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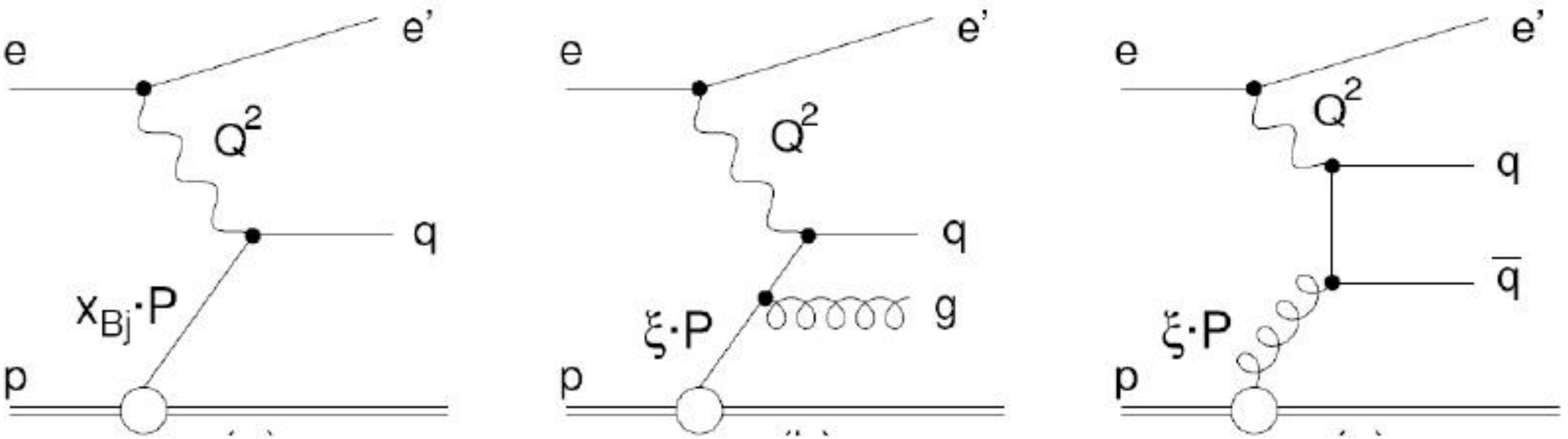
Jet Production at Low Q^2 DIS and determination of α_s

- Motivation
- Analysis:
  - Data sample, event selection
  - Correction procedure
  - Systematic errors
- Results
  - Cross sections, comparison with NLO
  - α_s fits
- Conclusions

Motivation

High P_T jets in Breit frame sensitive to α_s and to gluon content of the proton



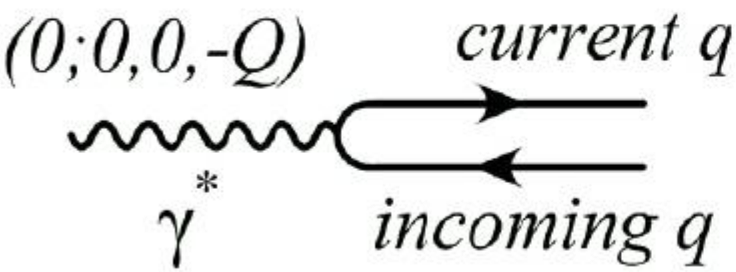
Born Level **QCD Compton** **Boson Gluon Fusion**

This analysis:

- Measure inclusive, 2-jets and 3-jets from HERA-1 data
- Extract α_s from these measurements

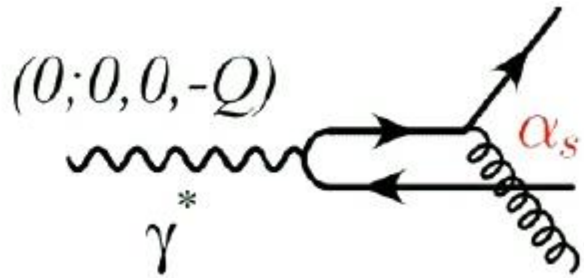
Together with high Q^2 analysis running of α_s can be tested at scales ~5÷100 GeV

NC Jet Production in DIS in Breit frame



Born level process

-Q/2



QCD compton

Breit frame: proton and virtual photon collide head-on, in the naive quark-parton model the quark bounces off from the photon

Born level contribution is suppressed

transverse momentum in Breit frame stems mainly from QCD process

Jets well separated from the proton remnant (P_T=0)

longitudinally invariant k_T jet-algorithm in the Breit frame,

collinear and infrared safe

Low Q^2 NC DIS Jet Event Selection

- **Kinematical Region** (eΣ method)
  - $5 < Q^2 < 100$ GeV^2
  - $0.2 < y < 0.7$

- **Jet Selection**
  - Inclusive kt algorithm in Breit frame
  - $p_{TBreit} > 5$ GeV
  - $-1.0 < \eta_{lab} < 2.5$
  - for 2,3 jet cross-sections: $M_{j1,j2} > 18$ GeV

Data statistics

Lumi	≥1 jet	≥ 2 jet (M_{JJ}>18 GeV)	≥ 3 jet (M_{JJ}>18 GeV)
43.5 pb^{-1}	164,520 ev. (230,140 jets)	31,550 ev.	4879 ev.

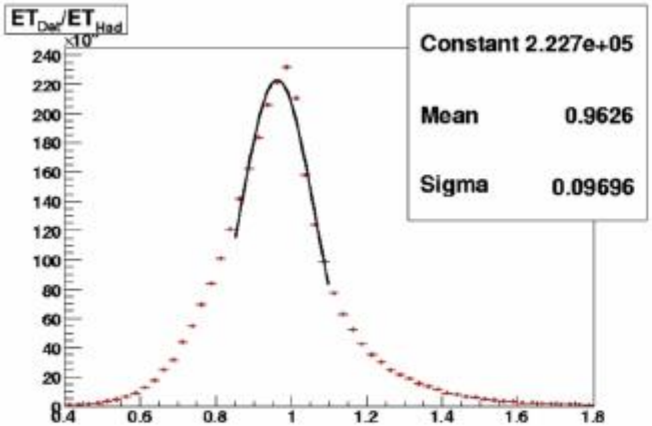
Monte Carlo files for detector corrections

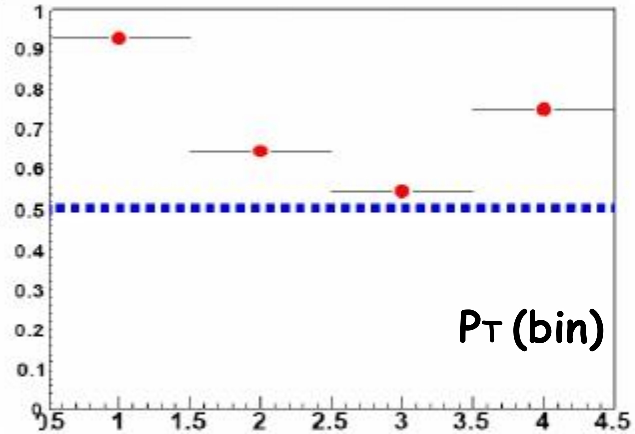
- DJANGOH 1.4 (CDM) Lumi=1070 pb^{-1}
- RAPGAP 3.1 Lumi=1550 pb^{-1} low-x
  4180 pb^{-1} high-x

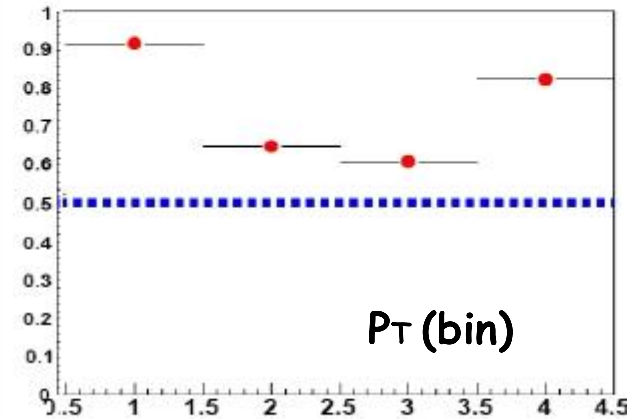
Jet resolution, purity, stability vs PT, Q2

