Dijets in Diffractive Photoproduction at HERA

Karel Černý
Institute of Particle and Nuclear Physics
Charles University in Prague

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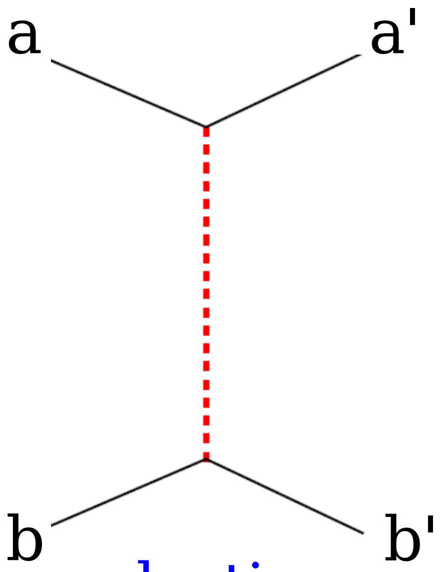
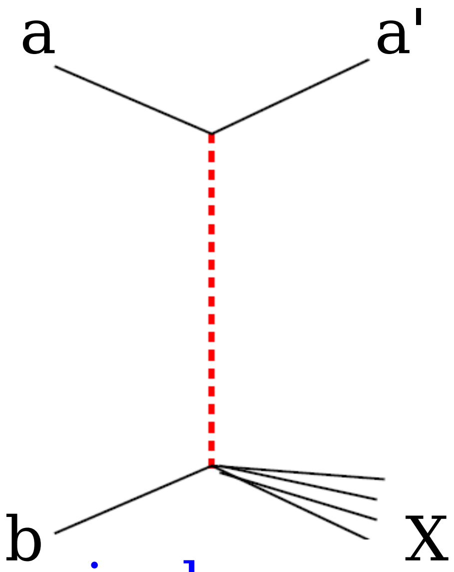
Introduction

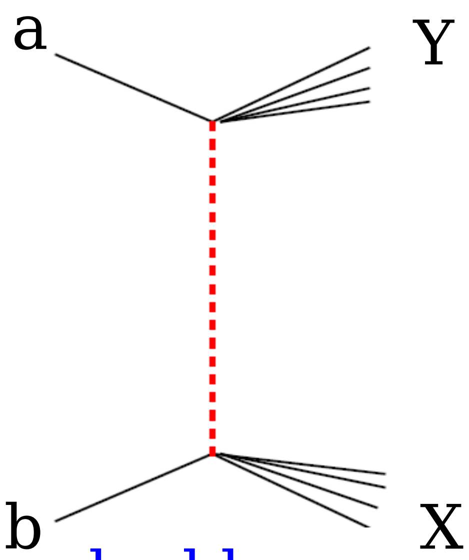
Diffraction: interaction with vacuum quantum number exchange.



elastic



single dissociation



double dissociation

Dissociation into low mass states may occur: $M_{X,Y} << E_{CMS}$

Hard diffraction: hard scale present => QCD calculable final states in either of the dissociated states

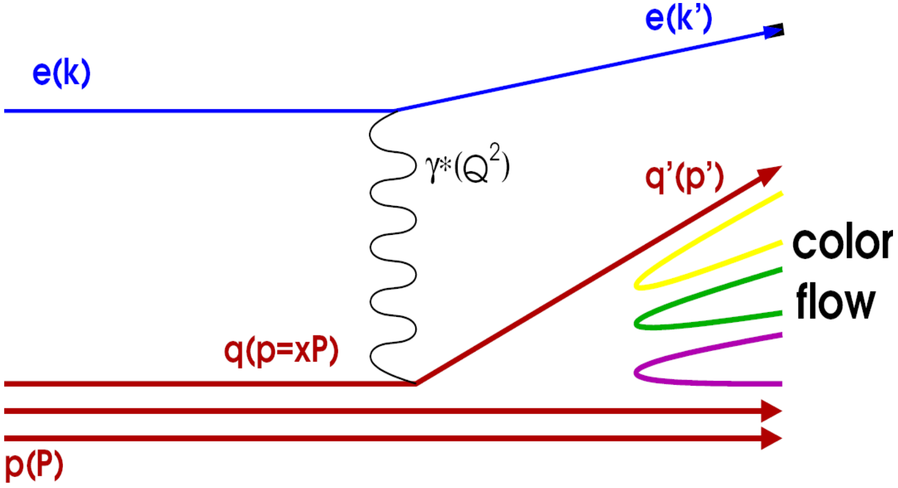
Diffractive Deep Inelastic Scattering (DDIS) at HERA

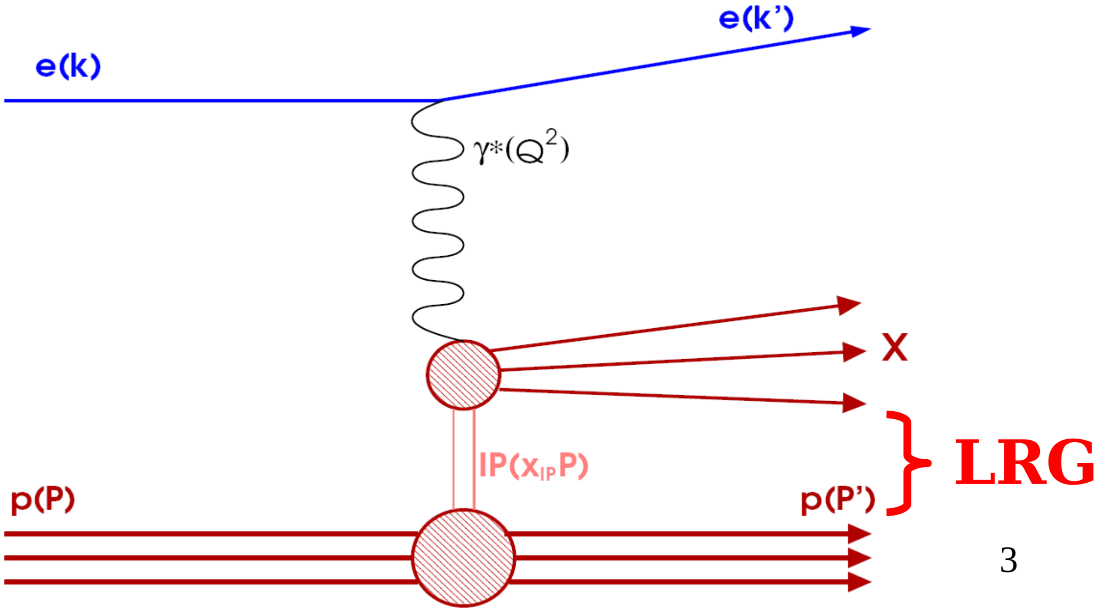
- Hard diffraction in DIS was not expected to be interesting.

- ~10% of DIS events at low x is DDIS, however.

- Jets or vector mesons observed in the final states in DDIS.

- Due to colourless exchange the DDIS is manifested with a Large Rapidity Gap (LRG).





Diffractive parton distribution functions (DPDF)

- In order to be able to make predictions of the cross sections of hard diffractive processes the DPDFs need to be measured.

- They are extracted from inclusive DDIS
(any final state & LRG & Q^2 the hard scale).

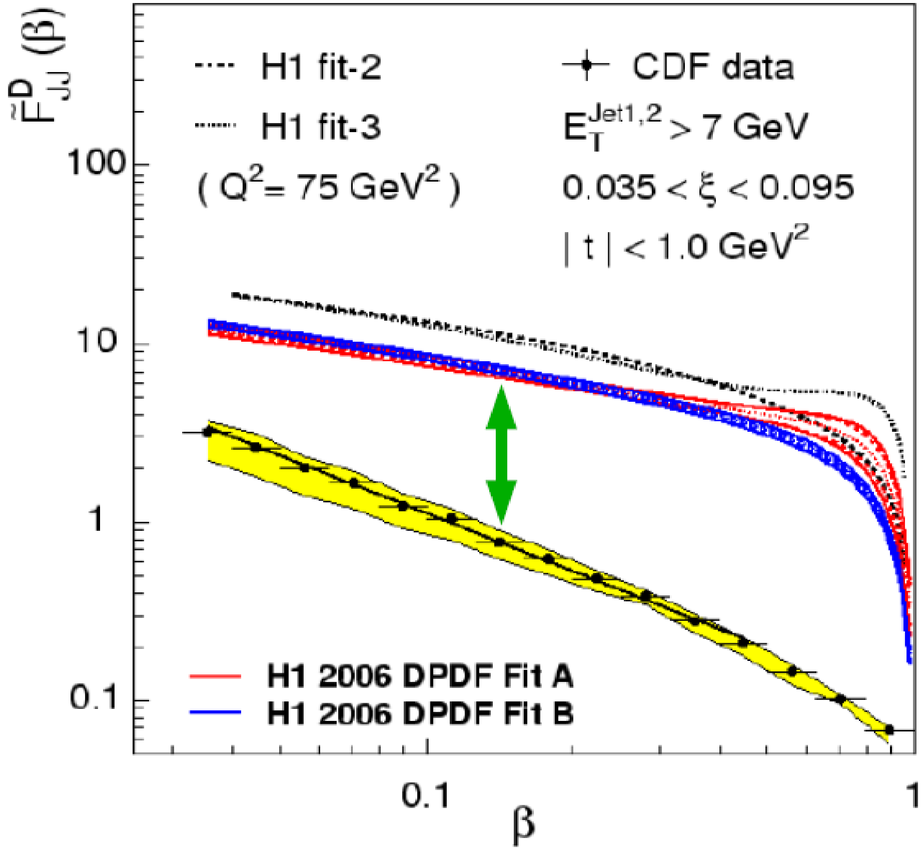
- QCD hard factorization theorem is then used for predictions.

universal partonic cross section

$$\sigma\,(\gamma^{*}p \rightarrow Xp) \;\approx\; f_{i/p}(z,Q^{2},x_{IP},t) \;\; \mathrm{x} \;\; \sigma_{\gamma^{*}p}(z,Q^{2})$$

Diffractive Parton Distribution Function (DPDF)

Diffractive parton distributions measured at **HERA** fail to predict dijet rates at **Tevatron!**



<ins>HERA DPDFs were expected to be universal but …</ins>

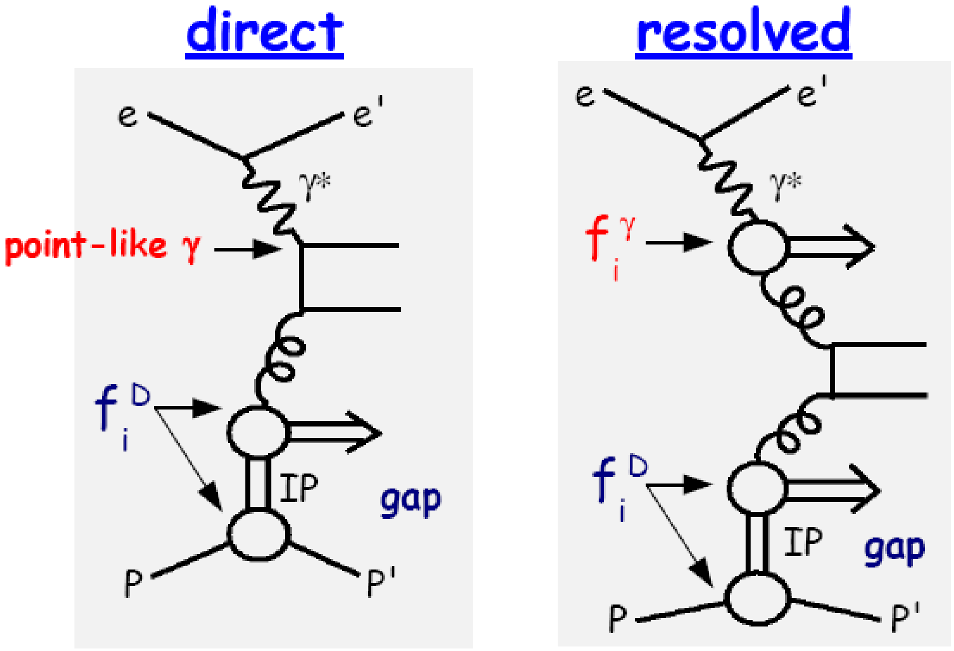
- Hard factorization **is expected** to hold in **DDIS** processes (Collins, 1998).

