When one photon is not enough...

The OLYMPUS Experiment

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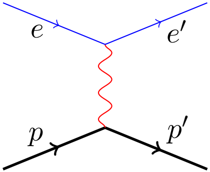
Form Factors

$\rightarrow$ Investigation of proton's structure



$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \cdot |F(q,\ldots)|^2$$

Form factor $F(q,\ldots) = \int e^{i\vec{q}\cdot\vec{r}/h} \cdot f(r,\ldots) d^3r$ mit $\vec{q} = \vec{p} - \vec{p'}$.

F(q,...) $\rightarrow$ Charge distribution

Rosenbluth Separation (1)

Rosenbluth Formula

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

with $\tau = \frac{Q^2}{4M_p^2}$.

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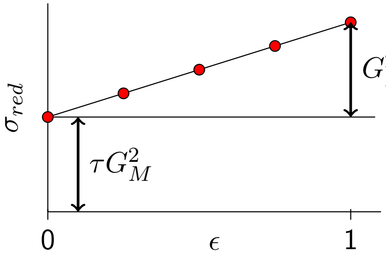
with $\tau = \frac{Q^2}{4M_p^2}$.

With $\epsilon = (1 + 2(1+\tau)\tan^2\theta/2)^{-1}$ $\rightarrow$ reduced cross section σ_{red}:

$$\sigma_{red} = \epsilon(1+\tau)\left(\frac{d\sigma}{d\Omega}\right)_R \Big/ \left(\frac{d\sigma}{d\Omega}\right)_{Mott} = \epsilon|G_E|^2 + \tau|G_M|^2.$$

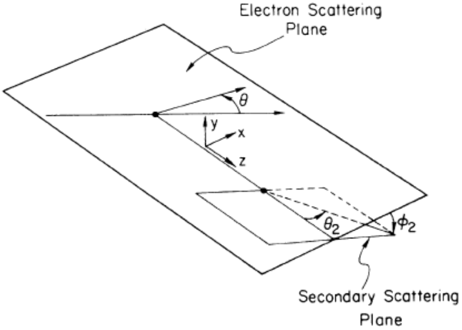
Rosenbluth Separation (2)



Linear Fit of $\sigma_{red}(\epsilon)$ with constant τ
$\Rightarrow G_E^2(\tau), G_M^2(\tau)$.

- Needs good ϵ-acceptance in each τ (Q^2) bin.
- Single photon exchange in Born approximation.

Recoil Polarization Technique



1. $\vec{e}p \to e\vec{p}$
2. $\vec{p}A \to pA$

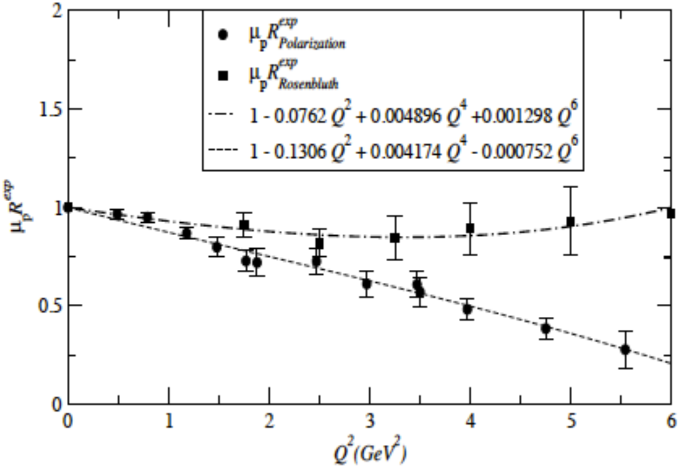
$\rightarrow$ P_l, P_t

$$\frac{G_E}{G_M} = -\sqrt{\frac{(1+\epsilon)\tau}{2\epsilon}}\frac{P_t}{P_l}$$

Phys.Rev.Lett.106:132501 (2011), M. Meziane et al.
Phys. Rev. C 23, 363 (1981), Arnold, Carlson, Gross

