OLYMPUS – Determining the Two-Photon Contribution to Elastic ep Scattering

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The Proton Electromagnetic Form Factors

The *proton*...

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

How is charge (and magnetization) distributed inside the proton?

Use elastic electron proton scattering

The Proton Electromagnetic Form Factors

Elastic electron proton scattering:

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

- τ, ϵ kinematic variables
- $G_E(Q^2)$ *electric* form factor
- $G_M(Q^2)$ *magnetic* form factor

The Proton Electromagnetic Form Factors

First measurements: in 1950s (Hofstadter, SLAC)

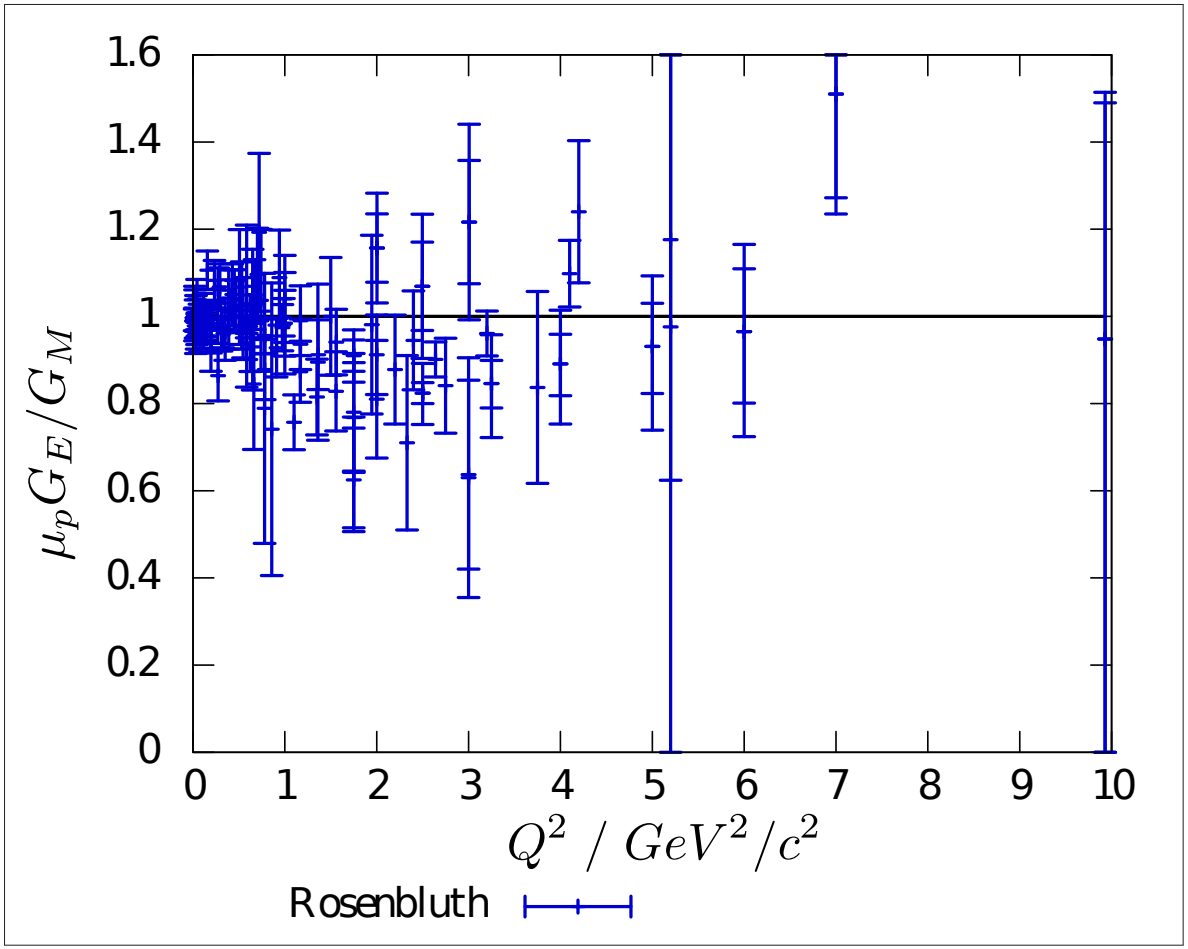
Separation of electric and magnetic FF:

- 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

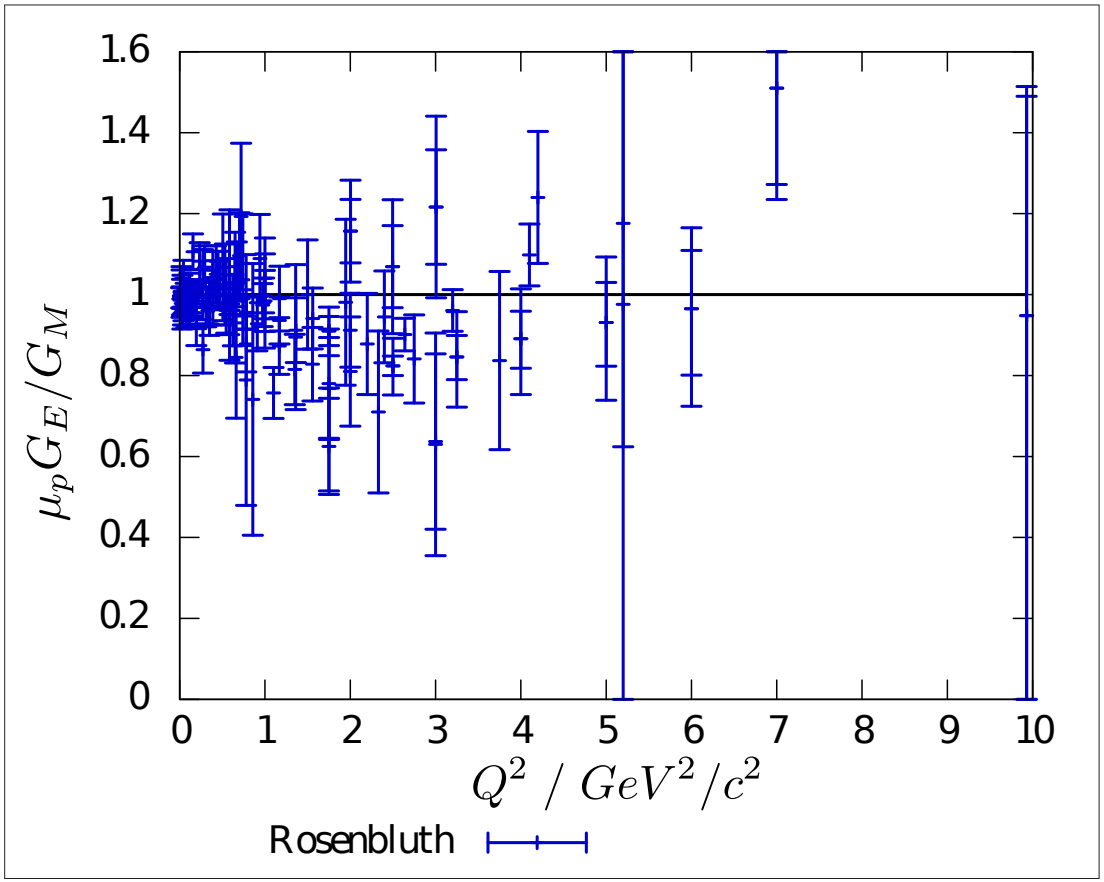
New technique used at Jefferson Lab in the 1990s:

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

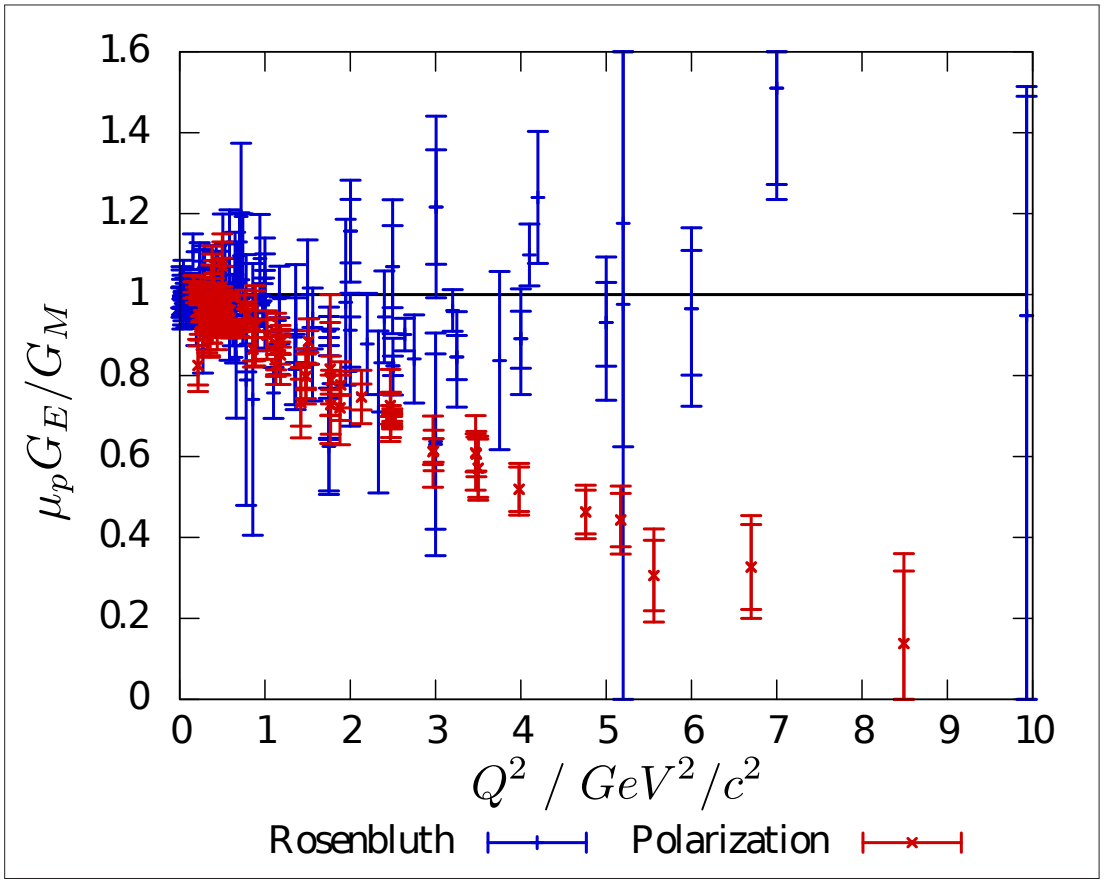
$$\frac{P_{\text{trans}}}{P_{\text{long}}} \sim \frac{G_E}{G_M}$$

