STRESS TESTING TARGET MASS CORRECTIONS IN A SIMPLE FIELD THEORY

QUARK-HADRON DUALITY WORKSHOP SEP 2018

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Introduction

- 12 GeV Experiments at Jlab
  - Unprecedented access to 3-D structure of the nucleon
  - Transition between hadronic and partonic degrees of freedom
  - Perturbative QCD can still be used
  - Target hadron masses don’t satisfy m << Q
    - Target Mass Corrections

Target Mass Corrections (TMCs)

- Different methodologies:
  - Georgi and Pollitzer,, 1976 (GP)
  - Ellis, Furmanski, and Petronzio, 1983 (EFP)
  - Aivazis, Olness, and Tung, 2011 (AOT)
- Some use assumptions about partonic dynamics
- Want to examine a method that is purely kinematical
  - AOT (see Ted's talk)
- When are these corrections relevant?

Testing in a Simple Field Theory

- Analytical solutions in QCD require approximation
- Factorization methods can be applied to any renormalizable field theory
- Choose a theory for which calculations can be completed without approximation:
  - Calculate exact solution
  - Calculate factorized solution
  - Compare results

Testing in a Simple Field Theory

- Demonstrated in Moffat, Melnitchouk, Rogers, Sato, 2017
  - Examined unintegrated low transverse momentum contribution in collinear factorization
- For testing TMCs:
  - Complete the full, integrated factorization

The Simple Field Theory

- Interaction Lagrangian Density:

$$\mathscr{L}_{\text{int}} = -\lambda \overline{\Psi}_N \psi_q \phi \; + \; \text{H.c.}$$

- where:
  - Ψ_N = Spin-1/2 “nucleon” with mass m_p
  - ψ_q = Spin-1/2 “quark” with mass m_q
  - ϕ = Scalar “di-quark” with mass m_s
- Nucleon and quark interact with the photon, but di-quark is a spectator
- Coupling constant:

$$a_\lambda = \frac{\lambda^2}{16\pi^2}$$

DIS Calculations

- Calculate transverse and longitudinal structure functions

$$F_T = 2x_{bj}F_1 \qquad F_L = \rho^2 F_2 - F_T$$

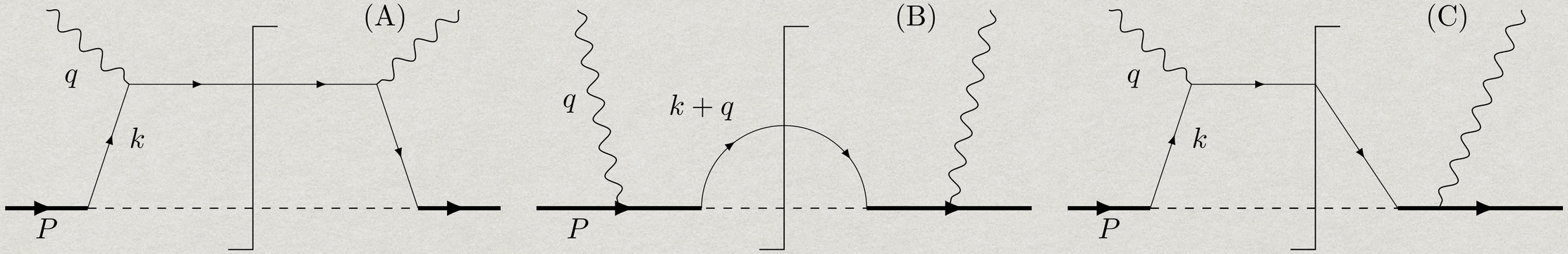
$$\rho^2 = 1 + \frac{4x_{bj}^2 M^2}{Q^2} \qquad x_{bj} = \frac{Q^2}{2P \cdot q}$$

- Calculate exact structure functions to order a_λ

- Calculate factorized structure functions to order a_λ

$$F^{(1)}_{i,fact} = \hat{F}^{(0)}_{i,f/f'} \otimes f^{(1)}_{f'/P} + \hat{F}^{(1)}_{i,f/f'} \otimes f^{(0)}_{f'/P}$$

