72. Physics Research Committee Meeting, DESY, Oct. 25-26, 2011

OLYMPUS

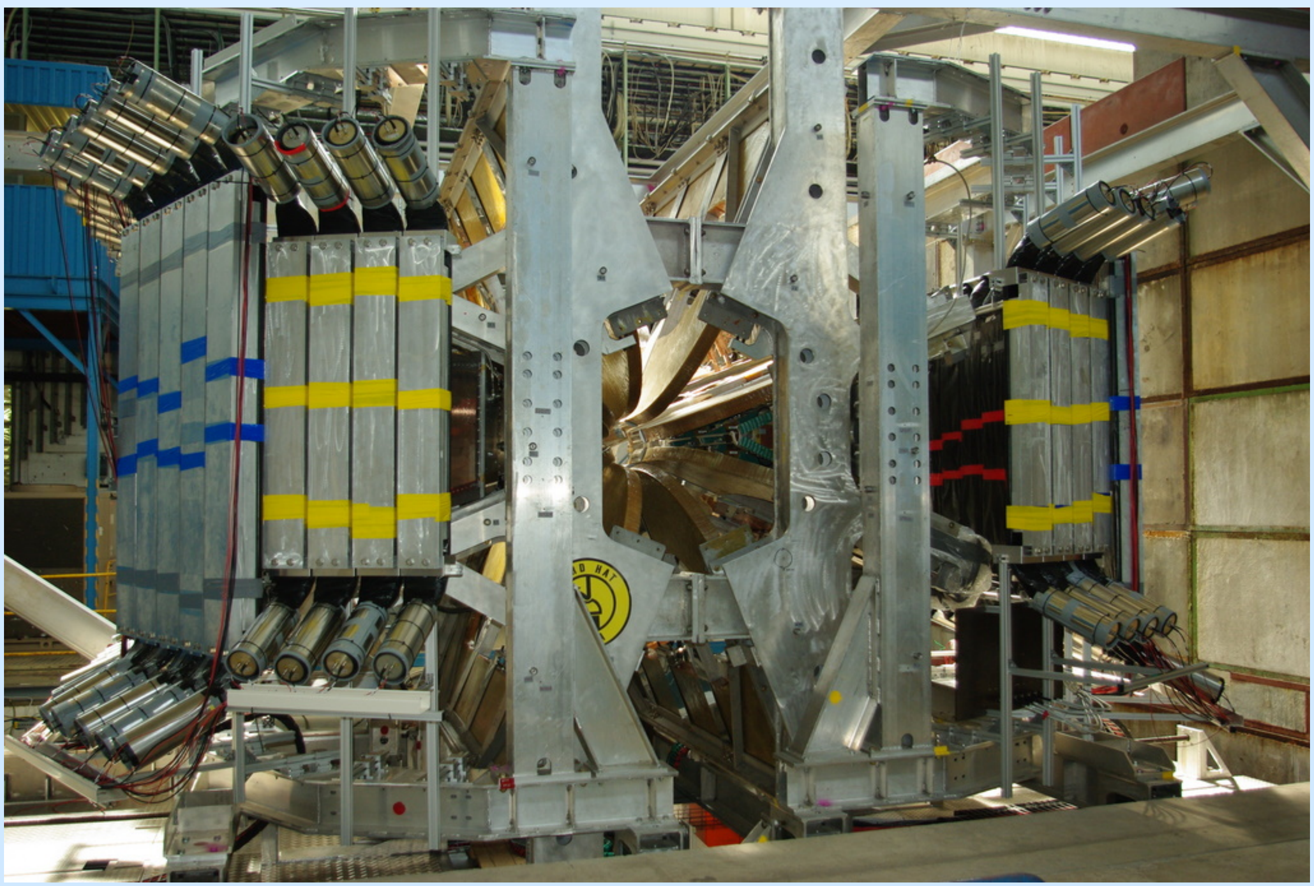
Michael Kohl *

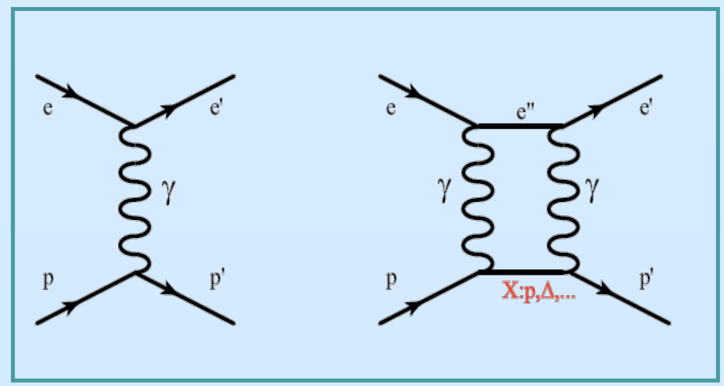
Hampton University, Hampton, VA 23668
Jefferson Laboratory, Newport News, VA 23606

* Supported by NSF grants PHY-0855473 and 0959521, and DOE Early Career Award DE-SC0003884

Outline

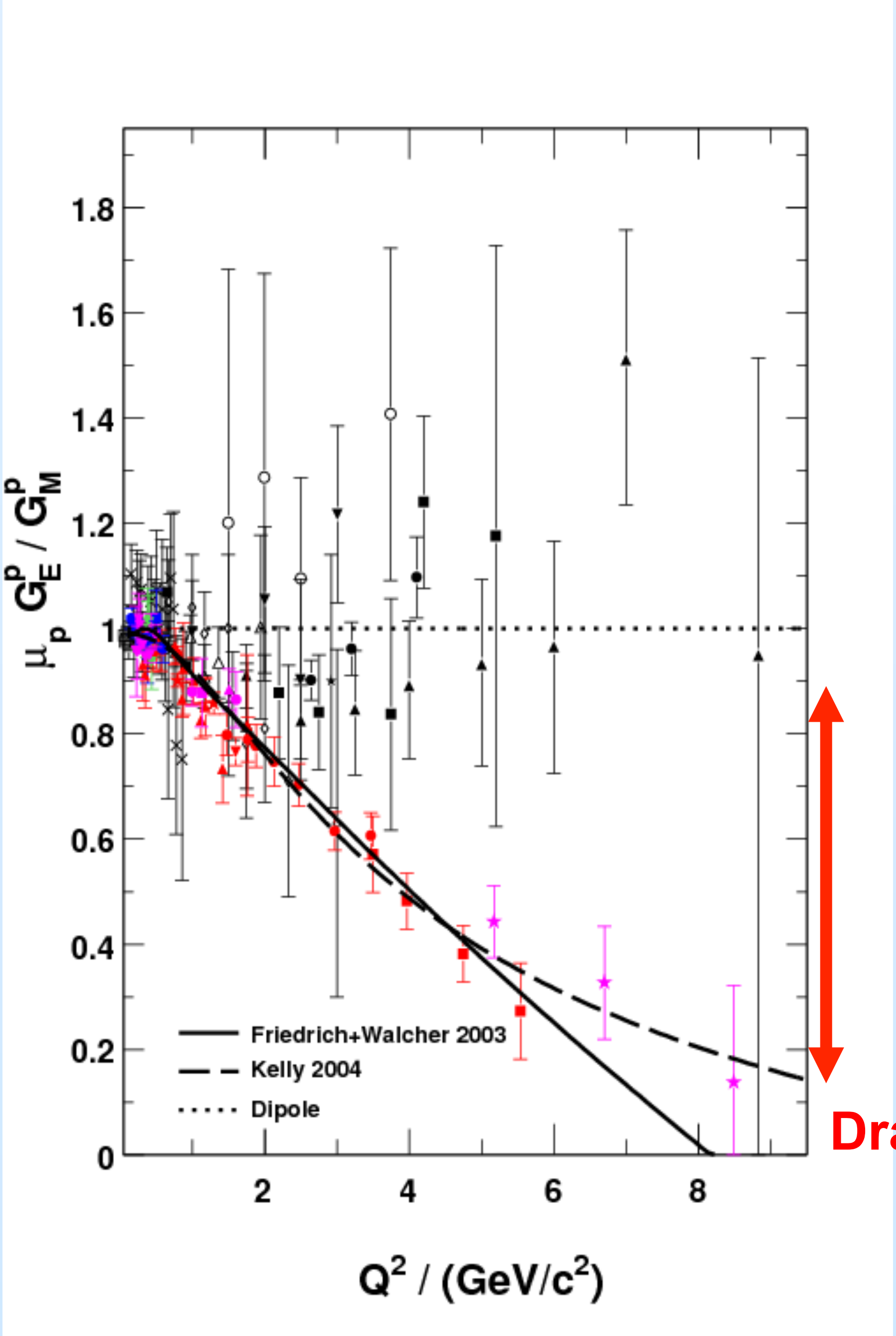
- The OLYMPUS experiment
- Detector tests at DESY testbeam area 22
- Installation and commissioning of OLYMPUS
- Online and offline analysis
- Schedule





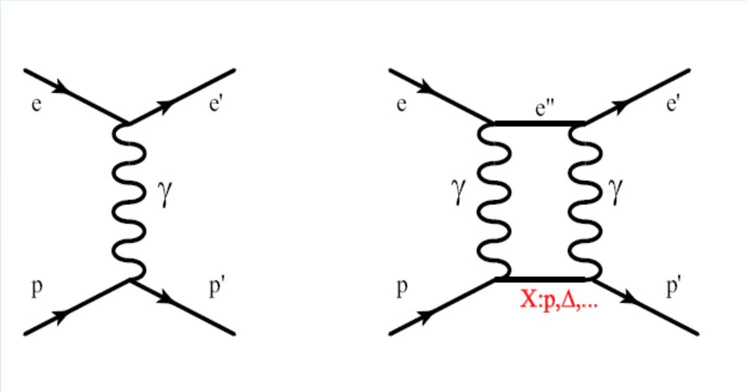
OLYMPUS @ DESY
Picture from July 6, 2011

Proton Form Factor Ratio



Jefferson Lab 2000–today

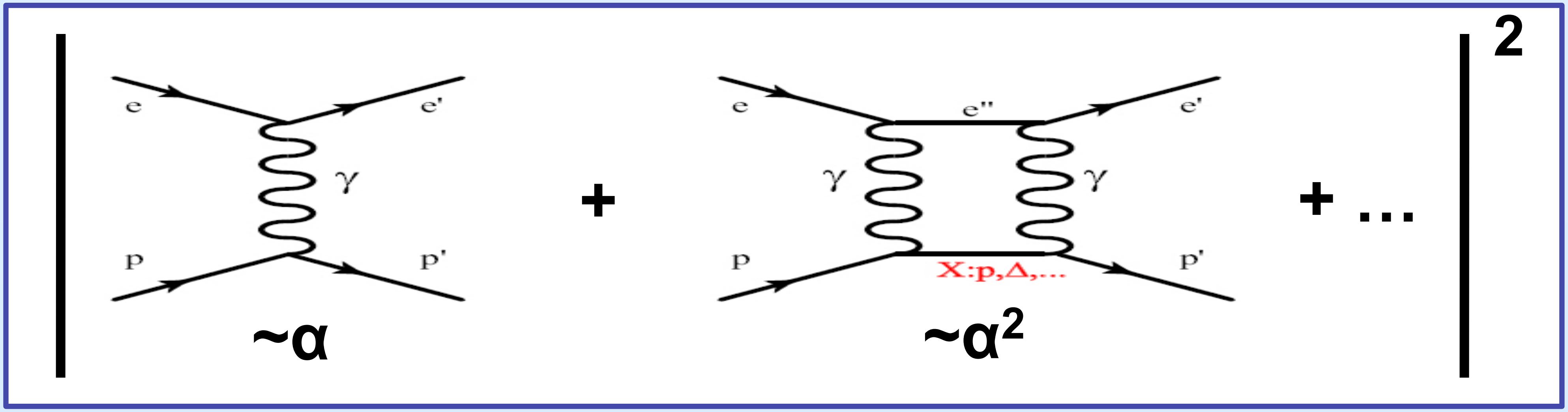
- All Rosenbluth data from SLAC and Jlab in agreement
- Dramatic discrepancy between Rosenbluth and recoil polarization technique
- Multi-photon exchange considered best candidate



Dramatic discrepancy!

>800 citations

Lepton-Proton Elastic Scattering



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

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

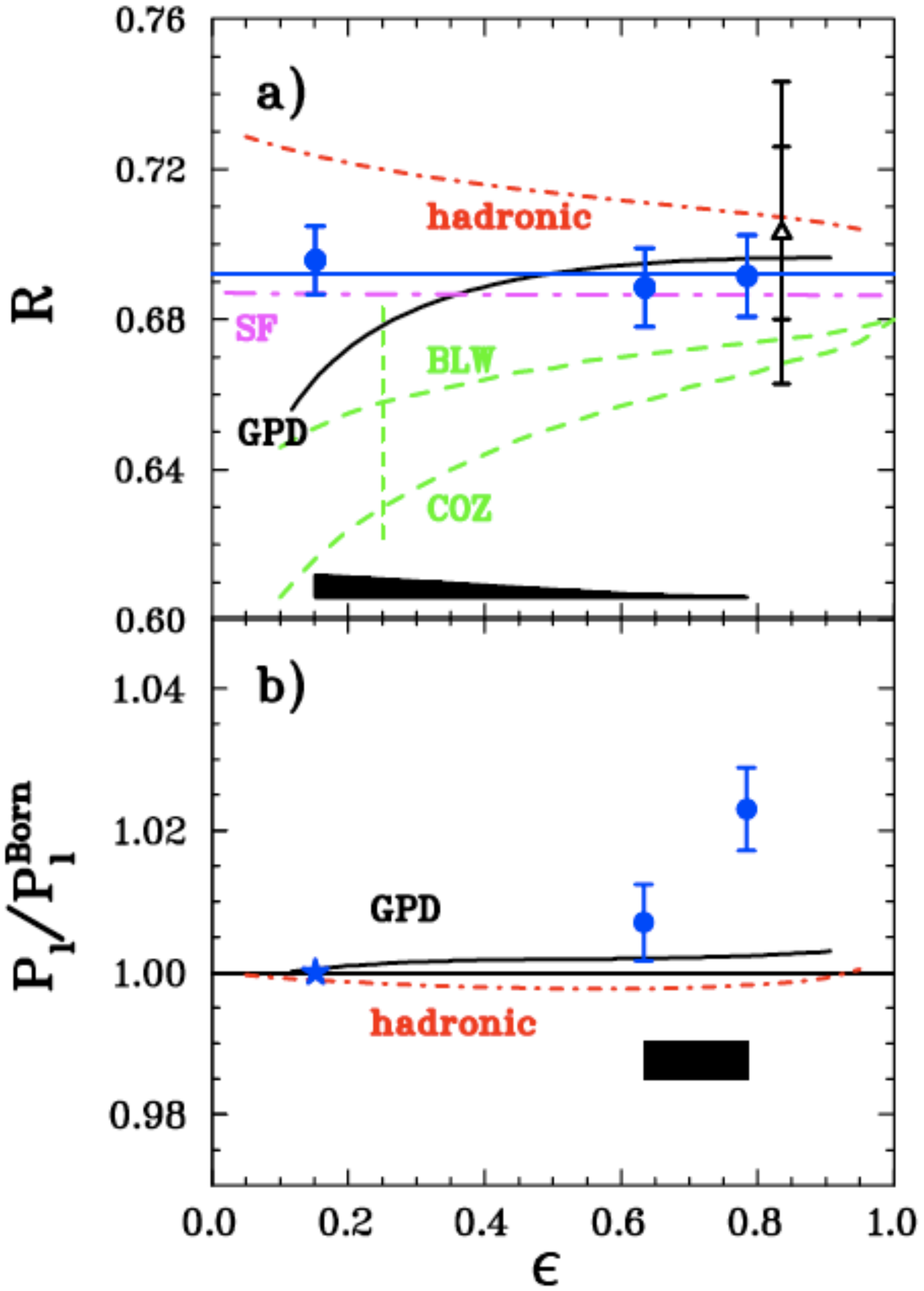
$$\sigma(\text{electron-proton}) = (1\gamma)^2\alpha^2 - (1\gamma)(2\gamma)\alpha^3 + ..$$

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

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

σ-ratio to deviate from 1 due to interference of 1γ and 2γ proportional to TPE

Jefferson Lab E04-019 (Two-gamma)



Jlab – Hall C
Q^2 = 2.5 (GeV/c)^2

G_E/G_M from P_t/P_l constant vs. ε

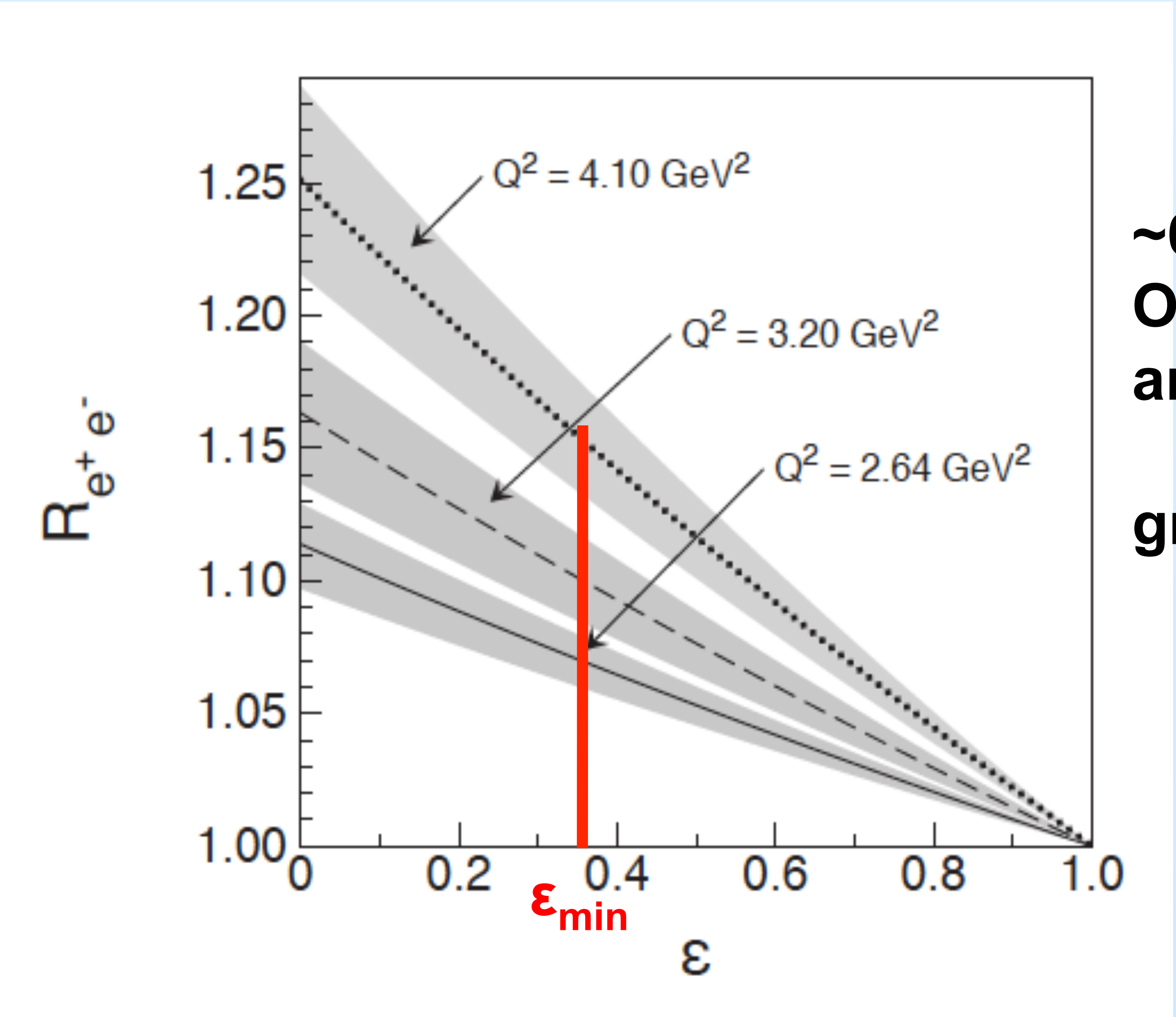
➔ **no effect in P_t/P_l**
➔ **some effect in P_l**

Expect larger effect in e+/e-!

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

Empirical Extraction of TPE Amplitudes

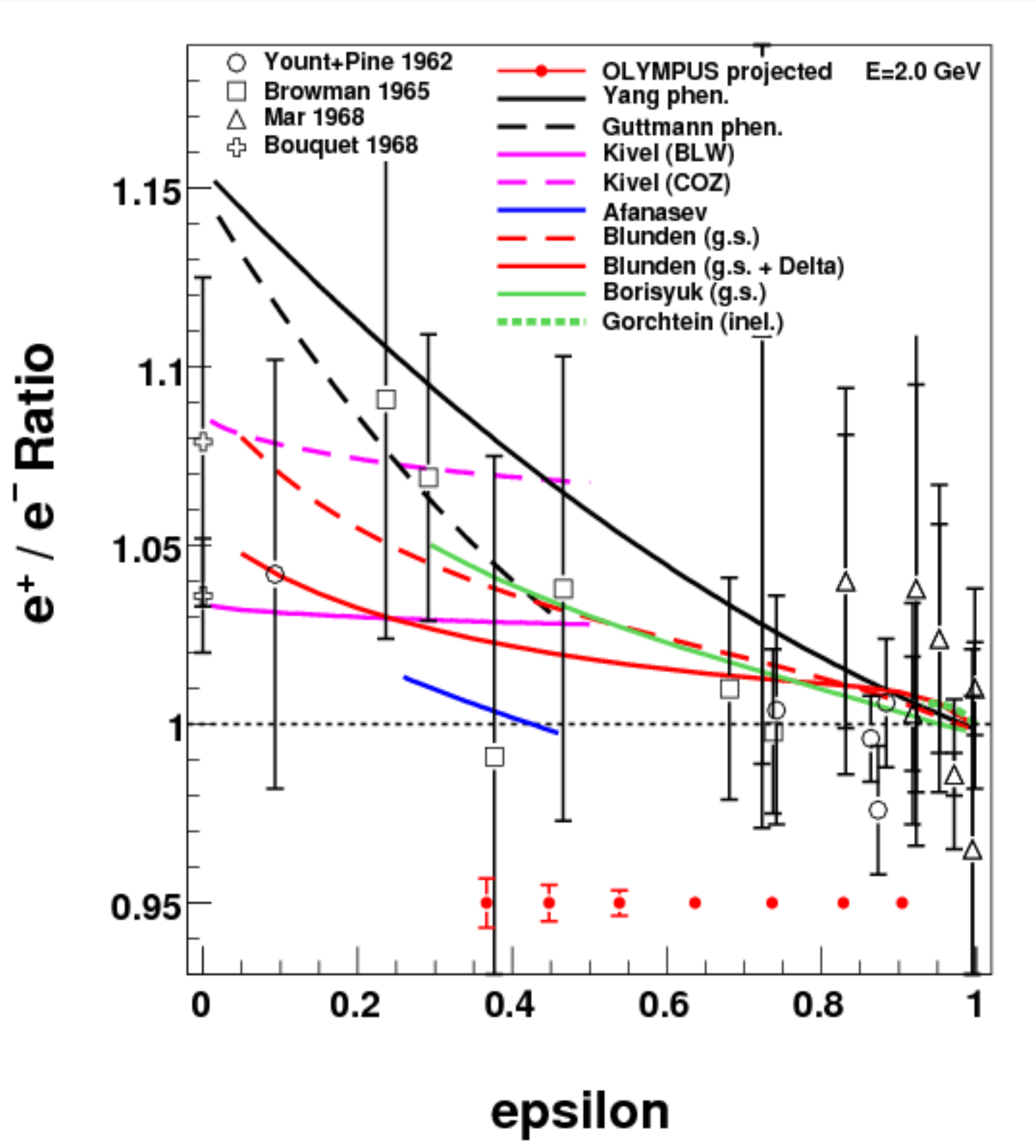
J. Guttmann, N. Kivel, M. Meziane, and M. Vanderhaeghen, hep-ph/1012.0564v1



~6% effect for OLYMPUS@2.0GeV and Q^2 ~2.2 $(GeV/c)^2$

grows with Q^2!

