Parton Distributions and Monte Carlos
Order of Partons – Optimal PDFs?

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Recalling comments (mine) in Parton Distribution plenary talk at DIS06.

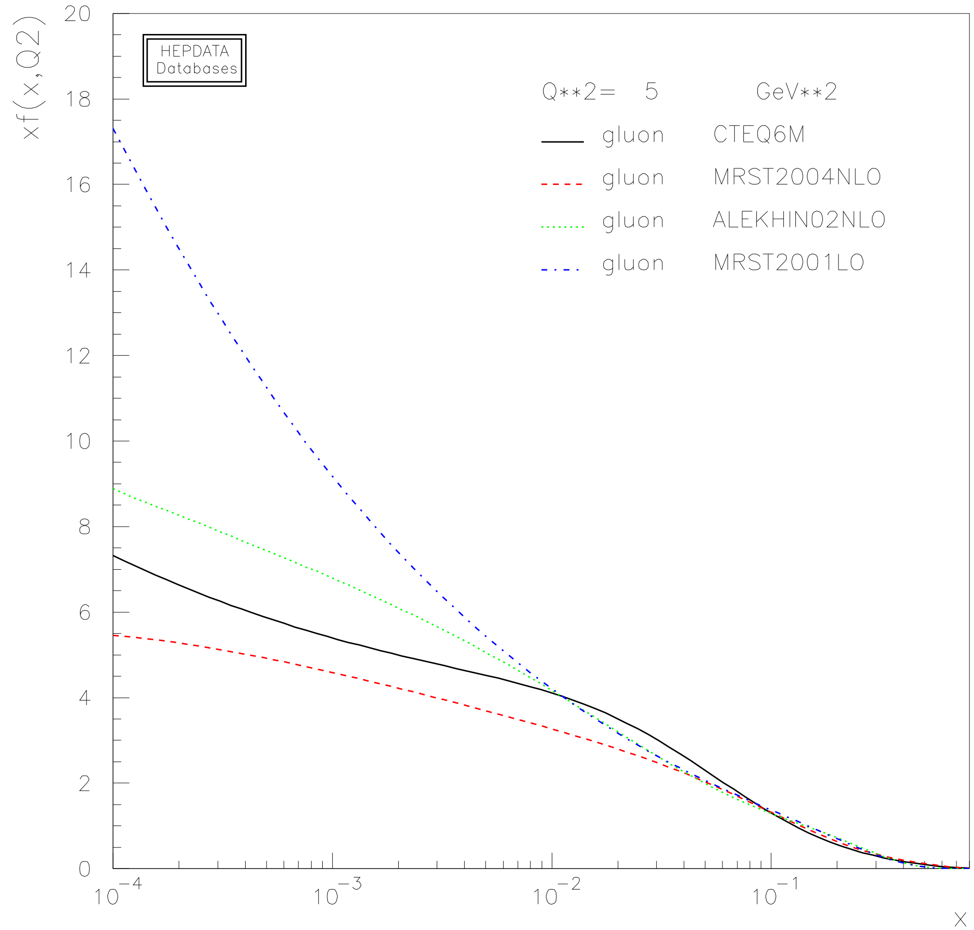
"LO partons in some regions qualitatively different to all NLO and NNLO partons. Due to important missing NLO corrections in splitting functions.

Can lead to wrong conclusions on size of small-x gluon, and conclusions on shadowing *etc.*

Nevertheless, LO partons are the appropriate ones to use with many LO Monte Carlo programs.

All such results should be treated with care."

Not NLO partons? Not a trivial issue. Look at indications from well-understood (simple) processes.



Drell-Yan corrections

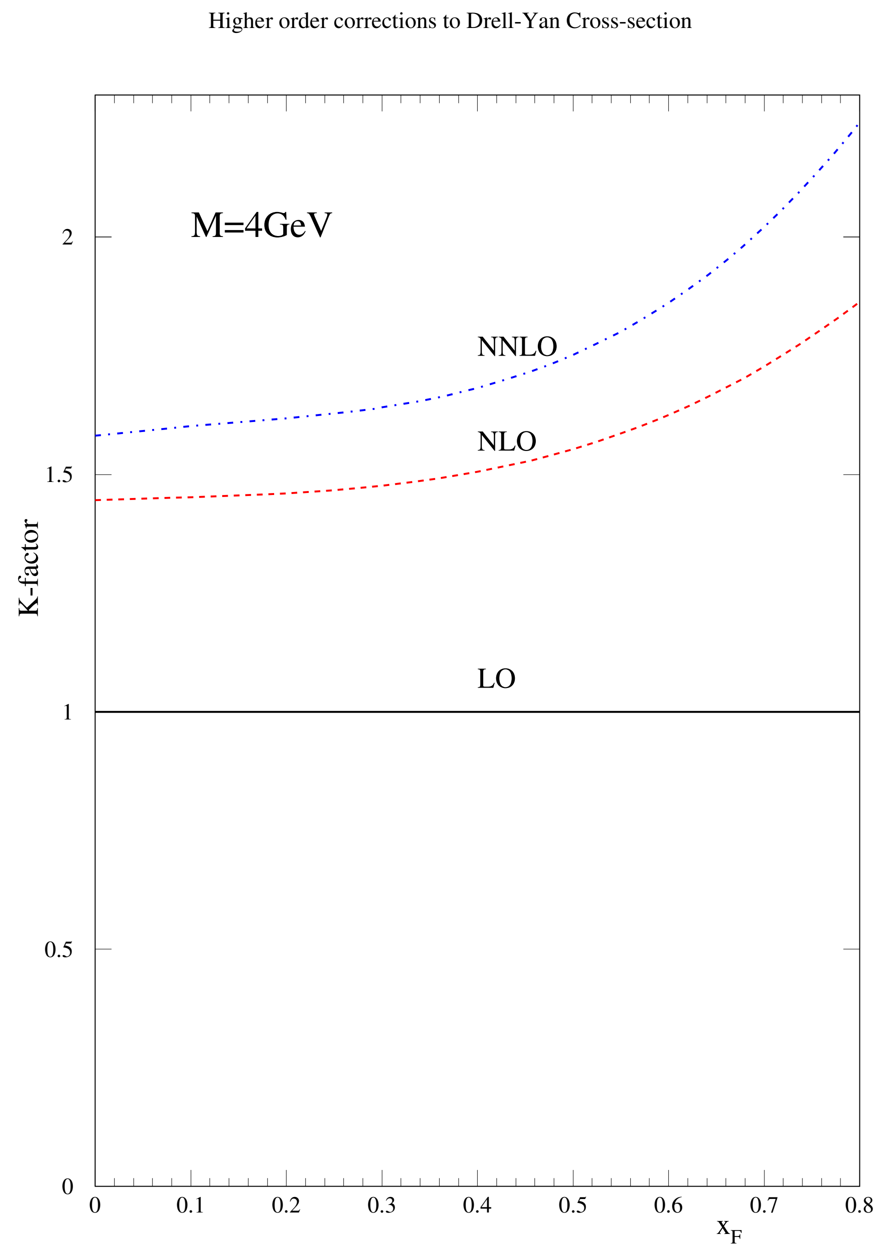
Example in change of hard cross-sections.

The K-factors for Drell-Yan production at E866 – $\sqrt{s} = 38.8\text{GeV}$.

Enhancement at higher $x_F = x_1 - x_2$ due to logarithms. Similar to $\ln(1-x)$ enhancement in structure functions.

NLO corrections large, NNLO corrections significant – 10% or more.

How do changes in quarks compensate?

