Searches for New Physics in ep Scattering at HERA

The 41st Rencontres de Moriond on

ELECTROWEAK INTERACTIONS AND UNIFIED THEORIES

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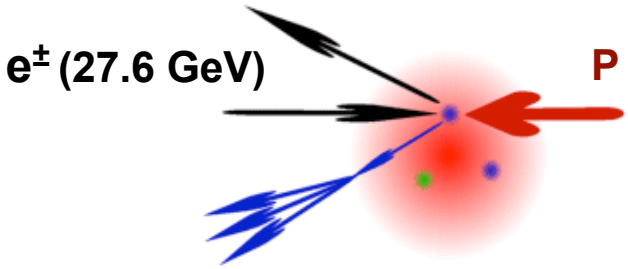
on behalf of the H1 and ZEUS collaborations

Electron-Proton Scattering at HERA



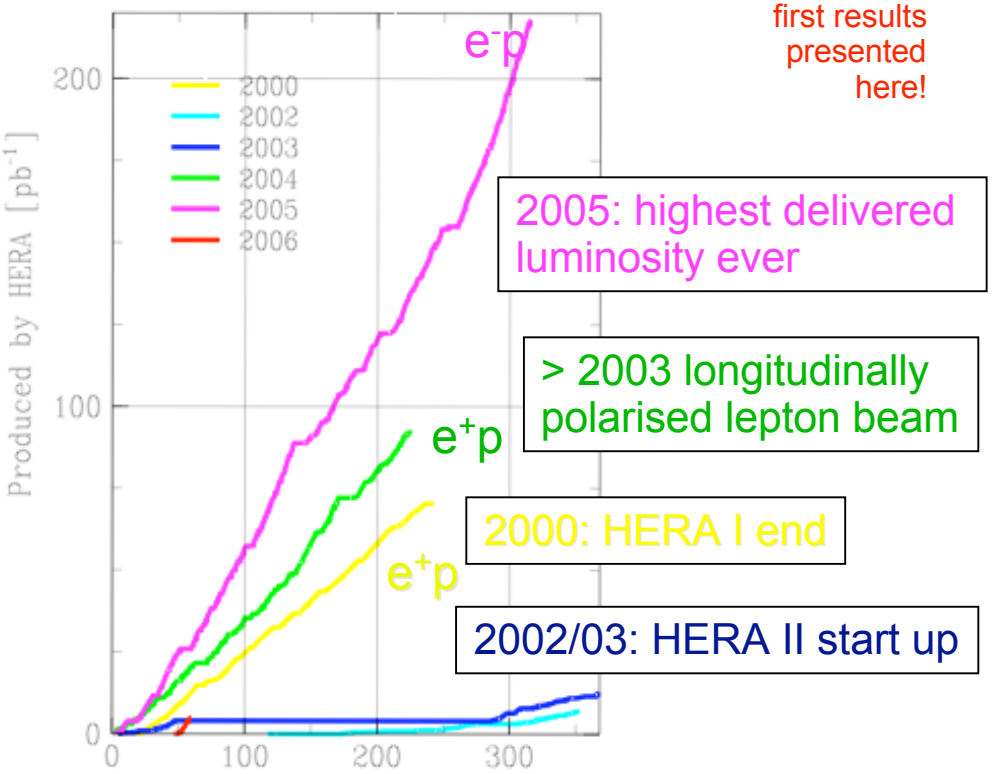
The HERA collider

- ***$e^{\pm}p$ scattering at E_{cm}= 300/320 GeV***
- ***Two colliding experiments: H1/ZEUS***

Data samples

HERA I (1992-2000)	HERA II (2002-2005)
• e^-p: L ≈ 15 pb^{-1}	• e^-p: L ≈ 130 pb^{-1}
• e^+p: L ≈105 pb^{-1}	• e^+p: L ≈ 50 pb^{-1}

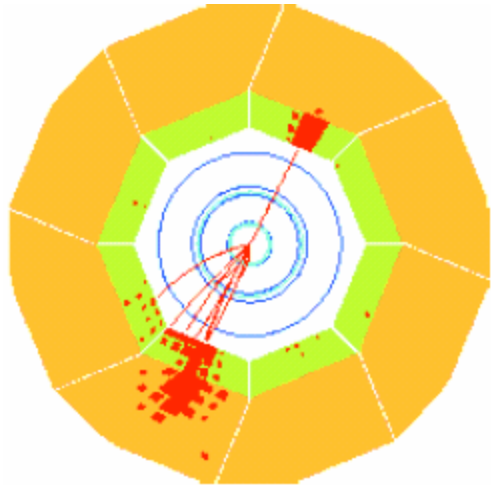
first results presented here!



