UPDATE ON THE OLYMPUS TWO-PHOTON EXCHANGE EXPERIMENT

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For the OLYMPUS Collaboration

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CONTENT

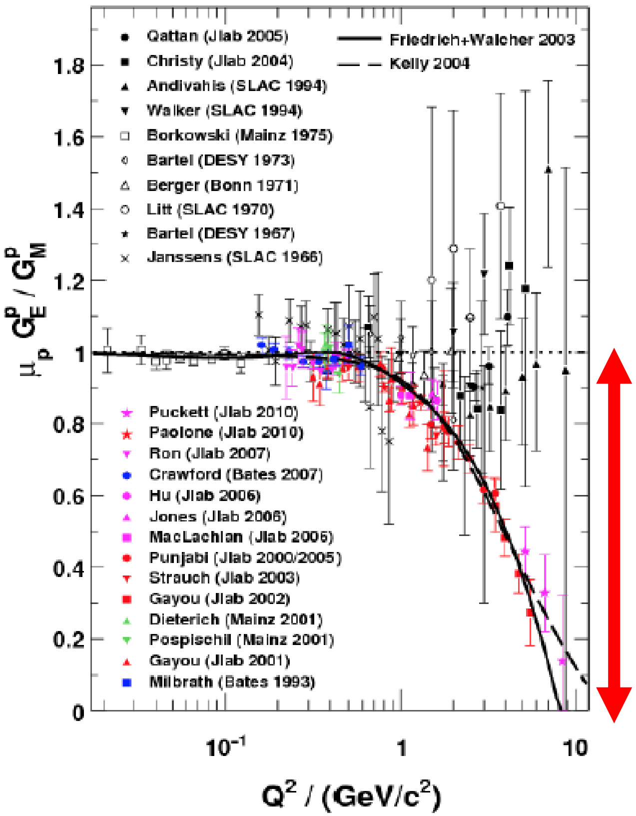
- Motivations
- Other experiments
- OLYMPUS Experiment
- Analysis status
- Conclusions

FORM FACTORS TO DESCRIBE ELASTIC EN SCATTERING

- Four fundamental observables $G_{E(p,n)}$ and $G_{M(p,n)}$ reflecting electric and magnetic charge distribution in 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 Factors Ratio

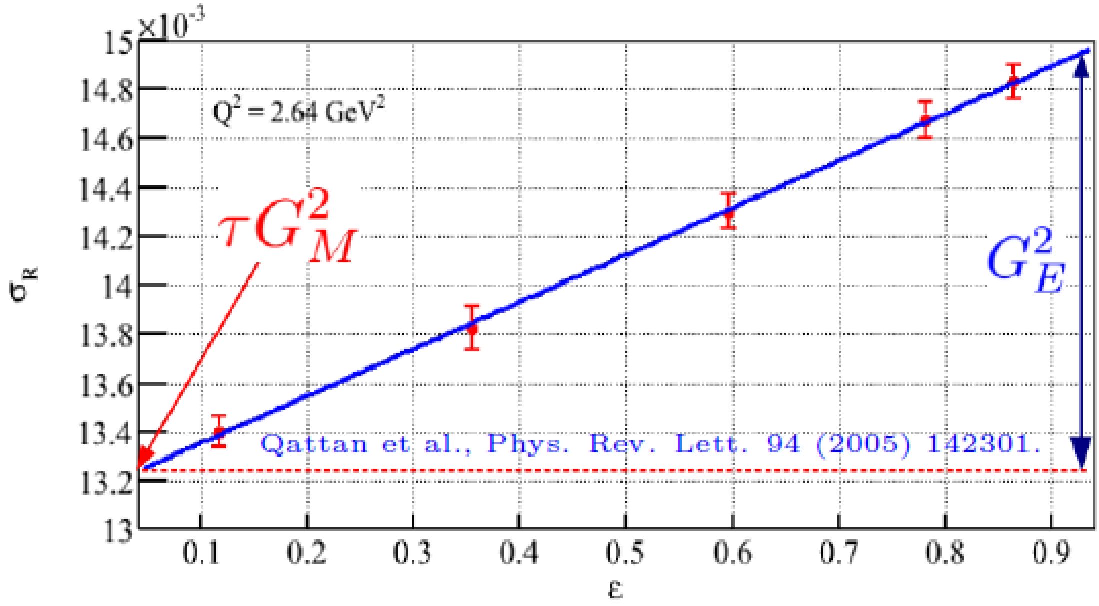


All Rosenbluth data in agreement

Dramatic discrepancy between Rosenbluth and recoil polarization technique (Jefferson Lab data >800 citations)

Interpreted as evidence for TPE in ep elastic scattering

Form factors: Rosenbluth method

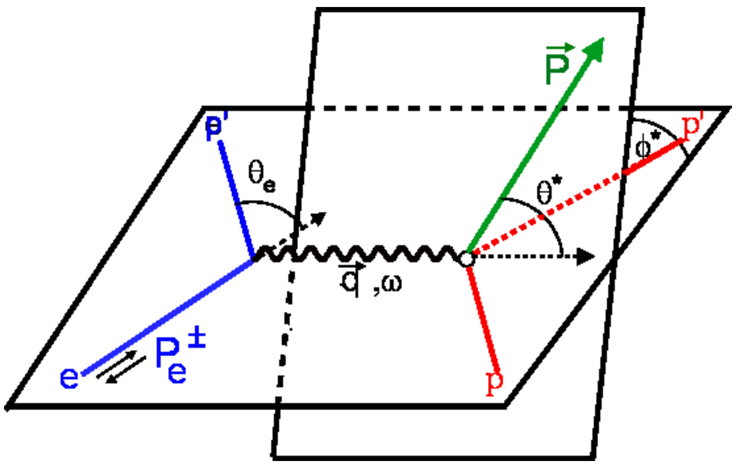


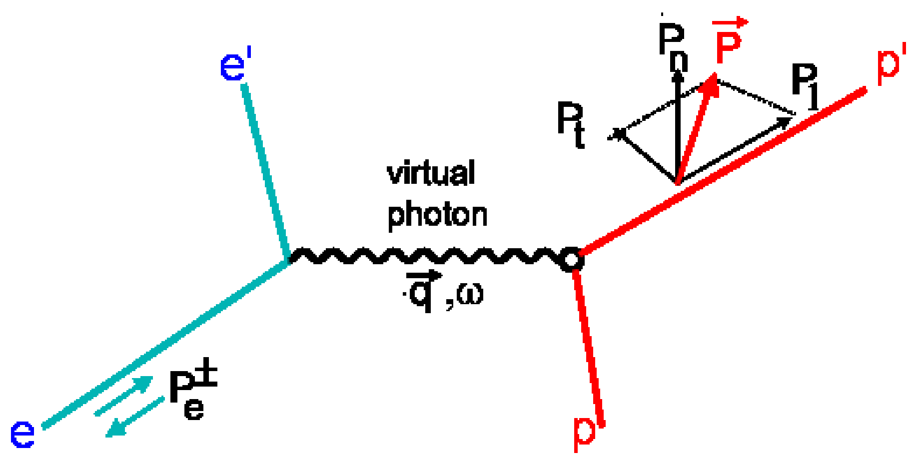
$$\sigma_R = \varepsilon(1+\tau)\frac{d\sigma}{d\Omega}/(\frac{d\sigma}{d\Omega})_{Mott} = \varepsilon G_E^2 + \tau G_M^2$$

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

- **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)



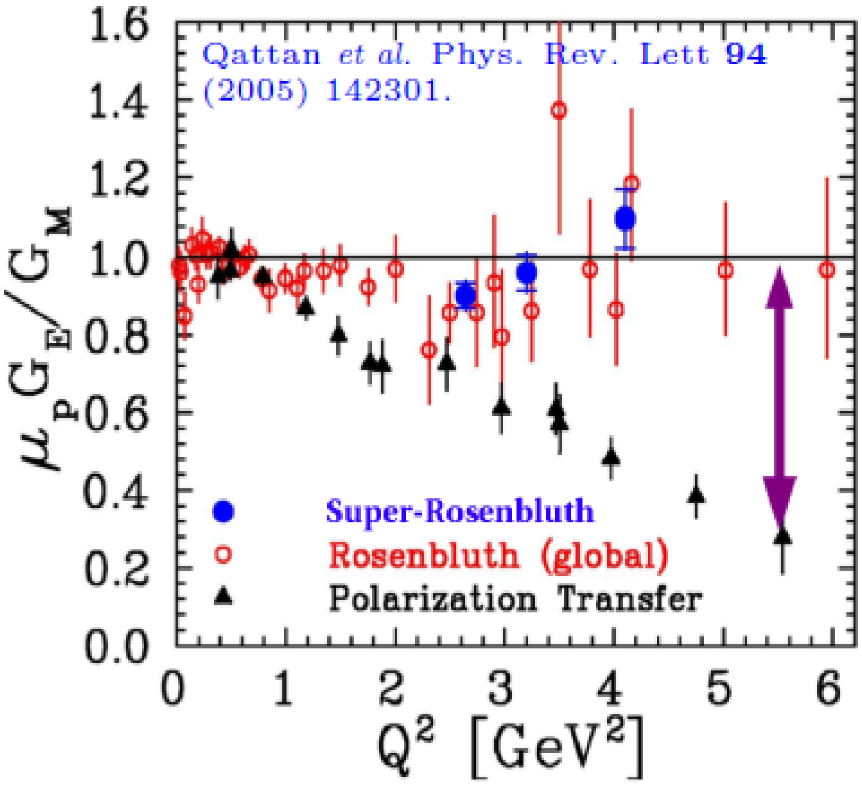


$$A = \frac{2\sqrt{\tau(1+\tau)}\tan(\vartheta_e/2)}{G_E^2 + \frac{\tau}{\varepsilon}G_M^2} \times$$

$$\left[\sin\vartheta^* \cos\varphi^* G_E G_M + \sqrt{\tau[1+(1+\tau)\tan^2(\theta_e/2)]}\cos\vartheta^* G_M^2\right]$$