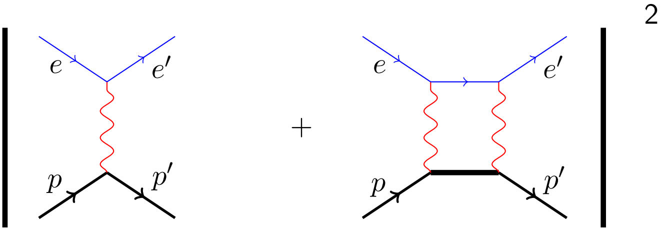
Form Factor Ratio Discrepancy

Phys.Rev.Lett. 91 (2003) 142303 Guichon, Vanderhaeghen



$\Rightarrow$ 2 photon exchange

Principle of Measurement



Difficult to calculate hard 2γ contribution

$\Rightarrow$ **Measure it!**

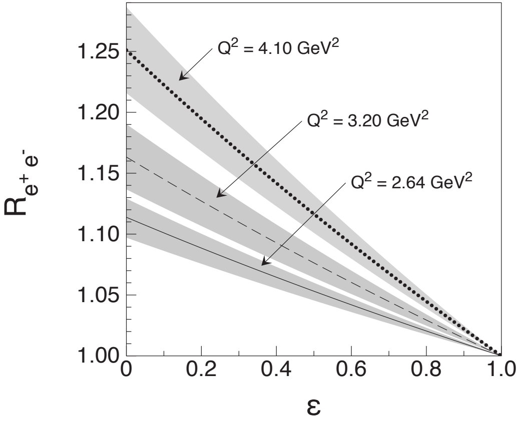
$$R = \frac{\sigma(e^+p)}{\sigma(e^-p)} \approx \frac{(1\gamma)^2\alpha^2 + 2\alpha^3(1\gamma)(2\gamma)}{(1\gamma)^2\alpha^2 - 2\alpha^3(1\gamma)(2\gamma)} \approx 1 + 4\alpha\frac{(2\gamma)}{(1\gamma)}$$

Different Experiments Measuring R

- Novosibirsk Experiment (VEPP-3) - nucl-ex/1112.5369v1
    - e^+/e^- beams up to 1.6 GeV
    - Calorimeter based setup
    - Small and disjunct acceptance
    - $\rightarrow$ First data point presented
- CLAS PR04-116 (JLab)
    - e^- beam $\rightarrow \gamma$ beam $\rightarrow e^+e^-$ beam
    - CLAS (magnetic spectrometer)
    - Large acceptance and kinematical phase space
    - Data were taken in 2011
    - Systematic uncertainties?
- OLYMPUS (DESY)
    - e^+/e^- beams at 2 GeV
    - Large acceptance magnetic spectrometer
    - Data taking in 2012

Prediction of R

Guttmann et. al, hep-ph/1012.0564v2



OLYMPUS

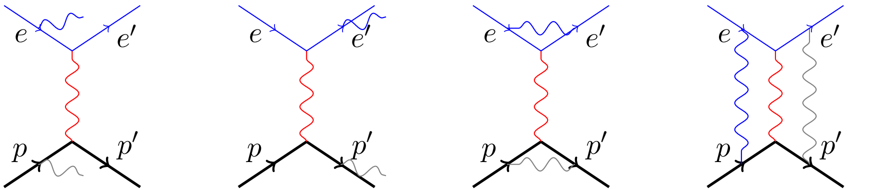
$Q^2 =$ 0.6 - 2.2 (GeV/c)^2

$\epsilon =$ 0.3 - 0.9

δ R / R< 1%

For pion electroproduction R $\approx$ 20-30% (p. c. A. Afanasev)

Radiative Corrections



- Processes generate radiative tail
- Elastic yield depends on acceptances, resolutions, and cuts

→ Need to correct for this (comparison between experiments)

- Weekly meeting at MIT
- Radiative Correction Workshops
  - July 2011 @ MIT
  - July 2012 @ St. Petersburg, Russia

Radiative Corrections II

Procedure

- Write radiative MC generator
  - Include standard radiative corrections[a][b]
  - Include soft 2γ exchange
  - $\nearrow$ Keep it modular and easy to change
- Add detectors with proper digitization
- Do same analysis as with real data
- Compare analysed data

[a] L. W. Mo and Y. S. Tsai, Rev. Mod. Phys. 41, 205 (1969)

[b] L. C. Maximon and J. A. Tjon, Phys. Rev. C 62, 054320 (2000)

Strategy to Obtain Results

Ingredients

- Intense e^+, e^- beams
- Proton target
- Large acceptance spectrometer
- Reliable luminosity measurement

Strategy to Obtain Results

Ingredients

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0. Have detector working and get data
1. Hit and track reconstruction
2. Elastic event selection
3. Applying radiative corrections with Monte Carlo methods
4. Extract Ratio

Schedule of Olympus

- Proposal (9/2008)
- DOE funding (1/2010)
- Shipping of Blast (spring 2010)
- Test experiment at DORIS (2/2011)
- Detector installation (until 7/2011)
- Detector Roll-in (7/16/2011)
- Olympus test beam at DORIS (8/2011)
- First data taking (1-2/2012)
- Second data taking (10-12/2012)

