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Forward neutron p_T distributions and forward photon spectra measured in FNC

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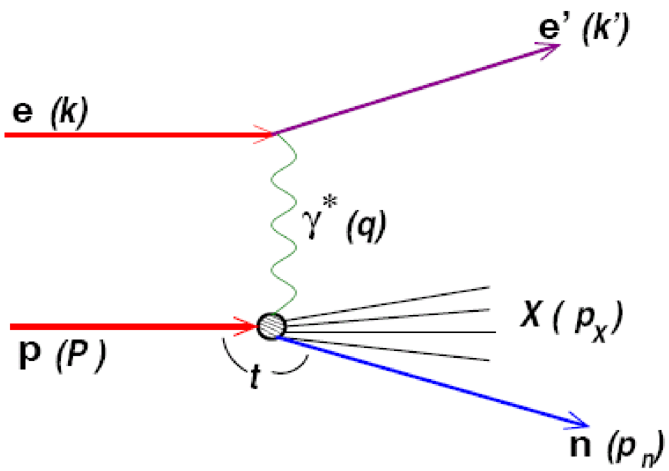
On behalf of the H1 Collaboration

Outline:

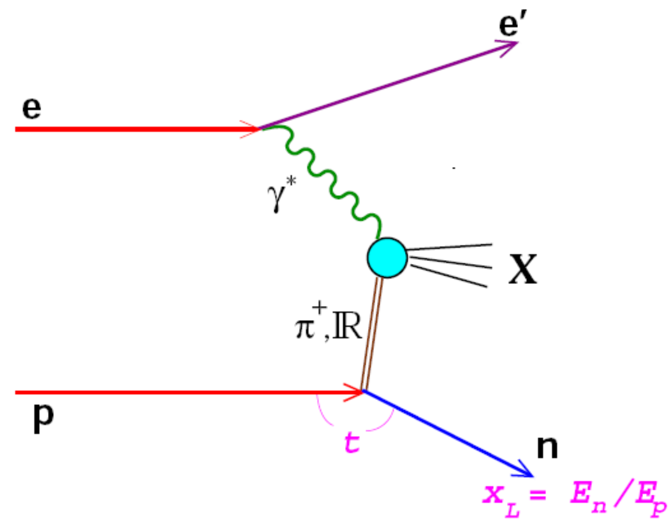
- **Forward neutron p_T distributions in DIS**
- **Forward photon spectra in DIS**

Introduction

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 . Different production mechanisms are available:



$x_L = E_n / E_p$

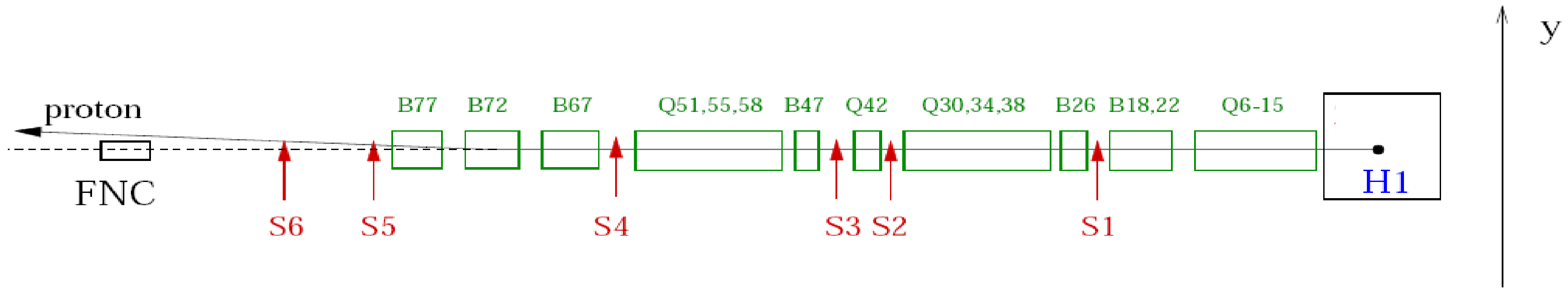


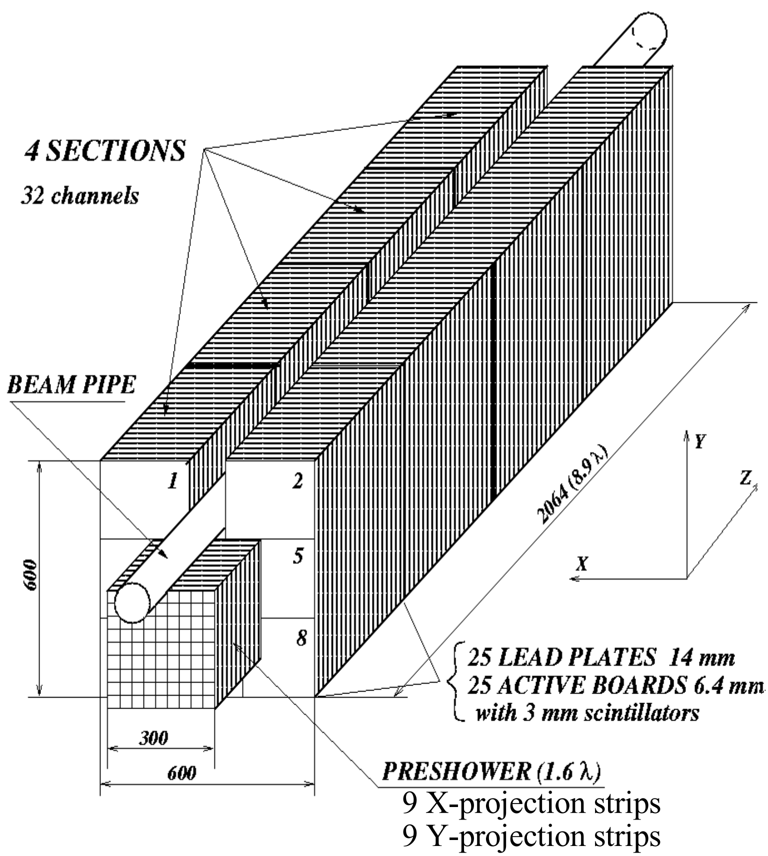
Leading neutron can come from "standard fragmentation" implemented in MC models

