Parton Distributions for LO Generators

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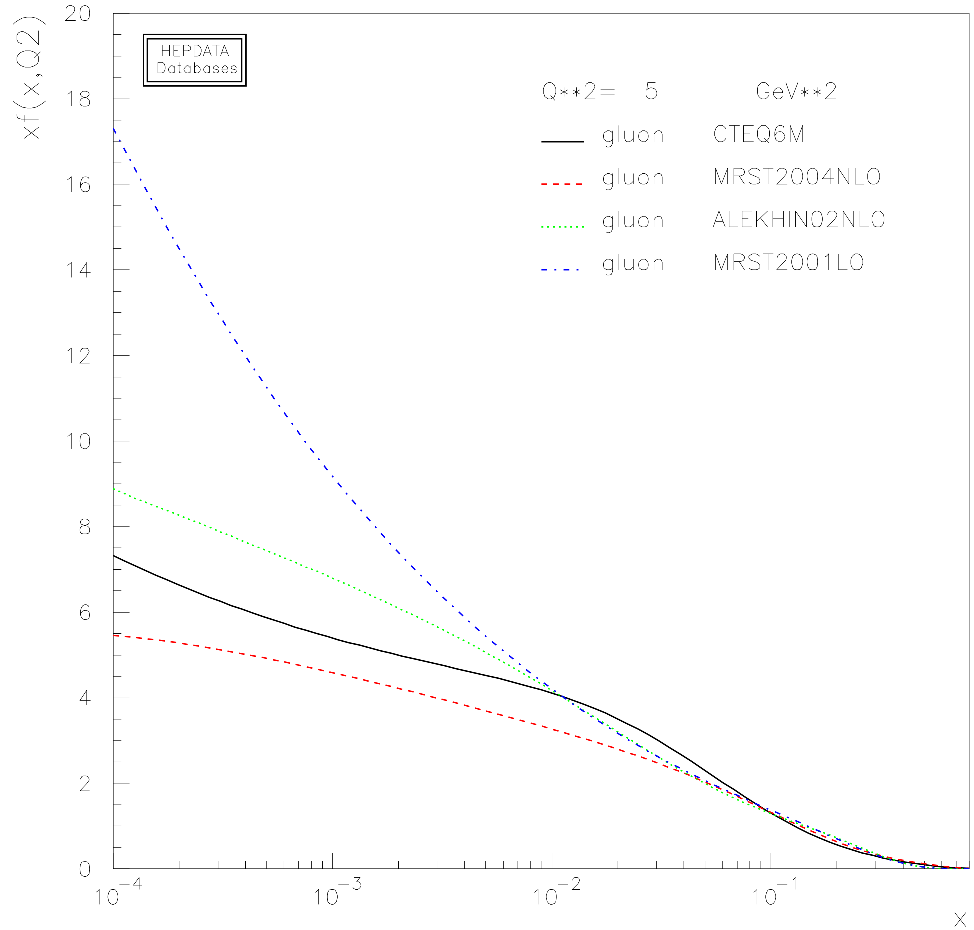
Which order of partons should be used in LO Monte Carlo generators.

Enormous change in partons, especially gluon when going from LO $\rightarrow$ NLO.

LO partons are the usual one used with many LO Monte Carlo programs.

All such results should be treated with care.

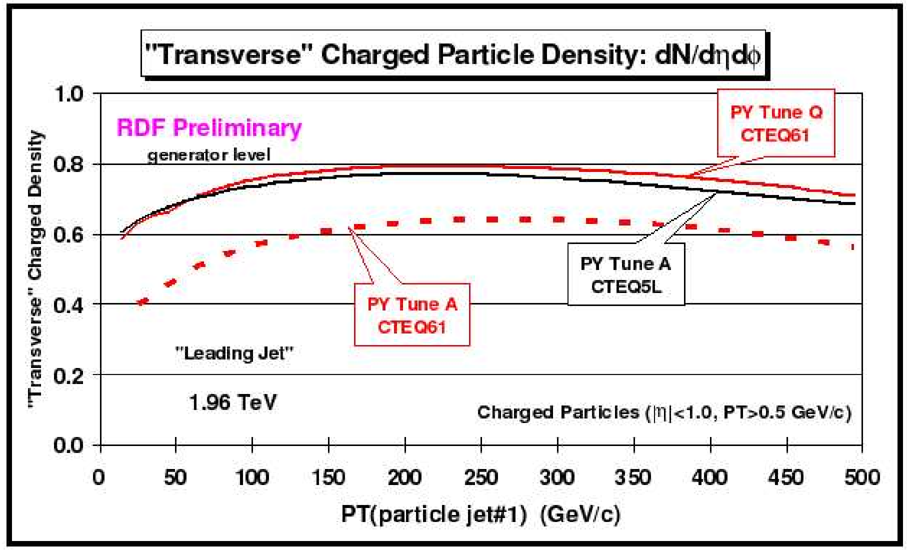
Not NLO partons? Not a trivial issue.

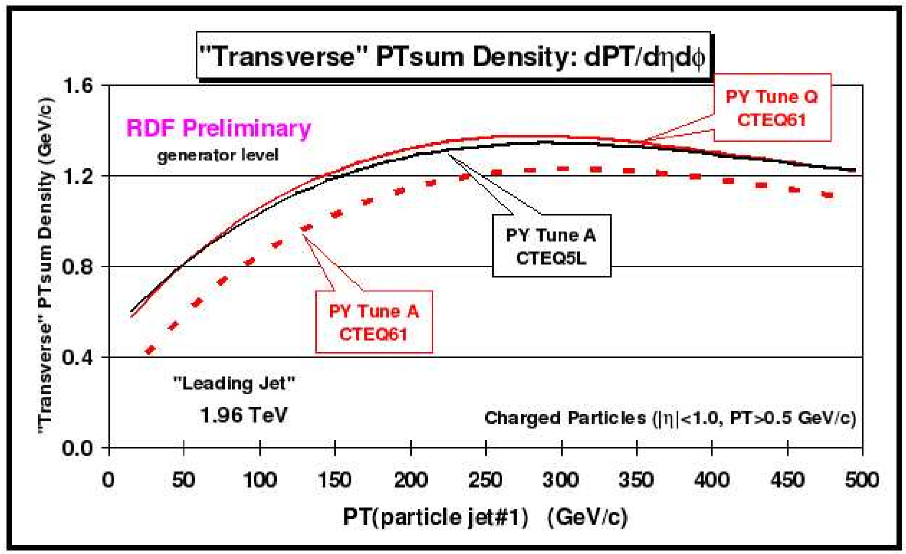


Already investigated in terms of tuning for underlying event (Field). See big difference between using CTEQ6L and CTEQ6.1M partons, mainly due to gluon.

Agreement can be reached by retuning. Will affect predictions for other quantities. Want universality.

