

HERA can teach the LHC

H. Jung (DESY)

“...The mechanic, who wishes to do his work well, must first sharpen his tools ...”

—Chapter 15, “**The Analects**” attributed to Confucius, translated by James Legge.
(from X. Zu talk at DIS05)



HERA AND THE LHC
A workshop on the implications of HERA for LHC physics

March 2004 - Jan 2005

Parton density functions
Multijet final states and energy flow
Heavy quark
Diffraction
Monte Carlo tools

Startup Meeting
March 26-27 2004
CERN, Geneva

Midterm Meeting
October 2004

Final Meeting
Jan 2005
DESY, Hamburg

Final Meeting
March 2005
DESY, Hamburg

Organizing Committee:
G. Altarelli (CERN), J. Blümlein (DESY),
M. Bojars (DESY), J. Butterworth (UCL),
A. Denner (CERN) (chair), K. Eggert (CERN),
H. Jung (DESY) (chair), M. Mangano (CERN),
A. Marach (CERN), P. Newman (Birmingham),
G. Polensio (NIPN), O. Schneider (EPFL),
R. Voss (ANL)

Advisory Committee:
J. Badstuber (Hamburg), M. Della Negra (CERN),
J. Ellis (CERN), J. Garraffo (CERN),
G. Gounaris (Lund), G. Ingelman (Uppsala),
P. Jona-Lasinio (CERN), R. Klanner (DESY),
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T. Matsuoka (CERN), D. Schafer (CERN),
T. Schutz (DESY), J. Schuster (CERN),
J. Sjöstrand (CERN), M. Taroni (CERN),
A. Wagner (DESY), R. Voss (ANL)

www.desy.de/~heralhc heralhc.workshop@cern.ch

HERA can teach the LHC

The poster features an aerial photograph of the DESY Hamburg facility, with a dashed orange line tracing a path through the site. The title 'HERA AND THE LHC' is at the top in large orange letters, with the subtitle 'A workshop on the implications of HERA for LHC physics' below it. The dates 'March 2004 - Jan 2005' are prominently displayed. A list of topics on the left includes Parton density functions, Multijet final states and energy flow, Heavy quark, Diffraction, and Monte Carlo tools. The CERN and DESY logos are in the center. The meeting schedule is listed on the right: Startup Meeting (March 26-27, 2004, CERN, Geneva), Midterm Meeting (October 2004), and Final Meeting (Jan 2005, DESY, Hamburg). An organizational committee and an advisory committee are also listed. A yellow banner at the bottom left reads 'Final Meeting March 2005 DESY, Hamburg'. The website 'www.desy.de/~heralhc' and email 'heralhc.workshop@cern.ch' are at the bottom.

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Final Meeting
March 2005
DESY, Hamburg

www.desy.de/~heralhc heralhc.workshop@cern.ch

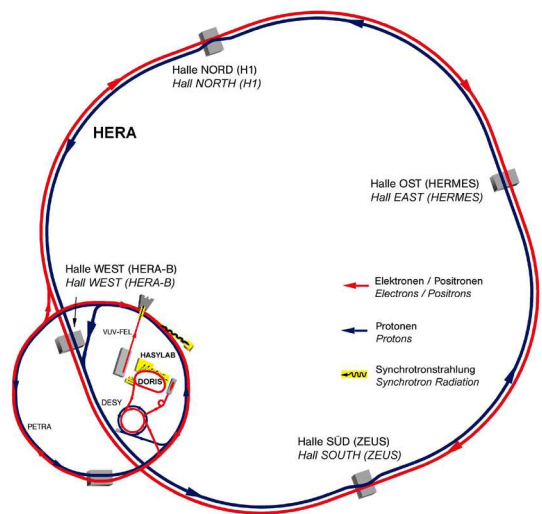
“...The mechanic, who wishes to do his work well, must first sharpen his tools ...”

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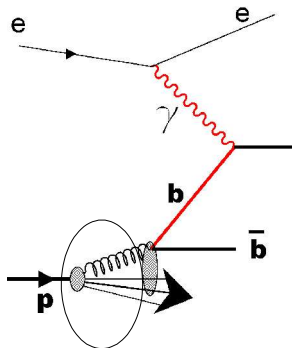
- *Aims of the workshop*
- *Outcome, results and future (highly biased.....):*
 - *HERA is important for the physics reach of LHC*
 - *further HERA measurements desirable*
 - *HERA experience valuable for LHC*

Why HERA and LHC ?

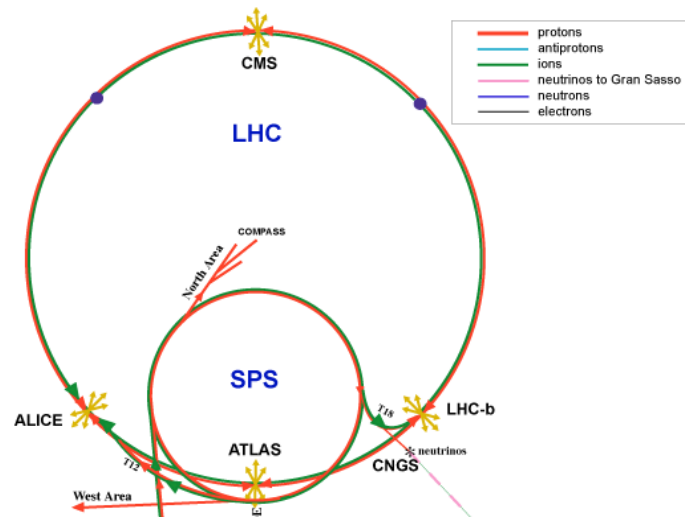
electron proton collider HERA
 $\sqrt{s} = 320 \text{ GeV}$



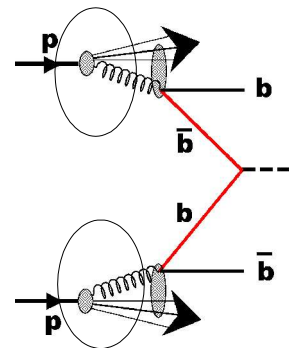
HERA: QCD
 structure of the proton



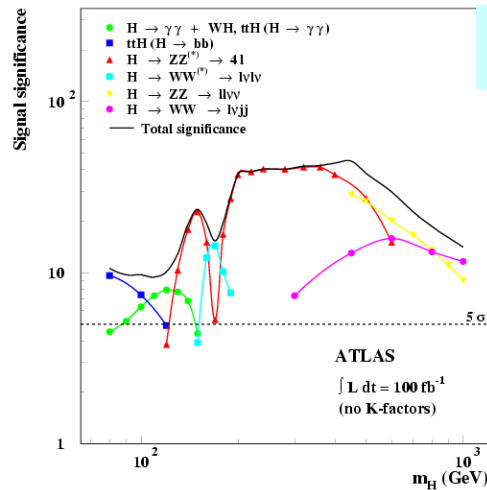
proton proton collider LHC
 $\sqrt{s} = 14 \text{ TeV}$



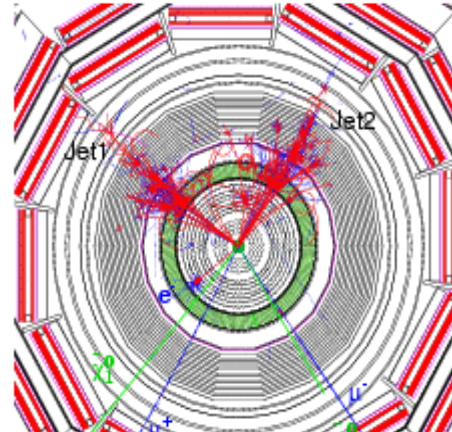
LHC: Higgs, SUSY etc,
 but mostly QCD...



Physics at the LHC: examples

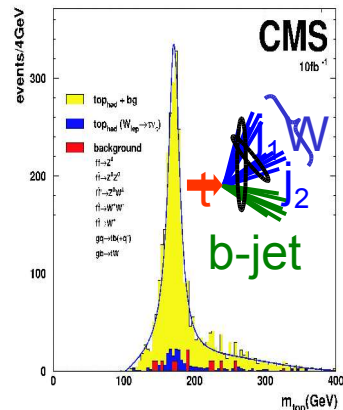
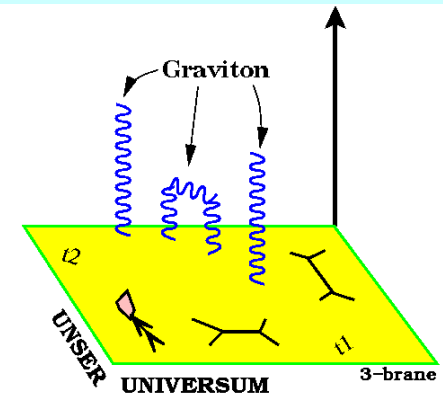


Higgs!



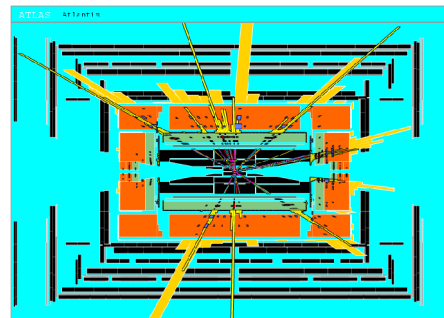
Supersymmetry?

Extra Dimensions?

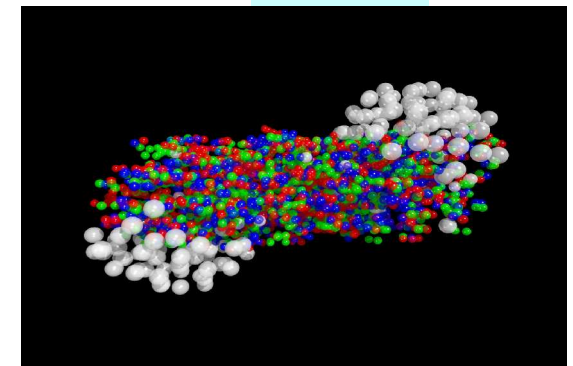


Precision measurements e.g top!

Black Holes???



QGP?



But also QCD, diffraction, b & c physics,... especially in the early phase
 These need to be understood for precision measurements, bkg understanding etc
 Important role for HERA data & HERA expertise

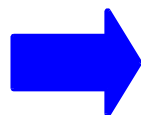
Workshop Aims

- To identify and prioritize those measurements to be made at HERA which have an impact on the physics reach of the LHC.
- To encourage and stimulate transfer of knowledge between the HERA and LHC communities and establish an ongoing interaction.
- To encourage and stimulate theory and phenomenological efforts.
- To examine and improve theoretical and experimental tools.
- To increase the quantitative understanding of the implication of HERA measurements on LHC physics.

<http://www.desy.de/~heralhc>

Chairs: A. De Roeck (CERN) , H. Jung (DESY)

Startup: 26-27 March CERN (~ 250-300 participants)
Final meeting: 21-24 March 2005/ DESY (~150 participants)

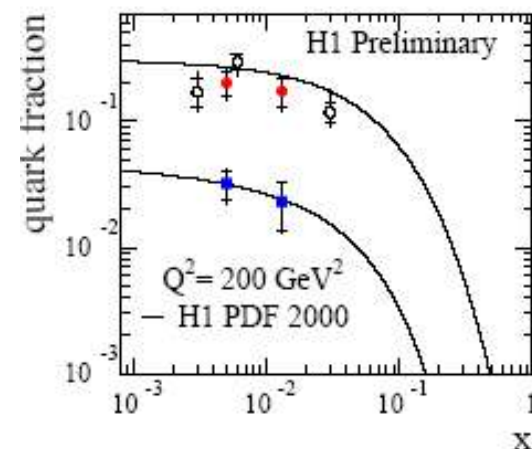
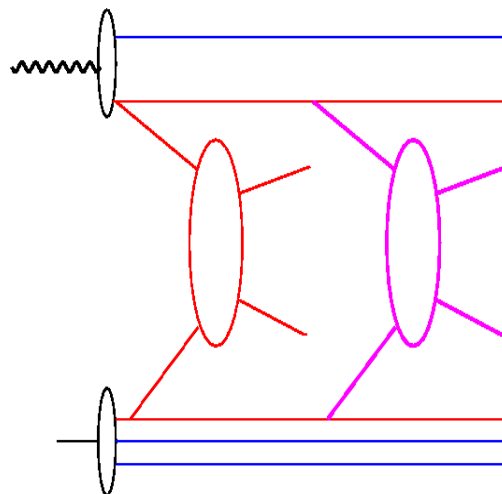
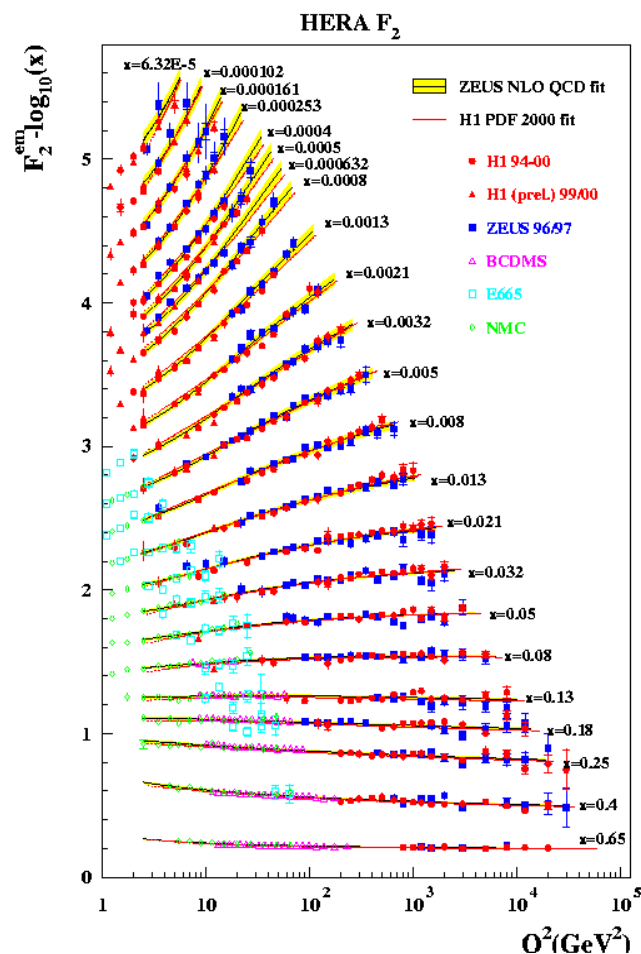


Joint DESY/CERN
Report in **Nov 2005**

HERA 2 and the LHC

**Where HERA2 investigations
will influence the physics reach
of LHC ?**

Topics of the workshop



Multijets & final states Underlying events, un-integrated pdfs

L. Lonnblad, V. Khoze, N Tuning,
C Buttar, J. Butterworth, S. Banerjee,
D. Traynor

Heavy quarks: B quark pdfs of the proton, fragmentation fct, u-pdfs

M. Cacciari, U. Uwer, M. Smizanska, M. Corradi,
A. Dainese, C. Weiser, A. Meyer

Structure functions and parton distributions

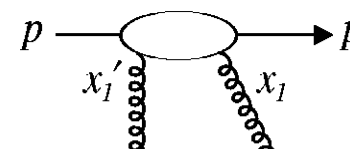
S. Forte, S. Moch, M. Dittmar, A. Glazov
M. Botje, J. Butterworth

Diffraction

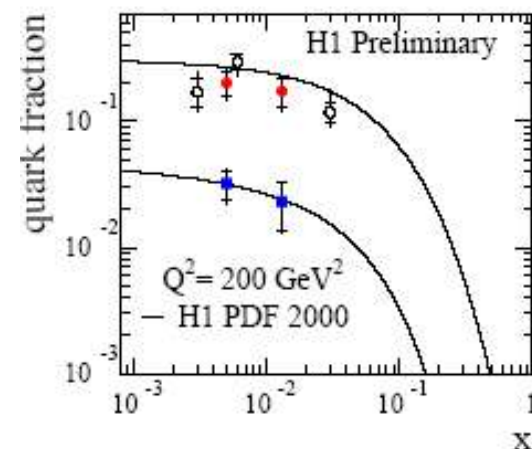
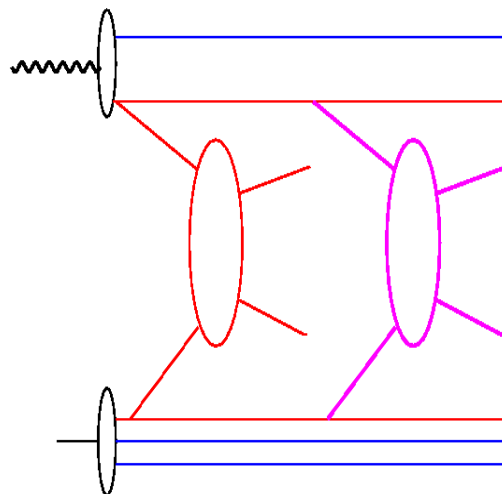
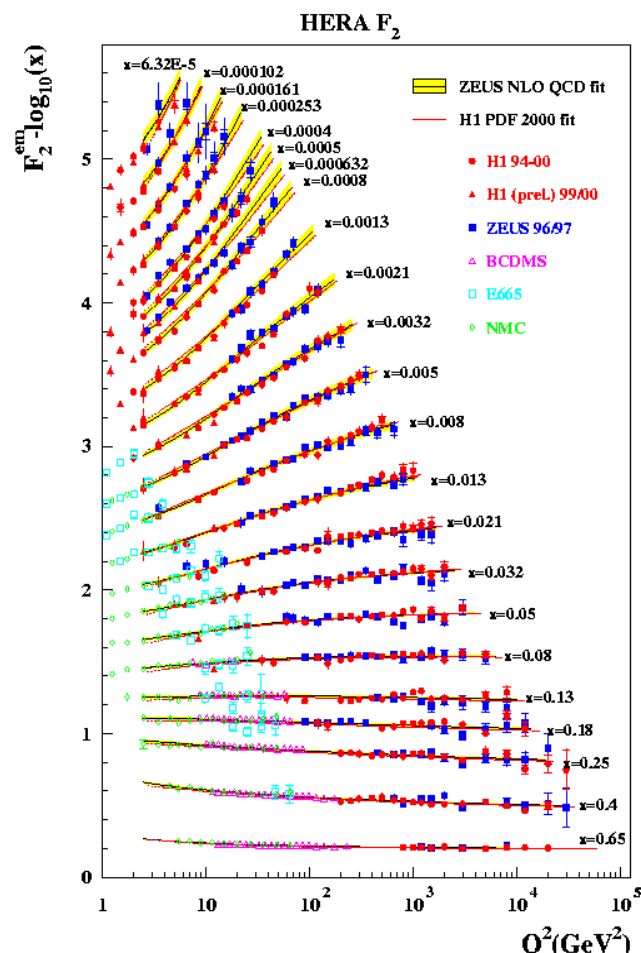
J. Forshaw, M. Diehl,
K. Piotrkowski, R. Orava,
H. Kowalski, P. van Mechelen,
M. Rijssenbeek, B. Cox

MC - Tools

M. Seymour, A. Nikitenko,
E. Richter-Was, P. Robbe,
V. Lendermann



Topics of the workshop

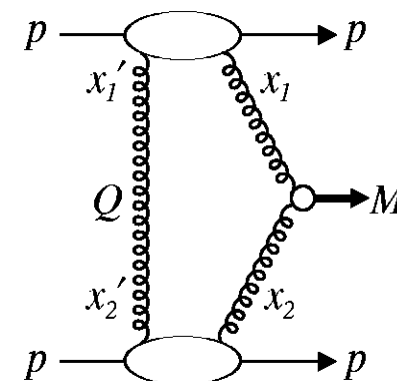


Multijets & final states
Underlying events,
un-integrated pdfs
LHC: event complexity,
jet x-section, Higgs

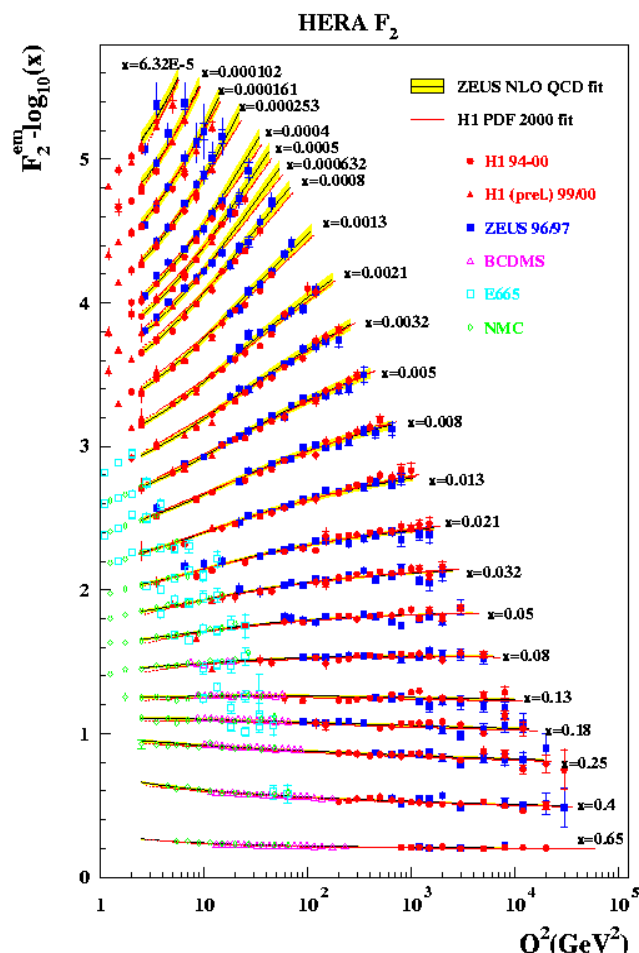
Heavy quarks:
B quark pdfs of the proton,
fragmentation fct, u-pdfs
LHC: Higgs production

Structure functions and
parton distributions
LHC: cross sections/precision

Diffraction
LHC: exclusive
Higgs production



Topics of the workshop



Structure functions and
parton distributions

LHC: cross sections/precision

Potential experimental and theoretical accuracy for various LHC processes (DY, W, Z, WW, +jet...)

Precision measurements at LHC/luminosity determination?

- Cross sections and distributions
- Benchmark with LHC detector simulation

Impact of PDF's on LHC measurements

- Making the most of HERA data
- Need for F_L or eD scattering?
- Can we judge which PDF is "preferred"?

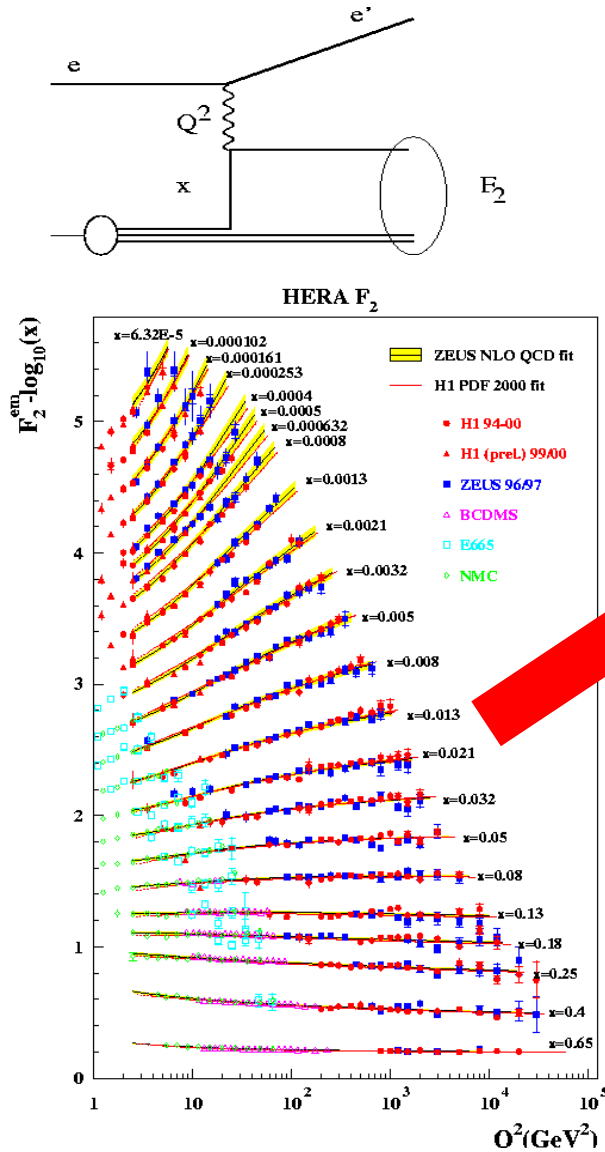
Most precise PDFs + errors

Impact of small x and large x resummations and saturation corrections on pdfs. QCD evolution validation (DGLAP,...)