Leading neutron can be produced via exchange of virtual particle: π^+, ρ^+, a_2^+

Forward neutrons:

H1 Forward Neutron Calorimeter





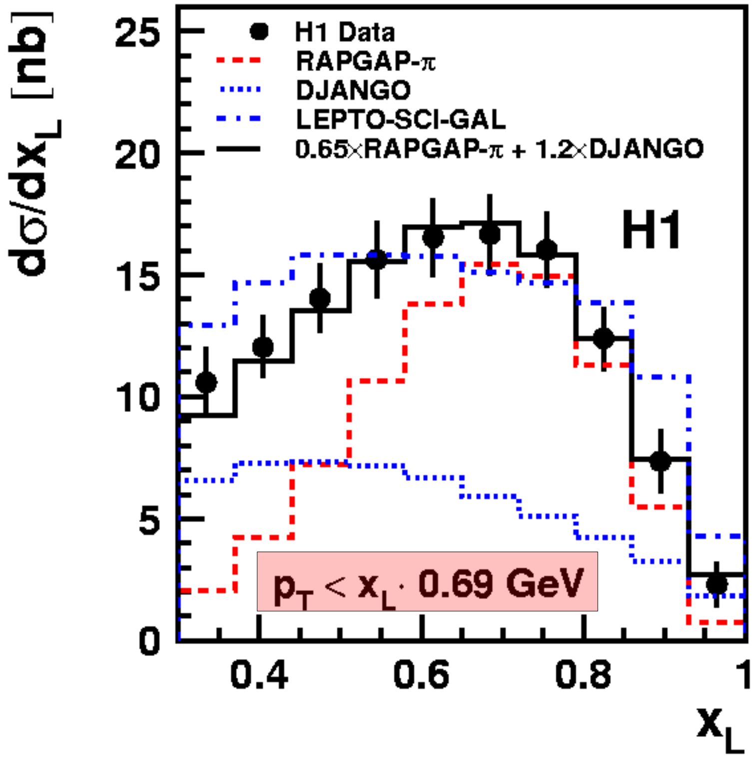
- **Dedicated detector at 106 m downstream in proton direction from the interaction point**
- **Acceptance limited by magnets aperture: $\theta_n < 0.8$mrad**
- **Two sandwich-type calorimeters: Main Calorimeter and Preshower Calorimeter in front of the Main.**
- **Energy resolution (hadrons): $\sigma(E)/E = 63\%/\sqrt{E} \oplus 3\%$**
- **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, more about it later**

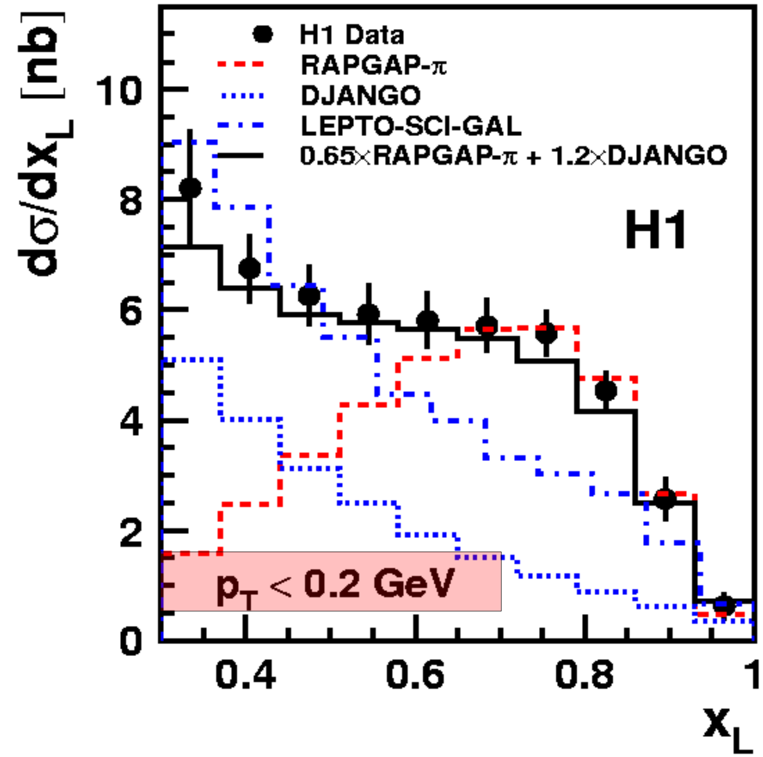
Forward neutrons:

Differential cross sections vs x_L

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

(Eur.Phys.J.C68:381-399,2010)





