Photon Structure at a Future e^+e^- Linear Collider

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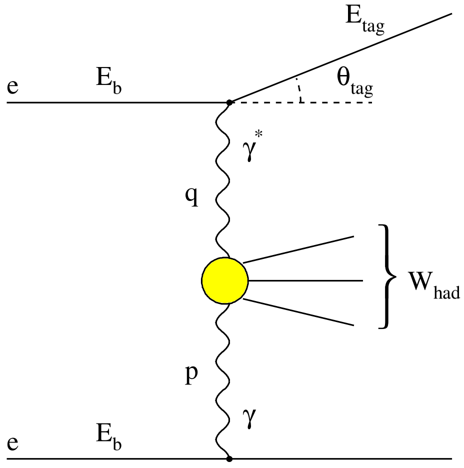
Electron Photon Scattering

Classical measurement: Deep inelastic $e\gamma$ scatt.

$$e^+e^- \to e^+e^-\gamma^*\gamma \to e(e)X \quad (Q^2 >> P^2)$$

$\Rightarrow$ (exp.) one tagged and one untagged scatered electron.



Cross section:

$$\frac{d\sigma(e\gamma\to eX)}{dE_{tag}\,d\cos\theta_{tag}} = \frac{4\pi\alpha^2 E_{tag}}{Q^4 y}\cdot$$

$$[\{1+(1-y)^2\}F_2^\gamma(x,Q^2) - y^2 F_L^\gamma(x,Q^2)]$$

F_2^γ, F_L^γ structure functions of the photon

Kinematic variables:

$$Q^2 = 2E_b E_{tag}(1-\cos\theta_{tag}), \quad W^2_{had} = (q+p)^2$$

$$x = \frac{Q^2}{Q^2+W^2_{had}+P^2}, \qquad y = 1 - \frac{E_{tag}}{E_b}\cos^2\left(\frac{\theta_{tag}}{2}\right)$$

Electron-Positron Colliders

Sofar F_2^γ from $e\gamma$ scattering at e^+e^- colliders

R.Taylor DIS2001; R. Nisius, Phys. Rep. 332 (2000) 165.

Future: High Energy Linear e^+e^- Collider

PROJECTS UNDER DISCUSSION

Machine	Tech.	"Proposal"	$\sqrt{s}_{max}$ TeV	Lumi $10^{34} cm^{-2} s^{-1}$
TESLA (DESY)	cold	March 2001	0.5/0.8	3-5
NLC (USA)	warm	2002/2003 ?	0.5/1	0.5-5
JLC (Japan)	warm	2002/2003 ?	0.5/1	0.5-5
CLIC (CERN)	TBA$^{(*)}$	2007/2008 ?	3/5	10

⇒ For Top, Higgs, SUSY, Extra Dimension, strong WW dynamics, TeV-strings, evaporating black holes, nylons...

Allow also to progress on QCD and structure of the photon (DESY 2001-011/TESLA-TDR, ADR hep-ph/0101075)

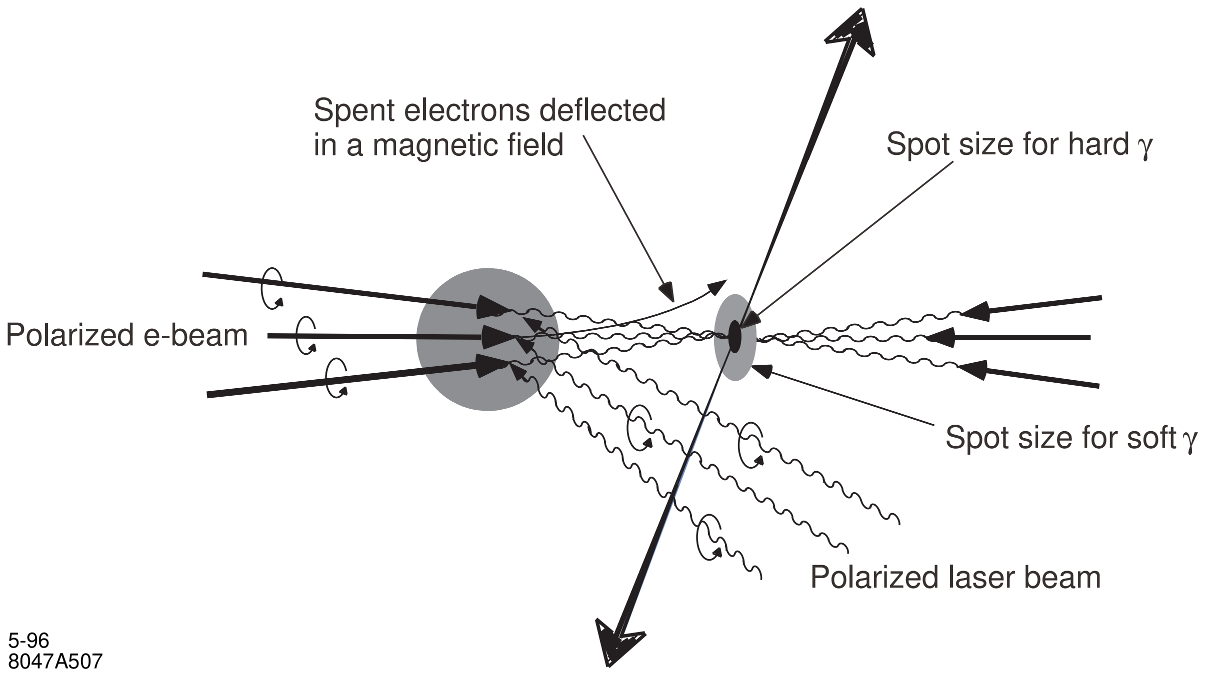
(*) TBA: Two-Beam Acceleration

$e\gamma$ at a LC

Two-photon options at a LC

- Using the Weizsacker -William WW spectrum for photon radiation
Problem: x variable needs to be reconstructed from hadronic final state. Even with TESLA-like detector this will be problematic (cfr. LEP studies)
- Convert e-beam into a photon beam via laser backscattering ⟶ a photon collider (PC) $(\gamma\gamma, e\gamma)$
Sharp energy spectrum, like HERA with a 10% smeared proton beam.

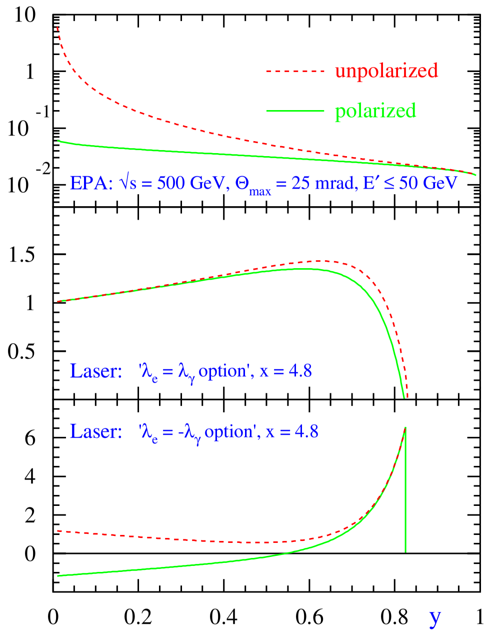
PC principle



- Beamstrahlung... (not used)

Experimental Constraints

Photon Spectra used: $(z = s_{e\gamma}/s_{ee})$



WW: $E_\gamma^{max} = E_e$

PC: $E_\gamma^{max} \sim 0.8 E_e$

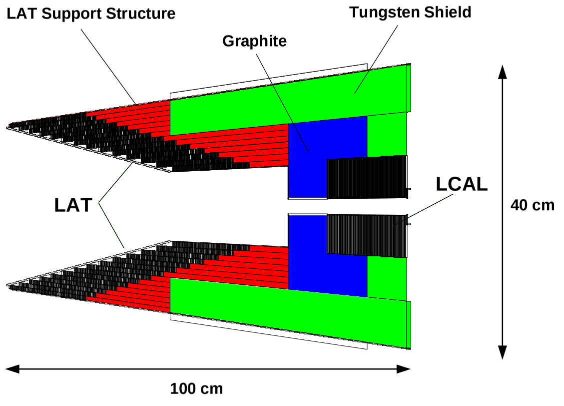
$\mathcal{L}_{e\gamma}^{0.8 z_m < y < z_m} \sim 0.3 \mathcal{L}_{ee}$

Polarised e and γ beams!!