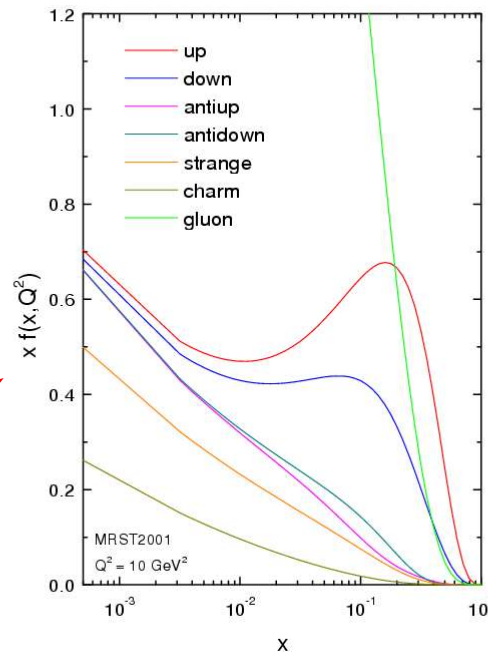
- Impact for LHC?
- Verify with HERA data.

NNLO for F_2 and F_L

From HERA F_2 to Higgs at LHC



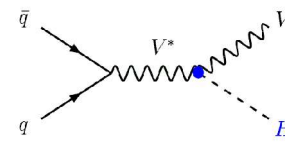
total x-section, F_2



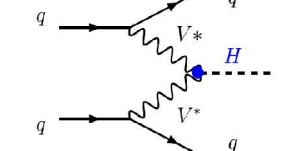
extract parton densities

from J. Stirling

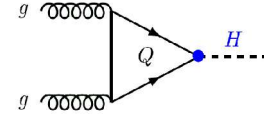
Higgs-strahlung



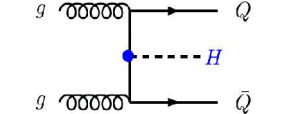
Vector boson fusion



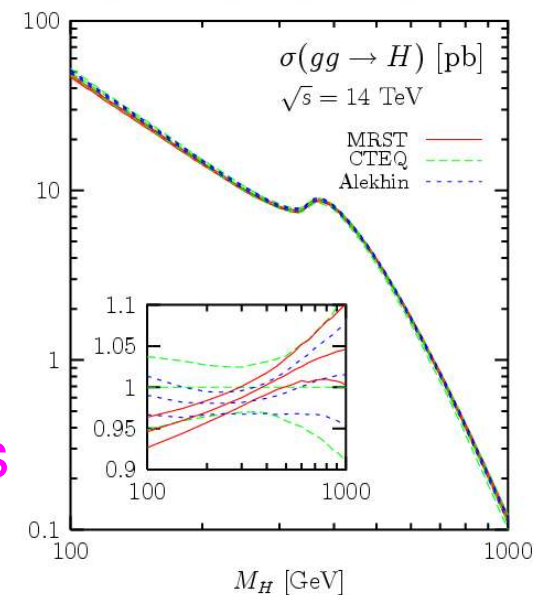
gluon-gluon fusion



in associated with $Q\bar{Q}$



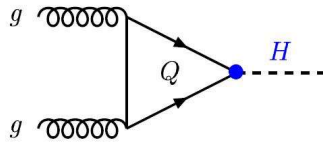
calculate Higgs prod



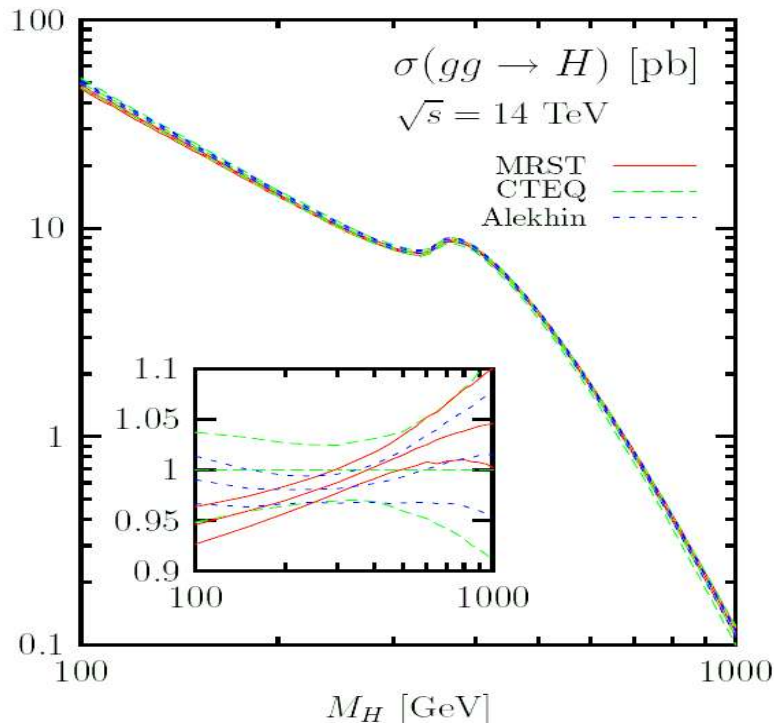
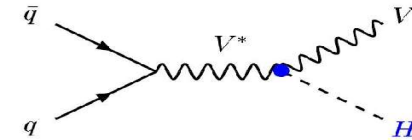
pdf uncertainty for Higgs prod.

gluon-gluon fusion

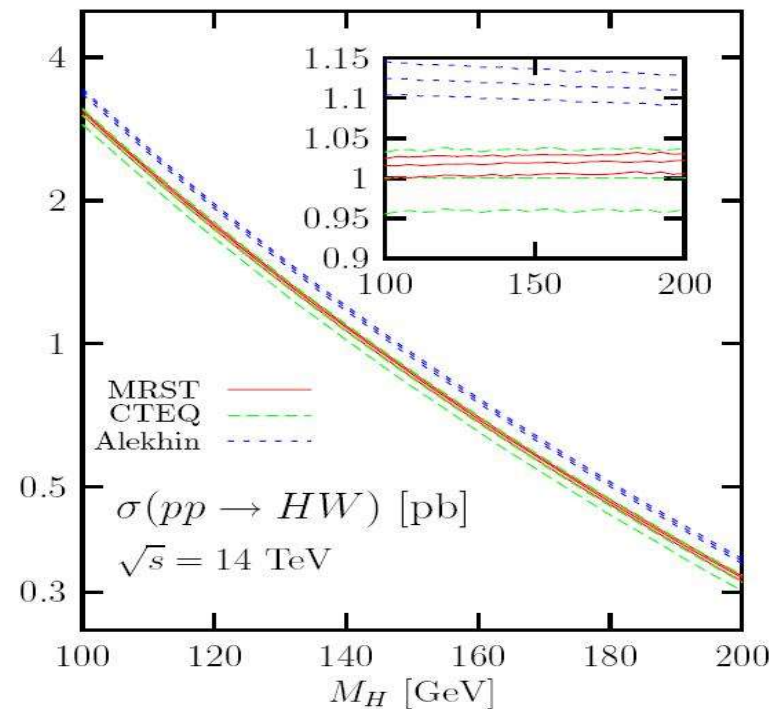
from Djouadi & Ferrag



Higgs-strahlung



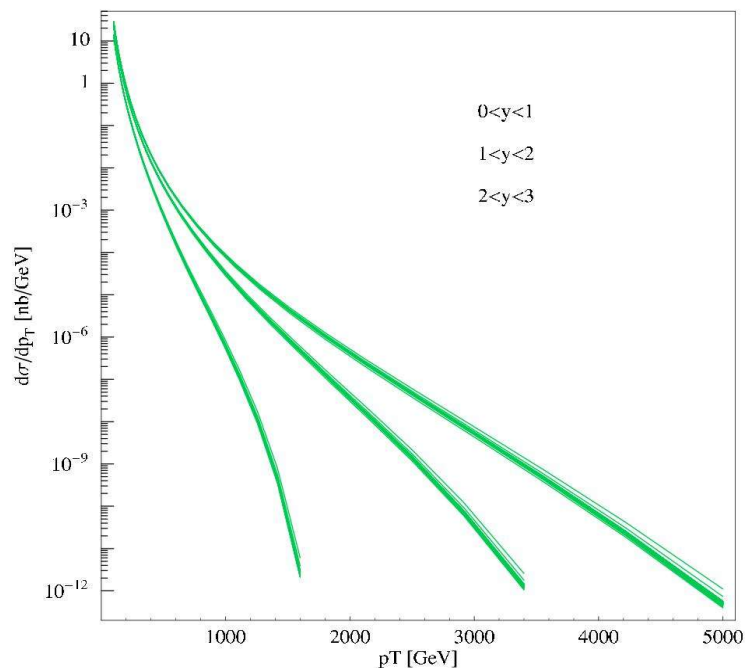
Gluon induced... ~ 10 %



Quark induced ~ 10 % difference

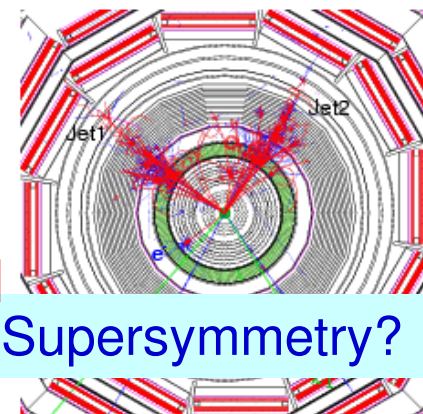
pdf do not agree within respective errors (J. Stirling) !!!!

Why precise pdfs for LHC



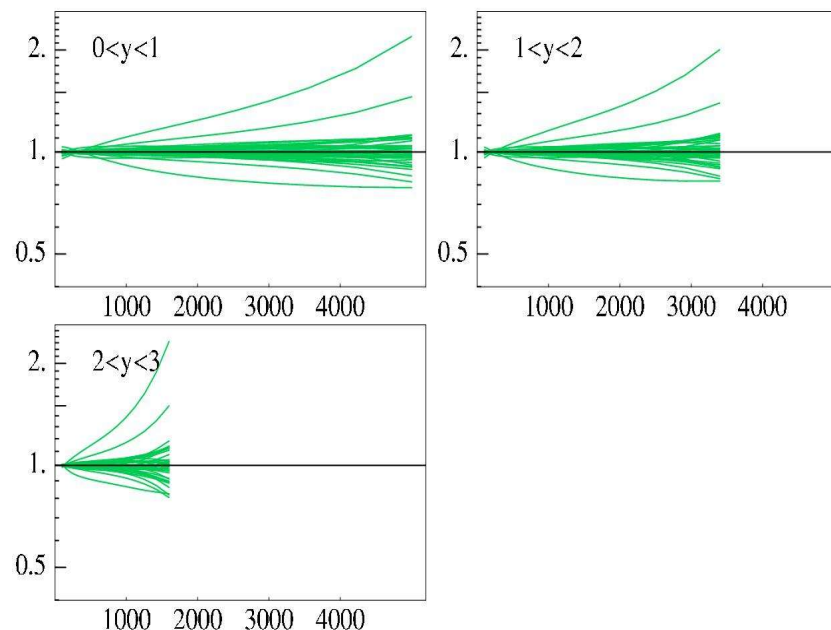
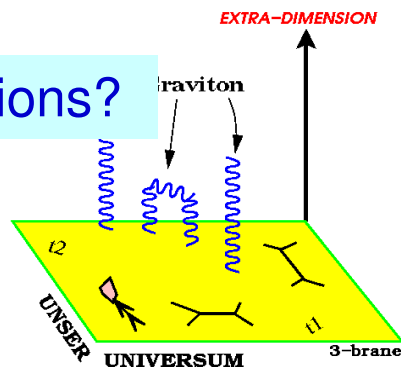
Signature for new physics
jet x-section

Discovery potential depend
on precise pdfs



Supersymmetry?

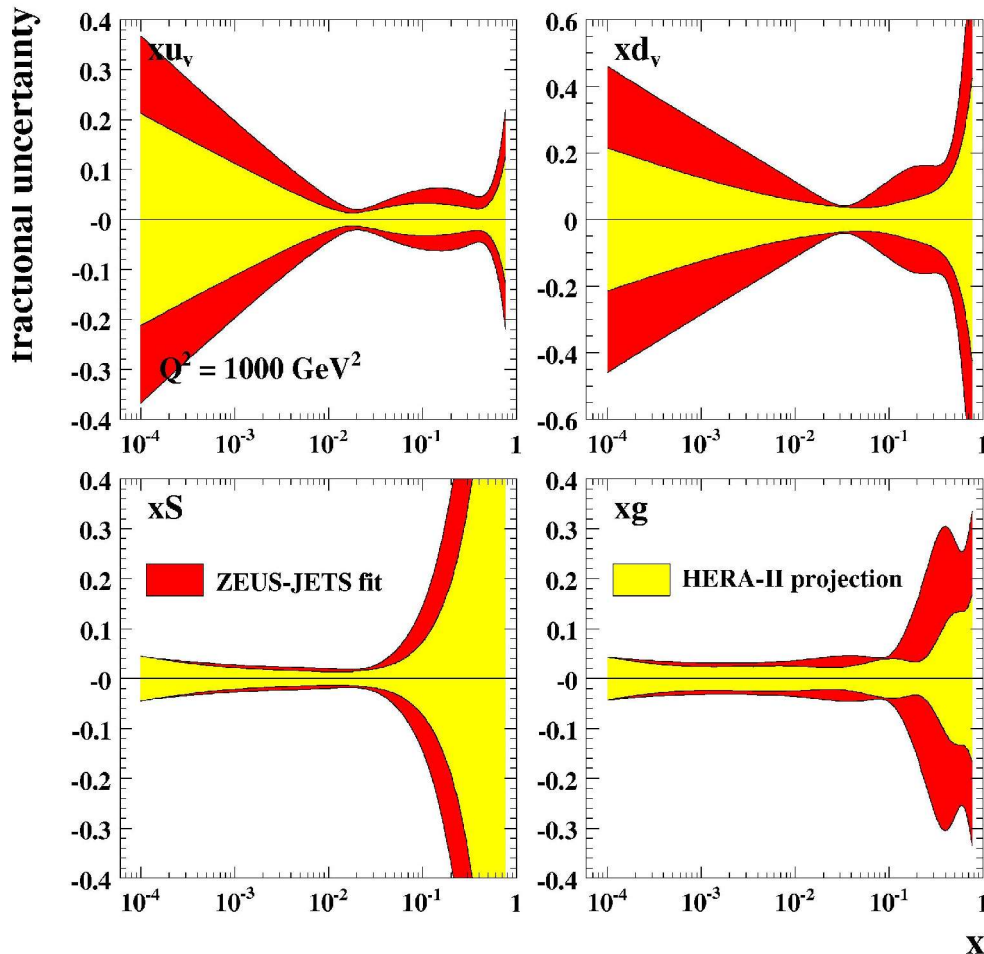
Extra Dimensions?



Precision determination of pdfs needed ...
understanding QCD is the key to new physics

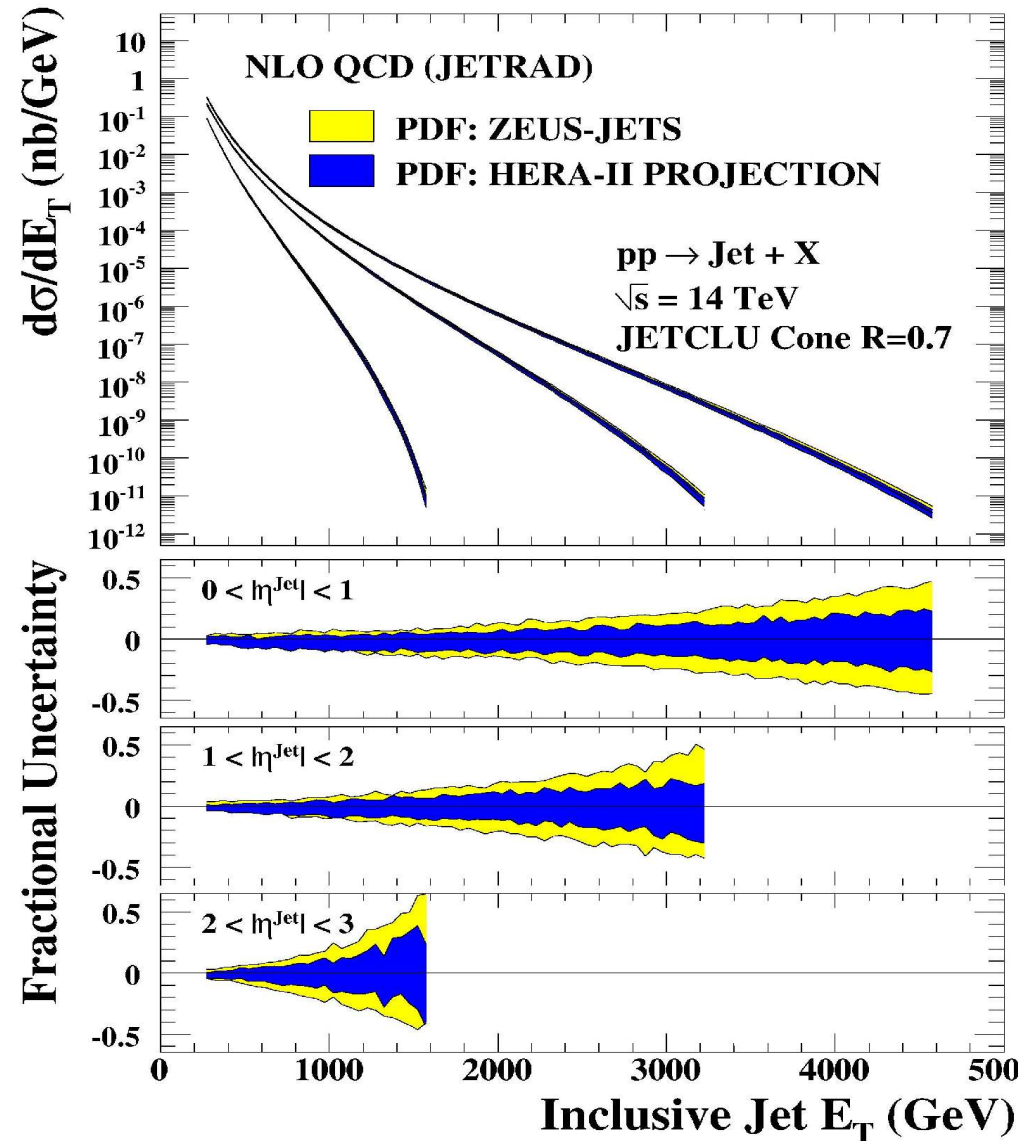
pdf uncertainty: improvements

Using jets together with F_2 (at large Q^2)
quark and gluon uncertainties



high statistics from HERA II is important
(assumed 700 pb⁻¹)

from C. Gwenlan, A. Cooper-Sarkar, C. Targett-Adams

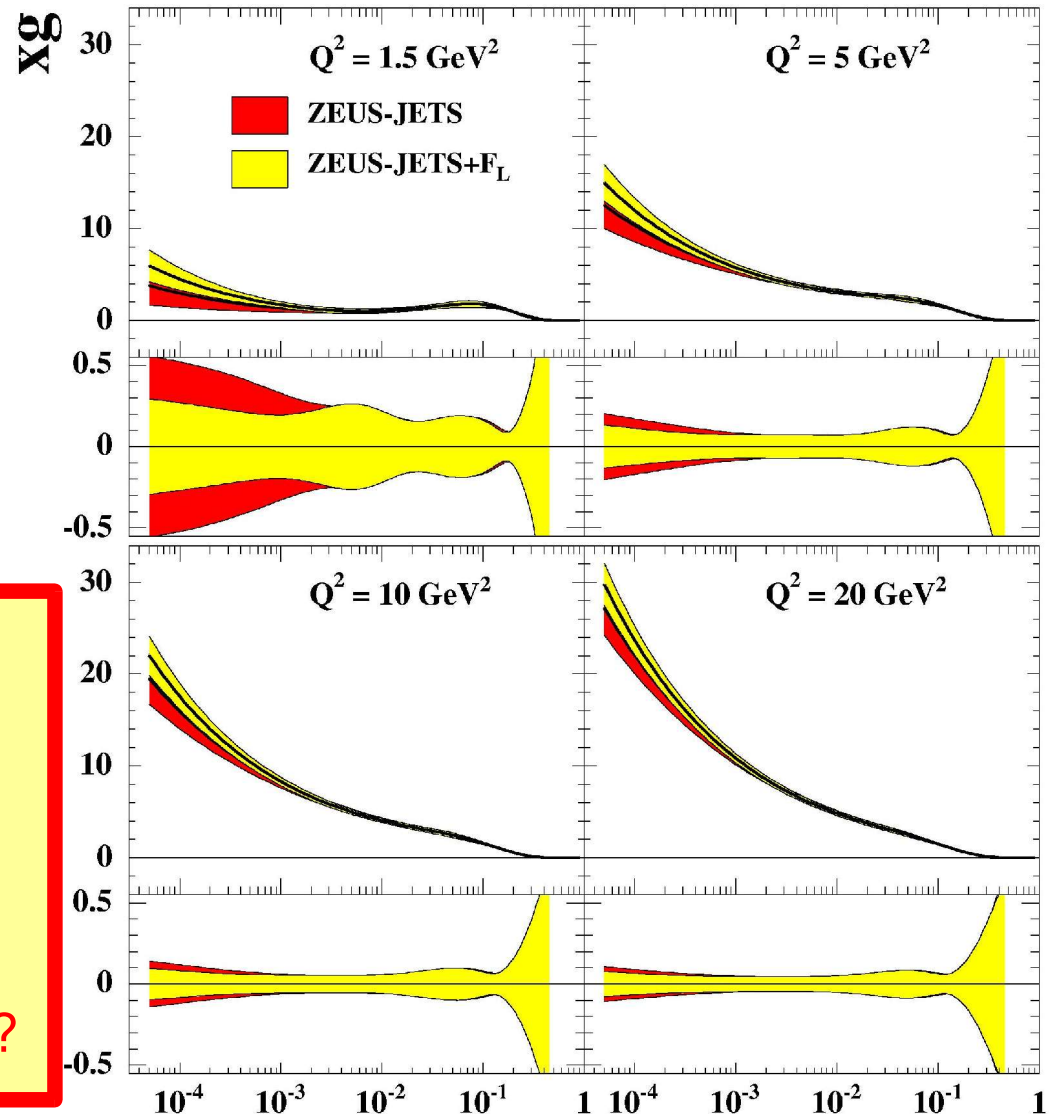
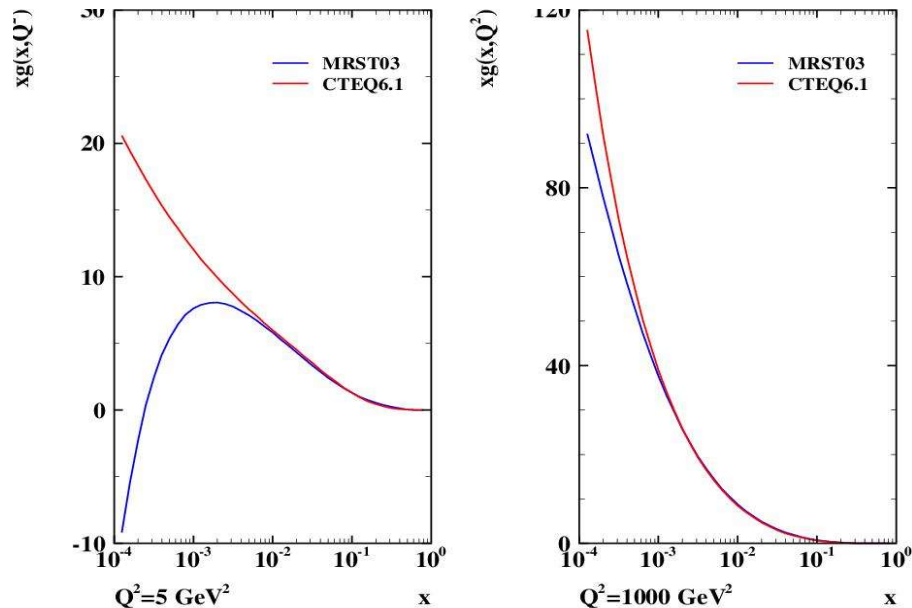


Error on LHC jet xsection reduced !!!

