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Leading Neutron production in DIS at HERA-II

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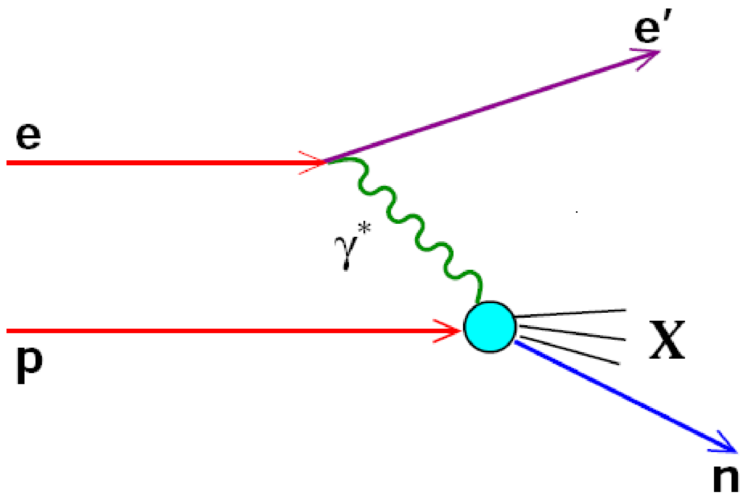
On behalf of the H1 collaboration

- Introduction
- Forward Neutron Calorimeter of H1
- Event selection
- Measurement of semi-inclusive structure function F_2^{LN}
- Estimate for pion structure function
- Conclusions

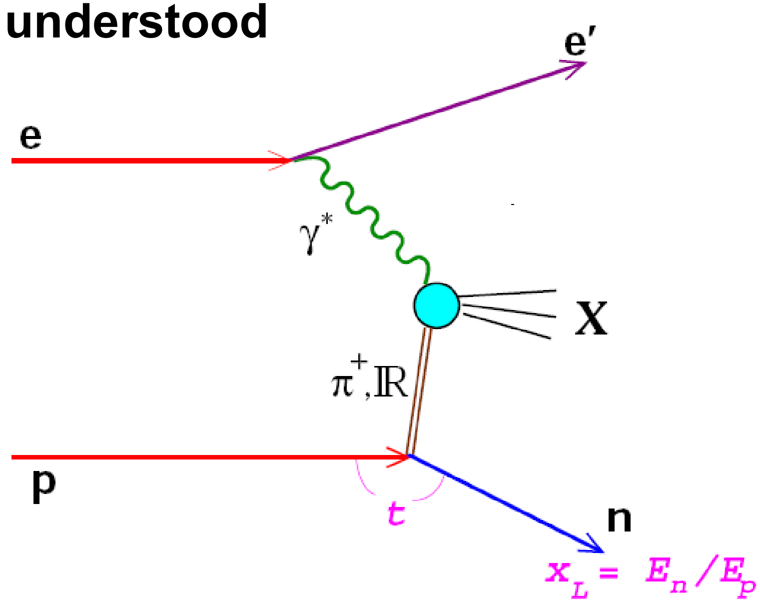
Motivation

- **Significant fraction of *ep* scattering events contain a leading neutron in the final state carrying a substantial portion of the energy of the incoming proton:**
  e+p → e+n+X
- **Production mechanism is not yet completely understood**



Leading neutron can come from "standard fragmentation"

- **Implemented in MC models (e.g. DJANGO CDM as used in this analysis)**



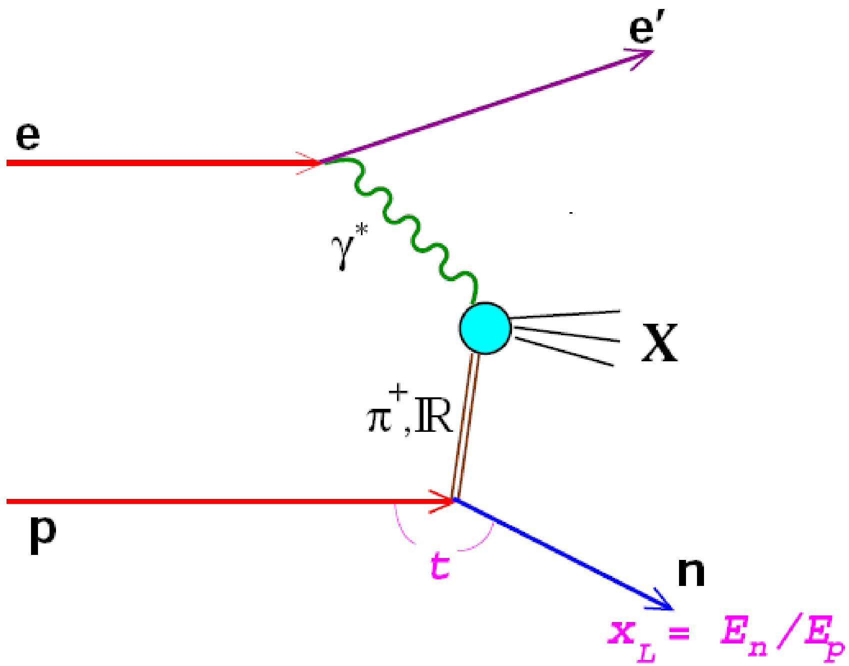
Leading neutron can be produced via exchange of virtual particle -- (π^+, ρ^+)

