A model for F_L at low Q^2 - revisited

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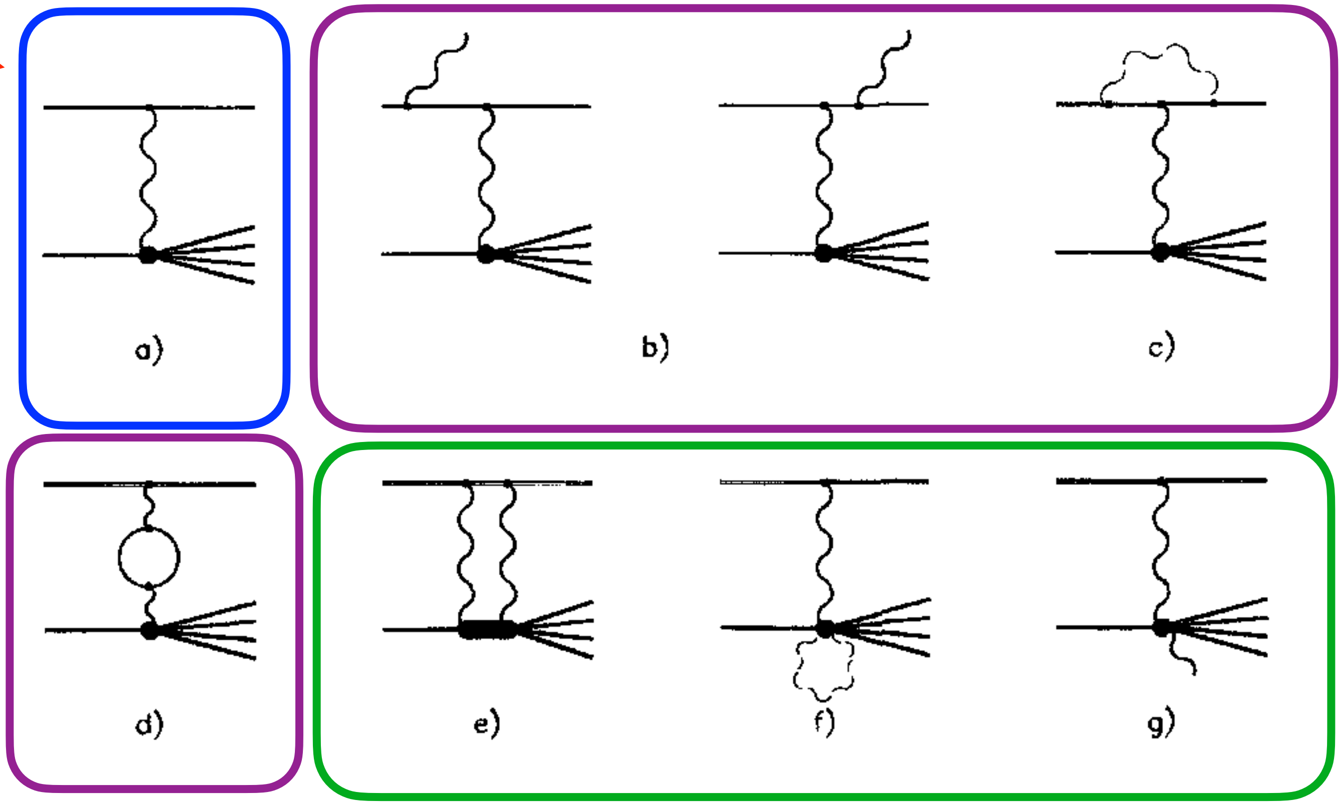
Outline

- Motivation for model of structure functions in the low Q^2 region: DIS radiative corrections (essential for EIC)
- Model for F_L at low Q^2: k_T factorization + higher twist
- Results: x and Q^2 behavior
- Comparison with JLAB, SLAC and HERA data
- Outlook

Radiative corrections

Extraction of the one - photon cross section from the measurement requires the correction for the ***radiative corrections***



RC factor:

$$\eta(x, y) = \frac{\sigma_{1\gamma}}{\sigma_{\mathrm{meas}}}$$

Examples:

Mo-Tsai scheme b)-d)

Dubna scheme b)-d)
and e)-g) hadron current corrections calculated using Quark Parton Model

Comparison of schemes *Badelek, Bardin, Kurek, Scholz Z. Phys. C 66 , 591 (1995)*

