Search for single top production in ep collisions at HERA

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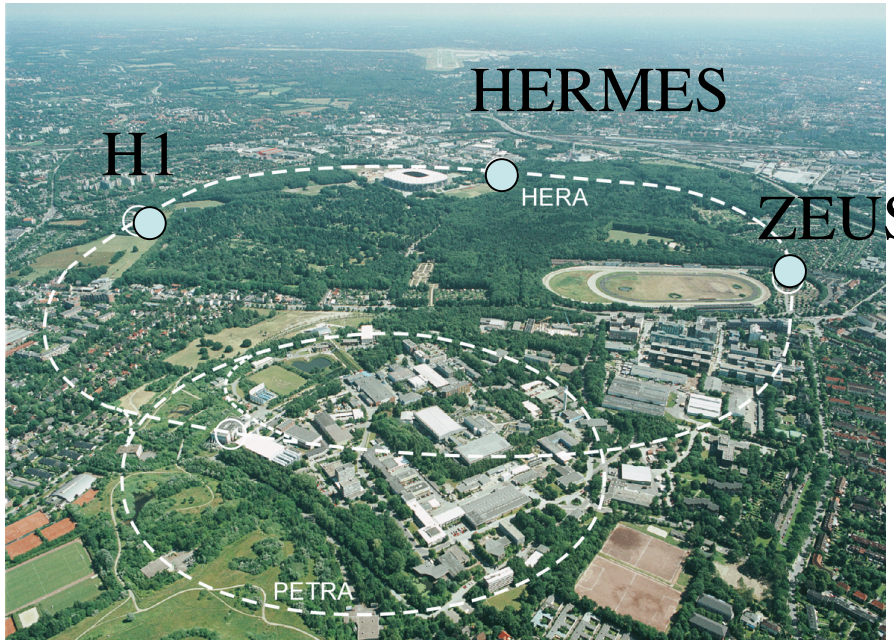
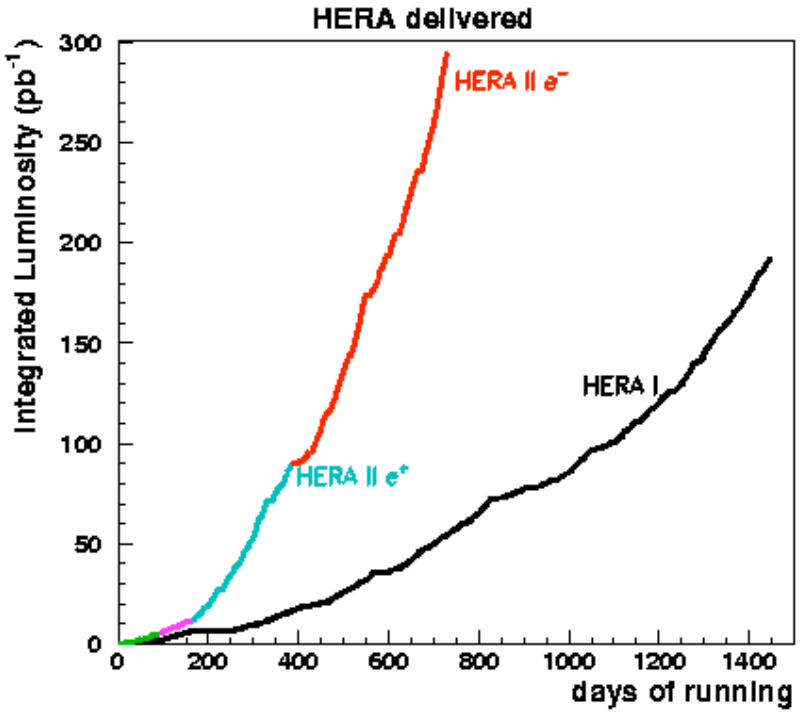
On behalf of H1 and ZEUS collaborations

Hera : Hadron Electron Ring Accelerator



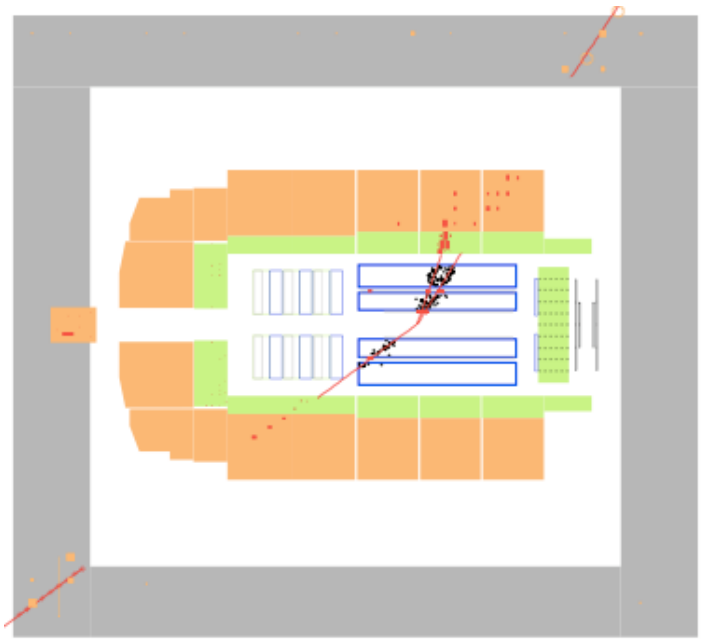


1. **Electron or positron on proton collisions at $\sqrt{s}$=315 GeV**

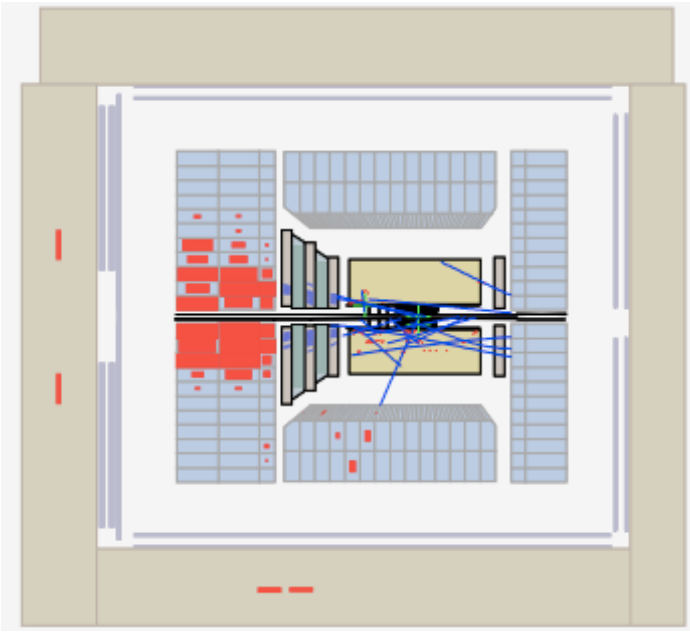
2. **Two collider experiments: H1 and ZEUS , and a fixed target experiment: HERMES**

