Precise extraction of elastic scattering for two-photon exchange measurements

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Rosen07/E05-017 collaboration, Hall C JLab

JPos17 workshop
09/17, Newport News, VA

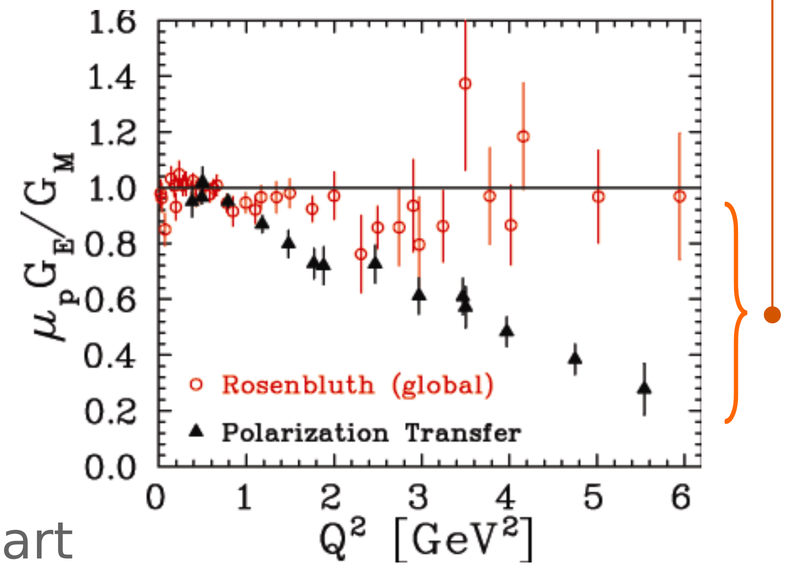
OUTLINE

1. Two photon exchange
2. Super Rosenbluth: E05-017
3. Super Rosenbluth with positrons

TPE TESTS

- Lepton scattering, e^+/e^- comparisons
  - $R = \frac{\sigma(e^+p)}{\sigma(e^-p)}$ measurements
- Spin dependent observables with e^-
  - ε - dependence in P_l, P_t or P_t/P_l - real part
  - non-zero *BNA*, *TNA*, or P_n - imaginary part
- Unpolarized scattering with e^-
  - deviation from linearity in Rosenbluth plot: $\sigma_R = \tau G_M^2(Q^2) + \varepsilon G_E^2(Q^2)$
  - comparison of LT and PT

TPE to resolve LT-PT discrepancy



J. Arrington, Phys. Rev. C69:022201, 2004
M. Jones et al, Phys. Rev. Lett. 84:1398-1402, 2000
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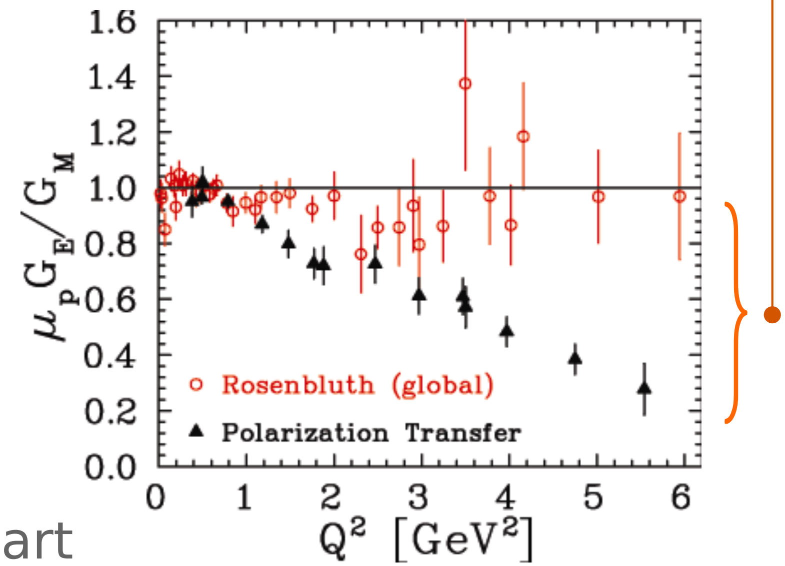

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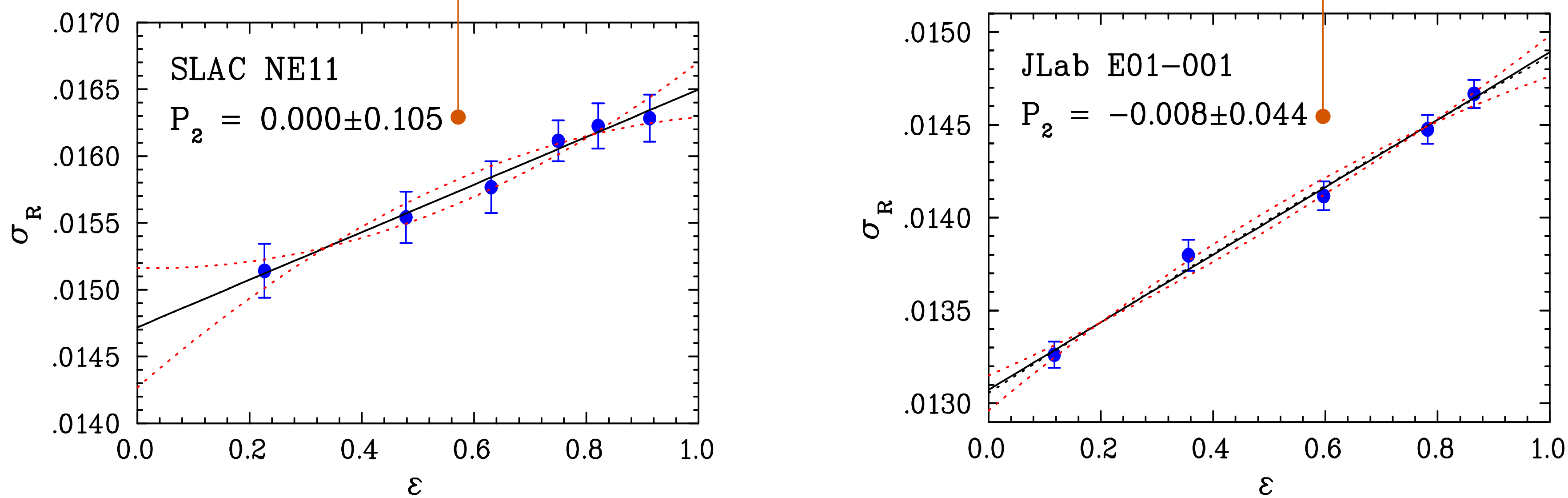
TPE in ROSENBLUTH TESTS

- Unpolarized scattering
  1. deviation from linearity in Rosenbluth plot
     - figure of merit to test linearity
     - previous measurements - P_2 is consistent with 0

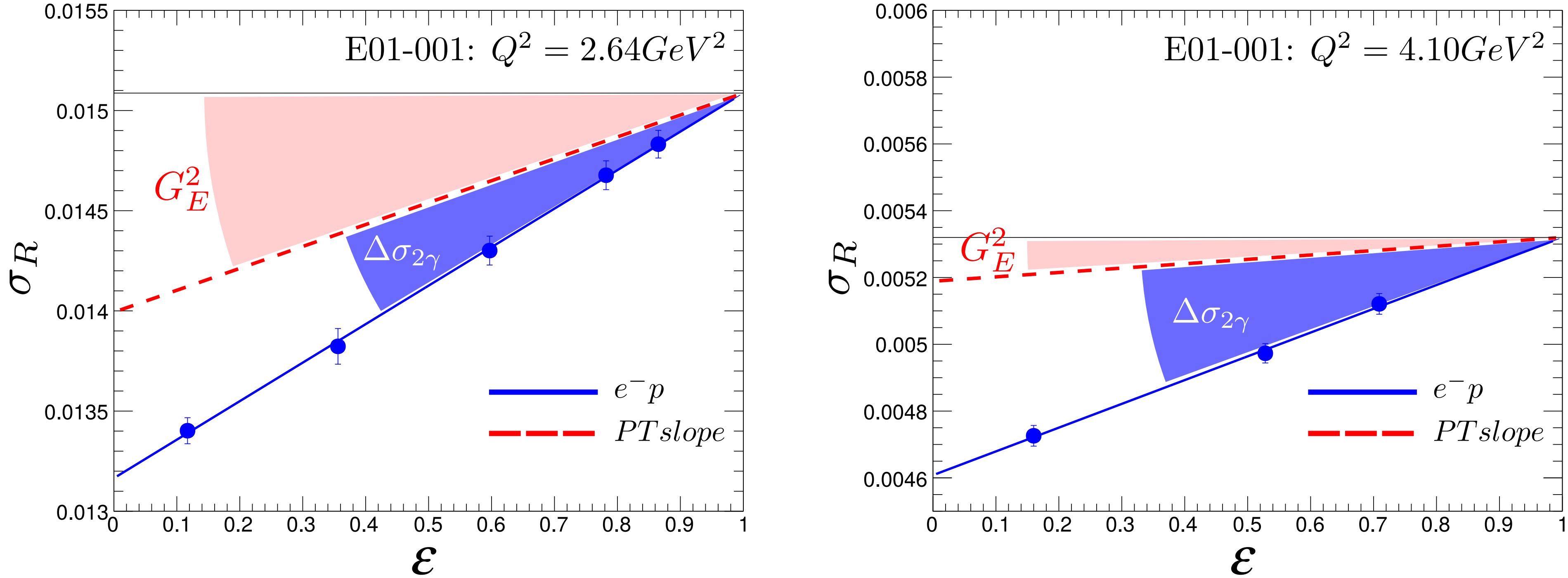
$$\sigma_R = P_0[1 + P_1\varepsilon + P_2\varepsilon^2]$$



