DOUBLE TRANSVERSE SPIN ASYMMETRIES AT NEXT-TO-LEADING ORDER IN QCD

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- Transversity and its measurement
- Problems with NLO calculation involving transverse polarization
- Recently proposed technique
- Applications and results
- Summary and outlook

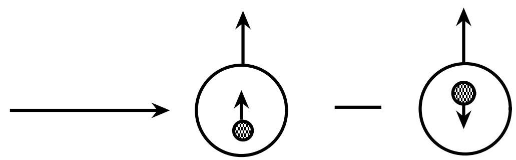
DIS’05

In collaboration with M. Stratmann (Regensburg) and W. Vogelsang (Brookhaven and Riken BNL)

What is Transversity ?

• Parton language : nucleon moving with (infinite) momentum along $\hat{z}$ direction but polarized in the transverse direction

Transversity $\delta q_a(x, Q^2) \rightarrow$ the number of partons of flavor a and momentum fraction x with spin parallel to the spin of the nucleon minus the number antiparallel



$$\delta f(x, \mu) = f_{\uparrow\uparrow}(x, \mu) - f_{\uparrow\downarrow}(x, \mu)$$

• Can be probed in

(1) Single transverse spin asymmetries in pp or ep scattering; azimuthal asymmetries..

(2) Double transverse spin asymmetries

Candidate processes $p^\uparrow p^\uparrow \rightarrow l^+ l^- X, p^\uparrow p^\uparrow \rightarrow \gamma X, p^\uparrow p^\uparrow \rightarrow jet X$...

Double Transverse Spin Asymmetry

A_{TT} defined as :

$$A_{TT} = \frac{(\sigma_{++} + \sigma_{--}) - (\sigma_{+-} + \sigma_{-+})}{(\sigma_{++} + \sigma_{--}) + (\sigma_{+-} + \sigma_{-+})}$$

$+$ and $-$ $\rightarrow$ transverse spin directions of the beam proton.

✓ A_{TT} depends only on transversity

× Small, because gluon initiated subprocesses contribute to the denominator but not to the numerator (only exception : Drell-Yan)
A_{TT} for DY small at RHIC due to small $\delta\bar{q}$.

Martin, Schäfer, Stratmann, Vogelsang 98

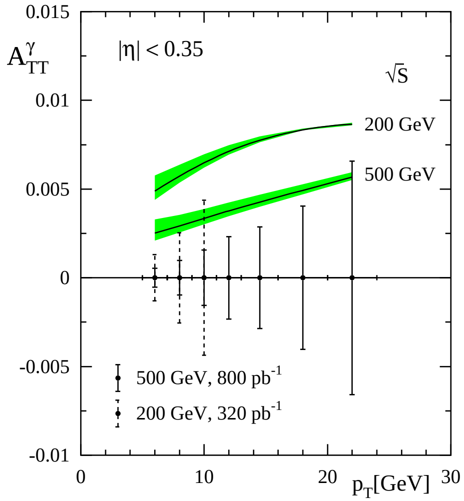
• Also : A_{TT} in $p^{\uparrow}\bar{p}^{\uparrow} \rightarrow l^{+}l^{-}X$ at GSI

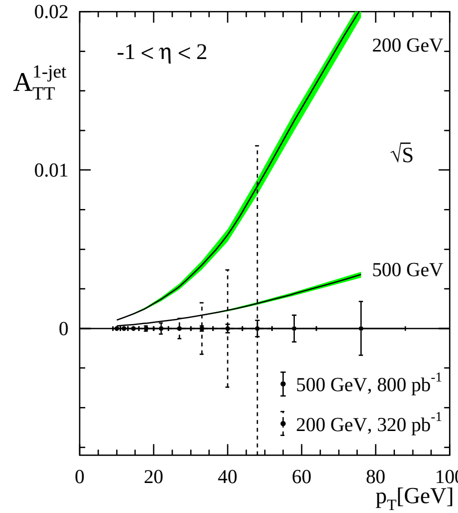
Anselmino, Barone, Drago, Nikolaev; Efremov, Goeke, Schweitzer 04;
Shimizu, Sterman, Vogelsang, Yokoya 05

× Much lower energy

✓ A_{TT} large

A_{TT} for other processes :