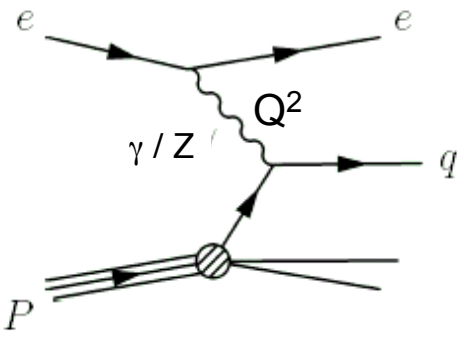
Dominant Processes at High P_T

Neutral Current (NC) DIS

$e\,p \rightarrow e\,j$

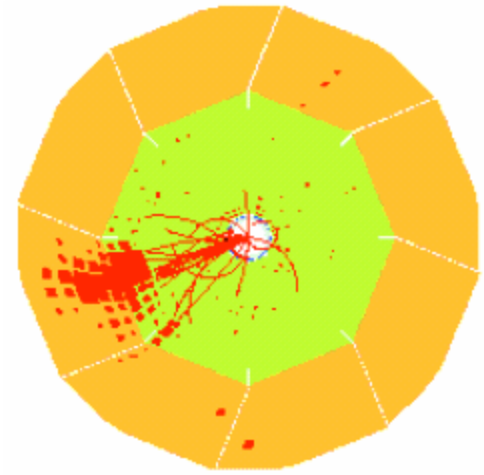


$Q^2 > 4$ GeV

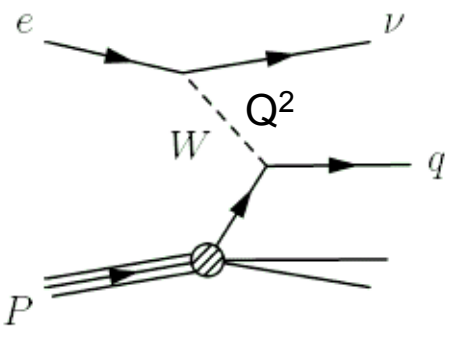


Charged Current (CC) DIS

$e\,p \rightarrow \nu j$

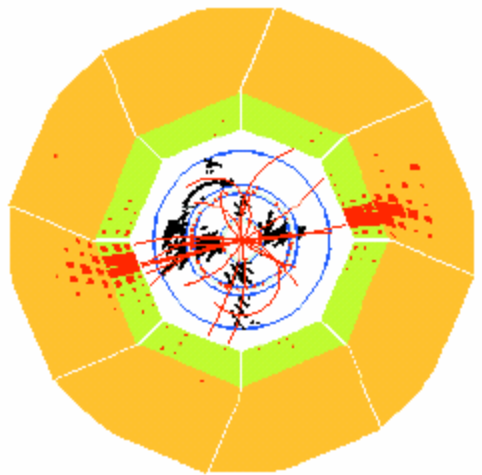


$Q^2 > 4$ GeV

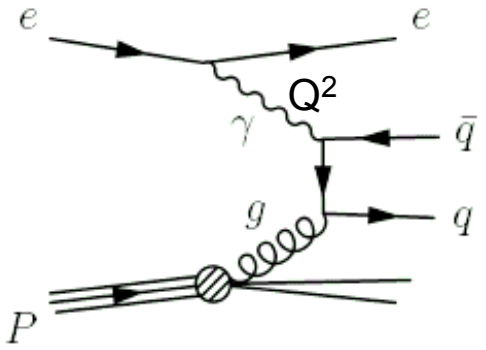


Photoproduction (γP)

$\gamma p \rightarrow j\,j$



$Q^2 \approx 0$ GeV



Searches at HERA

Model-dependent searches

Test models, verify predicted signatures and phase space

- Leptoquarks and LFV
- Excited Fermions
- Single Top Production
- Doubly Charged Higgs
- Supersymmetry

Model-independent searches

Compare data versus SM, reveal anomalies above small SM contribution

- Isolated Leptons and Missing P_T
- Multi Lepton Production
- General Search

Searches in inclusive DIS

Precision measurements allow for stringent constraints on new physics

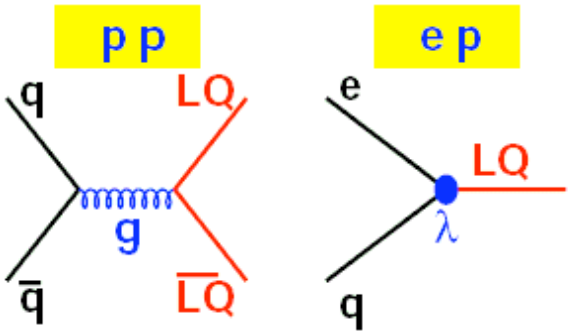
- NC: Quark Radius, CI, Extra-Dimensions
- CC: Polarization Dependence (HERA II)

Topics in in red covered in this talk

Leptoquarks

Motivation

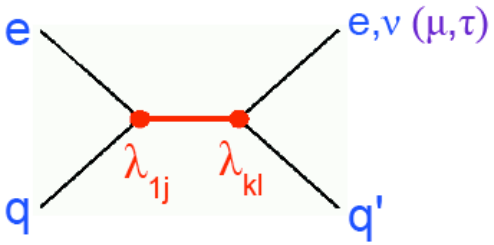
- Symmetry of quark and lepton generations raises the question of direct interactions
  → Connection: Leptoquarks
- LQs appear in many extensions of the SM
- Scalar or vector bosons with Lepton (L) and Baryon (B) number and fractional em. charge
- Define Fermion number F = 3B + L



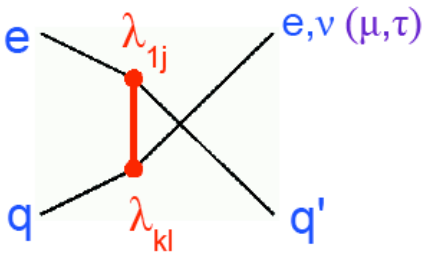
LQ at HERA: single production

Production and Decay

- $M_{LQ} < E_{cm}$: resonant production is dominant (s-channel)
- $M_{LQ} > E_{cm}$: u-channel contributes, transition to contact interactions
- Only 1st generation present in both production and decay
  → Interference with SM DIS
- Lepton flavour violating (LFV) process for muon or tau in final state (k≠1)



s-channel



u-channel

γ_{ij}: Yukawa coupling, family indices i j

Leptoquark Limits

H1 Coll., Phys. Lett. B629 (2005) 9; ZEUS Coll., Phys. Rev. D 68, 052004 (2003)