Setup Overview

Drift Chambers
MIT

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

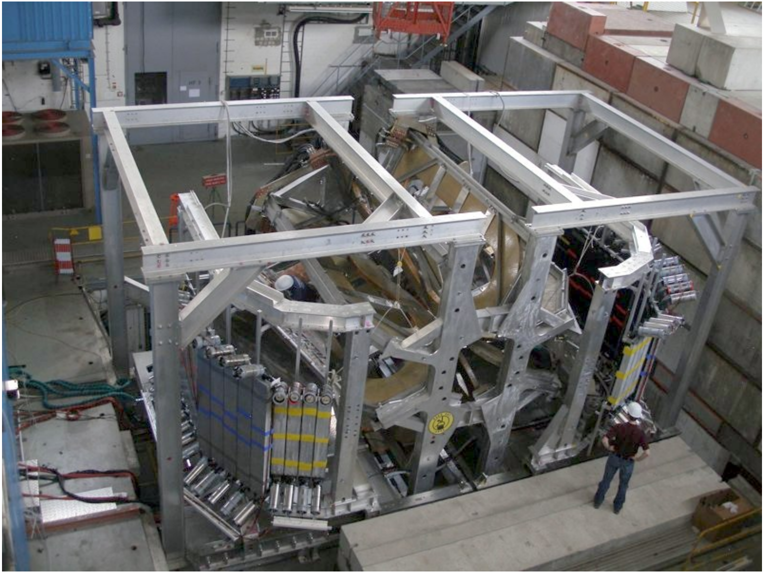
Internal Hydrogen Target
MIT, INFN Ferrara

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

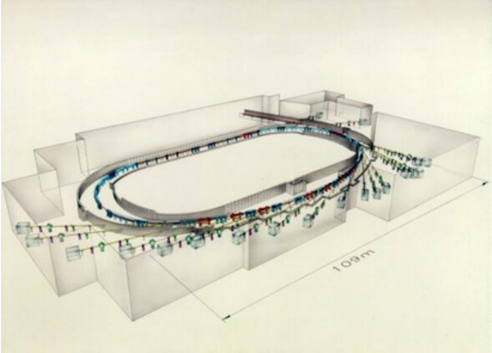
Symmetric Møller/ Bhabha Monitor
University of Mainz

based on a figure by R. Russell

Experiment in Reality

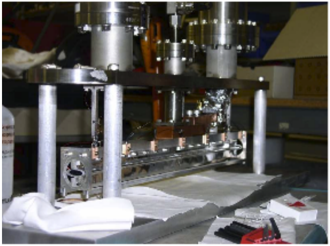


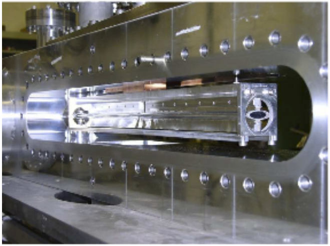
DORIS storage ring at DESY



- 2 GeV beam energy
- 100 mA e^+/e^-
- 10-Bunch-Mode
- $\tau \approx 0{,}8\,\mathrm{h}$ (full target)
- Beam switching $\approx$ $1/2\,\mathrm{h}$

