Summary of WG2
Multi-jet final states and energy flows

LUND UNIVERSITY

- Underlying event and minimum bias
- Rapidity gaps and survival probabilities
- Multi-jet topologies and multi-scale QCD
- Parton shower/ME matching

CERN
2006.06.08
Leif Lönnblad

Summary of WG2
Multi-jet final states and energy flows

- Underlying event and minimum bias $\Rightarrow$ WG5
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Summary of WG2 Multi-jet final states and energy flows

- Underlying event and minimum bias ⇒ WG5
- Rapidity gaps and survival probabilities ⇒ WG4
- Multi-jet topologies and multi-scale QCD
- Parton shower/ME matching

Summary of WG2
Multi-jet final states and energy flows

- Underlying event and minimum bias ⇒ WG5
- Rapidity gaps and survival probabilities ⇒ WG4
- Multi-jet topologies and multi-scale QCD
- Parton shower/ME matching ⇒ WG5

The talks

- NLO-GRID: Dan Clements
- FastNLO: Thomas Kluge
- Inclusive and di-jets production: Thomas Schörner-Sadenius (Claire Gwenlan)
- Low-x physics studies using the hadronic final state at H1: Daniel Traynor
- New fits to uPDFs: Hannes Jung
- Prompt Photons at HERA: Katharina Müller

NLO-GRID: Dan Clements

Hard 2 →2 scattering

$$\sigma(P_1,P_2)=\sum_{i,j}\int dx_1 dx_2 f_i(x_1,\mu^2) f_j(x_2,\mu^2)\hat{\sigma}_{ij}\left(x_1P_1,x_2P_2,\alpha_s(\mu^2),Q^2/\mu^2\right)$$

PDFs

Parton momenta

Hadron momenta

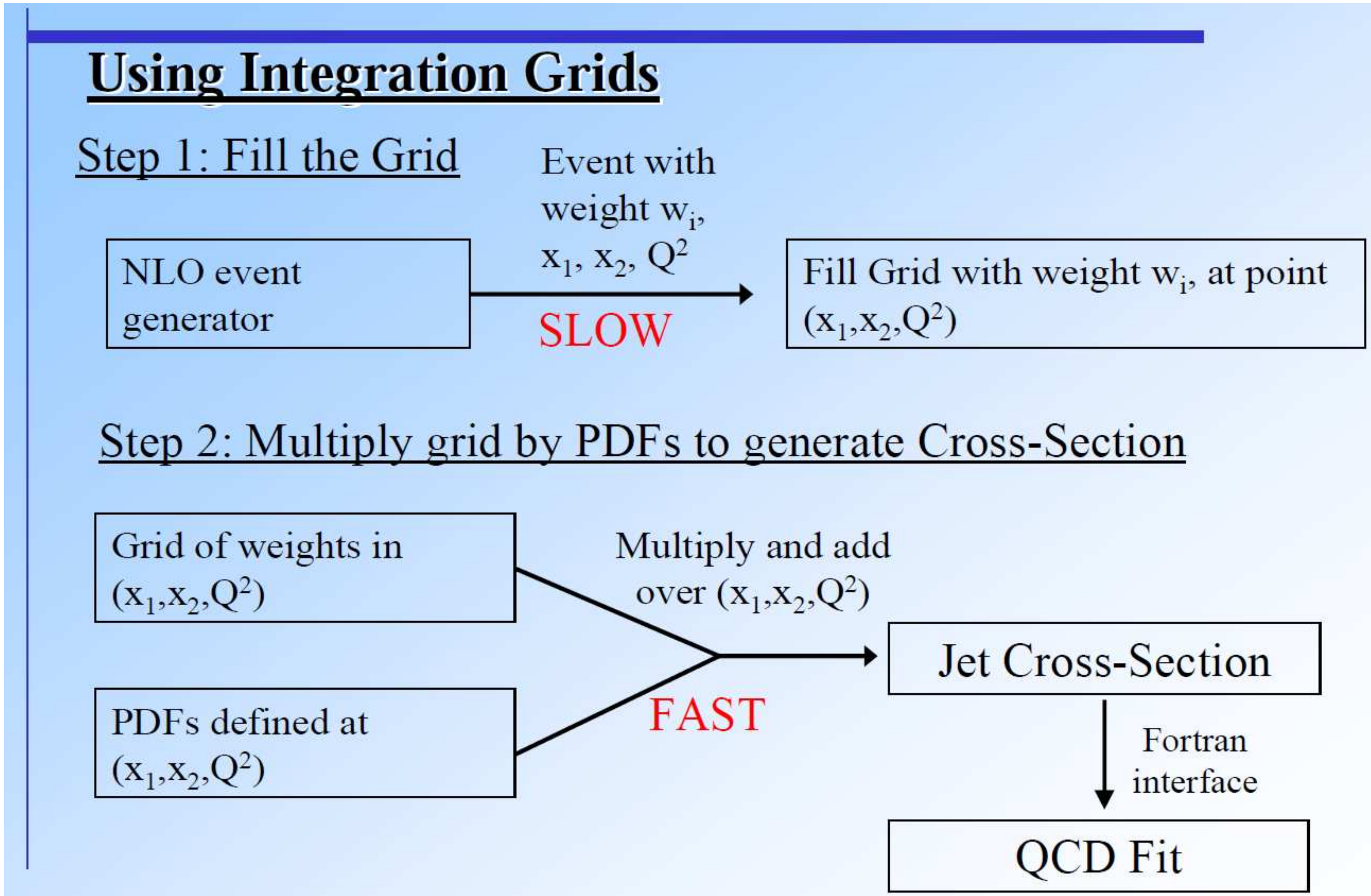
Sum over parton types

Parton Level Cross-Section
(we call this ‘weight’ in the following)

How to fit jet data to NLO PDFs?

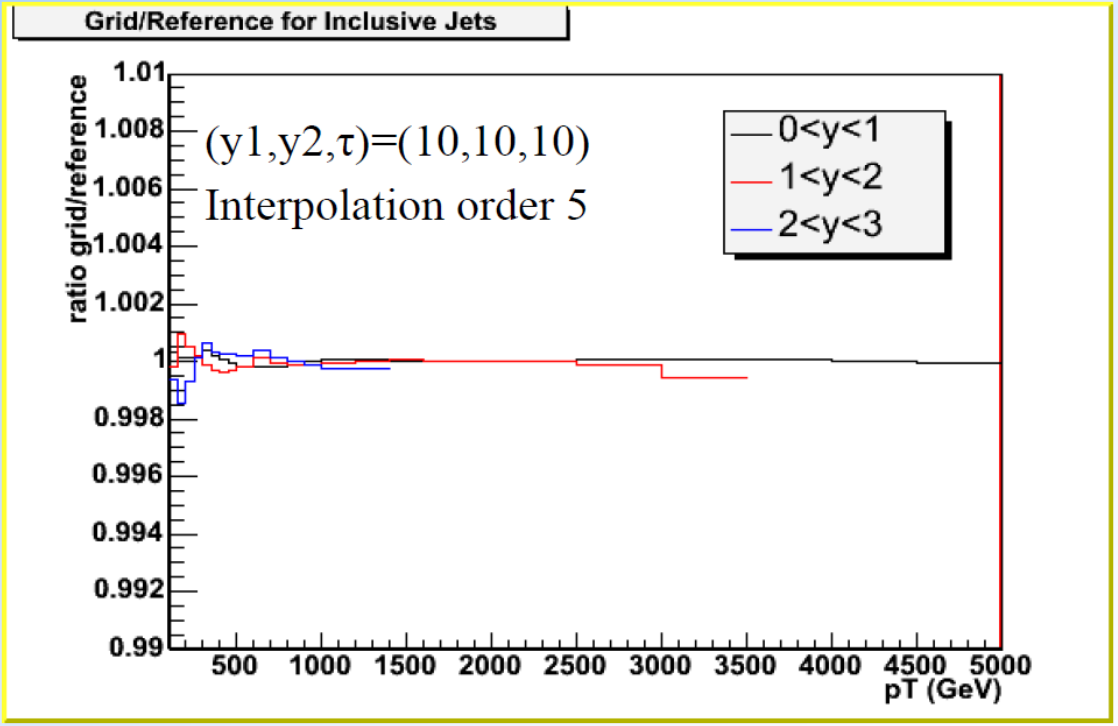
Very slow to evaluate cross section for each parameter settings of the PDF.