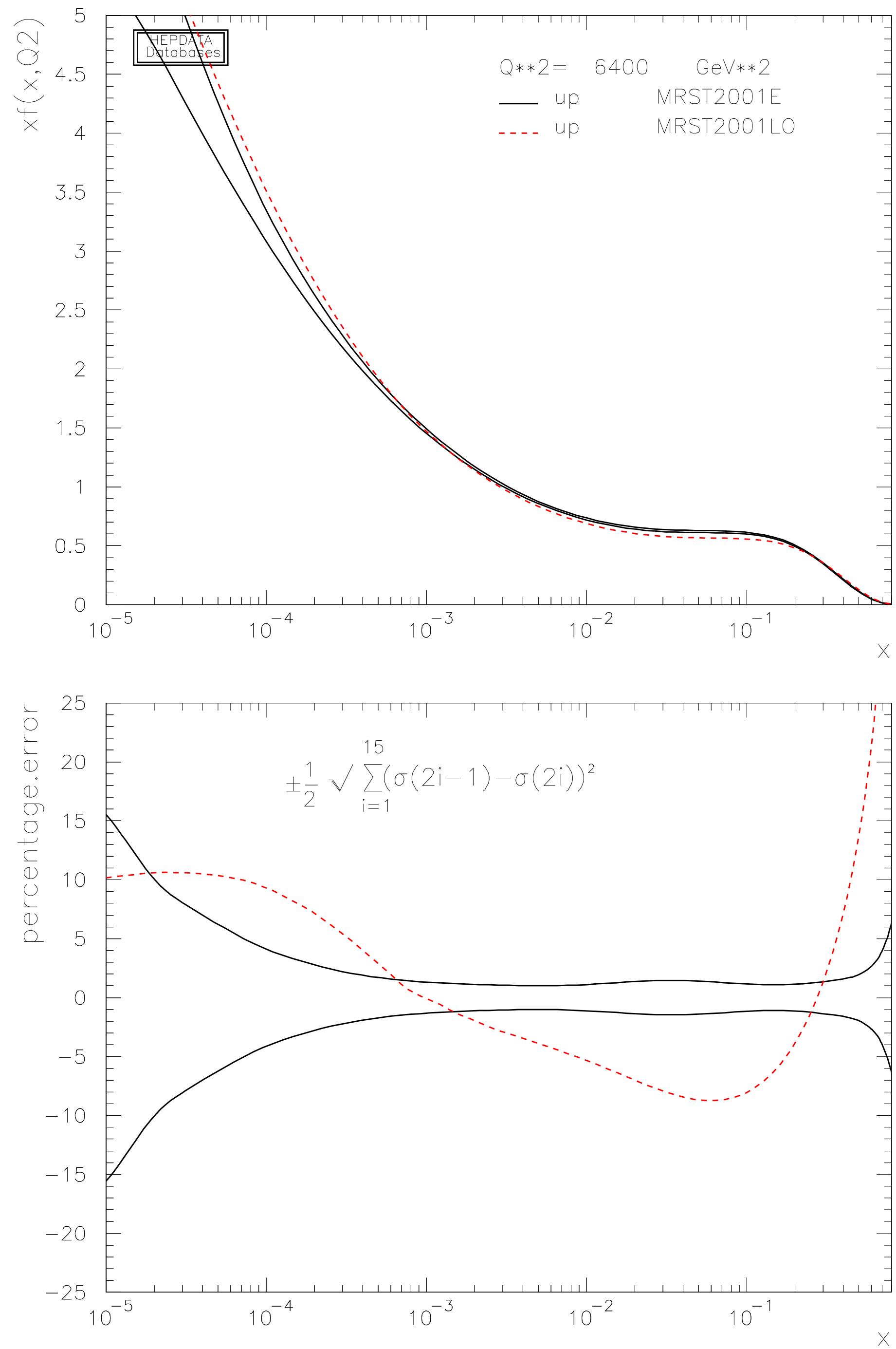


LO quarks over wide region of x qualitatively smaller than NLO.

Nearer to *truth* with LO matrix element and NLO parton than LO matrix element and LO parton. However, always too small.

If probing high x parton increase in LO parton compensates for increase in NLO matrix element. In this case best stability from parton and matrix element at same order.

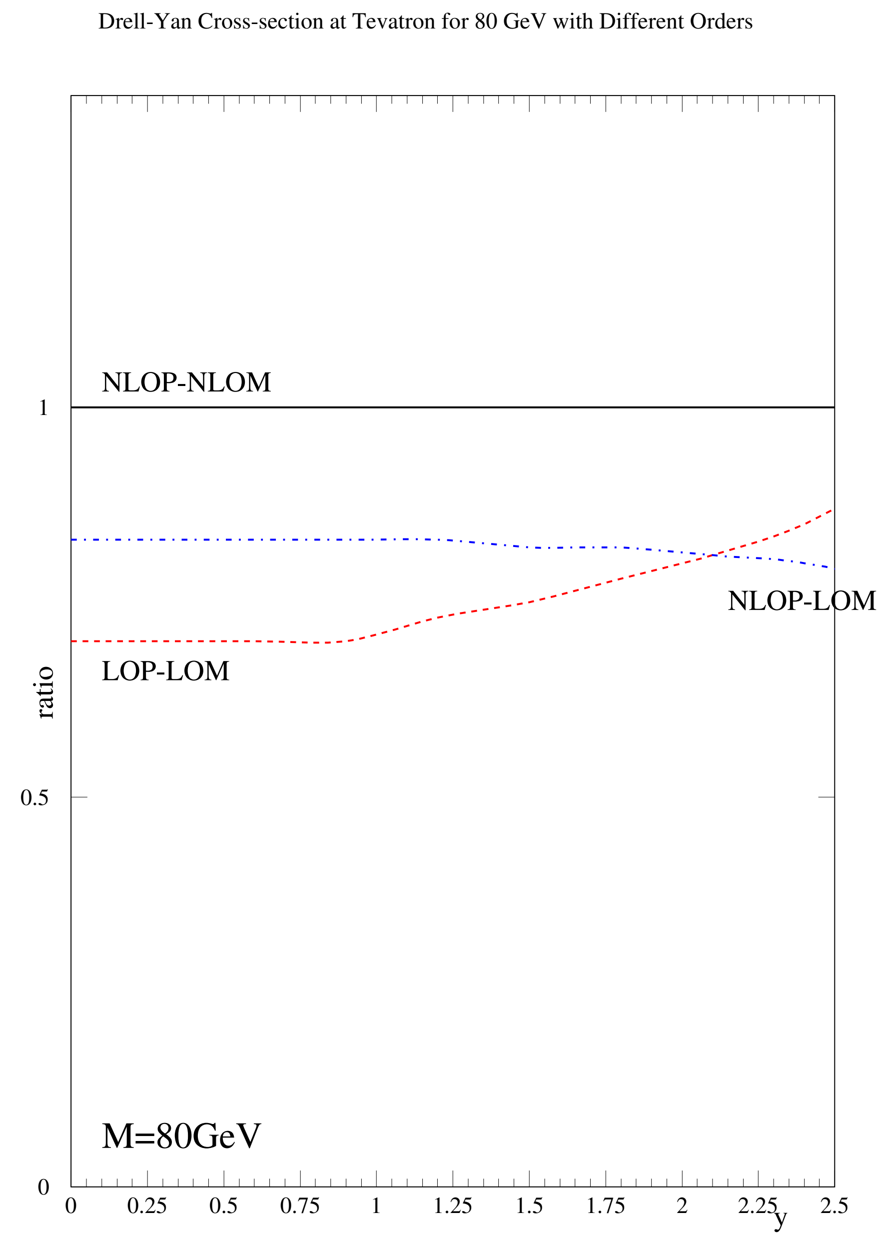
Usual story when enhancement due to large logs, in this case $\ln(1-x)$ terms in matrix elements for prediction and in matrix elements used to extract partons. Similar for $\ln(1/x)$ terms at small x.



Look at W production at Tevatron.

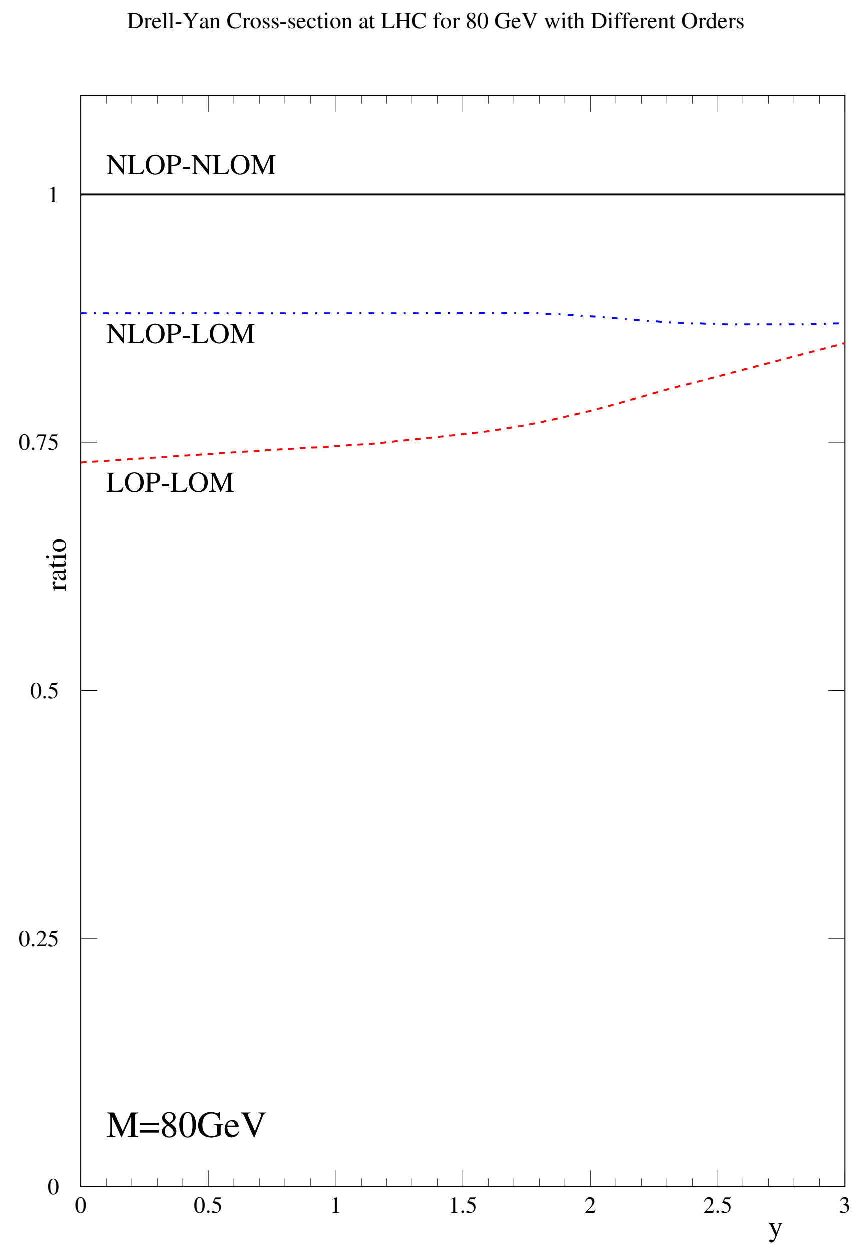
Indeed see that nearer to *truth* with LO matrix element and NLO parton than LO matrix element and LO parton. Shape good – too small.