3. **Total Luminosity analized so far 280 pb^{-1} per experiment. Data taking until mid 2007**

H1



ZEUS



Elements relevant to the results presented:

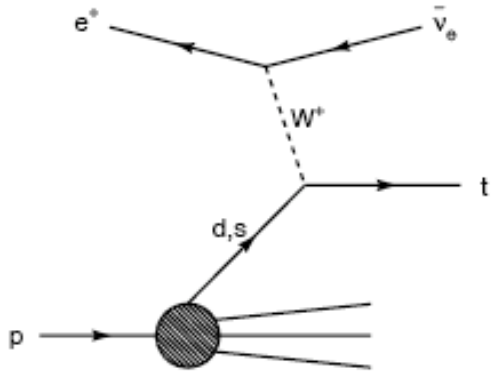
H1 Calorimeter
Resolution in energy
for particle e $0.12/\sqrt{E(GeV)}$
hadr. $0.50/\sqrt{E(GeV)}$
Precise measurement of scattered e

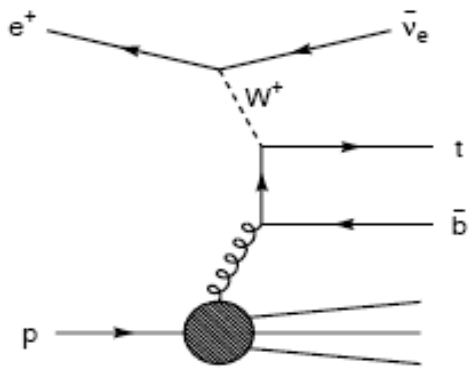
ZEUS Calorimeter
Resolution in energy
for particle e $0.18/\sqrt{E(GeV)}$
hadr. $0.35/\sqrt{E(GeV)}$
Precise measurement of hadronic final state

Muon detectors located in the outermost part of the detector

Single top production at HERA

In Standard Model



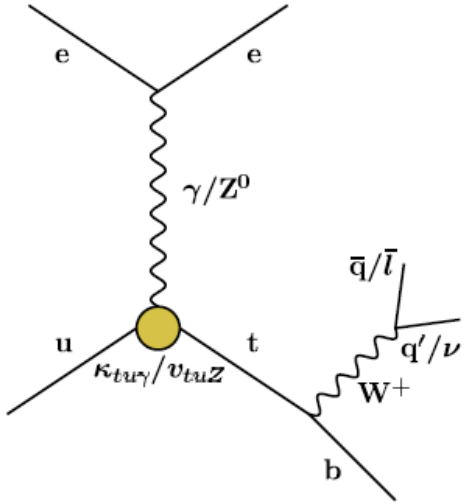


$\sigma_{top} \approx 1$ fb

Expect 0.1 event in 100 pb^{-1} of data
⇒ Single top in SM negligible

Observation of top production at HERA would be clear signal of new physics!

Beyond the Standard Model



Flavour Changing Neutral Current (FCNC) with anomalous $k_{tu\gamma}$ coupling at HERA could have sizeable cross section

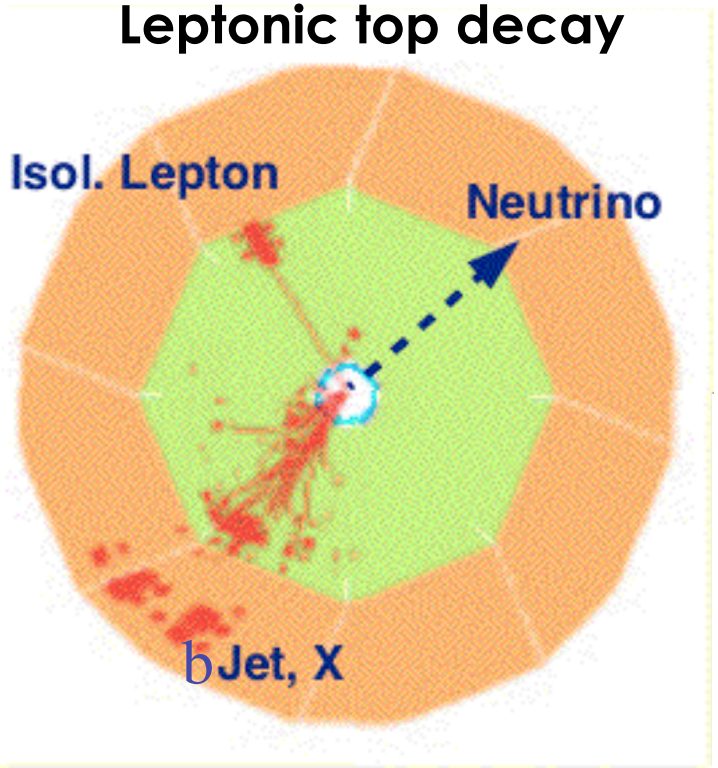
- **predicted in various models (e.g. SUSY)**
- **considered also at LEP and TEVATRON**