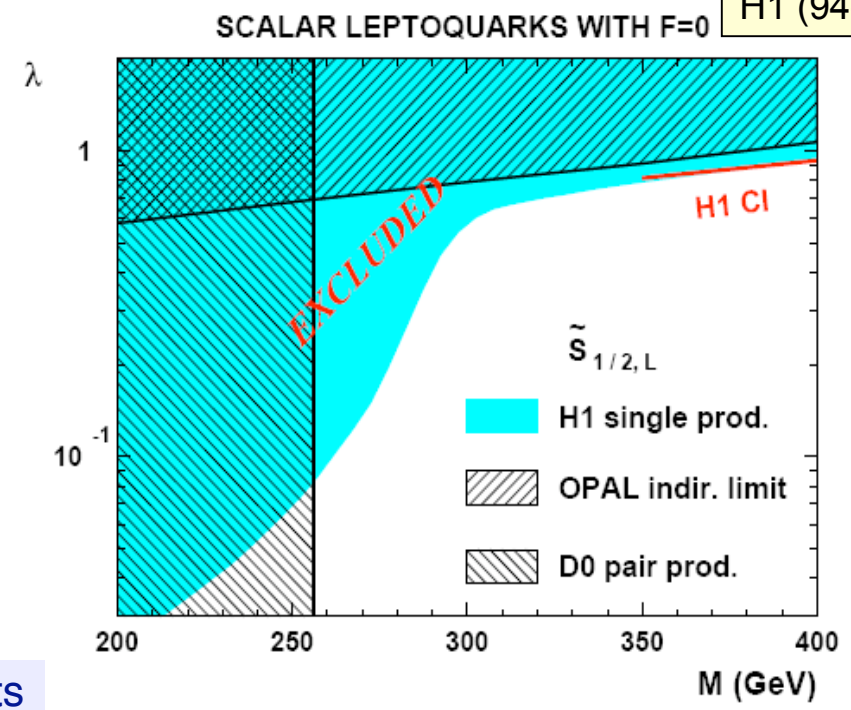
Search for 1st generation LQs

- H1 and ZEUS HERA I (94-00)
  - Lumi: e^+p (~100 pb^{-1}), e^-p (~15 pb^{-1})
  - LQ: F = 0 F = 2
- Largely complementary data set
- Processes:

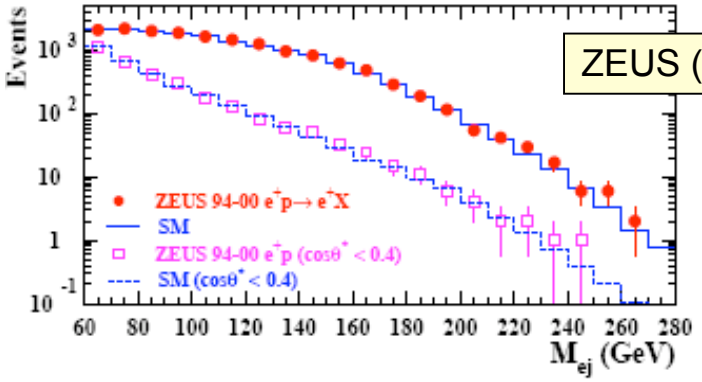
Topology	SM Background
e + jet	Neutral Current DIS → exploit angular dist. of LQ decay
ν + jet	Charged Current DIS

→ No evidence for signal by both experiments

H1 (94-00) e^+p



ZEUS (94-00) e^+p



θ^*: lepton scattering angle in l-jet CM frame

- Limits set on 14 types of LQ described by the BRW model (notation: $J^{L,R}_{Isospin}$)
- For couplings of em. strength ($\lambda \sim 0.3$): mass exclusion ~ 280 GeV
- Similar limits obtained by ZEUS
- HERA sensitivity at high M and high λ

LFV Leptoquarks

ZEUS Coll., Eur. Phys. J. C44 (2005) 463

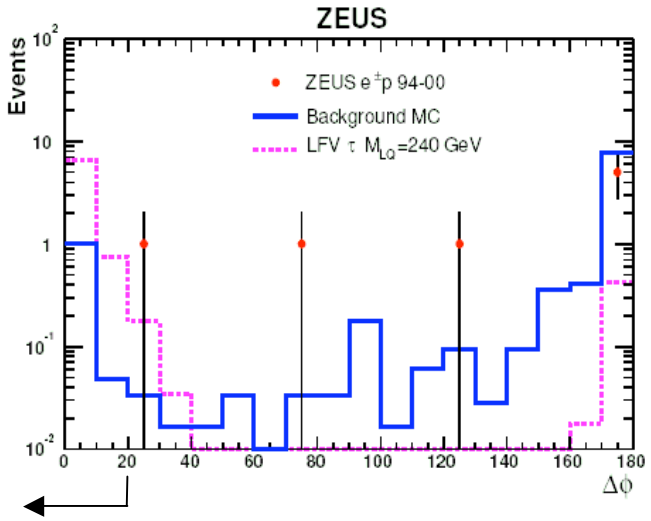
Search for LFV LQ decays

- Look for ep → μ + jet and ep → τ + jet
- Low background, high sensitivity

ZEUS (94-00)
130 pb^{-1}

Topology		$N_{observed}$ / $N_{background}$ LQ Selection
ep → μ + jet		**0 / 0.87 ± 0.15**
ep → τ + jet	τ → e / μ + P_T^{miss}	**0 / 0.43 ± 0.08**
	τ → had+ P_T^{miss}	**0 / 1.1 ± 0.5**

- No evidence for signal found



LQ selection
ΔΦ < 20°

ΔΦ Azimuthal angle between τ-jet and P_T^{miss} vector

Limits on LFV LQ decays

- For $M_{LQ} < E_{cm}$ limits on $\lambda_{eq} \times \sqrt{\beta_{\mu\tau,\, q'}}$
- For $M_{LQ} > E_{cm}$ limits on $\lambda_{eq}\, \lambda_{lq'} / M^2_{LQ}$

→ Compare searches for LFV B decays, e.g:

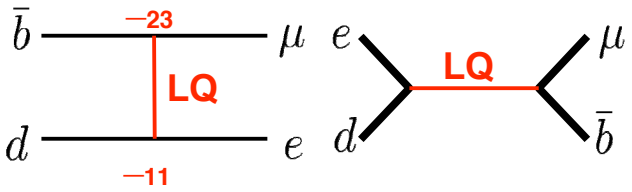
- Limits on $\lambda_{eq\_\alpha}\, \lambda_{lq\_\beta} / M^2_{LQ}$ in units of TeV^{-2}

ed → μb

eb → τs

1 3	*	$B \to \mu\bar{e}$ 0.4 **1.8**	$B \to \mu\bar{e}$ 0.4 **1.9**
3 2	*	$B \to \tau\bar{e}X$ 14 **11**	$B \to \tau\bar{e}X$ 14 **10**

Br(B_d → eμ) < 1.7 10^{-7}
Belle, PRD68 (2003) 11101

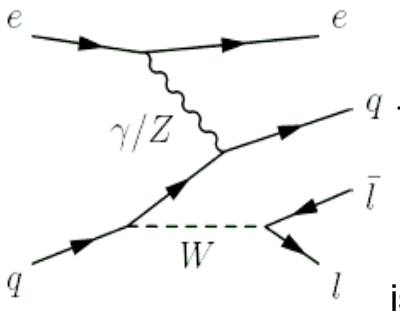


→ Several examples where DIS constraints are competitive with those from rare B decays

