Searches for new Physics at HERA I + II

ICHEP04 Beijing

16-22 August, 2004

André Schöning

ETH Zürich, Switzerland

- Model Independent General Search
- Events with isolated leptons + missing p_t
- Anomalous production of top quarks

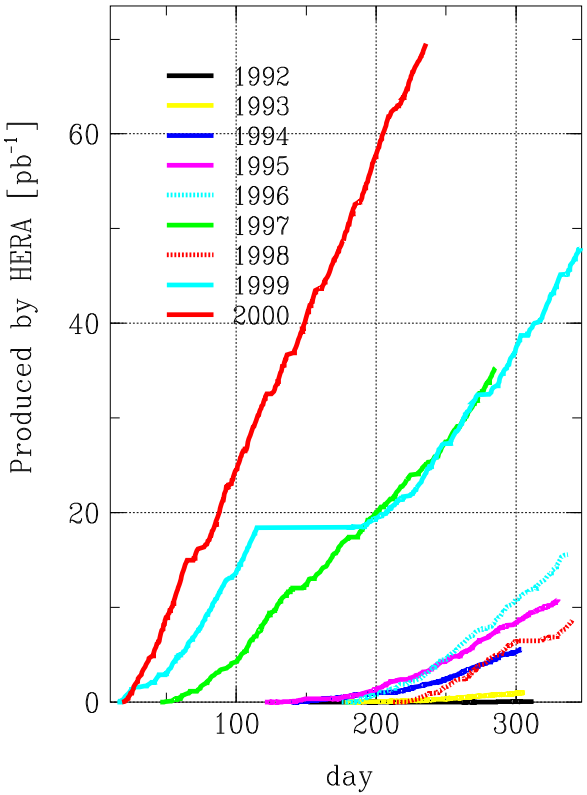
$\rightarrow$ analysed data $\approx 165 + 130$ pb^{-1}

HERA delivered Luminosities

HERA I

analysed here: H1 118 pb^{-1}

ZEUS 130 pb^{-1}



$\sqrt{s} = 320$ GeV:

e^+p (65 pb^{-1})

e^-p (17 pb^{-1})

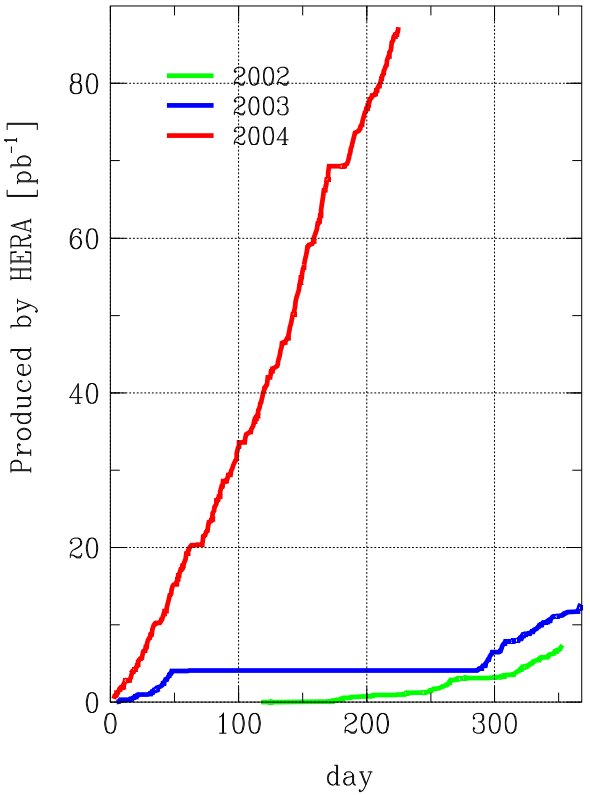
$\sqrt{s} = 300$ GeV:

e^+p (48 pb^{-1})

steady progress year by year

HERA II

analysed here: H1 45 pb^{-1}



$\sqrt{s} = 320$ GeV:

$e^+_L p$

$e^+_R p$

very good year 2004!

