Diffractive and Electromagnetic Processes at the LHC
Trento, January 4-8, 2010

Leading Baryon Production at HERA

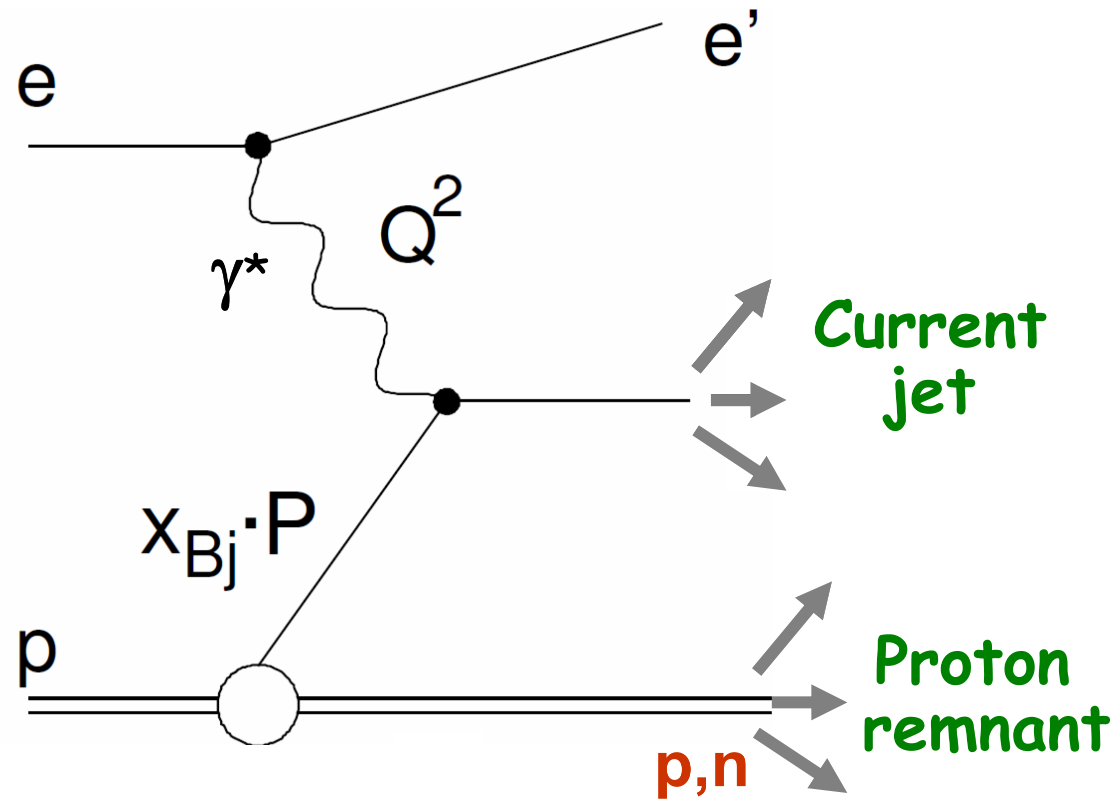
Armen Bunyatyan

Outline:

Leading Protons and Neutrons in DIS

Leading Neutrons in photoproduction of jets

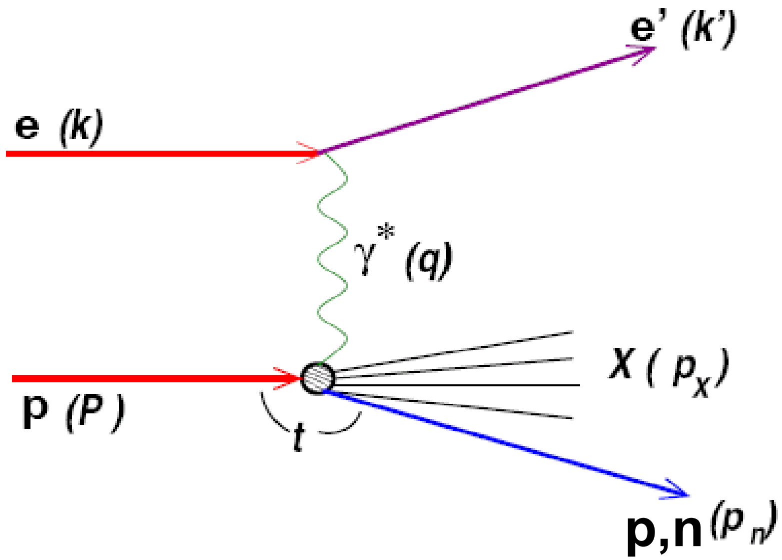
Leading Baryons and Cosmic Rays

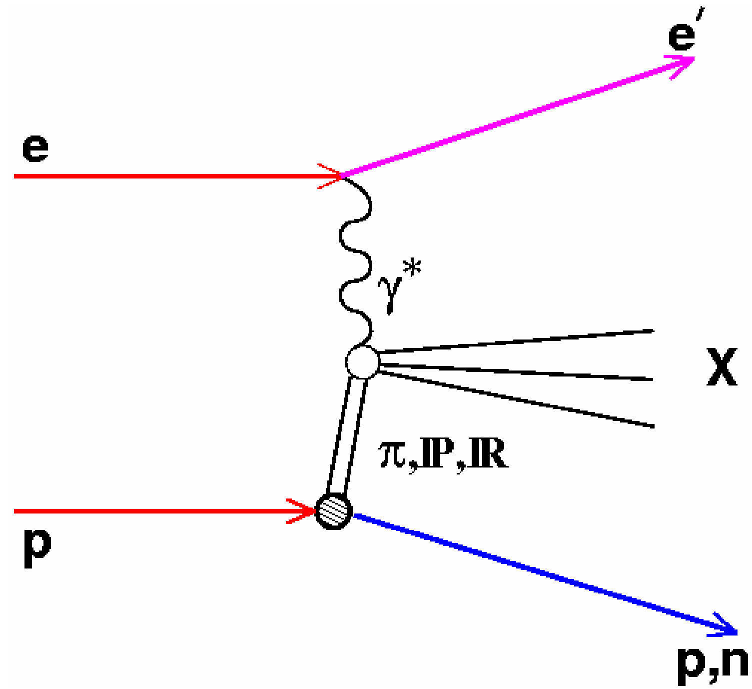


scale for secondary particle production decreases from Q^2 in current region (or high P_T jets if Q^2~0) to a <u>soft hadronic scale</u> (proton fragmentation region)

Significant fraction of *ep* scattering events contains in the final state a leading proton or neutron which carry a substantial portion of the energy of the incoming proton: e+p → e'+n+X or e'+p+X

Production mechanism of leading baryons:



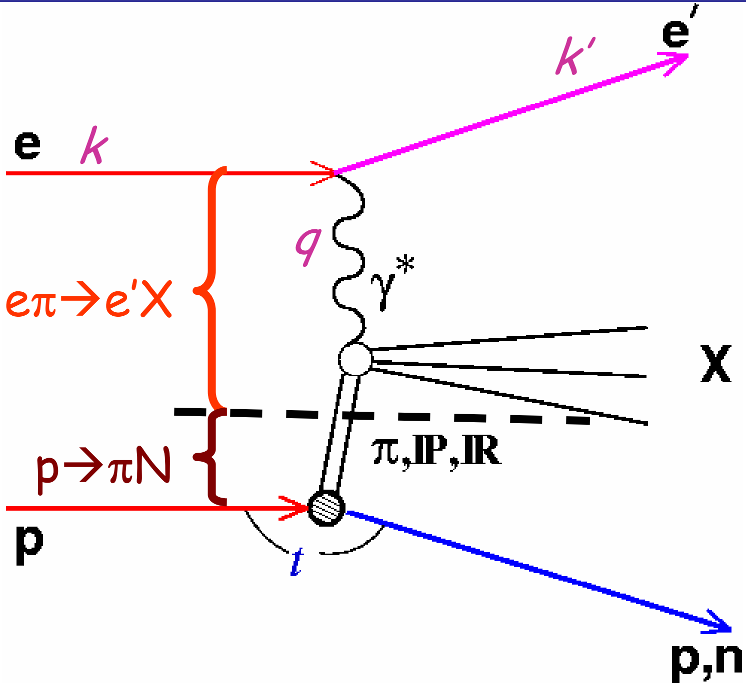


'conventional' fragmentation of proton remnant (e.g. Lund string)

exchange of virtual particle

- LP: neutral iso-scalar, iso-vector (π, IR, IP)
- LN: charged iso-vector (π+, ρ+, a_2..)

Kinematics and Vertex factorisation



ep→ e'NX

Lepton variables:

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

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

Leading baryon variables:

$x_L=E_{LB}/E_p$

$t=(p-p_{LB})^2$ (or $p^2_{T,LB}$)

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

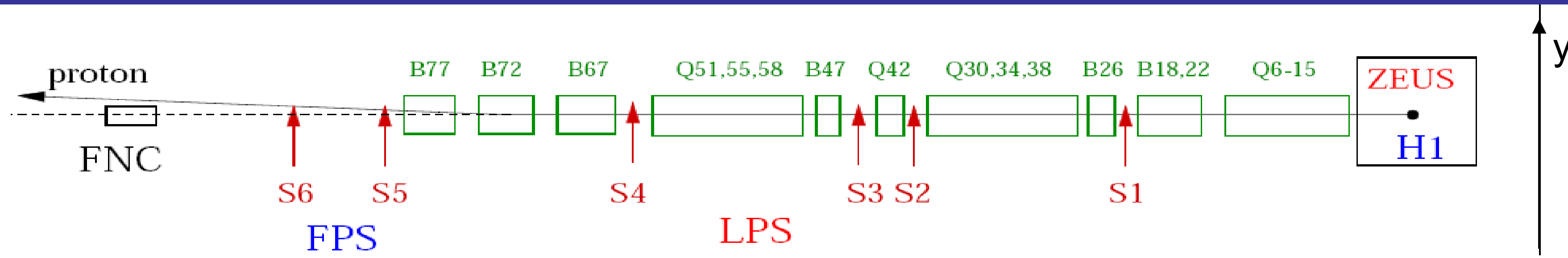
$$\sigma(ep\rightarrow e'NX) = f_{\pi/p}(x_L,t) \times \sigma(e\pi\rightarrow e'X)$$

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

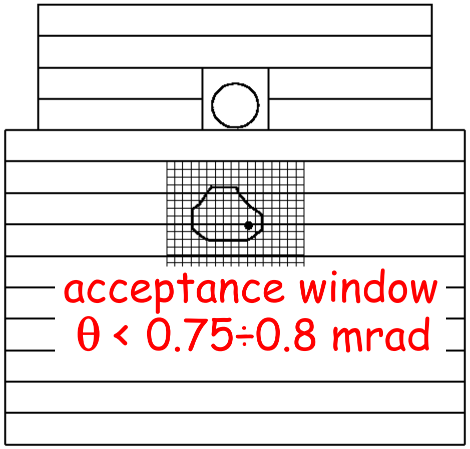
$\sigma(e\pi\rightarrow e'X)$ - cross-section of eπ scattering

-Leading Baryon production independent from photon vertex
-probe structure of exchanged particle
-factorisation violation predicted– absorption/rescattering

