Leptoquark Search at HERA

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for

H1 & ZEUS

Outline:

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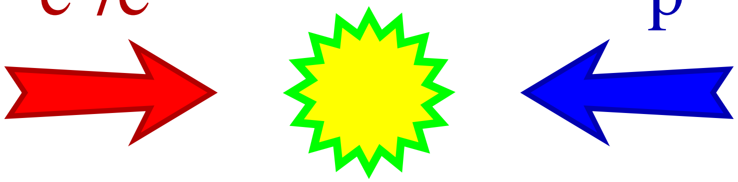
- High-Q^2 DIS $\Rightarrow$ Leptoquarks
- Leptoquarks
  - $\Rightarrow$ Leptoquark Model
  - $\Rightarrow$ Invariant Mass Spectra
  - $\Rightarrow$ Analysis methods
  - $\Rightarrow$ LQ limits
- Summary

X International Workshop on Deep Inelastic Scattering
Cracow, 1st May 2002

Introduction

HERA data

e^+/e^- p



27.5 GeV

820 GeV 1994-97

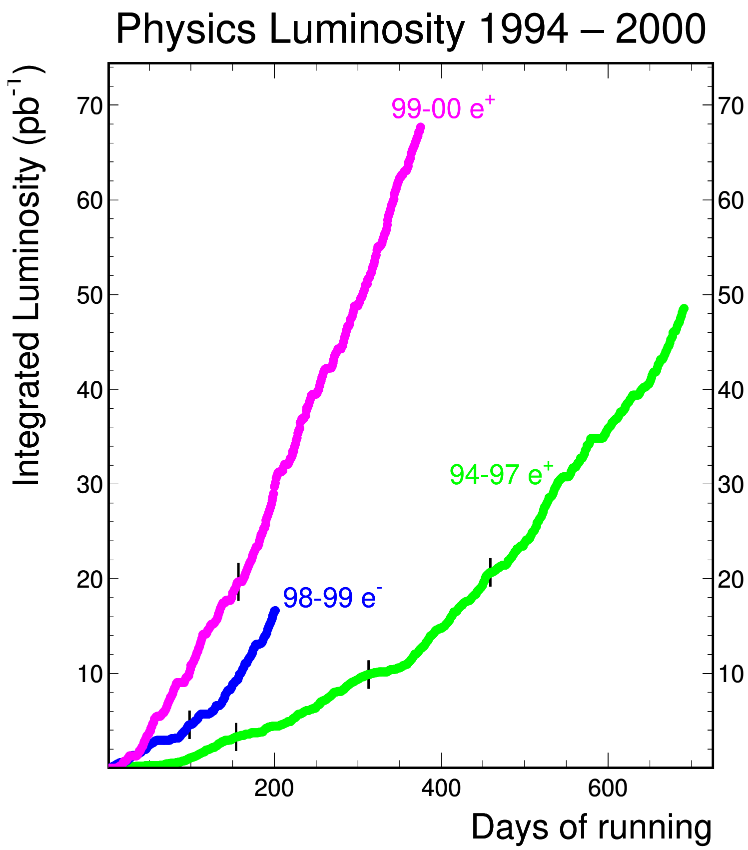
920 GeV 1998-00

Presented results

Year		$\sqrt{s}$	H1	ZEUS
1994-97	e^+p	300 GeV	37 pb^{-1}	48 pb^{-1}
1998-99	e^-p	318 GeV	15pb^{-1}	16 pb^{-1}
1999-00	e^+p	318 GeV	65 pb^{-1}	64 pb^{-1}

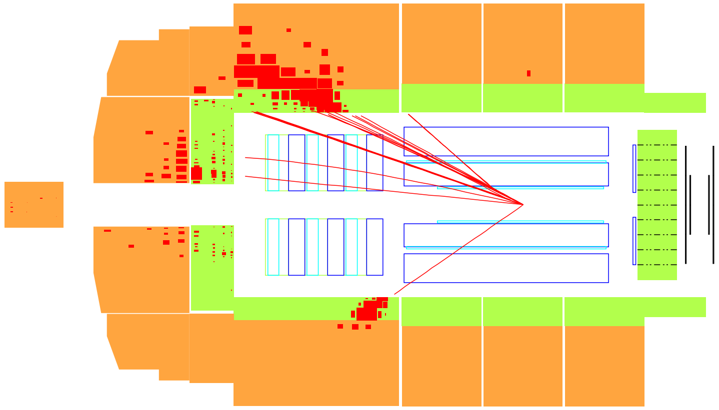
Total of about $\sim$ 240 pb^{-1} of $e^{\pm}p$ data.

e^+p data sample more than doubled in 1999-2000:

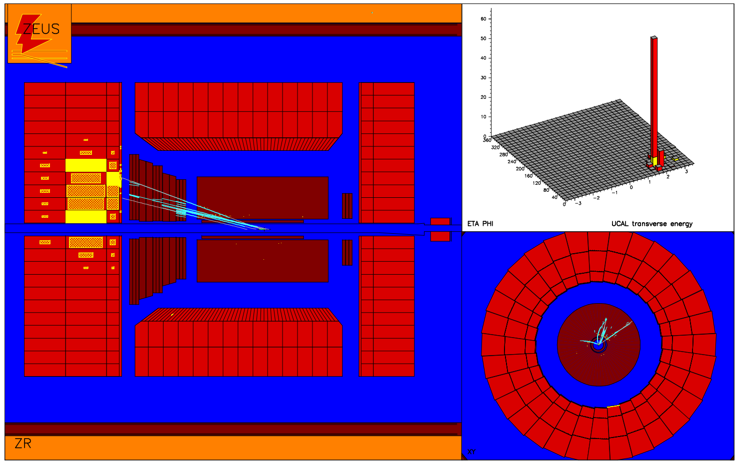


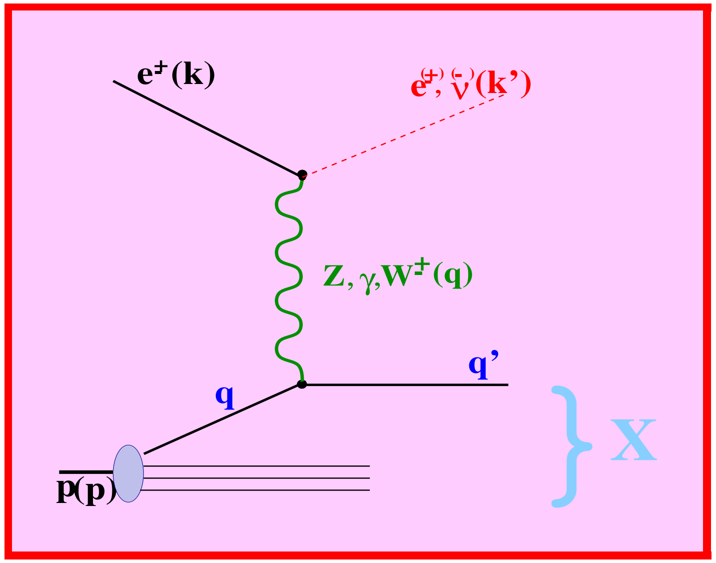
High-Q^2 DIS Background

NC DIS:



CC DIS:





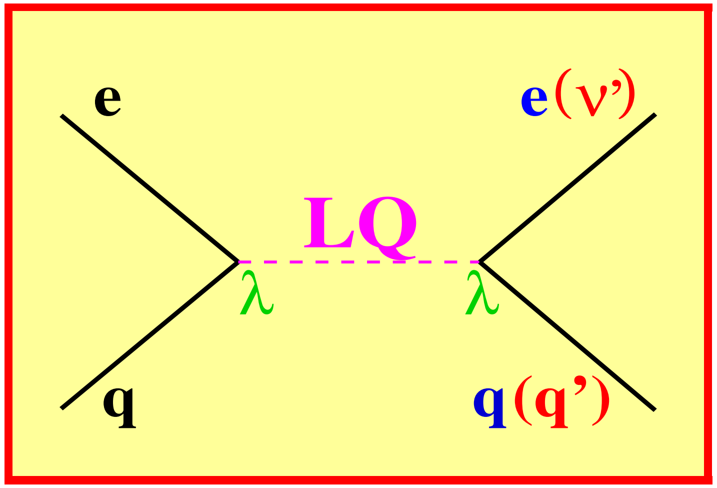
- Q^2 = -(4-momentum of propagator)^2 - the virtuality of the exchanged boson.
- x - fractional momentum of proton carried by struck quark q
- y - fractional energy of the incoming lepton transfered to the proton in the proton's rest frame

Introduction to the Leptoquark Model

LEPTOQUARKS:

Scalar or vector color triplet bosons carrying L and B numbers

$\Rightarrow$ **Fermion number** $F = 3B + L = 0, 2$



Buchmüller-Rückl-Wyler (BRW) model

- $SU(3)_C \times SU(2)_L \times U(1)_Y$ invariance
- lepton and baryon number conservation
- strong bounds from rare decays $\Rightarrow$ either left- or right-handed couplings
- family diagonal   if not $\Rightarrow$ LFV

$\Rightarrow$ 7 scalar and 7 vector leptoquarks:

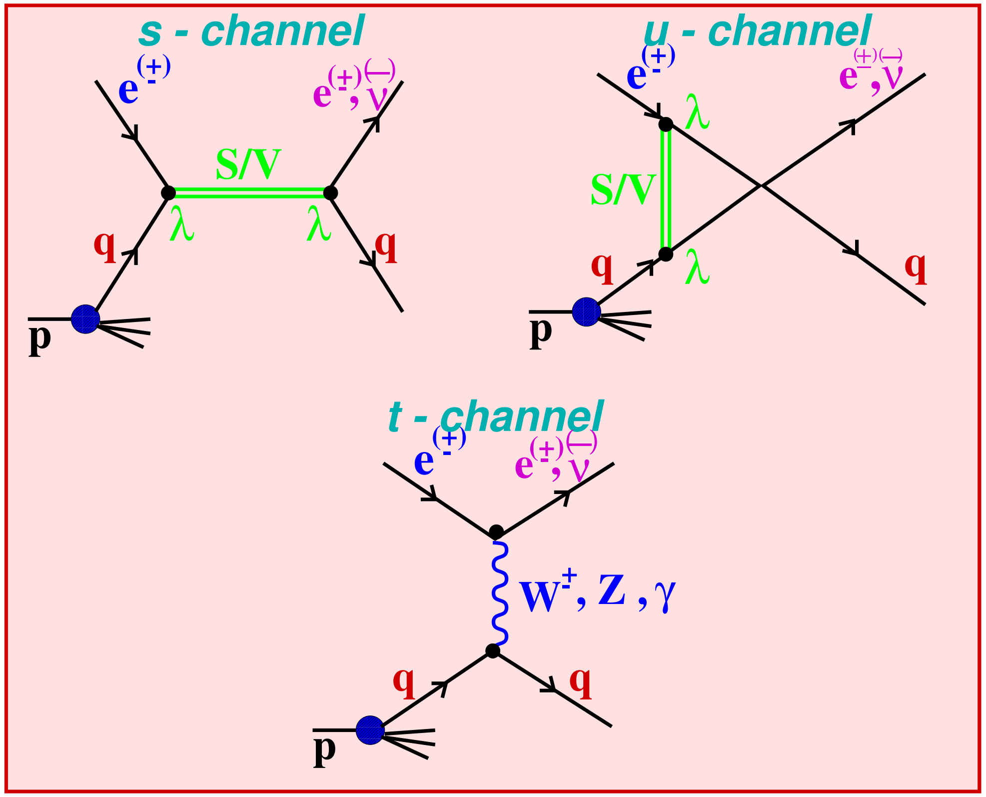
- All 14 LQ $\Rightarrow$ $LQ \rightarrow eq'$
- 2 scalar and 2 vector LQ couple to both eq and νq

Introduction to the Leptoquark Model

The total $e^{\pm}p \rightarrow \nu(e)X$ cross section with the resonance contribution:

$$\boxed{\sigma(e^{\pm}p) = \sigma_{SM} + \sigma^{Int}_{u/SM} + \sigma^{Int}_{s/SM} + \sigma_u + \sigma_s}$$

- The first term - the contribution from SM
- The second (third) term - interference between the SM and the u-channel (s-channel) LQ exchange
- The forth(fifth) term - the u-channel (s-channel) LQ exchange alone



Introduction to the Leptoquark Model

Narrow Width Approximation:

For small λ and $M_{LQ} \leq \sqrt{s}$:

- the s-channel dominates
- cross section

$$\boxed{\sigma^{NWA} = (J+1)\frac{\pi}{4s}\lambda^2 q(x_0, M_{LQ}^2)}$$

where:
$q(x_0, M_{LQ}^2)$ - quark density
J - spin of the leptoquark (J=0,1)

- $e^- p \Rightarrow$ F=2 LQ, $e^+ p \Rightarrow$ F=0 LQ
  (valence q $\gg$ sea q)
- Angular distribution

$$y = 0.5(1 - cos\theta^\star)$$

$\theta^\star$ - e scattering angle in eq (νq) rest frame

Scalar Leptoquarks

$$\left.\frac{d\sigma}{dy}\right|_{scalar} \rightarrow flat$$

Vector Leptoquarks

$$\left.\frac{d\sigma}{dy}\right|_{vector} \sim (1-y)^2$$

NC DIS (Background)

$$\frac{d\sigma^{e^\pm p}}{dy} \sim \frac{1}{y^2}$$

Mass reconstruction

$M_{LQ} \leq \sqrt{s} \Rightarrow$ **NWA** $\Rightarrow$ **High mass resonant state**

Invariant mass of the $\nu - jet$:

- H1: Global kinematic variables from hadronic final state
  $M_h = \sqrt{s \cdot x_h}$

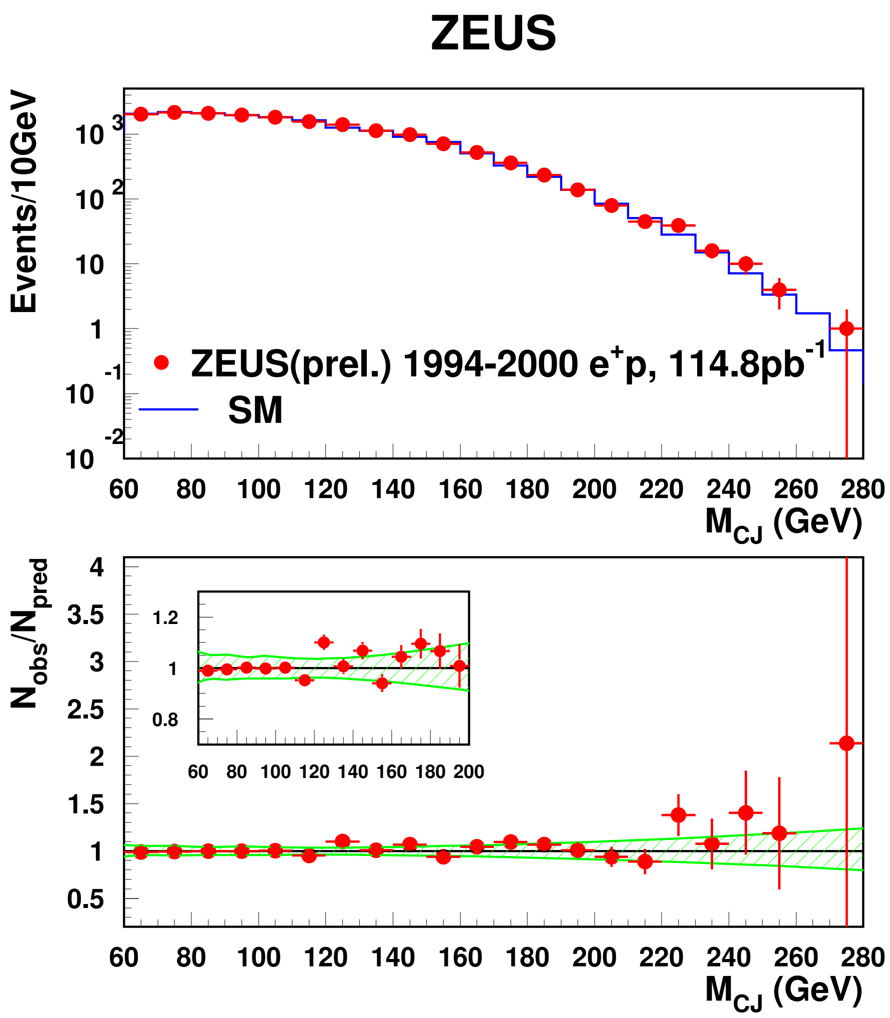
- ZEUS:$M_{\nu js}$ - Global kinematic and jets information combined

