# Highlights from PDF4LHC workshop

July 14 @ CERN http://indico.cern.ch/conferenceDisplay.py?confId=36364

## PDF4LHC Meeting

Monday 14 July 2008
from 09:00 to 19:00
Europe/Zurich
at CERN ( *40-S2-A01* )
chaired by: *A. De Roeck et al.*

**Description:** Meeting on PDFs for the LHC: to be used in LHC analyses, and information from LHC data for PDF determination

Modify key for uploading talks: pdf4lhc

Monday 14 July 2008 |

### Monday 14 July 2008

top

**09:00->*10:30* Theory developments**

| | | |
|---|---|---|
| 09:00 | theory errors for the one-jet inclusive cross section (20') | D. Soper |
| 09:20 | statistical parton distributions (15') | F. Buccella |
| 09:35 | Heavy Flavor PDFs (20') | J. Bluemlein |
| 09:55 | Heavy Flavor Schemes: critical comparison (20') | N.N. |
| 10:30 | Coffee break | |

**10:45->*12:30* parametrization choices**

| | | |
|---|---|---|
| 10:45 | MSTW (20') | R. Thorne |
| 11:05 | CTEQ (20') | J. Huston |
| 11:25 | HERAPDFs (20') | A. Cooper |
| 11:45 | NNPDFs (20') | S. Forte |
| 12:05 | Remarks on Theoretical uncertainties (10') | A Glazov |
| 12:30 | Lunch break | |

**14:00->*15:30* Errors on PDFs**

| | | |
|---|---|---|
| 14:00 | Discussion on Benchmark studies (20') | N.N. |
| 14:20 | PDFs at LHC startup (20') | all |
| 15:30 | Coffee break | |

**15:45->*17:30* PDF4LHC: PDFs for Monte Carlos**

| | | |
|---|---|---|
| 15:45 | Introduction and LO*/LO** sets (20') | R. Thorne |
| 16:05 | CTEQ equivalents and comparisons with LO*/LO** (20') | J. Huston |
| 16:25 | PDF4MC (20') | H. Jung |

# Theory uncertainties (D. Soper)

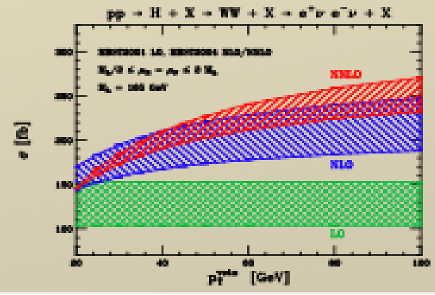
## Theory errors in the one-jet inclusive cross section

Davison E. Soper
*University of Oregon & CERN*
Fred Olness
*Southern Methodist University & CERN*

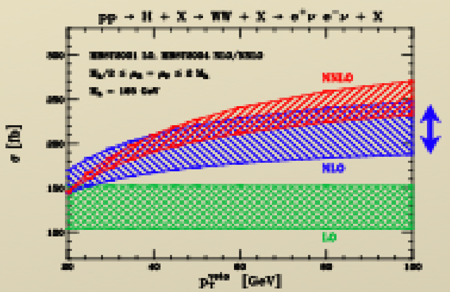
PDF4LHC workshop, CERN, July 2008

## Motivation

- Perturbative calculations are usually presented with an error estimate.
- For example, Anastasiou, Dissertori, and Stockli, JHEP 0709, 018 (2007):




- Suppose that we have only NLO.




- We hope our NLO error band gives a range where NNLO will fall.
- For cross sections used for parton distributions, we should include the estimated theory error in the fitting procedure.

- The one jet inclusive cross section is used in parton fitting.
- This cross section has relatively large theory errors since it is known only to NLO.
- We therefore provide an estimate of the theory error in a form suitable for fitting.
- *Caveat*: a theory error is a guess. Opinions can differ.

# Theory uncertainties (D. Soper)

$$\frac{d\sigma}{dE_T} = \frac{1}{2(y_{\max} - y_{\min})} \left[ \int_{-y_{\max}}^{-y_{\min}} dy + \int_{y_{\min}}^{y_{\max}} dy \right] \frac{d\sigma}{dE_T\, dy}$$

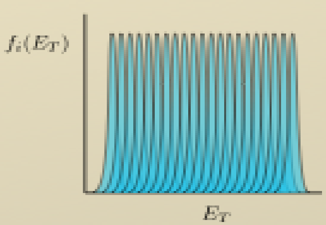
- In this talk, I present our results for $\sqrt{s} = 1960$ GeV, $y_{\min} = 0$, $y_{\max} = 1.0$, with a cone algorithm using $R = 0.7$ and $R_{\rm sep} = 1.3$.

## Format for theory errors

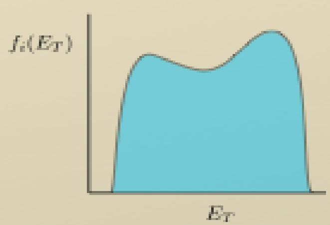
$$\frac{d\sigma}{dE_T} = \left[ \frac{d\sigma}{dE_T} \right]_{\rm NLO} \left\{ 1 + \sum_i \lambda_i f_i(E_T) \right\}$$

- $f_i(E_T)$ are functions to be specified.
- $\lambda_i$ are Gaussian random variables with standard deviation 1.
- The size of the functions $f_i(E_T)$ gives the size of the errors.
- This gives the complete error matrix as for experimental systematic errors.

$$\frac{d\sigma}{dE_T} = \left[ \frac{d\sigma}{dE_T} \right]_{\rm NLO} \left\{ 1 + \sum_i \lambda_i f_i(E_T) \right\}$$



uncorrelated errors



correlated errors

## Scale dependence

- Use dependence on renormalization and factorization scales.
- If we had an NNLO calculation, the dependence on the scales would be cancelled to that order.
- Thus the dependence on the scales gives an estimate of the error induced by truncating the perturbative expansion at one loop order.