Top decay signatures

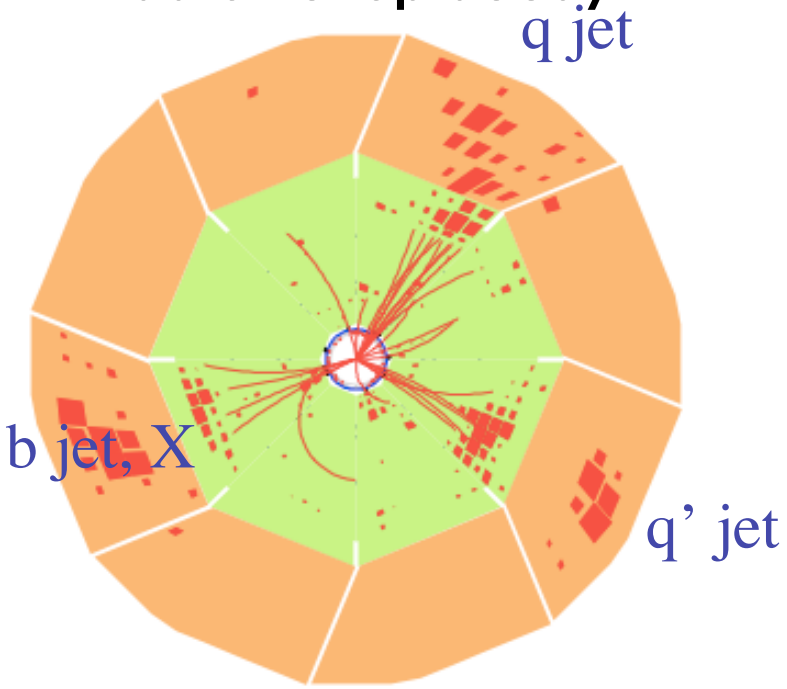
$t \rightarrow b\,W$

$\hookrightarrow l\,\nu$ or $q\,q'$

Leptonic top decay



Hadronic top decay

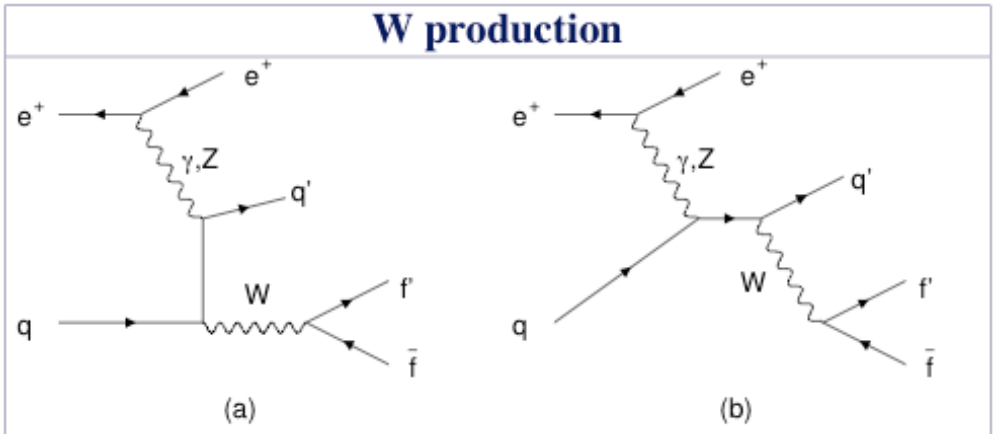


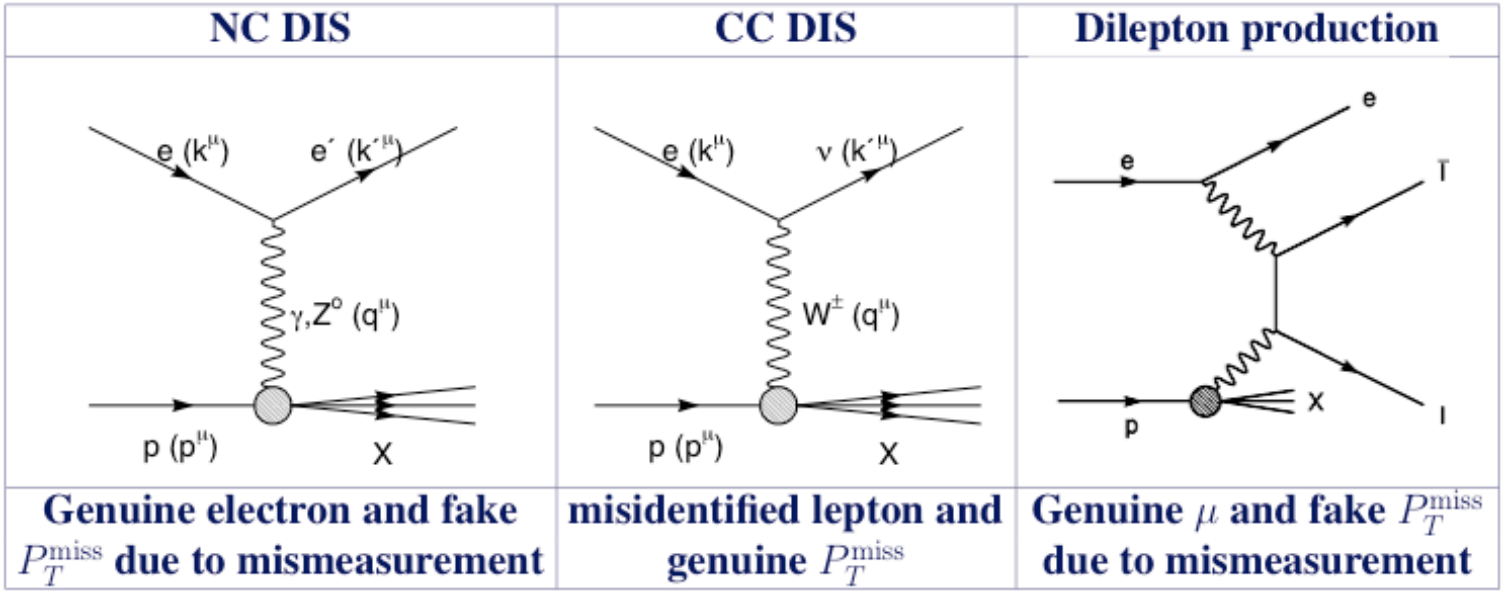
X : total hadronic final state, excluding W decay products

Scattered e mostly escapes detection

Standard Model Backgrounds

Leptonic top decay :





Hadronic top decay : main background is QCD jets in γP events

Search for single top production

Hadronic decay $t \to bW \to bqq'$

1. large total E_T
2. at least 3 jets with high p_T
3. M_{jj} within 2 σ from M_W

Leptonic decay $t \to bW \to b\, l\, \nu$

1. large missing P_T + isolated lepton
2. neutrino reconstructed ($M_{l\nu}$ constrained to M_W) *
3. charge lepton > 0 *

* Only H1

Both decay channels

4. Final selection based on top mass and top decay properties

The single top search in the leptonic decay channel starts from the search for isolated leptons in events with large missing p_T

Isolated lepton search results

Search for isolated, high P_T leptons in events with large missing transverse momentum

	H1	ZEUS
Lepton within detector acceptance	$5° < \theta < 140°$	$\theta < 115°$
High Transverse Momentum of Lepton	$p_T^l > 10\,\mathrm{GeV}$	$p^l_T > 5$ GeV
Lepton Isolation	$D_{\mathrm{track}} > 0.5$ $D_{\mathrm{jet}} > 1.0$	$D_{track} > 0.5$ $D_{jet} > 1$
Large Missing Transverse Momentum	$P_T^{\mathrm{miss}} > 12\,\mathrm{GeV}$	$P^{miss}_T > 20$
Acoplanarity	$e : \phi_{\mathrm{acop}} > 20°$ $\mu : \phi_{\mathrm{acop}} > 10°$	$\phi_{acop} > 8°$
		>1 jet, $p_T > 5$GeV