Purity

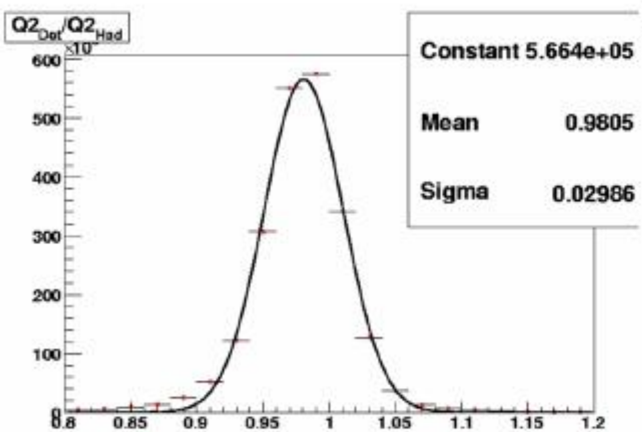
Stability

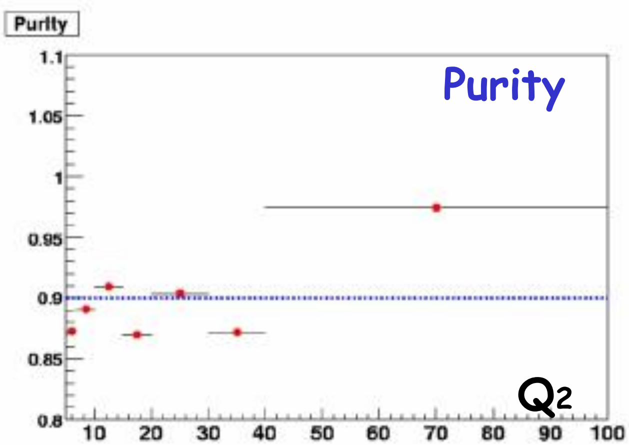


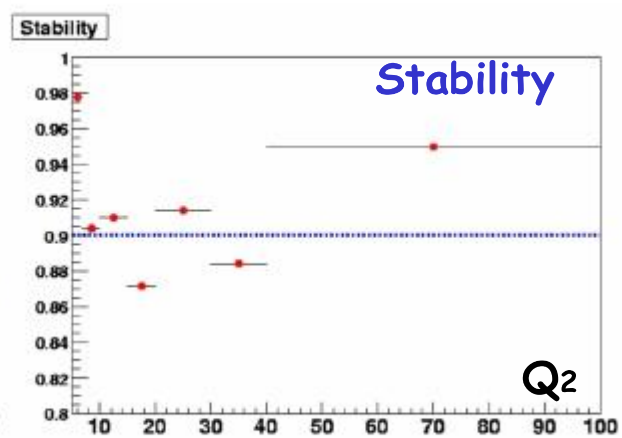




DJANGO







Cross-section measurements

Results are presented as differential and double differential cross-sections vs
- Q^2, P_T for inclusive jets
- Q^2 and $\langle P_T \rangle$ for 2-jets and 3-jets, 3j/2j ratios
- Q^2 and ξ for 2-jets.

$$\langle P_T \rangle \equiv \left(\frac{P_{T,jet1} + P_{T,jet2}}{2} \right) \qquad \xi \equiv x_{Bj} \left(1 + \frac{M_{jj}^2}{Q^2} \right)$$

7 bins in Q^2 (5-7-10-15-20-30-40-100 GeV^2) - for inclusive, 2-jets

4 bins in Q^2 (5-10-20-40-100 GeV^2) - for 3-jets, 3j/2j ratios

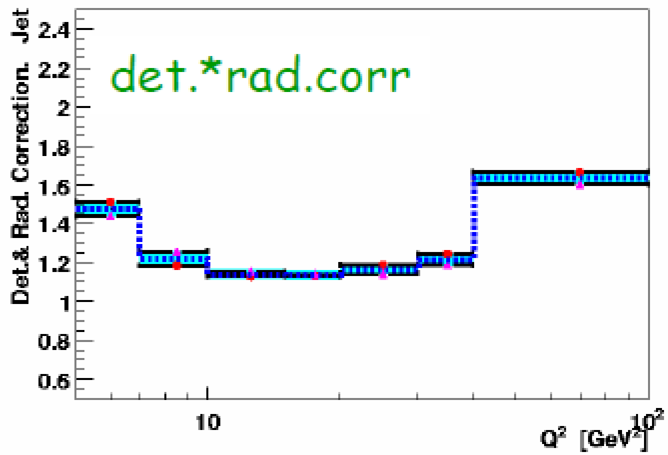
4 bins in P_T (5-10-15-20-80 GeV)

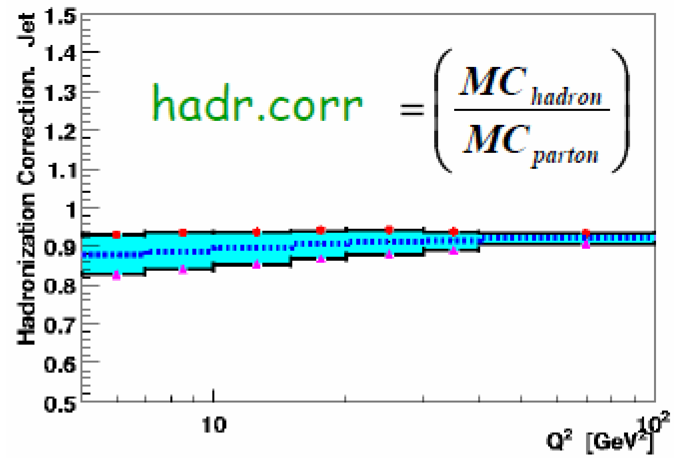
6 bins in ξ (0.004-0.006-0.01-0.025-0.05-0.1-0.3) - for 2-jets

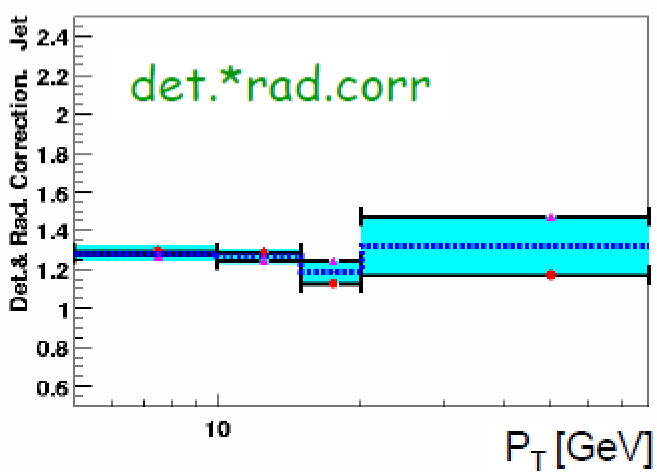
Det.Corr. Rad.Corr.

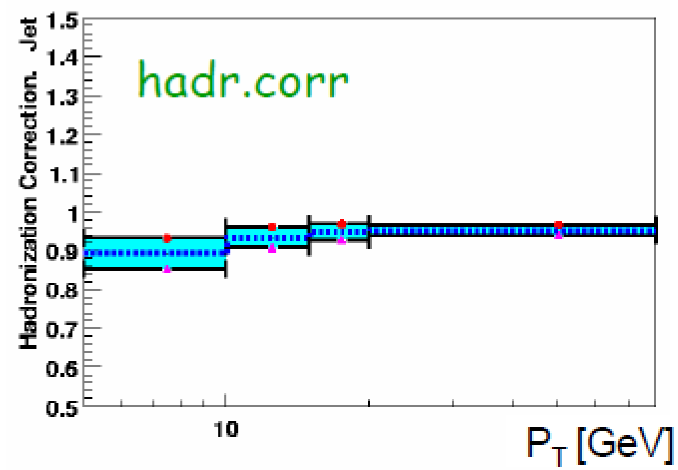
$$\frac{d^2\sigma}{dQ^2 dP_T} = \frac{N_{events} \times \left(\frac{MC^{Rad}_{Hadr}}{MC^{Rad}_{Det}} \right) \times \left(\frac{MC^{NoRad}_{Hadr}}{MC^{Rad}_{Hadr}} \right)}{\Delta P_T \times \Delta Q^2 \times Trig.eff \times Lumi}$$

Detector×Rad and Hadronisation Corrections for incl.jets



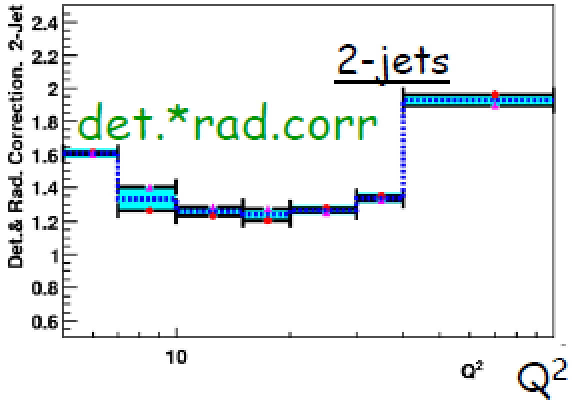


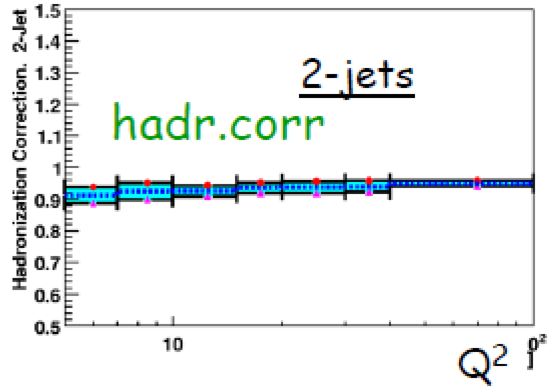




$$hadr.and.mod.unc. = \left| \frac{DJANGO - RAPGAP}{2} \right|$$

Detector × radiative, hadronisation corrections (Q^2 distributions)





