UPDATE ON THE OLYMPUS TWO-PHOTON EXCHANGE EXPERIMENT

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For the OLYMPUS Collaboration

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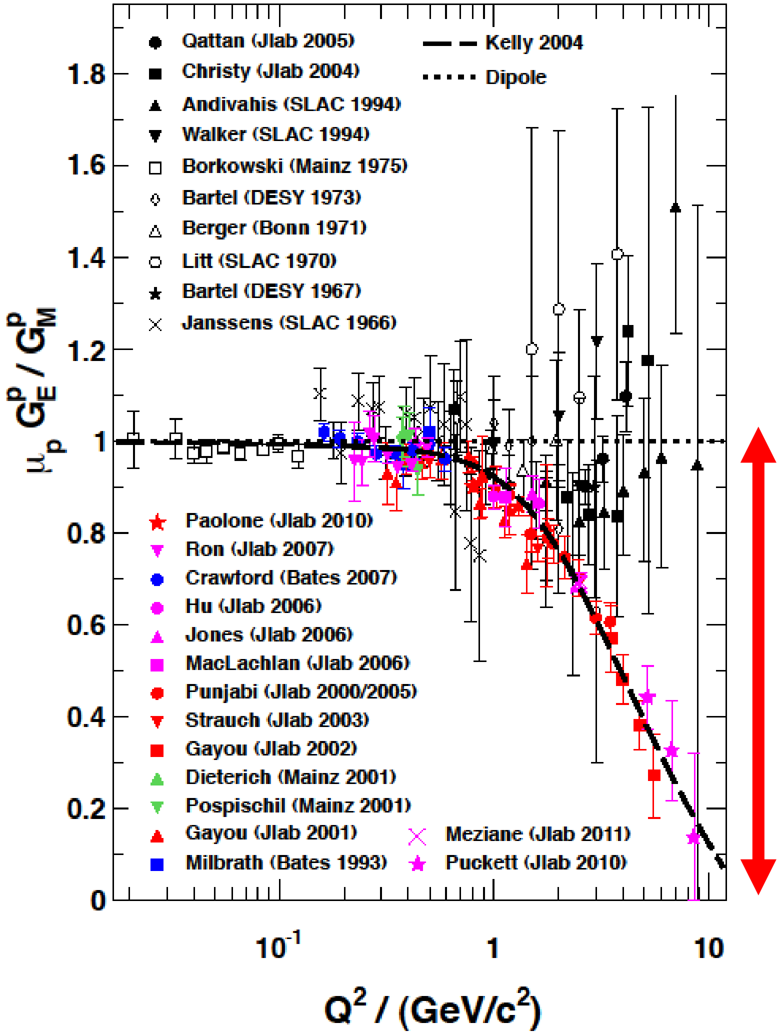
FORM FACTORS TO DESCRIBE ELASTIC EN SCATTERING

- Four fundamental observables $G_{E(p,n)}$ and $G_{M(p,n)}$ reflect the distribution of charge and magnetization in the nucleon
- Described by quark structure of nucleon
- Calculable in lattice QCD (at least at $0.5 < Q^2 < 4$ GeV^2)
- Until recently FFs were experimentally determined with unpolarized cross section measurements using Rosenbluth separation method
- In the last 15 years thanks to polarization technique (Jlab), a distinctly different Q^2 dependence in the FF ratio is observed contradicting the Rosenbluth based relation : $\mu G_{Ep} \sim G_{Mp}$

MOTIVATION FOR OLYMPUS EXPERIMENT

- Proton Form Factor Ratio



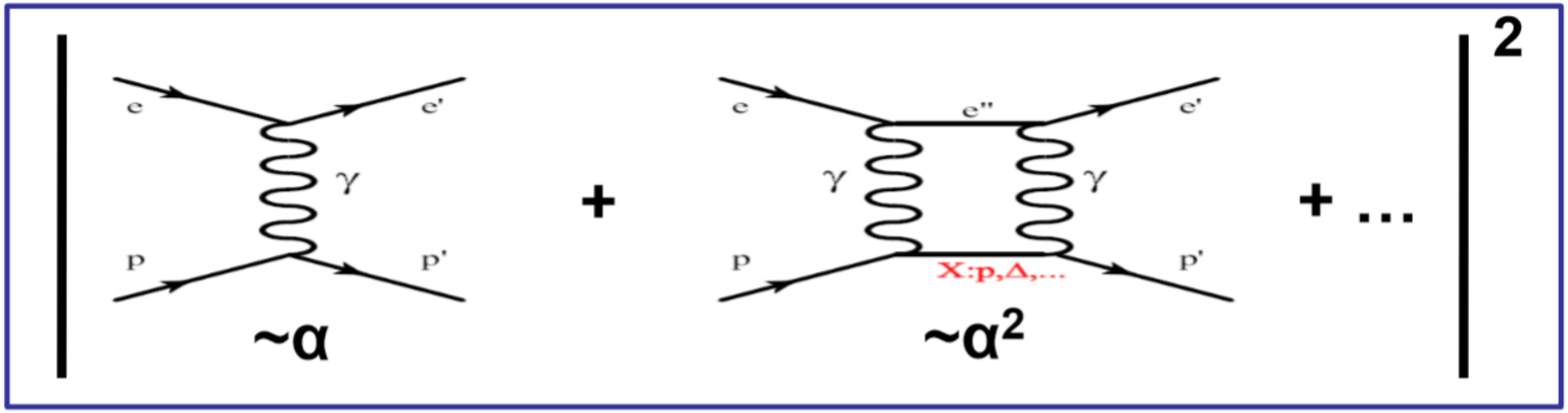
All Rosenbluth data in agreement

Dramatic discrepancy between Rosenbluth and recoil polarization technique (Jefferson Lab data >1000 citations) ⟶ Puzzle

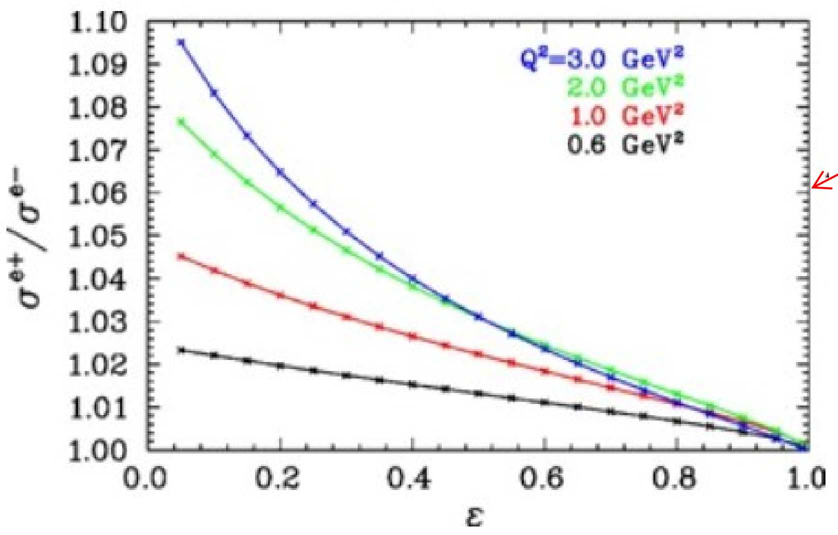
Interpreted as evidence for TPE

TPE can solve puzzle !

TWO PHOTON EXCHANGE (TPE) CONTRIBUTION



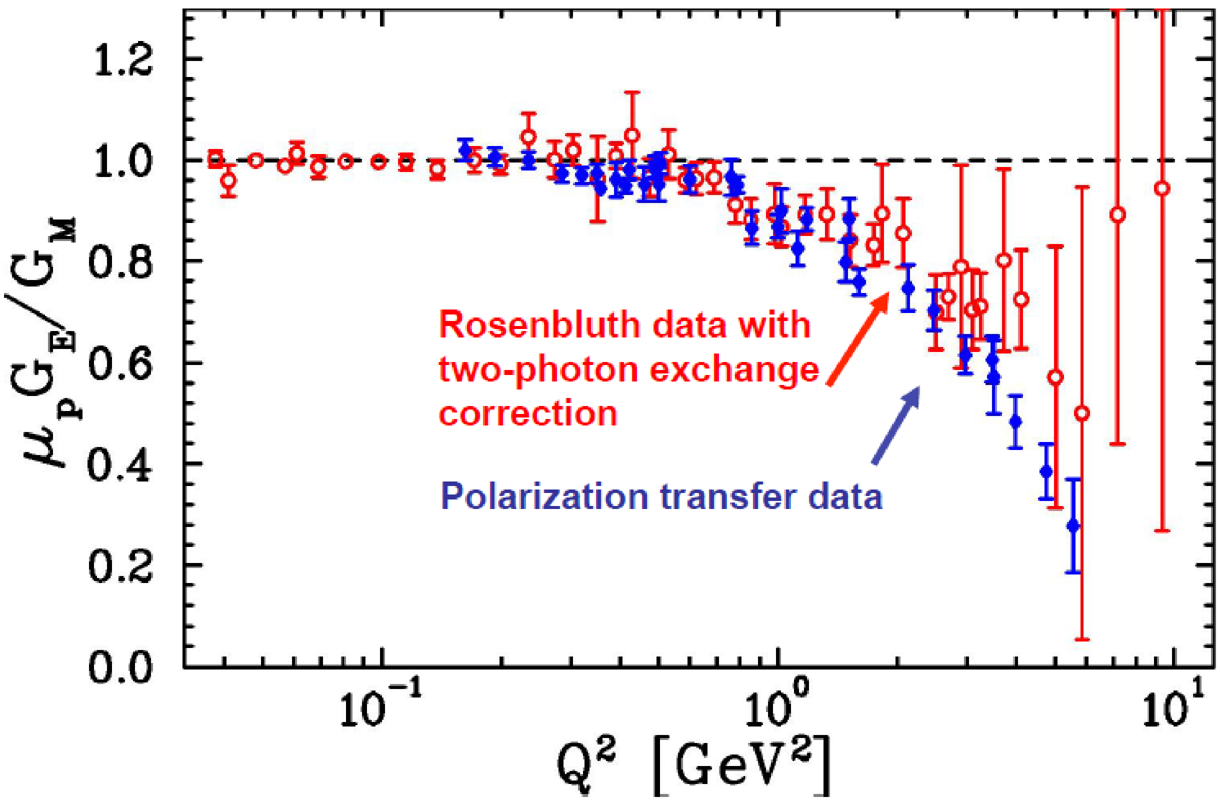
$$\frac{\sigma_{e^+p}}{\sigma_{e^-p}} = \frac{\left[|M_{Born}|^2 + 2\,\mathrm{Re}(M_{Born} M^*_{2\gamma}) + \ldots \right]}{\left[|M_{Born}|^2 - 2\,\mathrm{Re}(M_{Born} M^*_{2\gamma}) + \ldots \right]}$$



