Electroweak Physics in ep Collisions at HERA

Frontiers in Contemporary Physics
Vanderbilt University
May, 23-28, 2005

Christian Schwanenberger
DESY/Universität Bonn

on behalf of the

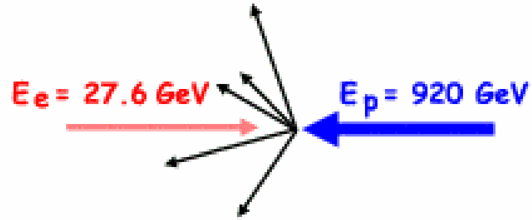
Collaborations

Electroweak Physics at HERA

- NC and CC cross section (unpolarised)
- W mass and electroweak parameters
- CC cross section with polarised leptons (HERA II)
- Isolated Leptons and missing pT (HERA II)
- W Production

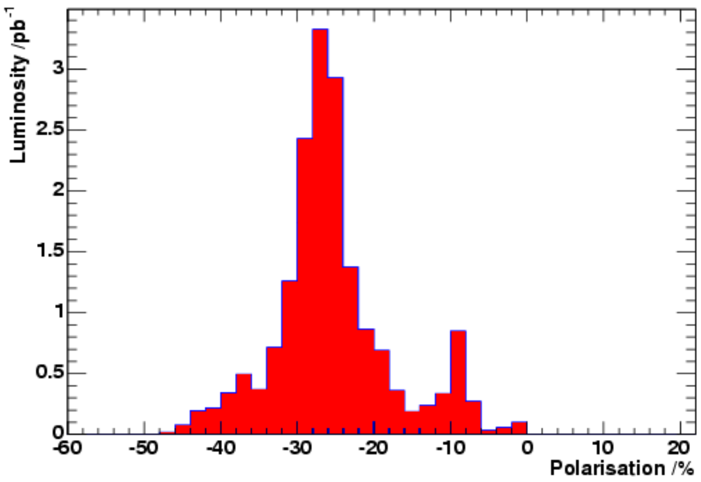
➡ **What is new compared to summer (ICHEP)**