# Theory uncertainties (D. Soper)

- We use the standard central choice

$$\mu_{\rm uv} = \mu_{\rm co} = E_T/2$$

- Define

$$x_1 = \log_2(2\mu_{\rm uv}/E_T)$$
$$x_2 = \log_2(2\mu_{\rm co}/E_T)$$

- Fit to

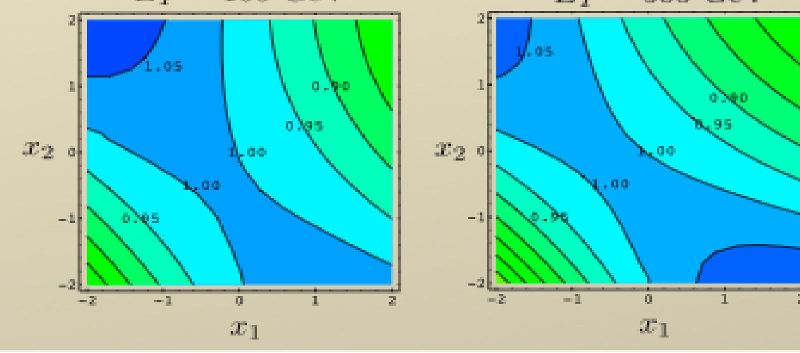
$$\left[\frac{d\sigma(x_1,x_2)}{dE_T}\right]_{\rm NLO} \approx \left[\frac{d\sigma(0,0)}{dE_T}\right]_{\rm NLO} P(\vec{x})$$

$$P(\vec{x}) = 1 + \sum_J x_J A_J + \sum_{J,K} x_J M_{JK} x_K$$

$$\left[\frac{d\sigma(x_1,x_2)}{dE_T}\right]_{\rm NLO} \approx \left[\frac{d\sigma(0,0)}{dE_T}\right]_{\rm NLO} P(\vec{x})$$

- Graphs of $P(\vec{x})$ (approximate: this is for $d\sigma/(dE_T\,dy)$ at $y=0$).

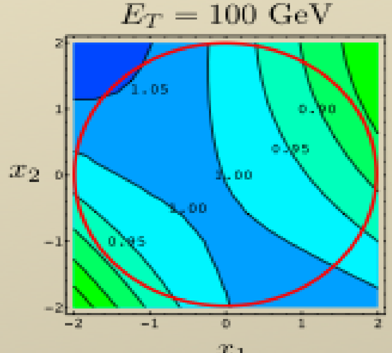
$E_T = 100$ GeV　　　$E_T = 500$ GeV



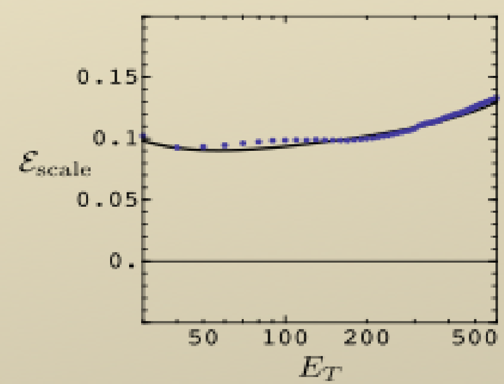

- Define estimated error

$$\mathcal{E}^2_{\rm scale} = \frac{1}{2\pi}\int_0^{2\pi} d\theta\ P(|\vec{x}|\cos\theta, |\vec{x}|\sin\theta)^2$$

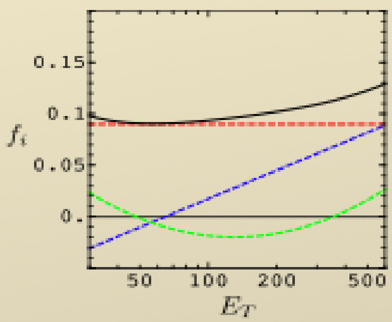
$E_T = 100$ GeV




- We find about a 10% error, slowly increasing with $E_T$.



# Theory uncertainties (D. Soper)




- Divide this into parts.
- The unknown contributions can have a shape.
- Higher order polynomials have smaller coefficients.

$$f_1(E_T) = 0.09$$

$$f_2(E_T) = 0.04\left\{\log(15E_T/\sqrt{s}) + 0.7\right\}$$

$$f_3(E_T) = 0.02\left\{[\log(15E_T/\sqrt{s})]^2 - 1.0\right\}$$

- Net error,

$$\mathcal{E}_{\rm scale} = \sqrt{f_1(E_T)^2 + f_2(E_T)^2 + f_3(E_T)^2}$$

## Summation of threshold logs

- Kidonakis, Owens, and Sterman have shown how to sum "threshold logs" in the jet cross section.
- The threshold logs are important when the variation of the parton distributions with $x$ is large.
- Since they represent terms beyond NLO, we can use the summed logs as an error estimate.

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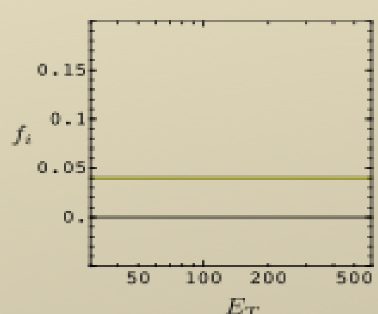
- The summed logs are available as part of "FastNLO" (Kluge, Rabbertz, Wobisch).
- For $\mu_{\rm uv} = \mu_{\rm co} = E_T/2$, the threshold logs contribution is about 4%, not strongly dependent on $E_T$.
- So we take

$$f_4(E_T) = 0.04$$




## Power suppressed corrections

- Some $E_T$ can be lost from the jet when the partons hadronize.
- Some $E_T$ can be gained by the jet from the underlying event.
- Dasgupta, Magnea and Salam have estimated these effects.
- Our estimate based on this work is

$$\delta E_T = 0.5 \pm 0.7 \text{ GeV}$$

# Theory uncertainties (D. Soper)

- To see the effect on the cross section, define

$$\frac{d\sigma(E_T)}{dE_T} = g(E_T)$$

$$\frac{1}{g(E_T)}\,\frac{dg(E_T)}{dE_T} = -\frac{n}{E_T} \qquad n \approx 7$$

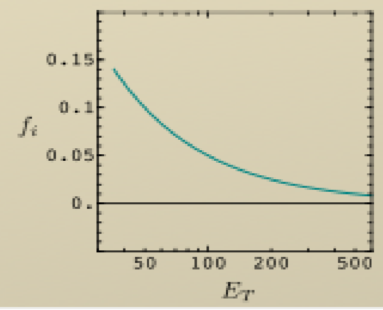
$$g(E_T) = g_{\rm pert}(E_T - \delta E_T)$$
$$\approx g_{\rm pert}(E_T)\left\{1 + n\frac{\delta E_T}{E_T}\right\}$$

**The estimated error**

$$\frac{d\sigma}{dE_T} \approx \frac{d\sigma_{\rm pert}}{dE_T}\left\{1 + n\frac{\delta E_T}{E_T}\right\}$$

$$\delta E_T = 0.5 \pm 0.7\ \mathrm{GeV} \qquad n \approx 7$$

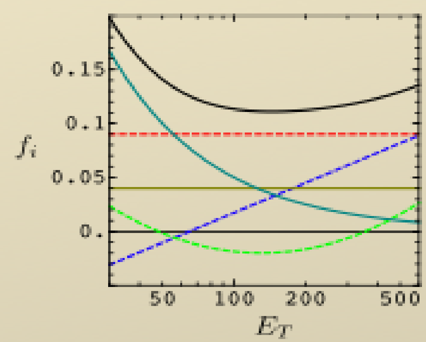
$$f_5(E_T) = n\,\frac{0.7\ \mathrm{GeV}}{E_T} = \frac{5\ \mathrm{GeV}}{E_T}$$