Detectors: Central detector for particles with

$\theta \geq 80 - 100$ mrad

$+$ additional electron tagging (LAT) in mask

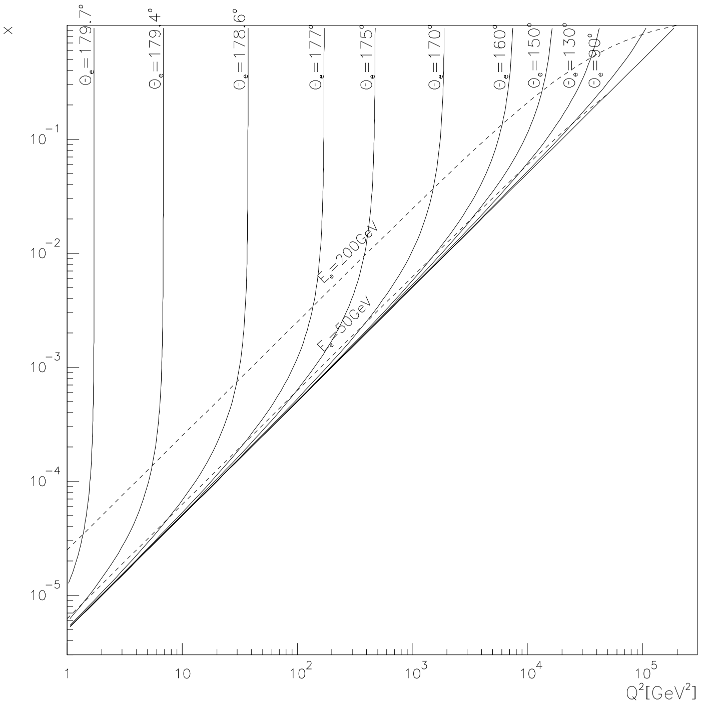


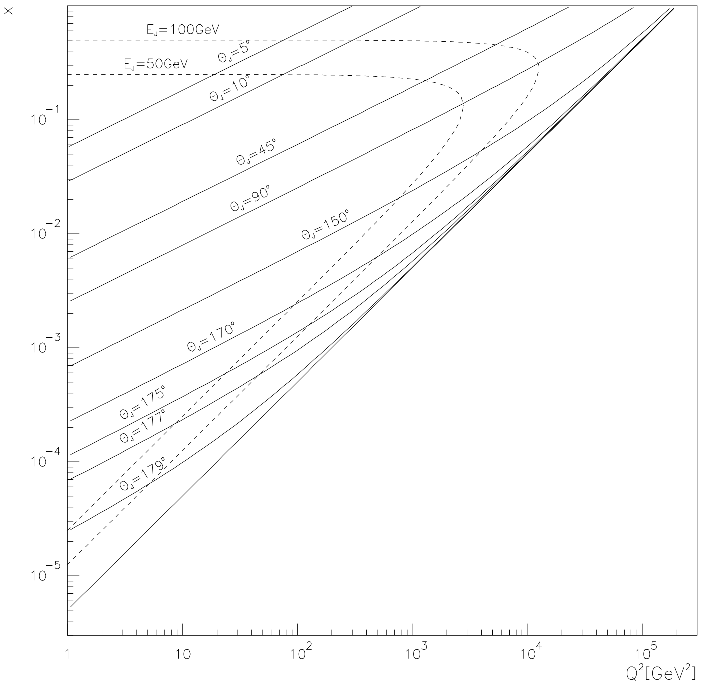
$\Rightarrow E_{\rm tag} \geq 50$ GeV and $\theta_{\rm tag} > 25$ mrad

Electron Photon Scattering

Kinematics for 250 GeV e beam on 200 GeV γ beam

25 mrad $\sim$ $\mathbf{178.6^0}$ (HERA convention)





Hadrons close to beam-pipe for small-x

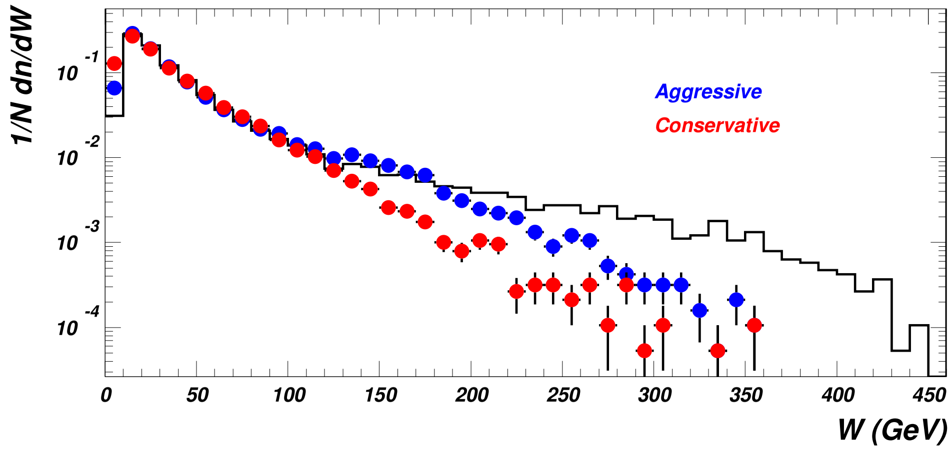
Electron Photon Scattering

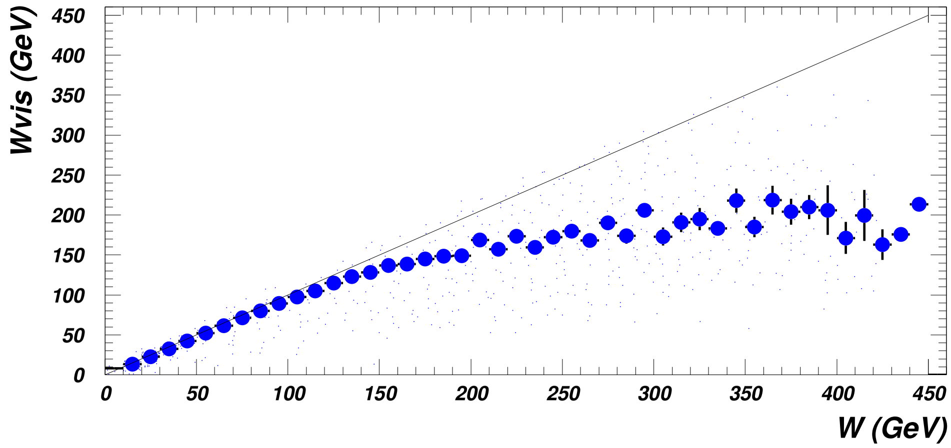
Study of the WW mode (e^+e^- 500 GeV) S. Magill

Study based on PYTHIA events for 2 options:

- Agressive mask: $\theta_{min}^{hadrons} = 30$ mrad
- Conservative mask: $\theta_{min}^{hadrons} = 80$ mrad

Compare visible $\boldsymbol{W}$ with true $\boldsymbol{W}$



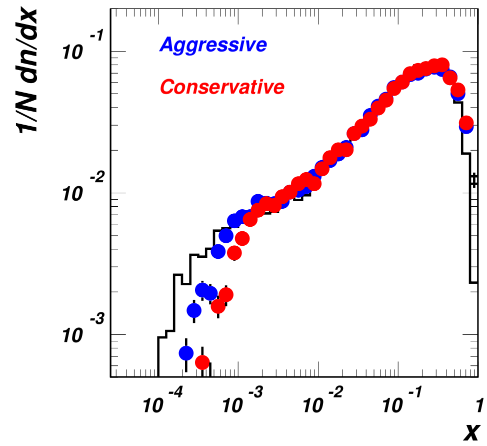


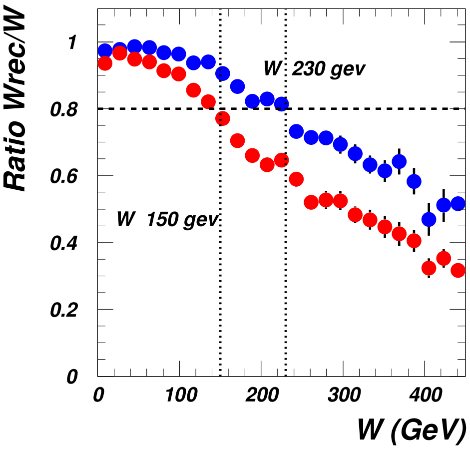
Electron Photon Scattering

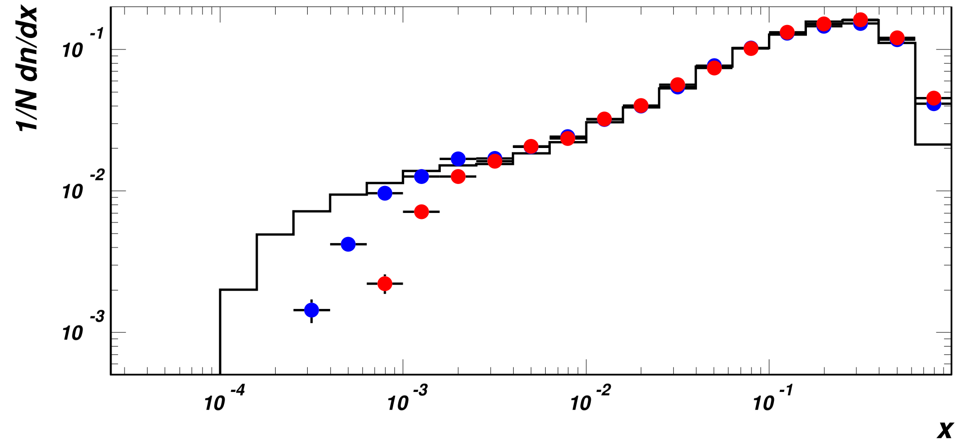
Require: Ratio $W_{vis}/W_{true} > 0.8 \Rightarrow$

Aggressive: $W < 230$ GeV

Conservative: $W < 150$ GeV







Reach:

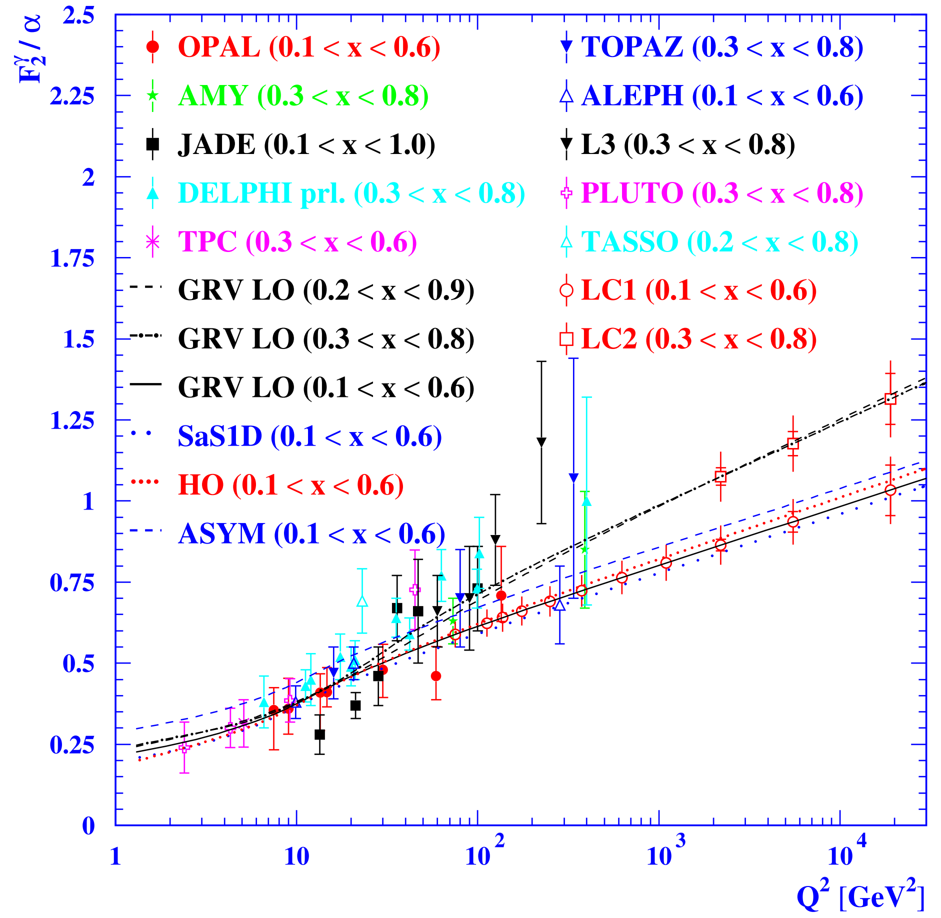
$\Rightarrow$ Agressive: $x \geq 4 \cdot 10^{-4}$

$\Rightarrow$ Conservative: $x \geq 10^{-3}$

Electron Photon Scattering

WW mode (e^+e^- 500 GeV): R. Nisius

Study of the high x region of the photon structure (asymptotic behaviour)



LC1: $\theta_{min} = 40$ mrad (conservative)

LC2: $\theta_{min} = 175$ mrad (no LAT)

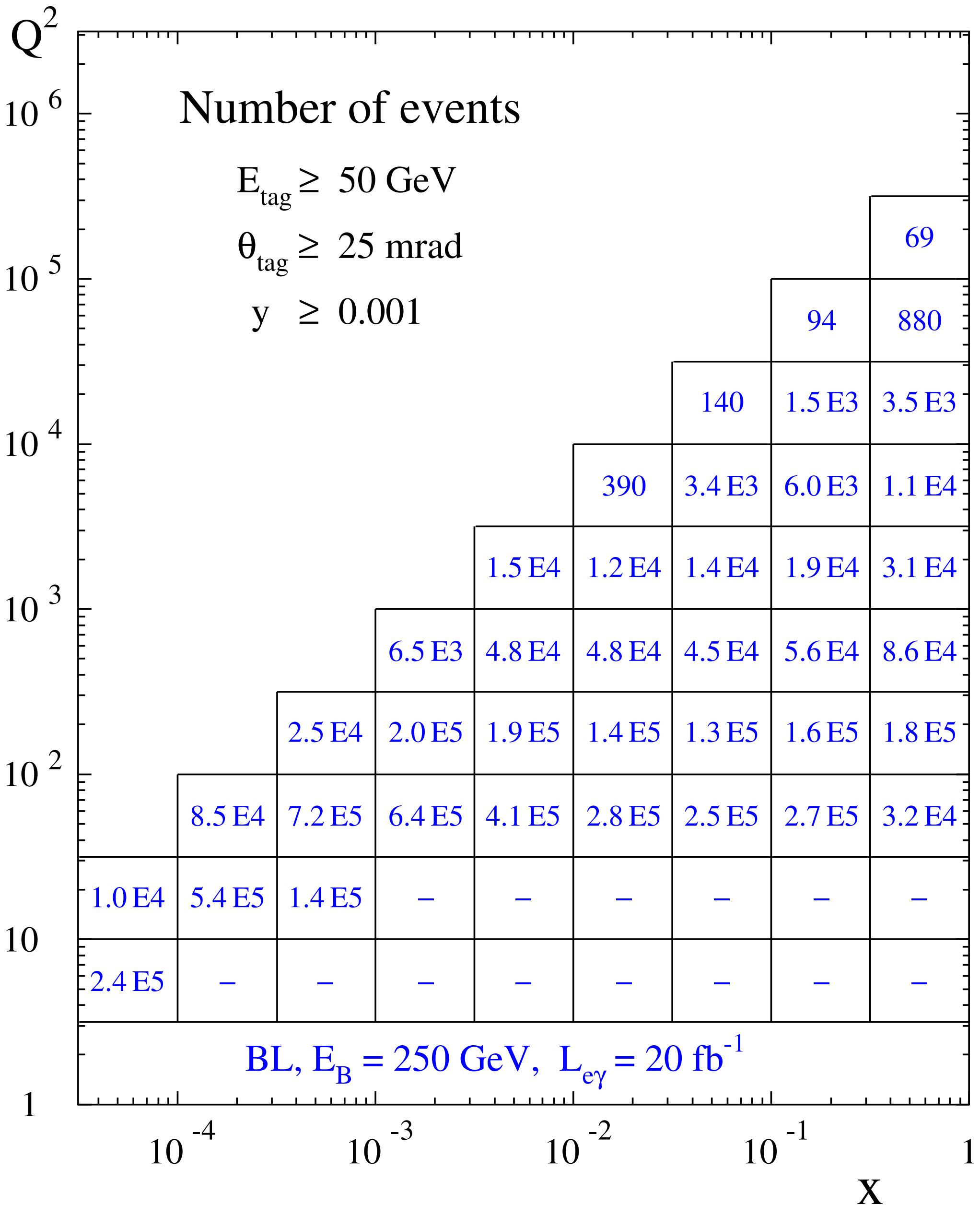
GRV structure function, 10 pb^{-1} (pre-Tesla TDR study)

Systematical error (6.7%) $\sim$ half of LEP errors

Extend Q^2 evolution study to $\sim 10^4$ GeV^2

$e\gamma$ Scattering: PC mode

A.Vogt, ADR LC-TH-2001-032

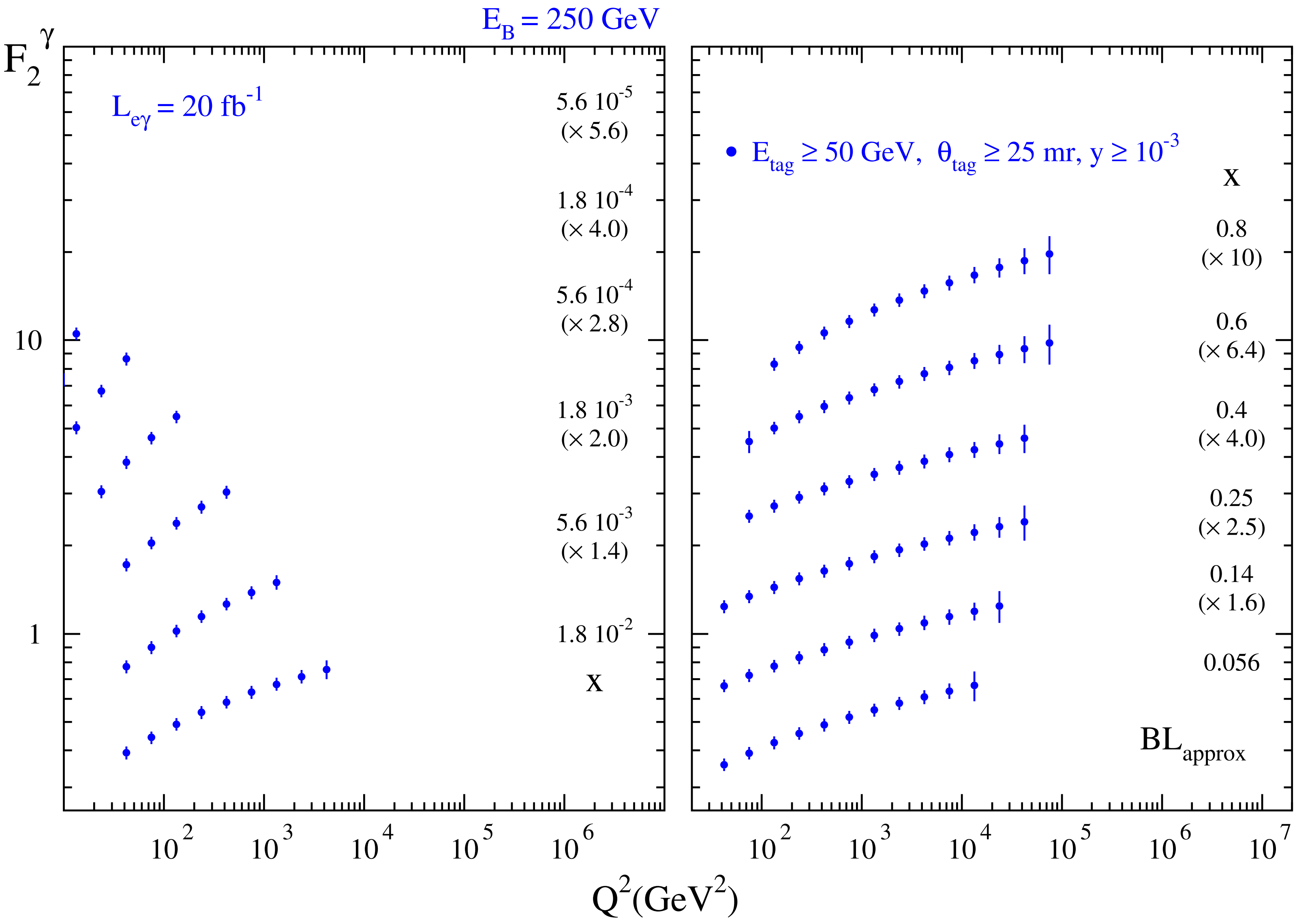


								69
							94	880
						140	1.5 E3	3.5 E3
					390	3.4 E3	6.0 E3	1.1 E4
				1.5 E4	1.2 E4	1.4 E4	1.9 E4	3.1 E4
			6.5 E3	4.8 E4	4.8 E4	4.5 E4	5.6 E4	8.6 E4
		2.5 E4	2.0 E5	1.9 E5	1.4 E5	1.3 E5	1.6 E5	1.8 E5
	8.5 E4	7.2 E5	6.4 E5	4.1 E5	2.8 E5	2.5 E5	2.7 E5	3.2 E4
1.0 E4	5.4 E5	1.4 E5	–	–	–	–	–	–
2.4 E5	–	–	–	–	–	–	–	–