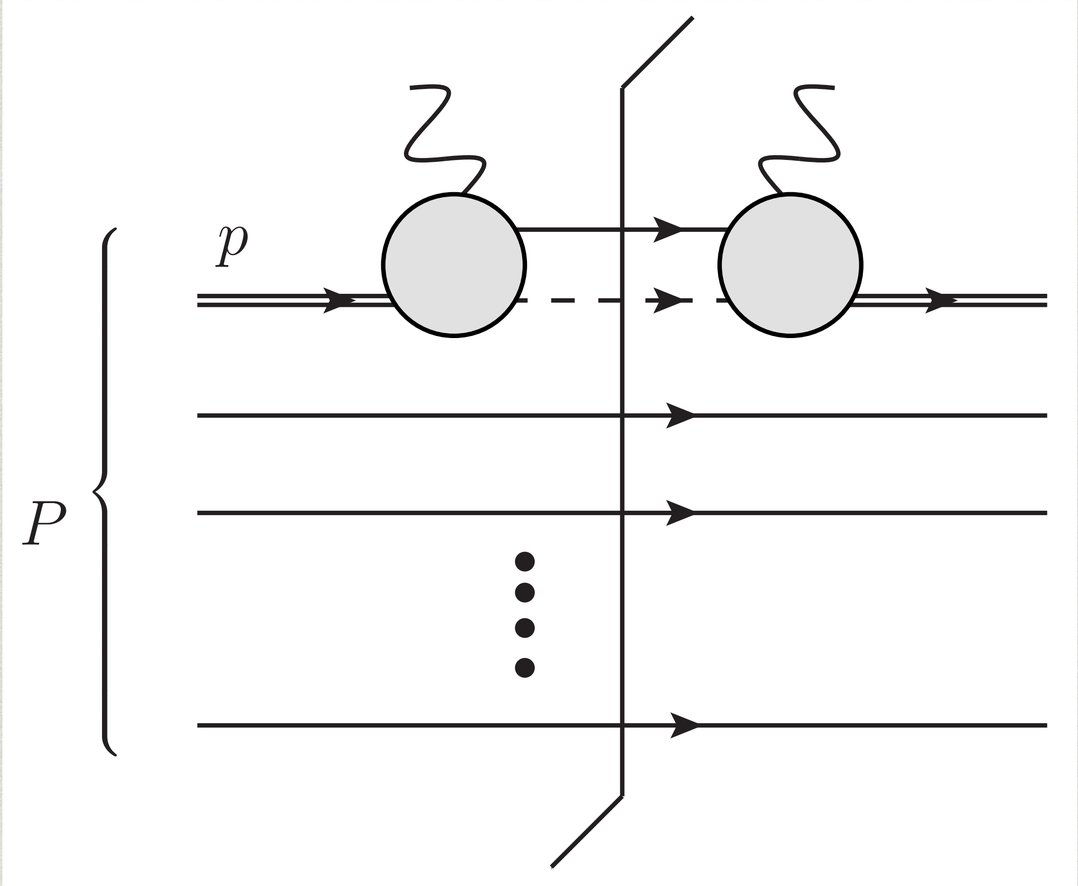
Order a_λ Diagrams



TMCs in the Yukawa Theory

- Need target mass ~ Q
- If $m_p > m_q + m_s$, particle is unstable
- Larger particle of mass M made up of non-interacting particles

$$\frac{d\sigma}{d^3\mathbf{l}'} = \int dX \frac{d\sigma^p}{d^3\mathbf{l}'} \delta(X - c)$$



TMCs in the Yukawa Theory

- Exact

$$F_1(x_N) = \frac{1}{c} F_1^p(x_N^p) \qquad F_2(x_N) = \frac{Q^2\left(Q^2 - M^2 x_N^2\right)}{\left(Q^2 + M^2 x_N^2\right)^2} F_2^p(x_N^p)$$

- Massless Target Approximation

$$F_1(x_N) = \frac{1}{c} F_{1,fact}^p(x_{bj}/c) \qquad F_2(x_N) = F_{2,fact}^p(x_{bj}/c)$$

