Role of $R = \sigma_L/\sigma_T$ in Semi-Inclusive Deep Inelastic Scattering Experiments

- What is R?
- Why is it important to measure?

Thanks to Rolf Ent, Thia Keppel, and Dave Gaskell for critical help in the preparation of this talk!

What is R?

Inclusive DIS: $$\frac{d^2\sigma}{d\Omega_e dE'} = \sigma_{Mott}\{W_2(Q^2,W^2) + 2W_1(Q^2,W^2)tan^2(\theta/2)\},$$

$$F_1(x,Q^2) = MW_1(\nu,Q^2)\ ,$$
$$F_2(x,Q^2) = \nu W_2(\nu,Q^2)\ .$$

$$\Rightarrow F_2(x) = 2xF_1(x) = x\sum_q e_q^2\,(q(x)+\bar{q}(x))$$

Inclusive DIS in terms of L and T cross sections: $$\frac{1}{\Gamma}\frac{d^2\sigma}{d\Omega dE'} = \sigma_T + \varepsilon\sigma_L$$

$$\Gamma = \frac{\alpha}{2\pi^2 Q^2}\frac{E'}{E}\frac{1}{1-\varepsilon}$$

$$\varepsilon = \left[1 + 2\left(1+\frac{\nu^2}{Q^2}\right)\tan^2\left(\frac{\theta}{2}\right)\right]^{-1}$$

What is R?

$$F_1(x, Q^2) = \frac{Q^2}{4\pi^2\alpha}\frac{(1-x)}{2x}\sigma_T$$

Purely Transverse: Sensitive to single parton densities

$$F_2(x, Q^2) = \frac{Q^2}{4\pi^2\alpha}\frac{1}{1+\frac{Q^2}{\nu^2}}(1-x)(\sigma_L + \sigma_T)$$

Mixture of L and T

Define Pure L and ratio R:

$$F_L(x, Q^2) = \frac{Q^2}{4\pi^2\alpha}(1-x)\sigma_L \qquad R(x, Q^2) = \frac{\sigma_L}{\sigma_T} = \frac{F_L}{2xF_1}$$

$R = \sigma_L/\sigma_T$ is a basic aspect of the photon-parton interaction

- First DIS evidence that quarks had spin ½ (R→0 as $Q^2 \to \infty$)

- At moderate fixed x, falls as $1/Q^2$

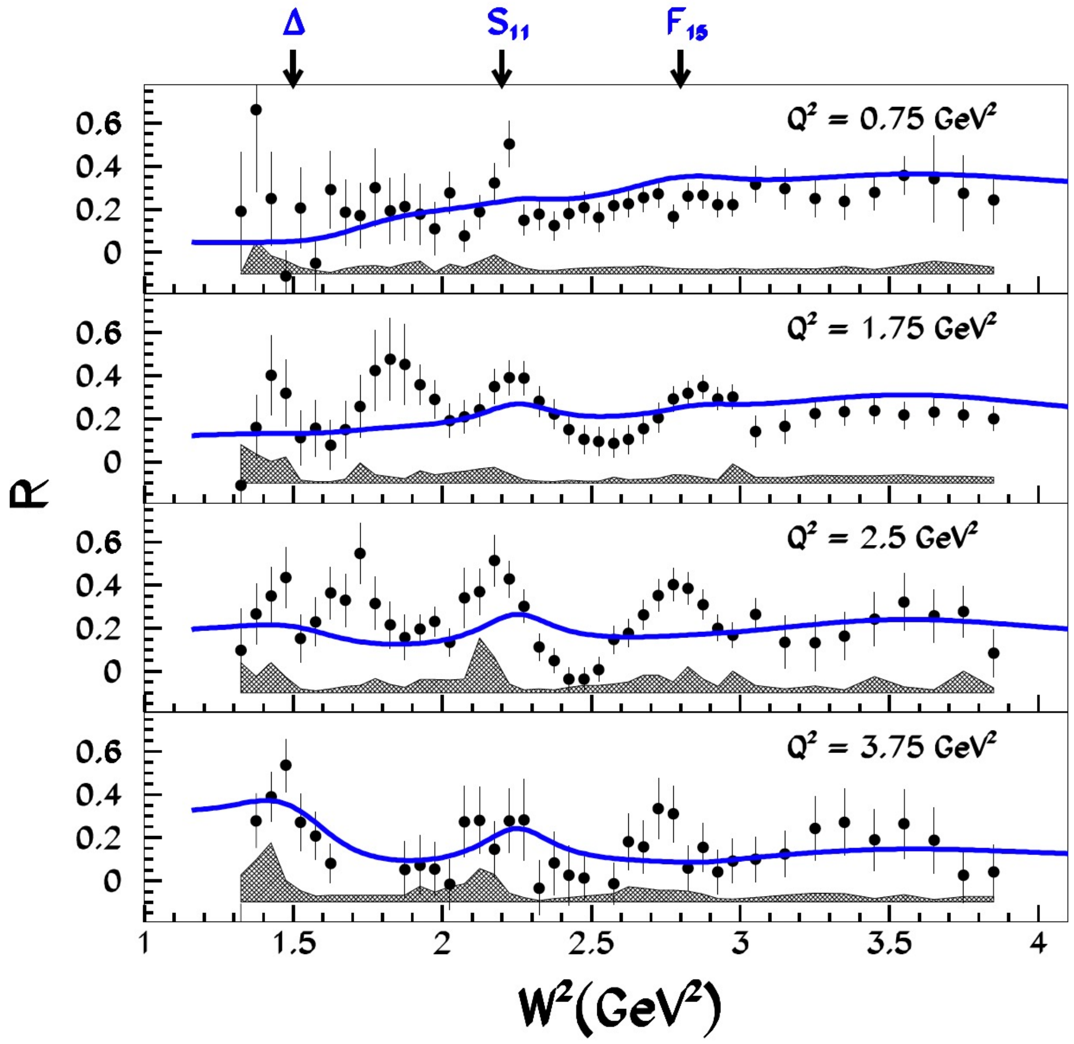
- At moderate Q^2 finite, non-zero, sensitive to indirect gluon effects and higher twist

