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Leading Neutron Production in DIS at HERA

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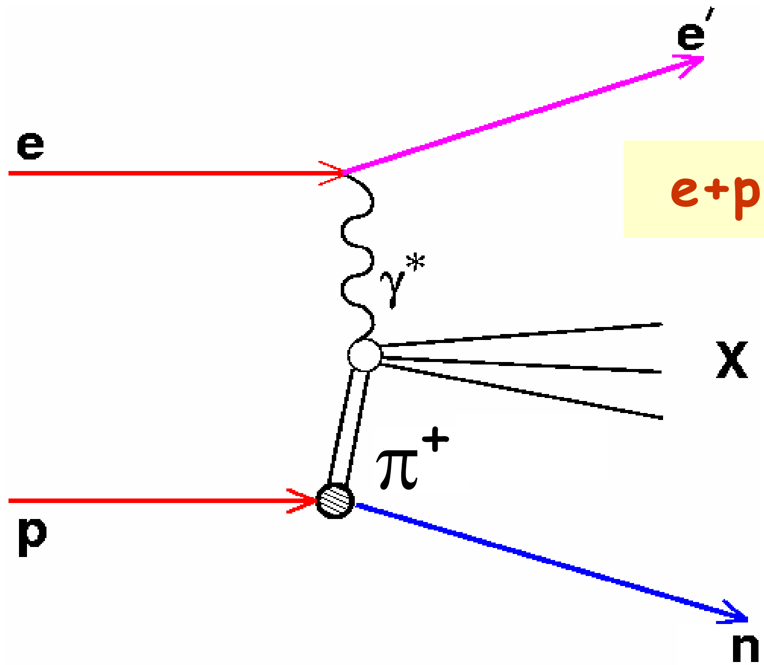
Representing the H1 Collaboration

Outline:

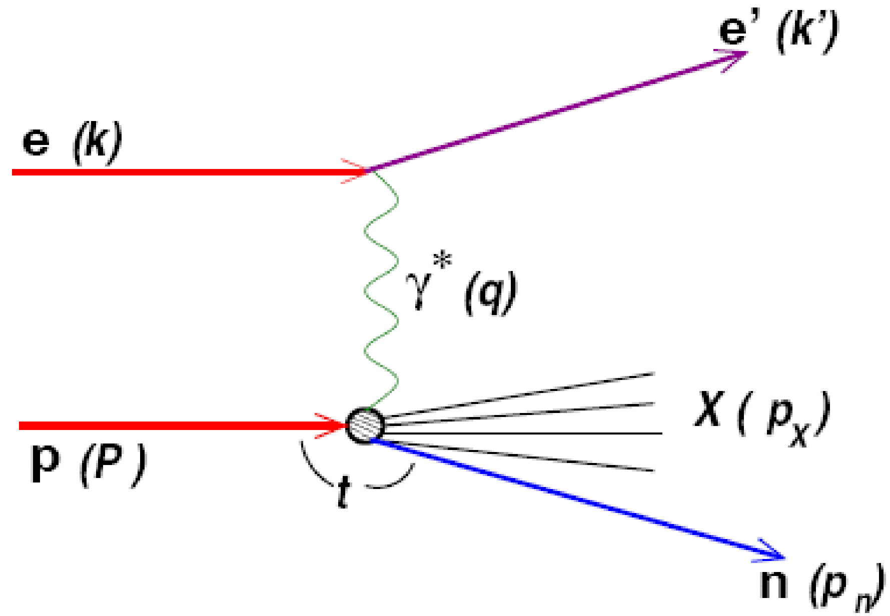
- Introduction
- Measurement of the cross sections and the semi-inclusive structure function $F_2^{LN(3)}$
- Estimate for pion structure function
- Summary

*H1 Collaboration, DESY-09-185,
arXiv:1001.0532 [hep-ex]*

A fraction of ep scattering events contains a high energy leading neutron (LN), produced at very small angles. The production of LN in a process with a hard scale (e.g. in DIS) provides a probe of QCD evolution and factorisation properties of proton fragmentation.



$e+p \rightarrow e'+n+X$



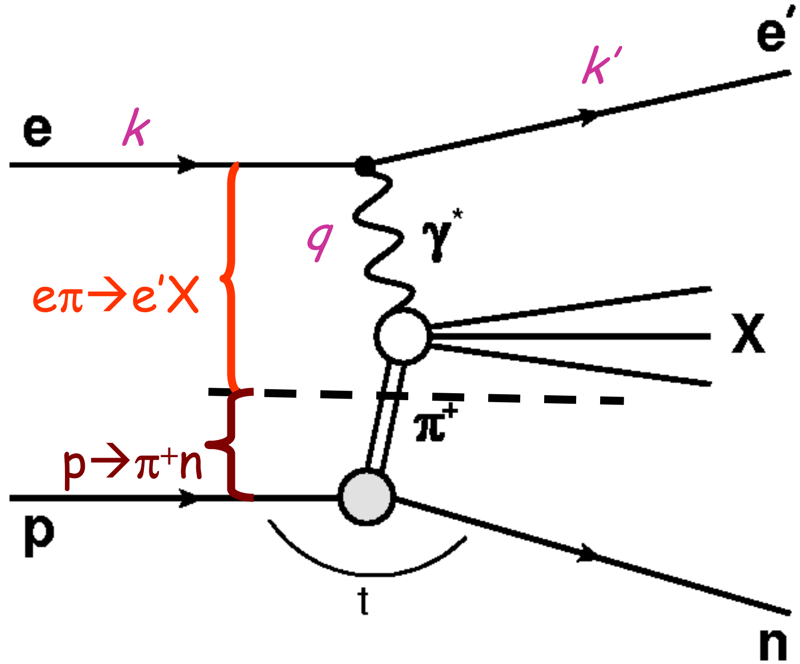
exchange of virtual particle (π^+,ρ^+, ..)

