On the Measurement of Photonic Structure of Protons in ep Collisions

Victor Lendermann
DESY

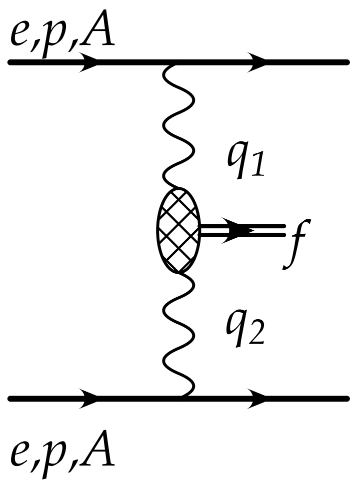
- Equivalent Photon Approximation
- QED Compton Events at HERA
- DICS Interpretation
- Comparison of Calculations
- Summary

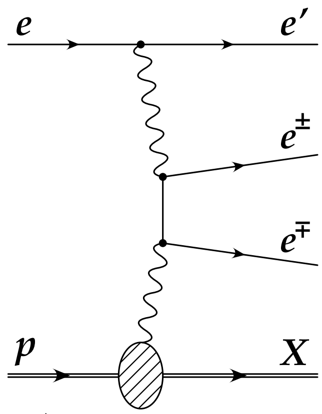
Hadron Structure 02 Herl'any 24 Sep 2002

Collinear Approximation

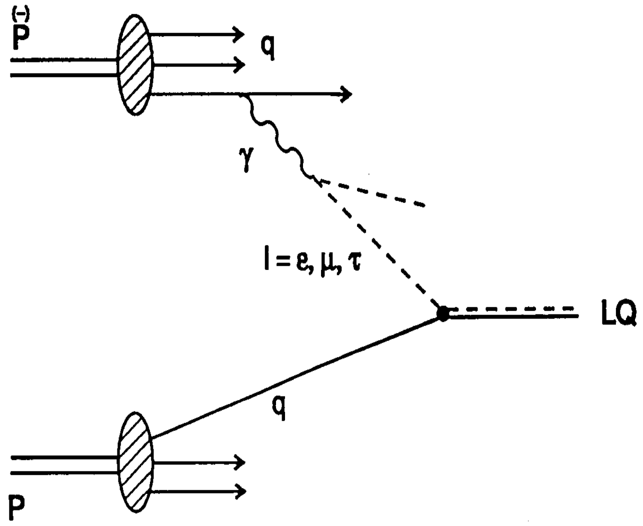
- Low $Q^2 \longleftrightarrow$ low $p_{t,\gamma^*} \Rightarrow$
  Collinear Approximation $\equiv$ EPA $\equiv$ WWA

  Photon is a parton in the incident particle
  It interacts with some virtual state (hard scale)





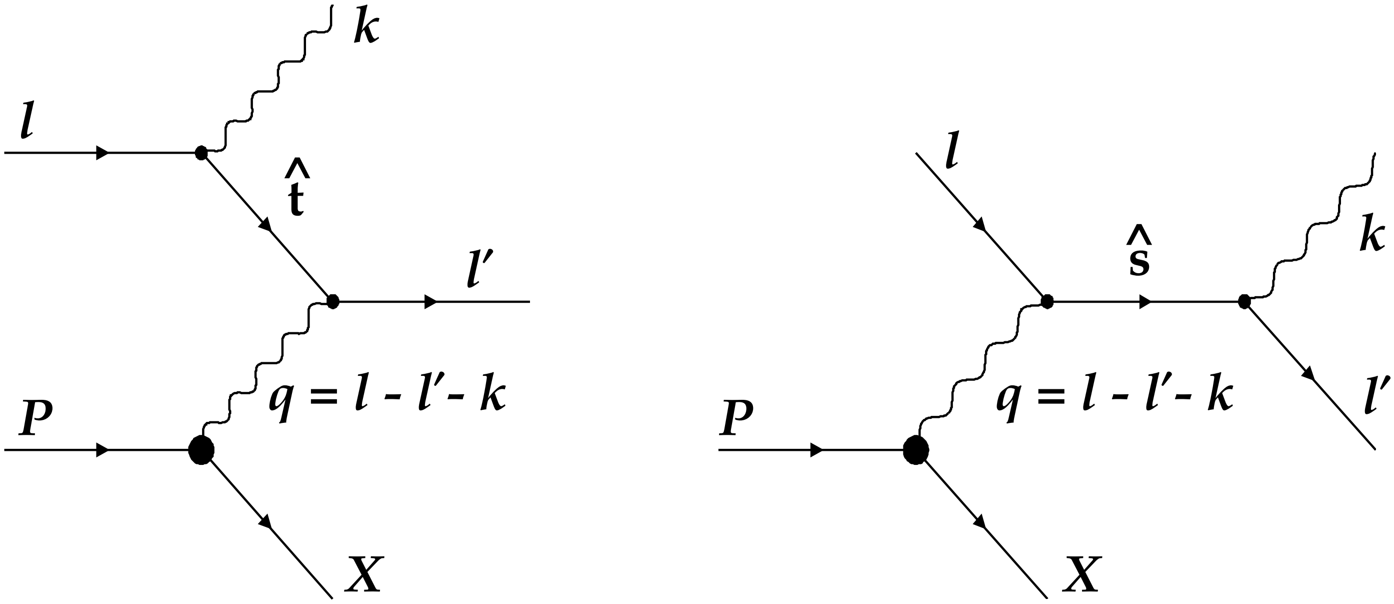
a)



- $f_{\gamma|e,p,A} \equiv \gamma -$ probability to find a photon
  in the initial particle
  = equivalent photon flux

Radiative ep Scattering

$$e + p \longrightarrow e + \gamma + X$$



- Radiative Corrections to DIS :
  $\vec{k} \parallel \vec{l}$ — Initial State Radiation (ISR)
  $\vec{k} \parallel \vec{l'}$ — Final State Radiation (FSR)