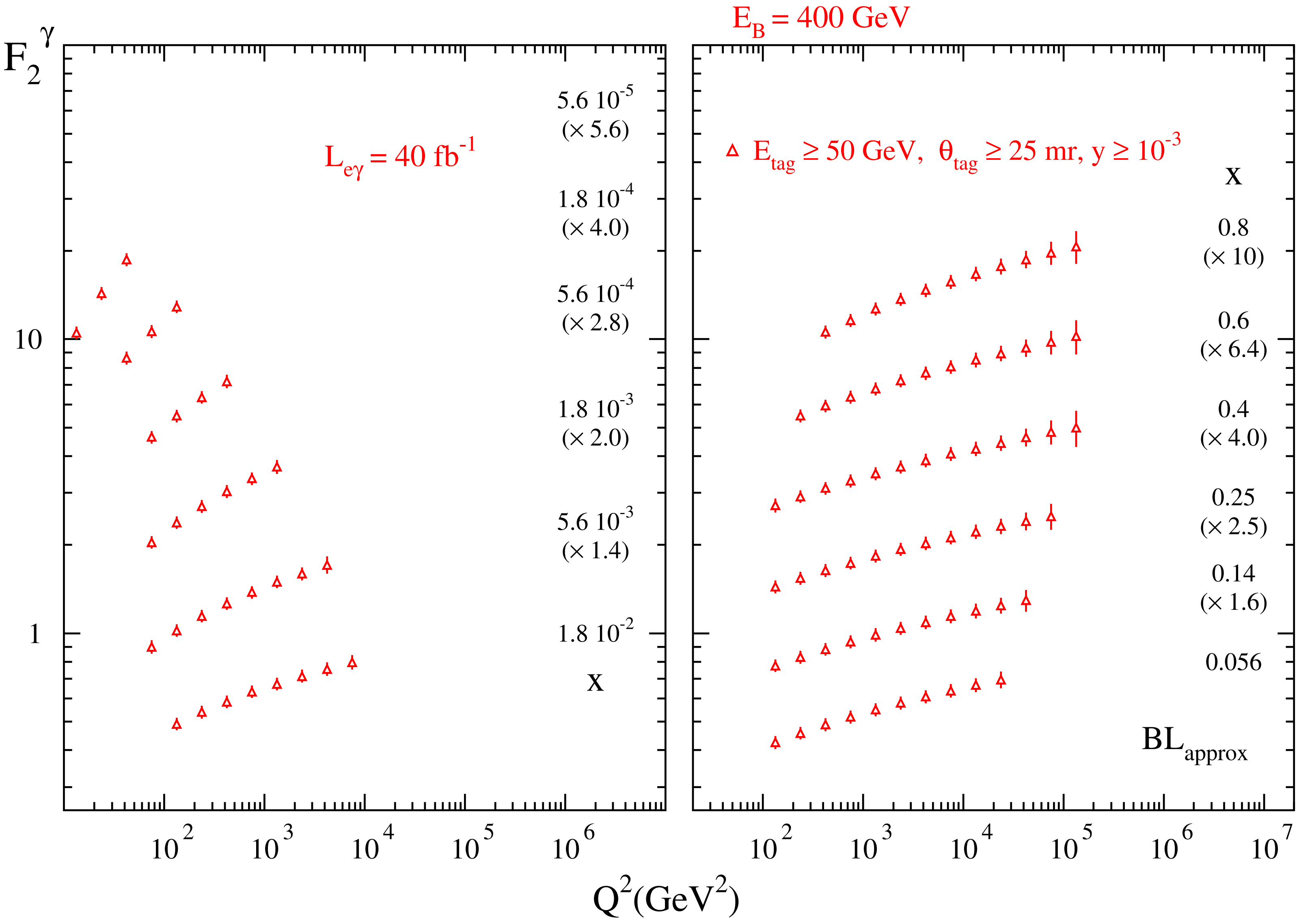
For study: Statistical + Systematic (5%) errors