Target System

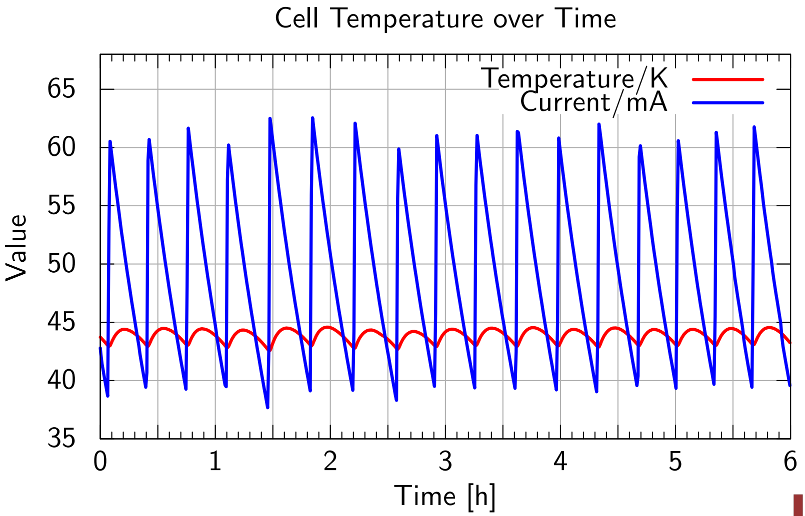




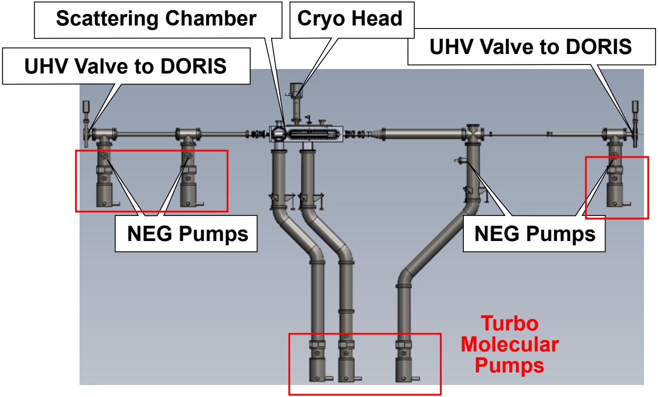
- Windowless internal gas target
- 60 cm long storage cell
- Elliptical cross section (27 mm x 9 mm)
- 100 μm thick aluminum wall
- Cryo cooled (43.5$\pm$1 K)
- $\mathcal{O}(10^{15})$ atoms/cm^2
- Hydrogen generator (electrolysis)

INFN Ferrara, MIT

Target Cell Temperature during Run



Vacuum System



- Pressure outside experiment: $2{\cdot}10^{-10}$ mbar ($7{\cdot}10^{-8}$ mbar)
- Beam life time: $\approx$6 h (0.8 h)
- Build-up time 0 $\leftrightarrow$ 0.8 sccm: 90 s

Wire Chambers

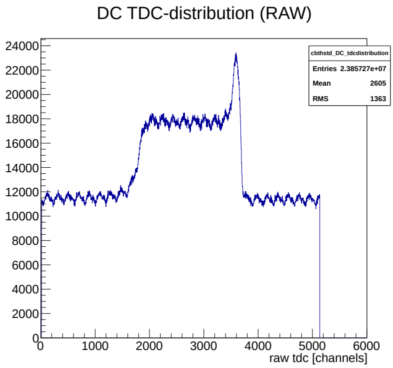
Specifications

- 3 in 1 chambers
- $ArCO_2$ (90:10) drift gas
- $V_{sense} = 3800\,V$

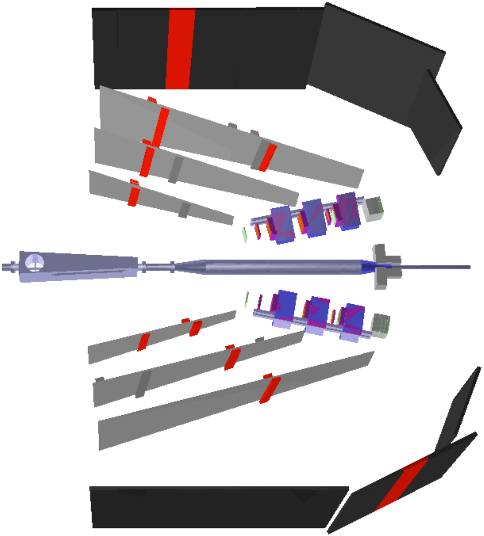
Status

- No hot wires
- 97.5% of cells working fine

$\rightarrow$ Repair in June



Event Display

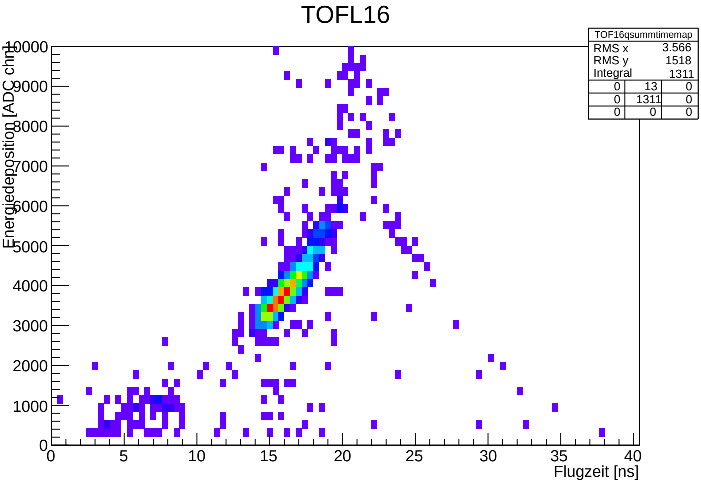


Time of Flight Detectors

- 18 detectors per sector
- Double sided PMT readout
  - → Noise suppression
  - → Hit location: $(t_1 - t_2)/2$
  - → Mean time: $(t_1 + t_2)/2$
- Measure ToF, E_{dep}
- Derive trigger signals
  - ORs, top bottom coincidence
  - Subsection OR
  - Kinematic trigger