Radiative corrections

Need following input for

$$x_{\mathrm{meas}} < x < 1$$

$$0 < Q^2 < Q^2_{\mathrm{max}}$$

Structure function

$$F_2(x, Q^2)$$

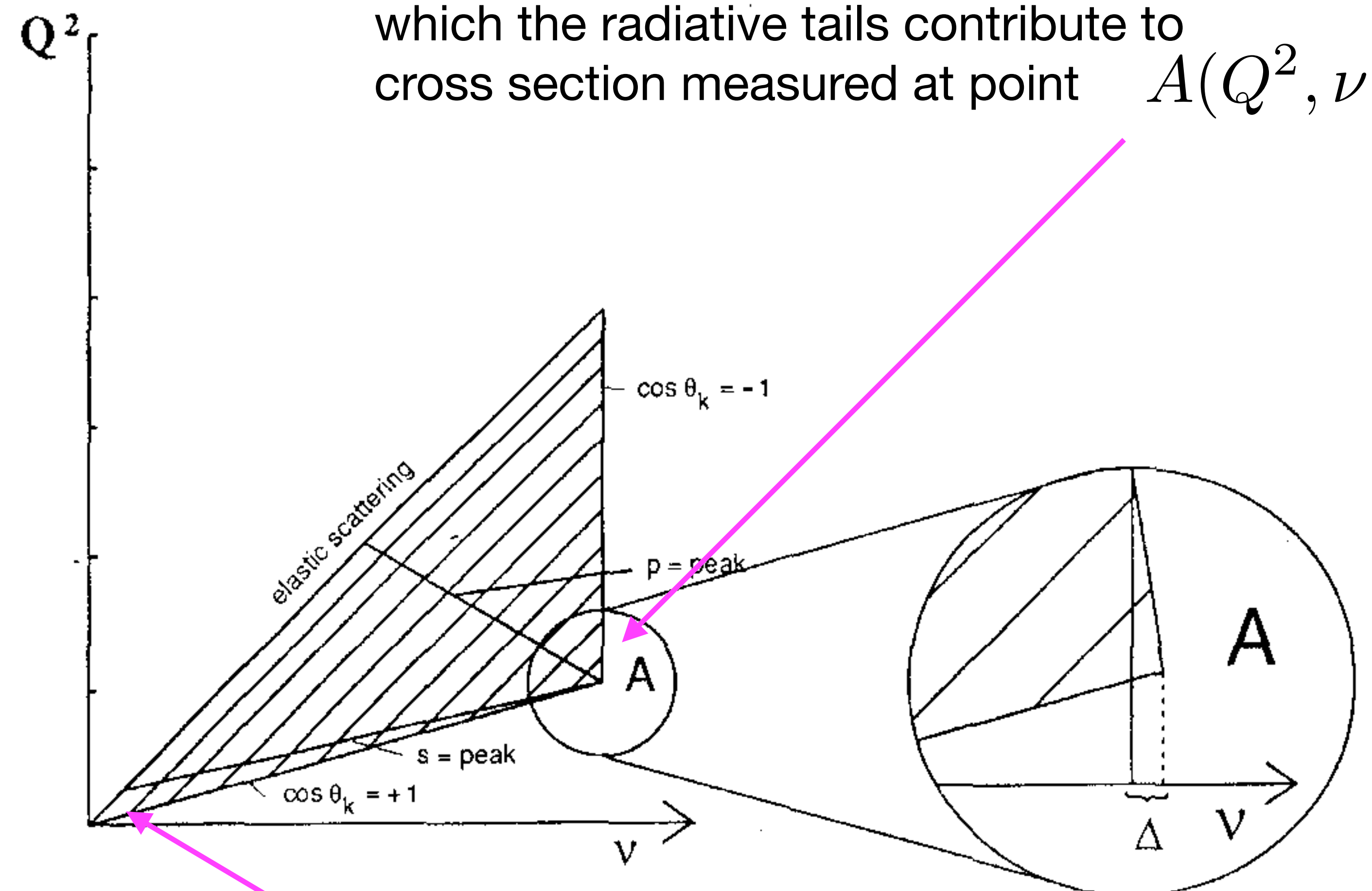
And structure function

$$F_L(x, Q^2)$$

Or the ratio $R(x, Q^2) = F_L(x, Q^2)/F_T(x, Q^2)$

Plot from *Badelek,Bardin,Kurek,Scholz Z. Phys. C 66 , 591 (1995)*

Range of kinematical variables from which the radiative tails contribute to cross section measured at point $A(Q^2, \nu)$

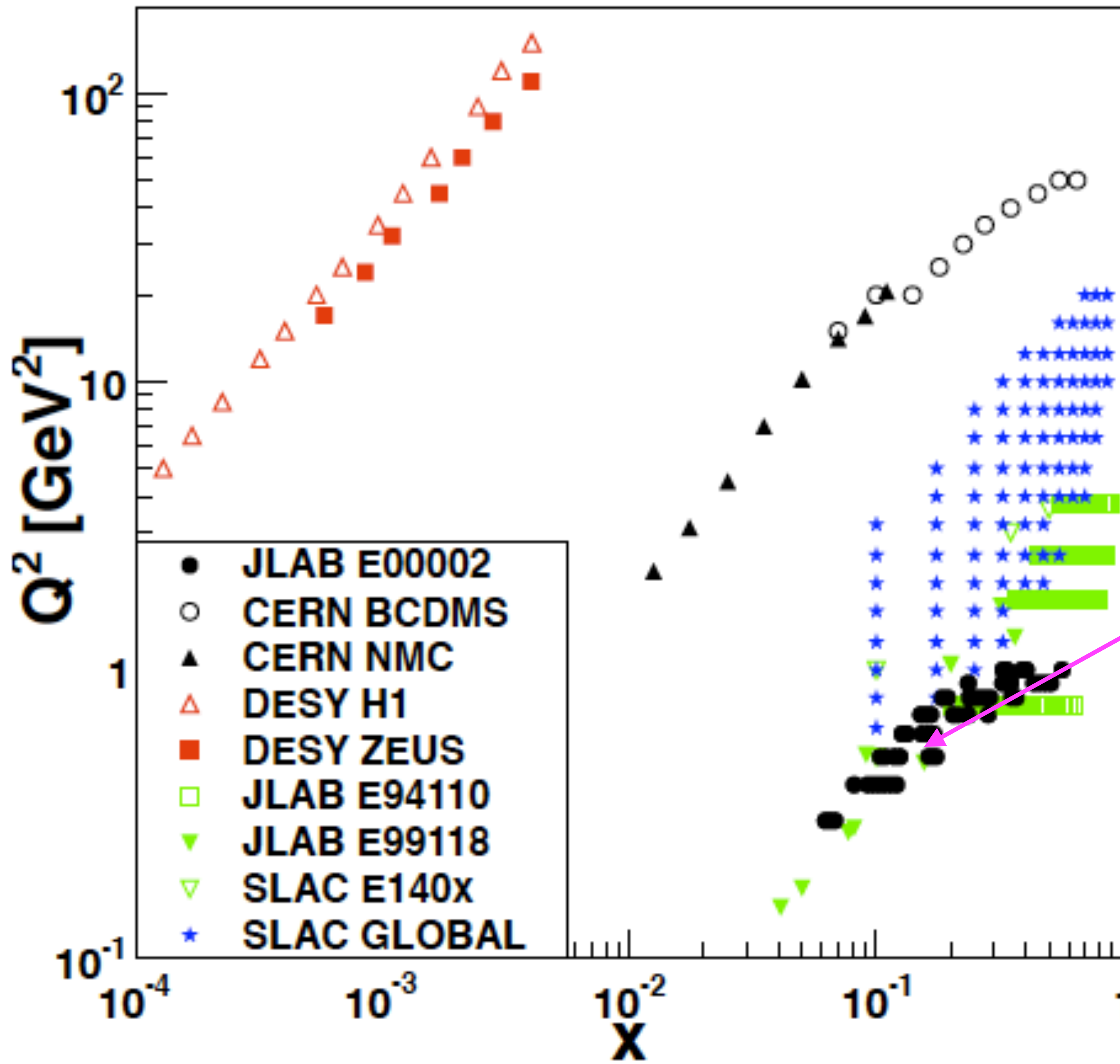


Needed down to $Q^2 \to 0$

Essential for DIS

Phase space (x,Q^2) for F_L

JLab E00002 Phys. Rev. C 97, 045204 (2018)



