EW at HERA

and "RELATED" NEW PHYSICS

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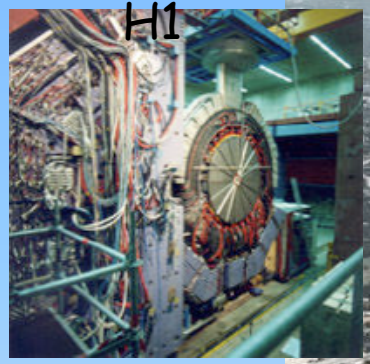
on behalf of ZEUS and H1 collaborations

- HERA: a QCD and EW machine

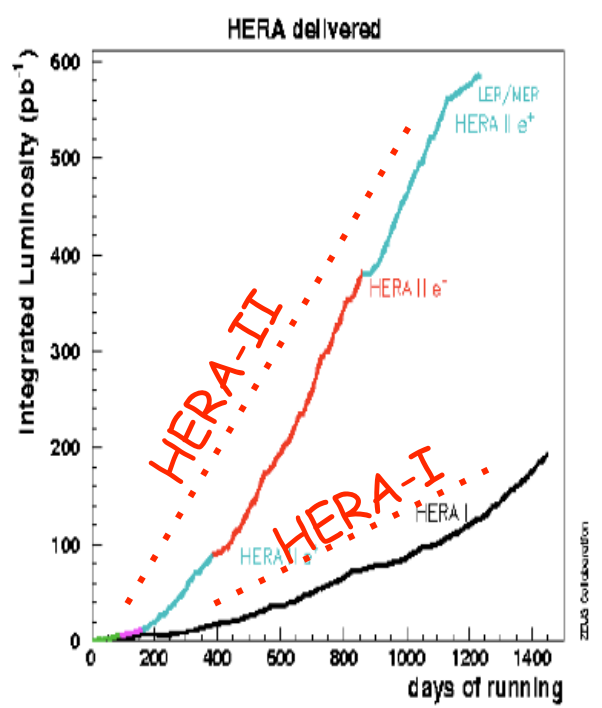
Results on:

- EW constraints
- Isolated Leptons
- Single TOP

HERA: a collider e-p



ZEUS

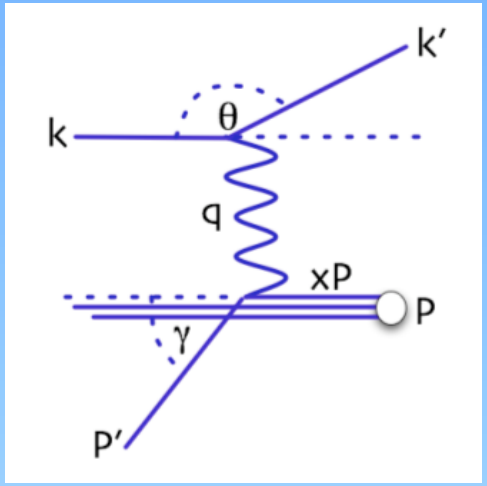


0.5 fb^{-1} per exp.: e^+p, e^-p, LowEnergyRange, MER

HERA-II feature: longitudinal polarization P_e

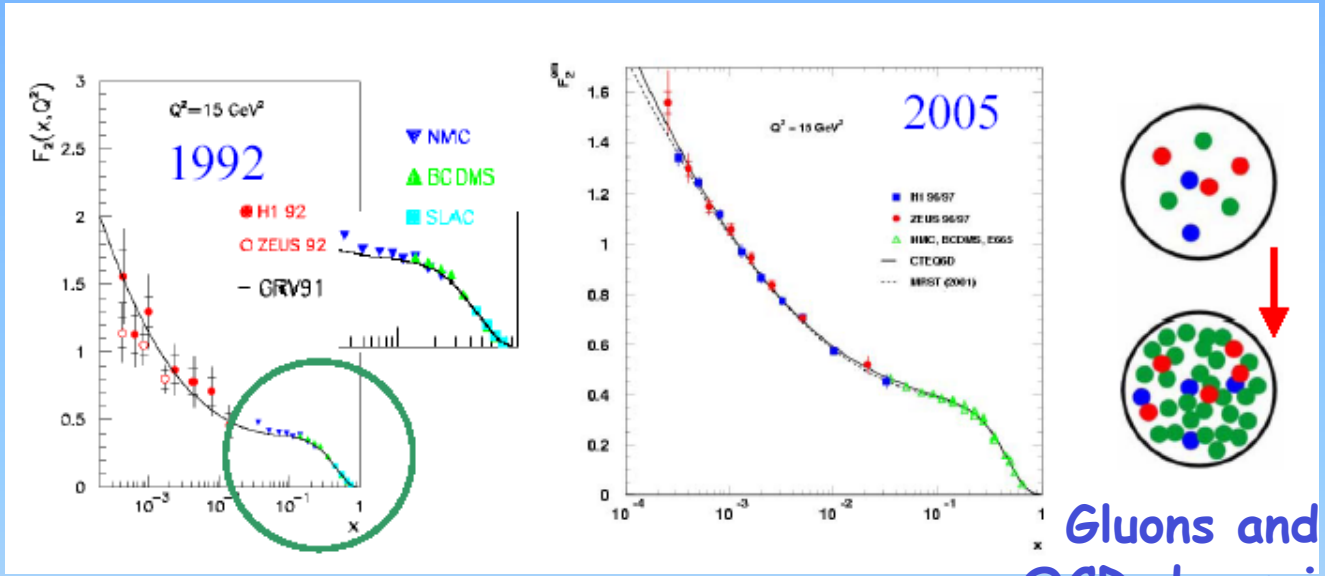
routinely achieved $P_e \approx 30\% - 40\%$

HERA: the QCD machine



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

$$x = \frac{Q^2}{2p \cdot q}$$



Gluons and QCD dynamics

$Q^2 \sim 1/\lambda$: the scale of the interaction corresponds to the spatial resolution at which the proton structure is probed

For $Q^2 \approx M^2_Z, M^2_W$ study also EW interactions:

$$\frac{d^2\sigma^{\pm}}{dx\, dQ^2} = (1 \pm P_e)\, \frac{G_F^2}{4\pi x} \left[\frac{M_W^2}{M_W^2 + Q^2} \right]^2 \left(Y_+ F_2 \mp Y_- x F_3 - y^2 F_L \right)$$

