At the Intersection of Spin and Saturation Physics

Transverse Spin Asymmetries in p-p and p-A Collisions

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Outline

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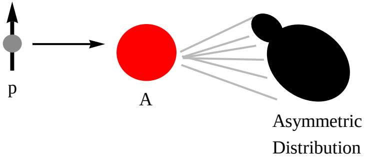

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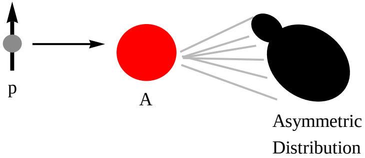

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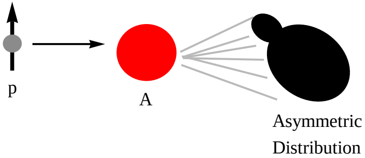

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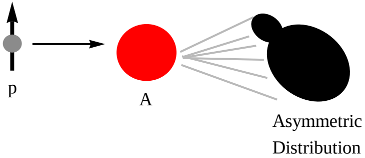

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- Left/right asymmetry and spin up/down asymmetry are equivalent due to rotational invariance.

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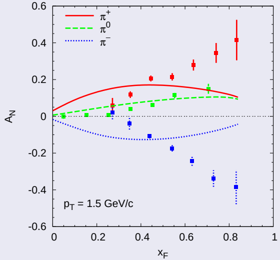
- RHIC at $\sqrt{s} \approx 200 GeV$ (00's) confirmed Fermilab's measurements over a wider kinematic range. Observed non-monotonic p_T dependence.

History and Observation of STSA

[D'Alesio and Murgia, '08]



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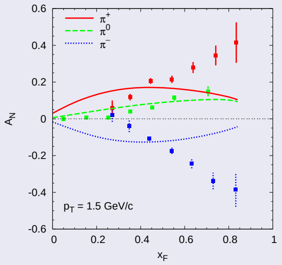
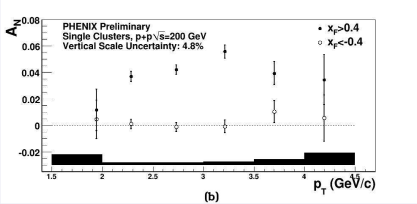


[Wei, '11] - PHENIX



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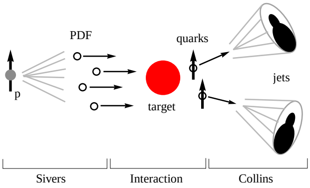

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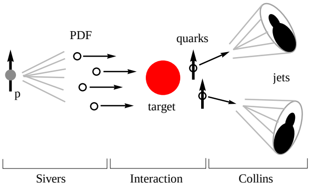

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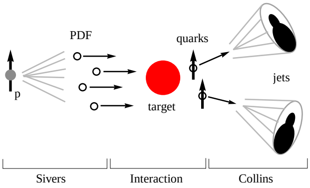

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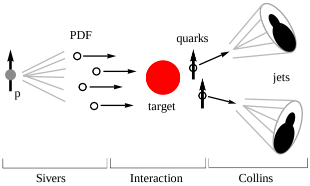

- Sivers effect: Asymmetric PDF's of polarized hadrons. Generally non-perturbative. [Sivers, '90]
- Interactions: Symmetric and asymmetric contributions from hard scattering processes. Generally perturbative.
- Collins effect: Asymmetric FF's of polarized quarks. Generally non-perturbative, and results in asymmetric distribution within a jet. [Collins, '93]

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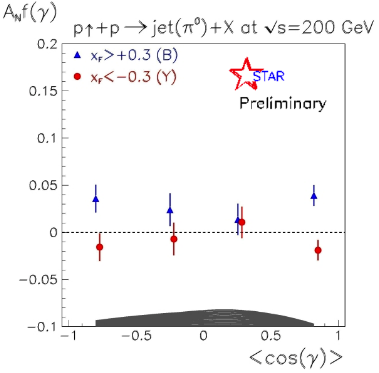
[Poljak, '11] - STAR



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- Collins effect is consistent with zero for π^0 production.

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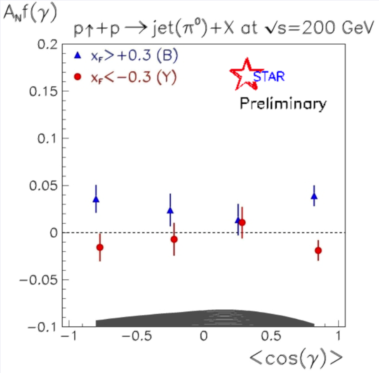

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- Specifically, 3-gluon exchange contributes to these operators, with the gluons in the C-even (f^{abc}) or C-odd (d^{abc}) color states. [Ji, '92], [Koike and Yoshida, '11]

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- At high enough energies that recoil can be neglected, quark and gluon propagators become Wilson lines.
- Easy to incorporate small-x evolution into the light-cone wave function.