Unlike for F_2 there are not many data for the longitudinal structure function

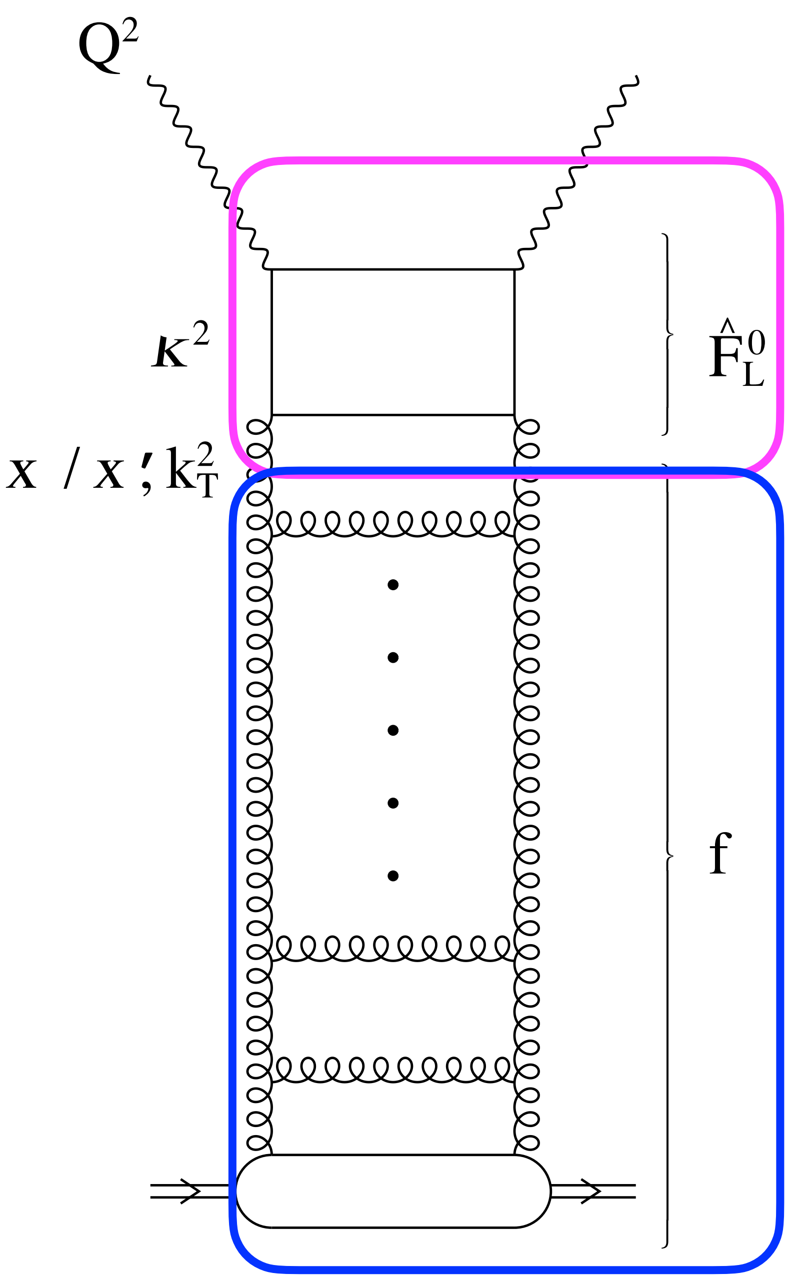
Lowest Q^2 data

Model for low Q^2

- Construct physically motivated model rather than pure parametrization
- Use of k_T factorization formula with off shell gluon
- Need unintegrated gluon distribution. Construct from the standard DGLAP collinear gluon distribution
- Extrapolation to low values of Q^2
- Introduce the cutoff parameter on the quark transverse momenta
- Higher twist contribution from the low quark transverse momenta. Match the normalization to the 'soft' contribution from the F_2 structure function

Revisiting original model: *Badelek, Kwiecinski, Stasto Z. Phys. C 74 , 297 (1997)*

k_T factorization



- k_T factorization, appropriate for small x is convolution of:
  - photon-gluon impact factor — off-shell matrix element
  - unintegrated gluon density

$$F_L(x,Q^2) = \int_x^1 \frac{dx'}{x'} \int \frac{dk_T^2}{k_T^2} \hat{F}_L^0(x',Q^2,k_T^2) f(\frac{x}{x'},k_T^2)$$

$$\hat{F}_L^0(x',Q^2,k_T^2) = \frac{Q^4}{\pi^2 k_T^2} \sum_q e_q^2 \int_0^1 d\beta \int d^2\kappa'_T x' \delta \left(x' - \left(1 + \frac{\kappa_T'^2 + m_q^2}{\beta(1-\beta)Q^2} + \frac{k_T^2}{Q^2}\right)^{-1} \right) \times$$

$$\times \alpha_s \beta^2 (1-\beta)^2 (\frac{1}{D_{1q}} - \frac{1}{D_{2q}})^2$$

Exact kinematics

<u>Denominators</u>

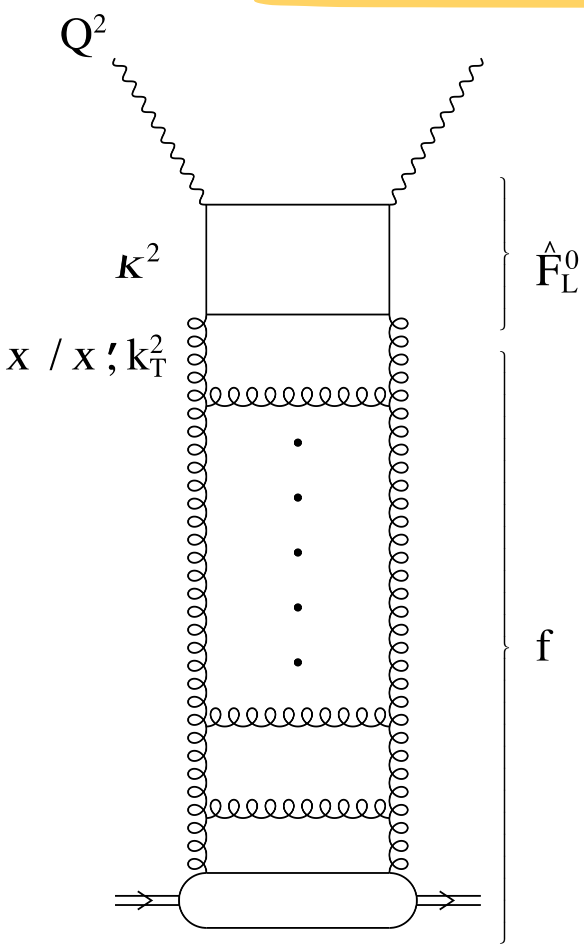
$$D_{1q} = \kappa_T^2 + \beta(1-\beta)Q^2 + m_q^2$$

$$D_{2q} = (\boldsymbol{\kappa_T} - \boldsymbol{k_T})^2 + \beta(1-\beta)Q^2 + m_q^2$$

