Low-x workshop on deep inelastic scattering,
diffraction, final states and related subjects
3-7. June 2011
Santiago de Compostela

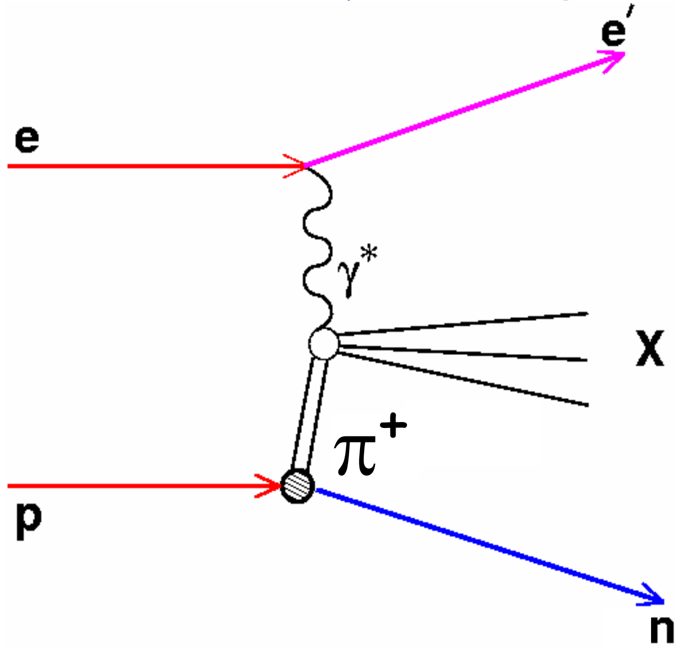
Forward Neutron and Photon results from HERA

Armen Bunyatyan

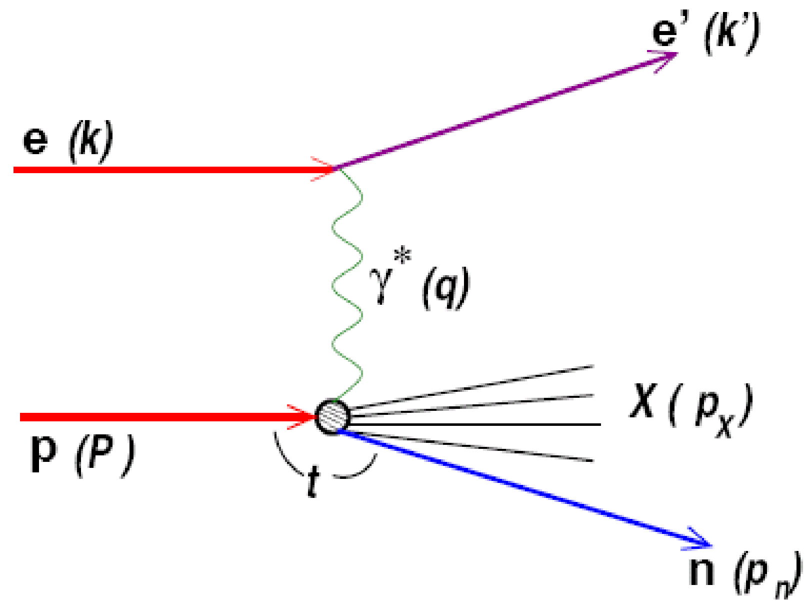
On behalf of the H1 and ZEUS Collaborations

- **Outline:**
- **Forward neutron measurements in DIS**
- **Forward neutrons in dijet photoproduction**
- **Forward photon spectra in DIS**

Significant fraction of ep scattering events contains a high energy forward neutron produced at very small angles.



e+p→e'+n+X

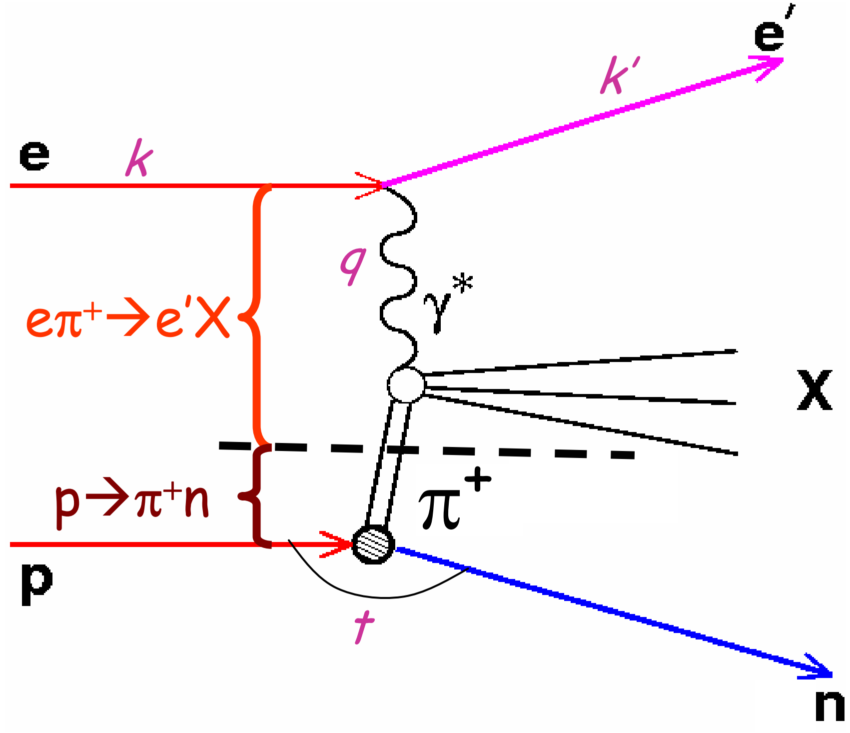


exchange of virtual particle (π^+,ρ^+, .)

(a virtual particle from the proton undergoes DIS with virtual photon)

→ expected to dominate the forward neutron production at large x_L (=En/Ep) and low $p_{T,n}$

fragmentation of proton remnant (e.g. Lund string)



ep→ e'nX

Lepton variables:

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

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

Leading neutron variables:

$x_L = E_n/E_p$

$t = (p-p_n)^2$ (or p_T^2)