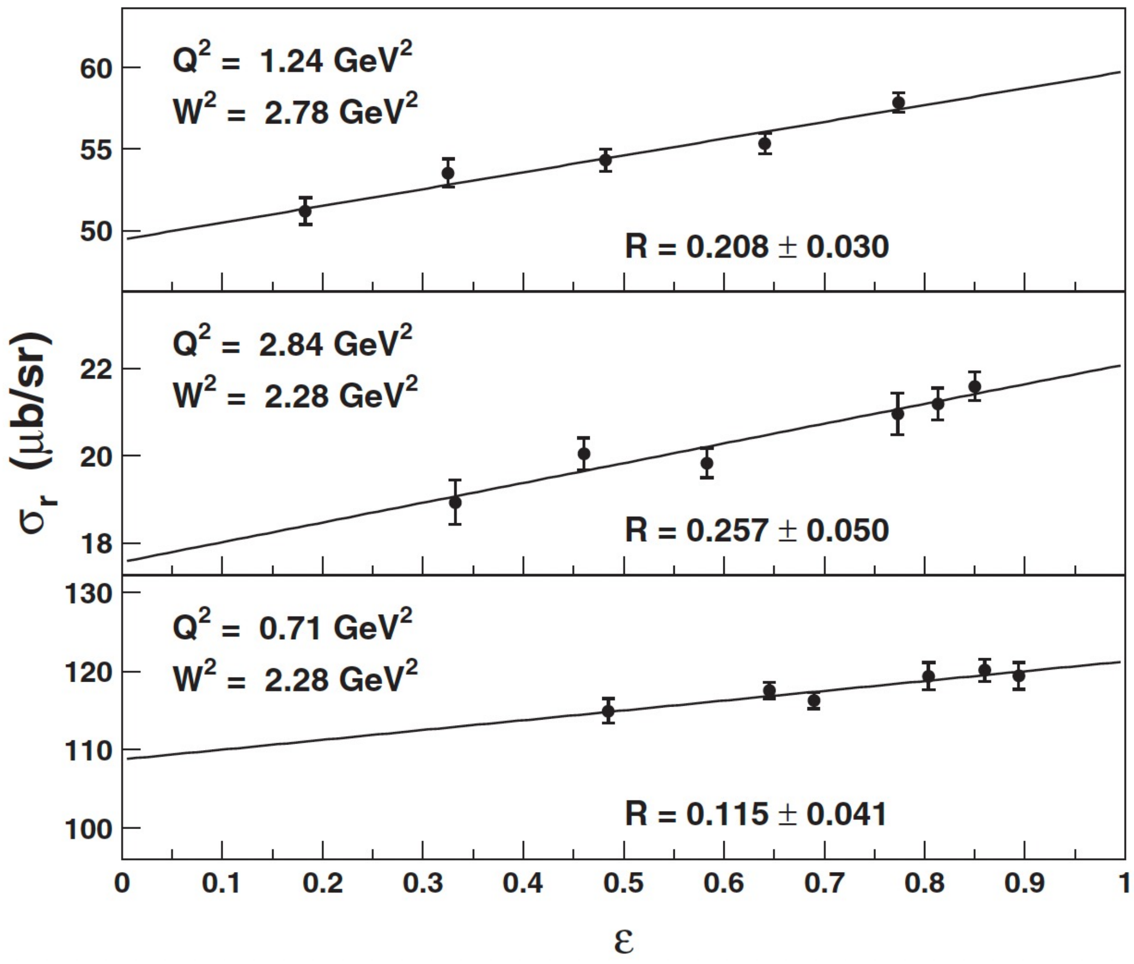
- In naïve quark model, sensitive to intrinsic transverse momentum k_T:

$$R = 4(M^2x^2 - \langle k_t^2 \rangle)/(Q^2 + 2\langle k_t^2 \rangle)$$

Connected to TMDs!

What is R in Inclusive DIS?





Taken from Y. Liang et al., PRC 105, 065205 (2022)

What is R in Semi Inclusive DIS?

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} =$$

$$\frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T}+\varepsilon F_{UU,L}+\sqrt{2\varepsilon(1+\varepsilon)}\,\cos\phi_h\,F_{UU}^{\cos\phi_h}$$

$$+\varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h}+\lambda_e\sqrt{2\varepsilon(1-\varepsilon)}\,\sin\phi_h\,F_{LU}^{\sin\phi_h}$$

$$+S_\parallel\left[\sqrt{2\varepsilon(1+\varepsilon)}\,\sin\phi_h\,F_{UL}^{\sin\phi_h}+\varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\right]$$

$$+S_\parallel\lambda_e\left[\sqrt{1-\varepsilon^2}\,F_{LL}+\sqrt{2\varepsilon(1-\varepsilon)}\,\cos\phi_h\,F_{LL}^{\cos\phi_h}\right]$$

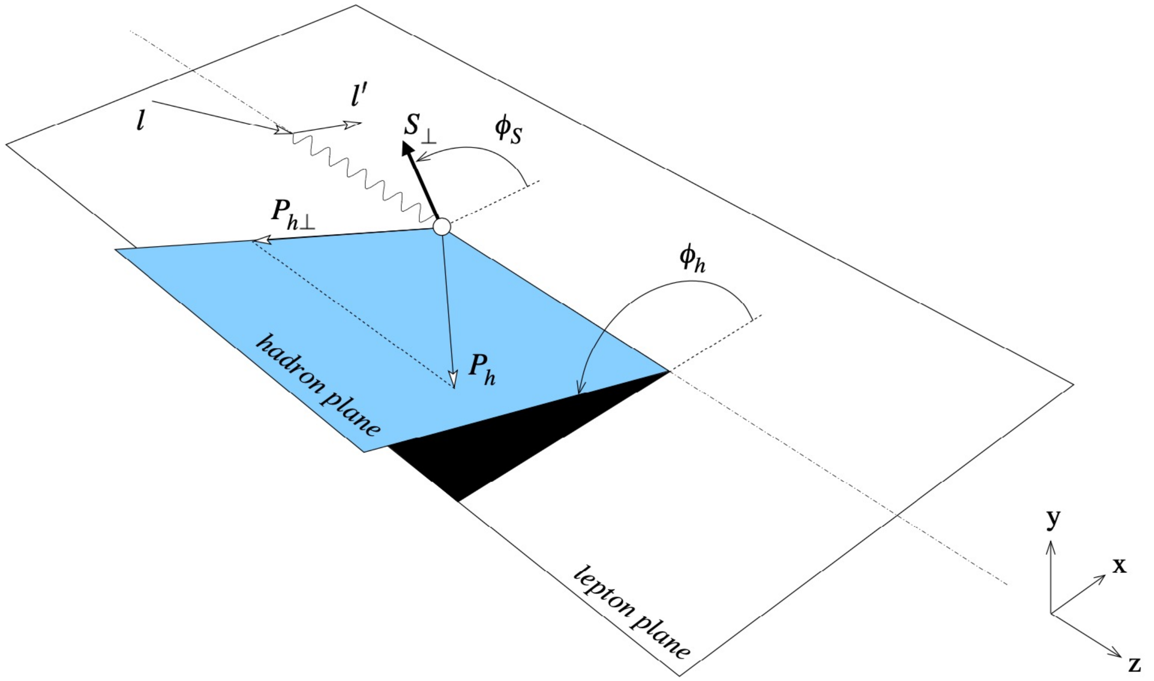
$$+|\boldsymbol{S}_\perp|\Big[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)}+\varepsilon\,F_{UT,L}^{\sin(\phi_h-\phi_S)}\right)$$

$$+\varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)}+\varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)}$$

$$+\sqrt{2\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S}+\sqrt{2\varepsilon(1+\varepsilon)}\,\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\Big]$$

$$+|\boldsymbol{S}_\perp|\lambda_e\Big[\sqrt{1-\varepsilon^2}\,\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)}+\sqrt{2\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S}$$

$$+\sqrt{2\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\},$$



Taken from A. Bacchetta et al., JHEP02, 093 (2007)

What is R in Semi Inclusive DIS?