H1 Phys. Lett. B 561 (2003) 241
ZEUS Phys. Lett. B 559 (2003) 153

HERA1 results on isolated leptons from H1 (118.3 pb^{-1})

Electron and muon combined

Phys. Lett. B 561 (2003) 241

H1 94-00 e^+p 118.3 pb^{-1}	N_{OBS}	N_{SM} (signal contribution)
Full sample	18	12.39 ± 1.67 (75%)
$P_T^X > 25$	10	2.92 ± 0.49 (87%)

e-p : 1 event observed , 2.06 ±0.28 expected

Excess of observed events at high P_T^X (> 25 GeV)

H1 94-00 e+p 118.3 pb-1	Measured cross section (pb)	SM NLO exp. cross section (pb)
Full sample	0.31 ± 0.10 ± 0.04	0. 237± 0.029
$P_T^X > 25$ GeV	0.164 ± 0.054 ± 0.023	0.043 ± 0.007

New HERA2 results from 

DESY-05-xxx

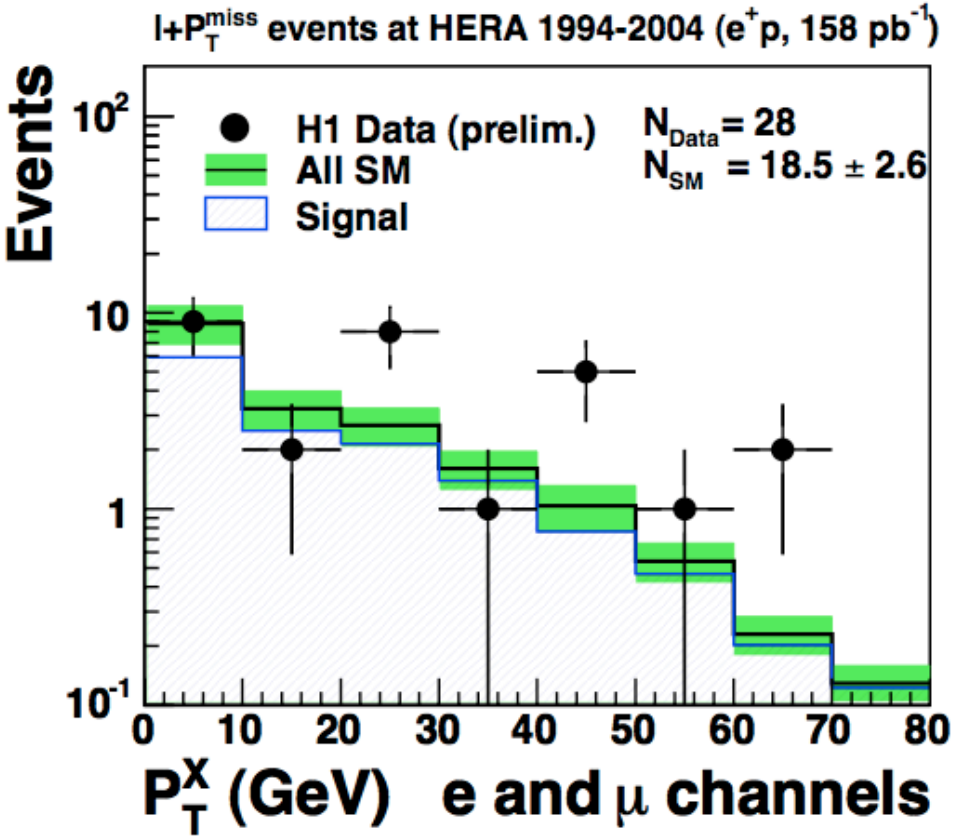
H1 Preliminary		Electron obs./exp. (Signal contribution)	Muon obs./exp. (Signal contribution)	Combined obs./exp. (Signal contribution)
1994-2004 e^+p	Full Sample	19 / 14.6 ± 2.0 (70%)	9 / 3.9 ± 0.6 (84%)	28 / 18.5 ± 2.6 (73%)
158 pb^{-1}	$P_T^X > 25$ GeV	9 / 2.3 ± 0.4 (80%)	6 / 2.3 ± 0.4 (84%)	15 / 4.6 ± 0.8 (82%)
1998-2005 e^-p	Full Sample	11 / 12.6 ± 1.8 (66%)	1 / 3.3 ± 0.5 (79%)	12 / 15.8 ± 2.2 (68%)
121 pb^{-1}	$P_T^X > 25$ GeV	2 / 2.4 ± 0.5 (62%)	0 / 2.0 ± 0.3 (76%)	2 / 4.4 ± 0.7 (68%)
1994-2005 $e^\pm p$	Full Sample	30 / 27.2 ± 3.8 (68%)	10 / 7.2 ± 1.1 (81%)	40 / 34.3 ± 4.8 (71%)
279 pb^{-1}	$P_T^X > 25$ GeV	11 / 4.7 ± 0.9 (69%)	6 / 4.3 ± 0.7 (78%)	17 / 9.0 ± 1.5 (73%)

- **Comparable luminosity for e-p and e+p data**
- **Excess at high p_T^X confirmed, significant only in e^+p data**