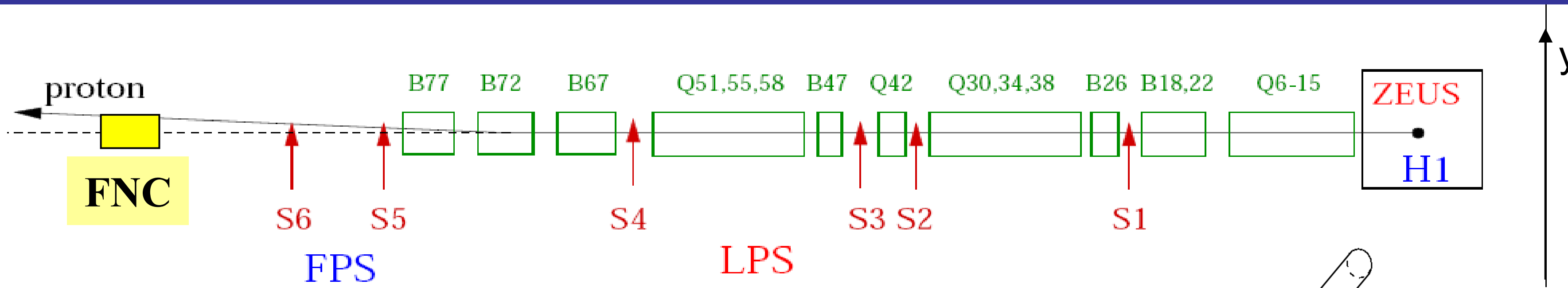
In the exchange model the cross sections factorise, e.g. for one pion exchange

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

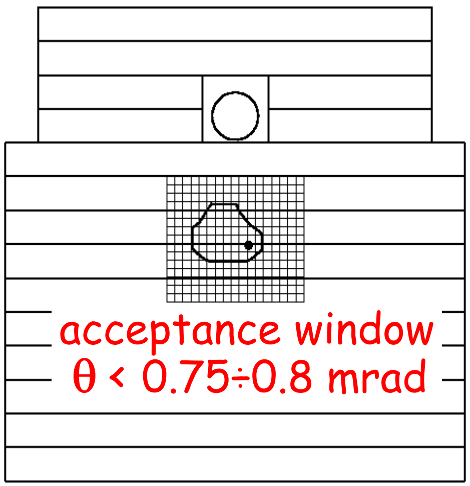
$f_{\pi/p}(x_L,t)$ - pion flux:
probability to emit pion from the photon with given x_L, t

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

- Leading Neutron production independent from photon vertex
  → probe structure of exchanged particle
- factorisation violation due to absorption/rescattering

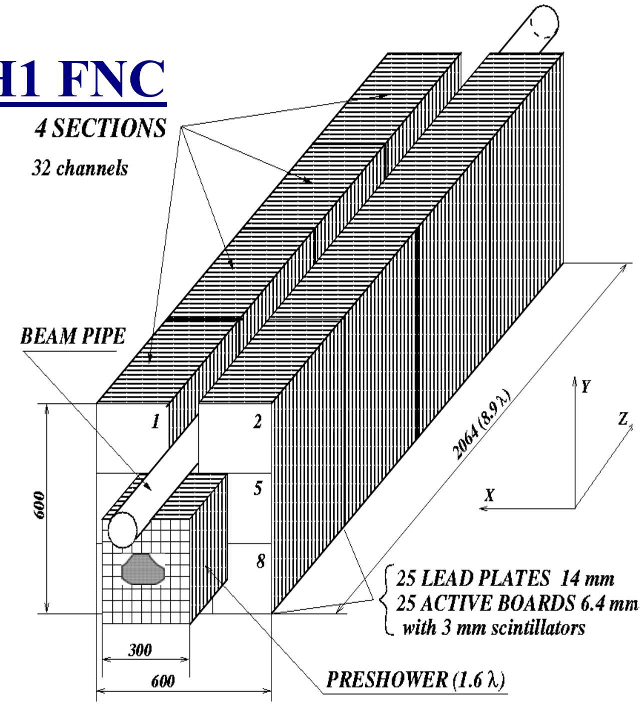


ZEUS FNC+FNT



14 towers, 17x15 grid of the FNT hodoscopes, $\sigma_E/E \approx 0.7/\sqrt{E}$

H1 FNC



$\sigma_E/E \approx 0.63/\sqrt{E} \oplus 2\%$

position resolution 2-3mm

- Longitudinal segmentation allows reliable discrimination between e/m and hadronic showers (i.e. between photons and neutrons)
- Acceptance limited by beam apertures and detector size
- p_T resolution is dominated by p_T spread of proton beam (50-100 MeV)

Forward neutron cross section vs x_L: DIS and γp jets

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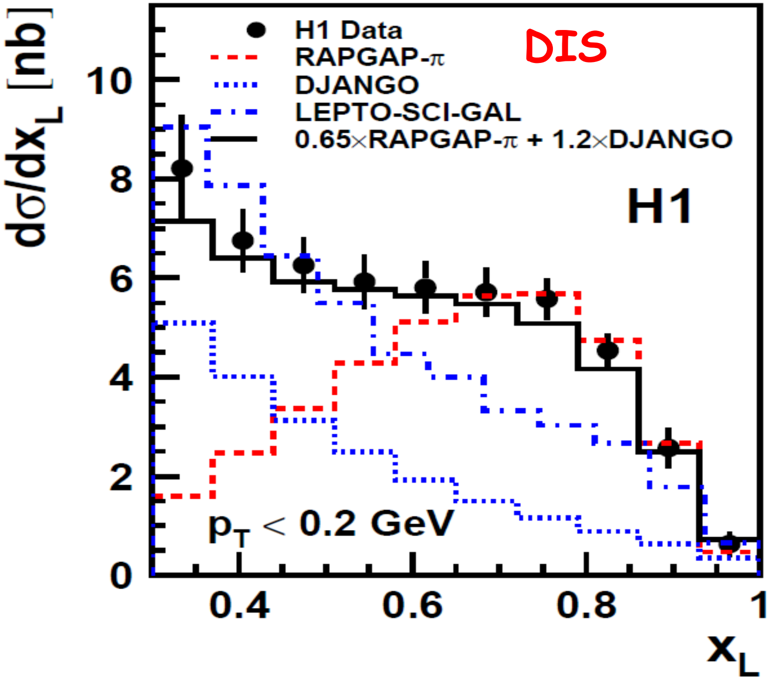