CC double diff. cross-section

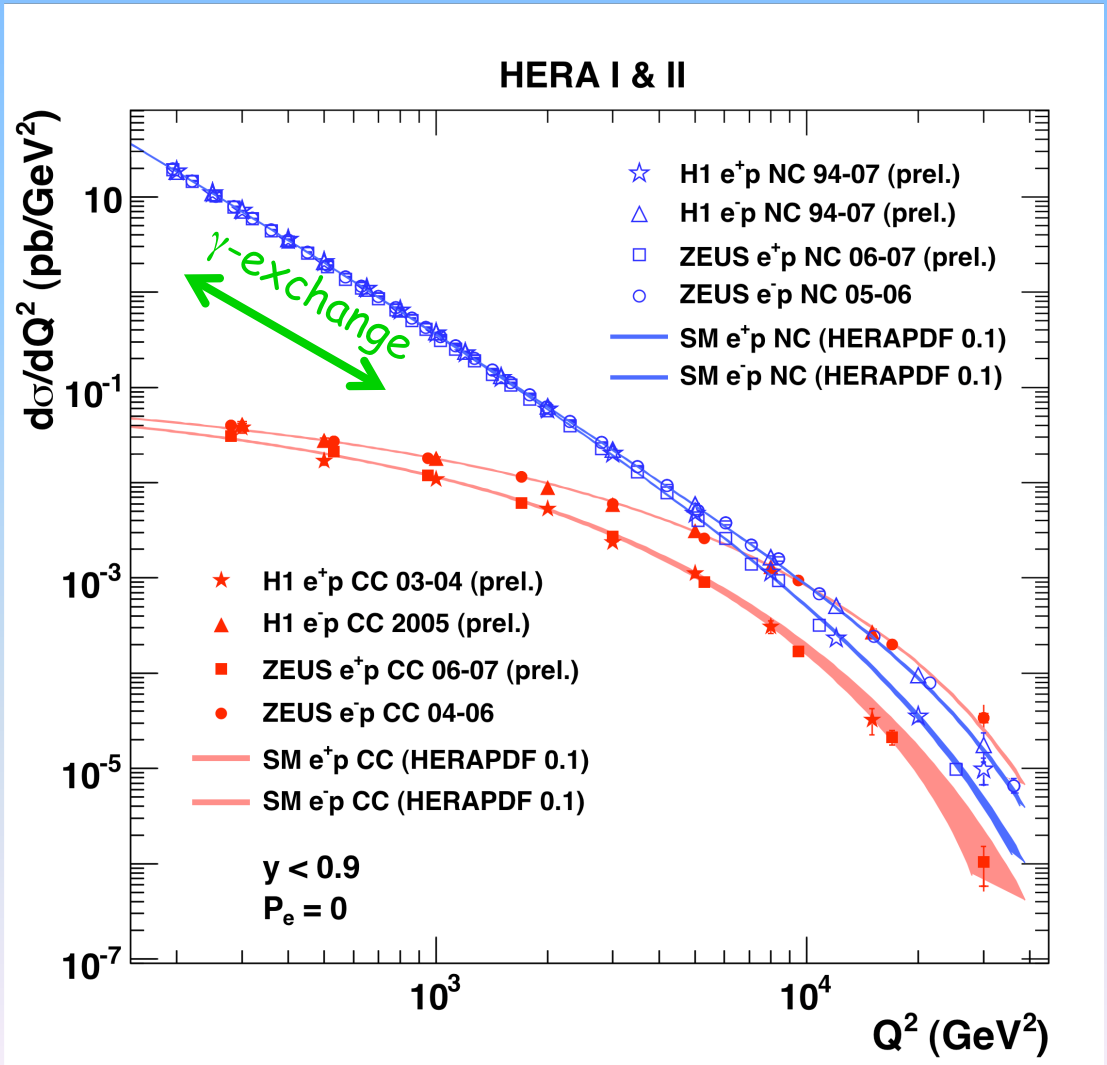
Beam Polarization

QPM Structure Functions

ElectroWeak unification: status-of-the-art

Neutral Current e-p (ZEUS publ., H1 prel.)
e+p (ZEUS prel., H1 prel.)

Charged Current e-p (ZEUS publ., H1 prel.)
e+p (ZEUS prel., H1 prel.)



$$\text{NC}: \quad \frac{d\sigma}{dQ^2} \sim \frac{1}{Q^4}$$

$$\text{CC}: \quad \frac{d\sigma}{dQ^2} \sim \frac{1}{(Q^2 + M_W^2)^2}$$

Z and **W** dominate exhanges

(corrected for the Polarization effects)

NC and Structure Functions: Parity Violation test

NC cross section written with structure function

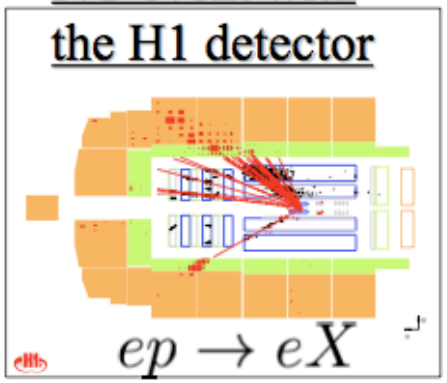
Parity violating structure function

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

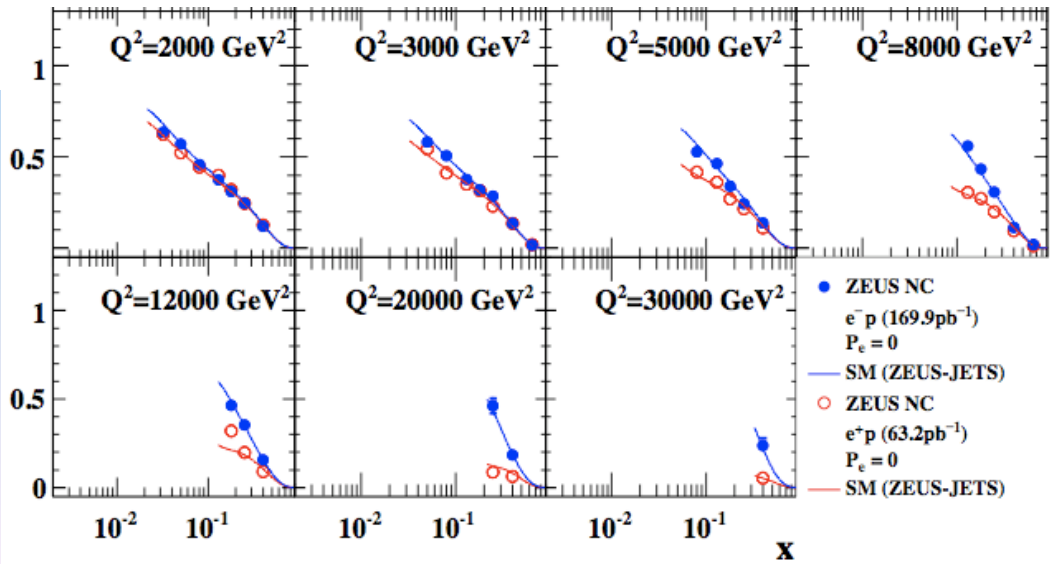
$$, Y_{\pm} = 1 \pm (1-y)^2$$

$$\tilde{\sigma}(e^{\pm}p) = \frac{xQ^4}{2\pi\alpha^2}\frac{1}{Y_+}\frac{d^2\sigma(e^{\pm}p)}{dxdQ^2}$$