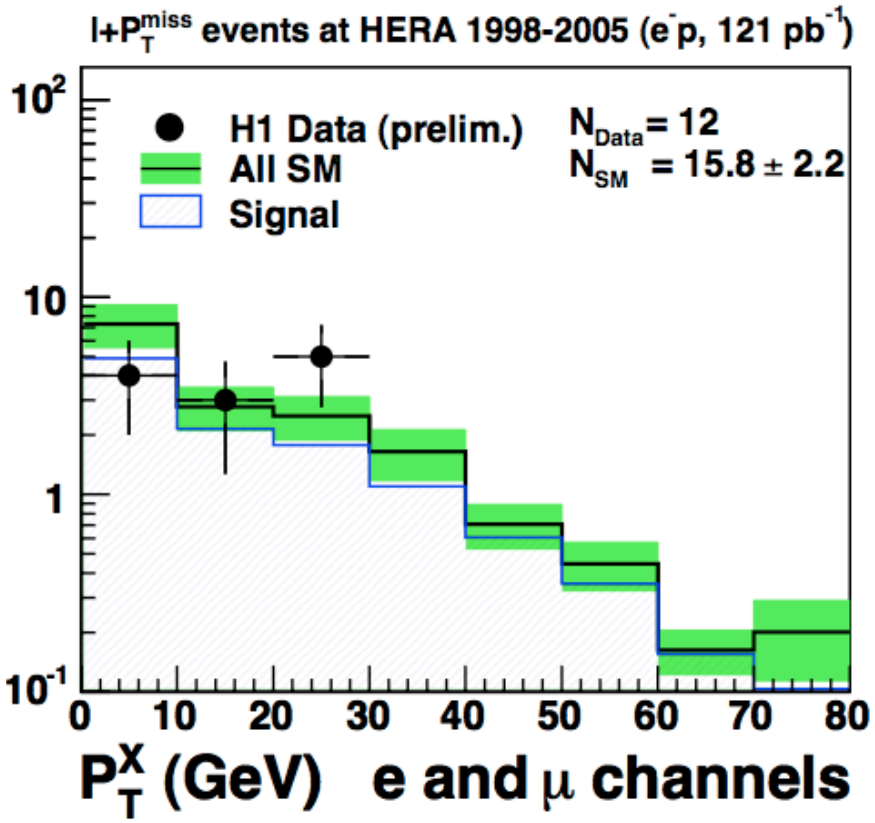
HERA1 and HERA2 combined results from

DESY-05-xxx

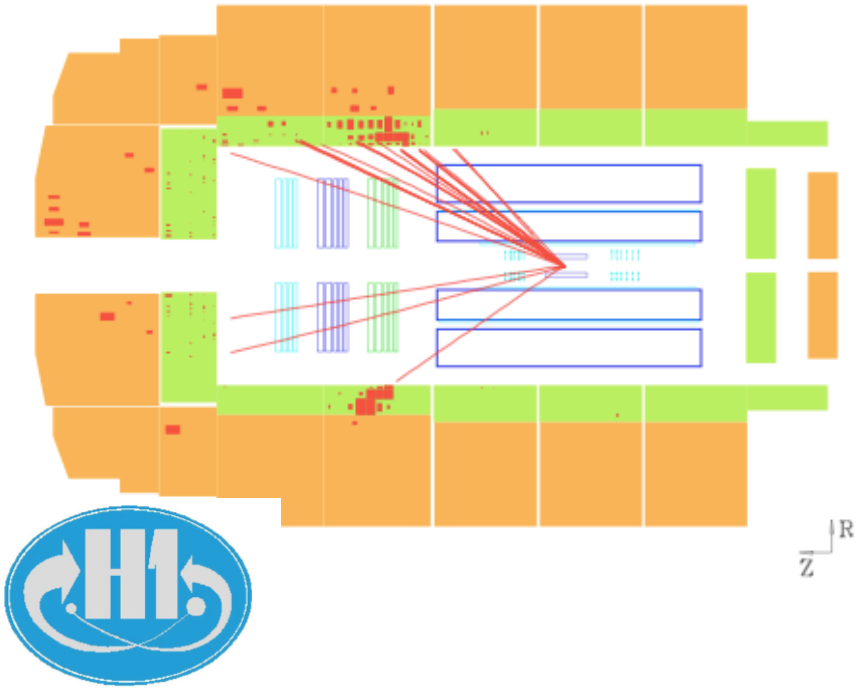
e+p

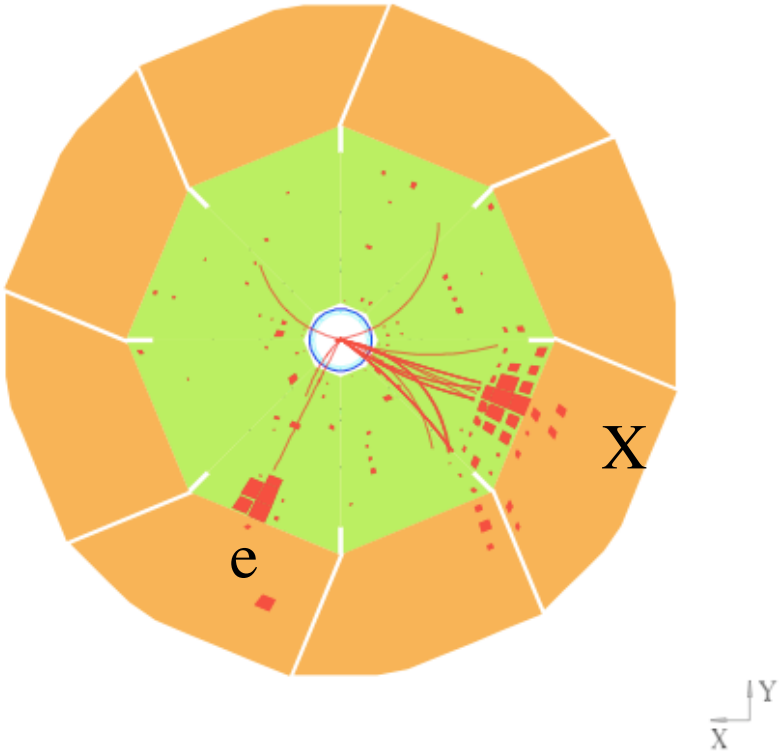


e-p



Isolated high p_T electron candidate event





Well isolated electron
Hadronic activity not back-to-back to electron

HERA1 results on isolated leptons from ZEUS (130 pb^{-1})

Phys.Lett. B559 (2003) 153

Electron and muon combined

ZEUS 94-00 130.1 pb^{-1}	N_{OBS}	N_{SM} (signal contribution)
Full sample	36	$32.5\ ^{+2.22}_{-4.65}$(17%)
$P_T^X > 25$ GeV	7	$5.65\ ^{+0.62}_{-0.77}$ (50%)

- No excess observed in ZEUS experiment at $P_T^X > 25$ GeV
- Analysis has worse signal over background ratio than H1

New HERA2 results

J.Ferrando, EPS05

Isolated e candidates	$12 < P_T^X < 25$ GeV	$P_T^X > 25$ GeV
ZEUS (prel.) 99-00 e^+p (66 pb^{-1})	$1/1.04 \pm 0.11(57\%)$	$1/0.92 \pm 0.09(79\%)$
ZEUS (prel.) 03-04 e^+p (40 pb^{-1})	$0/0.46 \pm 0.10(64\%)$	$0/0.58^{+0.08}_{-0.09}(76\%)$
H1 1994-2000 e^+p (104.7 pb^{-1})	$1/1.96 \pm 0.27(74\%)$	$4/1.48 \pm 0.25(86\%)$
H1 (prel.) 1994-2005 $e^\pm p$ (192 pb^{-1})	-	$11/2.9 \pm 0.6(81\%)$

- **Attempt to have ZEUS and H1 analyses leading to more similar background expectations started**