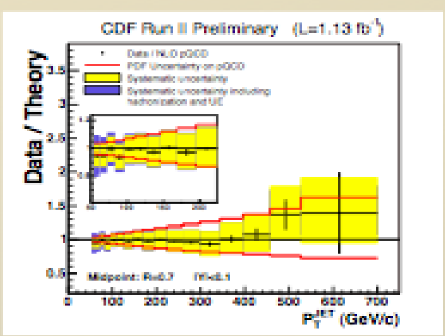

## Assembled errors

$$\frac{d\sigma}{dE_T} = \left[\frac{d\sigma}{dE_T}\right]_{\rm NLO}\left\{1 + \sum_i \lambda_i f_i(E_T)\right\}$$

$$f_1(E_T) = 0.09$$
$$f_2(E_T) = 0.04\,\{\log(15E_T/\sqrt{s}) + 0.7\}$$
$$f_3(E_T) = 0.02\,\{[\log(15E_T/\sqrt{s})]^2 - 1.0\}$$
$$f_4(E_T) = 0.04$$
$$f_5(E_T) = \frac{5\ \mathrm{GeV}}{E_T}$$




Theory errors




Experimental errors (CDF)

# LO** pdfs (R. Thorne)

## Parton Distributions for LO Monte Carlo Generators

Robert Thorne

July 14th, 2008

University College London

Royal Society Research Fellow

PDF4LHC08

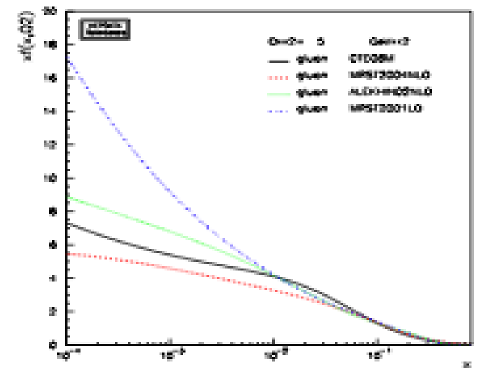
Which order of partons should be used in LO Monte Carlo generators.

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.



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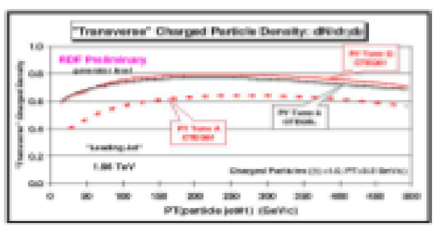
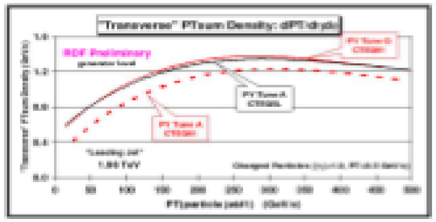
Already investigated in terms of tuning for underlying event (Field). See big difference between using CTEQ6L and CTEQ6.1M partons, mainly due to gluon.

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.

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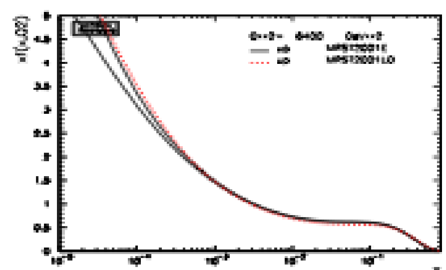
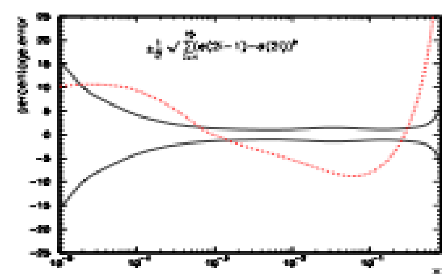
First note that the LO quarks over wide region of smaller $x$ qualitatively smaller than NLO. Lack of additional quark evolution at NLO.

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





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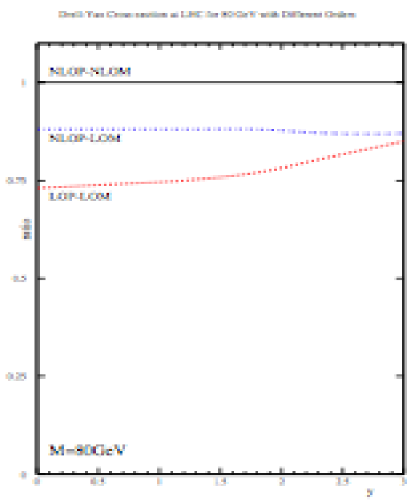
# LO** pdfs (R. Thorne)

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).

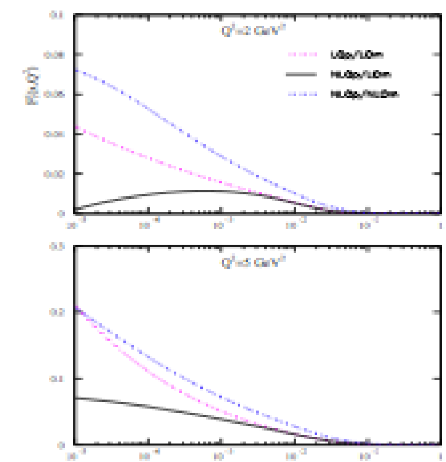
NLO matrix element contain divergence at small $x$ not present at LO.

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.

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.





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.

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 large $\alpha_S(M_Z^2)$.

However, Relaxing momentum sum rule at LO could make LO partons rather more like NLO partons where they are normally too small but would still be bigger than NLO where necessary.



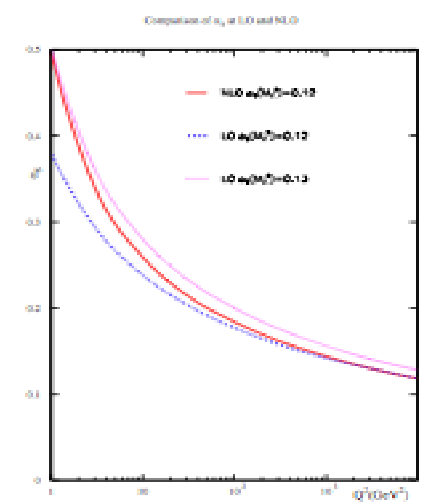
Also useful to use NLO definition of coupling constant.