Note: charm contribution at small x: 30-40%

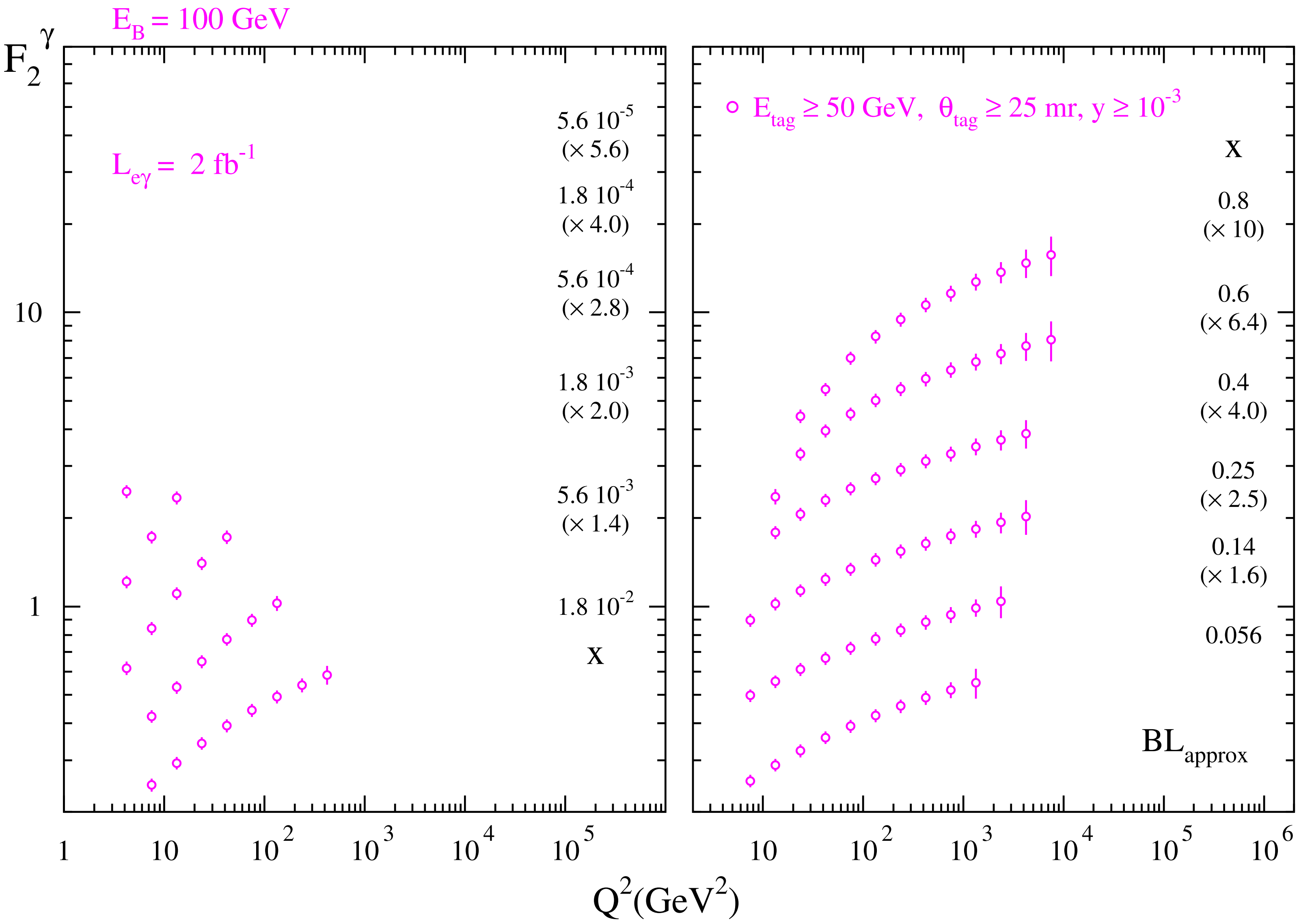
Electron Photon Scattering: PC mode



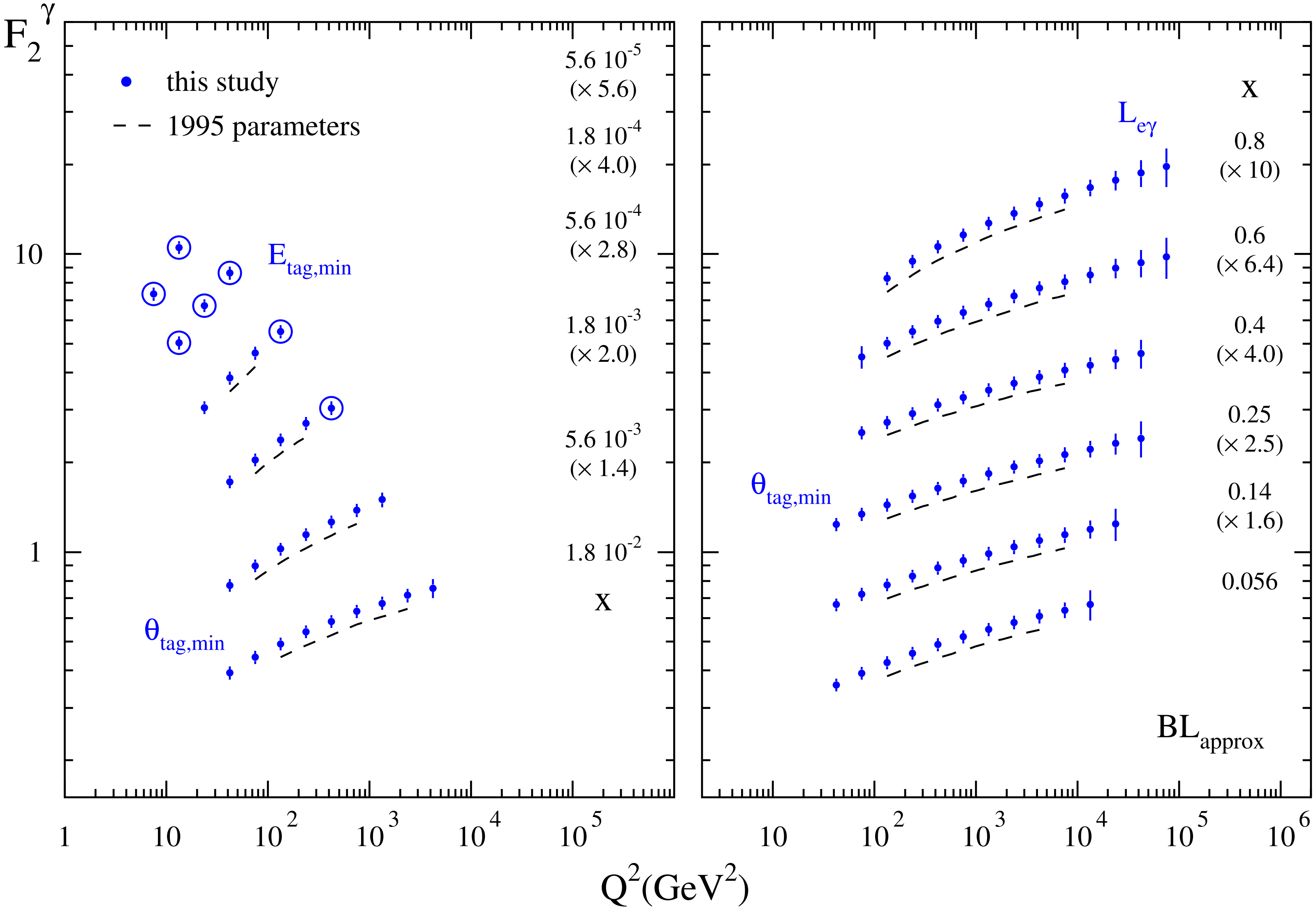
Electron Photon Scattering: PC mode



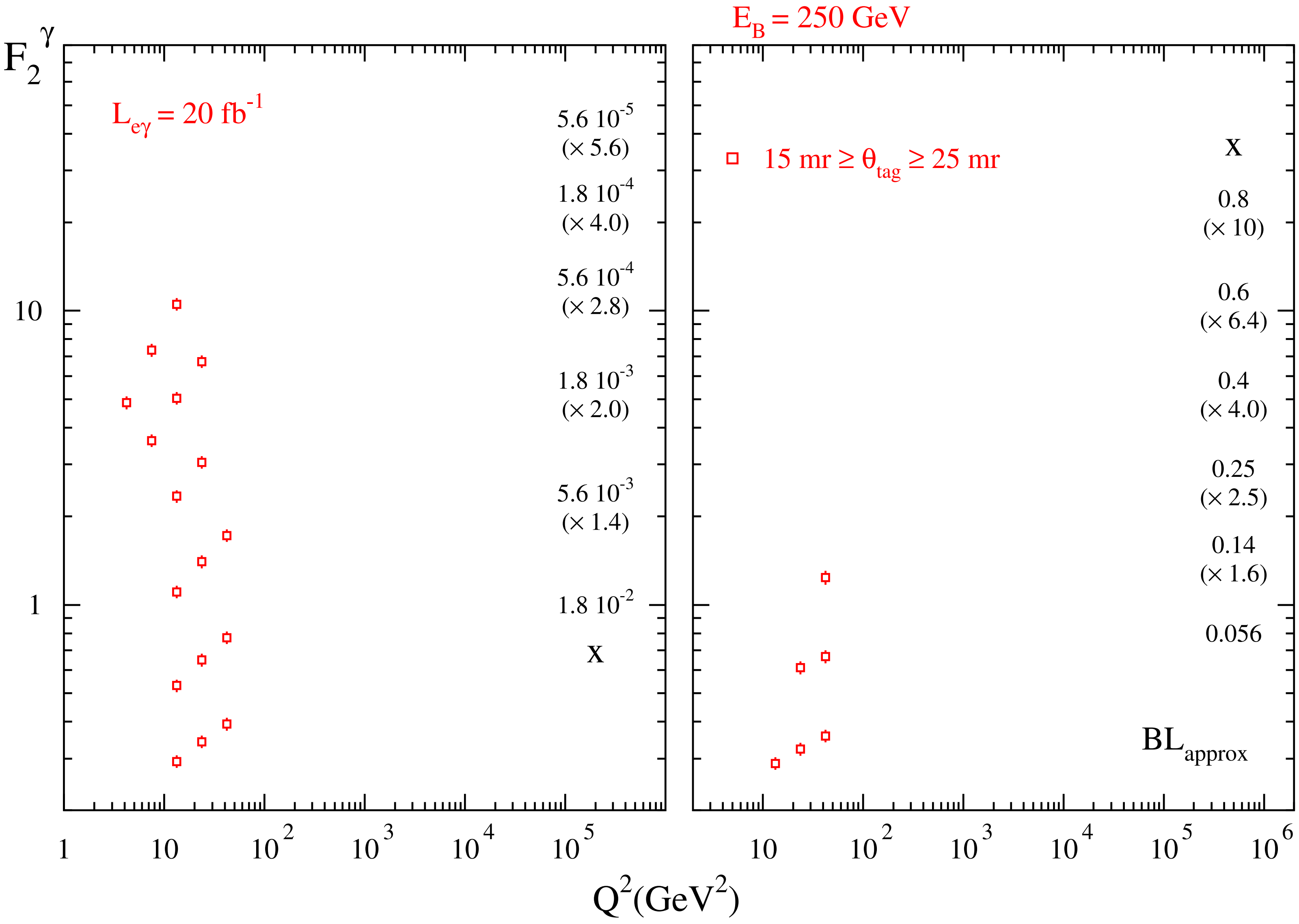
Electron Photon Scattering: PC mode



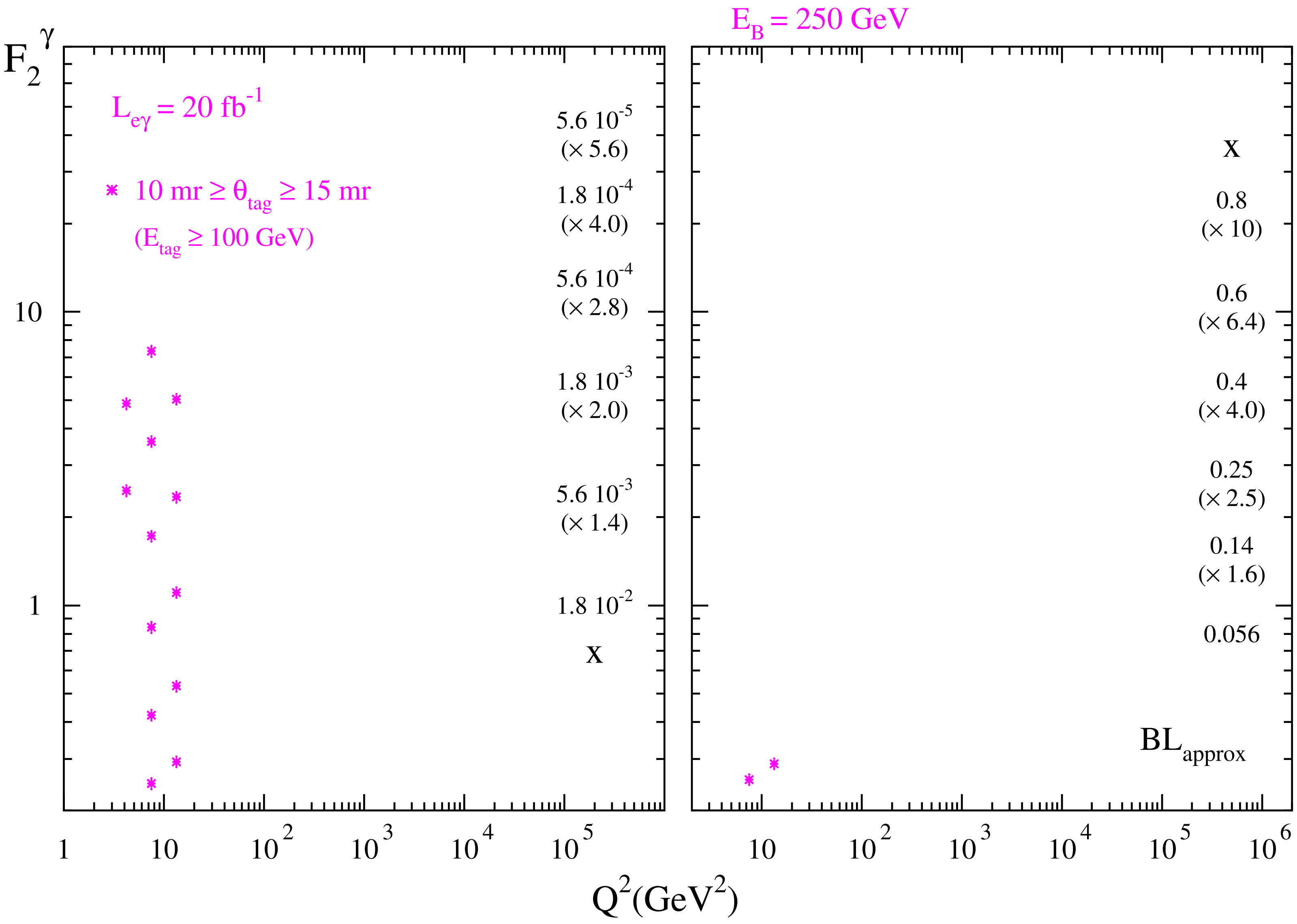
Electron Photon Scattering: PC mode



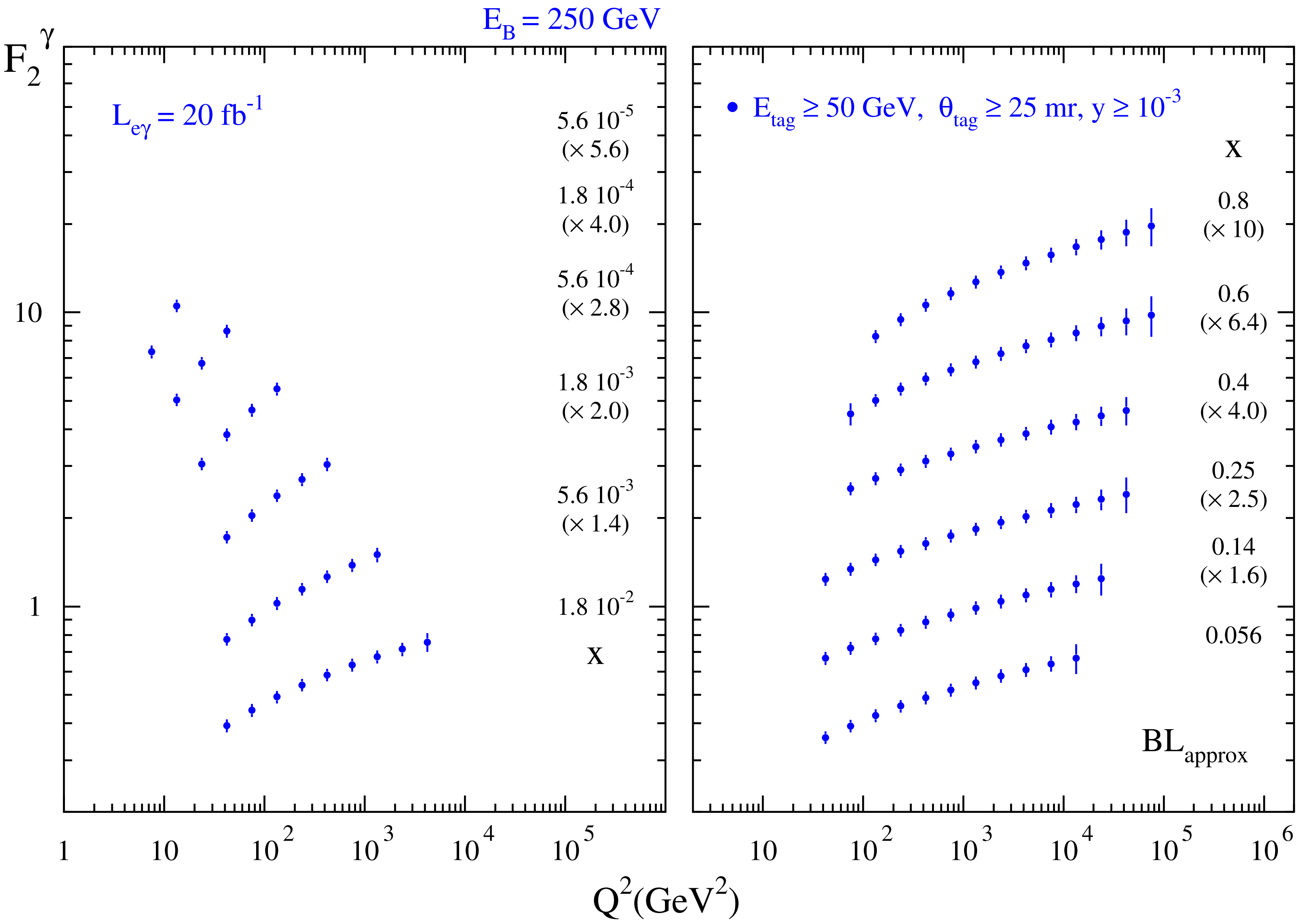
Electron Photon Scattering: PC mode



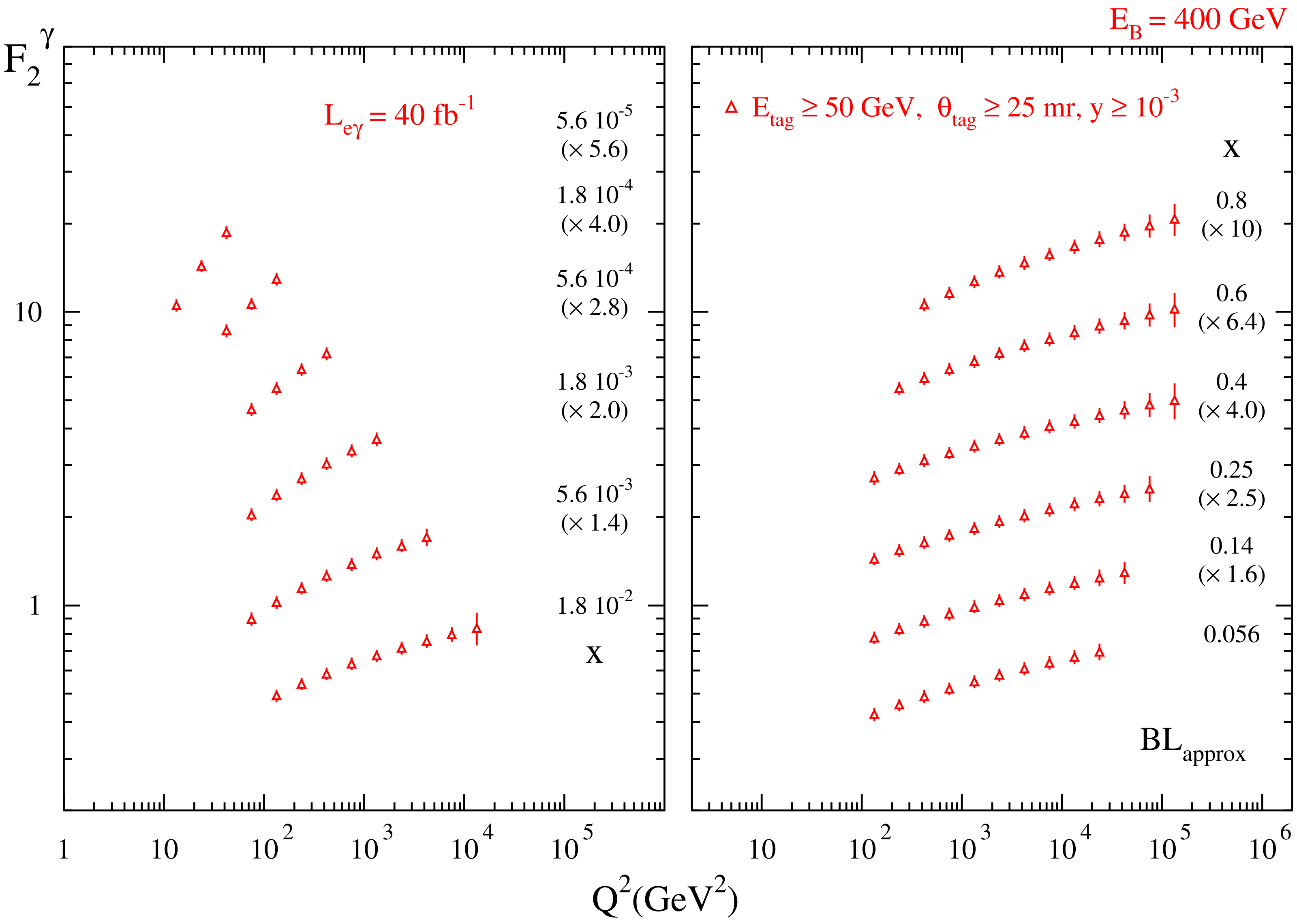
Electron Photon Scattering: PC mode



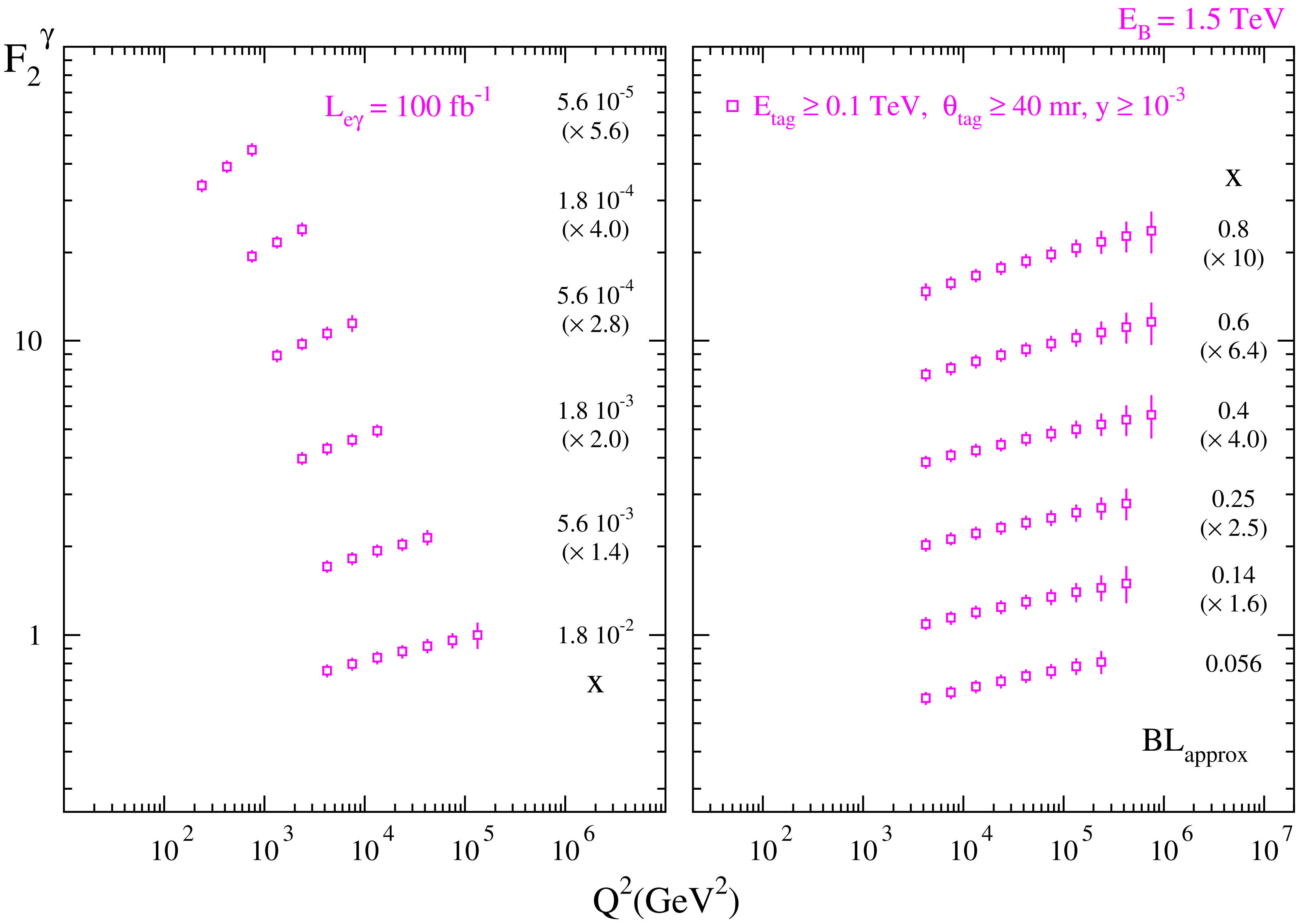