NC event with the H1 detector



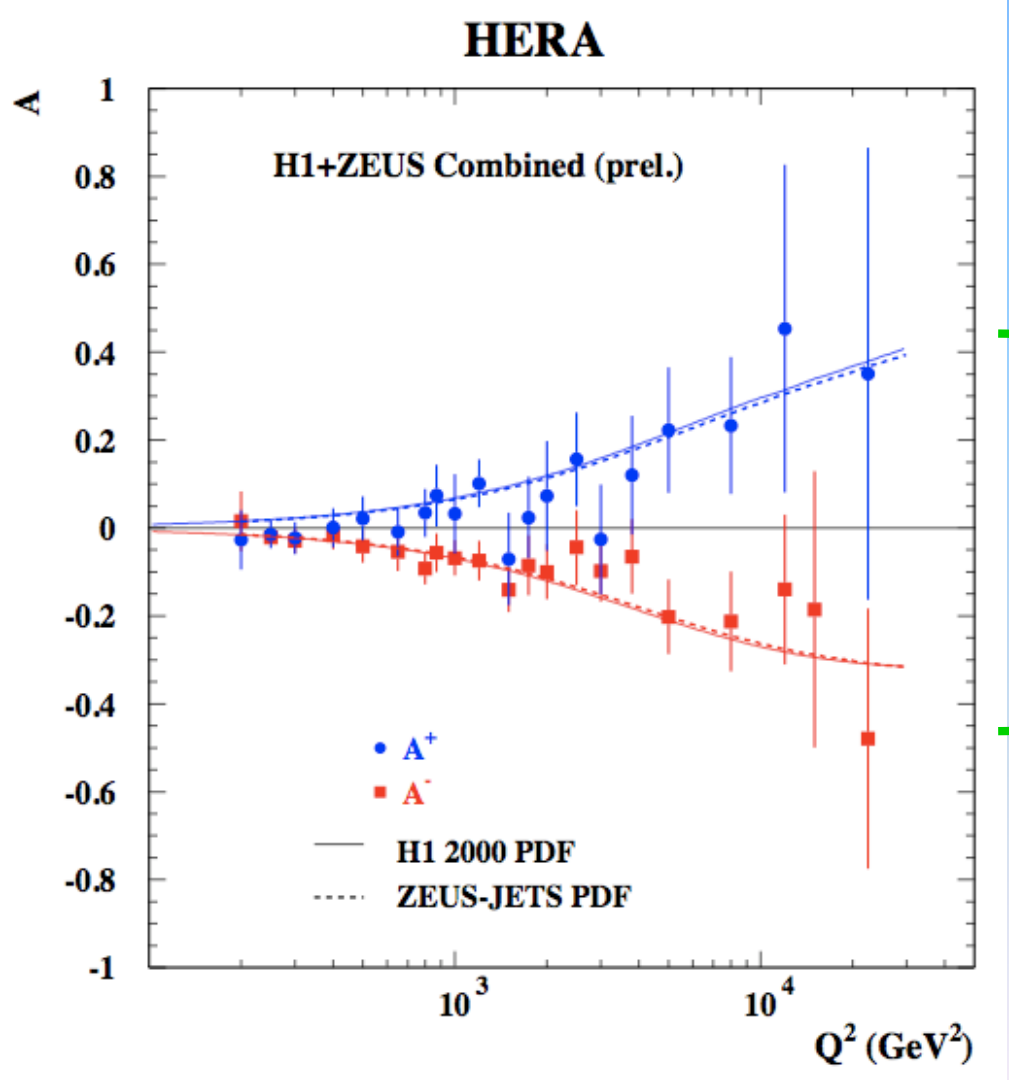
ZEUS *(e- HERA-II plus e+ HERA-I)*

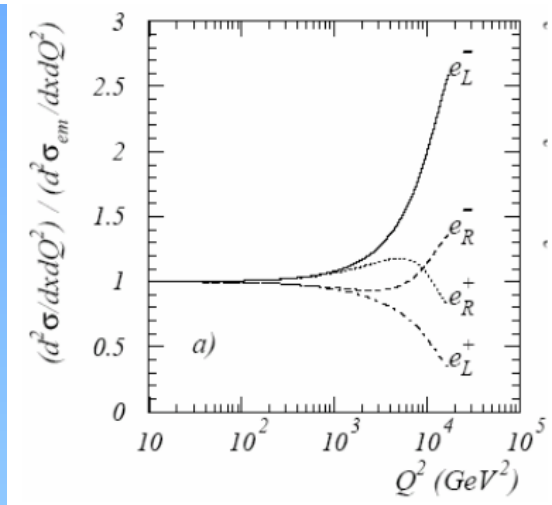


xF_3 term changes its sign pending incident e+ or e- beam

The e-p cross-section is larger than e+p, remarkably in high Q^2 region

Weak Interaction check with Polarization (NC)





$$F_2 \sim \sum_i x(q_i + \bar{q}_i) \times (e_i^2 + 2P_e \chi_Z a_e e_i \mathbf{v_i})$$

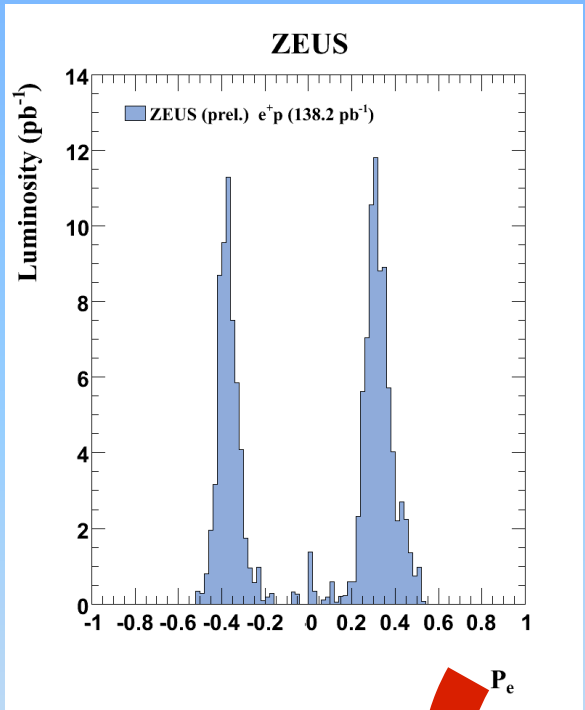
$$A^{\pm} = \frac{2}{P_R - P_L} \cdot \frac{\sigma^{e^{\pm}p}(P_R) - \sigma^{e^{\pm}p}(P_L)}{\sigma^{e^{\pm}p}(P_R) + \sigma^{e^{\pm}p}(P_L)}$$

Asymmetry proportional to vector coupling

Parity Violation size,

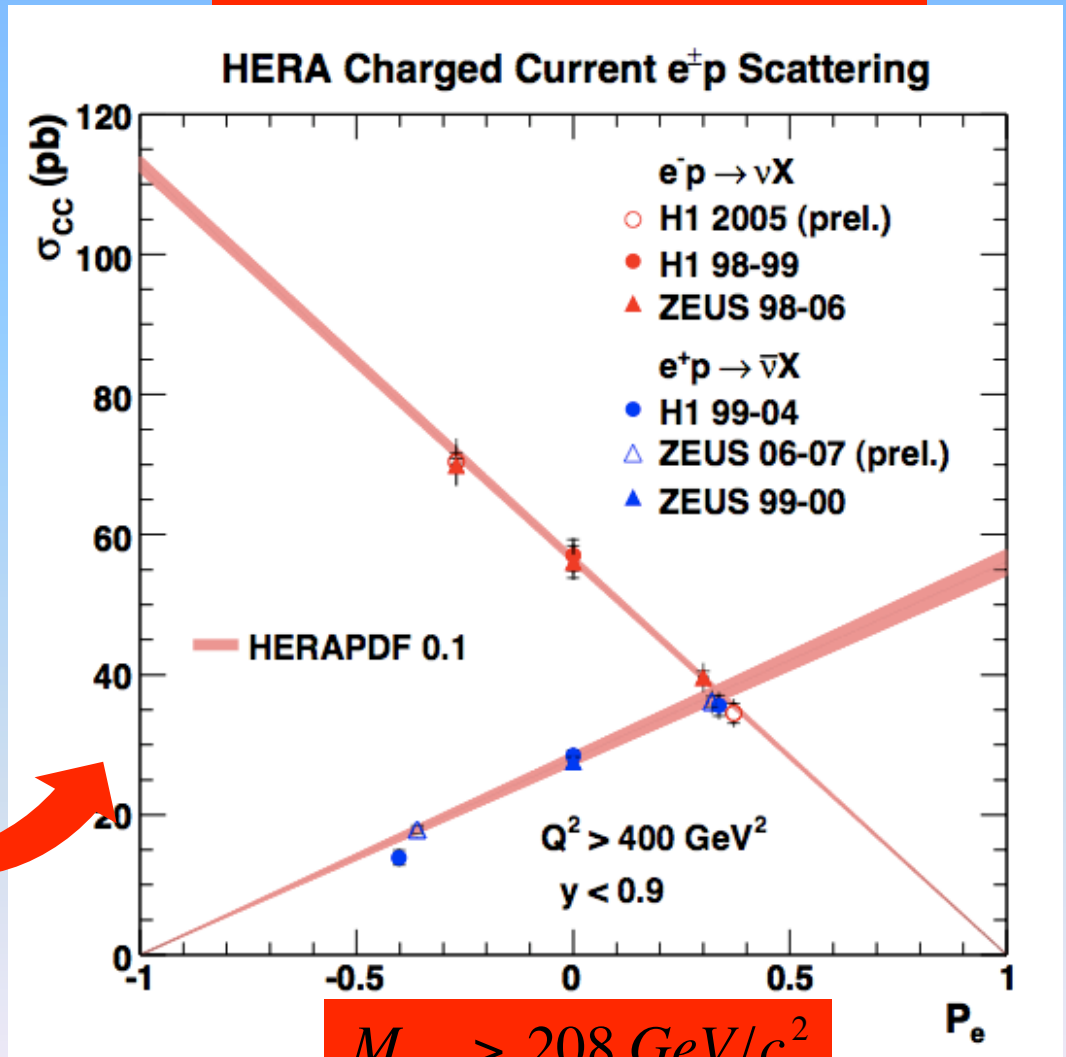
demonstrated down to 10^{-18} m

Weak Interaction check with Polarization (CC)



(ZEUS preliminary 2007)

