Recent Results from H1

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on behalf of the H1 collaboration

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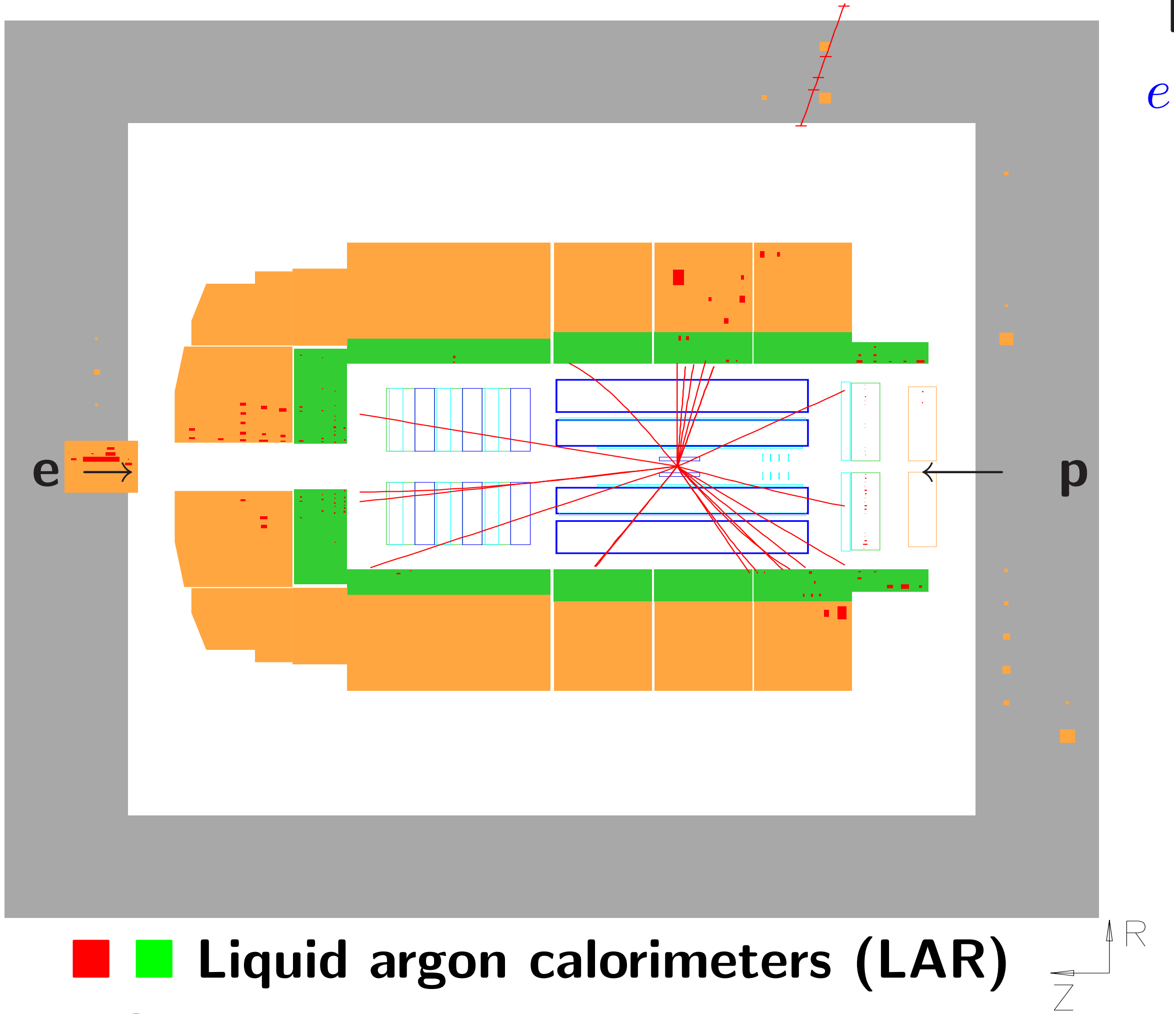
- Introduction
- Proton Structure Functions
- Heavy Quark Production
- Hadronic Final States
- Diffraction
- Search for New Physics
- Summary

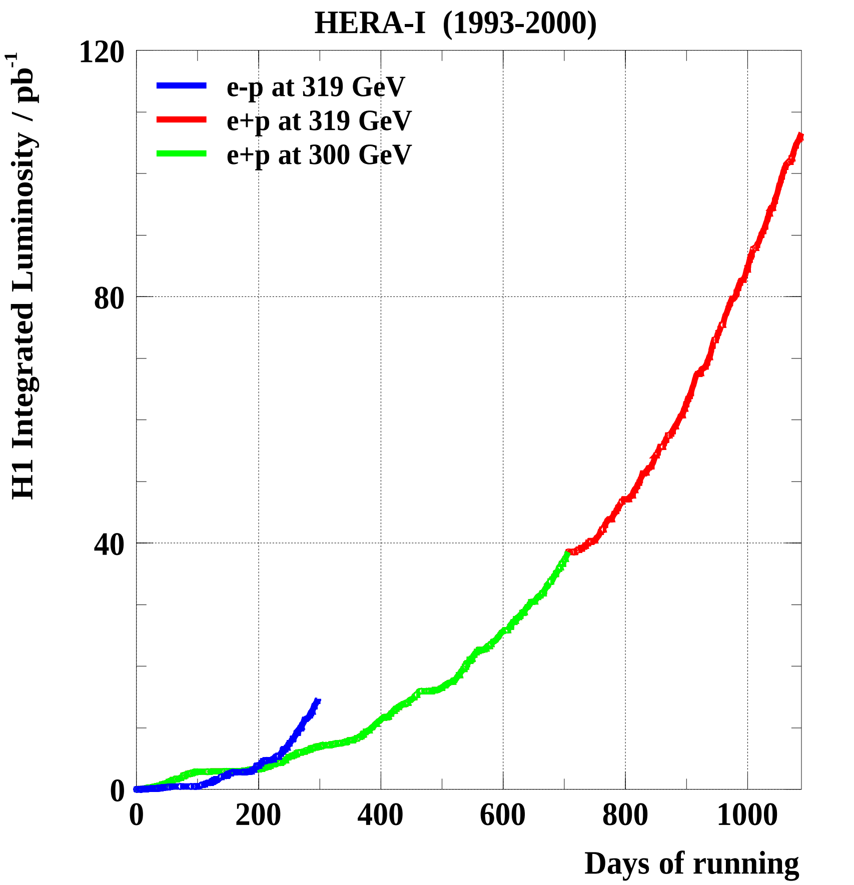
INTRODUCTION - H1 Experiment



- Liquid argon calorimeters (LAR)
- Central tracker
- SPACAL calorimeter
- –,– Silicon trackers
- Muon system

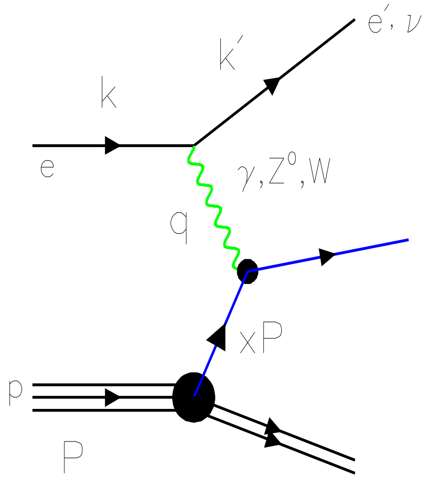
HERA I runs:

$e^{\pm}$(27.5GeV) $\Rightarrow\Leftarrow$ p(920/820 GeV)



Recent results from 1999/2000 data mostly

INTRODUCTION - DIS kinematics and cross sections



Kinematic variables

- $Q^2 = -q^2 = -(k-k')^2$ **momentum transfer squared**
- $x = Q^2/(2Pq)$ **momentum fraction of struck quark**
- $y = (P\cdot q)/(P\cdot k)$ **energy transfer to γ - inelasticity**
- $W^2 = (q+P)^2 = Q^2(1-x)/x + m_p^2$ **total energy squared of γp system**

Neutral current (NC) and charged current (CC) cross sections

$$\frac{d^2\sigma^{\pm}_{NC}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}[Y_+\tilde{F}_2 \mp Y_-\cdot x\tilde{F}_3 - y^2\tilde{F}_L]$$

$$\tilde{F}_2 \equiv F_2 - v_e\mathcal{K}F_2^{\gamma Z} + (v_e^2+a_e^2)\mathcal{K}^2\cdot F_2^Z$$

$$x\tilde{F}_3 \equiv -a_e\mathcal{K}\cdot xF_3^{\gamma z} + 2v_ea_e\mathcal{K}^2\cdot xF_3^Z$$

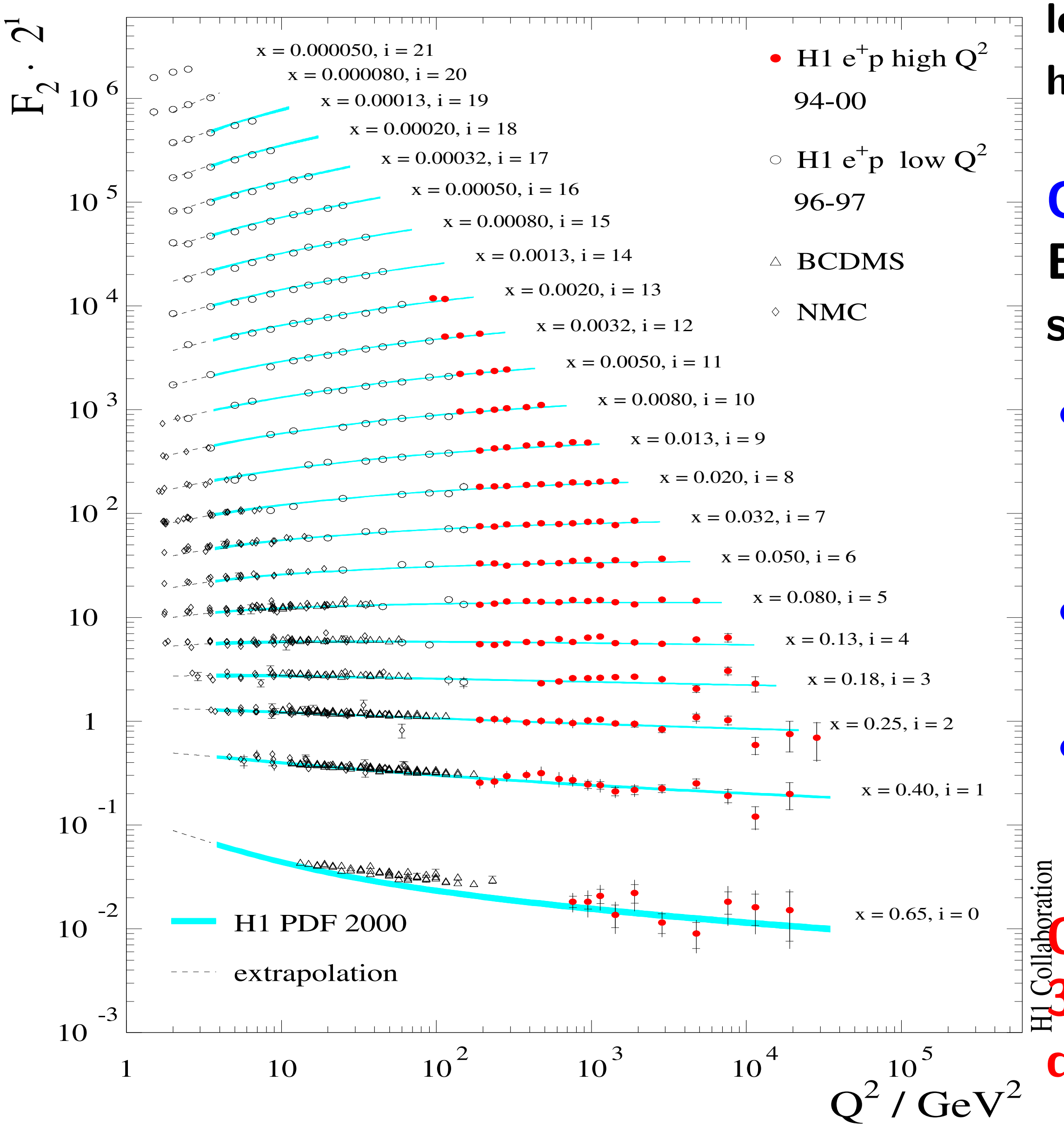
$$Y_\pm = 1\pm(1-y)^2,\quad \mathcal{K} = kQ^2/(Q^2+M_Z^2)$$

$$\frac{d^2\sigma^{\pm}_{CC}}{dxdQ^2} = \frac{G_F^2}{4\pi x}\left[\frac{M_W^2}{(Q^2+M_W^2)}\right]\left[Y_+F^{\pm}_{2,CC} \mp Y_-\cdot xF^{\pm}_{3,CC} - y^2F^{\pm}_{L,CC}\right]$$

QPM :

$$[F_2, F_3^{\gamma Z}, F_3] = x\cdot\sum_q[e_q^2, 2e_qv_q, v_q^2+a_q^2][q+\bar{q}],\qquad F^+_{2,CC} = x[d+s+\bar{u}+\bar{c}]$$

STRUCTURE FUNCTIONS - F_2



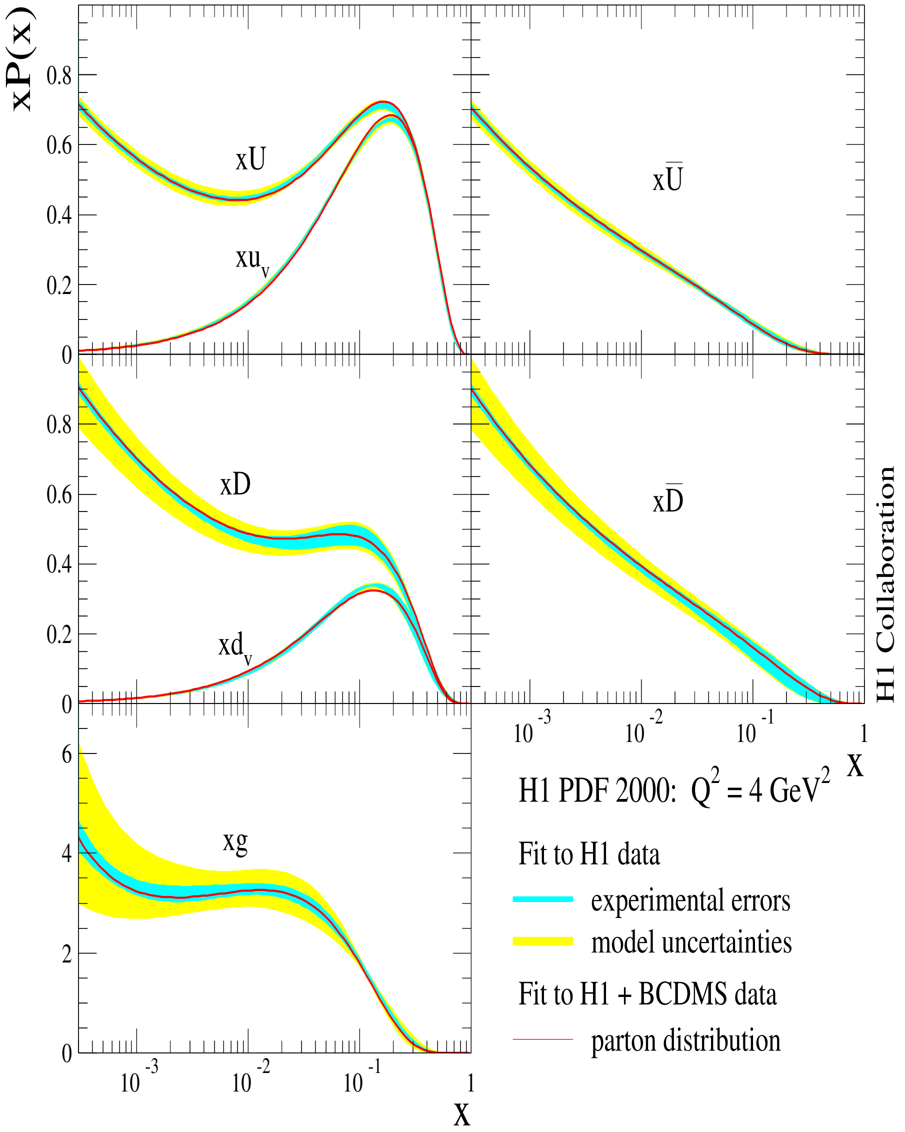
low Q^2 region: $1 < Q^2 < 100\ \mathrm{GeV}^2$
high Q^2 region: $Q^2 > 100\ \mathrm{GeV}^2$

Good precision data achieved
Extensive study of sources of systematic errors , e.g.