HERA future measurements: F_L

The gluon distribution

From J. Feltesse, C. Gwenlan, S. Glazov, M. Klein



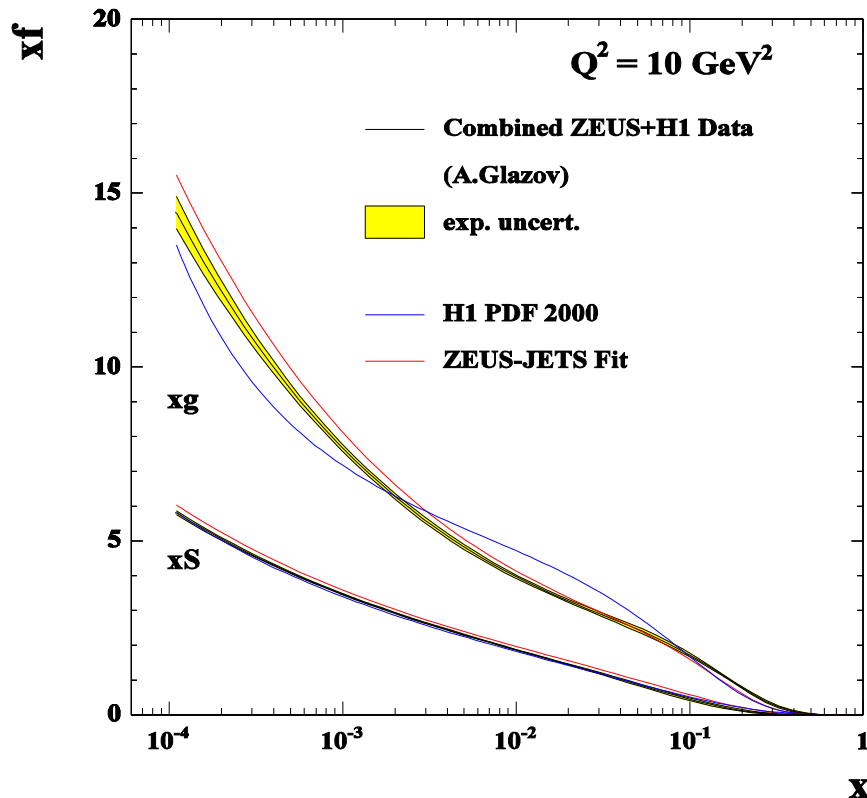
Precision measurement of F_L
(4 lower p-energies, 2-10 pb^{-1})

- cleanest for gluon
- provide tests of QCD at higher
- orders and consistency of theory
- where if not measured at HERA ?????

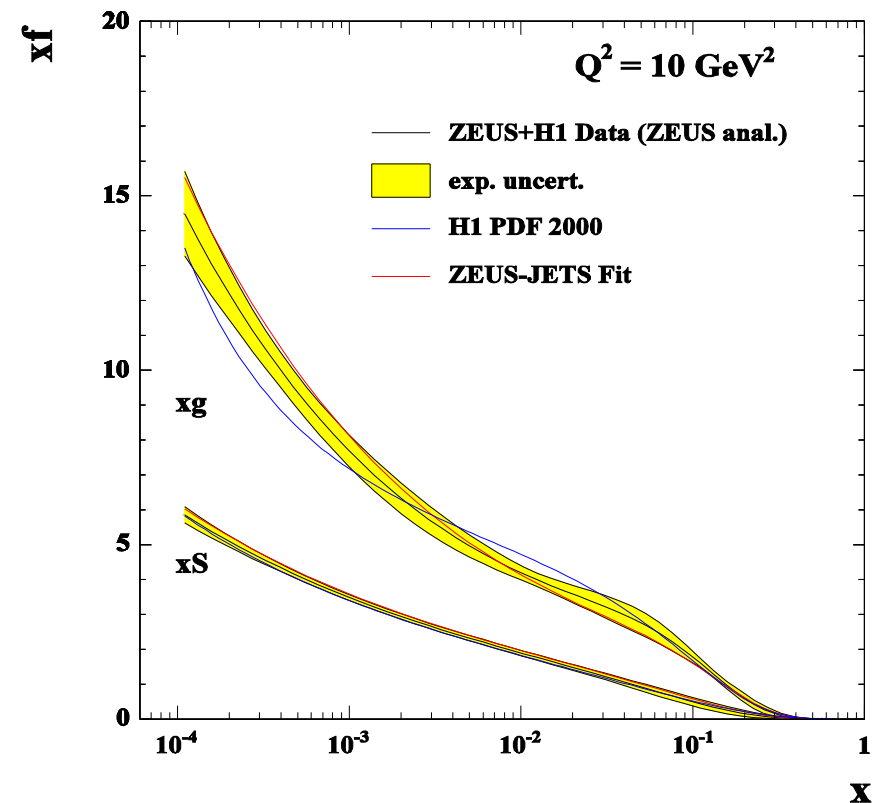
Average of HERA data

From M. Cooper-Sakar and S. Glazov

- Average H1&ZEUS data sets



- Combined PDF fit to H1 & ZEUS



Much reduced uncertainties

Consensus: Model independent analysis of data desirable

Joint H1 – ZEUS working group ... get HERA – pdf !!!!!

Is DGLAP all ??????

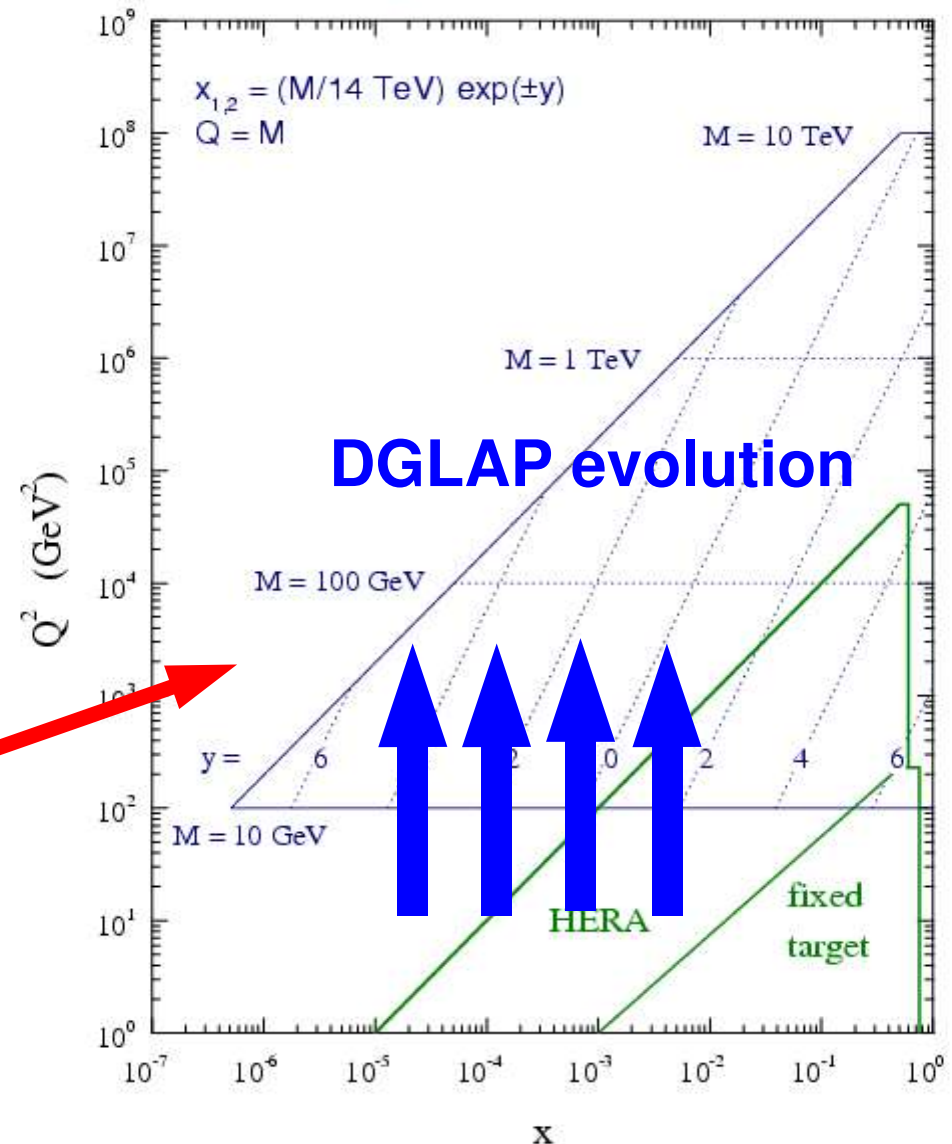
from J. Stirling

Can we just assume DGLAP is ok also at highest energies ?

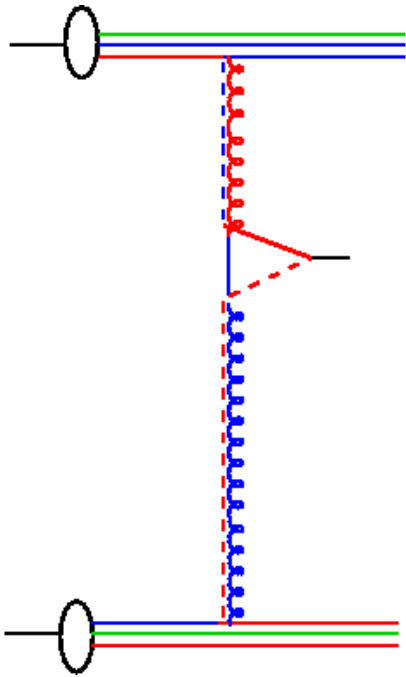
- remember surprises from HERA
- Is factorisation valid ?
- What about k_t -factorisation ?
- What about non-linear effects ?

Is NLO (or NNLO) DGLAP sufficient at small x ?
Are higher orders important ?

LHC parton kinematics

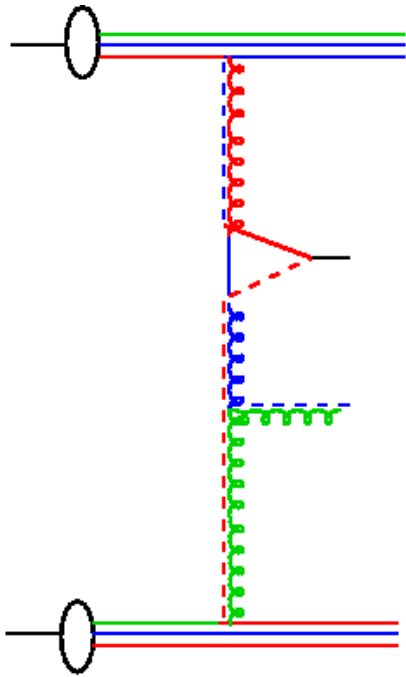


k_t effects at HERA and LHC



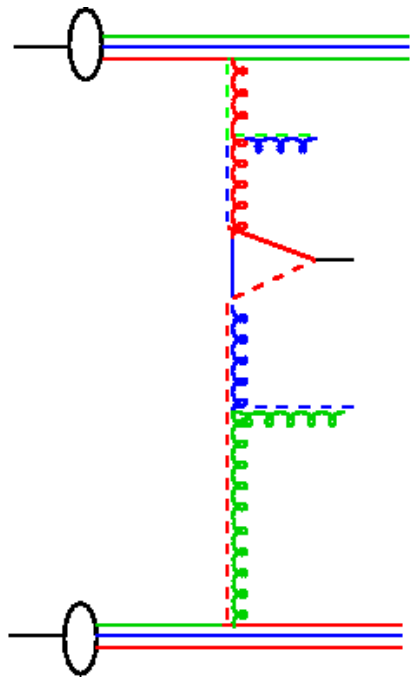
LO pretty bad

k_t effects at HERA and LHC



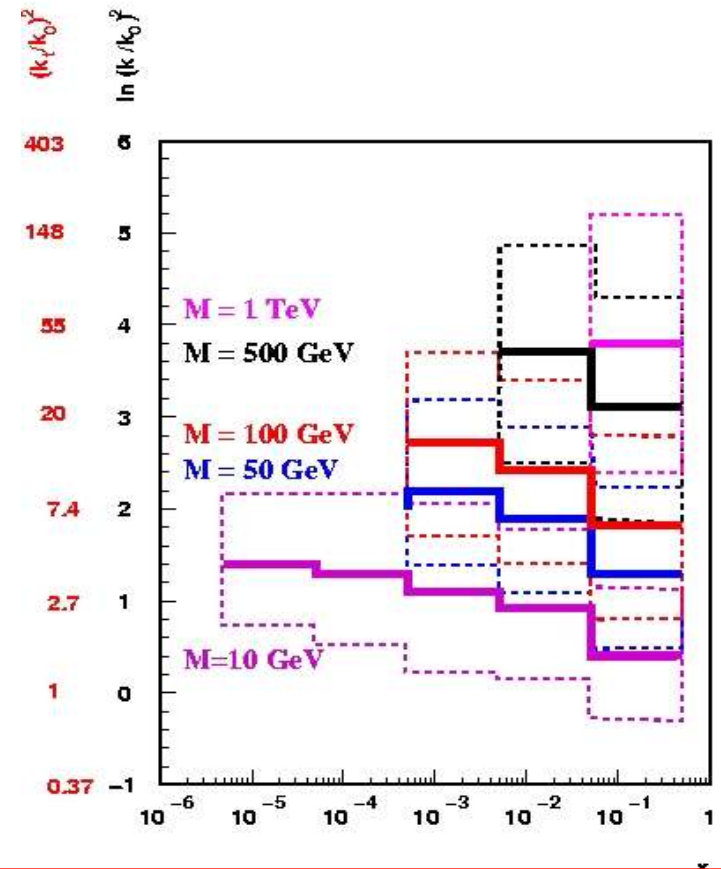
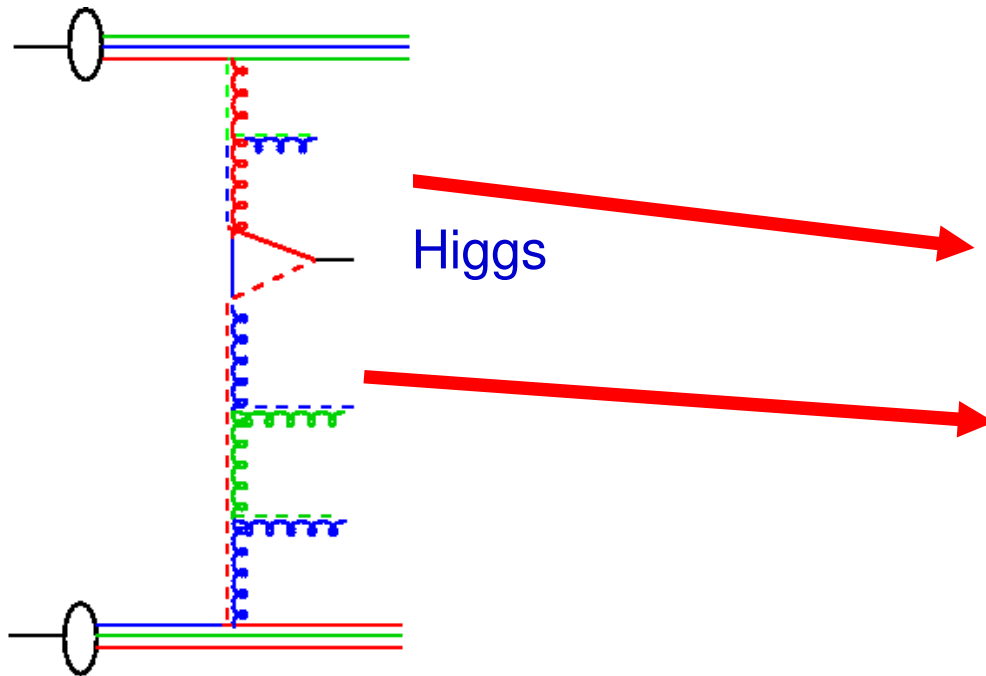
NLO better

k_t effects at HERA and LHC



NNLO bettttter

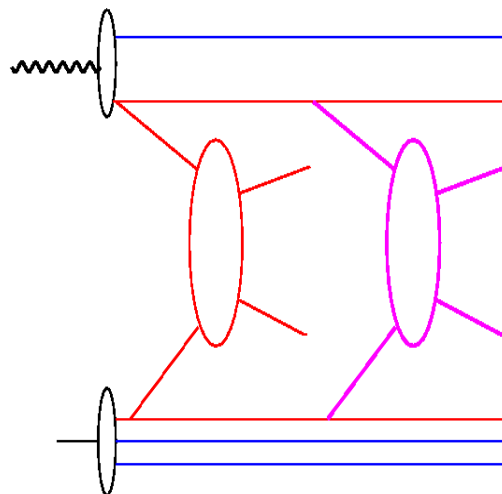
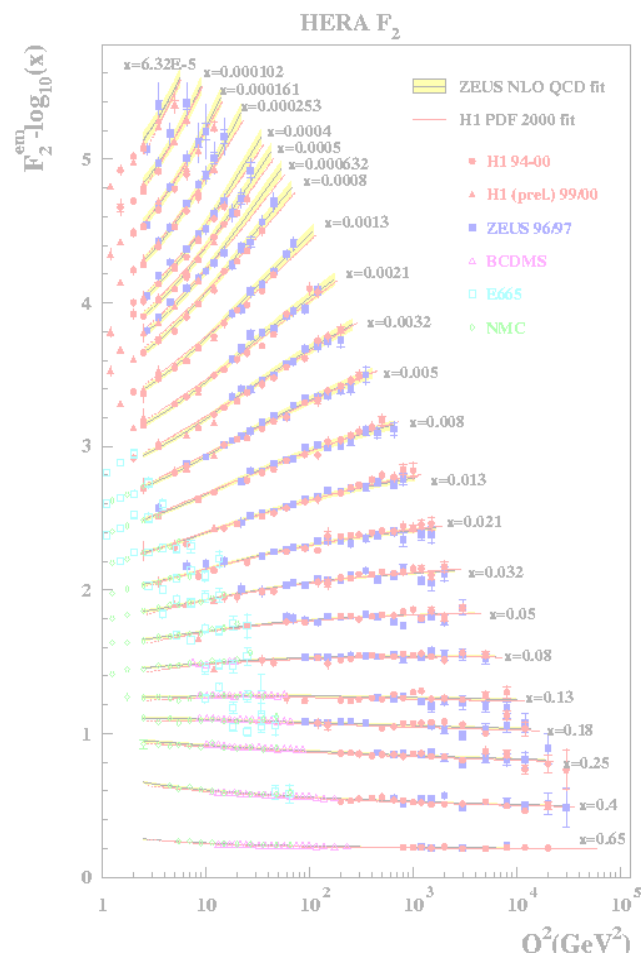
k_t effects at HERA and LHC



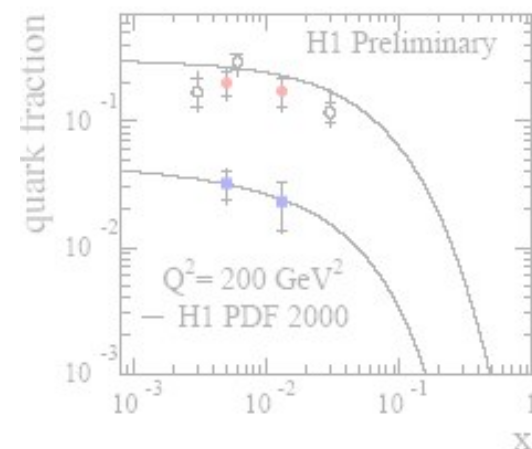
$\langle k_t \rangle$ large unintegrated parton PDFs will be needed

- Need to be better constrained from HERA
- Using more the just F_2 ... jets, heavy quarks, even TeVatron data ????
- Question on validity of factorisation formulae....

Topics of the workshop



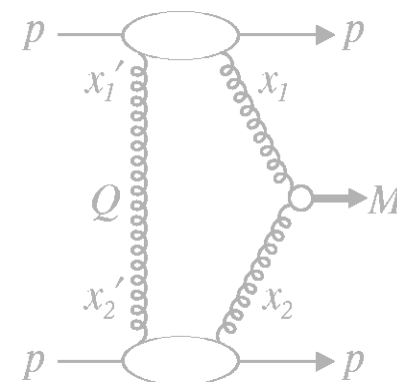
Multijets & final states
Underlying events,
un-integrated pdfs
LHC: event complexity,
jet x-section, Higgs



Heavy quarks:
B quark pdfs of the proton,
fragmentation fct, u-pdf
LHC: Higgs production

Structure functions and
parton distributions
LHC: cross sections/precision

Diffraction
LHC: exclusive
Higgs production



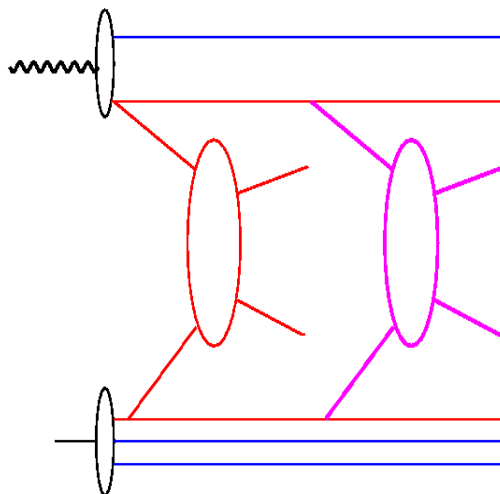
Topics of the workshop

- inclusive x-sections **fine**
- **BUT** measurements of final states jets, heavy quarks, higgs) **more difficult**
- ➔ need full final state
- ➔ **BUT** LO/NLO parton level insufficient and **unphysical**

...

NEW approaches:

- un-integrated pdfs
- MC@NLO
- ME + PS matching



Multijets & final states
Underlying events,
un-integrated pdfs
LHC: event complexity,
jet x-section, Higgs

• Underlying event/minimum bias events

- New models appeared during the workshop
- Tunes to pp data validated
- Study similar observables in ep as in pp

Task force in action

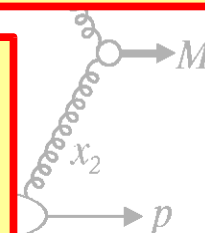
• Gap survival

- Still not understood: Consequences for the LHC!
- New measurements at HERA !

1 10 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5}
 $\alpha^2(\text{GeV}^2)$

Structure f
parton dist
LHC: cross

- Re-summations for event shape variables
- Future parton shower developments
 - Unintegrated parton correlation functions

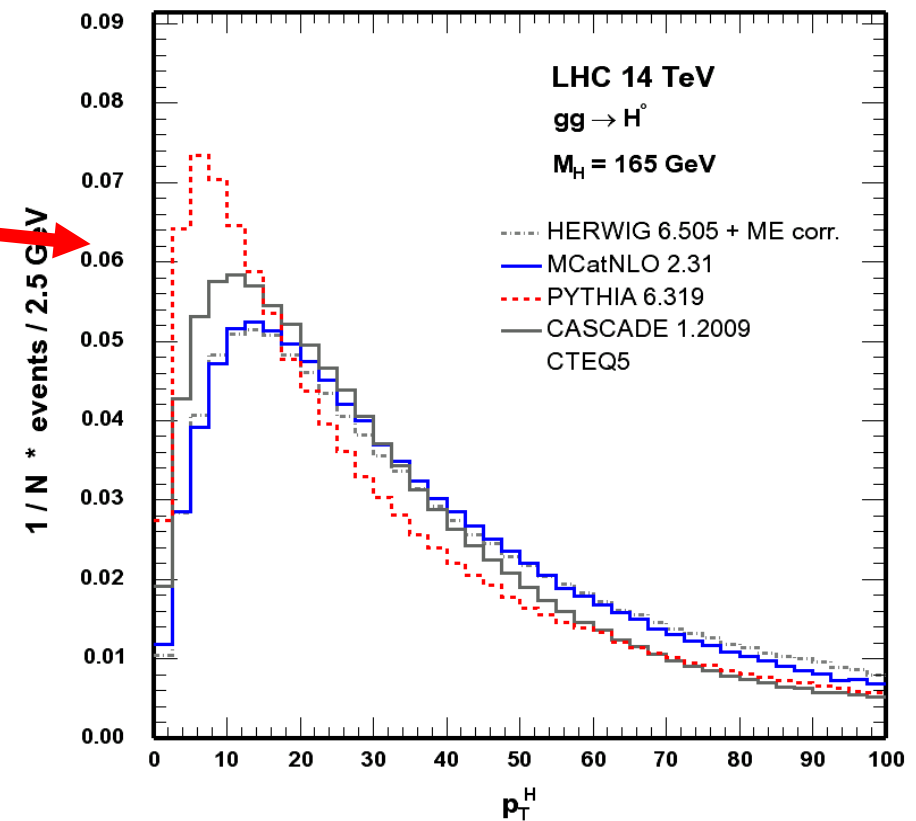
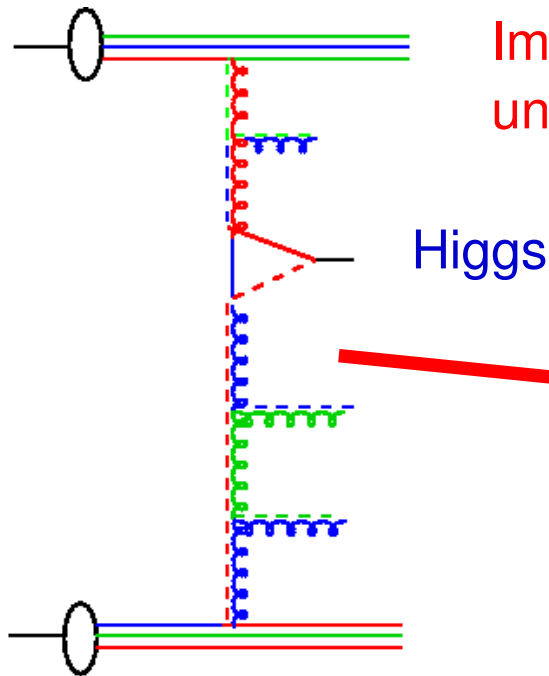


k_t effects at HERA and LHC

from G. Davatz

Do we understand the p_t spectrum of Higgs at LHC?