(proton emits a virtual particle, which undergoes DIS with virtual photon). This mechanism is expected to dominate the LN production at large x_L and low $p_{T,n}$

Implemented in RAPGAP-π-exchange model used in this analysis

fragmentation of proton remnant

as e.g. in DJANGO-CDM MC model used in this analysis



$ep \to e'nX$

Lepton variables:

$Q^2=-(k-k')^2$

$x=Q^2/(2p \cdot q)$

$y=s/(xQ^2)$

Leading neutron variables:

$x_L=E_n/E_p$

$t=(p-p_n)^2$

In the exchange model the cross sections factorise, i.e.

$$\sigma(ep \to e'nX) = f_{\pi/p}(x_L,t) \times \sigma(e\pi \to e'X)$$

$f_{\pi/p}(x_L,t)$ - pion flux:
probability to emit pion from the photon with given x_L, t

$\sigma(e\pi \to e'X)$ - cross-section of $e\pi$ scattering

- constraint the structure of pion at low to medium Bjorken-x
- test the validity of various pion SF parameterisations
- test the validity of limiting fragmentation and the proton vertex factorisation

Event sample

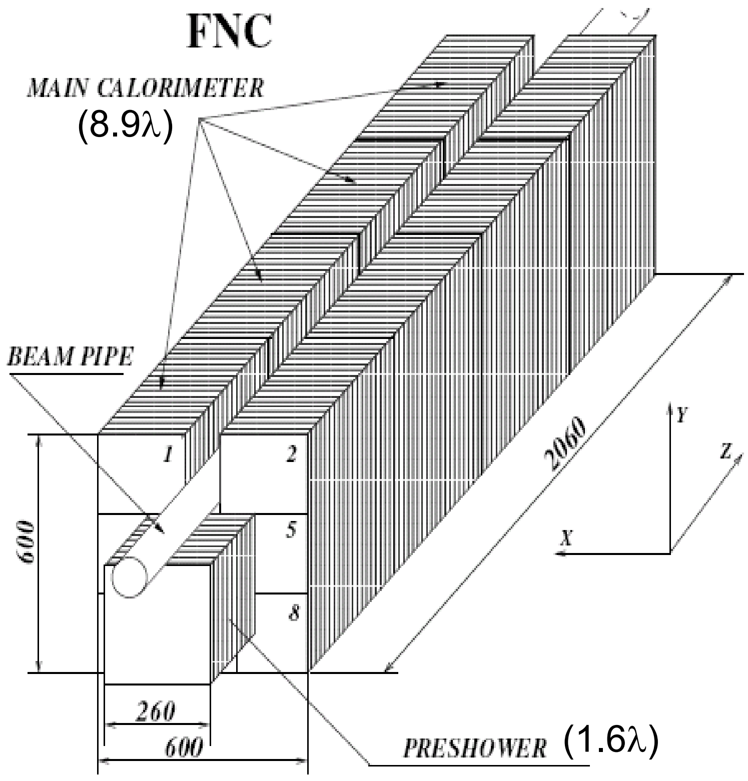
Data from 2006-2007 e+p collisions (27.6 GeV x 920 GeV)

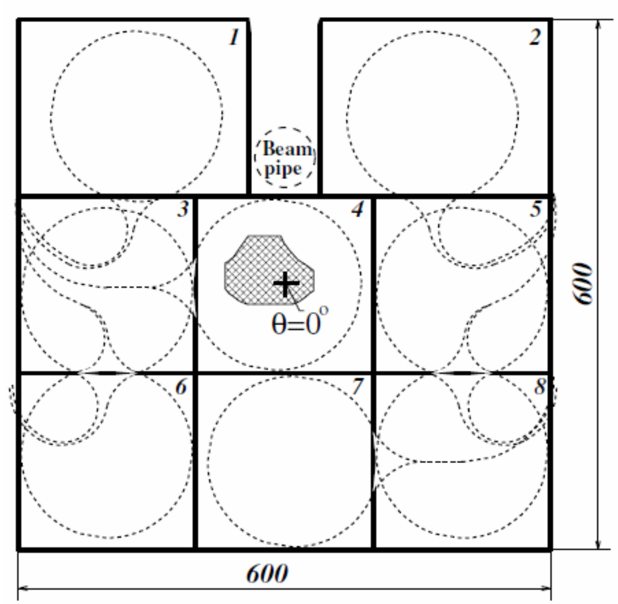
DIS kinematics: $6 < Q^2 < 100\ GeV^2$, $0.02 < y < 0.6$, $1.5 \cdot 10^{-4} < x < 3 \cdot 10^{-2}$

Neutron detected in the forward neutron calorimeter (FNC): $x_L = E_n/E_p > 0.3$

Luminosity=122 pb^{-1} → 36x larger than in previous H1 publication;
new FNC with much improved energy resolution and neutron identification

FNC: 106m downstream in proton direction from the interaction point.
Acceptance limited by the aperture of beam line magnets to $\theta_n < 0.8$ mrad with ~30% azimuthal coverage