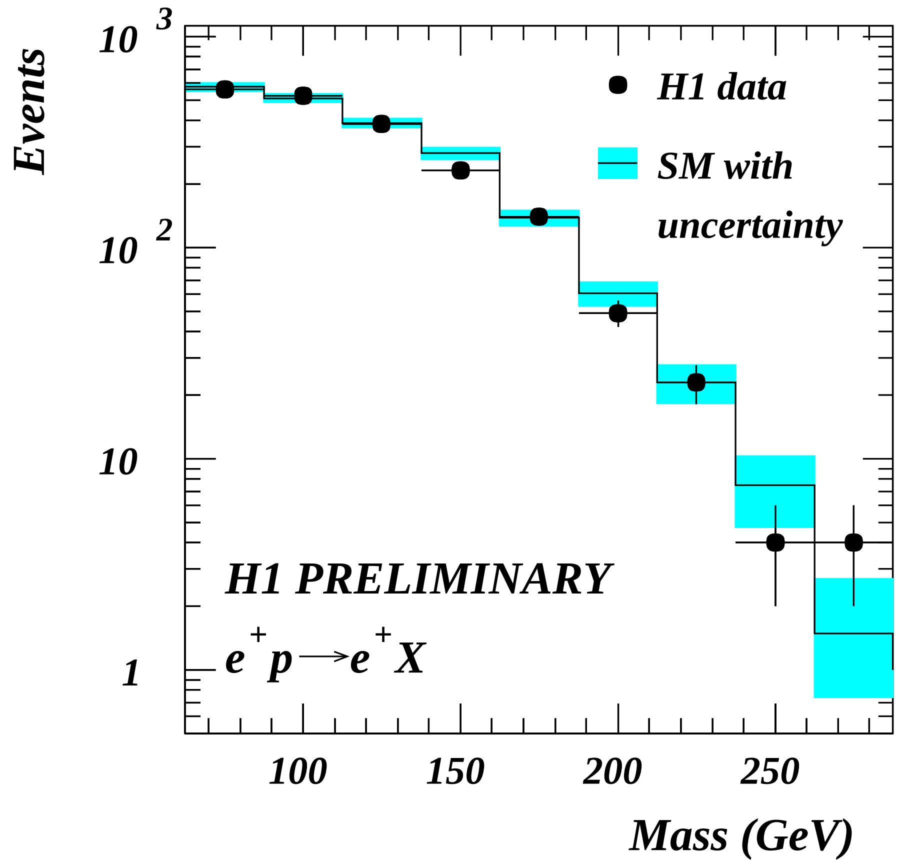
Invariant mass $e^{\pm} - jet$:

- H1: $M_e = \sqrt{s \cdot x_e}$
  x_e - the measured kinematics of the scattered electron

- ZEUS:M_{CJ}- scattered e and **all** jets final state

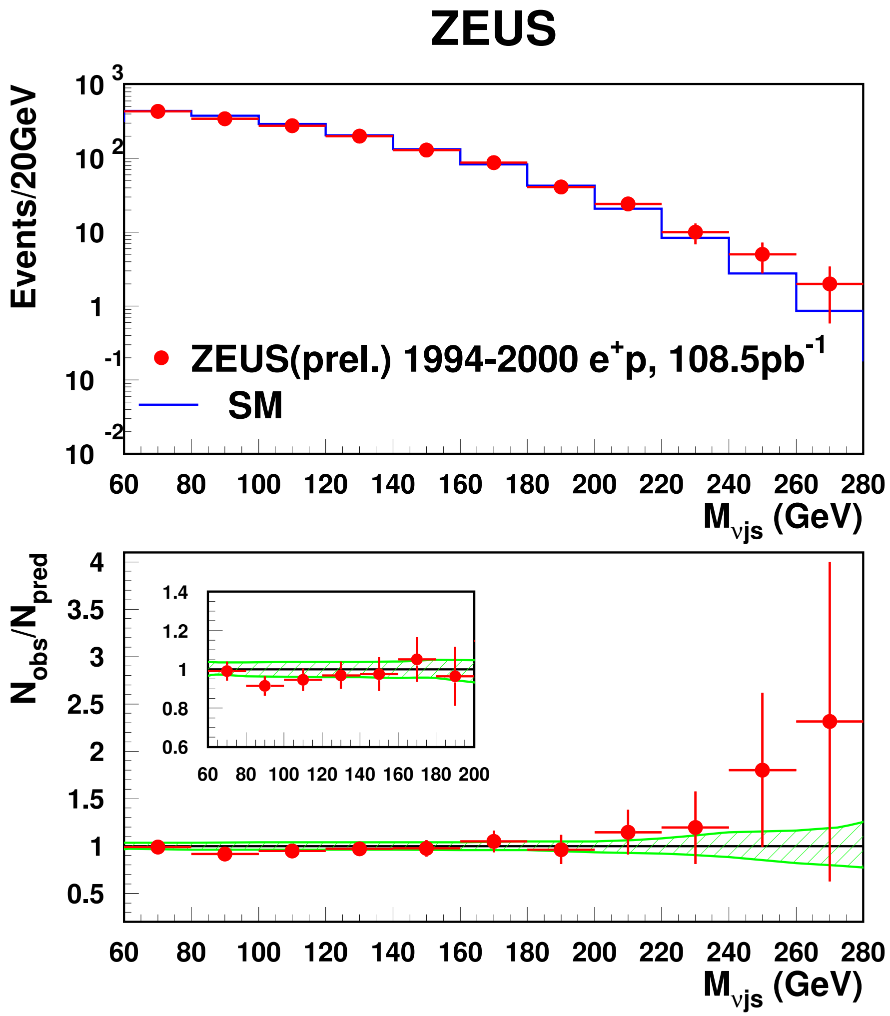
eq Invariant Mass Spectrum from HERA e^+p