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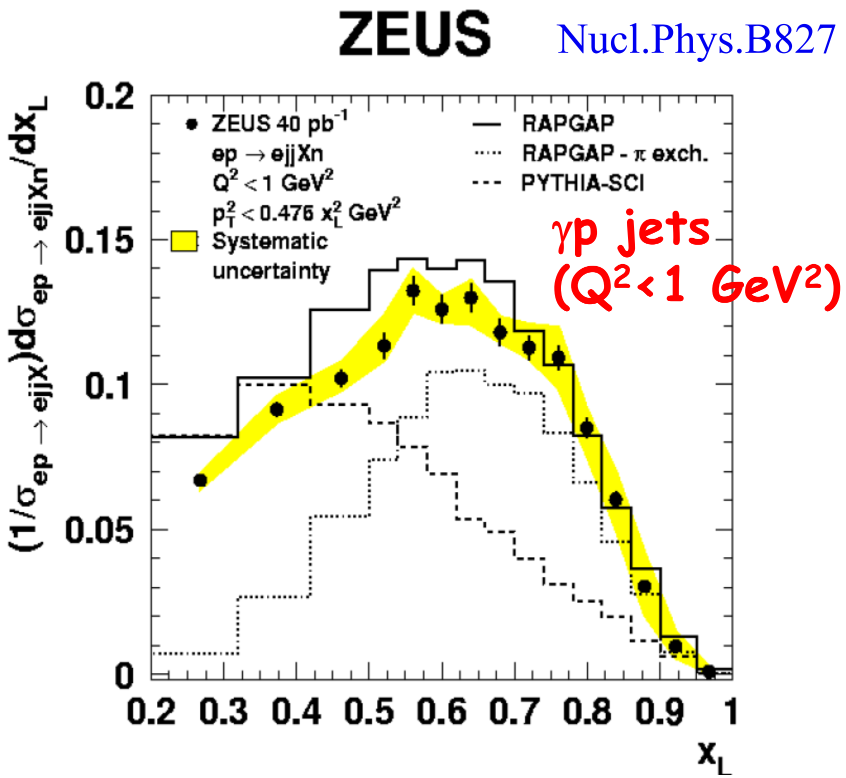


- Data described by a combination of <u>standard fragmentation</u> (DJANGO, RAPGAP) and <u>π^+-exchange</u> (RAPGAP-π) MC models over the full range

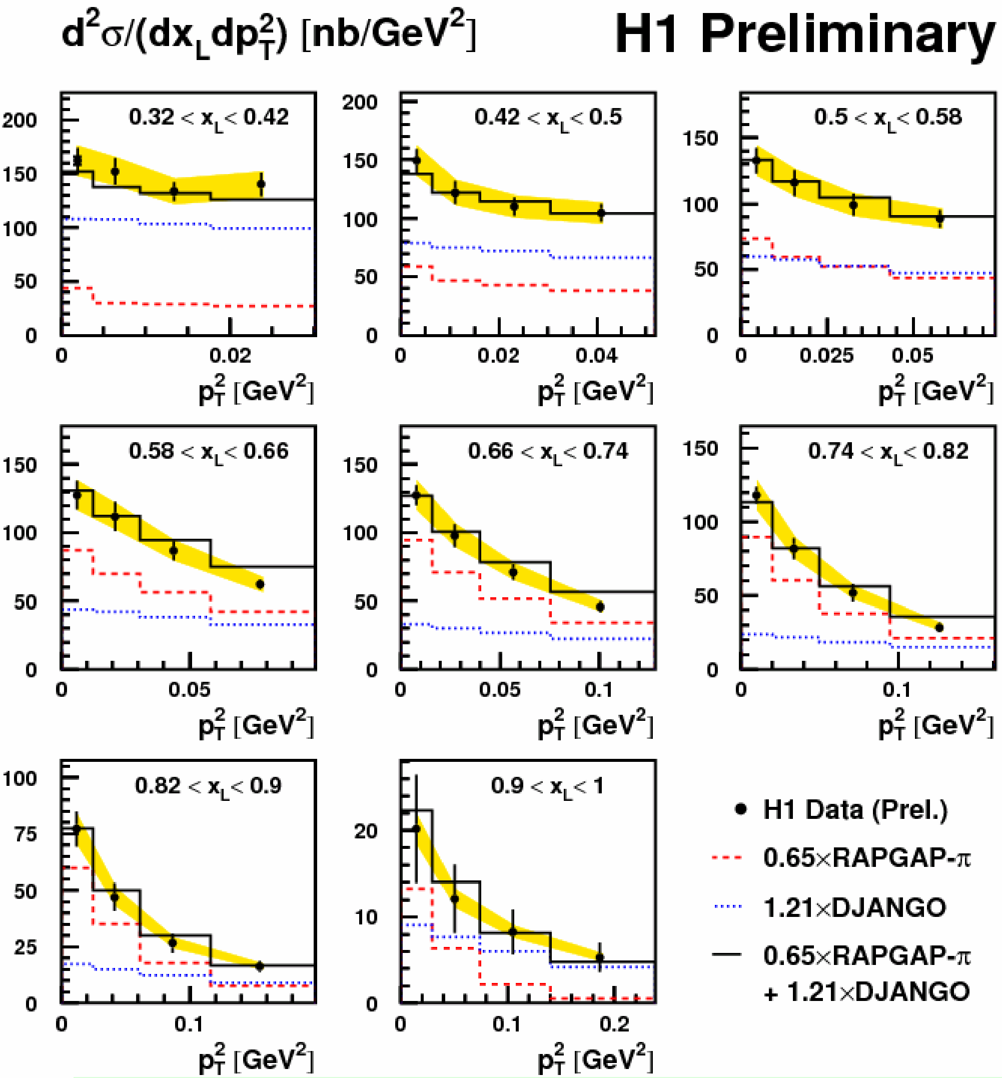
- 'Standard' fragmentation models (DJANGO, RAPGAP) don't describe the shape at high x_L
- SCI (soft colour interactions) models too low at high x_L

- π^+-exchange model (RAPGAP-π) describes the shape of data distribution well for x_L>0.7

<u>π-exchange- the dominant mechanism at large x_L</u>

Extend the measurement differentially in transverse momentum of neutron p_T

H1prelim-10-113 ($6 < Q^2 < 100$ GeV², $0.05 < y < 0.6$)

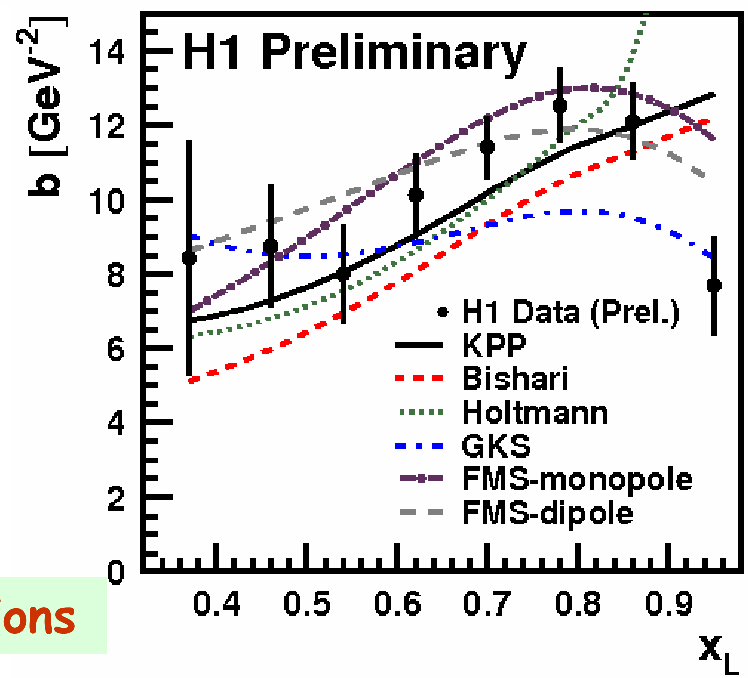


Combination of RAPGAP-π and DJANGO describes well the p_T^2 distributions (using same weighting factors as for x_L)

different p_T^2 slopes for standard fragmentation and pion-exchange: ~constant vs x_L for DJANGO; increasing with x_L for RAPGAP-π

