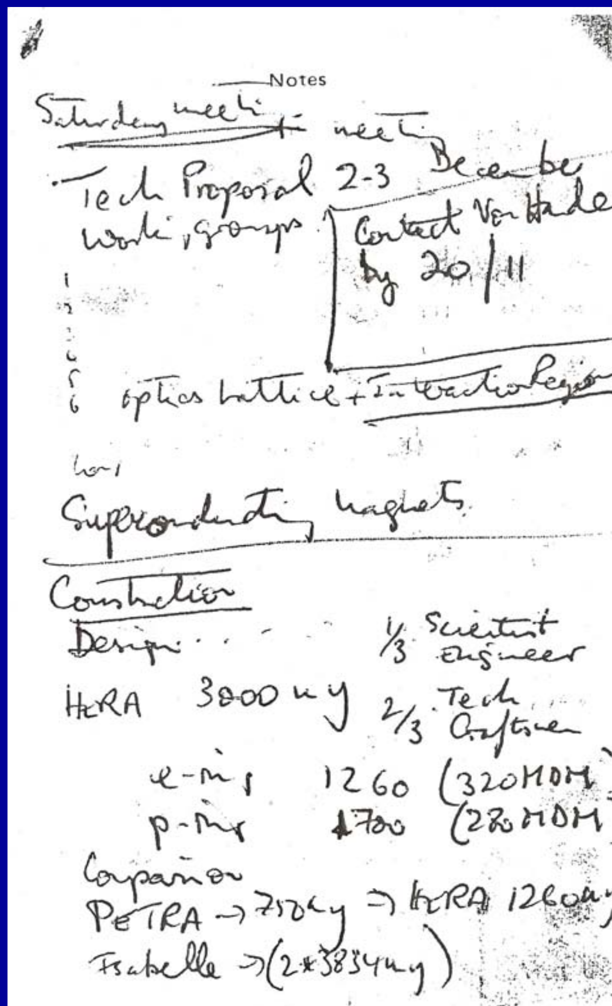
Impact of HERA on Physics at the Energy Frontier

Hugh Montgomery
Fermilab
June 29, 2007

Outline

- Credentials
- Structure of the Electroweak Interaction
- Electroweak Objects
- New Phenomena
- Multi-lepton Production
- Conclusion

Credentials I:
Particle Physics Notebook circa 1980


Notes

Saturday meeting → meeting

Tech Proposal 2-3 December
working groups | Contact Van Hade by 20/11

optics lattice + Interaction Region

Superconducting Magnets

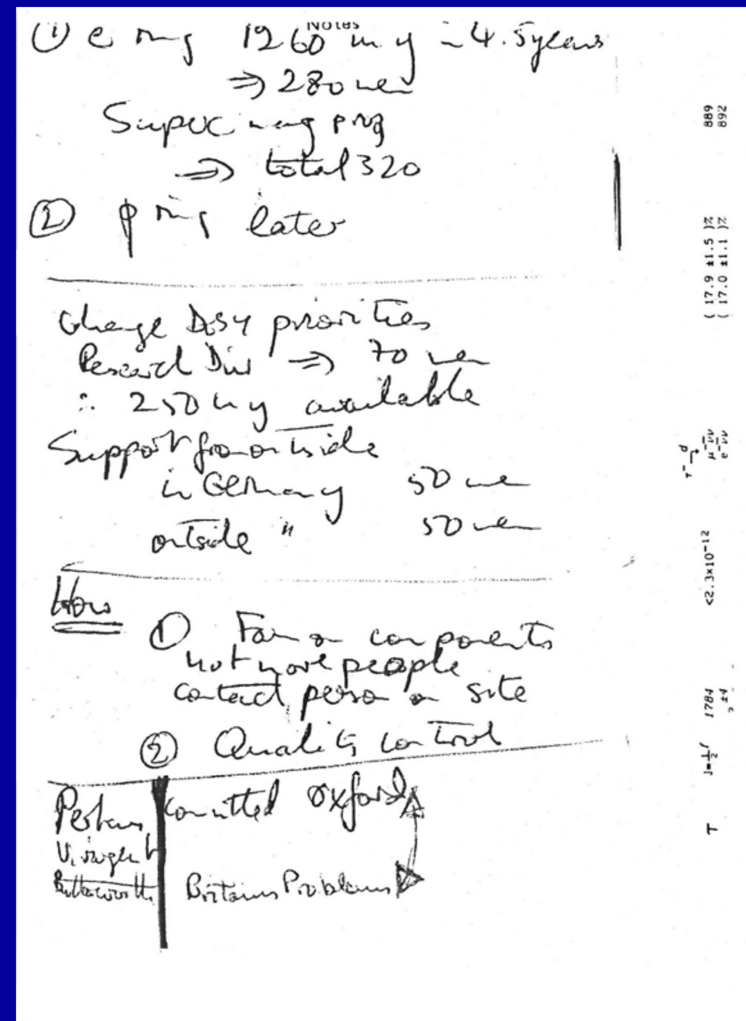
Construction

Design . . . 1/3 Scientist engineer

HERA 3800 my 2/3 Tech Craftsmen

e-ring 1260 (320 MDM)
p-ring 1700 (280 MDM)

Comparison
PETRA → 750 my ⇒ HERA 1260 my
Isabelle → (2*3834 my)


① e ring 1260 my ~4.5 years
⇒ 280 men
Superconducting ring
⇒ total 320
② p ring later

Change DESY priorities
Research Div ⇒ 70 men
∴ 250 my available
Support from outside
in Germany 50 men
outside " 50 men

How ① For components not more people contact person on site
② Quality control

Peters Committed Oxford
[illegible]
Butterworth Britain's Problems

Credentials II:
ECFA WORKING Group under Amaldi

On 11 May 1979, the Plenary ECFA session agreed with the positive spirit of these conclusions and asked me to organize the continuation of the study with the aim of producing a final report by the beginning of 1980. The organization was set up in a meeting with the Discussion Leaders of the Hamburg study and was based on four working groups.

WORKING GROUP	CONVENORS
Theory	G. Altarelli
	J. Ellis
	G. Kramer
	C.H. Llewellyn-Smith
Machine	B.H. Wiik
	E.J.N. Wilson
Experiments	P. Dalpiaz
	W. Hoogland
	H.E. Montgomery
	D.H. Perkins
	P. Söding
	K. Tittel
	R. Turlay
Superconducting Magnets	G. Horlitz

The choice of more than one convenor per group was dictated by the necessity of organizing around each of them local clusters of physicists working efficiently on different subjects while avoiding time-consuming plenary meetings.

The terms of reference of the working groups were discussed with the Convenors, with the Chairman of ECFA and with the Director of DESY. They had to take into account the evolution of the ideas in DESY. Already at the Hamburg meeting it was proposed to increase the energy of the electron beam of PROPER to about 45 GeV by modifying the focusing properties of the PETRA lattice[10)]. After the meeting, DESY looked into the largest ring that could be installed near PETRA and by summer 1979 the conclusion

Credentials II: Backgrounds in HERA

IV-53

5. BACKGROUNDS FOR EXPERIMENTS AT HERA

5.1 Introduction

In the study of the feasibility of experiments there is an obvious necessity to consider possible backgrounds which can perturb and, in the limit, prevent the foreseen measurement. For experiments at colliding beam machines there is the added complication that the interdependence of machine and experiment is complete and an early evaluation of mutual implications is necessary.

The work reported here has been concentrated on three rather well defined problems:

i) Synchrotron Radiation
ii) Electron Beam Gas Background
iii) Proton Beam Gas Background

The calculations have been performed using the tentative machine parameters available and certain measures to minimise the effect of the various background have been independently proposed. There are implications for machine design although a full optimisation of experimental conditions taking into account all backgrounds together with the machine design has not been performed. It is however the main conclusion of this study that such care is necessary in any machine design.

5.2 Synchrotron Radiation

The properties of the magnetic elements near the interaction point are summarised in Table I. BV1 - BV4 designate the vertical bends, BV1 nearest the crossing points and QE1, QE2 the low beta quadrupoles in the electron ring. The number of electrons is assumed to be 2.24×10^{13} (167 mA). The synchrotron radiation spectra are given in Fig. 5.1.

Radiation in the Crossing Region

In Fig. 5.2 the interaction region and its environs are shown and suggested positions for collimators and vacuum pipe are included. The arrangement of the collimators is guided by the principle that the

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the level of those explicitly calculated here. Experience with present electron colliders indicates that this is quite possible.

Significance for the Physics

The electrons entering the detector have angles of a few mrad with respect to the electron beam axis and they will impinge on the smallest angle electron detectors. Their apparent Q^2 under the assumption that their origin is the intersection point is $\lesssim 5$ GeV^2 and for conventional

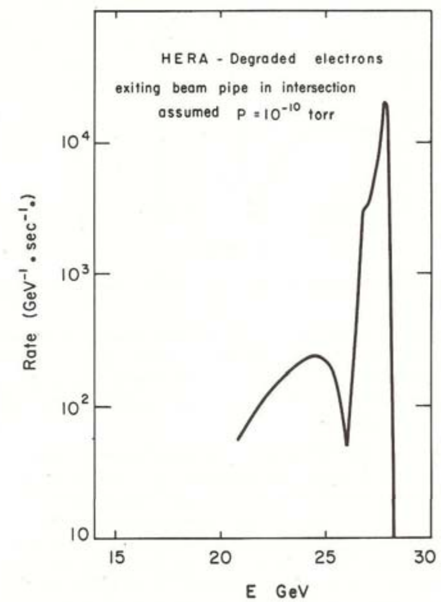


Fig. 5.5 - Rate of electrons exiting from beam pipe in the intersection region.