- **e.g. RAPGAP pion-exchange model as used in this analysis**

$$\sigma_{ep \to enX} = f_{\pi^+/p}(x_L, t) \times \sigma_{e\pi \to eX}$$

this mechanism expected to dominate for $x_L \sim 0.7$-0.9 and $p_{T,n} < 200$ MeV

Kinematics and Semi-Inclusive Structure Function



Lepton variables

$Q^2 = q^2$ -- photon virtuality

$x = Q^2/(2qp)$ -- Bjorken-x

$y = s/(xQ^2)$ -- inelasticity

Leading Neutron variables

$$t = (p - p')^2 \approx -\frac{p_T^2}{x_L} - \frac{(1-x_L)^2}{x_L} m_n^2$$

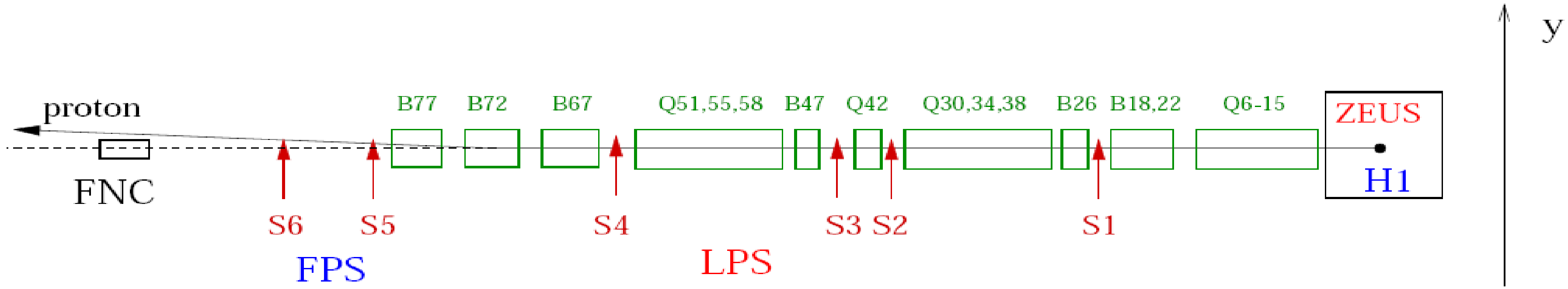
$$x_L = E_n / E_p$$

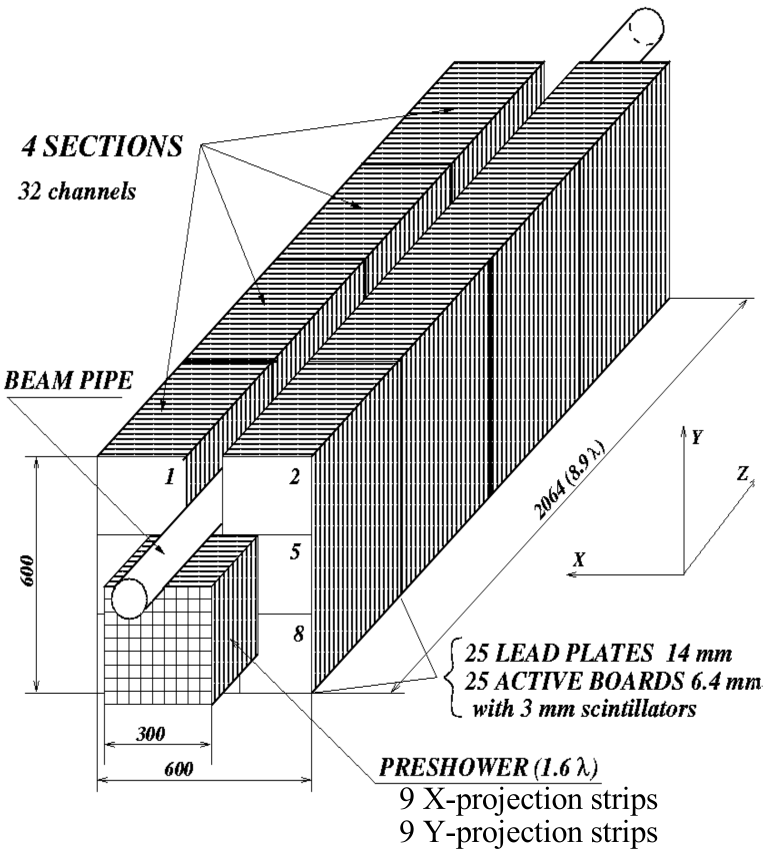
$$\beta = \frac{Q^2}{2q(p-p')} = x/(1-x_L)$$