H1 and ZEUS detectors for leading baryons

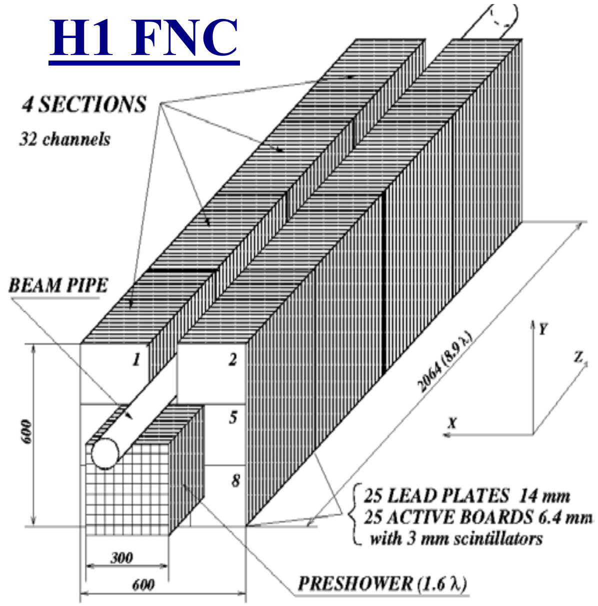


ZEUS FNC+FNT



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

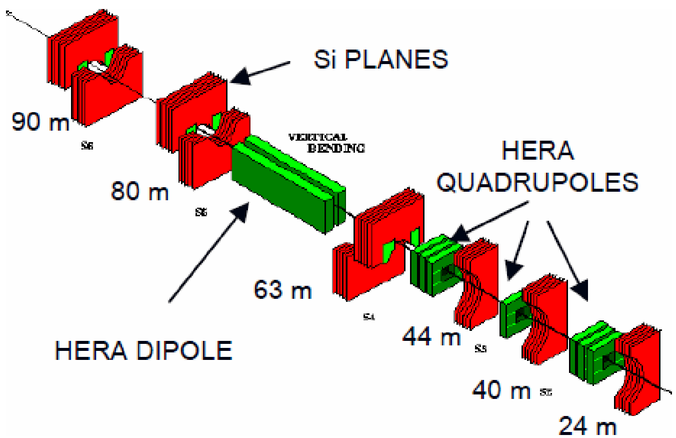
H1 FNC



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

position resolution 2-3mm

ZEUS LPS

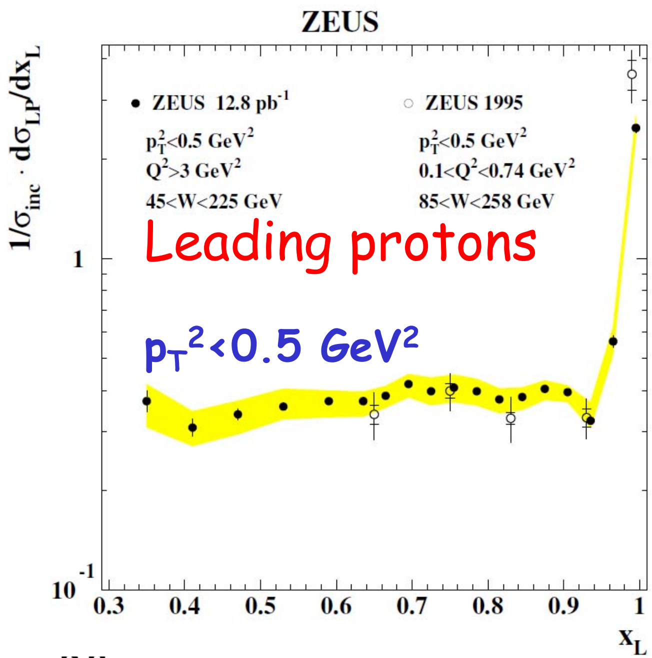


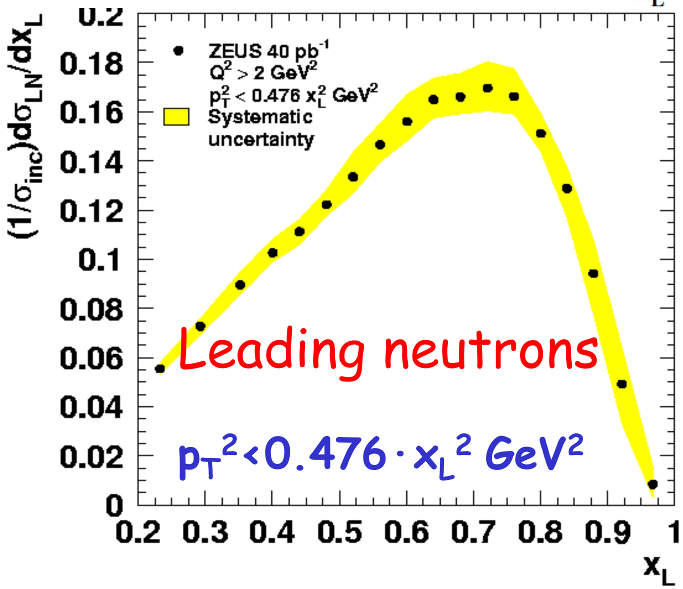
6 stations with μstrip detectors
hit position resolution ~30μm
$\sigma_{x_L}<1\%$, σ_{p_T}~few MeV

momentum accuracy <1%

Acceptance limited by beam apertures and detector size
p_T resolution is dominated by p_T spread of proton beam (50-100 MeV)

Cross sections vs x_L normalised to σ_{DIS} $(1/\sigma_{DIS} \times d\sigma/dx_L)$





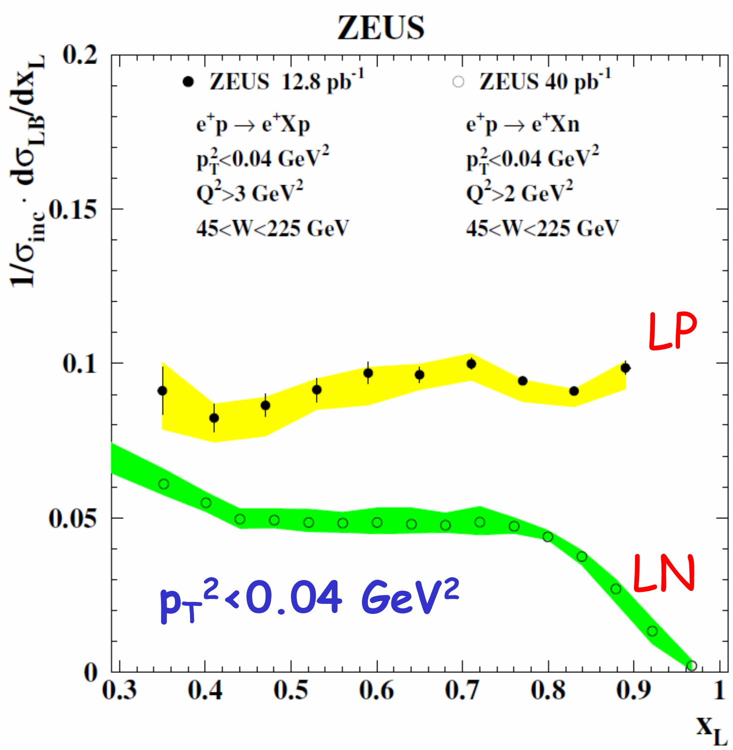
Leading protons: (JHEP 0906:074,2009)

- diffractive peak at x_L=1 ; flat at x_L<0.95

Leading neutrons: (Nucl.Phys.B776(2007)1)

- yield → 0 as x_L → 1 ;
- drop at x_L< 0.7 due to drop in acceptance

restrict to the same p_T^2 range

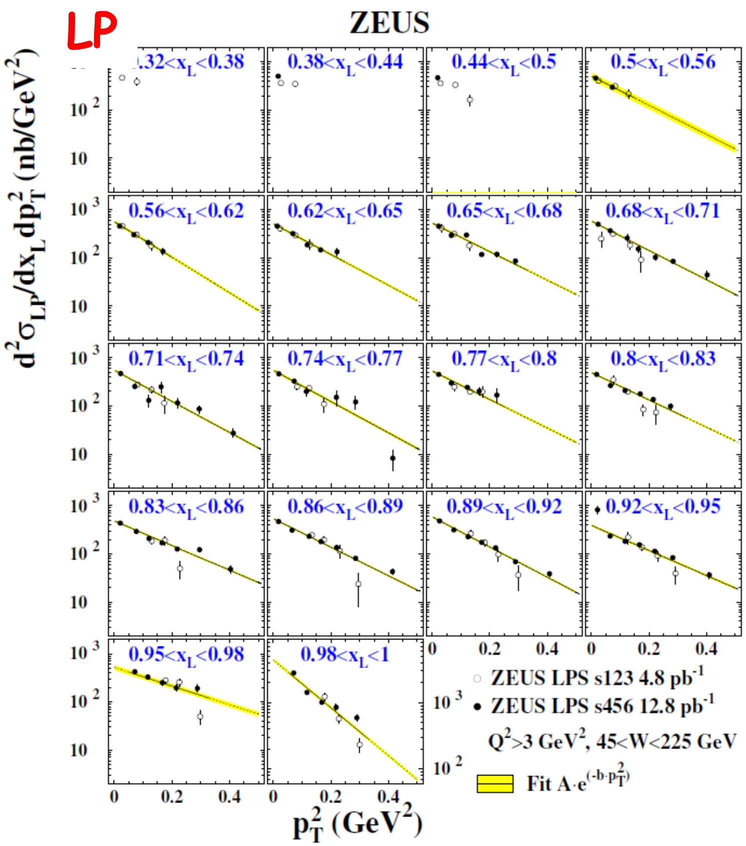


- measurement:
  LP ~ 2·LN
- for pure isovector particle exchange (e.g. pion) one expects
  LP = ½·LN

→ more isoscalar exchanges contribute to the LP rates

Double differential cross sections vs p_T^2 and x_L

JHEP 0906:074,2009



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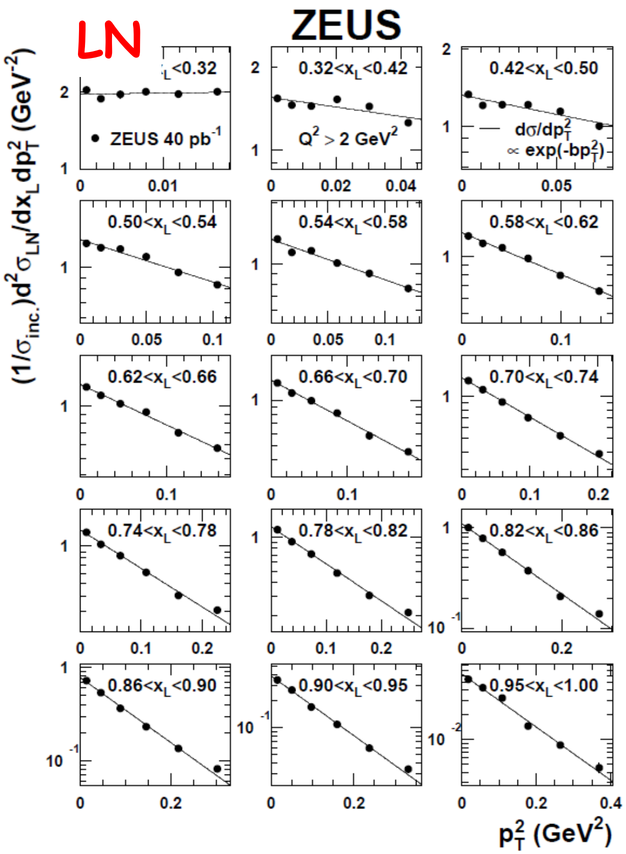
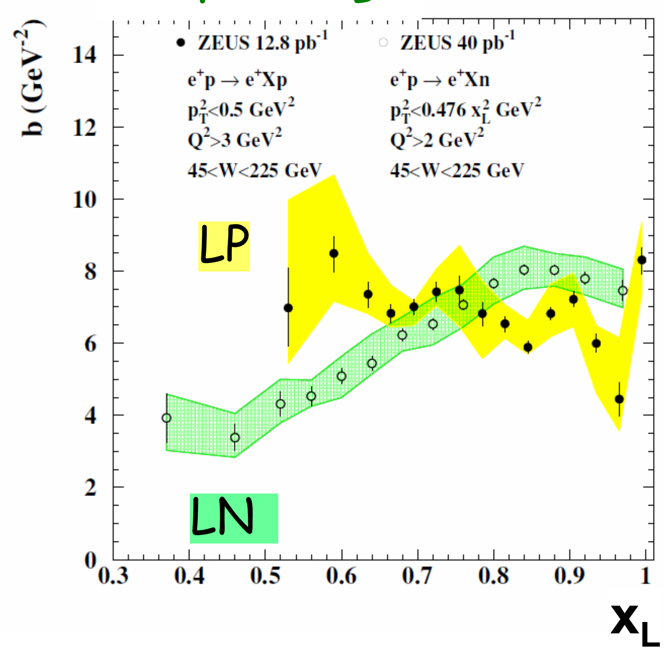


