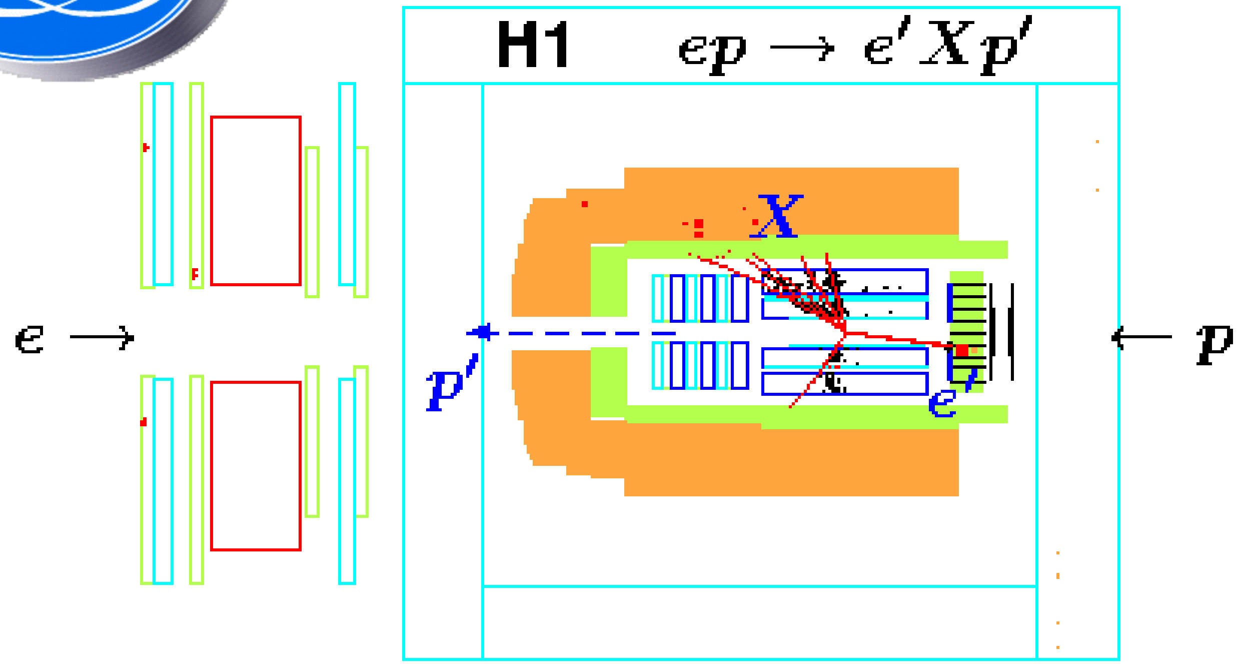
"Diffractive" Deep Inelastic Scattering: The Structure of Nothing

P.Newman (Uni. Birmingham), with
supporting material by George W. Bush



Manchester seminar
14 / 2 / 07

Thanks to many H1 colleagues, in particular Yves Coppens, Carrie Johnson, Paul Thompson (Birmingham), Micha Kapishin (Dubna), Paul Laycock (Liverpool) Frank-Peter Schilling (Karlsruhe)

Much of that shown is taken from these two closely related recently published papers, hep-ex/0606003,4

DESY 06-049
May 2006
ISSN 0418-9833

Measurement and QCD Analysis of the Diffractive Deep-Inelastic Scattering Cross Section at HERA

H1 Collaboration

Abstract

A detailed analysis is presented of the diffractive deep-inelastic scattering process $ep \to eXY$, where Y is a proton or a low mass proton excitation carrying a fraction $1-x_{I\!P} > 0.95$ of the incident proton longitudinal momentum and the squared four-momentum transfer at the proton vertex satisfies $|t| < 1\ \mathrm{GeV}^2$. Using data taken by the H1 experiment, the cross section is measured for photon virtualities in the range $3.5 \leq Q^2 \leq 1600\ \mathrm{GeV}^2$, triple differentially in $x_{I\!P}$, Q^2 and $\beta = x/x_{I\!P}$, where x is the Bjorken scaling variable. At low $x_{I\!P}$, the data are consistent with a factorisable $x_{I\!P}$ dependence, which can be described by the exchange of an effective pomeron trajectory with intercept $\alpha_{I\!P}(0) = 1.118 \pm 0.008\ (\mathrm{exp.})\ ^{+0.029}_{-0.010}\ (\mathrm{model})$. Diffractive parton distribution functions and their uncertainties are determined from a next-to-leading order DGLAP QCD analysis of the Q^2 and β dependences of the cross section. The resulting gluon distribution carries an integrated fraction of around 70% of the exchanged momentum in the Q^2 range studied. Total and differential cross sections are also measured for the diffractive charged current process $e^+p \to \bar{\nu}_e XY$ and are found to be well described by predictions based on the diffractive parton distributions. The ratio of the diffractive to the inclusive neutral current ep cross sections is studied. Over most of the kinematic range, this ratio shows no significant dependence on Q^2 at fixed $x_{I\!P}$ and x or on x at fixed Q^2 and β.

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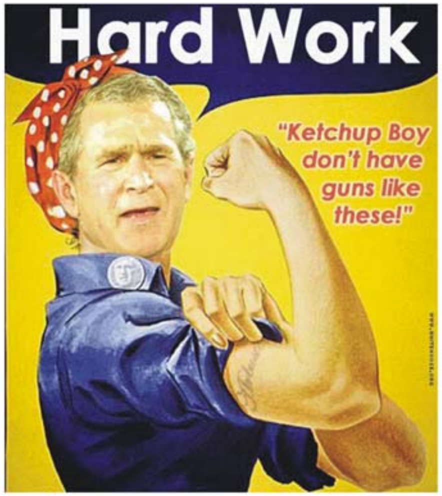
Diffractive Deep-Inelastic Scattering with a Leading Proton at HERA

H1 Collaboration

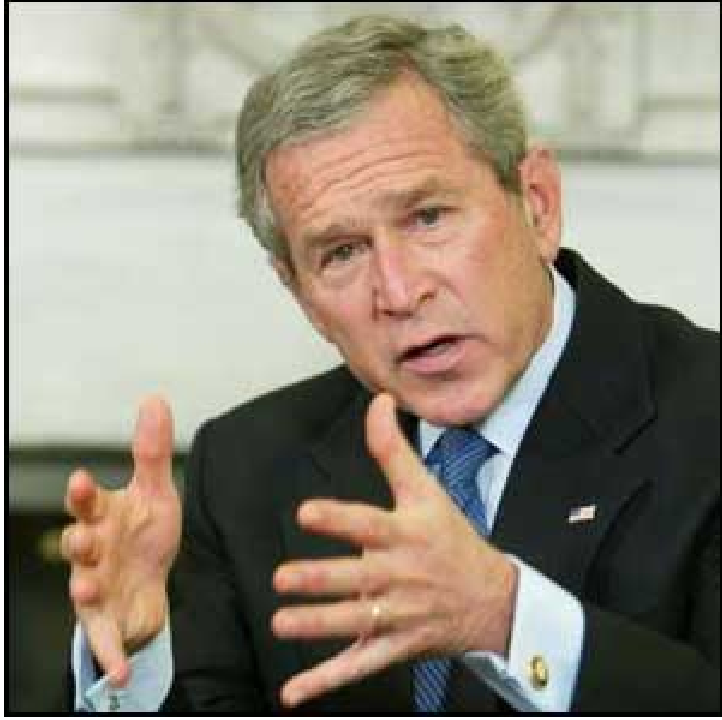
Abstract

The cross section for the diffractive deep-inelastic scattering process $ep \to eXp$ is measured, with the leading final state proton detected in the H1 Forward Proton Spectrometer. The data analysed cover the range $x_{I\!P} < 0.1$ in fractional proton longitudinal momentum loss, $0.08 < |t| < 0.5\ \mathrm{GeV}^{-2}$ in squared four-momentum transfer at the proton vertex, $2 < Q^2 < 50\ \mathrm{GeV}^2$ in photon virtuality and $0.004 < \beta = x/x_{I\!P} < 1$, where x is the Bjorken scaling variable. For $x_{I\!P} \lesssim 10^{-2}$, the differential cross section has a dependence of approximately $d\sigma/dt \propto e^{6t}$, independently of $x_{I\!P}$, β and Q^2 within uncertainties. The cross section is also measured triple differentially in $x_{I\!P}$, β and Q^2. The $x_{I\!P}$ dependence is interpreted in terms of an effective pomeron trajectory with intercept $\alpha_{I\!P}(0) = 1.114 \pm 0.018\,(\mathrm{stat.}) \pm 0.012\,(\mathrm{syst.})\ ^{+0.040}_{-0.020}\,(\mathrm{model})$ and a sub-leading exchange. The data are in good agreement with an H1 measurement for which the event selection is based on a large gap in the rapidity distribution of the final state hadrons, after accounting for proton dissociation contributions in the latter. Within uncertainties, the dependence of the cross section on x and Q^2 can thus be factorised from the dependences on all studied variables which characterise the proton vertex, for both the pomeron and the sub-leading exchange.



8 years, 93 pages, 833 data points … number of readers tbc!
"… almost worth the wait" (J.Forshaw)

Contents



• Introduction to parton densities, DIS, HERA and H1

• Diffractive DIS

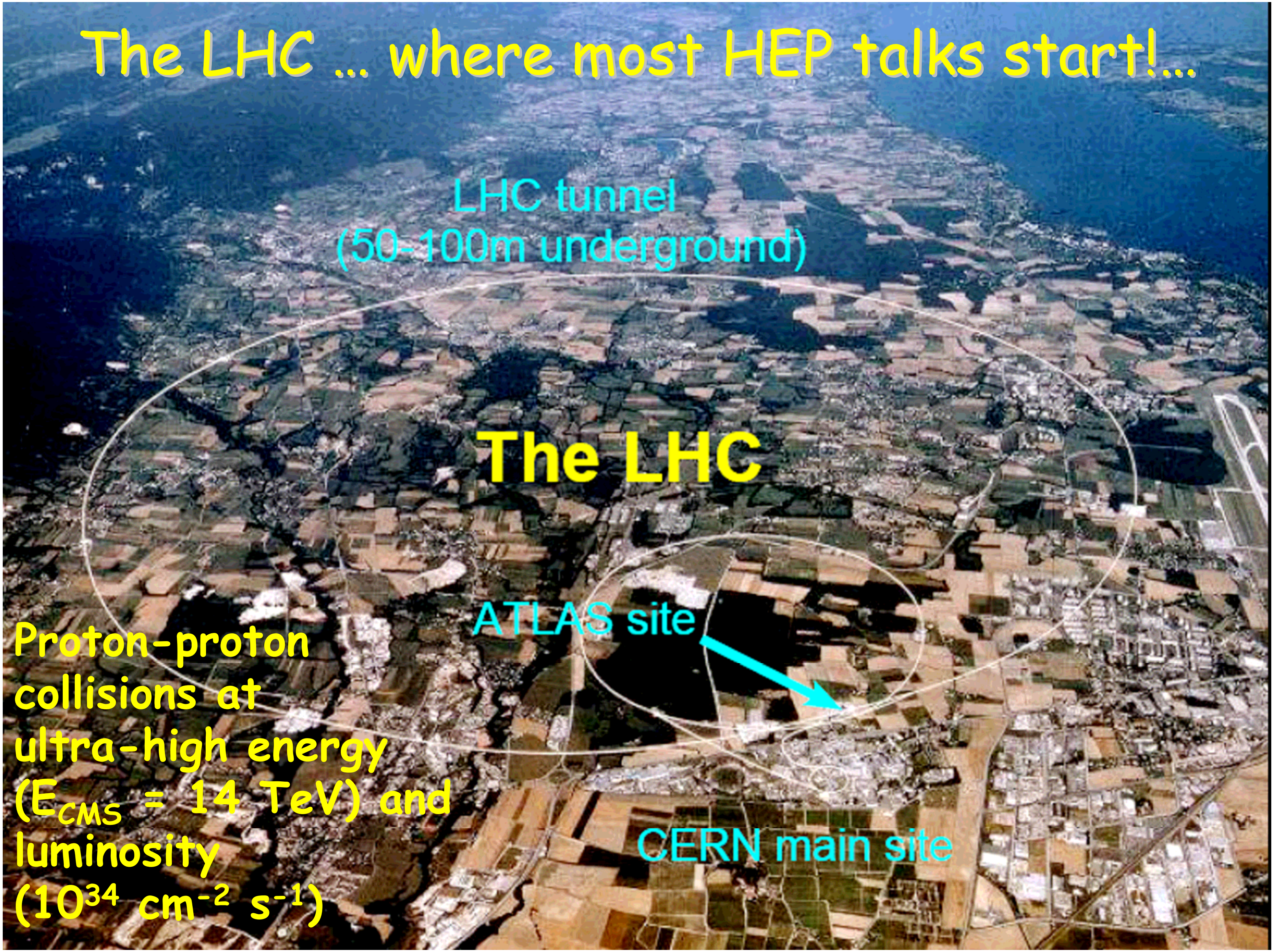
• Two measurement methods and their comparisons

• Describing the 'soft' physics aspects

• The 'hard' physics: tackling diffraction in QCD …
… diffractive parton densities (DPDFs)

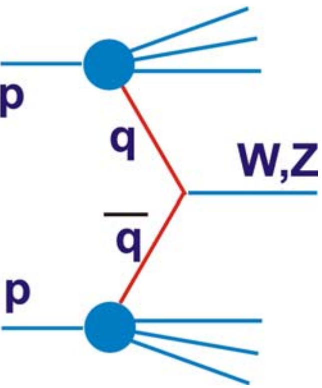
• Testing diffractive parton densities

• … but what do diffractive parton densities actually *mean*?


The LHC ... where most HEP talks start!...
LHC tunnel
(50-100m underground)
The LHC
ATLAS site
Proton-proton
collisions at
ultra-high energy
(E_CMS = 14 TeV) and
luminosity
(10^34 cm^-2 s^-1)
CERN main site

What is a Proton?

Most physics at LHC and Tevatron requires a precise knowledge of the quark and gluon contents of the proton.



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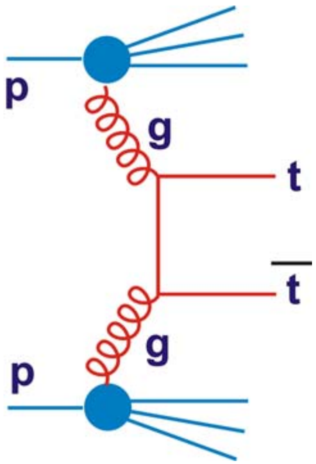

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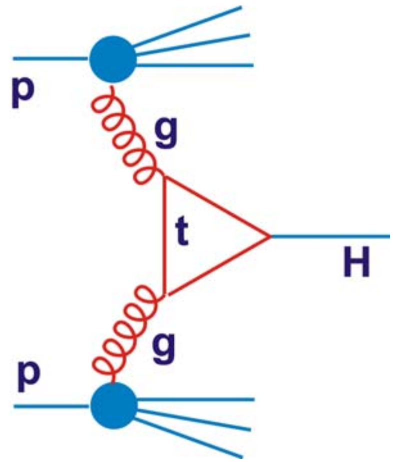
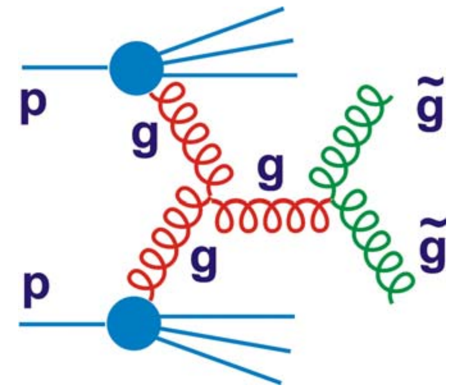
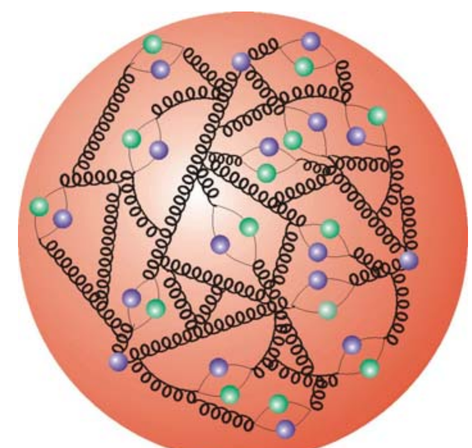


Higgs

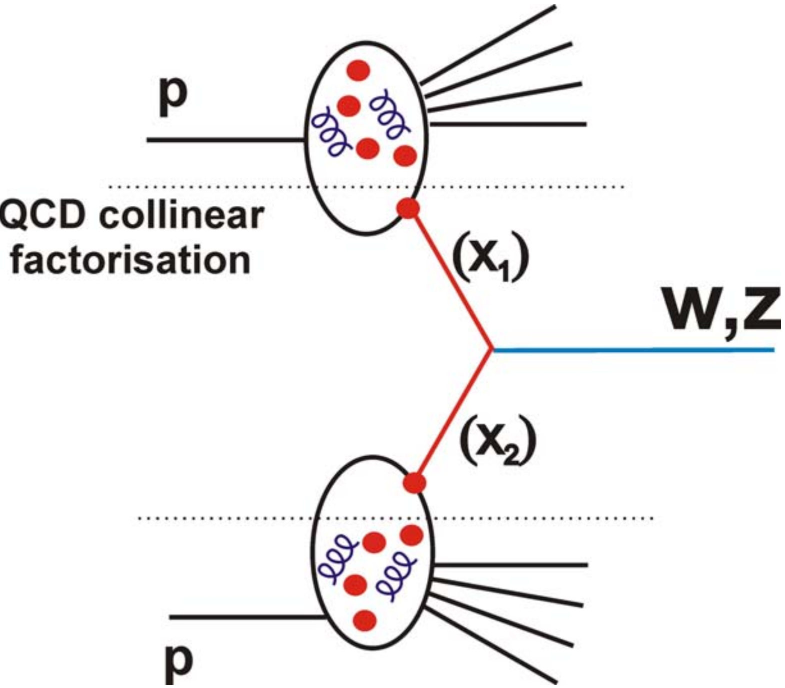


Exotics

To fully calculate strong interaction consequences of uud valence quarks, we would have to fully solve QCD.
… we can't do that, but we do know some things about it!…



Factorising away the Unknown

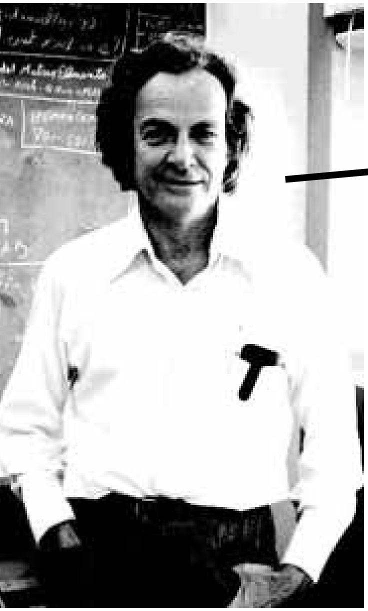


- **QCD factorisation theorem** allows us to define universal parton density functions (PDFs), same for proton in all contexts.

- **QCD evolution (`DGLAP' approx^n)** tells us how the partons evolve as scale (e.g. mass produced) changes. … i.e, we just need to know the x dependence at a single scale …

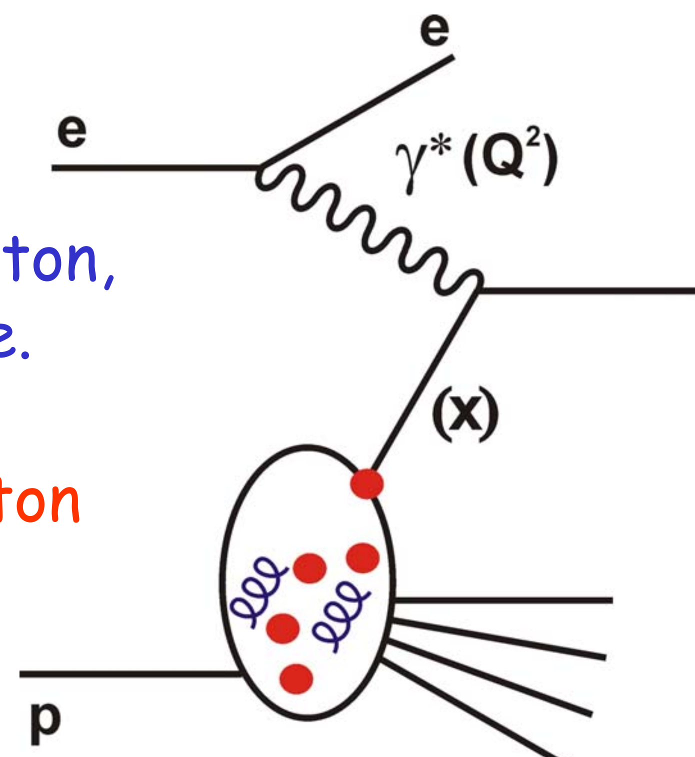
We cannot calculate PDFs (maybe one day on lattice)
… so we have to determine the PDFs experimentally

Parton Densities from Experiment… DIS



"You don't find out how a watch works by throwing other watches at it!"

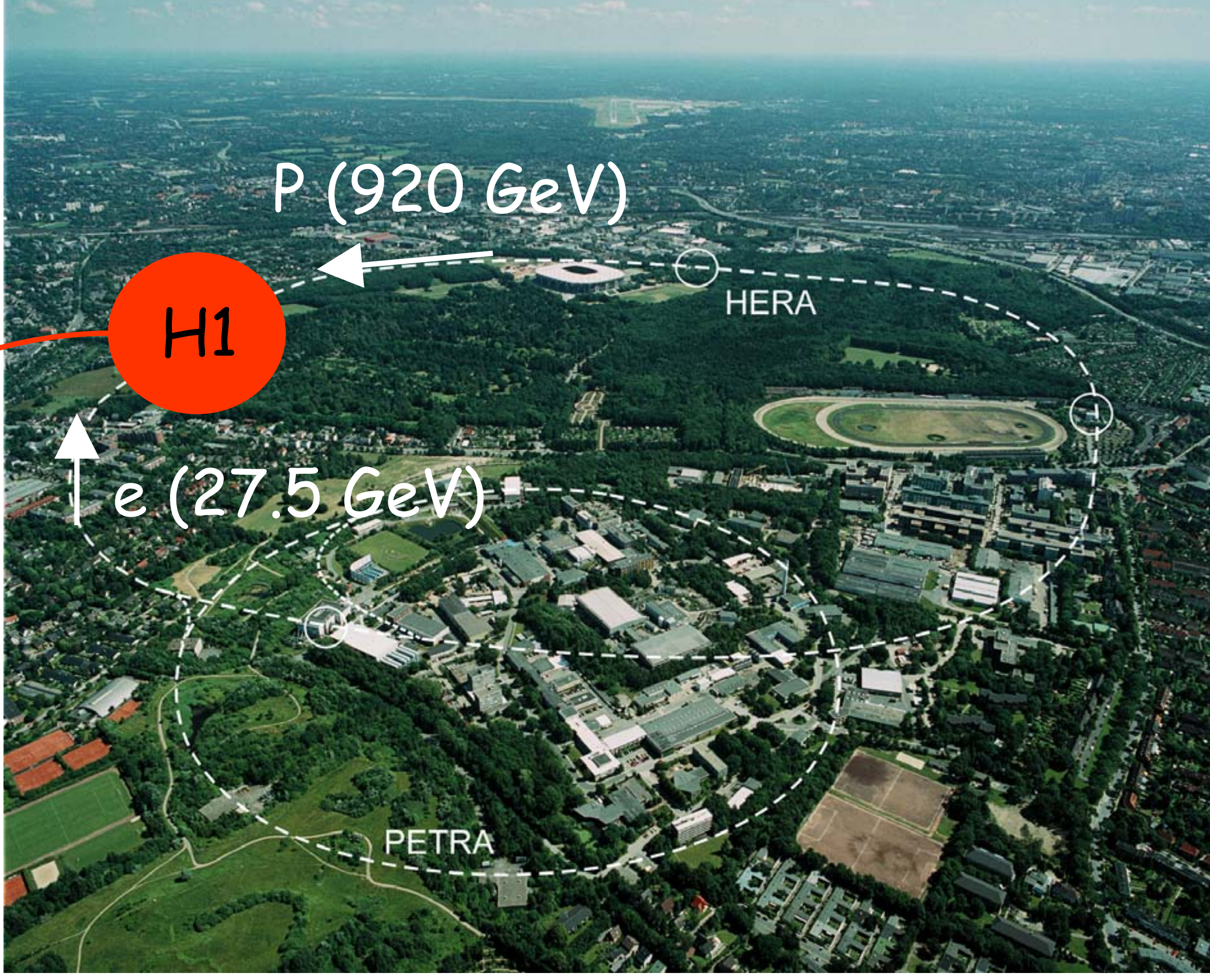
Most precise information on PDFs comes from **`Deep inelastic lepton-nucleon Scattering'** …
Point-like probe, which doesn't feel strong colour field … a `snapshot' of proton, mainly via photon exchange.

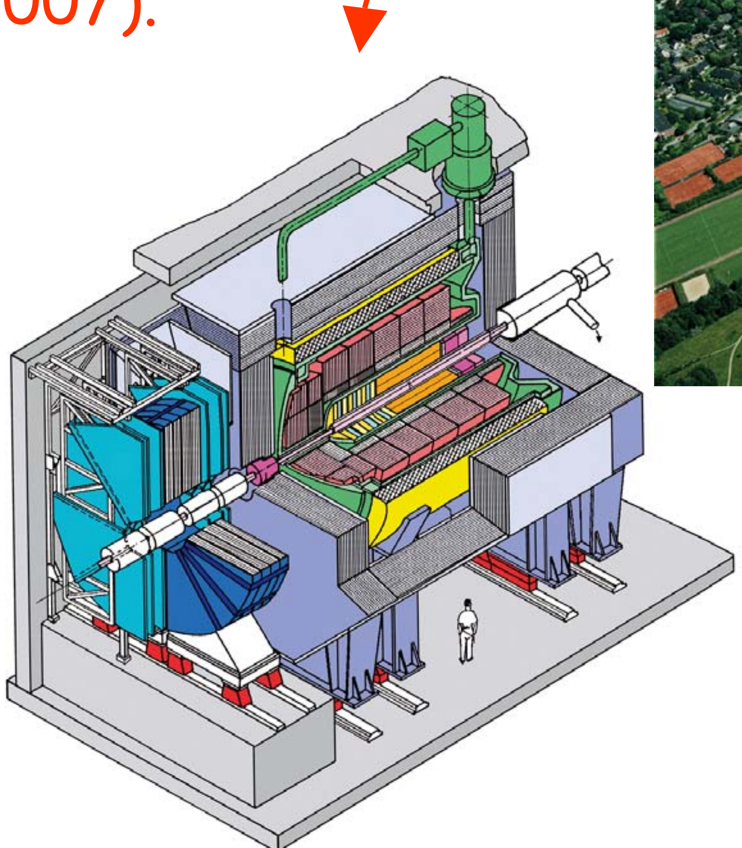


x = Momentum fraction of struck parton
Q^2 = Exchanged boson virtuality … scale or resolving power!