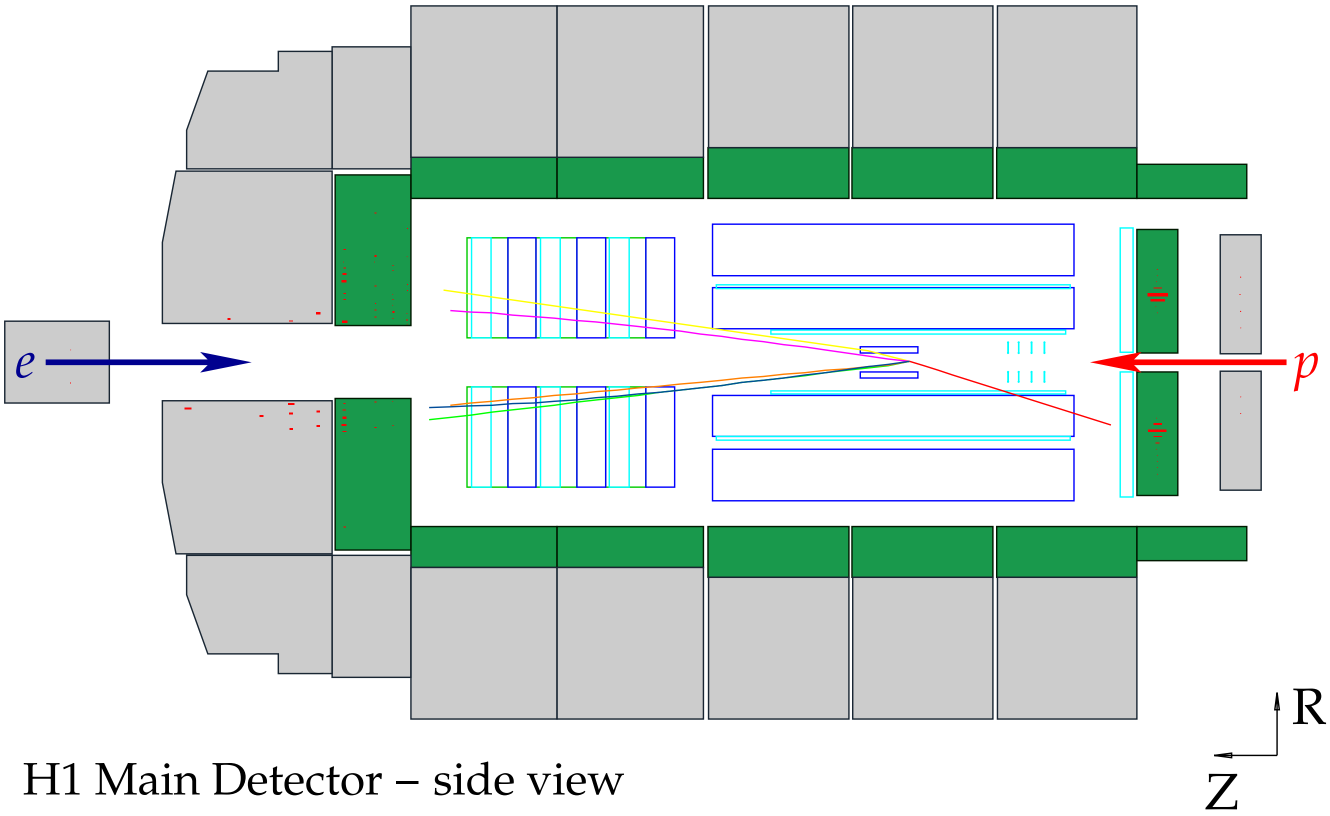
- QED Compton : $q^2 \sim 0 \iff \vec{q} \parallel \vec{P}$
  Compton scattering of a quasi-real photon off an electron

