Amita Raval
Penn State University
ZEUS & H1 Collaborations

WIN07
SINP, Kolkata
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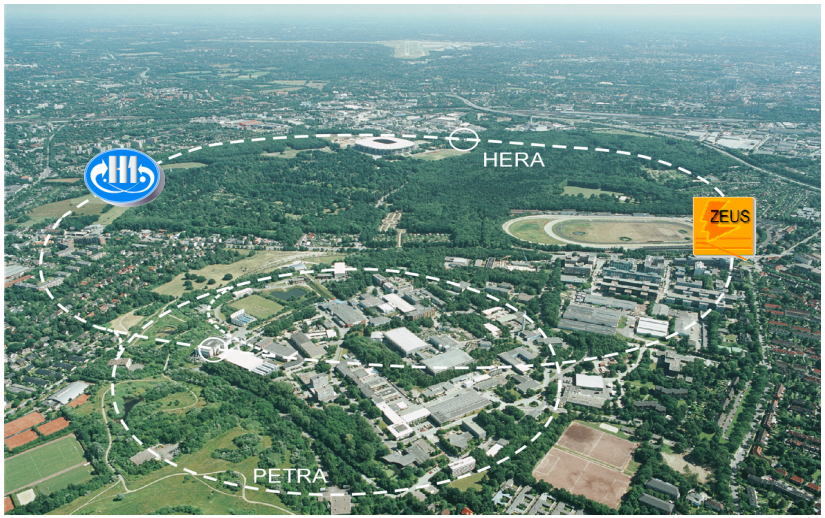
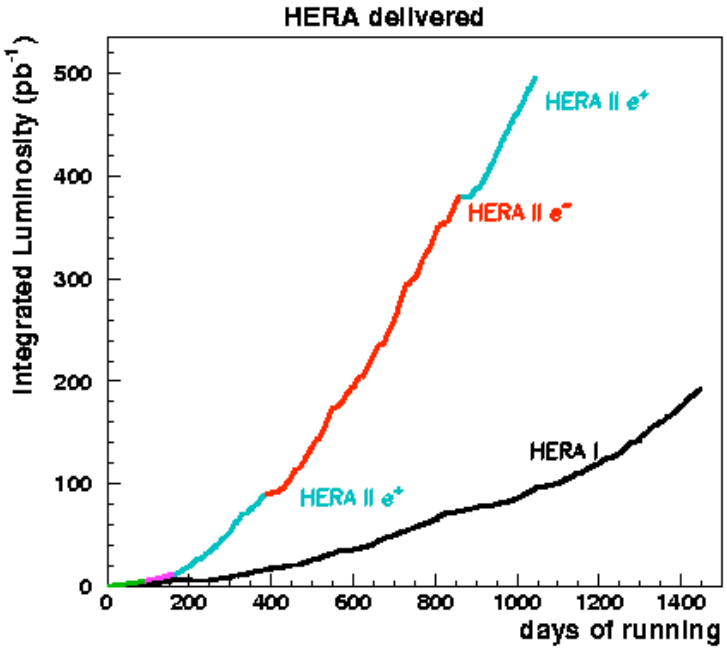
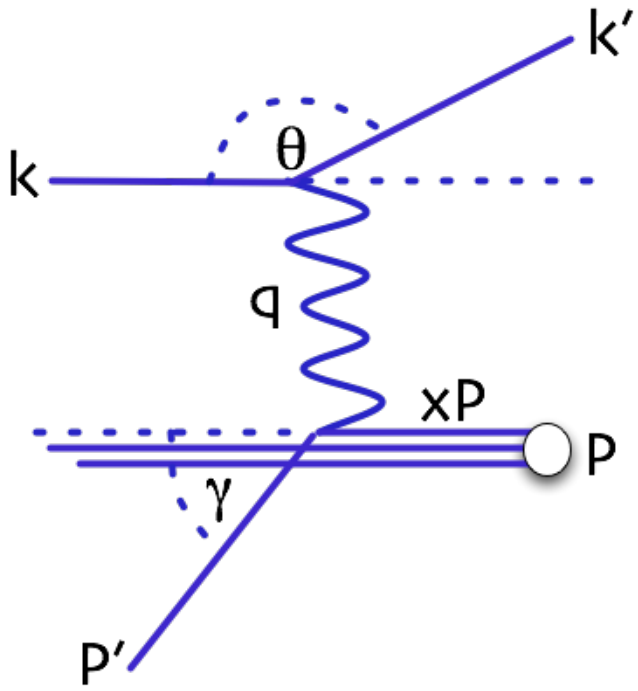
Searches for physics beyond the Standard Model at HERA

Introduction





Introduction



Two deep inelastic scattering processes:

- Neutral current: exchange of γ or Z°
- Charged current: exchange of W±

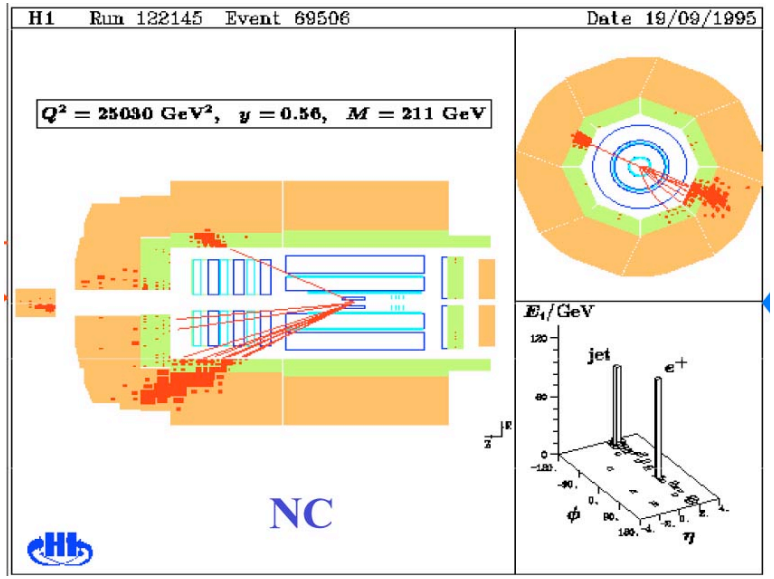
$$Q^2 = -q^2 = -(k - k')^2$$

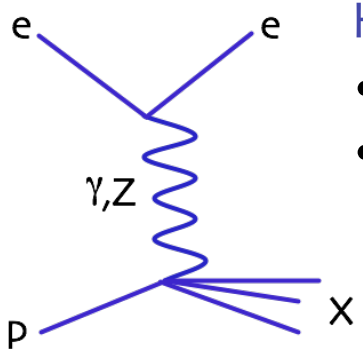
$$x = \frac{Q^2}{2p \cdot q} \qquad y = \frac{p \cdot q}{p \cdot k}$$

$$s = (p + k)^2 \qquad Q^2 = x \cdot y \cdot s$$

Q^2 is the probing power
x is the Bjorken scaling variable
y is the inelasticity

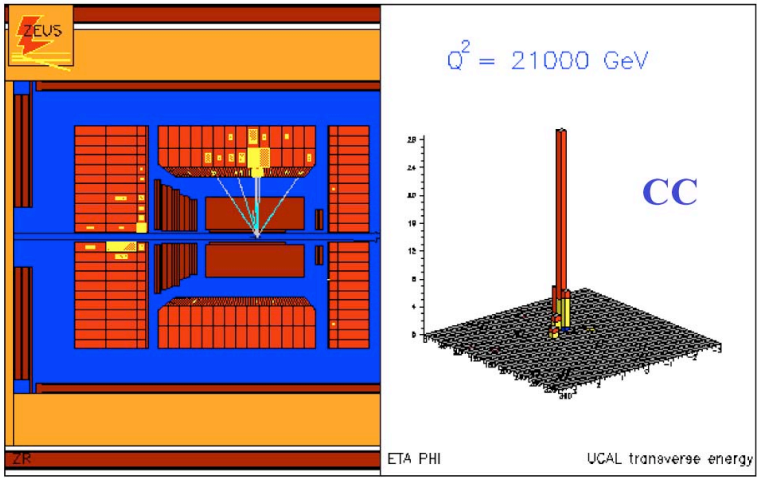
Introduction

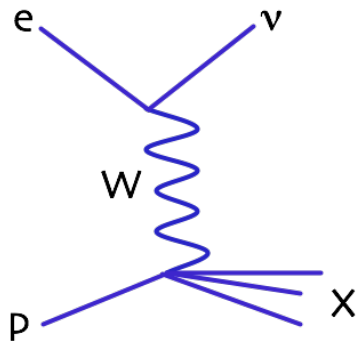




H1

- Liquid argon calorimeter
- Optimized for precision measurement of scattered electron





ZEUS

- Depleted uranium calorimeter
- Optimized for precision measurement of hadronic final state

Searches at HERA

Model dependent searches

- Leptoquarks
- Lepton flavor violation
- Excited fermions
- Single top production
- Doubly charged Higgs
- Supersymmetry

Model independent searches

- Events with isolated leptons and missing E_T
- Tau production
- Multi-lepton production
- Magnetic monopoles
- General searches

Limits from precision measurements

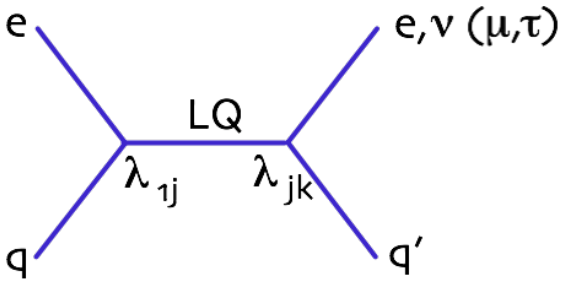
- NC DIS: CI, LEDs, quark radius
- CC DIS: Right-handed weak currents

Topics in blue covered in this talk (Inclusive measurements covered by Eram Rizvi yesterday)