LO parton and LO matrix element wrong shape and worse at central rapidity but indeed better at high rapidity.



Depends what you want. $\ln(1-x)$ corrections not such an issue at LHC (possibly for LHCb).

NLO partons still lead to best shape though.

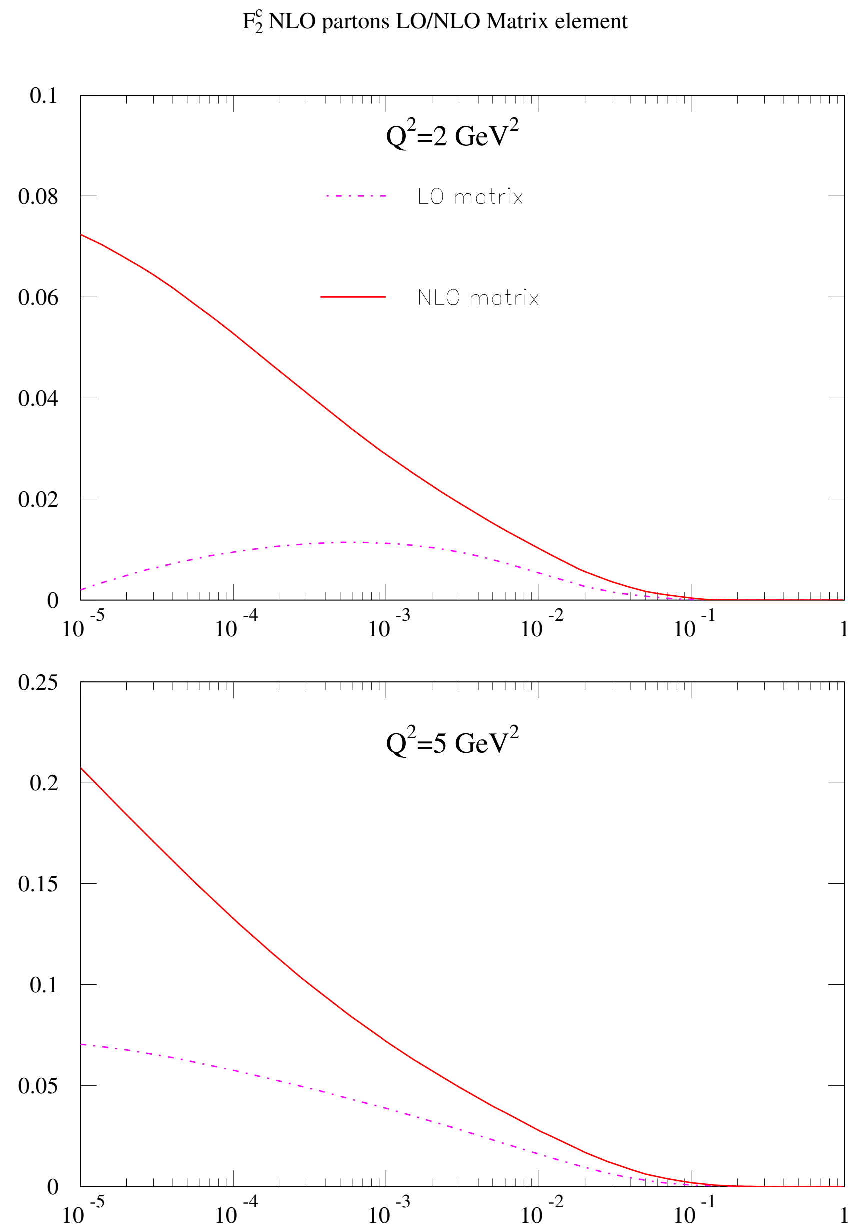


Small x *counter*-example. Consider production of charm in DIS. All charm produced in final state (FFNS).

NLO matrix element contain divergence at small x not present at LO.

Same issues in heavy flavour hadroproduction.

Using NLO partons the LO matrix element result is well below the *truth* at low scales. Shape totally wrong.

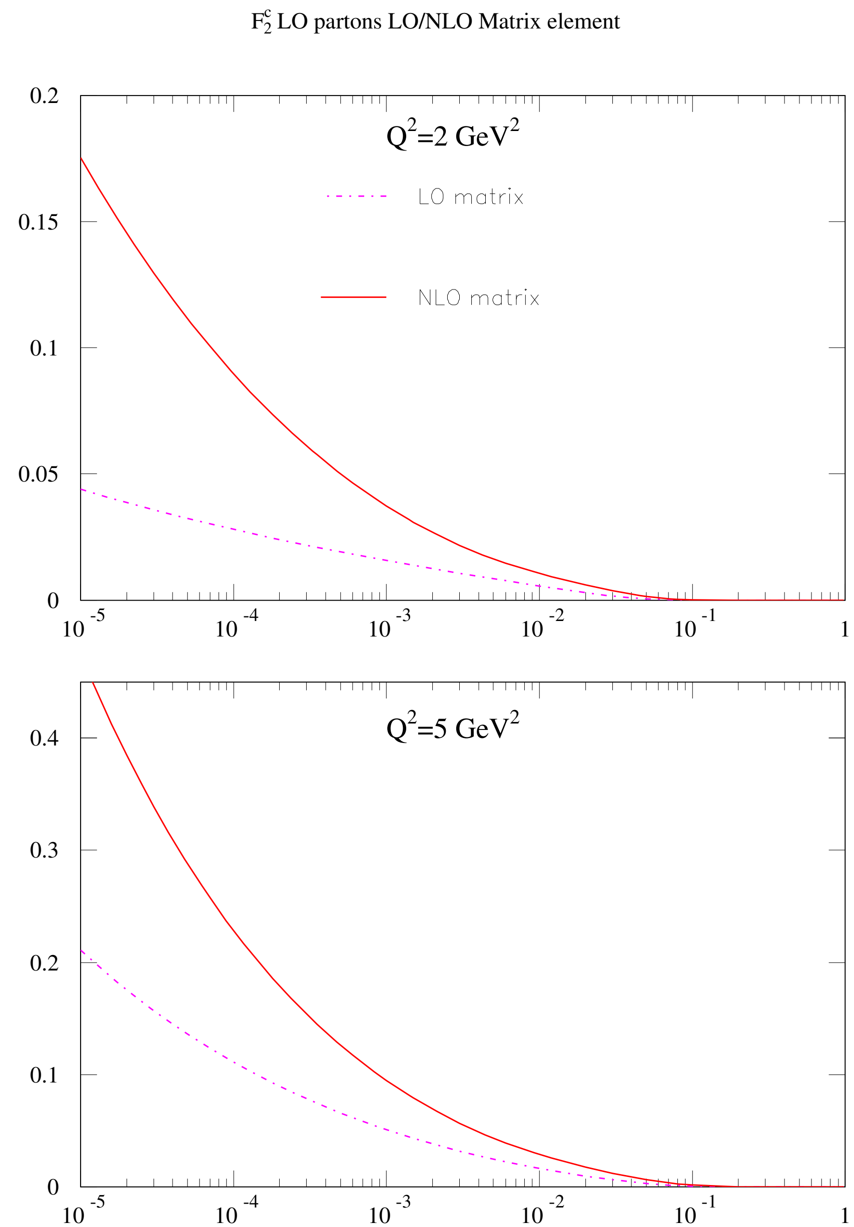


Consider using LO partons.

Using LO partons the NLO matrix element result is extremely large.