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

Polarization Transfer II

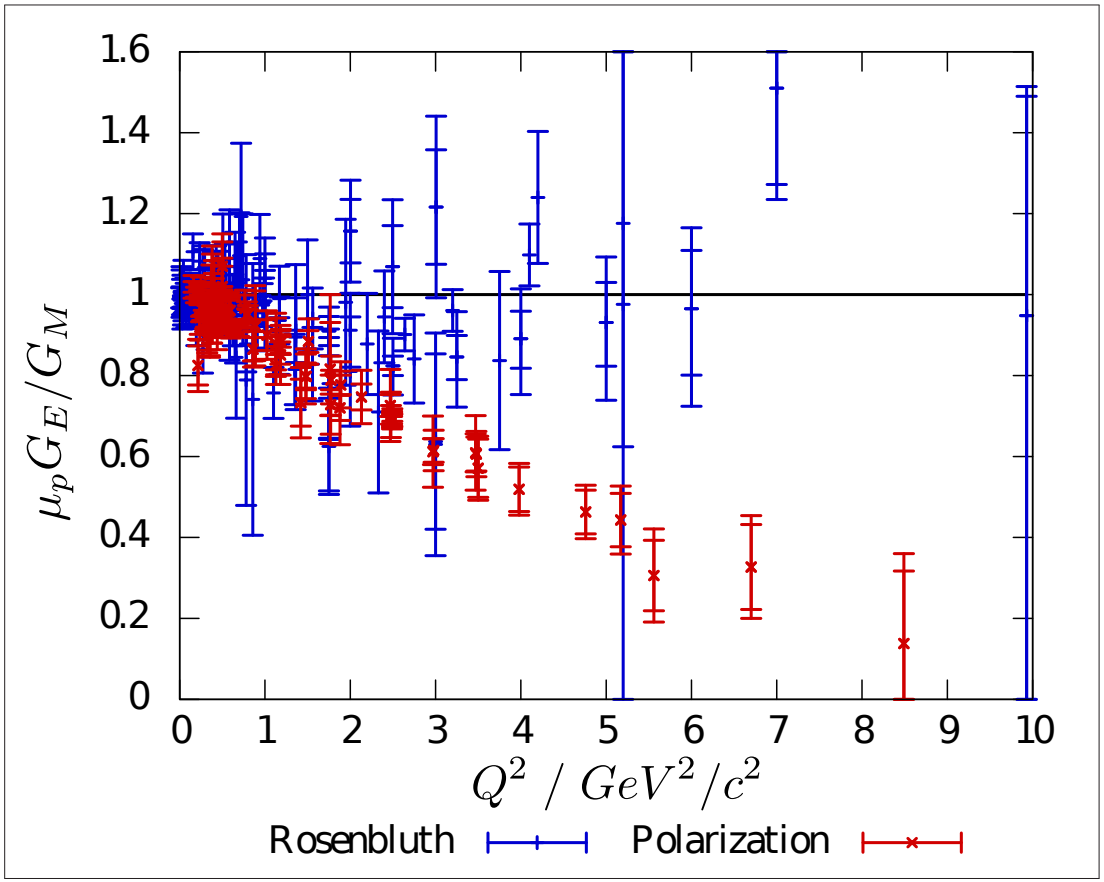


Polarization Transfer II



Discrepancy between Rosenbluth and Polarization Transfer!

Polarization Transfer II

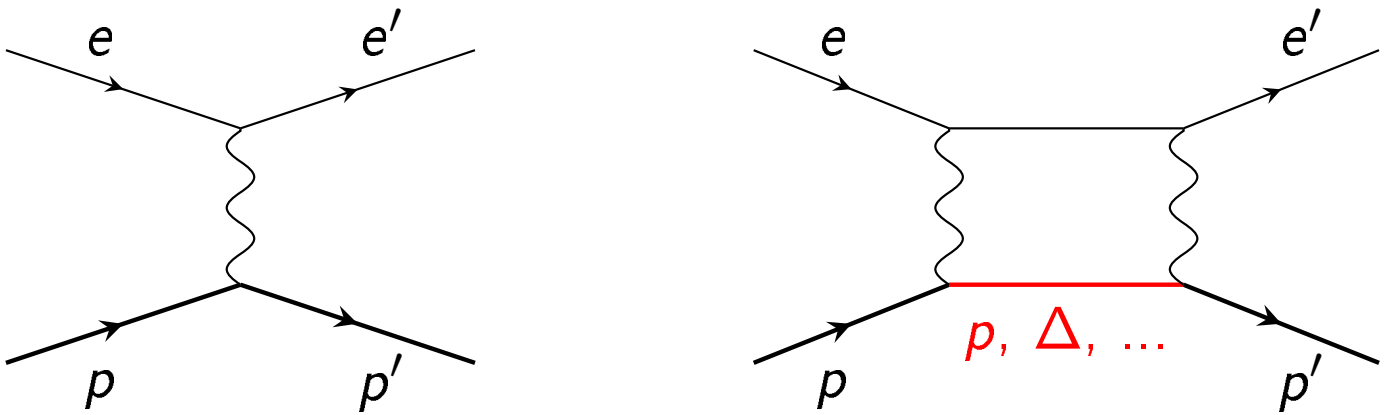


Discrepancy between Rosenbluth and Polarization Transfer!

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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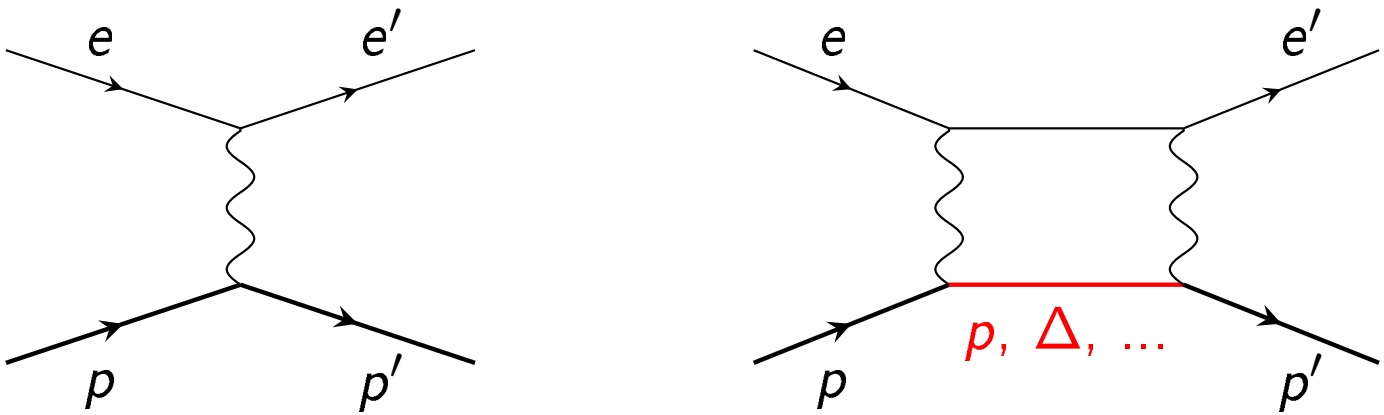


... but two (multiple) photon exchange can contribute!

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!

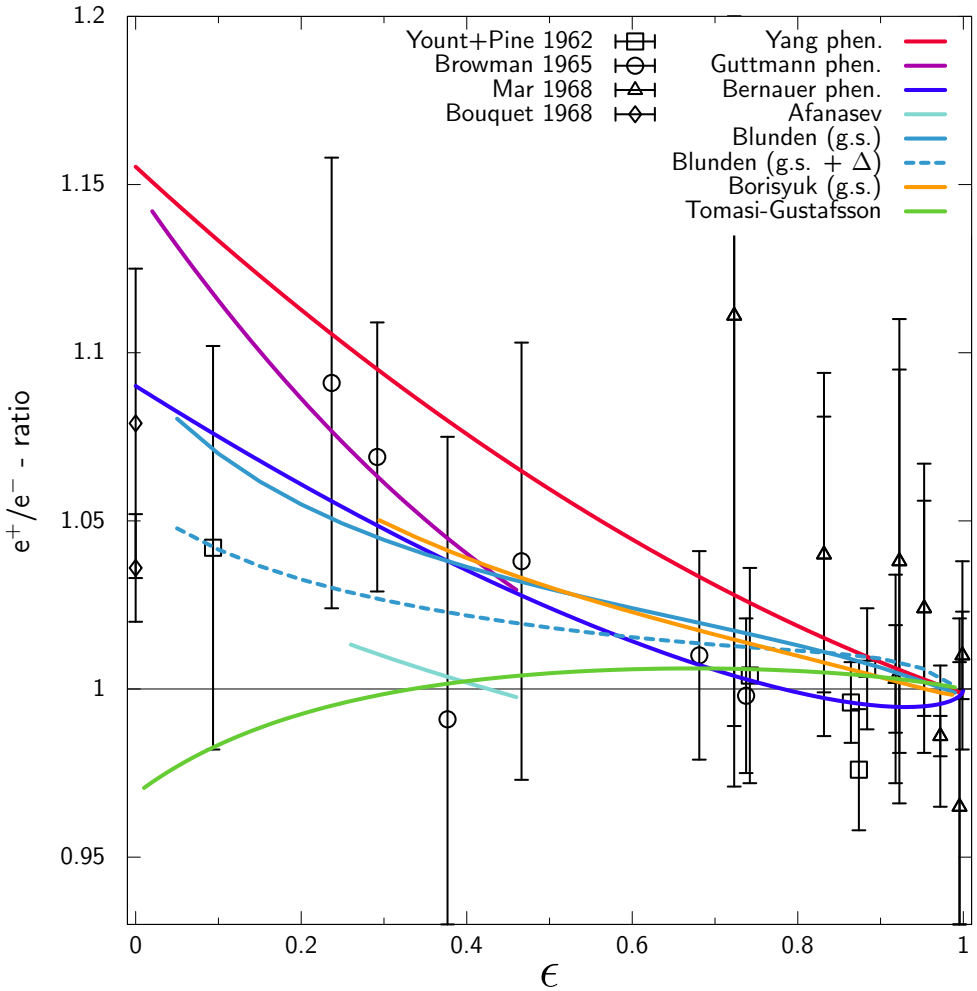
$$\sigma(e^- p) = |M_{1\gamma}|^2\,\alpha^2 - 2\,|M_{1\gamma}|\,|M_{2\gamma}|\,\alpha^3 + \ldots$$

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

Cross section ratio for elastic e^+ and e^- proton scattering:

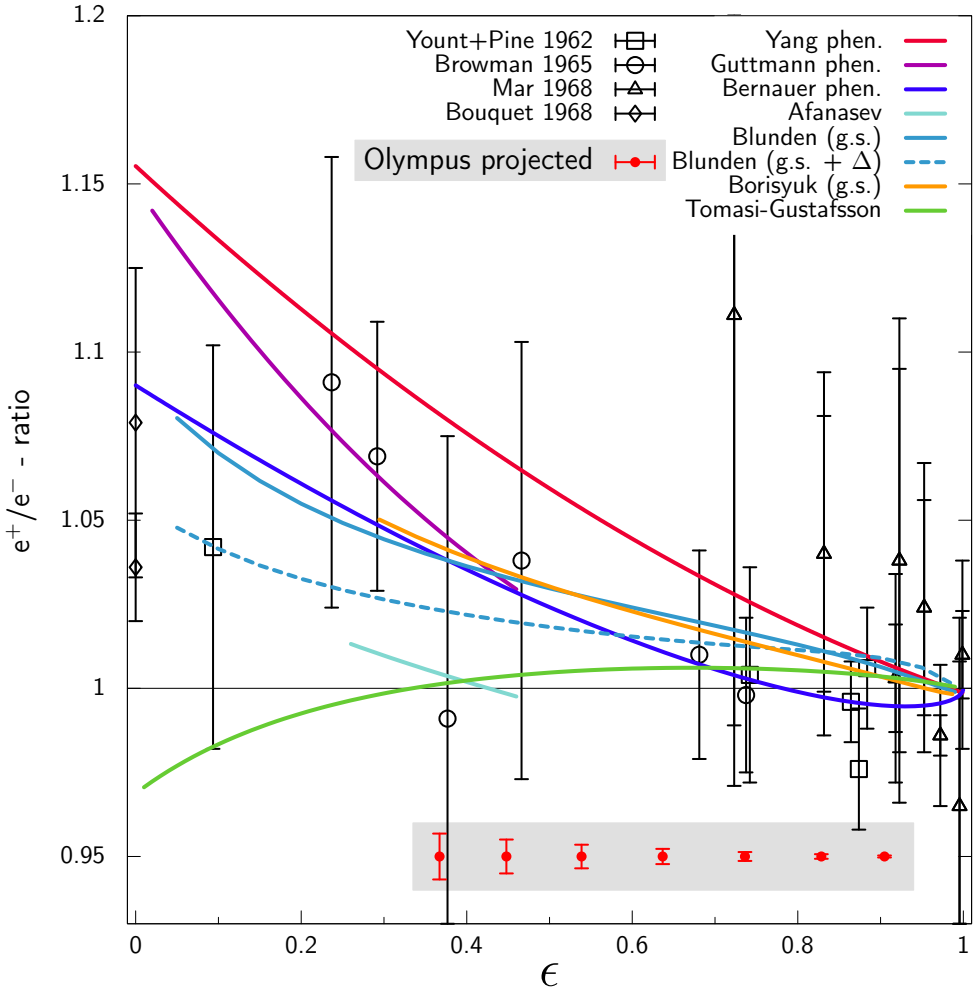
$$R = \frac{\sigma(e^+ p)}{\sigma(e^- p)} = 1 + \frac{4\,\Re(M_{1\gamma}^{\dagger} M_{2\gamma})}{|M_{1\gamma}|^2}$$

