Nowe wyniki z HERA

Aleksander Filip Żarnecki

Plan seminarium:

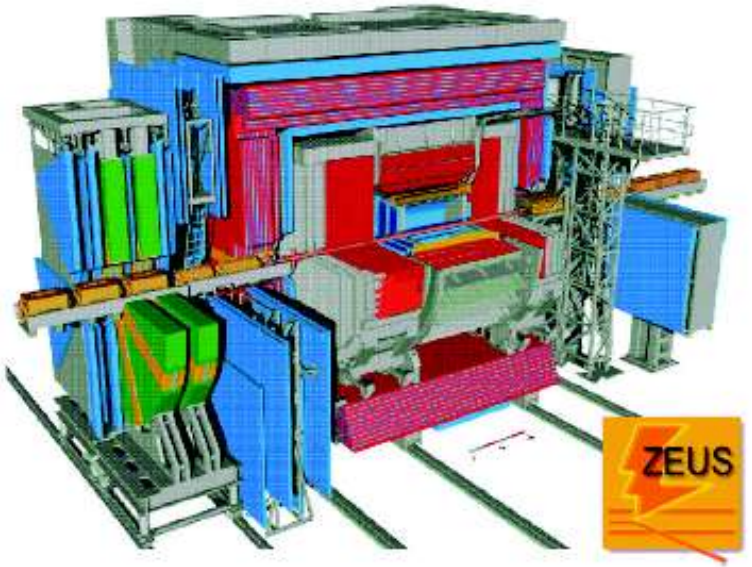
- Wprowadzenie
  HERA, H1, ZEUS
- Badanie struktury protonu
  Pomiary i ich analiza QCD
- Odstępstwa od przewidywań Modelu Standardowego
  Przypadki (wielo)leptonowe
- Poszukiwanie “nowej fizyki”
  Analiza danych HERA II
- Podsumowanie

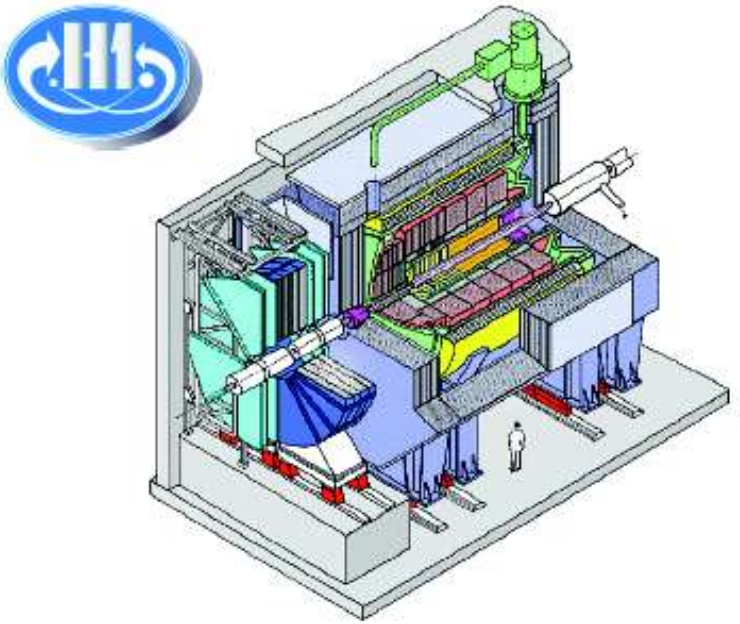
Seminarium Fizyki Wielkich Energii, 15 grudnia 2006

DESY, Hamburg

ZEUS and H1

- Omni-purpose detectors:
  silicon tracking, drift chambers, calorimeter, muon system





Uranium-Scintillator calorimeter:
em: $\sigma(E)/E = 18\%/\sqrt{E}$
had: $\sigma(E)/E = 35\%/\sqrt{E}$

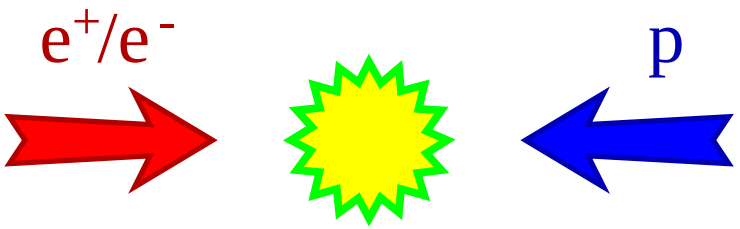
Fine-grained LAr calorimeter:
em: $\sigma(E)/E = 12\%/\sqrt{E} \oplus 1\%$
had: $\sigma(E)/E = 55\%/\sqrt{E} \oplus 1\%$

Backward lead-scintillator calo:
em: $\sigma(E)/E = 7\%/\sqrt{E} \oplus 1\%$

Introduction

HERA

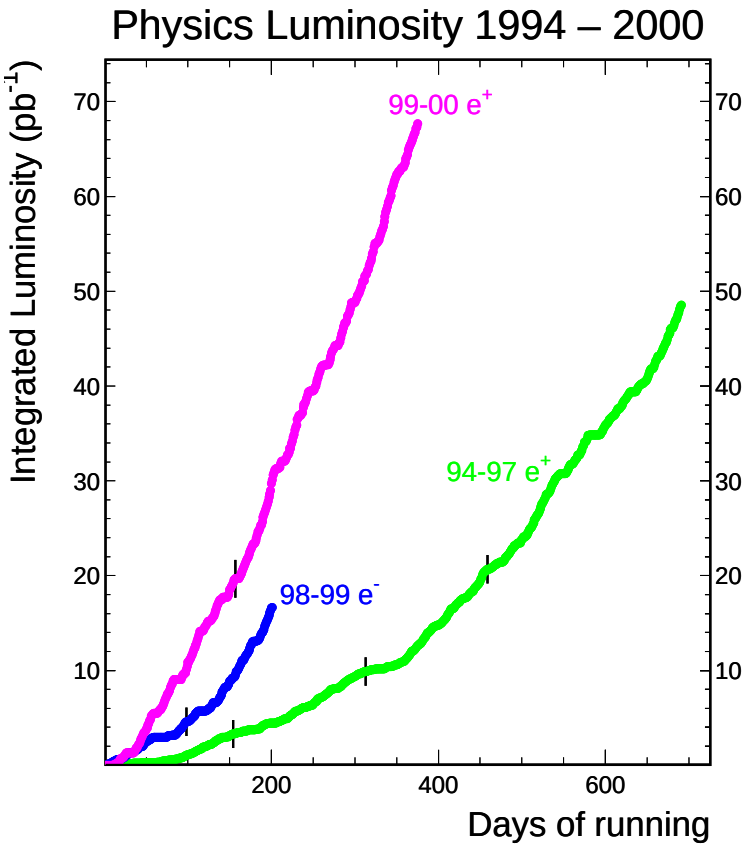
electron(positron)-proton collider at DESY



1994-97

1998-00

Very successful HERA operation in 1999-2000:



Presented results

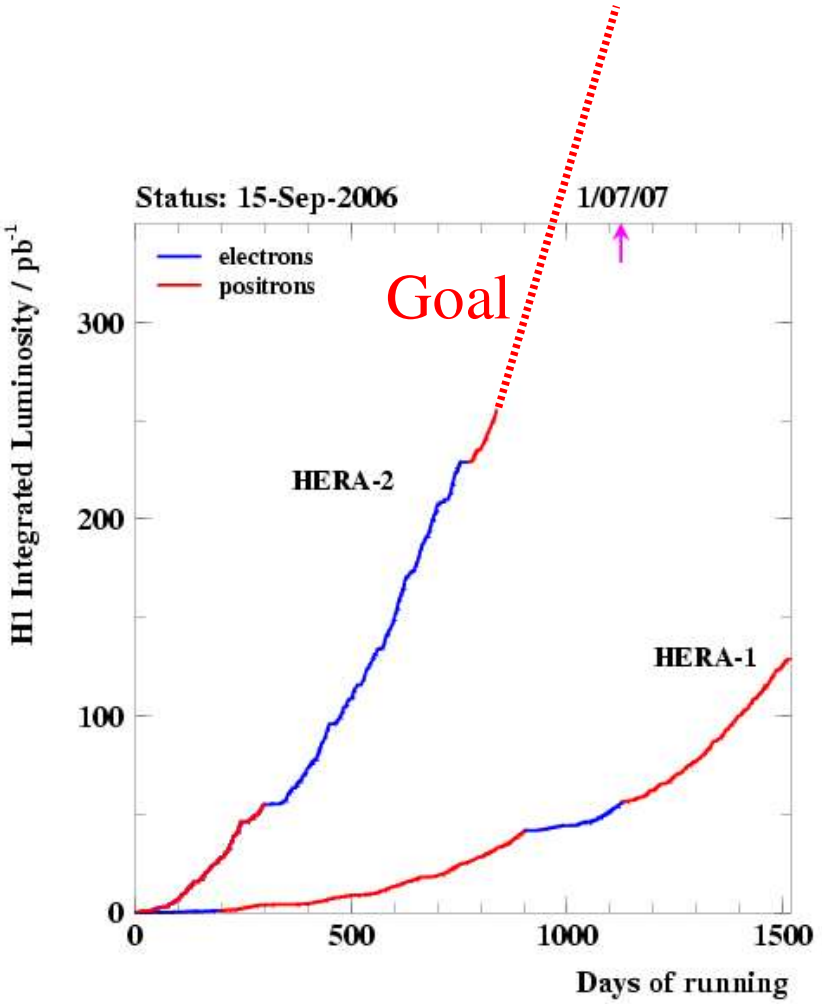
Year		$\sqrt{s}$	H1	ZEUS
1994-97	e^+p	300 GeV	36 pb^{-1}	48 pb^{-1}
1998-99	e^-p	318 GeV	15 pb^{-1}	16 pb^{-1}
1999-00	e^+p	318 GeV	46 pb^{-1}	64 pb^{-1}

Total of about $\sim$ 220 pb^{-1} of $e^{\pm}p$ data available.

Status of HERA-II

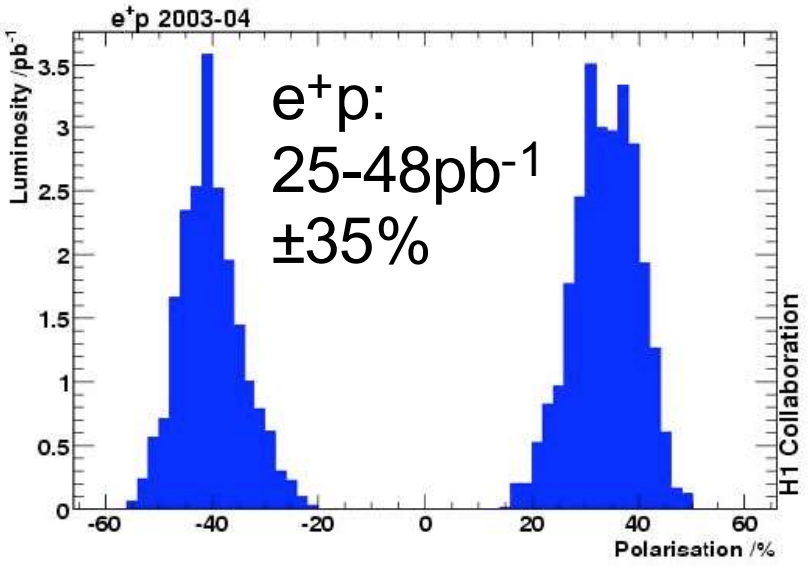
- HERA-I: 1992-2000:
  $16pb^{-1}$ $e^{-}p$, $120pb^{-1}$ $e^{+}p$
- Upgrade 2001-2002,
  slow startup
- HERA-II: 2003 - July 2007
  up to now:
  ~$175pb^{-1}$ $e^{-}p$, $105pb^{-1}$ $e^{+}p$
- e+ running will continue for 6 more months, then 3 months low energy run

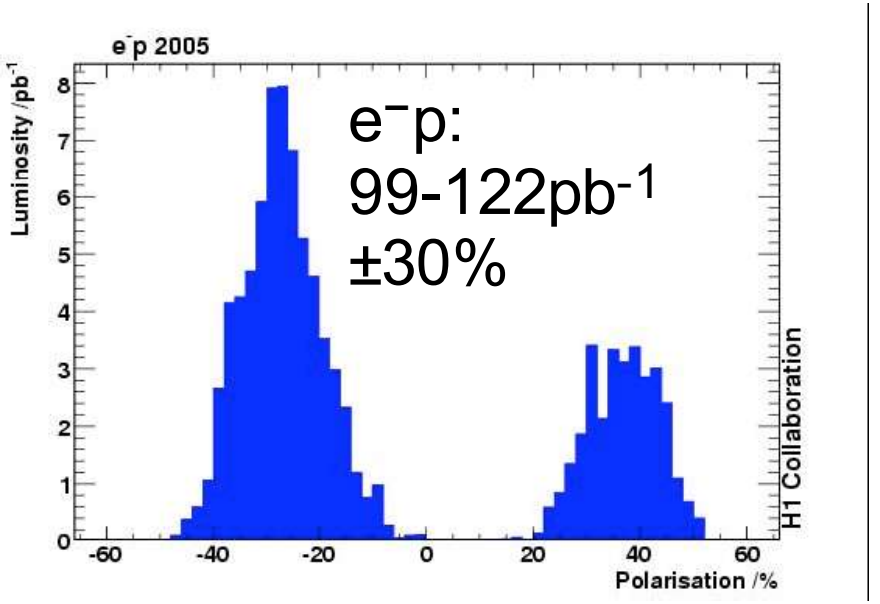
HERA: Integrated Luminosity



Lepton Polarization at HERA-II

- New HERA-II feature:
  Use spin rotators to produce <u>longitudinal</u> polarization in experiments
- Allows to measure polarization dependence of high-Q^2 processes:
  - Charged currents: limits on right-handed currents
  - Neutral current: γZ interference

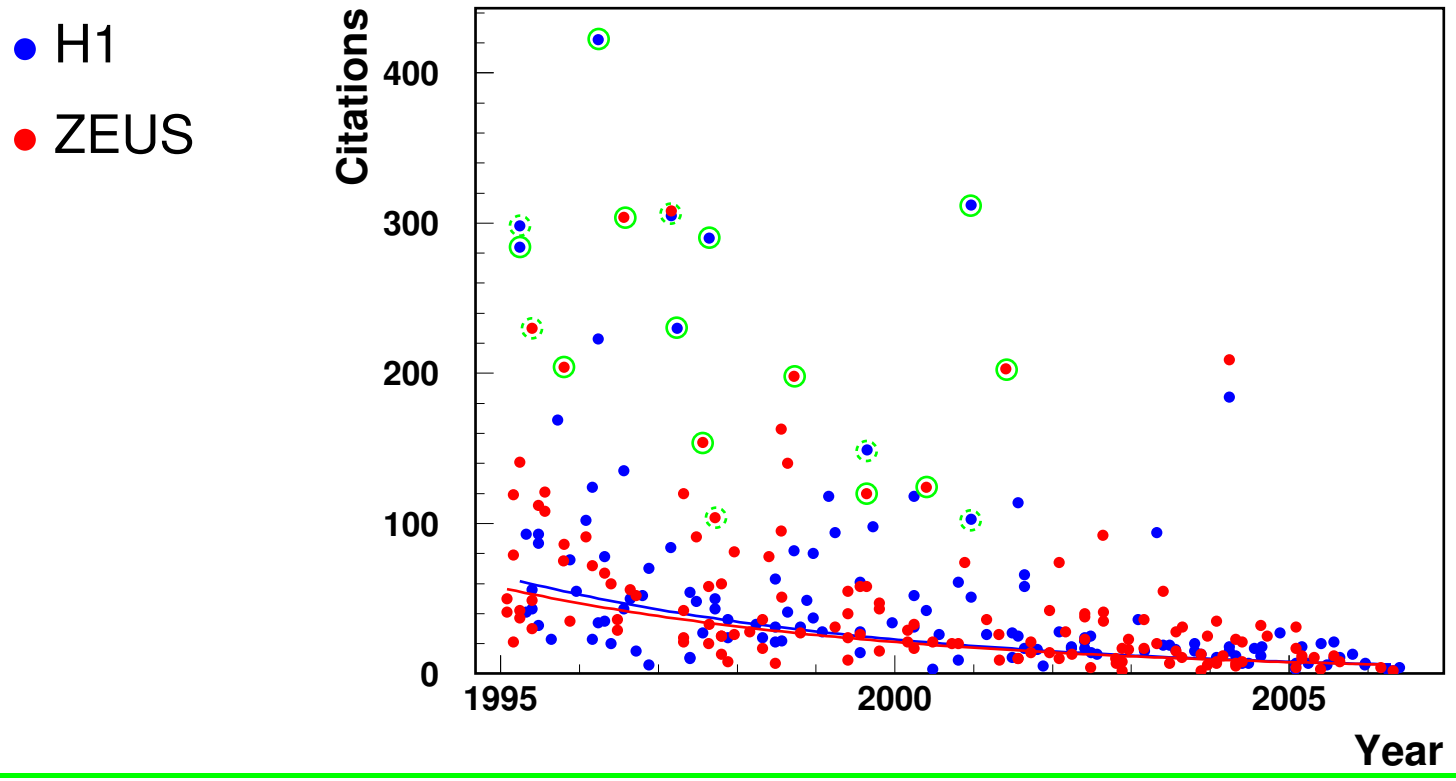




Badanie struktury protonu

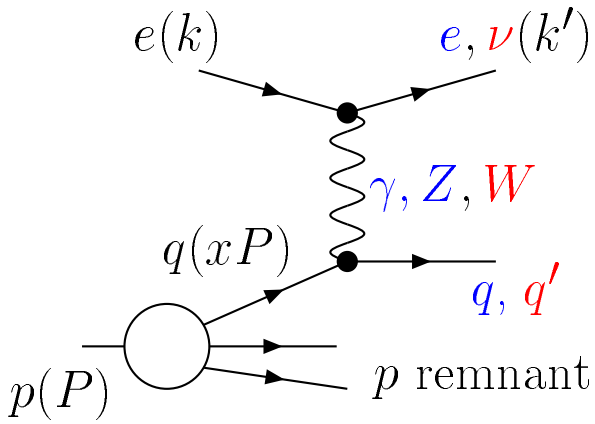
Precyzyjny pomiar funkcji struktury protonu i wyznaczenie rozkładów kwarków i gluonów w protonie było jednym z głównych celów budowy akceleratora HERA.

Prace poświęcone pomiarom funckcji struktury F_2 i ich analizie QCD należą do najczęściej cytowanych (hep-ex):



High-Q^2 DIS

Deep Inelastic Scattering

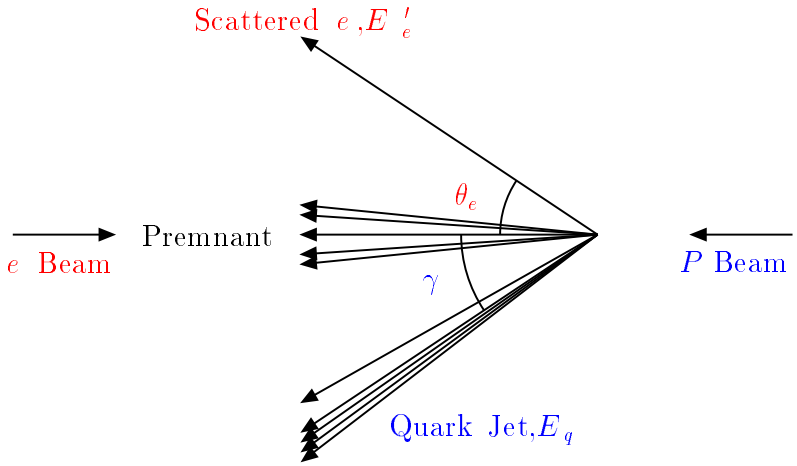


$$Q^2 = -(k - k')^2$$

$$x = \frac{Q^2}{2P \cdot (k - k')}$$

$$y = \frac{P \cdot (k - k')}{P \cdot k}$$

Kinematic Reconstruction



Virtuality Q^2

$\Rightarrow$ spatial resolution $\lambda \sim 1/Q$

$\Rightarrow$ sensitivity to new mass scales $\Lambda \sim Q$

eq invariant mass $M_{eq} = \sqrt{x \cdot s}$

$\Rightarrow$ search for resonances with $M < \sqrt{s}$

NC DIS events:

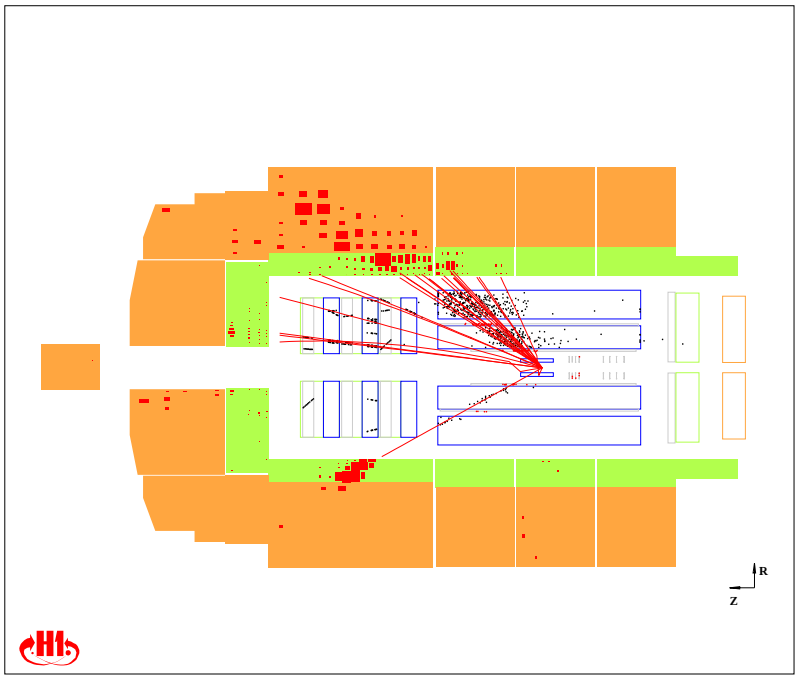
- electron: E_e, θ_e H1
- angles: θ_e, γ ZEUS

CC DIS events:

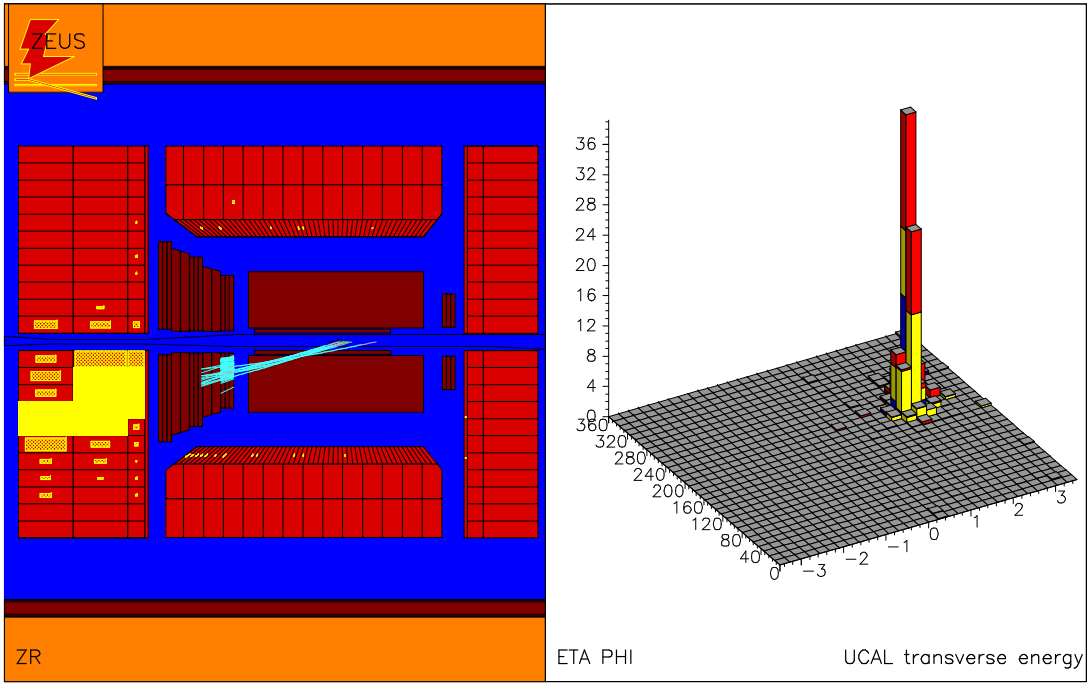
- quark jet: E_q, γ

High-Q^2 DIS

NC DIS



CC DIS



Inclusive DIS ep interactions

- **NC** $e^{\pm}p \to e^{\pm}X$

$$\frac{\mathrm{d}^2\sigma^{\pm}_{NC}}{\mathrm{d}x\,\mathrm{d}Q^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+\tilde{F}_2 \mp Y_- x\tilde{F}_3 - y^2\tilde{F}_L\right] \equiv \frac{2\pi\alpha^2}{xQ^4}\,Y_+\tilde{\sigma}^{\pm}_{NC}$$

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

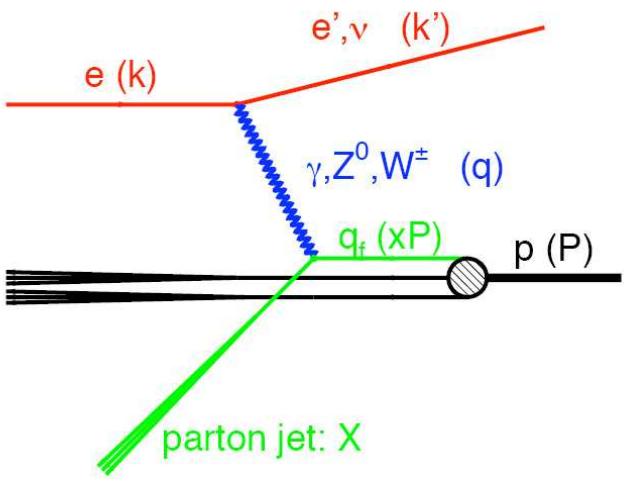
$\tilde{F}_2$	dominant contribution in LO QCD	$\{F_2, F_2^{\gamma Z}, f_2^Z\} = x\sum_q \{e_q^2, 2e_q v_q, v_q^2 + a_q^2\}(q+\bar{q})$
$x\tilde{F}_3$	γZ interference at $Q^2 \sim m_Z^2$	$\{xF_3^{\gamma Z}, xF_3^Z\} = 2x\sum_q \{e_q a_q, v_q a_q\}(q-\bar{q})$
$\tilde{F}_L$	sensitivity at low Q^2, high y	$\sim \alpha_s x g(x, Q^2)$

- **CC** $e^{\pm}p \to \nu X$

$$\frac{\mathrm{d}^2\sigma^{\pm}_{CC}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{G_F^2}{4\pi x}\left[\frac{m_W^2}{Q^2+m_W^2}\right]^2\left[Y_+\tilde{W}_2 \mp Y_- x\tilde{W}_3 - y^2\tilde{W}_L\right]$$

$\tilde{\sigma}^{+}_{CC} = x[(\bar{u}+\bar{c}) + (1-y)^2(d+s)]$	sensitive to d quark at high x
$\tilde{\sigma}^{-}_{CC} = x[(u+c) + (1-y)^2(\bar{d}+\bar{s})]$	sensitive to u quark at high x

Kinematics of ep interactions

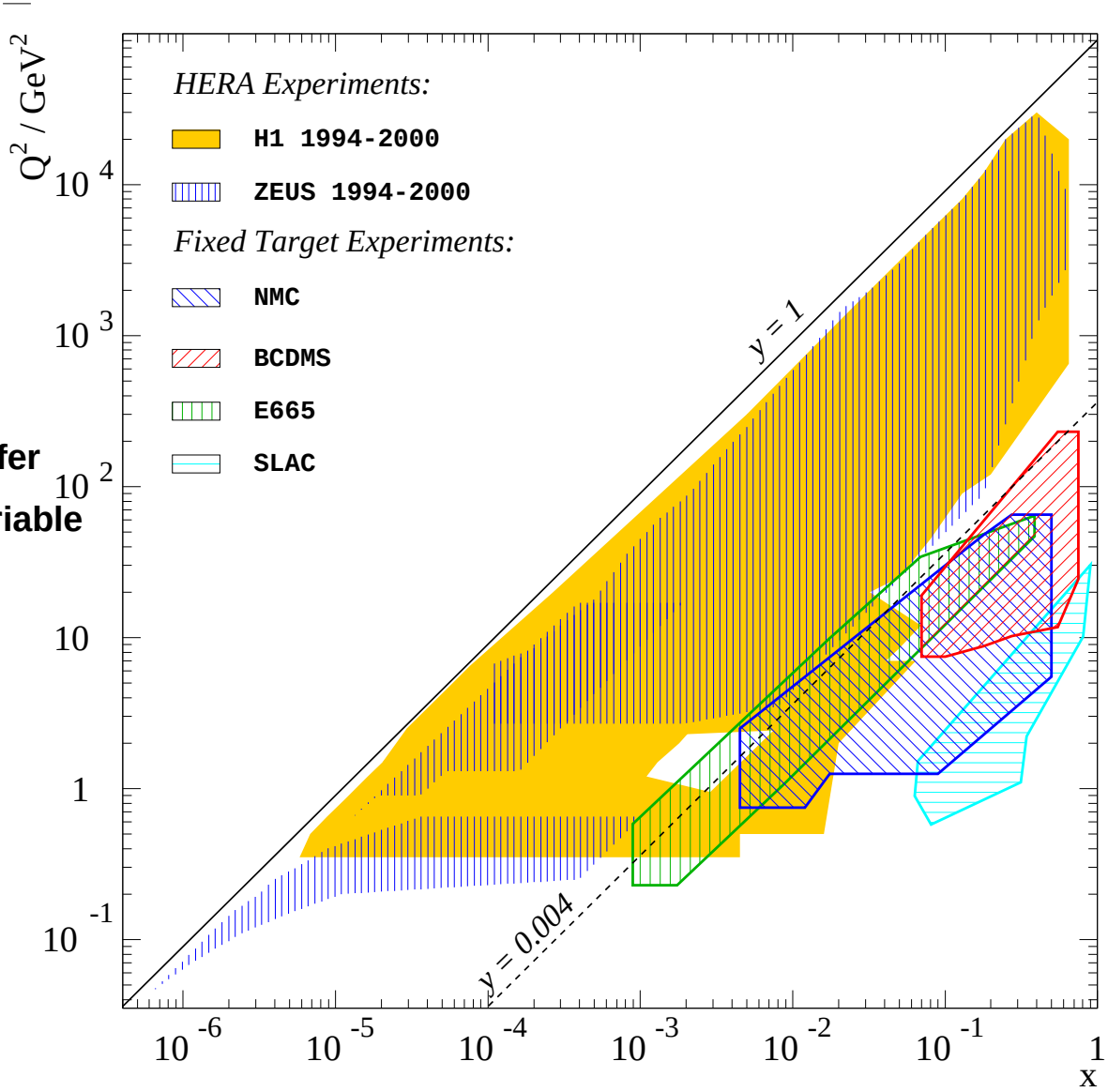


$Q^2 = -q^2$ **4-momentum transfer**

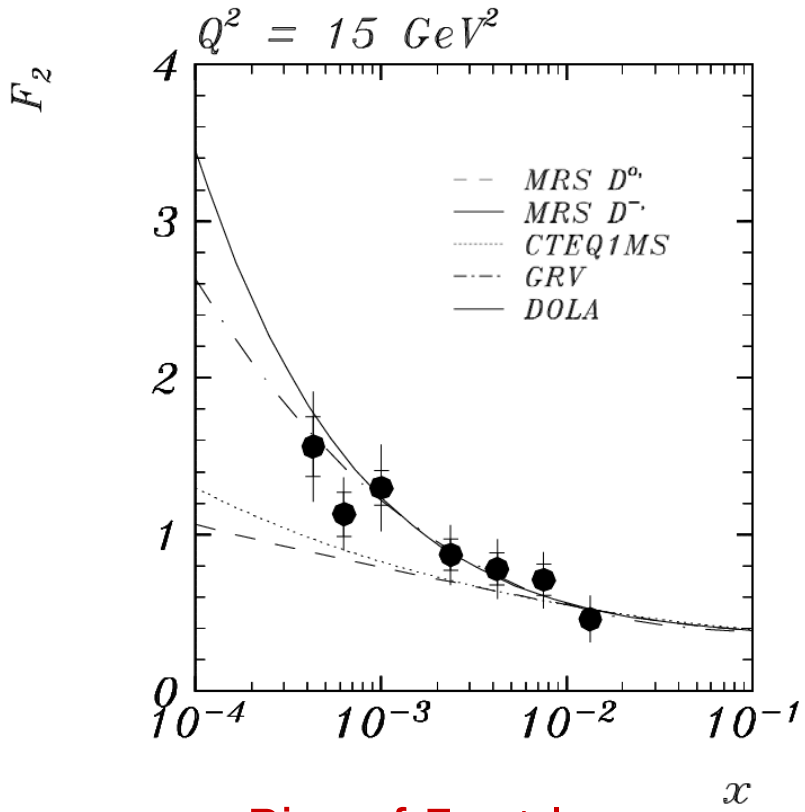
$x = Q^2/2(P \cdot q)$ **Bjorken scaling variable**

$y = (P \cdot q)/(P \cdot k)$ **inelasticity**

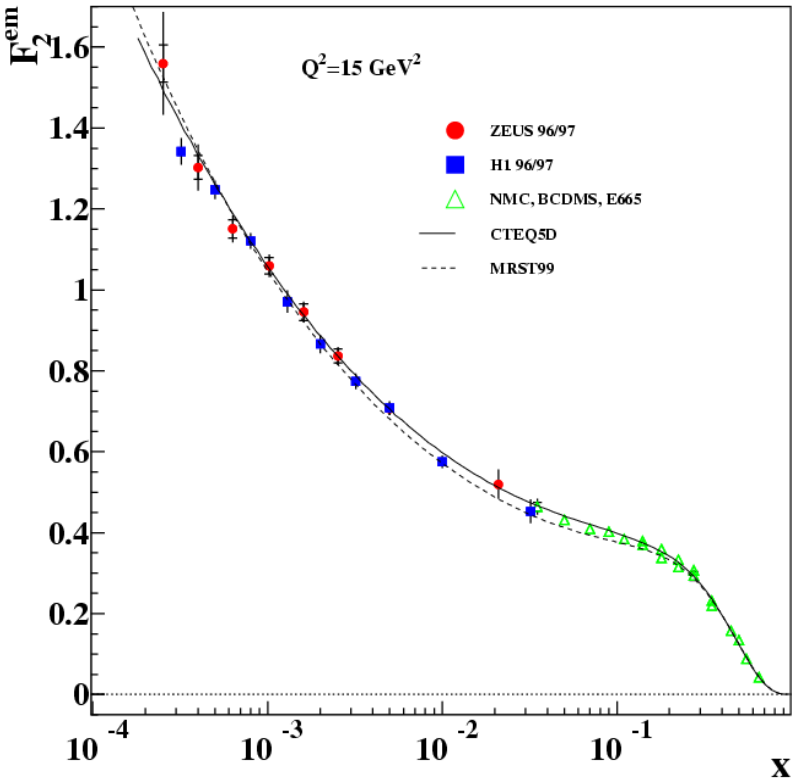
$Q^2 = x\,y\,s$



Introduction: proton PDFs @ HERA



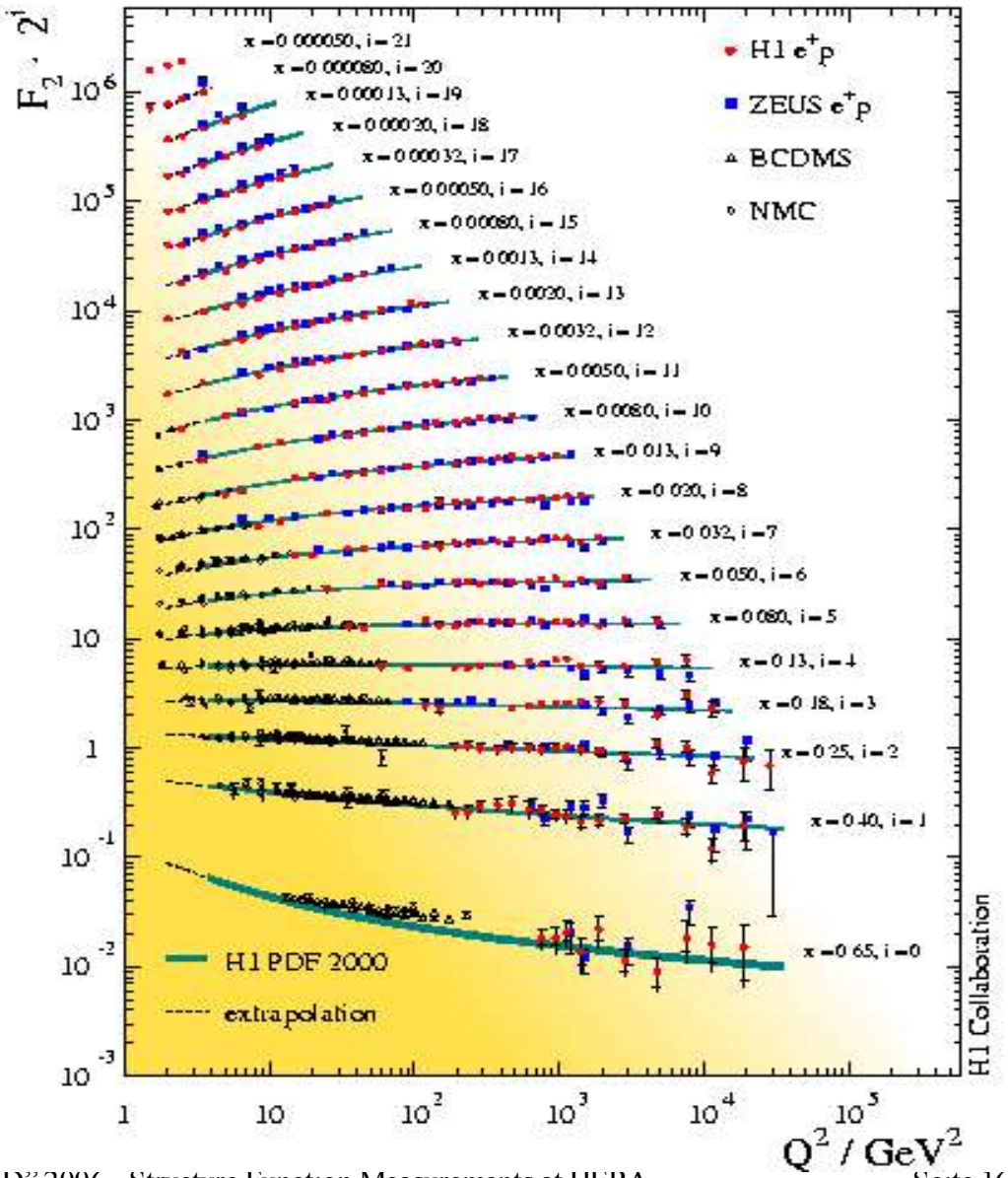
Rise of F_2 at low-x
(established with ~20 nb^{-1})



Precise F_2 determination
(1996-97 data samples)

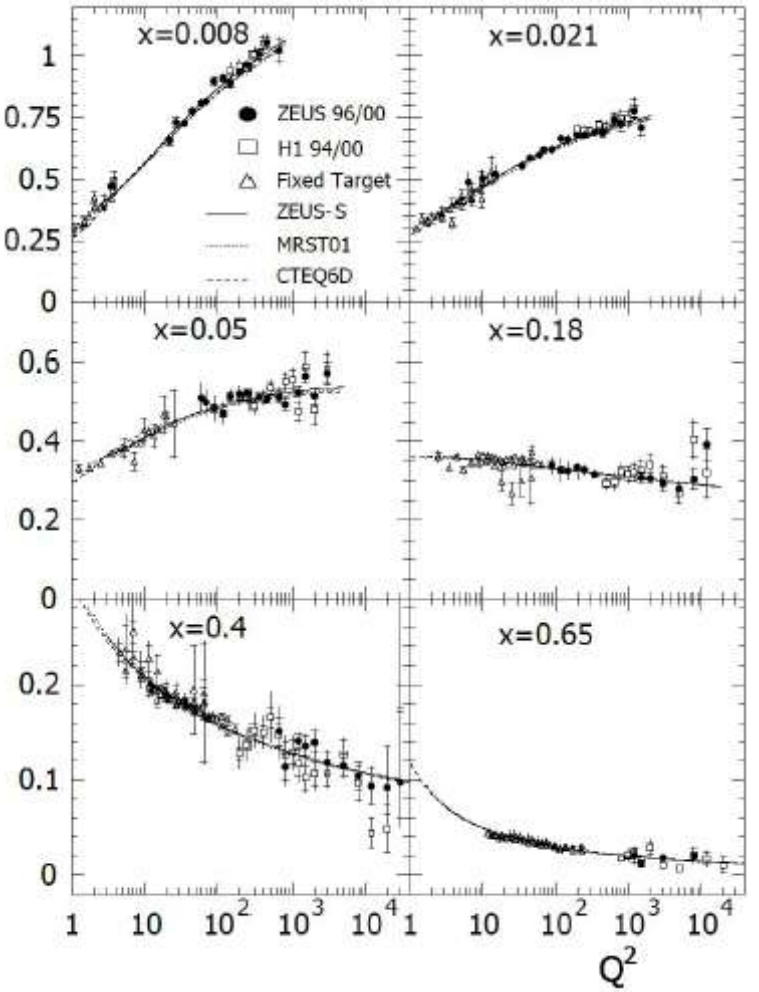
Overview over F_2

- Kinematic region:
  - 4 decades in x: $0.000065 < x < 0.65$
  - Q^2 up to 30000GeV^2
- HERA-I data completely analysed
- HERA-II:
  3 times (e+) to 10 times (e$^-$) more data expected
  => better accuracy at small x, large Q^2