$$Q^2 \sim p^2_{t,e\gamma}$$

QEDC-Event in H1-Detector

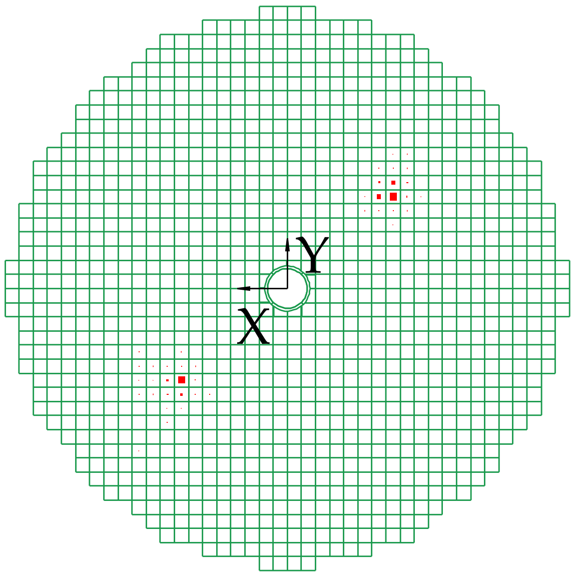
Run range: 1997

Beam energies: $E_e = 27.5\,\mathrm{GeV}$, $E_p = 820\,\mathrm{GeV}$

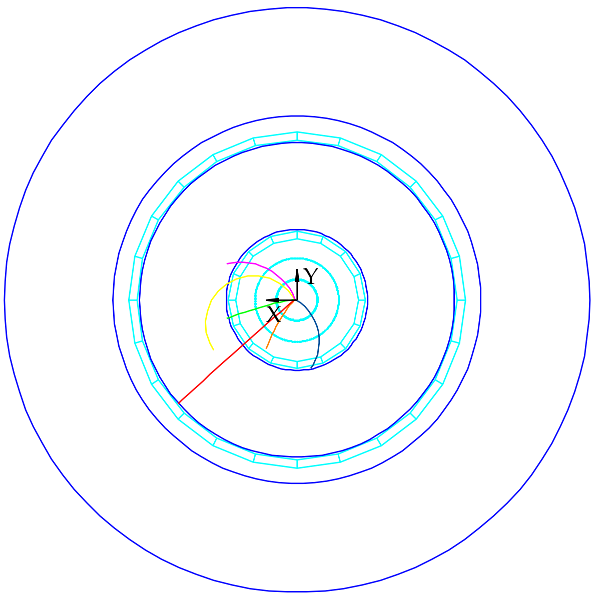


H1 Main Detector – side view

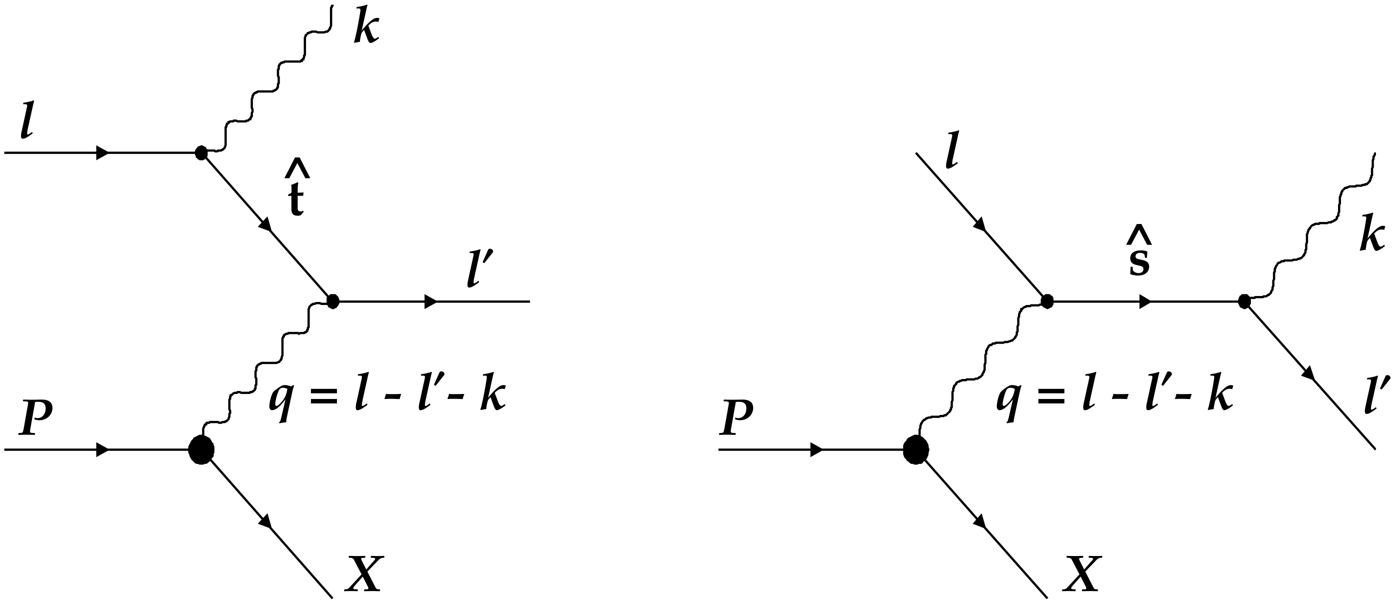
E.m. SpaCal – front view



Central Tracking Chambers



QED Compton Scattering



$$Q^2 = -q^2 = -(l - l' - k)^2 = -(X - P)^2$$

$$x = \frac{Q^2}{2P \cdot q} \qquad M_X^2 = Q^2 \frac{1-x}{x} + m_p^2$$

▶ Contributions to the cross section:

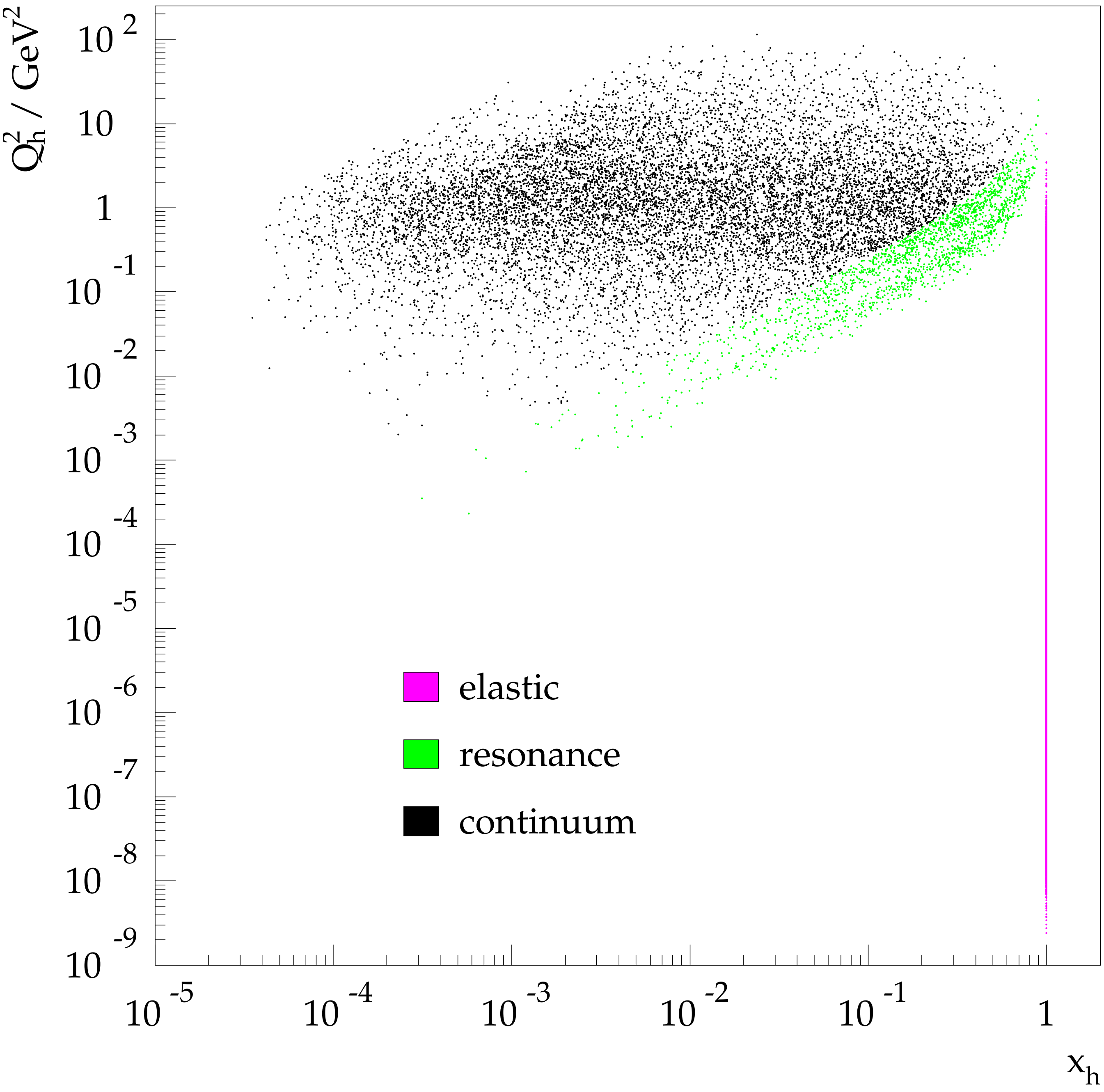
- Elastic : $M_X = m_p \,, \quad x = 1$
  σ_{el} *very well known* (e.m. form factors)

- Resonance : $m_p + m_\pi < M_X < 1.8 - 2\,\mathrm{GeV}$
  $\Delta(1236), N^*(1520), N^*(1680)$
  σ_{res} *well known, relatively small*

- Continuum Inelastic : $M_X > 1.8 - 2\,\mathrm{GeV}$
  $\sigma_{\mathrm{in}} \sim F_2$ *at small* Q^2