Model dependent

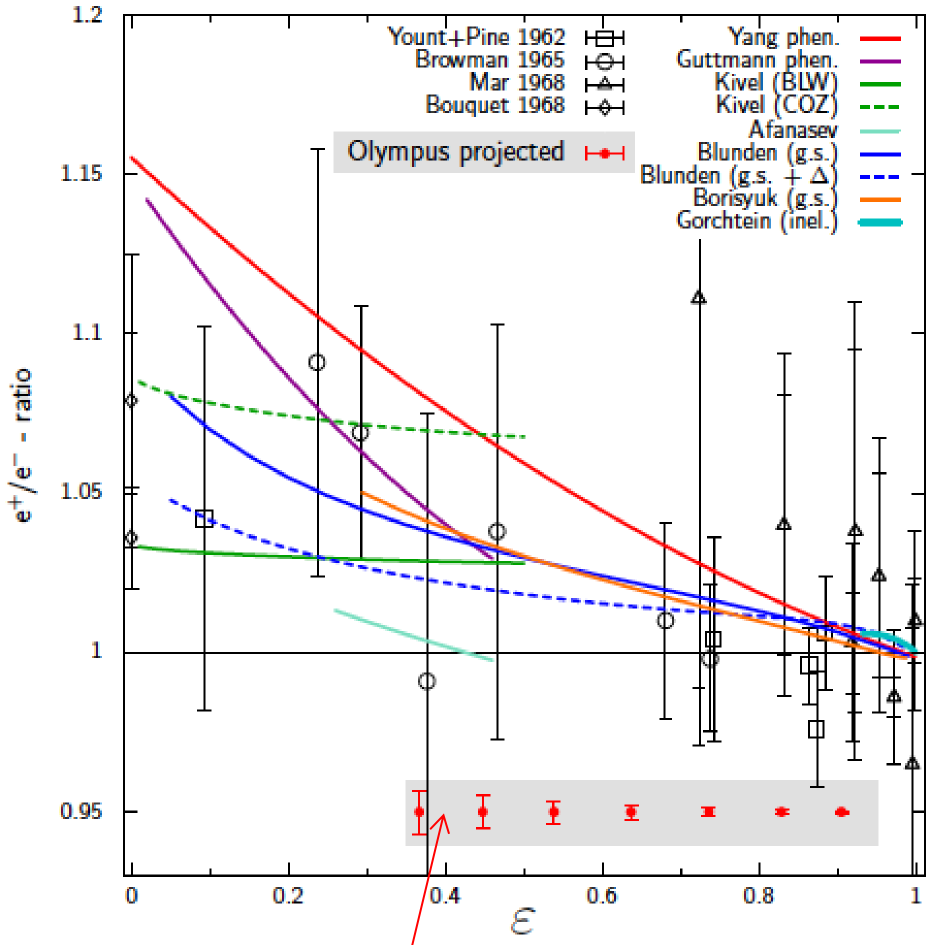
P.G. Blunden et al., Phys. Rev. C72 (2005) 034612

TPE CORRECTED ROSENBLUTH DATA



TPE **can explain** form factors ratio discrepancy:
J Arrington, W. Melnitchouk, J.A. Tjon, Phys. Rev. C 76 (2007) 035205

PREVIOUS TPE WORLD DATA AND PROJECTED OLYMPUS RESULTS



Expected sensitivity

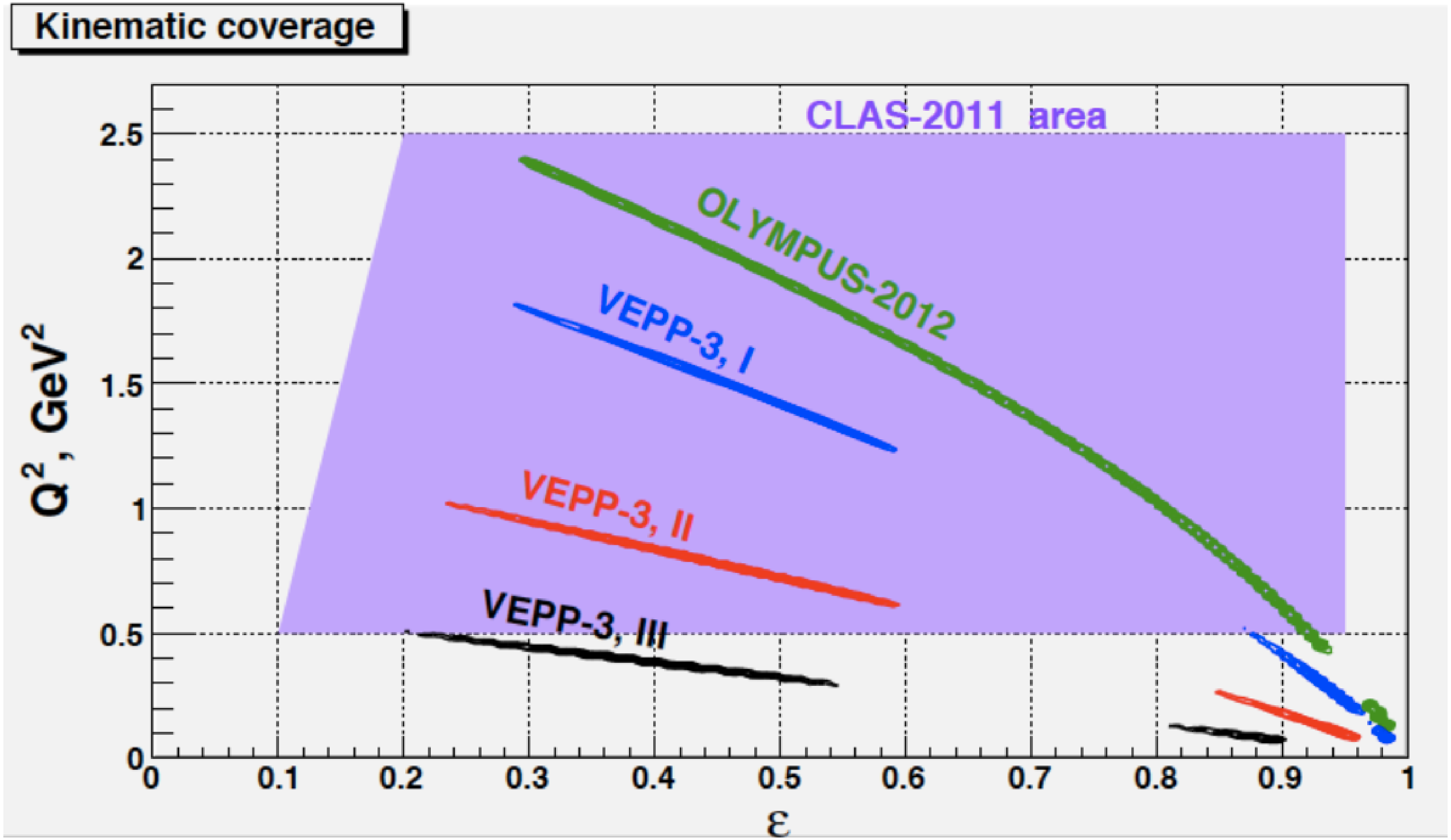
- TPE contribution measured in early 1960s → small effect
- Due to big errors → no conclusions