HERA and H1

• The world's only ever ep collider, studying proton structure and QCD (1992-2007).

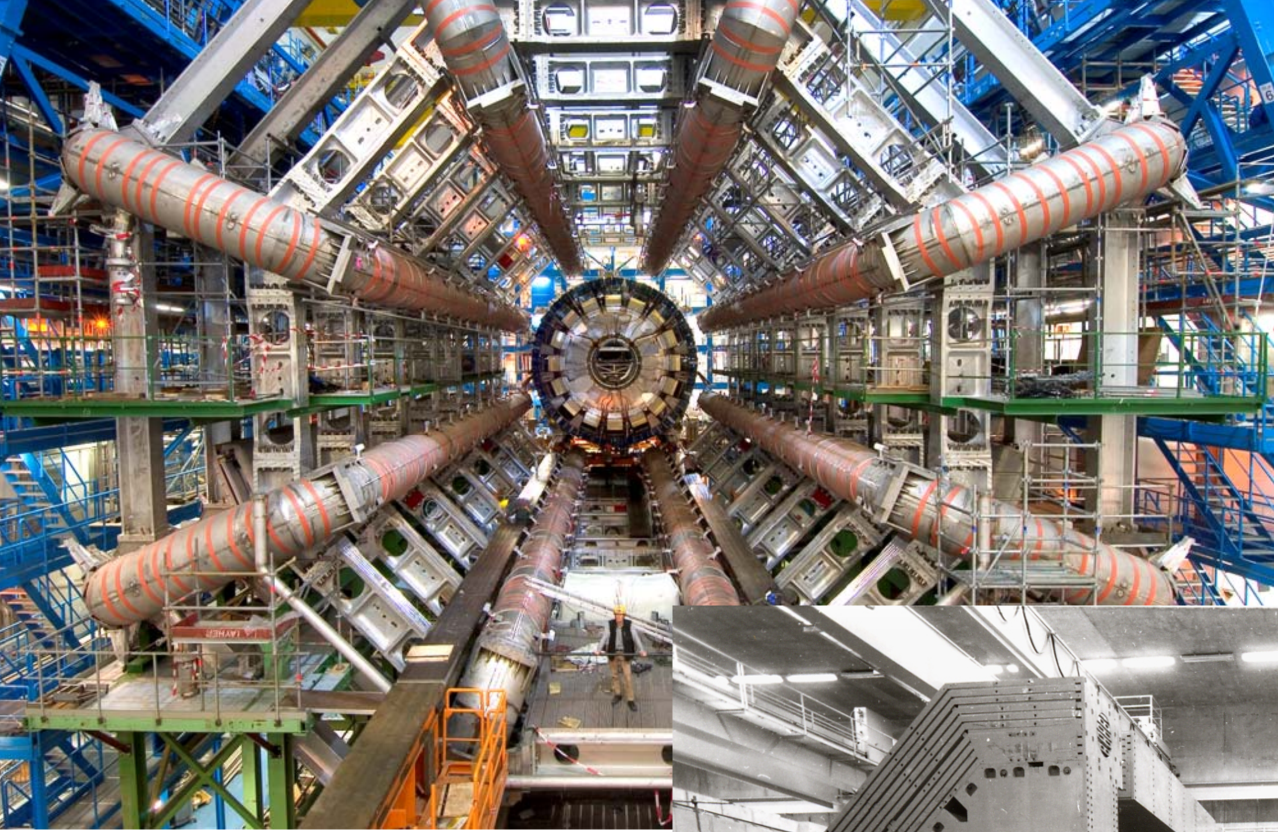


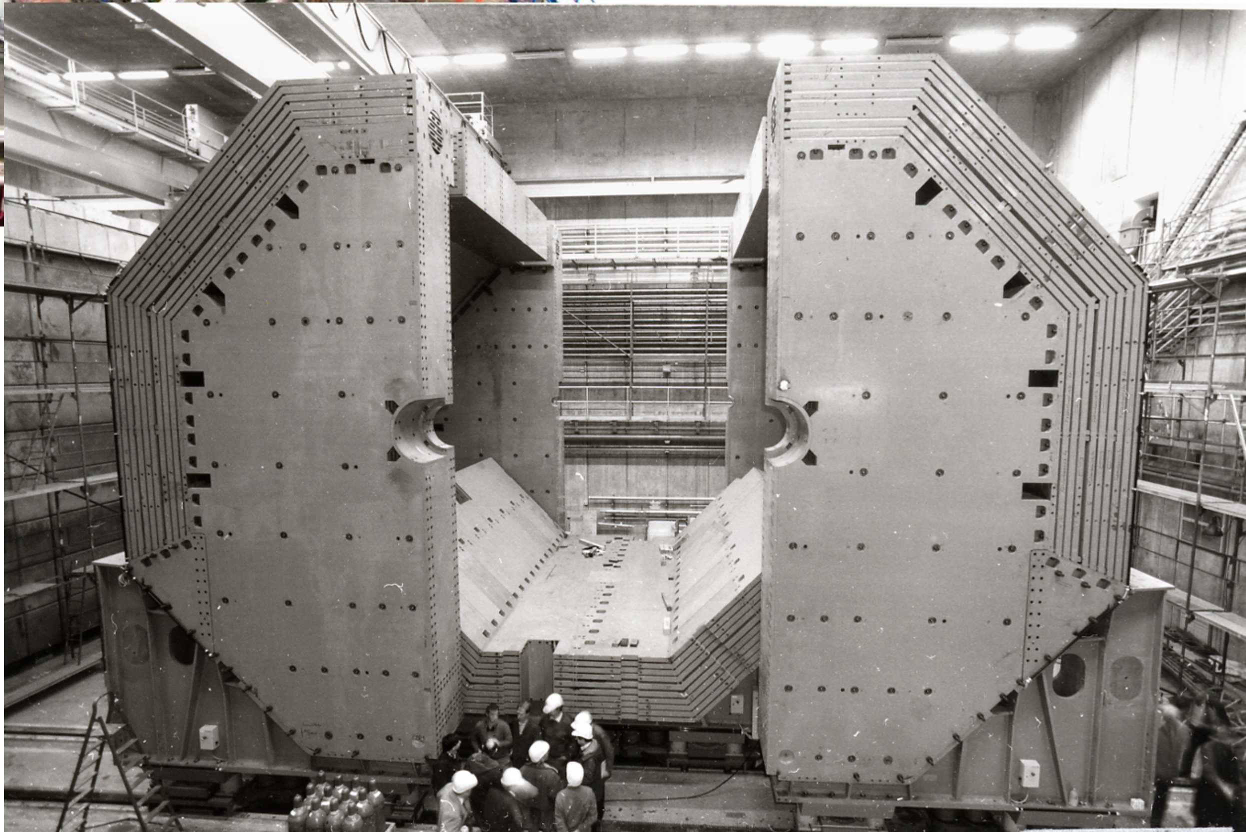


• Fixed target equivalent energy Of 50 TeV

• … "the world's most powerful microscope"

Scale:
H1 v
ATLAS





... yet x range of PDF sensitivity at HERA is very well matched to LHC requirements!

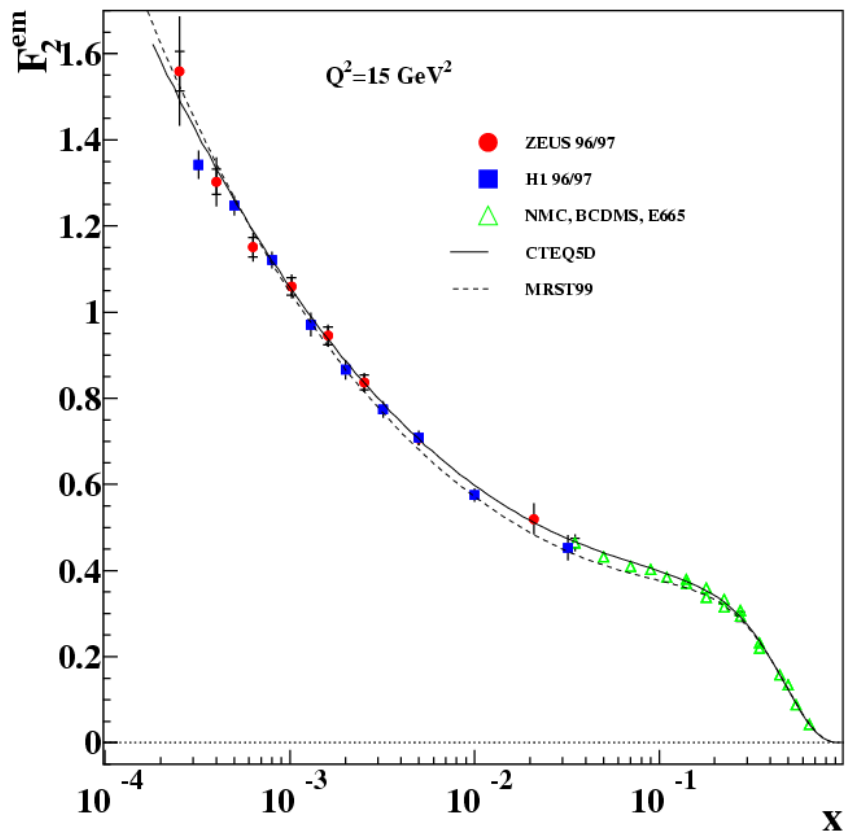
Sensitivity to Quark Densities

Inclusive data measure charge squared weighted quark density …

$$F_2(x,Q^2) \sim x\sum_q e_q^2(q+\overline{q})$$

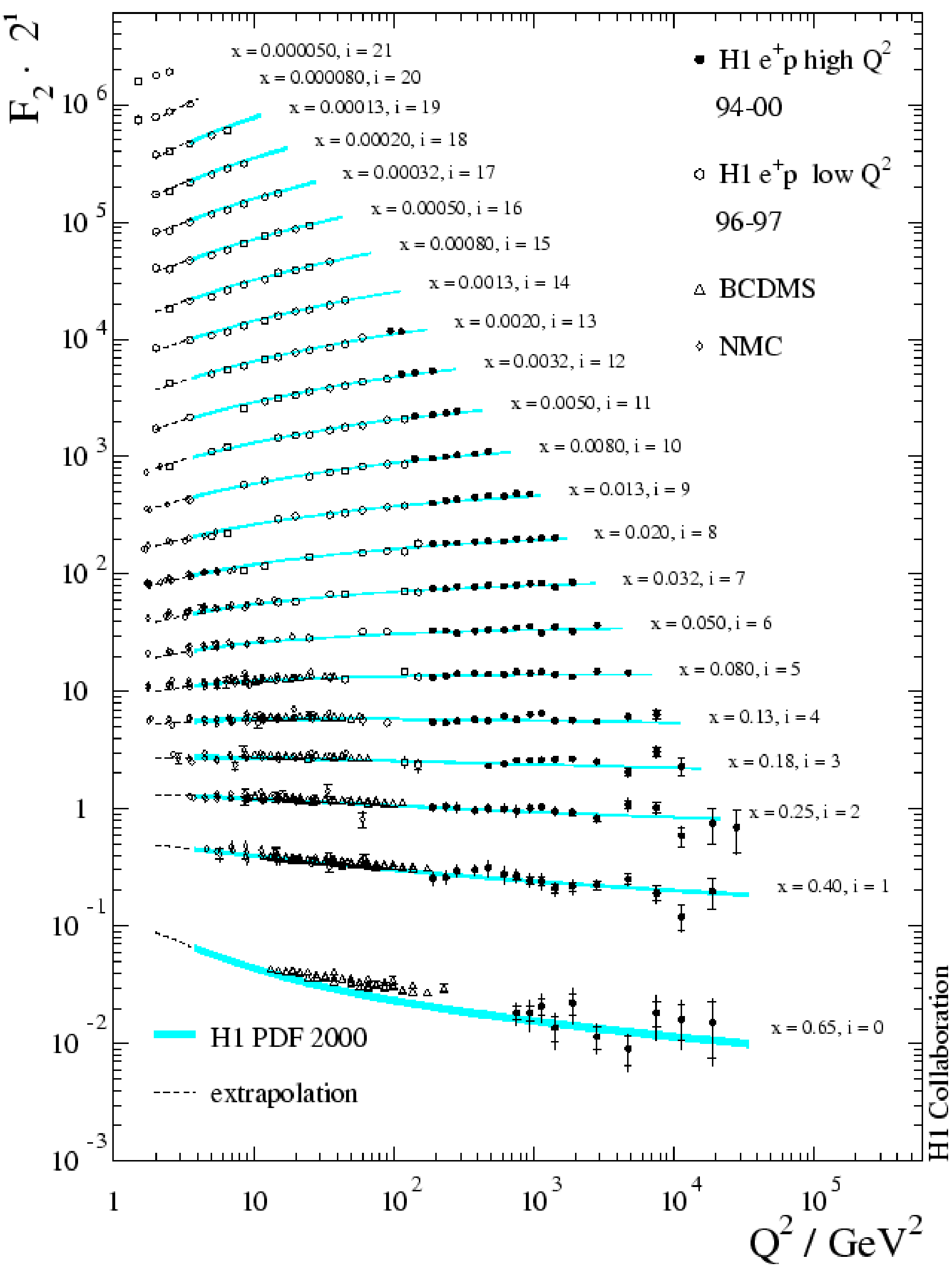
F_2 data published to 2-3%
… now working towards 1% measurement.

(Anti-)quark flavour decomposition sensitivity
via polarisation, charged current, e^+p v e^-p



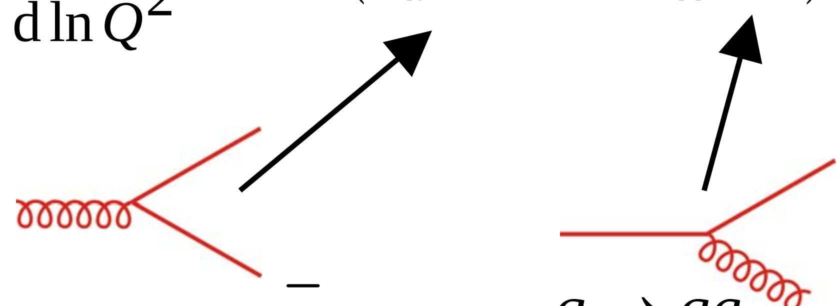
Biggest HERA discovery … powerful rise of F_2 at low x …

The Gluon Density!



Q^2 evolution of F_2 is used to extract gluon density, assuming DGLAP evolution.

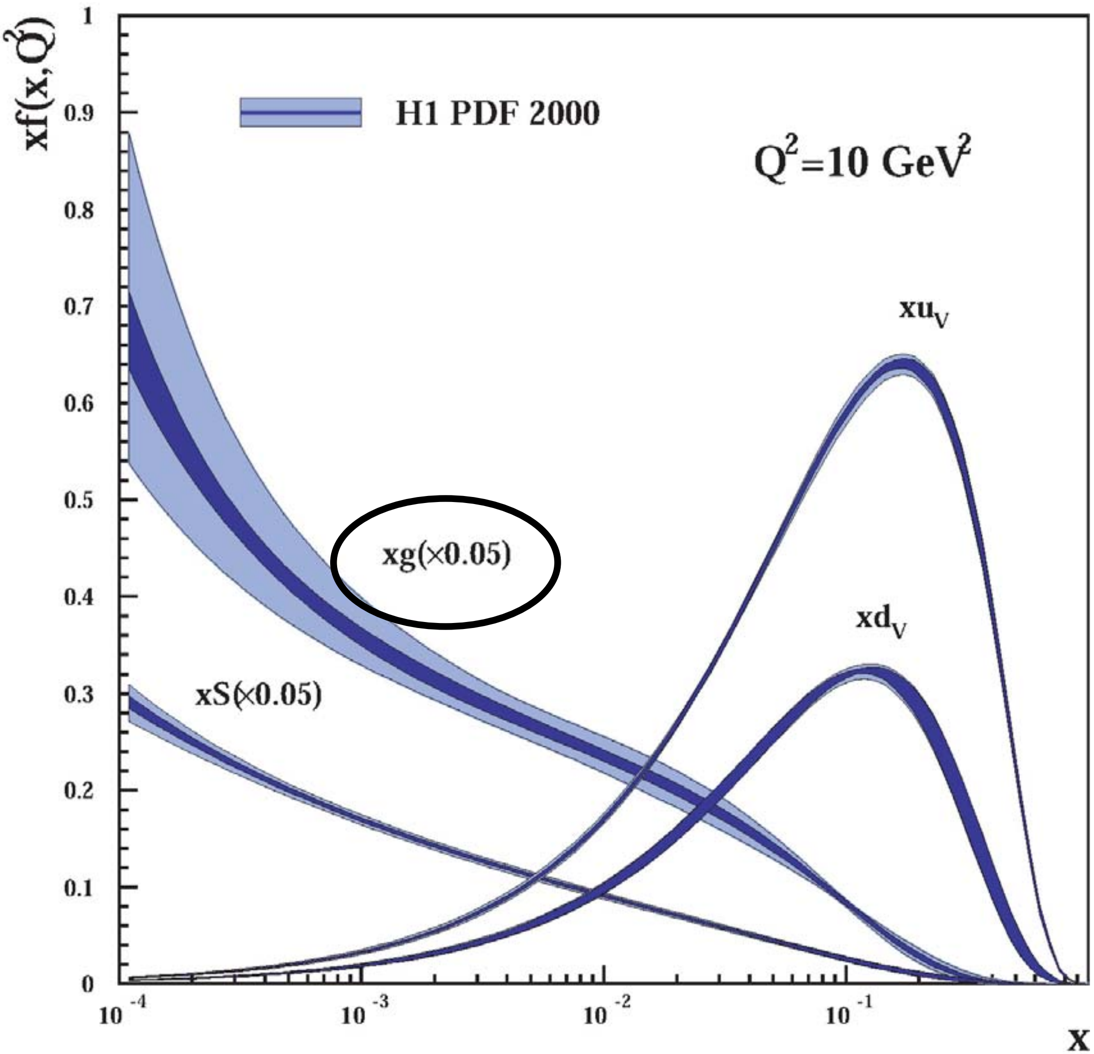
$$\frac{dF_2}{d\ln Q^2} \sim \alpha_s \left(P_{qg} \otimes g \; + \; P_{qq} \otimes q \right)$$



$g \rightarrow q\bar{q}$ $\qquad$ $q \rightarrow qg$

Internally self-consistent, but (unlike quark density extractions), this is model (DGLAP) dependent!

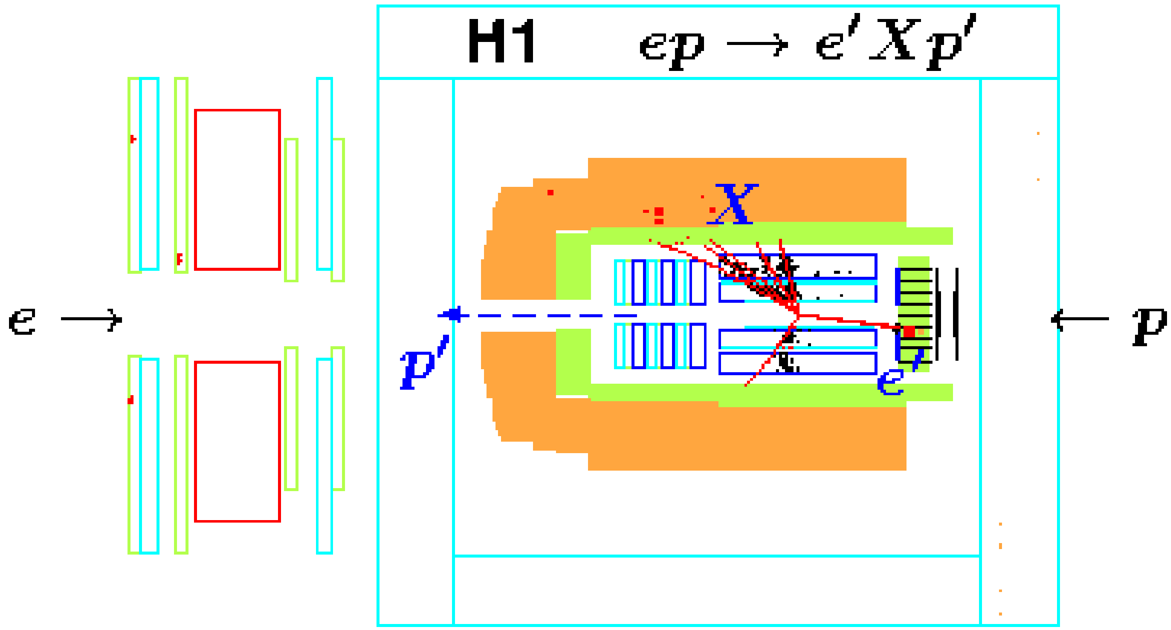
So what *is* a Proton?



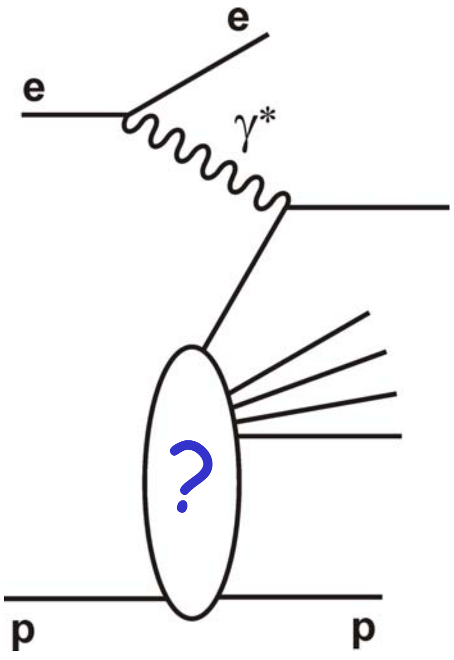
- DGLAP fits to NC and CC data, up to order α_s^2 in QCD used to obtain valence, sea quarks and gluon.
- Can be done using H1 data alone.
- Also `global' fits by MRST, CTEQ … use some input from pp and elsewhere.

Gluon density at low x becomes enormous!

What is Diffractive DIS?



- A special case of DIS, in which the proton stays intact, despite being struck with 10s of GeV of transverse momentum and a coloured quark being ejected!
- Happens in about 10% of low x DIS events



- Mechnanism poorly understood, but must involve an exchange with no net colour!

Kinematics

Standard DIS variables …

x = momentum fraction q/p
Q^2 = $|\gamma^*$ 4-momentum squared$|$

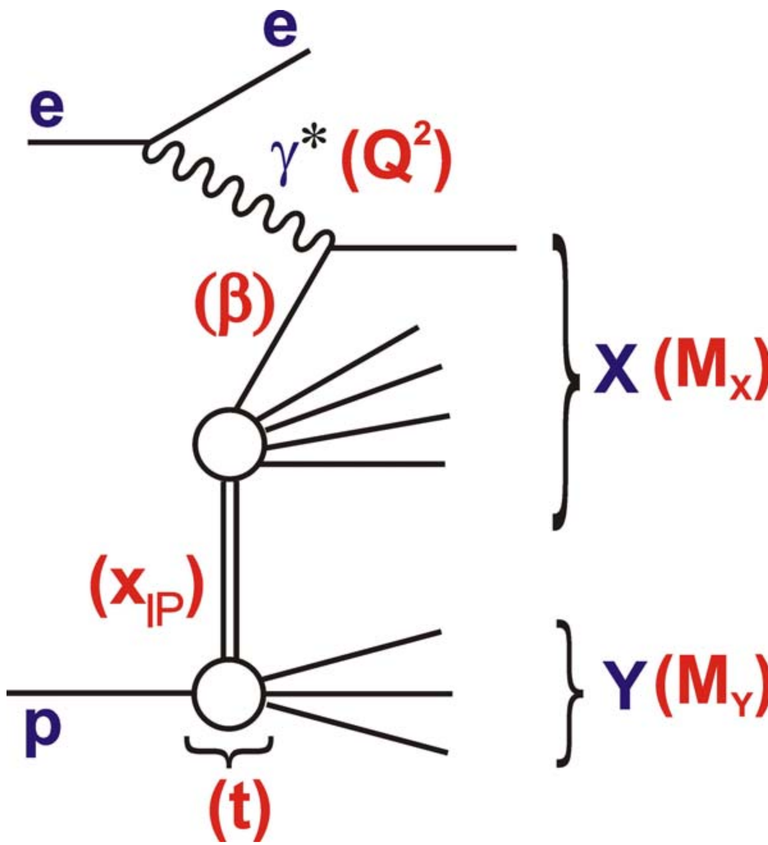
Additional variables for diffraction …

t = squared 4-momentum transfer at proton vertex

x_{IP} = fractional momentum loss of proton (momentum fraction IP/p)

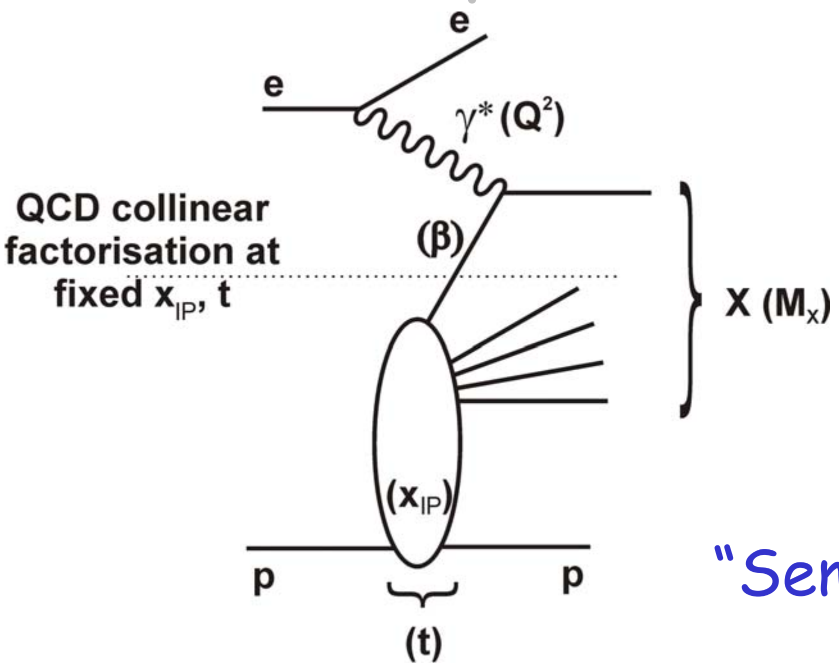
$\beta = x / x_{IP}$ (momentum fraction q / IP)

Most generally ep→eXY …



In most cases here, Y=p, (small admixture of low mass excitations)

The "Proper" Theory



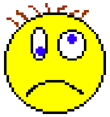
"Semi-inclusive QCD Factorisation"

QCD hard scattering collinear factorisation proved for diffraction at fixed scattered proton 4-vector (Collins 1997)

$$\mathrm{d}\sigma_{\text{parton } i}(ep \to eXY) = f_i^D(x, Q^2, x_{IP}, t) \otimes \mathrm{d}\hat{\sigma}^{ei}(x, Q^2)$$

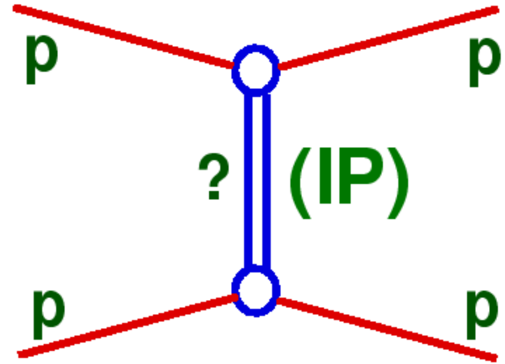
i.e. can define **diffractive PDFs (DPDFs), f_i^D**… 

At fixed (x_{IP}, t), DPDF Q^2 evolution is same as inclusive PDFs!

