Recent ZEUS Results

Uwe Schneekloth
DESY

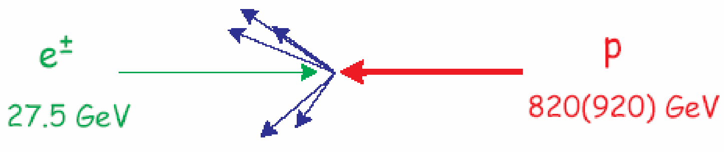
VIIIth International School-Seminar
The Actual Problems of Microworld Physics
26.07.2005

Outline

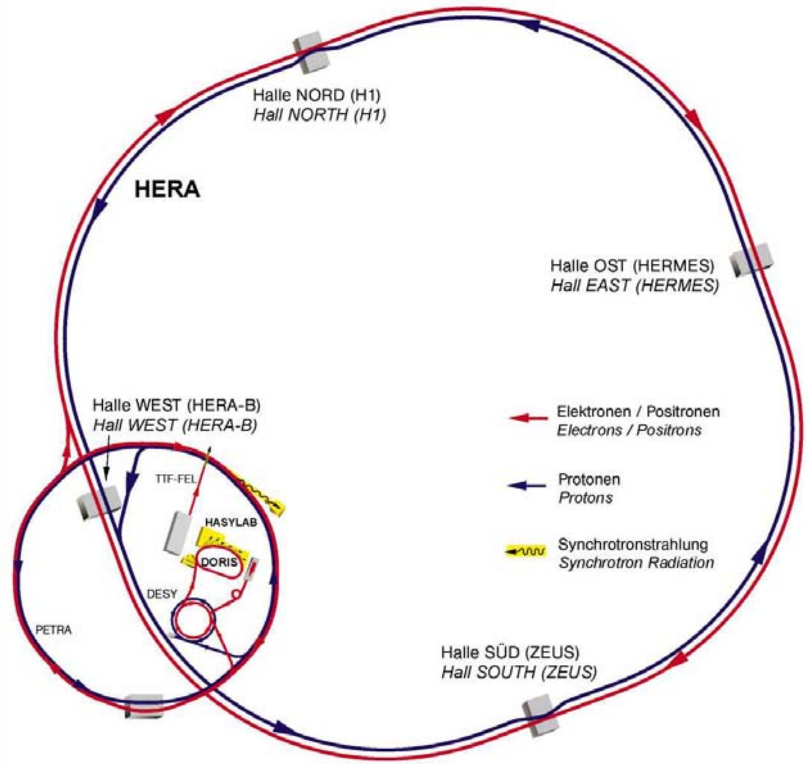
- Introduction
  - HERA
  - ZEUS Experiment
- Structure of the Proton
  - Structure function
- Neutral and Charged Current Scattering
  - Electroweak effects with polarized leptons
- QCD: Determination of Strong Coupling Constant α_s
- Heavy Quarks: Beauty Production (dimuon events)
- Physics beyond the Standard Model
  - Are quarks elementary?
  - Lepton-flavor violation
  - Single-top production
- Summary

HERA ep Collider at DESY

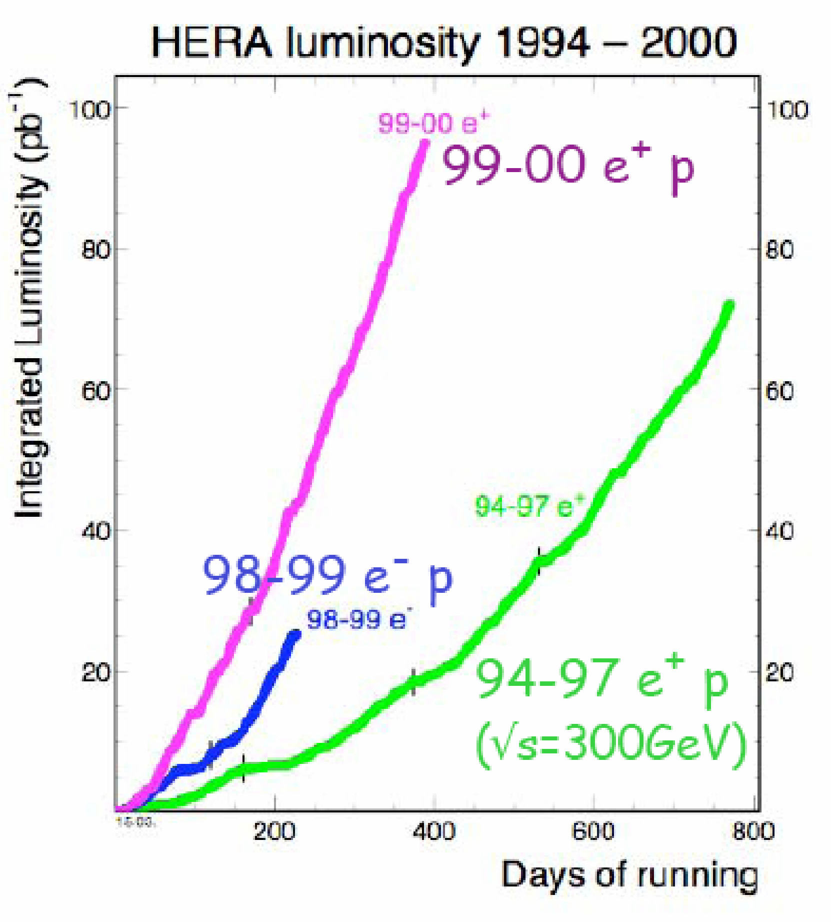
HERA – the world's only ep collider



equivalent to 50 TeV fixed target



HERA I - Integrated Luminosity

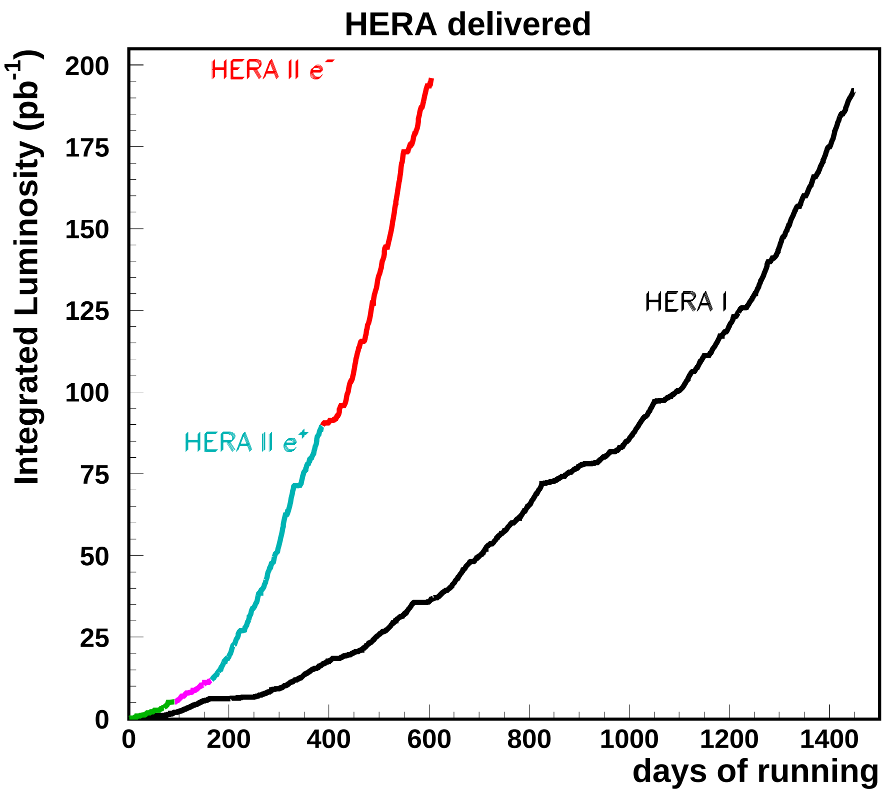


HERA I luminosity on tape:

- ~ 115 pb^{-1} $e^+ p$
- ~ 17 pb^{-1} $e^- p$

HERA II – Luminosity Upgrade

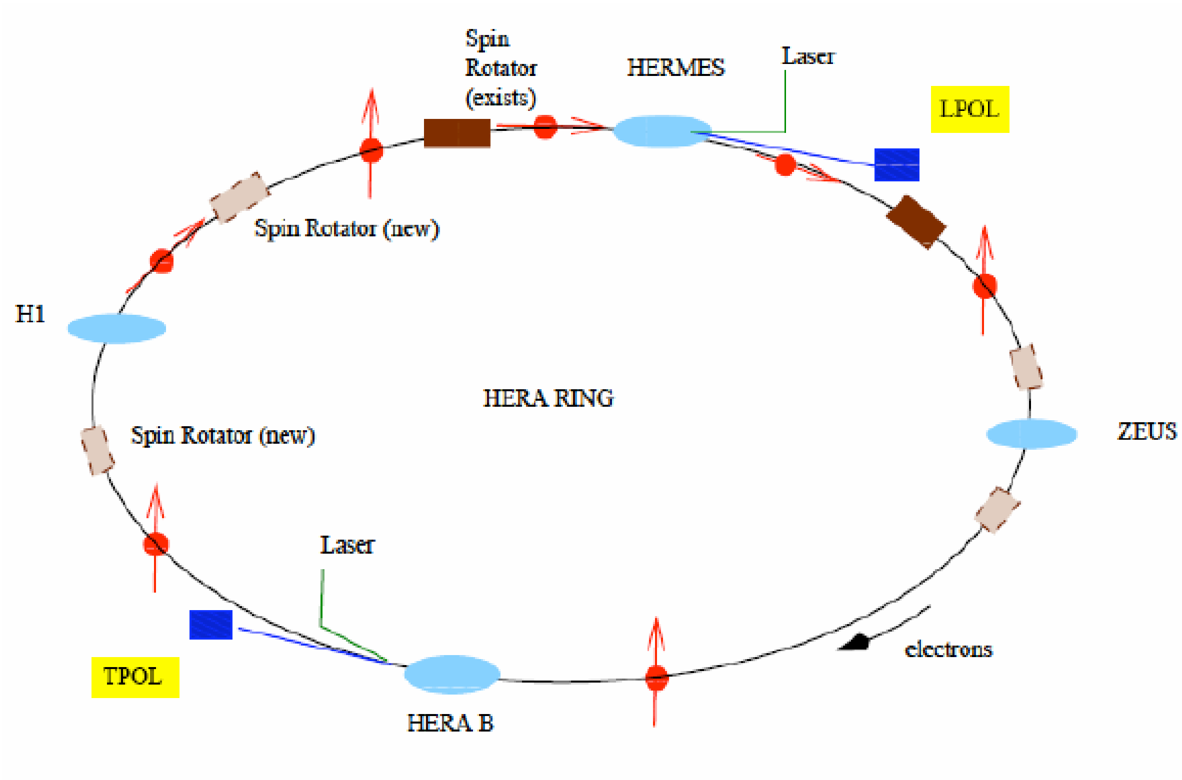
- Interaction regions rebuilt to increase beam focussing
  ➔ Luminosity increase by factor 3-4



Surpassed HERA I integrated luminosity

Will continue luminosity operation until summer 2007. Goal ~700 pb^{-1}.

Lepton Polarization – HERA II



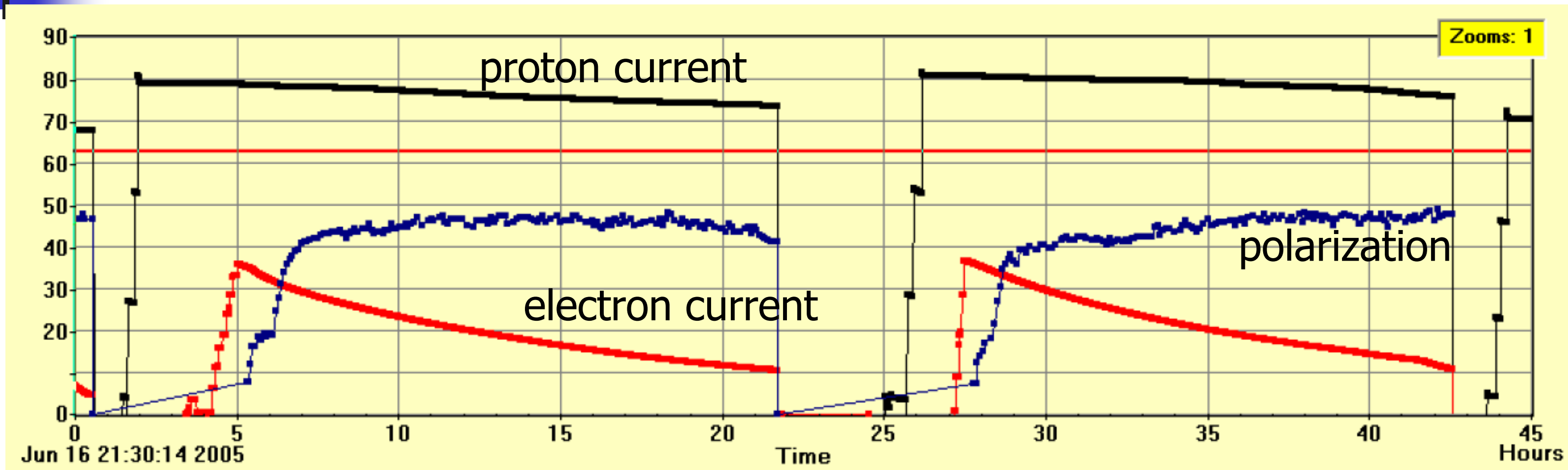
Electron (positron) beam is transversely polarized due to Sokolov Ternov effect.