- Target Mass Corrected

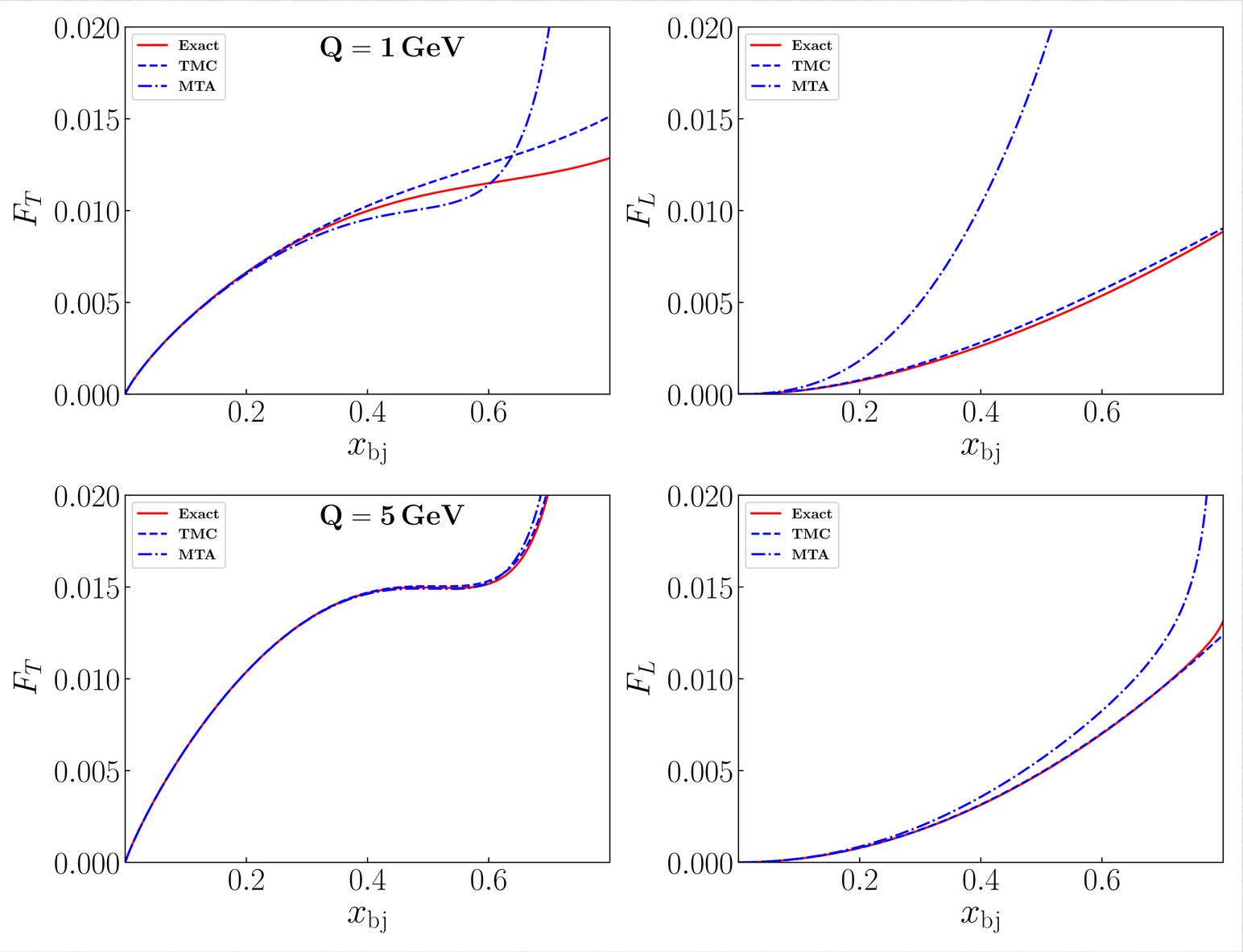
$$F_1(x_N) = \frac{1}{c} F_{1,fact}^p(x_N/c) \qquad F_2(x_N) = \frac{Q^2\left(Q^2 - M^2 x_N^2\right)}{\left(Q^2 + M^2 x_N^2\right)^2} F_{2,fact}^p(x_N/c)$$