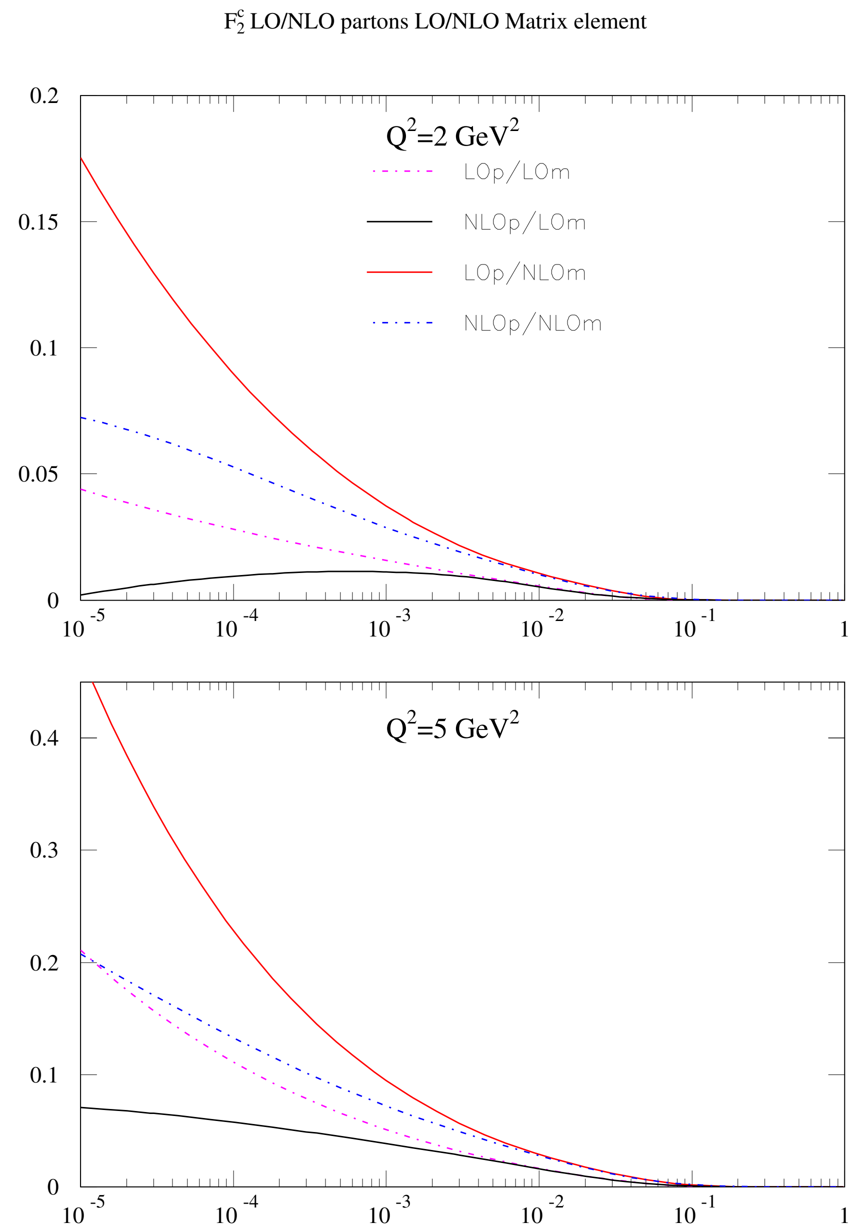
LO gluon is very large at small x since it has been extracted with missing enhancements at small x.

LO partons and LO matrix element more sensible. compensation between failings in both.



LO is very large at small x since it has been extracted with missing enhancements at small x.

Comparing all possibilities LO partons and LO matrix element near *truth* at low scales.



Conclusions - so far

Sometimes NLO partons better to use if only LO matrix elements are known.

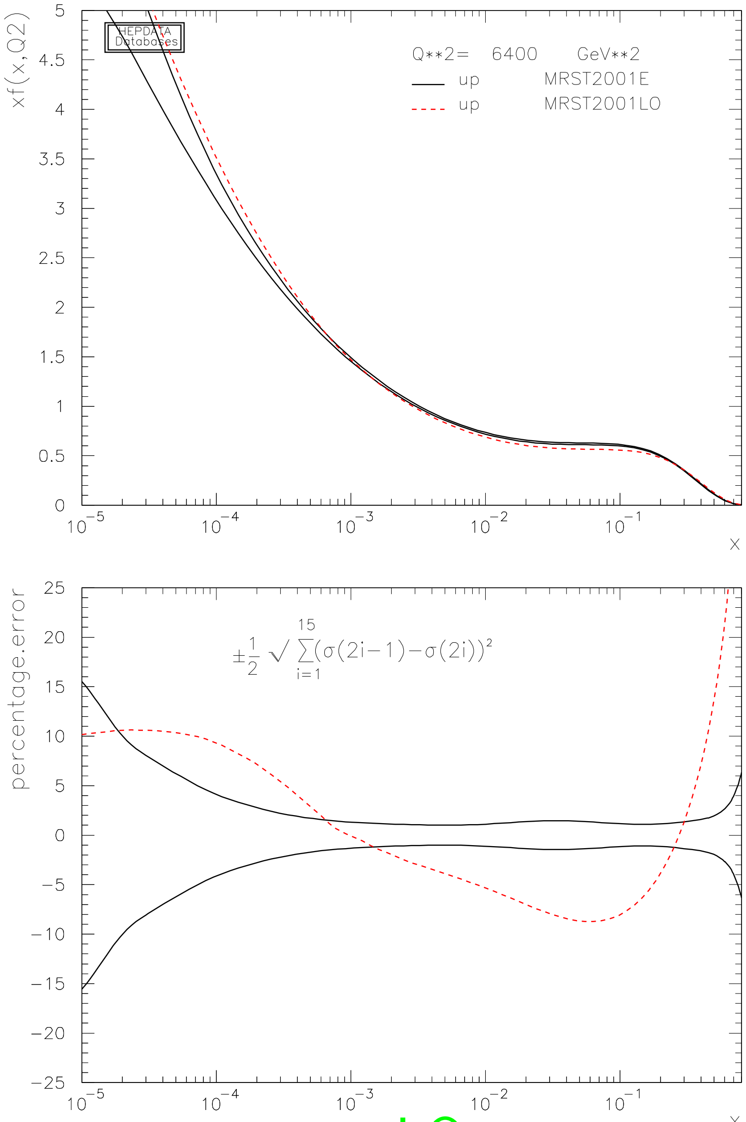
Can get significant problems with shape if LO partons used.

But can be completely wrong at small x using NLO partons due to $zero$-counting of $\ln(1/x)$ terms.

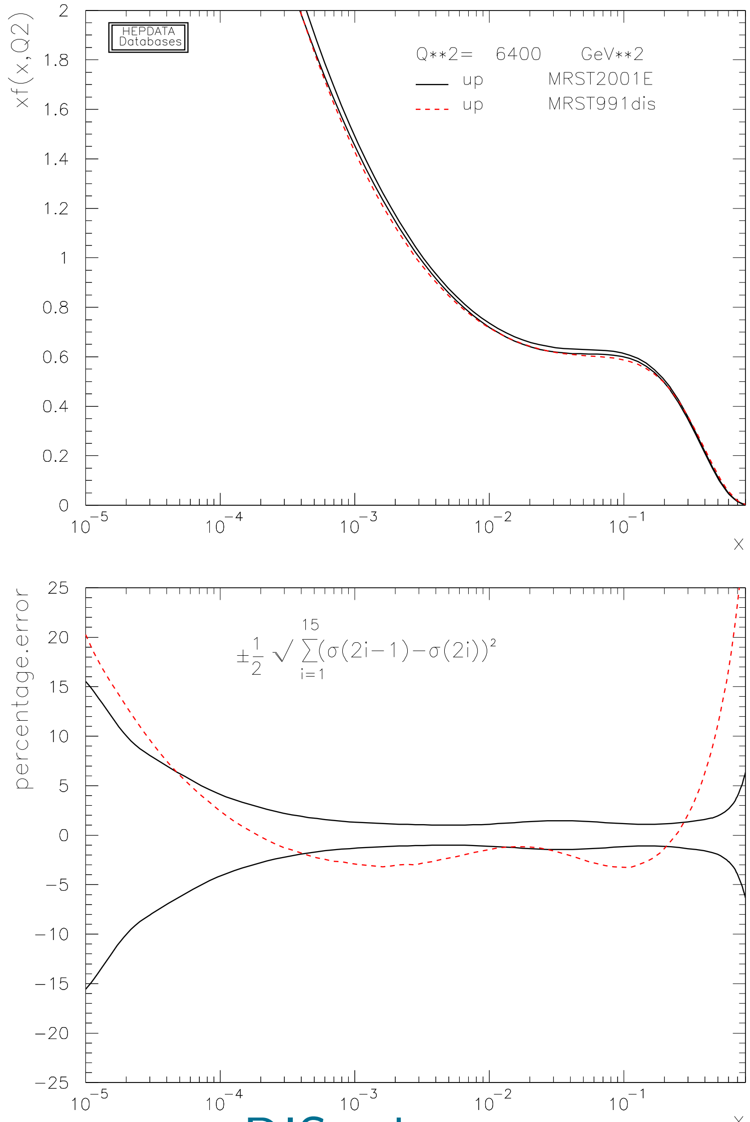
Can we find some optimal partons which have most desirable features?

Need to understand difference between LO and NLO partons better.