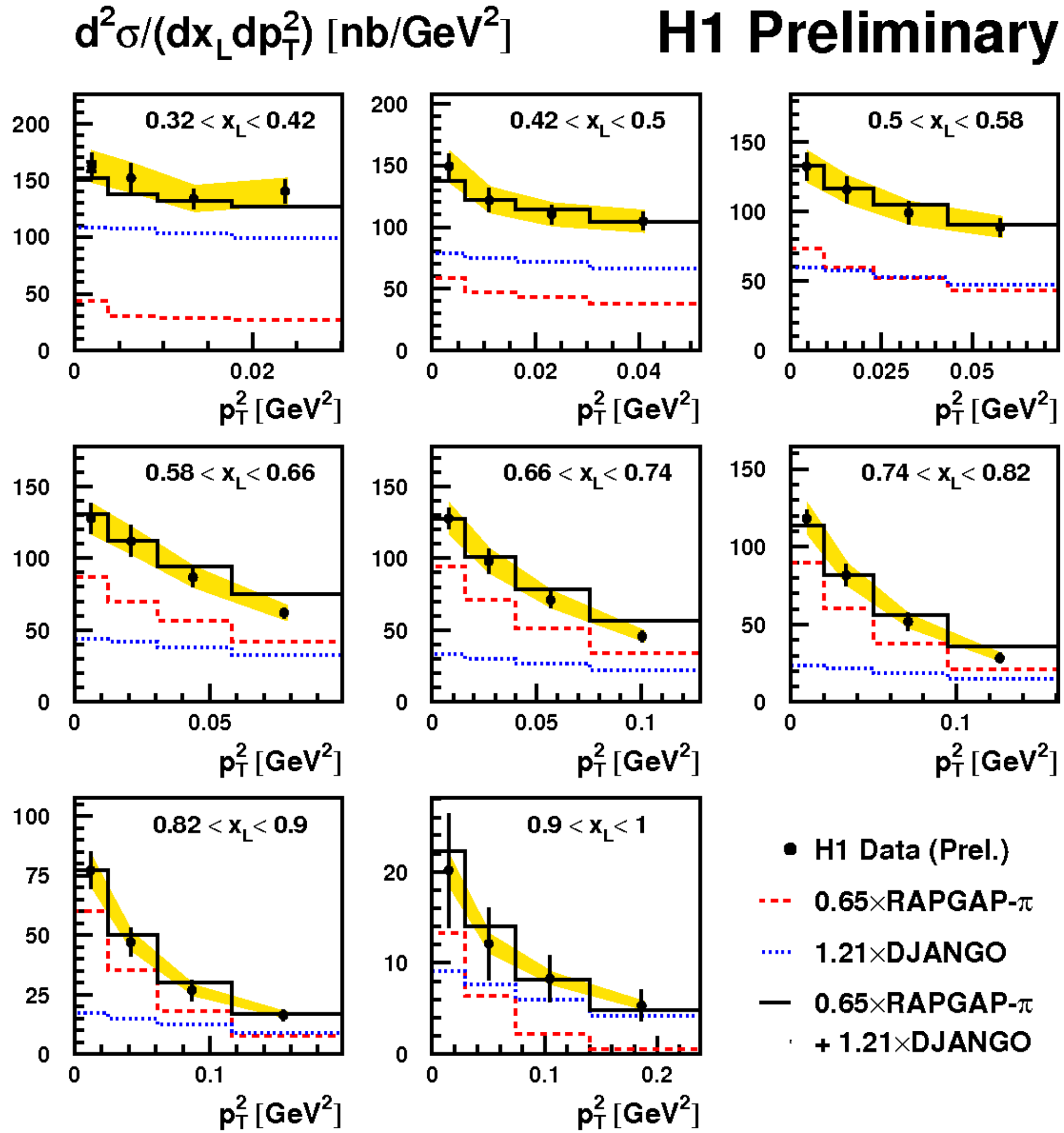
In previous analysis we measured cross section of leading neutron production versus $x_L = E_n/E_p$ variable, now we extended the measurement differentially in transverse momentum of neutron p_T

Forward neutrons:

Forward neutron p_T^2 distributions in x_L bins

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

Kinematic range: $6 < Q^2 < 100$ GeV^2, $0.05 < y < 0.6$, 2006-2007 data, Lumi=122pb^{-1}



Data can be described by a combination of standard fragmentation (DJANGO-CDM) and pion-exchange (RAPGAP-π+)

MC weight factors 0.65 and 1.21 taken from the fit to x_L distribution also describe p_T^2 distributions

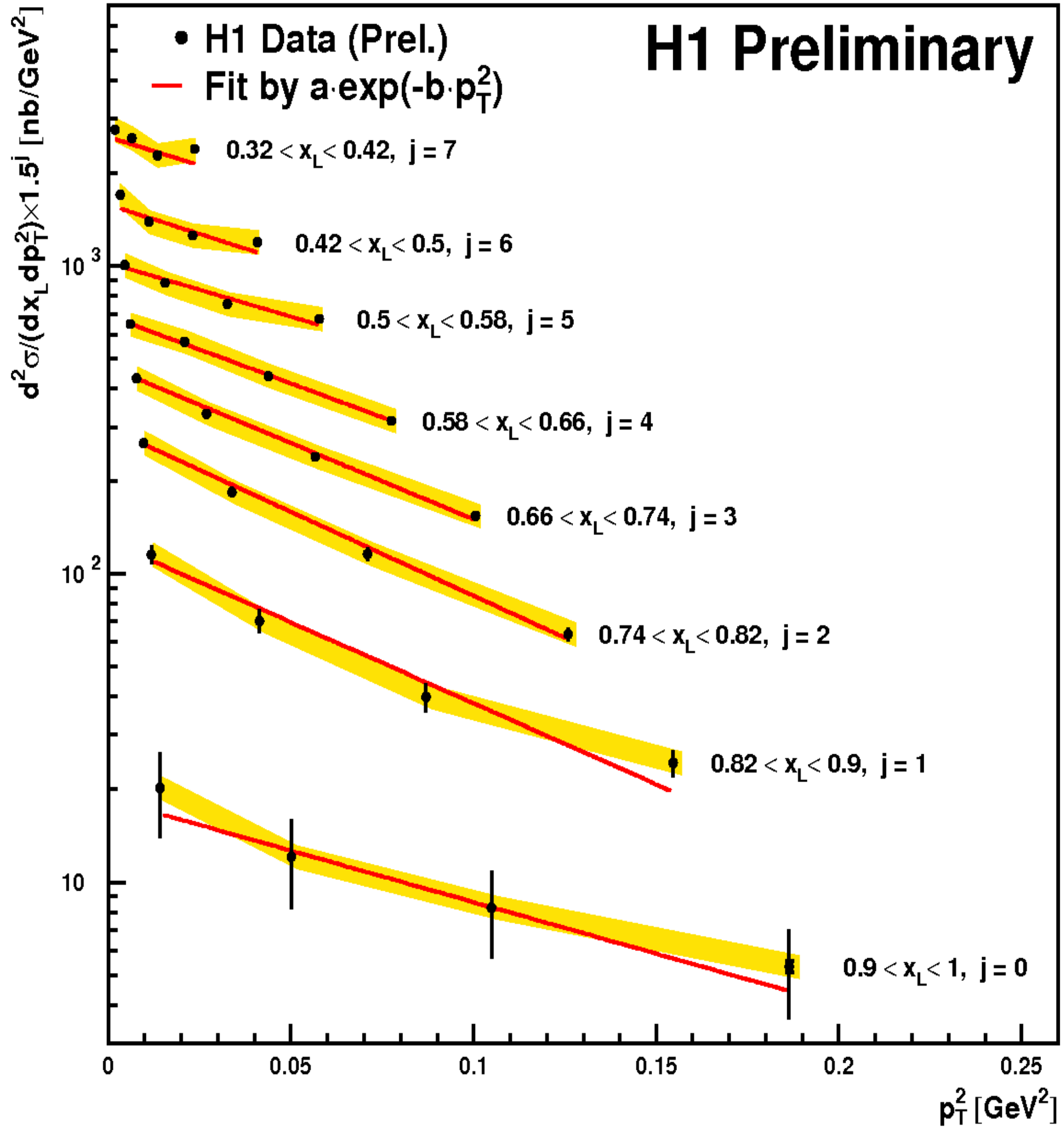
p_T^2 slopes are different for standard fragmentation and pion-exchange, constant vs x_L for DJANGO and increasing with x_L for RAPGAP

