

# DIS 2009

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## Leading Neutron production in DIS at HERA-II

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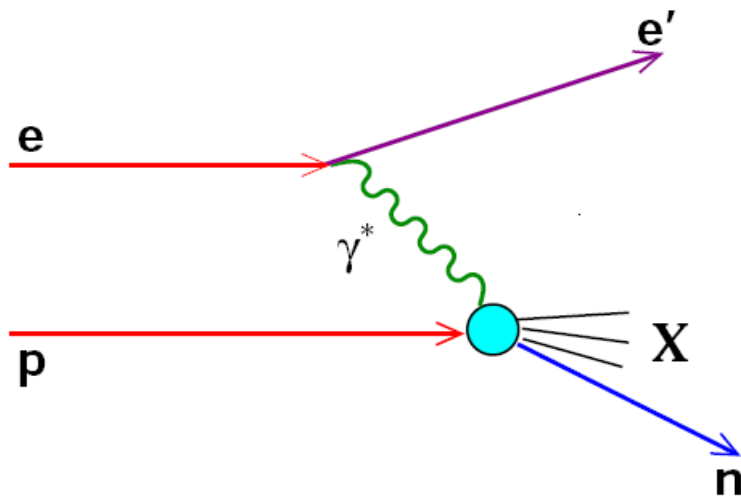
On behalf of the H1 collaboration

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



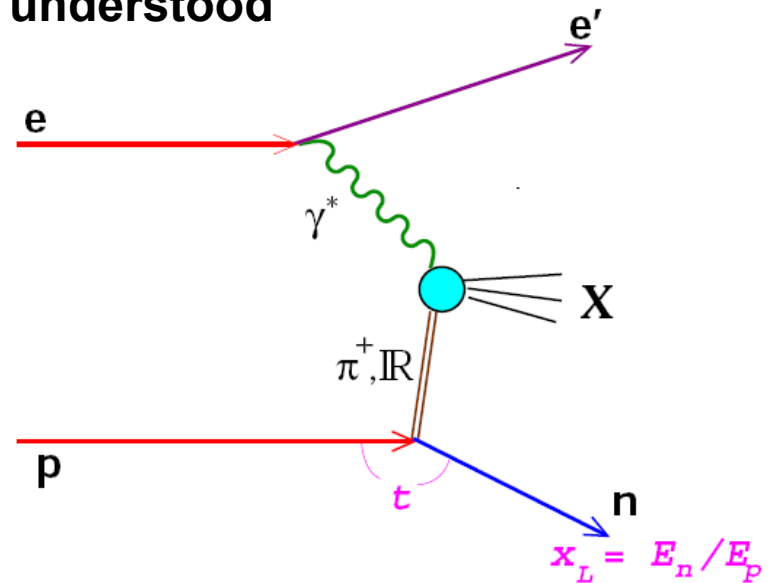
# Motivation

- 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:  
 $e+p \rightarrow e+n+X$
- 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)



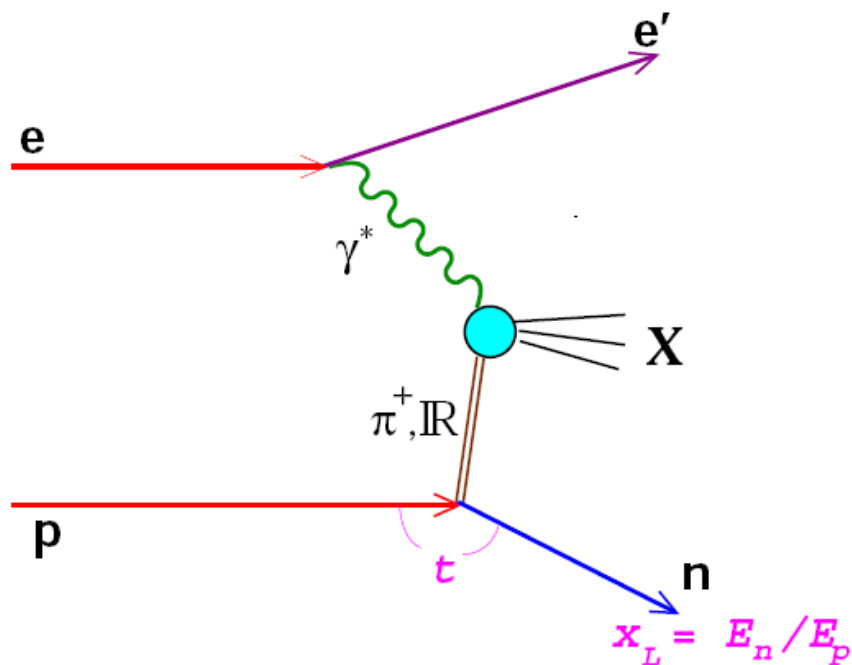
Leading neutron can be produced via **exchange** of virtual particle -- ( $\pi^+$ ,  $\rho^+$ )

