Searches for new physics at HERA

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on behalf of the H1 and ZEUS Collaborations

Overview

- Introduction to HERA
- Contact interactions:

  compositness,
  large extra dimensions,
  quark radius
- eq resonances:

  leptoquarks,
  squarks in Rp violating SUSY models,
  lepton-flavor violation processes
- Excited fermions
- Summary for HERA I running
- Outlook to the future running

Introduction

Lepton-hadron collisions properties:

- Initial state is no vacuum
  - -not optimal for gauge bosons or Higgs production

- Having L and B numbers initial state, unique sensitivity for:
  - -Compositness of fermions
    contact interactions,excited states
  - -Lepton-quark resonances
    Leptoquarks or squarks in R_p violating SUSY
  - - Forbidden transition of flavor
    LFV, FCNC rare processes (next talk)

Energy/distance scales probed at HERA:

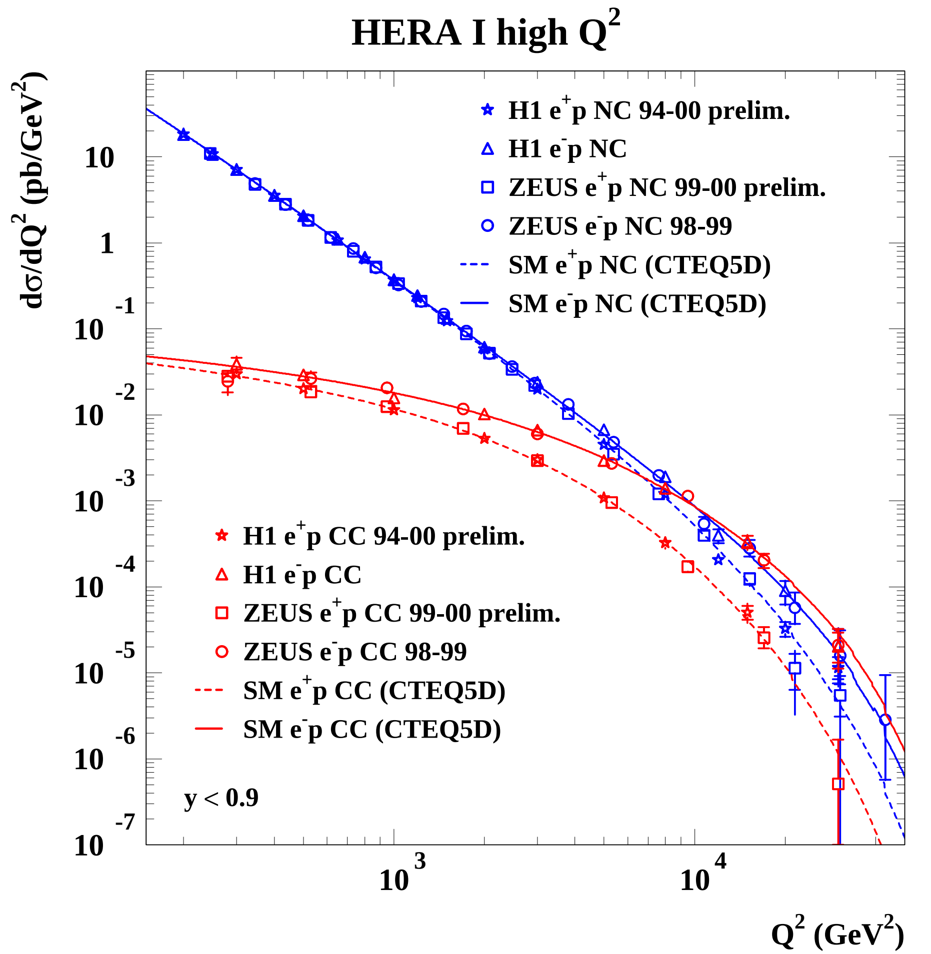
- Direct production up to CM energy (320 GeV)
- virtual effects down to $1/Q_{max} \sim 10^{-16}$ cm (1/1000 proton radius)

DIS cross section at high Q^2

Large Q^2 range covered by HERA up to $4 \cdot 10^4$ GeV^2

New physics would produce deviations from SM prediction at high Q^2

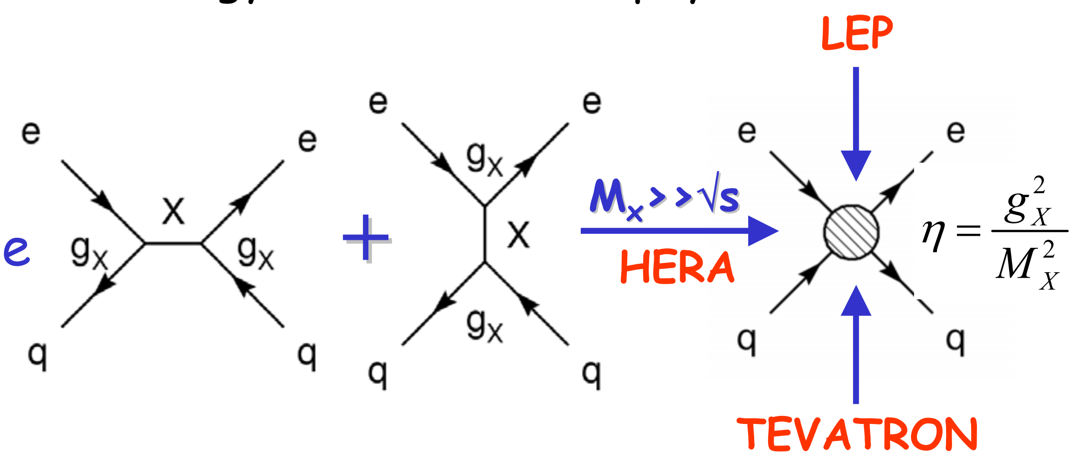
- High Q^2 SM cross section predicted using extrapolation from low Q^2 measurements
- Sensitivity to new physics depends on the uncertainties of the SM predictions:
~ 5% at Q^2 ~ 10^4 GeV^2



eeqq contact interactions

CI formalism allows to parameterise low energy effects of new physics at much higher energy scale:

- compositeness
- massive boson exchange
- gravitational effect of large extra dimensions
- quark radius



Search for deviation from SM prediction at high Q^2

(both upwards or downwards depending on the sign of the interference term)