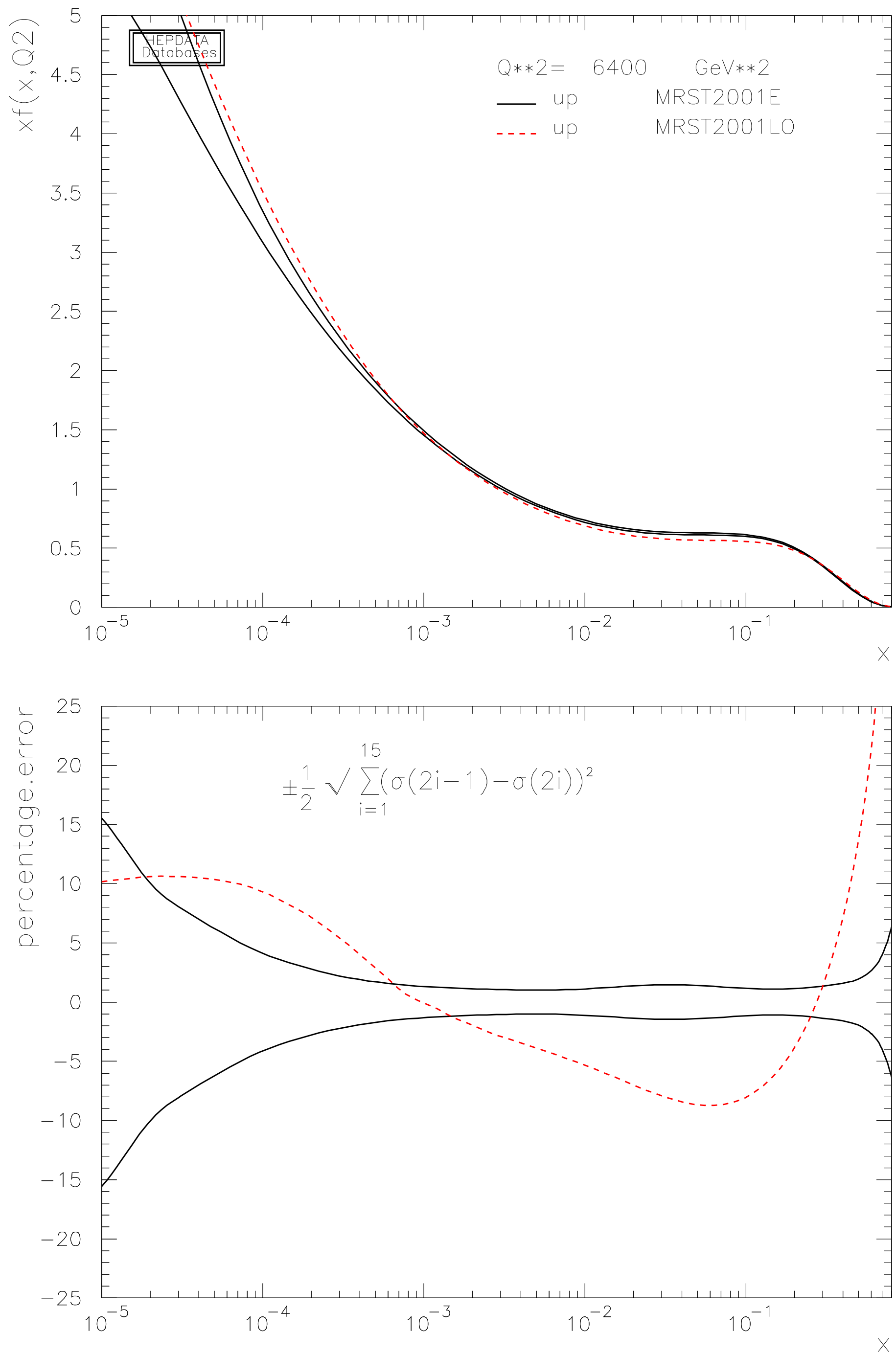
In order to investigate this look at indications from well-understood (simple) processes.





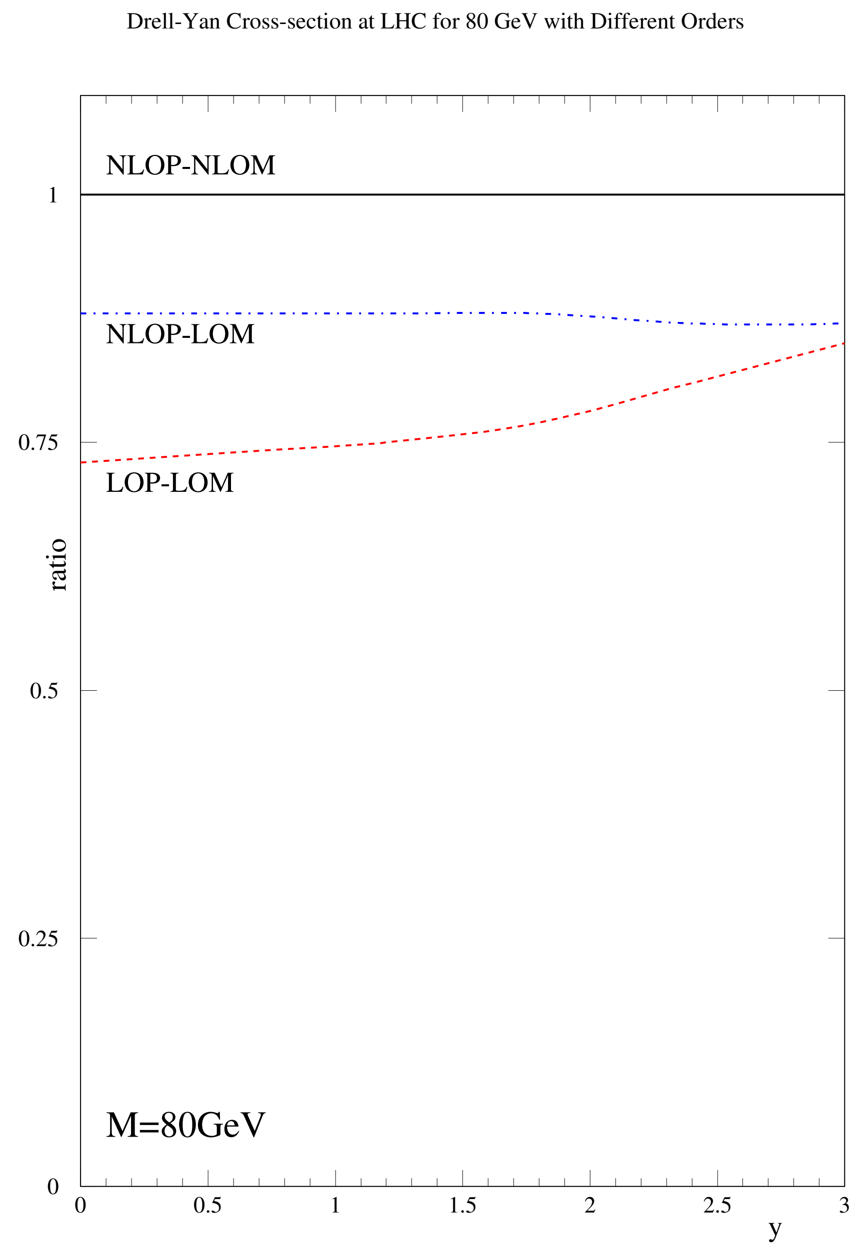
First note that the LO quarks over wide region of smaller x qualitatively smaller than NLO. Lack of additional quark evolution at NLO.

At high x $\ln(1-x)$ terms in NLO matrix elements lead to NLO quarks being smaller.



NLO partons lead to best shape for inclusive fixed order heavy boson production at the LHC.

Has lead to the proposal that NLO partons should always be used.

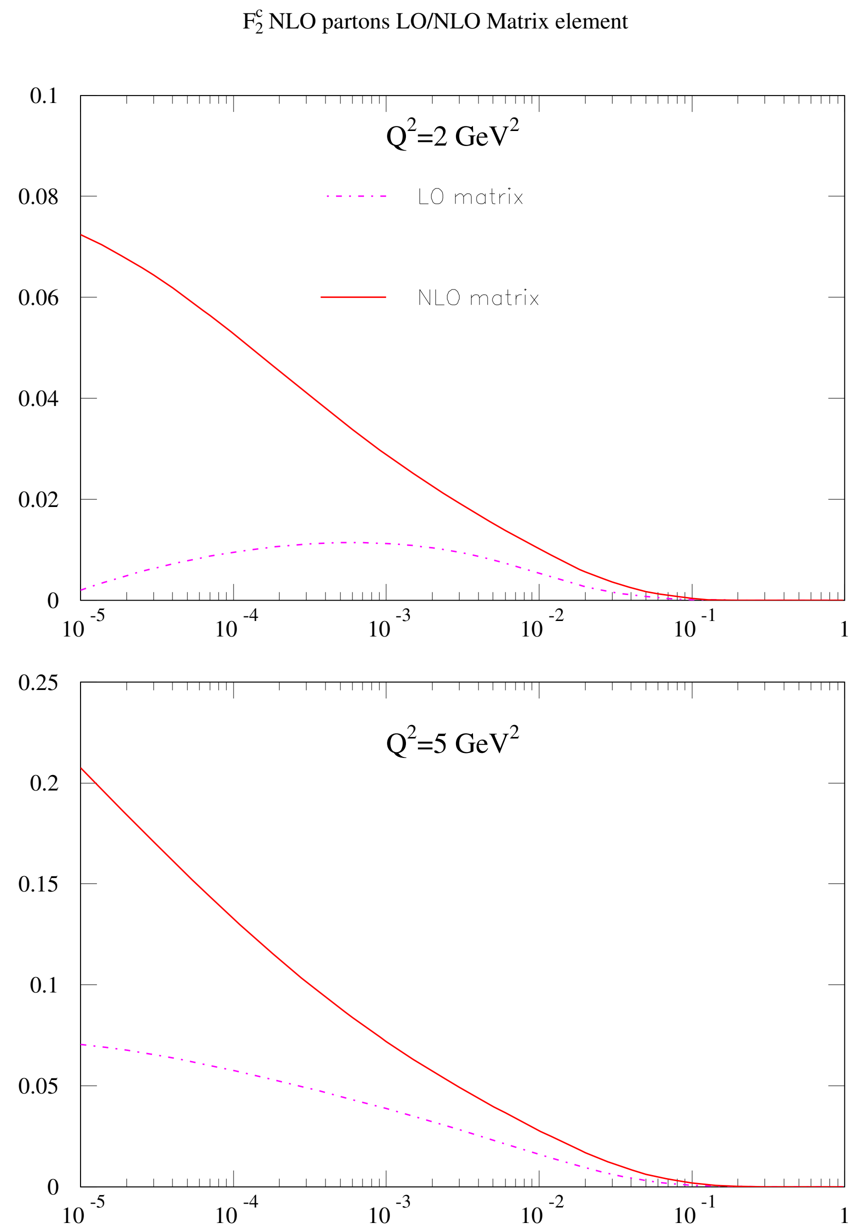


Small x *counter*-example. Consider production of charm in DIS. All charm produced in final state (FFNS).