- **Uncertainty of $e^\pm$ energy scale: 1% in SPACAL, 0.7-2 % in LAR**
- **Uncertainty of hadronic scale in LAR: 1.4-2%**
- **electron identification error 0.5-2%**

Overall total systematic errors : 3% (6%) for NC (CC) double diff. cross sections

STRUCTURE FUNCTIONS - H1 PDF 2000 fit



QCD fit (H1 PDF 2000) to H1 data only

- **Fit to the cross sections**
- **$\overline{\text{MS}}$ scheme, NLO DGLAP**
- **Parametrization of parton distributions**

  xg, $xU = x(u+c)$, $xD = x(d+s)$, $x\bar{U}$, $x\bar{D}$, e.g.
  $$xg = A_g x^{B_g}(1-x)^{C_g} \cdot [1 + D_g x]$$

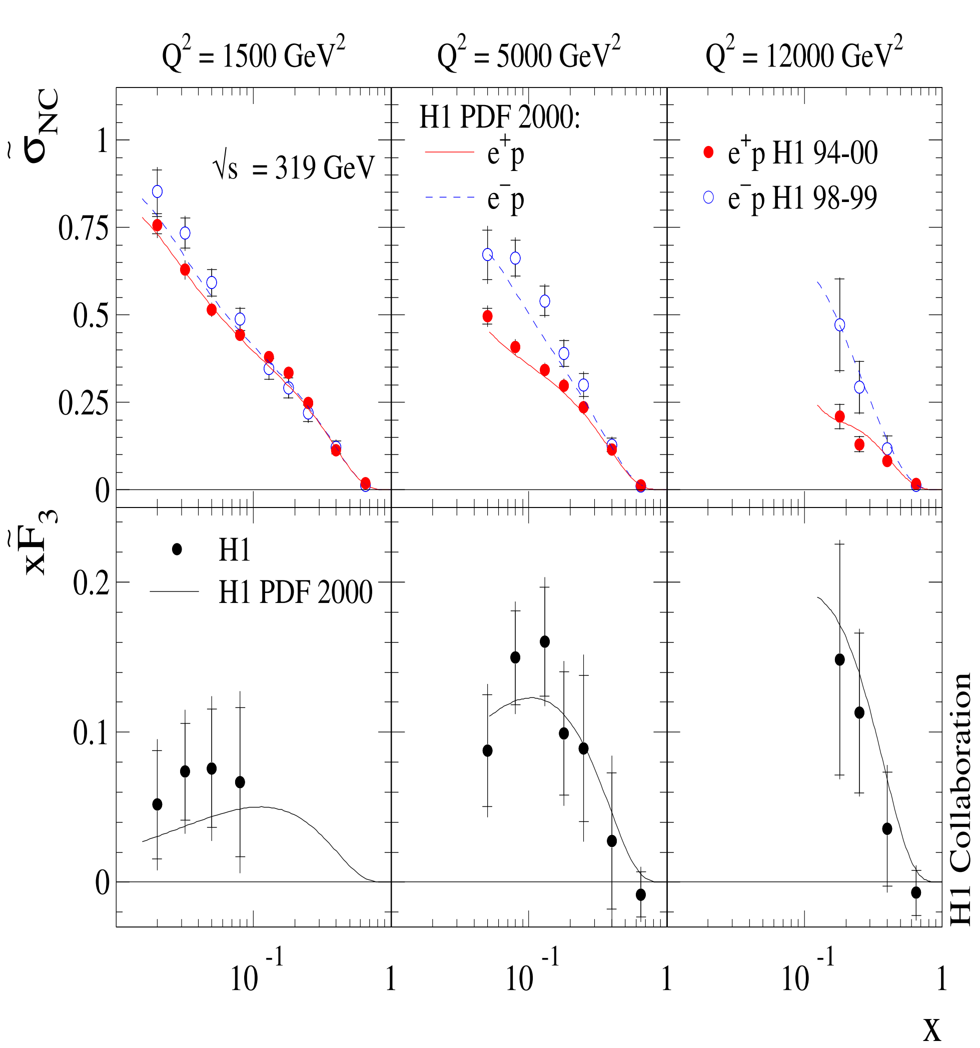
  at $Q^2 = Q_0^2 = 4\ \mathrm{GeV}^2$

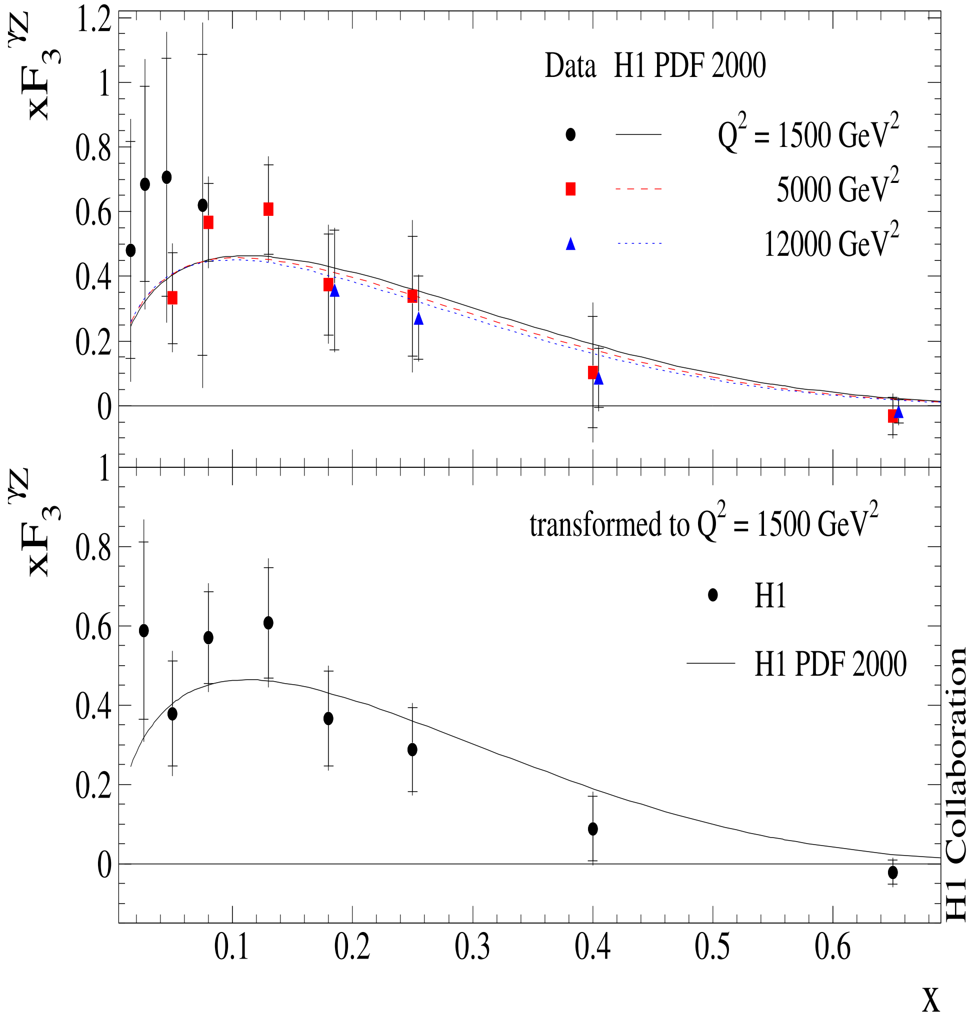
- $Q^2_{min} = 3.5\ \mathrm{GeV}^2$, $\alpha_S(M_Z^2) = 0.1185$

- **Various relations between parameters $\Longrightarrow$ 10 free parameters**

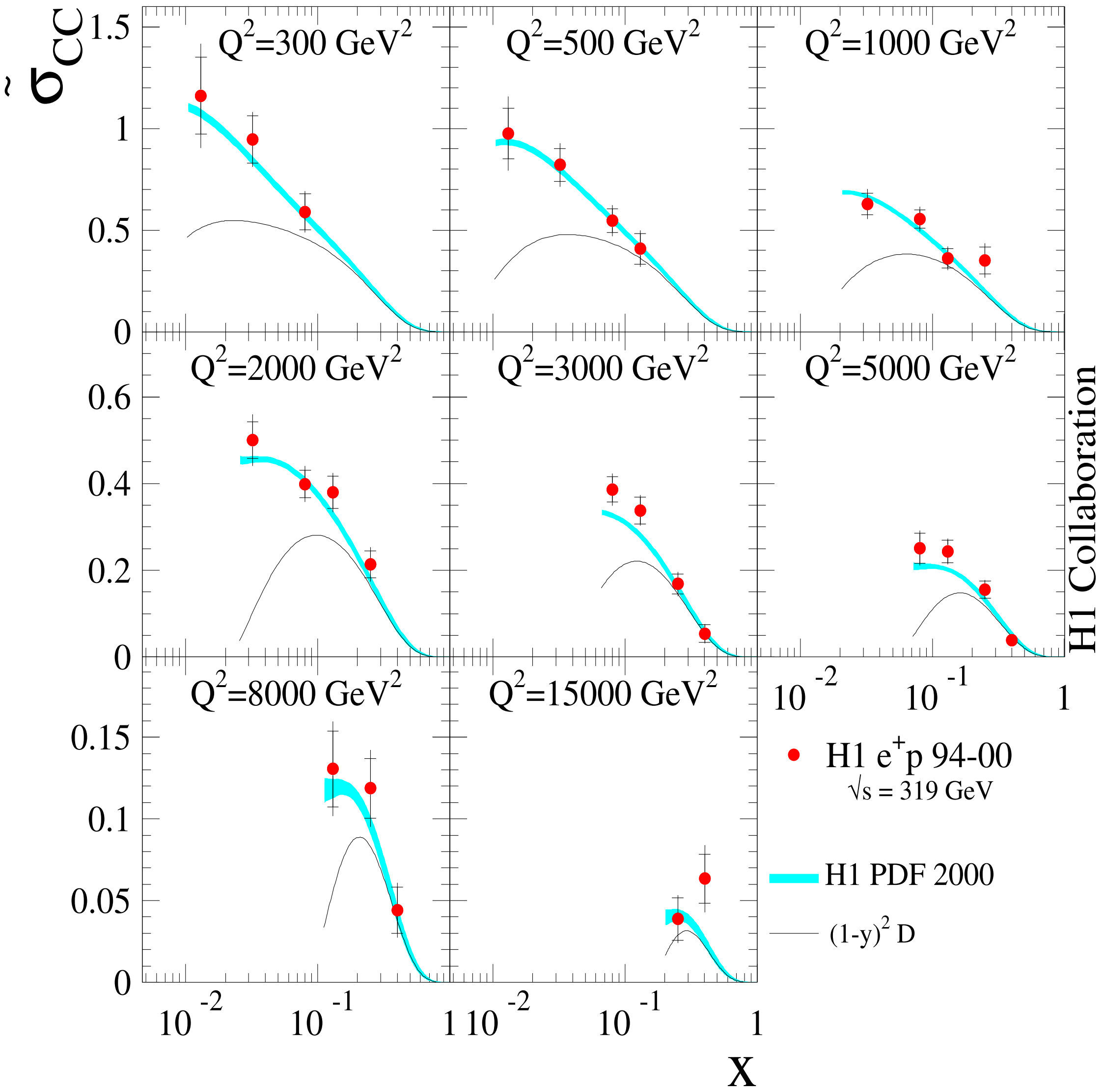
INCLUSIVE DIS - Neutral Current, High Q^2

$$x\tilde{F}_3 = \frac{1}{2Y_-}\left[\frac{d^2\sigma^-_{NC}}{dxdQ^2} - \frac{d^2\sigma^+_{NC}}{dxdQ^2}\right] \qquad F_3^{\gamma Z} \approx -x\frac{\tilde{F}_3(Q^2+M_Z^2)}{a_e k Q^2}$$





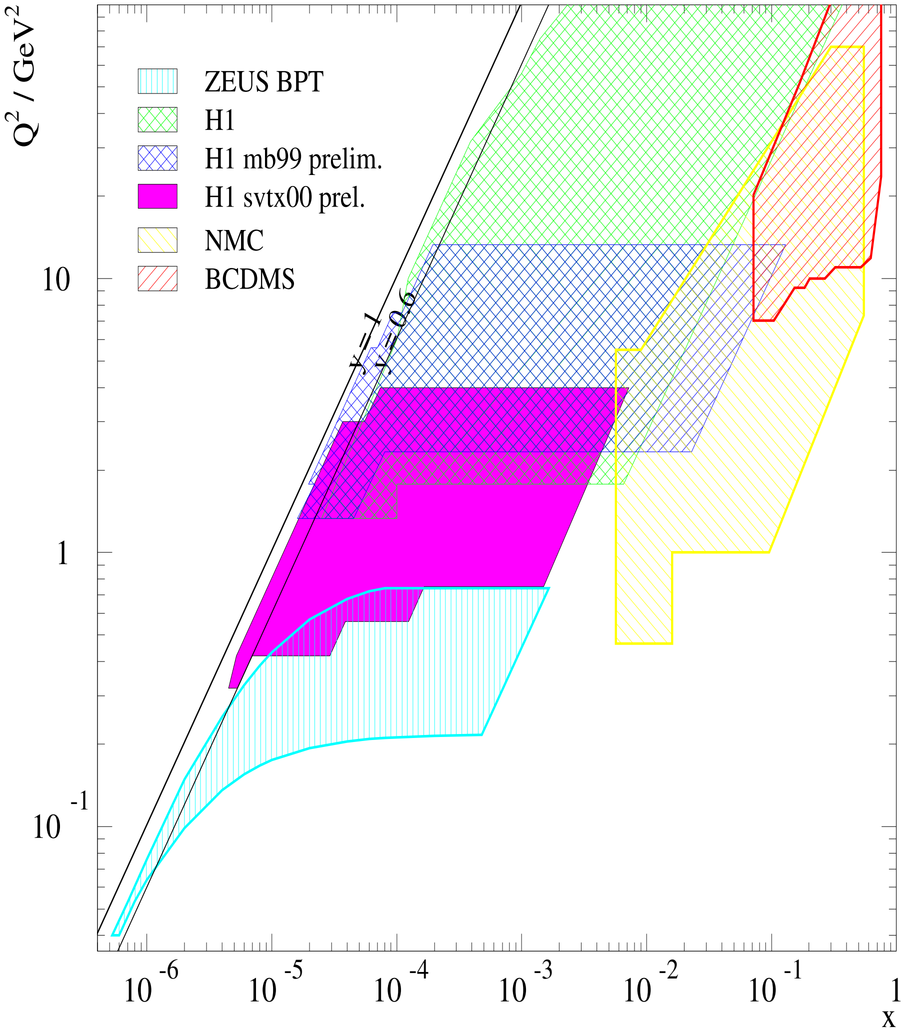
Reduced cross section



$$\tilde{\sigma}^{+}_{cc} \equiv \frac{2\pi x}{G_F^2}\left[\frac{M_W^2+Q^2}{M_W^2}\right]\frac{d^2\sigma^{+}_{CC}}{dx\,dQ^2}$$

- **H1 e^+ data 94-00**
- **H1 PDF fit 2000**
- $(1-y^2)\cdot x(d+s)$

F_L determination



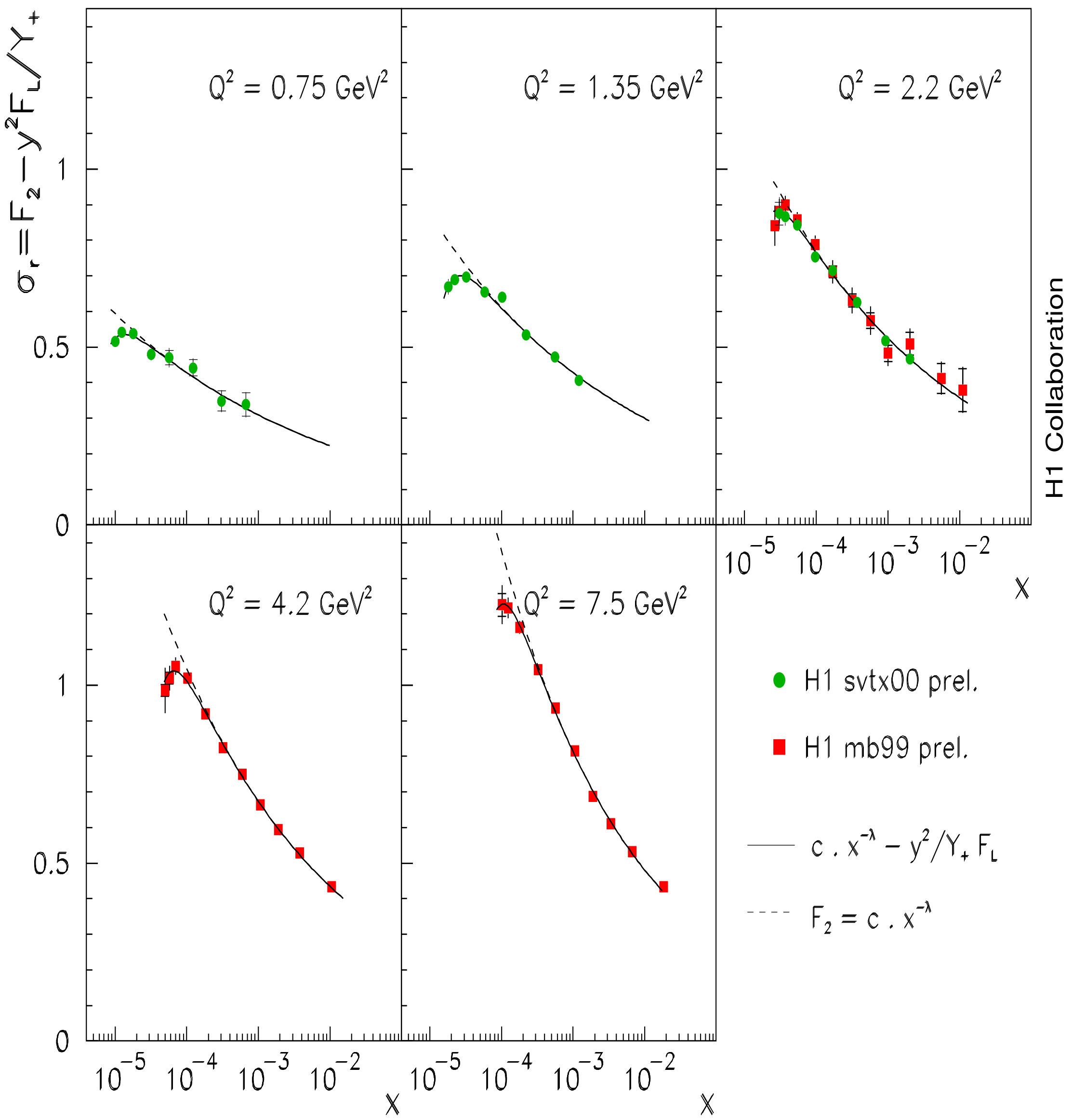
$$\sigma_r = \frac{d^2\sigma}{dxdQ^2}\frac{Q^4 x}{2\pi\alpha^2 Y_+} = F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2)$$