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.



# LO** pdfs (R. Thorne)

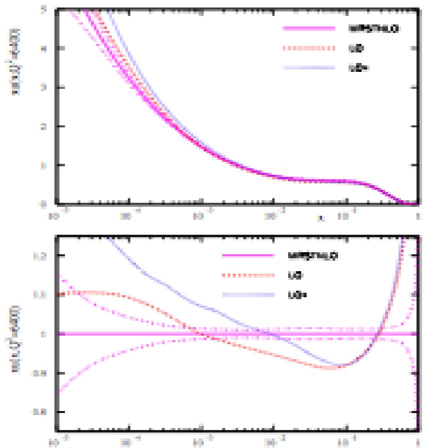
Relaxing momentum violation and allowing NLO definition of coupling does dramatically improve quality of LO global fit.

Momentum carried by input partons goes up to 113%.

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).

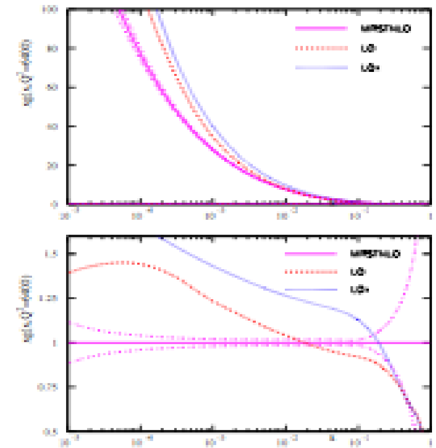
Full details of study in A. Shertsnev and R.S. Thorne, e-Print: arXiv:0711.2473 [hep-ph].





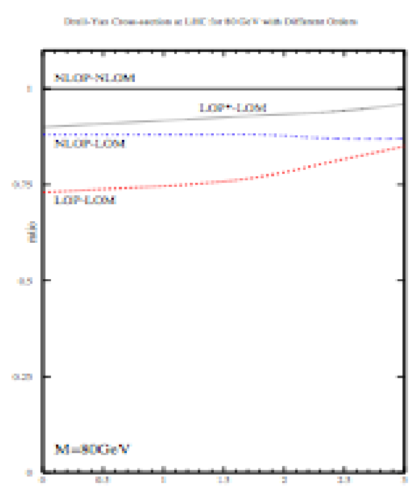

Similarly $g(x, Q^2)$ is significantly bigger at LO* than at LO, and much bigger than NLO at small $x$.

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



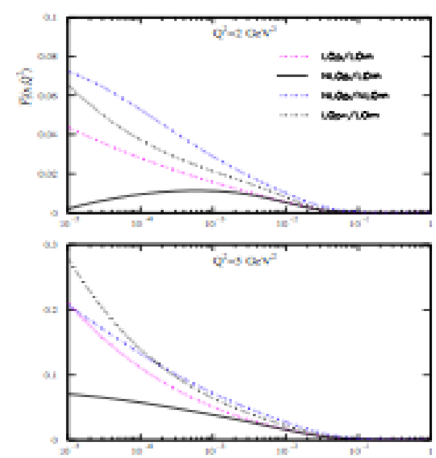



For LHC LO* partons lead to shape of comparable quality as NLO partons. Normalization better.






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



# LO** pdfs (R. Thorne)

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

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

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

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

NLO(ME)$\otimes$ NLO(pdf)$= 21.1nb$.

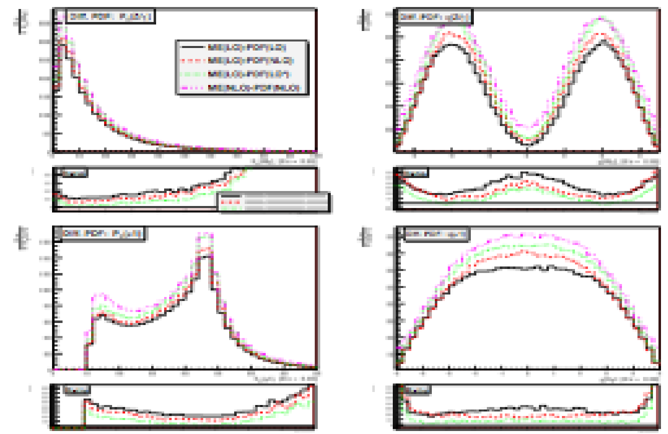
LO(ME)$\otimes$ LO(pdf)$= 17.5nb$.

LO(ME)$\otimes$ NLO(pdf)$= 18.6nb$.

LO(ME)$\otimes$ LO*(pdf)$= 20.6nb$.



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.



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

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

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

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

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

Similar for $t\bar{t}$ production.

NLO(ME)$\otimes$ NLO(pdf)$= 813pb$.

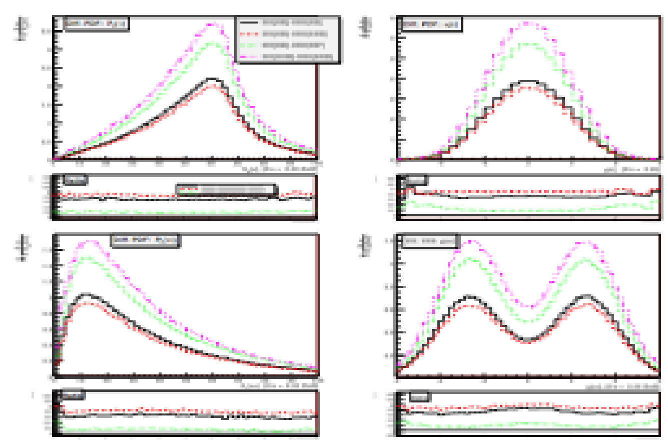
LO(ME)$\otimes$ LO(pdf)$= 561pb$.

LO(ME)$\otimes$ NLO(pdf)$= 531pb$.

LO(ME)$\otimes$ LO*(pdf)$= 699pb$.



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



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

# LO** pdfs (R. Thorne)

Consider instead single top production with $t \to \mu + \nu + b$ production at the LHC. Now a $t$-channel process.

NLO(ME)⊗ NLO(pdf)= $259pb$.

LO(ME)⊗ LO(pdf)= $238pb$.

LO(ME)⊗ NLO(pdf)= $270pb$.

LO(ME)⊗ LO*(pdf)= $297b$.

Similar for other $t$-channel process vector boson production of Higgs + two jets using NLO code VBFNLO (Zeppenfeld *et al*).

NLO(ME)⊗ NLO(pdf)= $4.52pb$.