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

FORM FACTORS RATIO: PUZZLE



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

Puzzle:

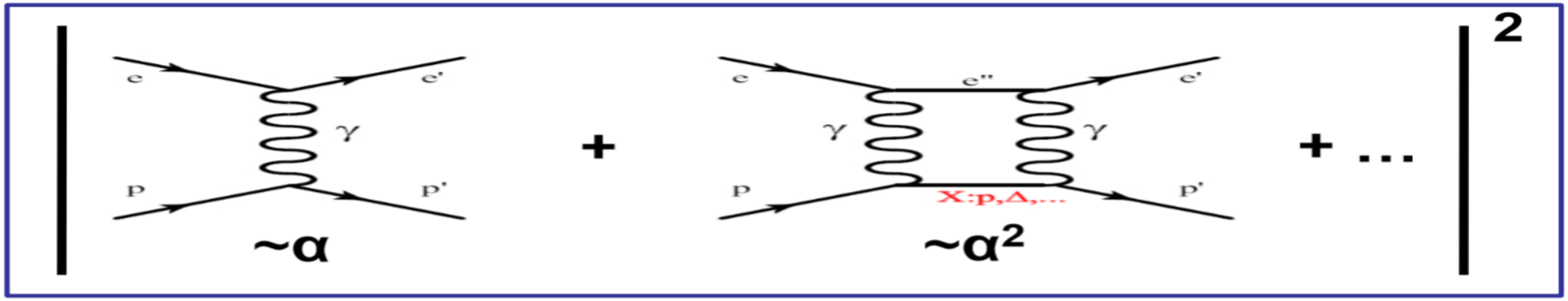
Huge discrepancy increasing with Q^2

Both methods assume OPE

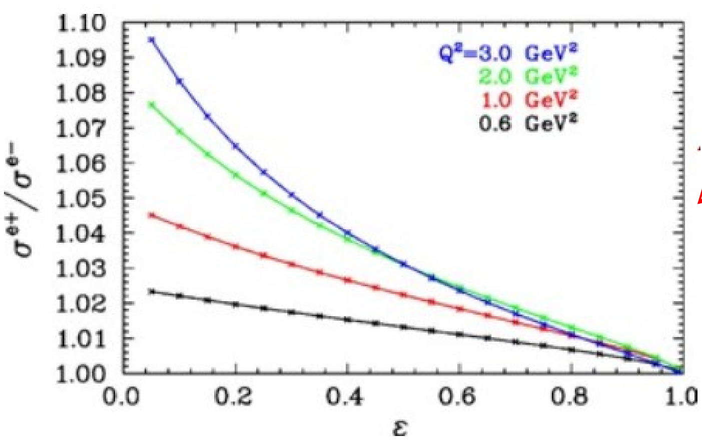
Rosenbluth has large stat. and syst. uncertainties

TPE can explain puzzle !

TWO PHOTON EXCHANGE (TPE) CONTRIBUTION



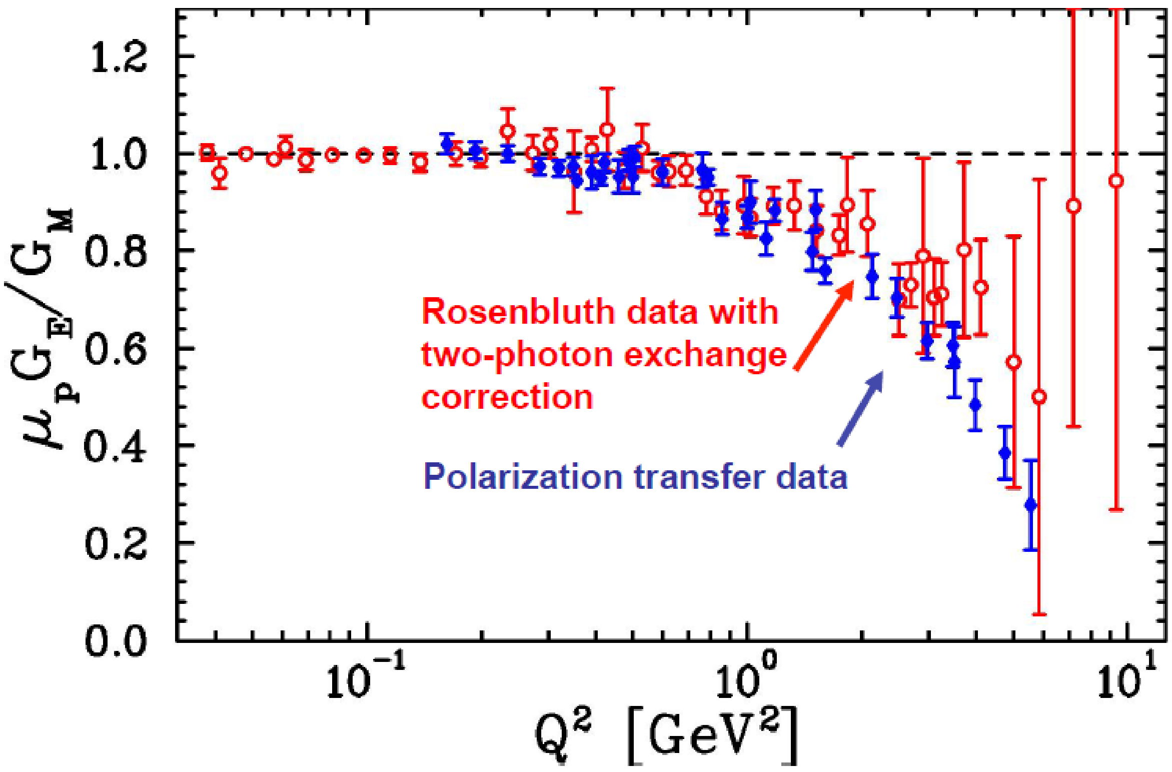
$$\frac{\sigma_{e^+p}}{\sigma_{e^-p}} = \frac{\left[\left|M_{Born}\right|^2 + 2e^2 M_{Born}\,\mathrm{Re}(M^*_{2\gamma}) + \ldots\right]}{\left[\left|M_{Born}\right|^2 - 2e^2 M_{Born}\,\mathrm{Re}(M^*_{2\gamma}) - \ldots\right]}$$



Model dependent

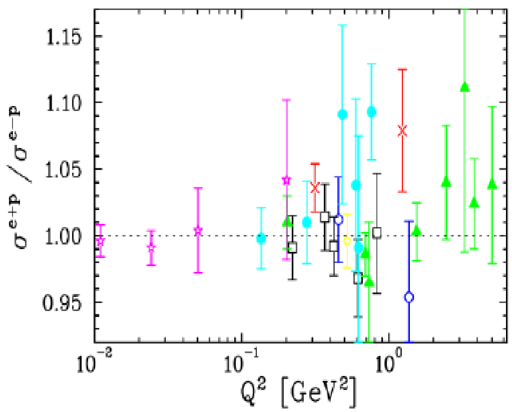
P.G. Blunden et al., Phys. Rev. C72 (2005) 034612

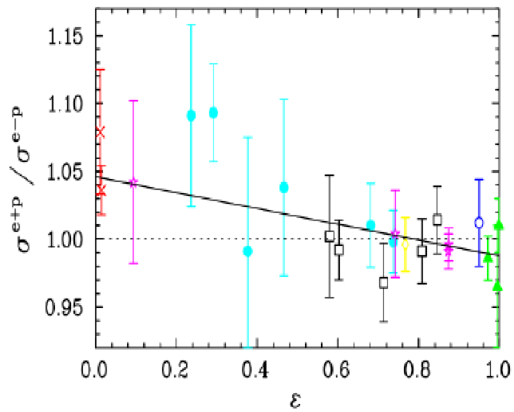
TPE CORRECTED ROSENBLUTH DATA

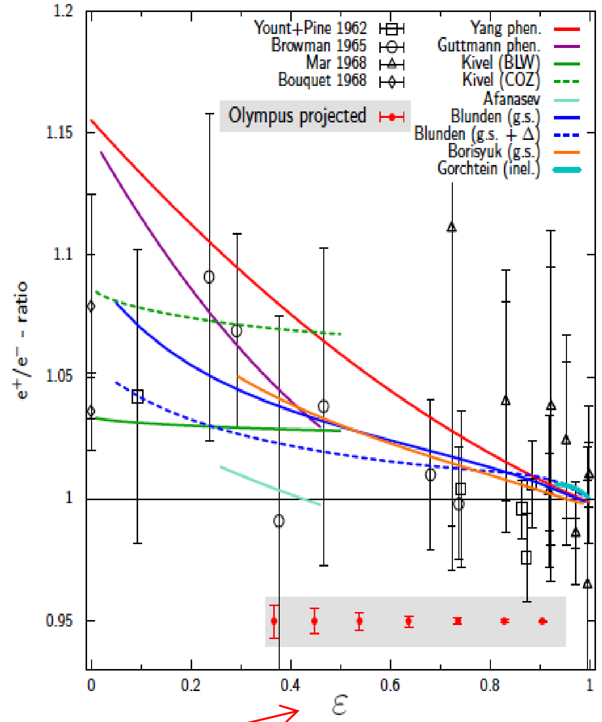


TPE can explain form factors ratio discrepancy:
J Arrington, W. Melnitchouk, J.A. Tjon, Phys. Rev. C 76 (2007) 035205