- Where

$$x_N = \frac{2x_{bj}}{1 + \sqrt{1 + \frac{x_{bj}^2 M^2}{Q^2}}} \qquad x_{bj} = \frac{Q^2}{2P \cdot q} \qquad x_N^p = \frac{2x_{bj}^p}{1 + \sqrt{1 + \frac{x_{bj}^{p2} m_p^2}{Q^2}}} \qquad x_{bj}^p = \frac{Q^2}{2p \cdot q} = \frac{x_N/c}{1 - \frac{x_N^2 M^2}{c^2 Q^2}}$$

Results

- c=0.8
- M=0.938 GeV
- $m_p=m_q=m_s=0.0938$ GeV



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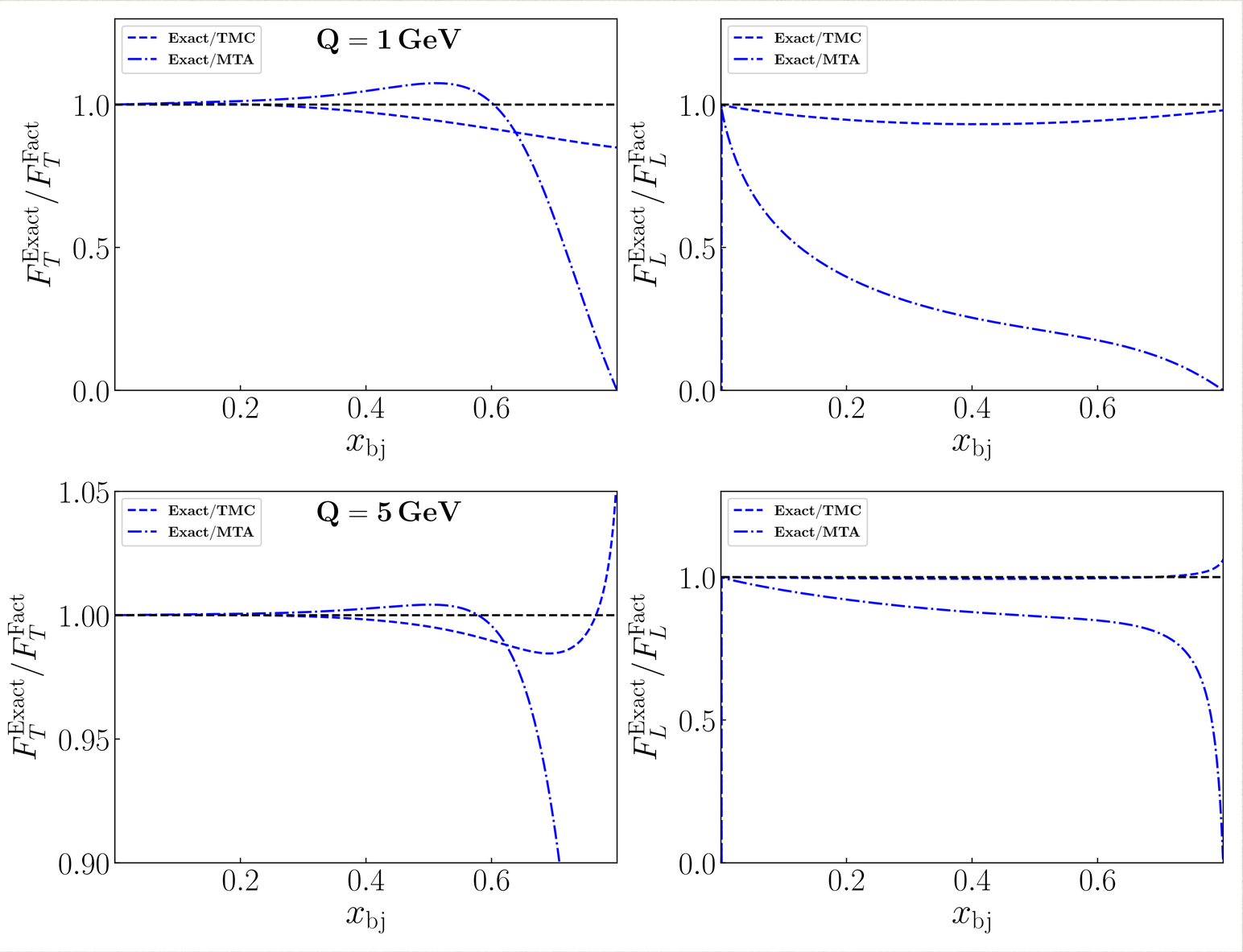
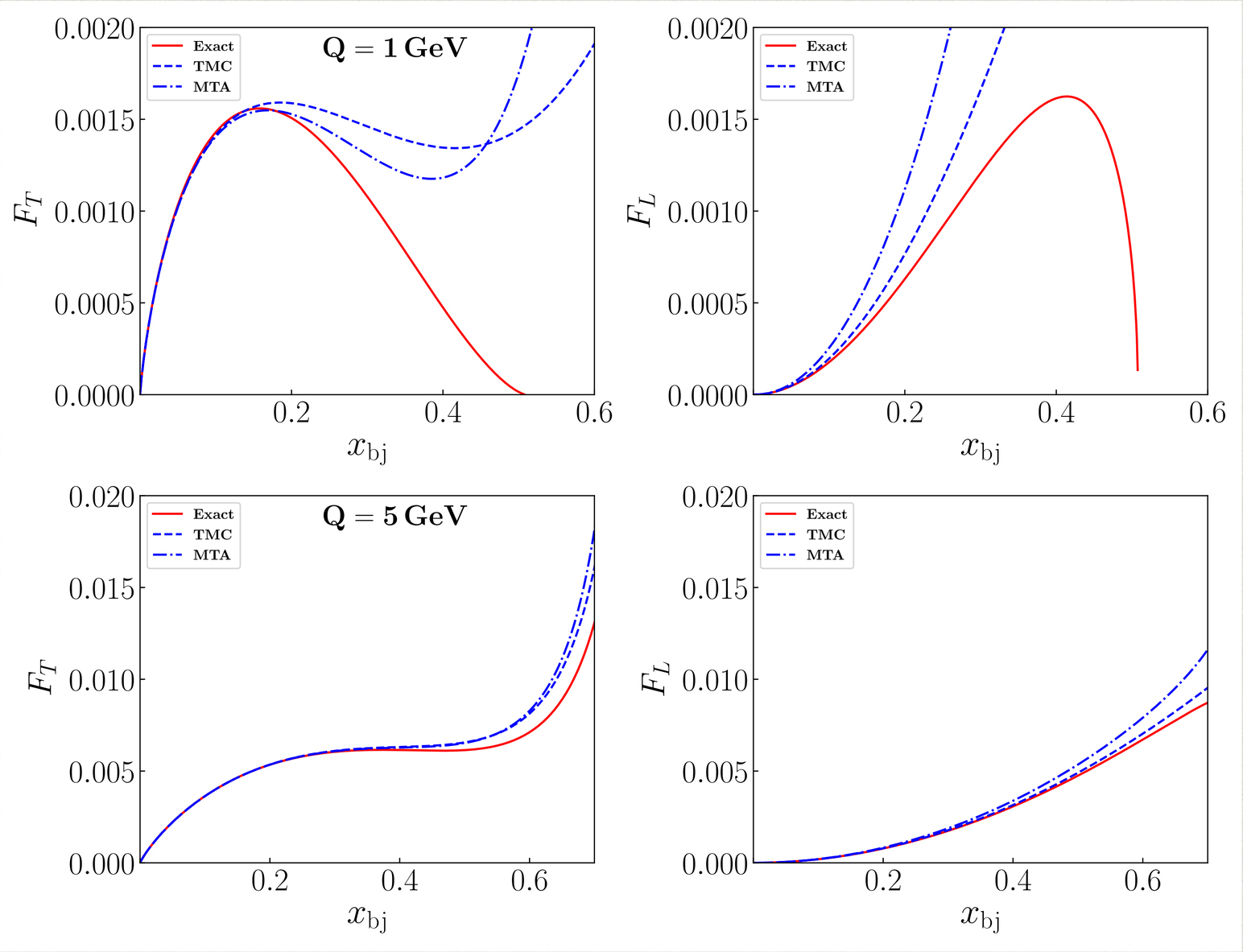