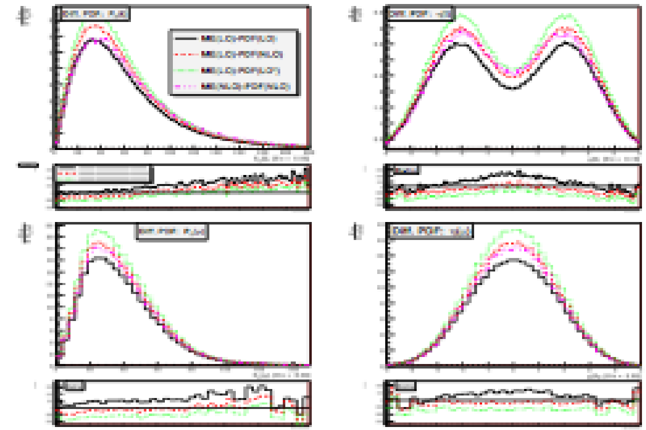
LO(ME)⊗ LO(pdf)= $4.26pb$.

LO(ME)⊗ NLO(pdf)= $4.65pb$.

LO(ME)⊗ LO*(pdf)= $4.95pb$.



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. Similar for Higgs via VBF.



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

NLO(ME)⊗ NLO(pdf)= $2.76\mu b$.

LO(ME)⊗ LO(pdf)= $1.85\mu b$.

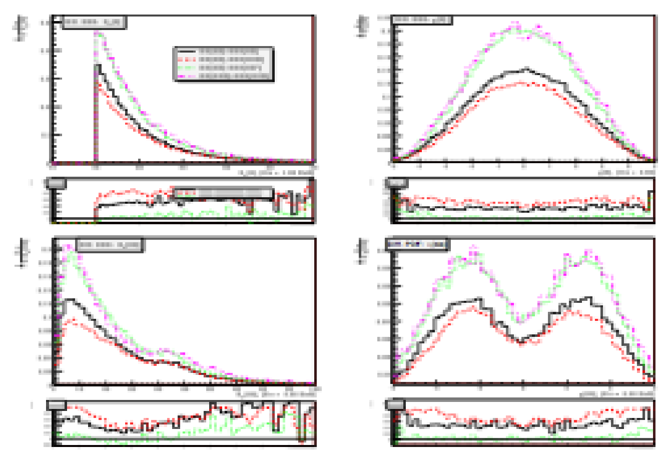
LO(ME)⊗ NLO(pdf)= $1.56\mu b$.

LO(ME)⊗ 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 $x$).

# LO** pdfs (R. Thorne)

**NLO Corrections**

Various reasons why NLO matrix elements may give large corrections.

- $1/z$ divergent terms in matrix elements.

- Large corrections from soft-gluon emissions near the edge of phase space, i.e. large threshold corrections.

- Large correction from analytic continuation from space-like to time-like region, i.e. $1 + \alpha_S C_F/2$ factor in Drell-Yan production.

$W$, $Z$, Higgs and $t\bar{t}$, $b$-production and jet production (including $W + j$) all have NLO enhancements from at least one of these sources. In each case the enhancement of LO* partons compared to LO compensates to some extent (often surprisingly well).

$t$-channel processes do not have these type of large corrections, and for e.g. single $t$ or Higgs via vector boson fusion the NLO matrix-element correction is small. In these cases LO* over-compensate.

However, leaves shape of distributions more-or-less unchanged. Unless probe very small-$x$ partons enhancement from LO* partons is not that big. But these processes do not probe very small-$x$ too much by the nature of processes.

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**More recent developments** - change of argument of coupling constant.

Monte Carlo generators use scale $p_t^2 = Q^2 * (1 - z)$ for the coupling constant in initial state parton branching rather than the standard PDF choice of $Q^2$. Automatically incorporates leading log corrections at high $z$.

Incorporated this scale in $P_{qg}$ splitting function (by far most important effect at high $z$ and $x$) in a parton number conserving manner - nonsinglet evolution still conserves number of valence quarks.

Quality of fit improves by $\sim 50$ units, mainly for high-$x$ structure functions where resummation speeds evolution.

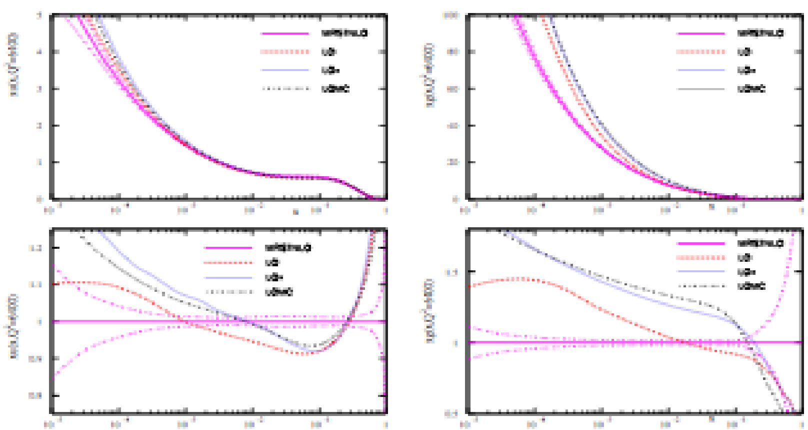
Allows $\alpha_S(M_Z^2)$ to lower to $0.115$.

Input partons now carry $117\%$ momentum, but this now falls with $Q^2$ since modified coupling leads to increased branching of high-$x$ quarks.

Overall change in partons LOMC compared to LO* very modest.

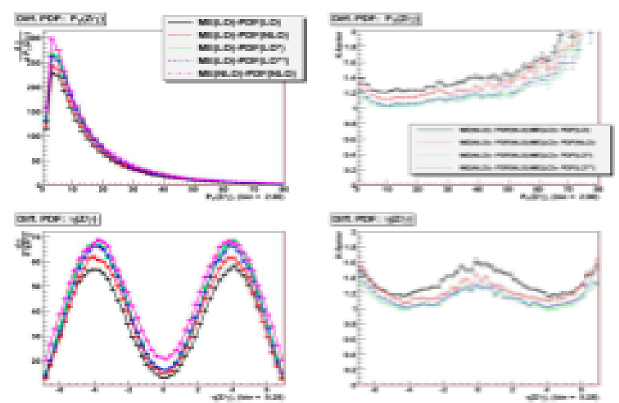
PDF4LHC08 21

Partons rather insensitive to change. LOMC far more similar to LO* than to LO and NLO.



PDF4LHC08 22

Look at distributions.