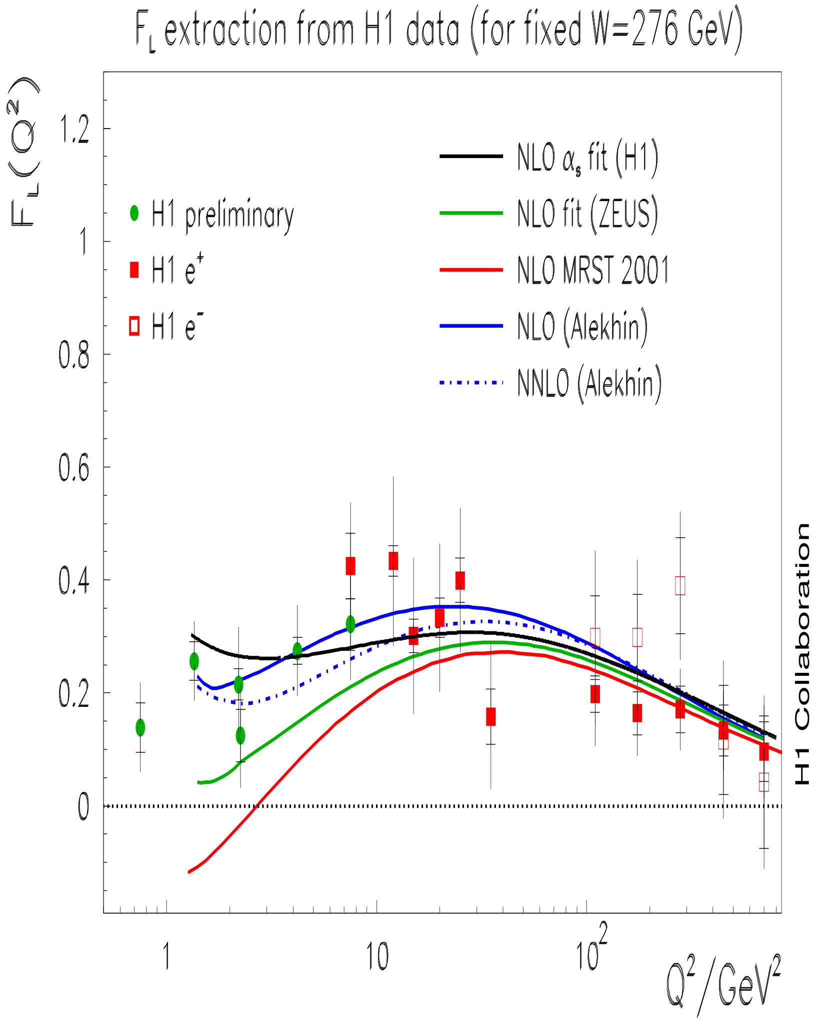
F_L determination needs access to high y region

- **Model free method :** different beam energies,not yet available at HERA
- **Extrapolation method :** assumption :F_2-QCD extrapolated to high y region
- **Shape method:** $F_2 = cx^{-\lambda}$ for each Q^2 bin

H1 data : svtx00-vertex shifted data 2000
mb99 - special low Q^2 run 1999

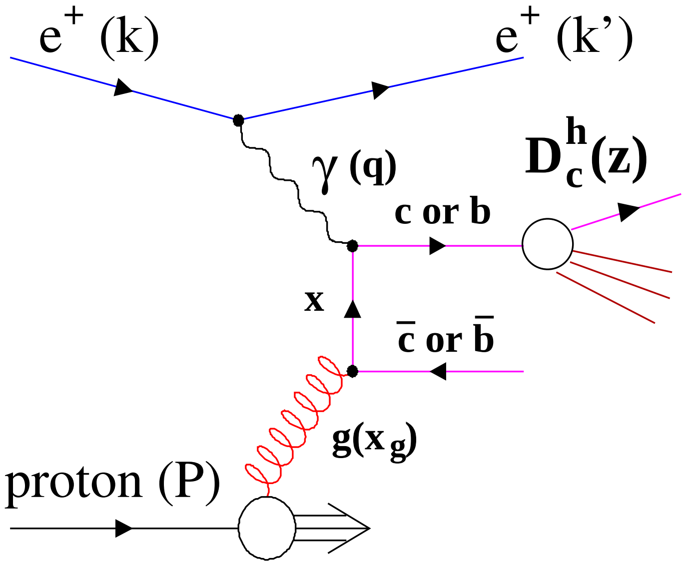
STRUCTURE FUNCTIONS -F_L





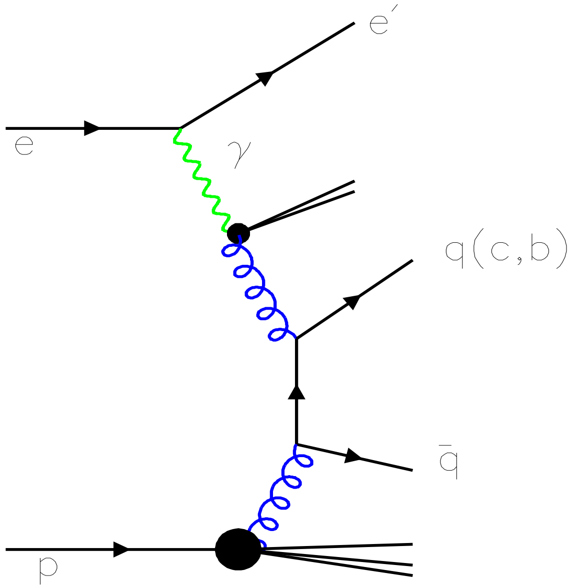
PRODUCTION of HEAVY QUARKS - Open c, b production

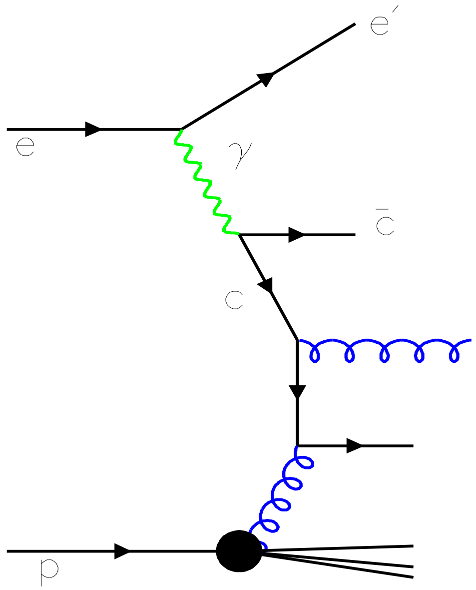
Heavy flavour production dominated by Boson Gluon Fusion (BGF)



Contribution of photoproduction :

resolved photon | **charm excitation**





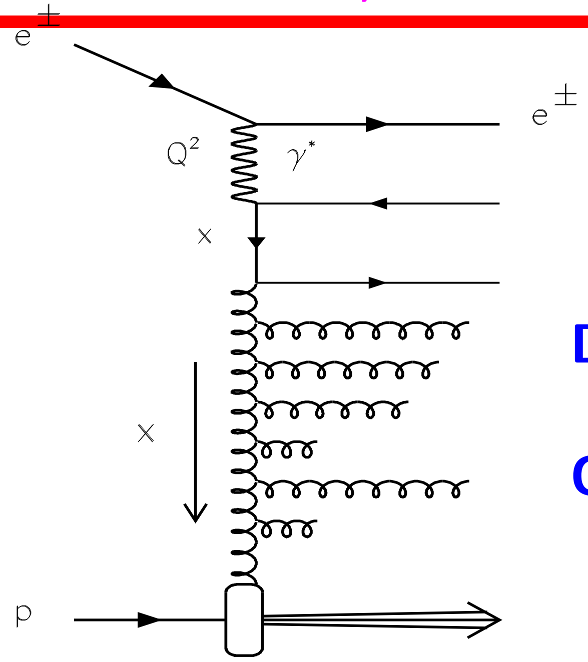
Factorization:

Proton structure $\otimes$ Photon structure $\otimes$ $\sigma(\gamma g \rightarrow q\bar{q})$ $\otimes$ Fragmentation function

PRODUCTION of HEAVY QUARKS - Motivation, Models

Why heavy flavours :

- heavy quark mass provides a hard scale $\longrightarrow$ testing QCD
- access to the parton densities in proton and photon
- sensitivity to the parton evolution models
- fragmentation issues



DGLAP
$\Updownarrow$
CCFM

NLO QCD calculations, DGLAP scheme

★ Fixed order ('massive'), valid for $p_T \sim m_{c,b}$
heavy quark produced dynamically via BGF
●γp:FNMR ●DIS : HQDIS

★ Resummed('massless') scheme,valid for $p_T \gg m_{c,b}$
heavy quarks in p and γ structure functions
●γp : Cacciari et al., Kniel et al.

★ fixed order + NLL, p_T resummantion Cacciari et al.

MC generators (LO ME + PS)

♠ AROMA:
direct γ only, LO DGLAP evolution of PS

♠ PYTHIA,RAPGAP,HERWIG:
direct+resolved, LO DGLAP

♠ CASCADE: CCFM evolution, angular ordering, k_t dependent gluon density

PRODUCTION of HEAVY QUARKS

Recent results :

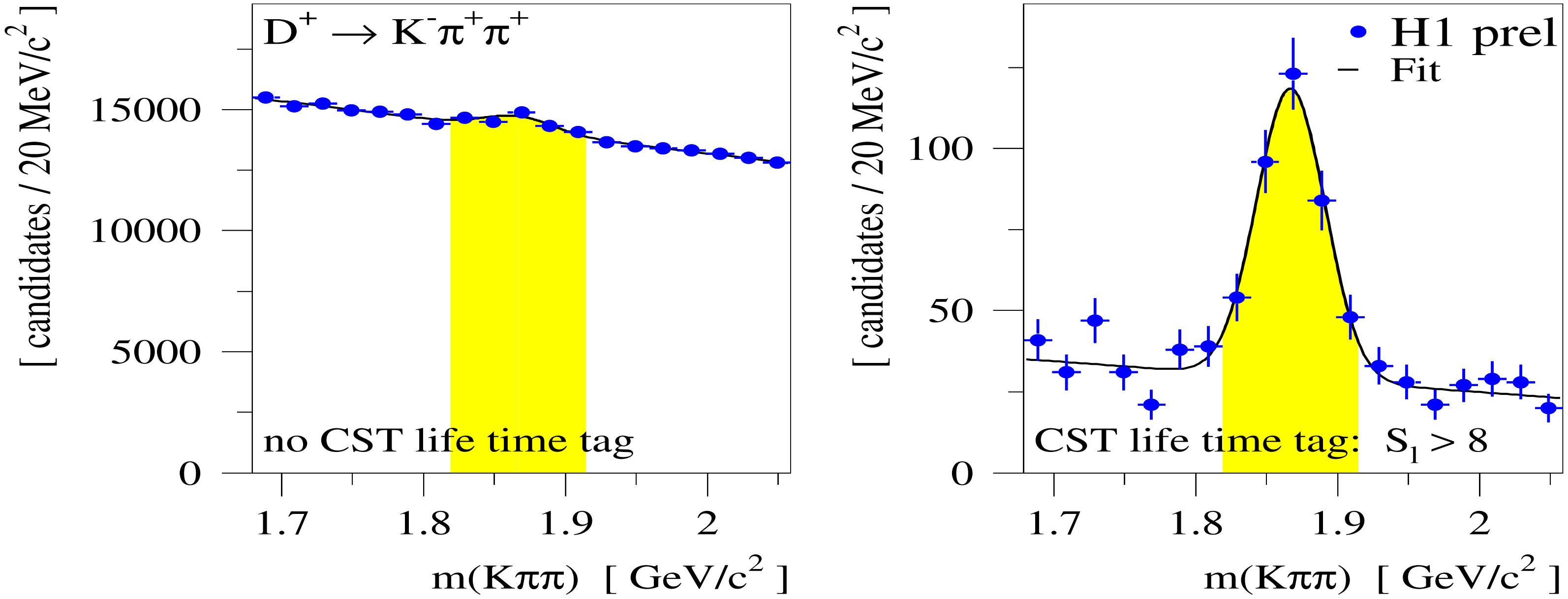
- D^+, D_S, D^0, D^* in DIS
- D^* in photoproduction
- Inclusive D^* Meson and Associated Dijet Production in Deep Inelastic Scattering
- D^* - muon correlations in ep scattering at HERA
- Beauty in photoproduction

- Elastic J/ψ production $\longrightarrow$ Diffraction
- Inelastic J/ψ production in DIS and photoproduction (published 2002)

PRODUCTION of HEAVY QUARKS - Charm Identification

$$D^+ \rightarrow K^-\pi^+\pi^-,\ D_S \rightarrow \Phi\pi^+\ ,\ D^0 \rightarrow K^-\pi^+,\ D^{*+} \rightarrow D^0\pi^+ \rightarrow K^-\pi^+\pi^+$$

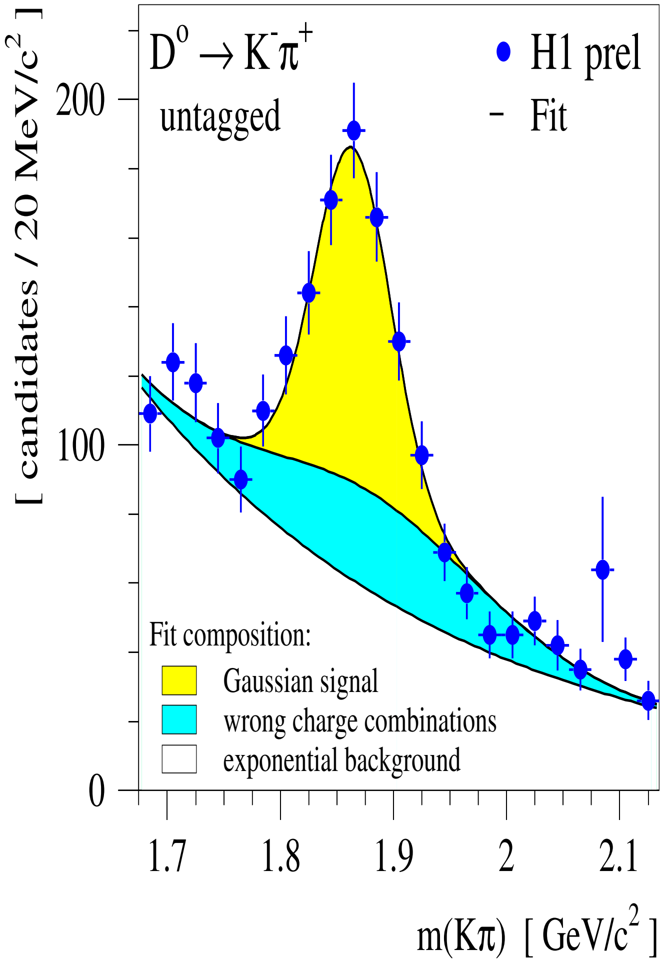
- no particle identification,selection of tracks in the drift chambers CJC
- hits in the central silicon tracker linked to tracks in CJC
- secondary vertex reconstruction,charm tagging via decay length
- (l=$\gamma c\tau$) $\sim 100\mu m$, separation factor $S_l = \frac{l}{\varepsilon_l}$



Background reduced by O(300), signal/backg improved by O(50)