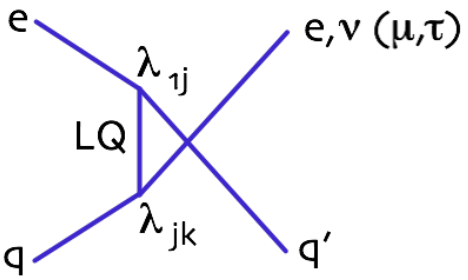
Leptoquarks

Motivation: LQs appear in many BSM theories eg. Technicolor and composite models

- Scalar and vector leptoquarks carry lepton number L and baryon number B
- BRW classification: 7 scalar and 7 vector LQs (notation $J_{I,L/R}$)
- Define fermion number F = 3B+L (e^+p F=0; e^-p F=2)



s-channel



u-channel

Production and decay

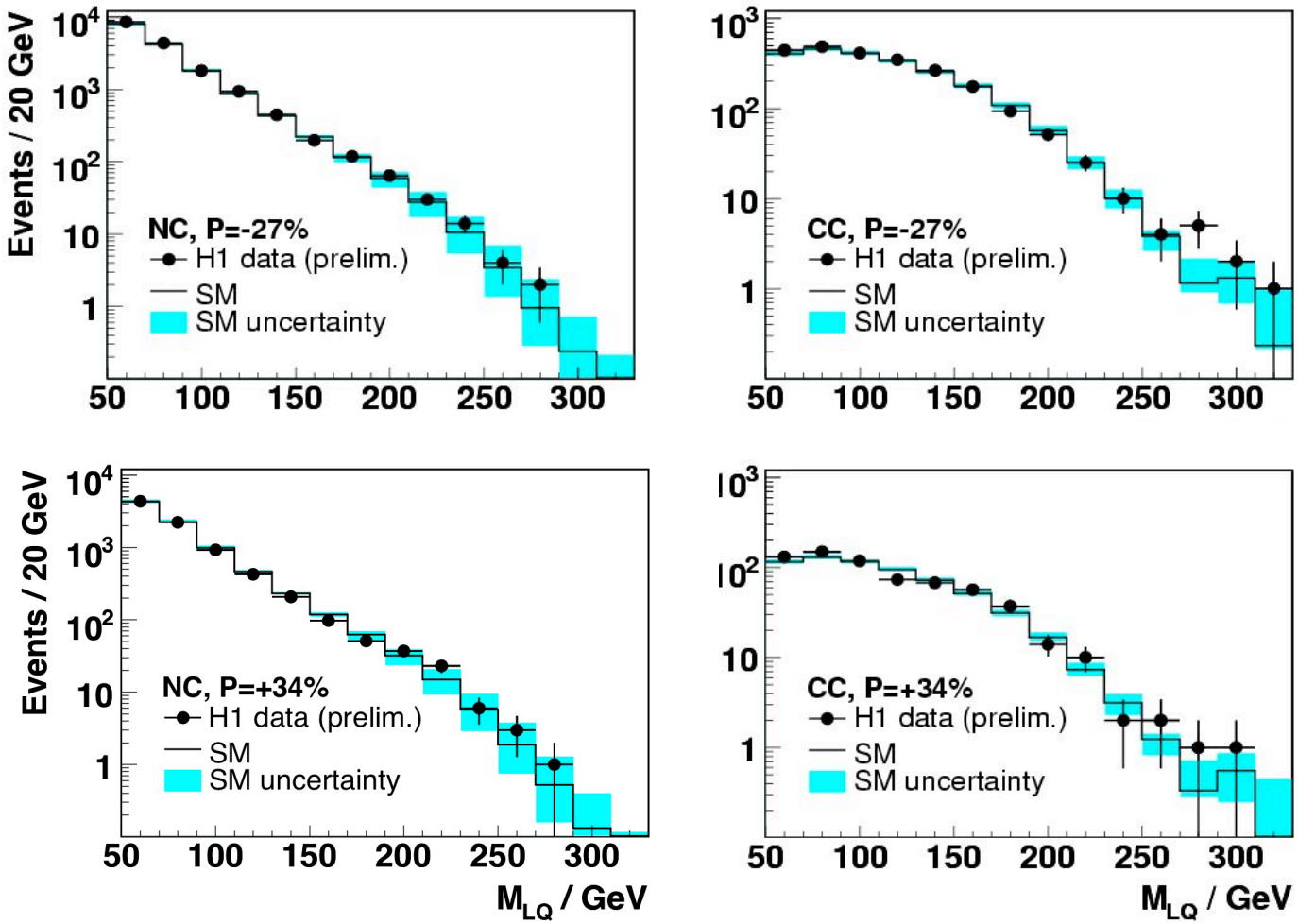
- $M_{LQ} < E_{CMS}$ resonant production (s-channel) in eq fusion
- $M_{LQ} > E_{CMS}$ contact interaction style production (contribution from u-channel)
- Only first generation considered in production and decay (don't consider LFV)
- Consider following topologies:

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

- Same final state ➔ interference with SM diagrams

Leptoquarks: H1 results

- 05 e^-p data
  - ➔ F = 2
- $\mathcal{L}$ = 92 pb $^{-1}$

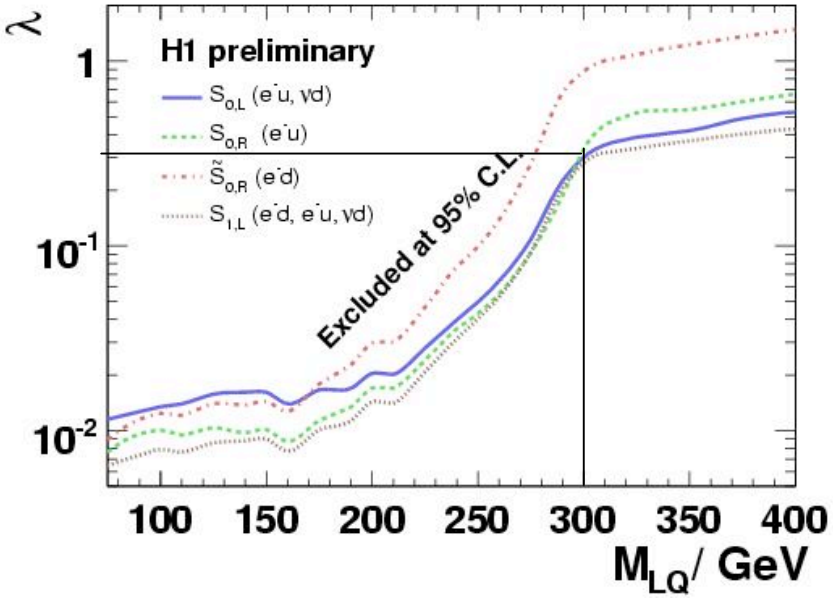


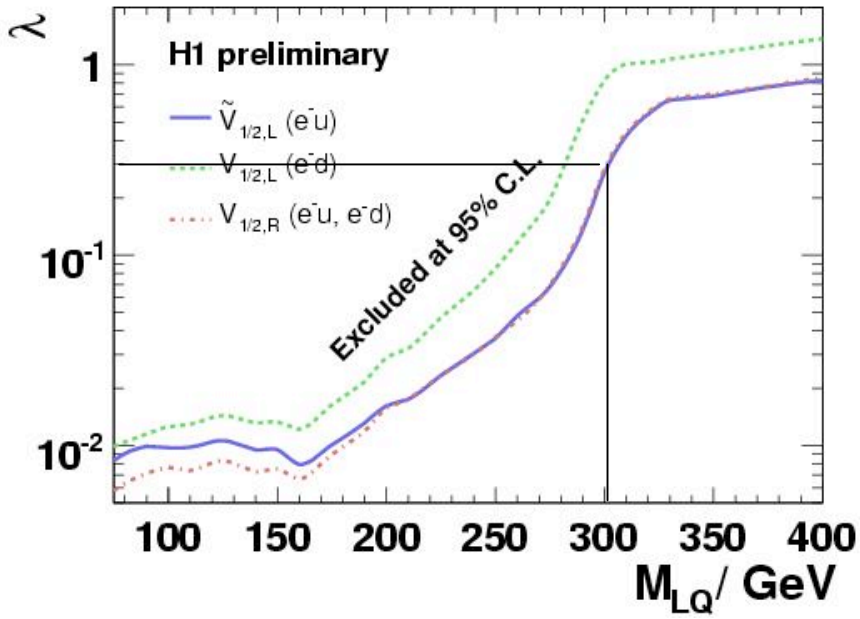
Good agreement between data and MC ➔ no sign of LQs