Without polarized beam and target

$$F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi_h\, F_{UU}^{\cos\phi_h} + \varepsilon\cos(2\phi_h)\, F_{UU}^{\cos 2\phi_h}\,.$$

$$\sigma = \Gamma(\,\sigma_T + \varepsilon\sigma_L + [\varepsilon(\varepsilon+1)/2]^{1/2}\cos(\phi)\sigma_{LT} + \varepsilon\cos(2\phi)\sigma_{TT}\,)$$

In addition to x and Q^2, can depend on z and p_T

Almost no experimental knowledge of R in SIDIS!!!

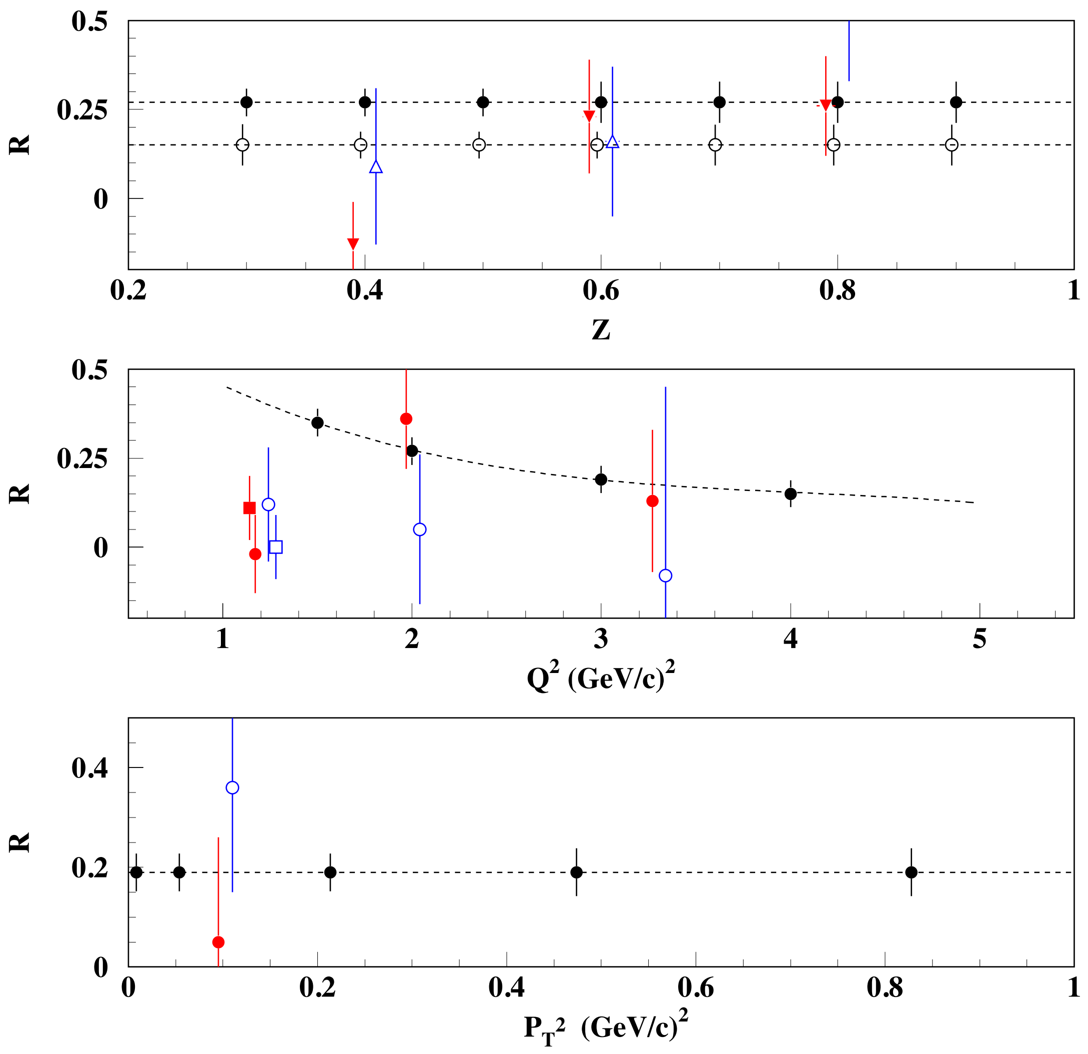
Hall C will explore this soon!