PRODUCTION of HEAVY QUARKS - Charm in DIS

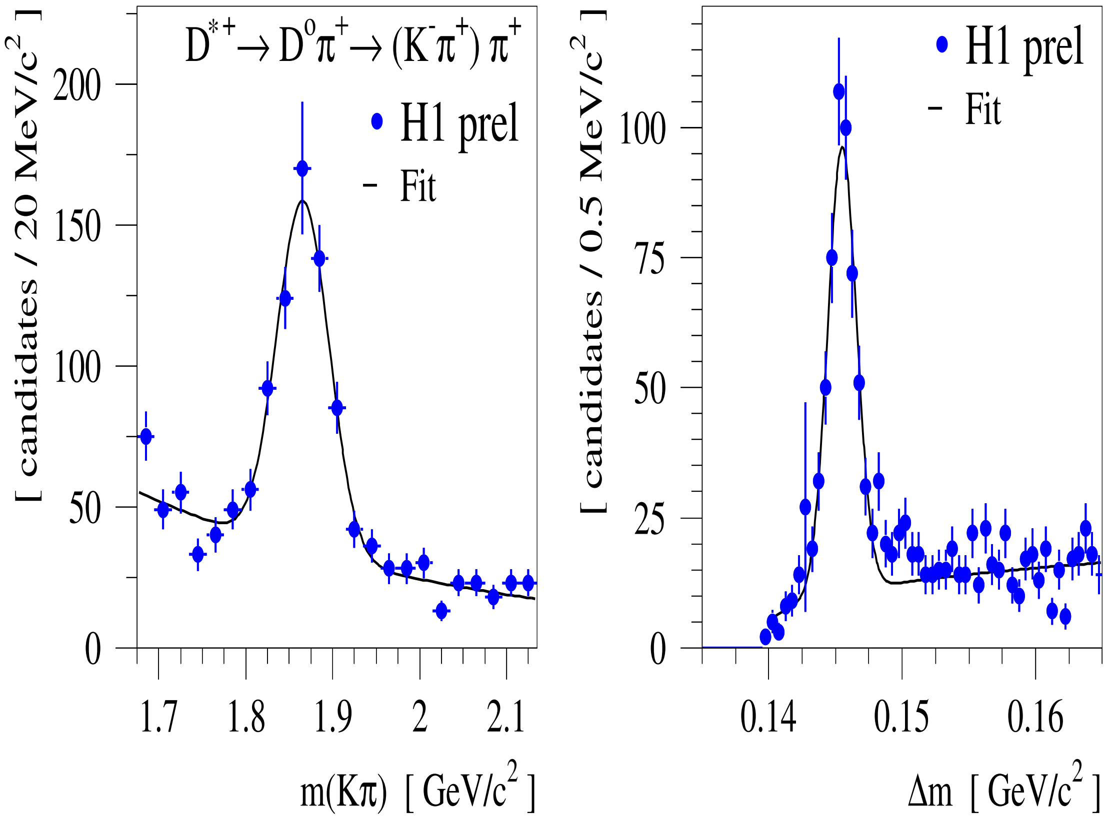
$D^0 \longrightarrow K^-\pi^+$



$D^{*\pm} \longrightarrow D^0\pi^\pm \longrightarrow K^\mp\pi^\pm\pi^\pm$

D^* identification via Δm method

m(D^*) - m(D^0)= 145.4 MeV



Δm : $mass(K\pi)$ $within$ $[m(D^0) \pm 3 \cdot width(D^0)]$

D^* : 3 sigma cut around Δ m peak - tagged D^0

PRODUCTION of HEAVY QUARKS - Charm in DIS

Visible cross sections $\sigma_{vis}(ep \to eDX)$

kinematic range: $2 < Q^2 < 100\ \mathrm{GeV}^2$, $0.05 < y < 0.7$

$$p_T(D) \geq 2.5\ \text{GeV}, \quad |\ \eta(D)\ | \leq 1.5$$

		data	AROMA	HQDIS
e.g.	$\sigma(D^+)$ (nb)	$2.16 \pm 0.19^{+0.46}_{-0.35}$	2.45 ± 0.30	
	$\sigma(D^{*+})$ (nb)	$2.90 \pm 0.20^{+0.58}_{-0.44}$	2.61 ± 0.31	2.55

Fragmentation factors extracted from $\sigma_{vis}(ep \to eDX)$, e.g.

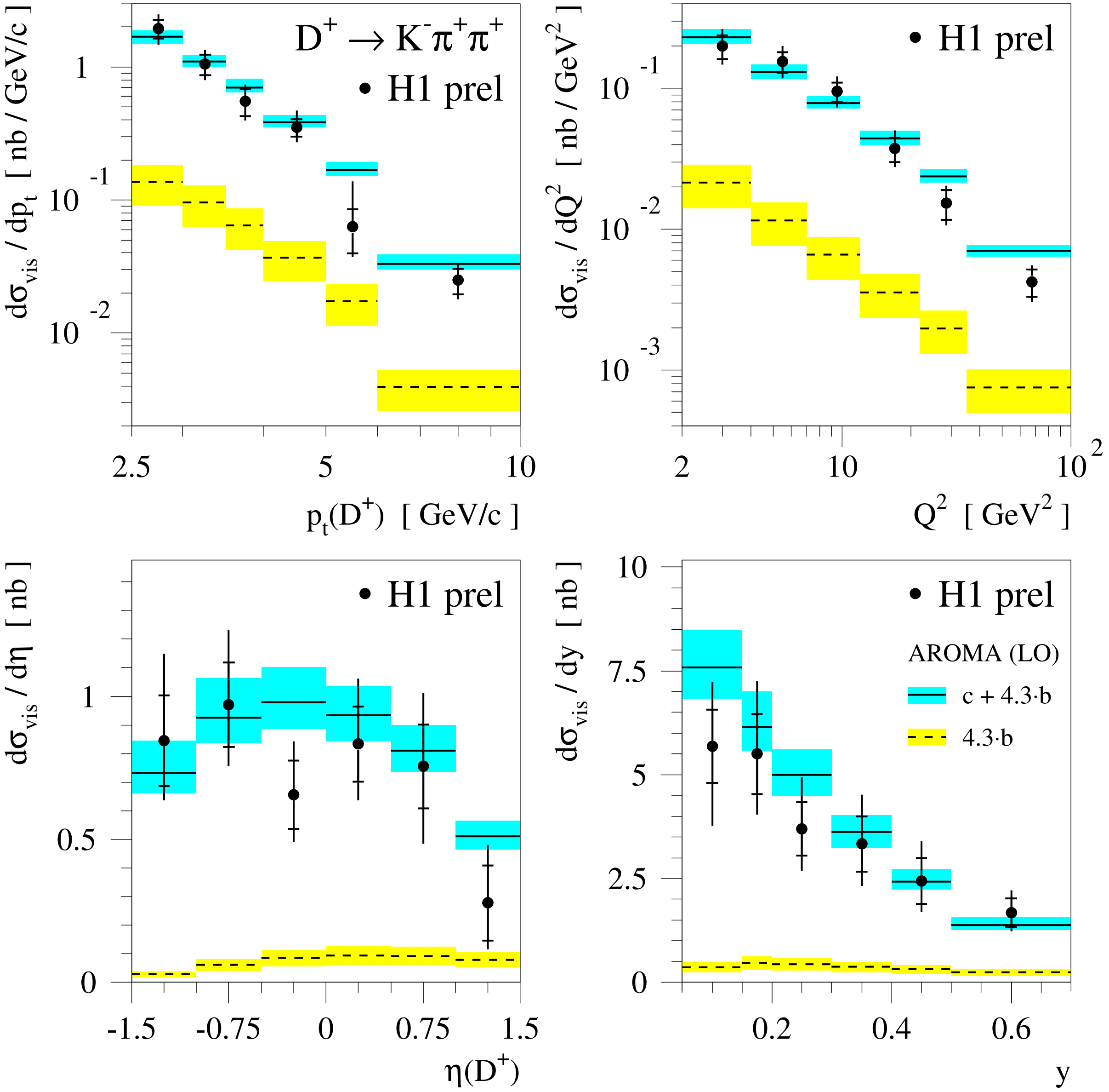
$f(c \to D^+) = 0.202 \pm 0.020^{+0.045+0.029}_{-0.033-0.029}$ world average 0.232 ± 0.018

stat. syst. theor.

Universality of charm fragmentation

PRODUCTION of HEAVY QUARKS - Charm in DIS

$D^+ \to K^-\pi^+\pi^+$ Differential cross sections of $p_t(D), \eta(D), Q^2, y$



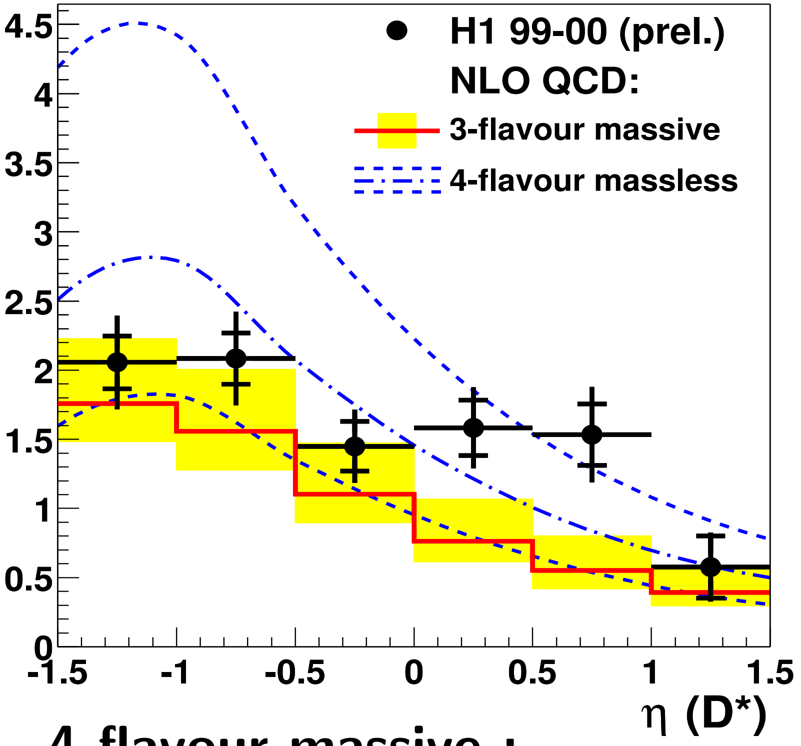
good agreement with AROMA

taking into account b-quark contribution

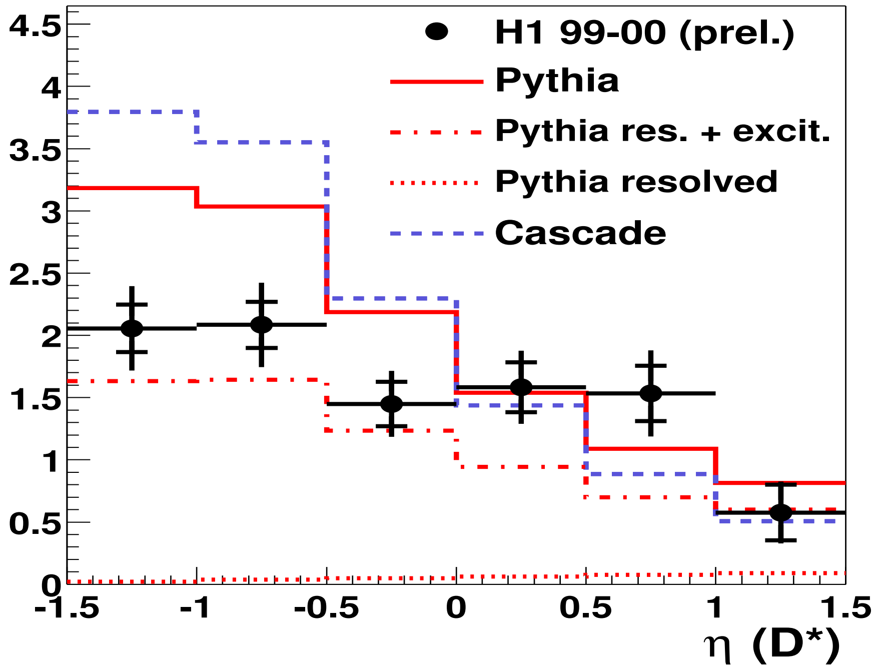
$D^{*\pm} \to K^{\mp}\pi^{\pm}\pi^{\pm}$, $\mathcal{L} = 49pb^{-1}$, tagged photoproduction events

$Q^2 \leq 0.01\ \mathrm{GeV}^2$, $171 < W < 256$ GeV, $|\eta(D^*)| < 1.5$, D^* - Δm method

$d\sigma/d\eta$ (nb)



$\longleftarrow$ $\mu_{r,f}$ changed by 0.5 and 2 (upper ,lower limits)



4-flavour massive :

$\mu_r = \mu_f = 2\sqrt{m_c^2 + p_{t,c}^2}$

$f(c \to D^*) = 0.235,$

PRODUCTION of HEAVY QUARKS - Beauty in γp

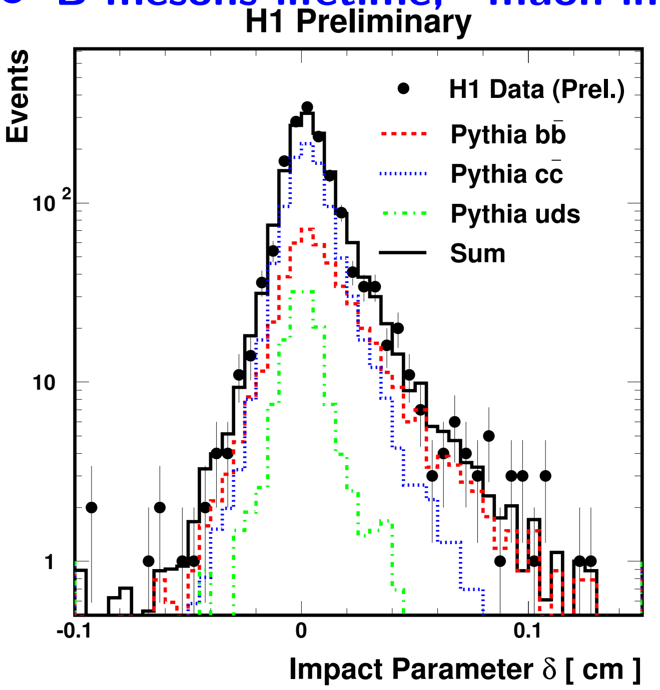
$$e^+p \rightarrow e^+b\bar{b}X \rightarrow e^+ + jj + \mu^+ + X$$

Kinematic range :

- $Q^2 \leq 1\ \mathrm{GeV}^2, \quad 0.2 < y < 0.8$
- $-0.55 < \eta^\mu < 1.1, \quad p_t^\mu > 2\ \mathrm{GeV}$
- $p_t^{jet_{1(2)}} >$ 7(6) GeV $\quad |\ \eta^{jet}\ |< 2.5$