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

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

**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

$$Q^2 = q^2 \quad \text{-- photon virtuality}$$

$$x = Q^2 / (2qp) \quad \text{-- Bjorken-}x$$

$$y = s / (x Q^2) \quad \text{-- inelasticity}$$

## Leading Neutron variables

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

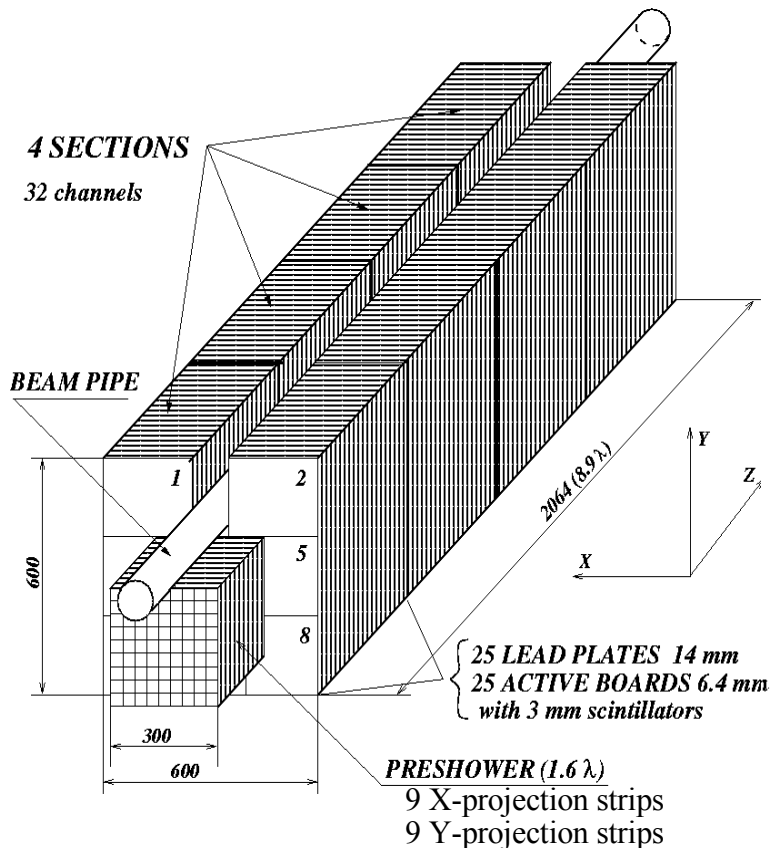
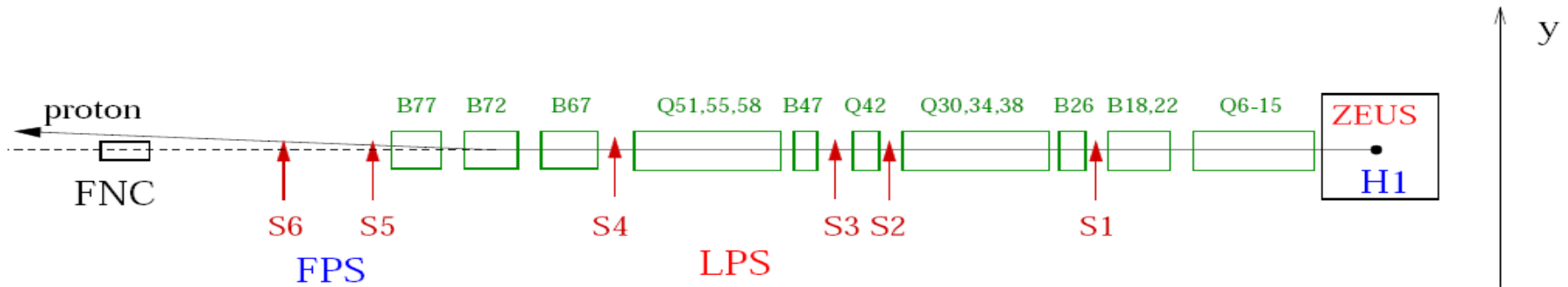
$$x_L = E_n / E_p$$