➔ set limits on mass and coupling

Leptoquark limits: H1 results

- 2005 e^-p data ➔ F = 2
- $\mathcal{L}$ = 92 pb^{-1}



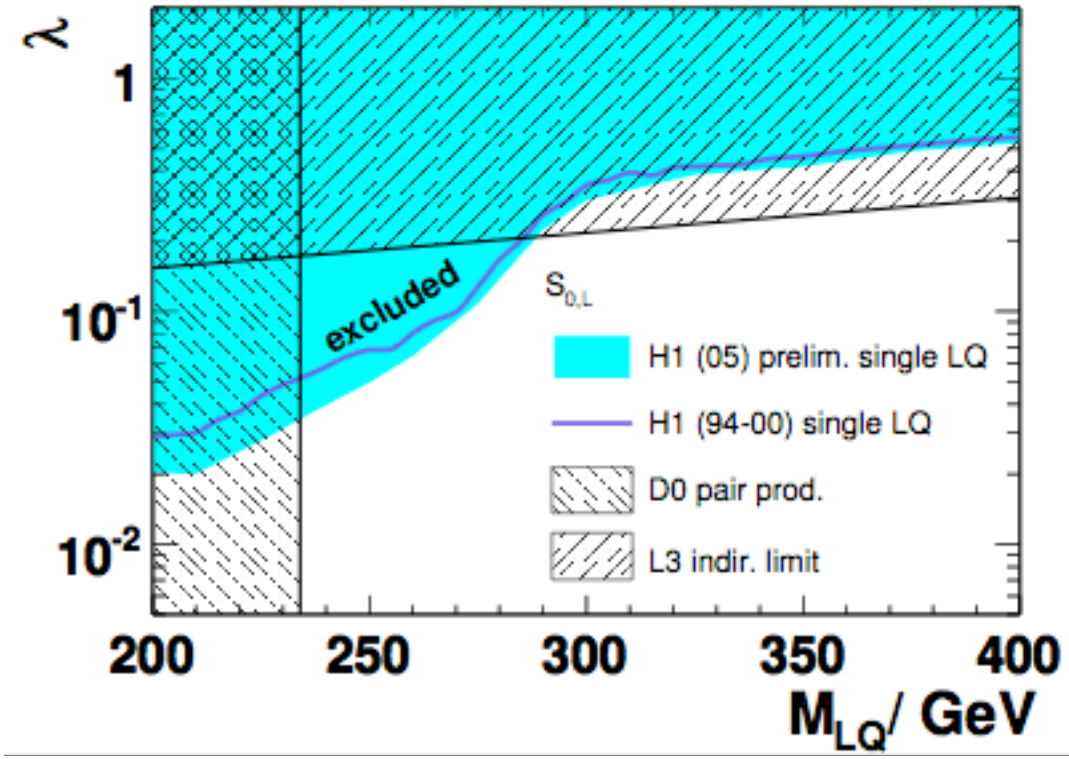


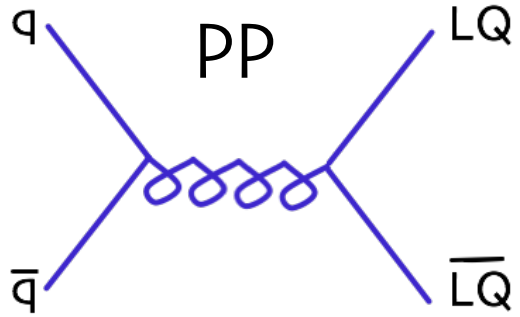
Mass exclusion 276 - 304 GeV at the EM coupling scale of 0.3

Limits comparable to those obtained at LEP and Tevatron….

Leptoquark limits

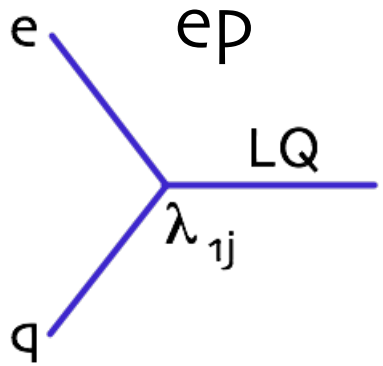
H1 results compared to DØ and L3





LQ at Tev: pair produced

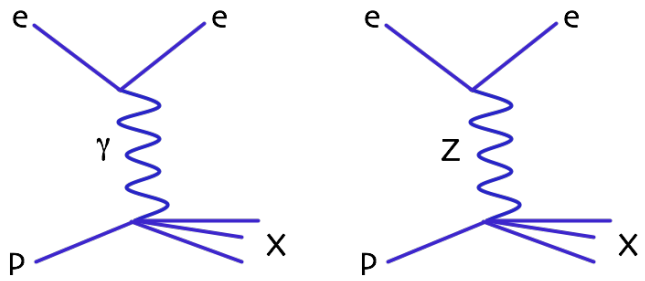
➔ no sensitivity to coupling λ



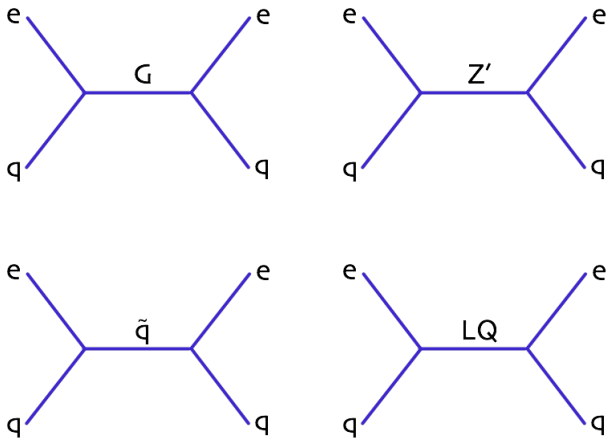
LQ at HERA: single production

Contact interactions

Standard Model processes

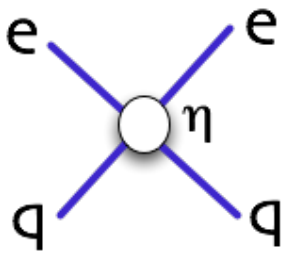


New physics processes



For CMS energy less than process scale

➔ effective parameterization



Effective Lagrangian for vector eeqq contact interaction:

$$L_{CI} = \sum_{\alpha,\beta=L,R} \eta^{eq}_{\alpha\beta} \cdot (\bar{e}_\alpha \gamma^\mu e_\alpha)(\bar{q}_\beta \gamma_\mu q_\beta)$$

Four possible couplings for each flavor

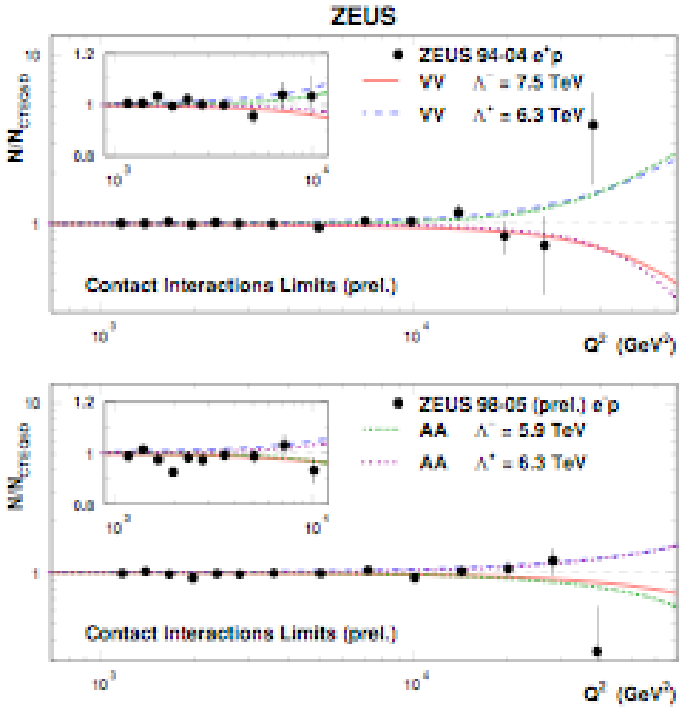
➔ Assume all u and d-type quarks have the same contact interactions - 8 couplings

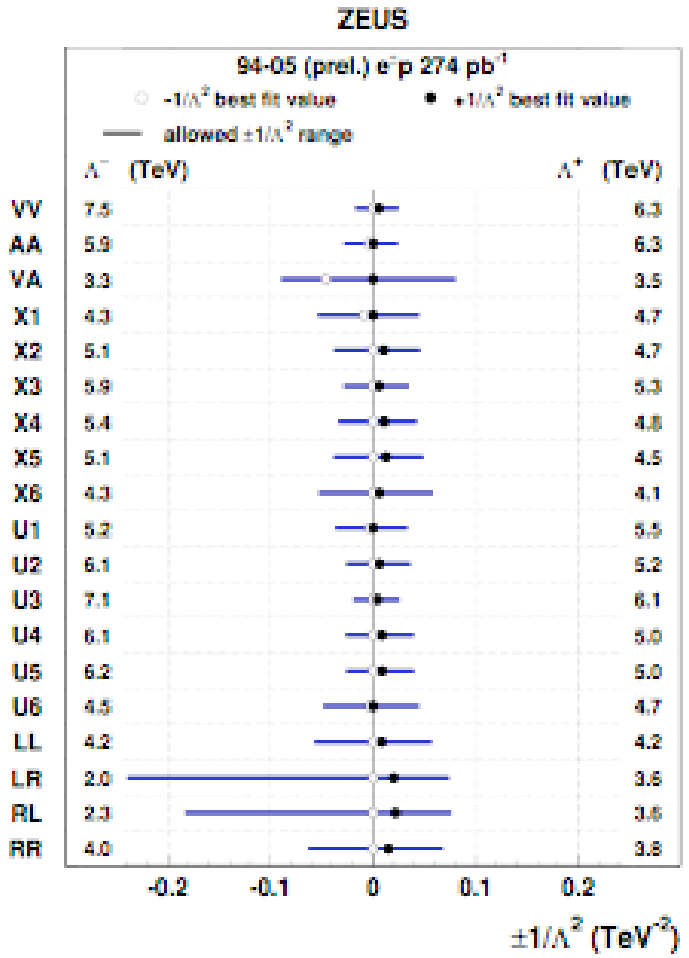
Contact interactions

Couplings are related to new physics mass scale by: $\eta_{\alpha\beta}^{eq} = \frac{\pm 4\pi}{\Lambda^2}$

Many different models with different helicity structures (see right) ➔

Fit to NC DIS data yields limits on Λ





95% CL Λ = 2.0 - 7.5 TeV

➔ comparable to LEP and Tevatron

Large extra dimensions and quark radius

In some models which predict large extra dimensions, contributions from graviton exchange can contribute to the NC DIS cross section.