Discretize and pretabulate the NLO partonic cross section in a grid.


Using Integration Grids
Step 1: Fill the Grid
NLO event generator
Event with weight w_i, x_1, x_2, Q^2
SLOW
Fill Grid with weight w_i, at point (x_1,x_2,Q^2)
Step 2: Multiply grid by PDFs to generate Cross-Section
Grid of weights in (x_1,x_2,Q^2)
PDFs defined at (x_1,x_2,Q^2)
Multiply and add over (x_1,x_2,Q^2)
FAST
Jet Cross-Section
Fortran interface
QCD Fit

How good are the grids?

•Compared the inclusive jet cross-section at ATLAS as generated using grids and standard NLO calculation (reference) agreement is better than 0.2%



FastNLO: Thomas Kluge

Basically the same idea:

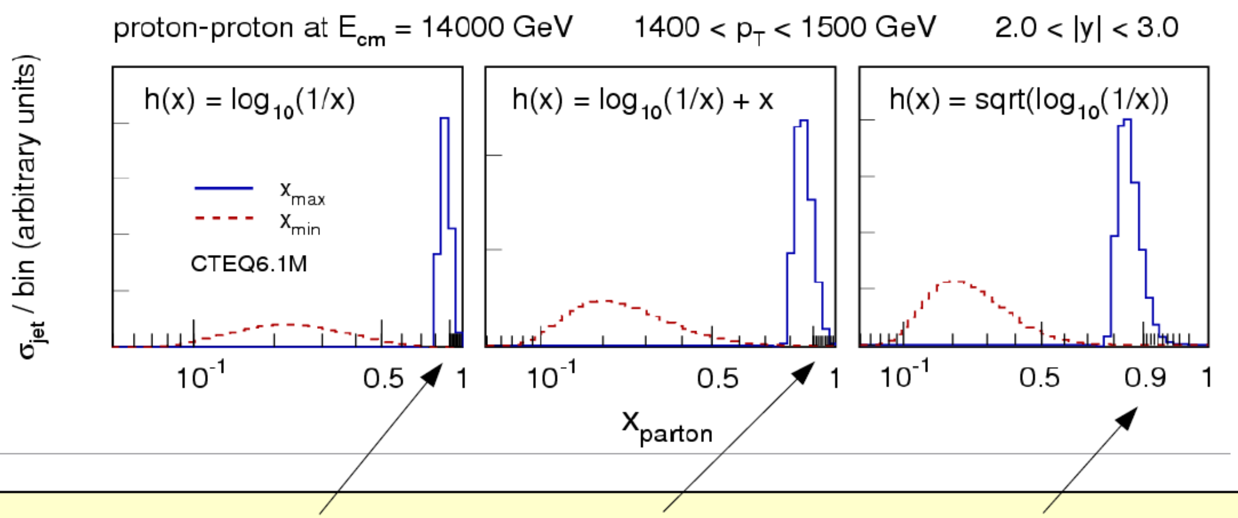
Put heavy NLO cross section calculation on a grid.

Difference eg. in how to bin things on the grid:

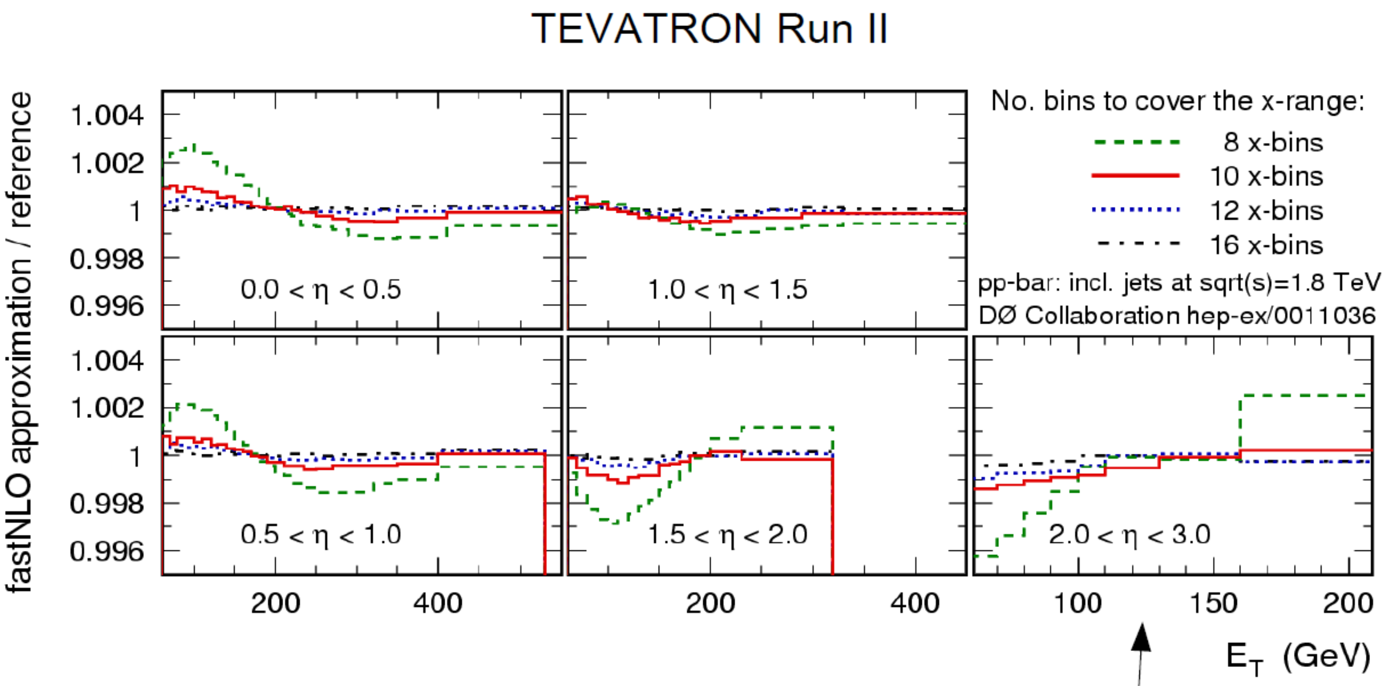
NLO-GRID uses $\log 1/x + a(1-x)$

FastNLO uses $\sqrt{\log 1/x}$

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



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



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

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

Inclusive and di-jets production: Thomas Schörner-Sadenius

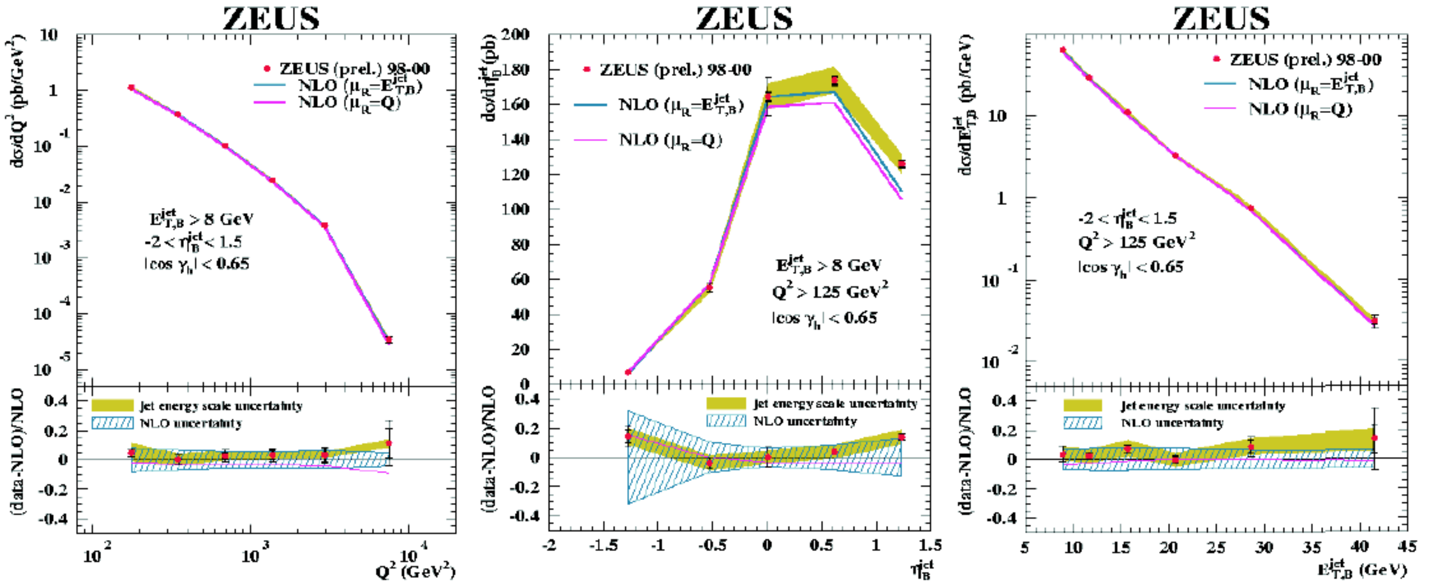
- ZEUS inclusive jets at high Q^2
- H1 inclusive jets at high Q^2
- ZEUS di-jets at high Q^2
- H1 multijets at high Q^2
- H1 dijets photoproduction
- ZEUS dijets photoproduction

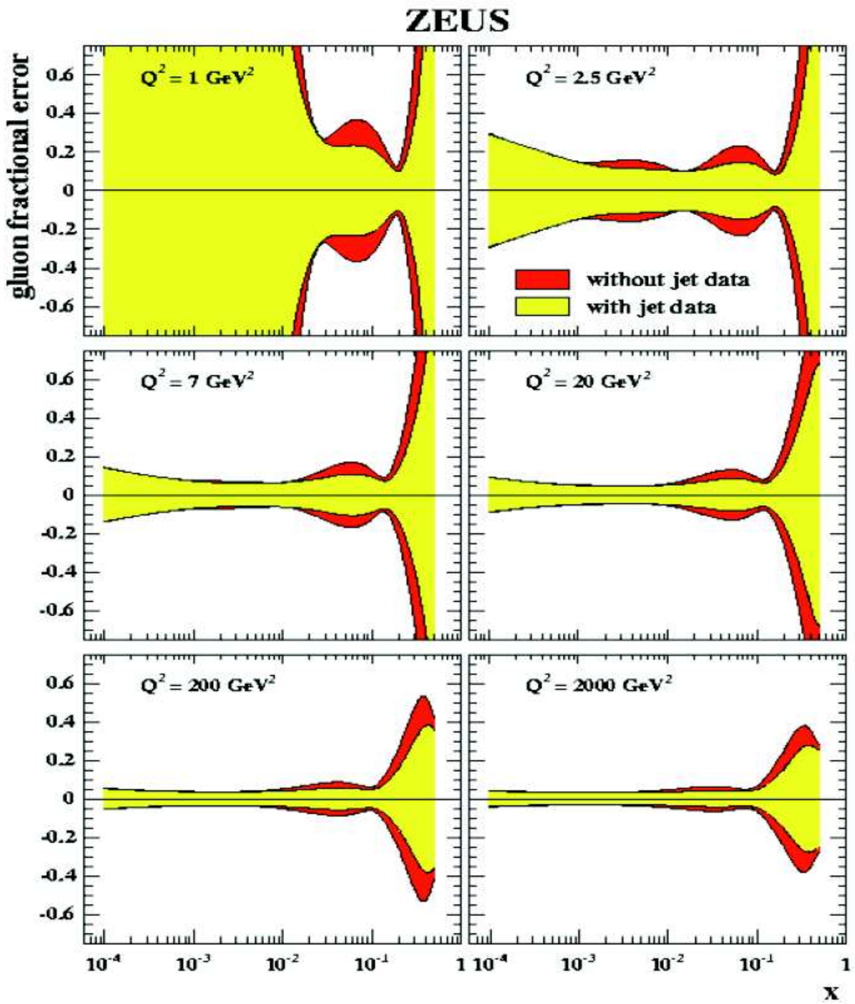
ZEUS INCLUSIVE JETS AT HIGH Q^2

`Simple' measurement – take PDFs/α_S as given

Phase Space:
$Q^2 > 125$ GeV^2
E_T(Breit) > 8 GeV
$-2 < \eta$(Breit) < 1.5
$|\cos\gamma_h| < 0.65$

- **Tests**: understanding of pQCD, factorisation, PDF universality,…
- **Data**: 82 pb^{-1} e^+p data from 98-00
- **Aims**: extraction of strong coupling, use data in QCD fits for PDF constraints

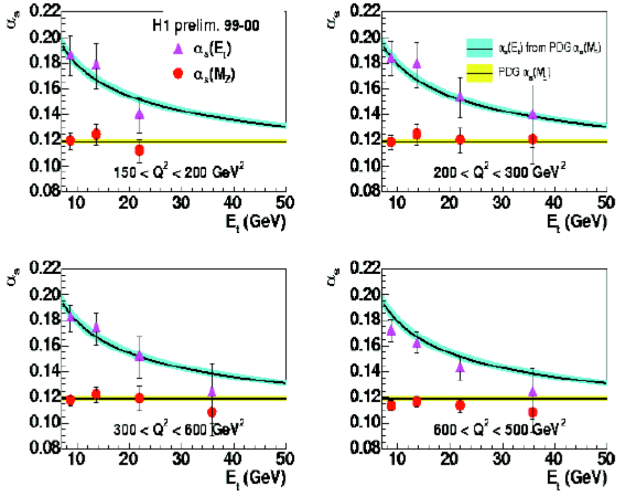




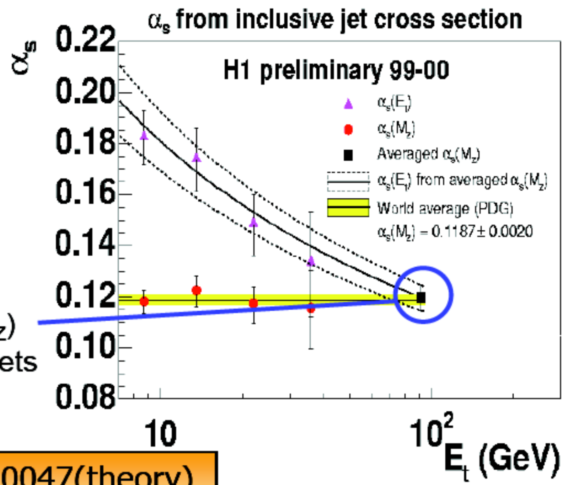
ZEUS
gluon fractional error
Q^2 = 1 GeV^2
Q^2 = 2.5 GeV^2
without jet data
with jet data
Q^2 = 7 GeV^2
Q^2 = 20 GeV^2
Q^2 = 200 GeV^2
Q^2 = 2000 GeV^2
x

