BNL spin discussion

09/09/03

A_{TT} in NLO - a status report

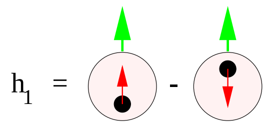
Marco Stratmann

Univ. of Regensburg

---

work done in collaboration with A. Mukherjee
and W. Vogelsang

recall main features of “transversity” $\delta\mathbf{q}(\mathbf{x}, \mu^2)$:

- “as partonic as” q and Δq: 

Ralston, Soper; Artru, Mekhfi; Jaffe, Ji

- reveals chiral-odd nature if described in helicity-basis

$$|\perp\rangle = \frac{1}{\sqrt{2}}(|+\rangle + i|-\rangle) \text{ and } |\top\rangle = \frac{1}{\sqrt{2}}(|+\rangle - i|-\rangle)$$

$\longrightarrow$ difficult to measure (fund. interactions preserve chirality)

$\longrightarrow$ no gluon density for spin 1/2 targets possible

Jaffe, Ji; Artru, Mekhfi; Ji

- simple non-singlet type evolution eqs.

NLO δP_{qq}: Vogelsang; Kumano, Miyama; Koike et al.

- vanishes at large scales (all $\int_0^1 x^{n-1}\delta q(x,\mu^2)dx$ decrease)

- constraint: Soffer; Sivers

$$\left|\delta q(x,\mu^2)\right| \leq \frac{1}{2}\left[q(x,\mu^2) + \Delta q(x,\mu^2)\right]$$

↑ unknown ↑ ↑ known (more or less)

- δq could provide info on chiral-sym. breaking in QCD

Collins, Diehl; Jaffe; Polyakov, Weiss . . .

- tensor charge $\sum_q \int_0^1 [\delta q - \delta\bar{q}](x,\mu^2)dx \leftrightarrow$ neutron EDM

Jaffe, Ji

Accessing δq at RHIC

chirality has to be flipped *twice* to access δq

$\swarrow$ $\searrow$

double-spin single-spin

asymmetries

A_{TT} A_{N}

$\mathbf{A}_{\mathsf{TT}}$:

✓ clean, involves only δq as "unknowns"

× expected to be small $\rightarrow$ exp. challenge

"selection rule" $A_{TT} \ll A_{LL}$

Artru, Mekhfi; Ji; Jaffe, Saito

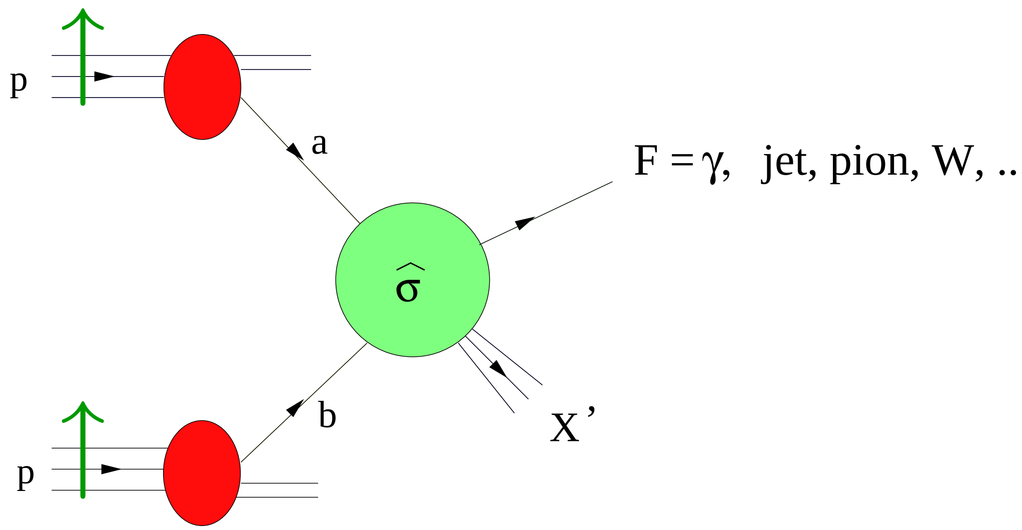
$\mathbf{A}_{\mathsf{N}}$:

× requires *other unknown* chiral-odd fct. $\rightarrow$ involved

Pandora's box: Collins fct., Sivers fct., . . .

