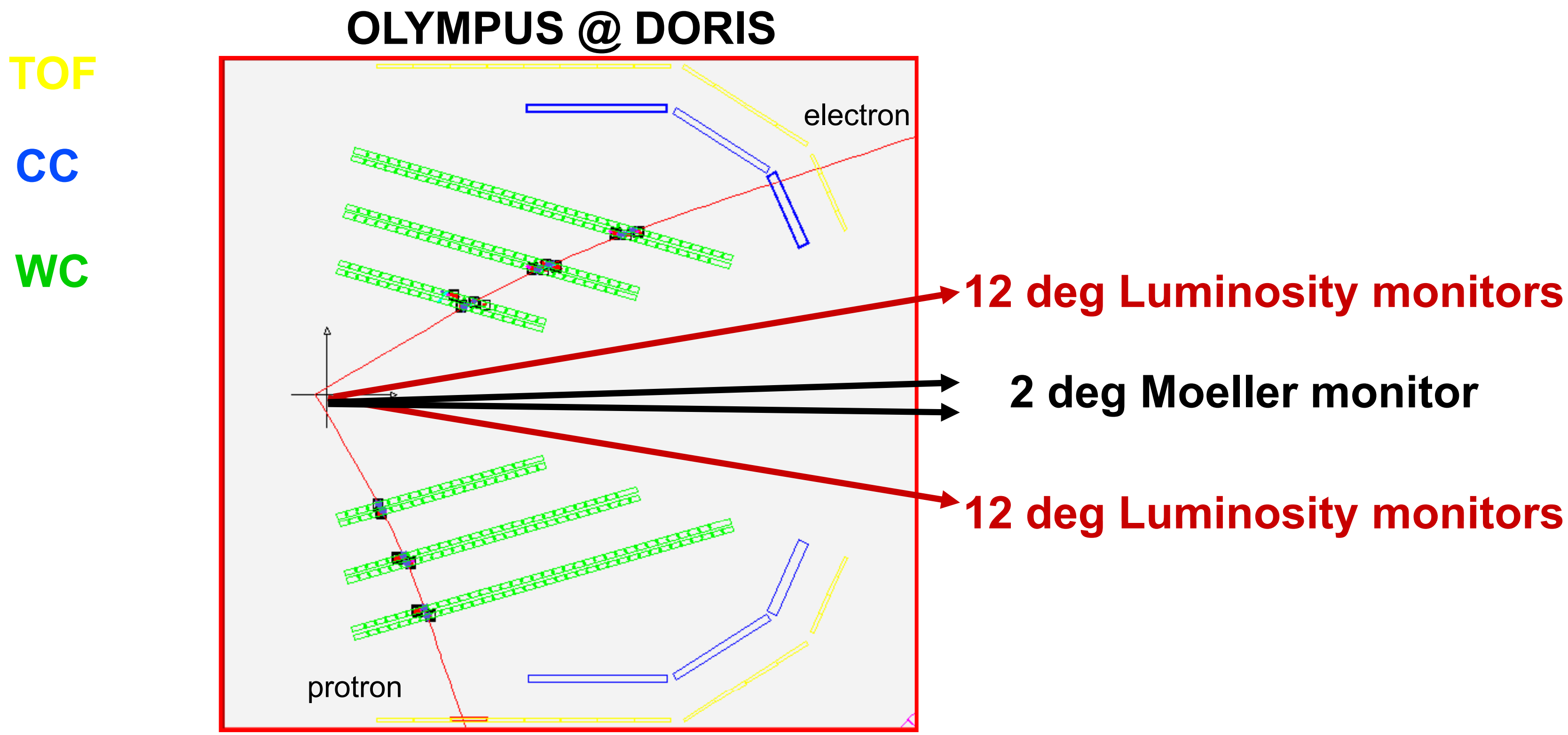
- e$^+$ and e$^-$ beams
  E = 2.0 (4.5)GeV
  Q^2 = 0.6-2.4(4.1) (GeV/c)^2
  OLPMPUS experiment fits
  in former ARGUS location





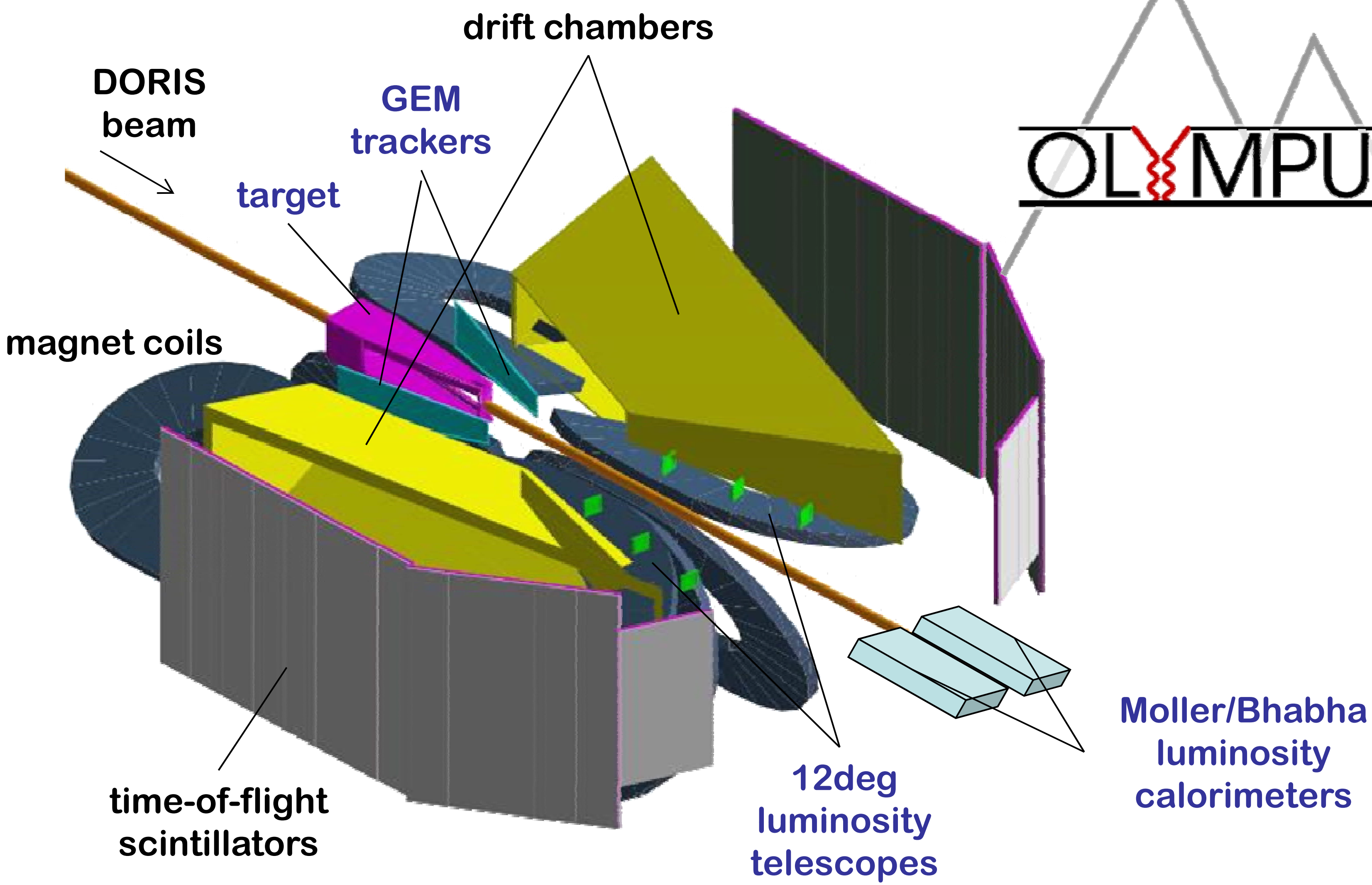
OLYMPUS Experiment

Parts of existing BLAST detector from MIT- Bates



- Change between electrons and positrons once a day
- Change toroidal coils polarity once a day
- Left-right symmetry