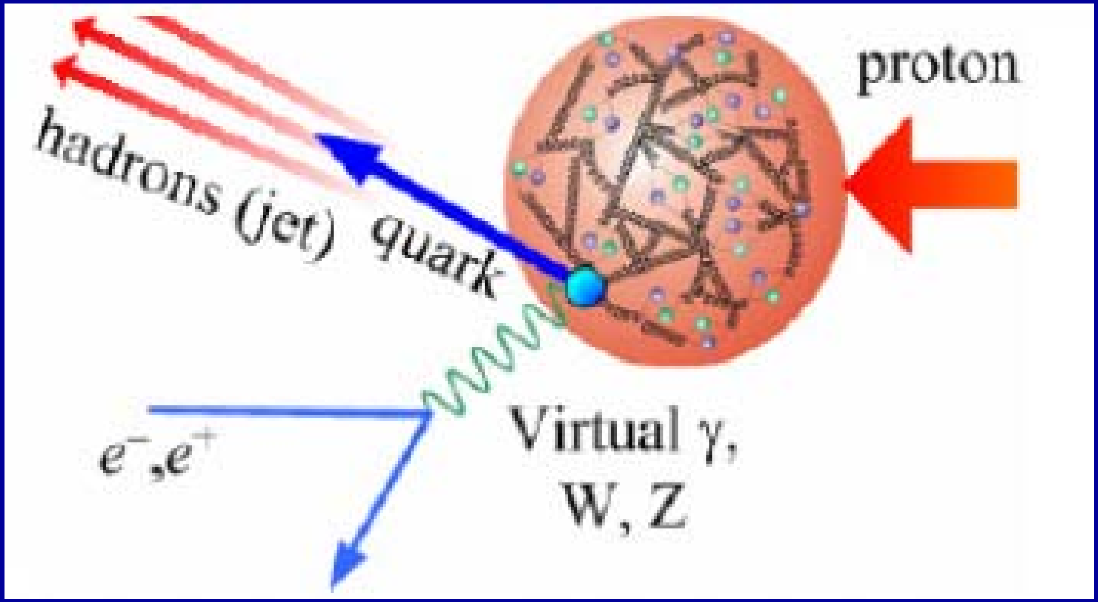
Credentials III: “Montgomery you Screwed up!”

I worked on the measurement of the longitudinal structure function in one of the studies. Chris Sachrajda was to give the plenary talk at a meeting here at DESY. Don Perkins, who was advising Chris, had a look at my work and concluded it was wrong.

Across the foyer of the Horsaal Perkins bellowed (he would say whispered)

“Montgomery you screwed up! “

HERA Fundamentals



$$Q^2_{MAX} = s$$

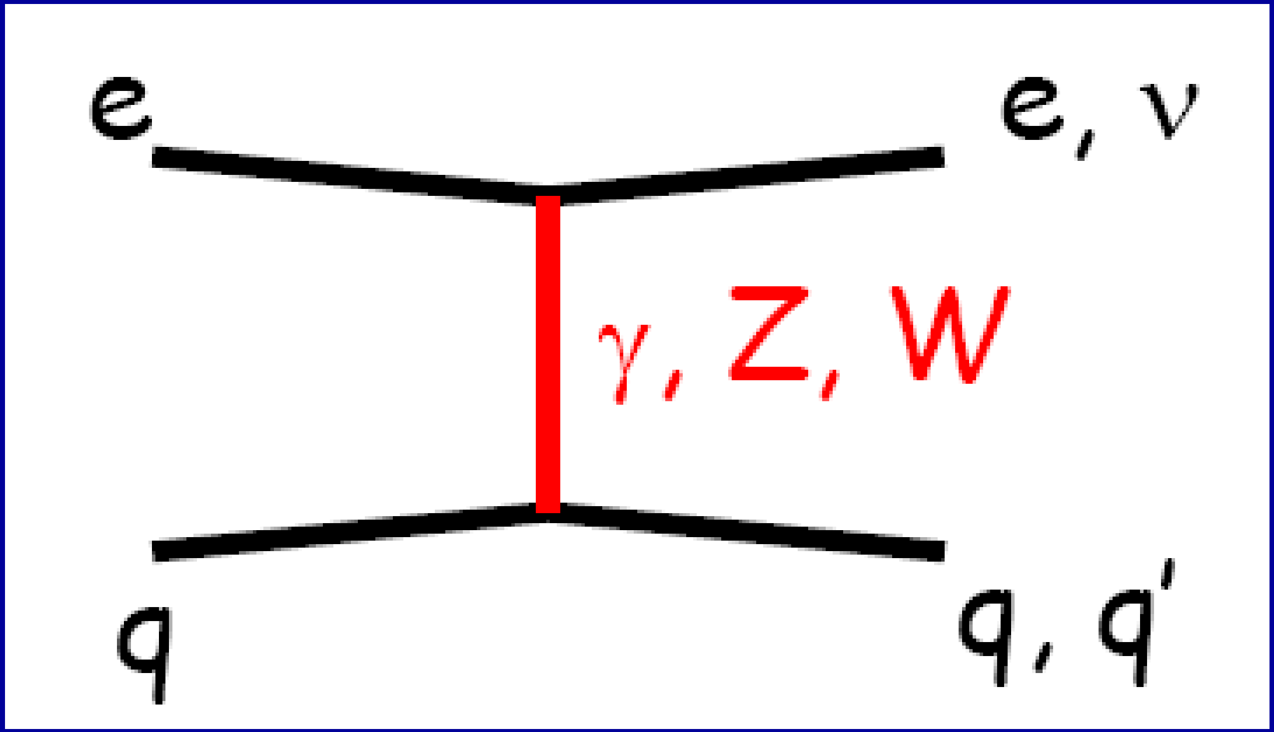
At HERA: Ee=27.5 GeV, Ep=920 GeV

$$\sqrt{s} = 320\,\text{GeV}$$

$$Q^2_{MAX} \sim 10^5\, GeV^2$$

$$\lambda_{MAX} \sim 1/1000\, r_{proton}$$

The Electroweak Interaction



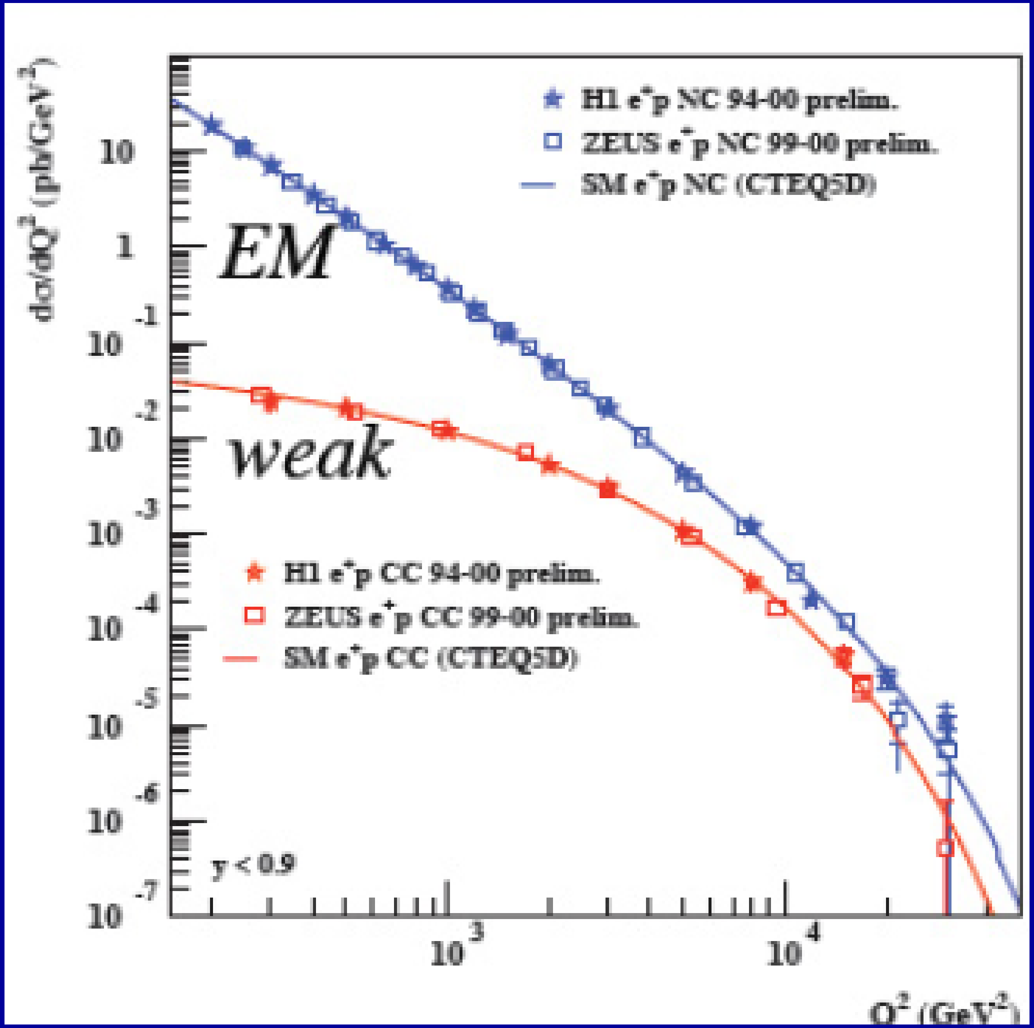
Photon and Z Boson exchange -- Neutral current

W Boson exchange – charged current

Electroweak Unification

At high momentum transfer the charged (W) and neutral (photon + Z) cross sections are equal

Weak and electromagnetic forces have the same strength !!