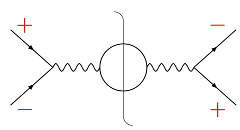
✓ $pp^{\uparrow} \rightarrow \pi X$ sizable (E704, STAR)

A_{TT} at RHIC



$$A_{\mathsf{TT}} = \frac{d\sigma^{p^{\uparrow}p^{\uparrow}} - d\sigma^{p^{\uparrow}p^{\downarrow}}}{d\sigma^{p^{\uparrow}p^{\uparrow}} + d\sigma^{p^{\uparrow}p^{\downarrow}}} \propto \sum_{a,b} \delta f_a \otimes \delta f_b \otimes \underbrace{\delta\widehat{\sigma}^{ab\to FX'}}_{\text{pQCD.}}$$

on the menu:

- **Drell-Yan process** 

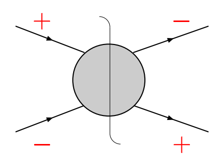
Ralston, Soper; Ji

Cortes, Pire, Ralston; Artru, Mekhfi; Jaffe, Ji

· most suited process: no gluons in LO

· NLO study: meas. suffers from limited $\mu^{\pm}$ acceptance
nevertheless, appears feasible

Martin, Schäfer, MS, Vogelsang

- **high-$\mathbf{p}_{\mathsf{T}}$ prompt photons, hadrons, jets** 

· A_{TT} small due to absence of $g^{\uparrow}g^{\uparrow}$ and $q^{\uparrow}g^{\uparrow}$ processes

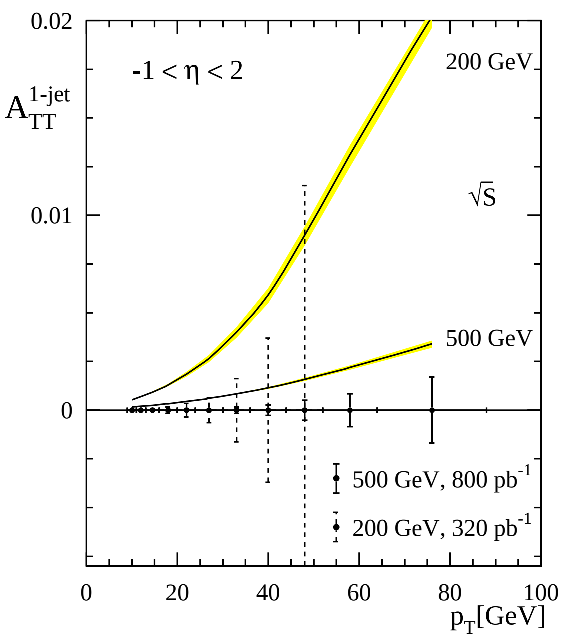
· sizable rates $\to$ statistics sufficient even if A_{TT} small

LO results assuming $\delta q(x,\mu_0) = \frac{1}{2}\left[q(x,\mu_0) + \Delta q(x,\mu_0)\right]$

Soffer, MS, Vogelsang

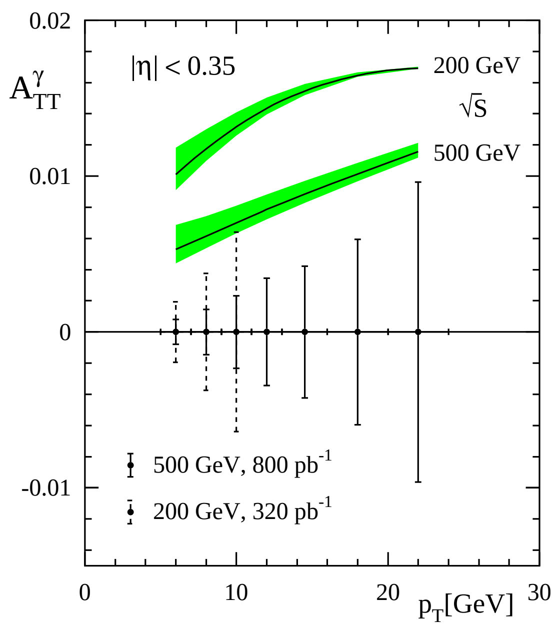
$p^{\uparrow}p^{\uparrow} \to \text{jet}\,X$