V-A chiral structure

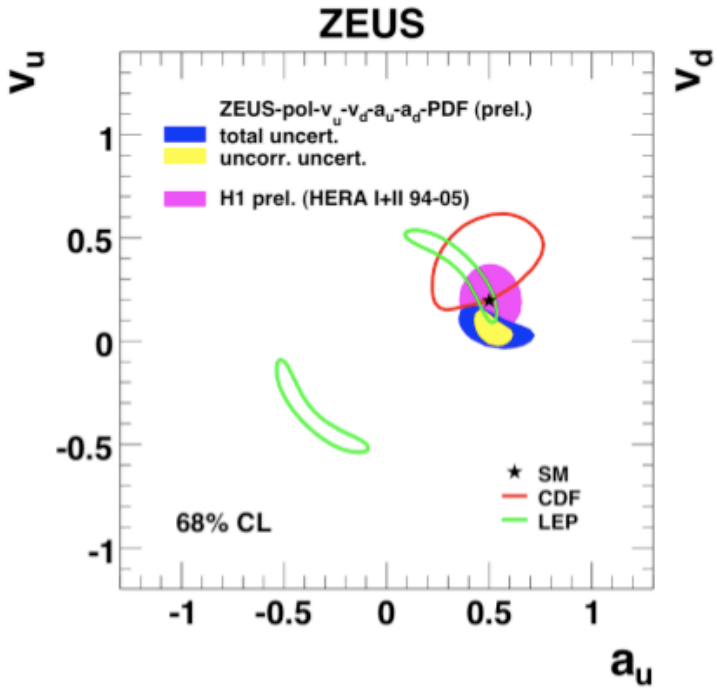


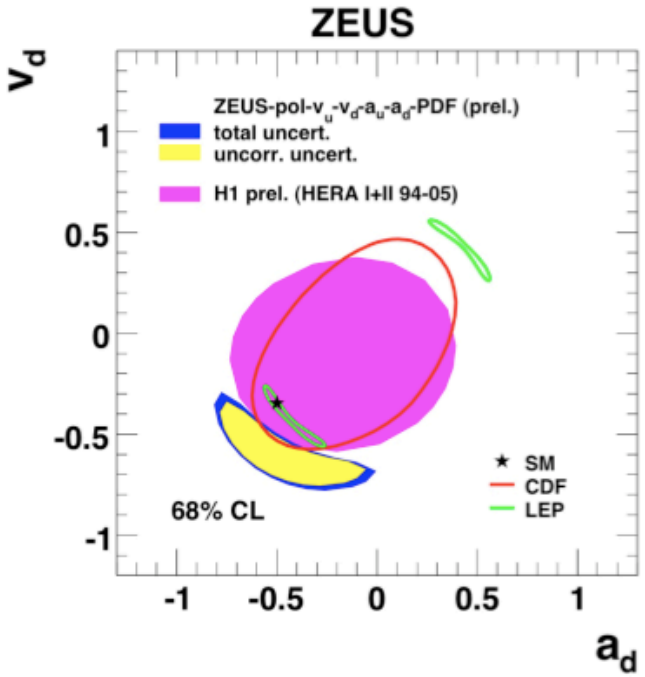
$$\sigma^{CC}_{e^\pm p}(P_e) = (1 \pm P_e)\underbrace{\sigma^{CC}_{e^\pm p}(P_e = 0)}$$

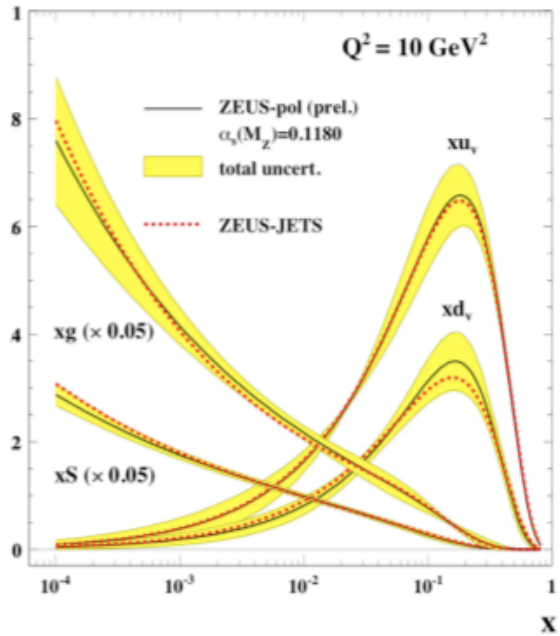
$$M_{W_R} > 208\ GeV/c^2$$

(H1 collaboration, Phys.Lett B634 173,2006)

DGLAP fits for QCD-EW: PDFs' and **uv-quarks** couplings

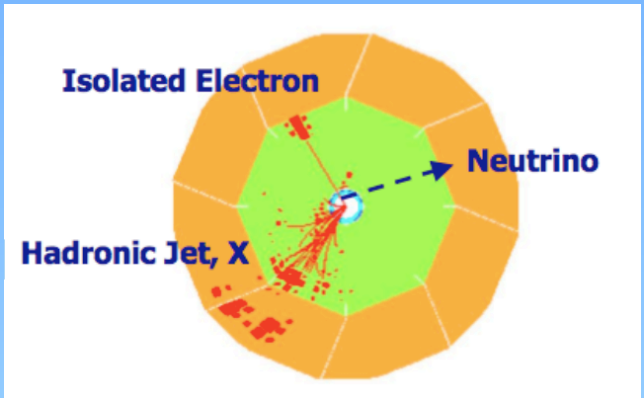




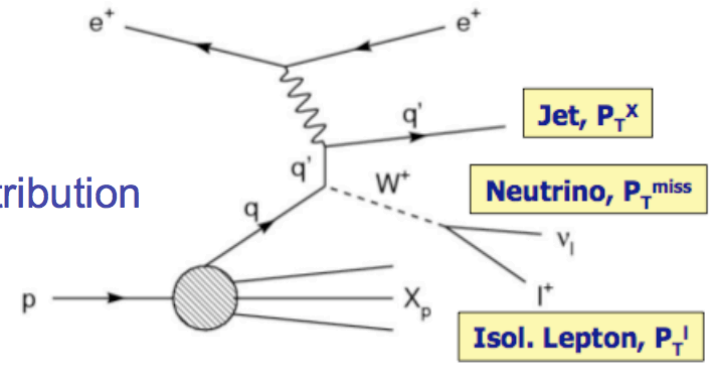


- Simultaneous test of the **EW** and **Strong** sectors of SM
- Best determination of **u**-coupling to **Z**
- Competitive with *Tevatron* and *LEP* results

Isolated high-p_T leptons: status-of-the-art

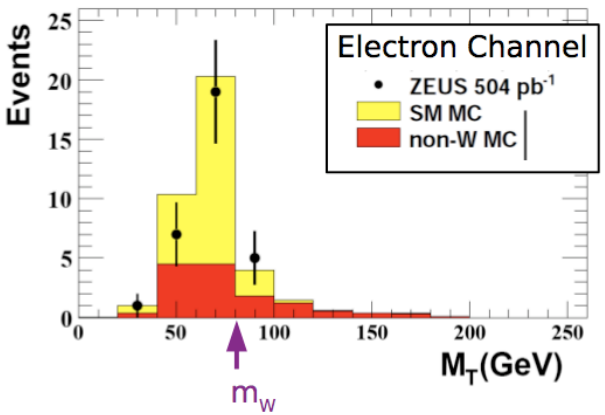


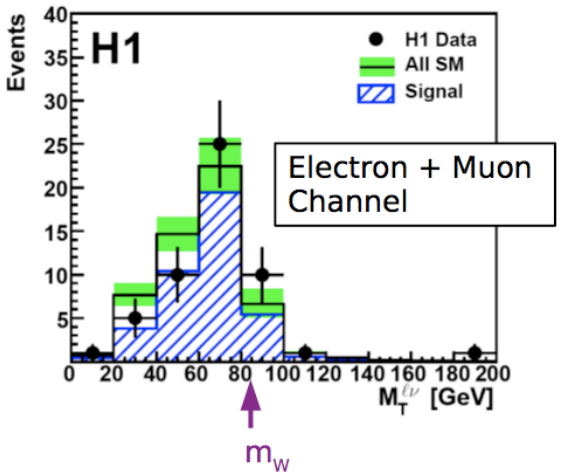
W production:
dominant SM contribution



Final analysis from H1 and ZEUS on Electron and Muon leptons
H1 looked also at the Tau leptons: challenging, large background

$$M_T^{\ell\nu} = \sqrt{(P_T^{\rm miss} + P_T^{\ell})^2 - (\vec{P}_T^{\rm miss} + \vec{P}_T^{\ell})^2}$$