OLYMPUS Experiment



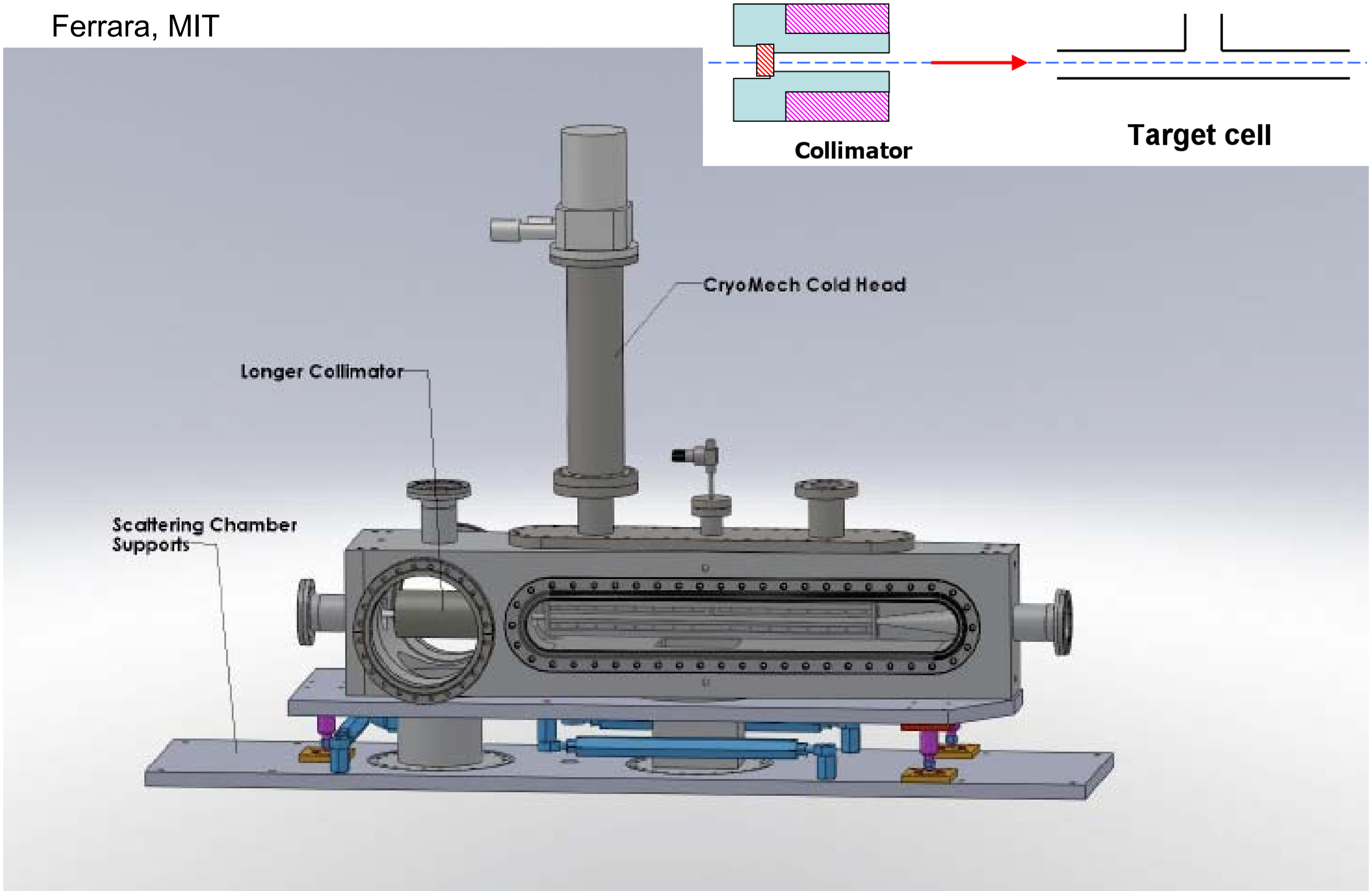
OLYMPUS Experiment

DESY, MIT

OLYMPUS Experiment

Target and Vacuum System

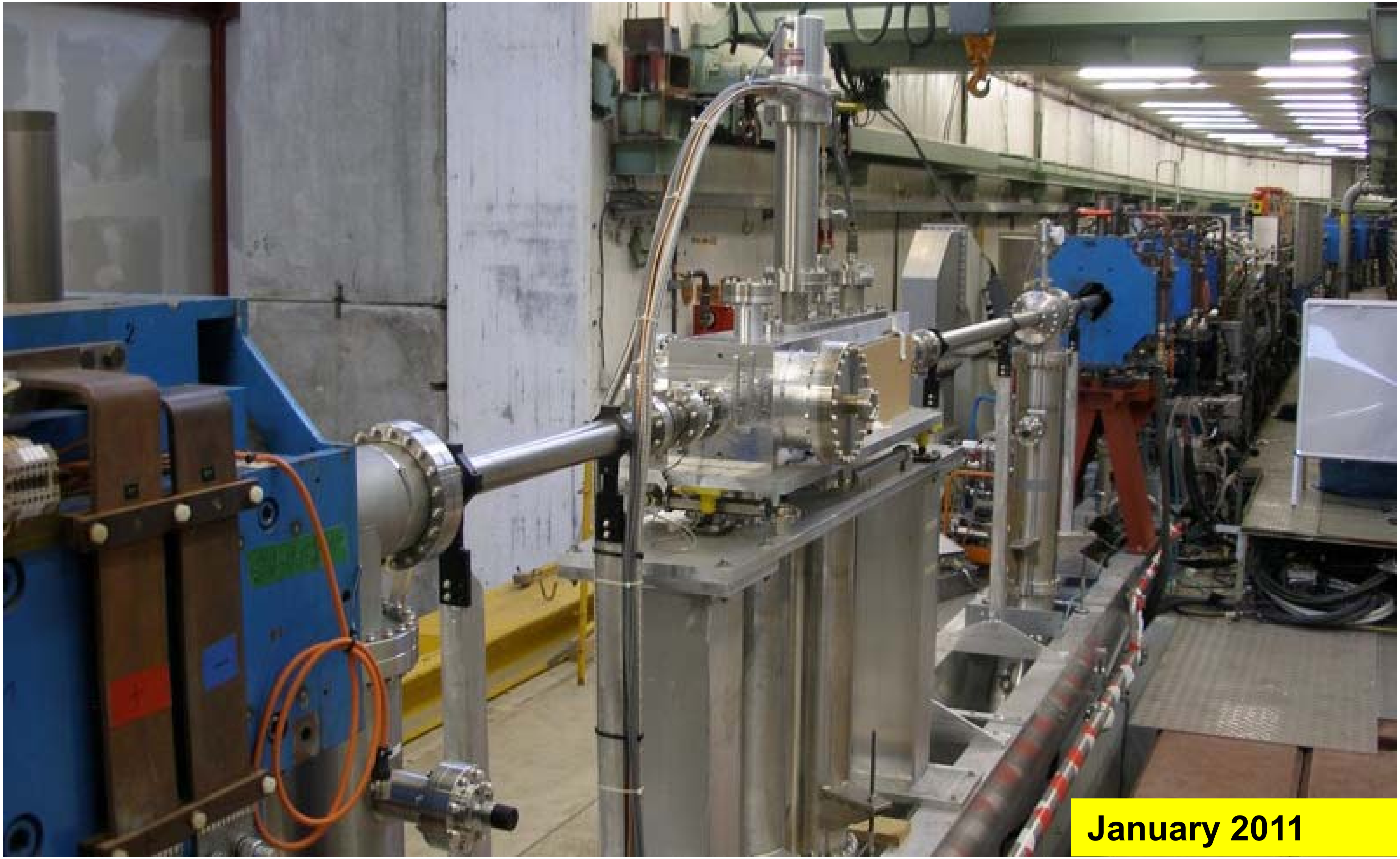
Ferrara, MIT



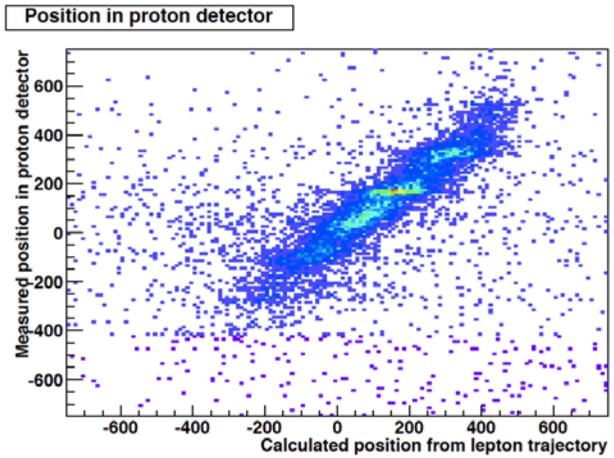
Target and Vacuum System

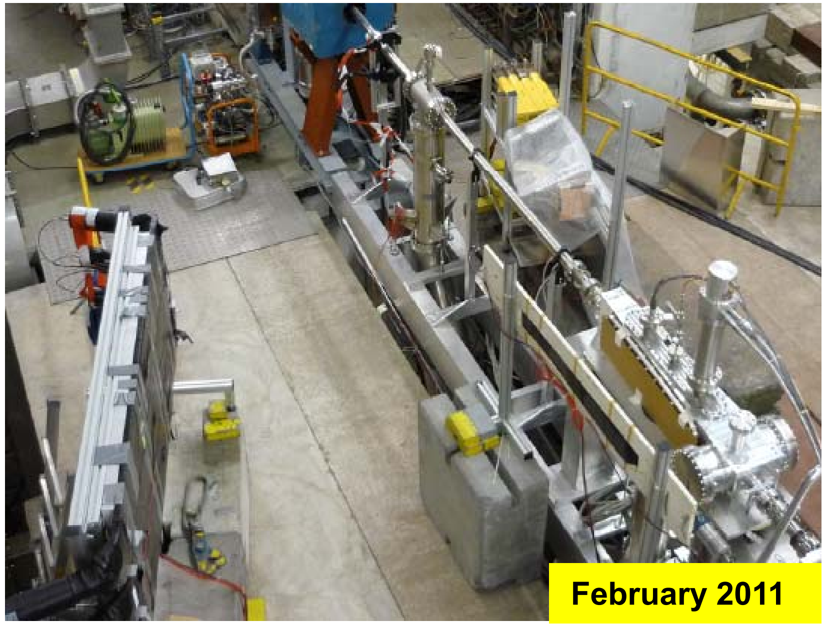
Target installed at DORIS beamline