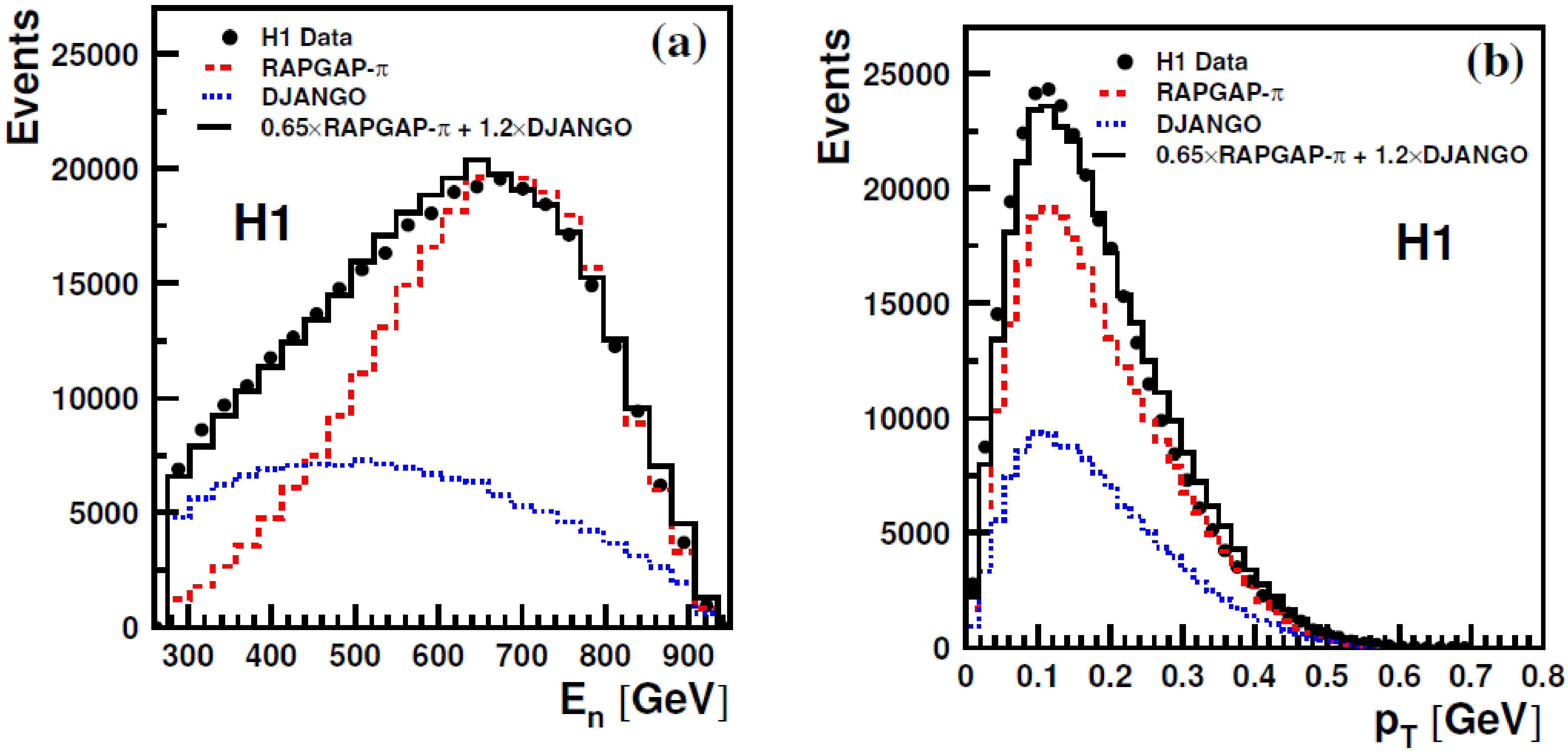


Energy resolution
$\sigma_E/E \approx 63\%/\sqrt{E(GeV)} \oplus 3\%$

Spatial resolution 2mm for the showers starting in Preshower and $100mm/\sqrt{E(GeV)} \oplus 6mm$ for the Main Calorimeter