EXISTING E+ / E- EXPERIMENTS

✓VEPP-3 (Novosibirsk): E_{beam} = 1.6, 1 and 0.6 GeV

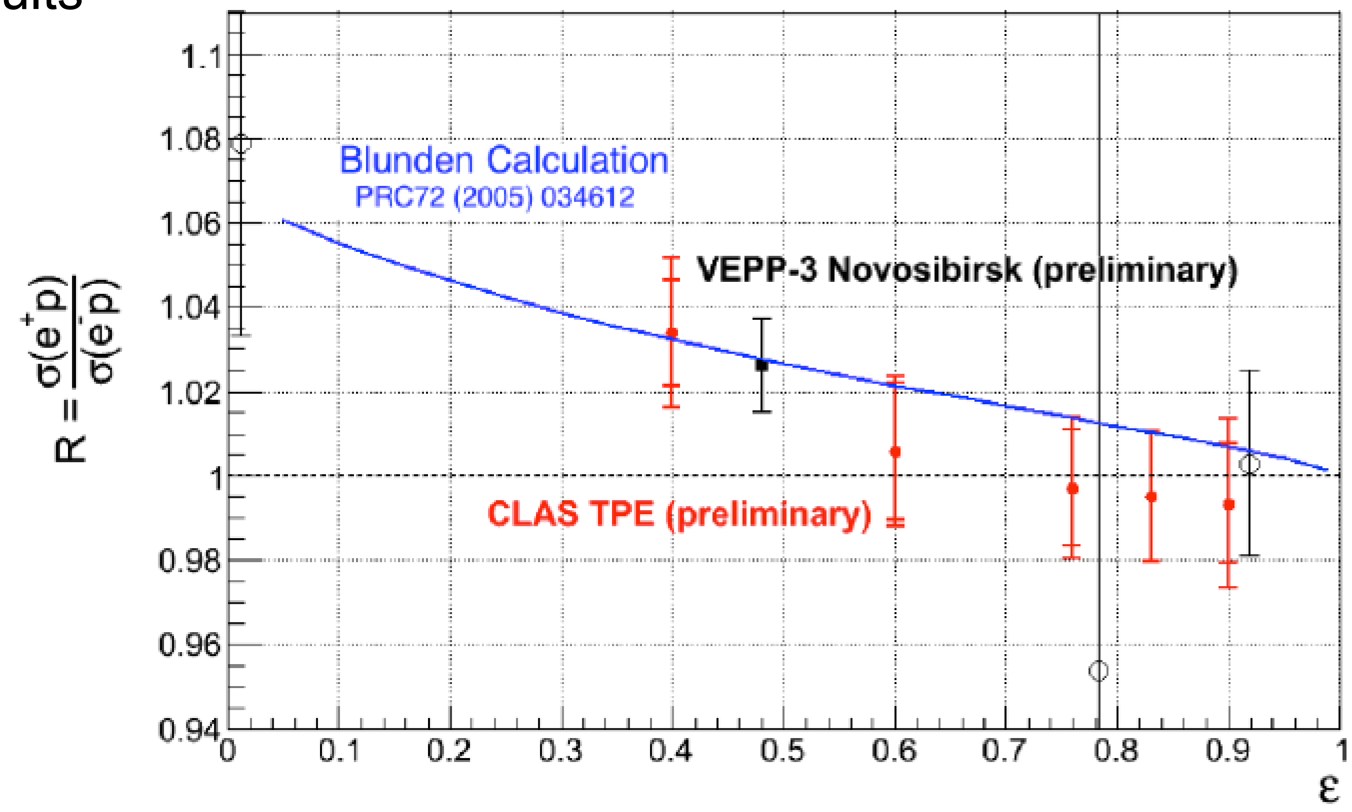
✓CLAS (Jlab): E_{beam} = 0.5 – 4 GeV

✓OLYMPUS (DESY): E_{beam} = 2 GeV

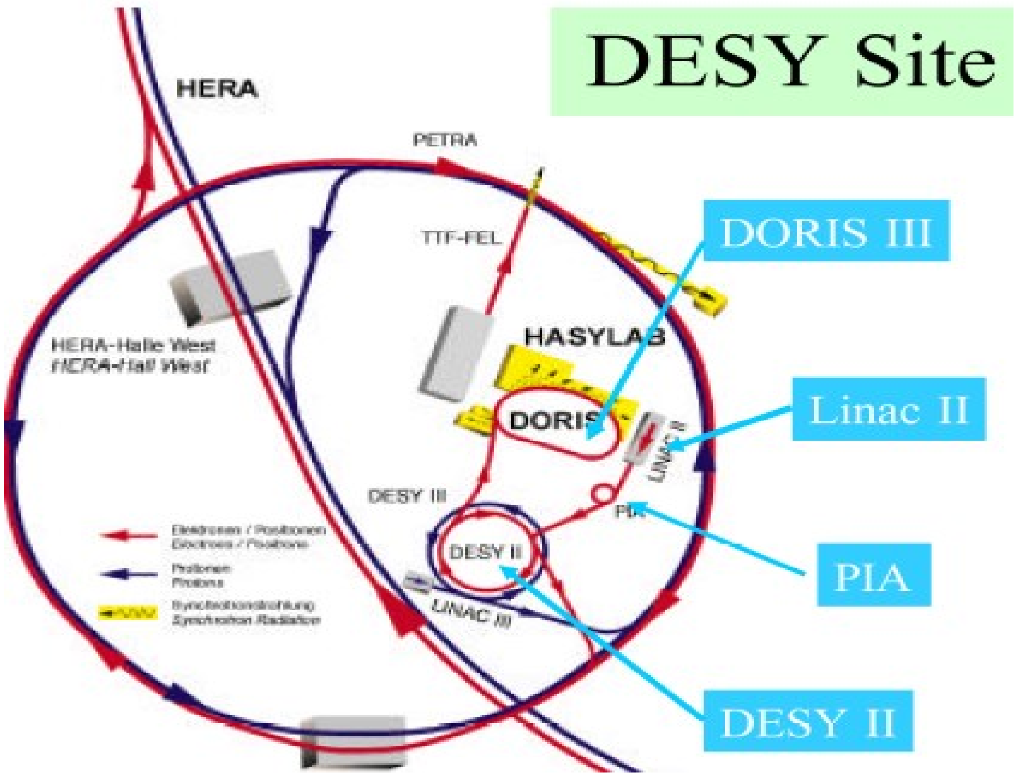


VEPP-3 AND CLAS TPE PRELIMINARY RESULTS

Good agreement between VEPP-3 and CLAS for preliminary results



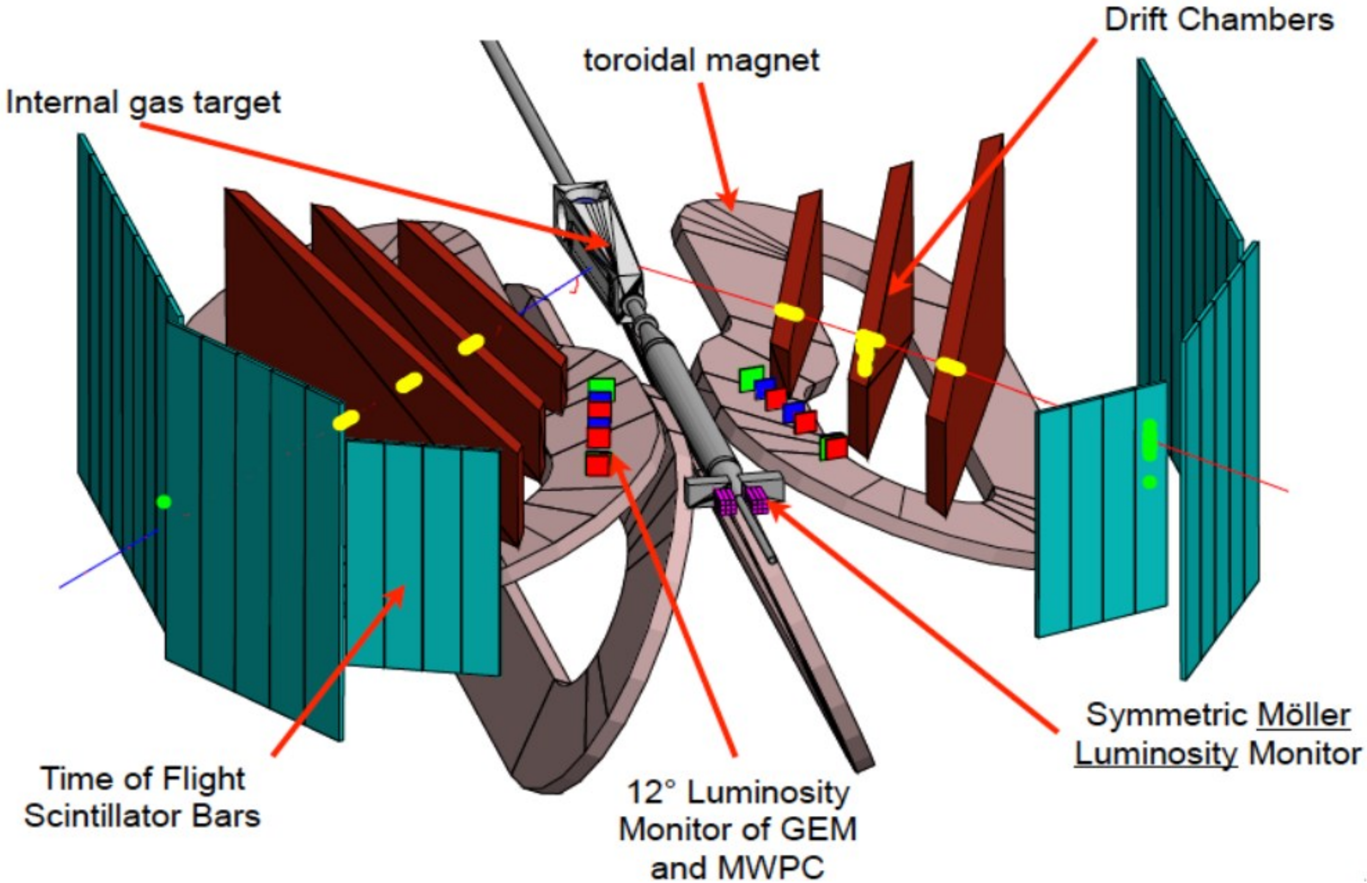
WHY DORIS?



- DORIS provides unique conditions:
  - ✓ High e+/e- beam current ~100mA
  - ✓ Fast switching between e+/e- on timescale of ~30 minutes
  - ✓ Top-up injection mode
  - ✓ Beam energy of 2 GeV measured with high < 0.5% precision

DETECTOR OVERVIEW

Modified (upgraded) Bates Large Acceptance Spectrometer Toroid - BLAST (MIT) detector

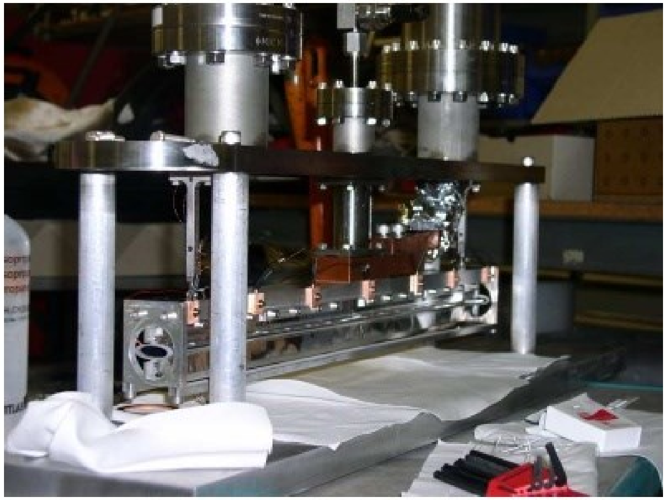


R. Milner et al, "The OLYMPUS experiment", Nucl. Instr. Meth. A 741 (2014) 1-17.

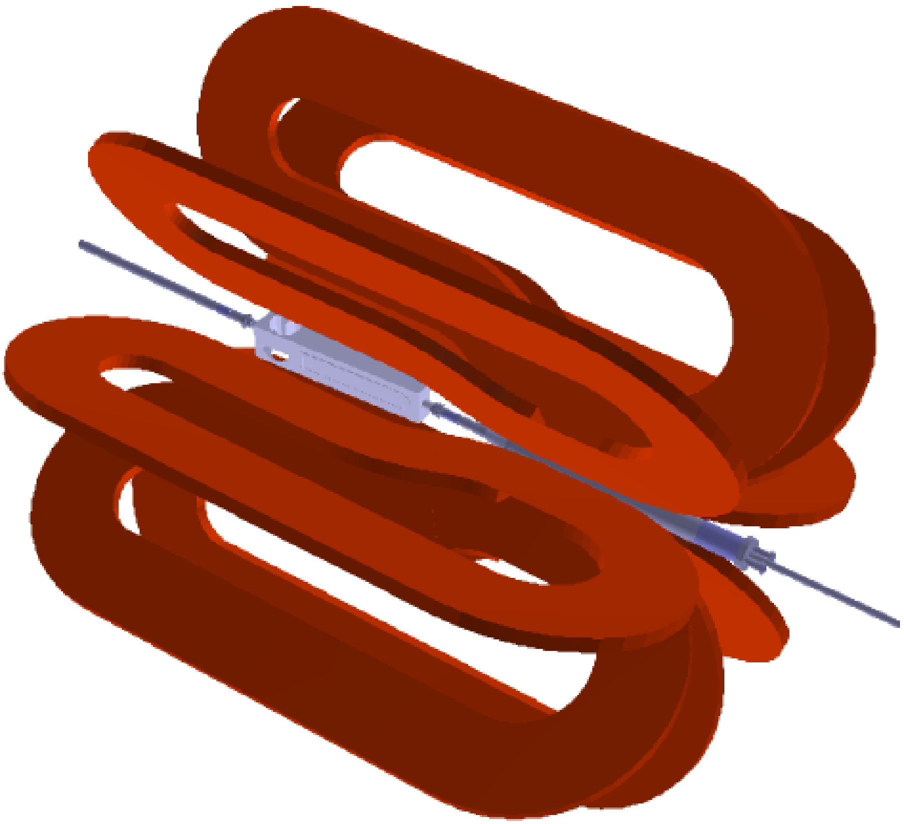
TARGET SYSTEM:

- Internal, windowless gas target
- 60 cm long storage cell
- Elliptical cross section (27^{x} 9) mm^2
- 100 μm thick aluminum wall
- O (10^{15}) atoms/cm^2
- Cryo cooled ~ 45 K
- Hydrogen produced by generator (electrolysis)

J.C. Bernauer et al., "The OLYMPUS internal hydrogen target" Nucl. Instr. Meth. A 755 (2014) 20-27

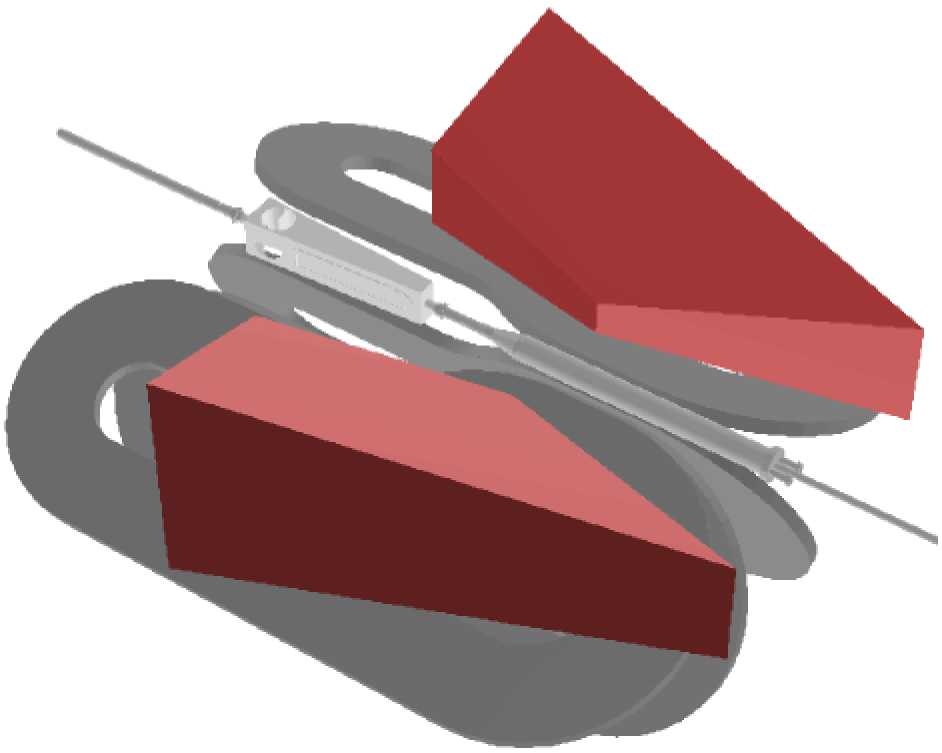


TOROIDAL MAGNET



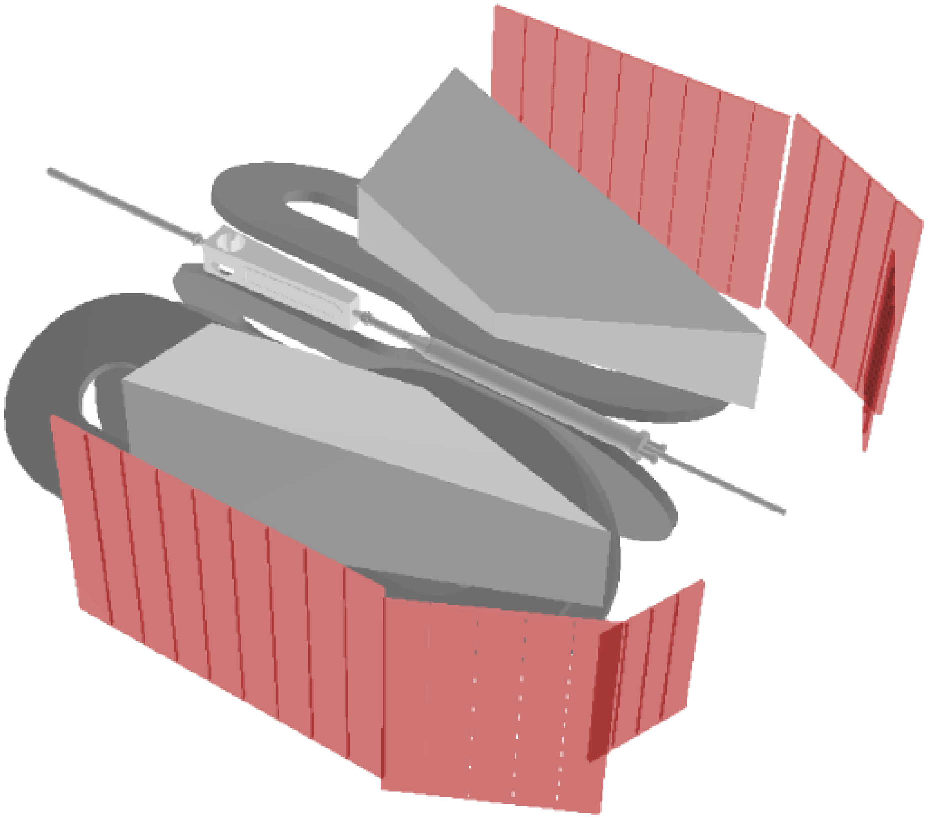
- ✓ 8 air coils from BLAST
- ✓ Operating at reduced field
- ✓ Positive and negative polarity
- ✓ Maximum filed 0.28 T at 5000 A

DRIFT CHAMBERS



- ✓ Two chambers, trapezoidal shape
- ✓ Jet-style drift cells
- ✓ 5000 wires each
- ✓ Tracks with up to 18 hits
- ✓ 10° stereo angle

TIME-OF-FLIGHT COUNTERS



- ✓ Scintillation counters from BLAST

- ✓ Trigger
- ▪ Top/bottom coincidence
- ▪ Kinematic constraint
- ▪ + 2-nd level wire chamber

- ✓ Time-of-Flight for particle ID

LUMINOSITY MONITORS

- Slow Control
  - Beam current and target density
  - 15 -20 % absolute, <5% relative uncertainty

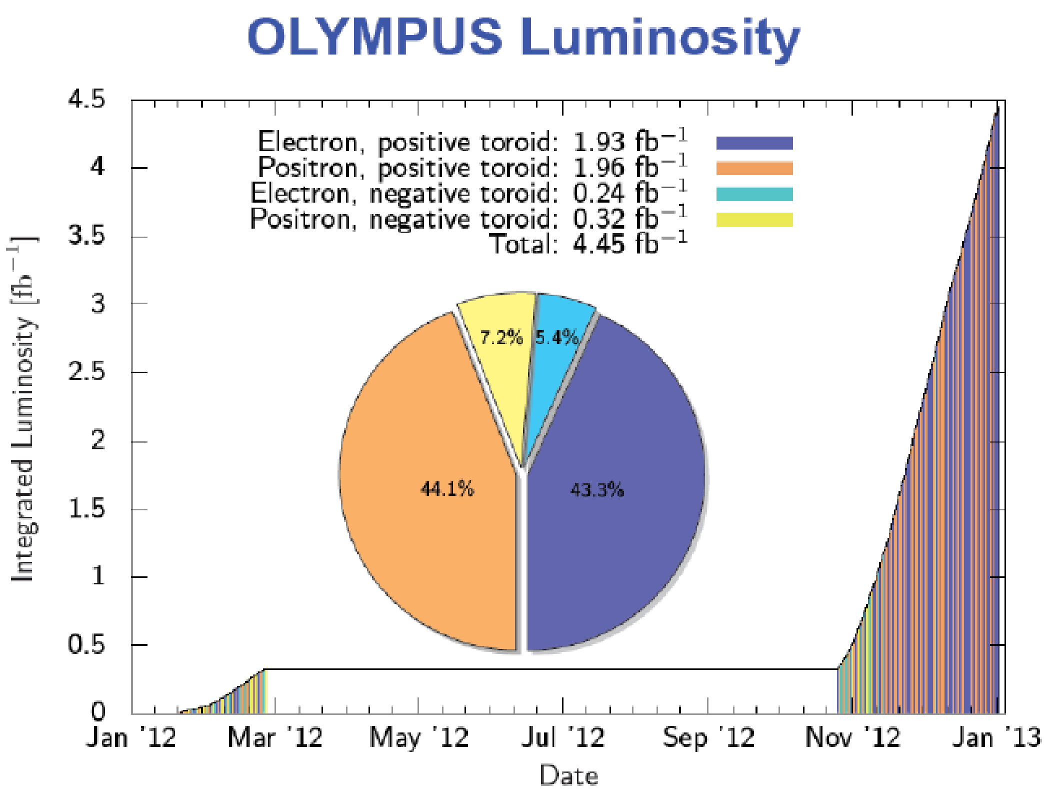
- Tracking telescopes at 12°
  - Elastic ep scattering at forward angles
  - Two independent tracking systems: MWPCs and GEMs

- Symmetric MØller/Bhabha monitor at 1.3°
  - High statistics measurement, no dead time