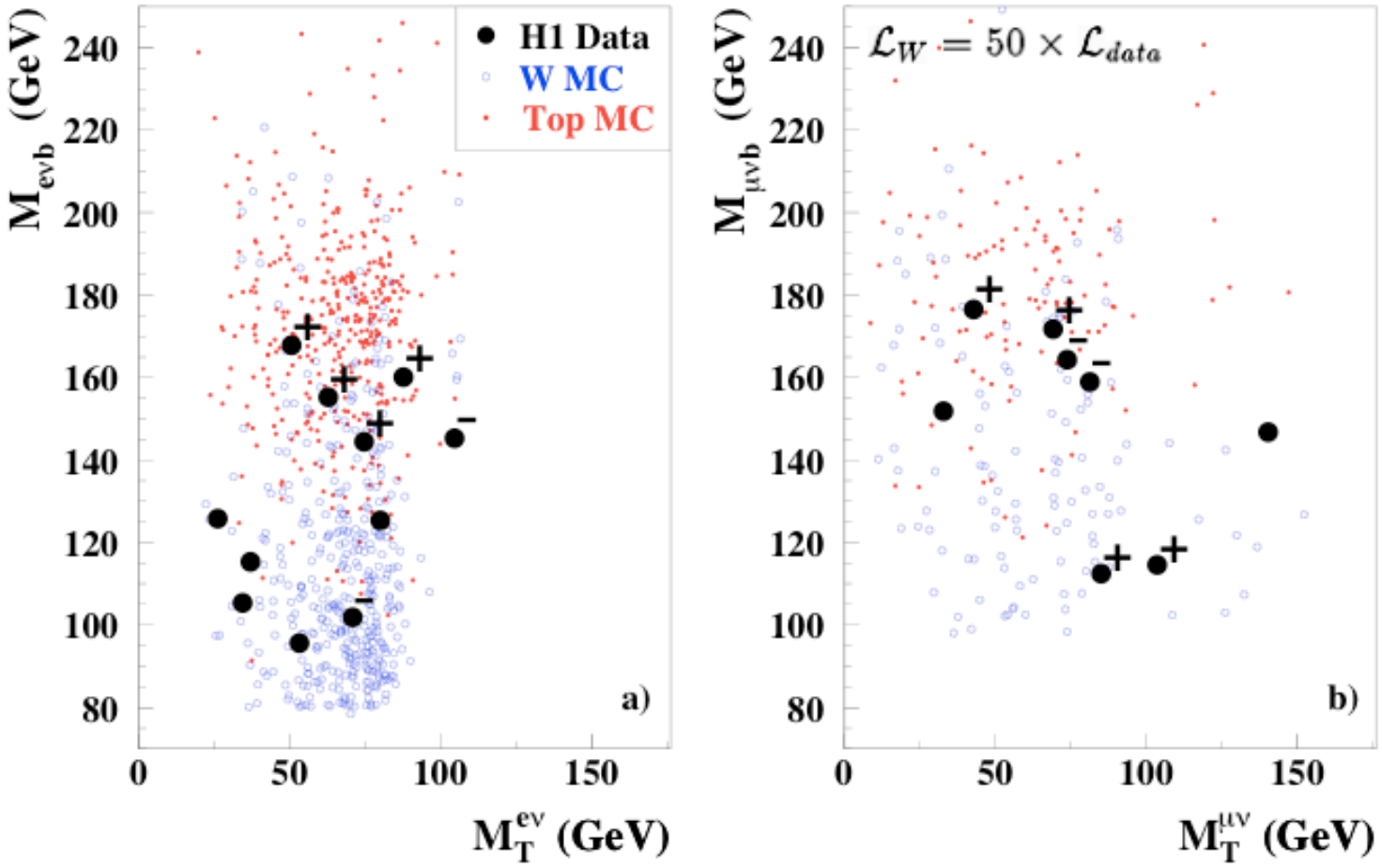
- **More data observed by H1 than ZEUS in the high p_T^X region**

	ZEUS
Lepton within detector acceptance	$\theta < 115°$
High Transverse Momentum of Lepton	$p_T^l > 10$ GeV
Lepton Isolation	$D_{\text{track}} > 0.5$ **implicit**
Large Missing Transverse Momentum	$P_T^{\text{miss}} > 12$ GeV
Acoplanarity	$e : \phi_{\text{acop}} > 17°$

Search for single top : full selection and results

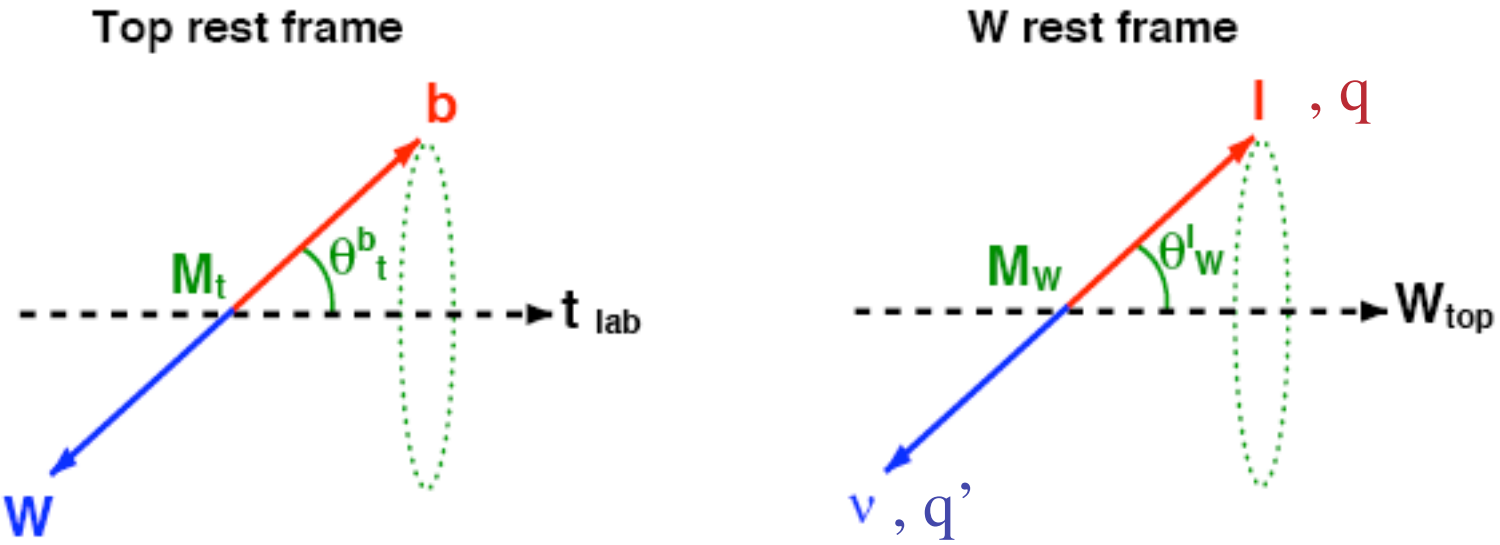
HERA1 Single top candidates in the leptonic channel

before applying final selection based on top mass and decay properties



- The data points are the isolated lepton candidates just discussed
- Charge reported only for leptons with well defined charge