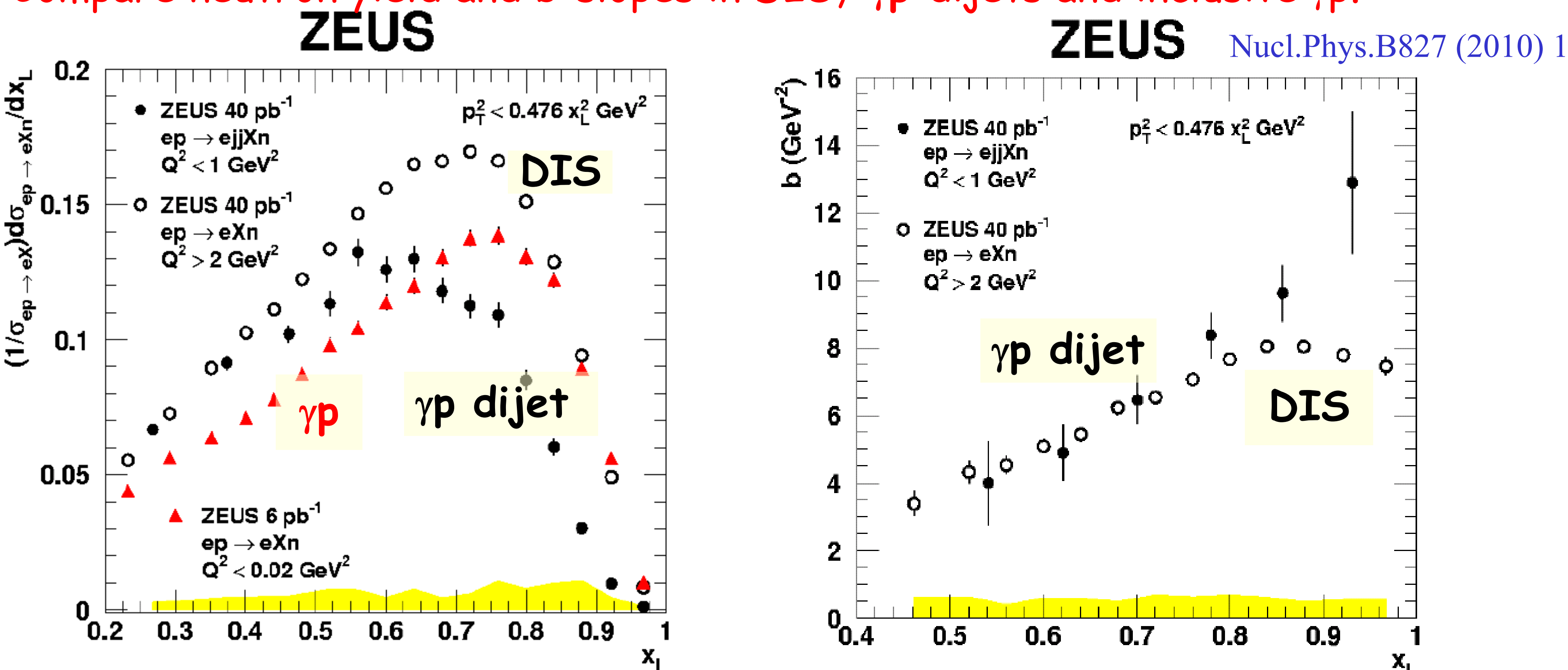
Fit the distributions by a single exponent.

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



Measurement sensitive to the π flux parameterisations

Compare neutron yield and b-slopes in DIS, γp-dijets and inclusive γp.



- photoproduction of forward neutrons suppressed at low x_L (x_L < 0.85)
  - ➔ consistent with neutron absorption through rescattering (more absorption in γp than in DIS due to larger transverse size of real photon)
- Suppression is not so prominent in jet production (hard scale provided by E_T^{jet})
- dijets suppressed at high x_L → phase space limitation
- similar b-slopes in DIS & γp-dijets; slightly different at high x_L
  → **same production mechanism for forward neutrons**

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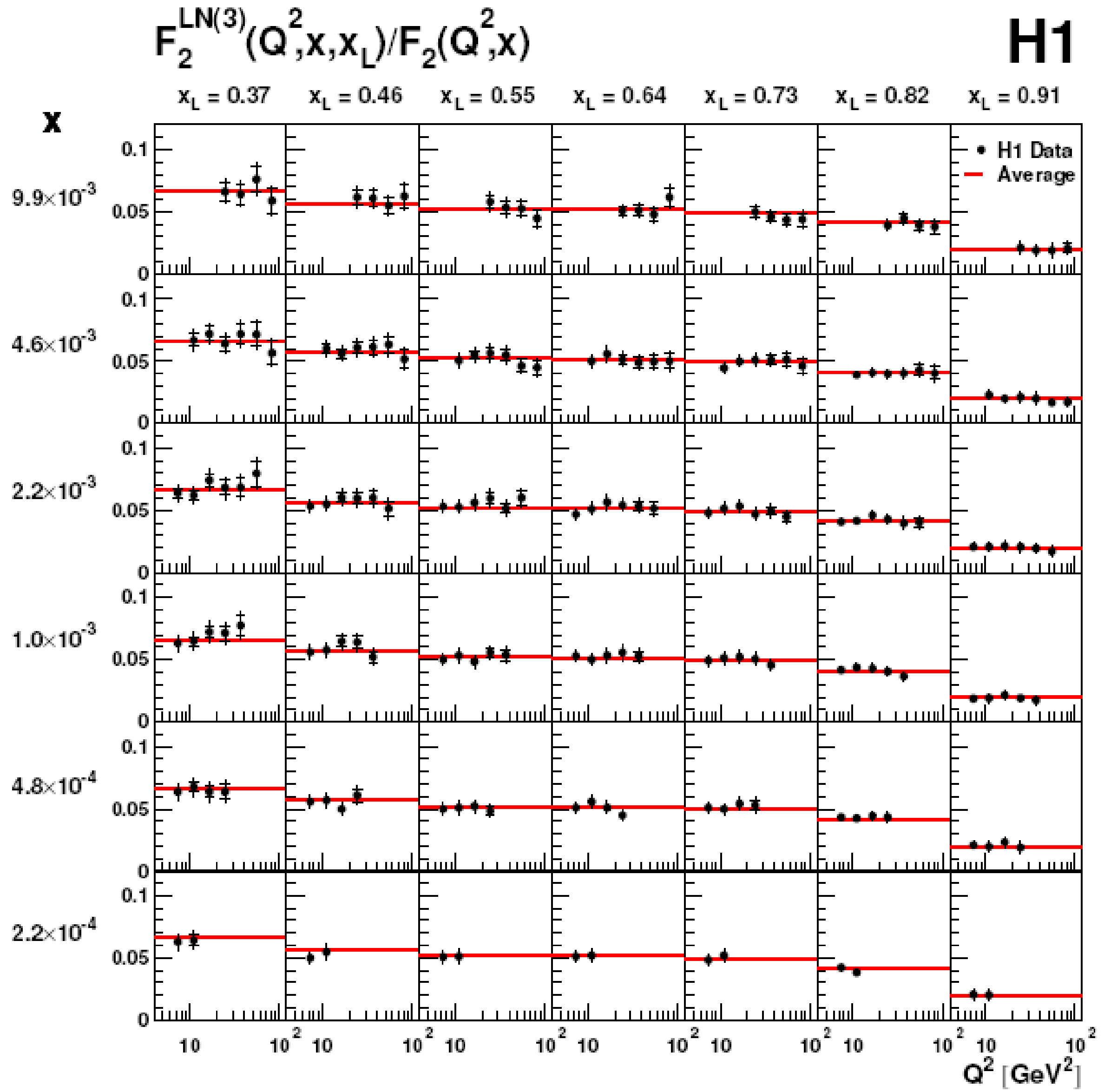
$$\frac{d^3\sigma(ep\to eNX)}{dQ^2dx\,dx_L}= \frac{4\pi\alpha^2}{xQ^4}\left[1-y+\frac{y^2}{2}\right]F_2^{LN}(Q^2,x,x_L)$$