Forward neutrons:

Forward neutron p_T^2 distributions with fit

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

Fit by: $$\frac{1}{\sigma_{inc}} \frac{d\sigma_{LN}}{dp_T^2\, dx_L} = a(x_L)\cdot e^{-b(x_L)\, p_T^2}$$



p_T^2 slopes change with increasing p_T^2

Fit the distributions by a single exponent

Forward neutrons:

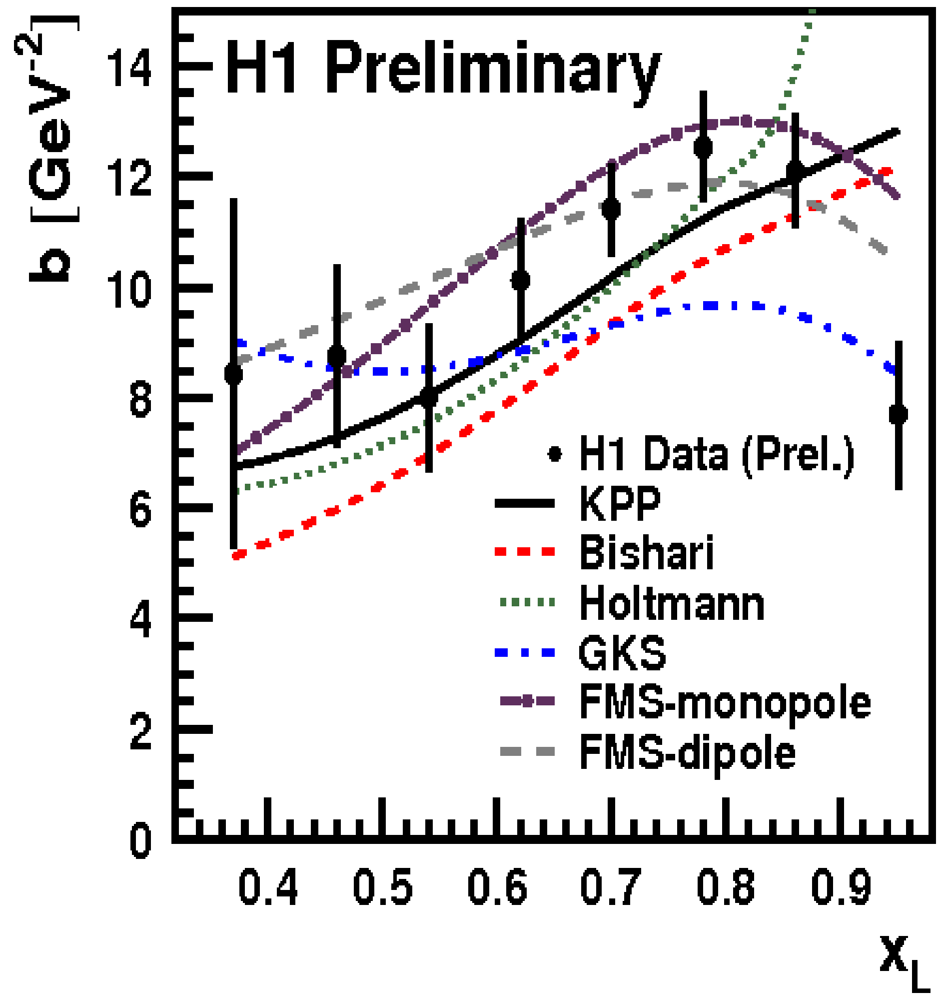
Forward neutron p_T^2 slopes

e+p → e+n+X

Fit by: $$\frac{1}{\sigma_{inc}}\frac{d\sigma_{LN}}{dp_T^2\,dx_L} = a(x_L)\cdot e^{-b(x_L)\,p_T^2}$$

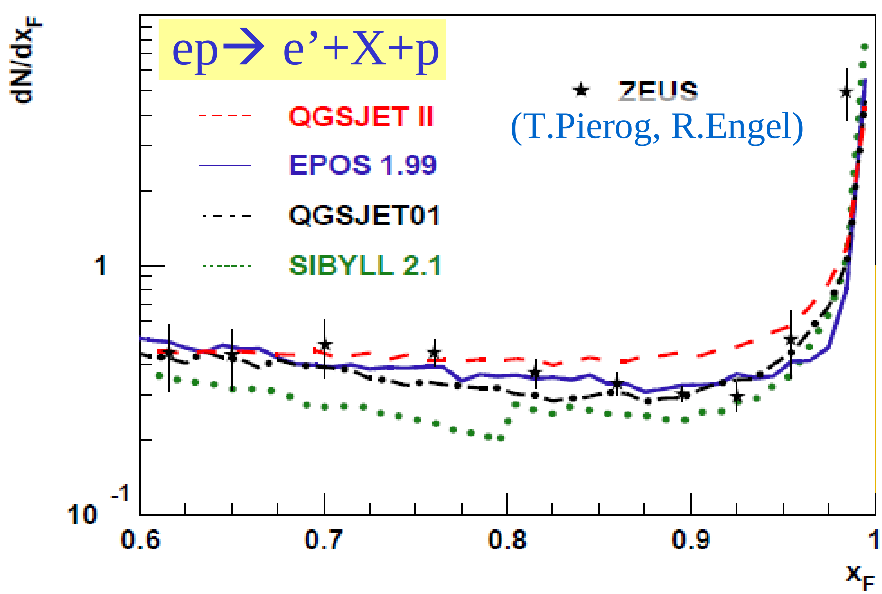
Slopes $b(x_L)$ as a function of x_L compared to several selected pion flux parameterizations:

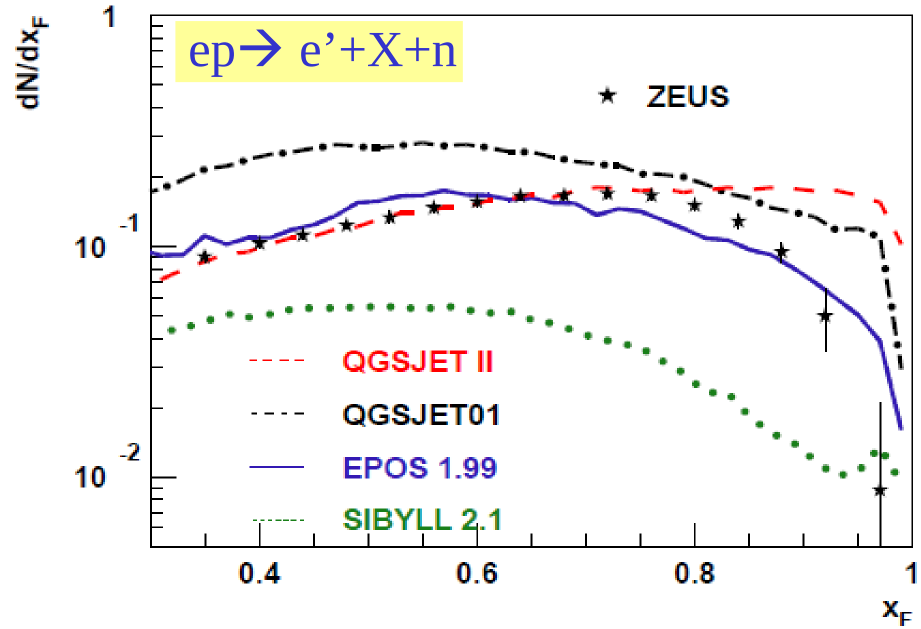
KPP:
B.Kopeliovich, B.Povh, I.Potsahnikova
Bishari:
M.Bishari
Holtmann:
H.Holtmann
GKS:
K.J.Golec-Biernat, J.Kwiecinski, A.Szczurek
FMS:
L.L.Frankfurt, L.Mankiewicz, M.I.Strikman



Measurement of forward photons

Forward particles sensitive to proton fragmentation.
Forward particles at HERA can contribute to the understanding of high energy cosmic rays





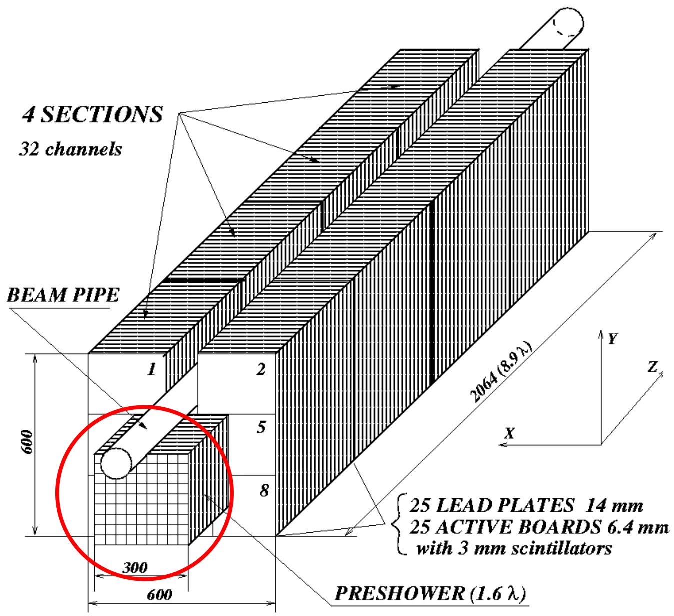
$x_F = x_L$

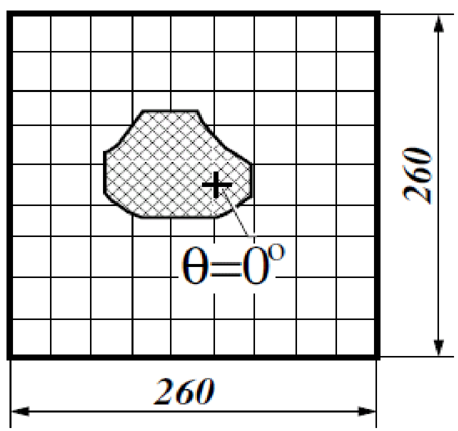
- EPOS 1.6, 1.9 *(Pierog,Werner)*
- QGSJET 01 and II *(Kalmykov,Ostapchenko)*
- SIBYLL 2.1 *(Engel,Fletcher,Gaisser,Lipari,Stanev)*

- **reasonable predictions for leading proton data (after model tuning)**
- **none of models describe leading neutron data well**
- **What about γ,π^0 ?**

Forward photons:

Forward Neutron Calorimeter





Preshower detector

- *$26x26x40\ cm^3$*
- *$60\ X_0,\ 1.6\ \lambda_i$*
- *readout 9 X and 9 Y projection strips*

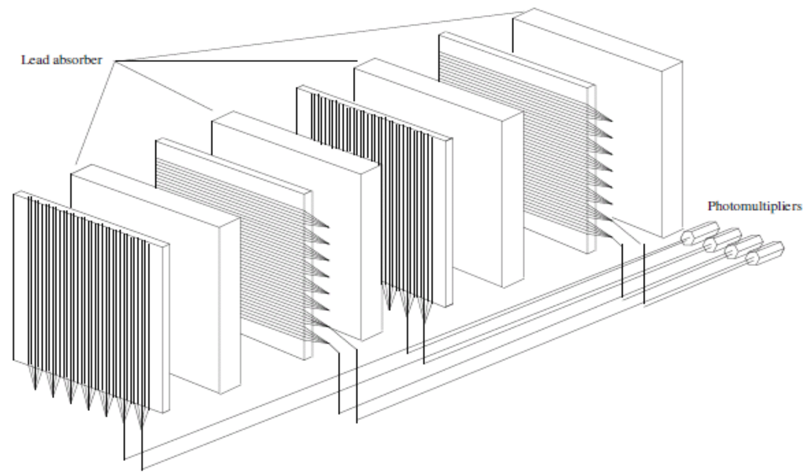


Figure 3: *The scheme of light collection for the Preshower.*

Segmentation in depth (Z-axis) allows reliable discrimination between electromagnetic and hadronic showers, that is between photons and neutrons.