Single top final selection



Final step of the selection uses the observables

P_T^b

Top mass M_t

W decay angle $\theta^{l,q}_W$ *

to perform search either using cuts or with a multivariate method

*** Only H1**

Cut based analysis (H1, ZEUS slightly harsher)

Leptonic

$p_T^b > 30$ GeV

$M_{l\text{-}\nu\text{-}b} > 140$ GeV *

Hadronic

$P_T^b > 40$ GeV *

$150 < M_{jets} < 210$ GeV

$\cos\theta^{q}_{W} > -0.75$ *

* Only H1

Likelihood analysis (only H1)

In both leptonic and hadronic channel, introduce a discriminator D

$$D = \frac{P_{signal}}{P_{signal} + P_{background}}$$

$$P = P(P^{b}_{T}, M_t, \theta^{l,q}_{W})$$

$$P = C(V)\prod p_i$$

C(V): Correct for correlations using PTC–method (OPAL)

D : probability for event to be more W like (D→0) or top like (D →1)

HERA1 single top search (118.3 pb^{-1})

Final results

Eur.Phys.J.C33(2004) 9

CUT ANALYSIS | LIKELIHOOD ANALYSIS

	Cut–based analysis		$\mathcal{D} > \mathcal{D}_{min}$		$\mathcal{D}_{min}$	Efficiency
	Data	SM	Data	SM		
Electron Channel	3	0.65 ± 0.10	3	0.67 ± 0.13	0.72	36%
Muon Channel	2	0.66 ± 0.12	2	0.62 ± 0.12	0.40	38%
Hadronic Channel	18	20.2 ± 3.6	20	17.5 ± 3.2	0.58	30%

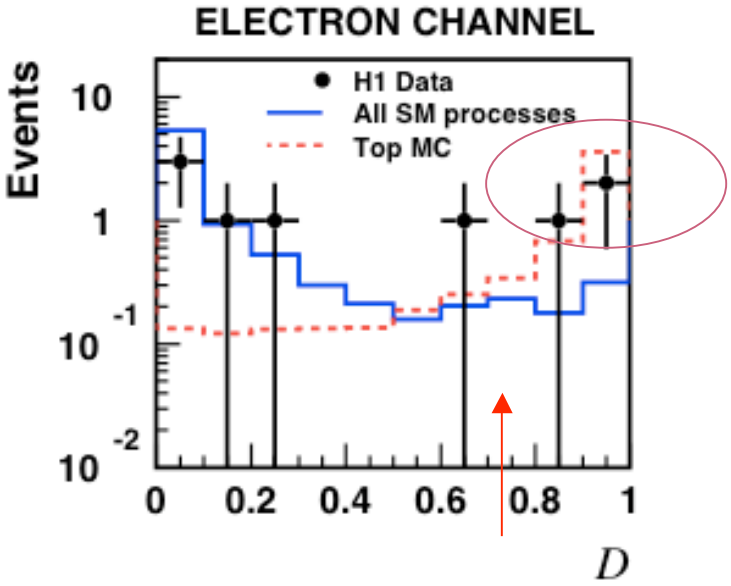
In leptonic channel

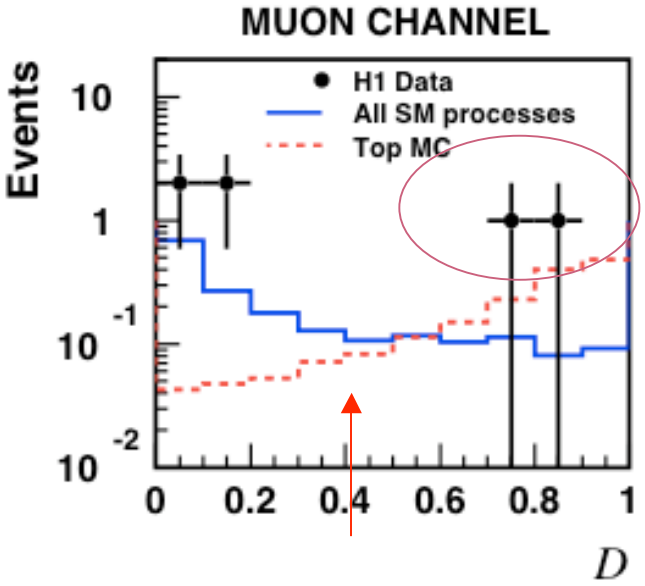
5 events observed vs 1.29 ± 0.25 expected.
Slight excess of data originating from isolated lepton search candidates passing single top selection

In hadronic channel

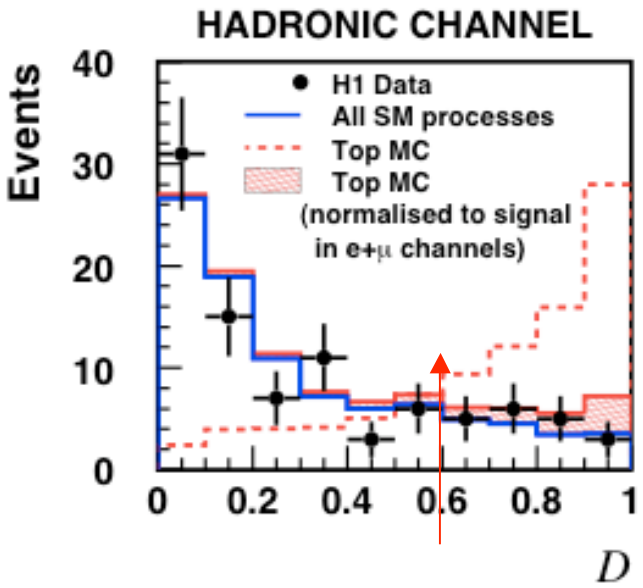
Number of events compatible with SM expectation

H1 results using multivariate analysis





⇐ W–like top–like ⇒



The 5 events surviving the cut-based analysis are concentrated at high values for the discriminant

