HERA and the LHC workshop

H. Jung (DESY)

"…The mechanic, who wishes to do his work well, must first sharpen his tools …"

—Chapter15, "**The Analects**" attributed to Confucius, translated by James Legge. (from X. Zu talk at DIS05)

HERA and the LHC workshop

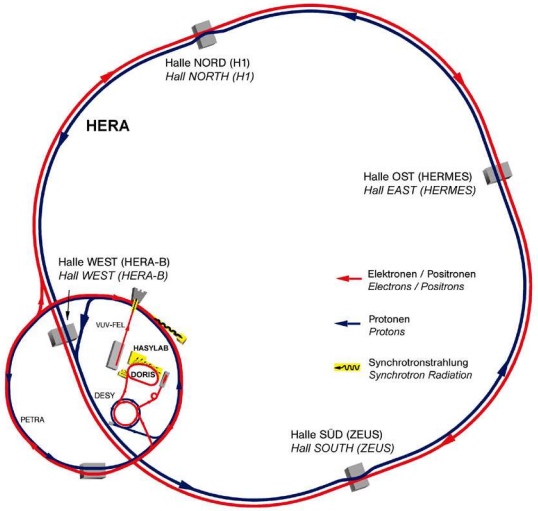
"…The mechanic, who wishes to do his work well, must first sharpen his tools …"

—Chapter15, "**The Analects**" attributed to Confucius, translated by James Legge. (from X. Zu talk at DIS05)

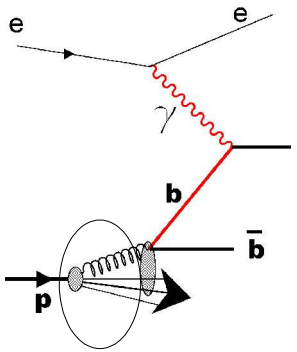
- *Aims of the workshop*
- *Outcome, results and future (highly biased.....):*
  - *HERA is important for the physics reach of LHC*
  - *further HERA measurements desirable*
  - *HERA experience valuable for LHC*

Why HERA and LHC ?

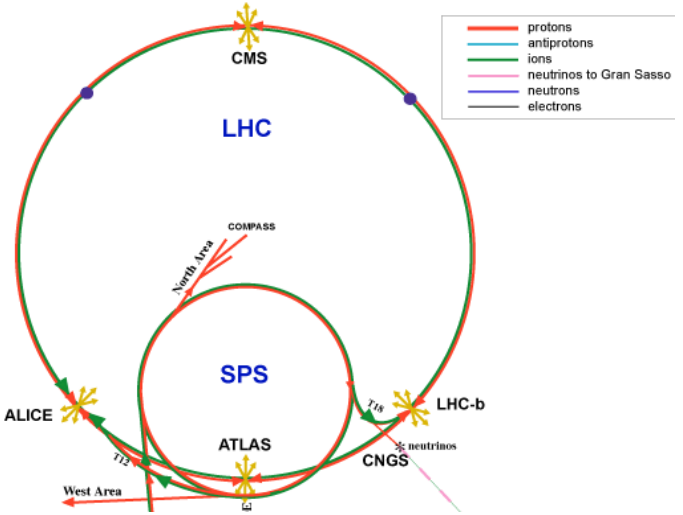
electron proton collider HERA
$\sqrt{s}$ = 320 GeV



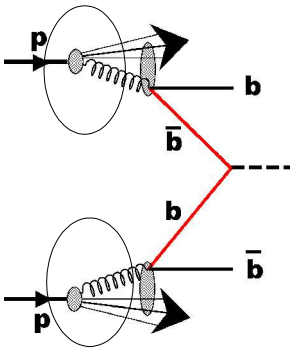
HERA: QCD
structure of the proton



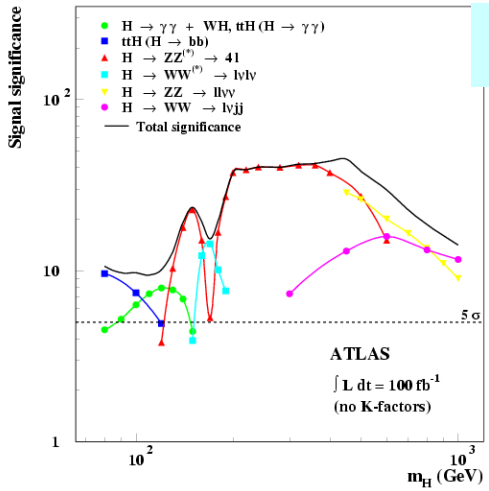
proton proton collider LHC
$\sqrt{s}$ = 14 TeV



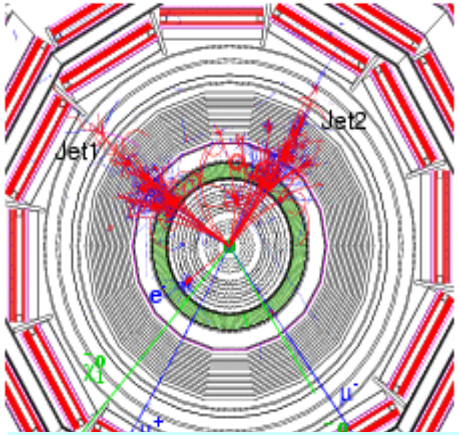
LHC: Higgs, SUSY etc,
but mostly QCD...



Physics at the LHC: examples

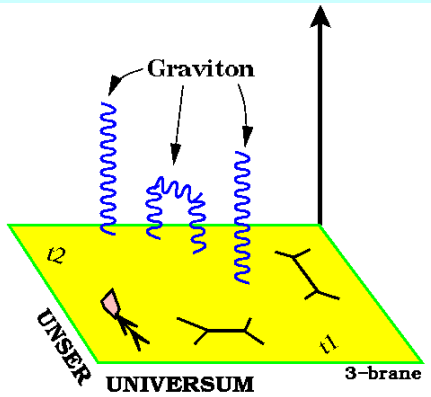


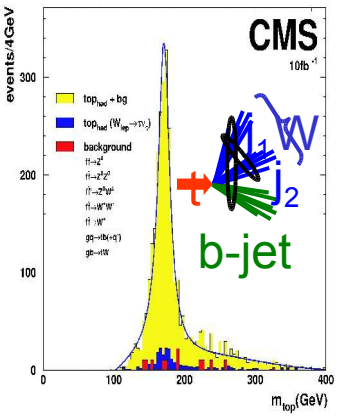
Higgs!



Supersymmetry?

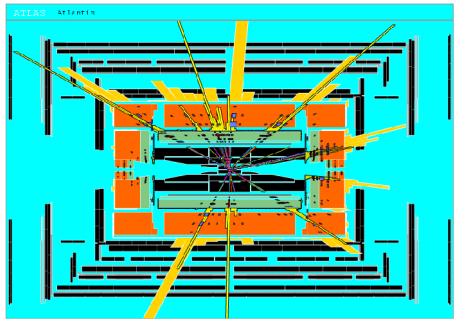
Extra Dimensions?



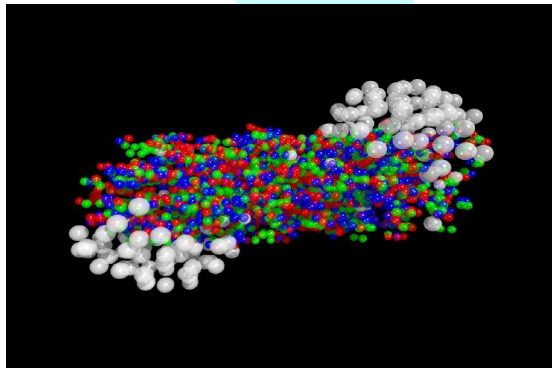


Precision measurements e.g top!

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.

Five Working Groups

Parton density functions (S. Forte, S. Moch M. Dittmar, A. Glazov M. Botje, J. Butterworth)

Multi-jet final states (L. Lonnblad, V. Khoze, N Tuning, C Buttar, J. Butterworth, S. Banerjee, D. Traynor)

Heavy quarks (charm and beauty) (M. Cacciari, U. Uwer, M. Smizanska, M.Corradi, A. Dainese, C. Weiser, A. Meyer)

Diffraction (J. Forshaw , M. Diehl, K. Piotrzkowski, R. Orava, H.Kowalski, P.vanMechelen, M.Rijssenbeek, B.Cox)

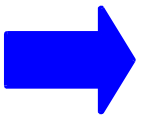
MC-tools (M. Seymour, A. Nikitenko, E.Richter-Was, P.Robbe, V.Lendermann)

Organization

First meeting:	26-27 March CERN	(~ 250-300 participants)
Intermediate meeting:	1- 4 June/ DESY	
Second meeting:	11-13 October CERN	
Intermediate meeting:	15-19 November/ DESY	
Intermediate meeting	17-21 January 2005/ CERN	
Final meeting:	21-24 March 2005/ DESY	(~150 participants)

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

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



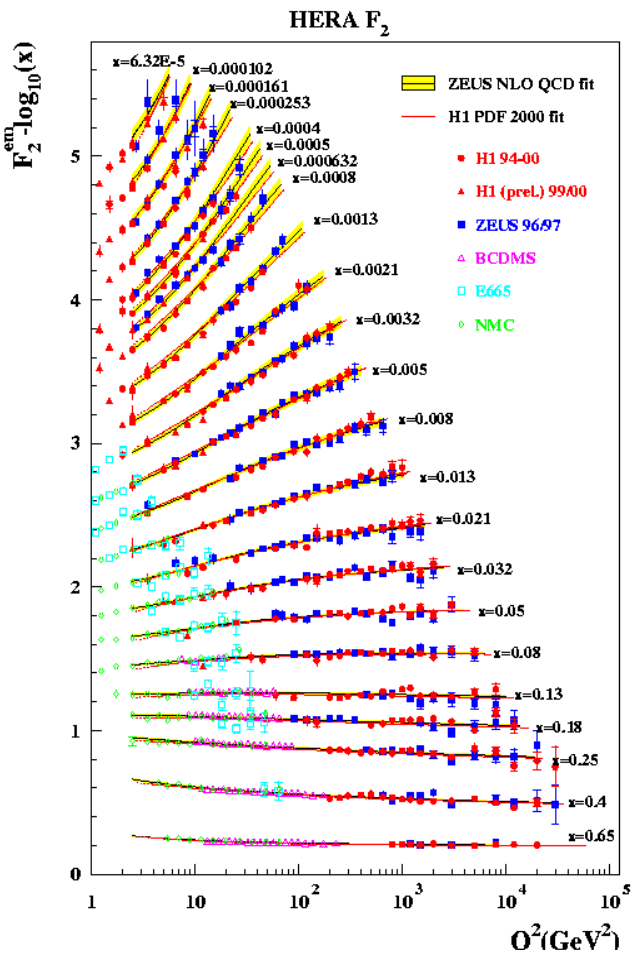
Joint DESY/CERN Report in 2005

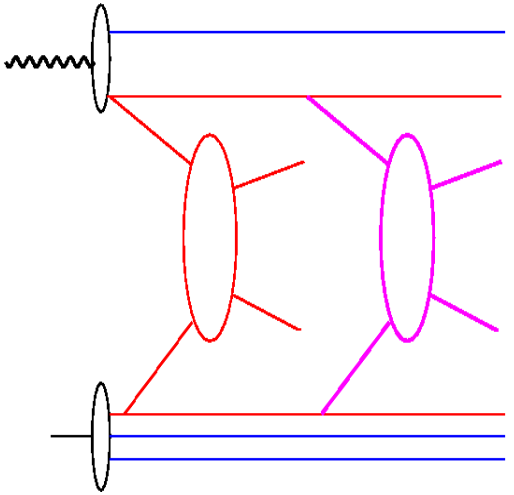
So, how did we do ?

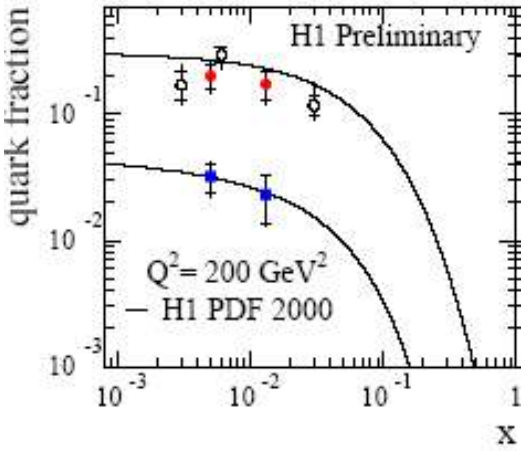
HERA 2 and the LHC

Where HERA2 investigations will influence the physics reach of LHC !

Topics of the workshop





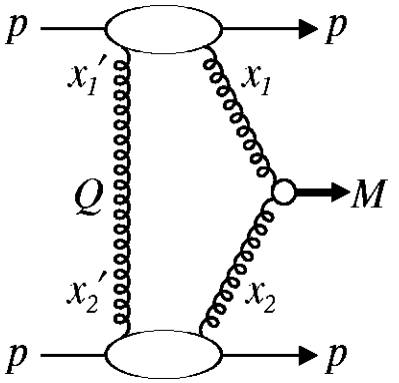


Multijets & final states
Underlying events,
un-integrated pdfs
LHC: event complexity,
jet x-section, Higgs

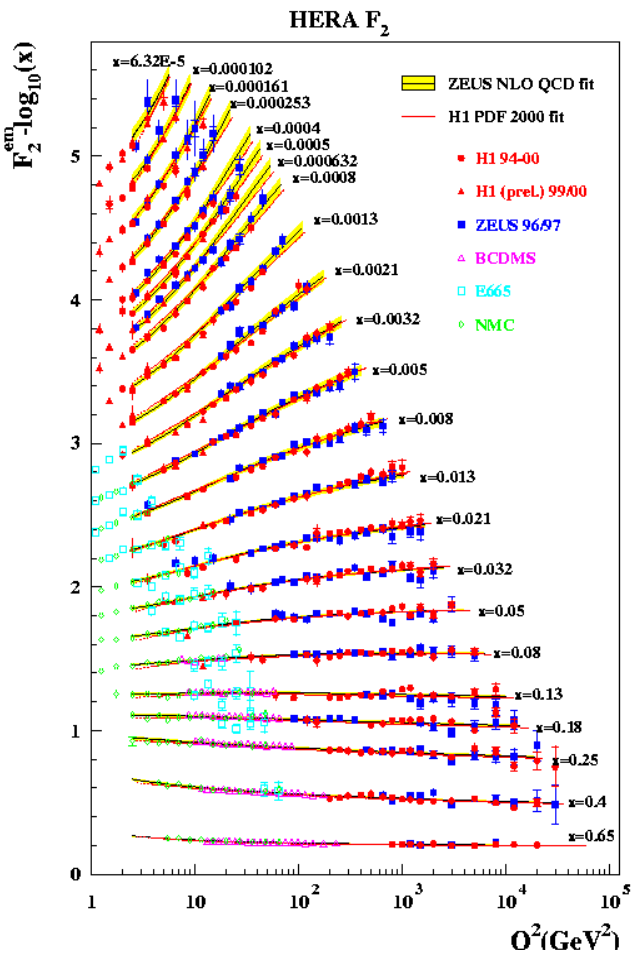
Heavy quarks:
B quark pdfs of the proton,
fragmentation fct, u-pdf
LHC: Higgs production

Structure functions and
parton distributions
LHC: cross sections/precision

Diffraction
LHC: exclusive
Higgs production



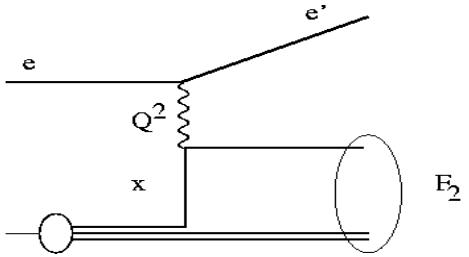
Topics of the workshop

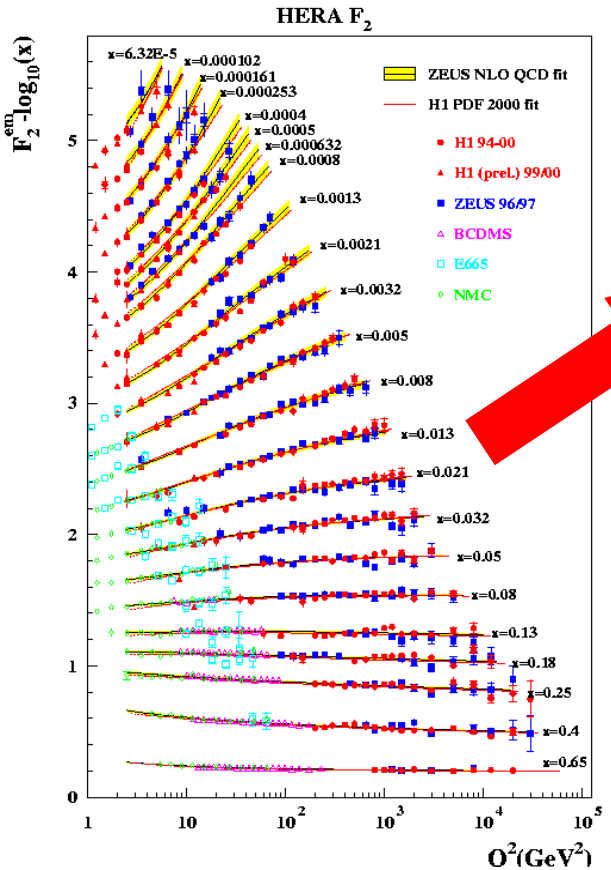


Structure functions and parton distributions
LHC: cross sections/precision

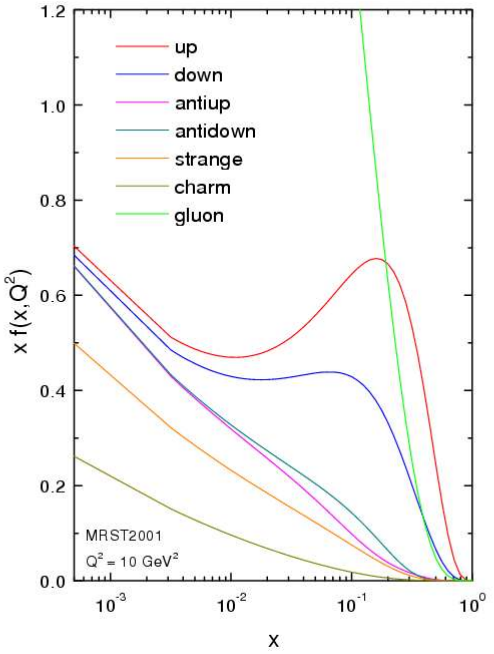
- Potential experimental and theoretical accuracy for various LHC processes (DY,W,Z,WW, +jet…)
  Precision measurements at LHC/luminosity determination?
  - Cross sections and distributions
  - Benchmark with LHC detector simulation
- Impact of PDF's on LHC measurements
  - Making the most of HERA data
  - 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 resumations 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



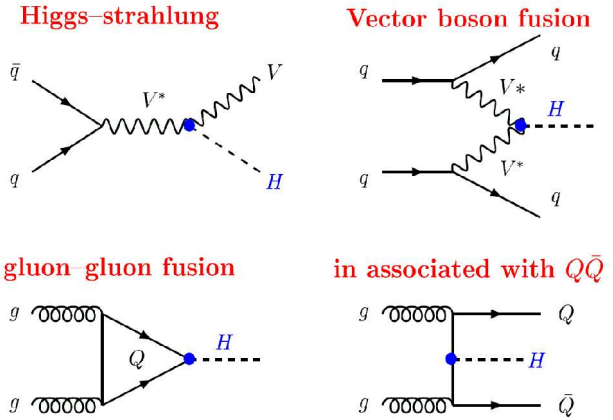


total x-section, F_2

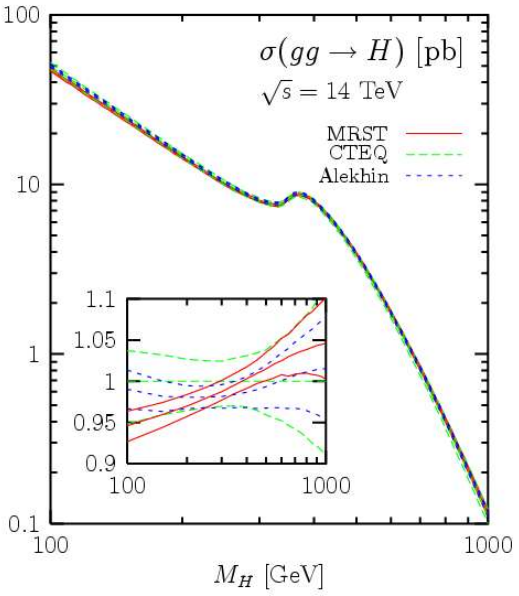


extract parton densities

from J. Stirling

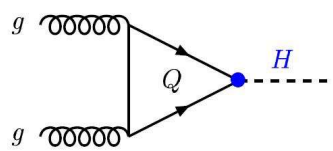


calculate Higgs prod



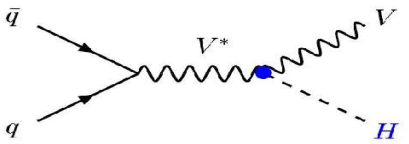
pdf uncertainty for Higgs prod.