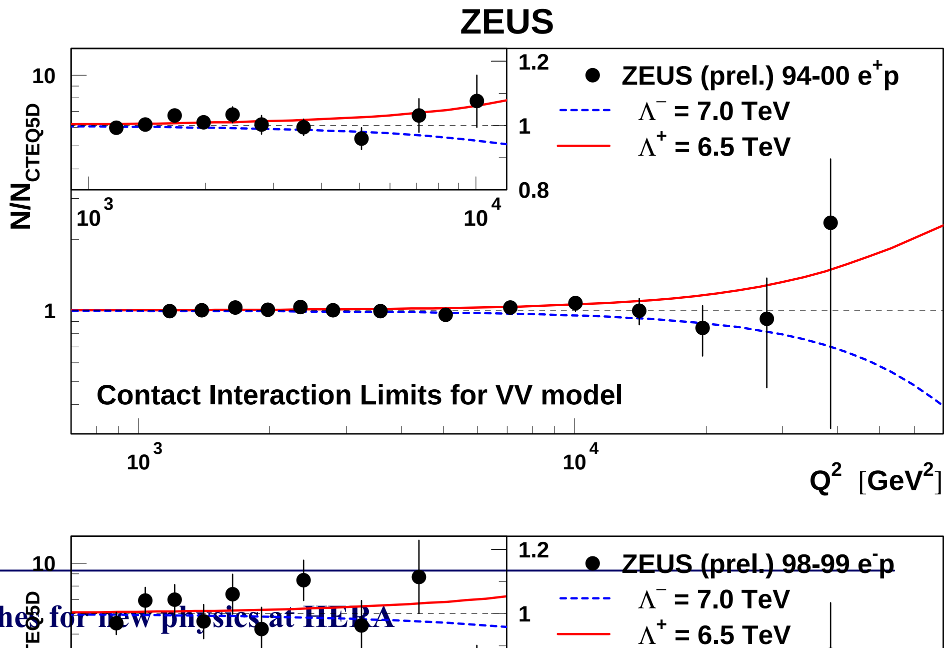
General CI models depends on chirality (LL, VV, LR)

$$\eta_{ij}^{q} = \pm \frac{g^2}{\Lambda_{ij}^{q\,2}}$$

$q = u, d$

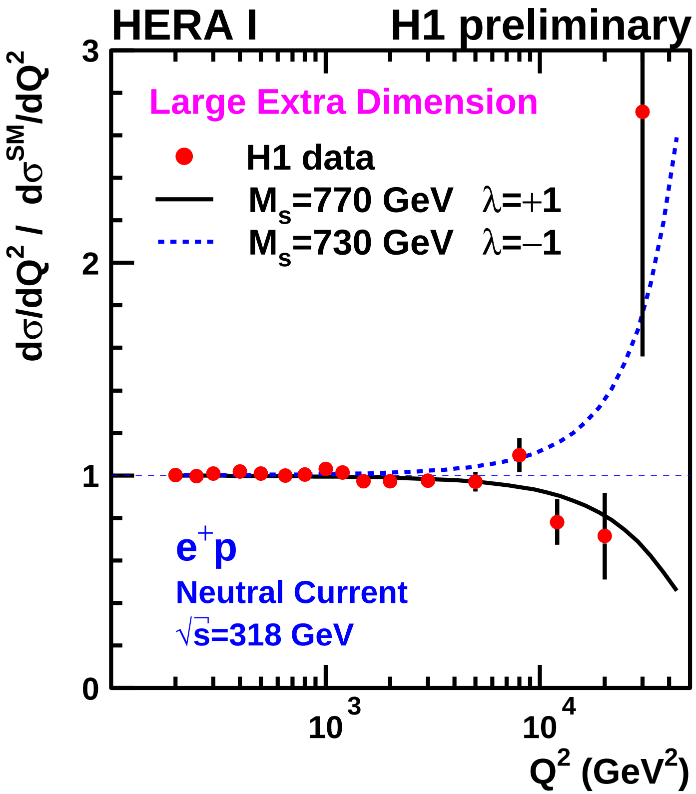
$i, j = L, R$

$g = \sqrt{4\pi}$



Large extra dimensions

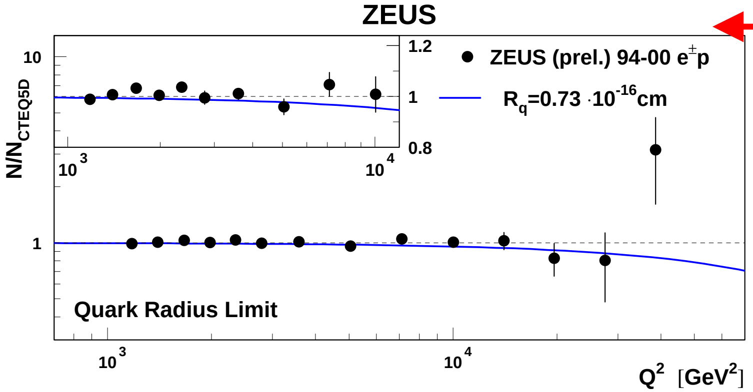
- n compactified extra dimensions on a scale R□ 1mm (gravitation not checked at sub-millimeter level)
- only graviton sees the extra dimensions while SM particles propagate on the 4 ordinary dimensions.
- large extra dimensions result in an effective Planck scale down to ~ 1 TeV