E12-06-104, *Spokespersons:* P. Bosted, R. Ent, E. Kinney, and H. Mkrtchyan

- This experiment will make precise measurements of R in charged π and K SIDIS on H and D targets as a function of Q^2, fractional hadron momentum *z*, and hadron transverse momentum p_T

- Standard technique to measure R: Vary the virtual photon polarization ε by using different incident beam energies and electron scattering angles, while keeping the Q^2, *x, z,* and p_T constant. Will use the two magnetic spectrometers in Hall C.

Previous compared to proposed



Projections for E12-06-104 vs existing Cornell Data (projections assume R_{SIDIS} = R_{DIS})

Comparable 1.6% systematic uncertainties not indicated

Projections: Solid Black H, Open Black D π

Cornell:

Top panel: solid red (open blue) π^+ (π^-) on LH_2

Middle : solid red (open blue) dots are π^+ (π^-) on LH_2

solid red (open blue) squares are π^+ (π^-) on LD_2

Bottom : solid red (open blue) dots are for π^+ (π^-) on LH_2

- We will be able to test many common assumptions used in SIDIS analyses:

$$R_{SIDIS} = R_{DIS}?$$

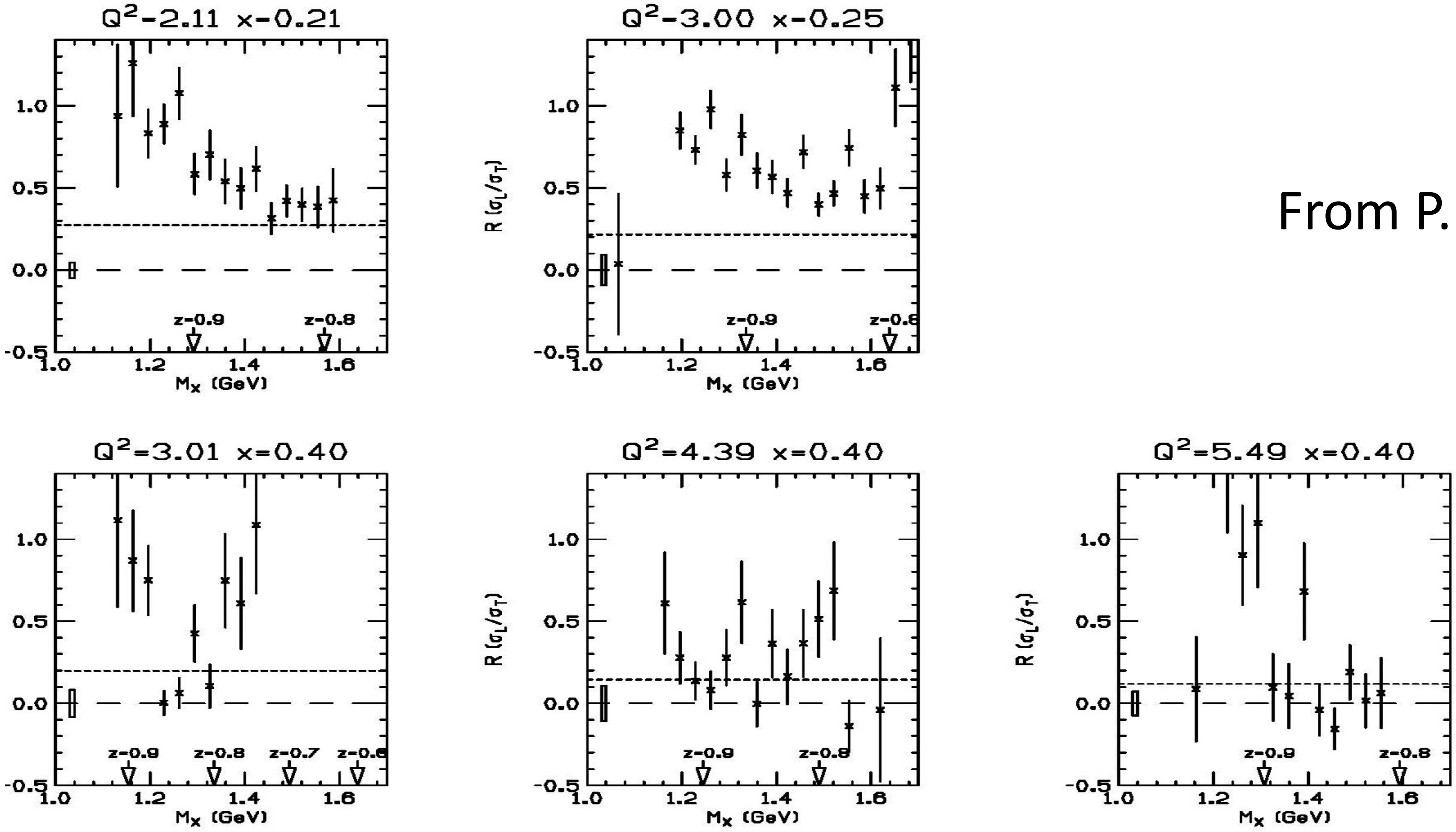
$$R^{\pi^+}_{SIDIS} = R^{\pi^-}_{SIDIS}? \qquad R^{H}_{SIDIS} = R^{D}_{SIDIS}? \qquad R^{\pi^+}_{SIDIS} = R^{K^+}_{SIDIS}? \qquad R^{K^+}_{SIDIS} = R^{K^-}_{SIDIS}?$$