Measure triple differential semi-inclusive structure function $F_2^{LN(3)}(Q^2,x,x_L)$ defined by:

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

H1 Forward Neutron Calorimeter





- **Dedicated detector at 106 m downstream in proton direction from the interaction point**
- **Acceptance limited by magnets aperture: $\theta_n < 0.8$mrad**
- **Two sandwich-type calorimeters: Main Calorimeter and Preshower Calorimeter in front of the Main.**
- **Energy resolution (hadrons): $\sigma(E)/E = 63\%/\sqrt{E} \oplus 3\%$**
- **Coordinate resolution is ~ 2 mm**
- **1.6 (preshower) + 8.9 (main) interaction lengths deep**
- **In HERA-II setup we can distinguish between e/m and hadronic showers**

Event selection

Kinematic range:

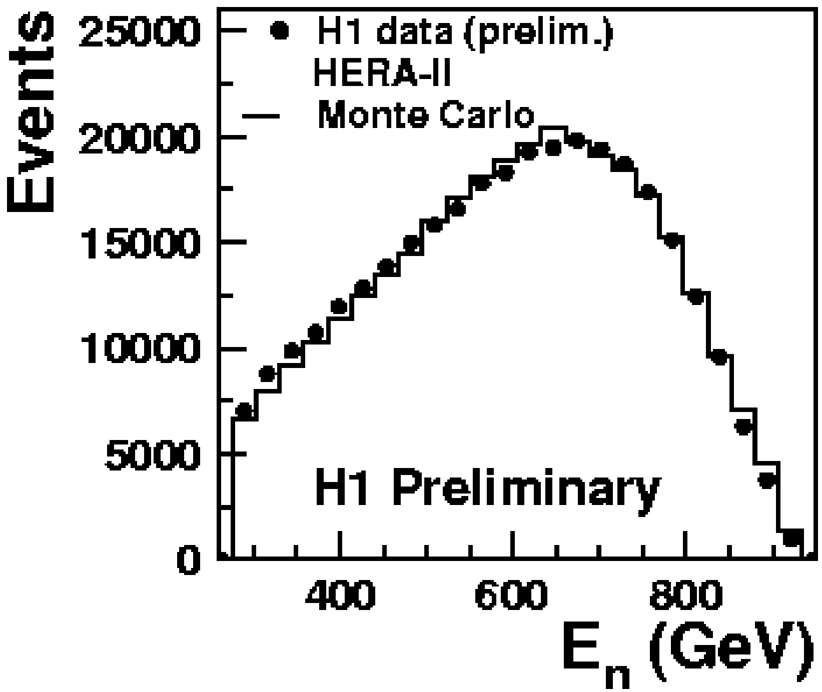
$6\ \text{GeV}^2 < Q^2 < 100\ \text{GeV}^2$, $1.5\times10^{-4} < x < 3\times10^{-2}$, $0.02 < y < 0.6$,

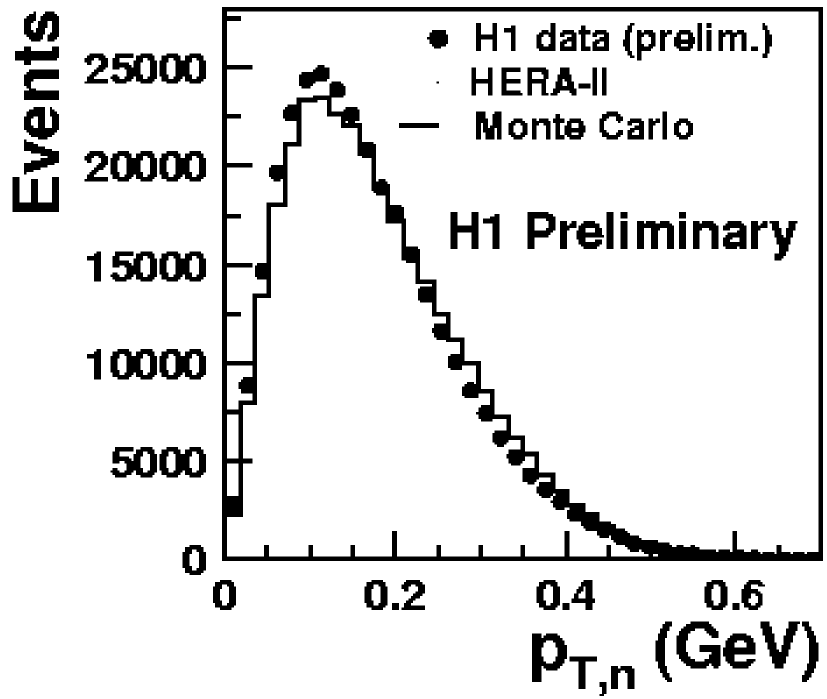
$0.32 < x_L < 0.95$, $p_{T,n} < 0.2$ GeV