Measurement of Two Photon Contribution



Current world data from the 1960s, several models/calculations

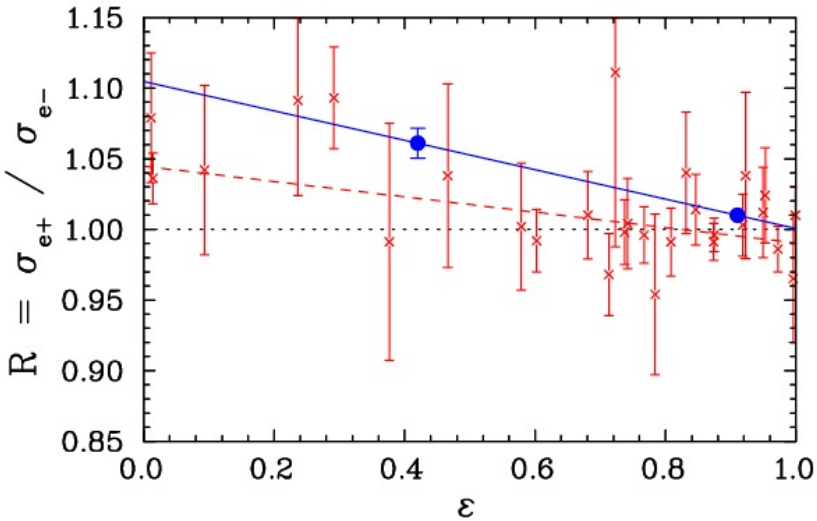
Measurement of Two Photon Contribution



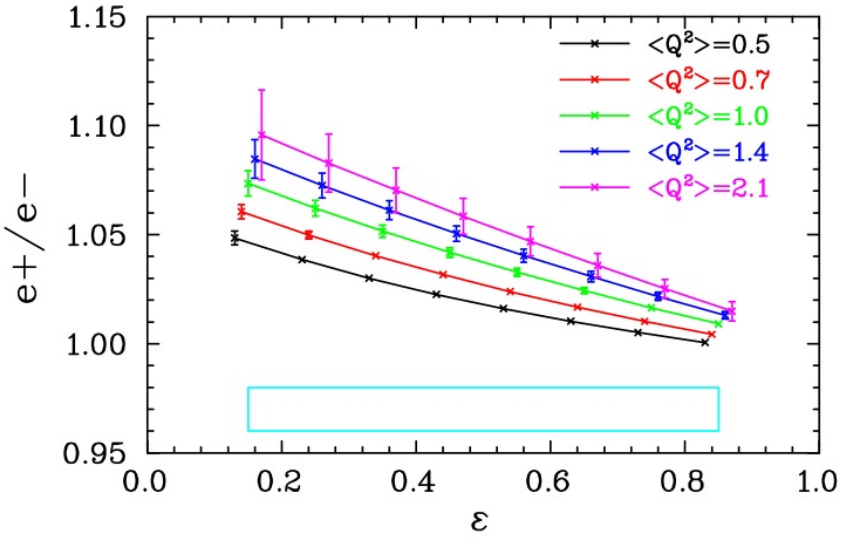
OLYMPUS will determine the two-photon contribution to ∼1%

Measurement of Two Photon Contribution

Other Experiments (projected accuracies)



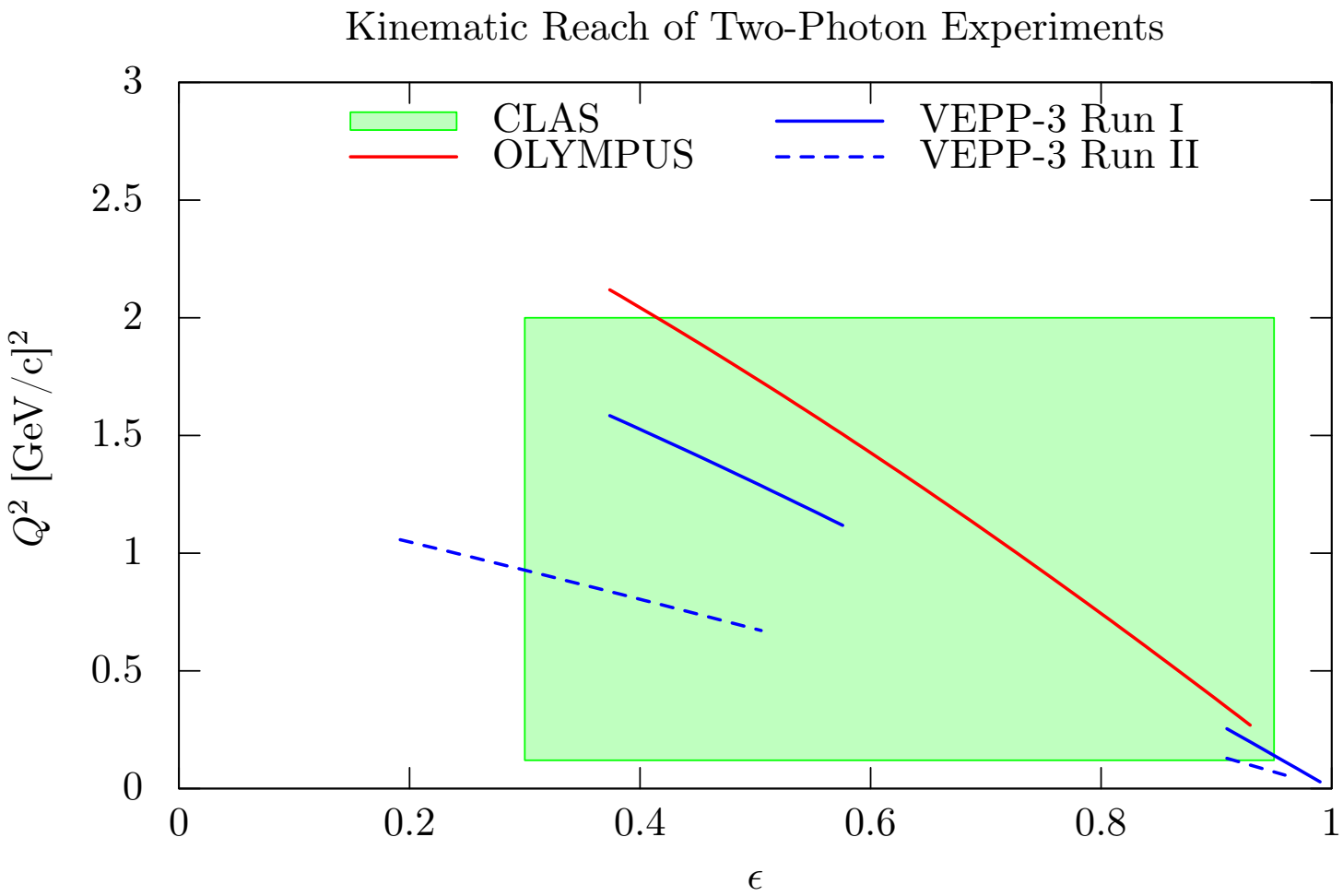
- Novosibirsk experiment, VEPP-3
- preliminary results: arXiv:1112.5369



- CLAS experiment, Jefferson Lab
- first results: arXiv:1306.2286

Measurement of Two Photon Contribution

Other Experiments (kinematical reach)

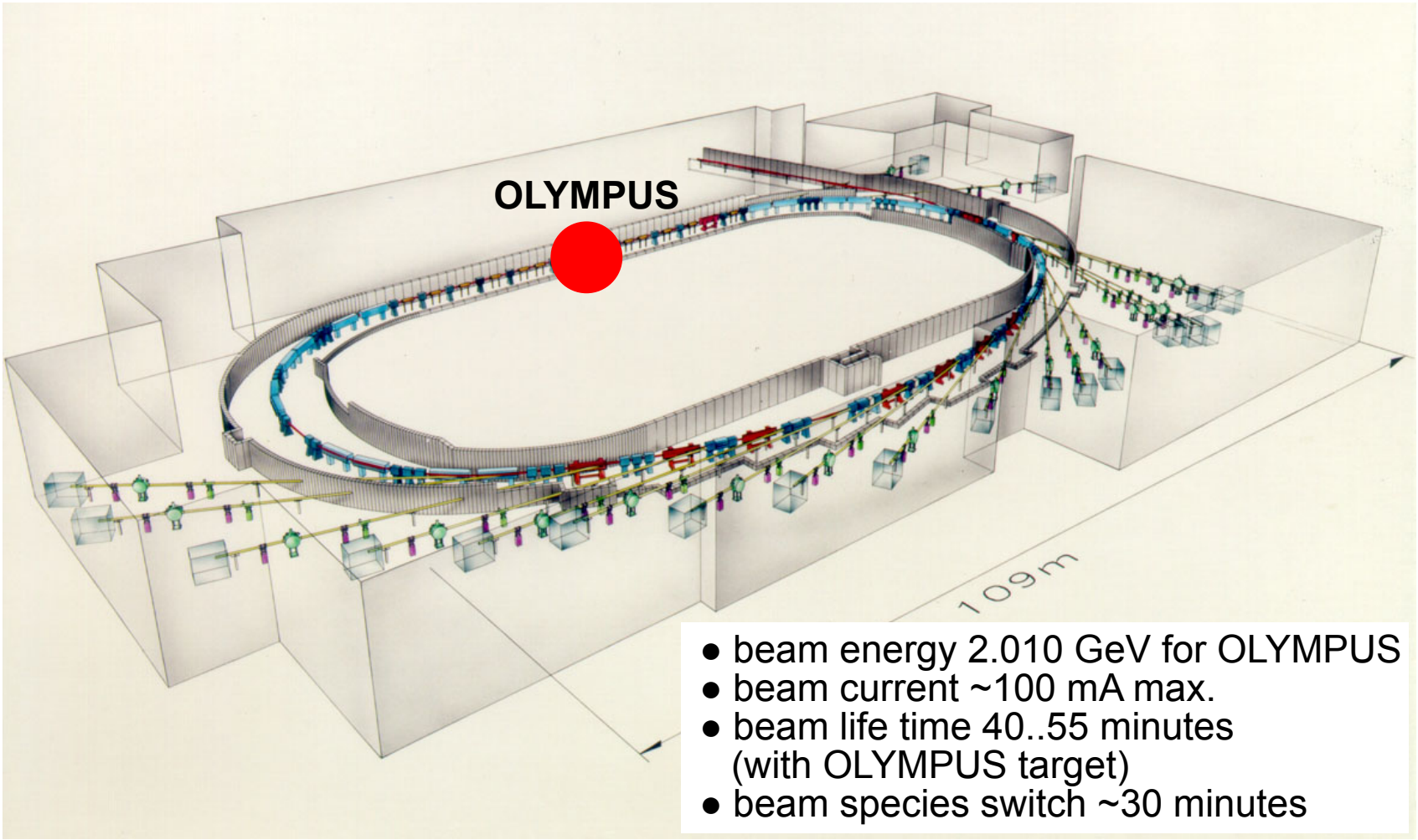


Timeline

Proposal	09/2008
DOE funding	01/2010
BLAST shipped to DESY	spring 2010
Modification of DORIS and Test experiment	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
Survey, Field mapping, etc.	2013
Data analysis	ongoing