PREVIOUS TPE WORLD DATA AND PROJECTED OLYMPUS RESULTS







- ➢ **TPE contribution measured in early 1960s**
  ⟶ small effect
- ➢ **Due to big errors ⟶ no conclusion**
  ⟶ not resolved discrepancy

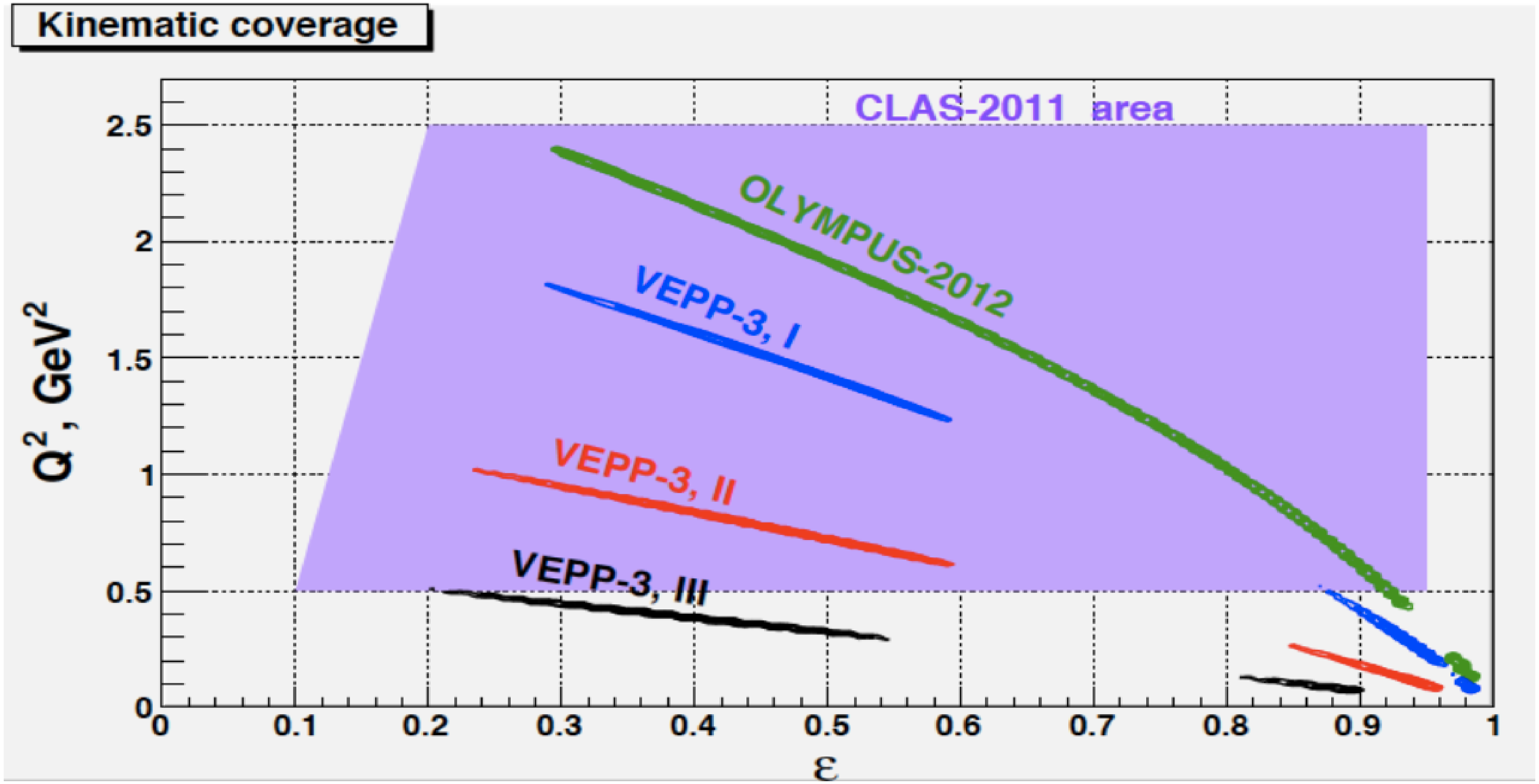
Expected sensitivity

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	storage ring	storage ring	secondary beam
target type	internal H target	internal H target	liquid H target
data taken	2009, 2011-12	2012	2011