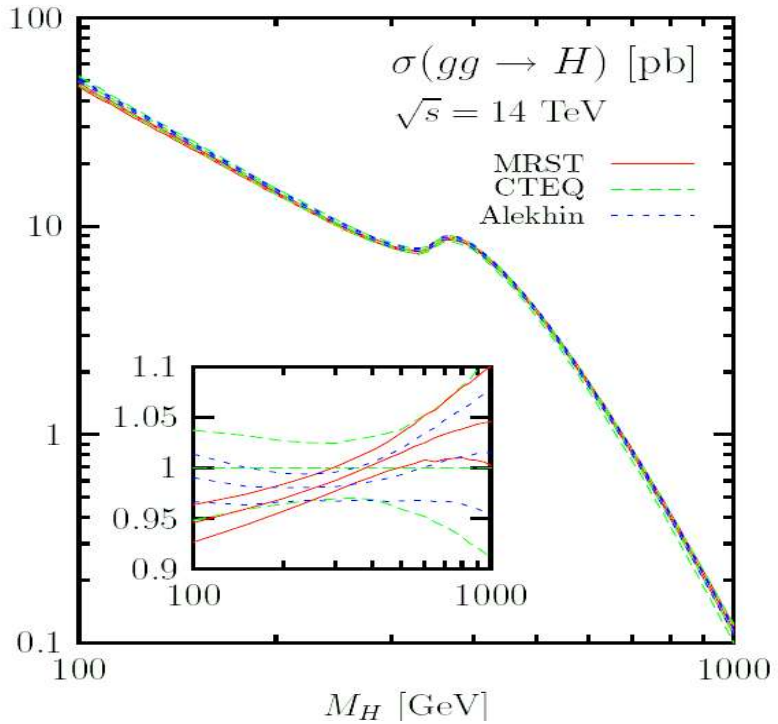
gluon–gluon fusion



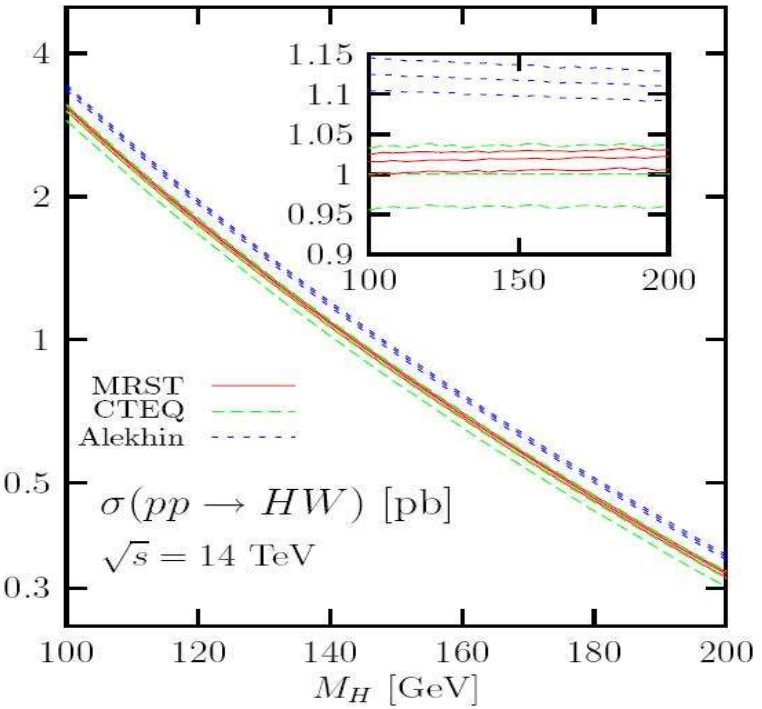
from Djouadi & Ferrag

Higgs–strahlung





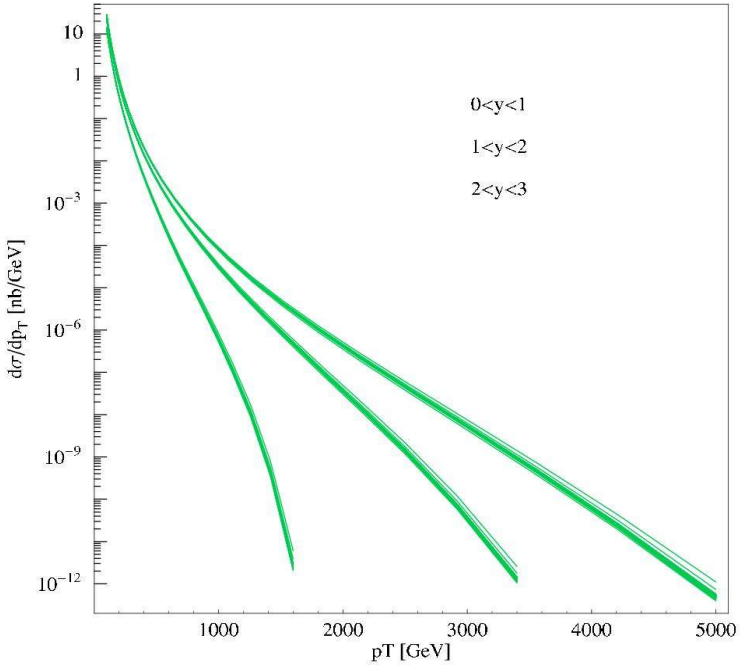
Gluon induced... ~ 10 %



Quark induced ~ 10 % difference

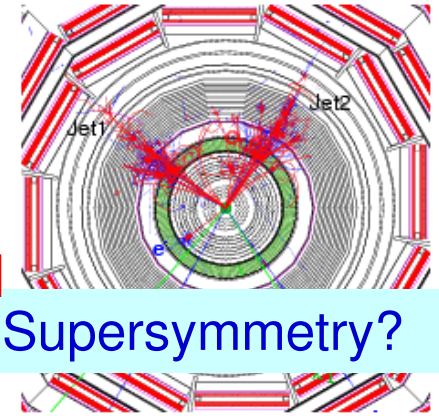
pdf do not agree within respective errors (J. Stirling) !!!!

Why precise pdfs for LHC

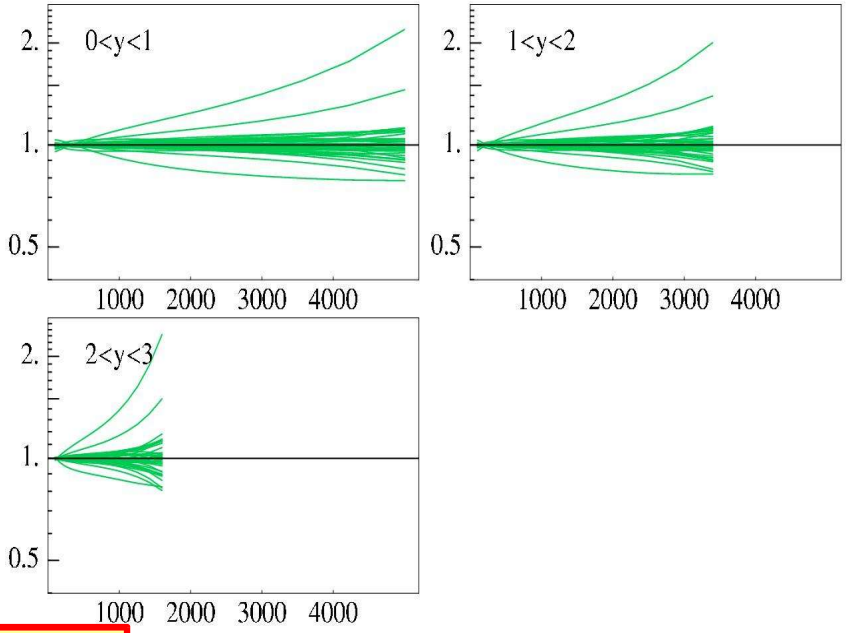


Signature for new physics
jet x-section

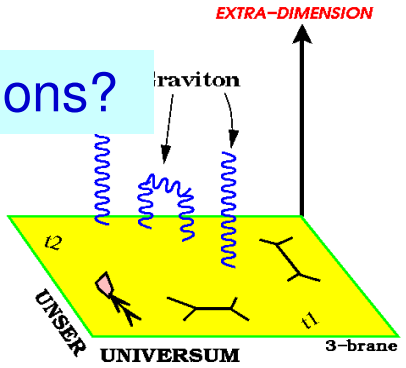
Discovery potential depend
on precise pdfs



Supersymmetry?



Extra Dimensions?



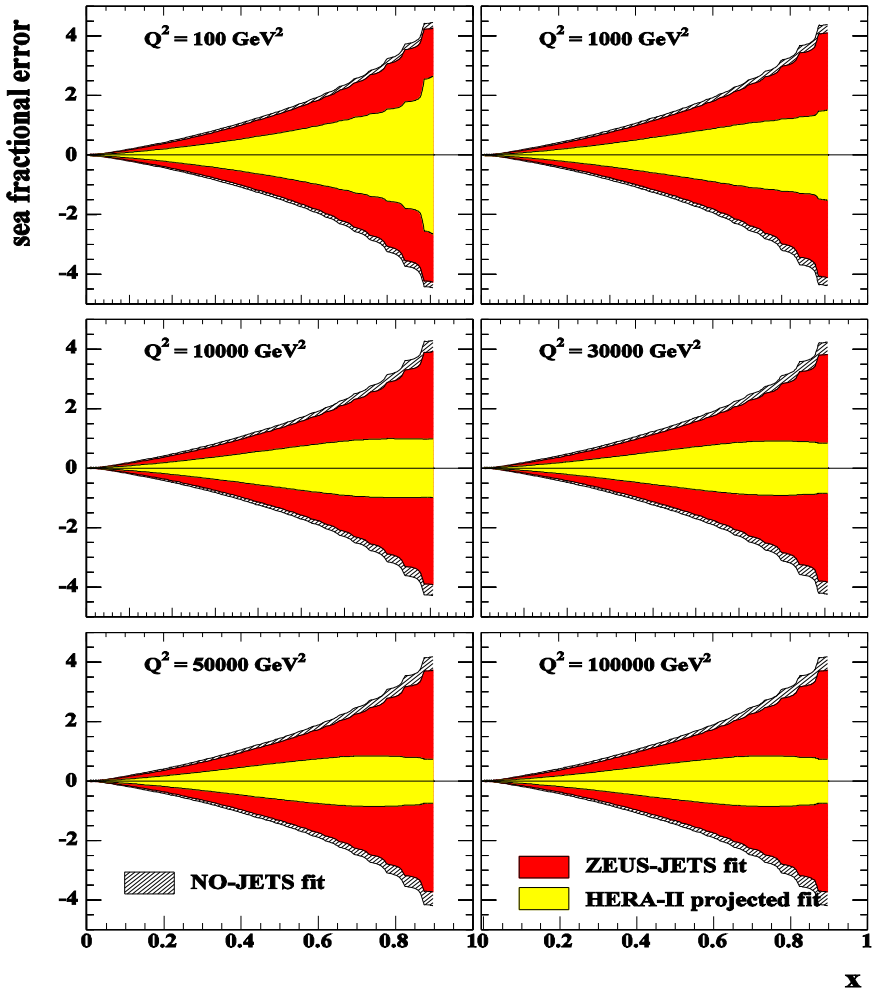
Precision determination of pdfs needed ...
understanding QCD is the key to new physics

pdf uncertainty: improvements

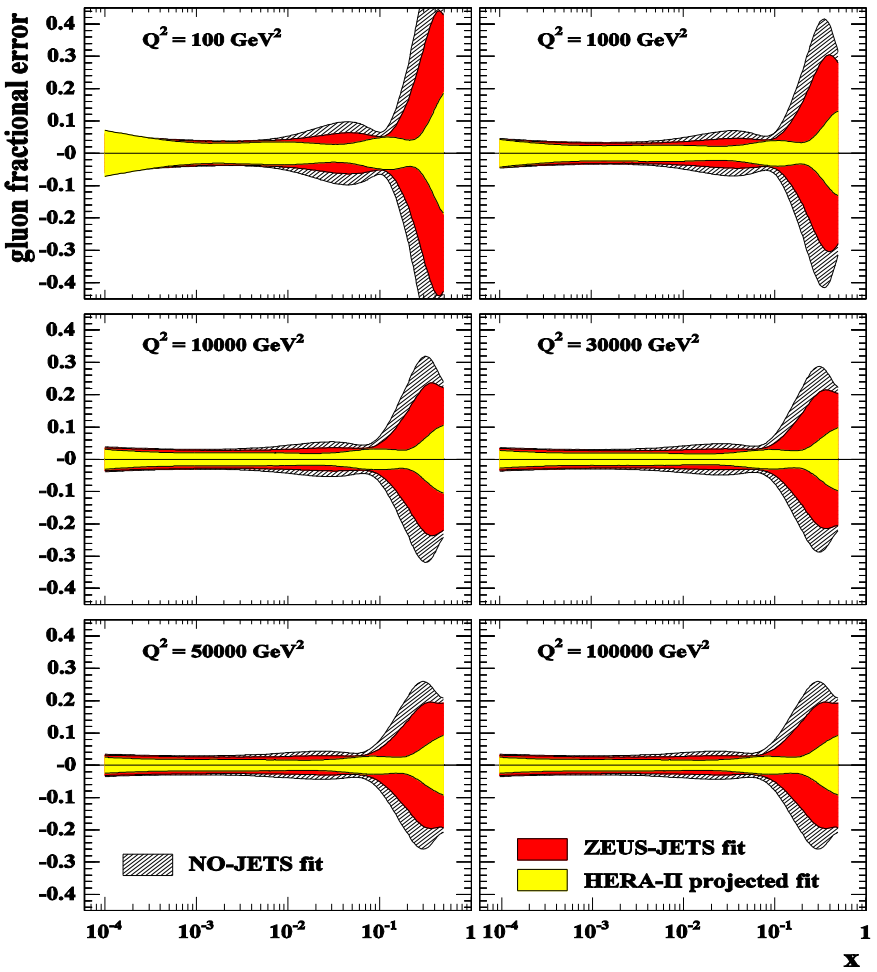
Using jets together with F_2 (at large Q^2)

from C. Gwenlan

Sea-quark uncertainties



gluon uncertainties



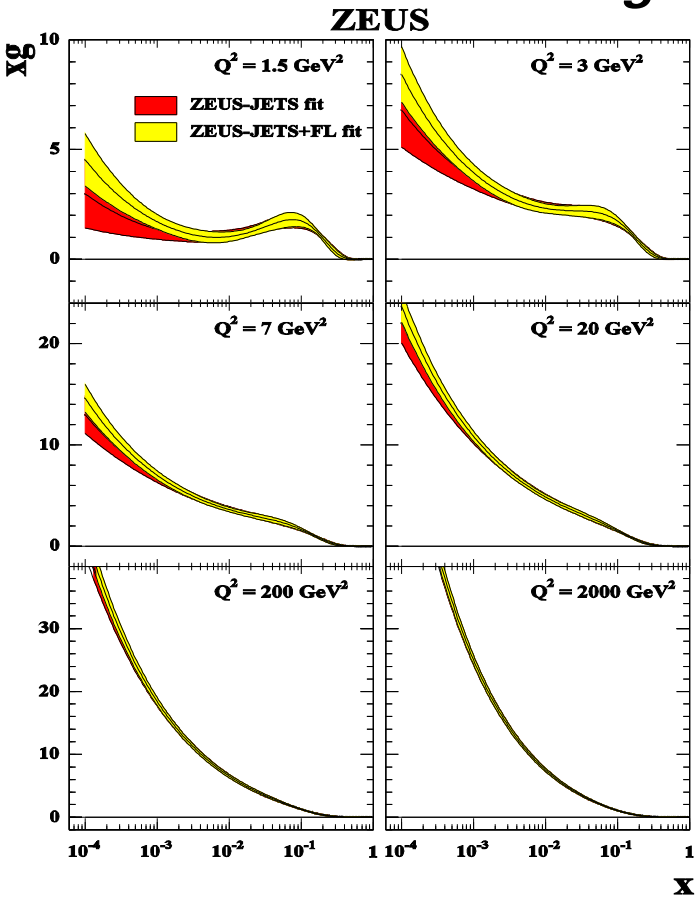
high statistics from HERA II helps (assumed 700 pb-1)