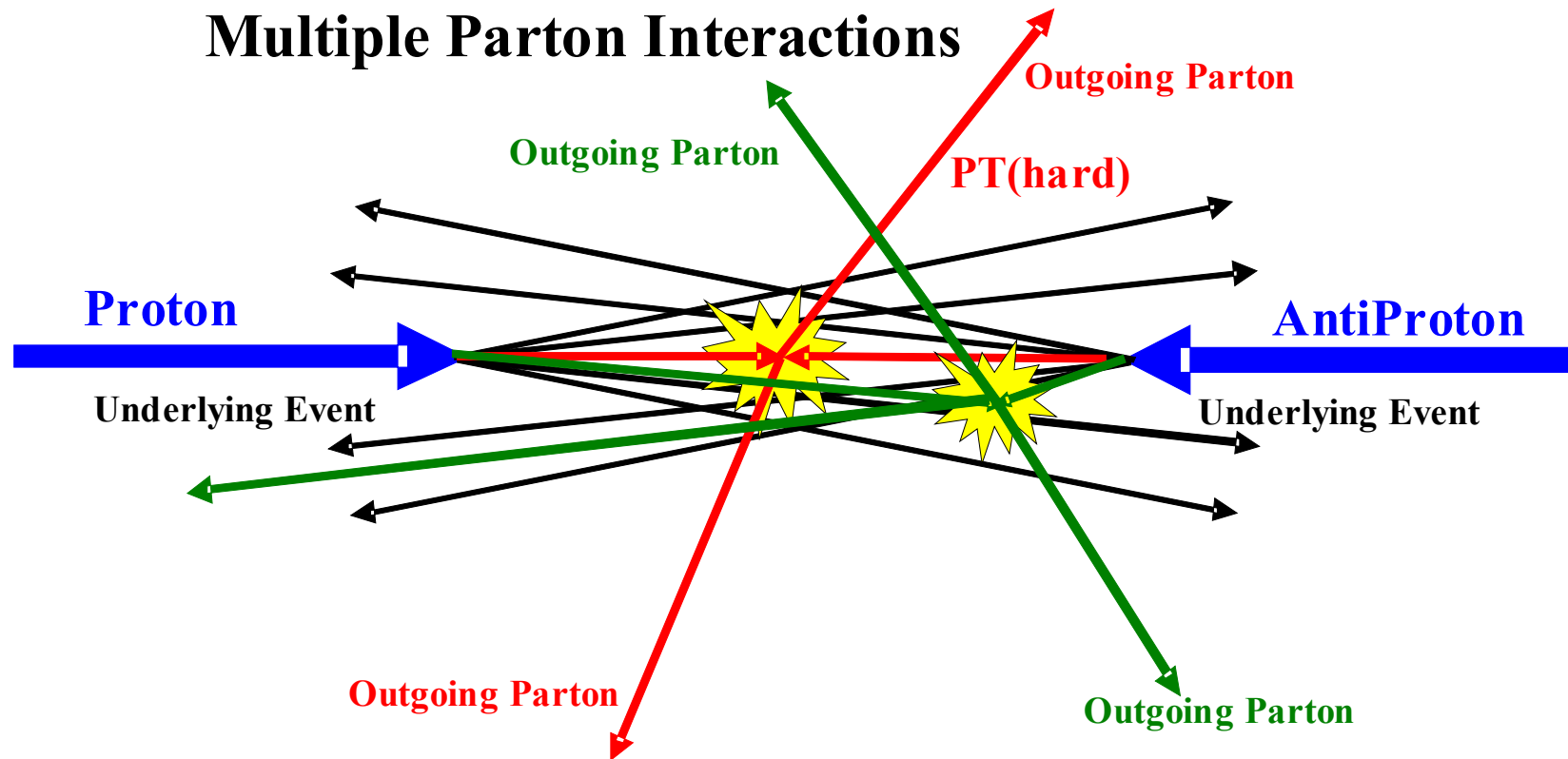
Important for the $gg \rightarrow \text{Higgs} \rightarrow WW \rightarrow \nu \nu$ to understand the jet-veto for $t\bar{t}$ suppression...



$\langle k_t \rangle$ large unintegrated parton PDFs will be needed
Need to be better constrained at HERA with final states

Multiple scatterings in pp

from R. Field



What is the underlying event, multiple scattering ?

- *Everything, except the LO process we're currently interested in*
- *Parton showers*
- *Additional remnant – remnant interactions*

Underlying event – multiple interaction

Basic partonic perturbative cross section

$$\sigma_{\text{hard}}(p_{\perp\text{min}}^2) = \int_{p_{\perp\text{min}}^2} \frac{d\sigma_{\text{hard}}(p_{\perp}^2)}{dp_{\perp}^2} dp_{\perp}^2$$

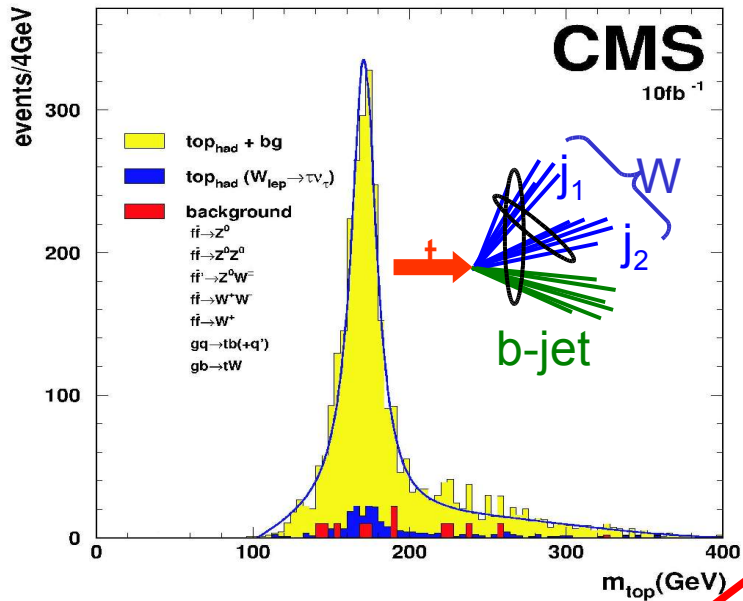
Diverges faster than $1/p_{\text{t min}}^4$ as $p_{\text{t min}} \rightarrow 0$ and exceeds eventually total inelastic (non-diffractive) cross section, resulting in multiple scatterings in each event

Average number of scatterings per event is given by:

$$\langle n \rangle = \sigma_{\text{hard}}(p_{\perp\text{min}}) / \sigma_{\text{nd}}$$

It depends, how to treat the soft interactions, and it also depends on the **parton densities** !!!!!!!!!!!!!!!

Multiple scattering and top mass



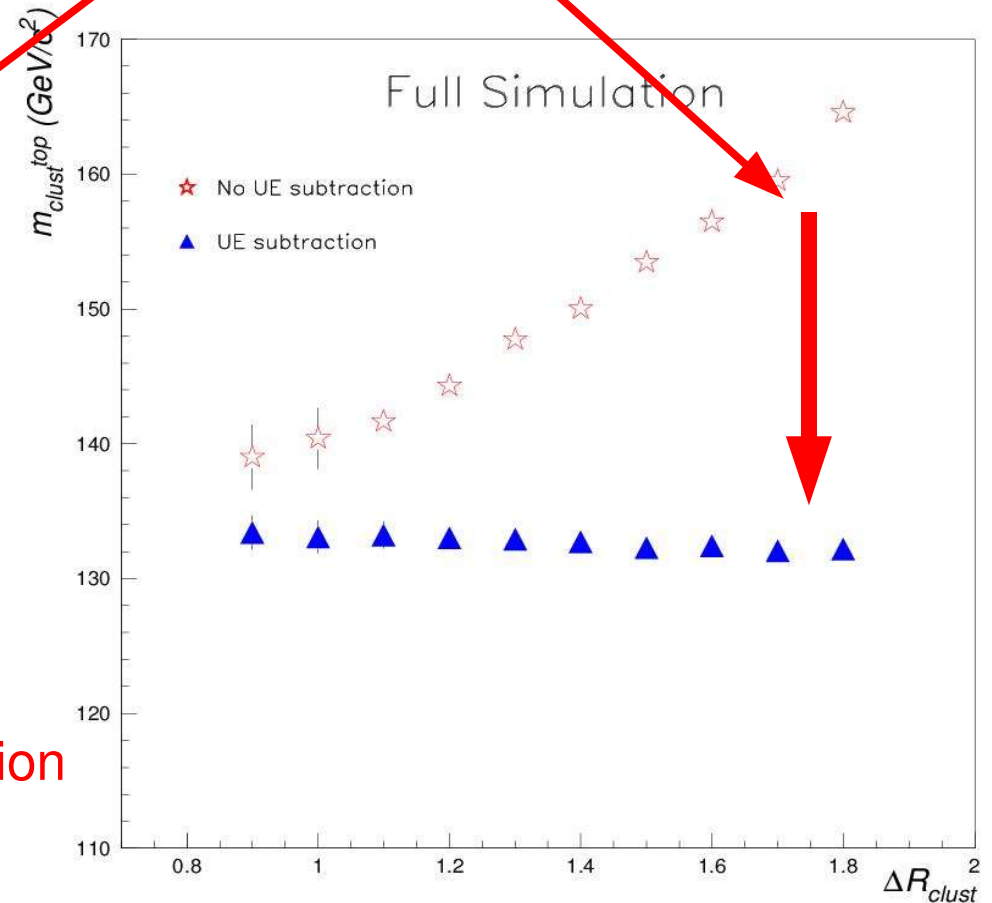
Source of error in GeV	Lepton+jets inclusive sample	Lepton+jets large clusters sample	Dilepton	All jets high pT sample
Energy scale				
Light jet energy scale	0.2	-	-	0.8
b-jet energy scale	0.7	-	0.6	0.7
Mass scale calibration	-	0.9	-	-
UE estimate	-	1.3	-	-
Physics				
Background	0.1	-	0.2	0.4
b-quark fragmentation	0.1	0.3	0.7	0.3
Initial state radiation	0.1	0.1	0.1	0.4
Final state radiation	0.5	0.1	0.6	2.8
PDF	-	-	1.2	-

from M. Mangano

hep-ex/04003021

- Multiple scatterings
- Jet fragmentation properties, jet profiles
- Final state QCD radiation
- B-fragmentation

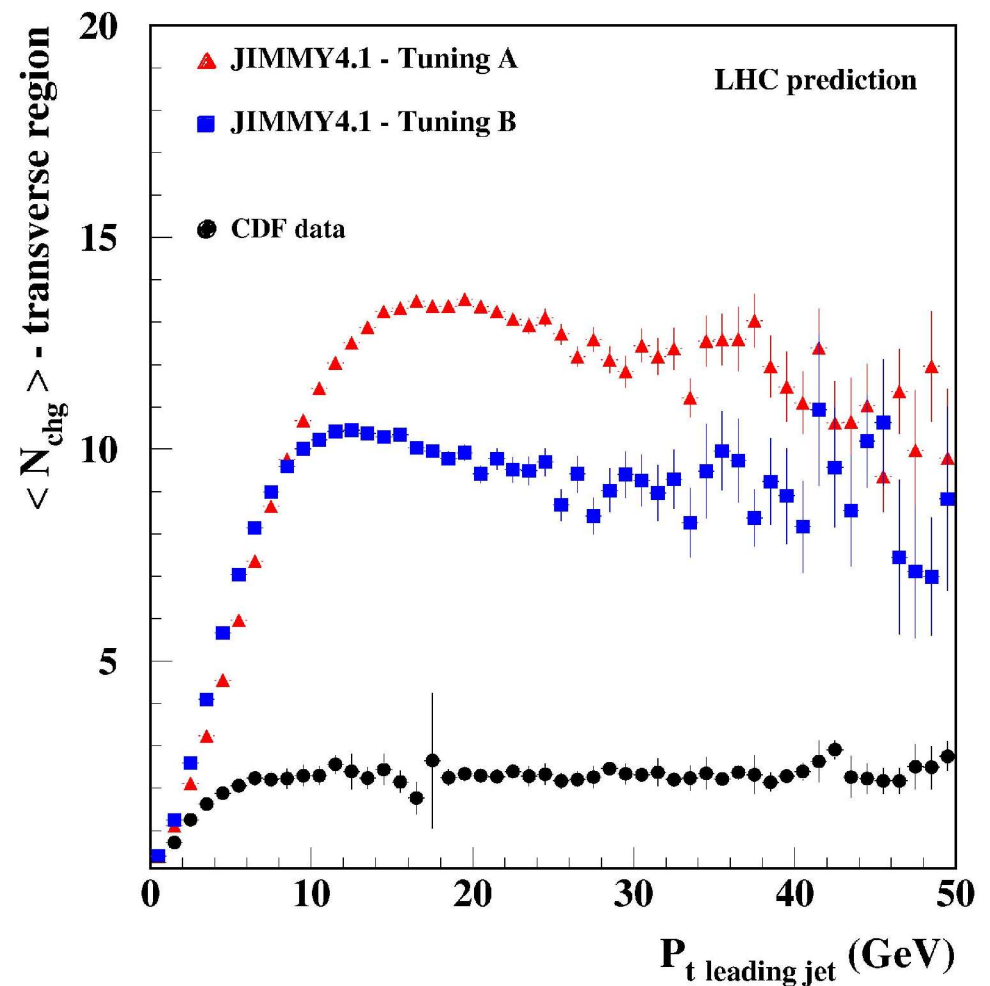
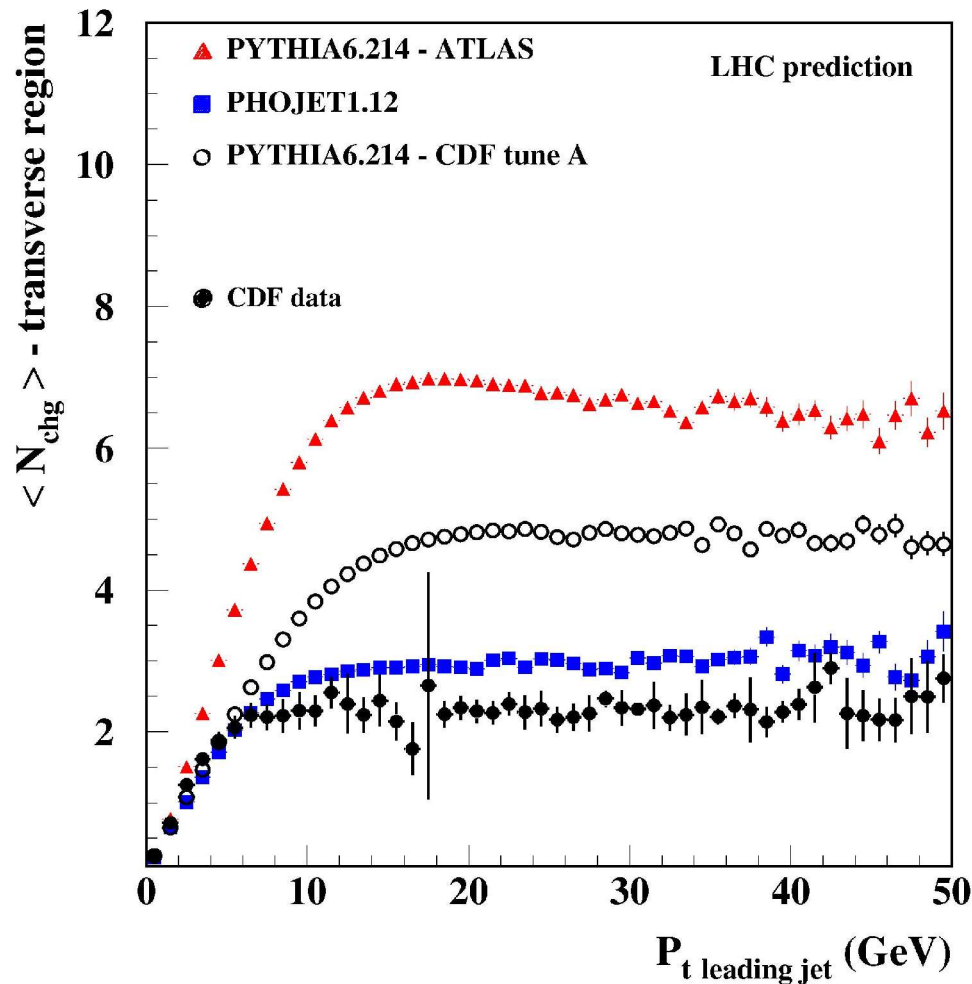
Significant effects on top mass determination
Better understand them !!!



Underlying events at LHC

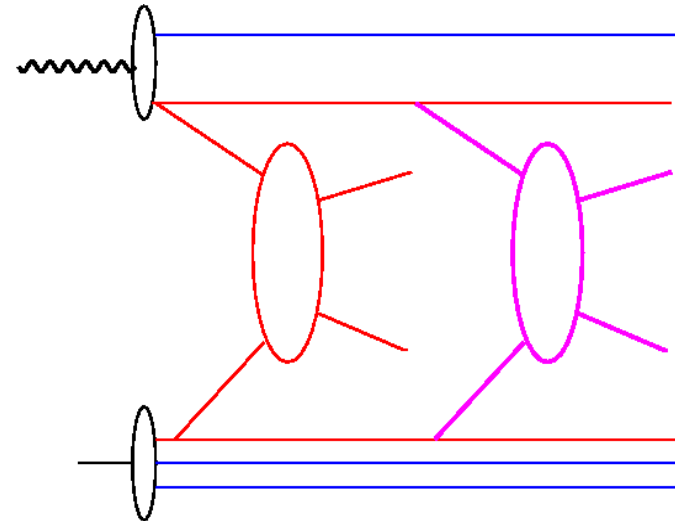
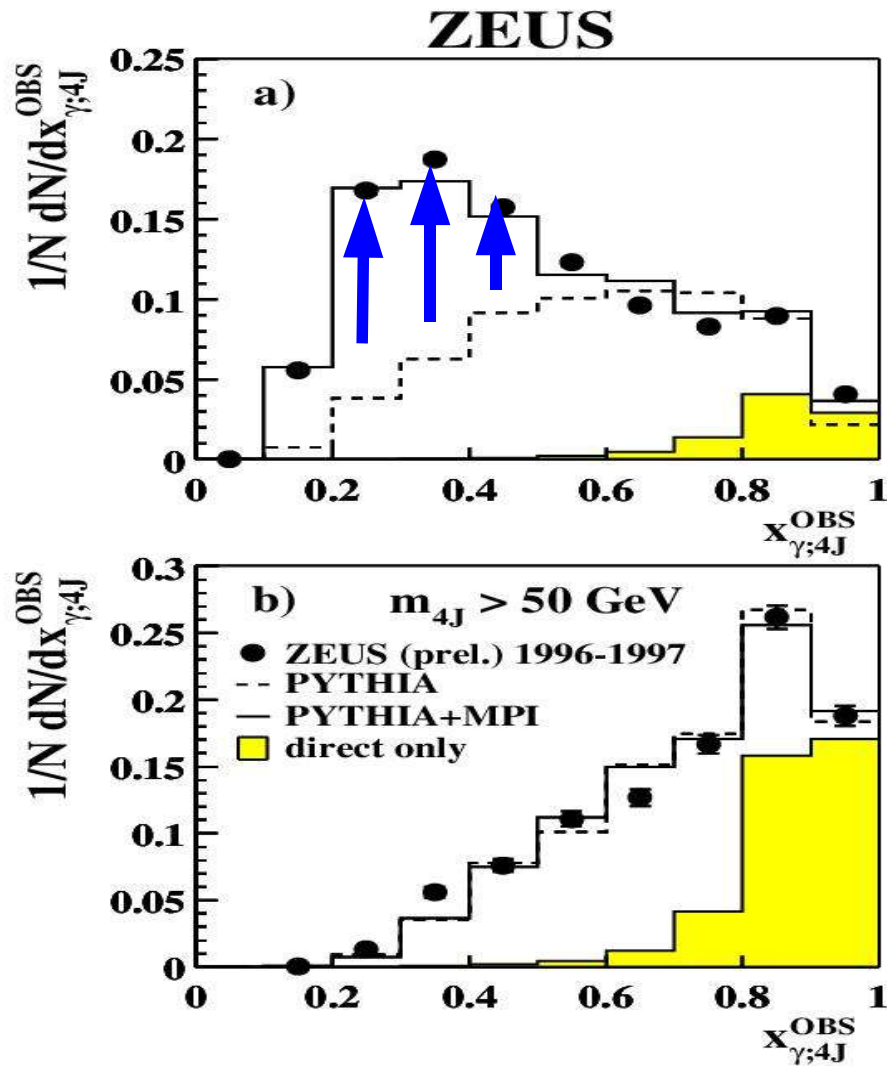
Charged multiplicities in transverse region

C. Buttar et al



- Models tuned to TeVatron data
- Give **HUGE** differences at LHC ... **Better understand the underlying event ...**

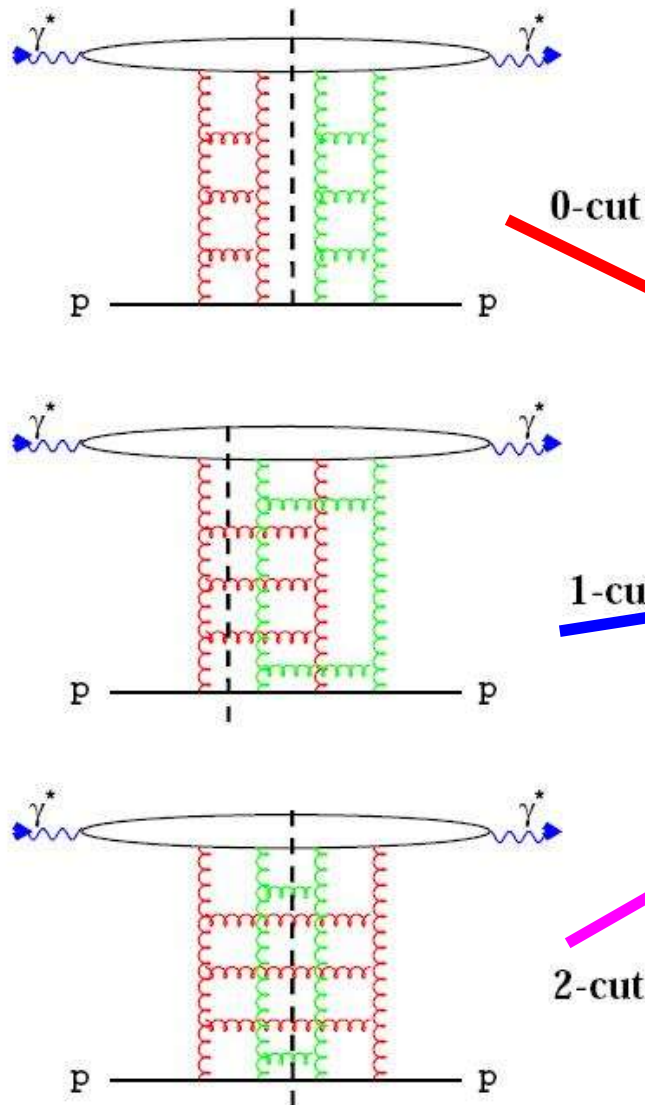
Multiple scatterings at HERA



photoproduction is effectively hadron-hadron production...
 test and understand multiple scatterings at HERA !!!