Experiments want longitudinal polarization.

Spin rotators at the interaction regions:
- HERMES since 1995
- H1 and ZEUS part of HERA luminosity upgrade

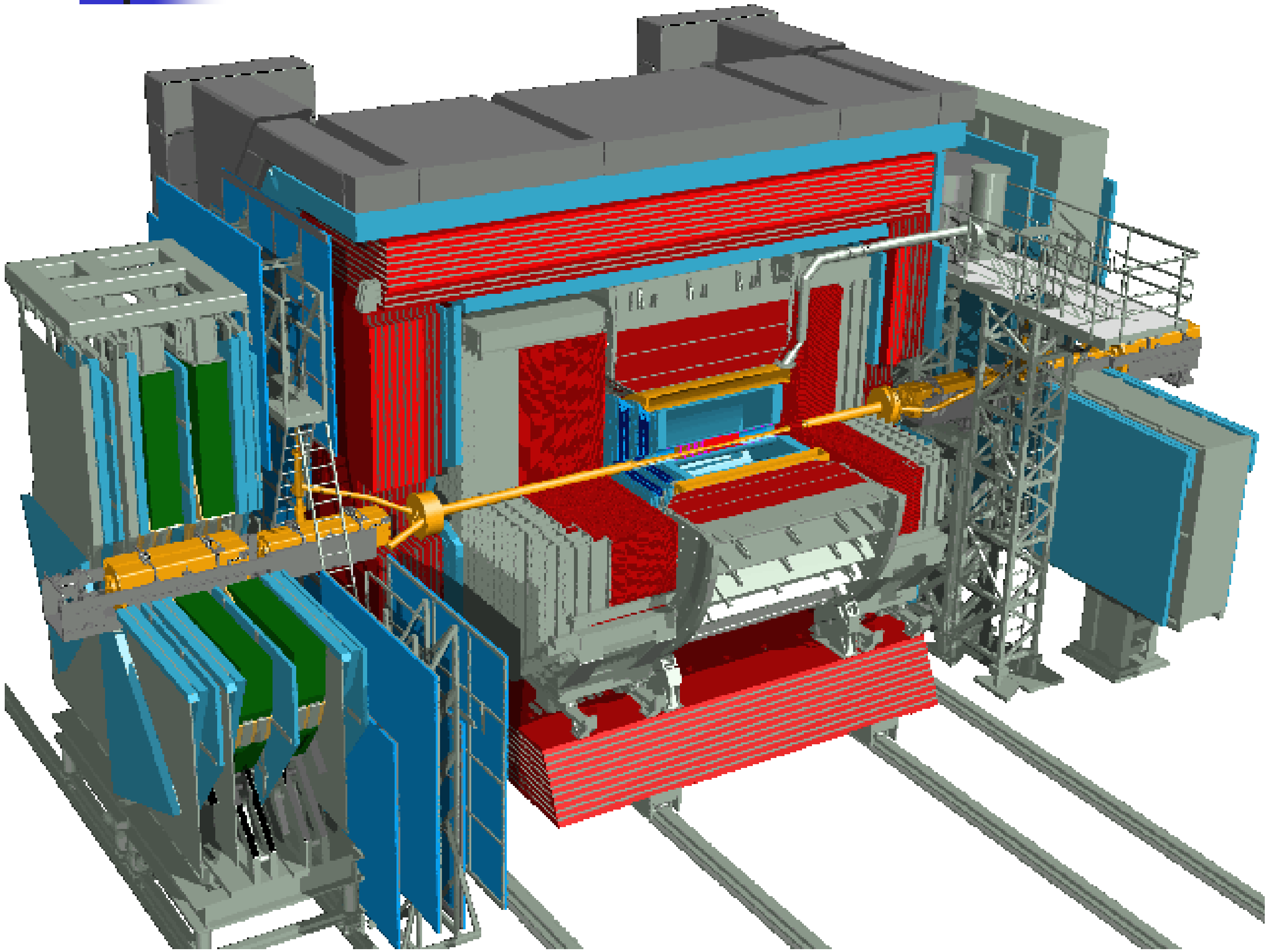
Transverse and longitudinal polarimeters to measure polarization.

Lepton Polarization



- Transverse polarization due to spin-flip synchrotron radiation emission in the arcs
- Maximum theoretical polarization 92% (transverse)
- Build-up time 40min at HERA (E_e =27.5GeV)
- In practice, polarization is reduced due to various effects (magnetic field errors, magnet and orbit misplacements, uncompensated solenoidal fields, spin rotators, beam-beam effects,…)
- HERA I ~60% polarization (only one rotator)
- HERA II presently up to 50% (expected maximum ~57%)

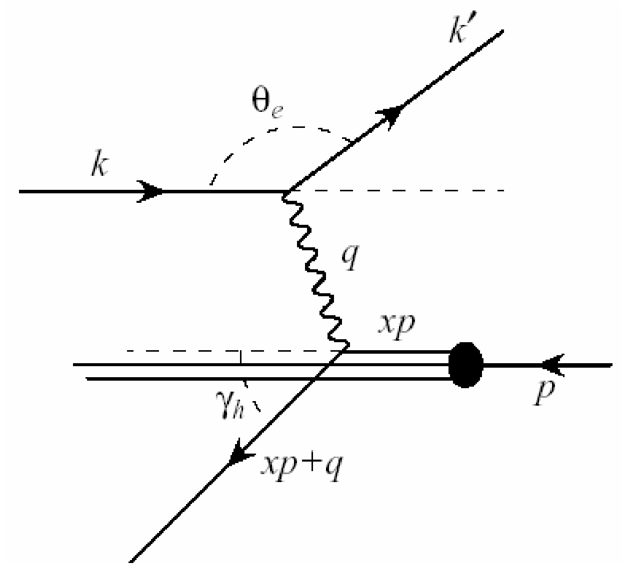
ZEUS Detector



Large collider detector
Main components:

- Micro vertex detector
- Central tracking
- Uranium-scintillator calorimeter
  $\sigma(E)/E = 18\%/\sqrt{E}$ em
  $\sigma(E)/E = 35\%/\sqrt{E}$ had
- Muon system

HERA Kinematics



Kinematical variables:

- (Negative) squared 4-moment transfer carried by exchange boson

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

- Fraction of proton momentum carried by struck quark (Bjorken scaling variable)

$$x \equiv \frac{Q^2}{2p.q}$$

- Inelasticity

$$y \equiv \frac{p.q}{p.k} = 1 - \frac{E_l'}{E_l}$$

- Center-of-mass squared

$$s = (k + p)^2$$

- Hadronic center-of-mass

$$W^2 = (q + p)^2 = ys - Q^2$$

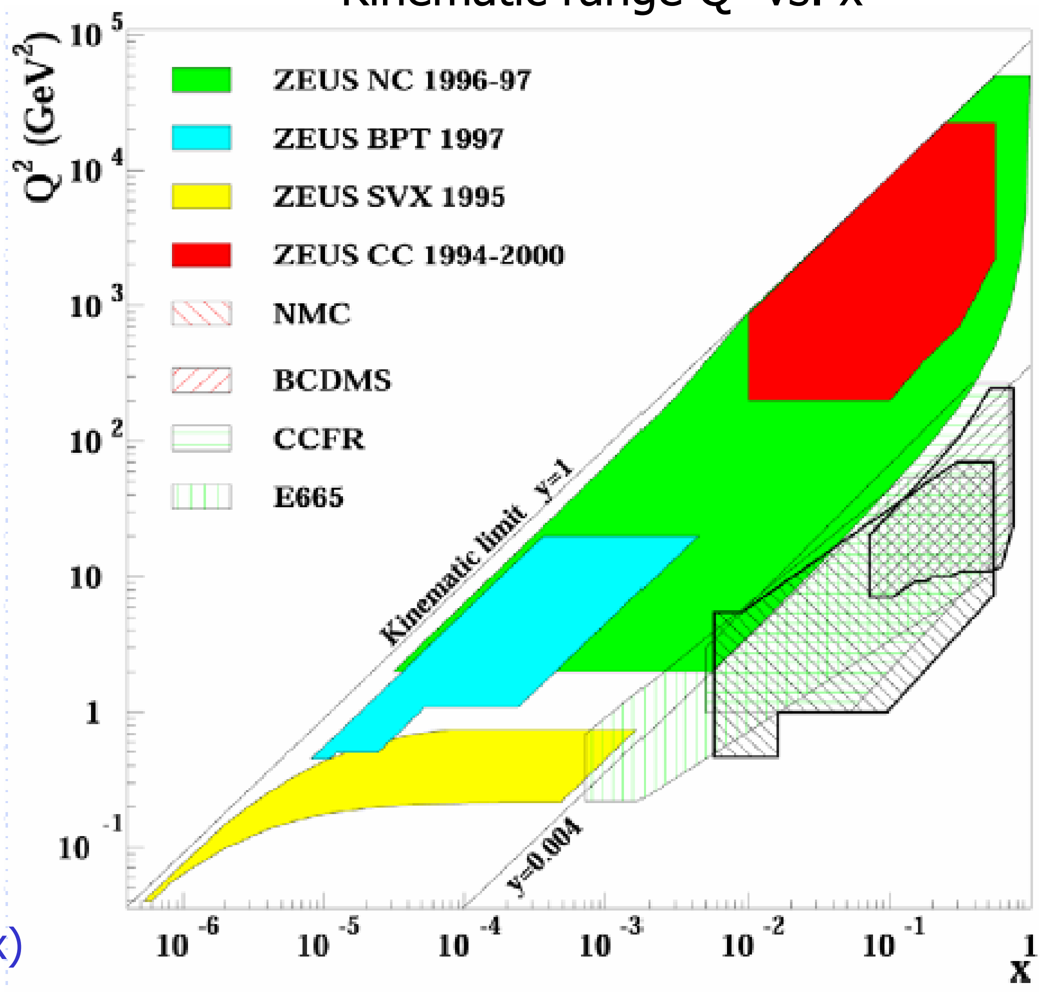
HERA Kinematic Region

- >100x larger kinematic reach compared to fixed-target DIS experiments
  (If proton at rest, HERA CM energy equivalent to E_e = 54 TeV)

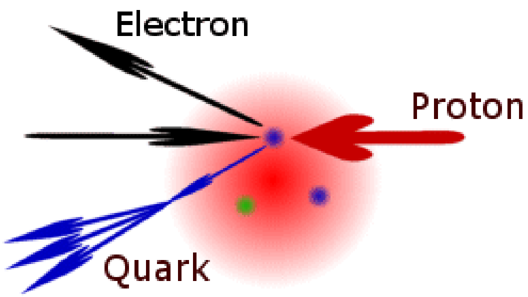
- At high Q^2, probe validity of QCD at smallest distance
  ➔ quark structure? new particles?
  Q^2 = 40000 GeV^2 => 1/Q=0.001 fm

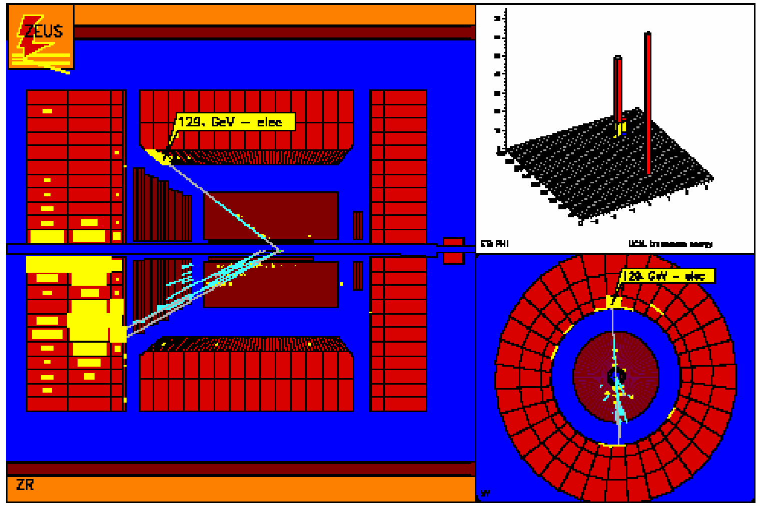
- At low Q^2, probe the low-x region
  ➔ very soft constituent of proton
  Experimental method:
  electron tagged at very small angles
  (beam pipe calorimeter, shifted vertex)

Kinematic range Q^2 vs. x



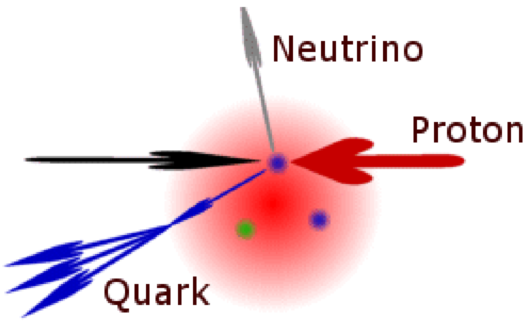
High Q^2 Neutral/Charged Current Events

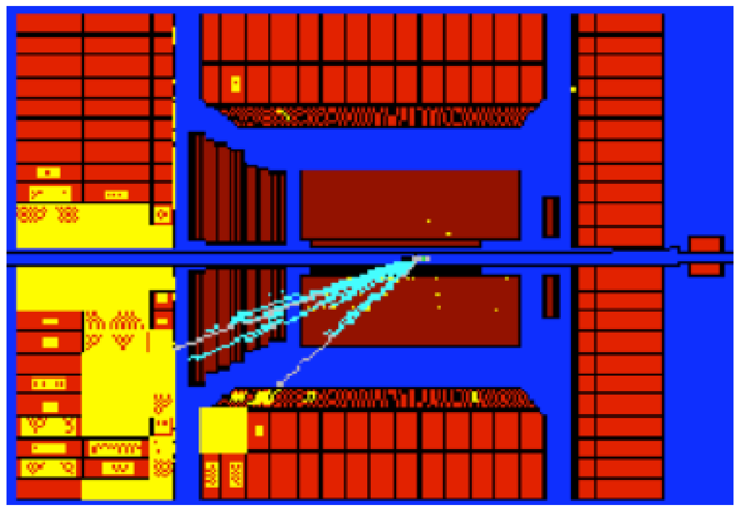




Reconstruction of (x,Q^2)