Kinematic Region of QEDC Scattering

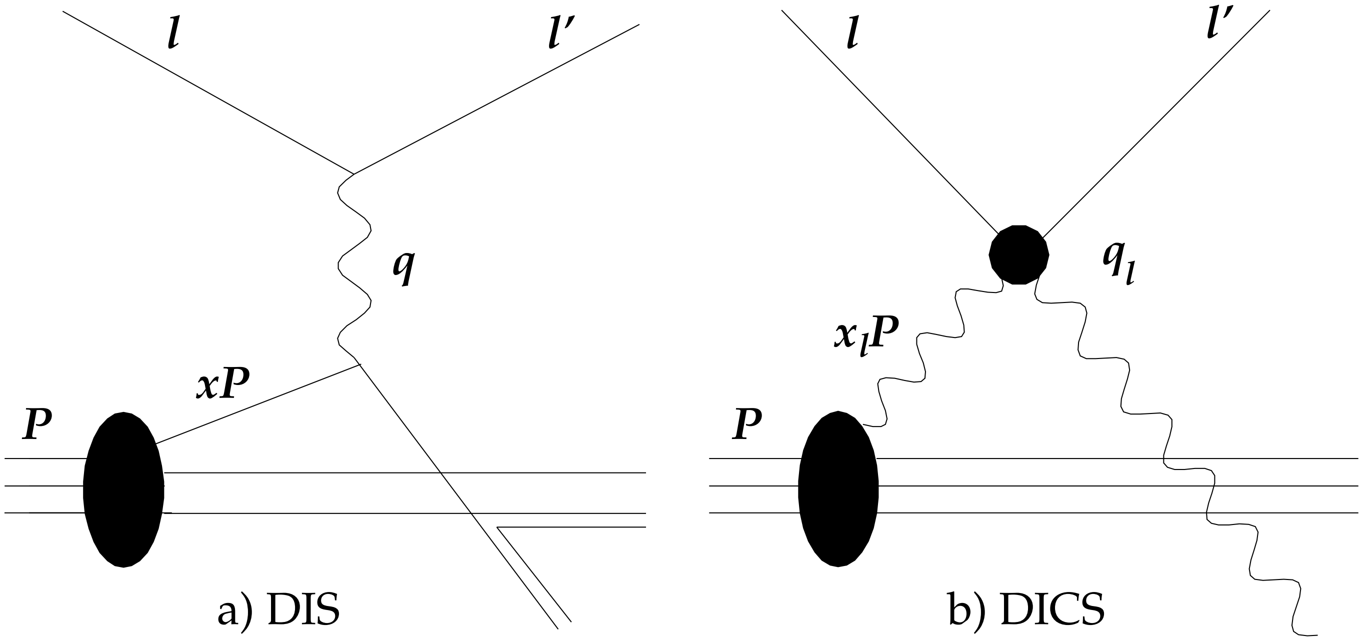
↪ COMPTON 2.00 (Courau, Kessler, Kermiche, Carli)
Version 2.14 - present work:
resonance - Brasse *et al*, continuum - ALLM97



DICS Interpretation

- Low $Q_h^2 \longleftrightarrow$ low $p_{t,\gamma^*} \Rightarrow$
  Equivalent Photon Approximation

  The photon is a parton in the proton
  It interacts with the virtual lepton



a) DIS

b) DICS

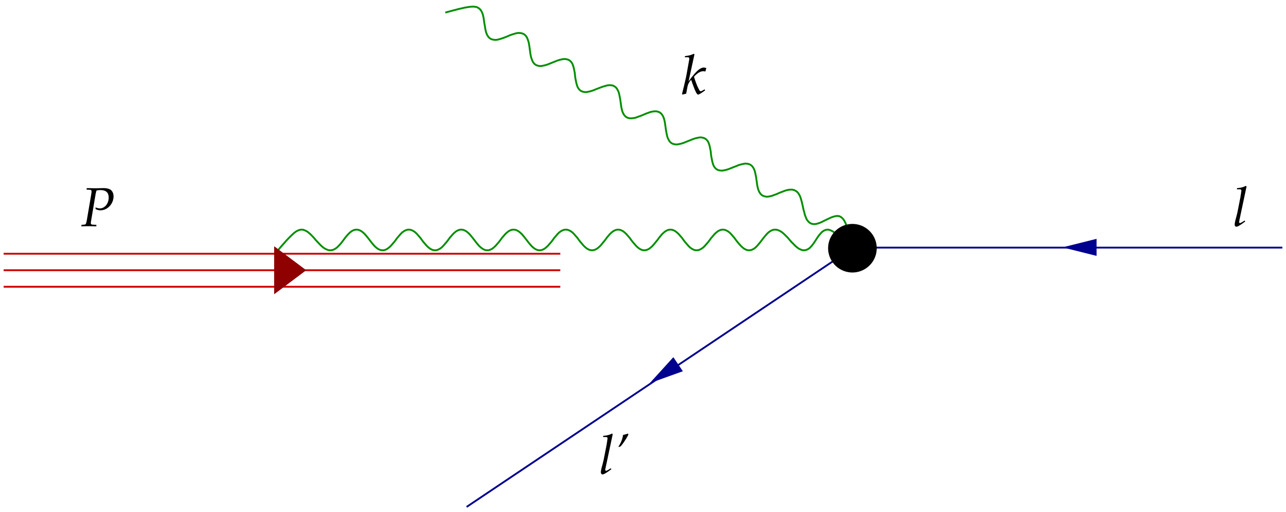
- Variables on the *lepton* vertex:

$$q_l = l - l', \quad Q_l^2 = -q_l^2, \quad x_l = \frac{Q_l^2}{2P \cdot q_l}$$

$-q_h \approx x_l P$	—	similar to x_{Bj}	in DIS
Q_l^2 large	—	similar to Q^2	in DIS

- Deep Inelastic Compton Scattering (DICS)

"Structure Function" $\gamma(x_l, Q_l^2)$



- Collinear Approximation: $\vec{q}_h \| \vec{P}$

$$\frac{d^2\sigma}{dx_l\, dQ_l^2} = \int_{x_l}^{1} \frac{dz}{z} \gamma(z, Q_l^2) \frac{d^2\hat{\sigma}^{e\gamma\to e\gamma}}{d(x_l/z)\, dQ_l^2}$$

- $\gamma(x_l, Q_l^2)$ – probability to find a photon "as a parton" in a proton

$$\gamma(x_l, Q_l^2) = \gamma_{\rm el}(x_l) + \gamma_{\rm in}(x_l, Q_l^2)$$

  - Sensitivity to F_2 at small Q_h^2

$$\gamma_{\rm in}(x_l, Q_l^2) = \int_{x_l}^{1} dx_h \int_{\Lambda^2}^{Q_l^2} \frac{dQ_h^2}{Q_h^2} \ldots F_2(x_h, Q_h^2)$$

  - "fundamental" function
    $\gamma \longleftrightarrow g$ (De Rujula and Vogelsang)

Comparison

$\gamma(x, Q^2) \longleftrightarrow g(x, Q^2)$

- 'QED evolution' equation:

$$\frac{\partial\, \gamma_{\rm in}(x,Q^2)}{\partial \ln Q^2} = \frac{\alpha_{em}}{2\pi} \int_x^1 \frac{dz}{z} \sum_q e_q^2 P_{Aq}\left(\frac{x}{z}\right) \times$$