STAR



$p^{\uparrow}p^{\uparrow} \to \gamma X$

PHENIX



however, NLO QCD corrections are in general a must:

(scale dependence, ...) $\rightarrow$ Barbara's talk

further motivation for NLO: "technical challenge"

· general paucity of NLO calculations with transverse spin (until recently: NLO only for incl. DY and evol. kernels)

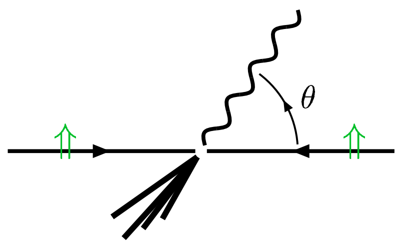
· provide and apply a feasible technique

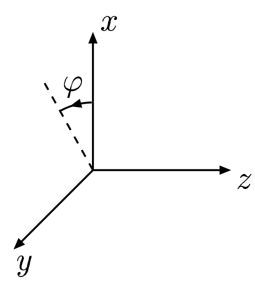
Why transverse spin is more complicated to handle:

long. polarization: spin *aligned* with momentum ✓

trans. polarization: spin = *extra spatial direction*

$\leftrightarrow$ non-trivial azimuthal dep.





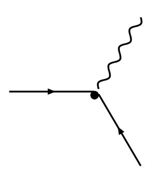
always of the form $\frac{d^3\delta\sigma}{dp_T d\eta d\Phi} \equiv \cos(2\Phi) \left\langle \frac{d^2\delta\sigma}{dp_T d\eta} \right\rangle$

$\longrightarrow$ ϕ integration not appropriate

but standard NLO techniques rely on integrations over

full azimuthal phase space *plus* use of particular

reference frame



Gottfried, Jackson

$\Rightarrow$ difficult to deal with azimuthal angle

(in particular, in $d = 4 - 2\varepsilon$ dimensions) recent progress:

$\boxed{\text{NLO corrections to } p^{\uparrow}p^{\uparrow} \to \gamma X}$

A. Mukherjee, MS, W. Vogelsang

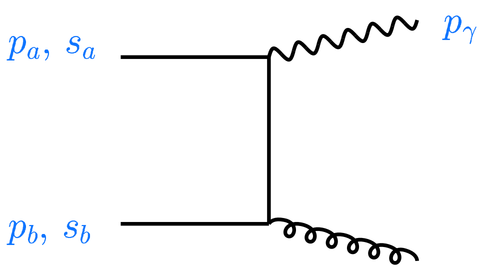
key point: ϕ-dep. always results from covariant expression

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

$=$ cos(2ϕ) in hadronic c.m.s.

$\Rightarrow$ use $\mathcal{F}$ to project out Φ covariantly

LO example: $q\bar{q} \to \gamma g$



$$p_a\cdot s_a \;=\; p_b\cdot s_b \;=\; 0$$

$$s_a^2 = s_b^2 = -1$$

matrix element [use $u(p_a,s_a)\,\bar{u}(p_a,s_a) = \frac{1}{2}\not{p}_a\,[1+\gamma_5\not{s}_a], \ldots$]

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

project with $\mathcal{F}$:

$$\frac{1}{\pi}\int d\Omega_\gamma\,\mathcal{F}(p_\gamma,s_a,s_b)\delta|M|^2 = (ee_q g)^2\,\frac{4C_F}{N_C} = \langle\delta|M|^2\rangle \;\checkmark$$

$\updownarrow$

terms involving $p_\gamma\cdot s_a\,,\,p_\gamma\cdot s_b$ can be integrated "covariantly" easily generalized to NLO calculation in d dimensions:

(1) multiply any $\delta|M|^2$ with $\mathcal{F}(p_\gamma, s_a, s_b)$

(2) integrate all resulting scalar products with $s_{a,b}$

for example: [up to $\mathcal{O}(\varepsilon)$]

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

(3) arrive at a structure similar to an unpol. $|M|^2$

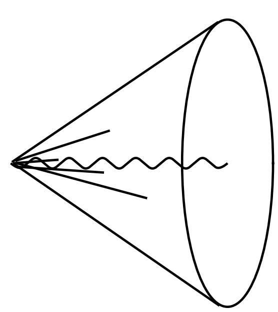
(4) employ *standard techniques* for phase space integr.

(5) restore ϕ dependence afterwards

remarks:

- cancellation of divergencies proceeds as usual
  $\rightarrow$ Barbara's talk

- at colliders, impose "isolation cut" on photon:



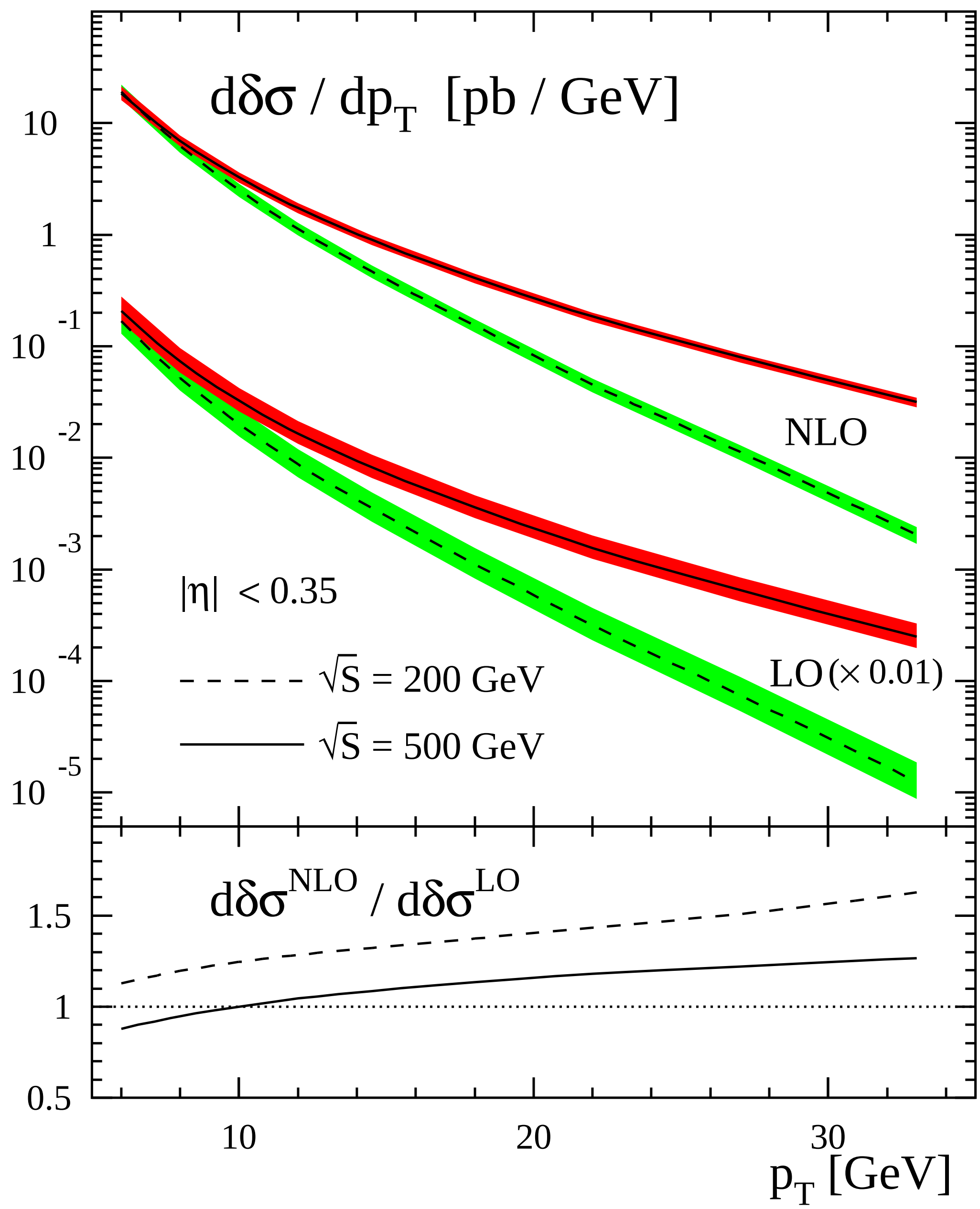
typically, demand $E_{\text{had}} \leq \epsilon \, E_\gamma$