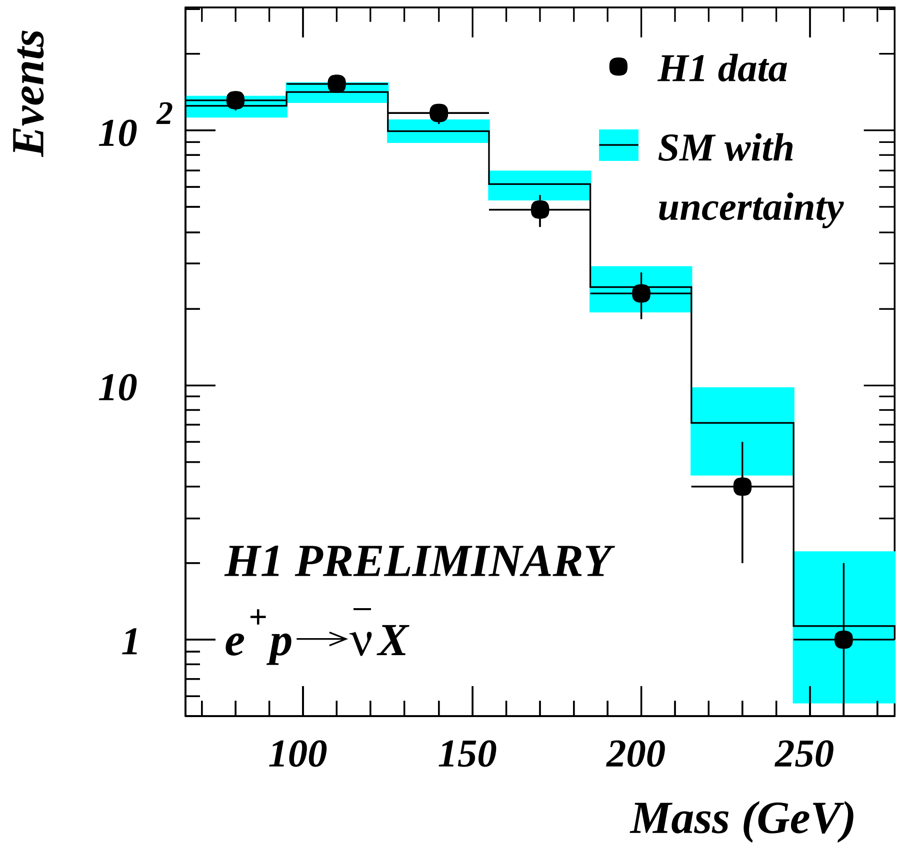




Good agreement between data and SM $\rightarrow$ no evidence of LQ

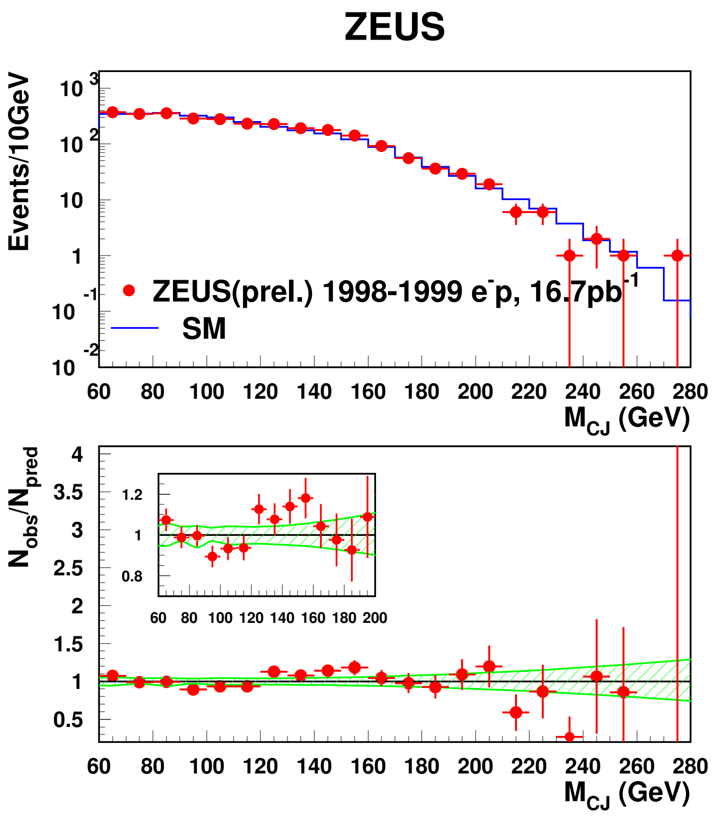
νq Invariant Mass Spectrum from HERA e^+p



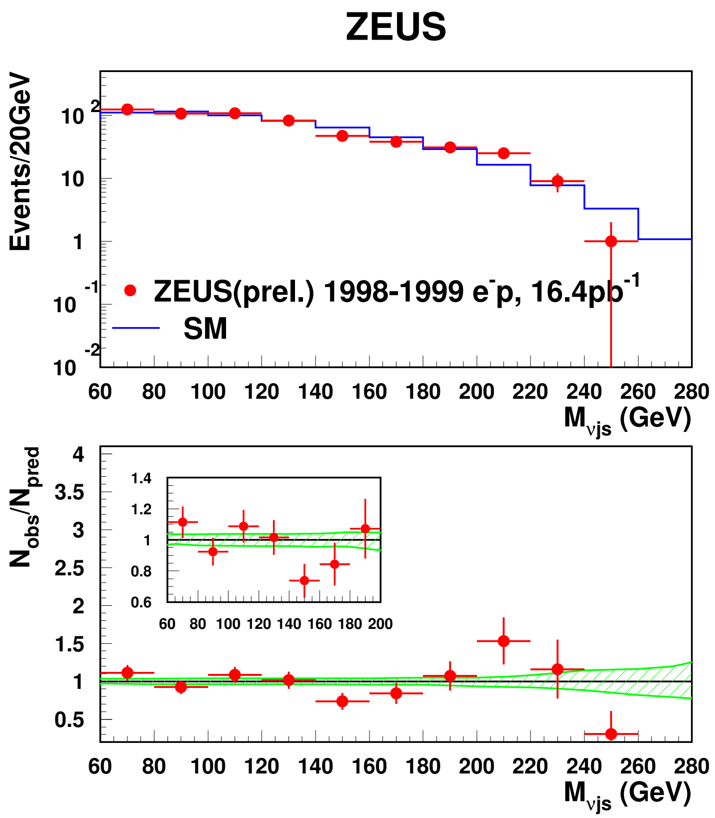


Invariant Mass Spectrum from HERA $e^{-}p$

NC DIS:



CC DIS:



H1 has similar plots (Phys. Lett. B523 (2001) 234 ,07/01)

LQ Limits with 2 Dim Likelihood Method

- H1 modified frequentistic approach (cf. T. Junk Nucl. Instrum. Meth. A434 (1999) 435, hep-ex/9902006)

- ZEUS: Bayesean approach :

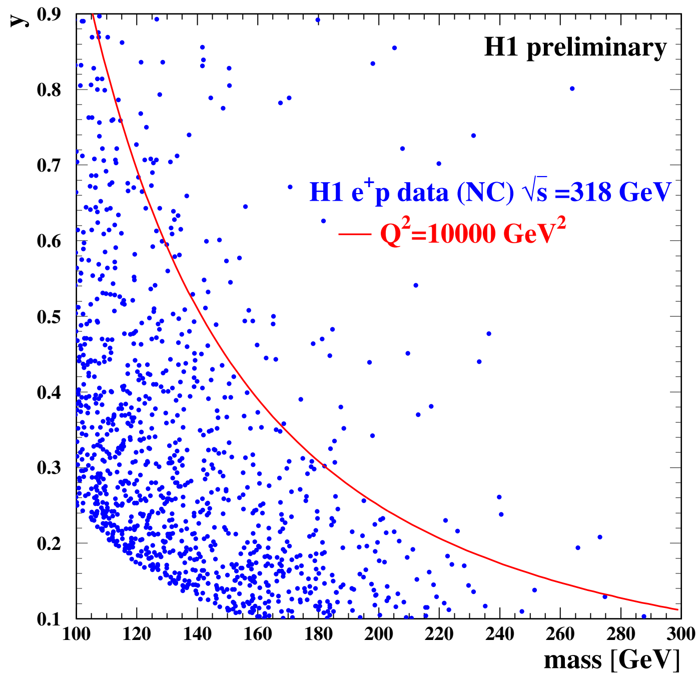
$$0.95 = \int_0^{\lambda_{lim}} P(\lambda)d\lambda / \int_0^{\infty} P(\lambda)d\lambda$$

$$P(M_{LQ}, \lambda_{LQ}) = \prod_{i}^{N} e^{-\mu_i(\lambda)} \mu_i(\lambda)^{N^i_{obs}} / N^i_{obs}!$$

