Next-to-Leading Order Issues in Spin Pdf Determinations

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SUMMARY

It was demonstrated that the leading order (LO) pdf's are process dependent to $\mathcal{O}(\alpha_s)$, while the next-to-leading order (NLO) ones are process dependent only to $\mathcal{O}(\alpha_s^2)$. Using NLO, or higher, pdf's it is thus possible to test the validity parton model by verifying explicitly the reduction in process dependence as one goes to higher orders in perturbation theory. The same applies to the ratio of the polarized to unpolarized pdf's. This should manifest itself through a convergence of the perturbation series to the experimental result for new processes which were not included in the fits. The issue of factorization scheme dependence was discussed and the mechanism for the evolution of $\Delta\Sigma$ was illustrated without making explicit use of the ABJ anomaly. The result for that evolution is in exact agreement with that obtained via the above mentioned anomaly, at two-loops, as is required.

Consistent NLO predictions for all longitudinal Drell-Yan type processes at RHIC ($W^{\pm}$, Z and γ^*) were made using polarized parton distributions which fit the recent DIS data. Particular attention was paid to regularization and factorization scheme dependences. The HOC increased the cross sections substantially and had a major impact on the asymmetries, while preserving the features of the LO asymmetries. The exact sign and magnitude of the HOC depended on the details of the parton distributions used, especially the polarized gluon distribution. Faced with either low rates or small asymmetries, γ^* production didn't prove very interesting for longitudinal polarization (unless the agreement between the various parton distributions at small-x is an artificial one). The Z- asymmetries were all quite sensitive to the sea quarks; the parity violating ones being the largest, with unexpected sensitivity due to a coincidental cancellation between u and d valence contributions. With large rates and asymmetries, $W^{\pm}$ production can directly measure the sea and valence distributions as well as the unpolarized $u/\bar{d}$ ratio. Lower energy running could measure directly $\bar{u}$ and $\bar{d}$ at rather large x (both polarized and unpolarized).

NLO Issues in Spin pdf Determinations

- Process Inependence of pdf's

  Provides best test of Parton Model (PM) for pol. & unpol. processes.

  Why?

  Can almost always fit some specific piece of data just by playing with pdf's.

  But

  PM expression in reality involves all-orders pdf's & x-sctns (or high order in pert. theor: N-loop, N>>1, where series best approximates reality).

Specifically:

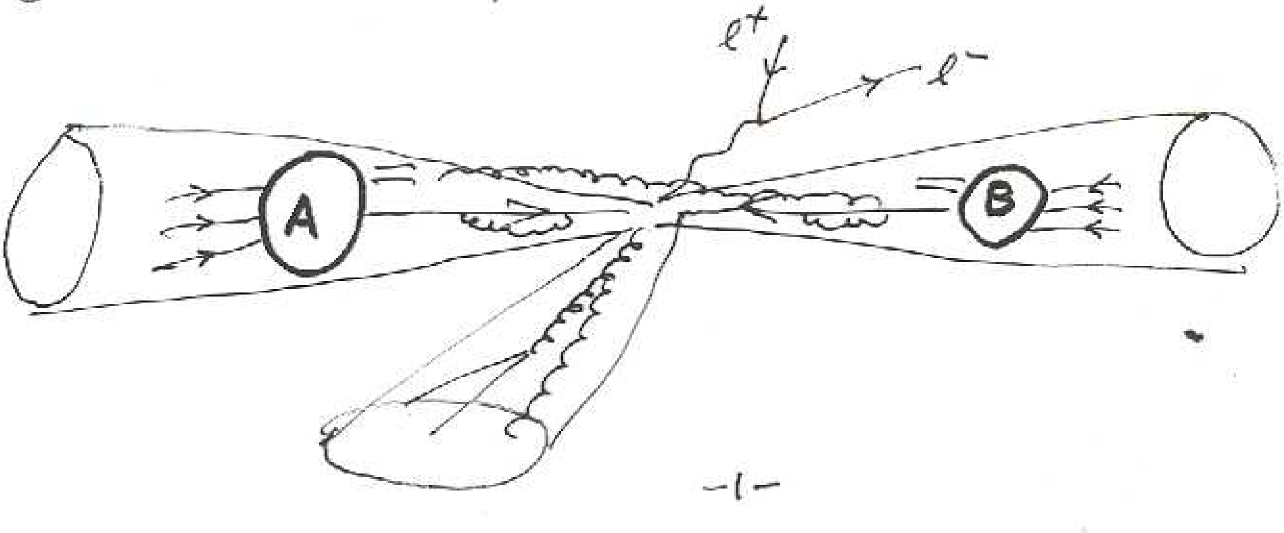
arbitrary scale

$$[\Delta]\sigma_{AB}^{exp}(M^2) \simeq \sum_{ij} \int dx_1 dx_2 \, [\Delta] f_{i/A}^{N}(x_1,\mu^2) \, [\Delta] f_{j/B}^{N}(x_2,\mu^2) \, [\Delta] \hat{\sigma}_{ij}^{N}(\mu^2, \dots)$$