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

Same issues in heavy flavour hadro-production.

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

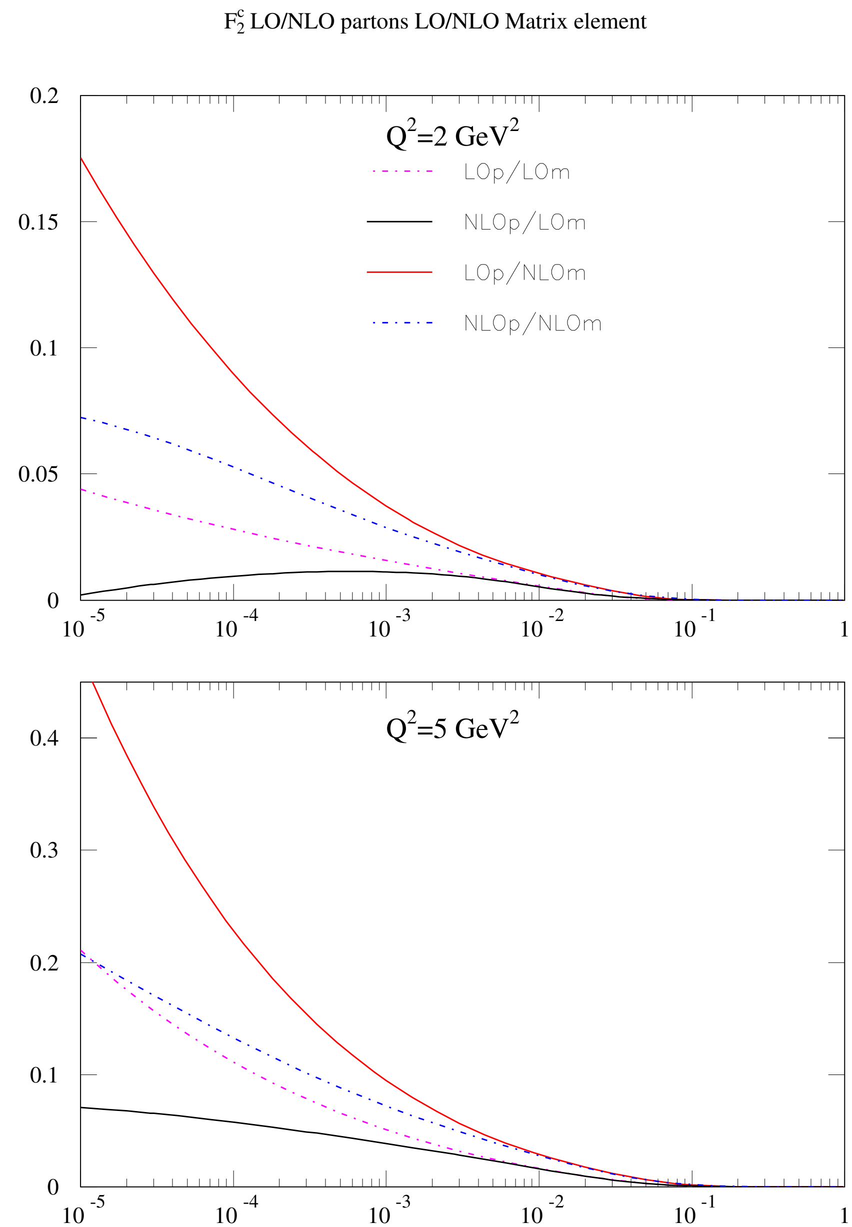


Consider using LO partons.

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.



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.

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 $\alpha_S(M_Z^2) \geq 0.130$.

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.

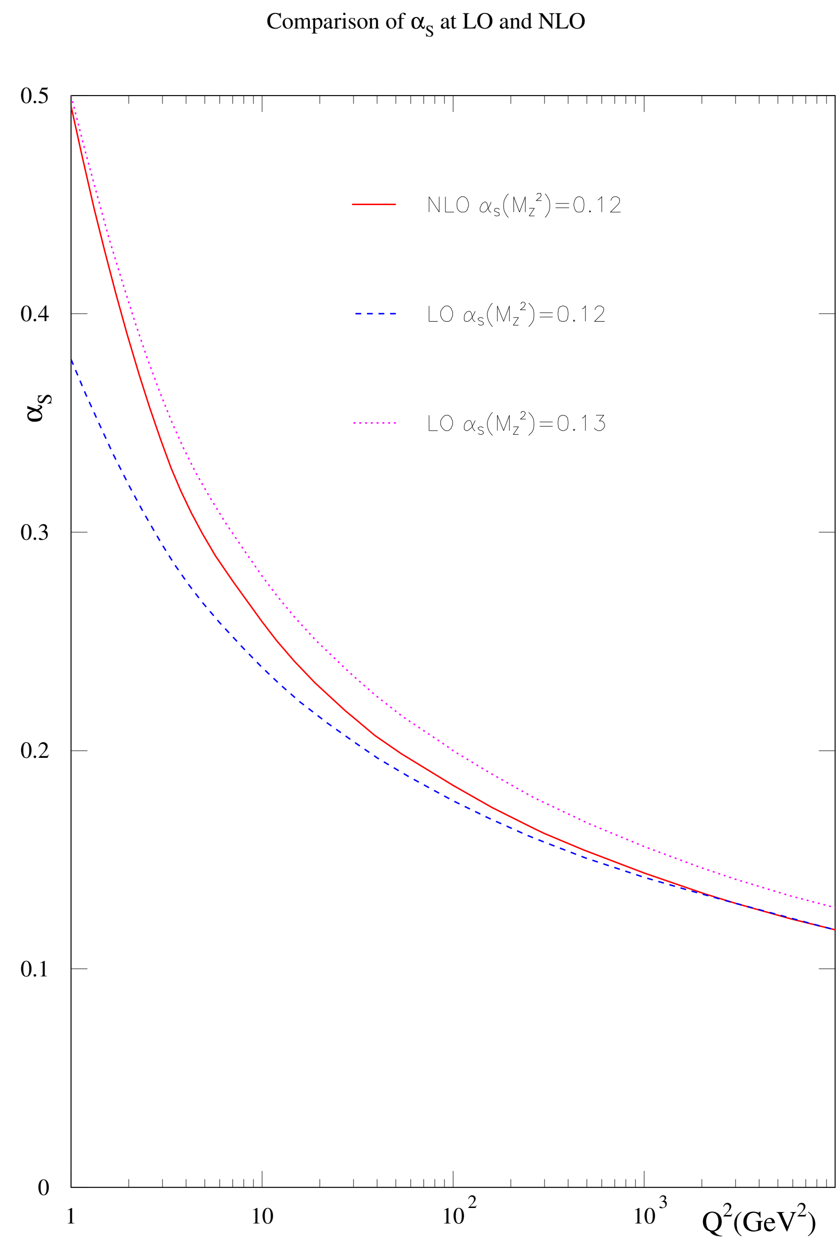
Also useful to use NLO definition of coupling constant.

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 alleviate discrepancy between different orders.