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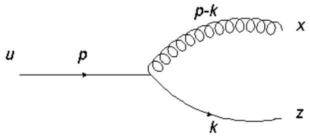

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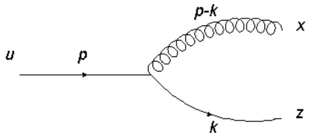

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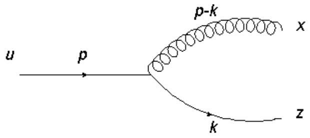

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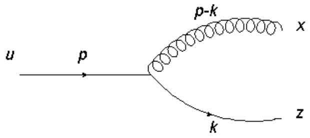

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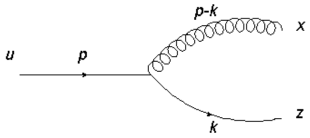

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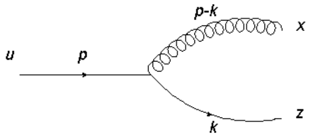

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- Modified mass $\tilde{m} \equiv (1 - \alpha) m$

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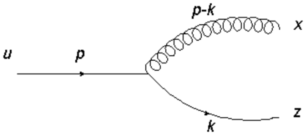

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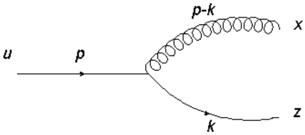

$$\Phi_{\lambda\chi\chi'}(\underline{z}-\underline{x})T^a\delta^2[\underline{x}-\underline{u}+\alpha(\underline{z}-\underline{x})] = \int \frac{d^2k}{(2\pi)^2}\frac{d^2p}{(2\pi)^2}\, e^{i\underline{k}\cdot(\underline{z}-\underline{x})}e^{i\underline{p}\cdot(\underline{x}-\underline{u})}\frac{gT^a}{p^- - k^- - (p-k)^-}\frac{\bar{U}_{\chi'}(k)}{\sqrt{k^+}}\left(\gamma\cdot\epsilon^{(\lambda)}\right)\frac{U_\chi(p)}{\sqrt{p^+}}$$

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- Note vector structure of the two terms.
- Entire splitting function is proportional to the quark mass: a consequence of not being in a pure helicity state.

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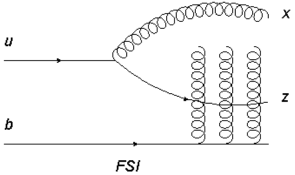

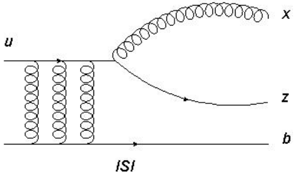

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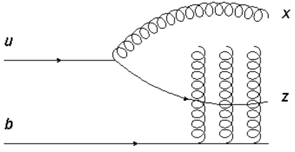
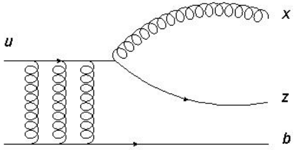
- Represent eikonal scattering with Wilson lines
  $V_{\underline{x}} =$
  $\mathcal{P} \exp \left[-ig \int dx^+ T^a A^{a-}(\underline{x}, x^+, \underline{b}) \right]$



FSI



ISI

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$$\langle \psi_{int}^2 \rangle = \delta^2[\underline{u} - \alpha \underline{z} - (1-\alpha)\underline{x}]\,\delta^2[\underline{w} - \alpha \underline{y} - (1-\alpha)\underline{x}] \times$$
$$\times \langle \Phi_\chi^2 \rangle (\underline{z} - \underline{x}, \underline{y} - \underline{x})\, \mathcal{I}(\underline{x}, \underline{y}, \underline{z}, \underline{u}, \underline{w}, \underline{b})$$

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- Splitting wave function:
$$\langle \Phi_\chi^2 \rangle =$$
$$\frac{2\alpha_s}{\pi} \tilde{m}^2 \Bigg[(1+\alpha^2) \frac{(\underline{z}-\underline{x})\cdot(\underline{y}-\underline{x})}{|\underline{z}-\underline{x}|\,|\underline{y}-\underline{x}|}\, K_1(\tilde{m}|\underline{z}-\underline{x}|) K_1(\tilde{m}|\underline{y}-\underline{x}|) +$$
$$+ (1-\alpha)^2 K_0(\tilde{m}|\underline{z}-\underline{x}|) K_0(\tilde{m}|\underline{y}-\underline{x}|) -$$
$$-\chi\alpha(1-\alpha) \Bigg(\frac{z^{(2)}-x^{(2)}}{|\underline{z}-\underline{x}|} K_0(\tilde{m}|\underline{y}-\underline{x}|) K_1(\tilde{m}|\underline{z}-\underline{x}|) +$$
$$+ \frac{y^{(2)}-x^{(2)}}{|\underline{y}-\underline{x}|} K_1(\tilde{m}|\underline{y}-\underline{x}|) K_0(\tilde{m}|\underline{z}-\underline{x}|) \Bigg) \Bigg]$$

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- Need to reorganize into manageable pieces.

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- After averaging over impact parameters d^2b, rotationally non-invariant terms vanish (vector structure vs. k_T-parity):
  $\Phi^2_{pol}\mathcal{I}_{symm} = 0$
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- Explicitly separate each trace into a symmetric piece S_{xy} (the Pomeron) and an antisymmetric piece O_{xy} (the Odderon):

  $i\mathcal{I}_{anti} = C_F(iO_{zy} + iO_{uw}) + N_c(iO_{yx}S_{xu} + iO_{xu}S_{yx} +$

  $+ iO_{wx}S_{xz} + iO_{xz}S_{wx}) + \frac{1}{N_c}(iO_{zw} + iO_{uy})$

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- $(\mathrm{ISI})^2$ and $(\mathrm{FSI})^2$ contribute to $d\sigma_{unp}$. Only (ISI/FSI) interference terms generate the relative phase needed for STSA.

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- To generate any asymmetry from the interaction, finite size effects must be incorporated.

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- More suppressed overall, but with weaker dependence on A.

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- Qualitatively, we expect a crossover between the edge effects and the nonlinear effects generating STSA at some value of A.

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- This method hinges on eikonal kinematics; recoil corrections cannot be incorporated into the Wilson lines.
- Describing finite-size effects with Θ-functions is *very* crude. Is that really better than assuming a nonperturbative ansatz?

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Thank You!