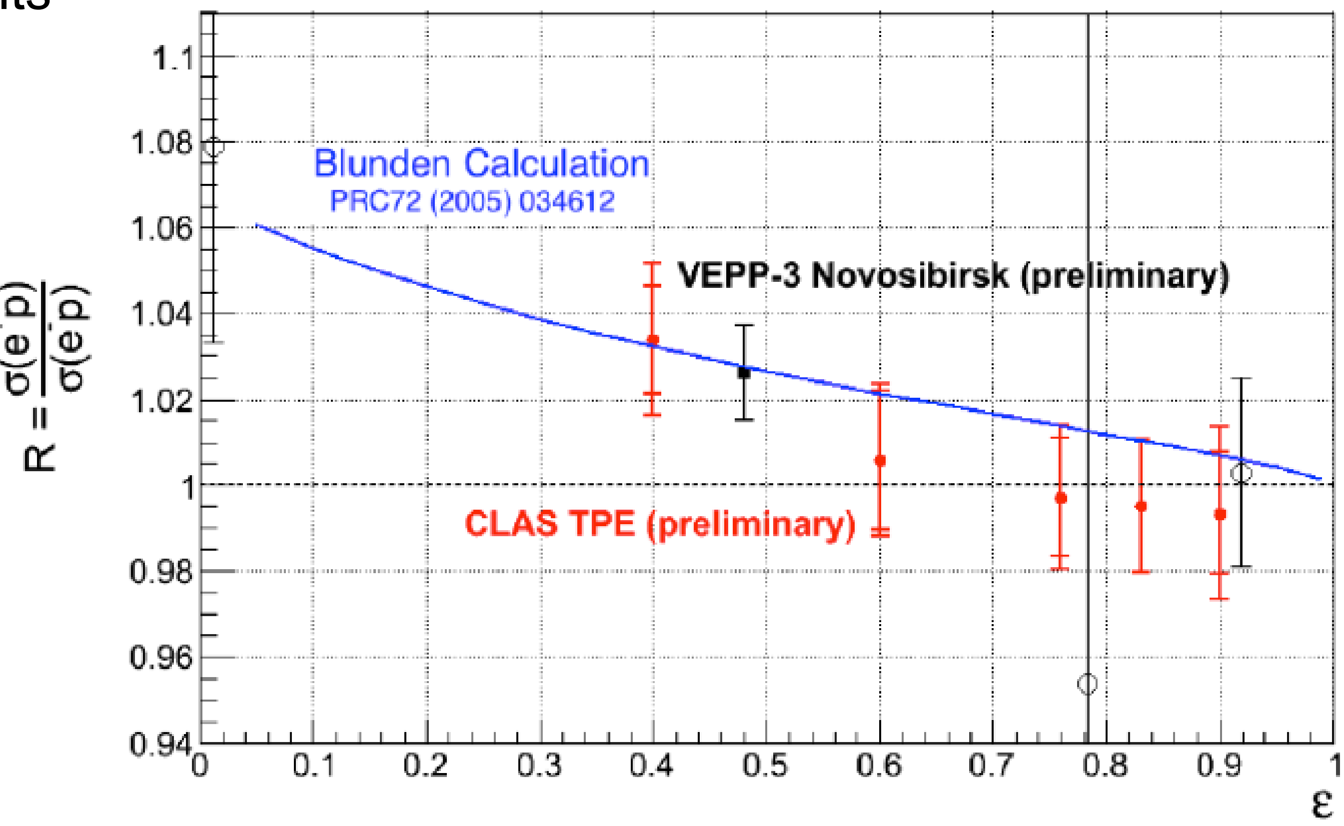
EXISTING E^+ / E^- EXPERIMENTS

- ✓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

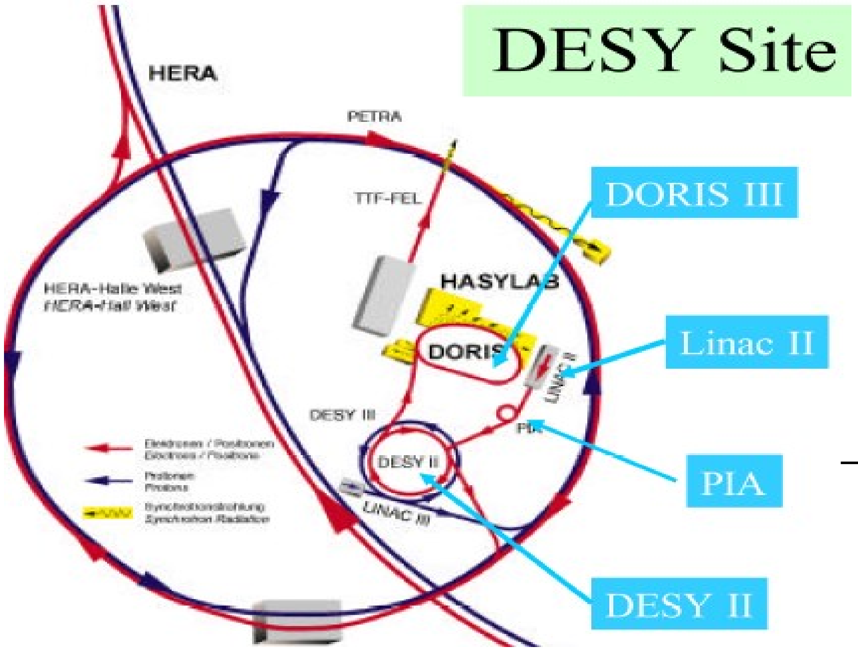


VEPP-3 AND CLAS TPE PRELIMINARY RESULTS

Good agreement between VEPP-3 and CLAS for preliminary results



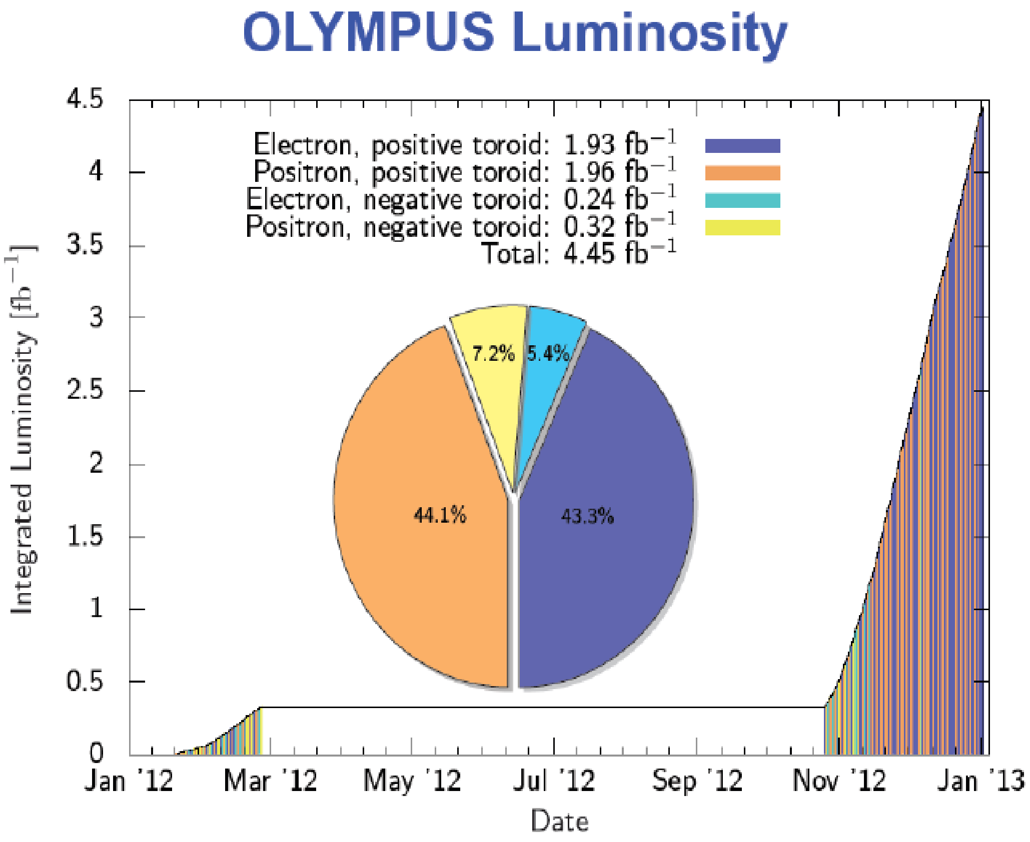
WHY DORIS?



→

- ❑ **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**

DATA TAKING IN 2012



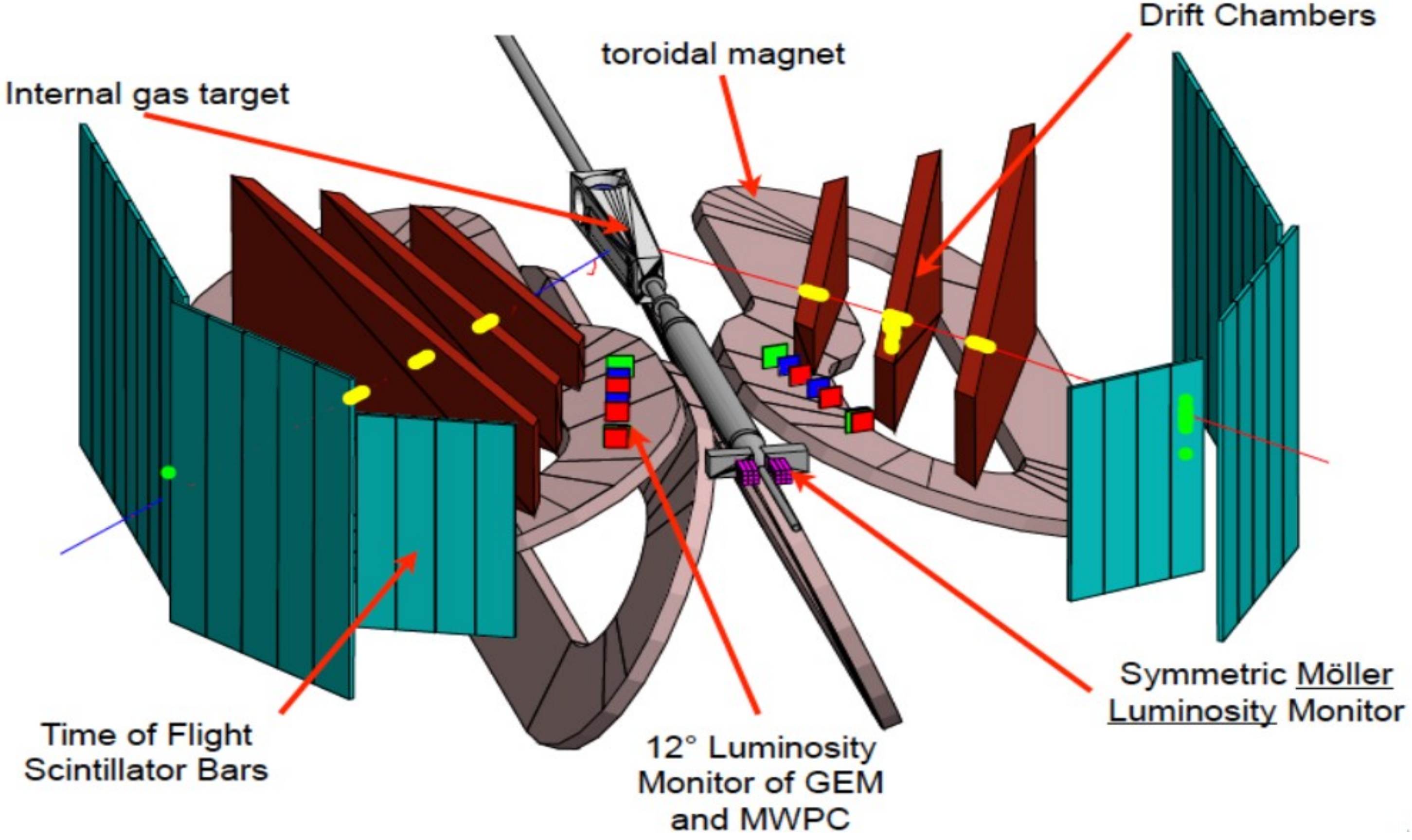
Limited flow and luminosity in Feb. run

Fall run

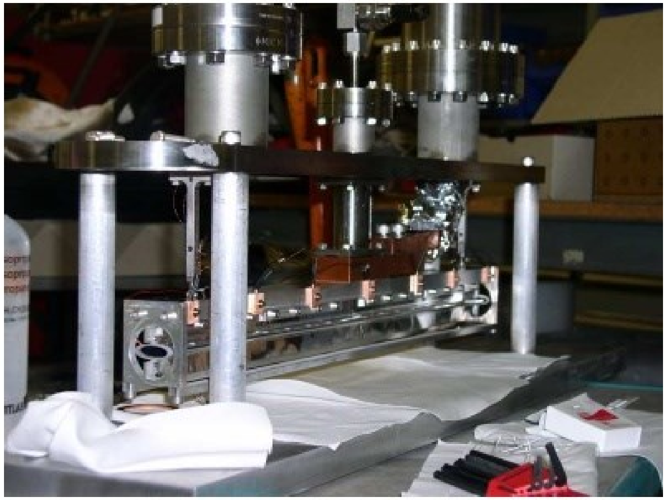
- Full hydrogen flow
- DORIS top-up mode
- Excellent performance
- Exceeded integrated luminosity:
  - Design 3.6fb^{-1}, achieved 4.45fb^{-1}
- Daily switch of beam species, good balance
- Mainly positive toroid polarity due to background
- Negative field for systematics checks

DETECTOR OVERVIEW: R. MILNER ET AL, "THE OLYMPUS EXPERIMENT", NUCL. INSTR. METH. A 741 (2014) 1-17.