PR05-017, JLab Hall C, 2004

TPE in ROSENBLUTH TESTS

- Unpolarized scattering
  2. probe TPE by measuring discrepancy between Rosenbluth and PT
     - TPE effects is ~50% of ε dependence at $Q^2 = 2.64$
     - $Q^2 > 4$ ε dependence is almost entirely TPE



TPE in ROSENBLUTH TESTS

- Unpolarized scattering

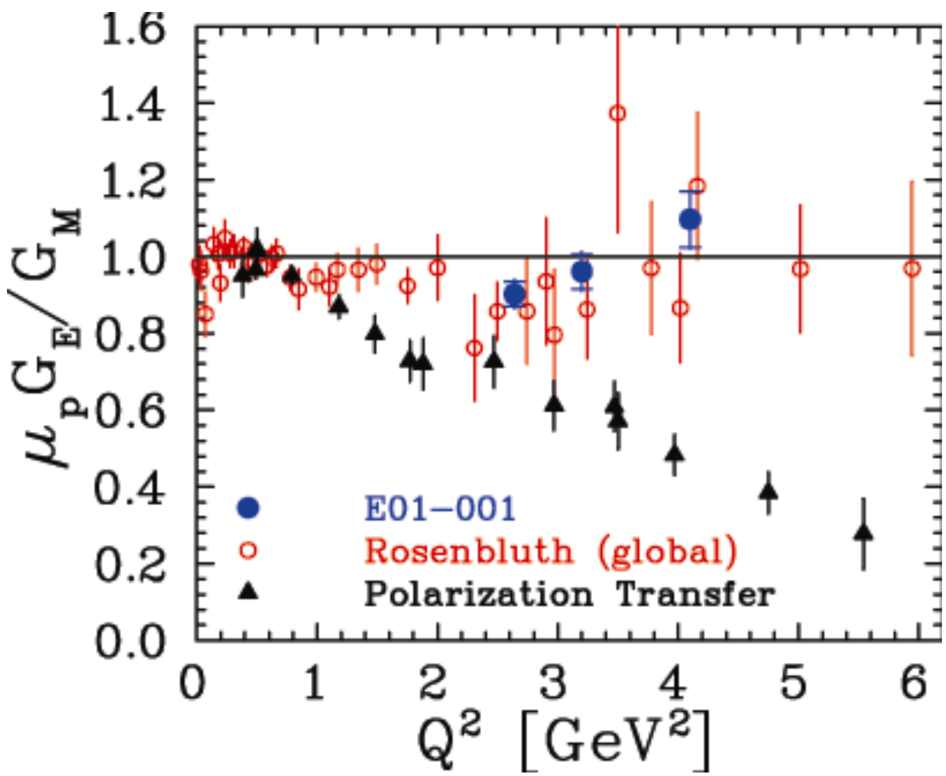
1. deviation from linearity in Rosenbluth plot
   - figure of merit to test linearity:
   - previous measurements - P_2 is consistent with 0
   - maximize range and # of ε measurements at selected Q^2

2. probe TPE by measuring discrepancy between Rosenbluth and PT
   - TPE effects is ~50% of ε dependence at $Q^2 = 2.64$
   - $Q^2 > 4$ ε dependence is almost entirely TPE
   - improve Rosenbluth precision, particularly at larger Q^2

DETECT PROTON instead of ELECTRON

Improve Rosenbluth precision by minimizing ε- dependent corrections

- much weaker variation of σ_{ep}
- less sensitive to offsets
- access smaller θ'_{elec}
- $P'_{prot} = const$ at fixed Q^2
- smaller rad. corrections
- JLab Hall A E01-001 run



I. A. Qattan et. al, Phys. Rev. Lett. 94:142301, 2005

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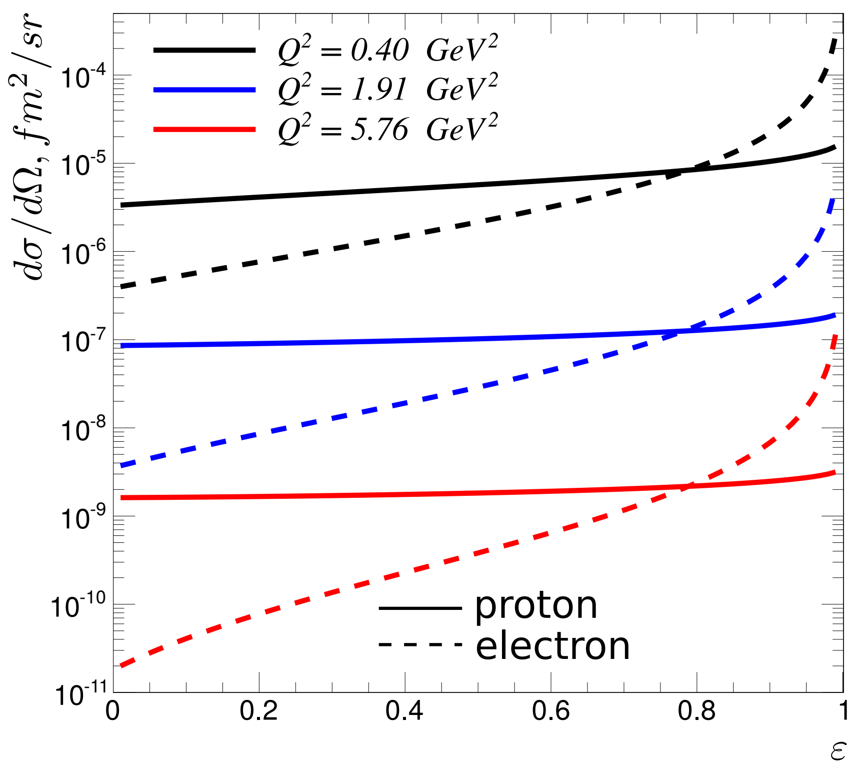