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



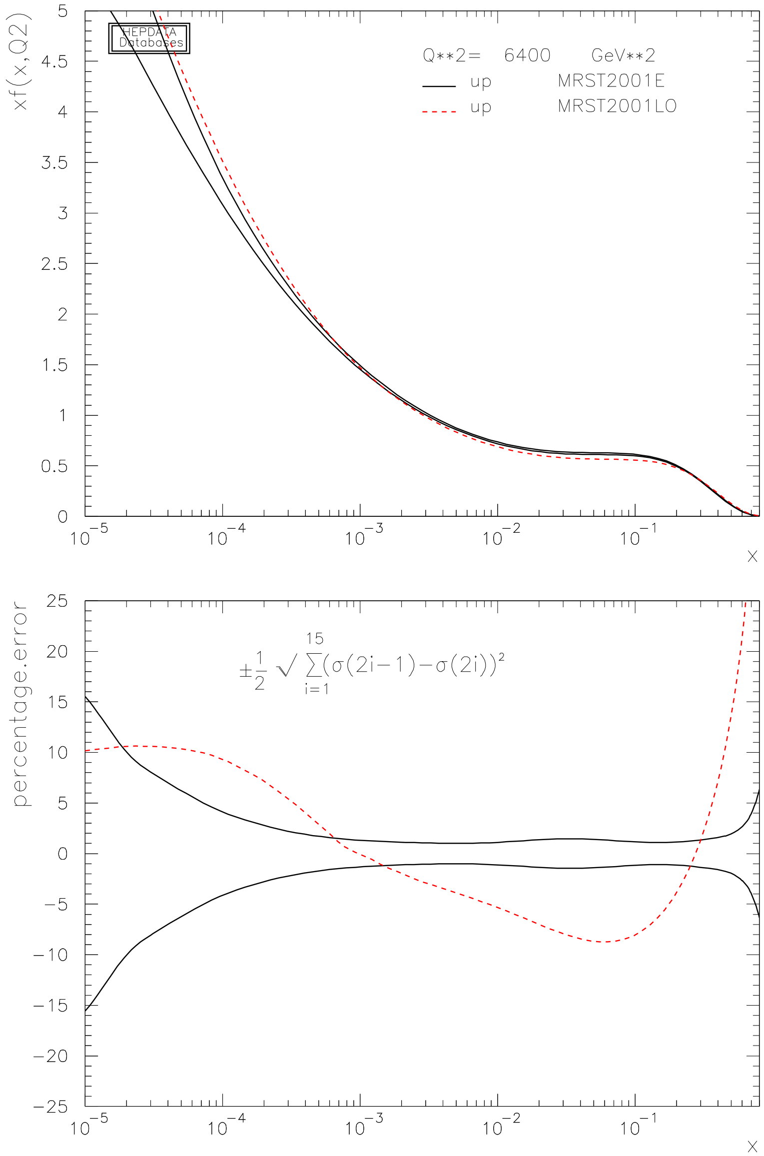
Relaxing momentum violation and allowing NLO definition of coupling does dramatically improve quality of LO global fit (K-factor of 1.3 necessary for fixed target Drell-Yan data).

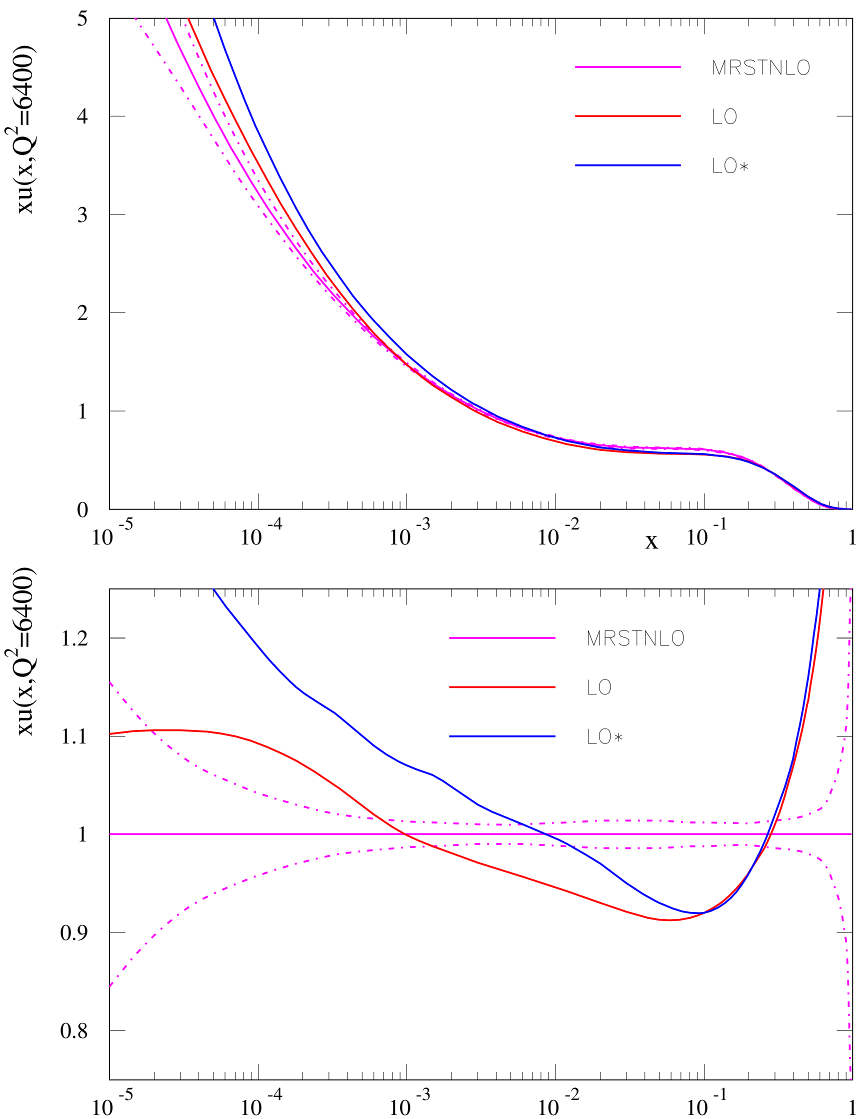
$\chi^2 = 3066/2235$ for standard LO fit becomes $\chi^2 = 2691/2235$. Big improvement in HERA data.

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 $\alpha_S(M_Z^2) = 0.121$.

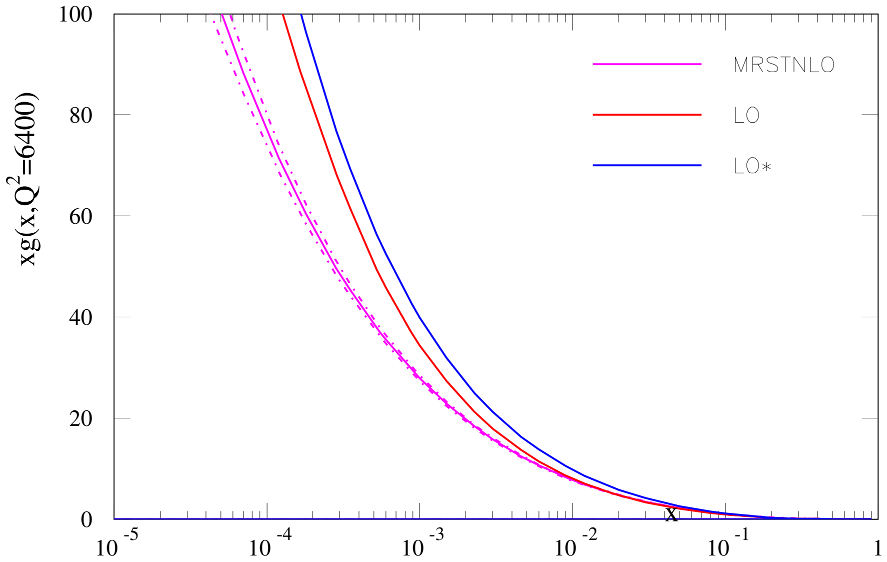
The LO* and NLO partons are more similar in this case, particularly for $x \sim 0.001 - 0.01$. (LO* often bigger – compensates for smaller cross-section at LO).