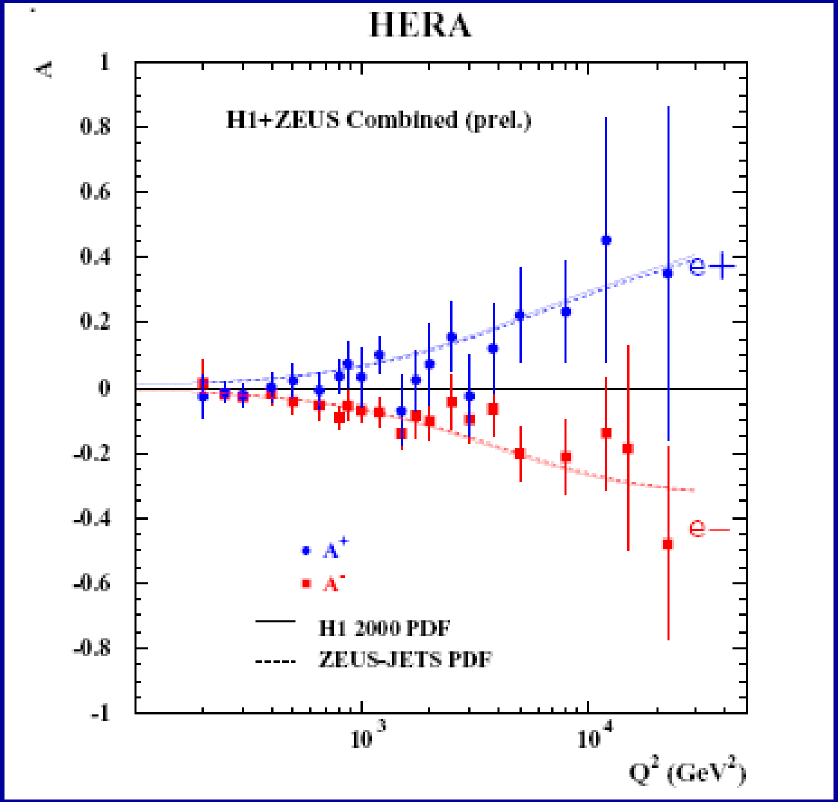
Parity Violation in Neutral Currents

$A=(\sigma\uparrow-\sigma\downarrow)/(\sigma\uparrow+\sigma\downarrow)$

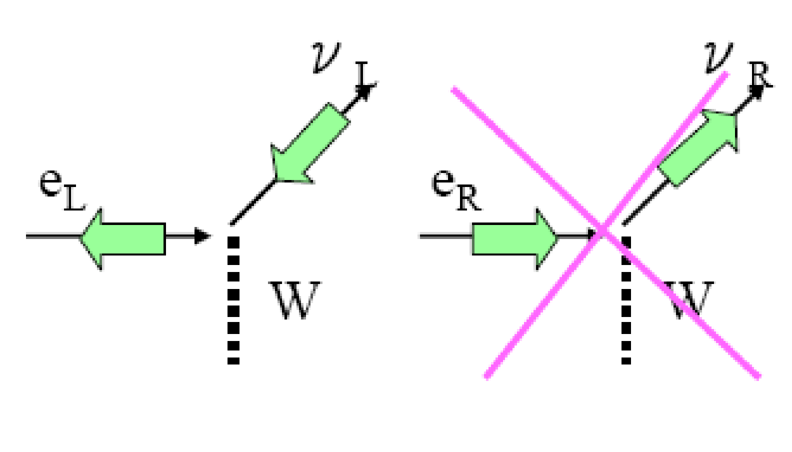
Right Handed positrons, Left Handed electrons

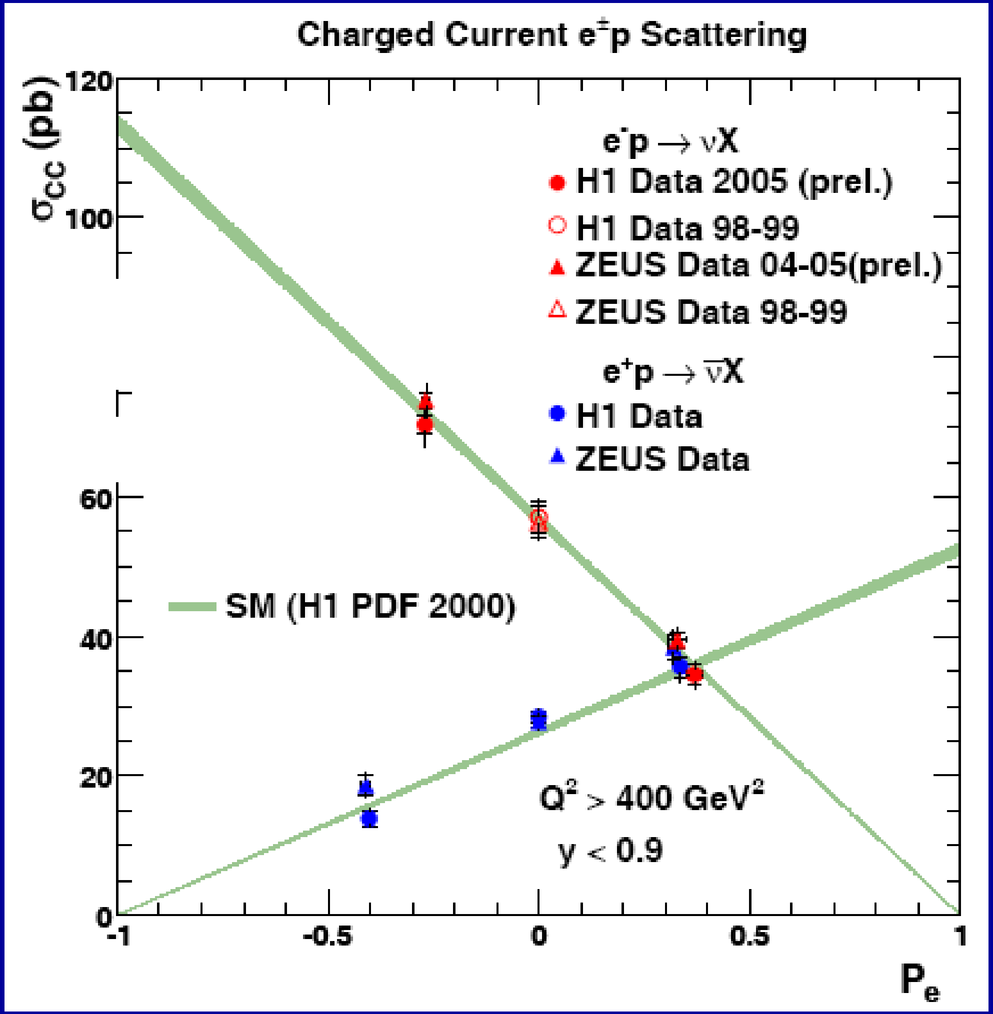
Cross Section asymmetries grow with Q2 as a result of the Electroweak Interference