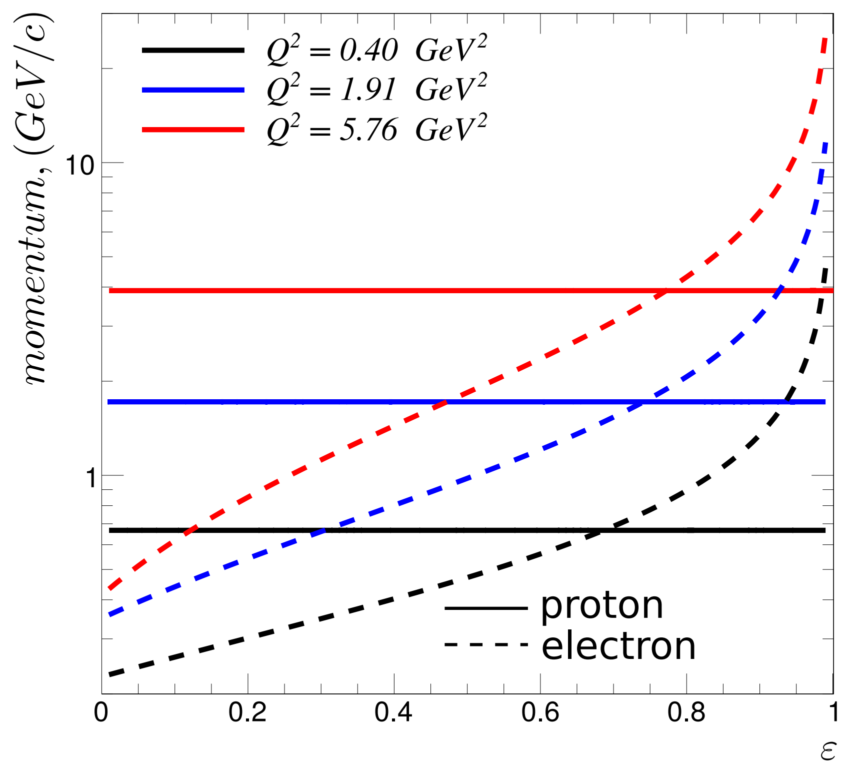

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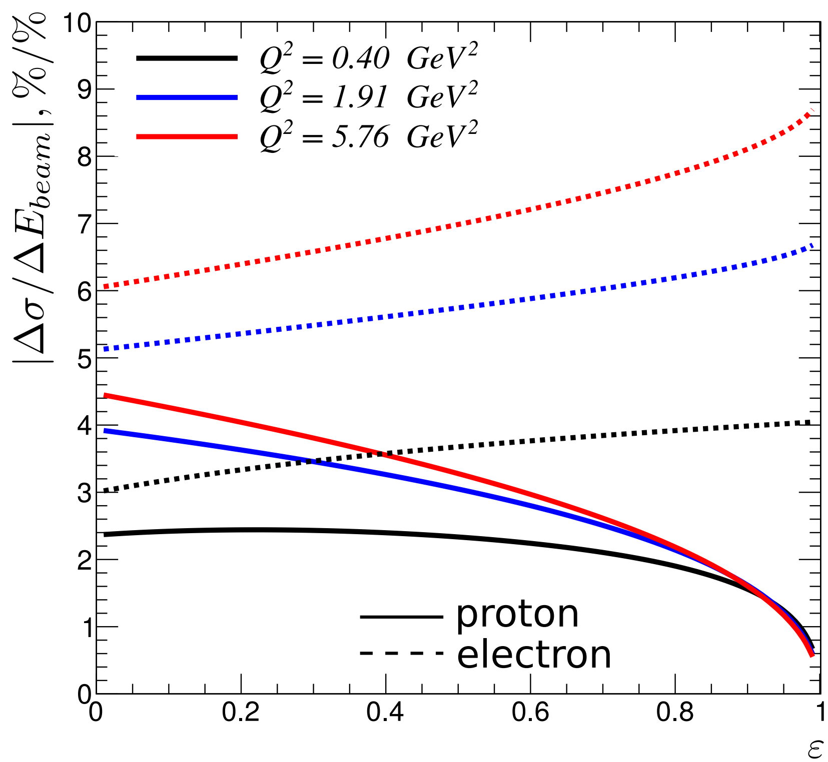
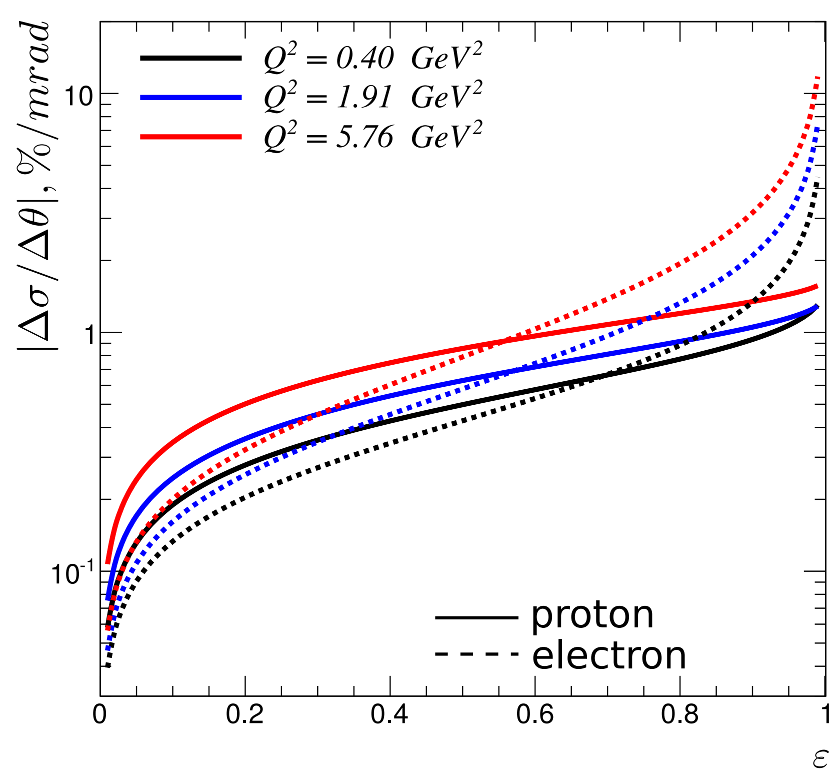




E05-017 goals

PROTON Rosenbluth to map out ε and Q^2 dependence of TPE

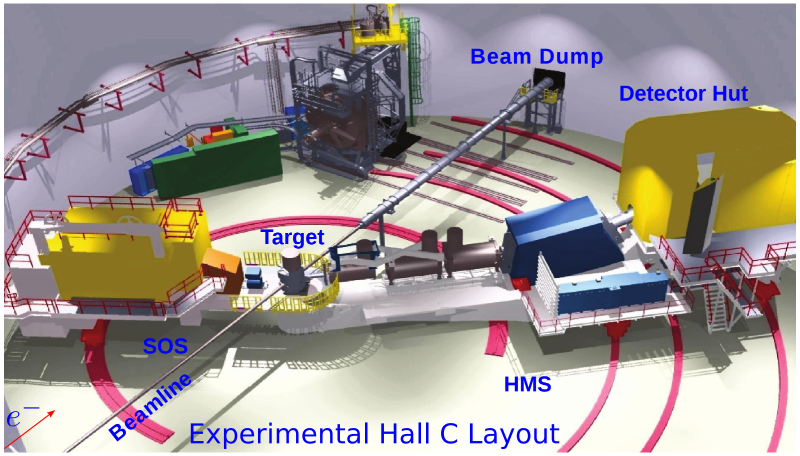
- High precision Rosenbluth extraction of $\mu_p G_E/G_M$ for $0.4 \lesssim Q^2 \lesssim 5.7$
- Tight limits on deviations from linearity in ε dependence

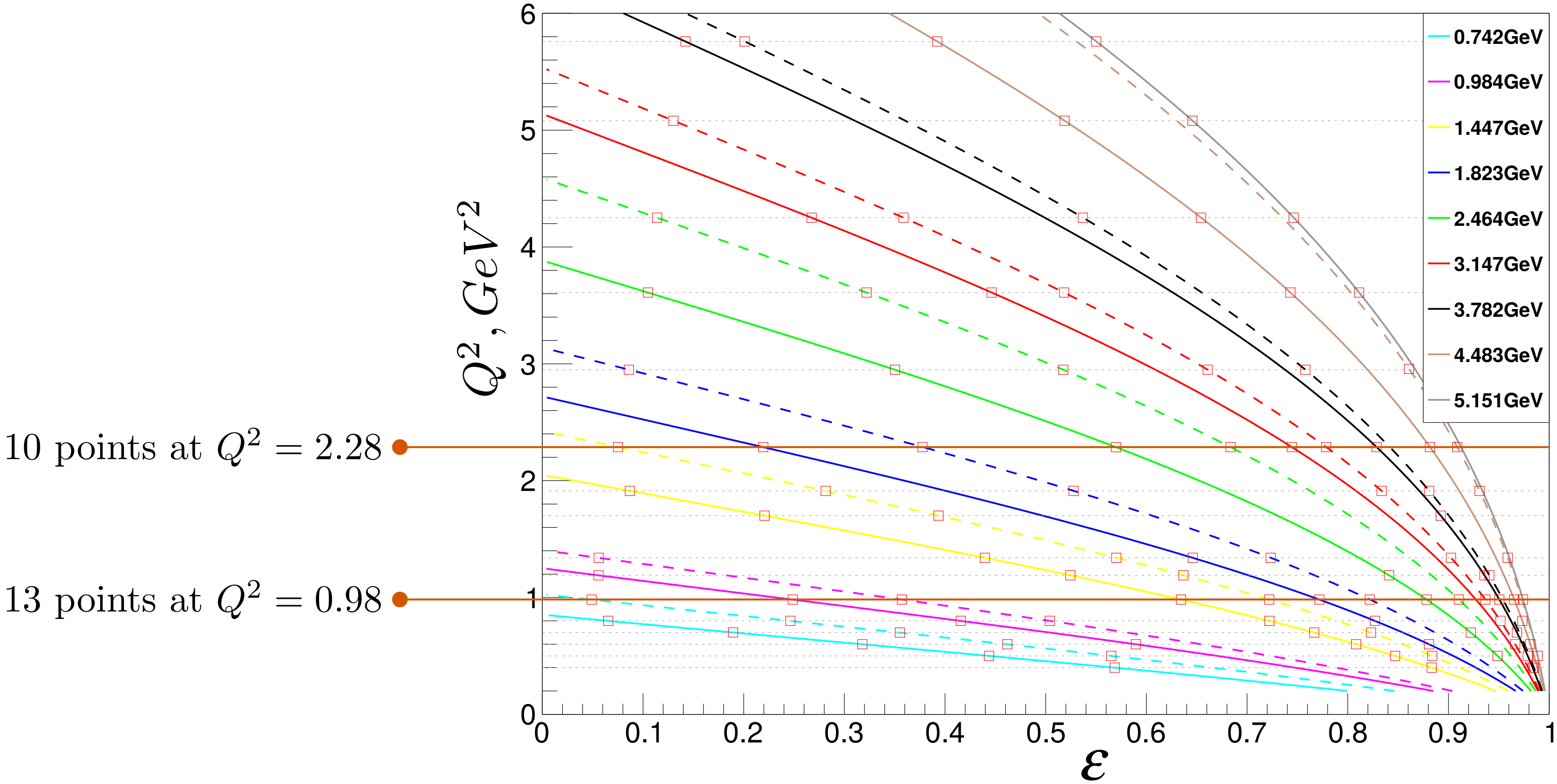
Difference from E01-001

- Reaches extremes of ε where TPE is expected to be largest
- Gets higher Q^2 where discrepancy is largest
- Maps lower Q^2 to check if discrepancy is present