315,960 events in the data sample

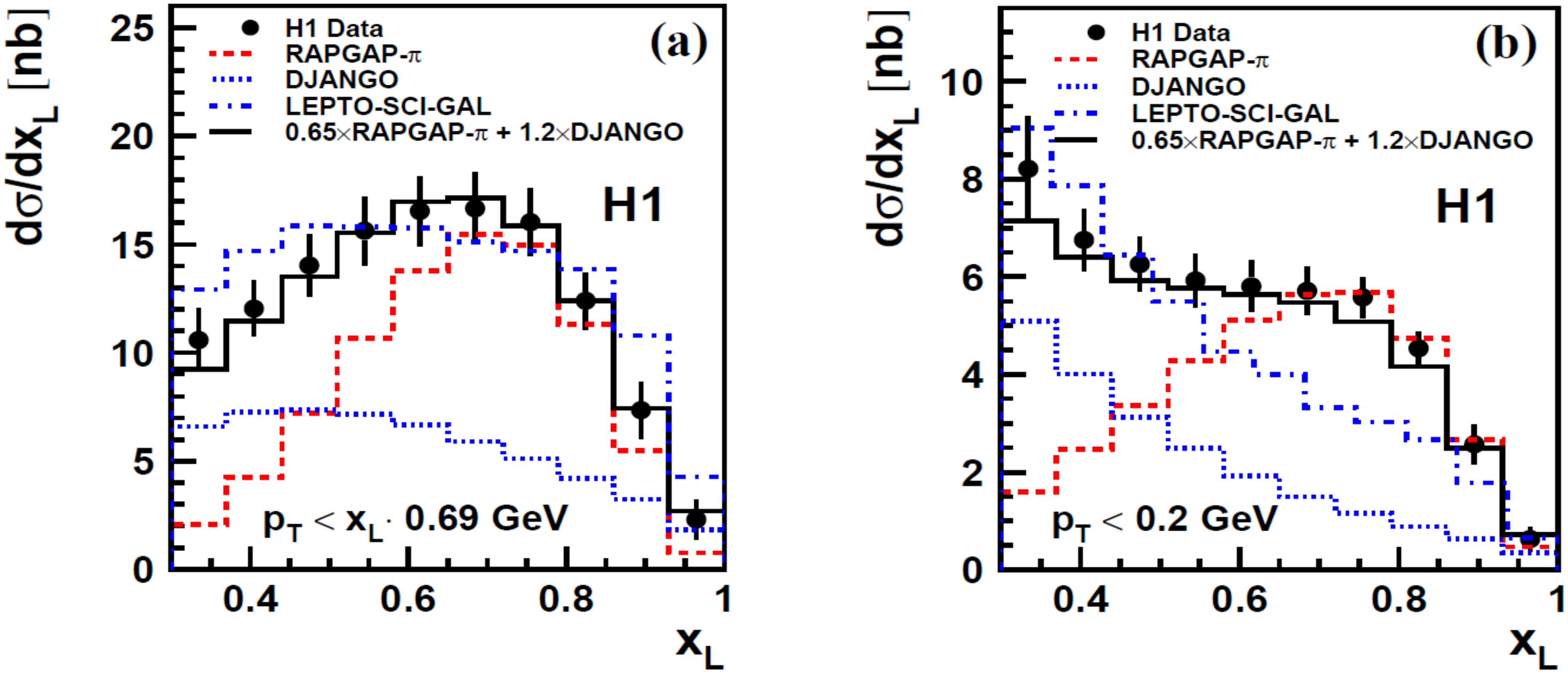
Leading neutron energy and p_T distributions measured by the FNC



- RAPGAP-π-exchange MC describes data well for E_n>650 GeV, underestimate data at E_n<600 GeV.
- the standard fragmentation model (DJANGO-CDM) predicts a large contribution at low E_n.

- The best description of data gives a mixture of RAPGAP-π-exchange and DJANGO Monte Carlo simulations

Diff. cross section vs x_L: comparison with fragmentation and exchange models



- typical syst.uncertainties 10-14% (dominated by uncert. of neutron position and energy)
- the geometrical acceptance of the FNC restricts the $p_{T,n}$ to the range $p_T < x_L \cdot 0.69$ GeV
  → apply $p_T < 0.2$ GeV for x_L independent p_T acceptance and to enhance π-exch. contribution
- RAPGAP-π–exchange describes the shape of data distribution well for $x_L > 0.7$
  ➔ π-exchange is the dominant mechanism at high x_L
- DJANGO-CDM underestimate the neutron yield at high x_L
- SCI (soft colour interactions) model is better, but still too low at low $p_{T,n}$ and high x_L
- Mixture of RAPGAP-π-exch. and DJANGO-CDM describes the data over the full range

Measure triple-differential cross section:

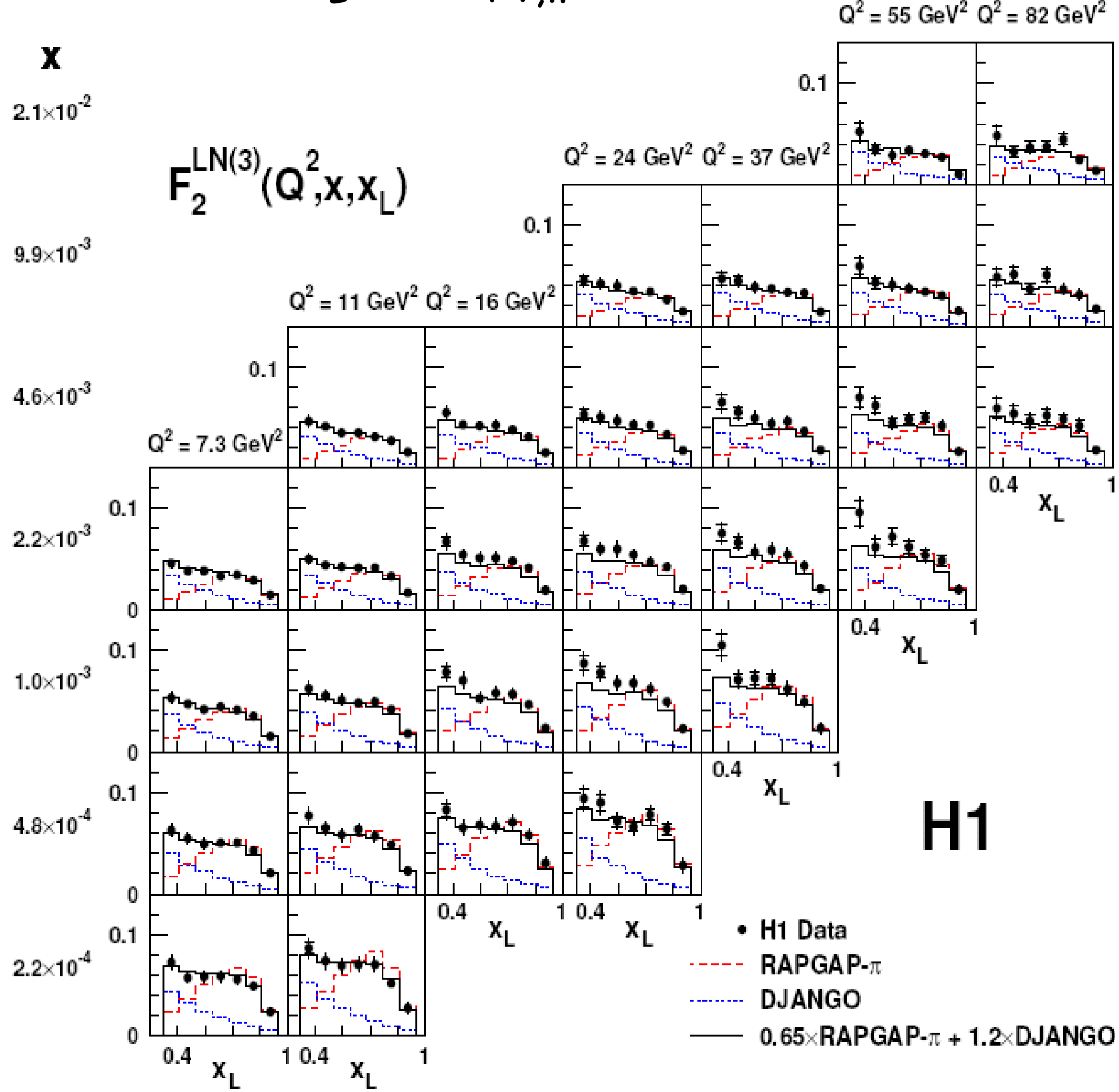
$6<Q^2<100$ GeV^2; $0.02<y<0.6$; $1.5\cdot10^{-4}<x<3\cdot10^{-2}$; $0.32<x_L<0.95$, $p_{T,n}<0.2$ GeV