- **HERA-II data, e+p collisions, $E_p = 920$ GeV, $E_e = 27.6$ GeV, 122 pb^{-1} accumulated luminosity, 300000 events**
- **Upgraded Forward Neutron Calorimeter (better resolution and photon identification)**
- **DJANGO-CDM and RAPGAP π^{+-}-exch. MC's mixture used for acceptance/radiative corrections calculation**
- **Q^2, x, y kinematic variables are calculated using y-average combined method**

Example Leading Neutron Spectra measured by FNC

p_T < 0.2 GeV cut is not applied here



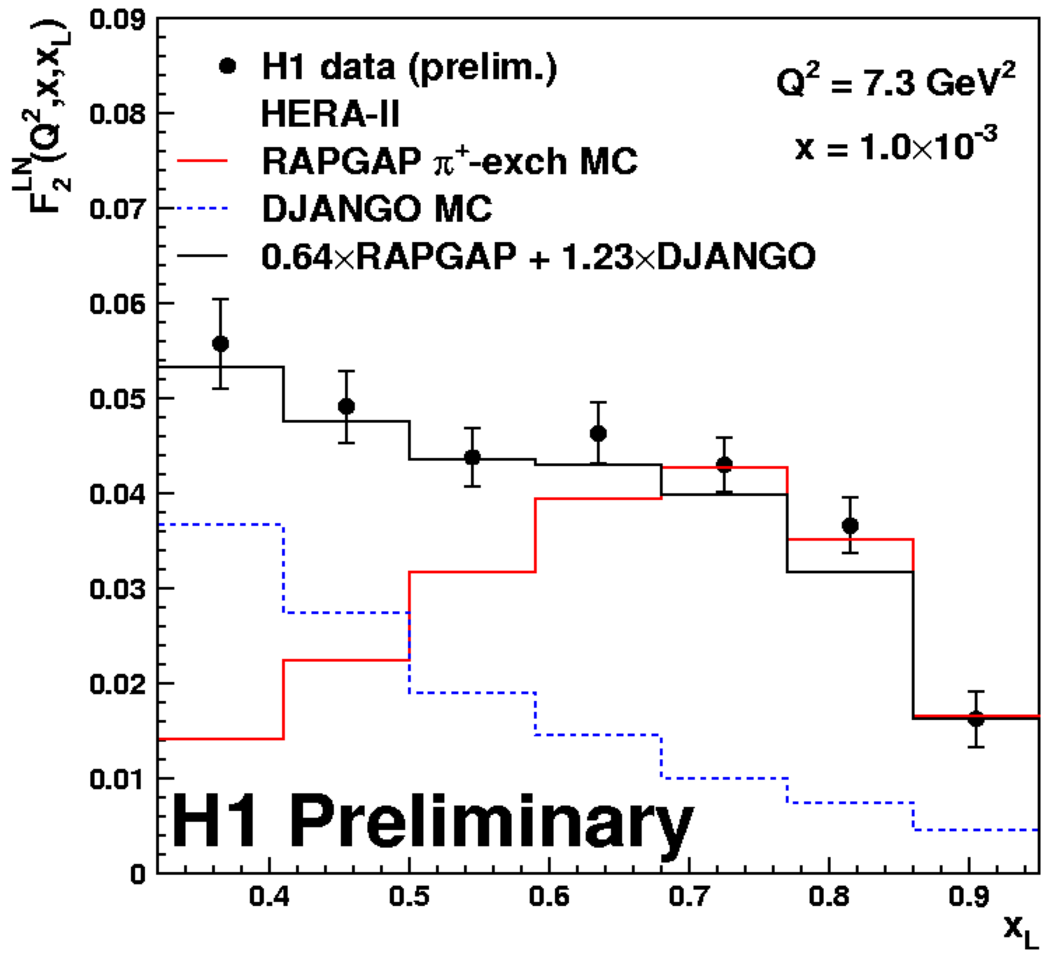


MC simulation done using a mixture of events generated by RAPGAP-π-exchange and DJANGO-CDM generators