Kinematical coverage:

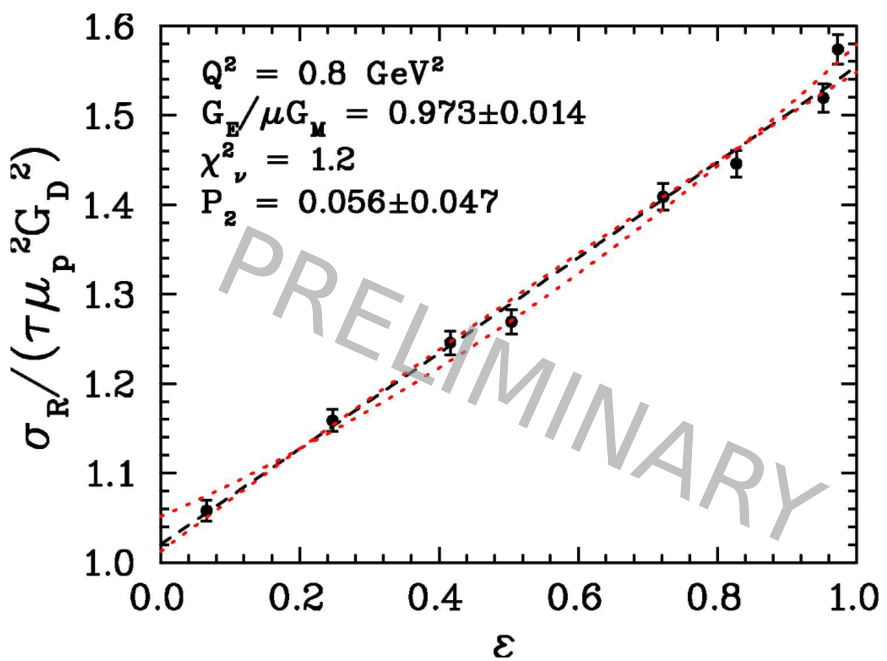
- 102 kinematic points
- 16 values of Q^2
- 17 settings of beam energy
- 2 detailed scans in ε

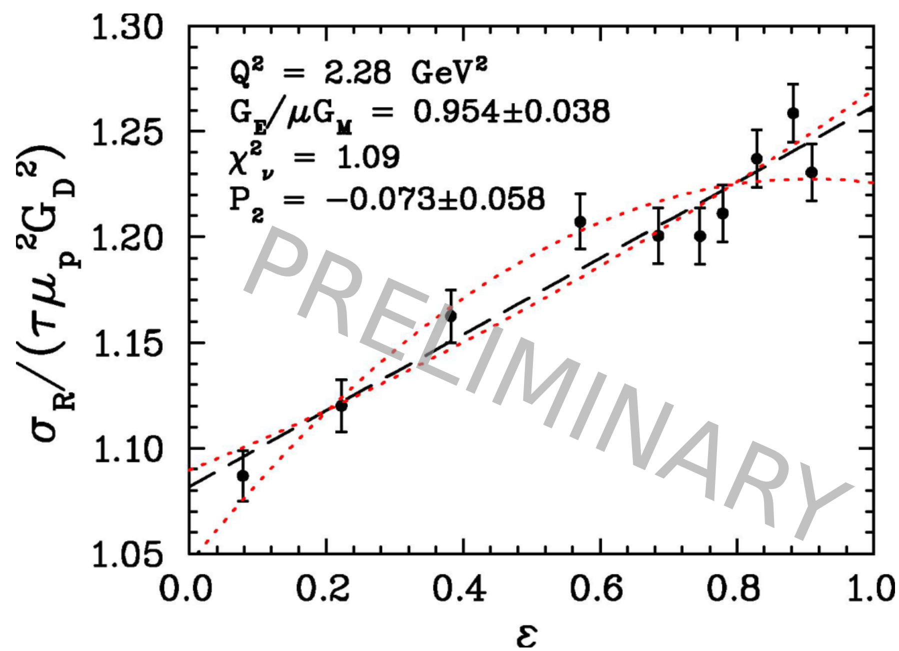




PRELIMINARY RESULTS

- Linearity extraction:





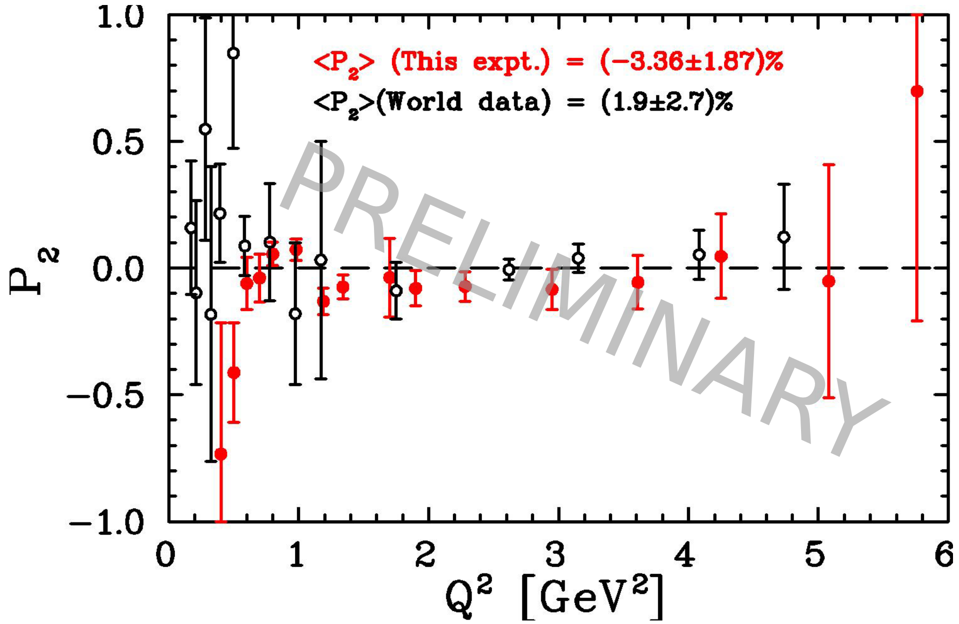
- quadratic fit to estimate the size of nonlinearity: P_2

- improvements on prior limits at $Q^2 < 2GeV^2$

- nonzero signature is not yet apparent

PRELIMINARY RESULTS

- Linearity extraction:
  - P_2 limits comparable to previous global analysis at $2 < Q^2 < 5 GeV^2$
  - single extraction, better low ε coverage
  - already a better P_2 limits than world data
  - expect improvement at high Q^2