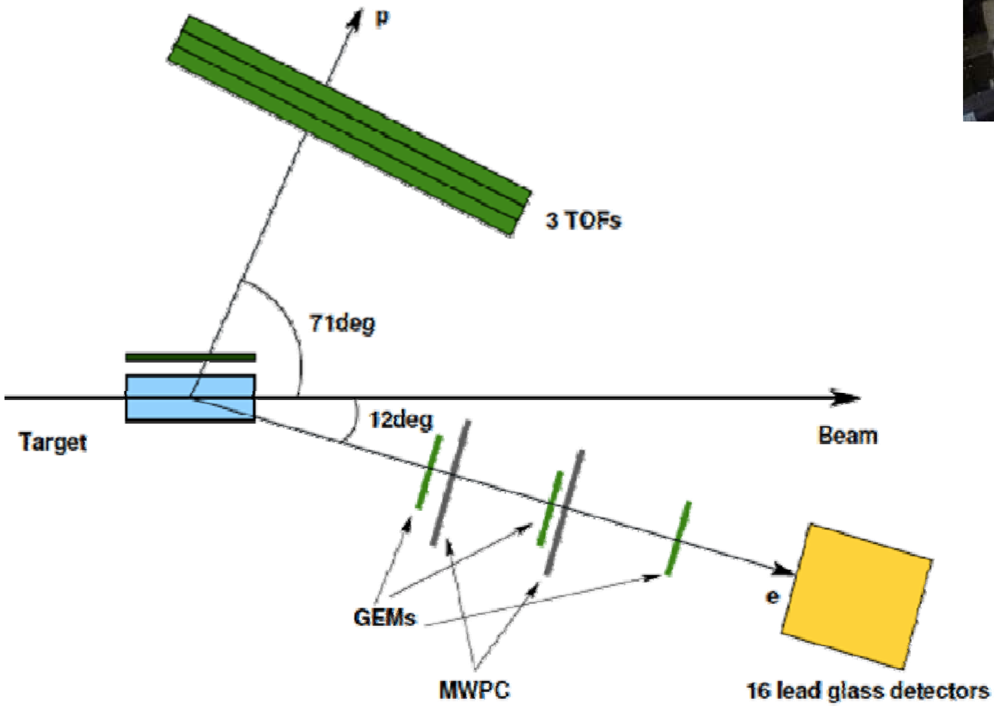
DESY, MIT



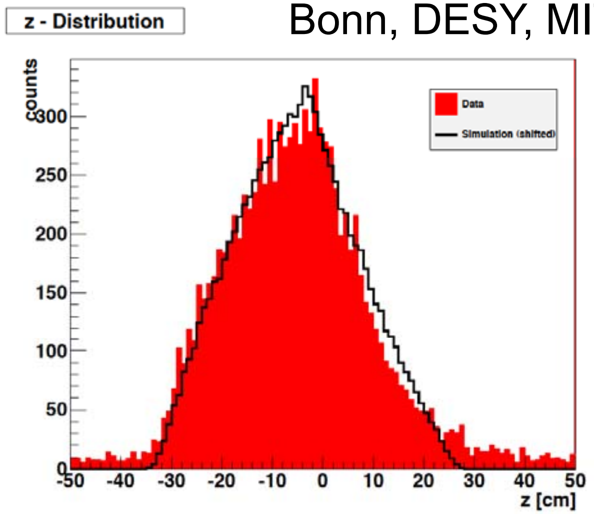
DORIS Test-Experiment





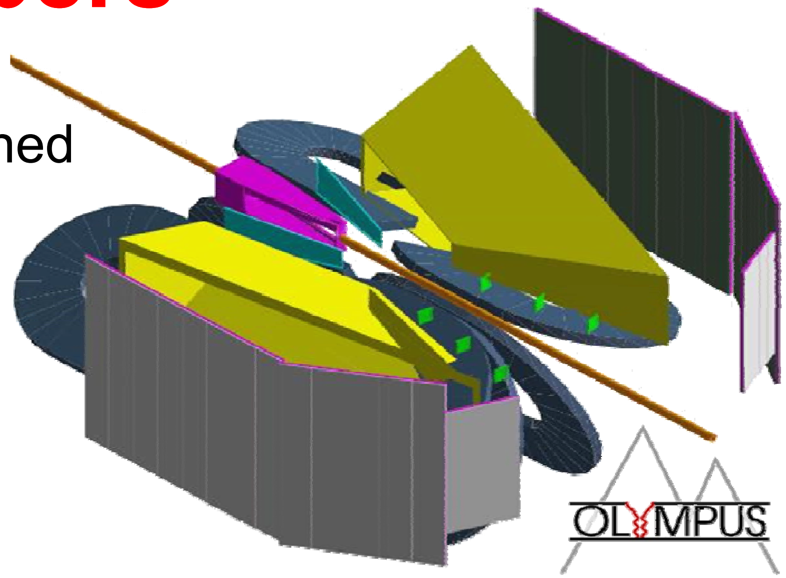


Bonn, DESY, MIT

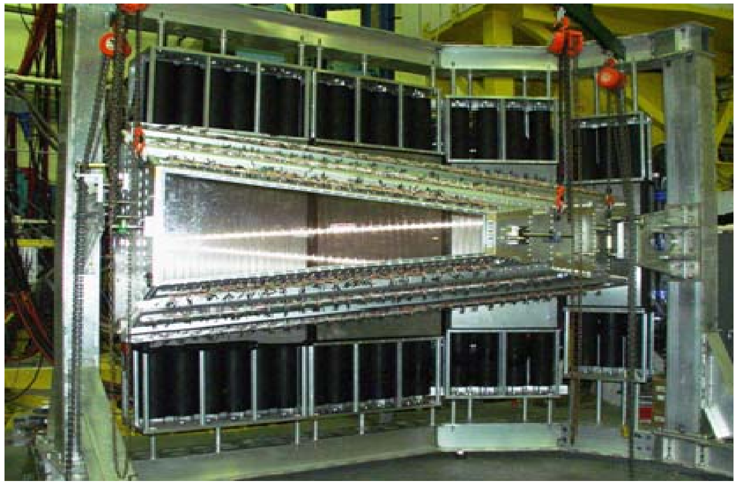


Wire Chambers

- All chambers completely reconditioned
- rewired, new windows
- Test and calibration of cells in progress