H1 INCLUSIVE JETS

extraction of strong coupling



- Coupling $\alpha_s(M_Z)$ [also $\alpha_s(\langle E_T \rangle)$] extracted from double differential cross section in E_T(Breit) and Q^2 (15 data points) and single differential cross section in E_T(Breit)
  - all single measurements consistent



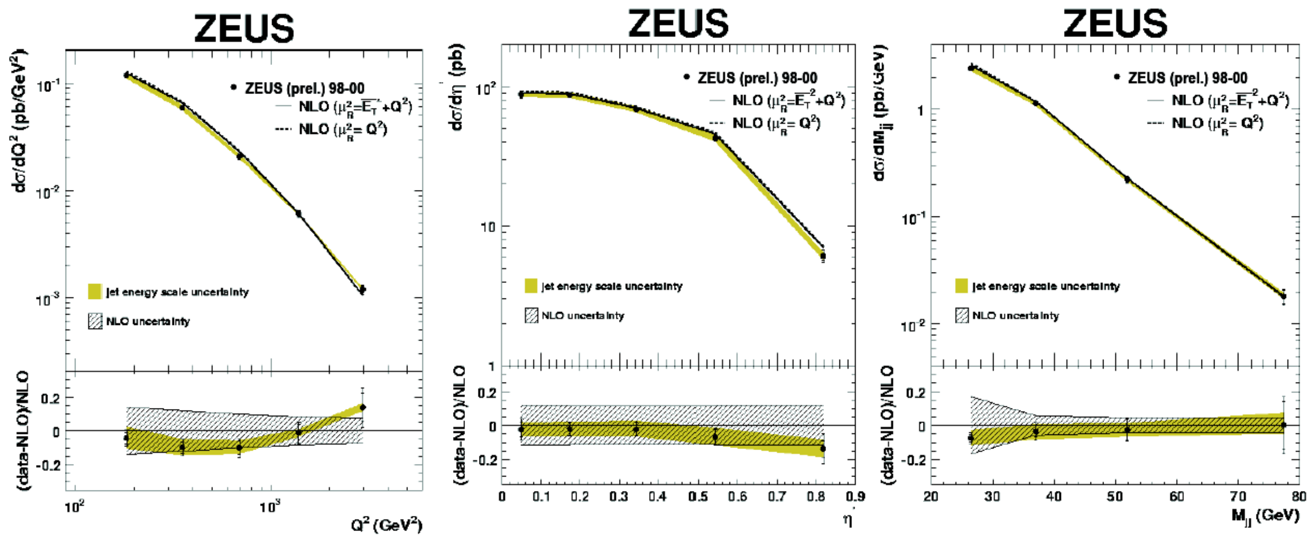
- 15 double differential points used for average $\alpha_s(M_Z)$
- Result consistent with world average + ZEUS incl. jets
- Theory error dominates (effect of higher orders)

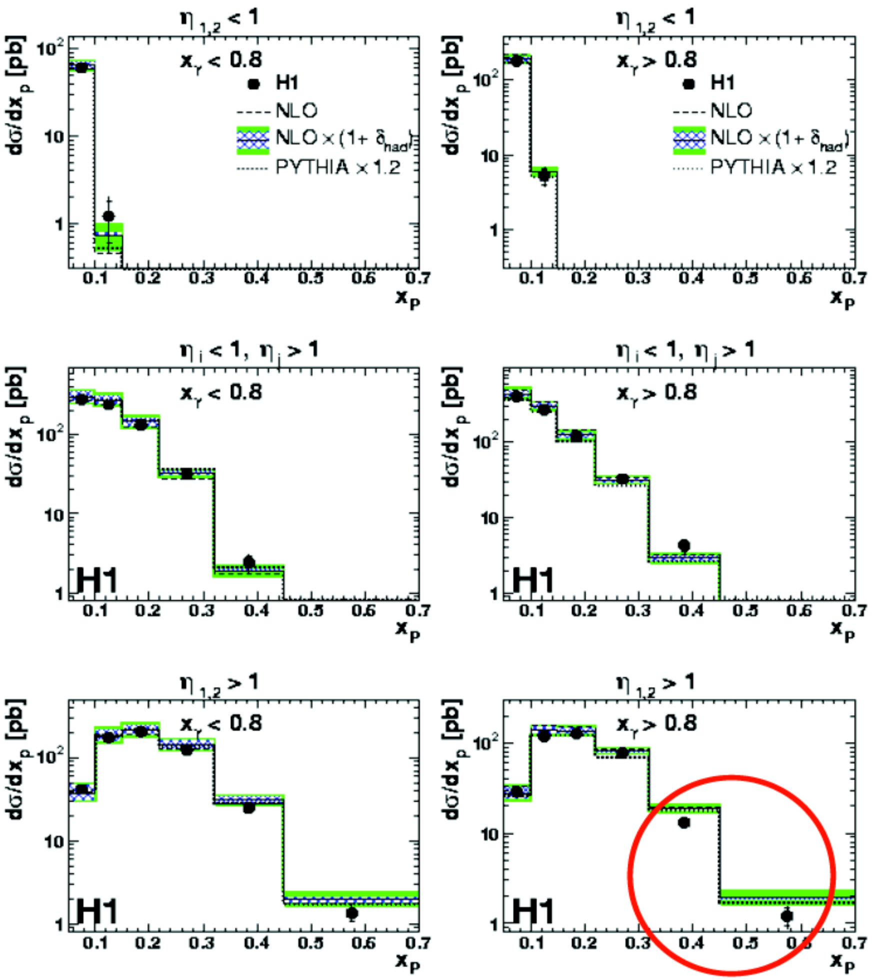
H1 inclusive: $\alpha_s(M_Z) = 0.1197 \pm 0.0016(\text{exp}) \pm 0.0047(\text{theory})$

c.f. ZEUS inclusive: $\alpha_s(M_Z) = 0.1196 \pm 0.0025(\text{exp}) \pm 0.0023(\text{theory})$

