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Possible ways to extract transversities at PAX

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A. P. Contogouris, B. Kamal, Z. Merebashvili, Phys. Lett. **B 337**, 169, 1994 – first NLO calculation in dimensional scheme, work done as members of RHIC SPIN collaboration.

Considered energies: $\sqrt{s} = 100, 200, 500$ GeV.

Collinear QCD and Q_T distributions in Drell-Yan process

Parton model based decription for Q_T-distributions is not satisfactory

Most disturbing: NLO pQCD predictions for unpolarized Drell-Yan process

$$p + p(\bar{p}) \to l^+ + l^- + X \ (S, Q^2 \gg \Lambda^2 \sim 0.1\,\mathrm{GeV}^2,\ \tau = Q^2/S \ \text{ fixed})$$

do not describe experimentally measured Q_T-distributions (e.g. underestimate data at high Q_T). Note, at NLO transverse momentum is generated radiatively.

Theoretical Problems:

▲ Cross sections singular at $Q_T = 0$.

Large logarithms for differential cross sections spoil convergence of perturbation theory

How to deal with it ?

- Resummation $\Longrightarrow$ Phenomenological relevance ?

Drawbacks

- Resummed cross sections not always reliable: trouble is $Q_T \gg m_Q$ or $Q_T \sim 0$ are not quantitative statements

- Not all the soft terms are summed up

- Usual LO, NLO or NNLO $\overline{\mathrm{MS}}$ parton densities cannot be used. Factorization has to be shown for the newly invented densities

- Calculate average squared $< Q_T^2 >$:

$$< Q_T^2 >= \frac{\int Q_T^2 (d\sigma_{NLO}/dp_T dQ^2 ...) dp_T}{d\sigma_{NLO}/dQ^2}.$$

The above value is factor of 2 smaller then width of Q_T distribution measured by Fermilab experiment E866.

What is done to improve theoretical description

Natural approach to generate additional Q_T-dependence is to consider extra degree of freedom for quark motion in nucleon – intrinsic parton transverse momentum.

■ Various approaches, including considerations of nonperturbative primordial quark transverse momentum and of quark off–shellness, with or without higher twist effects, i.e. power corrections of order $\mathcal{O}(1/Q)$.

■ Considerations restricted to the LO field theoretical approach and discard contributions suppressed by orders of $1/Q^2$.

We will start from the work of

R. D. Tangerman and P. J. Mulders, Phys. Rev. D**51**, 3357, 1995,

originated from J. P. Ralston and D. E. Soper, Nucl. Phys. B152, 109, 1979.

Consider cross section for Drell-Yan process with photon exchange

$$\frac{d\sigma}{d^4q d\Omega} \sim L_{\mu\nu} W_{\mu\nu}.$$

Since $L_{\mu\nu}$ is symmetric $\Longrightarrow W_{\mu\nu}$ also symmetric.

- Kinematics: in Collins-Soper frame expanding $L^{\mu\nu}$ and $W_{\mu\nu}$, using light-cone component representation.

Hadronic tensor presented as a sum of products of tensors and scalar functions – structure functions, employing hermiticity, parity, time reversal invariance as constraints for construction of the quark-quark correlation function.

Result: general expressions for the four combinations of polarization:

$$\frac{d\sigma(0,0)}{d^4q d\Omega}, \qquad \frac{d\sigma(\lambda_A,\lambda_B)}{d^4q d\Omega}, \qquad \frac{d\sigma(\mathbf{S}_{AT},\lambda_B)}{d^4q d\Omega}, \qquad \frac{d\sigma(\mathbf{S}_{AT},\mathbf{S}_{AT})}{d^4q d\Omega},$$

with dozen of T-even structure functions in terms of 6 real distribution functions, depending on x and $\mathbf{k_T^2}$. Also q_T dependence is preserved.

Expressions include azimuthal angular dependences.

If q_T dependence is integrated out, only three conventional structure functions survive (in terms of 3 parton densities).

If time reversal invariance constraint is lifted, extra T-odd structure function appears, so called Sivers function (D. Boer, Phys. Rev. D**60**, 014012, 1999).

Open questions:

- Time reversal symmetry $\Longrightarrow$ incoming hadron in plane wave state, i.e. T-odd functions are zero

- Explanation: initial state interactions between the two incoming hadrons, or effects due to the finite size of a hadron.

- Initial state interactions $\longrightarrow$ factorization breaking effect $\Longrightarrow$ nonuniversality of the DF's or universality in some restricted sense

- Large effects due to finite size of hadrons should not affect factorization, but could result in larger higher twist contributions

Unintegrated DF's:

$$f_1(x) = \int d^2\mathbf{k}_T f_1(x, \mathbf{k}_T^2),$$

$$g_1(x) = \int d^2\mathbf{k}_T g_{1L}(x, \mathbf{k}_T^2),$$

$$h_1(x) = \int d^2\mathbf{k}_T \left[h_{1T}(x, \mathbf{k}_T^2) + \frac{\mathbf{k}_T^2}{2M^2} h_{1T}^{\perp}(x, \mathbf{k}_T^2) \right].$$

Monte Carlo simulation for double transverse spin asymmetries, integrated over $\mathbf{q}_T$ (excluding small values of $\mathbf{q}_T$), done in A. Bianconi and M. Radici, Phys. Rev. D**72**, 074013, 2005.

However, $\mathbf{k}_T$ evolution is not taken into account.

To evolve also with $\mathbf{k}_T$, one could use Kwiecinski equations for the unintegrated DF's. Widening in transverse momentum of all partonic distributions, e.g. $< k_T^2 >$ grows with the probing scale as $Q^2\,\alpha(Q^2)$.

Our Project

Our aim on theoretical side:

- Clean isolation of transversities h_1
- Looking for possibility to measure other distributions, by means of constructing various asymmetries, once- or twice-weighted with momenta as well as with azimuthal angles
- Doing research in different (other than CS) kinematical frames

Our aim on numerical side:

- Fully taking into account k_T into evolution equations
- Estimation of rates and asymmetries
- Building a complete Monte Carlo event generator for PAX fully taking into account the detector configuration