Need $e^+ e^-$ luminosity ratio, not precise absolute luminosity

Details in talk by D. Khaneft

DATA TAKING IN 2012



Limited flow and luminosity in Feb. run

Fall run

- Full hydrogen flow
- DORIS top-up mode
- Excellent performance
- Exceeded integrated luminosity:
  - Design 3.6fb^{-1}, achieved 4.45fb^{-1}
- Daily switch of beam species, good balance
- Mainly positive toroid polarity due to background
- Negative field for systematics checks

RECENT PROGRESS WITH TOF PERFORMANCE

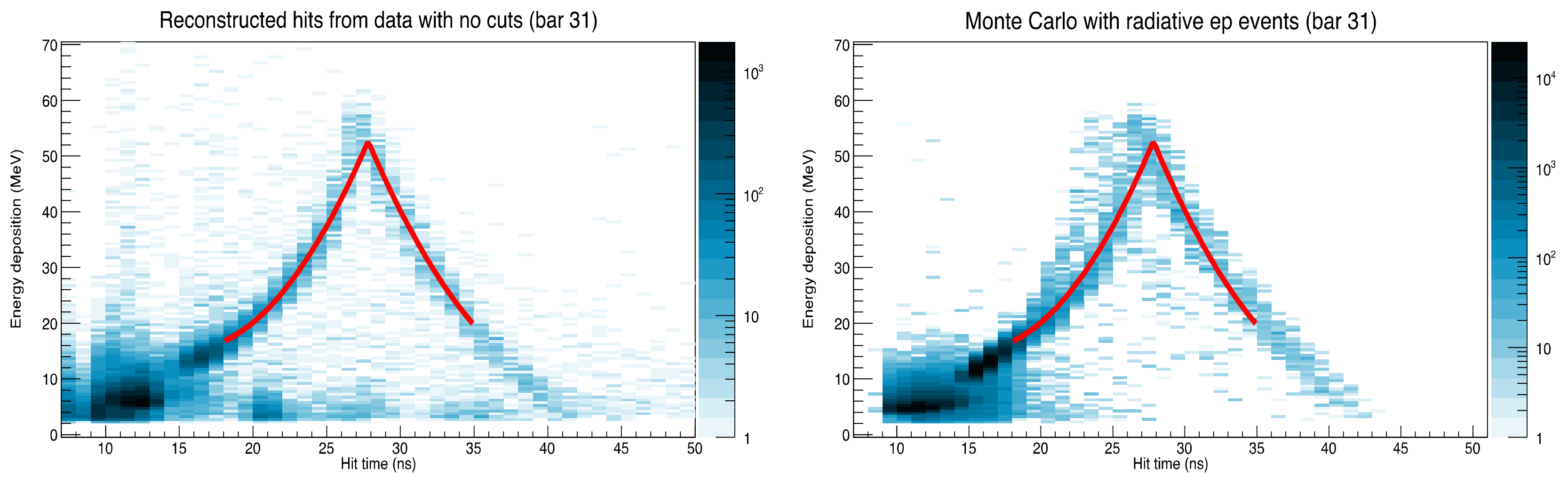
Calibration quite advanced

Improved calibration with tracking extended to ToF detectors

Developed cosmic ray MC generator for better understanding

and use of cosmic data for calibration

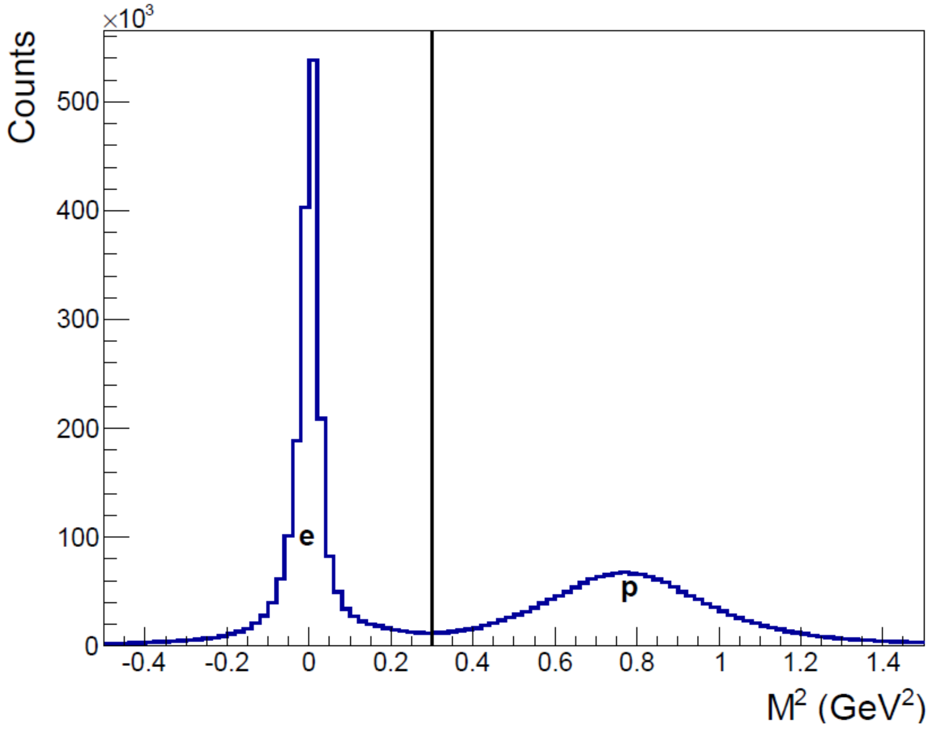
Energy loss vs. hit time

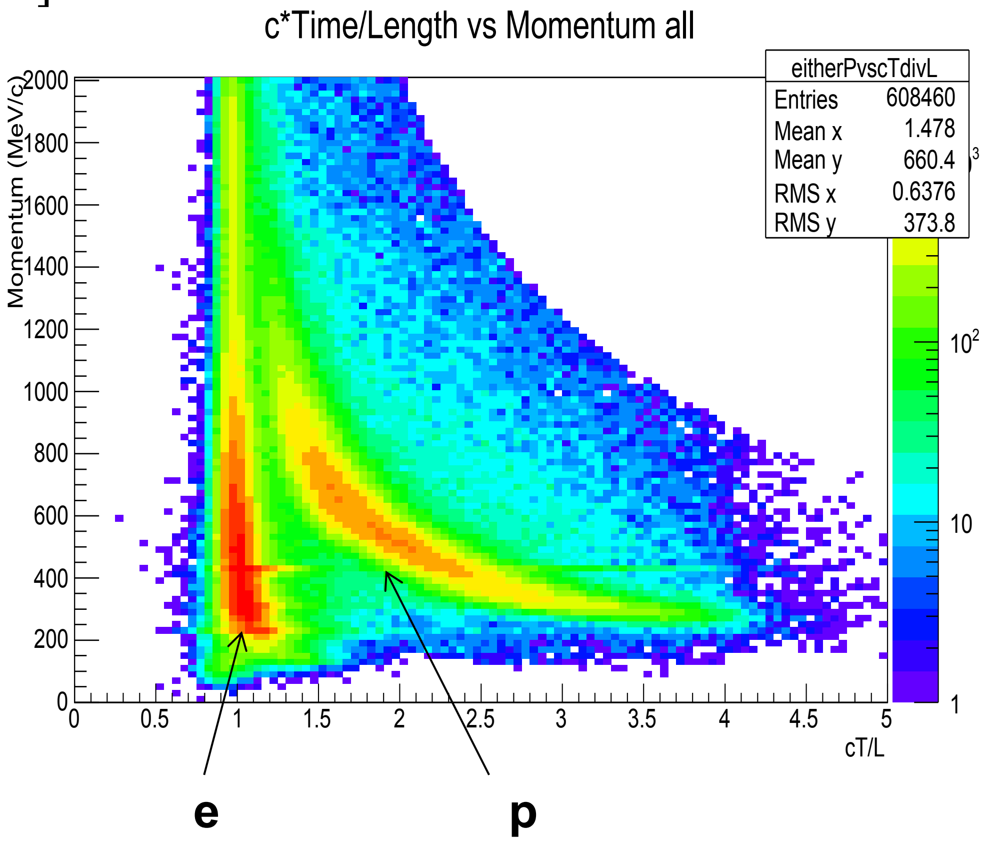


TOF AND TRACKING BASED PID

Particle **ID** based on calculated mass (M) using tracking momentum (P), ToF track path length (L) and hit time (T)

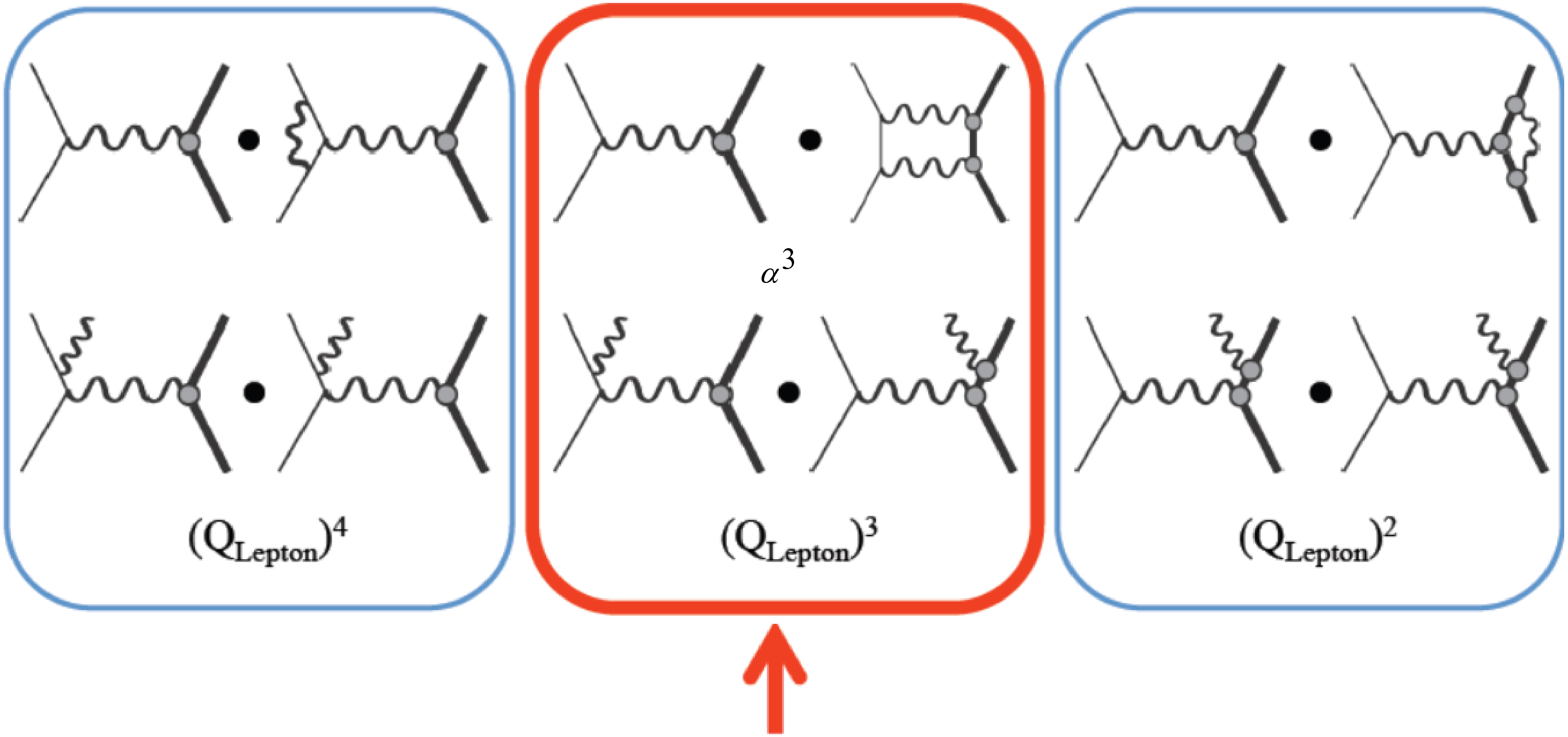
Calculated mass square: $M^2 = P^2[(cT/L)^2 - 1]$





