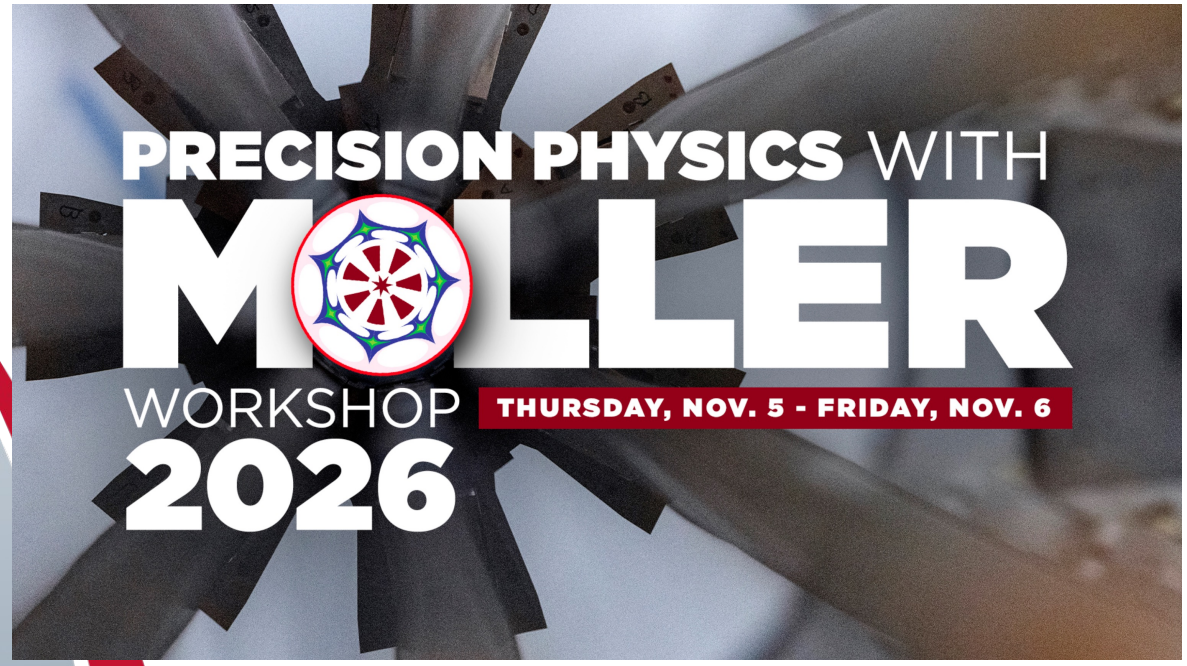
Precision Physics with MOLLER Workshop

November 5-6, 2026
Jefferson Lab, Newport News, Virginia

Discussion:

- Joint QCD + QED + Weak (?) (or Standard Model?)
- Factorization Approach for studying
  - lepton-lepton,
  - lepton-hadron, and
  - hadron-hadron

  Scattering Processes



In collaboration with
J. Cammarota, T.B. Liu, S. Mantry,
W. Melnitchouk, N. Sato, K. Watanabe, J.-Y. Zhang, …

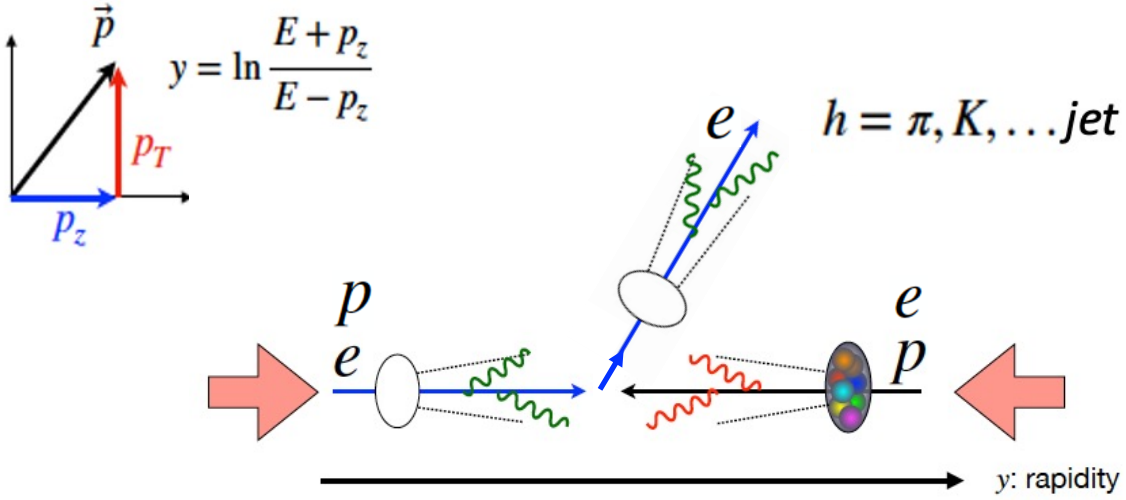
Jianwei Qiu
Jefferson Lab, Theory Center

Jefferson Lab

U.S. DEPARTMENT of ENERGY

Why Factorization Approach?