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

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

i.e. LN production rate, kinematics is approx. independent of (Q^2,x)
➔ consistent with factorisation, limiting fragmentation (overall suppression of LN events is also possible)

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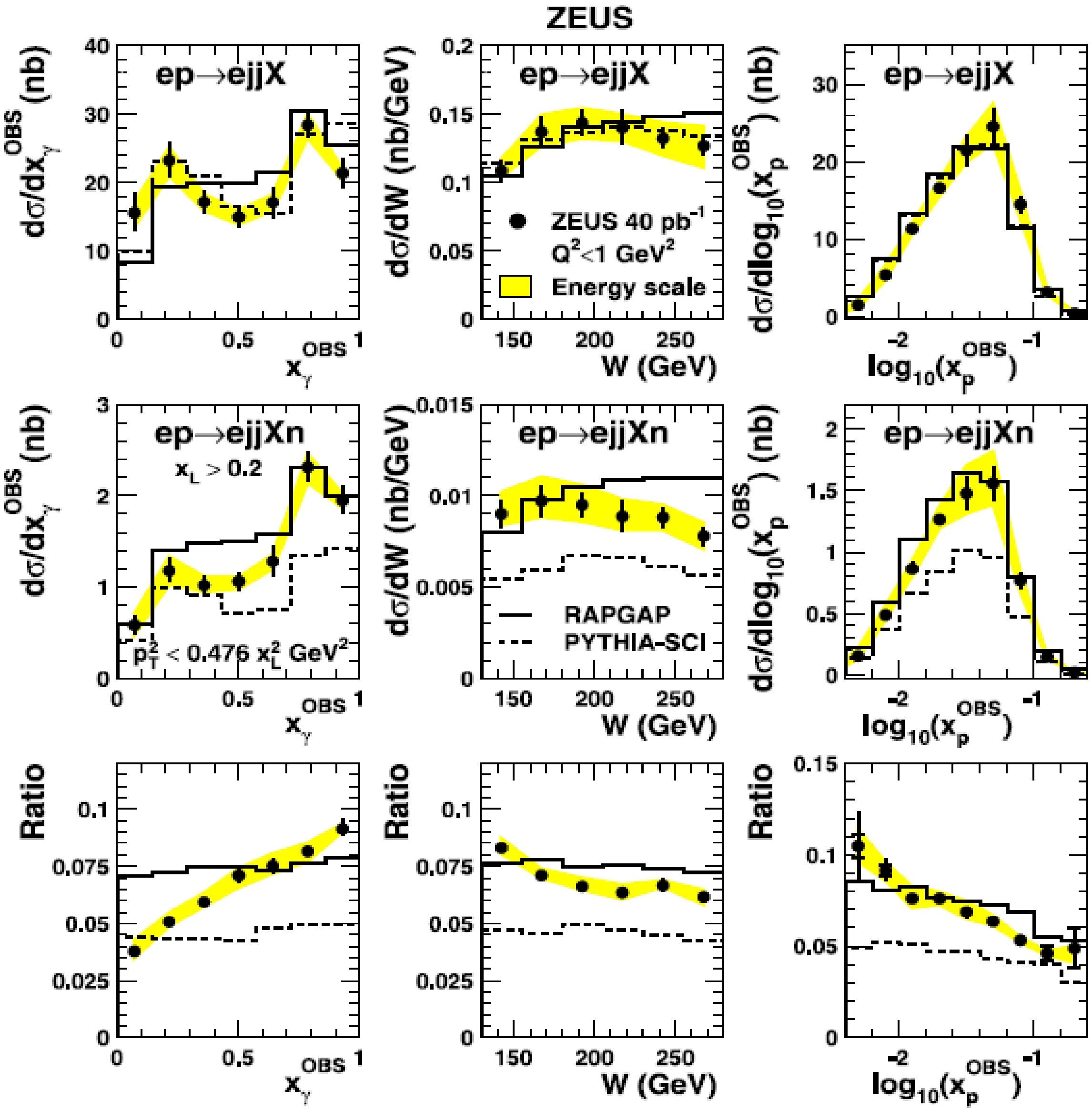
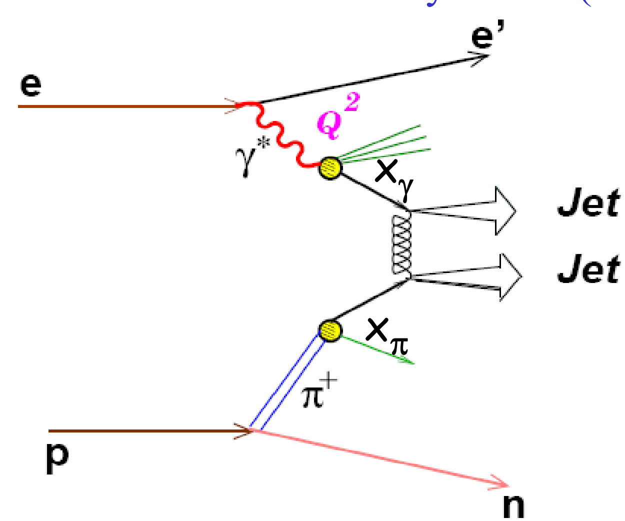
Dijet cross sections in inclusive γp and in γp with LN, and their ratios.