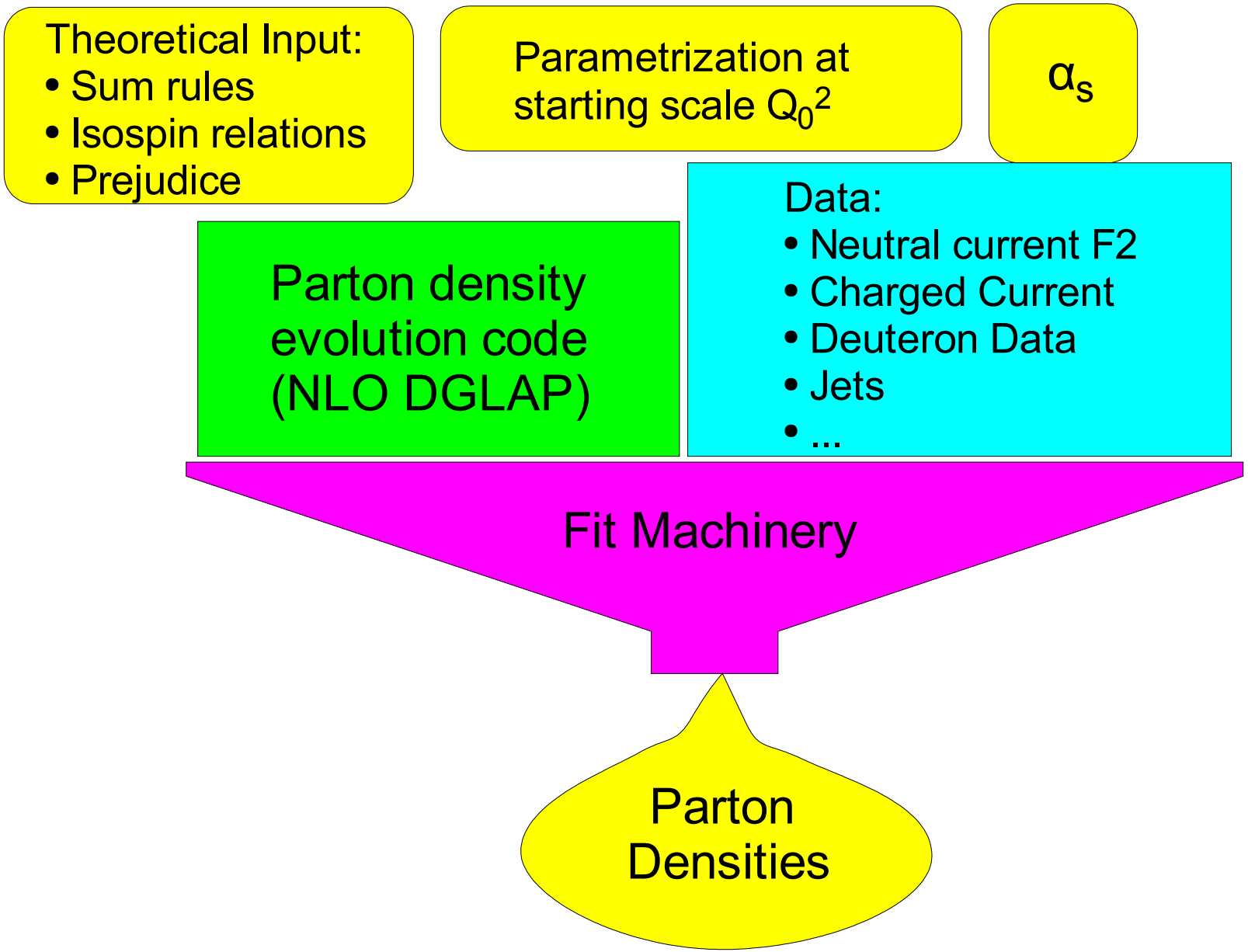


A Success for DGLAP

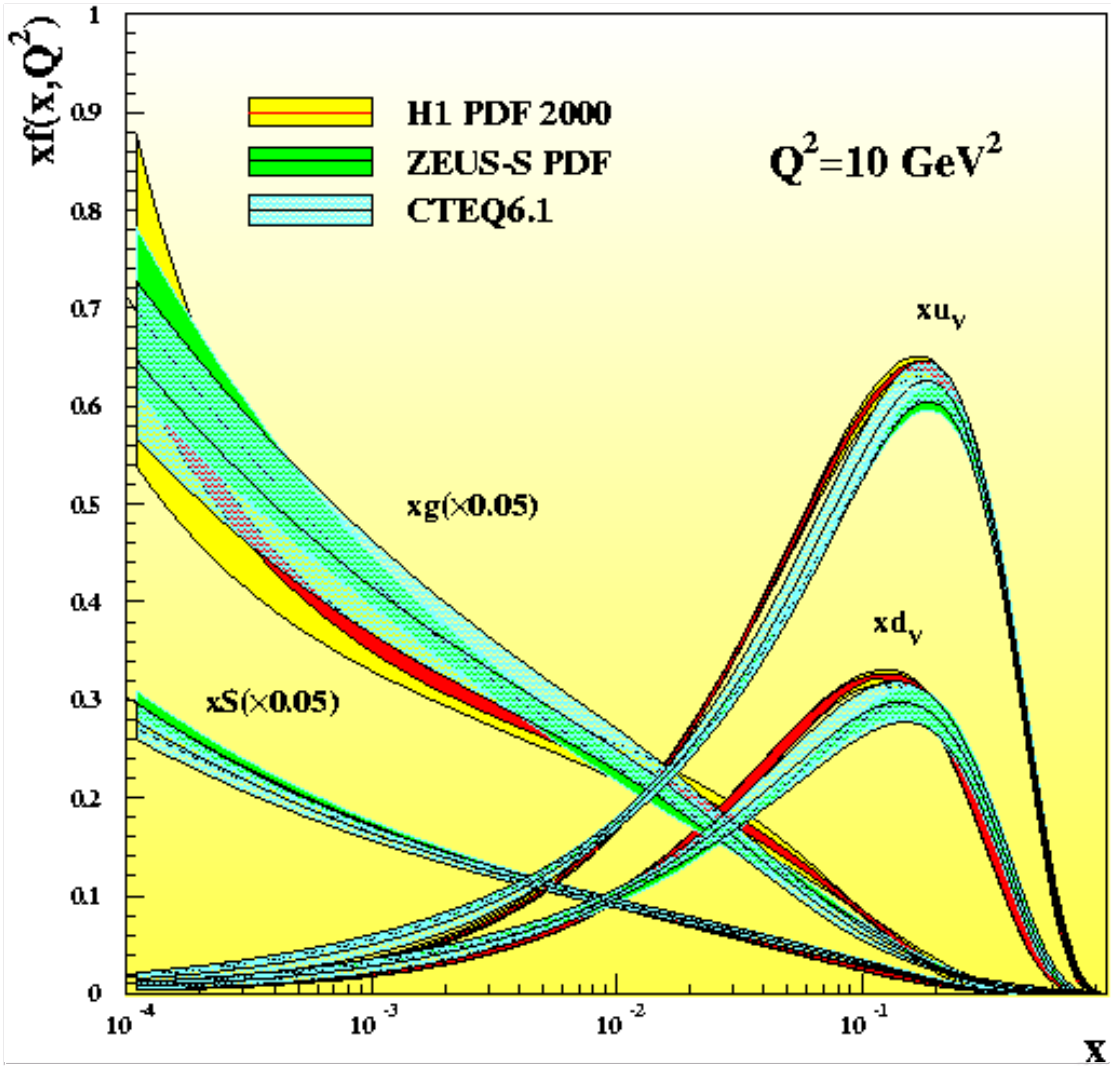
- Together with fixed target data: Test of scaling violations over 4 orders of magnitude in Q^2 at fixed x
- NLO-QCD fits based on DGLAP-evolution describe data very well
- No obvious deviations from "Standard Model of Parton Densities"



Fitting Parton Densities



Parton Densities

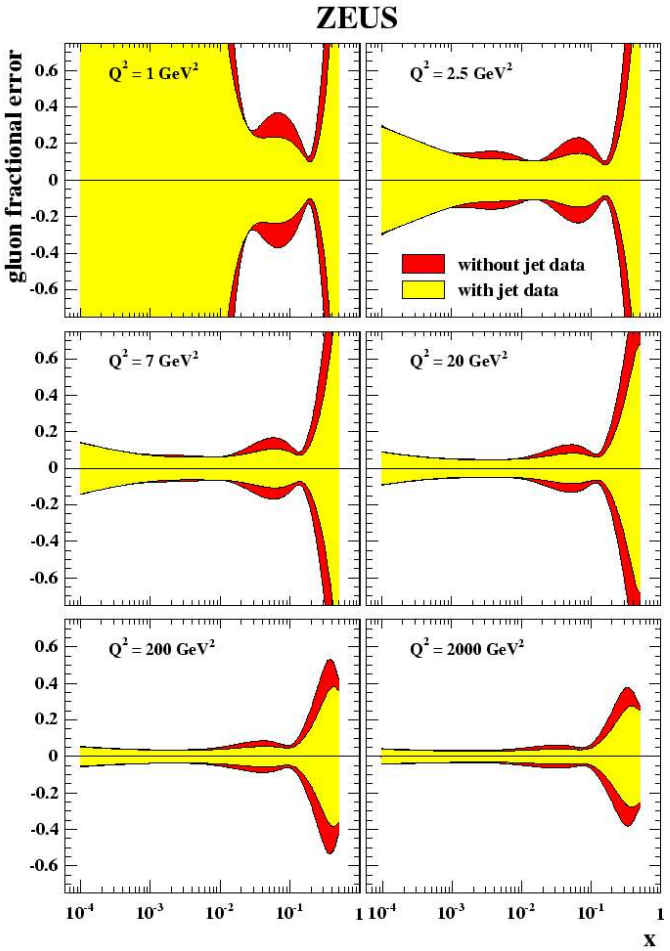


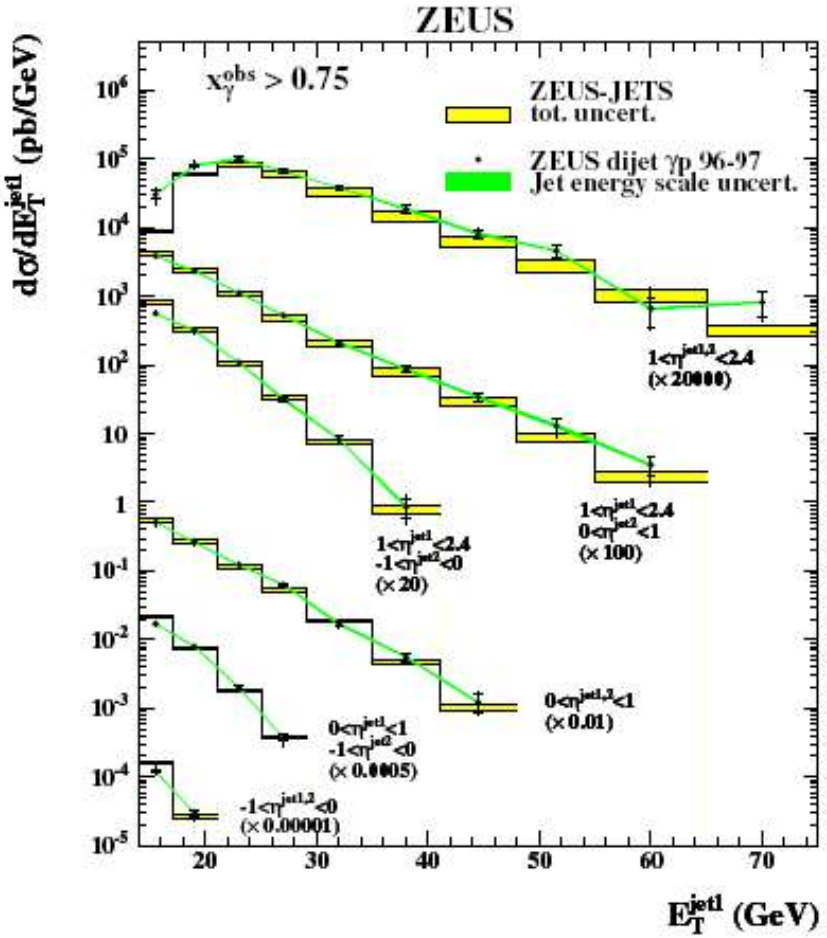
- Qualitative Agreement H1-ZEUS
- Differences due to different methods and data sets

Note: sea quark density *S* and gluon density *g* scaled down by faktor 20!

Adding Jet Data

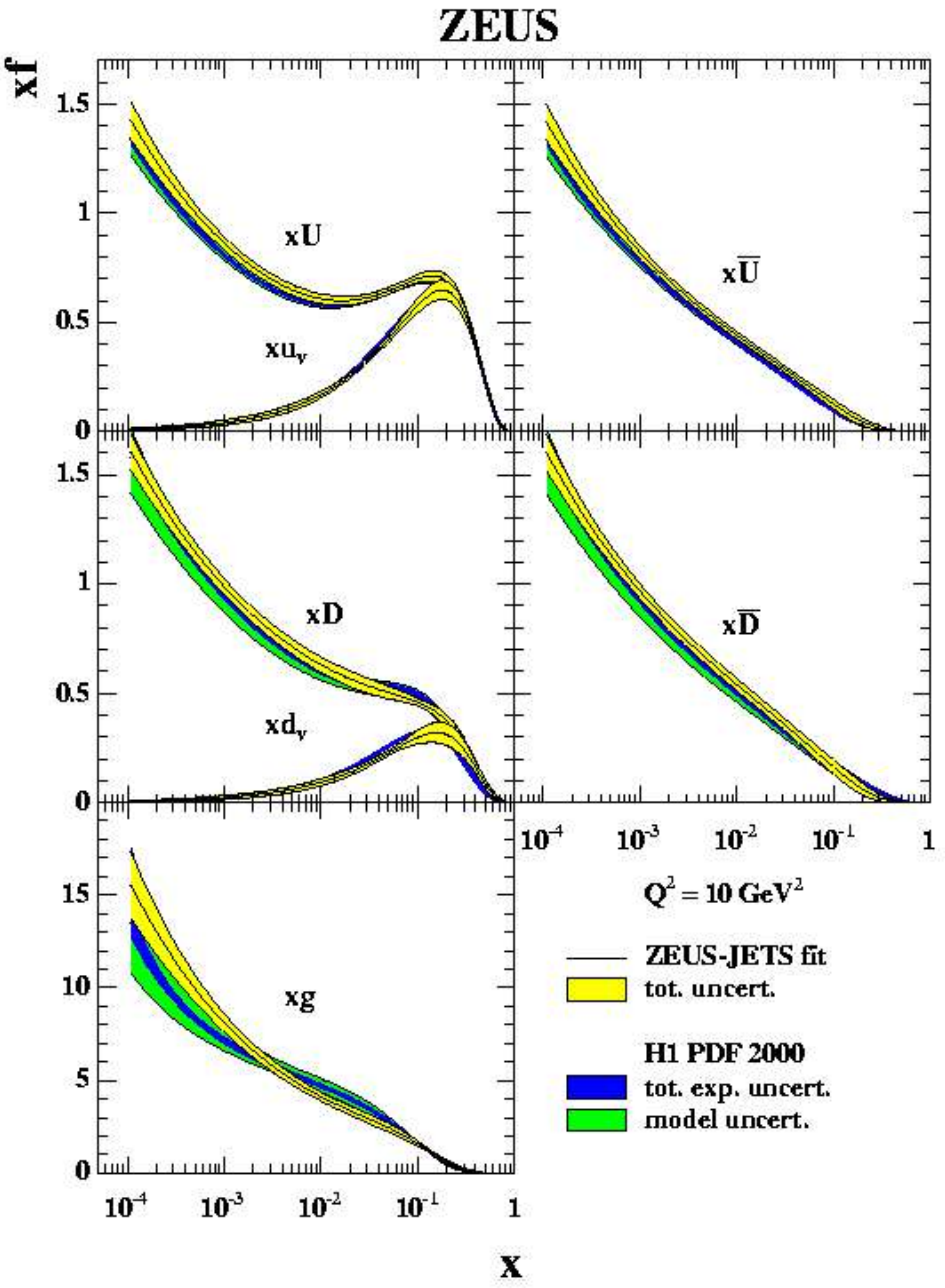
- New ZEUS analysis [EPJ **C42**(2005)1]:
- Add DIS and γp dijet data (direct photoproduction): adds to knowledge of gluon density at large *x*





ZEUS-Jets vs. H1-2000

- After inclusion of Jets data by ZEUS, H1 and ZEUS pdf fits agree well
- Still differences for gluon



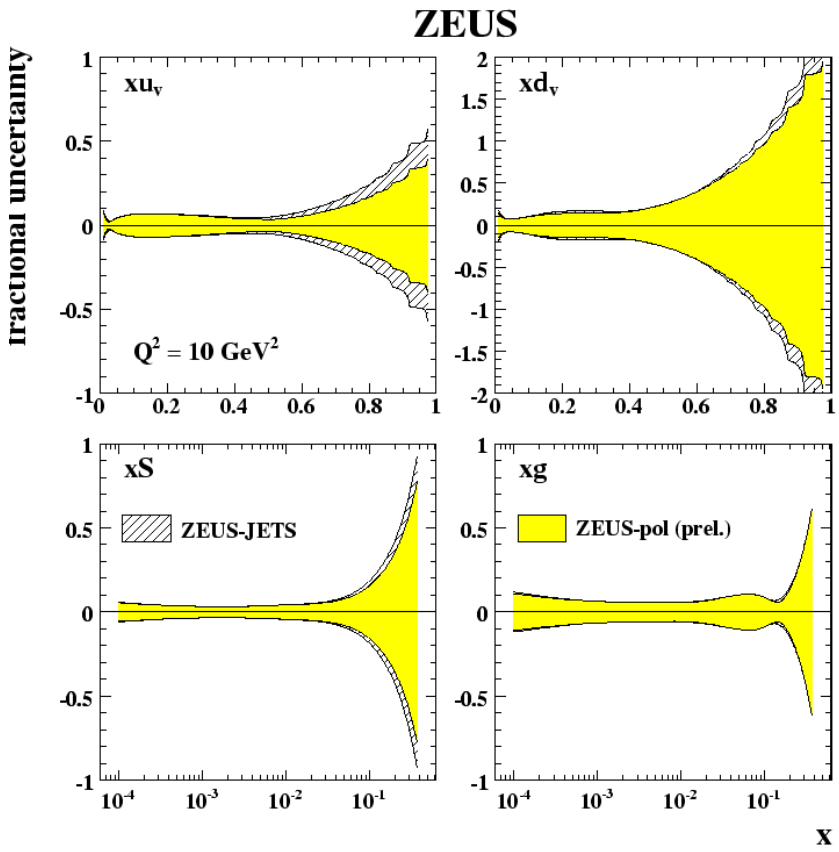
Zeus-Pol PDFs

ZEUS-prel-06-003

Since 2002 HERA has been running with long. polarized e± beam (P~30-40%)

	HERA-I	HERA-II
e-	~20 pb^{-1}	e^- R : ~ 40 pb^{-1} @ Pe=~ +37% e^- L : ~ 80 pb^{-1} @ Pe=~ -27%
e+	~100 pb^{-1}	e^+ R: ~ 20 pb^{-1} @ Pe=~ +34 % e^+ L: ~ 20 pb^{-1} @ Pe=~ -40 %

Q^2=10 GeV^2



A new PDF fit has been performed including the new $e^-_{L,R}$-p NC and CC cross sections

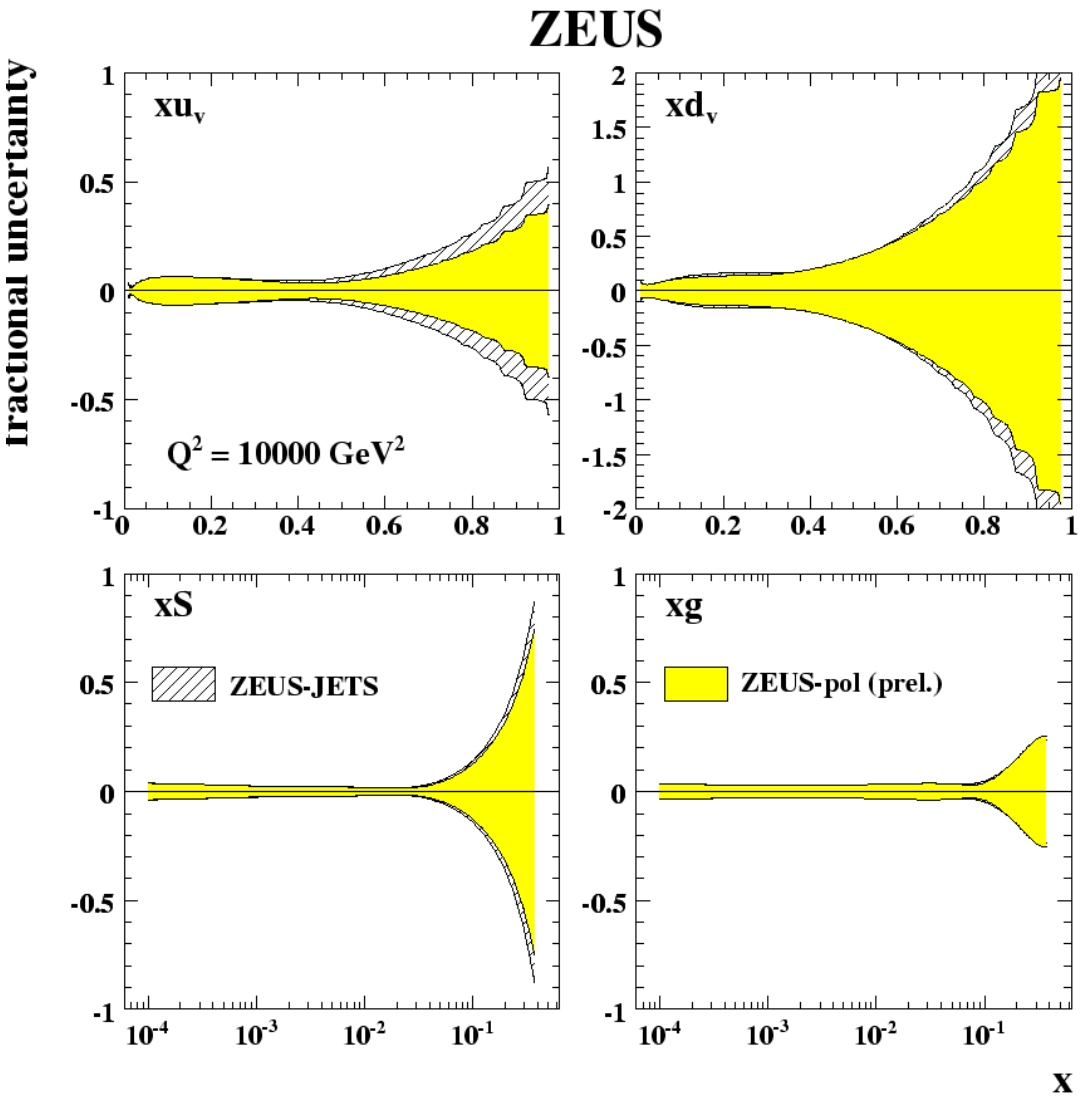
Improved determination of the PDFs at high-x: in particular xu_v

$$\sigma_{NC}(e^-p) \propto (4u + d), \quad \sigma_{CC}(e^-p) \propto u$$

Using Polarized Data

- Preliminary ZEUS result (ZEUS-prel-006-03):
- Polarized HERA-II data improves valence quark uncertainty at large x
- Central values unchanged compared to ZEUS-Jets fit

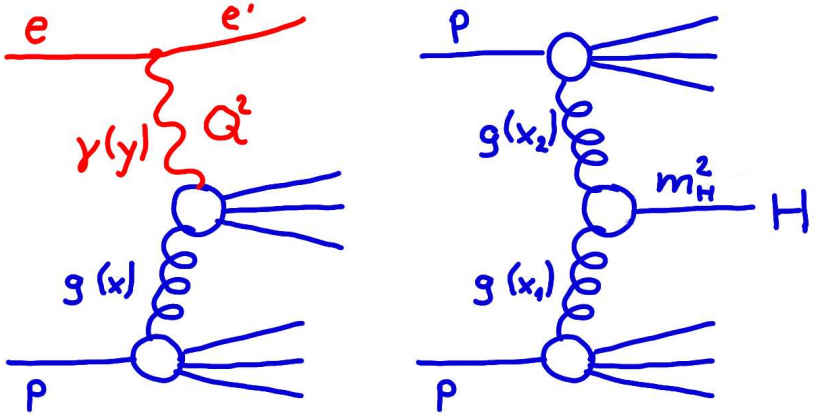
Q^2=10000GeV^2

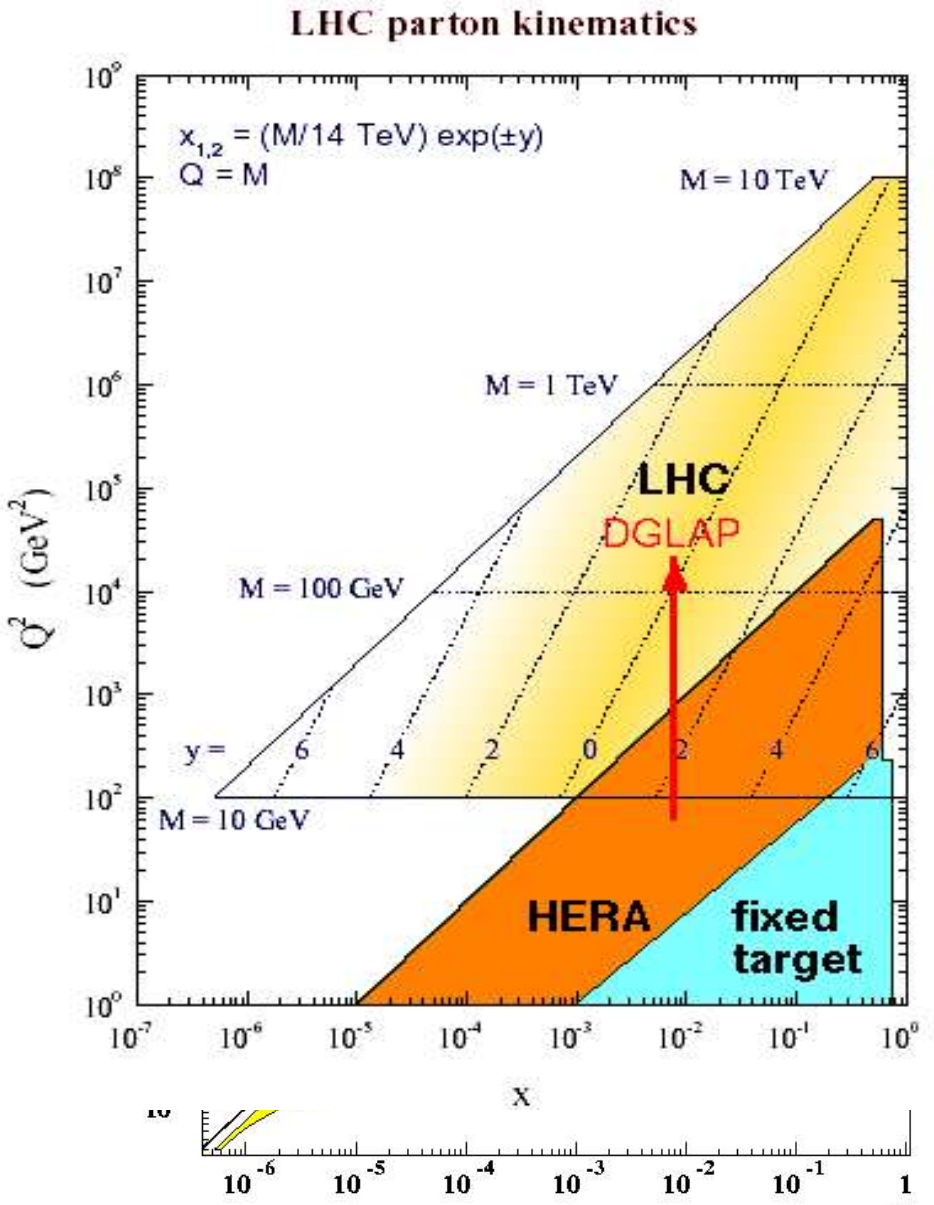


HERA and LHC

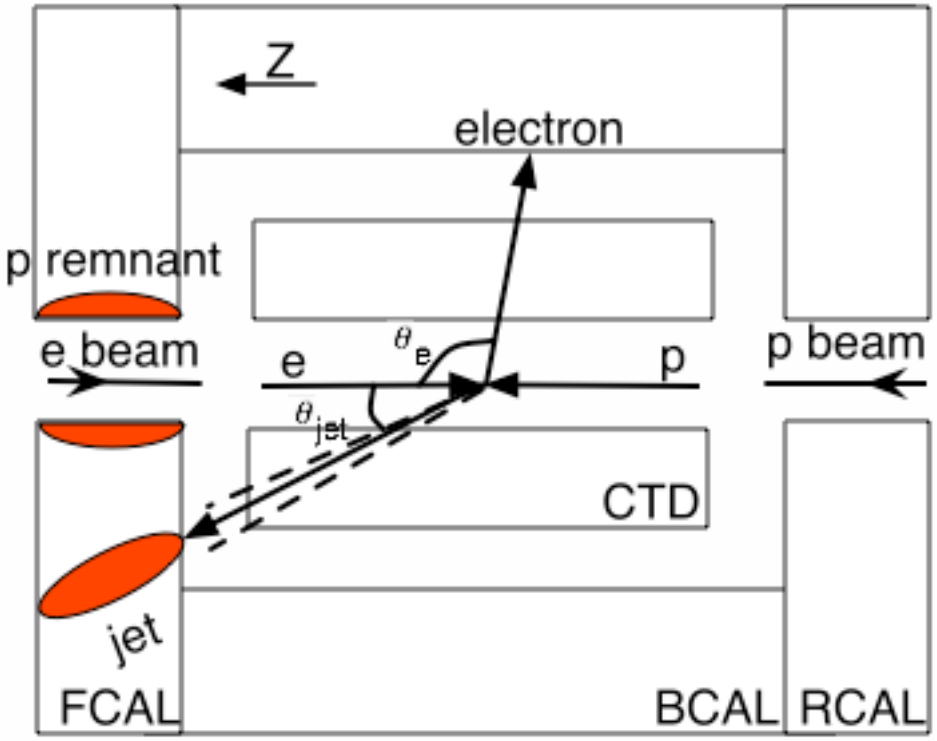
HERA results essential for predictions of LHC processes

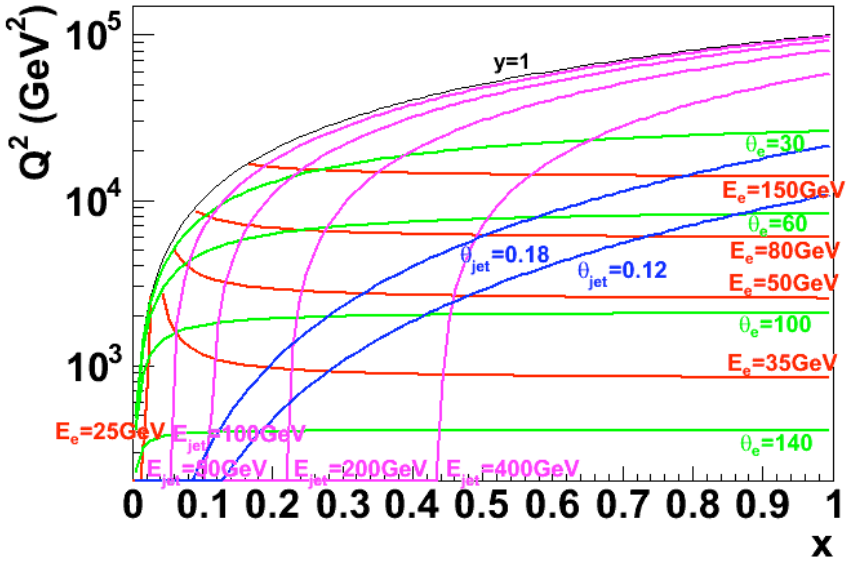
- Gluon density
- Quark density at large x => Discovery potential! Needs high Luminosity: HERA-II!





HERA high-x





- At high Q^2, scattered electron seen with ≈100% acceptance
- Need jet to measure x - not too high x

High-x incl. cross sections

ZEUS-pub-06-003

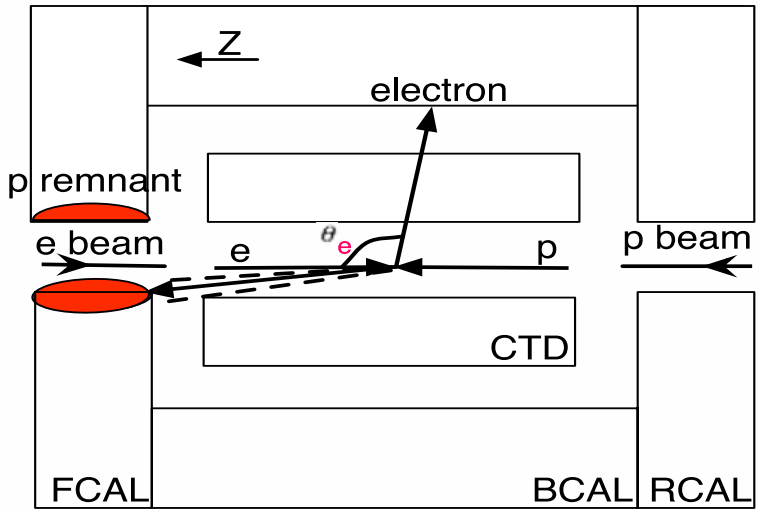
- Motivation: Poor knowledge of high-x PDFs (HERA x~0.65, BCDMS~ 0.75)
- New technique which allows the meas. of incl. cross sections up to Bjorken x=1

Re-analysis of HERA I high-Q^2 $e^{\pm}p$ data ($Q^2 > 425$ GeV^2)

<u>Electron-Jet Method</u>:

Use elec. and jet E and θ to reconst. Q^2,x

1. Always use E_e and θ_e for Q^2
2. For each Q^2 bin define x-bins
   a) Jet far from beam pipe (low-x)
      → x from E_{jet} , θ_{jet}
   b) Jet near the beam-pipe (high-x)
      → collect events in [x_{edge},1]



Measure:

$$\frac{d^2\sigma}{dQ^2 dx} \quad \text{and} \quad \int_{x_{edge}}^{1} dx \frac{d^2\sigma}{dQ^2 dx}$$

High-x incl. cross sections

ZEUS-pub-06-003

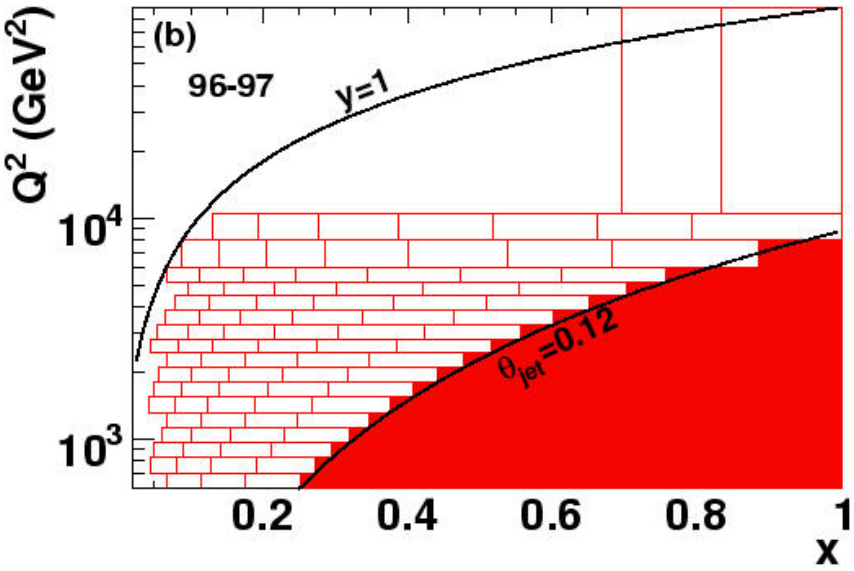
- Motivation: Poor knowledge of high-x PDFs (HERA x~0.65, BCDMS~ 0.75)
- New technique which allows the meas. of incl. cross sections up to Bjorken x=1

Re-analysis of HERA I high-Q^2 $e^{\pm}p$ data ($Q^2 > 425$ GeV^2)

<u>Electron-Jet Method</u>:

Use elec. and jet E and θ to reconst. Q^2,x

1. Always use E_e and θ_e for Q^2
2. For each Q^2 bin define x-bins
   a) Jet far from beam pipe (low-x)
      → x from E_{jet} , θ_{jet}
   b) Jet near the beam-pipe (high-x)
      → collect events in [x_{edge},1]



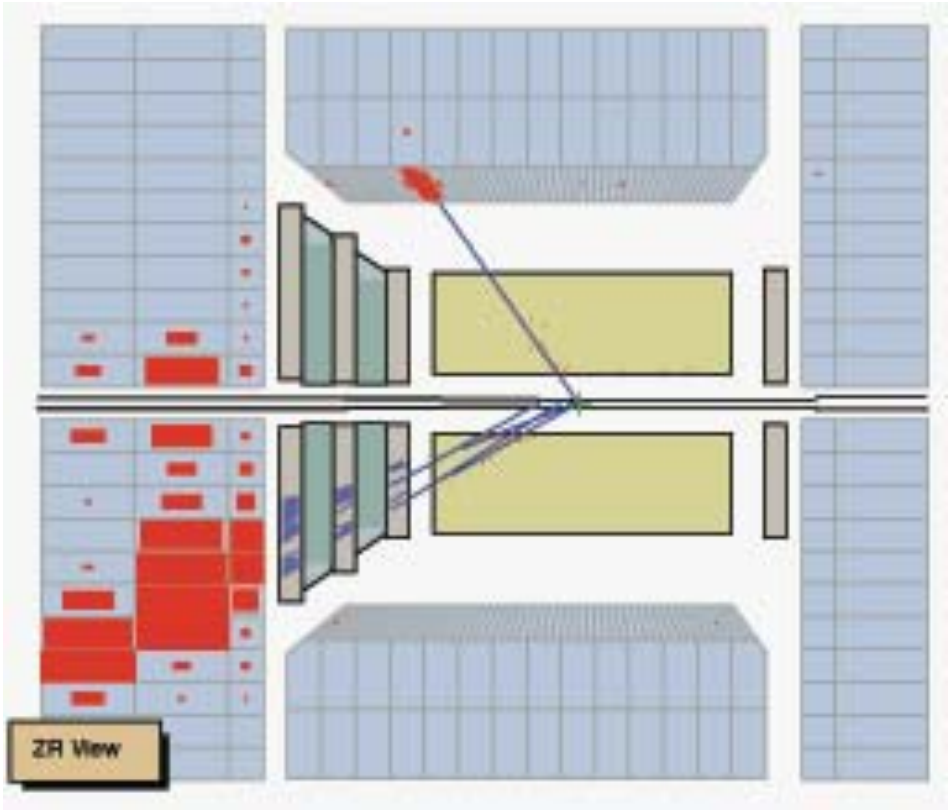
Measure:

$$\frac{d^2\sigma}{dQ^2dx} \quad \text{and} \quad \int_{x_{edge}}^{1} dx \frac{d^2\sigma}{dQ^2dx}$$

HERA Kinematics

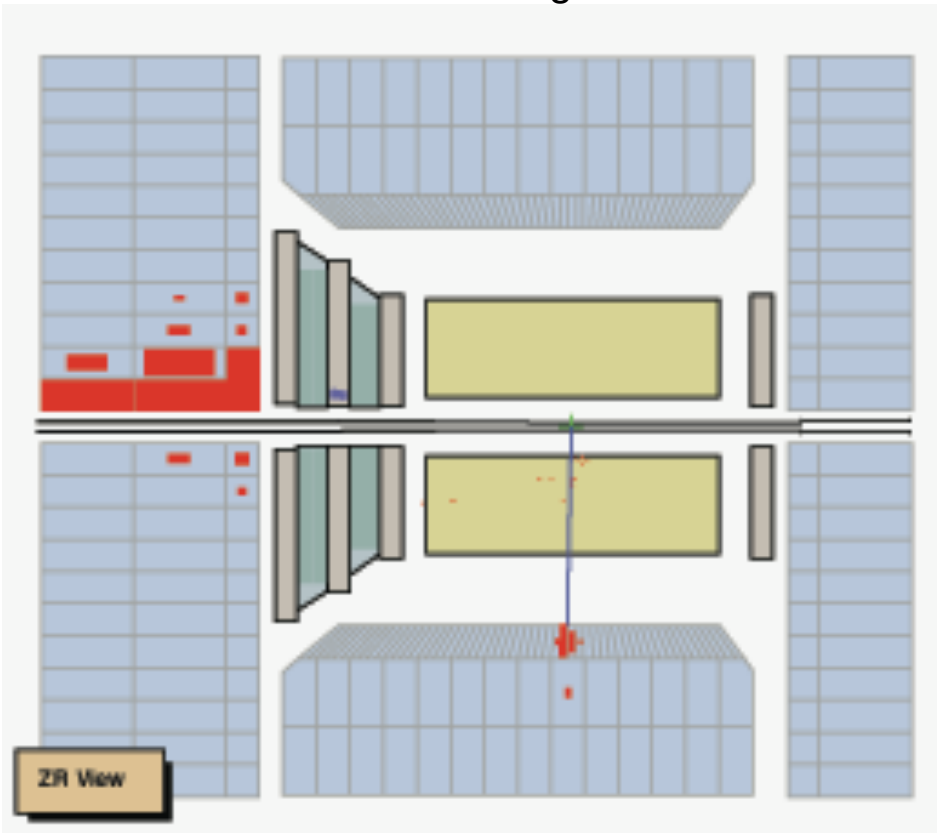
Jet found

$x<x_{Edge}$



No jet found

$x>x_{Edge}$

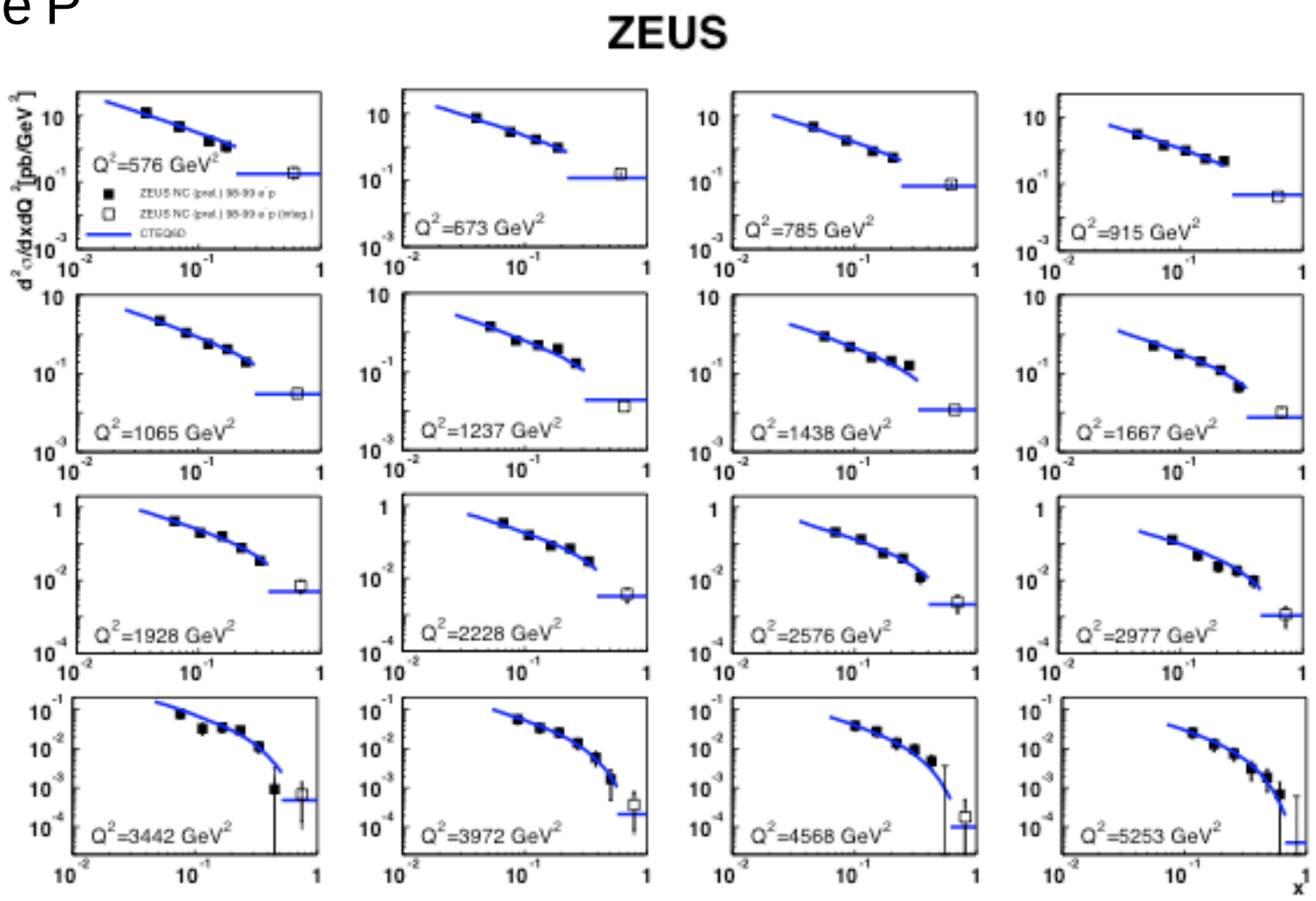


Jet definition: $E_T>10$ GeV, $\theta_{jet}>0.12$

only 0,1 jet events used

Results

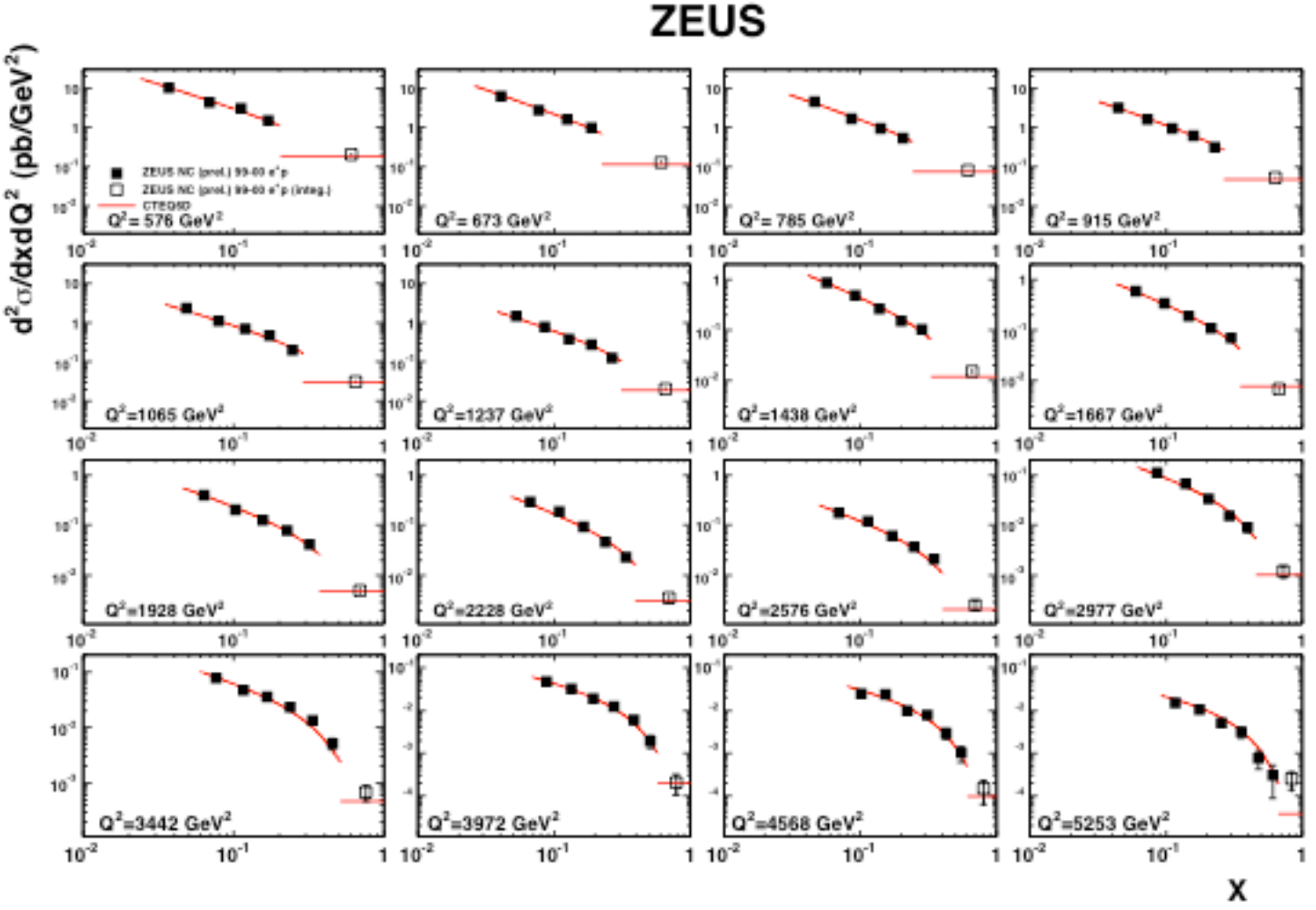
98-99 $e^{-}P$



Blue line is CTEQ6D expectation

Results

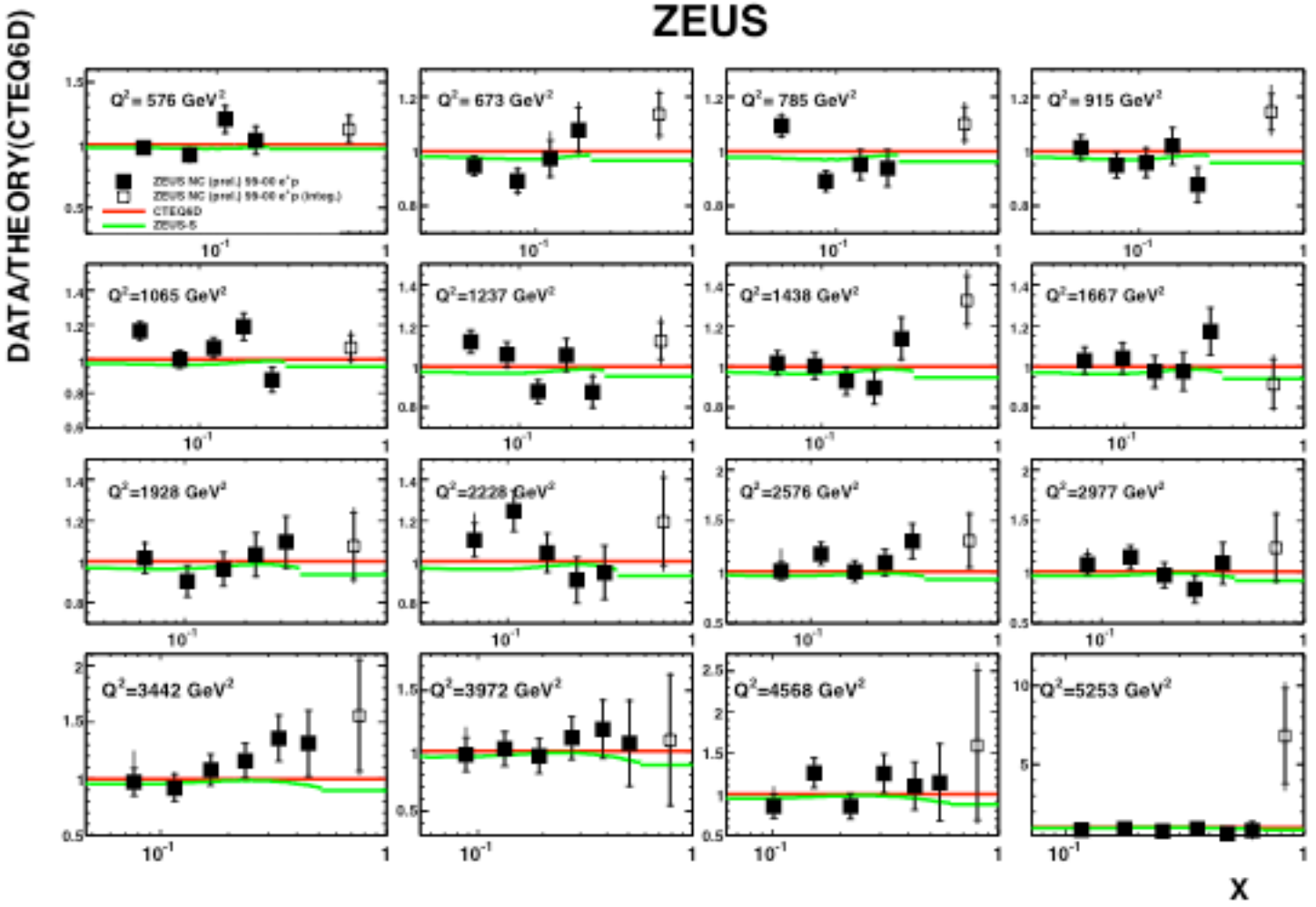
99-00 e^+P



Red line is expectation from CTEQ6D

Results

99-00 e^+P



Good agreement with CTEQ6D in previously measured region.
Data tend to lie above expectations at highest x.