HERA: ep Collider and Experiments



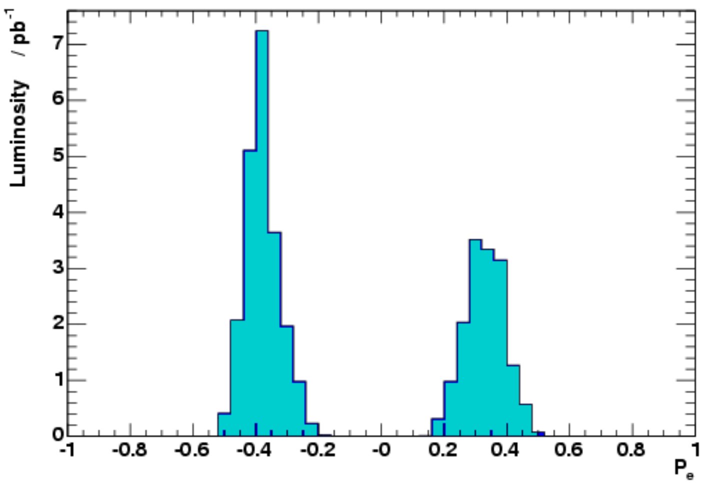
HERA Delivered Luminosities

longitudinally polarised electron beam

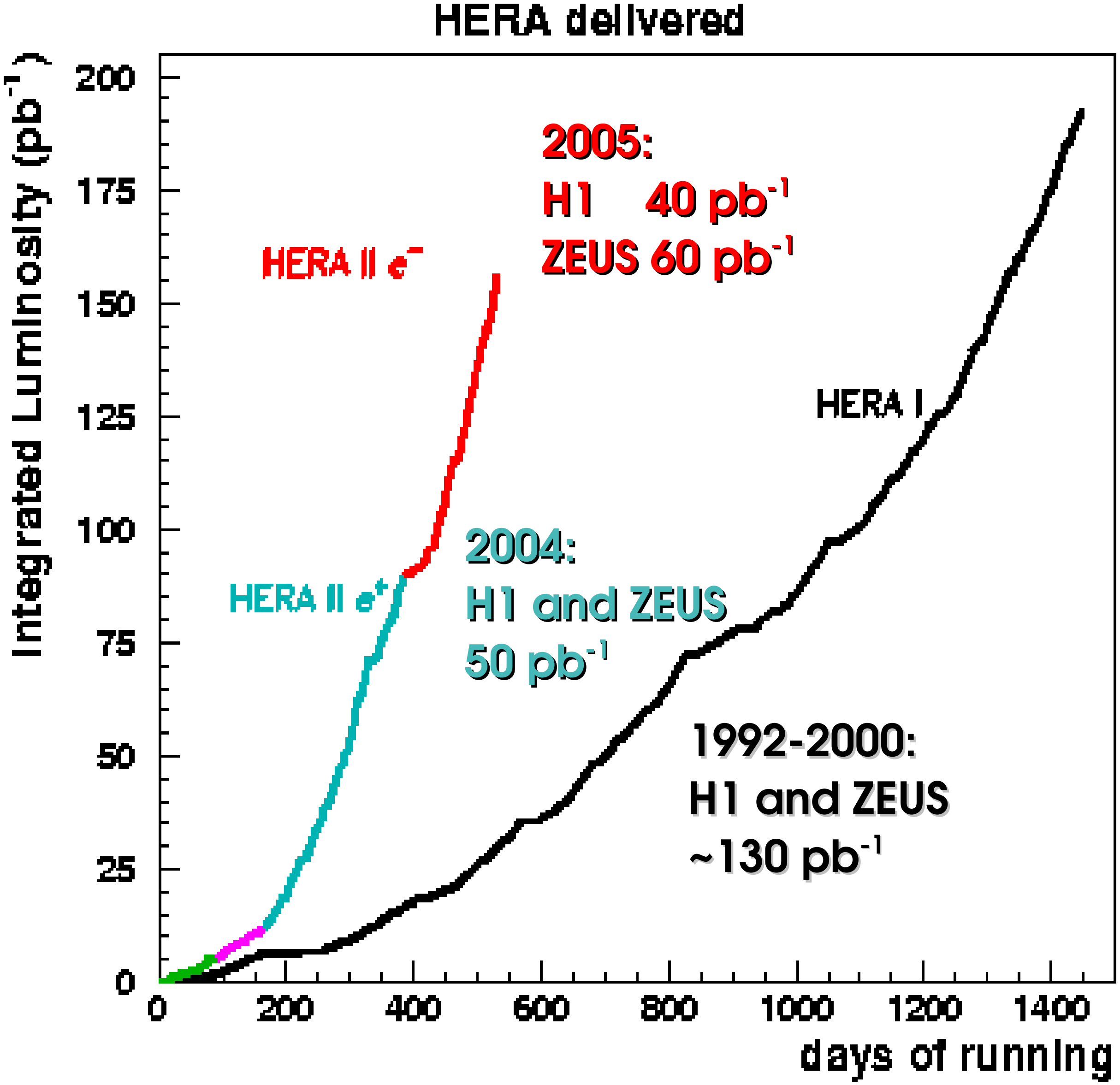


P_e

longitudinally polarised positron beam

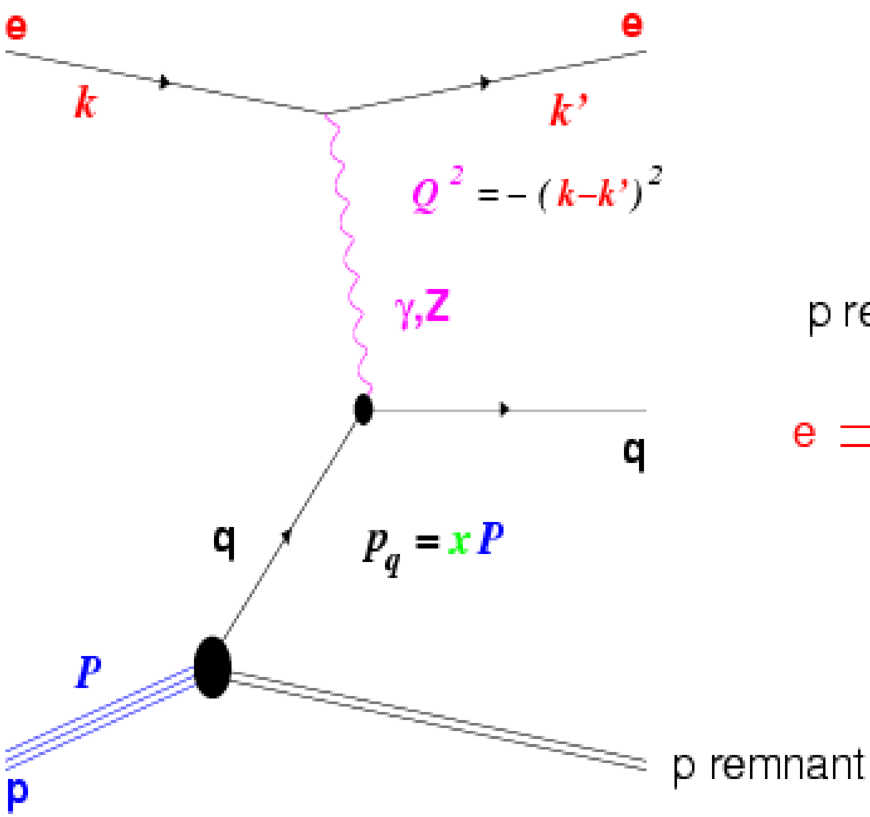


P_e

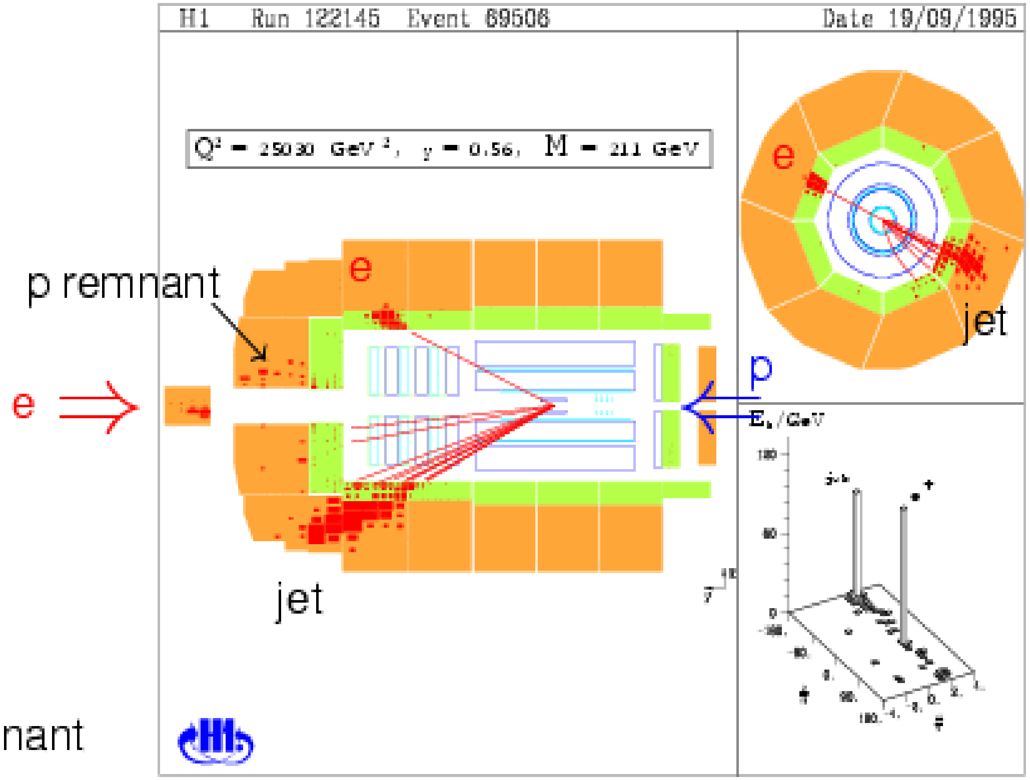


DIS – Neutral Current (NC)

deep inelastic scattering (DIS):



H1 detector



Q^2: four-momentum transfer

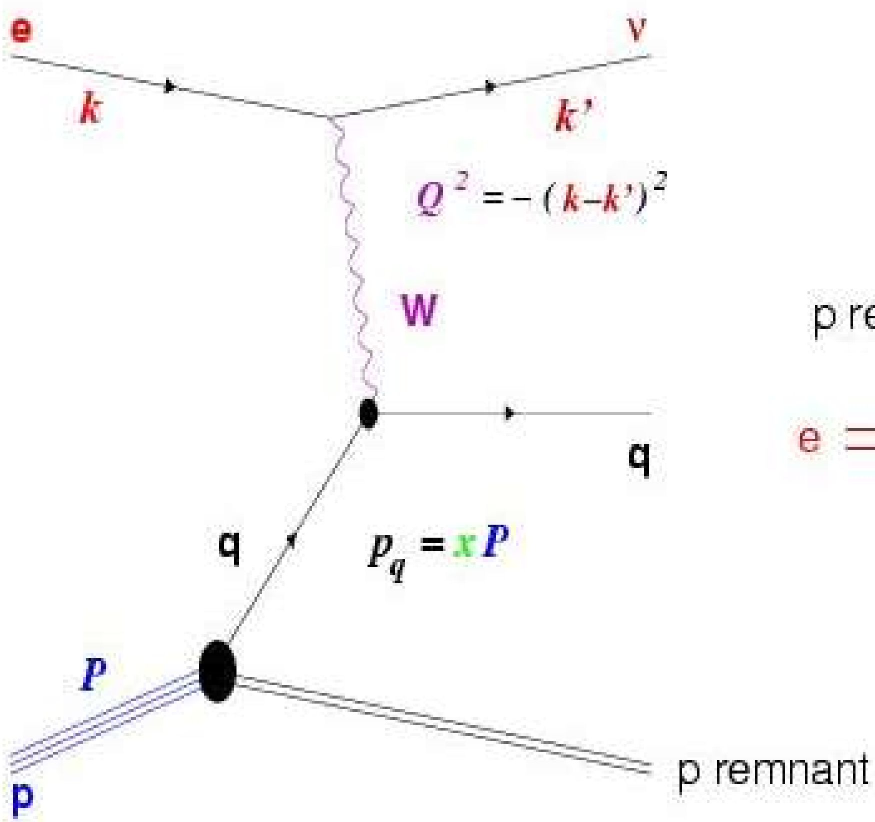
spatial resolution $\sim 1/Q$

$\Rightarrow 10^{-16}$ cm

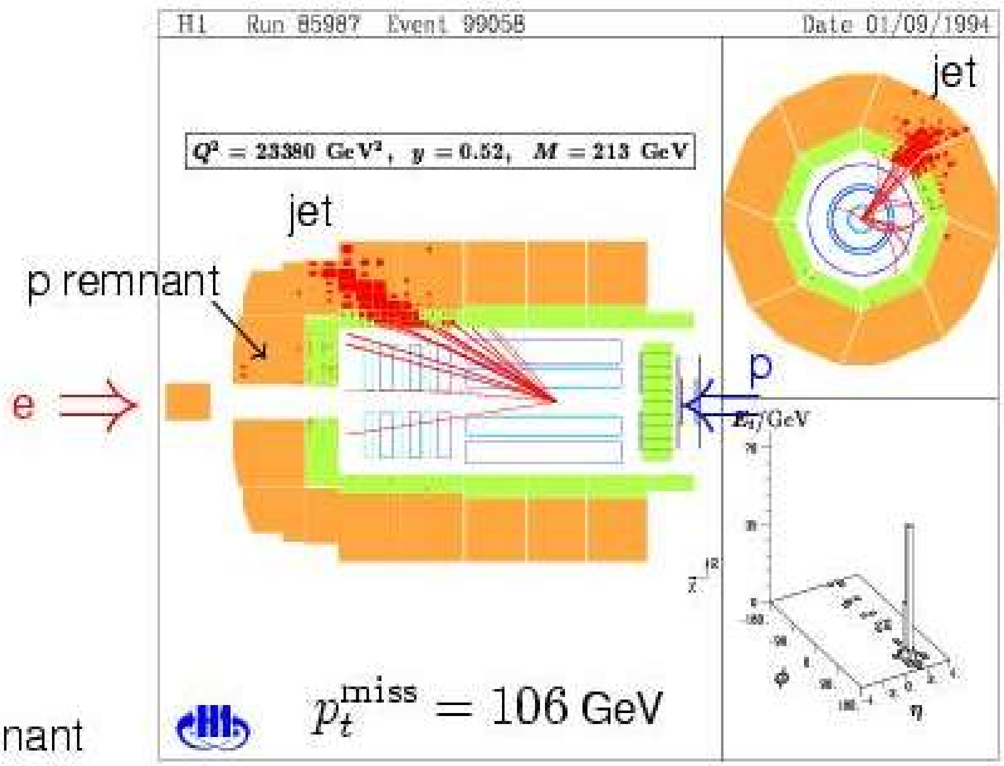
x: fractional momentum of the struck quark

DIS - Charged Current (CC)

deep inelastic (DIS) scattering:



H1 detector



Deep Inelastic Scattering at High Q^2

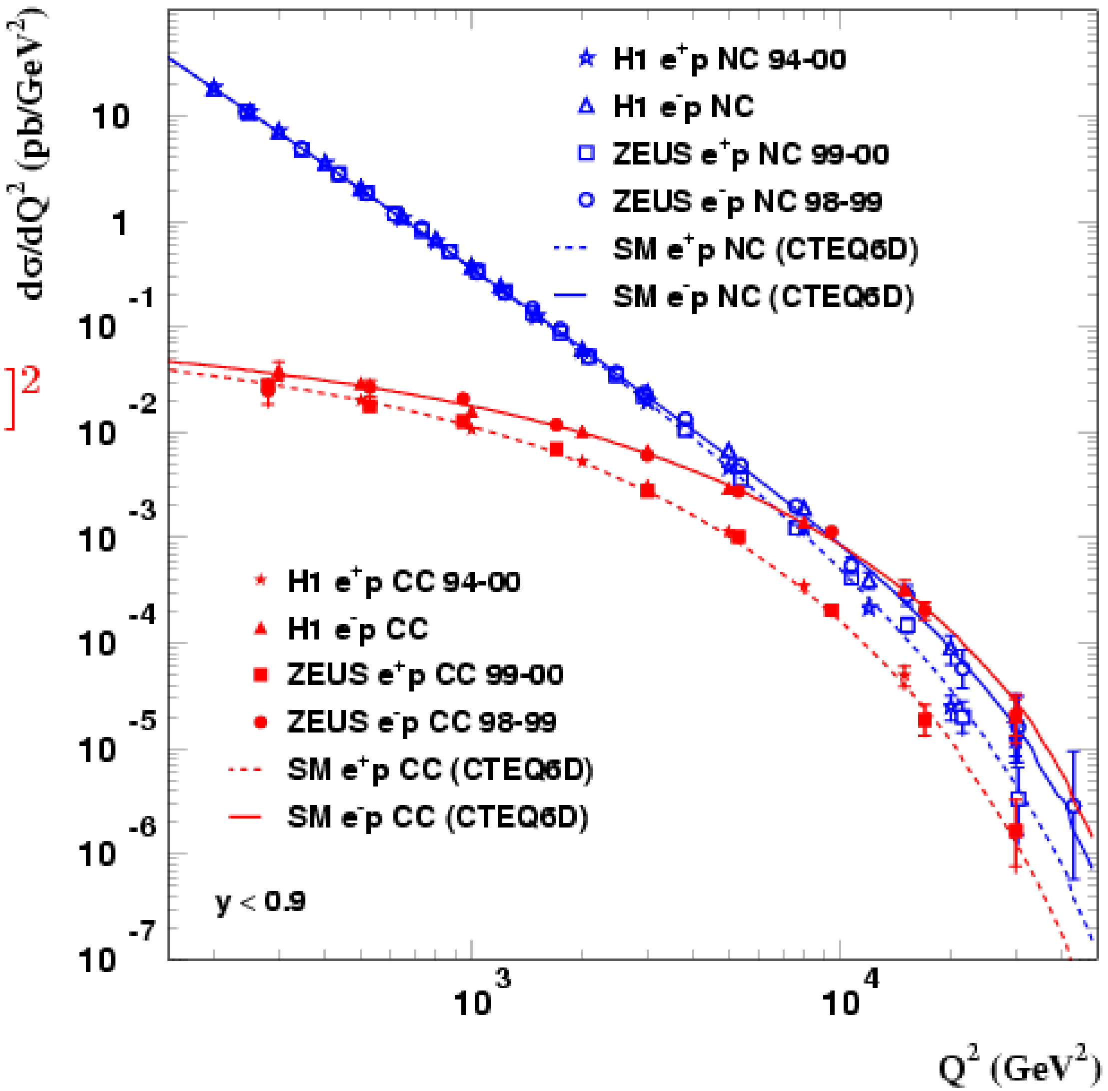
(unpolarized beams)

$\sim 1/Q^4$

photon

$\sim [\frac{M_W^2}{(Q^2+M_W^2)}]^2$

W boson



unification of electromagnetic and weak interations

Determination of W-Mass

$$\frac{d^2\sigma^{\pm}_{CC}}{dx\, dQ^2} = \frac{G^2}{2\pi} \cdot \left(\frac{M_W^2}{Q^2 + M_W^2} \right)^2 \cdot \Phi^{\pm}(pdfs)$$

Mw is propagator mass (enters in Q2 dependency)
Fermi constant G includes most of the radiative corrections

➡ model independent measurement

➡ t-channel exchange unique at HERA

$$\frac{d^2\sigma^{\pm}_{CC}}{dx\, dQ^2} = \frac{\pi\alpha^2}{4M_W^4 \left(1 - \frac{M_W^2}{M_Z^2}\right)^2} \cdot \frac{1}{|1-\Delta r|^2} \cdot \left(\frac{M_W^2}{Q^2 + M_W^2} \right)^2 \cdot \Phi^{\pm}(pdfs)$$

OMS scheme : Mw also enters in normalization
Radiative correction Δr computed in SM framework

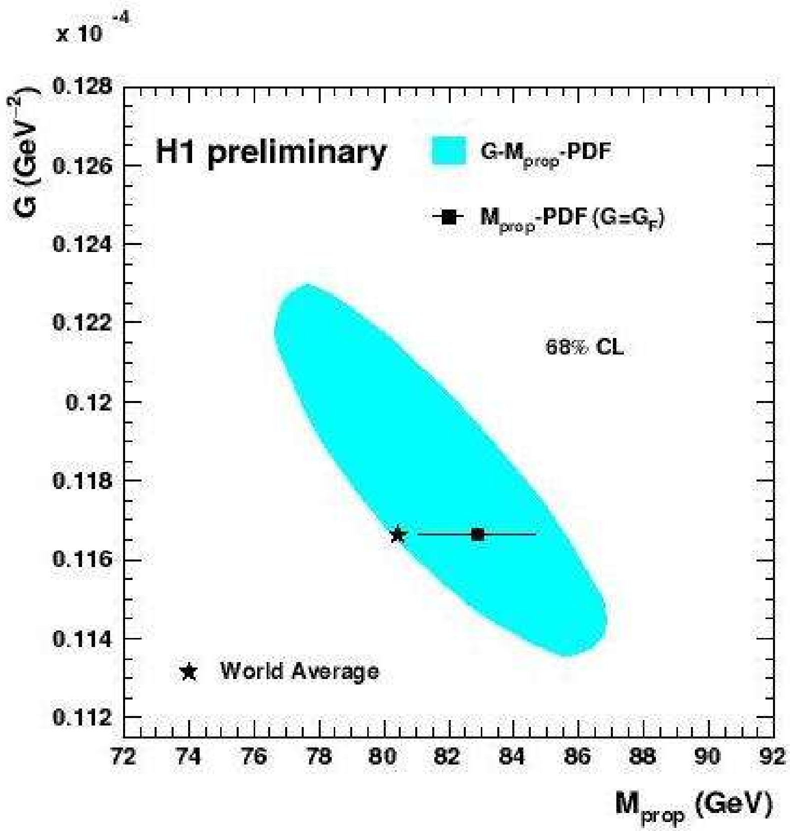
➡ Standard Model-dependent
(H. Spiesberger: EPRC)

On Mass Shell renormalisaton scheme

➡ combined EW-QCD fit to determine EW parameters accounting for their correlation with parton distributions

Results of Mass Fits:

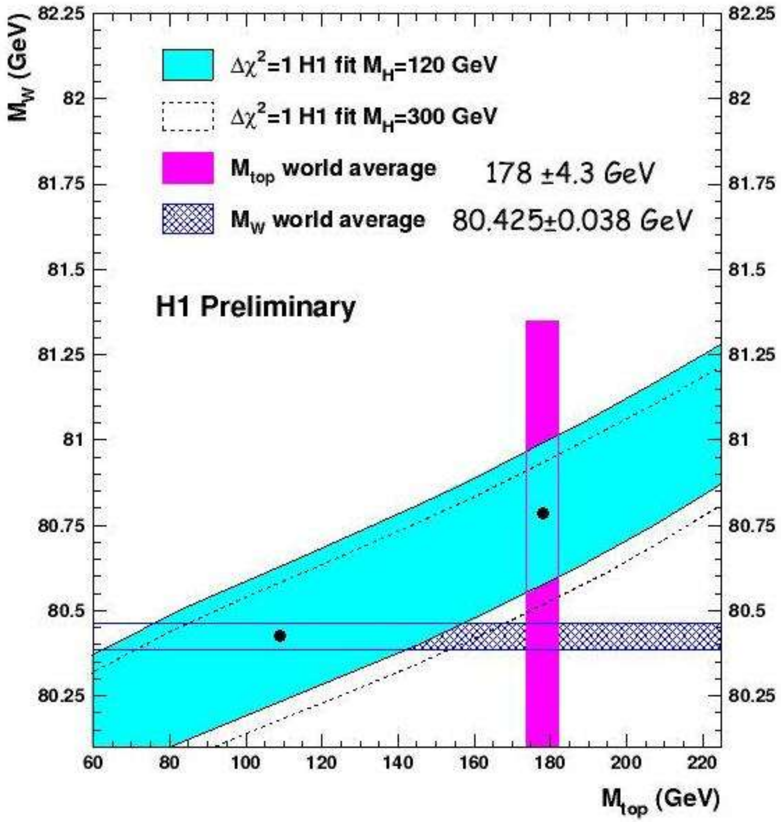
G-Propagator



$$M_W = 82.87 \pm 1.83\,(\text{exp})\ ^{+0.30}_{-0.16}\,(\text{mod})\ \text{GeV}$$

Model uncertainties (α_s, Q_0^2,...)