$$\frac{d^3\sigma(ep \to enX)}{dQ^2\,dx\,dx_L} = \frac{4\pi\alpha^2}{xQ^4}\left[1-y+\frac{y^2}{2}\right]F_2^{LN}(Q^2,x,x_L)$$

F_2^{LN} analogous to the proton structure function F_2 for events containing leading neutron

- RAPGAP-π+-exchange model describes data well for $x_L>0.7$

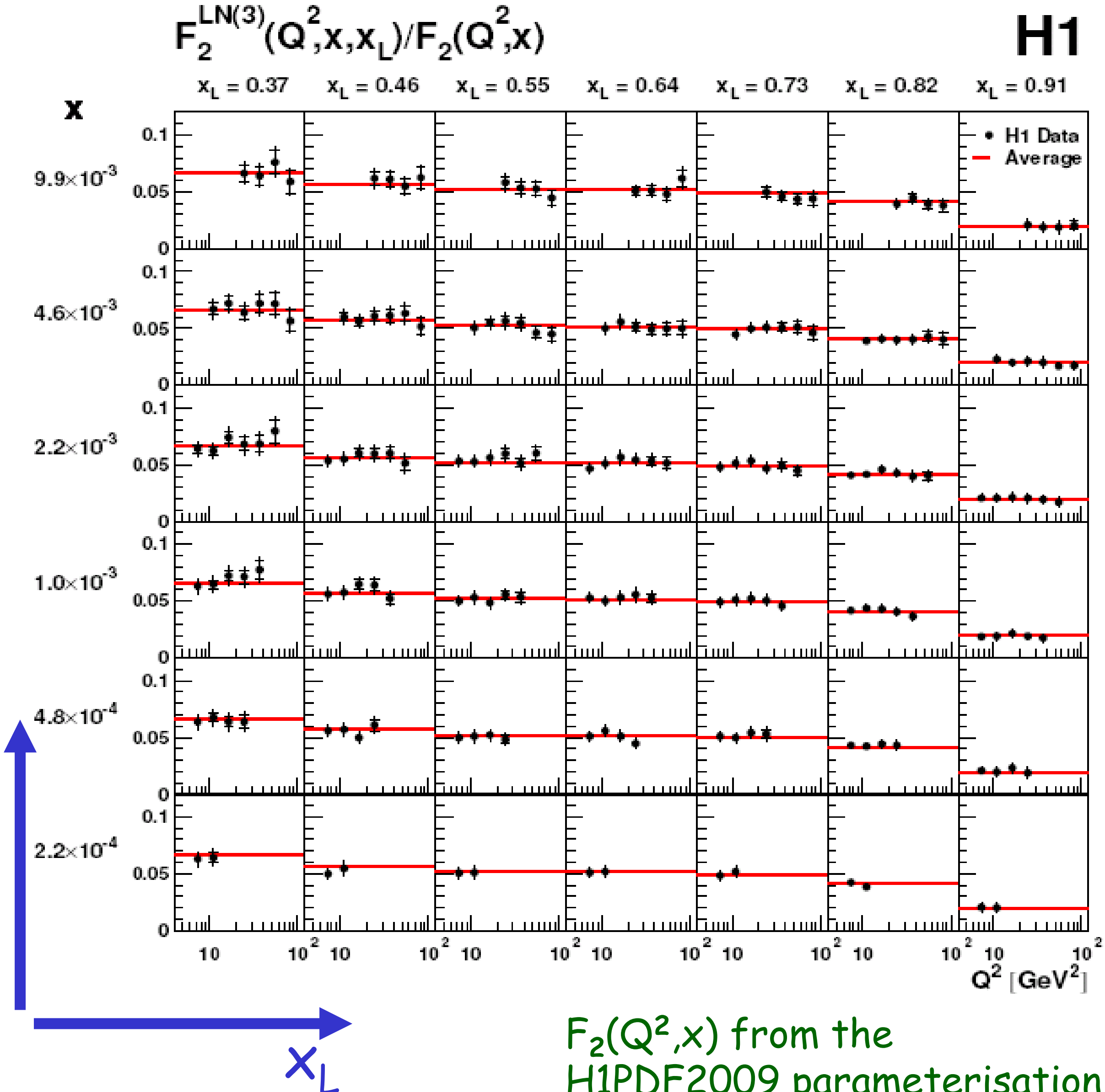
- combination of RAPGAP-π-exch. and DJANGO-CDM gives the best description of the data over full range