longitudinally polarisied positron beam

General Analysis (H1 Collaboration)

(submitted to *Phys.Lett.***B** [hep-ex/0408044])

Aim:

- investigate high p_t final states in ep scattering in a coherent analysis
- search for deviations from SM expectation in a model independent way

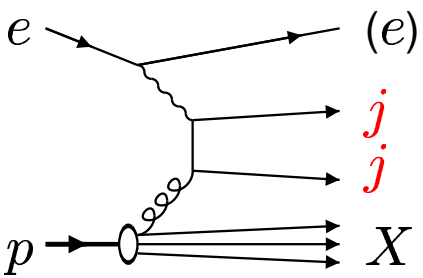
Strategy:

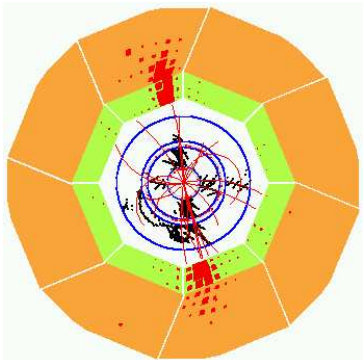
- define objects: e, μ, γ, j, ν with $p_T > 20$ GeV and $10^\circ < \Theta < 140^\circ$
- define events classes with at least two objects: e.g. ej, νjj.
- compare event yields with SM expectation