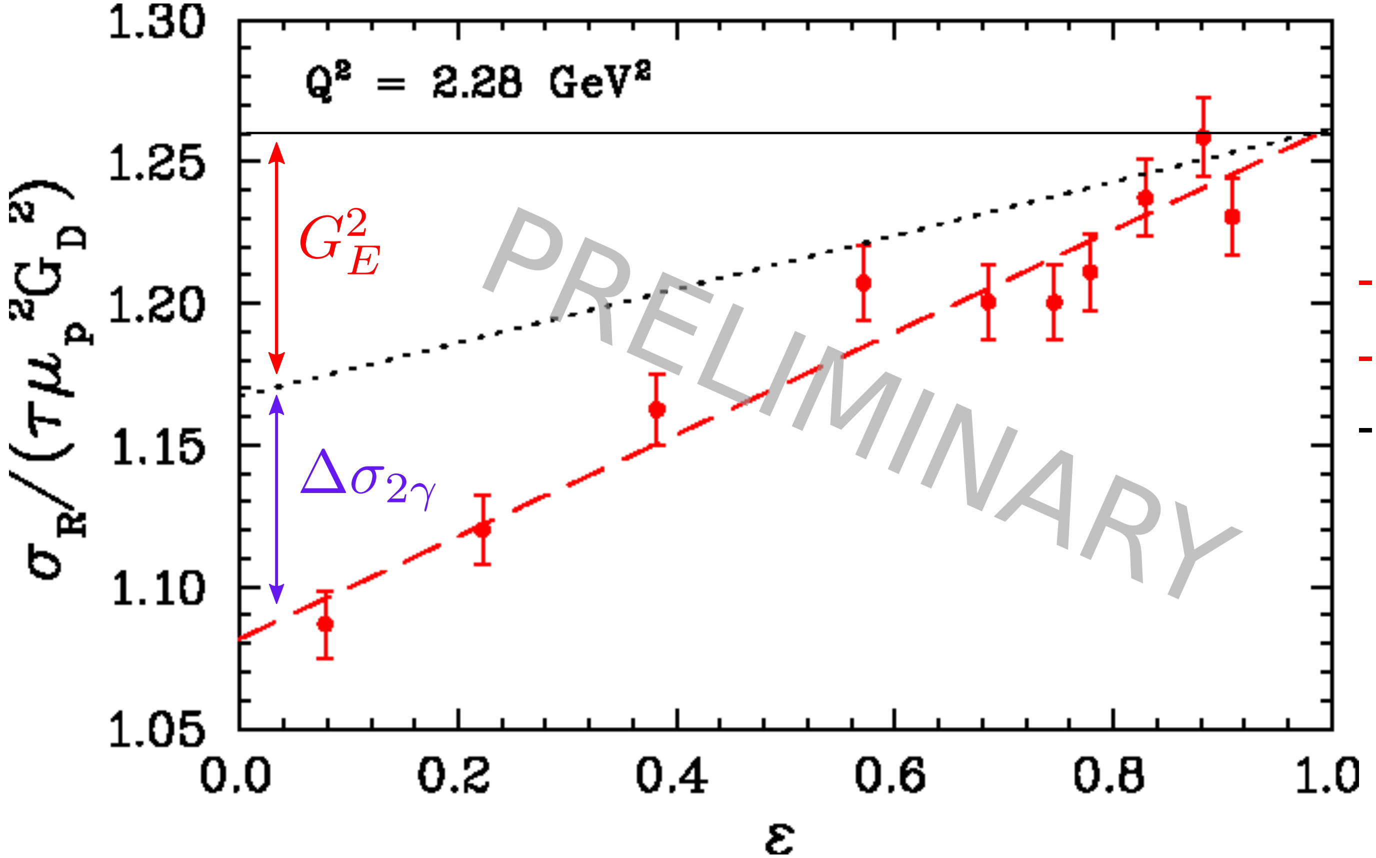


V. Tvaskis et. al

- expected uncertainty reduction:
  - point-to-point by factor 1.7 at high Q^2, small improvement at $Q^2 < 2$

PRELIMINARY RESULTS

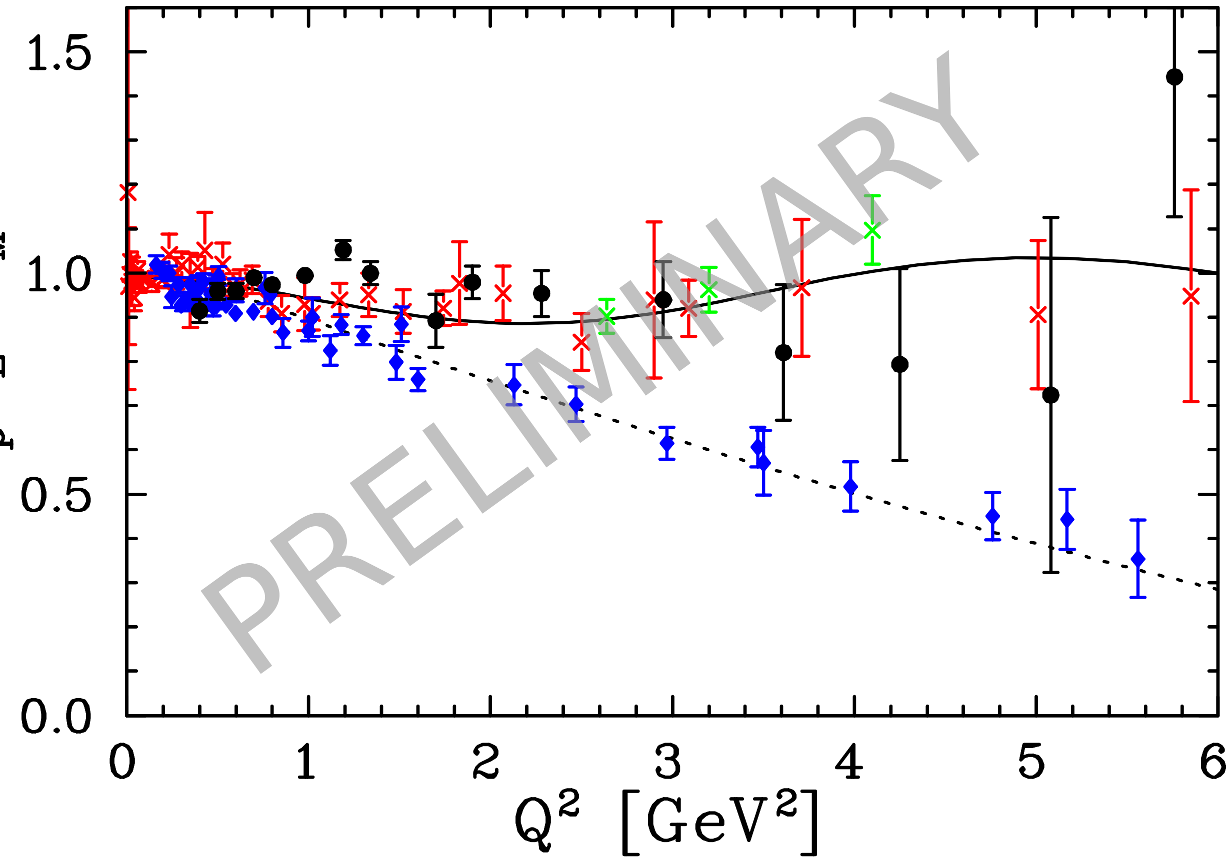
- Rosenbluth separation:
  - linear fit to extract FF ratio
  - second fit (not shown) with data shifted by δ_{slope} for systematics
  - $\Delta\sigma_{2\gamma}$ separates TPE size from G_E^2 slope



- this E05-017
- dashed: linear fit
- dotted: PT prediction

PRELIMINARY RESULTS

- $\mu_p G_E/G_M$ extraction:
  - from analysis that focused on low Q^2 settings
- expected uncertainty reduction:
  - slope by factor of 2 everywhere
  - point-to-point by factor 1.3 at $Q^2 < 2$ and by 1.5 above



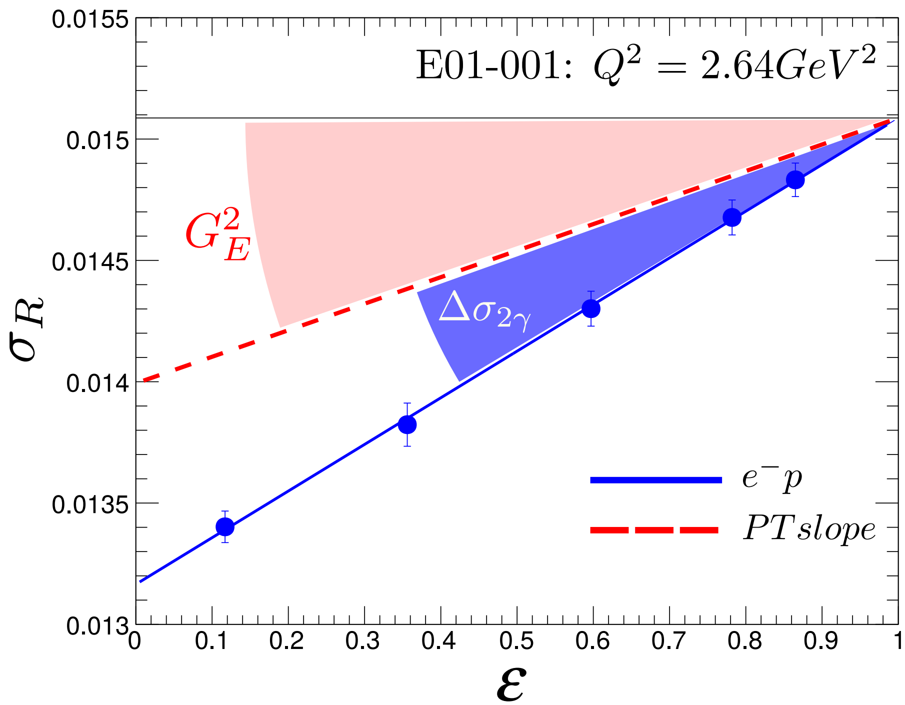
- this E05-017
- proton LT
- global LT
- PT
- solid: fit to LT
- dashed: fit to PT