$F_2^{LN}(Q^2,x,x_L)/F_2(Q^2,x)$ is 2÷7% depending on x_L;
In each x_L bin the ratio almost independent of Q^2 and x
(lines show the average ratios for x_L bin)

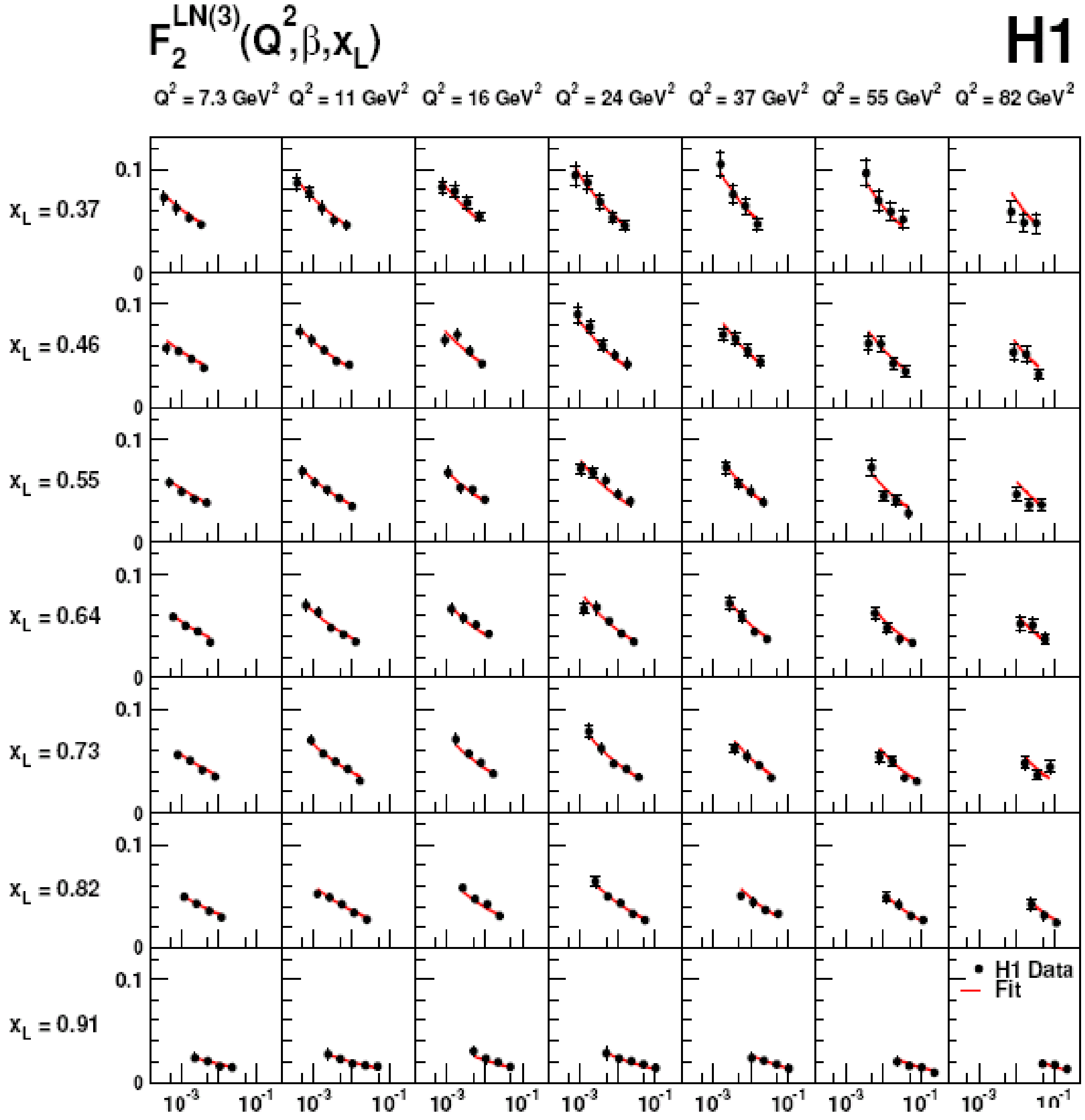
- $F_2^{LN}(Q^2,x,x_L)$ and $F_2(Q^2,x)$ have a similar (Q^2,x) behavior
- leading neutron production in the proton fragmentation region in DIS is insensitive to Q^2 and x

➔consistent with the hypothesis of limiting fragmentation
(i.e. target fragmentation is independent of the projectile)