❑ Inclusive processes with an identified "hard" momentum transfer:



- **MOLLER scattering:**

$$e^- + e^- \rightarrow e^- + X$$

- **Inclusive lepton-hadron DIS:**

$$e^- + H \rightarrow e^- + X$$

- **Inclusive single hadron or jet:**

$$e^- + \ell \rightarrow h(\pi, K, \ldots jet) + X$$

$$e^- + H \rightarrow h(\pi, K, \ldots jet) + X$$

$$H + H' \rightarrow h(\pi, K, \ldots jet) + X$$

❑ Factorization Approach:

- **Separation of perturbative physics (calculable) from nonperturbative physics (universal + power corrections)**
- **Resummation of large logarithms – Renormalization group equations**
- **Predictive power:**

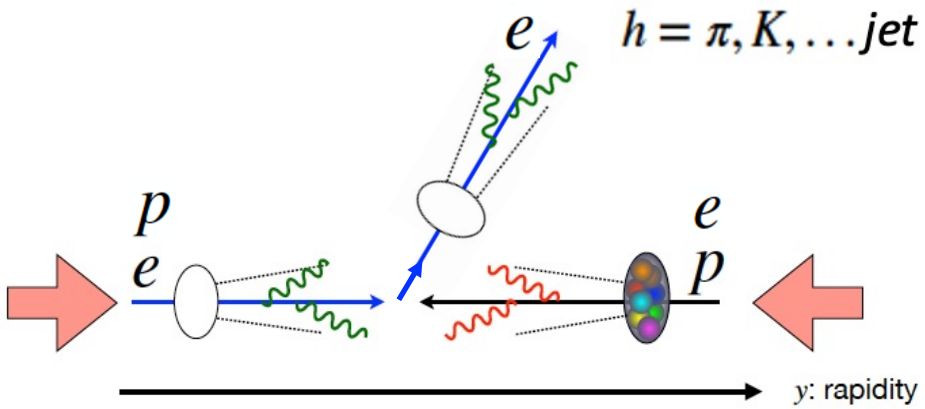
Universality of nonperturbative physics, ability to calculate perturbative contributions, resummation of large logarithms, …

Measured cross sections do not depend how theorists factorize them!

Jefferson Lab

Factorization Formula – Single "hard" scale

❑ Joint QCD + QED Collinear Factorization:



One collinear function for each observed particle

$$E_p \frac{d\sigma^{\text{Resum}}}{d^3p} = \frac{1}{2S} \sum_{abc} \int \frac{dz}{z^2} D_{e/c}(z) \int \frac{dx_1}{x_1} f_{a/e}(x_1) \int \frac{dx_2}{x_2} f_{b/e}(x_2)$$

$$\times \widehat{H}_{ab\to c}(x_1, x_2, z, p; \mu) + \mathcal{O}((m/p_T)^\alpha)$$

$$\alpha > 0$$

Perturbatively calculable

❑ Joint QCD + QED Resummation:

$$\frac{d}{d\ln\mu_i^2}\left[E_p \frac{d\sigma^{\text{Resum}}}{d^3p}\right] = 0 \qquad \text{"}i\text{" for each identified particle}$$

$$\Rightarrow \quad \frac{d}{d\ln\mu_i^2} f_{a/e}(x,\mu_i^2) = \sum_{a'} \int \frac{dx'}{x'} P_{aa'}(x/x',\alpha_i)\, f_{a'/e}(x',\mu_i^2)$$

Solution resums the logarithms

Measured cross sections do not depend how theorists factorize them!

Jefferson Lab

Factorization Formula – Match to fixed order calculations

❑ Why do we need factorization for a "pure" QED calculation?

Factorization provides a systematic way to re-organize the perturbative series with resummation of large logarithms, making the perturbative calculations more reliable.

$$E_p \frac{d\sigma^{\text{Exp}}}{d^3p} = E_p \frac{d\sigma^{\text{Resum}}}{d^3p} + E_p \frac{d\sigma^{\text{Fixed-Order}}}{d^3p} - E_p \frac{d\sigma^{\text{Matching}}}{d^3p}$$

$$E_p \frac{d\sigma^{\text{Matching}}}{d^3p} = E_p \frac{d\sigma^{\text{Resum}}}{d^3p}\Big|_{\text{fixed order}} \Rightarrow \begin{cases} E_p \frac{d\sigma^{\text{Matching}}}{d^3p} \to E_p \frac{d\sigma^{\text{Resum}}}{d^3p} \text{ when } \ln(p_T/m) \to 0 \\ E_p \frac{d\sigma^{\text{Matching}}}{d^3p} \to E_p \frac{d\sigma^{\text{Fixed-Order}}}{d^3p} \text{ when } \ln(p_T/m) \to \text{large} \end{cases}$$