- Hard factorization **not expected** to hold in diffractive **h-h** scattering (Kaidalov et. al., 2003).

Diffractive Dijets in Photoproduction

- Photoproduction = $Q^2 \sim 0\ \mathrm{GeV}^2$, two leading order (LO) classes of photon interaction: **direct / resolved**.

- The resolved events resemble h-h scattering.



no γ remnant

interaction with γ remnant can fill the Gap(LRG).

Recent Results on Diffractive Dijets in Photoproduction

- Published H1 results (96/97 ~ 18 pb^{-1}) conclude that an overall suppression factor of 0.5 is needed for NLO.

- Recent ZEUS results: NLOs agree with data with weaker suppression factors or - within the uncertainties almost without suppression.

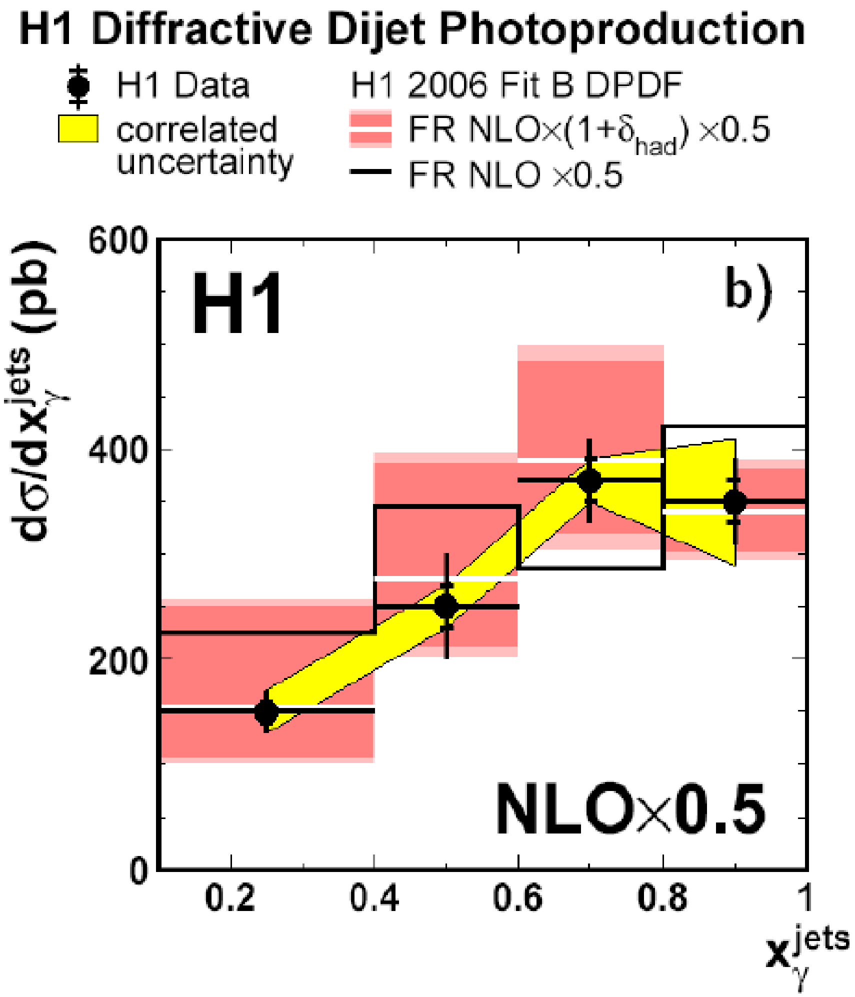
- Both experiments observe no special suppression of resolved w.r.t. direct.

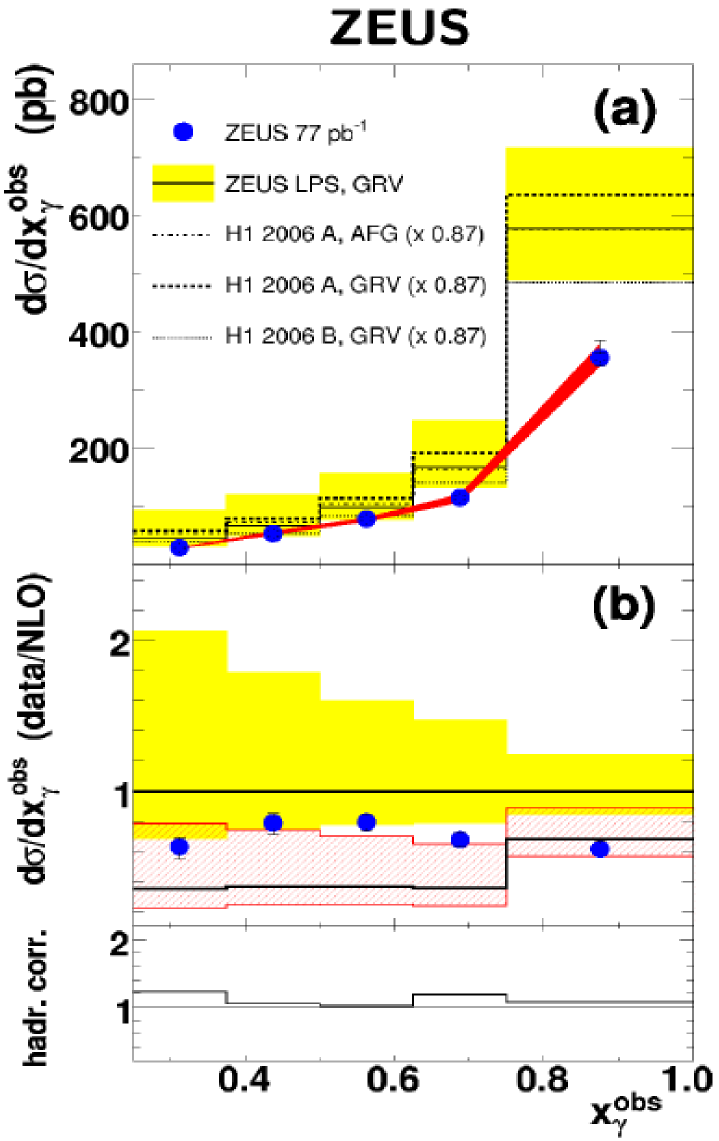
- There may be an E_T dependence of the suppression explaining the different H1 <-> ZEUS conlusions.

- The analysis is, therefore, carried out in two E_T cut schemes:

  - low E_T ... jets above 5 and 4 GeV in p_T (H1)

  - high E_T ... jets above 7.5 and 6.5 GeV in p_T (ZEUS)





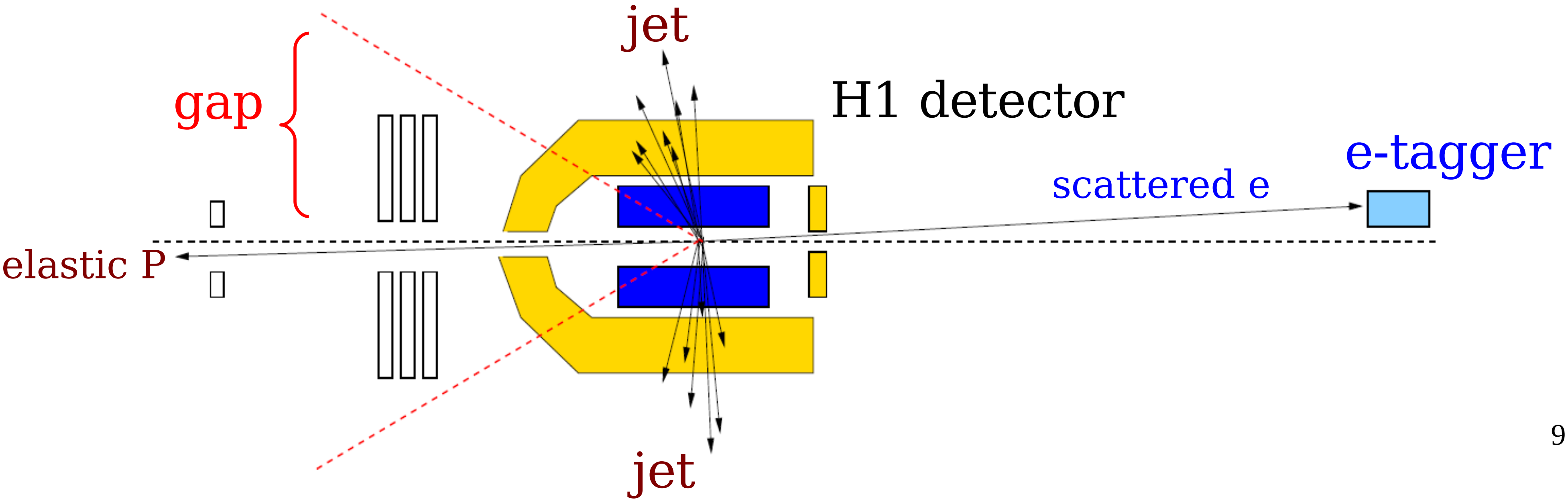
H1: suppression of NLO is needed! ... NLO × 0.5

ZEUS: NLO × 0.6 - 0.9 ... varying with DPDFs

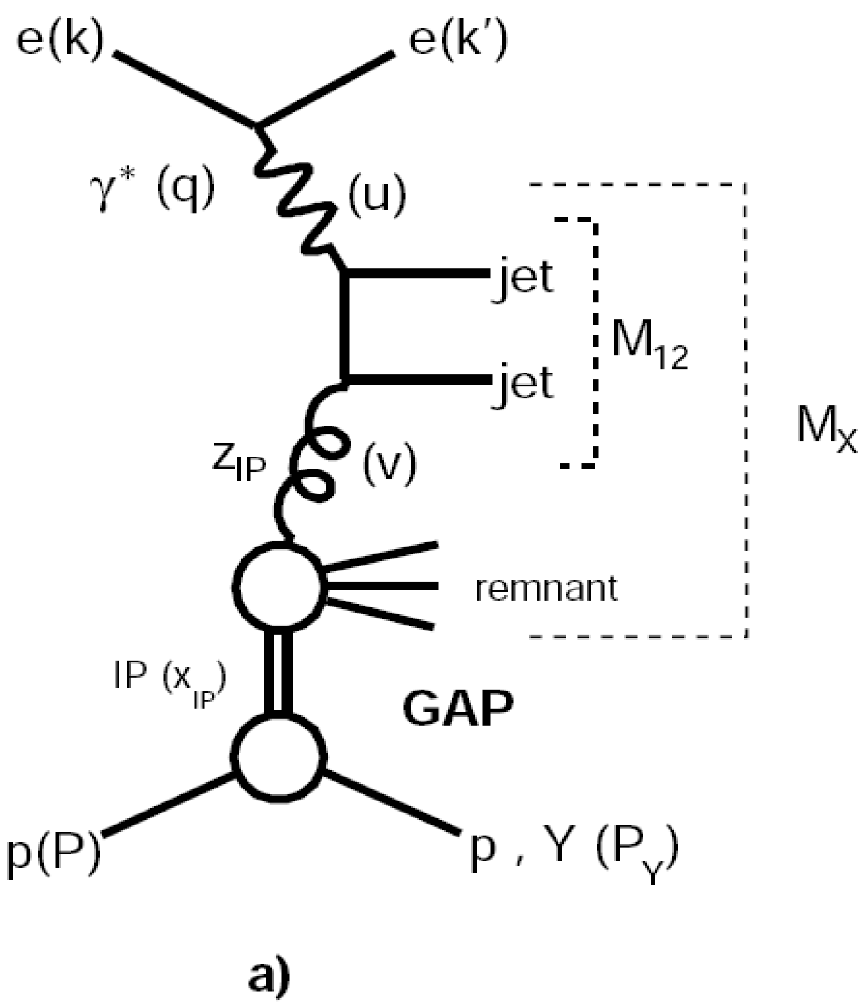
H1+ZEUS: no x_γ dependence of the suppression!