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

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

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

# H1 Forward Neutron Calorimeter



- Dedicated detector at 106 m downstream in proton direction from the interaction point
- Acceptance limited by magnets aperture:  $\theta_n < 0.8 \text{ mrad}$
- 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  $\sim 2 \text{ mm}$
- 1.6 (preshower) + 8.9 (main) interaction lengths deep
- In HERA-II setup we can distinguish between e/m and hadronic showers

### **Kinematic range:**

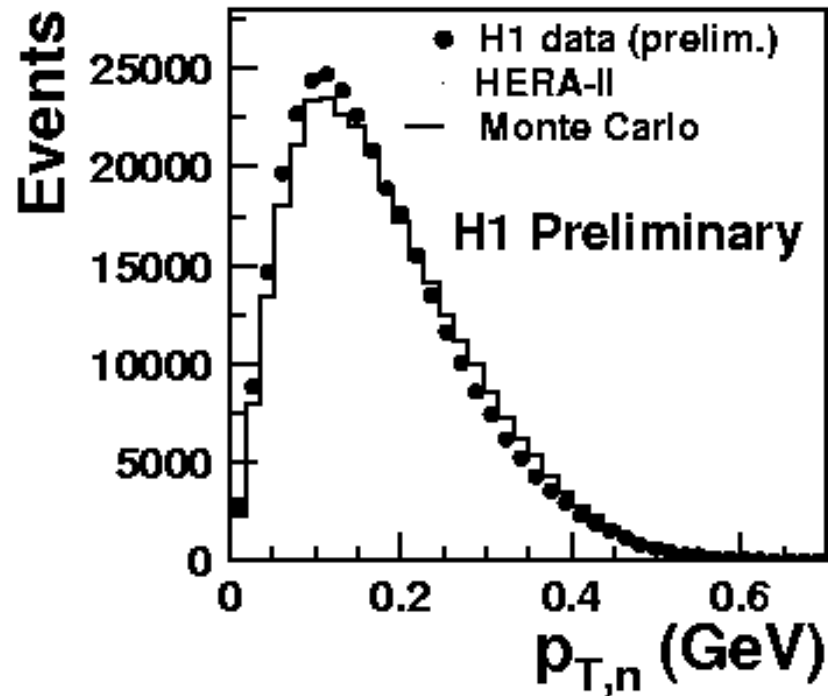
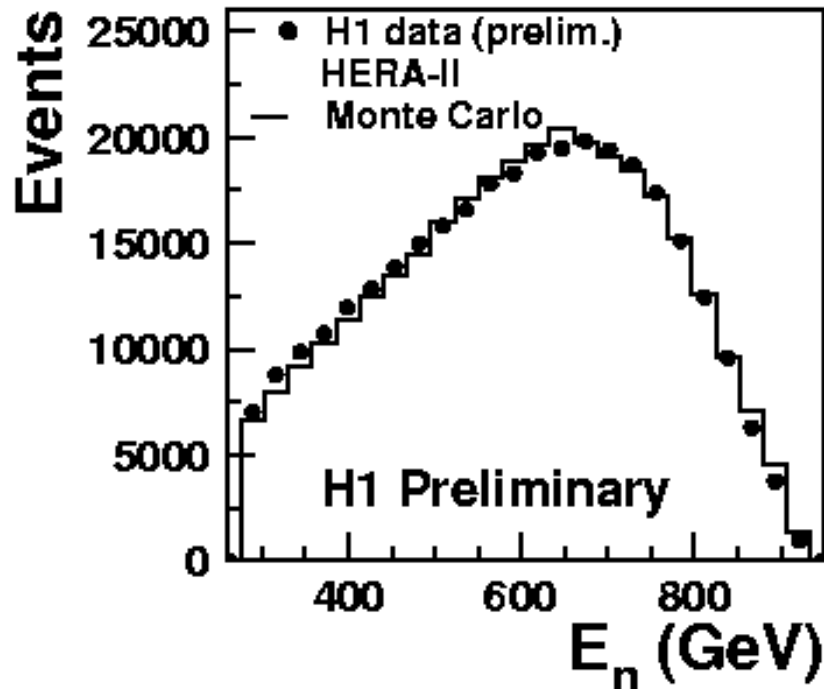
$$6 \text{ GeV}^2 < Q^2 < 100 \text{ GeV}^2, \quad 1.5 \times 10^{-4} < x < 3 \times 10^{-2}, \quad 0.02 < y < 0.6,$$