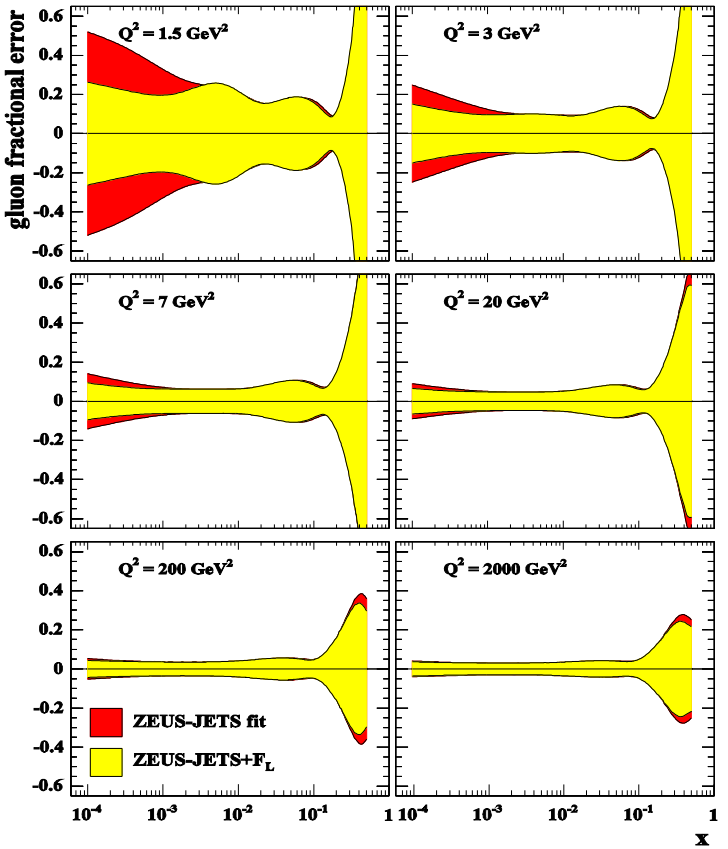
optimised cross section from jets help

HERA future measurements: F_L

The gluon distribution

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





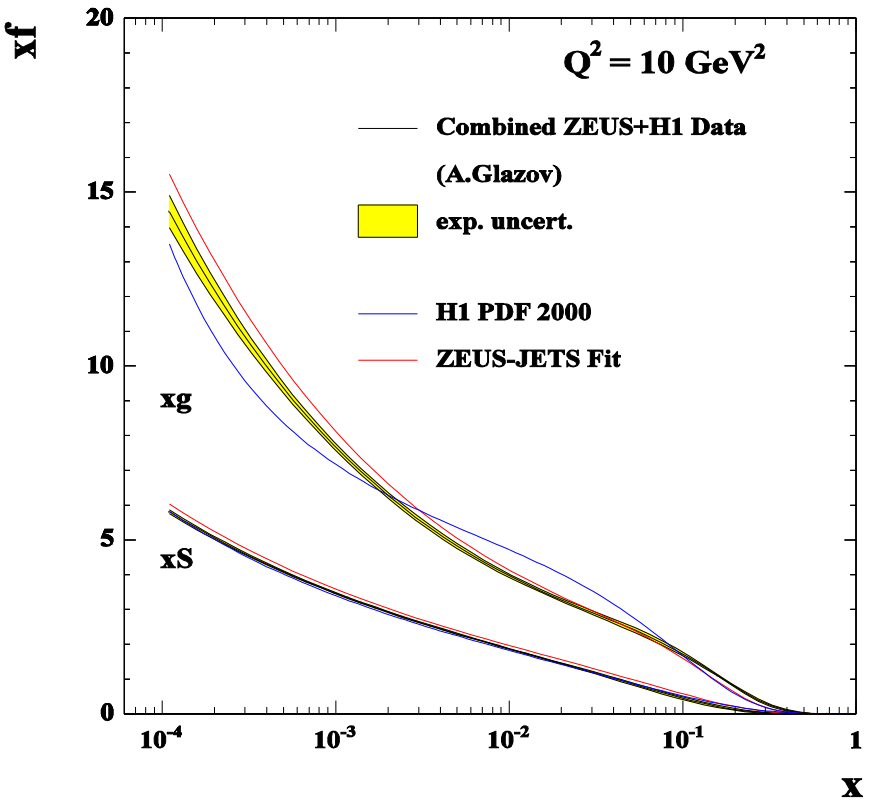
Precision measurement of F_L (3 lower p-energies, 3-5 pb-1)

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

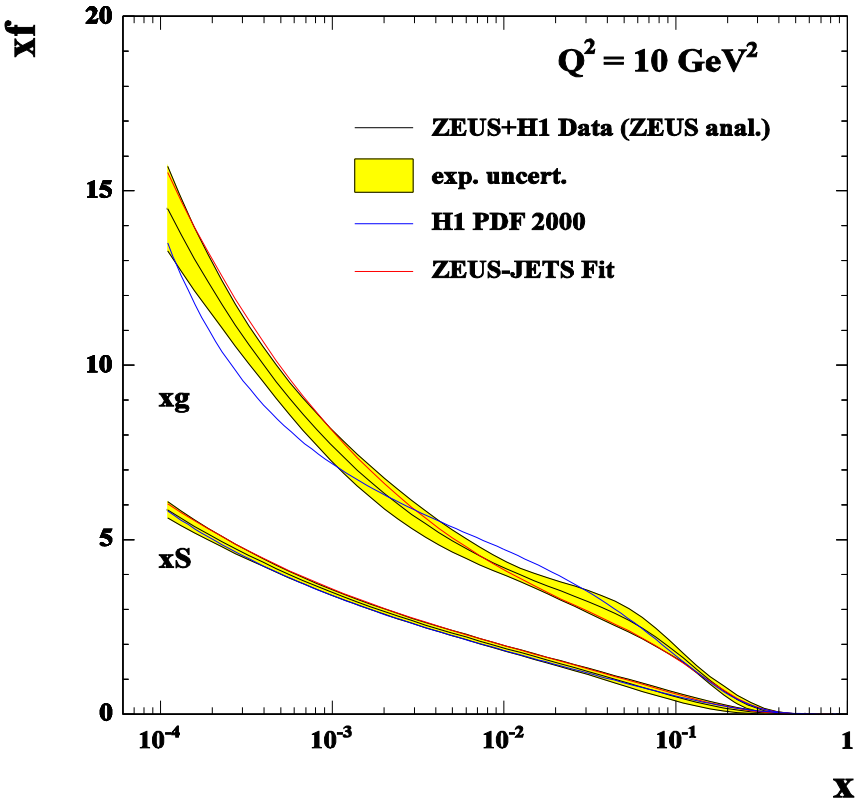
Average of HERA data

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 !!!!!

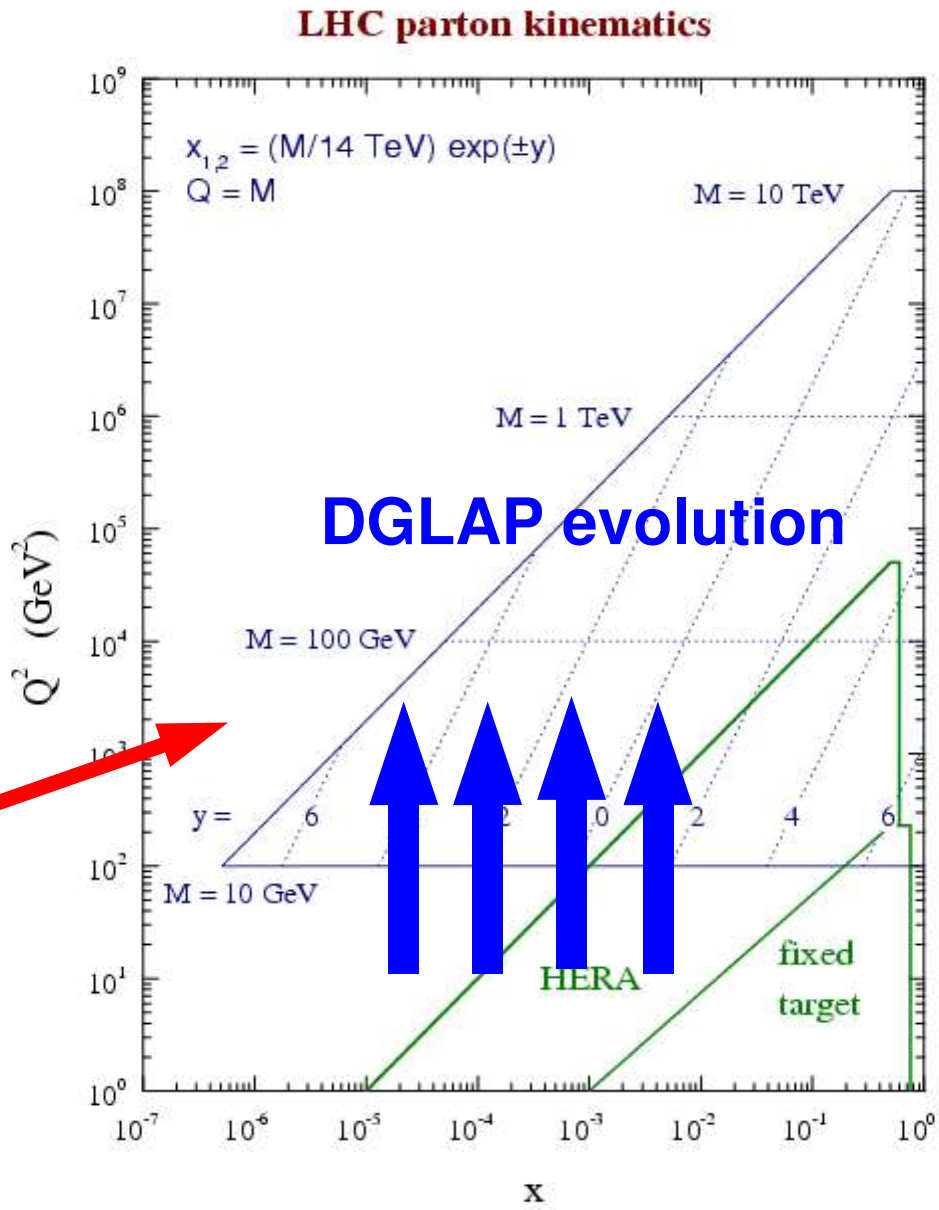
Is DGLAP all ????

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

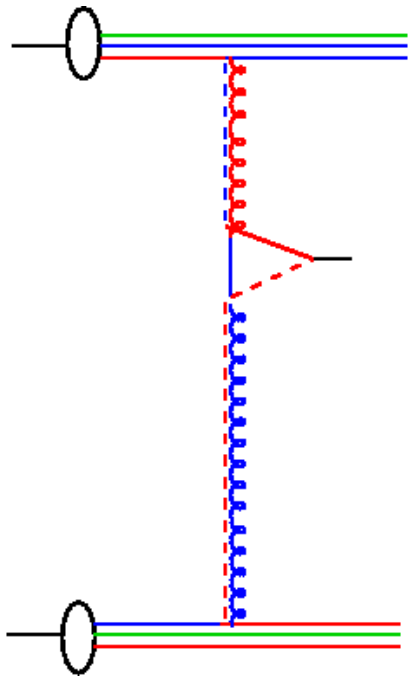
- remember surprises from HERA
- Is factorisation valid ?
- What about k_t-factorisation ?
- What about non-linear effects ?

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

from J. Stirling

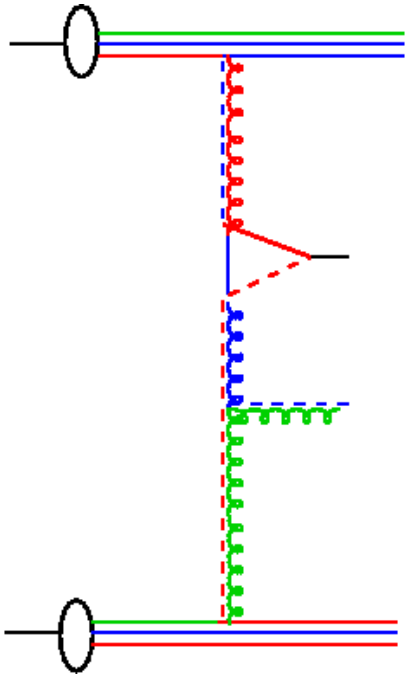


k_t effects at HERA and LHC



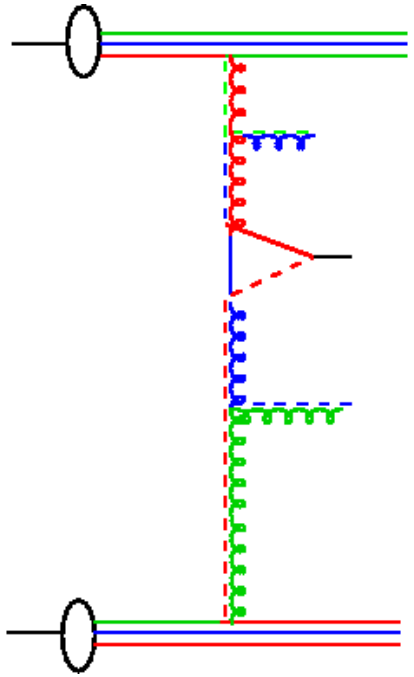
LO pretty bad

k_t effects at HERA and LHC



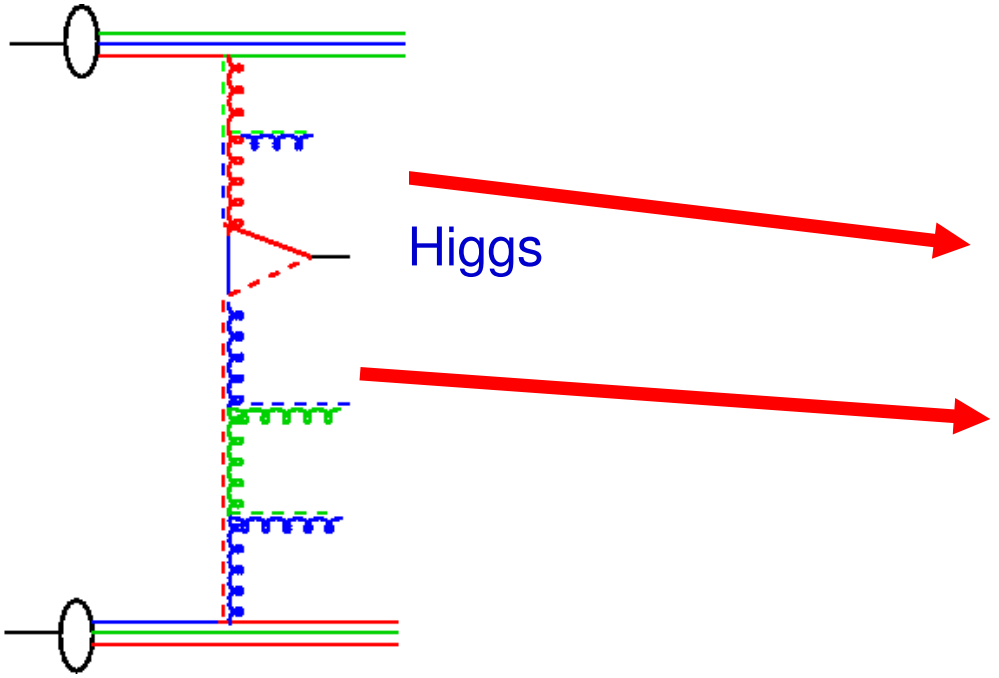
NLO better

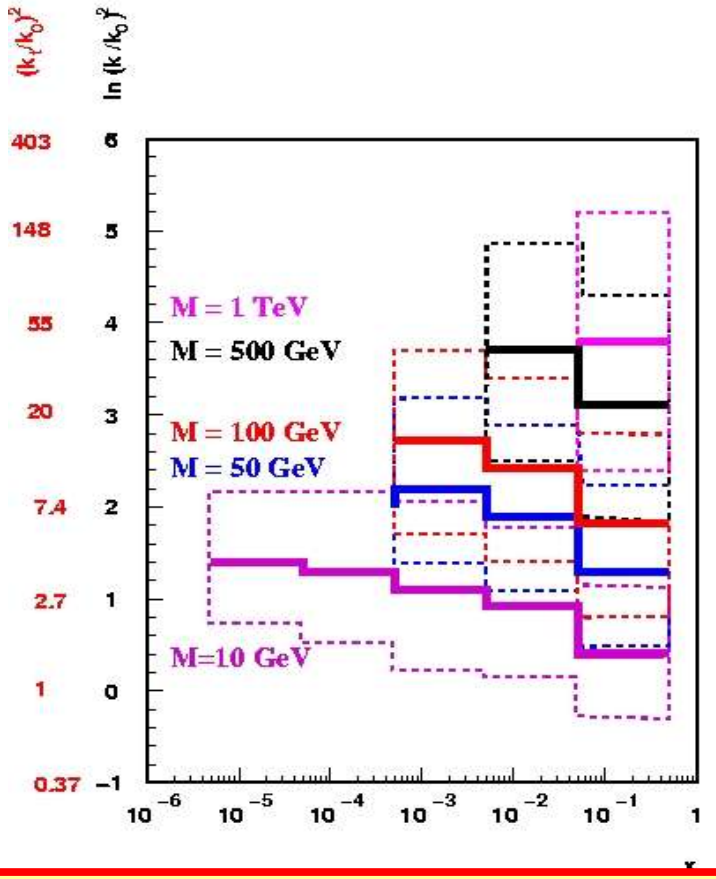
k_t effects at HERA and LHC



NNLO betttttter

k_t effects at HERA and LHC

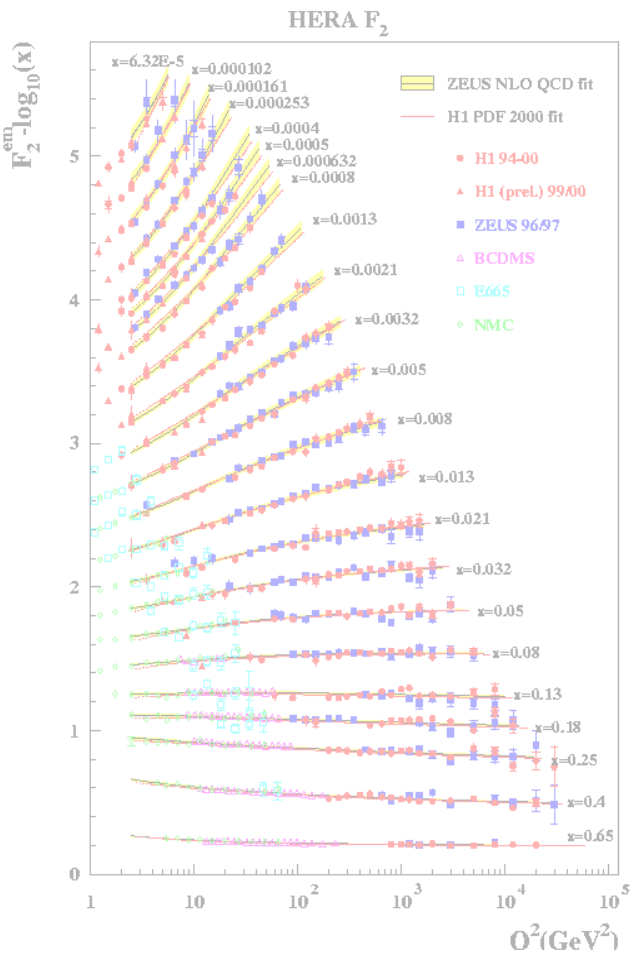


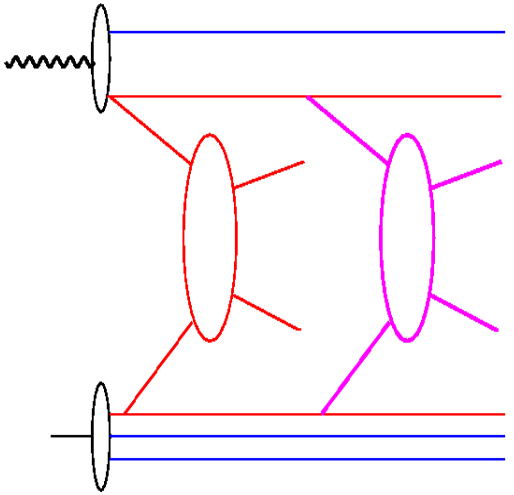


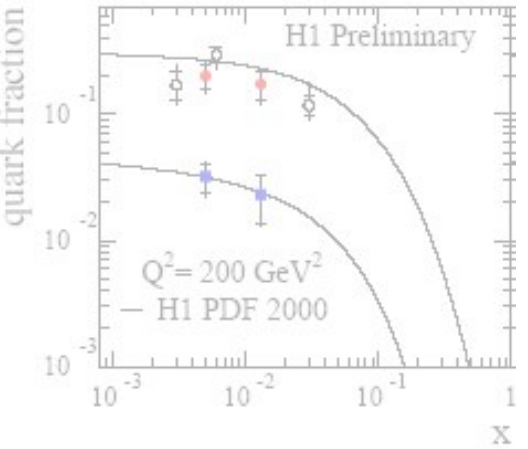
$\langle k_t \rangle$ large .... unintegrated parton PDFs will be needed

- 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

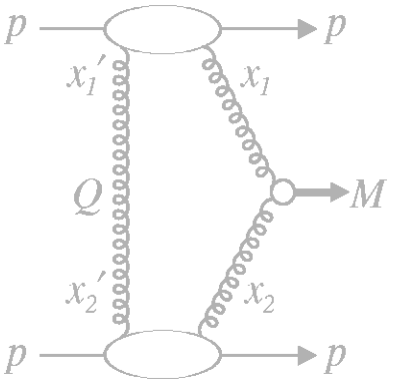






Multijets & final states
Underlying events,
un-integrated pdfs
LHC: event complexity,
jet x-section, Higgs

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

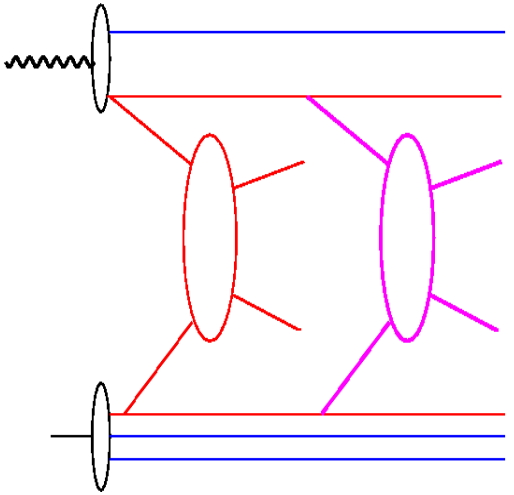
➔ need full final state

➔ BUT LO/NLO parton level insufficient and unphysical

...