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



TARGET SYSTEM: J.C. BERNAUER ET AL., “THE OLYMPUS INTERNAL HYDROGEN TARGET” NUCL. INSTR. METH. A 755 (2014) 20-27.

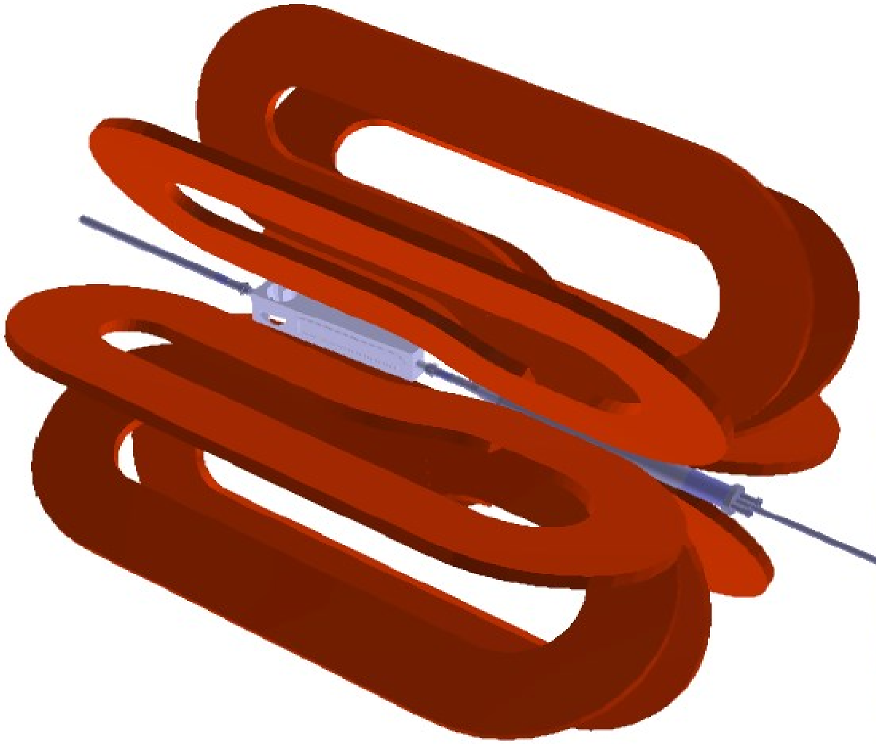


- Internal, windowless gas target
- 60 cm long storage cell
- Elliptical cross section (27^{x} 9) mm^2
- 100 µm thick aluminum wall

- O (10^{15}) atoms/cm^2
- Cryo cooled ~ 45 K
- Hydrogen produced by generator (electrolysis)

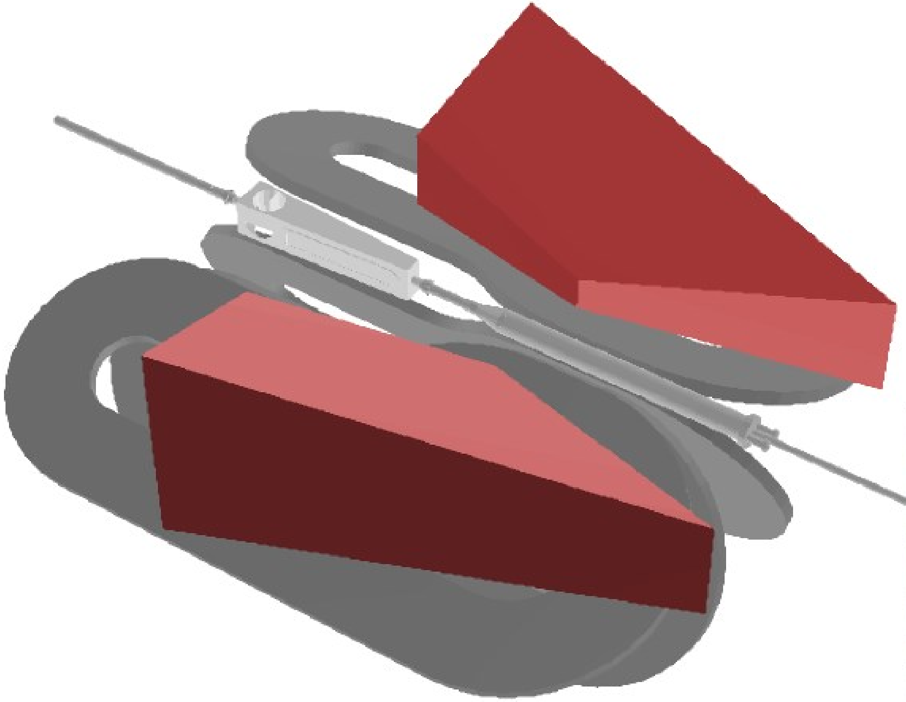
INFN Ferrara, MIT

TOROIDAL MAGNET



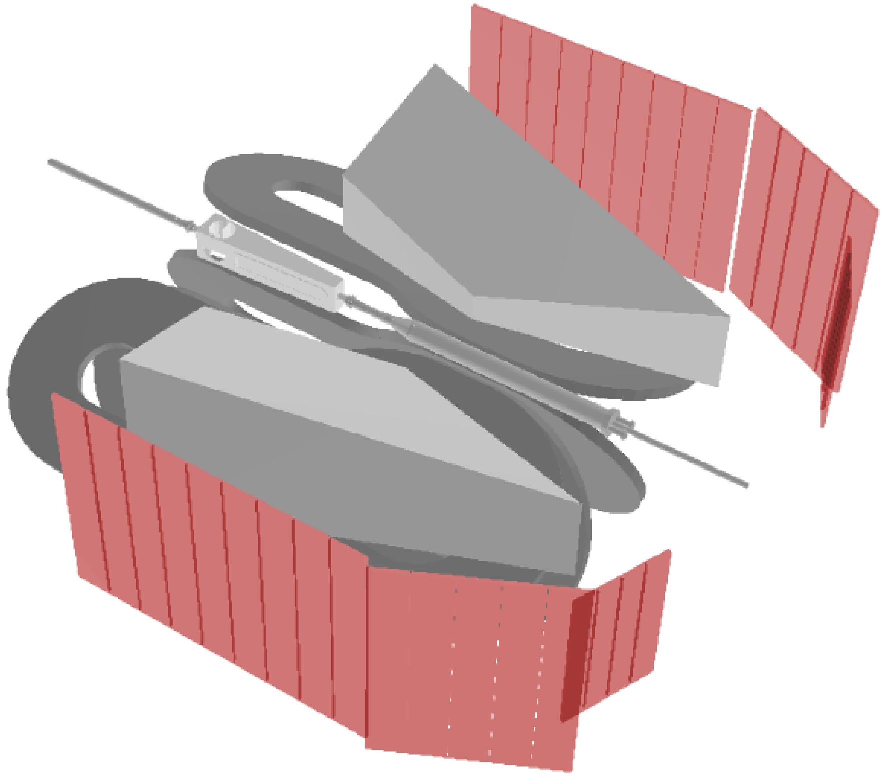
- 8 air coils from BLAST
- Operating at reduced field
- Positive and negative polarity
- Maximum field 0.28 T

DRIFT CHAMBERS



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

TIME-OF-FLIGHT COUNTERS



- Scintillation counters from BLAST
- Trigger
  - Top/bottom coincidence
  - Kinematic constraint
  - + 2nd 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 low angles
  - Two independent tracking system: MWPCs and GEMs
- Mőller/Bhabha monitor at 1.3°
  - High statistics measurement, no dead time