OMS Scheme



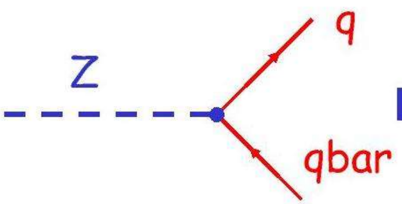
$$M_W = 80.786 \pm 0.207(\text{exp})\ ^{+0.048}_{-0.029}\,(\text{mod}) \pm 0.025\,(\text{top})$$
$$\pm 0.033\,(\text{th}) - 0.084\,(\text{Higgs})\ \text{GeV}$$

(120->300 GeV)

➡ $\sin^2\theta_W = 0.2151 \pm 0.0040\ (\text{exp})\ ^{+0.0019}_{-0.0011}\ (\text{th})$

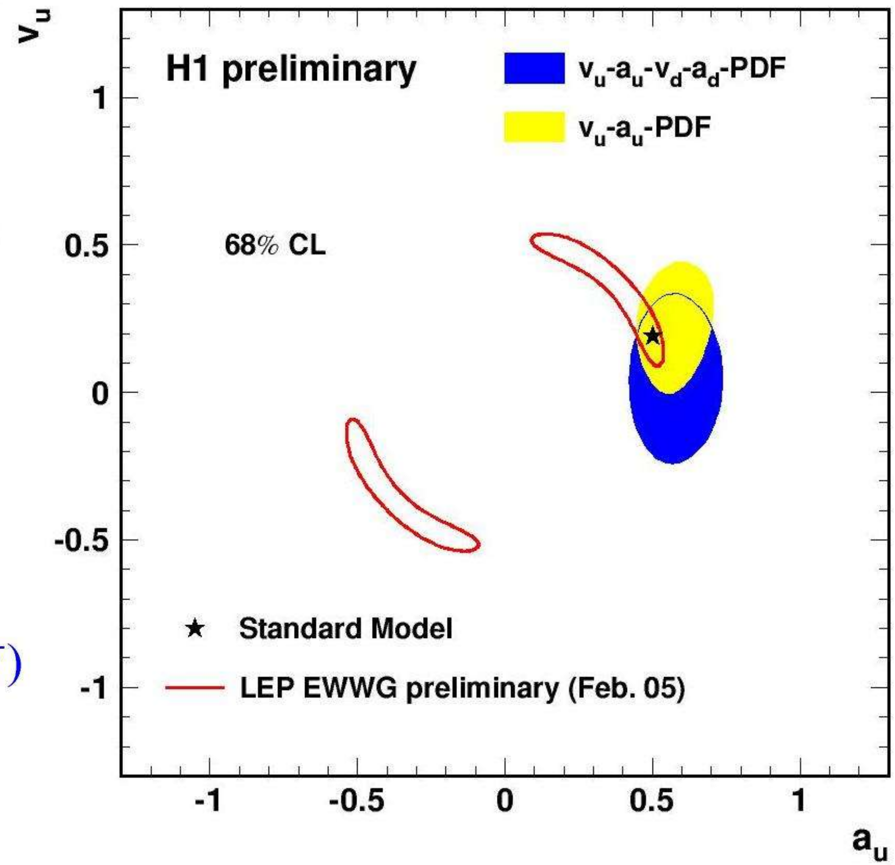
➡ **consistent with the Standard Model**

Quark Couplings to the Z Boson



$$\frac{ig}{\cos\theta_W}\gamma^\mu \frac{v_q - a_q\gamma^5}{2}$$

Fit: PDF+couplings



$a_q = I_3^L$ Axial coupling, I^3=+1/2 for u, -1/2 for d

$v_q = I_3^L - 2e_q \sin^2\theta_W$ Vector coupling

$$F_2 = \sum_q \left[e_q^2 - 2e_q v_q v_e \chi_Z + (v_q^2 + a_q^2)(v_e^2 + a_e^2)\chi_Z^2 \right] x(q+\bar{q})$$

$$xF_3 = \sum_q \left[-2e_q a_q a_e \chi_Z + 4v_q a_q v_e a_e \chi_Z^2 \right] x(q-\bar{q})$$