<u>Quark transverse momentum</u>

$$\boldsymbol{\kappa'_T} = \boldsymbol{\kappa_T} - (1-\beta)\boldsymbol{k_T}$$

Model for higher twist



Cutoff

<u>Large quark transverse momenta:</u> $\kappa^2 > \kappa_0^2$

- Use standard kT factorization formula

<u>Small quark transverse momenta:</u> $\kappa^2 < \kappa_0^2$

- Make on-shell approximation $k_T^2 \to 0$
- Make ansatz $\alpha_s x g(x,Q^2) \to A$

$$F_L^{HT} = 2A \sum_q e_q^2 \frac{Q^4}{\pi} \int_0^1 d\beta \beta^2 (1-\beta)^2 \int_0^{\kappa_{0T}'^2} d\kappa_T'^2 \frac{\kappa_T'^2}{D_q^4}$$

$$D_q = \kappa_T'^2 + \beta(1-\beta)Q^2 + m_q^2 \; .$$

Higher twist contribution: $\sim 1/Q^2$ when $Q^2 \to \infty$

$\sim Q^4$ when $Q^2 \to 0$

Model for HT cont'd

Constant A is not free parameter.
Estimate it from the F_2 assuming the non-perturbative contribution also comes from the low quark transverse momenta.

$$F_T(x,Q^2) = 2\sum_q e_q^2 \frac{Q^2}{4\pi}\alpha_s \int_0^1 d\beta \int d\kappa_T'^2 \frac{x}{x'} g(\frac{x}{x'},Q^2) \times$$
$$\times \left[\frac{\beta^2+(1-\beta)^2}{2}\left(\frac{1}{D_q^2} - \frac{2\kappa_T'^2}{D_q^3} + \frac{2\kappa_T^2\kappa_T'^2}{D_q^4}\right) + \frac{m_q^2\kappa_T'^2}{D_q^4}\right]$$

Integrate over low quark transverse momentum $\kappa^2 < \kappa_0^2$

Again assume $\alpha_s x g(x,Q^2) \to A$

$$F_2^{Bg} = A \times \frac{\sum_q e_q^2}{\pi} \int_0^\infty dt \int_0^{\kappa_{0T}'^2} d\kappa_T'^2 \left[\frac{1}{2}\left(\frac{1}{D_q^2} - \frac{2\kappa_T'^2}{D_q^3} + \frac{2\kappa_T^2\kappa_T'^2}{D_q^4}\right) + \frac{m_q^2\kappa_T'^2}{D_q^4}\right]$$

Set the background (soft) contribution (from separate analysis)

$$F_2^{\mathrm{bg}} \to 0.4$$

Input for model

Different models for unintegrated gluon density:

- Small *x* linear BFKL
- Small *x* with nonlinear corrections, Balitsky-Kovchegov
- DGLAP motivated: Kimber-Martin-Ryskin formalism

Unintegrated gluon from integrated gluon PDF:

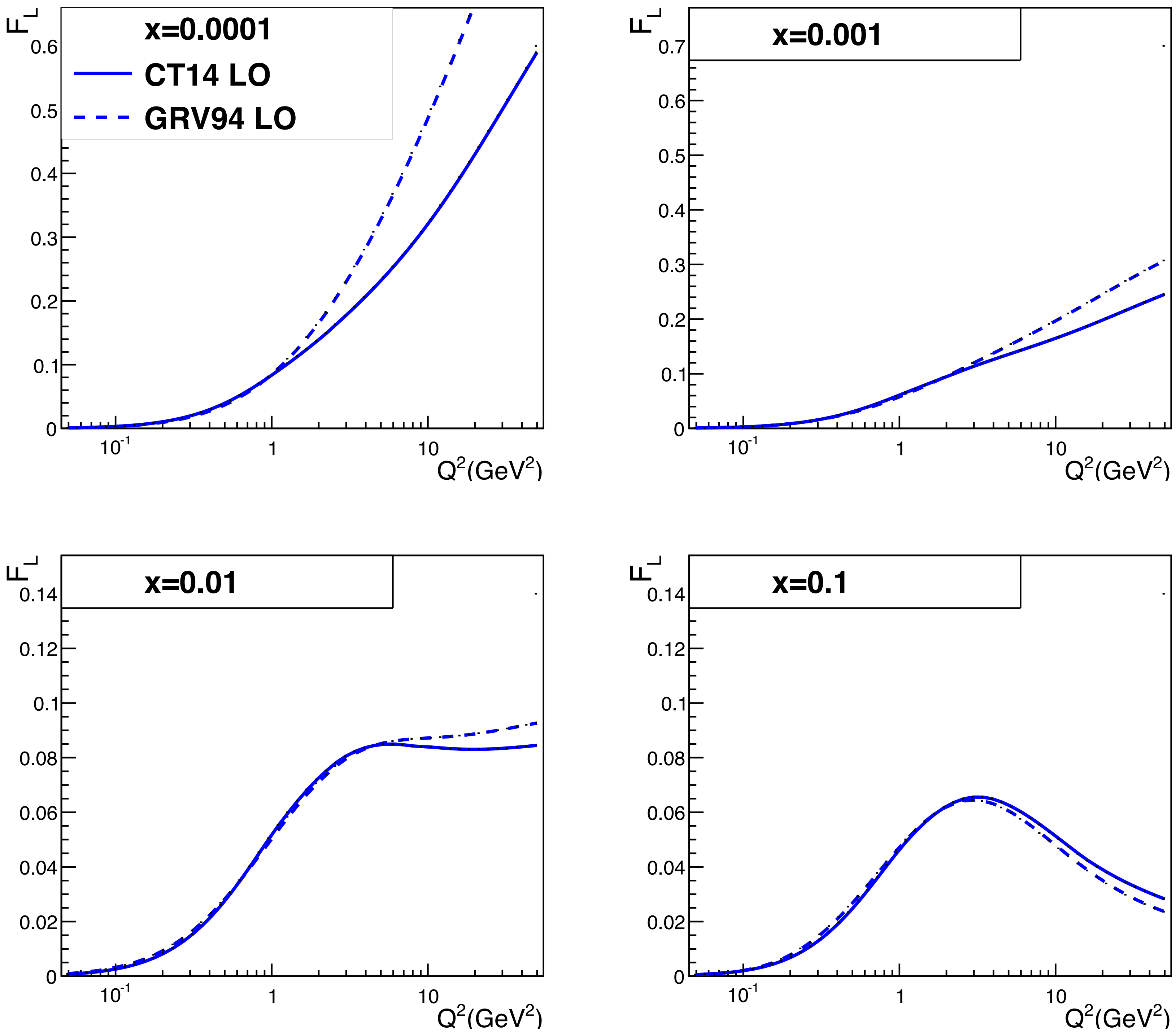
$$f(y,k_T^2) = y\frac{\partial g^{\rm AP}(y,Q^2)}{\partial \ln Q^2}|_{Q^2=k_T^2}$$