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

- **HERA-II data, e+p collisions,  $E_p = 920 \text{ GeV}$ ,  $E_e = 27.6 \text{ GeV}$ ,  
122 pb<sup>-1</sup> accumulated luminosity, 300000 events**
- **Upgraded Forward Neutron Calorimeter (better resolution and  
photon identification)**
- **DJANGO-CDM and RAPGAP  $\pi^+$ -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

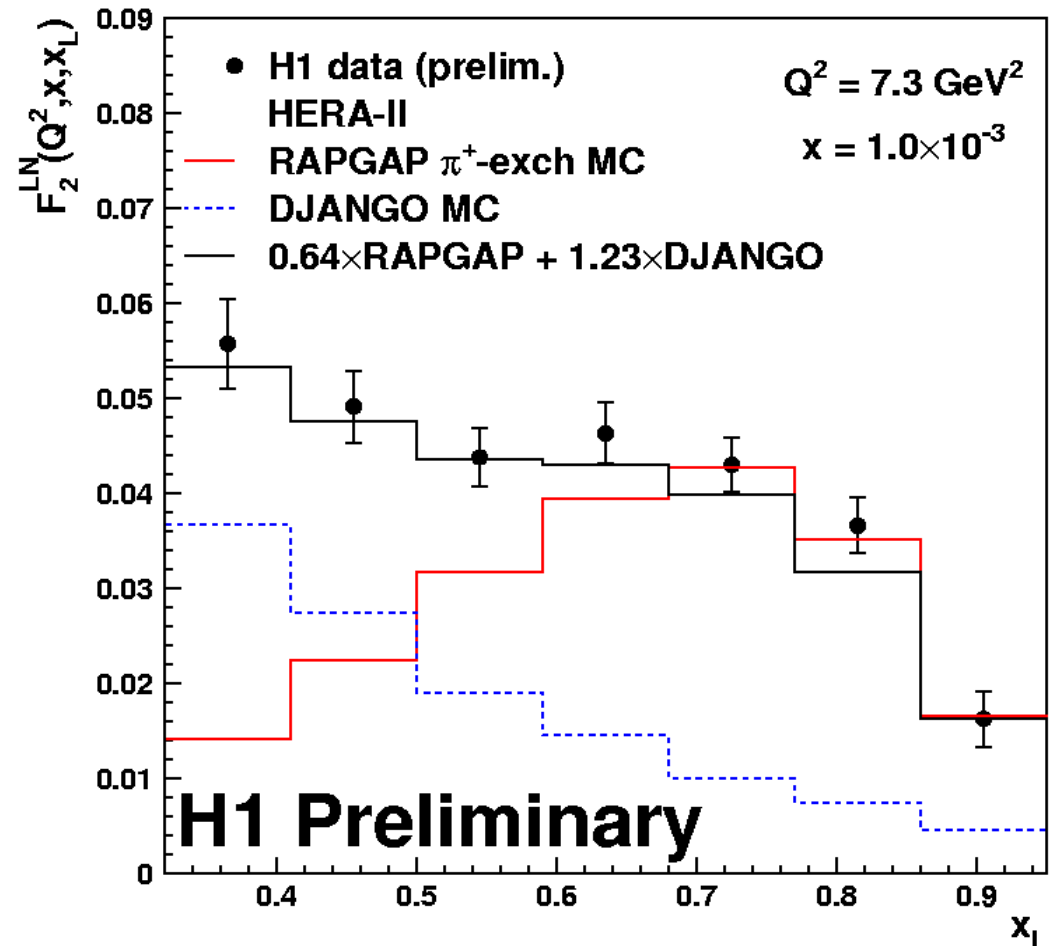


MC simulation done using a mixture of events generated by RAPGAP- $\pi$ -exchange and DJANGO-CDM generators