$F_2(Q^2,x)$ from the H1PDF2009 parameterisation

$F_2^{LN(3)}(Q^2,\beta,x_L)$: proton vertex factorisation



in particle exchange picture expect proton vertex factorisation:

$$F_2^{LN(3)}(Q^2,\beta,x_L) \sim f(x_L) \times F_2^{LN(2)}(Q^2,\beta)$$

$\beta=x/(1-x_L)$ - fraction of exchange's momentum carried by the struck quark

$F_2^{LN(3)}(Q^2,\beta,x_L)$ shows a similar β dependence in all Q^2,x_L bins

$$F_2^{LN(3)}(Q^2,\beta,x_L) \sim \beta^{-\lambda}$$

- λ is almost independent of x_L → consistent with the proton vertex factorisation

- λ increases with Q^2: from 0.23 to 0.3 – similar to the rise towards low x of proton structure function F_2

Fit $\lambda = a \cdot \ln(Q^2/\Lambda^2)$ → $a=0.052 \pm 0.003$;

$\Lambda = 416 \pm 52$ MeV

→ similar Q^2 evolution of $F_2^{LN(3)}$ and F_2

Estimate the pion structure function from $F_2^{LN(3)}$

Assuming proton vertex factorisation and the dominance of π^+-exchange at high x_L and low p_T, we estimate pion structure function at low x_{Bj} from measured $F_2^{LN(3)}$ at $0.68 < x_L < 0.77$:

$$F_2^{LN(3)}(\beta, Q^2, x_L) = \Gamma_\pi(x_L) \cdot F_2^\pi(\beta, Q^2)$$

$\beta = x/(1-x_L)$ - the fraction of pion momentum carried by struck quark

$\Gamma_\pi(x_L)$ - integrated over t pion flux

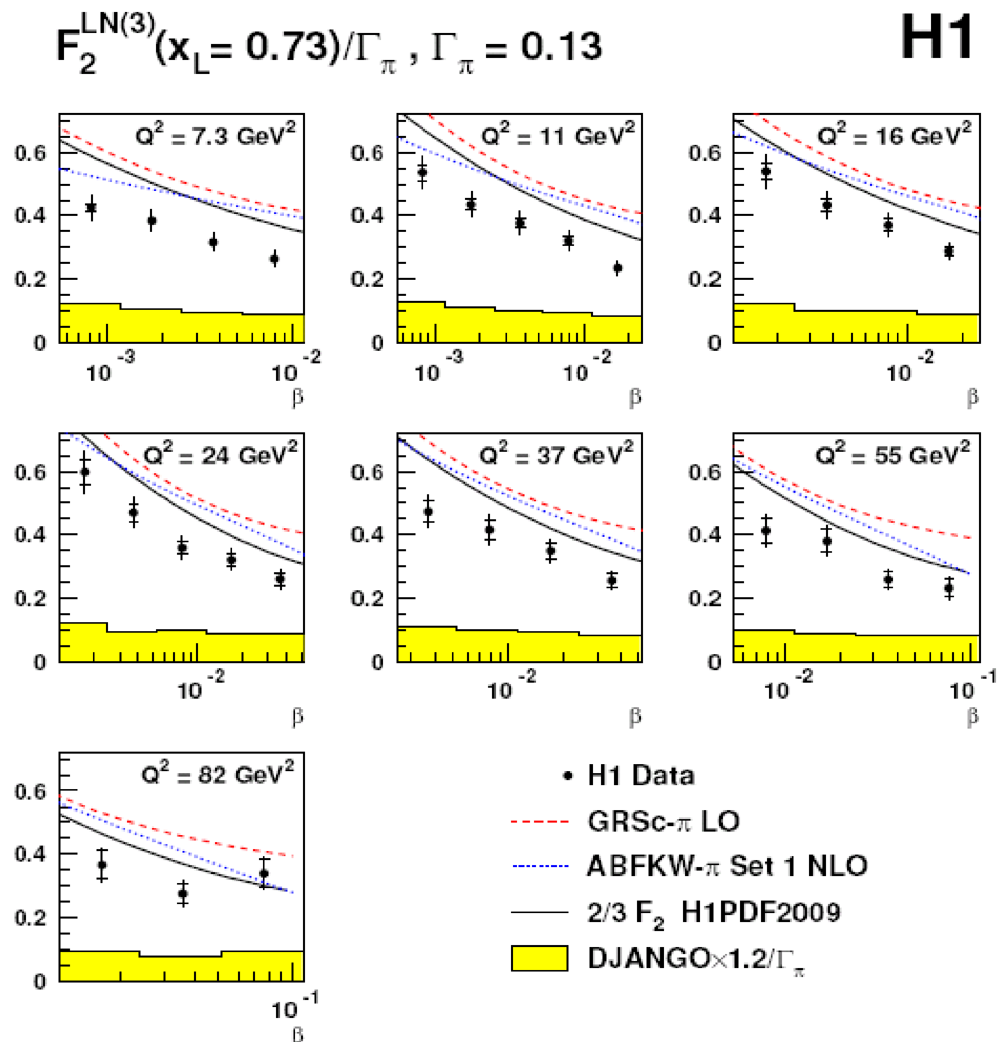
$$\Gamma_\pi = \int f_{\pi/p}(x_L = 0.73, t)\, dt$$

Use pion flux parameterisation (Holtmann et al.):

$$f_{\pi^+/p} = \frac{1}{2\pi} \frac{g_{p\pi\pi}^2}{4\pi} (1-x_L) \frac{-t}{(m_\pi^2 - t)^2} \cdot \exp\left(-R_{\pi n}^2 \frac{m_\pi^2 - t}{1-x_L} \right)$$

(other pion formfactors give values of Γ_π which may differ by up to 30%)

Contribution from fragmentation (DJANGO) is ~30%, largely independent of Q^2 and β.