Soffer, Stratmann, Vogelsang 02

- LO estimate by saturating Soffer's inequality at a low input scale; at higher scales transversity is obtained by solving the evolution eqn.
- Hard to detect : good control over systematic and statistical errors necessary
- Higher order correction a must : reduction of scale dependency ..
- Further motivation : technical challenge for NLO calculation of cross sections involving transversely polarized particles in the initial state

Problem with Transverse Polarization Beyond LO

- Spin vectors introduce extra spatial directions : nontrivial Φ dependence

- Assuming both initial spin vectors in $\pm x$ direction in cm frame of the initial hadrons; for a parity conserving theory with vector couplings

$$\frac{d^3\delta\sigma}{dp_T\,d\eta\,d\Phi} \;\equiv\; \cos(2\Phi)\,\left\langle \frac{d^2\delta\sigma}{dp_T\,d\eta} \right\rangle$$

- Φ cannot be integrated out !

- Difficult to use standard tools for doing phase space integrations at NLO (especially for dimentional reg.)

- Need : A general technique to perform calculations at NLO with transverse polarization

Projection Technique for Azimuthal Dependence

Integrate with $cos 2\Phi$ weight :

$$\left\langle \frac{d^2\delta\sigma}{dp_T d\eta} \right\rangle = \frac{1}{\pi} \int_0^{2\pi} d\Phi \cos(2\Phi) \frac{d^3\delta\sigma}{dp_T d\eta d\Phi}$$

Consider prompt photon production as an example

LO $\rightarrow q\bar{q} \rightarrow \gamma g$

Polarization for initial quark projected out by

$$u(p_a, s_a)\,\bar{u}(p_a, s_a) = \frac{1}{2} \not{p}_a \left[1 + \gamma_5 \not{s}_a\right]$$

Note : Covariant expression below give $cos 2\Phi$ in the c. m. frame of initial hadrons

$$\mathcal{F}(p_\gamma, s_a, s_b) = \frac{s}{\pi t u} \left[2\,(p_\gamma \cdot s_a)\,(p_\gamma \cdot s_b) + \frac{tu}{s}\,(s_a \cdot s_b) \right]$$

AM, Stratmann, Vogelsang 03

Projection Technique (Continued)

At LO for $q\bar{q} \to \gamma g$ we have

$$\frac{d\delta^2 \hat{\sigma}^{(0)}_{q\bar{q}\to\gamma g}}{dt d\Phi} = \frac{1}{32\pi^2 s^2} \, \delta|M(q\bar{q} \to \gamma g)|^2 \; ,$$

$$\delta|M(q\bar{q} \to \gamma g)|^2 = (e e_q g)^2 \, \frac{4C_F}{N_C} \, \frac{s}{tu} \left[2 \, (p_\gamma \cdot s_a) \, (p_\gamma \cdot s_b) \; + \; \frac{tu}{s} \, (s_a \cdot s_b) \right]$$

- Multiply $\delta|M|^2$ by $\mathcal{F}(p_\gamma, s_a, s_b)$

- Dependence on spin vectors : $(p_\gamma \cdot s_a)^2 (p_\gamma \cdot s_b)^2$, $(p_\gamma \cdot s_a)(p_\gamma \cdot s_b)(s_a \cdot s_b)$, and $(s_a \cdot s_b)^2$

- Expand tensors $p_\gamma^\mu p_\gamma^\nu p_\gamma^\rho p_\gamma^\sigma$ and $p_\gamma^\mu p_\gamma^\nu$ into all possible tensors made up of the metric tensor and the incoming partonic momenta

Projection Technique (Continued)

$$\int d\Omega_\gamma\,(p_\gamma\cdot s_a)^2(p_\gamma\cdot s_b)^2 = \int d\Omega_\gamma\,\frac{t^2u^2}{8s^2}\left(2(s_a\cdot s_b)^2+s_a^2 s_b^2\right) \;=\; \int d\Omega_\gamma\,\frac{3t^2u^2}{8s^2}\;,$$

$$\int d\Omega_\gamma\,(p_\gamma\cdot s_a)(p_\gamma\cdot s_b)(s_a\cdot s_b) = -\int d\Omega_\gamma\,\frac{tu}{2s}(s_a\cdot s_b)^2 \;=\; -\int d\Omega_\gamma\,\frac{tu}{2s}\;,$$

- $s_i\cdot p_a = s_i\cdot p_b = 0$ $(i=a,b)$ and $s_a^2 = s_b^2 = -1$
- Now integrate phase space over p_γ including the (now trivial) azimuthal part
- Particularly suitable at NLO : $ab\to\gamma cd$
- Dimensional regularization : $d=4-2\epsilon$ dimension