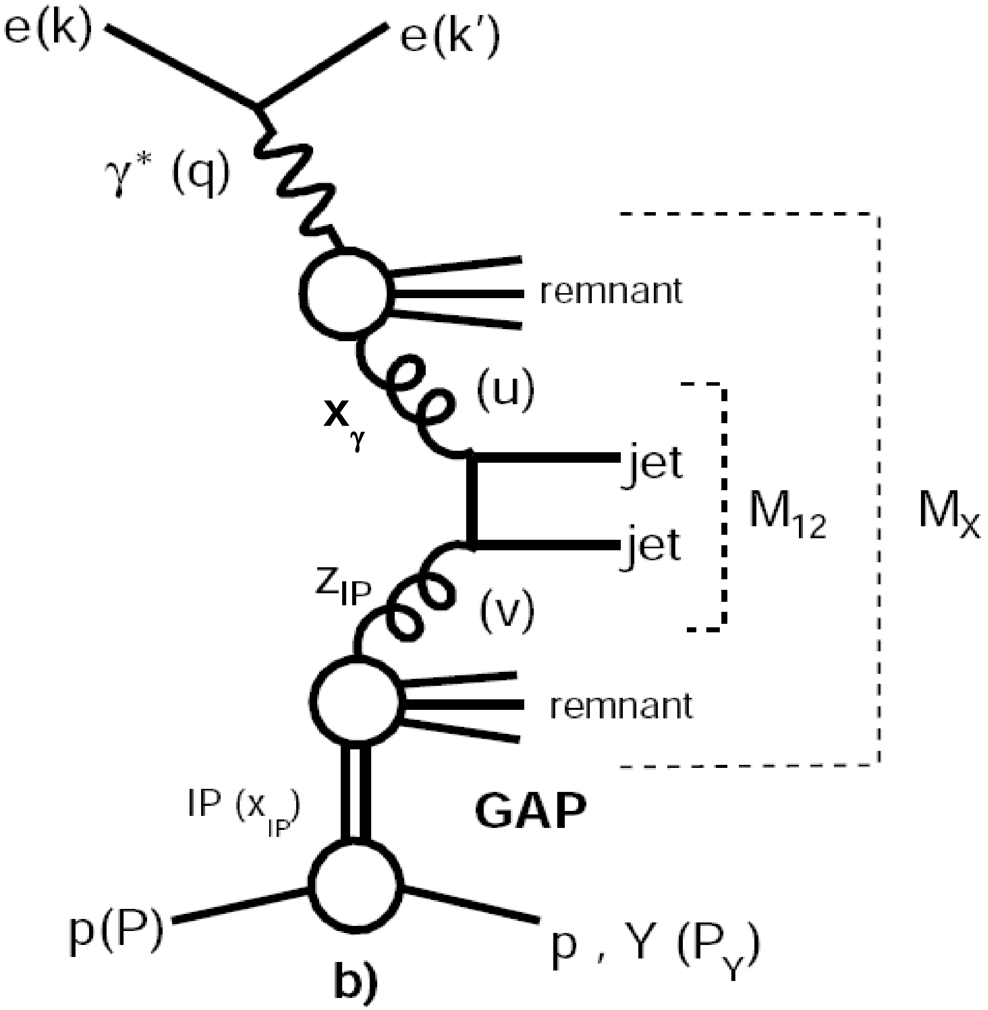
Data and Event Selection

- Analysis is based on 1999e+/2000 HERA data.
- Integrated luminosity ~ 54 pb^{-1}.
- Outgoing electron is tagged in the electron tagger (e-tag33m).
- Diffractive events selected by means of LRG method.



Kinematics of the events





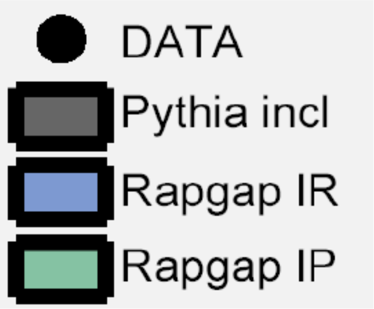
Kinematics of the events

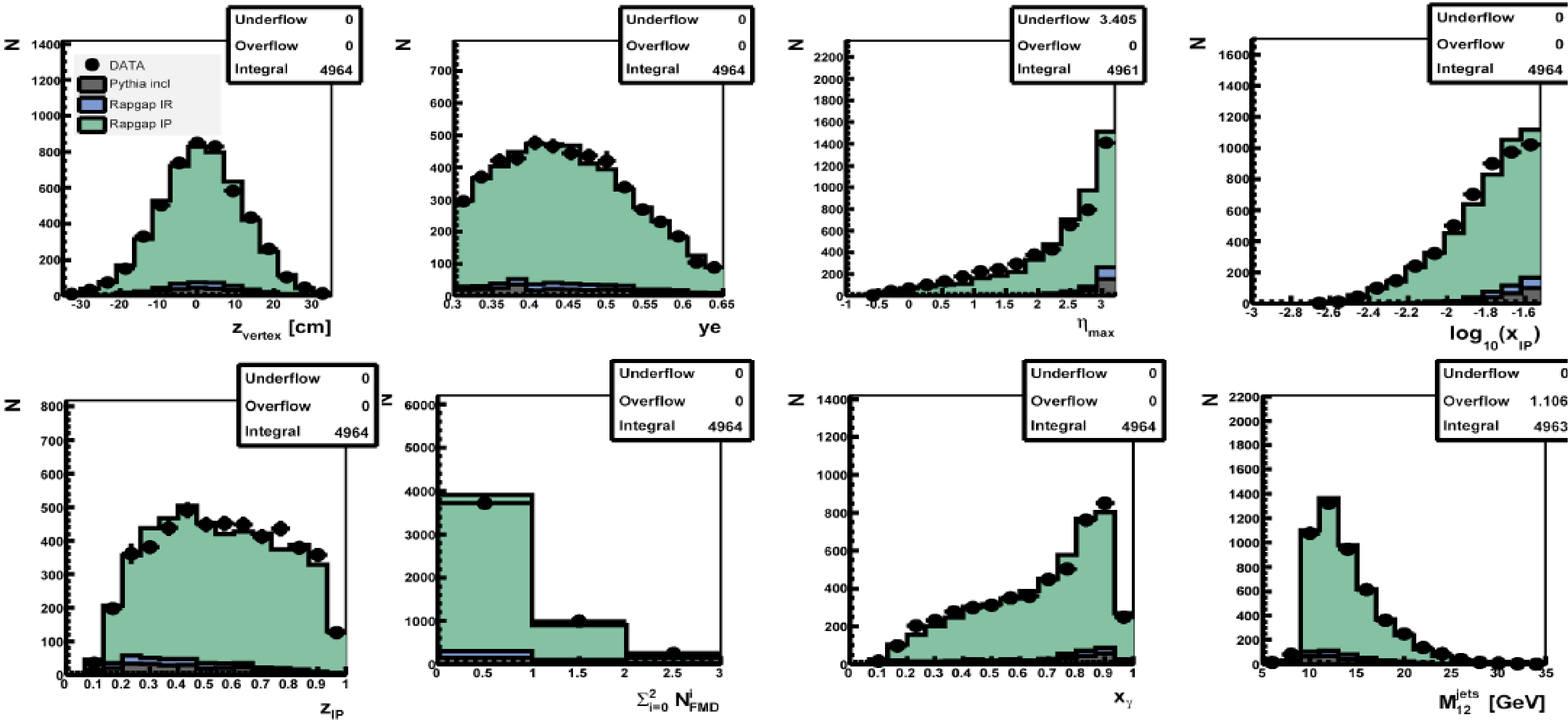
	low E_T		**high E_T**
	$E_T^{jet1} > 5$ GeV		$E_T^{jet1} > 7.5$ GeV
	$E_T^{jet2} > 4$ GeV		$E_T^{jet2} > 6.5$ GeV
	$-1 < \eta^{(\text{jet 1 and 2})} < 2$		$-1.5 < \eta^{(\text{jet 1 and 2})} < 1.5$
	$x_{IP} < 0.03$		$x_{IP} < 0.025$
e-tagger limitation	$0.3 < y_e < 0.65$	different from ZEUS	$0.3 < y_e < 0.65$
	$Q^2 < 0.01$ GeV^2		$Q^2 < 0.01$ GeV^2
	$\lvert t\rvert < 1$ GeV^2		$\lvert t\rvert < 1$ GeV^2
	$M_Y < 1.6$ GeV		$M_Y < 1.6$ GeV

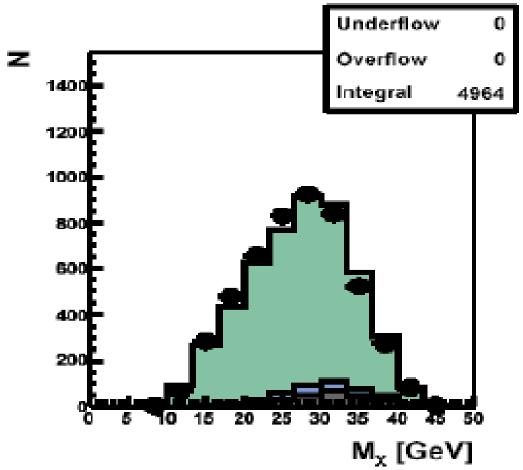
These cuts define the cross section measurement phase space

Control Plots

- Monte Carlo (MC) samples are generated and simulated
- Good description of the reconstructed level is needed.
- Rapgap 3.1 MC generator is used for signal events.
- Pythia 6.1 is used for background estimation.

