Leading Neutron Energy & \( p_T \) Distributions from ZEUS

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Outline:

- Motivations: LN production, One Pion Exchange (OPE), absorption
- Data sets: DIS, photoproduction (\( \gamma p \)), LN measurement
- LN in DIS: energy, \( p_T \) distributions
- Comparison: LN in photoproduction & DIS
- Comparison: LN & leading protons
- Comparison: OPE models, absorption (rescattering) models
- Comparison: LN in non-OPE MC models
Motivations: LN production, OPE

- LN can come from 'standard' fragmentation (baryon # has to go somewhere)
- Can compare to 'standard' MC gens.: $x_L, p_T^2$ distributions

- LN can be produced via isovector exchange: One Pion Exchange (OPE)
- Parameterizations from low energy hadronic scattering data. Can compare: $x_L, p_T^2$ distributions
Motivations: Absorption

In DIS $\gamma^*$ is small; in photoproduction $\gamma$ large, rescattering (absorption) of $n$ may occur:

- Compare photoproduction & DIS:
  - $x_L, p_T^2$ distributions
  - effects of absorption?
- Recently: Kaidalov, Khoze, Martin, Ryskin 'Leading neutron spectra' hep-ph/0602215
- They calculate the effects of absorption (rescattering), and subsequent migration of LN in $(x_L, p_T^2)$ space
- Next speaker for details <

DIS small $\gamma$, no rescattering

photoproduction large $\gamma$, rescattering

$n$ kicked to lower $x_L$, higher $p_T$; may escape detection (migration)
Data Sets

Inclusive data (i.e. no LN tag):
- **DIS**: $Q^2 > 2 \text{ GeV}^2$, $\langle Q^2 \rangle \approx 14 \text{ GeV}^2$
- **$\gamma p$**: $Q^2 < 0.02 \text{ GeV}^2$, $e^+$ tagged $\Rightarrow 180 < W_{\gamma p} < 255 \text{ GeV}$

**LN measurement**: Forward Neutron Calorimeter (FNC) & Tracker (FNT)
- $10.2 \lambda_1$ Pb-scint. calorimeter 105m from I.P.
- Scintillator hodoscope 1 $\lambda_1$ into calorimeter for position detection
- Energy resolution $\sigma_E/E \approx 0.7/\sqrt{E}$
- $p_T$ resolution dominated by proton beam $p_T$ spread $\sim 50-100 \text{ MeV}$
- Magnet apertures limit $\Theta_n < 0.75 \text{ mrad} \Rightarrow p_T^2 < 0.476 x_L^2 \text{ GeV}^2$

**LN yields**:
- DIS, $\gamma p$ have very different inclusive cross sections $\sigma_{\text{inc}}$
- For sensible comparisons look at LN yields: $\sigma_{\text{LN}}/\sigma_{\text{inc}}$
- Additional benefit: systematic uncertainties of central ZEUS cancel; only have LN systematic uncertainties
LN in DIS: $x_L$ distribution

- LN yield $\rightarrow 0$ at kinematic limit $x_L^2 \rightarrow 1$
- Below $x_L^2 \approx 0.7$ yield drops due to decreasing $p_T^2$ range

Systematic uncertainties from:
- Proton beam 0° point
- FNC energy scale
- Dead material before FNC
$p_T^2$ distributions DIS

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

ZEUS

log scale

Note varying $p_T^2$ ranges $\propto x_L^2$

Well described by exponential in $p_T^2$

ZEUS (prel.) 40 pb$^{-1}$
$Q^2 > 2$ GeV$^2$
Fit $d\sigma/dp_T^2 \propto \exp(-bp_T^2)$
\( p_T^2 \) distributions: slopes & intercepts

- \( p_T^2 \) distributions well described by exponential:

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

- Together intercepts \( a(x_L) \) and slopes \( b(x_L) \) fully characterize \( (x_L,p_T^2) \) distribution
$p_T^2$ distributions: slopes & intercepts

- DIS intercepts $a(x_L)$:

- DIS slopes $b(x_L)$:

\[
\frac{1}{\sigma_{inc}} \frac{d^2\sigma_{LN}}{dx_L dp_T^2} = a(x_L)e^{-b(x_L)p_T^2}
\]
Comparing $\gamma p$ & DIS

To minimize systematic uncertainties in comparison:

- Use only DIS from period when $\gamma p$+LN trigger active (~20% of DIS sample)
- Many LN systematic uncertainties cancel taking ratios:
  - Ratio of $x_L$ distributions: $\gamma p$/DIS
  - Ratio of $p_T^2$ distributions: $\gamma p$/DIS

$$\Rightarrow \Delta b = b(\gamma p) - b(DIS)$$
Comparison $\gamma p$/DIS: $x_L$ distributions

- Ratio $\sim 70\%$ mid-$x_L$, rising to 1 as $x_L \to 0.9$
- Qualitatively similar to D' Alesio & Pirner (loss through absorption)
- Know for $\gamma^{(*)}p$: $\sigma_{\gamma p}$, $\sigma_{\text{DIS}-p}$ have different $\alpha$'s: $\sigma \propto W^\alpha (W = \gamma^{(*)}p$ c.m. energy)
- Assume same $\alpha$'s for $\sigma_{\gamma \pi}$, $\sigma_{\text{DIS}-\pi}$
- Also: $W^2_\pi = (1-x_L)W^2_p$
- $\Rightarrow$ scale absorption ratio by $(1-x_L)^{-0.1}$
- Nice agreement with data
Comparison $\gamma p$/DIS: $p_T^2$ distributions

- Small but clear difference: $b(\gamma p) > b(\text{DIS})$ for $0.6 < x_L < 0.9$
- Qualitatively consistent w/ absorption:
  more abs. @ small $r_{n\pi} \sim$ large $p_T$
- Quantitative comparison: next speaker
Comparison: LN & leading protons

- DIS $x_L$ distribution $p_T^2 < 0.04$ GeV$^2$:

  ![Graph showing DIS $x_L$ distribution for LN and LP]

  - For pure isovector exchange isospin Clebsch-Gordan $r_{LP} = \frac{1}{2} r_{LN}$
  - $r_{LP} > r_{LN} \Rightarrow$ other exchanges needed

- DIS b-slopes:

  ![Graph showing DIS b-slopes for LN and LP]

  - Different exchanges conspire to give $\sim$flat $b(x_L)$ for LP
Comparison: OPE models

- Numerous parameterizations of pion flux $f_{\pi/p}(x_L, p_T)$ in literature
- Here compare to measured DIS $b(x_L)$:
- Best agreeing models shown here; others wildly off
- All give too large $b(x_L)$
- More refinement needed: absorption, migration
Comparison: OPE w/ absorption

- Recent work of Kaidalov, Khoze, Martin & Ryskin:
  - start with pure OPE
  - some $n$ rescatter on $\gamma$
  - rescattered $n$ migrate in $(x_L, p_T)$

- Very nice agreement with LN in $\gamma p$:

- Much more next speaker
Comparison: non-OPE MC models

- Compare to several popular MC models w/o OPE
  (i.e. RAPGAP in standard mode)
- ~default settings for all models
- Here compare to DIS $x_L$ distribution:
  - LEPTO ~OK in shape, magnitude
  - Others too few $n$, too low $x_L$
Comparison: non-OPE MC models

- Intercepts in DIS:
  - LEPTO ~hint of shoulder high $x_L$
  - Others wrong dependence, too low for $x_L > 0.5$

- Slopes in DIS:
  - No models have the steep $b(x_L)$ in the data
Summary

- Best measured LN $x_L, p_T$ distributions in DIS, $\gamma p$
- Comparison DIS$\leftrightarrow\gamma p$: evidence for absorption of $n$ in large $\gamma$
- Pure OPE does not fully describe data
- More refined calculations: OPE+absorption+migration
  $\Rightarrow$ very promising agreement with data (next speaker)
- MC models with 'standard' fragmentation do not describe the data (LEPTO has some promise)