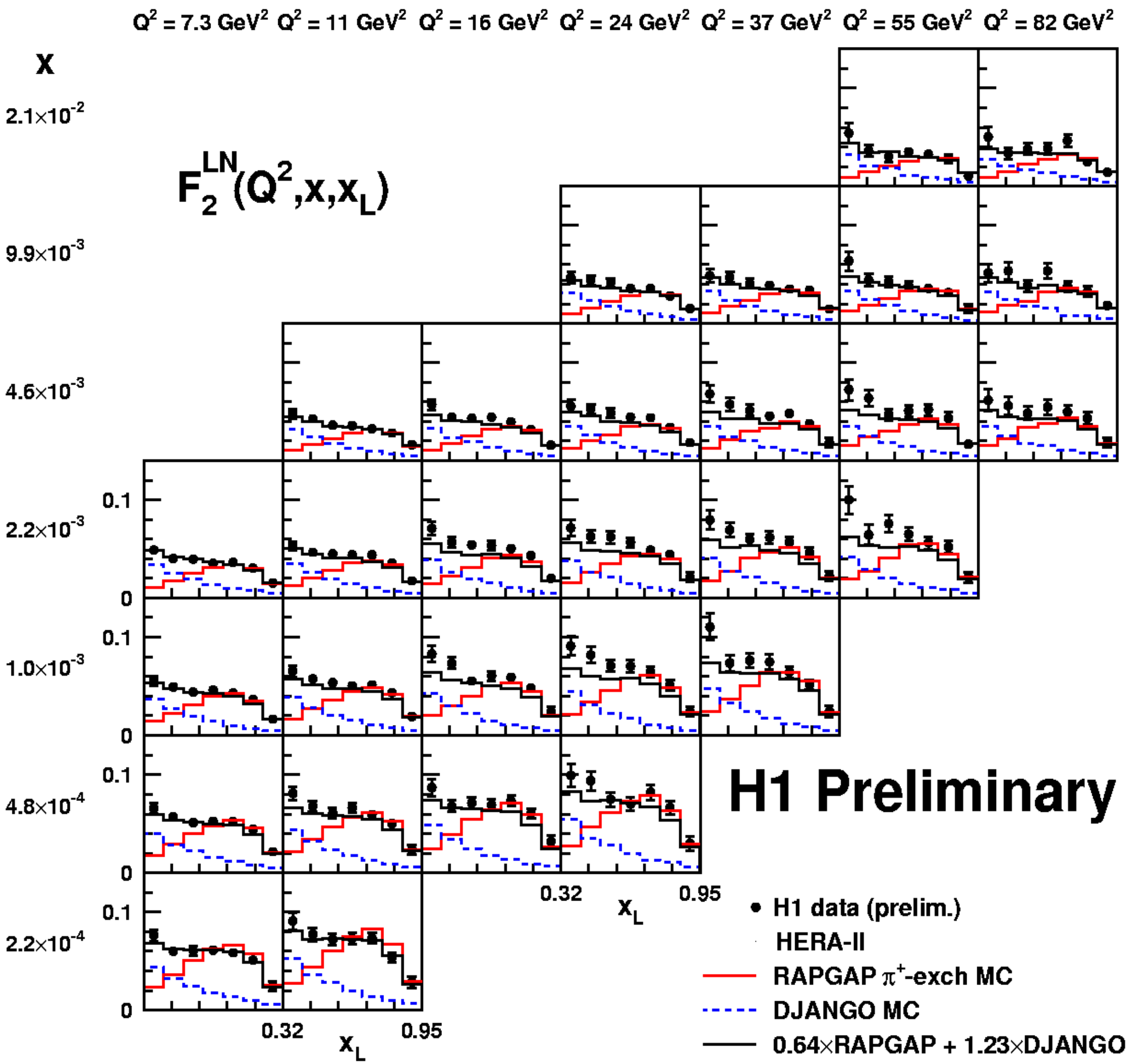
Triple differential reduced cross section

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

- DJANGO (standard fragmentation) predicts too low cross section, also x_L spectrum shape is too different
- RAPGAP π^+-exchange describes data well for $x_L > 0.7$
- Mixture of the DJANGO and the RAPGAP MC's can be used to describe data in the whole kinematic region