But we don't know how DPDFs change with (x_{IP}, t) 

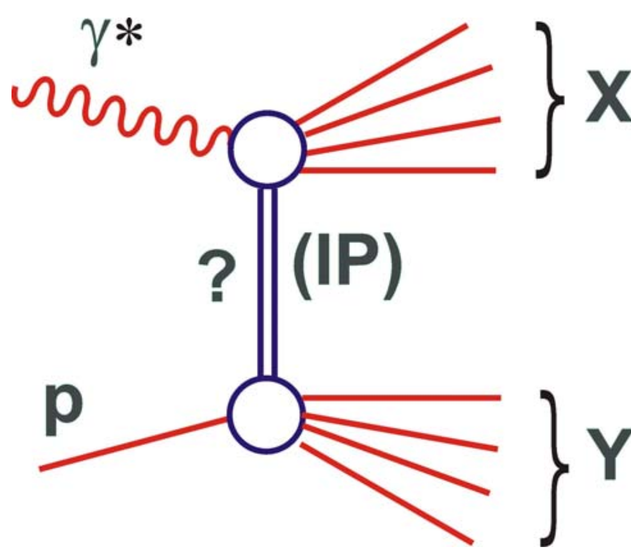
(x_{IP},t) Dependences: Exchanging `Nothing'

• Diffractive DIS reminiscent of (soft) `diffractive' scattering in hadronic interactions, governing high energy elastic and total hadronic cross sections.



• Net quantum #s exchanged = nothing!!!

• The **vacuum exchange `pomeron' (IP)** was introduced to describe this exchange in the context of Regge theory

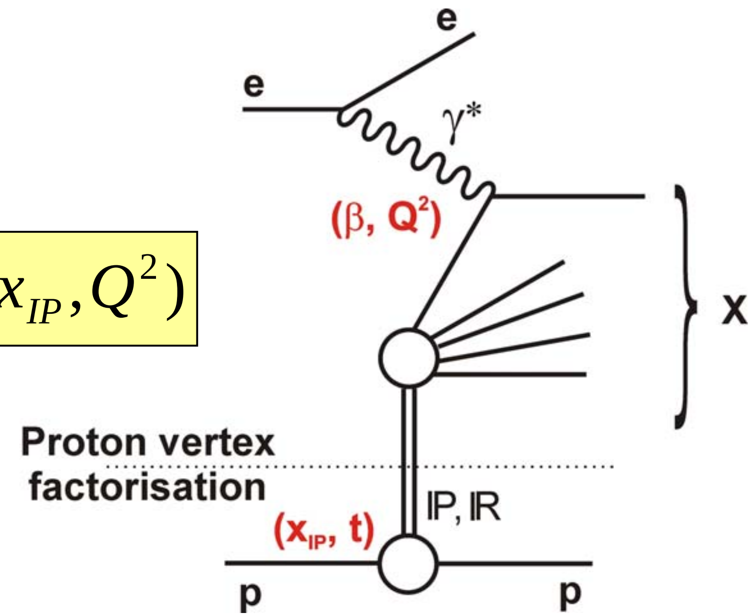


• ?... related to $\gamma^* p \rightarrow XY$, where the virtual photon resolves the structure of the exchange (IP) ...?

A deeper factorisation?

'Proton vertex' factorisation
… completely separate (x_{IP}, t)
from (β, Q^2) dependences.

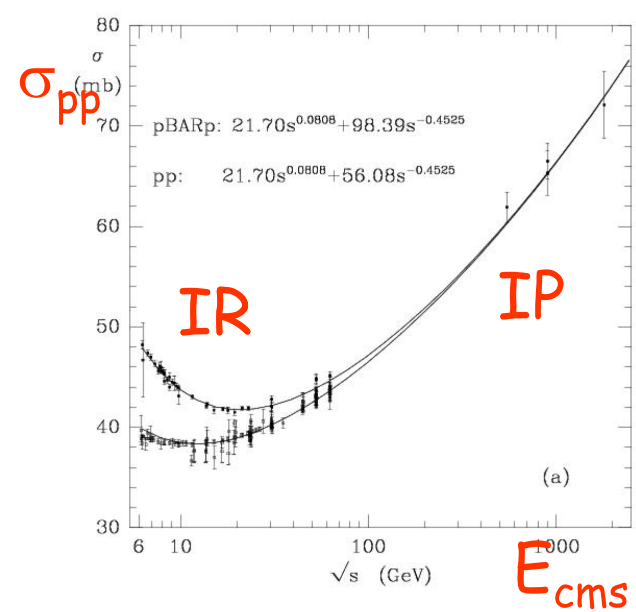
$$f_i^D(x, Q^2, x_{IP}, t) = f_{IP/p}(x_{IP}, t) \cdot f_i^{IP}(\beta = x / x_{IP}, Q^2)$$



No firm QCD basis, but consistent with all experimental data!

DPDFs at fixed x_{IP} and t then measure partonic structure of the exchanged system (IP)

… in fact there a `sub-leading' (IR) exchange is also present at high x_{IP} (as for total, elastic pp cross sections)



So why is this interesting?…

• Understanding QCD at low x … test of new factorisation theorem, field theory description of multi-particle exchange.

• Relationship diffractive v inclusive DIS?

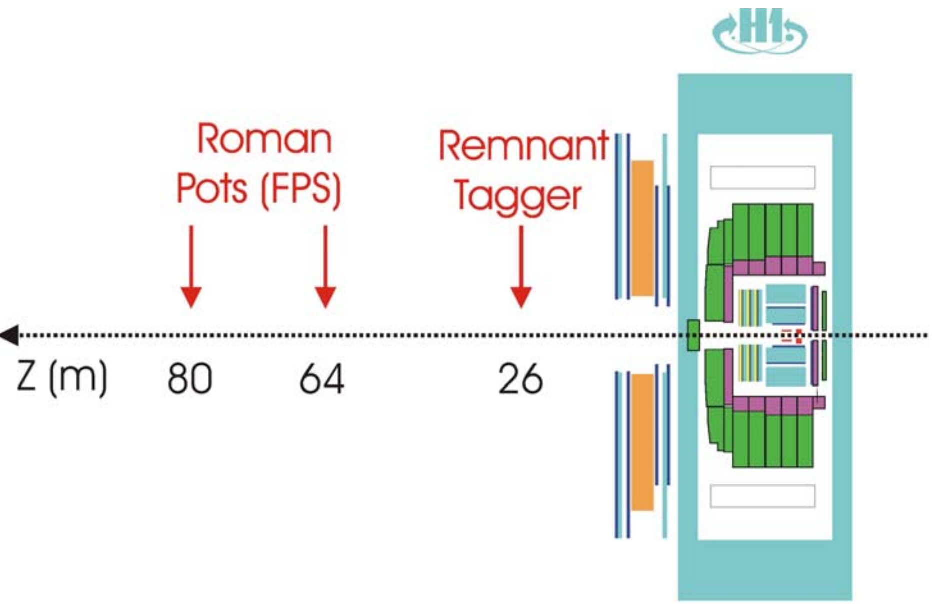
• Relationship diffractive DIS v hadronic diffraction?

• Relation to diffractive producion, especially Higgs (pp →ppH) at Tevatron / LHC.

• … relation to confinement?

• Clarify historical disagreement between H1 and ZEUS … some strange methods have been used … with some strange results!

Detecting Diffractive DIS (FPS Method)

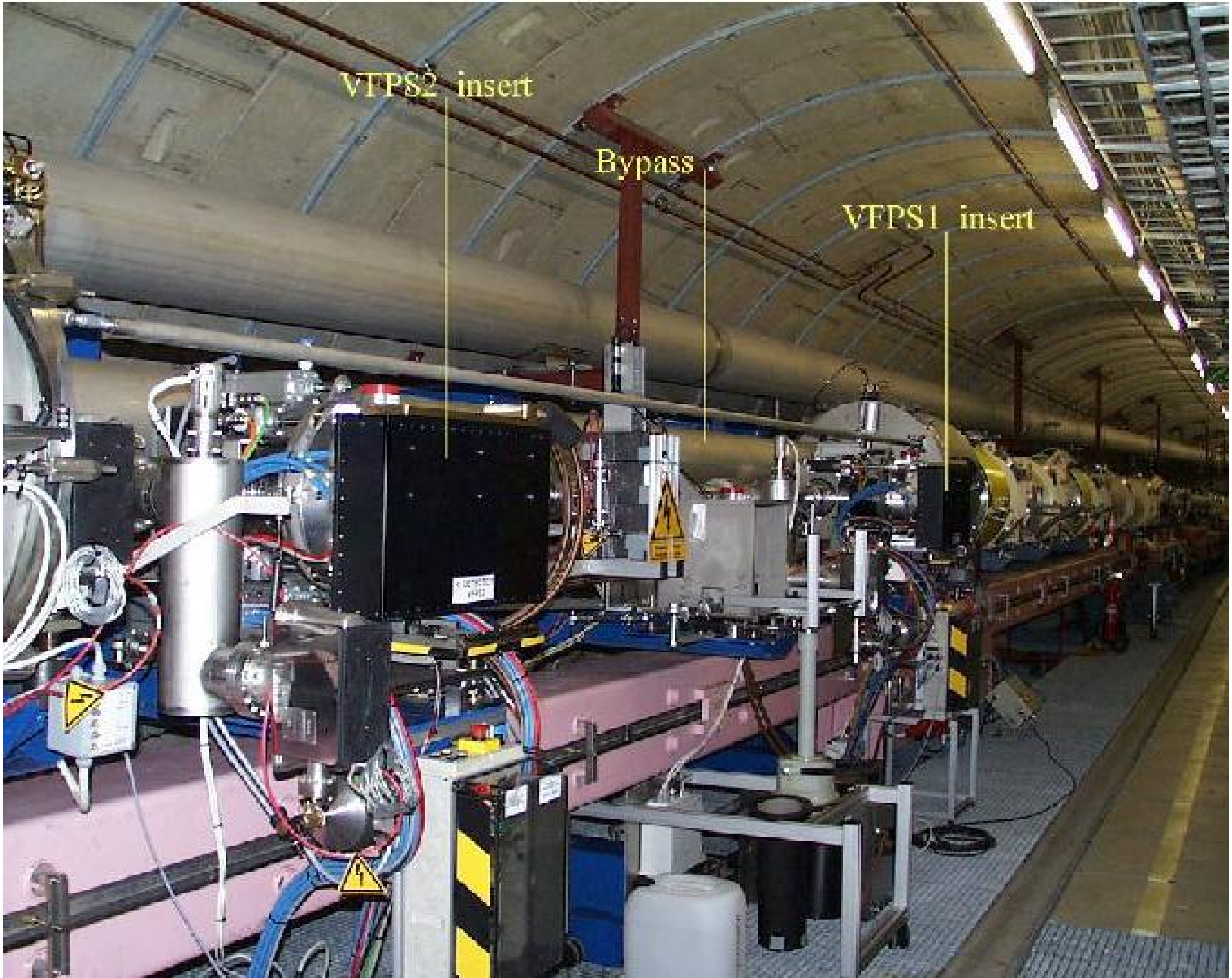


By far the cleanest selection method is to detect and measure final state proton

Done with `Roman Pot' inserts to beampipe (`Forward Proton Spectrometer, FPS')

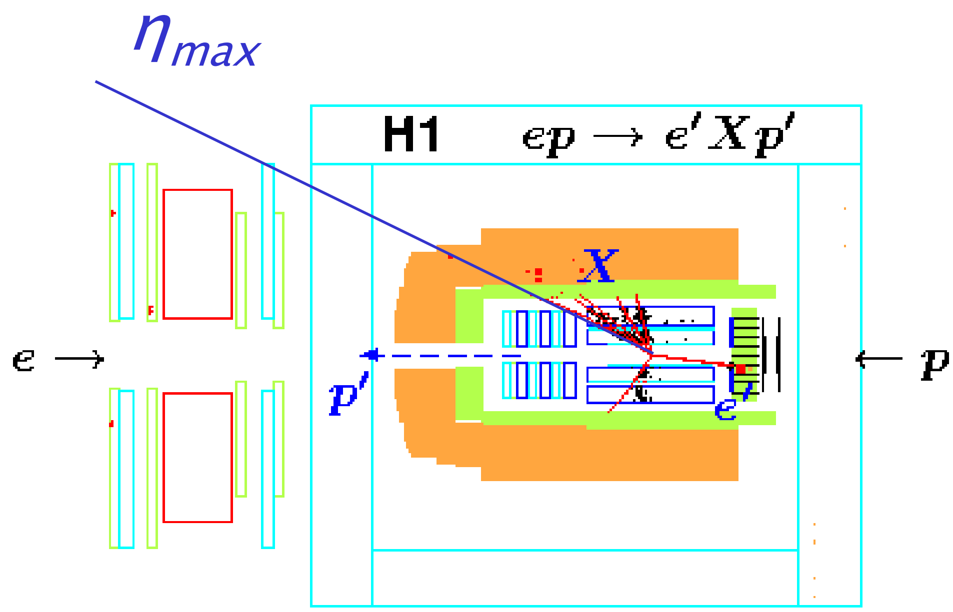
- No proton dissociation
- Can measure all variables, including t and get to high x_{IP}
- Difficult operation, low acceptance … poor statistics (though HERA-II data are looking promising!)

Example Roman Pots (H1 VFPS)



Alternative Method based on Event Topology

- Colour singlet exchange to produce low mass system X implies Large Rapidity Gap separating leading proton from hadrons comprising X.
- Select by requiring absence of activity in forward part of calorimeter and specialised forward detector components (LRG method)



Scattered proton unobserved → some p dissociation, no t measurement (measure for M_Y<1.6 GeV, |t|<1 GeV^2)

Near perfect acceptance at low x_{IP}

FPS and LRG methods together are hugely powerful!

Data Sets

- **FPS sample** 1999-2000 data (28 pb^{-1})
- **LRG sample** 1997 data (2 pb^{-1} for $Q^2 < 13.5$ GeV^2)
  1997 data (11 pb^{-1} for $13.5 < Q^2 < 105$ GeV^2)
  1999-2000 data (62 pb^{-1} for $Q^2 > 133$ GeV^2)

- **FPS and LRG measurements statistically independent and only very weakly correlated through systematics.**

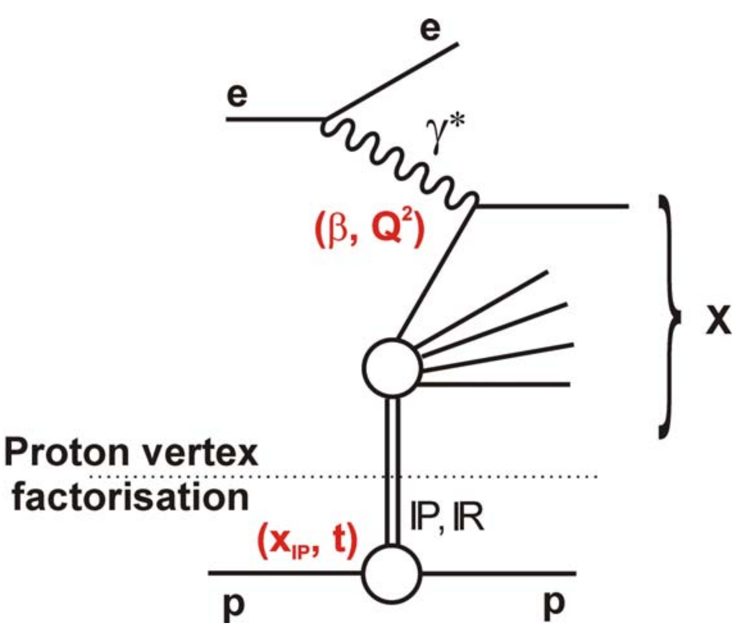
- **Measurements over unprecedented kinematic range, $2.7 < Q^2 < 1600$ GeV^2!**

Measurements and Observables

Main observable is the Diffractive `reduced cross section' …

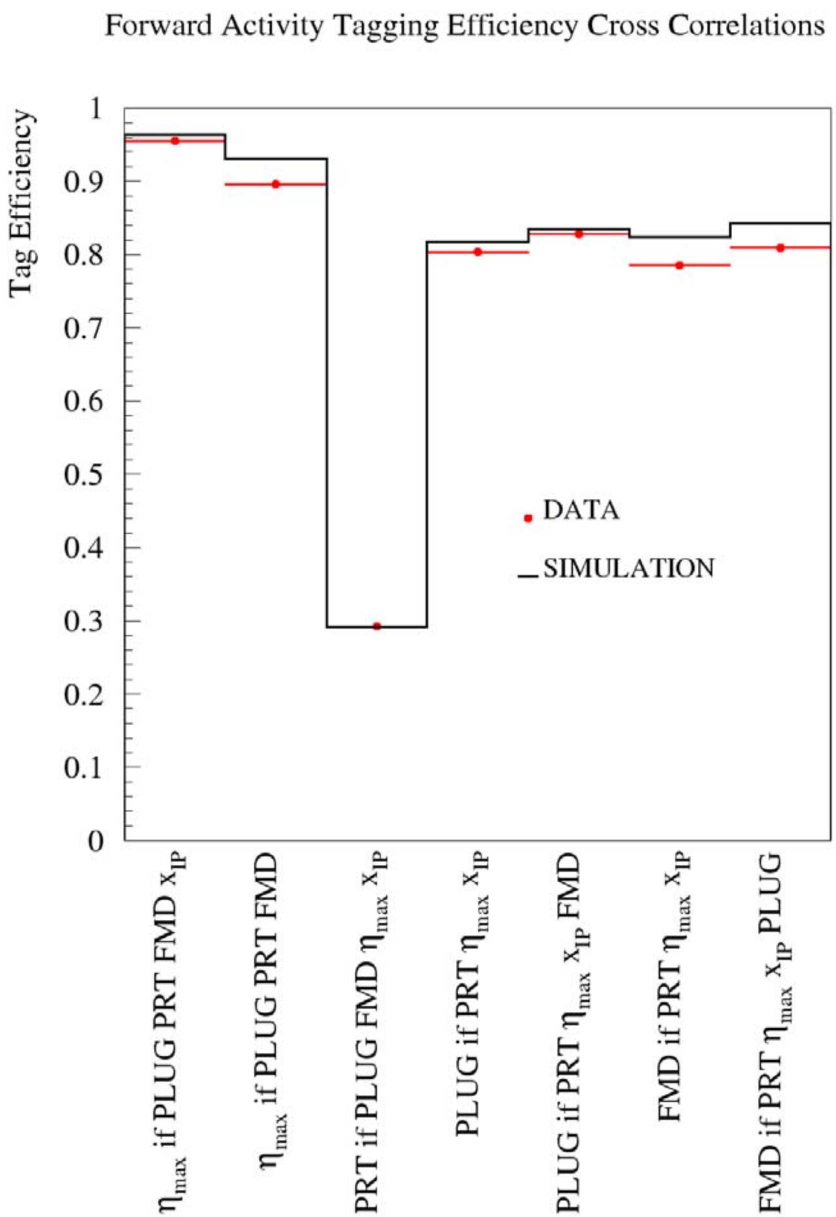
$$\sigma_r^{D(3)}(\beta, Q^2, x_{IP}) = F_2^{D(3)} - \frac{y^2}{Y_+} F_L^{D(3)} \approx F_2^{D(3)}$$

… cross section (or structure fn.) dependent on 3 variables
… 4 if you also include t → $\sigma_r^{D(4)}(\beta,Q^2,x_{IP},t)$!
… can only realistically study 1 (maybe 2) variables at a time!



- (x_{IP},t) dependences at fixed (β,Q^2) for soft (Pomeron) physics
- (β,Q^2) dependences at fixed (x_{IP},t) for hard (QCD) physics … Diffractive quarks and gluons

Understanding the LRG Method



Forward detectors sensitive to energy flow in the region

$$3.3 < \eta <\sim 7.5$$

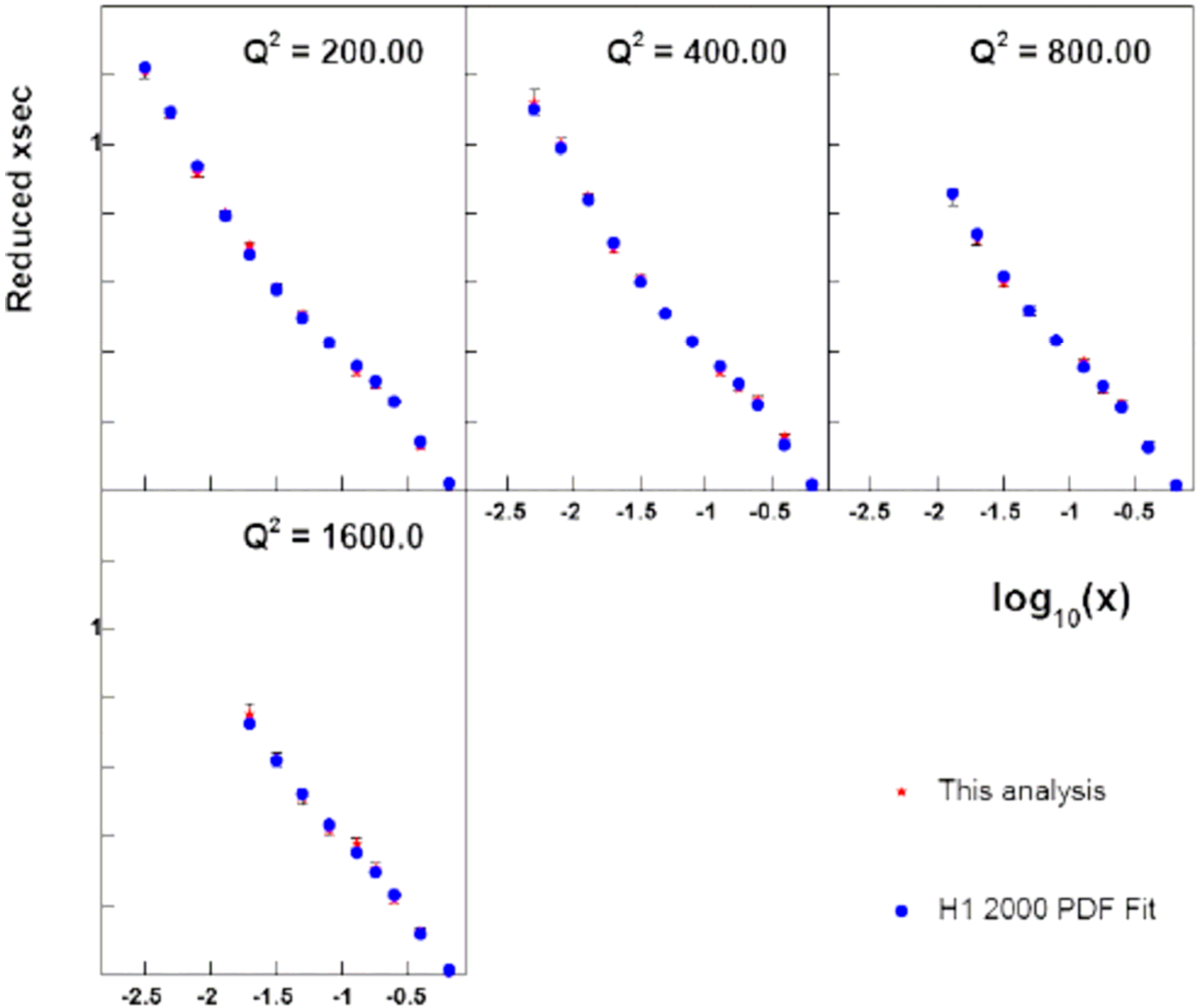
Cross-calibrate forward detectors using response to non-diffractive events.

Correcting to M_Y<1.6 GeV is largest systematic error.