The systematic uncertainties

- convoluting the P with a Gaussian function

- Divide y (H1)/ $\cos\theta^\star$ (ZEUS) vs. M 2 dimensional plane in to N bins

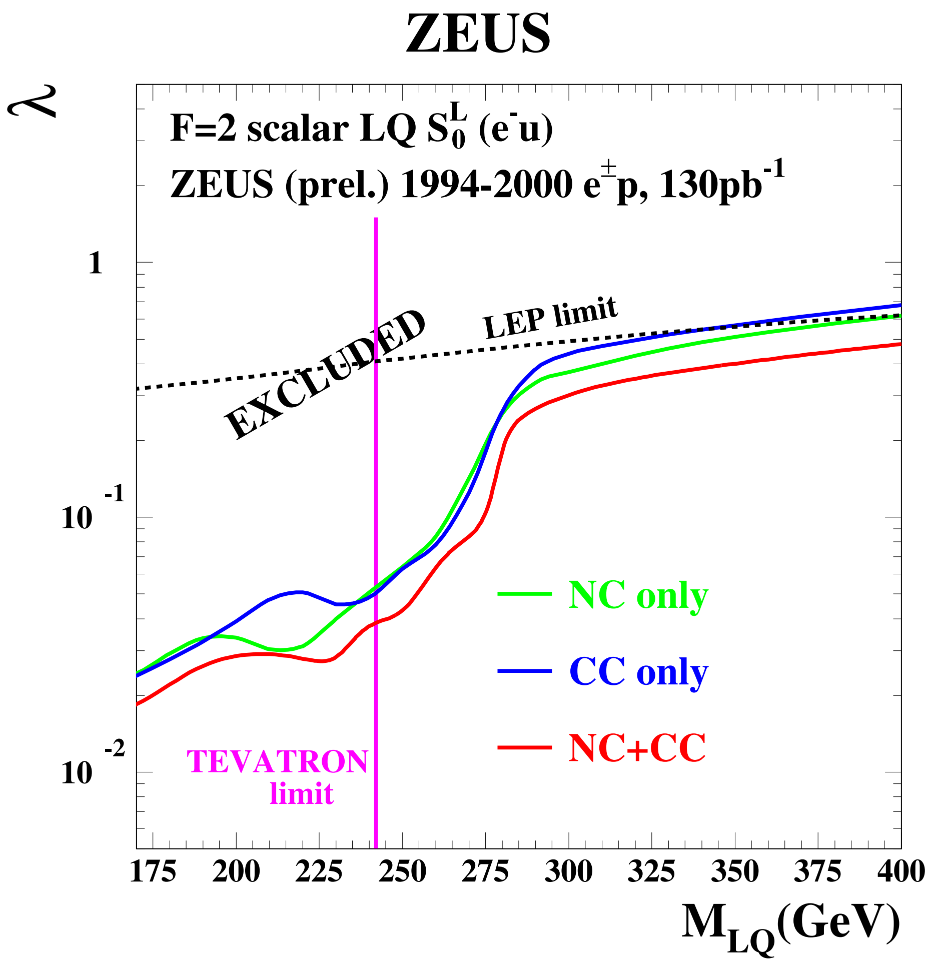


Advantage: 1. LQ limits can be evaluated for masses above 300 GeV

$\Rightarrow$ Set limit for virtual LQ.

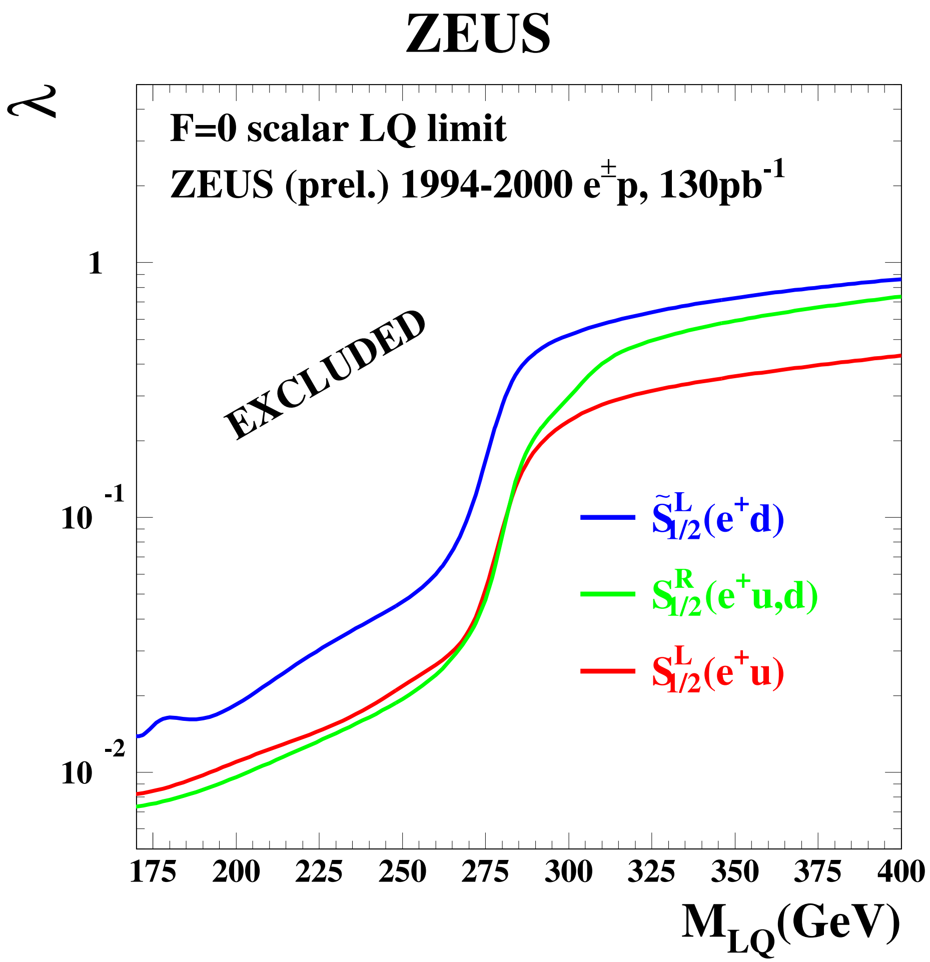
2.Both M and y information of LQ are taken into account