F_3

- Remember:

$$\frac{\mathrm{d}^2\sigma^{\pm}_{\mathrm{NC}}}{\mathrm{d}x\,\mathrm{d}Q^2} = \frac{2\pi\alpha^2}{xQ^4}\left(Y_+\tilde{F}_2 \mp Y_- x\tilde{F}_3 - y^2\tilde{F}_{\mathrm{L}}\right) \qquad Y_\pm = 1 \pm (1-y)^2$$

- F_3 enters with different sign for e^-p and e^+p scattering:
  measured from difference of e^-p and e^+p cross sections
  => needs high accuracy data with both lepton charges!

- F_3 dominated by γZ interference,
  measures difference of quark and antiquark densities: valence quarks

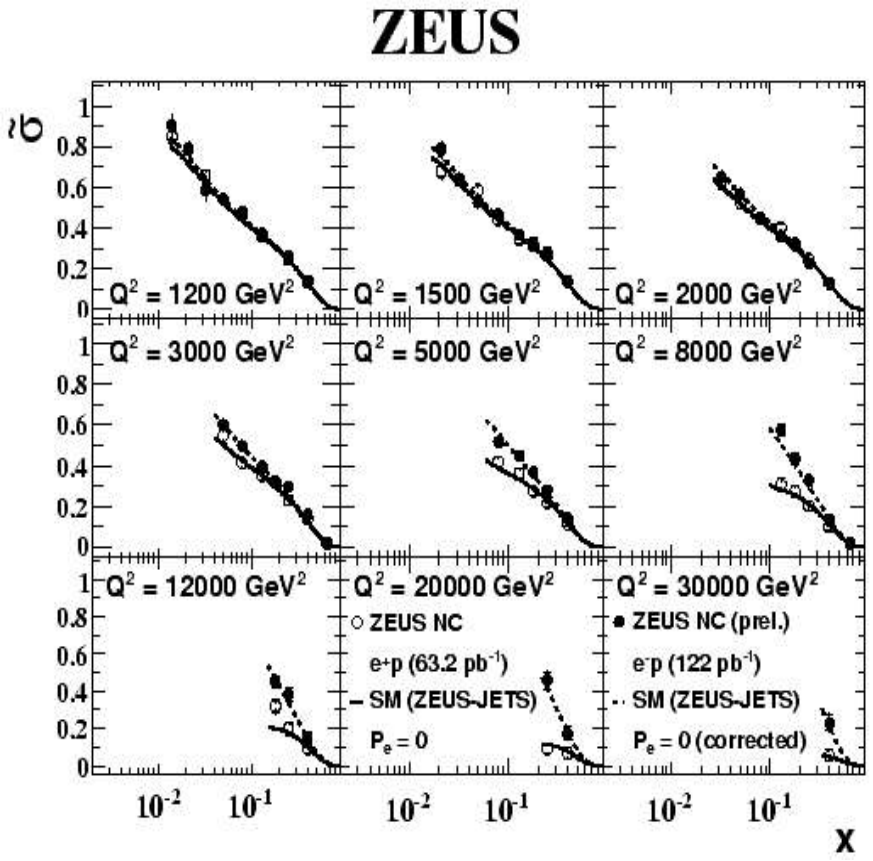
$$x\tilde{F}_3 = k(-a_e)xF_3^{\gamma Z} + k^2(2v_e a_e)xF_3^Z$$

$$xF_3^{\gamma Z} = 2x\sum_q (e_q a_q)(q-\bar{q}) = 2x(2u_v + d_v)$$

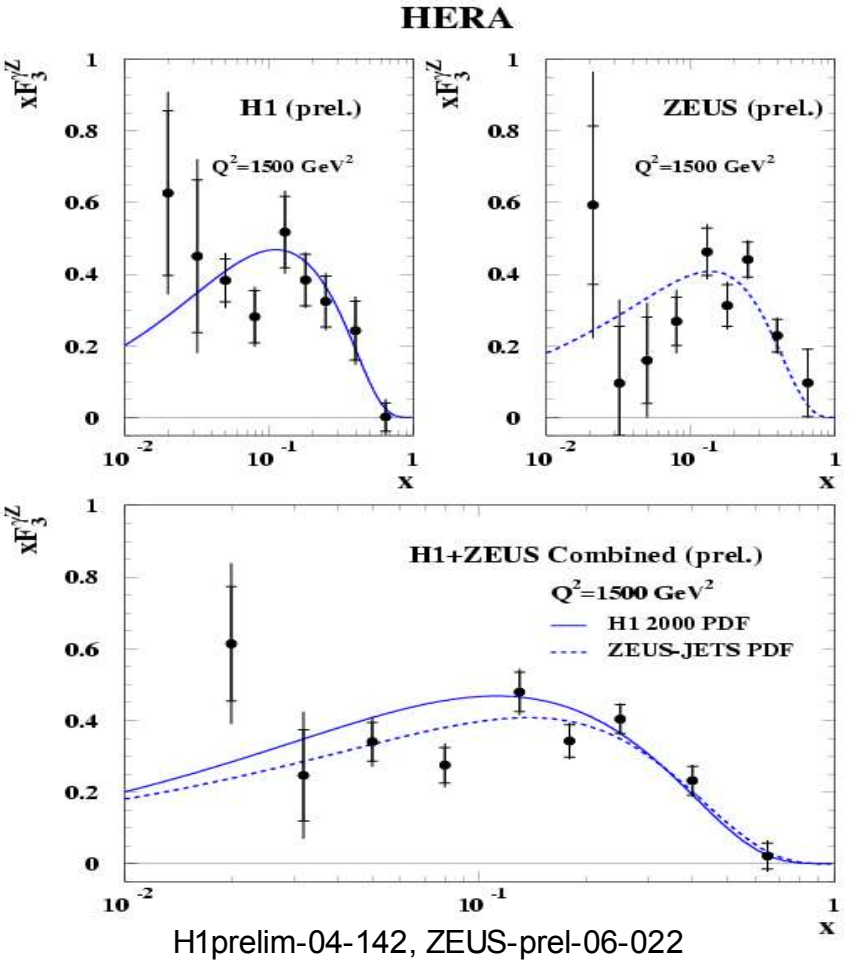
- **Dominated by u quark contribution**: larger charge and 2 u quarks

Measurements of F_3

- ZEUS and H1 have measured F_3, using latest HERA-II e^-p data
- First combined H1/ZEUS measurement => overall 478.8pb^{-1}
- Measurement of u valence quark density



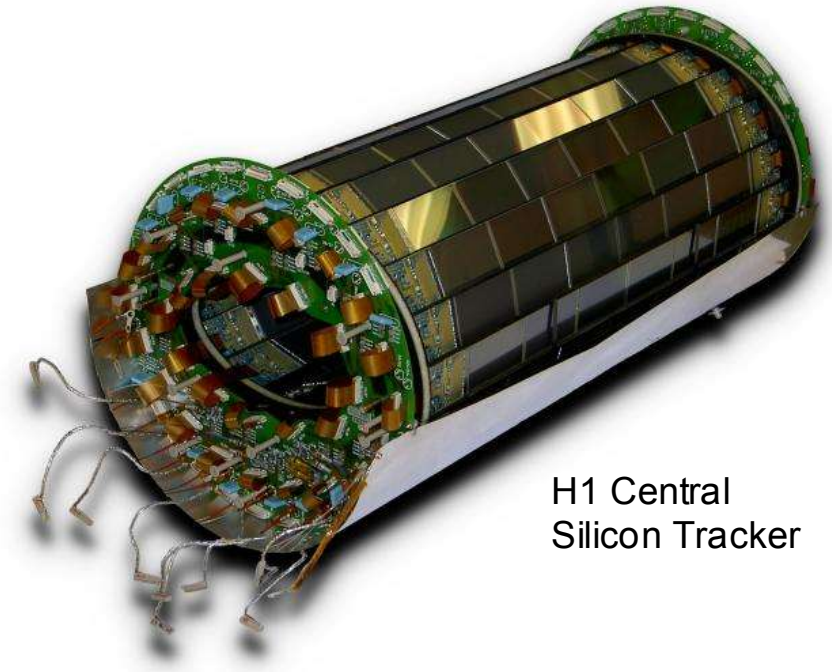
ZEUS-prel-06-001



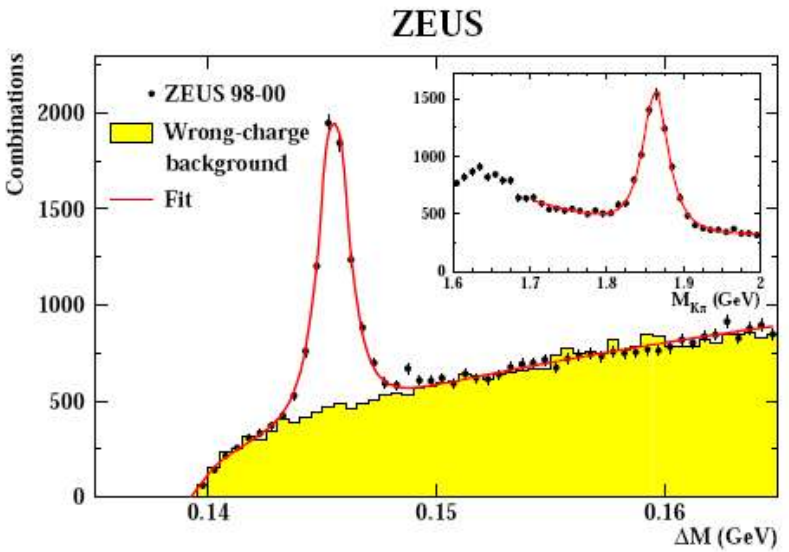
H1prelim-04-142, ZEUS-prel-06-022

Flavour-Exclusive Measurements

- Define structure functions $F_2^{c\bar{c}}$, $F_2^{b\bar{b}}$ for charm and beauty production
- Charm tagging: D* or lifetime tag; beauty: lifetime tag



H1 Central
Silicon Tracker



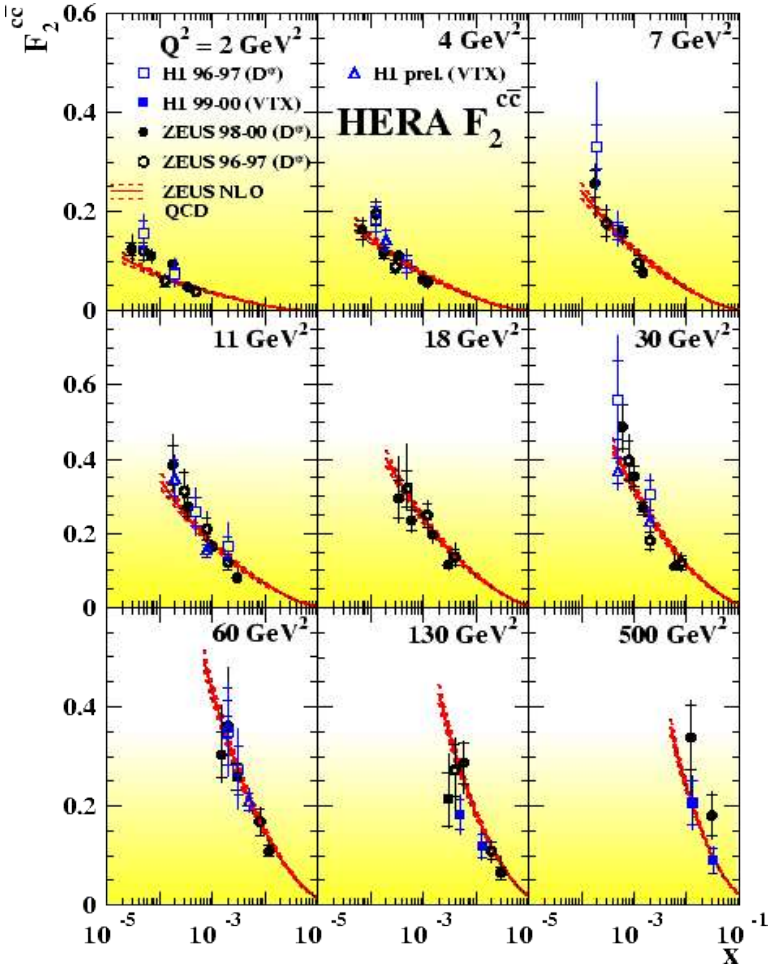
ZEUS, PR **D69** (2004) 012004.

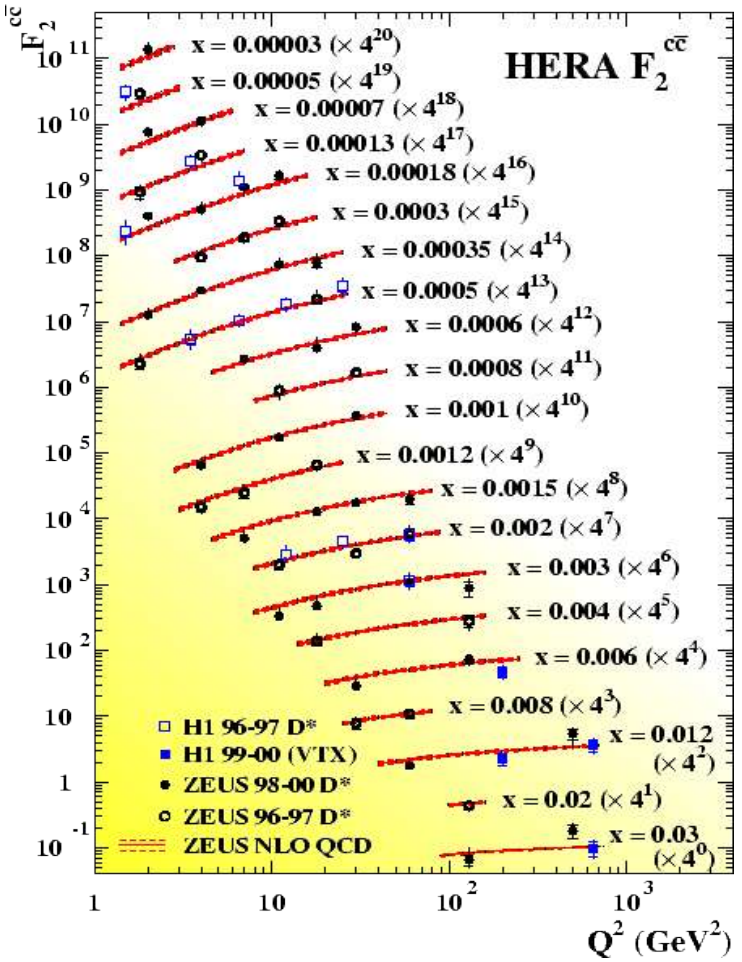
$D^* \rightarrow (K\pi)\ \pi_s$

ZEUS BOTTOM MICRO VERTEX DETECTOR

Charm Contribution

- Charm well described by NLO QCD; at low Q^2: slight deviations
- Precise enough to constrain the gluon, but: theory uncertainties!

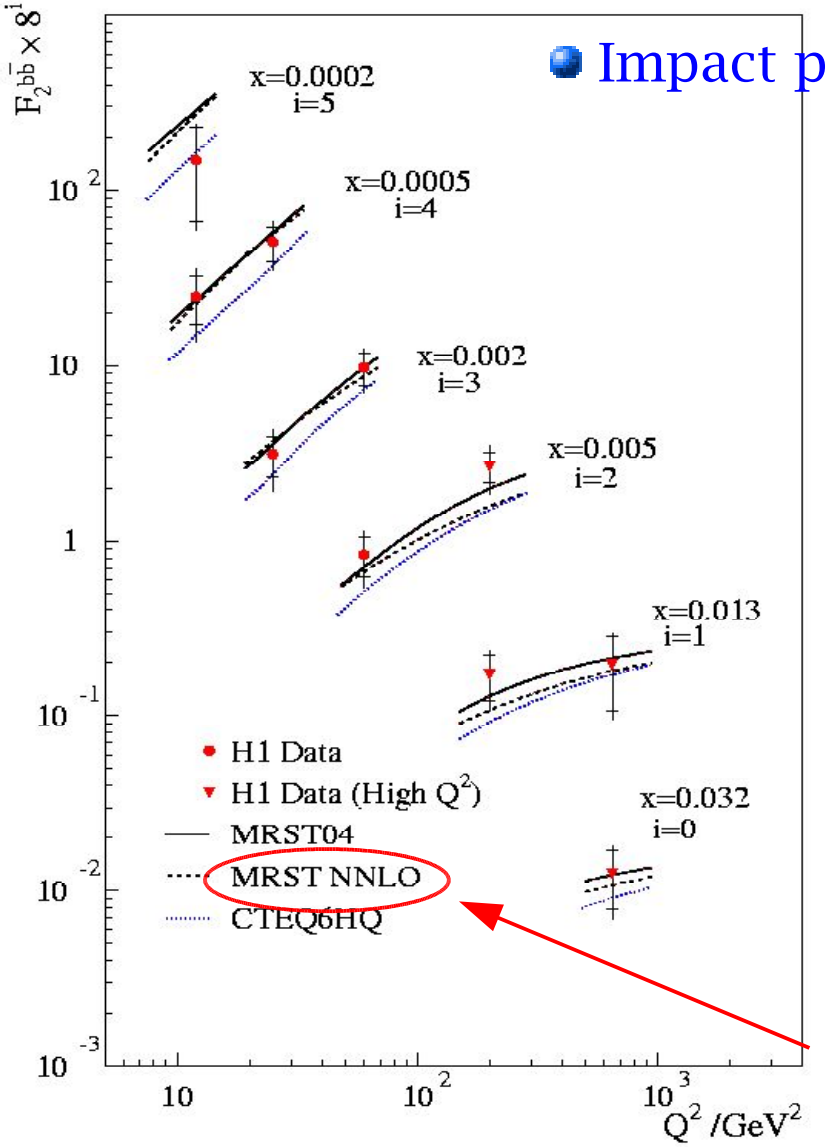




ZEUS, PR **D69**(2000)012004. H1, EPJ **C40** (2005) 349. H1, EPJ **C45** (2006) 23.

First measurement of $F_2^{b\bar{b}}$

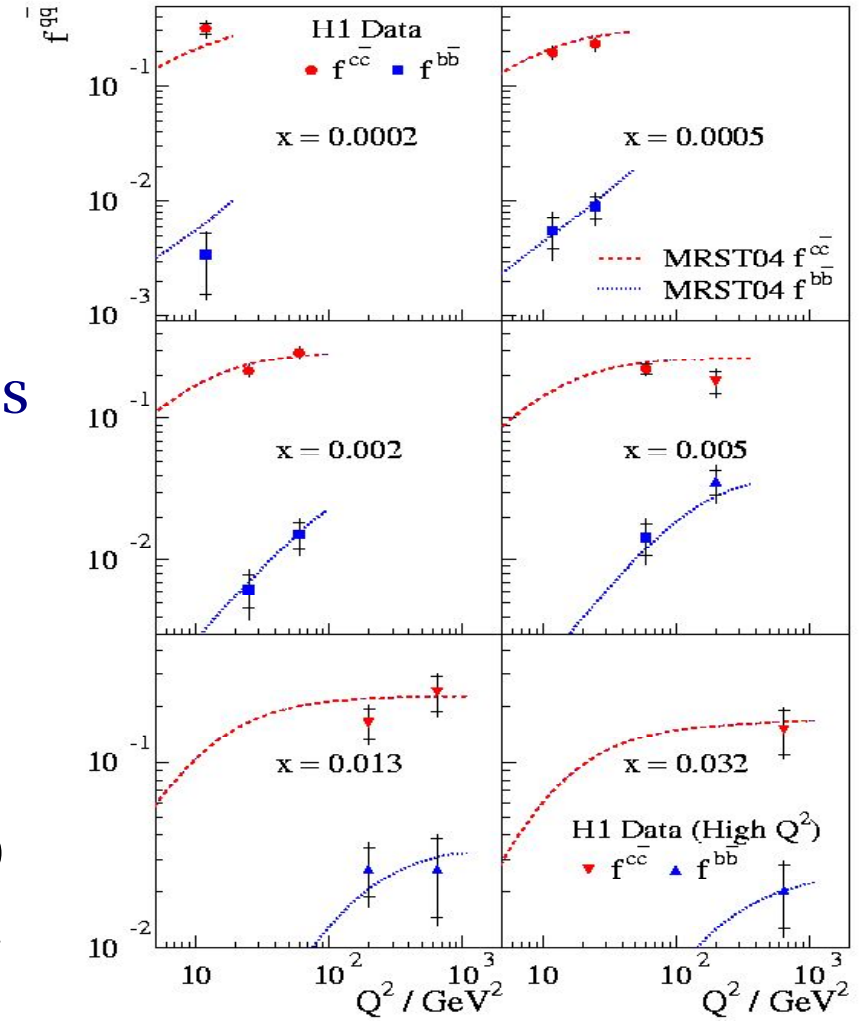
- Impact parameter method.



Beauty contributes up to 3%

First NNLO calculation

F_2^b/F_2



Prospect: Measurement of F_L

$$\sigma_r = F_2(x,Q^2) - \frac{y^2}{Y_+} F_L(x,Q^2)$$

Longitudinal structure function gives direct access to poorly known gluon density at low x, theoretically very uncertain, important to understanding of pQCD

$$F_L = \frac{\alpha_s}{4\pi} x^2 \int_x^1 \frac{dz}{z^3} \left[\frac{16}{3} F_2 + 8 \sum e_q^2 \left(1 - \frac{x}{z}\right) zg \right]$$

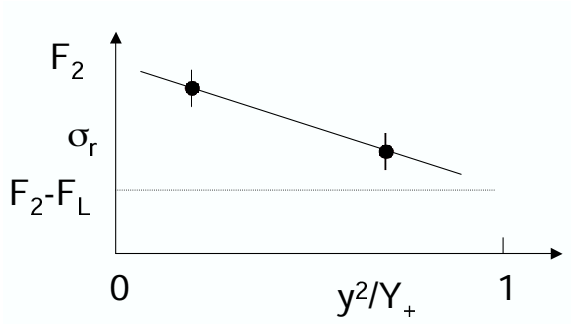
sizeable at large $y > 0.6$

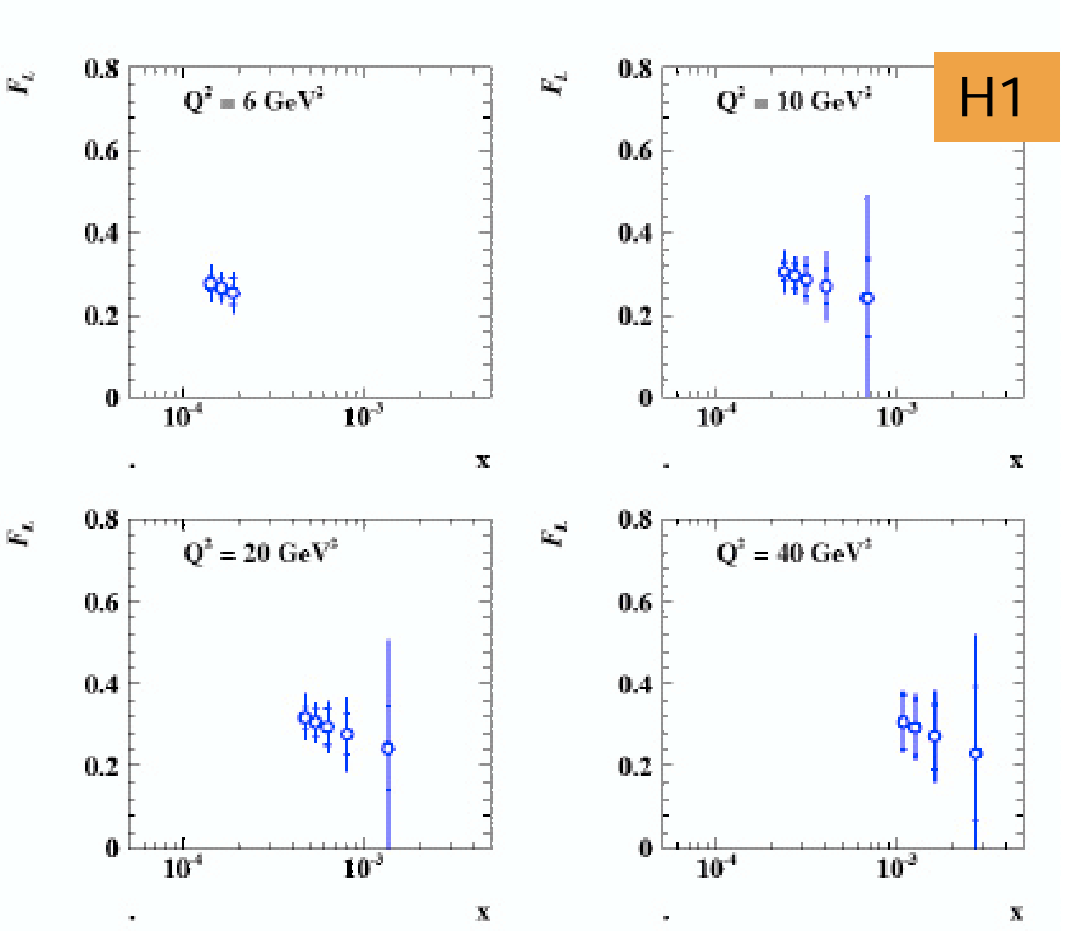
Measure cross section at same x, Q^2 and different y, change $y = Q^2/xs$ by lowering s with $E_p = 460\,\mathrm{GeV}$

Challenge to machine lower E_p, reduced lumi $\sim 1/4$
Challenge to experiment low scattered e^+ $E'_e \gtrsim 3\,\mathrm{GeV}$, huge γp bkg at high y

H1 + ZEUS: F_L is a must for HERA

agreed to collect $\mathcal{L} = 10\,\mathrm{pb}^{-1}$
3 months data taking
$Q^2 = 5 - 40\,\mathrm{GeV}^2$, $x = (0.1 - 4) \cdot 10^{-3}$
expect moderate precision $\delta F_L \sim 0.05$
corresponding to 5 st. dev depending on F_L

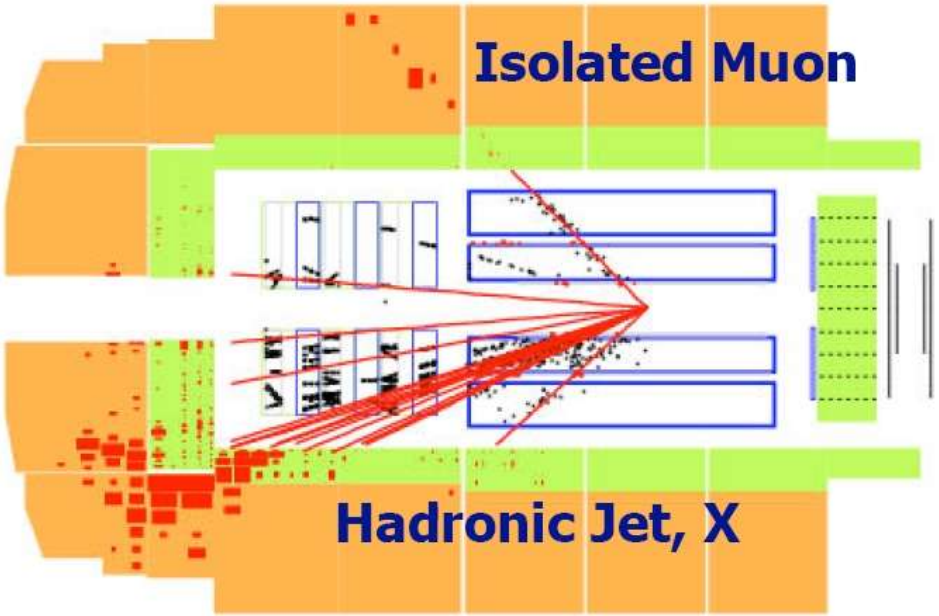




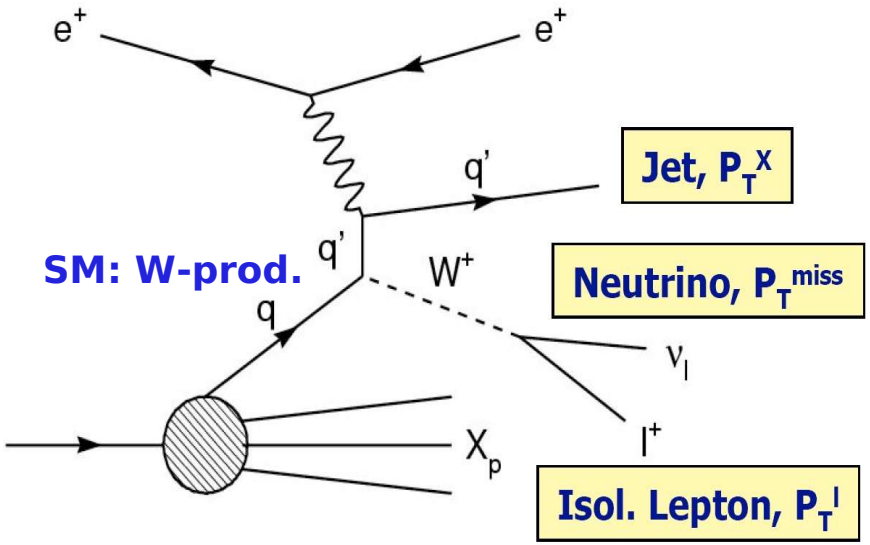
Odstępstwa od przewidywań Modelu Standardowego

Isolated Leptons - Reminder

➔ Most prominent excess over SM seen in HERA I : Isolated leptons!



HERA I μ + P_T^{miss} event

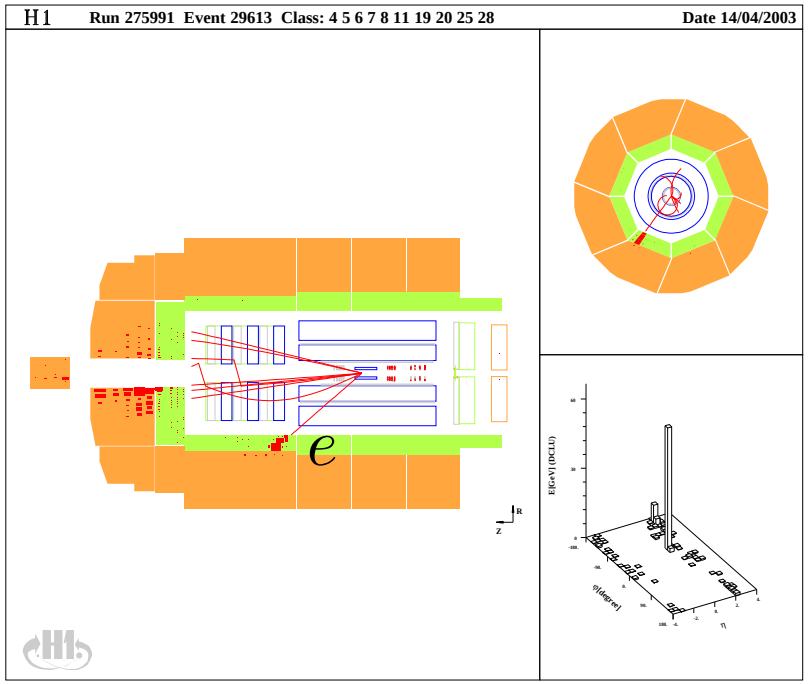


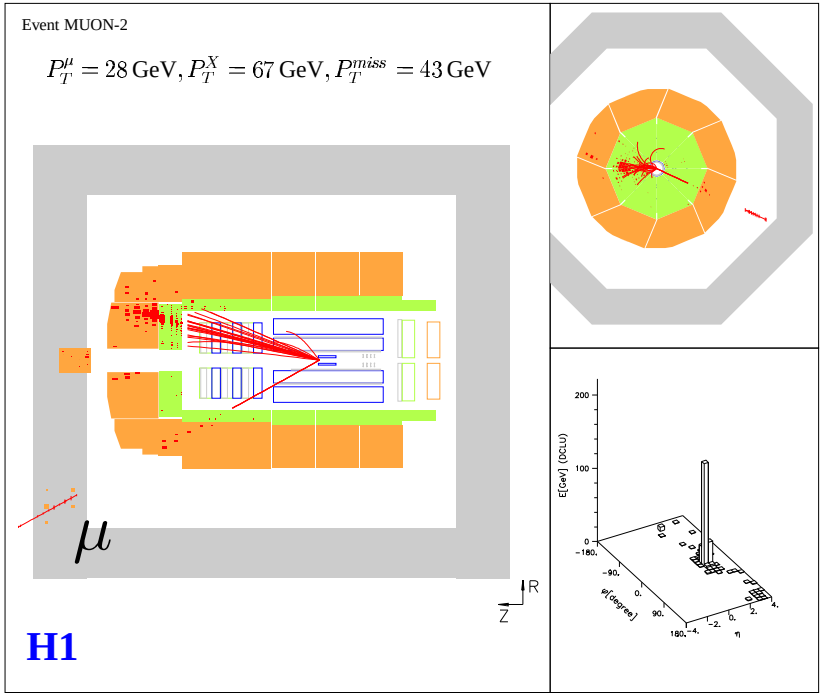
➔ Excess observed for p_T^X >25 GeV

1994-97

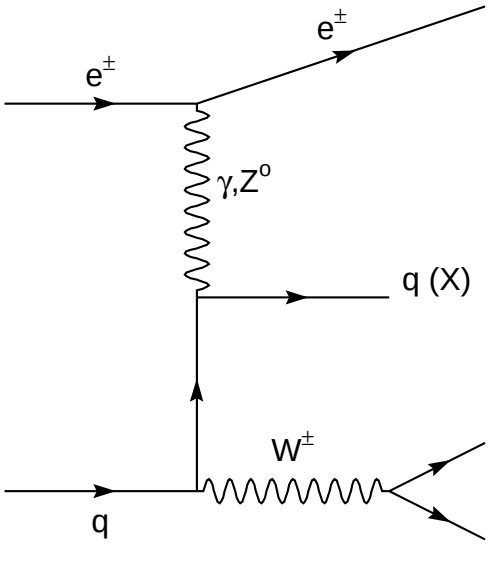
H1 observed an **excess of events** with a high P_T isolated lepton and missing P_T

[Eur. Phys. J. C **5** (1998) 575]





- Only significant contribution to this **signal** comes from SM W **production** with leptonic decay



Jet $\Longrightarrow P_T^X$
(Hadronic recoil)

Isol. lepton

Missing P_T

- Standard Model (LO) predicts
  $\sigma(ep \to eW^{\pm}X) \approx 1$ pb

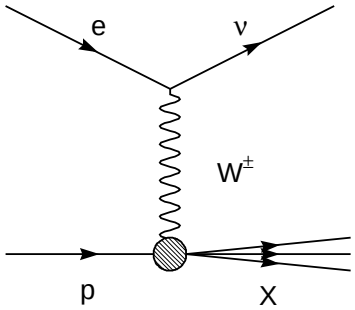
- **Branching ratio**
  $W \to$leptons$\approx 10.7\% \cdot 3$
  $W \to$hadrons$\approx 68\%$

- NLO SM W calculations
  now available

  K. P. Diener, C. Schwanenberger, M. Spira,
  Eur. Phys. J. C **25** (2002) 405

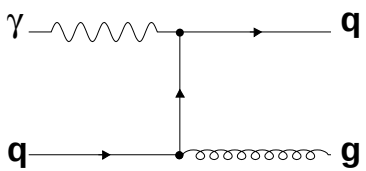
  $\Longrightarrow$ talk of C. Schwanenberger

Charged Current (CC) processes :



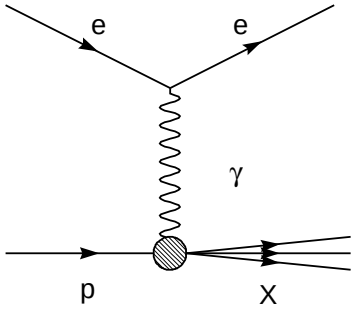
hadron or radiative photon
can be misidentified as lepton

Photoproduction of jets $(\gamma \mathrm{p})$:



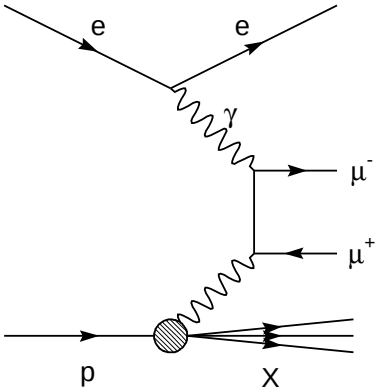
real or fake lepton from
hadronic final state
and P_T^{miss}
from mismeasurement
or non-containment

Neutral Current (NC) processes :



scattered lepton and P_T^{miss}
from mismeasurement or
non-containment can fake
$W \rightarrow e\nu$ candidates

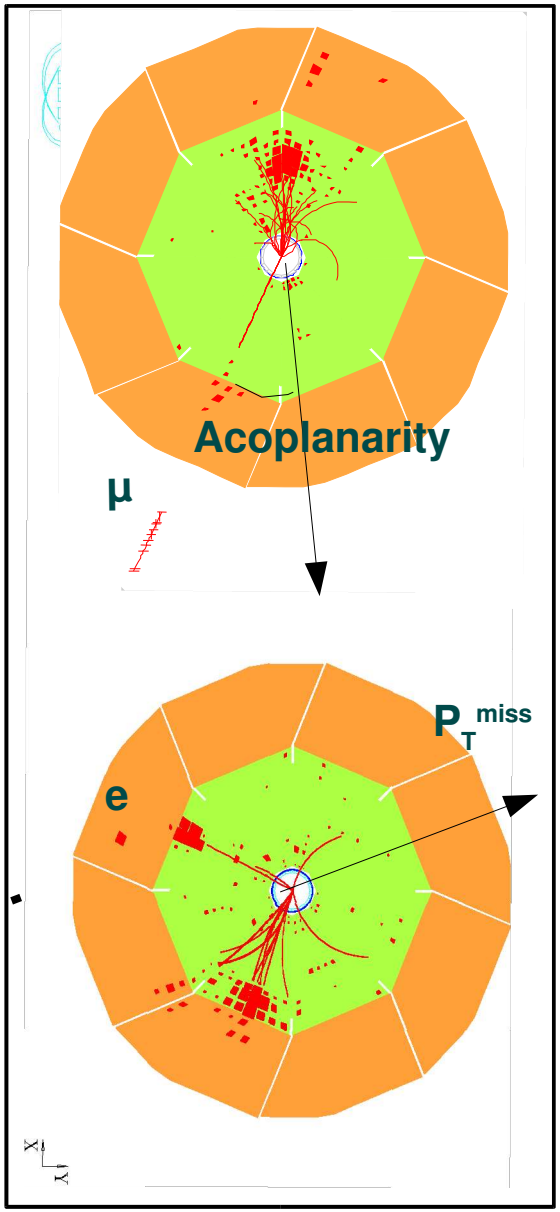
Lepton pair (LP) production :