Part of the dip in LO partons compared to NLO is due to extra coefficient function contribution at NLO (particularly $x \sim 0.1$) but mostly just a problem with LO, – reflected in fit quality.



LO



DIS scheme

At LO compared to NLO (and higher orders) missing terms in $\ln(1-x)$ and $\ln(1/x)$ in coefficient functions and/or evolution.

$\rightarrow$ partons at LO bigger at $x \rightarrow 1$ and at $x \rightarrow 0$ in order to compensate.

From momentum sum rule not enough partons to go around.

Leads to bad global fit at LO – partially compensated by LO extraction of $\alpha_S(M_Z^2) \sim 0.130$.

However, leads to suggestion (Sjostrand) that relaxing momentum sum rule at LO could make LO partons rather more like NLO partons where they are normally too small.

Resulting partons would still be bigger than NLO where necessary.

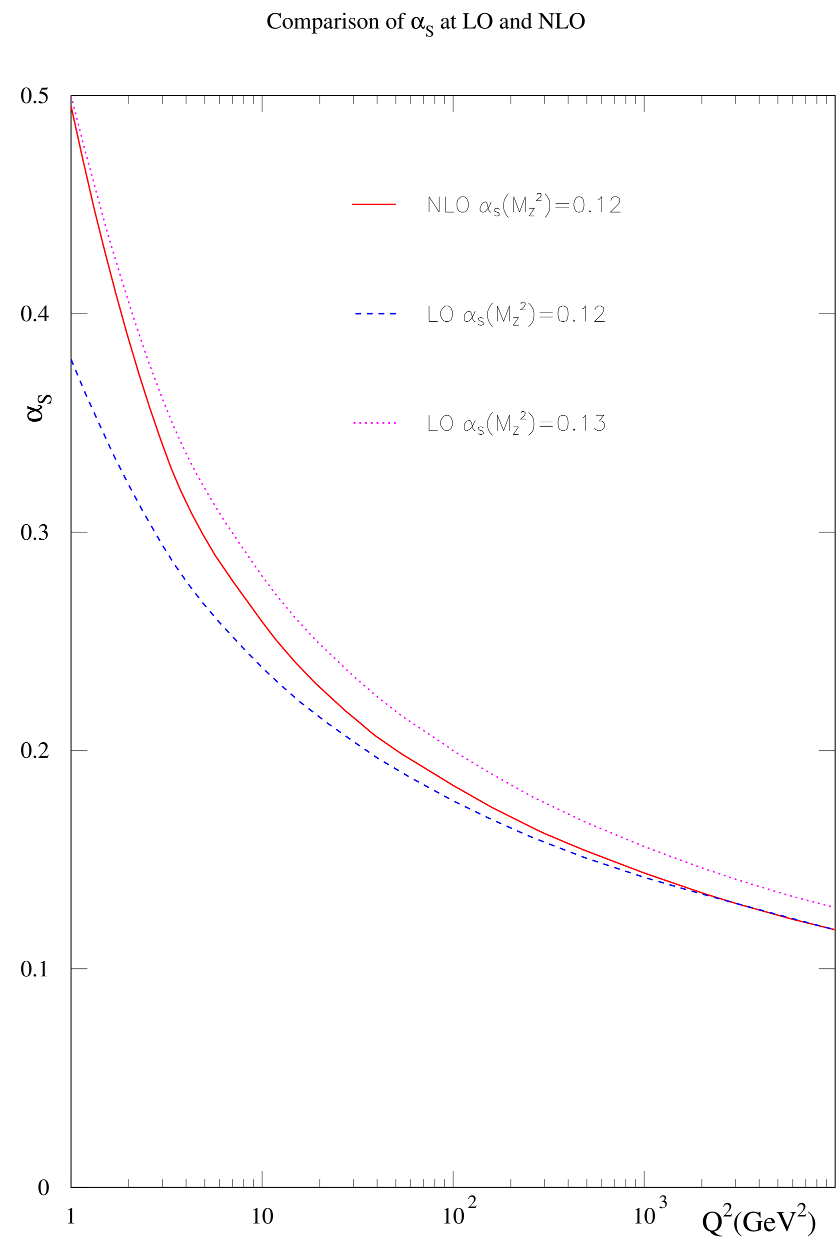
Also useful to use NLO definition of coupling constant.

Because of quicker running at NLO couplings with same value of $\alpha_S(M_Z^2)$ very different at lower scales where DIS data exists.

Near $Q^2 = 1\mathrm{GeV}^2$ NLO coupling with $\alpha_S(M_Z^2) = 0.120$ similar to LO coupling with $\alpha_S(M_Z^2) = 0.130$.

Use of NLO coupling helps aleviate discrepency between different orders.

NLO coupling already used in CTEQ LO partons and in Monte Carlo generators.



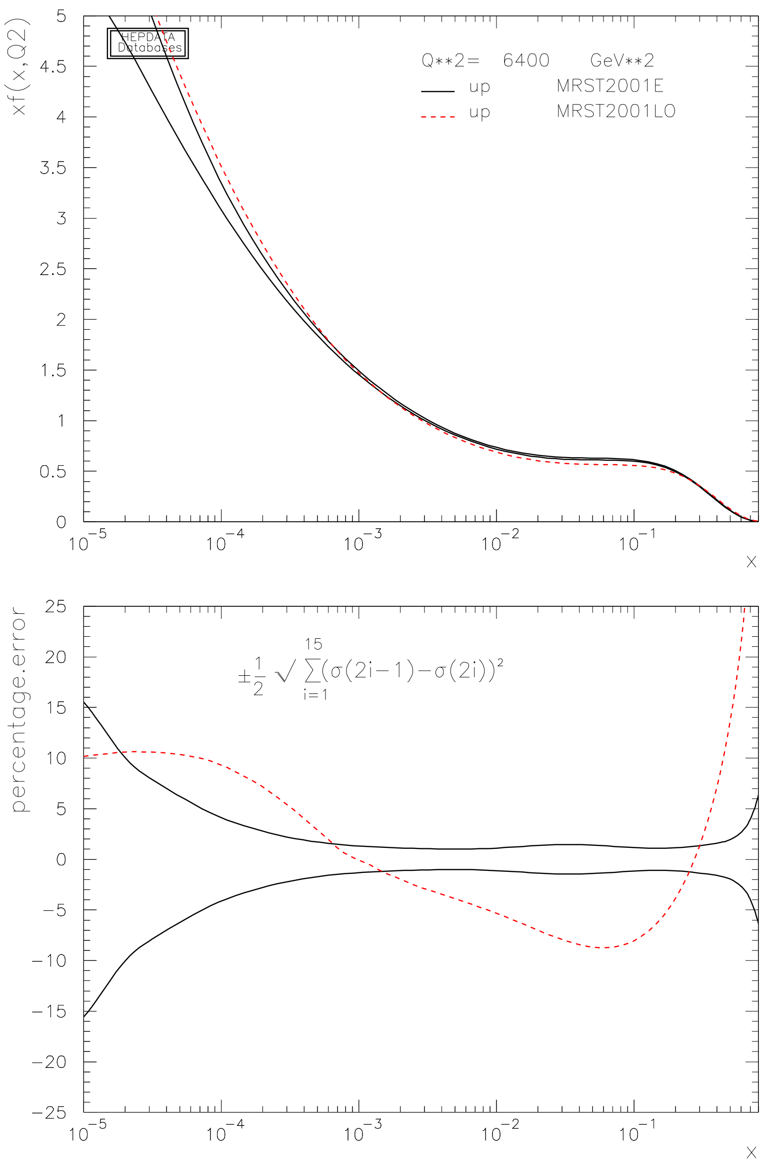
Relaxing momentum violation and allowing NLO defition of coupling does dramatically improve quality of LO global fit (K-factor of 1.3 necessary for fixed target Drell-Yan data).