Triple differential reduced cross section



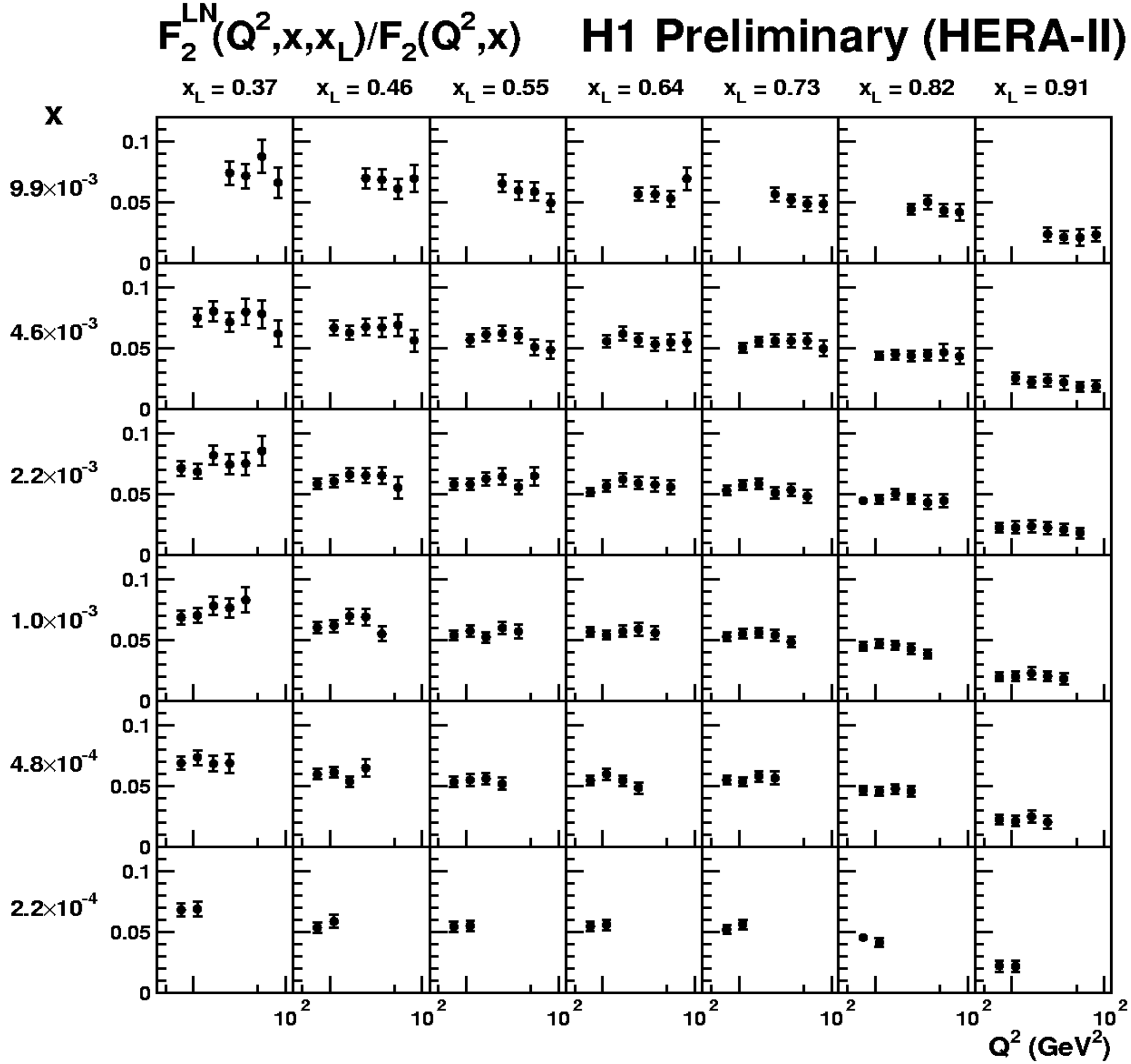
$F_2^{LN}(Q^2,x,x_L)$ to $F_2(Q^2,x)$ ratio

$F_2(Q^2,x)$ from the H1 parameterisation (Eur.Phys.J.C21 (2001) 33)

$F_2^{LN}(Q^2,x,x_L)/F_2(Q^2,x)$ is mostly flat in Q^2 and x

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

(although common suppression of neutron production is also possible)



Estimate for Pion Structure Function from F_2^{LN}

In the π-exchange picture leading neutron production cross section can be expressed as the product of the pion flux and the pion structure function F_2^{π}:

$$\sigma_{ep\to enX}(\beta,Q^2,x_L,t)=f_{\pi^+/p}(x_L,t)\times\sigma_{e\pi\to eX}(\beta,Q^2),\quad where\ \beta=x/(1-x_L)$$

Assuming that pion exchange is dominating at $x_L \approx 0.7$ and $p_T < 0.2$ GeV we can estimate F_2^{π} from the $F_2^{LN(3)}$ measurement according to:

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

where Γ_π is integrated over t pion flux at $x_L \approx 0.7$

Using pion flux $\quad f_{\pi^+/p} = \frac{1}{2\pi}\frac{g^2_{p\pi n}}{4\pi}(1-x_L)\frac{-t}{(m_\pi^2-t)^2}\exp\left(-R^2_{\pi n}\frac{m_\pi^2-t}{1-x_L}\right)$ => $\Gamma_\pi = 0.131$

