Fast pQCD Calculations for QCD Fits

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fastNLO

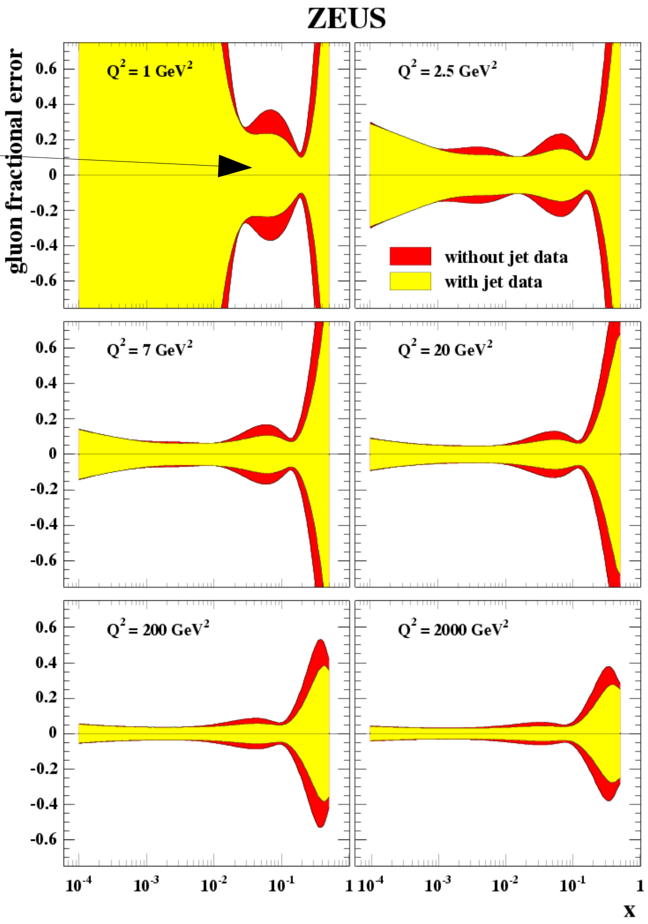
http://hepforge.cedar.ac.uk/fastnlo

basic concept: shown e.g. in talks at DIS06, TeV4LHC

this talk: status of project, selected details

Motivation

- Wealth of jet measurements from HERA and TEVATRON not yet exploited by global pdf fits
- Jets give additional constraints on gluon at higher x
- Exclusive variables, need time consuming MC integration
- Required for fits: fast and precise prediction as function of α_s and pdfs
- Key: separate integration of ME from α_s and pdf



CPU weeks, months, years

Calculate once per measured data set
Save in

Table

0.5 ms

Plug in pdf and α_s
Get cross section

Scope of fastNLO

Produce ready to use packages for pdf fitters

Package contains precalculated table, FORTRAN (alternative: C++) code returns cross sections, with interface to α_s and pdfs

Results in bins and units etc. as published

Provide info of stat. and syst. precision of the result binwise

Up to now: use NLOJET++ for DIS and hadron-hadron at NLO
plus 2-loop threshold corrections (hadron-hadron) Kidonakis, Owens
Tables available for HERA, TEVATRON, RHIC, LHC
Product available for download since June, 5, 2006

Not only fits, convenient for estimation of theory uncertainties, etc.
fastNLO going to be used for upcoming publications of H1, ZEUS, D0, STAR

Bonus: quick and easy access to cross sections via web interface

remaining part of the talk, details about precision, efficiency, some results, plans

Efficiency of pdf interpolation

Need to interpolate pdfs between discrete points in x

Hadron-hadron: no brute force (ultra fine binning) due to quadratic growth of table

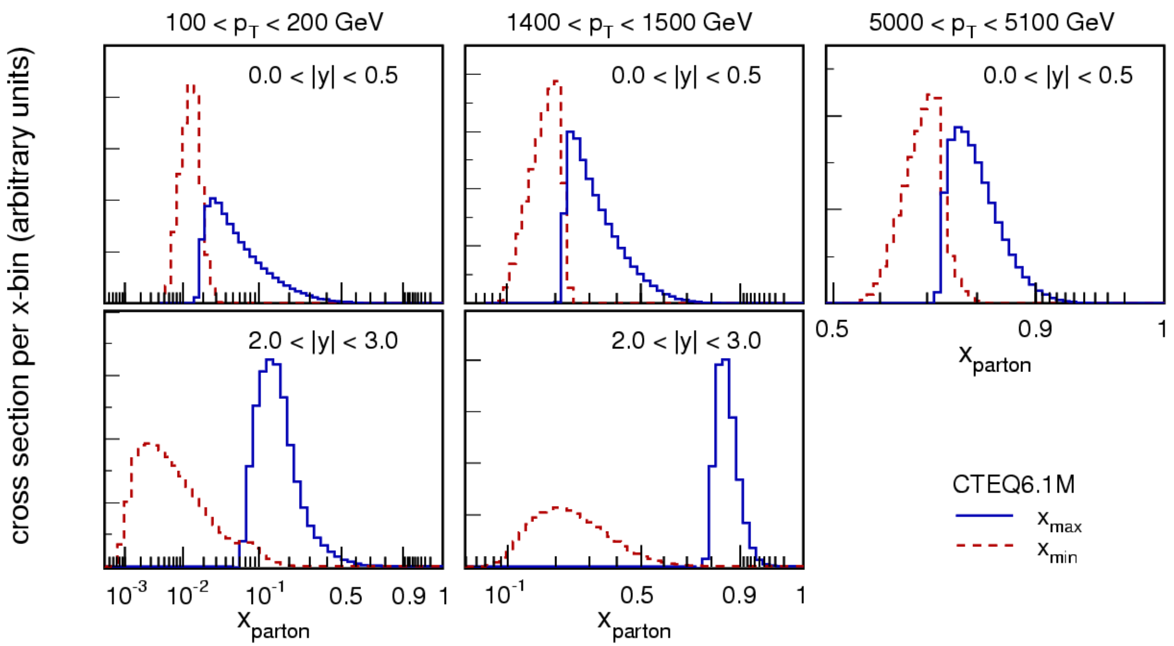
Get best precision for given number of x "bins"
Crucial: steep, curved regions