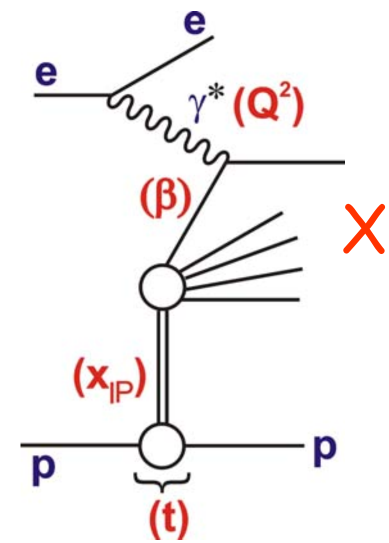
Ensuring Measurement Quality

Have to ensure that we reproduce the inclusive reduced cross section, $\sigma_r(x,Q^2)$...

... electron well understood



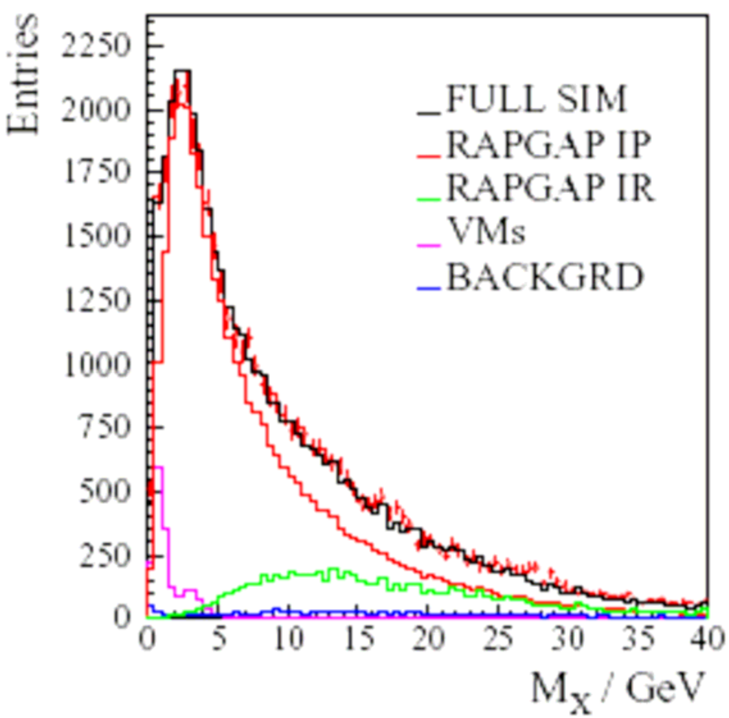
Ensuring Measurement Quality II

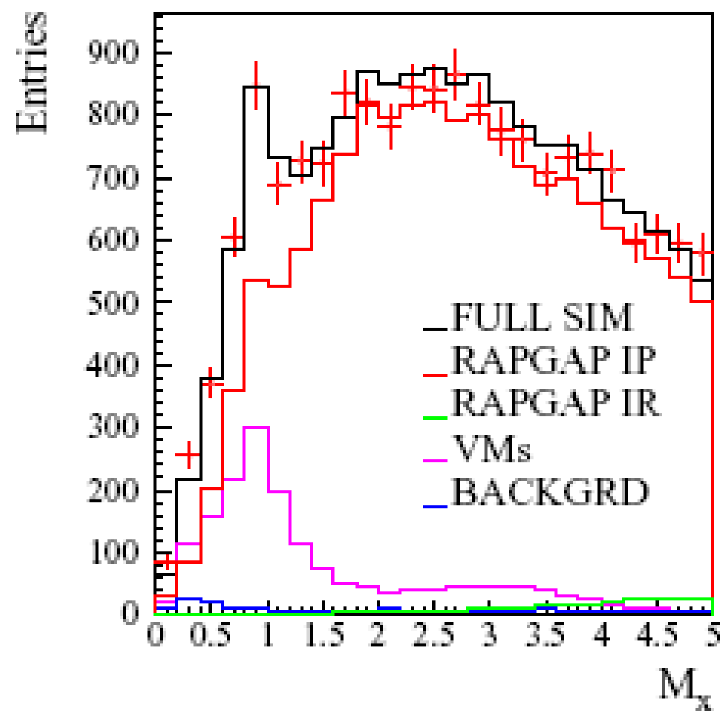


Have to ensure we understand the hadrons, especially M_X mass measurement, from which …

$$\beta = Q^2 / (Q^2 + M_X^2)$$

$$x_{IP} = x / \beta$$





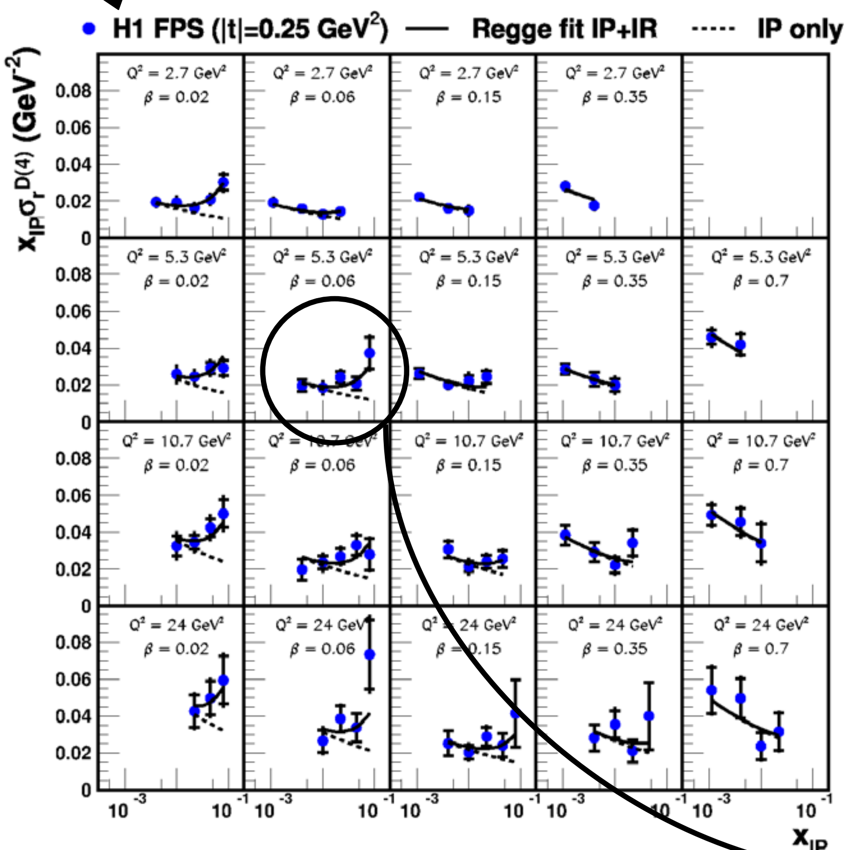
ep → eXY Data

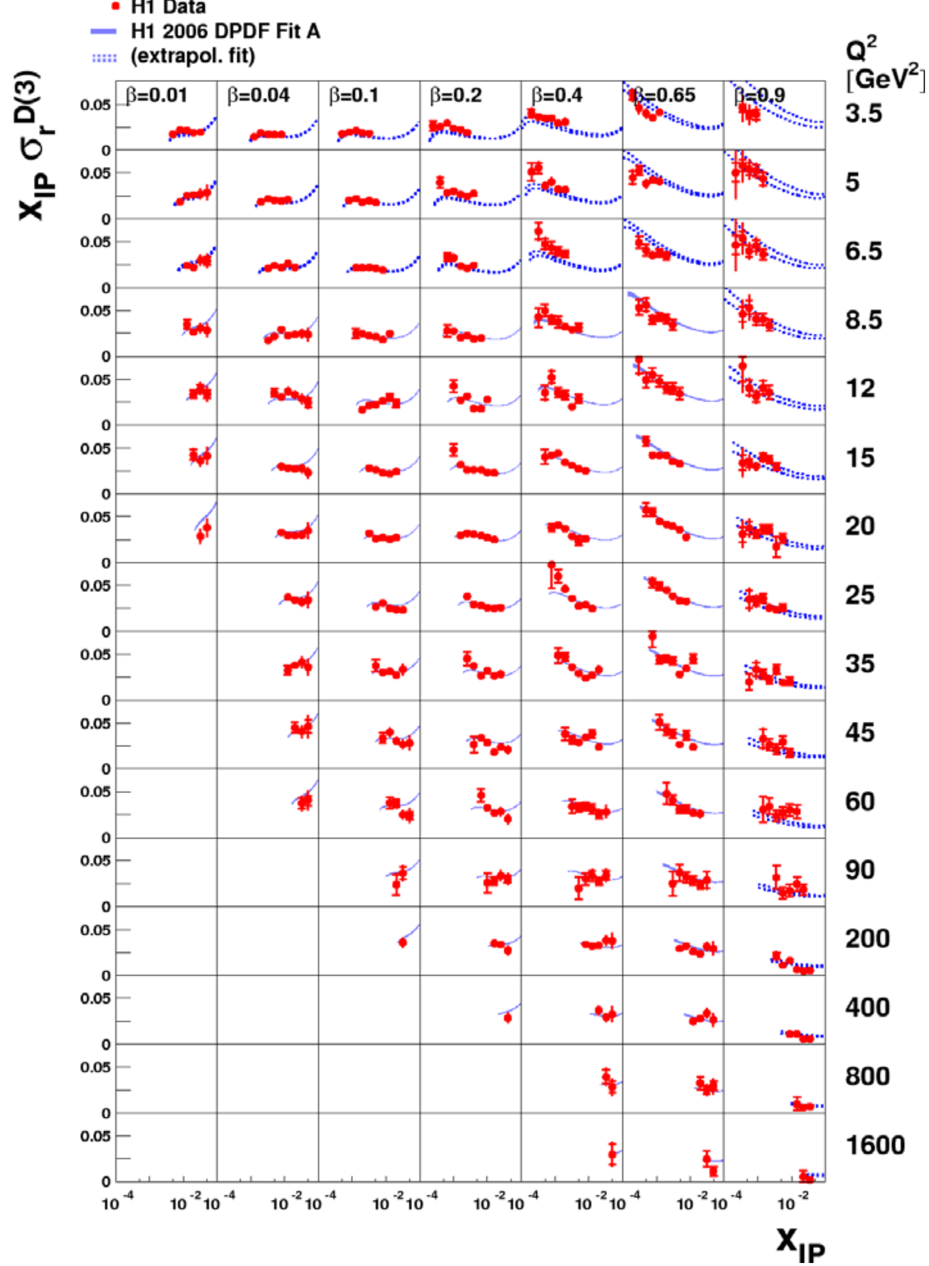
LRG: M_Y < 1.6 GeV →

$$3.5 \leq Q^2 \leq 1600 \text{ GeV}^2$$

FPS: Y=p

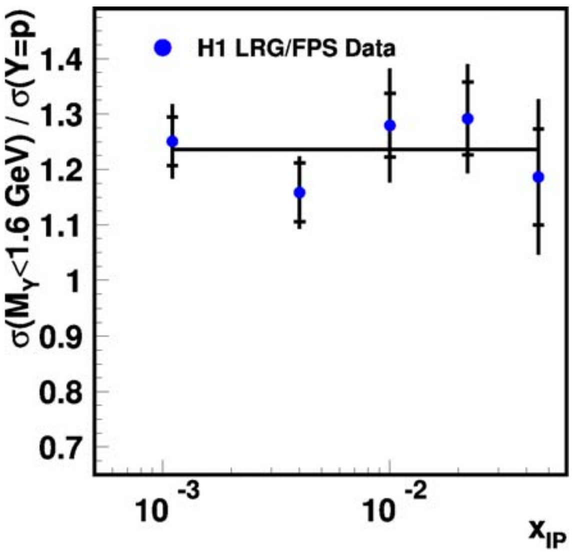
$$2.7 \leq Q^2 \leq 24 \text{ GeV}^2$$

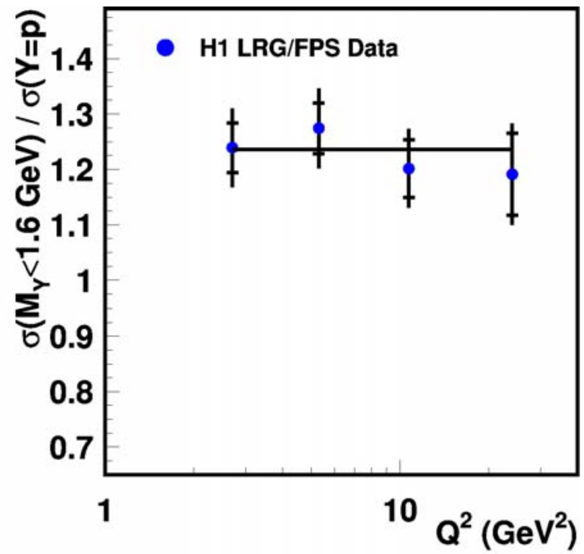


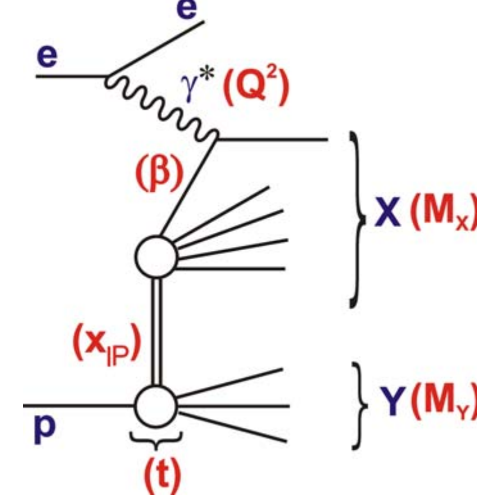


x_{IP} dependence shows clear IP+IR structure

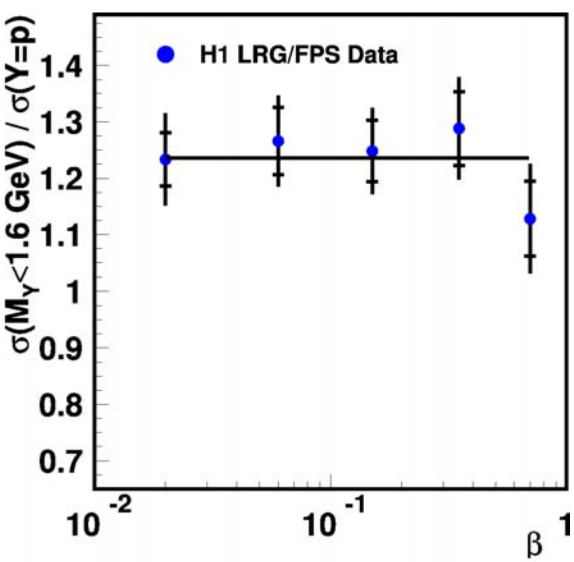
Detailed Comparison LRG v FPS







LRG measurement also done in FPS bins



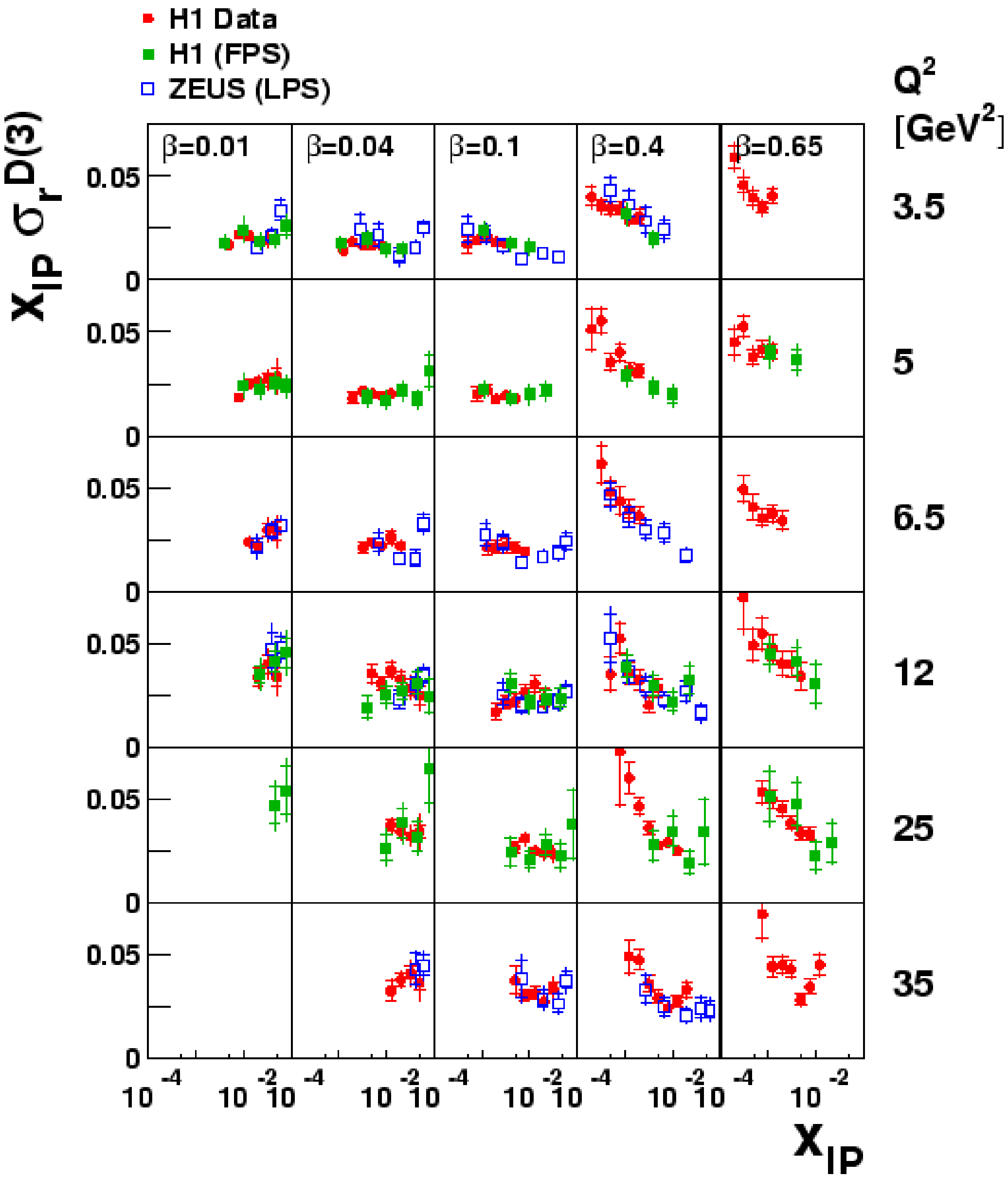
- Form ratio of measurements as a function of x_{IP}, β or Q^2 after integration over others

$$\frac{\sigma(M_Y < 1.6\ \text{GeV})}{\sigma(Y = p)} = 1.23 \pm 0.03\ (\text{stat.}) \pm 0.16\ (\text{syst.})$$

independently of kinematics within errors

- Agreement in detail between methods
- M_Y dependence factorises within (10%) (non-norm^n) errors

H1 LRG v H1 FPS v ZEUS LPS Data



- ZEUS and H1 Roman pot data agree to well within normalisation uncertainties

- Very good agreement between proton-tagging and LRG methods.

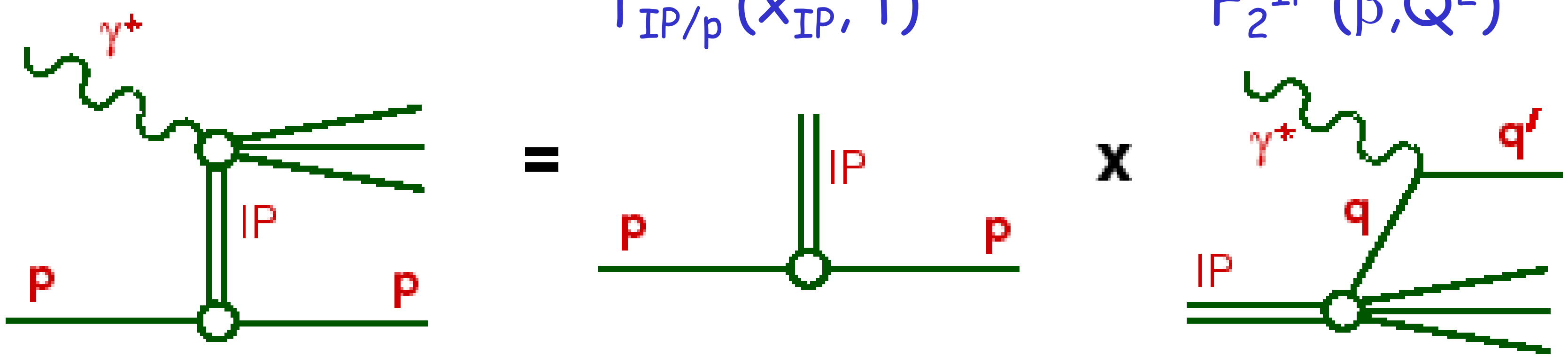
- Roman Pot data scaled by global factor of 1.23 to account for proton dissociation (M_Y<1.6 GeV) in LRG data.

Proton Vertex Factorisation and 'Pomeron Flux'

If proton vertex factorisation works, we can factorise out x_{IP}, t (and M_Y) dependence into a `flux factor'

MEASUREMENT = IP FLUX x IP STRUCTURE

$f_{IP/p}(x_{IP}, t)$ $F_2^{IP}(\beta, Q^2)$



'Flux' parameterisation inspired By Regge theory ...

$$f_{IP/p}(x_{IP}, t) = \frac{e^{B_{IP}t}}{x_{IP}^{2\alpha_{IP}(t)-1}}$$

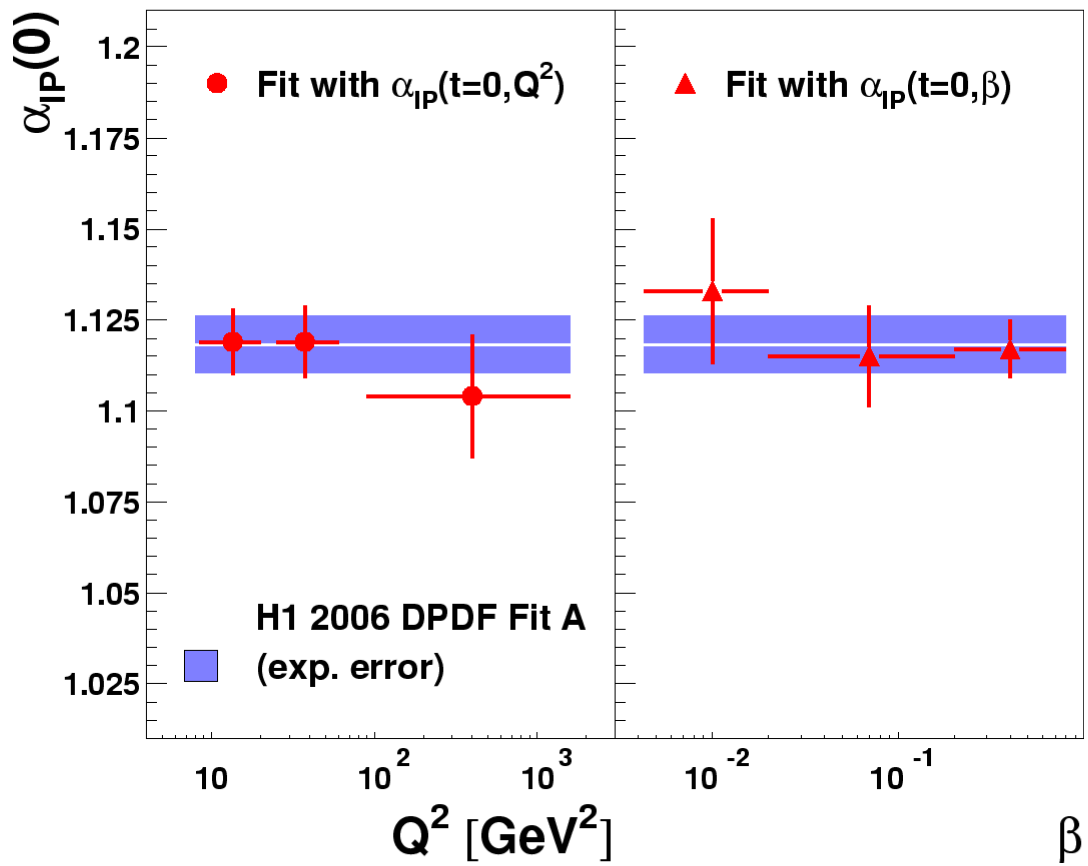
Free parameters - pomeron `trajectory' $\alpha_{IP}(t) = \alpha_{IP}(0) + \alpha'_{IP}\, t$

Effective Pomeron Intercept (x_{IP} Dependence)

From fit to x_{IP} dependence of LRG data (see later …)

$$\alpha_{IP}(0) = 1.118 \pm 0.008\ (\text{exp.})\ ^{+0.029}_{-0.010}\ (\text{theory})$$

Adding extra parameters for $\alpha_{IP}(0)$ in different Q^2 or β regions shows no significant variation (as required for proton vertex factorisation)