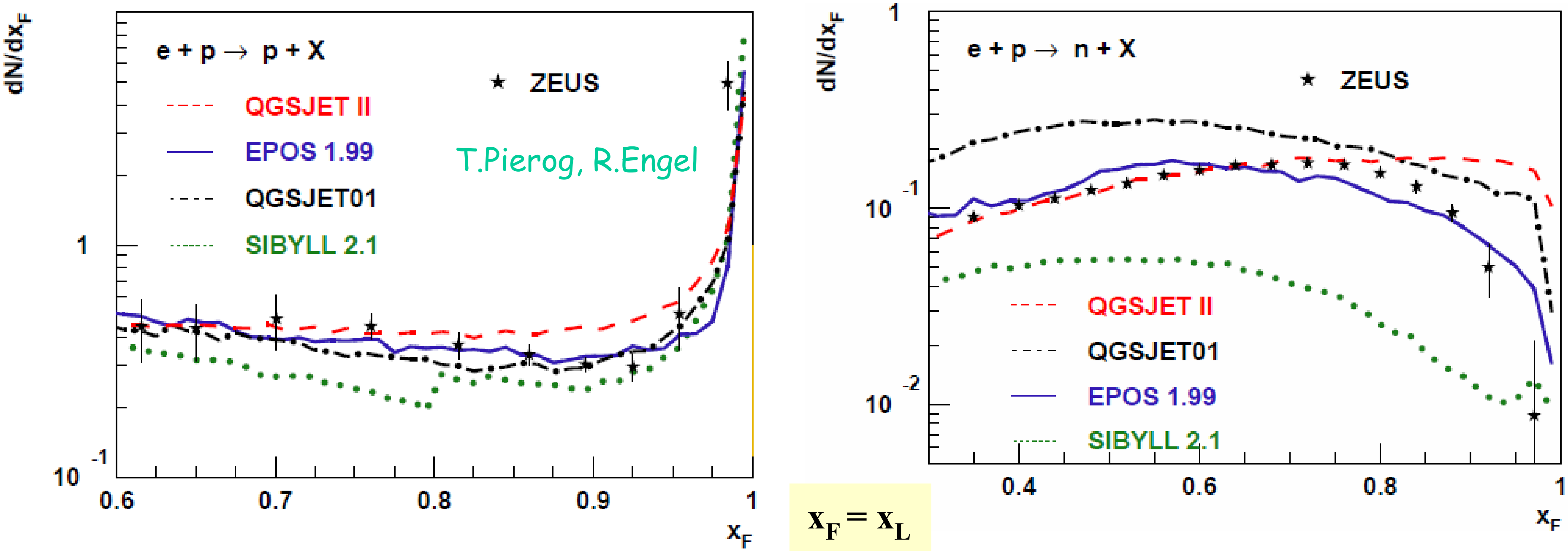


- W – total energy of γp system
- $x_\gamma = \Sigma_{jets}(E-p_z)/(2yE_e)$
- $x_p = \Sigma_{jets}(E+p_z)/(2E_p)$

- ***strong dependence of ratio of x_γ distributions for data, flat in MC***
- ***resolved photon is suppressed in events with neutron.***

The tuning of cosmic ray interaction models crucially depends on the input from the measurements at accelerators

In particular, the forward measurements (baryons, π^0, γ) are of the greatest importance for the model tuning, since the shower development is dominated by the forward, soft interactions.



$x_F = x_L$

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

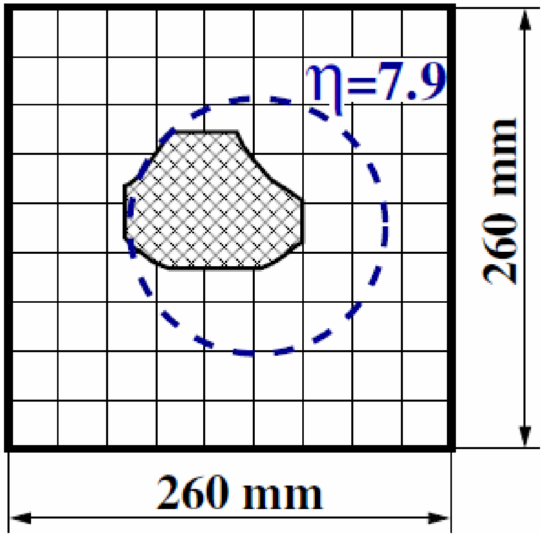
EPOS 1.9: ***(Pierog, Werner),***

QGSJET 01 and II: ***(Kalmykov, Ostapchenko),***

SIBYLL 2.1: ***(Engel, Fletcher, Gaisser, Lipari, Stanev)***

H1prelim-11-012

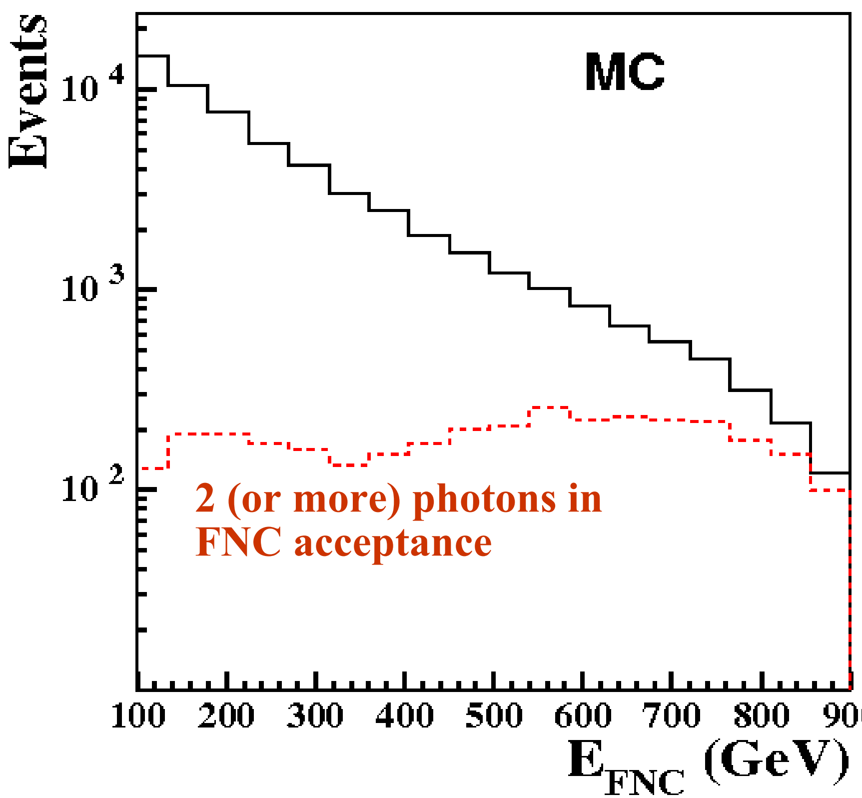
Measure forward photons in FNC, compare to
- MC models (CDM and LEPTO)
- hadronic interaction models used for analysis of cosmic rays (EPOS, SIBYLL, QGSJET)



What are our photon candidates?