Towards understanding of MI

Bartels, Kowalski, Sabio-Vera

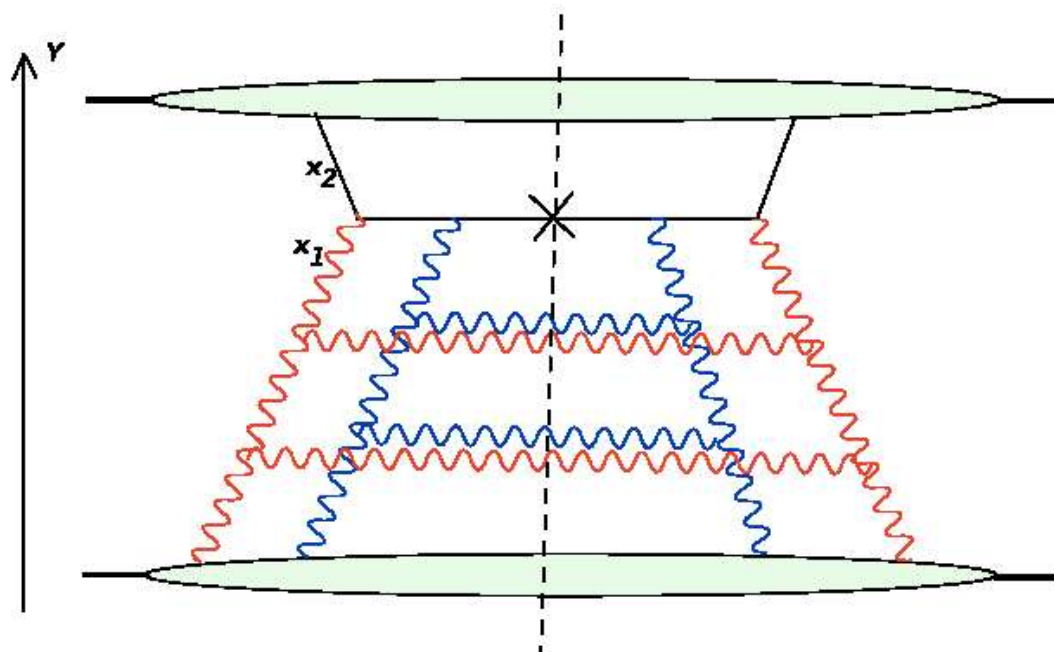


- Cutting rules (AGK) extended to QCD
- Relate diffraction, multiple scatterings and saturation
- All from the same amplitude, but different factors:
 - +1 Diffraction
 - - 4 Saturation
 - +2 Multiple Scatterings
- Extended now also to pp !!!!
- Much further work needed ...
- Towards the descriptions of *“everything”* !!!!!

Multiple Interactions

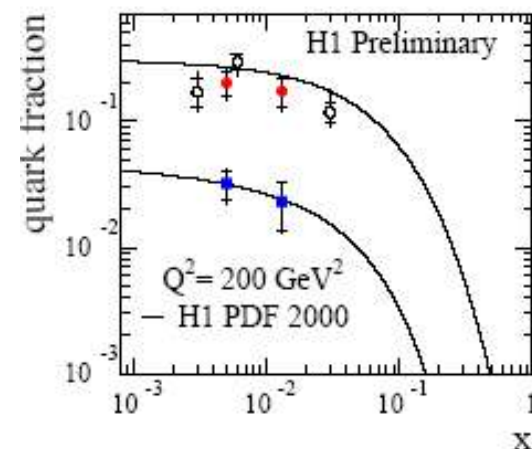
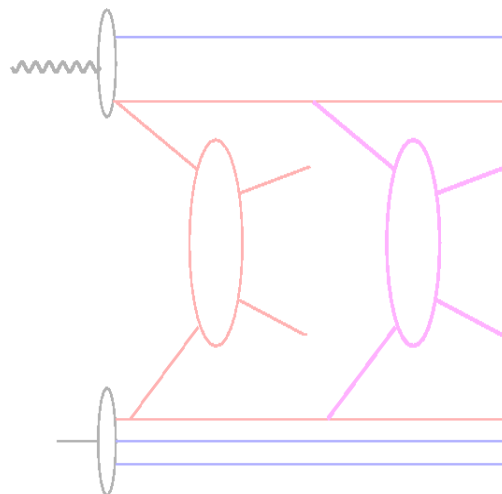
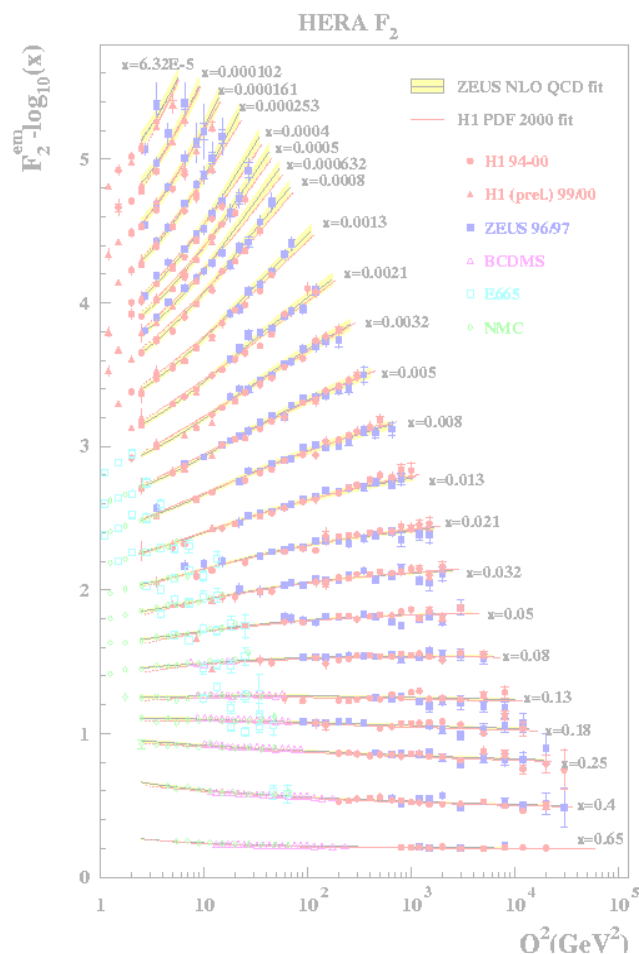
- Measure in forward region
- Observe Multiple Interactions - **Factorization breaking**

LHC: jet near the beam directions ($x_1 \ll x_2$)



Multiple interaction across large rapidity intervals.

Topics of the workshop

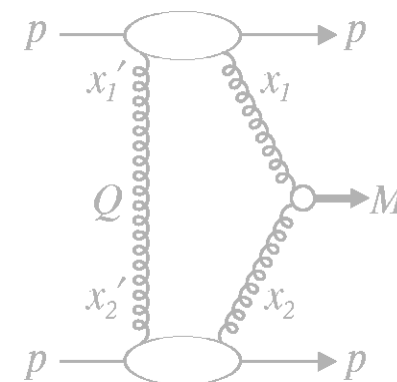


Multijets & final states
Underlying events,
un-integrated pdfs
LHC: event complexity,
jet x-section, Higgs

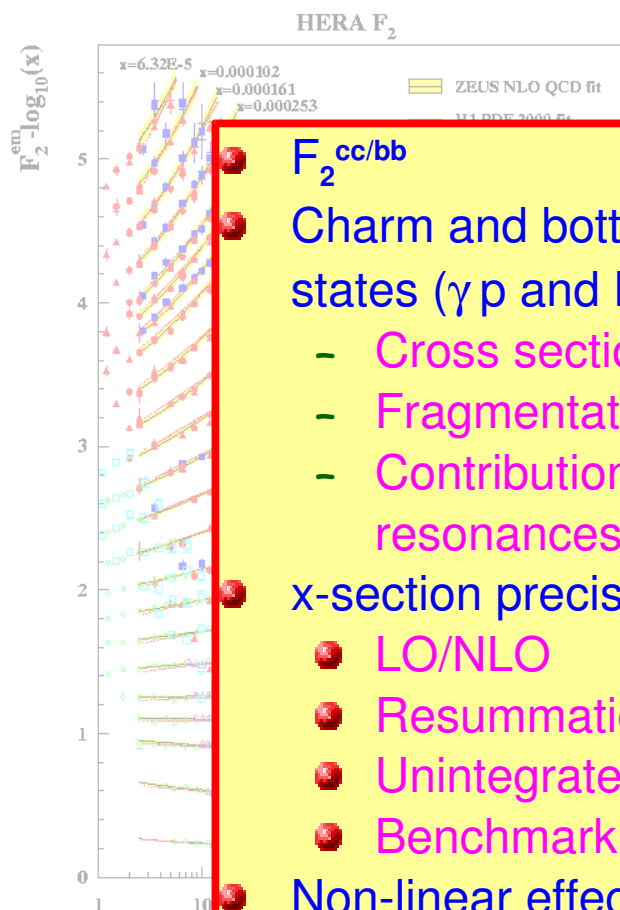
Heavy quarks:
B quark pdfs of the proton,
fragmentation fct, u-pdf
LHC: Higgs production

Structure functions and
parton distributions
LHC: cross sections/precision

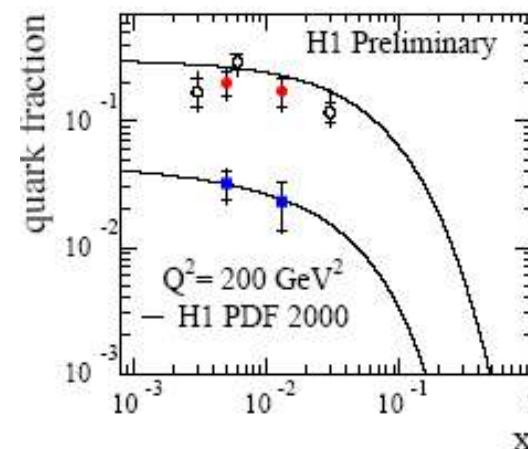
Diffraction
LHC: exclusive
Higgs production



Topics of the workshop



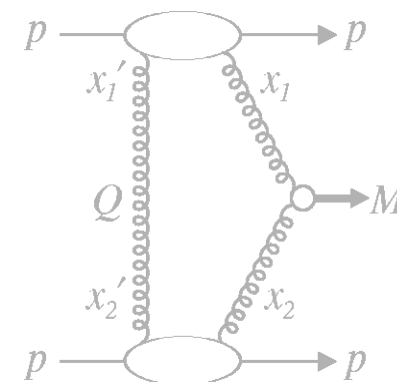
- $F_2^{\text{cc/bb}}$
- Charm and bottom exclusive final states (γp and DIS)
 - Cross sections
 - Fragmentation universality
 - Contribution from higher charm resonances
- x-section precision
 - LO/NLO
 - Resummation
 - Unintegrated pdfs
 - Benchmark x-section
- Non-linear effects/saturation



Heavy quarks:
 B quark pdfs of the proton,
 fragmentation fct, u-pdf
 LHC: Higgs production

Structure functions and
 parton distributions
 LHC: cross sections/precision

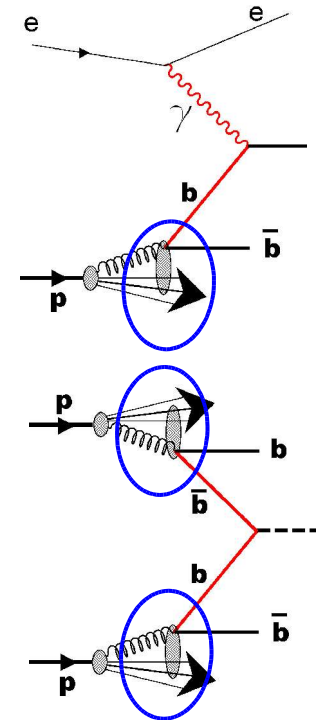
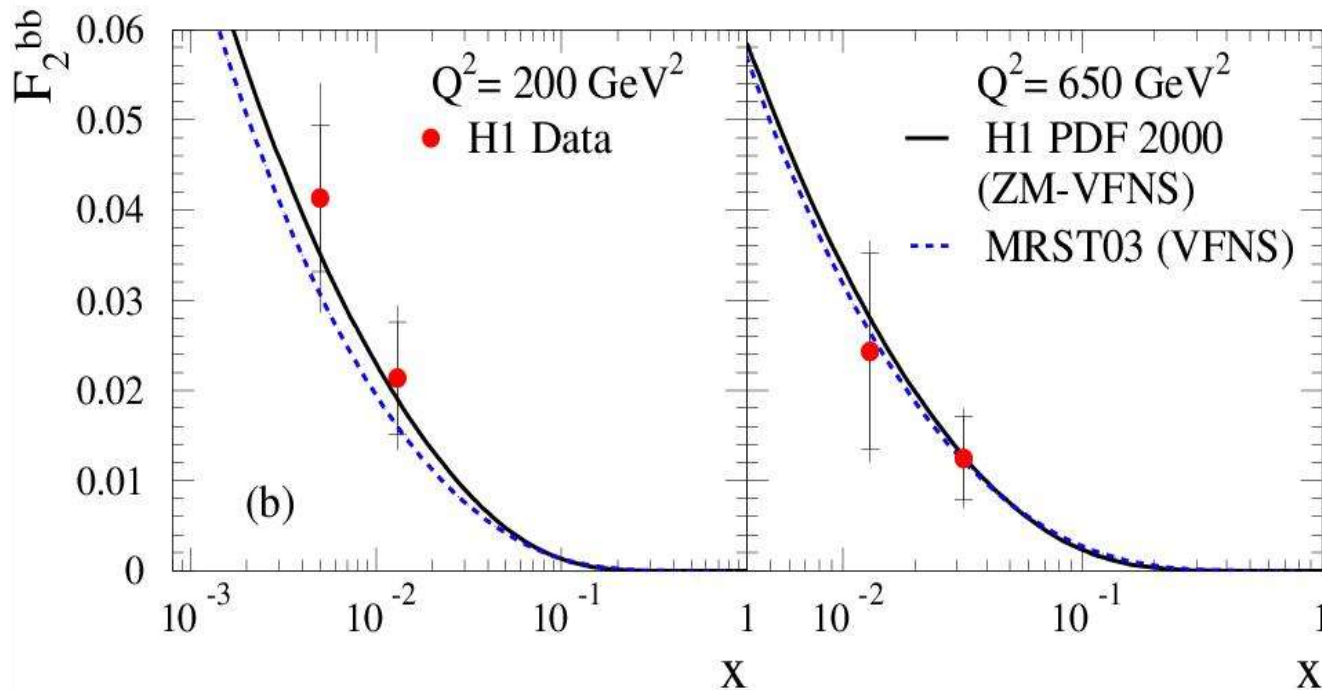
Diffraction
 LHC: exclusive
 Higgs production



F_2^b at large Q^2

From P. Thompson, A. Geiser

- Current H1 (HERA I) analysis: first measurement

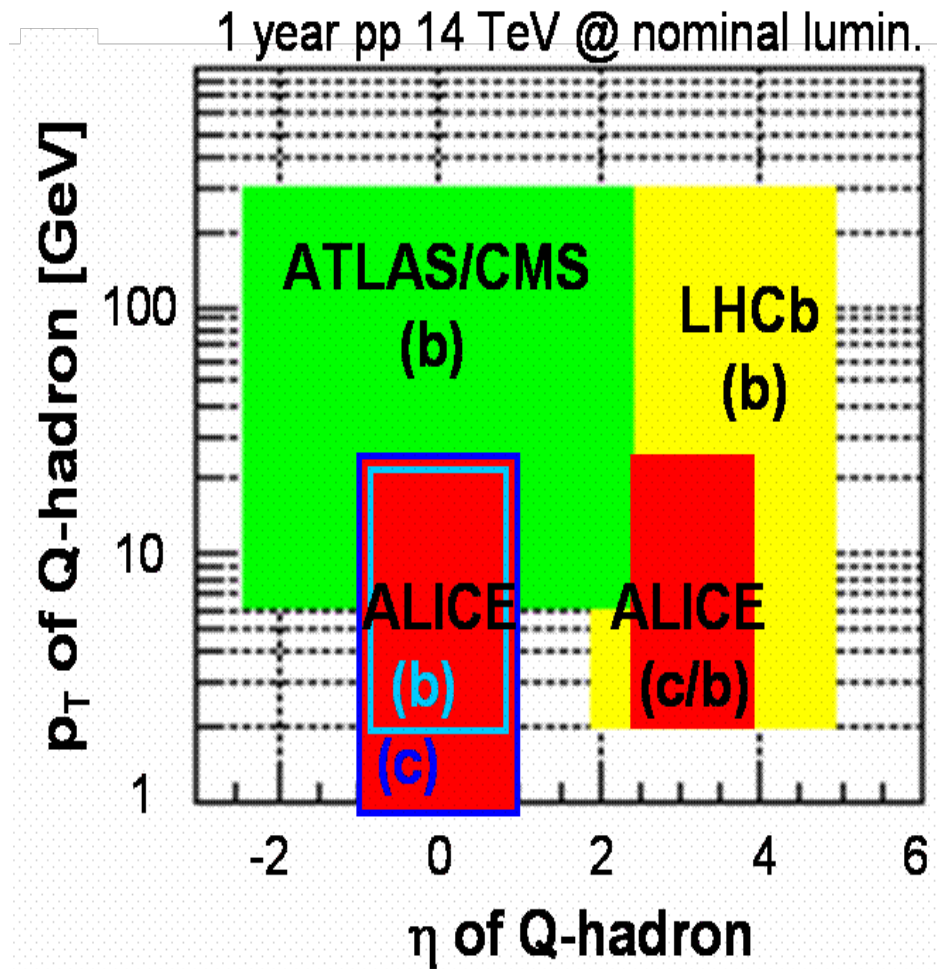


- HERA II analysis (expected)

- more statistics (> factor 10), larger kinematic range, two experiments
- > test „b content of proton“ (at $Q^2 \gg m_b^2$) much more precisely
- relevant for many LHC processes!

- Understand b-production mechanism (...remember b-puzzle at the TeVatron...)

Heavy flavors at LHC

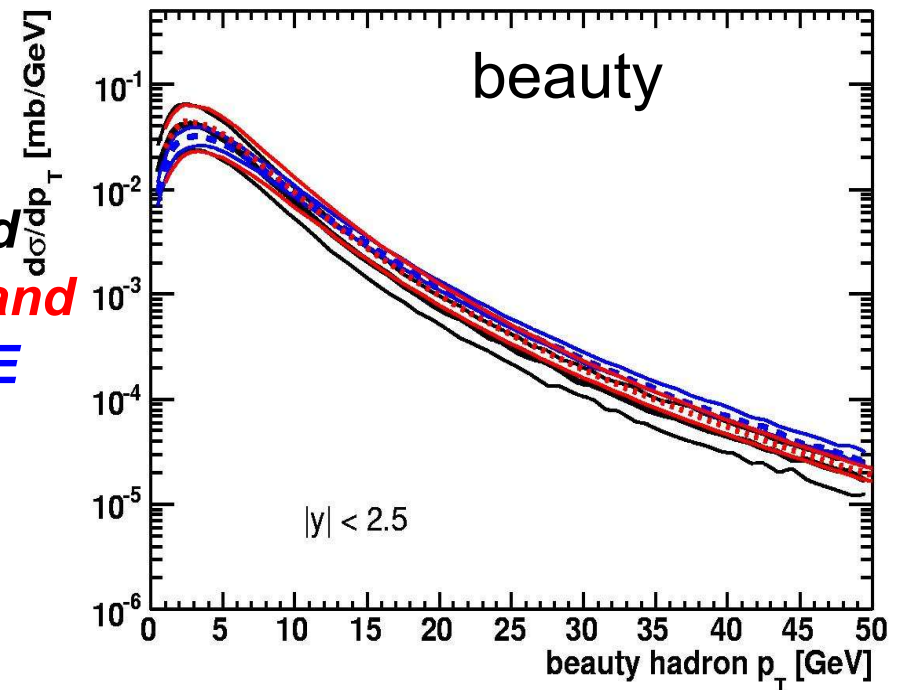
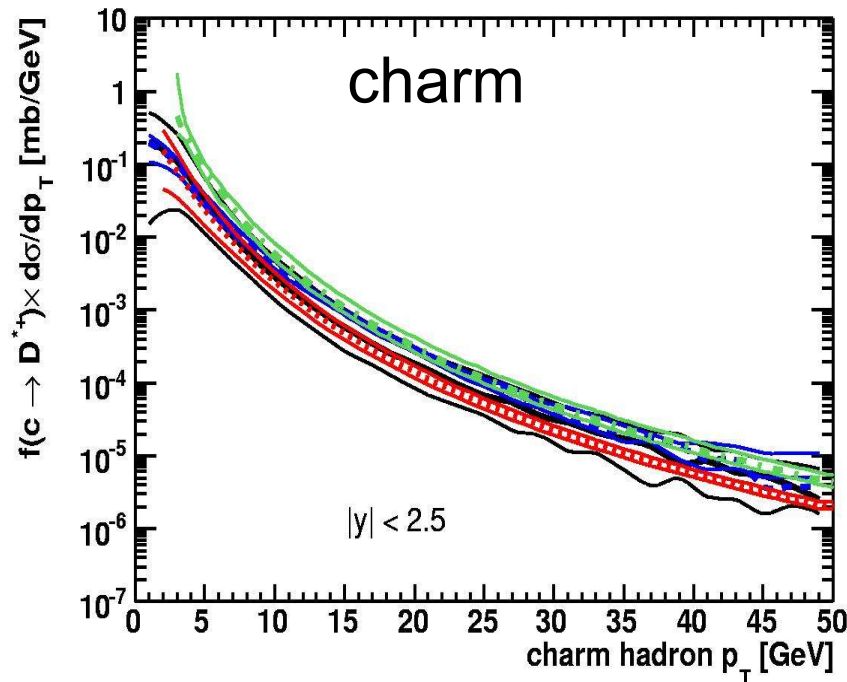


- ATLAS/CMS at large p_t
- ALICE/LHCb extends to smaller p_t
- interesting and challenging region
- Benchmark x-sections:
 - Collinear factorization:
 - Massless vrs massive
 - Matched resummed
 - LO + PS MCs
 - k_t -factorization
 - MC@NLO
- compare predicts for HERA γ -p and DIS and LHC
- identify regions of difference
 - check predictions and models
 - new effects
- Can tell right from wrong ?

charm and beauty at the LHC

MNR (massive NLO) – **FONLL** (matched NLL) – **CASCADE** (uPDF) - **VFNS**

benchmarks at hadron level in central region



CASCADE agrees well with **MNR** and **FONLL** for charm and beauty.
VFNS is larger for charm...

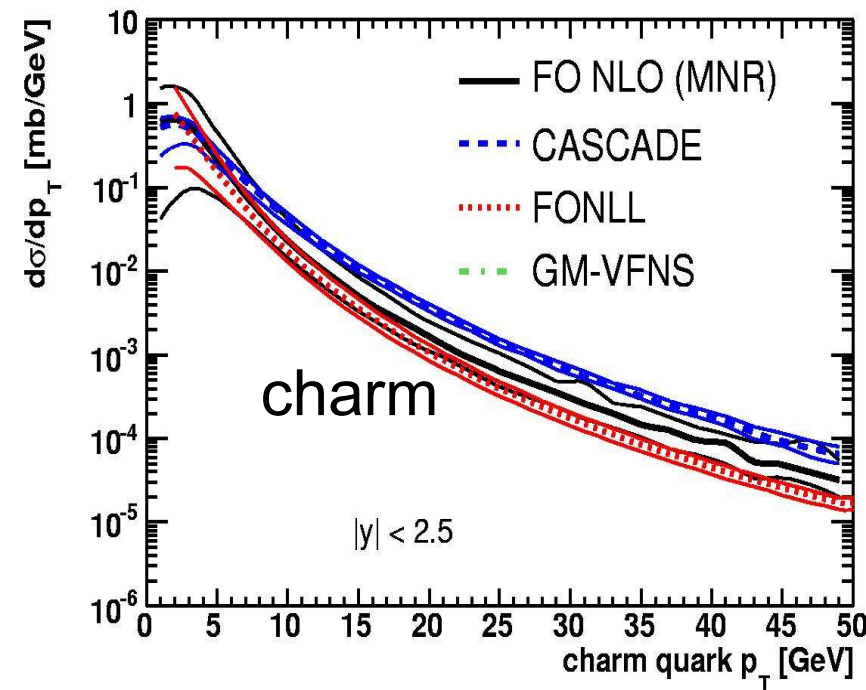
BUT all agree reasonably well ... success !!!