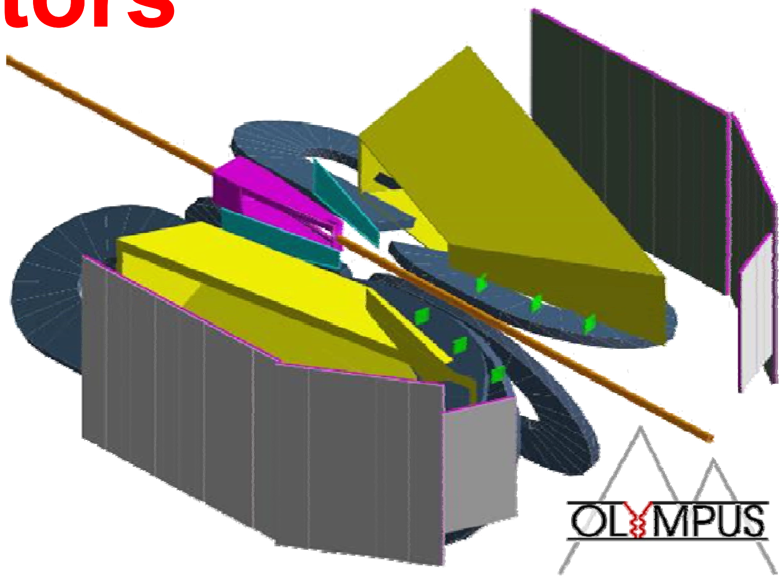


DESY, MIT

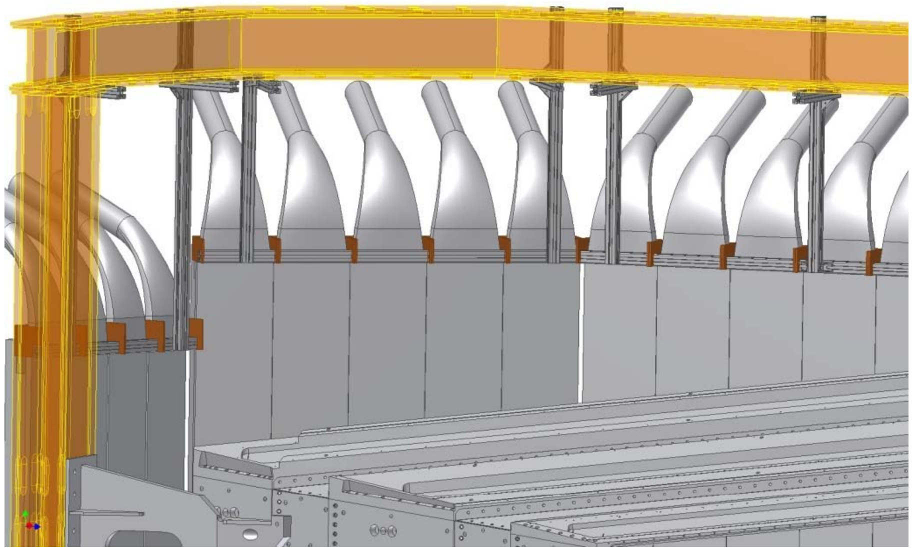


TOF Detectors

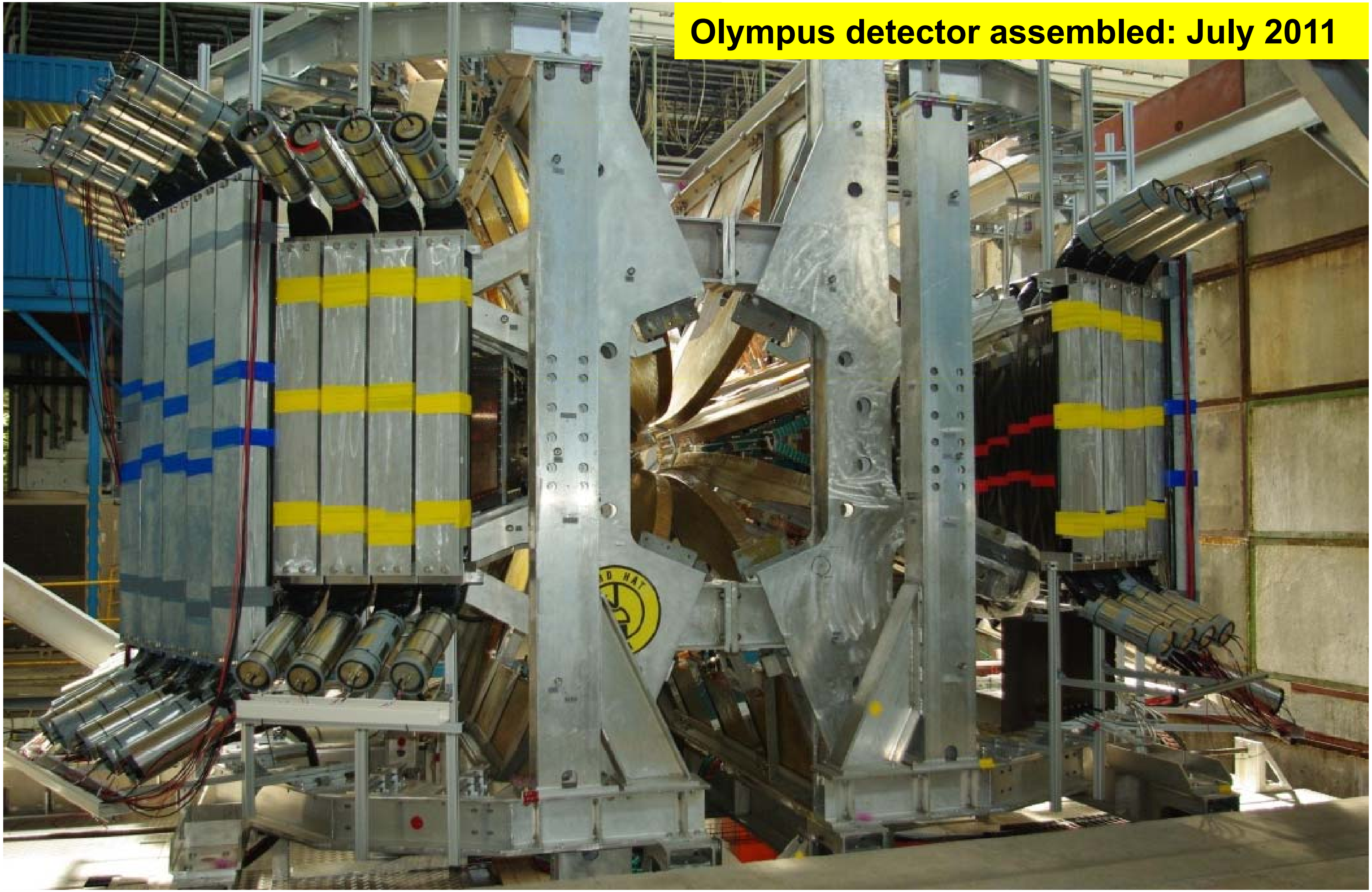
- Situated behind wire chambers
- Provide trigger an relative timing
  - calibration in progress
- A new flasher system



Glasgow, Yerewan



OLYMPUS Experiment



Olympus detector assembled: July 2011

Experimental Requirements

- Requirements
  - electron and positron beams
    - E ~ 2 GeV
    - frequent switch
  - pure proton target
  - lepton-proton coincidence measurement
  - large theta coverage (epsilon range)
  - minimise systematic uncertainties
    - symmetric arrangement
    - precise relative luminosity

OLYMPUS

Experimental Requirements

- Redundant monitoring of Luminosity

  2 symmetric luminosity monitors
  - 12deg telescopes: GEMs + MWPCs (coincident)
  - 2deg Moller/Bhabha calorimeters
- Regular change of both
  - particle type: i = e^+ or e^-
  - magnet polarity: j= pos or neg
- Combination
  - efficiency and acceptance effects cancel to first order