Single top production cross section

Eur.Phys.J.C33(2004) 9

Using the likehood analysis results one can measure

$\sigma(ep \rightarrow etX) = 0.29\ ^{+0.15}_{-0.14}$ pb at $\sqrt{}$319 GeV

with

$\sigma(ep \rightarrow etX) = 0.41\ ^{+0.29}_{-0.19}$ pb for leptonic channel

$\sigma(ep \rightarrow etX) = 0.04\ ^{+0.27}_{-0.23}$ pb for hadronic channel

} Compatible within 1.1 σ

Considering excess of data wrt SM expectation as a background fluctuation, one can produce limit on σ and $k_{ut\gamma}$ (assuming k_{utZ} =0)

H1 94-00 118.3 pb-1	σ * Br(t $\rightarrow$Wb) At $\sqrt{}$ s = 319 GeV	$K_{ut\gamma}$
Leptonic channel	< 0.90 pb	< 0.35
Hadronic channel	< 0.48 pb	< 0.25
Combined	< 0.55 pb	< 0.27

HERA1 single top search (130.1 pb^{-1})

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Final results

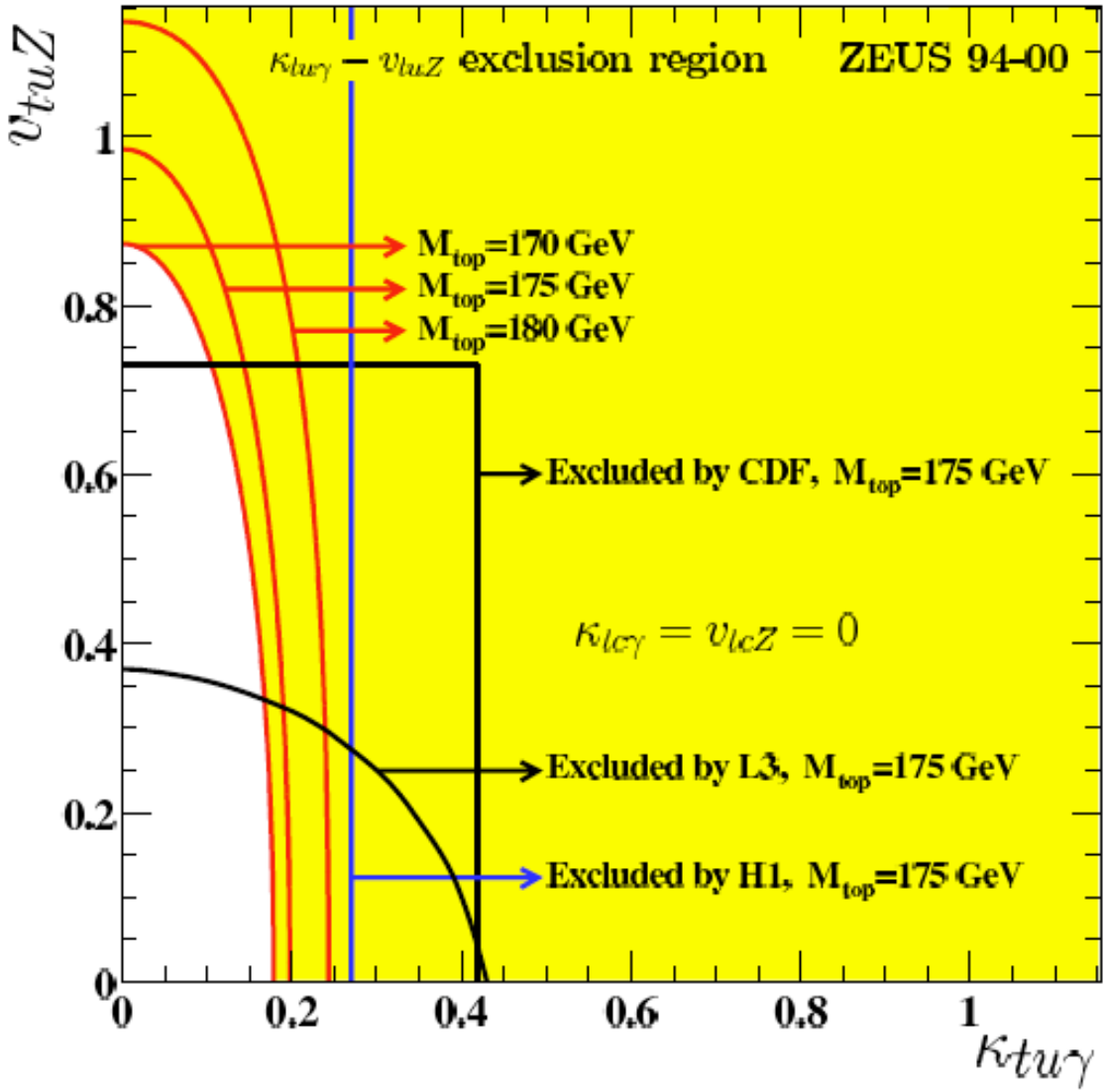
CUT BASED ANALYSIS

ZEUS 94-00 130.1 pb-1	N_{Data} obs	N_{SM} expected	Eff. Br (%)
Leptonic channel	0	$1.89\ ^{+0.24}_{-0.20}$	7
Hadronic channel	14	$17.6\ ^{+2.5}_{-1.5}$	16.5

ZEUS 94-00 130.1 pb-1	σ * Br(t →Wb) At $\sqrt{s}$ = 300 / 318 GeV	$K_{utγ}$
Leptonic channel	< 0.906 / 0.514 pb	< 0.223
Hadronic channel	< 0.998 / 0.426 pb	< 0.241
Combined	< 0.225 pb at 318 GeV	< 0.174

- Number of observed events is compatible with SM background
- Limit more stringent than H1 on σ and $k_{utγ}$ (assume k_{utZ} =0)

HERA1 limits on utγ and utZ FCNC coupling



Plot of ZEUS Updated results, including a non zero utZ coupling

What next ?

1. Collect more data (HERA will run until mid 2007)

2. Compare carefully ZEUS and H1 analyses , helpful to investigate nature of excess observed in H1

3. $W \rightarrow \tau\nu$ channel :
   ZEUS has already published results for HERA1,
   2 events observed and 0.2 ± 0.05 expected from SM processes.
   H1 has preliminary result for HERA1, no excess observed.

4. Both experiments should review their single top searches on their full data sets

Summary

The HERA experiments are able to put strong limits on the anomalous FCNC coupling constants for single top production processes

An interesting excess in the rate of events with an isolated high p_T e or μ and large missing momentum is observed by the H1 experiment, and is currently not confirmed by the ZEUS experiment

Hopefully the additional data collected up to mid 2007 will allow us to understand the importance of such observation