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

At lower x_L we can assume that to a good approximation to measure single photon.



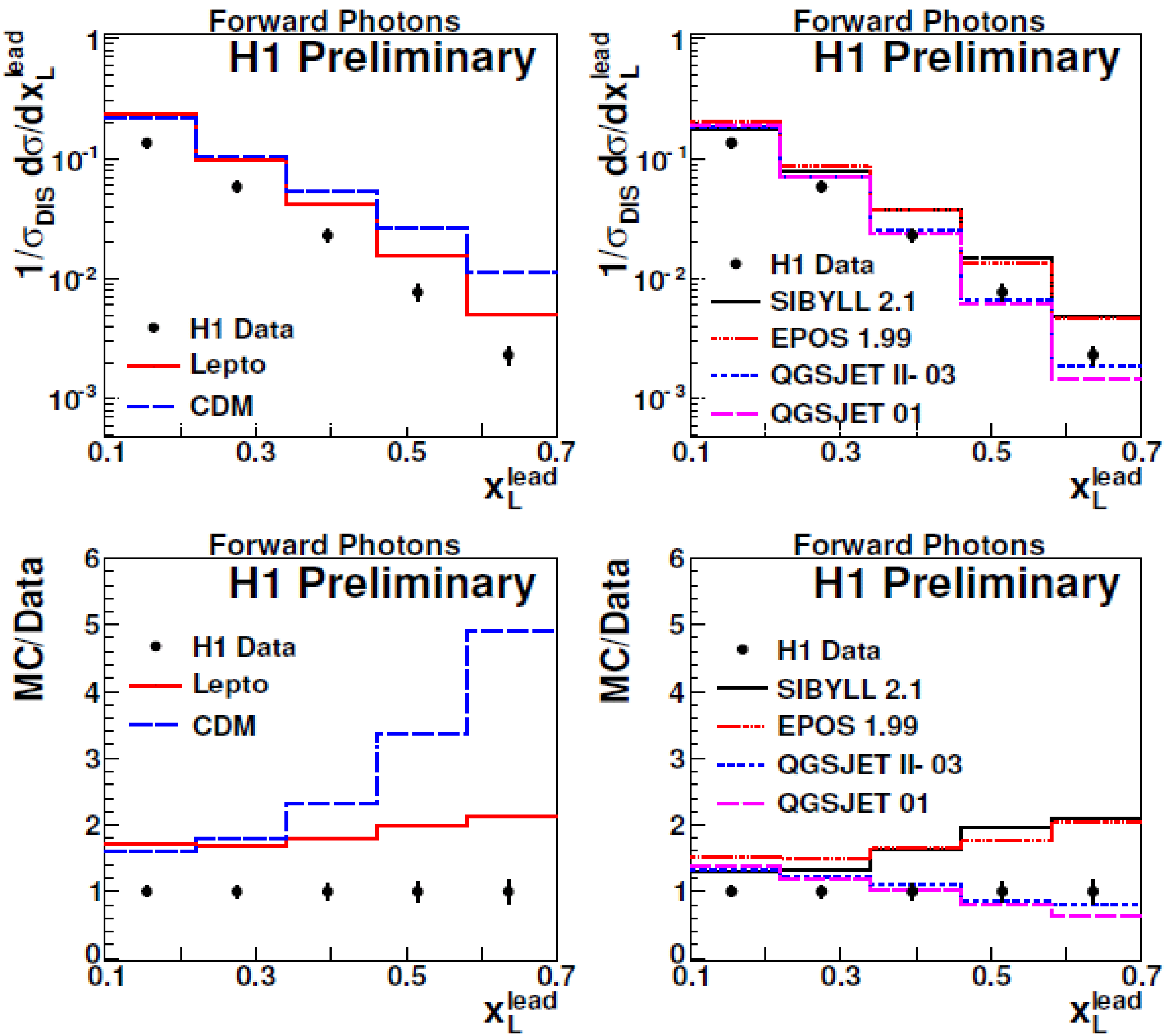
For photons with η>7.9 provide cross sections:

- x_L and p_T of most energetic photon in the range $0.1<x_L< 0.7$

- x_L of sum of all photons

H1prelim-11-012

$6 < Q^2 < 100$ GeV^2, $0.05 < y < 0.6$,
2006-2007 data, Lumi=126pb^{-1}



Photon rate in all tested MC 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

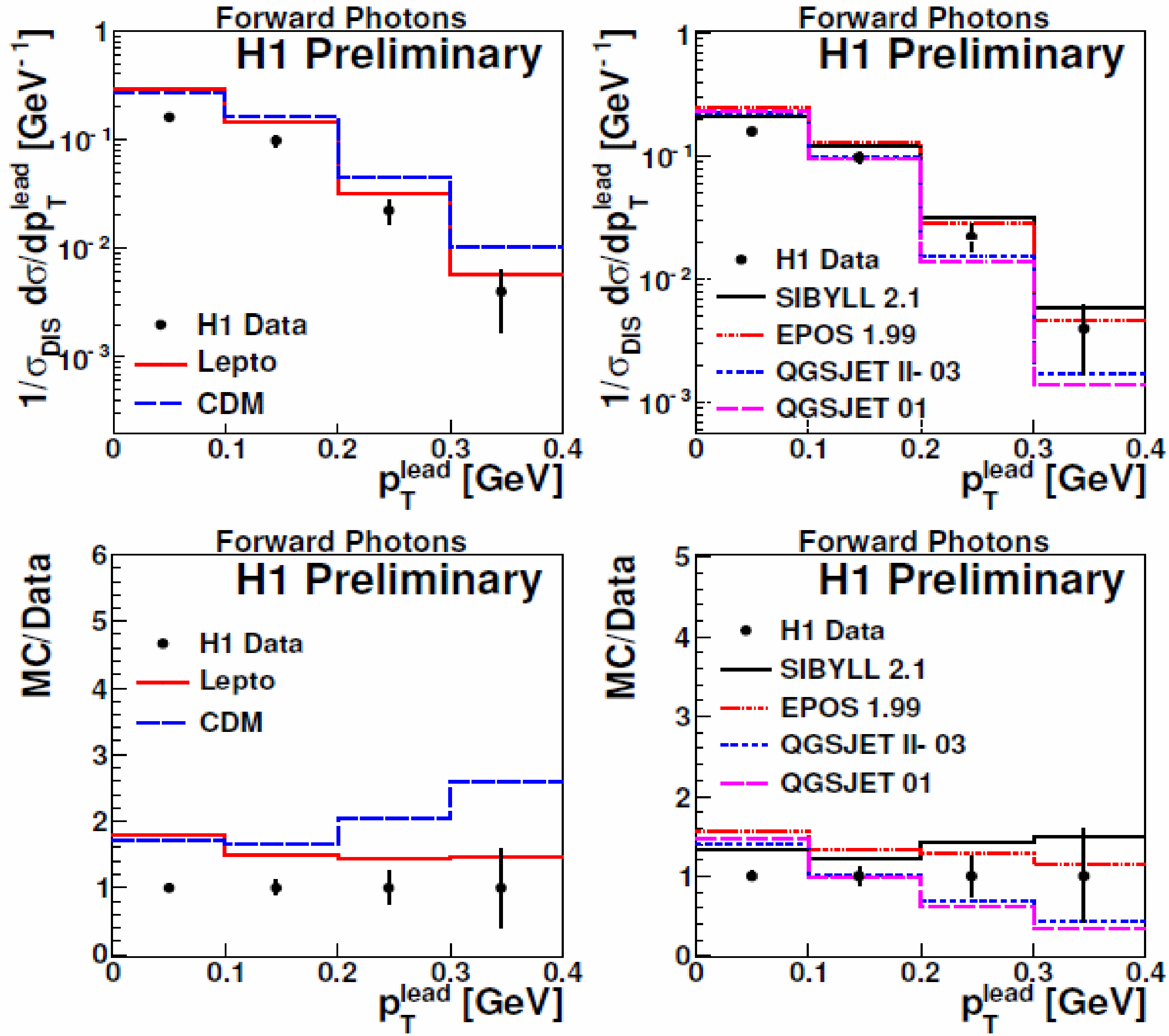
Forward photon production cross sections