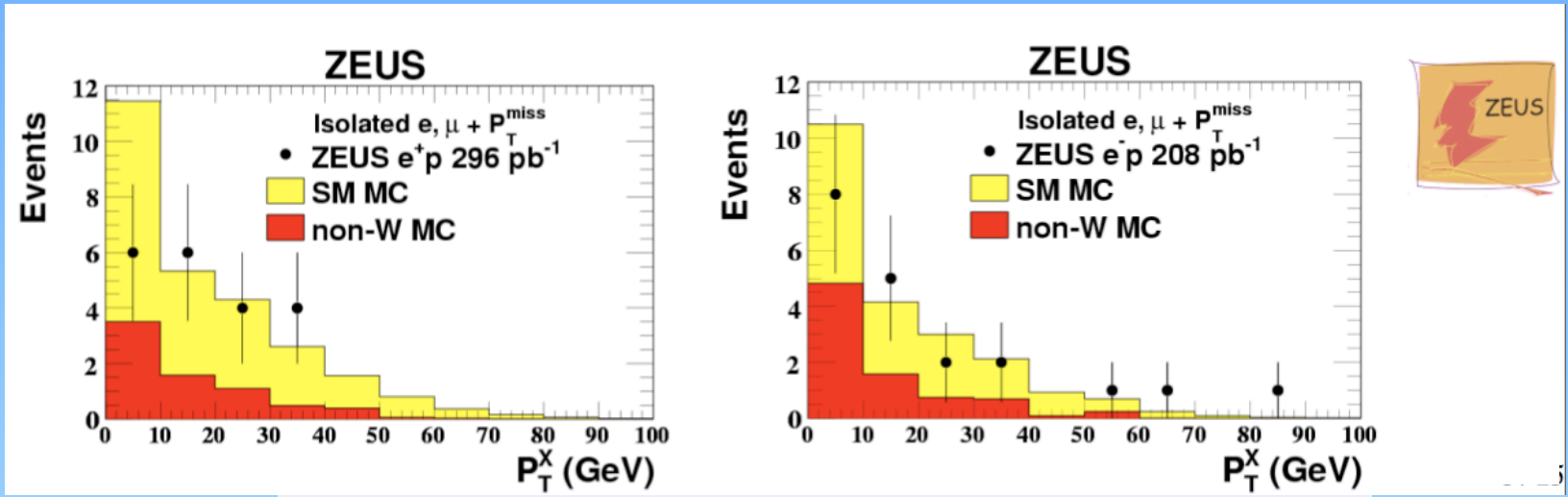




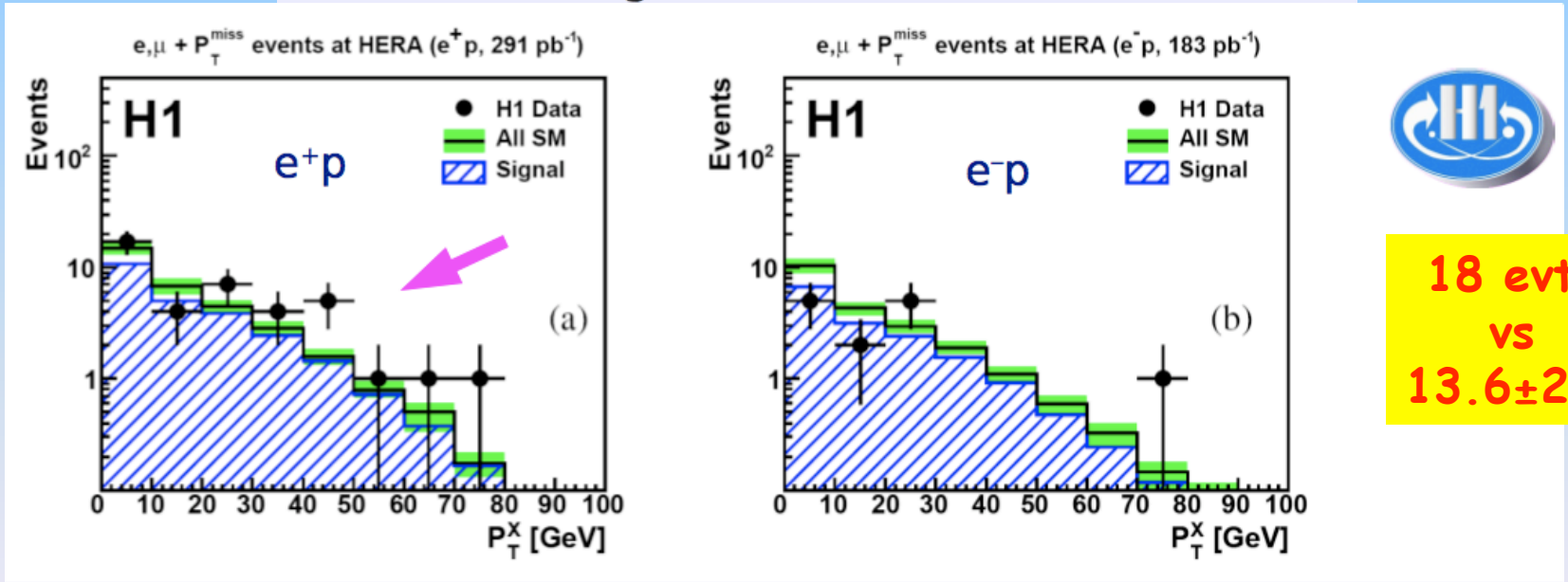
ZEUS	$0.89^{+0.25}_{-0.22}(stat.) \pm 0.10(syst.)\ pb$
H1	$\sigma_W = 1.14 \pm 0.25(stat.) \pm 0.14(syst.)\ pb$
EPVEC	$1.27 \pm 0.19\ pb$

(combined in progress)

nice Jacobian peaks, however at higth p_T...



Good overall agreement with Standard Model



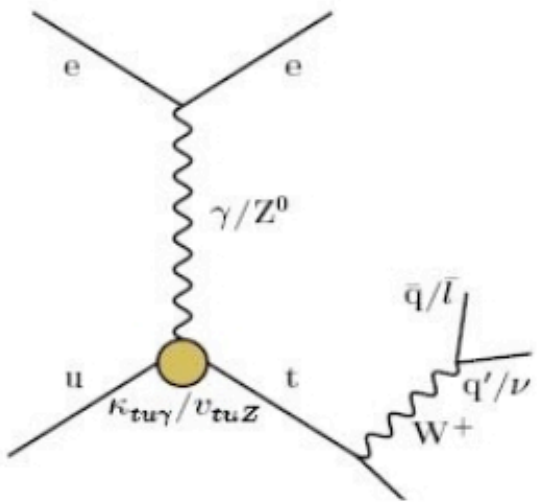
18 evts vs 13.6±2.2

Interesting events at high hadronic P_T^X > 25 GeV observed in e^+p by H1

H1: $\sigma_{\ell+P_T^{miss}} = 0.23 \pm 0.05\ (\text{stat.}) \pm 0.04\ (\text{sys.})\ \text{pb}.$

Anomalous **Single TOP** production at HERA

Final results from H1 (HERAII: 474 pb^{-1}), **HERAI+II in DESY-09-50**
ZEUS preliminary: 277 pb^{-1} (HERAII), **combined with HERAI** (120 pb^{-1})

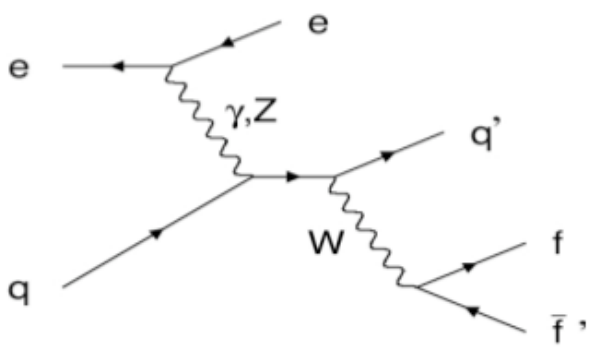


Anomalous single top production (BSM) proceeds via FCNC with a coupling $\kappa_{tu\gamma}$.

$$\mathcal{L} = \frac{e e_u}{\Lambda} \bar{t} \sigma_{\mu\nu} q^{\nu} \kappa_{\gamma} u A^{\mu}$$

Neglect **c** and Z couplings.