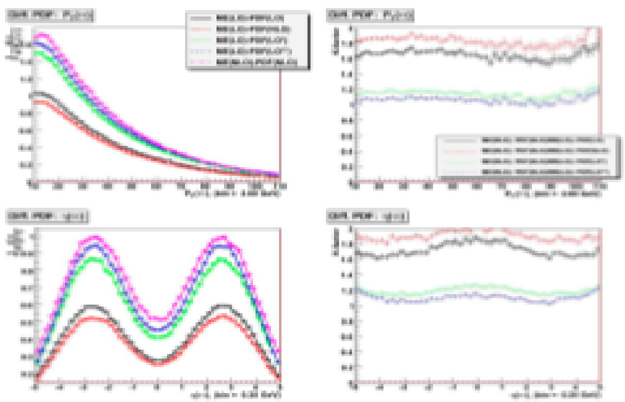
Results using LO** partons extremely similar to those using LO* partons for $Z$ production.

Very similar for $W$ production.

PDF4LHC08 23

# LO** pdfs (R. Thorne)

Look at gluon dominated quantity



Results using LO** partons extremely similar to those using LO* partons for Higgs production from gluon-gluon fusion.

Very similar for $b\bar{b}$ production.



Consider instead single top production with $t \to \mu + \nu + b$ production at the LHC. Now a $t$-channel process.

NLO(ME)$\otimes$ NLO(pdf)$= 259pb$.

LO(ME)$\otimes$ LO(pdf)$= 238pb$.

LO(ME)$\otimes$ NLO(pdf)$= 270pb$.

LO(ME)$\otimes$ LO*(pdf)$= 298b$.

LO(ME)$\otimes$ LO*(pdf)$= 288b$.

LO** slightly better than LO*. Similar for other $t$-channel process vector boson production of Higgs + two jets using NLO code VBFNLO (Zeppenfeld *et al*).

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

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

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

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

LO(ME)$\otimes$ LO**(pdf)$= 4.85pb$.



**Conclusions**

Neither standard LO and NLO partons ideal for LO generators.

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

Introduce modified LO* partons, i.e. momentum violation plus NLO coupling constant, and now Monte Carlo-inspired scale choice.

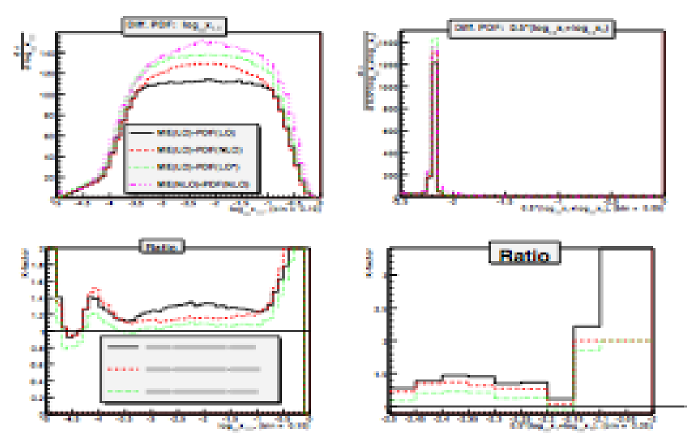
Comparison with processes where NLO known suggests modified LO* partons usually provides most reliable results – especially if sensitive to smallish $x$. Additional partons allowed by extra momentum compensate semi-universally for higher orders.

LO** partons, with additional Monte Carlo-inspired scale choice for coupling work even better.

Not always most accurate way to predict full NLO cross-sections ($t$-channel processes). However, never badly wrong for any particular parton in any particular range, unlike standard fixed order.



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.

# PDF4MC

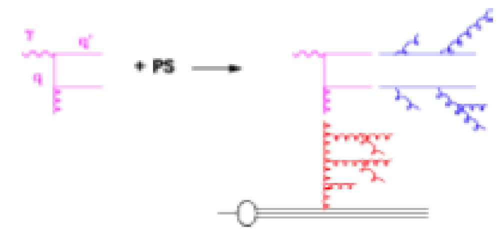
## PDF4MC

H. Jung, F. Samson-Himmelstjerna, M. von den Driesch
(DESY)

- PDF4MC
  why special PDFs for MCs are needed, necessary and important
  - Strategy:
    HOWTO obtain PDF4MC
  - which data to use for fits
    final states from HERA
  - dependence on MC
- Conclusions



## Motivation: example from HERA




- **Collinear approach:** incoming/outgoing partons are on mass shell
  $(y+q)^2 = q'^2$ , $-Q^2 + x\,y\,s = 0$ → $x = Q^2/(ys)$
- **BUT** final state radiation:
  $(y+q)^2 = q'^2$ , $-Q^2 + x\,y\,s = m^2$ → $x = (Q^2+m^2)/(ys)$
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- Collinear approach: $q'^2 = q^2 = 0$, order by order ....
- Well known.... since years....
- NLO corrections... better treatment of kinematics... but still not all....



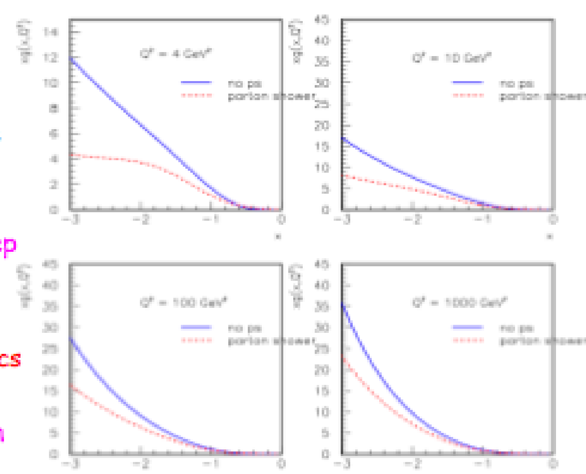
## gluon from $F_2$

- $F_2$ described by PYTHIA with reasonable $\chi^2$
- significant difference from including initial state parton showers
- gluon much less steep !!!!

→ change of kinematics

→ better treat kinematics from beginning

- special machinerie in DIS needed....