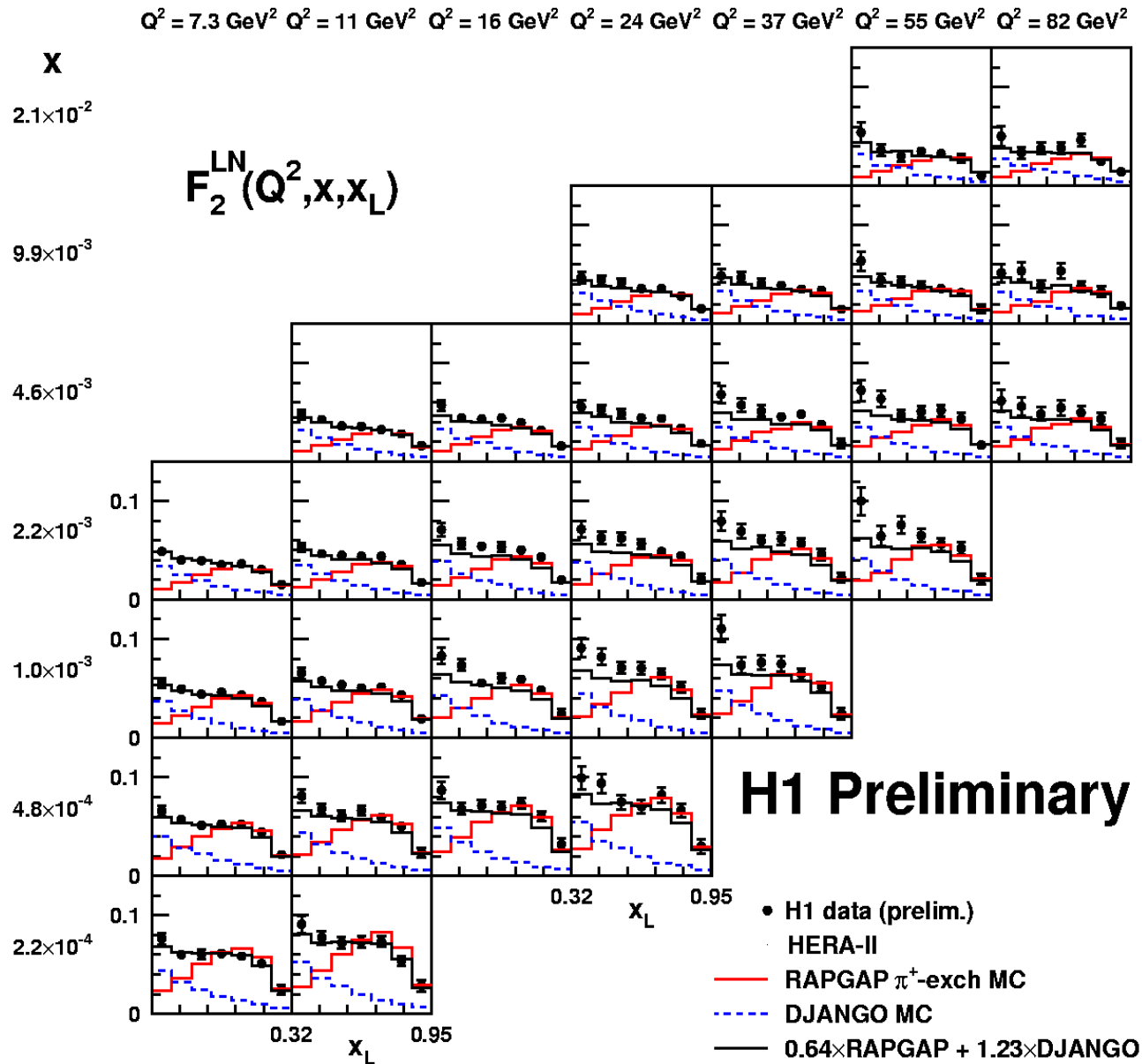
## Triple differential reduced cross section

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

- DJANGO (standard fragmentation) predicts too low cross section, also  $x_L$  spectrum shape is too different
- RAPGAP  $\pi^+$ -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