Isolated Leptons and Missing P_T

Event Topology: ep → l + P_T^{miss} (+ jet)

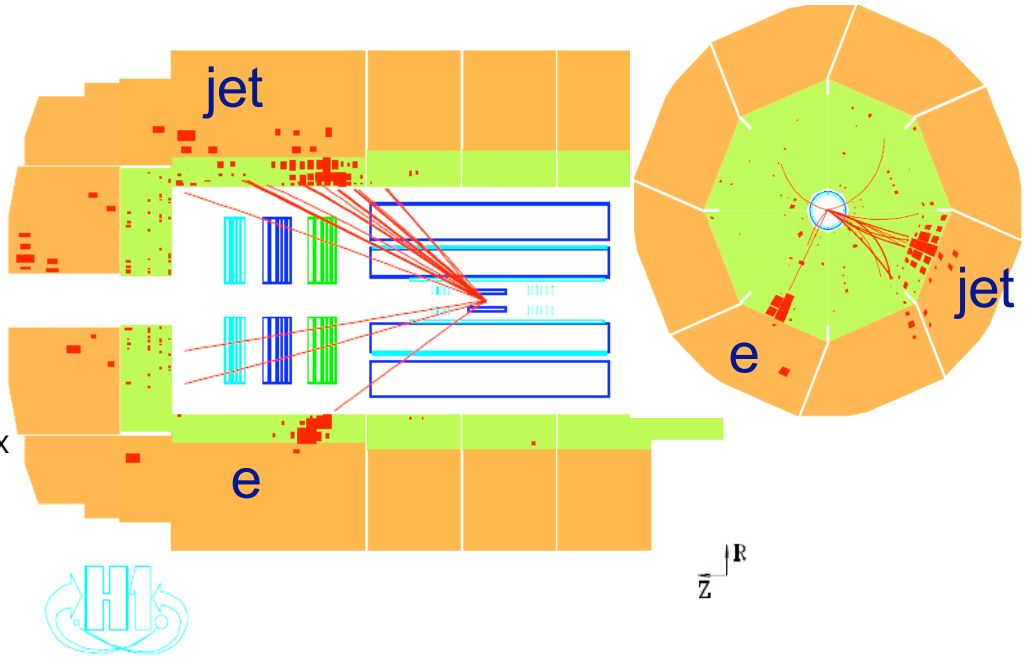
- High P_T isolated lepton (e, μ, τ)
- Large missing P_T
- P_T of hadronic system X



jet, hadronic system P_T^X

neutrino P_T^{miss}

isolated lepton P_T^l



SM Process: ep → e $W^{\pm}$ (→lν) X

- Real W production with leptonic decay
- Usually soft hadronic system
- Total cross section ~ 1 pb

Backgrounds:

- NC DIS: real lepton and fake P_T^{miss}
- CC DIS: real P_T^{miss} and fake lepton
- Pair Production: real lepton and fake P_T^{miss}

“Anomalous” W production

H1 Coll., Phys. Lett. B561 (2003) 241; ZEUS Coll., Phys. Lett. B559 (2003) 153, Phys. Lett. B583 (2004) 41

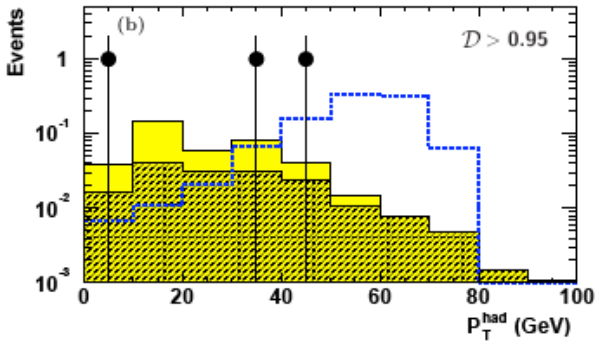
HERA I:

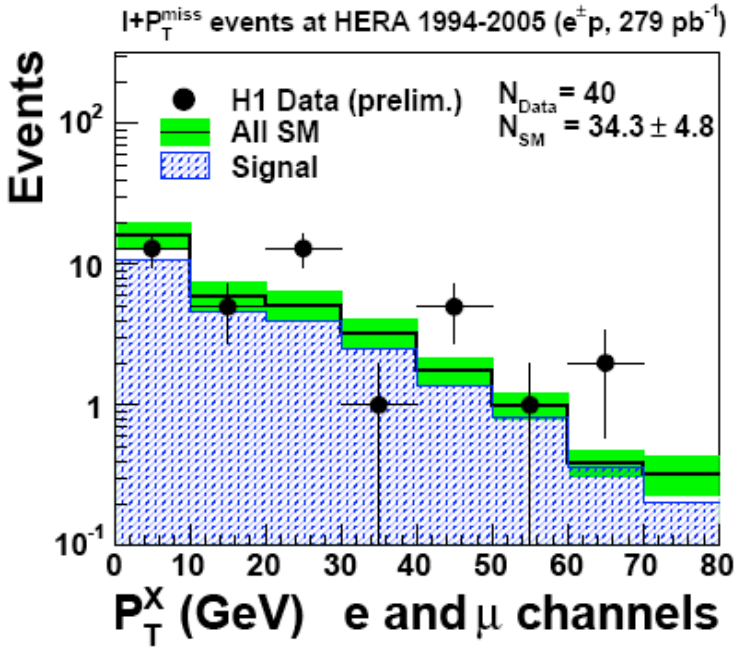
- H1: excess of observed events at high P_T^X (e,μ); τ channel agrees with SM
- ZEUS: e,μ channels agree with SM, but 2 spectacular τ events at high P_T^X

$P_T^X > 25$ GeV	combined e & μ
H1 94-00 118 pb^{-1}	**11 / 3.4 ± 0.6**

$P_T^X > 25$ GeV	τ channel
ZEUS 94-00 130 pb^{-1}	**2 / 0.2 ± 0.1**

ZEUS PLB 583 (2004)





H1/HERA II:

- Events still show up in HERA II with higher rate compared to the SM prediction

$P_T^X > 25$ GeV	e channel	μ channel	combined e & μ
H1 94-05 279 pb^{-1}	**11 / 4.7 ± 0.9**	**6 / 4.3 ± 0.7**	**17 / 9.0 ± 1.5**
ZEUS 99-04 106 pb^{-1}	**1 / 1.5 ± 0.2**	ZEUS previous search: 7 / 5.7 (e,μ) (HERA I, 130 pb^{-1}, W 45%)	

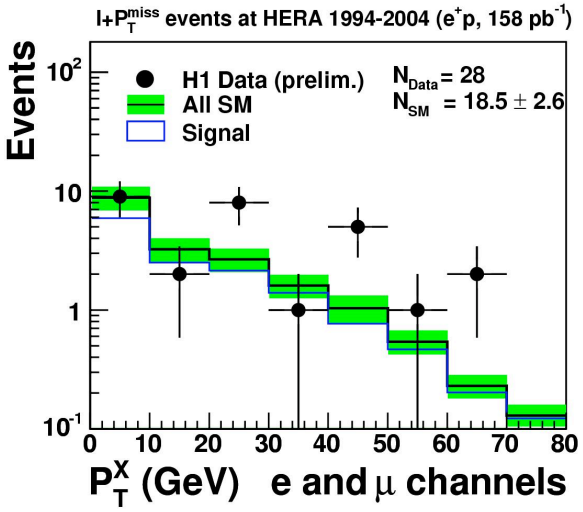
ZEUS/HERA I revised:

- New ZEUS analysis closer to H1 cuts
- Events still not observed in ZEUS data
- ZEUS and H1 SM expectations agree

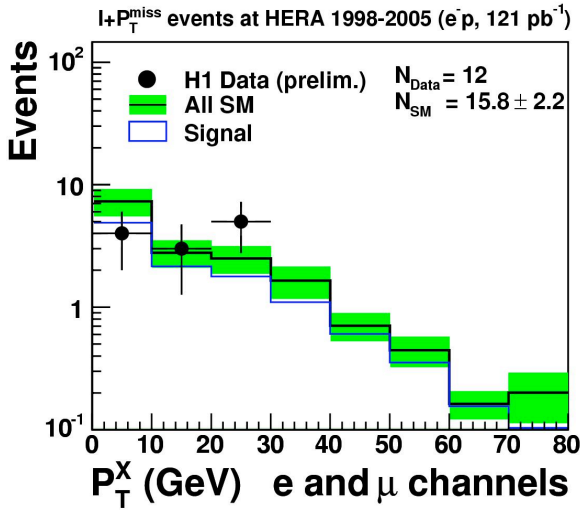
Isolated Leptons: Prospects

The lepton beam charge dependence

H1 e^+p data



H1 e^-p data

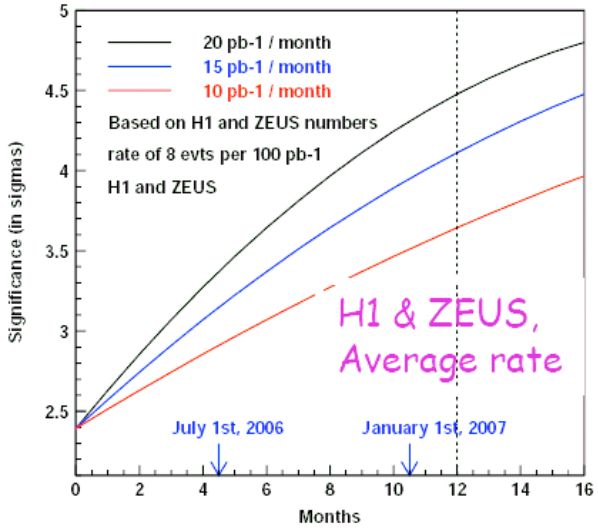


$P_T^X > 25$ GeV	e channel	μ channel	combined e & μ
H1 94-04 e^+p 158 pb^{-1}	**9 / 2.3 ± 0.4**	**6 / 2.3 ± 0.4**	**15 / 4.6 ± 0.8**
H1 98-05 e^-p 121 pb^{-1}	**2 / 2.4 ± 0.5**	**0 / 2.0 ± 0.3**	**2 / 4.4 ± 0.7**

- H1 excess only appears in e^+p data
- Asymmetry or statistical fluctuation (3.4 σ)?

Extrapolation for e+p data

- Assume upward / downward fluctuation for H1 / ZEUS
- Take average rate from H1 and ZEUS in e-channel: 4 events per 100 pb^{-1}
- Take same rate for μ channel



A 4 - 5 σ effect might be seen with the full HERA II data set

Anomalous Single Top Production

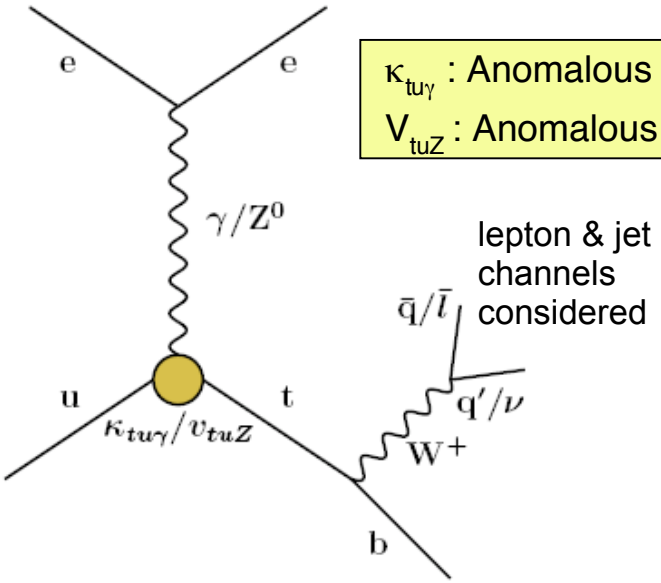
H1 Coll., Eur. Phys. J. C33 (2004) 9; ZEUS Coll., Phys. Lett. B559 (2003) 153

H1 excess of events with isolated high P_T lepton (e,μ) and large P_T^{miss} at high P_T^X

- High P_T^X improbable for W production
- But typical signature of top decay t → bW
- Tiny SM top prod. cross section < 1 fb

→Anomalous top production via FCNC ?

