Leading Baryons and $\sigma_{tot}(\gamma p)$ at HERA

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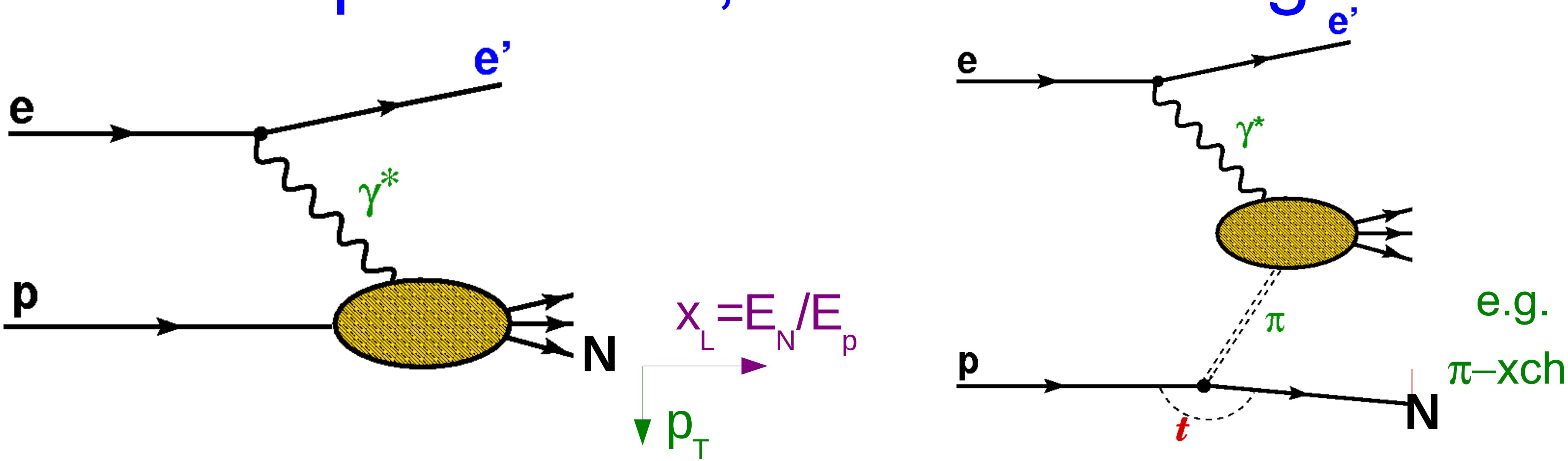
non-pQCD recent results from HERA (QCD laboratory) on:

- Leading particles: @ HERA $ep \to eBX$, B is leading baryon (LB)
  - results on leading neutrons (LN) and leading protons (LP)
- Hadronic total cross sections: σ_{tot}(hadron+hadron)
  - new from HERA: energy dependence of $\sigma_{tot}(\gamma p)$ via $\gamma \leftrightarrow$"hadron"

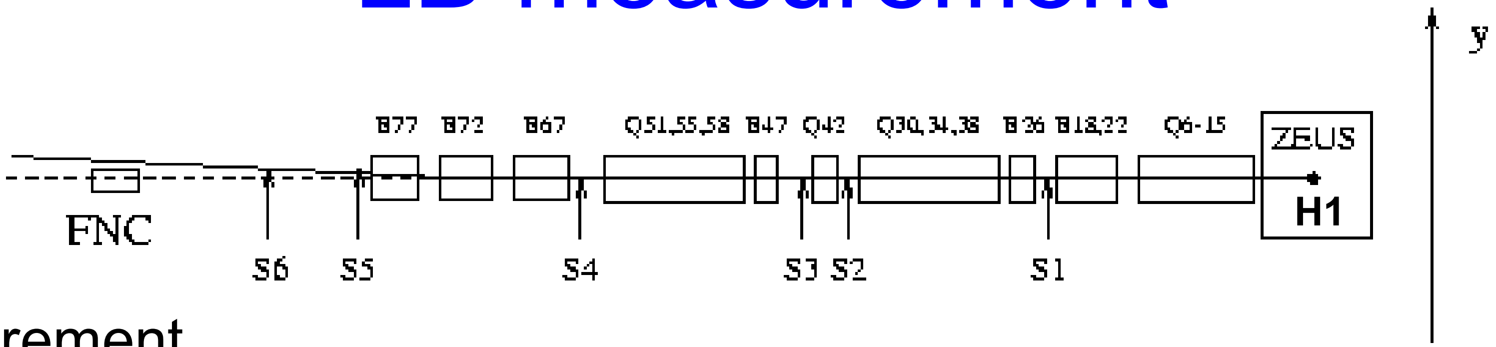
LB production, virtual exchange



- LB can come from 'standard' fragmentation (e.g. MEPS, Lund...) (baryon # has to go somewhere)
- Can compare to 'standard' MC gens.: x_L, p_T^2 distributions
- LB can be produced via exchange of virtual particles: isovector (*p*&*n*) and isoscalar (*p* only).
- Parameterizations from low energy hadronic data. Compare: x_L, p_T^2 dist.
- Cross section factorizes:

$$\sigma_{ep\to eNX}(x,Q^2,x_L,p_T) = f_{\pi/p}(x_L,p_T)\ \sigma_{e\pi\to eX}(x/(1-x_L),Q^2)$$

LB measurement



<u>LB measurement</u>

- HERA proton beam-line downstream of H1/ZEUS:
- Analyzing magnets for leading proton spectrometer: Si-strip detectors
- Sweeping magnets for forward neutron calorimeter (FNC): Pb-Sci calor.