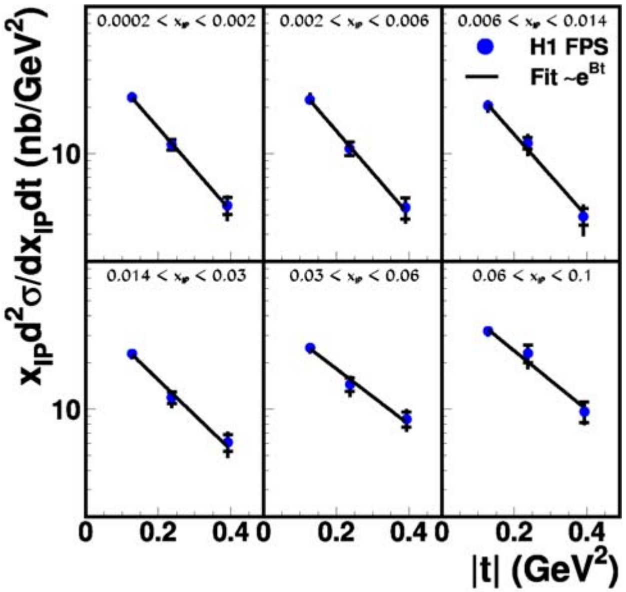


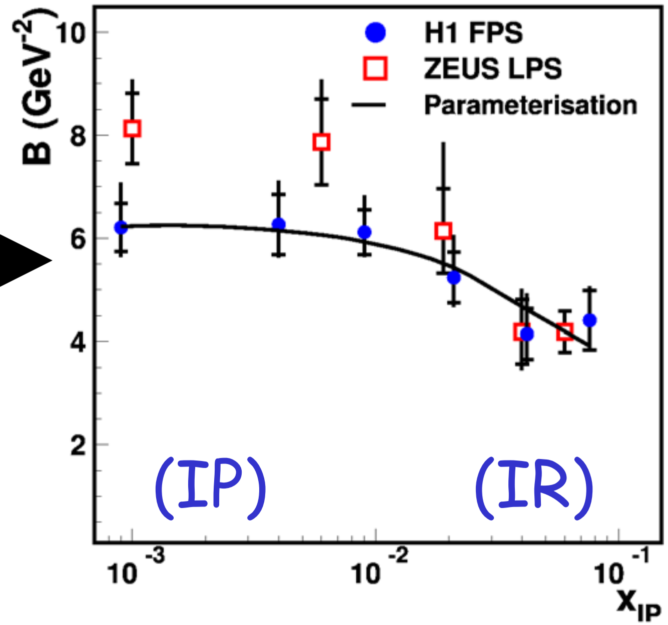
Consistent result from similar fit to x_{IP} dependence of FPS data:

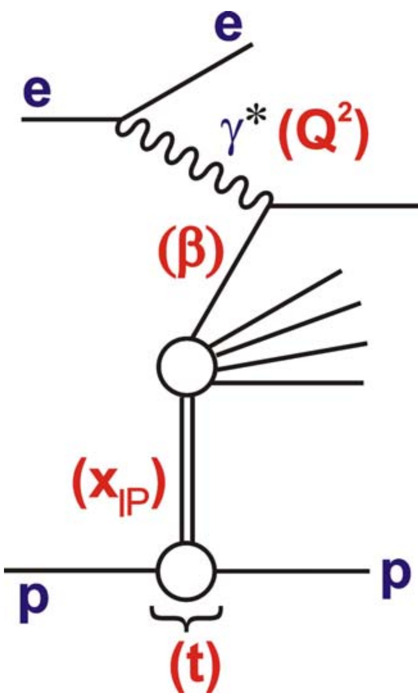
$$\alpha_{IP}(0) = 1.114 \pm 0.018\ (\text{stat.}) \pm 0.012\ (\text{syst.})\ ^{+0.040}_{-0.020}\ (\text{theory})$$

t Dependence from FPS Data

Fit to exp(Bt) in bins of x_{IP}







$B(x_{IP})$ data constrain pomeron trajectory slope α'_{IP} in proton vertex factorisation model…

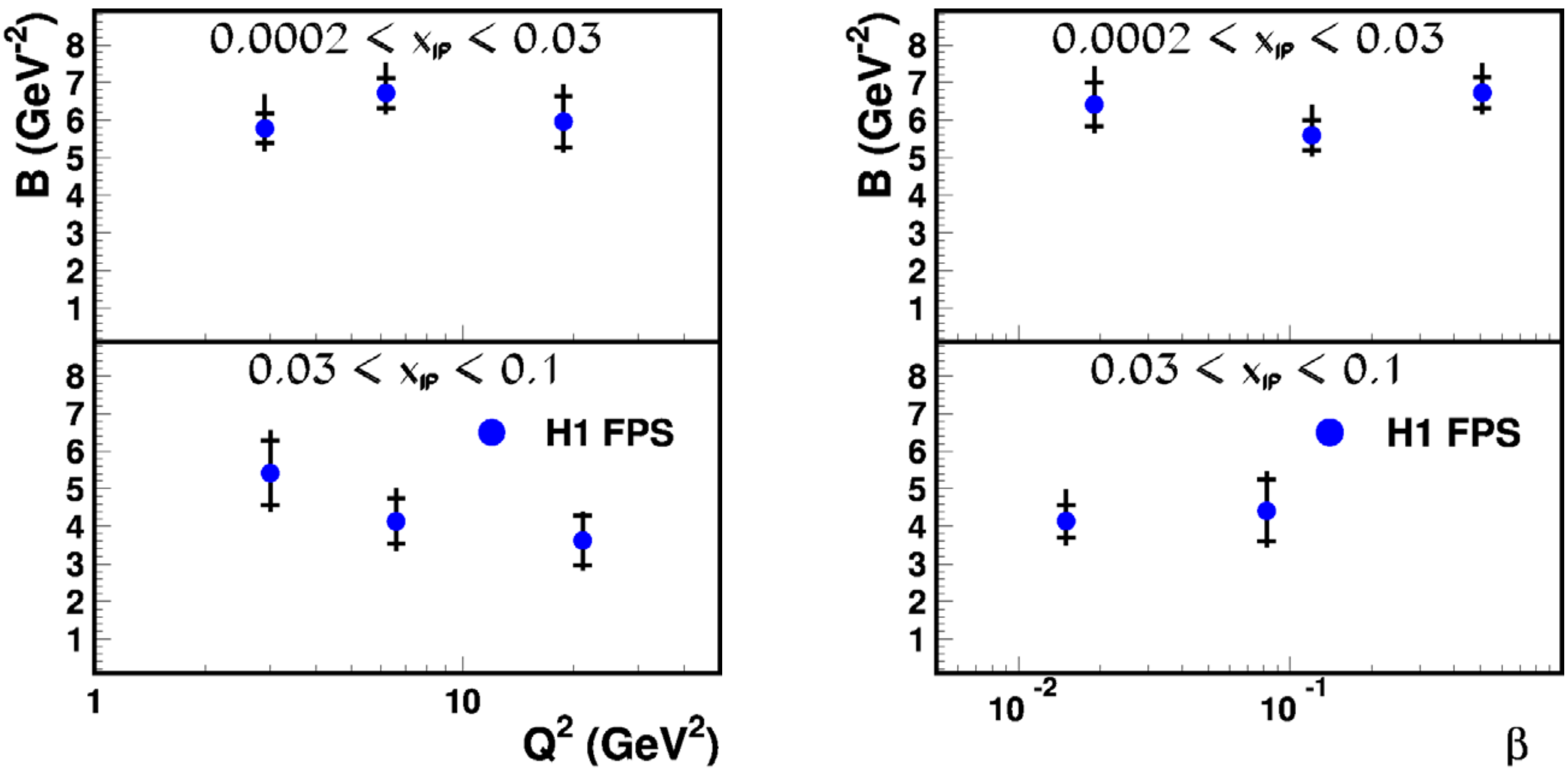
$$B = B_0 + 2\alpha'_{IP} \ln(1/x_{IP})$$

No strong dependence of B on x_{IP} in IP region …

$$\alpha'_{IP} = 0.06^{+0.19}_{-0.06}\ \mathrm{GeV}^{-2}$$

t Slope Dependence on β or Q^2?

... B measured double differentially in (β or Q^2) and x_{IP}



- t dependence does not change with β or Q^2 at fixed x_{IP}
- Proton vertex factorisation of (x_{IP},t) from (β,Q^2) working!

... in contrast to many multi-component models (BEKW, KGB ...)

QCD Aspects! $\sigma_r^{D(3)}(\beta, Q^2, x_{IP})$ at $x_{IP} = 0.0003$

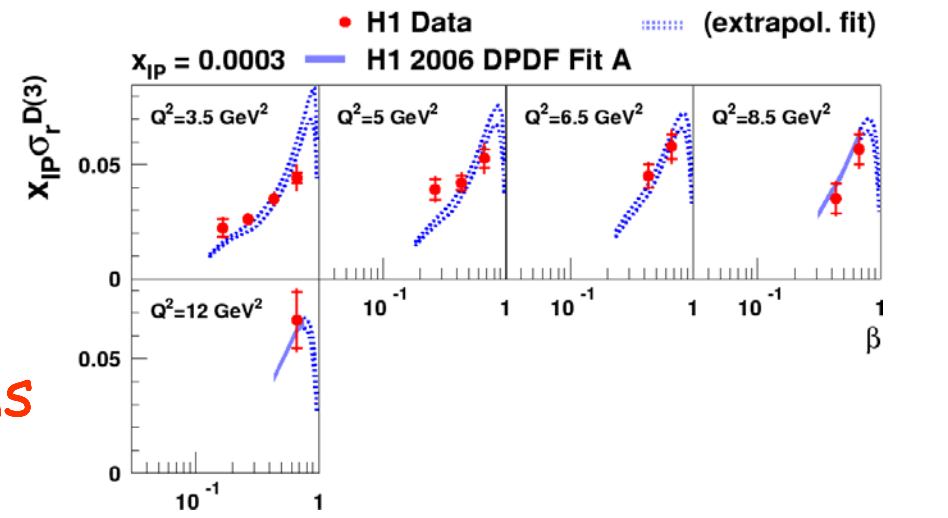
- Study QCD structure with LRG data …Q^2 and β (= x / x_{IP}) dependences at a small number of fixed x_{IP} values.

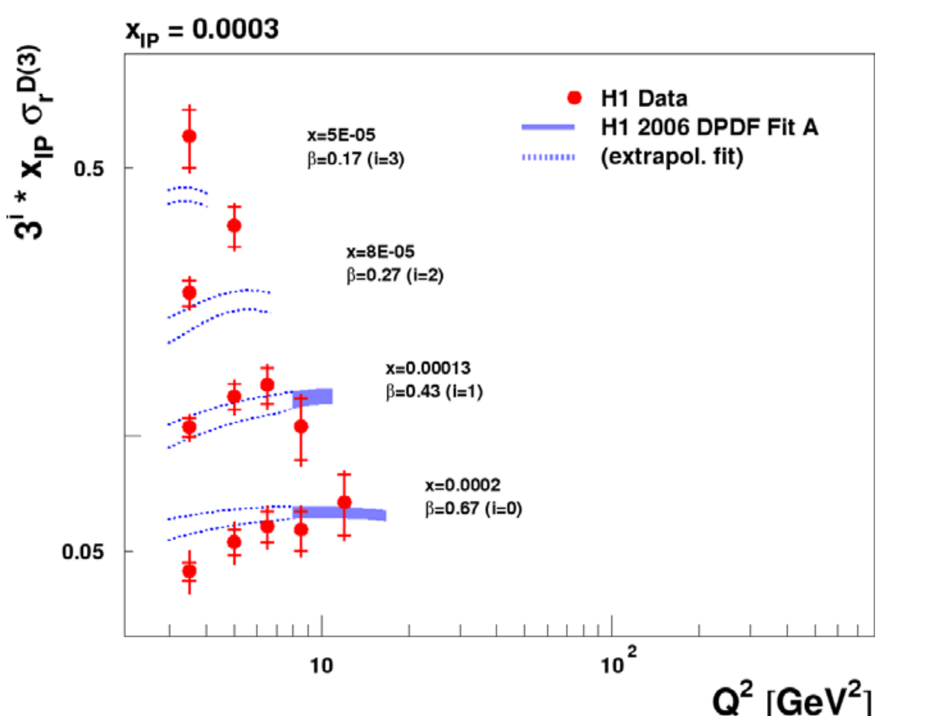
- Good precision – in best regions 5% (stat.), 5% (syst) 6% (norm)

- Directly measures diffractive quark density at fixed x_{IP}

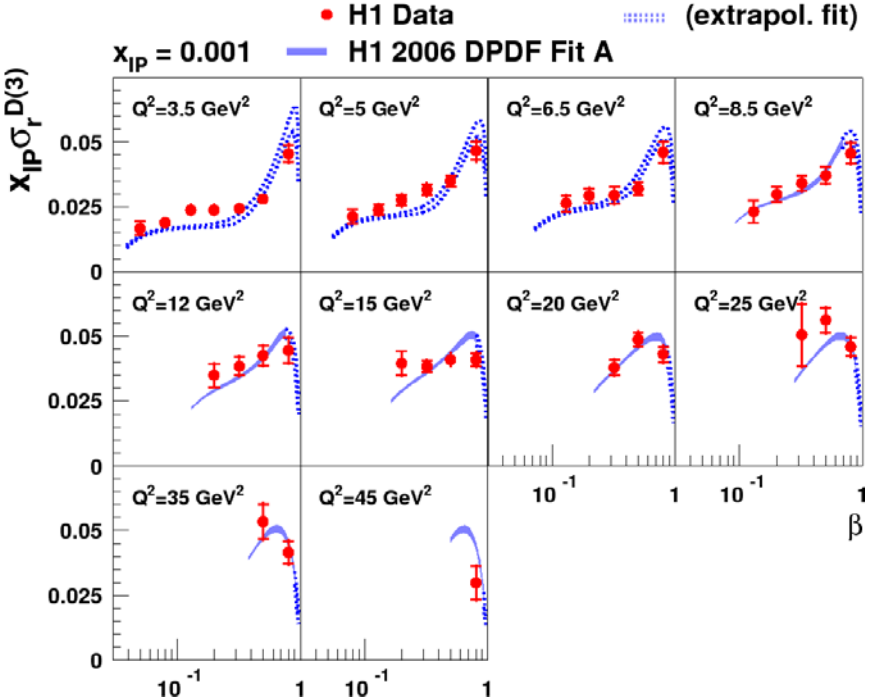
$$\sigma_r^D(\beta, Q^2) \sim F_2^D = \Sigma\, e_q^2\ (q + \bar{q})$$

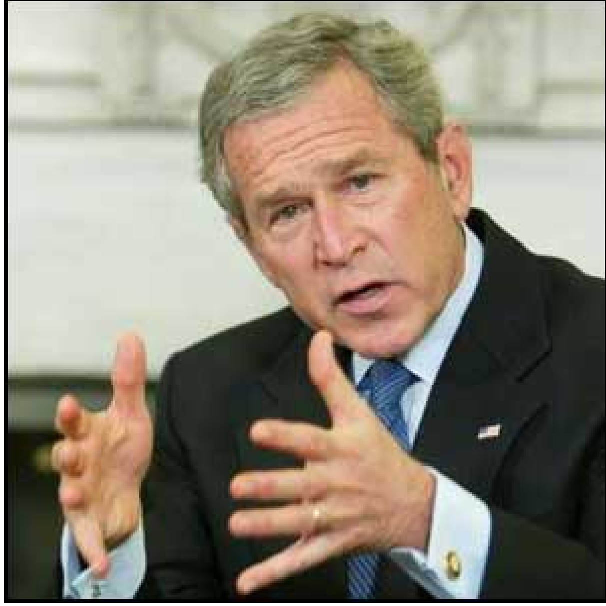
- Data compared with \` H1 2006 DPDF Fit' and error band (assumes proton vertex factorisation - see later)

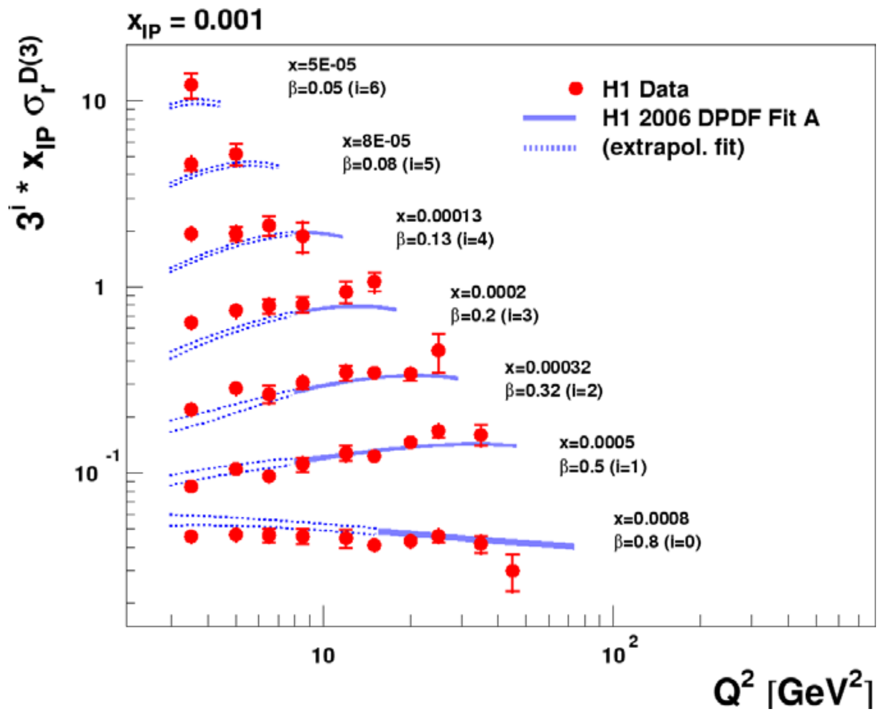




$\sigma_r^{D(3)}(\beta, Q^2, x_{IP})$ at $x_{IP} = 0.001$

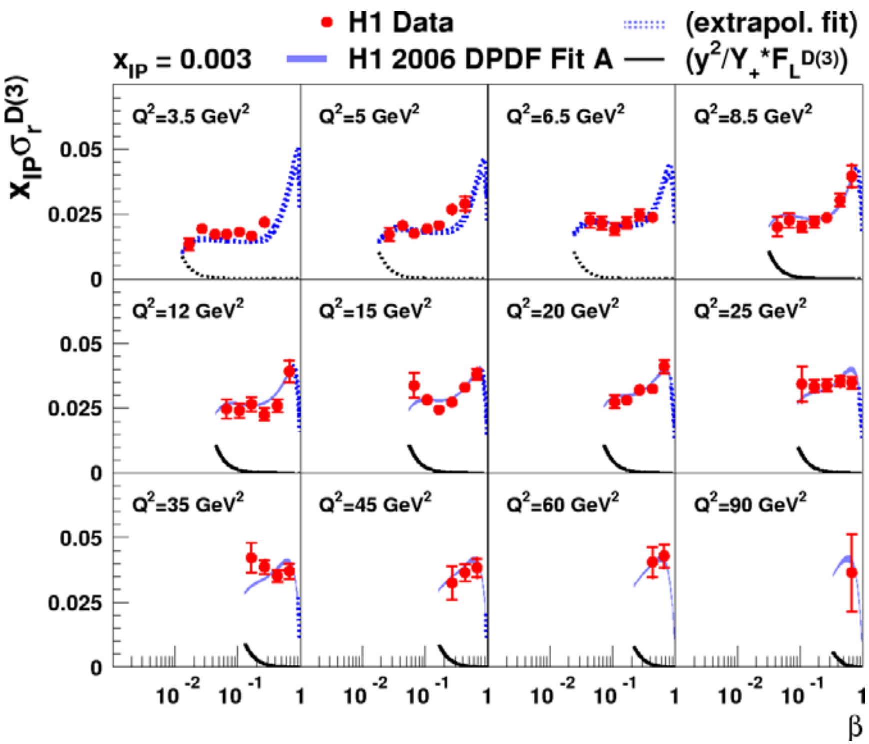


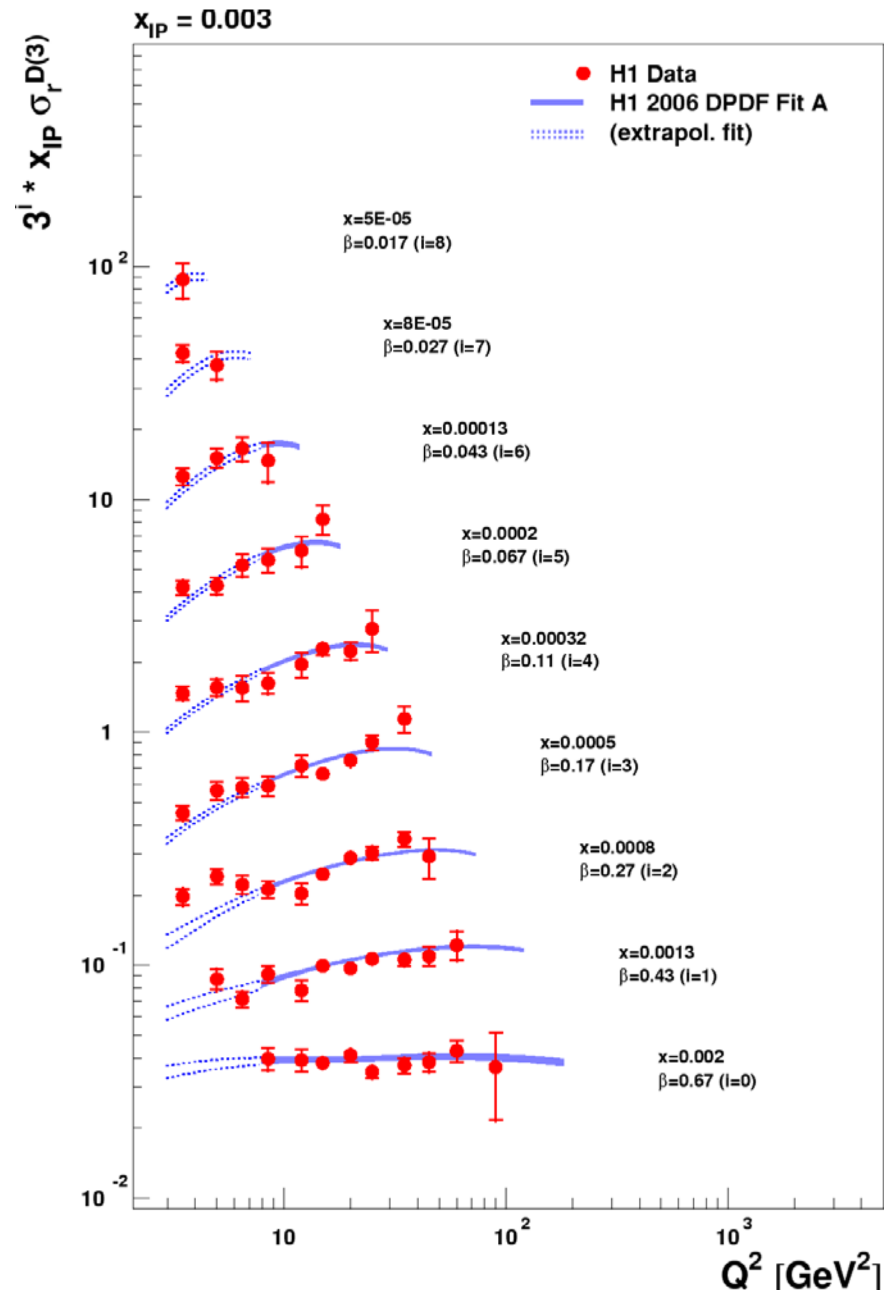




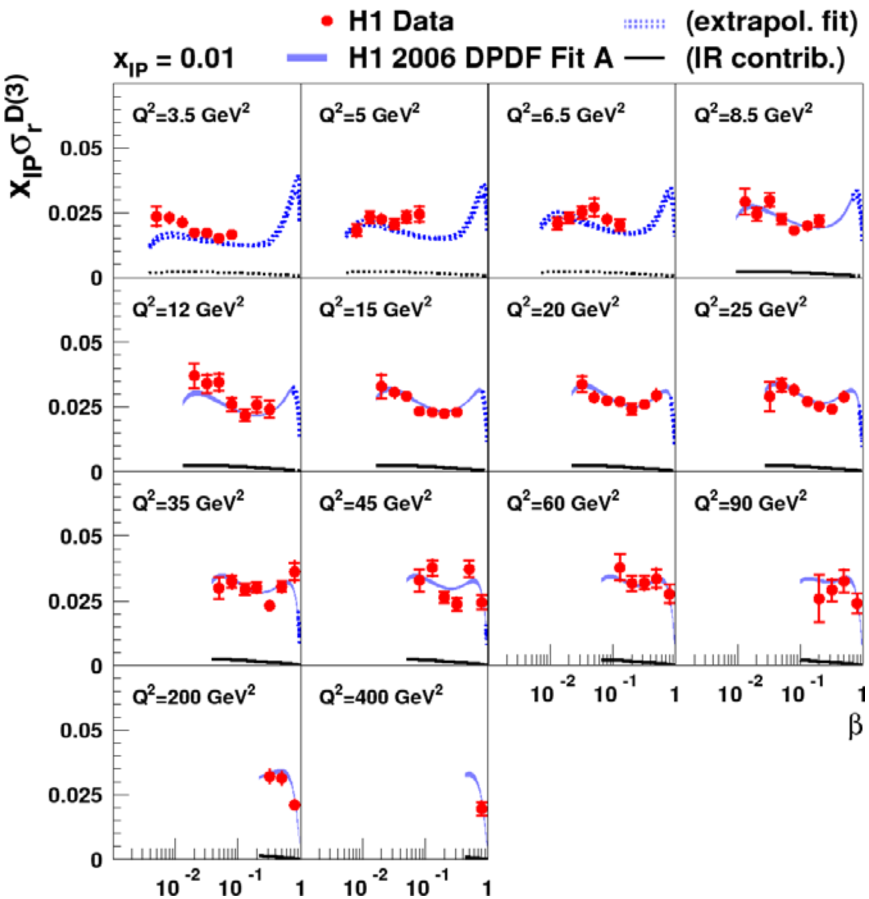
(Like an inclusive F_2 measurement at each value of x_{IP})