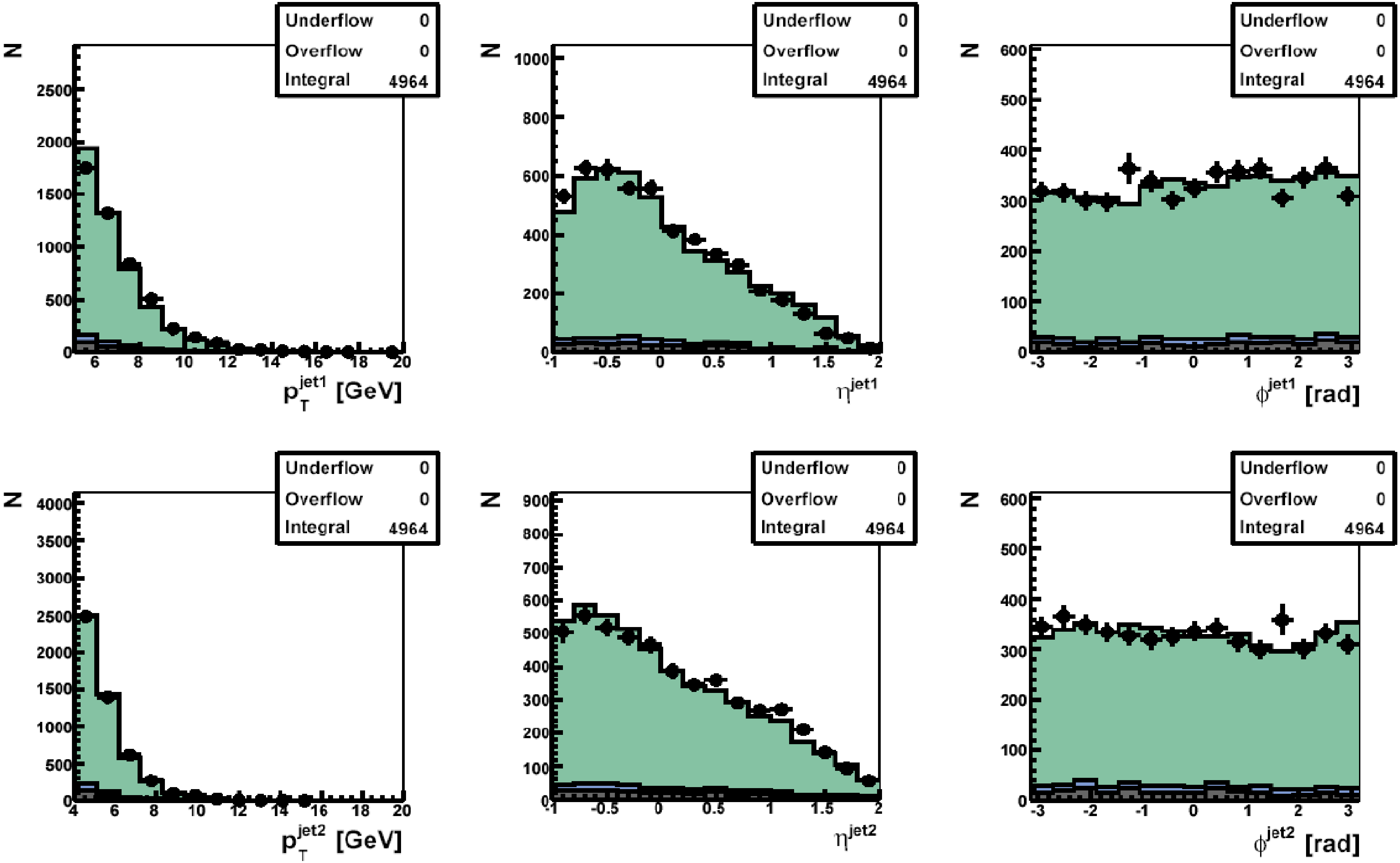


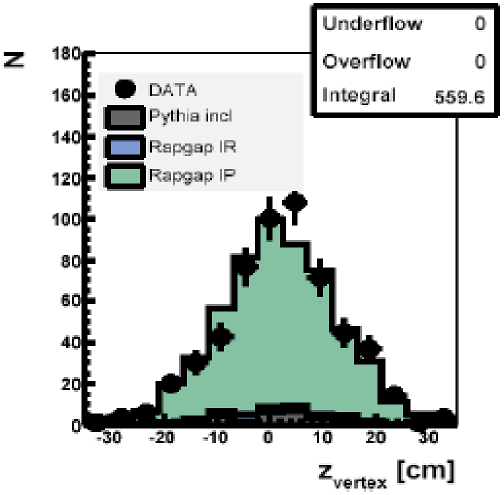

N
Underflow 0
Overflow 0
Integral 4964
DATA
Pythia incl
Rapgap IR
Rapgap IP
z_{vertex} [cm]
ye
Underflow 3.405
Overflow 0
Integral 4961
η_{max}
$\log_{10}(x_{IP})$
z_{IP}
$\Sigma_{i=0}^{2} N_{FMD}^{i}$
x_{γ}
Overflow 1.106
Integral 4963
M_{12}^{jets} [GeV]

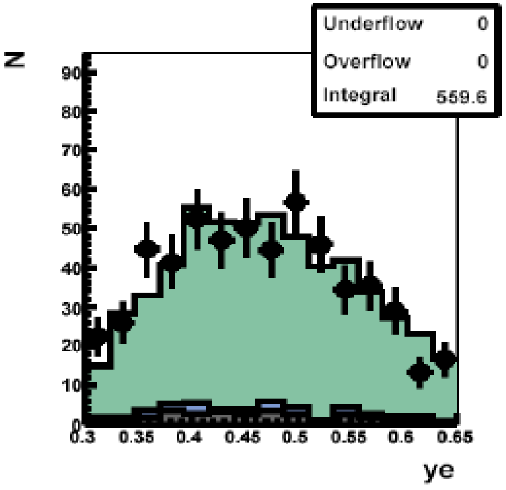

N
Underflow 0
Overflow 0
Integral 4964
M_X [GeV]

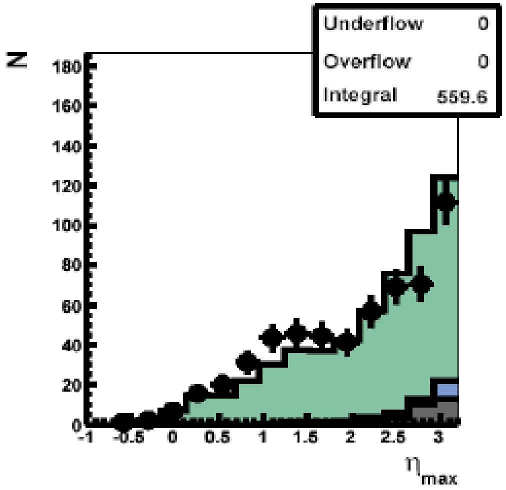
low E_T

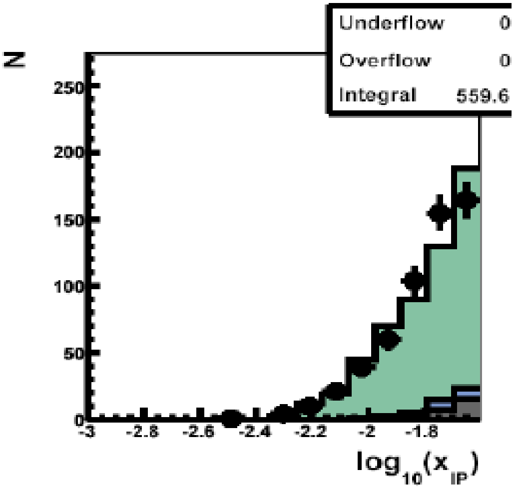
low E_T

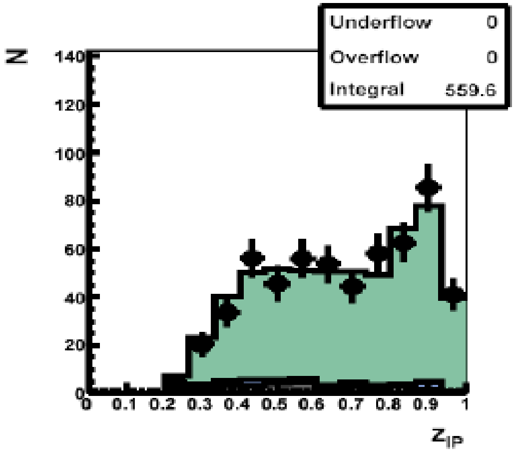

Underflow 0
Overflow 0
Integral 4964
N
0
500
1000
1500
2000
2500
6
8
10
12
14
16
18
20
p_T^{jet1} [GeV]
Underflow 0
Overflow 0
Integral 4964
N
0
200
400
600
800
1000
-1
-0.5
0
0.5
1
1.5
2
η^{jet1}
Underflow 0
Overflow 0
Integral 4964
N
0
100
200
300
400
500
600
-3
-2
-1
0
1
2
3
ϕ^{jet1} [rad]
Underflow 0
Overflow 0
Integral 4964
N
0
500
1000
1500
2000
2500
3000
3500
4000
4
6
8
10
12
14
16
18
20
p_T^{jet2} [GeV]
Underflow 0
Overflow 0
Integral 4964
N
0
100
200
300
400
500
600
700
800
900
-1
-0.5
0
0.5
1
1.5
2
η^{jet2}
Underflow 0
Overflow 0
Integral 4964
N
0
100
200
300
400
500
600
-3
-2
-1
0
1
2
3
ϕ^{jet2} [rad]

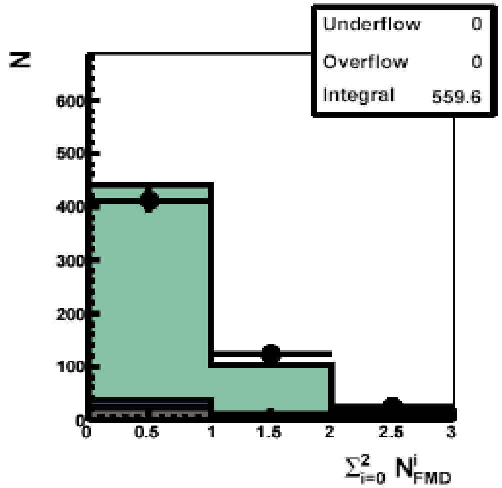

Underflow 0
Overflow 0
Integral 559.6
N
0 20 40 60 80 100 120 140 160 180
-30 -20 -10 0 10 20 30
DATA
Pythia incl
Rapgap IR
Rapgap IP
z_{vertex} [cm]

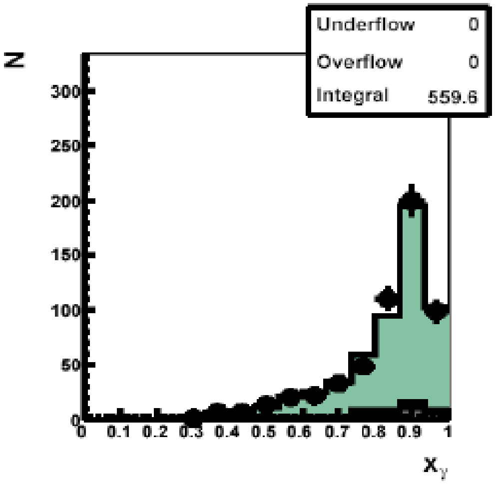

Underflow 0
Overflow 0
Integral 559.6
N
0 10 20 30 40 50 60 70 80 90
0.3 0.35 0.4 0.45 0.5 0.55 0.6 0.65
ye

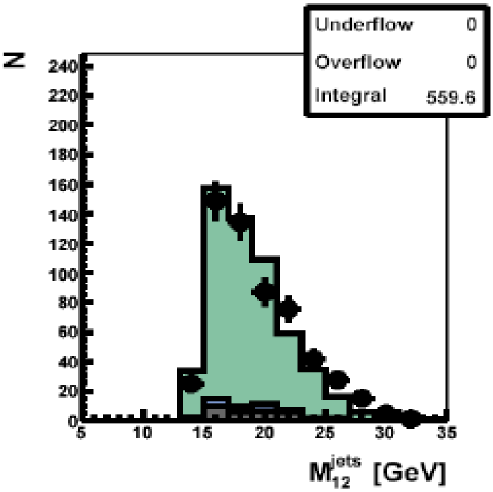

Underflow 0
Overflow 0
Integral 559.6
N
0 20 40 60 80 100 120 140 160 180
-1 -0.5 0 0.5 1 1.5 2 2.5 3
η_{max}

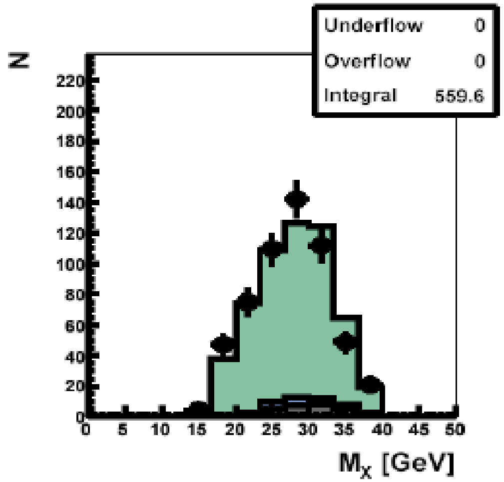

Underflow 0
Overflow 0
Integral 559.6
N
0 50 100 150 200 250
-3 -2.8 -2.6 -2.4 -2.2 -2 -1.8
$\log_{10}(x_{IP})$


Underflow 0
Overflow 0
Integral 559.6
N
0 20 40 60 80 100 120 140
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
z_{IP}


Underflow 0
Overflow 0
Integral 559.6
N
0 100 200 300 400 500 600
0 0.5 1 1.5 2 2.5 3
$\Sigma_{i=0}^{2} N_{FMD}^{i}$