Use standard PDFs, LO, NLO, not much sensitivity in the low Q^2

Cutoff variation $\kappa_0^2 = 0.8 - 1.5 \ {\rm GeV}^2$ Results not very sensitive

Masses for quarks (u,d,s,c): 0.35, 0.35, 0.5, 1.2-1.5 GeV

$F_L(Q^2)$ bins in x



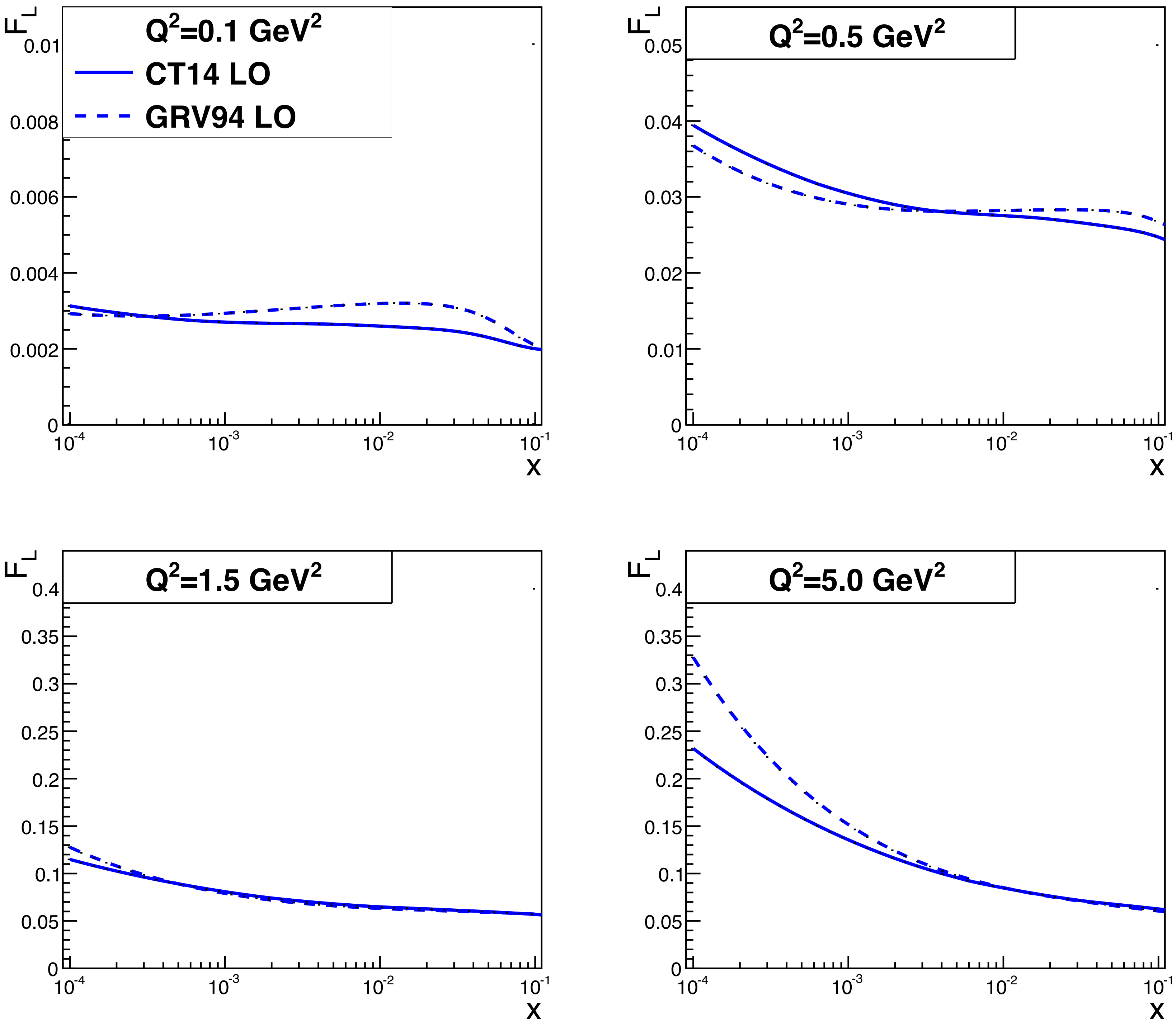
Comparison of old (GRV94) vs updated (CT14) calculation