Sensitive to **u** (valence) and anomalous **γ** exchange



Search for signal in **muon**, **electron**, **hadron** channels

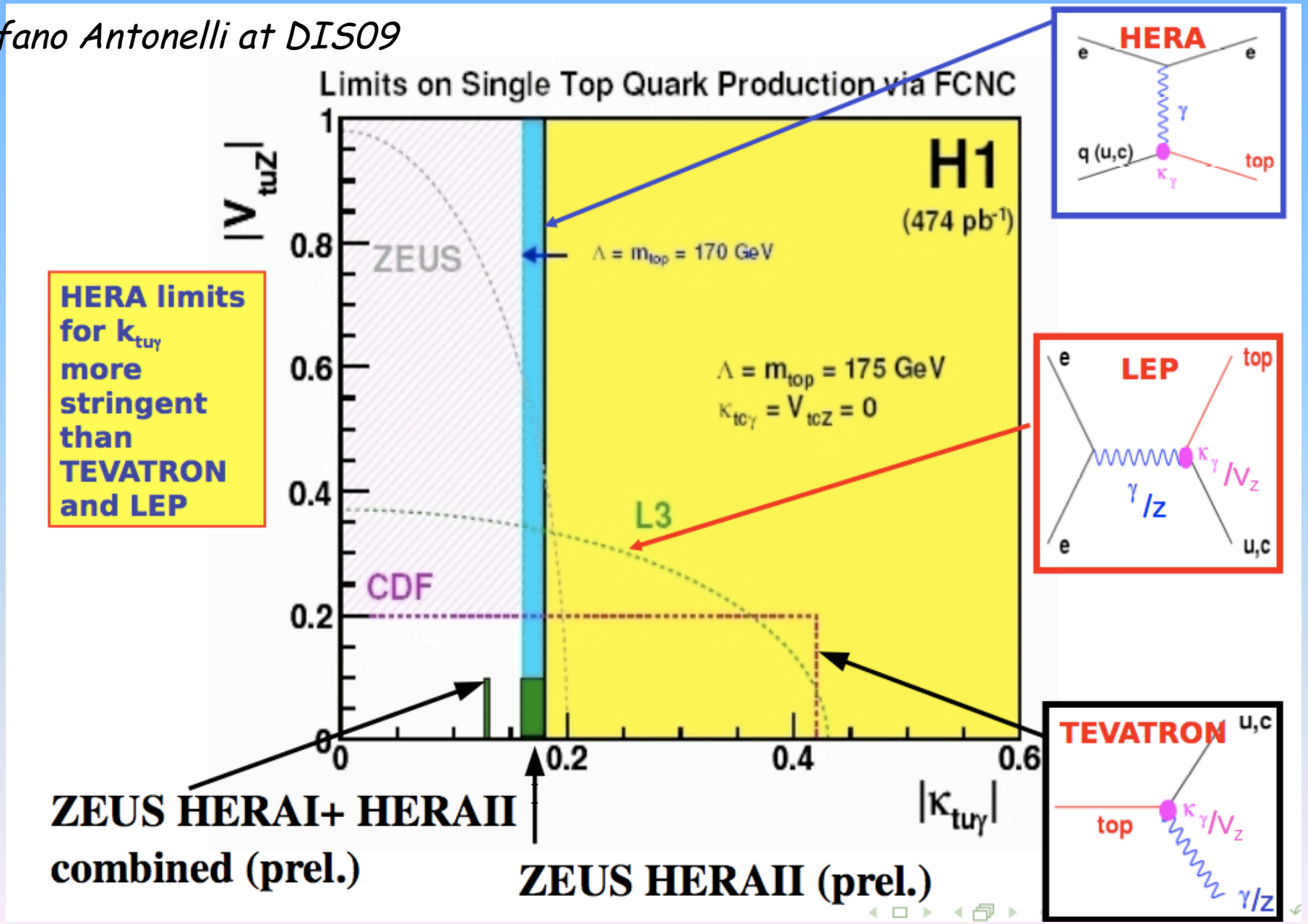
Intrinsic background from SM production of W *(lepton decay)*

(think also to previous "signal"...)

No excess ➔ limits, H1: $\sigma < 0.25$ pb, $k_{tu\gamma} < 0.18$, ZEUS: $\sigma < 0.13$, $k_{tu\gamma} < 0.13$

(slight excess)

Stefano Antonelli at DIS09



Conclusions

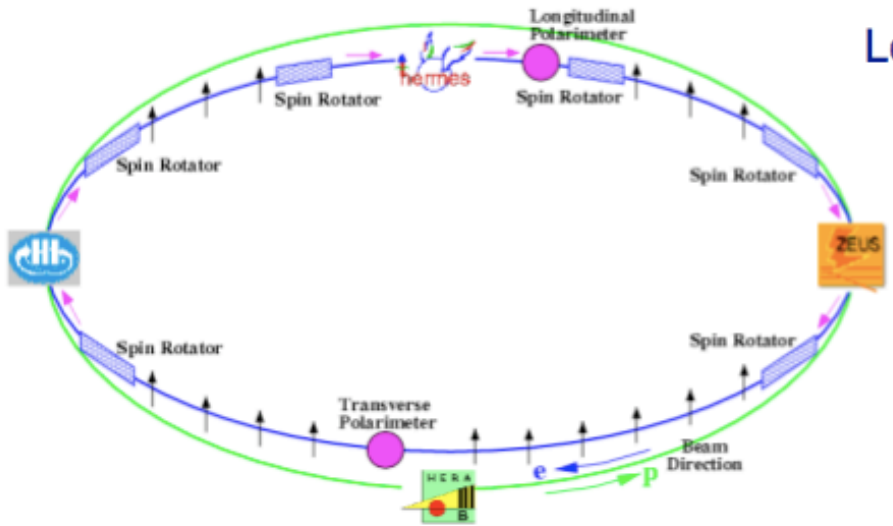
- H1 and ZEUS exploit most of HERA DATA for EW studies
- Unique HERA results done and undergoing

- Many EW checks, Universality, Chiral Structure, Parity Violation
- Single W production, measured, intriguing signal left at hight p_T
- Anomalous Single TOP production, SM checked (Colliders complementarity)

BIG thanks to HERA !!

Backup Slides

HERA-II feature: Polarization



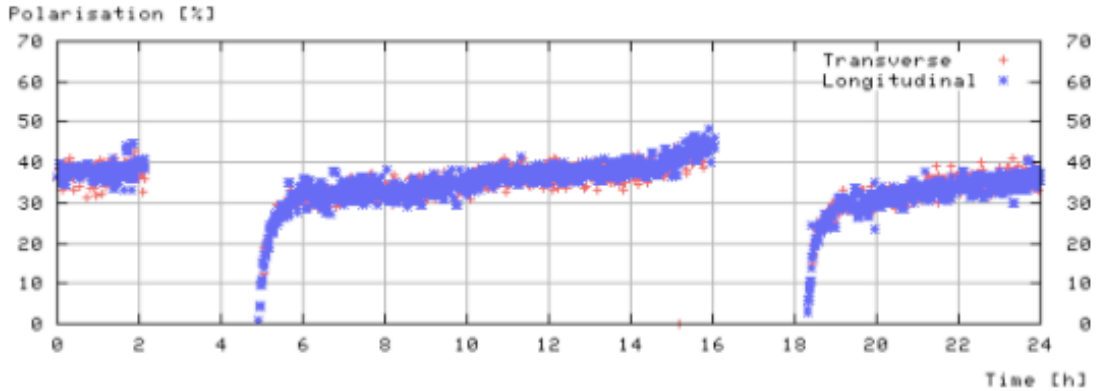
Longitudinal polarisation of the lepton beam

- Transverse polarization builds up naturally (Sokolov-Ternov effect, rise time ~30 min)
- Spin rotators before/after H1 and ZEUS
- Polarisation = Asymmetry of helicity states:

$$P_e = \frac{N_R - N_L}{N_R + N_L}$$

Polarisation build-up
P_e ~ 30-40% routinely achieved

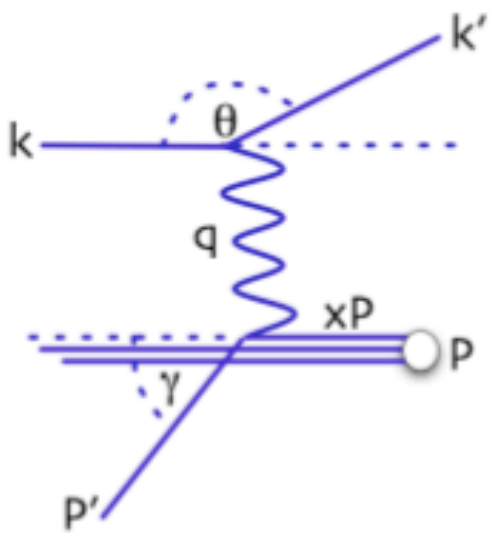
Measured by two independent Compton polarimeters.