- use 2 out of $(E_e, \theta_e, E_h, \theta_h)$





- use (E_h, θ_h)

Cross Section and Structure Functions

Neutral current differential cross section

$$\frac{d^2\sigma(e^\pm p)}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+ F_2^{L,R}(x,Q^2) - y^2 F_L^{L,R}(x,Q^2) \pm Y_- xF_3^{L,R}(x,Q^2)\right]$$

Structure functions (sum of quark and antiquark Parton Density Functions)

$$F_2^{L,R} = \sum xq_f^+(x,Q^2)\left[e_f^2 - 2e_f v_f v_e P_Z + (v_f^2 + a_f^2)(v_e^2 + a_e^2)P_Z^2\right]$$

$$xF_3^{L,R} = \sum_{f=u,d,c,s,b} xq_f^-(x,Q^2)\left[-2e_f a_f a_e P_Z + 4v_f a_f v_e a_e P_Z^2\right]$$

only at large x,Q^2
Measured by difference of e^-p, e^+p cross sections.

$$F_L = F_2 - 2xF_1$$

0 at LO QCD, negligible at NLO QCD except at y close to 1

Parton Distribution Functions $xq_f^\pm = xq_f(x,Q^2) \pm x\bar{q}_f(x,Q^2)$

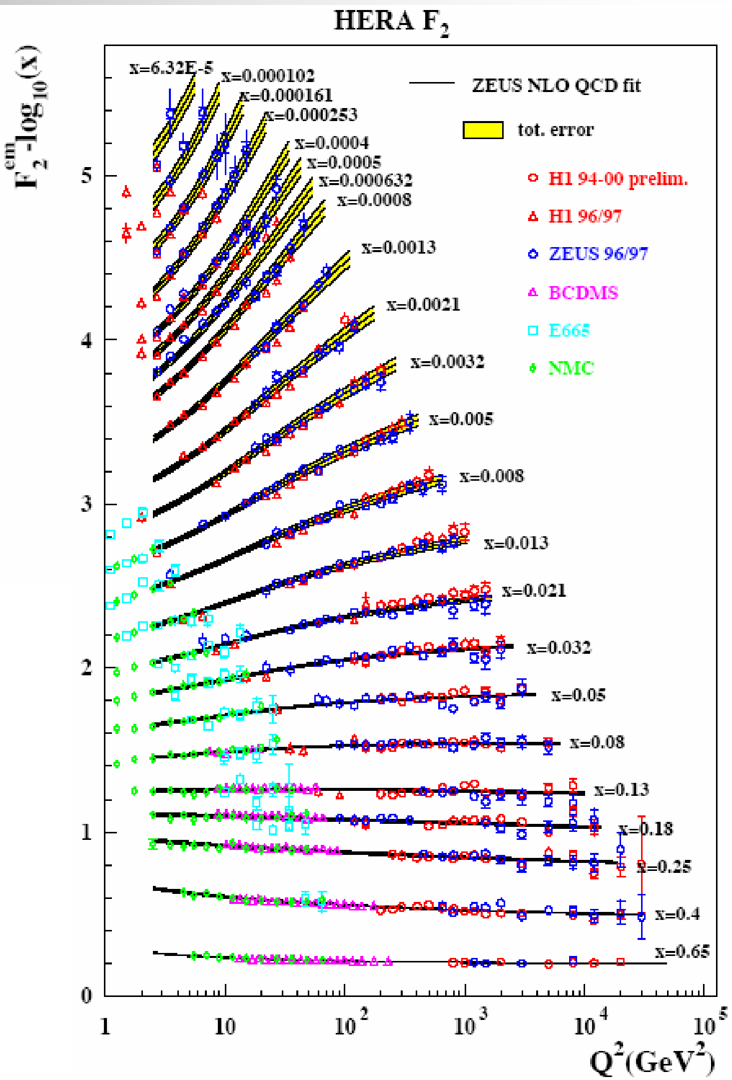
$$P_Z = \frac{1}{\sin^2 2\theta_W}\frac{Q^2}{Q^2 + M_Z^2}$$

$$Y_\pm = 1 \pm (1-y)^2$$

Proton Structure Function F_2

Observe strong scaling violation at low x

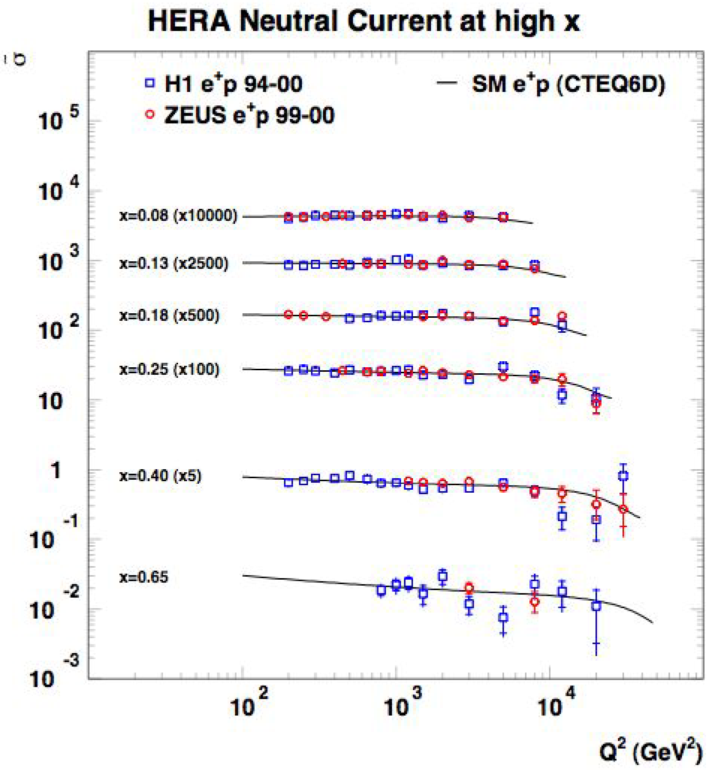
- large gluon density + g ➔ qq splitting
  ➔ F2 increases
- Lines are results of NLO QCD fits
  Data well described over 5 orders of magnitude



NC Cross Section at High x

Neutral current cross section is hard to measure in high x region (Use 2 out of (E_e, θ_e, E_h, θ_h) for x and Q^2 determination)

- For current jet at very low angle, jet angle is measured poorly, or jet is not detected at all
- PDFs decrease very quickly at high x, low statistics and large migration
- x range ends at 0.65
- Determination of PDF at high x very limited
  - Fixed target highest point at x=0.75, but at low W



NC Cross Section at High x

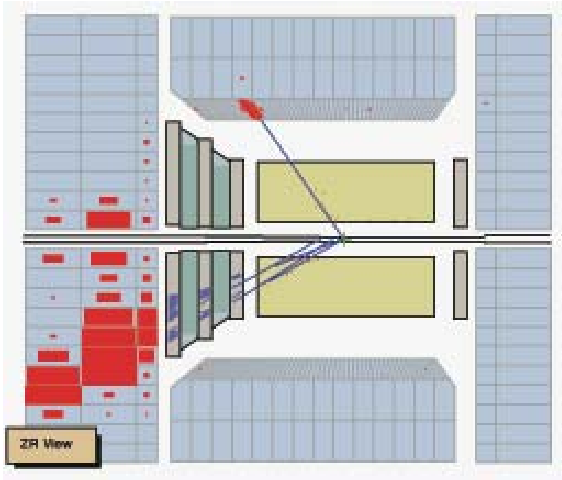
New reconstruction method (instead of classical "double angle method"):

- Use electron to determine Q^2

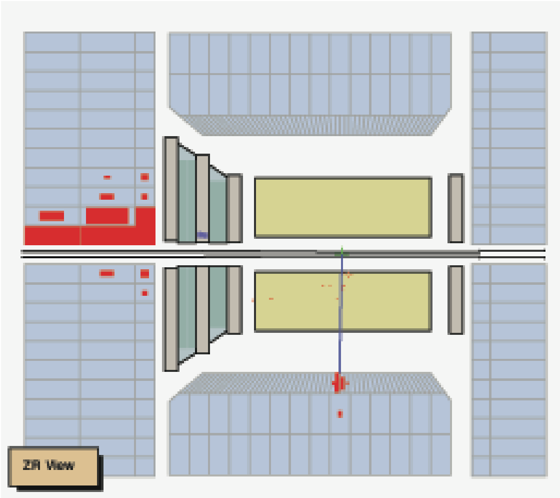
  $$Q^2 = 2E_e E_e^{'}(1+\cos\theta_e)$$

- In each Q^2 bin determine x:
  - using jet finder and measure E_{jet} and θ_{jet} (good resolution),
  - if jet near beam hole, count events in integrated bin (x_{max}<x<1)