- look for deviations and perform a (global) statistical interpretation

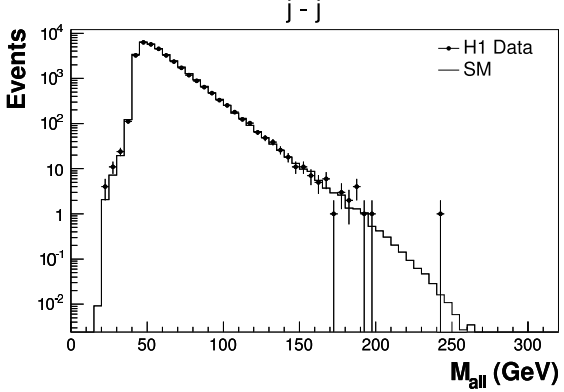
Main SM Processes at high p_T

γp: $\gamma^* p \to jj$

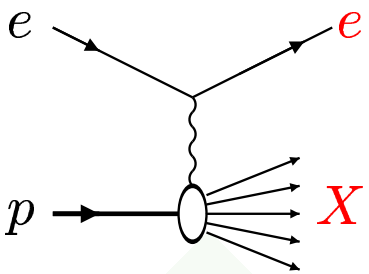


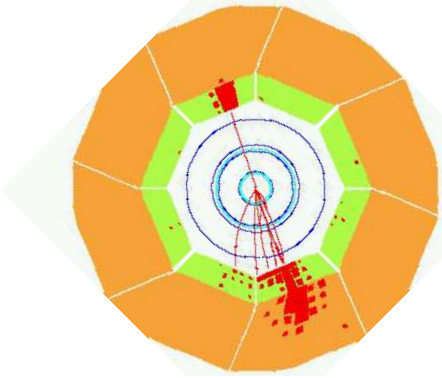


j - j

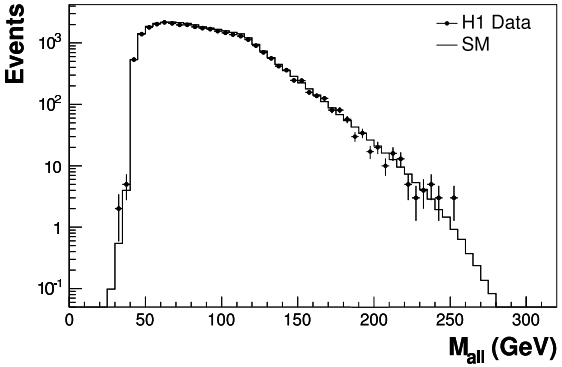


NC-DIS: $ep \to eX$