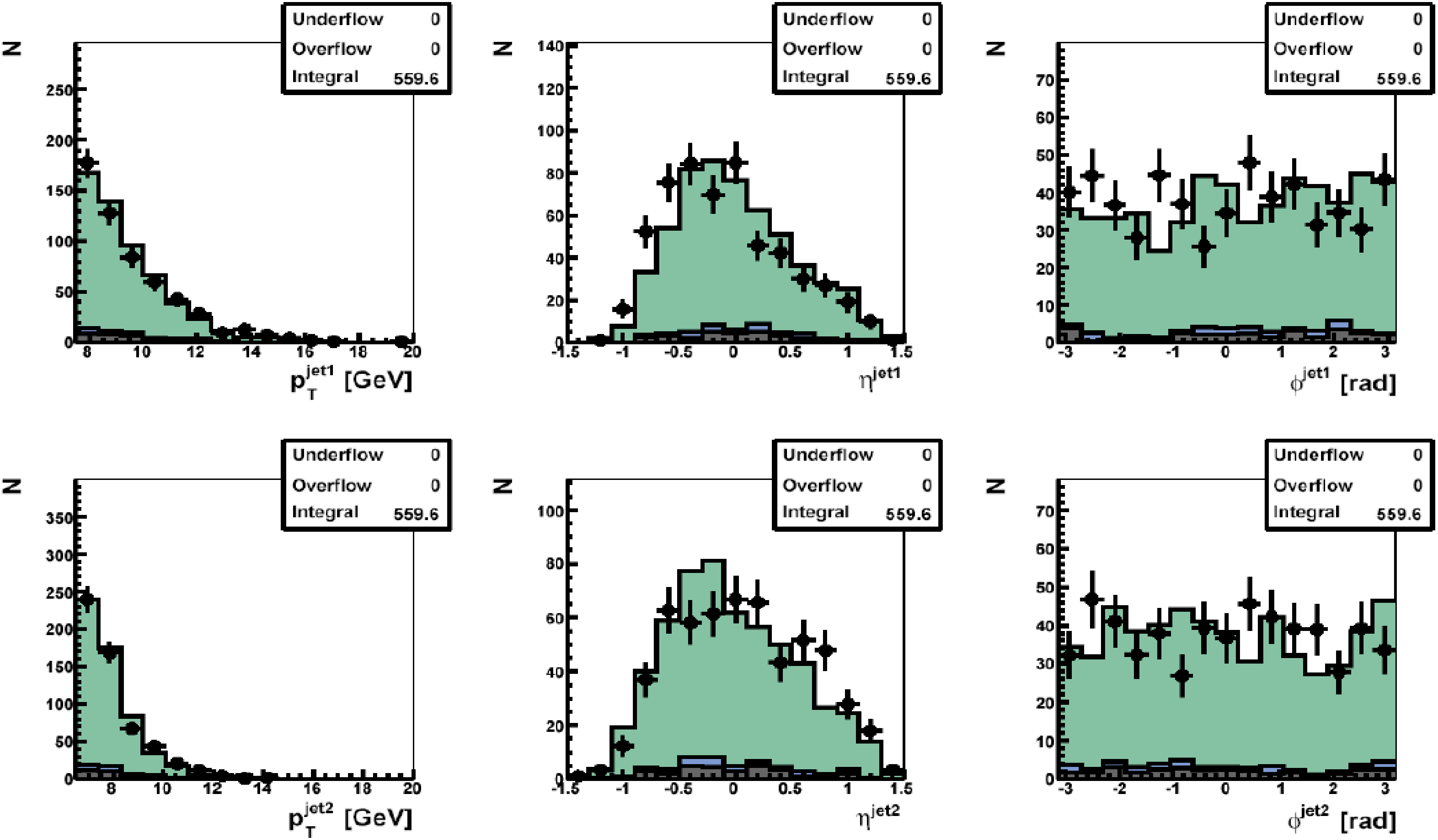

Underflow 0
Overflow 0
Integral 559.6
N
0 50 100 150 200 250 300
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
x_γ


Underflow 0
Overflow 0
Integral 559.6
N
0 20 40 60 80 100 120 140 160 180 200 220 240
5 10 15 20 25 30 35
M_{12}^{jets} [GeV]


Underflow 0
Overflow 0
Integral 559.6
N
0 20 40 60 80 100 120 140 160 180 200 220
0 5 10 15 20 25 30 35 40 45 50
M_X [GeV]

high E_T

high E_T


Underflow 0
Overflow 0
Integral 559.6
N
p_T^{jet1} [GeV]
η^{jet1}
ϕ^{jet1} [rad]
p_T^{jet2} [GeV]
η^{jet2}
ϕ^{jet2} [rad]
0
50
100
150
200
250
300
350
8
10
12
14
16
18
20
-1.5
-1
-0.5
0.5
1
1.5
-3
-2
2
3

Cross Section Measurement

- In each bin of given variable cross section is measured by means of following formula:

$$\frac{d\sigma}{dx_i} = \frac{\overset{\text{measured events}}{N^{data}} / \overset{\text{trigger eff.}}{\varepsilon^{trigg}} - \overset{\text{background events, from MC}}{N^{bgd.}}}{\underset{\text{acceptance}}{A} \,.\, \underset{\text{luminosity}}{L} \,.\, \underset{\text{bin-width}}{\Delta_{x_i bin}}}$$

- Eventually, a factor [$C^{pdiss} = 0.94$ +/- 7%(syst.)] is applied accounting on proton dissociation correction into: $M_Y < 1.6$ GeV and $|t| < 1$ GeV^2.

Systematic Uncertainties

SOURCE	ELEM. SHIFT	$\Delta\sigma$ low E_T	$\Delta\sigma$ high E_T
HFS	2.5%	6.8%	12.3%
LRG	30.0%	8.1%	6.4%
TE	5.0%	5.0%	5.0%
Lumi	2.0%	2.0%	2.0%
p-diss	7.0%	7.0%	7.0%
FMD noise	0.6%	0.8%	0.8%
etag A	1.5%	1.5%	1.5%
bgd.	50.0%	2.7%	2.9%
y^{gen}-shape	0.3	0.2%	0.9%
$\|t^{gen}\|$-shape	2	4.2%	3.2%
$p_T^{hadr.\,jet1}$-shape	0.4 (0.8 for high p_T)	1.0%	1.3%
x_{IP}^{hadr}-shape	0.2 (0.4 for high p_T)	5.0%	9.7%
z_{IP}^{hadr}-shape	0.3	3.0%	5.2%
	total =	~16%	~20%

Results

- Next-to-leading order (NLO) QCD calculations are used to predict the measured cross sections in both analyses.

- NLO program of Frixione et al. (FR) is used.

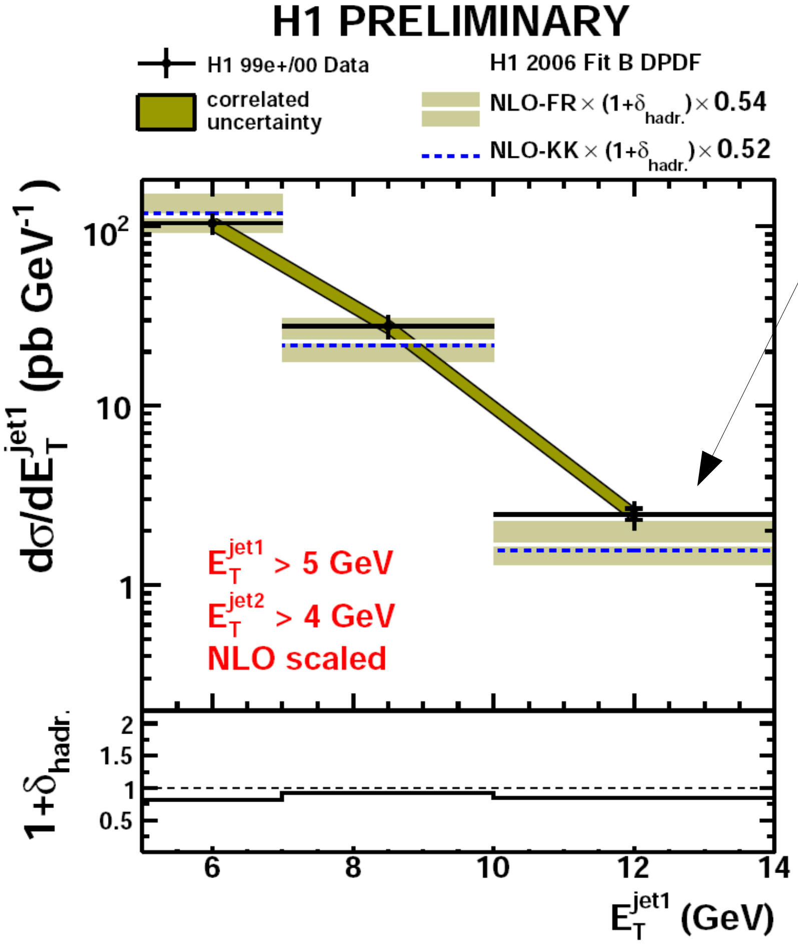
- NLO program of Kramer-Klasen (KK) is used.

- Both NLOs use the H1 2006 fit B parton distr. functions.

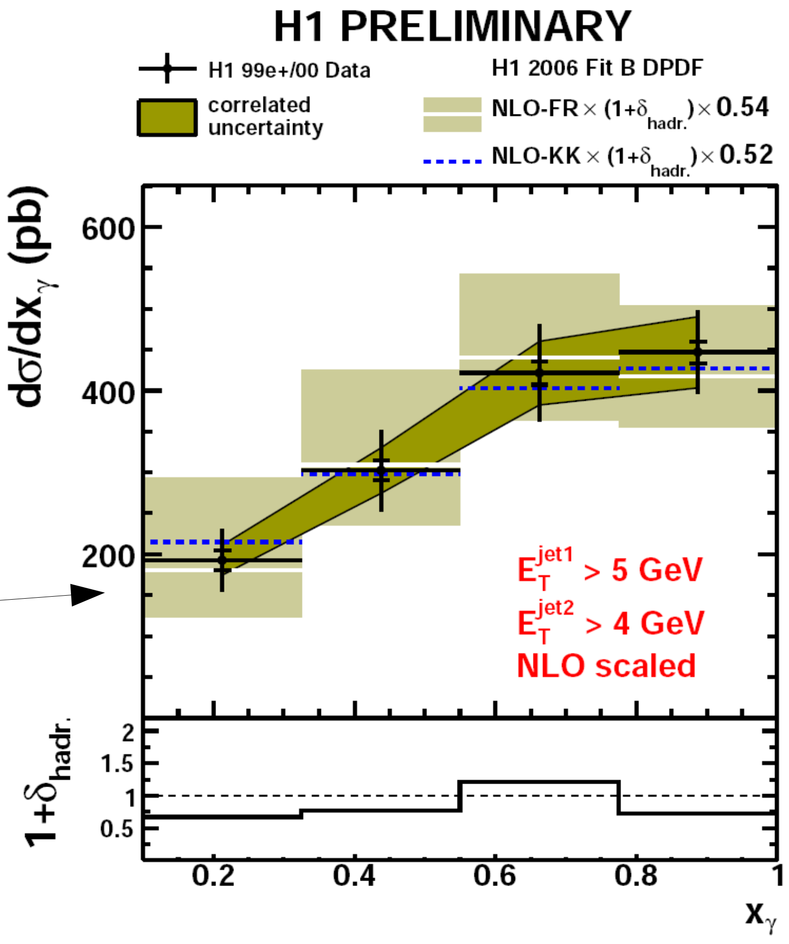
- Hadronization corrections are applied to the NLOs.

$$(1+\delta_{had})_i = \left(\frac{\sigma_{dijet}^{hadron}}{\sigma_{dijet}^{parton}}\right)_i$$