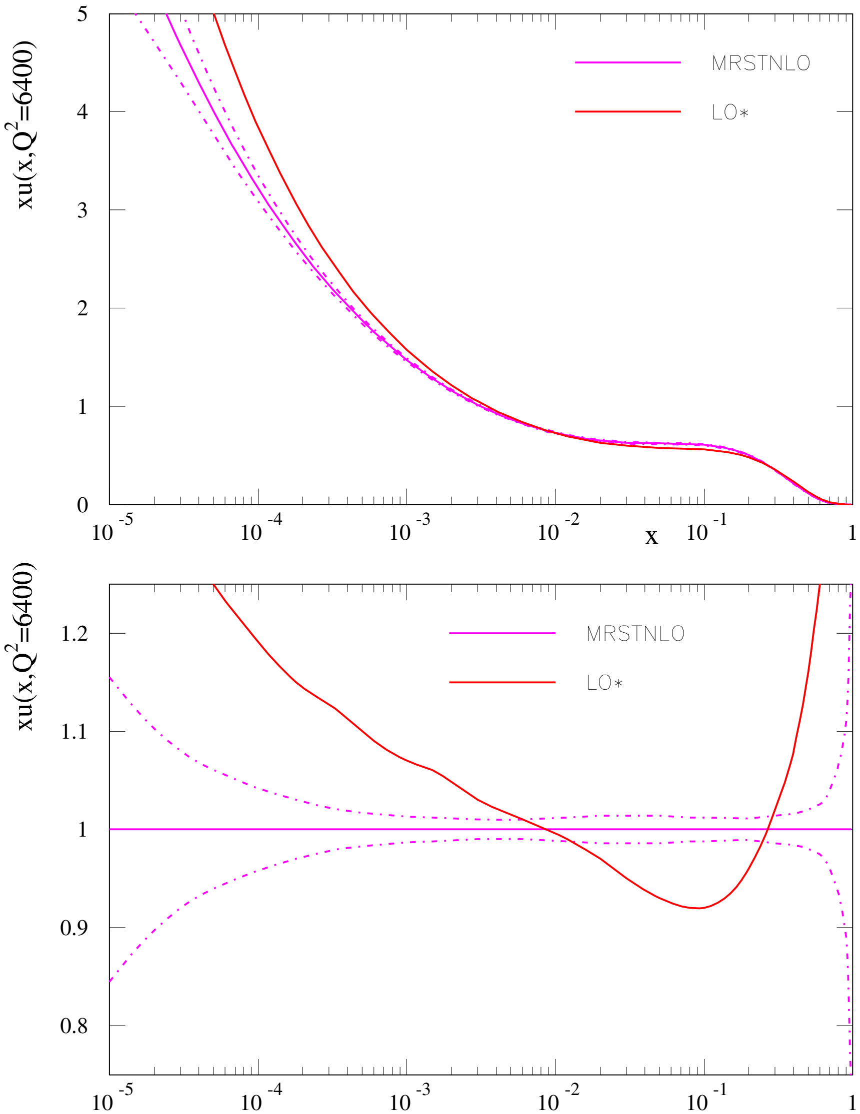
$\chi^2 = 3066/2235$ for standard LO fit becomes $\chi^2 = 2691/2235$. Big improvement in HERA data.

Momentum carried by input partons goes up to 113%. Much more similar to NLO partons, in particular at small x LO quark distributions evolve as quickly at NLO partons.

Using NLO definition $\alpha_S(M_Z^2) = 0.121$.

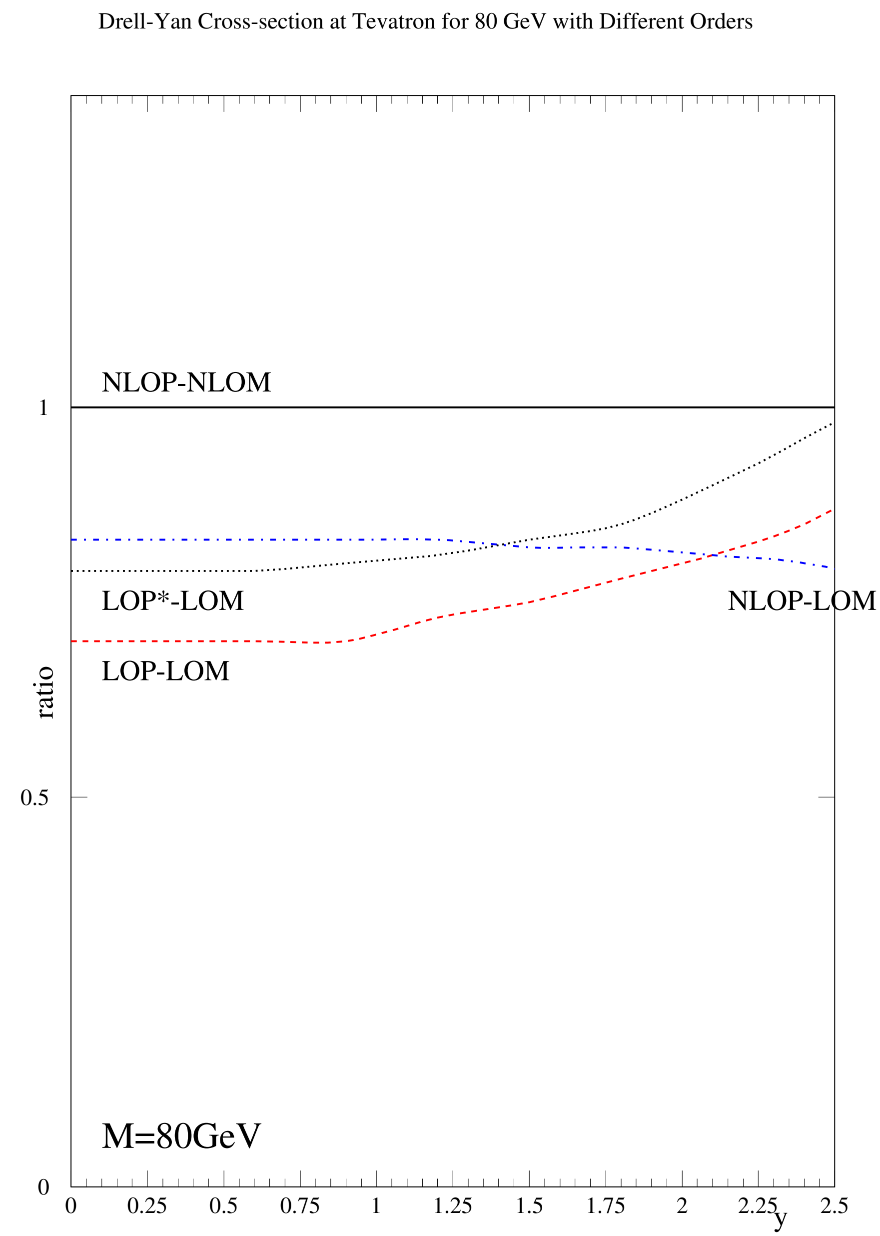
The LO* and NLO partons are more similar in this case, particularly for $x \sim 0.001 - 0.01$. (LO* often bigger – compensates for smaller cross-section at LO).



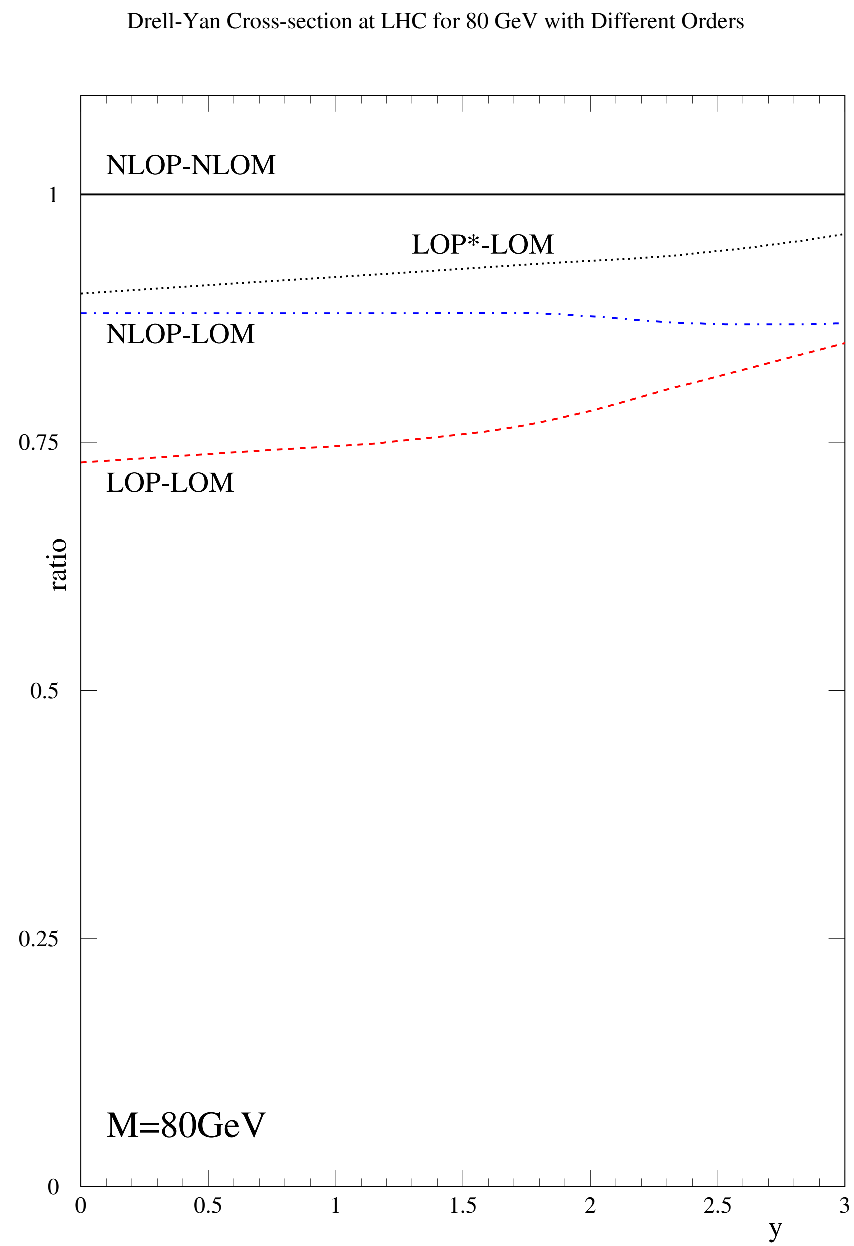


Back to W production at Tevatron.