Exponential behavior

$$\frac{d^2\sigma}{dx_L dp_T^2} \sim a(x_L)\, e^{-b(x_L)p_T^2}$$

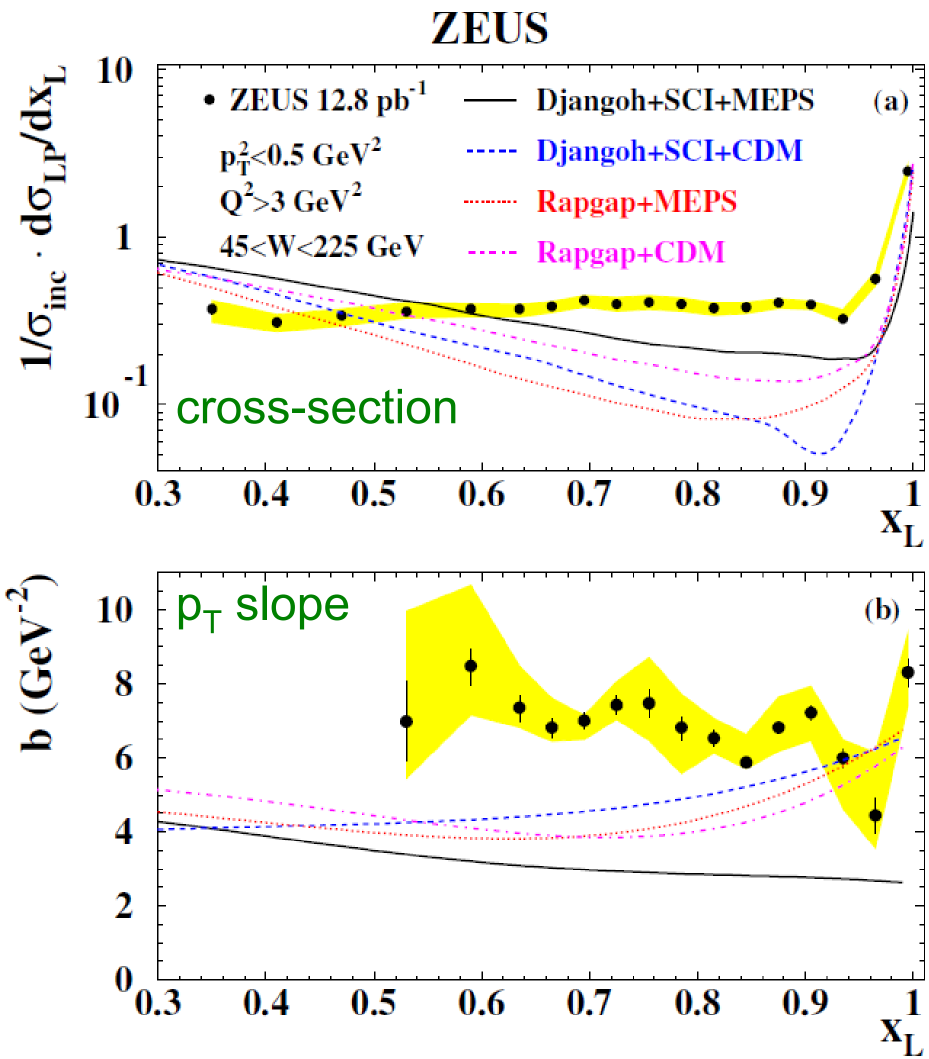
slope $b(x_L)$

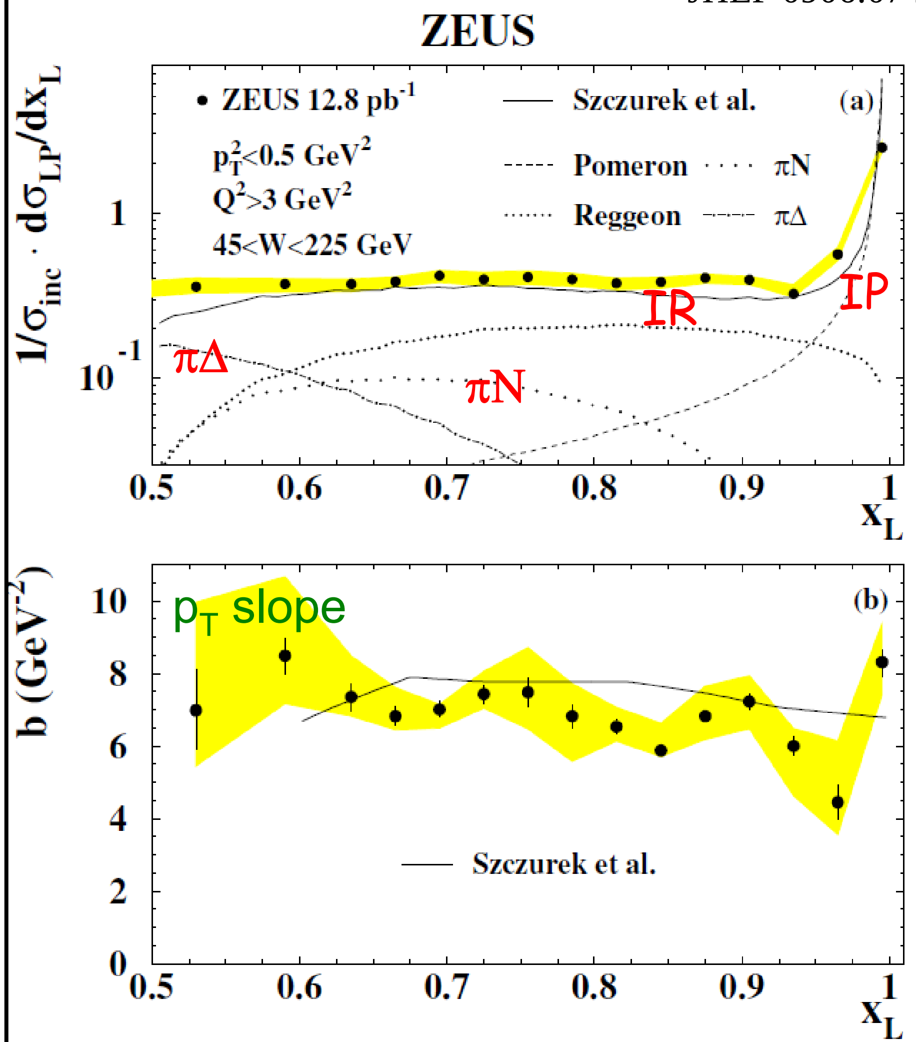


- different behavior for LP and LN
- similar around x_L~0.7

Comparison with fragmentation and exchange models: Leading Protons in DIS

JHEP 0906:074,2009





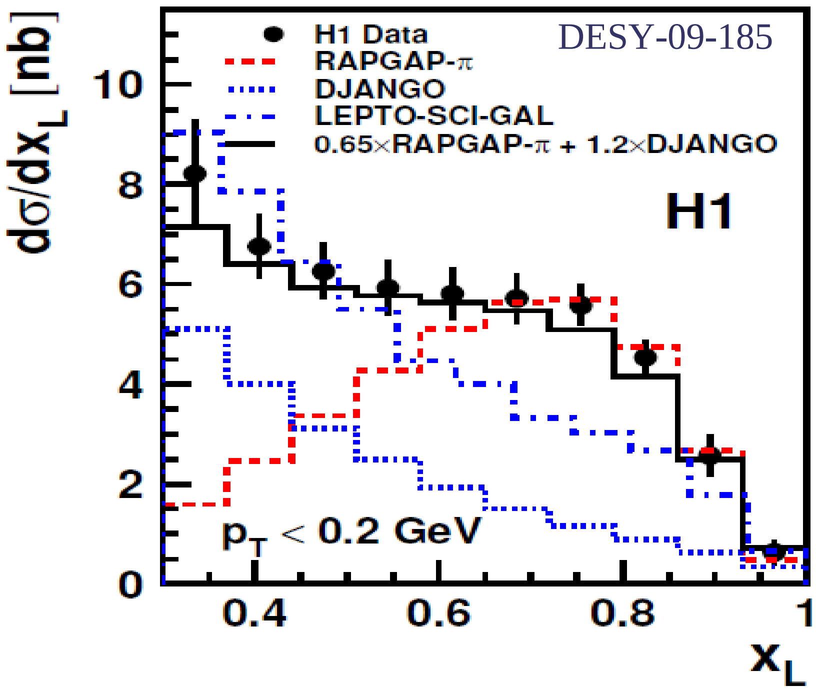
- standard fragmentation MC models don't describe the data out of the diffractive peak
- slopes too low at low x_L

- good description by exchange models
- isoscalar reggeon dominant at intermediate x_L

- all standard fragmentation models underestimate the neutron yield at high x_L
- LEPTO-SCI better for x_L shape, but not for the slope

- RAPGAP-π-exchange describes data well for x_L>0.6, underestimate data at lower x_L

- Mixture of RAPGAP-π-exchange and standard fragmentation (e.g. DJANGO-CDM) gives the best description of the data