apertures limit Θ_n<0.75 mrad $\Rightarrow$ p_T^2<0.476 x_L^2 GeV^2

<u>LB are selected from inclusive data sets (i.e. no LB tag):</u>

- DIS: Q^2 > 2-3 GeV^2, γp: Q^2 < 0.02 GeV^2, e^+ tagged

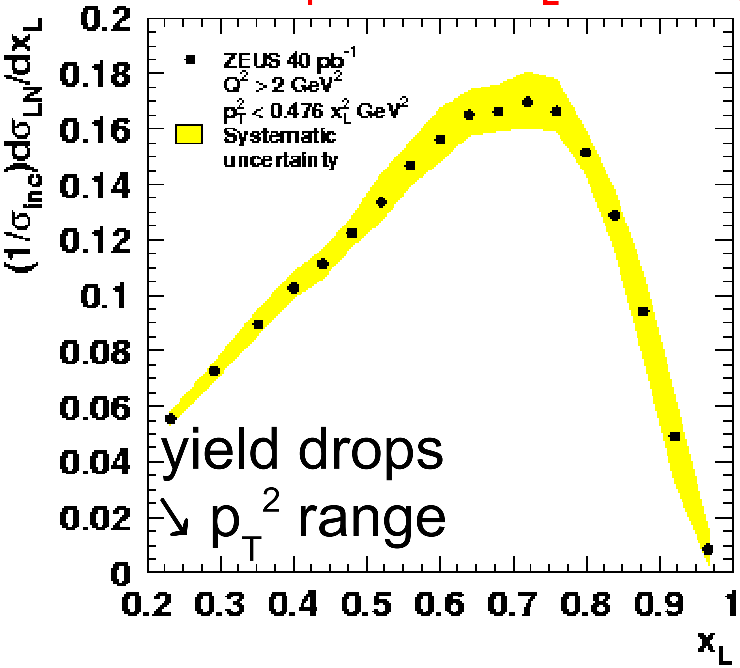
<u>LB yields:</u>

- DIS, γp have very different inclusive cross sections σ_{inc}
- For sensible comparisons look at LN yields: $r_{LB} \equiv \sigma_{LB} / \sigma_{inc}$
- From factorization: $r_{LB} \propto \sigma_{e\pi\to eX}(x/(1-x_L),Q^2)$ / $\sigma_{ep\to eX}(x,Q^2)$

  $\sigma_{e\pi}$, σ_{ep} similar x,Q^2 dependences $\Rightarrow$ r_{LB}~independent of x,Q^2
- Additional benefit: systematic uncertainties of central detector cancel

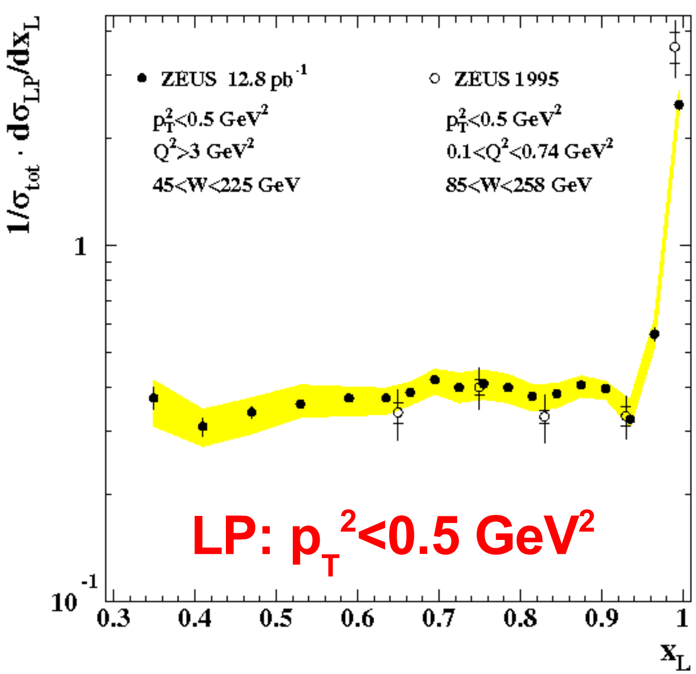
DIS LB x_L & p_T^2 distributions

LN: $p_T^2 < 0.476\, x_L^2$ GeV^2 (Θ_n limit)



kin. limit

$x_L \rightarrow 1$

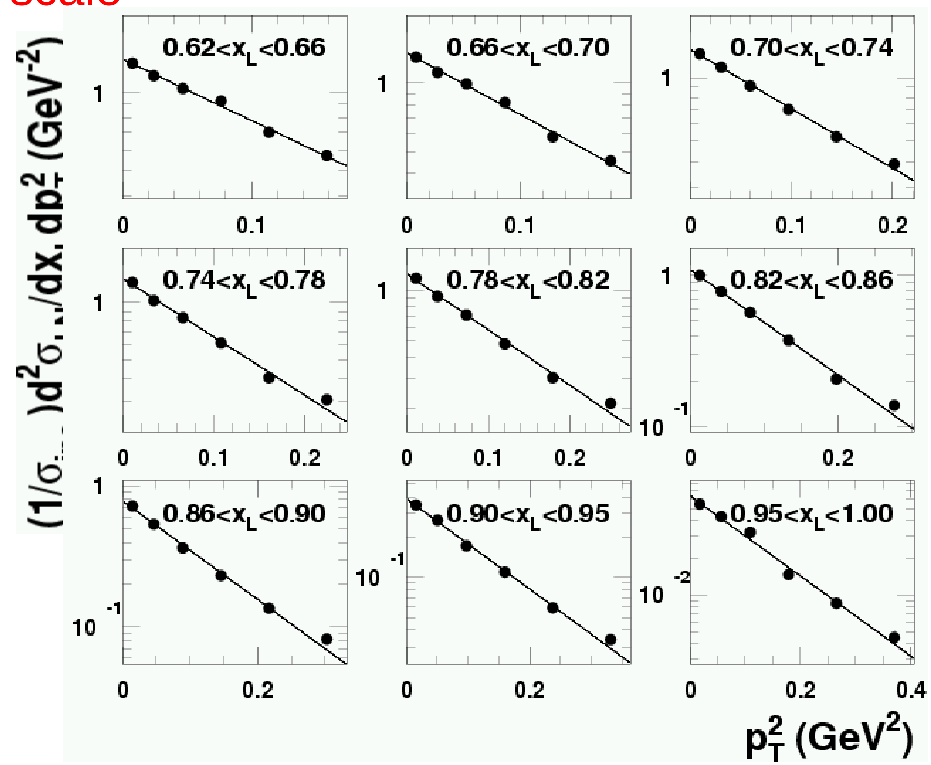


diffractive

peak $x_L \rightarrow 1$

log scale

LN: $\dfrac{1}{\sigma_{inc}} \dfrac{d^2\sigma_{LN}}{dx_L dp_T^2}$



- Described by exponential in p_T^2:

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

- Intercepts $a(x_L)$ and slopes $b(x_L)$ fully characterize (x_L, p_T^2) dist.