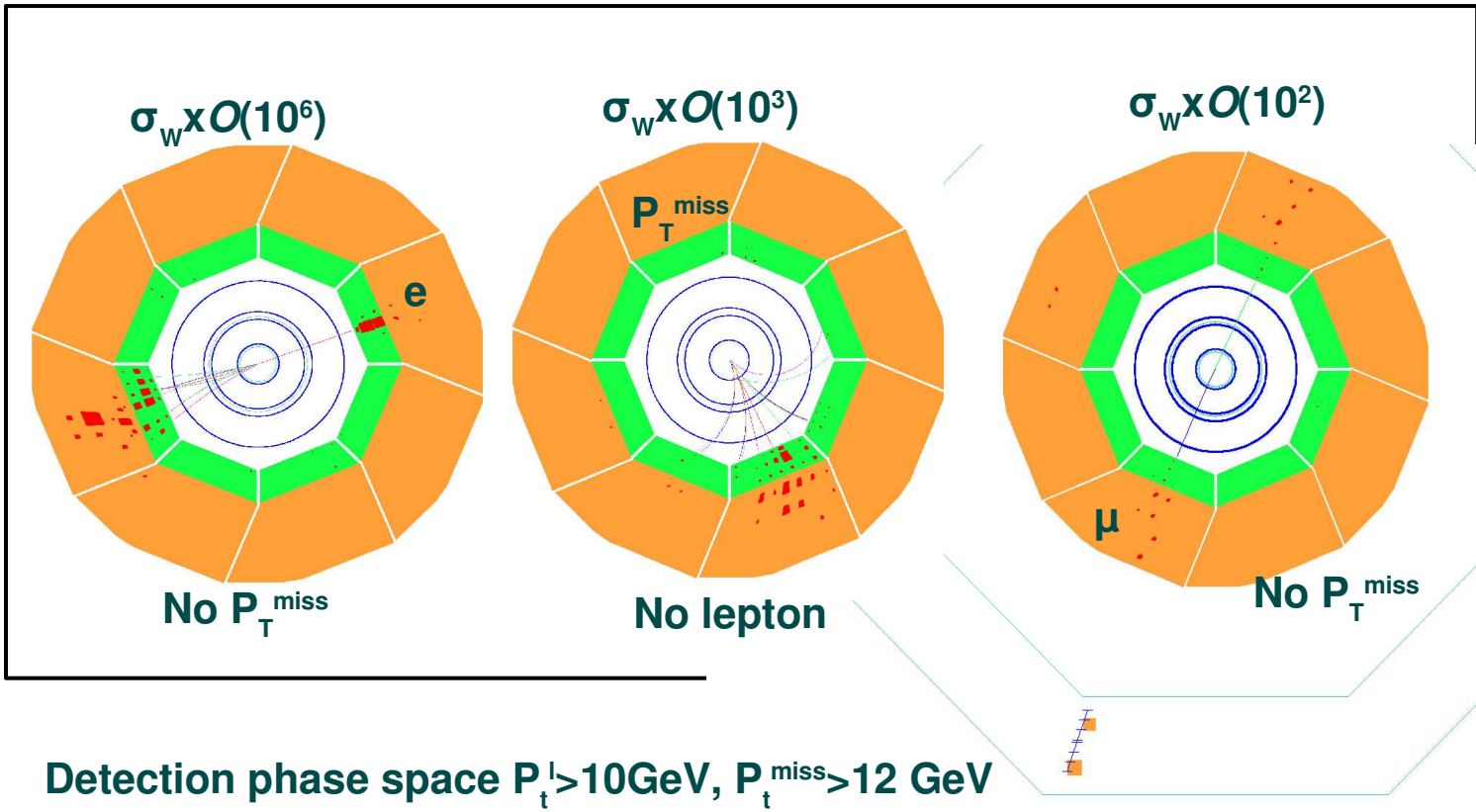
One lepton is not detected

Signal/Background Discrimination

Signal



Backgrounds



Detection phase space P_t^l>10GeV, P_t^{miss}>12 GeV

reduce most of the background

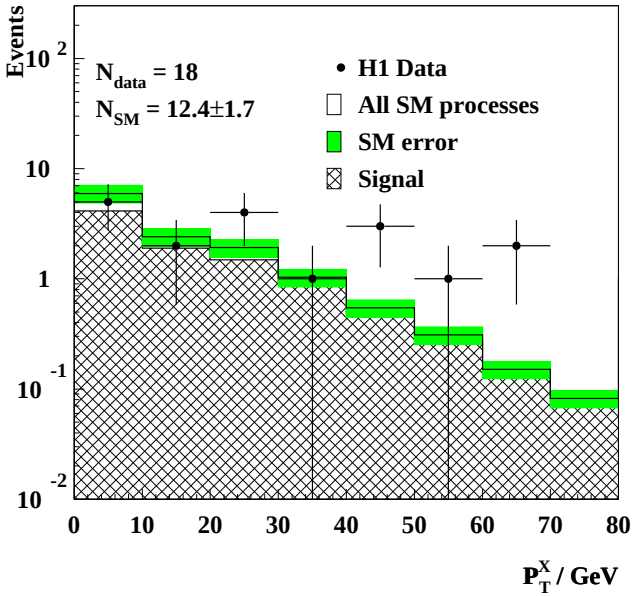
Further background supression using:

- -lepton isolation D_{track} , D_{Jet}
- -event balance (Acoplanarity)
- -extra-kinematics (M_T^{lv}) + other topological variables

1994-2000

Electron and Muon	H1 Data	SM Total	W Signal	Other SM processes
$25 < P_T^X < 40$ GeV	4	1.83 ± 0.27	1.59 ± 0.26	0.24 ± 0.06
$P_T^X > 40$ GeV	6	1.08 ± 0.22	0.96 ± 0.22	0.12 ± 0.04

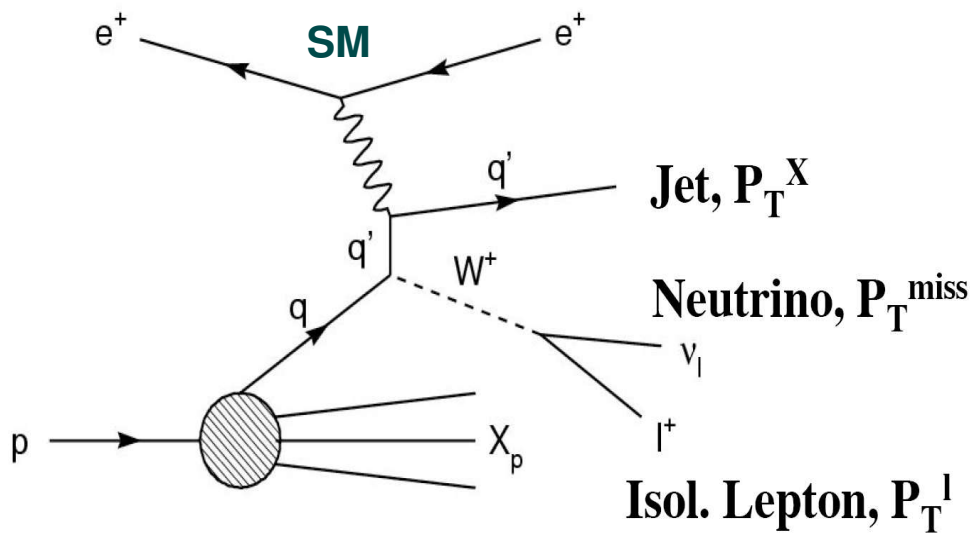
$\Longrightarrow$ **H1** sees largest excess at large P_T^X
where background is very small



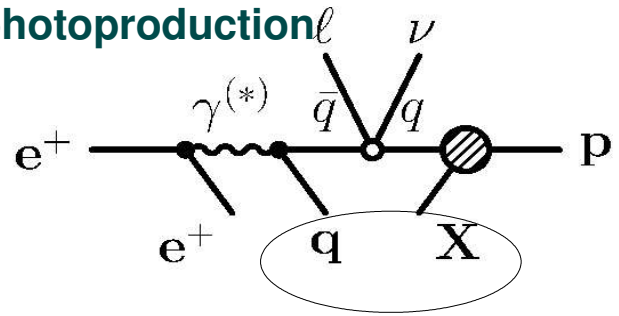
ZEUS data compatible with
expectation in whole P_T^X-range:

ZEUS preliminary 94-00 $e^{\pm}p$ 130 pb^{-1}	Electrons Obs./exp. (W)	Muons Obs./exp. (W)
$P_T^X > 25$ GeV	2 / $2.90^{+0.59}_{-0.32}$ (45%)	5 / $2.75^{+0.21}_{-0.21}$ (50%)
$P_T^X > 40$ GeV	0 / $0.94^{+0.11}_{-0.10}$ (61%)	0 / $0.95^{+0.14}_{-0.10}$ (61%)

Events with isolated leptons and P_T^{miss}



Mostly W photoproduction



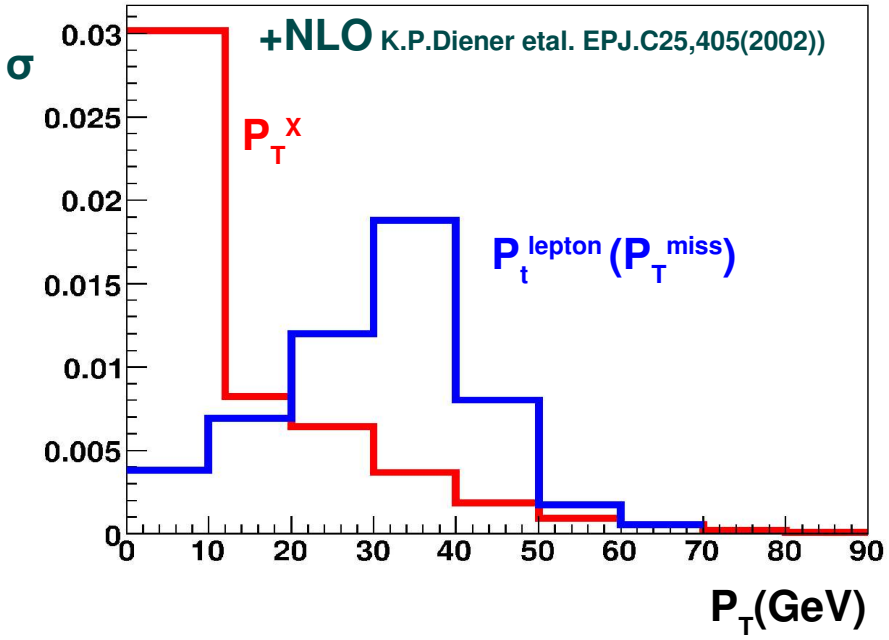
hadronic system
typically "quiet"

Total Cross Section ~1.3 pb

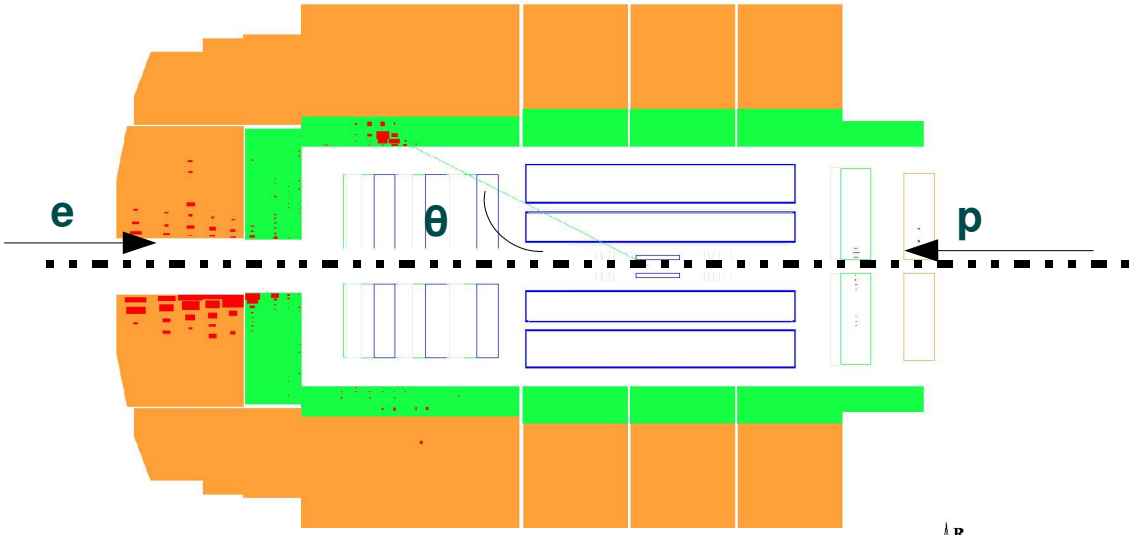
=> ~5 events/100pb^{-1}with e or μ

[Hadronic channel is difficult, due to QCD background.]

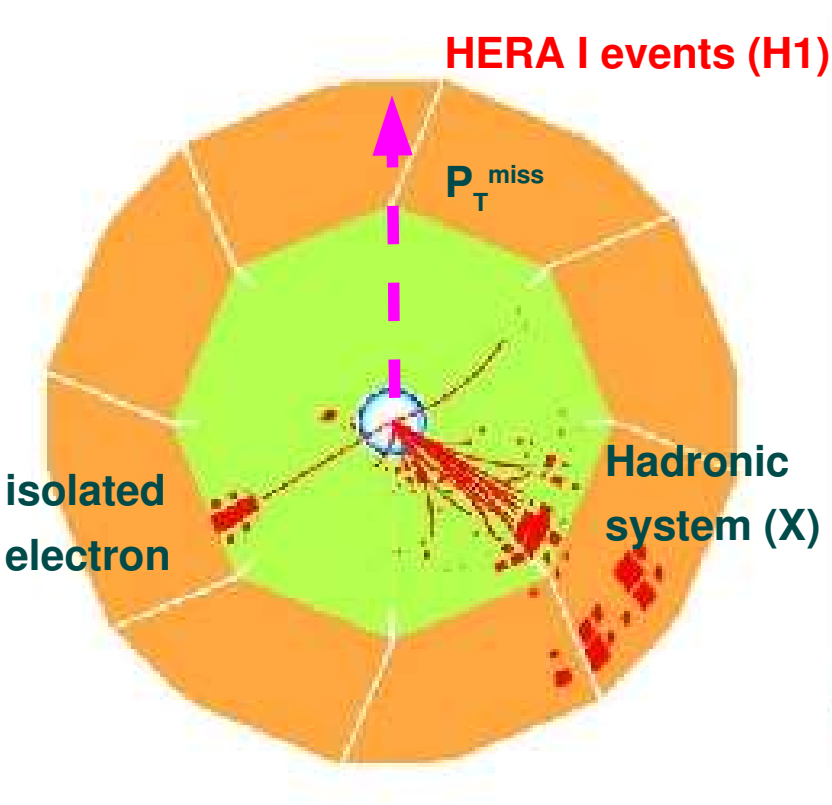
EPVEC Generator U.Baur at al., Nucl.Phys.B375:3(1992

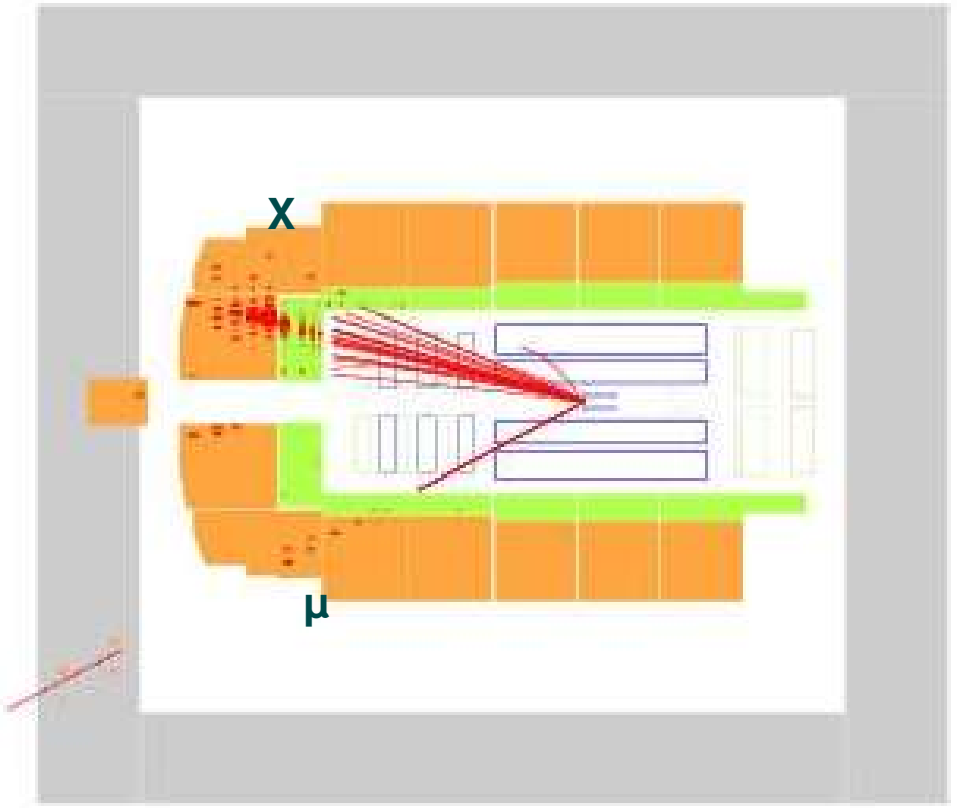


Typical W→e+P_T^{miss} event (Monte Carlo)



Event with isolated leptons and P_T^{miss}





Observation by H1: L=118 pb^{-1} (mainly e^+p, first events in 1994)

Spectacular events at large PTX in excess (still consistent with a stat. fluct.)

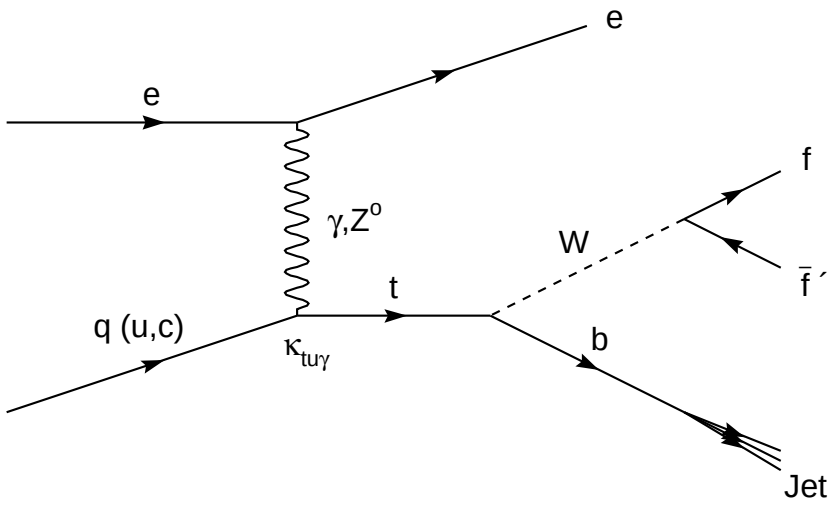
P_T^X>25 GeV 11 (Data) / 3.5±0.6 (SM) Phys.Lett.B561:241-257,2003

Not supported by ZEUS (search for top, higher P_T) Phys.Lett.B559:153-170,2003

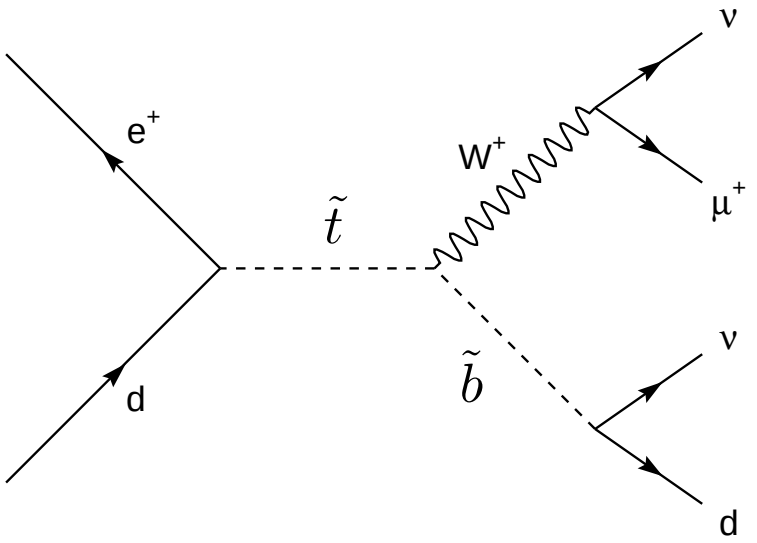
Interpretation?

Beyond the SM, other processes have similar topology, e.g.

FCNC single top production



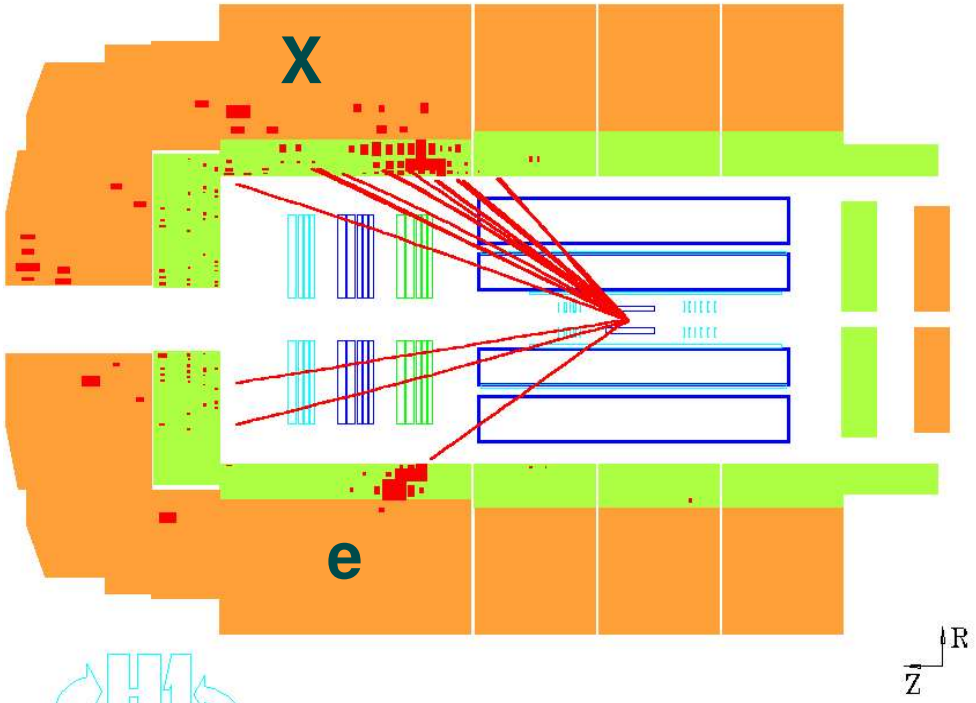
$\not{R}_p$ supersymmetry stop production

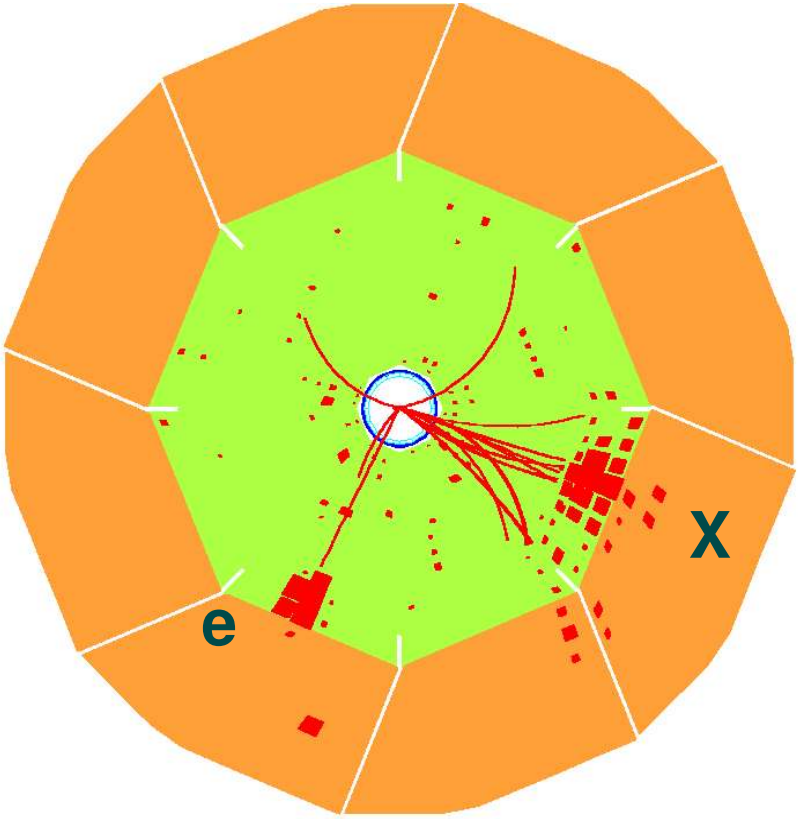


$\Longrightarrow$ Both examples expect large hadronic recoil

$\rightarrow$ see talks on top production (e.g. A. Schöning)

H1 candidate from e^+p HERA 2 data

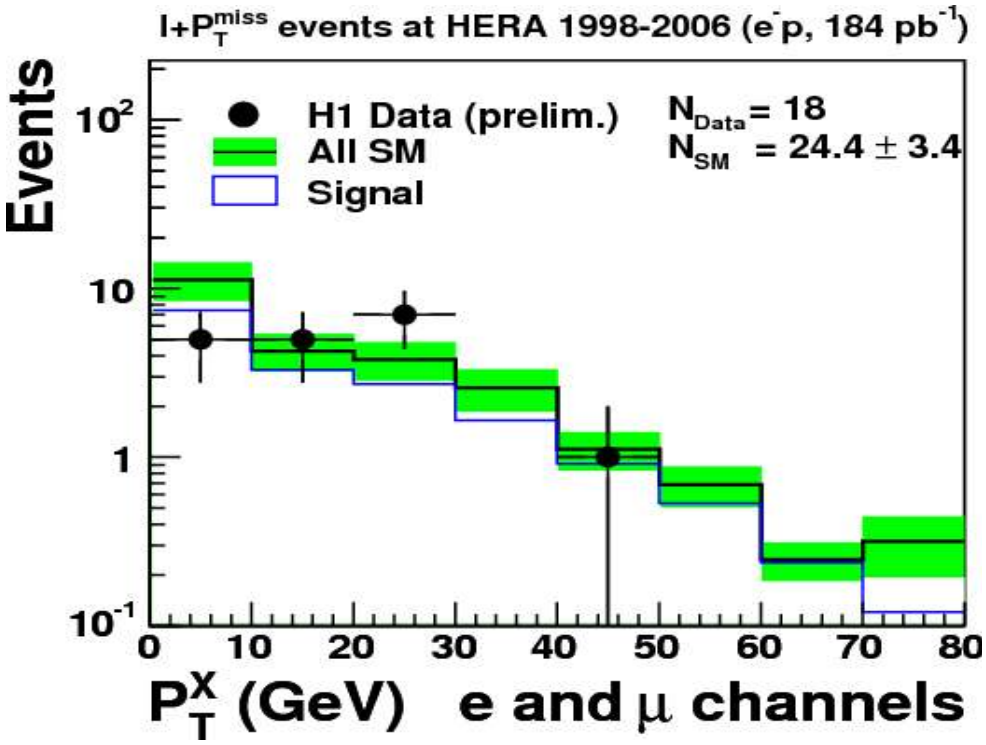




$$\mathbf{P}_T^e = 37 \text{ GeV}, \mathbf{P}_T^{miss} = 44 \text{ GeV}, \mathbf{P}_T^X = 29 \text{ GeV}$$

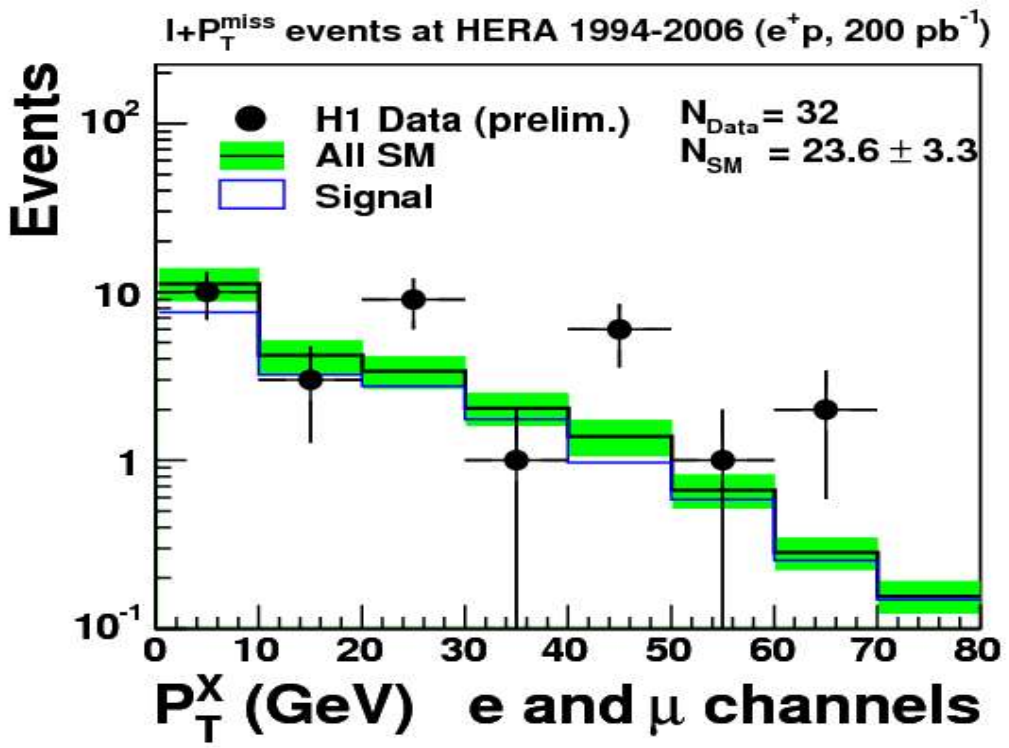
Isolated leptons: all HERA I+II data

➔ e^-p, (184 pb^{-1}) including 65 pb^{-1} (2006):



➔ No indications for excess in e^-p

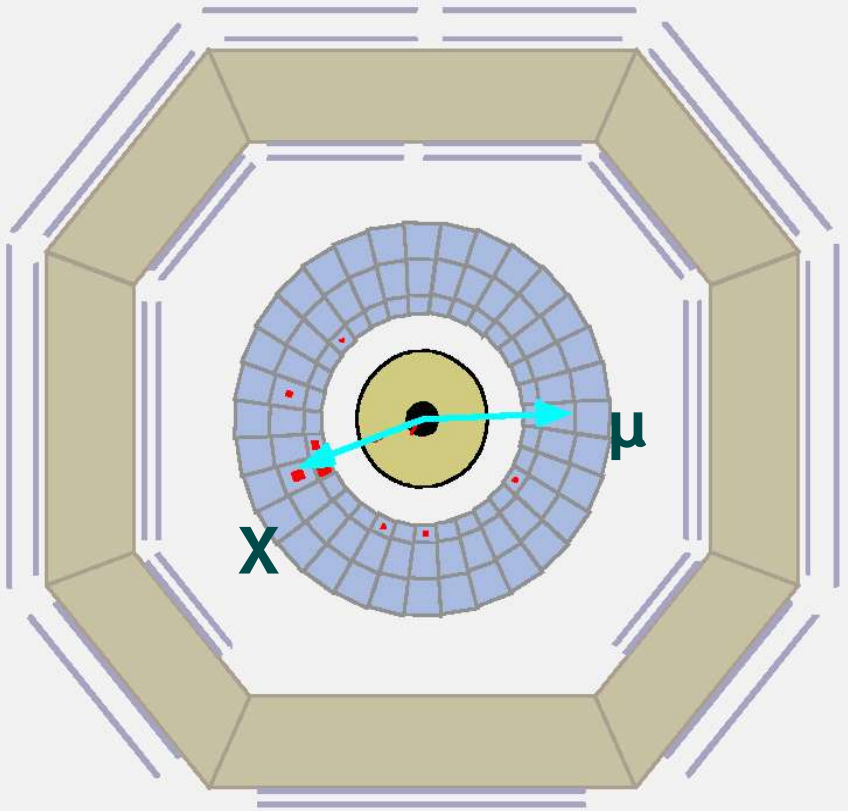
➔ e^+p, (200 pb^{-1}) including brand-new 42 pb^{-1} (2006):



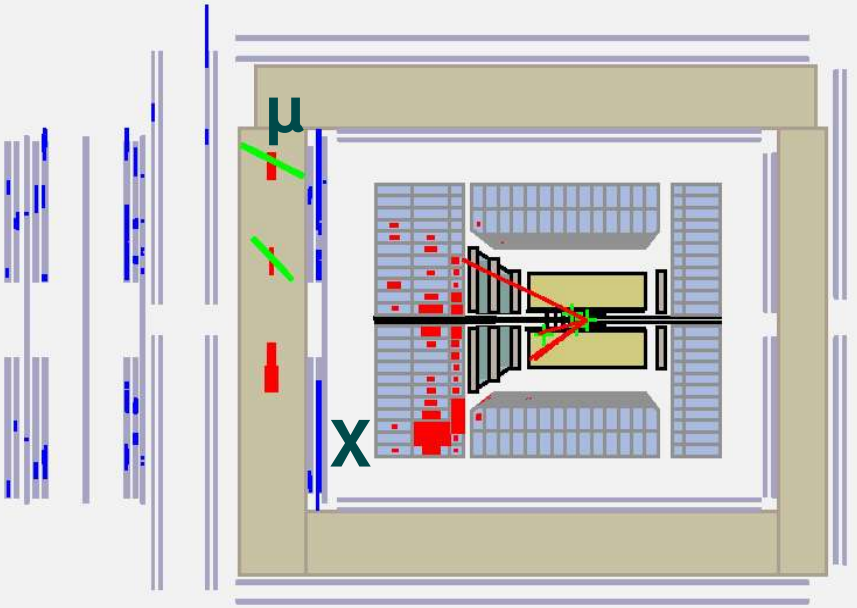
$p_T x$>25 GeV: 17 (obs.) / 6.0±1.0 (exp.)

➔ Excess at 3.3 σ level

ZEUS μ candidate at large P_T^X



XY View



P_T^X=66 GeV

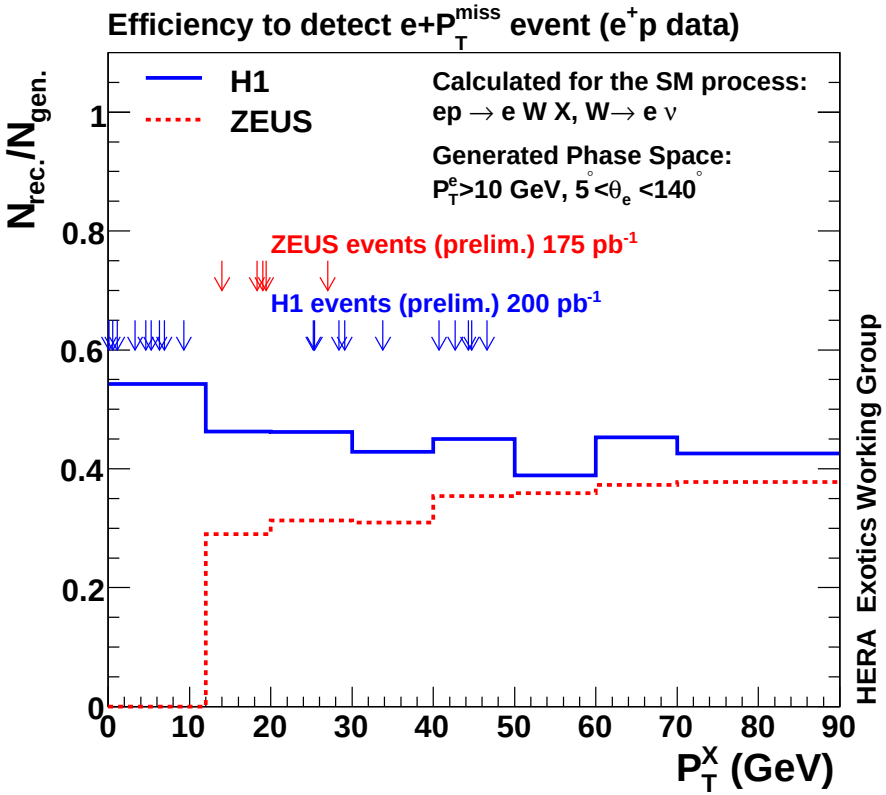
ZR View

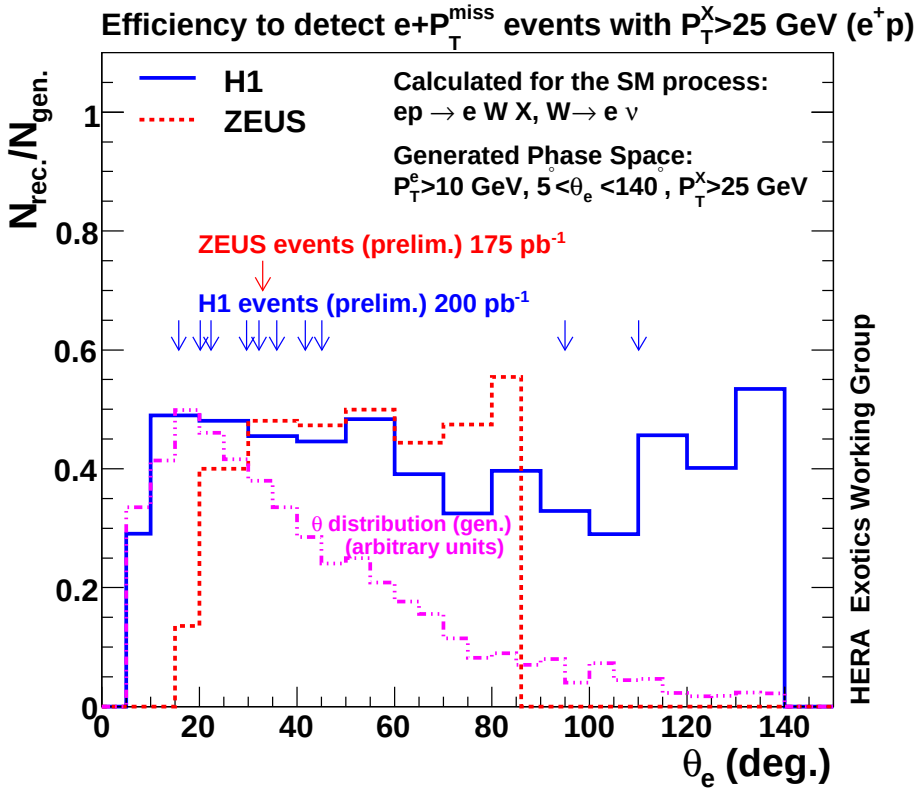
Total Numbers

Isolated e	$12 < p_T^X < 25$ **GeV**	$p_T^X > 25$ **GeV**
ZEUS (prel.) 96-06 e^+p (175 pb^{-1})	**4**/2.1 ± 0.3 (63%)	**1**/2.2 ± 0.3 (75%)
ZEUS (prel.) 98-06 e^-p (204 pb^{-1})	**6**/2.9 ± 0.5 (56%)	**5**/3.8 ± 0.6 (55%)
ZEUS (prel.) 96-06 $e^\pm p$ (379 pb^{-1})	**10**/5.0 ± 0.6 (59%)	**6**/6.0 ± 0.7 (63%)

Isolated μ	$12 < p_T^X < 25$ **GeV**	$p_T^X > 25$ **GeV**
ZEUS (prel.) 96-06 e^+p (175 pb^{-1})	**3**/1.9 ± 0.4 (71%)	**1**/2.3 ± 0.4 (78%)
ZEUS (prel.) 98-06 e^-p (204 pb^{-1})	**2**/2.2 ± 0.3 (68%)	**2**/2.2 ± 0.3 (86%)
ZEUS (prel.) 96-06 $e^\pm p$ (379 pb^{-1})	**5**/4.1 ± 0.5 (75%)	**3**/4.5 ± 0.5 (82%)

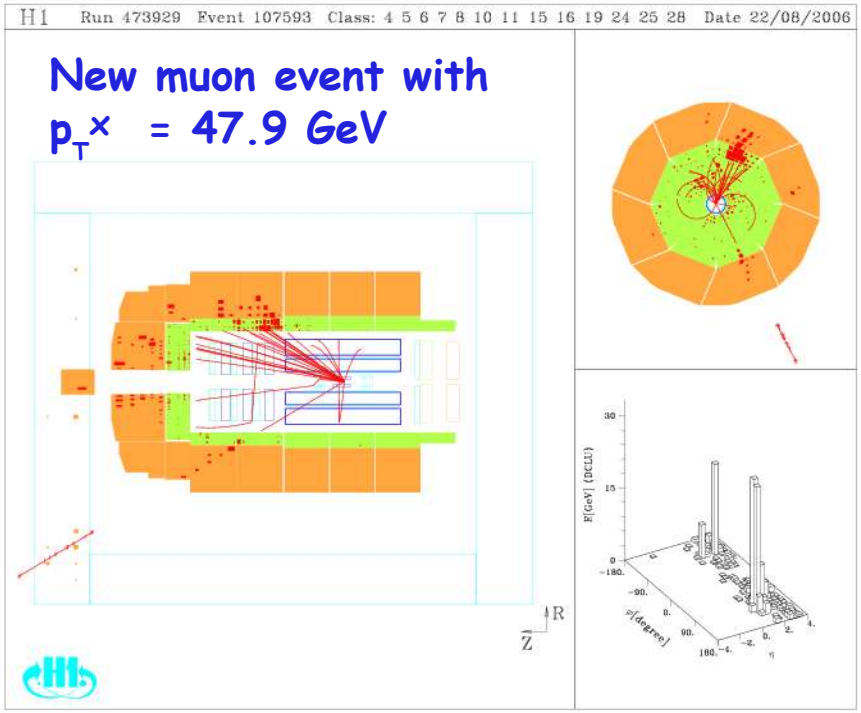
In 30 pb^{-1} 2006 e^+p data: 1 new e event and 1 new μ event, both with $12 < P_T^X < 25$ GeV.