NEW approaches:

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



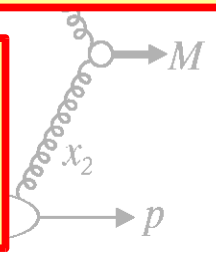
Multijets & final states
Underlying events,
un-integrated pdfs
LHC: event complexity,
jet x-section, Higgs

- 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 !

Structure f
parton dist
LHC: cross

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

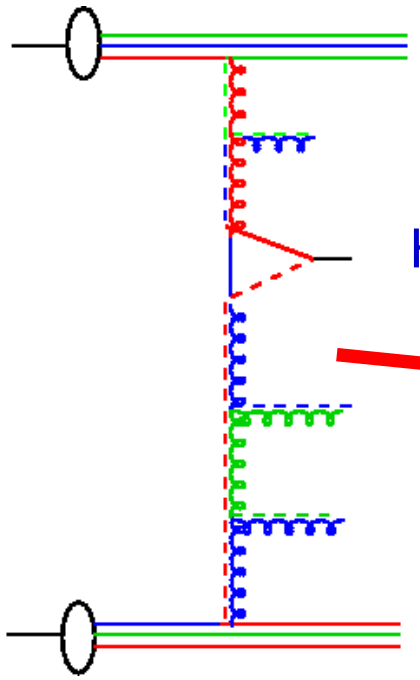


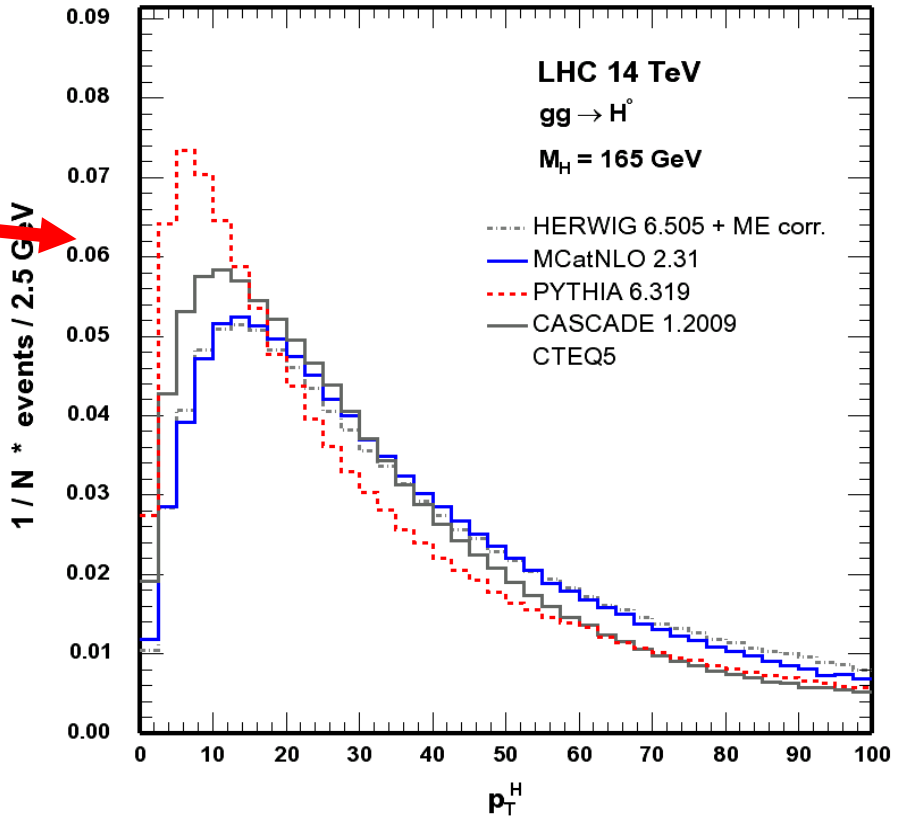
k_t effects at HERA and LHC

from G. Davatz

Do we understand the p_t spectrum of Higgs at LHC?

Important for the *gg* →Higgs → *WW* →*lν lν* to understand the jet-veto for *tt* suppression...

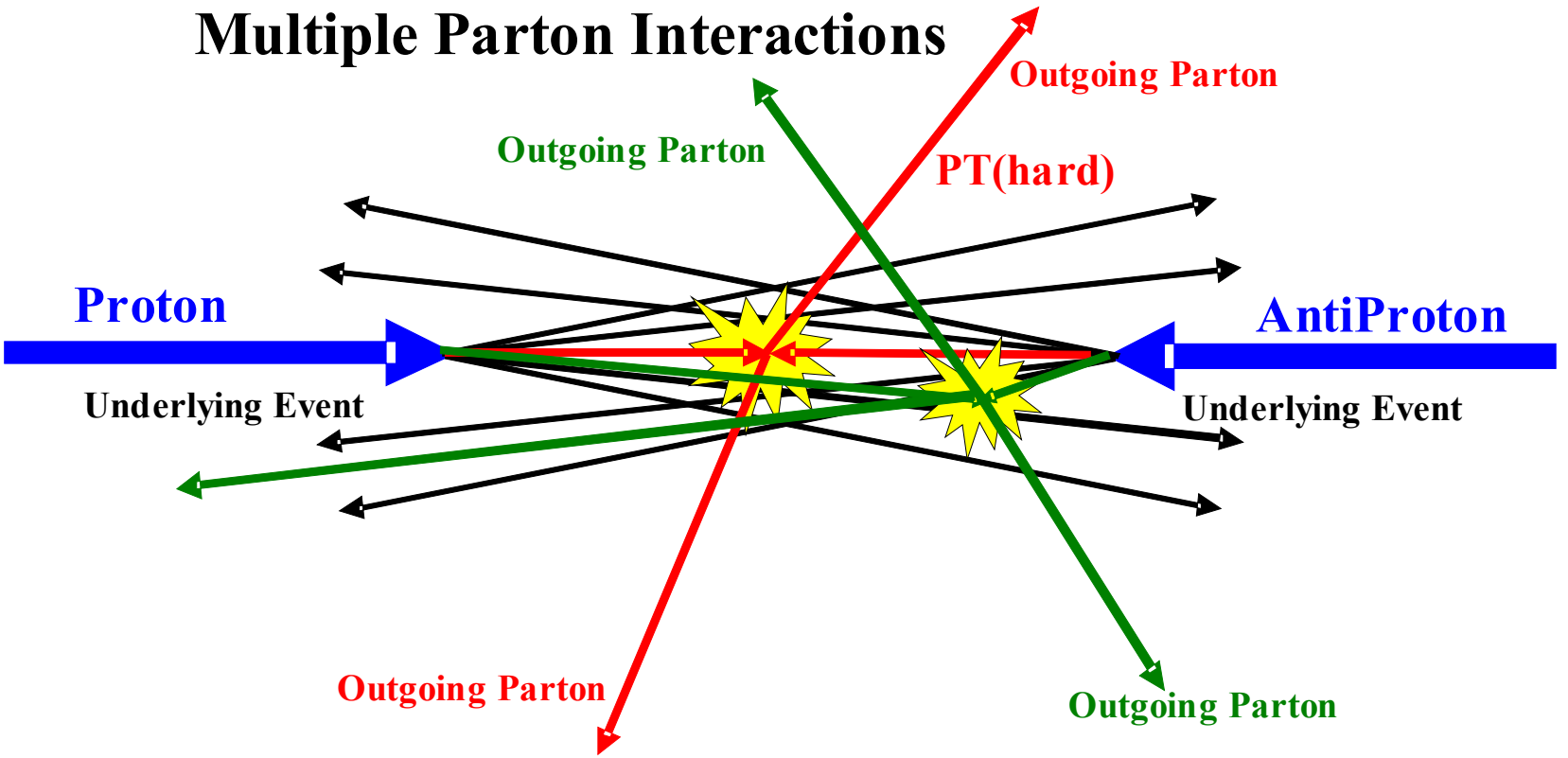




<k_t> large .... unintegrated parton PDFs will be needed
Need to be better constrained at HERA with final states

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

$$\sigma_{\rm hard}(p^2_{\perp \rm min}) = \int_{p^2_{\perp \rm min}} \frac{d\sigma_{\rm hard}(p^2_\perp)}{dp^2_\perp} dp^2_\perp$$

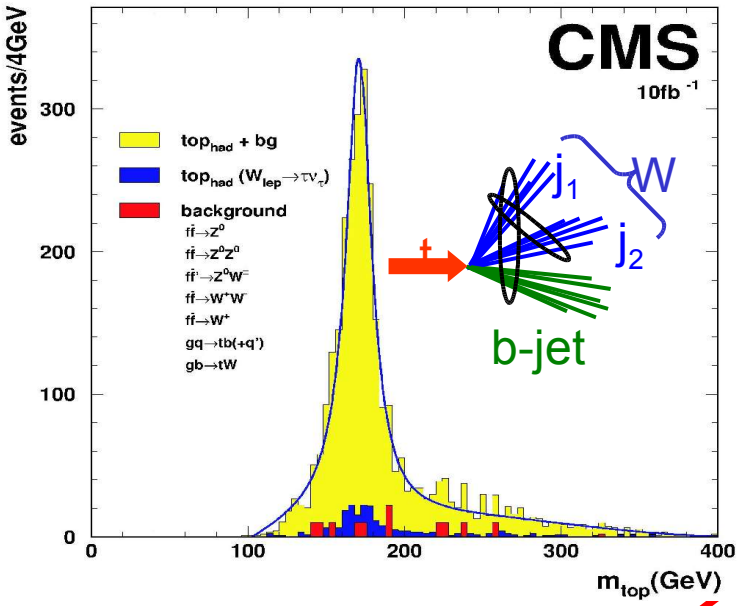
Diverges faster than $1/p^4_{\rm t\,min}$ as $p_{\rm t\,min}$ -> 0 and
exceeds eventually total inelastic (non-diffractive) cross section,
resulting in multiple scatterings in each event

Average number of scatterings per event is given by:

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

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

Multiple scattering and top mass

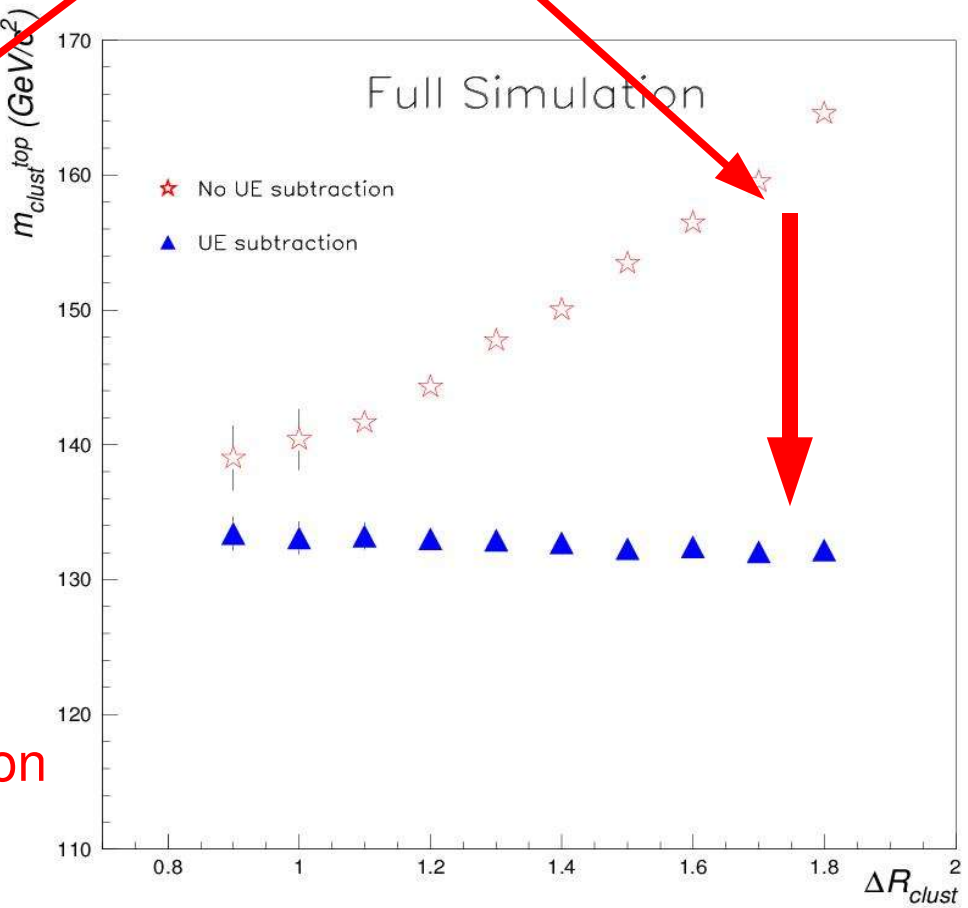


from M. Mangano

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	-

hep-ex/04003021

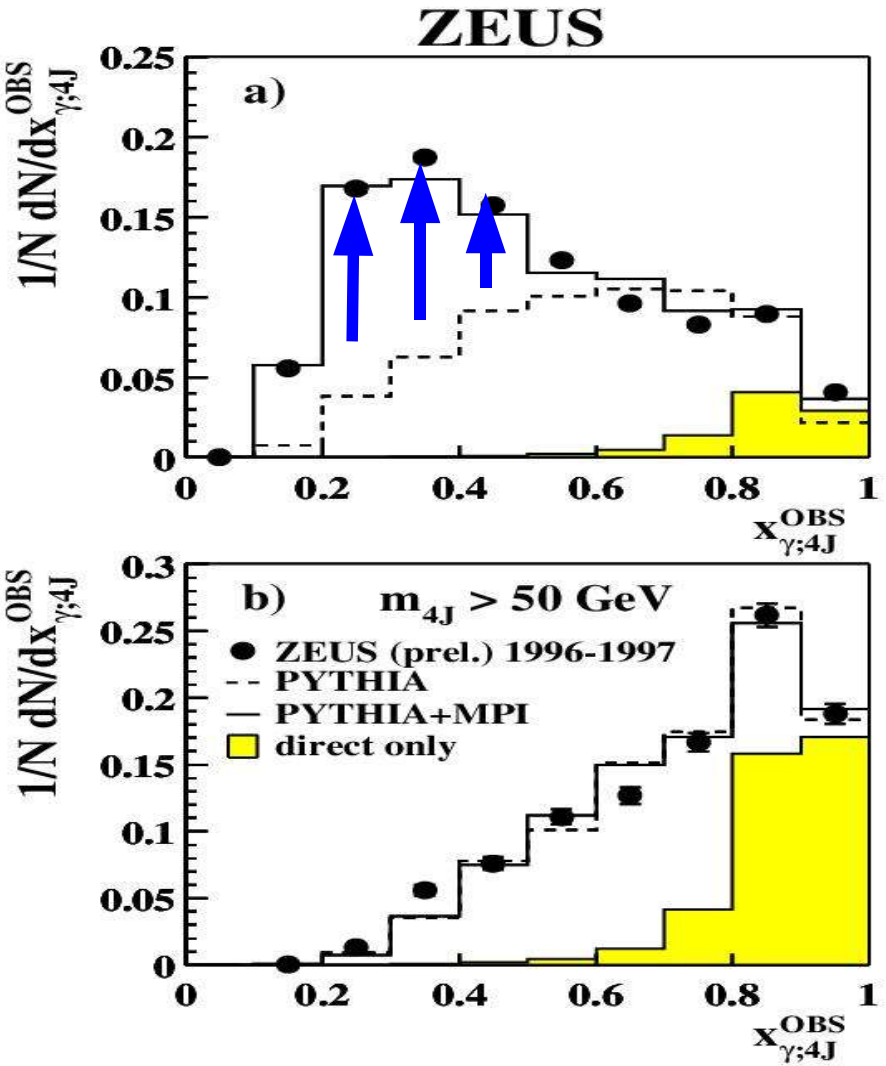
Are we sure ?