Projected Results for OLYMPUS



- **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 @ $2x10^{33}$ / cm^2s e+,e-
  to be run in 2012
- **Workshop at MIT, July 30, 2011 on Radiative Corrections**

Radiative Corrections Workshop @ MIT

Organized by R. Milner and T.W. Donnelly; ~40 participants

Saturday, July 30, 2011 in the Kolker Room 26-414

4 theory talks

8:30—9:00 Richard Milner MIT

Welcome and Overview

9:00—9:30 Carl Carlson College of William & Mary

Two-photon Corrections using GPDs

9:30—10:00 Nikolay Kivel Helmholtz-Institut, Mainz, Germany

Phenomenological Analysis of Two-photon Exchange Amplitudes from Elastic ep Scattering

~~10:00—10:30 Andrei Afanasev JLab~~

~~*Higher-order Electromagnetic Effects and the C-odd Asymmetry of Elastic ep Scattering*~~

10:30—11:00 Coffee break

11:00—11:30 Ulf Meissner Bonn U., Germany

Two-photon Corrections from Dispersion Relations

11:30—12:00 Peter Blunden U. of Manitoba, Canada

Review of Two-photon Exchange in Electron Scattering

13:30—13:50 Robert Bennett ODU

Overview of JLab Experiment

13:50—14:10 Alexander Gramolin INP, Novosibirsk, Russia

Overview of Novosibirsk Experiment

14:10—14:30 Michael Kohl Hampton U.

Overview of OLYMPUS Experiment

14:30—15:00 Coffee break

15:00—17:00 Discussion Moderator: Bill Donnelly (MIT)

3 experiment talks

Radiative Correction for e+/e-

- Radiative correction of cross section sizeable, depending on momentum cutoff, the latter on resolution – correction is smaller if momentum is not measured
- About 20-30% of the correction is C-odd (“soft TPE”)
- Radiative correction of polarization observables very small (<1%) due to approximate factorization
- How big is the radiative correction for the e+/e- ratio?
- How does the correction for e+/e- depend on the momentum cutoff?
- How sensitive is it to the magnetic field used for momentum measurement?
- **Need a common, suitable framework to account for radiative effects**

OLYMPUS @ DESY

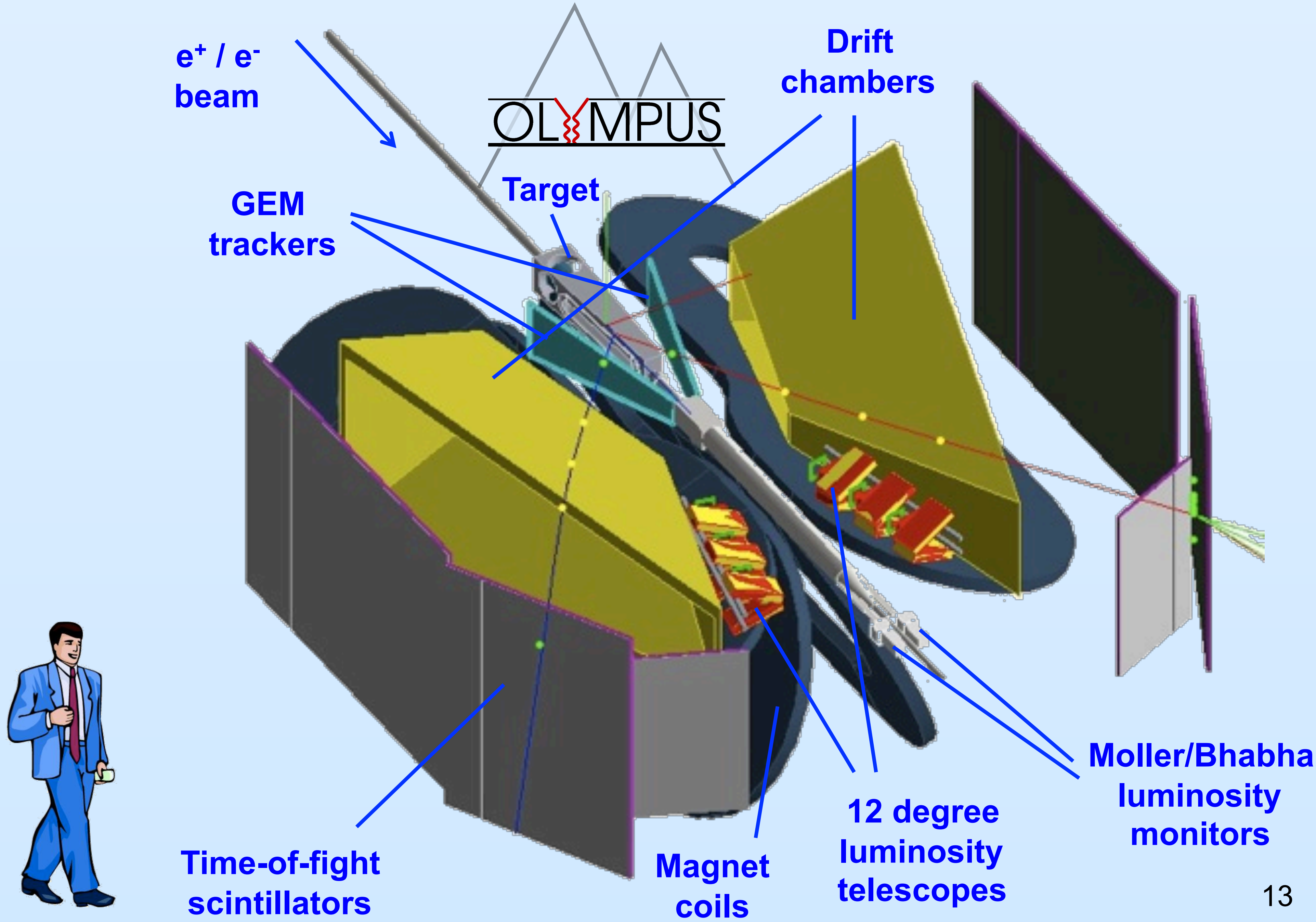
Collaboration Organization

- **Nov 2006 – Idea first formulated (D. Hasell, M.K., R. Milner)**
  Jun 2007 – Letter of Intent; Sep 2008 – Full Proposal
  Sep 2009 – Technical review; Jan 2010 – Funded and officially approved
- **Regular collaboration meetings since technical review**
  Nov 30–Dec 1, 2009 Feb 23–24, 2010 Apr 26–27, 2010 Jun 28–29, 2010
  Aug 30–31, 2010 Nov 1–2, 2010 Jan 24–25, 2011 Apr 26–27, 2011
  Jun 27–28, 2011 Sep 8-9, 2011
- **Elected management of OLYMPUS at June 2011 meeting:**
  Spokesman: M.K. (Hampton U.)
  Deputy spokesman: Alexander Winnebeck (MIT)
  Technical coordinator: Douglas Hasell (MIT)
  Project manager: Uwe Schneekloth (DESY)
- **Appointed coordinators:**
  Target – Richard Milner (MIT)
  Tracking – Douglas Hasell (MIT)
  TOF Scintillators – Inti Lehmann (U. Glasgow)
  GEM Luminosity Monitor – Jürgen Diefenbach (Hampton U.)
  Multiwire Proportional Chambers – Alexander Kiselev (PNPI)
  Symmetric Moller Monitor – Roberto Perez Benito (U. Mainz)
  Data Acquisition – Christian Funke (U. Bonn)
  Trigger – Alexander Winnebeck (MIT)
  Slow Controls – Anton Izotov (PNPI)
  Offline Analysis and Simulation – Jan Bernauer (MIT)

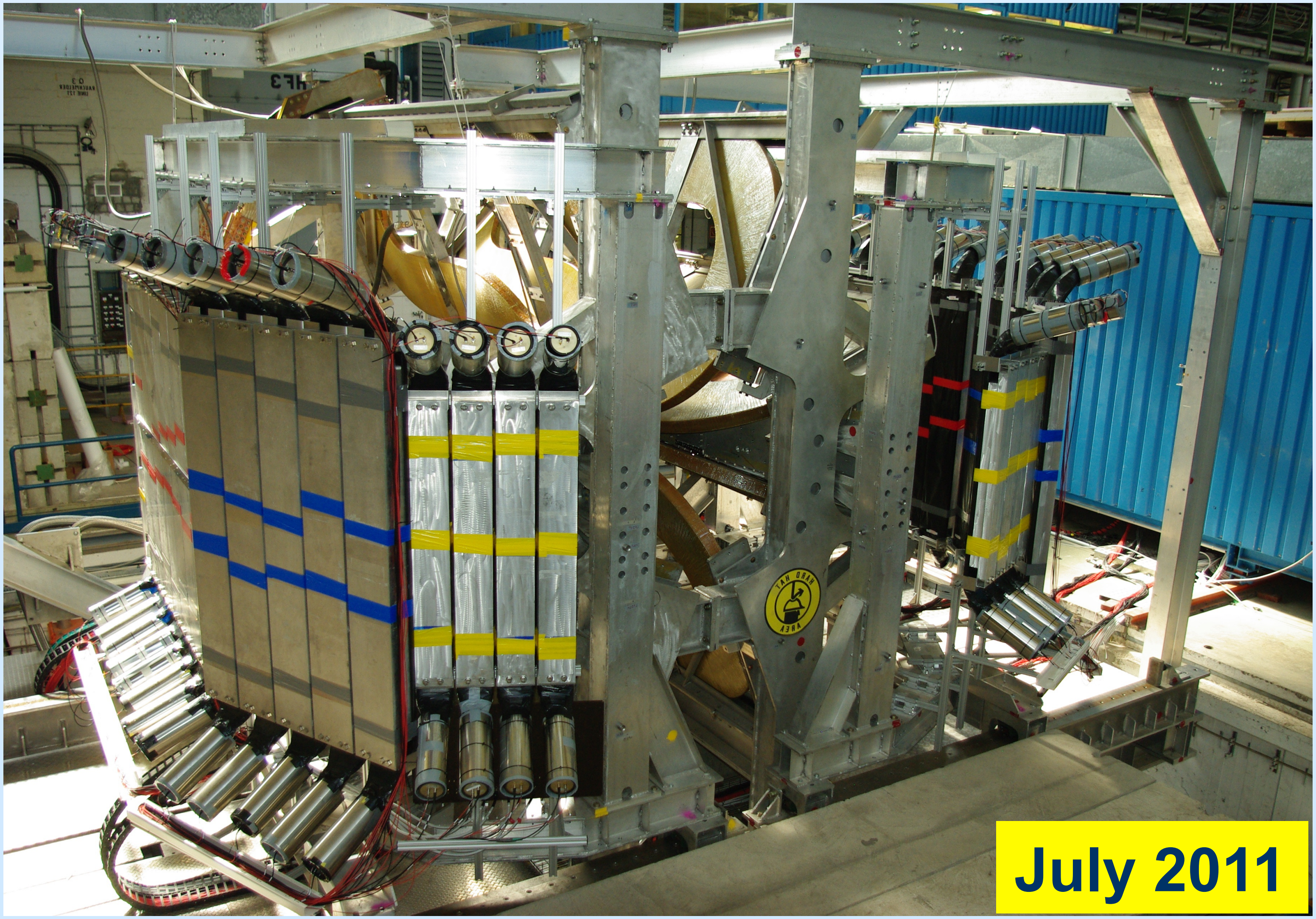
The OLYMPUS Experiment

- Electrons/positrons (100mA) in multi-GeV storage ring
  DORIS at DESY, Hamburg, Germany
- Unpolarized internal hydrogen target (buffer system)
  3×10^{15} at/cm^2 @ 100 mA $\rightarrow$ L = 2×10^{33} / (cm^{2}s)
- Large acceptance detector for e-p in coincidence
  BLAST detector from MIT-Bates available
- Redundant monitoring of luminosity
  Pressure, temperature, flow, current measurements
  Small-angle elastic scattering at high epsilon / low Q^2
  Symmetric Moller/Bhabha scattering
- Measure ratio of positron-proton to electron-proton unpolarized elastic scattering to 1% stat.+sys.

The Designed OLYMPUS Detector



The Realized OLYMPUS Detector

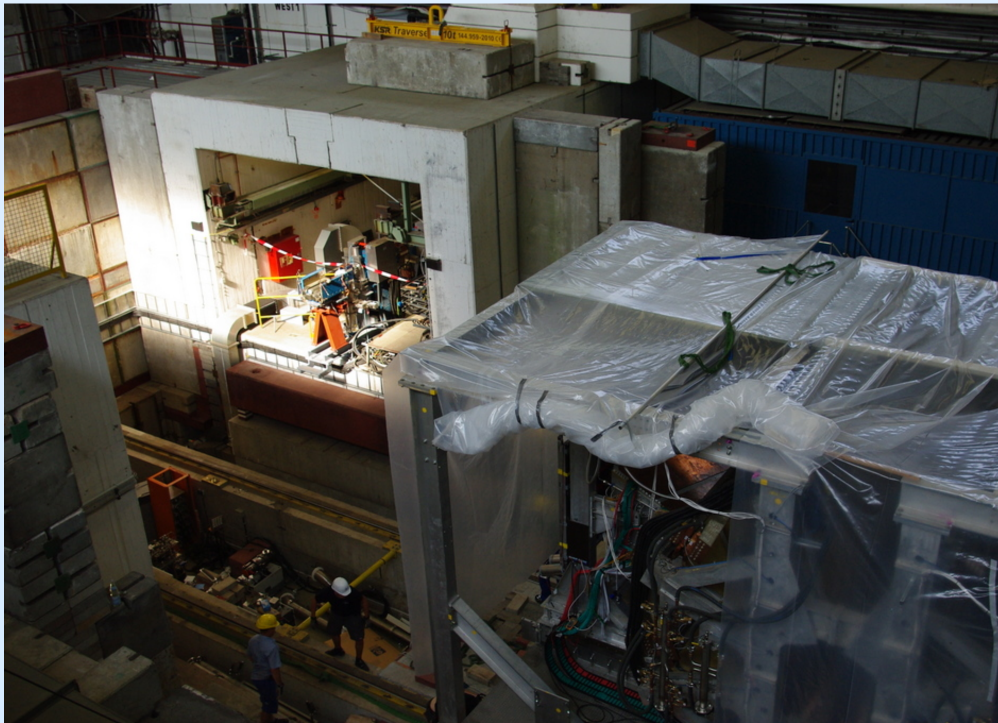


Preparation of OLYMPUS

- **OLYMPUS detector**
  - **ARGUS removed; BLAST disassembled and shipped (May-July 2010)**
  - **OLYMPUS assembly at DESY started in June 2010, completed by July 2011**
- **Target and vacuum system**
  - **New target chamber designed, constructed (MIT), target cells by INFN Ferrara**
  - **Target tested and shipped, installed in Jan. 2011; DORIS test run in Feb. 2011**
  - **Improved target reinstalled in July 2011; smoothly operating without problems!**
- **Drift Chambers**
  - **Rewired drift chambers at DESY in summer 2010, installed April-May 2011**
- **TOFs**
  - **TOFs tested and calibrated at Bates in January 2010**
  - **Supports redesigned, coordinated by U. Glasgow, installed in May 2011**
- **Luminosity Monitoring**
  - **12-degree elastic scattering telescopes (Hampton & PNPI), installed in Jun 2011**
  - **Symmetric Moller/Bhabha monitors (U. Mainz), to be installed Oct 2011**
  - **Test of all elements at DESY testbeam facility in May-Jun 2011**
- **DAQ**
  - **U. Bonn coordinating, system brought into operation at DESY in summer 2010**
- **Slow Controls**
  - **Control system (PNPI) tested and commissioned in summer 2011**

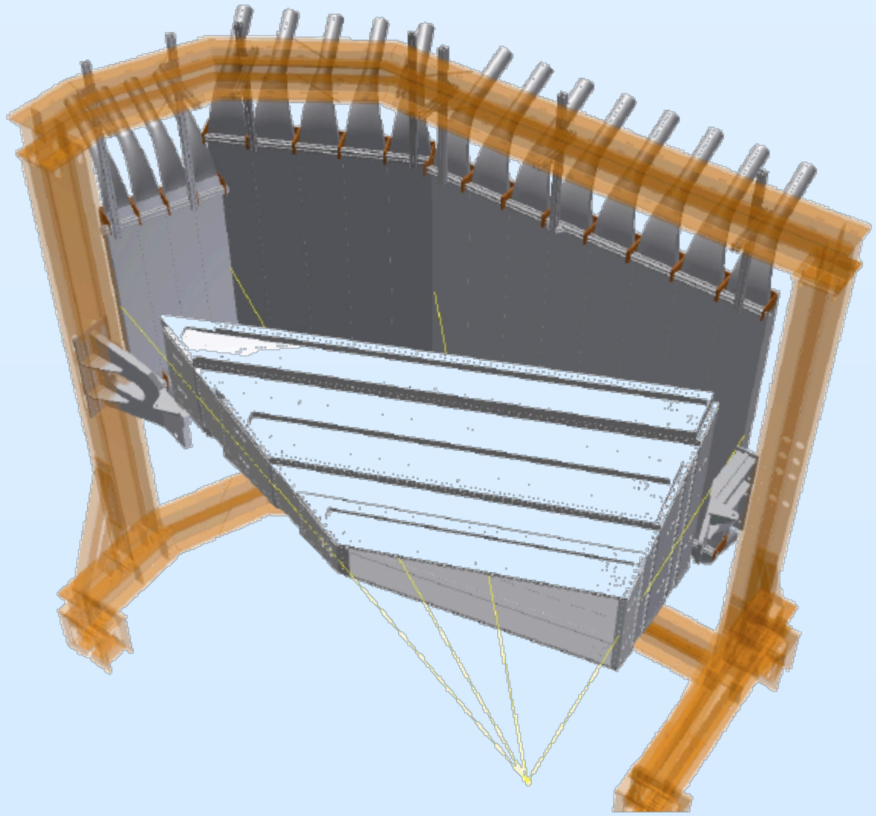
- **"ROLLING-IN" of final OLYMPUS detector into DORIS accomplished in July 2011**

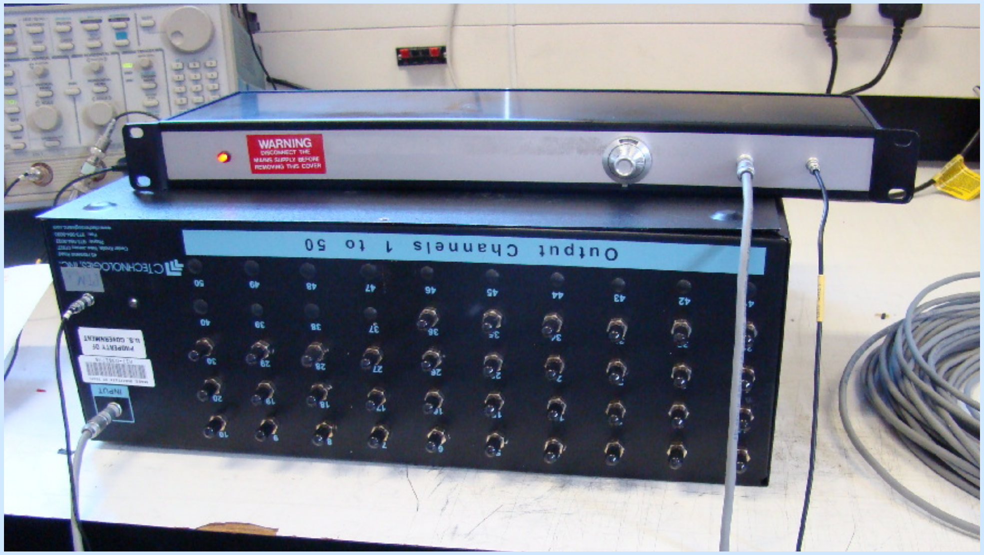
Roll-in of OLYMPUS on July 15, 2011



TOF Scintillators

- **2x18 TOFs for PID, timing and trigger**
- **TOFs refurbished from BLAST**
  TOF rewrapped
  New support structure
  New LED flasher system
  HV control
- **Installed in OLYMPUS Apr-May 2011**
- **Coverage: TOF ~19°–85° (WC ~24°–76°)**
- **Commissioning ongoing**

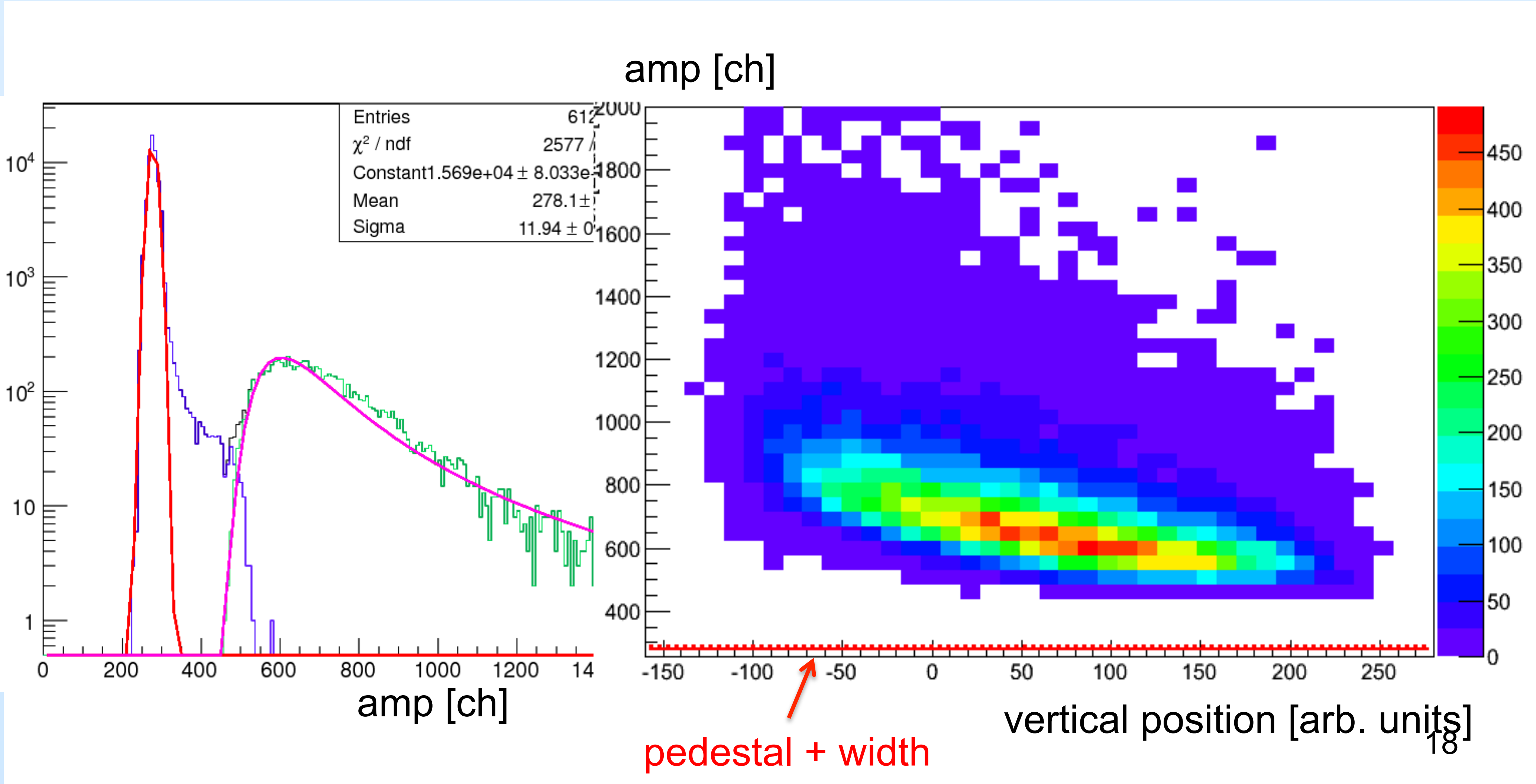




TOF Signals

- **Signals show pedestal + MIP peak**
- **Optimization of thresholds and gains in progress**
- **Attenuation visible for far-side MIPs**