Noise improved after installation of transformer

TOF Spectrum



Large angle TOF bar with trigger on 12 degree particle

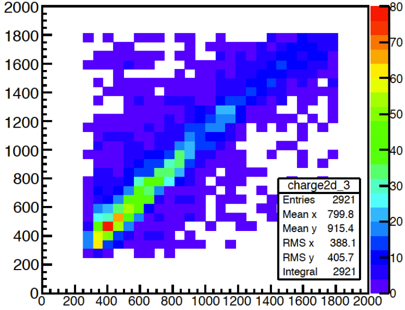
Luminosity Monitoring

Need precise relative luminosity measurements to compare relative cross sections

- 12° tracking telescopes
  - Elastic ep at $\epsilon > 0.97$ (TPE $\lesssim 1\%$)
  - Count tracks with protons in coincidence in TOFs
  - 2 telescopes, each has 3 GEMs and 3 MWPCs
- Symmetric Møller/Bhabha Detector
  - Count symmetric events

Lumi GEMs

Cluster amplitude correlation



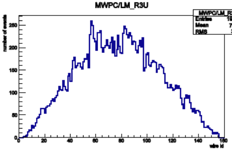
Plot by J. Diefenbach

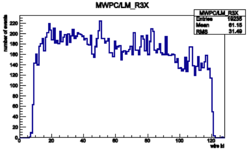
Specs and Status

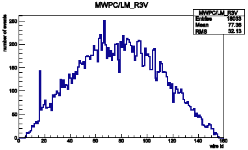
- 3 detectors per telescope
- Triple GEM stack with 2D readout
- APV readout working fine
- $\delta^i_{res} \approx 100\,\mu$m

Hampton, INFN, MIT

Multi Wire Proportional Chambers

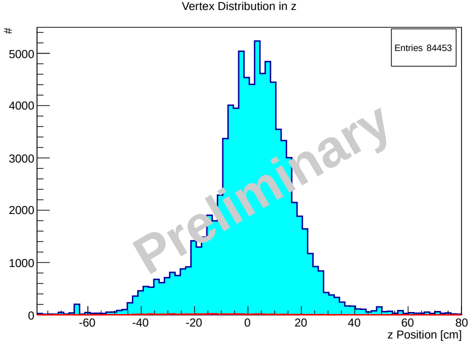






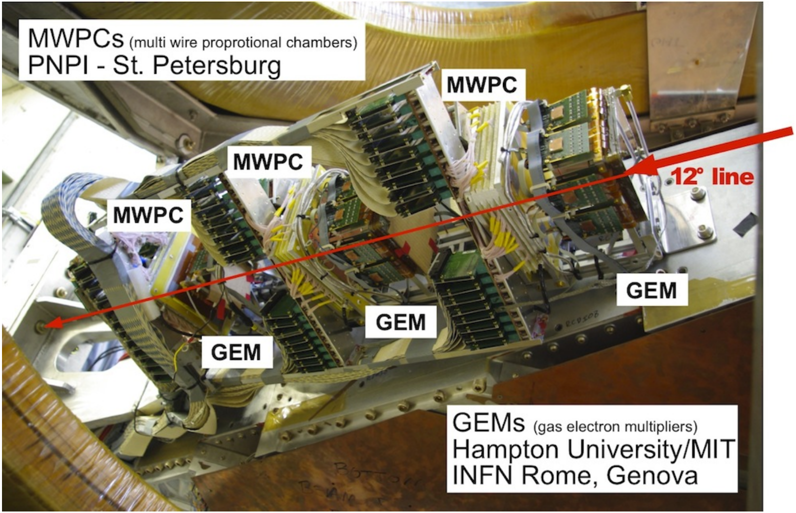
Specifications

- 3 chambers per telescope
- 3 planes per detector
- 99.9% of wires working fine
- $\eta_c = 0.98\text{-}0.99$