$$N_{ij} = L_{ij}\sigma_i \kappa^p_{ij} \kappa^l_{ij}$$

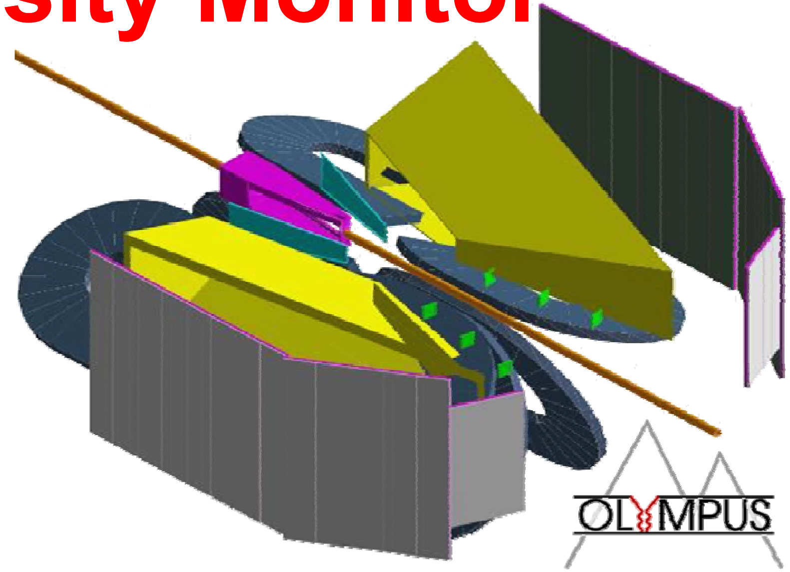
lumi proton, lepton efficiency

acceptance

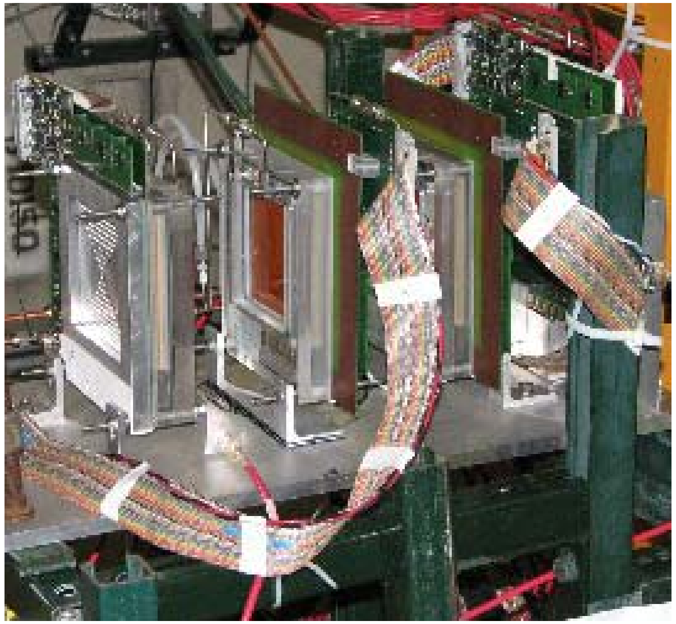
$$\frac{\sigma_{e^+}}{\sigma_{e^-}} = \left[\left(\frac{N_{e^+ +} + N_{e^+ -}}{N_{e^- +} + N_{e^- -}} \Big/ \frac{A_{e^+ +} + A_{e^+ -}}{A_{e^- +} + A_{e^- -}} \right) \Big/ \left(\frac{N^{fwd}_{e^+ +} N^{fwd}_{e^+ -}}{N^{fwd}_{e^- +} N^{fwd}_{e^- -}} \Big/ \frac{A^{fwd}_{e^+ +} A^{fwd}_{e^+ -}}{A^{fwd}_{e^- +} A^{fwd}_{e^- -}} \right) \right]^{\frac{1}{2}}$$

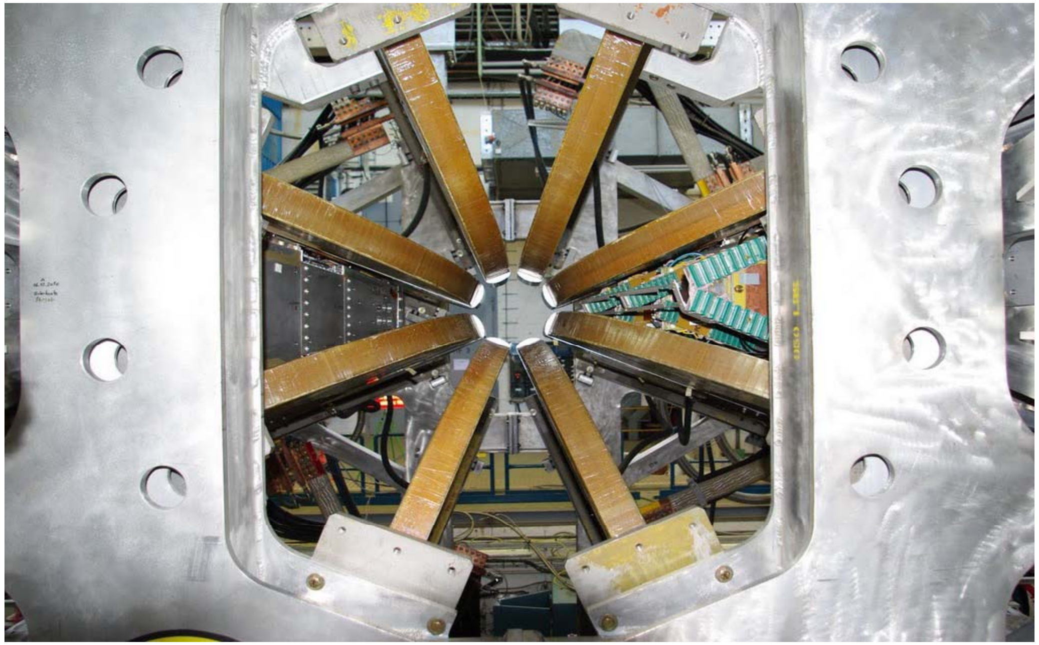
12 deg Luminosity Monitor

- Redundant monitoring of Luminosity
  - 3 GEMs + 3 MWPCs
  - Already installed and tested



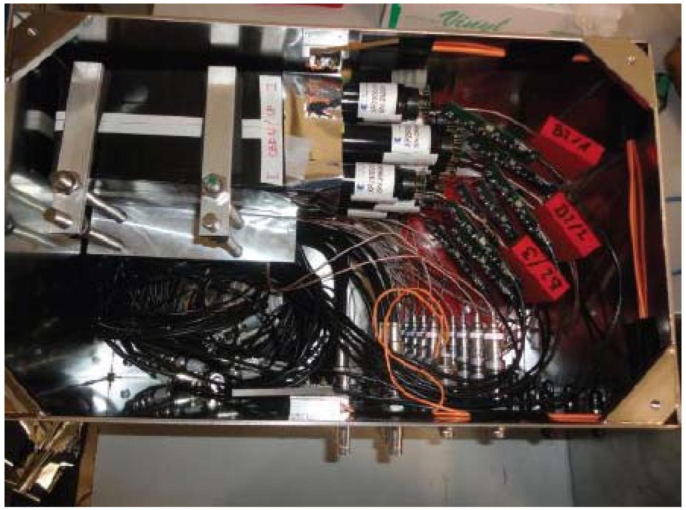
Hampton, PNPI, Rome



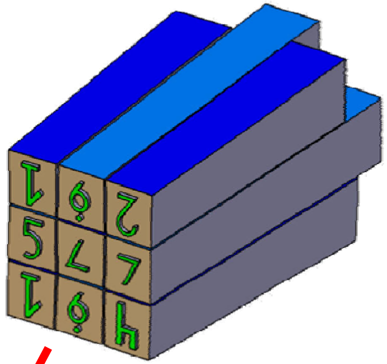


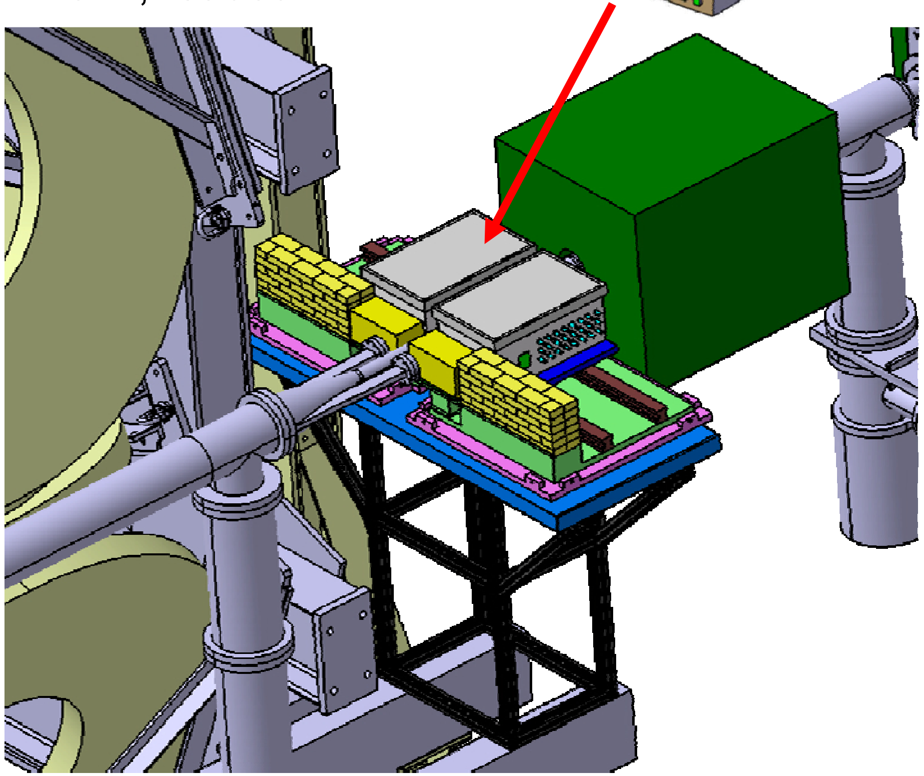
Moller/Bhabha Luminosity Monitor

- Existing radiation hard PbF_2 crystals from A4-Mainz
- Installed and will be tested in October beam time