Need many points there: equidistant bins after transfomation, here sqrt(log(1/x))

$x_1, x_2 \rightarrow x_{min}, x_{max}$ (exploit symmetry)

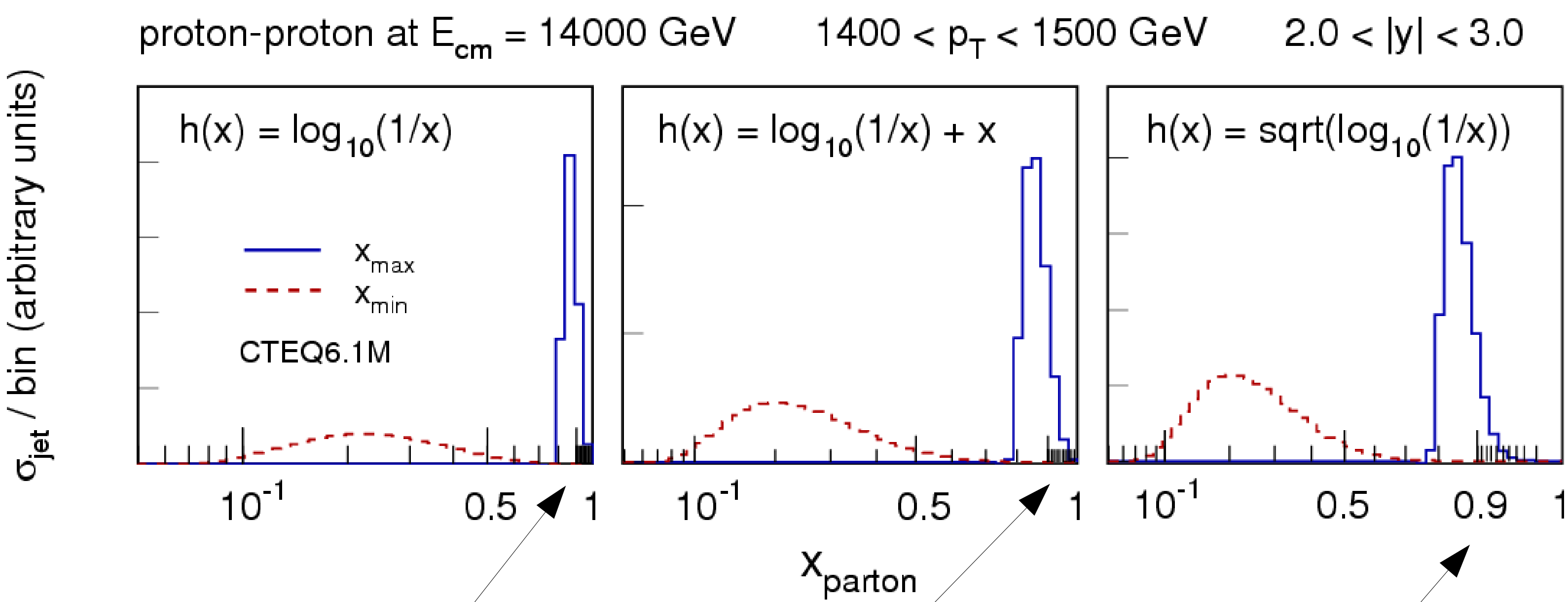
Issue: forward region
phasespace squeezed into small range,
reason for sqrt(log(1/x))

LHC inclusive jet scenario



Efficiency of pdf interpolation

Advantage of sqrt(log(1/x)) to other transformation functions (example):