Unpolarised electrons and positrons show no (small) difference



W Bosons are Left Handed





Polarised Charged Currents

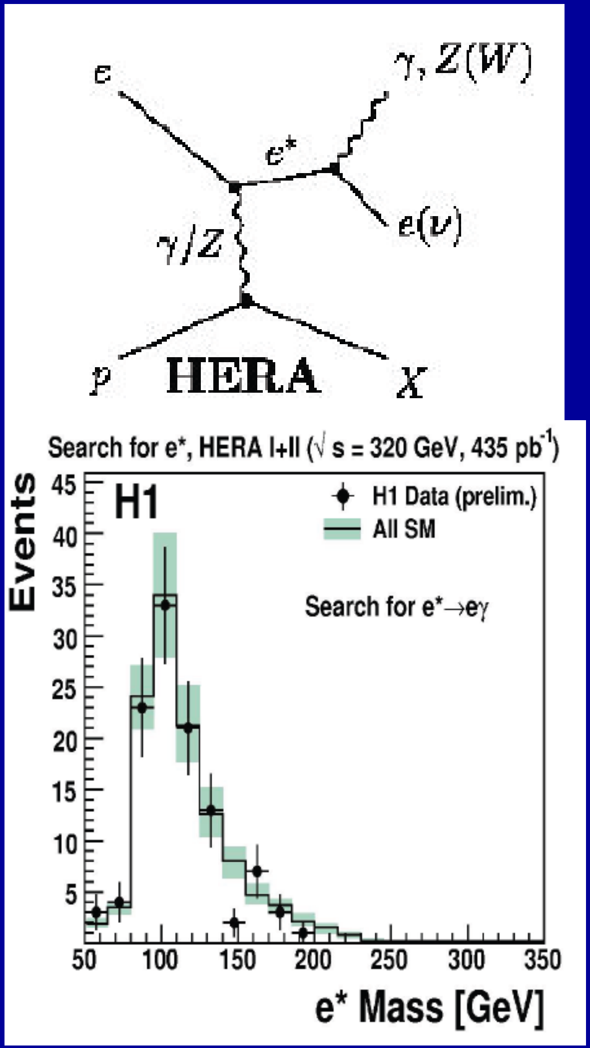
Cross Section is Zero for P_e= 1

Right Handed W Mass Limit
M_{WR}> 208 GeV

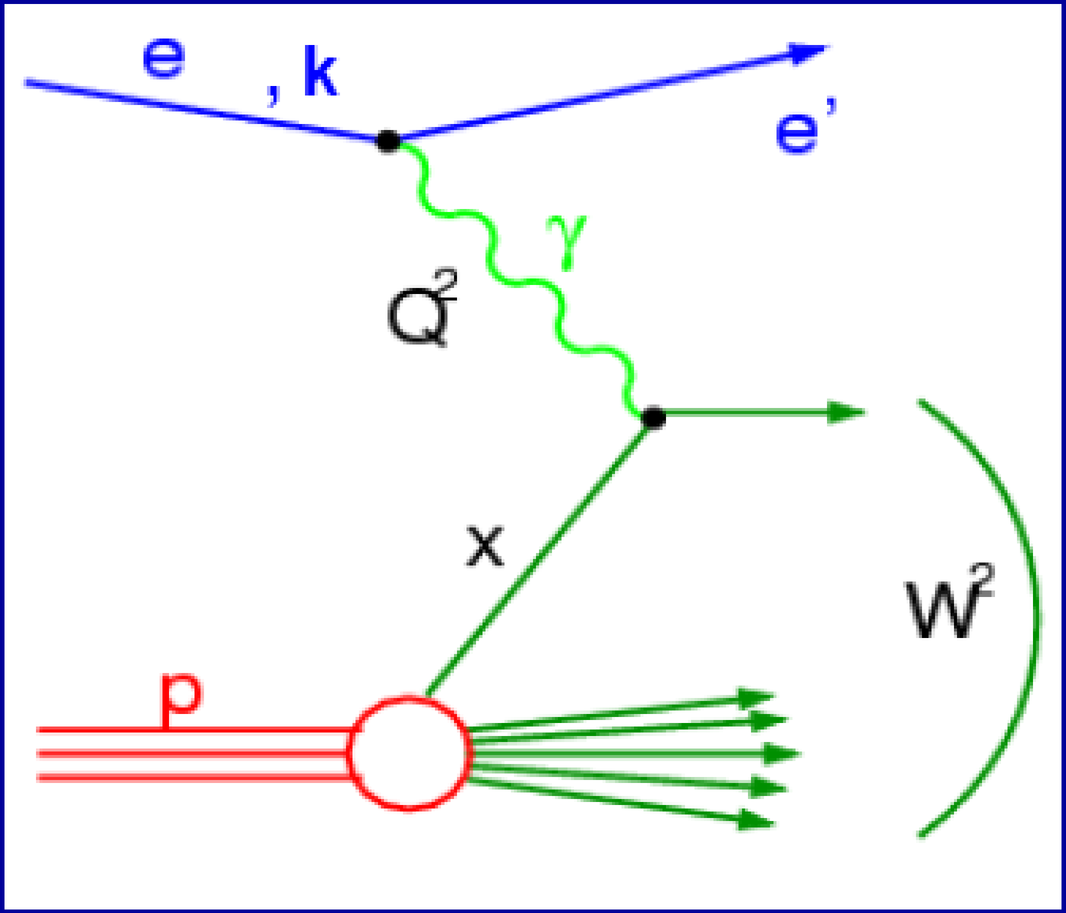
Heavy Leptons

Look for resonances in the effective mass of the photon and the electron/positron in the final state.

Excludes heavy lepton (e^* or ν^*) with mass below about 300 GeV in direct production

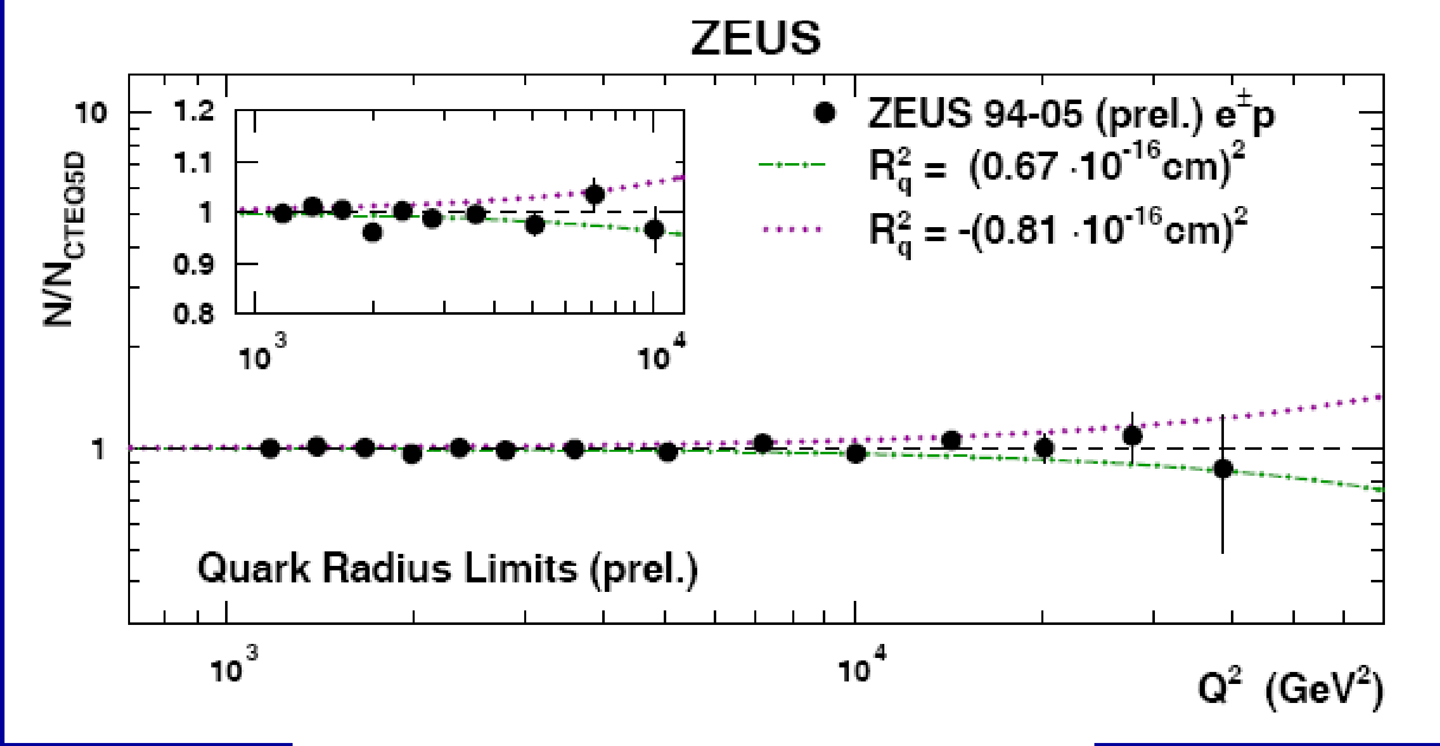


Scattering from Quarks



Quarks are Pointlike

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



EW Quark radius (RMS)

$R_q < 0.67 \times 10^{-3}$ fm (prel.)

Old Physics : New Physics

Cool demonstrations of how we can describe our world using the “Standard (read familiar) Model”