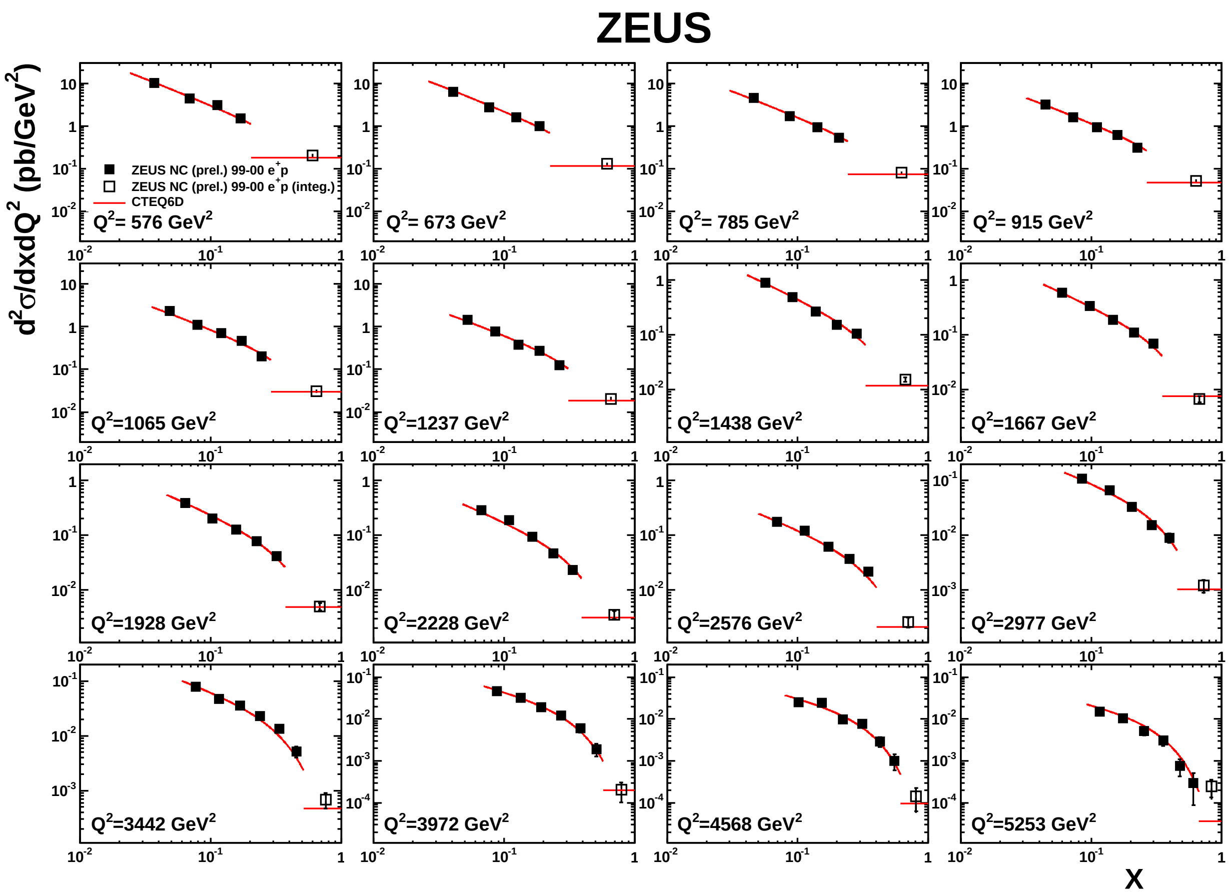
one jet



no jet



NC Cross Section at High x

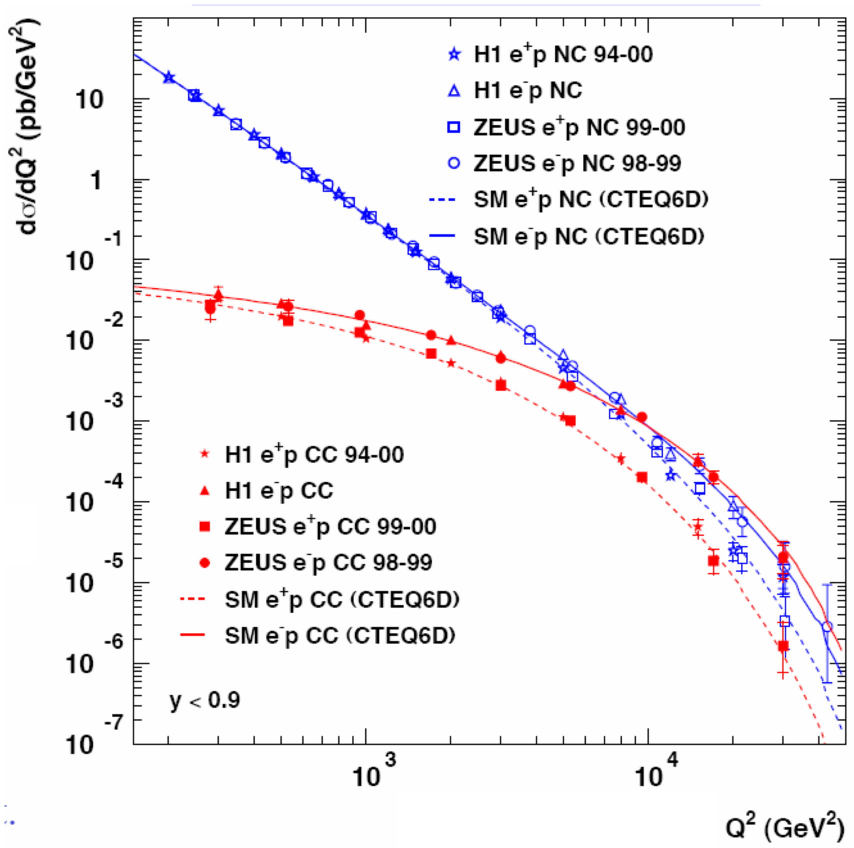


- Good agreement with PDFs
- Uncertainties at high x similar to lower x in previous measurements
- Important for valence quarks
- First time applied at HERA

Evidence for Electro-Weak Unification

Neutral and charged current cross differential sections

- at low Q^2:
  - NC ~ 1/ Q^4 (em current)
  - CC ~ G_F^2 (weak current)
- at high Q^2 ($>M_Z^2$, $>M_W^2$):
  - both NC and CC mediated by unified EW current $\sigma_{NC} \sim \sigma_{CC}$
  - e^- enhanced, e^+ reduced by F_3
- NC (CC) cross section decreases by 7 (4) orders of magnitude due to Z (W)-boson propagator and decreasing quark density at large x
- Excellent agreement data and standard model prediction.
- Space-like boson (q^2 <<0)
  - LEP and Tevatron time-like
  - Completely different phase-space
  - Complementary measurements

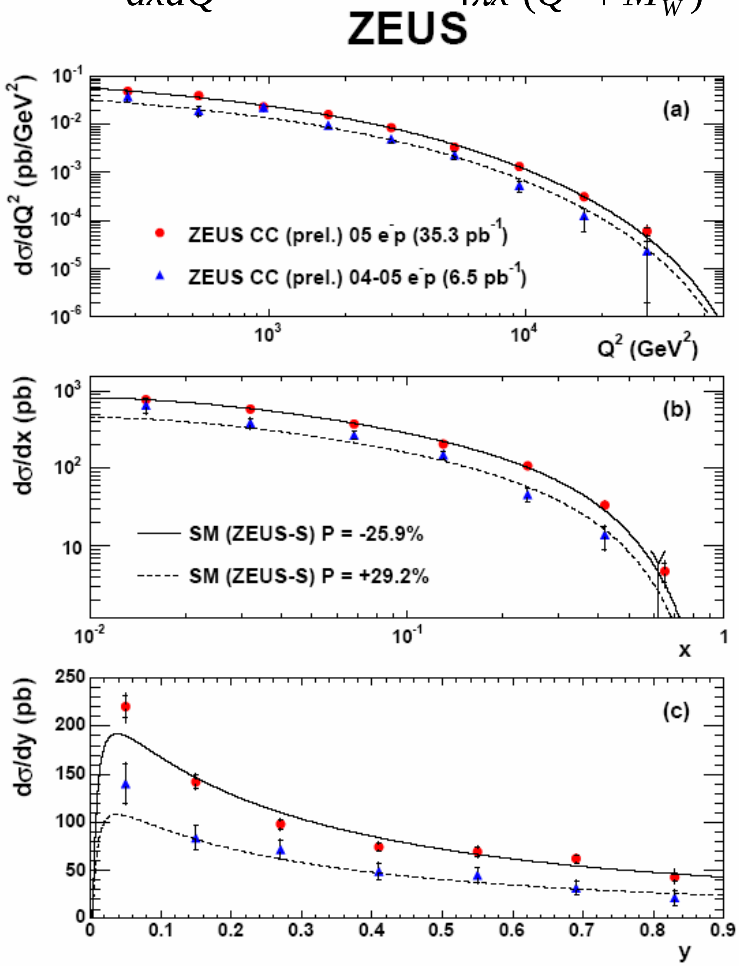


Lepton Polarization

- All ZEUS and H1 HERA I measurements without polarization
  (In fact, lepton beam was transversely polarized at IP)
- New HERA II measurements with longitudinally polarized electron/positron beam
  - Electron-weak physics
  - Searches beyond standard model

Polarized Charged Current Cross Section

$$\frac{d^2\sigma^{CC}_{Born}(e^{\pm}p)}{dxdQ^2} = (1 \pm P)\frac{G_F^2}{4\pi x}\frac{M_W^4}{(Q^2+M_W^2)^2}\left[Y_+F_2^{CC}(x,Q^2) - y^2F_L^{CC}(x,Q^2) \mp Y_- xF_3^{CC}(x,Q^2)\right]$$



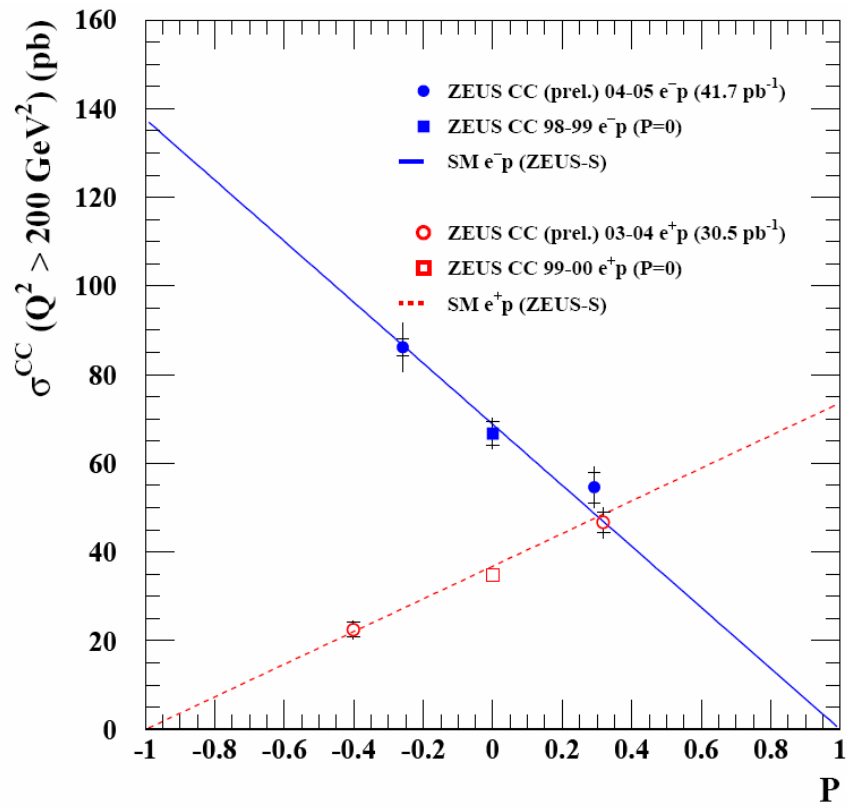
Differential cross sections 2004/2005 e^-p data

- Clear difference between positive and negative polarization
- Well described by standard model prediction

Polarized Charged Current Cross Section

Total cross section as function of polarization

$$\sigma^{CC}(e^{\pm}p,P) = (1 \pm P)\sigma^{CC}(e^{\pm}p,P=0)$$



$$\sigma^{CC}(e^{-}) \rightarrow 0 \text{ for } P \rightarrow +1$$

No right-handed W^-

$$\sigma^{CC}(e^{+}) \rightarrow 0 \text{ for } P \rightarrow -1$$

No left-handed W^+

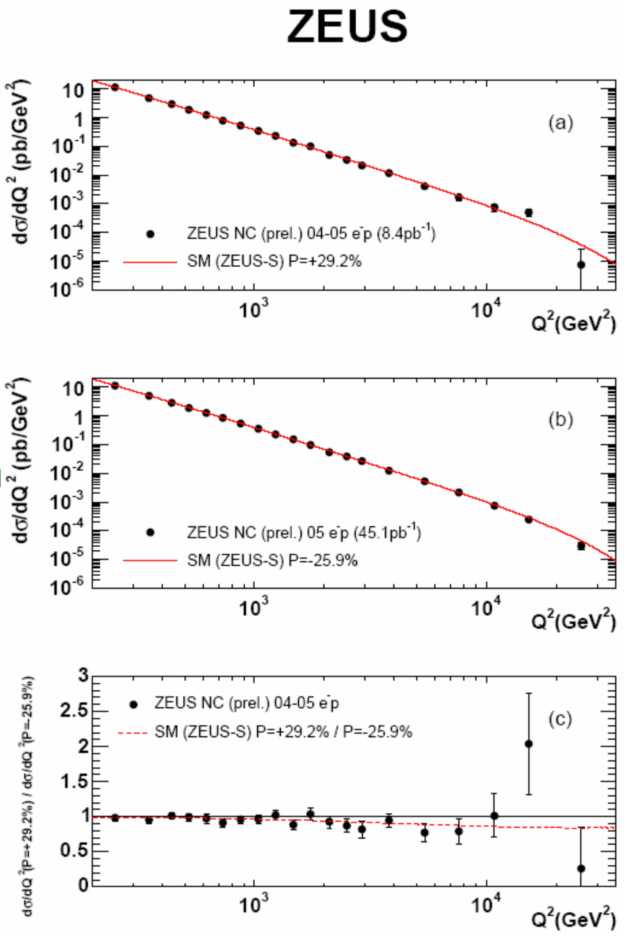
Polarized Neutral Current Cross Sections

$$\frac{d^2\sigma^{NC}_{Born}(e^- p)}{dxdQ^2} = \frac{4\pi\alpha^2}{xQ^4}\left[H_0^-(x,Q^2) + PH_P^-(x,Q^2)\right]$$

positive

negative polarization

ratio



H_0^-, H_P^- unpolarized and polarized structure functions

Differential cross sections

2004/2005 e^-p data

- Data well described by standard model prediction
- Effect due to polarization small (parity violating coupling of Z^0 in t-channel), not yet statistically significant.
- Will measure axial and vector couplings of light quark in future.

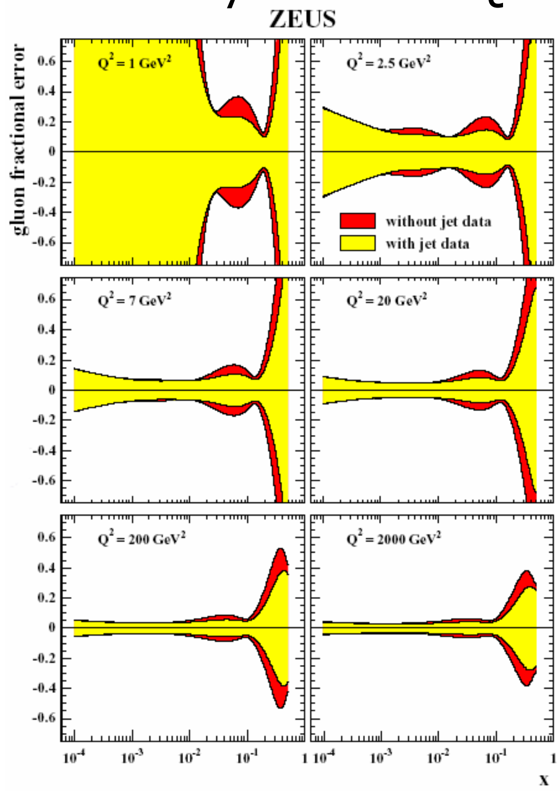
Strong Coupling Constant α_s

- One of the most fundamental parameters
- Not predicted by theory, must be measured experimentally
- Stringent test of perturbative QCD: precise and consistent measurements from different phenomena
- Now a wealth of α_s determinations at HERA from a variety of observables
  - Jet, di-, multi-jet cross sections, multiplicities, structure functions. DIS and photoproduction.
- New method: QCD analysis of NC/CC cross-section and jet data