Largest difference in moderate to large Q^2 and low x

No difference in low Q^2 region

Observe different vertical scale on different panels

$F_L(x)$ bins in Q^2



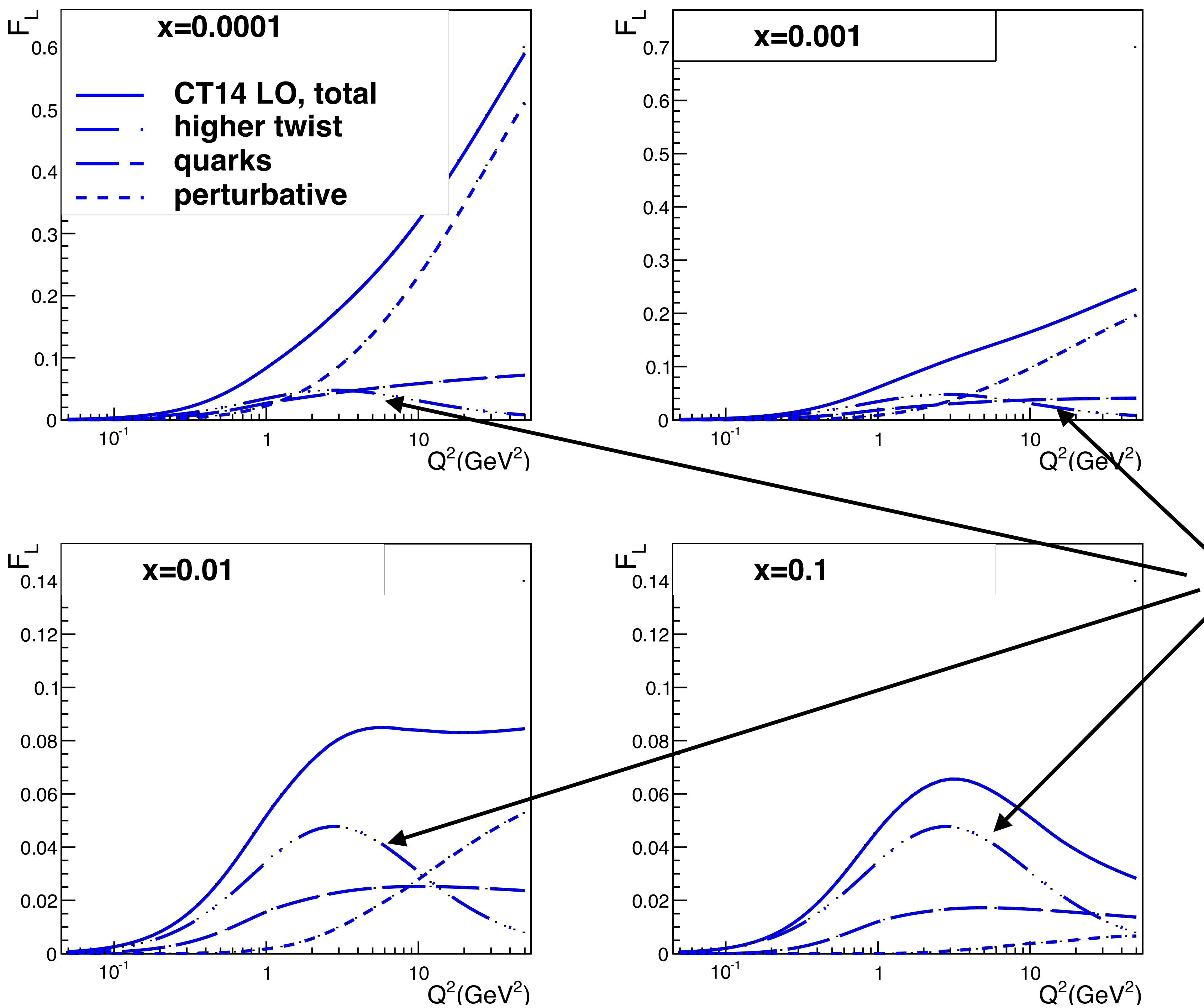
Comparison of old (GRV94) vs updated (CT14) calculation

Largest difference in moderate to large Q^2 and low x. Update gluon has slower x dependence