## Motivation

C.P. Yuan, DIS2007

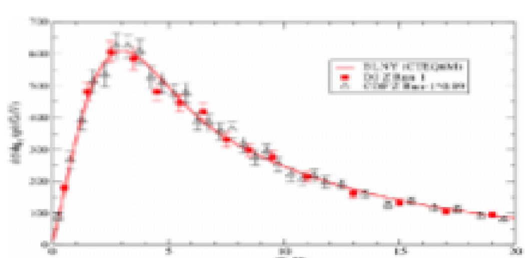
New from DIS07

New Task of Global Analysis

- Include Transverse Momentum $p_T$ distributions
- New Data: include not only rapidity ($y$) but also $p_T$ of Drell-Yan pairs and $Z$ bosons

QCD $P_T$ Resummation
Global Analysis

hep-ph/0212159
Brock, Landry, Nadolsky, CPY



# PDF4MC

## PDF4MC – why ?

- MC generators include not only LO ME – calculations, but include resummation to all orders via parton showers
- as resummations are now included in PDF determiantions, parton showers should also
- "factorization scheme" in MC event generators is not DIS, nor MSbar, but a MC specific factorization scheme
- in a global analysis, PDF and also parton shower parameters can be simultaneously determined ...
- kinematic effects of including transverse momenta can be important for PDFs



## Strategy

- fully consistent approach would require doubly uPDFs and appropriate factorization theorem, which will include collinear factorization and kt-factorization as asymptotic limits...
- branch 1: use uPDFs and $k_t$-factorization as done with CCFM and CASCADE (see talks at HERA-LHC WS 2008 by F. Houtmann, A. Knutsson and CASCADE)
- branch 2: use standard MCEG like PYTHIA/HERWIG/RAPGAP but also ALPGEN/SHERPA etc and obtain PDFs from fits to $F_2$ and TeVatron data, as done in global analyses
  - neither LO or NLO is appropriate
  - define MC-PDFs, depend on generator, parton showers etc
    - **MC-factorization scheme.... instead of MS bar**
  - include proper treatment of parton showers in initial and final state
  - include all kinematics from full simulation, no approximations



## Strategy (cont'd)

- use LHAPDF library for parton evolution and alphas
  - use any distribution and evolution code
  - evolve for every call (fast enough, can be improved if necessary...)
  - massive/massless treatment
- use HZTool/RIVET for comparison of MC prediction with measurements
  - HERA H1/ZEUS: $F_2$, $F_2^c$, jets etc....
  - and at a later stage ....
    - TeVatron CDF/D0: jets, W/Z x section as fct of pt
- use general fit program (PROFFIT A. Bacchetta, A. Knutsson, K. Kutak)
  - easily extendable for other MC generators and also NLO programs
  - Improvements for fits (in progress: A. Knutsson, K.Kutak, H. Hoeth)
    - ➔ calculation in grid points
      - ➔ parametrization
      - ➔ fit to data (including uncertainties)



## Which MCs to use for PDF4MC fit ?

Lund string fragmentation

- PYTHIA 6
  - for pp ok
  - not really applicable for ep DIS
    - inclusive $F_2$: NOT really
    - charm in DIS: NO
    - dijets: ok
- PYTHIA 8
  - for pp ...
  - DIS and ep NOT implemented
- RAPGAP
  - applicable for ep DIS
  - using PS similar to PYTHIA (but not exactly (conserve x...)
  - virtuality ordered shower
  - use Lund string

Cluster fragmentation

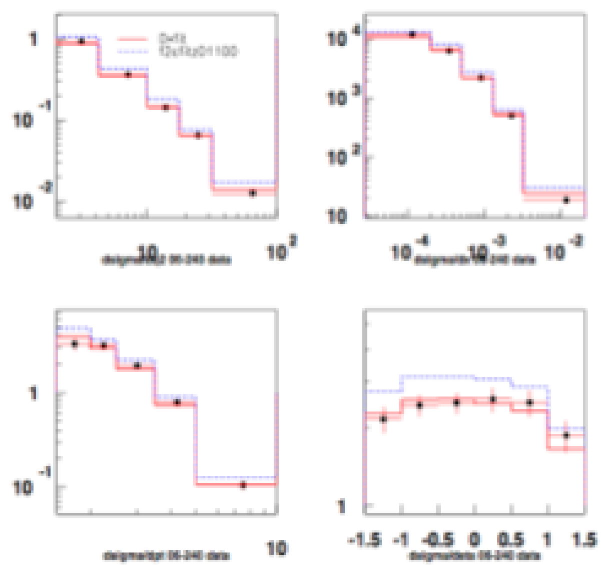
- HERWIG 6
  - for pp ok
  - not fully applicable for ep DIS
    - inclusive $F_2$
    - charm in DIS
    - dijets
- HERWIG++
  - for pp
  - DIS and ep NOT implemented

- USE RAPGAP
- for PDF4MC determiantion
- Use PYTHIA in dijets as x-check
- test "universality" of PDF4MC

# Fits to D* cross section

- use measured xsection of D*
- fit $Q^2, x, p_t, \eta$
- improve $\chi^2$ by 6 units compared to starting values
- much improved $\chi^2$ compared to F2c fit

Production of D*+- Mesons with Dijets in Deep-Inelastic Scattering at HERA.
H1 Collaboration (A. Aktas et al) Eur.Phys.J.C51:271-287,2007.hep-ex/0701023





# Gluon from D* with jets

- only slightly changed parameters
- BUT further constraints due to different kinematic regions
- Gluon can be well determined from visible charm x-section

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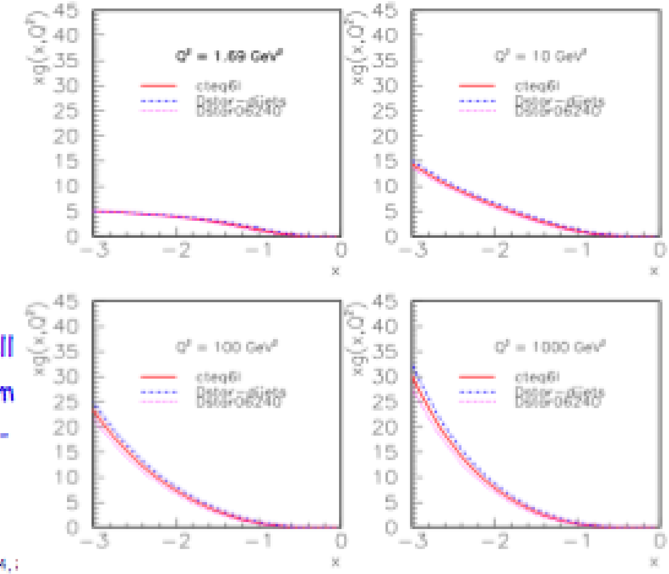



# Resume from heavy quarks

- use only visible cross sections,
  - at least for MC fits.... extrapolations to total x-section highly model dependent
  - D* and D*+jet measurements give consistent results for gluon
  - result is nearly identical to CTEQ6l
    - BUT pdf in massless scheme, and ME massive ...
    - NLO alphas in pdf, BUT LO alphas in ME
    - need to check consistency on mass parameters etc



# PDF4MC from dijets in DIS

- dijets in DIS, sensitive to gluons but also to quarks ...
- dijets can be calculated by PYTHIA and RAPGAP
  - consistency check and check for "universality" of PDF4MC

# PDF4MC

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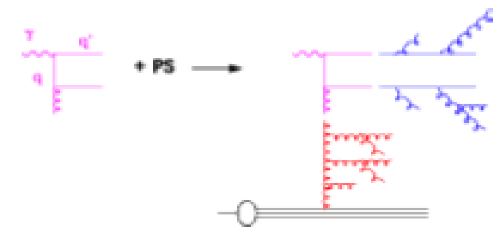