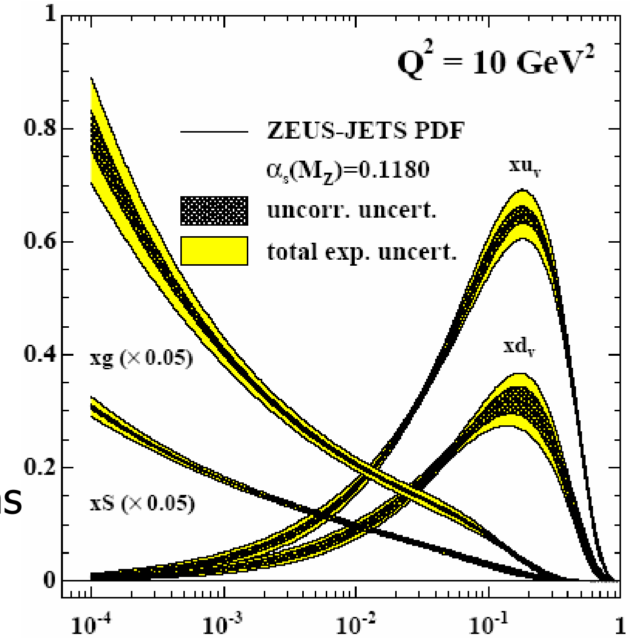
α_s Determination from NLO QCD Fits

- Obtain PDFs from fit to combined inclusive DIS & jet data
  - uncertainty of the mid-to-high x gluon distribution in inclusive DIS constrained by the jet cross sections
  - ➔ sufficient sensitivity to determine PDFs entirely in one experiment

Gluon distribution: relative uncertainty in bins of Q^2



Valence, sea quark and gluon distributions



α_s Determination from NLO QCD Fits

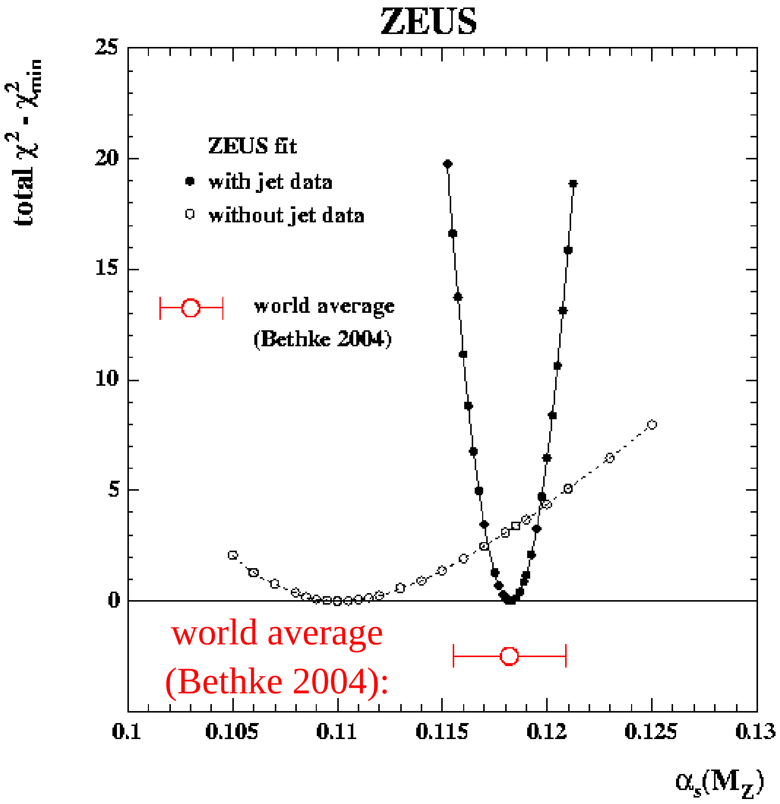
Method can also be used to determine $\alpha_s(M_Z)$ as a free parameter in the fit

$\alpha_s(M_Z)$ = 0.1183± 0.0028 (exp.) ± 0.0008 (model) ± 0.0050(th.)

Largest uncertainty from scale variation (±0.005), estimate of terms beyond NLO

Result

- in agreement with world average $\alpha_s(M_Z)$=0.1182 ± 0.0027
- first determination of α_s from HERA data alone



Strong Coupling Constant α_s

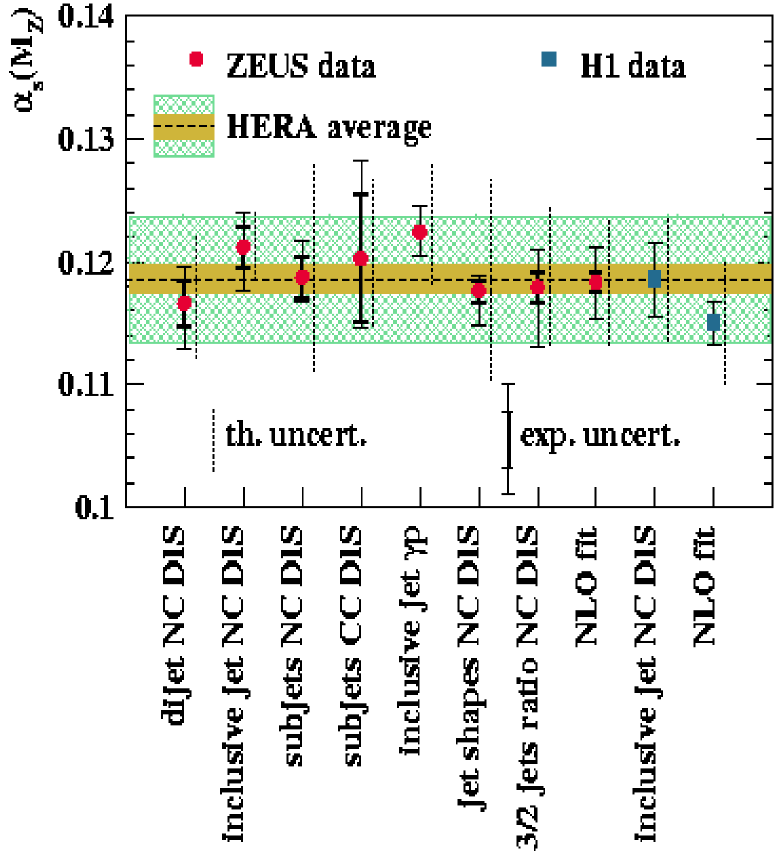
Average of HERA $\alpha_s(M_Z)$ measurements C. Glasman, DIS2005

- Comprehensive average of $\alpha_s(M_Z)$ measurements at HERA
  - conservative assumptions on correlations of theoretical uncertainties (higher order, PDFs, hadronization)

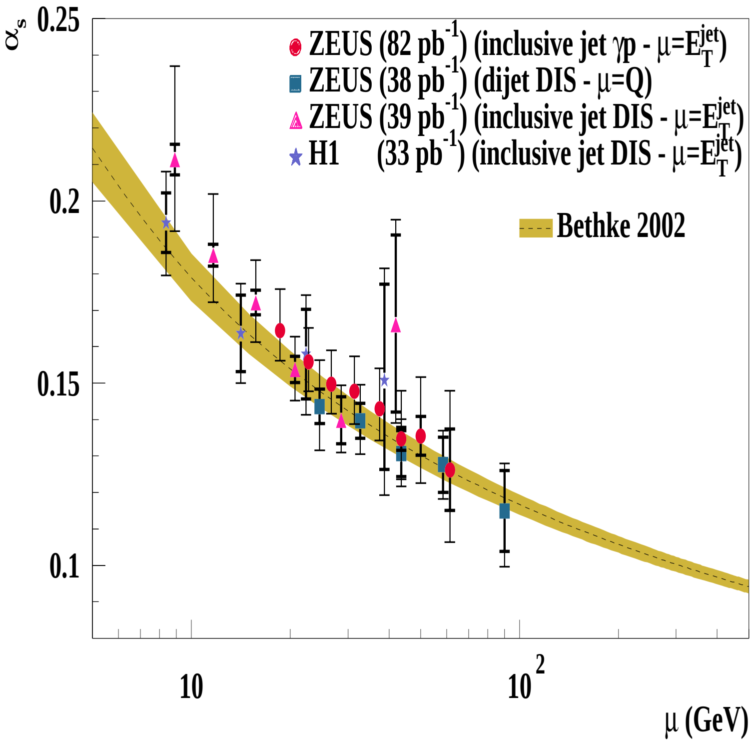
→ $\alpha_s(M_Z)=0.1186\pm0.0011$ (exp) ±0.0050 (th)

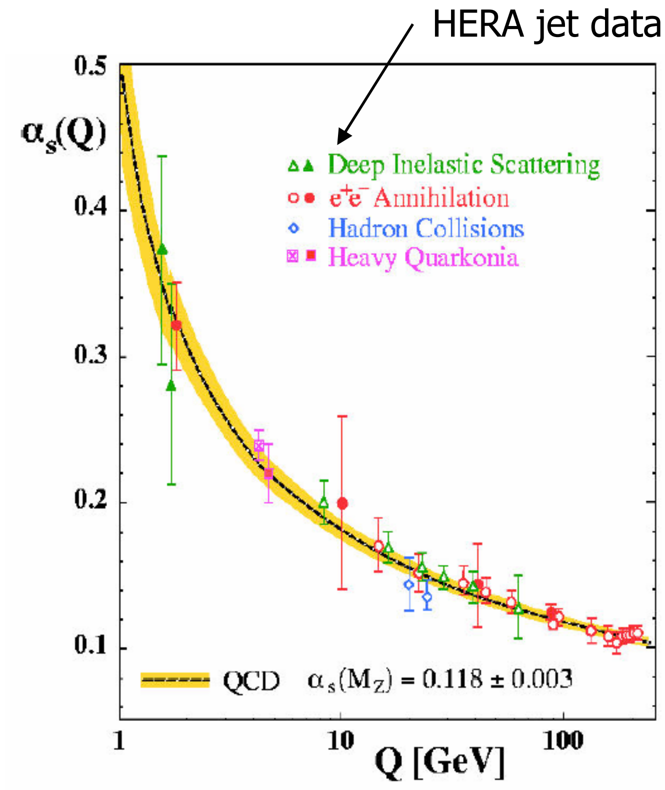
- experimental uncertainty ~0.9%, theoretical ~4%

→ Need for NNLO calculations



Running of α_s





Bethke and Zerwas, Physik J. Dec/2004

HERA results

- consistent with running of α_s predicted by QCD over large energy range
- consistent with other experiments
- very precise and competitive

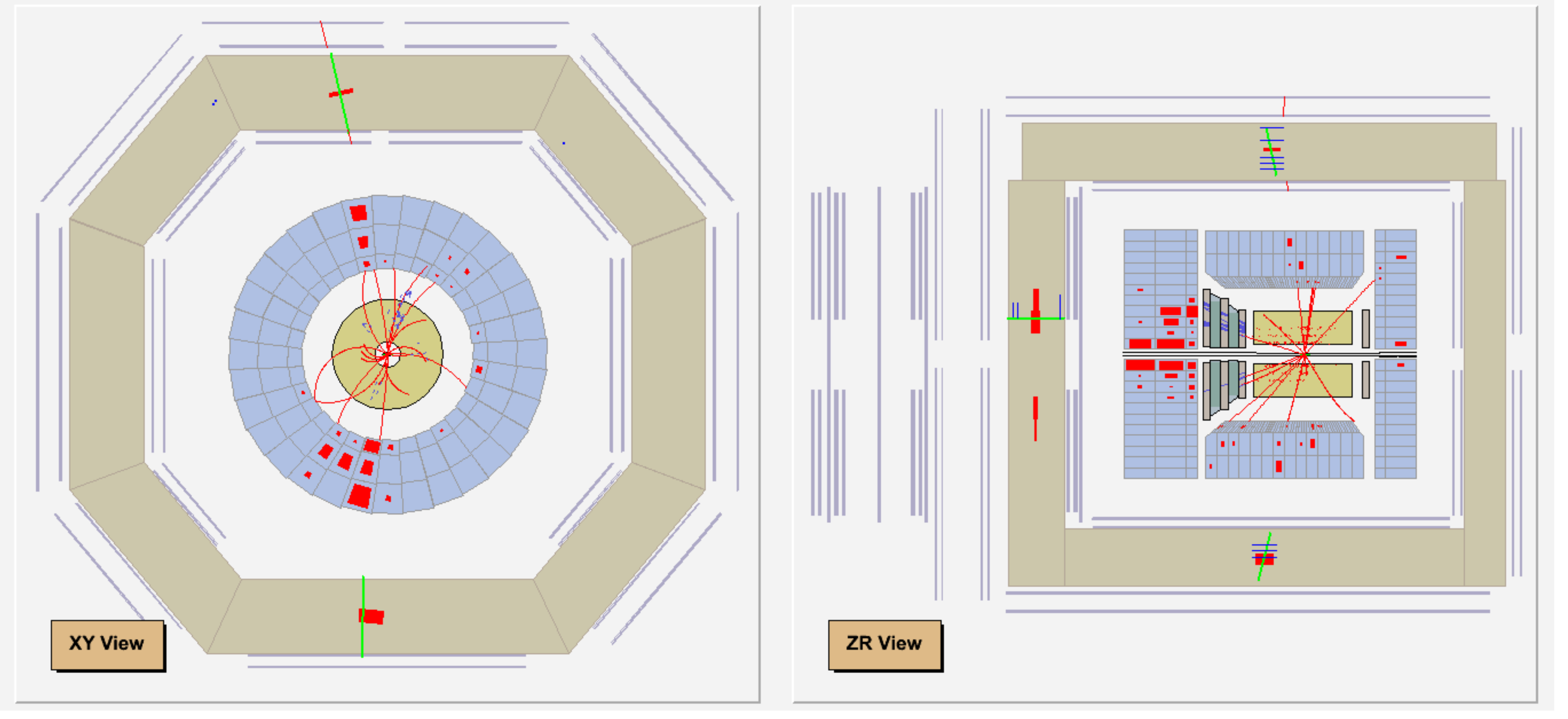
Beauty Production from Dimuon Events

$$ep \rightarrow b\bar{b}X \rightarrow \mu\mu X'$$

- Motivation
  - B quark production is stringent test of perturbative QCD, large b quark mass provides hard scale reliable predictions.
- Previous analysis
  - semi-leptonic decays, $P_{T,rel}$ cut to enriched b sample
  - D^* μ analysis
  - Strong cuts in phase space to suppress background → large extrapolation to get cross section
  - Some measurements have access, in particular at low p_T large η
- This analysis
  - Low p_t threshold for μ identification
  - Large rapidity coverage of ZEUS muon system