Inti Lehmann coordinating



Wire Chambers

Douglas Hasell coordinating

- 2 WCs for PID and tracking (z,θ,φ,p)
  - Refurbished from BLAST, rewired at DESY
- Progress since PRC71:
  - Both chambers installed in OLYMPUS
  - Frontend electronics mounted and cabled
  - Gas system connected and leak tested
  - Chambers conditioned with high voltage
  - Wiring problems repaired
  - Operated in fall test beam periods
  - Integrated with data acquisition chain

- Some problems remain
  - Some HV cards breaking down
  - New cards designed, will be produced for January
  - 5 new prototypes of the new HV cards installed and tested this week
  - Test results show start of TDC distribution but swamped by noise
  - Possible problem with LV power supplies and/or grounding scheme
  - New HV cards have better grounding options

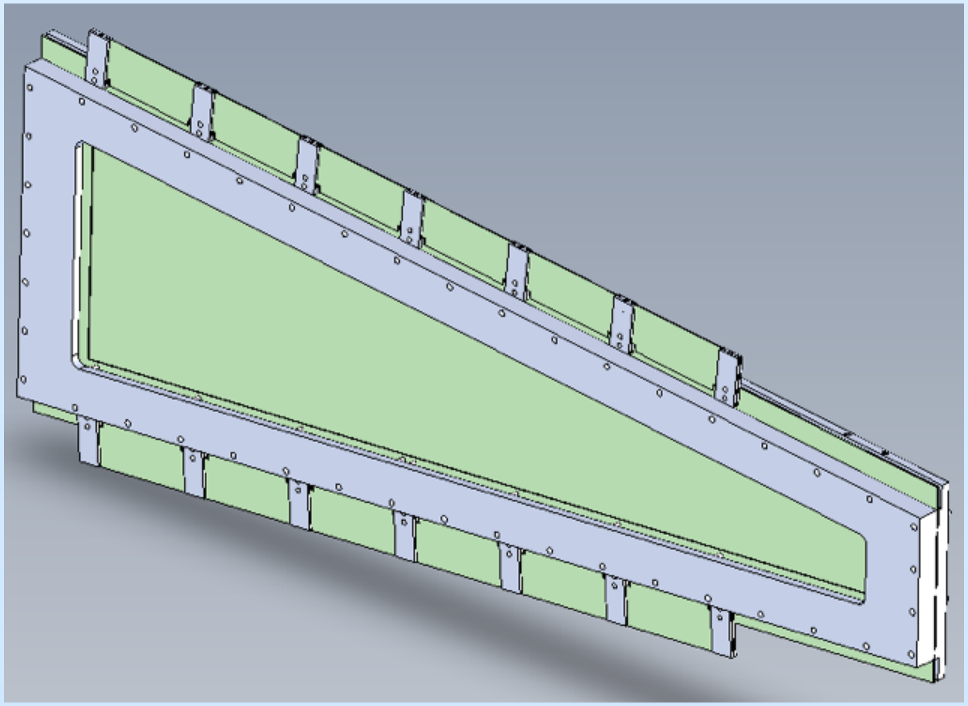
GEM tracker

MIT could not proceed because of lack of funds

- Design was well along; readout electronics, APV chips, power supplies, etc. had been ordered and received, but cost over runs with shipping, target and vacuum system, and manpower left MIT unable to continue

Collaboration has graciously stepped forward to help

- DESY will order GEM foils
- Bonn will machine mechanical parts
- Hampton will order readout boards
- MIT will complete design, assemble, test, and ship early in 2012

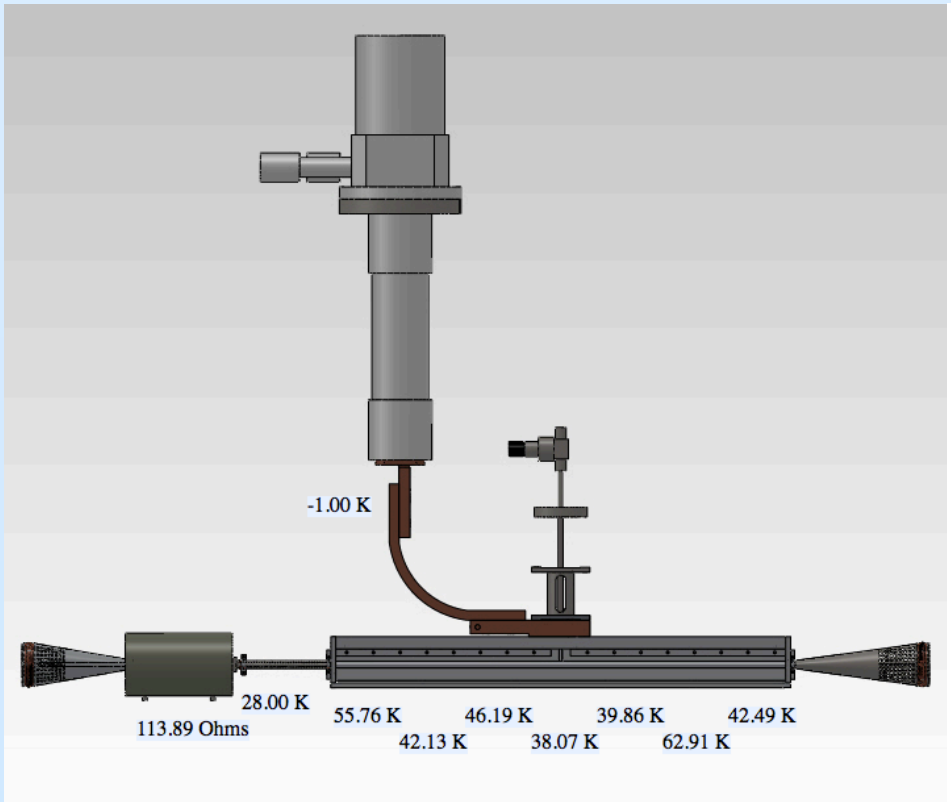


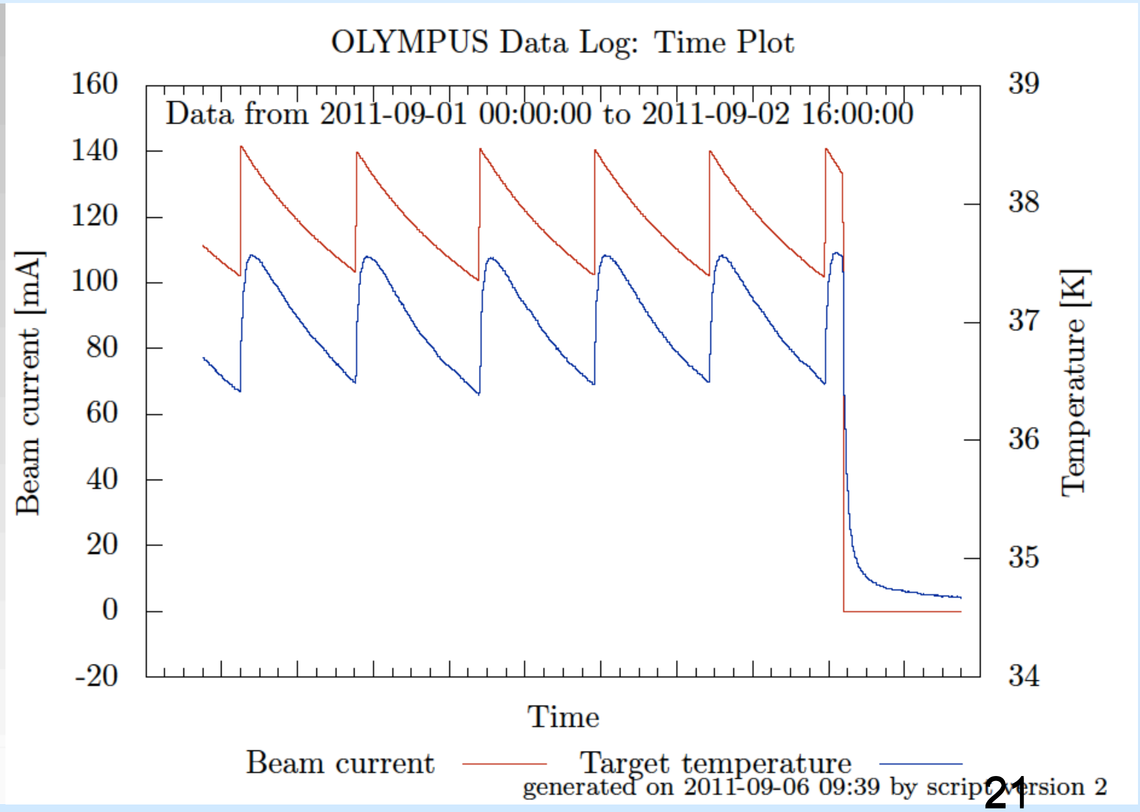
- Large area triple GEM detector
- Trapezoidal shape
- Active area 84 cm x (25 to 11) cm
- Split GEM foils and readout boards
- O-ring sealed Al box
- Mylar entrance and exit windows

Target and Vacuum System

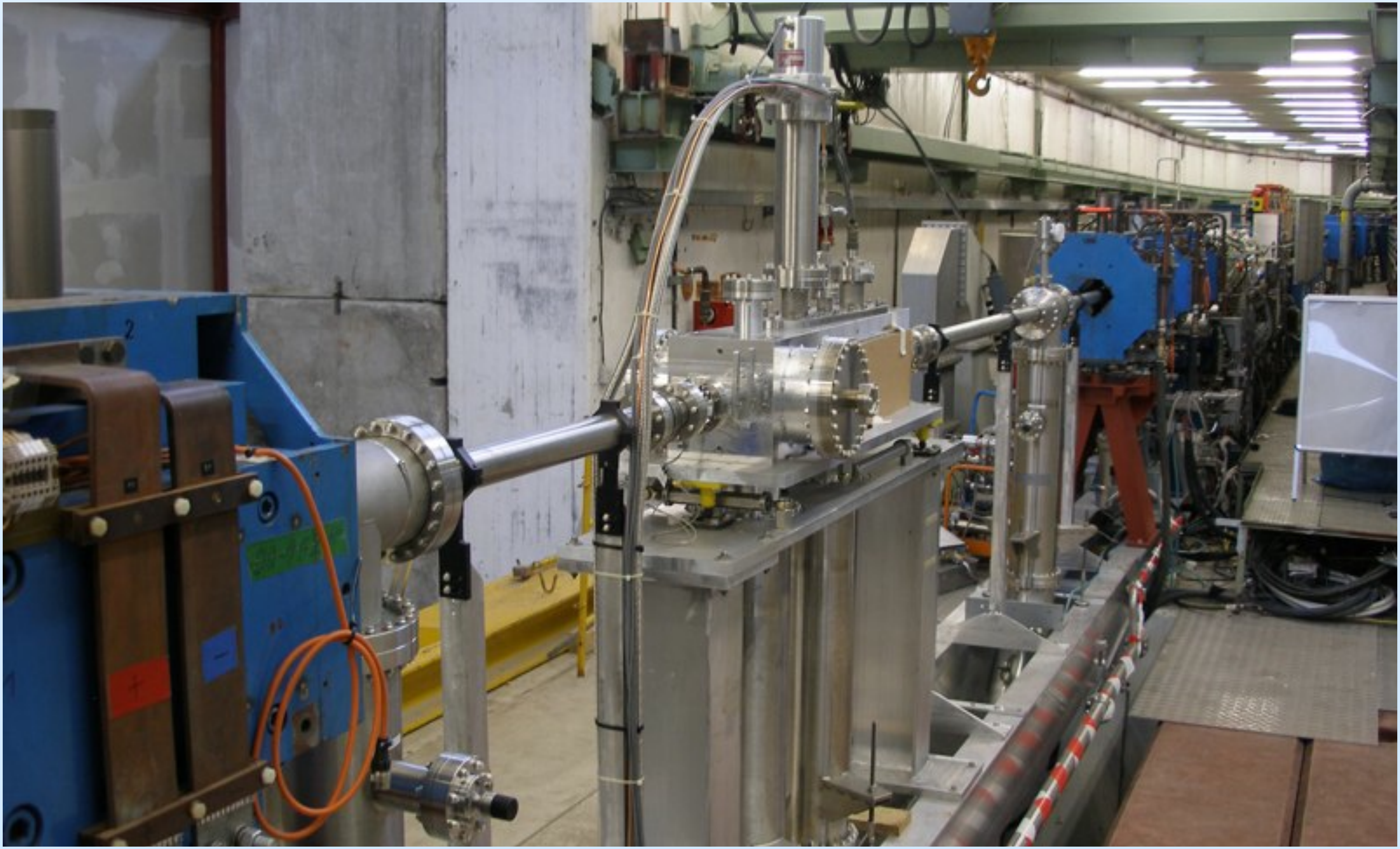
Richard Milner coordinating

- Replaced cell
- Improved design of wakefield suppressor to cell connection
- Added additional temperature sensors
- Bought spares for turbo pumps
- Implemented Interlock system





Target and Vacuum System



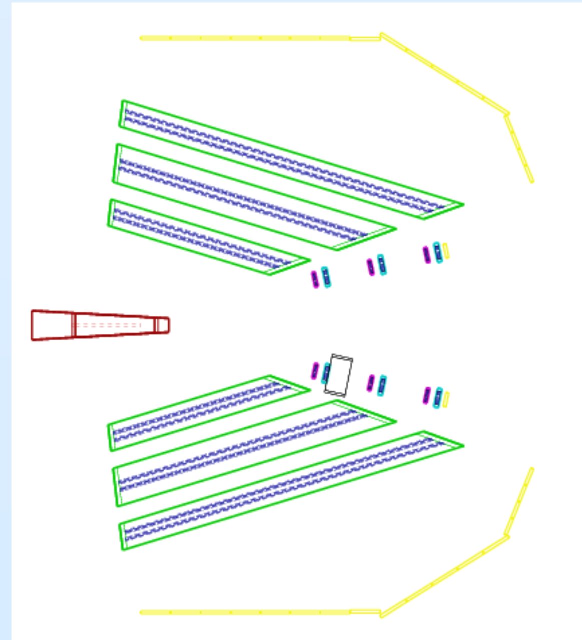
Installed in DORIS in January 2011

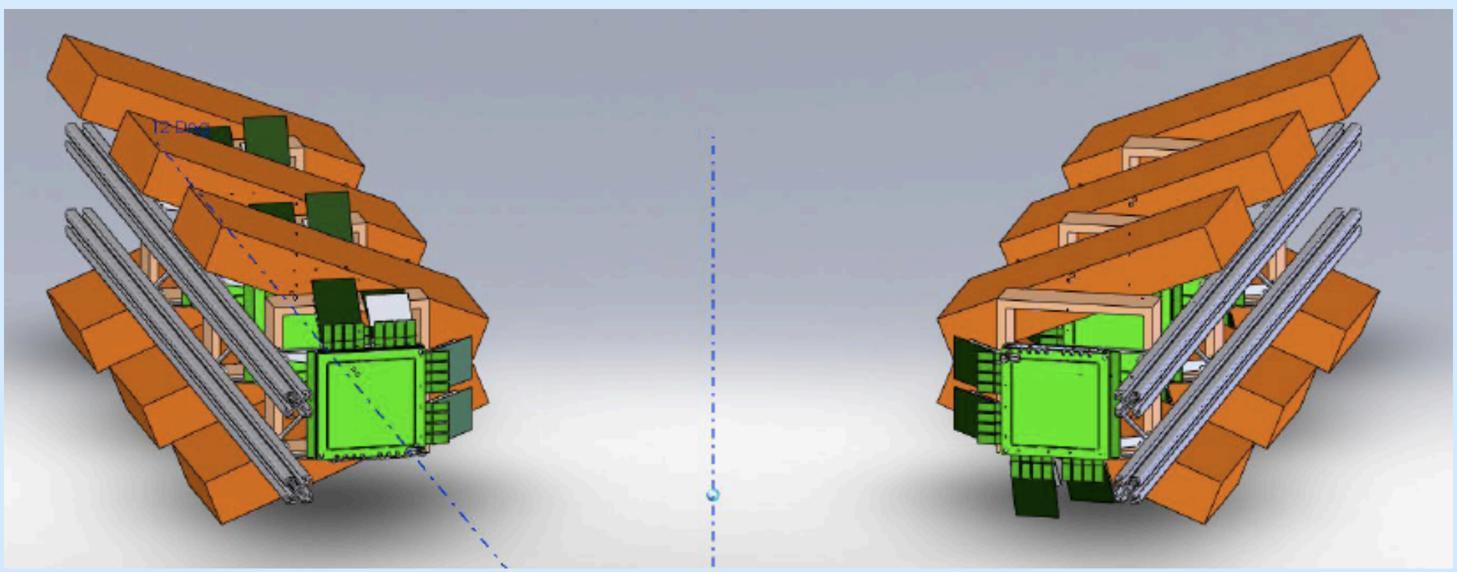
Target and Vacuum System

Re-installed in DORIS after roll-in in July 2011

Luminosity Monitors: GEM + MWPC

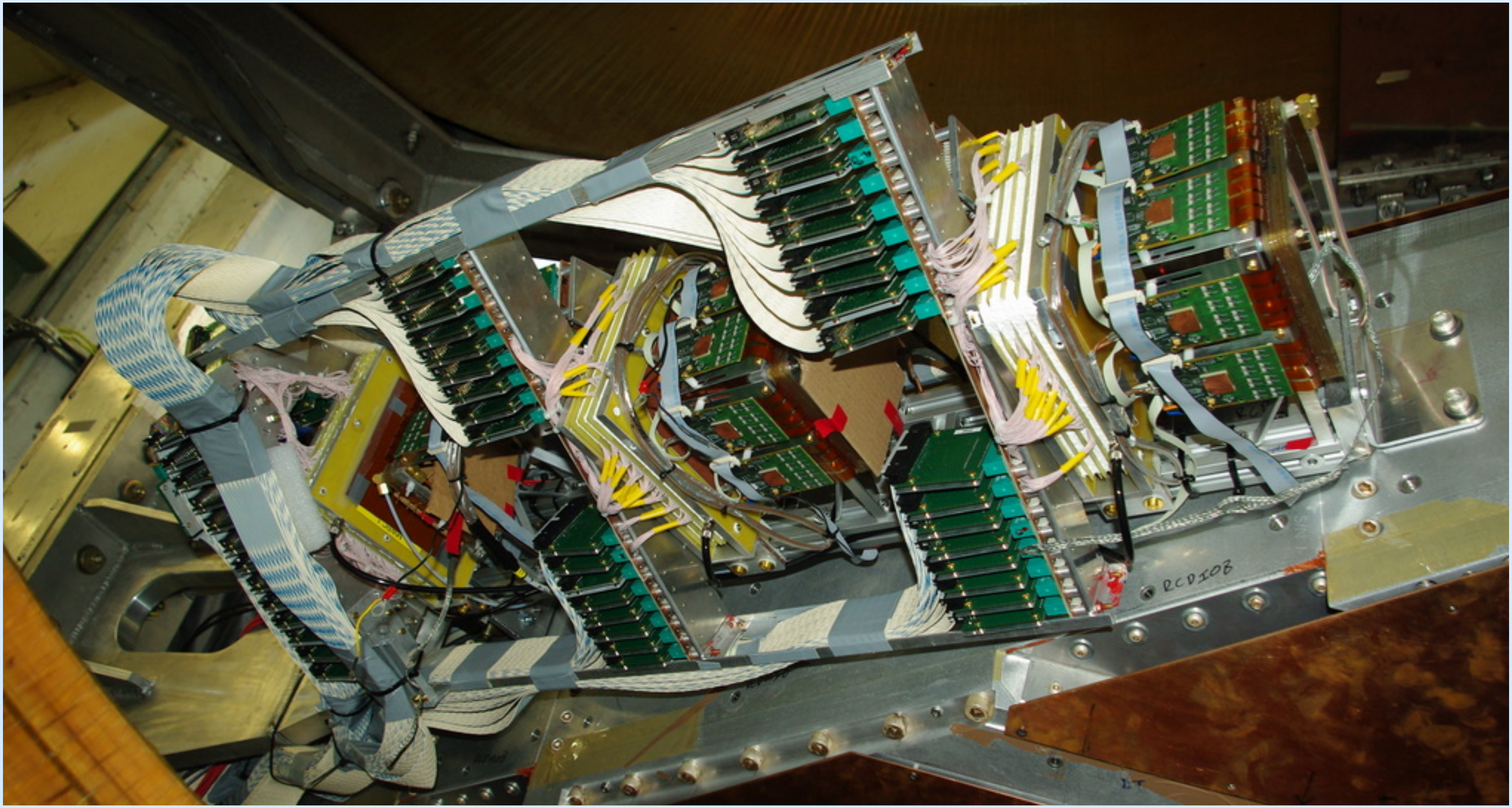
- Forward elastic scattering of lepton at 12°
  in coincidence with proton in main detector
- Two GEM + MWPC telescopes with
  interleaved elements operated independently
- Scintillator for triggering and timing
- Sub-percent (relative) luminosity measurement
  per hour at 2.0 GeV, per day at 4.5 GeV
- High redundancy – alignment, efficiency
  Two independent groups (Hampton, PNPI)





Designed to fit into forward cone

Luminosity Monitors: GEM + MWPC



Telescopes of three GEMs and MWPCs interleaved
Mounted on wire chamber forward end plate
Extensively tested at DESY test beam facility

Luminosity Monitors: GEM + MWPC

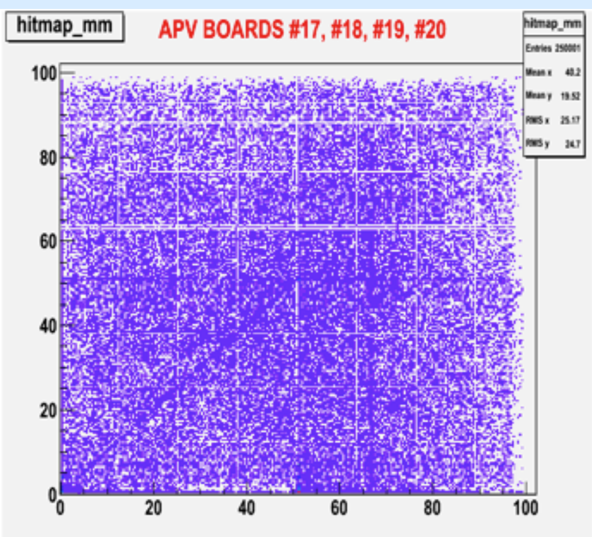
Installed telescope fits (left arm Jul. 5, 2011)

GEM Luminosity Monitor

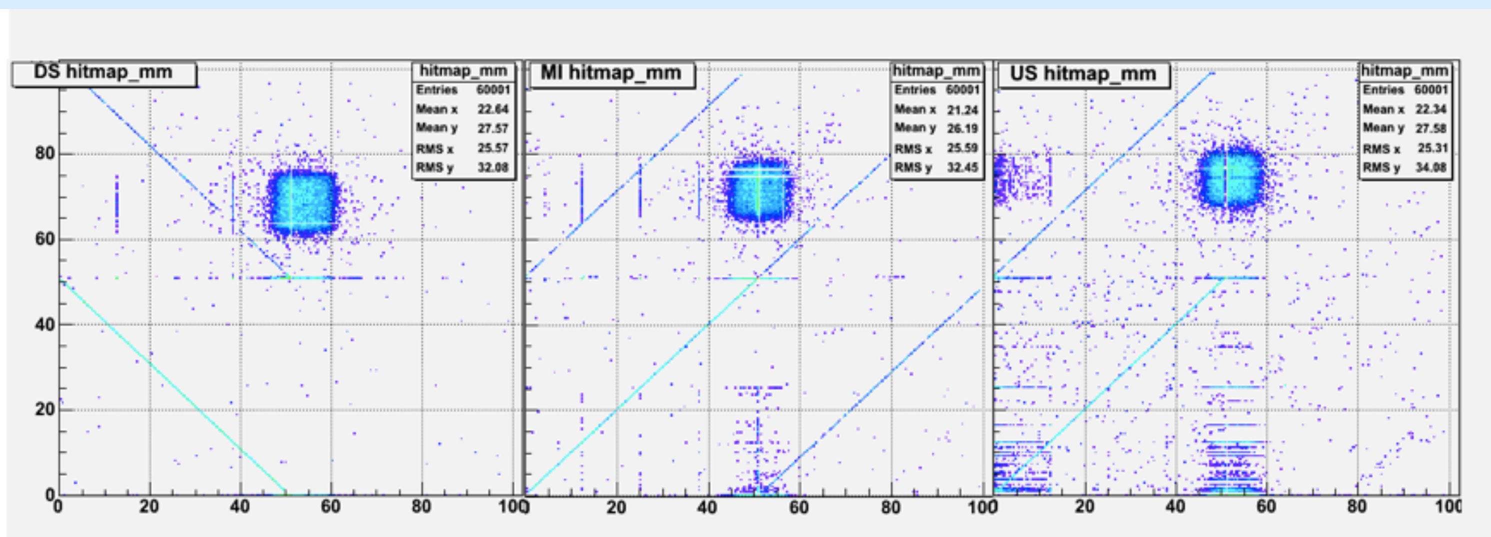
Jürgen Diefenbach coordinating

Progress at Testbeam-22:

- 9 GEM modules tested (leak tight, signals from beam)
- Readout code for INFN electronics adapted
- All 24 APV readout chips tested and good
- Tests with single GEM – reading out 4 APVs in parallel
- Adjustment of digital/analog phases (signal cabling)
- Full telescope readout – 3 GEMs / 12 APVs in final configuration



2D Hitmap



Beam spot on three GEM elements of telescope

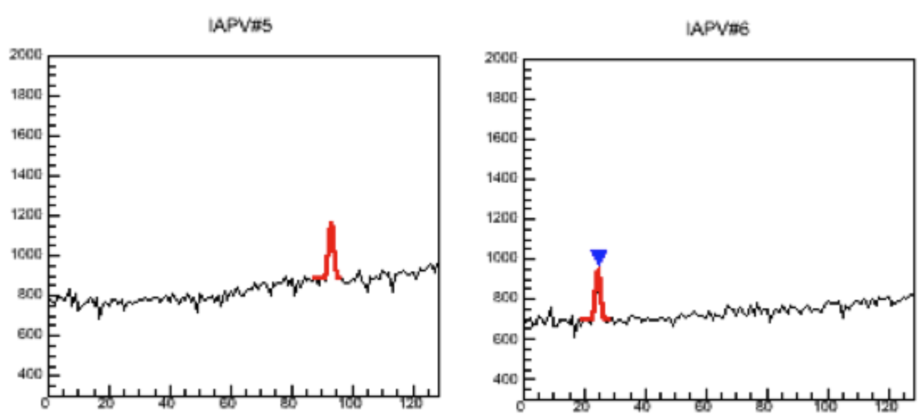
GEM Luminosity Monitor

Installation in OLYMPUS

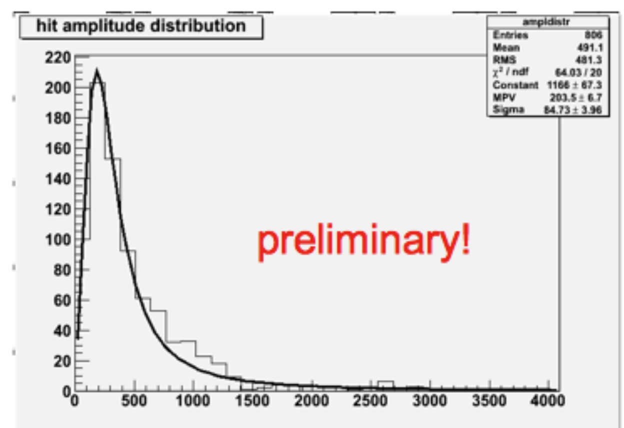
- Both telescopes installed, 6 GEMs and 24 APV FE boards
- 2 channels with readout problems (1 chip, 1 cable): both fixed!
- took runs in August and September with 2 GeV beam
- since September readout implemented in OLYMPUS DAQ system

Remaining tasks

- Sparsification in progress to minimize deadtime
- Extract fast signal from GEMs for self triggering



Example GEM hits, 2GeV e^+, toroid on

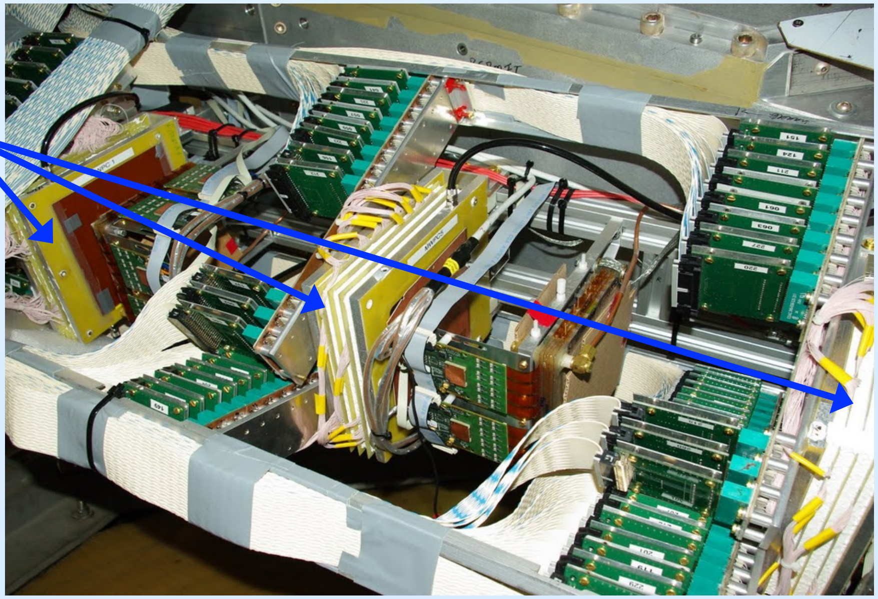


Landau distribution of cluster amplitudes

MWPC Luminosity Monitor

Alexander Kiselev coordinating

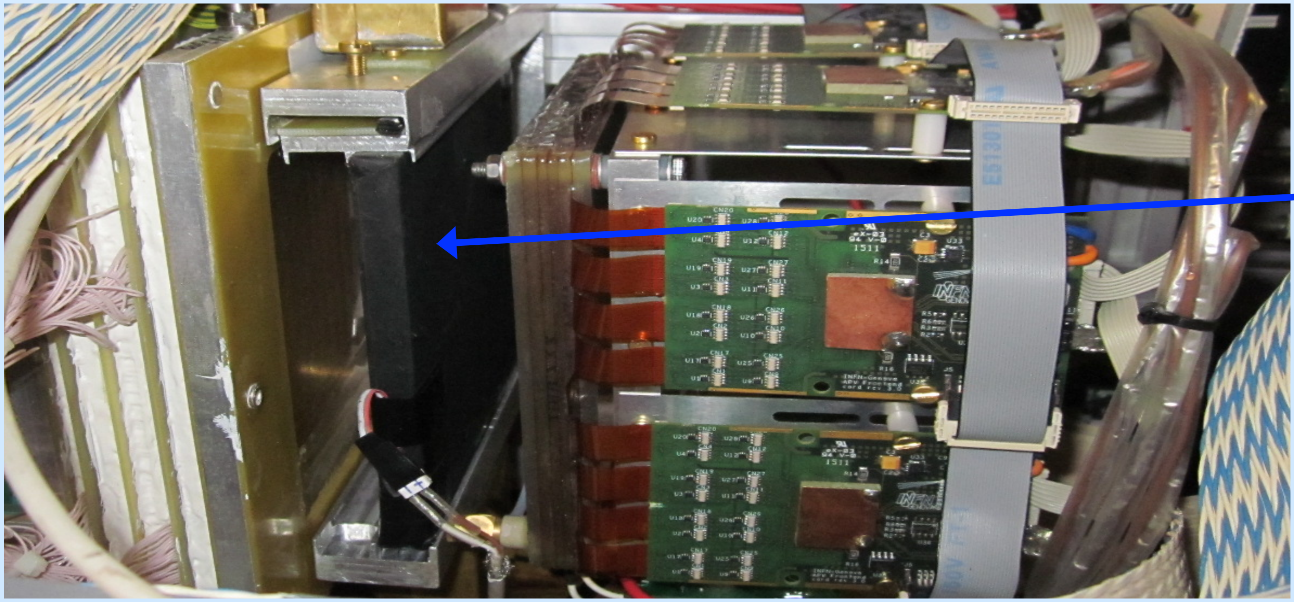
MWPC



Installation in July 2011

- Installation in OLYMPUS went smoothly
- No conflicts with other subdetectors
- Cabling work done
- Installation in Electronics Hut complete

Install SiPM based trigger scintillators

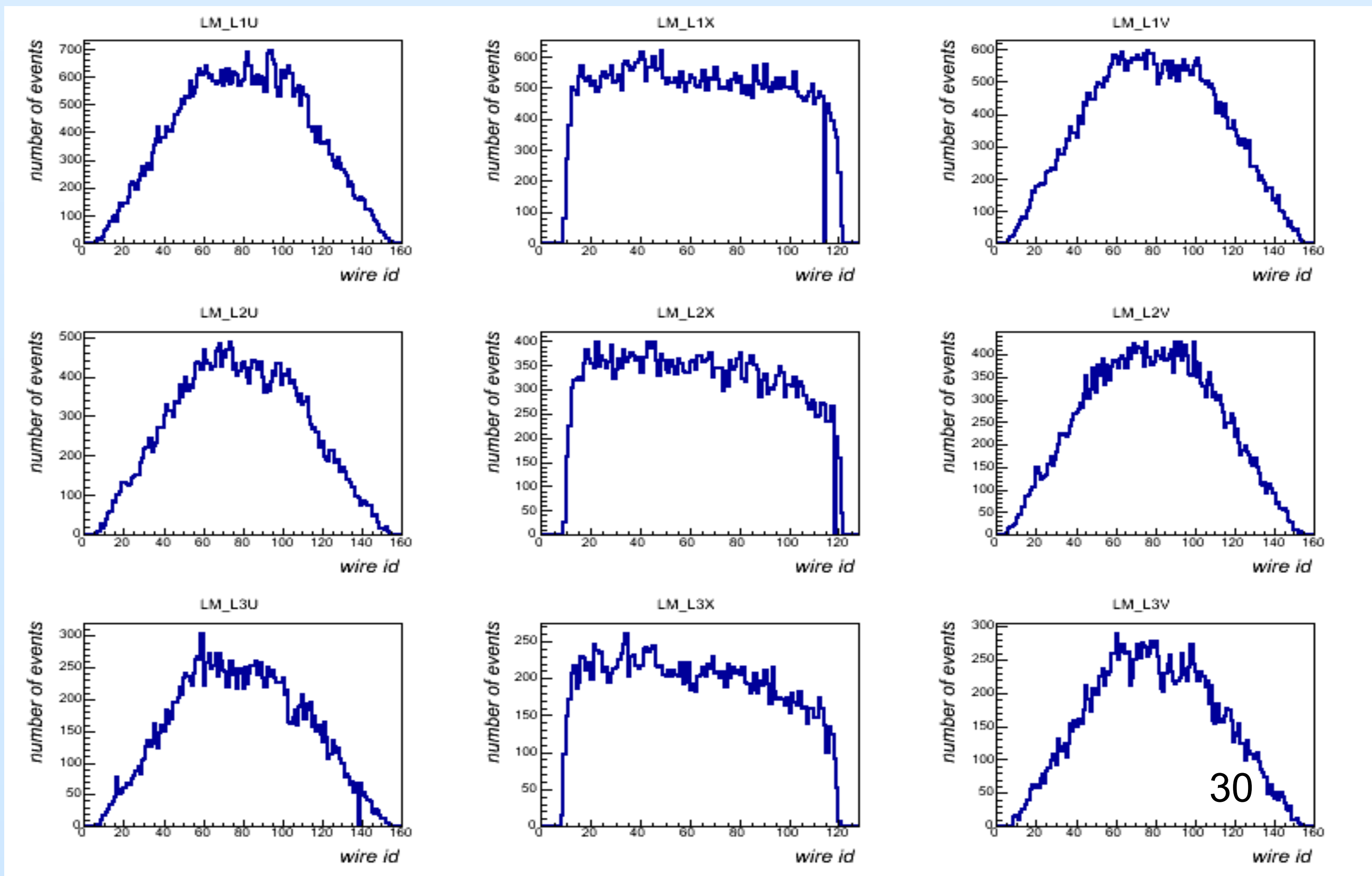


SiPM based trigger scintillator
Final version to be installed
in January

MWPC Luminosity Monitor

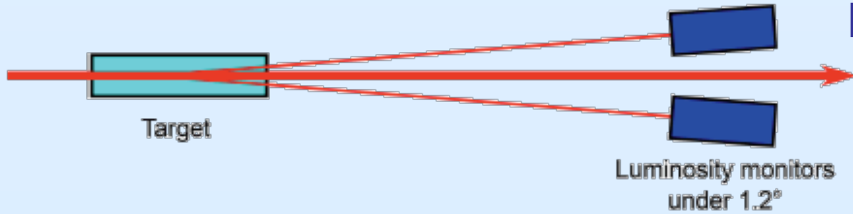
Aug/Sep test runs:

- Small leakage currents (typically below 100nA per plane)
- Readout (~2700 channels CROS3) works stable, low hit occupancy
- No trips, even during injection
- No extra cooling necessary, temperature is monitored

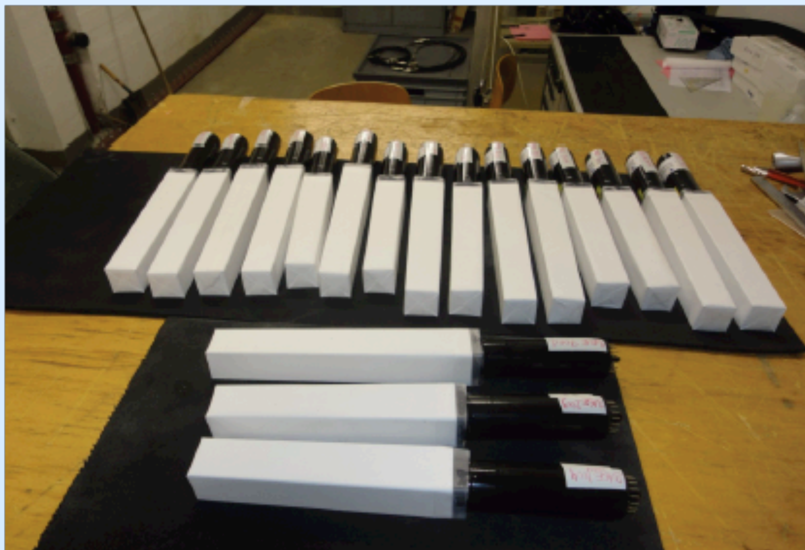


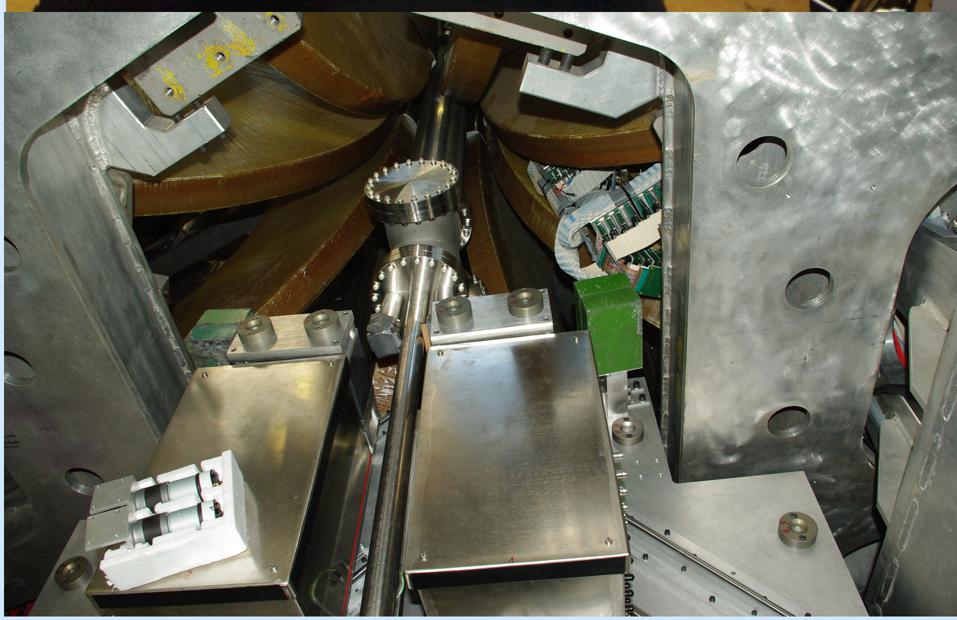
Test run wire maps (right arm)

Symmetric Møller/Bhabha Monitor



Roberto Perez Benito coordinating

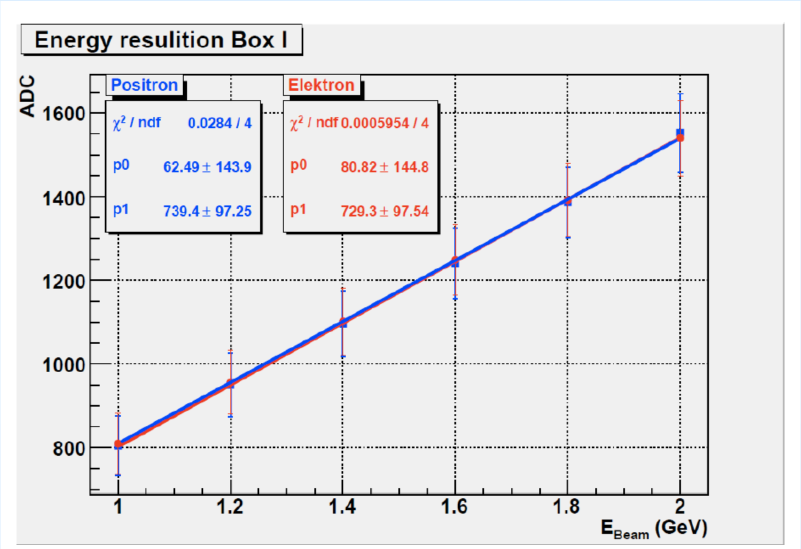


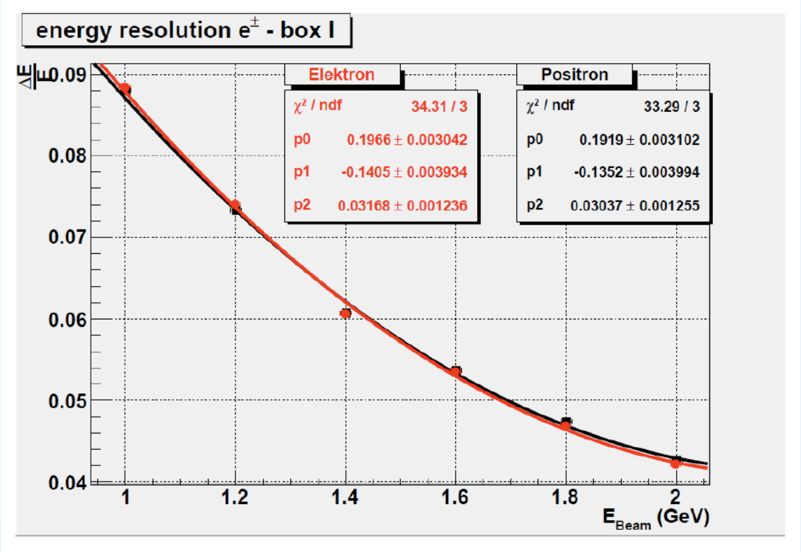


- Symm. angle 1.3° @ 2 GeV
- Matrix of 3x3 PbF_2 crystals
- Tested at DESY and MAMI
- Supports installed July 2011
- Install crystals in Oct. 2011

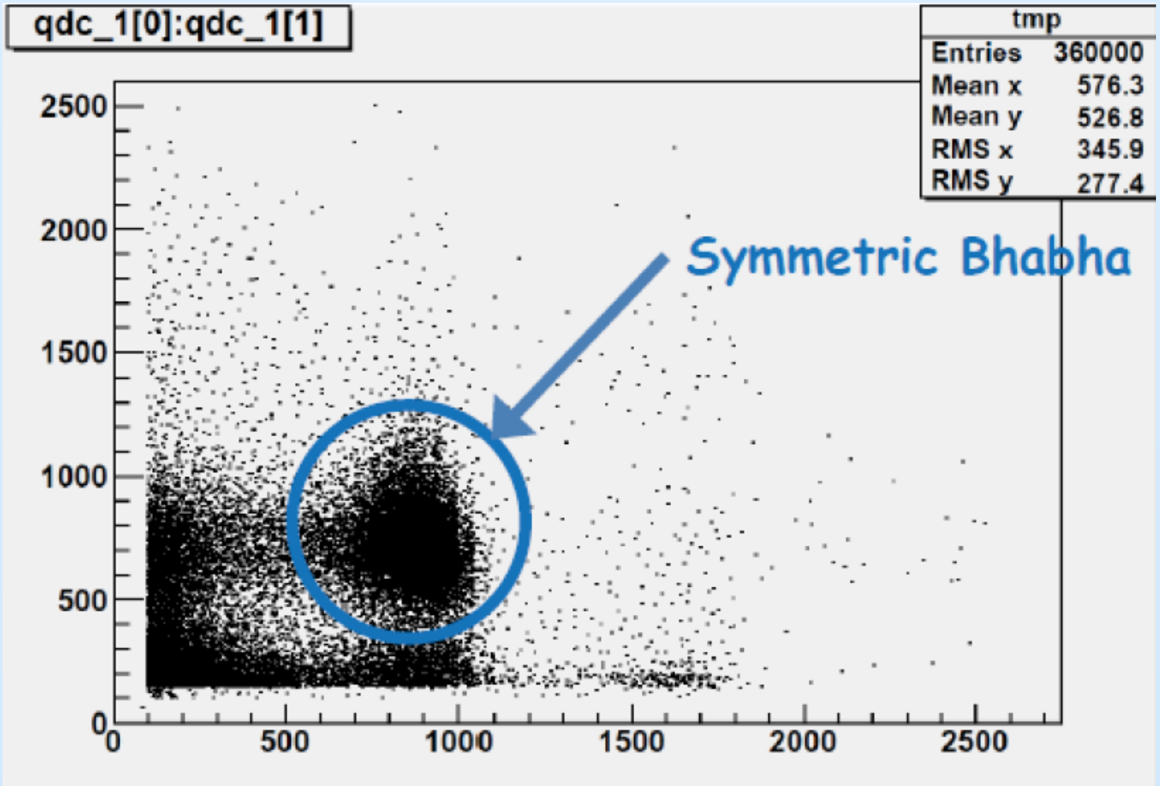
Symmetric Møller/Bhabha Monitor

- **Testbeam-22 results: Energy calibration and resolution**

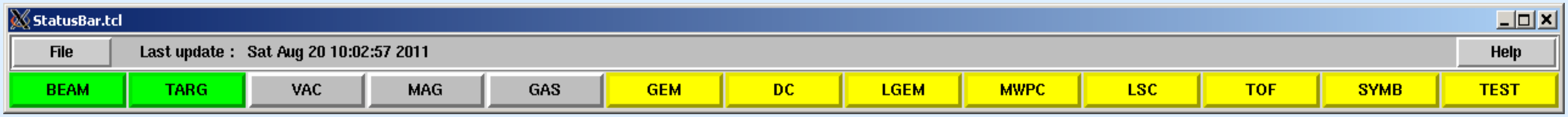




- **DORIS beamtest Aug 5-8, 2011**
- **First symmetric Bhabha events seen**



Slow Control



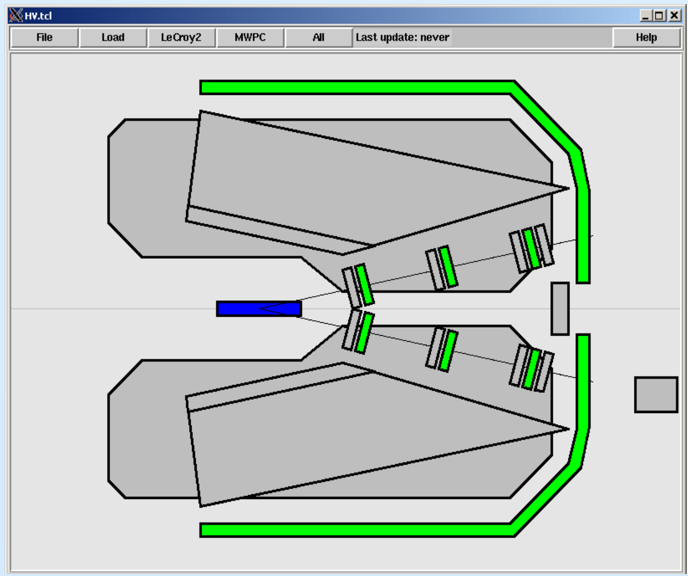
Anton Izotov coordinating

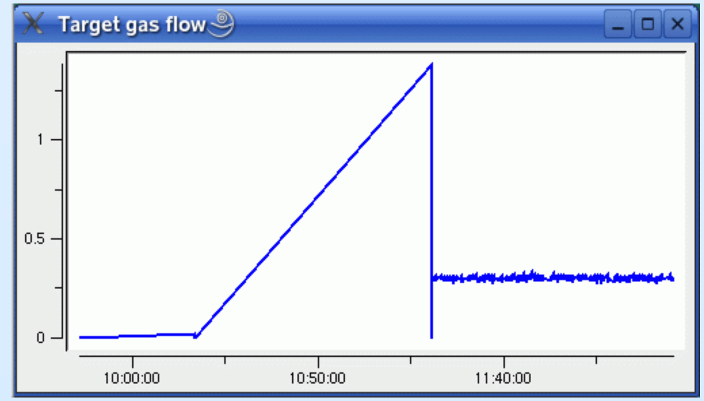
Jobctrl@oslow

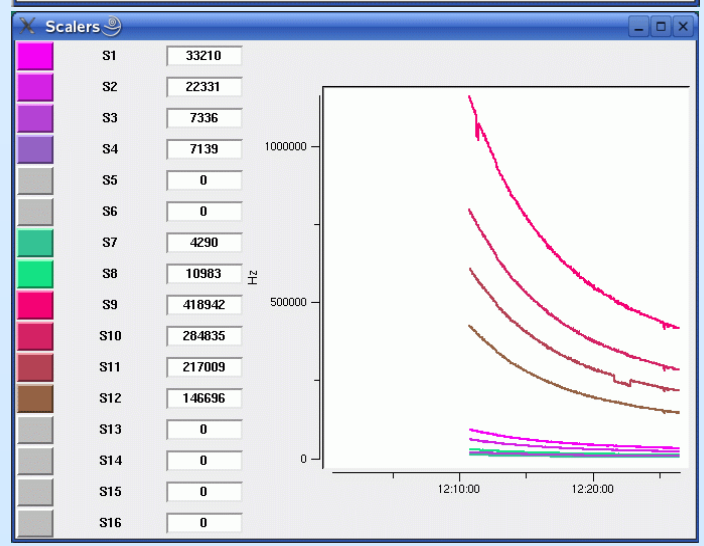
- sb – StatusBar client
- SB – StatusBar picture
- HV – hv display
- beam – TINE beam client
- bunch – TINE bunch client
- bpm – TINE BPM client
- BEAM – beam info display
- targ – target watchdog
- TFLOW – target gas display
- SCAL – scalars display
- sps – Siemens SPS client
- MAG – magnet info display
- PCT – MWPS temperatures displ
- VAC – vacuum timeraph