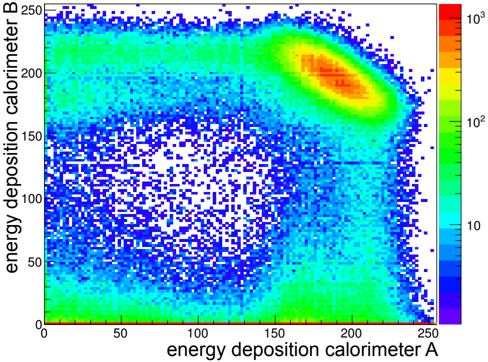


PNPI

12° Tracking Telescopes



Symmetric Møller/Bhabha Detector

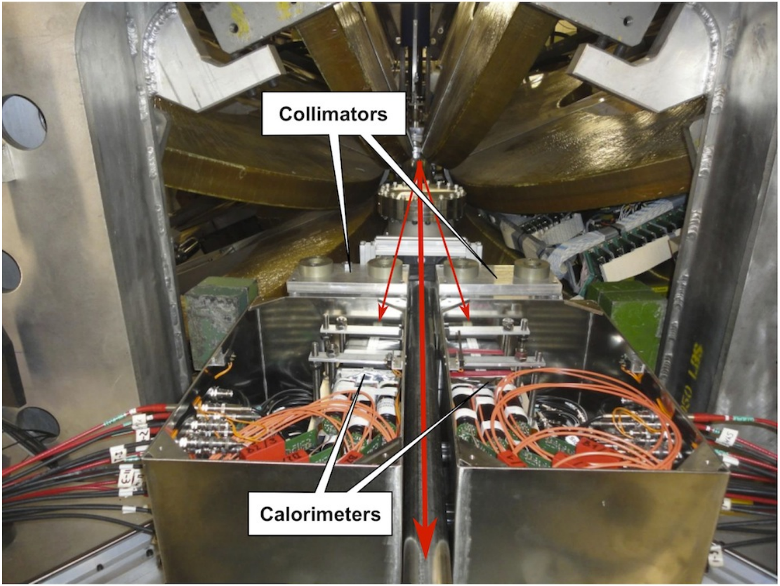


Plot by J. Diefenbach

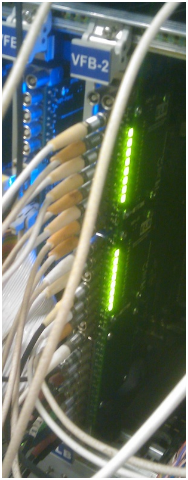
- Pure QED processes
- Independent measurement
- Quasi dead time free ($t_d = 20\,\text{ns}$)
- Left/right coincidence with 1 GeV each
- Possible to see also elastic ep

Univ. of Mainz/HIM

Symmetric Møller/Bhabha Detector



Main Trigger System



MIT

- Single level scheme
- VME based FPGA board
- Dynamically configurable at runtime
- 16 parallel trigger conditions (incl. veto + pre-scaler)
  - Main trigger (≈75%)
  - 2 Luminosity trigger
  - 8 Calibration trigger
- Counters for inputs and trigger conditions

Data Acquisition System

- Easy to use DAQ GUI
- Online data display
- Data backup
  - Raid + mirror server
  - DESY computing center
  - External hard drive
- Automated data mapping and pre-processing
- Run database + Elog

Run I (1st-27th February)

- 1 billion triggers collected
- 1710 runs
- Raw data on disc: 3.4 TB
- DAQ active: 19d 11h 14m (74%)
- Average dead time: 25%

Univ. of Bonn/HISKP

Control and Monitoring

MIT, Univ. of Bonn/HISKP

Slowcontrol

- Single system
- Web front end
- TINE interface

Monitoring

- Monitor online data stream
- Simple histograms + first analysis
- Checks DAQ and trigger

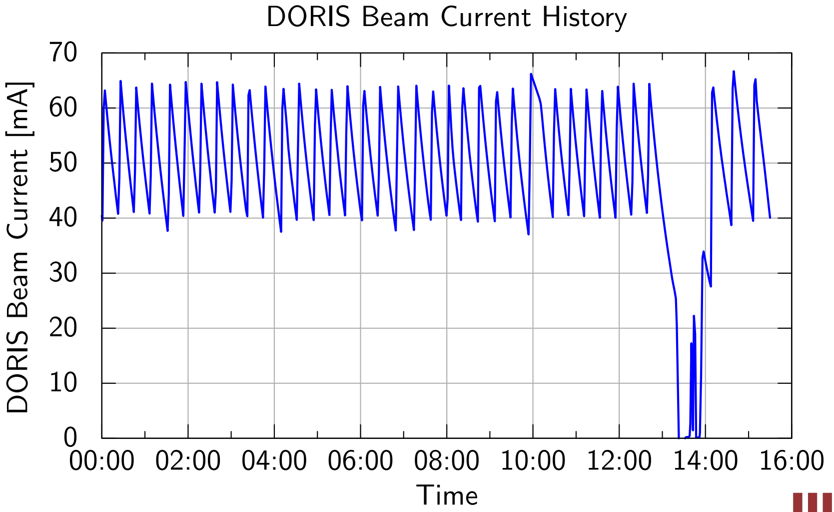
Operation schedule

1^{st} run (1^{st}-27^{th} February 2012)