    ➔ access to essentially full phase space for b quark production
  - low background data sample
  - higher branching ratios than D^* analysis
- Impact parameter analysis (Micro Vertex Det) preliminary results

Dimuon Event

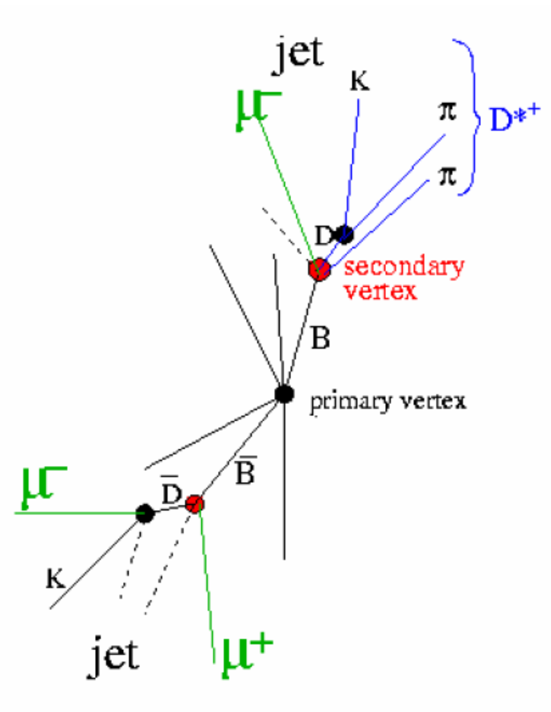


Large rapidity range: barrel, rear and forward muon system

$2.5 > \eta = -\ln \tan \theta/2 > -2.2$

Beauty Production from Dimuon Events

Signal topologies: dimuon mass and muon charge



Muons from b-quark decays:
- like or unlike sign charge
  direct b $\bar{b}$, chain decays, B^0B^0 mixing

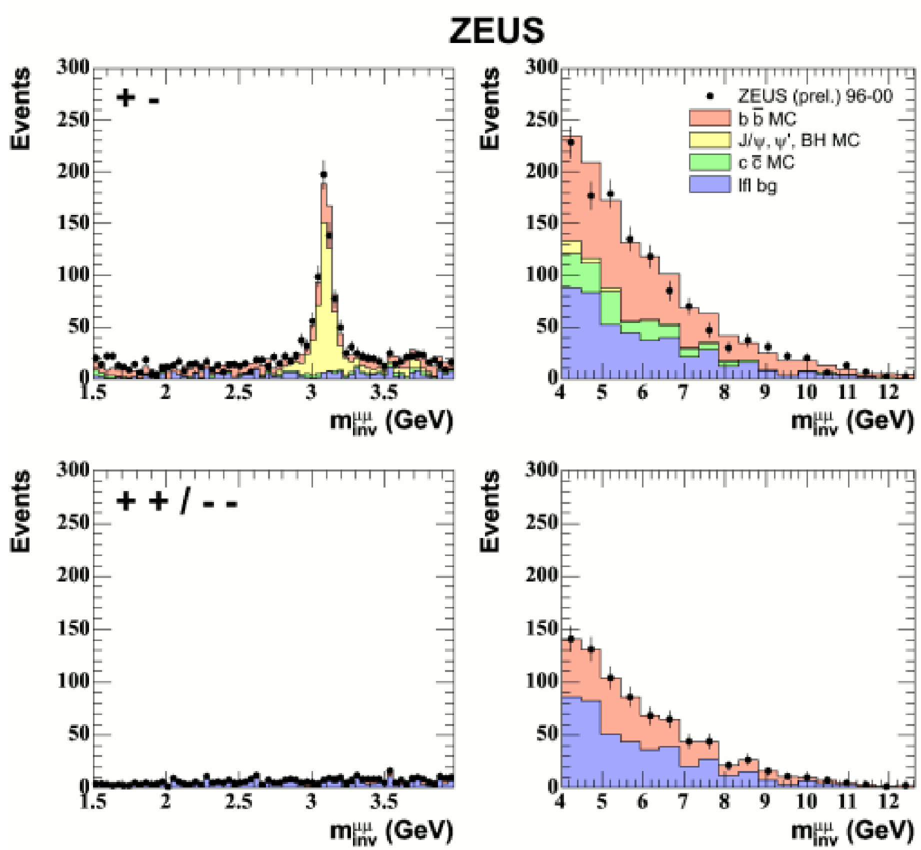
Background:
- charm: μ unlike sign only
- light flavor: like and unlike sign

same b	different b's
m < 4 GeV +-	m > 4 GeV +-
m < 4 GeV ++/--	m > 4 GeV ++/--

Low background ➔ low p_T^{μ} cut possible
p_T^{μ} > 0.75 (1.5) GeV for high (low) quality μ

Beauty Production from Dimuon Events

Dimuon mass distributions



HERA I data, 121 pb^{-1}
DIS and photoproduction

Background:

- charm pair, J/Ψ, Bethe Heitler from Monte Carlo
- like sign is light flavor + beauty (no charm).
  Use beauty MC to estimate light flavor.
  Assume:
  - light flavor like sign = light flavor unlike sign bgrd

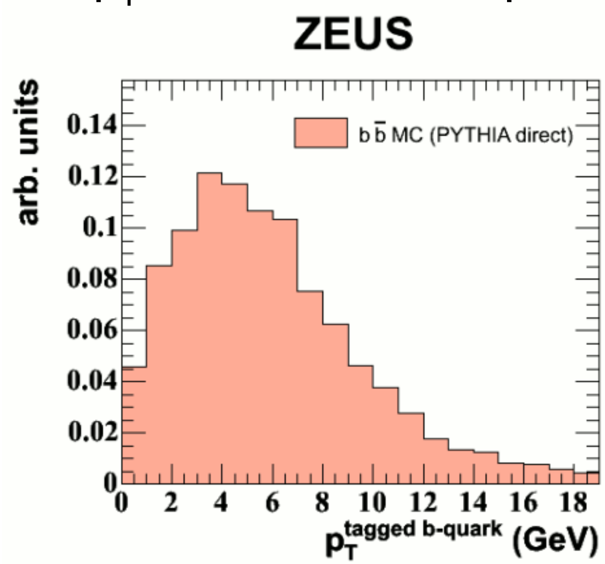
Monte Carlo (PYTHIA + RAPGAP) normalization scaled up by factor 2.06 to agree with data.

Beauty Production from Dimuon Events

Signal extraction (beauty purity 50%)

$$N_{b\bar{b}\to\mu\mu} = (N^{unl}_{data} - N^{like}_{data} - (N_{charm} + N_{J/\Psi} + N_{BH} + N_{\Upsilon})) \times \left(\frac{N^{unl}_{b\bar{b}} + N^{like}_{b\bar{b}}}{N^{unl}_{b\bar{b}} - N^{like}_{b\bar{b}}} \right)_{MC}$$

p_T distibution of b-quarks



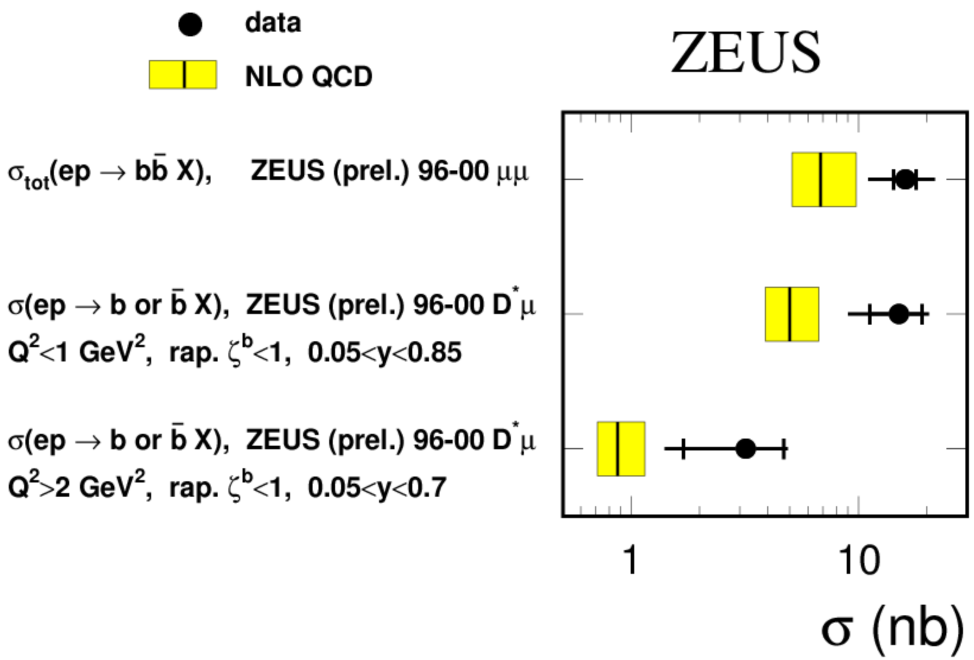
Method sensitive to b-quarks 'at rest'
Large rapidity range
➔Extraction of total beauty cross section (small acceptance correction)

Beauty Production from Dimuon Events

Visible cross section $\sigma_{vis}(ep \to b\bar{b}X \to \mu\mu X') = 63 \pm 7(\text{stat.})\,^{+20.2}_{-17.6}(\text{syst.})\,\text{pb}$

Total cross section $\sigma_{b,tot}(ep \to b\bar{b}X\,(318\text{GeV})) = 16.1 \pm 1.8(\text{stat.})\,^{+5.3}_{-4.8}(\text{syst.})\,\text{nb}$

NLO QCD predictions $6.8^{+3.0}_{-1.7}\ \text{nb}\ \begin{matrix} 4.5<m_b\,5.0 \\ 0.5<\mu/\mu_0<2 \end{matrix}$ DIS ~ 15%



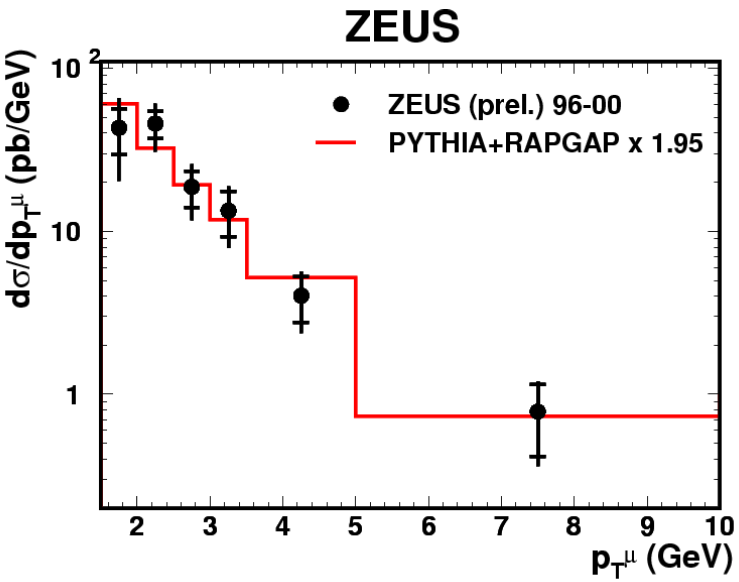
Main systematic uncertainties
- μ detection efficiency
- branching ratios
- decay spectra

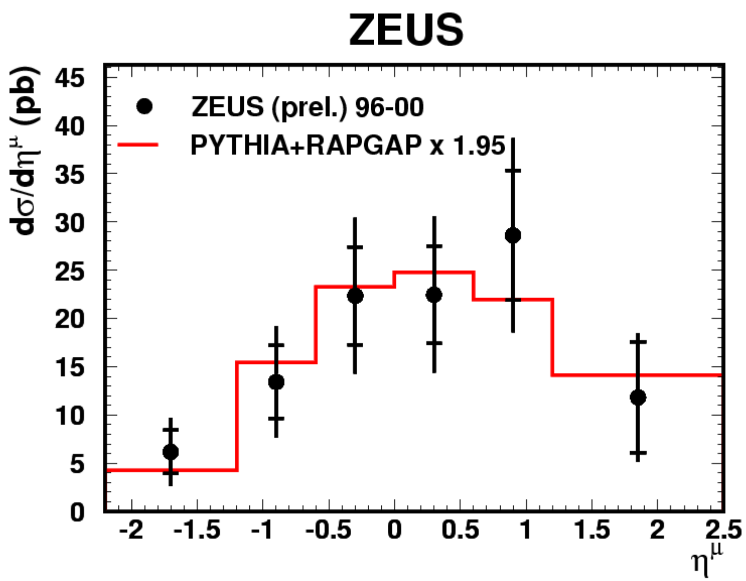
NLO QCD calculations factor 2.4 higher than measurement, still compatible within errors.