Electron Photon Scattering: PC mode



Electron Photon Scattering: PC mode



Electron Photon Scattering: PC mode



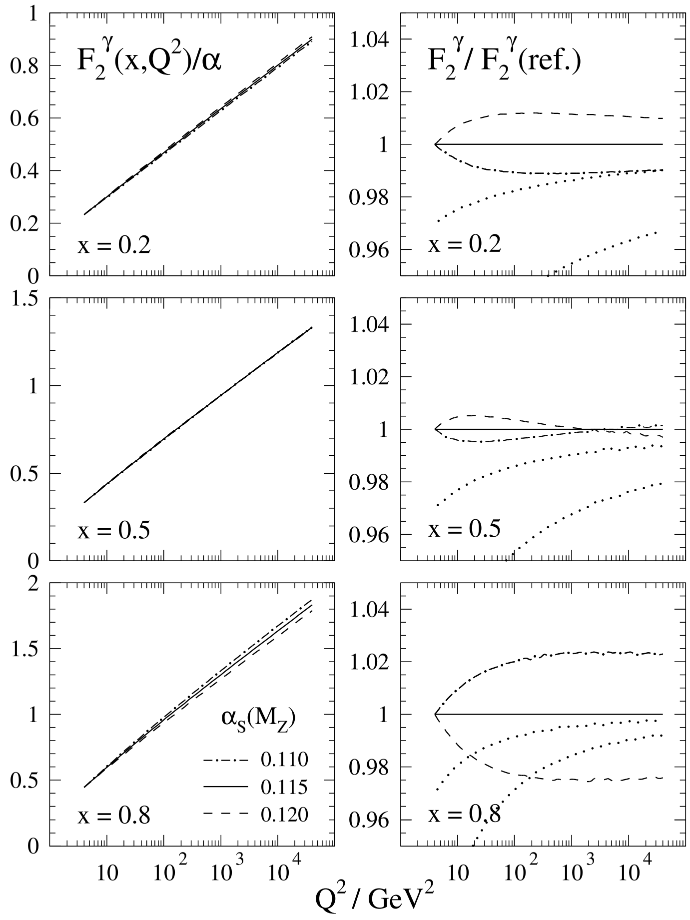
Electron Photon Scattering

A. Vogt

Extract α_s at high x?

α_s dependence of the large NLO evolution from fixed $Q_0^2 = 4\ \text{GeV}^2$

(dots: normalization off-sets of 3% and 10%)



α_s sensitive to absolute values of F_2^γ at large x and large Q^2

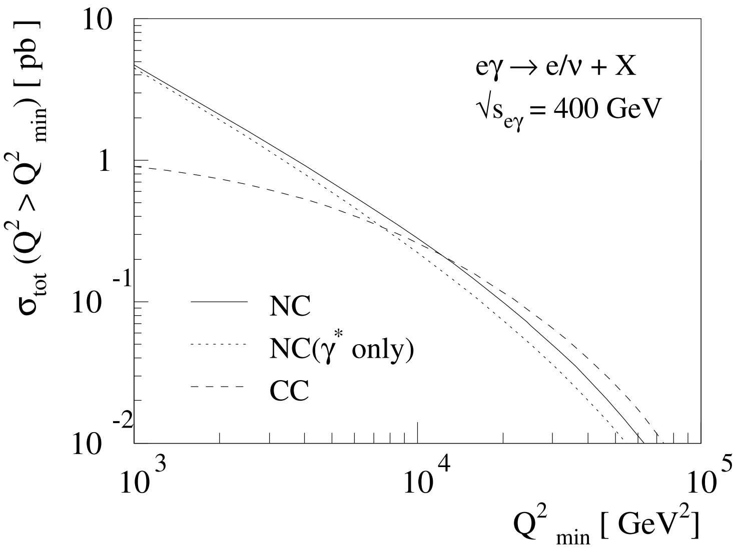
At $x = 0.8$: a 5% change in $\alpha_s \longrightarrow$ 3% change in F_γ^2 only. Measurable?