PRELIMINARY RESULTS

- performed Rosenbluth FF extraction in $0.4 < Q^2 < 5.7 GeV^2$
  - expect further uncertainties reduction for final results
  - get better extraction of $\mu_p G_E / G_M$ at low to moderate Q^2 and match existing data at larger Q^2
- P_2 analysis suggested negative curvature
  - consistent with calculations of Blunden and Chen
  - set better limits than global analysis with single extraction

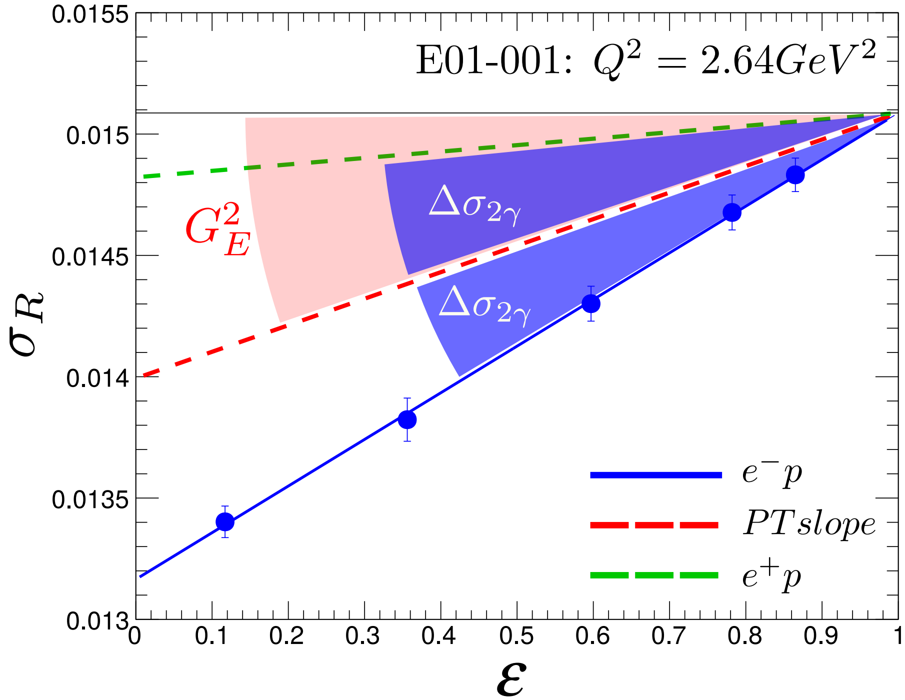
POSITRON ROSENBLUTH

- Unpolarized scattering
  - ② probe TPE by measuring discrepancy between Rosenbluth and PT
    - provides the only meaningful experimental limits above $2GeV^2$
    - affected by PT uncertainties, TPE effects, extrapolation to $\varepsilon = 1$



POSITRON ROSENBLUTH

- Unpolarized scattering
  - (2) probe TPE by measuring discrepancy between Rosenbluth and PT
    - provides the only meaningful experimental limits above $2GeV^2$
    - affected by PT uncertainties, TPE effects, extrapolation to $\varepsilon = 1$



POSITRON ROSENBLUTH

- Unpolarized scattering with positron beam

  1. deviation from linearity in Rosenbluth plot
     - the opposite sign of curvature parameter P_2
     - factor of 2 improvement
     - need to cover similar ε range and many ε points

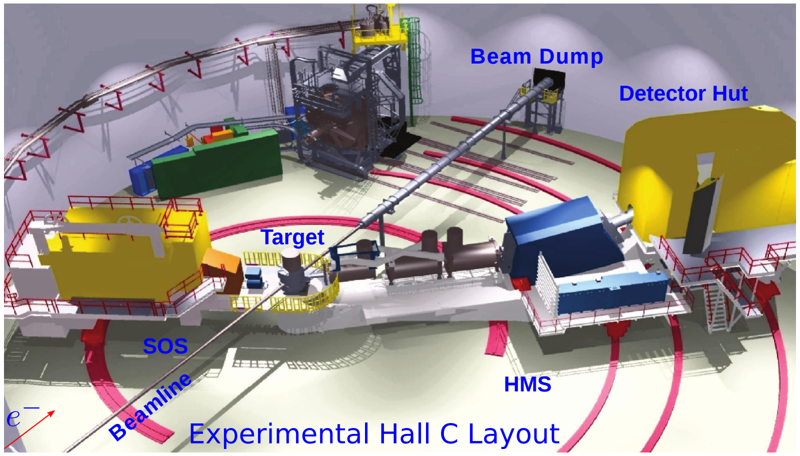
  2. switching from $LT(e^-)$-$PT(e^-)$ to $LT(e^-)$-$LT(e^+)$ comparisons
     - eliminates dependence on PT uncertainty and TPE corrections
     - doubles sensitivity
     - need statistical uncertainty under ~1%
     - useful range of Q^2
     - positron beam of appropriate energy and intensity

POSITRON ROSENBLUTH

E05-017 configuration:

- 3 settings of beam current
- 4 cm LH2 and dummy targets
- acceptance: 3.2 msr

E05-017 beam time: ~340hrs (production)



I_{beam}	$Q^2[GeV^2]$	N_ε	$T_\varepsilon[hrs]$	$T[hrs]$	$\Delta_{stat}[\%]$
$I_{beam} = 30\mu A$	0.40	4	0.5	2.0	0.10
	0.50	7	1.0	7.0	0.10
	0.60	7	1.5	10.5	0.10
	0.70	6	2.0	12.0	0.10
	0.80	8	2.5	20.0	0.10
	0.98	13	2.5	32.5	0.10
$I_{beam} = 50\mu A$	1.19	6	3.0	18.0	0.10
	1.34	7	3.0	21.0	0.10
	1.70	3	4.0	12.0	0.20
	1.91	6	4.0	24.0	0.20
	2.29	10	4.5	45.0	0.20
$I_{beam} = 80\mu A$	2.95	6	4.5	27.0	0.20
	3.61	6	5.0	30.0	0.20
	4.25	6	5.0	30.0	0.30
	5.08	3	7.0	21.0	0.40
	5.76	4	7.0	28.0	0.40

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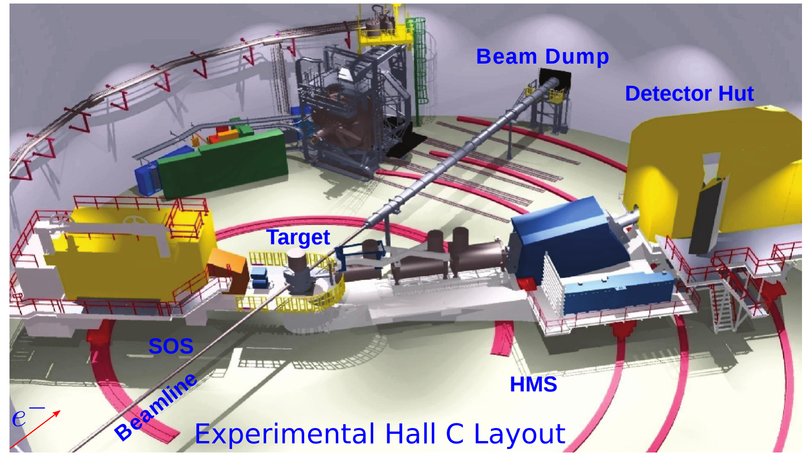


$5\mu A$ $1\mu A$ of positron beam

	$Q^2[GeV^2]$	N_ε	$T_\varepsilon[hrs]$	$T[hrs]$	$\Delta_{stat}[\%]$	$\Delta_{stat}[\%]$ ($5\mu A$)	$\Delta_{stat}[\%]$ ($1\mu A$)
$I_{beam} = 30\mu A$	0.40	4	0.5	2.0	0.10	0.24	0.55
	0.50	7	1.0	7.0	0.10	0.24	0.55
	0.60	7	1.5	10.5	0.10	0.24	0.55
	0.70	6	2.0	12.0	0.10	0.24	0.55
	0.80	8	2.5	20.0	0.10	0.24	0.55
	0.98	13	2.5	32.5	0.10	0.24	0.55
$I_{beam} = 50\mu A$	1.19	6	3.0	18.0	0.10	0.32	0.71
	1.34	7	3.0	21.0	0.10	0.32	0.71
	1.70	3	4.0	12.0	0.20	0.63	1.41
	1.91	6	4.0	24.0	0.20	0.63	1.41
	2.29	10	4.5	45.0	0.20	0.63	1.41
$I_{beam} = 80\mu A$	2.95	6	4.5	27.0	0.20	0.80	1.79
	3.61	6	5.0	30.0	0.20	0.80	1.79
	4.25	6	5.0	30.0	0.30	1.20	2.68
	5.08	3	7.0	21.0	0.40	1.60	3.58
	5.76	4	7.0	28.0	0.40	1.60	3.58