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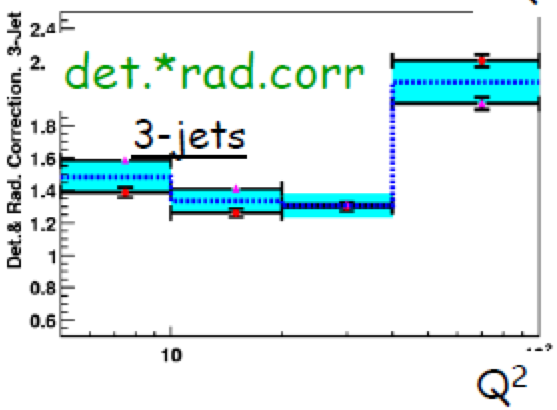
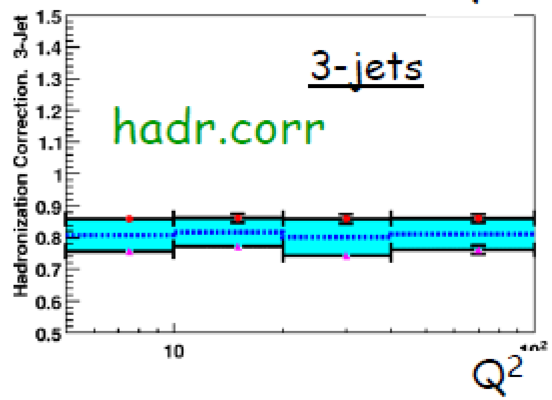
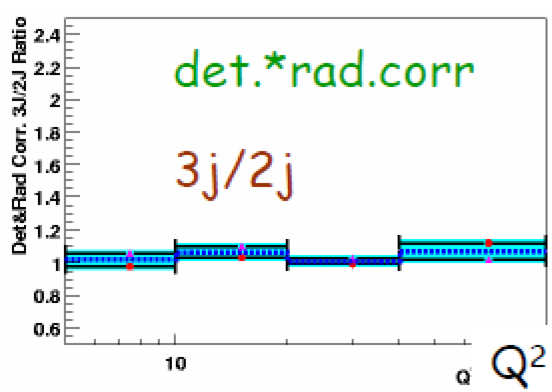
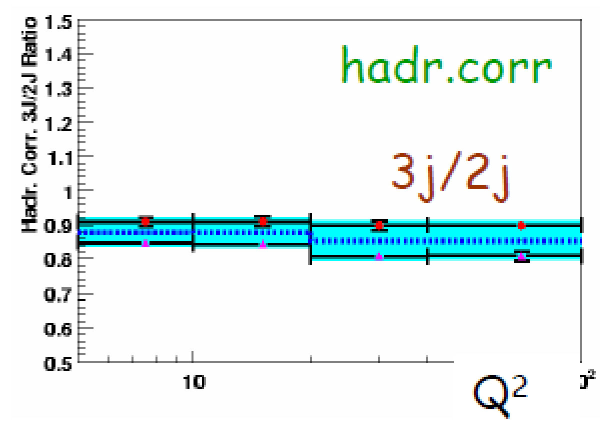
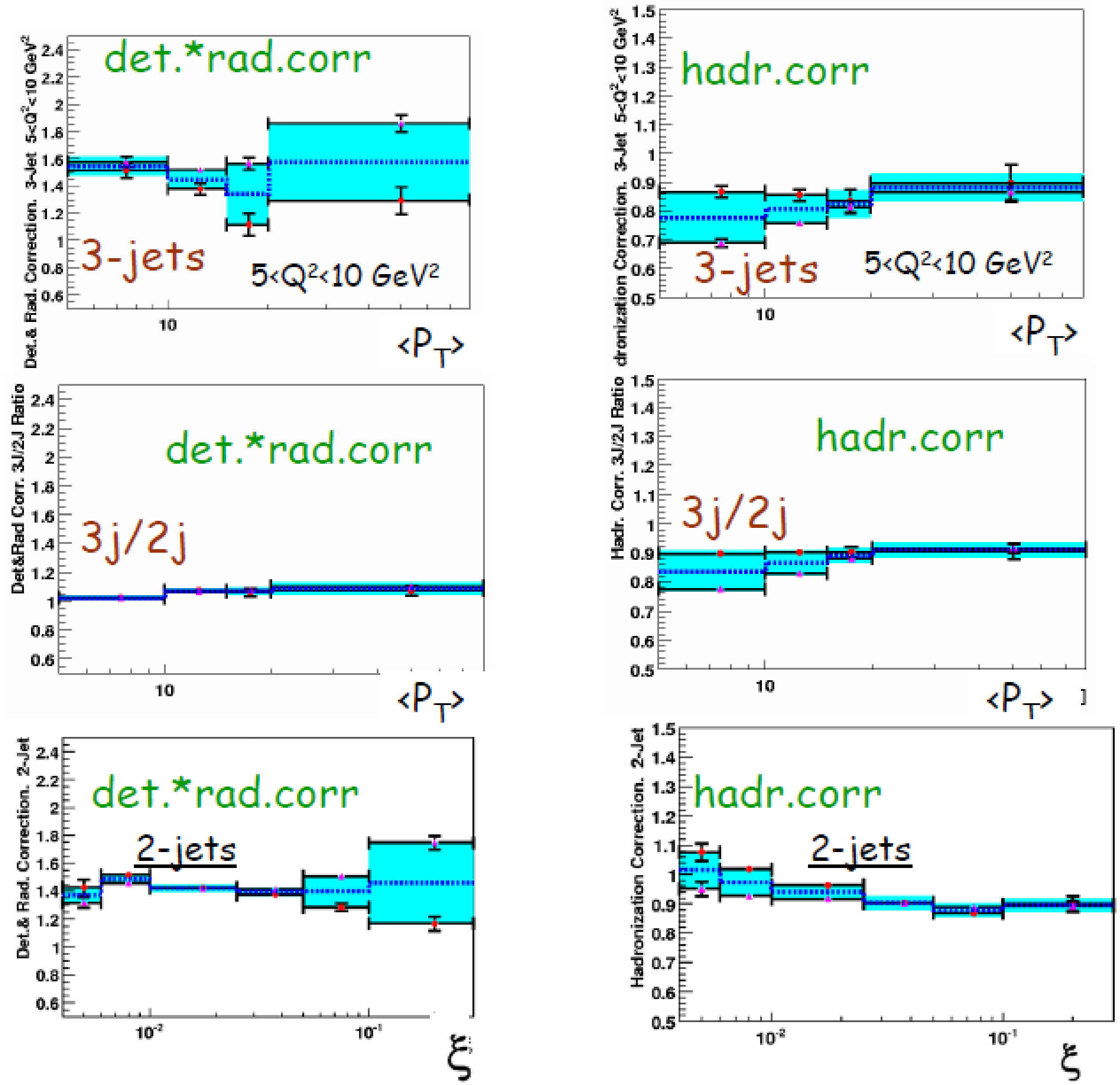








Detector x radiative, hadronisation corrections



Summary systematic errors

Systematic uncertainties are calculated for each bin

source	variation	effecton cross-section
Electron energy	±1%	< 2%
Electron angle	±1mrad	< 2%
Hadron energy	±2%	4÷10%
Model dep. (det×rad)	(Django-Rapgap)/2	2÷ 15%
lumi		1.5%
trig.eff.		<1%

Results

Cross-section measurements

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NLO calculation: NLOJET++

$$\mu_f, \mu_r = \sqrt{\frac{Q^2 + P_T^2}{2}}$$

α_s=0.118

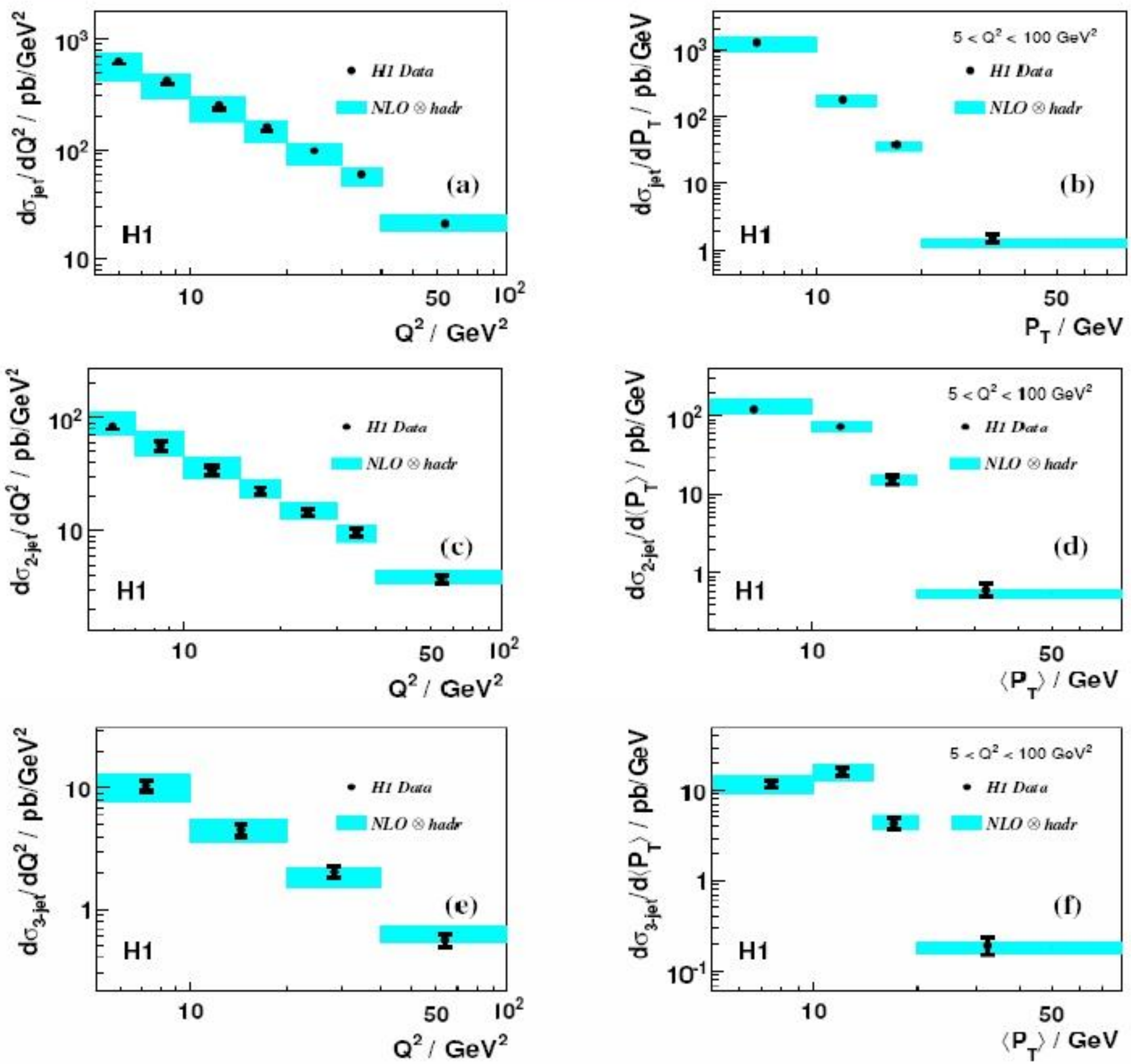
CTEQ6.5M proton PDF

Single differential cross sections vs Q^2 and P_T (or $\langle P_T \rangle$)