graviton exchange modifies DIS cross-section

Typical limits at HERA: M_s □ $0.8 TeV$

Quark radius



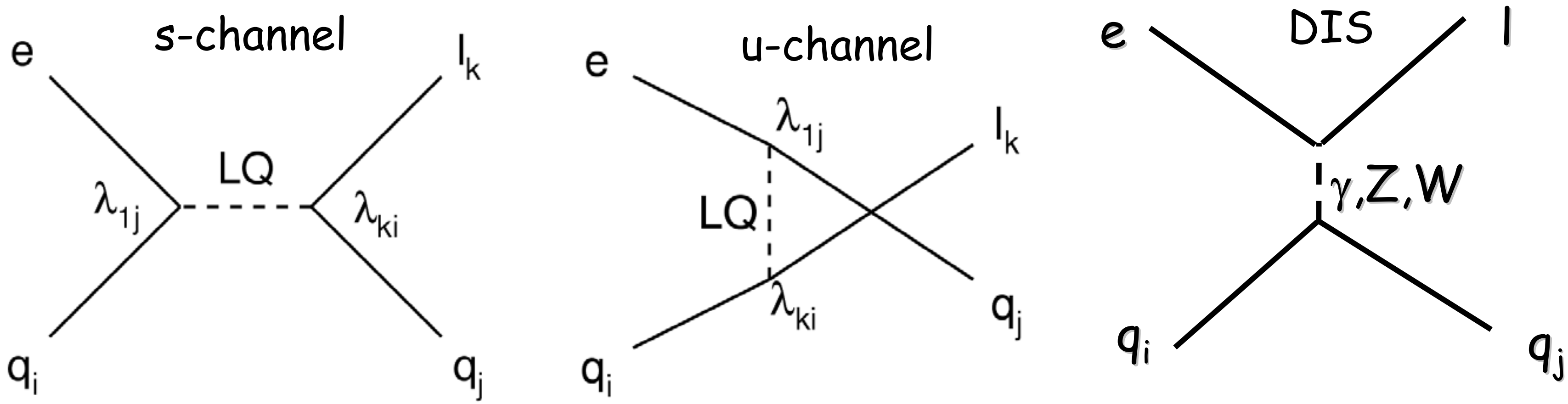
Assuming electron point-like

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

Quark charge radius probed down to < 10^{-16} cm, 1/1000 of the proton radius

Leptoquarks

Quarks and leptons show a remarkable symmetry (same structure of families, $q_e = q_p$ to 1 part in 10^{21}) but have no connection in the SM.
A higher symmetry which allows direct quark-lepton interactions needs LQ .



Coloured bosons with B and L $\neq$ 0 predicted by many models (GUT, Technicolor, Compositeness) which extend the SM

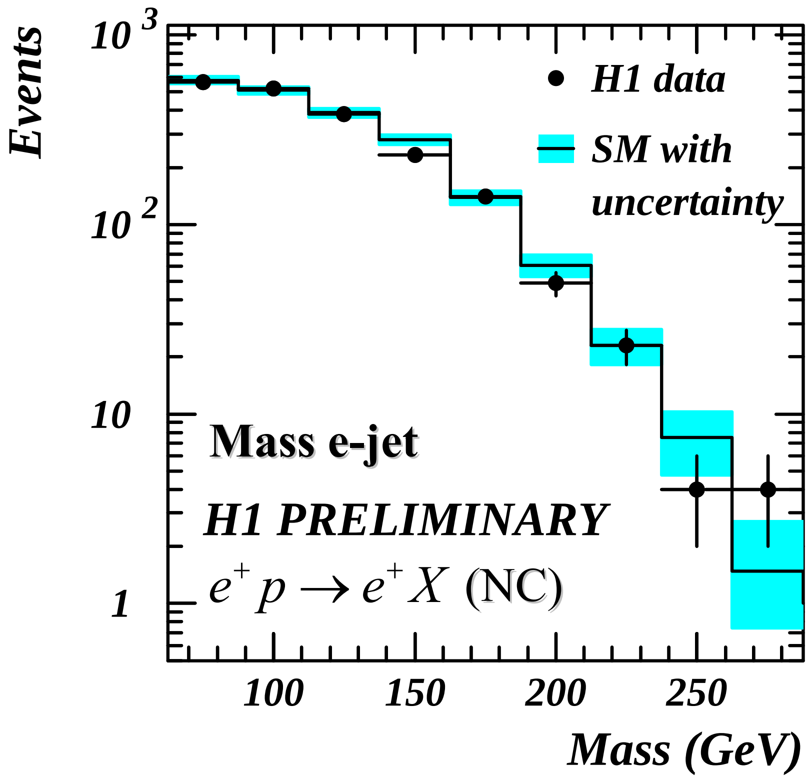
Fermion number F=3B+L=0,2

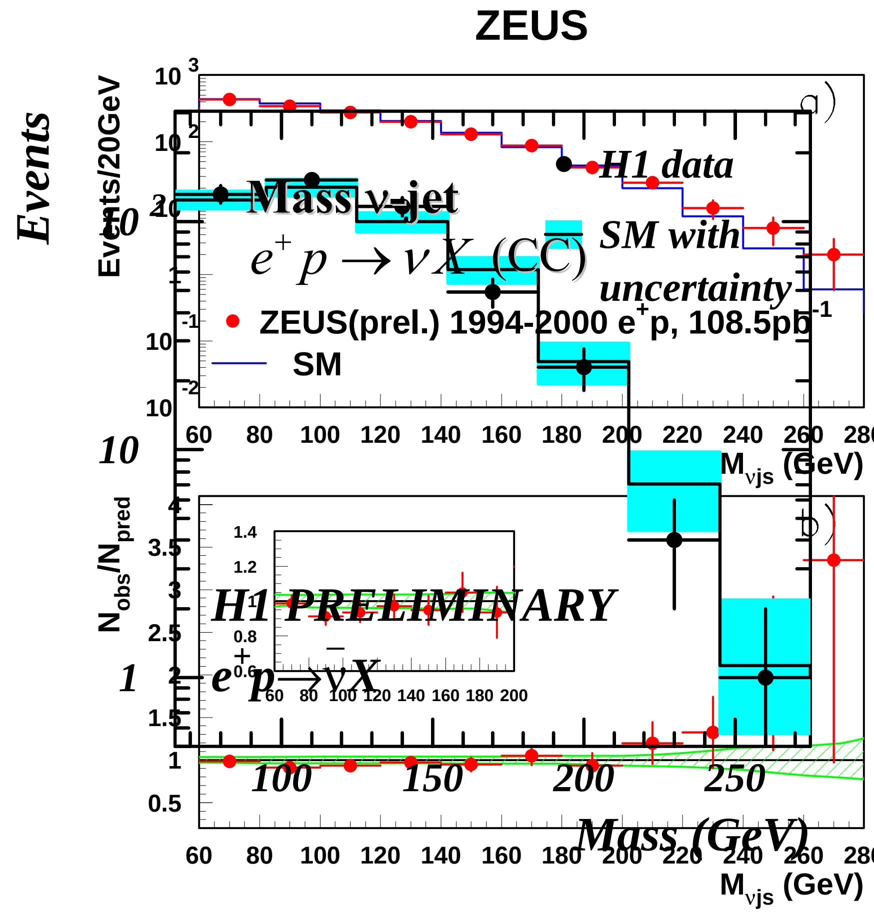
$e^+q \rightarrow F=0$ $e^-q \rightarrow F=2$

According to the Buchmüller-Rückl-Wyler (BRW) model:
- new interactions respect SM symmetry
- left or right handed coupling with leptons