- Important for determining spin structure function g_1^h (need term $(1+\varepsilon R)$ to get g_1^h/F_1^h from $A_\parallel{}^h$)

- At low z, expect DIS Q^2 behavior ($\sim 1/Q^2$), but as z→ 1, expect Deep-Exclusive Q^2 behavior ($\sim Q^2$)

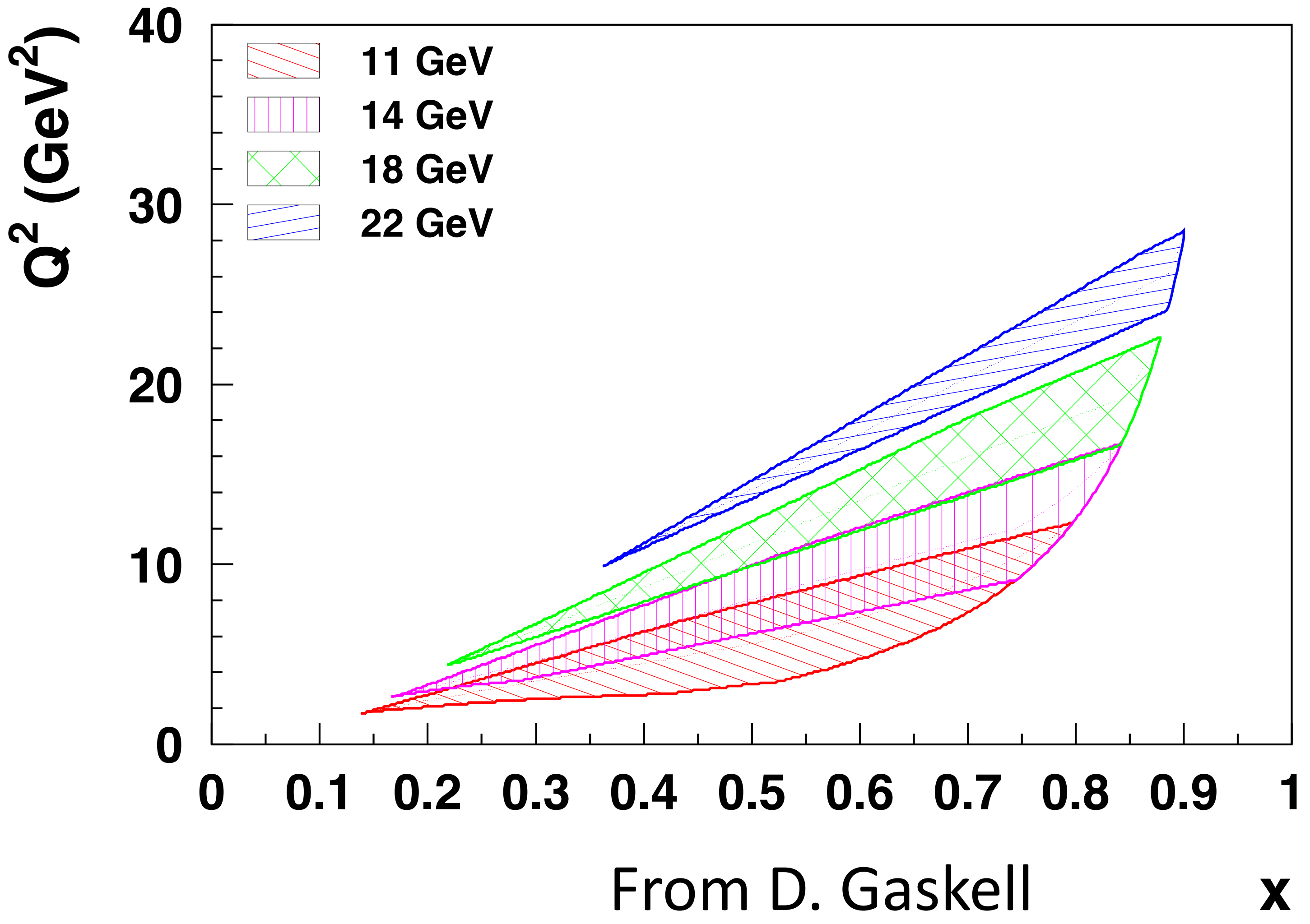
- Completely unknown p_T behavior, which might impact on TMD analyses

Preliminary SIDIS Results from Hall C!!!