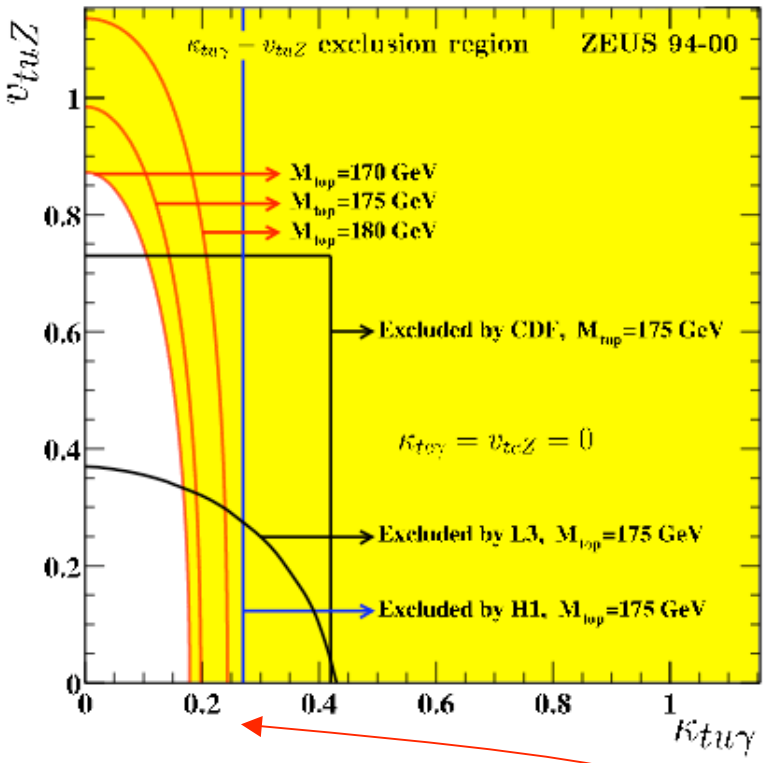
(but could not explain e^+p / e^-p difference)



lepton & jet channels considered

$\kappa_{tu\gamma}$: Anomalous magnetic coupling

V_{tuZ} : Anomalous Z vector coupling



H1 / HERA I (118 pb^{-1}): 5 / 1.31 ± 0.22 top-like events

- σ(ep → etX) < 0.55 pb (95% CL)

ZEUS / HERA I (130 pb^{-1}): no evidence

- σ(ep → etX) < 0.225 pb (95% CL)

HERA competitive!

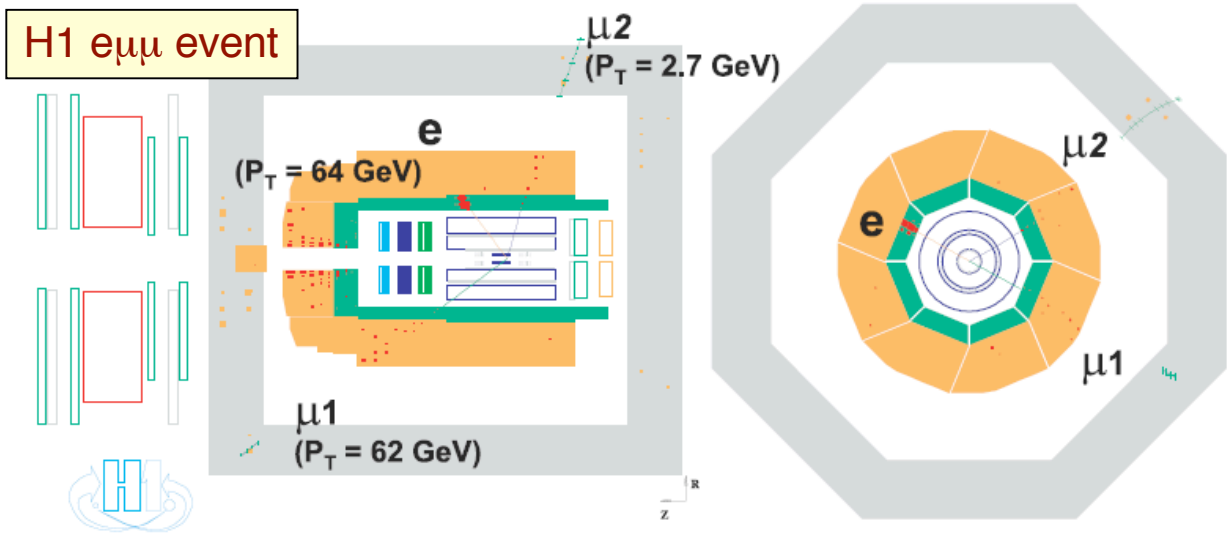
Multi Lepton Production

H1 Coll., Eur. Phys. J. C31 (2003) 17

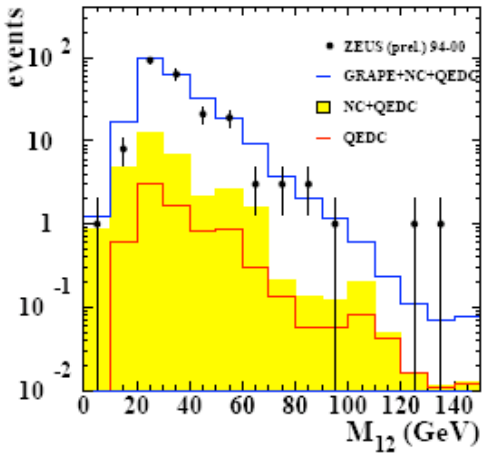
Motivation: If anomalous l-ν production, what about l-l final states?