→ 7 scalar + 7 vector states
Fixed branching ratios to eq and νq

e-jet and ν-jet invariant mass

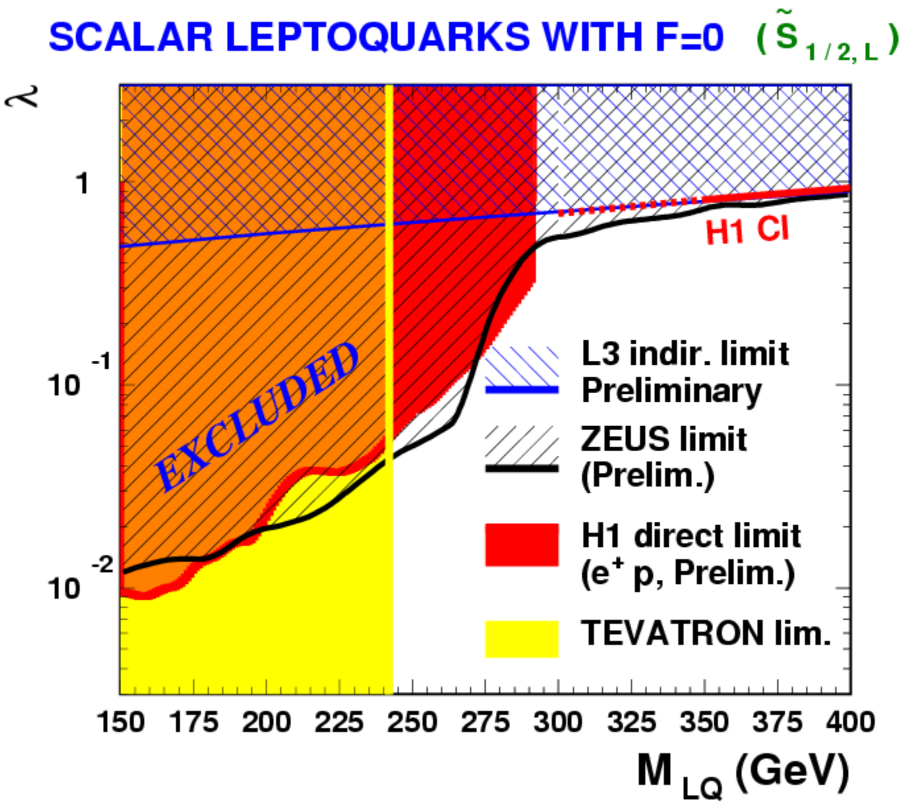




Good agreement with SM expectations both in eq qnd νq channel

Excess observed in 94-96 NC data at high x and Q^2 not confirmed by the full HERA I statistics

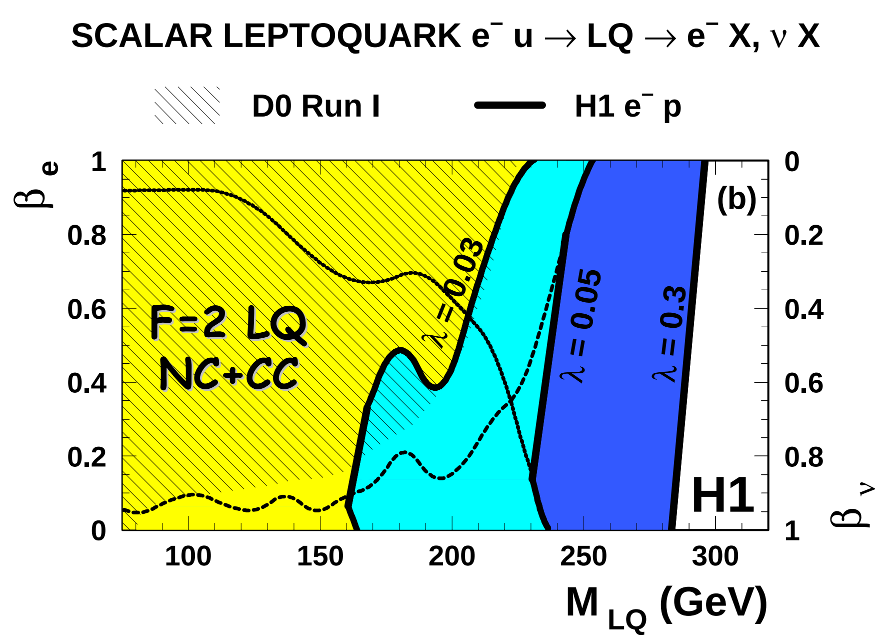
limits on coupling vs. mass



If we release the BRW conditions allowing for free β in eq and νq

➡ For $\beta(eq)+\beta(\nu q)=1$ limits are almost independent from β

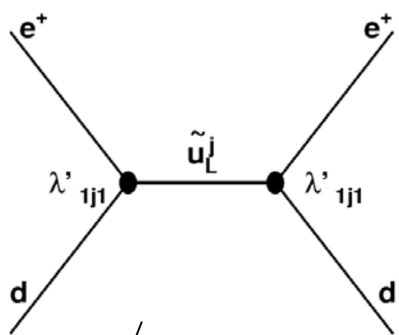
Unique sensitivity for $\beta(eq) \ll 1$



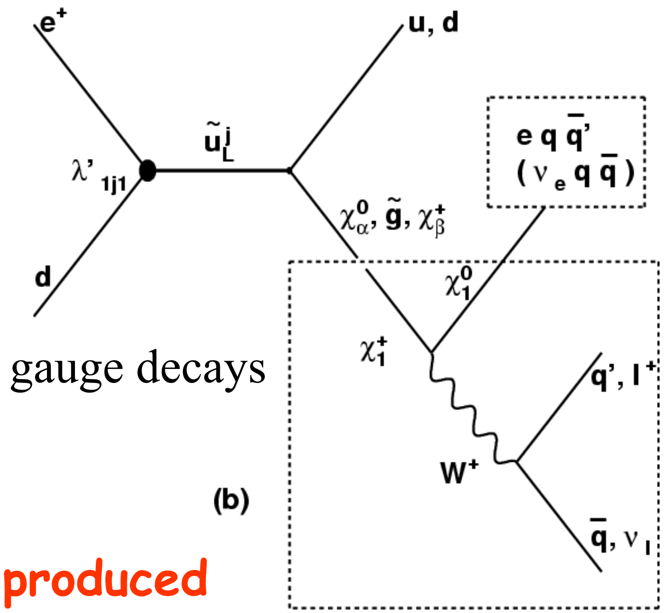
Tevatron: pair production independent of λ