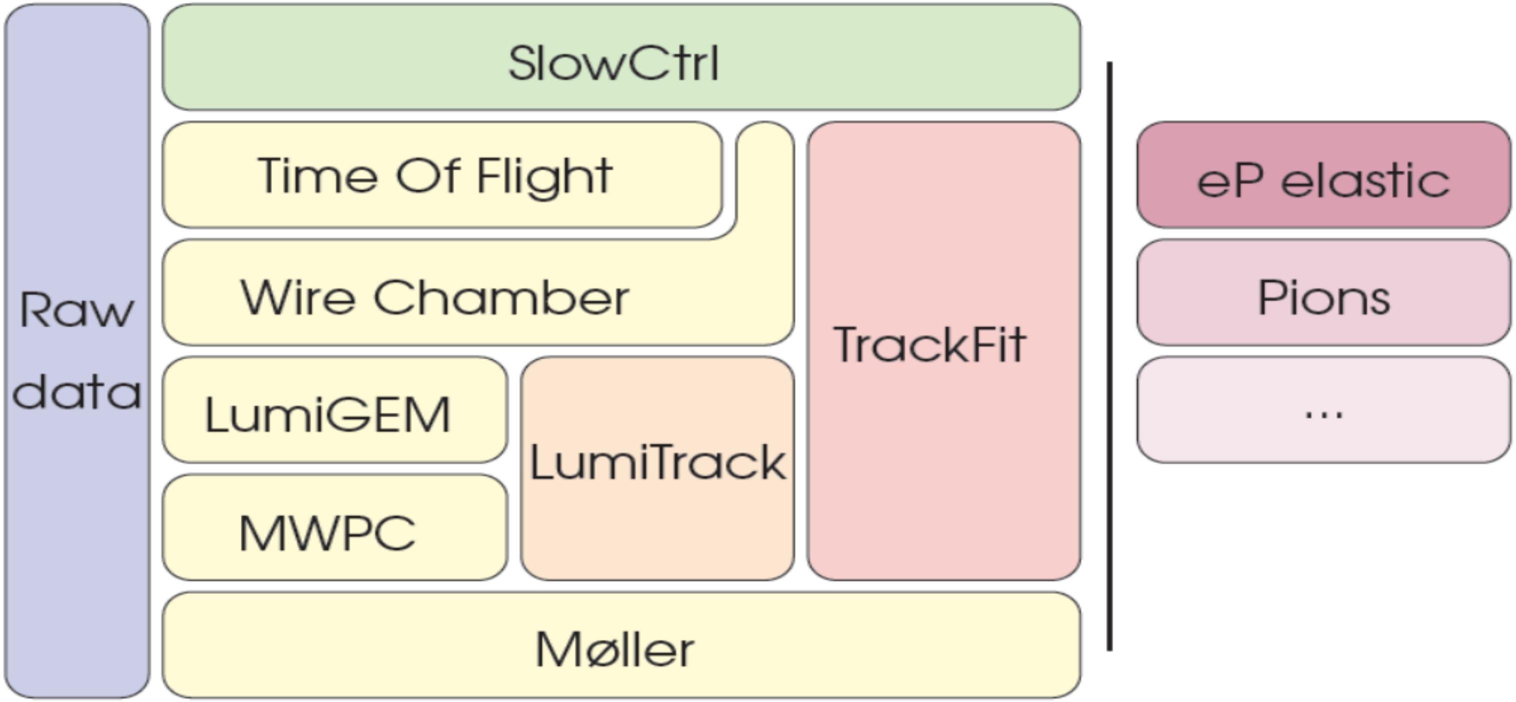
Need $e^+ e^-$ luminosity ratio, not precise absolute luminosity

Details in talk by D. Khaneft

ANALYSIS FRAMEWORK

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

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



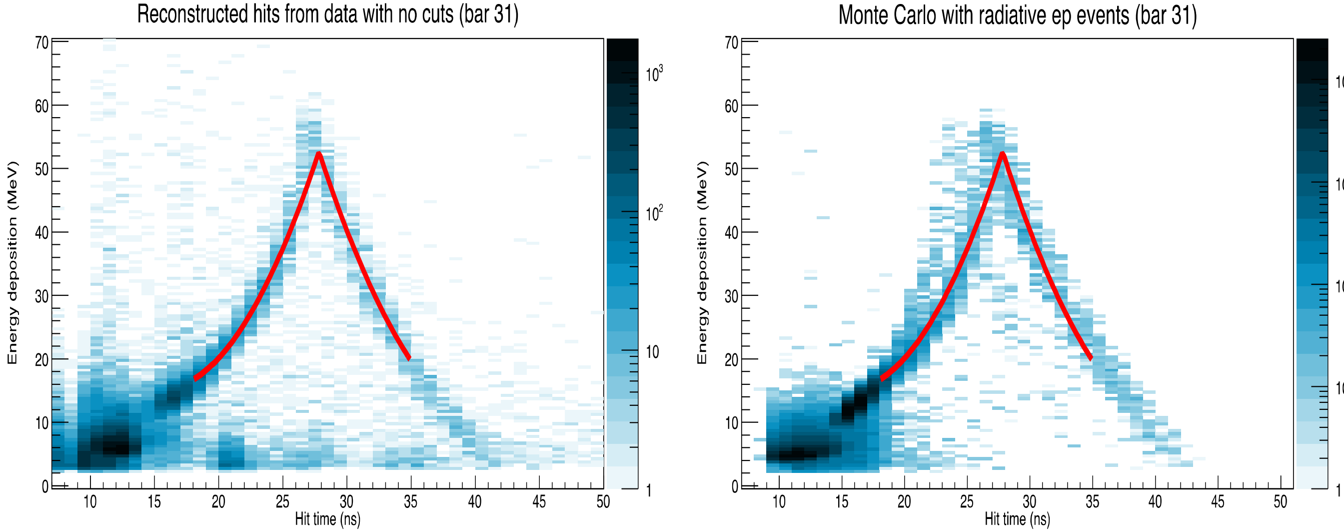
RECENT PROGRESS WITH TOF

Calibration quite advanced

Improved calibration with tracking extended to ToF detectors

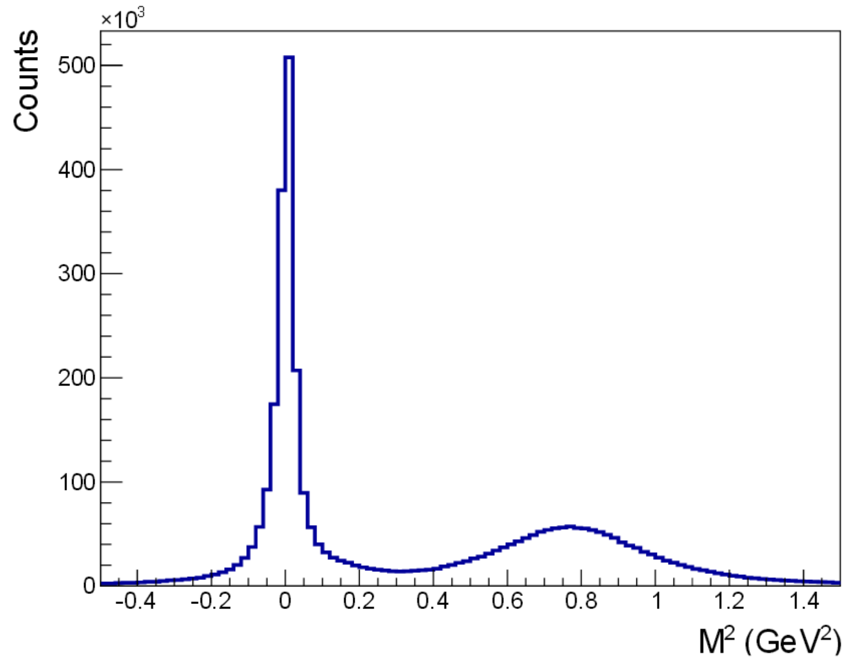
Developed cosmic ray MC generator for better understanding and use of cosmic data for calibration

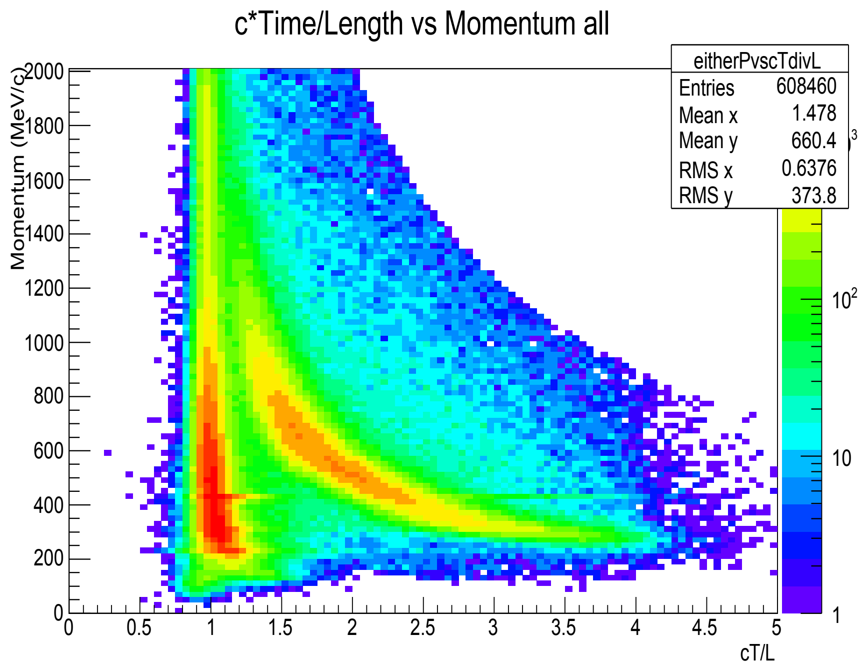
Energy loss vs. hit time



TOF AND WC BASED PID

Particle **ID** based on calculated mass (M) using WC momentum (P), ToF track path (L) and hit time (T): $M^2 = P^2[(cT/L)^2 - 1]$