Inclusive Jets

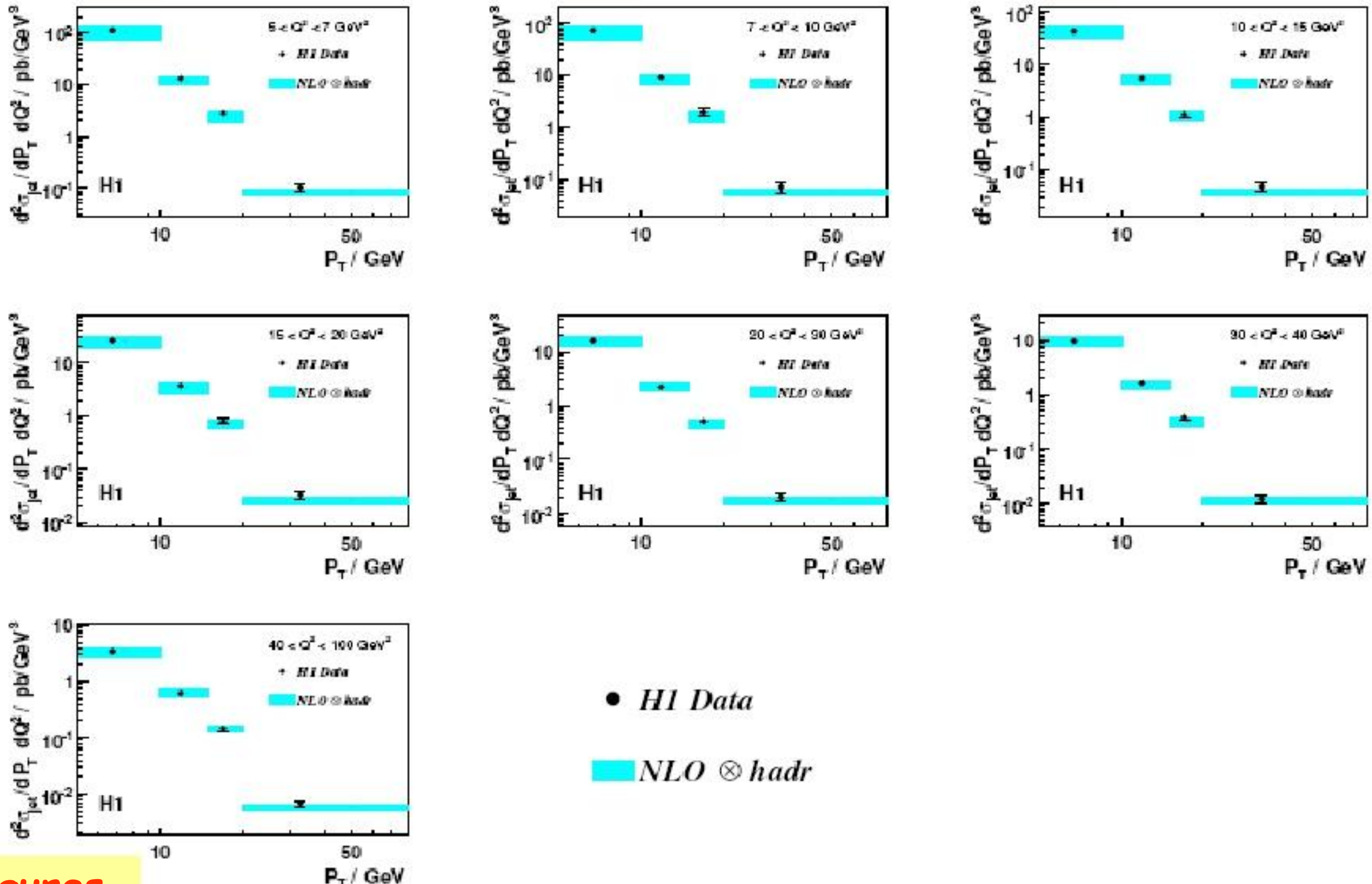
2-Jets

3-Jets



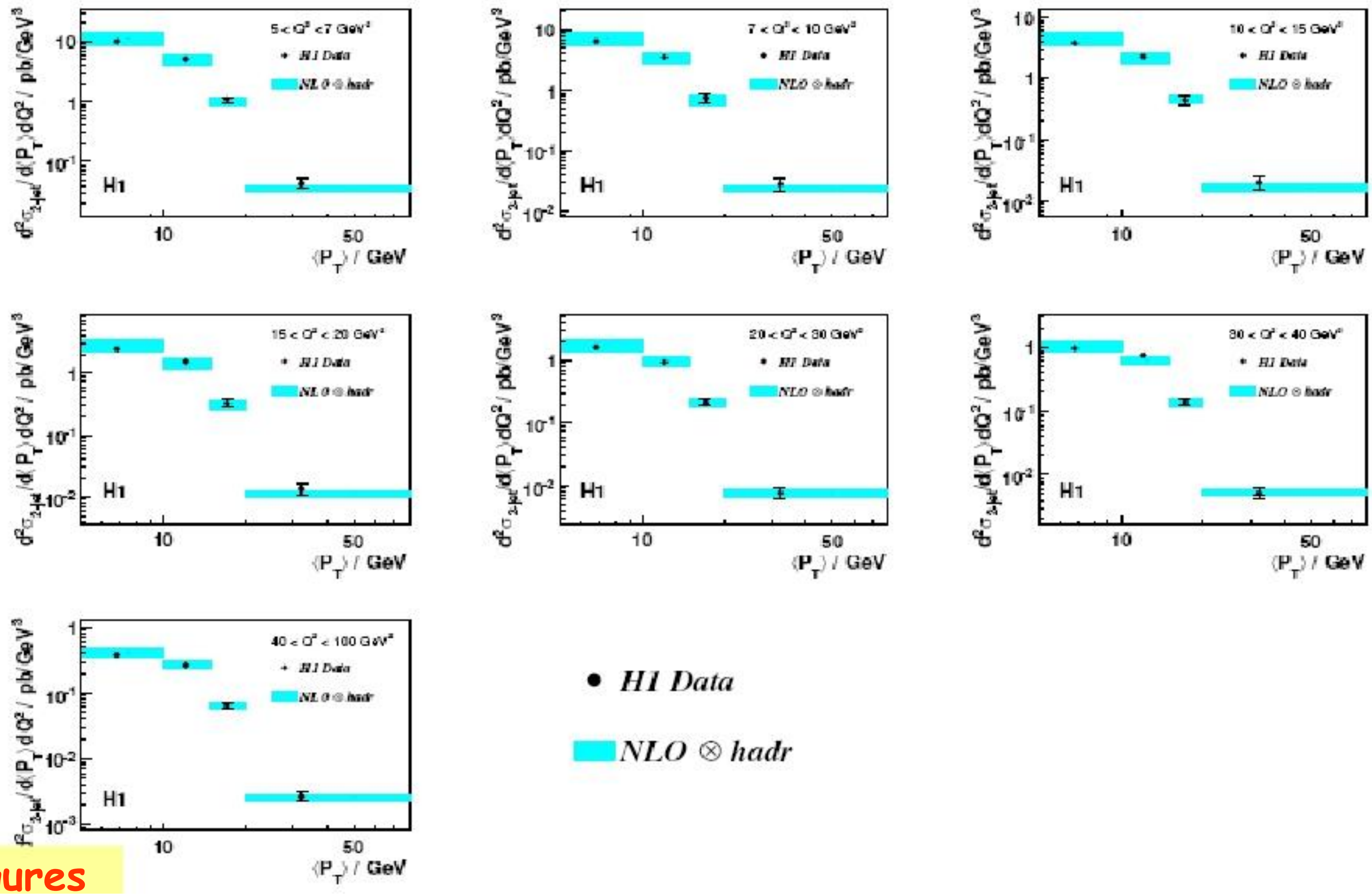
figures from paper

Double differential cross sections vs Q2 and PT (inclusive jets)