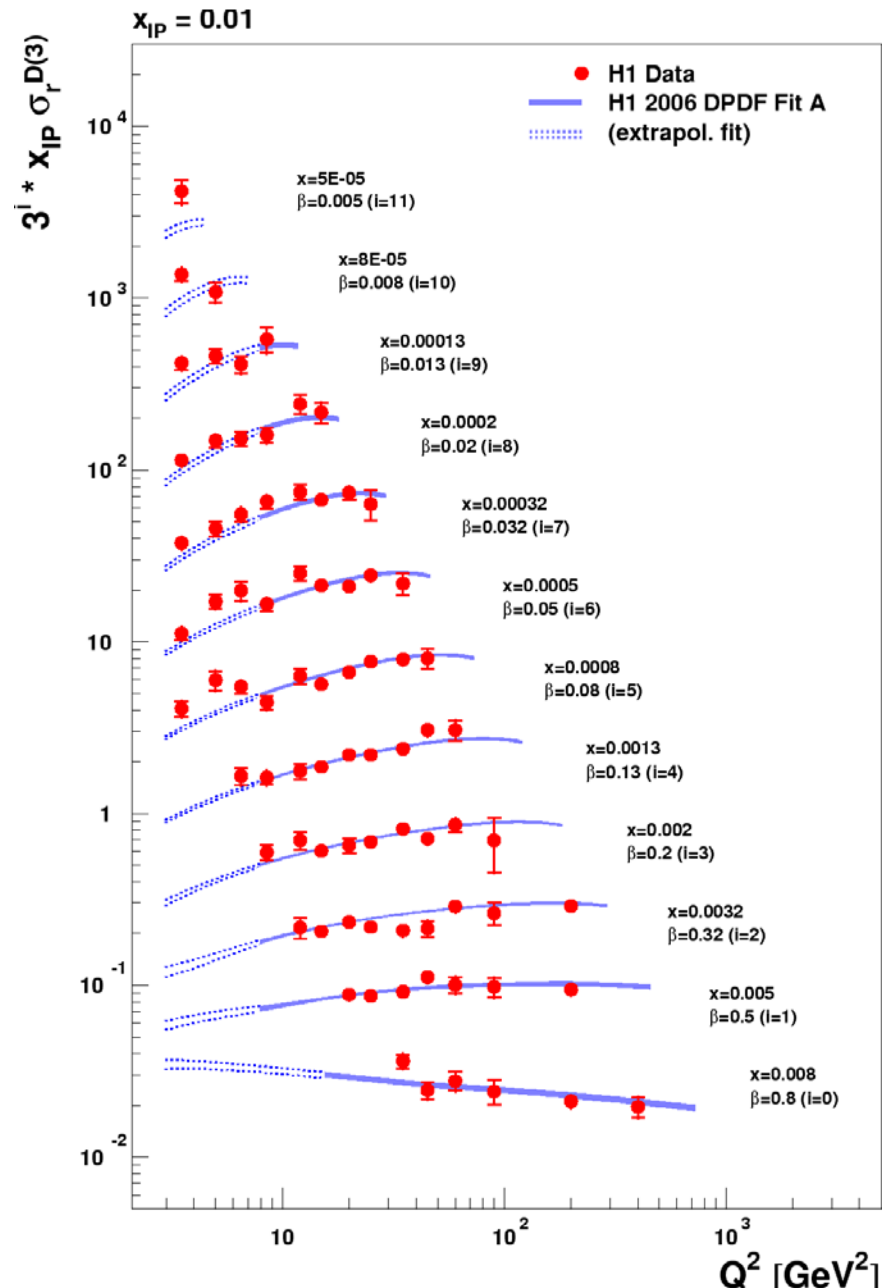
$$\sigma_r^{D(3)}(\beta, Q^2, x_{IP}) \text{ at } x_{IP} = 0.003$$



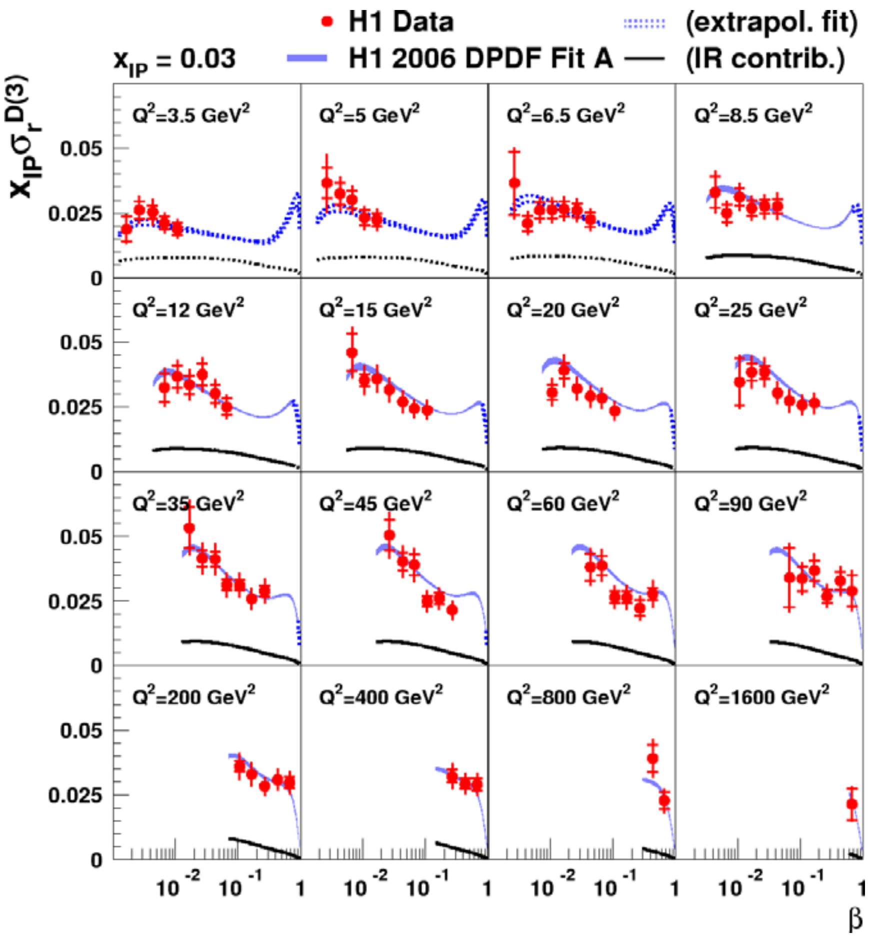


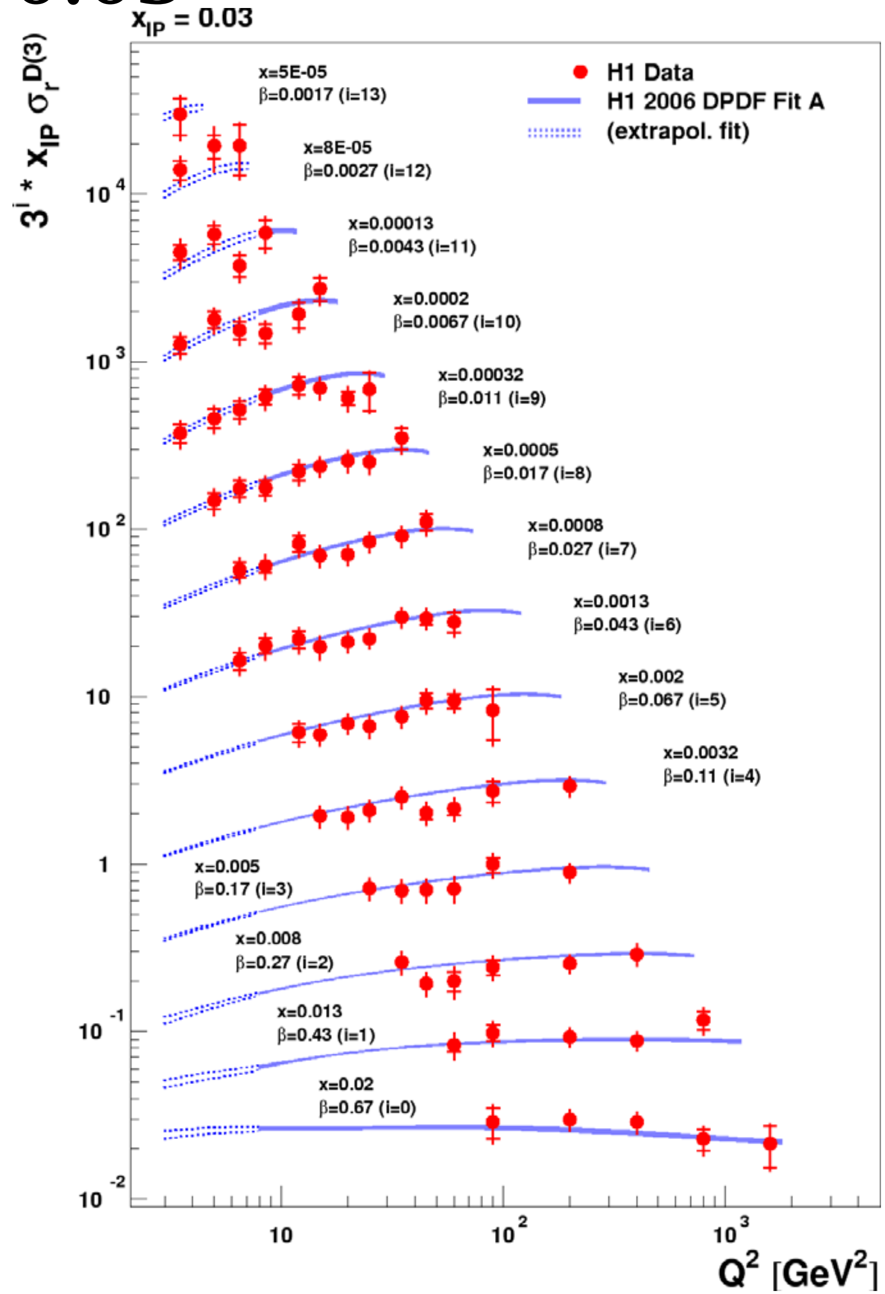
$\sigma_r^{D(3)}(\beta, Q^2, x_{IP})$ at $x_{IP} = 0.01$





$\sigma_r^{D(3)}(\beta, Q^2, x_{IP})$ at $x_{IP} = 0.03$



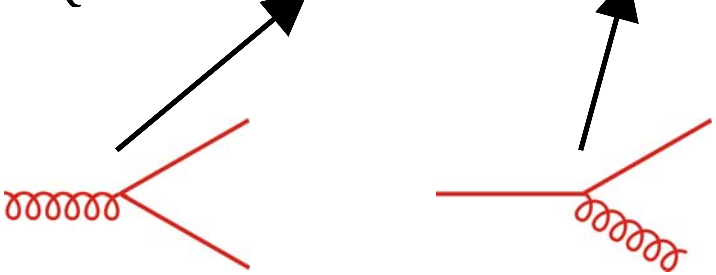


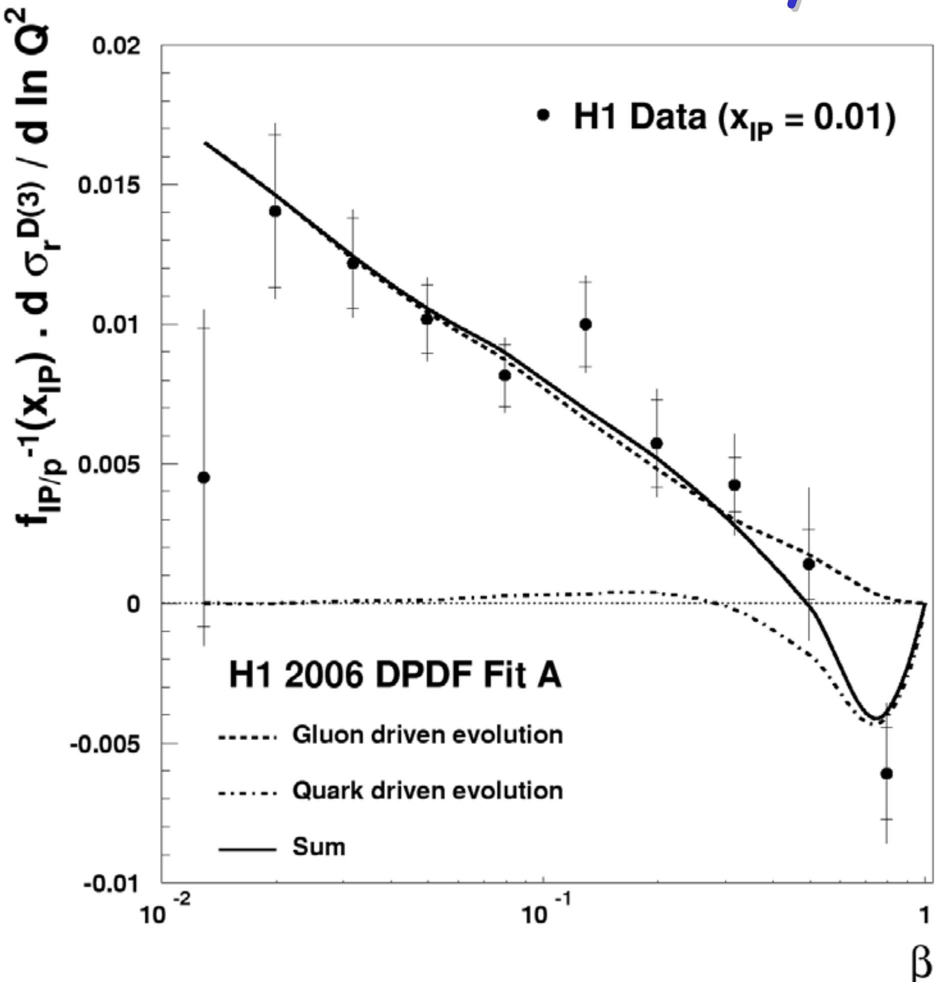
Q^2 Dependence and the Gluon Density

$\sigma_r^{D(3)}$ measures diffractive quark density.

Its dependence on Q^2 is sensitive to diffractive gluon density.

$$\frac{d\sigma_r^D}{d\ln Q^2} \sim \frac{\alpha_s}{2\pi}\left[P_{qg}\otimes g \;+\; P_{qq}\otimes q\;\right]$$

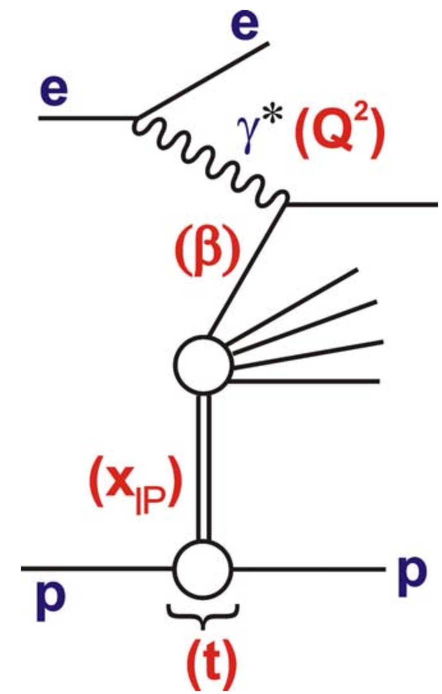




Extract $d\sigma_r^D/d\ln Q^2$ by fitting data at fixed x, x_{IP}

- Low β evolution driven by $g \rightarrow q\bar{q}$ … strong sensitivity to gluon
- High β, relative error on derivative grows, $q \rightarrow qg$ contribution to evolution becomes dominant … sensitivity to gluon is lost!

Extracting the Quarks and Gluons



• Fit β and Q^2 dependence of LRG data from fixed x_{IP} binning scheme (χ^2 minimisation)

• Parameterise DPDFs at starting scale Q_0^2 for QCD evolution …
… evolve to higher Q^2 using NLO DGLAP equations (massive charm) and fit β and Q^2 dependence for DPDFs

• Use proton vertex factorisation with $\alpha_{IP}(t)$ from FPS and LRG data to relate data from different x_{IP} values with complementary β, Q^2 coverage.

• Exclude data with $M_X < 2$ GeV or $\beta > 0.8$ (higher twist region) and with $Q^2 < 8.5$ GeV^2 (NLO insufficient?)

Free Parameters of H1 2006 DPDF Fit

5 free parameters for singlet quark $z\Sigma(z,Q_0^2)$, gluon $zg(z,Q_0^2)$ densities, where z is parton momentum fraction (= β for quarks at lowest order, otherwise >β)

$$z\Sigma(z,Q_0^2) = A_q z^{B_q}(1-z)^{C_q}$$

$$zg(z,Q_0^2) = A_g (1-z)^{C_g}$$

(gluon insensitive to B_g)

- 1 free parameter $\alpha_{IP}(0)$ describes x_{IP} dependence via flux factor
- 1 free parameter describes normalisation of sub-leading IR, which is otherwise treated as a π^0
- Results reproducible within errors with many variations in assumptions, parameterisations and other details

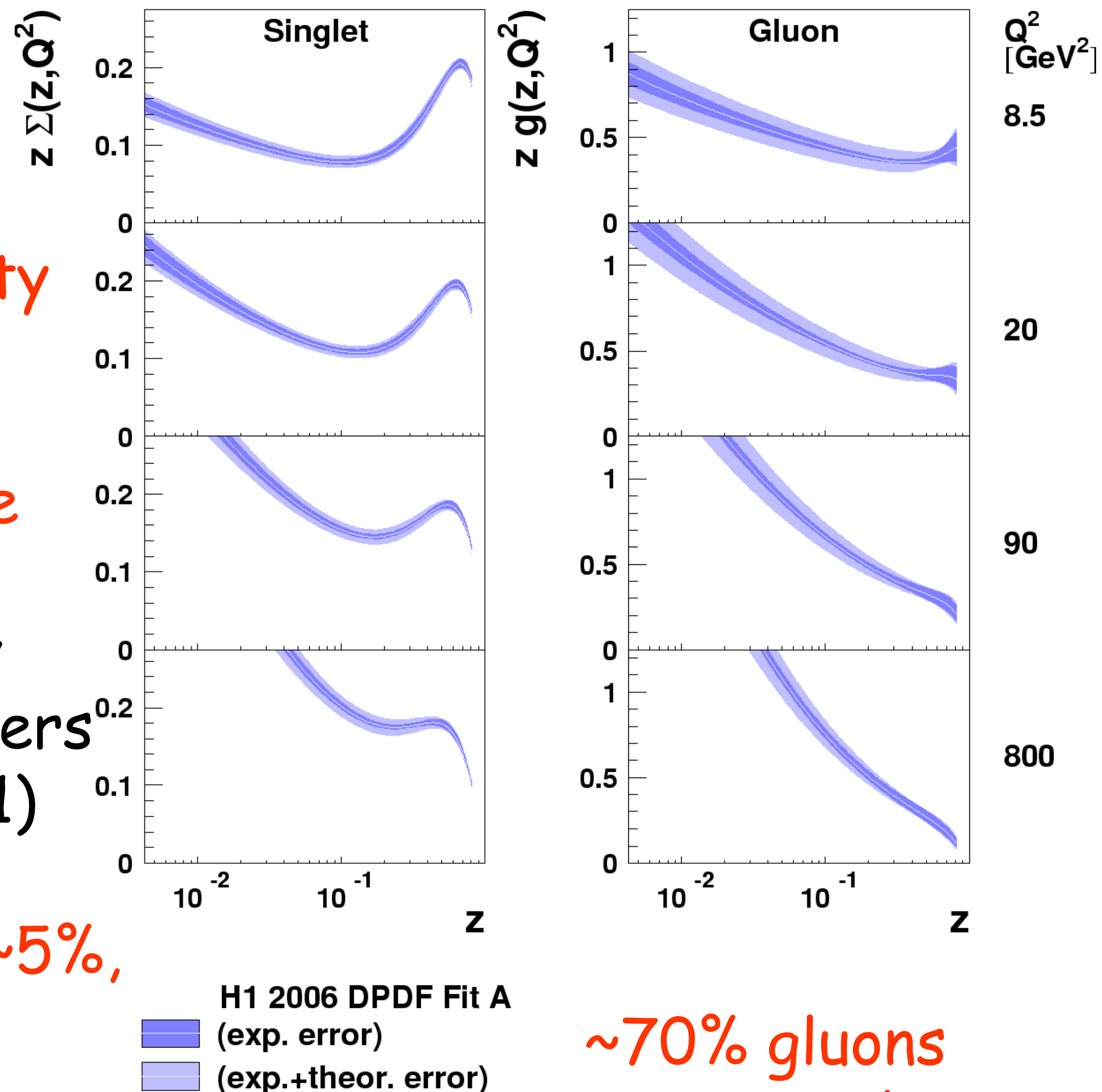
'H1 2006 DPDF Fit A' (log z scale)

χ^2 ~158 / 183 d.o.f.

- Experimental uncertainty obtained by propagating errors on data through χ^2 minimisation procedure

- Theoretical uncertainty by varying fixed parameters of fit and Q^2_0 (s.t. $\Delta\chi^2 = 1$)

- Singlet constrained to ~5%, gluon to ~15% at low z, growing a lot at high z



~70% gluons integrated over z

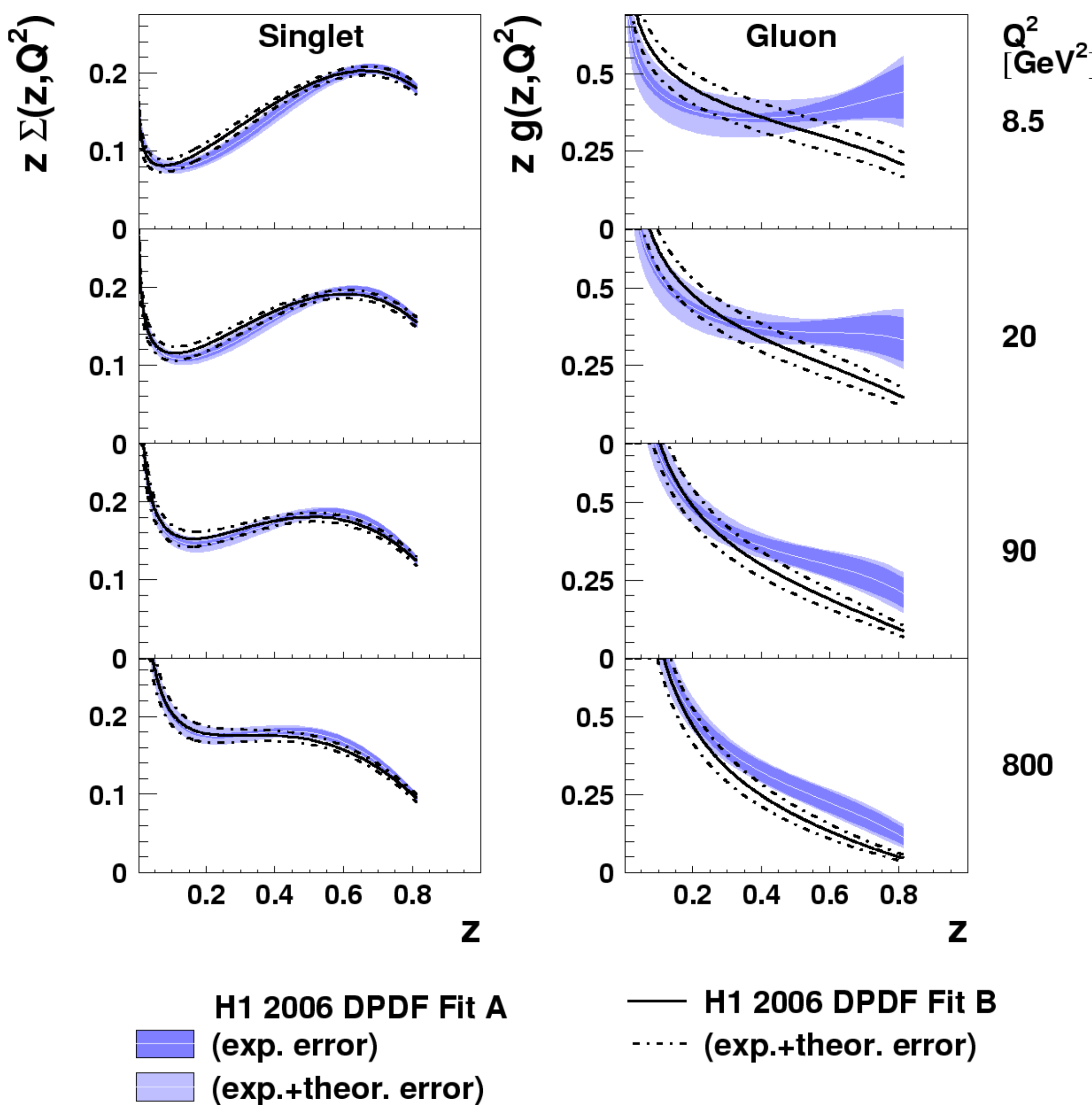
`Fit A' and `Fit B' DPDFs (linear z scale)

- Lack of sensitivity to high z gluon confirmed by dropping (high z) C_g parameter, so gluon is a constant at starting scale!

- **Fit B**

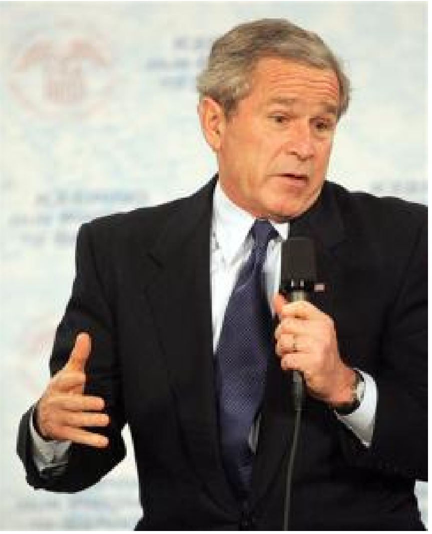
  χ^2 ~164 / 184 d.o.f.