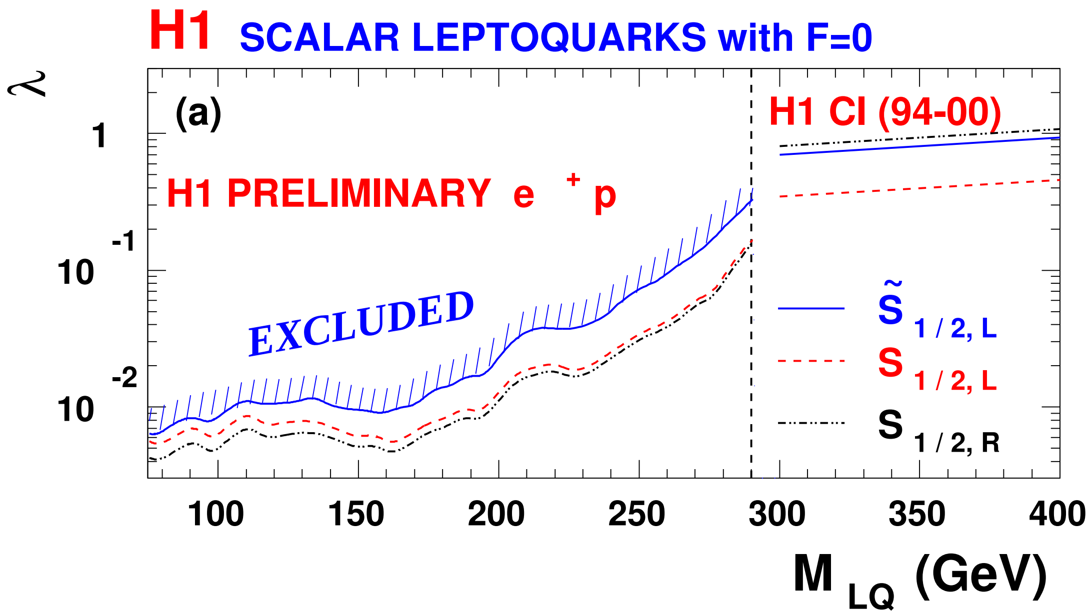
Scalar LQ with F=2



- F=2 S_0^L BRW LQ model
  $\Rightarrow$ e^-p data more sensitive than e^+p
- Combing NC + CC data
  $\Rightarrow$ increases sensitivity

Limits on F=0 scalar with eq

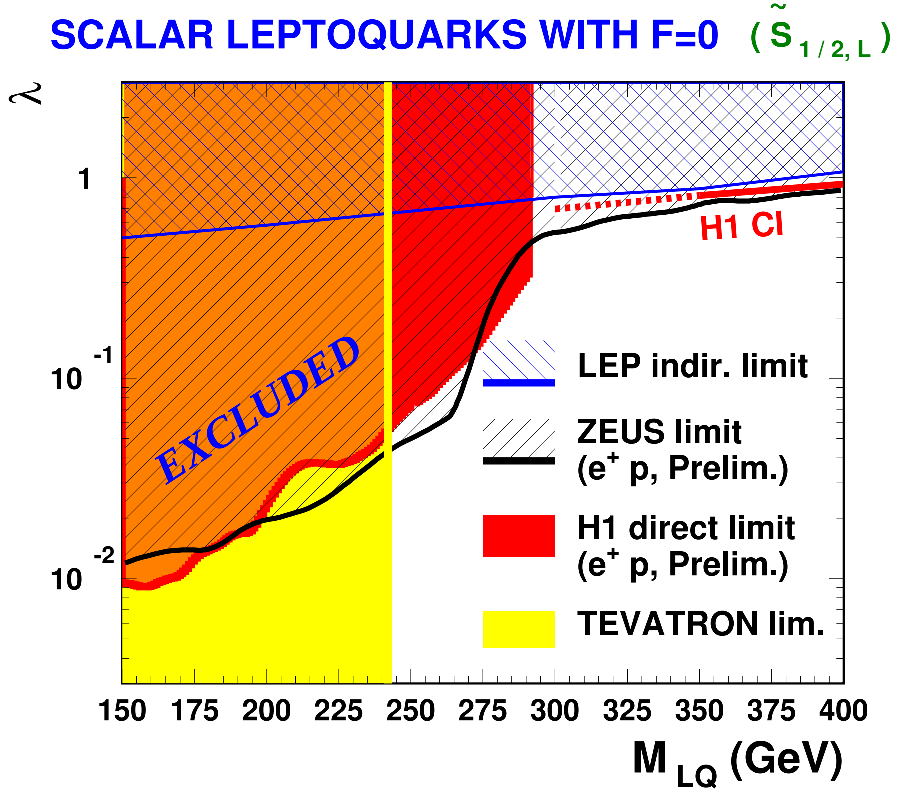


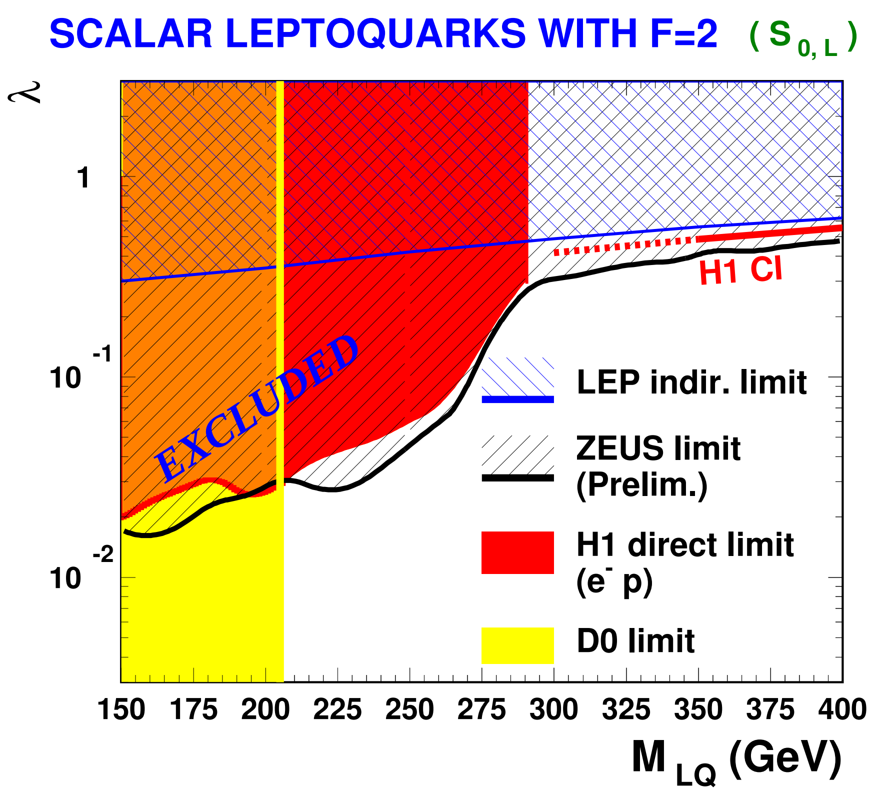


- F=0 scalar BRW LQ model ⇒
- couples to eq only

- Limit extends above CM energy

Comparison with LEP and TEVATRON





- TeVatron: λ independent

  LQ pair production with gauge coupling

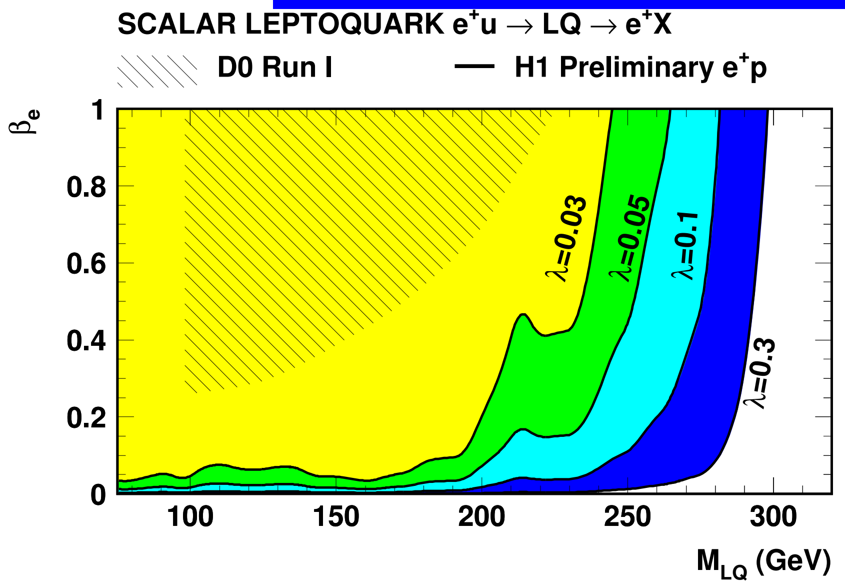
  $q\bar{q} \rightarrow l^+ l^- q\bar{q}$