#bins for x_{max}>0.9: **3** **4** **8**

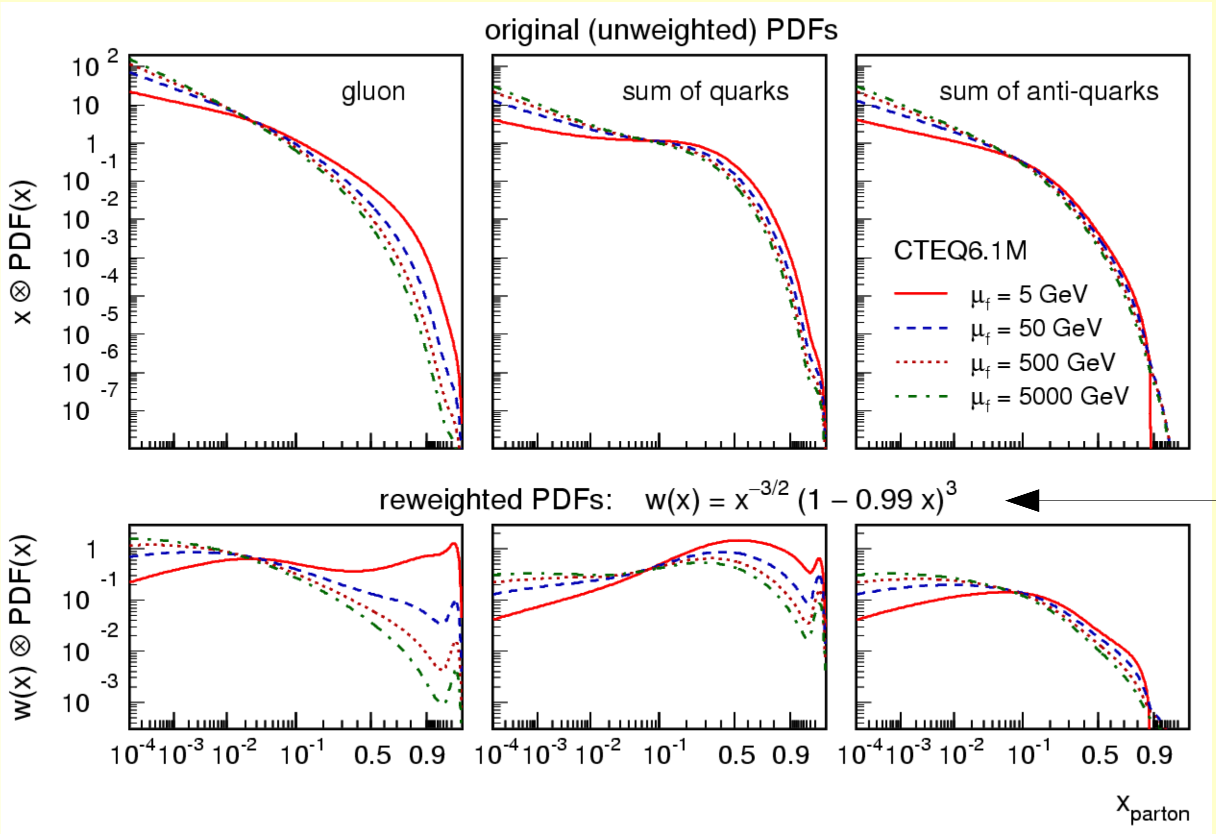
Interpolation of pdfs hampered by curvature

Reweight pdfs! Instead x·pdf(x) interpolate f(x)·pdf(x)

After reweighting: use cubic interpolation for remaining curvature...

before

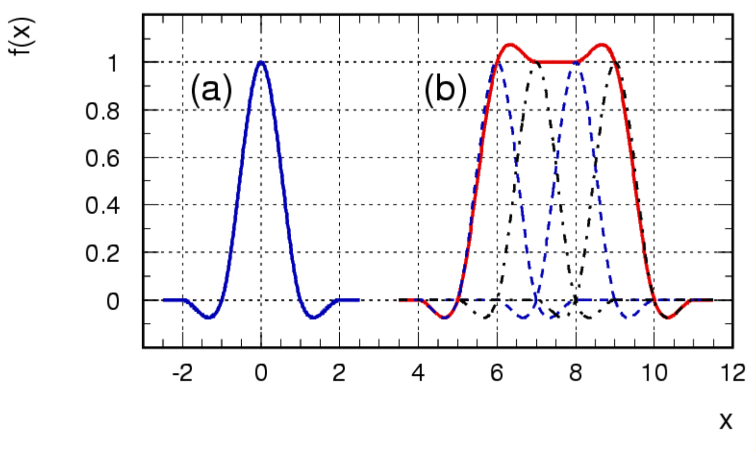
after



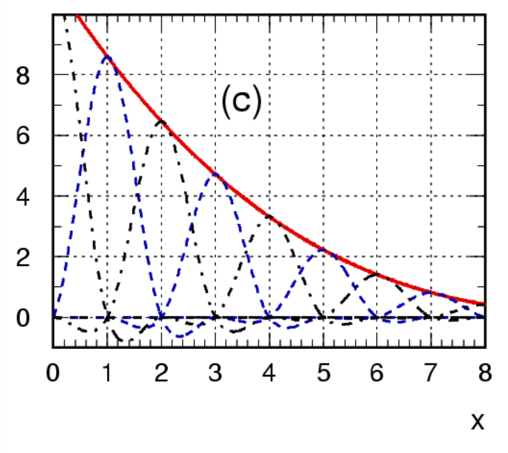
reweighting function

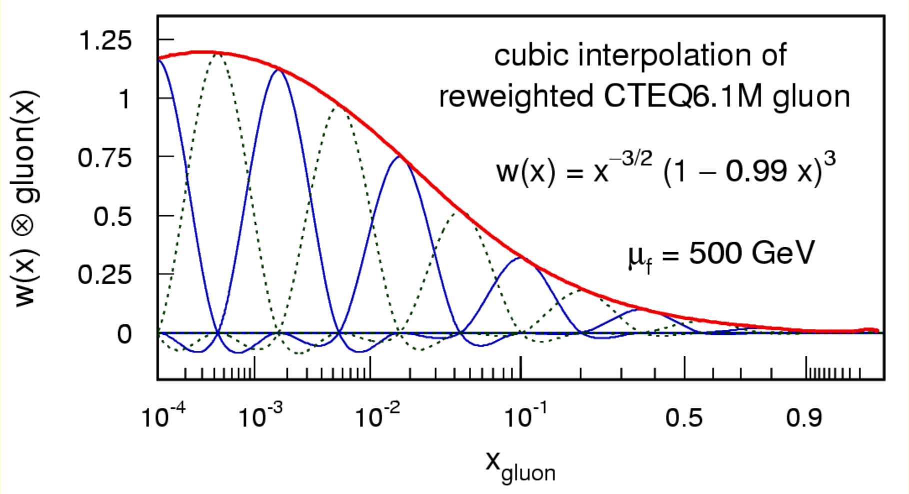
Cubic Interpolation

Several Eigenfunctions a).....