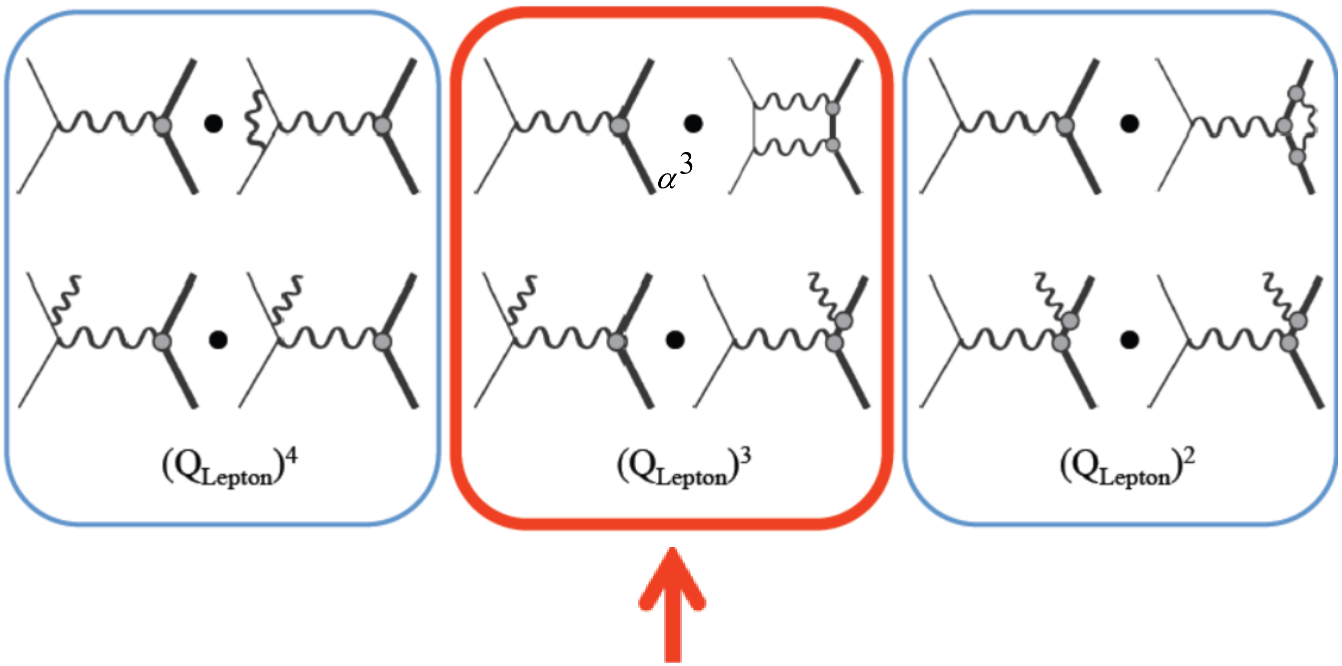




RADIATIVE CORRECTIONS OF α^3 ORDER

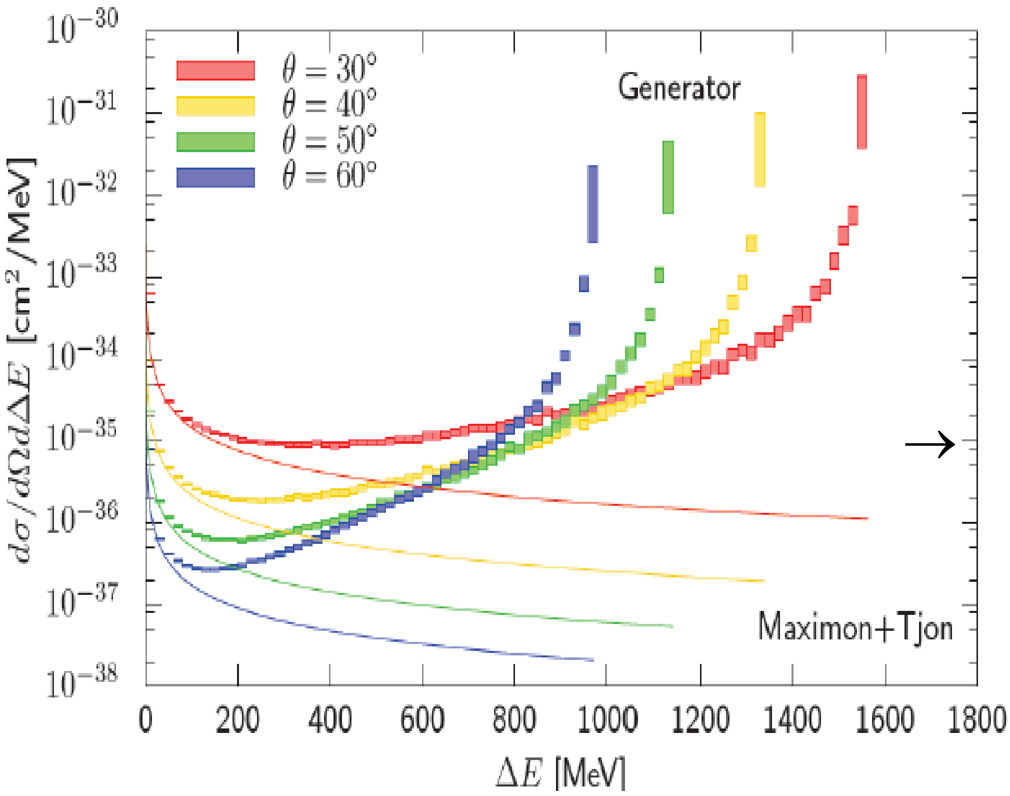
•All standard RC's are implemented in MC framework to extract hard TPE effect

Consistency between different experiments (VEPP-3, Jlab, Olympus)



Changes sign with the lepton charge

MIT RADIATIVE GENERATOR



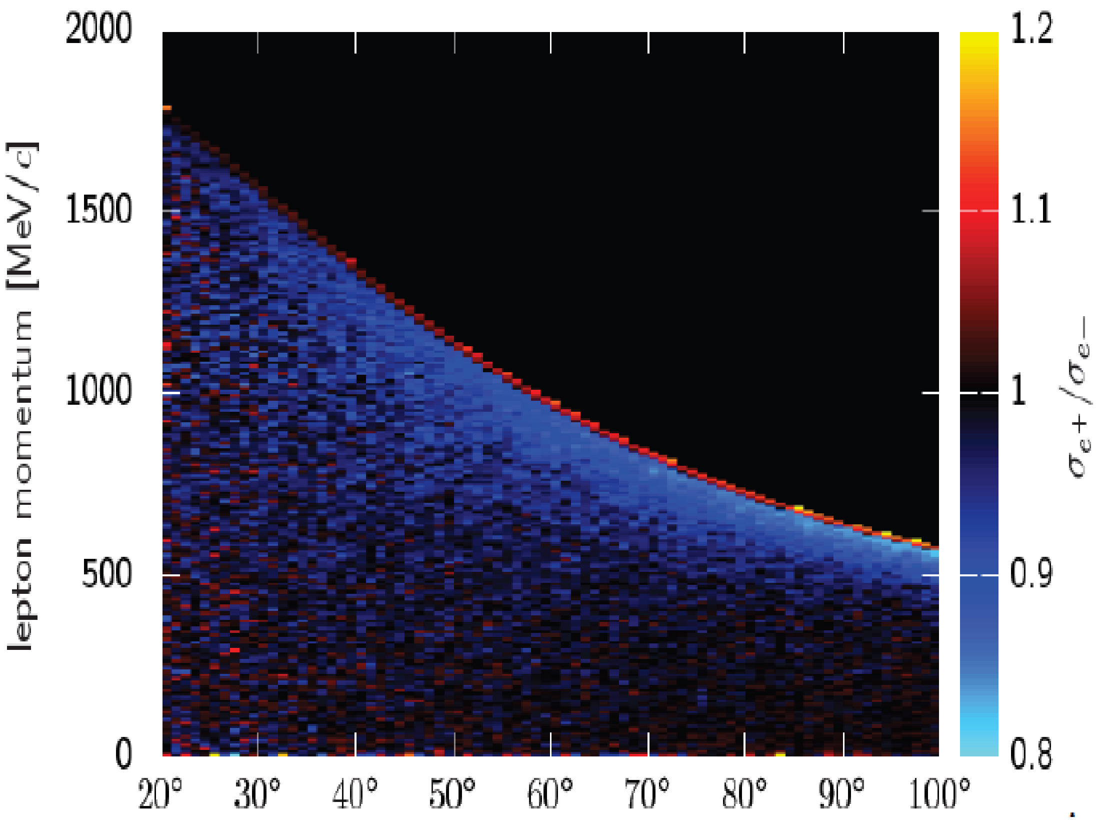
Agreement with Maximon&Tjon at low ΔE (soft photons)

Nice agreement with VEPP-3 generator

Numerical calculations of bremsstrahlung matrix element

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

MIT RADIATIVE GENERATOR



epton scattering angle

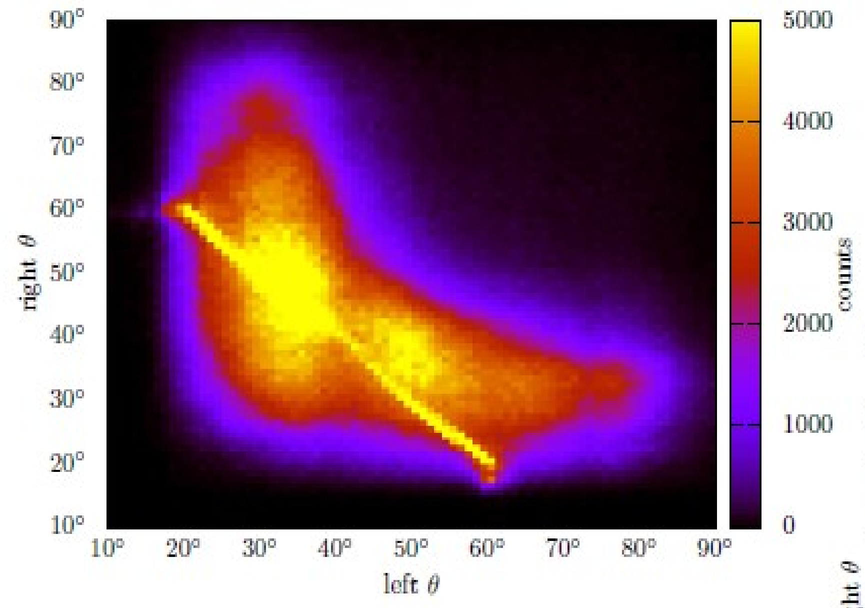
Effect on $\frac{\sigma_{e^+}}{\sigma_{e^-}}$ ratio