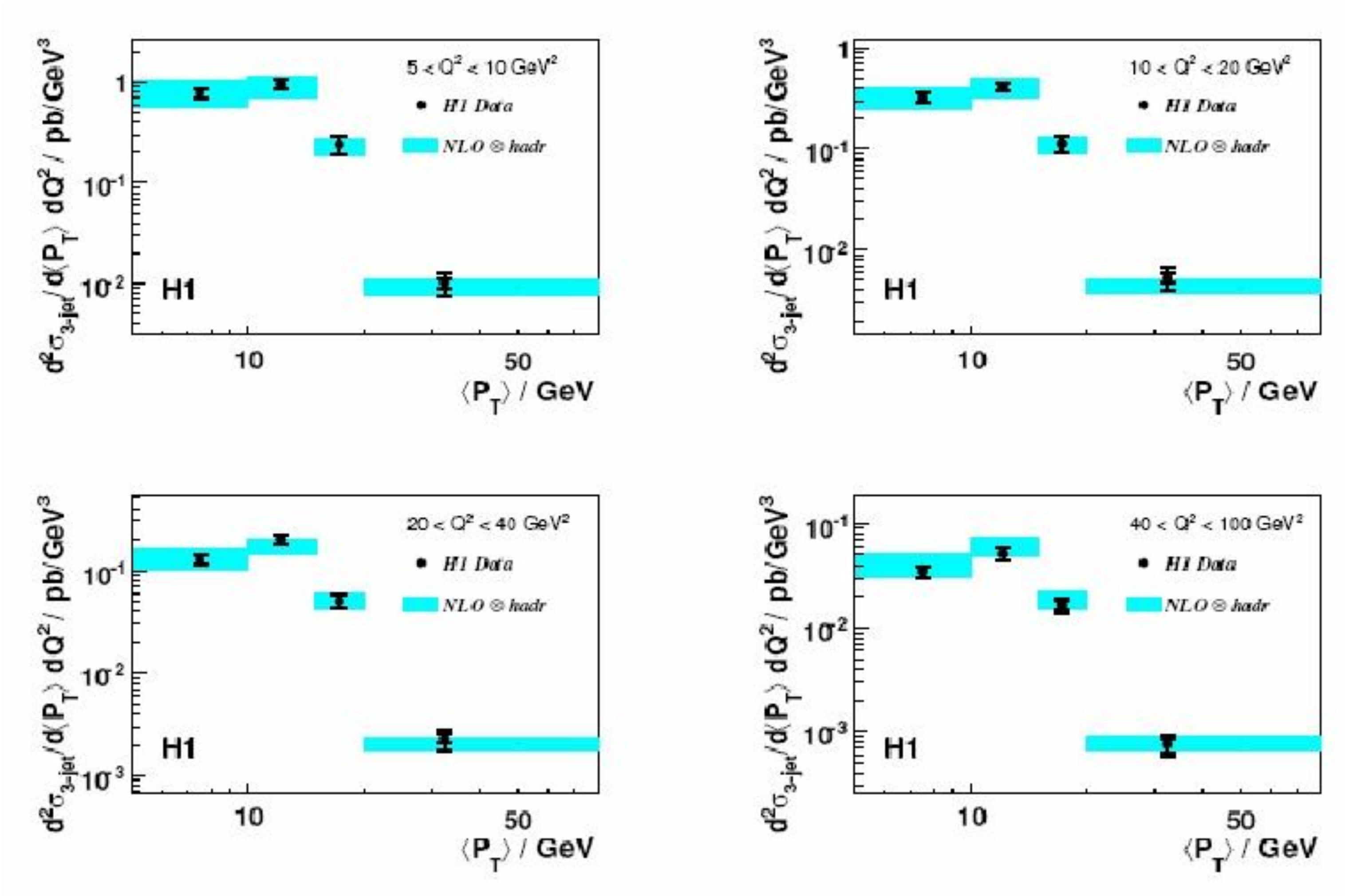
figures from paper

2-jets: Double differential cross sections vs Q2 and <PT>



figures from paper

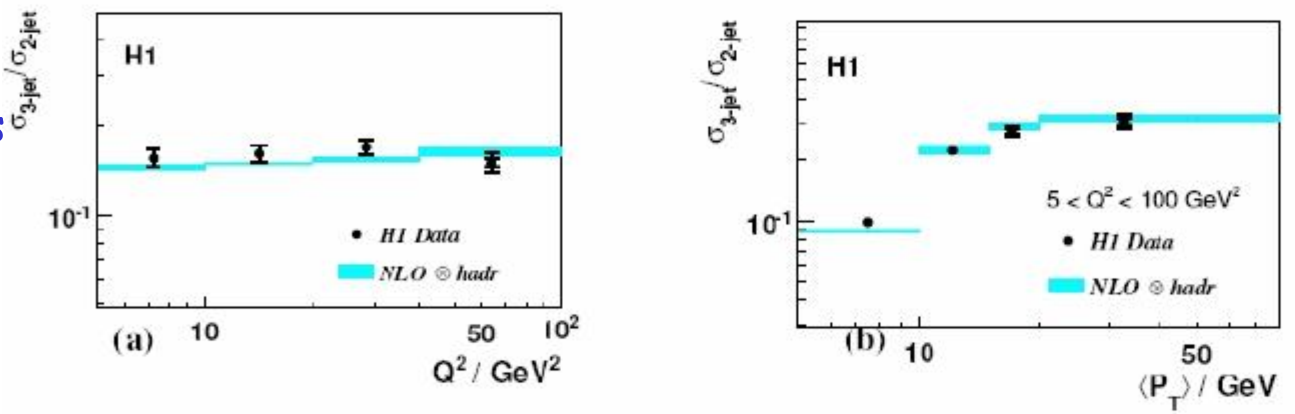
3-jets: Double differential cross sections vs Q^2 and $\langle P_T \rangle$