translate into

Incisive limits on any “Beyond the Standard Model” description of that world

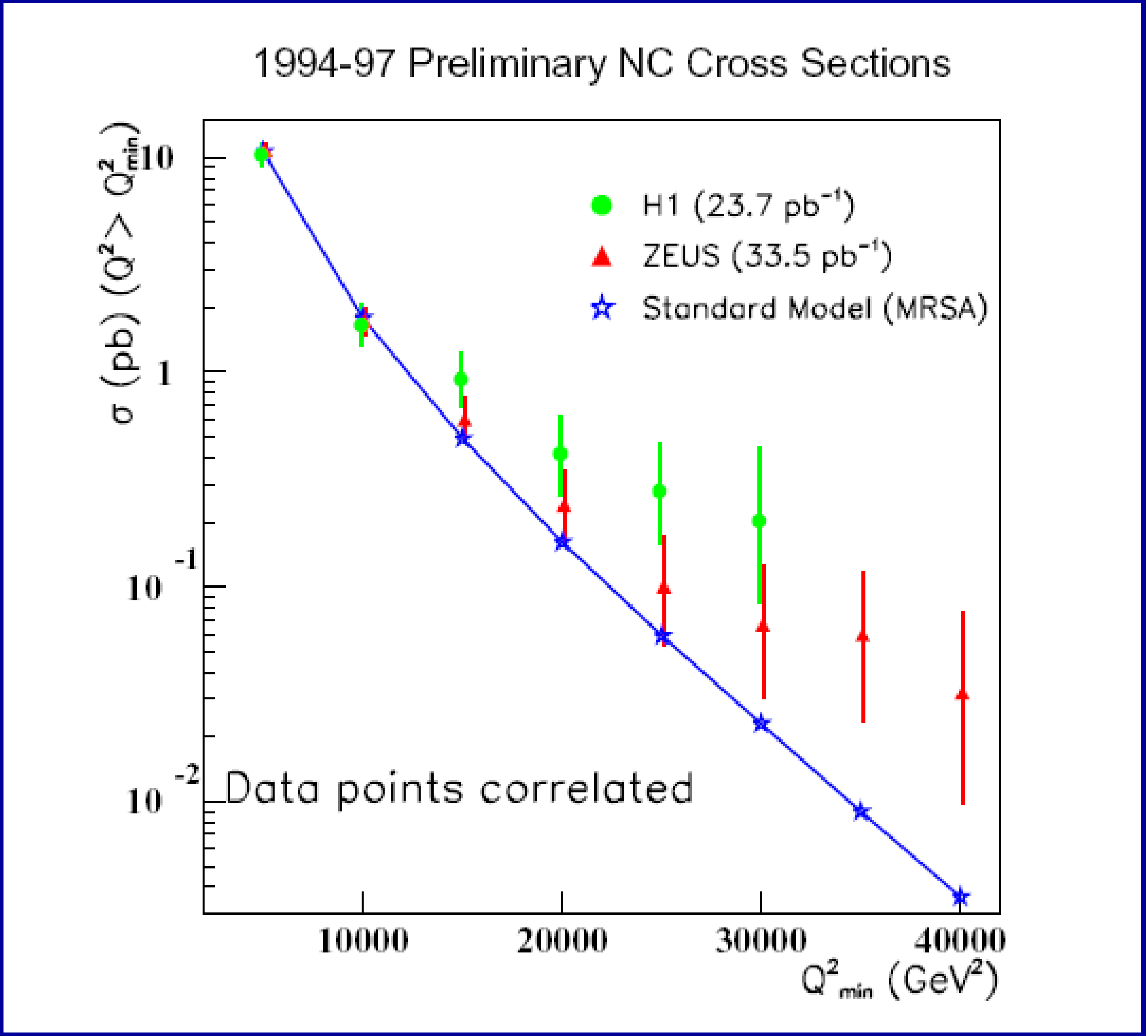
Failures of the description

translate into

Potential New physics

High Q2 Excess -- 1996-7

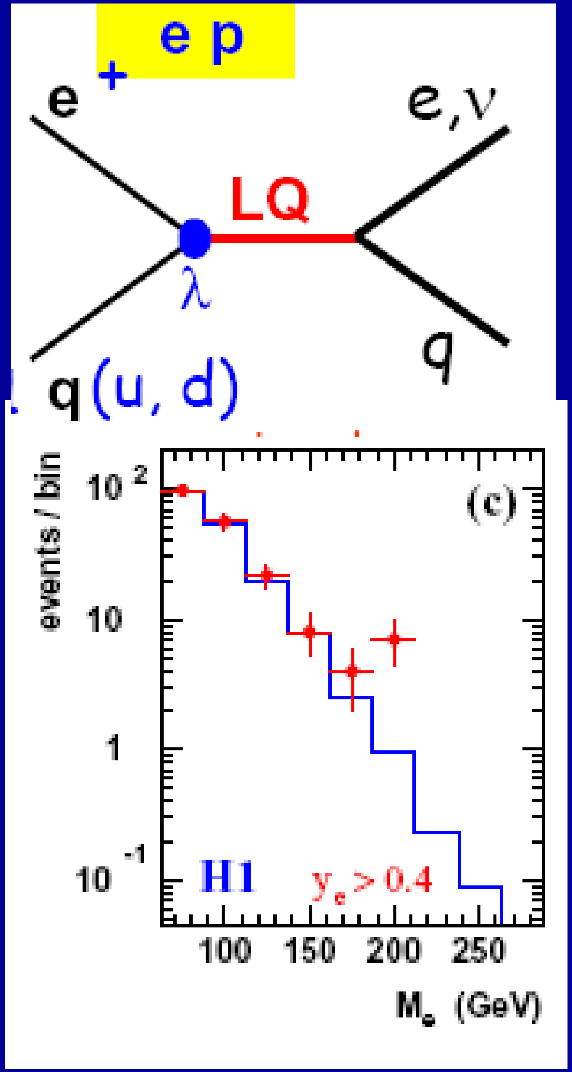
Comparison of the event yields at the highest Q2 shows an excess!



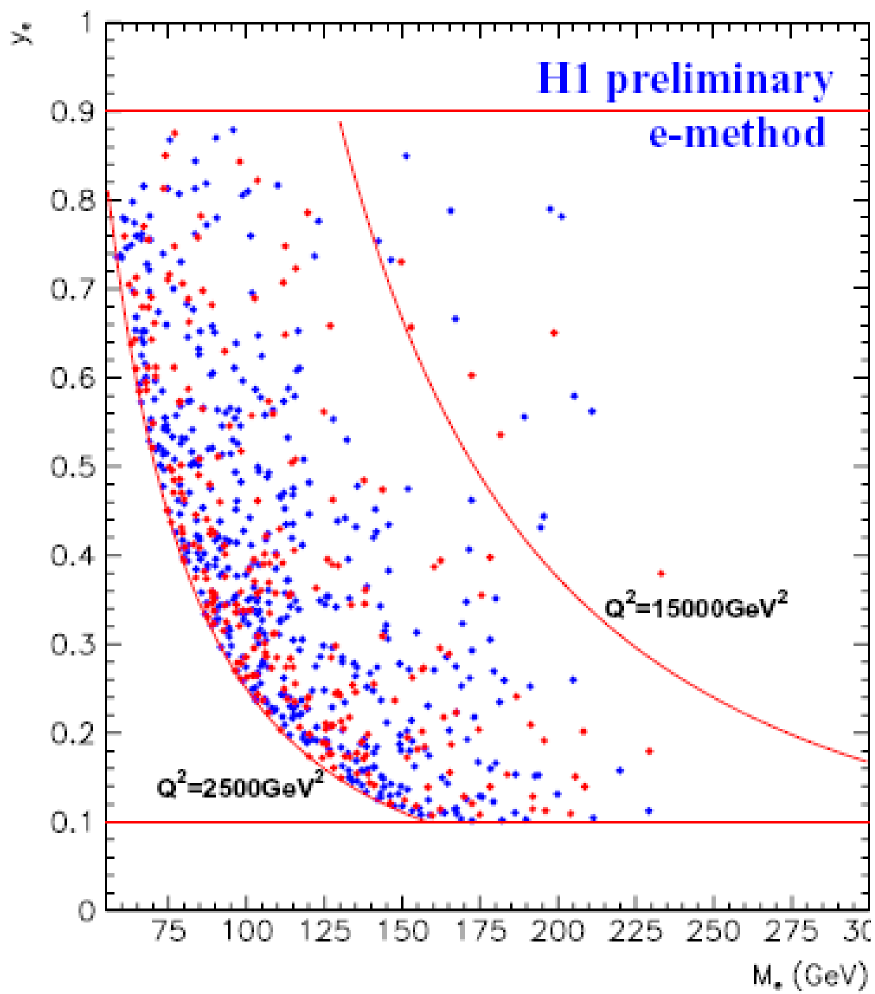
Leptoquarks -- 1996-7

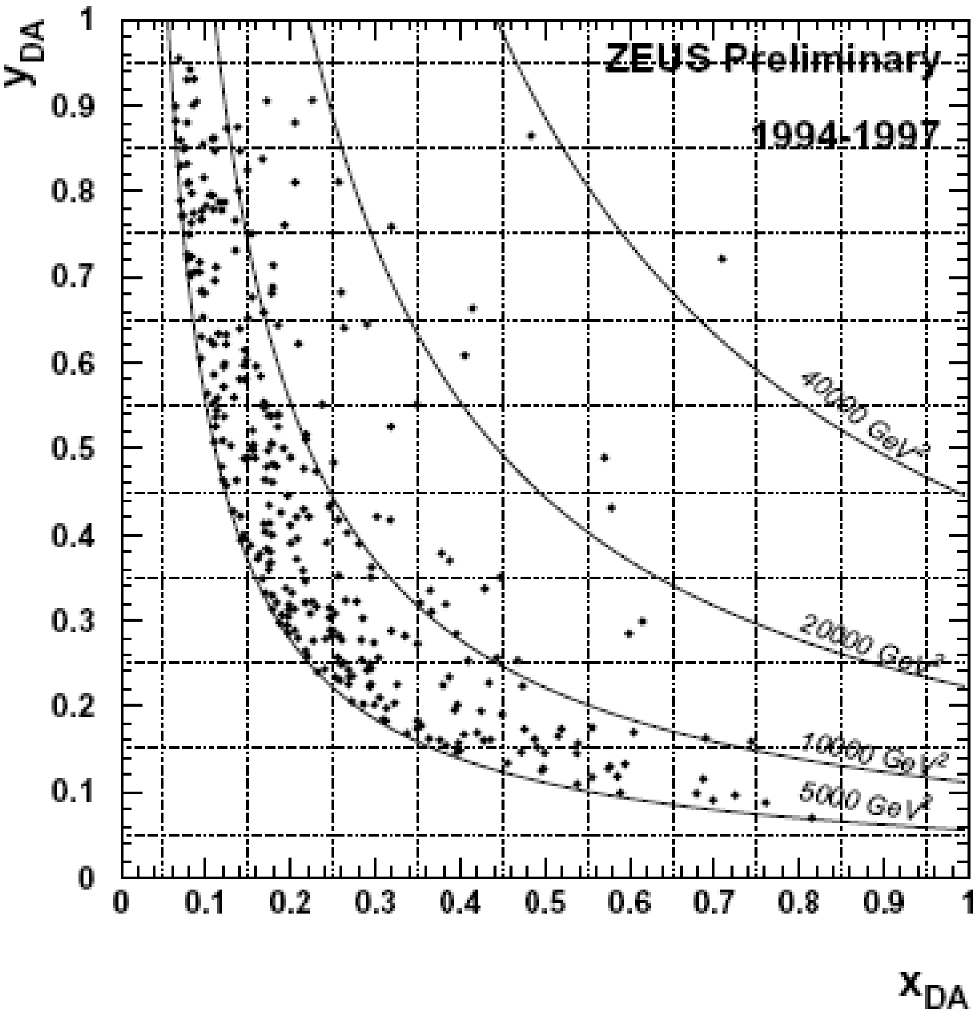
Leptoquarks potentially appear in formation

Peak in sub-process energy (electron-jet or neutrino-jet systems) corresponding to leptoquark mass.