Beauty tagging methods

- $p_t^{rel}(\mu)$ w.r.t. jet axis
- B mesons lifetime, muon impact parameter δ



H1 data 1999/2000

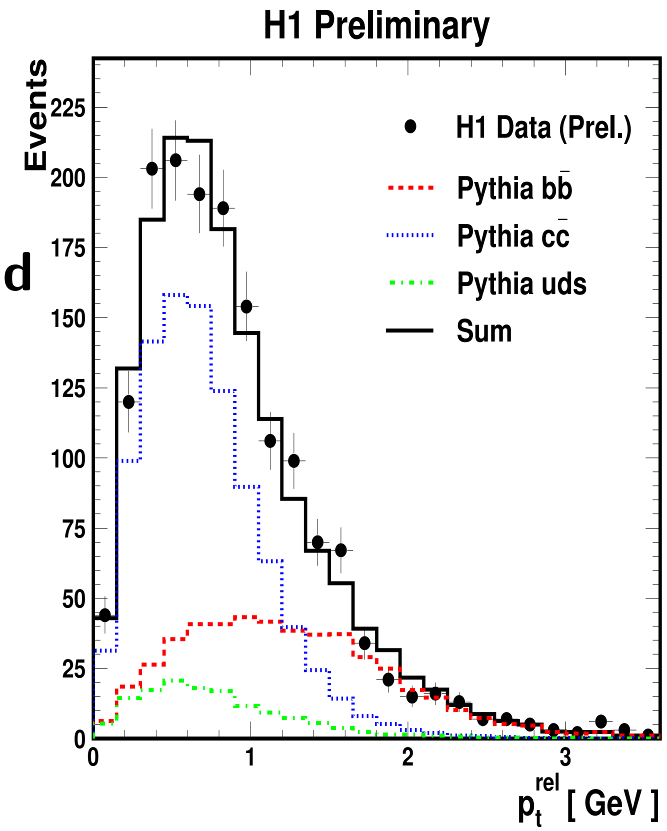
$\mathcal{L} = 48pb^{-1}$

combined fit of $\frac{dN}{d\delta}$ **and** $\frac{dN}{dp_t^{rel}}$

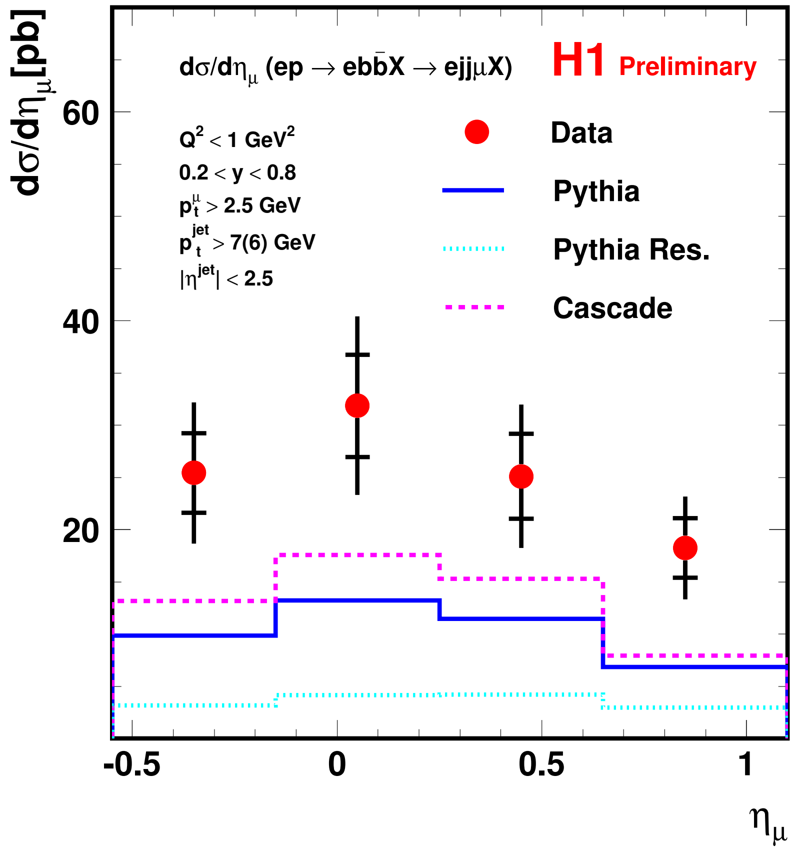
shapes from PYTHIA

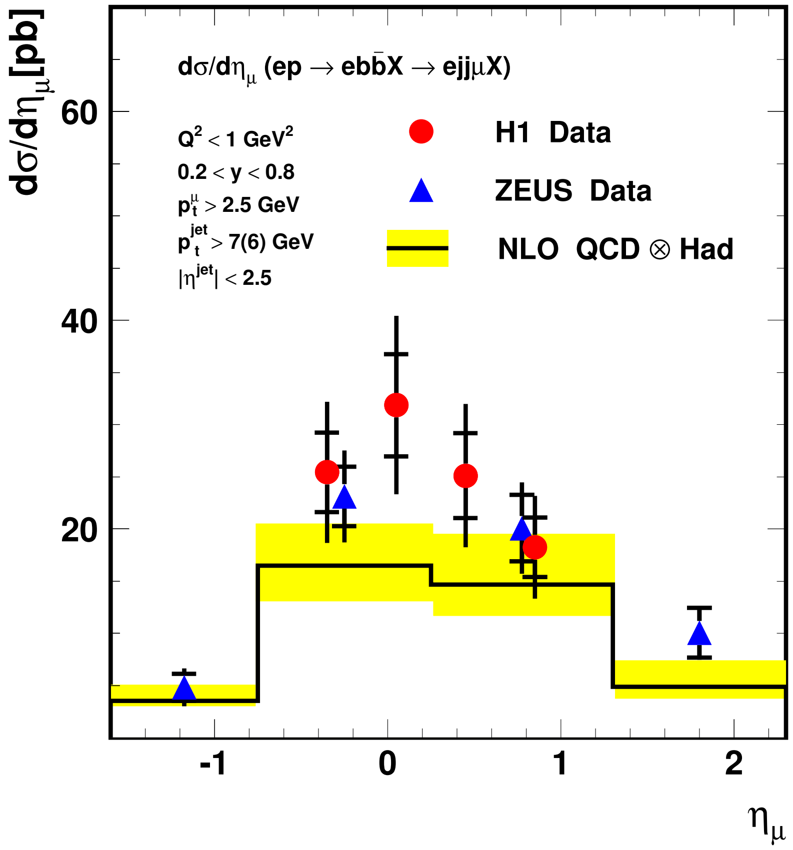
b contribution:

$30.7 \pm 2.5\%$



PRODUCTION of HEAVY QUARKS - Beauty in γp





$$\sigma_{vis}(e^+p \rightarrow e^+b\bar{b}X \rightarrow e^+ + jj + \mu^+ + X) = (42.5 \pm 3.4(stat) \pm 8.9(sys))pb$$

NLO (Frixione et al.) (24+7.2-5.1) pb

DATA/NLO $\sim$ 1.8 ($\sim 1.5\cdot$ experimental error)

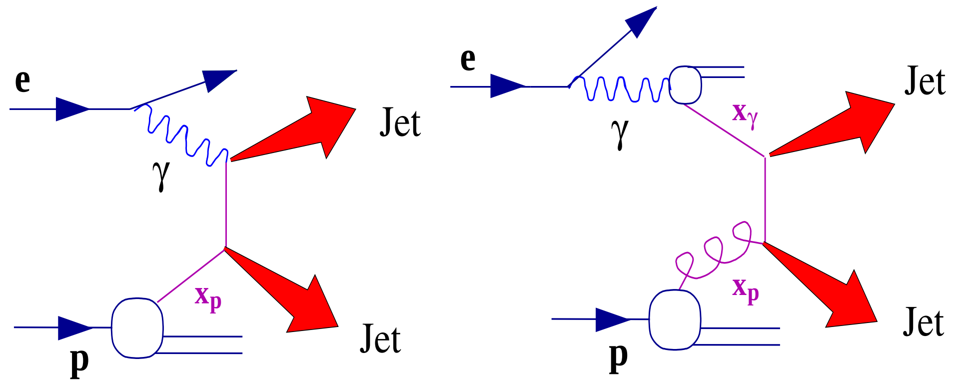
HADRONIC FINAL STATES

Recent results:

- Inclusive jets in photoproduction
- Inclusive dijet at low Bjorken-x in DIS
- Two and three jet differential event shape in DIS
- Forward jets

- Forward π^0 production
- Resonances η, ρ, f_0, f_2 in photoproduction
- Promt photon production in γp

HADRONIC FINAL STATES - Inclusive Jets in photoproduction



Datat 96/97 , $\mathcal{L} = 24pb^{-1}$

Kinematic range:

$Q^2 < 1$ GeV^2,
$95 \leq W_{\gamma p} \leq 285$ GeV
$5 \leq E_T^{jet} \leq 75 GeV$,
$-1 < \eta^{jet} < 2.5$

jets: k_t or cone algorithm

Cross section for $ep \rightarrow e + N\, jets + X$, contributions from direct and resolved γ

e.g. $\sigma_{dir} = \int_\Omega d\Omega f_{\gamma/e}(y, Q^2) \sum_{i/p} f_{i/p}(x_p, \mu_p^2) d\hat{\sigma}(\gamma i \rightarrow N jets)$

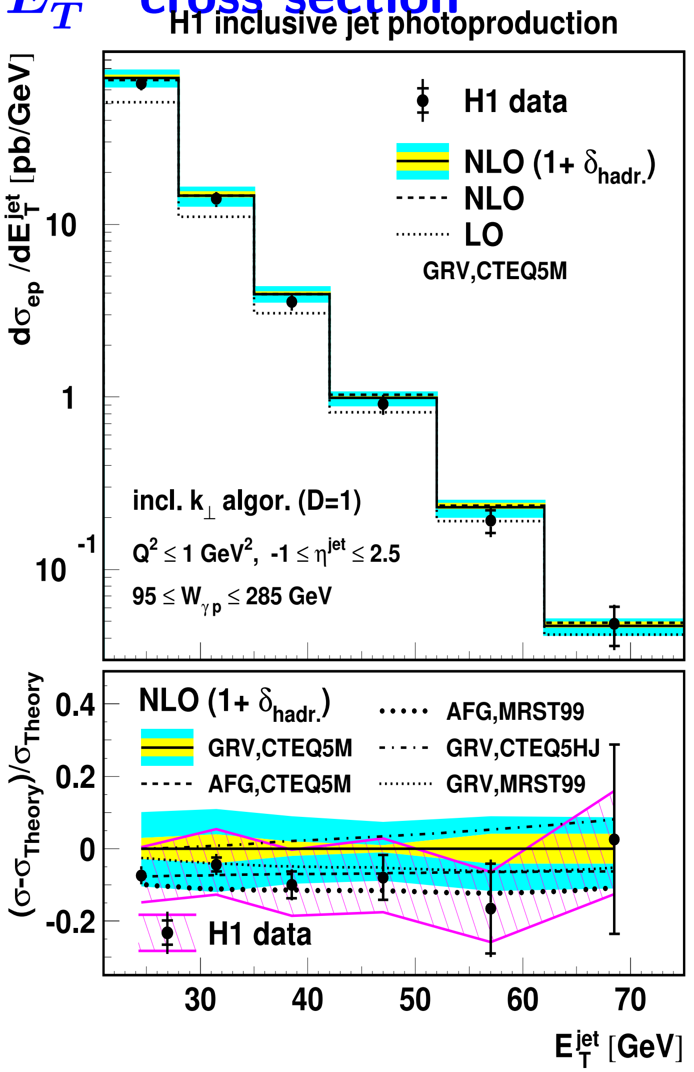
μ_p -factorisation scale, $f_{\gamma/e}$- photon flux, $f_{i/p}$- proton PDF for parton i

QCD calculations : LO and NLO, S.Frixione, G.Ridolfi ,1997

Monte Carlo simulations: PYTHIA, HERWIG, PHOJET

HADRONIC FINAL STATES - Inclusive Jets in Photoproduction

E_T^{jet} cross section



- **proton pdf:**
  CTEQ5M, MRST99,CTEQ5HJ
- **photon pdf :**
  GRV-HO, AFG-HO
- **renorm. and fact. scale**
  $[E_T^{parton_1} + E_T^{parton_2}]/2$
  changed by x0.5 or x2

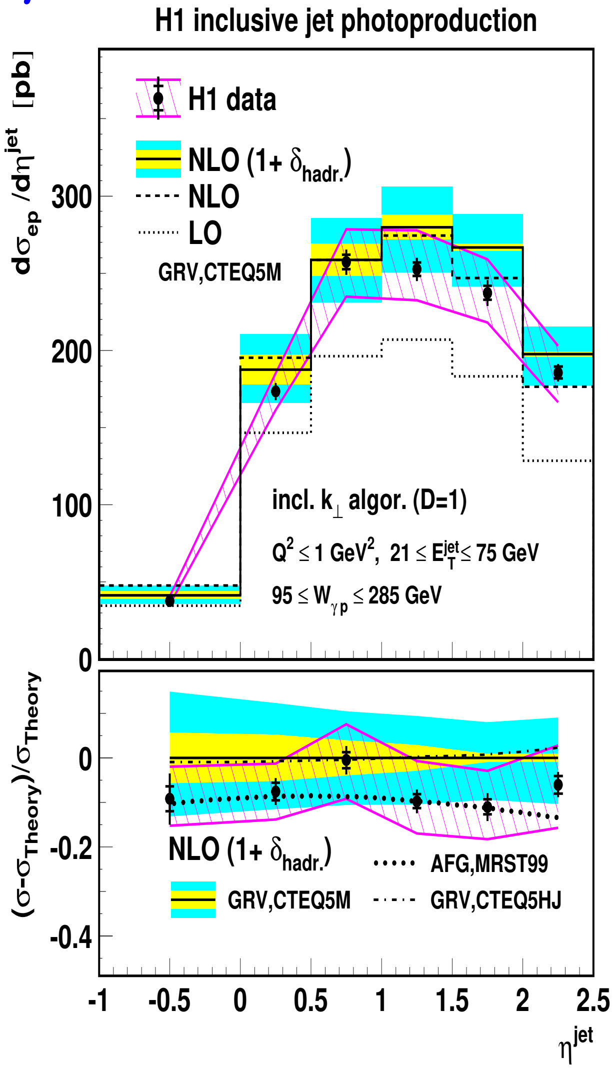
QCD calculation:

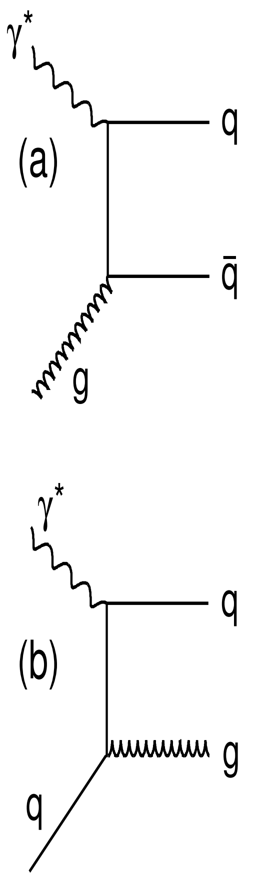
NLO - good agreement

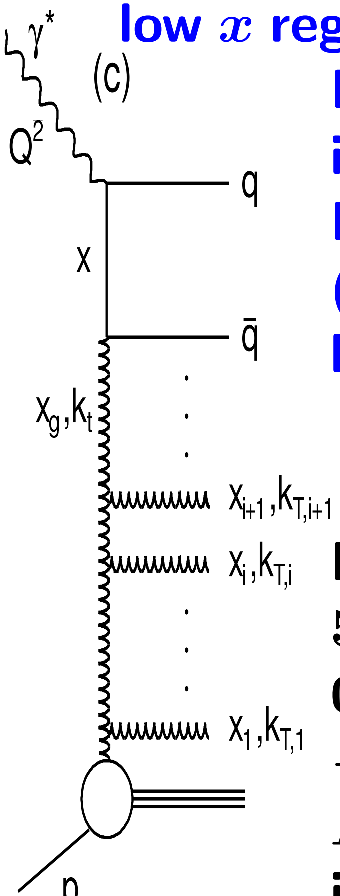
QCD errors :

- hadronis. corrections
- renorm. and fact. scale

η^{jet} cross section







low x region: $(10^{-4} - 10^{-2})$

DGLAP (k_t ordering) not valid?

BFKL or CCFM (angular ordering) better?

Kinematic range :

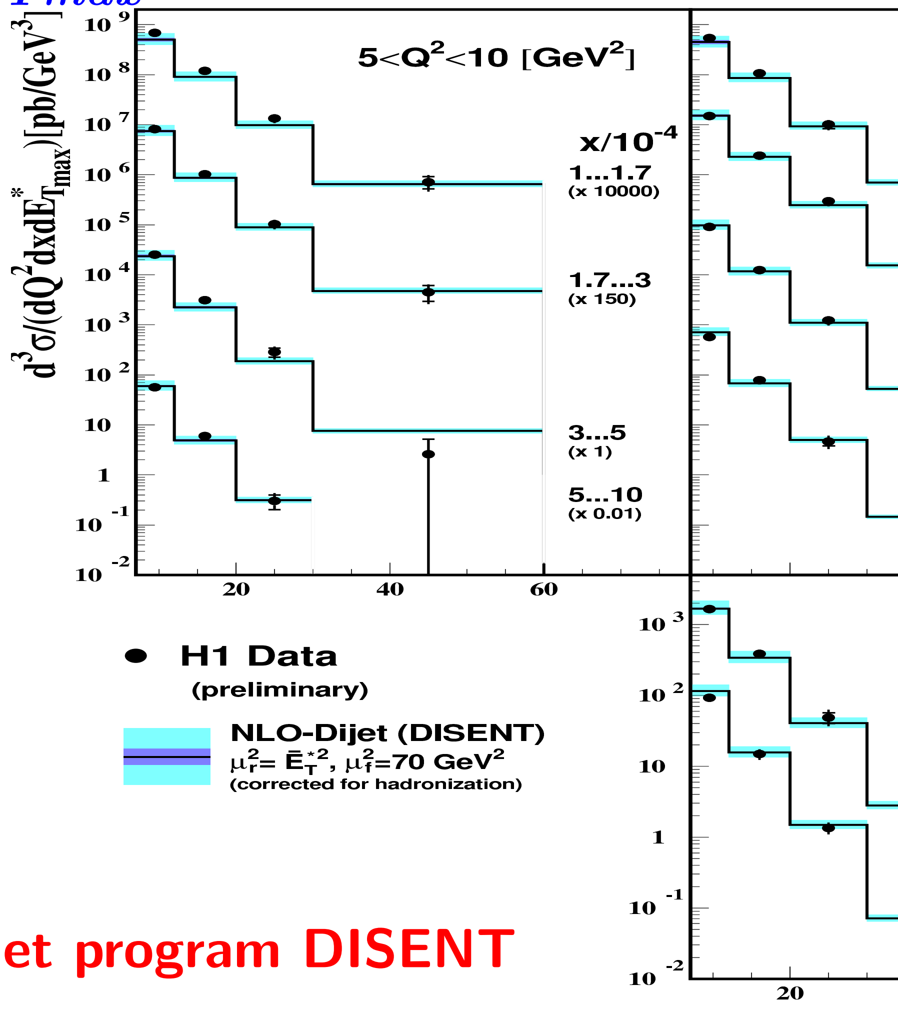
$5 < Q^2 < 100$ GeV^2,

$0.1 < y < 0.7$

$-1 < \eta^{jet} < 2.5$

E_T^* **of jets** > 5 GeV **in** γp **CMS**

E^*_{Tmax} of jets in hadronic CMS



$\frac{d^3\sigma}{dQ^2 dx dE^*_{Tmax}}$ - **good description by NLO QCD dijet program DISENT**