From P. Bosted

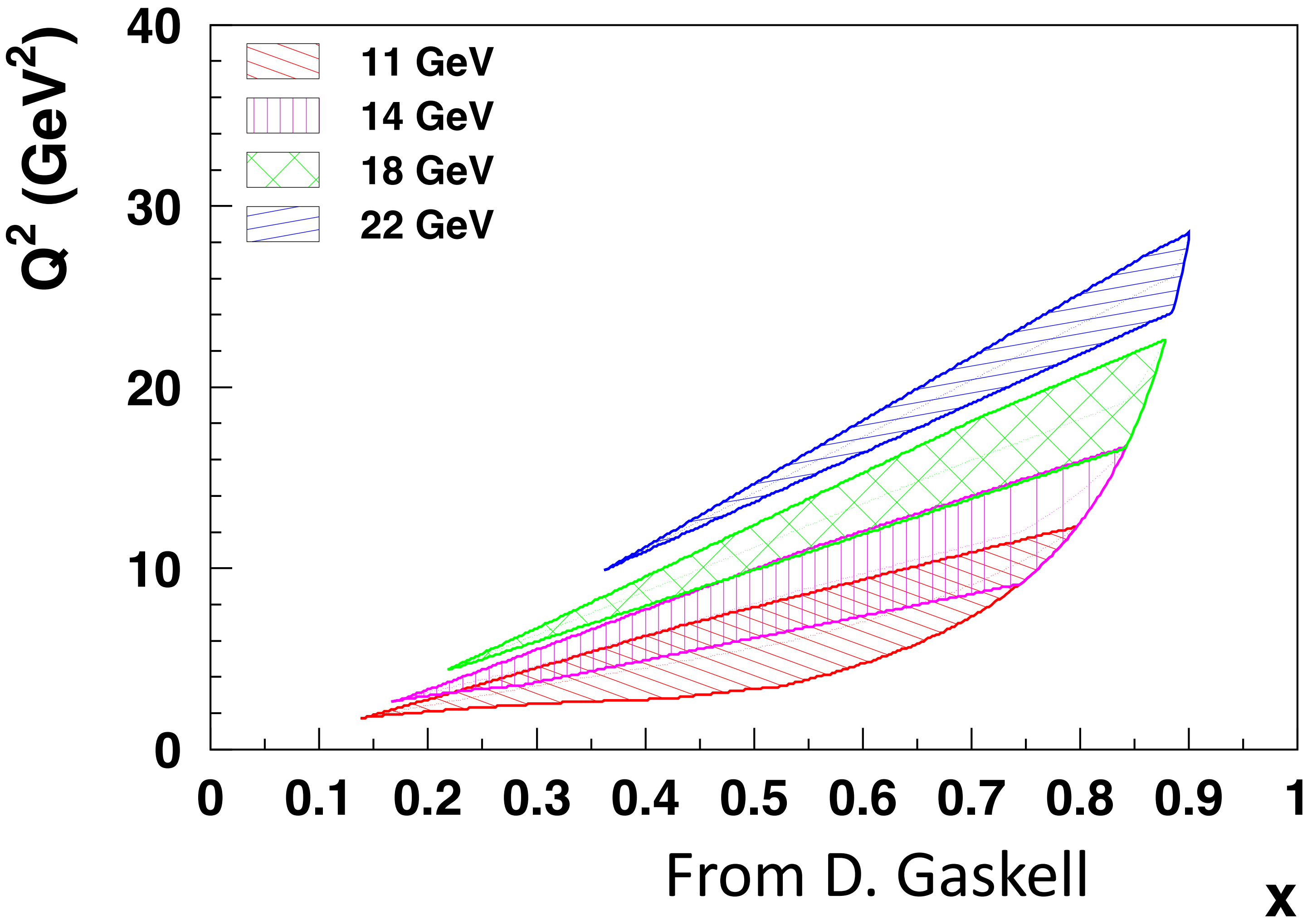
What can we do at 22 GeV?



From D. Gaskell

Kinematic ranges accessible in Hall C with existing HMS and SHMS spectrometers and that can achieve two ε values separated by 0.2 with a minimum ε of 0.1

What can we do at 22 GeV?