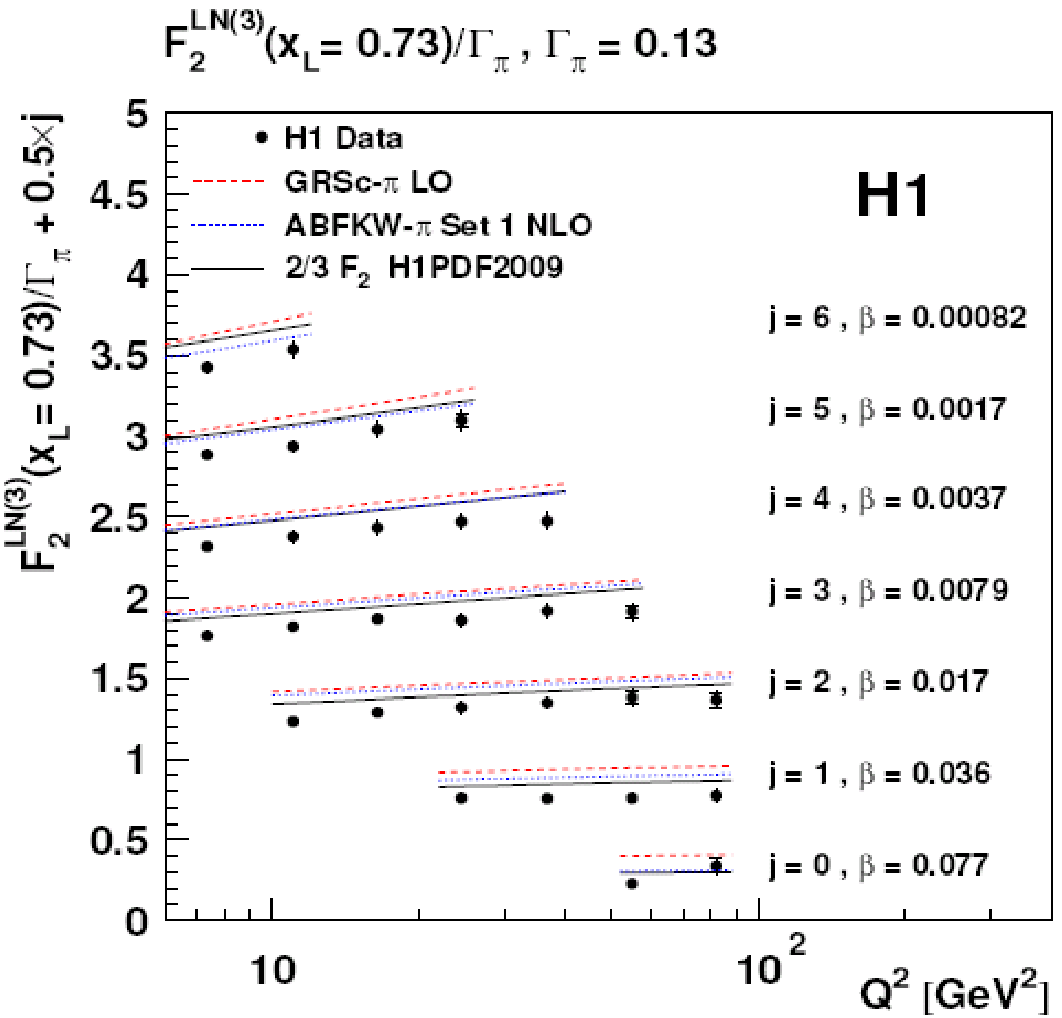
- rise with decreasing β at all Q^2, shape similar to the parameterisations of F_2^π and F_2^p
- in absolute values F_2^{LN}/Γ below the F_2^π parameterisations
- data are sensitive to the π-structure function parameterisations (constrained for x>0.1 from the fixed target experiments).

- $F_2^{LN(3)}/\Gamma$ as function of β in bins of Q^2

Rise with Q^2 (scaling violation) for all β
Similar in size and shape to F_2^{π} and F_2^{p} parameterisations
→universality of hadron structure at low x

In absolute values F_2^{LN}/Γ below the F_2^{π} parameterisations

However: large uncertainty of pion flux normalisation: choice of pion flux, absorption/rescattering, background processes (ρ,a_2 exchange, Δ production, diffr.diss.)...



Summary

- New measurement of triple differential cross sections and semi-inclusive $F_2^{LN(3)}(Q^2,x,x_L)$ structure function by H1 using HERA-II data

- $F_2^{LN(3)}$ measured in the kinematic range:
  $6\ \mathrm{GeV}^2 < Q^2 < 100\ \mathrm{GeV}^2$, $1.5\cdot 10^{-4} < x < 3\cdot 10^{-2}$, $0.32 < x_L < 0.95$, $p_{T,n} < 0.2$ GeV

- Standard fragmentation models do not describe leading neutron production.
  The pion exchange model describes data well for $x_L > 0.7$

- Within the measured kinematic range $F_2^{LN(3)}$ and F_2 have similar (Q^2,x) behaviour, consistent with hypothesis of limiting fragmentation

- The dependence of $F_2^{LN(3)}$ on β is similar for all x_L, consistent with proton vertex factorisation

- The scaling violation observed in $F_2^{LN(3)}$ is similar to those seen in parameterisations of the pion and the proton structure functions

- $F_2^{LN(3)}$ measurement is used to estimate the structure function of the pion