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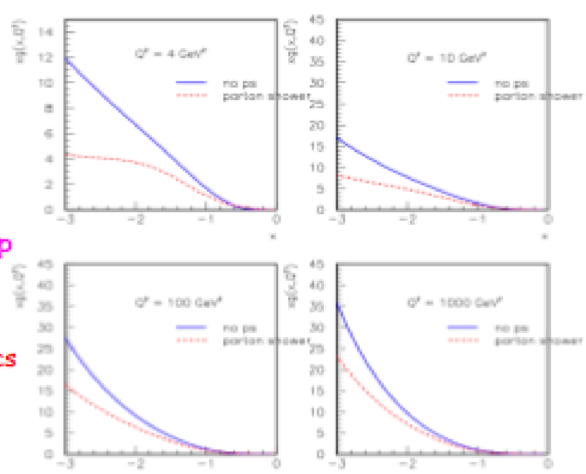




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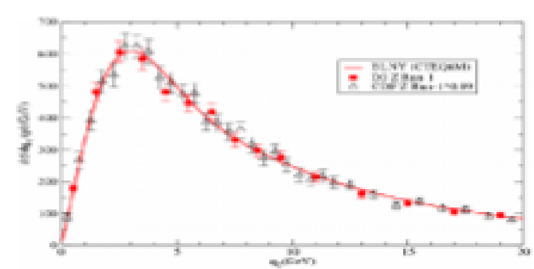
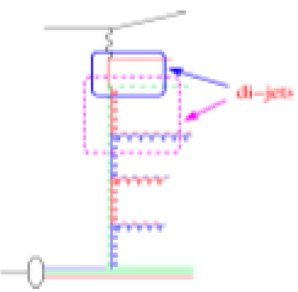


## Jets in DIS




- Using PYTHIA for jets in DIS NEW !!!
- gives reasonable results...
- for $E_t$ distributions gives

$$\frac{\chi^2}{ndf} = \frac{66}{36} = 1.8$$

with CTEQ6L

- Using H1 jet measurements (H1 EPJC 33 (2004) 477)

$5 < Q^2 < 100\ \mathrm{GeV}^2$

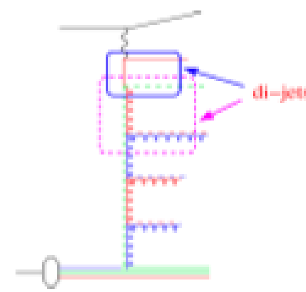
$-1 < \eta < 2.5$

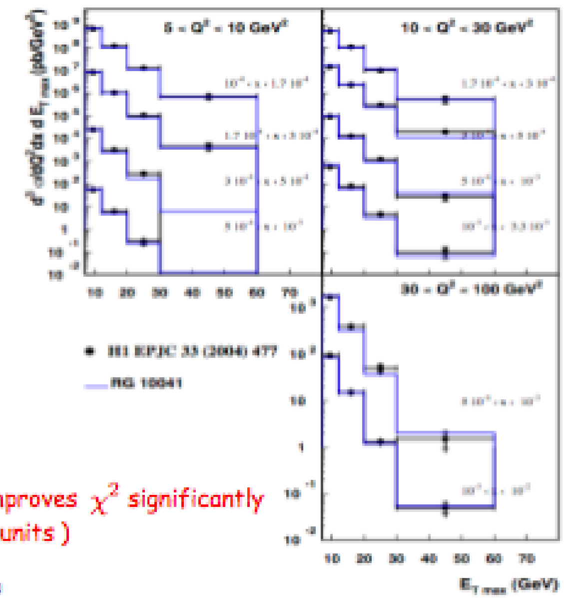
$E_T > 5\ \mathrm{GeV}$

- investigate x dependence of starting distribution



## Jets in DIS... after fit ...




- Using H1 jet measurements (H1 EPJC 33 (2004) 477)

$5 < Q^2 < 100\ \mathrm{GeV}^2$

$-1 < \eta < 2.5$

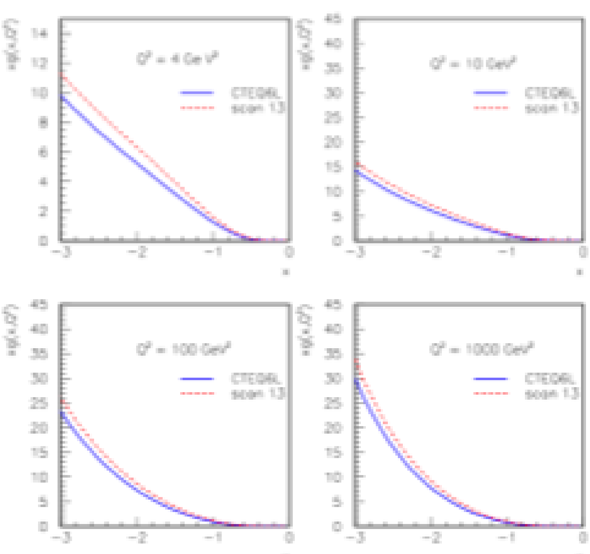
$E_T > 5\ \mathrm{GeV}$

Fit improves $\chi^2$ significantly (~30 units )



## Gluon from dijets

- fit normalisation of gluon, other params give similar results.
- significant $\chi^2$ improvement in
- norm different from D* fits
- need to investigate influence of quarks... which also lead to similar $\chi^2$ improvement in






## Universality checks

- Dijets in DIS calculated with PYTHIA / RAPGAP
  - both using $Q^2$ ordered PS and Lund string fragmentation
  - matrix element and ME+PS matching is different
- Important check for consistency of both MCs
  - never done before, in terms of PDF fits
- consistency of PDF fits with both generators

➔ little dependance on details of PS

# PDF4MC

## Next steps …

- tools are available …
- relevant data are selected and available ( would be even better to use precise preliminary measurements of D* !!!!!)
- investigate fitting of quark initial parameters
- real fits including error treatment can start now
- expect 1st PDF4MC during summer

➔ PDF4MC is one of the activities of MC group of Terascale Analysis Center at DESY ….



## Conclusions

- using PDF4MC helps to improve description of data by MCs
- PDF4MC are "universal":
  - ➔ depend on parton showers and fragmentation (?)
  - ➔ do not depend on MC generator (if same PS is used…)
- concept of PDF4MC works
  - ➔ fitted parameters are close to global fits
    - ➔ but improve $\chi^2$ significantly
  - ➔ ready for a global PDF4MC fit of HERA
- Plan to have 1st PDF4MC from HERA final state released by end of summer (2008) !