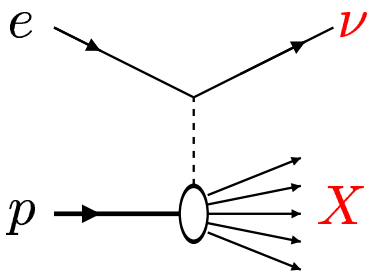


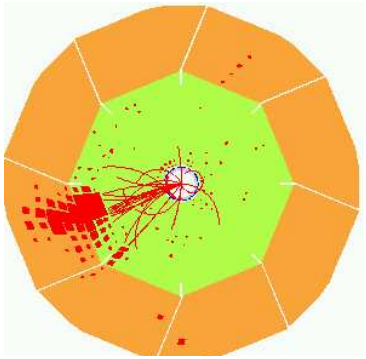


e - j

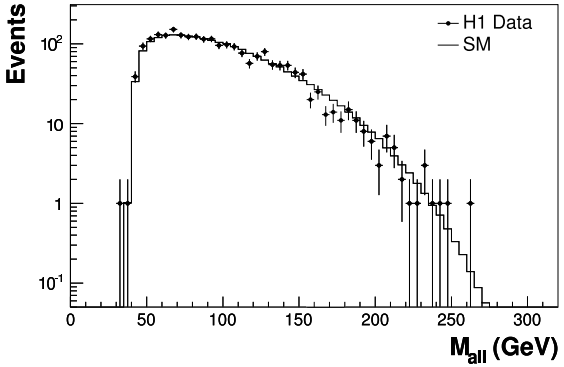


CC-DIS: $ep \to \nu X$

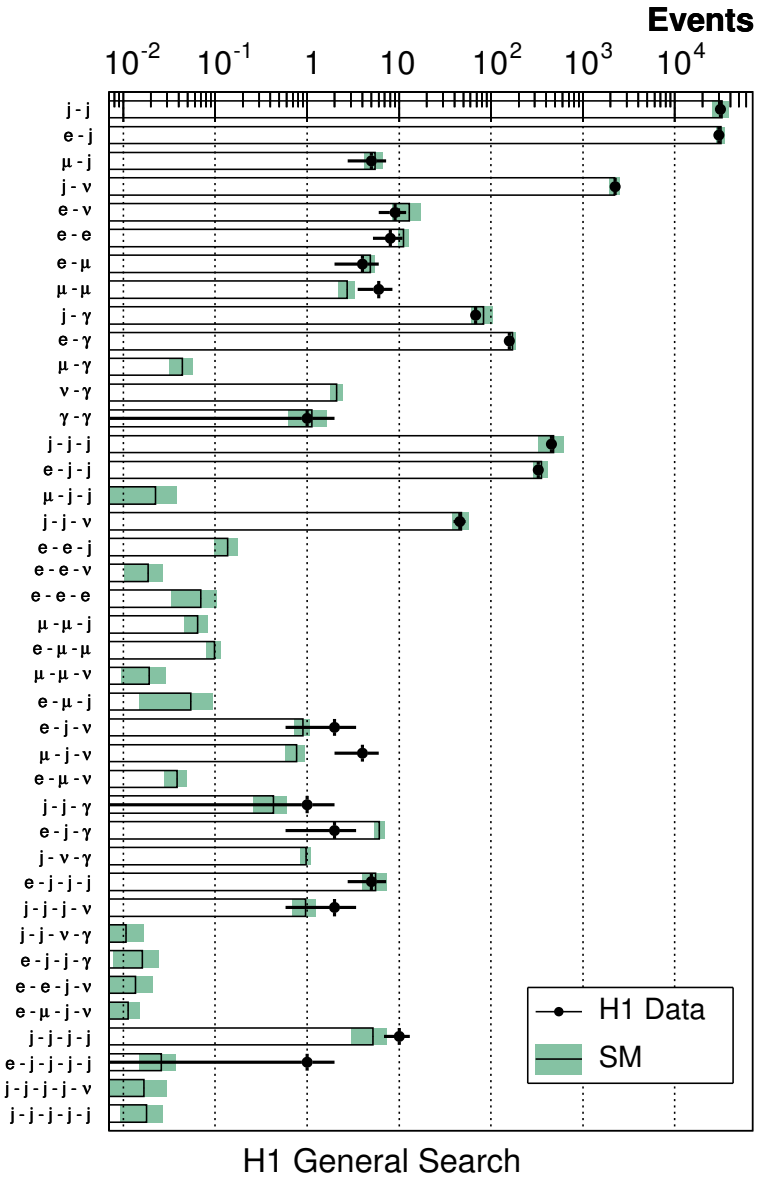




j - ν



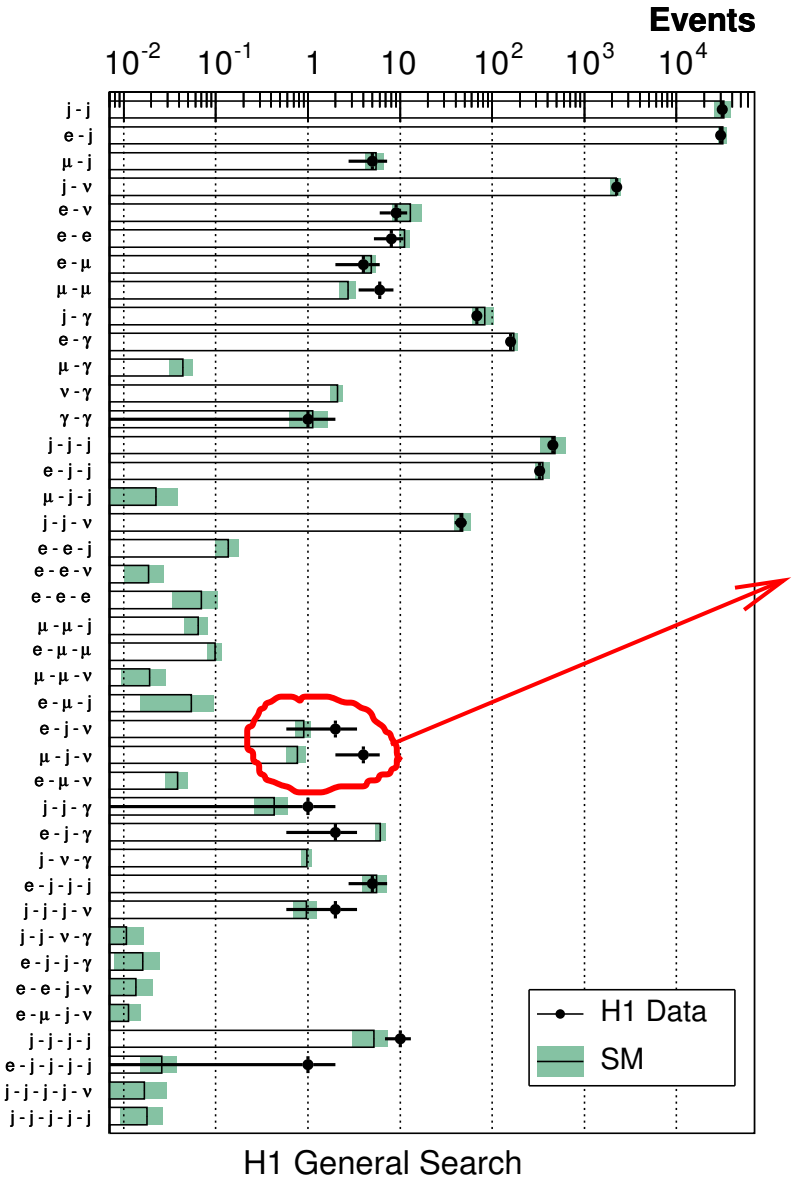
H1 General Search Event Yields (HERA I)



in general:

good agreement with SM expectation!