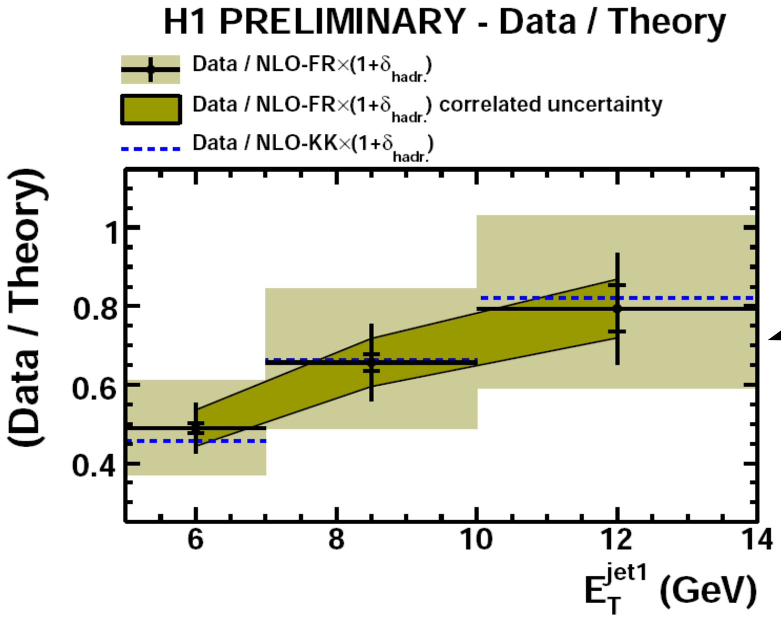
low E_T


H1 PRELIMINARY

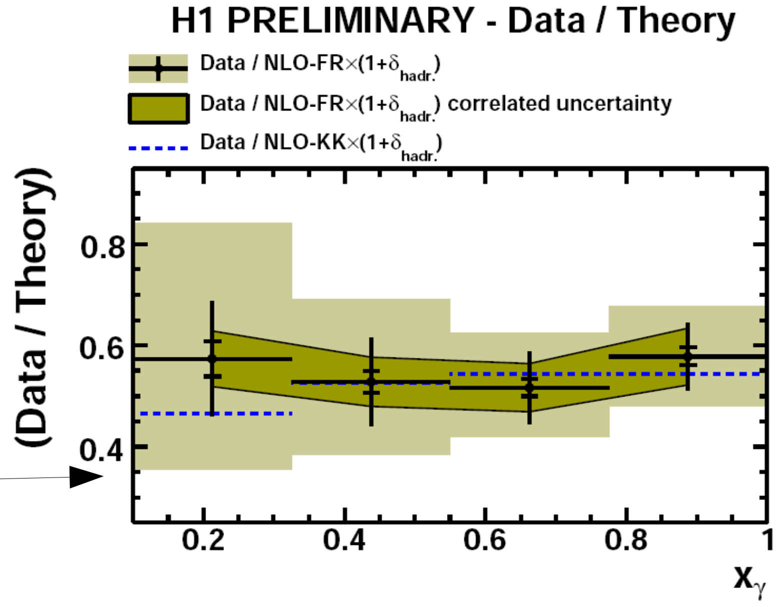
harder E_T slope of data than NLO


H1 PRELIMINARY

good description of x_γ shape

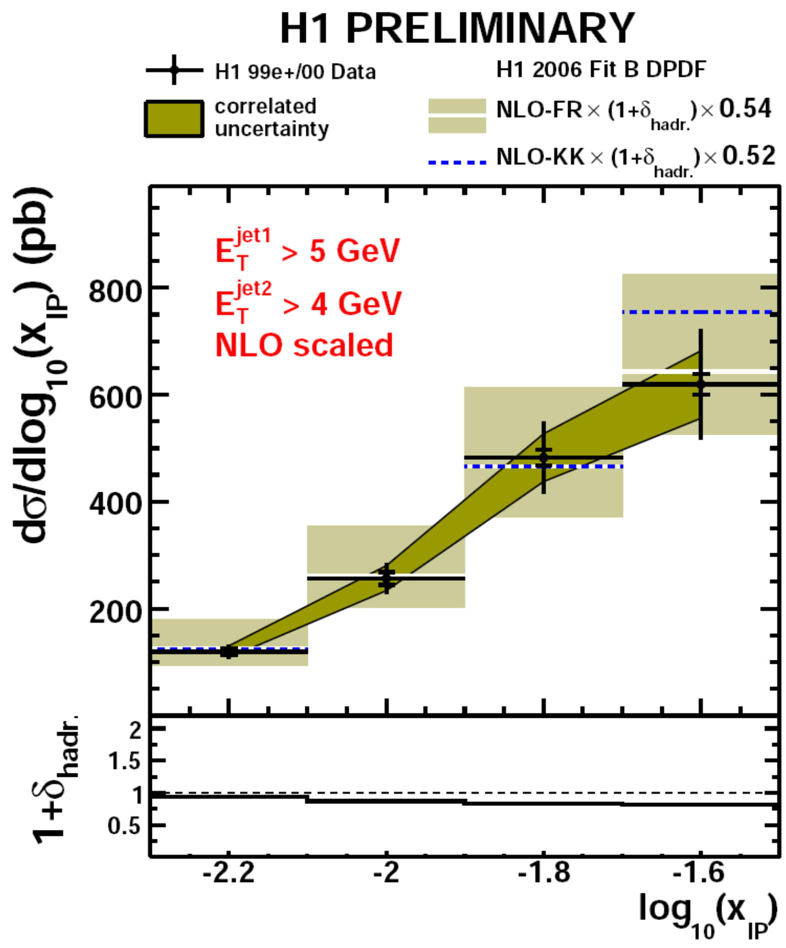

H1 PRELIMINARY - Data / Theory

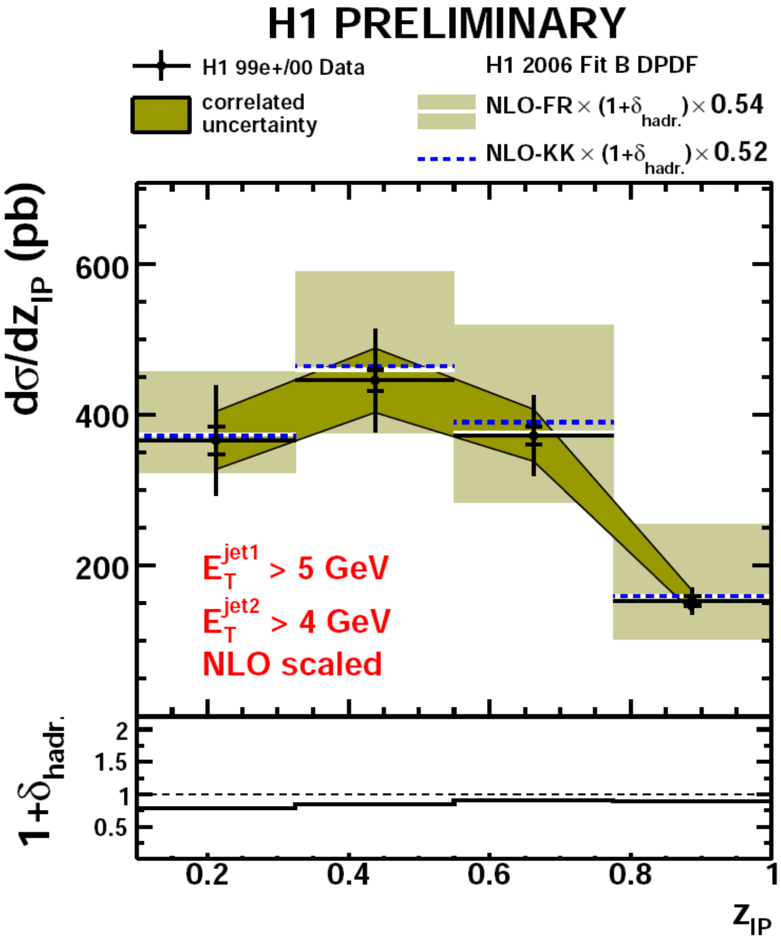
obvious E_T dependence

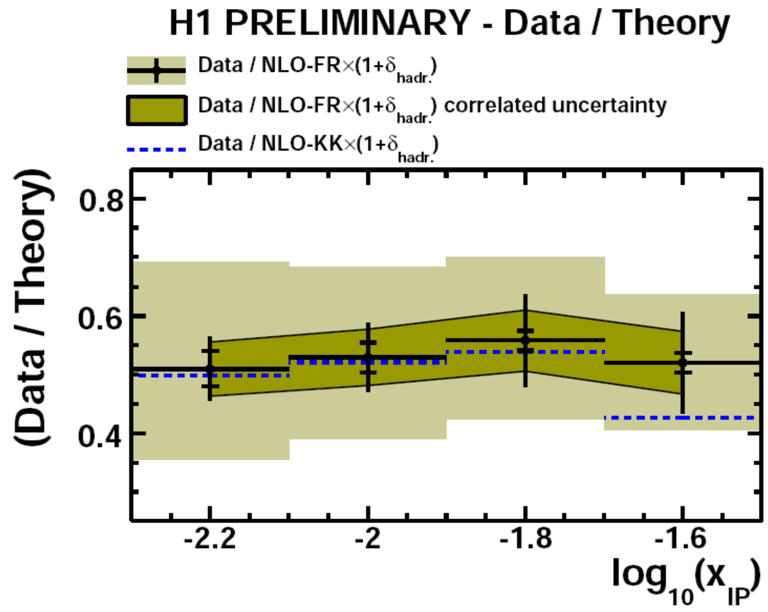

H1 PRELIMINARY - Data / Theory

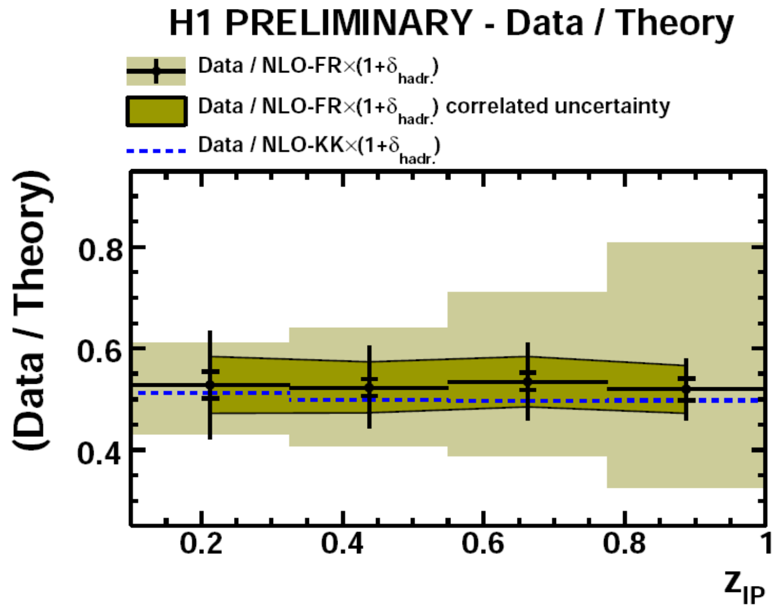
flat in x_γ

low E_T

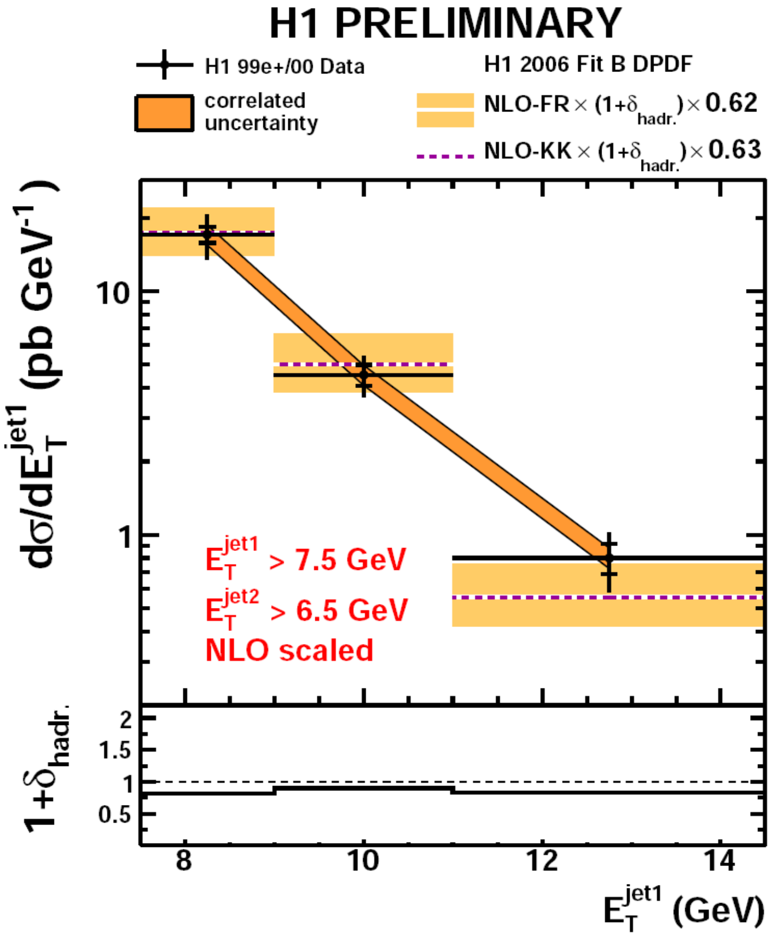

H1 PRELIMINARY
H1 99e+/00 Data
correlated uncertainty
H1 2006 Fit B DPDF
NLO-FR × (1+δ_hadr.)× 0.54
NLO-KK × (1+δ_hadr.)× 0.52
E_T^jet1 > 5 GeV
E_T^jet2 > 4 GeV
NLO scaled
dσ/dlog10(x_IP) (pb)
800
600
400
200
1+δ_hadr.
2
1.5
1
0.5
-2.2
-2
-1.8
-1.6
log10(x_IP)