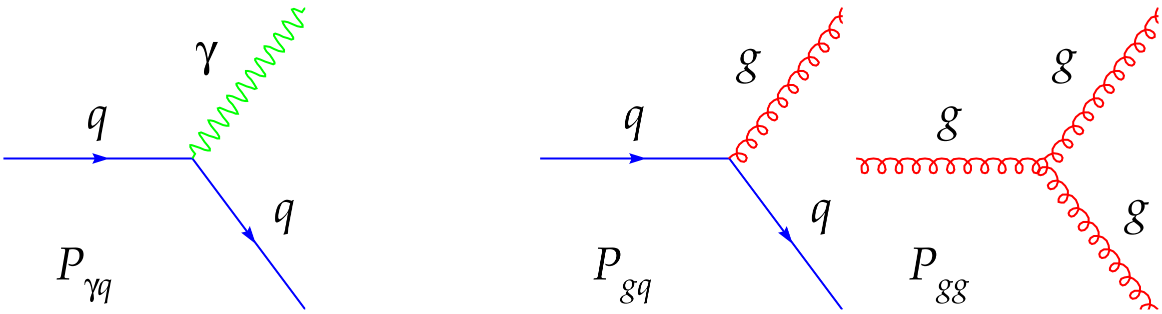
$$\times \left[q(z,Q^2) + \bar{q}(z,Q^2)\right]$$

- QCD gluon evolution equation – non-Abelian:

$$\frac{\partial\, g(x,Q^2)}{\partial \ln Q^2} = \frac{\alpha_s}{2\pi} \int_x^1 \frac{dz}{z} \left[\sum_q \frac{4}{3} P_{Aq}\left(\frac{x}{z}\right) \times \right.$$

$$\left. \times \left[q(z,Q^2) + \bar{q}(z,Q^2)\right] + P_{gg}\left(\frac{x}{z}\right) g(z,Q^2) \right]$$

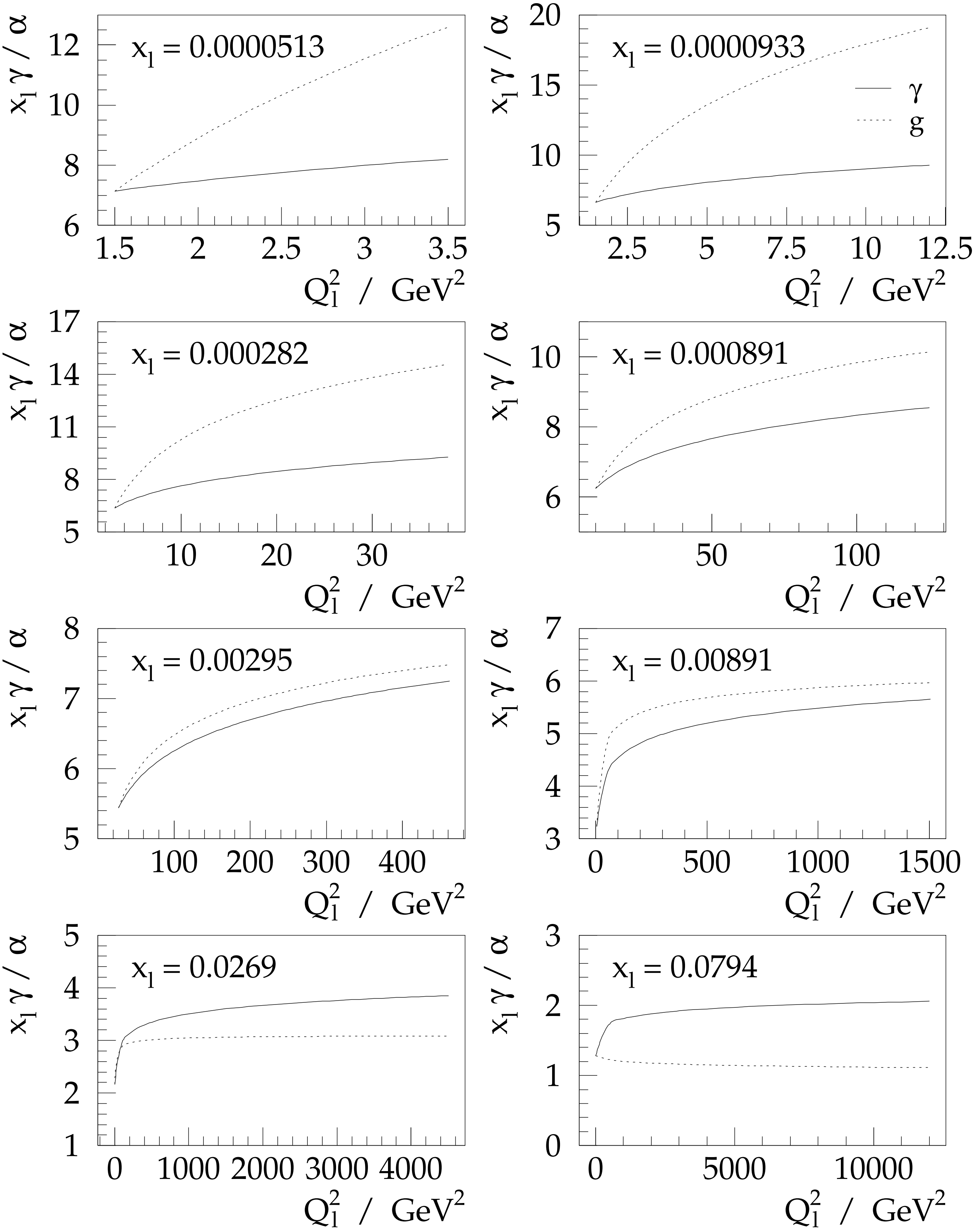
QED $\longleftrightarrow$ QCD



- Test of gauge theories — comparison of non-Abelian QCD with Abelian QED
Different Q^2 evolution should be observed