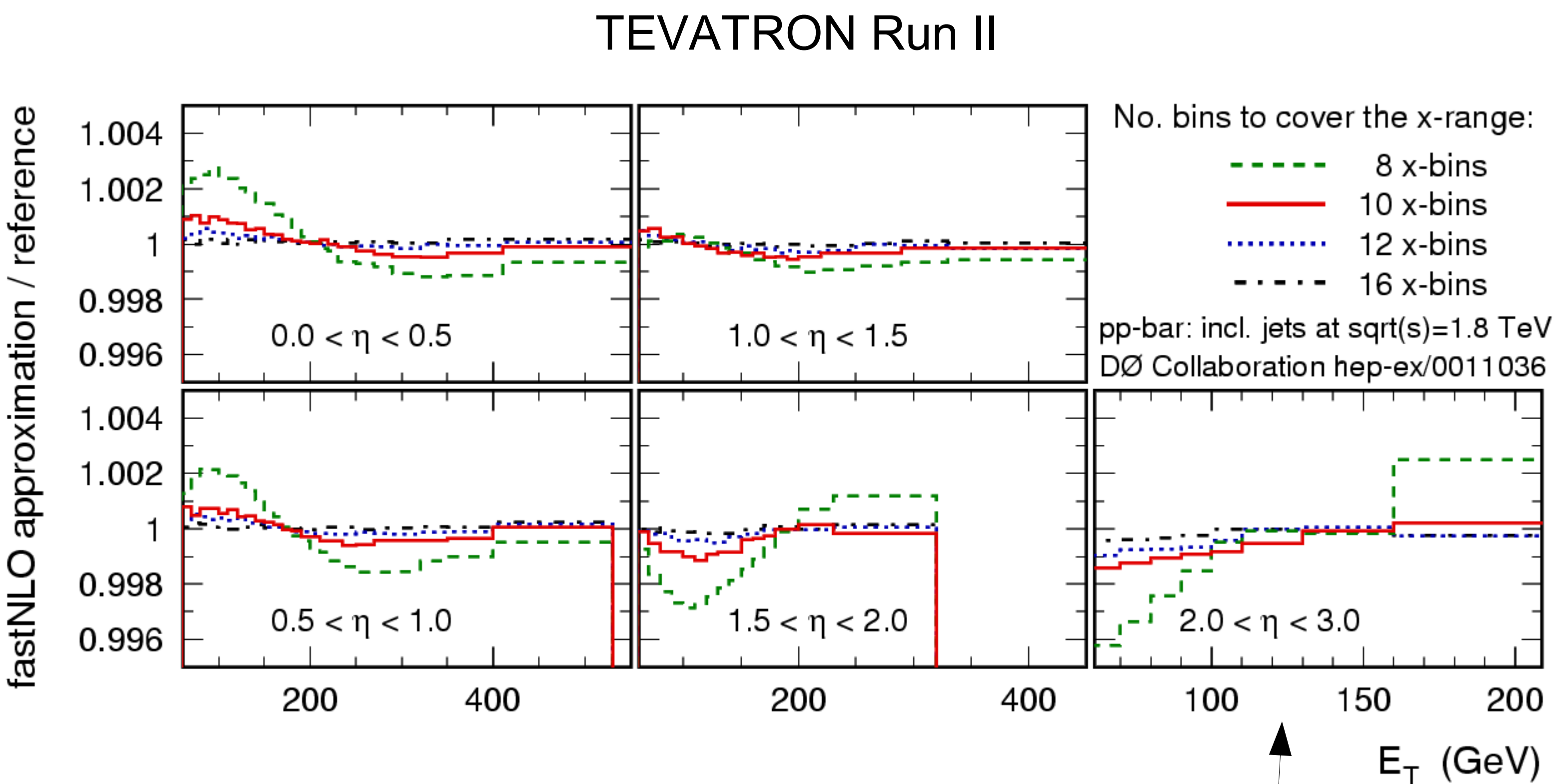
...approximate nicely a curved function c) ....





...such as a reweighted gluon density, with only 12 “x-bins”

Precision

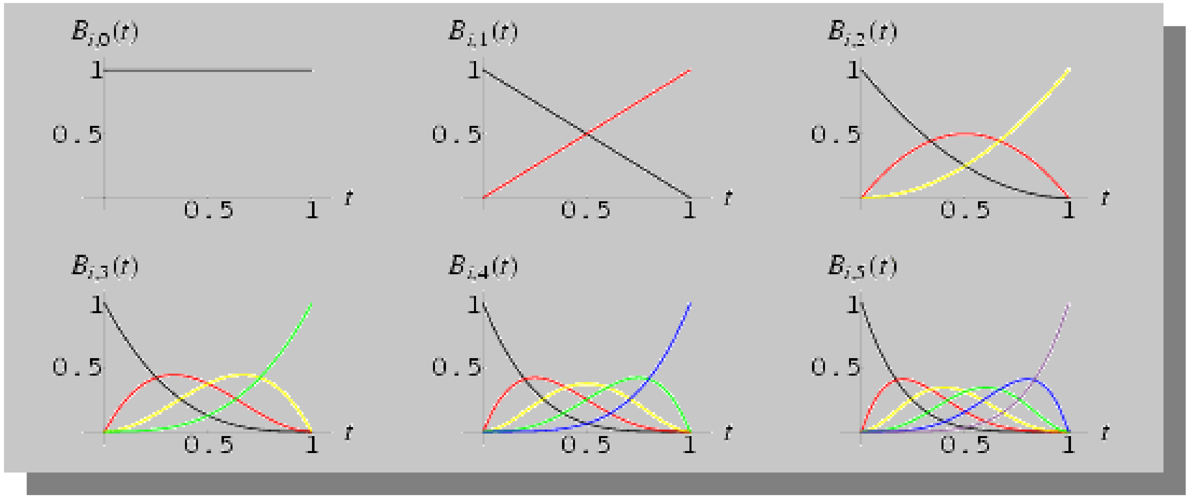


only 10 x-bins sufficient for precision of 0.1%, even in forward region

Scales

factorisation scale: choose between 4 scales: $1/4p_t$, $1/2p_t$, p_t, $2p_t$
renormalisation scale: arbitrary scale variation possible (for LO+NLO part)