Model comparisons: DIS LN

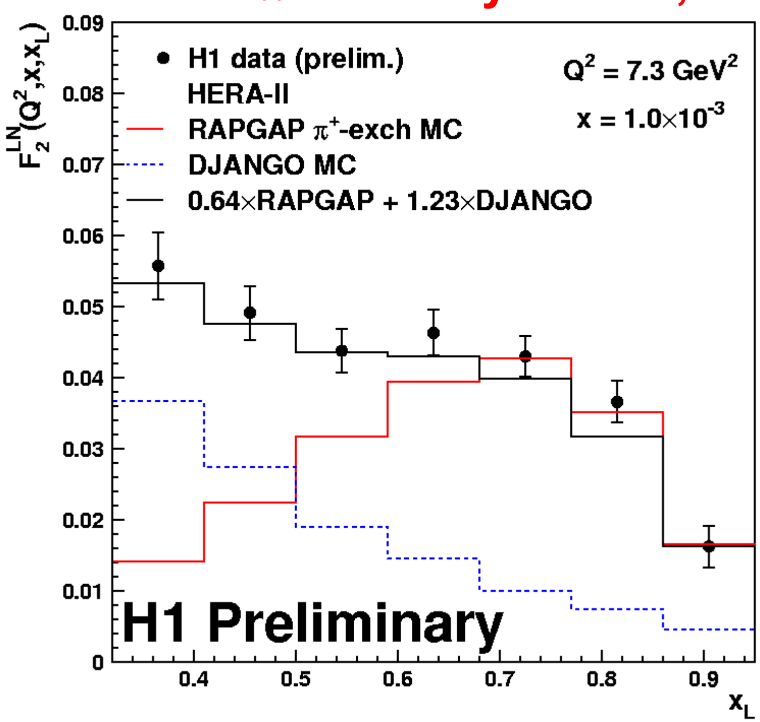
- Compare to MC models, options:

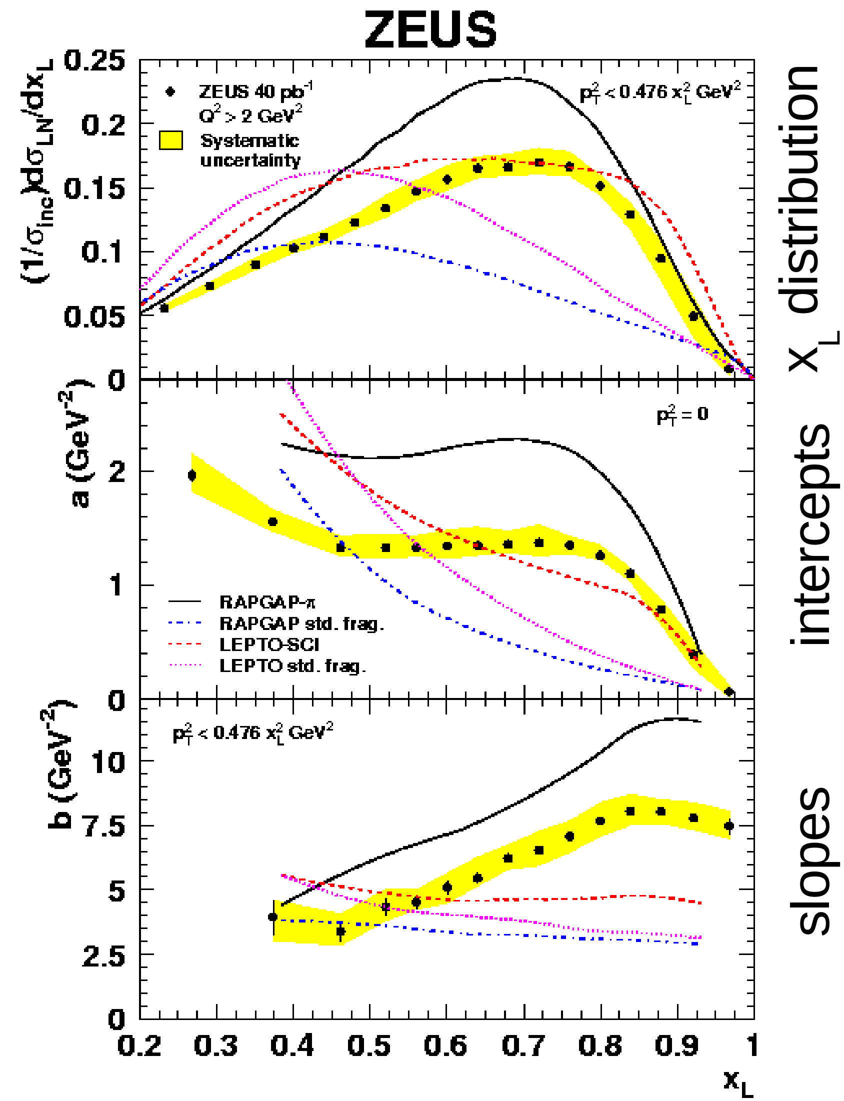
  - RAPGAP 'std. frag.' &/or π-xch.

  - LEPTO w/ 'std. frag.' or soft color int.

  - DJANGO 'std. frag.', mix w/ π-xch.

- All std. frag. too few *n*, too low x_L; LEPTO-SCI ~OK
- **RAPGAP w/ π-xch. close to data**
- **Best mix of DJANGO w/ π-xch. very nice fit, here for one (x,Q^2) bin:**