Mainz, detector
Bonn, readout





Expected Results

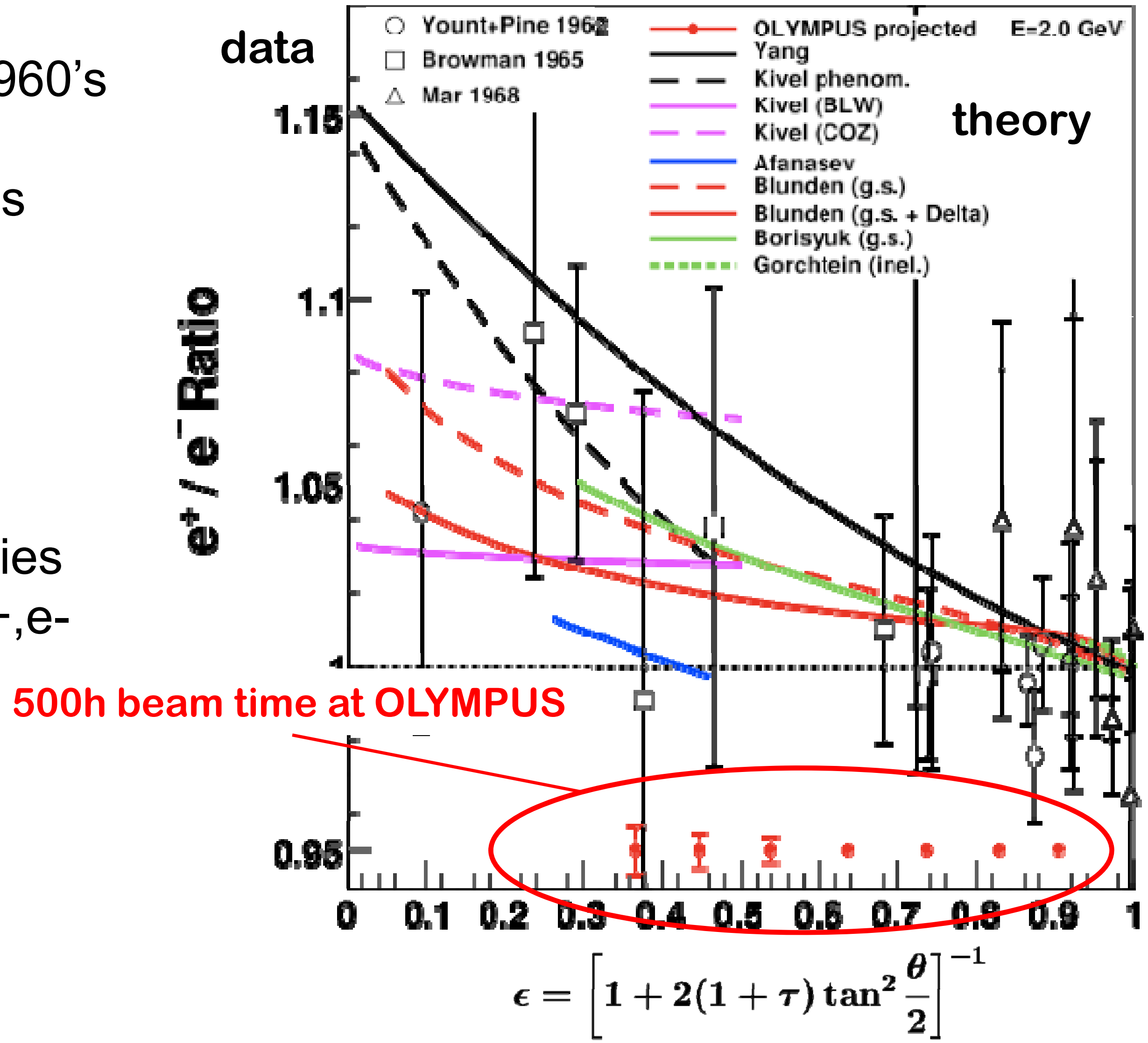
Open symbols data from 1960's

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 @ 2×10^{33} / $cm^2 s$ e+,e-

data run in 2012



DORIS Requirements

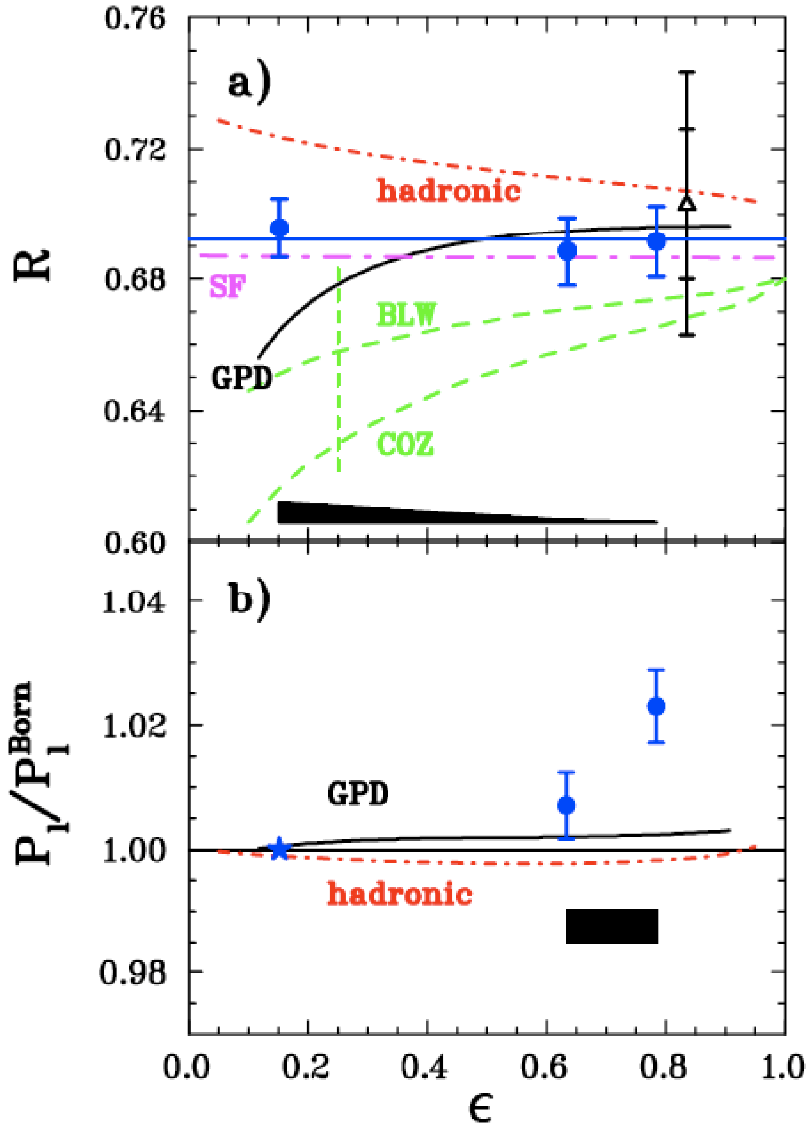
- Experiment requires frequently switching from e^+ beam to e^- beam.
- Measure ratio R of positron-proton to electron-proton unpolarized elastic scattering to 1% stat.+sys.
- Control of systematic uncertainties essential.
- DORIS Parameter (1% effect on R)

- beam offset	< 1mm
- beam direction	< 0.03 deg
- beam energy	< 0.5 %

-> factor 10 better would be ideal only 0.1% systematic effect !