Measured bins span range in jet p_t, what to choose when calculating table?
Bin center not exactly known (depends on pdf, α_s)...
Interpolate!
1) small p_t range: fixed scale at middle of bin
2) larger range: interpolation with Bernstein polynomials, (used e.g. for HERA jets)



MathWorld

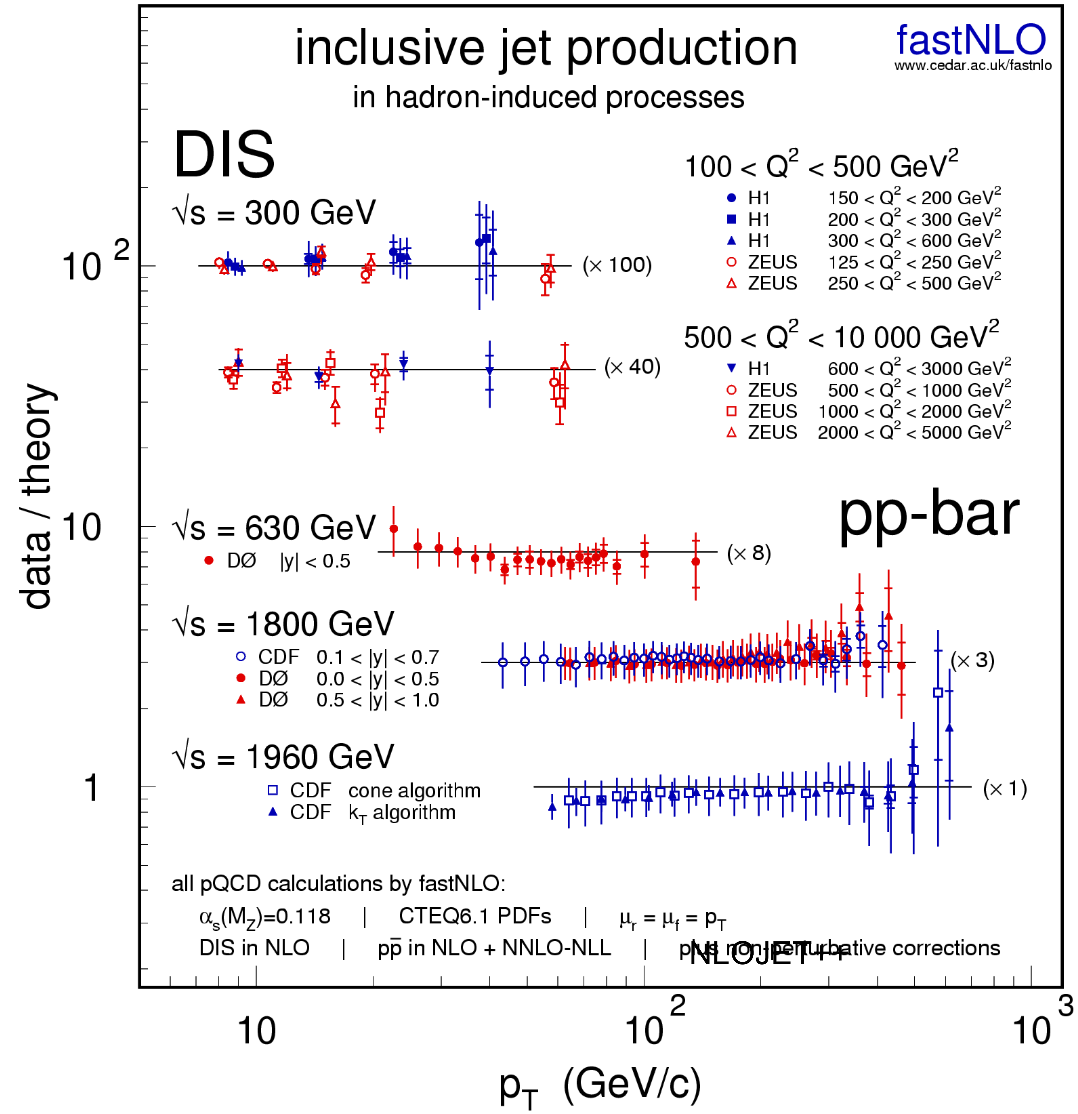
Applications

Inclusive jet data:
several processes, experiments, center of mass energies and p_t ranges