LEP: virtual effects in $e^+e^- \to$ hadrons strongly dependent on λ

R-parity violating SUSY



$\not{R}_p$ decays

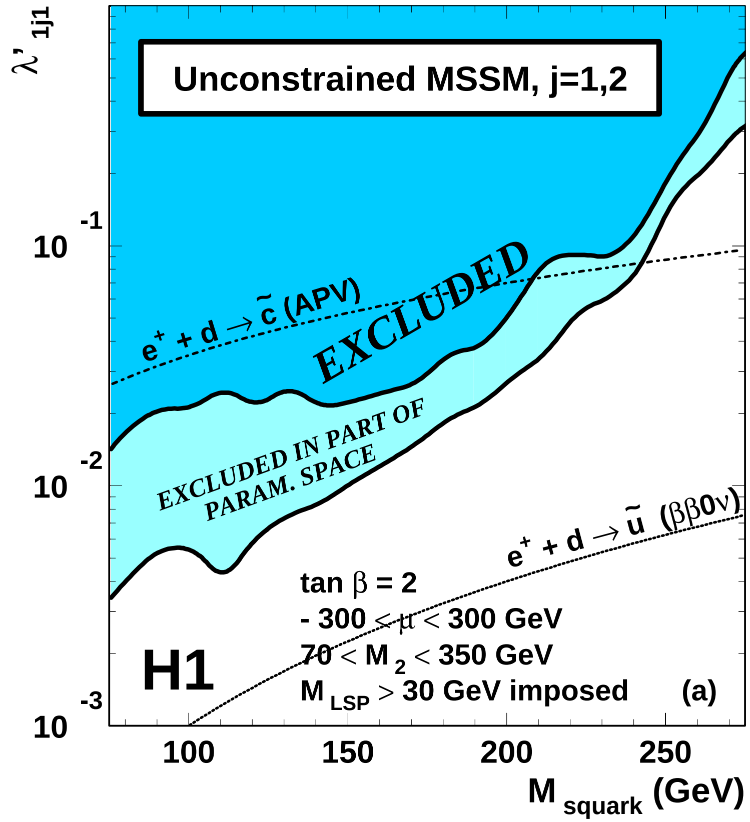


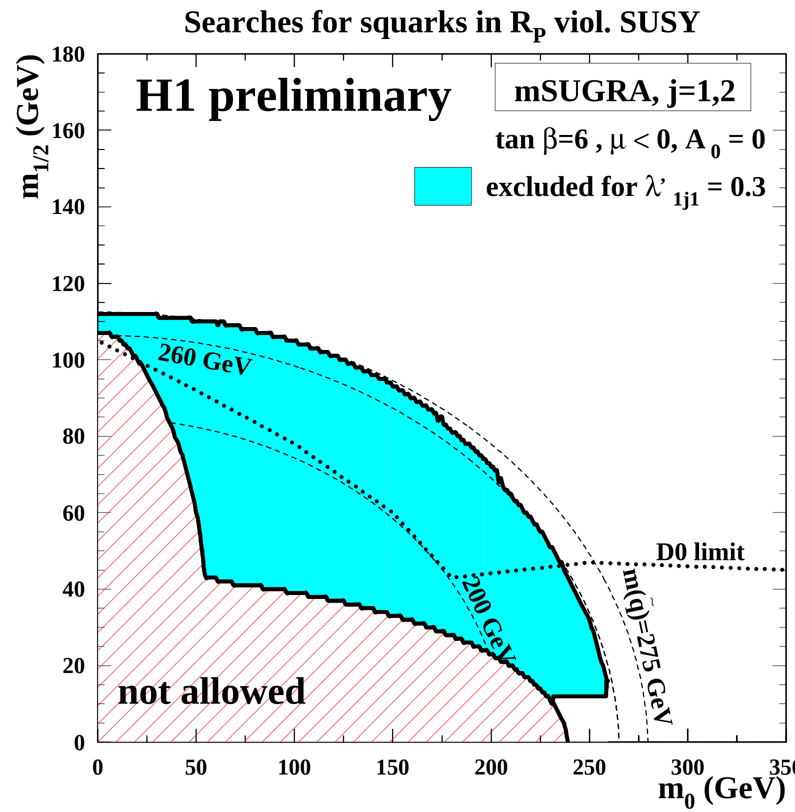
gauge decays

- $R_p = (-1)^{F+2S} = (-1)^{L+3B+2S}$
  If R_p is violated: sparticles can be single produced
  LSP not stable (no dark matter candidate)
- $L_i Q_j \overline{D}_k$ term in the SUSY lagrangian is of interest for ep scattering
  coupling λ'_{ijk} is involved: $\lambda'_{121} \neq 0$ ➡ $e^+d \rightarrow \tilde{c}_L$
- gauge decays induce final state more complicated than in the LQ case
  $\chi^0 \rightarrow e^\pm q \overline{q}, \nu q \overline{q}$ ➡ wrong sign lepton gives bg free channels

No evidence of signal found : limits in unconstrained MSSM (squark mass independent of μ, M_2, $\tan\beta$) or in mSUGRA

Limits for Rp violating SUSY





Unconstrained MSSM

Squark mass vs coupling varying the SUSY parameters

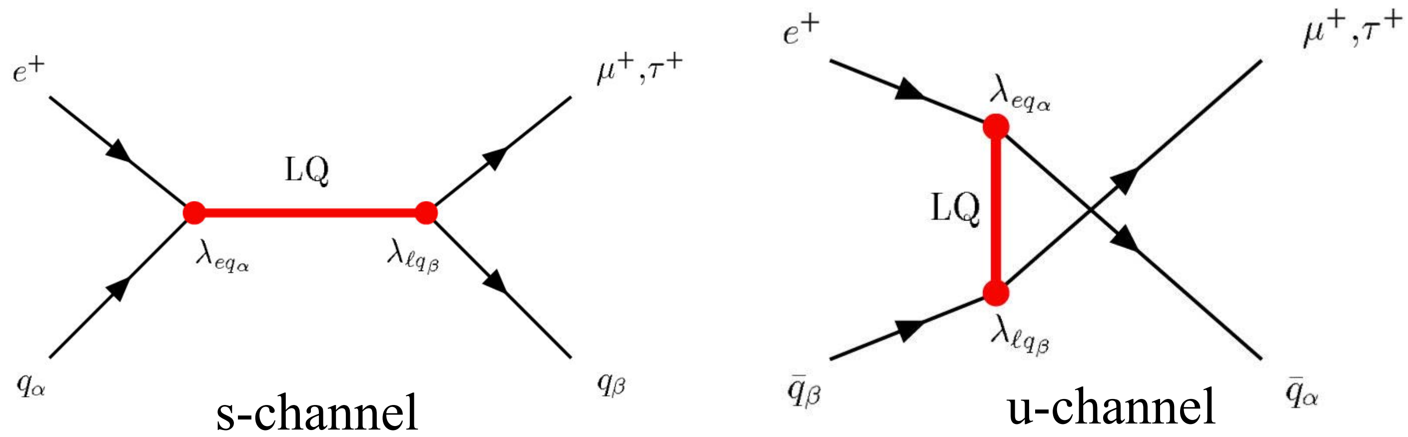
HERA λ'_{121} □ 0.05 for M=200 GeV

$\lambda'_{121} <$ 0.07 from APV

Minimal SuperGravity Model (mSUGRA) - constrained by:

- m_0 (universal mass parameter for sfermion at GUT scale)
- EW simmetry breaking driven by radiative corrections

Lepton-flavor violation



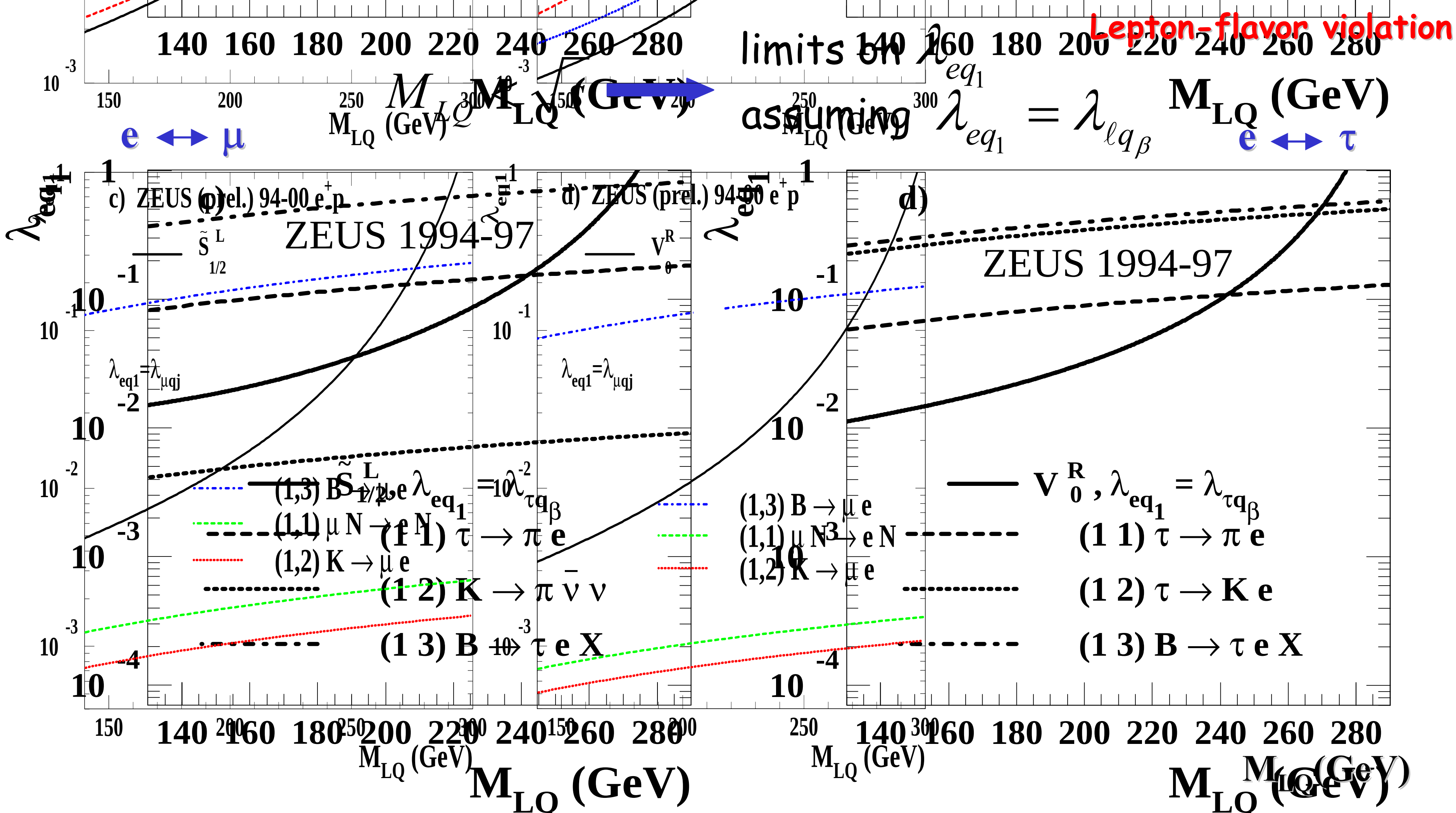
Such FCNC processes can be mediated by LQ or squarks

Topology: similar to NC DIS but a μ or τ replaces the scattered electron

Signature: high pt μ or τ balances the jet in the transverse plane
→ high missing calorimeter Pt and a μ or τ aligned with the missing Pt