Some Applications

- Prompt Photon Production

Two processes contribute at NLO :

$$\begin{aligned} q\bar{q} &\rightarrow \gamma X; X = g(LO); X = q\bar{q} + gg + q'\bar{q}'(NLO); \\ qq &\rightarrow \gamma X; X = qq \end{aligned}$$

- Single Inclusive Pion Production

Four processes contribute at LO :

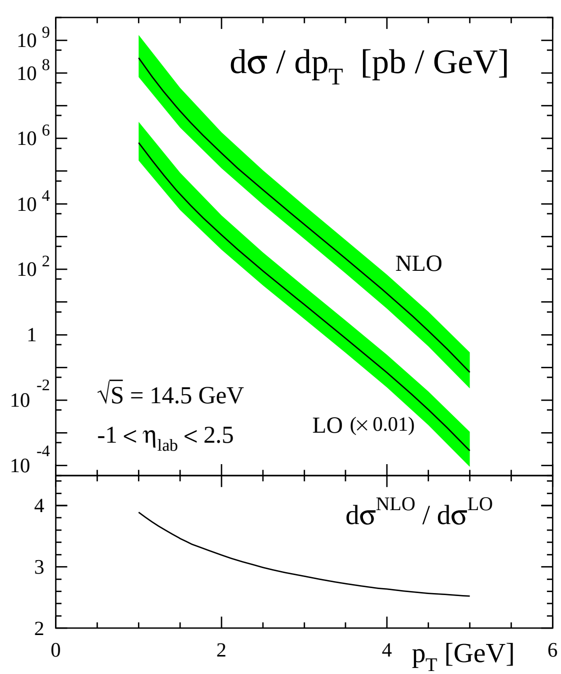
$$qq \rightarrow qX;\ \ q\bar{q} \rightarrow qX;\ \ q\bar{q} \rightarrow q'X;\ \ q\bar{q} \rightarrow gX.$$

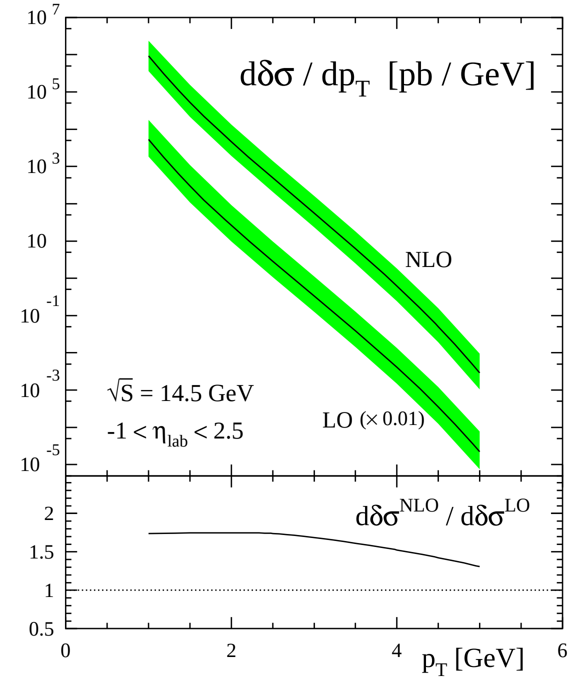
At NLO, there are $O(\alpha_s)$ corrections to these processes
And another process $qq \rightarrow gX$.

(i) Virtual corrections to LO

(ii) $2 \rightarrow 3$ processes

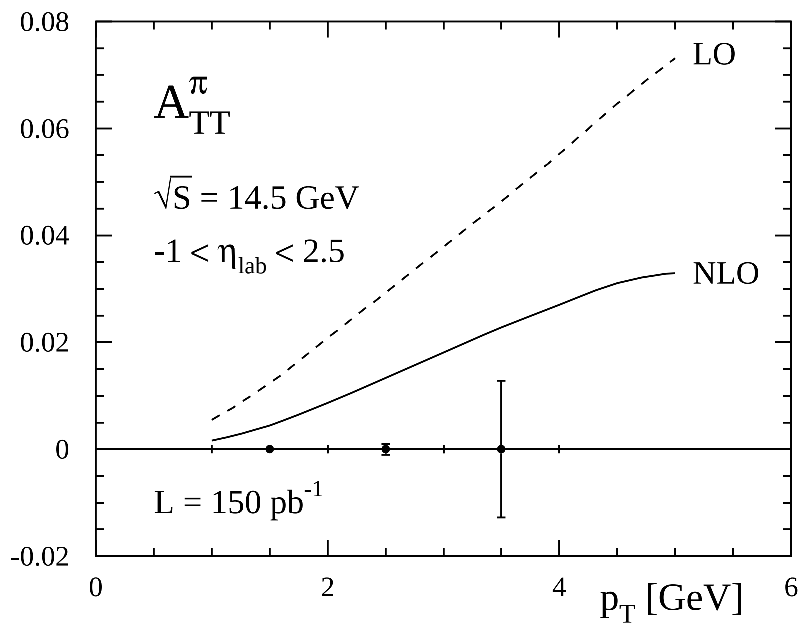
Numerical Results : Single Inclusive Pion Production at GSI