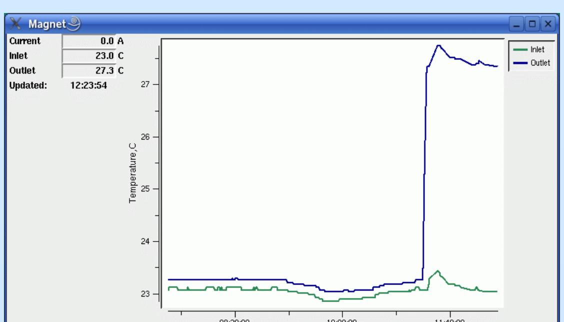
Jobctrl@osc

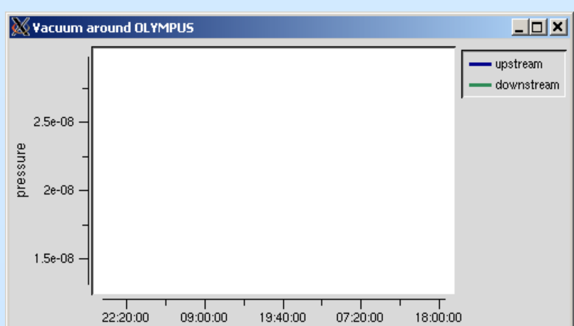
- caen – MWPC HV client

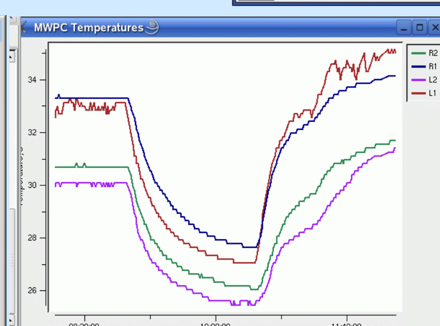


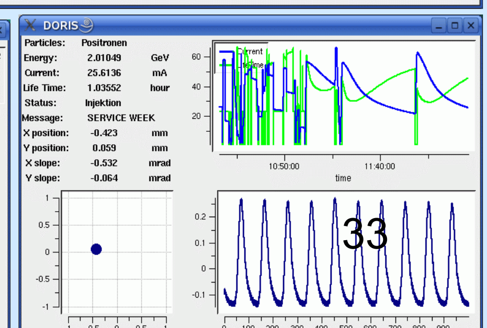








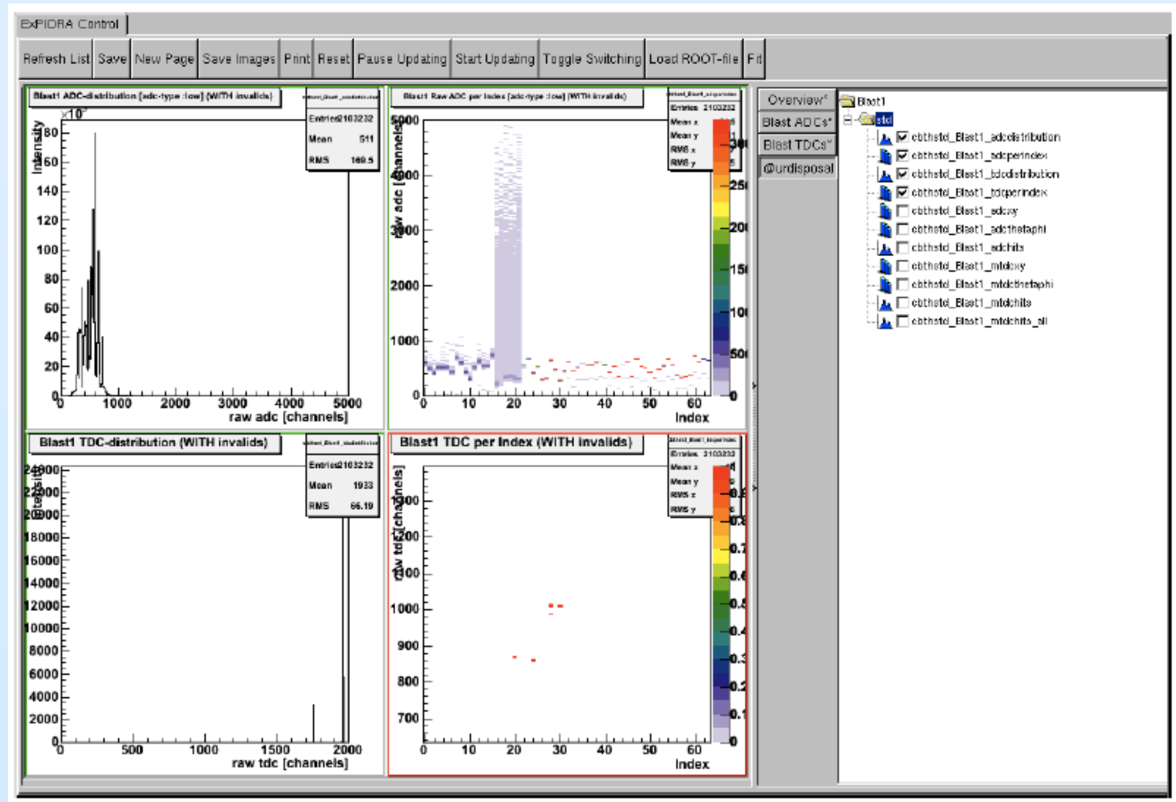




Trigger and DAQ

Trigger: Alexander Winnebeck coordinating

- FPGA based programmable trigger
- Main trigger
  - 16 parallel trigger conditions
  - Running scaler for each input
  - Trigger latched pattern
- Sub-detector trigger
  - 36 top-bottom coincidences
  - 18 left-right combinations



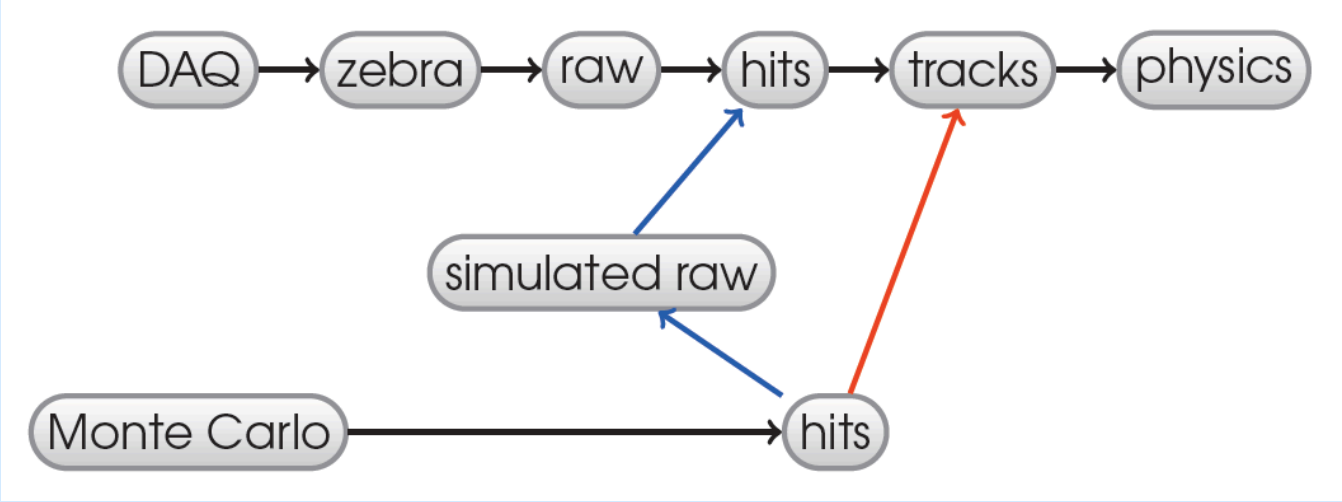
DAQ: Christian Funke coordinating

- Readout of all subdetectors has been implemented
- Run control; run database; ONLINE monitoring of raw data, recon data via plugins
- Slowcontrol data integrated into the data stream
- Raw data in ZEBRA format, converted to ROOT for offline analysis
- Synchronous design – 25MB/s sustained data rate
- Readout rate ~2200Hz with all detectors enabled and 100% deadtime (fastbus limit)

Offline Analysis

Jan Bernauer coordinating

- Offline analysis framework implemented – modular design based on Root, Geant4
- Version control system (git) – independent development
- Cooker (analysis control) – xml parsing
- Plug-ins (recipes) to handle tree data
- Single framework for geometry, calibration, hits, reconstruction, simulation
- Identical reconstruction code for measured and simulated hits



- In process of integrating into grid-computing infrastructure, using facilities at DESY, MIT and Hampton

Geant4 Based Event Reconstruction

ROOT data file

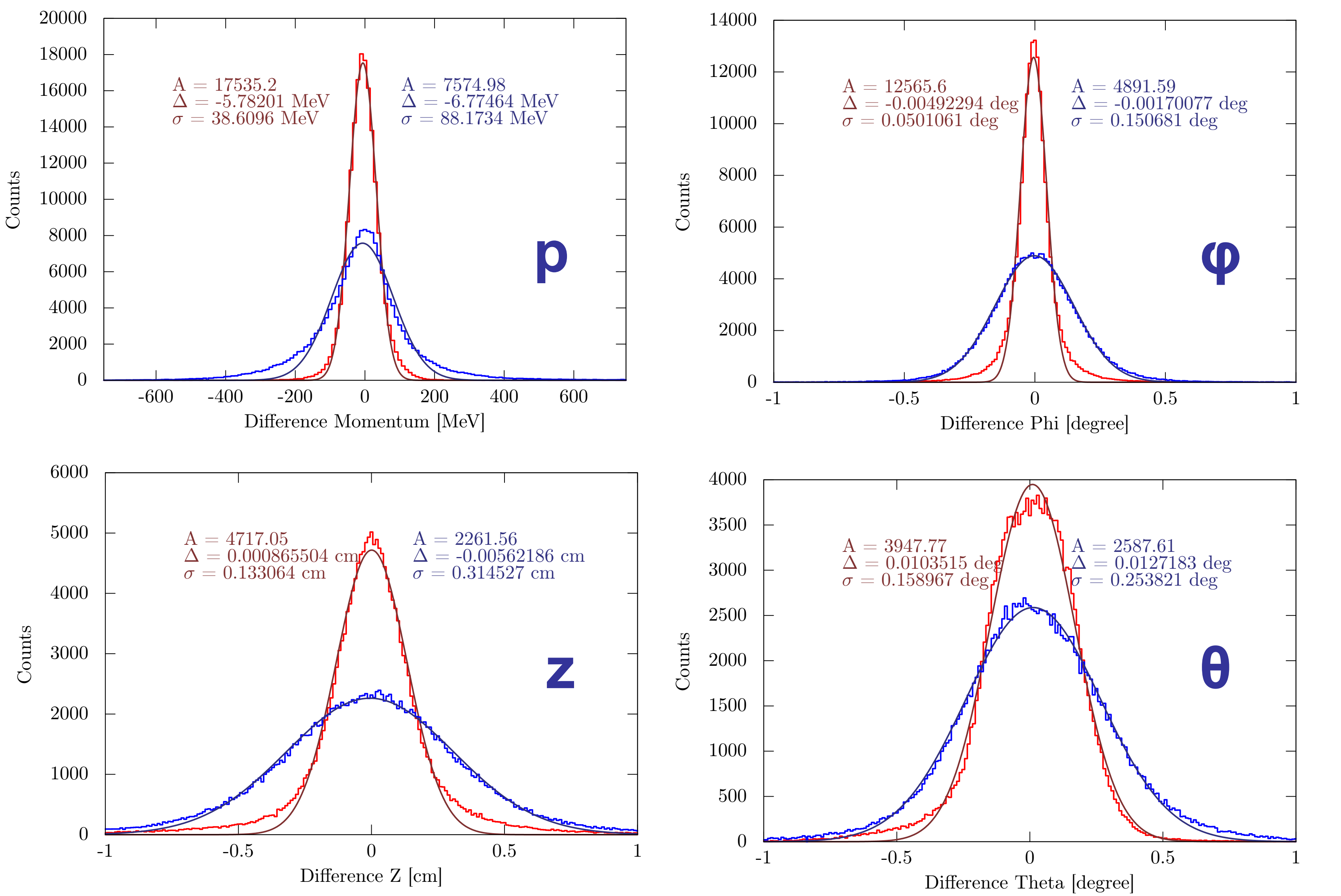
- each detector group provides a plugin to convert raw data into hit info in the local coordinate system of their detector
  - e.g. (X, Y) locations of hits in the GEM tracker

Reconstruction code

- selects combinations of hits as track candidates and makes initial estimate for track candidate parameters (p, θ, φ, z)
- generates charged geantino in GEANT4 with these parameters
  - charged geantino curves in magnetic field and scores hit location in active detectors but no physics processes like energy loss, multiple scattering, etc.
  - tracking geantinos in GEANT4 is very fast because no physics processes
- compare geantino hit locations with hits from data, fit to minimize chi2
  - in local detector coordinate system
  - no need to convert to global coordinate system
- Kalman filter for optimized reconstruction in presence of noise

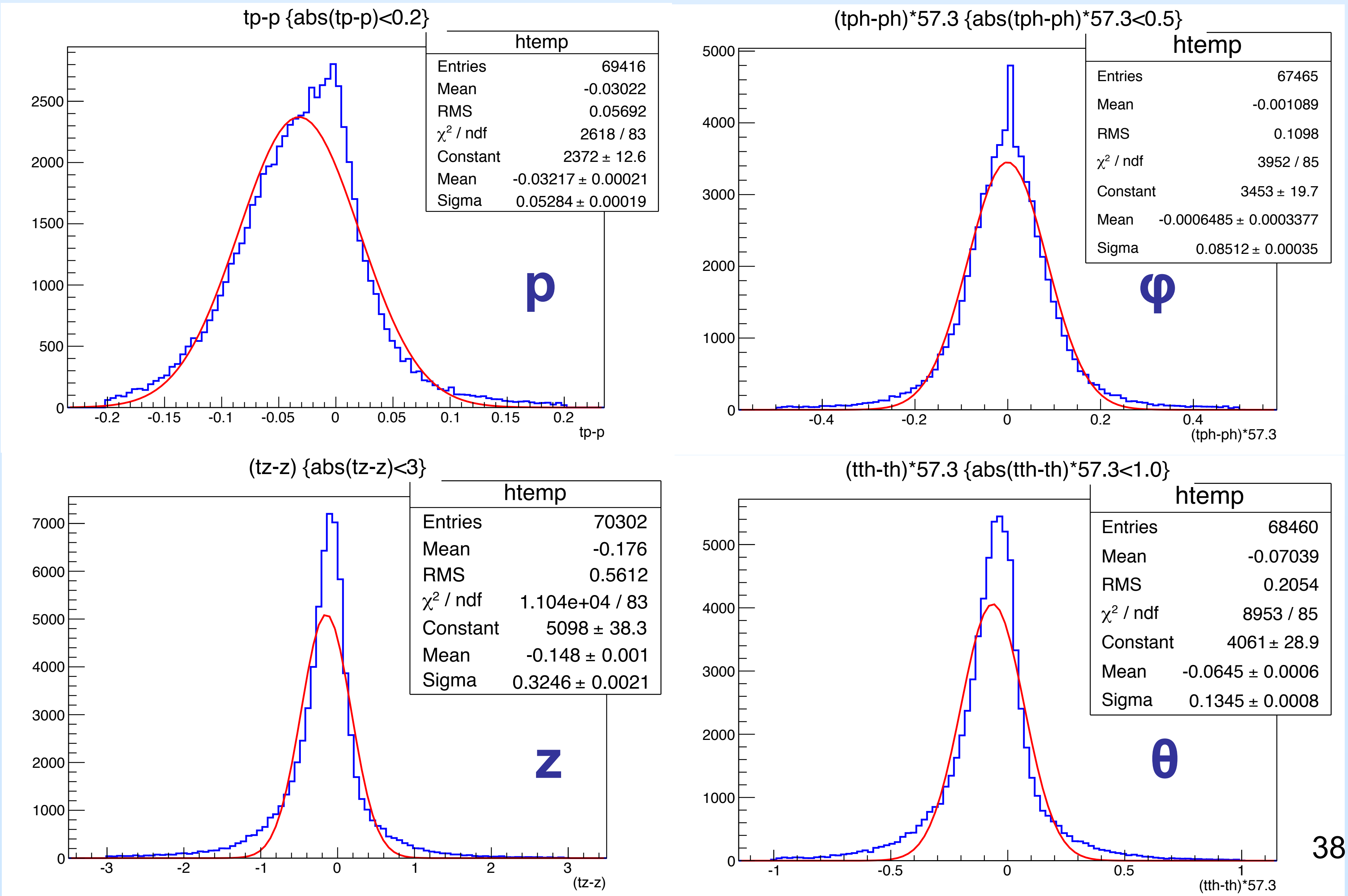
Some first reconstruction results

- **Polynomial based reconstruction to obtain good start values – very fast**
  RED: Reconstructed versus generated Geant4 without detector smearing
  BLUE: with additional detector hit uncertainties



Some first reconstruction results

- **Geantino based reconstruction (full acceptance, isotropic) – fast**
  Reconstructed versus generated Geant4 with geantino fitting



Tasks

- **OLYMPUS commissioning**
  - TOF tuning
  - Wire chamber debugging
  - Trigger and DAQ optimization
  - SYMB commissioning
  - 12 degree monitor:
    SiPM scintillators, GEM self trigger
- **GEM tracker construction**
- **Analysis and simulation**
- **Toward the first run**
  - Test with 2 GeV beam and full target Oct. 25-26 (today!), Oct. 28-29
  - Testing with 4.5 GeV and empty target until end of 2011
  - DORIS shutdown in January 2012, final installations and repairs

Data runs 4 weeks (Jan 30 – Feb 24, 2012), 8 weeks late 2012

Backup slides – OLYMPUS

Institutional Responsibilities

- **Arizona State University:** TOF support, particle identification, magnetic shielding
- **DESY:** Modification of DORIS, toroid support, infrastructure, main effort of installation
- **Hampton University:** GEM luminosity monitor, simulations
- **INFN Bari:** GEM electronics
- **INFN Ferrara:** Target
- **INFN Rome:** GEM electronics
- **MIT:** BLAST spectrometer, wire chambers, tracking upgrade, target and vacuum system, transportation to DESY, simulations
- **Petersburg Nuclear Physics Institute:** Slow controls, MWPC luminosity monitor
- **University of Bonn:** Trigger and data acquisition
- **University of Glasgow**: Particle Identification, TOF scintillators and support structure
- **University of Mainz:** Symmetric Moller/Bhabha monitor
- **University of New Hampshire:** TOF scintillators
- **Yerevan Physics Institute:** Removal of ARGUS, TOF system

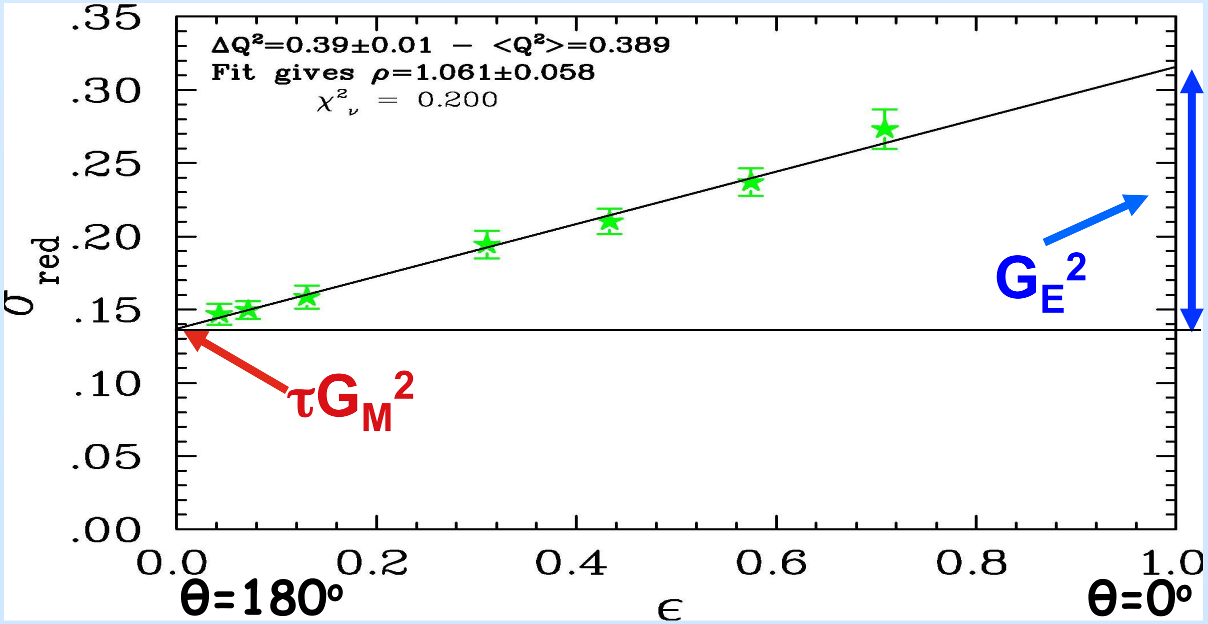
Form Factors from Rosenbluth Method

- In One-photon exchange approximation, elastic form factors are observables of elastic electron-nucleon scattering

$$\frac{d\sigma/d\Omega}{(d\sigma/d\Omega)_{Mott}} = S_0 = A(Q^2) + B(Q^2)\tan^2\frac{\theta}{2}$$