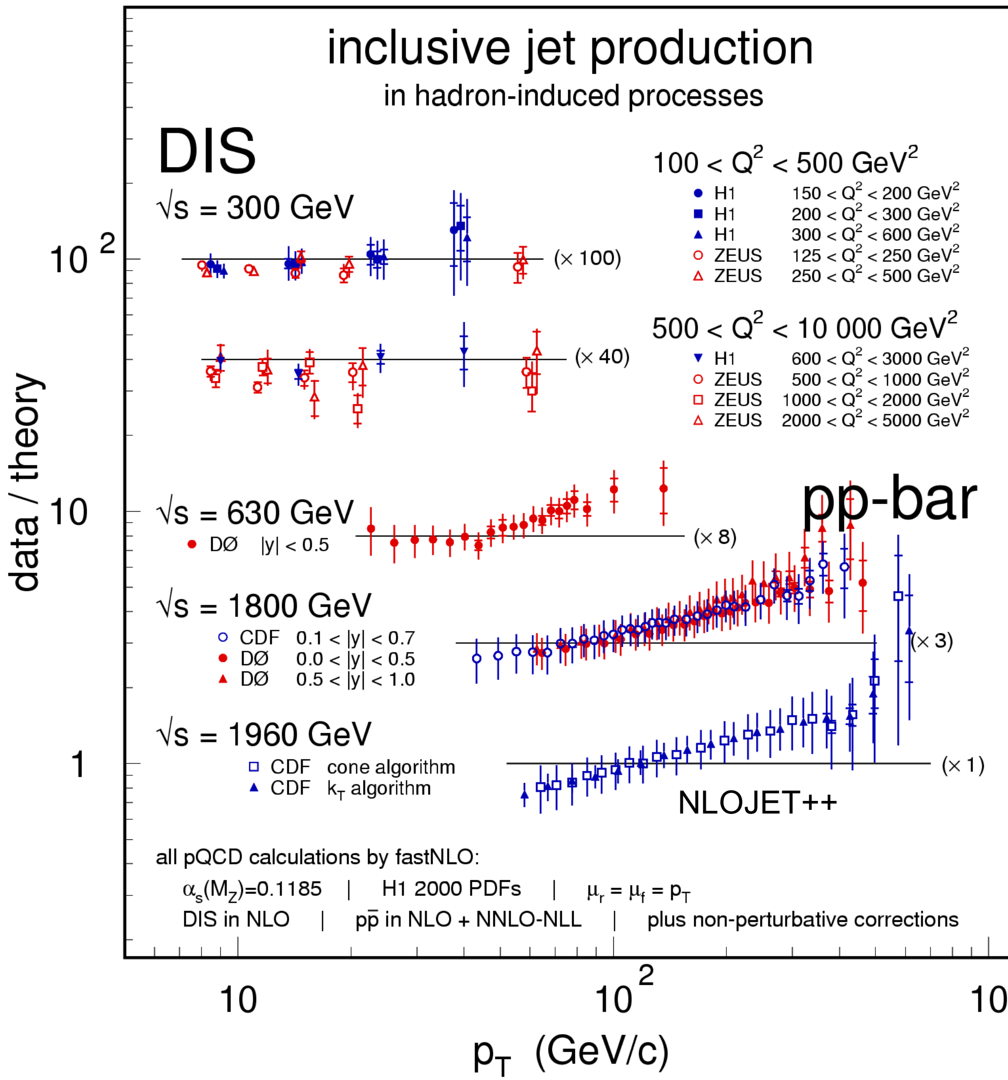
Predictions obtained with fastNLO based on NLOJET++, CTEQ 6.1 pdfs and $\alpha_s(m_Z)=0.118$

Good description of all the data

Can be used in fits!



The same, now with H1 2000 pdfs



This pdfs do not include jet data into fit

Cannot describe TEVATRON jets,
wrong p_t dependence

Do not describe HERA jets neither,
-> use jets in next fit!

Available Applications

LHC: pp @ sqrt(s)=14TeV		
fnl2004	test-scenario for ATLAS, incl. jets, kT algo (pT, y)	
	code	table
Tevatron Run II: pp-bar @ sqrt(s)=1.96TeV		
fnt2001	DØ dijets, cone algo (DeltaPhi, pT)	
	hep-ex/0409040,	(the data at Durham)
	code	table1 and table2
fnt2002	CDF incl. jets, cone algo (pT)	
	hep-ex/0512020,	(the data at Durham)
	code	table (midpoint), table (Rsep)
fnt2003	CDF incl. jets, kT algo (pT)	
	hep-ex/0512062	(the data at Durham)
	code	table

HERA: ep @ sqrt(s)=300GeV or 320GeV		
fnh1001	H1 incl. jets, kT algo (ET, Q2)	
	hep-ex/0010054	(see table 2 in hep-ex/0010054)
	code	table
fnh1002	ZEUS incl. jets, kT algo (ET, Q2)	
	hep-ex/0208037	(the data at Durham)
	code	table
fnh1003	H1 incl. jets, kT algo (ET) @low Q2	
	hep-ex/0206029	(the data at Durham)
	code	table
fnh1004	H1 dijets, kT algo (ET, Q2)	
	hep-ex/0010054	(the data at Durham)
	code	table
RHIC: pp @ sqrt(s)=200GeV		
fnr0001	STAR preliminary incl. jets, cone algo (pT)	
	code	table (midpoint)