ZEUS DIJETS AT HIGH Q^2

More single-differential results





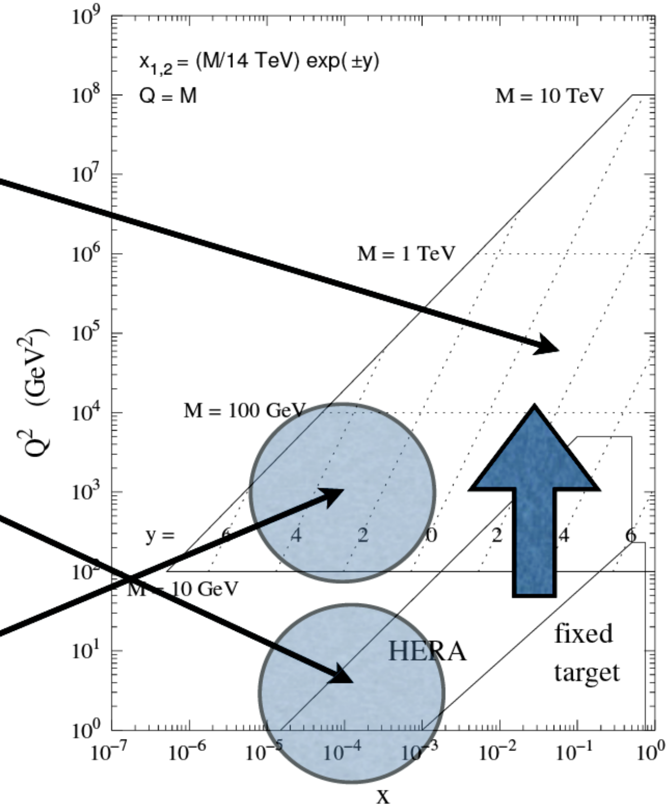
η 1,2 < 1
x_γ < 0.8
H1
NLO
NLO × (1+ δ_had)
PYTHIA × 1.2
x_γ > 0.8
η i < 1, η j > 1
η 1,2 > 1
dσ/dx_p [pb]
x_p

Low-x studies at H1: Daniel Traynor

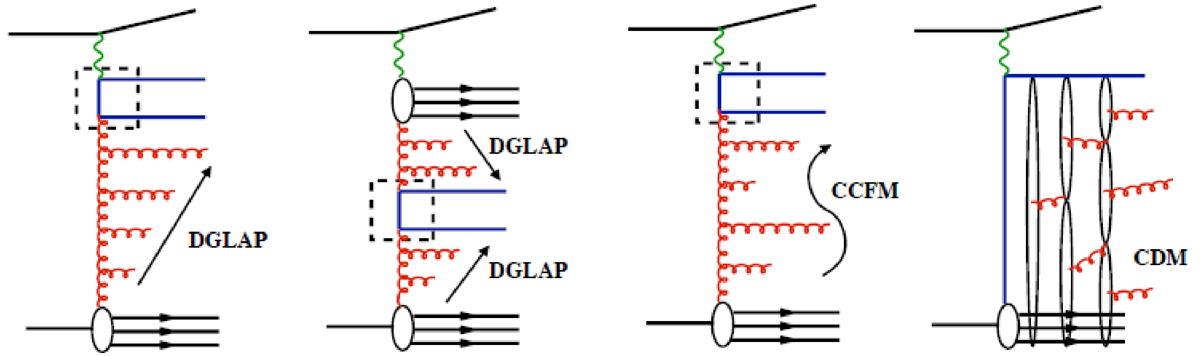
Conventional DGLAP QCD approach evolves with Q

Possibility of non DGLAP behaviour of the parton evolution at HERA

What does this mean for the LHC?



Monte Carlos for DIS



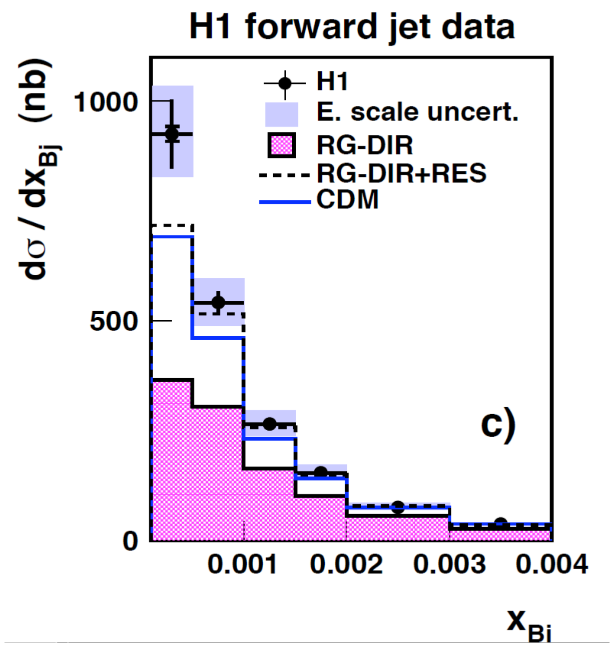
Rapgap (dir) | Rapgap (dir+res) | Cascade | Ariadne

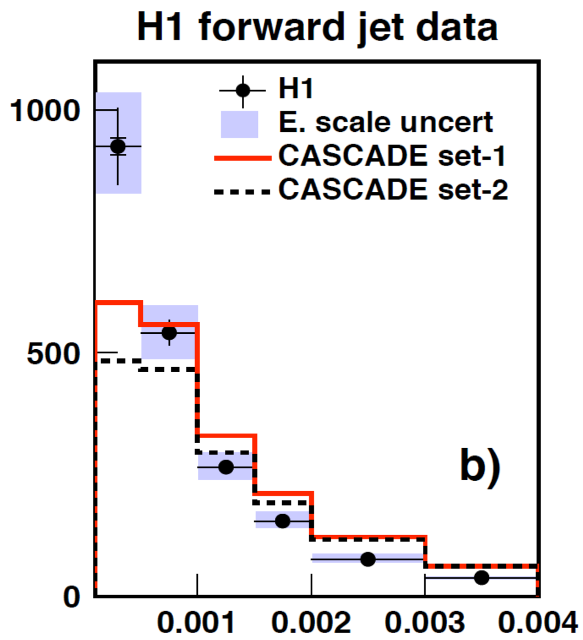
Strong ordering in k_t
of emitted partons
as is PYTHIA and HERWIG
DGLAP

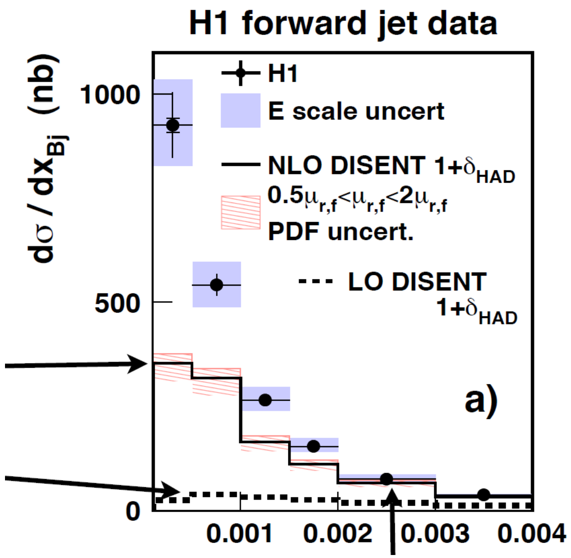
CCFM resums both
$\log(Q^2)$ and $\log(1/x)$
angular ordering
CCFM