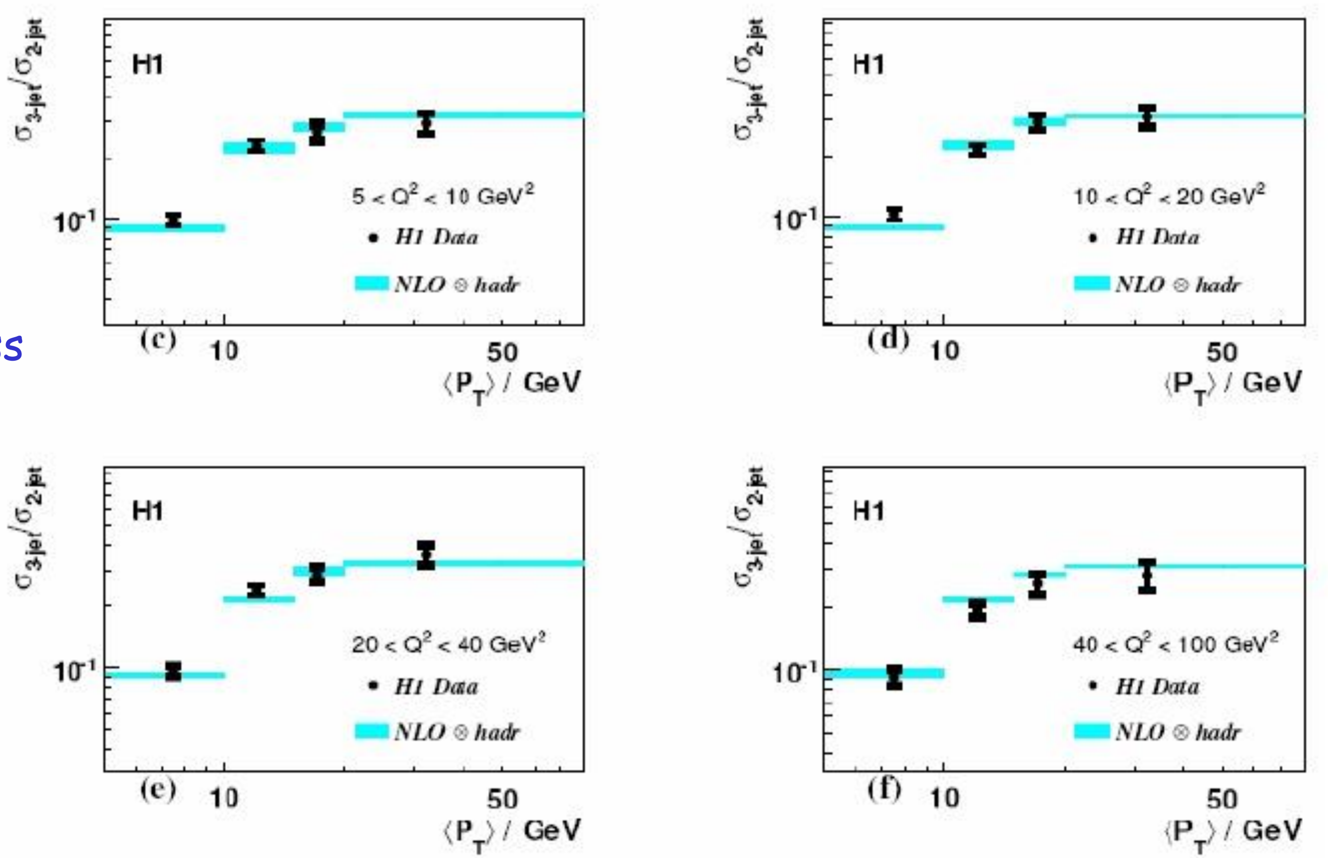
figures from paper

Ratios of 3j/2j cross sections vs Q2 and <PT>

Ratios of single differential cross sections vs Q2 and <PT>

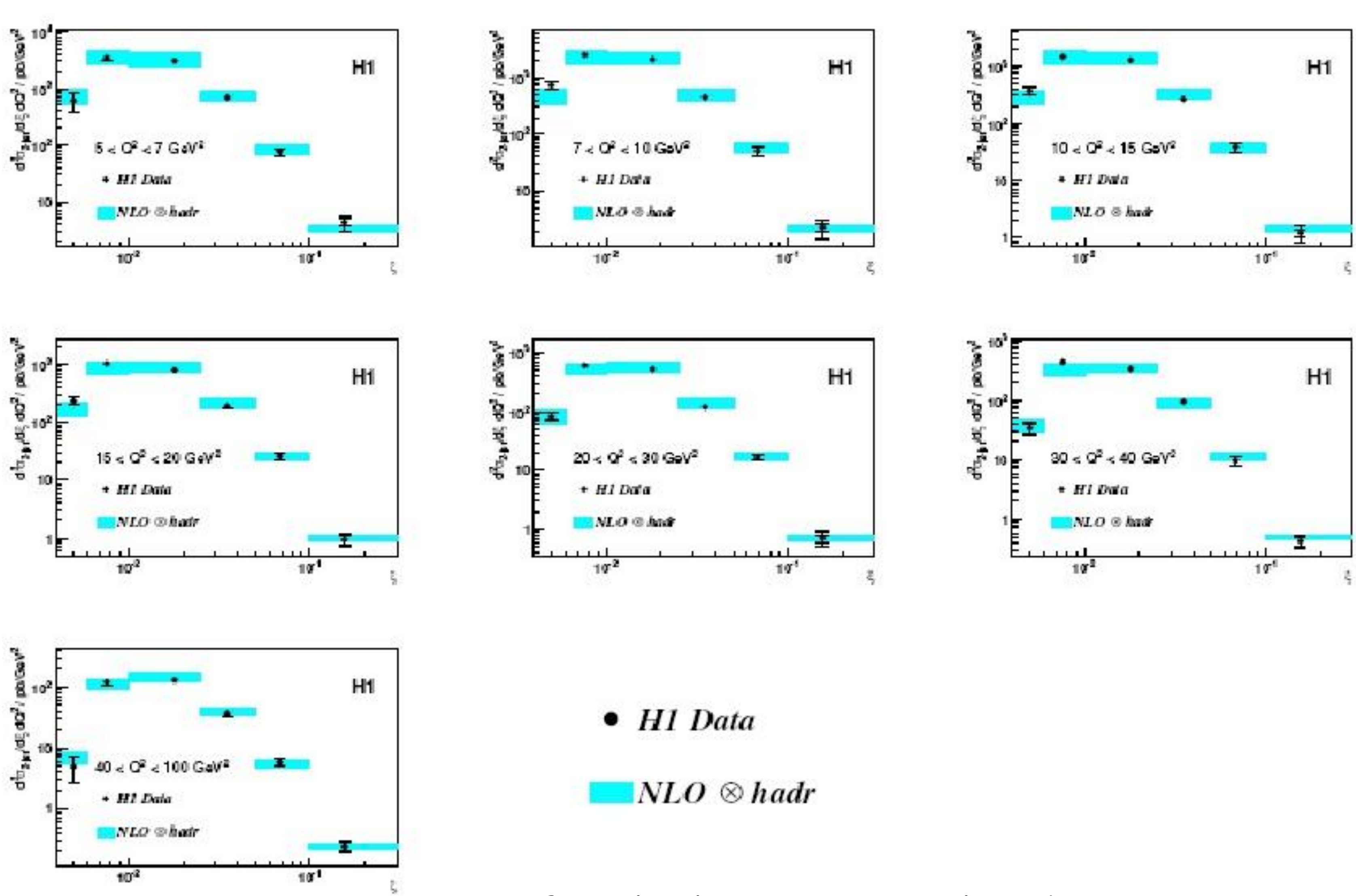


Ratios of double differential cross sections



figures from paper

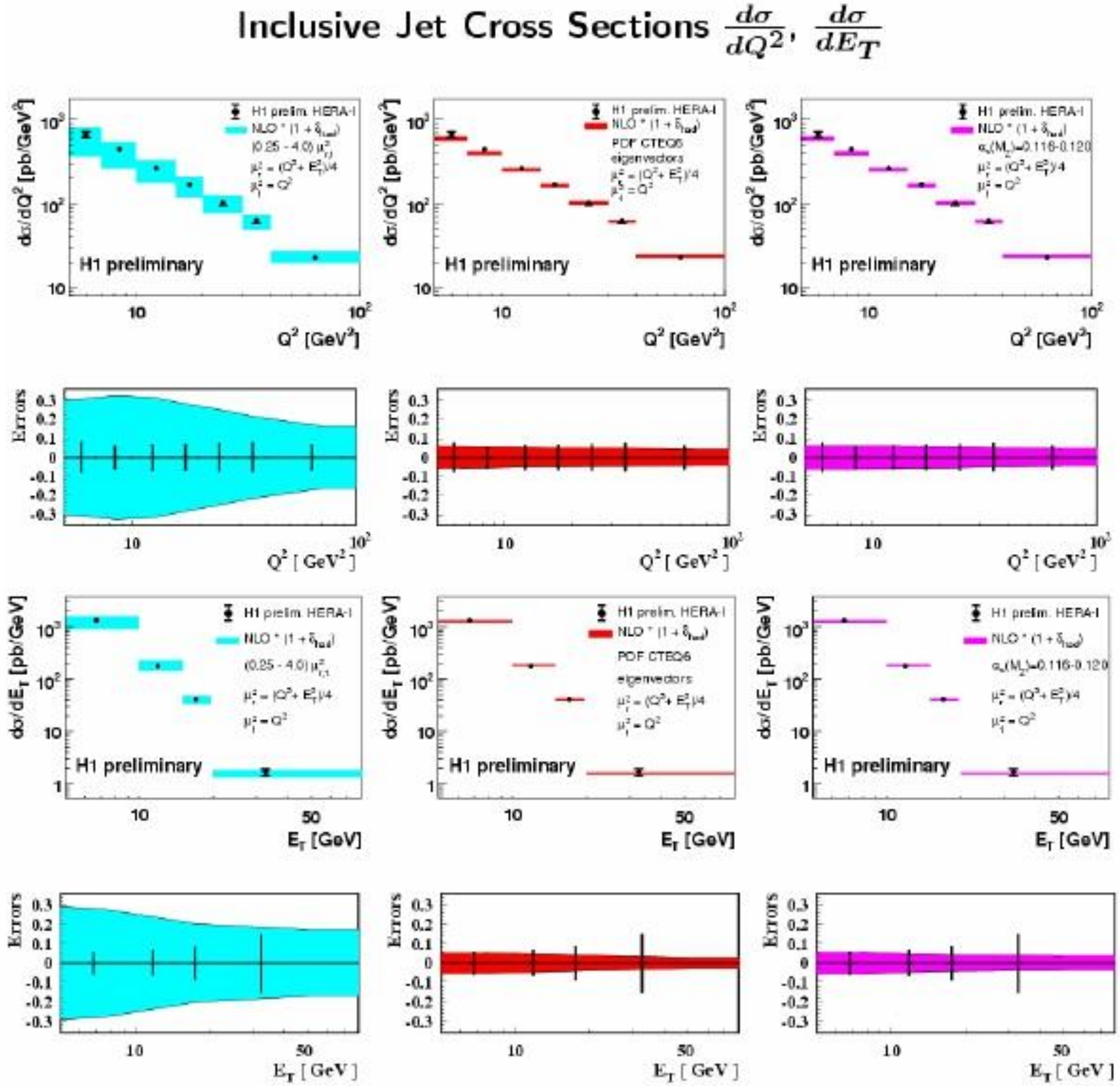
Double differential cross sections vs Q_2 and ξ (2-jets)



Plot from paper

As for high Q_2 paper, this distribution- $f(Q_2, \xi)$- is introduced for PDF

Inclusive cross-sections: compare experimental and theoretical uncertainties



scale+hadronization PDF $\alpha_s(M_Z)$

Main uncertainties in NLO are from scale variation.