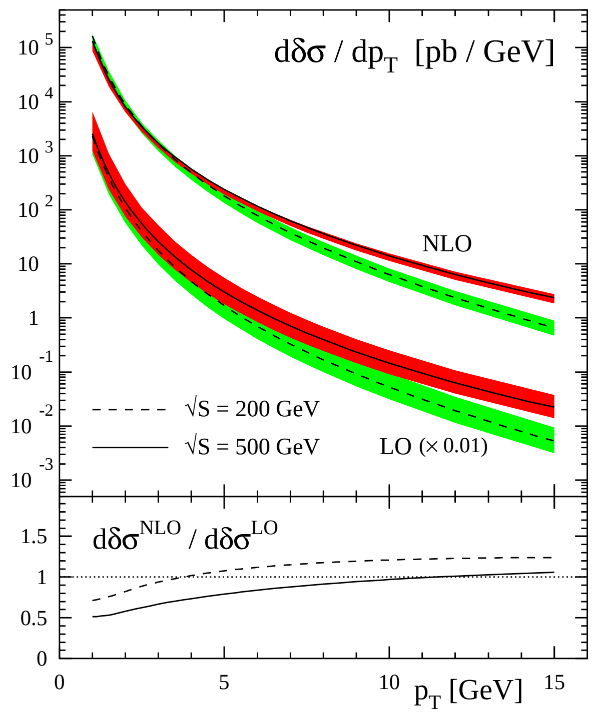
- Saturate Soffer's inequality at a low input scale $\mu_0 \simeq 0.6\,\mathrm{GeV}$ using CTEQ6M and GRSV, for higher scale transversity density is obtained by solving the evolution eq.
- Collider upgrade of GSI. $\bar{p}p$ collider at $\sqrt{S} = 14.5$ GeV
- $E_p = 3.5$ GeV (pol. 50 %), $E_{\bar{p}} = 15$ GeV (pol. 30 %)
- Scale : p_T to $4p_T$

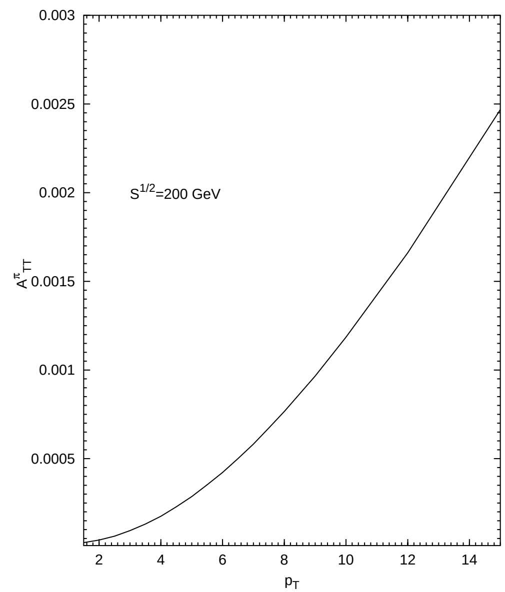
Numerical Results : Single Inclusive Pion Production at GSI



- Integrated over rapidity $-1 < \eta_{lab} < 2.5$
- Statistical error : $\delta A^{\pi}_{\mathrm{TT}} \simeq \frac{1}{P^2\sqrt{\mathcal{L}\sigma_{\mathrm{bin}}}}$