CASCADE: H.Jung and G.P.Salam,
Eur.Phys.J. **C19** (2001) 351

charm and beauty at the LHC

MNR (massive NLO) – FONLL (matched NLL) – CASCADE (uPDF)

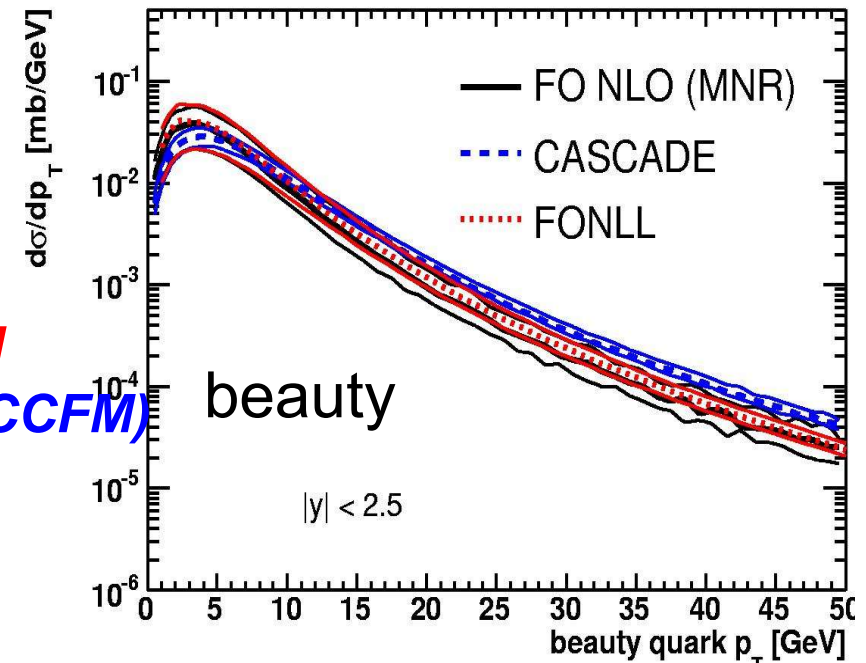
benchmarks at quark level



MNR band

FONLL band

CASCADE (CCFM)



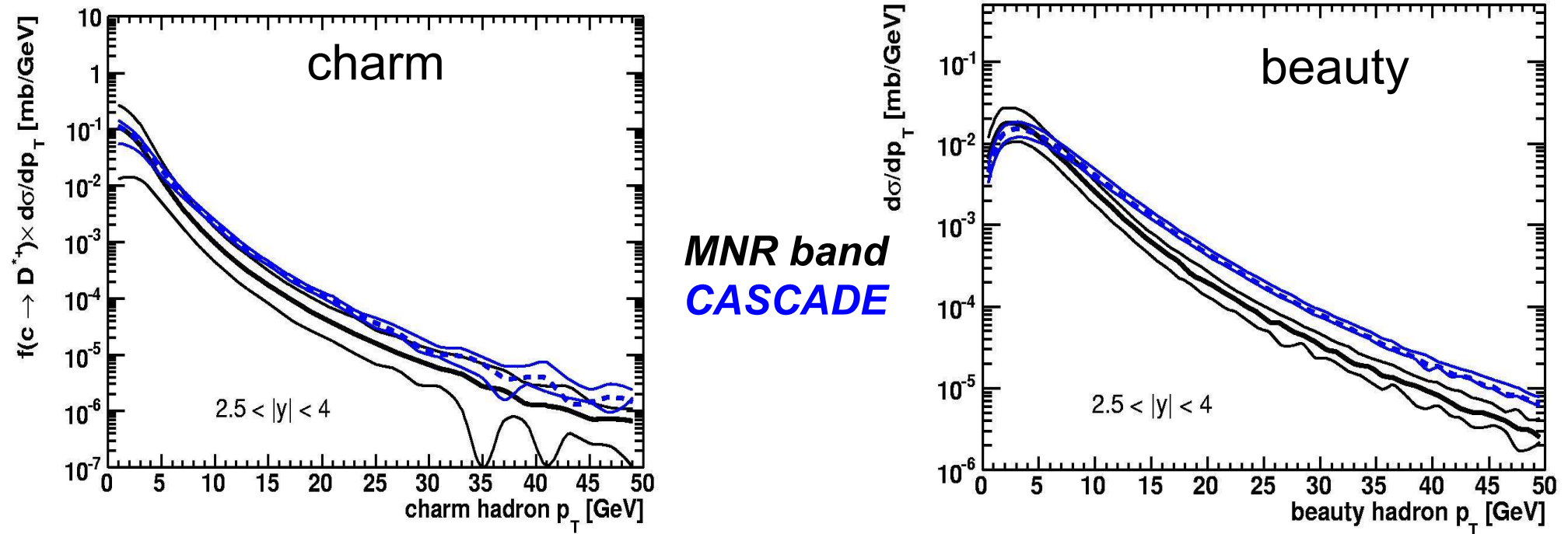
for beauty **CASCADE** agrees well with **FONLL**,
BUT differences in charm at larger p_T

M.Cacciari, H.Jung, K.Peters, A.Dainese

charm and beauty at the LHC

MNR (massive NLO) - CASCADE (uPDF)

benchmarks at hadron level in forward region

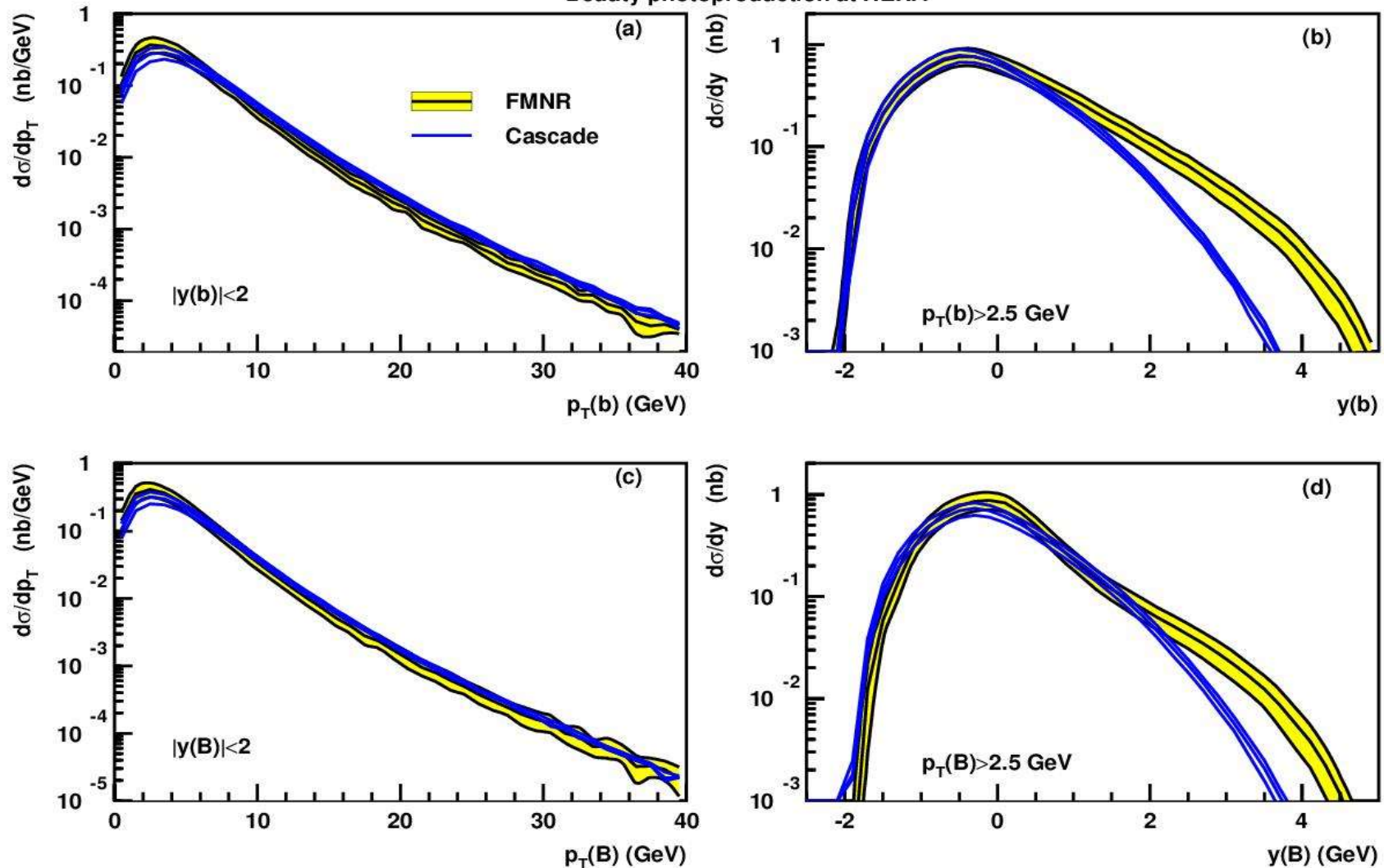


CASCADE is larger than **MNR** for beauty
in forward region !!!!!

M.Cacciari, H.Jung, K.Peters, A.Dainese

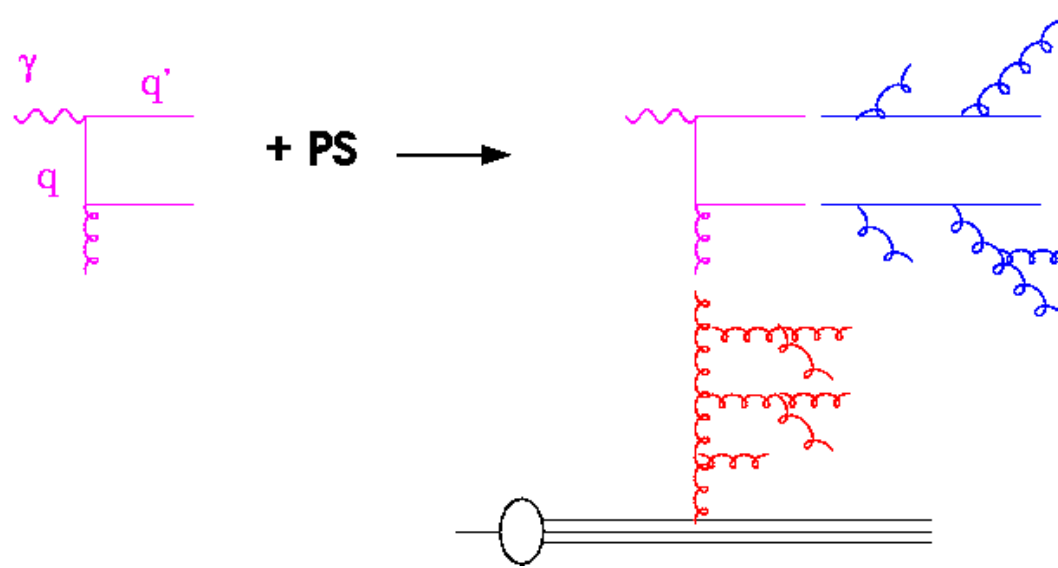
Beauty at HERA

Beauty photoproduction at HERA



➡ **Perfect agreement of NLO(FMNR) calc with CASCADE on quark and hadron level for $x < 0.01$!!!**

The problem of collinear factorization

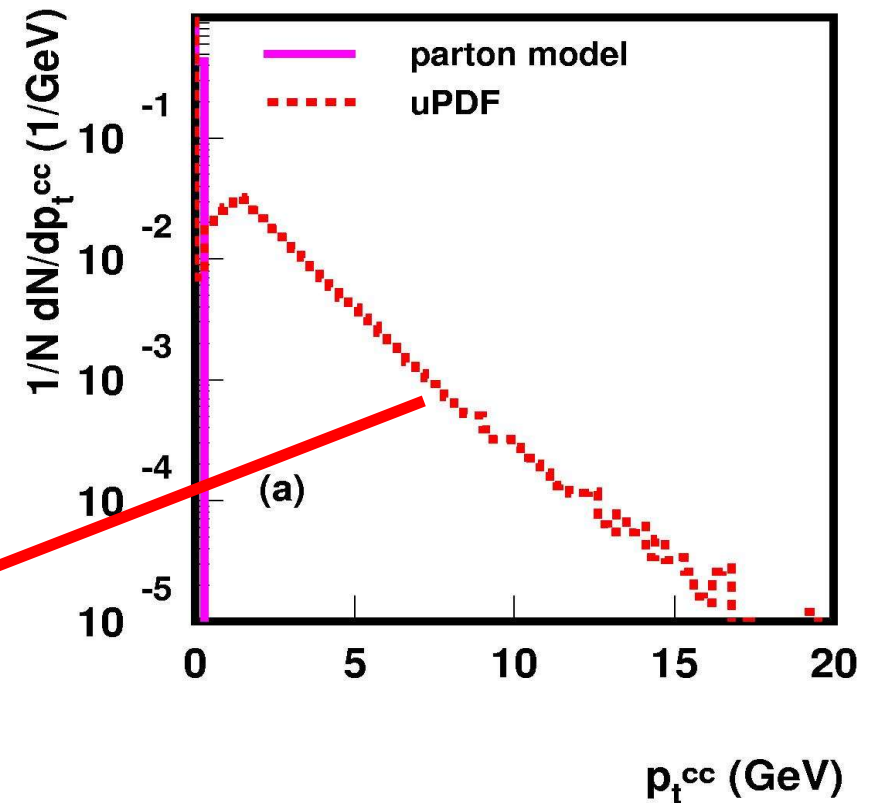
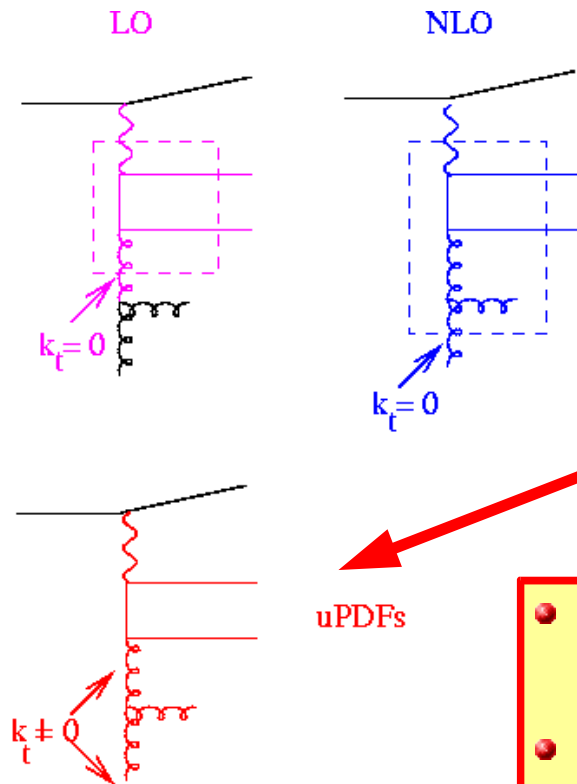


- **Collinear approach:** incoming/outgoing partons are on mass shell
 $(\gamma+q)^2 = q'^2$, $-Q^2 + x y s = 0 \rightarrow x = Q^2/(ys)$
- **BUT** final state radiation:
 $(\gamma+q)^2 = q'^2$, $-Q^2 + x y s = m^2 \rightarrow x = (Q^2+m^2)/(ys)$
- **AND** initial state radiation:
 $(\gamma+q)^2 = q'^2$, $-Q^2 + x y s + q^2 = 0 \rightarrow x = (Q^2-q^2)/(ys)$
- **Collinear approach:** $q'^2 = q^2 = 0$, order by order
- Well known.... since years....
- NLO corrections... better treatment of kinematics...

The need for unintegrated PDFs

J. Collins, H. Jung

- using integrated pdfs ignores proper kinematics
- large NLO corr comes from wrong kinematics in LO



- collinear factorization is wrong if details of final state are investigated
- Need for fully unintegrated fcts
- reason why CASCADE even better than NLO

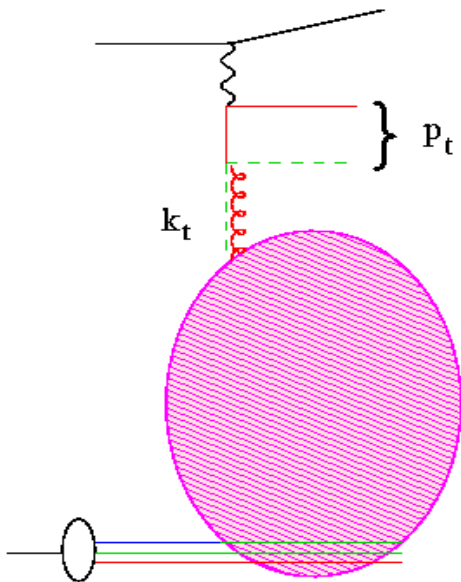
Need for uPDFs

J. Collins, H. Jung

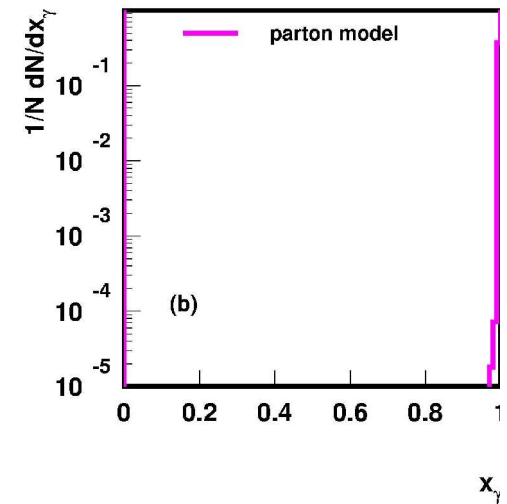
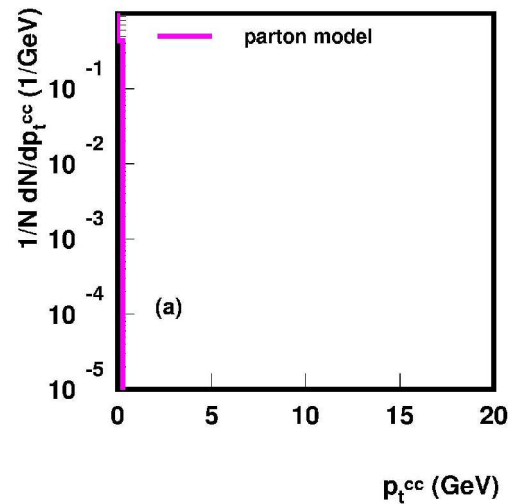
Define:

- $p_{Tq\bar{q}}$

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



- parton kinematics



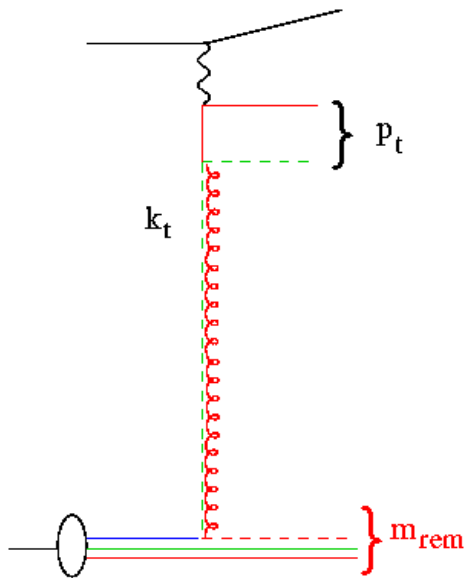
Need for uPDFs

J. Collins, H. Jung

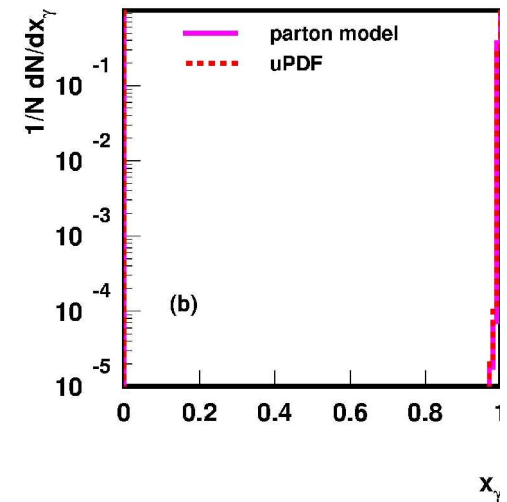
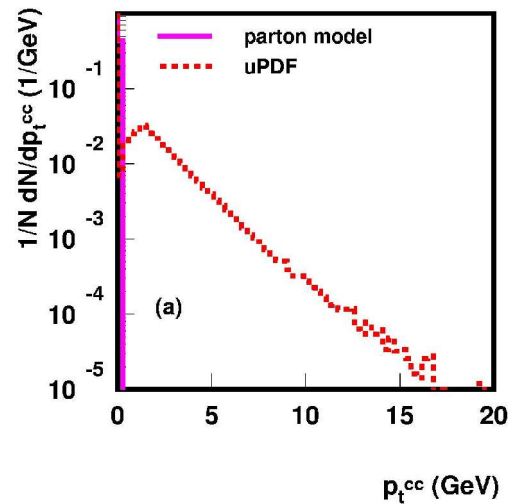
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- parton kinematics
- uPDFs

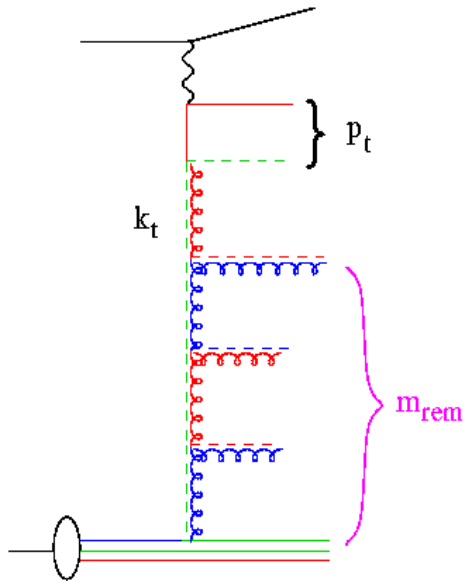


Need for uPDFs

Define:

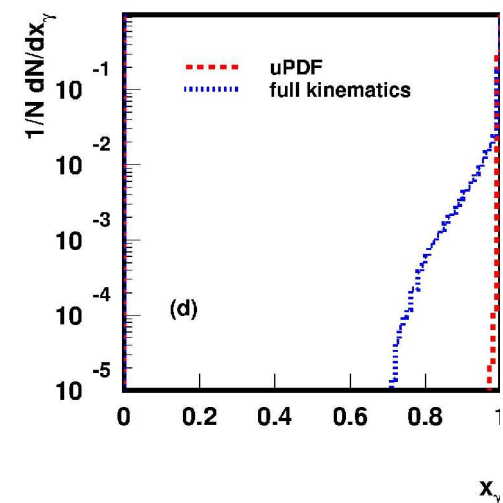
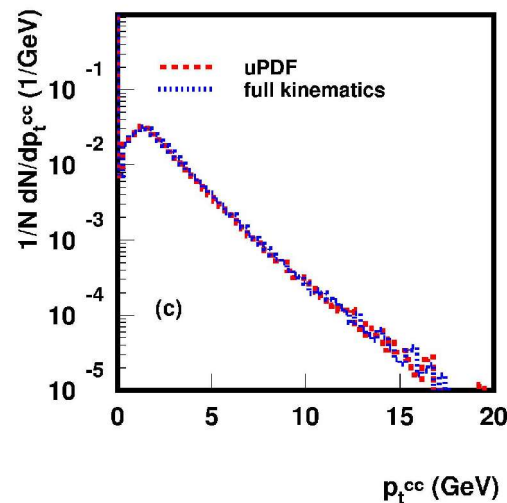
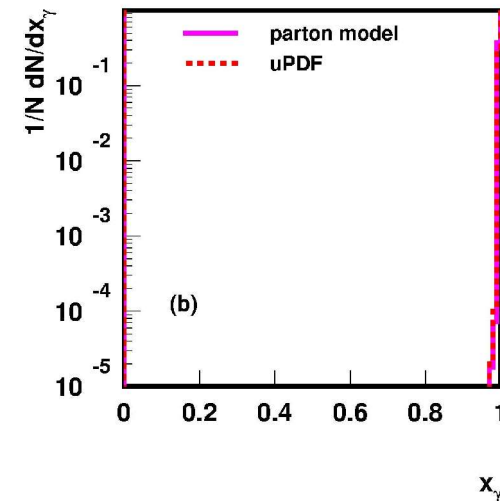
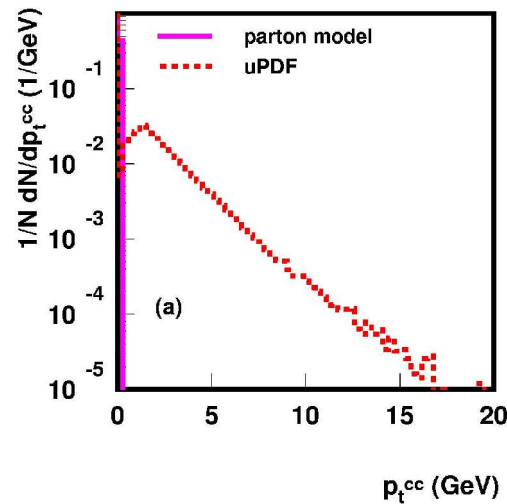
- $p_{Tq\bar{q}}$

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



- parton kinematics
- uPDFs
- full kinematics

J. Collins, H. Jung



Deviations: non-linear effects ?