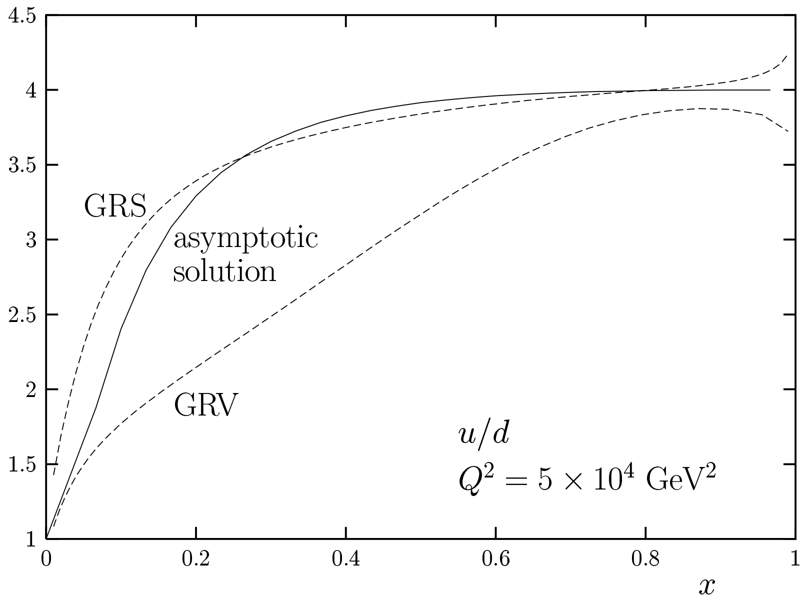
Electron Photon Scattering

A. Gehrmann-De Ridder, H.Spiesberger, P. Zerwas

PC mode: Very high Q^2 region ($Q^2 > 10^4$ GeV²)

⇒ EW neutral and charged current SF's





Determine separately up- and down-type quarks in photon!

Polarized Partons Distributions

M. Stratmann, W. Vogelsang

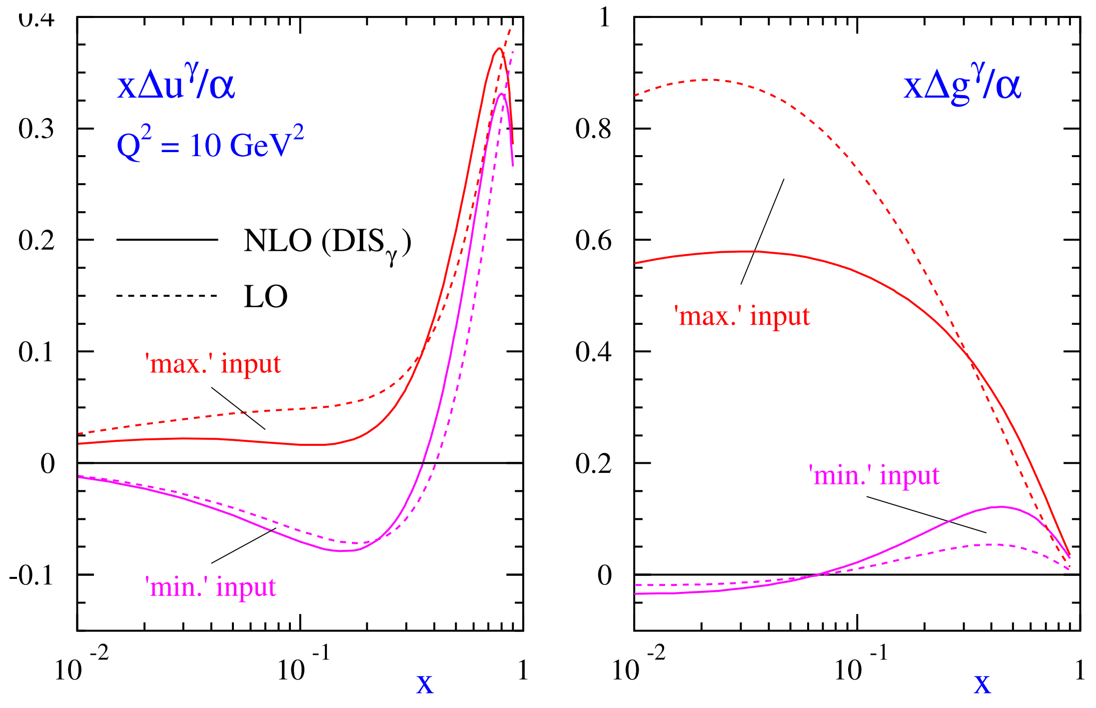
Polarised e and γ beams (WW & PC) allow to
determinine the spin structure of the photon Δf^{γ}

present experimental information ∼ zero
proton (EMC) → Spin Puzzle: spin proton $\neq \sum$ spin quarks