Efficiency to detect e+P$_T^{miss}$ event (e$^+$p data)
H1
ZEUS
Calculated for the SM process:
ep → e W X, W→ e ν
Generated Phase Space:
P$_T^e$>10 GeV, 5°<θ$_e$ <140°
ZEUS events (prelim.) 175 pb^{-1}
H1 events (prelim.) 200 pb^{-1}
N$_{rec.}$/N$_{gen.}$
P$_T^X$ (GeV)
HERA Exotics Working Group


Efficiency to detect e+P$_T^{miss}$ events with P$_T^X$>25 GeV (e$^+$p)
H1
ZEUS
Calculated for the SM process:
ep → e W X, W→ e ν
Generated Phase Space:
P$_T^e$>10 GeV, 5°<θ$_e$ <140°, P$_T^X$>25 GeV
ZEUS events (prelim.) 175 pb^{-1}
H1 events (prelim.) 200 pb^{-1}
θ distribution (gen.)
(arbitrary units)
N$_{rec.}$/N$_{gen.}$
θ$_e$ (deg.)
HERA Exotics Working Group

	$e^{\pm}p$ **Data Preliminary** $P_T^X > 25$ **GeV**		Electron obs./exp.	Muon obs./exp.	Combined obs./exp.
e^+p	H1	200 pb^{-1}	10 / 3.1 $\pm$ 0.6	7 / 2.9 $\pm$ 0.5	17 / 6.0 $\pm$ 1.0
	ZEUS	175 pb^{-1}	1 / 2.2 $\pm$ 0.3	1 / 2.3 $\pm$ 0.4	2 / 4.5 $\pm$ 0.7
	H1+ZEUS	375 pb^{-1}	11 / 5.3 $\pm$ 0.9	8 / 5.2 $\pm$ 0.9	**19 / 10.5 $\pm$ 1.7**
e^-p	H1	184 pb^{-1}	3 / 3.8 $\pm$ 0.6	0 / 3.1 $\pm$ 0.5	3 / 6.9 $\pm$ 1.1
	ZEUS	204 pb^{-1}	5 / 3.8 $\pm$ 0.6	2 / 2.2 $\pm$ 0.3	7 / 6.0 $\pm$ 0.9
	H1+ZEUS	388 pb^{-1}	8 / 7.6 $\pm$ 1.2	2 / 5.3 $\pm$ 0.8	**10 / 12.9 $\pm$ 2.0**

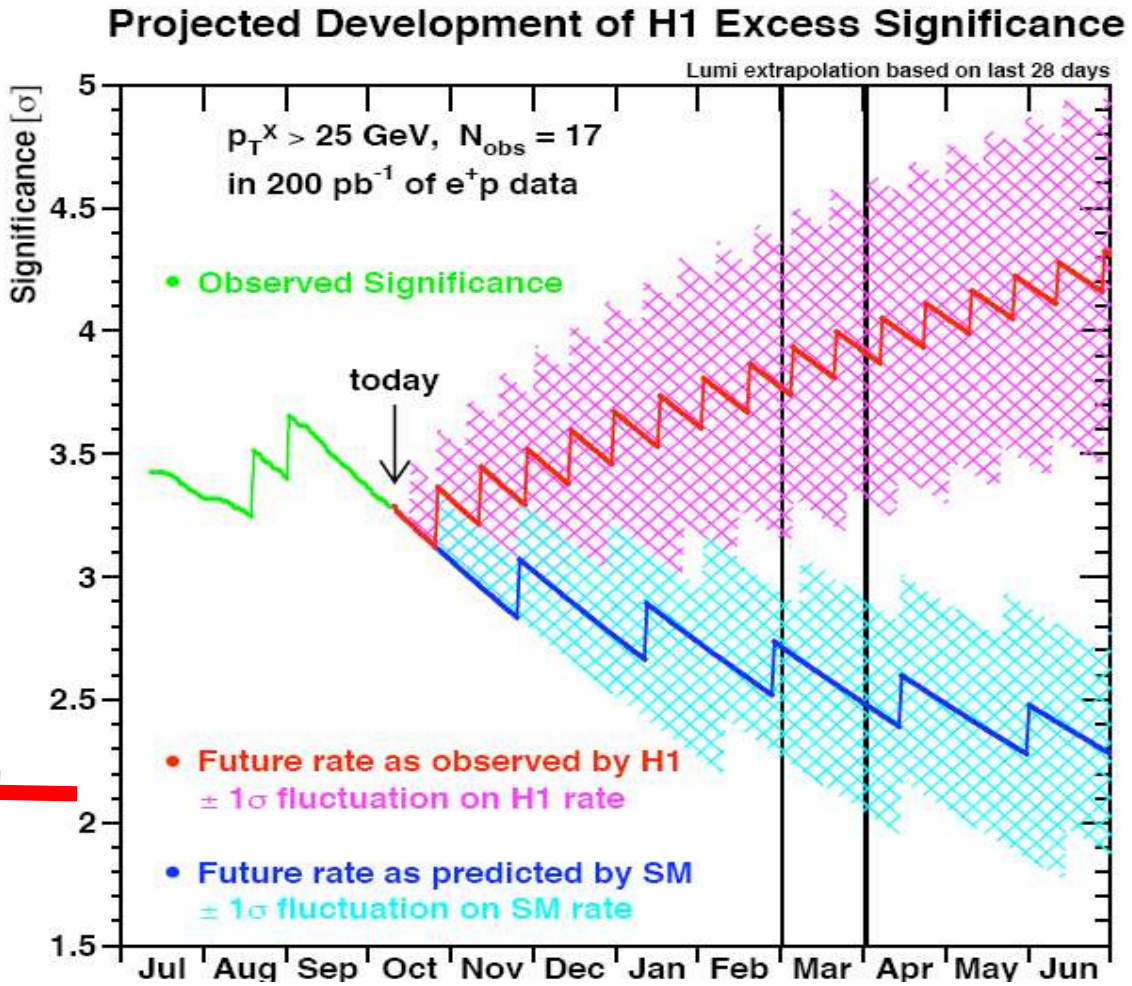
Isolated Leptons in recent e⁺p data (2006)



Yields in 2006 e⁺p data (42pb^{-1}):

Total: 4(obs.) / 5.1±0.7 (exp.)

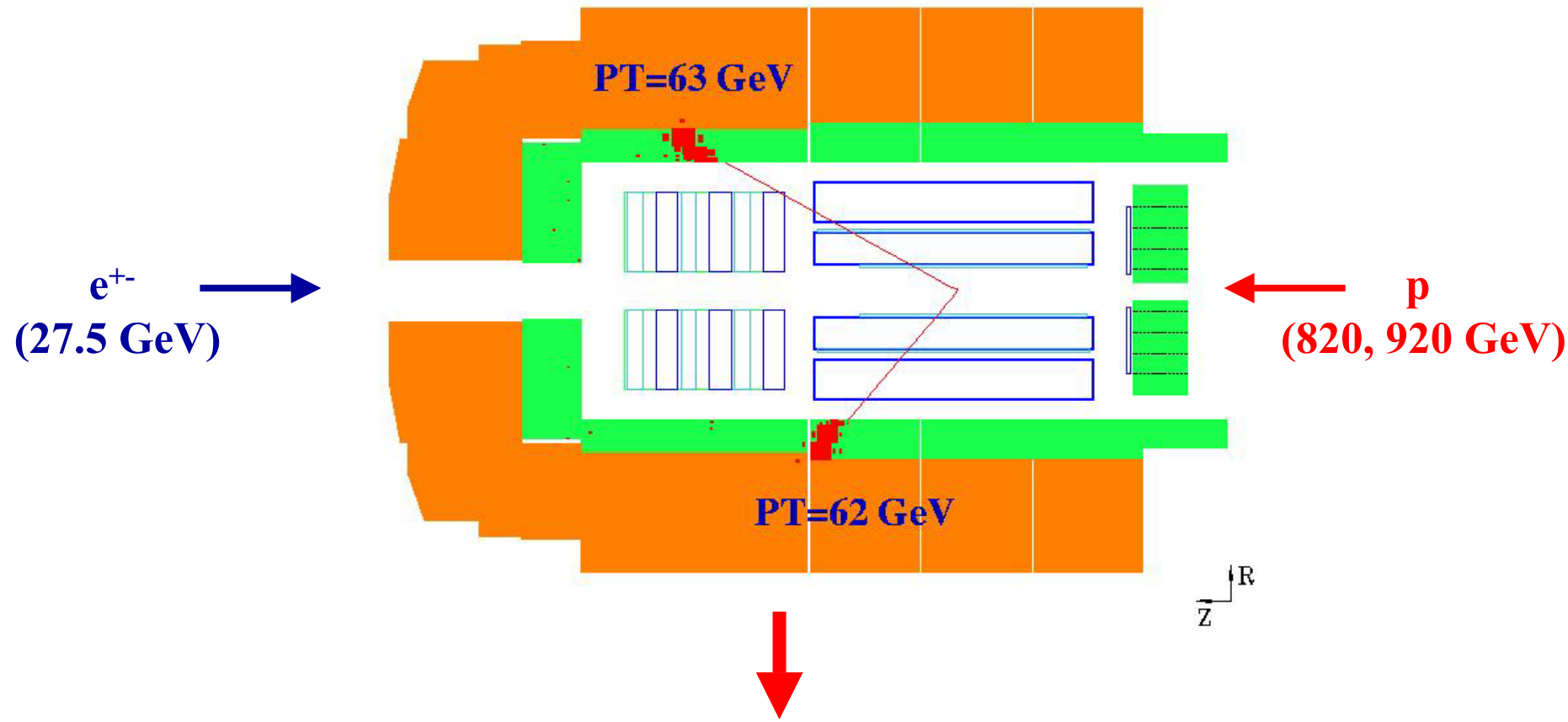
p_T^X>25 GeV: 2(obs.) / 1.4±0.2 (exp.)



Needs highest lumi to clarify!

Outstanding high-P_T multi-electron events observed at HERA I

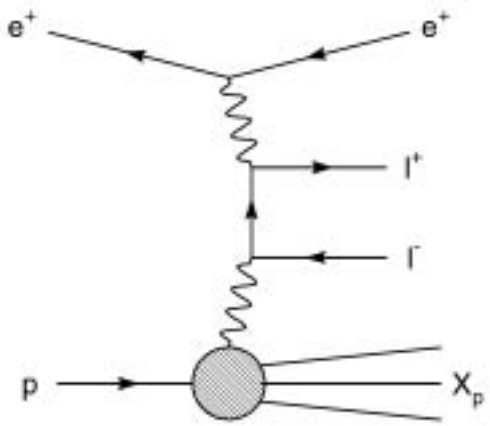
Eur. Phys. J. C31 (2003) 17



Extend search to muon channels and to latest HERA II data

Multi-Lepton Events

Analyses of Events with multiple e, μ, τ



SM Signal Processes

- Dominant: $\gamma\gamma \rightarrow l^+ l^-$

SM Background Processes

- NC-DIS, Compton
  (hadrons, photons misidentified as leptons)

Possible BSM Interpretation: $H^{\pm\pm}$ → *next topic*

Final states covered at HERA

Channel	***Lumi***	***Lumi***
ee, eee	*275 pb^{-1}*	*296 pb^{-1}*
μμ	*275 pb^{-1}*	*101 pb^{-1}*
eμ, eeμ	*275 pb^{-1}*	—
ττ	*118 pb^{-1}*	*135 pb^{-1}*

Multi-Lepton Selection (e, μ)

Selection

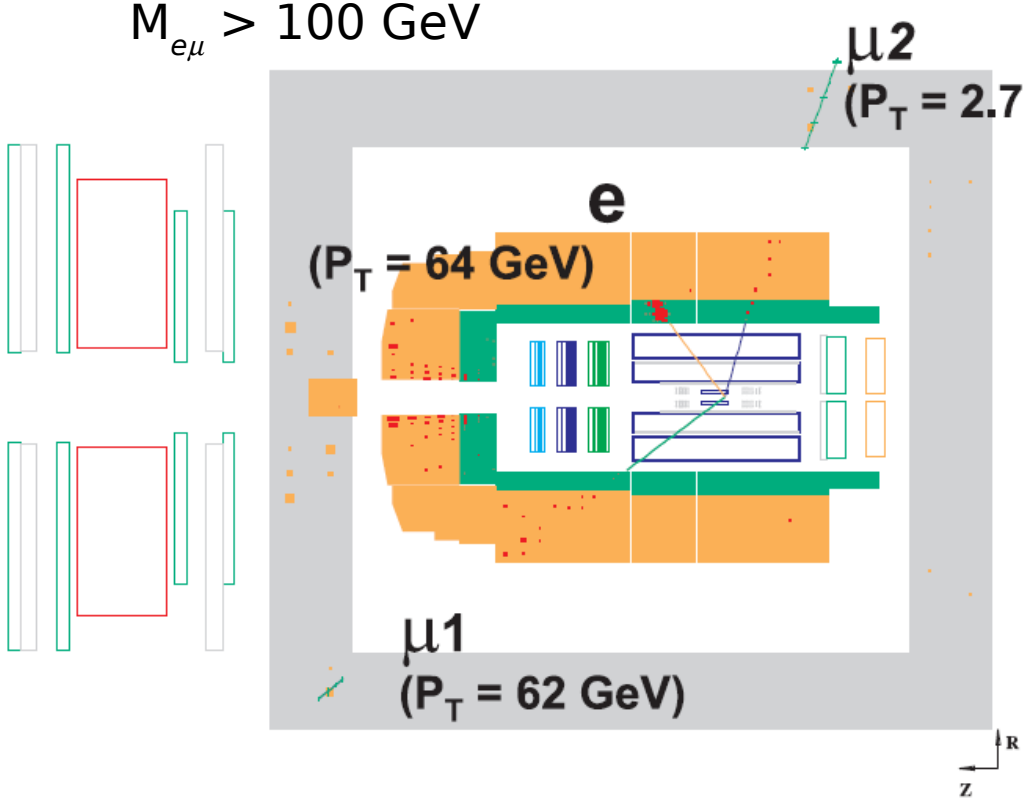
- $P_{T,1(2)} > 10\ (5)$ GeV
- $20° < \theta < 150°$
- count all e, μ and classify

Selection

- $P_{T,1(2)} > 10\ (5)$ GeV
- $17° < \theta < 164°$
- count e and classify

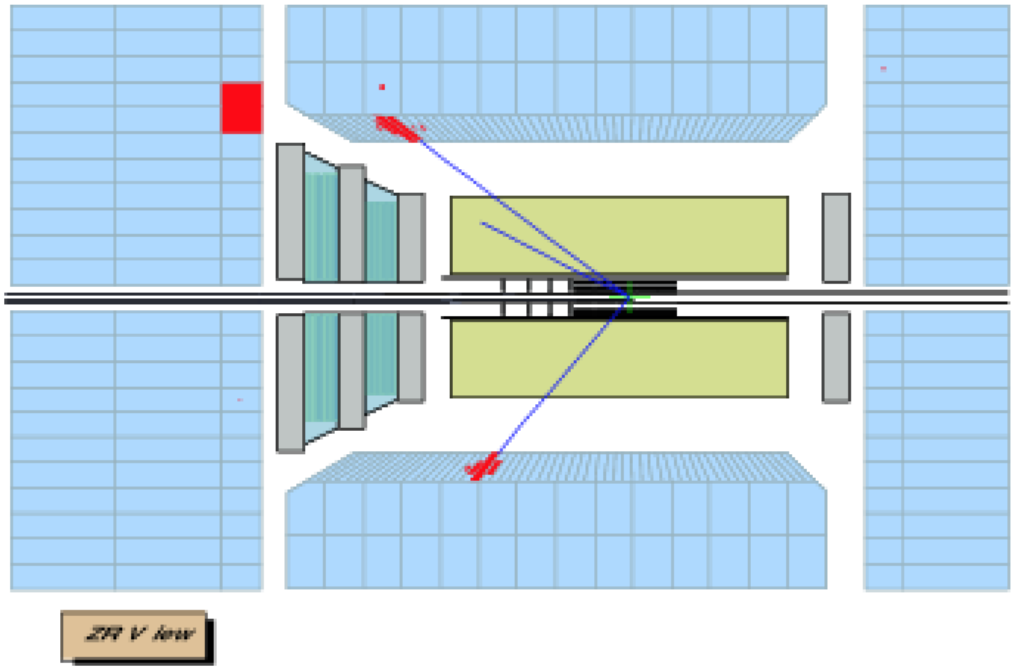
Event in eμμ Sample

$M_{e\mu} > 100$ GeV

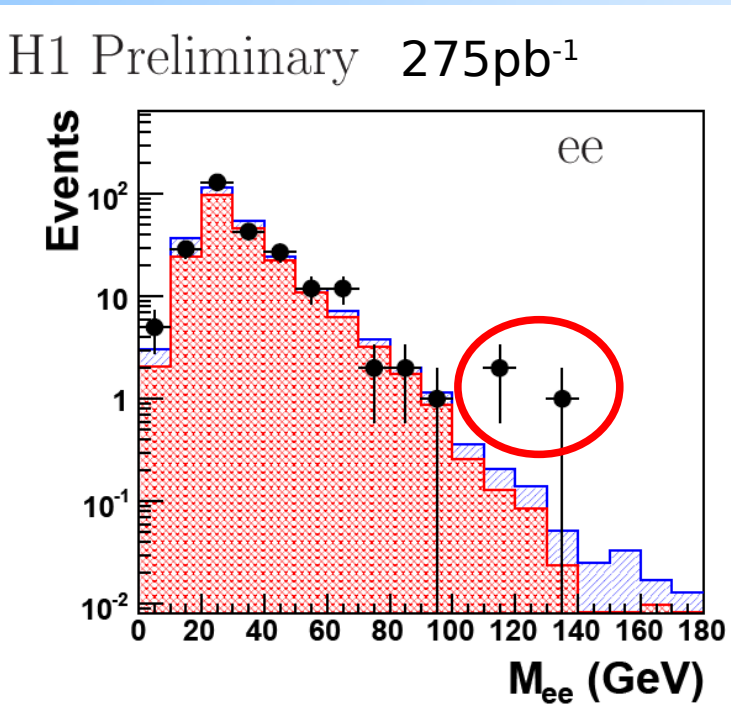


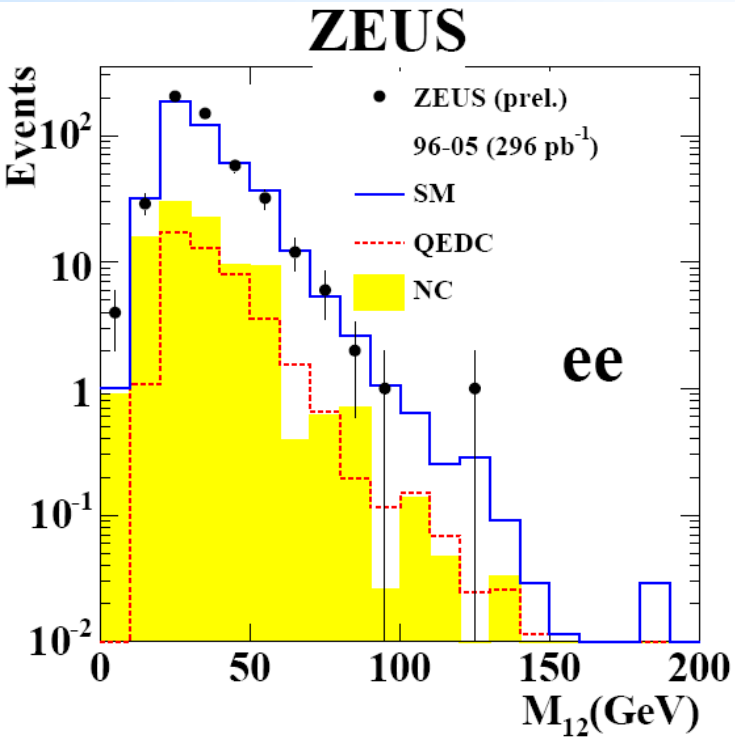
Event in eee Sample

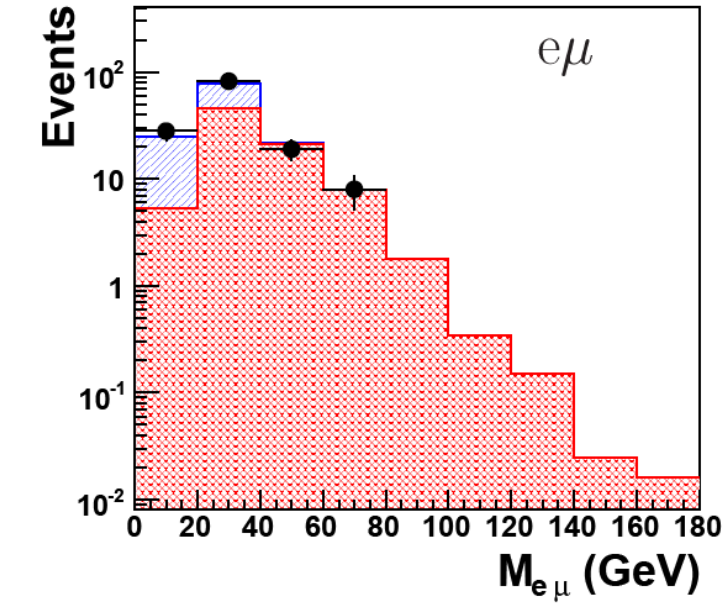
$M_{12} = 103$ GeV

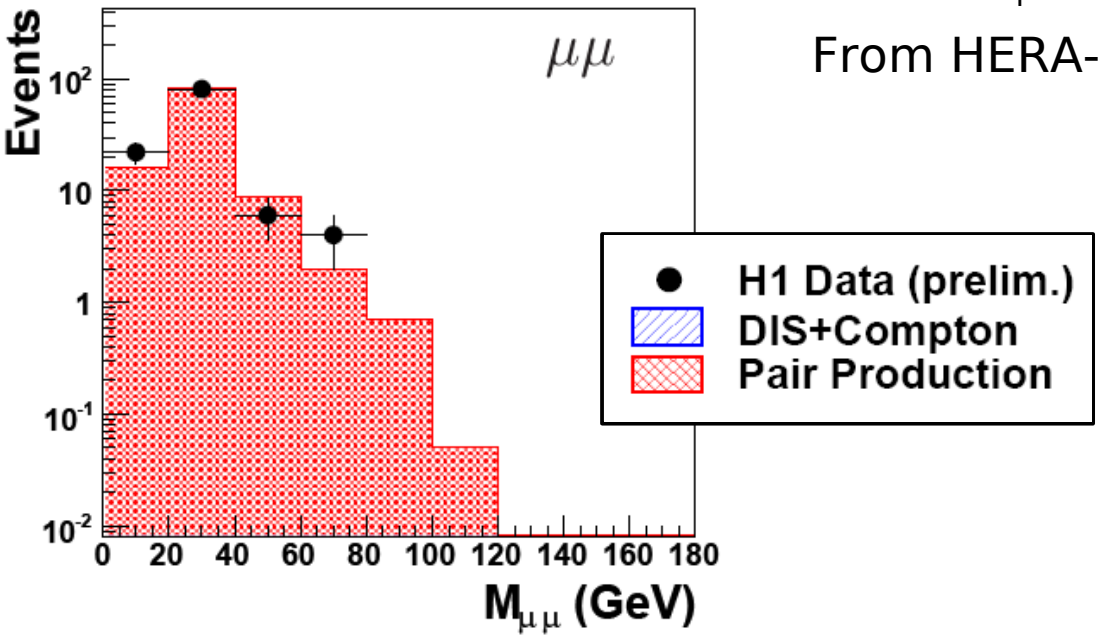


Di-Lepton Results



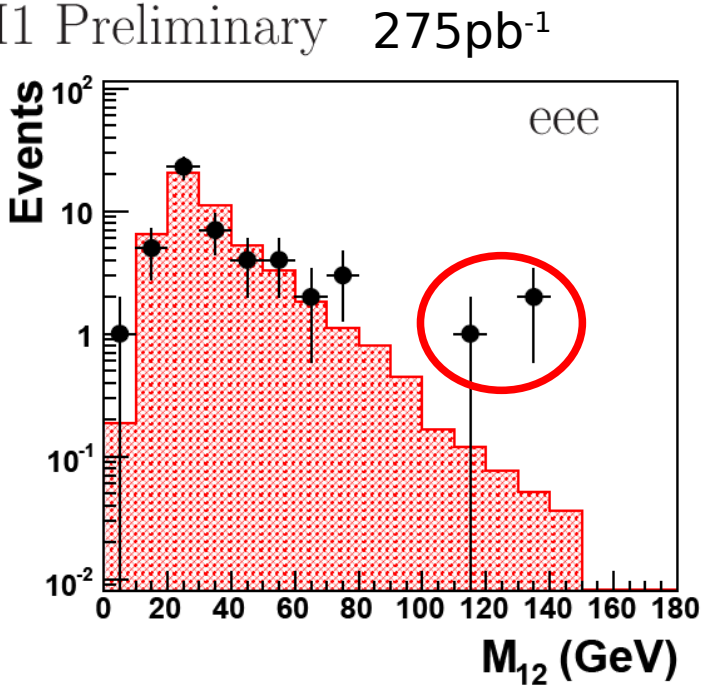


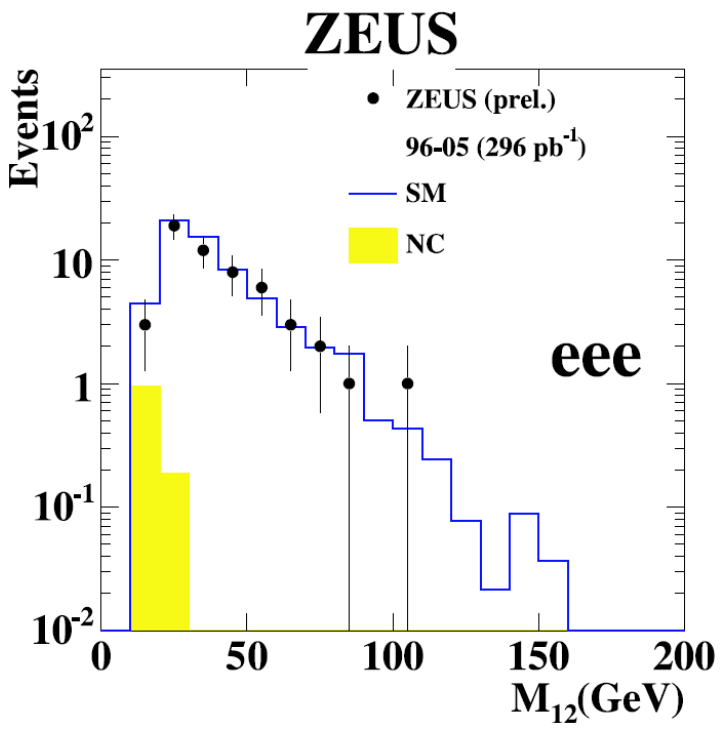




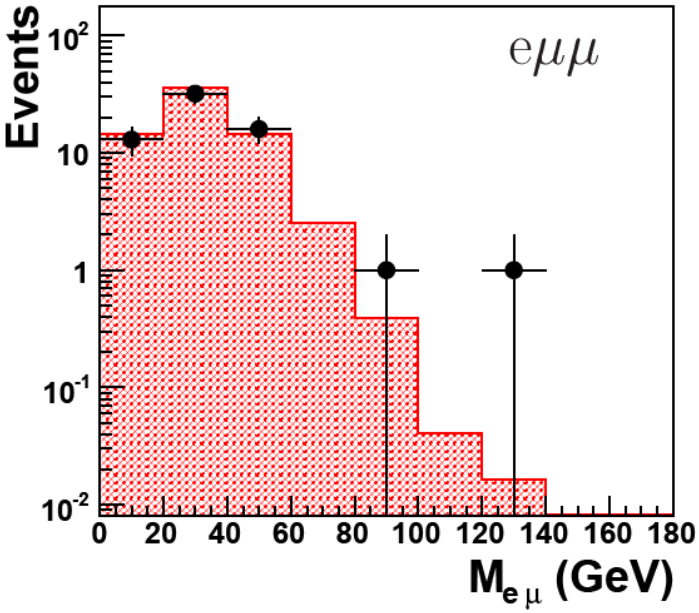
- Overall good agreement with the standard model
- Interesting events in H1 *ee* sample:
  At M_{ee}>100 GeV
  3 obs. / 0.86 exp.
  Have $\sum P_T$ > 100 GeV
  From HERA-I e^+p

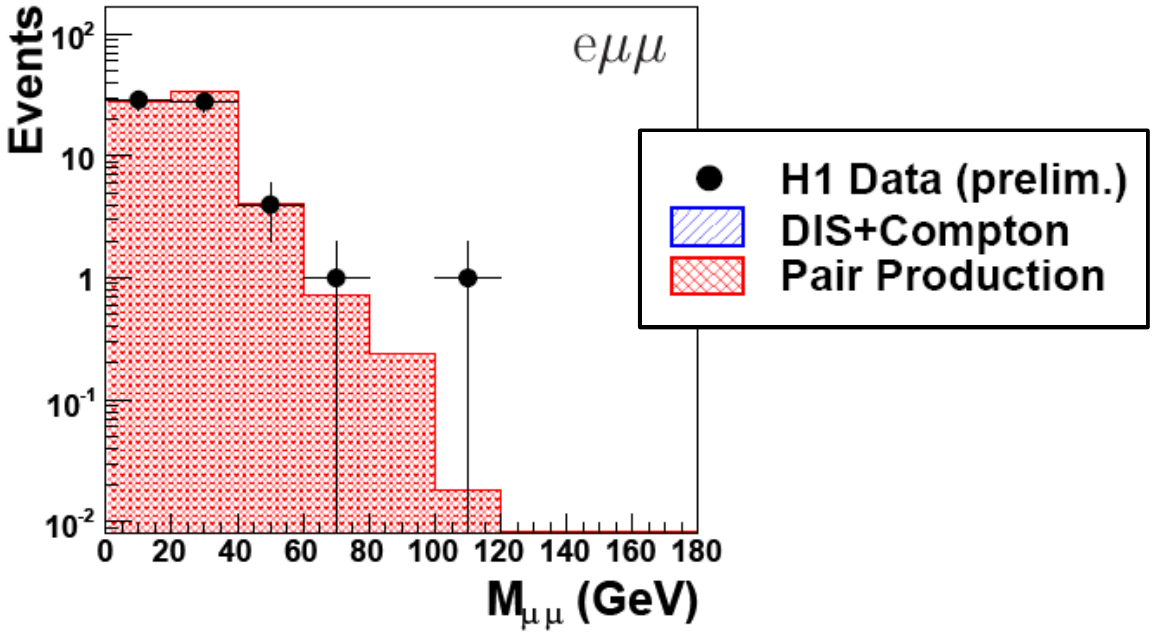
Tri-Lepton Results





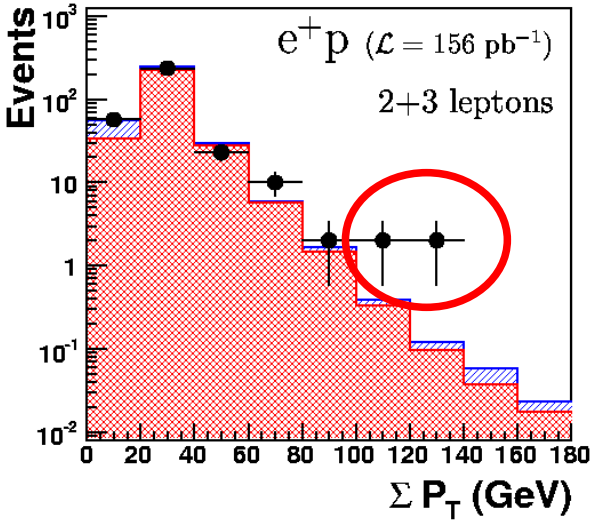
- Overall good agreement with the standard model

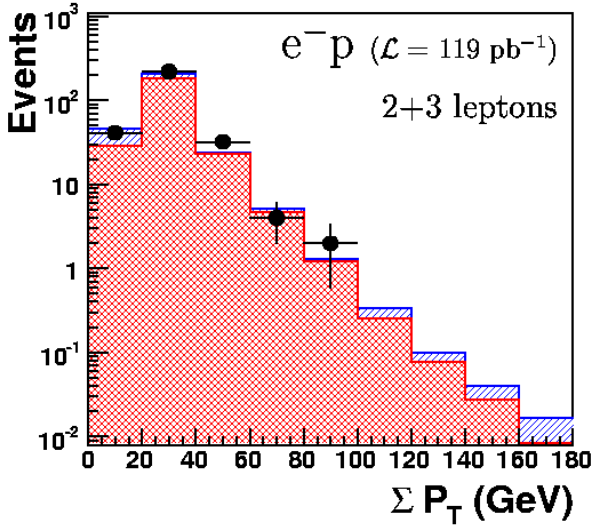


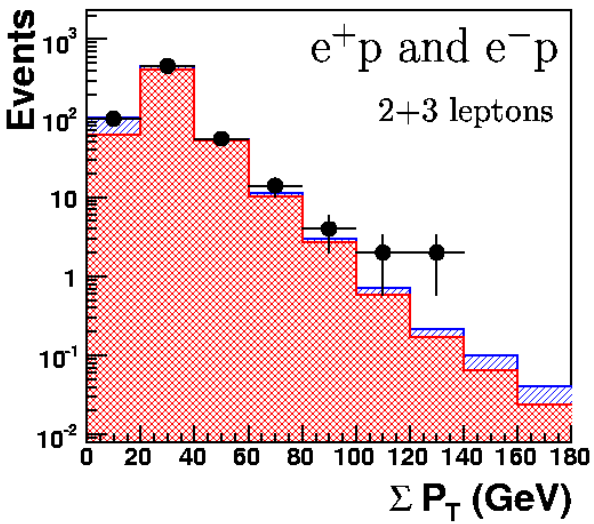


$\sum P_T$ DISTRIBUTIONS

H1 Preliminary Multi-lepton analysis (275 pb^{-1})







H1 Data (prelim.)
DIS+Compton
Pair Production

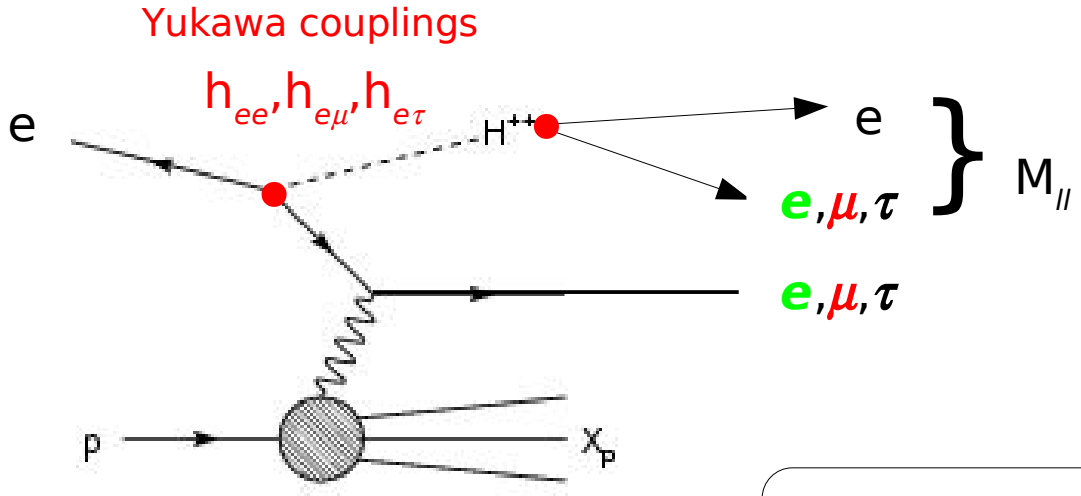
H1 Preliminary 275 pb^{-1} (1994–2005)

Selection	Data	SM	Pair Production	NC-DIS + Compton
$e^+p \sum P_T > 100$ GeV	4	0.6 ± 0.1	0.49 ± 0.09	0.11 ± 0.04
$e^-p \sum P_T > 100$ GeV	0	0.5 ± 0.1	0.37 ± 0.10	0.13 ± 0.04
All $\sum P_T > 100$ GeV	4	1.1 ± 0.2	0.86 ± 0.18	0.24 ± 0.06

No new event at very high $\sum P_T$ in the recent e^-p data

Search for Doubly Charged Higgs $H^{\pm\pm}$

- Occur in extensions of the Higgs sector with H triplet(s) with $Y \neq 0$
- Explanation for events at high M_{ee} / $\sum P_T$ observed in HERA-I ee sample?



Selection

- Sample: HERA-I (118 pb^{-1})
  - ee, $e\mu$ (based on Multi-Leptons)
  - $e\tau$ with $\tau \rightarrow e, \mu,$ *hadrons*
- 2 high-P_T leptons with same charge as beam lepton
- Reconstruct invariant mass M_{ll} of Higgs candidate

$H^{\pm\pm}$ Analysis Results

At $M_{ll} > 65$ GeV:

ee	3 obs. / 2.45 ± 0.11 exp.
$e\mu$	1 obs. / 4.17 ± 0.44 exp.
$e\tau$	1 obs. / 2.07 ± 0.54 exp.

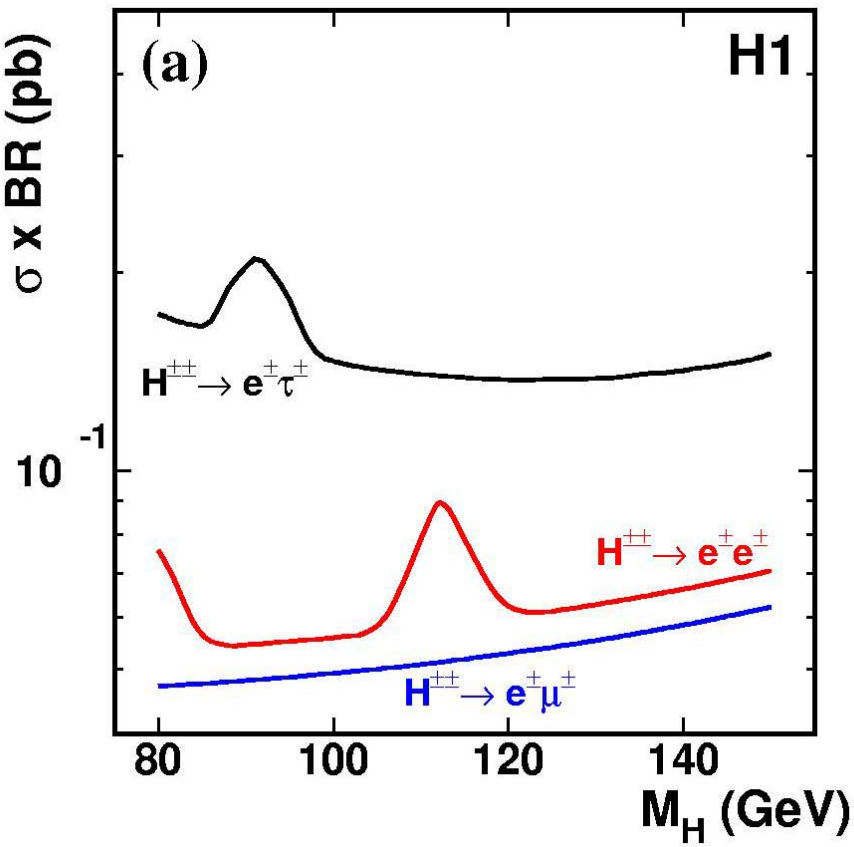
At $M_{ll} > 100$ GeV:

Only 1 ee event survives

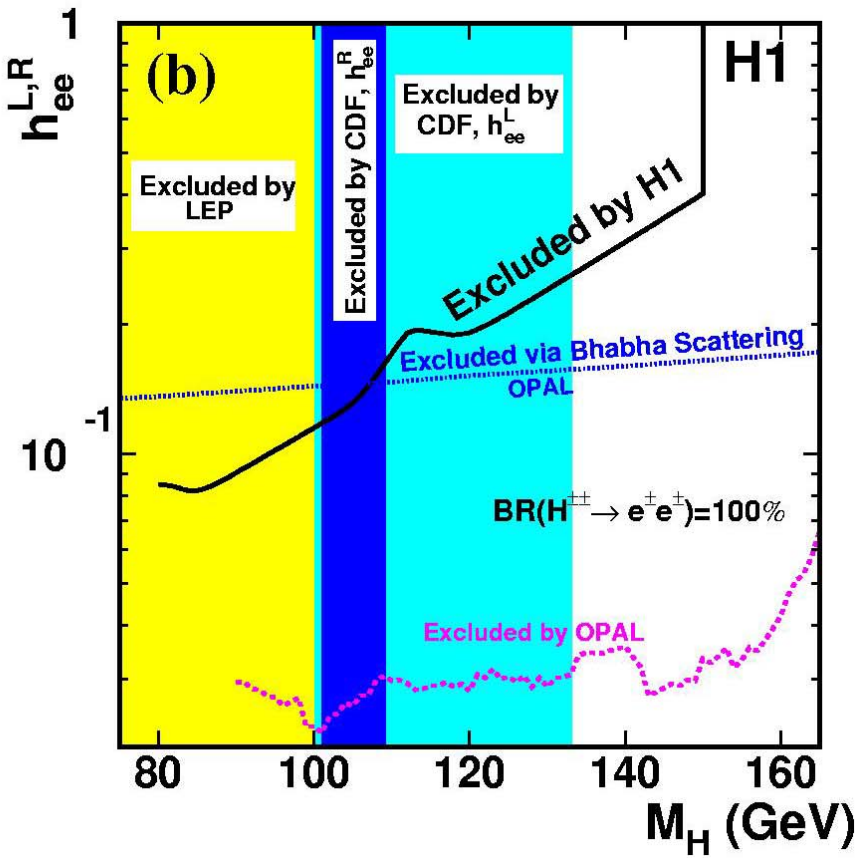
No excess – set limits

DOUBLY CHARGED HIGGS : RESULTS

σ * branching ratio



Limit on h_{ee}



Confirms that high-P_T multi-electron events are unlikely to be due to $H^{\pm\pm}$ decay

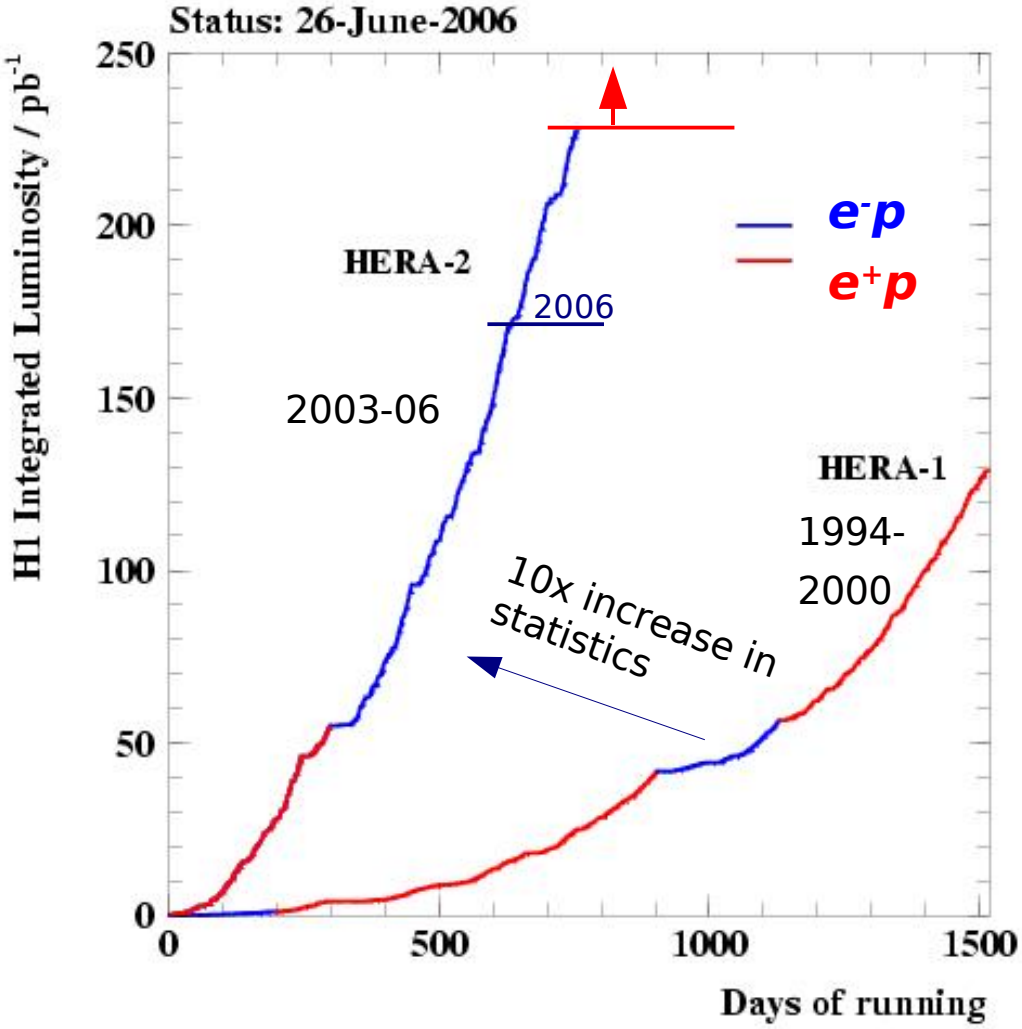
Poszukiwanie “nowej fizyki”

HERA Running and Data

- **HERA Collider**
  $e^{\pm}p$ Collisions at $\sqrt{s}$ = 320 GeV
  Running Periods:
  - HERA-I : 1994-00 (~130 pb^{-1} per exp.)
  - HERA-II: 2003-07 luminosity upgrade
    long. *e* polarisation
- Collider Experiments