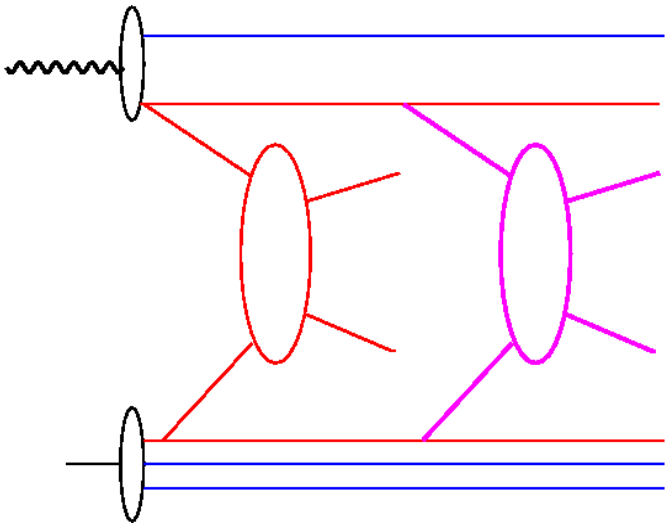
- Multiple scatterings
- Jet fragmentation properties, jet profiles
- Final state QCD radiation
- B-fragmentation

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

Multiple scatterings at HERA

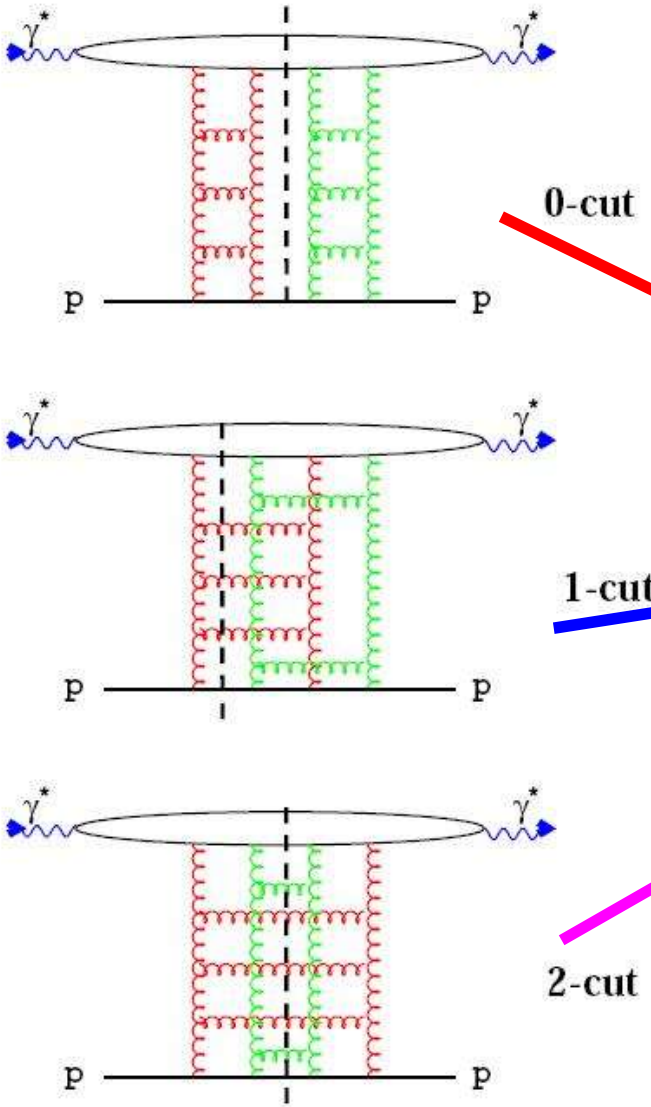


From G. Grindhammer



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

Towards understanding of MI



Bartels, Kowalski, Sabio-Vera

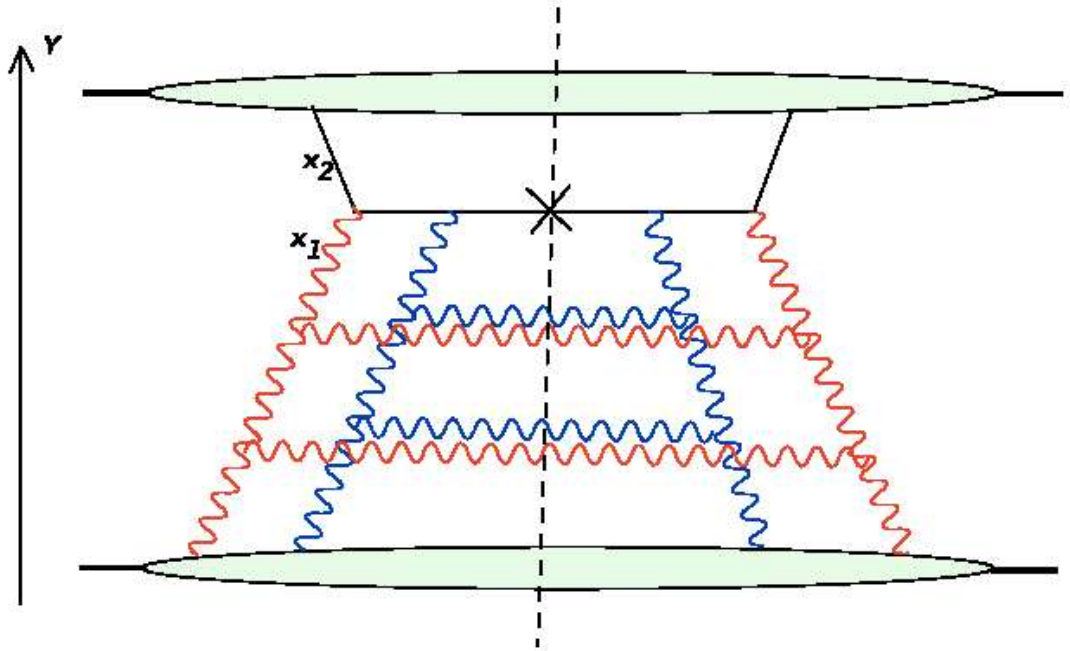
- Cutting rules (AGK) extended to QCD
- Relate diffraction, multiple scatterings and saturation
- All from the same amplitude, but different factors:
  - +1 Diffraction
  - - 4 Saturation
  - +2 Multiple Scatterings

- Extended now also to pp !!!!
- Much further work needed ...
- Towards the descriptions of *"everything"* !!!!!

Multiple Interactions

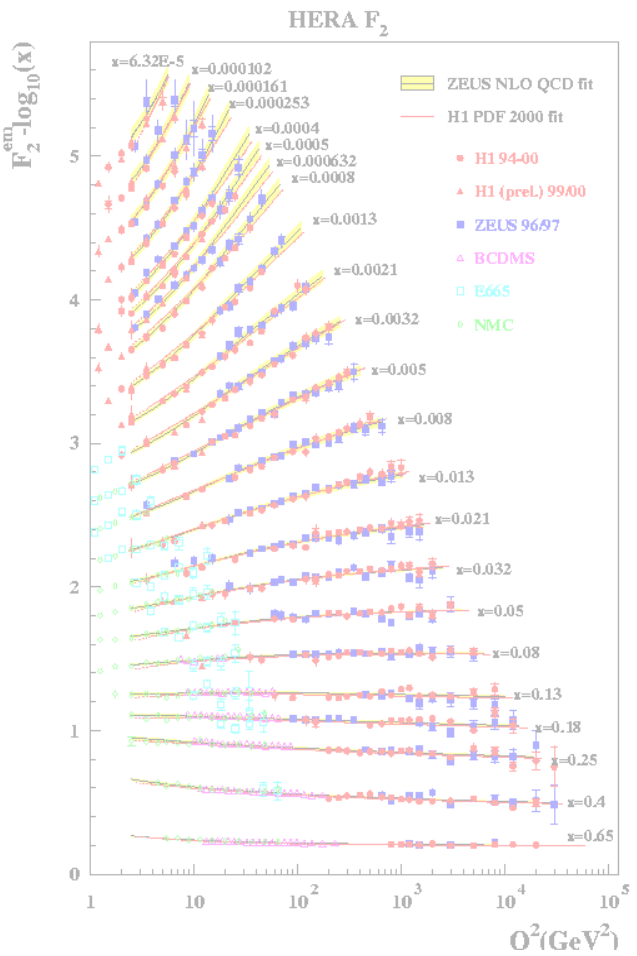
- Measure in forward region
- Observe Multiple Interactions - **Factorization breaking**

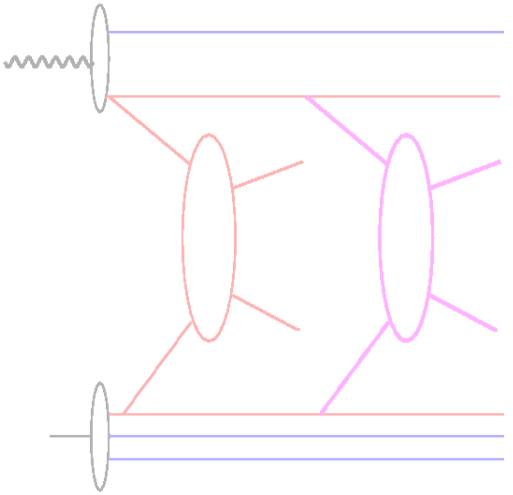
LHC: jet near the beam directions ($x_1 \ll x_2$)

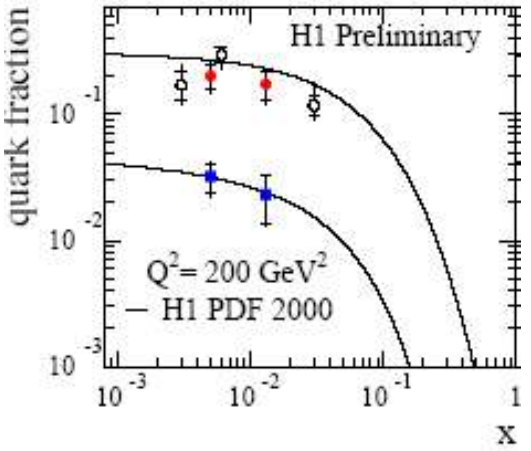


Multiple interaction across large rapidity intervals.

Topics of the workshop

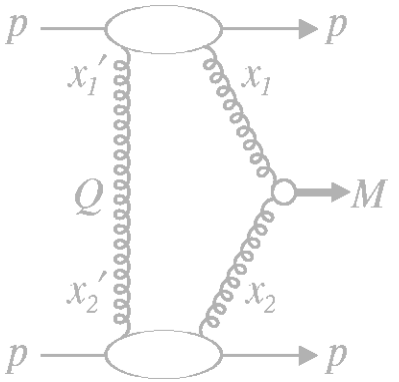






Multijets & final states
Underlying events,
un-integrated pdfs
LHC: event complexity,
jet x-section, Higgs

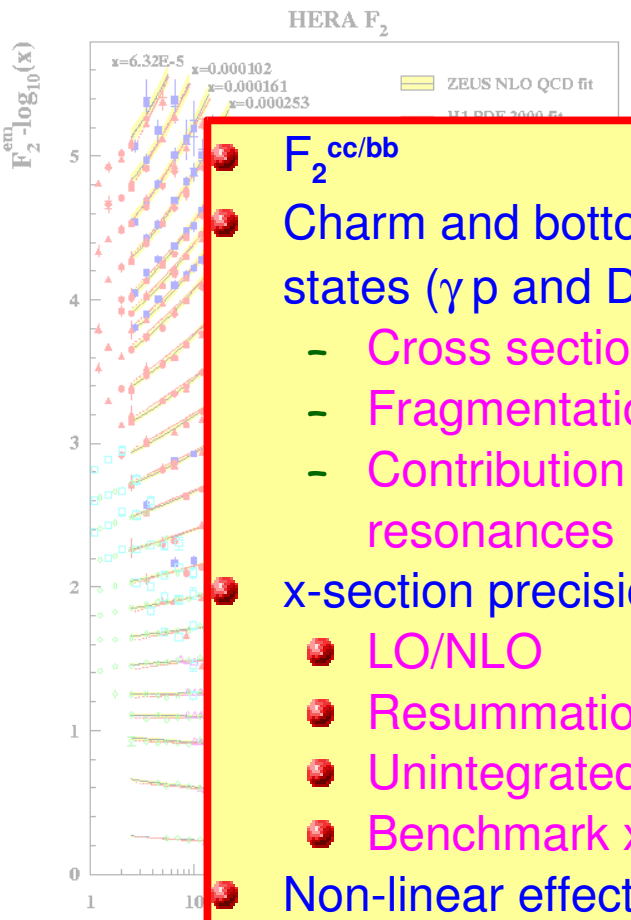
Heavy quarks:
B quark pdfs of the proton,
fragmentation fct, u-pdf
LHC: Higgs production

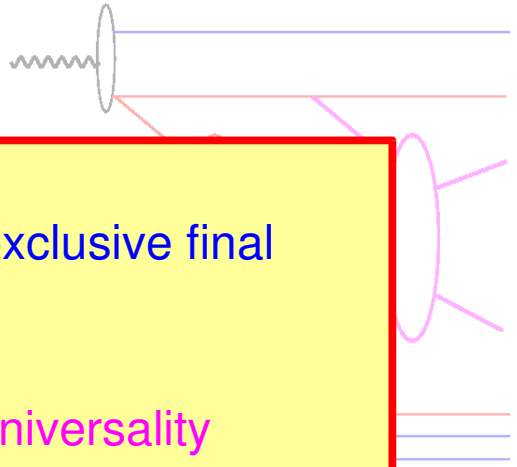


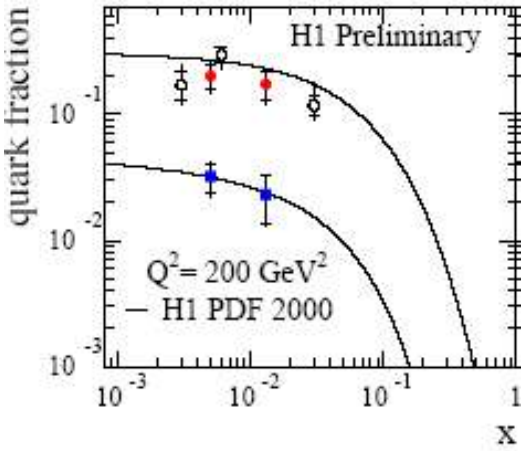
Structure functions and
parton distributions
LHC: cross sections/precision

Diffraction
LHC: exclusive
Higgs production

Topics of the workshop

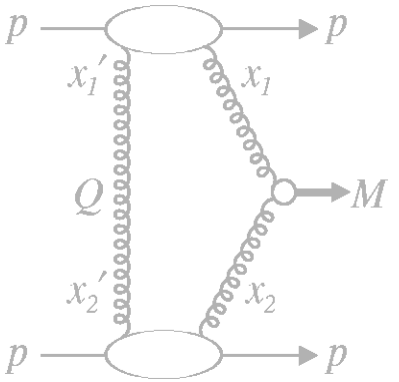






- $F_2^{cc/bb}$
- Charm and bottom exclusive final states (γ p and DIS)
  - Cross sections
  - Fragmentation universality
  - Contribution from higher charm resonances
- x-section precision
  - LO/NLO
  - Resummation
  - Unintegrated pdfs
  - Benchmark x-section
- Non-linear effects/saturation

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



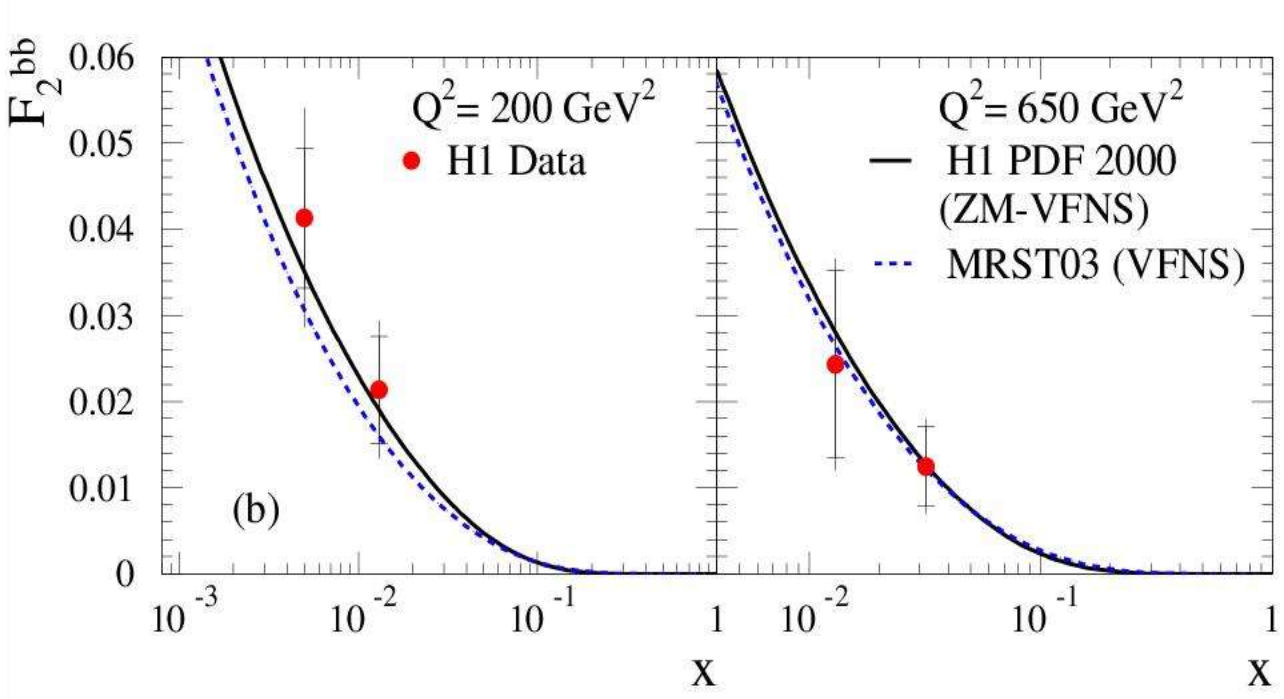
Structure functions and parton distributions
LHC: cross sections/precision

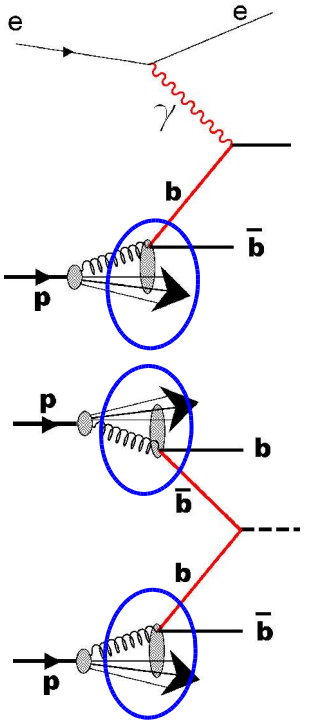
Diffraction
LHC: exclusive Higgs production

F_2^b at large Q^2

From P.Thompson, A. Geiser

- Current H1 (HERA I) analysis: first measurement





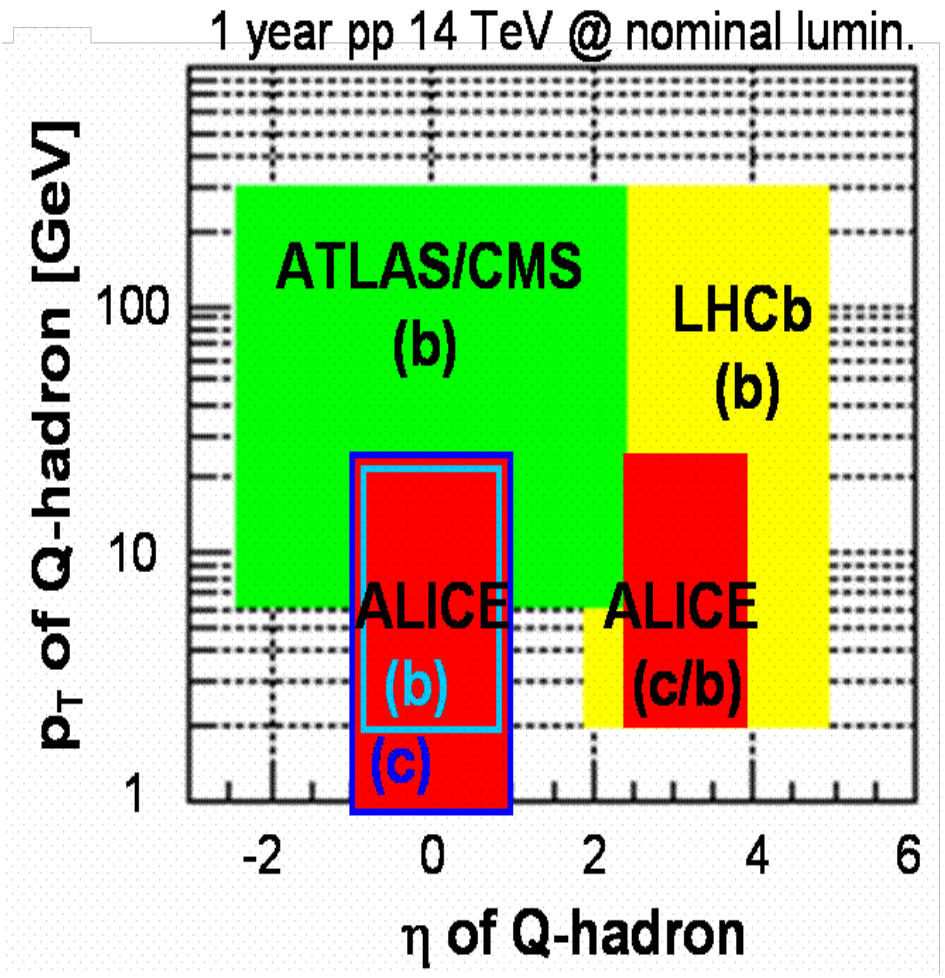
- HERA II analysis (expected)
  - more statistics (> factor 10), larger kinematic range, two experiments

-> test „b content of proton“ (at $Q^2 >> m_b^2$) much more precisely

relevant for many LHC processes!

