General Search for New Phenomena in ep Scattering at HERA

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Motivation & Strategy

- many dedicated searches for new physics models (LQ, LFV, FCNC, SUSY, …)
- some model-independent searches in exclusive final states (lepton production)

But: Are we missing something?

- investigate all final states produced at high $P_T$ in $ep$ collisions
- do not rely on assumptions about characteristics of a SM extension

- considered particles
  - electron, photon, muon, jet, neutrino
- common phase space
  - $P_T > 20$ GeV
  - $10^\circ < \theta < 140^\circ$
- classification of events into exclusive classes
  - $e$-$j$ or $\mu$-$\nu$-$j$ or $j$-$j$-$j$-$j$
- systematic search for deviations using dedicated statistic algorithm
General Search @ H1

Data samples

- $e^-p \approx 15 \text{ pb}^{-1}$
- $e^+p \approx 105 \text{ pb}^{-1}$

HERA II (2002-2007)
- $e^-p \approx 160 \text{ pb}^{-1}$
- $e^+p \approx 200 \text{ pb}^{-1}$

- HERA II: large $e^-p$ data sample (GS 2005/06 e^-p, Preliminary)
General Search needs SM prediction for all ep processes

- **neutral current DIS** \( ep \rightarrow eX \)
- **charged current DIS** \( ep \rightarrow \nu X \)
- **photoproduction** \( \gamma p \rightarrow X \)
- **lepton pair production** \( ep \rightarrow e\ell X \)
- **QED Compton** \( ep \rightarrow e\gamma X \)
- **W production** \( ep \rightarrow eWX \)

QCD processes: \( O(\alpha_s) + \text{PS} \) or QED processes: \( O(\alpha^2) + \text{PS} \)
Event Yields

HERA I (117 pb⁻¹)

HERA II e⁻p (159 pb⁻¹)

→ good agreement for most event classes
→ some deviations
Multi-Jet Final States

First analysis investigating ≥4 jet final states at high $P_T$

- slight overshoot of data in j-j-j-j-j class
- one event found in j-j-j-j-e and j-j-j-j-ν classes

⚠ dominant SM contributions (γP, NC/CC DIS) contain two jets produced by PS

1. Is the j-j-j-j-X MC prediction reliable?
   - tests using low $P_T$ γP and DIS samples show an adequate description of distributions

2. Does used MC prediction contain all relevant SM processes?
   - MC prediction yields only $\sim 10^{-4}$ events in tails of distributions $\rightarrow \sigma$ of $O(10^{-3} \text{ fb})$
   - rare SM processes might contribute (ep→eWWX)
   - j-j-j-j-X classes excluded from search for deviations
systematic search for deviations between data and SM prediction in differential (1-dim) distributions with high sensitivity to BSM signals

\[ M_{all} : \text{invariant mass of objects} \quad \sum P_T : \text{sum of transverse momenta} \]

dedicated statistical algorithm:

1. **regions of most interest**
   search region of largest deviation in given histogram

2. **event class of most interest**
   weigh up significance of deviations found

3. **global significance**
   decide if “event class of most interest” is interesting at all
1. Region of Largest Deviation

- scan all possible connected regions with size ≥ resolution and calculate probability $p$ that data agrees with SM

- region of most interest is that with smallest probability $p = p_{\text{min}}$

$N_{\text{obs}} = 3$

$N_{SM} = 0.5 \pm 0.2$

$p_{\text{min}} = 0.02$

excess region

$N_{\text{obs}} = 1$

$N_{SM} = 6.4 \pm 3.9$

$p_{\text{min}} = 0.10$

deficit region
2. Event Class of Most Interest

determine a measure of the deviations’ statistical significance which allows to compare event classes

What is the probability \( \hat{P} \) to observe a deviation with \( p < p_{\text{min}} \)?

- dice hypothetical histograms \( H_{\text{hyp}} \) according to pdf of SM expectation
- for each \( H_{\text{hyp}} \) run the algorithm to find region of largest deviation: \( p_{\text{min}}^{\text{hyp}} \)

\[
\hat{P} = \frac{\text{num } H_{\text{hyp}} \text{ with } p_{\text{min}}^{\text{hyp}} < p_{\text{min}}^{\text{data}}}{\text{tot num } H_{\text{hyp}}}
\]

\( \hat{P} \) is measure for significance of \( p_{\text{min}}^{\text{data}} \)

event class of most interest is that with smallest \( \hat{P} \) value
3. Global Significance

- take into account that small $\hat{P}$ values (have to) occur among the multiplicity of studied event classes

- What would be the outcome if we could redo the experiment?

- replace data histograms with MC pseudo-data and determine according $\hat{P}_{MCE}$ values

$$\hat{P}_{MCE} = \frac{\text{num } H_{hyp} \text{ with } p_{hyp} < p_{pseudo} \text{ min}}{\text{tot num } H_{hyp}}$$

- expectation for data $\hat{P}$ values is given by distribution of $\hat{P}_{MCE}$ from multiple MC experiments
all event classes have systematically been scanned for deviations

allows quantification of overall agreement between HERA data and SM
**Search Results**

**HERA I (117 pb⁻¹)**

**HERA II e⁺p (159 pb⁻¹)**

- **μ⁻j⁻ν:** ~3% of MC experiments would produce a deviation more significant
- No event classes with remarkably small $\hat{P}$ values observed

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Sensitivity to New Physics

- pseudo data samples have been used to test sensitivity to new physics

**Example**
- anomalous top production via FCNC

![Diagram of anomalous top production](image)

- event classes sensitive on $t \rightarrow bW$ decay considered ($j-j-j, e-j-\nu, \mu-j-\nu$)
- $-\langle \log \hat{p} \rangle$ as function of top production cross-section investigated

**Sensitivity to Anomalous Top Production**

- largest sensitivity for $\Sigma P_T$ scan in $j-j-j$ event class:
  $-\langle \log \hat{p} \rangle$ of 2 for $\sigma_{\text{top}} \sim 0.5$ pb
- all 3 event classes with $-\langle \log \hat{p} \rangle$ be above 3 for $\sigma_{\text{top}} \sim 1.5$ pb

**H1:** $\sigma_{t \rightarrow bqq} < 0.48$ @ 95% CL
Summary

• a model-independent search for new physics signals is performed at HERA using all possible final state configurations at high $P_T$

• no significant deviation has been observed

• factor 2 increase in $e^+p$ data sample expected: watch the unexpected!