POSITRON ROSENBLUTH

Optimize for positron intensity: $5\mu A$

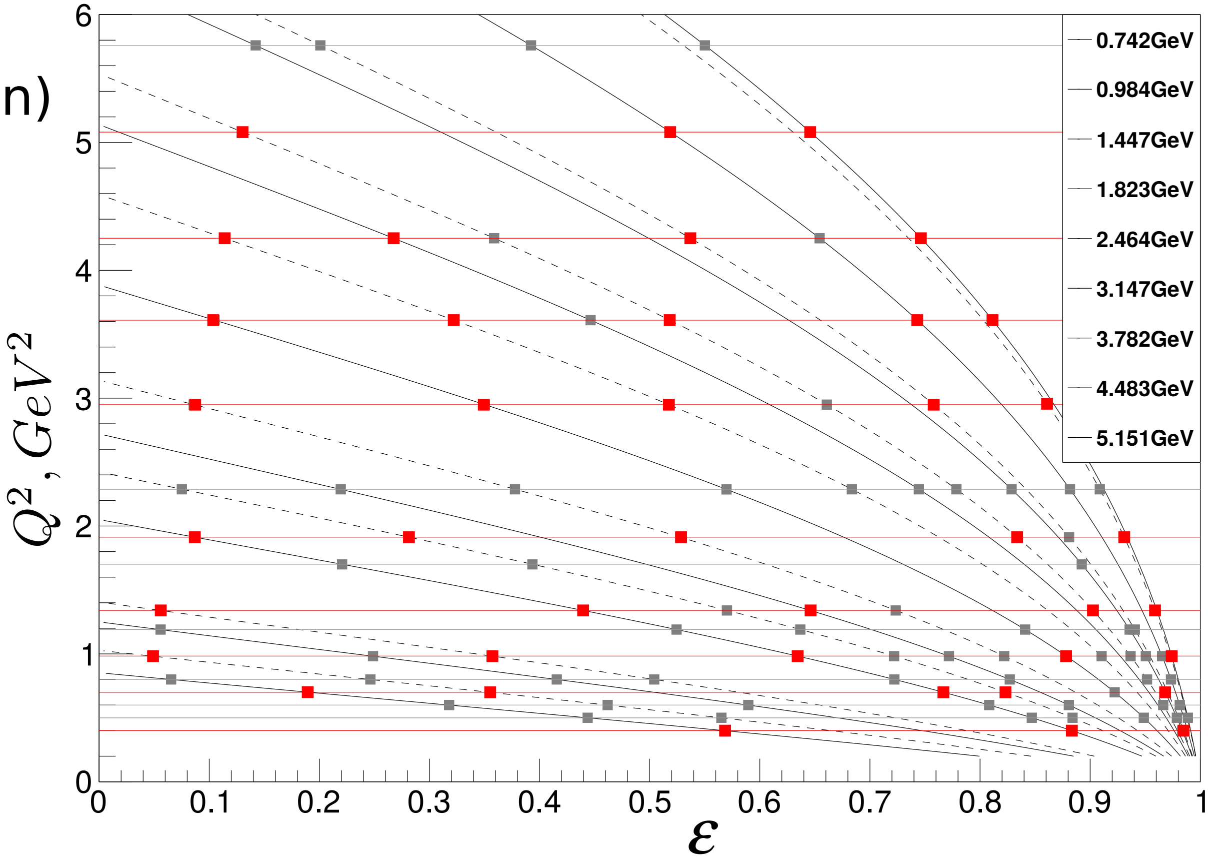
- reduce kinematic coverage
- keep Δ_{stat} in 0.5-0.8% range
- 4 cm target
- acceptance: 3.2 msr

$Q^2[GeV^2]$	N_ε	$T_\varepsilon[hrs]$	$T[hrs]$	$\Delta_{stat}[\%]$	$\Delta_{stat}[\%]$
0.40	4	1.0	4.0	0.17	0.39
0.70	5	2.0	10.0	0.24	0.55
0.98	5	3.0	15.0	0.22	0.50
1.34	5	3.0	15.0	0.32	0.71
1.70	3	6.0	18.0	0.52	1.15
2.95	5	12.0	60.0	0.49	1.10
3.61	5	12.0	60.0	0.52	1.15
4.25	4	20.0	80.0	0.60	1.34
5.08	3	25.0	75.0	0.85	1.89

$5\mu A$ $1\mu A$

Beam time:

~348hrs (production)



POSITRON ROSENBLUTH

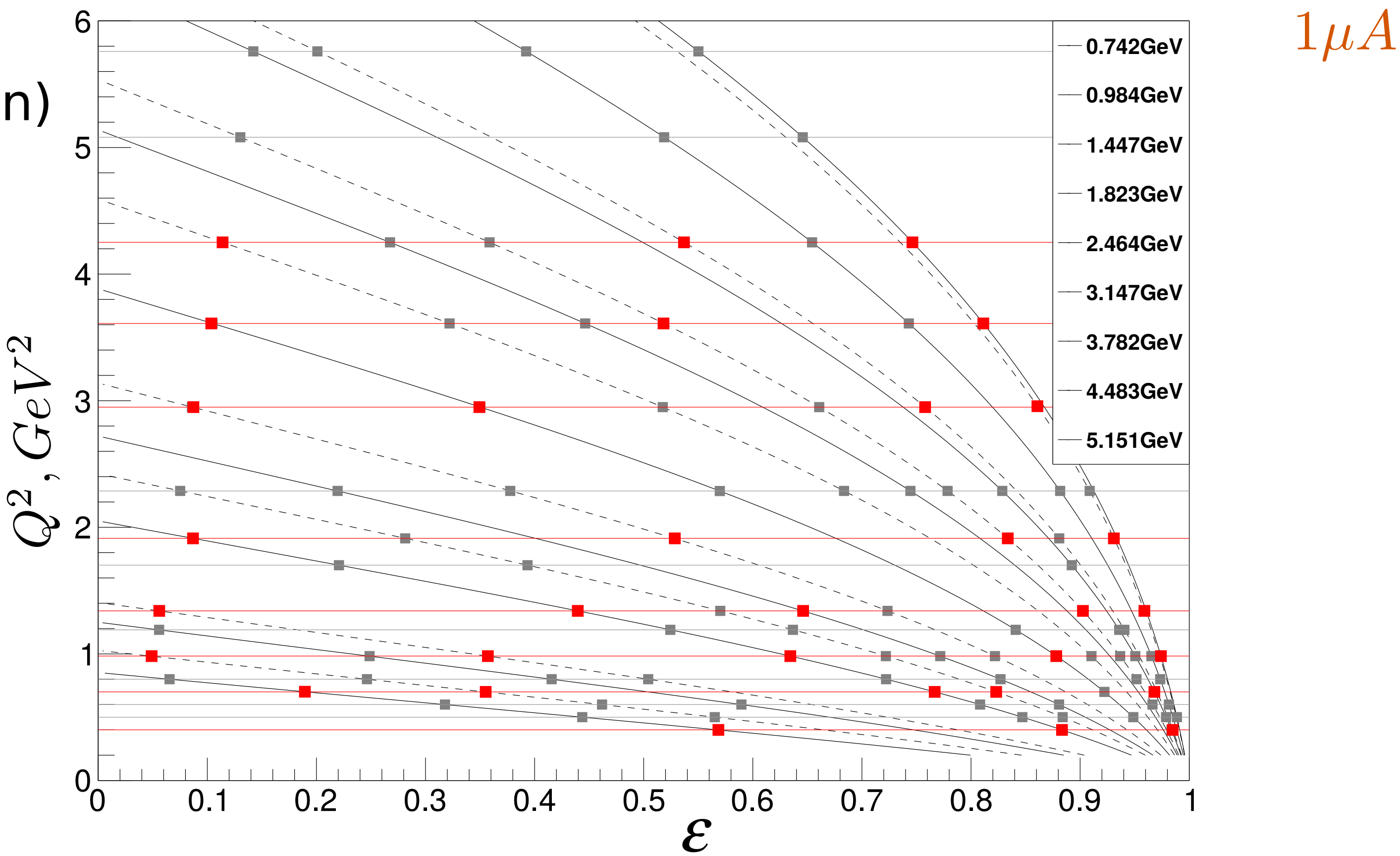
Optimize for positron intensity: $1\mu A$

- reduce kinematic coverage
- keep Δ_{stat} in 0.5-0.8% range
- 4 cm target
- acceptance: 3.2 msr

Beam time:

~431hrs (production)