Deep Inelastic Scattering at HERA

Two processes:

Neutral Current (NC) - exchange γ and Z^0 ($e^{\pm} p \rightarrow e^{\pm} X$))
Charged Current (CC) - exchange of $W^{\pm}$ ($e^{\pm} p \rightarrow \nu X$)



$$Q^2 = -q^2 = (k - k')^2$$ Virtuality of exchanged boson

$$x = \frac{Q^2}{2p \cdot q}$$ Bjorken scaling variable

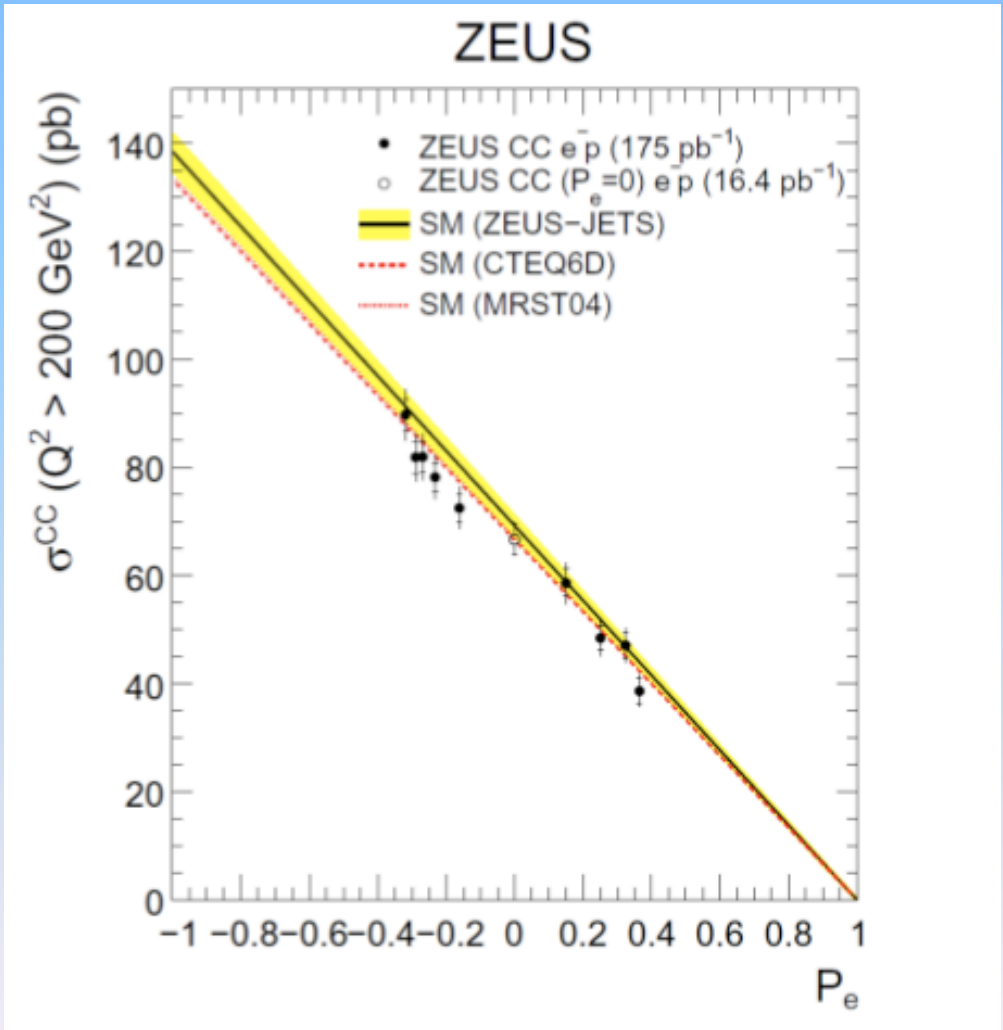
$$y = \frac{p \cdot q}{p \cdot k}$$ Inelasticity

$$Q^2 = sxy$$

Q^2 ~ 1/λ : the scale of the interaction corresponds to the spatial resolution at which the proton structure is probed

Main observables of interest: double differential cross sections $d^2\sigma/dxdQ^2$

Chiral Structure of CC, by ZEUS



DESY-08-177

Total cross-section
vs Electron Polarization
provides striking evidence

Isolated Lepton yield

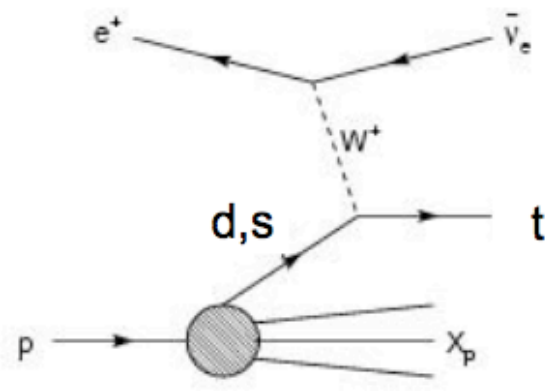
- H1: Good overall agreement of data and SM prediction, 18 / 13±2 at high P_T^X
- ZEUS: Good overall agreement of data and SM prediction, also at high $P_T X$

H1 1994-2007 $e^{\pm}p$ 474 pb^{-1}		Data	SM Expectation	SM Signal	Other SM Processes
Electron	Total	39	43.1 ± 6.0	30.3 ± 4.8	12.9 ± 3.4
	$P_T^X > 25$ GeV	10	7.5 ± 1.3	5.79 ± 0.99	1.71 ± 0.71
Muon	Total	14	11.0 ± 1.8	10.1 ± 1.7	0.88 ± 0.29
	$P_T^X > 25$ GeV	8	6.1 ± 1.0	5.64 ± 0.99	0.47 ± 0.15
Combined	Total	53	54.1 ± 7.4	40.4 ± 6.3	13.7 ± 3.5
	$P_T^X > 25$ GeV	18	13.6 ± 2.2	11.4 ± 1.9	2.18 ± 0.80

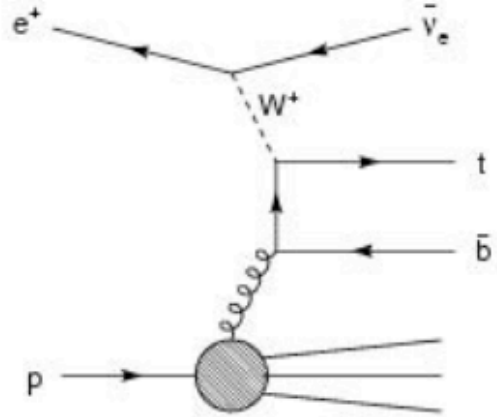
- What are those high-P_T^X events?
- Does H1 control their background?
- Study the main background contributions to the channels →

ZEUS Isolated Lepton Candidates	$P_T^X < 12$ GeV	$12 < P_T^X < 25$ GeV	$P_T^X > 25$ GeV
e^-p 208 pb^{-1}	$9/11.3 \pm 1.5$ (54%)	$6/5.1 \pm 0.7$ (67%)	$5/5.5 \pm 0.8$ (75%)
e^+p 296 pb^{-1}	$7/12.6 \pm 1.7$ (68%)	$7/6.2 \pm 0.9$ (75%)	$6/7.4 \pm 1.0$ (79%)
$e^{\pm}p$ 504 pb^{-1}	$16/23.9 \pm 3.1$ (61%)	$13/11.2 \pm 1.5$ (71%)	$11/12.9 \pm 1.7$ (77%)

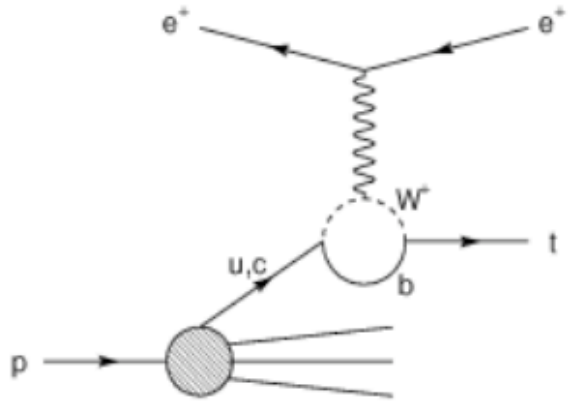
Single TOP production at HERA in the SM



Charged Current
W coupling to light
down-type quark



Charged Current
involving *b*-quark



Neutral Current
FCNC at loop level
("penguin")