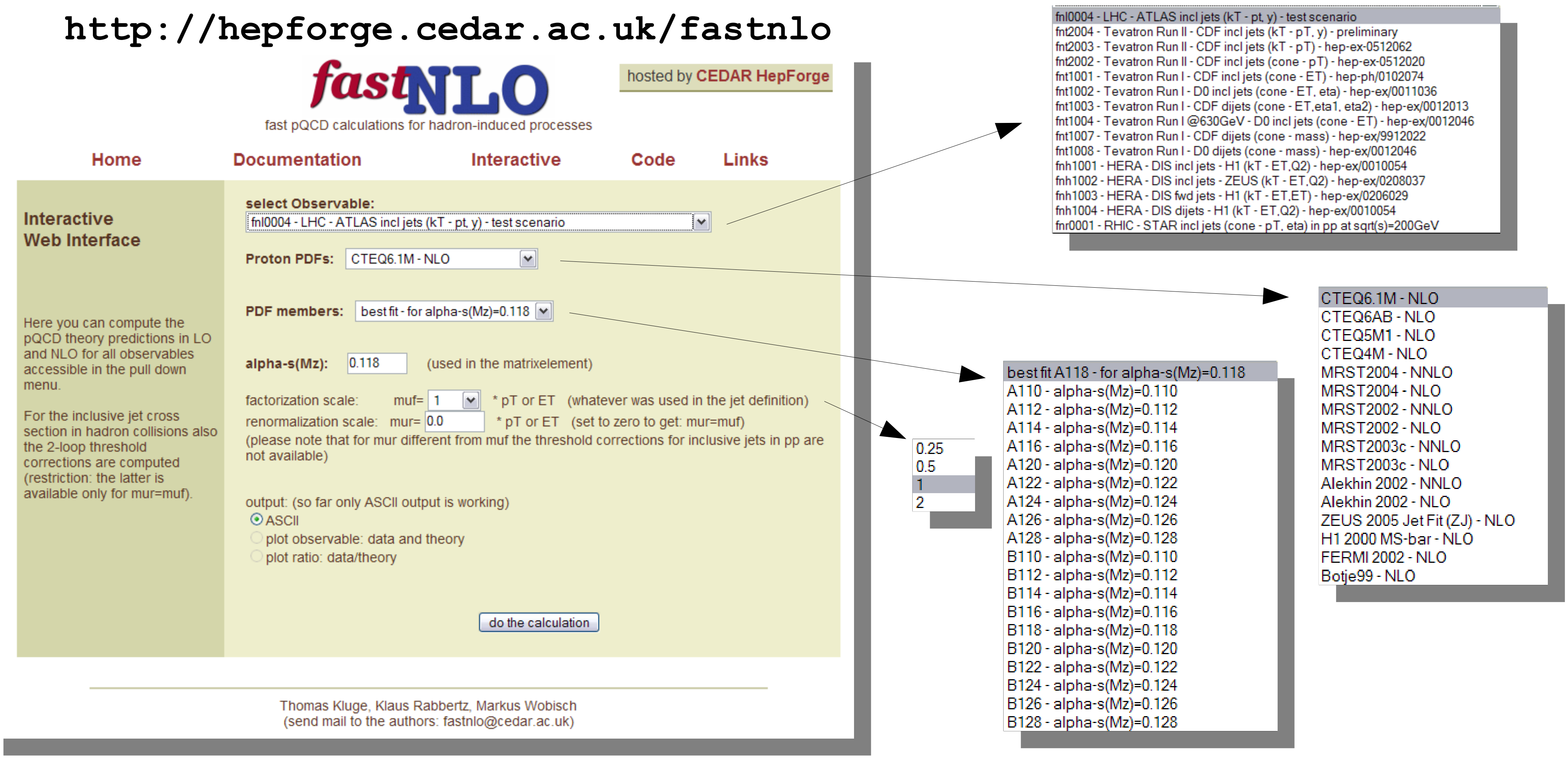
Tevatron Run I: pp-bar @ sqrt(s)=1.8TeV		
fnt1001	CDF incl. jets, cone algo (ET)	
	hep-ph/0102074	(the data at Durham)
	code	table (midpoint), table (Rsep)
fnt1002	DØ incl. jets, cone algo (ET, eta)	
	hep-ex/0011036	(the data at Durham)
	code	table (midpoint), table (Rsep)
fnt1003	CDF dijets, cone algo (ET, eta1, eta2)	
	hep-ex/0012013	(the data at Durham)
	code	table (midpoint), table (Rsep)
fnt1004	DØ incl. jets @ sqrt(s)=630GeV, cone algo (ET)	
	hep-ex/0012046	(the data at Durham)
	code	table (midpoint), table (Rsep)
fnt1005	DØ incl. jets, ratio 630/1800GeV, cone algo (xT)	
	hep-ex/0012046	(the data at Durham)
	code	table1, table2 (midpoint) or table1 table2 (Rsep)
fnt1007	CDF dijets, cone algo (mass)	
	hep-ex/9912022	(the data at Durham)
	code	table (midpoint), table (Rsep)
fnt1008	DØ dijets, cone algo (mass)	
	hep-ex/0012046	(the data at Durham)
	code	table (midpoint), table (Rsep)

All with high statistics, typically 6 CPU months

Combined effort of H1 Farm, D0 Farm and GRID

Web Interface to fastNLO

http://hepforge.cedar.ac.uk/fastnlo



Choose measurement, pdf set and member, α_s and scales....