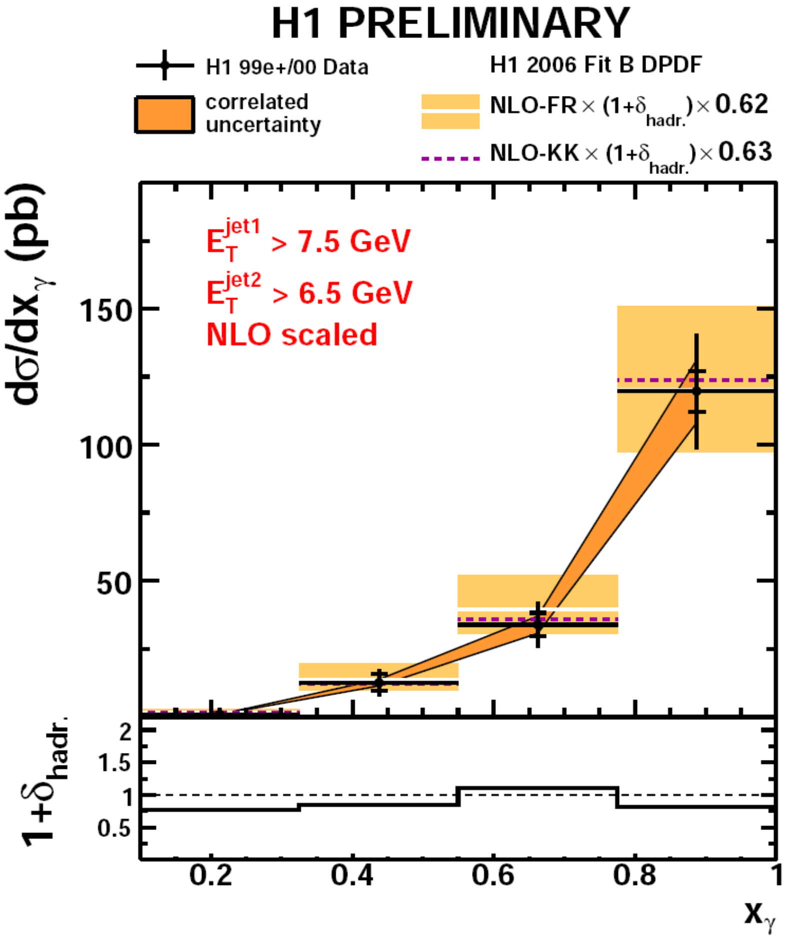

H1 PRELIMINARY
H1 99e+/00 Data
correlated uncertainty
H1 2006 Fit B DPDF
NLO-FR × (1+δ_hadr.)× 0.54
NLO-KK × (1+δ_hadr.)× 0.52
dσ/dz_IP (pb)
600
400
200
E_T^jet1 > 5 GeV
E_T^jet2 > 4 GeV
NLO scaled
1+δ_hadr.
2
1.5
1
0.5
0.2
0.4
0.6
0.8
1
z_IP

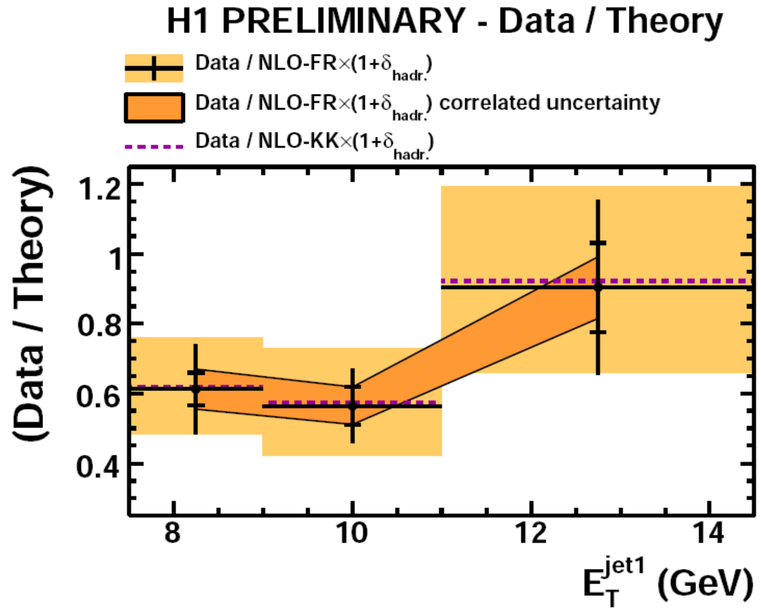

H1 PRELIMINARY - Data / Theory
Data / NLO-FR×(1+δ_hadr.)
Data / NLO-FR×(1+δ_hadr.) correlated uncertainty
Data / NLO-KK×(1+δ_hadr.)
(Data / Theory)
0.8
0.6
0.4
-2.2
-2
-1.8
-1.6
log10(x_IP)

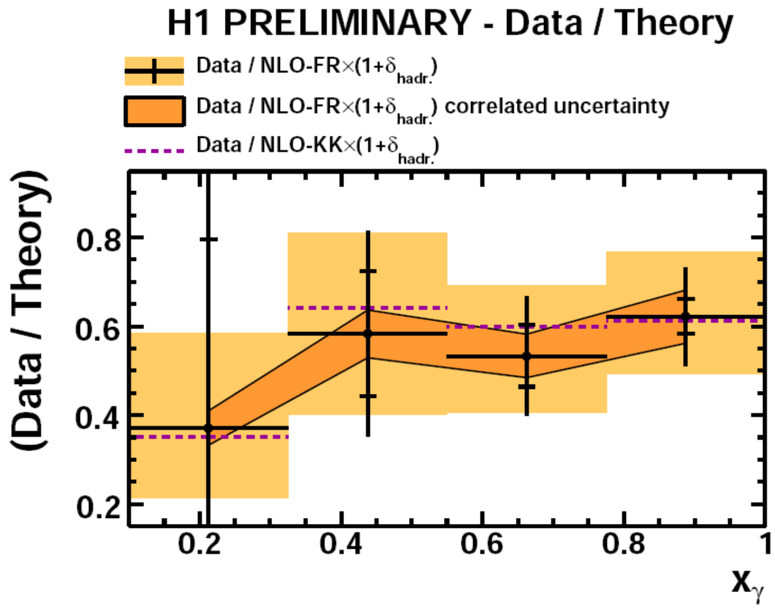

H1 PRELIMINARY - Data / Theory
Data / NLO-FR×(1+δ_hadr.)
Data / NLO-FR×(1+δ_hadr.) correlated uncertainty
Data / NLO-KK×(1+δ_hadr.)
(Data / Theory)
0.8
0.6
0.4
0.2
0.4
0.6
0.8
1
z_IP

high E_T

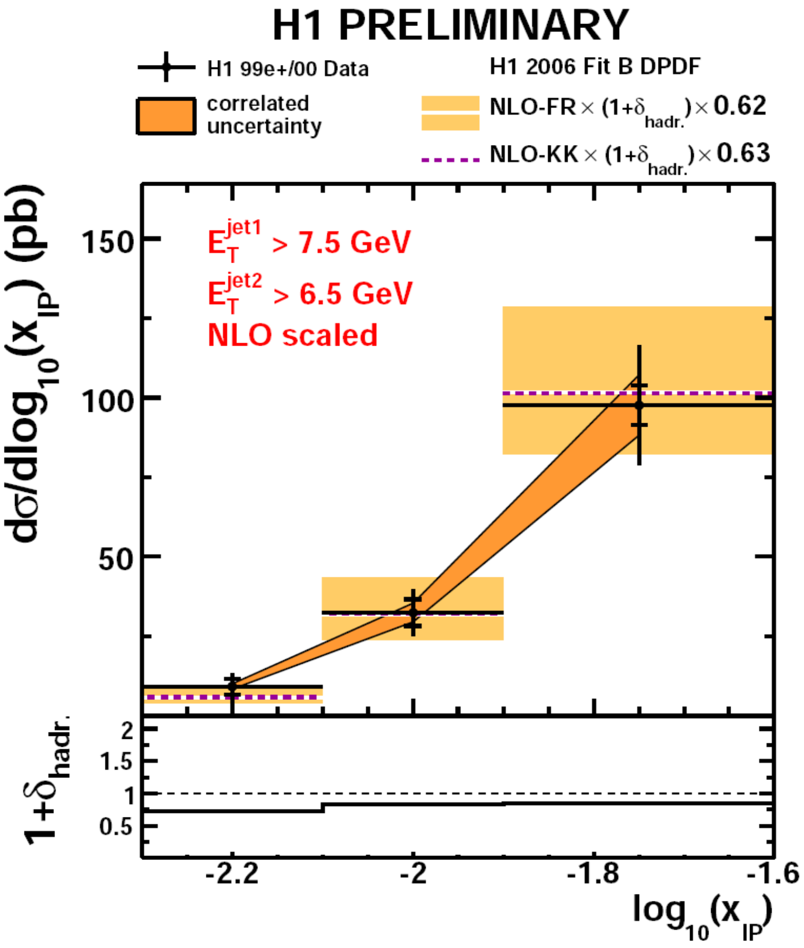

H1 PRELIMINARY
H1 99e+/00 Data
correlated uncertainty
H1 2006 Fit B DPDF
NLO-FR × (1+δhadr.)× 0.62
NLO-KK × (1+δhadr.)× 0.63
dσ/dE_T^jet1 (pb GeV^-1)
10
1
E_T^jet1 > 7.5 GeV
E_T^jet2 > 6.5 GeV
NLO scaled
1+δhadr.
2
1.5
1
0.5
8
10
12
14
E_T^jet1 (GeV)