From D. Gaskell

- Explore R and σ_L at higher x and Q^2
- Combine with 11 GeV results. Can we see approach to constituent (dressed) parton behavior?
- Need to simulate!
- Effect of upgrade to HMS under study

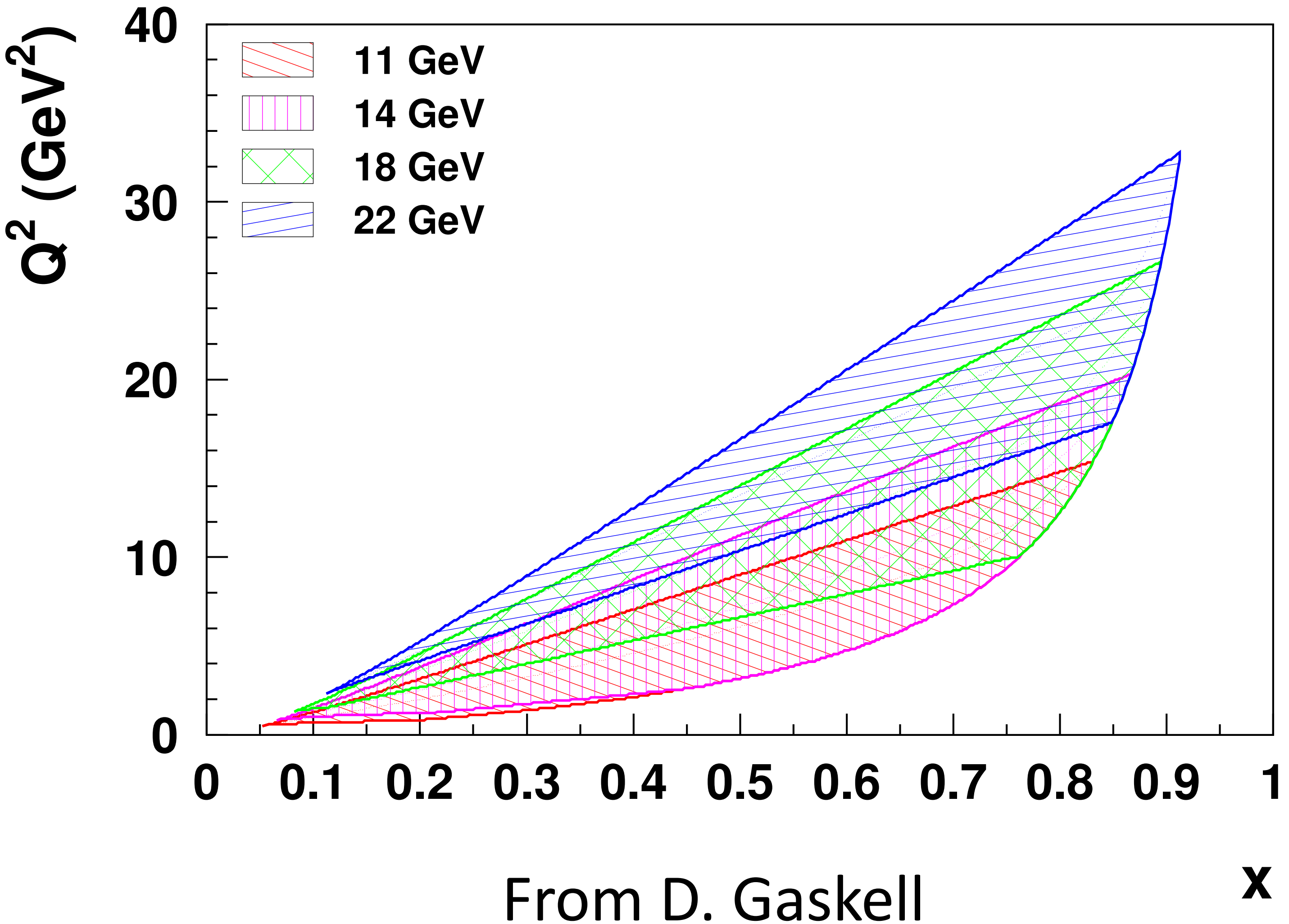
Why at Jefferson Lab at 22 GeV?

- R is a fundamental measurement of hadron structure
  - *Critical to precise determination of pdfs and TMDs*
  - *Longitudinal cross section explores "non-perturbative" structure beyond simple quark model*

- Very difficult to access at high energy colliders due to small range of ε, whereas Jefferson has luminosity and ε range to carry out timely and precise measurements!

Backup Slide

Upgraded HMS (θmin=5°, Pmax =11 GeV/c)



From D. Gaskell