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

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



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

➔Determine

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

Nucleon Form Factors and Polarization

- **Double polarization in elastic ep scattering:**
  Recoil polarization or (vector) polarized target

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

- **Polarized cross section / transferred polarization**

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

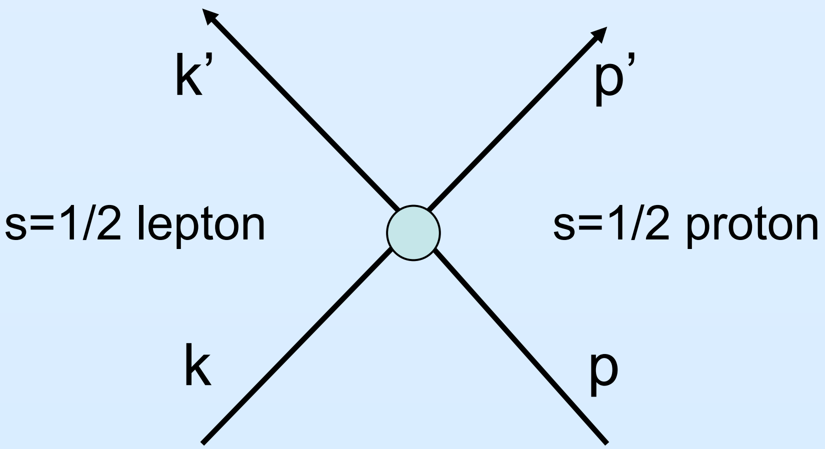
- **Double spin asymmetry = spin correlation**

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

- **Asymmetry ratio ("Super ratio")** $\frac{P_\perp}{P_\parallel} = \frac{A_\perp}{A_\parallel} \propto \frac{G_E}{G_M}$

  independent of polarization or analyzing power

Elastic ep Scattering Beyond OPE



$$P \equiv \frac{p+p'}{2}, \qquad K \equiv \frac{k+k'}{2}$$

Kinematical invariants :

$$\begin{aligned} Q^2 &= -(p-p')^2 \\ \nu &= K \cdot P = (s-u)/4 \end{aligned}$$

Next-to Born approximation:

$$\begin{aligned} T^{non-flip}_{h'\lambda'_N, h\lambda_N} &= \frac{e^2}{Q^2} \bar{u}(k', h') \gamma_\mu u(k,h) \\ &\times \quad \bar{u}(p', \lambda'_N) \left(\tilde{G}_M \gamma^\mu - \tilde{F}_2 \frac{P^\mu}{M} + \tilde{F}_3 \frac{\gamma.K P^\mu}{M^2} \right) u(p, \lambda_N) \end{aligned}$$

($m_e = 0$)

The T-matrix still factorizes, however a new response term F_3 is generated by TPE
Born-amplitudes are modified in presence of TPE; modifications ~α^3

$$\begin{aligned} \tilde{G}_M(\nu, Q^2) &= G_M(Q^2) + \delta\tilde{G}_M \\ \tilde{F}_2(\nu, Q^2) &= F_2(Q^2) + \delta\tilde{F}_2 \\ \tilde{F}_3(\nu, Q^2) &= 0 + \delta\tilde{F}_3 \end{aligned}$$

$$\tilde{G}_E \equiv \tilde{G}_M - (1+\tau)\, \tilde{F}_2$$

$$\tilde{G}_E(\nu, Q^2) = G_E(Q^2) + \delta\tilde{G}_E$$

New amplitudes are complex!

Observables involving real part of TPE

$$P_t = -\sqrt{\frac{2\varepsilon(1-\varepsilon)}{\tau}}\frac{G_M^2}{d\sigma_{red}}\left\{R + R\frac{\Re\left(\delta\tilde{G}_M\right)}{G_M} + \frac{\Re\left(\delta\tilde{G}_E\right)}{G_M} + Y_{2\gamma}\right\}$$

$$P_l = \sqrt{(1+\varepsilon)(1-\varepsilon)}\frac{G_M^2}{d\sigma_{red}}\left\{1 + 2\frac{\Re(\delta\tilde{G}_M)}{G_M} + \frac{2}{1+\varepsilon}\varepsilon Y_{2\gamma}\right\}$$

$$\frac{P_t}{P_l} = -\sqrt{\frac{2\varepsilon}{(1+\varepsilon)\tau}}\left\{R - R\frac{\Re\left(\delta\tilde{G}_M\right)}{G_M} + \frac{\Re\left(\delta\tilde{G}_E\right)}{G_M} + 2\left(1 - R\frac{2\varepsilon}{1+\varepsilon}\right)Y_{2\gamma}\right\}$$

E04-019 (Two-gamma)

$$d\sigma_{red} / G_M^2 = 1 + \frac{\varepsilon R^2}{\tau} + 2\frac{\Re(\delta\tilde{G}_M)}{G_M} + 2R\frac{\varepsilon\Re(\delta\tilde{G}_E)}{\tau G_M} + 2\left(1+\frac{R}{\tau}\right)\varepsilon Y_{2\gamma}$$

e^+/e^- x-section ratio CLAS,VEPP3,OLYMPUS

Rosenbluth non-linearity E05-017

$$\Re(\tilde{G}_E) = G_E(Q^2) + \Re(\delta\tilde{G}_E(Q^2,\varepsilon))$$

$$\Re(\tilde{G}_M) = G_M(Q^2) + \Re(\delta\tilde{G}_M(Q^2,\varepsilon))$$

$$R = G_E / G_M \qquad Y_{2\gamma} = 0 + \sqrt{\frac{\tau(1+\tau)(1+\varepsilon)}{1-\varepsilon}}\frac{\Re(\tilde{F}_3(Q^2,\varepsilon))}{G_M}$$

Born Approximation | **Beyond Born Approximation**

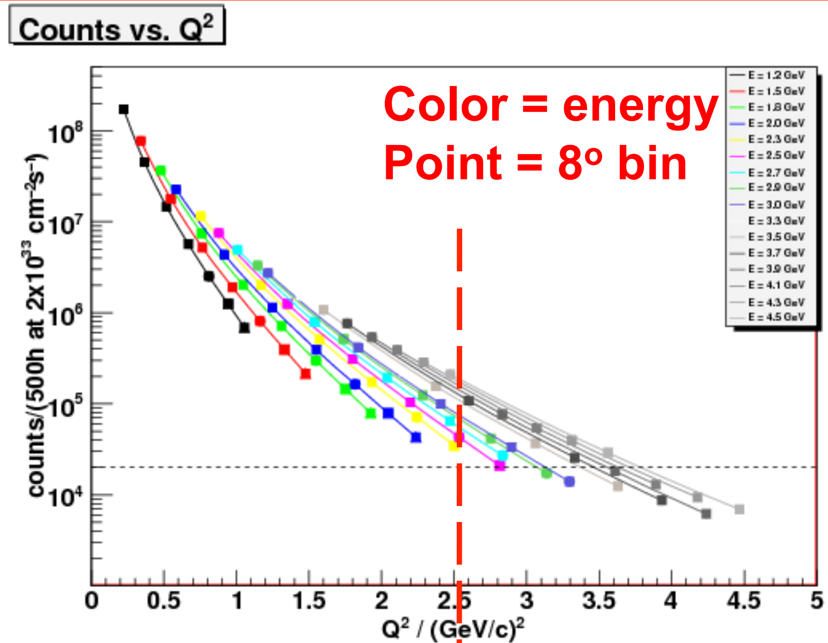
Slide idea: L. Pentchev

P.A.M. Guichon and M.Vanderhaeghen, Phys.Rev.Lett. 91, 142303 (2003)

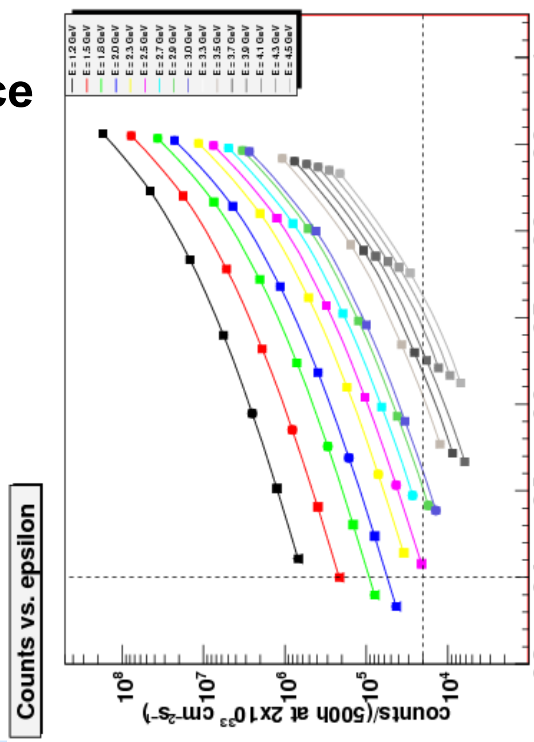
M.P. Rekalo and E. Tomasi-Gustafsson, E.P.J. A 22, 331 (2004)

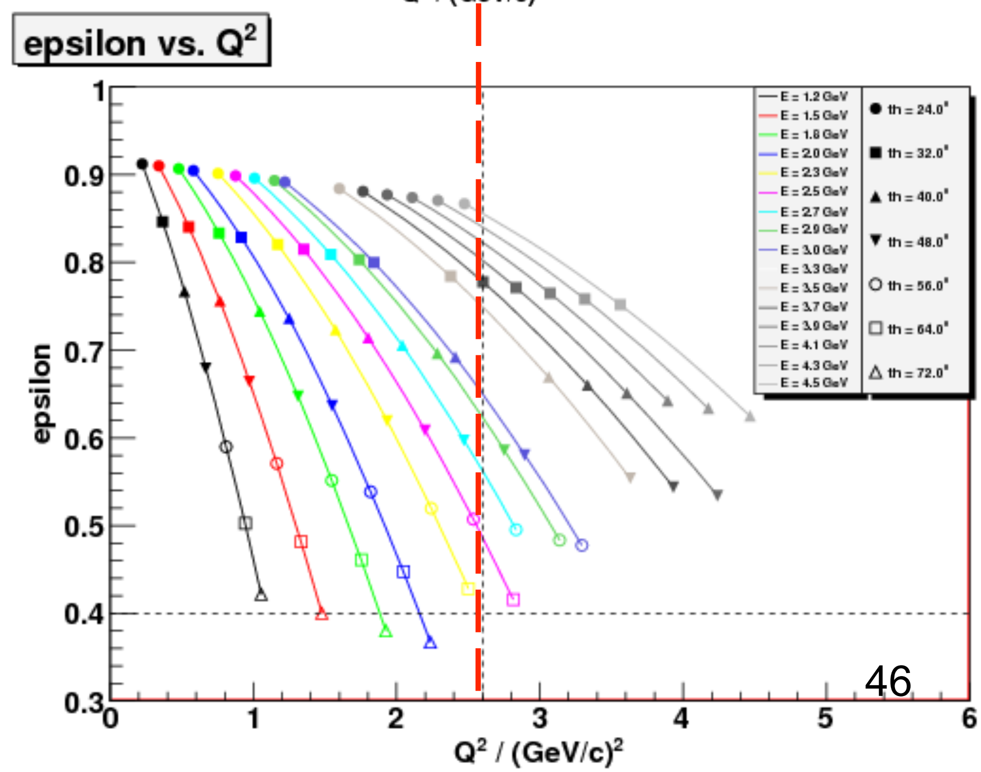
Kinematics vs. Statistics

E_0 [GeV]	θ_e	$p_{e'}$ [GeV/c]	θ_p	p_p [GeV/c]	Q^2 [(GeV/c)^2]	ϵ	Counts
2.0	24	1.69	56.4	0.83	0.6	0.905	22613100
	32	1.51	48.1	1.08	0.9	0.828	4321570
	40	1.33	41.3	1.30	1.2	0.736	1141960
	48	1.17	35.7	1.50	1.6	0.636	389822
	56	1.03	31.0	1.66	1.8	0.538	162355
	64	0.91	27.1	1.80	2.0	0.447	78744
	72	0.81	23.8	1.91	2.2	0.367	42954

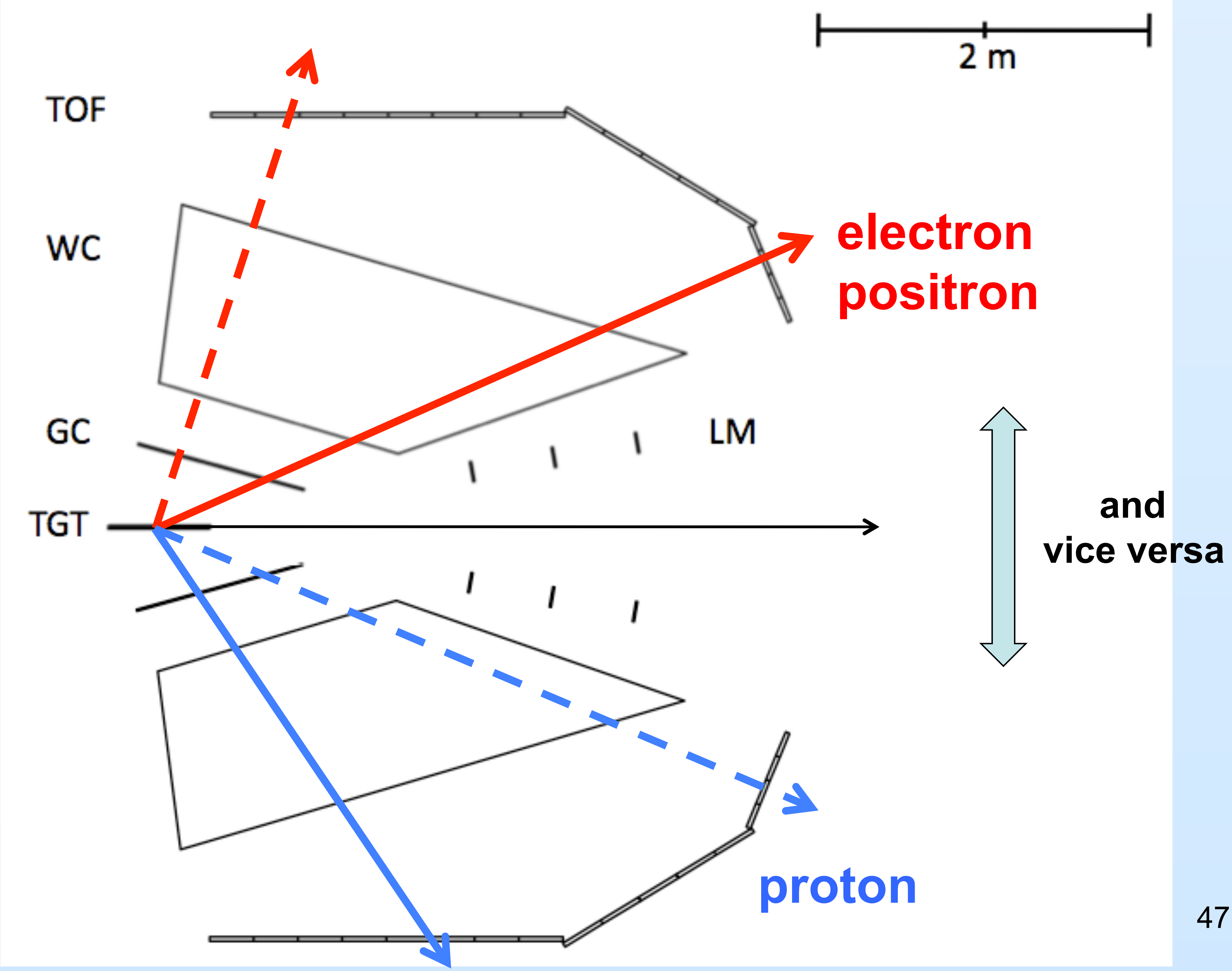


- E small enough for sufficient statistics within 500 hours e+,e- @ 2x10^{33} / cm^{2}s
- E large enough to maximize Q^2 / minimize ε
- E = 2 GeV best choice
- Impact on DORIS running cost

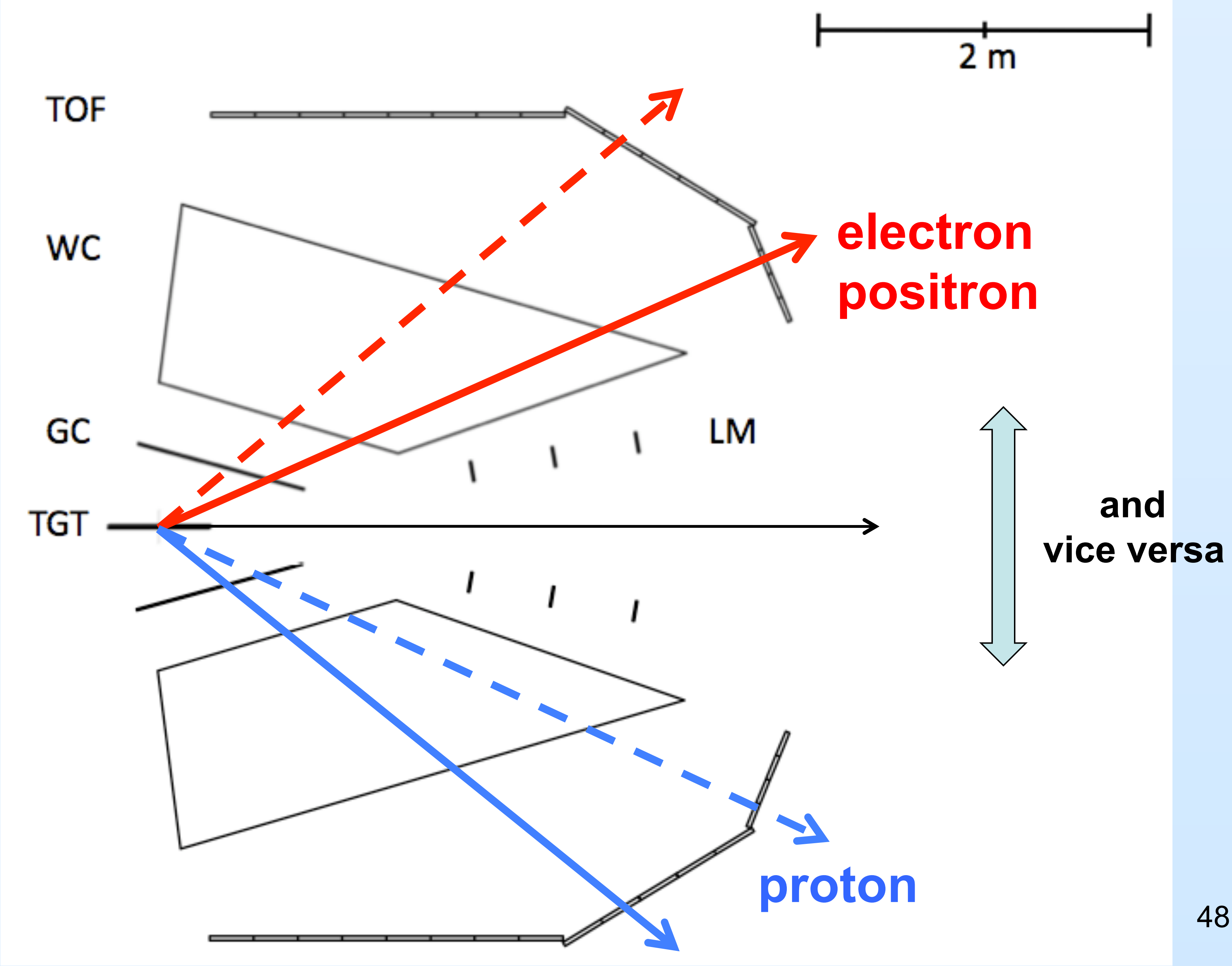




OLYMPUS Kinematics at 2 GeV



OLYMPUS Kinematics at 4.5 GeV



Expected OLYMPUS Statistics

E_0 [GeV]	θ_e	$p_{e'}$ [GeV/c]	θ_p	p_p [GeV/c]	Q^2 [(GeV/c)^2]	ϵ	Counts
2.0	24	1.69	56.4	0.83	0.6	0.905	22613100
	32	1.51	48.1	1.08	0.9	0.828	4321570
	40	1.33	41.3	1.30	1.2	0.736	1141960
	48	1.17	35.7	1.50	1.6	0.636	389822
	56	1.03	31.0	1.66	1.8	0.538	162355
	64	0.91	27.1	1.80	2.0	0.447	78744
	72	0.81	23.8	1.91	2.2	0.367	42954
4.5	24	3.18	39.1	2.05	2.5	0.867	210161
	32	2.60	31.0	2.68	3.6	0.751	28812
	40	2.12	25.4	3.18	4.5	0.625	6907
	48	1.74	21.2	3.58	5.2	0.505	2385
	56	1.44	18.0	3.88	5.7	0.402	1049
	64	1.22	15.5	4.12	6.2	0.318	544
	72	1.04	13.5	4.30	6.5	0.250	317

e+,e- each
500h @ 2x10^{33} / cm^{2}s
8^o bins

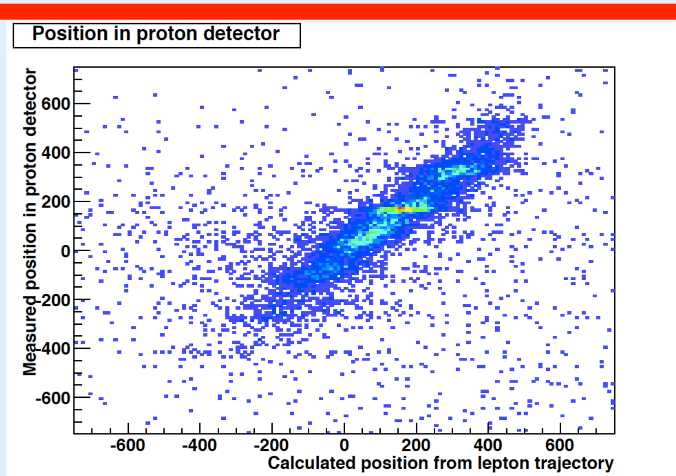
40k events total = 0.7% stat. precision for e+/e- ratio

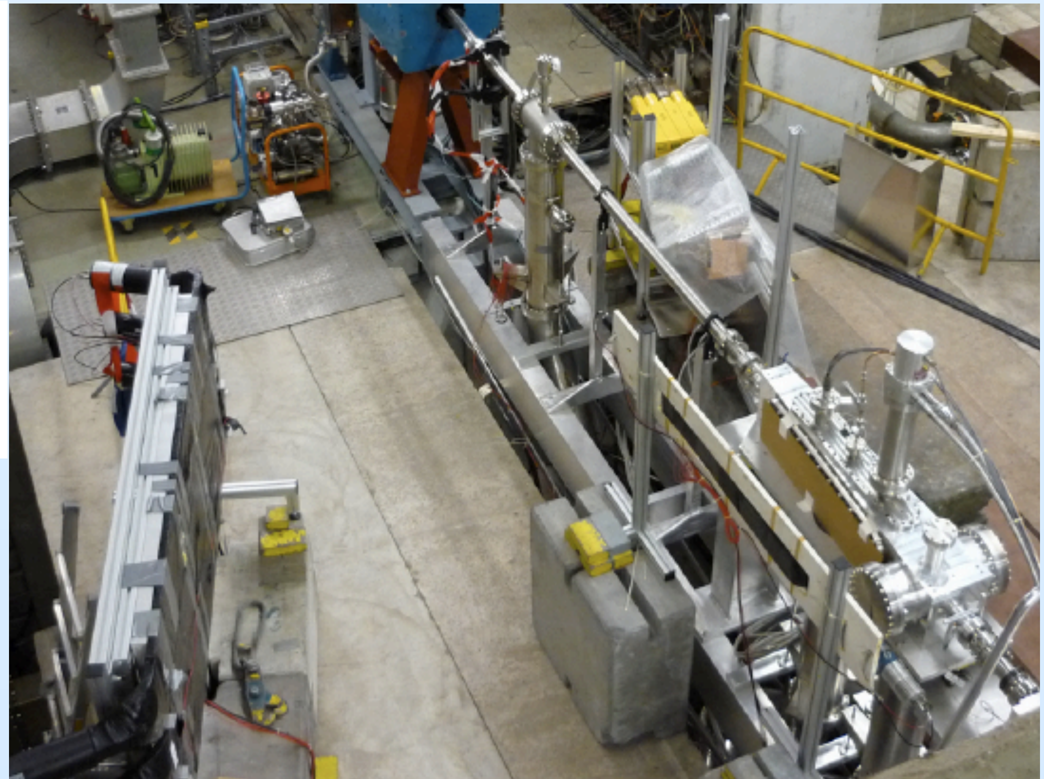
Count rate at similar Q^2 factor 5 higher at 4.5 GeV ~100 hours