α_S determination

Apply same method as for high Q^2 analysis: use FASTNLO tables, Hessian method

Chi2 definition

HESSIAN χ

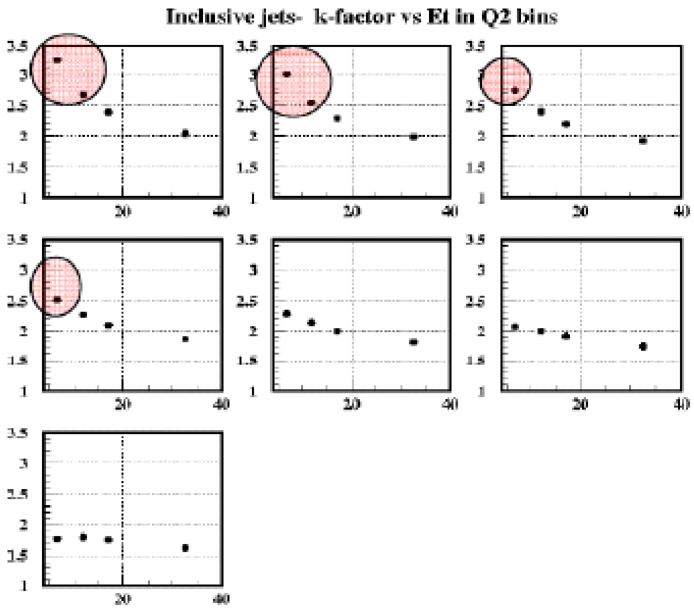
$$\chi_i = \frac{Data_i - Thr_i(1 - f_i)}{\sigma_{uncor,i}}$$

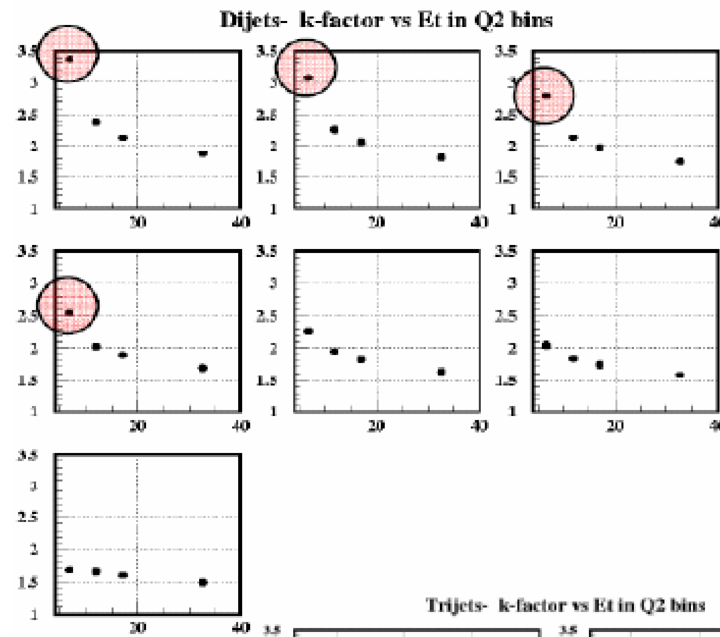
$$f_i = \sum_{\text{corr sys}} \delta_j \varepsilon_j$$

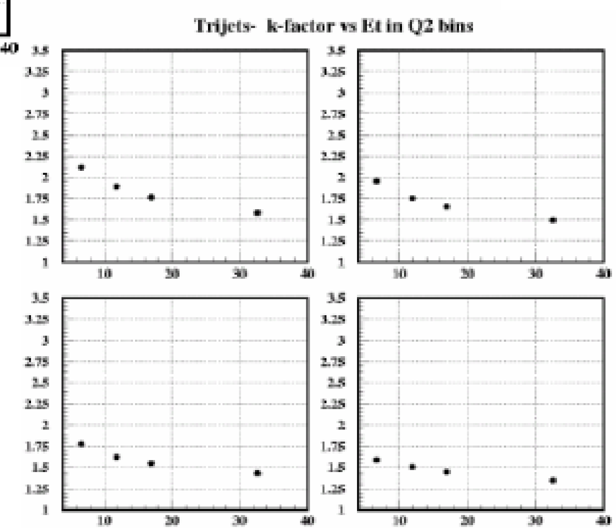
$$\chi^2 = \sum_i \chi_i^2 + \sum_{\text{corr sys}} \varepsilon_j^2$$

Cross-check with interpolation method, using NLOJET++ to calculate grids of μ_r, μ_f and a_S

k-factors (NLO/LO) vs P_T







Large k-factors (>2.5) serious doubts about convergence of perturbative series

All	K-fact.<2.5	K-fact.<2
72	62	50

Fit results comparison

Measurement	$\alpha_S(M_Z)$	α_s fit with Interpolation method
$\sigma_{\text{jet}}\,(Q^2, P_T)$	0.1180	0.1203
$\sigma_{\text{2-jet}}\,(Q^2, \langle P_T \rangle)$	0.1155	0.1155
$\sigma_{\text{3-jet}}\,(Q^2, \langle P_T \rangle)$	0.1170	0.1179
$\sigma_{\text{jet}},\ \sigma_{\text{2-jet}},\ \sigma_{\text{3-jet}}$	0.1160	0.1169

So we use FastNLO approach and extract α_s using the following data set:

1. Inclusive Jets = $f(Q^2, P_T)$ 28 bins
2. 2-jet $f(Q^2, \langle P_T \rangle)$ 28 bins
3. 3-jet $f(Q^2, \langle P_T \rangle)$ 16 bins
4. Scale choice similar to high Q^2 ($\mu_f = Q$ appear to be too small)

$$\mu_f, \mu_r = \sqrt{\frac{Q^2 + P_{T,obs}^2}{2}}$$

As FastNLO wants to operate with identical measured and scale variables ->

$P_{T,obs} = P_T$ for inclusive jet,

$P_{T,obs} = \langle P_T \rangle$ for di- and trijet.

Measurement	$\alpha_S(M_Z)$	Uncertainty			χ^2/ndf
		experimental	theory	PDF	
$\sigma_{\text{jet}}\ (Q^2, P_T)$	0.1180	0.0018	$^{+0.0122}_{-0.0090}$	0.0022	17.5/21
$\sigma_{\text{2-jet}}\ (Q^2, \langle P_T \rangle)$	0.1155	0.0018	$^{+0.0121}_{-0.0090}$	0.0025	14.3/23
$\sigma_{\text{3-jet}}\ (Q^2, \langle P_T \rangle)$	0.1170	0.0017	$^{+0.0090}_{-0.0072}$	0.0014	11.0/15
$\sigma_{\text{jet}},\ \sigma_{\text{2-jet}},\ \sigma_{\text{3-jet}}$	0.1160	0.0014	$^{+0.0093}_{-0.0077}$	0.0016	50.6/61
$\sigma_{\text{3-jet}}/\sigma_{\text{2-jet}}$	0.1215	0.0032	$^{+0.0066}_{-0.0058}$	0.0013	11.9/13

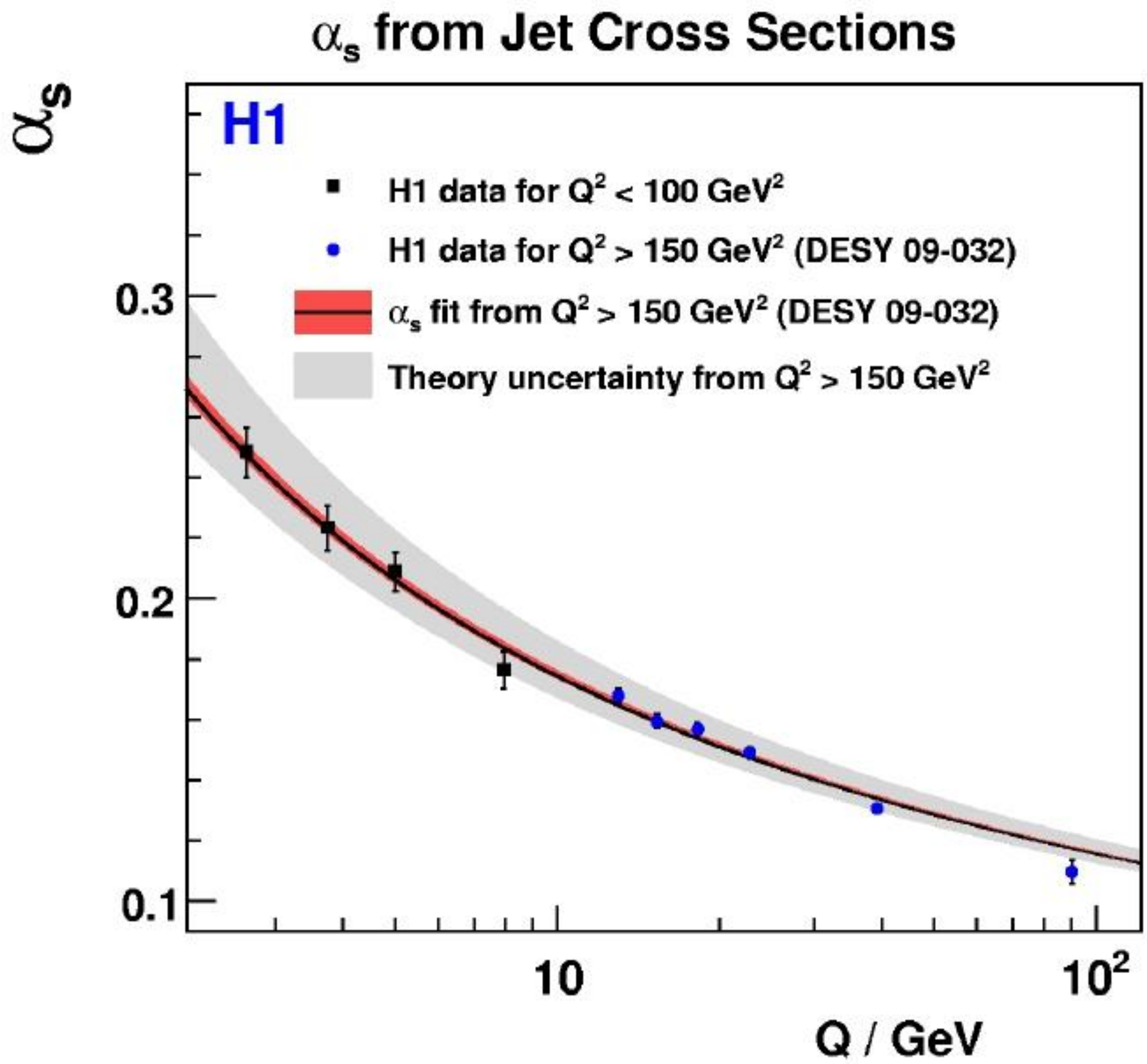
for high Q^2 Jets (Q^2>150 GeV^2) was

$$\alpha_s(M_Z) = 0.1168 \pm 0.0007(exp.)^{+0.0046}_{-0.0030}(th.) \pm 0.0016(\text{PDF})$$