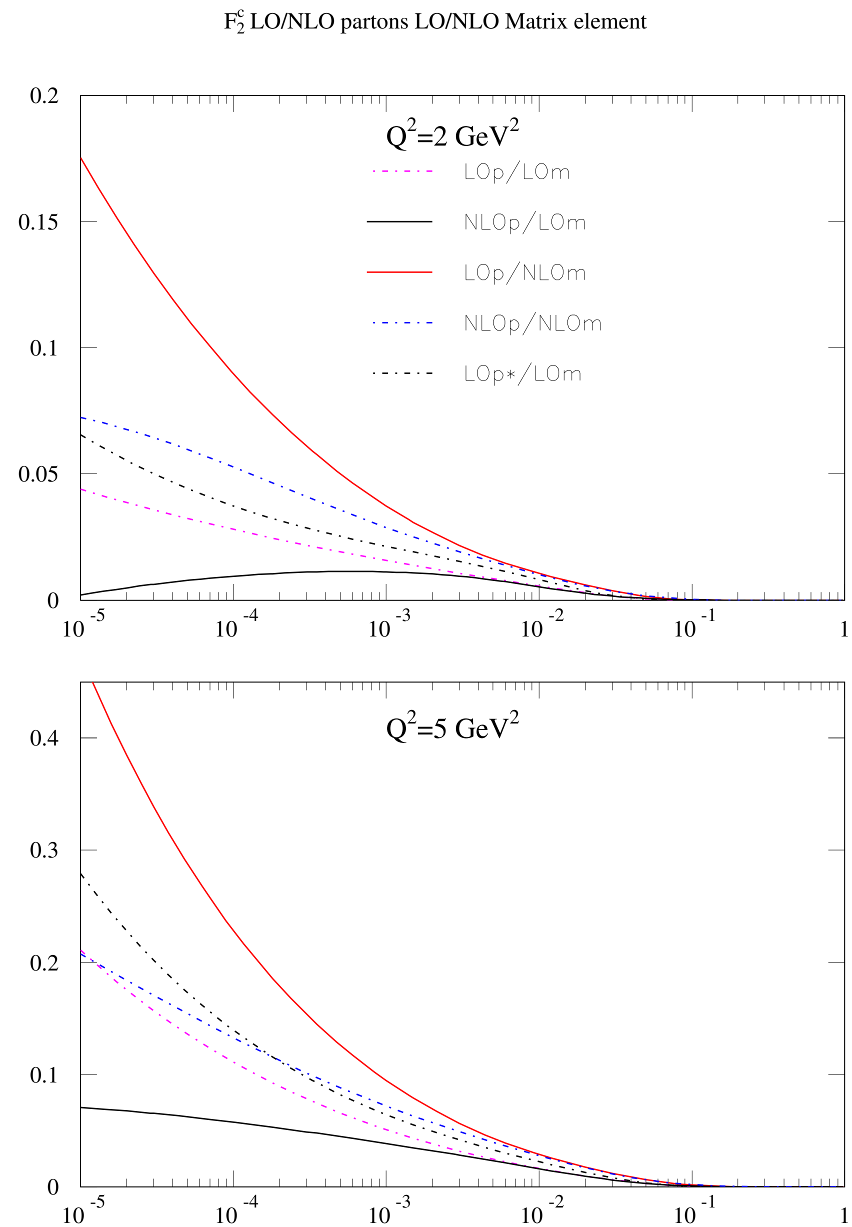
Indeed see that nearer to *truth* with LO matrix element and LO* parton. Shape similar quality to NLO partons (nearly) with LO matrix element.



For LHC LO* partons lead to shape of comparable quality as NLO partons. Normalization better.



For charm structure function comparing all possibilities LO* partons and LO matrix element is indeed nearest to *truth* at low scales.



Appears to be similar situation for hadroproduction of b quarks at LHC.

Consider $\sigma(b\bar{b})$ with $p_T > 10\mathrm{GeV}$, $|\eta| \leq 5$ (thanks to A Sherstnev).

NLO(ME)$\otimes$ NLO(pdf)$= 41.5mb$.

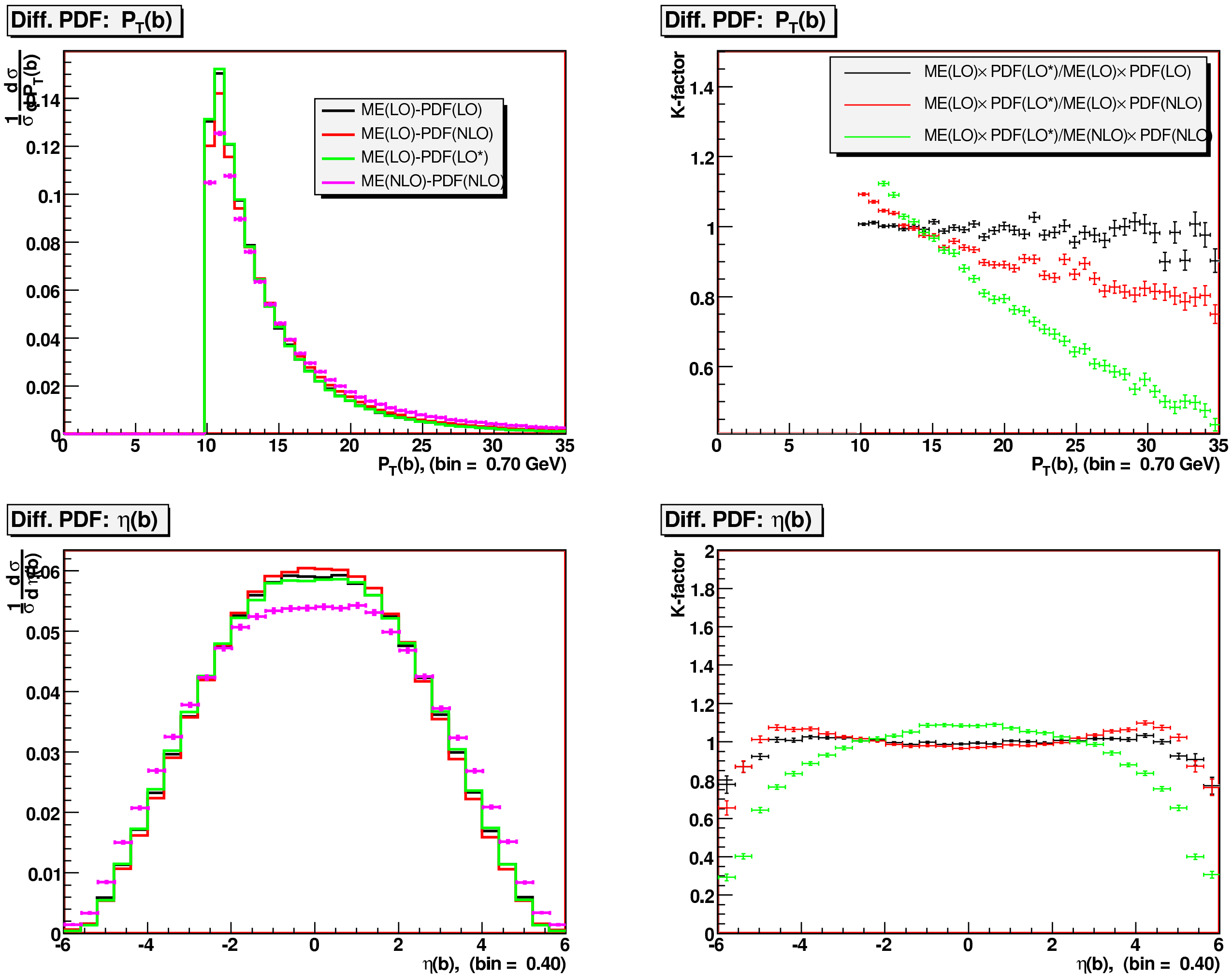
LO(ME)$\otimes$ NLO(pdf)$= 16.8mb$.

LO(ME)$\otimes$ LO(pdf)$= 24.8mb$.

LO(ME)$\otimes$ LO*(pdf)$= 34.8mb$.

With deficit occuring at low p_T (which dominates cross-section) which probes low $x \sim 0.001$.

However, problem with shape as function of p_T. NLO matrix element has large positive effect at high p_T. LO and LO* gluons smaller at high x than NLO – shape problem slightly worse. Something to work on – high-x gluon bigger?