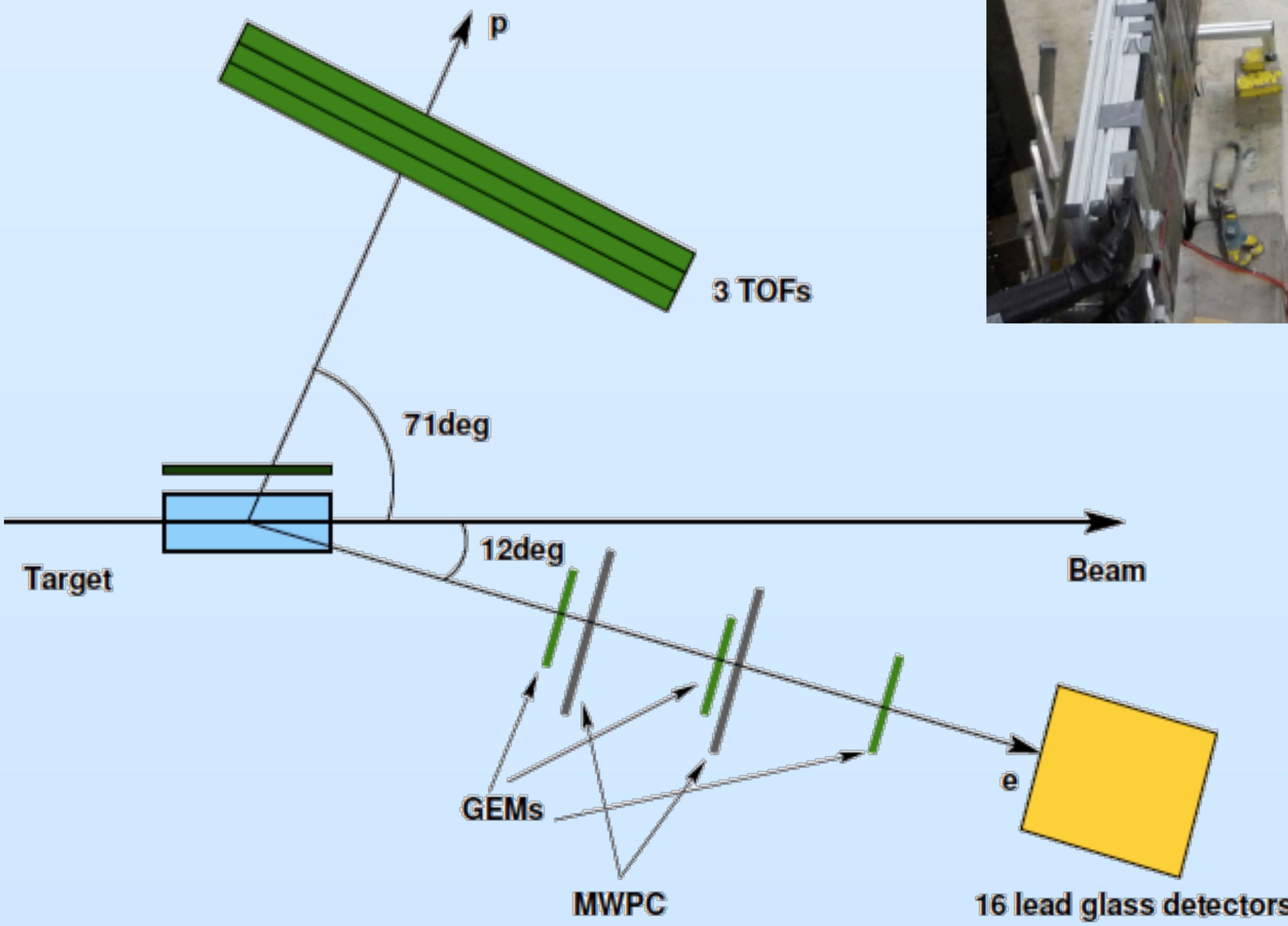
"Quasi"-Rosenbluth separation of e$^+$/e$^-$ vs. ε at constant $Q^2 \approx$ 2–2.5 (GeV/c)^2 if running at 2.0 and 4.5 GeV (within beamtime budget)

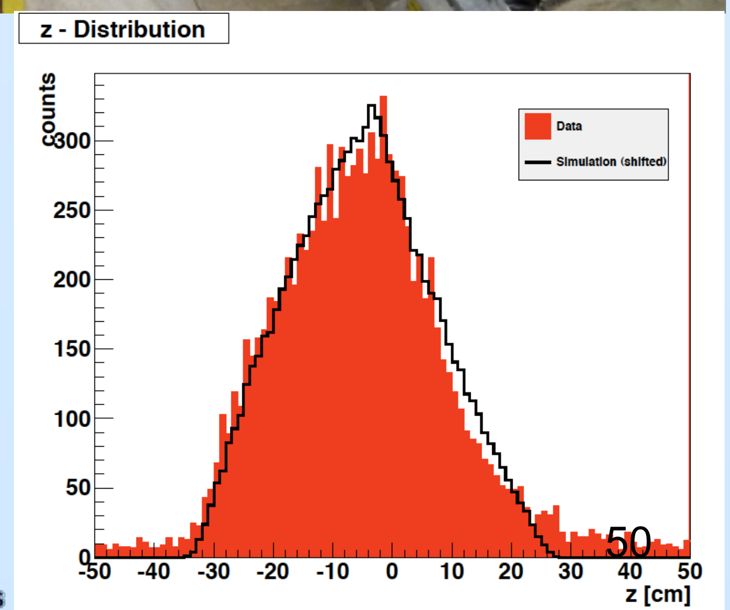
Reach Q^2 ~ 3–4.5 (GeV/c)^2 with suitable statistics for E=4.5 GeV and intermediate ε (requires additional running time)

DORIS Test Experiment in Feb 2011





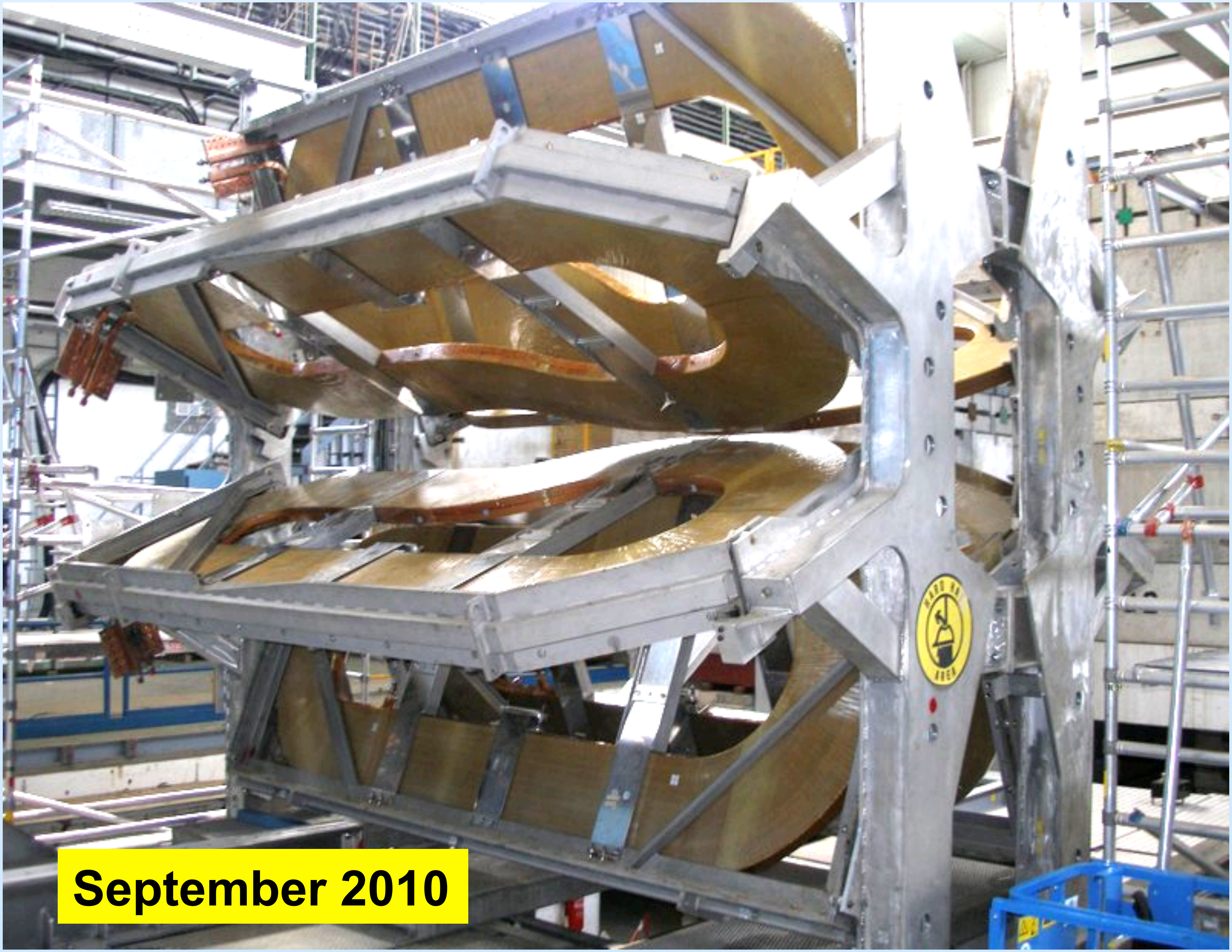




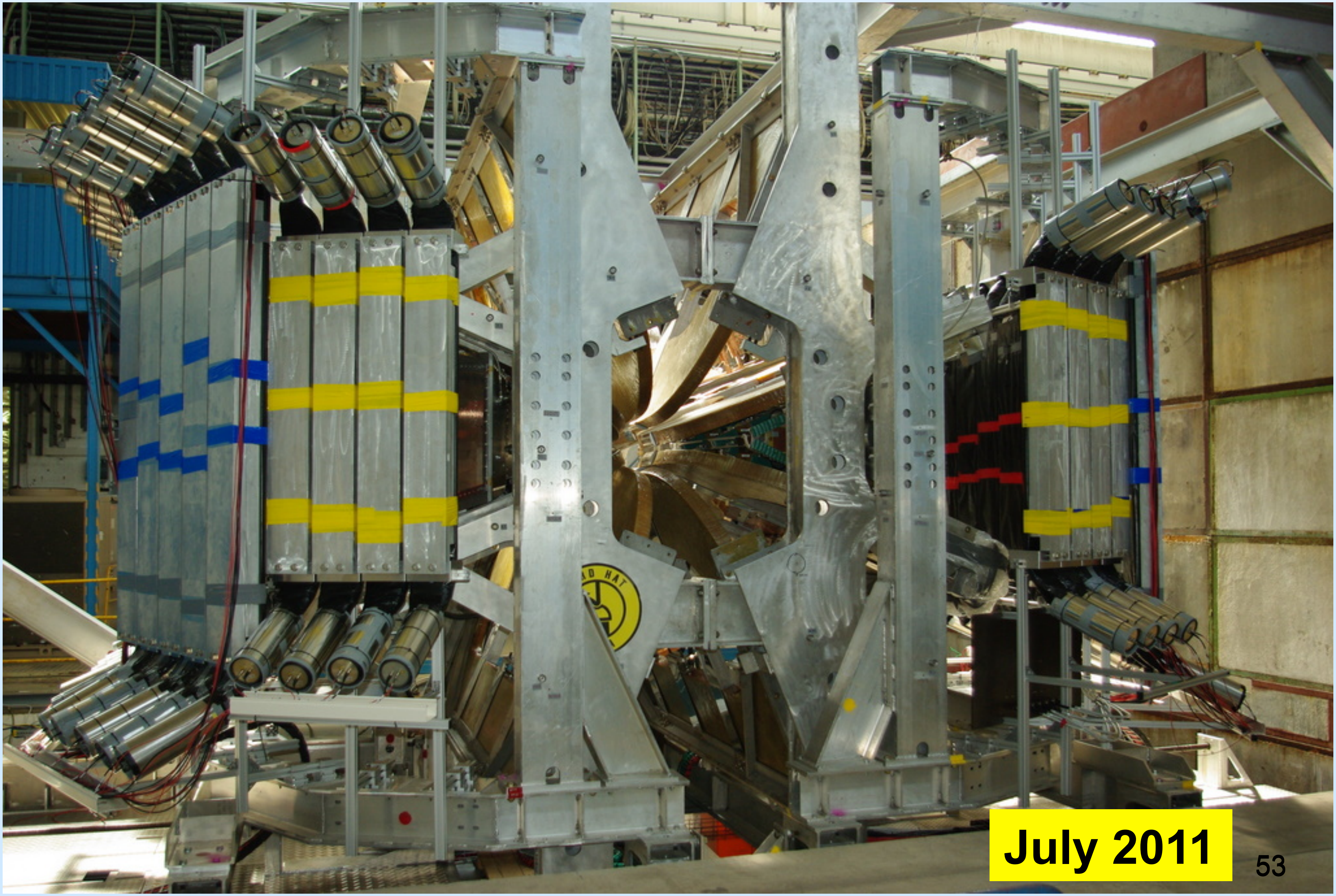
OLYMPUS: BLAST@DESY/DORIS

August 2010

OLYMPUS: BLAST@DESY/DORIS



OLYMPUS: BLAST@DESY/DORIS



July 2011

Wire Chambers

Desired TDC distribution

- "church" profile
- steeple corresponds to tracks passing close to sense wire
- main body shows uniform distribution across drift cell
- well separated from noise and random events

What is observed so far

- steeple in correct location
- some evidence of body but still quite noisy
- noise appears periodic and high frequency
  - ~10 MHz
  - some wires worse than others but evident on all wires
- Improvements expected this week

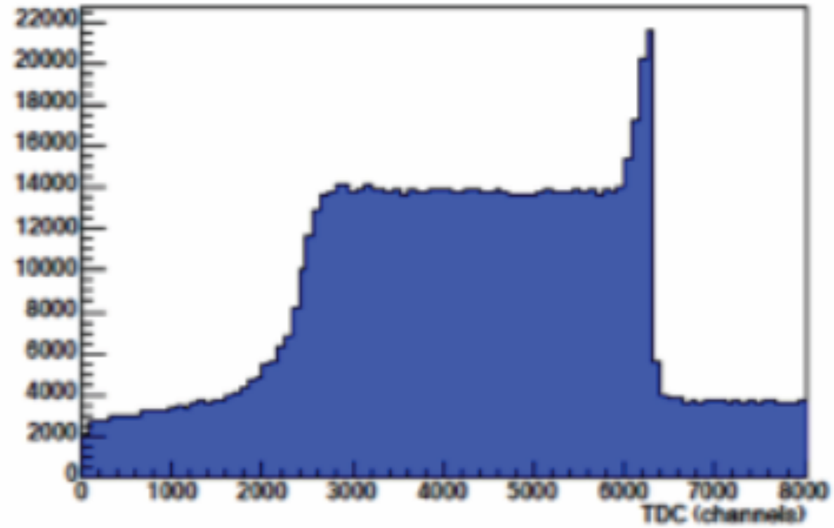
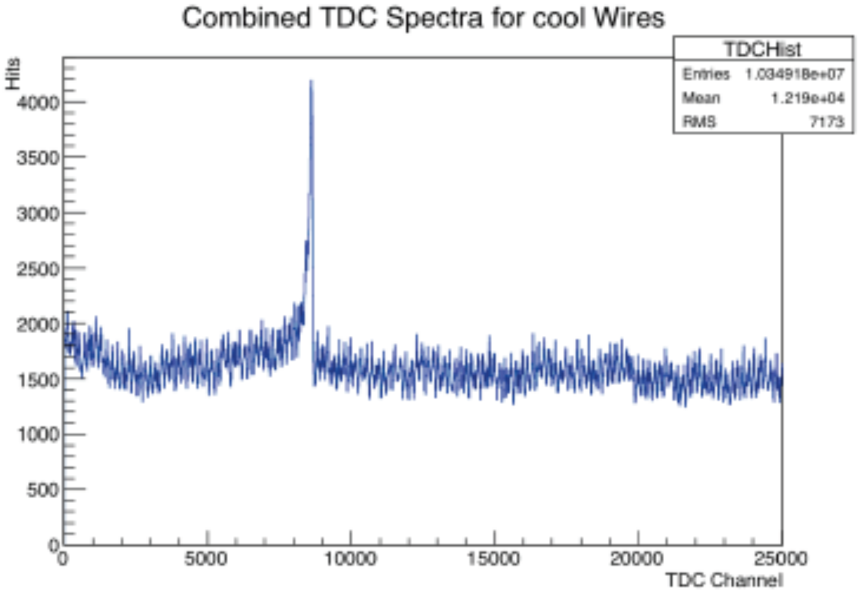
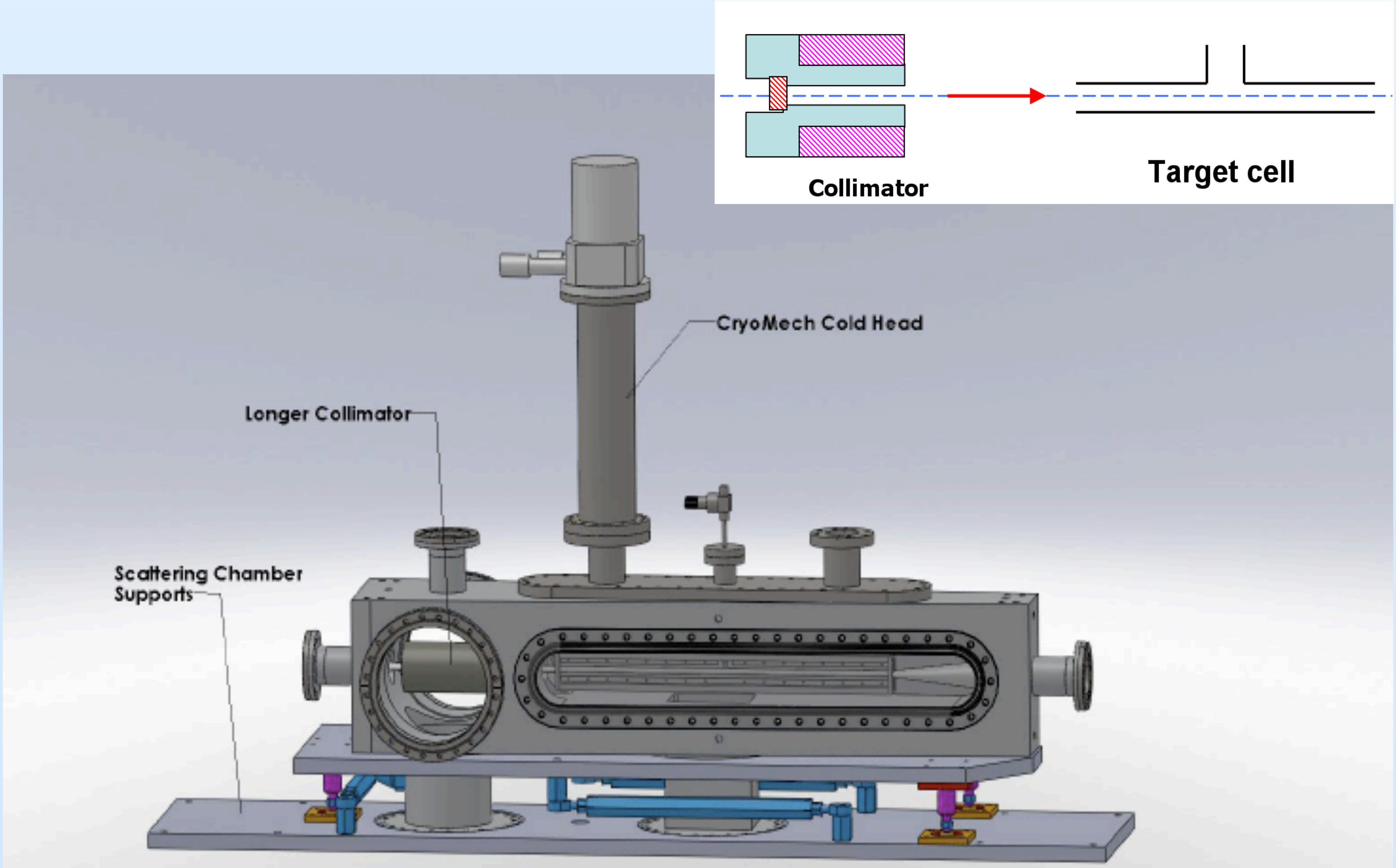


Figure 3-14: Drift chamber TDC spectrum.