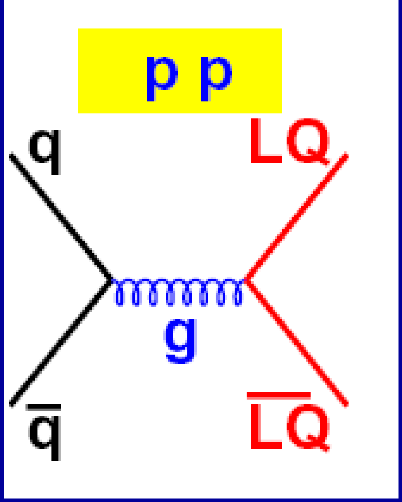
H1, ZEUS did not agree





Leptoquarks at Hadron-Hadron Colliders

Leptoquark Pair Production independent of LQ coupling

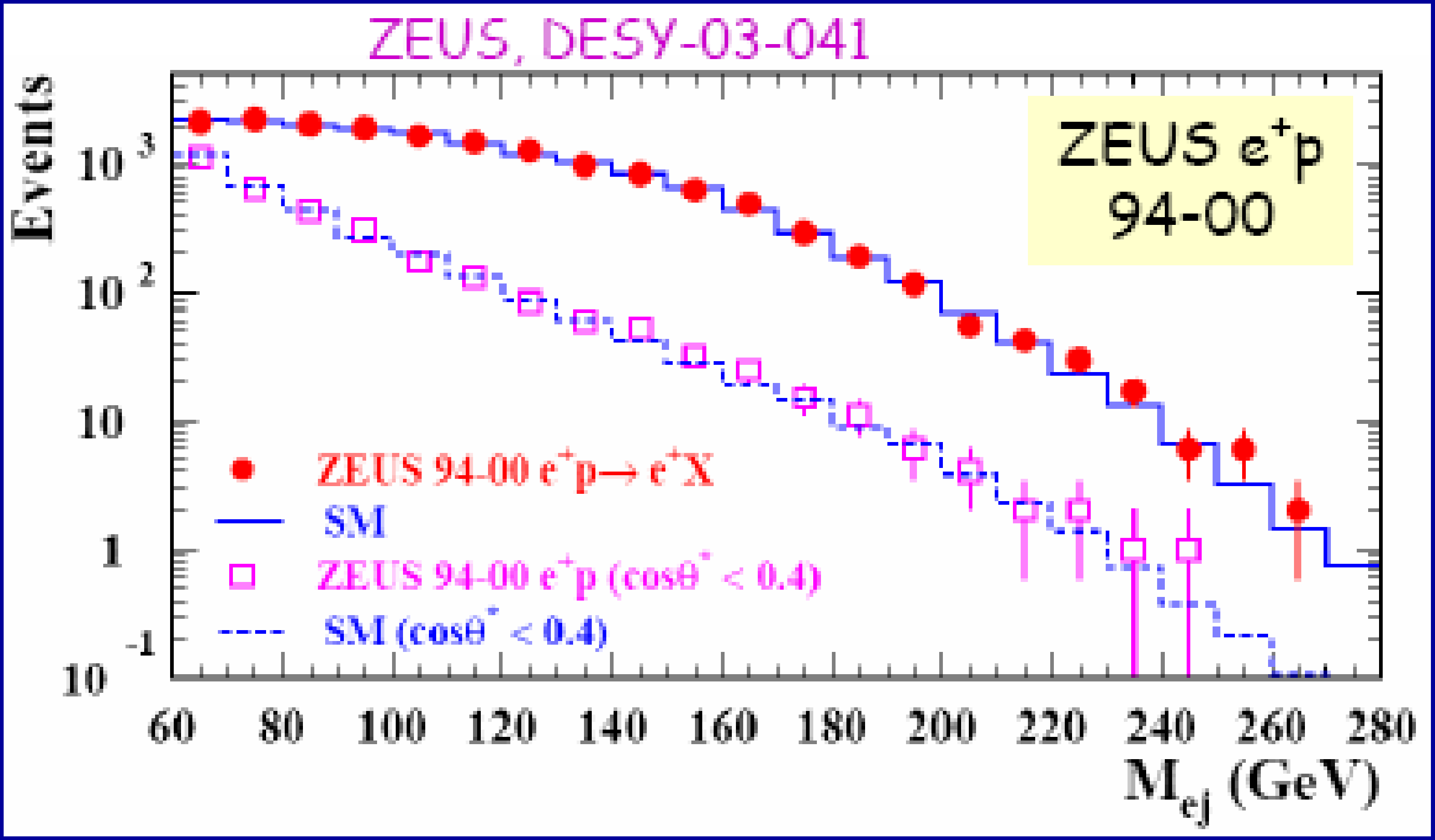


Search for eq, μq, τq, νq decays

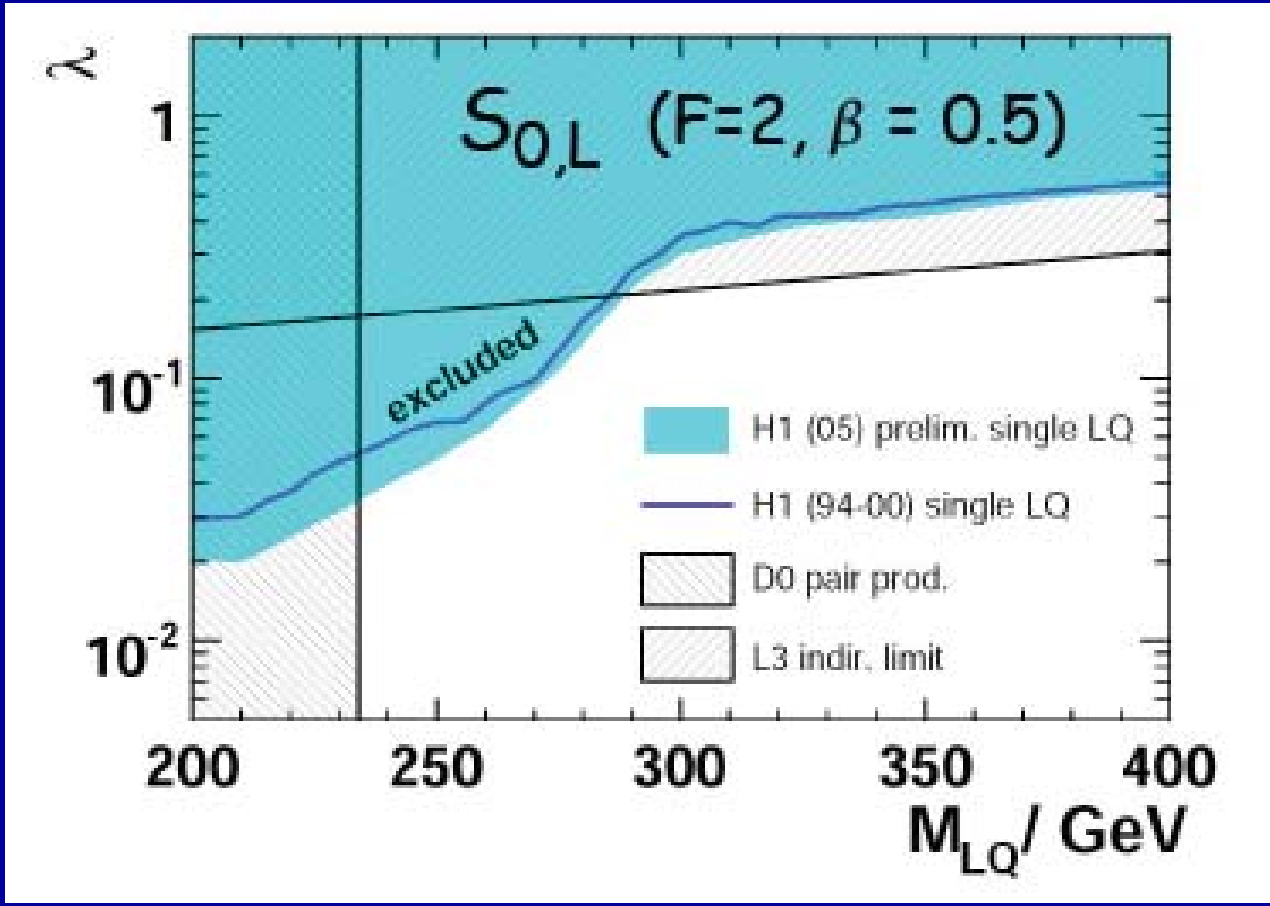
Can cover full range of branching ratios and all three generations