Clear signal detectable with high efficiency, negligible SM background

Lepton-flavor violation

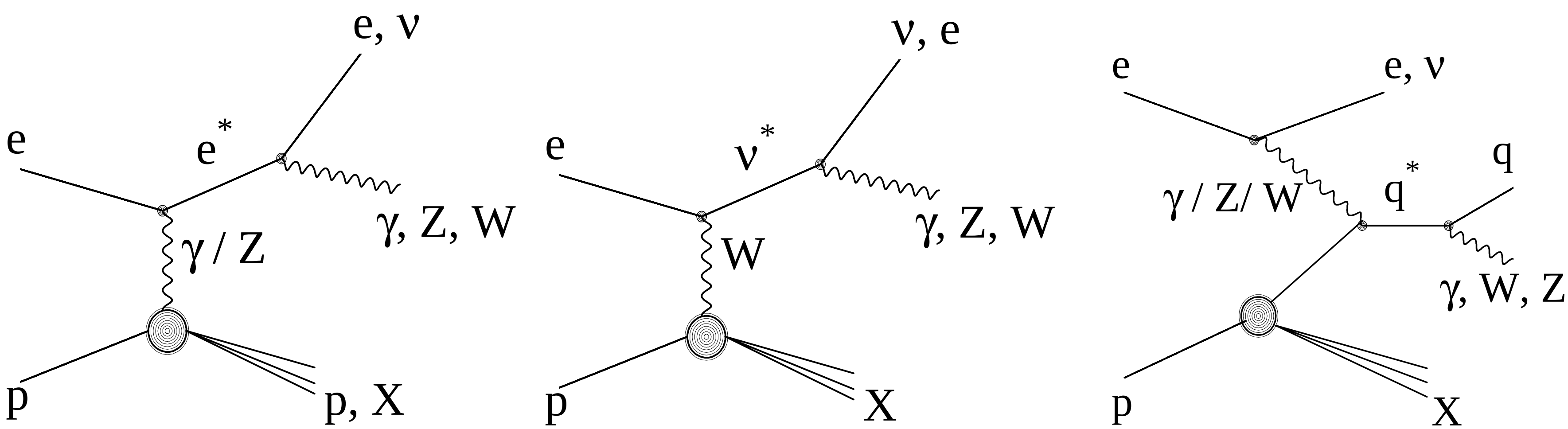


$M_{LQ} \lesssim \sqrt{s}$ → limits on λ_{eq_1} assuming $\lambda_{eq_1} = \lambda_{\ell q_\beta}$

$M_{LQ} \gg \sqrt{s}$ → Limits on the contact interaction term $\dfrac{\lambda_{eq_\alpha}\lambda_{\ell q_\beta}}{M_{LQ}^2}$

Both for low and high mass LFV LQ competitive limits when c,b quarks involved especially for the τ case

Excited fermions



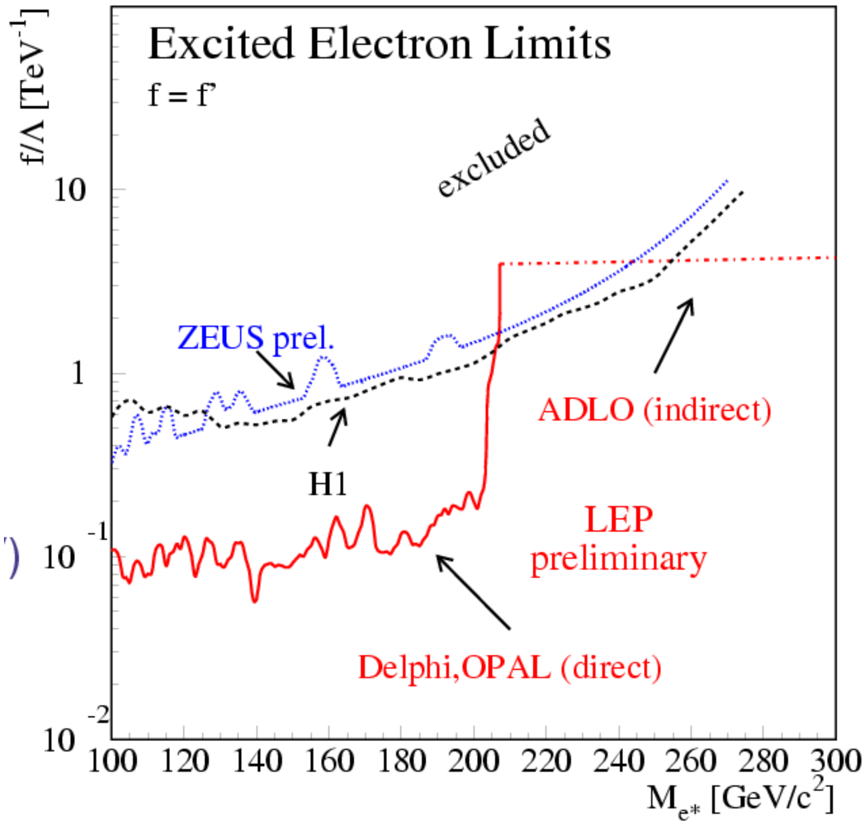
Compositness models predicts excited fermion states which decays in fermion and boson (magnetic coupling)

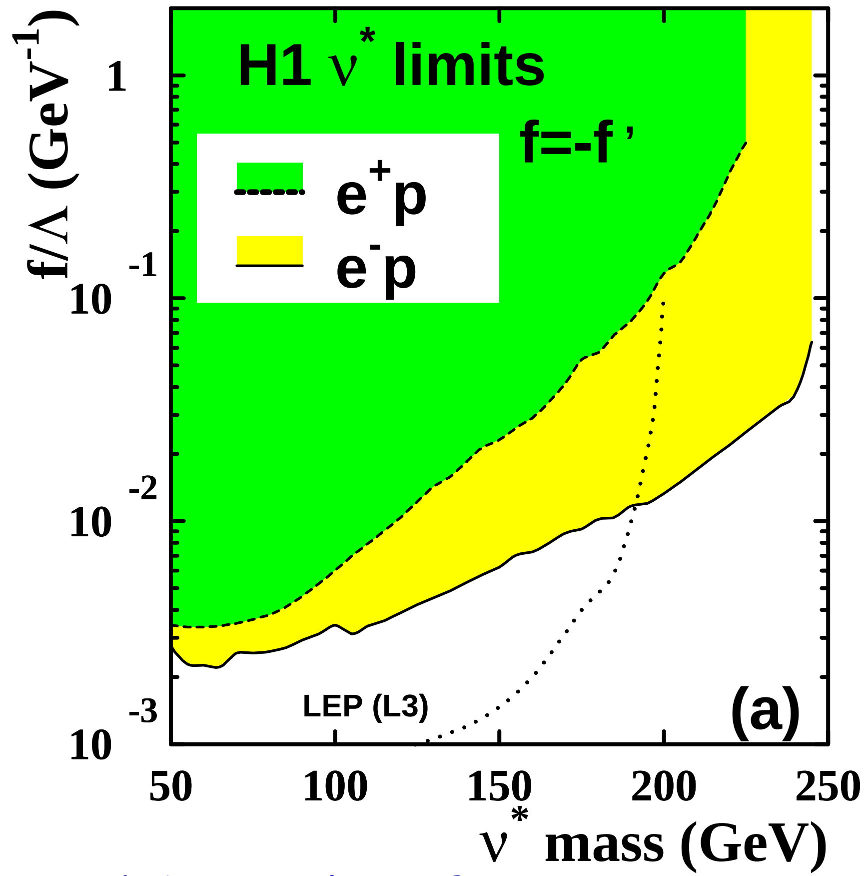
$$L_{eff} \propto \frac{1}{\Lambda}(f \cdot SU(2)_W + f' \cdot U(1)_Y + f_s \cdot SU(3)_c)$$ (Hagiwara, Komamiya, Zeppenfeld)