$$\gamma(x_l, Q_l^2) \longleftrightarrow g(x_l, Q_l^2)$$

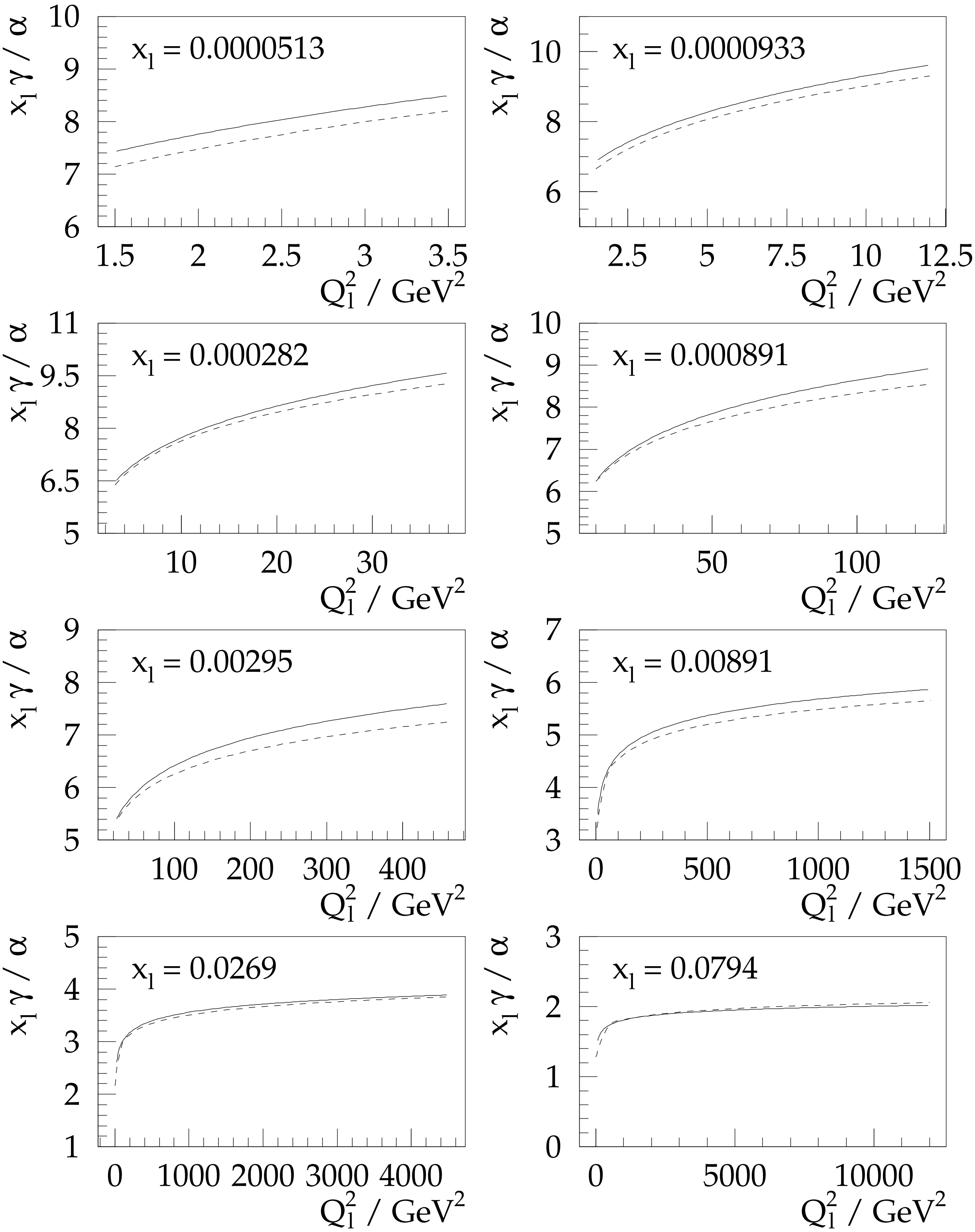
Prediction



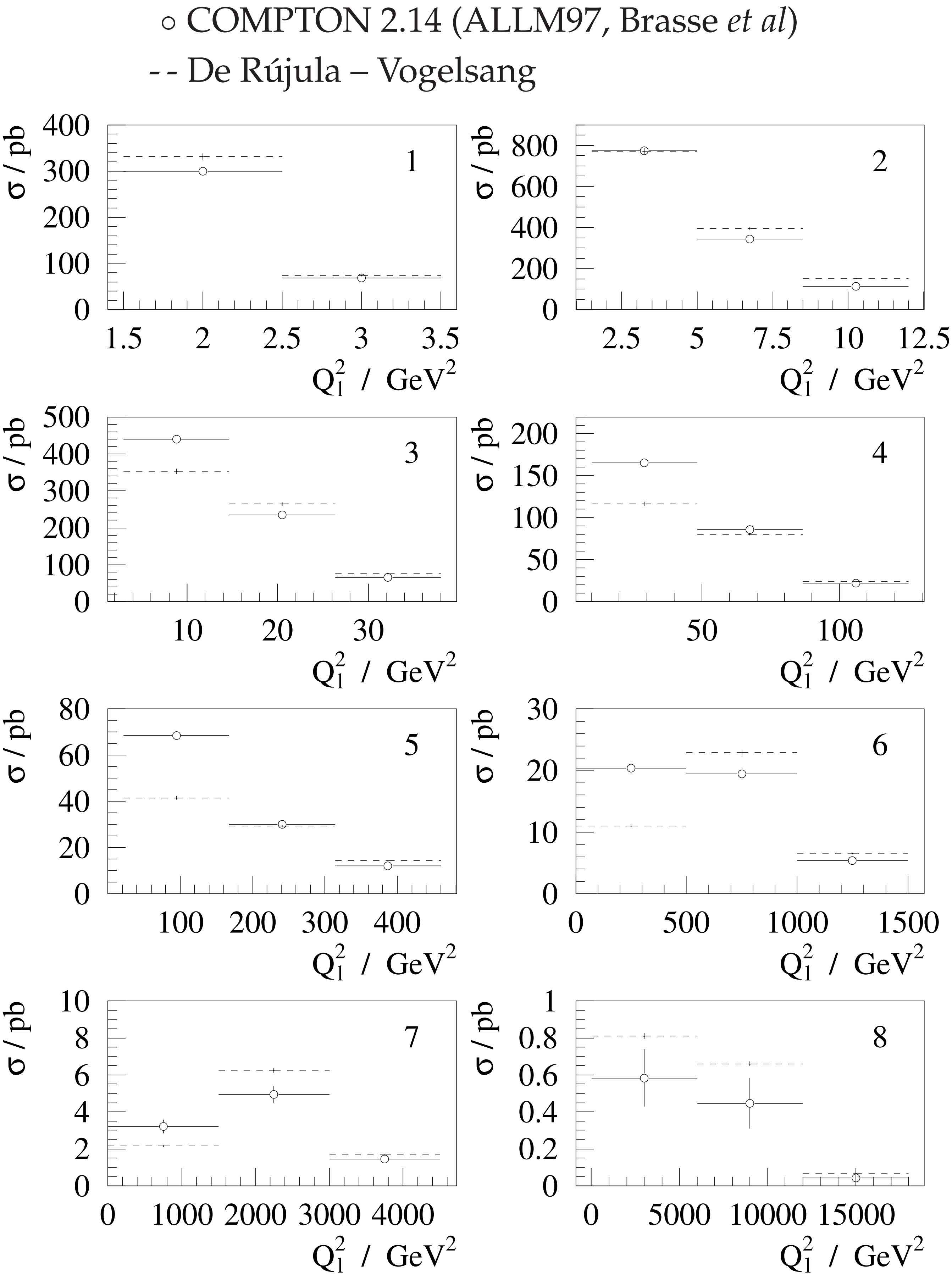
Equivalent γ Function

$$\gamma(x_l, Q_l^2) = \gamma_{\mathrm{el}}(x_l) + \int_{x_l}^{1} dx_h \int_{\Lambda^2}^{Q_l^2} \frac{dQ_h^2}{Q_h^2} \ldots F_2$$