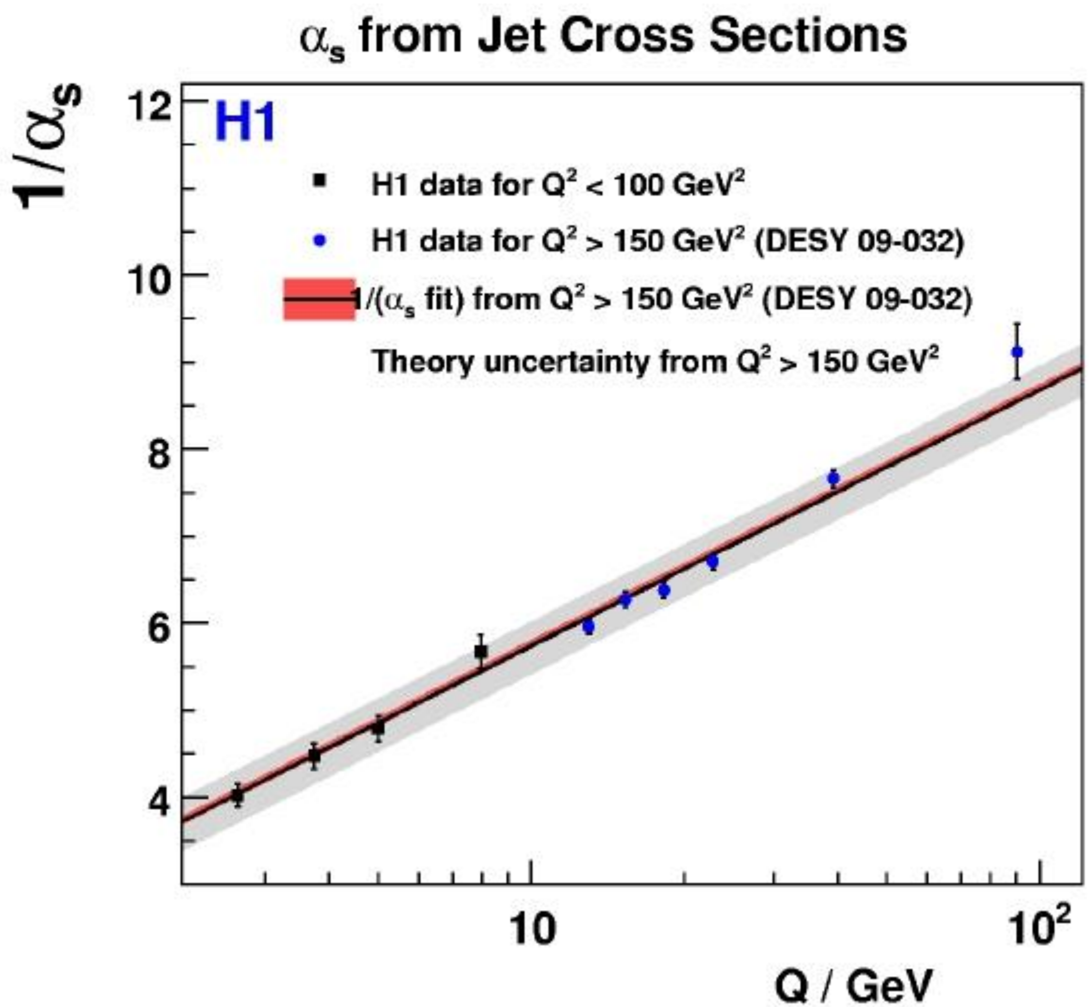
k-factor dependence

Measurement	$\alpha_S(M_Z)$	Uncertainty			χ^2/ndf
		experimental	theory	PDF	
σ_{jet}, $\sigma_{\text{2-jet}}$, $\sigma_{\text{3-jet}}$ k-factor<2.5	0.1160	0.0014	$^{+0.0093}_{-0.0077}$	0.0016	50.6/61
all k-factors	0.1171	0.0014	$^{+0.0104}_{-0.0087}$	0.0017	95.4/71

α_s Running plot

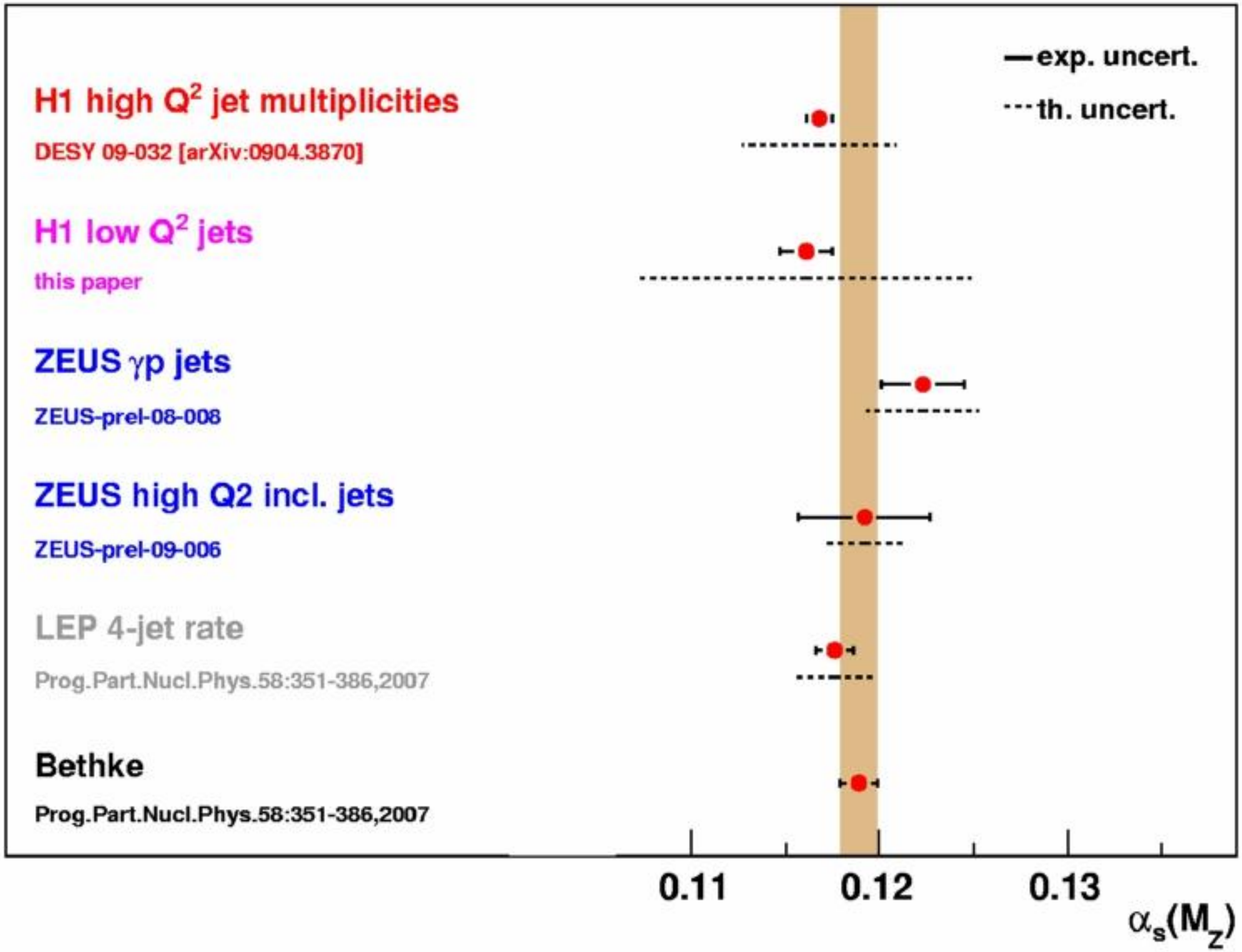


figures from paper



αs from Jet Cross Sections
1/αs
H1
H1 data for Q² < 100 GeV²
H1 data for Q² > 150 GeV² (DESY 09-032)
1/(αs fit) from Q² > 150 GeV² (DESY 09-032)
Theory uncertainty from Q² > 150 GeV²
12
10
8
6
4
10
10²
Q / GeV

αs summary


H1 high Q^2 jet multiplicities
DESY 09-032 [arXiv:0904.3870]
H1 low Q^2 jets
this paper
ZEUS γp jets
ZEUS-prel-08-008
ZEUS high Q2 incl. jets
ZEUS-prel-09-006
LEP 4-jet rate
Prog.Part.Nucl.Phys.58:351-386,2007
Bethke
Prog.Part.Nucl.Phys.58:351-386,2007
exp. uncert.
th. uncert.
0.11
0.12
0.13
$\alpha_s(M_Z)$

Summary

- The first time in the world differential and double differential cross sections for inclusive, di-jet and three-jet cross sections at low Q2 DIS are measured (Eur.Phys.J. C67 (2010) 1, 11/09)

- the measured cross sections are in good agreement with NLO QCD calculations (NLOJET++) using the renormalization scale $\mu_r^2=(Q^2+P_T^2)/2$

  - NLO scale uncertainty is the dominant theory uncertainty

- α_s is determined from the fit to the data.
  It is consistent between different points and is in good agreement with the measurements at high Q^2