DORIS

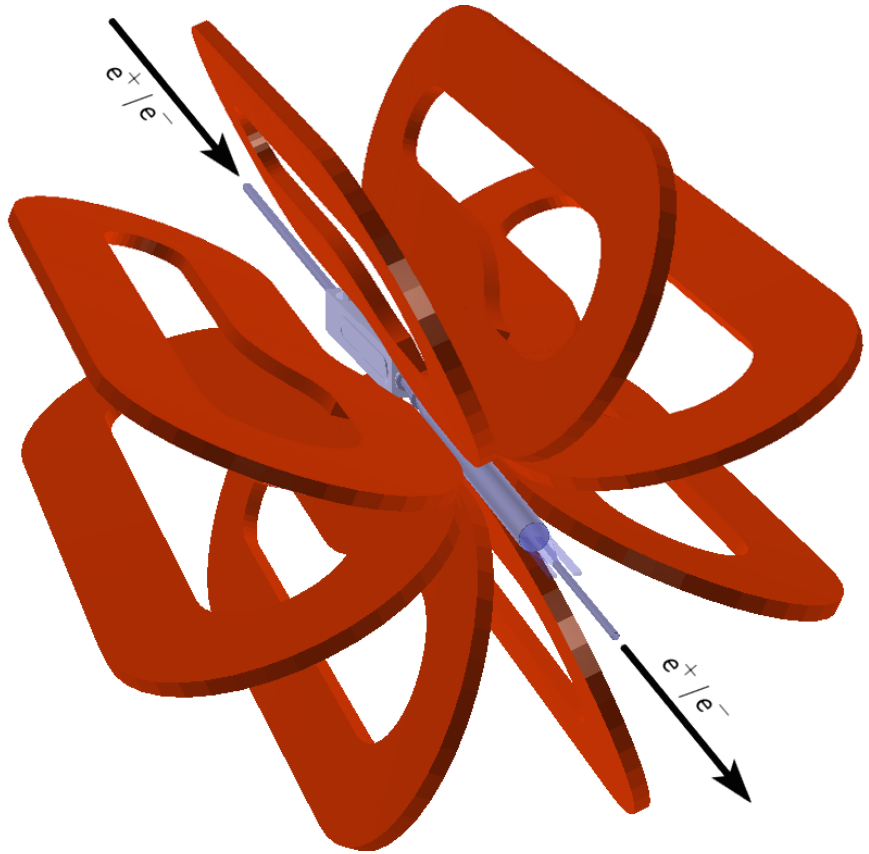


- beam energy 2.010 GeV for OLYMPUS
- beam current ~100 mA max.
- beam life time 40..55 minutes (with OLYMPUS target)
- beam species switch ~30 minutes

OLYMPUS detector

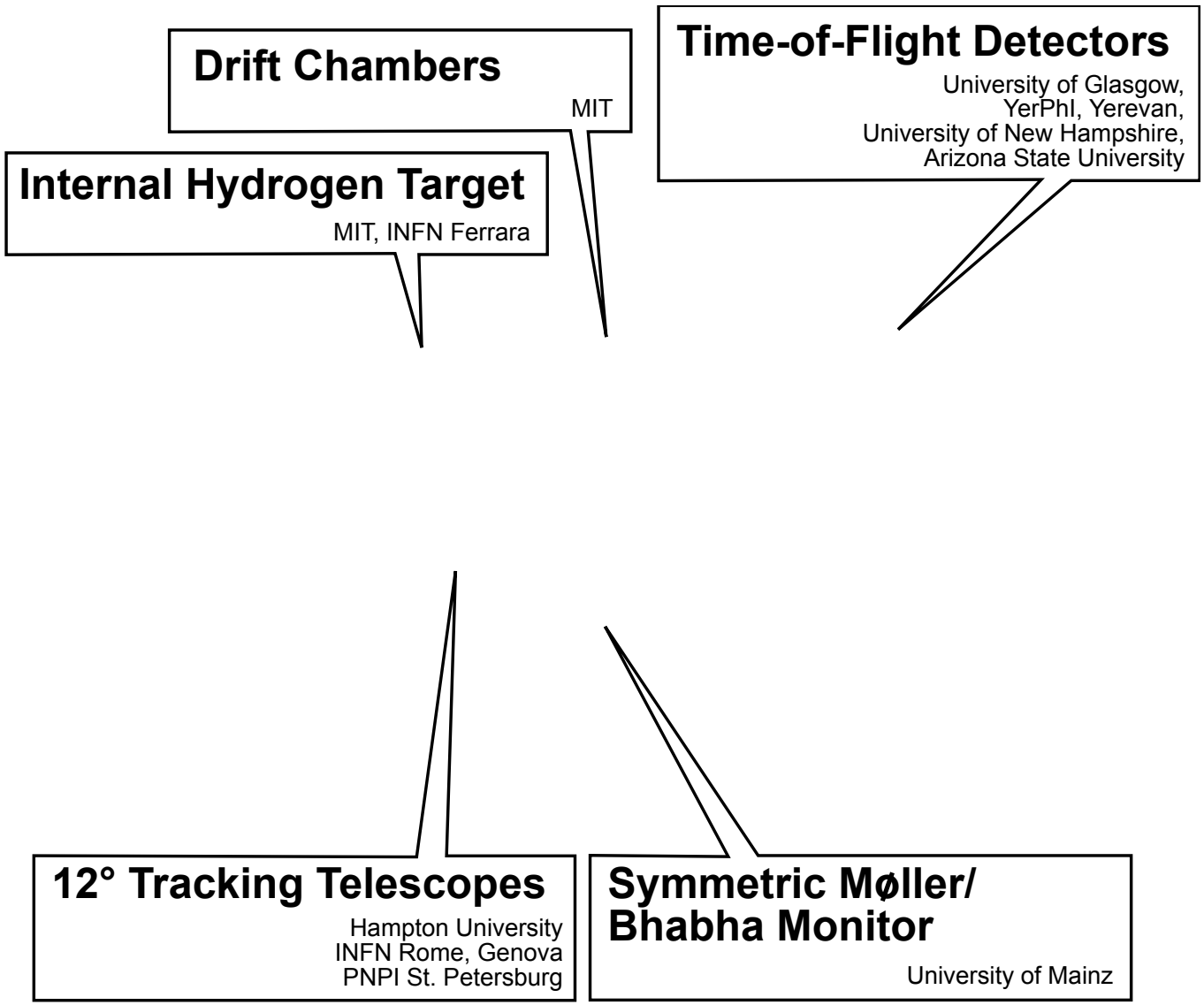
- Large acceptance detector:
  $20^\circ < \theta < 80^\circ$ and $-15^\circ < \phi < 15^\circ$
  $0.37 < \epsilon < 0.9$ and $0.6 < Q^2 < 2.2$ (GeV^2/c^2)
- Toroidal magnetic field
- Left/right symmetric (two sectors)
- Time of flight scintillator walls
- Drift chambers for lepton and proton tracking
- Luminosity monitoring:
  two independent systems:
  - 12° forward tracking telescopes (ep)
    internally redundant (GEMs + MWPCs)
  - 1.2° very forward calorimeters (ee)

OLYMPUS detector



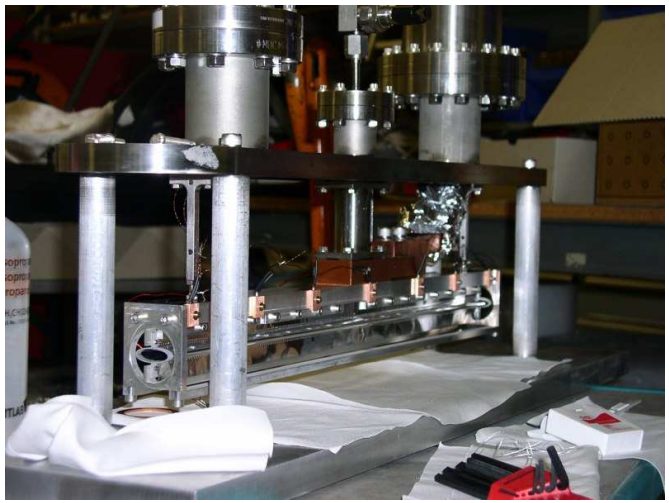
based on a figure by R. Russell

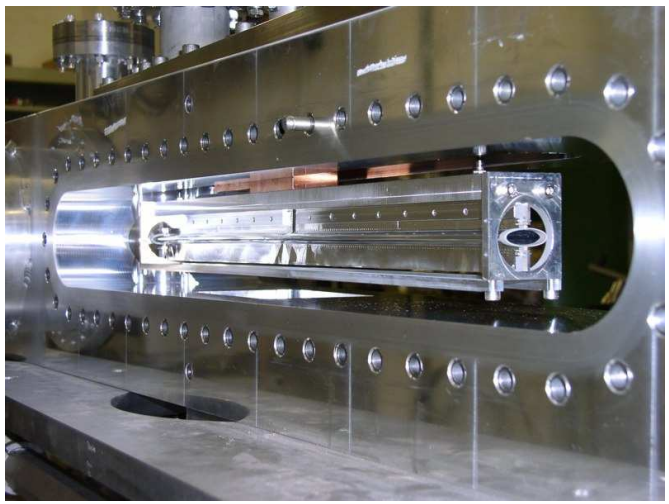
OLYMPUS detector



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)





Drift Chambers

- jet style drift cells
  3 chambers per sector
- $\sim$10 000 wires in total
- 954 sense wires
- $ArCO_2$ 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

Kinematic trigger: coincidence matrix for elastic ep kinematics

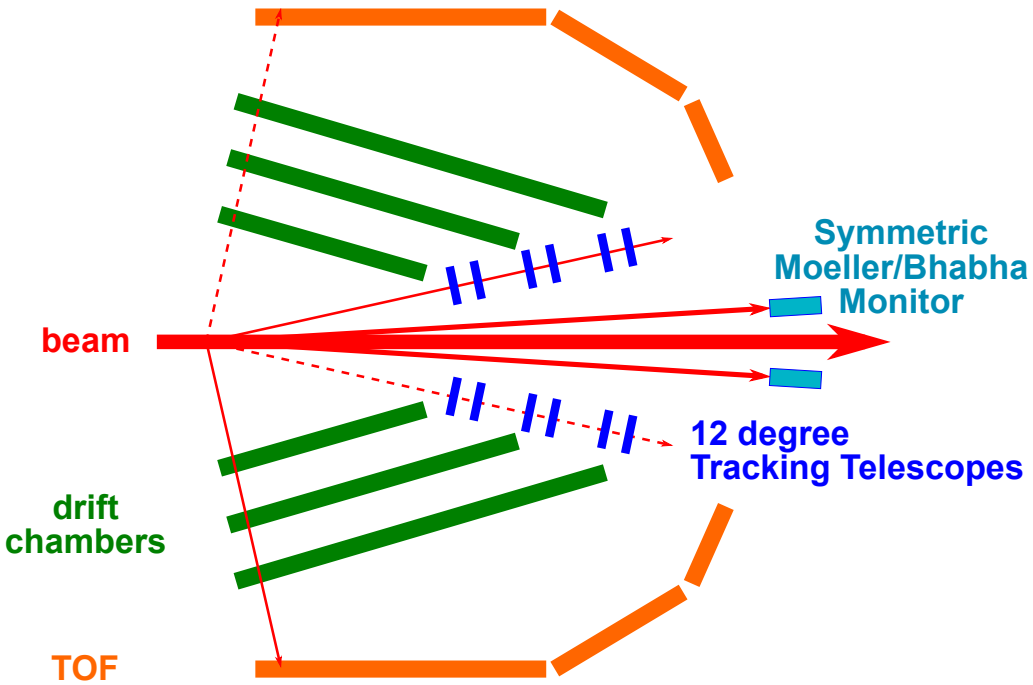
Luminosity Monitoring

- cross section ratio
- e^+/e^- switch once per day

$\rightarrow$ **Monitoring of (relative!) luminosity is crucial:**

Two *independent* systems:

- 12 degree telescopes
  elastic ep, high ϵ
- 1.2° symmetric Møller/Bhabha calorimeters
  fast, quasi deadtime-free



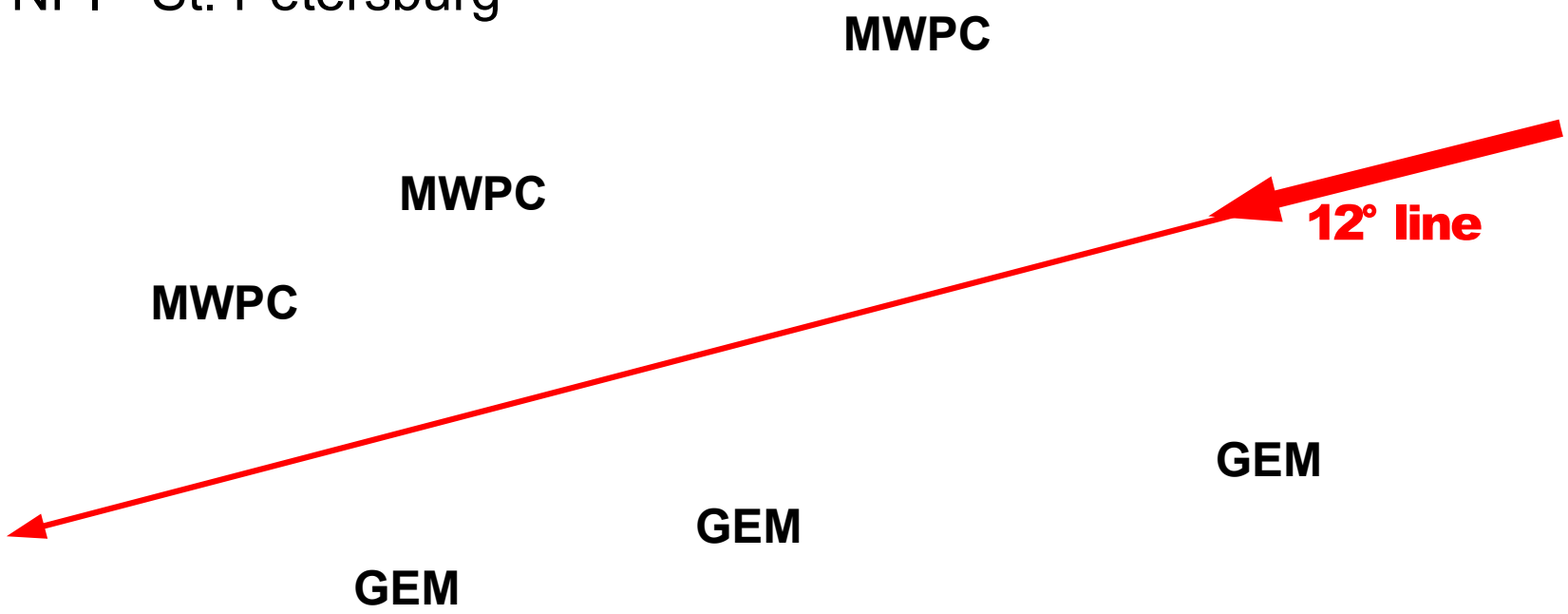
12 degree Tracking Telescopes

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

- 12° corresponds to high ϵ
  $\longrightarrow$ 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

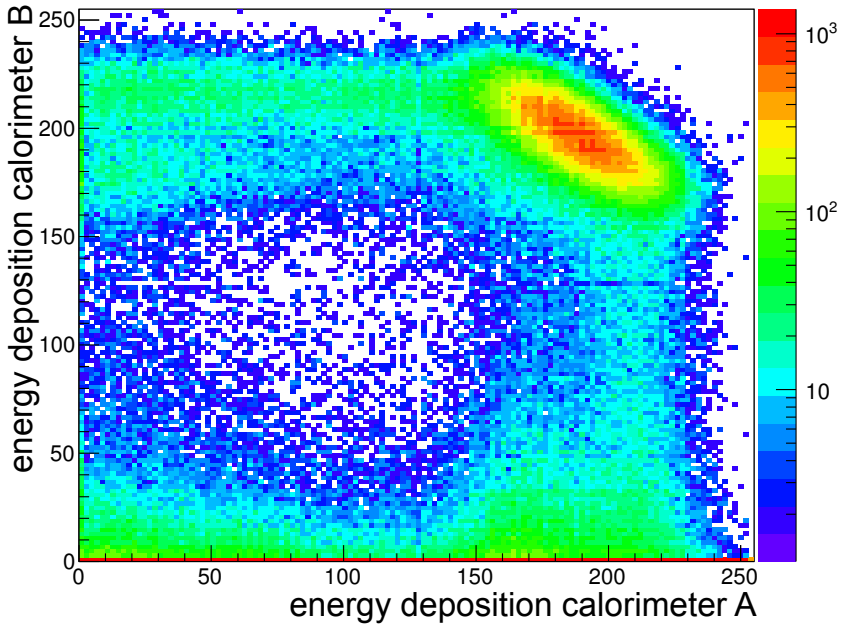


GEMs (gas electron multipliers)
Hampton University/MIT
INFN Rome, Genova

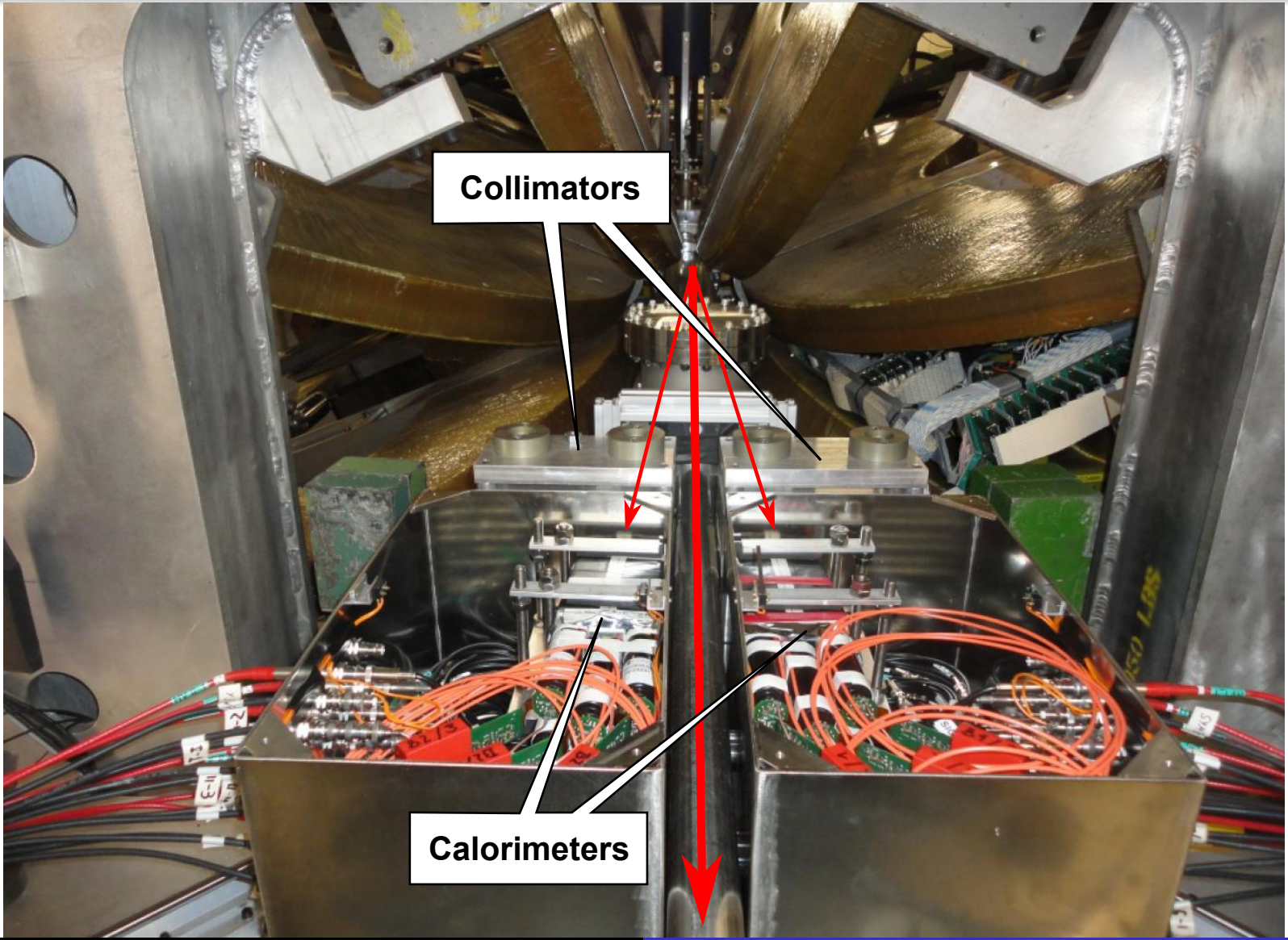
Symmetric Møller/Bhabha Monitor

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

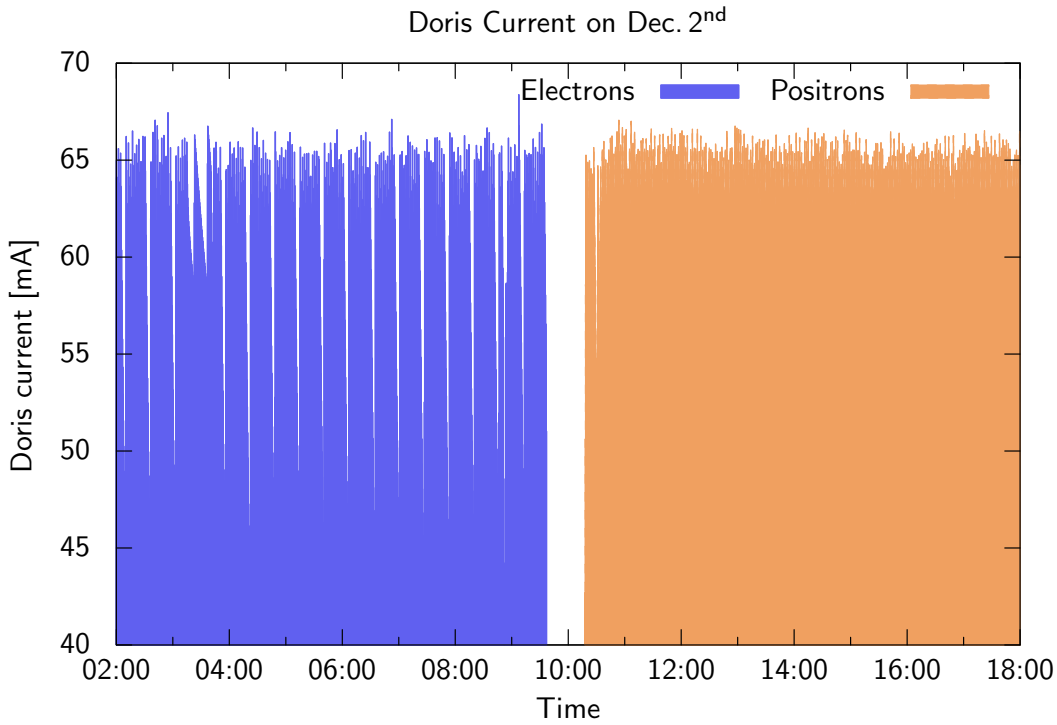


Symmetric Møller/Bhabha Monitor



OLYMPUS Data Taking – DORIS Performance

- beam current typ. >60 mA
- DORIS operation in top-up mode
- e^+: top-up about every 2 minutes
- e^-: top-up interruptions for PETRA refills with e^+
- beam species switch: 30 to 60 minutes