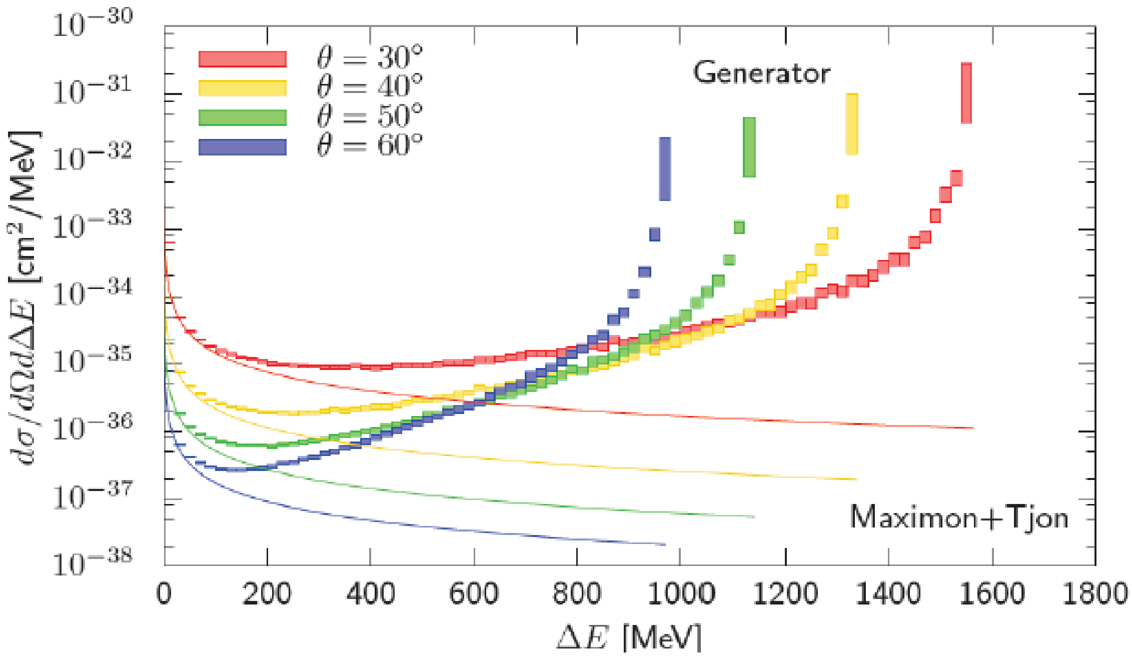
RADIATIVE CORRECTIONS OF α^3 ORDER

- All standard RC's are implemented in MC framework to extract hard TPE effect
- Consistency of radiative corrections between different experiments (VEPP-3, Jlab, Olympus) desirable



Changes sign with the lepton charge

MIT RADIATIVE GENERATOR

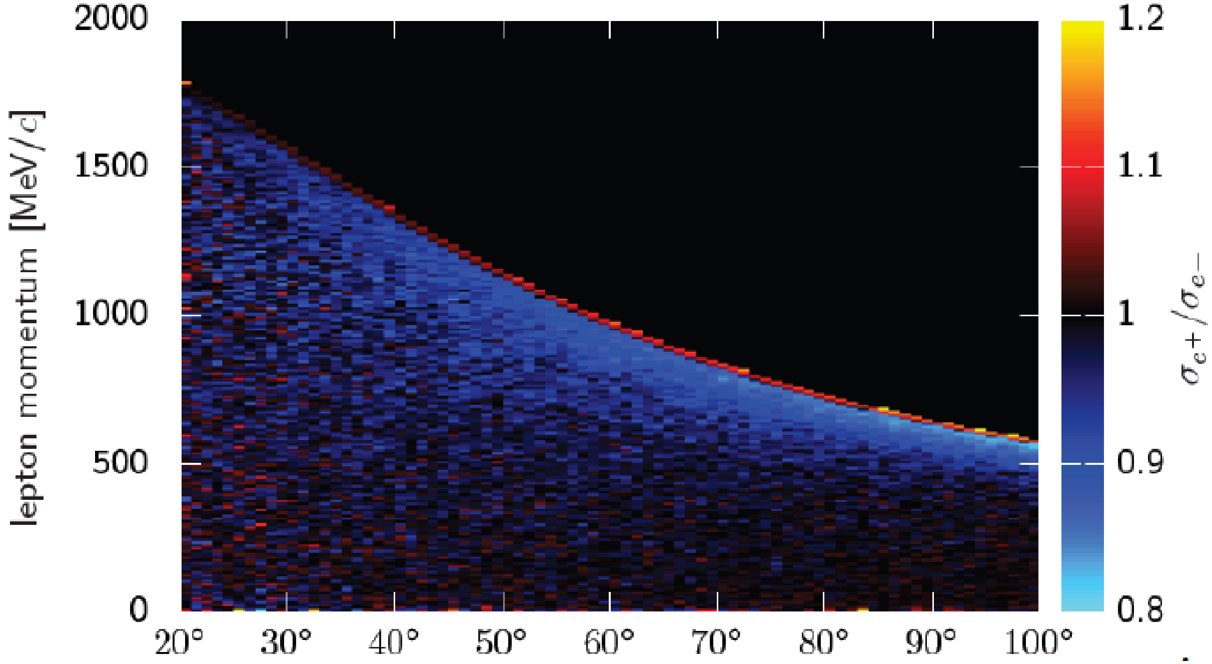


Agreement with Maximon&Tjon at low ΔE (soft photons)

Exact calculations of bremsstrahlung matrix element

Due to initial state radiation lowering effective incident beam energy → rise in cross section at high ΔE

MIT RADIATIVE GENERATOR



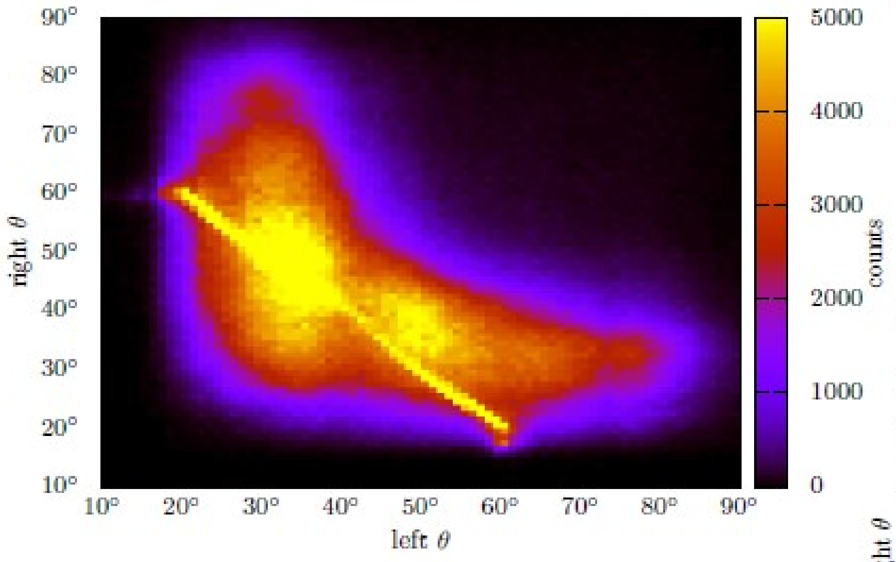
Lepton scattering angle

Effect on $\frac{\sigma_{e^+}}{\sigma_{e^-}}$ ratio up to 10% depending on kinematics