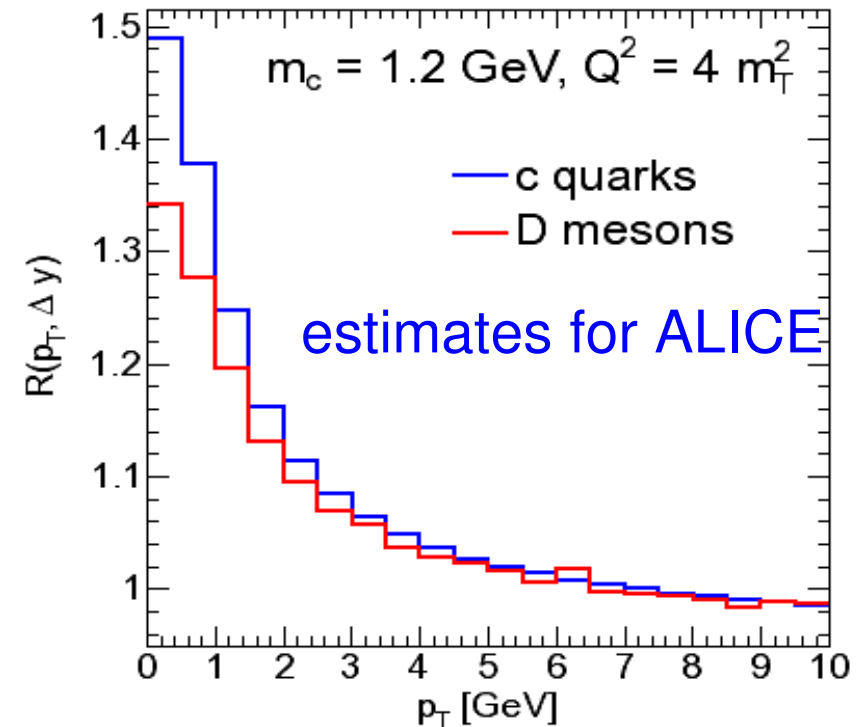
$$\frac{\partial xg(x, Q^2)}{\partial \log Q^2} = \frac{\partial xg(x, Q^2)}{\partial \log Q^2} \Big|_{\text{DGLAP}} - \frac{9\pi\alpha_s^2}{2Q^2} \int_x^1 \frac{dy}{y} y^2 G^{(2)}(y, Q^2)$$

$$x^2 G^{(2)}(x, Q^2) = \frac{1}{\pi R^2} [xg(x, Q^2)]^2.$$

- non-linear (quadratic) correction has “-” sign
 Q^2 evolution is slower

- Refit HERA F_2 data, reduces F_2 at low x a moderate Q^2

- $xg(x, Q^2)$ at low Q^2 ($< 10 \text{ GeV}^2$) and x ($< 10^{-3}$) is larger than in DGLAP



- Get these non-linear effects better understood from HERA !
- Violation of factorisation ?????

Non-linear effects at ALICE

Nonlinear evolution equation for unintegrated gluon distribution.

$$f(x, k^2) = \tilde{f}^{(0)}(x, k^2) + K^1 \otimes f - K^2 \otimes f^2$$

$$\tilde{f}^{(0)}(x, k^2) \rightarrow \text{input}$$

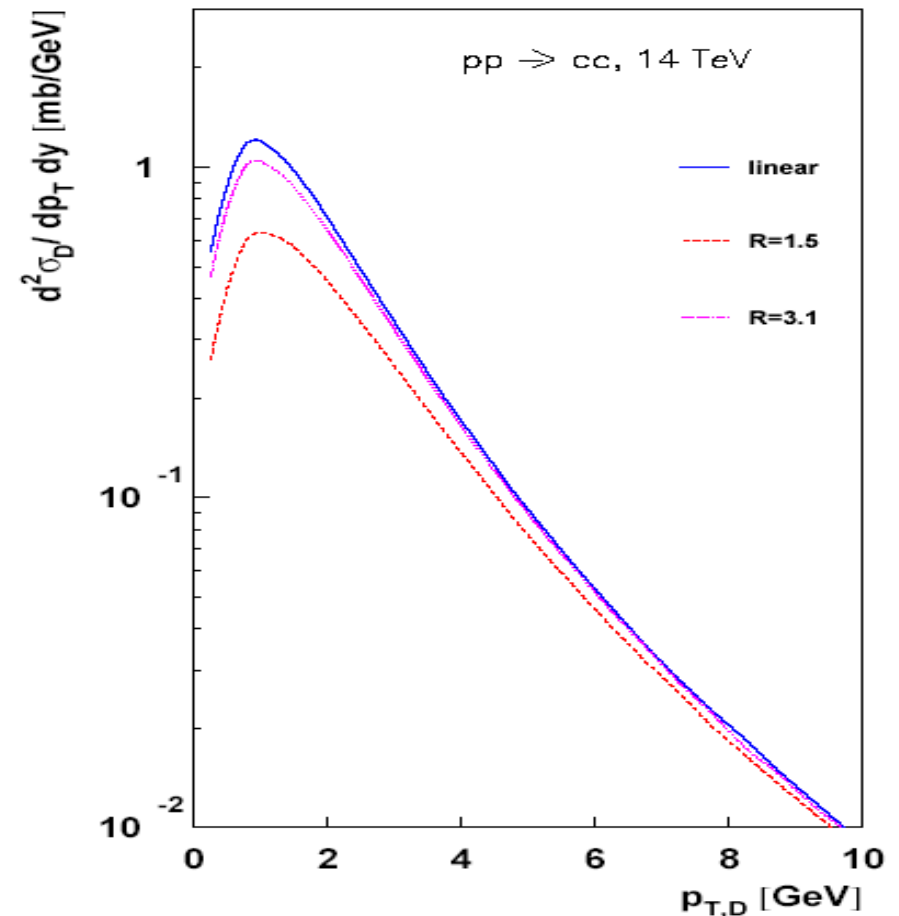
$$K^1 \otimes f \rightarrow \text{BFKL}$$

$$K^2 \otimes f^2 = \left(1 - k^2 \frac{d}{dk^2}\right)^2 \frac{k^2}{\overline{R^2}} \times$$

$$\int_x^1 \frac{dz}{z} \left[\int_{k^2}^{\infty} \frac{dk'^2}{k'^4} \alpha_s(k'^2) \ln \left(\frac{k'^2}{k^2} \right) f(z, k'^2) \right]^2$$

Charm suppression due to non-linear effects in BK

estimates for ALICE



Significant effects at small p_t
different pred. compared to GLR

Non-linear effects at LHC

Nonlinear evolution equation for unintegrated gluon distribution.

$$f(x, k^2) = \tilde{f}^{(0)}(x, k^2) + K^1 \otimes f - K^2 \otimes f^2$$

$$\tilde{f}^{(0)}(x, k^2) \rightarrow \text{input}$$

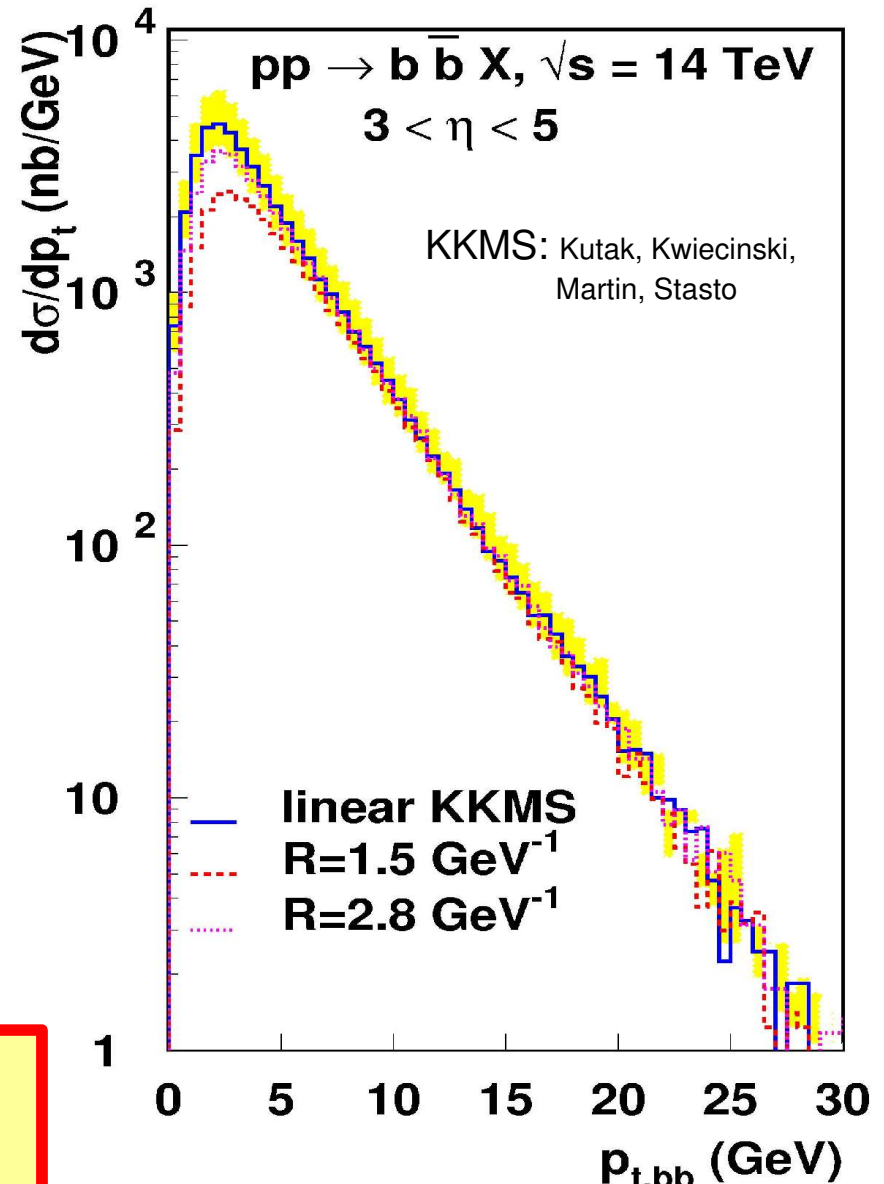
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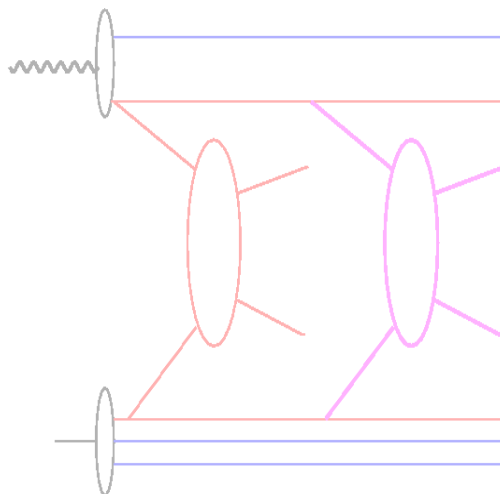
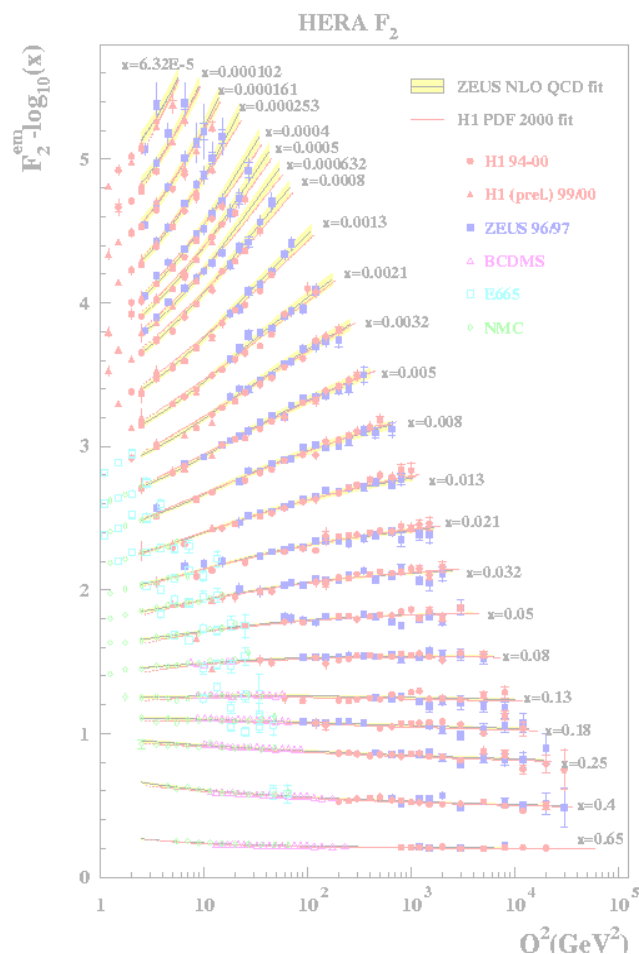
$$\int_x^1 \frac{dz}{z} \left[\int_{k^2}^{\infty} \frac{dk'^2}{k'^4} \alpha_s(k'^2) \ln \left(\frac{k'^2}{k^2} \right) f(z, k'^2) \right]^2$$

Bottom suppression due to non-linear effects in BK

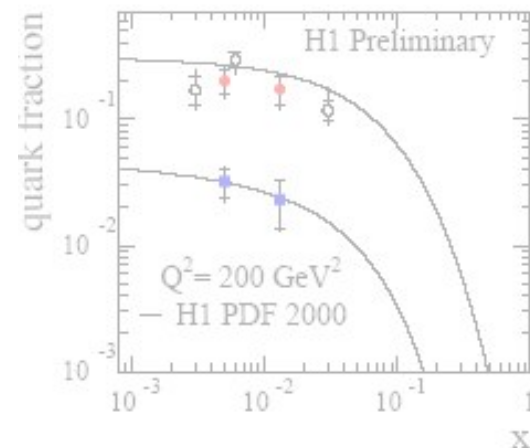
- Significant effects...
- up to factor of 2 in hot spot scenario
- factorization still ok ?



Topics of the workshop



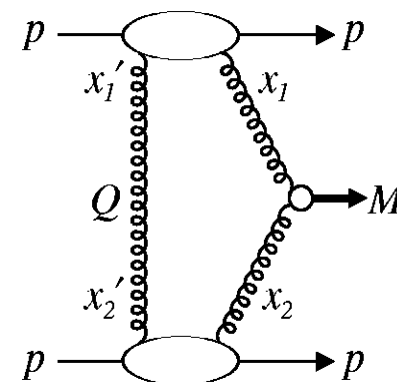
Multijets & final states
Underlying events,
un-integrated pdfs
LHC: event complexity,
jet x-section, Higgs



Heavy quarks:
B quark pdfs of the proton,
fragmentation fct, u-pdf
LHC: Higgs production

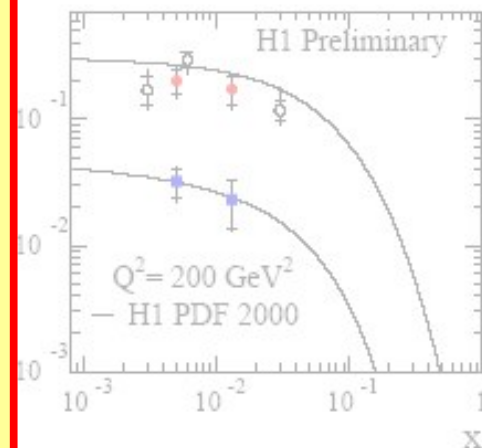
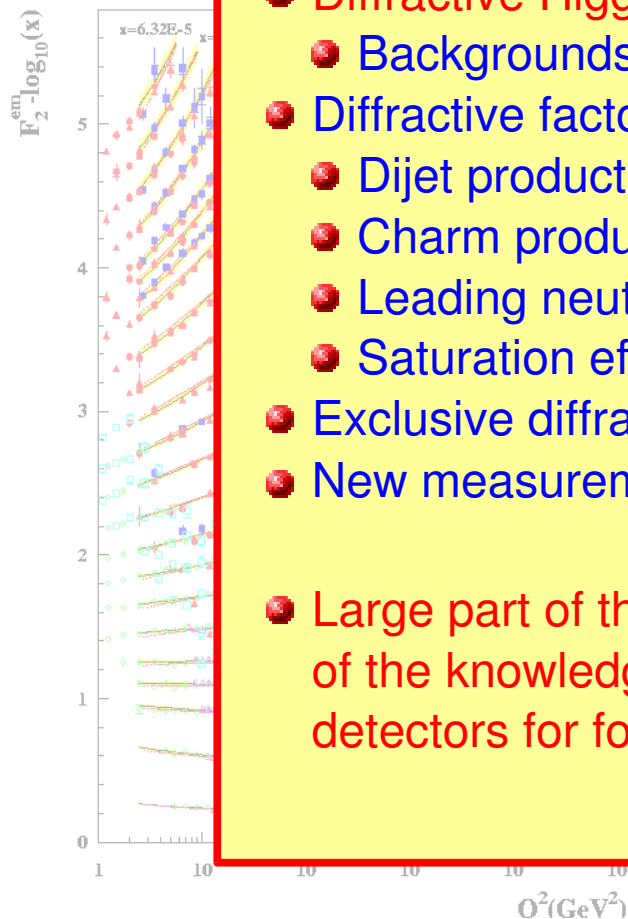
Structure functions and
parton distributions
LHC: cross sections/precision

Diffraction
LHC: exclusive
Higgs production



Topics of the workshop

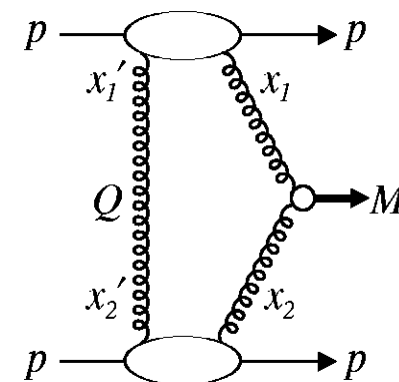
- Diffractive Higgs production
- Backgrounds to diffractive Higgs
- Diffractive factorization breaking
- Dijet production
- Charm production
- Leading neutrons
- Saturation effects and relation to MI/gap survival
- Exclusive diffractive dijets
- New measurements e.g F_L^D
- Large part of the activities was transfer of experience of the knowledge and design and operation of detectors for forward physics from HERA to the LHC



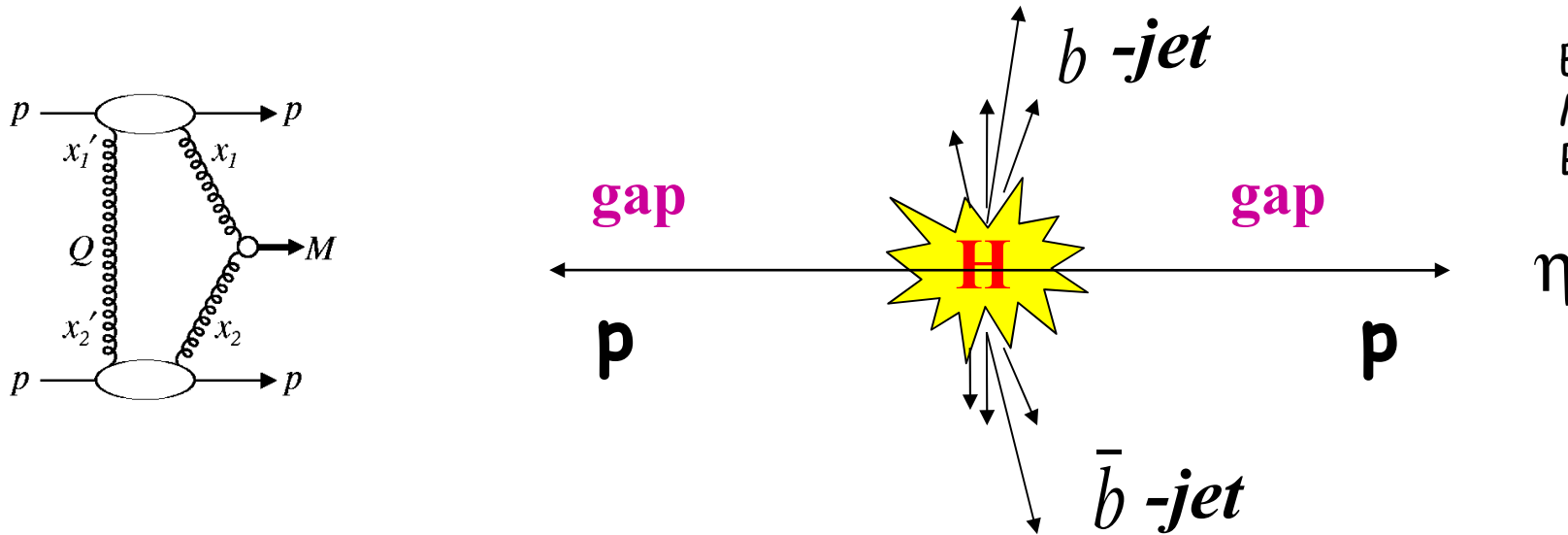
y quarks:
ark pdfs of the proton,
entation fct, u-pdf
Higgs production

Structure functions and
parton distributions
LHC: cross sections/precision

Diffraction
LHC: exclusive
Higgs production



Diffractive Higgs Production



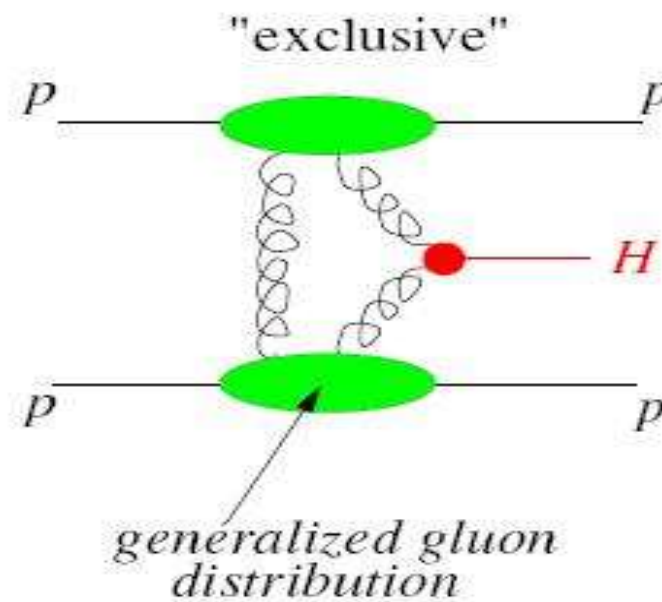
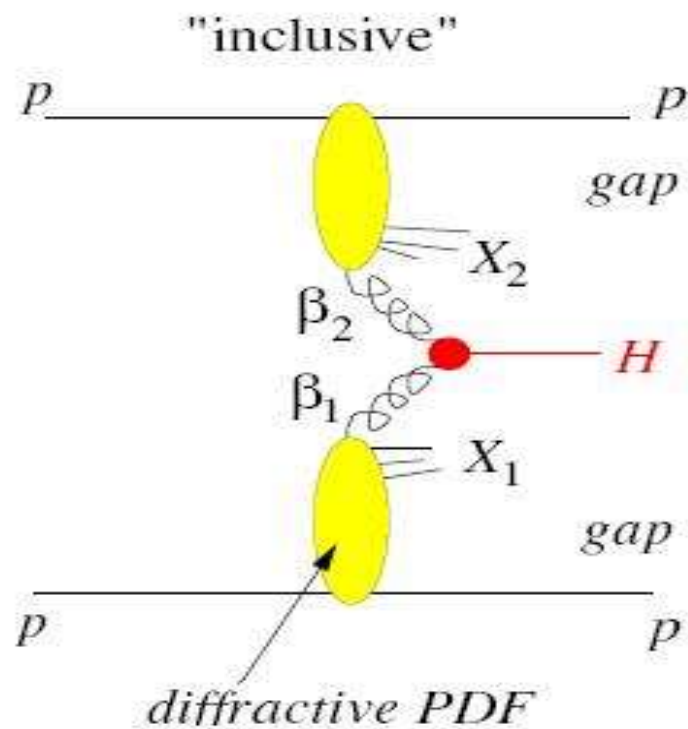
E.g. V. Khoze et al
M. Boonekamp et al.
B. Cox et al. ...

$$M_H^2 = \{p + \bar{p} - p' - \bar{p}'\}^2$$

- Exclusive diffractive Higgs production $p + p \rightarrow p + H + p$ 2-10 fb
- Inclusive diffractive Higgs production $pp \rightarrow p + X + H + Y + p$ O(100) fb
- Advantages: Mass resolution
from energy of protons determine mass
precise mass determination
- Sensitive to un-integrated pdfs