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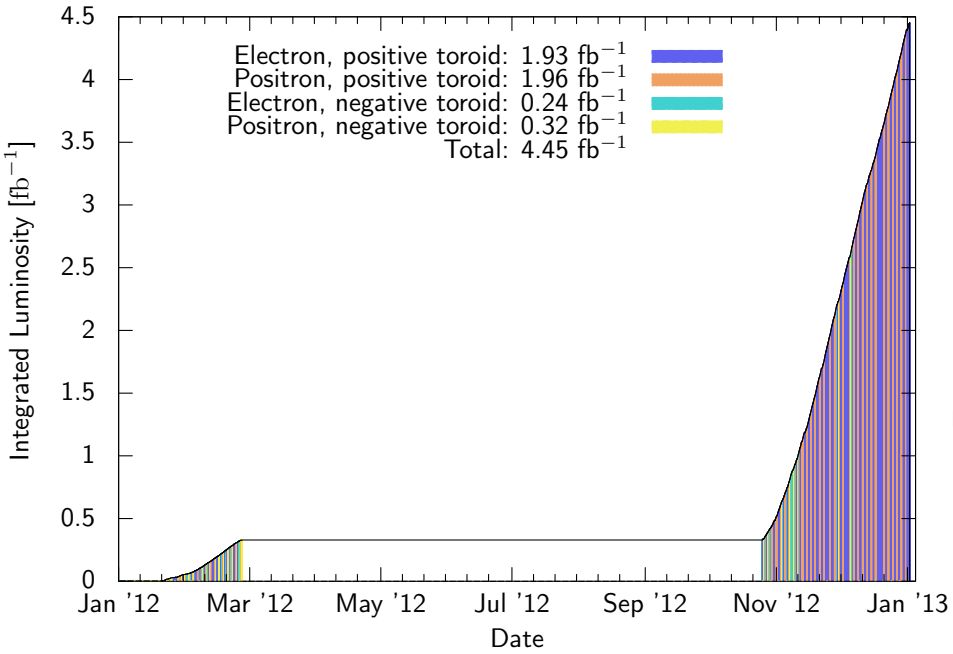
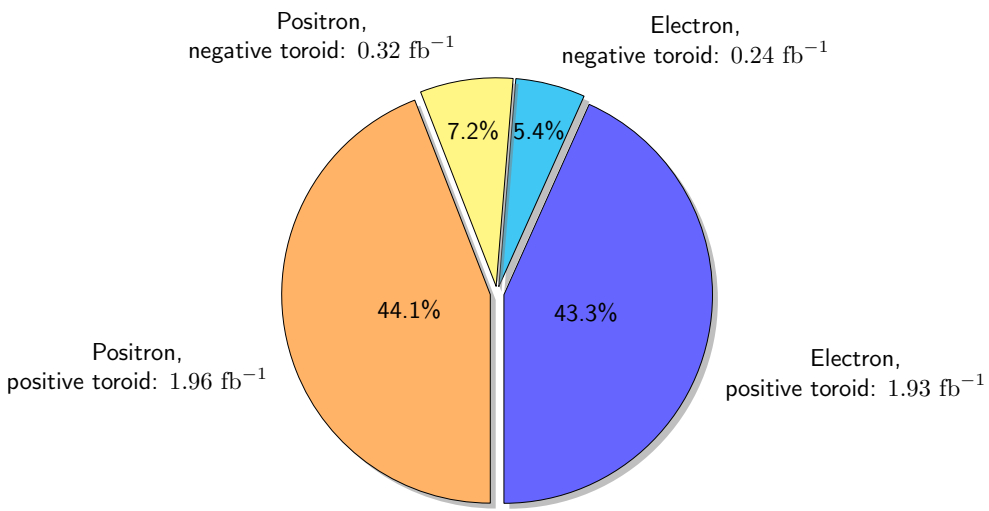
OLYMPUS Data Taking – Integrated Luminosity





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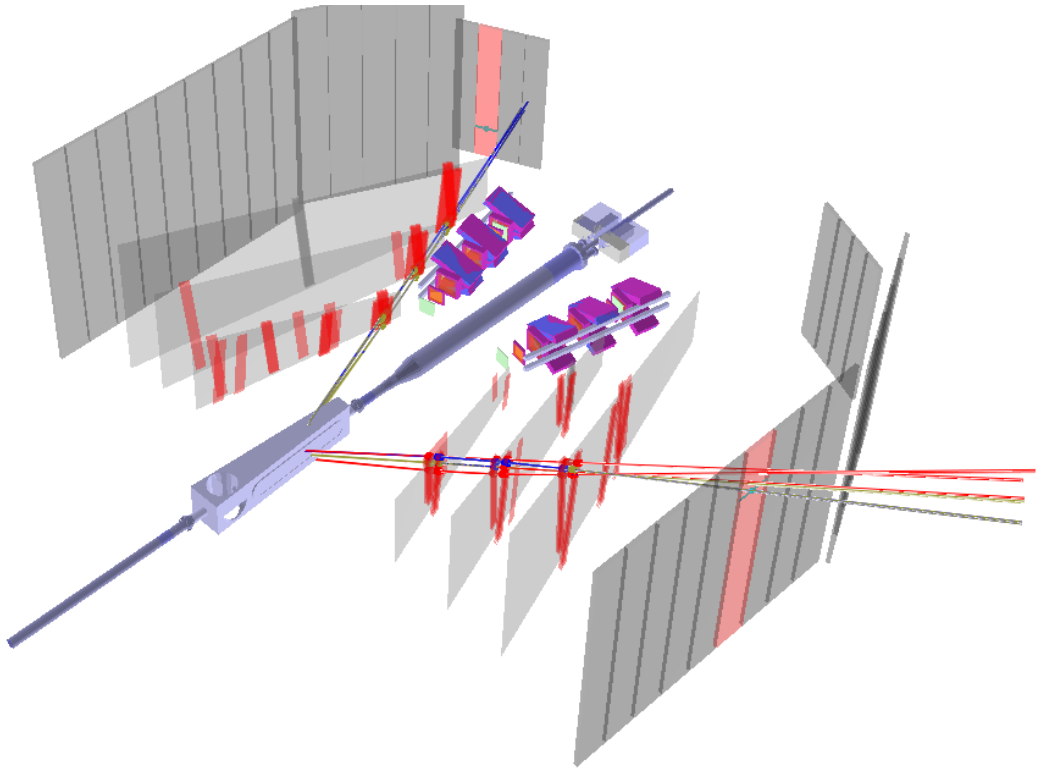
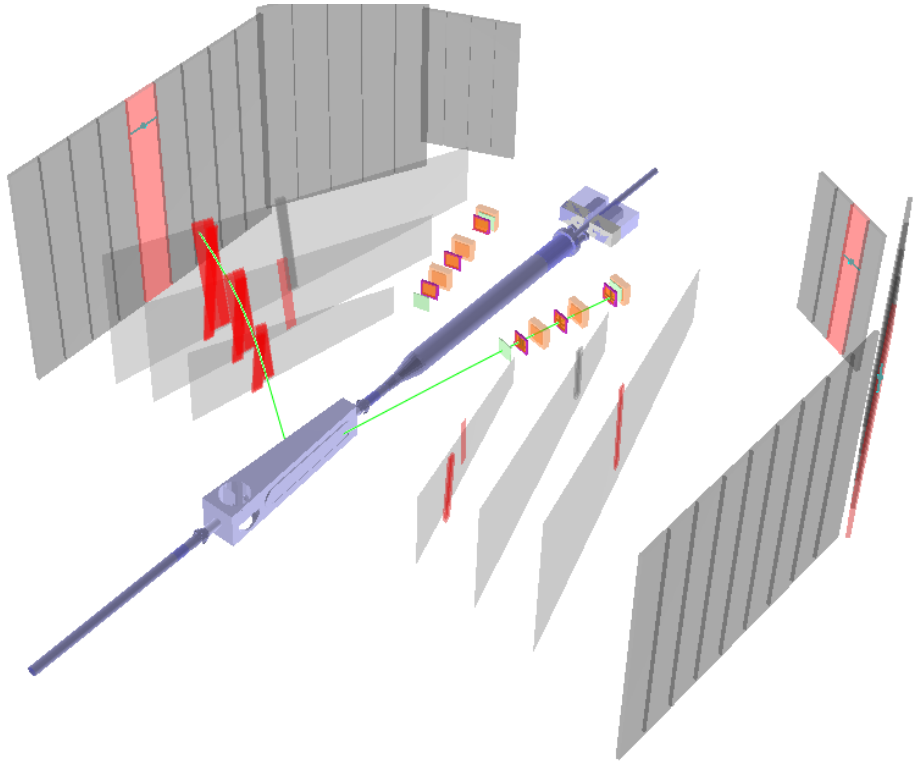
- well-balanced e^+, e^- data sets
- additional negative toroid data (systematics!)
- $\mathcal{L}_{\text{int}}$ goal of 4 fb^{-1} exceeded!