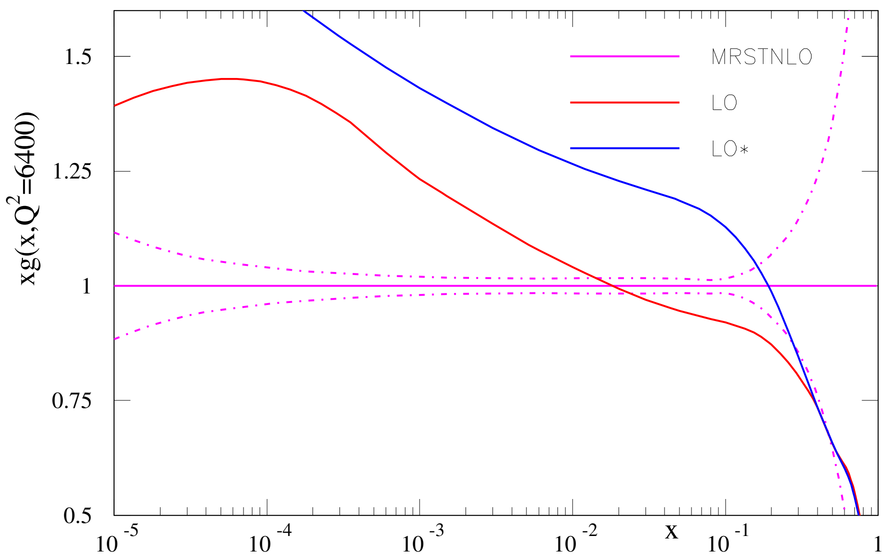




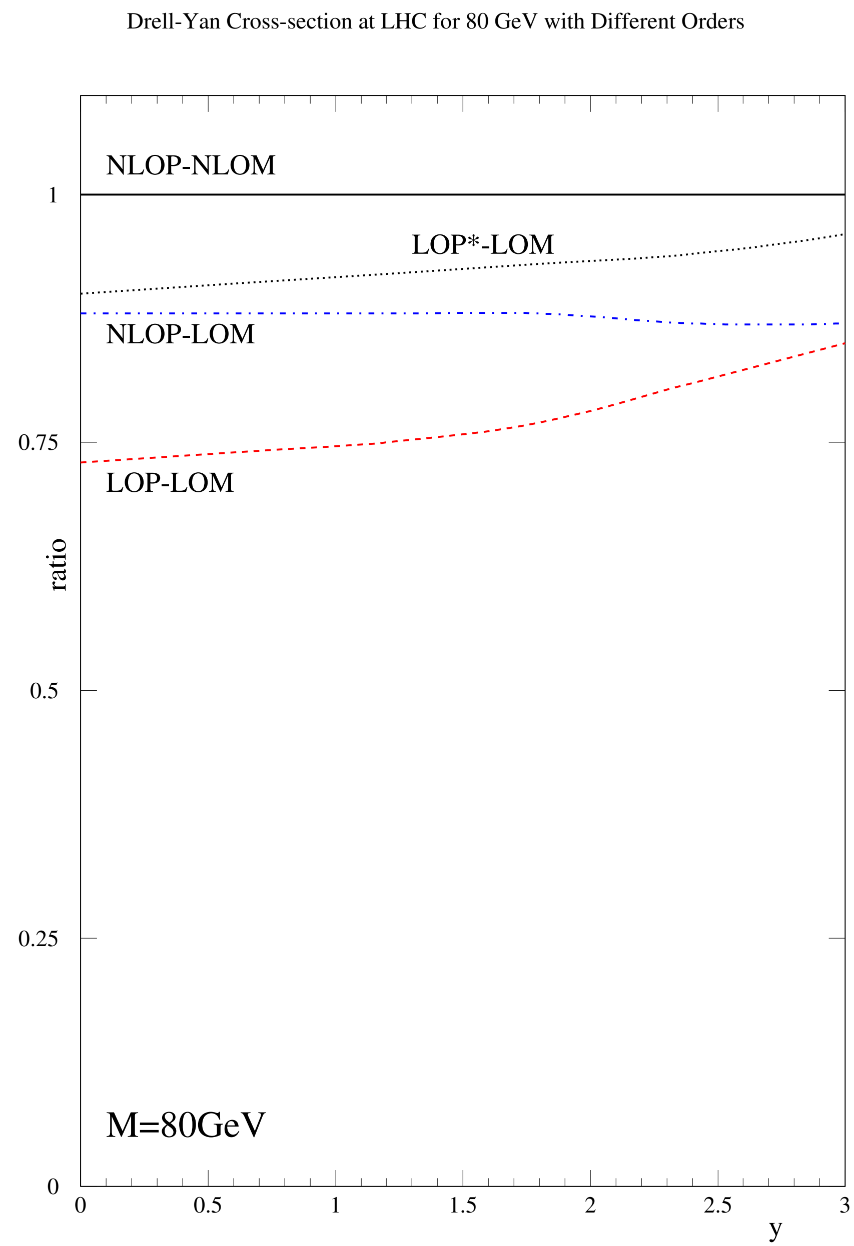
Similarly $g(x, Q^2)$ is significantly bigger at LO* than at LO, and much bigger than NLO at small x.

Should do better for gluon-gluon initiated processes (e.g. Higgs production where K-factors are often much greater than unity).

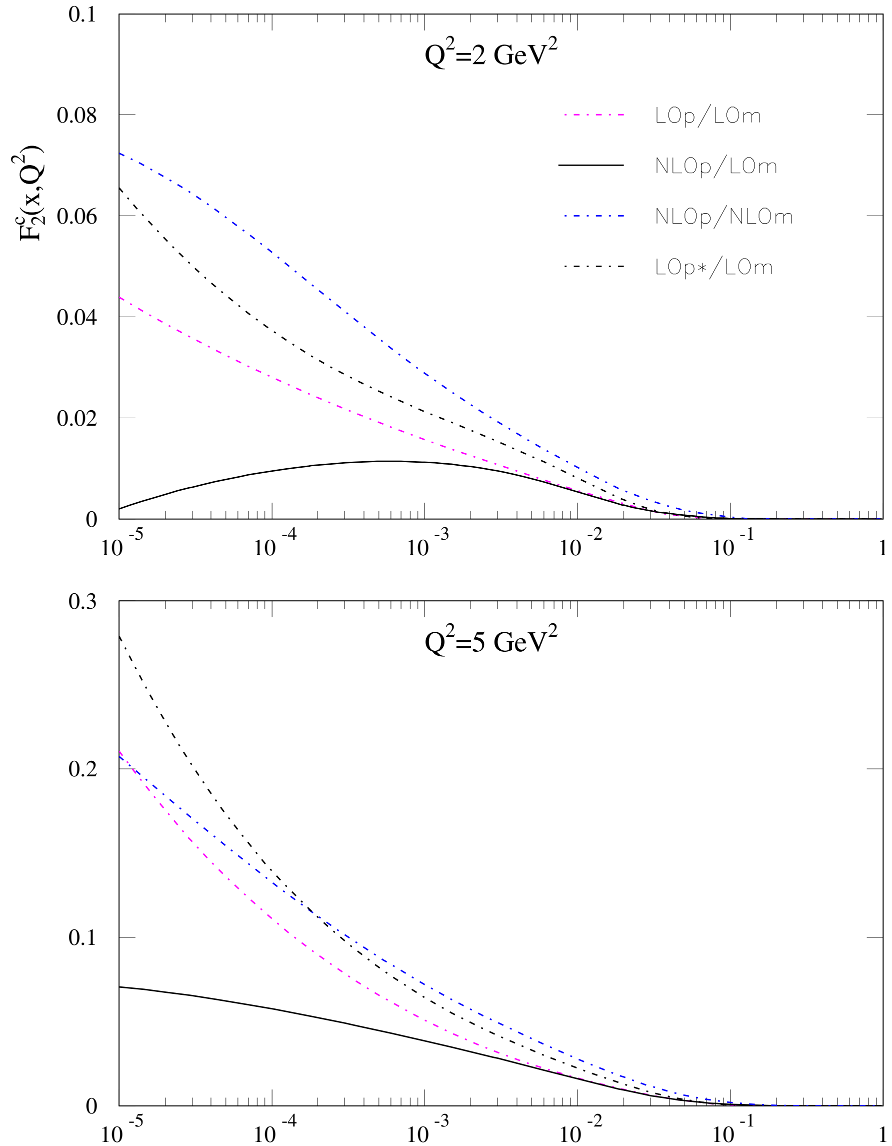




For LHC LO* partons lead to shape of comparable quality as NLO partons. Normalization better.



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



These are for totally inclusive, strictly fixed order calculations. Consider using generators (work with/by A Sherstnev) and include parton showering (i.e. use MC@NLO at NLO).

Consider first $Z \to \mu^+\mu^-$ production at the LHC with $p_T > 10\mathrm{GeV}$ and $|\eta| < 5$

NLO(ME)$\otimes$ NLO(pdf)$= 2.40nb$.