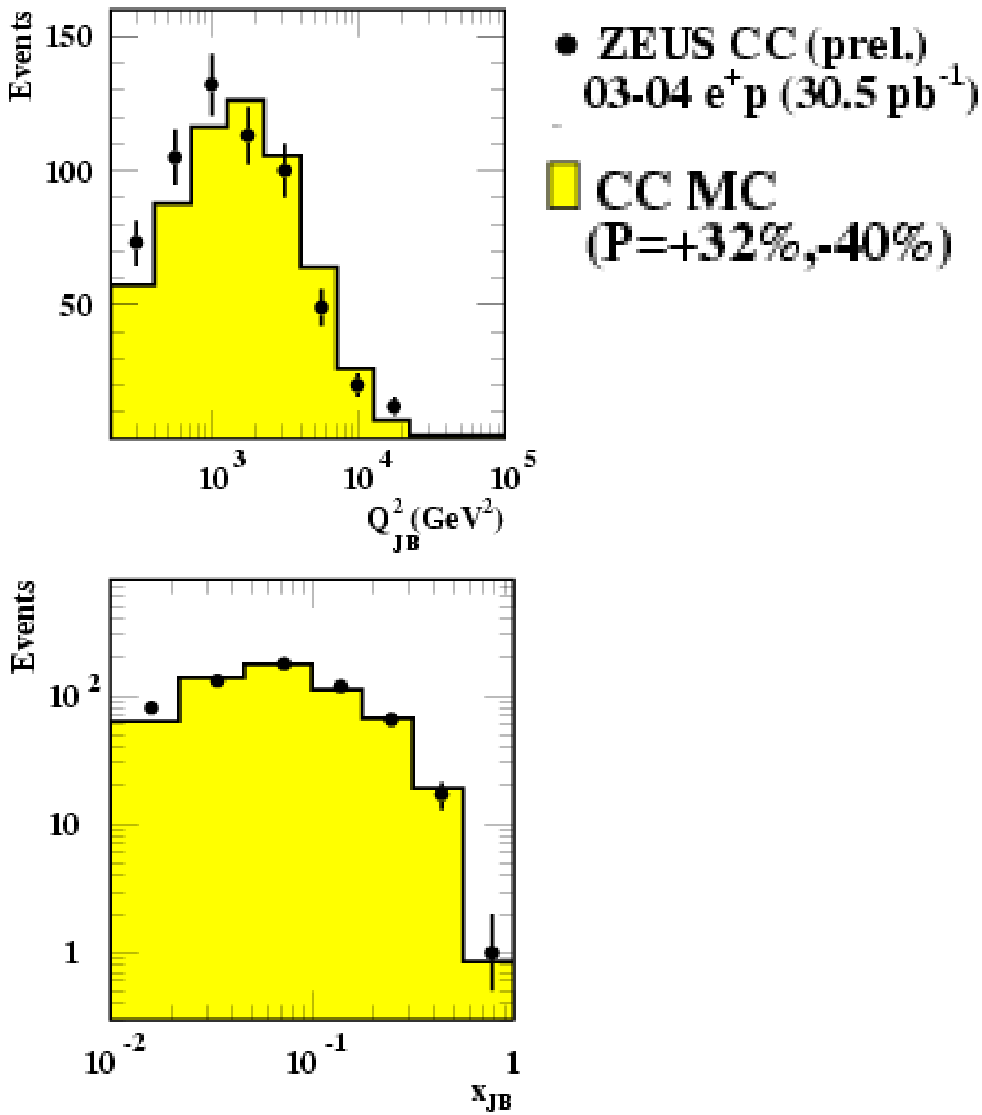
➡ already as sensitive as LEP

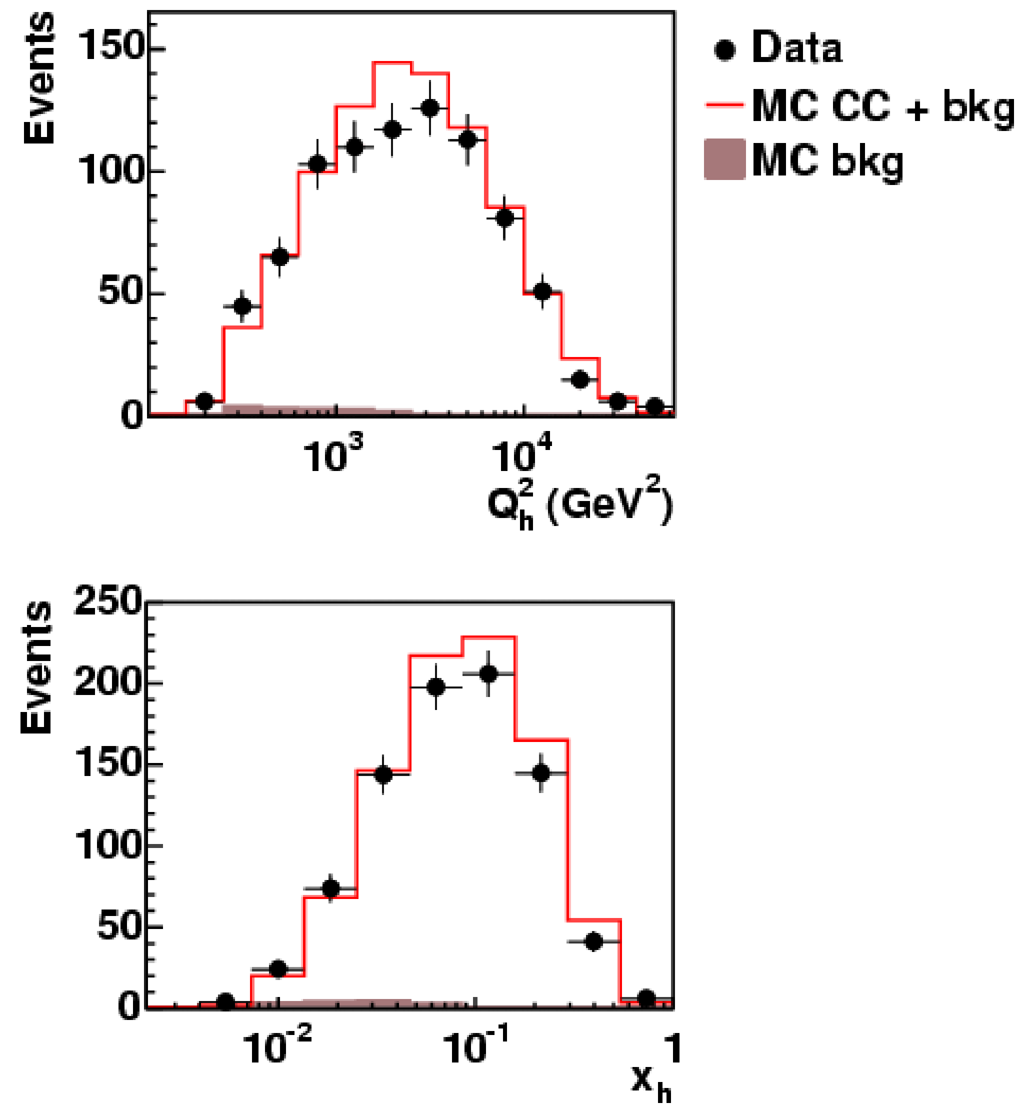
➡ removes LEP ambiguities

➡ polarisation: shrinks in v_u

CC with Polarized Leptons

ZEUS e^+p, 31 pb^{-1}, P_e= +32%, -40% **New: H1 e^-p, 18 pb^{-1}, P_e= -25%**





➡ **good understanding of detectors**

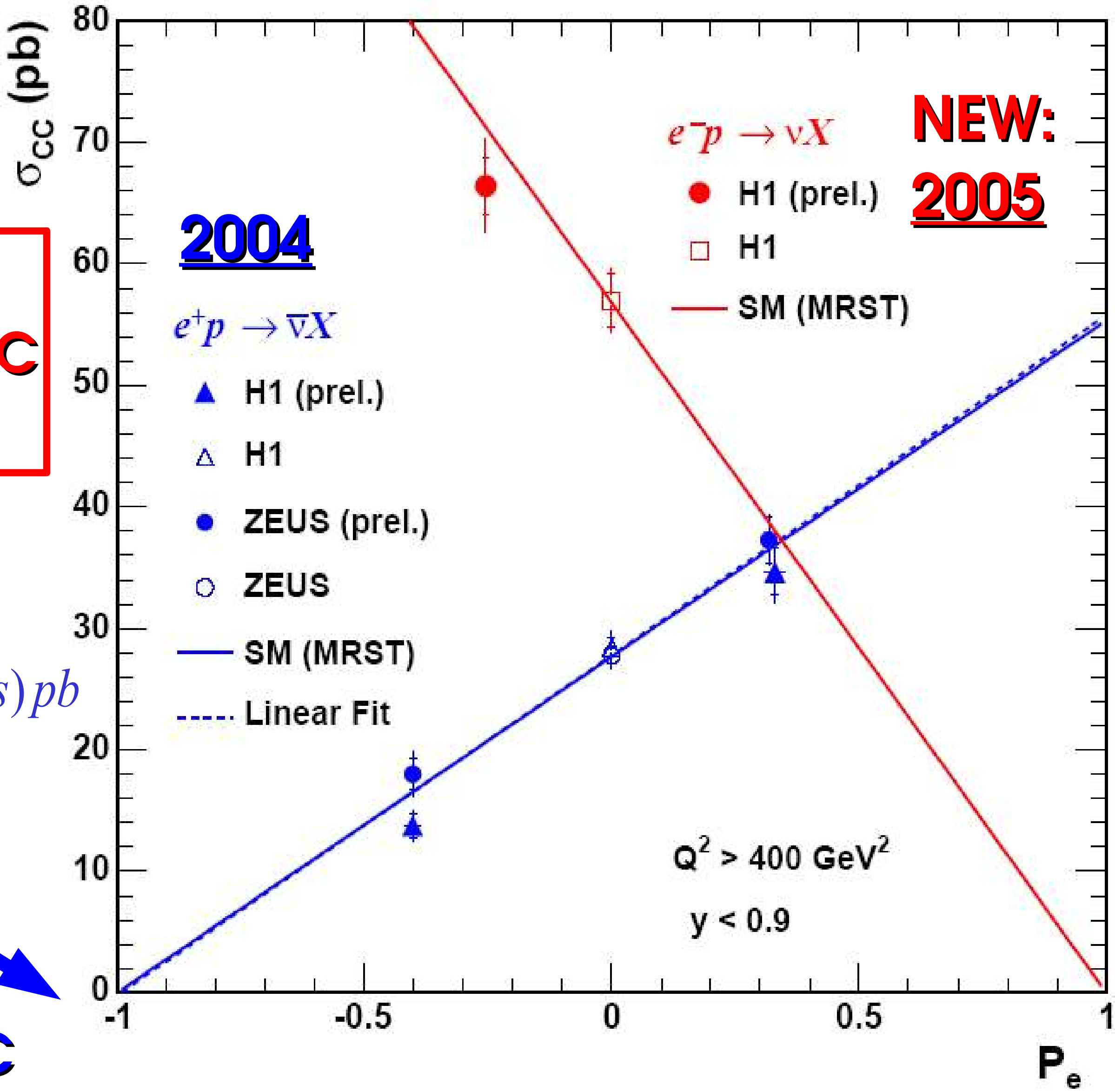
CC with Polarised Leptons

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

$P=(N_{RH}-N_{LH})/(N_{RH}+N_{LH})$

first measurements of the helicity dependence of the CC cross section

$$\sigma_{e^+ p \to \bar{\nu} X}(P_{e^+} = -1) = 0.2 \pm 1.8(sta) \pm 1.6(sys)\, pb$$