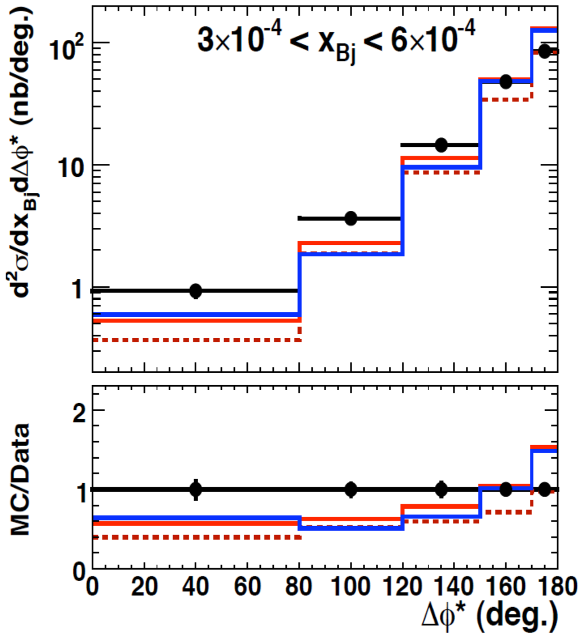
Dipoles radiate
independently

BFKL like

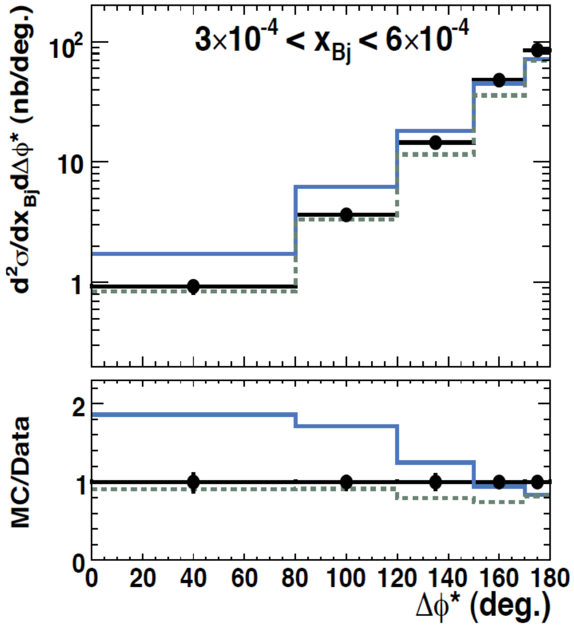

H1 forward jet data
H1
E. scale uncert.
RG-DIR
RG-DIR+RES
CDM
c)
dσ / dx_Bj (nb)
1000
500
0
0.001
0.002
0.003
0.004
x_Bj


H1 forward jet data
H1
E. scale uncert
CASCADE set-1
CASCADE set-2
b)
1000
500
0
0.001
0.002
0.003
0.004

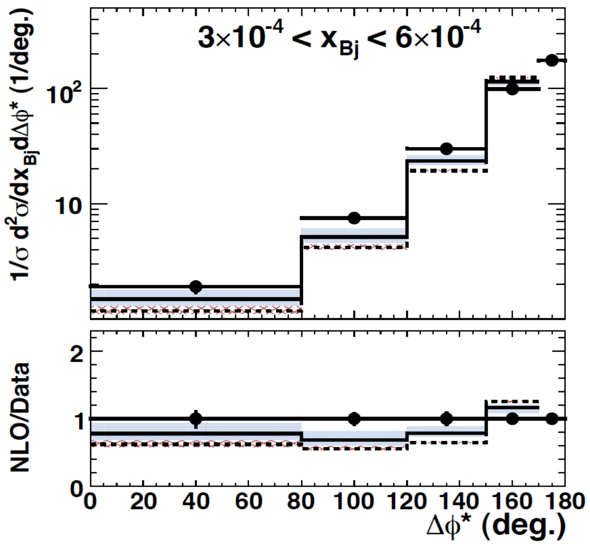

H1 forward jet data
H1
E scale uncert
NLO DISENT 1+δ_HAD
0.5μ_r,f<μ_r,f<2μ_r,f
PDF uncert.
LO DISENT
1+δ_HAD
a)
dσ / dx_Bj (nb)
1000
500
0
0.001
0.002
0.003
0.004



3×10^-4 < x_Bj < 6×10^-4
d²σ/dx_Bj dΔφ* (nb/deg.)
MC/Data
Δφ* (deg.)



3×10^-4 < x_Bj < 6×10^-4
d²σ/dx_Bj dΔφ* (nb/deg.)
MC/Data
Δφ* (deg.)

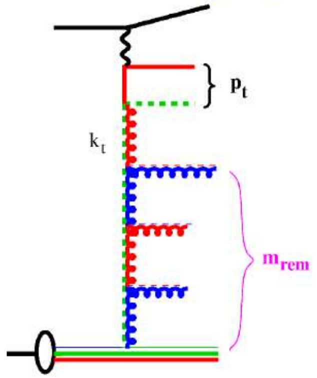


3×10^-4 < x_Bj < 6×10^-4
1/σ d²σ/dx_Bj dΔφ* (1/deg.)
NLO/Data
Δφ* (deg.)

New fits to uPDFs: Hannes Jung

Define:

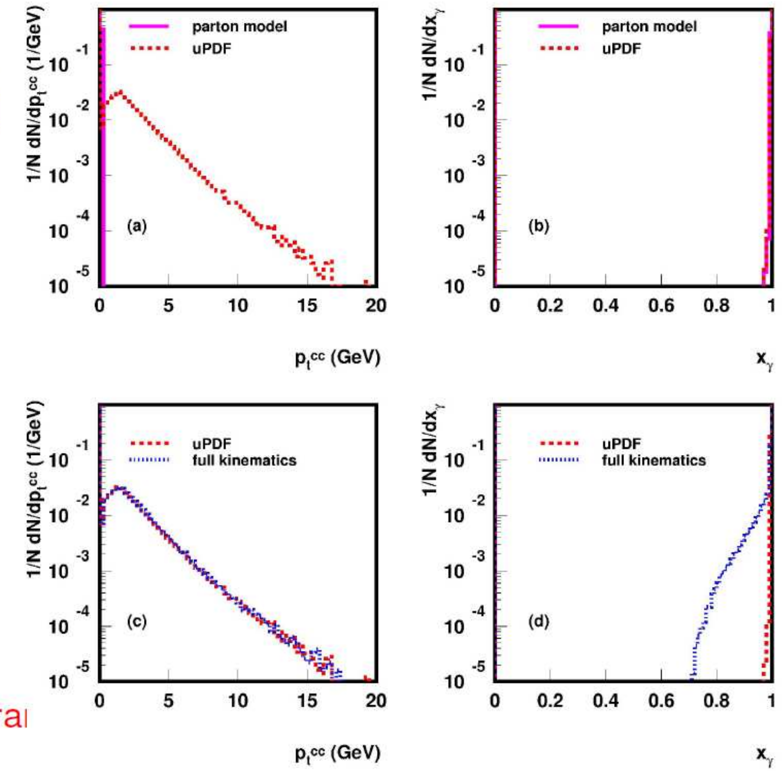
- $p_{Tq\bar{q}}$
- $x_\gamma = \frac{\sum_{i=q,\bar{q}}(E_i - p_{z\ i})}{2yE_e} = \frac{p^-_{q\bar{q}}}{q^-}$