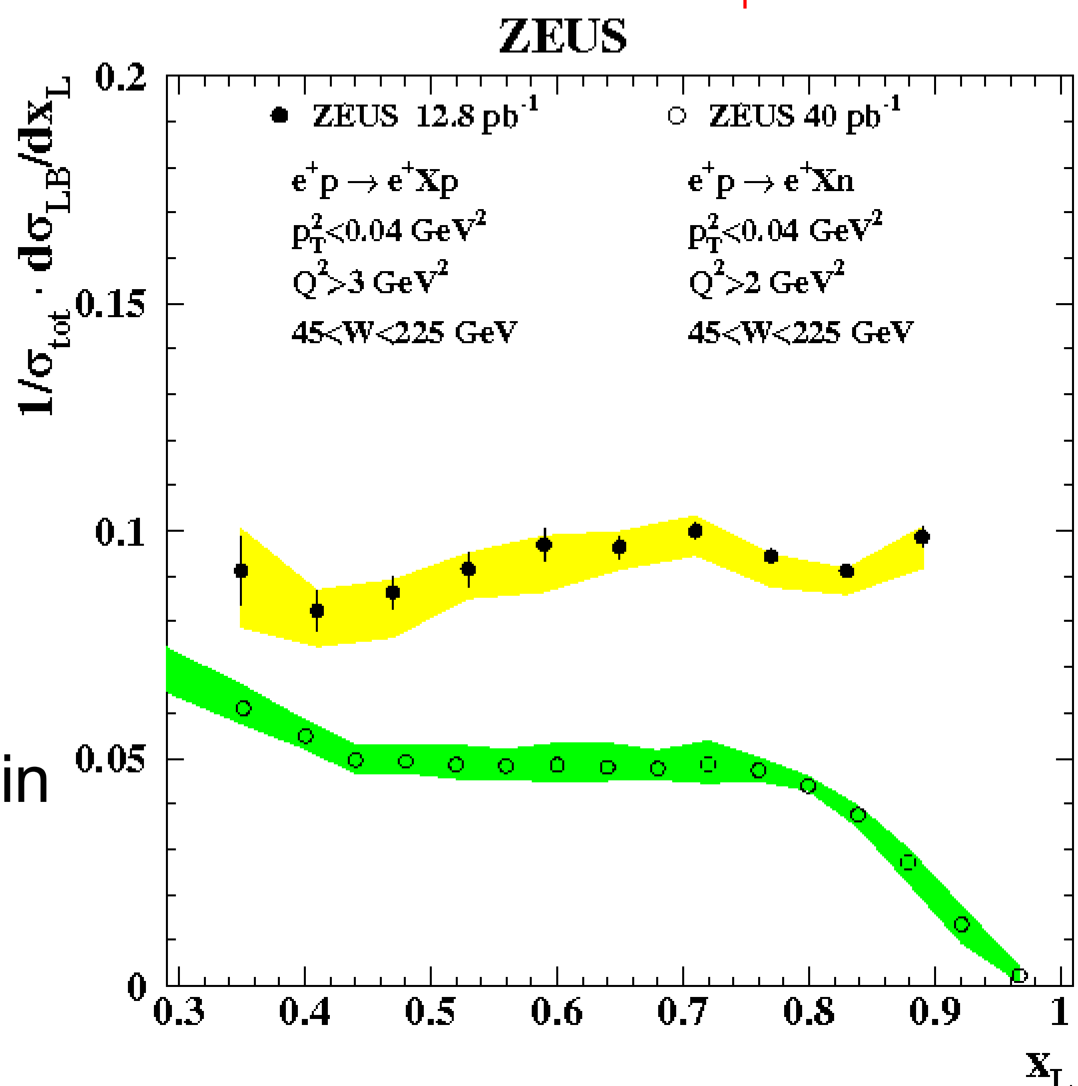


- **Other std. frag. MCs also fail: ARIADNE, CASCADE, PYTHIA, PHOJET, ...**

Compare: LP/LN x_L distributions

- LP/LN same range: $p_T^2 < 0.04$ GeV^2

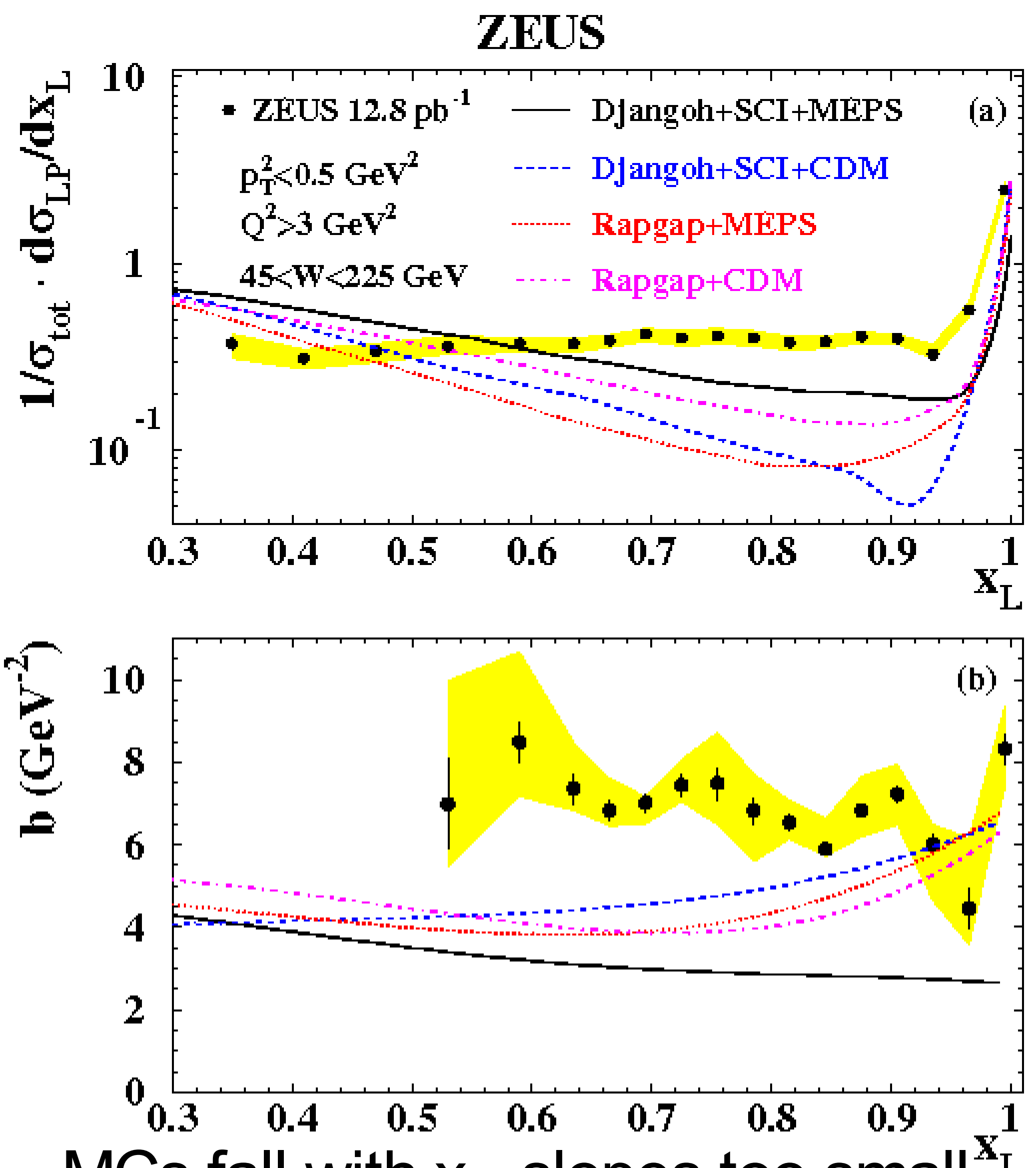
Both detectors acceptances overlap at low p_T for $0.5 < x_L < 0.9$:



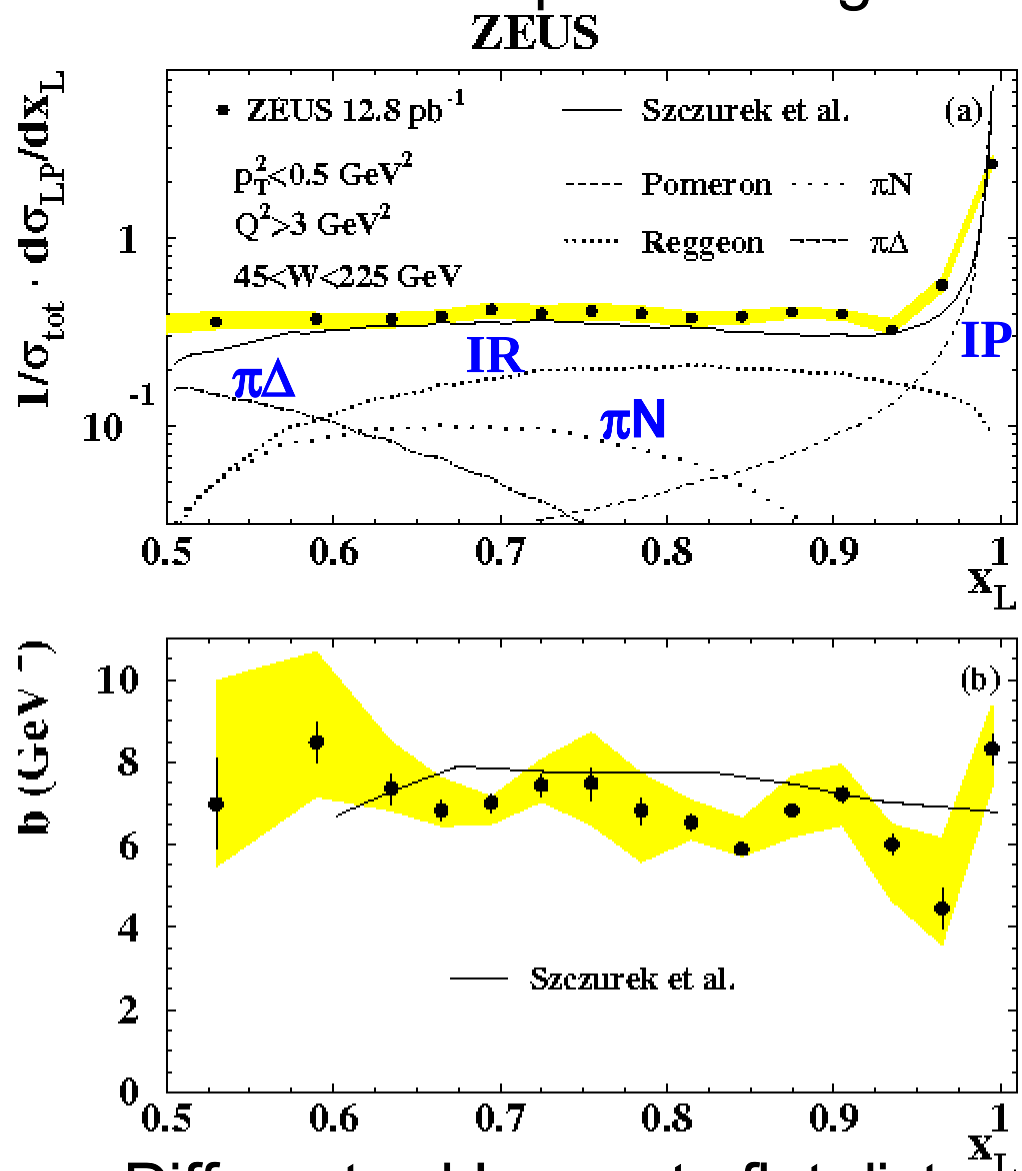
- For pure isovector exchange isospin Clebsch-Gordan $\Rightarrow r_{LP} = \frac{1}{2} r_{LN}$
- Data: $r_{LP} \approx 2\, r_{LN}$
- $\Rightarrow$ additional exchanges (isoscalar) needed for LP

Model comparisons: DIS LP x_L & slopes

- 'Std. fragmentation'+diffraction MCs:



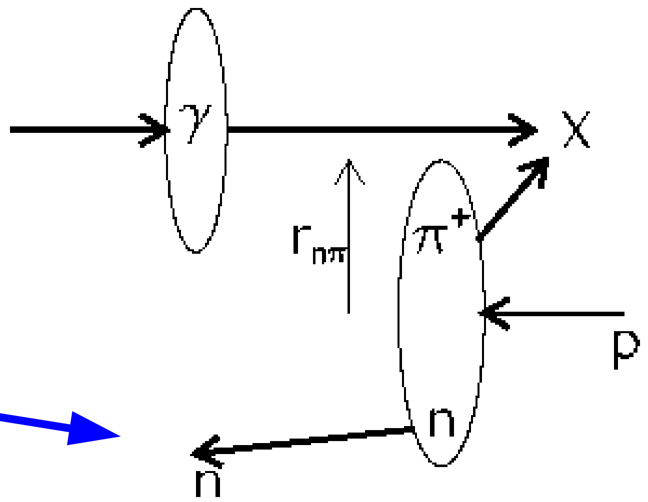
- Model w/ multiple exchanges:



- MCs fall with x_L, slopes too small
- MCs w/o meson xch. fail
- Different xch's sum to flat dist.
- Good agreement w/ data

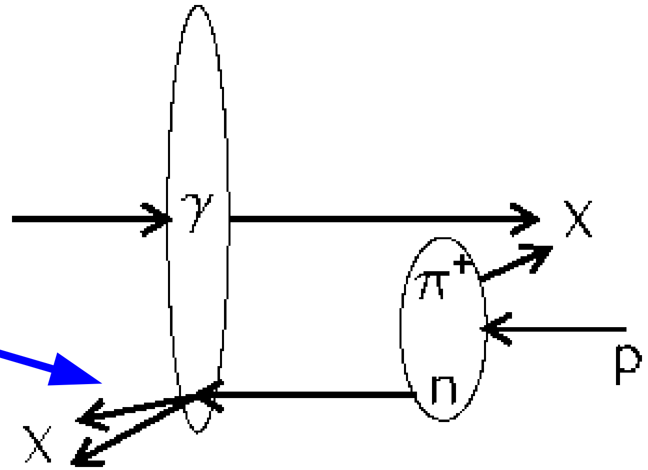
Xch. model refinements: Absorption

For e.g. LN production via π-exchange:



- In DIS γ^* small; small chance both n,π scatter on γ^*: n reaches detector

- In photoproduction γ large; if n-π separation smaller rescattering of n may also occur: n kicked to lower x_L & higher p_T, and may escape detection (absorption loss)