physical scale

All orders $\simeq$ N-loop

Validity of PM relies on process independence of $[\Delta] f_{i/A}^{N}$ since experimental cuts can never eliminate collinear, soft & virtual partonic radiation



Hence, even with most stringent cuts, need to know $\hat{\sigma}^N_{virt+soft+collin.}$ → contains all scheme, scale dep's

→ cancel w/opposite scheme, scale dep's in f_i^N to $\mathcal{O}(\alpha_s^{N+1})$

$$\Rightarrow \sigma^{exp} = \sigma^N_{theor.} + \mathcal{O}(\alpha_s^{N+1}) \qquad \text{if PM works}$$

⟺ $[\Delta] f_i^N$ process indep., since $[\Delta]\hat{\sigma}_{ij}^N$ based only on PQCD → not a source of problems if expansion well-behaved.

Now:

Process indep. of $[\Delta] f^N_{i/A}(x,\mu^2)$ [to $\mathcal{O}(\alpha_s^{N+1})$]

⇒ process dep. of $[\Delta] f^{LO}_{i/A}(x,\mu^2)$ of $\mathcal{O}(\alpha_s)$

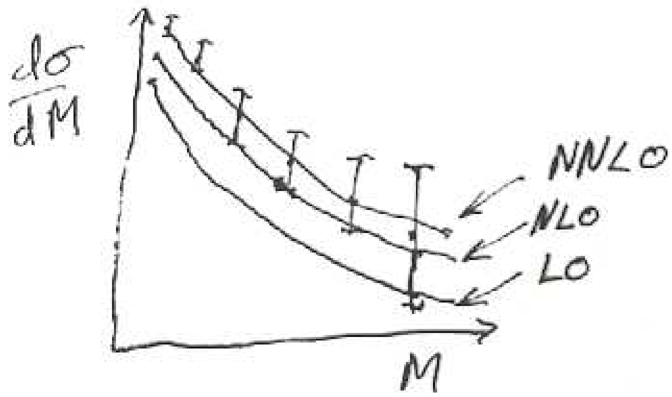
because σ^{exp} is unique, but $\hat{\sigma}_{ij}^N$ & $\hat{\sigma}_{ij}^{LO}$ differ by a (K-) factor which is different in magnitude and x dependence from process to process. Also, new $\hat{\sigma}_{ij}$ enter @ NLO, NNLO, ...

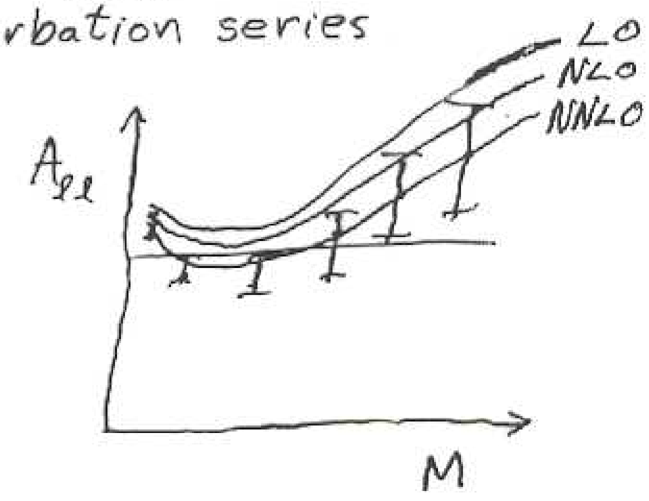
⇒ Roughly speaking, processes w/ larger (smaller) K-factors will tend to give $[\Delta] f_i^{LO}$ which are larger than (closer to) $[\Delta] f^N$, etc...

Ex: DIS has small K-factor, DY has large K-factor → $[\Delta] f^{LO}$ determined from DIS closer to $[\Delta] f^N$ than $[\Delta] f^{LO}$ determined from DY, which will be larger.

Similar issue for $\Delta f_i^{LO}/f_i^{LO}$ since asymmetries receive a K-factor as well, which is also process dependent.