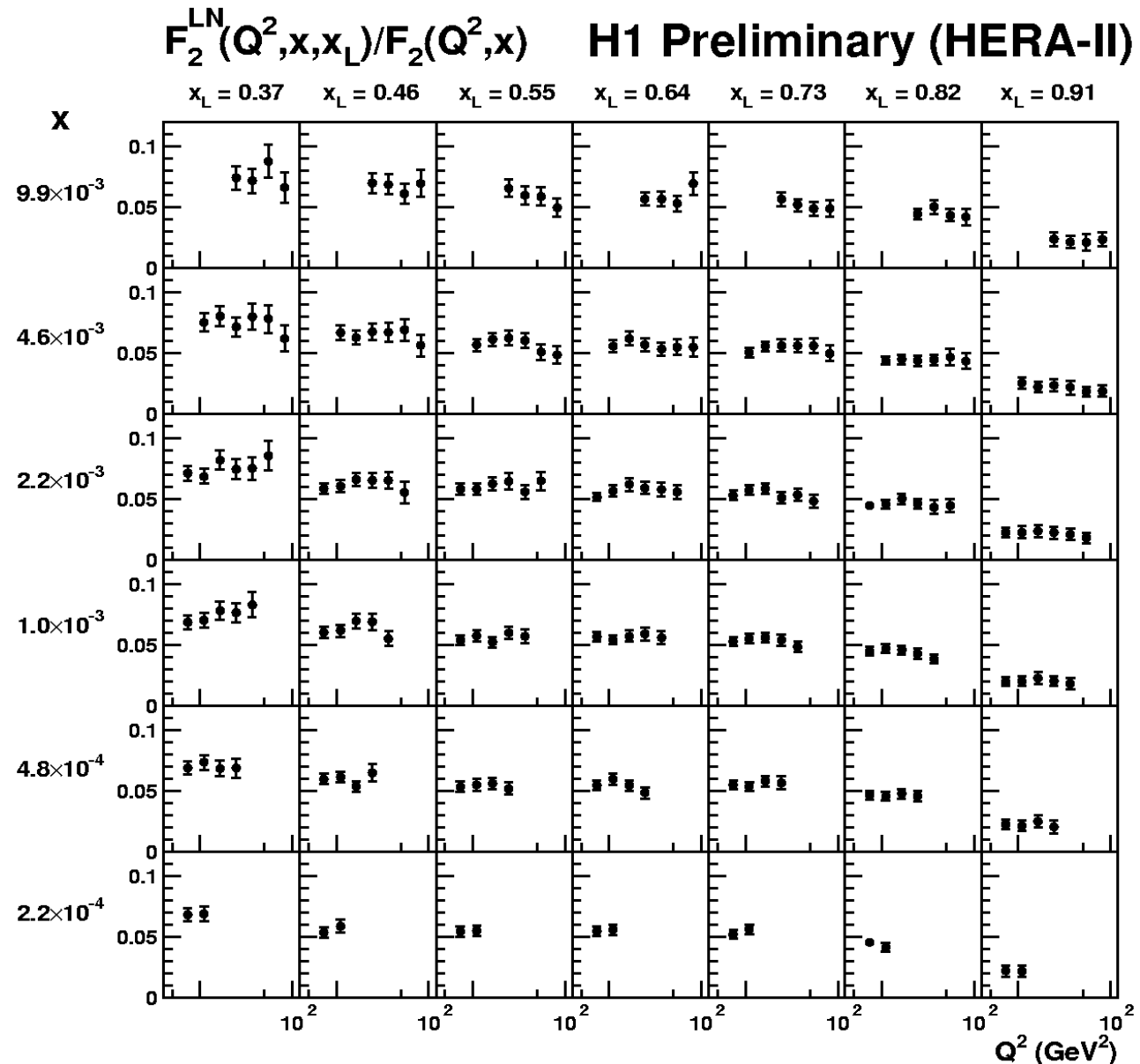
# $F_2^{\text{LN}}(Q^2, x, x_L)$ to $F_2(Q^2, x)$ ratio

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

$F_2^{\text{LN}}(Q^2, x, x_L)/F_2(Q^2, x)$   
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 $F_2^{\text{LN}}$

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

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

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

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

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

Using pion flux  $f_{\pi^+/p} = \frac{1}{2\pi} \frac{g_{p\pi n}^2}{4\pi} (1-x_L) \frac{-t}{(m_\pi^2 - t)^2} \exp\left(-R_{\pi n}^2 \frac{m_\pi^2 - t}{1-x_L}\right) \Rightarrow \Gamma_\pi = 0.131$