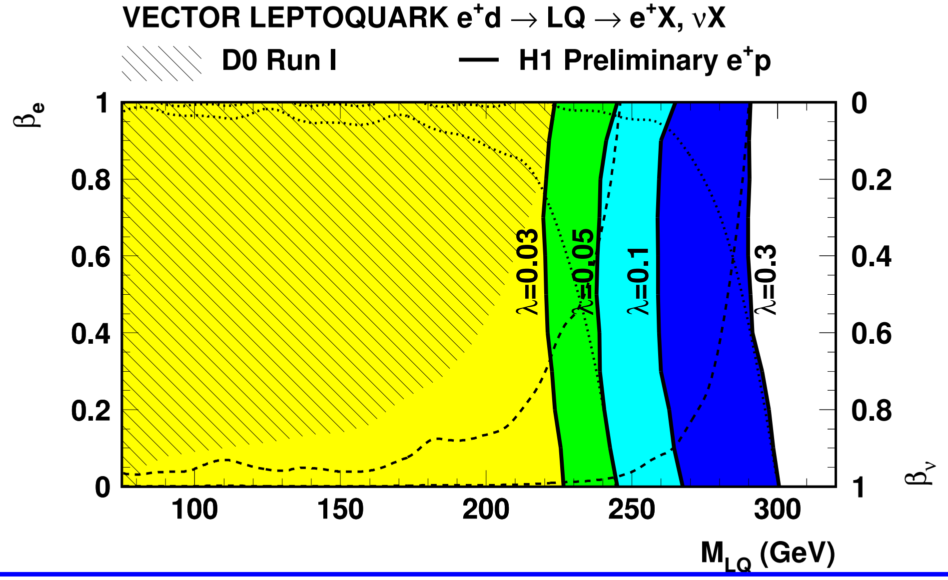
- LEP: indirect t-channel effect

  quark-pair production in

  $e^+ e^- \rightarrow q\bar{q}$

General F=0 LQ limit from HERA e^+p





General LQ Model (**No** $\beta(eq)$ **constraint**)

- Combined limit (NC & CC) assuming $\beta(eq) + \beta(\nu q) = 1$
- At λ 0.1, M_{LQ} up to 265 GeV excluded, independent of β
- Tevatron limits independent of λ, but less sensitive to $\nu q \Rightarrow$ degrade at low β

Summary

- Over $\sim$ 240 pb^{-1} of $e^{\pm}p$ data collected by H1 and ZEUS
- No evidence for LQ
- For coupling $\lambda = 0.1$ - $M_{LQ} >$ 245 - 288 GeV

H1 & ZEUS Preliminary

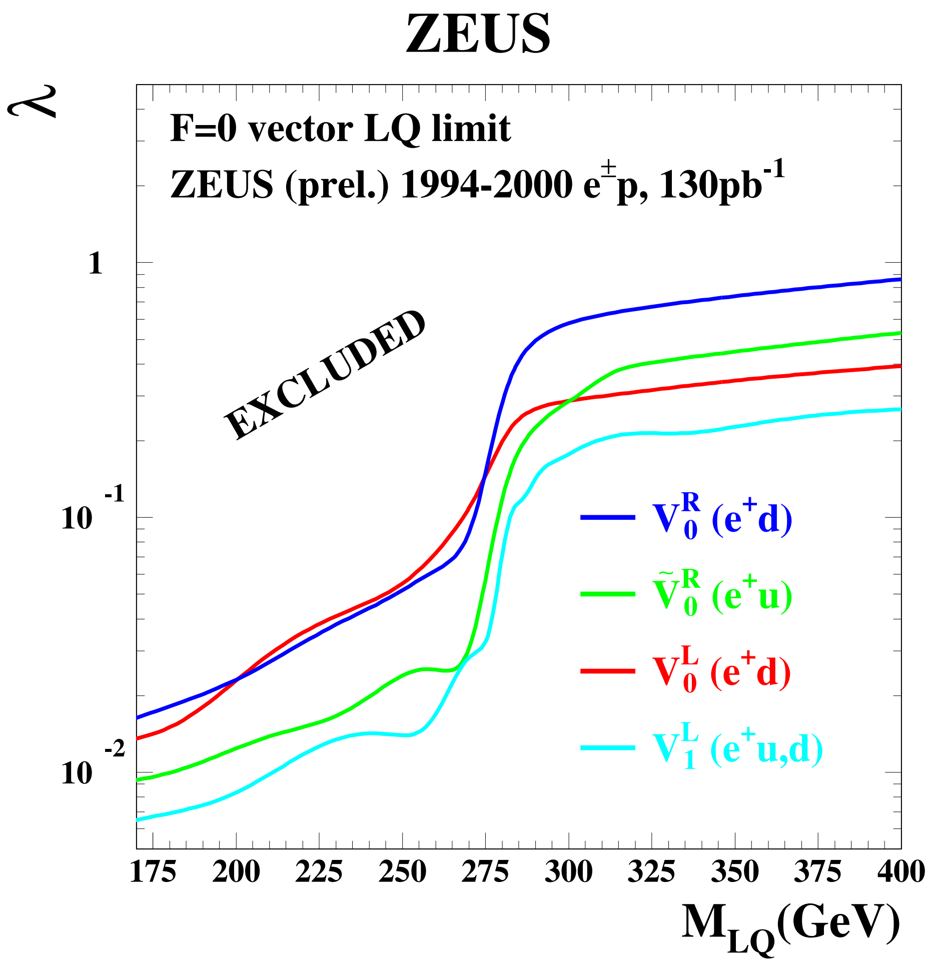
LQ Type (F=0)	V_0^L	V_0^R	$\bar{V}_0^R$	V_1^L	$S_{1/2}^L$	$S_{1/2}^R$	$\bar{S}_{1/2}^L$
M(GeV) ZEUS	268	271	279	283	281	281	270
M(GeV) H1	259	266	283	288	282	283	261

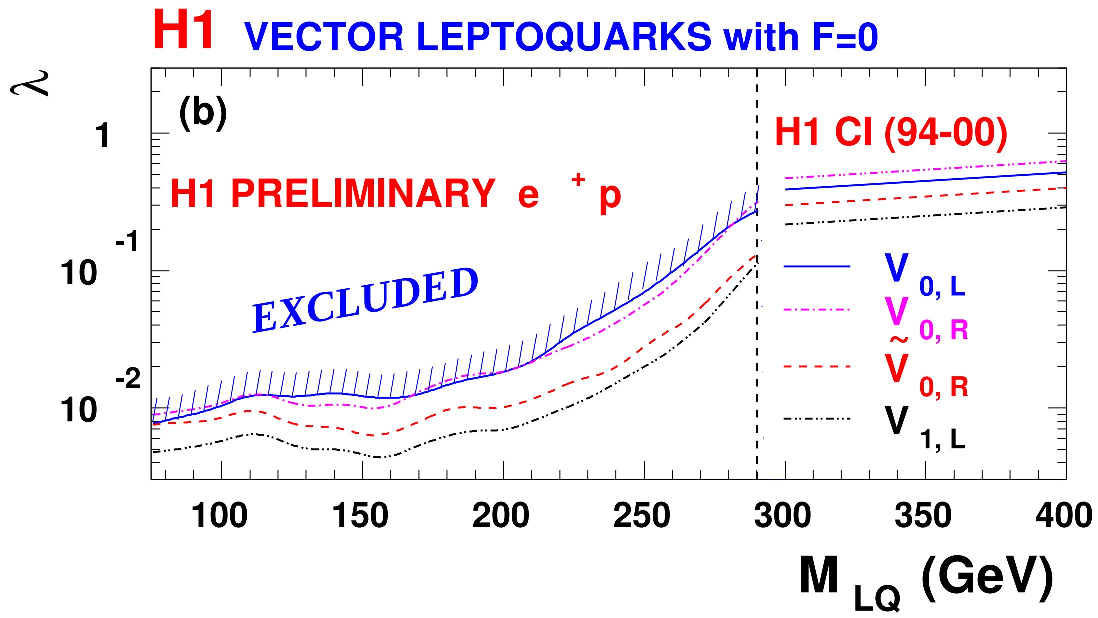
LQ Type (F=2)	S_0^L	S_0^R	$\bar{S}_0^R$	S_1^L	$V_{1/2}^L$	$V_{1/2}^R$	$\bar{V}_{1/2}^L$
M(GeV) ZEUS	274	272	249	274	248	273	272
M(GeV) H1	269	273	245	273	262	278	279