Describe by effective contact interaction type parameterization:

$$\eta_G = \frac{\pm\lambda\cdot\varepsilon^2}{M_S^4}$$

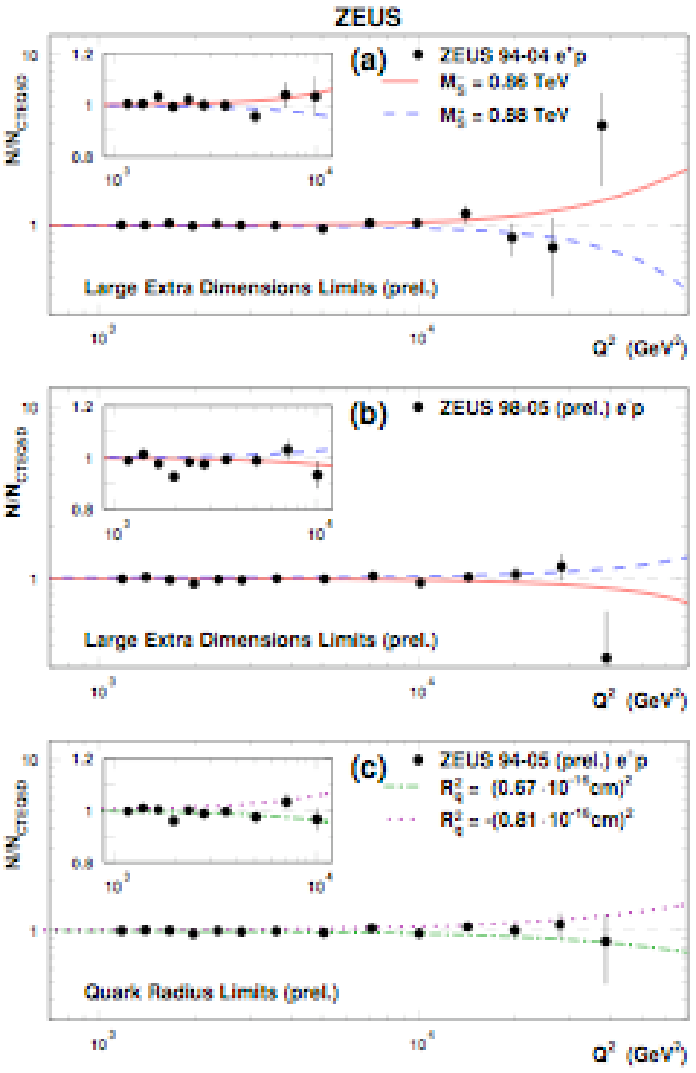
Analysis yields: $M_S > 0.86$ TeV

Similarly search for finite quark radius, using form-factor type analysis:

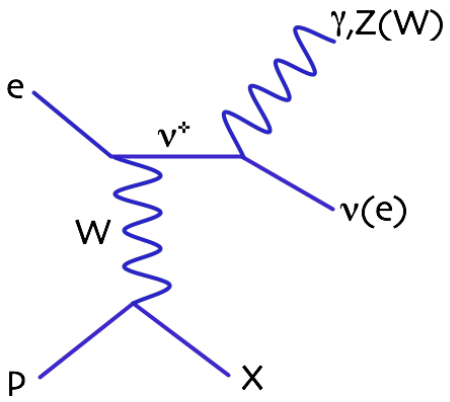
$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2}\cdot\left(1-\frac{R_q^2}{6}Q^2\right)^2$$

R_q is the RMS radius of the EW charge of the quark ➔ $R_q < 0.67 \times 10^{-16}$ cm

(or 0.67×10^{-3} fm = 1/1000 R_{proton}!)

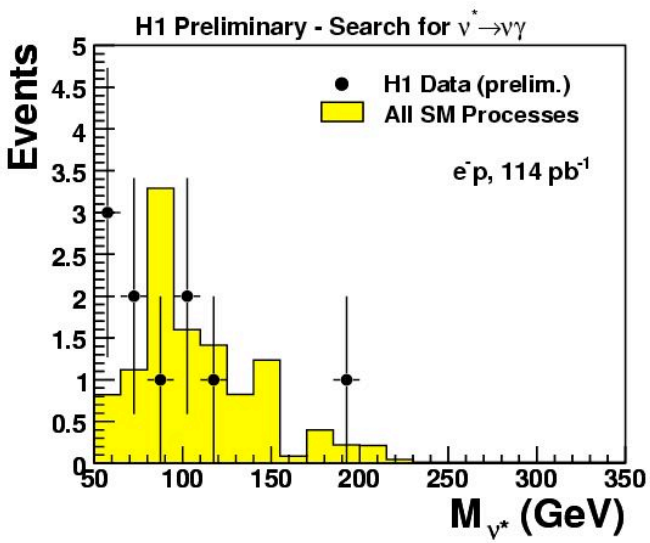


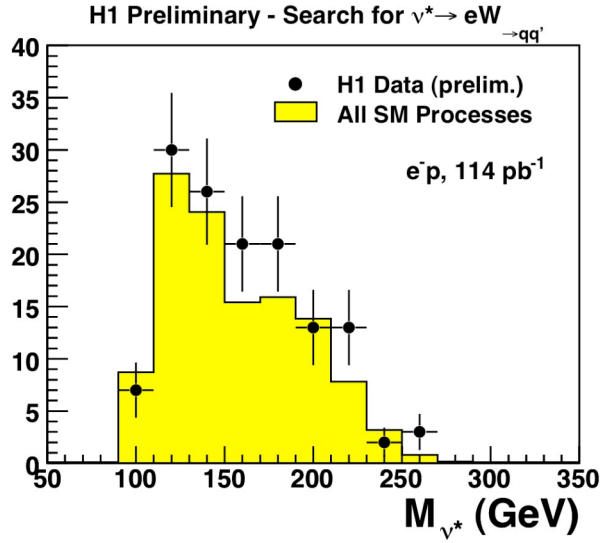
Excited neutrinos

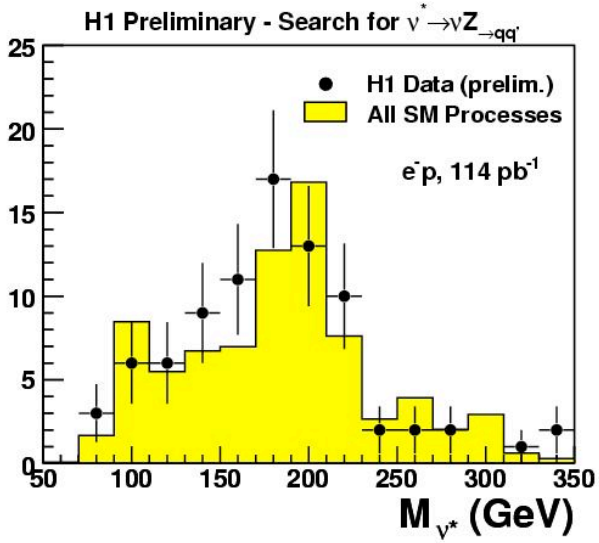


- Search for excited neutrinos
  ➔ would be proof of compositeness
- Topologies look like CC DIS but with extra jets
- Consider: $ep \rightarrow \nu\gamma$, $ep \rightarrow eW$, $ep \rightarrow \nu Z$
- Cross section in e^-p scattering much larger than in e^+p

Analysis of latest H1 e^-p data (114 pb^{-1}) ➔



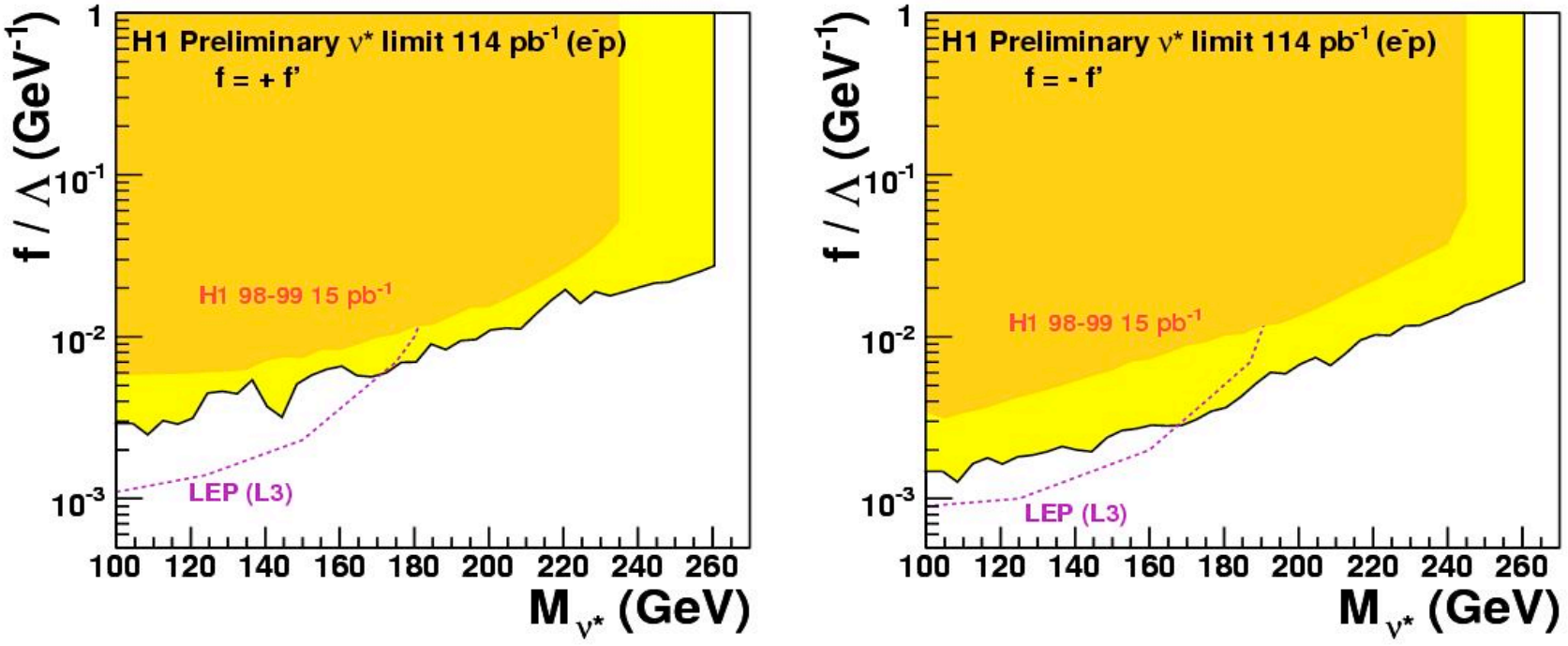




Excited neutrinos

No signal observed ➔ set limits on f/Λ as a function of M_{ν^*}

(f=coupling, Λ=compositeness scale)



Significant improvement on previous results (10 x lumi!)