$Q^2[GeV^2]$	N_ε	$T_\varepsilon[hrs]$	$T[hrs]$	$\Delta_{stat}[\%]$
0.40	3	1.0	3.0	0.39
0.70	5	2.0	10.0	0.55
0.98	5	3.0	15.0	0.50
1.34	5	6.0	30.0	0.50
1.70	4	18.0	72.0	0.67
2.95	4	25.0	100.0	0.76
3.61	3	27.0	81.0	0.77
4.25	3	40.0	120.0	0.95



POSITRON ROSENBLUTH

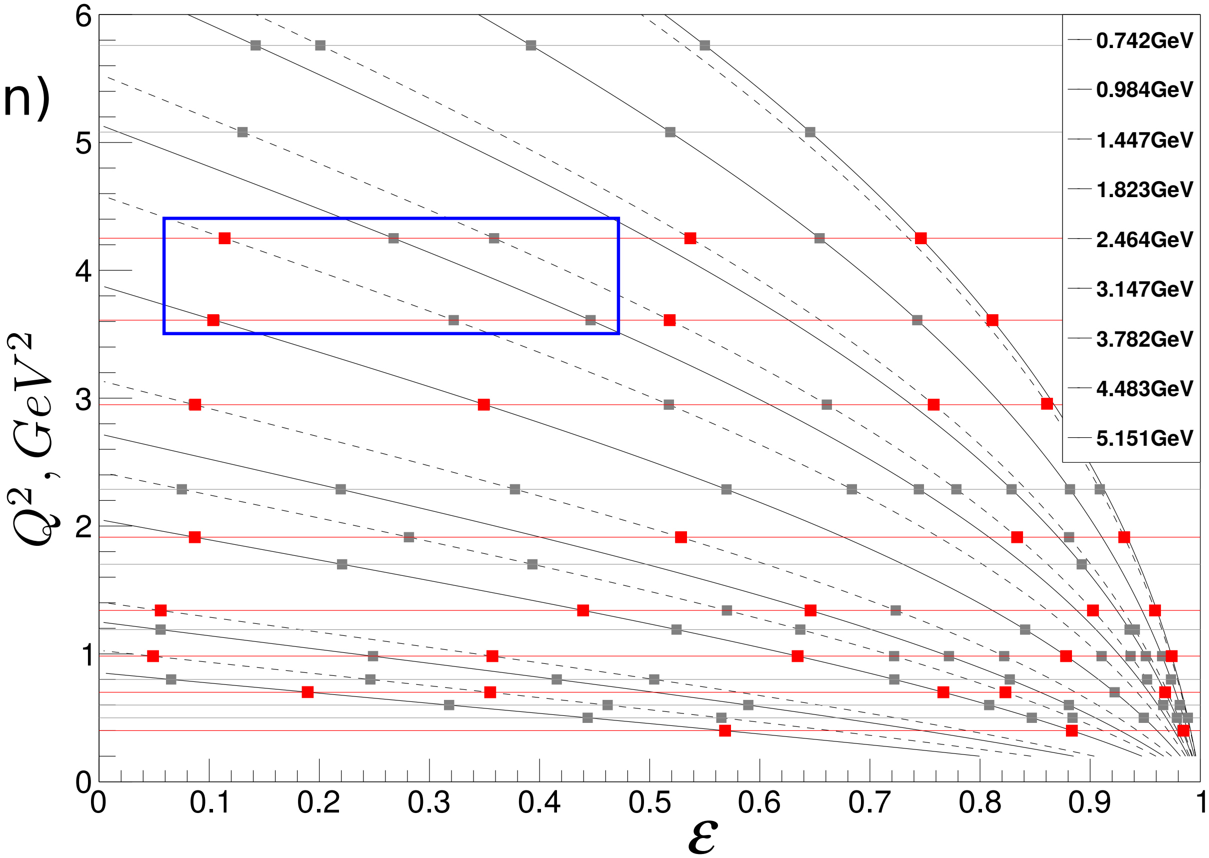
Optimize for positron intensity: $1\mu A$

- restrict kinematics to low ε
- keep Δ_{stat} in 0.5-0.8% range
- 10 cm target
- acceptance: 3.2 msr

$Q^2[GeV^2]$	N_ε	$T_\varepsilon[hrs]$	$T[hrs]$	$\Delta_{stat}[\%]$
0.40	3	1.0	3.0	0.39
0.70	5	2.0	10.0	0.55
0.98	5	3.0	15.0	0.50
1.34	5	6.0	30.0	0.50
1.70	4	18.0	72.0	0.67
2.95	4	25.0	100.0	0.76
3.61	3	20.0	60.0	0.57
4.25	3	30.0	90.0	0.69

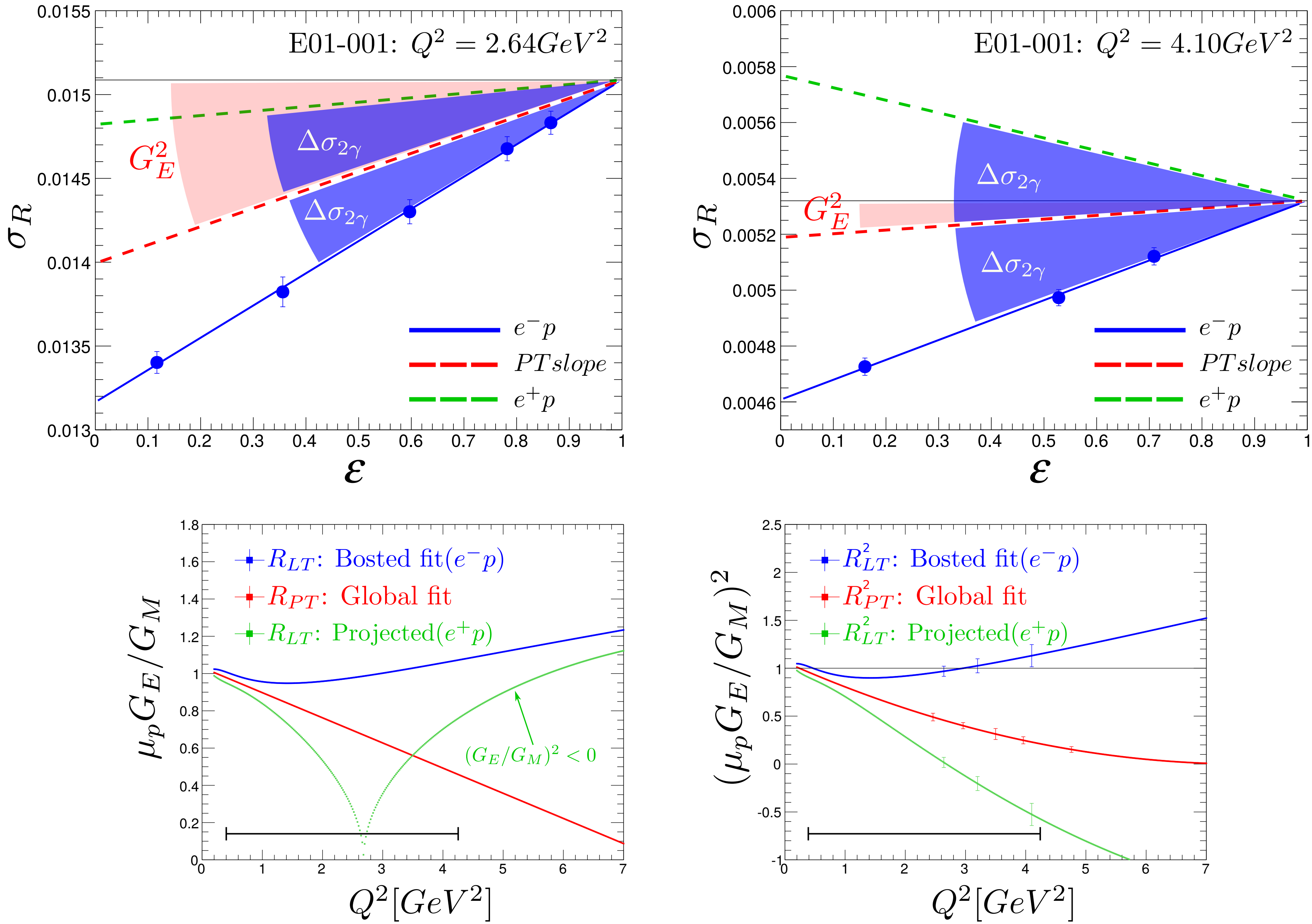
Beam time:

~380hrs (production)



$1\mu A$

POSITRON ROSENBLUTH



CONCLUSIONS

- comparison of e^+/e^- Rosenbluths combined with proton detection

  - doubles sensitivity

  - avoids model-dependent uncertainties

- prospects with 1uA positron beam

  - good coverage up to 4GeV^2 and statistical uncertainty under 1% in 18 days with HMS alone

  - further improvements with longer targets and SHMS

THANK YOU