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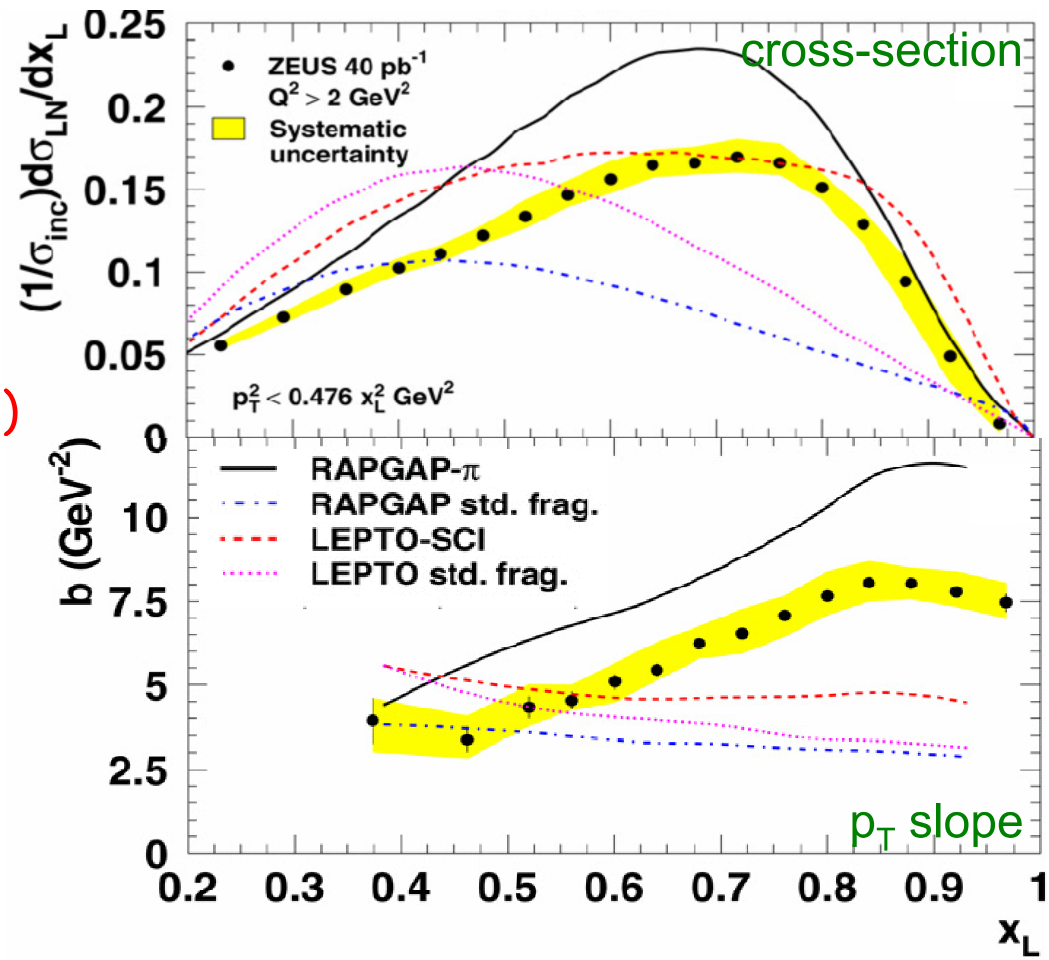
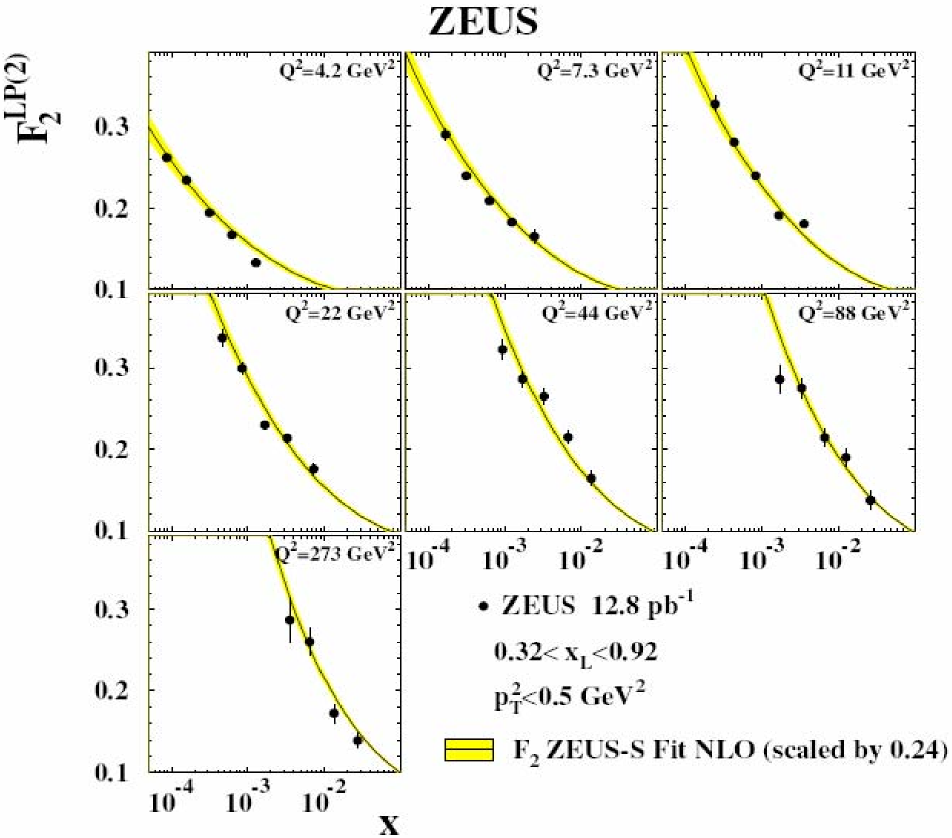