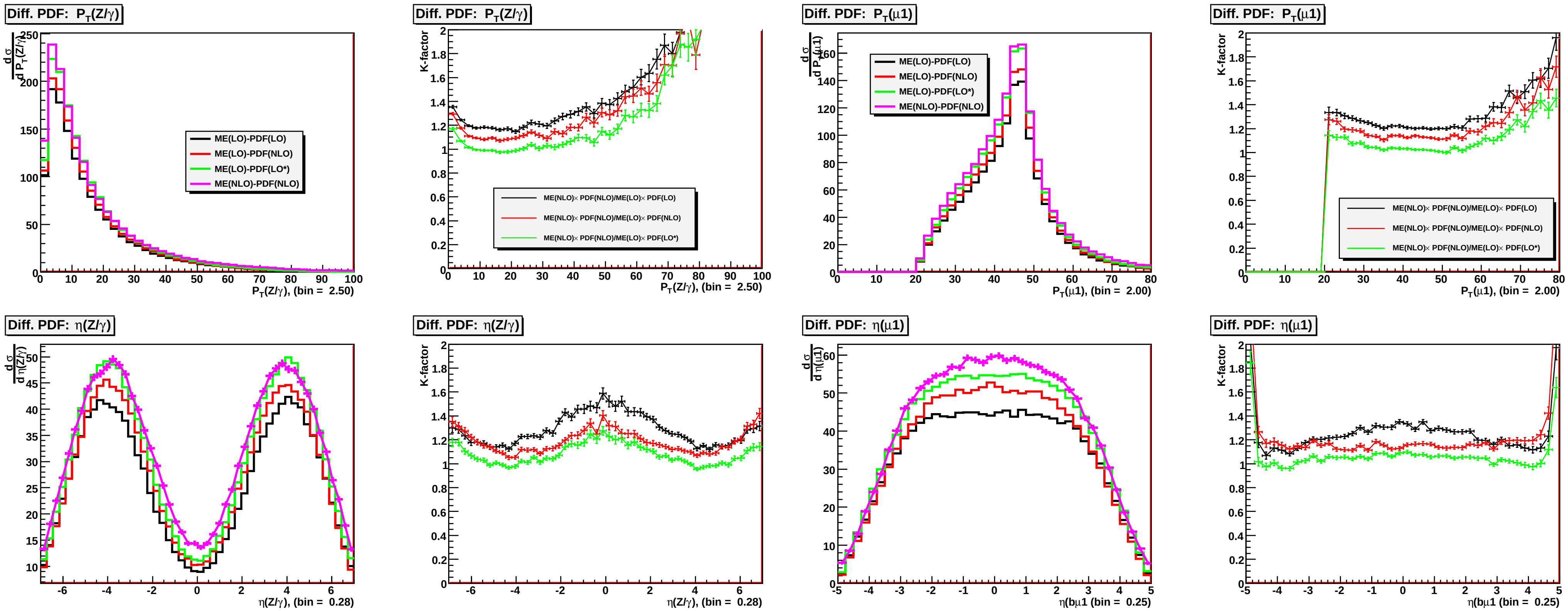
LO(ME)$\otimes$ NLO(pdf)$= 1.98nb$.

LO(ME)$\otimes$ LO(pdf)$= 1.85nb$.

LO(ME)$\otimes$ LO*(pdf)$= 2.19nb$.

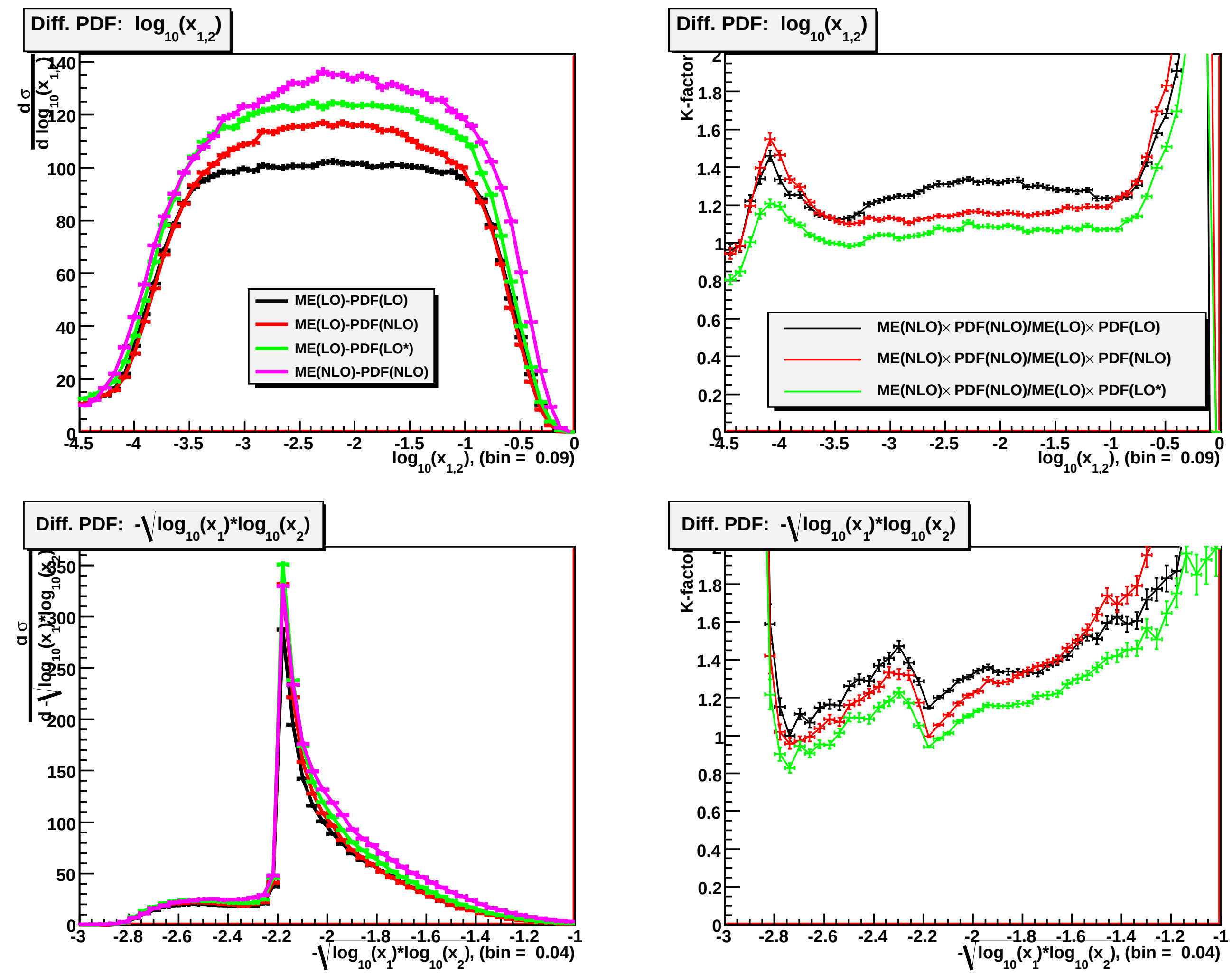
With very similar relative results for $W \to \nu\mu$.

Also look at distributions for Z boson and final state muon.



Results using LO* partons clearly best. No parton can account for details of p_T-distribution due to hard emissions at NLO.

Examination of values of x sampled in cross-section shows that deficit in LO rates due to lack of partons for $x \sim 0.01$.



NLO partons have better distribution, but LO* are good in normalization and shape.

Consider also single top production with $t \rightarrow \mu + \nu + b$ production at the LHC.

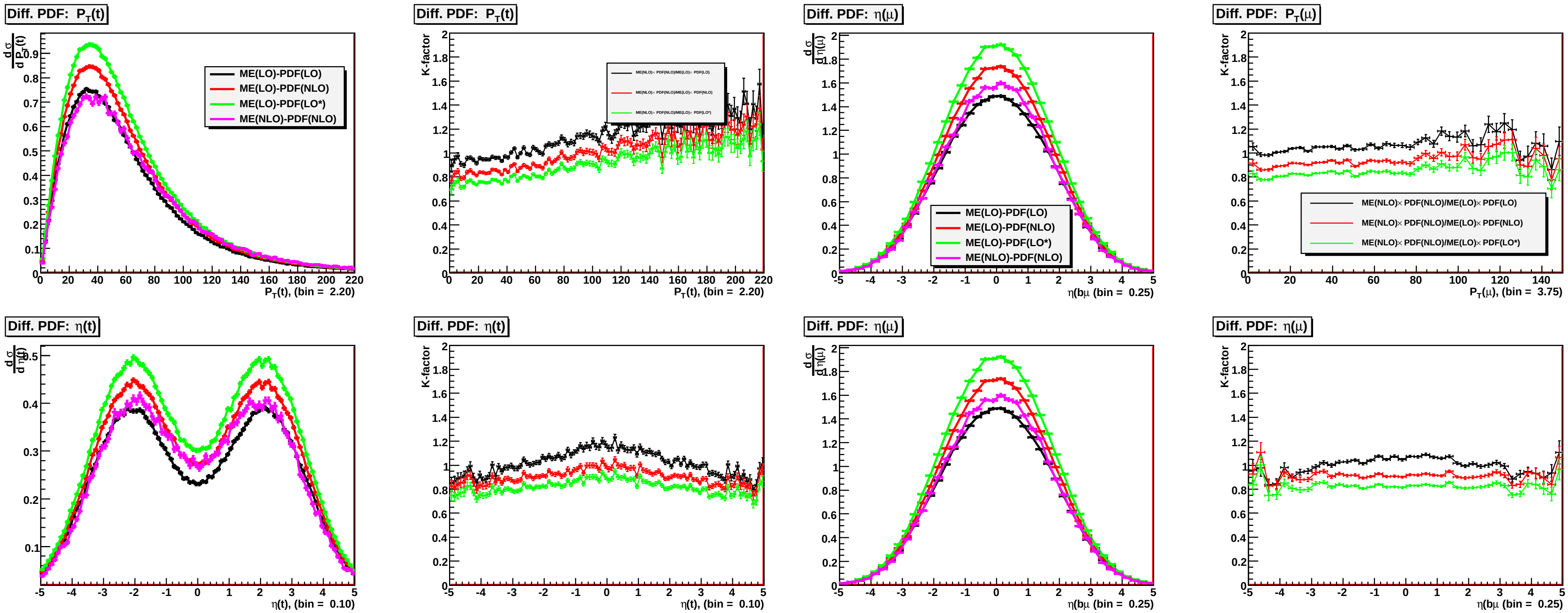
NLO(ME)$\otimes$ NLO(pdf)$= 27.6pb$.