This factorized formula covers observables with a wide range of momentum transfer, with resummation of all large collinear logarithms associated with identified particles

It works for both QCD and QED effects with "fixed" order (at least leading order) Weak effects

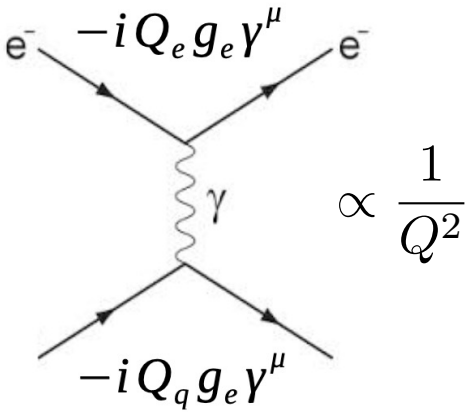
Consistent approach goes beyond the "one-boson" exchange approximation for MOLLER & DIS processes!

One-Boson Exchange Approximation and Beyond

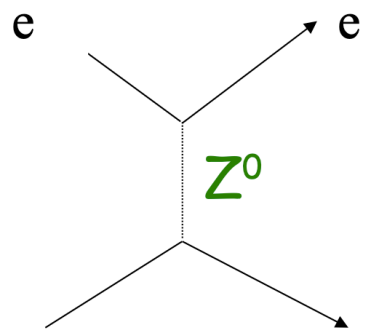
❑ Parity Violating Asymmetry:

$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = \frac{\Delta\sigma}{\sigma}$$

Expressed in terms of "Structure Functions" under "one-boson" exchange



$$\propto \frac{1}{Q^2}$$



$$-i\frac{g_Z}{2}\gamma^\mu\left[g_V^q - g_A^q\gamma^5\right] \qquad \propto \frac{1}{M_Z^2 + Q^2}$$

➡ **Need for "Radiative Corrections"!**

➡ **How to handle the "box" diagram?**

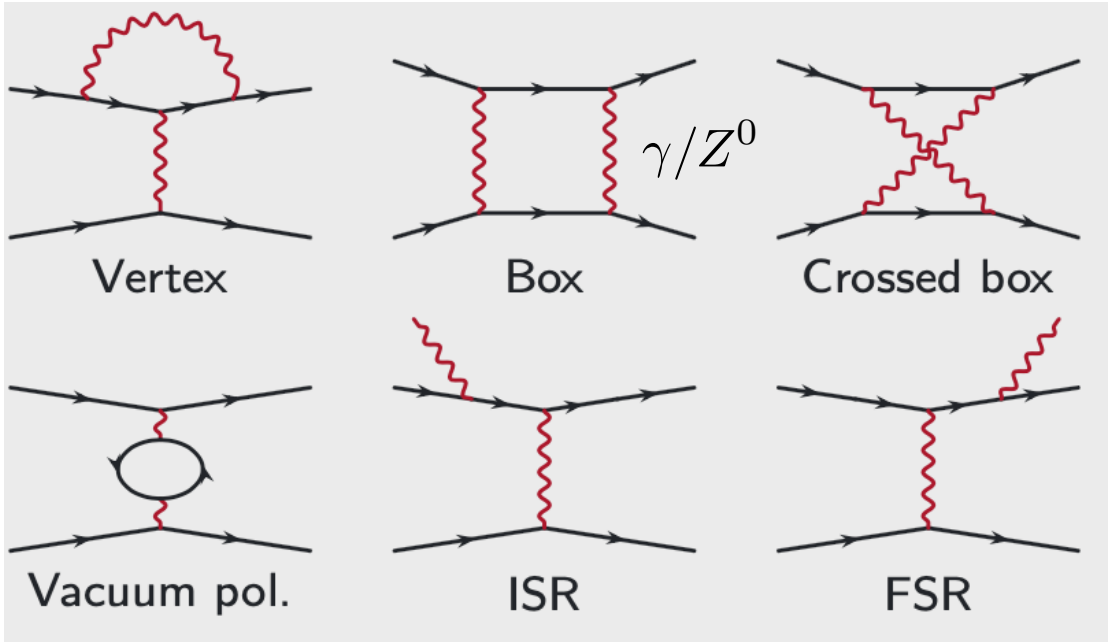
Exiting approach:

➡ $$Q^2\left[\frac{Q^2\ \Delta\sigma}{Q^4\ \sigma}\right]_{Q^2\to 0}\left[1 + \mathcal{O}\left(\frac{Q^2}{M_Z^2}\right)\right]$$

Treat box at the forward limit!

Joint QCD + QED:

No "Structure Functions", but, universal parton/lepton distributions.



Jefferson Lab