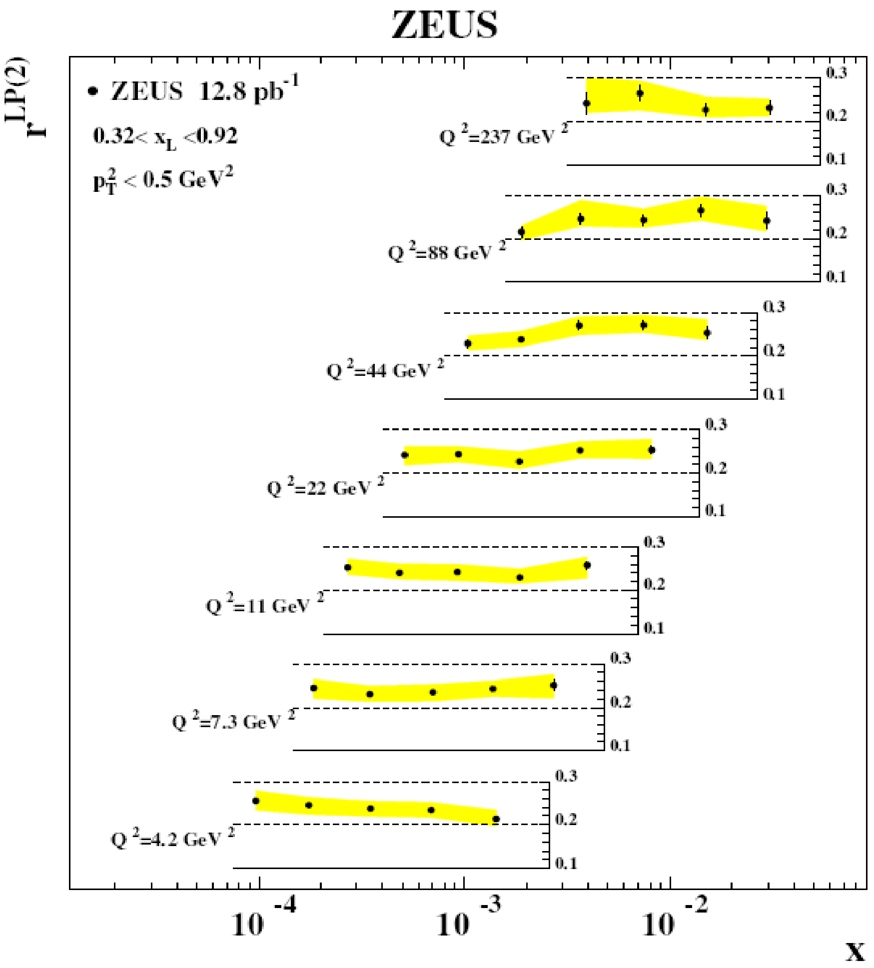
Structure function $F_2^{LP(2)}$

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



Same trend as inclusive F_2 is observed

Rates to inclusive DIS

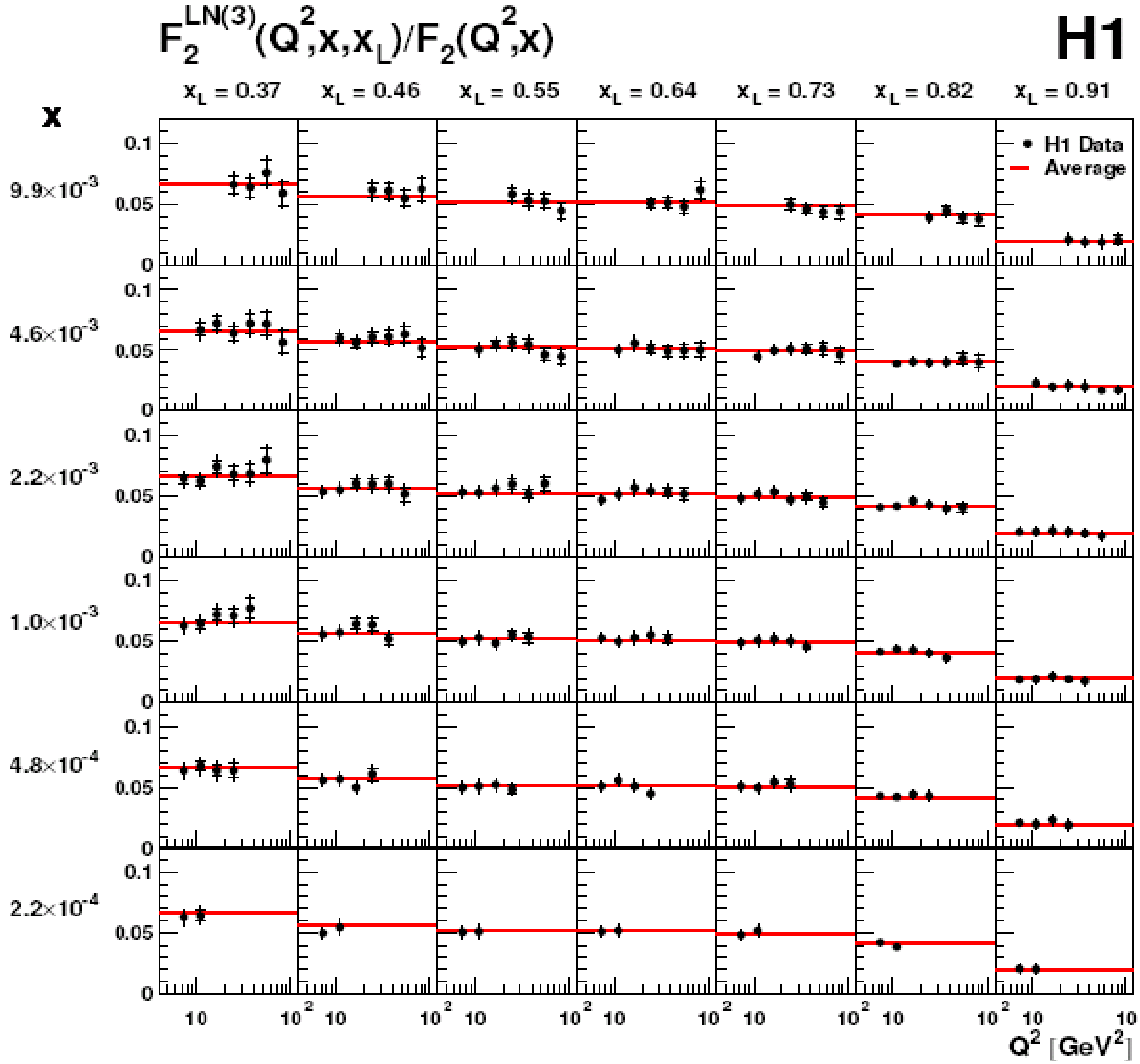


$r^{LP(2)}$ is approximately constant vs x and Q^2 with average value ~0.24

$6 < Q^2 < 100$ GeV^2 , $p_T < 0.2$ GeV

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

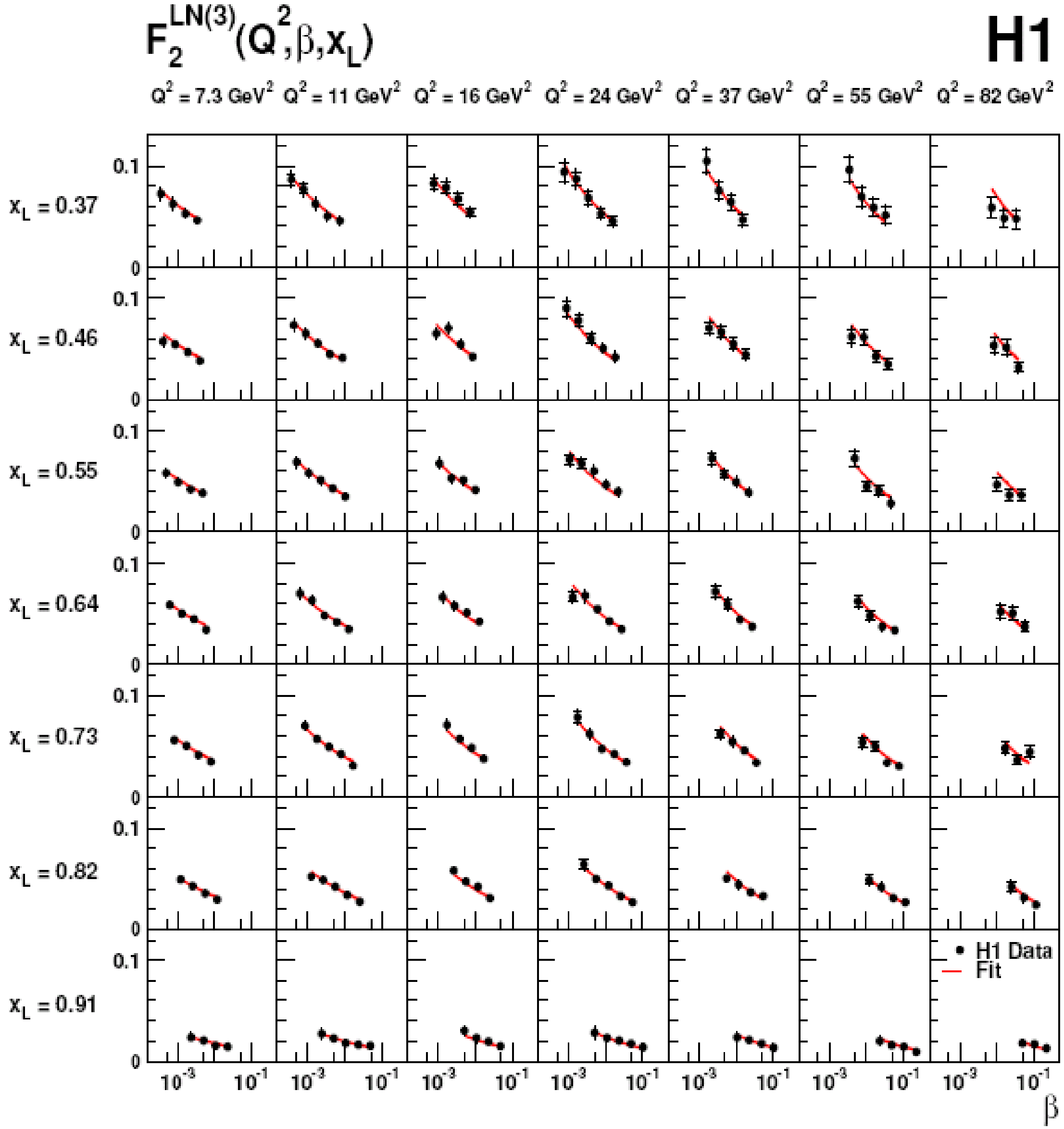
$F_2(Q^2,x)$ from the H1-2000-PDF parameterisation



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

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



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

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

λ is almost independent of x_L →

consistent with vertex factorisation

Estimate the Pion structure function from $F_2^{LN}(Q^2,x,x_L)$

within π^+-exchange model we may try to estimate F_2^{π} from measured F_2^{LN}:

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

where

$\beta = x/(1-x_L)$ - fraction of pion momentum carried by struck quark (i.e. x_{Bj} for pion)

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

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

use pion flux parameterisation (Holtmann et al.):

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

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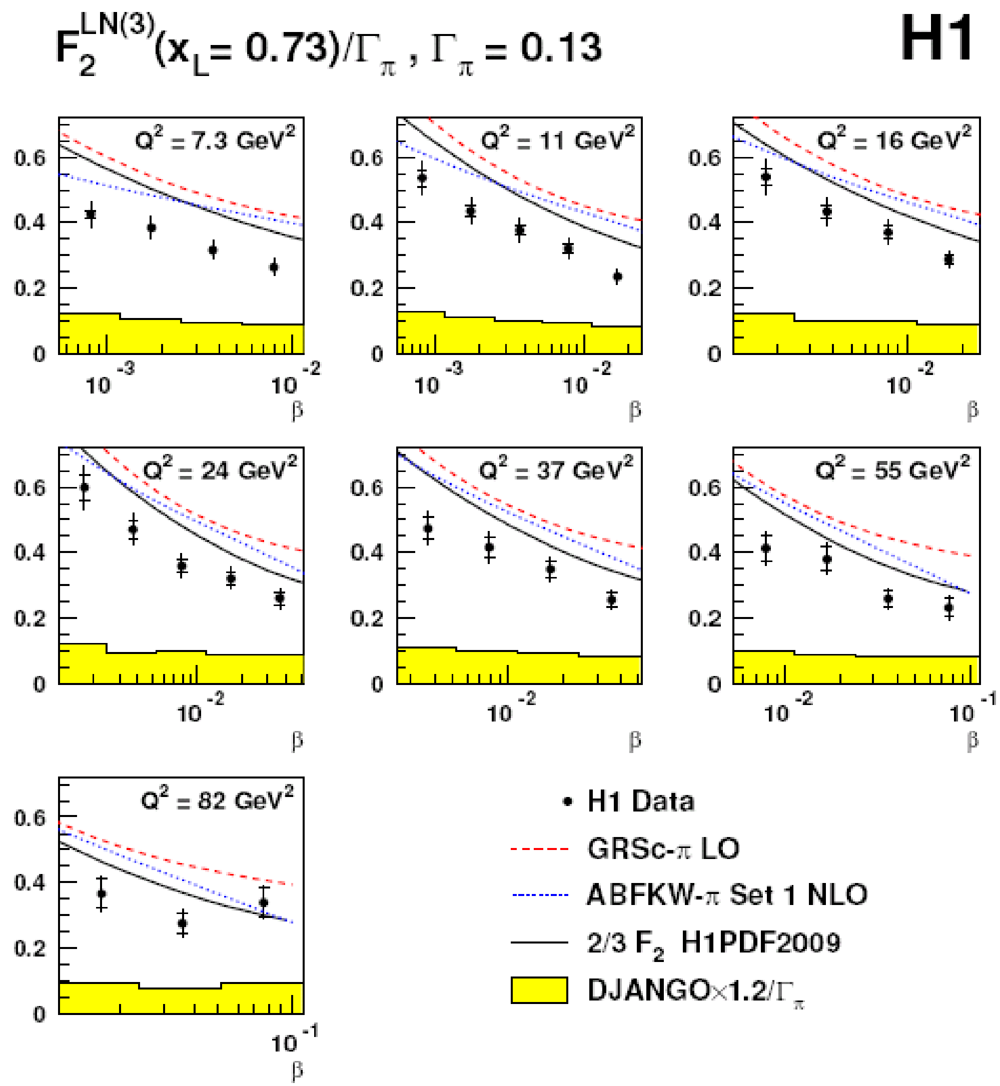

Data are sensitive to the parameterisations of the pion structure function (constrained for x>0.1 from the fixed target experiments).

Estimate the Pion structure function from $F_2^{LN}(Q^2,x,x_L)$

DESY-09-185

within π-exchange model we can estimate F_2^{π} from measured F_2^{LN}:

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

where

$\beta = x/(1-x_L)$

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

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

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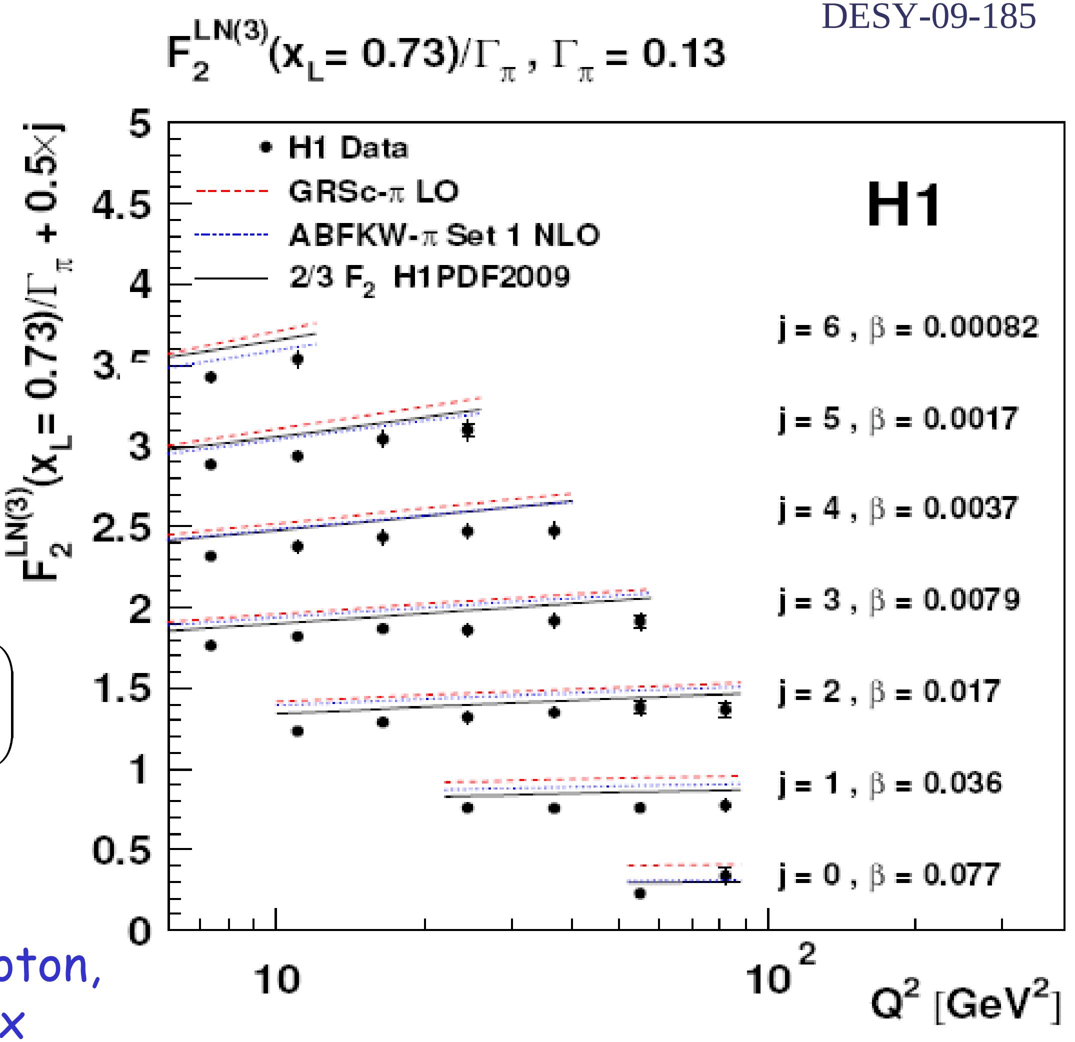
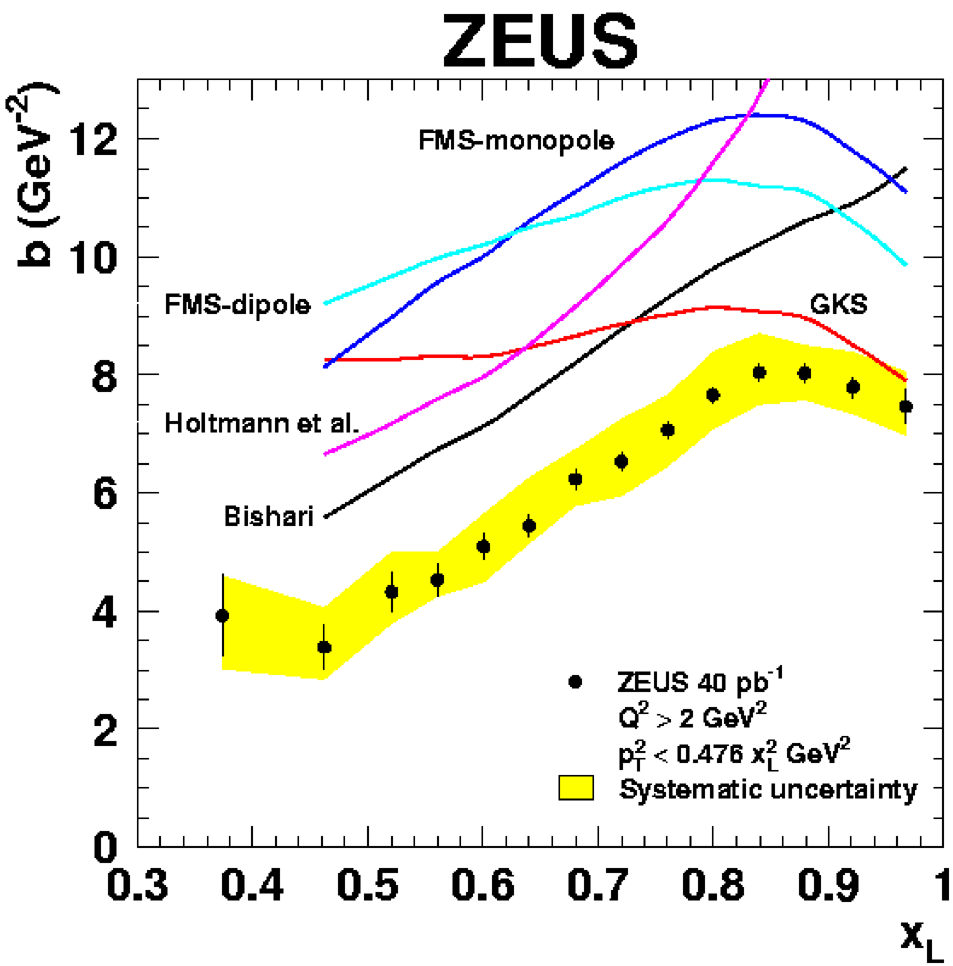