Event Display



Elastic event candidate in main detector

Event Display

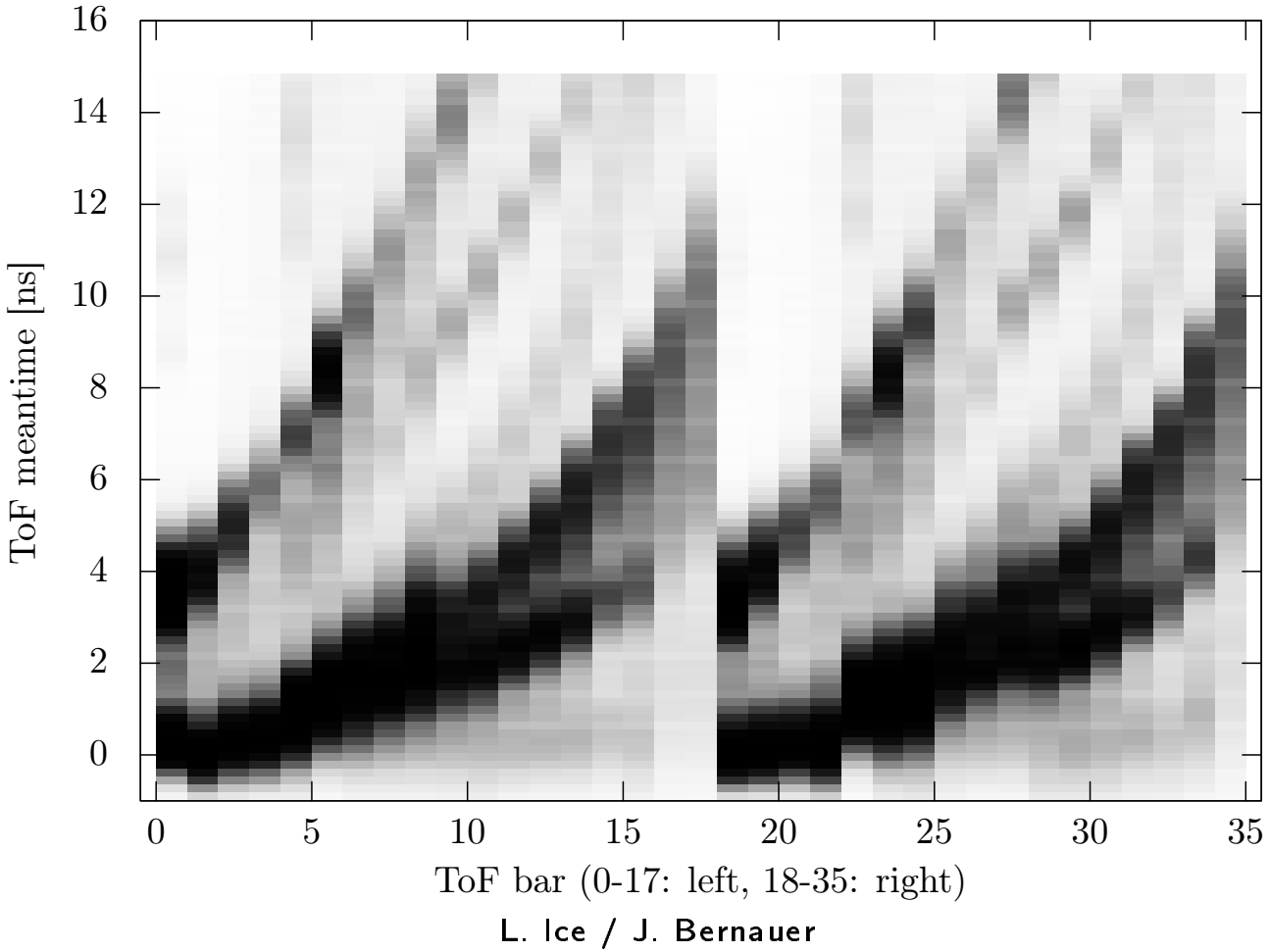


Elastic event candidate in 12 degree luminosity telescope

Data Analysis Progress

- Magnetic Field mapping analyzed, small improvements pending
- Beam Position monitors: calibration finished, analysis in progress (important for luminosity monitors!)
- Time of Flight: in good shape, still some improvements
- Wire Chamber tracking
  - complicated, but a lot of progress, still ongoing
  - alternative reconstruction code for cross-checks
- Luminosity
  - Møller/Bhabha: digitization underway, then study systematics
  - 12 degree Telescopes: details of detector efficiencies, resolutions, control effects of possible charge asymmetry!
- Monte Carlo
  - fully integrated with data analysis chain
  - radiative ep generator by MIT group – in contact with other experiments for cross-checks
- e^+p / e^-p ratio analysis will be blinded!

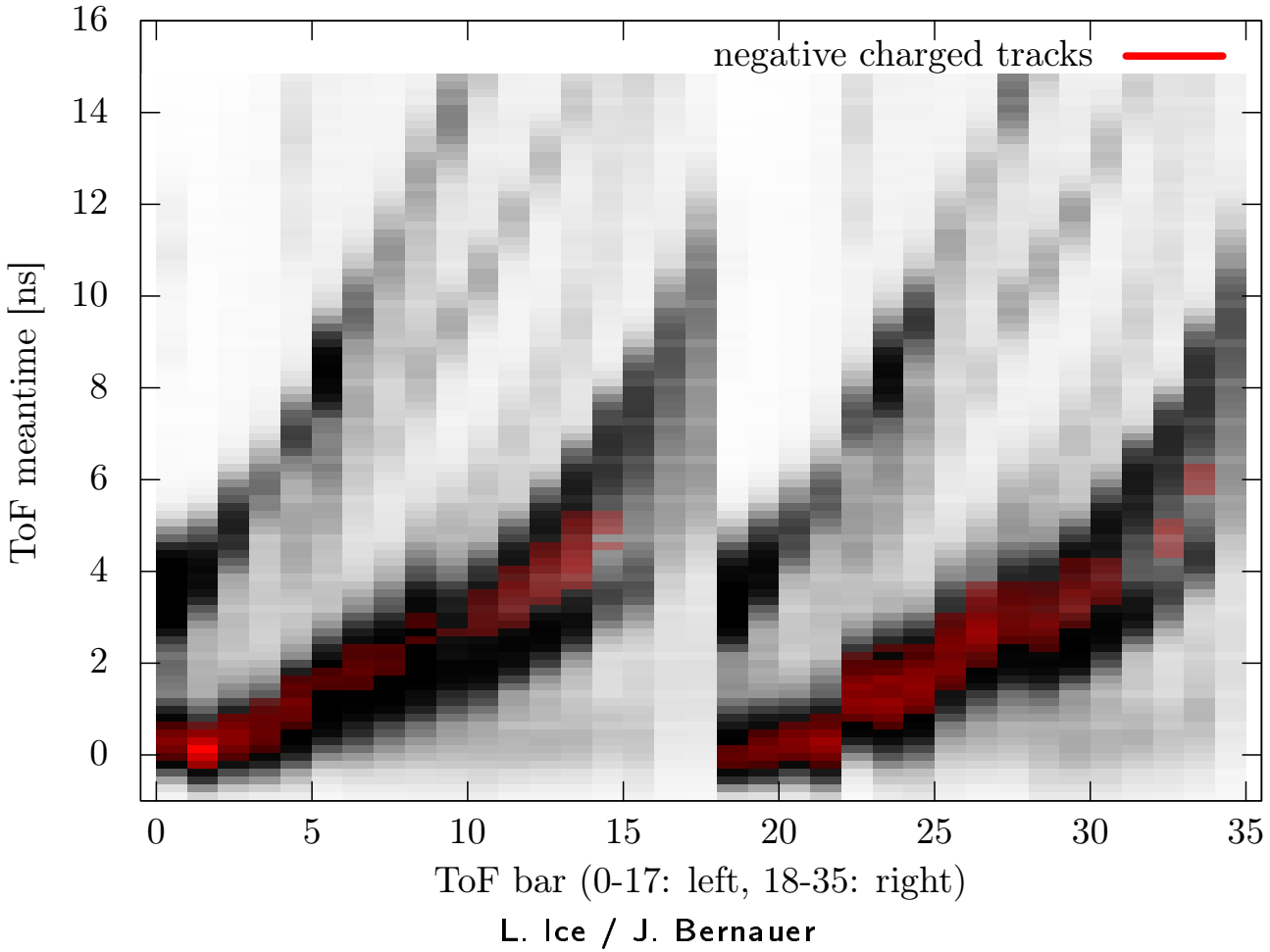
Time of Flight Detectors



L. Ice / J. Bernauer

TOF detector meantimes – charge from wire chamber tracking

Time of Flight Detectors



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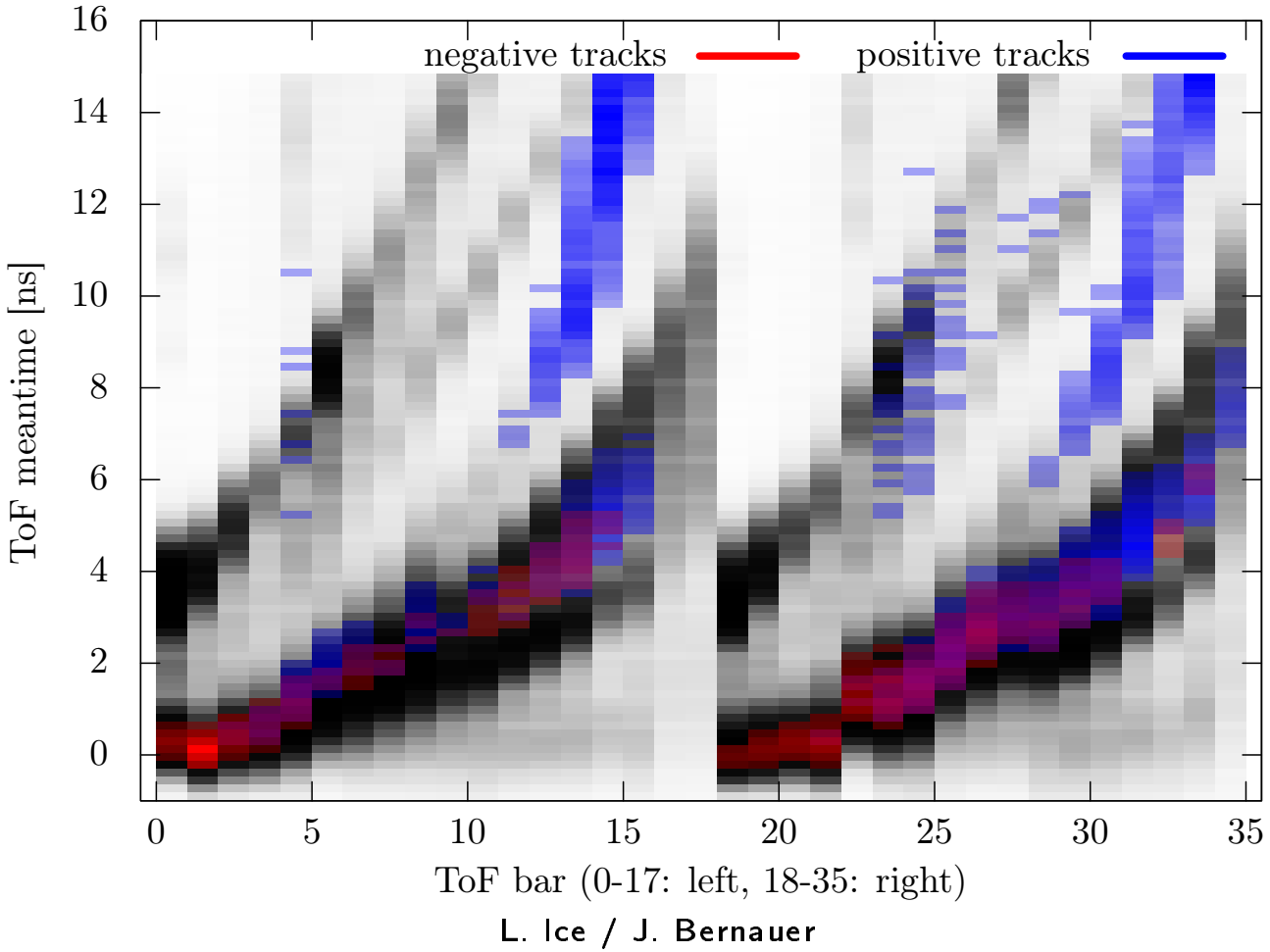