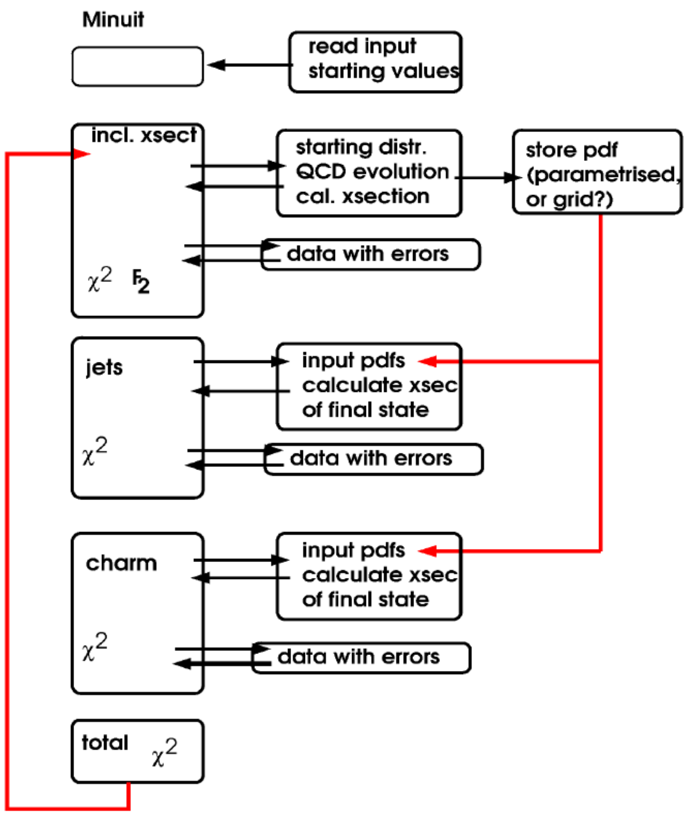


- parton kinematics
- uPDFs
- full kinematics

➔ history is needed for long. and trai components

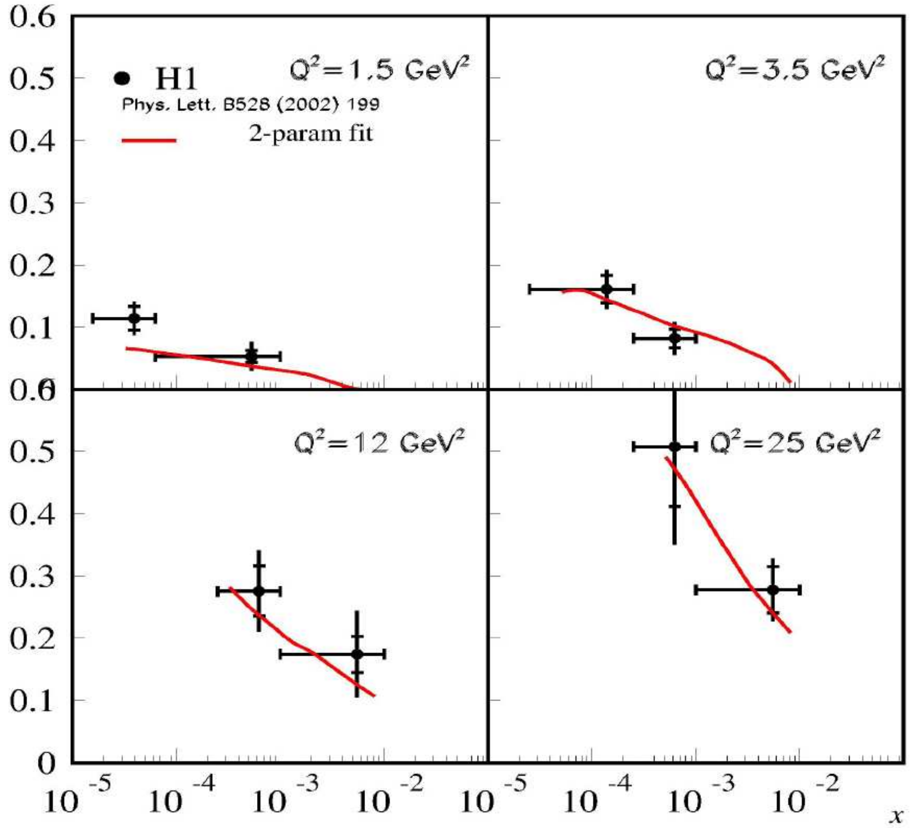
J. Collins, H. Jung





Goals for PDF fits:

- fit inclusive and exclusive measurements
- using as many measurements as possible ... which can constrain the PDFs
  - ➔ HZTool
- using full information of final states
  - ➔ MC@NLO or similar
  - ➔ CASCADE
- consistent treatment of experimental and theoretical errors



0.6
0.5
0.4
0.3
0.2
0.1
0
H1
Phys. Lett. B528 (2002) 199
2-param fit
Q^2=1.5 GeV^2
Q^2=3.5 GeV^2
Q^2=12 GeV^2
Q^2=25 GeV^2
10^{-5} 10^{-4} 10^{-3} 10^{-2}
x

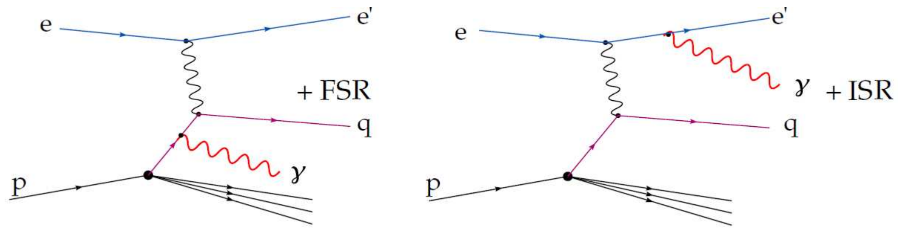
Prompt Photons at HERA: Katharina Müller

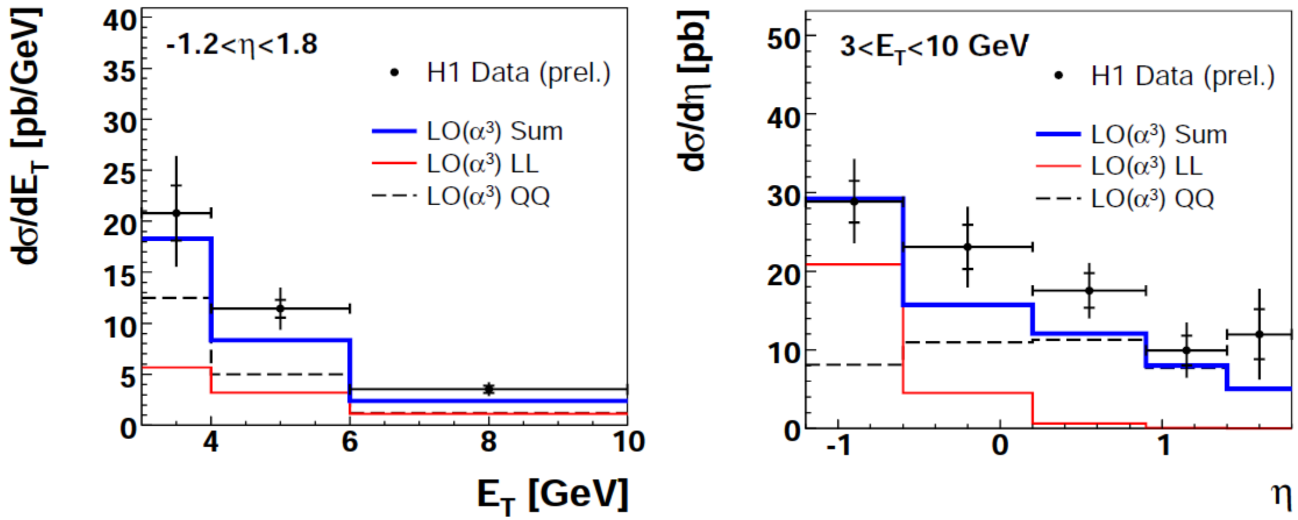
Main LHC motivation: $H \to \gamma\gamma$

How well do we know prompt photon cross section?