- F_2^{LN} dependence on x and Q^2 similar to proton,
  → universality of hadron structure at low x
- in absolute values F_2^{LN}/Γ below the F_2^{π} and F_2

However: large uncertainty of pion flux normalisation: choice of pion flux (formfactor), absorption/rescattering, background…



in π-exchange picture

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

- p_T^2 (or t) distribution is determined solely by pion flux

$$f_{\pi/p} = \frac{1}{2\pi}\frac{g^2_{p\pi\pi}}{4\pi}(1-x_L)^{1-2\alpha(t)}\frac{-t}{(m_\pi^2-t)^2}\cdot\left|F(x_L,t)\right|^2$$

- many parameterizations of pion flux $f_{\pi/p}(x_L,t)$ in literature

- compare measured p_T-slope $b(x_L)$ with models (shown best agreeing models)

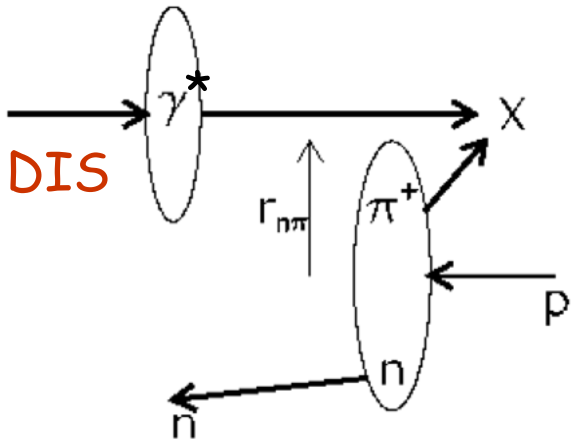
- reasonable agreement in shape but not in absolute values: all give too large $b(x_L)$

- π-exchange models alone don't describe p_T^2 distribution

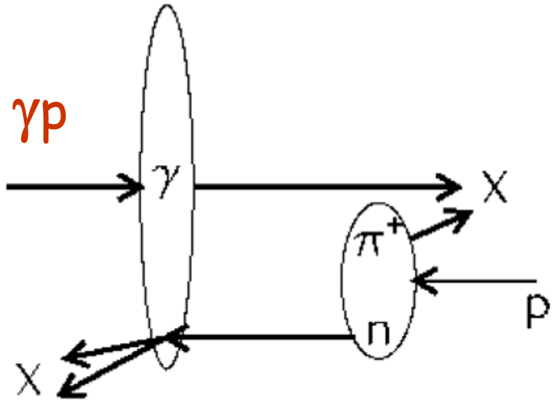
Exchange model refinement: absorptive corrections

Absorption: important ingredient to interpret the results in terms of particle exchange

DIS



γp



Neutron absorption through rescattering:

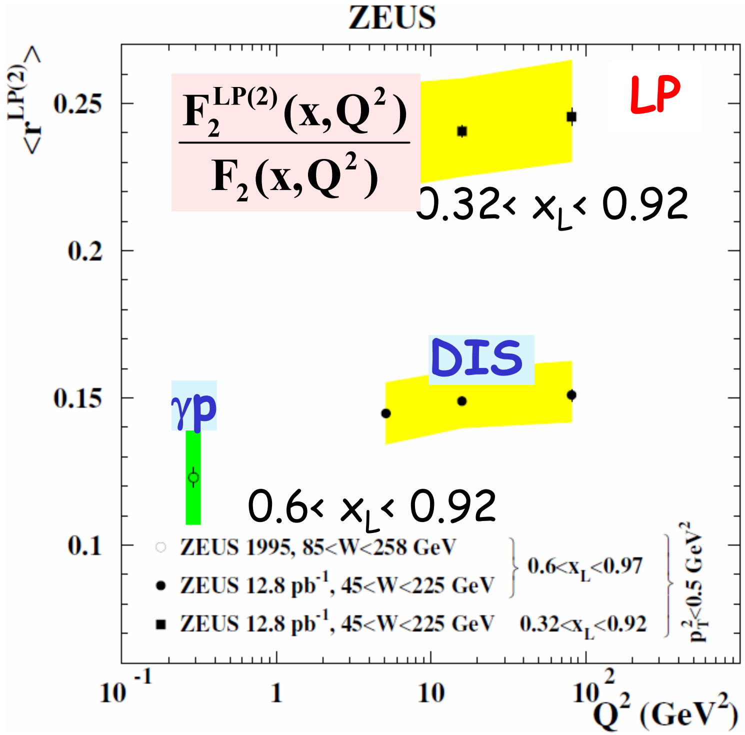
enhanced when size of π-n system $r_{\pi n} \sim 1/p_T$ is small w.r.t. the transverse size of γ, e.g. at high p_T, low x_L
→neutron breaks up or
→is kicked to lower x_L,higher p_T (migration) and/or escapes detector acceptance (absorption loss)
(in other language: multi-Pomeron exchange)

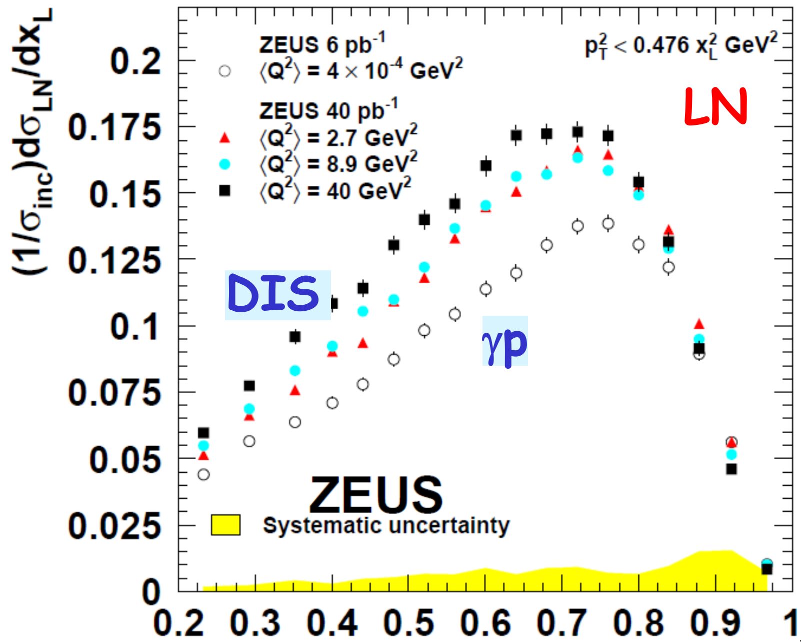
- Affects the relative rate of leading neutrons (depends on the scale Q)

more absorption in photoproduction then in DIS, (real γ transverse size larger than at higher Q^2)
→The calculations/models made without absorption may overestimate the measurements

Effects of absorption and migration estimated:
D'Alesio,Pirner; Nikolaev,Speth,Zakharov;
Kaidalov,Khoze,Martn,Ryskin ;
Kopeliovich,Potashnikova,Schmidt,Soffer

Absorption- key ingredient in calculations of gap-survival probability in pp interactions at LHC, critical in interpreting hard diffractive processes, e.g. central exclusive Higgs prod.





increase of LP and LN rate from γp to DIS

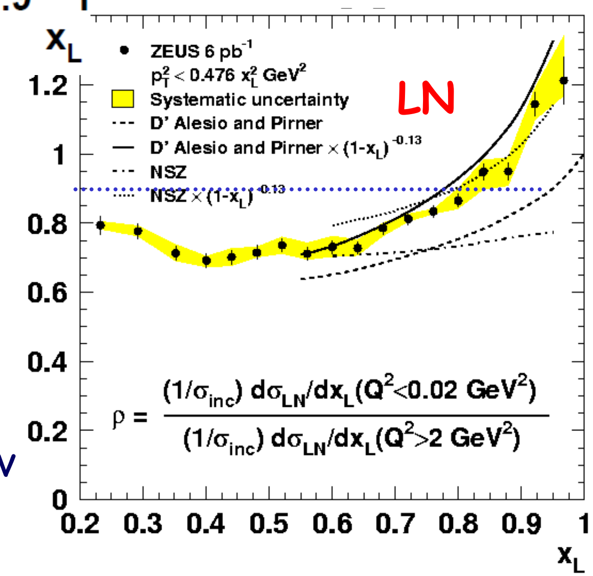
Suggest violation of vertex factorisation

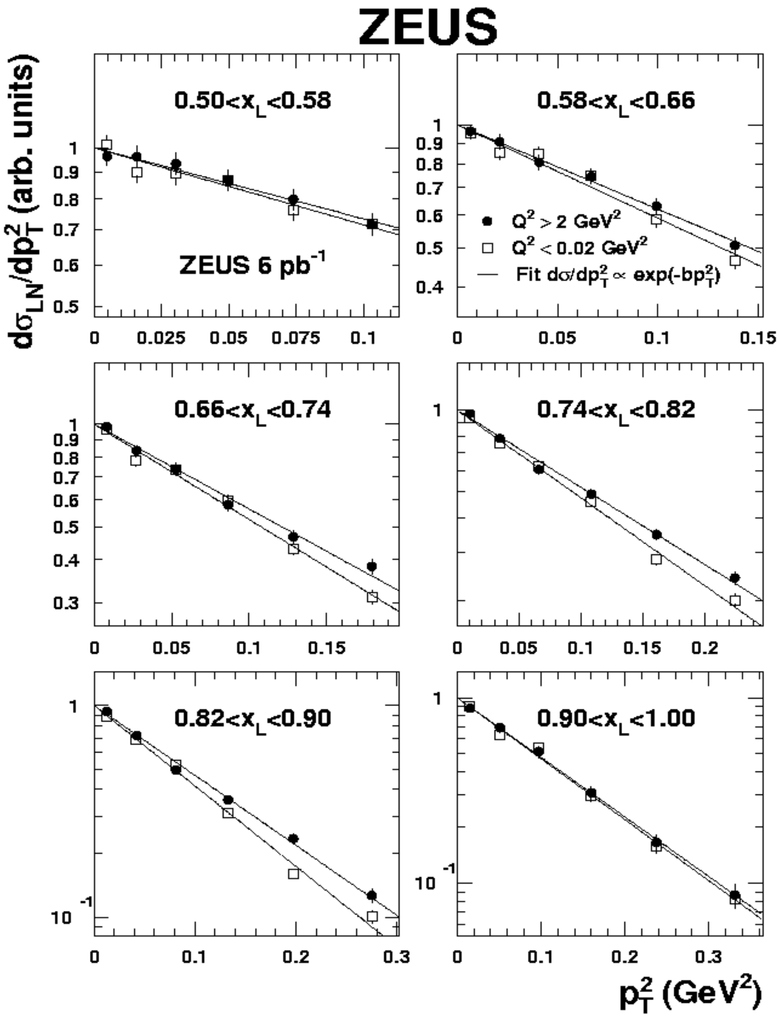
From geometrical picture:
smaller γ* transverse size at higher Q^2
→ less absorption → larger event yield