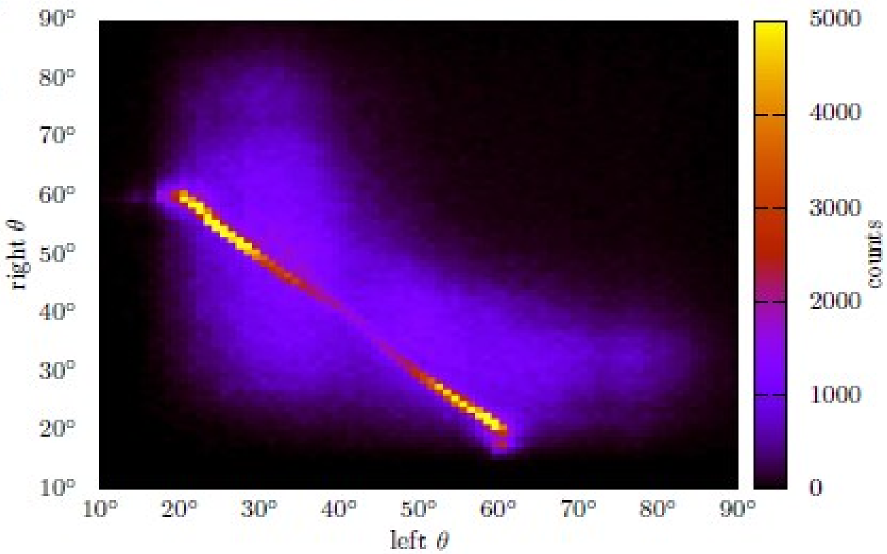
STATUS OF ANALYSIS: DATA SELECTION

preliminary

Right vs. left theta angle after initial cuts



After coplanarity cut

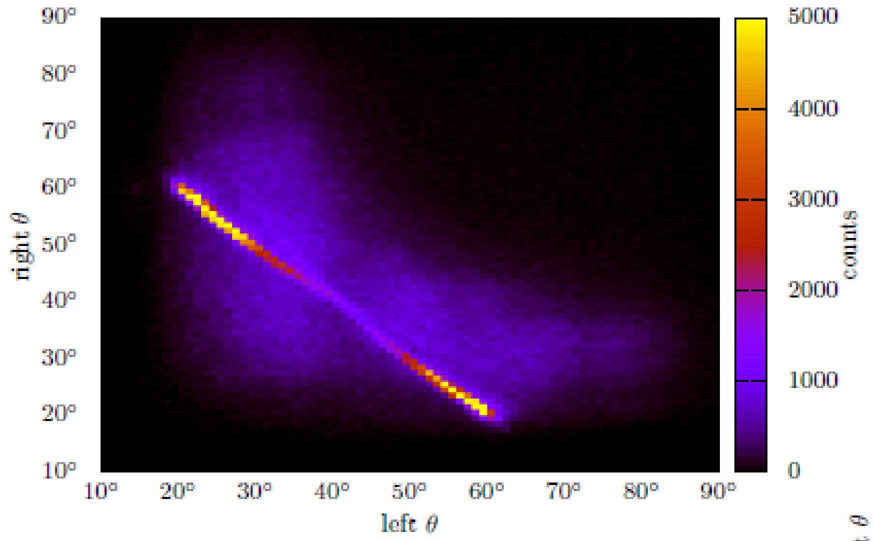


Several independent analyses of data in progress

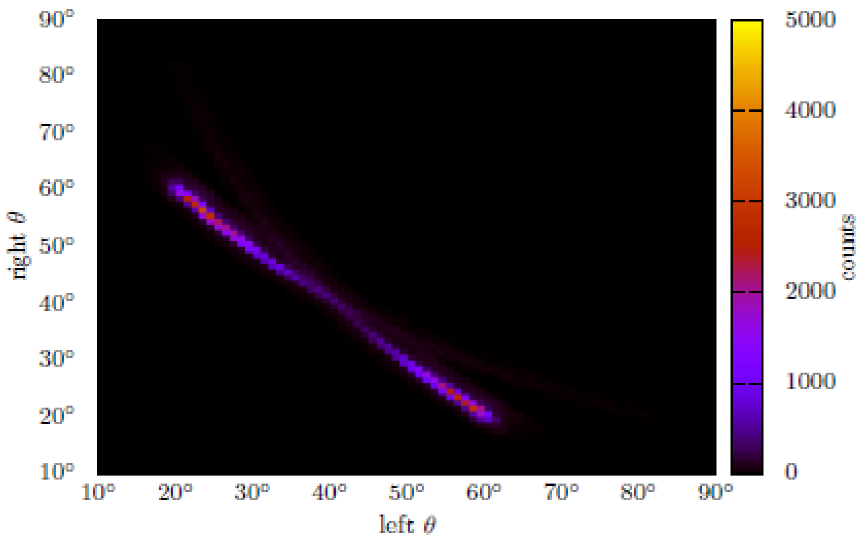
STATUS OF ANALYSIS: DATA SELECTION

preliminary

Right vs. left theta angle after vertex cuts

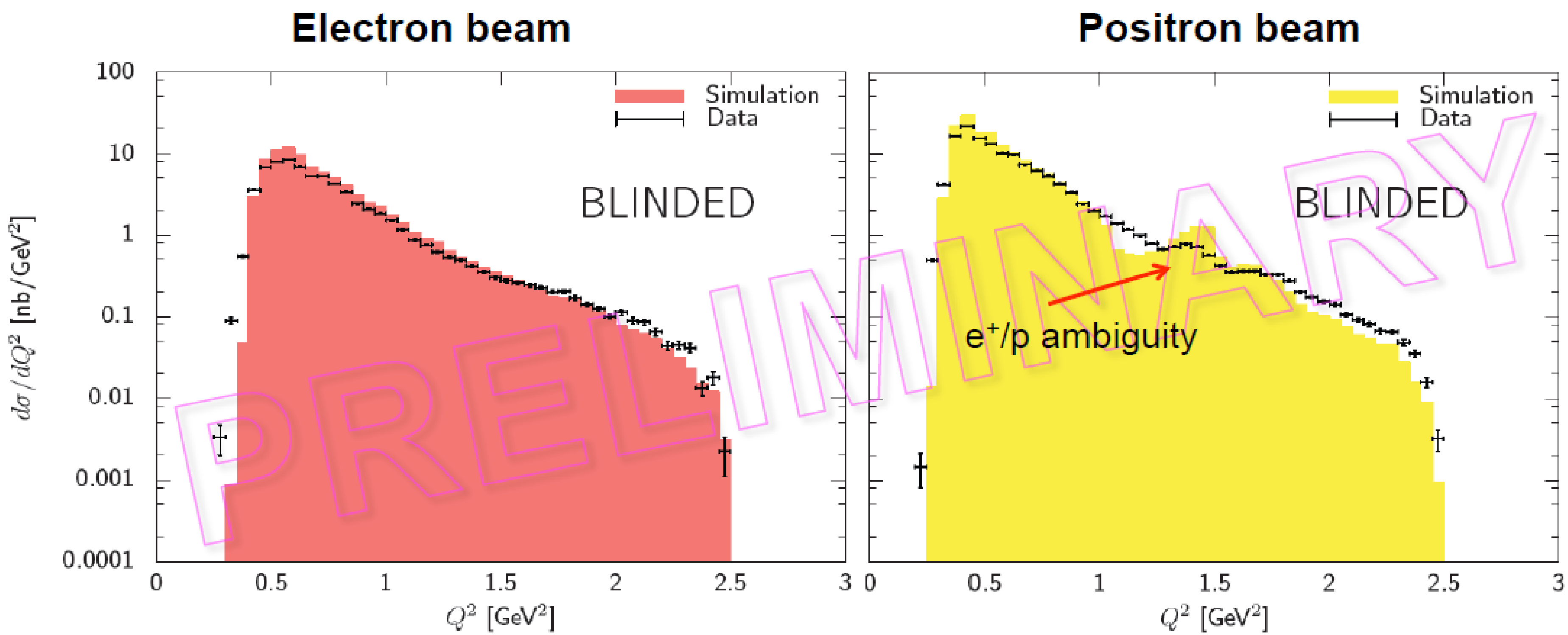


After theta and momentum cuts



STATUS OF ANALYSIS: YIELDS

~2% of total collected statistics



CONCLUSIONS/OUTLOOK

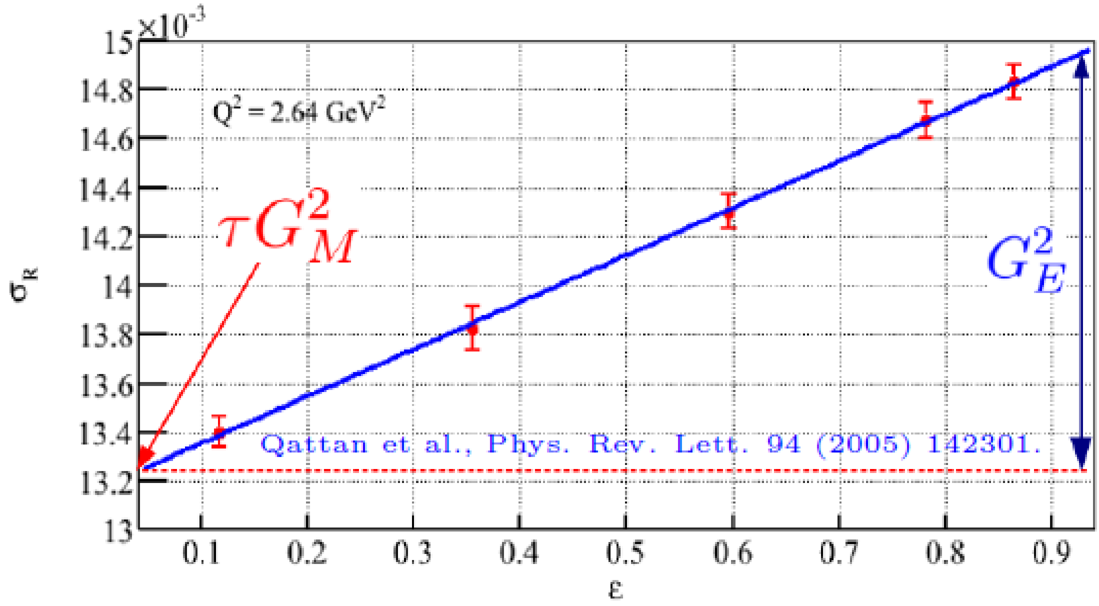
- Importance of TPE study to solve FFs ratio puzzle
  - Two other experiments at Novosibirsk and Jlab
- Successful data taking in 2012
- Data analysis in progress
- Large efforts to solve the problems with RCs, as well to understand systematic uncertainties to achieve e+/e- ratio measurement at 1% level
- Preliminary results expected at the end of this year

BACKUP SLIDES

CONTENT

- Motivations
- Other experiments
- OLYMPUS Experiment
- Analysis status
- Conclusions