Tevatron limits covered range suggested by HERA results

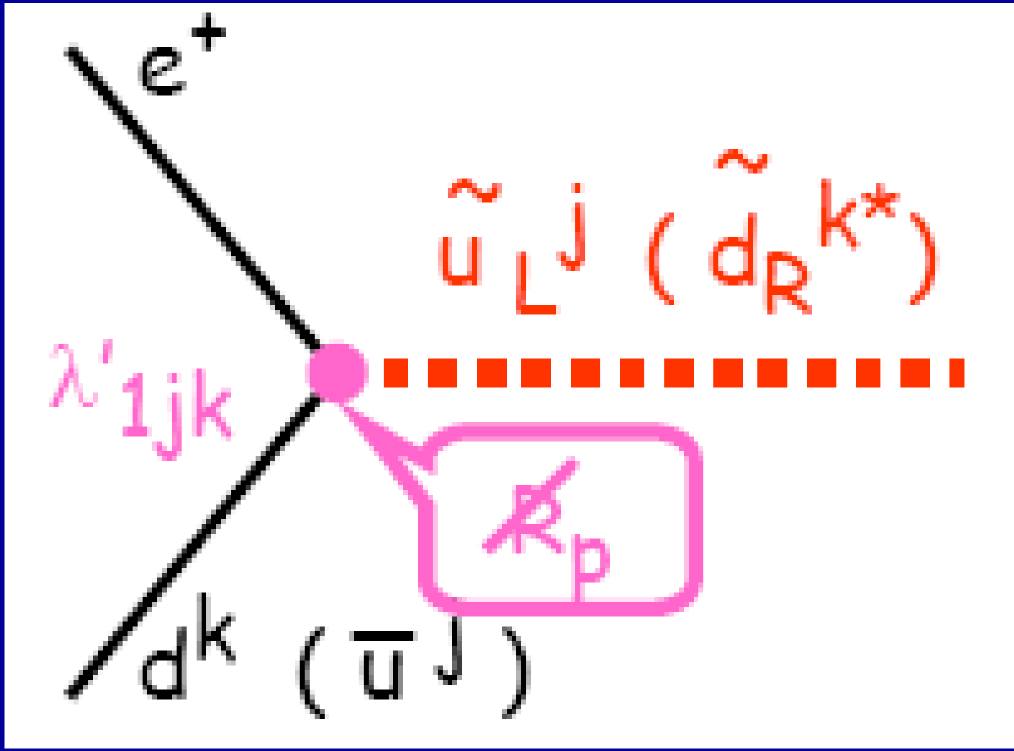
Leptoquarks 2000



Leptoquark Limits



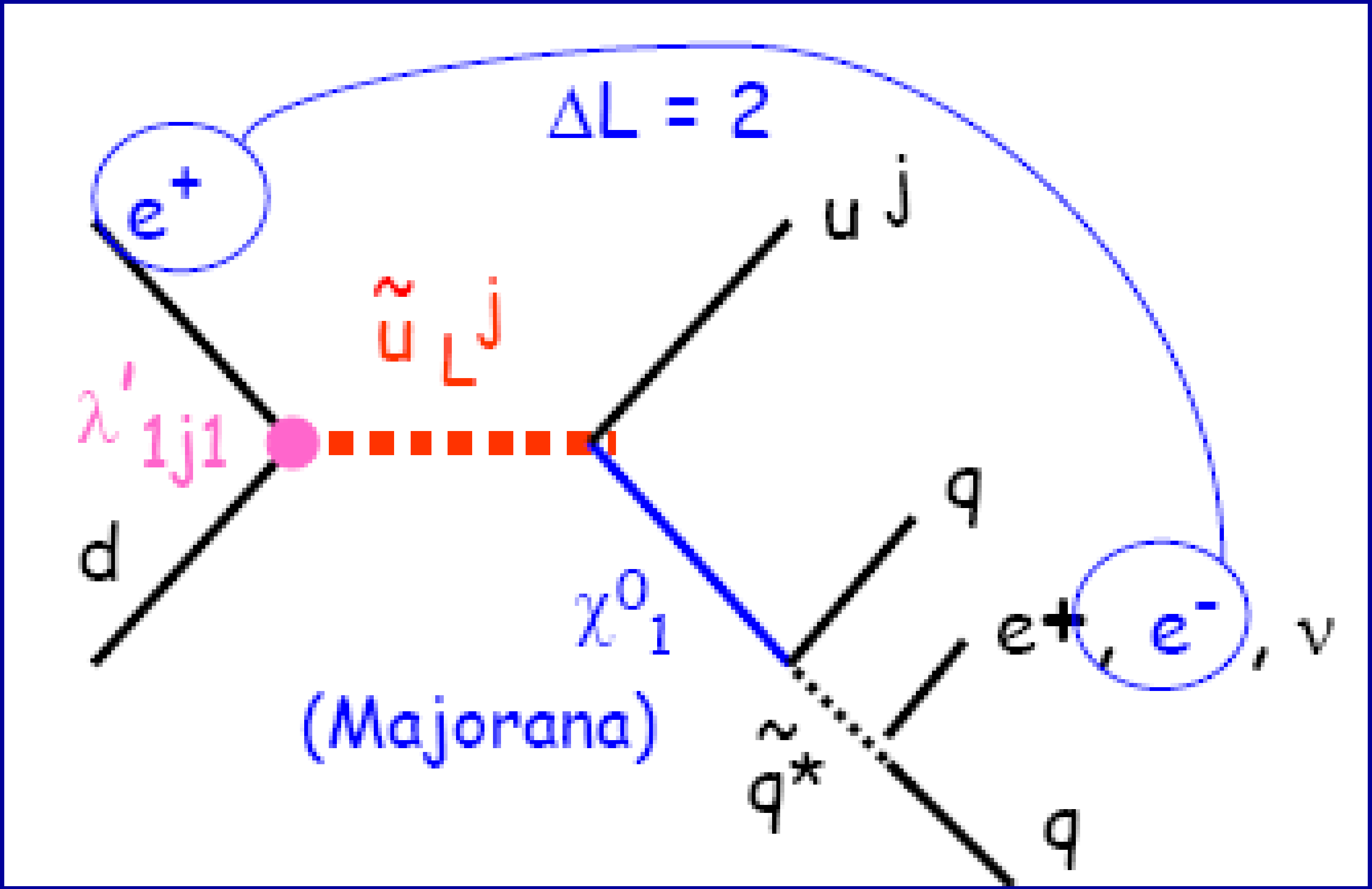
Supersymmetric Quarks: Squarks



Structurally similar to the production of Leptoquarks

Note the R parity violating vertex

Isolated Leptons/ Extra Leptons



Multi-Leptons -- 2005

H1 Preliminary, 211 pb-1

obs. / exp.

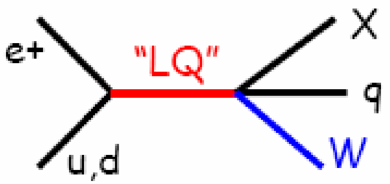
P_T^X > 25 GeV	e channel	μ channel	Combined e & μ
Electrons, 98-05 53 pb-1	2 / 0.9 ± 0.2	0 / 0.9 ± 0.2	2 / 1.8 ± 0.3
Positrons, 94-04 158 pb-1	9 / 2.3 ± 0.4	6 / 2.3 ± 0.4	15 / 4.6 ± 0.8

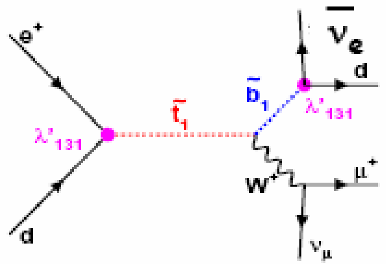
H1 excess not seen in e^-p !

3.4 σ effect…

Might be a 3.4σ fluctie. But if NP, likely to appear soon at the Tevatron as well …

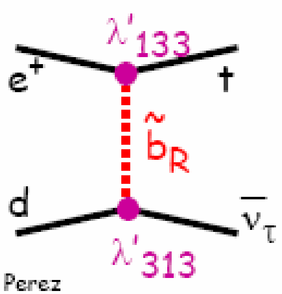
Possible explanations ??