H1prelim-11-012

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

LEPTO model describes the shape reasonably well.

p_T^2 spectrum shape is well described by SIBYLL and EPOS models. QGSJET also agree with data within uncertainties (except lowest p_t)



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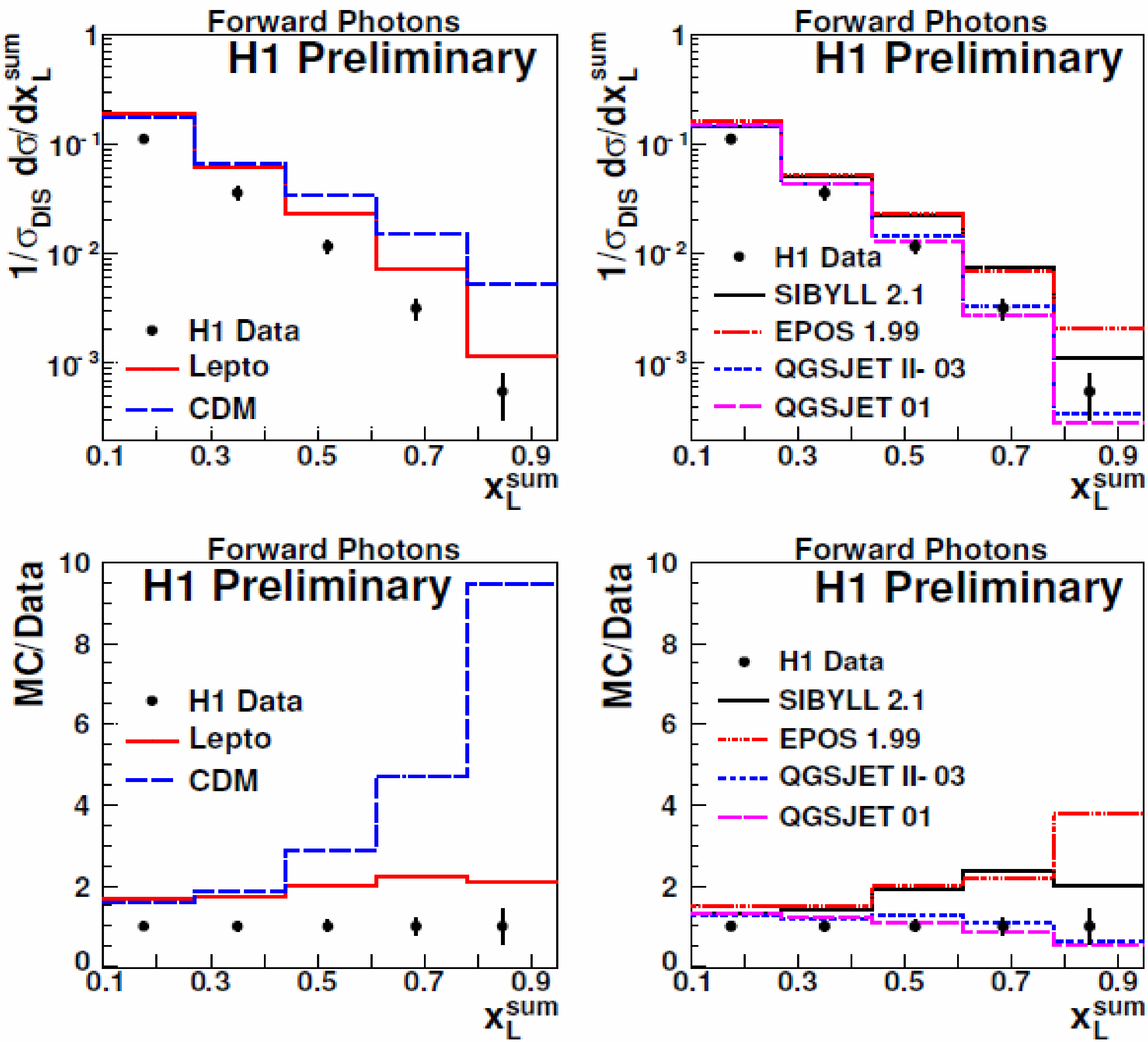
Photon rate in all tested MC models is significantly higher than in data.

LEPTO model describes the shape reasonably well. CDM – large discrepancy at higher x_L

QGSJET models describe data shape better than SIBYLL and EPOS



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

Summary

- precise measurements of forward neutron x_L and p_T^2 in DIS and dijet photoproduction
- the measurements well described by the combination of 'standard' fragmentation models and models with pion exchange
- Pion flux can be further constrained using the measurement.
- In photoproduction the leading neutron production is suppressed at x_L<0.85. Suppression is not prominent in dijet photoproduction
- x_γ distribution: different shapes observed in events with neutrons and inclusive photoproduction- not reproduced in MC

- First measurement of very forward photon production in DIS.
- Measurements show sensitivity to proton fragmentation MC models
- MC models predict significantly higher yield of photons than in the data
- LEPTO describes the shape well; too many photons at high energies in CDM
- Useful input for models of cosmic ray interactions with matter