D^* + μ and H1 measurements show the same trend.

Beauty Production from Dimuon Events

Differential cross sections





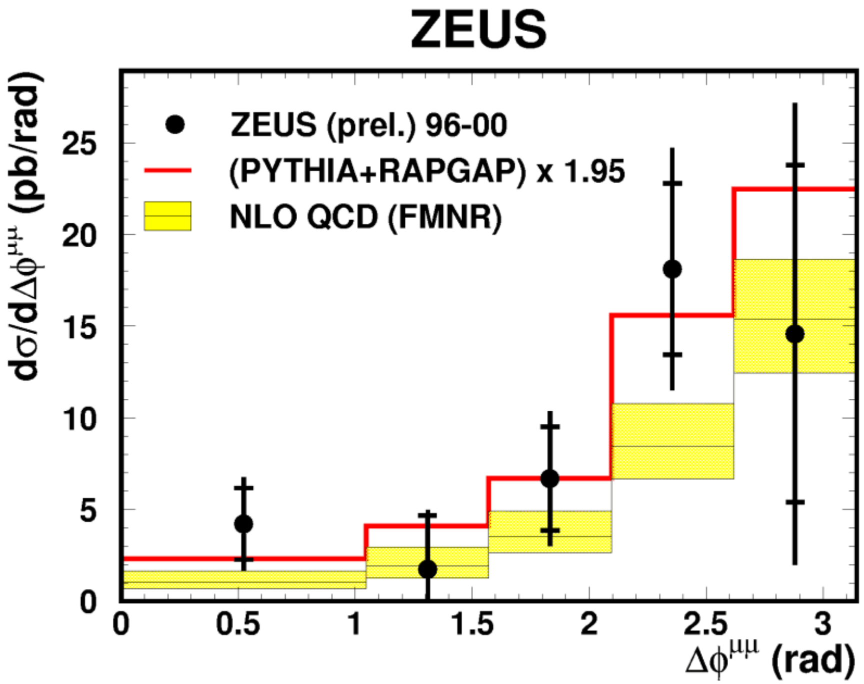
Very good agreement with photoproduction (PYTHIA) + DIS (RAPGAP) predictions scaled up by factor 1.95

(P_t^{μ} > 1.5 GeV for both muons)

Beauty Production from Dimuon Events

$b\bar{b}$ quark correlations

- Look at muons from different b quarks ($m_{inv}^{\mu\mu}$ > 3.25 GeV)



Good agreement with photoproduction (PYTHIA) + DIS (RAPGAP) predictions scaled up by factor 1.95

NLO consistent with data (large errors).

Beyond the Standard Model

- New interactions between electron and quarks involving mass scales above center-of-mass energy can modify cross section at high Q^2 via virtual effects.
- Should observe deviations from Standard Model predictions.
- Many interactions, e.g. mediated by heavy leptoquarks, can be modeled as four-fermion contact interactions.
- Use SM predictions at high Q^2 from evolution of accurate measurements of the proton structure functions made at lower Q^2 for searches for:
  - four-fermion interactions,
  - graviton exchange in models with extra large dimensions or
  - finite charge radius of quarks.

Are Quarks Elementary?

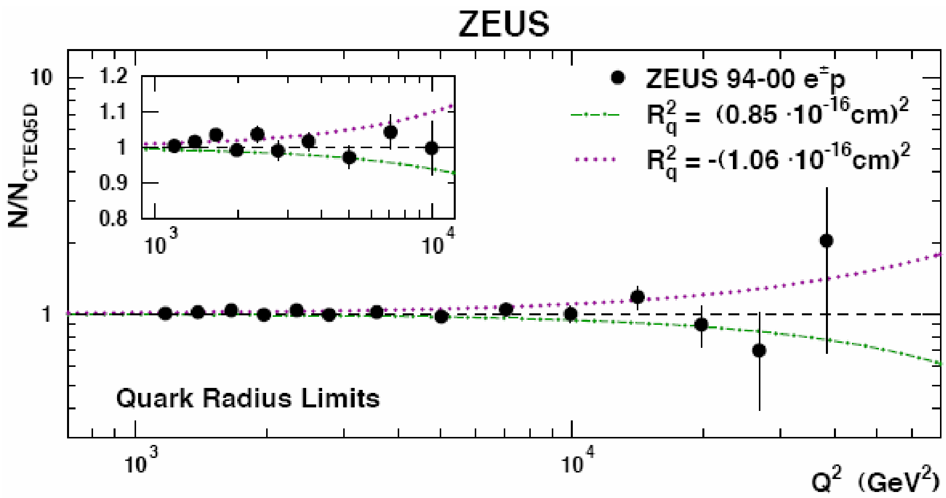
- Quark substructure can be detected by measuring spatial distribution of quark charge.
- If quark has finite radius, cross section will decrease as probe penetrates into it.

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

R_q is rms of electroweak charge

- Limit on quark size (assuming point-like electron)
  - $R_q < 0.85\ 10^{-16}$ cm (95%CL)
  - $R_q^2 < -(1.06\ 10^{-16}\ \text{cm})^2$ If charge changes sign as function of radius

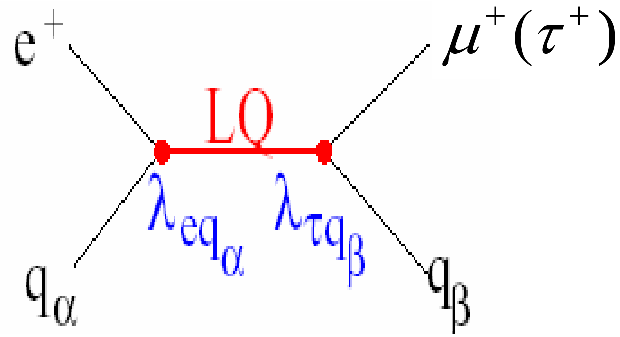
Similar limits by H1, CDF and L3.



Search for Lepton-Flavor Violation

Motivation for search $e^+p \rightarrow \mu^+(\tau^+)X$

- Many extensions of Standard Model allow lepton-flavor violation
- Lepton-flavor violation occurs in neutrino section as shown by neutrino oscillation experiments



- Leptoquark (LQ): both lepton and baryon numbers and lepton-quark Yukawa couplings
- LFV if LQ couples to two different generations

- Mediated by squarks in R-parity-violation SUSY models

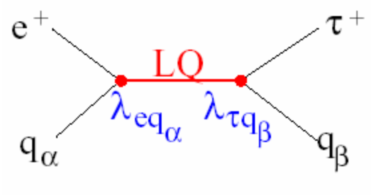
Search for Lepton-Flavor Violation

Buchmüller-Rückl-Wyler model: 14 LQ types,
fermionic number (F=3B+L) 0 or 2

Narrow width approximation

$$(M_{LQ} < \sqrt{s})$$

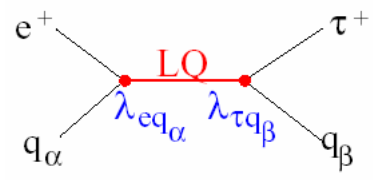
$$\sigma^{NWA}(\lambda, M_{LQ}) \propto \lambda^2_{lq_i} B_{lq_j}$$

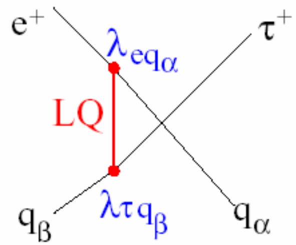


High mass approximation

$$(M_{LQ} >> \sqrt{s})$$

$$\sigma^{HMA}(\lambda, M_{LQ}) \propto \left[\frac{\lambda_{eq_i}\lambda_{eq_j}}{M^2_{LQ}}\right]^2$$





λ_{eq_i} LQ coupling to electron and quark (generation i)

B_{lq_i} Branching ratio to lepton and quark

Search for Lepton-Flavor Violation

- e - μ transition
  - Isolated muon with high transverse momentum, easy to identity
  - No event found, 0.87±0.15 expected from SM background
- e – τ transition
  - High transverse momentum isolated τ balanced by a jet
  - Only tau decay products visible in detector
    → large transverse momentum imbalance $P_{t,mis}$
  - leptonic (35%) decay
    - Isolated e or μ with missing momentum
    - No event found, 0.43±0.08 expected from SM background
  - hadronic (65%) decay
    - More difficult, see next slide

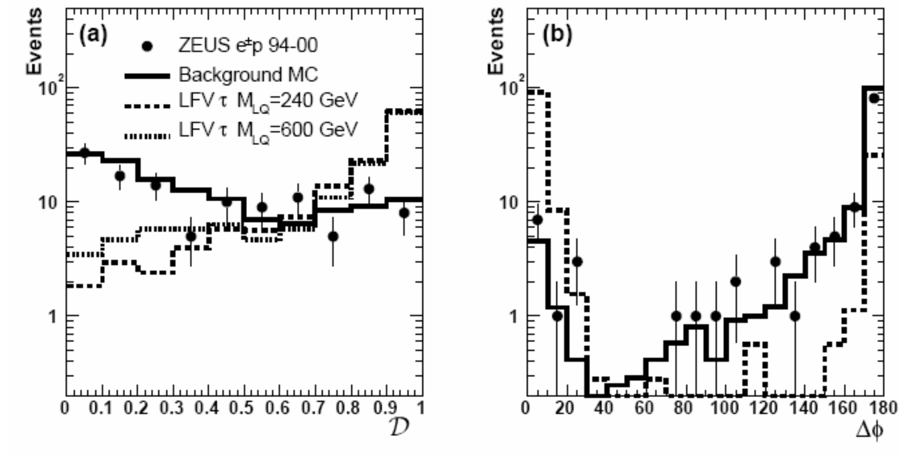
Search for Lepton-Flavor Violation

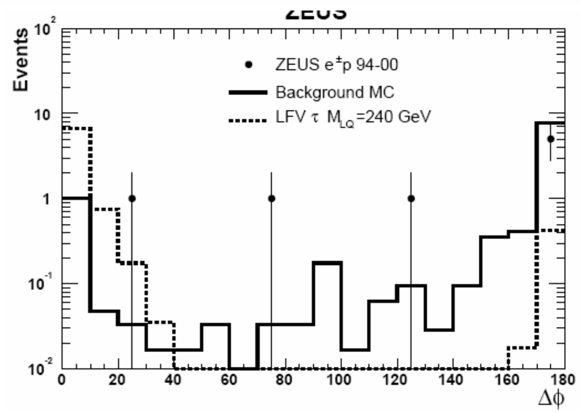
Hadronic τ decays:

- No electron with E > 10 GeV
- E_t > 45 GeV
- 15 < $E-P_z$ < 60 GeV
- τ jet candidate:
  - p_t > 15 GeV
  - 1 to 3 tracks
- τ discriminant:
  - jet shape: 6 observables

  (radial extension of jet energy)

  D > 0.9, $\Delta\varphi < 20^0$



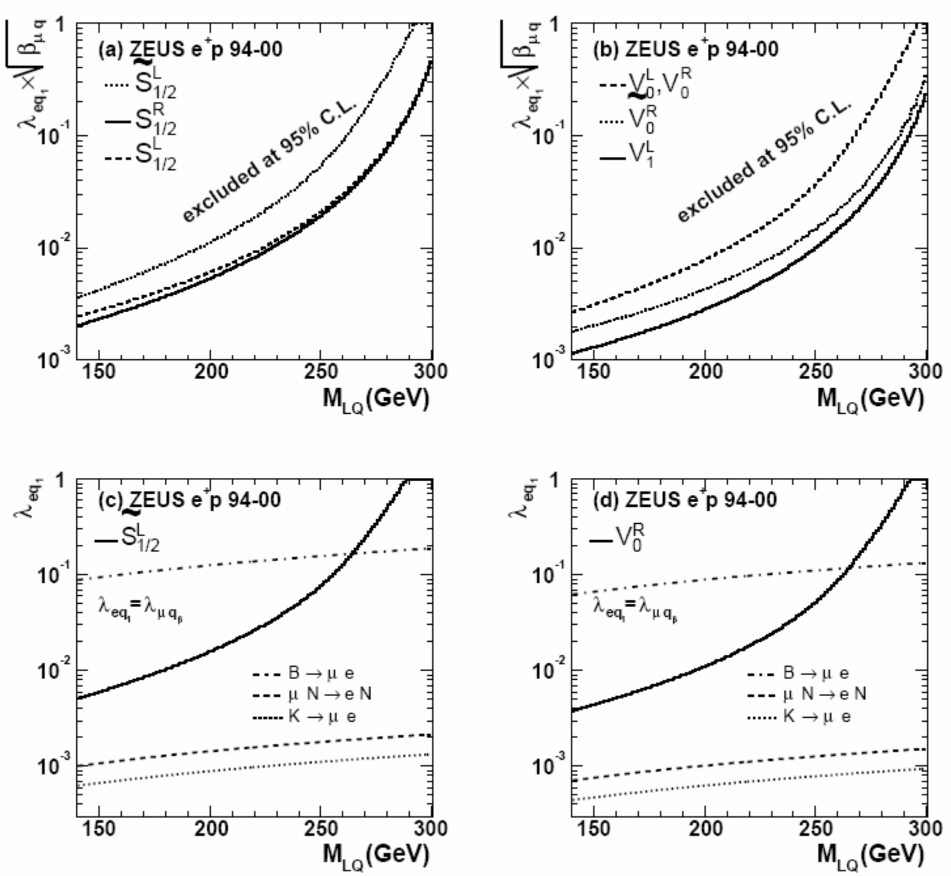


No event event found in hadronic channel, 1.1±0.5 expected from SM bgrd

No candidate in any channel ➔ set limits

Search for Lepton Flavor Violation

Results: Limits on $\lambda_{eq_1}\sqrt{B_{\tau q}}$ as function of M_{LQ} for lower mass scalar and vector leptoquarks