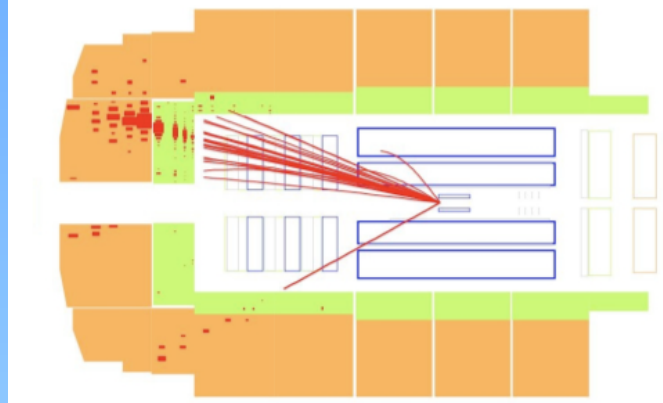
- $\sqrt{s}$ at HERA sufficient for single *top* production
- Production in SM possible but strongly suppressed
- Cross section ~1 fb
  (About 1 *top* event was produced at HERA in the SM)

Not observable

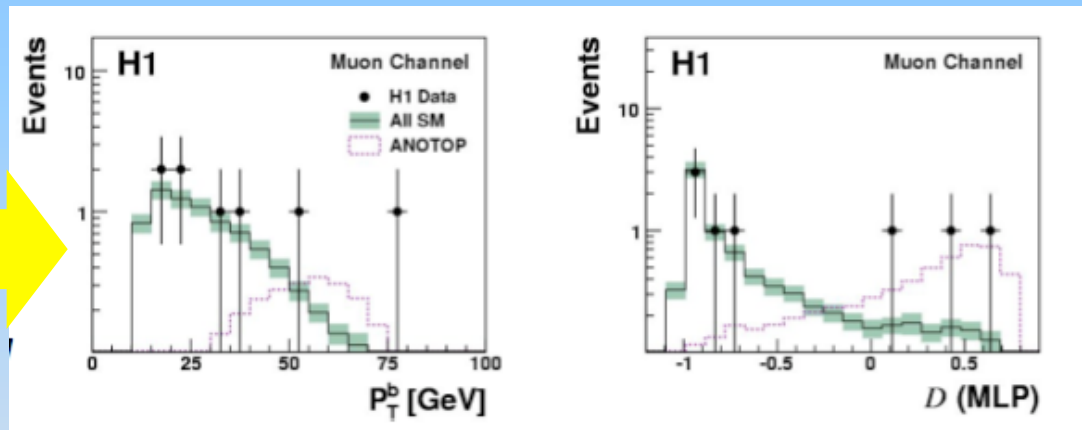
Single TOP results from H1

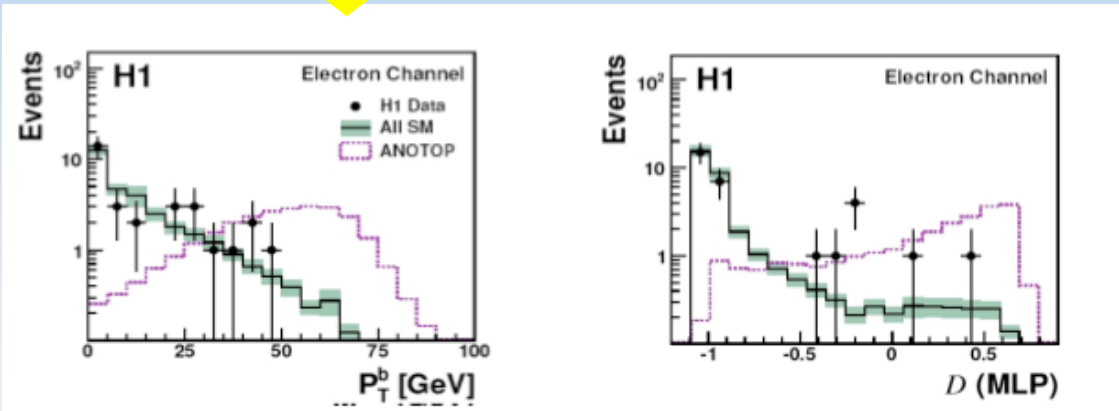
Result published:
DESY-09-050

Full data sample collected by H1 at HERA: integrated luminosity $474 pb^{-1}$

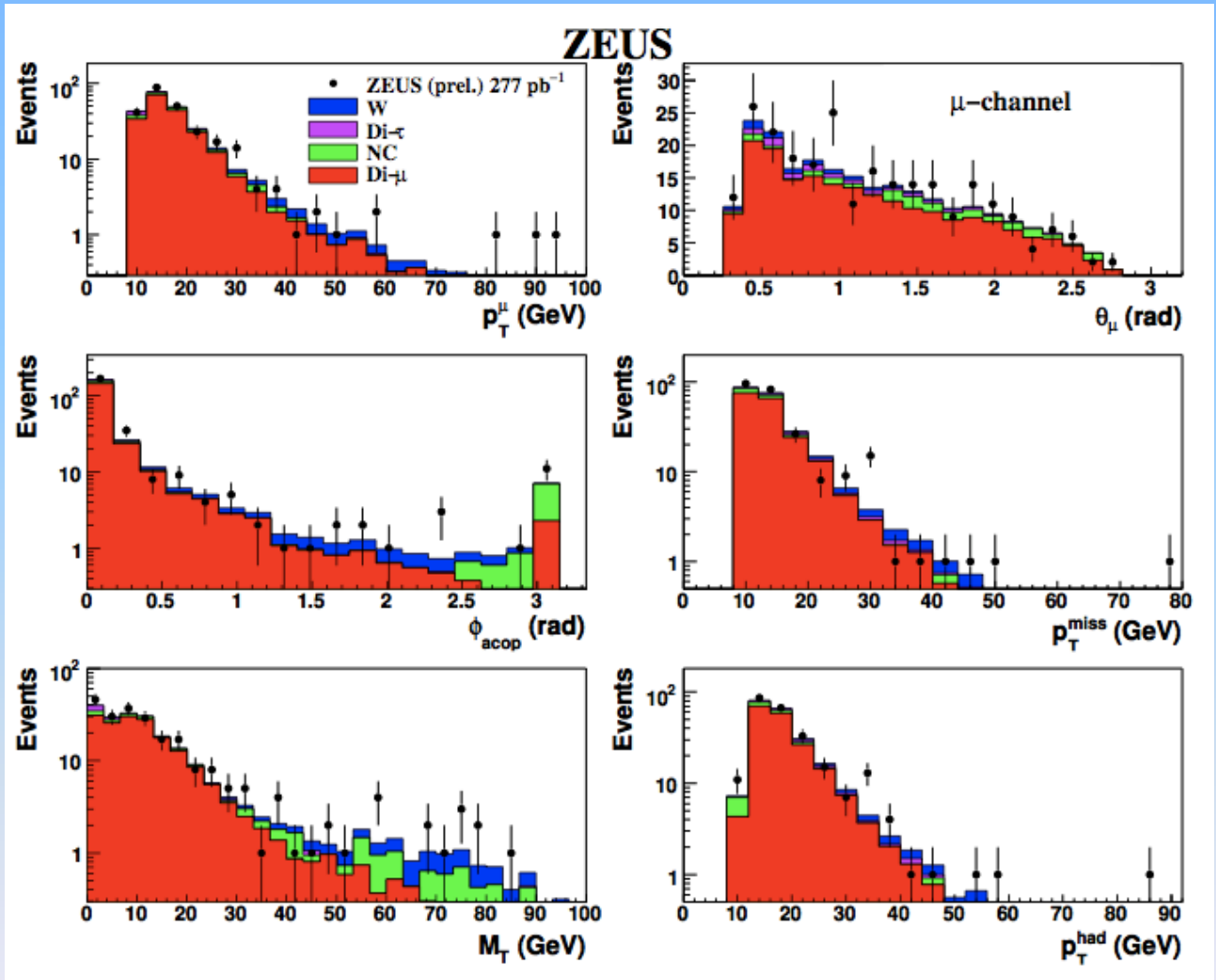


Slight excess in the muon and electron channels





Single TOP results from ZEUS



Muon channel

Main background: di-muon production.

W contribution visible at high transverse mass M_T.