Results

- c=0.8
- M=0.938 GeV
- m_p=0.0938 GeV
- m_q=m_s=0.496 GeV



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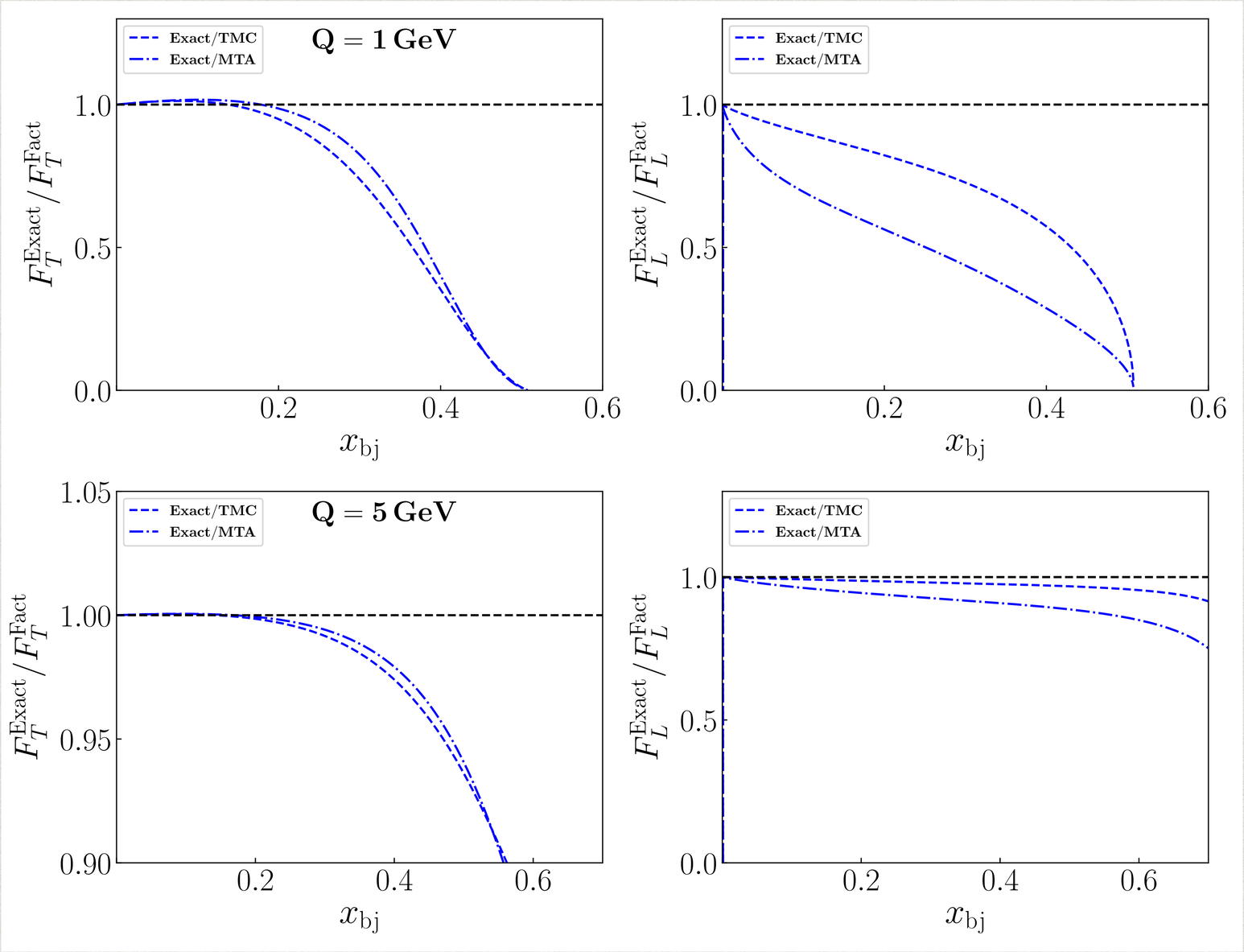

Conclusion

- Target mass corrections get larger with increasing x_{bj}
- Target masses are relevant when:
  - x_{bj} is large
  - $M \sim Q$
  - $M >>$ partonic masses