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

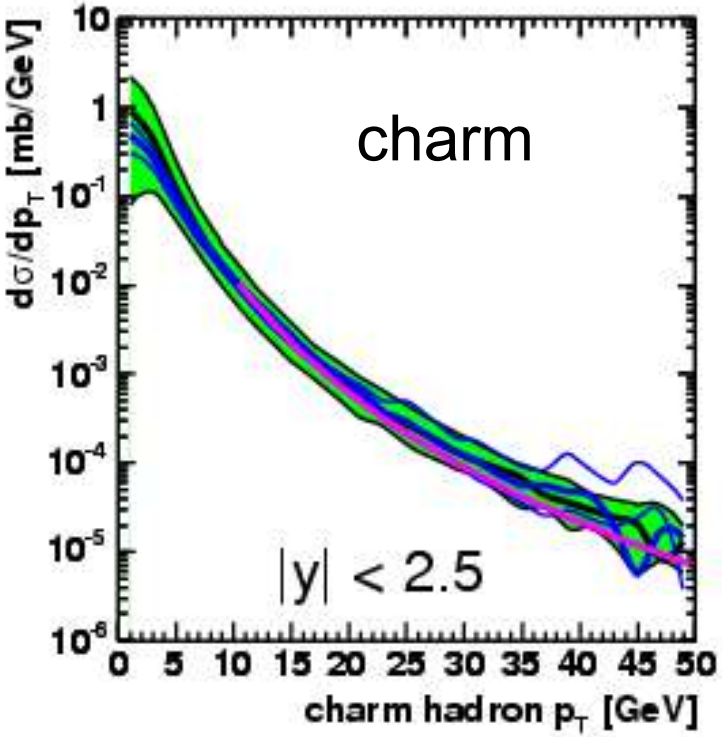
Heavy flavors at LHC



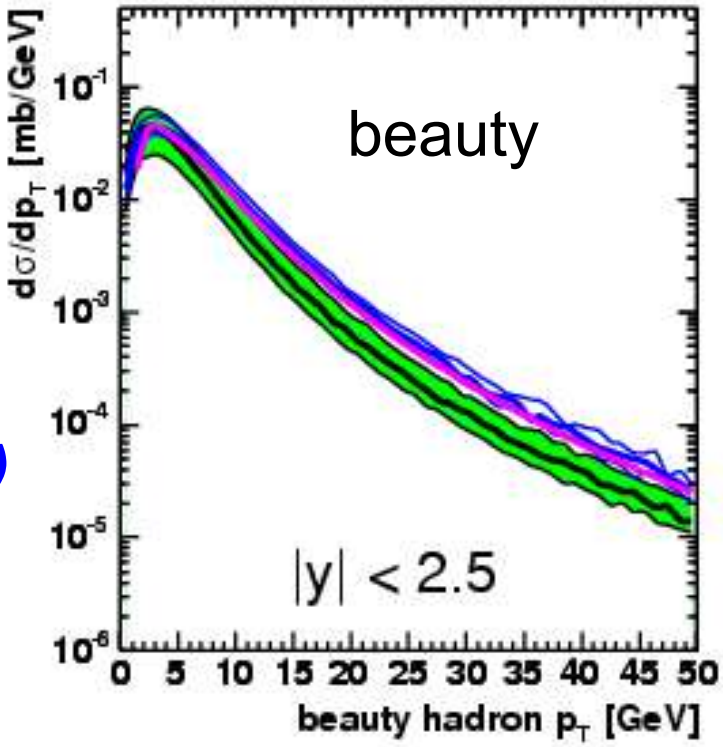
- ATLAS/CMS at large p_t
- ALICE/LHCb extends to smaller p_t
  - interesting and challenging region
- Benchmark x-sections:
  - Collinear factorization:
    - Massless vrs massive
    - Matched resummed
    - LO + PS MCs
  - k_t-factorization
  - MC@NLO
- compare predicts for HERA γ-p and DIS and LHC
- 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)



MNR band
FONLL central
CASCADE (CCFM)

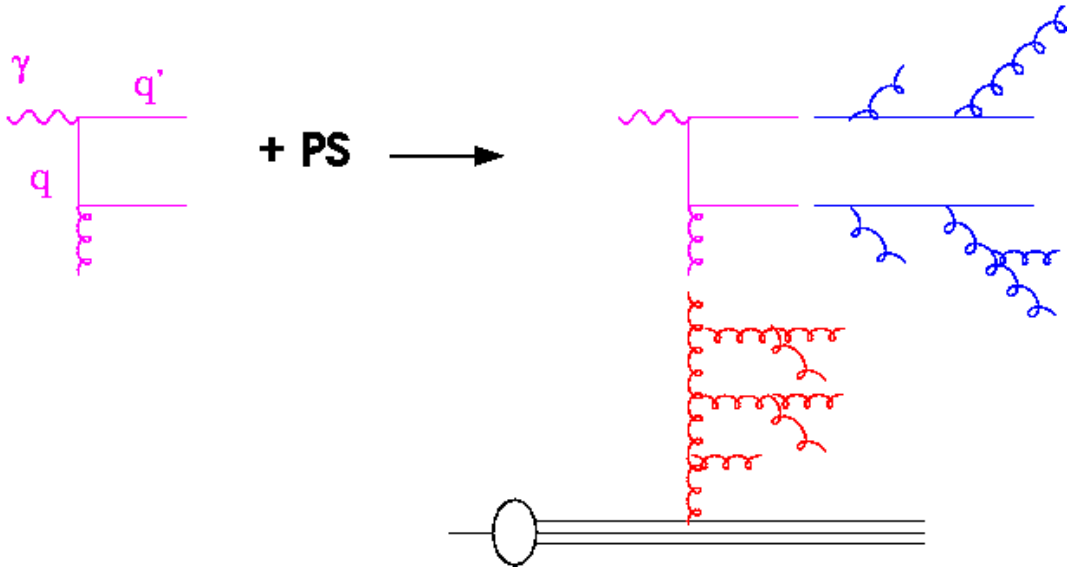


CASCADE agrees better with **FONLL**. But …?
here **CASCADE** uses Peterson FF with same ε as in **MNR**

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

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

The problem of collinear factorization



- **Collinear approach:** incoming/outgoing partons are on mass shell

  $(\gamma+q)^2 = q'^2$, $-Q^2 + x\,y\,s = 0$ ➔ $x = Q^2/(ys)$

- **BUT** final state radiation:

  $(\gamma+q)^2 = q'^2$, $-Q^2 + x\,y\,s = m^2$ ➔ $x = (Q^2+m^2)/(ys)$

- **AND** initial state radiation:

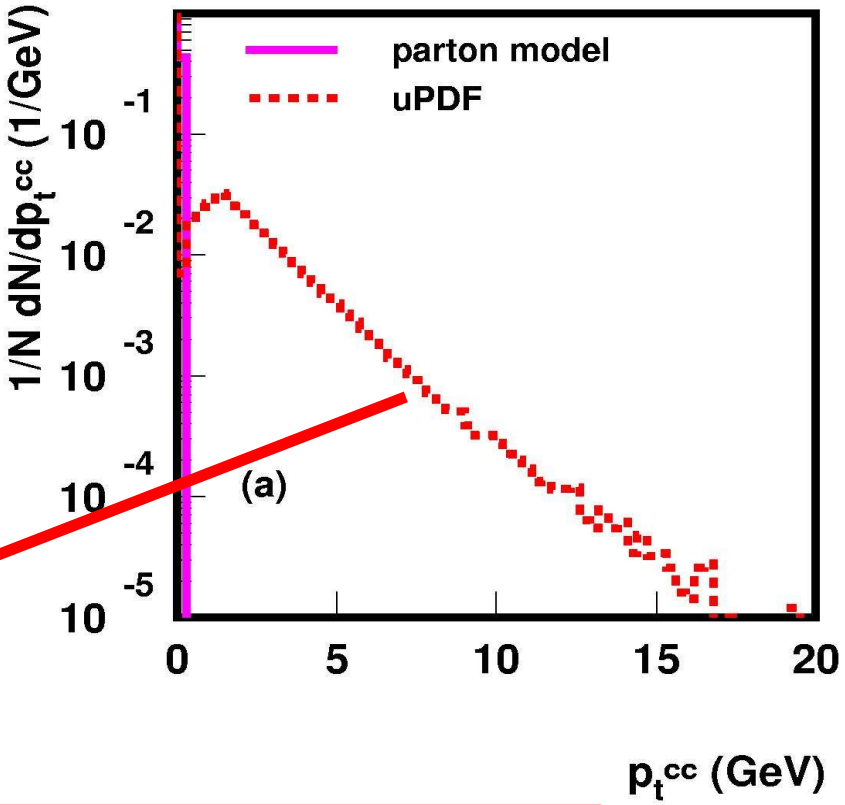
  $(\gamma+q)^2 = q'^2$, $-Q^2 + x\,y\,s + q^2 = 0$ ➔ $x = (Q^2-q^2)/(ys)$

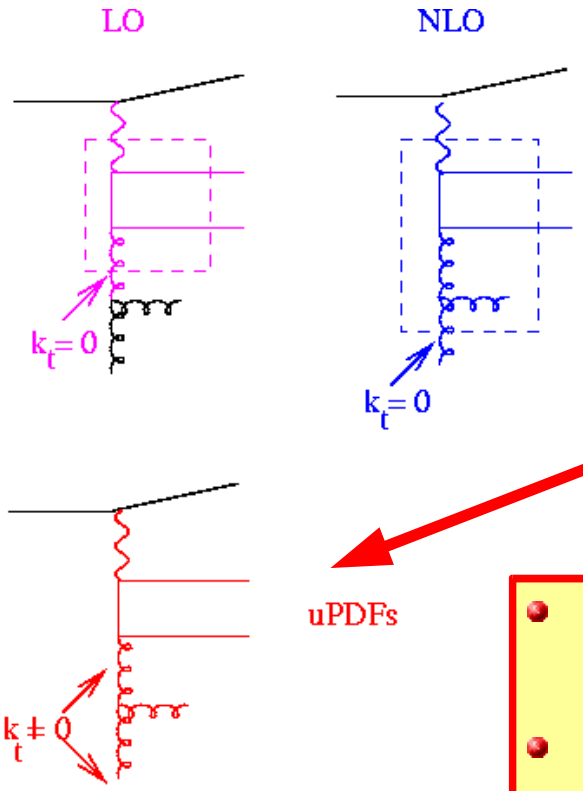
- **Collinear approach: $q'^2 = q^2 = 0$, order by order ....**
- Well known.... since years....
- NLO corrections... better treatment of kinematics...

The need for unintegrated PDFs

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

J. Collins, H. Jung





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

Deviations: non-linear effects ?

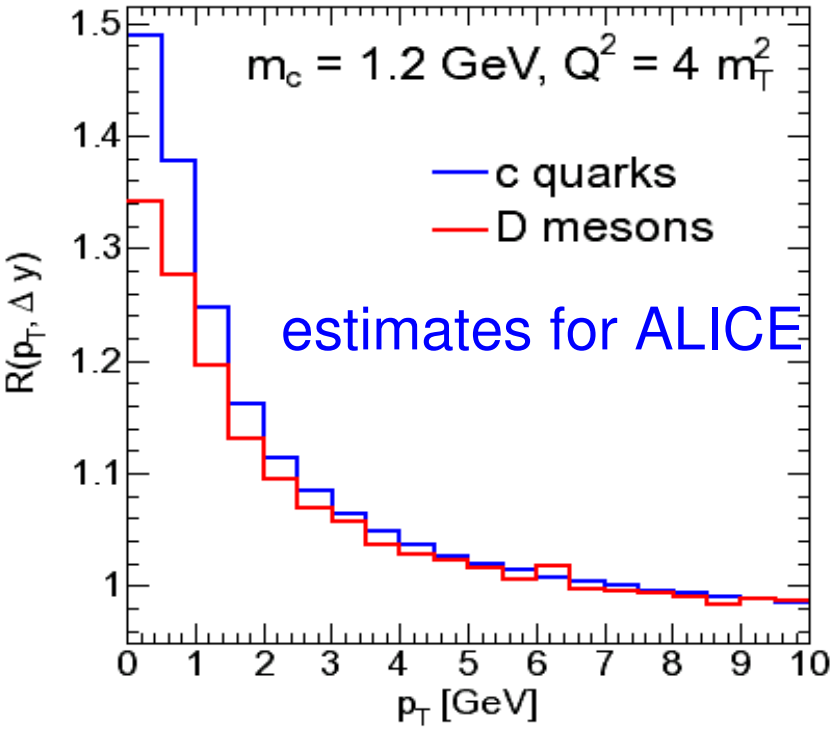
$$\frac{\partial x g(x,Q^2)}{\partial \log Q^2} = \frac{\partial x g(x,Q^2)}{\partial \log Q^2}\Big|_{\mathrm{DGLAP}} - \frac{9\pi}{2}\frac{\alpha_s^2}{Q^2}\int_x^1 \frac{dy}{y} y^2 G^{(2)}(y,Q^2)$$

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

- 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 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.

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

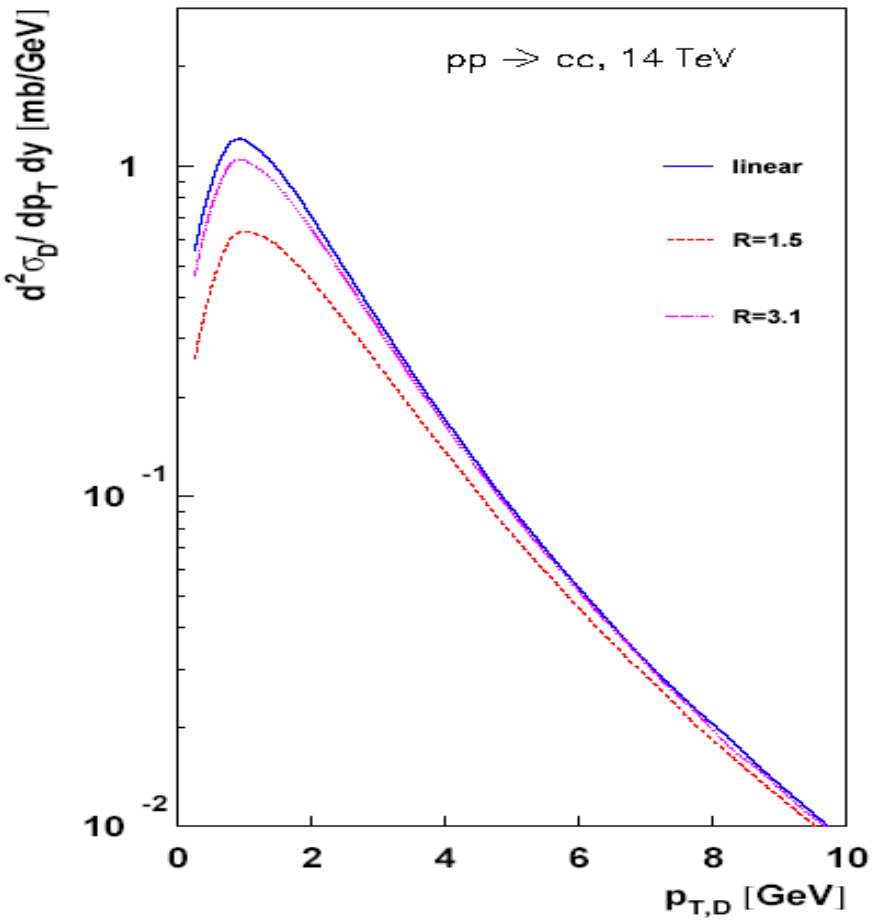
$$\tilde{f}^{(0)}(x,k^2) \longrightarrow \text{input}$$

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

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

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

estimates for ALICE

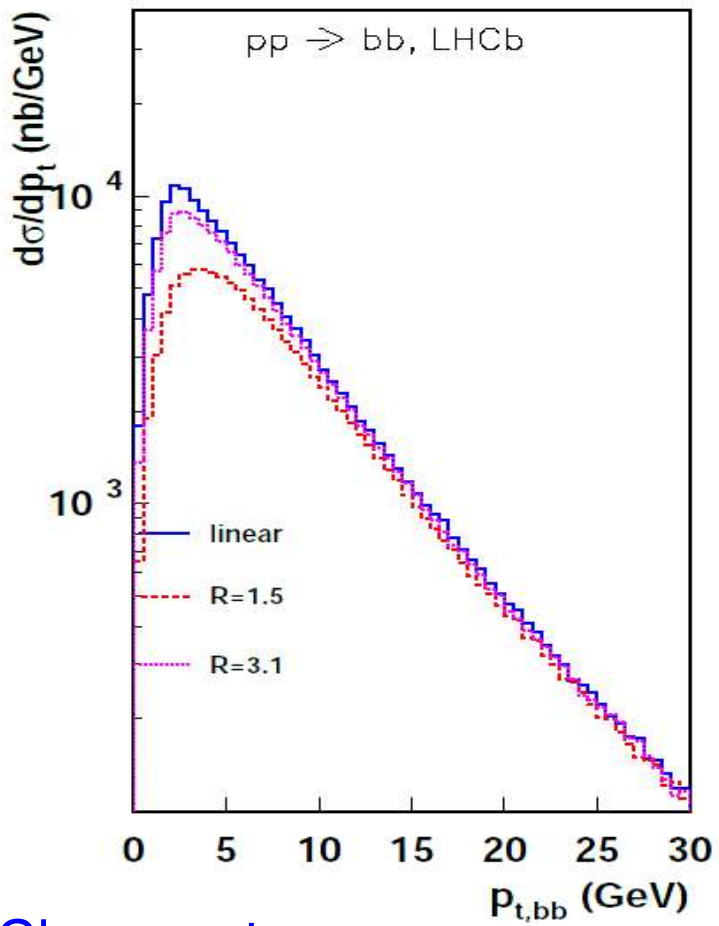


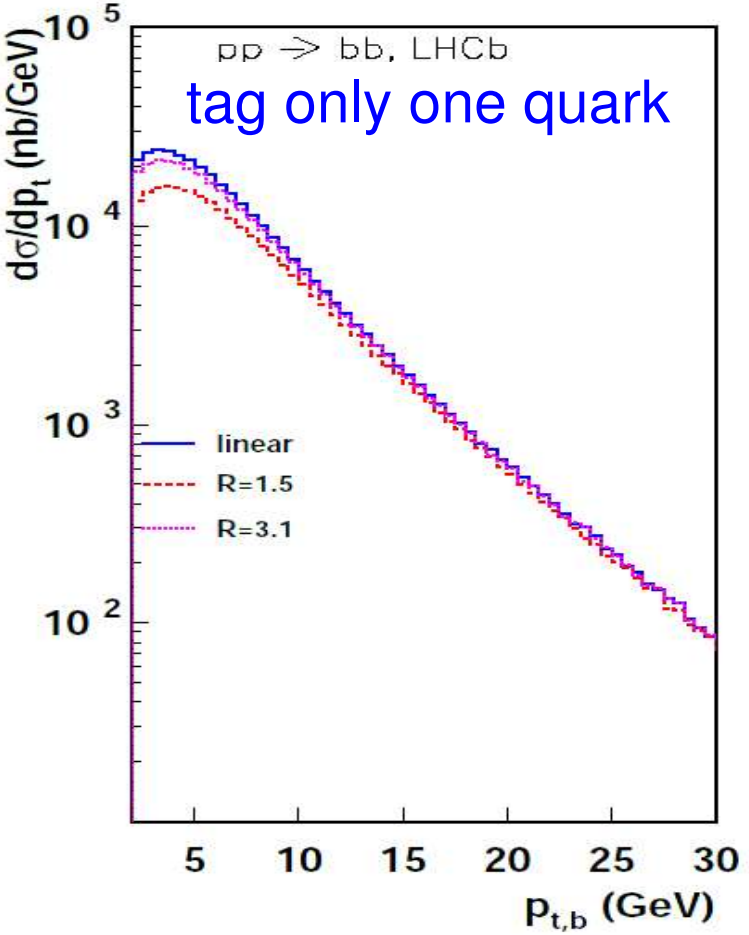
Charm suppression due to non-linear effects in BK