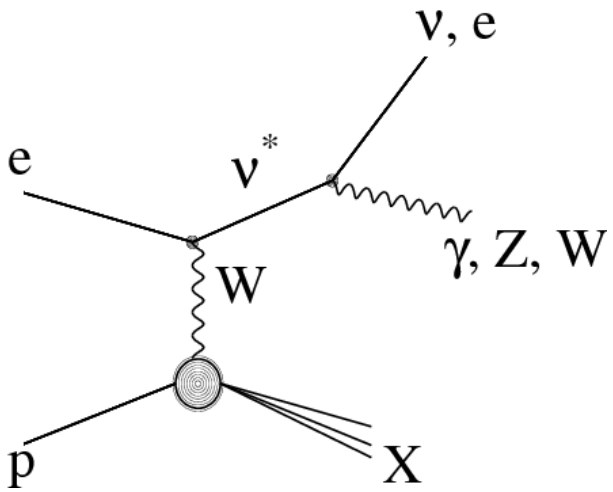
Integrated Luminosities used for the analyses presented in this talk

	H1	ZEUS
e^+p	158 pb^{-1}	144 pb^{-1}
e^-p	184 pb^{-1}	152 pb^{-1}



- Different sensitivity to e^+p / e^-p for some processes

Search for Excited Neutrinos ν^*



- Model: Fermions composite at Scale **Λ**, Cross-section and branching ratios described by *f*, *f'* (ew. sector)

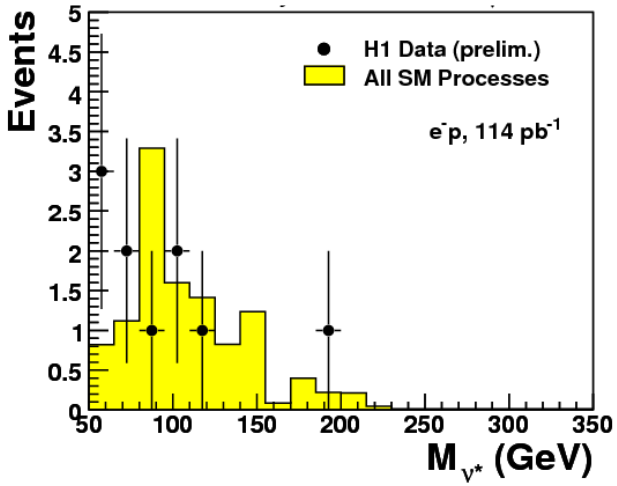
$$L_{F^*F} = \frac{1}{2\Lambda}\overline{F_R^*}\sigma^{\mu\nu}[g f \frac{\vec{\tau}}{2}\partial_\mu \overrightarrow{W_\nu} + g' f' \frac{Y}{2}\partial_\mu B_\nu] F_L + \text{h.c.},$$

SU(2) **U(1)**

- $\sigma(e^- p) \sim 100\text{x}\ \sigma(e^+ p)$ at $M_{\nu^*} > 200$ GeV (*W* exchange)
- Data Sample: 2005 $e^- p$ 114 pb^{-1}

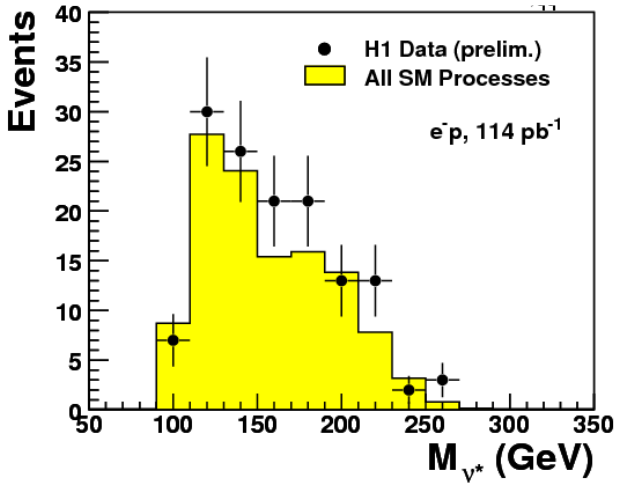
$\nu^* \to \nu\gamma$

Missing Pt + Photon



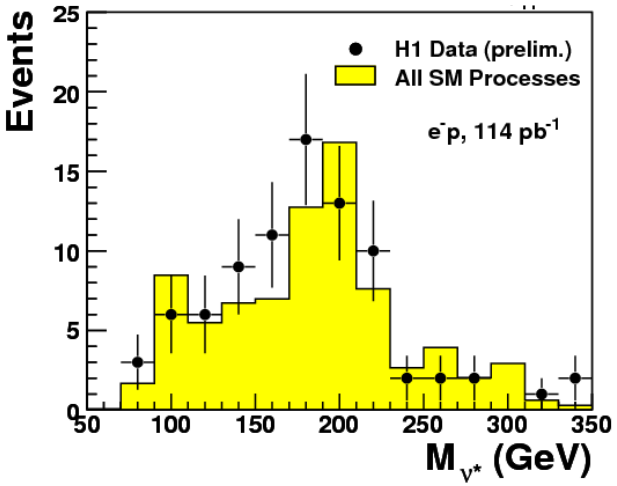
$\nu^* \to \nu Z_{\to qq}$

Missing Pt + Jets



$\nu^* \to eW_{\to qq}$

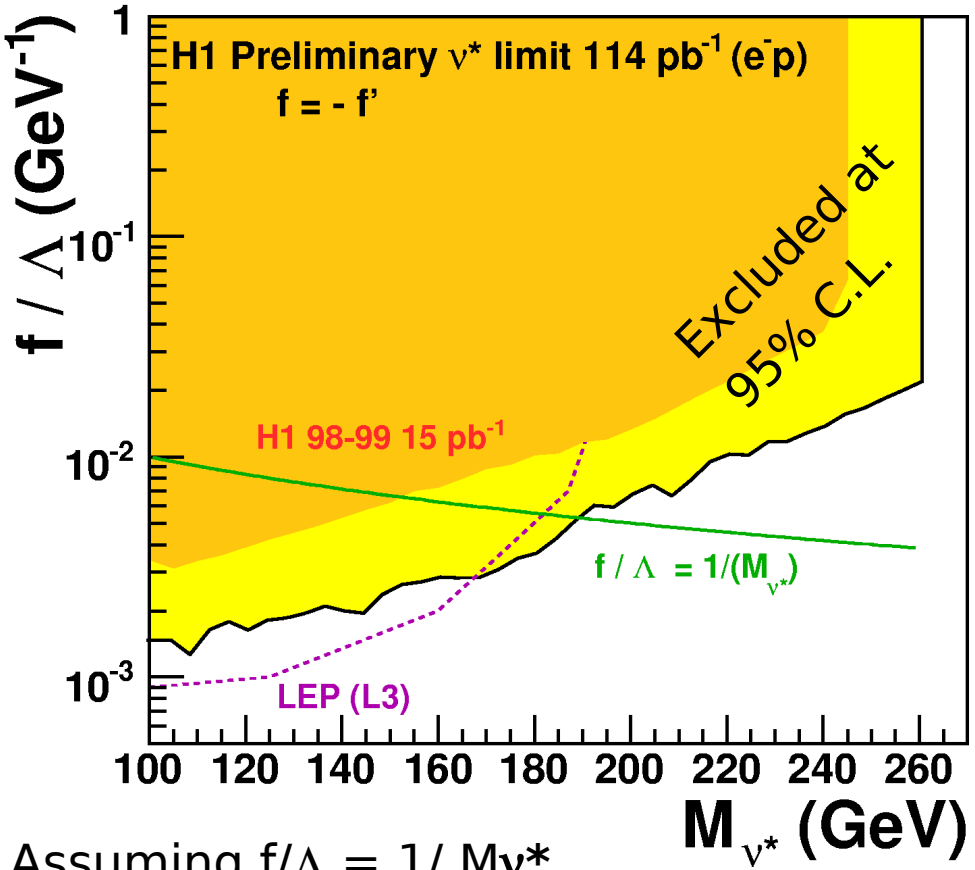
Electron + Jets



No evidence for Excited Neutrino Production found

Excited Neutrinos – Limits for $f = -f'$

- Scenario: $f = -f'$ (max. coupling to photon)
- $\sigma_{\nu^*}(f/\Lambda, M\nu^*)$ in NWA



- Assuming $f/\Lambda = 1/ M\nu^*$

$M\nu^* < 188$ GeV excl. at 95% C.L.

- Sensitivity extends beyond LEP reach

Introduction to the Leptoquark Model

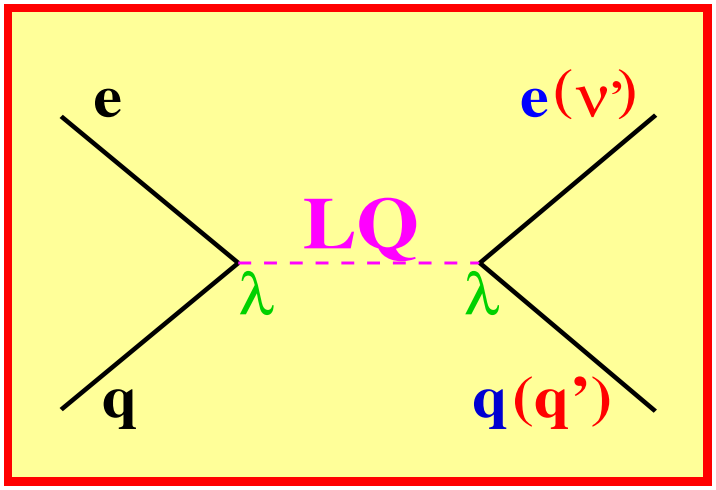
LEPTOQUARKS:

Scalar or vector color triplet bosons carrying L and B numbers

$\Rightarrow$ **Fermion number** $F = 3B + L = 0, 2$

Buchmüller-Rückl-Wyler (BRW) model

Resonant production in $e^{\pm}p$



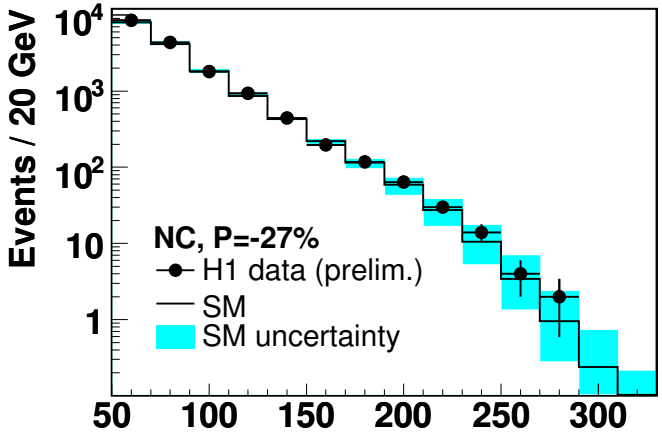
- $SU(3)_C \times SU(2)_L \times U(1)_Y$ invariance
- lepton and baryon number conservation
- strong bounds from rare decays $\Rightarrow$ either left- or right-handed couplings
- family diagonal if not $\Rightarrow$ LFV

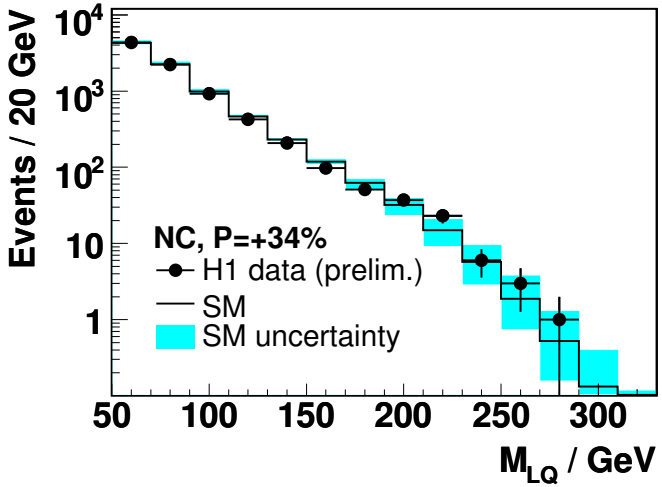
$\Rightarrow$ 7 scalar and 7 vector leptoquarks:

- All 14 LQ $\Rightarrow LQ \rightarrow eq'$
- 2 scalar and 2 vector LQ couple to both eq and νq

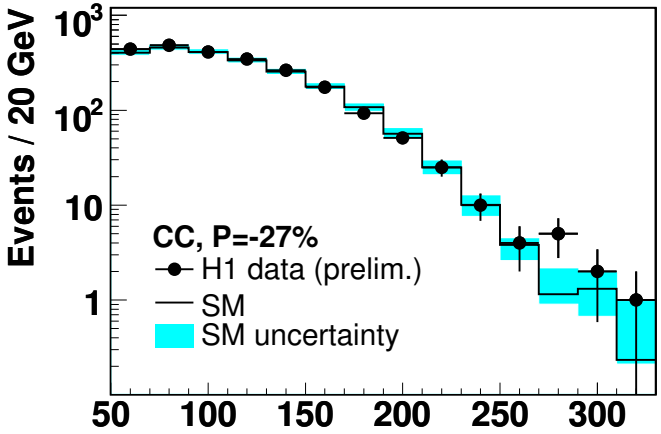
Invariant Mass Spectra from HERA II $e^- p$

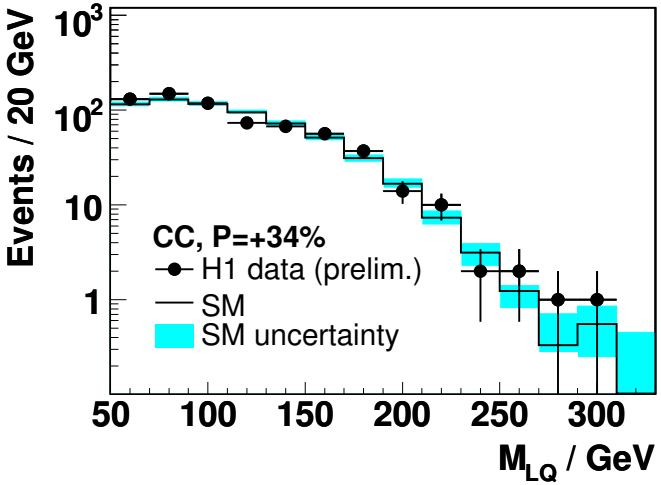
NC DIS:





CC DIS:

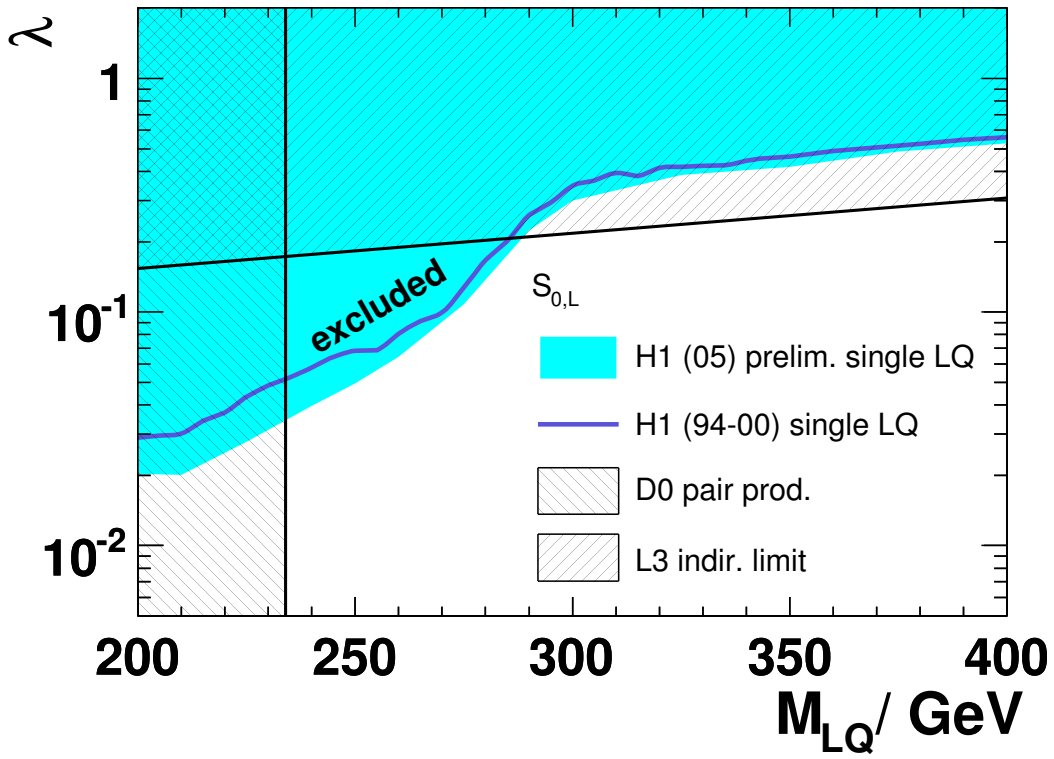




Good agreement between data and SM $\longrightarrow$ no evidence of LQ

Comparison with LEP, TEVATRON and HERA I

Scalar leptoquarks with F=2 S_0^L



TeVatron:

LQ pair production - λ independent

$$q\bar{q} \to l^+ l^- q\bar{q}$$

LEP:

indirect t/u-channel effect

in $q\bar{q}$-pair production

$$e^+e^- \to q\bar{q}$$

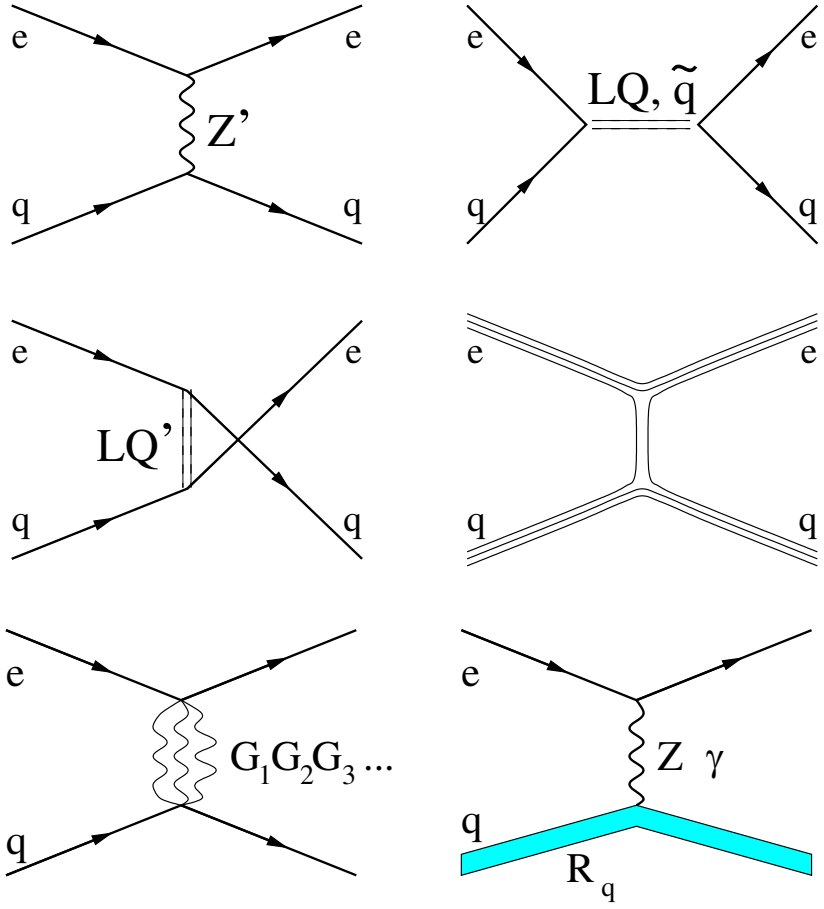
For couplings of em strength ($\lambda \sim 0.3$): mass exclusion $\sim$ 300 GeV

Limits comparable to those obtained at LEP and Tevatron

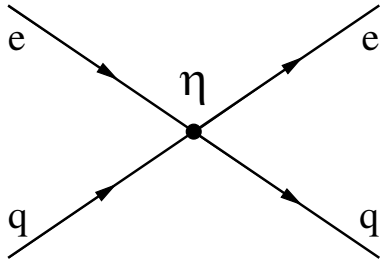
Models

Neutral Current eq Scattering

Possible "new physics" processes:



For $\sqrt{s}$ much smaller than "new" scale Λ



$eeqq$ contact interactions (CI)

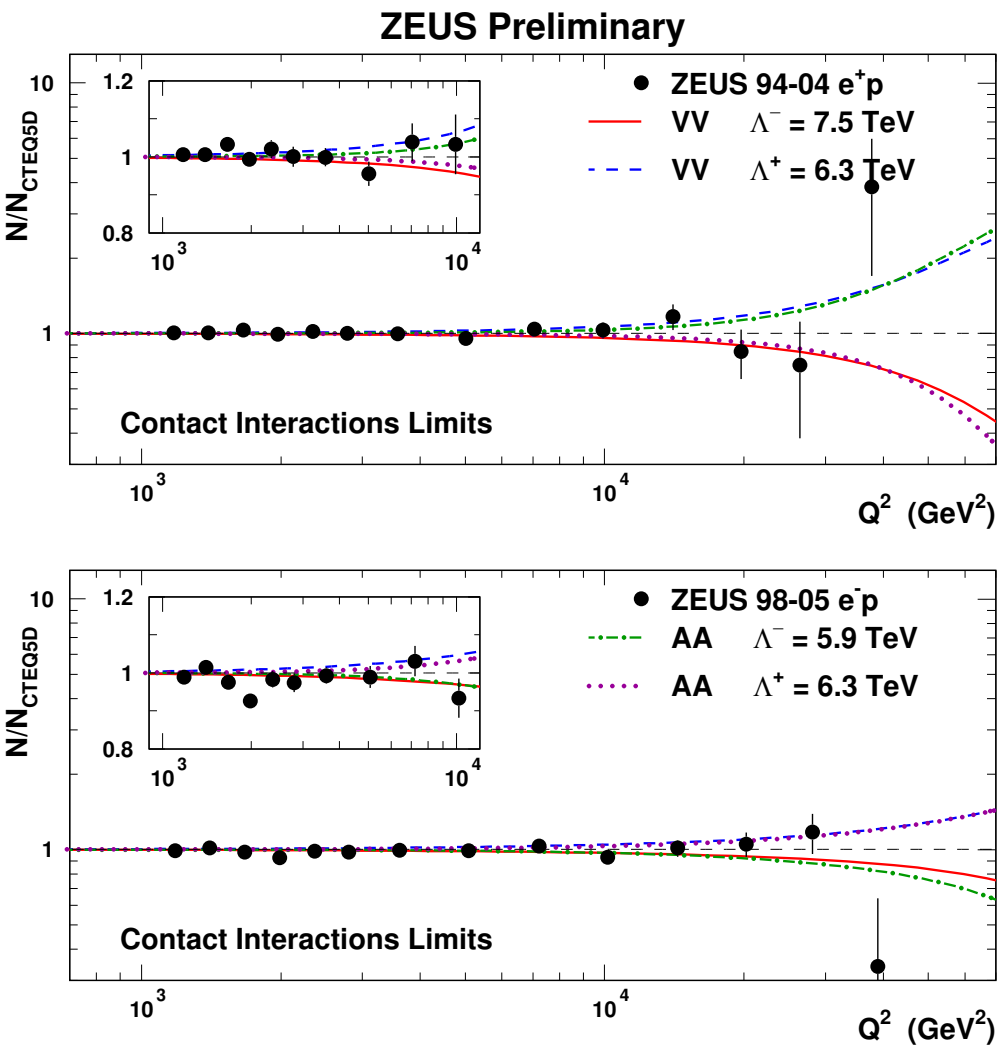
Effective Lagrangian for vector $eeqq$ contact interactions:

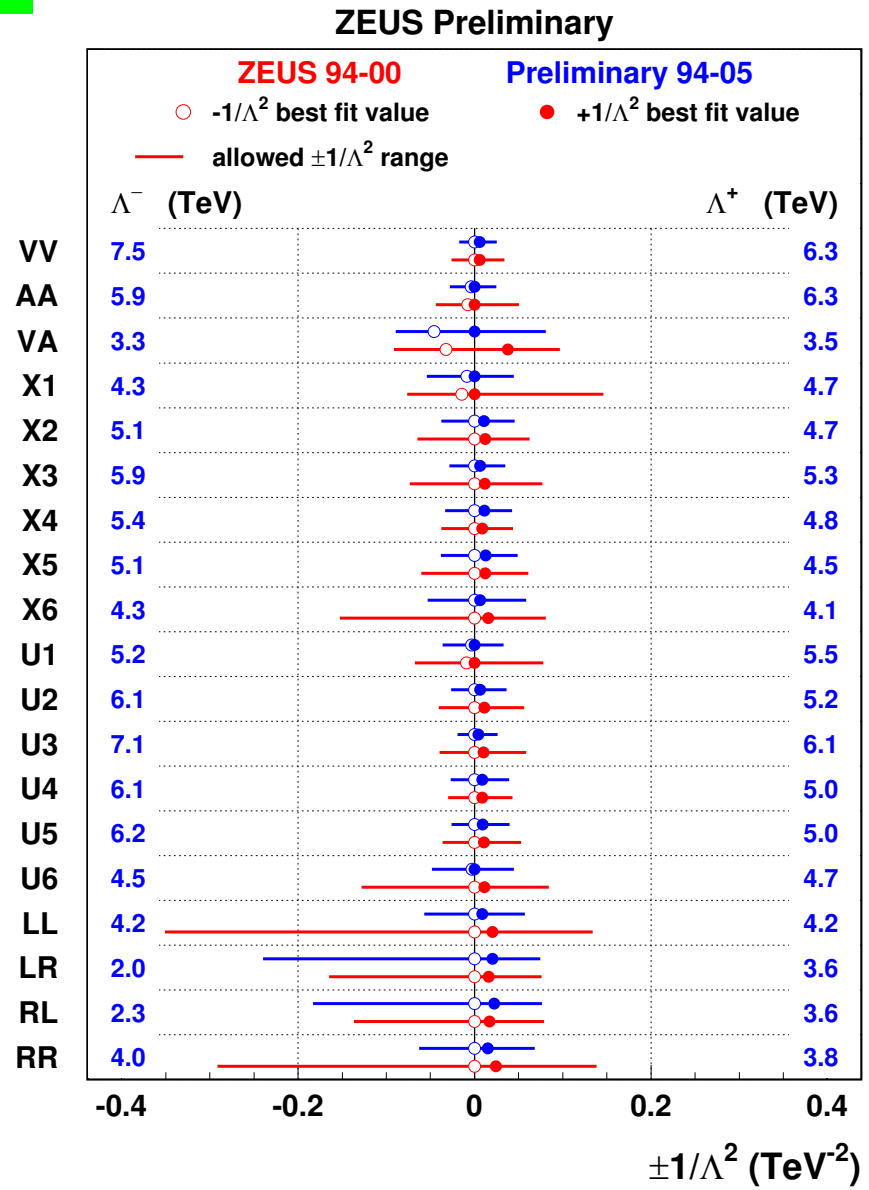
$$\mathcal{L}_{CI} = \sum_{\substack{\alpha,\beta=L,R \\ q}} \eta^{eq}_{\alpha\beta} \cdot (\bar{e}_\alpha \gamma^\mu e_\alpha)(\bar{q}_\beta \gamma_\mu q_\beta)$$

Scalar and tensor CI constrained beyond HERA sensitivity.

Results

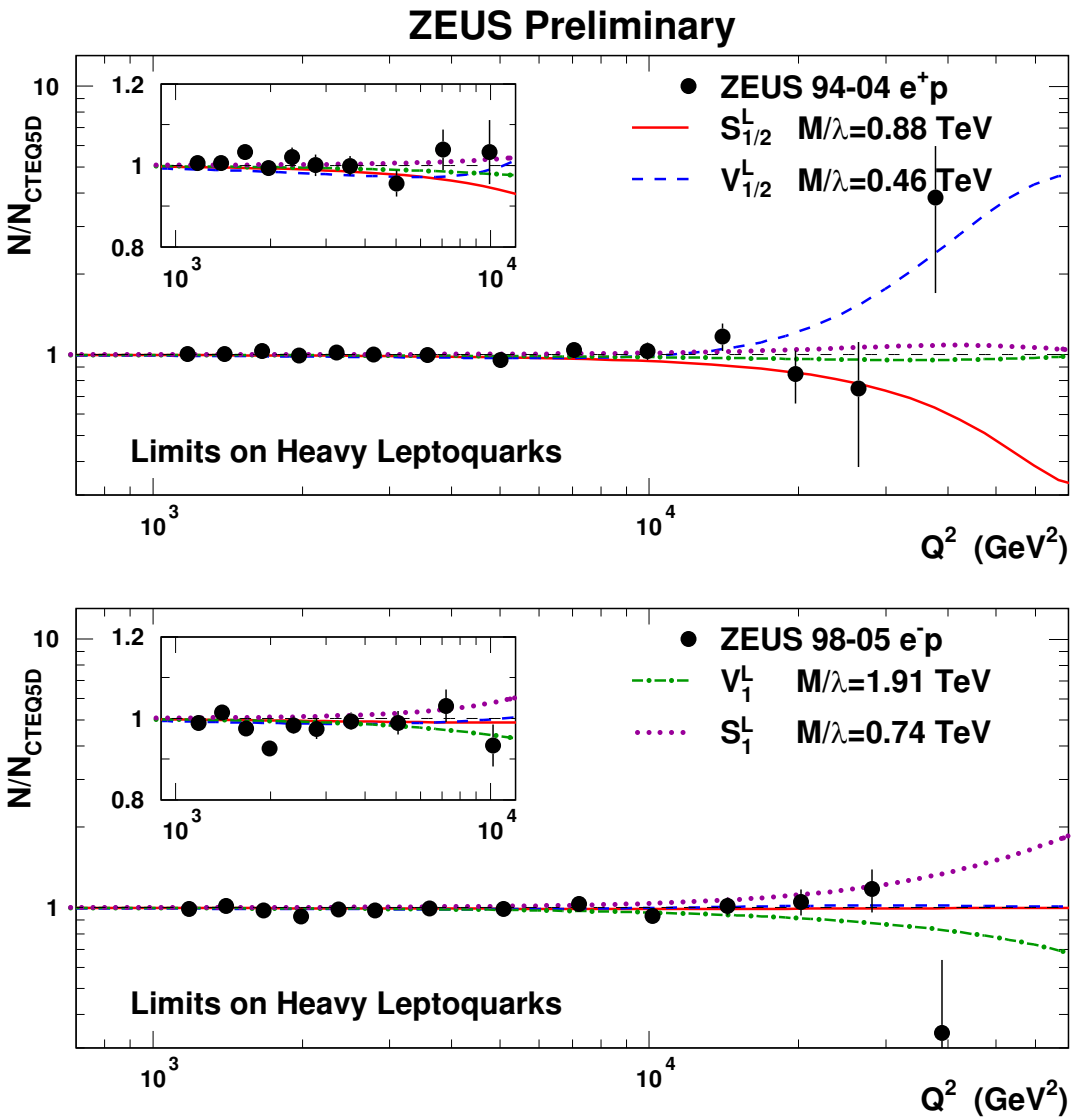
Public plots: CI





Results

Public plots: LQ



Large Extra Dimensions

Arkani-Hamed–Dimopoulos–Dvali Model

If gravity propagates in the $4 + \delta$ dimensions, the effective mass scale M_S can be as low as 1 TeV.

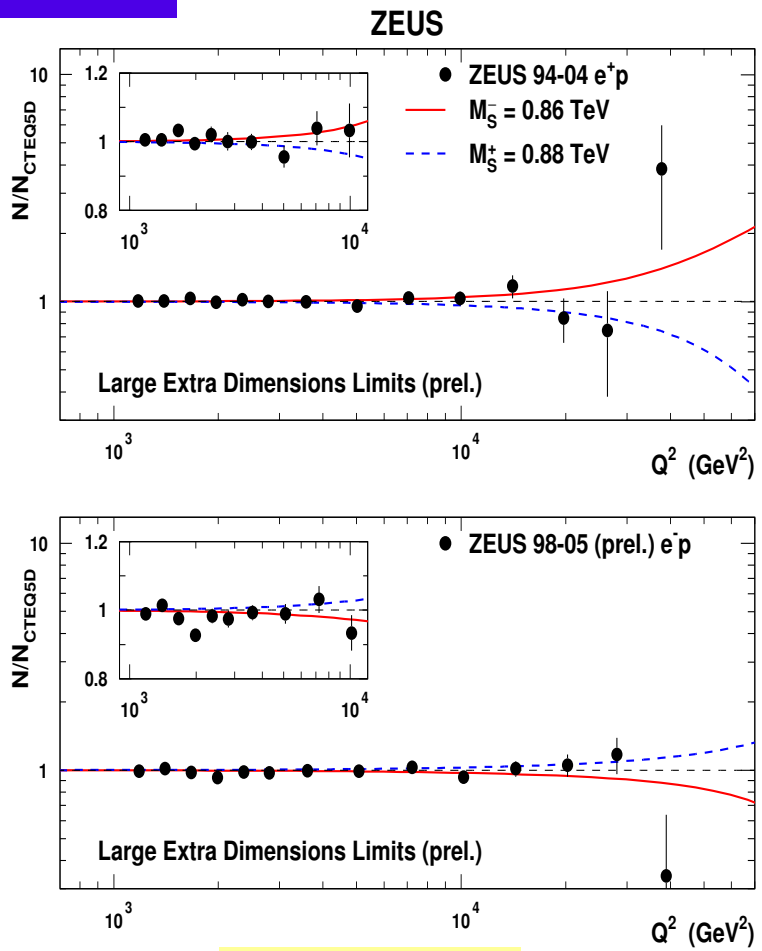
$\Rightarrow$ Gravitational interactions become comparable in strength to electroweak interactions.

The contribution of graviton (Kaluza-Klein tower) exchange to the $e^{\pm}p$ NC DIS cross section can be described by an effective contact interaction type coupling:

$$\eta_G = \pm\lambda \cdot \frac{\mathcal{E}^2}{M_S^4}$$

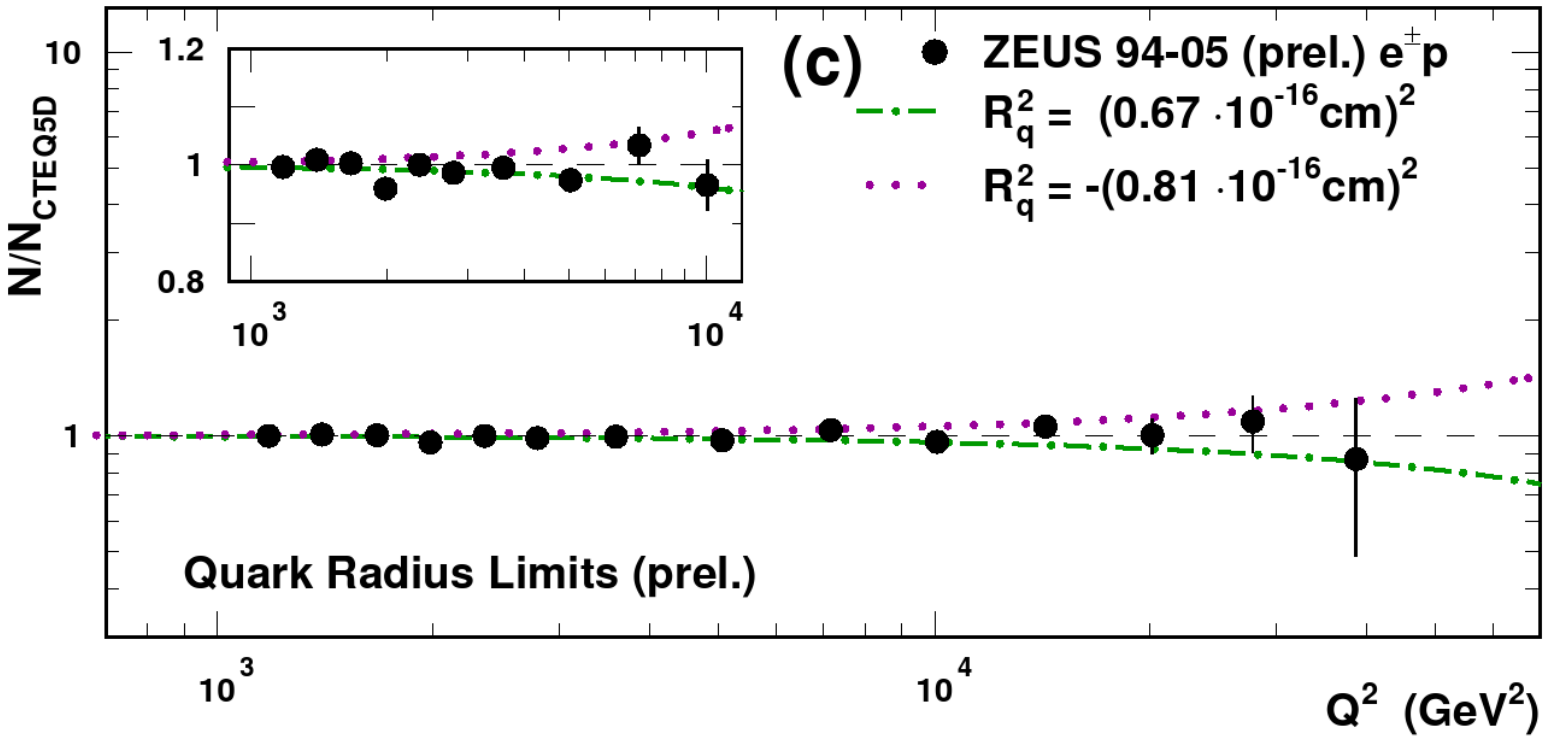
where λ is the coupling strength and $\mathcal{E}$ is related to the energy scales of hard interaction. $(\sqrt{s}, Q^2)$

CI results from H1 (HERA I) $\Rightarrow$ Phys Lett B568 (2003) 35-47



ZEUS results

$M_S^- > 0.86$ TeV
$M_S^+ > 0.88$ TeV



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

$$R_q < 0.67 \times 10^{-3} \text{ fm}$$

Podsumowanie

Akcelerator HERA zakończy zbieranie danych już za pół roku.

HERA II dostarczyła wielu nowych danych ($e^- p$!),
które dopiero zaczynają być analizowane.

Większa statystyka i nowe metody analizy pozwalają oczekiwać
istotnej poprawy w wyznaczaniu partonowej struktury protonu.

Widoczne są pewne "rysy" na Modelu Standardowym (przypadki H1),
ale HERA może nie zdążyć ich wyjaśnić...