No difference in low Q^2 region

Observe different vertical scale on different panels

$F_L(Q^2)$ bins in x



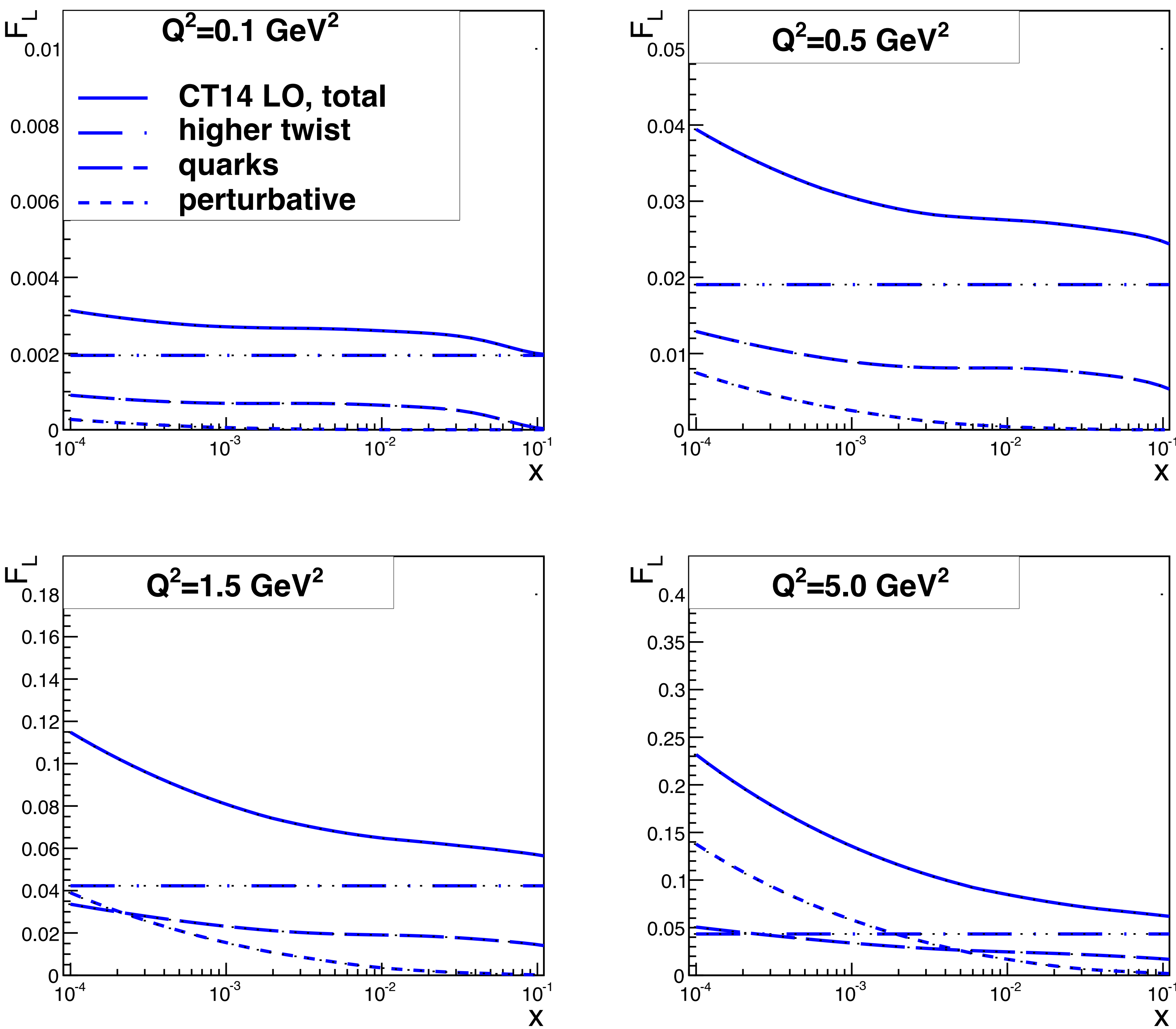
Components of the model

Perturbative component dominates at large Q^2 and low x

Higher twist significant at low to moderate Q^2. Dominates at large x

Observe different vertical scale on different panels

$F_L(x)$ bins in Q^2



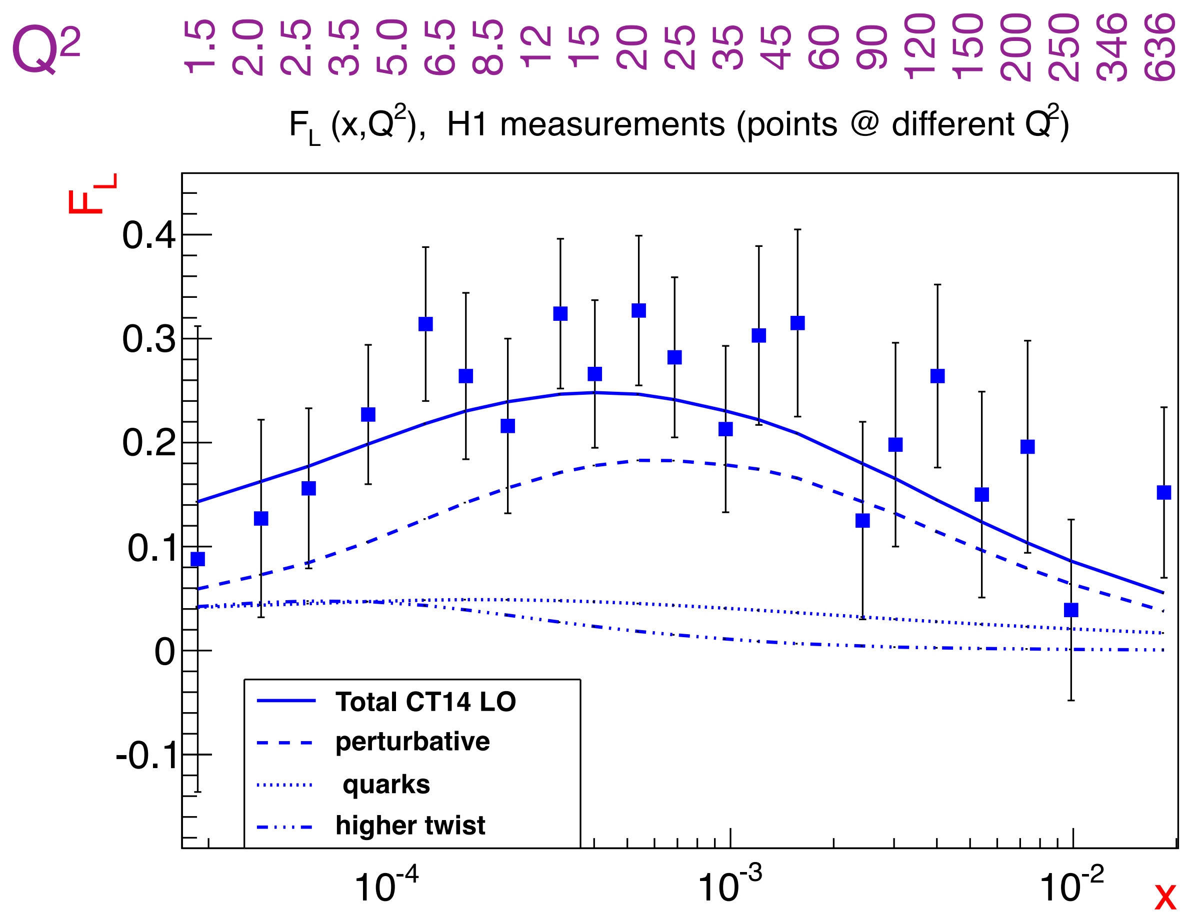
Components of the model

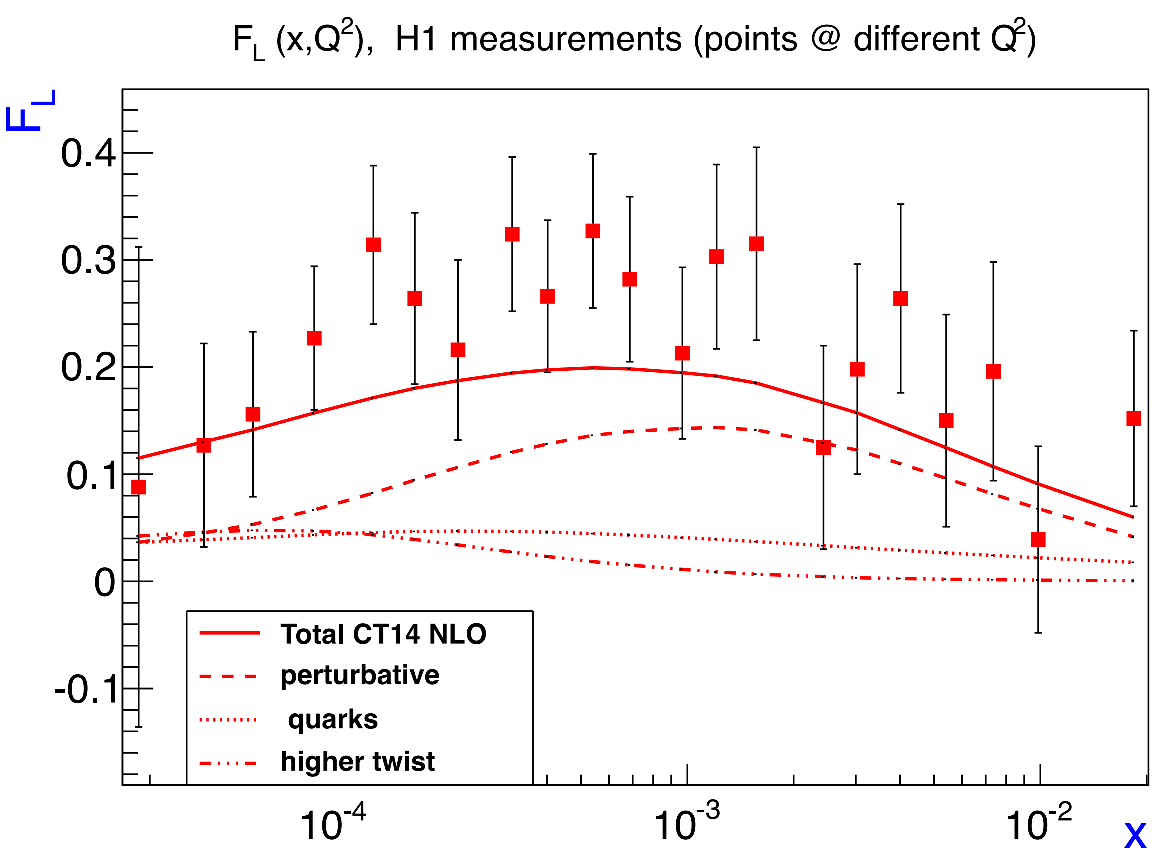
Perturbative component dominates at large Q^2 and low x