Status on Two Photon Exchange

M. Meziane et al., hep-ph/1012.0339v2
Phys. Rev. Lett. 106, 132501 (2011)



- Recoil polarization measurement

Jlab – Hall C: Q^2 = 2.5 $(GeV/c)^2$

$$R \propto \frac{P_t}{P_l} \propto \mu_p \frac{G_E}{G_M} \quad (1 + \text{cor. of } 2\gamma)$$

G_E/G_M from P_t/P_l constant vs. ε

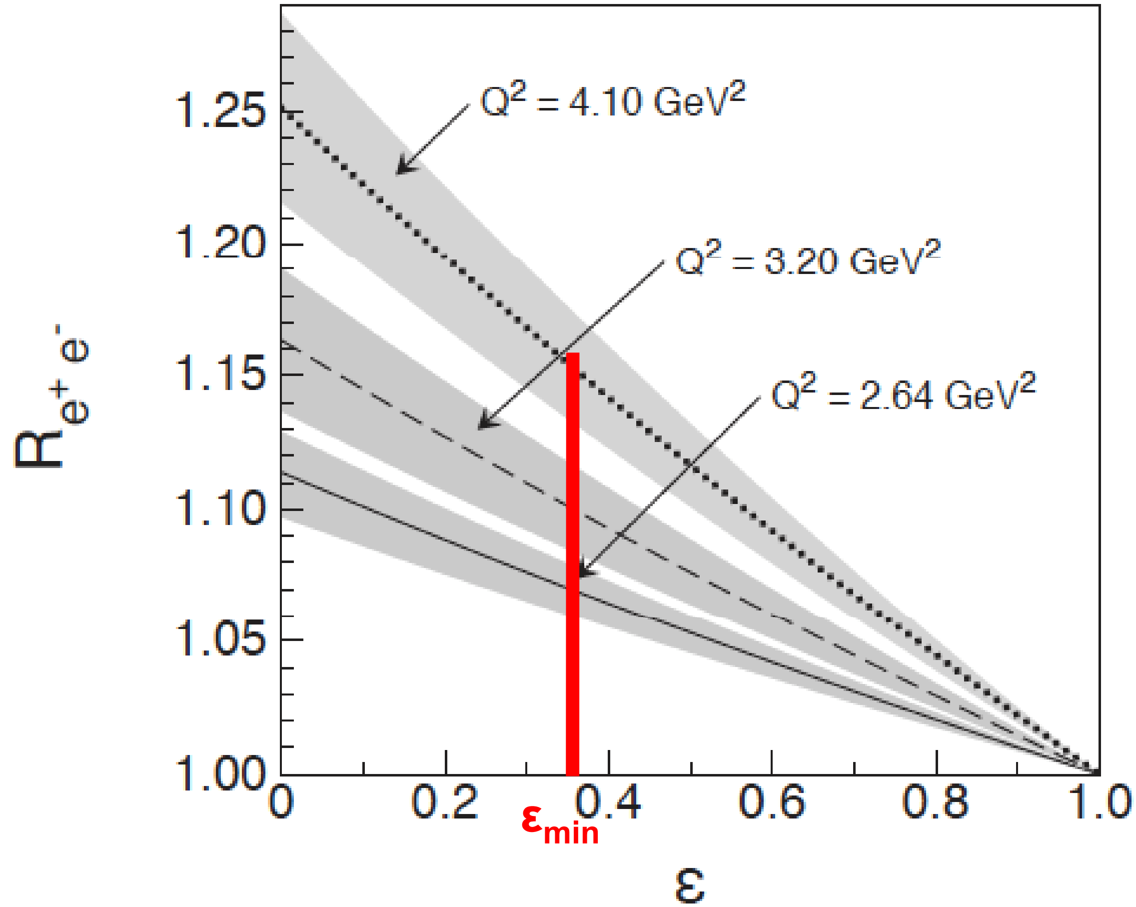
➔ no effect in P_t/P_l

➔ some effect in P_l

Expect larger effect in e+p/e-p ratio!

Status on Two Photon Exchange

J. Guttmann, N. Kivel, M. Meziane, and M. Vanderhaeghen, hep-ph/1012.0564

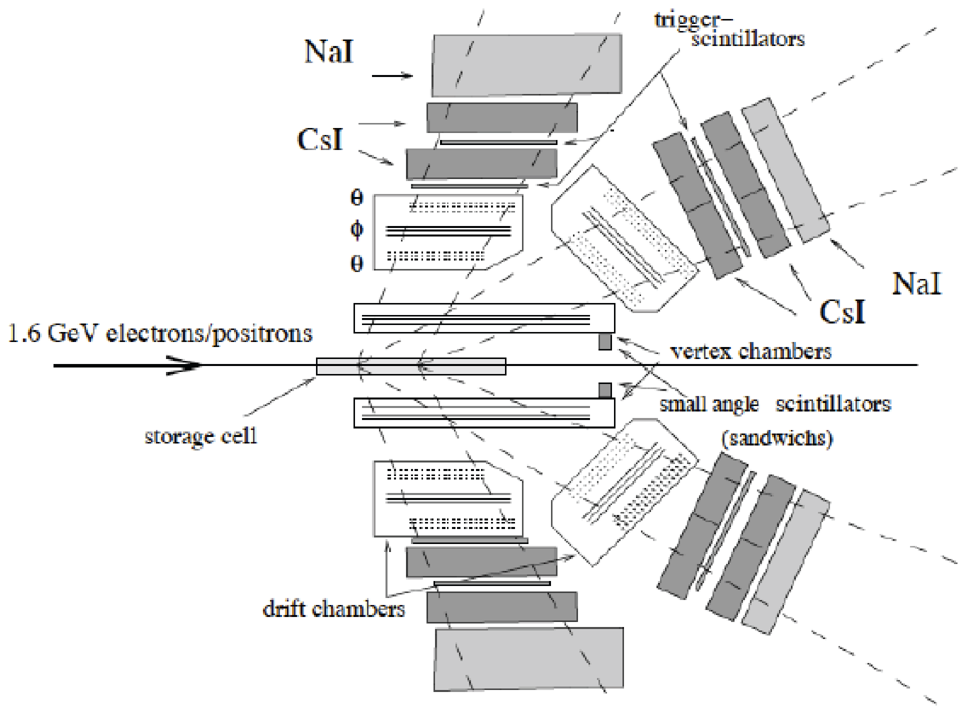


~6% effect for OLYMPUS@2.0GeV

grows with Q^2!

VEPP-3 Experiment, Novosibirsk

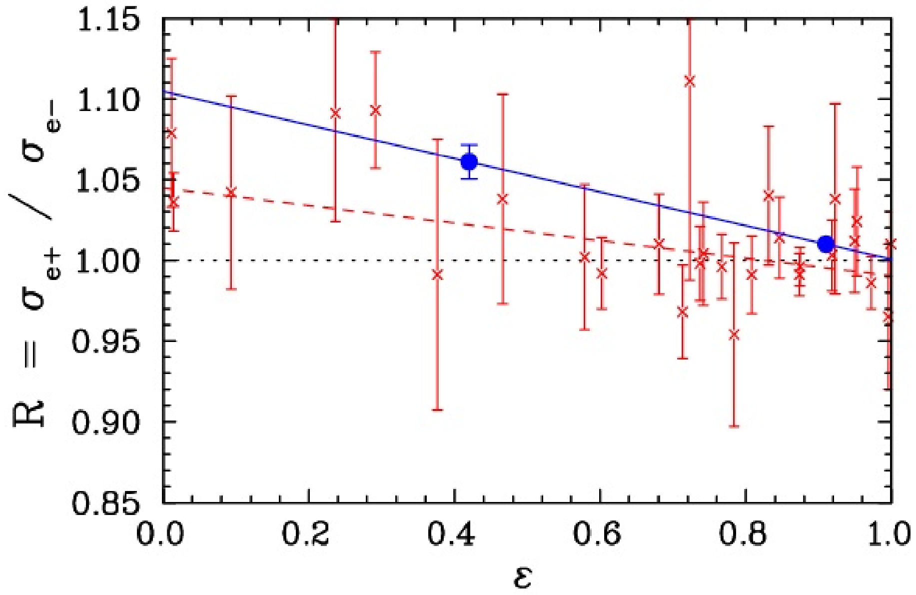
e+/e- ratio: **VEPP3/Novosibirsk** storage ring / intern. target – 2009
low Q2 range
no momentum measurement



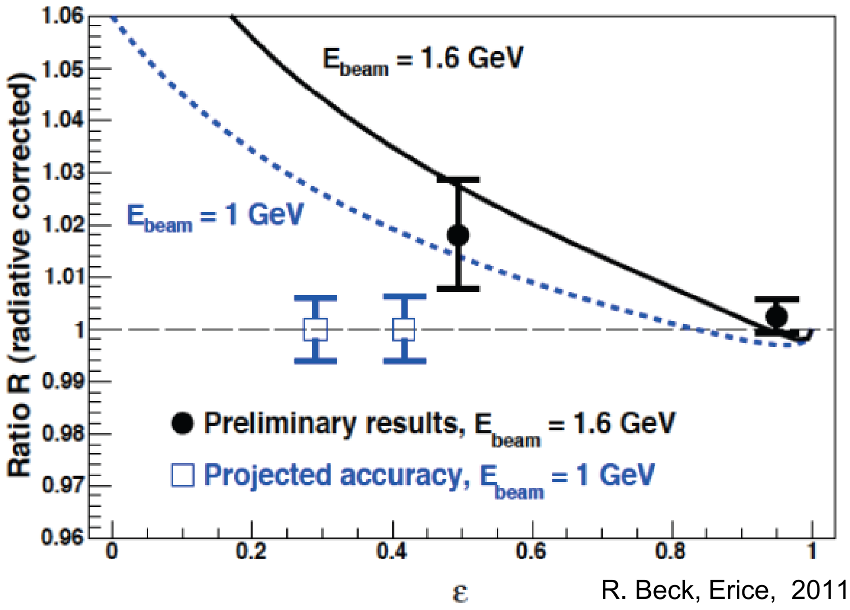
arXiv:nucl-ex/0408020

e^-/e^+ Strahl (1,6 GeV)
θ_e: $(24\pm4)^\circ$, $(70\pm10)^\circ$
ϵ: 0,91 und 0,4
Q^2 Abdeckung:
$(0{,}36\pm0{,}1)\,(\mathrm{GeV}/c)^2$,
$(1{,}58\pm0{,}18)\,(\mathrm{GeV}/c)^2$

