Drell-Yan Energy Loss and the Target-Length Condition

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Factorization

- Consider Drell-Yan lepton-pair production for a collision between an incoming elementary hadron (projectile) and a nucleus (target).
- QCD factorization predicts that, for Drell-Yan production in leading twist, there is no energy loss because of interactions of the incoming parton with spectator partons in the nucleus.
  (Collins, Soper, Sterman (1983, 1984, 1985), (GTB (1985)).
  - Because of the hard-scattering interaction ($q\bar{q}$ annihilation), there is no leading pinch surface for Glauber scattering between the incoming parton and the spectator partons in the nucleus.
  - Interactions between the incoming parton and spectators in the nucleus proceed through exchanges of gluons that are collinear to the nucleus.
  - All of the nuclear effects are contained in the nuclear parton distributions.
- Higher-twist processes can induce energy loss, but these processes are suppressed as $\Lambda^2_{\rm QCD}/Q^2$.

Target-Length Condition

- Factorization breaks down if the target is too long relative to the energy of the incident parton.
- Factorization holds only if a "target-length condition" is satisfied:

$$x_q P^2 \gg LM\langle l_\perp^2 \rangle .$$

x_q is the longitudinal momentum fraction of the incoming parton.
P is the momentum of the incoming hadron in the rest frame of the nucleus.
L is the length of the nucleus ($\propto A^{1/3}$) in its rest frame.
M is the mass of the nucleus.
$\langle l_\perp^2 \rangle \sim \Lambda_{\rm QCD}^2$ is the mean square transverse momentum "kick" in an initial-state interaction of the incoming parton with a spectator in the nucleus.

- If the target-length condition is not satisfied, then Glauber scattering becomes important, energy loss occurs, and factorization breaks down.

- If the target-length condition is satisfied, then there is no Glauber scattering in leading twist, but the incoming parton does pick up transverse momentum through eikonal interactions with the spectators in the nucleus.
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  - The transverse-momentum "kicks" increase the transverse momentum of the Drell-Yan pair and lead to a Cronin effect (enhanced $d\sigma/dp_T$).
  - The Cronin effect is higher twist:

$$\sim \frac{\frac{d^2}{dp_t^2}(d\sigma/dp_T) \times \langle l_T^2 \rangle \times L}{d\sigma/dp_T}.$$

  - But, because $d\sigma/dp_T$ falls steeply with p_T, the Cronin effect produces deviations from A^1 in the cross section out to rather large values of p_T.