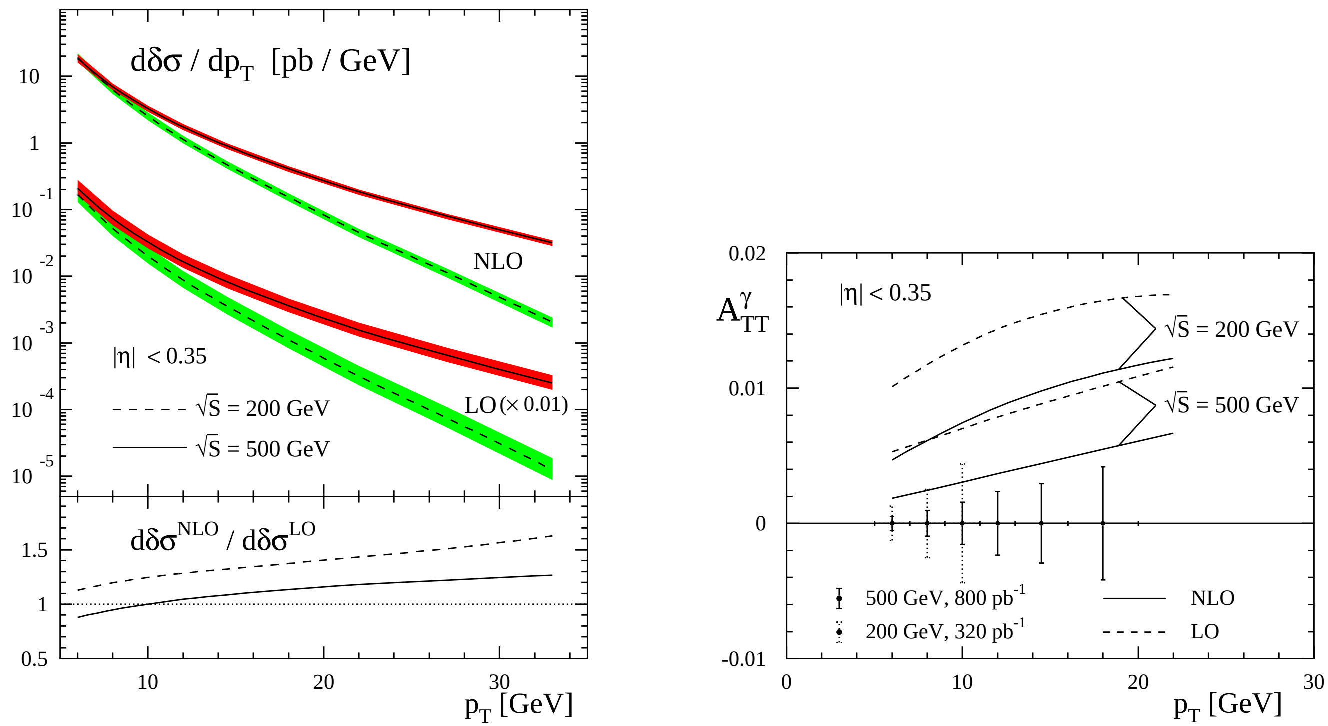
Numerical Results : Single Inclusive Pion Production at RHIC





- PHENIX detector at RHIC : pseudorapidity $|\eta| \leq 0.35$; $-\pi/4 < \Phi < \pi/4$ and $3\pi/4 < \Phi < 5\pi/4$
- Substantial reduction of scale dependency at NLO
- Asymmetry very small $O(10^{-4} - 10^{-3})$
- Scale : p_T to $4p_T$

Numerical Results : Isolated Prompt Photon Production at RHIC



- Isolation cuts to separate the photon signal from hadronic background
- PHENIX detector at RHIC : pseudorapidity $|\eta| \leq 0.35$; $-\pi/4 < \Phi < \pi/4$ and $3\pi/4 < \Phi < 5\pi/4$
- Substantial reduction of scale dependency at NLO

Summary

- Presented first calculation of cross sections and spin asymmetries for single inclusive pion production in transversely polarized pp and $p\bar{p}$ collisions at NLO

- A^{π}_{TT} sizable at GSI ($\sqrt{S} = 14.5$GeV); becomes smaller at NLO; interesting future study : effect of resummation

- A^{π}_{TT} very small at RHIC, substantial reduction of scale dependency at NLO

- A^{γ}_{TT} slightly larger, also substantial reduction of scale dependency at NLO

- Further possible applications of projection technique; $p^{\uparrow}p^{\uparrow} \rightarrow jetX$,$pp^{\uparrow} \rightarrow \Lambda^{\uparrow}X$....