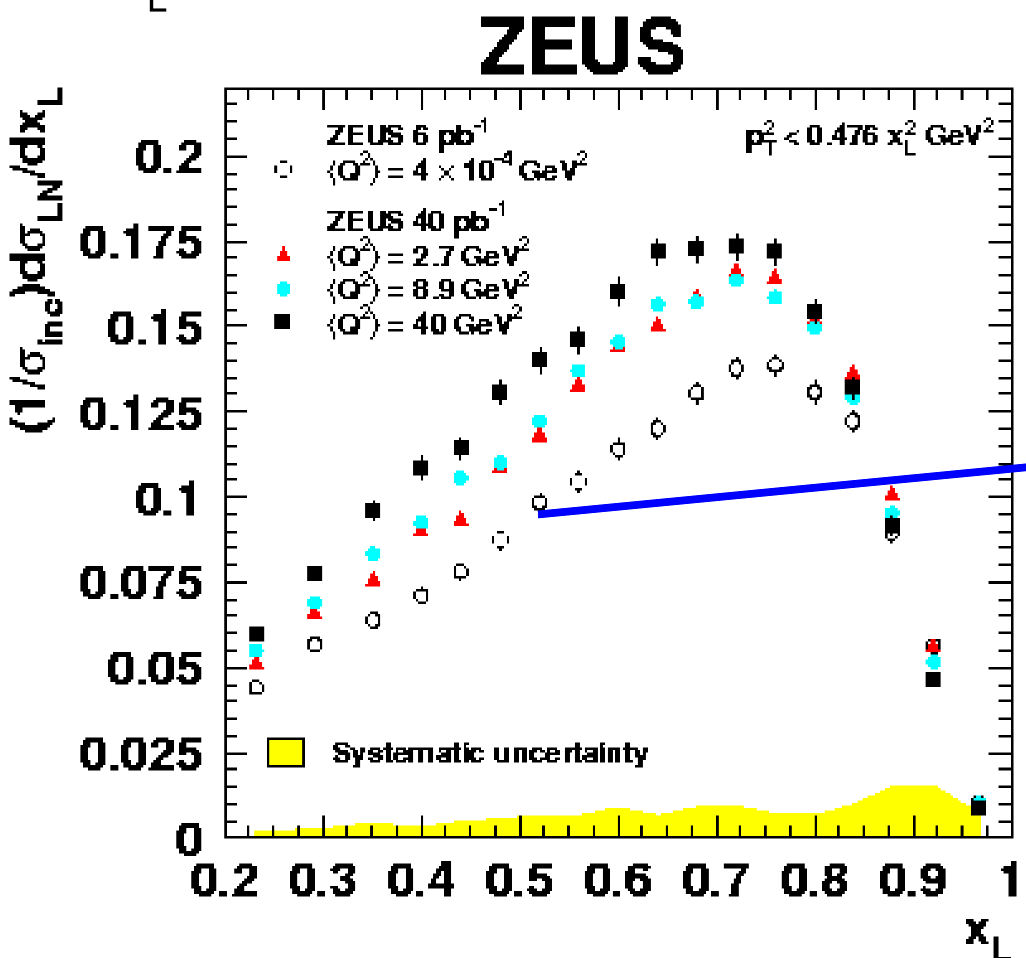


- In another language: multi-Pomeron exchange
- Compare photoproduction & DIS Q^2 dependence:
  - effects of absorption?

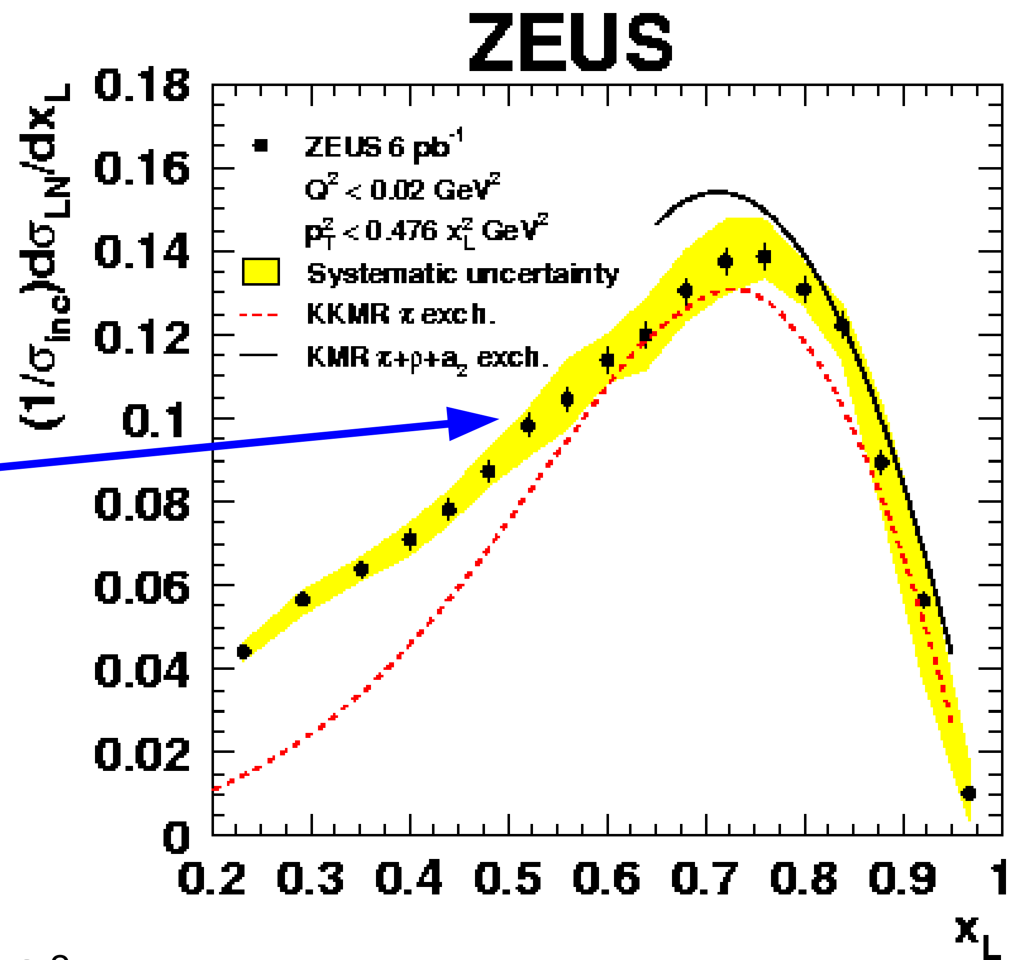
Q^2 dependence of LN production

3 Q^2 bins DIS + γp:

- x_L distributions:



- Calculations: pion, additional mesons with absorption:



- LN yield increases monotonically w/ Q^2
- Consistent w/ absorption:

  larger $Q^2 \Rightarrow$ smaller γ, less absorp.