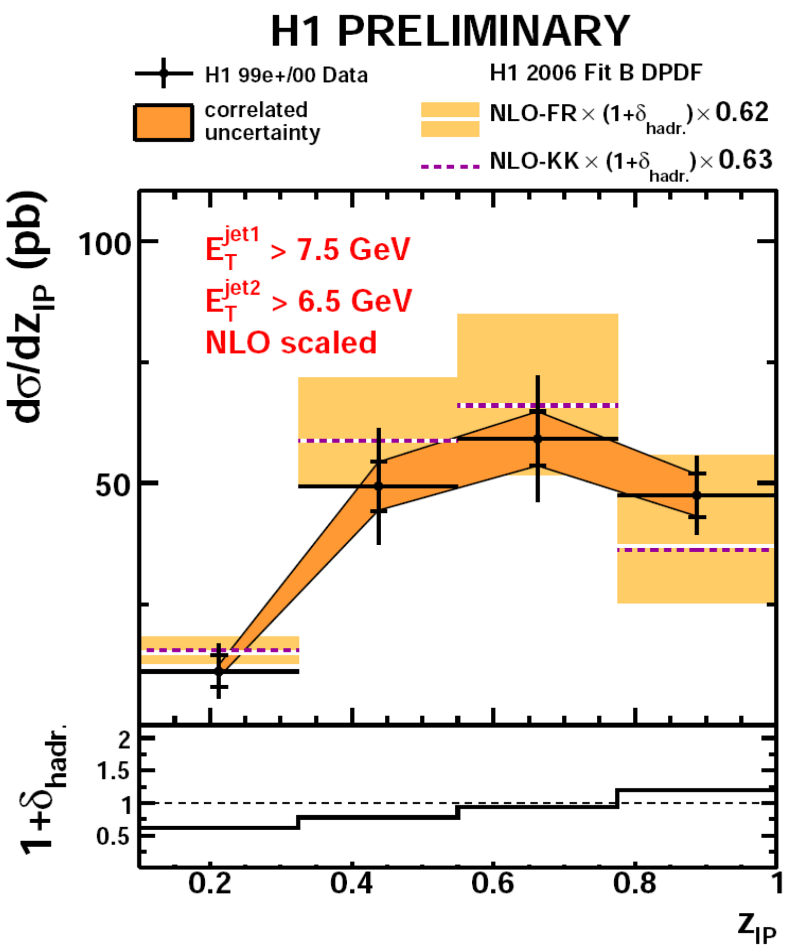

H1 PRELIMINARY
H1 99e+/00 Data
correlated uncertainty
H1 2006 Fit B DPDF
NLO-FR × (1+δhadr.)× 0.62
NLO-KK × (1+δhadr.)× 0.63
dσ/dxγ (pb)
150
100
50
E_T^jet1 > 7.5 GeV
E_T^jet2 > 6.5 GeV
NLO scaled
1+δhadr.
2
1.5
1
0.5
0.2
0.4
0.6
0.8
1
xγ

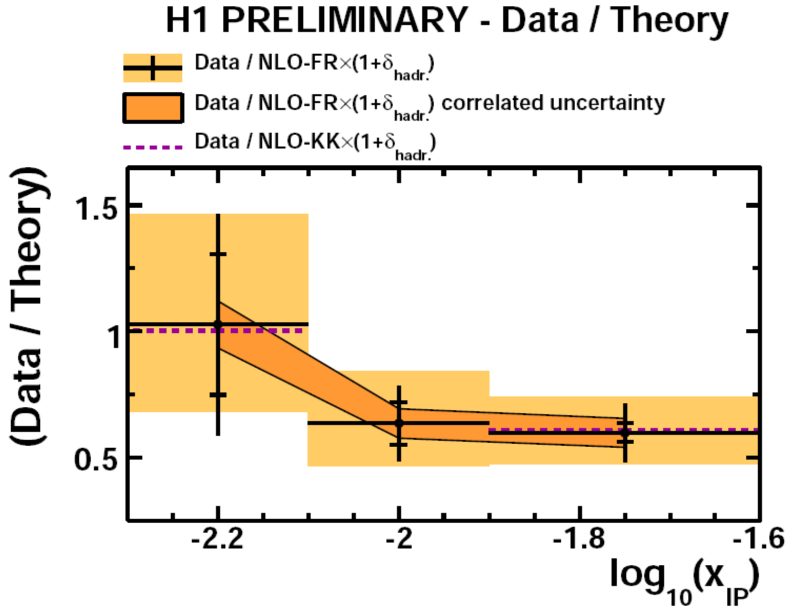

H1 PRELIMINARY - Data / Theory
Data / NLO-FR×(1+δhadr.)
Data / NLO-FR×(1+δhadr.) correlated uncertainty
Data / NLO-KK×(1+δhadr.)
(Data / Theory)
1.2
1
0.8
0.6
0.4
8
10
12
14
E_T^jet1 (GeV)

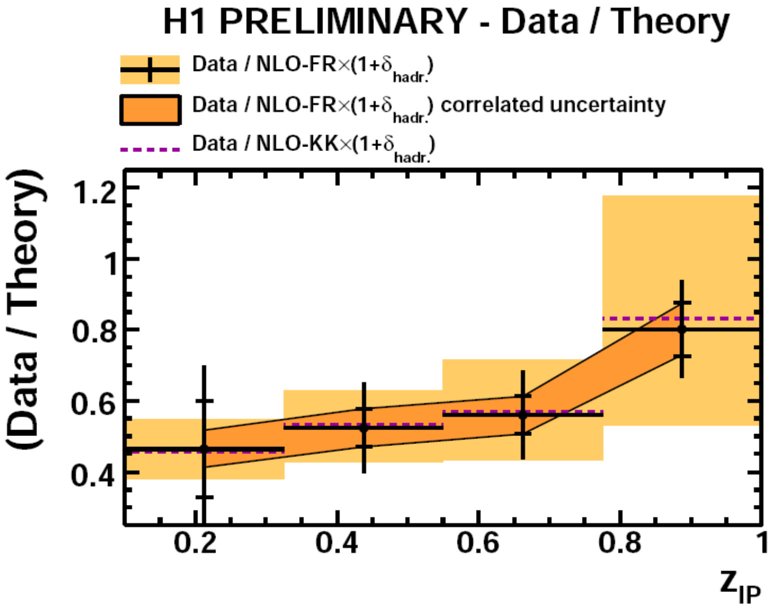

H1 PRELIMINARY - Data / Theory
Data / NLO-FR×(1+δhadr.)
Data / NLO-FR×(1+δhadr.) correlated uncertainty
Data / NLO-KK×(1+δhadr.)
(Data / Theory)
0.8
0.6
0.4
0.2
0.2
0.4
0.6
0.8
1
xγ

high E_T


H1 PRELIMINARY
H1 99e+/00 Data
correlated uncertainty
H1 2006 Fit B DPDF
NLO-FR × (1+δhadr.) × 0.62
NLO-KK × (1+δhadr.) × 0.63
E_T^jet1 > 7.5 GeV
E_T^jet2 > 6.5 GeV
NLO scaled
dσ/dlog10(xIP) (pb)
150
100
50
1+δhadr.
2
1.5
1
0.5
-2.2
-2
-1.8
-1.6
log10(xIP)


H1 PRELIMINARY
H1 99e+/00 Data
correlated uncertainty
H1 2006 Fit B DPDF
NLO-FR × (1+δhadr.) × 0.62
NLO-KK × (1+δhadr.) × 0.63
E_T^jet1 > 7.5 GeV
E_T^jet2 > 6.5 GeV
NLO scaled
dσ/dzIP (pb)
100
50
1+δhadr.
2
1.5
1
0.5
0.2
0.4
0.6
0.8
1
zIP


H1 PRELIMINARY - Data / Theory
Data / NLO-FR×(1+δhadr.)
Data / NLO-FR×(1+δhadr.) correlated uncertainty
Data / NLO-KK×(1+δhadr.)
(Data / Theory)
1.5
1
0.5
-2.2
-2
-1.8
-1.6
log10(xIP)


H1 PRELIMINARY - Data / Theory
Data / NLO-FR×(1+δhadr.)
Data / NLO-FR×(1+δhadr.) correlated uncertainty
Data / NLO-KK×(1+δhadr.)
(Data / Theory)
1.2
1
0.8
0.6
0.4
0.2
0.4
0.6
0.8
1
zIP

- The suppression factors applied to NLO predictions are calculated from the total data and NLO cross sections.

low E_T

$$f^{FR} = 0.54 \pm 0.01\,(stat.) \pm 0.09\,(syst.)\,^{+0.14}_{-0.13}\,(scale)$$

$$f^{KK} = 0.52 \pm 0.01\,(stat.) \pm 0.08\,(syst.)$$

high E_T

$$f^{FR} = 0.62 \pm 0.04\,(stat.) \pm 0.13\,(syst.)\,^{+0.16}_{-0.14}\,(scale)$$

$$f^{KK} = 0.63 \pm 0.03\,(stat.) \pm 0.13\,(syst.)$$

Conclusions

- The NLO predictions overestimate measured cross section in both analyses – stronger suppression in the low E_T analysis.

- E_T dependence of the suppression observed in the low E_T analysis.

- With respect to the larger uncertainties the E_T dependence of the suppression in the high E_T analysis is not excluded.

- New analyses might illuminate the issue:
  - Photoproduction: $\sigma^{diffr.}_{dijets} / \sigma^{incl.}_{dijets}$
  - Photoproduction & DIS: $\dfrac{\sigma^{Php,data}_{dijets} / \sigma^{Php,NLO}_{dijets}}{\sigma^{DIS,data}_{dijets} / \sigma^{DIS,NLO}_{dijets}}$

Backup – cuts

!! the analysis is carried out in 2 cut schemes !!

1) cuts identical with previous H1 measurement
2) ZEUS-like analysis cuts (harder jets,...)

detector level cuts

	low E_T	**high E_T**
scattered electron cuts	$0.3 < y_e < 0.65$ $\lvert X_{clus}^{etag} \rvert < 6.5\,cm$ $E_{photon\,det.} < 2\,GeV$	
jet cuts	$p_T^{jet1} > 5\,GeV$ $p_T^{jet2} > 4\,GeV$ $-1 < \eta^{jet1\ and\ jet2} < 2$	$p_T^{jet1} > 7.5\,GeV$ $p_T^{jet2} > 6.5\,GeV$ $-1.5 < \eta^{jet1\ and\ jet2} < 1.5$
diffr. cuts	$\eta^{max} < 3.2$ $x_{IP} < 0.03$ $\Sigma_{i=1}^{5} N_i^{PRT} < 1$ $\Sigma_{i=1}^{3} N_i^{FMD} < 3 \wedge \Sigma_{i=1}^{2} N_i^{FMD} < 2$	$x_{IP} < 0.025$

Backup – MC samples

- Rapgap 3.1 IP and IR exchange with H1 2006 fit b for DPDFs:

	IP	IR
BGF-c	870k	110k
BGF-uds	1.82M	190k
QCD Compton-uds	330k	140k
resolved-uds	12M	2.5M

- GRV-G LO photon structure function

- Pythia 6.2 inclusive photoproduction sample for background

Backup – reconstruction of kinematics

rec. level	**hadron. level** (GKI stable hadrons)	**parton. level** (GKI partons)
$y_e=1-\frac{E_{etag}}{E_e^{beam}}$	$y_e=1-\frac{E_e^{gen}}{E_e^{beam}}$	$-//-$
$W=\sqrt{s.y_e}$	$-//-$	$-//-$
$x_\gamma=\frac{\Sigma_{jets}E_i-p_{z,i}}{\Sigma_{HFS}E_i-p_{z,i}}$	$-//-$	$-//-$
$x_{IP}=\frac{\Sigma_{HFS}E_i+p_{z,i}}{2.E_P^{beam}}$	$x_{IP}=\frac{\Sigma_{hadrons}^{no\ elas.P}E_i+p_{z,i}}{2.E_P^{beam}}$	$x_{IP}=x_{IP}^{gen}$
$z_{IP}=\frac{\Sigma_{jets}E_i+p_{z,i}}{2.x_{IP}.E_P^{beam}}$	$-//-$	$-//-$
$M_{12}=\sqrt{J_1^\mu.J_{2,\nu}}$	$-//-$	$-//-$
$M_X=\sqrt{s.y_e.x_{IP}}$	$M_X=\sqrt{X^\mu.X_\mu}$ … $X^\mu=\Sigma_{hadrons}^{no\ elas.P}P_i^\mu$	$M_X=\sqrt{X^\mu.X_\mu}$ … $X^\mu=\Sigma_{partons}P_i^\mu$

Backup – FR NLO settings

resolved, IP

```
  5                              ! # of flavours
  4 1                                  ! Hadron type
 1001                            ! PDF set for the hadron, negative
for
 DPDFLib - 1150 =  fit2
 5003                            ! PDF set for 1. particle
 0.228E+00                       ! Lambda_5, 0 for default
 'MS'                            ! Scheme for hadron
```

direct, IP:

```
  5                              ! # of flavours
  1                              ! Hadron type
 1001                            ! PDF set for the hadron, negative
for
DPDFLib - 1150 =  fit2
 0.228E+00                       ! Lambda_5, 0 for default
 'MS'                            ! Scheme for hadron
 'DI'                            ! Scheme for photon
```