LO(ME)$\otimes$ NLO(pdf)$= 30.0pb$.

LO(ME)$\otimes$ LO(pdf)$= 26.4pb$.

LO(ME)$\otimes$ LO*(pdf)$= 33.1b$.

Also look at distributions for t and final state muon.



Results using LO* partons a bit high in normalization, but a better shape than LO which has the best normalization. No parton can account completely for details of p_T-distribution due to hard emissions at NLO.

Consider Higgs ($130\mathrm{GeV}$) production at the LHC.

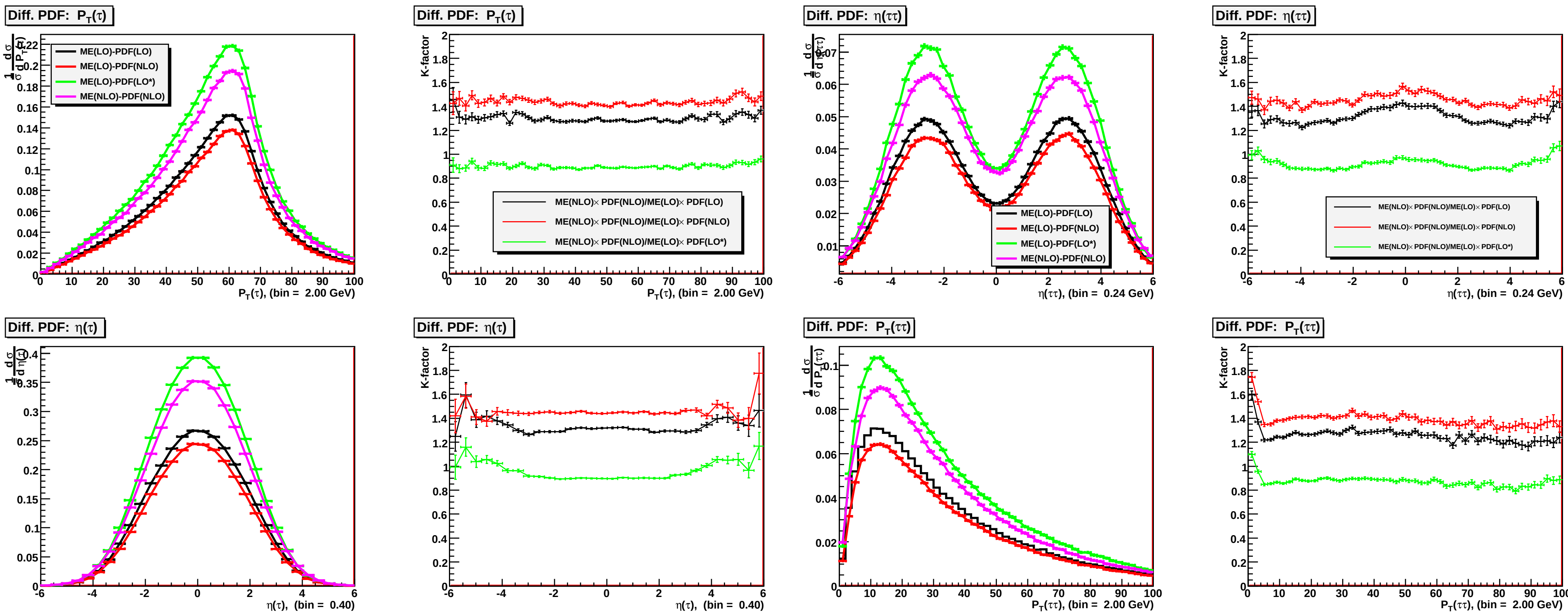
NLO(ME)$\otimes$ NLO(pdf)$= 38.0pb$.

LO(ME)$\otimes$ NLO(pdf)$= 20.3pb$.

LO(ME)$\otimes$ LO(pdf)$= 22.4pb$.

LO(ME)$\otimes$ LO*(pdf)$= 32.4pb$.

Also look at distributions with $H \rightarrow \tau^+\tau^-$ for single τ and $\tau^+\tau^-$ pair.



Results using LO* partons clearly best in normalization. All reasonable in shape.

Consider $b\bar{b}$ production with the included contribution for radiated $g \rightarrow b\bar{b}$ at the LHC. Noted contribution strictly NLO but vital for p_T-distribution and included in LO generators. Cuts $p_t > 20\mathrm{GeV}$, $|\eta(b)| < 5$, $\Delta R(b,b) > 0.5$.

NLO(ME)$\otimes$ NLO(pdf)$= 2.76\mu b$.

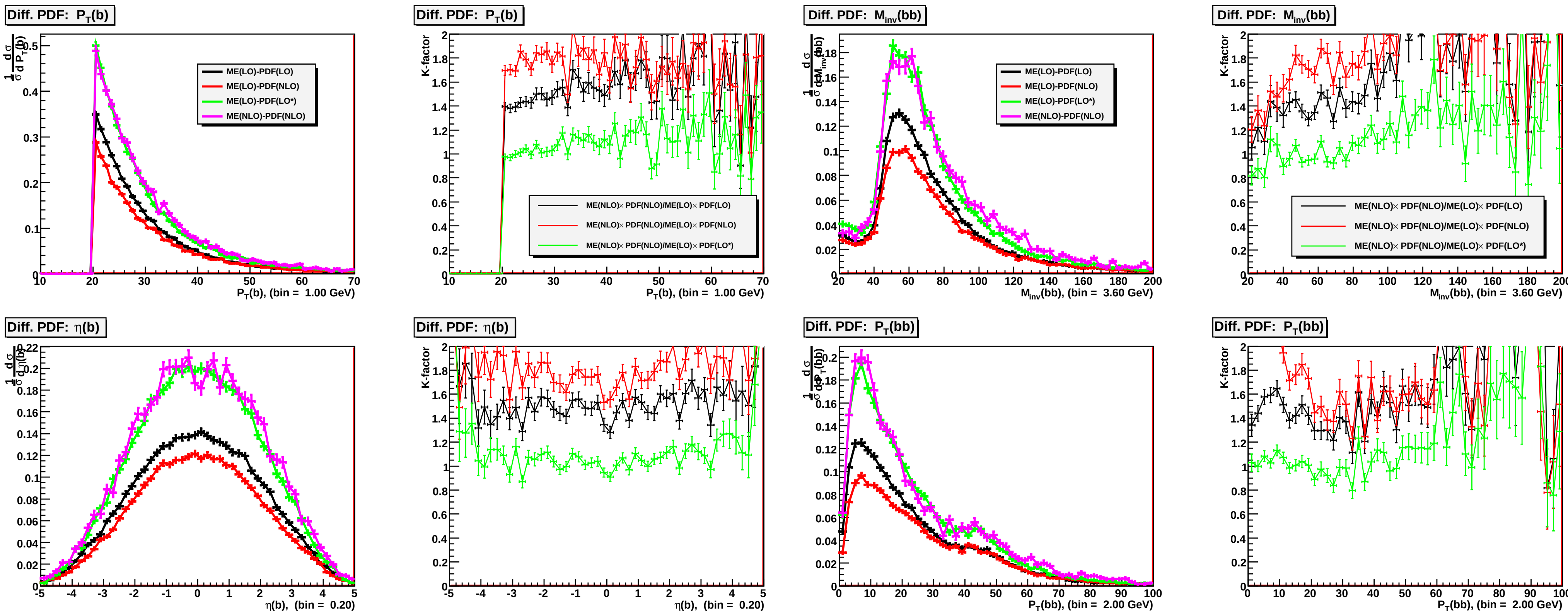
LO(ME)$\otimes$ NLO(pdf)$= 1.56\mu b$.