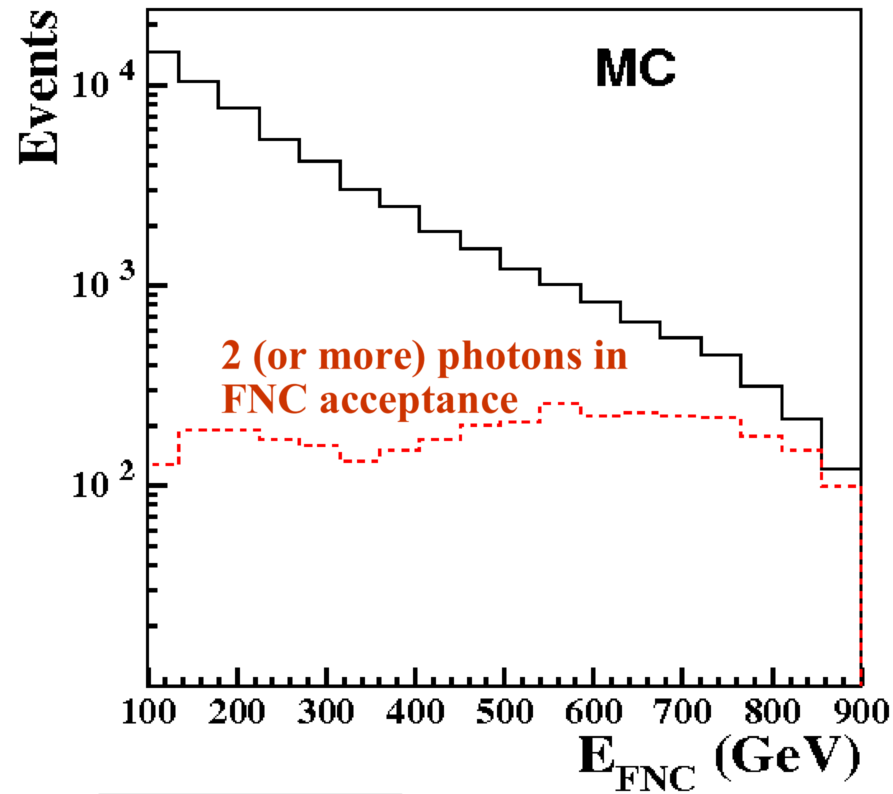
At low energy (x_L<0.1) neutrons can be misidentified as photons => measure cross sections for $x_L > 0.1$

Photon candidates

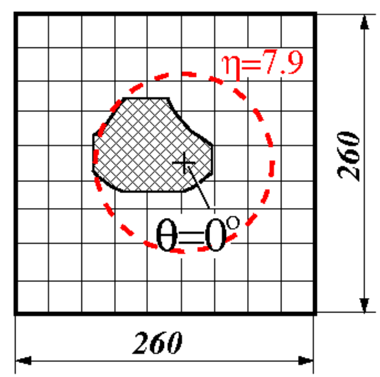
What are our photon candidates ?

At high x_L, many FNC clusters are from more than one photon! So measurement represents the sum of photons inside the angular range defined by the FNC geometrical acceptance (η>7.9).

But at lower x_L we can assume that to a good approximation we measure one photon.



provide cross sections:
- **x_L and p_T of most energetic photon in a range η>7.9 for x_L < 0.7**
- **x_L of sum of photons in a range η>7.9**



Forward photons:

Results

Kinematic range: $6 < Q^2 < 100$ GeV^2, $0.05 < y < 0.6$, 2006-2007 data, Lumi=126pb^{-1}
σ_{DIS} is inclusive cross section in the same kinematic range

Presented cross sections:

$1/\sigma_{DIS}\, d\sigma/dx_L^{lead}$ ($x_L^{lead} = E/E_{p\text{-}beam}$ of most energetic γ in $\eta>7.9$)
$1/\sigma_{DIS}\, d\sigma/dp_T^{lead}$ ($p_T^{lead} = E*\sin(\theta)$ of most energetic γ in $\eta>7.9$, $0.1<x_L<0.7$)
$1/\sigma_{DIS}\, d\sigma/dx_L^{sum}$ ($x_L^{sum} = \Sigma E_i/E_{p\text{-}beam}$ of γ with $\eta>7.9$)

Data compared to
- CDM and LEPTO MC
- Hadronic interaction models used for analysis of cosmic rays
EPOS, SIBYLL, QGSJET II, QGSJET 01

- EPOS 1.9 *(Pierog,Werner)*
- QGSJET II and 01 *(Kalmykov,Ostapchenko)*
- SIBYLL 2.1 *(Engel,Fletcher,Gaisser,Lipari,Stanev)*