in $\sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} \leq R$

- for isolation with $\epsilon \propto (r/R)^2$ one can eliminate the fragmentation component altogether Frixione

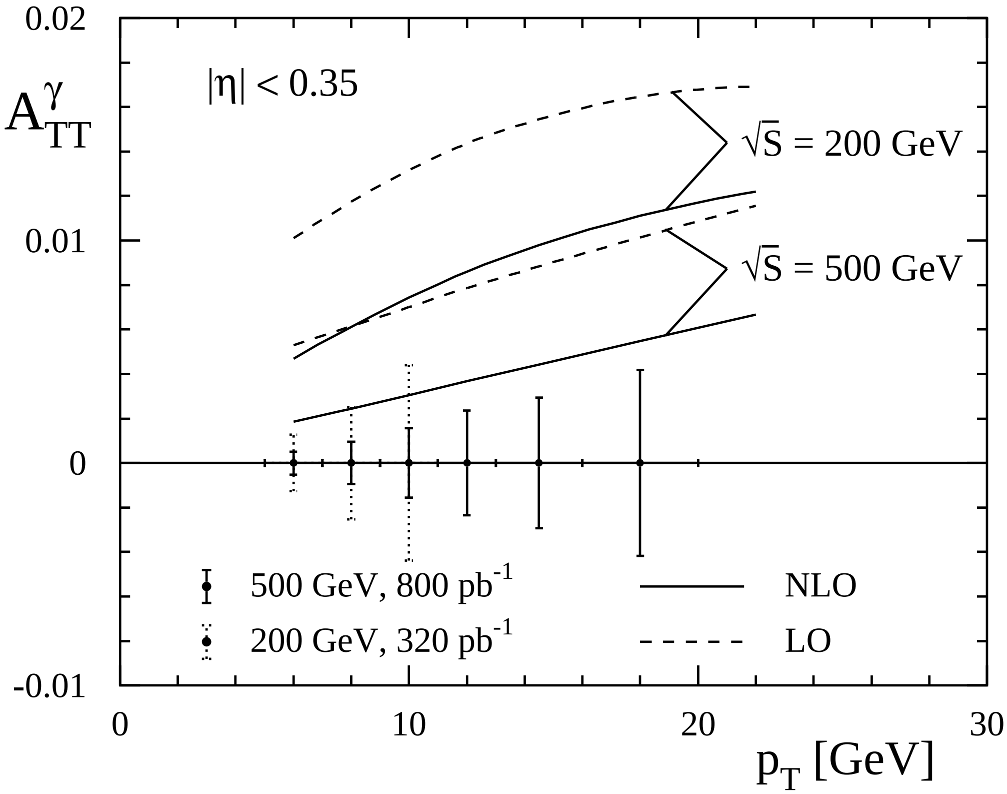
results for $\mathbf{p^{\uparrow}p^{\uparrow} \to \gamma X}$:

- improved scale dependence
- reasonable “K-factors”



A. Mukherjee, MS, W. Vogelsang

results for $\mathbf{A}_{\mathsf{TT}}$:



A. Mukherjee, MS, W. Vogelsang

work in progress:

- half-way through with $p^{\uparrow}p^{\uparrow} \rightarrow \pi X$
- future: $p^{\uparrow}p^{\uparrow} \rightarrow$ jet$X$ ...