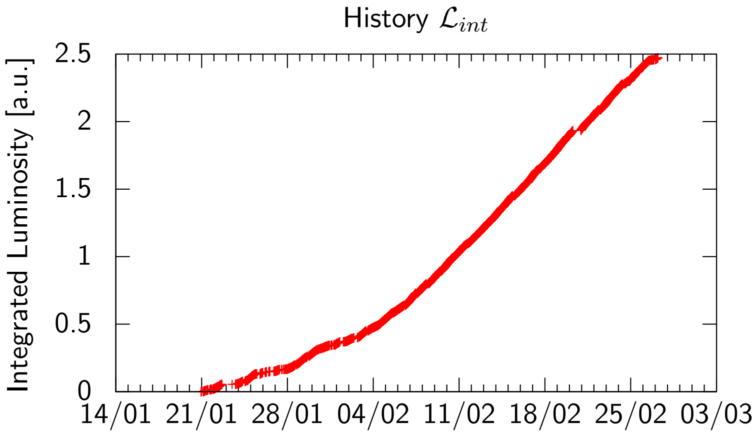
- Switch beam species every day ($\lesssim 30$ min)
- Switch magnet polarity 2.5 times a day (+ - - +, - + + -)
- Target flow 0.8 sccm (2 empty target runs per day)
- Beam current 60..40 mA
- Beam refill every 20 min (takes 1-2 min)