Improve on LEP results for masses greater than 180 GeV

Supersymmetry

Fundamental symmetry between fermions and bosons

- has many motivations which are well known (an attempt to motivate in a few lines would anyway be too simplistic …)

R-parity: $R_p = (-1)^{3B+L+S}$

- If conserved only pair production of SUSY particles possible; LSP is candidate for dark matter;
- If violated can produce single SUSY particles which can decay to SM particles;

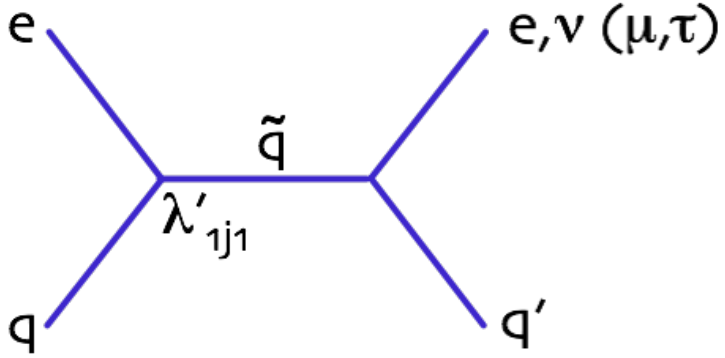
  ➔ Consider the latter at HERA

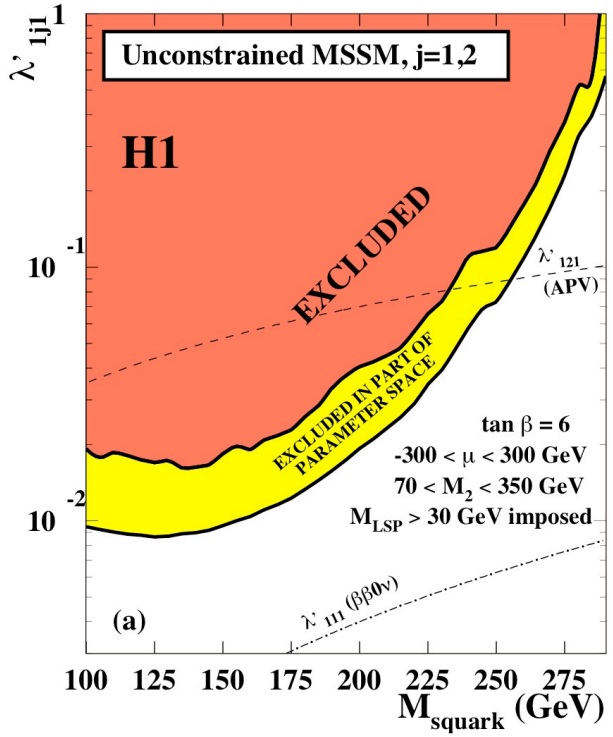
- Terms in super-potential:

$$W_{\not R_p} = \lambda_{ijk} L_i L_j \overline{E}_k + \lambda'_{ijk} L_i Q_j \overline{D}_k + \lambda''_{ijk} \overline{U}_i D_j \overline{D}_k$$

Supersymmetry at HERA

- H1 searches for R_p violating squark production in unconstrained MSSM [Eur. Phys. J. C36 (2004) 425]





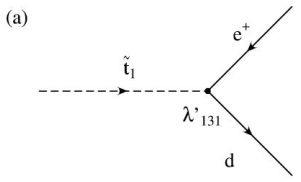
- Rule out squarks of all flavors below 275 GeV at 95% CL for EM coupling strength of 0.3
- Presented here: new ZEUS analysis considers a constrained search for stop quark in MSSM and mSUGRA ➔ ➔ ➔

Supersymmetry: Stop production (ZEUS)

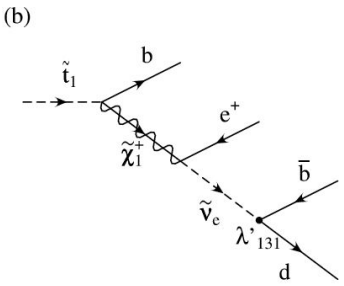
- Assume stop is lightest squark (others set to 1 TeV)
- Stop decays directly to SM particles or to charginos

➔ Different topologies

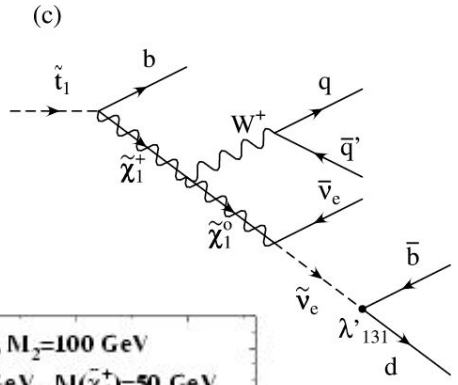
e + jet



e + many jets



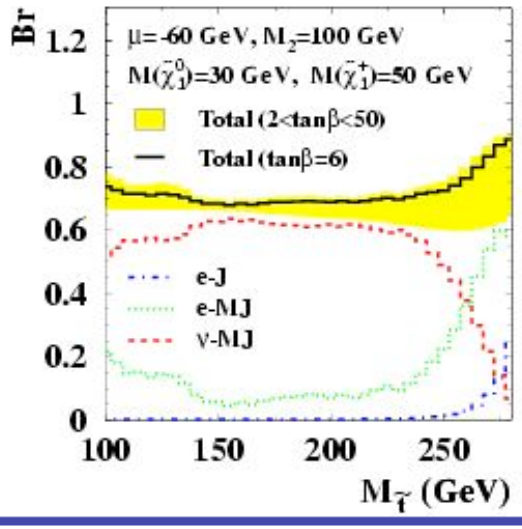
ν + many jets



- Branching ratios

➔ between three channels, cover large amount of phase space

➔ sum to ~80%, so good coverage of phase space



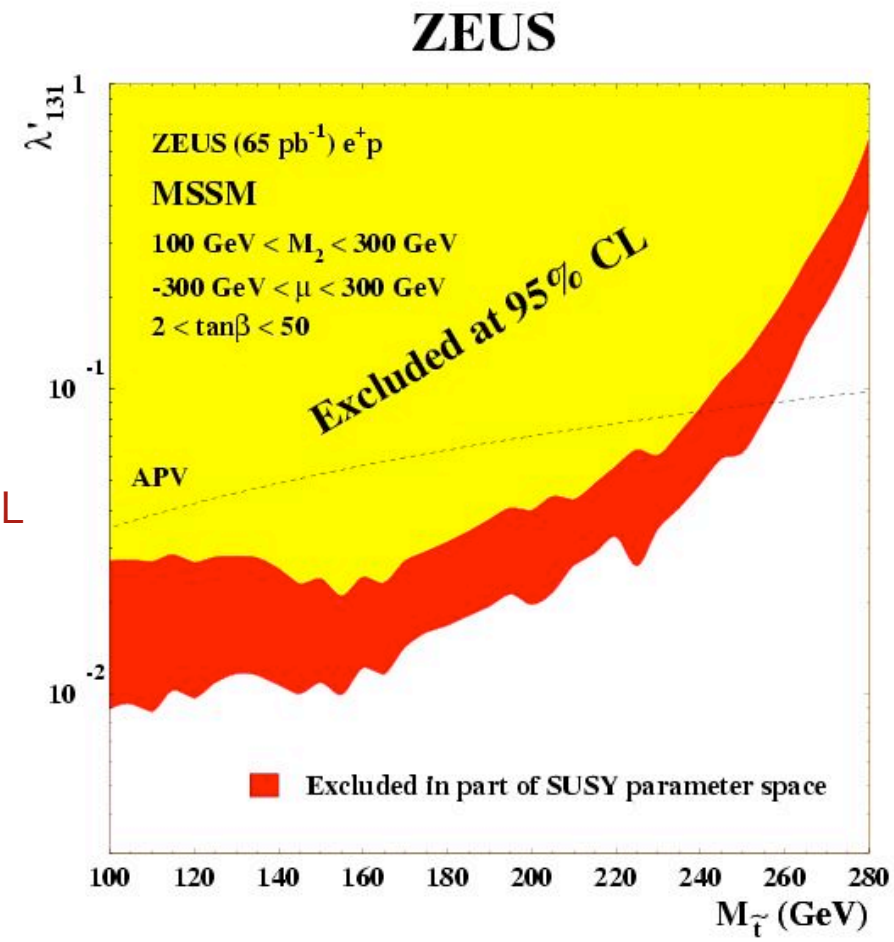
Supersymmetry: ZEUS limits

MSSM

- μ = mass term-mixes Higgs superfields
- M1, M2 and M3 = SUSY breaking parameters for U(1), SU(2) and SU(3). Assume related at the GUT scale to relate M1 and M3 to M2.
- tanβ =ratio of vevs for two neutral Higgs fields

$\mathcal{L}$=65 pb^{-1} e$^+$p scattering: NO SIGNAL

- Combine 3 decay channels to set limits
- Weakly dependent on MSSM parameters
- Rule out M<270-280 at 95% CL for EM coupling strength of 0.3
- For M>250 GeV, better than APV results