Significant effects at small p_t

different pred. compared to GLR

Non-linear effects at LHCb





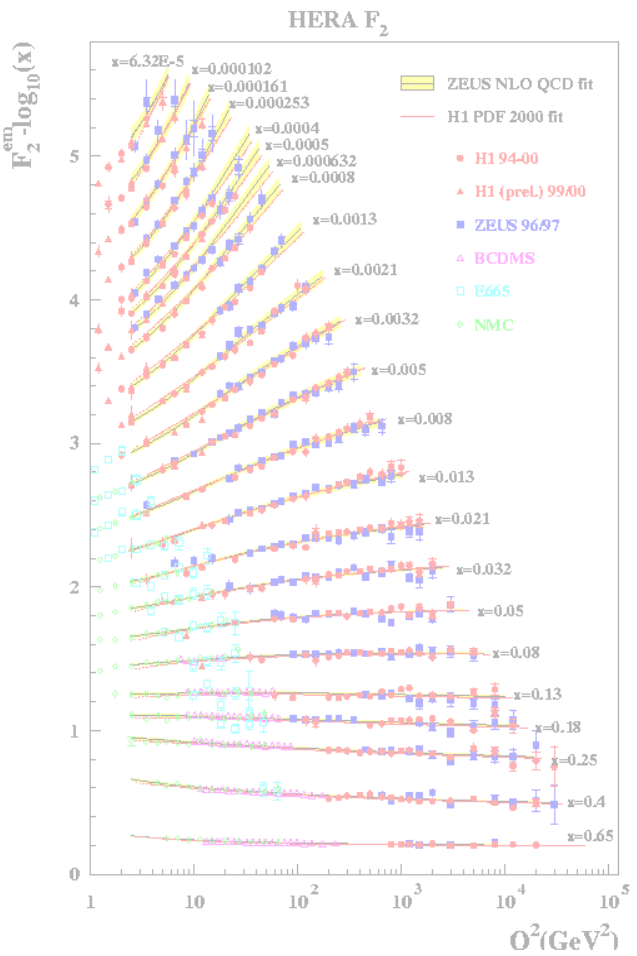
LHCb acceptance

$$1.9 < \eta_{b,\bar{b}} < 4.9$$

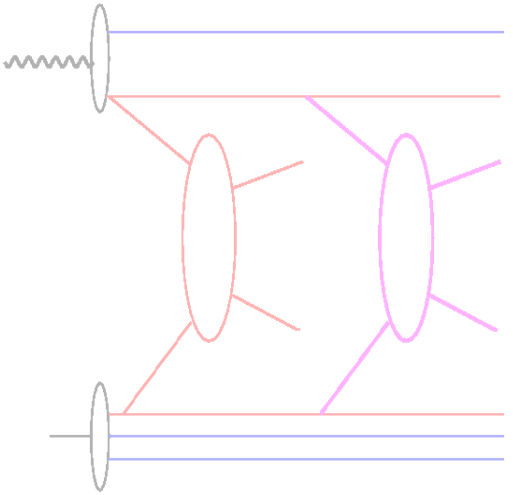
$$p_{t\ b}, p_{t\ \bar{b}} > 2\mathrm{GeV}$$

- Significant effects...
- up to factor of 2
- factorization still ok ?

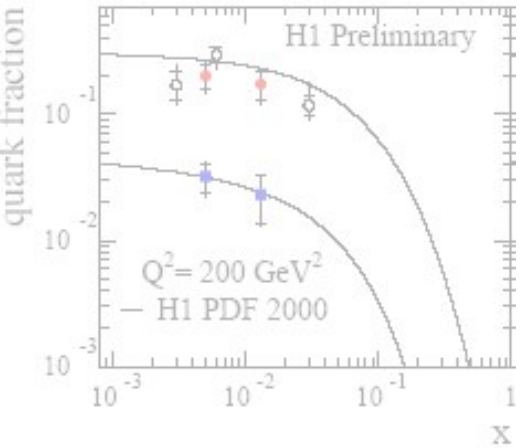
Topics of the workshop



Structure functions and parton distributions
LHC: cross sections/precision

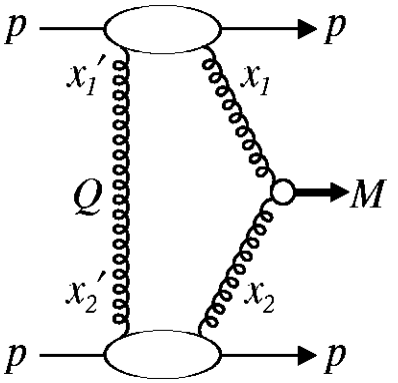


Multijets & final states
Underlying events, un-integrated pdfs
LHC: event complexity, jet x-section, Higgs



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

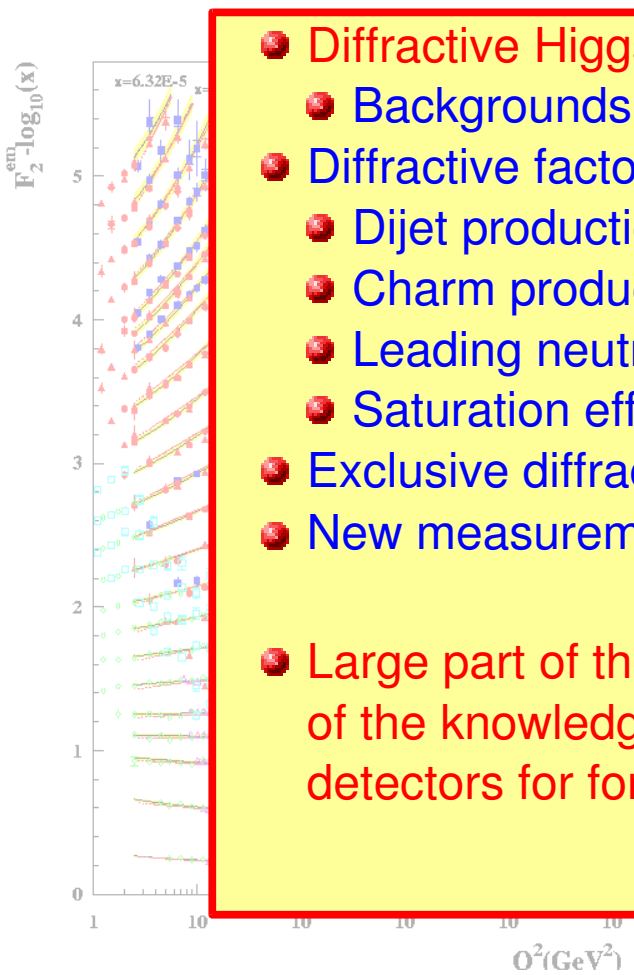
Diffraction
LHC: exclusive Higgs production

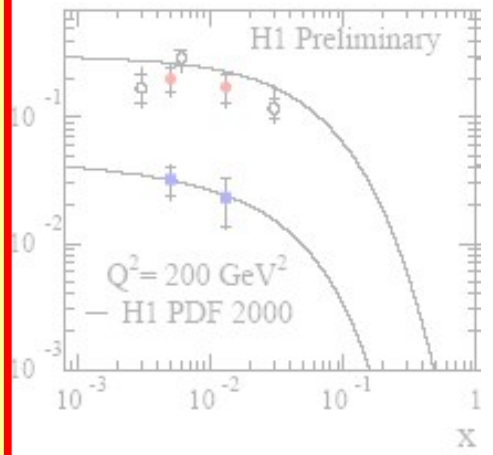


Topics of the workshop

- 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

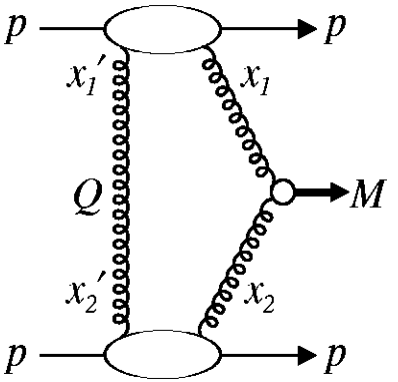




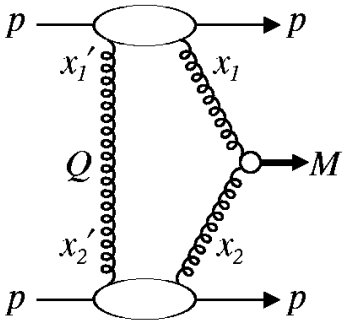
y quarks:
rk pdfs of the proton,
entation fct, u-pdf
Higgs production

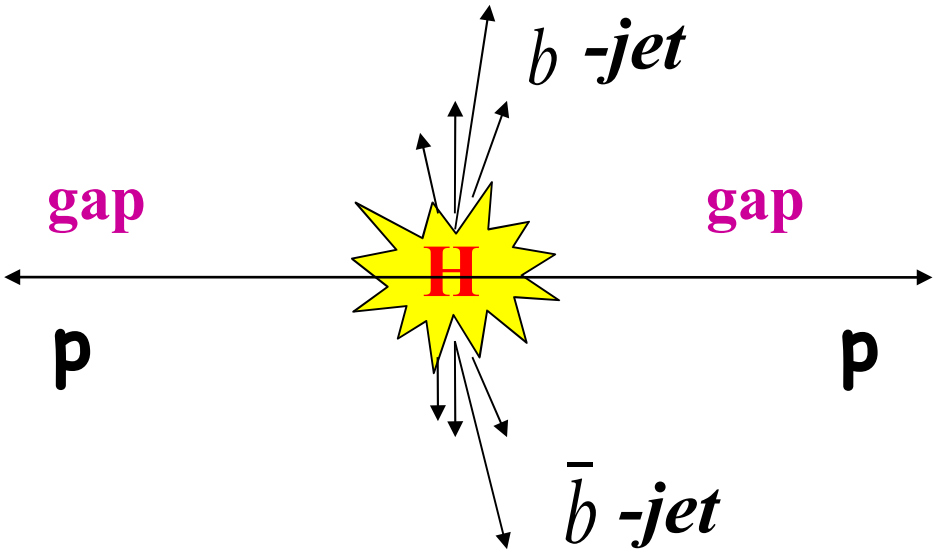
Structure functions and
parton distributions
LHC: cross sections/precision

Diffraction
LHC: exclusive
Higgs production



Diffractive Higgs Production





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

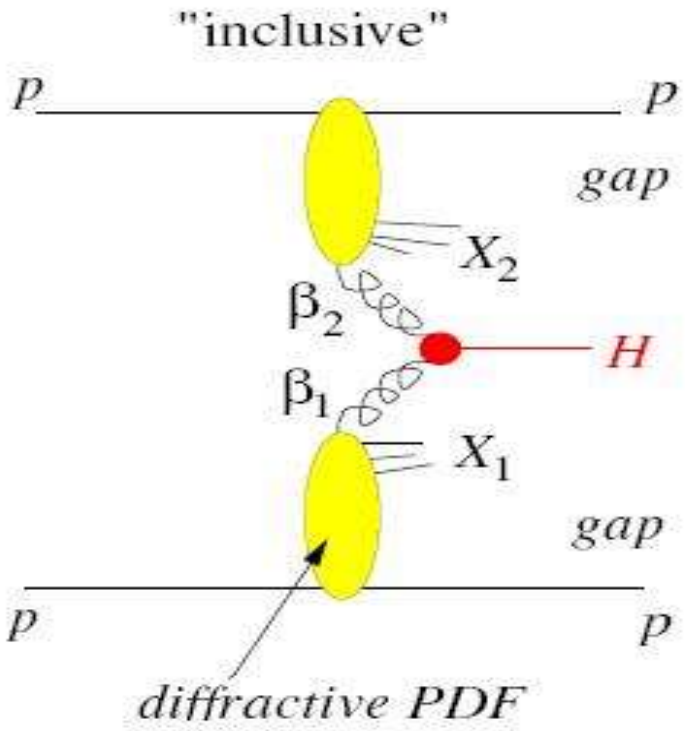
$$M_H^2 = (p + \bar{p} - p' - \bar{p}')^2$$

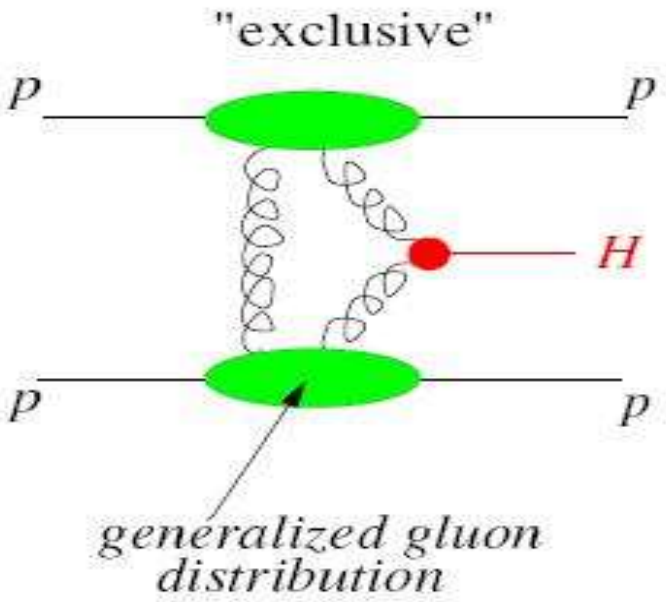
- Exclusive diffractive Higgs production $p + p \to p + H + p$ 2-10 fb
- Inclusive diffractive Higgs production $pp \to p + X + H + Y + p$ O(100) fb

- 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



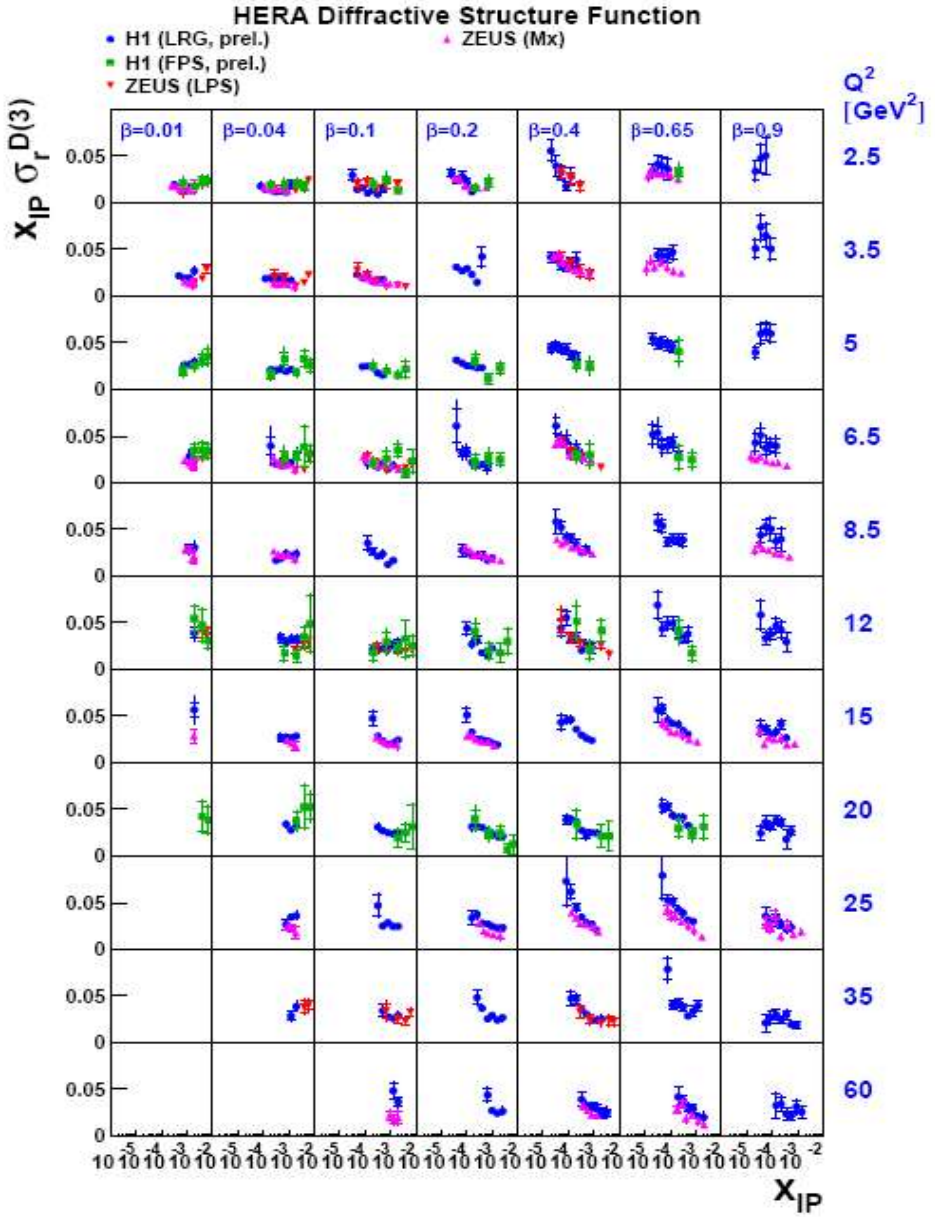


- Inclusive diff. events become background to exclusive one, when remnant systems X become soft...
- relevant region for diff. Pdfs:

$\beta \rightarrow 1$ and $Q^2 \sim M^2_h$

- 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!

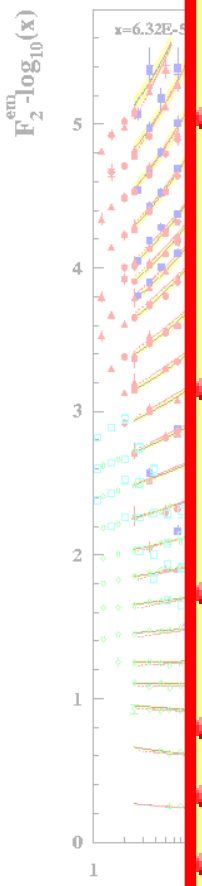
Present status: In unified analysis of measured cross-sections reasonable global agreement between H1 & ZEUS is found, and regions of significant discrepancies identified.