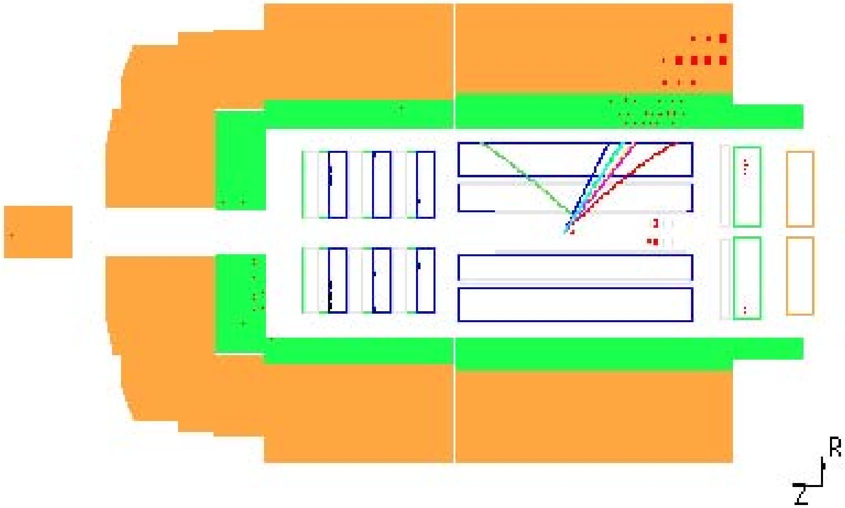
- Quarks very stable
- Gluon similar at low z
- Substantial change to gluon at high z

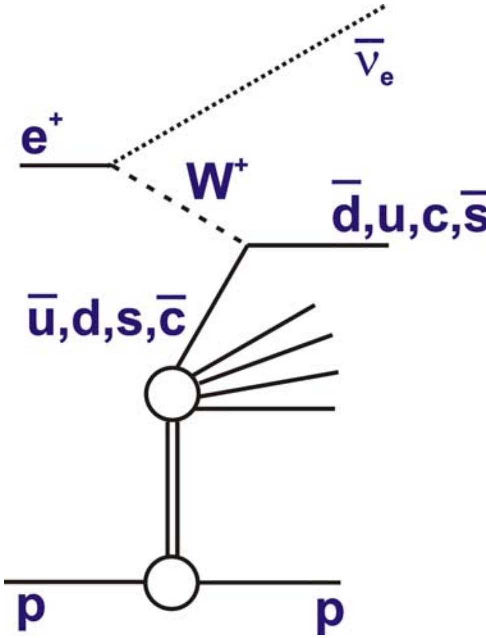


Testing Factorisation and Quark Density with Diffractive Charged Current Scattering

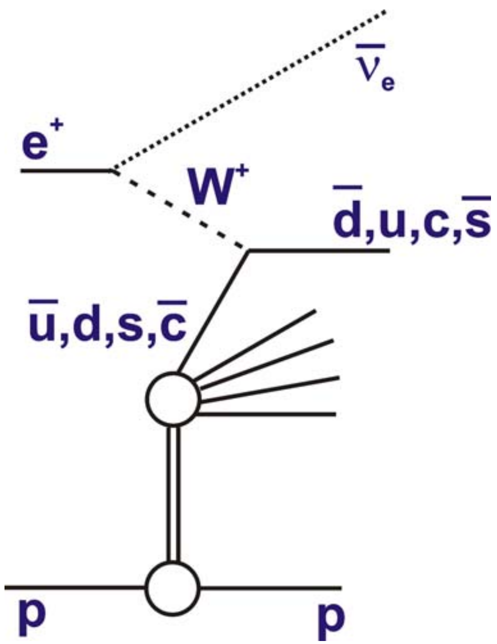
First observation of diffractive charged current events
… sensitive to flavour decomposition of quark density
(completely unconstrained by neutral current data)

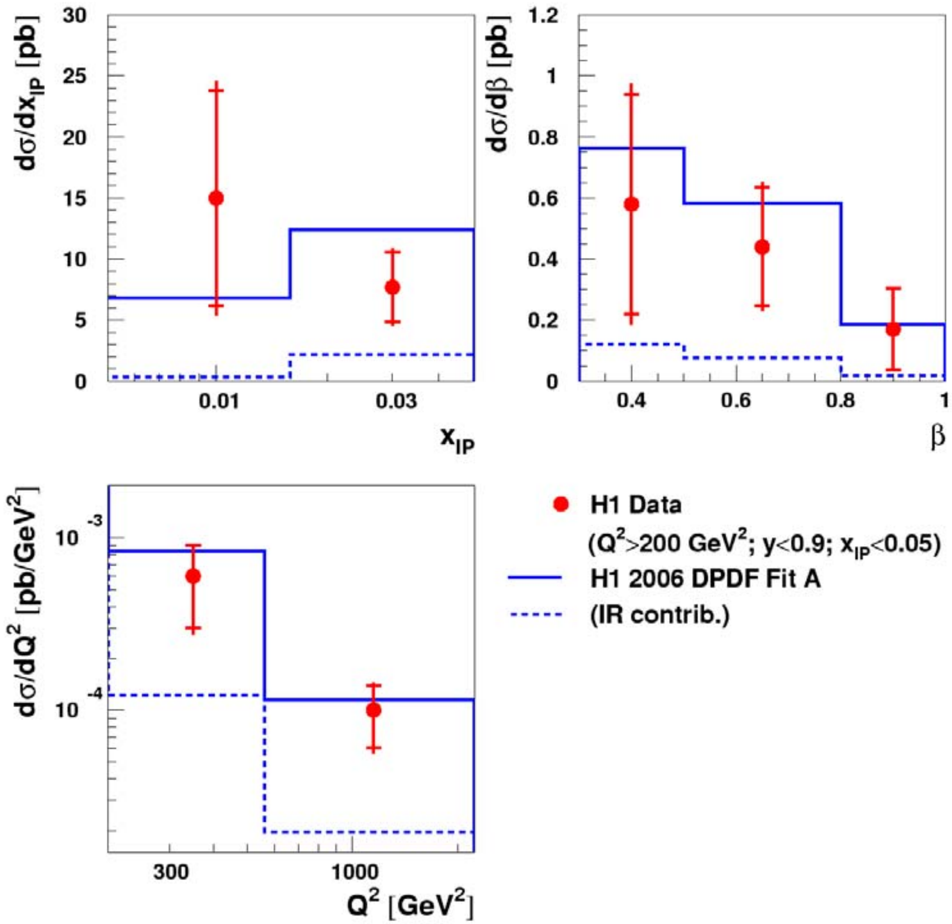






Diffractive Charged Current Cross Section



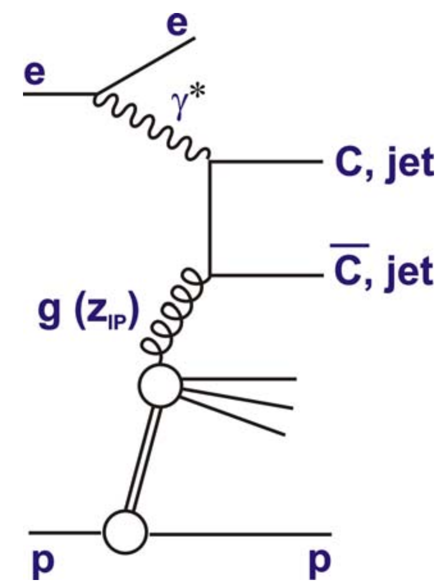


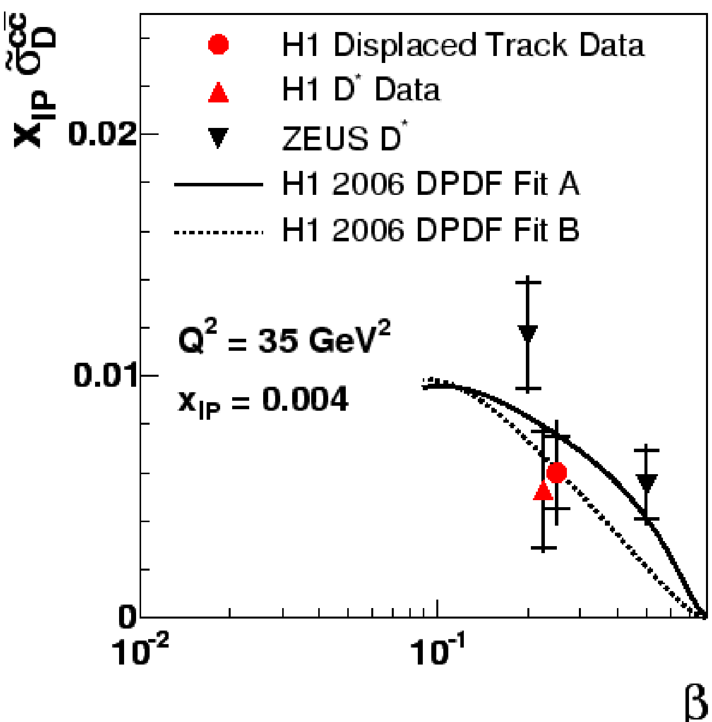
Very similar method of measurement to Neutral Current case.

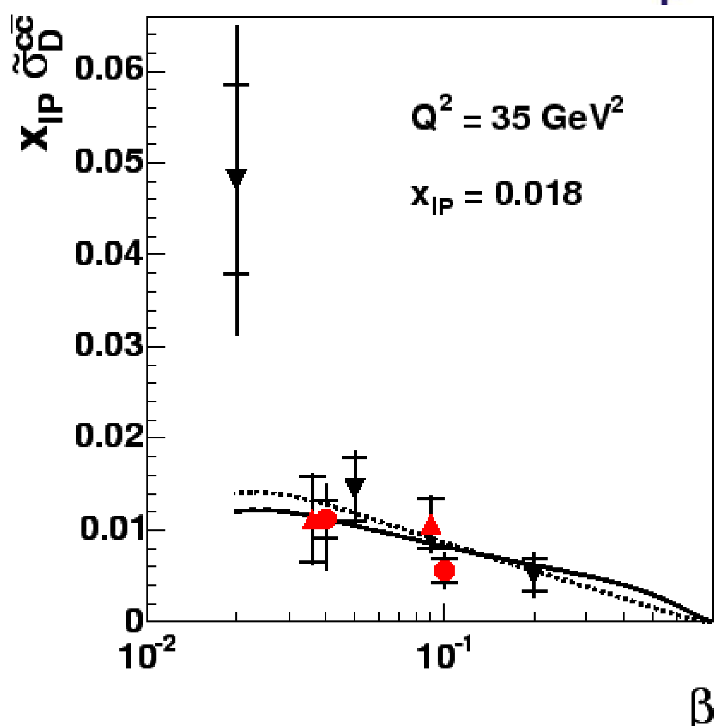
Good agreement with fit prediction (assumes $u = d = s = \bar{u} = \bar{d} = \bar{s}$ and c from BGF) though statistical precision limited so far

Testing Factorisⁿ and the Gluon with Charm

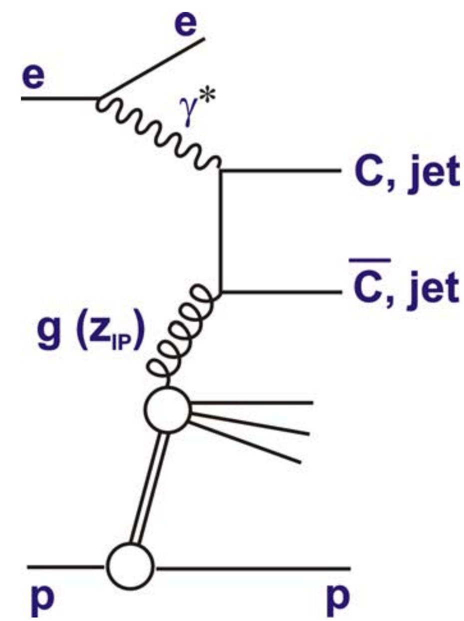
- Measure diffractive charm cross section by two different methods
- Charm production up to 30% of total diffractive cross section!
- Well described by prediction from DPDFs





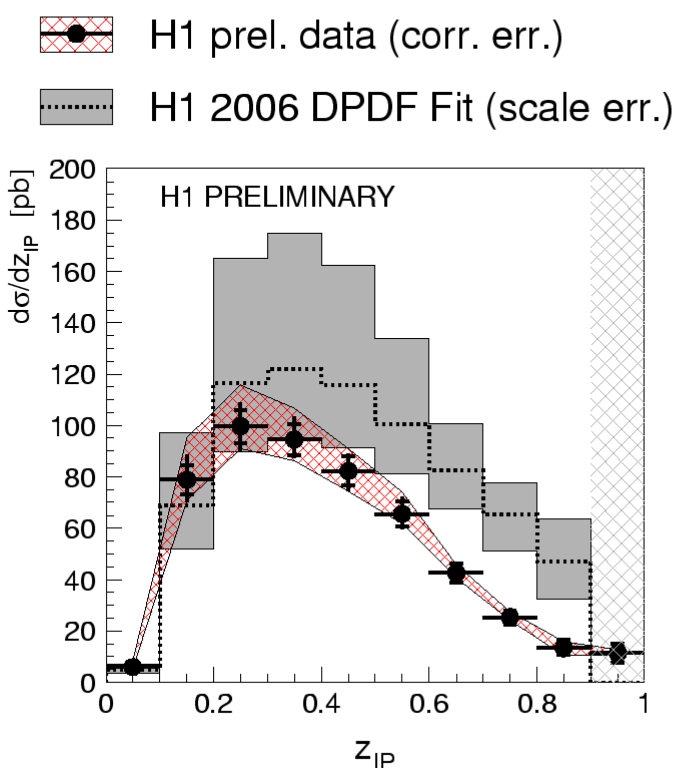


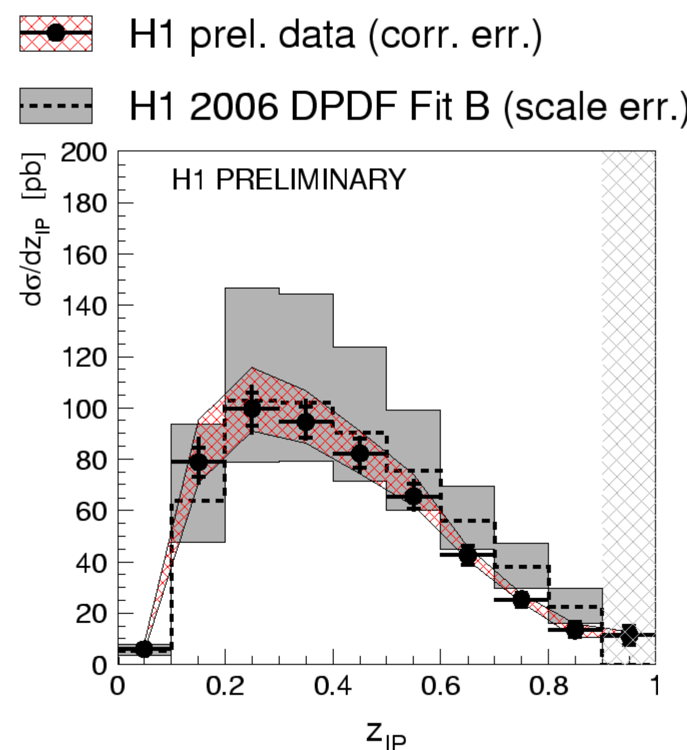
Resolving High z Gluon with Dijets



- Dijet data particularly sensitive to gluon density at high z … which is poorly constrained by inclusive data.
- Good description by DPDFs at 'low' z
- Prefer flatter gluon at high z …

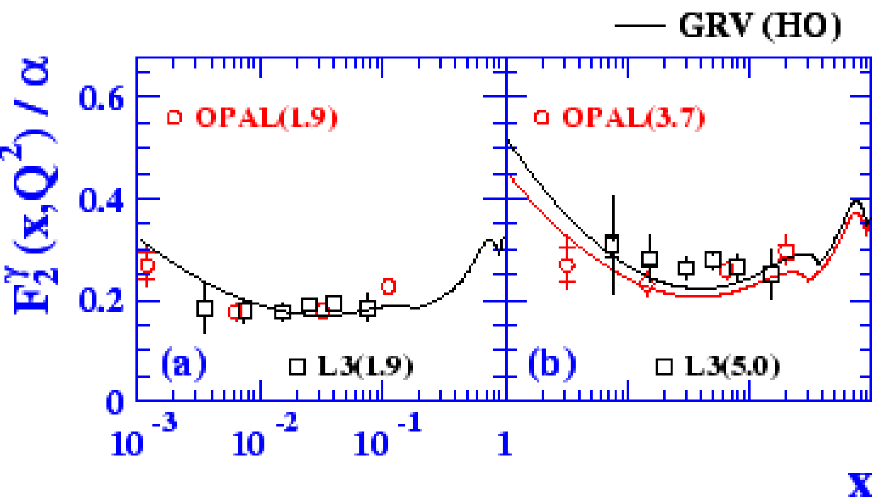
Ongoing work to include dijets with inclusive data in combined fit …

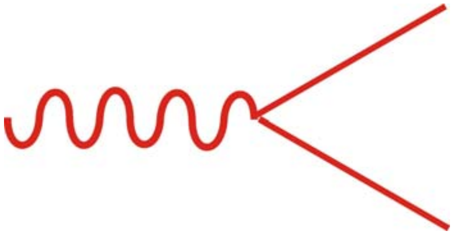




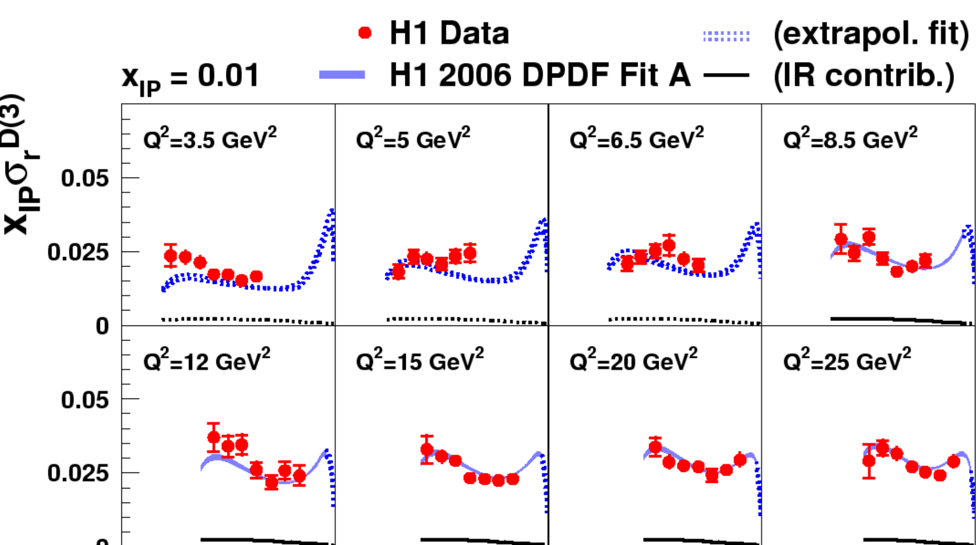
… but what do the DPDFs actually *mean*?

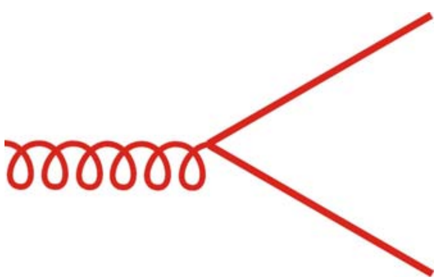
High z behaviour looks a lot like the photon structure function …





Photon `structure' derived from $\gamma \rightarrow q\bar{q}$



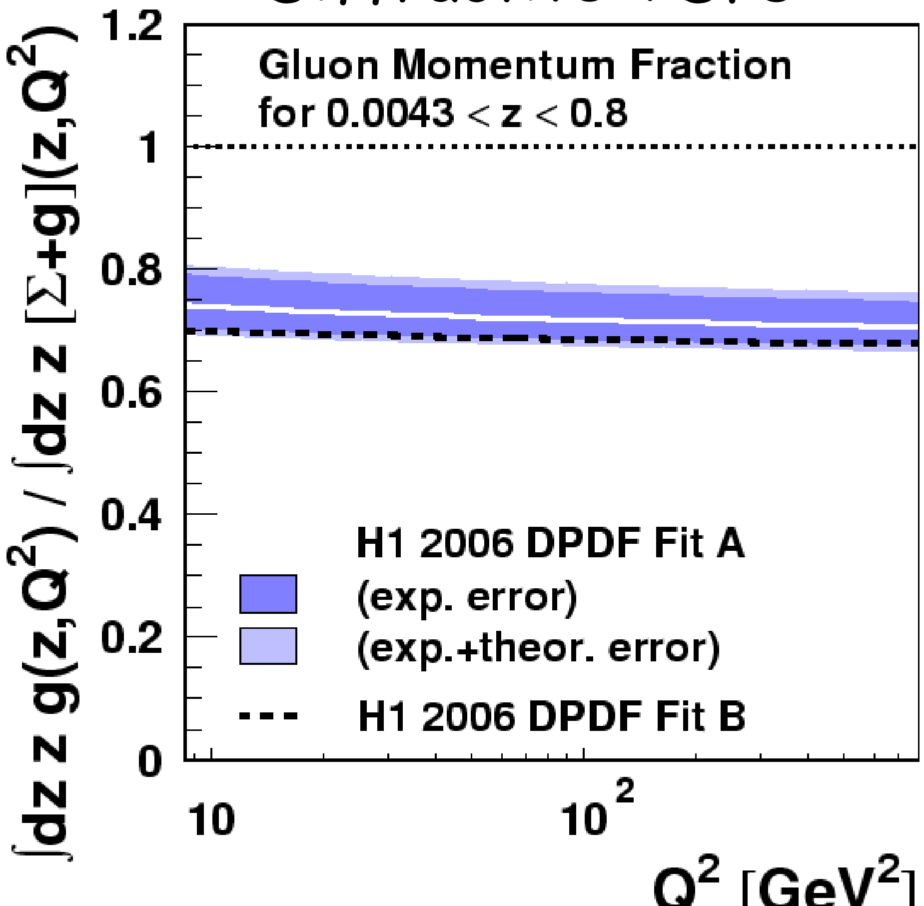


Diffractive DIS derived from $g \rightarrow q\bar{q}$ (and $g \rightarrow gg$ …)
… leading gluon exchange?

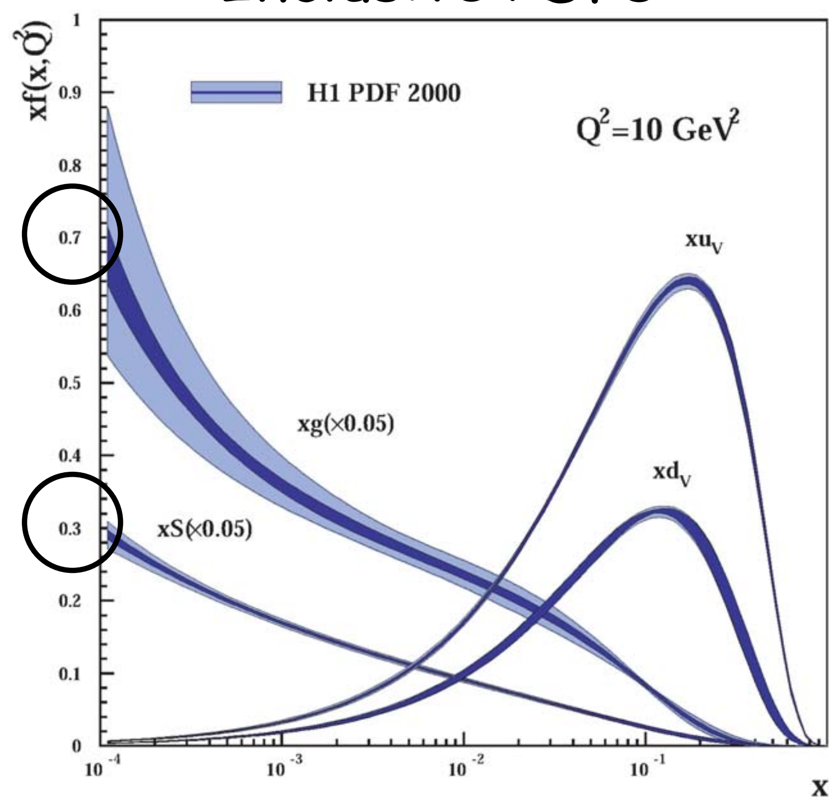
… but what do the DPDFs actually *mean*?

… what about **low z** … ratio of quarks to gluons is about 70:30 for both diffractive PDFs and (low x) inclusive PDFs …

Diffractive PDFs



Inclusive PDFs

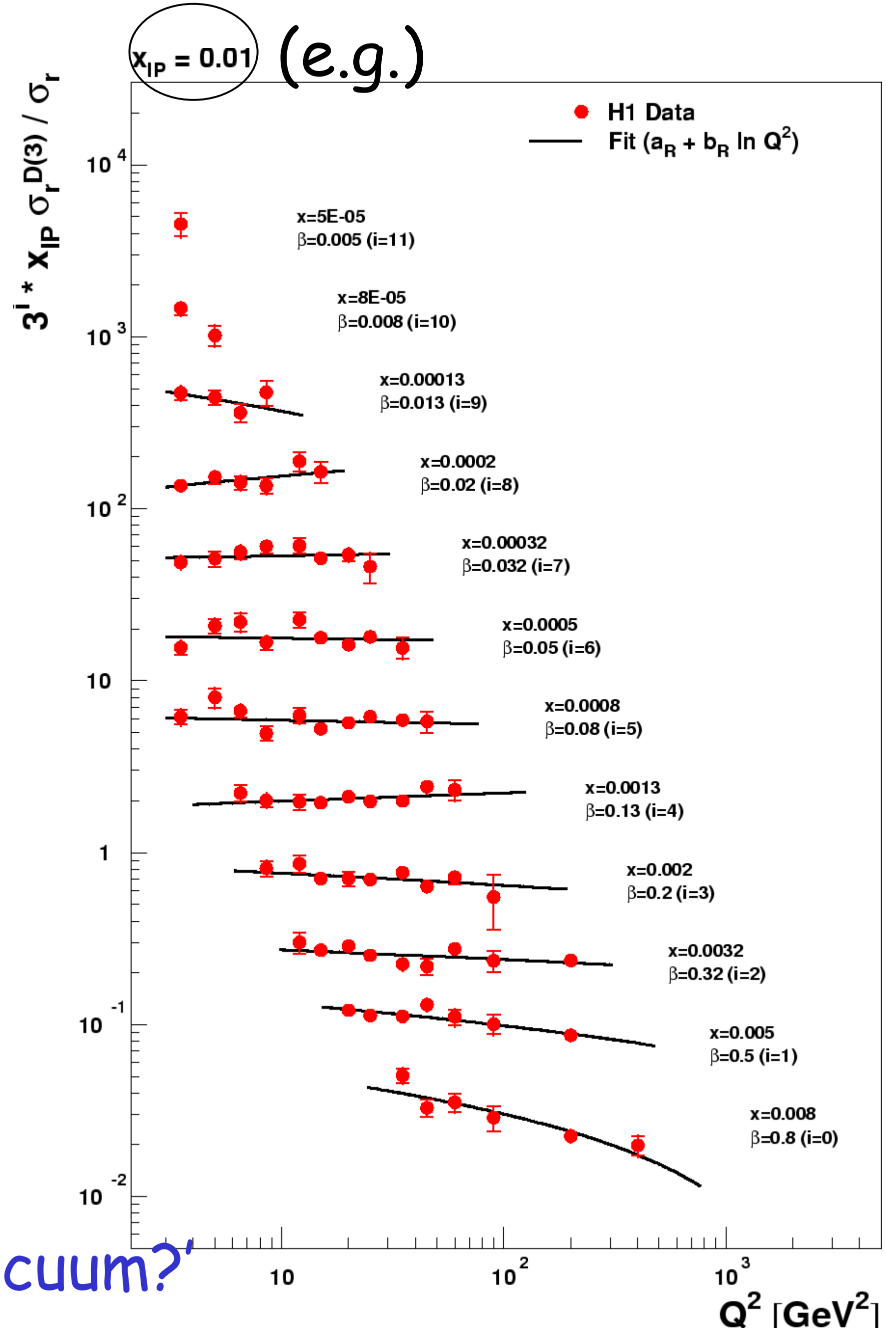


Low x similarity of diffractive & inclusive PDFs

- Similar ratios of quarks to gluons reflected in similar Q^2 evolution of inclusive and diffractive cross sections at low x…

- …Ratio σ_r^D/σ_r ~ independent of Q^2 at fixed x_{IP} and x.