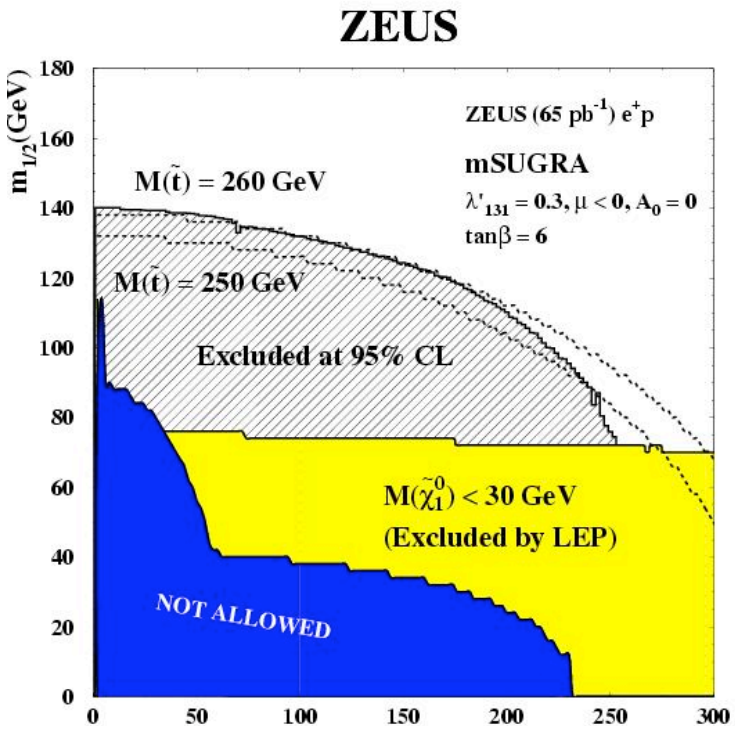


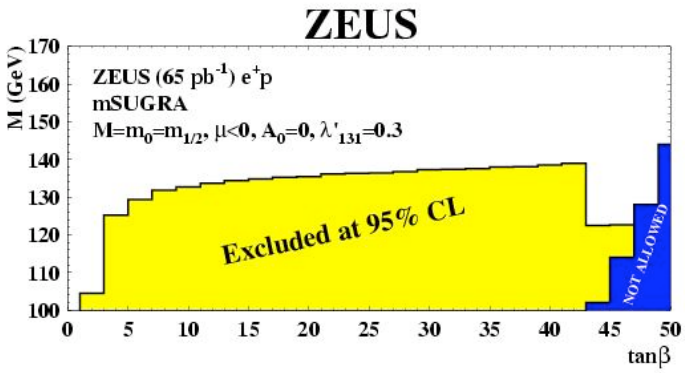
Supersymmetry: ZEUS limits

mSUGRA

- More constrained model than MSSM
- Extra constraint of common masses for scalars (M_0) and gauginos ($M_{1/2}$) at GUT scale
- Five parameters
  - M_0 and $M_{1/2}$
  - tanβ
  - Sign of μ
  - A_0 (common trilinear coupling)

- Set limits in the M_0-$M_{1/2}$ plane at fixed values of the other parameters
  - ➔ Masses below 260 GeV excluded in large part of the parameter space
- Assume common mass $M = M_0 = M_{1/2}$ and set limits in M-tanβ plane
  - ➔ Rule out tanβ<45 for M<135 GeV



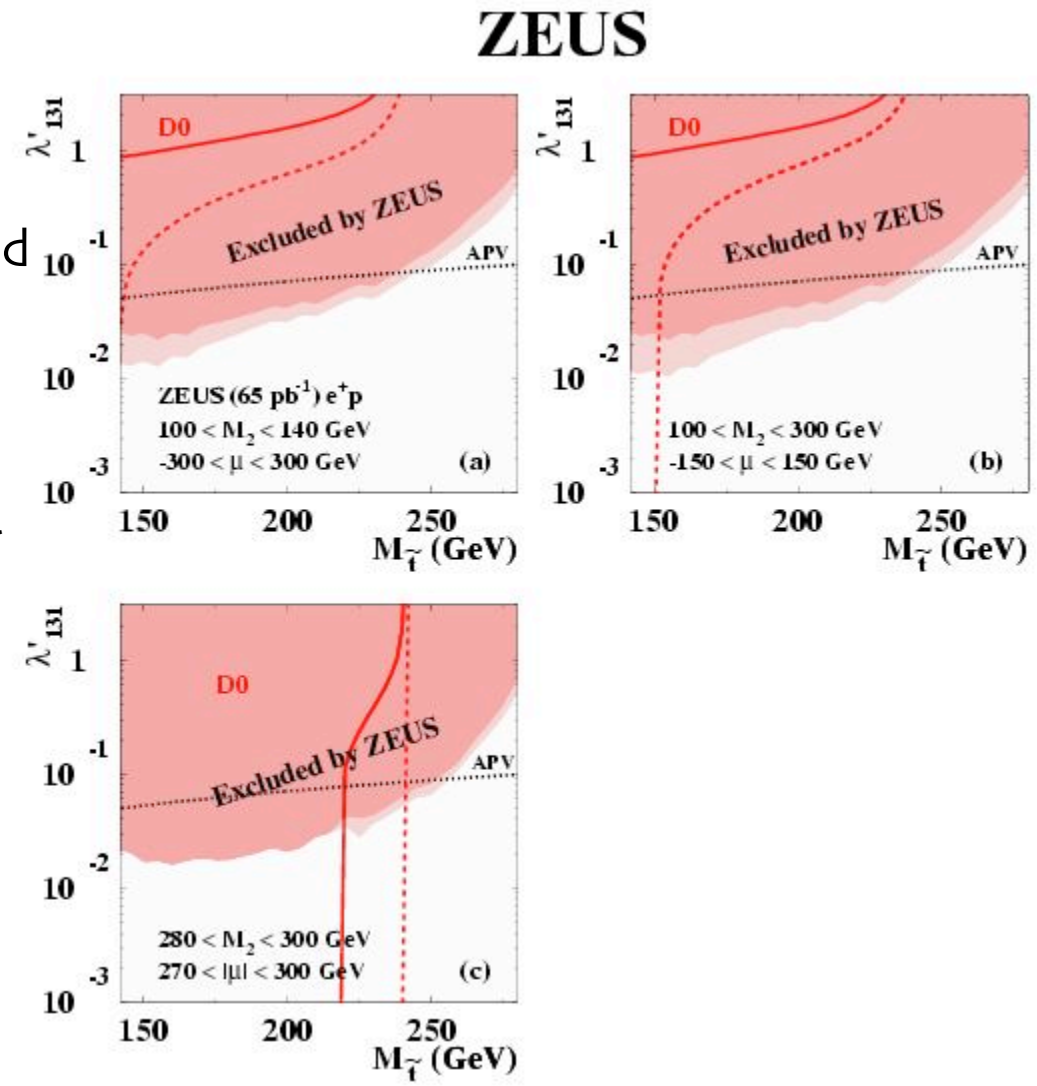


Supersymmetry: Comparing ZEUS and DØ

- Tevatron limits on leptoquarks as a function of the BR to eq can be converted into stop limits [ref]

- MSSM
  - ZEUS limits better for lower values of M_2 and μ
  - At high values of M_2 and μ DØ limits are competitive

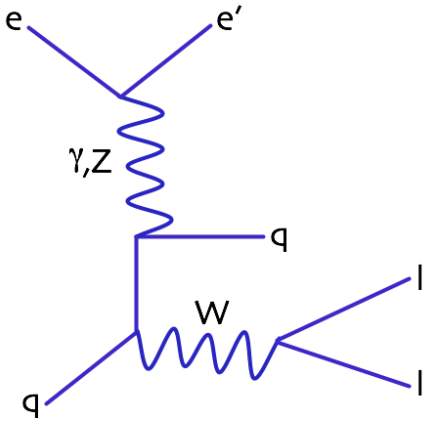
- mSUGRA
  - ZEUS limits better

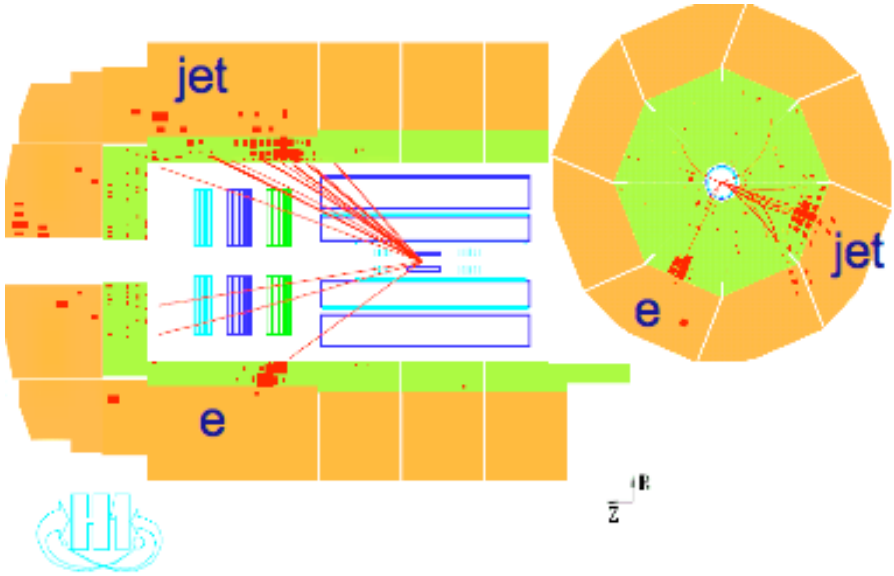


Events with isolated high-P_T leptons and P_T^{miss}

Event topology

- High-P_T lepton (e, μ,τ)
- P_T^{miss} from ν
- Jet in some events (P_T^X)