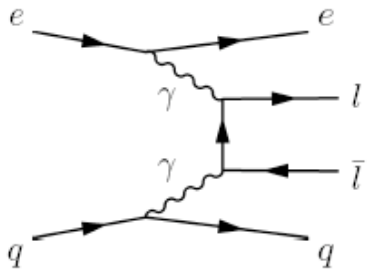
→ Search for events with at least 2 isolated high P_T leptons (e, μ)

H1 eμμ event



ZEUS Preliminary





Dominant SM process:

- Two-photon interaction

Backgrounds:

- Misidentified hadrons, photons from NC DIS and QED Compton

HERA I

M_{12} > 100 GeV	2e channel	3e channel
H1 94-00 115 pb^{-1}	**3 / 0.30 ± 0.04**	**3 / 0.23 ± 0.04**
ZEUS 94-00 131 pb^{-1}	**2 / 0.77 ± 0.08**	**0 / 0.37 ± 0.04**

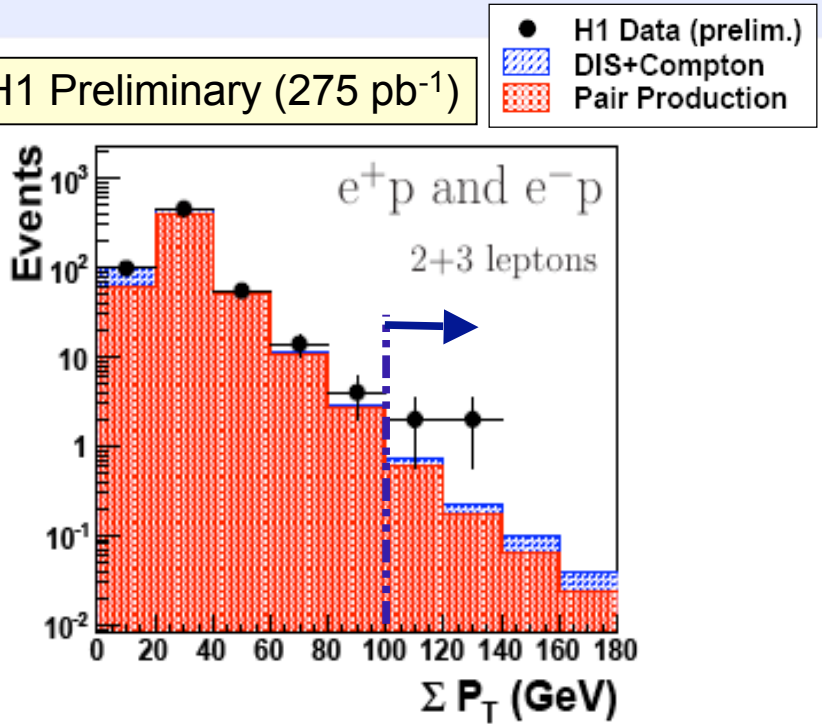
- H1 excess of 2e and 3e events at high M_{12} (mass of two highest P_T electrons)
- No such excess seen in the ZEUS data

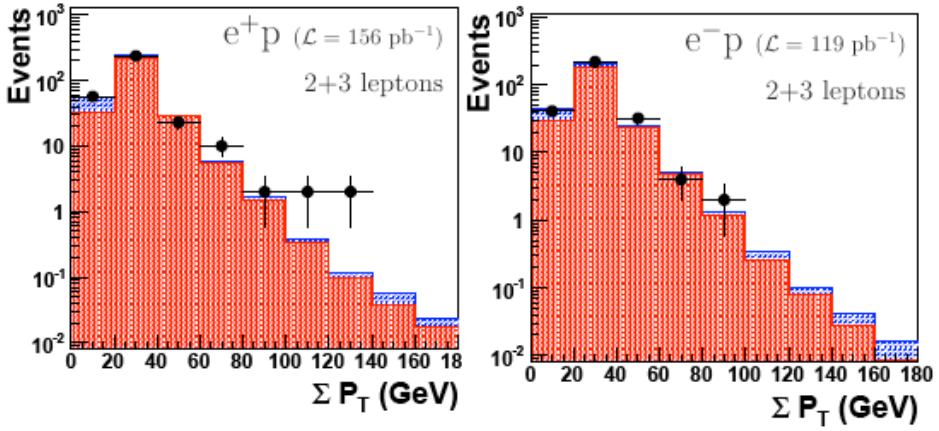
Multi Lepton Production

H1/HERA II

- Analysis extended to 2003-05 data
- Consideration of other 2 lepton and 3 lepton topologies (now ee, μμ, eμ, eee, eμμ)
- No new 2e/3e event at high M_{12}
- One new eμμ event at $M_{\mu\mu} > 100$ GeV
- One new eμμ event at $M_{e\mu} > 100$ GeV

H1 Preliminary (275 pb^{-1})





Scale of Multi Lepton Production

- ΣP_T = scalar sum of transverse momenta
- Altogether at $\Sigma P_T > 100$ GeV

$N_{observed} = 4 / N_{SM} = 1.1 \pm 0.2$

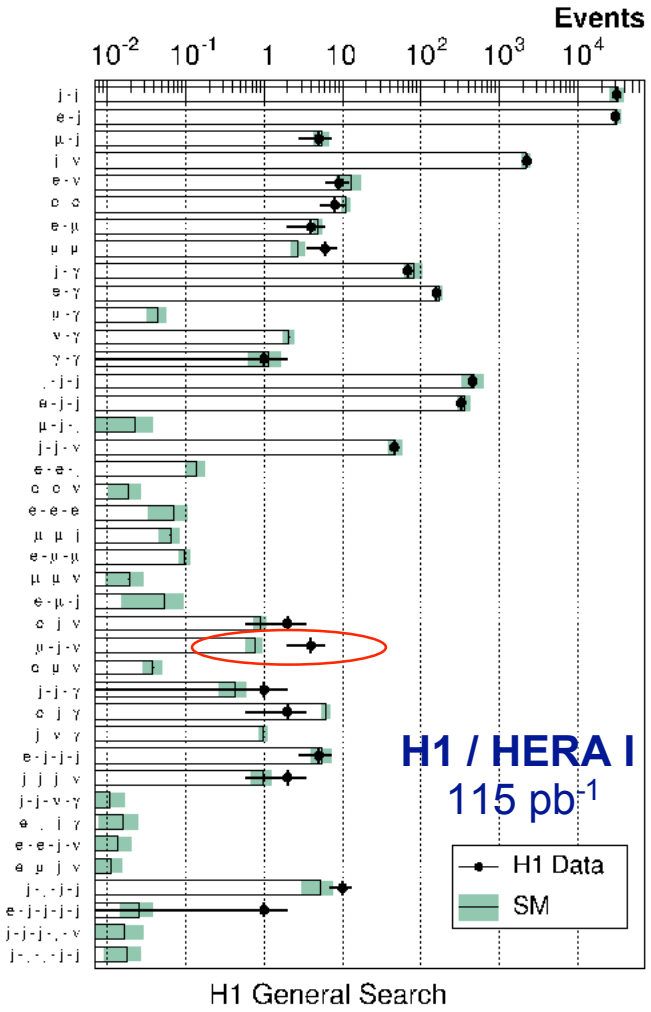
- Highest ΣP_T events appear in e^+p collisions