→ Measure helicity depended cross sections $\sigma_{++}, \sigma_{+-} \ldots$

NLO QCD model for Δf^{γ}, $(f = q, g)$

MAX: $\Delta f^{\gamma} = f^{\gamma}$ at Q_0^2/ MIN: $\Delta f^{\gamma} = 0$ at Q_0^2



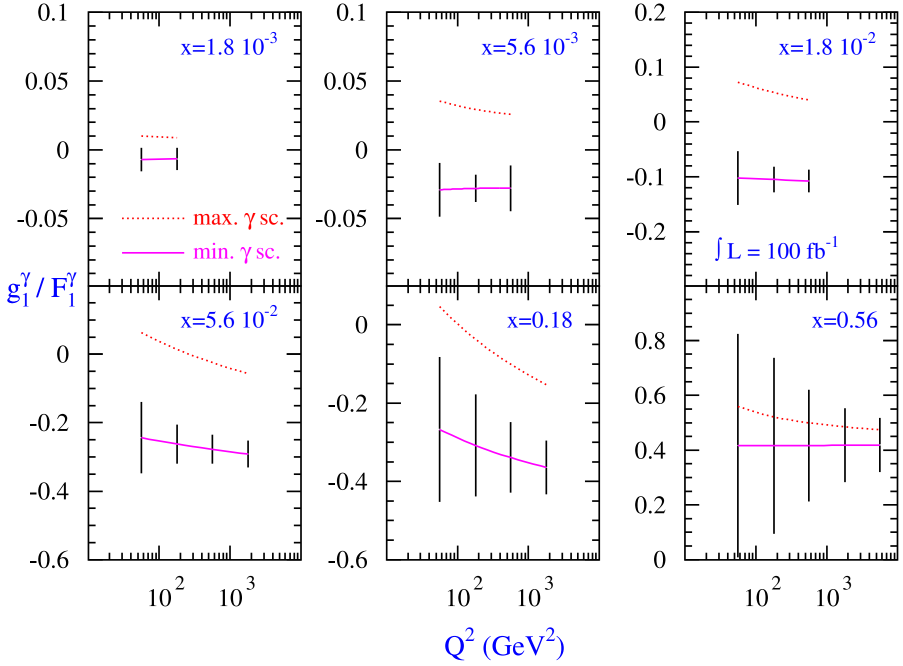
Study: e^{-} beam 80% and laser 100% polarization

Polarized Parton Distributions in the Photon

Δf^{γ} sensitivity at a 500 GeV LC

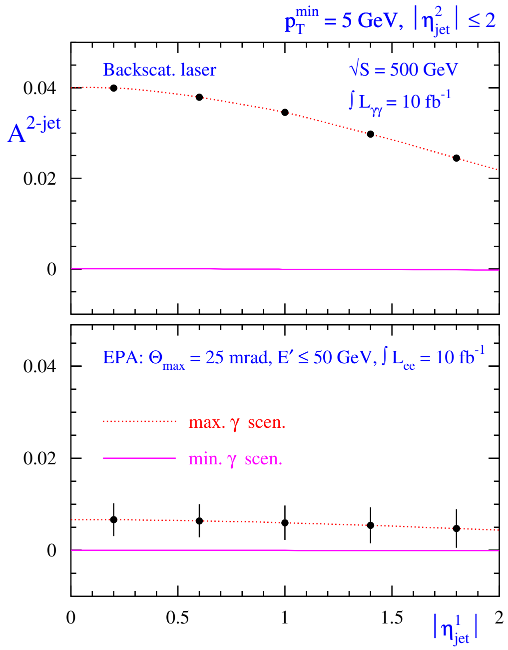
DIS $g_1^{\gamma}/F_1^{\gamma}$

PC mode only



di-jet events (double resolved)

PC & WW mode



- Large sensitivity for PC to Δf^{γ}'s via g_1 and di-jets
- for WW, only di-jets channel sufficiently sensitive to Δf^{γ}'s

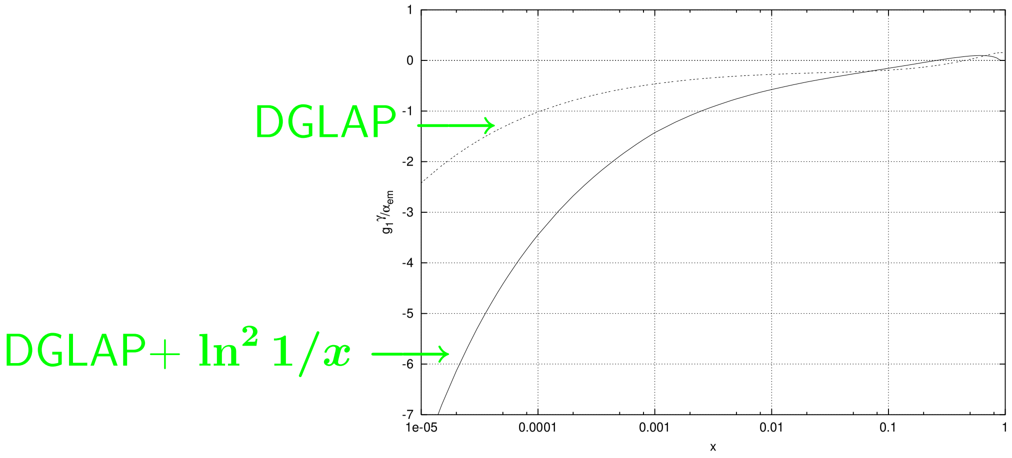
Polarized $e\gamma$ Scattering

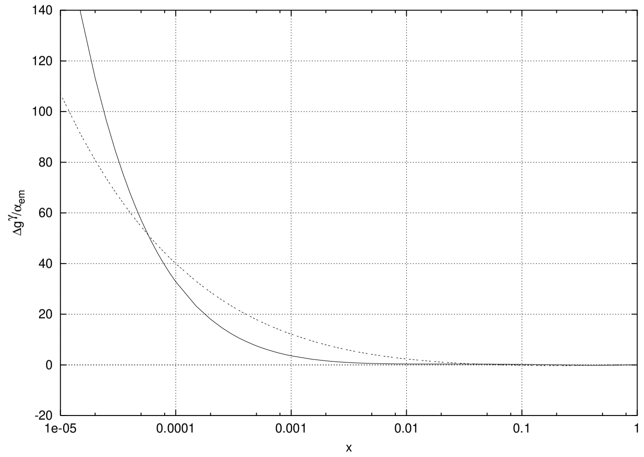
J. Kwiecinski, B. Ziaja

Predictions for $g_1^\gamma(x, Q^2)$ and $\Delta g^\gamma(x, Q^2)$ at small x

- DGLAP + $\ln^2 1/x$ term (proton evolution eqns + inhomogenous term
- VDM non-perturbative input: $\Delta g^v(x) \sim (1-x)^3(1+ax)$

$$g_1^\gamma(x, Q^2) = \frac{1}{2}\Sigma_i e_i^2 \Delta q_i$$





- g_1 and Δg can be large at small x
- Large $\ln^2 1/x$ effects in g_1 and Δg
- (Important effects of the non-perturbative input)

Summary

Photon Structure at LC, with e-tagging down to 25 mrad

- In the WW mode F_2^γ can be measured in the region $10^{-3} < x$ and Q^2 up to a few times 10^4 GeV^2. Usefull for high-x measurements and long Q^2 evolution arm.
- In the PC mode F_2^γ can be measured in the region $6 \cdot 10^{-5} < x < 0.8$, $7 < Q^2 < 10^5$ GeV^2.
  Smaller Q^2 can be reached with smaller angle tagging (15 mrad?) and lowering the beam energy.
  Large Q^2 region allows to study NN/CC events and distributions for different quark flavours.
  Region is extended to $Q^2 \sim 10^6$ GeV^2, $x \sim 10^{-6}$ with CLIC.
- Unique measurements can be made of polarized parton distributions, Δf^γ, from polarised $e\gamma$ scattering and di-jet measurements. g_1^γ is very sensitive to $1/x$ logs.
- Possible improvements and extentions
  ∗ Better understanding and confidence in hadronic final state/kinematic reconstruction (WW mode)
  ∗ Better detector coverage
  ∗ Asymmetric collisions to increase acceptance
  ∗ Gluon Distributions from Charm and Dijets (Jankowski, Krawczyk, Wengler, ADR)

- In all, extention of two order of magnitude in x and Q^2 possible for photon structure studies
  Low-x: Rise of F_2^γ?
  High-x: Asymptotic predictions? (α_s?)
  High-Q^2: Charged currents, flavour separation