Smooth machine operation and very good collaboration with machine group

Machine Stability

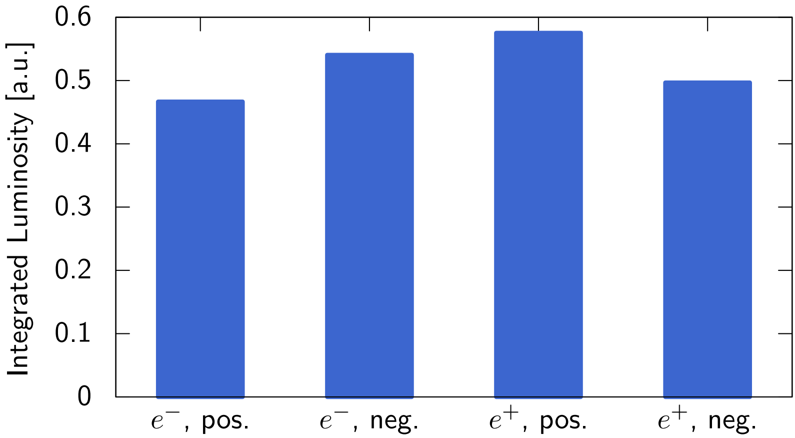


Integrated Luminosity over Time

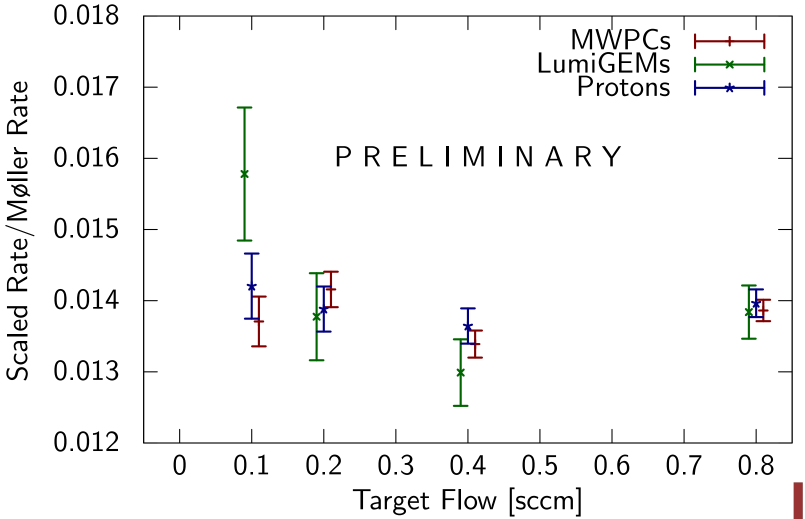


$\Rightarrow$ 4 million elastic events

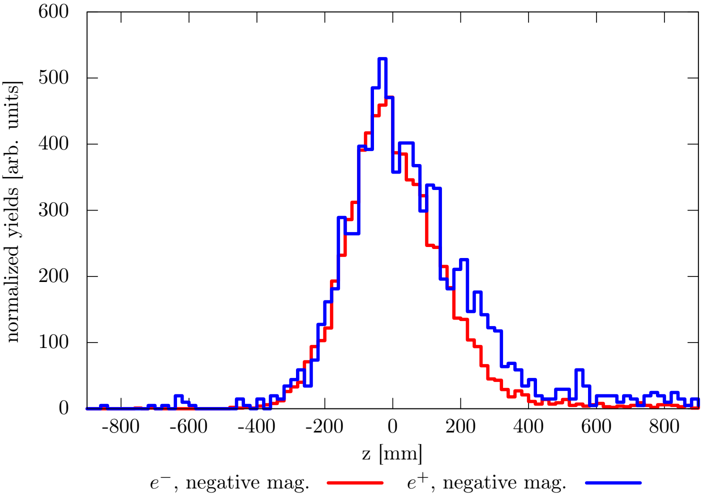
Integrated Luminosity per Configuration



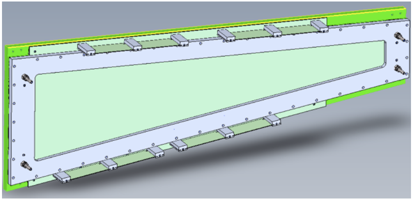
Luminosity Monitors vs. Target Flow



Vertex Distribution (preliminary)



GEM Tracker (Upgrade for 2^{nd} run)



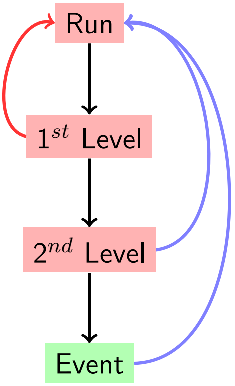
- Active area: 840 mm x 250/110 mm
- Patched triple GEM stack
- 2D readout board with 18.4° stereo angle
- 12 APVs per detector

MIT, DESY, Hampton, Bonn

Status

- Aluminum parts manufactured
- Readout boards delivered
- 14/24 GEM foils delivered
- Readout electronics ready
- DAQ and offline ready
- Assembly: May/June (MIT)
- Testing: July (DESY)

2^{nd} Level Trigger



Trigger condition

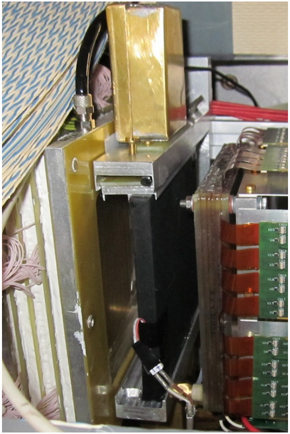
1 out of 6 wires in middle and outer chamber
$\Rightarrow$ Reduction factor ≈ 10

Trigger efficiency

Assume $p_w = 0.8$
$\rightarrow p^{1/6} = 0.99994$
$\rightarrow p = 0.9999$

Integration into main trigger FPGA

12° Telescope Scintillators



- Trigger for 12° tracking telescopes
- 2 detectors per sector
- Scintillator 120 mm x 120 mm x 8 mm
- Light readout 2-4 SiPMs per detector
- Pre-amps & bias voltage in corporation with University of Mainz

Summary

- OLYMPUS experiment installed at DORIS
- Stable operation of beam, target, and detectors
- DAQ, online monitoring, and slowcontrol easy to use and reliable
- Collected a good data sample (4M elastic events)
- Most of the reconstruction implemented
- Detailed treatment of radiative effects and corrections

Outlook

- Upgrades
  - GEM tracker
  - Improved 12° trigger scintillators
  - 2^{nd} level trigger
- Complete reconstruction
- Analysis including radiative corrections

$\Rightarrow$ **Measurement of 2 photon contribution**

Looking forward to run II (Oct 22^{nd} - Dec 21^{st}) to collect full statistics we need.

OLYMPUS Collaboration

- Arizona State University, USA
- DESY, Hamburg, Germany
- Hampton University, USA
- INFN Bari, Ferrara, Rome, Italy
- Massachusetts Institute of Technology, 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

OLYMPUS