A General Search for New Phenomena

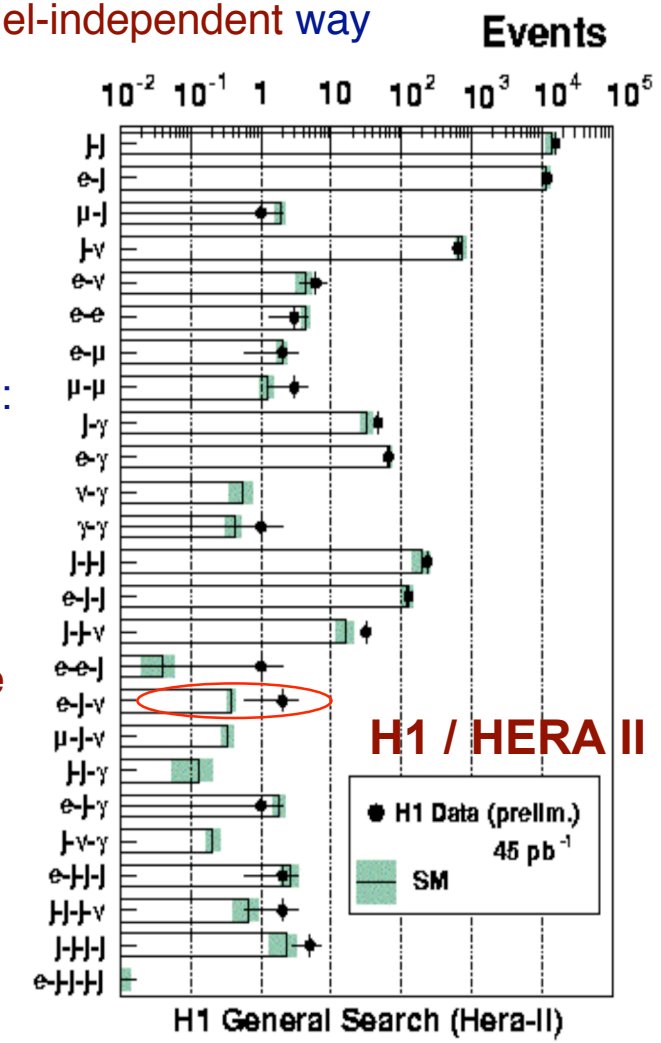
H1 Coll., Phys. Lett. B602 (2004) 14

Motivation

- Study all high P_T final states in a single and coherent analysis
- Search for deviations from the SM in a model-independent way

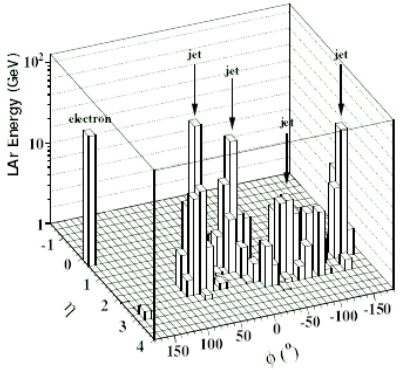


- Identify isolated particles at high P_T: e, μ, γ, jet ν
- Unique phase space: $P_T > 20$ GeV, $10° < \theta < 140°$
- Classification of events into exclusive classes
- Overall good agreement
- Some deviations found



A General Search for New Phenomena

H1 Coll., Phys. Lett. B602 (2004) 14



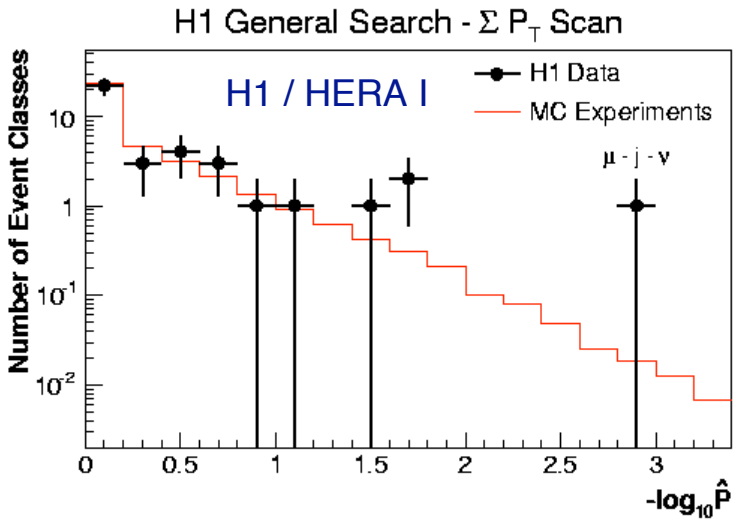
Interesting Event

- e-j-j-j-j class: 1 / 0.03 ± 0.01 (M_{inv}=262 GeV)
- At high mass NC DIS prediction only ~10^{-3} fb
- Rare SM processes might contribute, e.g. ep → eWWX

Statistical quantification

- Systematic scan for deviations in M_{inv} / ΣP_T spectra of all event classes using dedicated statistical algorithm
- P quantifies significance of deviations found
- Lepton-jet-P_T^{miss} anomaly reappeared: μ-j-ν

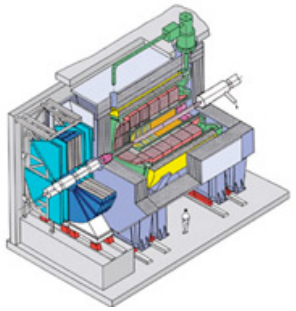
General Search ideally suited to discover unexpected manifestations of new physics (watchdog)



Requirement: precise knowledge of overall detector performance

Summary

- Much activity and a lot of progress in BSM physics at HERA promoted by better understanding of the data, improved analysis techniques and new ideas
- Results often competitive and complementary to other colliders
- Some puzzling fluctuations which will need final clarification with most precise analysis
- HERA II - large part of the lumi still to come!



→ More interesting results from HERA expected in near future