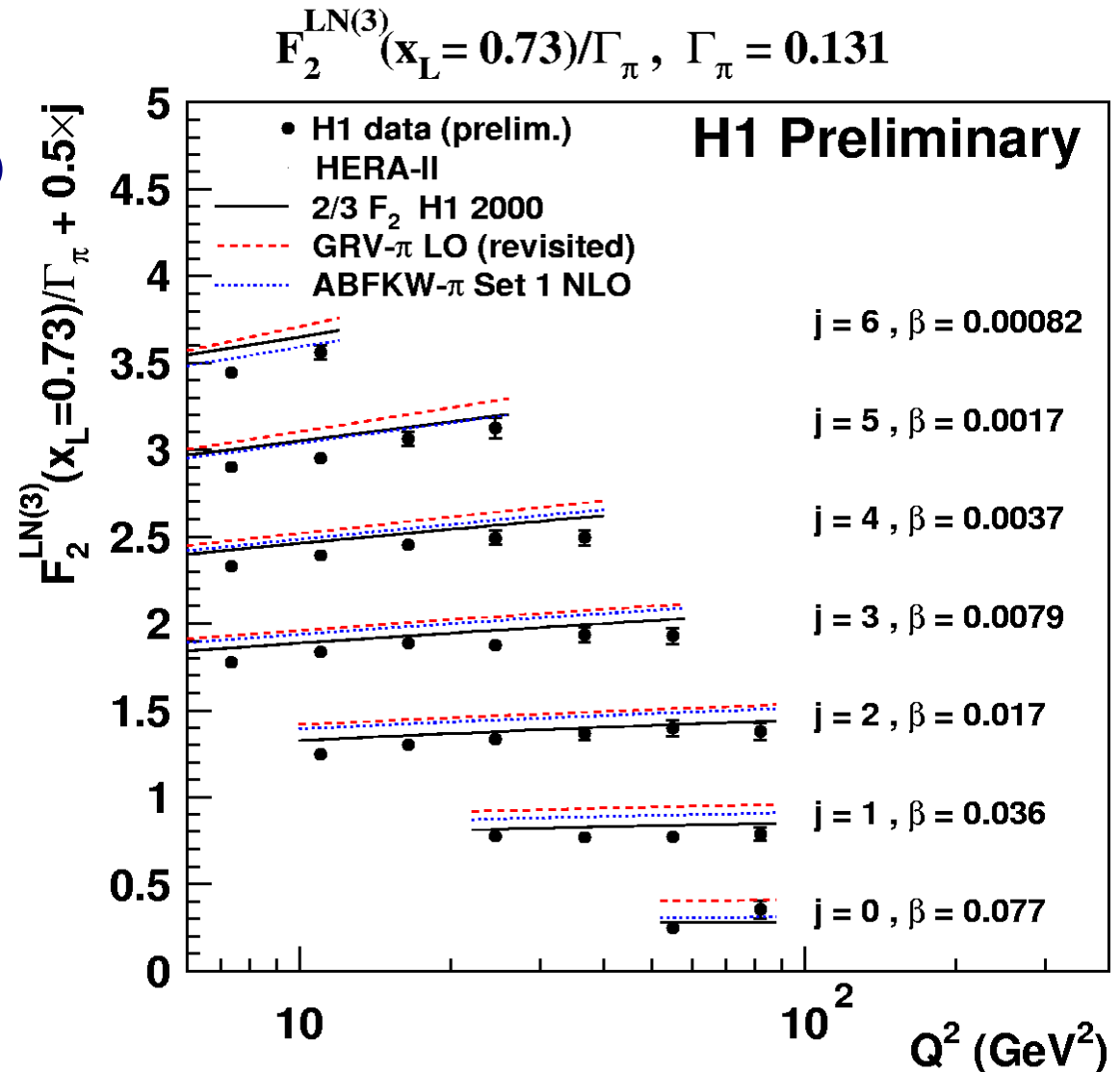
(other pion flux form-factors give other values of  $\Gamma_\pi \Rightarrow$  global normalization factor on  $F_2^\pi$ )

No background subtraction or absorption correction applied

# Pion Structure Function from $F_2^{\text{LN}}$

- Data compared to parameterisations:
- 2/3 of proton  $F_2$  (naive quark model)
  - GRV- $\pi$  LO (revisited)
  - ABFKW- $\pi$  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.