Λ=compositness scale
f, f', f_s= weight factors associated with the SM gauge groups
Assuming relation between f, f', f_s, production cross section $\propto (f/\Lambda)^2$

Signature: peak in fermion-boson invariant mass

No deviation from SM → limits for f/Λ





HERA has access above LEP2 c.m.e.
Direct limit better than LEP
for M_{e*} □ 200 GeV

Much better limit for e^-p since a u-quark in the proton is involved (instead of a d-quark) and the helicity suppression in e^+p due to W exchange

* High potential to improve in next running

Summary for HERA I running

HERA I : ~ 110 pb^{-1} $e^{+}p$ and ~15 pb^{-1} $e^{-}p$ data

So far no clear evidence for physics beyond SM
(some deviations in the high pt leptons searches → next talk)

New constraints have been set on:

- eeqq contact interaction: Compositness, LED, quark form factors
- Leptoquarks, squarks in R_p violating SUSY
- Lepton flavor violation
- Excited electrons, neutrinos,quarks
- FCNC neutral current (next talk)

Limits are comparable/complementary to LEP and Tevatron

All results fit in the Standard Model framework apart from the deviations in the high pt leptons sector

What about the future?

HERA II perspectives

In summer HERA will restart operation after the Spring shutdown

increase in luminosity:

further test of the SM and eventually improvement of existing constraints

longitudinal polarization:

enhance/disentangle possible signal since in many cases chiral leptons are involved.

control background since NC and CC DIS depend of lepton chirality

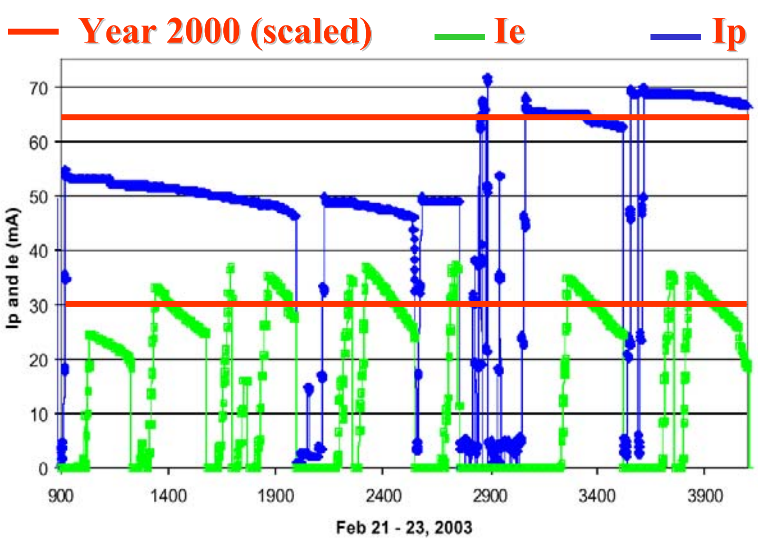
upgrade of the detectors:

heavy flavor tagging allowed by new Si microstrip vertex detectors and forward tracking improvement will increase sensitivity to flavor specific processes

The HERA II program will provide few years of exciting data in this post LEP-pre LHC period!

Fresh results from HERA

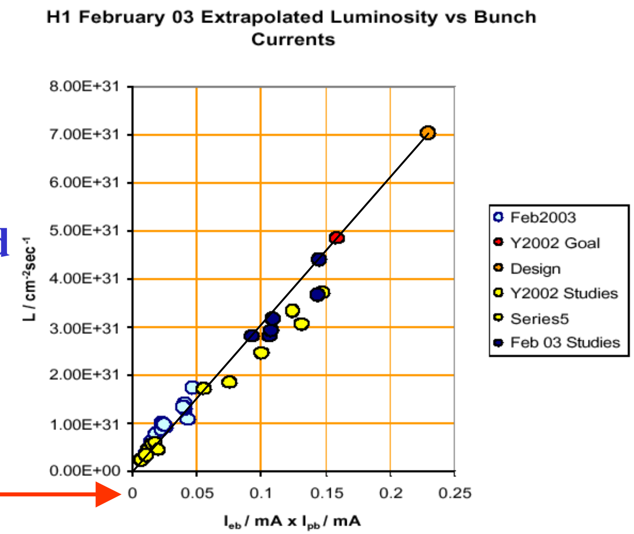
HERA during the machine studies just before the spring shutdown reached very promising performances both for high-luminosity and polarization

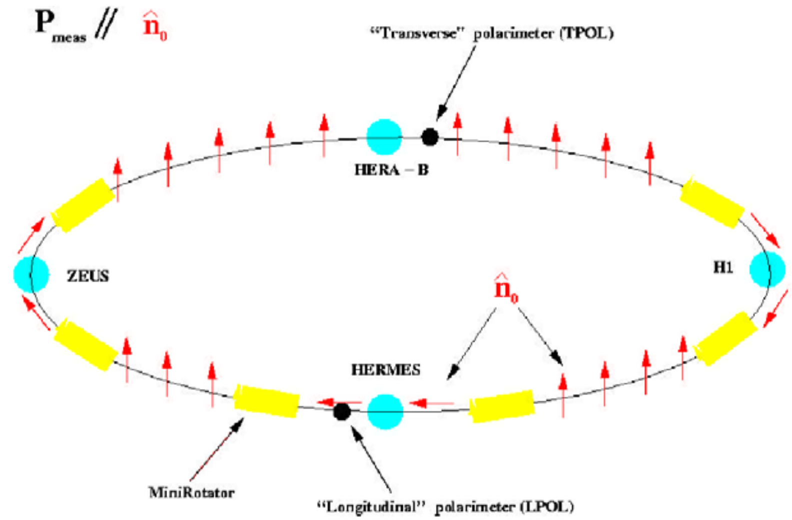


Currents similar to year 2000 (scaling from 180 to 120 bunches)

Peak performances:
Colliding bunches: 120
I_p/I_e = 67/32 mA
L_{peak}=2.7x10^{31}cm^{-2} sec^{-1}
Currents limited by bad background conditions to ~2000 mA^2

Extrapolated results compatible to design





Polarization studies: Feb 28 – Mar 3, 2003 with colliding beams and all 3 rotators turned on

P_{max} = (51 ± 1)%