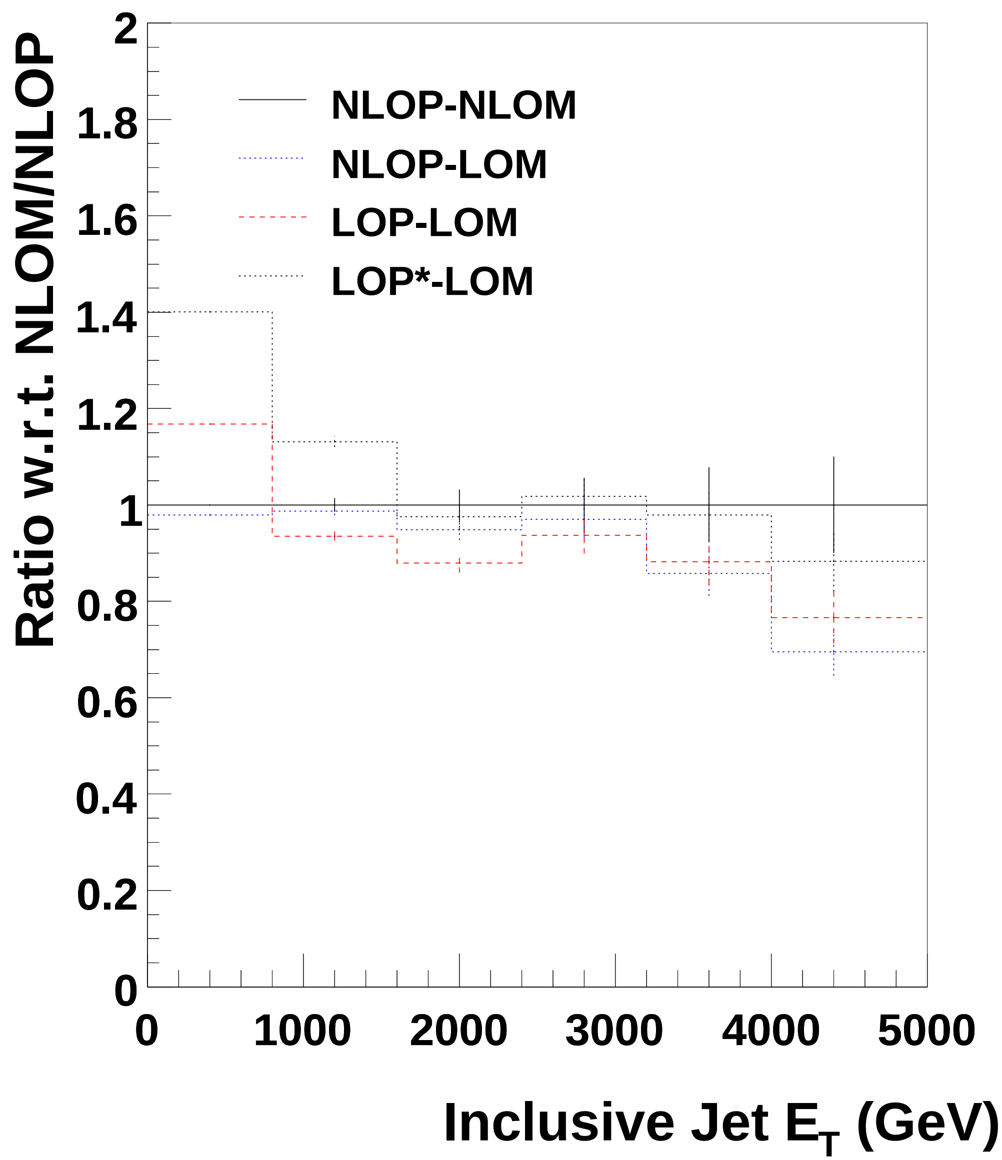


Impossible for parton shape to account for all NLO corrections.

Also look at other quantities, e.g. very high-E_T jets at ATLAS (thanks to Claire Gwenlan).

Compare LO* partons with CTEQ6 partons at LO and NLO.

Ignoring lowest E_T bin where hadronization and underlying event (not yet considered), and possibly small x physics, an issue, LO and LO* a bit better in normalization and shape than NLO.

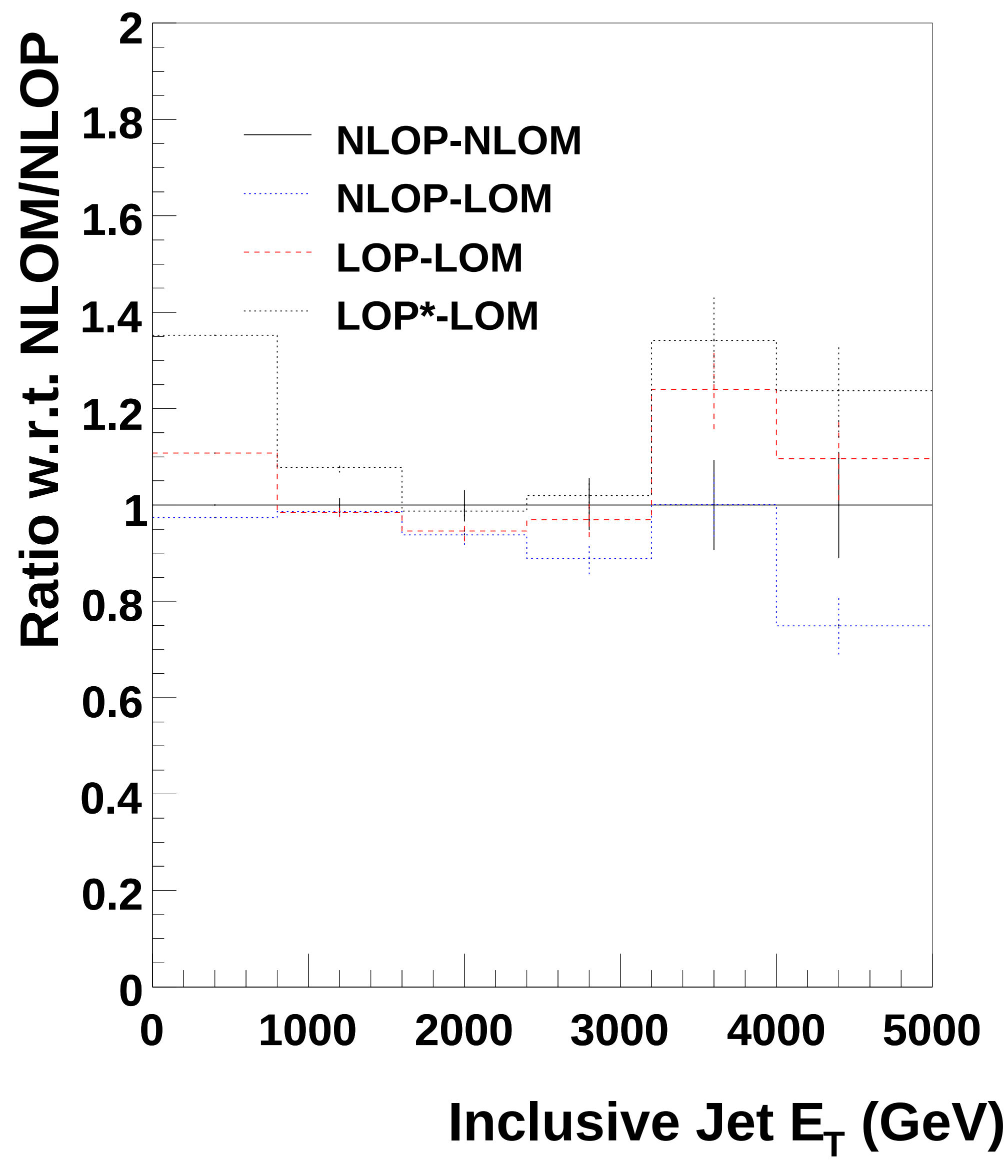


Also compare LO* and LO partons with MRST04 partons.

MRST04 NLO gluon a bit smaller at high-x than CTEQ.

In this case LO and NLO partons deviate in shape in opposite directions.

However, difference between two plots indicates intrinsic uncertainty in this prediction.



Conclusions

Higher order Matrix elements usually positive. Partons at higher orders sometimes bigger, sometimes smaller – sum rules.

Large logarithms in $\ln(1-x)$ and $\ln(1/x)$ tend to consistently lead to enhanced matrix elements in these regions.

Due to this partons extracted in these regions smaller at higher orders $\rightarrow$ most consistency combining matrix elements of given order with partons of same order.

Partons away from these regions generally smaller at higher orders from sum rules. In practice at $x \sim 0.1 - 0.001$. Often region of most interest at hadron colliders.

Fixed prescription of either LO or NLO partons (in particular) with LO Monte Carlo will lead each to be very wrong in some cases.

Suggested an optimal set of partons for Monte Carlos. Essentially LO but with various modifications to make results more NLO-like. Seem to work reasonably well. Quarks nearer to NLO for W and Z production at LHC. Gluon appropriately large at small x. Not ideal at high x. Still under investigation. More work to do.