95% C.L. lower limits on LQ assuming $\lambda_{eq_1} = \lambda_{\tau q} = 0.3$ (electromagnetic strength)

$\tilde{S}^L_{1/2}$	$S^L_{1/2}$	$S^R_{1/2}$	V^L_0	V^R_0	$\tilde{V}^R_0$	V^L_1
276	293	293	274	278	296	299

Limits on $\lambda_{eq_1}\sqrt{B_{\tau q}}$ equivalent to limits on $\lambda'_{ej1}\sqrt{B_{\tilde{u}^j\to\tau q}}$ for $\tilde{u}^j$ squarks

Search for Lepton Flavor Violation

Upper 95%C.L. limits on $\lambda_{eq_\alpha} \lambda_{\tau q_\beta}/M^2_{LQ}$ (TeV^{-2}) for F=0 high mass LQs

$e \to \tau$ ZEUS $e^{\pm}p$ 94-00 $F = 0$

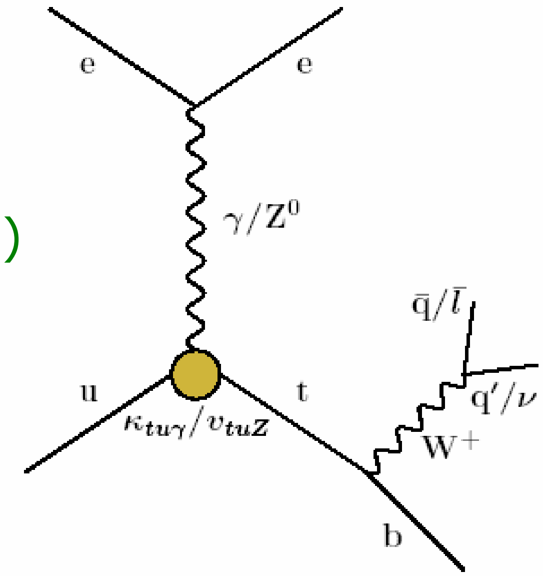
$\alpha\beta$	$S^L_{1/2}$ $e^-\bar{u}$ e^+u	$S^R_{1/2}$ $e^-(\bar{u}+\bar{d})$ $e^+(u+d)$	$\tilde{S}^L_{1/2}$ $e^-\bar{d}$ e^+d	V^L_0 $e^-\bar{d}$ e^+d	V^R_0 $e^-\bar{d}$ e^+d	$\tilde{V}^R_0$ $e^-\bar{u}$ e^+u	V^L_1 $e^-(\sqrt{2}\bar{u}+\bar{d})$ $e^+(\sqrt{2}u+d)$
1 1	$\tau \to \pi e$ 0.4 **1.8**	$\tau \to \pi e$ 0.2 **1.5**	$\tau \to \pi e$ 0.4 **2.7**	$\tau \to \pi e$ 0.2 **1.7**	$\tau \to \pi e$ 0.2 **1.7**	$\tau \to \pi e$ 0.2 **1.3**	$\tau \to \pi e$ 0.06 **0.6**
1 2	**1.9**	$\tau \to Ke$ 6.3 **1.6**	$K \to \pi\nu\bar{\nu}$ 5.8×10^{-4} **2.9**	$\tau \to Ke$ 3.2 **2.1**	$\tau \to Ke$ 3.2 **2.1**	**1.6**	$K \to \pi\nu\bar{\nu}$ 1.5×10^{-4} **0.8**
1 3	*	$B \to \tau\bar{e}$ 0.3 **3.2**	$B \to \tau\bar{e}$ 0.3 **3.3**	$B \to \tau\bar{e}$ 0.13 **2.6**	$B \to \tau\bar{e}$ 0.13 **2.6**	*	$B \to \tau\bar{e}$ 0.13 **2.6**
2 1	**6.0**	$\tau \to Ke$ 6.3 **4.1**	$K \to \pi\nu\bar{\nu}$ 5.8×10^{-4} **5.2**	$\tau \to Ke$ 3.2 **2.3**	$\tau \to Ke$ 3.2 **2.3**	**2.1**	$K \to \pi\nu\bar{\nu}$ 1.5×10^{-4} **0.9**
2 2	$\tau \to 3e$ 5 **10**	$\tau \to 3e$ 8 **5.6**	$\tau \to 3e$ 17 **6.5**	$\tau \to 3e$ 9 **3.4**	$\tau \to 3e$ 9 **3.4**	$\tau \to 3e$ 3 **5.5**	$\tau \to 3e$ 1.6 **2.1**
2 3	*	$B \to \tau\bar{e}X$ 14 **8.1**	$B \to \tau\bar{e}X$ 14 **7.8**	$B \to \tau\bar{e}X$ 7.2 **5.5**	$B \to \tau\bar{e}X$ 7.2 **5.5**	*	$B \to \tau\bar{e}X$ 7.2 **5.5**
3 1	*	$B \to \tau\bar{e}$ 0.3 **7.8**	$B \to \tau\bar{e}$ 0.3 **7.2**	V_{ub} 0.12 **2.5**	$B \to \tau\bar{e}$ 0.13 **2.5**	*	V_{ub} 0.12 **2.5**
3 2	*	$B \to \tau\bar{e}X$ 14 **11**	$B \to \tau\bar{e}X$ 14 **10**	$B \to \tau\bar{e}X$ 7.2 **4.2**	$B \to \tau\bar{e}X$ 7.2 **4.2**	*	$B \to \tau\bar{e}X$ 7.2 **4.2**
3 3	*	$\tau \to 3e$ 8 **15**	$\tau \to 3e$ 17 **14**	$\tau \to 3e$ 9 **8.1**	$\tau \to 3e$ 9 **8.1**	*	$\tau \to 3e$ 1.6 **8.1**

α and β quark generations
Upper entry: most stringent low energy limits
Lower entry: ZEUS limits
yellow: ZEUS best limit

Similar limits for |F|=2 LQs

Some limits also apply to R_p-violating squarks.
If higher generation quarks involved ZEUS limits most stringent

Search for Single-top Production



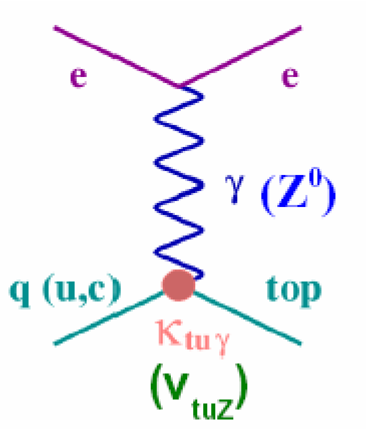
Motivation

- Single-top production through flavor-changing neutral current (FCNC)
- Standard Model contribution < 1fb (GIM mechanism)
- Several theories beyond the SM predict FCNC
- FCNC coupling at tuV,tcV
  Most sensitive to tuV (charm PDF of proton small at high x)
- Effective anomalous coupling at t-u-γ or t-u-Z vertex

$$\Delta L_{eff} = ee_t \bar{t} \frac{i\sigma_{\mu\nu} q}{\Lambda} \kappa_{tu\gamma} u A^{\mu} + \frac{g}{2\cos\theta_W} \bar{t} \gamma_{\mu} v_{tuZ} u Z^{\mu} + h.c.$$

magnetic — vector coupling

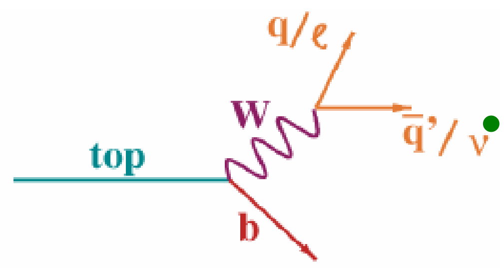
Single-top: Experimental Signature



Production modes:

Final states for gamma and Z exchange quite different

- γ-exchange: $e^{\pm}$ forward peaked (escapes through rear beam pipe hole 65%)
- Z-exchange: $e^{\pm}$ in central part



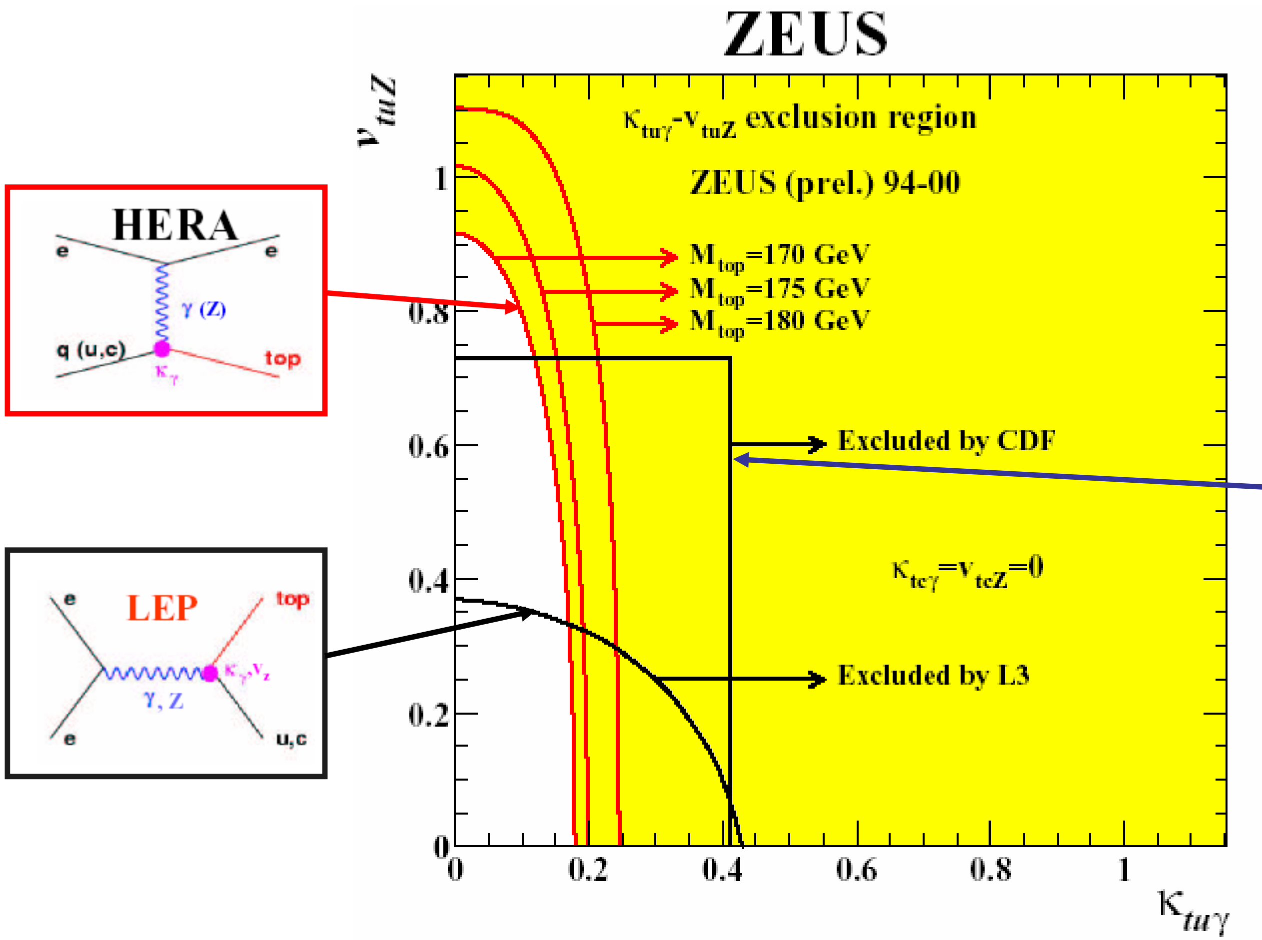
Decay modes:

- Standard Model
  - leptonic (BR 32%): t→bW, W→lν isol.lepton, jet, p_{Tmiss}
  - hadronic (BR 68%): t→bW, W→q q̄ 3 jets, m_W, m_{top}
- Flavor Changing Neutral Currents
  - $\kappa_{t-u-\gamma}$ t→uγ n-jets (+lepton pairs)
  - v_{t-u-Z} t→uZ^0

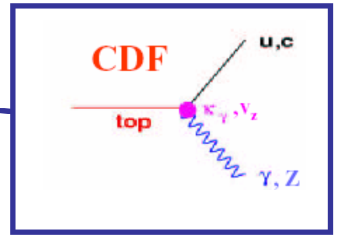
Data sample:

integrated luminosity: 130.1 pb^{-1} √s 300 and 318 GeV

Single-top Production: Results



No candidates found
→ set limts



Limits on anomalous couplings significantly improved

Conclusions

- Structure of the Proton
  - Structure function measurement
- Neutral and Charged Scattering
  - Electroweak effects with polarized leptons
- QCD
  - Precise determination of strong coupling constant α_s
- Heavy Quarks:
  - Beauty Production (dimuon events) cross sections
- Physics beyond the Standard Model
  - Are quarks elementary? Limits on quark size
  - Limits on lepton-flavor violation
  - Limits on single-top production