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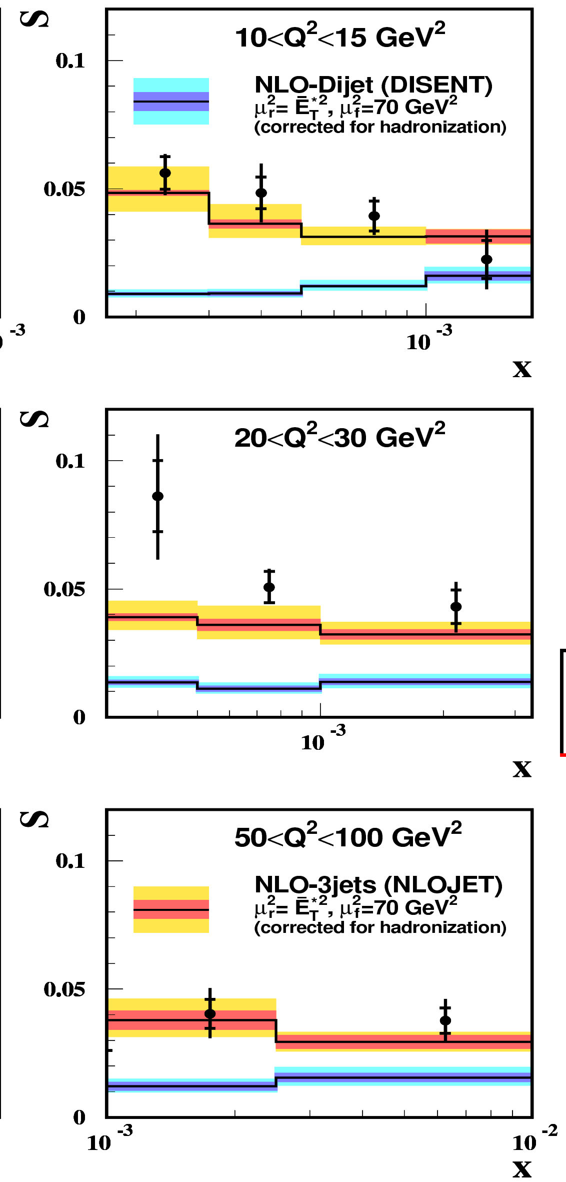
Hadronic final states-inclusive dijets at low x in DIS



Azimuthal correlations

$\Delta\phi^*$ between jets

transverse plane in γp CMS

no hard gluon emission in the gluon ladder

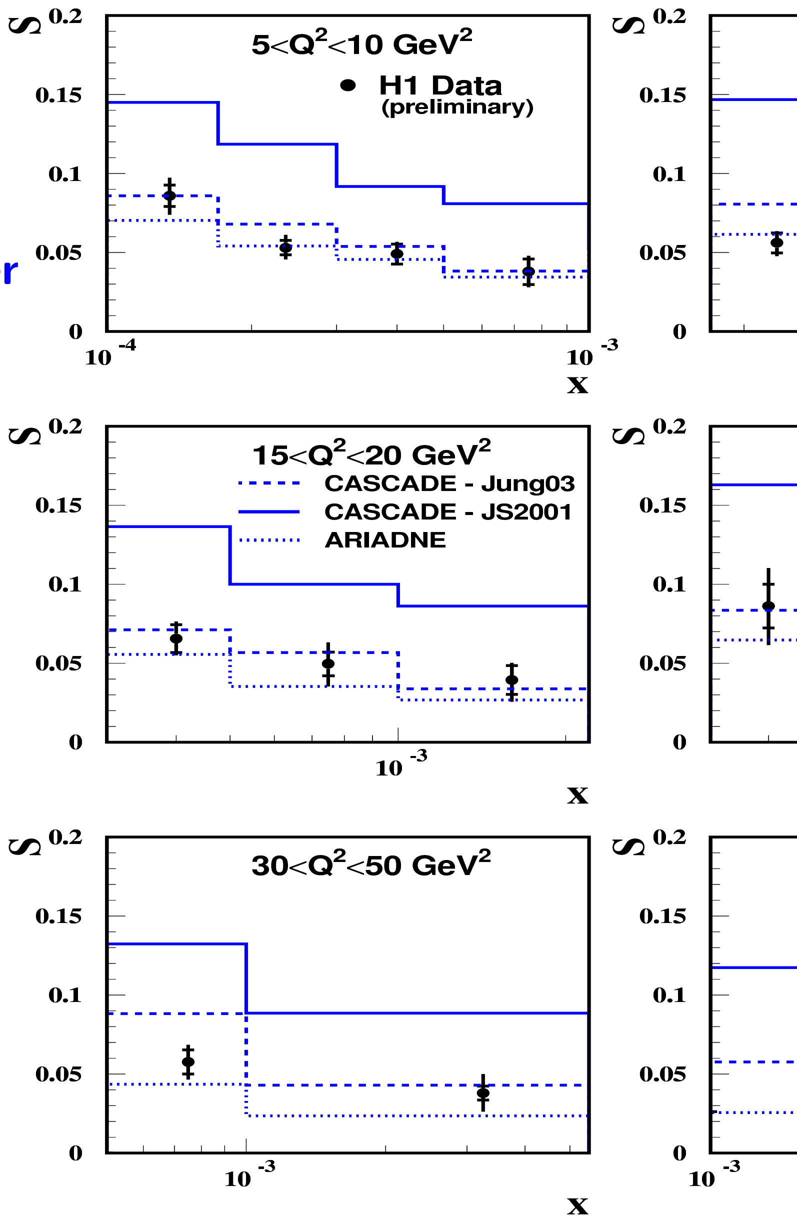
$$\Longrightarrow \Delta\phi^* \sim \pi$$

$$S = \frac{N_{2-jet}(\Delta\phi^* < 2\pi/3)}{N_{2-jet}(\Delta\phi^* < \pi)}$$

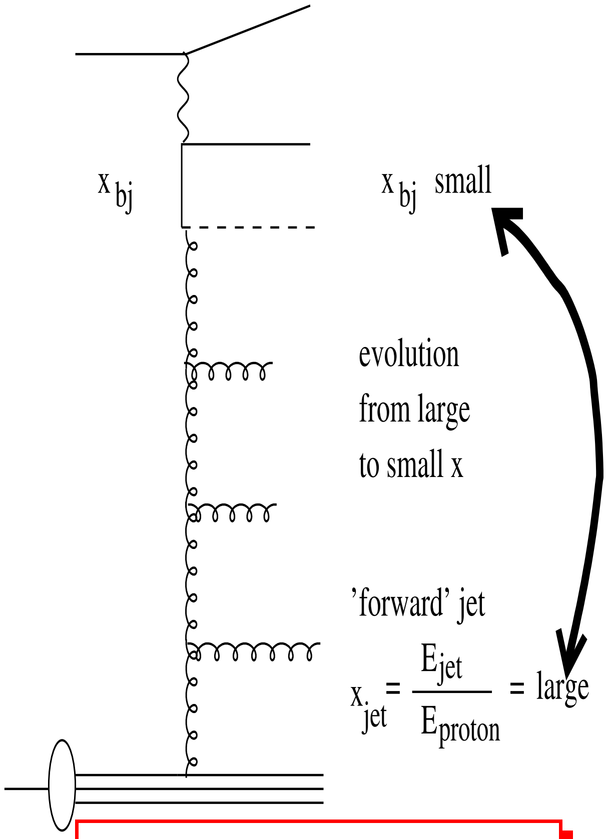
S sensitive to non DGLAP effects

good agreement :

- **QCD NLO three jets (NLOJET)**
  DGLAP collinear approach
- **RAPGAP** (LO DGLAP+resolve γ)
- **ARIADNE** (color dipole model)
- **CASCADE** (CCFM evolution,
  JUNG unintegrated gluon density)



HADRONIC FINAL STATES - Forward Jets in DIS

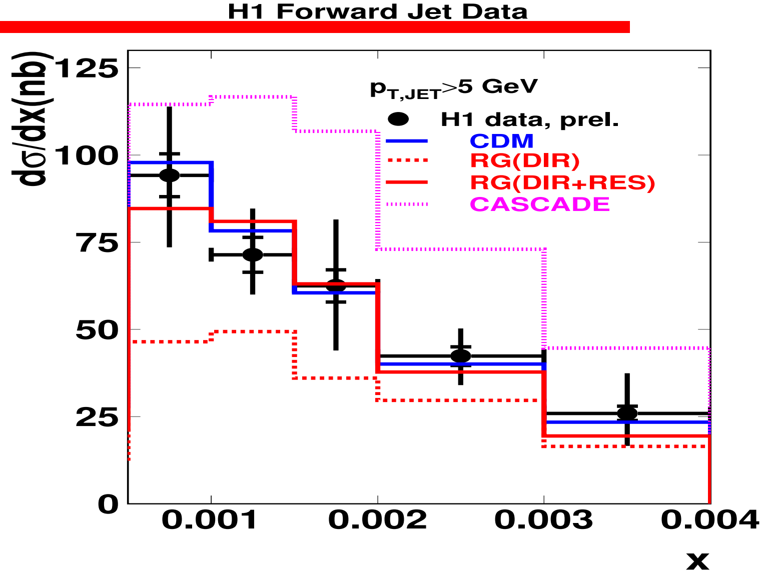


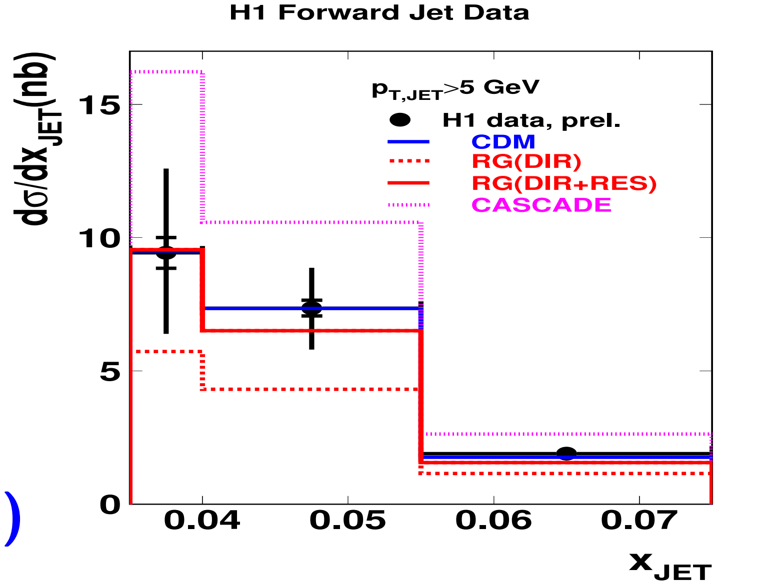
BFKL region: $p_{t,jet}^2 \sim Q^2$

Jets: k_t **algorithm**

- $p_{t,jet} > 3.5$ GeV
- $7^o < \theta_{jet} < 20^o$
- $x_{jet} = E_{jet}/E_p > 0.035$
- $0.5 < p_{t,jet}^2/Q^2 < 2$

- $5 < Q^2 < 75$ GeV^2
- $0.1 < y < 0.7$
- $x \equiv x_{bj} < 0.004$





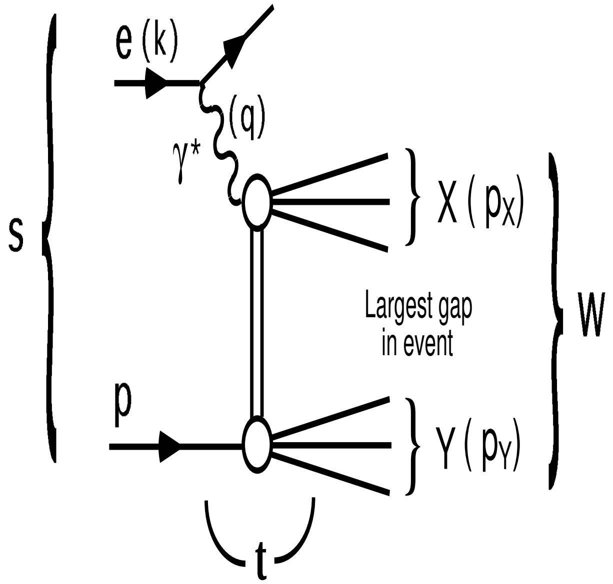
Good description : **ARIADNE (CDM)**

RAPGAP (RP) with resolved γ (DIR+RES)

DIFFRACTION

Recent results:

- Inclusive cross section for diffractive deep inelastic scattering at high Q^2.
- Diffractive photoproduction of high p_t photons
- Dijets and D^* in diffractive photoproduction
- Elastic and diffractive photoproduction at high t of J/ψ mesons
- Deeply virtual Compton scattering

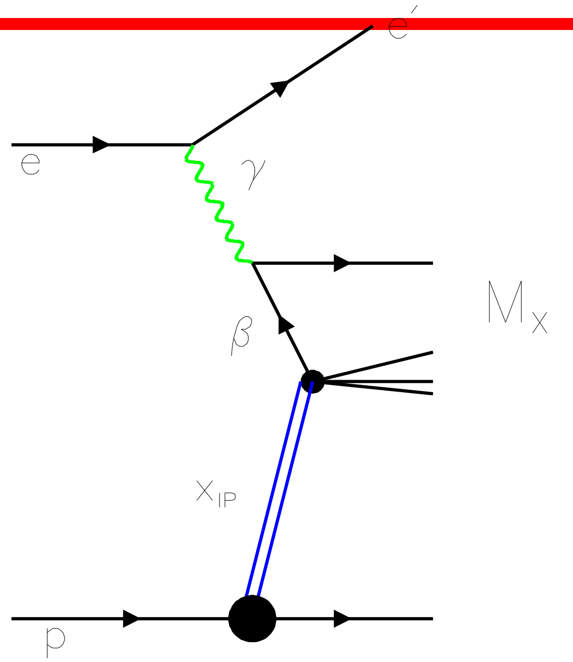


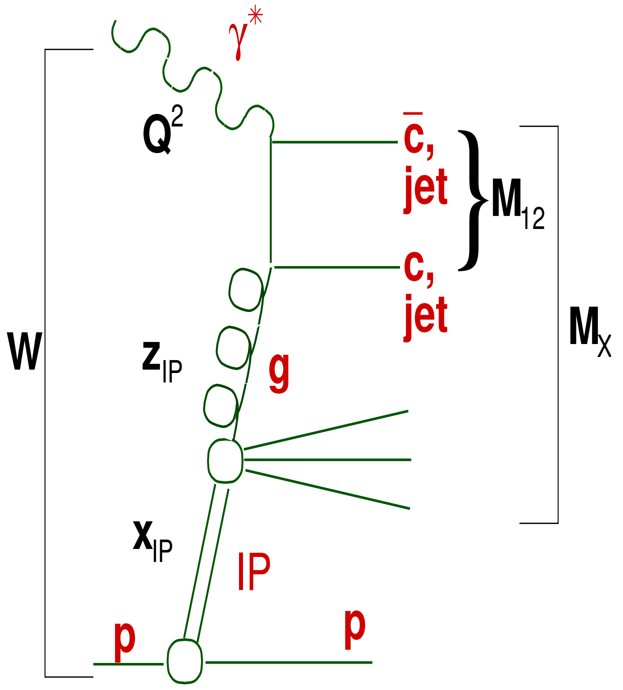
Kinematics:
momentum transfer squared t between proton and Y;
two longitudinal momentum fractions
- of the proton carried by colourles exchange $I\!P$

$$x_{I\!P} = \frac{q(P-p_Y)}{q \cdot P} \sim \frac{Q^2+M_X^2}{Q^2+W^2}$$

- of $I\!P$ carried by the struck quark $\quad \beta = \frac{x}{x_{I\!P}}$

DIFFRACTION





$z_{IP} \equiv z$
longitudinal momentum fraction :
$0 < \beta < z$

Reduced cross section(integrated over t)

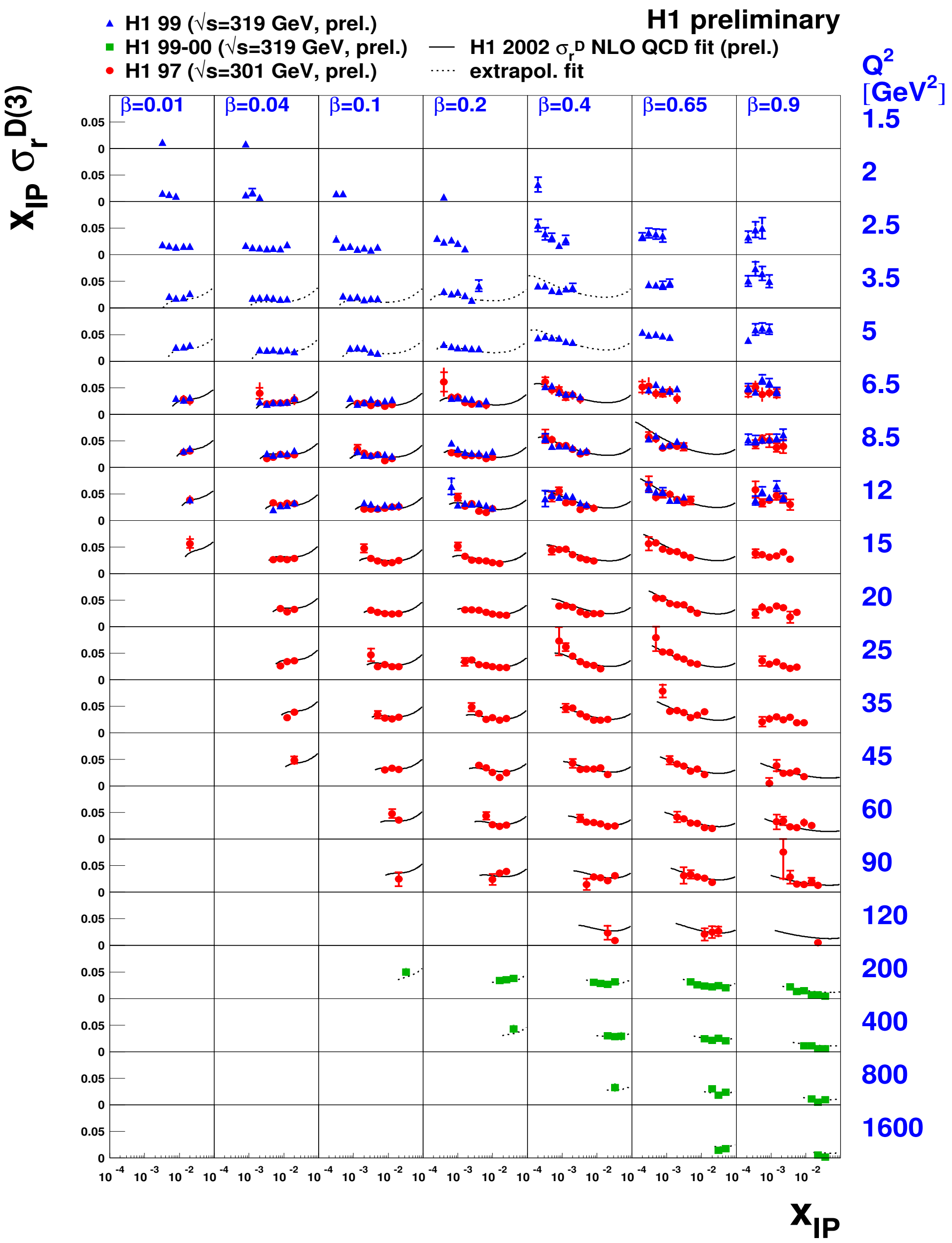
$$\frac{d^3\sigma^D}{dx_{IP}d\beta dQ^2} = \frac{4\pi\alpha^2}{xQ^4}(1 - y + \frac{y^2}{2})\sigma_r^{D(3)}(x_{IP}, \beta, Q^2); \; \sigma_r^{D(3)} = F_2^{D(3)} - \frac{y^2}{1+(1-y)^2}F_L^{D(3)}$$