Target and Vacuum System



Designed until summer 2010

Target and Vacuum System

Target chamber machined by October 2010

Simplistic Analysis Scheme

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

i = e+ or e-
j= pos/neg polarity

Geometric proton efficiency: $\kappa^p_{\mathrm{e}+j} = \kappa^p_{\mathrm{e}-j}$

$$\frac{N_{\mathrm{e}+j}/L_{\mathrm{e}+j}}{N_{\mathrm{e}-j}/L_{\mathrm{e}-j}} = \frac{\sigma_{\mathrm{e}+}}{\sigma_{\mathrm{e}-}} \cdot \frac{\kappa^l_{\mathrm{e}+j}}{\kappa^l_{\mathrm{e}-j}}$$

Ratio in single polarity j

Geometric lepton efficiency: $\kappa^l_{\mathrm{e}++} = \kappa^l_{\mathrm{e}--}$ and $\kappa^l_{\mathrm{e}+-} = \kappa^l_{\mathrm{e}-+}$

Simplistic Analysis Scheme

Super ratio:

$$\left[\frac{N_{e^+ +}/L_{e^+ +}}{N_{e^- +}/L_{e^- +}} \cdot \frac{N_{e^+ -}/L_{e^+ -}}{N_{e^- -}/L_{e^- -}}\right]^{\frac{1}{2}} = \frac{\sigma_{e^+}}{\sigma_{e^-}}$$

Cycle of four states ij
Repeat cycle many times

- Change between electrons and positrons every other day
- Change toroid polarity every other day
- Left-right symmetry

In reality, need detailed simulation to account for inefficiencies, acceptances, radiative effects

Event Reconstruction

Based on OLYMPUS GEANT4 Monte Carlo

- all OLYMPUS detectors already modeled
- toroidal magnetic field grid also in Monte Carlo
- GEANT4 has already coded routines which:
  - track particles through a magnetic field
  - determine when trajectories cross active detectors
  - record position, energy, time, etc. for hits in active detectors
- OLYMPUS Monte Carlo knows detector positions
  - can use local coordinates for each detector
  - do not need to convert to a “global” coordinate system
- GEANT4 is well integrated with ROOT
  - OLYMPUS Monte Carlo data is written as ROOT trees
  - similarly OLYMPUS data is written as ROOT trees

Therefore

- use GEANT4 for event reconstruction
- no need to reinvent the wheel

Geant4 Based Event Reconstruction

ROOT data file

- each detector group provides a plugin to convert raw data into hit info in the local coordinate system of their detector
  - e.g. (X, Y) locations of hits in the GEM tracker

Reconstruction code

- selects combinations of hits as track candidates and makes initial estimate for track candidate parameters (p, θ, φ, z)
- generates charged geantino in GEANT4 with these parameters
  - charged geantino curves in magnetic field and scores hit location in active detectors but no physics processes like energy loss, multiple scattering, etc.
  - tracking geantinos in GEANT4 is very fast because no physics processes
- compare geantino hit locations with hits from data, fit to minimize chi2
  - in local detector coordinate system
  - no need to convert to global coordinate system
- Kalman filter for optimized reconstruction in presence of noise

Reconstruction Improvements

Identify track candidates and initial parameters

- Neural network study on wire chamber and GEM tracker hits was able to identify track candidates and initial track parameters
- Similar approach transforms hit information into track parameters e.g. polynomial expansion (matrix elements)

Realistic particles

- After geantino fits use electron, positron, or proton (as appropriate) to fit track accounting for energy loss

Kinematic fits

- Identify pairs of tracks as ep elastic candidates and fit together with kinematic constraints

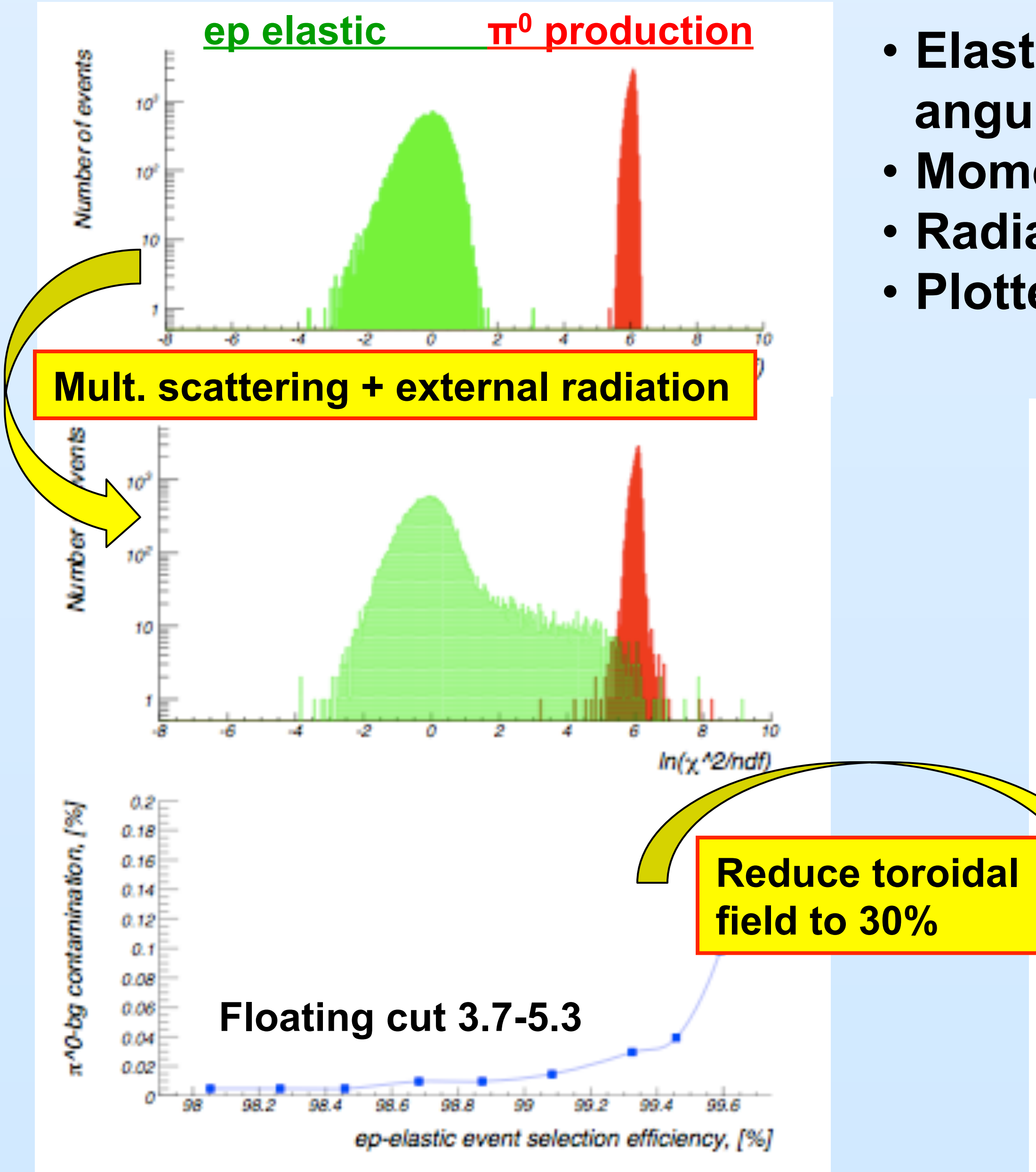
Kalman filter

- For optimized reconstruction in presence of noise hits

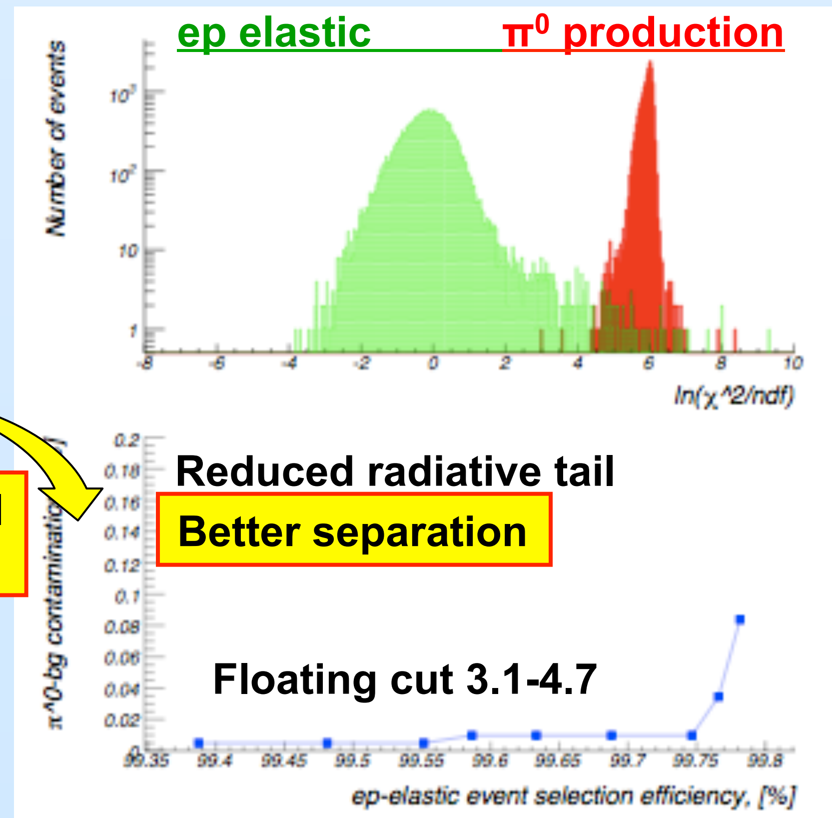
Impact of Magnetic Field

- Magnetic Toroidal field: 1.6 MW
  - Dominates OLYMPUS running cost
  - Cleaning effect: prevent low-energy particles (Moller) from entering wire chambers
  - Momentum measurement, $\delta p/p \sim 4\%$ @ 1 GeV/c
- Acceptance for e^+p / e^-p depending on magnetic field
- Size of radiative corrections depending on magn. field
  ➔ corrections smaller w/ less field, momentum cut
- Event selection less dependent on momentum,
  use of angular resolution more powerful
- Optimal toroidal field to be investigated experimentally
  "As large as necessary, as small as possible"

OLYMPUS Elastic Event Selection



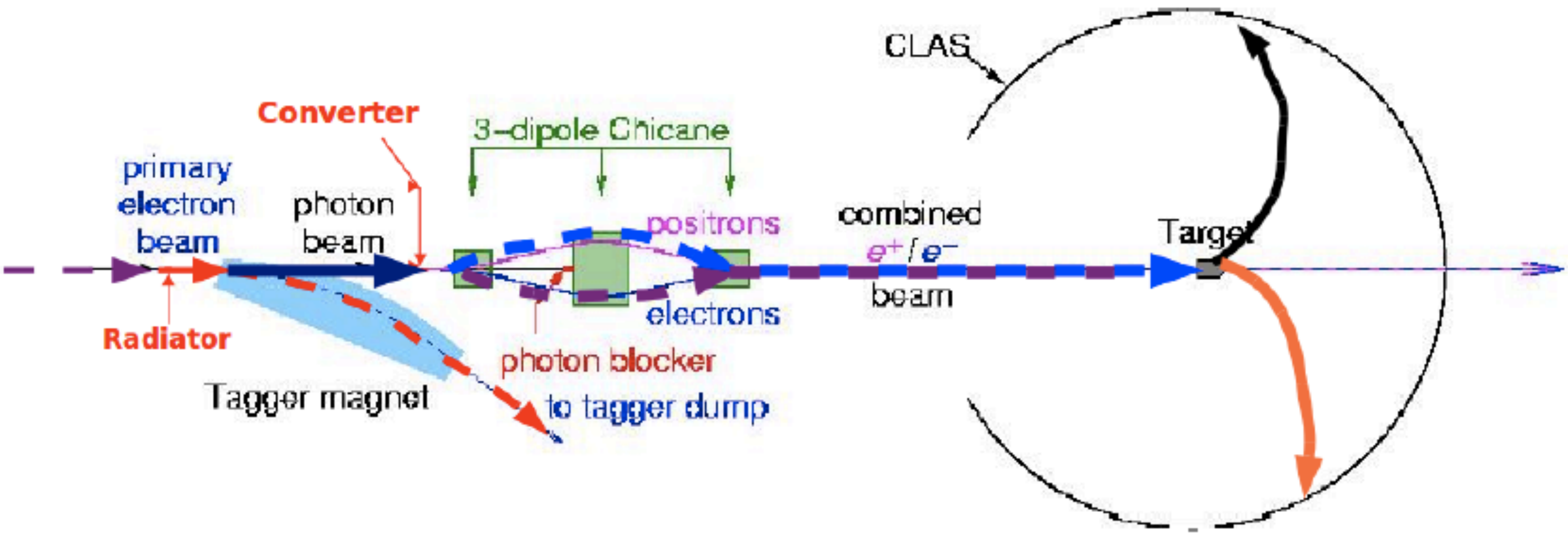
- Elastic event selection governed by angular resolution
- Momentum resolution less relevant
- Radiative tails
- Plotted *ln(Chi^2/ndf)* for (recon-expected)



Study by A. Kiselev, PNPI

Robert Bennett (Old Dominion)

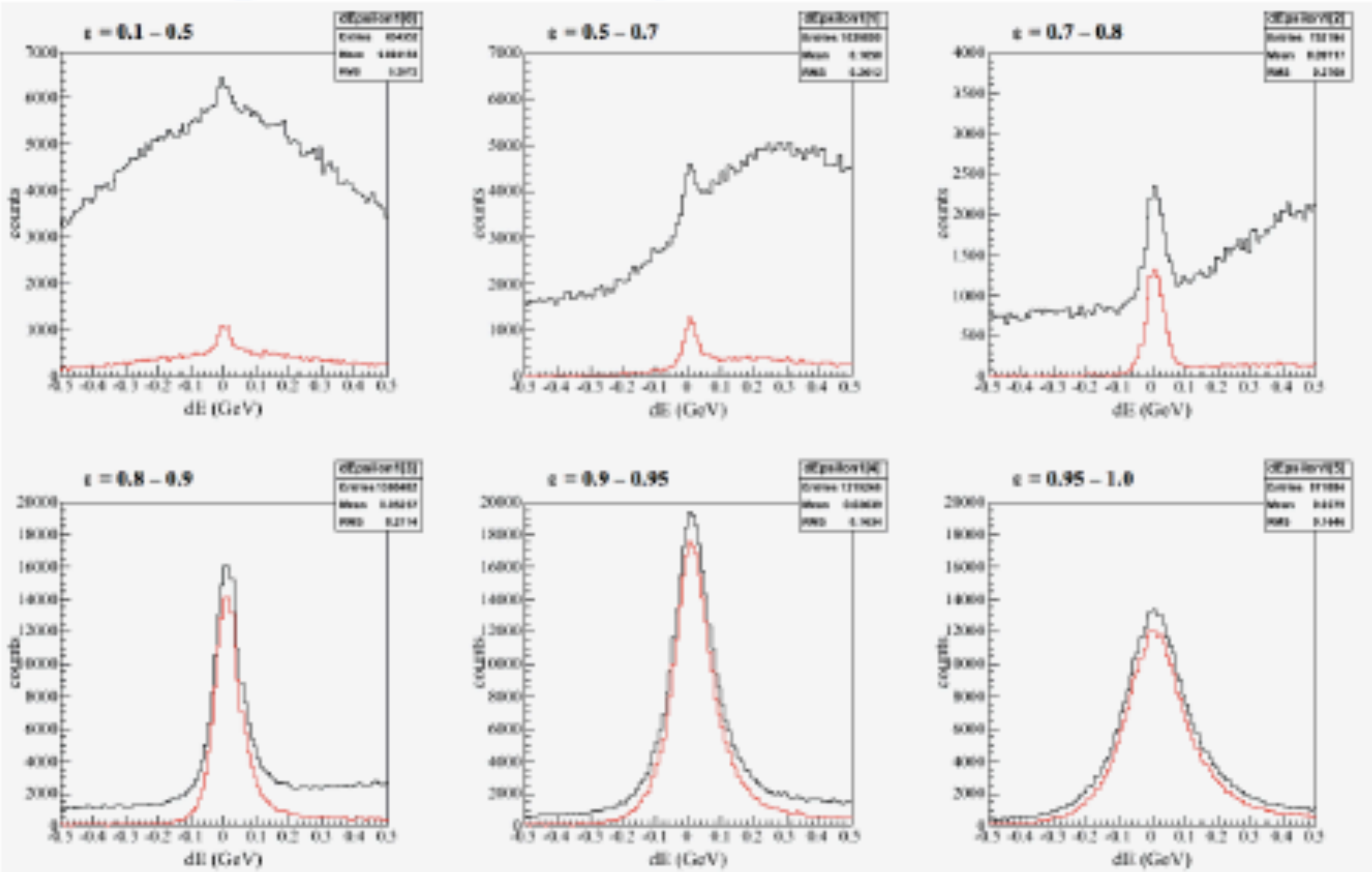
Simultaneous, Idential e^+/e^- Beams



- 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)

Robert Bennett (Old Dominion)

Negative Torus Polarity: Electron-Proton Events



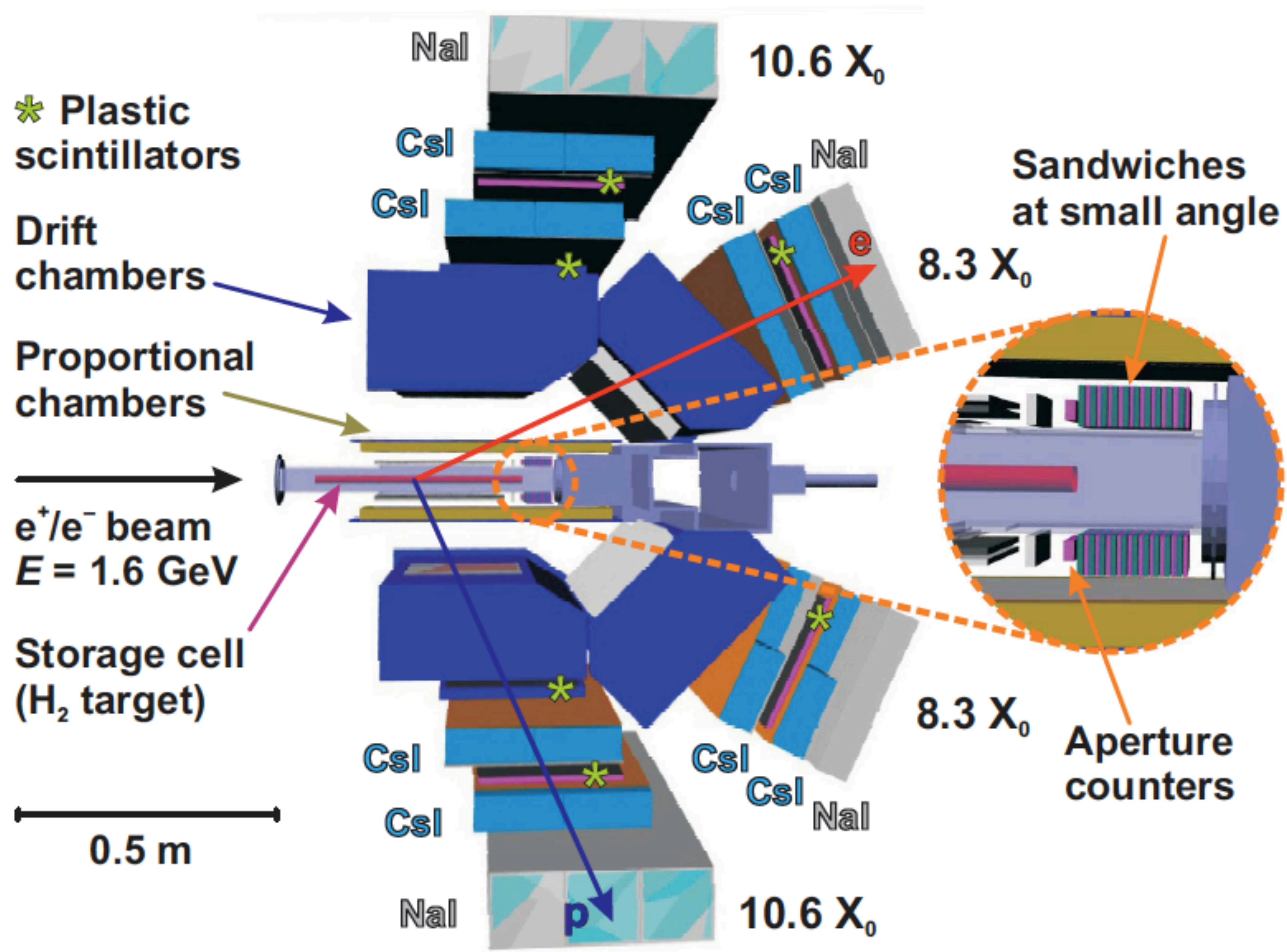
$\Delta E = E_1 - E_2$ · Before $\Delta\phi$ cuts · After $\Delta\phi$ cuts

$$E_1 = M\left[\cot\frac{\theta_e}{2}\cot\theta_p - 1\right],\ E_2 = p_e\cos\theta_e + p_p\cos\theta_p$$

Preliminary · Explore other kinematics

Alexander Gramolin (Novosibirsk)

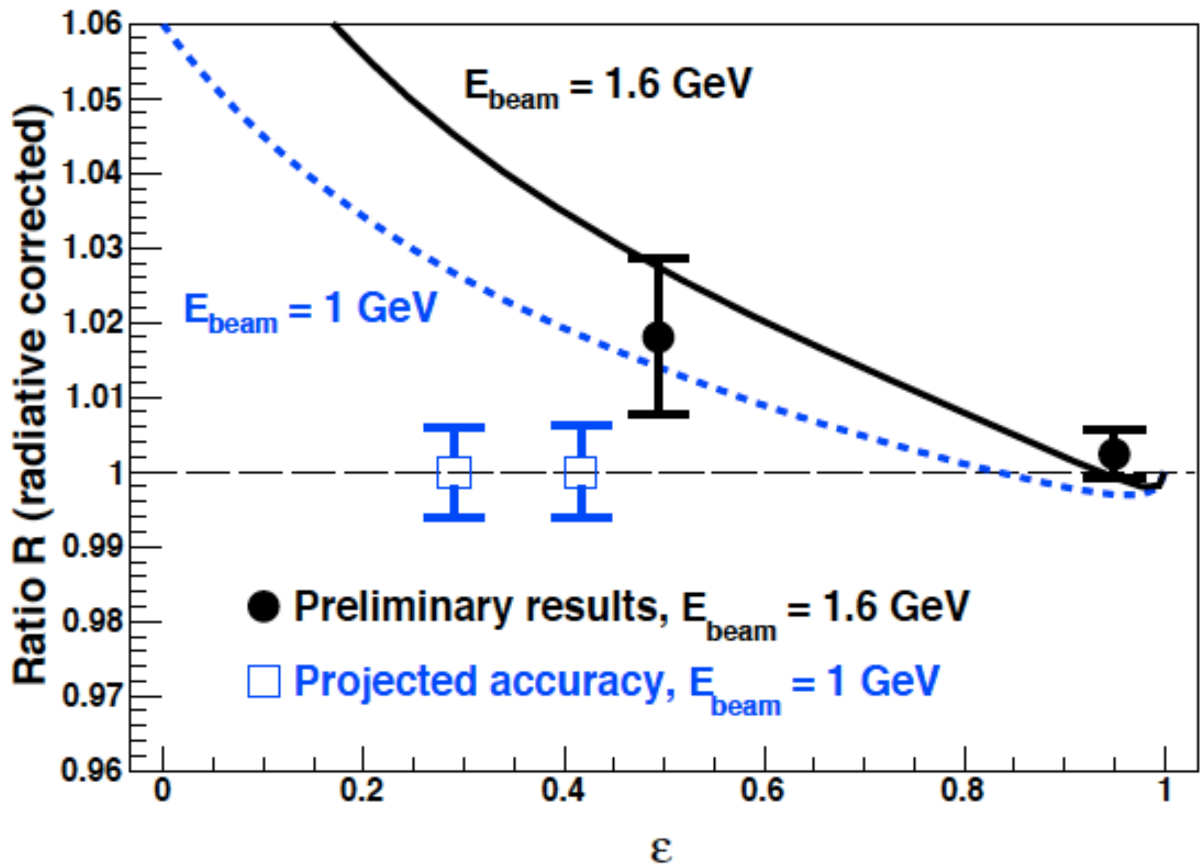
Schematic side view of the particle detection system



Novosibirsk Preliminary Result

The next phase of the experiment

The measurement will be continued at other kinematics:
$\varepsilon = 0.42,\ Q^2 = 0.82\ \text{GeV}^2$ & $\varepsilon = 0.29,\ Q^2 = 0.96\ \text{GeV}^2$.



The figure shows projected statistical accuracy (blue squares) and our preliminary results (black circles). The lines represent the corresponding results of the theoretical prediction by Blunden, et al.

- *P. G. Blunden, W. Melnitchouk, and J. A. Tjon.* PRC **72** (2005) 034612.

Schedule

- OLYMPUS experiment approved December 2009
- BLAST toroid and detectors disassembled in spring 2010
- All shipped to DESY by summer 2010
- Wire chambers rewired in summer 2010

- OLYMPUS toroid reassembled, powered and field mapped in DORIS hall November 2010
- OLYMPUS target system shipped to DESY in November 2010
- Target system installed in DORIS in January 2011
- Test experiment installed in December 2010
- Test experiment completed in February 2011, target chamber removed

- Testbeam-22 running in May-June 2011 for detector tests
- Wire chambers, TOFs and 12 deg. lumi monitor moved to DORIS Hall in June 2011
- Roll-in of OLYMPUS setup successfully completed July 15, 2011
- Experiment being commissioned in fall 2011
- Data taking planned for two running blocks in 2012

Summary

- The limits of OPE have been reached with available today's precision
  ➔ Nucleon elastic form factors, particularly G_E^p under doubt
- The TPE hypothesis is suited to remove form factor discrepancy, however calculations of TPE are model-dependent
- Experimental probes: Real part of TPE –
  - ε-dependence of polarization transfer
  - ε-nonlinearity of cross sections
  - Comparison of positron and electron scattering
- Need both positron and electron beams for a definitive test of TPE
  OLYMPUS, CLAS, VEPP-3
- OLYMPUS has been installed into DORIS in July 2011 ("rolling-in")
  - Commissioning of OLYMPUS August – December 2011
  - Take data in two running blocks beginning and end 2012
  - Reach ε below 0.4 for $Q^2 \approx 2.2$ $(GeV/c)^2$ at E = 2.0 GeV
  - Reach high ε for $Q^2 \approx 2.5$ $(GeV/c)^2$ at E = 4.5 GeV ("Rosenbluth")