- Absorption calculation accounts for large depletion DIS $\rightarrow \gamma p$

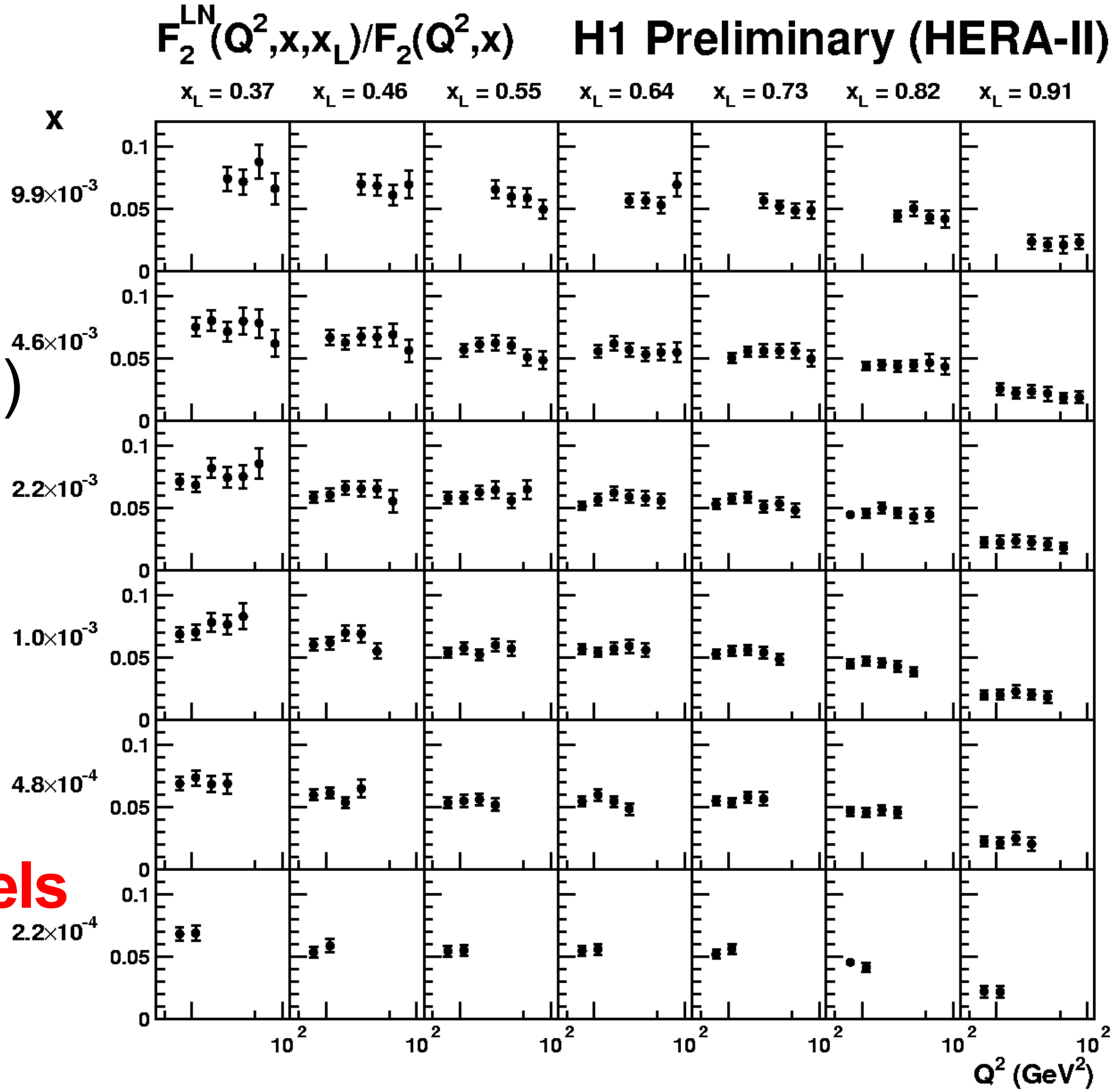
F_2^{LN} & ratio to F_2^{P}

- With neutron tag can define LN structure analogous to proton s.f. with LN variable: $F_2^{LN}(x,Q^2,x_L)$
- Look at ratio:

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

- r^{LN}~independent of (x,Q^2):
- LB production rate, kinematics ~independent of (x,Q^2)

⇒ **factorization as in xch. models**



F_2^{π} from F_2^{LN}

- From factorization in intro. write: $F_2^{LN}(x,Q^2,x_L) = f_{\pi/p}(x_L)\ F_2^{\pi}(\beta,Q^2)$

  $\beta = x/(1-x_L)$ parton fraction π-momentum

- From π-xch. model for $f_{\pi/p}(x_L)$,

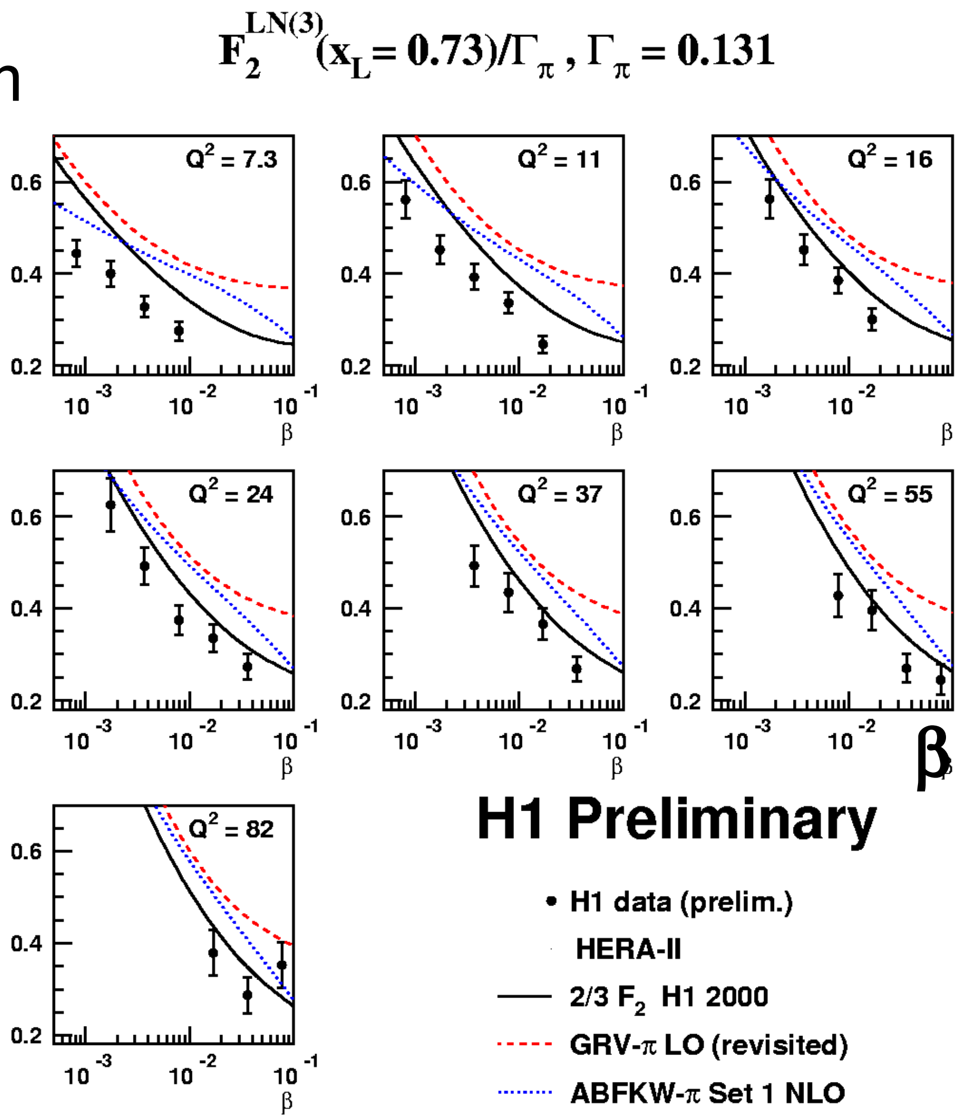
  with $\Gamma_{\pi} = \int f_{\pi/p}(x_L)dx_L$ can extract