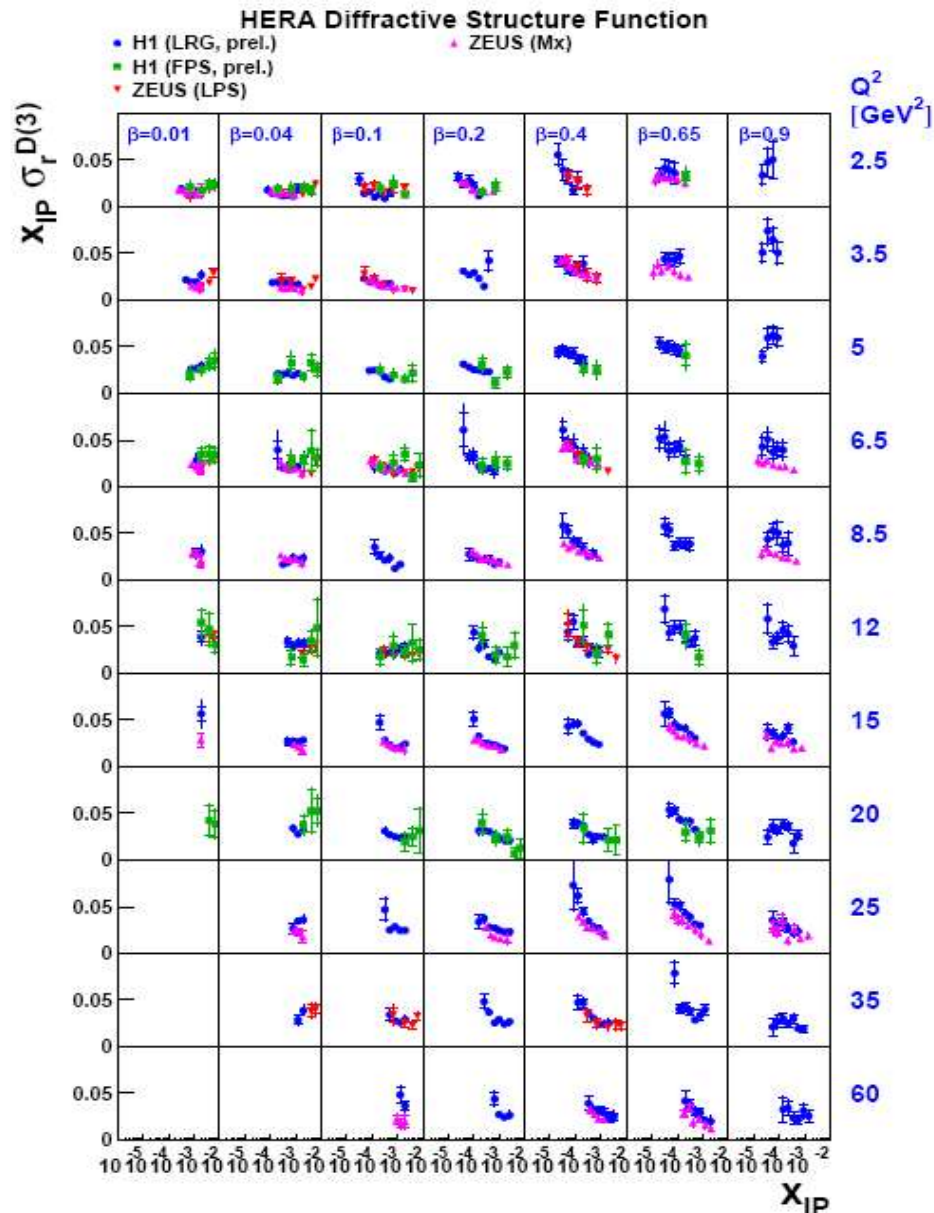
Exclusive Higgs and diff. at HERA

from M. Diehl



- Inclusive diff. events become background to exclusive one, when remnant systems X become soft...
- relevant region for diff. Pdfs:
 $\beta \rightarrow 1$ and $Q^2 \sim M_h^2$
- measure diff pdf at highest Q^2 and highest β

Grand F_2^D summary at HERA



From FP Schilling, P. Newman

F_2^D is crucial for understanding CSE in hadronic interactions:

At this workshop 1st step was made towards final, combined F_2^D from HERA!

Present status: In unified analysis of measured cross-sections reasonable global agreement between H1 & ZEUS is found, and regions of significant discrepancies identified.

- get the best out of HERA
- precise determination of diffractive PDFs

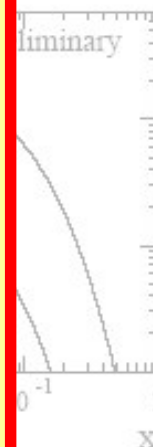
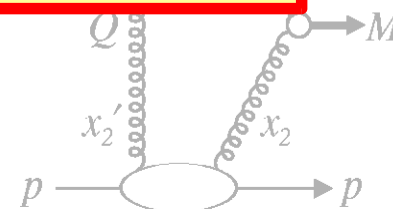
Topics of the workshop

MC&Tools WG (V. Lendermann)

- Parton distribution library:
 - LHAPDF now official carrier of the PDFs
 - HERA pdfs have been added
 - Pion and photon added, particularly for HERA. F2D next?
- NLOLIB framework for NLO QCD programs
 - Uniform user interface/interface to HZTOOL
 - e+e-/ep included, pp can be added (but not done yet?)
- HZTOOL/JetWeb/RunMC/Cedar(?) for tuning
 - all HERA results included, important ones from pp
- JetWeb/RunMC graphical interface to MC generators
- NEW MC developments
- Continuation of the MC@LHC workshop, concerning validation

Structure functions and
parton distributions
LHC: cross sections/precision

Diffraction
LHC: exclusive
Higgs production



proton,
pdf
ion

$\rightarrow p$

RunMC session...

from S. Chekanov

The screenshot displays the RunMC software interface with several windows open:

- JRunMC**: The main configuration window. It shows the 'MC model' set to 'CASCADE', 'Events No.' set to '10000', and 'Project name' set to 'hztoolv3'. The 'run' button is visible. Below, it indicates 'e+(27.0 GeV) p(920.0 GeV)' and 'current run was finished'.
- Variables and Histogram editor**: A table defining variables and histograms.

No	Title	D	Min	Max	Bins	W	Comments
1	PTtot	1	0.0	50.	100	1	transverse event momenta
2	N(tot)	1	0.0	100.	100	1	total number of particles in...
- Histograms**: A window showing a list of histograms created during the run, such as 'h301;1', 'h302;1', etc., with their respective titles and options.
- oolv3.log**: A log window showing the output of the CASCADE MC generator. It includes details about the model (CASCADE version 1.20/07), parameters (e.g., α_s , α_{em}), and the final state of the event.


```

I particle/jet KS  KF  orig  p_x  p_y  p_z  E
1 le+!  21    -11    0  0.000  0.000 -26.700  26.70
2 lp+!  21   2212   0  0.000  0.000  920.000  920.00
sum:  0.00  0.000  0.000  0.000  0.000

*****
*   You are using the CASCADE MC generator   *
*   version 1.20/07                         *
*   neutral current interaction selected      *
*   gamma + gluon p+ --> q q_bar max flav = 5 *
*   EPA + gamma* gluon --> q q_bar used      *
*   semihard approach for BGF Catani et al  *
*   no cut on max angle of scattered electron *
*   no cut on min angle of scattered electron *
*   q^2_min = 4.000                         *
*   q^2_max = 80.000                        *
*   y_min = 0.010                          *
*   y_max = 0.800                          *
*****
#   parton shower selection:                 #
#   CCFM initial state parton showers including #
#   angular ordering                         #
#   no timelike initial state partons        #
#   final state parton shower                #
*****
#   proton remnant parameters                #
#   energy sharing IREM = 4                  #
*****
cm energy 313.460 GeV
scale for alpha_s: m_q**2 + p_t**2
scale or alpha_s is multiplied by: 1.
++++ gluon density selection +++++
++++ ISEL= 1 +++++
      
```
- hzxxxx.inc**: A file containing macro calls for the run, such as 'call HZ98143 (IPLAG)' and 'call HZ98050 (IPLAG)'.


```

call HZ98143 (IPLAG)
call HZ98050 (IPLAG)
      
```
- unmchztool.f**: A Fortran file defining the generator 'CAS' and the initial state 'istat=0'.


```

Gen='CAS'
istat=0

C initialization:
if (im.eq.1) then
  Call hlimit (NWPACV)

C get project name from temporary file
C do not change this line
open(3, FILE='proj.tmp', S
read(3, *) fname
close(3)

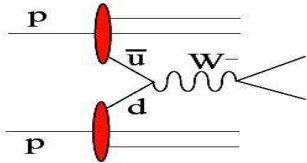
C initialize H2tool calculations
Call hropen(45, 'HISTO', fna
iflag=1
INCLUDE 'hzxxxx.inc'
Call HZ95108 (1)
Call HZ95007 (1)
Call HZ96160 (1)
else if (im.eq.2) then
C run over events
Call Hzfihelp ! fill HEPEV
iflag=2
INCLUDE 'hzxxxx.inc'
      
```
- RunMC**: A window displaying two histograms. The top histogram is for 'PTtot' (transverse event momenta) with a peak around 15. The bottom histogram is for 'N(tot)' (total number of particles) with a peak around 40. Both histograms show the distribution of the respective variable over the 10000 events.

HERA and the LHC

**Where further measurements at
HERA are desirable for the
physics reach of LHC !**

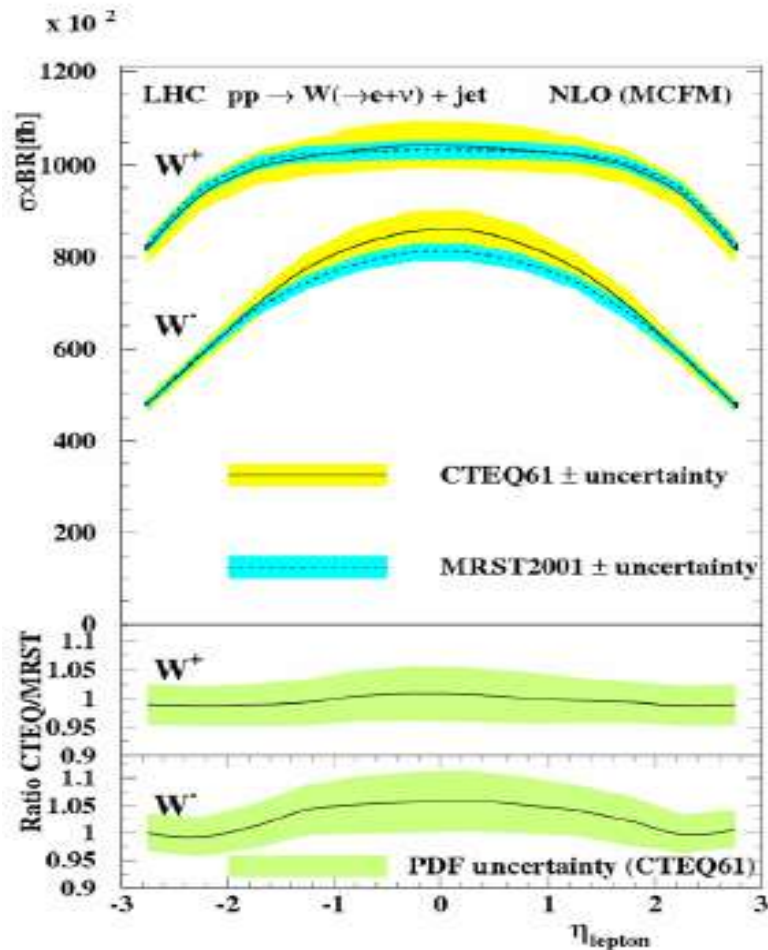
HERA future measurement: deuteron

W xsection at LHC



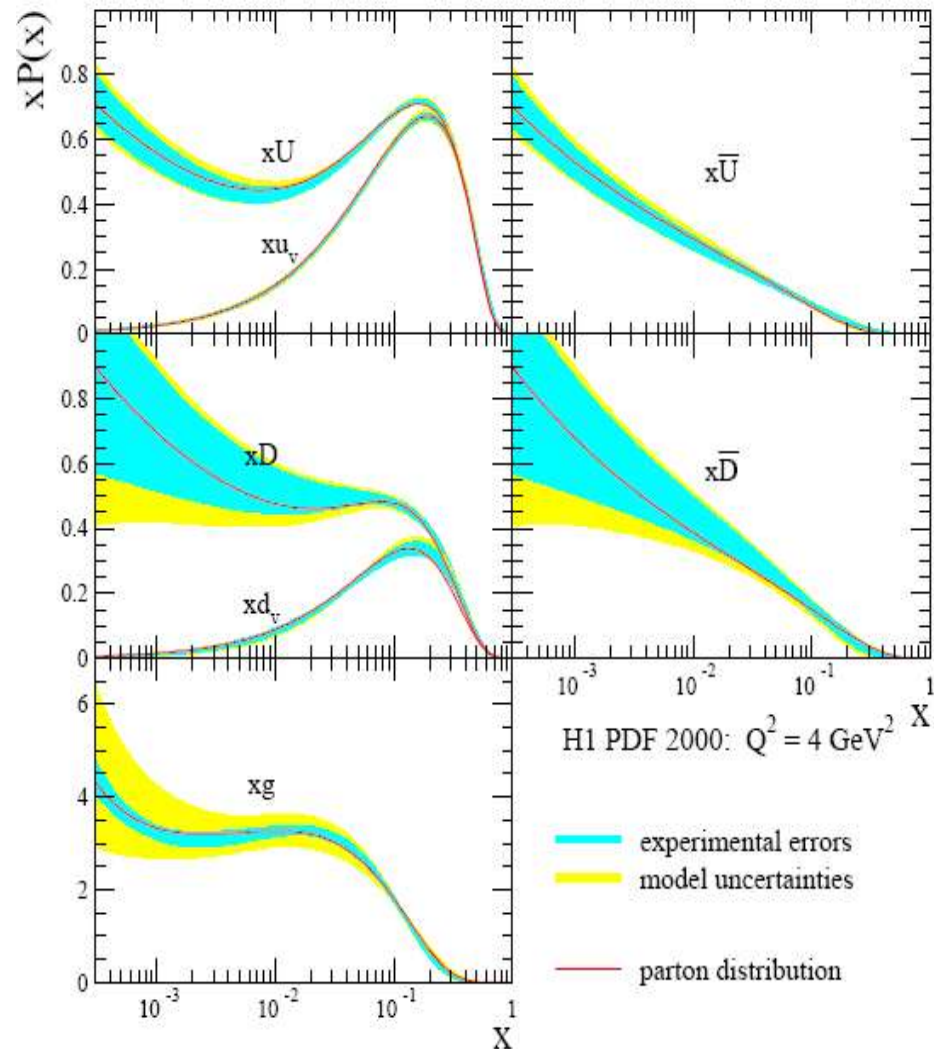
Global fits assume $u=d$ at small x

from M. Klein



H. Stenzel

H1 + BCDMS fit (no constraint on A, b)



Future HERA measurement: deuteron

from M. Klein

The light sea quark asymmetry is expected and has been assumed to vanish at low x . However, F_2 rises strongly towards low x which deserves to be studied.

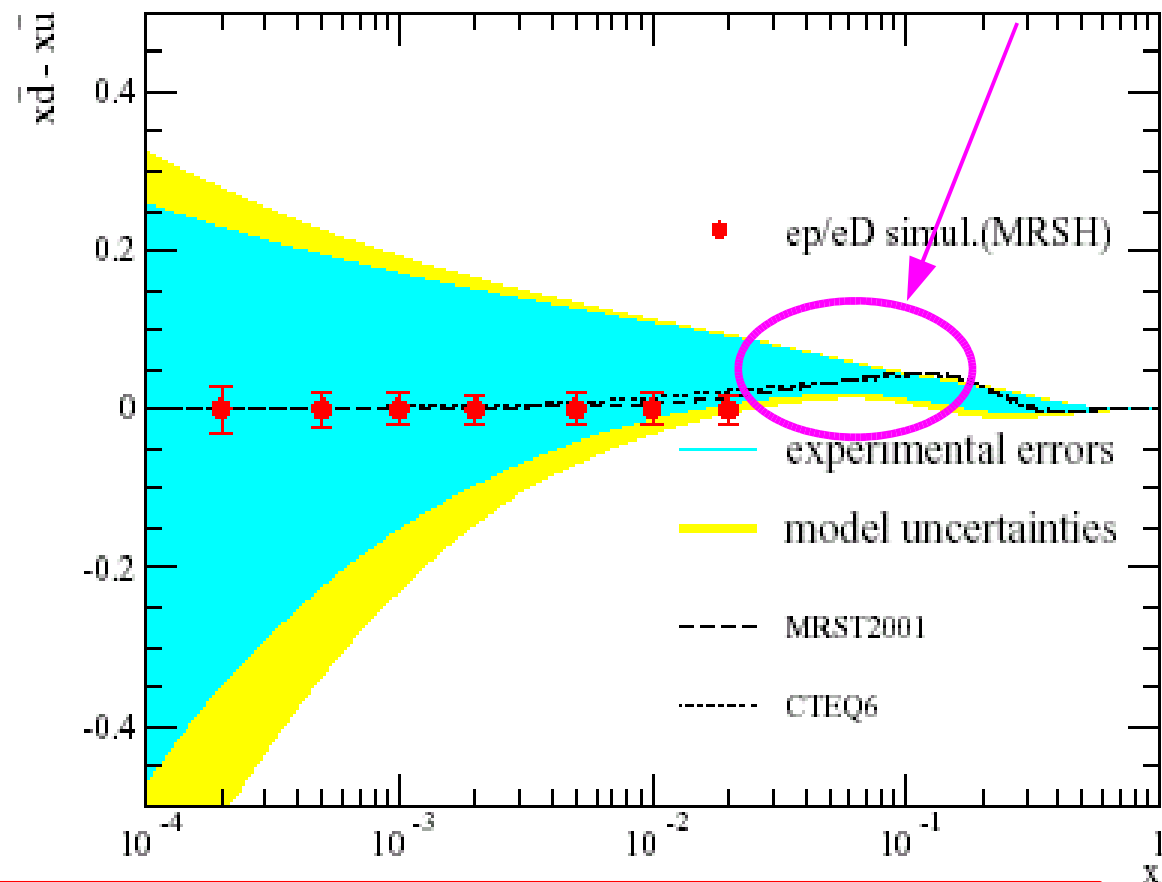
Tevatron with W

$$\frac{1}{2}(F_2^p + F_2^n) - F_2^p$$

$$\rightarrow x \left(\frac{1}{6} d_v - \frac{1}{6} u_v + \frac{1}{3} \bar{d} - \frac{1}{3} \bar{u} \right)$$

$$\gg \frac{1}{3} x (\bar{d} - \bar{u}) \text{ at low } x$$

simulated accuracy:
(20 pb⁻¹ eD, 40 pb⁻¹ ep)



Can obtain important information for LHC ...

HERA and the LHC

**Where HERA experience is
valuable for the LHC !!!**

HERA experience

- experience in QCD analyses:
pdfs, jet-physics, heavy quarks
- experience in QCD phenomenology:
parton level calculations and Monte Carlo event generators.... which are now also used for LHC studies....
- What LEP was in the electro-weak sector, HERA is in QCD
Only that QCD is more complicated but also much richer....

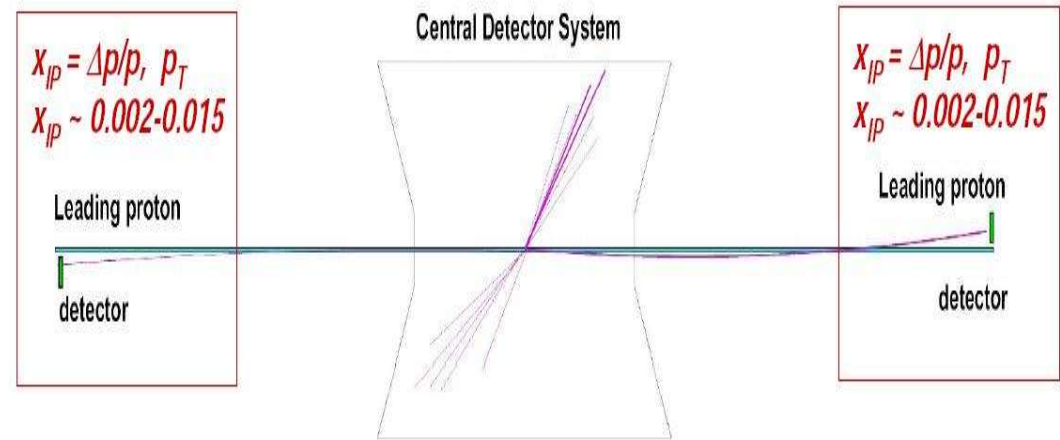
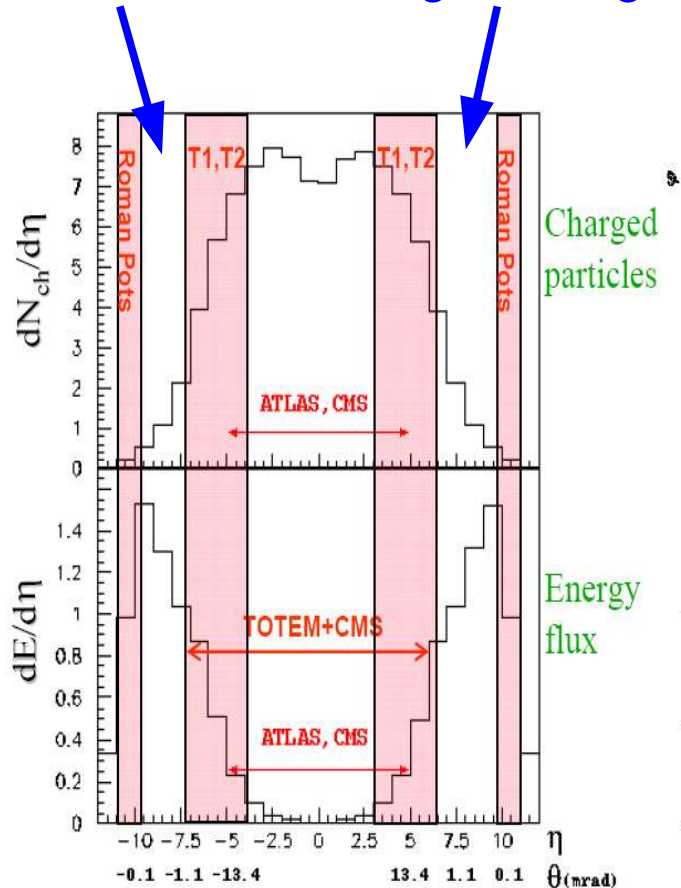
But also...

HERA experience in forward physics.....

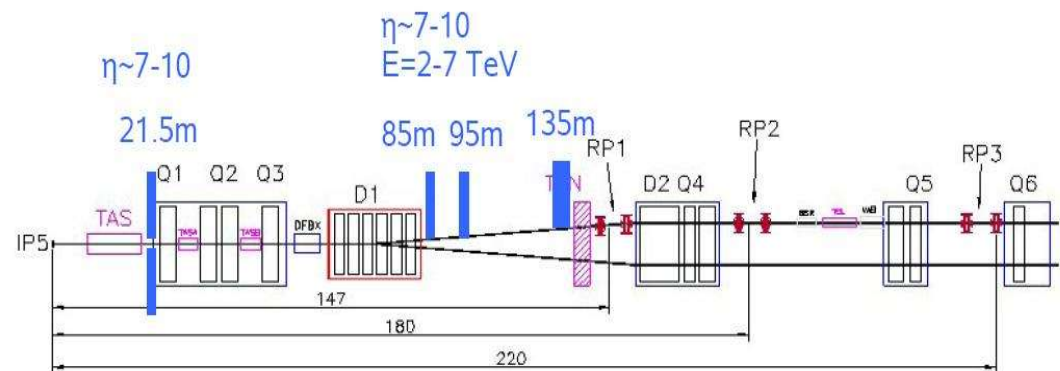
Ideas for upgrading forward region

from H. Kowalski

Here is something missing



from V. Andreev, A. Buniatian, L. Lytkine, M. Kapishin, H.J.



Wait.... this is not the end



- Phase I of this workshop is over and will be concluded with the proceedings
 - However an important link between communities has been established.
- We should not just let it fade away, but strongly exploit it, to the benefit of both communities.

Therefore this is not THE END

Proceedings are coming out in Nov 2005 (**NOW**)

- Keep momentum with one plenary HERA/LHC meeting per year

Spring 2006	CERN
March 2007	DESY
March 2008	CERN... (first physics @ LHC!?!)

- Keep also good contacts with TeV4LHC (a common meeting some time?)



HERA and the LHC



**This will be the beginning of a
beautiful friendship !**