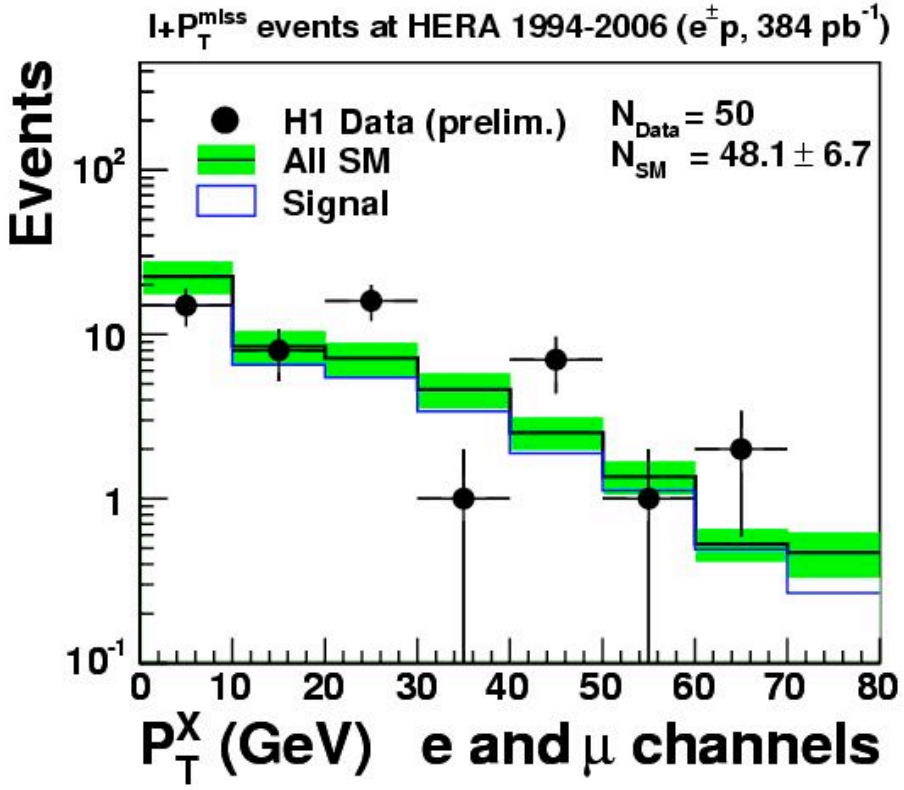
SM process $ep \rightarrow eW^{\pm}(\rightarrow \nu l)X$

- Real W production with leptonic decay
- Soft hadronic system
- Cross section ~1 pb

Backgrounds

- NC DIS: Real lepton and fake P_T^{miss}
- CC DIS: Real P_T^{miss} and fake lepton
- Lepton pair production: Real lepton and fake P_T^{miss}

Events with isolated high-P_T leptons and P_T^{miss}



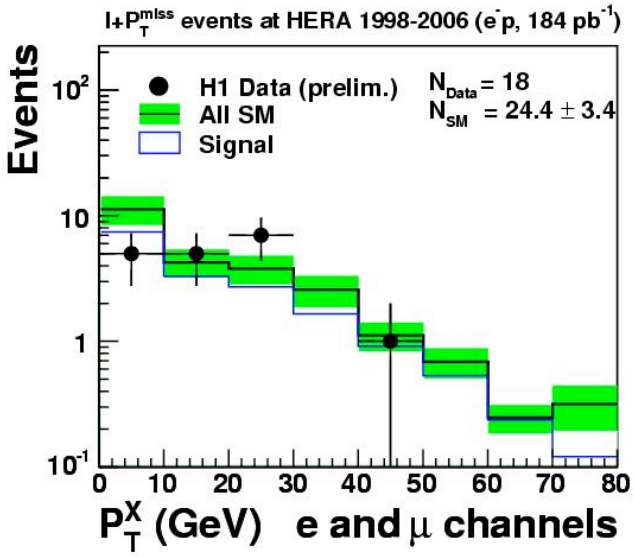
Clear evidence for W production at HERA (70% signal).

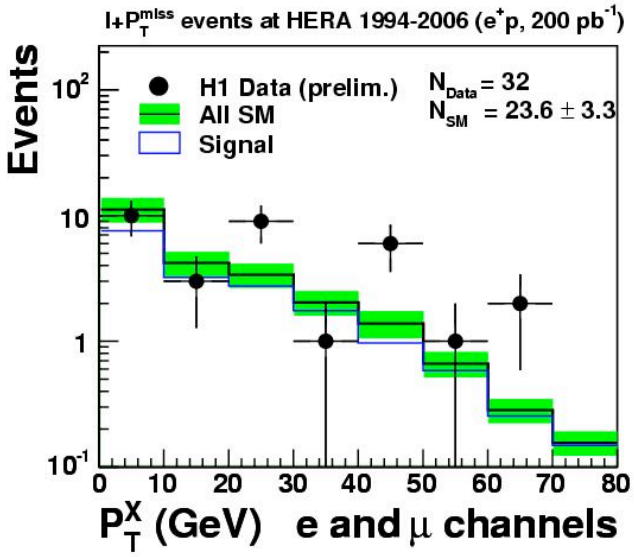
<u>Dependence on lepton beam?</u>

Look in more detail in e^+p/e^-p scattering ➔

H1 $e^{\pm}p$ data 94 - 06 (384 pb $^{-1}$)	Electron channel obs/exp (signal)	Muon channel obs/exp (signal)	Combined obs/exp (signal)
Full sample	37/38.1 ± 5.3 (68%)	13/10.0 ± 1.5 (81%)	50/48.1 ± 6.7 (71%)
$P_T^X > 25$ GeV	13/6.9 ± 1.2 (67%)	7/6.0 ± 1.0 (78%)	20/12.9 ± 2.1 (72%)

Events with isolated high-P_T leptons and P_T^{miss}





P_T^X > 25 GeV	Electron channel	Muon channel	Combined
H1 e^-p 184 pb $^{-1}$	3/3.8 ± 0.6(61%)	0/3.1 ± 0.5 (74%)	3/6.9± 1.0 (67%)
H1 e^+p 200 pb $^{-1}$	10/3.1 ± 0.6 (77%)	7/2.9 ± 0.5 (84%)	17/6 ± 1.0 (80%)
ZEUS e^-p 204 pb $^{-1}$	5/3.8 ± 0.6 (55%)	2/2.2 ± 0.3 (86%)	
ZEUS e^+p 175 pb $^{-1}$	1/2.2 ± 0.3 (75%)	1/2.3 ± 0.4 (78%)	

Excess at 3.3σ level seen at high P_T^X by H1 in e^+p scattering (none in e^-p)

Not confirmed by ZEUS analysis…. Study differences ➔

Events with isolated high-P_T leptons and P_T^{miss}

<u>Compare efficiencies</u>

Generally H1 more efficient due to larger range in θ

➔ Not huge effect

➔ Ongoing work by ZEUS to improve θ range

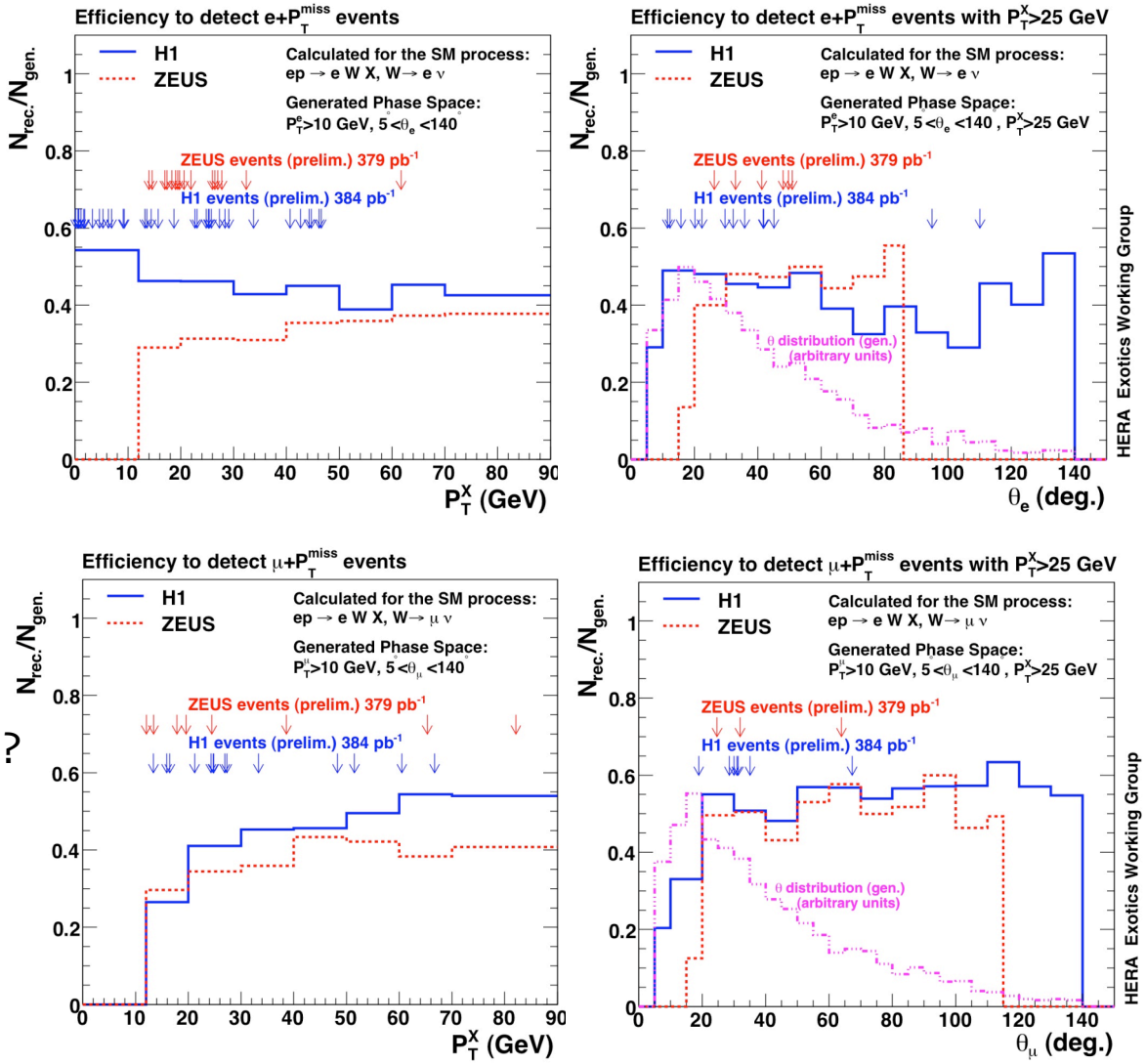
Most H1 events within ZEUS acceptance

H1 excess in e^+p a puzzle!