- LQ Limits at HERA complementary to Tevatron (limit depends strongly on β)
- In general HERA has better limit than LEP
- HERA2: Luminosity upgrade, $\sim 1 fb^{-1}$ in 5 years, with ZEUS & H1 detectors upgrade

Exciting future with HERA upgrade

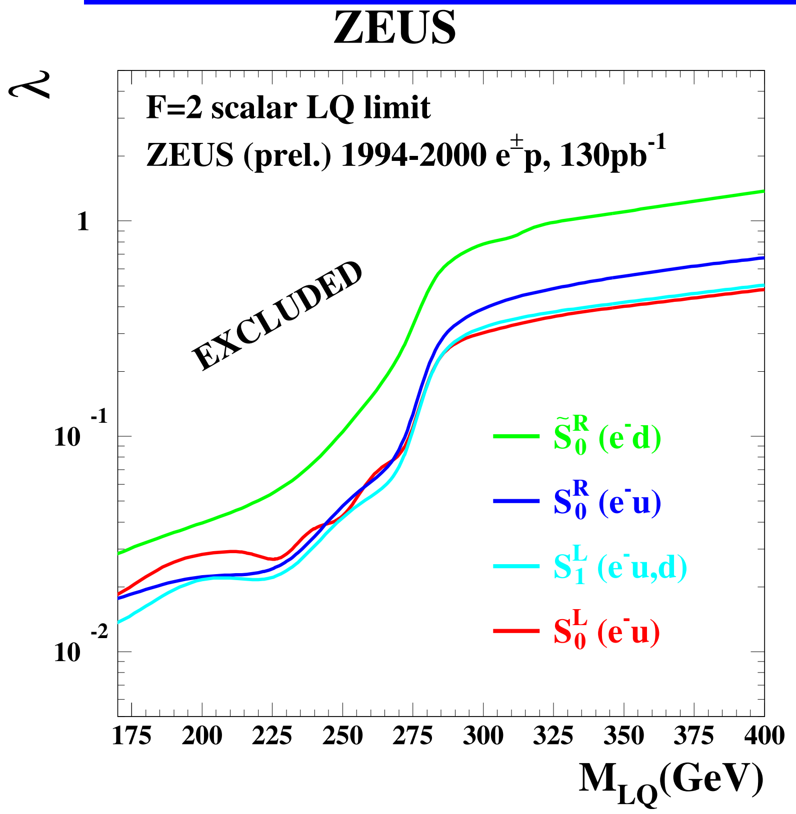
Limits on F=0 vector with $eq + \nu q$

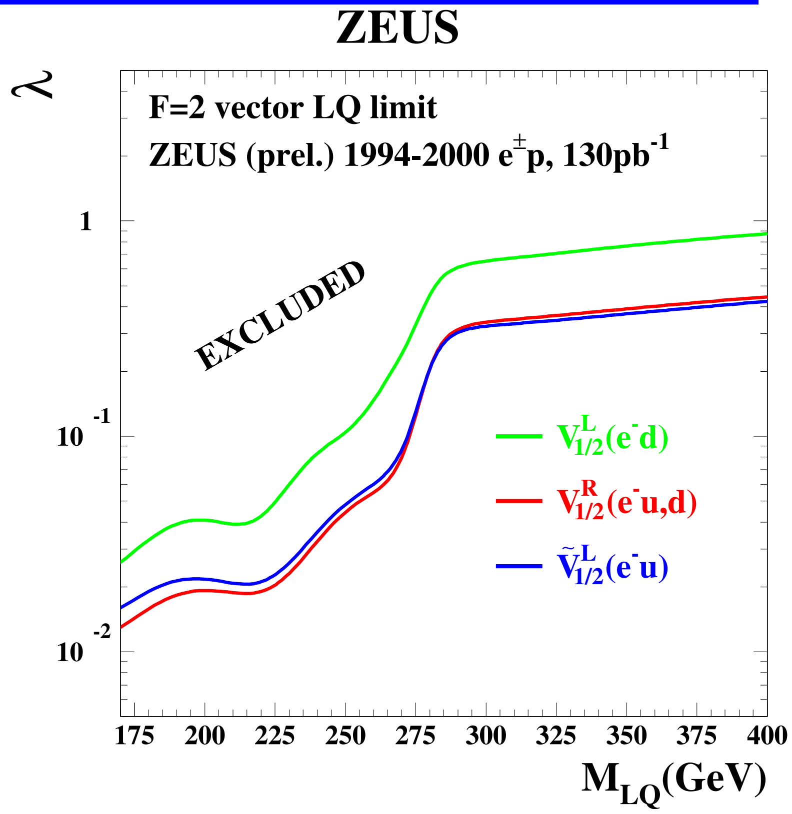




- F=0 vector BRW LQ model $\Rightarrow$
- $\beta_{eq} = 0.5$ $\beta_{\nu q} = 0.5$ fixed
- Combine eq & νq channel

Limits on F=2 BRW LQ with $eq + \nu q$ from ZEUS





- F=2 scalar BRW LQ model
  $\Rightarrow$ Combine eq & νq channels
- F=2 vector BRW LQ model
  $\Rightarrow$ eq channel only

Models

Leptoquarks

Aachen notation

Model	Fermion number F	Charge Q	$BR(LQ \to e^{\pm}q)$ β	Coupling		Squark type
$S_\circ^L$	2	$-1/3$	1/2	$e_L u$	νd	$\tilde{d}_R$
$S_\circ^R$	2	$-1/3$	1	$e_R u$		
$\tilde{S}_\circ$	2	$-4/3$	1	$e_R d$		
$S_{1/2}^L$	0	$-5/3$	1	$e_L \bar{u}$		
		$-2/3$	0		$\nu \bar{u}$	
$S_{1/2}^R$	0	$-5/3$	1	$e_R \bar{u}$		
		$-2/3$	1	$e_R \bar{d}$		
$\tilde{S}_{1/2}$	0	$-2/3$	1	$e_L \bar{d}$		$\overline{\tilde{u}_L}$
		$+1/3$	0		$\nu \bar{d}$	$\overline{\tilde{d}_L}$
S_1	2	$-4/3$	1	$e_L d$		
		$-1/3$	1/2	$e_L u$	νd	
		$+2/3$	0		νu	
$V_\circ^L$	0	$-2/3$	1/2	$e_L \bar{d}$	$\nu \bar{u}$	
$V_\circ^R$	0	$-2/3$	1	$e_R \bar{d}$		
$\tilde{V}_\circ$	0	$-5/3$	1	$e_R \bar{u}$		
$V_{1/2}^L$	2	$-4/3$	1	$e_L d$		
		$-1/3$	0		νd	
$V_{1/2}^R$	2	$-4/3$	1	$e_R d$		
		$-1/3$	1	$e_R u$		
$\tilde{V}_{1/2}$	2	$-1/3$	1	$e_L u$		
		$+2/3$	0		νu	
V_1	0	$-5/3$	1	$e_L \bar{u}$		
		$-2/3$	1/2	$e_L \bar{d}$	$\nu \bar{u}$	
		$+1/3$	0		$\nu \bar{d}$	