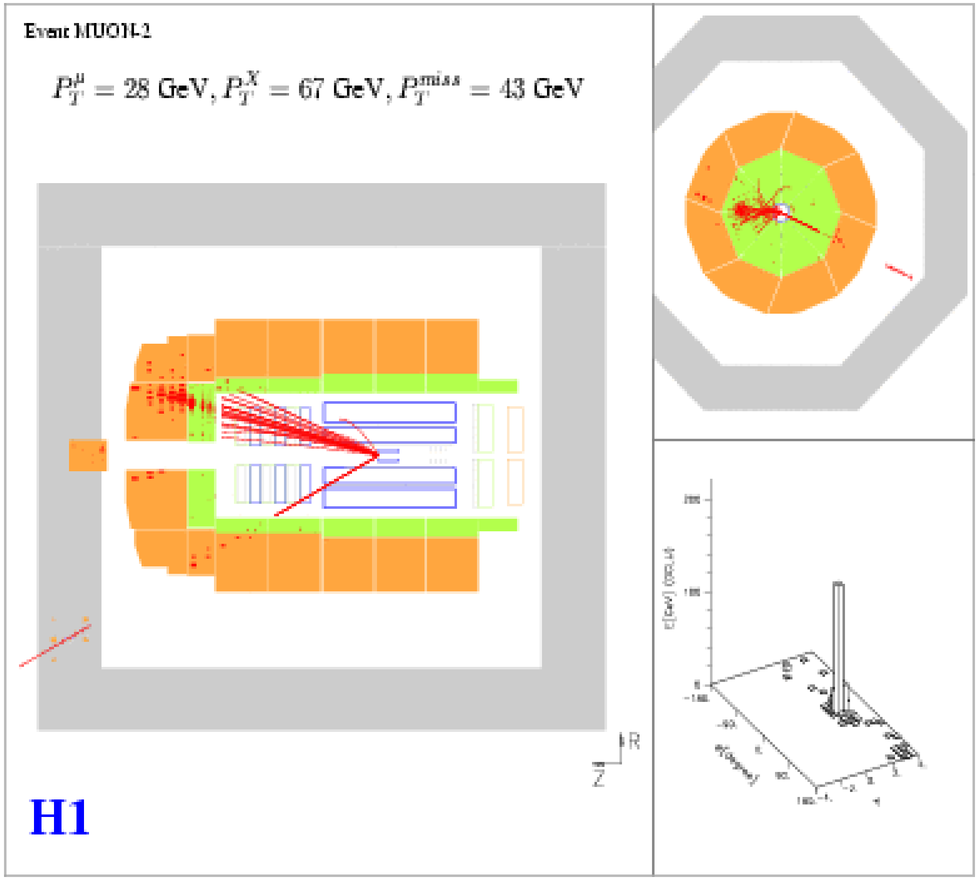


➡ **no hint for right-handed CC**

High p_t Lepton Events at HERA

Phys. Lett. B 561 (2003) 241

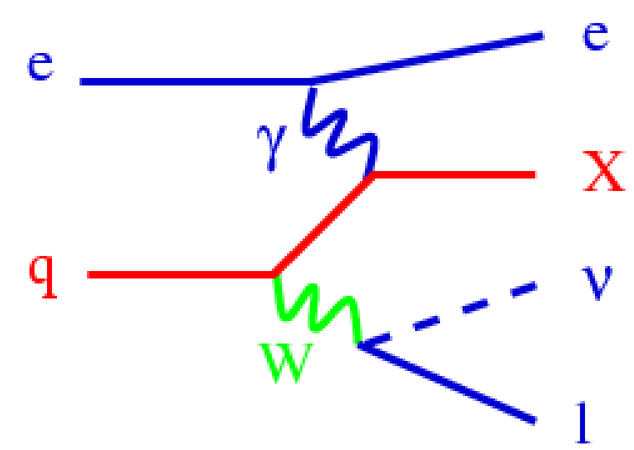
$$e^+p \to \mu^+X + PTmiss$$



- isolated lepton (e or μ)
- high hadronic p_T
- missing calorimeter p_T

Standard Model:

dominated by W production



in NLO-QCD: Diener, C.S., Spira

Eur. Phys. J C 25 (2002) 405

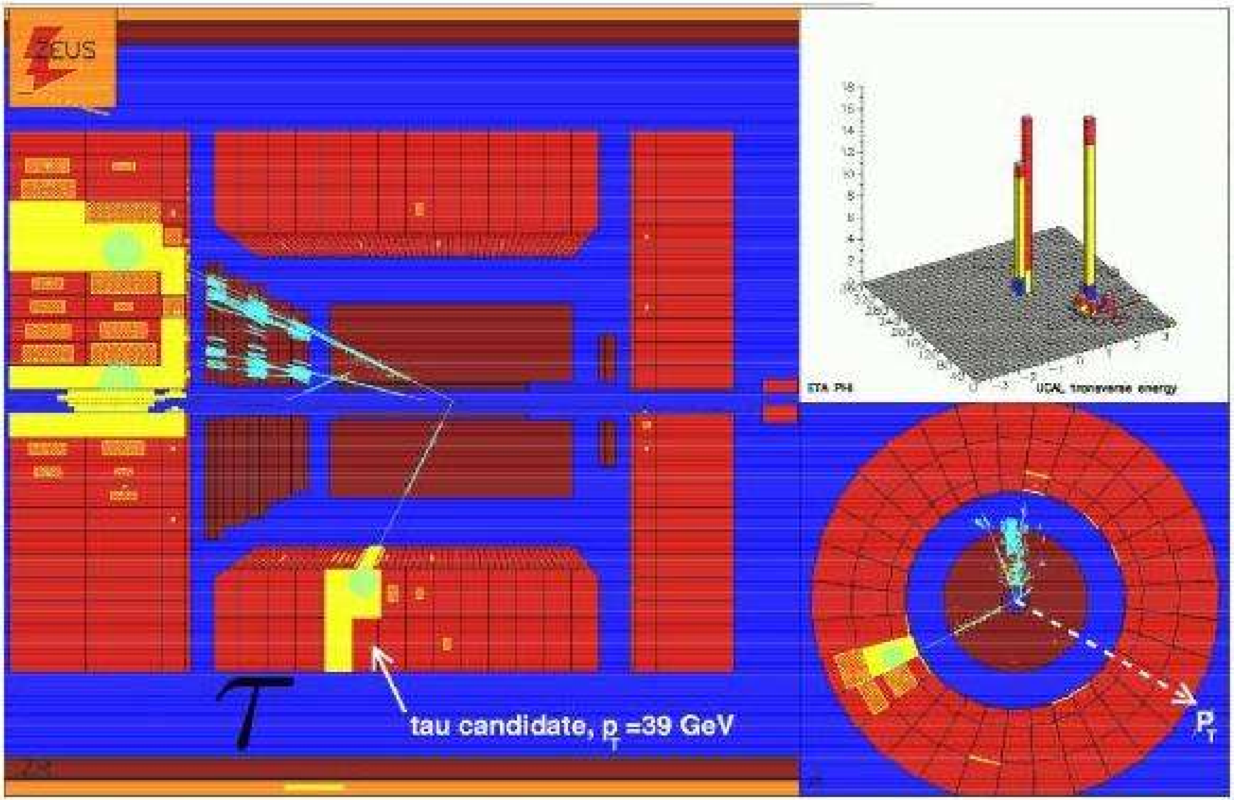
- **Possible other explanations:**

Anomalous top production, RPV SUSY: e.g. $ep \to \tilde{t} \to \tilde{b}W$ (talk by C.N. Nguyen)

High p_t Lepton Events at HERA

Phys. Lett. B 583 (2004) 41

Example of Tau Candidate



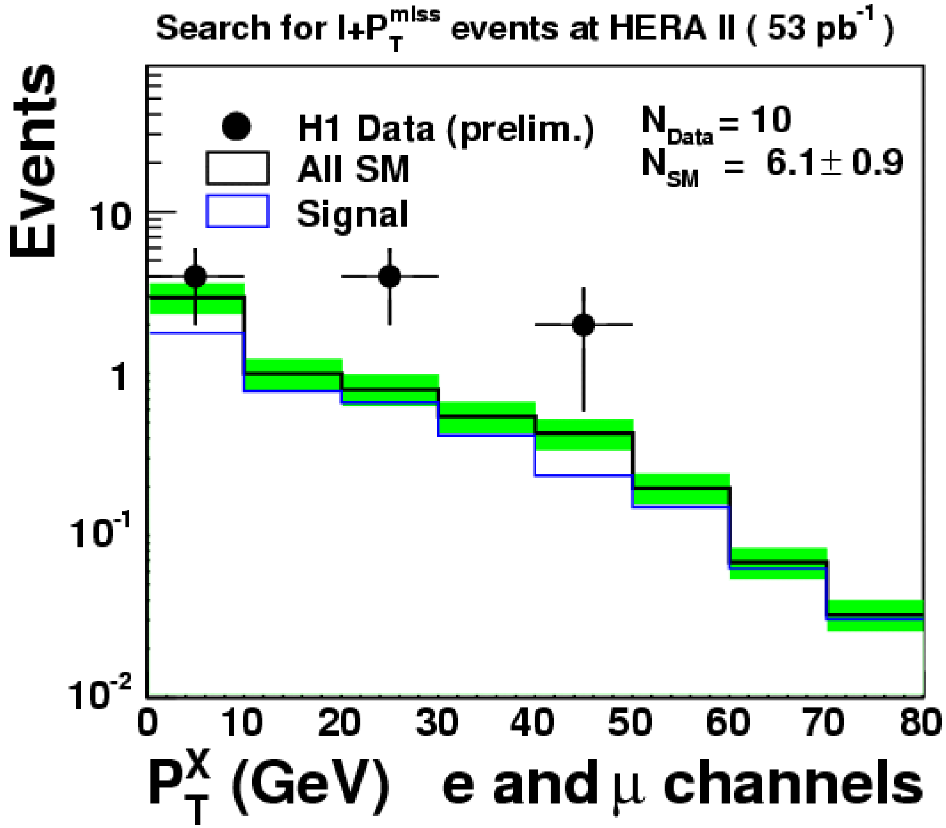
$P_T^{CAL} = 39\ GeV$ $\quad P_T^X = 37\ GeV$ $\quad M_T = 68\ GeV$