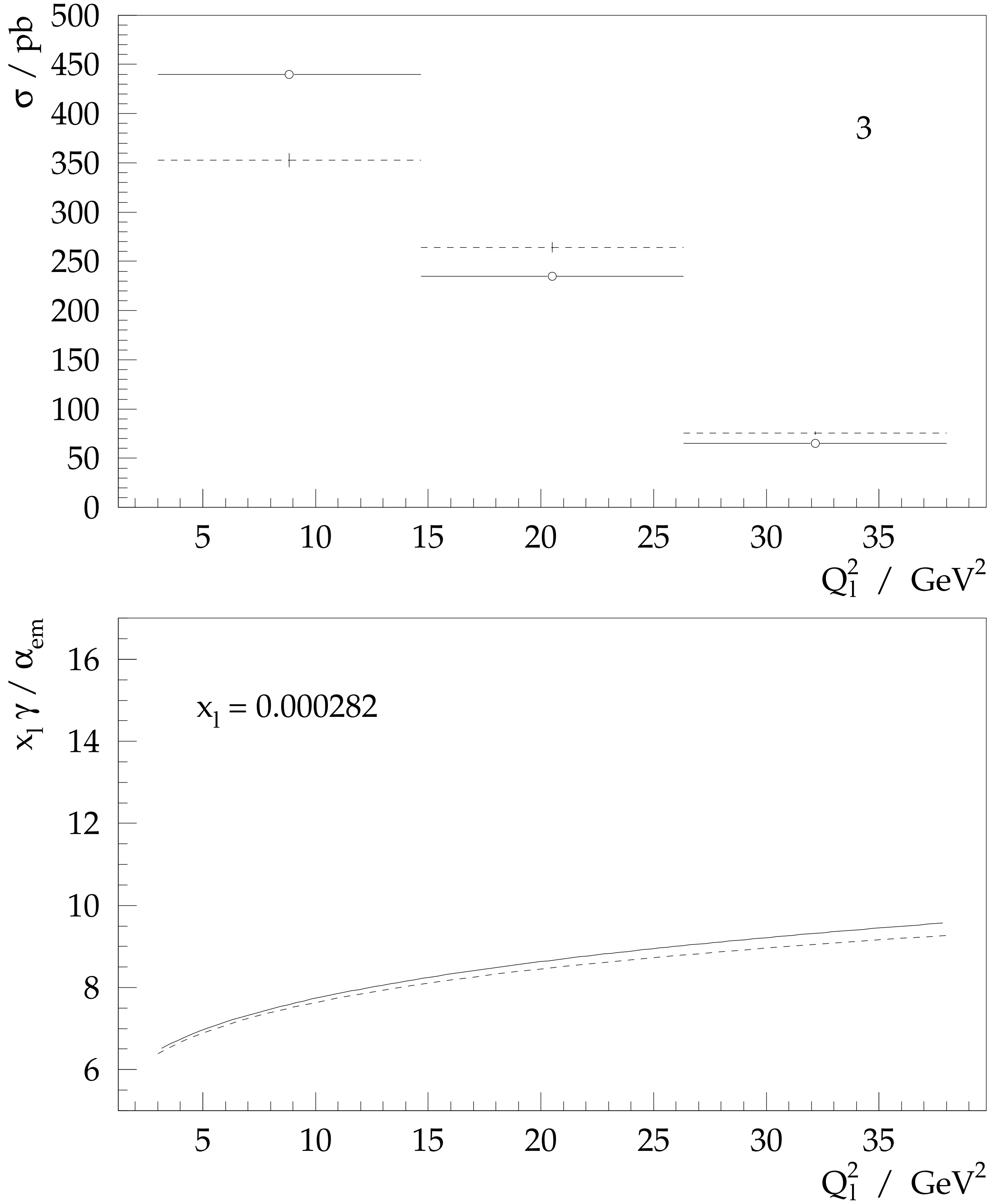
— This analysis (ALLM97, Brasse *et al*) - - De Rújula – Vogelsang



QEDC Cross Section



$\sigma(x_l, Q_l^2) \longleftrightarrow \gamma(x_l, Q_l^2)$



- EPA is too rough:

$$\frac{d^2\sigma_{\rm in}}{dx_l\, dQ_l^2} \neq \int_{x_l}^{1} \frac{dz}{z} \gamma_{\rm in}(z, Q_l^2) \frac{d^2\hat{\sigma}^{e\gamma\to e\gamma}}{d(x_l/z)\, dQ_l^2}$$

Event Kinematics

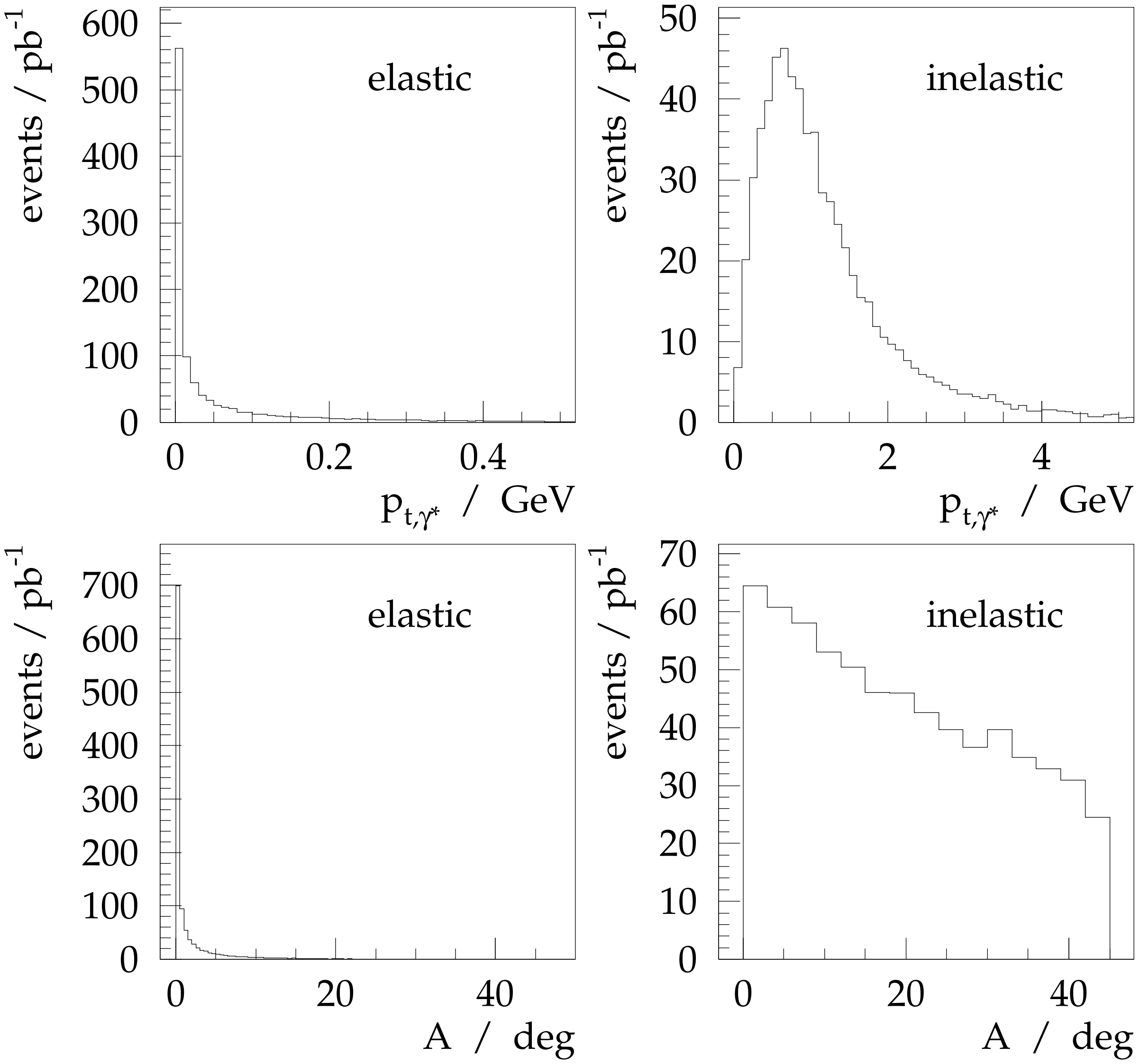
- Collinear Approximation:

$$\frac{d^2\sigma}{dx_l\, dQ_l^2} \quad \leftarrow \text{ 2 degrees of freedom}$$

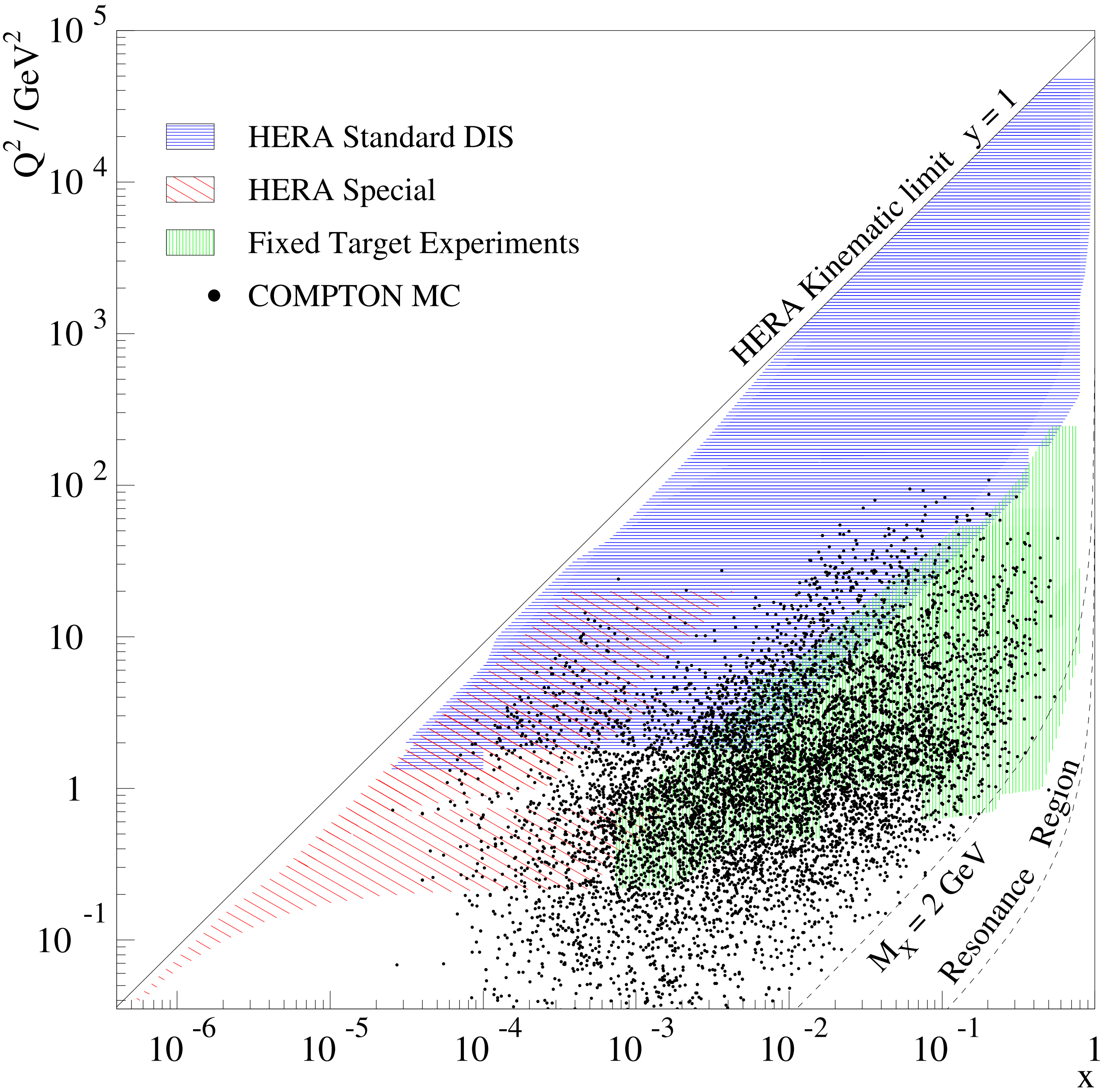
- COMPTON MC –
  Exact calculation of kinematics:

$$\frac{d^5\sigma}{dx_h\, dQ_h^2 \ldots} \quad \leftarrow \text{ 5 degrees of freedom}$$

$$e.g.\ \ E_e, \theta_e, E_\gamma, \theta_\gamma, \Delta\phi$$



Kinematic Region of Continuum QEDC



Summary

- EPA is common tool used at $Q^2 \approx 0$,
  allows simplified calculation of σ

- γ – photonic constituency defined in EPA
  γ in QEDC at HERA should show difference:
  $$\gamma \longleftrightarrow g \quad = \quad \mathrm{QED} \longleftrightarrow \mathrm{QCD}$$

- EPA works very well in elastic QEDC,
  at $Q^2 \leq 0.1\,\mathrm{GeV}^2$

- EPA is too rough in inelastic domain
  up to 25% difference
  $\Longrightarrow \gamma$ measurement is not reasonable

- But one can measure F_2 at low Q^2
  in QED Compton scattering!