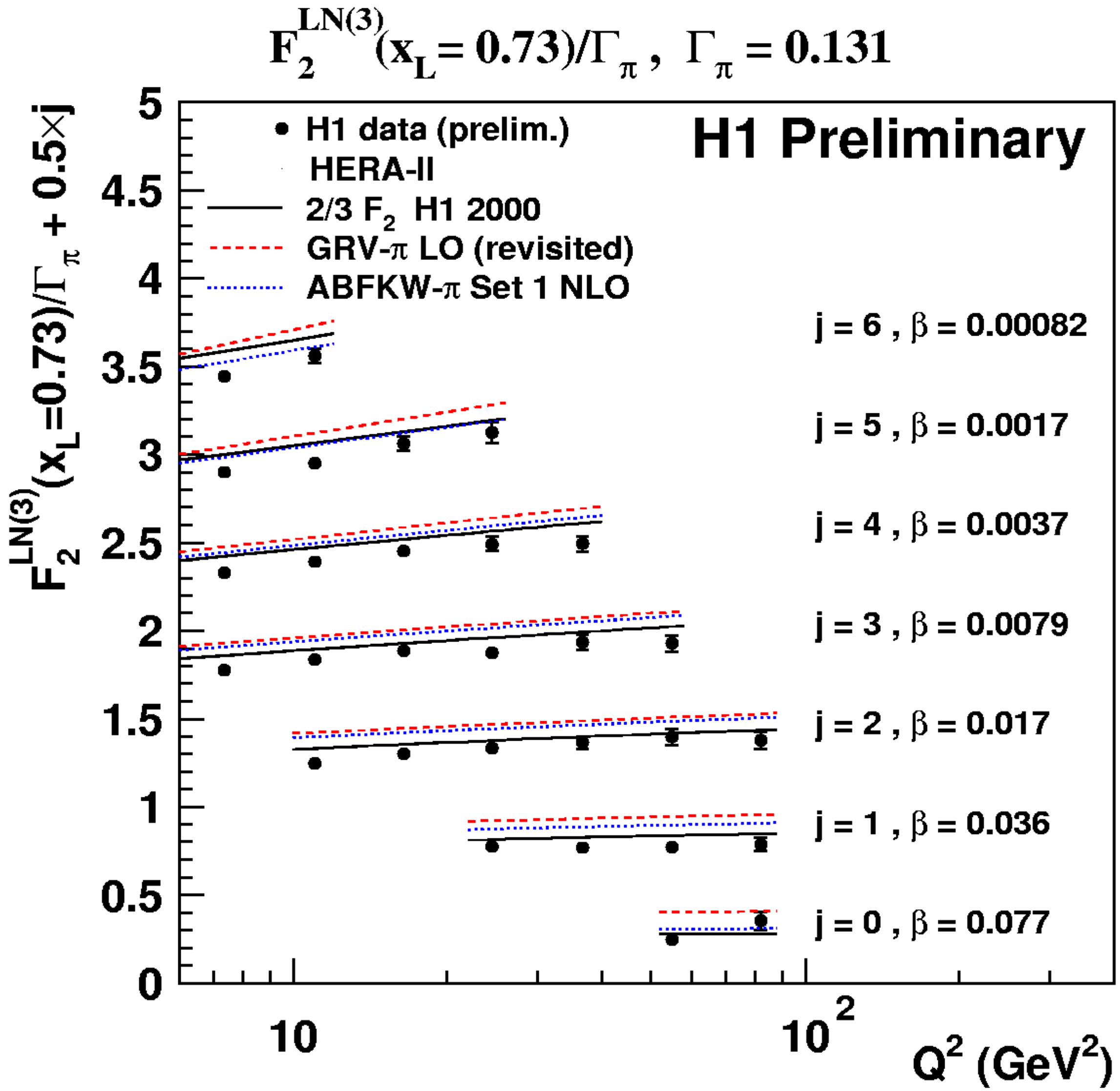
(other pion flux form-factors give other values of Γ_π => global normalization factor on $\mathbf{F_2^{\pi}}$)

No background subtraction or absorption correction applied

Pion Structure Function from F_2^{LN}

Data compared to parameterisations:

- 2/3 of proton F_2 (naive quark model)
- GRV-π LO (revisited)
- ABFKW-π Set 1 NLO