τ jet: collimated "pencil like"

Isolated Leptons at HERA II

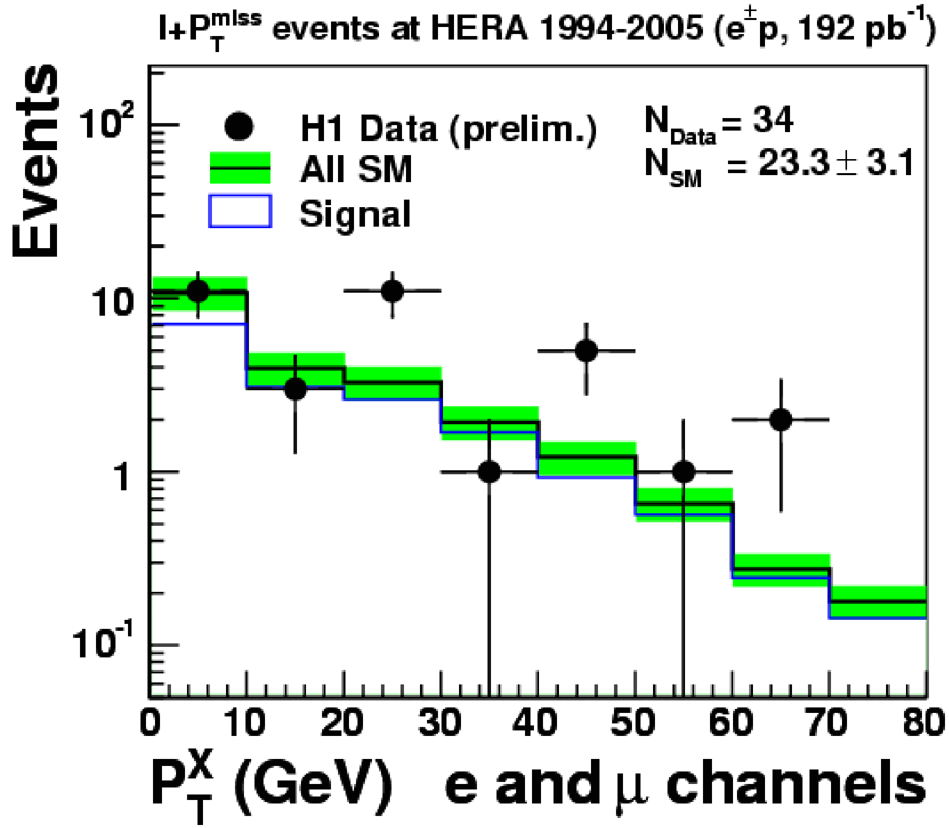
H1 Collaboration (updated since ICHEP)

HERA II: complete positron sample



➡ slight excess at high p_T^X

HERA I+II combined electron+positron



➡ clear excess at high p_T^X

Updated Isolated Lepton Results at HERA II

H1 1994-2005 $\mathcal{L}(e^{\pm}p) = 192$ pb^{-1}	Electron obs./exp.	Muon obs./exp.	Tau$^{prel.}$ obs./exp.	W contrib. $e\mu$ (τ)
Full sample	25/18.4 ± 2.5	9/4.9 ± 0.8	5 / 5.81 ±1.36	≈ 75(15)%
$P_T^X > 25$ GeV	11/2.9 ± 0.6	6/2.9 ± 0.6	0 / 0.53 ±0.10	≈ 85(50)%

ZEUS 1994-2000 $\mathcal{L}(e^{\pm}p) = 130$ pb^{-1}	Electron obs./exp.	Muon obs./exp.	Tau obs./exp.	W contrib. $e\mu$ (τ)
Full sample	24 / 20.6 ±3.2	12 / 11.9 ±0.6	3 / 0.4 ±0.12	≈ 17(48)%
$P_T^X > 25$ GeV	2 / 2.9 ±0.46	5 / 2.75 ±0.21	2 / 0.2 ±0.05	≈ 50(50)%

➡ **combined electron+muon (H1):**

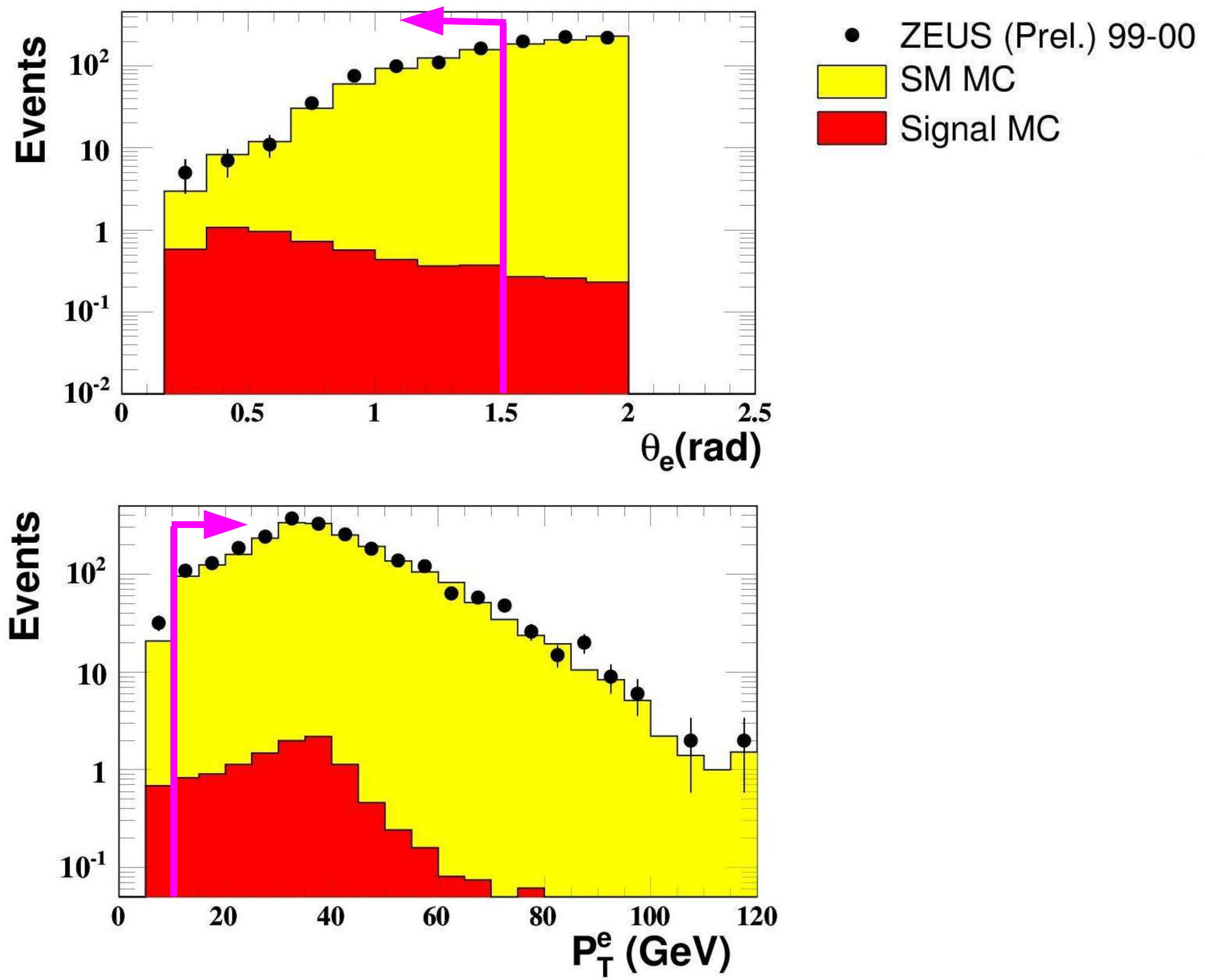
full sample : 34/23.3 ± 3.2 (73%)

P_T^X>25 GeV : 17/5.8 ± 1.1 (84%)