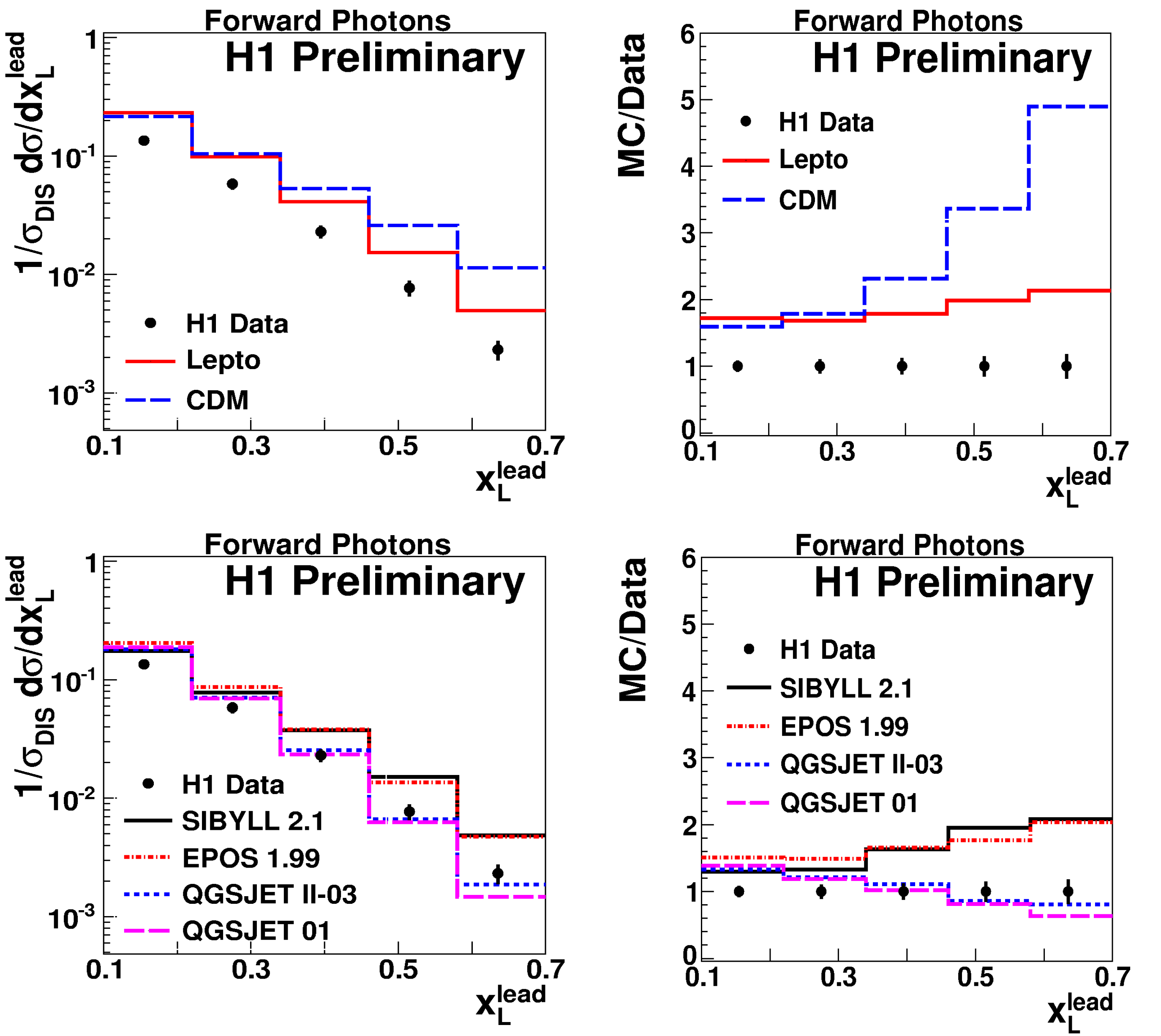
Forward photons:

Leading photon production cross sections vs x_L

Photon rate in all tested Monte Carlo models is significantly higher than in data.

LEPTO model describes the shape reasonably well. CDM to data discrepancy larger at higher x_L

QGSJET models describe data well except at low x_L



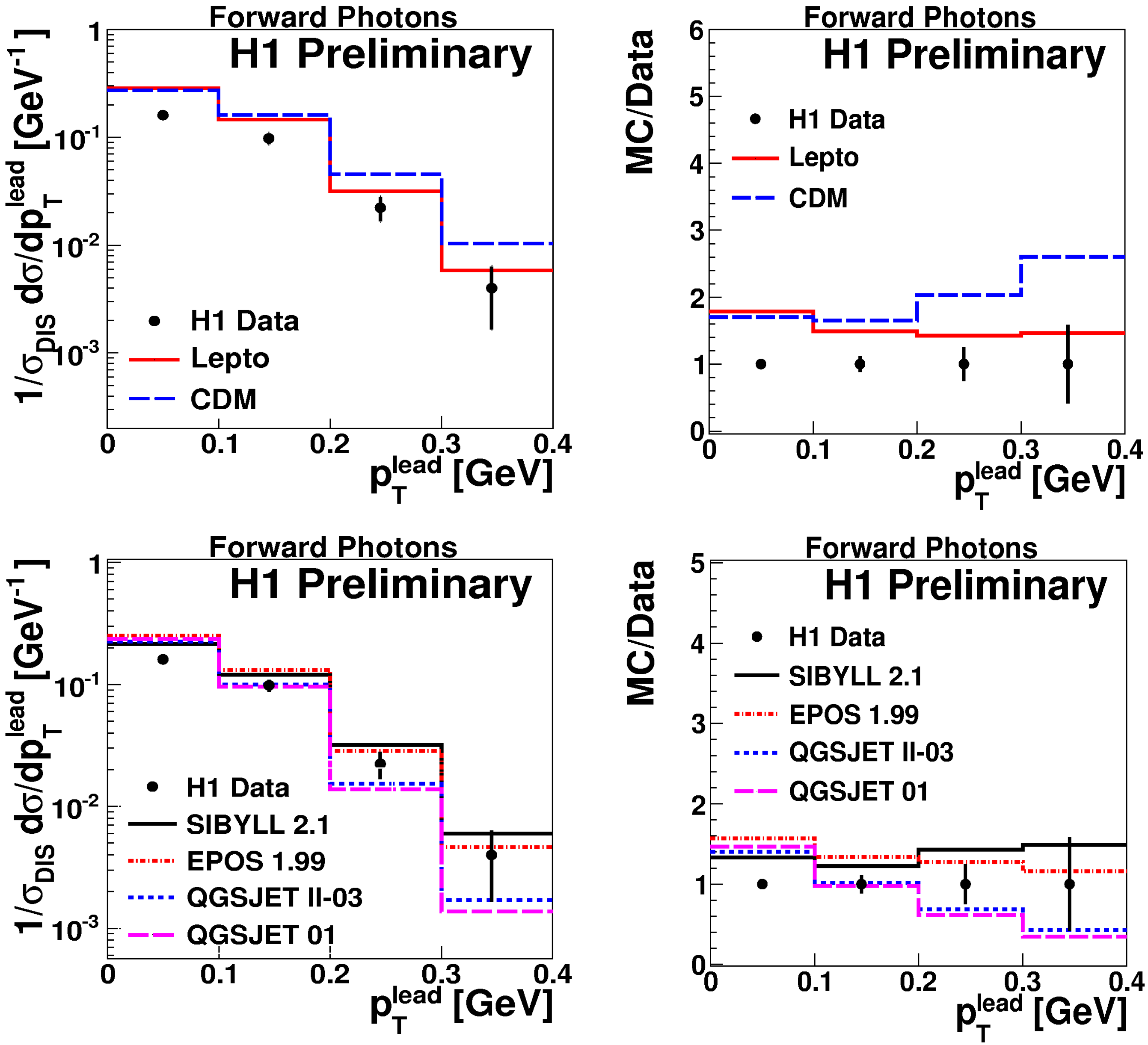
Forward photons:

Leading photon production cross sections vs p_T

Photon rate in all tested Monte Carlo models is significantly higher than in data.