FORM FACTORS: Rosenbluth method

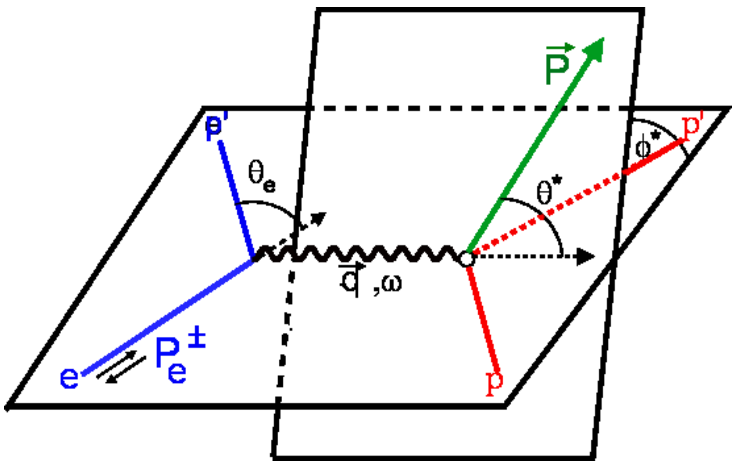


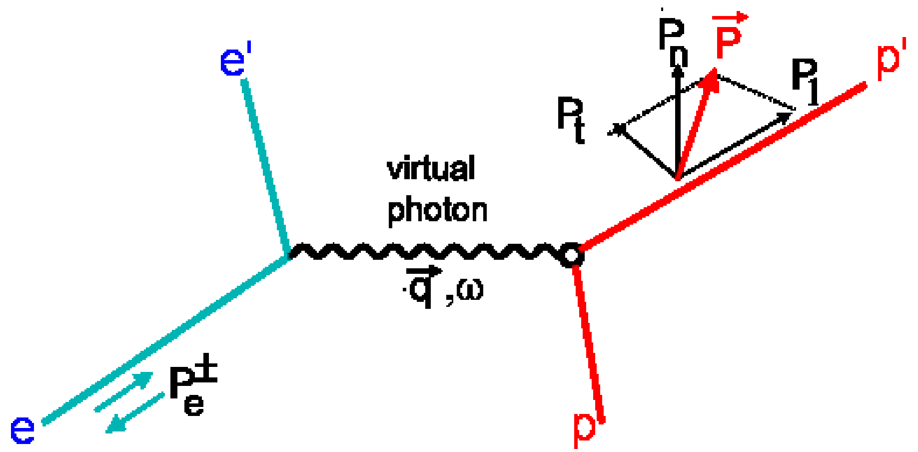
$$\sigma_R = \varepsilon(1+\tau)\frac{d\sigma}{d\Omega} / \left(\frac{d\sigma}{d\Omega}\right)_{Mott} = \varepsilon G_E^2 + \tau G_M^2$$

$$\tau = \frac{Q^2}{4M_N^2}, \quad \varepsilon = [1 + 2(1+\tau)\tan^2(\theta/2)]^{-1}$$

- **Extract G_E and G_M as a slope and intercept respectively**
- **At high Q^2 contributions from G_M dominates over G_E**

FORM FACTORS: POLARIZATION TRANSFER (RIGHT) AND BEAM-TARGET ASYMMETRY (LEFT)



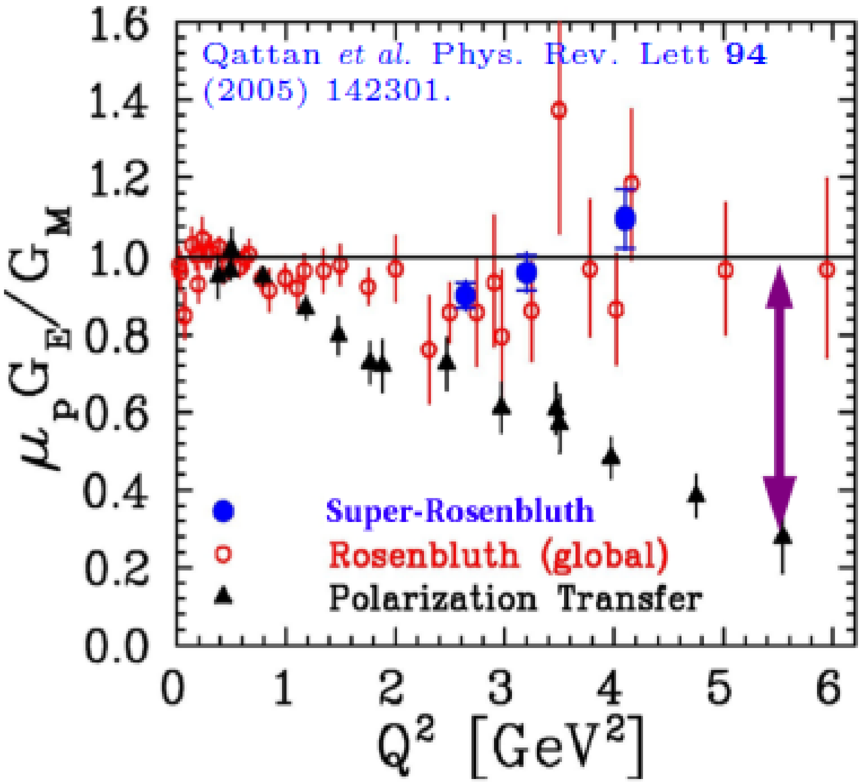


$$A = \frac{2\sqrt{\tau(1+\tau)}\tan(\Theta_e/2)}{G_E^2 + \frac{\tau}{\varepsilon}G_M^2} \times$$

$$\left[\sin\Theta^* \cos\Phi^* G_E G_M + \sqrt{\tau[1+(1+\tau)\tan^2(\Theta_e/2)]}\cos\Theta^* G_M^2\right]$$

$$\frac{G_E}{G_M} = -\frac{P_t}{P_l}\frac{(E_e + E_e')}{2M_p}\tan\left(\frac{\Theta_e}{2}\right)$$

FORM FACTORS RATIO: PUZZLE



Puzzle:

Huge discrepancy increasing with Q^2

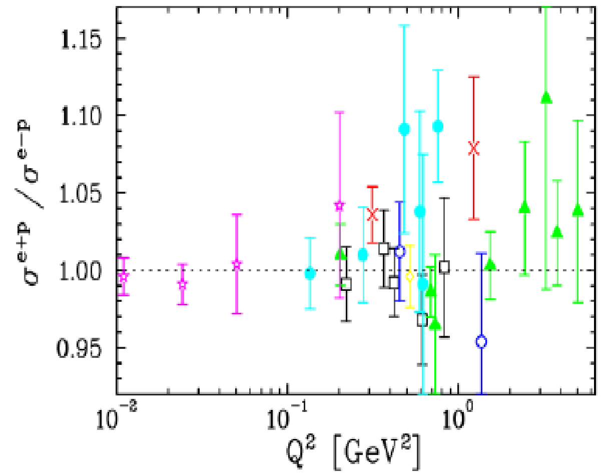
Both methods assume OPE

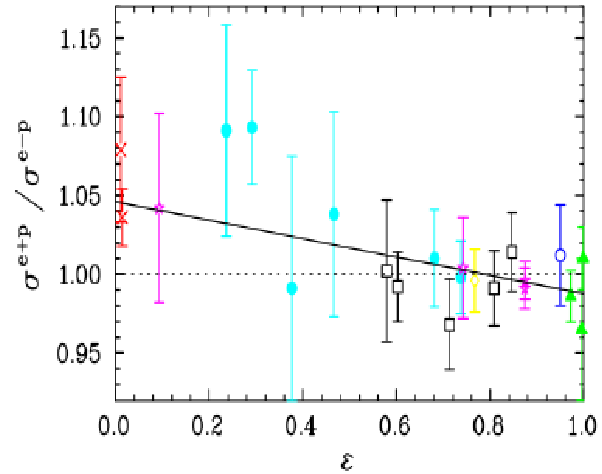
Rosenbluth has large stat. and syst. uncertainties and more problem with RC

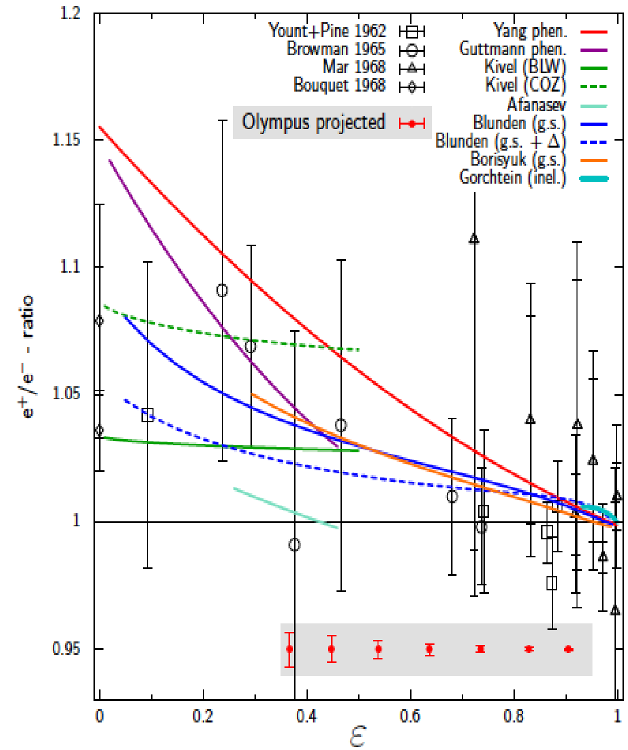
TPE can explain puzzle !

Arrington et al. Phys. Rev. C76 (2007) 035205

PREVIOUS TPE WORLD DATA AND PROJECTED OLYMPUS RESULTS







- **TPE contribution measured in early 1960s**
  ⟶ small effect
- **Due to big errors ⟶ no conclusion**

Expected sensitivity

EXISTING E^+ / E^- EXPERIMENTS

	VEPP–3 Novosibirsk	OLYMPUS DESY	EG5 CLAS JLab
beam energy	3 fixed	1 fixed	wide spectrum
equality of $e^{\pm}$ beam energy	measured	measured	reconstructed
e^+/e^- swapping frequency	half-hour	24 hours	simultaneously
e^+/e^- lumi monitor	elastic low-Q^2	elastic low-Q^2, Möller/Bhabha	from simulation
energy of scattered $e^{\pm}$	EM-calorimeter	mag. analysis	mag. analysis
proton PID	$\Delta E/E$, TOF	mag. analysis, TOF	mag. analysis, TOF
e^+/e^- detector acceptance	identical	big difference	big difference
luminosity	1.0×10^{32}	2.0×10^{33}	2.5×10^{32}
beam type target type	storage ring internal H target	storage ring internal H target	secondary beam liquid H target
data taken	2009, 2011-12	2012	2011

ANALYSIS FRAMEWORK

ROOT based C^{++} ("cooker")

With plug-ins and recipes to work equivalently with Data and MC