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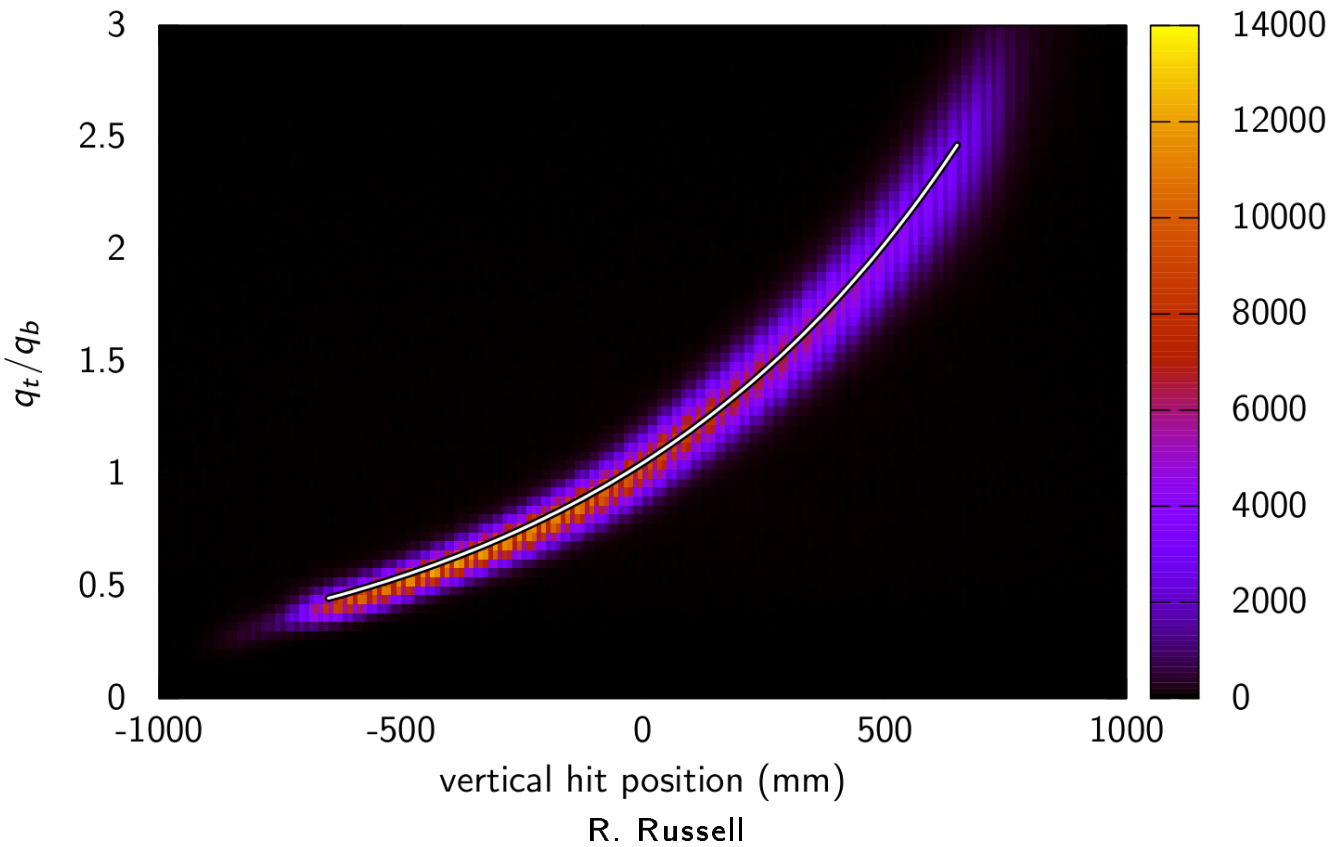
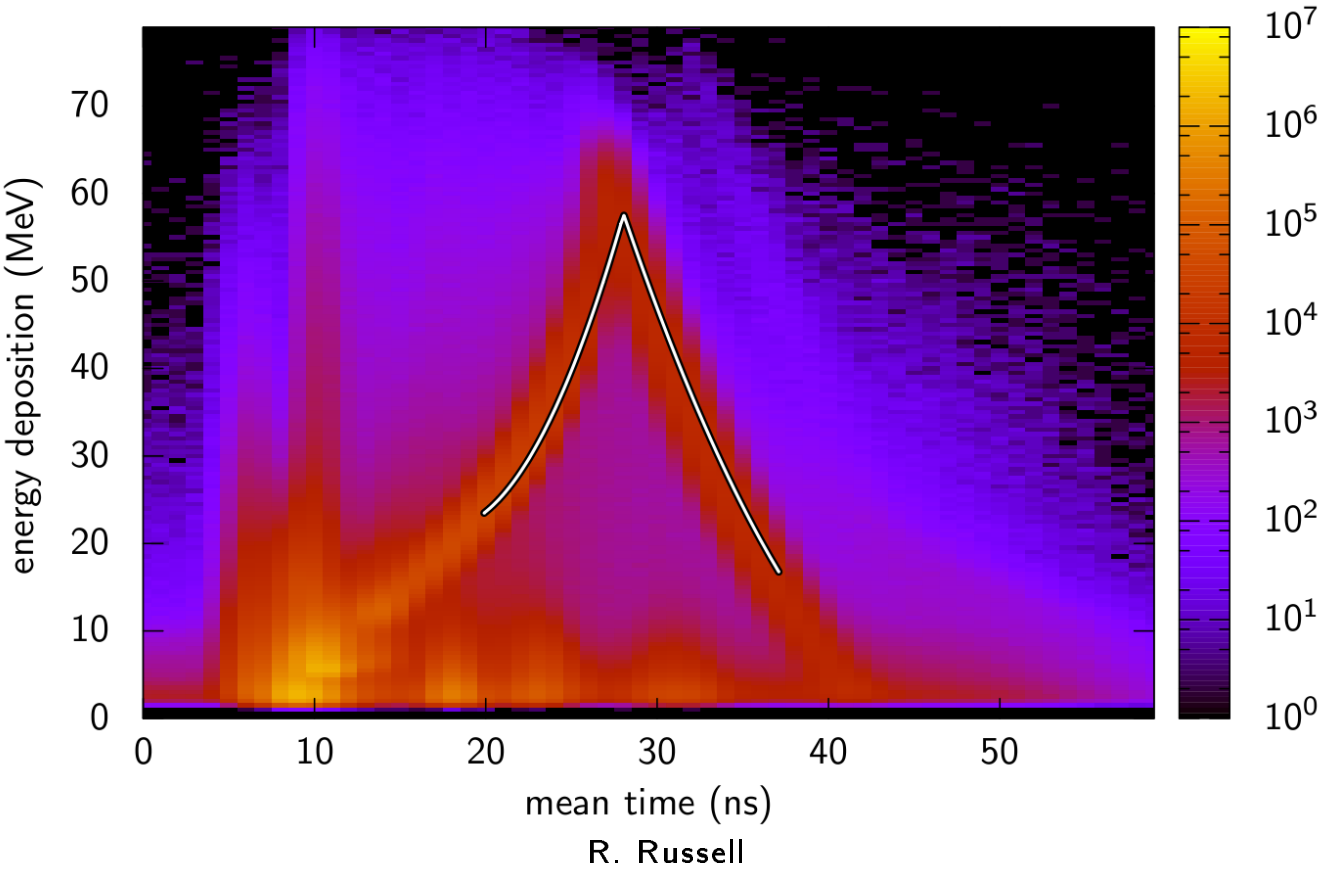


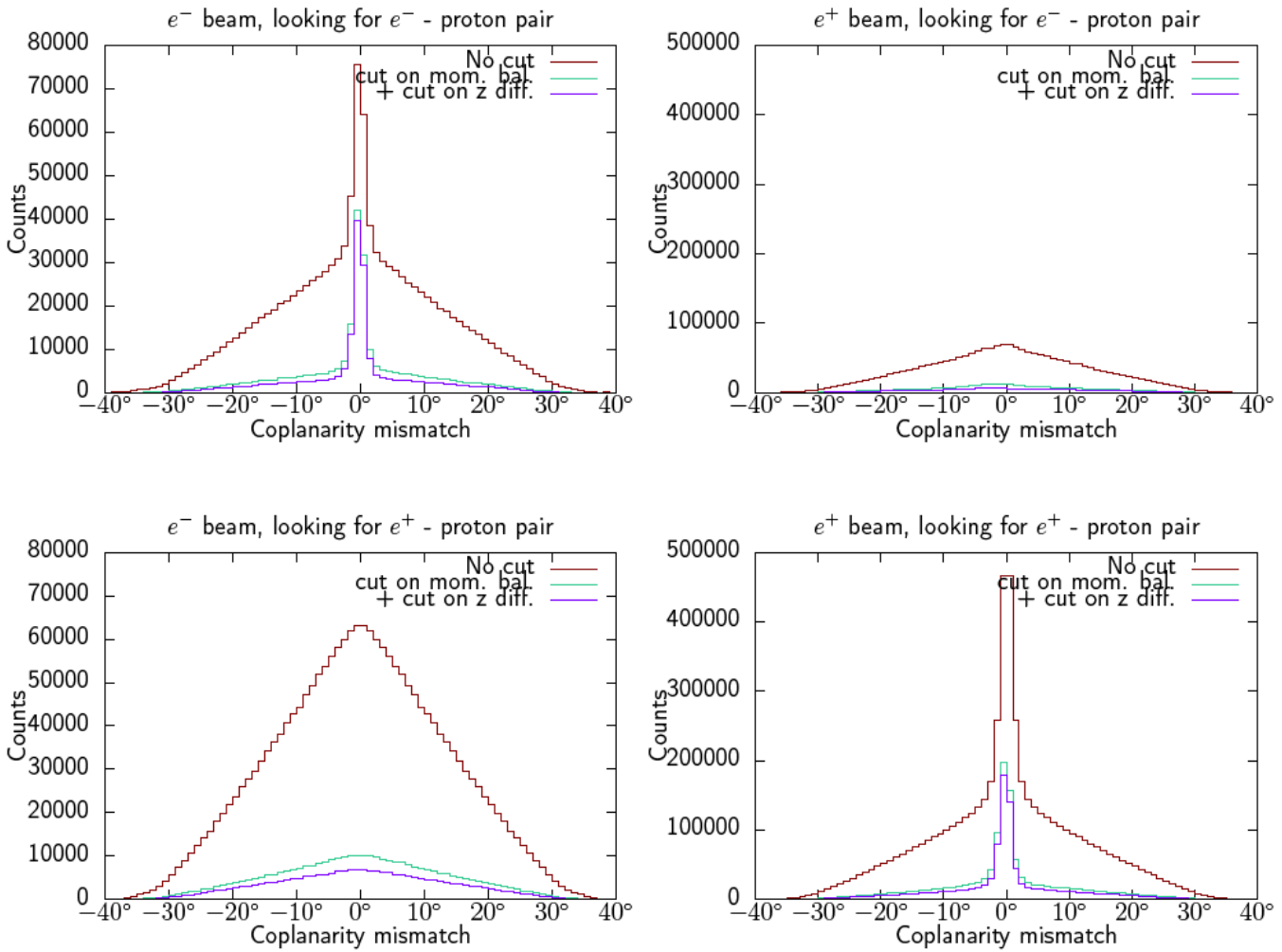
TOF attenuation length – top PMT / bottom PMT vs. hit position

Time of Flight Detectors



TOF energy calibration – energy deposition of protons

Wire Chamber Tracking



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Preliminary – tracking constantly improving

Summary

Unique combination of OLYMPUS and DORIS:

- OLYMPUS will determine the contribution of two photon exchange to elastic ep scattering on the percent level

Data taking periods Feb 2012 and Nov/Dec 2012:

- top-up operation of DORIS
- daily routine switching of beam species
- anticipated data taking efficiency reached
- goal of $\mathcal{L}_{\text{int}}$ of 4 fb^{-1} exceeded
- analysis ongoing
- blinded analysis of cross section ratio!

OLYMPUS Collaboration

- Arizona 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