➔ Fluctuation or new physics?

➔ Collect more e^+p data

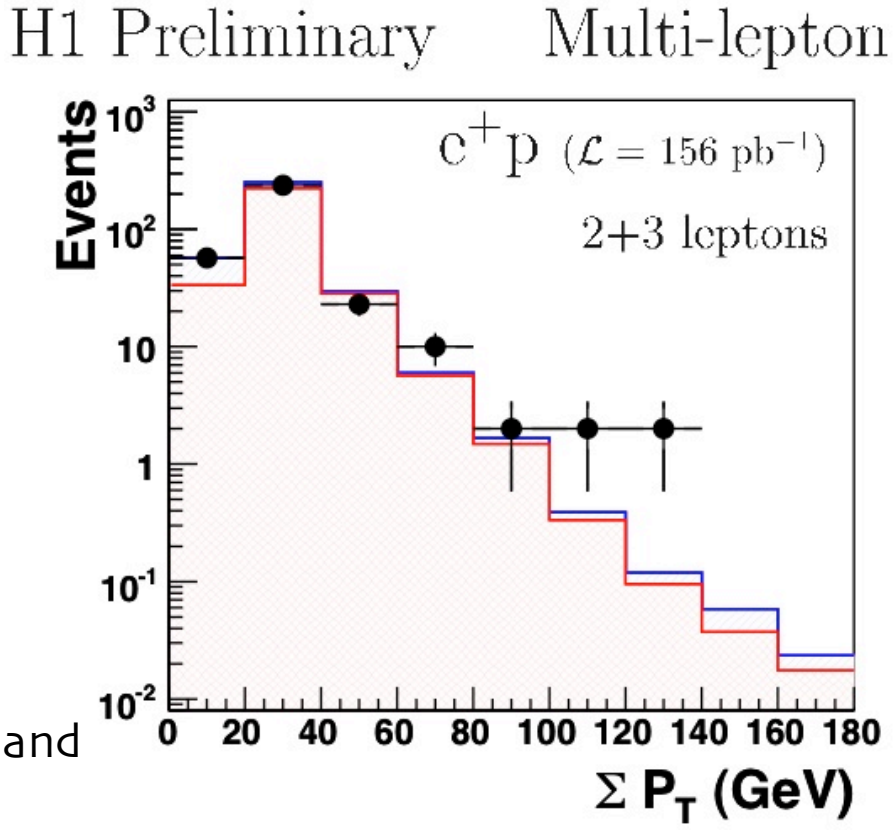
…combined working group for high-p_T leptons and other channels!



Multi-lepton events at HERA

Search for multi-lepton events at high P_T

➔ Production of di-lepton and tri-lepton events is sensitive to new physics, especially at high masses



H1: $\mathcal{L}$ = 275 pb^{-1}

ee, μμ and eμ; eee and eμμ channels

- combining all channels
- for $\Sigma P_T > 100$ GeV
- in e^+p ….
  observe 4 events where
  SM prediction: 1.1 ± 0.2

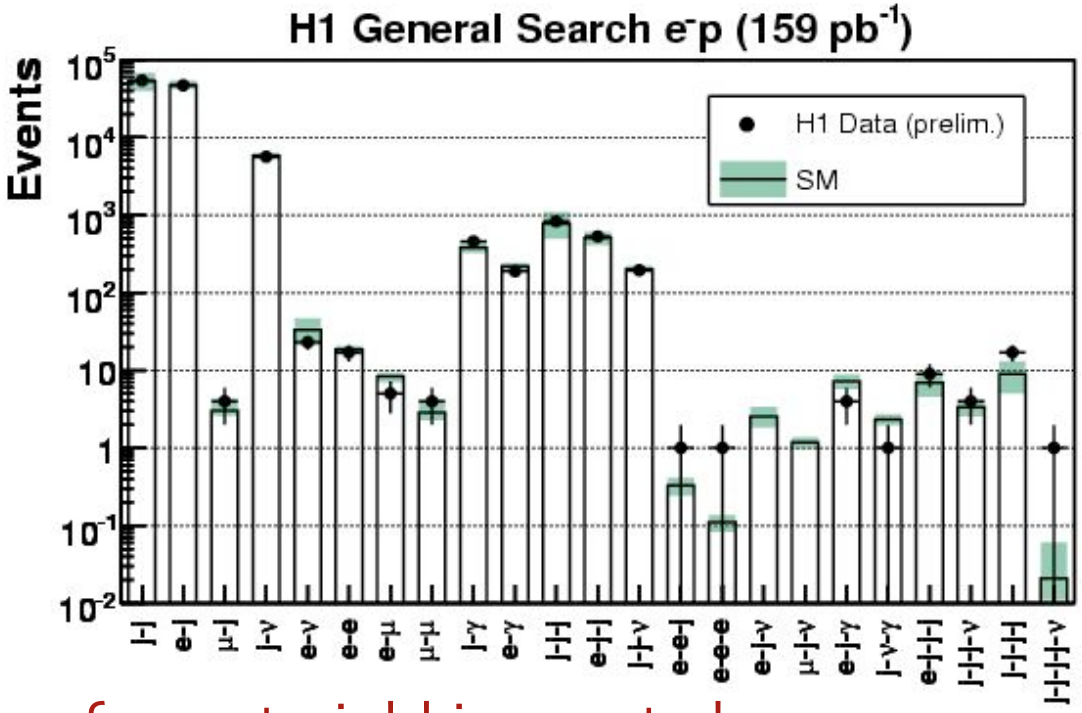
ZEUS: $\mathcal{L}$ = 296 pb^{-1}

➔ No excess observed by ZEUS in ee and eee channels

General search for high-P_T phenomena

Model independent generic search in final states with two or more high-P_T objects

- Consider e, μ, γ, ν and jets with P_T>20 GeV and 10°<θ<140°
- Classify exclusively by final state
- SM predictions for all HERA processes considered
- New analysis based on 159 pb^{-1} e^-p data

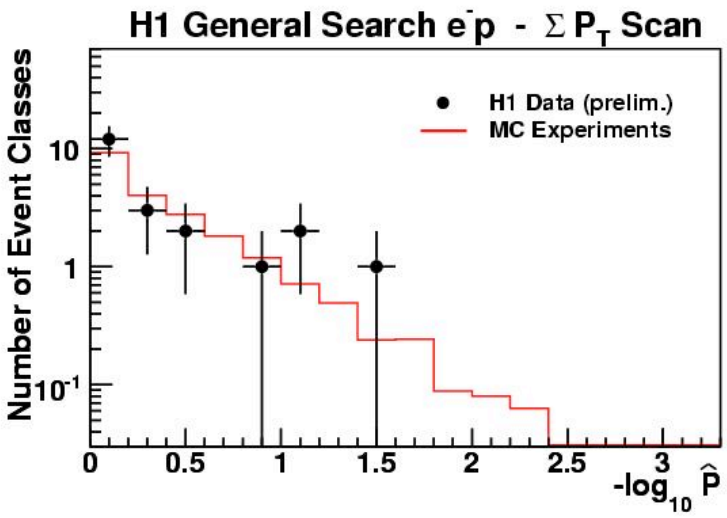


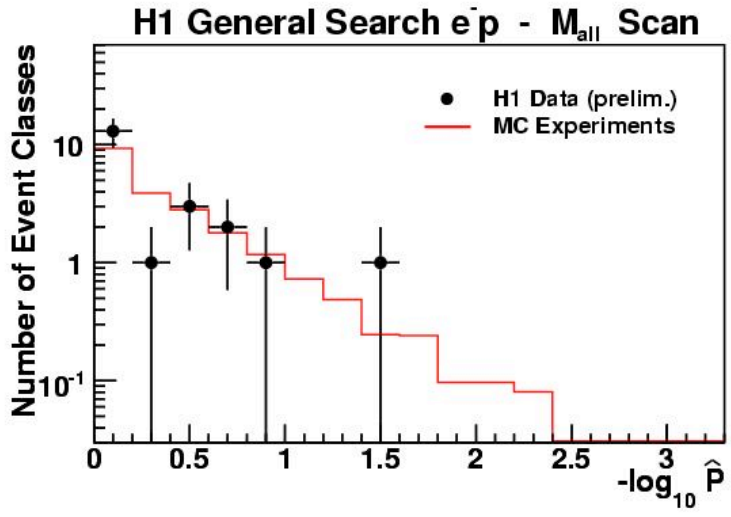
Good description of event yield in most classes

General search for high-P_T phenomena

- Perform Statistical Analysis to find all possible deviations in channel spectra of M_{all} (total invariant mass) and ΣP_T of objects in class
- In each spectrum, find region with lowest probability p_{min}
- Plot probability p for deviation $p < p_{min}$ anywhere in class

  ➔ p > 3% for all channels





No significant deviation from the Standard Model…

Summary and Outlook

- New results on
  - Leptoquarks
  - Compositeness
  - Large Extra Dimensions
  - Excited fermions
  - Supersymmetry
- HERA results competitive in most areas and complementary in others …
- Interesting excess/fluctuations
- Still more HERA II data to come…