Ratio γp/DIS:
absorption models describe the data

-d'Alesio,Pirner
geometrical model

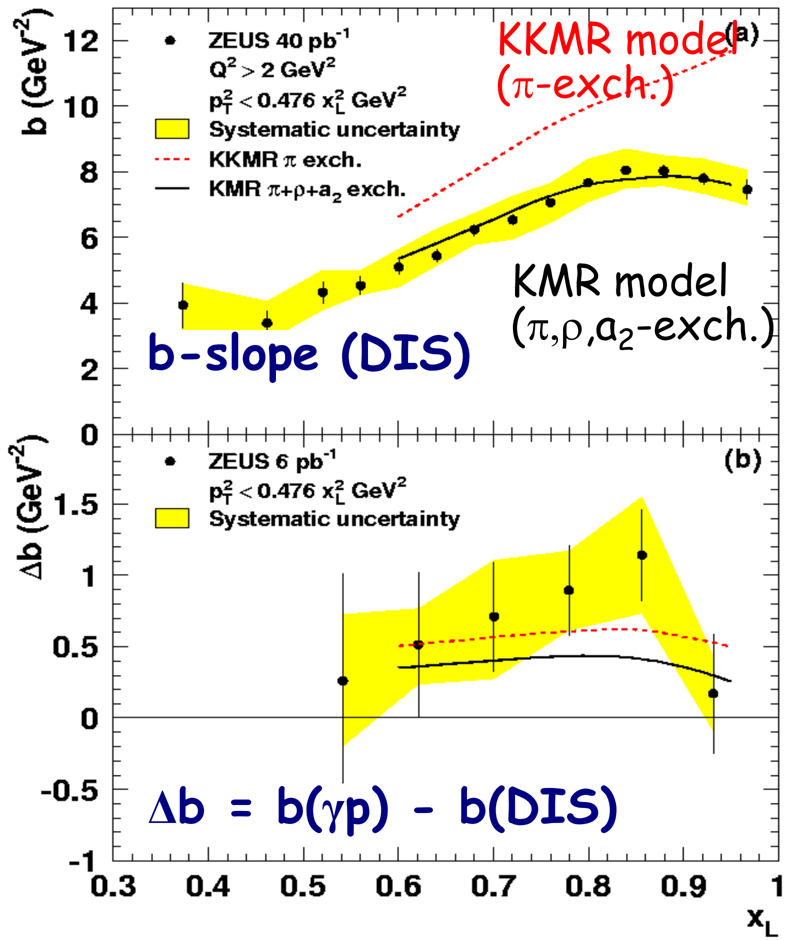
-Nikolaev,Speth,Zakharov
Regge based model with multipomeron exchanges





model of Kaidalov,Khoze,Martin,Ryskin

- rescattering on intermediate partons in central rapidity region; migration of LN in (x_L,p_T)
- ~50% absorption loss in γp
- addition of (ρ,a_2) exchanges

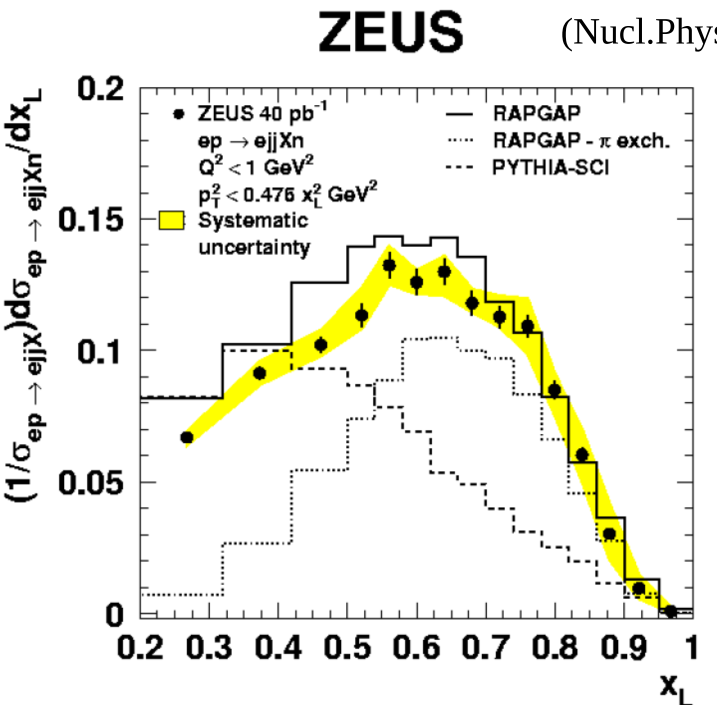


p_T^2 slopes steeper in γp than in DIS

From geometrical picture:

Larger p_T → smaller $r_{\pi n}$ → more absorption → less neutrons at high p_T → steeper slope

Dijet photoproduction with Leading Neutrons



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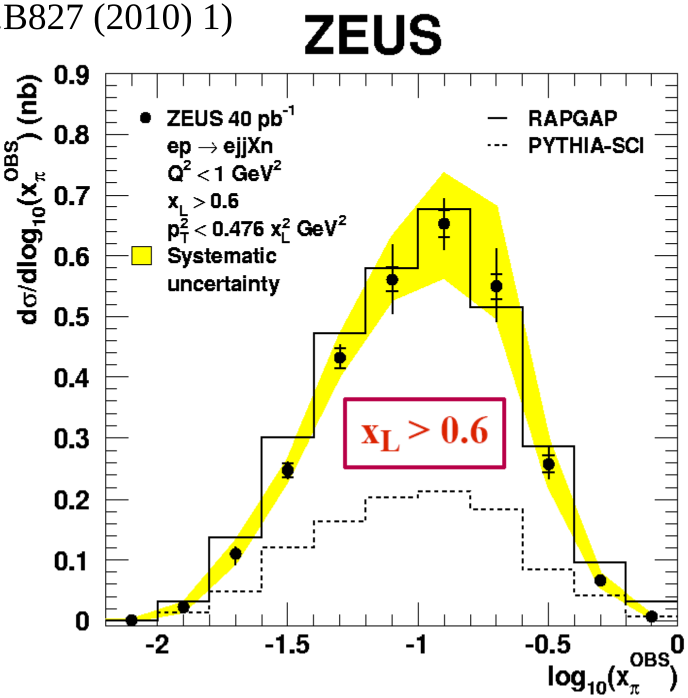

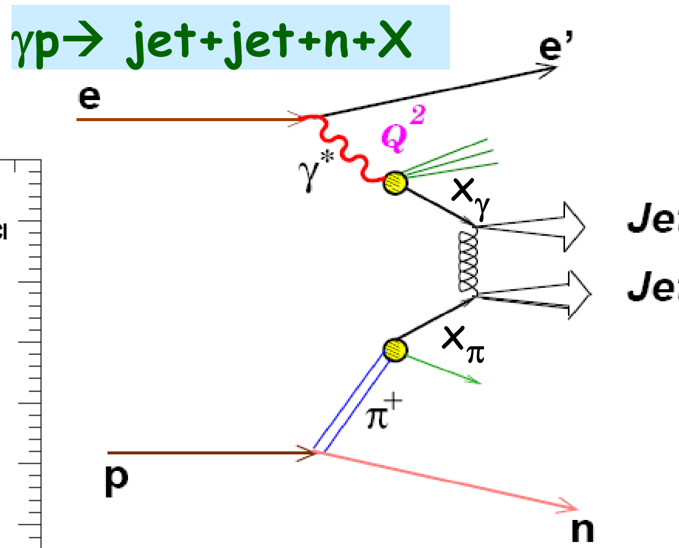

- In photoproduction (Q^2~0) hard scale provided by jets with high P_T^{jet}
- RAPGAP-π-exchange and PYTHIA-SCI describe data poor
- Pion exchange is dominating mechanism at high x_L
- Full RAPGAP (π-exchange + inclusive DIS) gives good description of data

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

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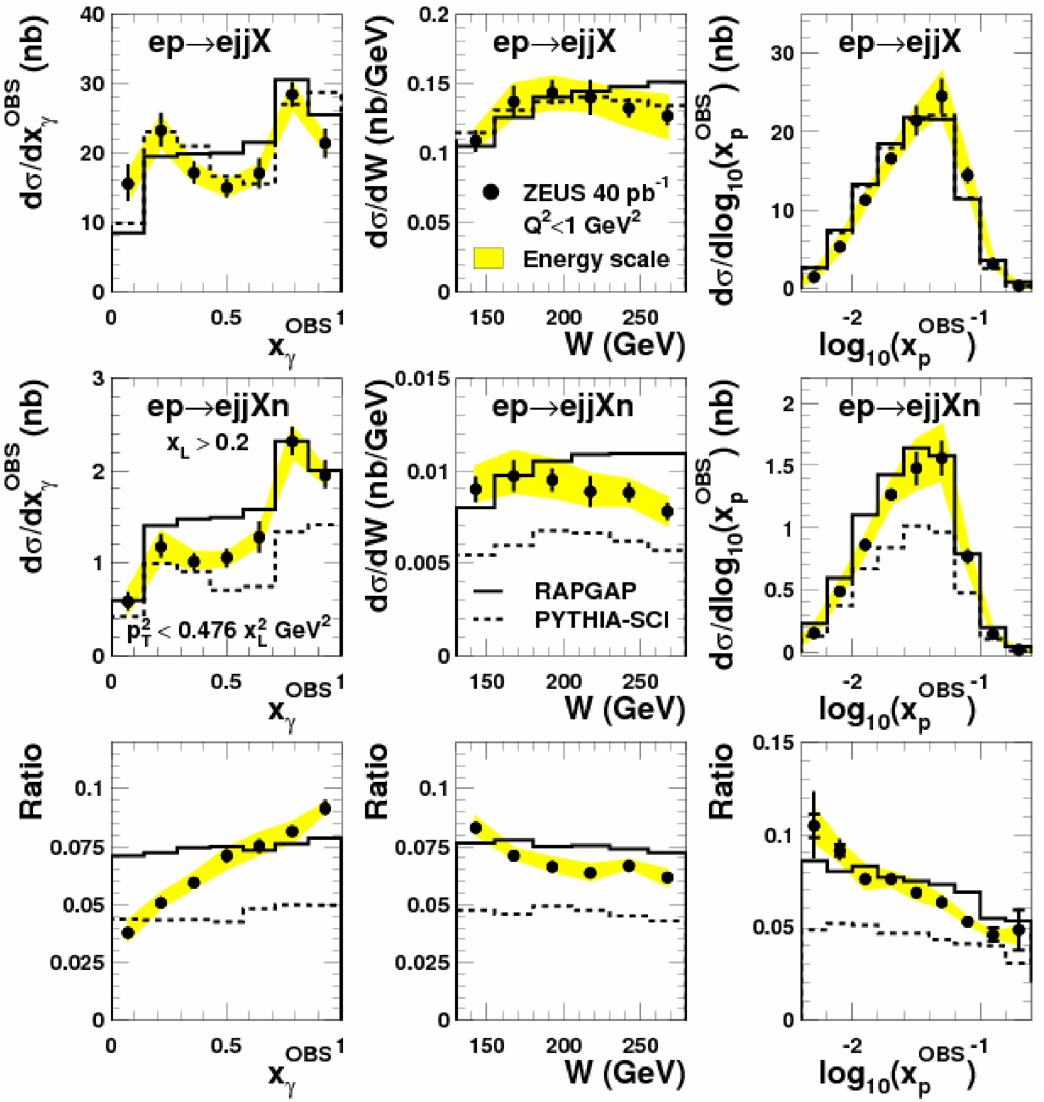
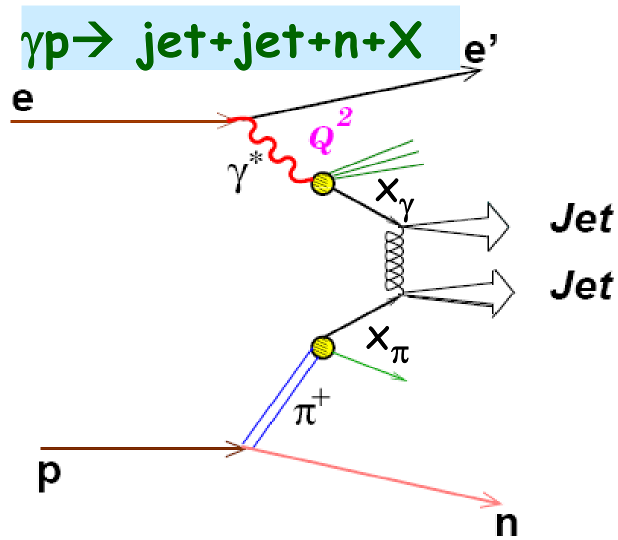