Większość badanych rozkładów wykazuje bardzo dobrą zgodność
z przewidywaniami Modelu Standardowego

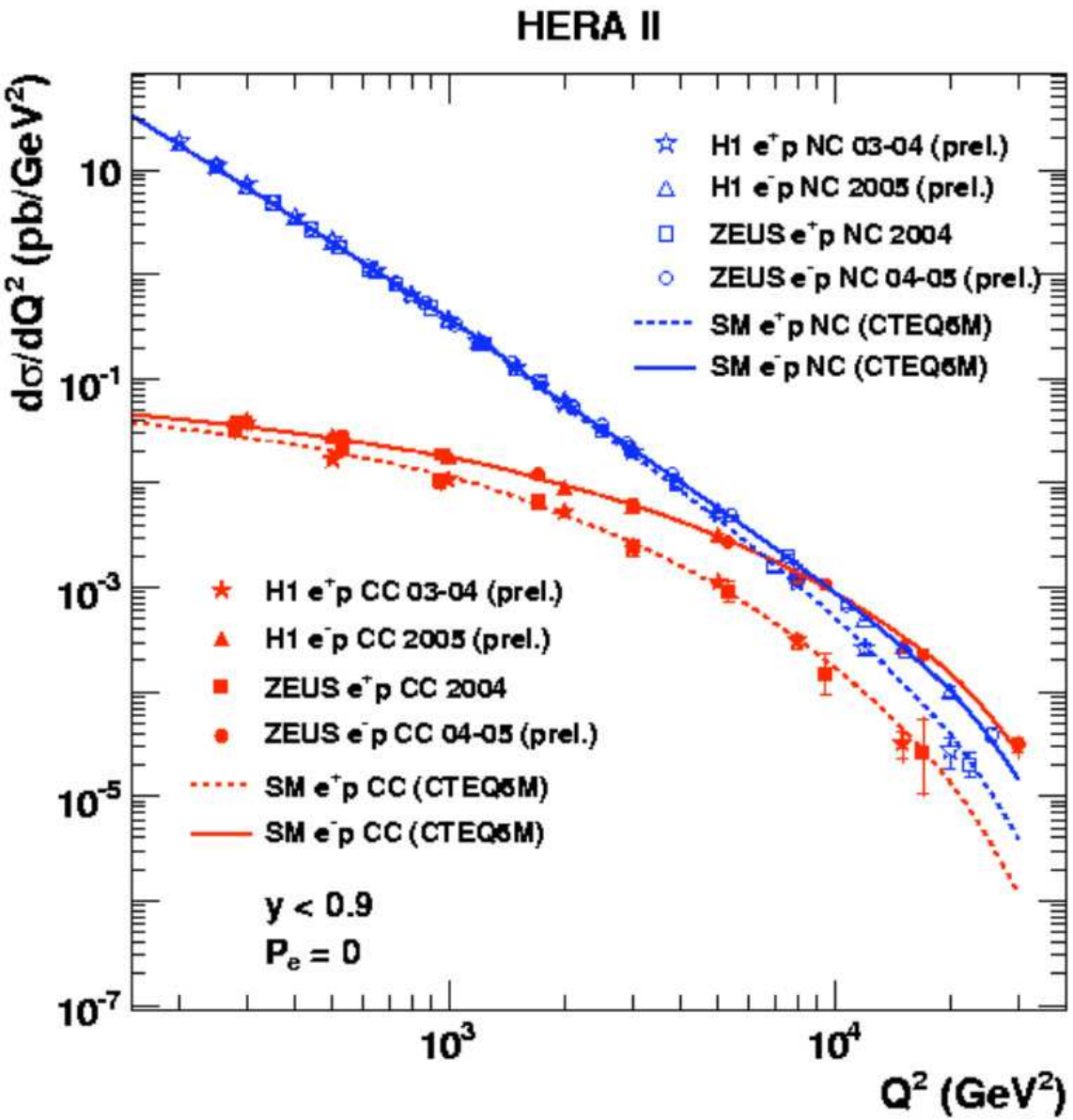
Strony dodatkowe

NC & CC cross sections

- Excellent agreement with SM prediction over many orders of magnitude
- CC cross section suppressed at low Q^2 by W propagator
- NC and CC comparable cross sections at high $Q^2 \sim M_W^2$
- $\sigma^{e^- p} > \sigma^{e^+ p}$ at high Q^2 electroweak effects

$\Rightarrow$ Stringent limits on eq compositeness

quark radius $R_q < 1 \cdot 10^{-18}$ m
LQ's $M_{LQ}/\lambda \gtrsim 1\,\mathrm{TeV}$
LED $M_S > 0.8\,\mathrm{TeV}$



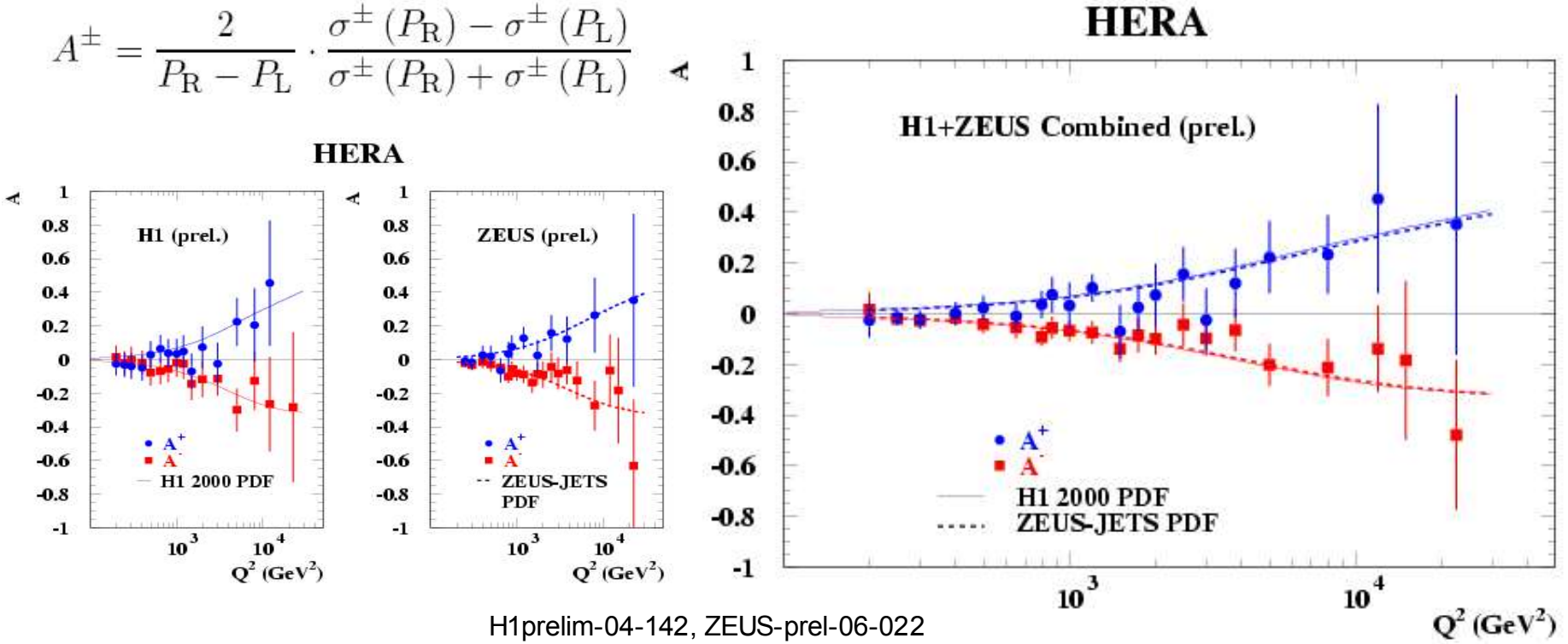
Polarized NC Measurements

- F_2 and F_3 contain polarization dependent terms from γZ interference and Z exchange:

$$\begin{aligned} \tilde{F}_2 &= F_2 + k(-v_e \mp P a_e) x F_2^{\gamma Z} + k^2(v_e^2 + a_e^2 \pm P v_e a_e) x F_2^Z \\ x\tilde{F}_3 &= k(-a_e \mp P v_e) x F_3^{\gamma Z} + k^2(2 v_e a_e \pm P(v_e^2 + a_e^2)) x F_3^Z \end{aligned}$$

- Measure asymmetry between cross sections for left- and righthanded electron positron-proton cross sections:

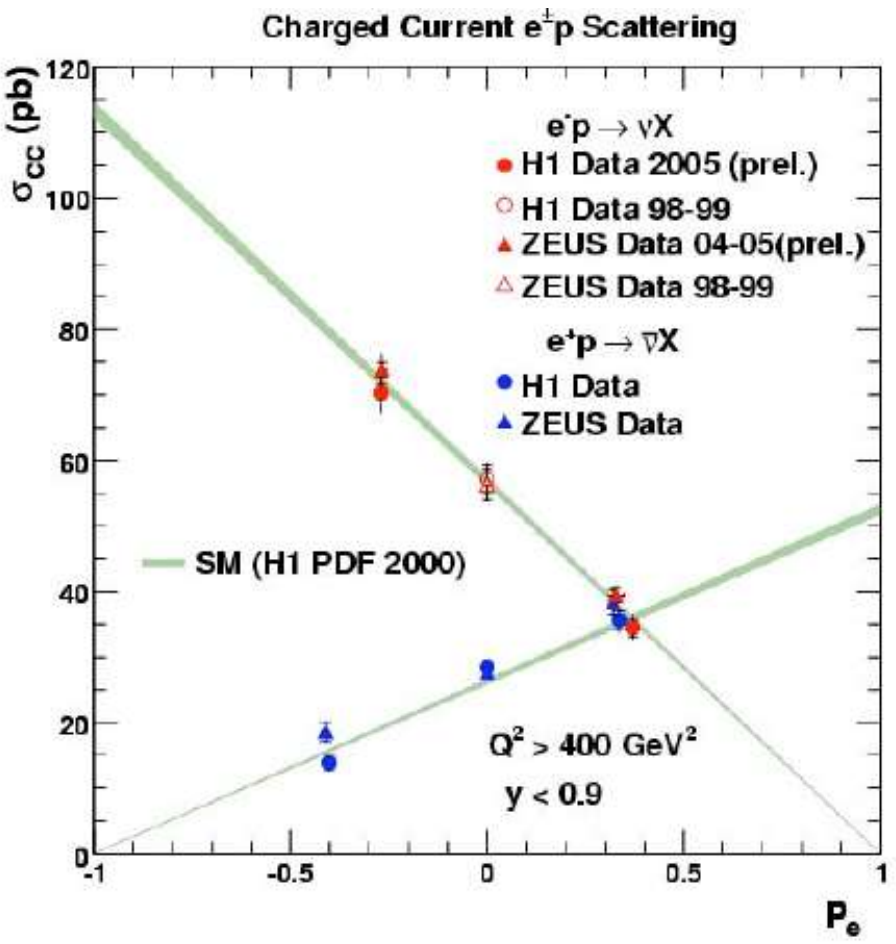
$$A^{\pm} = \frac{2}{P_R - P_L} \cdot \frac{\sigma^{\pm}(P_R) - \sigma^{\pm}(P_L)}{\sigma^{\pm}(P_R) + \sigma^{\pm}(P_L)}$$

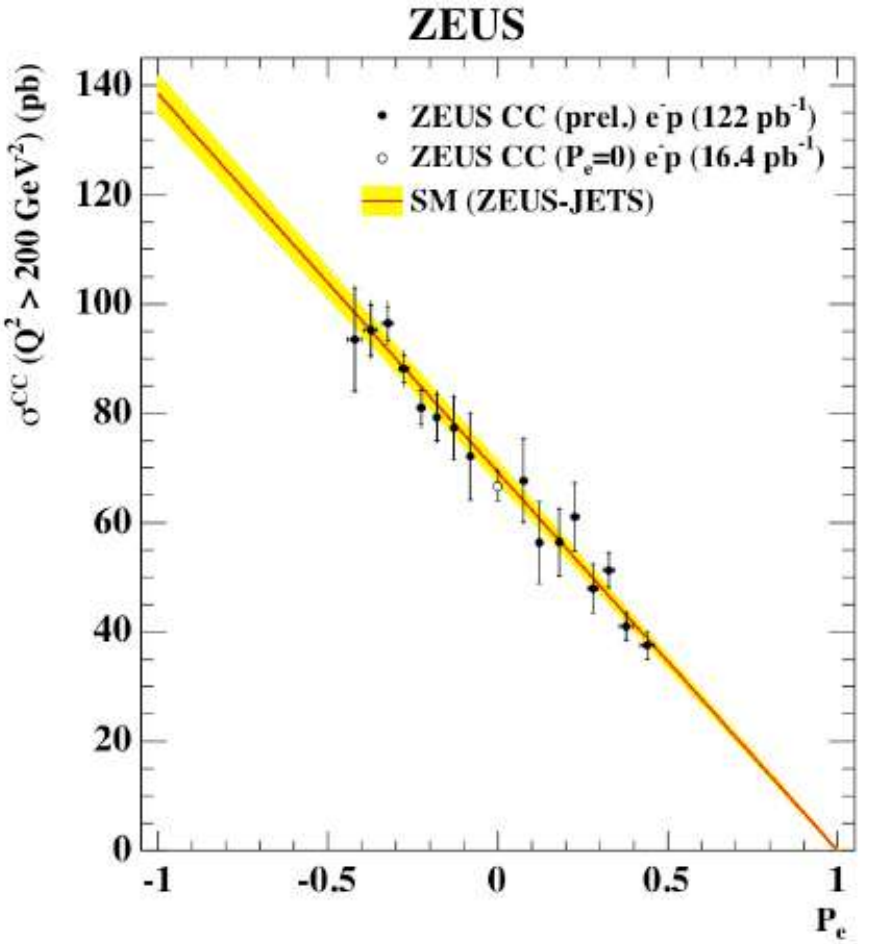


H1prelim-04-142, ZEUS-prel-06-022

Probing the Helicity Structure

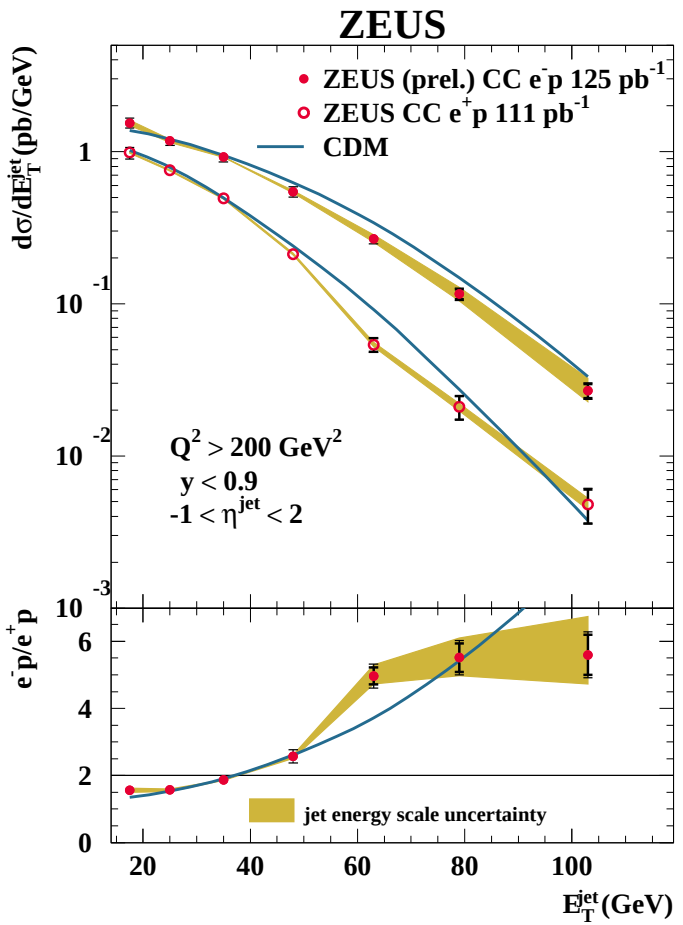
- Integrated CC cross section proportional to $(1 \pm P_e)$:
  A textbook plot!





Our first HERA II Jet measurements:

- Test of SM
- Factor $\times 7$ more $e^- p$ lumi than in HERA I
- Measurements were compared to $e^+ p$ data
- Cross section in good agreement with SM expectations



Selection of e+P_T^{Miss}

H1	ZEUS	
Detection phase space		
$P_T^e > 10$ GeV	$P_T^e > 10$ GeV	
$P_T^{miss} > 12$ GeV	$P_T^{miss} > 12$ GeV	
$5° < \theta_e < 140°$	$17° < \theta_e < 86°$	(*)
	$P_T^X > 12$ GeV	(*)

+Background Supression criteria based on topology & kinematics

(*)Main differences: angular range, restricted PTX domain (ZEUS)

Selection μ+P_T^{Miss}

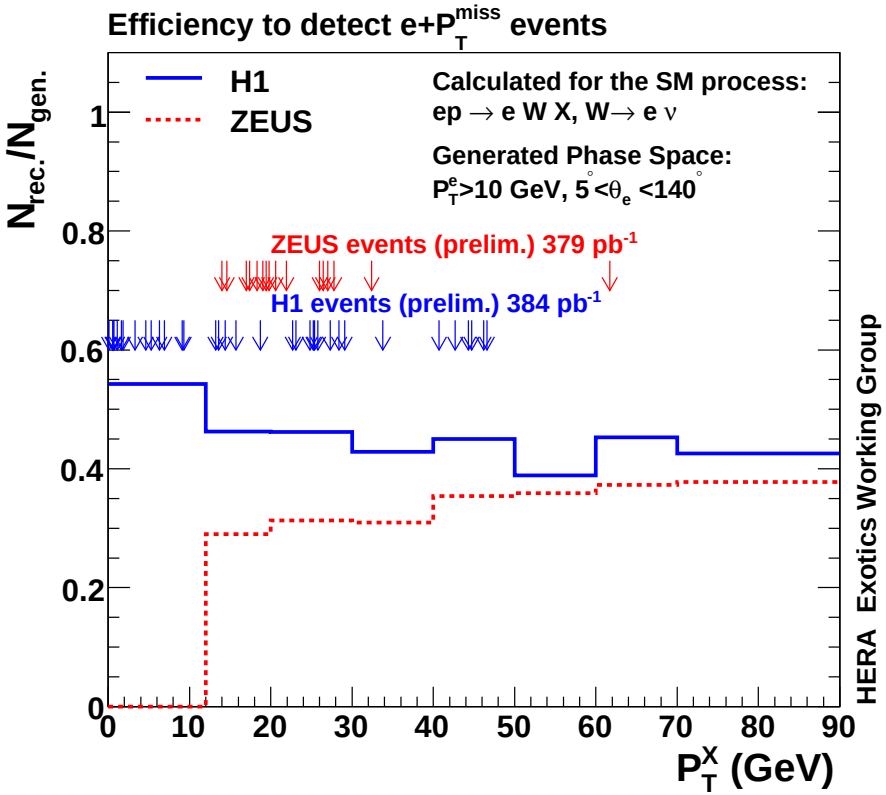
H1 **ZEUS**

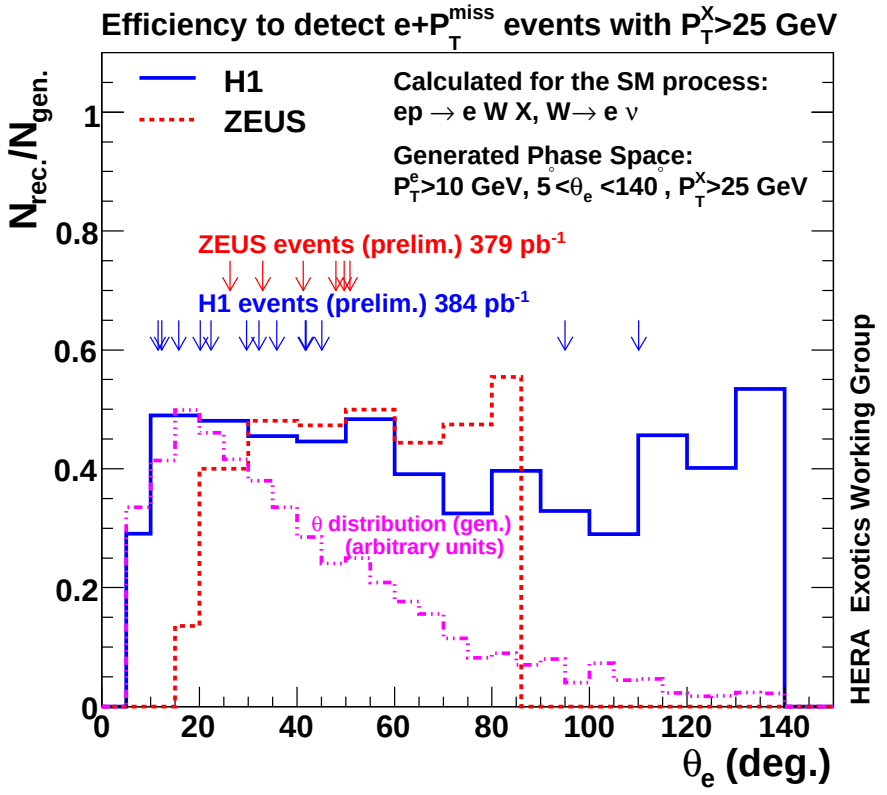
Detection phase space

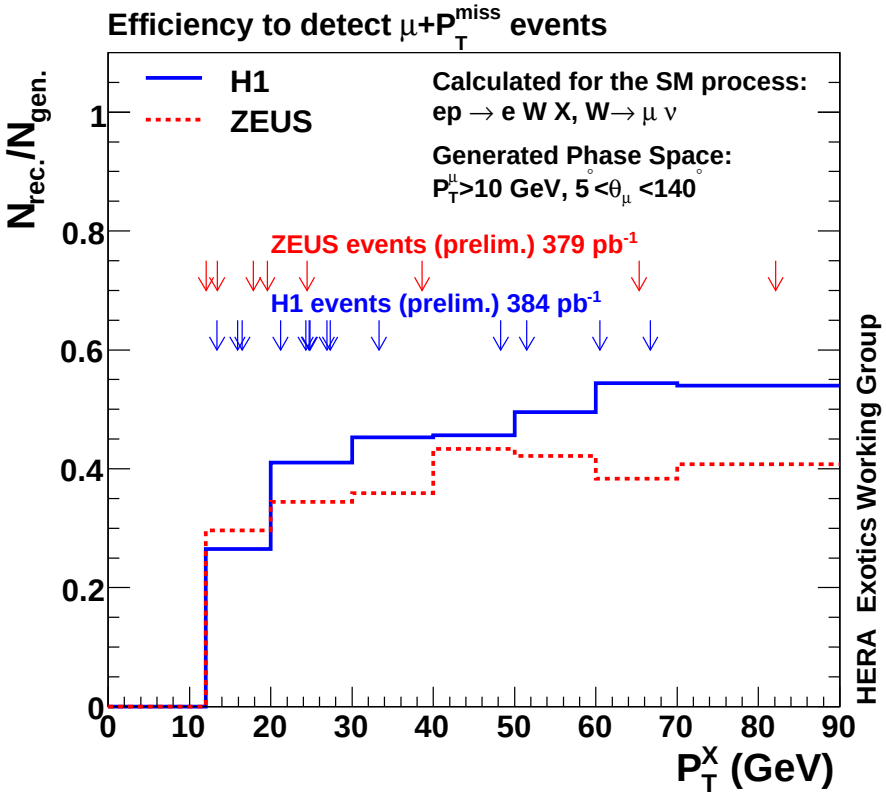
H1	ZEUS	
$P_T^\mu > 10$ GeV	$P_T^\mu > 10$ GeV	
$5^\circ < \theta_\mu < 140^\circ$	$17^\circ < \theta_\mu < 115^\circ$	(*)
$P_T^{miss} > 12$ GeV	$P_T^{miss} > 12$ GeV	
$P_T^X > 12$ GeV	$P_T^X > 12$ GeV	

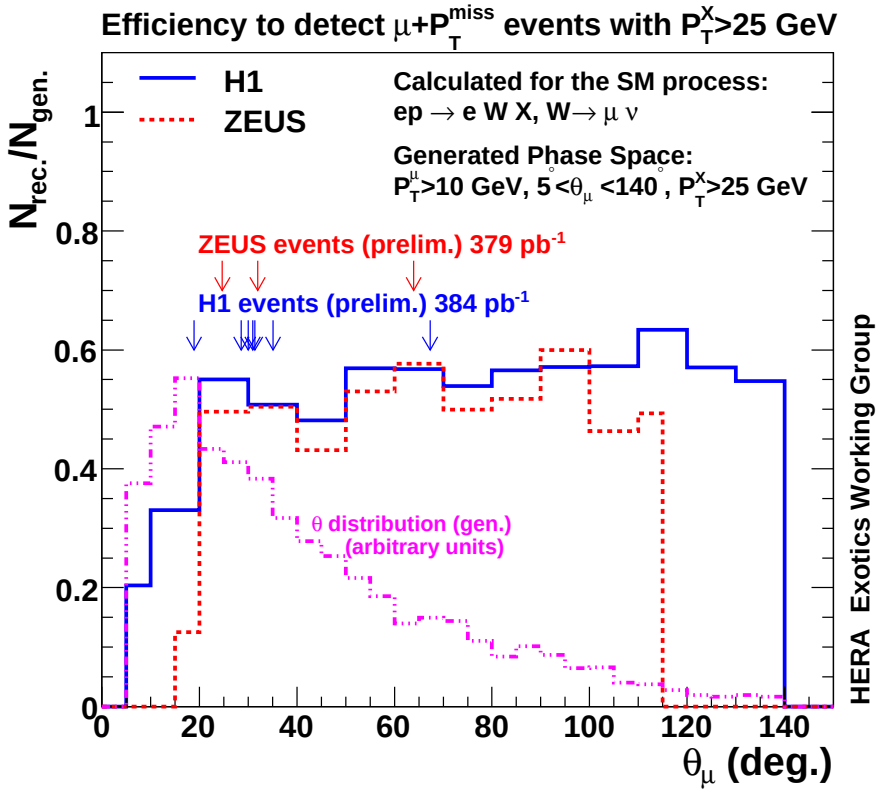
+Background Supression criteria based on topology & kinematics

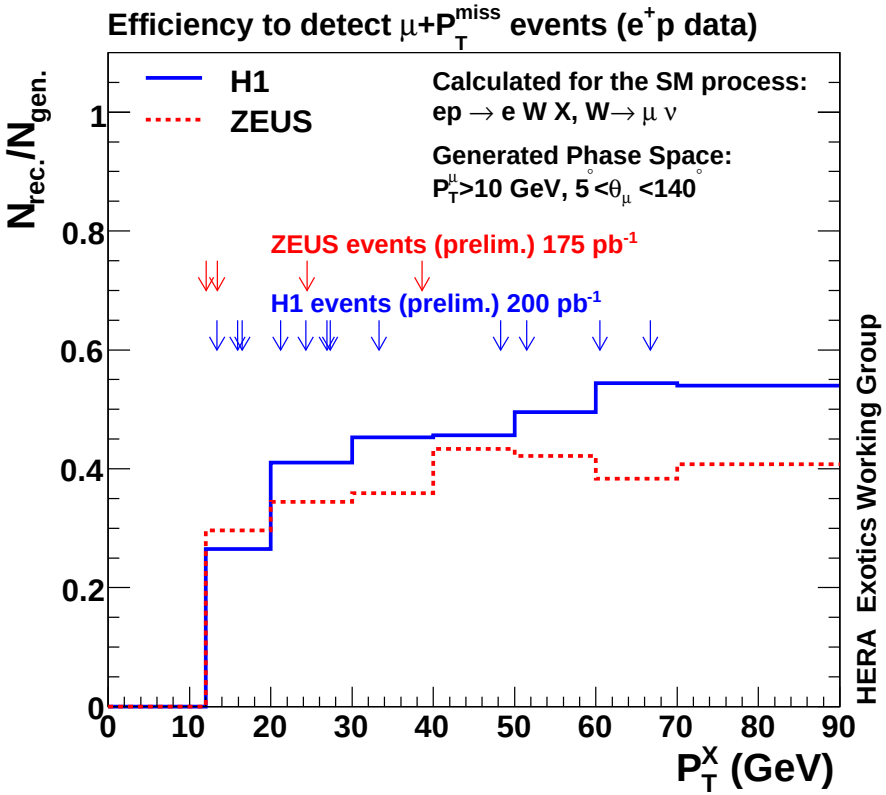
(*) Main Difference: restricted angular range (ZEUS)

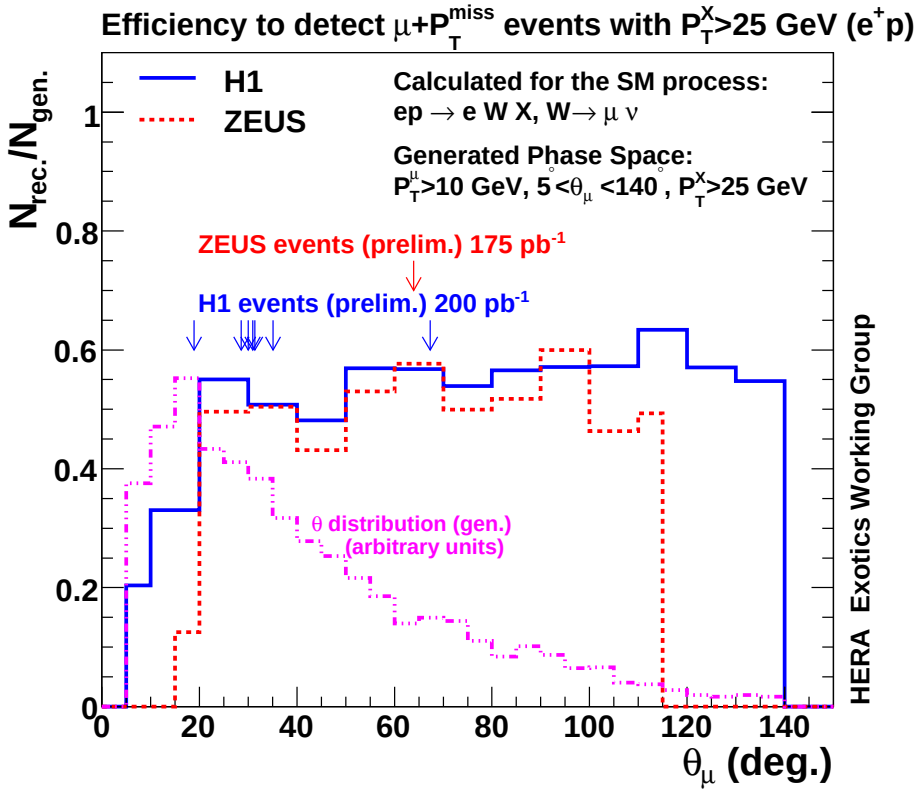

Efficiency to detect e+P$_T^{miss}$ events
H1
ZEUS
Calculated for the SM process:
ep → e W X, W→ e ν
Generated Phase Space:
P$_T^e$>10 GeV, 5°<θ$_e$ <140°
ZEUS events (prelim.) 379 pb^{-1}
H1 events (prelim.) 384 pb^{-1}
N$_{rec.}$/N$_{gen.}$
P$_T^X$ (GeV)
HERA Exotics Working Group


Efficiency to detect e+P$_T^{miss}$ events with P$_T^X$>25 GeV
H1
ZEUS
Calculated for the SM process:
ep → e W X, W→ e ν
Generated Phase Space:
P$_T^e$>10 GeV, 5°<θ$_e$ <140°, P$_T^X$>25 GeV
ZEUS events (prelim.) 379 pb^{-1}
H1 events (prelim.) 384 pb^{-1}
θ distribution (gen.)
(arbitrary units)
N$_{rec.}$/N$_{gen.}$
θ$_e$ (deg.)
HERA Exotics Working Group


Efficiency to detect μ+P_T^miss events
H1
ZEUS
Calculated for the SM process:
ep → e W X, W→ μ ν
Generated Phase Space:
P_T^μ>10 GeV, 5°<θ_μ <140°
ZEUS events (prelim.) 379 pb-1
H1 events (prelim.) 384 pb-1
N_rec./N_gen.
P_T^X (GeV)
HERA Exotics Working Group


Efficiency to detect μ+P_T^miss events with P_T^X>25 GeV
H1
ZEUS
Calculated for the SM process:
ep → e W X, W→ μ ν
Generated Phase Space:
P_T^μ>10 GeV, 5°<θ_μ <140°, P_T^X>25 GeV
ZEUS events (prelim.) 379 pb-1
H1 events (prelim.) 384 pb-1
θ distribution (gen.)
(arbitrary units)
N_rec./N_gen.
θ_μ (deg.)
HERA Exotics Working Group


Efficiency to detect μ+P_T^miss events (e+p data)
N_rec./N_gen.
H1
ZEUS
Calculated for the SM process:
ep → e W X, W→ μ ν
Generated Phase Space:
P_T^μ>10 GeV, 5°<θ_μ <140°
ZEUS events (prelim.) 175 pb-1
H1 events (prelim.) 200 pb-1
HERA Exotics Working Group
P_T^X (GeV)


Efficiency to detect μ+P_T^miss events with P_T^X>25 GeV (e+p)
N_rec./N_gen.
H1
ZEUS
Calculated for the SM process:
ep → e W X, W→ μ ν
Generated Phase Space:
P_T^μ>10 GeV, 5°<θ_μ <140°, P_T^X>25 GeV
ZEUS events (prelim.) 175 pb-1
H1 events (prelim.) 200 pb-1
θ distribution (gen.)
(arbitrary units)
HERA Exotics Working Group
θ_μ (deg.)

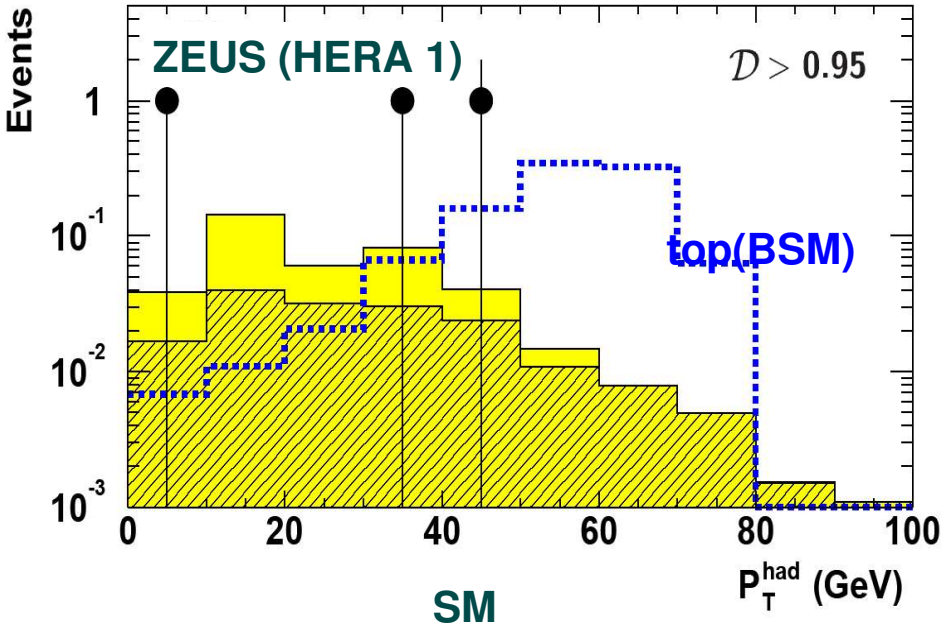
Search for events with $\tau + P_T^{miss}$

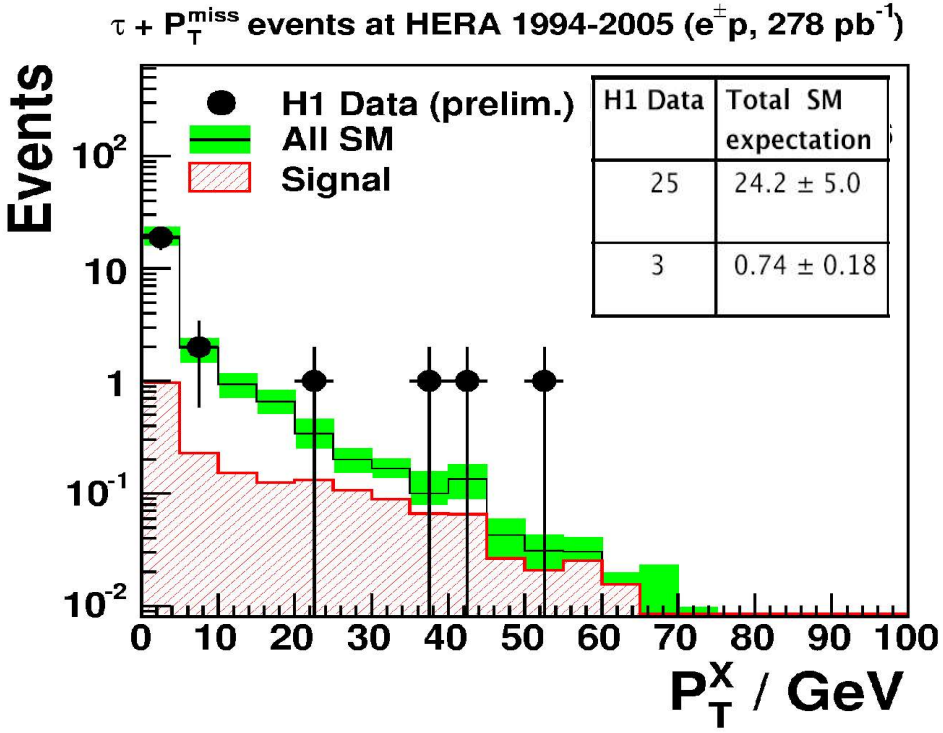
- Use 1-prong hadronic channel
  - remaining hadrons -> X
- Large background from CC-jets
- ZEUS HERA 1(mainly e+p data)

$P_T(\tau\text{-jet})>7$ GeV

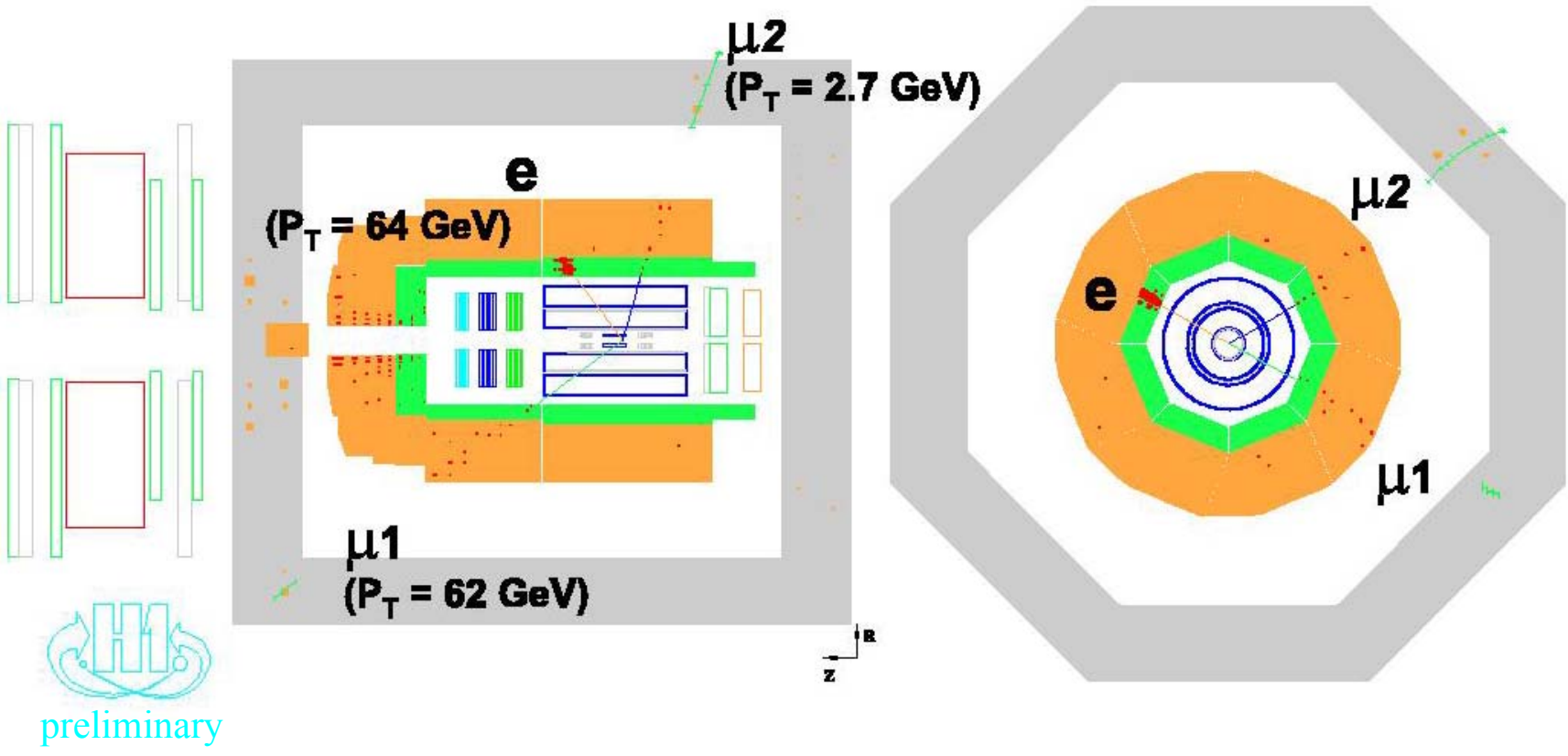
$20<\theta<140$

anti-CC/NC cuts



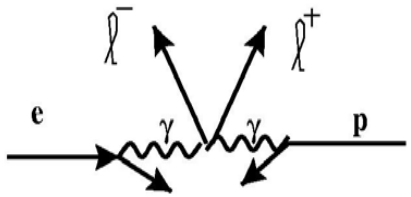


	H1 e^+p 158 pb^{-1}	H1 e^-p 121 pb^{-1}	ZEUS $e^{\pm}p$ 130 pb^{-1}
All	$8/10.6 \pm 2.9$	$17/13.5 \pm 2.6$	$3/0.40 \pm 0.12$
$P_T^X > 25$ GeV	$0/0.40 \pm 0.10$	$3/0.35 \pm 0.09$	$2/0.20 \pm 0.05$

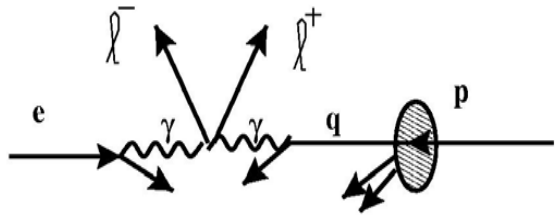


preliminary

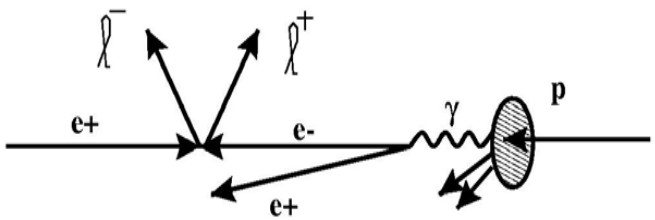
THE SM PROCESSES AND THEIR SIMULATION



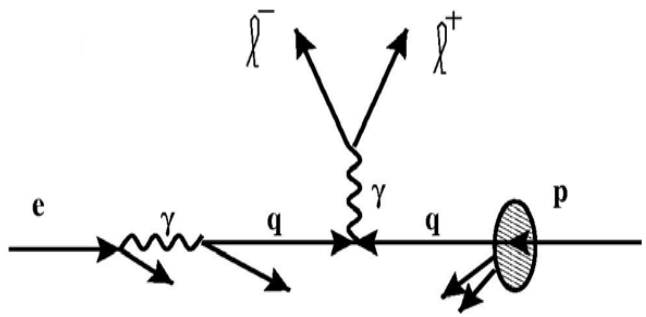
elastic γγ



inelastic γγ



Cabibbo-Parisi



Drell-Yan (negligible)

GRAPE: elastic + inelastic γγ with interference terms + ISR + FSR
+ internal conv. ($\gamma \rightarrow e^+e^-$) + Cabibbo-Parisi + EW processes
interfaced with the H1 detector

Tau Pair Events

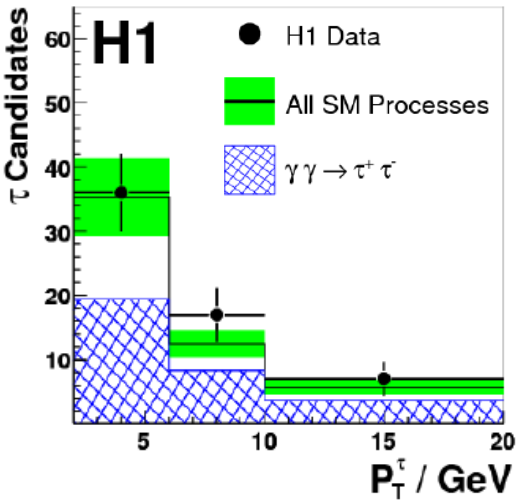
Measurement of $\sigma(\gamma\gamma \to \tau\tau)$
(HERA-I $e^{\pm}p$, 118 pb^{-1})

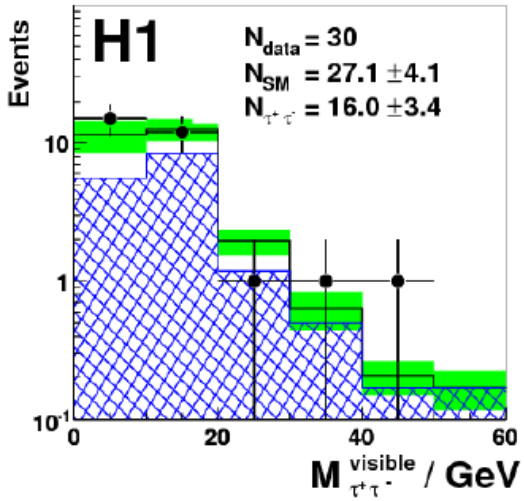
- Final states: *e-μ, e-jet, μ-jet, jet-jet*
- vis. $P_T > 2$ GeV, $20° < \theta < 140°$

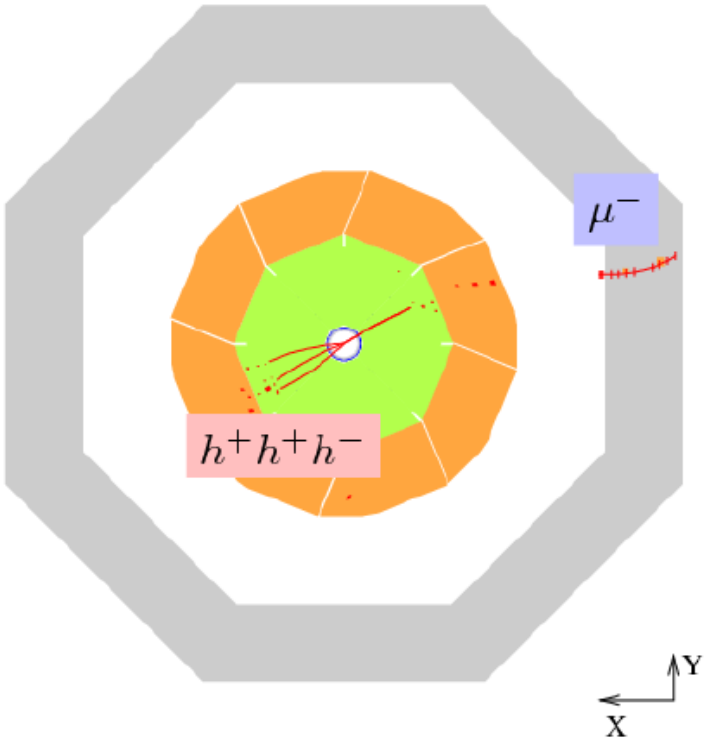
30 obs. / 27.1 ± 4.1 exp. (~60% $\tau\tau$)

$\sigma^{\tau\tau}_{\text{measured}} = 13.6 \pm 5.7$ pb

$\sigma^{\tau\tau}_{\text{expected}} = 11.2 \pm 0.3$ pb





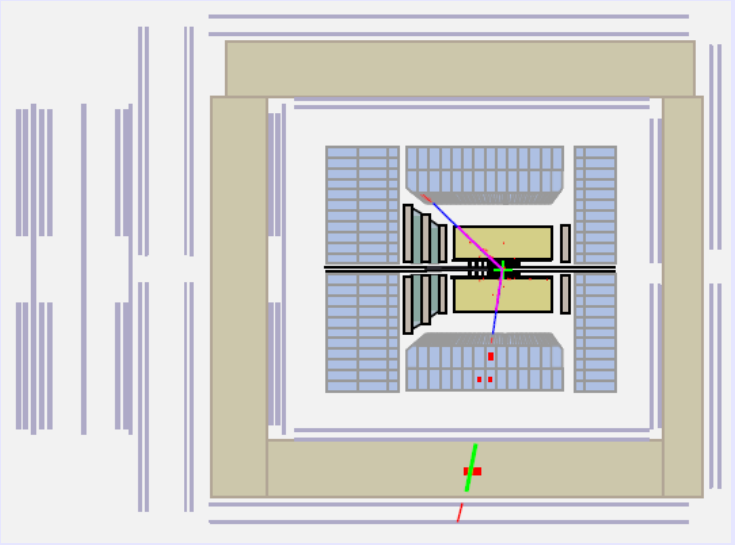


ZEUS

Di-Tau Search (HERA-II e^-p 135 pb^{-1})

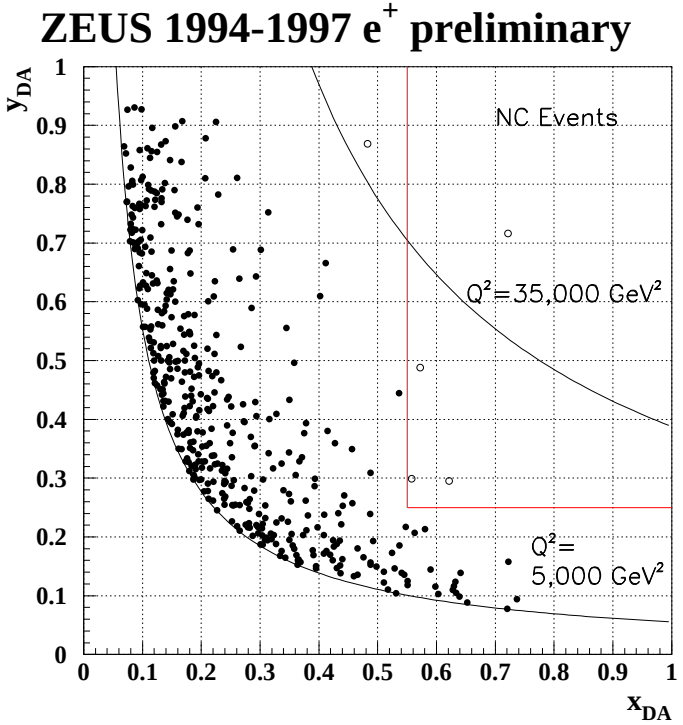
- Final state: *e-μ*
- vis. $P_T > 2$ GeV, $17° < \theta < 164°$

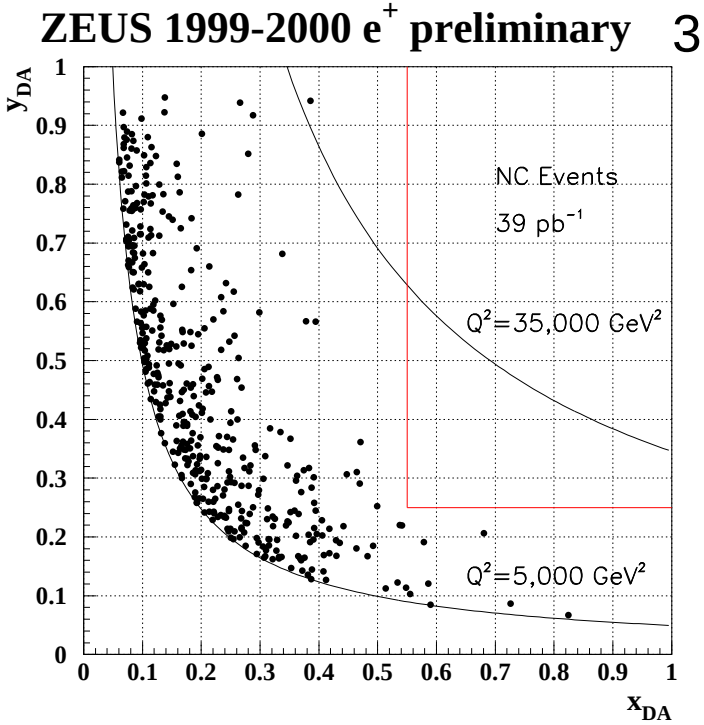
3 obs. / 2 ± 0.8 exp. (~100% $\tau\tau$)



High-Q^2 DIS

High-Q^2 / high-x excess ?