LEPTO describes the shape reasonably well.

p_T^2 spectrum shape is well described by SIBYLL and EPOS models.



Forward photons:

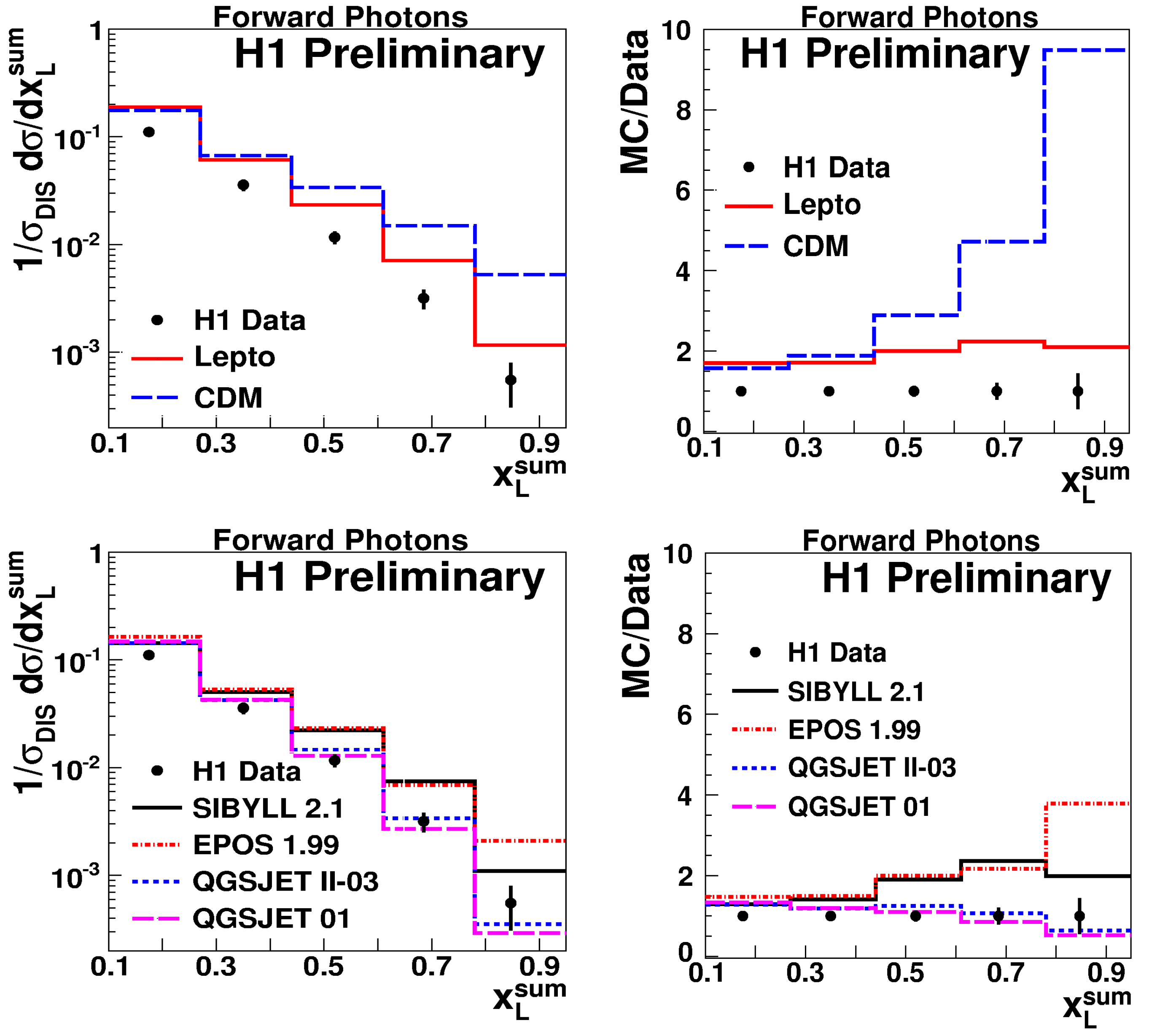
Photon production cross sections vs sum of x_L

$x_L^{sum} = \Sigma E_i / E_{p\text{-beam}}$ of γ with $\eta > 7.9$

Photon rate in all tested Monte Carlo models is significantly higher than in data.

LEPTO describes the shape reasonably well. At higher x_L CDM to data ratio is even worse.

For energy sum QGSJET models describe data shape better than SIBYLL and EPOS.



Summary

- **Measurement of double-differential cross section vs x_L and p_T^2 of leading neutron production is presented in the kinematic range Q^2=6-100 GeV^2, 0.05<y<0.6.**
- **Fragmentation MC-models without meson exchange do not describe the data.**
- **Addition of model with pion exchange mechanism allows a better description of the data.**
- **Pion flux can be further constrained using the measurement.**

- **First measurement of $1/\sigma_{DIS}$ normalized cross section of Forward Photons production, in the kinematic range Q^2=6-100 GeV^2; 0.05<y<0.6,**
- **Measurements show sensitivity to proton fragmentation MC models**
- **Photon rate in Monte Carlo models is significantly higher than in data;**
- **LEPTO describes the shape reasonably well.**
- **CDM predicts too many photons at high energies**
- **QGSJET models provide reasonable description of x_L dependence while EPOS and SIBYLL provide similar level of description of p_T dependence.**