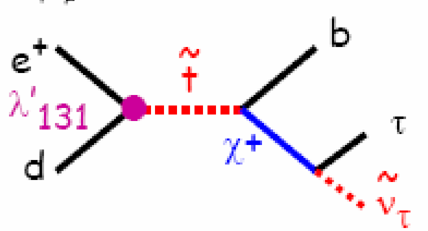


H1, PLB 599 (2004) 159

Unlikely because of the had. channel (jjj + $P_{T,miss}$ in that case, good S/B)



Two RpV couplings with 3rd gene. fields (Not too much $P_{T,miss}$ in that case)



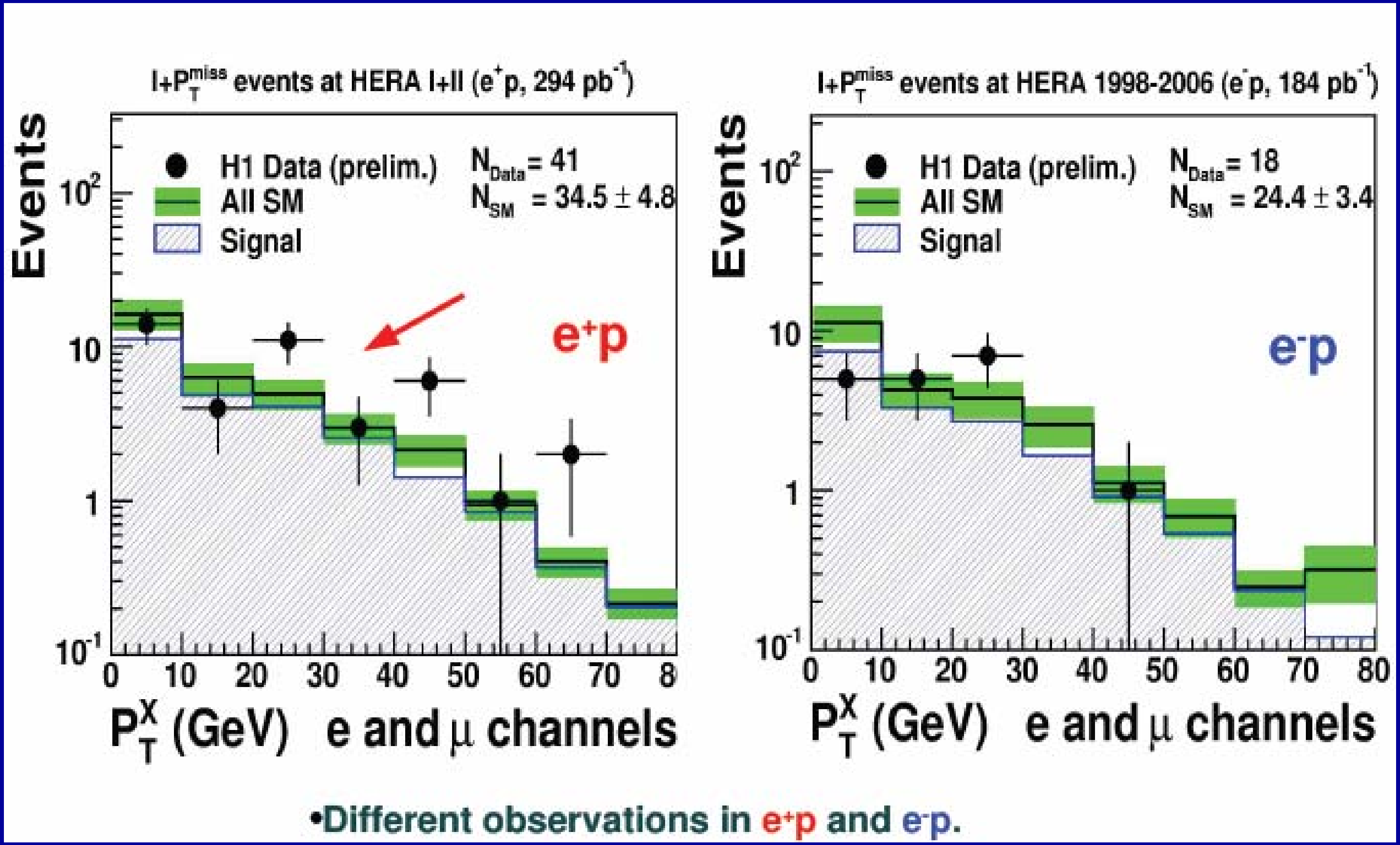
RpV Susy with LSP = $\tilde{\nu}_\tau$

E. Perez

There are possibilities. First clarify the excess !!

04/11/05

Multi-Leptons -- 2007



Consistent with standard model processes

Multi-Leptons -- 2007

	P_T^X > 25 GeV		electrons Data/SM	muons Data/SM
e^+p	H1	294 pb^{-1}	11/4.7±0.9	10/4.2±0.7
	ZEUS	228 pb^{-1}	1/3.2±0.4	3/3.1±0.5
e^-p	H1	184 pb^{-1}	3/3.8±0.6	0/3.1±0.5
	ZEUS	204 pb^{-1}	5/3.8±0.6	2/2.2±0.3

e^+p H1 observation: 21/8.9±1.5 (3.0σ)

no events in excess observed by ZEUS

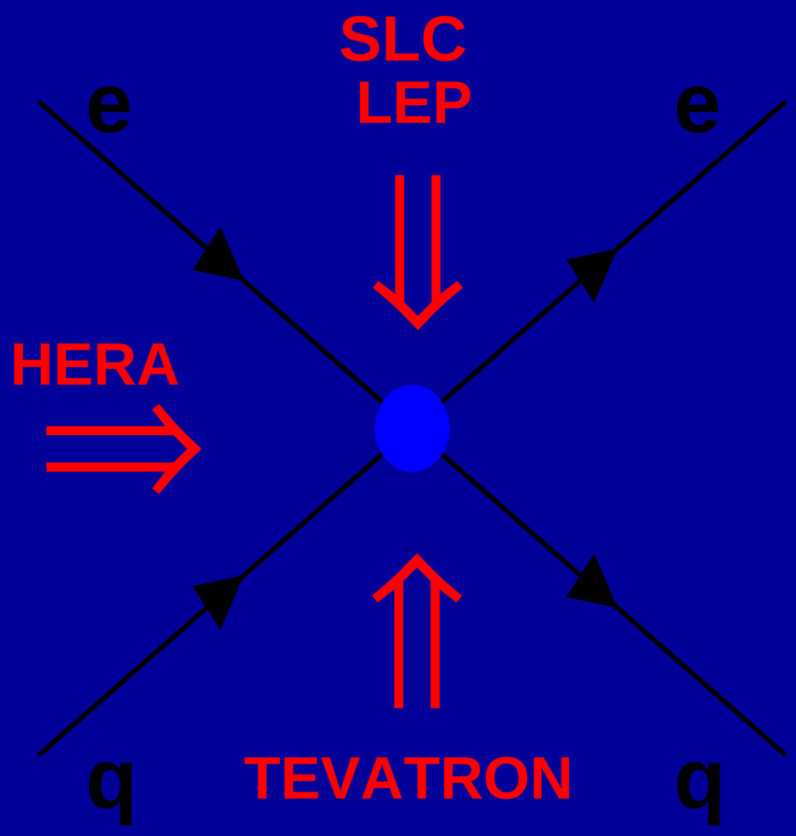
e^-p Agreement with SM (H1 and ZEUS)

Most of H1 events in ZEUS acceptance (though smaller)

H1 excess remains at high P_T^X in e^+p data at 3.0σ lev

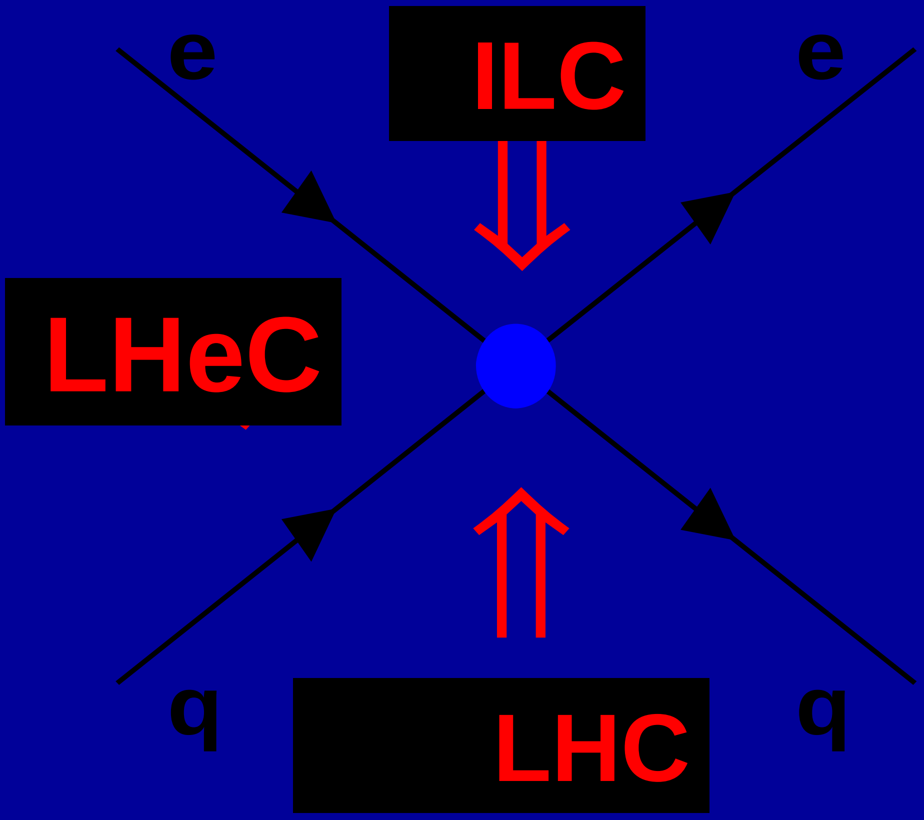
not clarified with HERA II data

Colliders of the Past Two Decades



Lots of excitement – all standard model (so far!)

Colliders of the Next Two Decades??



Acknowledgements

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Thanks to those who gave us this machine, Soergel, Steffen(s), Voss, and many others

but most of all

Thanks to Bjorn Wiik

HERA!

one of the colliders, which explored the electroweak energy frontier