Web Interface to fastNLO

```
     fastNLO: compute the cross section
# #################################################################
#
#   fastNLO - version 1.4          Jan. 31, 2006
#
#   Thomas Kluge, Klaus Rabbertz, Markus Wobisch
#
#   if you use this code, please cite as reference:
#       T. Kluge, K. Rabbertz and M. Wobisch,
#          publication in preparation,
#          (hep-ex No. to be added)
#
#      .... now reading the coefficient table:
#       tableformat is version  1.4
#       26200000000 events in LO
#       24600000000 events in NLO
#           2764800 events in NNLO-NLL-(threshold-corrections)
#           No. of x bins:  12
#
#      this table contains: d2sigma-jet_dpT_dy_(pb_GeV)
#      as published in:     not-published
#      by:                  ATLAS-test-scenario
#
#      reaction: proton-proton
#      process:  inclusive jets
#      total No. of observable bins:  103
#      jet algo: kT algorithm
#         parameter 1:  D    =  0.7
#         parameter 2:  n/a         =  0.
#
#
#      the single contributions have been computed
#      using the following codes:
#      LO
#         by: NLOJET++
#      NLO
#         by: NLOJET++
#      NNLO-NLL-(threshold-corrections)
#         by: Kidonakis-Owens
#
#   for NLOJET++ please cite:
#       Z. Nagy, Phys. Rev. Lett. 88, 122003 (2002),
#       Z. Nagy, Phys. Rev. D68, 094002 (2003).
#
#   the 2-loop threshold corrections for the inclusive jet
#   cross section in pp and ppbar have been computed by:
#   N. Kidonakis and J.F. Owens - please cite
#      N. Kidonakis, J.F. Owens, Phys. Rev. D63, 054019 (2001).
```

```
 --  fastNLO - results for  d2sigma-jet_dpT_dy_(pb_GeV)
 --    cross sections:                LO          NLOcorr       2-loop        total
 --------  muf/mu0=  1.      mur/mu0=  1.
        from    0. -    0.8  in:  y
pT_in_GeV      60.00-   80.00:   0.1300E+06   0.2101E+05   0.2955E+05   0.1805E+06
pT_in_GeV      80.00-  100.00:   0.3811E+05   0.6493E+04   0.7745E+04   0.5235E+05
pT_in_GeV     100.00-  130.00:   0.1184E+05   0.1977E+04   0.2197E+04   0.1602E+05
pT_in_GeV     130.00-  160.00:   0.3617E+04   0.6351E+03   0.6145E+03   0.4866E+04
pT_in_GeV     160.00-  200.00:   0.1210E+04   0.2100E+03   0.1911E+03   0.1611E+04
pT_in_GeV     200.00-  250.00:   0.3766E+03   0.6726E+02   0.5525E+02   0.4991E+03
pT_in_GeV     250.00-  300.00:   0.1256E+03   0.2277E+02   0.1723E+02   0.1656E+03
pT_in_GeV     300.00-  350.00:   0.4964E+02   0.9113E+01   0.6447E+01   0.6520E+02
pT_in_GeV     350.00-  400.00:   0.2211E+02   0.4131E+01   0.2742E+01   0.2898E+02
pT_in_GeV     400.00-  450.00:   0.1079E+02   0.2067E+01   0.1285E+01   0.1414E+02
pT_in_GeV     450.00-  500.00:   0.5650E+01   0.1087E+01   0.6497E+00   0.7387E+01
pT_in_GeV     500.00-  600.00:   0.2476E+01   0.4901E+00   0.2730E+00   0.3239E+01
pT_in_GeV     600.00-  700.00:   0.8916E+00   0.1813E+00   0.9326E-01   0.1166E+01
pT_in_GeV     700.00-  800.00:   0.3642E+00   0.7596E-01   0.3645E-01   0.4766E+00
pT_in_GeV     800.00-  900.00:   0.1635E+00   0.3504E-01   0.1576E-01   0.2143E+00
pT_in_GeV     900.00- 1000.00:   0.7893E-01   0.1733E-01   0.7368E-02   0.1036E+00
pT_in_GeV    1000.00- 1200.00:   0.3095E-01   0.7007E-02   0.2788E-02   0.4074E-01
pT_in_GeV    1200.00- 1400.00:   0.9430E-02   0.2238E-02   0.8150E-03   0.1248E-01
pT_in_GeV    1400.00- 1600.00:   0.3234E-02   0.8099E-03   0.2718E-03   0.4316E-02
pT_in_GeV    1600.00- 1800.00:   0.1205E-02   0.3129E-03   0.9957E-04   0.1618E-02
pT_in_GeV    1800.00- 2000.00:   0.4759E-03   0.1284E-03   0.3905E-04   0.6434E-03
pT_in_GeV    2000.00- 2200.00:   0.1958E-03   0.5551E-04   0.1611E-04   0.2674E-03
pT_in_GeV    2200.00- 2400.00:   0.8285E-04   0.2437E-04   0.6895E-05   0.1141E-03
pT_in_GeV    2400.00- 2600.00:   0.3568E-04   0.1095E-04   0.3028E-05   0.4966E-04
pT_in_GeV    2600.00- 2800.00:   0.1552E-04   0.4956E-05   0.1353E-05   0.2183E-04
pT_in_GeV    2800.00- 3000.00:   0.6765E-05   0.2256E-05   0.6106E-06   0.9631E-05
pT_in_GeV    3000.00- 3500.00:   0.1811E-05   0.6408E-06   0.1739E-06   0.2626E-05
pT_in_GeV    3500.00- 4500.00:   0.1154E-06   0.4618E-07   0.1292E-07   0.1745E-06
        from    0.8 -    1.6  in:  y
pT_in_GeV      60.00-   80.00:   0.1160E+06   0.1968E+05   0.2947E+05   0.1651E+06
pT_in_GeV      80.00-  100.00:   0.3347E+05   0.5487E+04   0.7472E+04   0.4643E+05
pT_in_GeV     100.00-  130.00:   0.1025E+05   0.1792E+04   0.2056E+04   0.1410E+05
pT_in_GeV     130.00-  160.00:   0.3078E+04   0.5313E+03   0.5566E+03   0.4166E+04
pT_in_GeV     160.00-  200.00:   0.1014E+04   0.1786E+03   0.1682E+03   0.1361E+04
pT_in_GeV     200.00-  250.00:   0.3106E+03   0.5500E+02   0.4717E+02   0.4128E+03
pT_in_GeV     250.00-  300.00:   0.1019E+03   0.1854E+02   0.1425E+02   0.1347E+03
pT_in_GeV     300.00-  350.00:   0.3963E+02   0.7346E+01   0.5181E+01   0.5216E+02
```

... and obtain a second later cross sections, precision based on months of CPU time

Summary

- Available: fastNLO on the web with jet observables from
  - HERA, TEVATRON, RHIC, LHC
  - LO+NLO (NLOJET++), hadron-hadron: 2-loop threshold corrections
- After >1 year of hard work (beta released 9 months ago):
  Ready, download **now**: code to be used for fits, instructions how to use
  - needs 0.5ms per point
  - precision typically better than 0.1%
  - ... to be used in global pdf fits
- Plans:
  - include photoproduction (when included in NLOJET++)
  - other processes, Drell-Yan, ...
- Towards V2.0:
  - establish future proof standard for tables, XML (code exists, using Xerces DOM)
  - fastNLO could be a common repository of calculations (not only NLO), together with www.arXiv.org and Durham database -> future impact of today measurements