= HERA I+II

W production: $W \rightarrow e\,\nu$

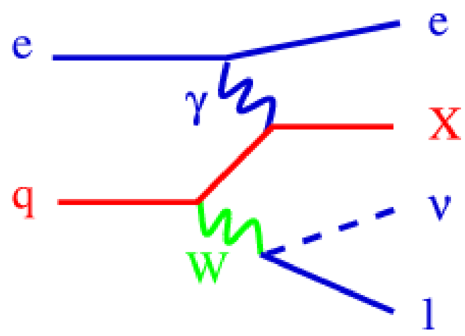
New ZEUS analysis (66 pb^{-1}, e^+p, HERA I)

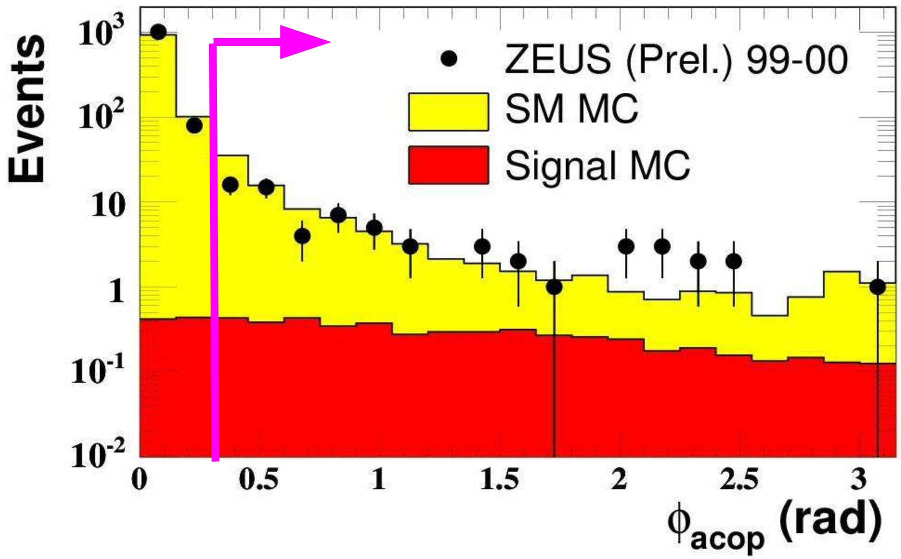


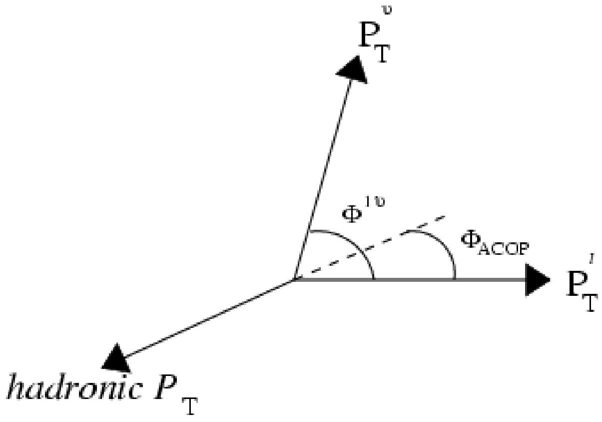
➡ **good understanding of detector**

W production: W → e ν

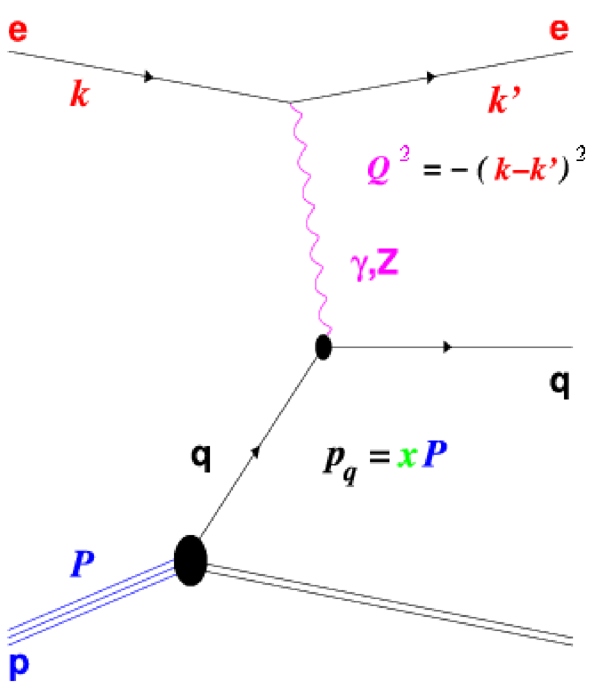
W production

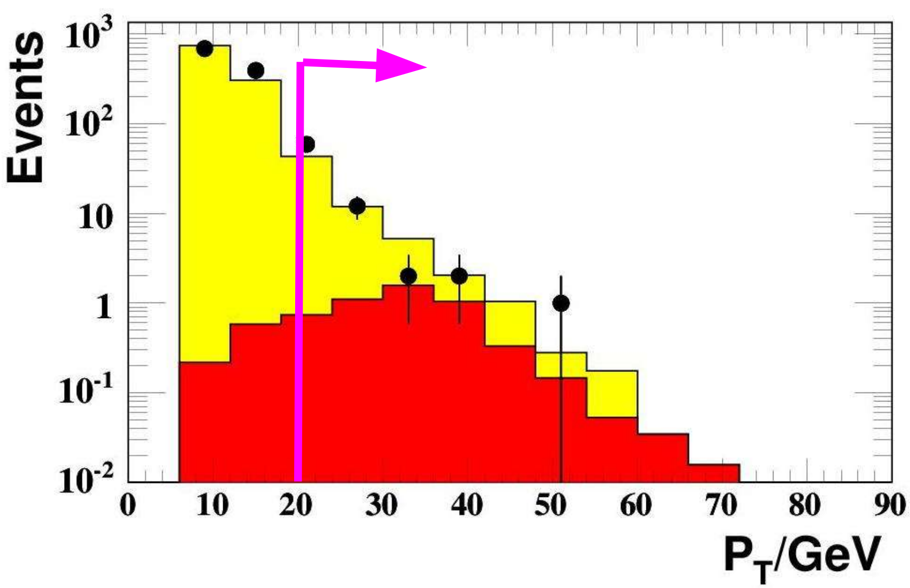






NC DIS





5 events found → σ < 2.8 pb at 95% CL

Summary

- HERA performs a wide range of analyses of electroweak physics
- very good understandig of NC and CC cross section over more than 7 orders of magnitude!
- measurement of W mass for t-channel W-exchange (unique at HERA)
- remove LEP ambiguities for Zqq couplings
- lepton polarisation: parity violation of CC interaction in agreement with SM
- limit on W production cross section
- Still very interesting excesses in $ej\nu + \mu j\nu$ by H1, in $\tau j\nu$ by ZEUS and also in recent data $ej\nu$ by H1

➡ more luminosity needed to solve "Isolated Lepton Puzzle"

Outlook

- HERA provides now e^-p collisions (only $\cong$20 pb^{-1} from 1998/99)

➡ interesting potential for more "Electroweak Physics from HERA"

Backup

Isolated Lepton Results at HERA I

H1 1994-2000 $\mathcal{L}(e^{\pm}p) = 118\,\text{pb}^{-1}$	Electron obs./exp.	Muon obs./exp.	Tau$^{\text{prel.}}$ obs./exp.	W contrib. $e\mu\,(\tau)$
Full sample	11 / 11.5 ±1.5	8 / 2.94 ±0.50	5 / 5.81 ±1.36	≈ 75(15)%
$P_T^X > 25$ GeV	5 / 1.76 ±0.30	6 / 1.68 ±0.30	0 / 0.53 ±0.10	≈ 85(50)%
$P_T^X > 40$ GeV	3 / 0.66 ±0.13	3 / 0.64 ±0.14	0 / 0.22 ±0.05	≈ 90(55)%

ZEUS 1994-2000 $\mathcal{L}(e^{\pm}p) = 130\,\text{pb}^{-1}$	Electron obs./exp.	Muon obs./exp.	Tau obs./exp.	W contrib. $e\mu\,(\tau)$
Full sample	24 / 20.6 ±3.2	12 / 11.9 ±0.6	3 / 0.4 ±0.12	≈ 17(48)%
$P_T^X > 25$ GeV	2 / 2.9 ±0.46	5 / 2.75 ±0.21	2 / 0.2 ±0.05	≈ 50(50)%
$P_T^X > 40$ GeV	0 / 0.94 ±0.11	0 / 0.95 ±0.12	1 / 0.07 ±0.02	≈ 60(70)%

W contribution is NLO: Diener, Schwanenberger, Spira
Eur. Phys. J C 25 (2002) 405

➡ **observed excesses in H1 + Zeus do not match channels**