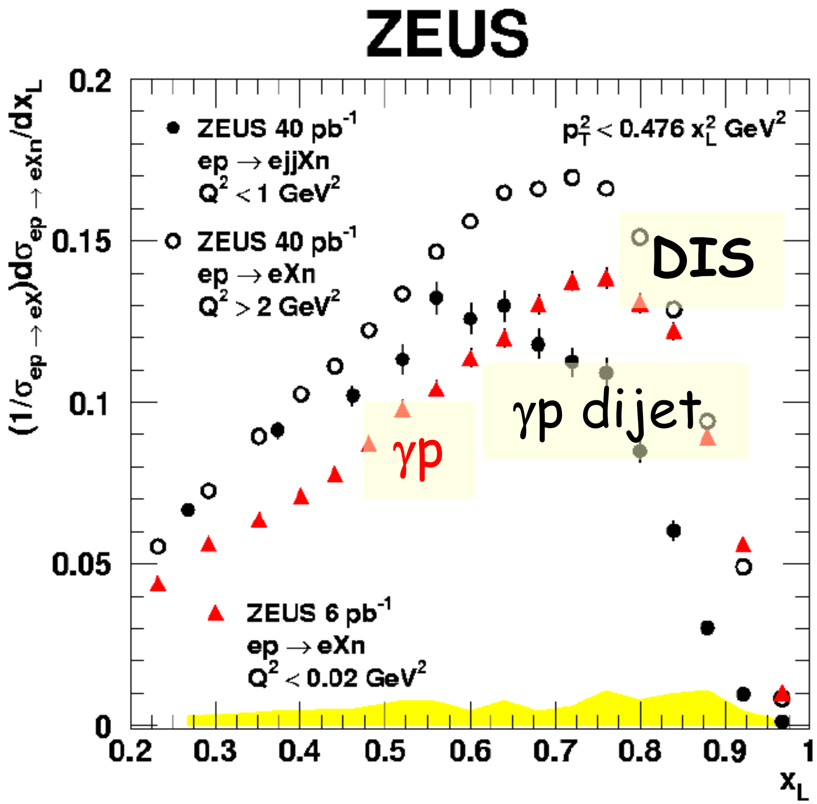


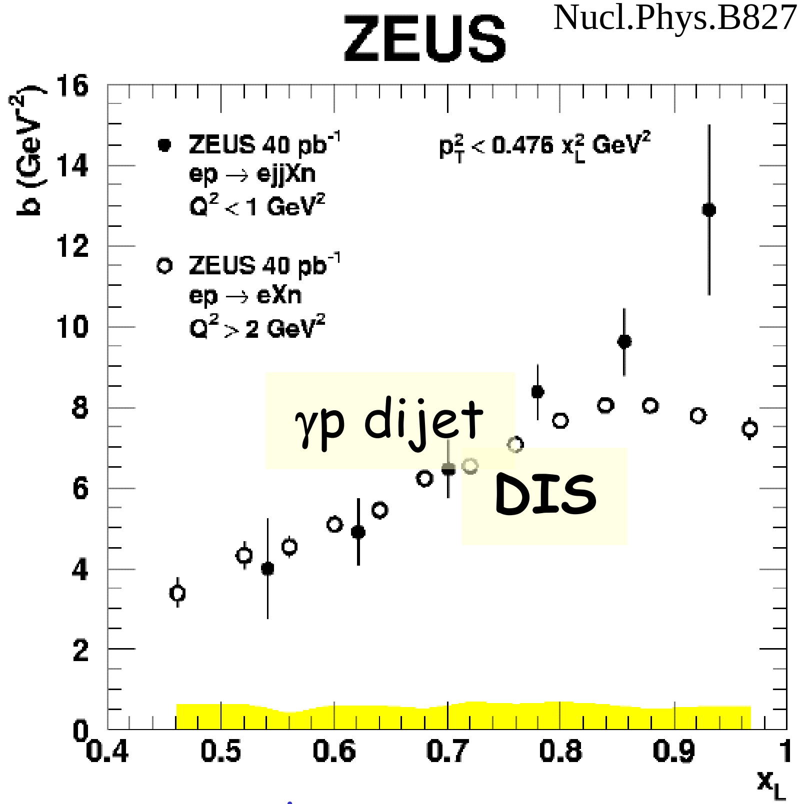
- W – total energy of γp system
- $x_\gamma = \Sigma_{jets}(E-p_z)/(2yE_e)$
- $x_p = \Sigma_{jets}(E+p_z)/(2E_p)$

- strong dependence of ratio on x_γ (also on W, x_p)
- **resolved photon processes seem to be suppressed in LN events**

Dijet photoproduction with leading neutrons

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





- photoproduction suppressed at low x_L → consistent with rescattering; effect is not so prominent in jet production (hard scale provided by E_T^{jet})
- dijets suppressed at high x_L → phase space limitation (dijets in the final state leave little room for energetic neutrons)
- similar b-slopes in DIS & γp-dijets; slightly different at high x_L

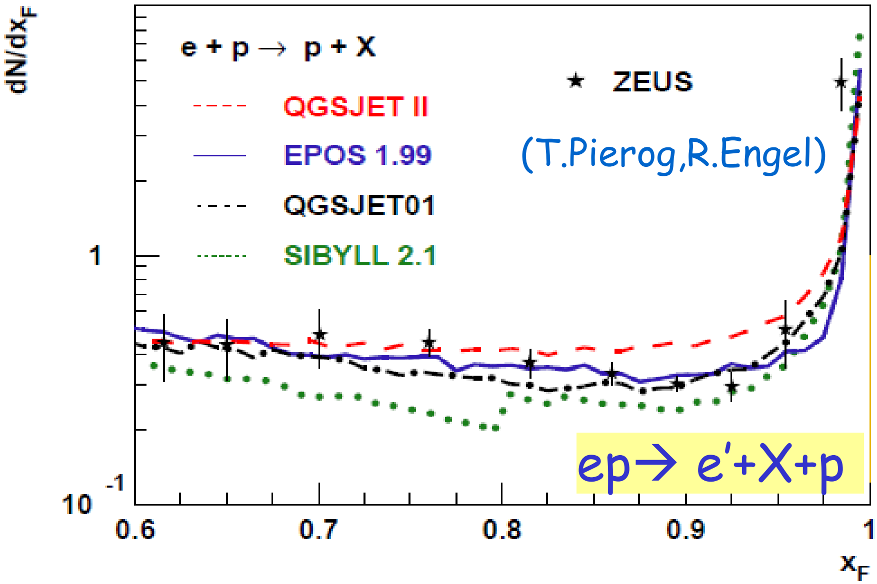
Above 10^{14} eV, primary cosmic rays particles are detected via air showers-determination of their primary energy and mass relies on the modeling of hadronic interactions.

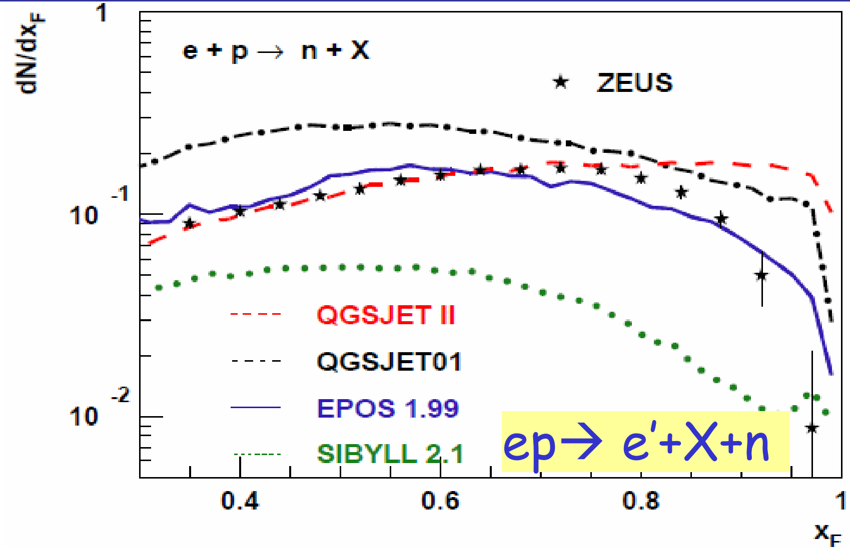
Precision of elemental composition analyses limited by modeling of hadronic interactions; significant differences between the model predictions for particle multiplicities, energy flow etc.

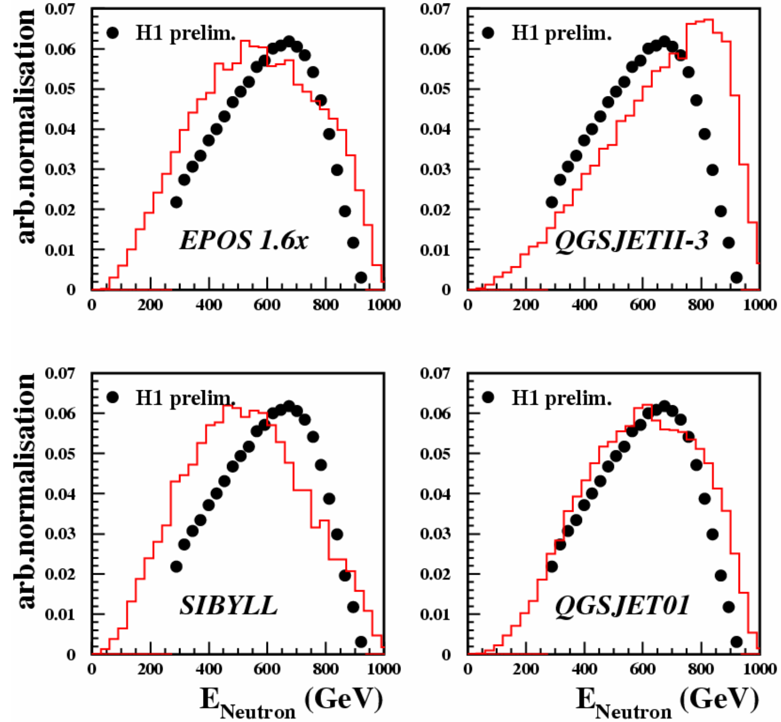
➔

The measurements at accelerators can contribute to the tuning of the models

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







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

- reasonable predictions for LP data (after model tuning)
-none of models describe LN data well
→ HERA can further contribute to the understanding of high energy cosmic rays
→ The forward measurements (p,n,γ) are possible also at lower proton beam energies

Summary

Leading Baryons are good ground to study interplay of soft and hard physics

- precise measurements of LB x_L and p_T^2 presented in γp, DIS, γp with dijets
- 'standard' fragmentation models without meson exchange do not describe the data; models with virtual particle exchange describe data better;
- F_2^{LP}/F_2 and F_2^{LN}/F_2 ratio is mostly independent of x and Q^2
- For leading neutron production the pion structure function estimated, compared with parameterisations of F_2^{π}
- neutron energy spectrum in γp compatible with effects of absorption and migration; suppression in γp at low x_L, high p_T
  absorption effects not prominent in high P_T jet photoproduction
- leading baryon data important for an improved theoretical understanding of the proton fragmentation; provide very useful input for models of CR interactions with matter