LO(ME)$\otimes$ LO(pdf)$= 1.85\mu b$.

LO(ME)$\otimes$ LO*(pdf)$= 2.63\mu b$.

This process probes the fairly small x gluon, i.e. $x \sim 0.001$, so NLO partons are worst due to small gluon at small x.

Also look at distributions for single b and $b\bar{b}$ pair.



Results using LO* partons clearly best in normalization. NLO worst and problems with shape at low scales (i.e. small x).

Finally consider vector boson production of Higgs + two jets using NLO code VBFNLO (Zeppenfeld *et al*).

NLO(ME)$\otimes$ NLO(pdf)$= 4.52pb$.

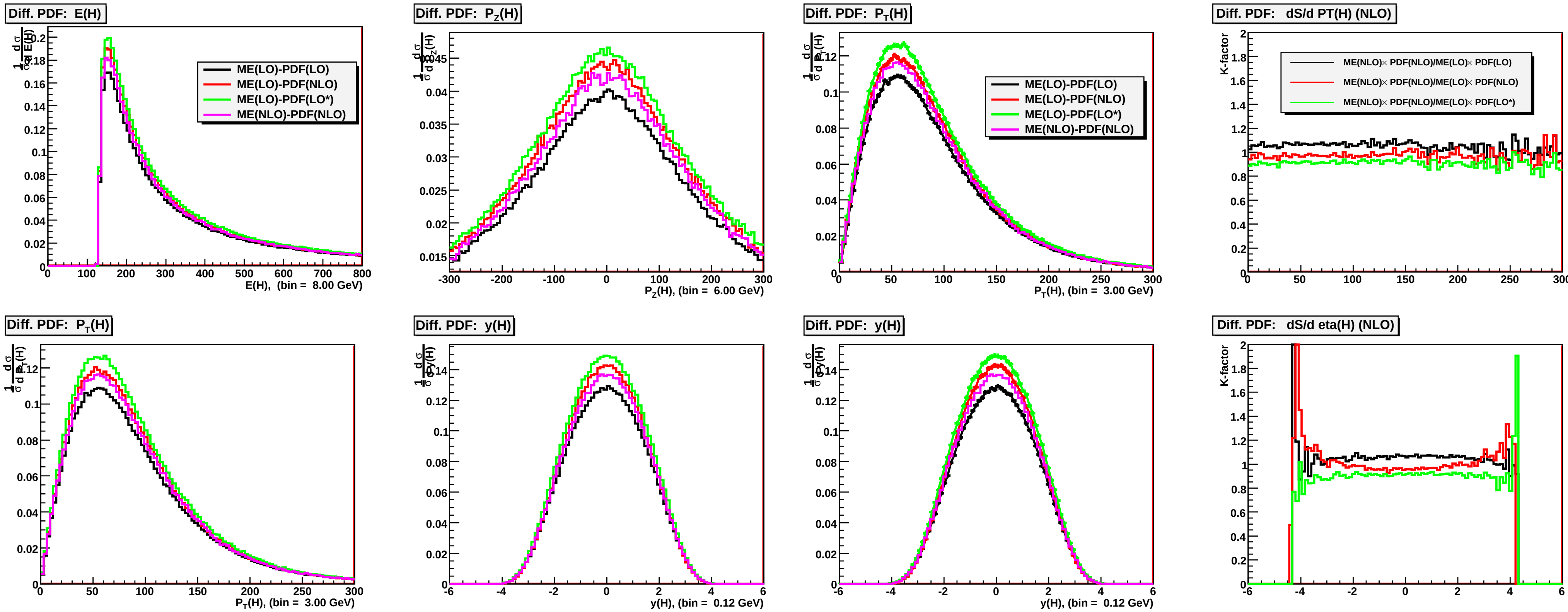
LO(ME)$\otimes$ NLO(pdf)$= 4.65pb$.

LO(ME)$\otimes$ LO(pdf)$= 4.26pb$.

LO(ME)$\otimes$ LO*(pdf)$= 4.95pb$.

This process probes the fairly high-x quarks, i.e. $x \sim 0.1$, and in this case the LO* partons lead to a slight overestimate of the results.

Also look at distributions for Higgs.



Results using LO* partons a bit high in normalization. NLO partons a little off in rapidity distribution.

Conclusions

Neither standard LO and NLO partons ideal for LO generators.

NLO gluon much smaller at small $x \rightarrow$ qualitative changes. LO quarks usually too small.

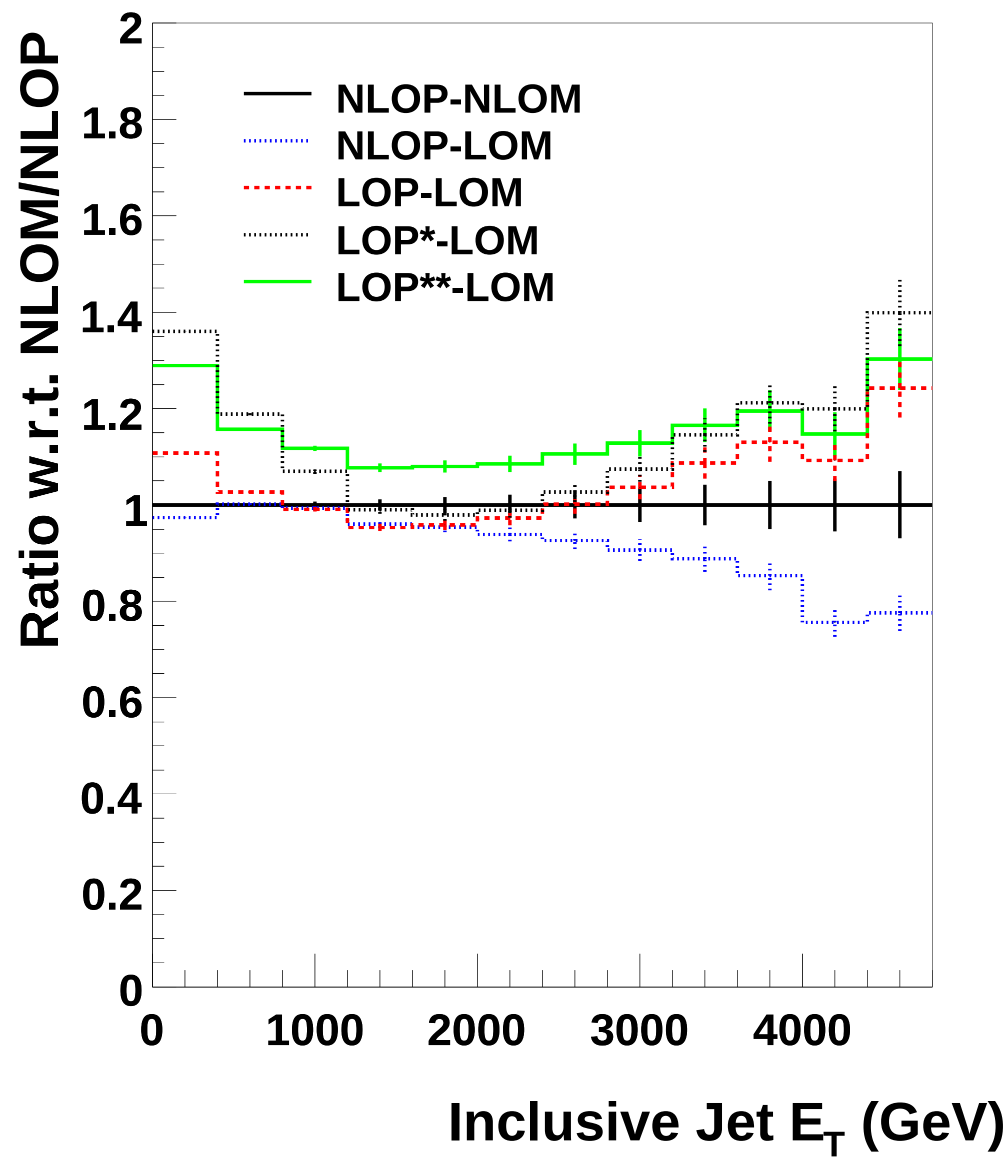
Introduce modified LO partons, i.e. momentum violation plus NLO coupling constant.

Comparison with processes where NLO known suggests modified LO partons usually provides most reliable results – especially if sensitive to smallish x. Additional partons allowed by extra momentum compensate semi-universally for higher orders.

Never badly wrong for any particular parton in any particular range, unlike standard fixed order.

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

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



Situation for hadro-production of b quarks at LHC using strict LO cross-section. (Some bugs here -general features hold).

Particularly large matrix element effect for p_T distribution in this case.