Then, ideally, if we measured $[\Delta]f^N$ in some set of processes (DIS, etc...), we could go to another set of processes (DY, etc...) and test the convergence of the perturbation series





In this way, we <u>test</u> the process independence of the pdf's.

$\Rightarrow$ Just need to pick a factorization scheme.
At NLO, can work in any scheme & differences $\mathcal{O}(\alpha_s^2)$. $\rightarrow$ Use whatever available.

At LO, differences $\mathcal{O}(\alpha_s) \rightarrow$ <u>traded</u> a process dependence for a scheme dependence. But, ... now $A_{\ell\ell}$, etc... represent first term in a (hopefully) meaningful expansion.

• How does factorization scheme dependence enter?

In order to cancel mass singularities @ 1-loop, must express bare parton dists in terms of renormalized ones, similar to UV renormalization:

"Master Eq'n"

AP splitting fn

$$f^{o}_{i/A}(x) = f^{r}_{i/A}(x) + \frac{C(\epsilon)}{\epsilon}\frac{\alpha_s}{2\pi}\sum_j \int_x^1 \frac{dy}{y} f^{r}_{j/A}(y)\left[P_{ij}(x/y) + \epsilon\, T_{ij}(x/y)\right]$$

$\frac{1}{\epsilon} - \gamma_E + \ln 4\pi$

defines fact. scheme

Can determine rel'n between $f^{r}_{i/A}$ of different schemes using above eq'n since $f^{o}_{i/A}$ factoriz'n scheme indep. (depends only on regularization scheme)

The possibilities are endless: $(\Delta_\ell P_{ij} \equiv \Delta P_{ij},\ \Delta_u P_{ij} \equiv P_{ij})$ $k = u, \ell$

	$\overline{MS}$	$\overline{MS}_{HC}$ (2-loop pol split fn's)	$\overline{MS}_{\epsilon}$ (BK)	$\overline{MS}_{p}$ (Gordon + Vogelsang)
$\Delta_k T_{qq}$	0	$\Delta_\ell P^{\epsilon}_{qq} - \Delta_u P^{\epsilon}_{qq}$	$\Delta_k P^{\epsilon}_{qq}$	$\Delta_\ell P^{\epsilon}_{qq} - \Delta_u P^{\epsilon}_{qq}$
$\Delta_k T_{qg}$	0	0	$\Delta_k P^{\epsilon}_{qg}$	$\Delta_\ell P^{\epsilon}_{qg}$
$\Delta_k T_{gq}$	0	0	$\Delta_k P^{\epsilon}_{gq}$	$\Delta_\ell P^{\epsilon}_{gq}$
$\Delta_k T_{gg}$	0	0	$\Delta_k P^{\epsilon}_{gg}$	$\Delta_\ell P^{\epsilon,<}_{gg}$

most commonly used GRSV, GS

• How do we know pdf's so obtained contain any meaningful physics? Pdf's should satisfy positivity

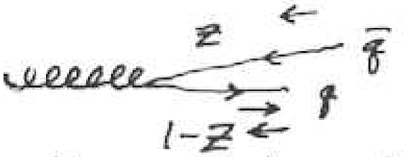
$$\Delta f_i < f_i$$

What else?

Note the following peculiarity of DREG/HVBM regulariz'n

$$P^{n}_{qg,++}(z) \neq P^{n}_{qg,-+}(1-z) \qquad [\mathcal{O}(\varepsilon)\text{ effect}]$$

Hence, in n-dimensions, when a gluon splits into a collinear $q\bar{q}$ pair, they don't necessarily have opposite chirality



$\Rightarrow$ indirectly violates chirality conservation & leads to the evolution of $\Delta\Sigma$ via ΔP^{PS}_{qq}, in $\overline{MS}_{HC}$.

Question: Do we need to enforce chirality conservation strictly to obtain meaningful pdf's? Answer: Not clear.

Note: Schemes like $\overline{MS}_{p}$, $\overline{MS}_{\varepsilon}$, ... restore chirality conservation and prohibit the evolution of $\Delta\Sigma$
$\longrightarrow$ Makes life simpler if nothing else.

- Drell-Yan

Working in $\overline{MS}_{HC}$ scheme & using corresponding NLO pdf's throughout, all mass differential Drell-Yan observables were calculated for longitudinal polarization ($\underline{\underline{W^{\pm}}}$, Z^{0}, γ^{*})

see
B.K. hep-ph/9710374 & PRD online, June 1.