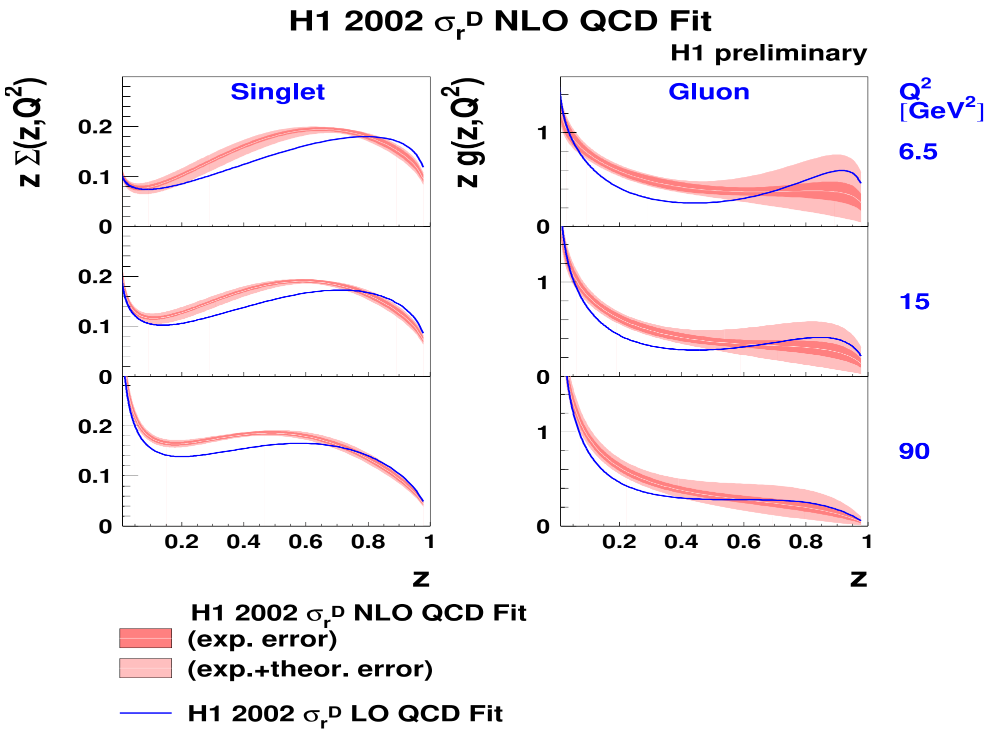
QCD models $\Longrightarrow$ Regge factorisation $\Longrightarrow$ Parton densities f_i^D of parton i:

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

$\downarrow$ **Pomeron flux** $\quad \downarrow$ **parton densities** $\quad \Longrightarrow \boxed{\sigma_r^{D(3)} = f_{IP/p}(x_{IP}) \cdot A_{IP}(\beta, Q^2)}$

DIFFRACTION - DIS at High Q^2



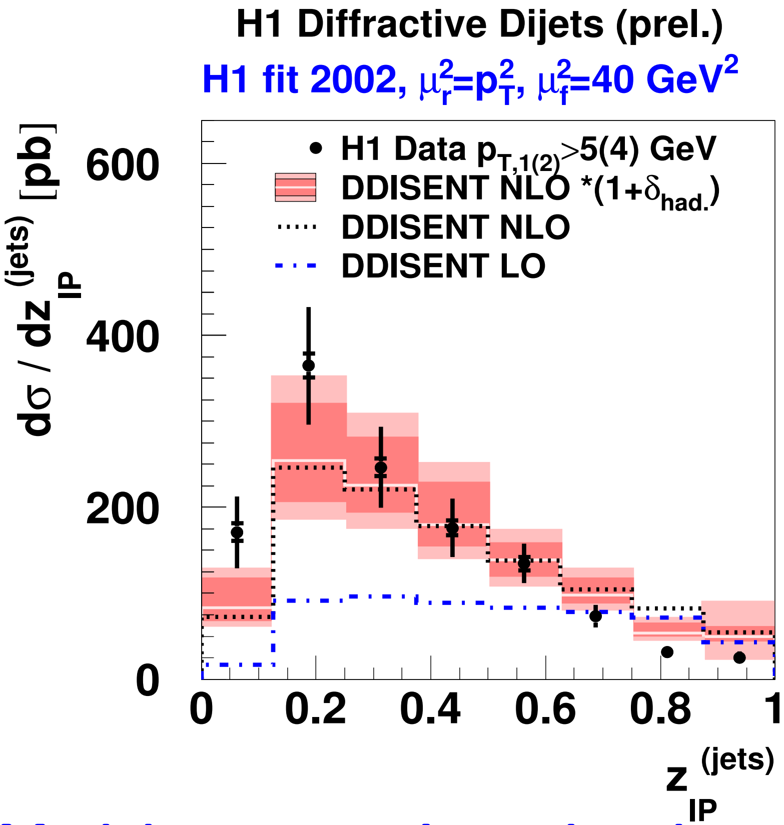


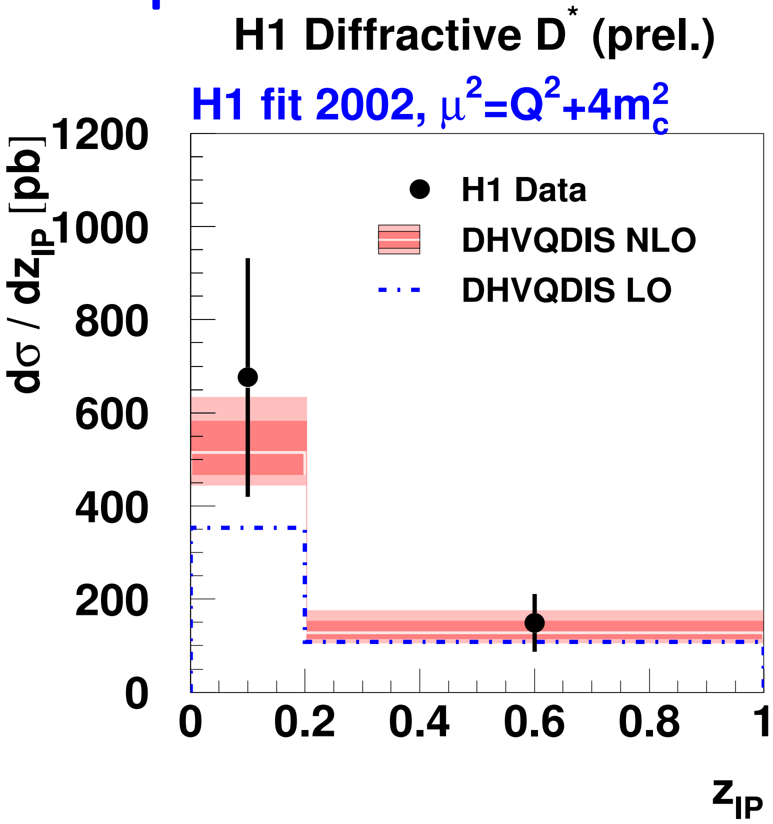
Large Q^2 region covered by H1.

QCD fit to medium Q^2 data (NLO QCD fit 2002) for diffractive parton densities describes new data at high Q^2 well.

Gluon contributon dominates

Application of diffractive pdf to dijet and D^* production.



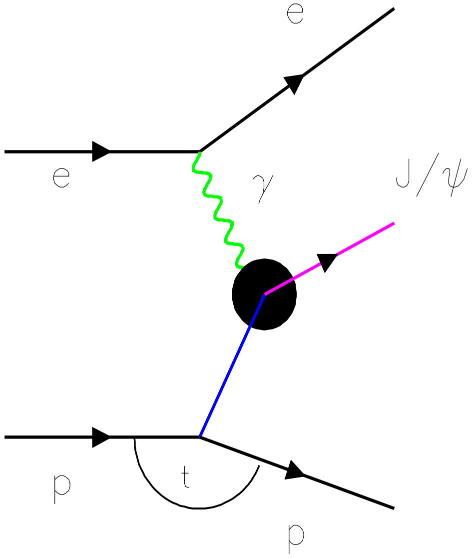


Model errors : inner band-renormalization scale uncertainty

outer band includes uncertainty of the hadronization

Reasonable description of data $\Longrightarrow$ **factorisation seems to work**

DIFFRACTION - Elastic J/ψ Production



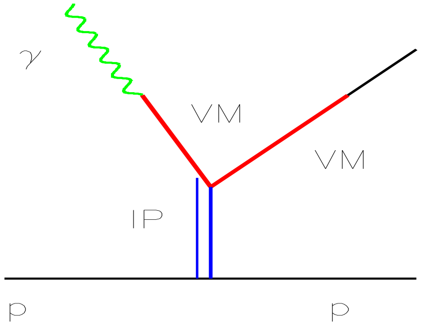
t - (four momentum transfer)^2 at p vertex

$$\gamma\, p \to J/\psi\, p \qquad J/\psi \to \mu^-\mu^+$$

H1 data : 1999/2000 , $\mathcal{L}$ = 54.8 pb^{-1}

- $Q^2 < 1\ \mathrm{GeV}^2$, **40 GeV** $\leq W_{\gamma p} \leq 150\ \mathrm{GeV}$
- $|\,t\,|^2 \sim p_T^2(J/\psi) \leq 1.2\ \mathrm{GeV}^2$

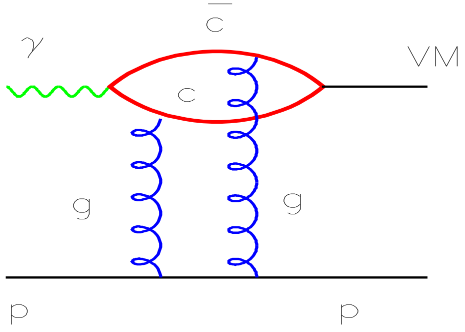
Vector meson production mechanismus:



Regge + VDM approach

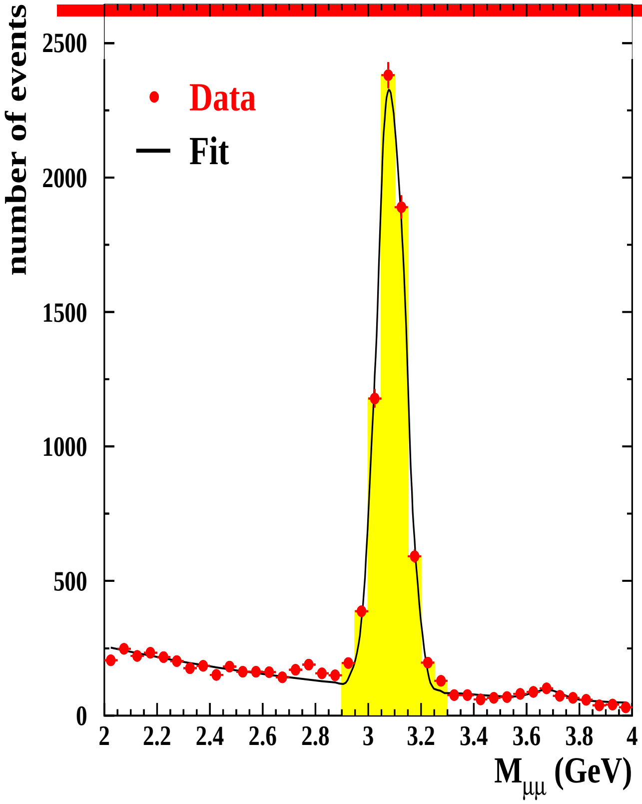
$$\frac{d\sigma}{dt} \sim e^{b_0 t}\left(\frac{W}{W_0}\right)^{4(\alpha_{IP}(t)-1)}$$

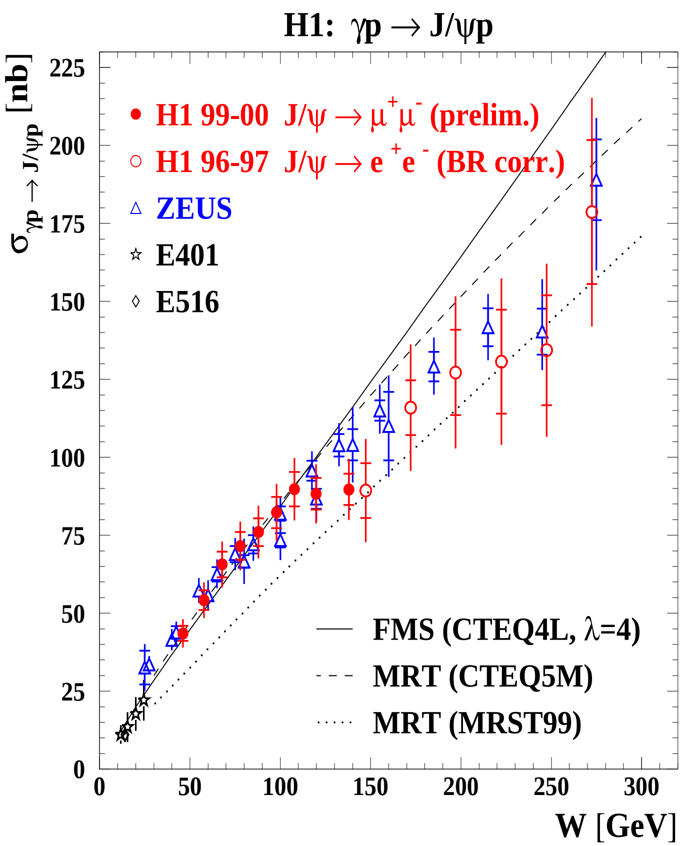
$$\alpha_{IP} = \alpha_0 + \alpha' \cdot t$$

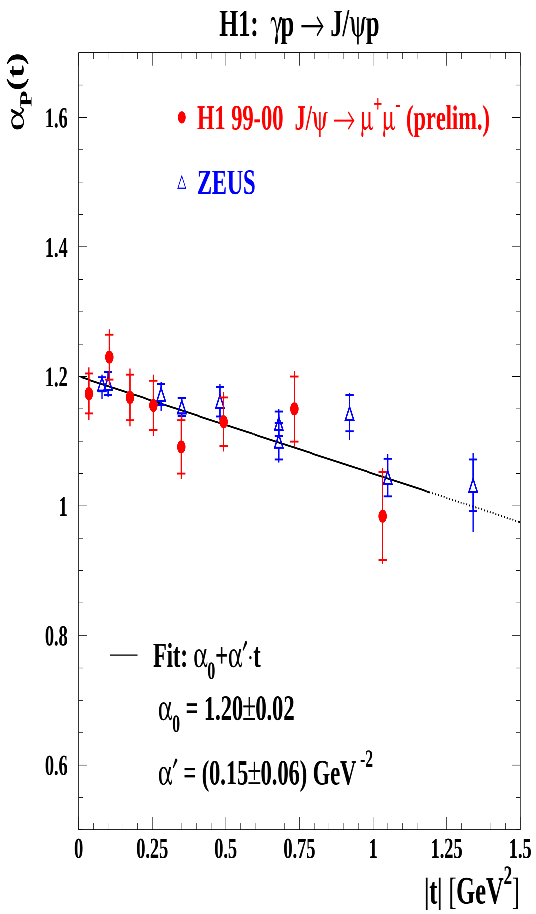


pQCD approach
two gluon exchange

$$\sigma \sim |\, xG(x, Q^2)\,|^2$$





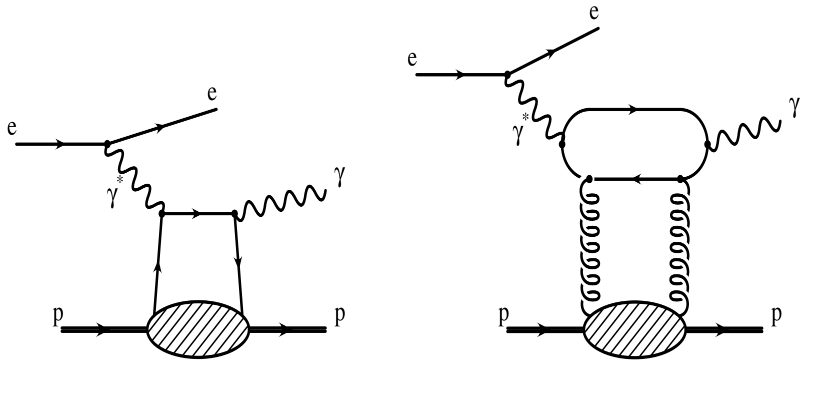


$$\alpha_P \equiv = \alpha_{IP} = \alpha_0 + \alpha' \cdot t$$

$$\sigma(W) \approx W^{\delta},\ \delta = 4(\alpha_{IP} - 1) = 0.70 \pm 0.08$$

$$\alpha' = (0.15 \pm 0.06)\ \mathrm{GeV}^{-2} \Longrightarrow$$ **shrinkage is observed**