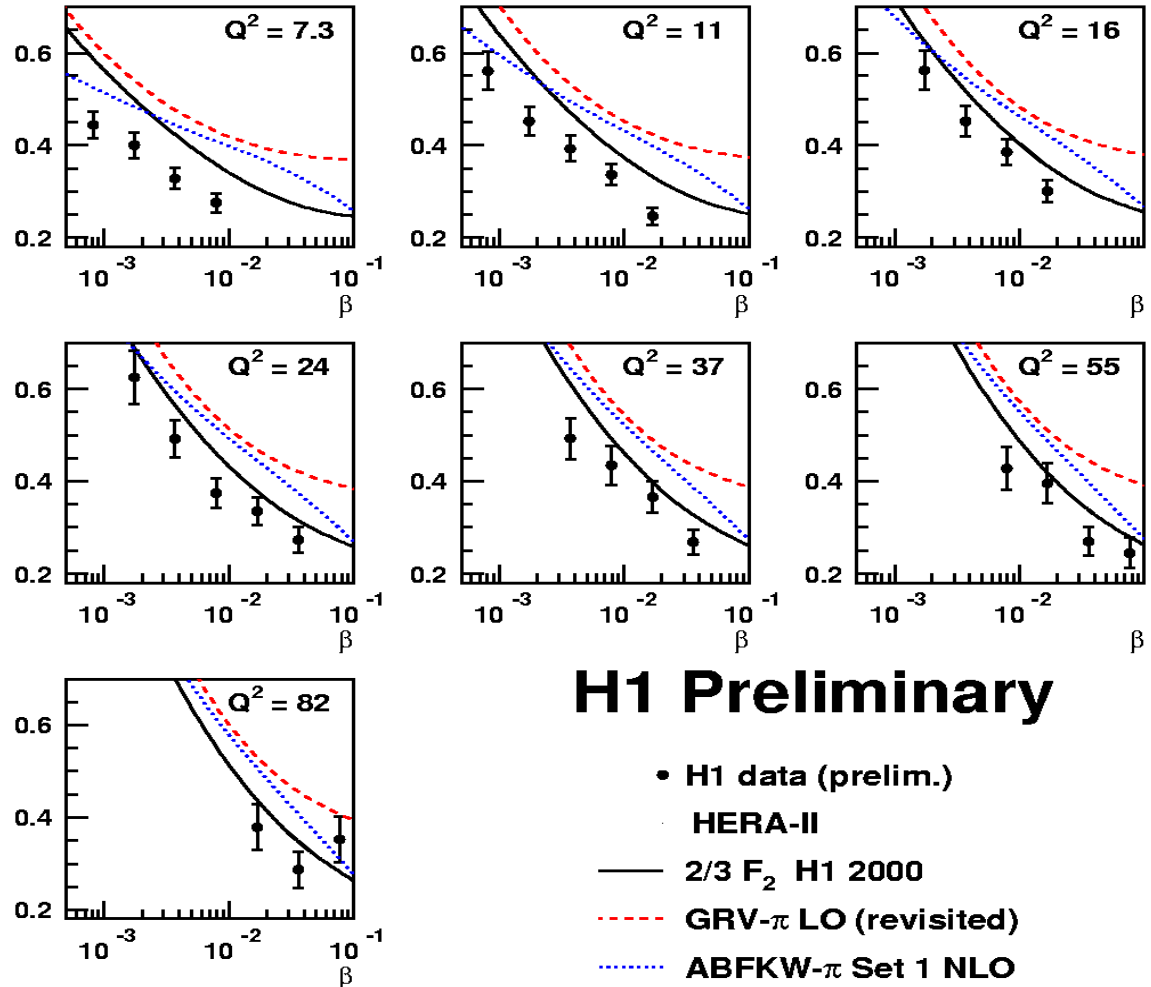


# Pion Structure Function from $F_2^{\text{LN}}$

$$F_2^{\text{LN}(3)}(x_L = 0.73) / \Gamma_\pi, \Gamma_\pi = 0.131$$

- Data compared to parameterisations:
- 2/3 of proton  $F_2$  (naive quark model)
  - GRV- $\pi$  LO (revisited)
  - ABFKW- $\pi$  Set 1 NLO

Steep rise with decreasing  $\beta$  similar to pion and proton structure functions parameterisations.



# Conclusions

- **New measurement of  $F_2^{\text{LN}(3)}(Q^2, x, x_L)$  structure function by H1 using HERA-II data.**
- **Kinematic range:**  
 $6 \text{ GeV}^2 < Q^2 < 100 \text{ GeV}^2, 1.5 \times 10^{-4} < x < 3 \times 10^{-2}, 0.32 < x_L < 0.95, p_T < 0.2 \text{ GeV}$
- **Standard fragmentation models do not describe leading neutron production**
- **The pion exchange model describes data well for  $x_L > 0.7$**
- **$F_2^{\text{LN}}/F_2$  ratio is consistent with limiting fragmentation hypothesis**
- **$F_2^{\text{LN}(3)}$  is interpreted in terms of pion structure function  $F_2^\pi$  and compared to different parameterisations of  $F_2^\pi$**

# Backup

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## Lepton variables: $Q^2, x, y$

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

$$y_{DA} = \frac{\sin \gamma (1 + \cos \theta_e)}{\sin \gamma + \sin \theta_e + \sin(\theta_e + \gamma)}$$

$$y_e = 1 - \frac{E'_e}{E_e} \sin^2(\theta_e/2)$$

$$y_{av} = y_e^2 + y_{DA}(1 - y_{DA})$$

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

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

## Leading Neutron variables: $x_L, t$

$$x_L = E_n / E_p$$

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

-- Double-Angle method “elasticity”

-- Electron method “elasticity”

-- y-average method “elasticity”

-- Virtuality of exchanged photon

-- Bjorken-x

## H1 HERA-I measurement