- … away from the influence of valence quarks, PDFs and their evolution is driven only by QCD … same for proton, pomeron, pion, photon …?



…`universal structure of QCD vacuum?'

Summary

- FPS and LRG measurements of diffractive DIS:
  - New level of precision and kinematic range.
  - Agreement in detail between the two methods.

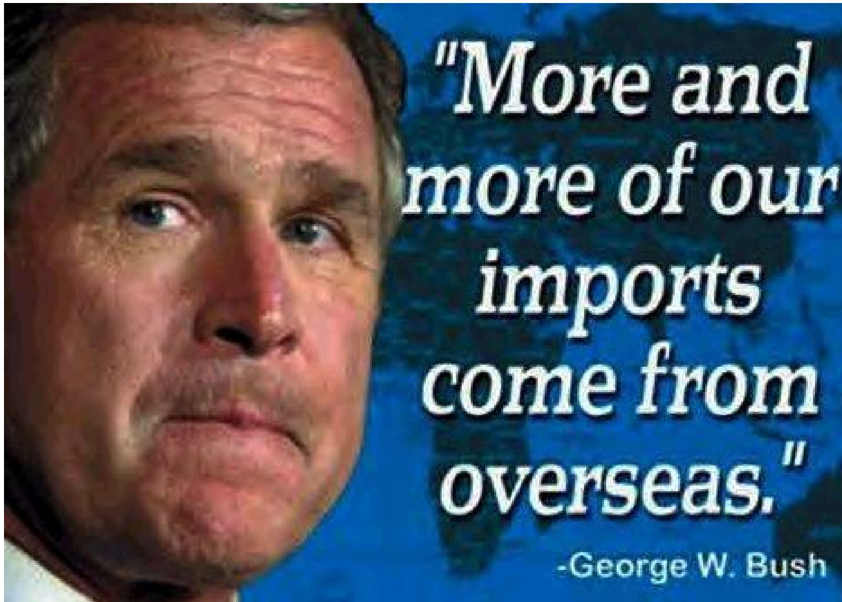
- Proton vertex factorisation with $\alpha_{IP}(t) \sim 1.118 + 0.06t$ & $B_{IP} \sim 6$ GeV^{-2} is good model for the 'soft' physics (x_{IP},t) deps.

- β and Q^2 dependences tackled with NLO QCD → DPDFs
  - Singlet quarks very well constrained (~5%).
  - Gluon to ~15% (can be improved at high z with jet data)

- DPDFs predict other diffractive DIS processes well:
  Charged current, charm, jets at low z, more to come!
  Many Tevatron / LHC applications still to be explored

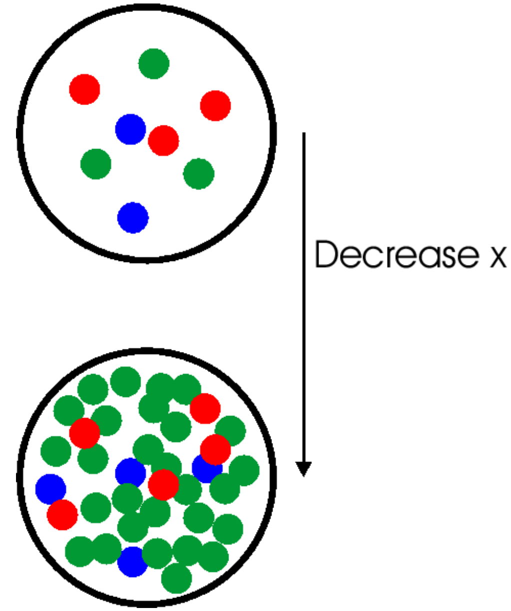
- Still lack detailed understanding of inclusive / diffractive DIS relationship… low x as QCD consequence of `nothing'?

George's Summary …



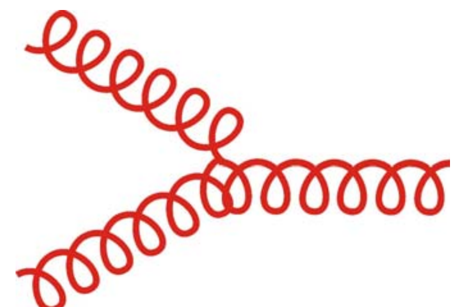
Back up's follow …

Can the Rise of Gluon be True?

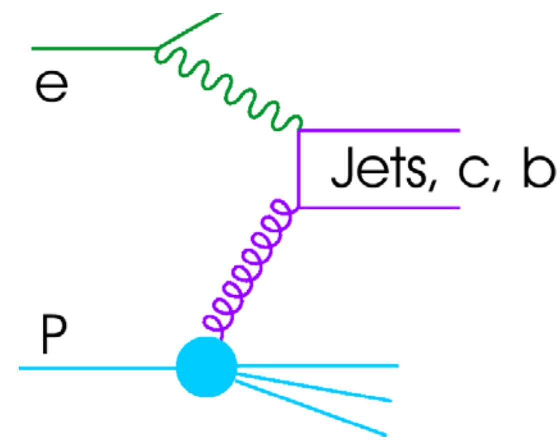


- Gluon density cannot rise indefinitely as x decreases (unitarity effects / parton `saturation' ?...)

- DGLAP approximation to QCD evolution may become insufficient, e.g. due to neglect of $gg \rightarrow g$ `recombination'.



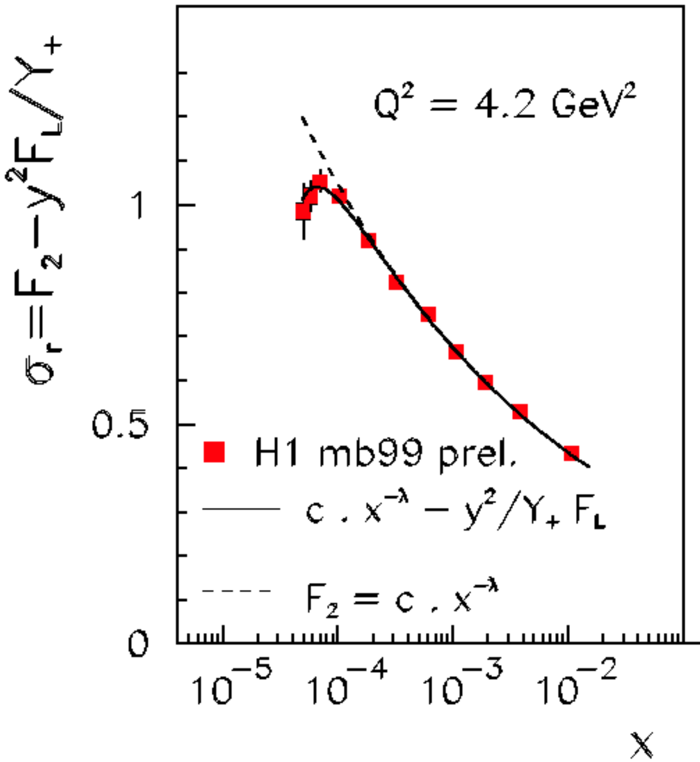
- Same approximations are used for evolution to LHC … essential to test the gluon density through direct measurement …
… e.g. `boson-gluon fusion' → many Dijet, charm, beauty measurements!

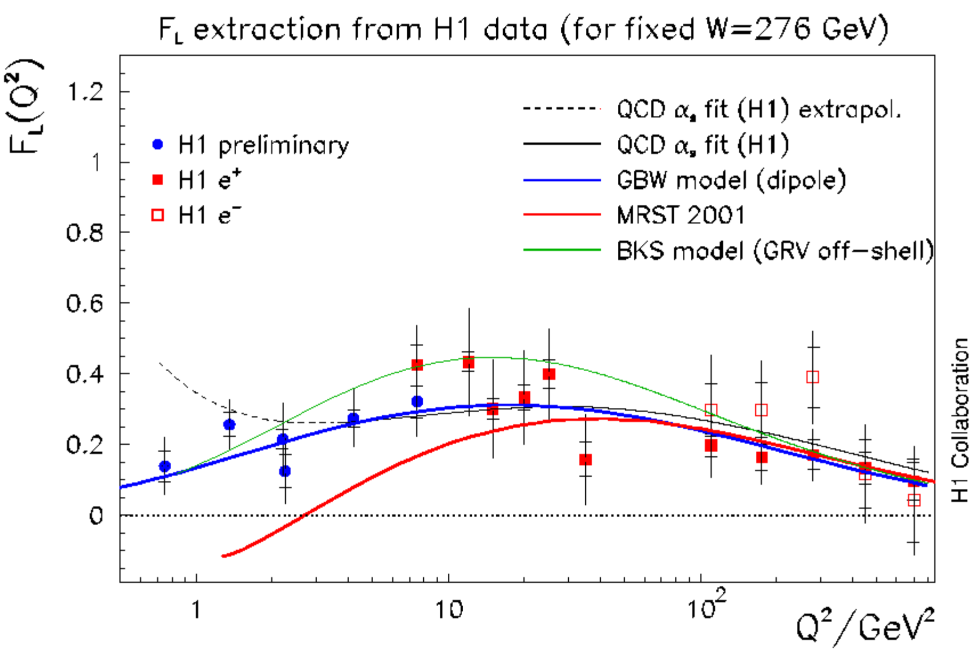


Structure Function $F_L(x,Q^2)$

If gluon dominates, **$F_L \sim \alpha_s xg(x)$,** provides another test of self-consistency and gluon.

$$\tilde{\sigma}^{NC} = F_2 - \frac{y^2}{Y_+} F_L$$

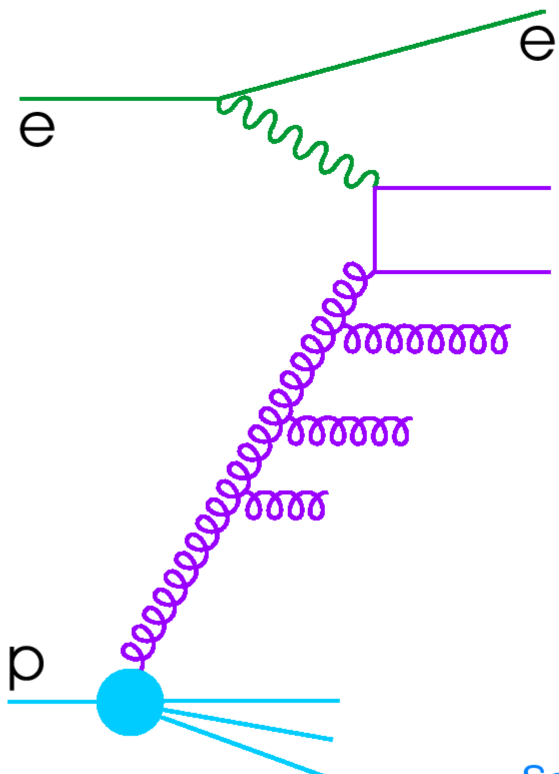


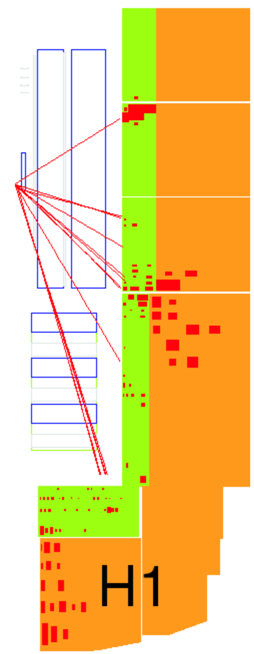


Influence visible at low x and low Q^2, consistent with expectations if F_2 is well behaved

Model-free extraction requires changes to beam energies …

Beyond Inclusive Measurements





Structure Functions

Precision QCD tests

Alpha-s

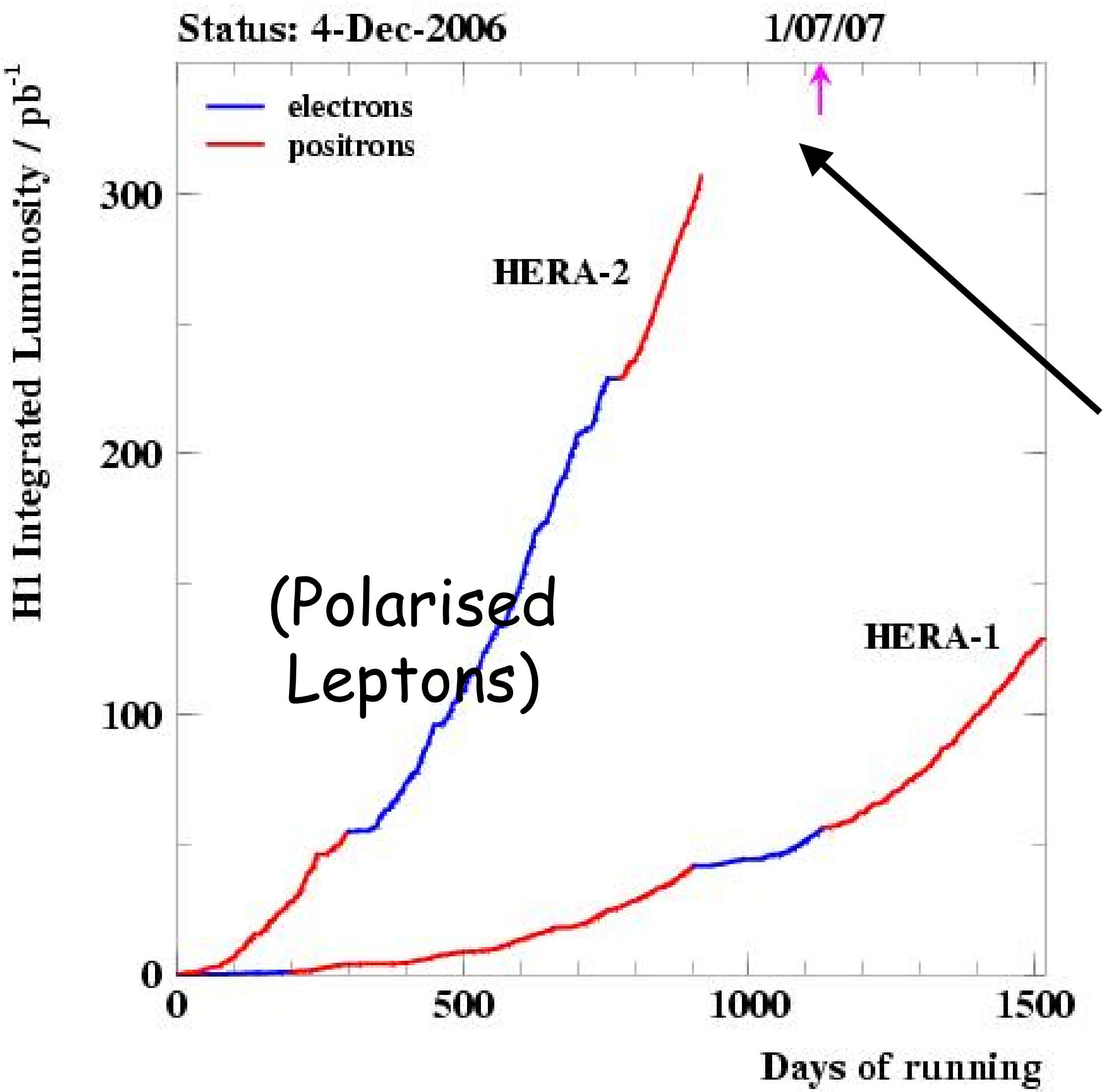
Parton dynamics

Rapidity Gaps, Diffraction

Searches at highest $\sqrt{s}$ with initial state lepton

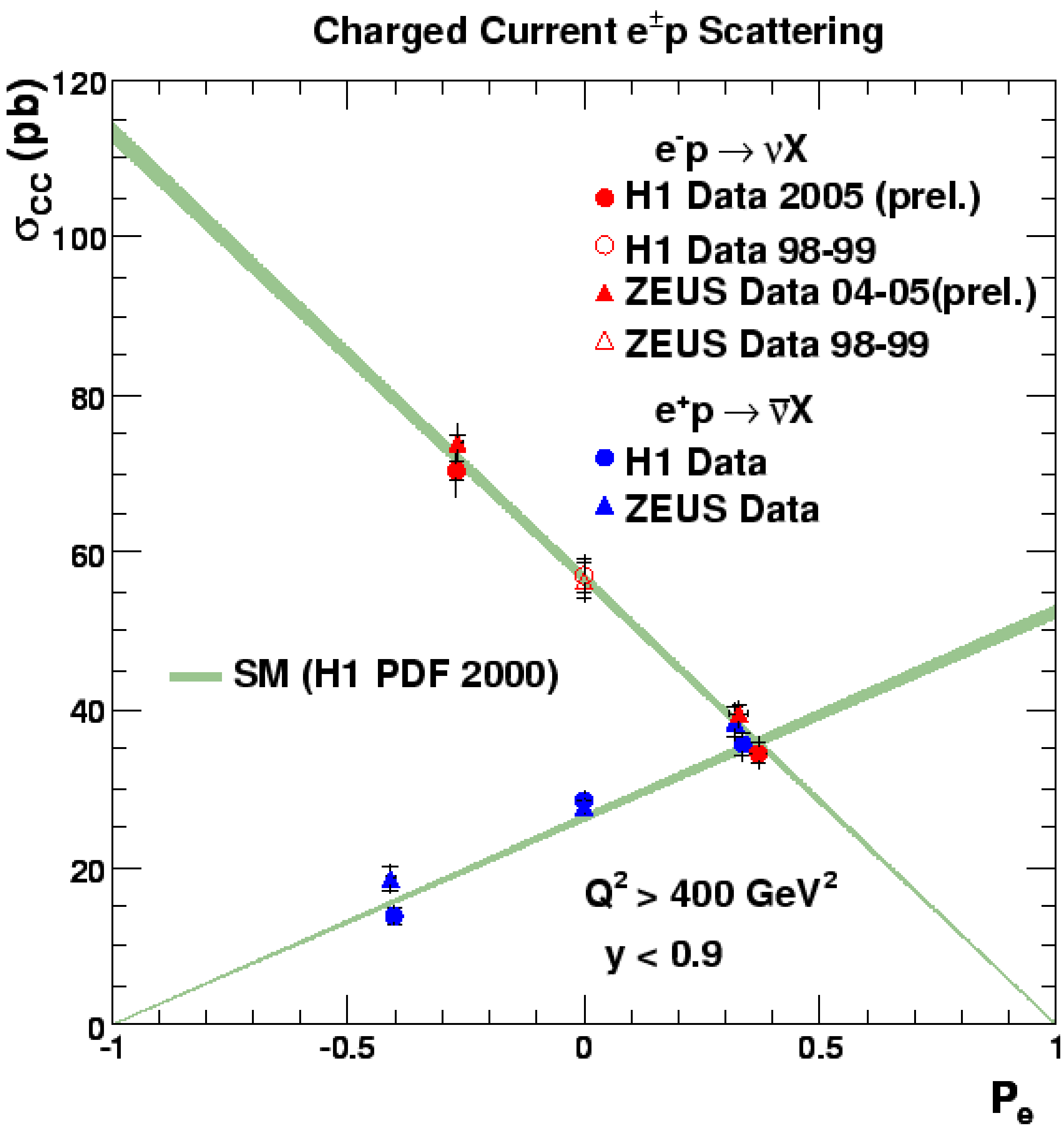
Hadronic final states test our understanding of parton dynamics in complementary ways….. Is the huge gluon for real?

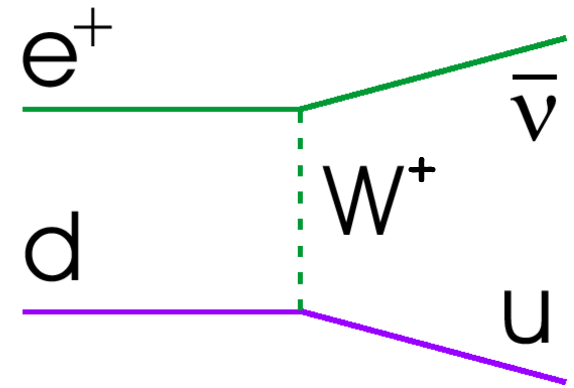
HERA-II and the Future



- HERA-I was ~ 130 pb^{-1}
- HERA-II will be ~ 320 pb^{-1} at full energy, plus a reduced Ep run at the end to measure F_L properly and test gluon density
- Data analysis underway, … first results appearing … many more high precision results to come!

Polarised Charged Current Cross Section



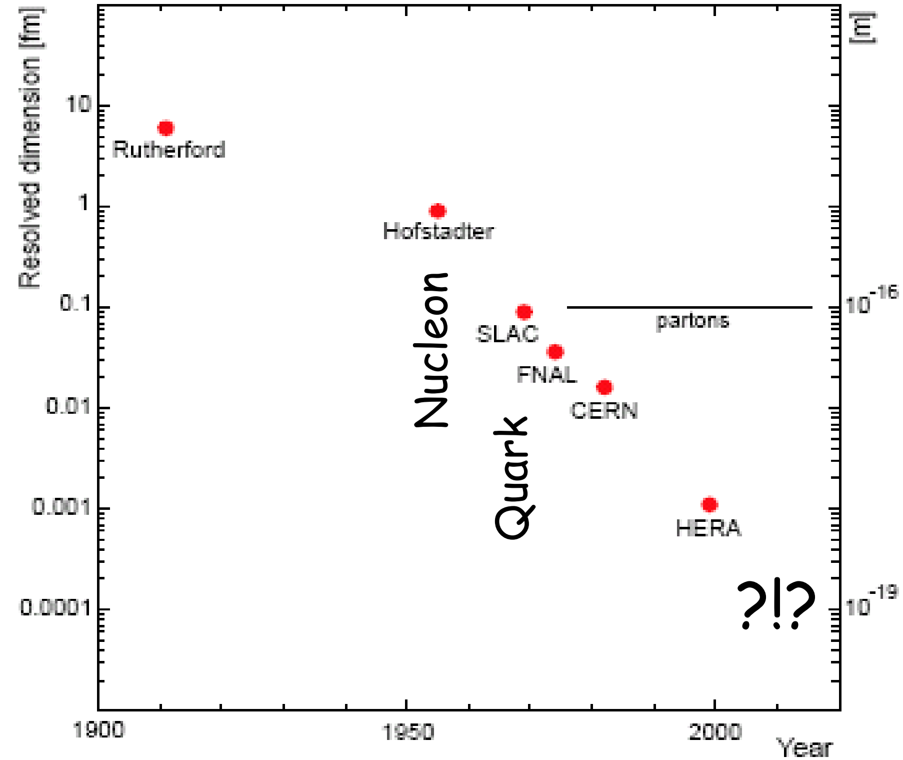


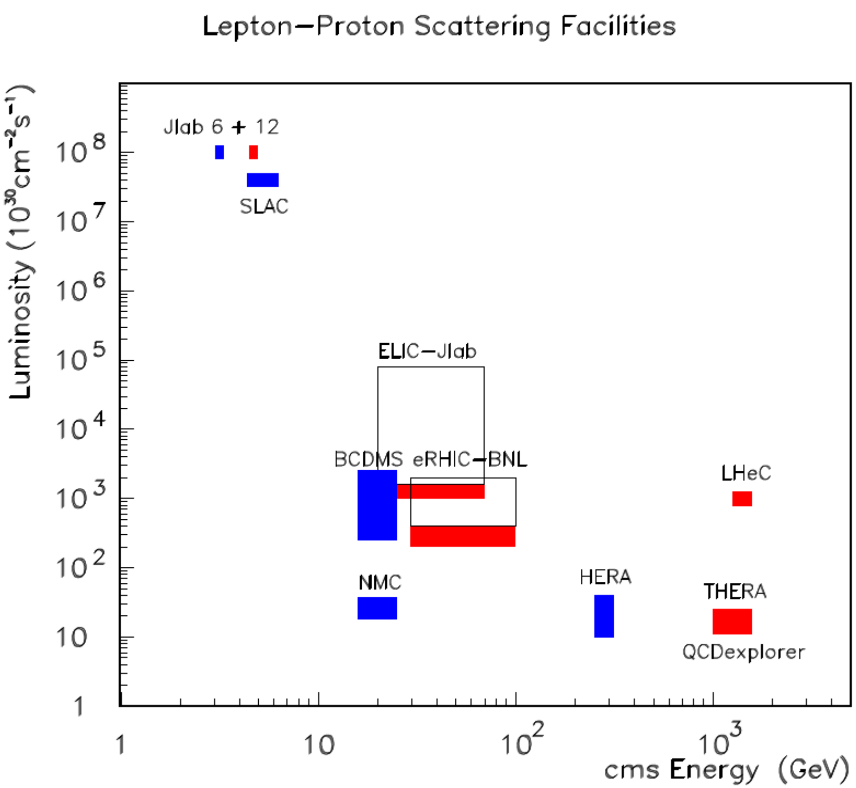
- Standard model does not allow right handed charged currents

- Data consistent with prediction of linear dependence…
… $M(W_R) > 200$ GeV

A possible future?

No high energy ep Physics
Approved beyond 2007!..
LHeC: Latest of several proposals to take ep physics into the TeV energy range …
… but with unprecedented lumi!





• Combining LHC protons with a new electron beam (70 GeV) Is technically possible and pushes frontiers of ep physics:

… $x \rightarrow 10^{-7}$, $M_{eq} \rightarrow 1.4$TeV,
Resolved dimension → 10^{-19}m