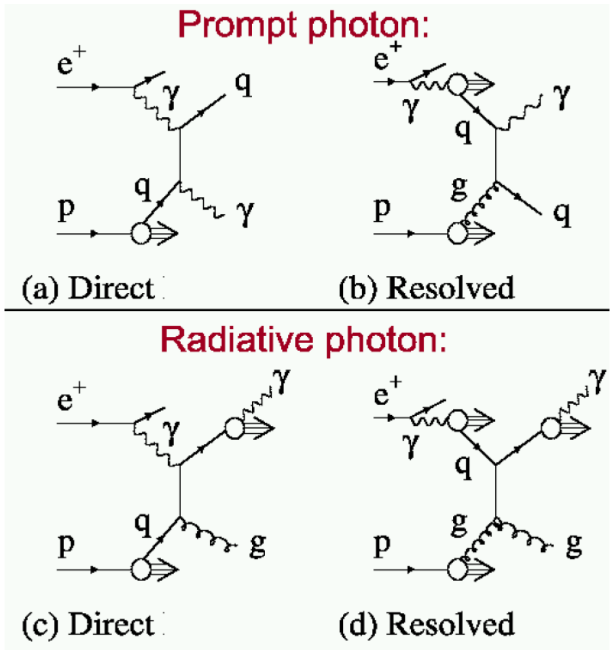
How well do we know quark-to-photon fragmentation function?

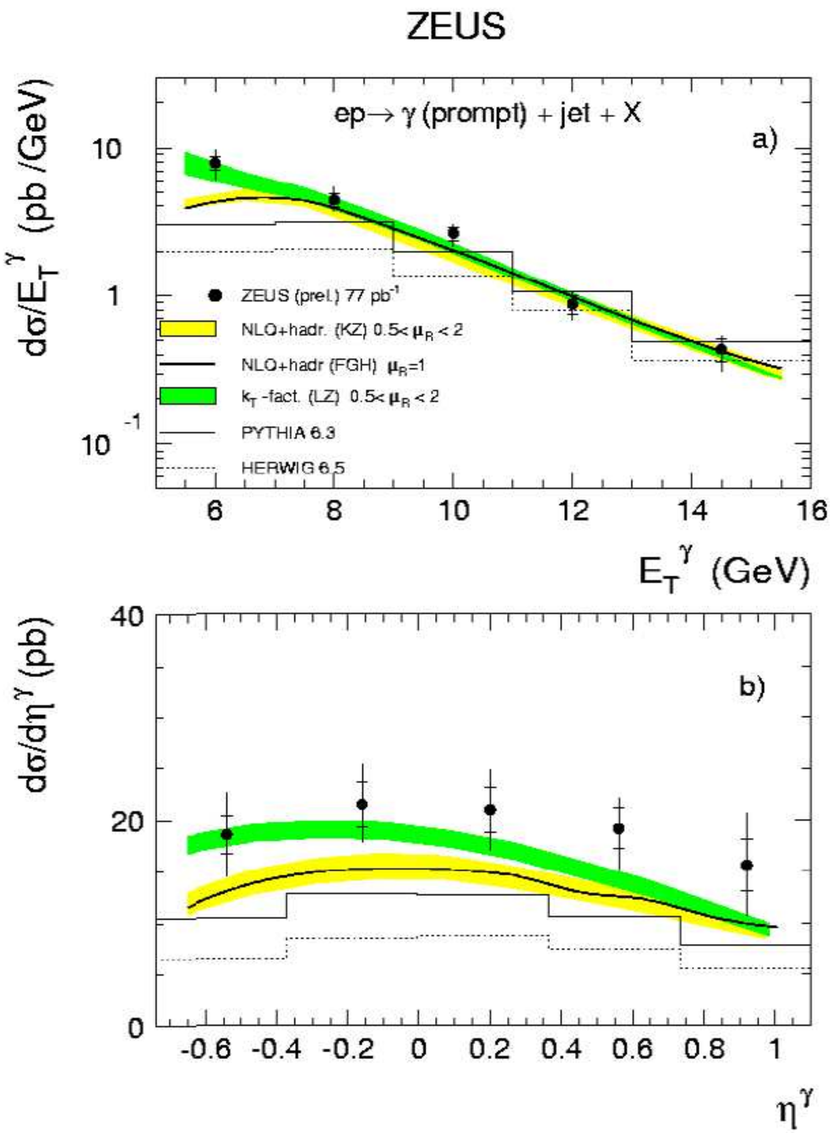
How do we tell a photon from eg. $\pi^0 \to \gamma\gamma$?

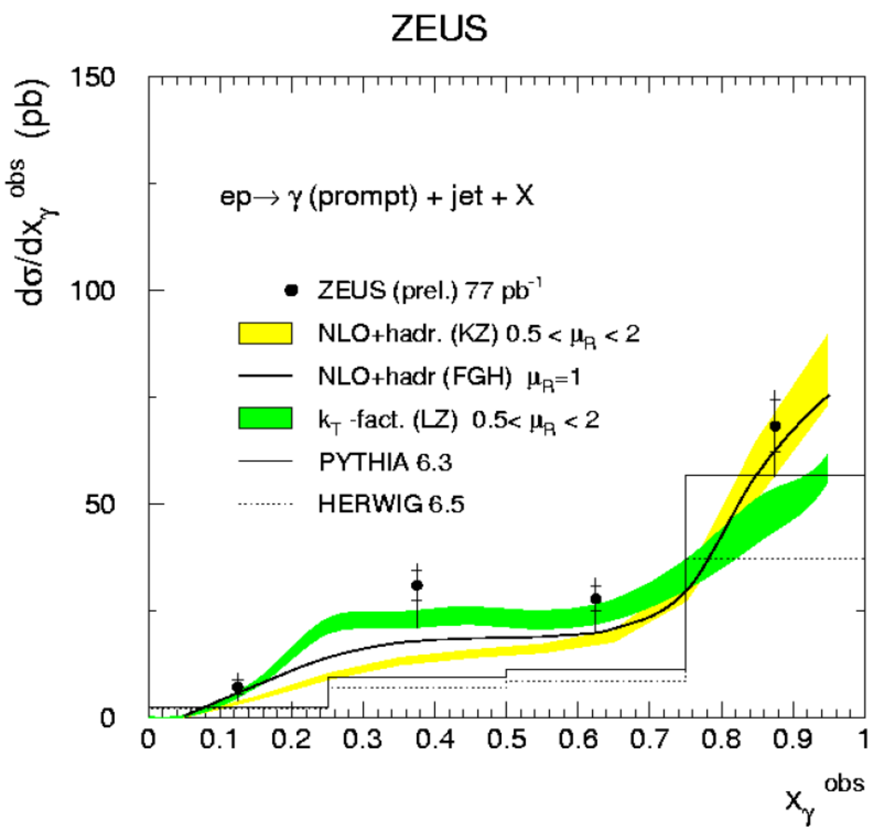




- LO calculation by Gehrmann et al. (hep-ph/0601073, hep-ph/0604030)
- Good description of data, normalization and shapes reproduced
- Data slightly higher
- Large η: QQ term dominates


Prompt photon:
(a) Direct
(b) Resolved
Radiative photon:
(c) Direct
(d) Resolved


ZEUS
ep→ γ (prompt) + jet + X
a)
ZEUS (prel.) 77 pb-1
NLO+hadr. (KZ) 0.5< μR < 2
NLO+hadr (FGH) μR=1
kT -fact. (LZ) 0.5< μR < 2
PYTHIA 6.3
HERWIG 6.5
dσ/dETγ (pb /GeV)
ETγ (GeV)
b)
dσ/dηγ (pb)
ηγ


ZEUS
ep→ γ (prompt) + jet + X
ZEUS (prel.) 77 pb⁻¹
NLO+hadr. (KZ) 0.5 < μR < 2
NLO+hadr (FGH) μR=1
kT -fact. (LZ) 0.5< μR < 2
PYTHIA 6.3
HERWIG 6.5
dσ/dxγ obs (pb)
xγ obs
0
50
100
150
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1