up to 10% depending on kinematics

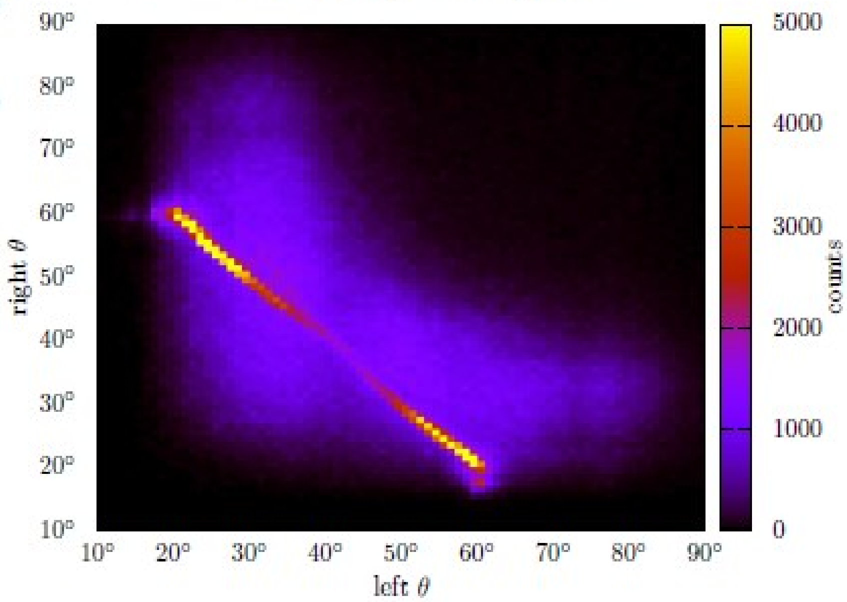
STATUS OF ANALYSIS: DATA SELECTION

Right vs. left theta angle after initial cuts

preliminary



After coplanarity cut

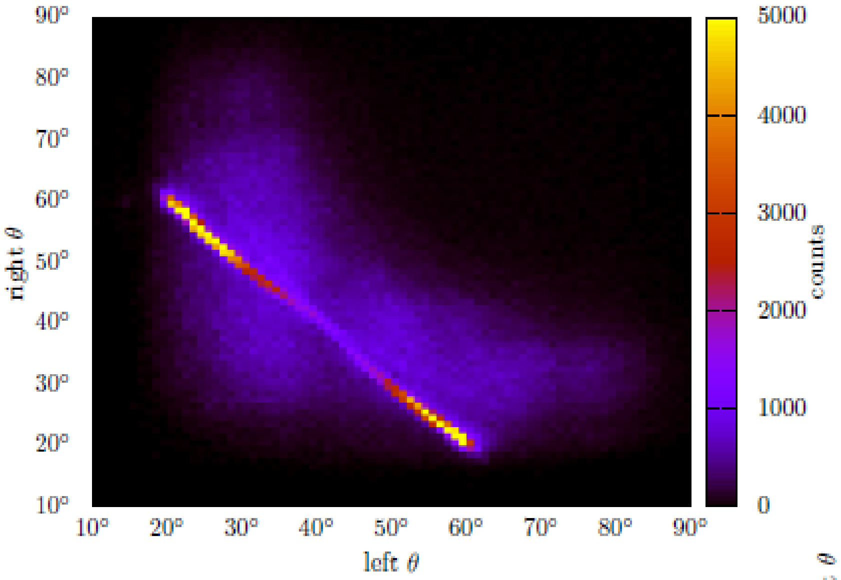


Several independent analyses of data **in progress**

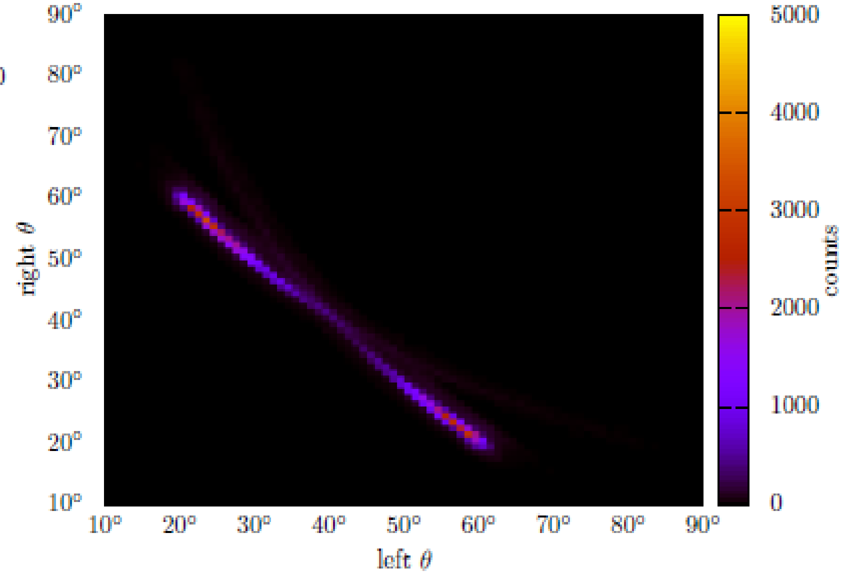
STATUS OF ANALYSIS: DATA SELECTION

Right vs. left theta angle after vertex cuts

preliminary

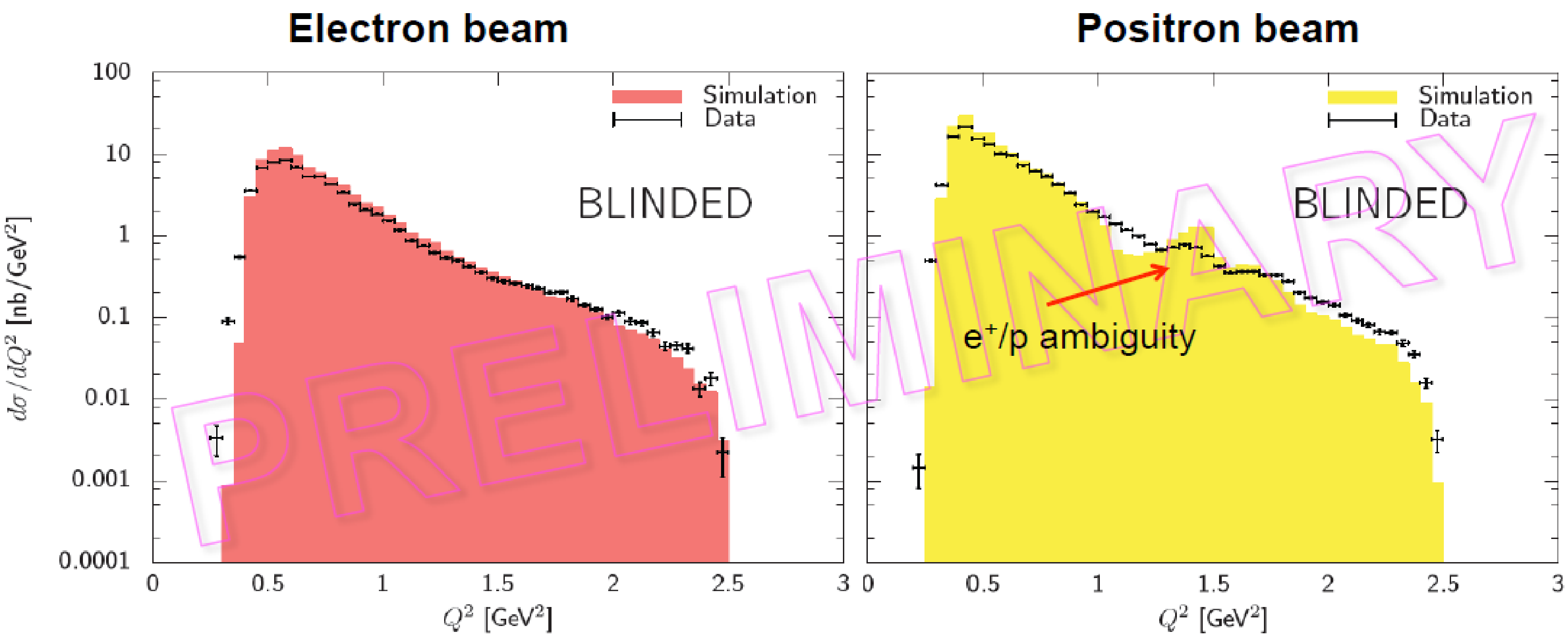


After theta and momentum cuts



STATUS OF ANALYSIS: YIELD (VERY PRELIMINARY)

~2% of total collected statistics



Nice MC-Data agreement

CONCLUSIONS/OUTLOOK

- Importance of TPE study to solve FFs ratio puzzle
- Two other experiments at Novosibirsk and Jlab
- Based on former BLAST detector moved from MIT/Bates to DORIS (DESY) upgraded and reassembled → very 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