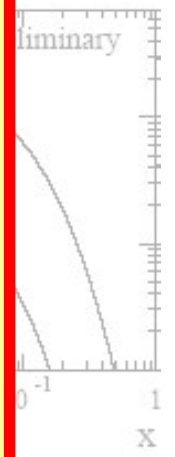
- **get the best out of HERA**
- **precise determination of diffractive PDFs**

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

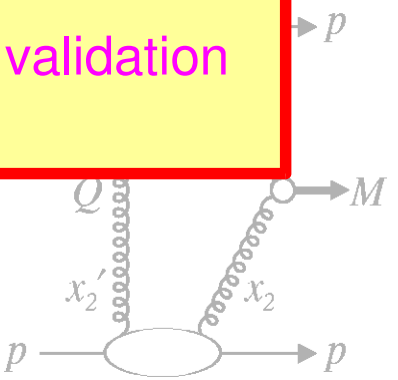




proton,
-pdf
ion

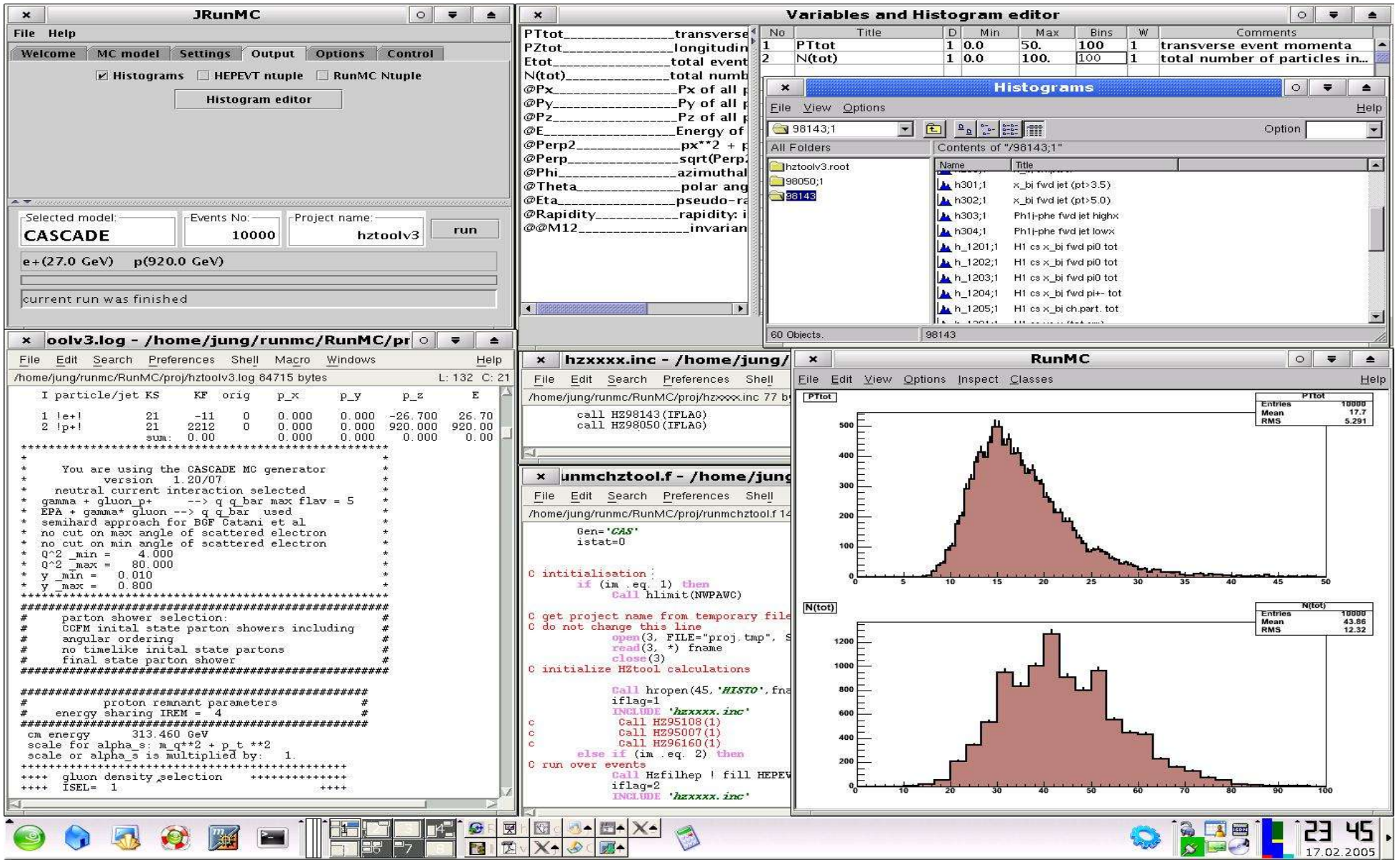
Structure functions and
parton distributions
LHC: cross sections/precision

Diffraction
LHC: exclusive
Higgs production



RunMC session...

from S. Chekanov

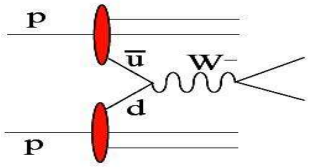


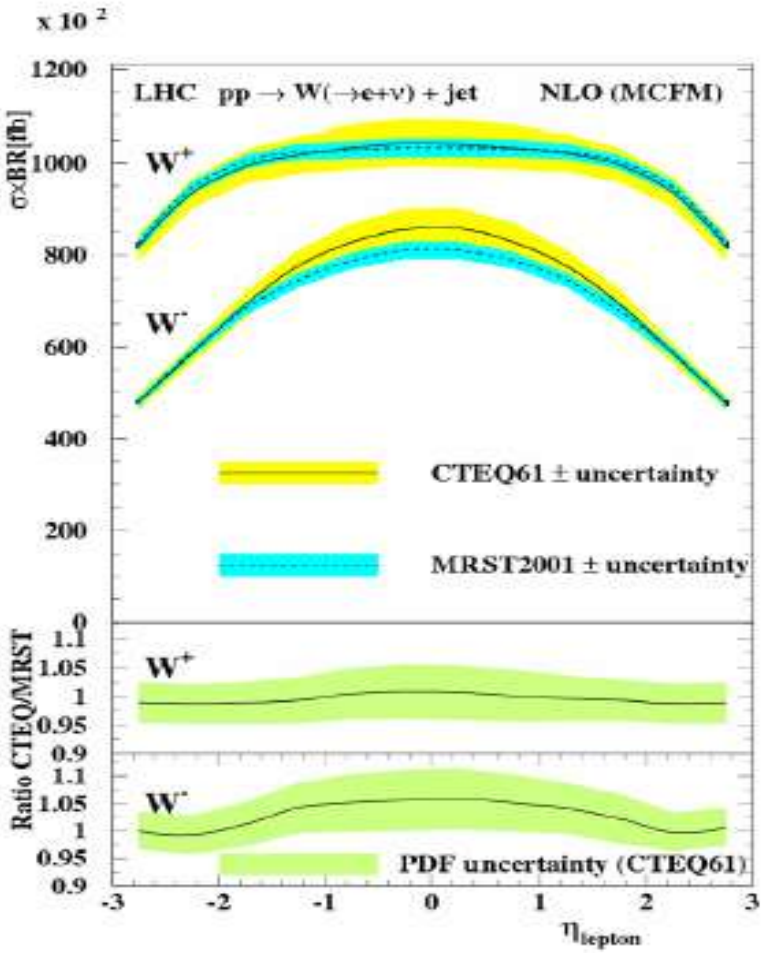
HERA and the LHC

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

HERA future measurement: deuteron

W xsection at LHC

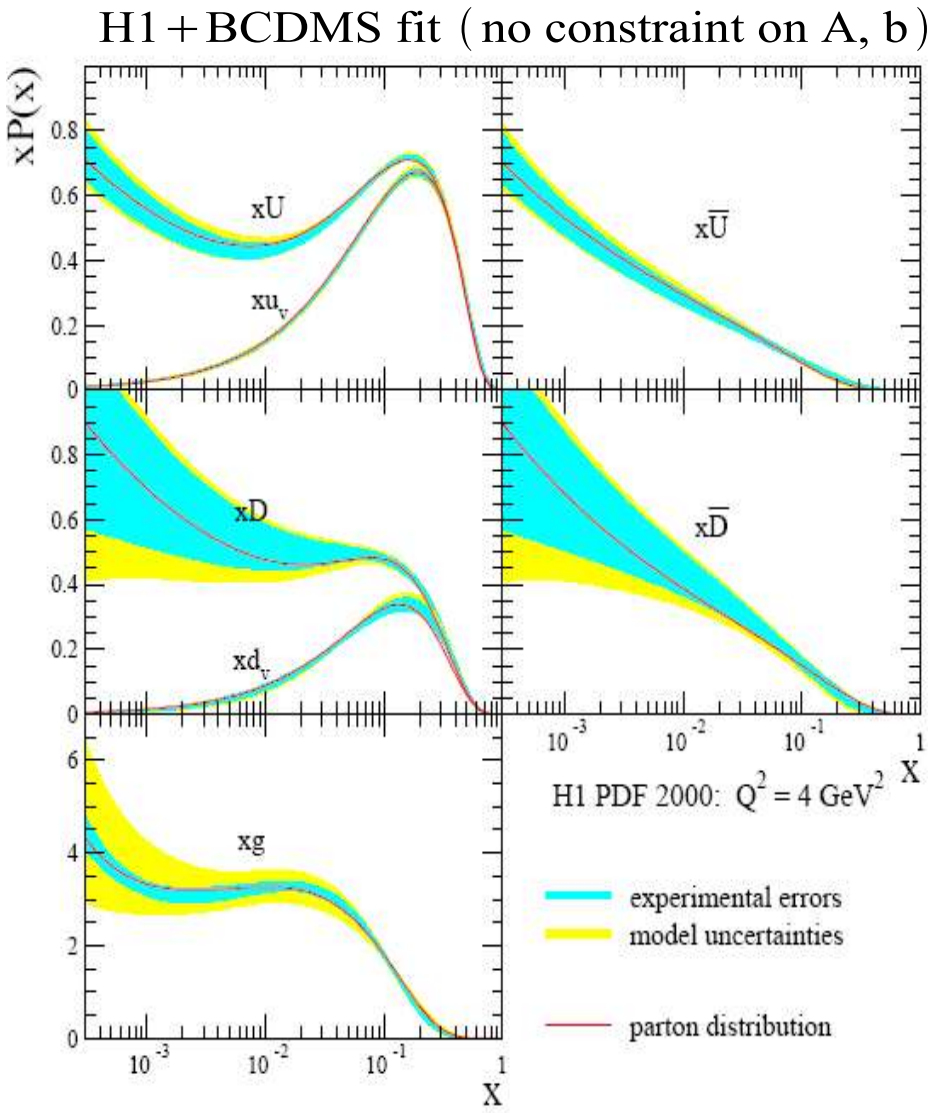




H. Stenzel

Global fits assume u=d at small x

from M. Klein



Future HERA measurement: deuteron

from M. Klein

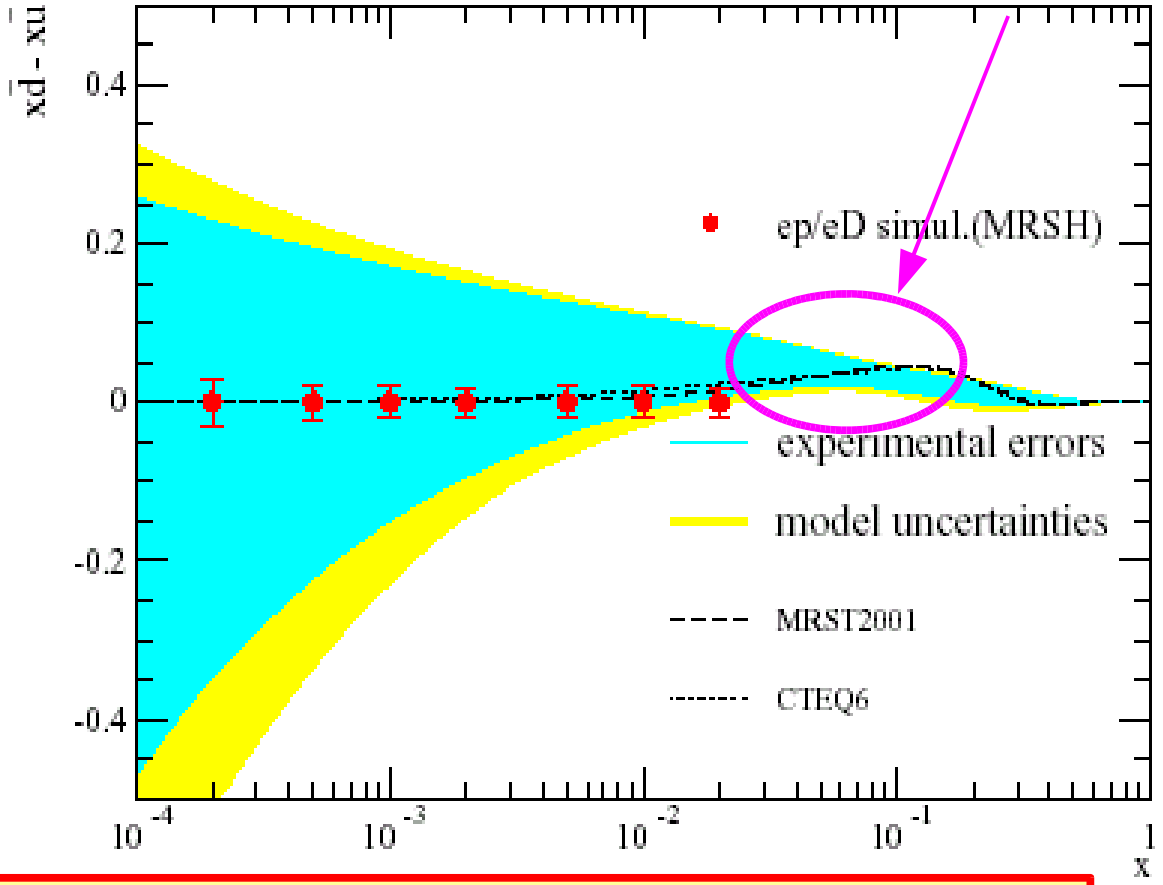
The light sea quark asymmetry is expected and has been assumed to vanish at low x. However, F_2 rises strongly towards low x which deserves to be studied.

Tevatron with W

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

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

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



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 !!!

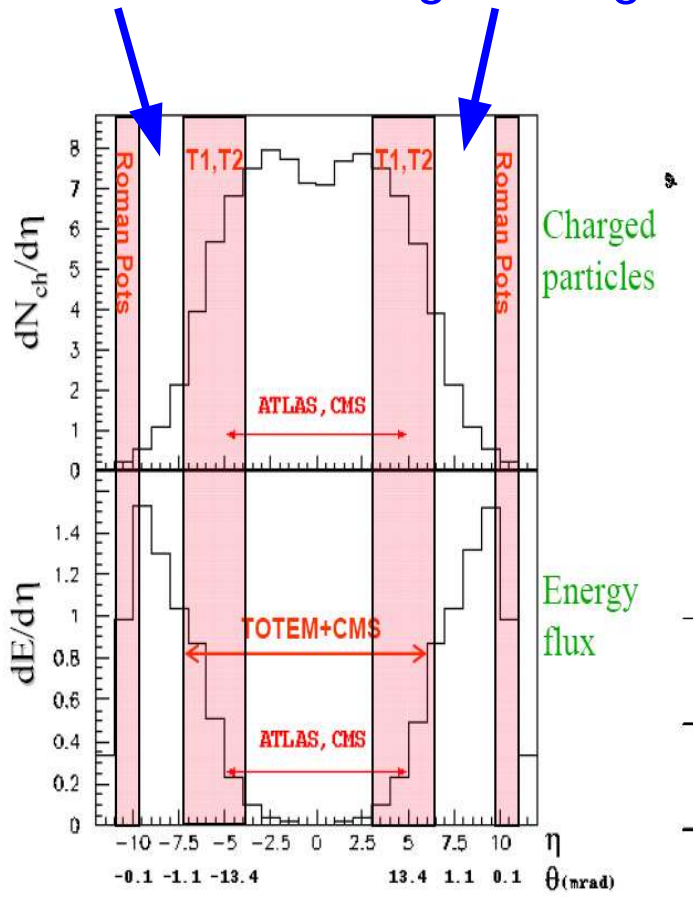
HERA experience

- 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....

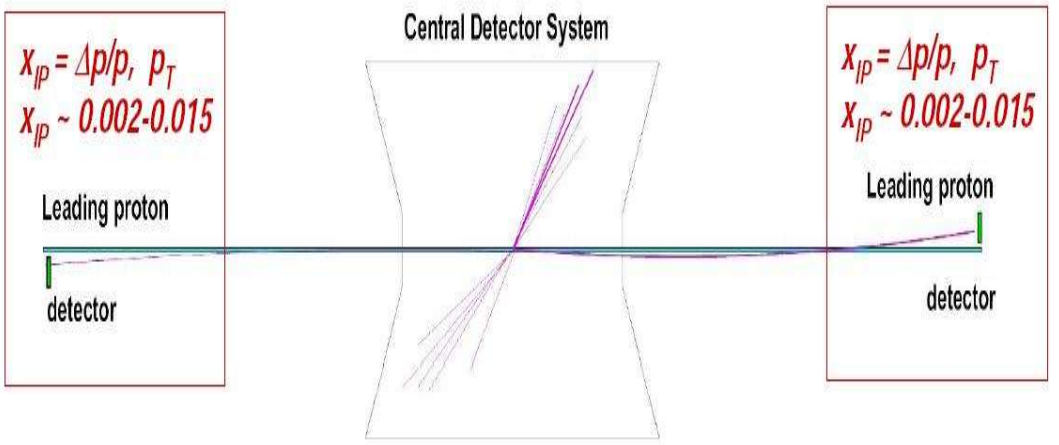
But also...
HERA experience in forward physics.....

Ideas for upgrading forward region

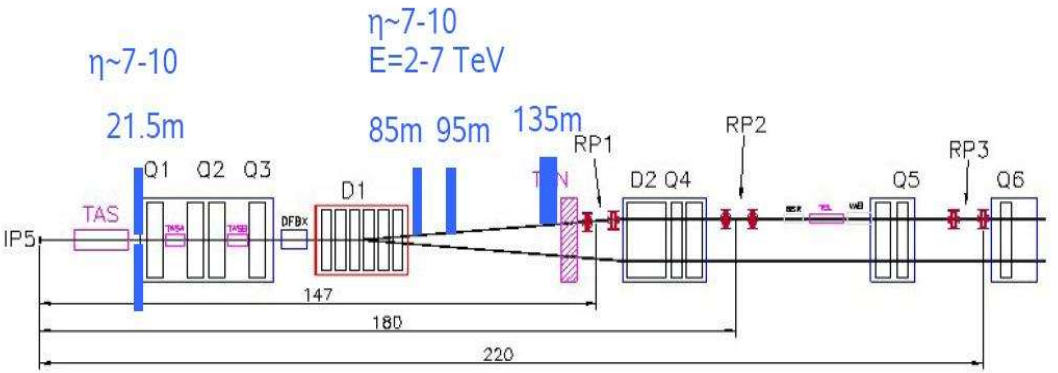
Here is something missing



from H. Kowalski



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

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

March	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 !