Excess observed in old data not confirmed

ZEUS

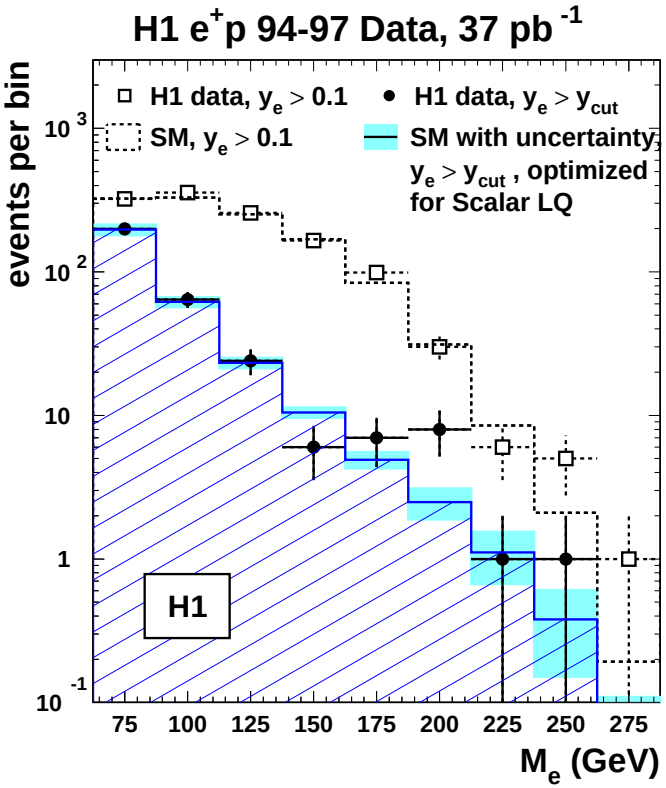
N_{obs} (N_{exp})	1994-97	1998-99	1999-00(part)
$Q^2 > 35\,000$ GeV^2	2 (0.34)	2 (1.02)	1 (0.53)
$x > 0.55$ & $y > 0.25$	4 (1.9)	1 (1.3)	0 (1.6)

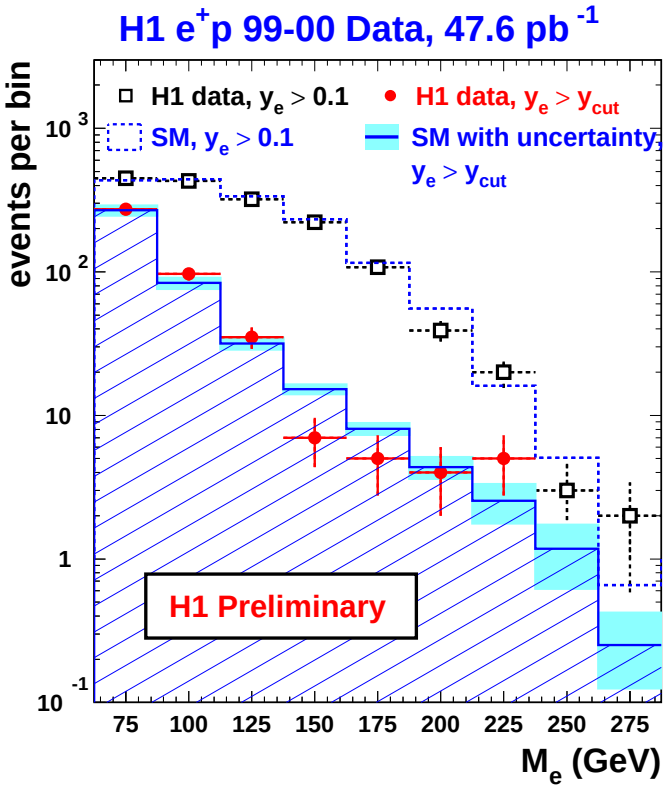
1994-96
2 (0.15)
4 (0.91)

High-Q^2 DIS

High mass excess ?

Old H1 e^+p data (especially in 1994-96) showed excess at M$\sim$ 200 GeV





excess at high y
consistent with leptoquark production

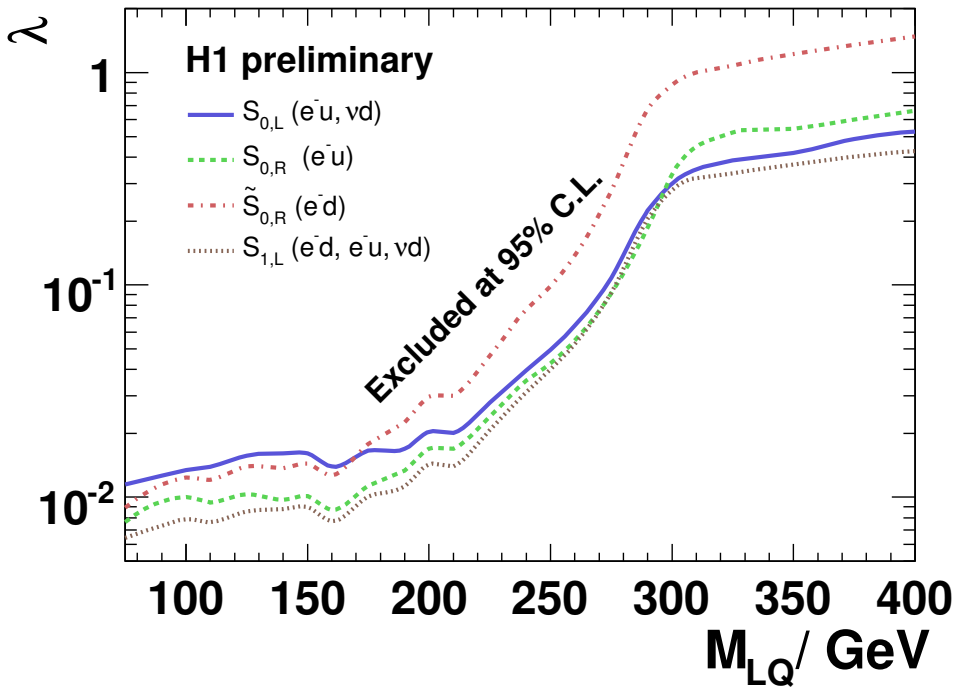
$\Rightarrow$ not confirmed by new data...

Scalar LQs with F=2 from H1 (HERA II)

No evidence for LQ production

$\Downarrow$

Limits on LQ Yukawa coupling λ as a function of M_{LQ}:



F=2 BRW LQ models

$\Rightarrow e^- p$ data more sensitive than $e^+ p$

Combing NC + CC data

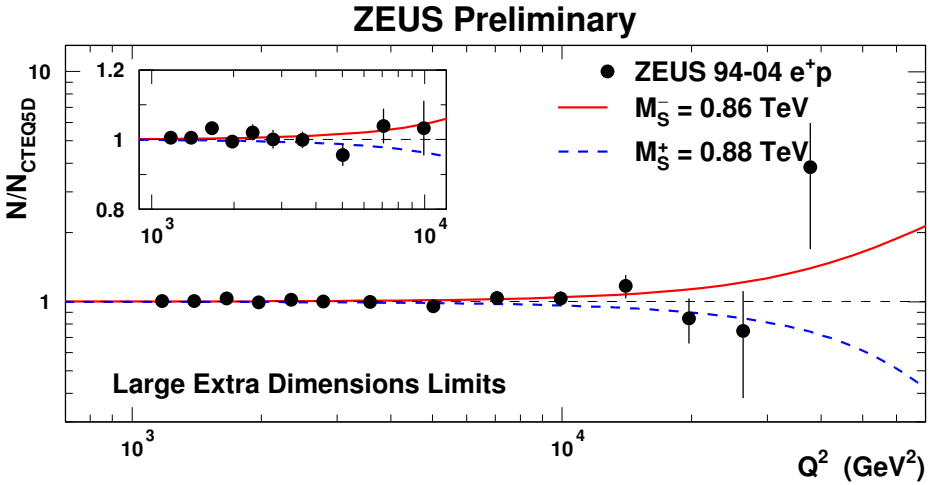
for S_0^L and S_1^L LQ model

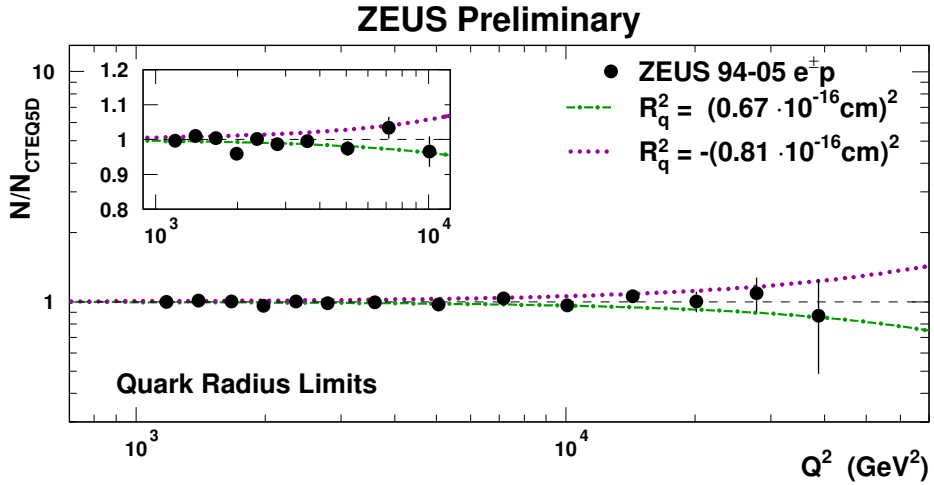
$\Rightarrow$ increases sensitivity

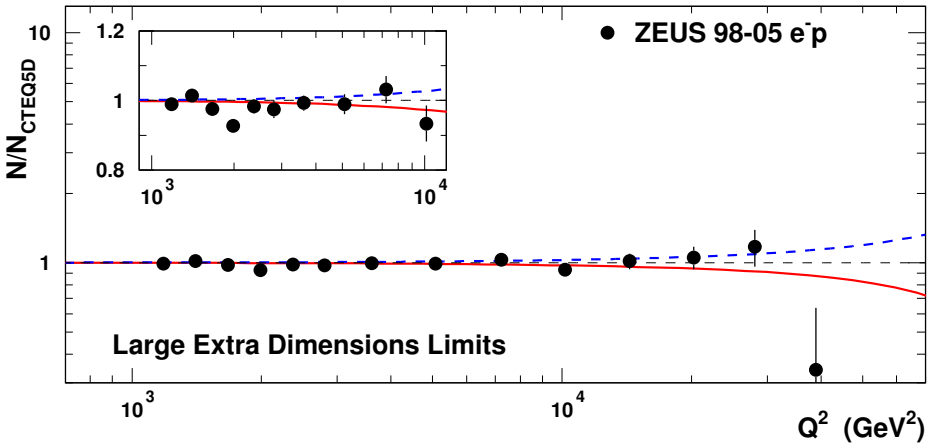
At $\lambda = \sqrt{4\pi\alpha} \approx 0.3$ lower limits on M_{LQ}: > 276 - 304 GeV

Results

Public plots: LED and R_q



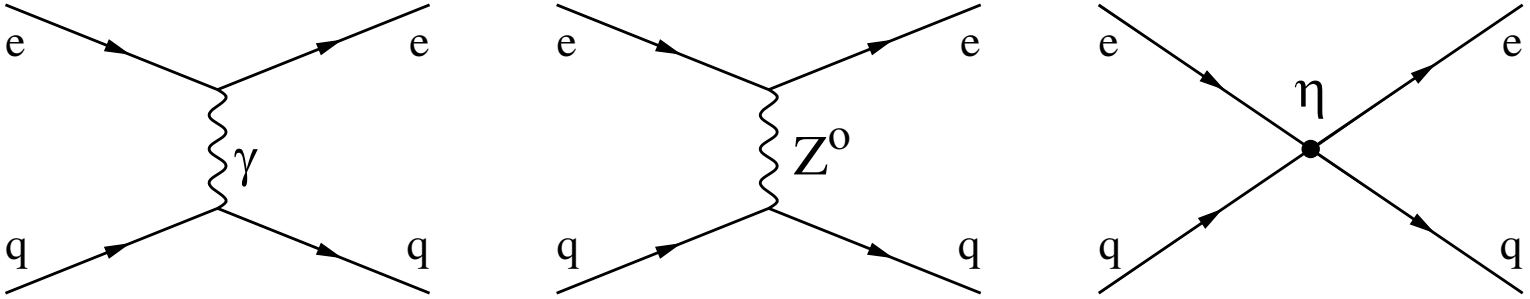




Models

Contact Interactions

Contact Interactions modify tree level $eq \to eq$ scattering amplitudes $M^{eq}_{\alpha\beta}$:



$$M^{eq}_{\alpha\beta}(Q^2) = \underbrace{\frac{e^2 e_q}{Q^2}}_{\gamma} - \underbrace{\frac{e^2}{sin^2\theta_W \cdot cos^2\theta_W} \cdot \frac{g^e_\alpha g^q_\beta}{Q^2 + m^2_Z}}_{Z^\circ} + \underbrace{\eta^{eq}_{\alpha\beta}}_{?}$$

$\eta^{eq}_{\alpha\beta}$ - 4 possible couplings for every flavor q

Different models assume different helicity structure of new interactions

Models

Cross-section formula

For NC e^-p DIS with unpolarized beam

$$\frac{d^2\sigma^{e^-p}}{dxdy} =$$

$$\frac{sx}{16\pi}\sum_q \quad q(x)\left\{ \quad |M^{eq}_{LL}|^2 + \quad |M^{eq}_{RR}|^2 + (1-y)^2\left[\quad |M^{eq}_{LR}|^2 + \quad |M^{eq}_{RL}|^2\right]\right\}$$

$$+ \quad \bar{q}(x)\left\{ \quad |M^{eq}_{LR}|^2 + \quad |M^{eq}_{RL}|^2 + (1-y)^2\left[\quad |M^{eq}_{LL}|^2 + \quad |M^{eq}_{RR}|^2\right]\right\}$$

$\Rightarrow$ most sensitive to η^{eq}_{LL} and η^{eq}_{RR} (q=u,d)

Models

Cross-section formula

For NC e^-p DIS with polarized beam

$$\frac{d^2\sigma^{e^-p}}{dxdy} =$$

$$\frac{sx}{16\pi}\sum_q \quad q(x)\left\{\mathcal{P}_-|M^{eq}_{LL}|^2+\mathcal{P}_+|M^{eq}_{RR}|^2+(1-y)^2\left[\mathcal{P}_-|M^{eq}_{LR}|^2+\mathcal{P}_+|M^{eq}_{RL}|^2\right]\right\}$$

$$+ \quad \bar{q}(x)\left\{\mathcal{P}_-|M^{eq}_{LR}|^2+\mathcal{P}_+|M^{eq}_{RL}|^2+(1-y)^2\left[\mathcal{P}_-|M^{eq}_{LL}|^2+\mathcal{P}_+|M^{eq}_{RR}|^2\right]\right\}$$

$\Rightarrow$ most sensitive to η^{eq}_{LL} and η^{eq}_{RR} (q=u,d)

where: $\mathcal{P}_\pm = (1 \pm P)$

P is electron beam polarization

Models

Cross-section formula

For NC e^+p DIS with polarized beam

$$\frac{d^2\sigma^{e^+p}}{dxdy} =$$

$$\frac{sx}{16\pi}\sum_q \quad q(x)\left\{\mathcal{P}_+|M^{eq}_{LR}|^2+\mathcal{P}_-|M^{eq}_{RL}|^2+(1-y)^2\left[\mathcal{P}_+|M^{eq}_{LL}|^2+\mathcal{P}_-|M^{eq}_{RR}|^2\right]\right\}$$

$$+ \quad \bar{q}(x)\left\{\mathcal{P}_+|M^{eq}_{LL}|^2+\mathcal{P}_-|M^{eq}_{RR}|^2+(1-y)^2\left[\mathcal{P}_+|M^{eq}_{LR}|^2+\mathcal{P}_-|M^{eq}_{RL}|^2\right]\right\}$$

$\Rightarrow$ most sensitive to η^{eq}_{LR} and η^{eq}_{RL} (q=u,d)

$\Rightarrow$ Combining e^+p and e^-p can significantly improve limits

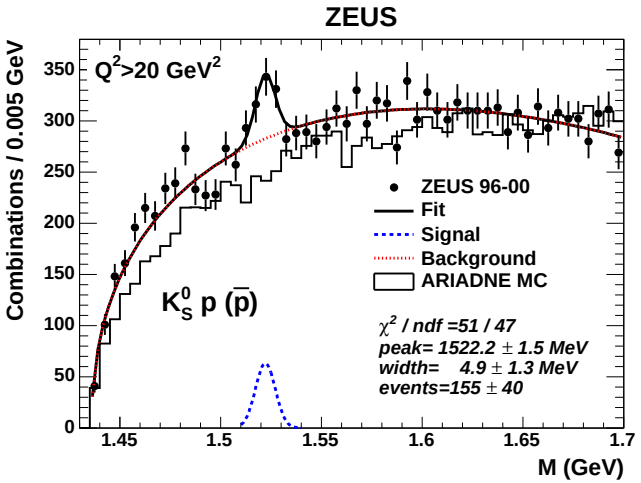
Results

Public numbers

ZEUS Preliminary 1994-2005 $e^{\pm}p$			
	Coupling structure	95% C.L. (TeV)	
Model	$[\epsilon_{LL}, \epsilon_{LR}, \epsilon_{RL}, \epsilon_{RR}]$	Λ^-	Λ^+
LL	[+1, 0, 0, 0]	4.2	4.2
LR	[0, +1, 0, 0]	2.0	3.6
RL	[0, 0, +1, 0]	2.3	3.6
RR	[0, 0, 0, +1]	4.0	3.8
VV	[+1, +1, +1, +1]	7.5	6.3
AA	[+1,−1,−1, +1]	5.9	6.3
VA	[+1,−1, +1, −1]	3.3	3.5
X1	[+1,−1, 0, 0]	4.3	4.7
X2	[+1, 0, +1, 0]	5.1	4.7
X3	[+1, 0, 0, +1]	5.9	5.3
X4	[0, +1, +1, 0]	5.4	4.8
X5	[0, +1, 0, +1]	5.1	4.5
X6	[0, 0, +1, −1]	4.3	4.1
U1	$[+1,-1, 0, 0]^{eu}$	5.2	5.5
U2	$[+1, 0, +1, 0]^{eu}$	6.1	5.2
U3	$[+1, 0, 0, +1]^{eu}$	7.1	6.1
U4	$[0, +1, +1, 0]^{eu}$	6.1	5.0
U5	$[0, +1, 0, +1]^{eu}$	6.2	5.0
U6	$[0, 0, +1,-1]^{eu}$	4.5	4.7

ZEUS Preliminary 1994-2000 $e^{\pm}p$		
Model	Coupling Structure	95% C.L. (TeV) M_{LQ}/λ_{LQ}
$S_\circ^L$	$a_{LL}^{eu} = +\frac{1}{2}$	0.96
$S_\circ^R$	$a_{RR}^{eu} = +\frac{1}{2}$	0.82
$\tilde{S}_\circ^R$	$a_{RR}^{ed} = +\frac{1}{2}$	0.32
$S_{1/2}^L$	$a_{LR}^{eu} = -\frac{1}{2}$	0.88
$S_{1/2}^R$	$a_{RL}^{ed} = a_{RL}^{eu} = -\frac{1}{2}$	0.46
$\tilde{S}_{1/2}^L$	$a_{LR}^{ed} = -\frac{1}{2}$	0.44
S_1^L	$a_{LL}^{ed} = +1,\ a_{LL}^{eu} = +\frac{1}{2}$	0.74
$V_\circ^L$	$a_{LL}^{ed} = -1$	0.80
$V_\circ^R$	$a_{RR}^{ed} = -1$	0.62
$\tilde{V}_\circ^R$	$a_{RR}^{eu} = -1$	1.33
$V_{1/2}^L$	$a_{LR}^{ed} = +1$	0.46
$V_{1/2}^R$	$a_{RL}^{ed} = a_{RL}^{eu} = +1$	1.00
$\tilde{V}_{1/2}^L$	$a_{LR}^{eu} = +1$	1.10
V_1^L	$a_{LL}^{ed} = -1,\ a_{LL}^{eu} = -2$	1.91

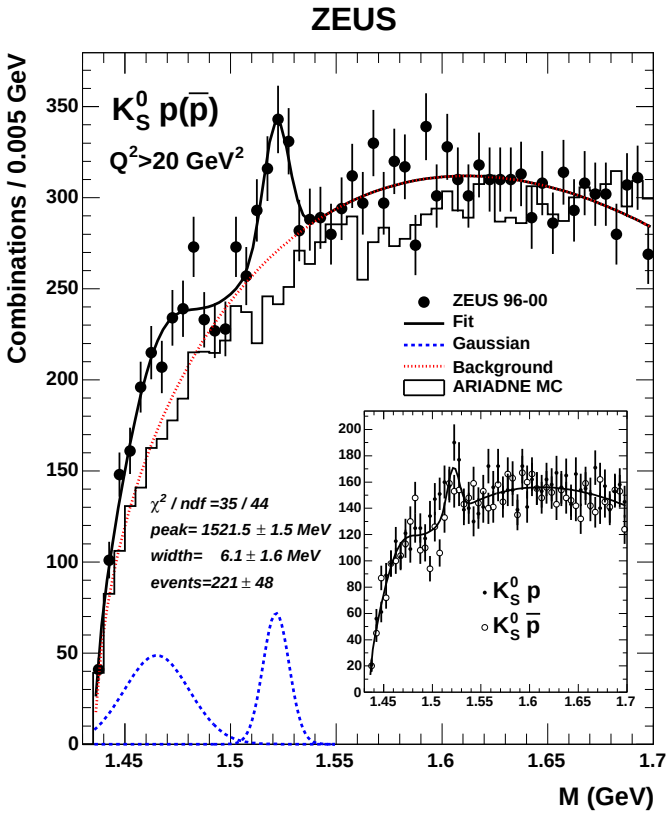
$M(K^0_s p(\bar{p}))$ for $Q^2 > 20\,\mathrm{GeV}^2$



$Q^2 > 20\,\mathrm{GeV}^2$: best signal identification

Fit with Gaussian + background (3 par.)

$N = 155 \pm 40$, $M = 1522.2 \pm 1.5\,\mathrm{MeV}$
width compatible with resolution



Fit with 2nd Gaussian for (Σ ?) bump around 1465 MeV

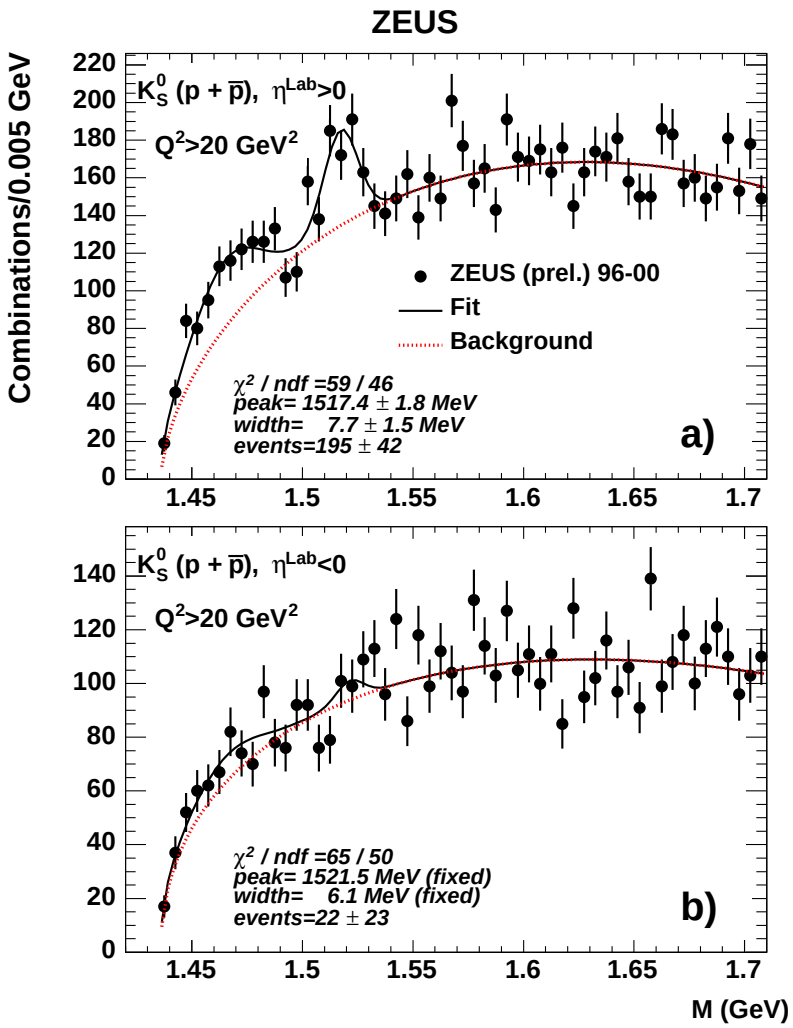
$N = 221 \pm 48$, $M = 1521.5 \pm 1.5\,\mathrm{MeV}$
width compatible with resolution

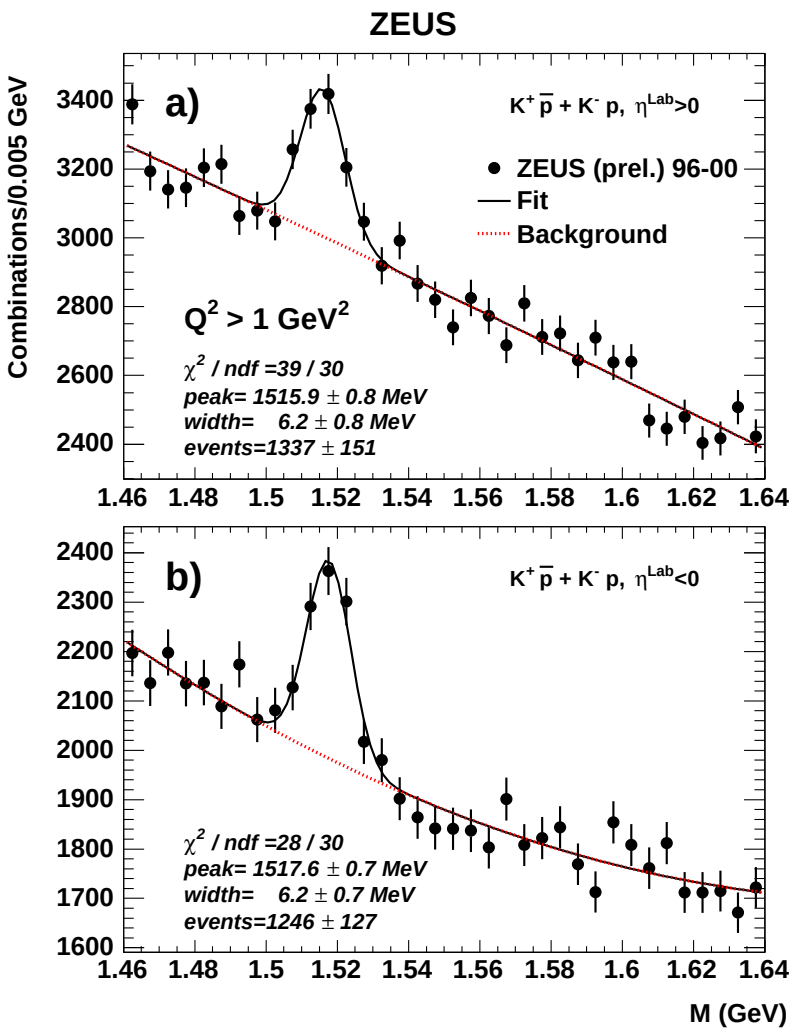
For BW: $\Gamma = 8 \pm 4$ (stat.) MeV

$\Longleftarrow$ signal seen in both charges

$N(\Theta^- \to K^0_s \bar{p}) = 96 \pm 34$

Θ^+ production mechanism in ep collisions ?





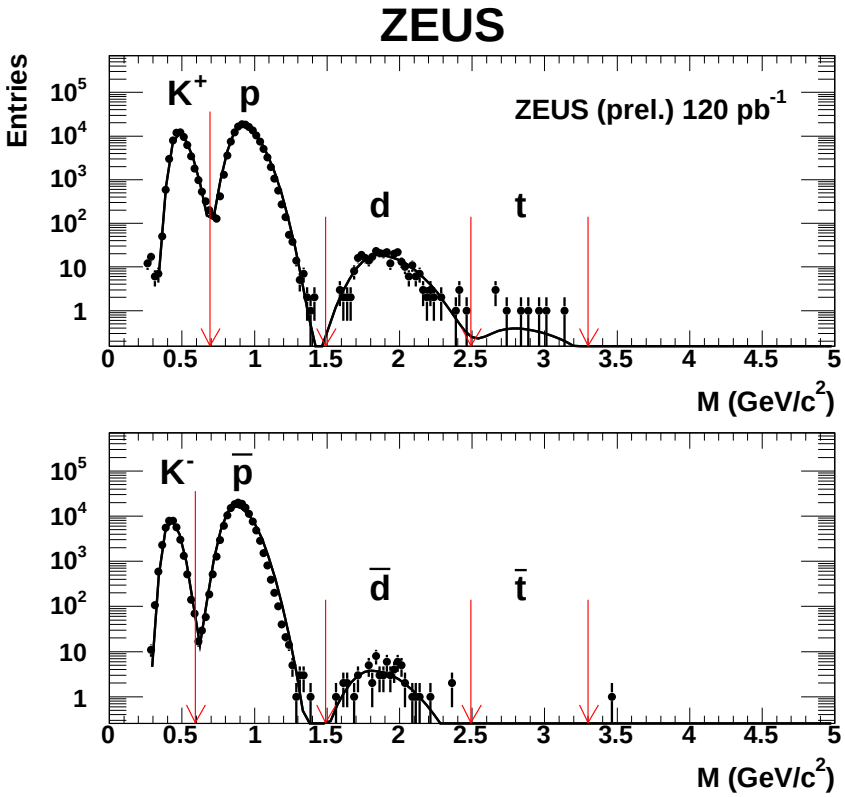
$\Theta^{\pm}$ produced mostly in forward (proton) direction

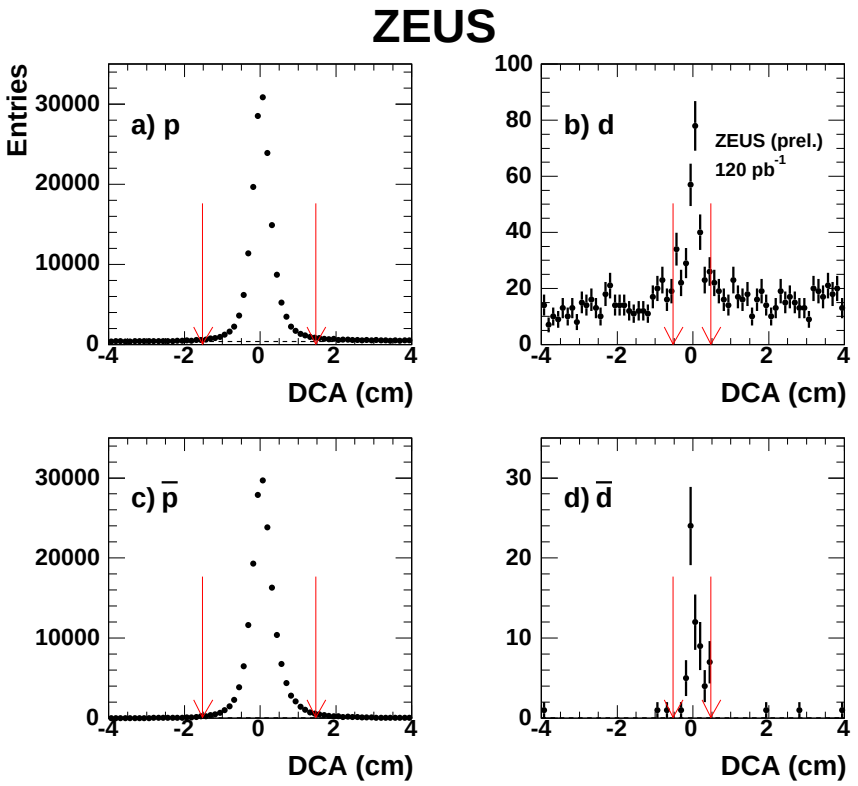
It is not a case for $\Lambda(1520)$ produced in q/g fragmentation

$\Theta^{\pm}$ may have unusual production mechanism related to p-remnant fragmentation ?

in case of coalescence, should be sizeable $d/\bar{d}$ production in DIS

$d/\bar{d}$ production in DIS with $Q^2 > 1\,\mathrm{GeV}^2$





$M = P/f_{BB}^{-1}(dE/dx)$

for tracks with $dE/dx > 2.5$

Distance of Closest Approach to beam spot in transverse plane

Subtracting side-band background: $N(d) = 195 \pm 18$

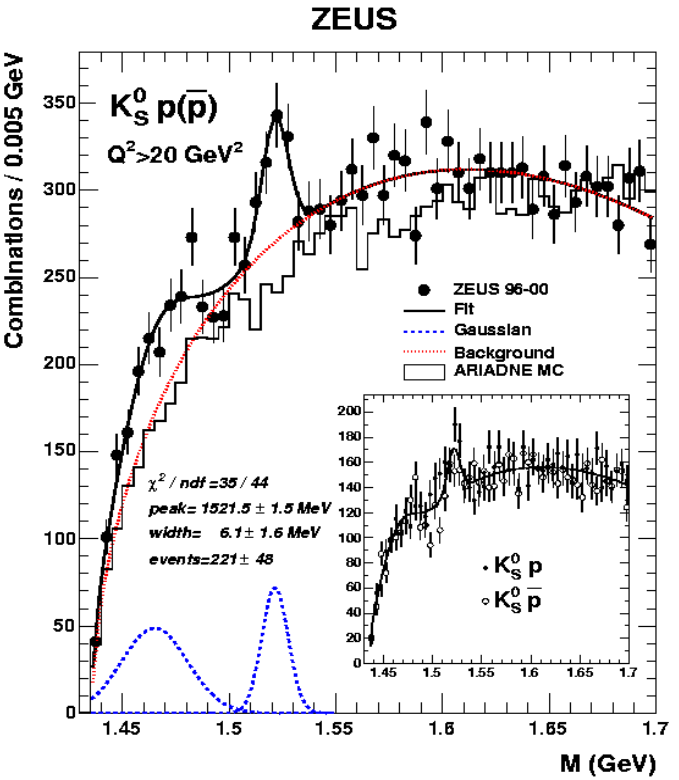
$N(\bar{d}) = 61 \pm 8$

Yes, $d/\bar{d}$ are produced in DIS as well

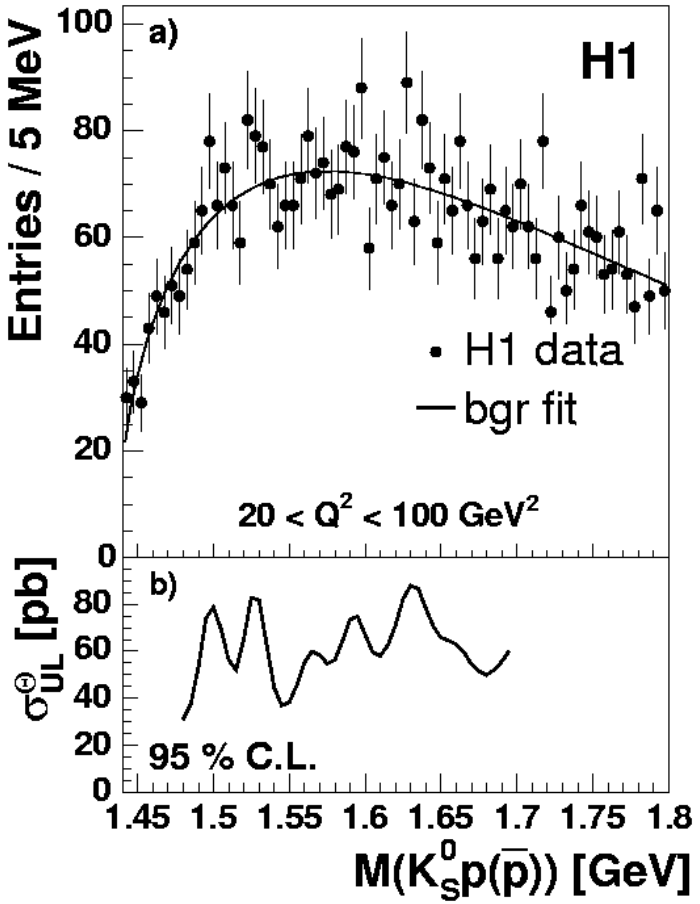
Search for the $\Theta^+(1530)$ Pentaquark

Compare with the ZEUS analysis

$p(p) < 1.5$ GeV
$Q^2 > 20$ GeV^2



H1 data with "ZEUS cuts"



H1:

$\sigma(M{=}1.52) < 72\ pb\ (95\%\ C.L.)$

When extrapolated to ZEUS y-range

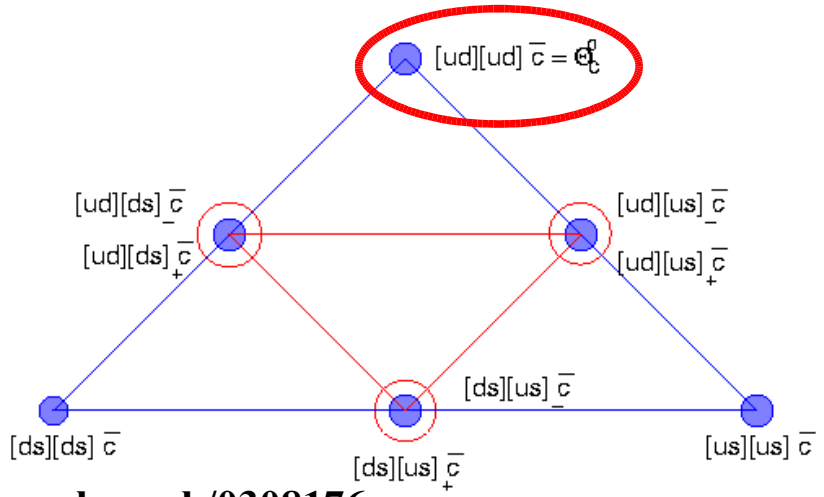
$\sigma(M{=}1.52) < 100\ pb\ (95\%\ C.L.)$

ZEUS Prel.:

$\sigma = 125 \pm 27\,^{+36}_{-28}\ pb$

H1 does not confirm the ZEUS result

Anticharmed Pentaquark Θ_c° $(D^*p(3100))$



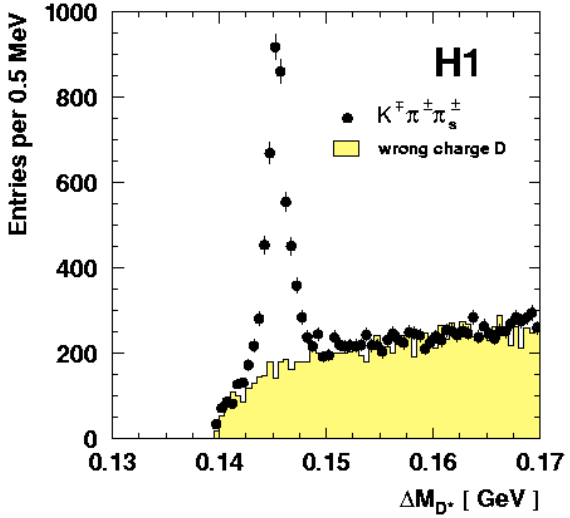
Cheung hep-ph/0308176

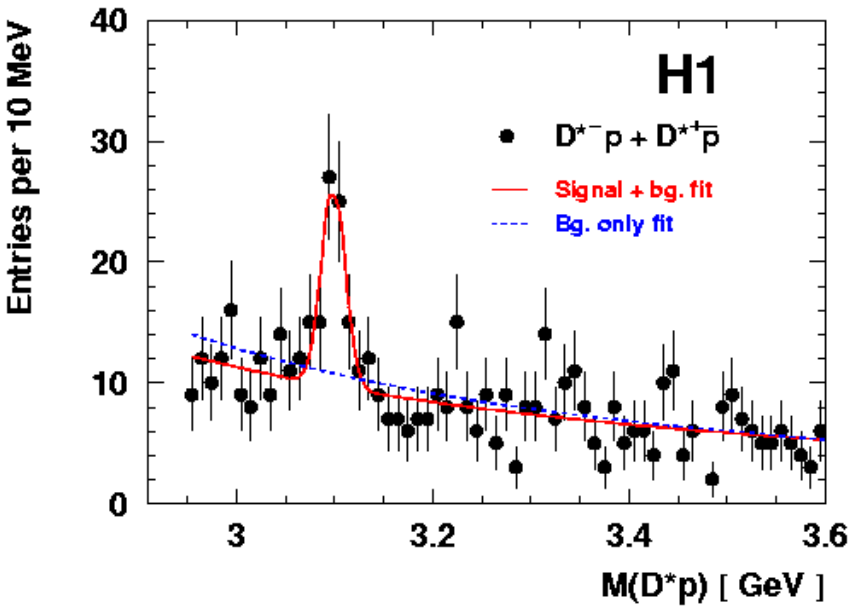
Predicted mass: ~ 3 GeV

Possible Decays:

$$\Theta_c^\circ \to D^- p, \quad \Theta_c^\circ \to \overline{D^\circ} n$$

If heavy enough, decay to $D^{*-} p$ possible





Evidence published
Phys.Lett. B588 (2004) 17

So far, no other experiment could confirm this signal

Here: Acceptance corrected yields ratios, differential distributions (H1 Prel.)