  F_2^{π} from measured F_2^{LN}

- $F_2^{\pi} \approx 2/3\ F_2^{p} \Longrightarrow$ additive quark model

- Test, constrain p.d.f. parameterizations

  GRV, ABFKW shown here

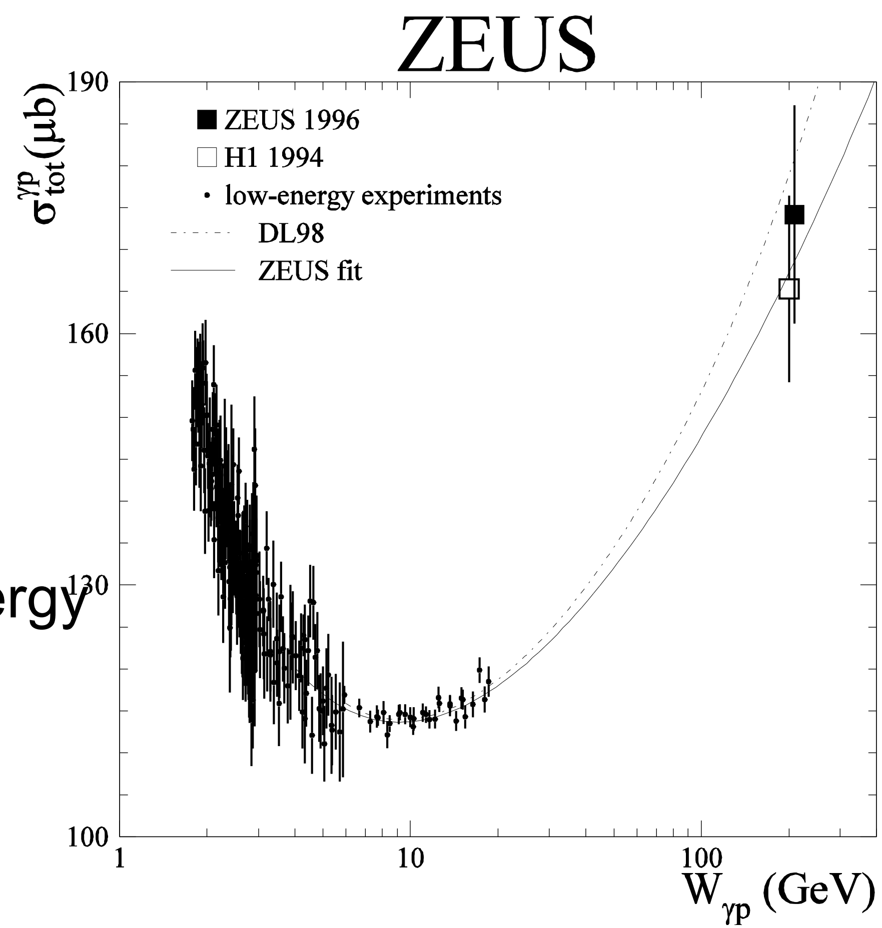


Hadronic Total Cross Sections

- Universal behavior (Donnachie & Landshoff): σ_{tot}(had.+had.) = $As^{\varepsilon} + Bs^{-\eta}$
- ε,η same for all hadronic cross sections (seen in many reactions)
- High energy power ε first fixed by $Sp\bar{p}S$ & Tevatron $p\bar{p}$: ε=0.08-0.096
- Photon behaves like hadron: $\gamma \leftrightarrow q\bar{q}$;

  Early HERA result $\sigma_{tot}(\gamma p)$: $\varepsilon=0.100\pm0.012$
- Results from different low/high energy experiments: large systematic uncertainties
- End of HERA: lowered *p*-energy, same *e*-energy

  Measurement repeated @ two values $s=W^2_{\gamma p}$



- Measure ε by cross section ratio

  - Same apparatus: acceptance, many systematics cancel

$\sigma_{tot}(\gamma p)$ ratio @ HERA

- γp cross section ratio HER/LER (High-Energy-Run/Low-Energy-Run)

$$R = \frac{\sigma^{\gamma p}_{\text{HER}}}{\sigma^{\gamma p}_{\text{LER}}} = \frac{N^{\text{HER}}_{\text{evt}}}{N^{\text{LER}}_{\text{evt}}} \cdot \frac{\mathcal{L}_{\text{LER}}}{\mathcal{L}_{\text{HER}}} \cdot \frac{f_{\text{LER}}}{f_{\text{HER}}}$$

f=e→eγ photon flux

Uncertainties:

±0.52% (stat.) ±1.05%(sys.) ±1% ±3.5%

from: signal measurement LUMI γ-tag (much room to improve!)

- Final result: R = 1.050 ±0.005 (stat.) ±0.040(sys.)

- In D&L model $\sigma \propto W^{2\varepsilon}$: ε = 0.070 +0.054 / -0.056 (sys.)

  consistent w/ previous: ε = 0.08-0.10

- Improvements coming in signal measurement & γ-tag understanding

Summary

Important non-pQCD experimental results from HERA:

✯ Leading particles ⇒ leading baryons (LB) @ HERA:

- Standard fragmentation models do not describe LB production
- Exchange (meson...) models describe LB kinematics, Q^2 dependence
- For LN production, π-xch. ⇒ extract pion structure $F_2^{\pi}(x,Q^2)$

✯ Hadronic total cross sections:

- Independent (one experiment) measure of high-energy

  dependence of $\sigma_{tot}(\gamma p)$ ⇔ consistent w/ previous measurements

- Improved measurement coming:

  ⇒ Universal high-energy dependence hadronic total cross sections