Higher twist flat as a function of x. Soft Pomeron-like behavior with intercept equal to unity

Observe different vertical scale on different panels

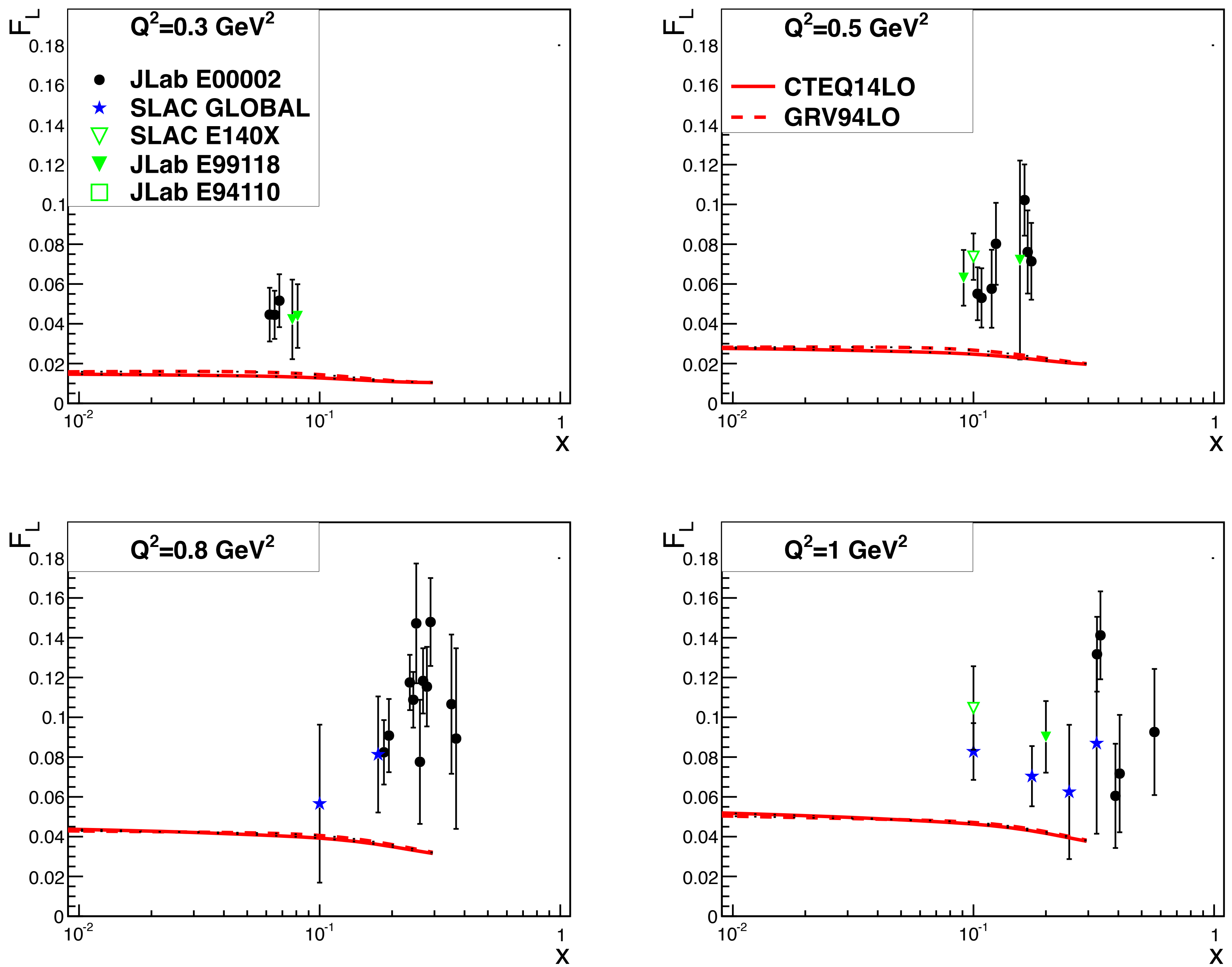
Comparison with H1 data





- Good description of H1 data
- Mostly small *x*, and not low Q^2
- Most sensitive to perturbative component, variation of PDF

Comparison with JLAB and SLAC



- Comparison with low Q^2 data: SCLAC, JLAB
- Model underestimates the data
- However, model constructed for low *x*, beyond the region of applicability since data mostly at large *x* (additional contributions)
- Black points: new JLab data
- Caveat : SLAC and JLab(old) data are rebinned with models assumptions

Summary

- Knowledge of F_2 and F_L in the low Q^2 region necessary for radiative corrections
- Will be crucial for EIC precision measurement
- Revisited model for F_L at low Q^2: k_T factorization + higher twist
- In the kinematic region of the model (low x and low Q^2), dependence on the PDFs is negligible
- Comparison with HERA: good matching to data, mostly sensitive to pertubative part, can be matched correctly by varying PDFs
- Comparison with JLab: model is underestimating the data, which are mostly at large x, beyond the region of applicability of the model
- Outlook: compare with other models (low x specific), other sources of HT, target mass corrections…