DIFFRACTION - Deeply Virtual Compton Scattering



a) b)

- **NLO calculation sensitive to the Generalised Parton Densities (GPD)**

GPD parametrisation : unintegrated gluon pdf with correlations and

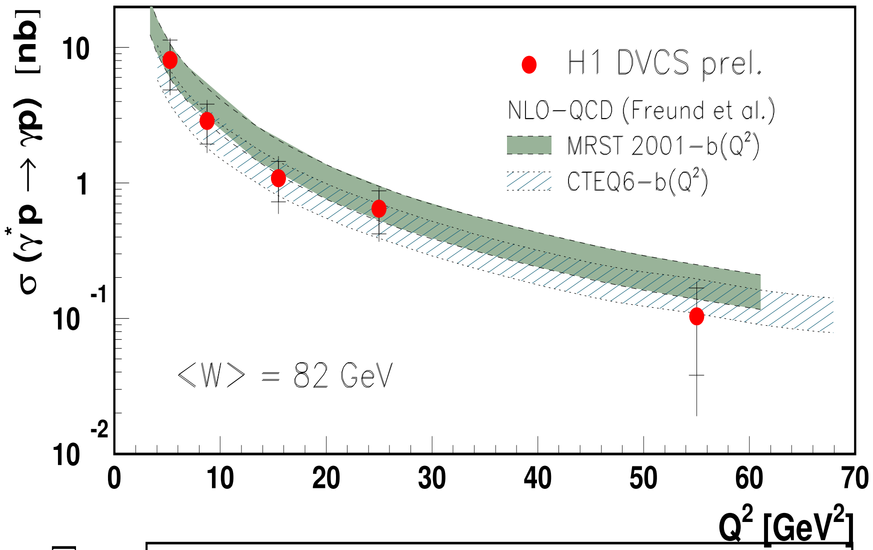
$$d\sigma/dt \sim e^{bt}$$

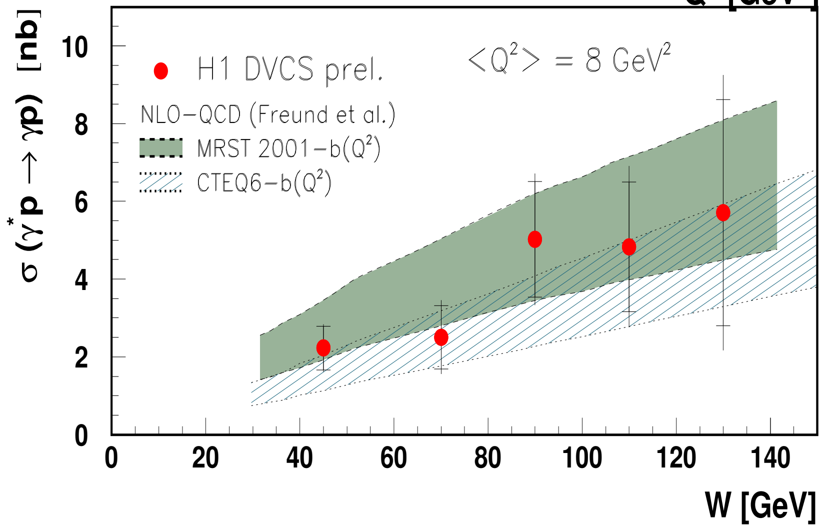
$$b = b_0[1 - 0.15log(Q^2/2)] \ \mathrm{GeV}^{-2}$$

good agreement with data

Cross section described also well by Colour Dipole Model

$4 < Q^2 < 80 \ \mathrm{GeV}^2$





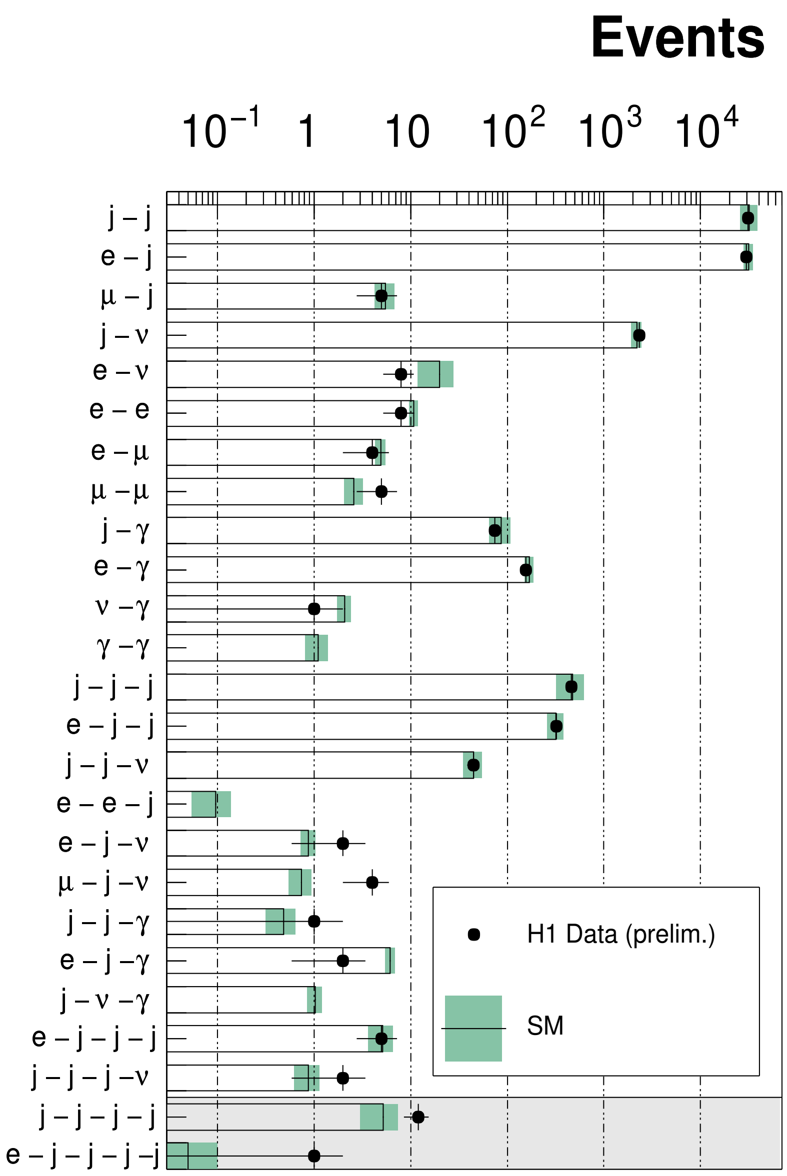
Theory error bands $b_0 = (5-9)GeV^{-2}$

SEARCH for NEW PHYSICS

Recent results:

- General search for new phenomena.
- Contact interactions
- Multi electron production
- Isolated electrons and muons
- R-parity violating SUSY
- Search for superlight gravitino

SEARCH for NEW PHYSICS - General Search



H1 General Search

Compatibility of H1 data with Standard Model ?

Define final state objects :

$jets(j)$, $e, \mu, \gamma, P_T^{miss}$,

$p_T^{object} > 20$ GeV; $10^o < \theta^{object} < 140^o$

Estimators :

- $\sum_{object} p_T^{object}$
- **Total effective mass of all objects** M_{all}

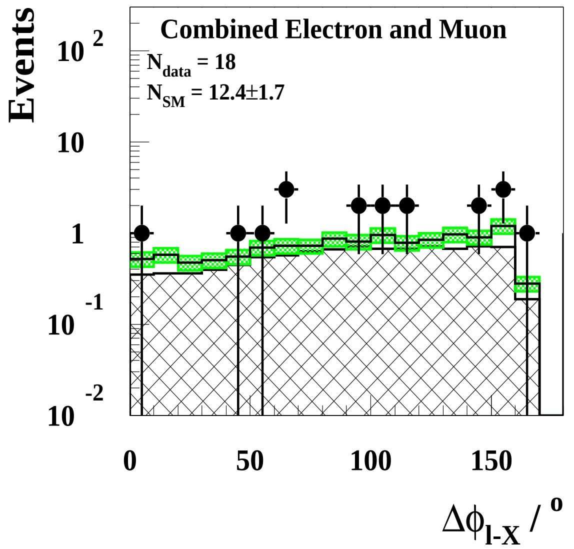
Comparison of various topologies
with many MC models - $O(\alpha_s)+$ PS in QCD

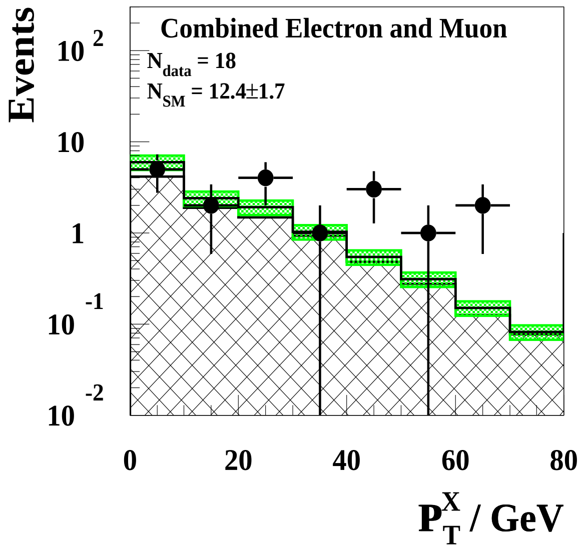
Good agreement for most channels

Biggest deviation for $\mu - j - \nu$ channel

SEARCH for NEW PHYSICS - Isolated Leptons

Detailed analysis





All available data

$p_T^l > 10$ GeV

$p_T^X \equiv p_T$ of all other particles

Isolation criteria in $\eta - \phi$ space of a lepton from the closest jet or track

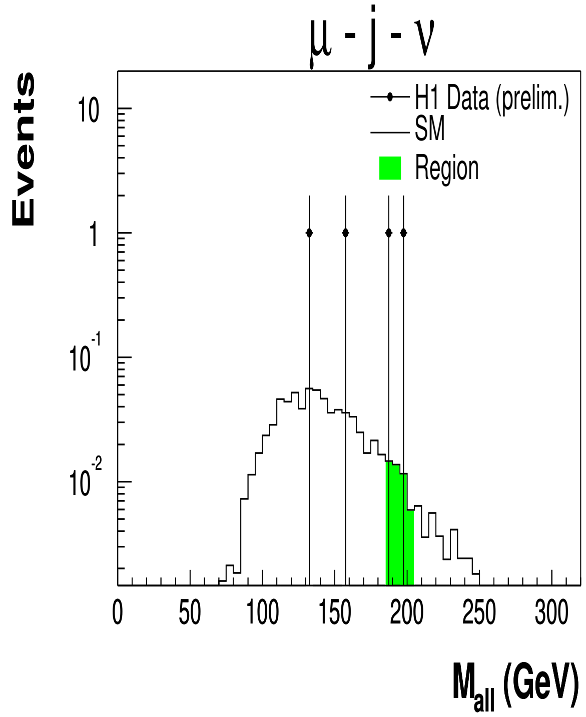
Dominant Standard Model process for this topology:

$$ep \to e(\nu) + W^{\pm} + X$$

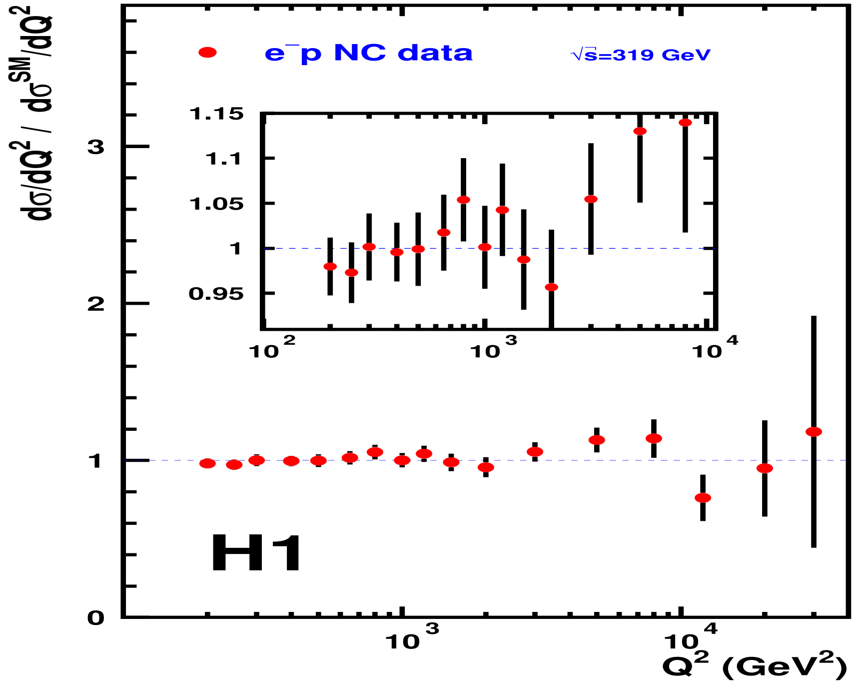
For $p_T^X > 25$ GeV

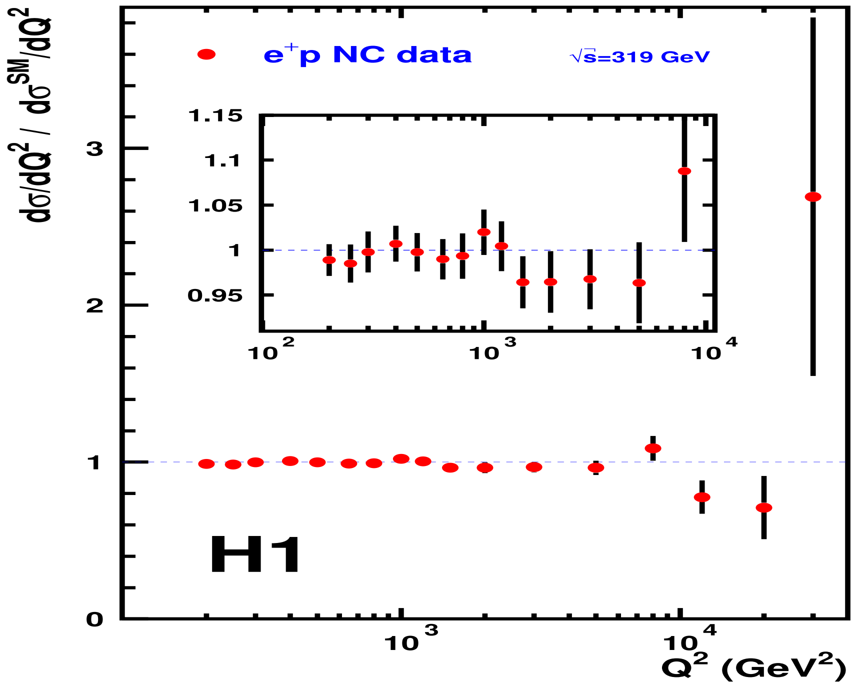
10 events found ; expected 2.92 ± 0.49

General search



SEARCH for NEW PHYSICS - Contact Interactions





Contact interactions:

$$L = \sum_q \sum_{a,b=L,R} \epsilon^q_{ab} \frac{4\pi}{\Lambda^q_{ab}} (\bar{e}_a \gamma_\mu e_a)(\bar{q}_b \gamma^\mu q_b); \;\; L, R - helicities, \epsilon^q_{ab} = \pm 1$$

$\mathcal{L} = 117.2 pb^{-1}$ **H1 NC data consistent with Standard Model**

Quark radius $< 10^{-18}$m

Λ between 1.6 and 5.6 TeV

Summary

Many new results of the analysis of HERA-I data were released this year

- **Higher statistics of 1999/2000 data $\Longrightarrow$ extended kinematic limits $0.5 < Q^2 < 20000\ \mathrm{GeV}^2$ and $0.00005 < x < 0.65$ for the measurement of proton structure functions and determination of parton densities.**

- **Heavy flavour production with different final state topologies were compared with theoretical results.**
  - *Good agreement for D mesons in DIS.*
  - *Model improvement is still needed for D mesons in photoproduction.*
  - *A discrepancy between theory and data for b-quark in photoproduction has decreased.*

- **NLO predicitons of properties of various hadronic final states are consistent with data within experimental errors and theoretical uncertainties.**

- **Diffractive parton densities were extracted and their application to the diffractive jet and D^* production has showed good agreement between data and theory. The basic assumptions about the dynamics of diffraction were verified.**

- **Comparison of various final state topologies of jets, particles and missing energy showed no significant deviations from the Standard Model predictions except for the configuration** *isolated lepton-jet-$\boldsymbol{\nu}$*.

- **Analysis of HERA-I events is still going on.**

- **HERA II will increase physics possibilities in ep collisions.**