VEPP-3 Experiment, Novosibirsk



Projected Results compared to data from 1960's

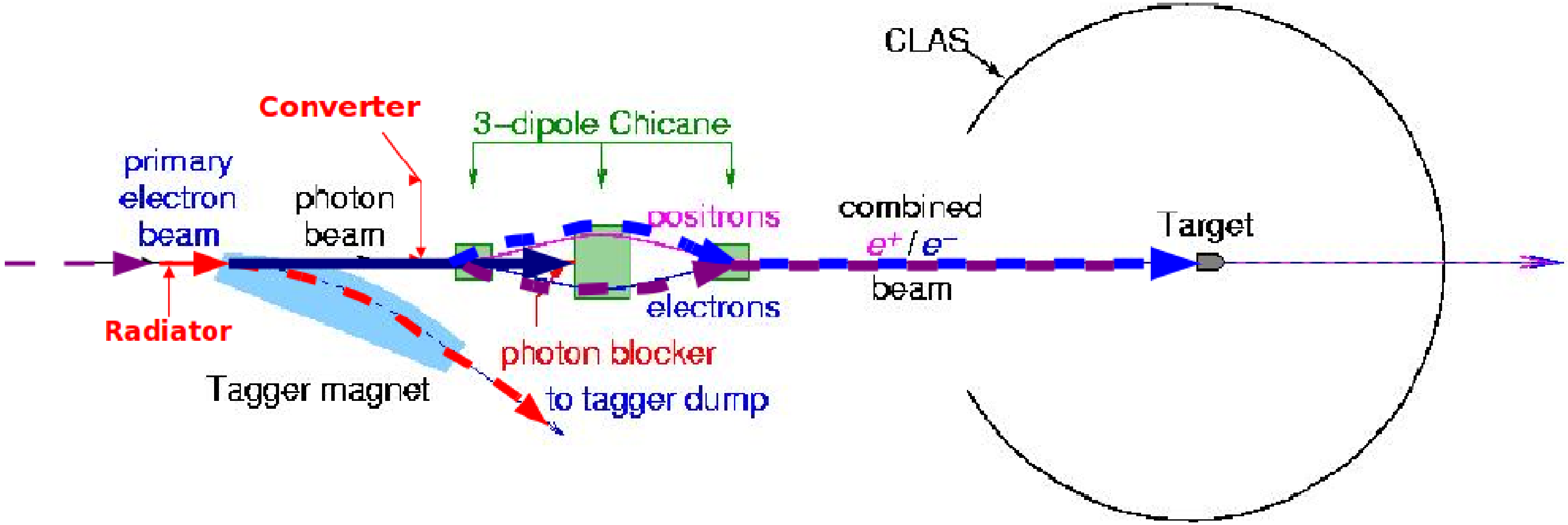


R. Beck, Erice, 2011

preliminary result presented at Radiation Workshop August 2011, MIT
A. Gramolin, INP, Novosibirsk

CLAS-Experiment, Jlab

e+/e- ratio: **CLAS/PR04-116** secondary e+/e- beam/ext. target



- Primary electron beam: 5.5 GeV and 100 nA
- Radiator: 1% of primary electrons radiate high energy photons
- Tagger magnet: Transport electrons tagger dump
- Converter: 10% of photons are converted to electron/positron pairs
- Chicane: separate the lepton beams
- Remaining photons are stopped at the photon blocker
- e^+ ande^- beams are then recombined and continue to the target
- Target: liquid hydrogen: length = 18cm (30 cm) & diameter = 6cm (6 cm)
- Detector: CLAS (DC, TOF)

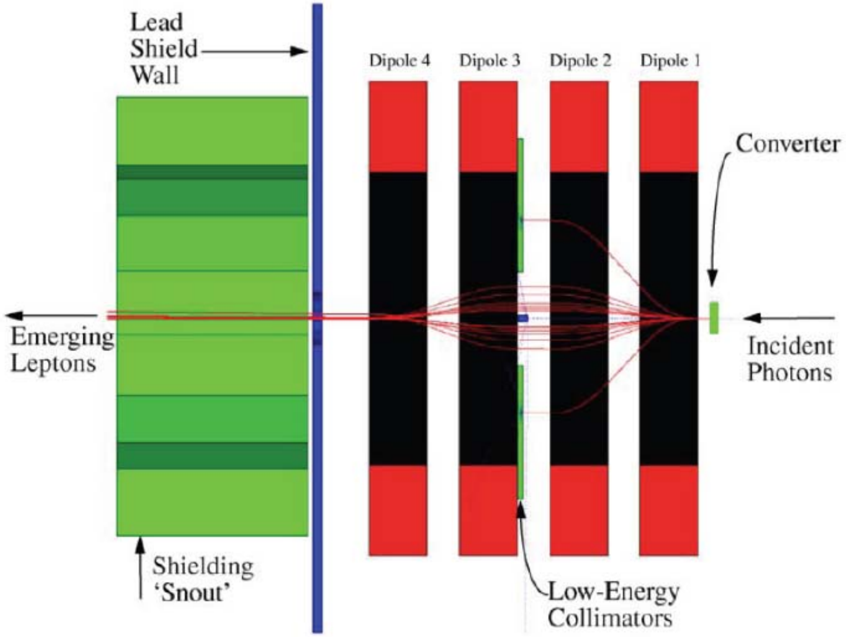
CLAS-Experiment, Jlab

e+/e- ratio: **CLAS/PR04-116** secondary e+/e- beam/ext. target – 2010/11
(completed in Feb. 2011)

Status presented
at Radiation Workshop
August 2011, MIT
R.P. Bennett, ODU

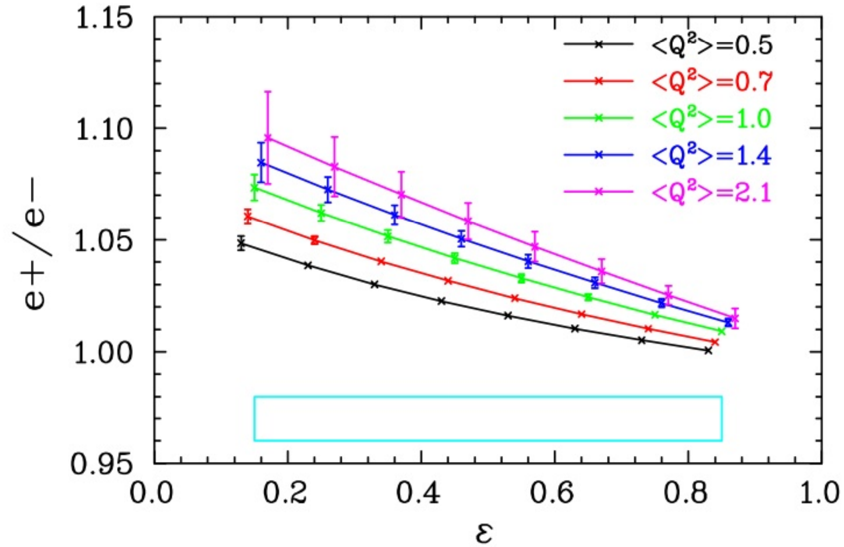
unknown beam energy

large background



CLAS@JLab: primary beam 1 μA @ 5,7 GeV, LH_2 Target

Projected Results



Summary

- Clear evidence for two photon contribution
  - Rosenbluth data against polarization transfer data
  - SSA Asymmety
- No apparent evidence from polarization versus ε
  - no evidence in transversal polarization component vs. ε
  - small effect in longitudional component at large ε
- Experimental verification underway in $e^+ p$ versus $e^- p$ comparison
  - CLAS at Jlab
  - VEPP-3 at Novosibirsk
  - OLYMPUS at DESY