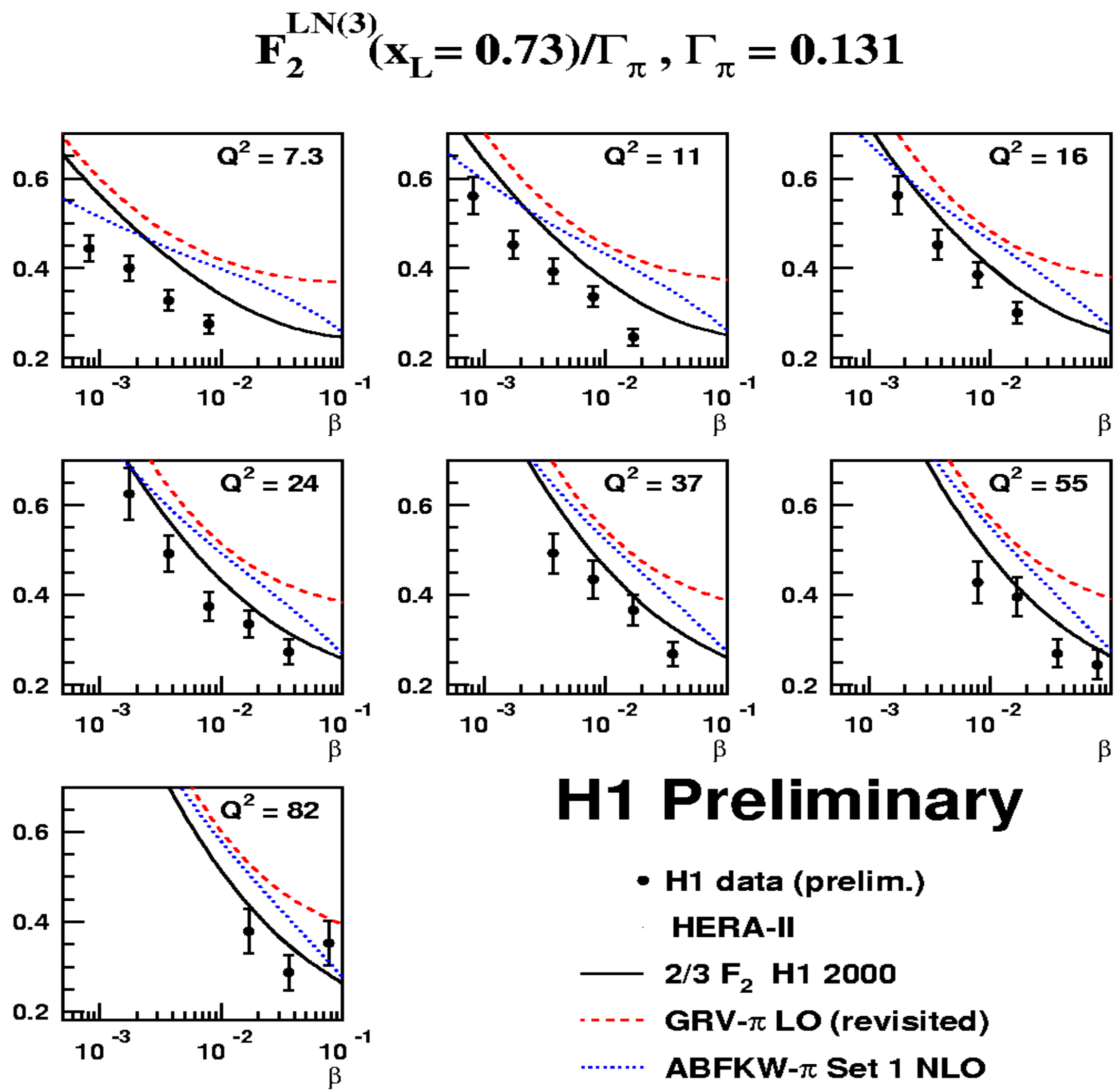
The Q^2 distribution exhibits a rise with Q^2 (i.e. scaling violation). Similar to pion and proton structure functions parameterisations.

Pion Structure Function from F_2^{LN}

Data compared to parameterisations:

- 2/3 of proton F_2 (naive quark model)
- GRV-π LO (revisited)
- ABFKW-π Set 1 NLO

Steep rise with decreasing β similar to pion and proton structure functions parameterisations.



Conclusions

- New measurement of $F_2^{LN(3)}(Q^2,x,x_L)$ structure function by H1 using HERA-II data.
- Kinematic range:
  $6\ GeV^2 < Q^2 < 100\ GeV^2$, $1.5\times10^{-4} < x < 3\times10^{-2}$, $0.32 < x_L < 0.95$, $p_T < 0.2\ GeV$
- Standard fragmentation models do not describe leading neutron production
- The pion exchange model describes data well for $x_L > 0.7$
- F_2^{LN}/F_2 ratio is consistent with limiting fragmentation hypothesis
- $F_2^{LN(3)}$ is interpreted in terms of pion structure function F_2^{π} and compared to different parameterisations of F_2^{π}

Backup

Lepton variables:
Q^2, x, y

$$\cos\gamma = \frac{p_{xh}^2 + p_{yh}^2 - (E_h - p_{zh})}{p_{xh}^2 + p_{yh}^2 + (E_h - p_{zh})}$$

$$y_{DA} = \frac{\sin\gamma(1+\cos\theta_e)}{\sin\gamma + \sin\theta_e + \sin(\theta_e + \gamma)}$$ -- Double-Angle method "elasticity"

$$y_e = 1 - \frac{E_e'}{E_e}\sin^2(\theta_e/2)$$ -- Electron method "elasticity"

$$y_{av} = y_e^2 + y_{DA}(1 - y_{DA})$$ -- y-average method "elasticity"

$$Q_{av}^2 = \frac{4E_e^2(1-y_{av})}{\tan^2(\theta_e/2)}$$ -- Virtuality of exchanged photon

$$x_{av} = \frac{s}{Q_{av}^2 y_{av}}$$ -- Bjorken-x

Leading Neutron variables:
x_L, t

$$x_L = E_n / E_p$$

$$t = (p - p')^2 \approx -\frac{p_T^2}{x_L} - \frac{(1-x_L)^2}{x_L} m_n^2$$

H1 HERA-I measurement