H1 General Search Event Yields (HERA I)



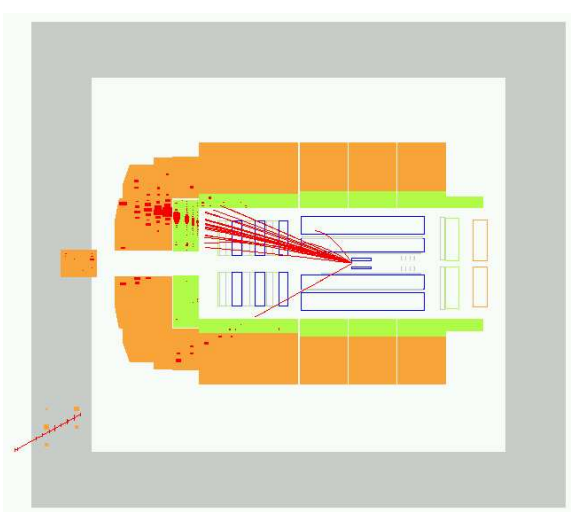
H1 General Search

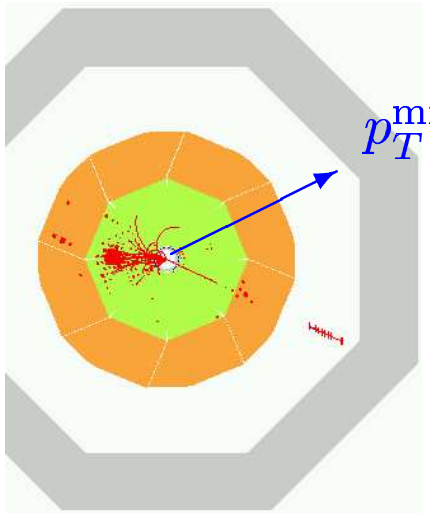
Isolated Lepton + Missing p_T classes:

- $ej\nu$
- $\mu j\nu$

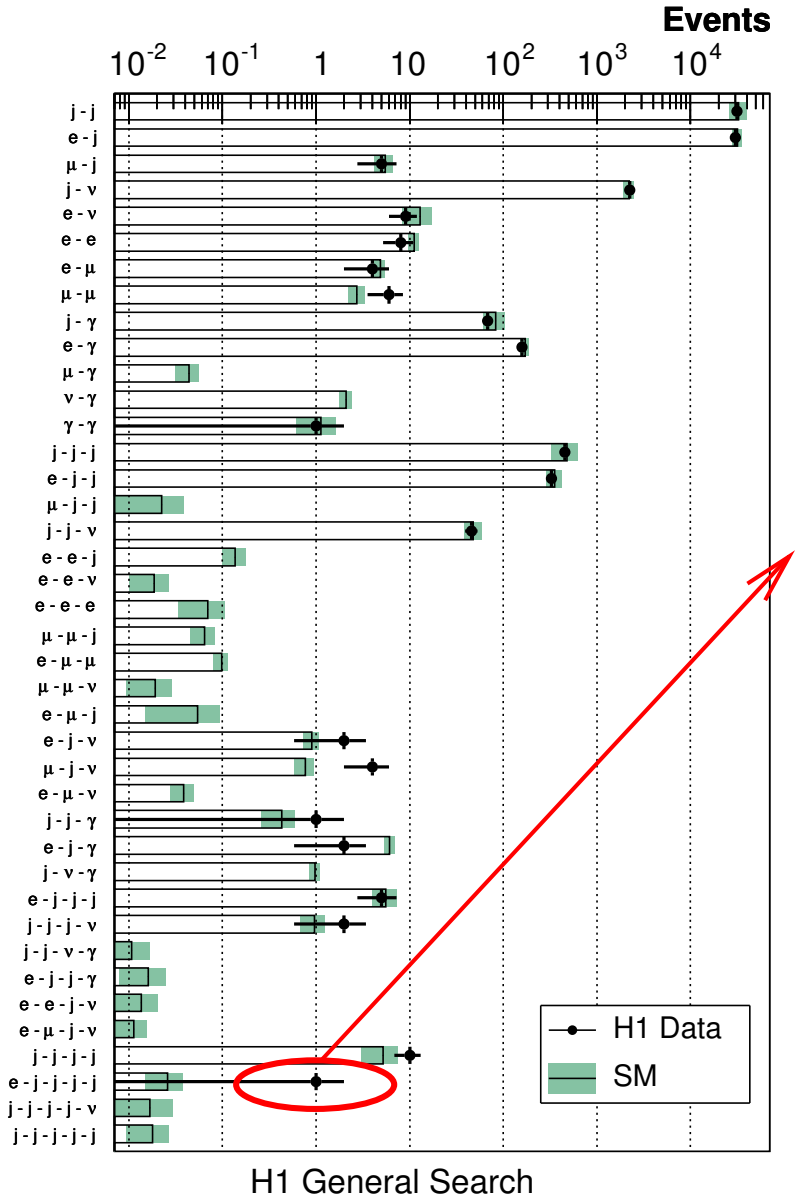
SM process W production:

- $ep \to (e)WX \to (e)\ell\nu j$
- SM cross section $\approx 1\,pb$



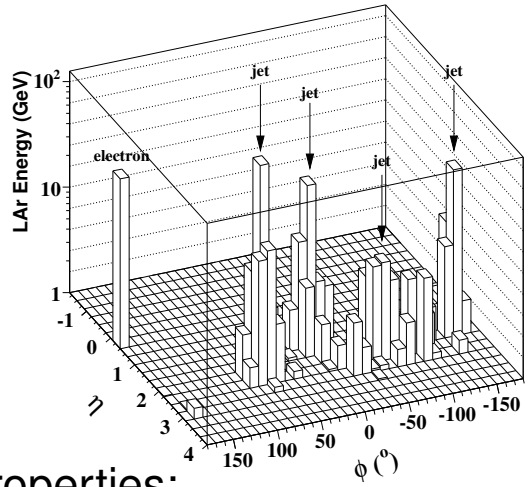


H1 General Search: Event Yields (HERA I)



H1 General Search

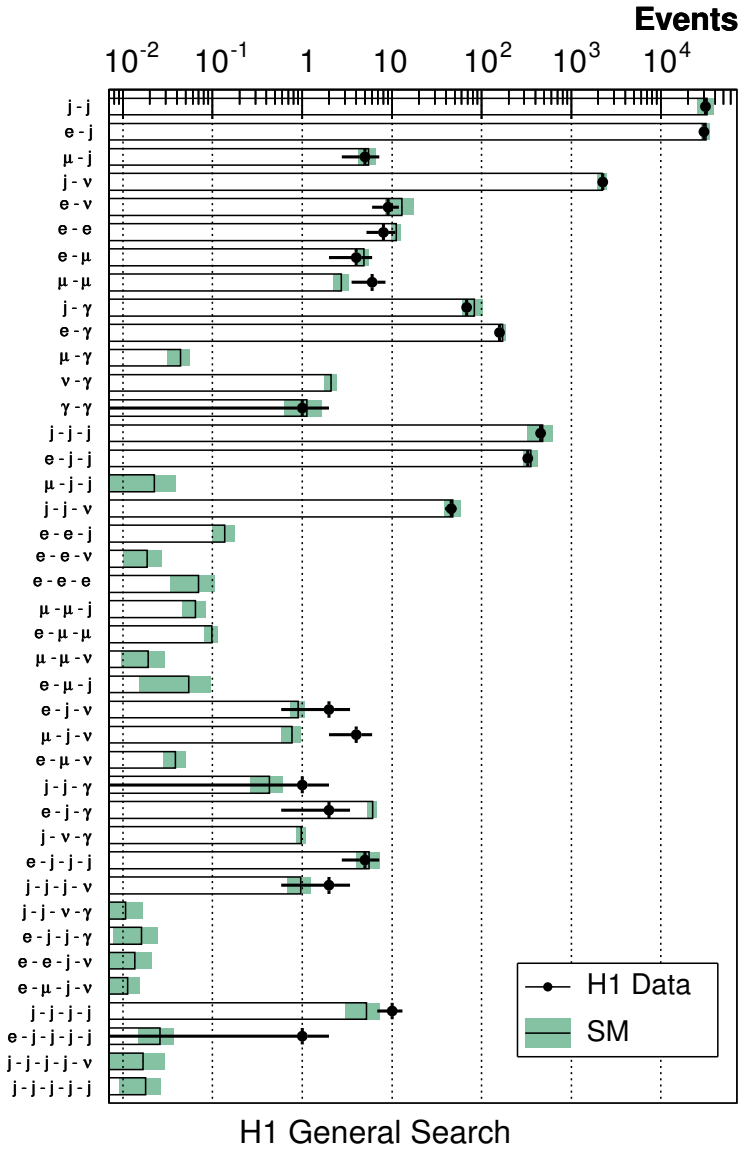
Interesting $ejjjj$ event observed



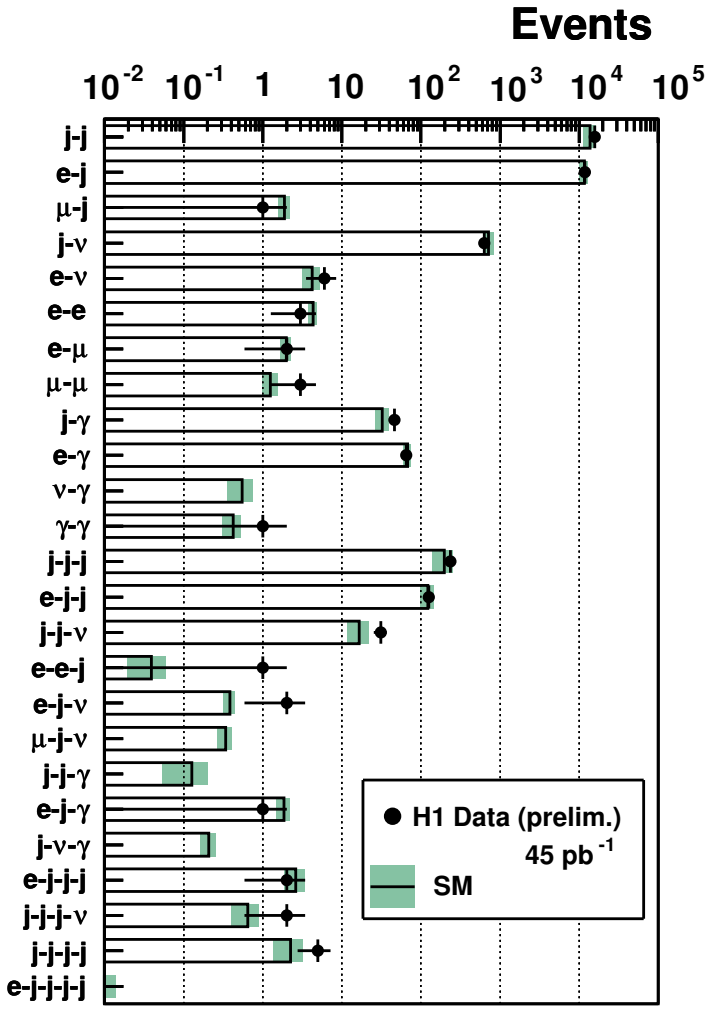
Properties:

- total invariant mass $M_{\mathrm{all}} = 262$ GeV
- SM exp. from higher order QCD processes
  ≈ 0.02 events
- Other (rare SM/BSM) explanations:
  - (anomalous) top quark production
  - WW production, Higgs ?

H1 General Search Event: Yields (HERA I+II)



(H1 ICHEP04 Conf. Paper 12-765)



$\Rightarrow$ results consistent - again excess in $e\nu j$ channel

Statistical Interpretation of General Search

Look in differential distributions with high sensitivity to BSM processes:

- $M_{\rm all}$: invariant mass of all objects
- $\sum p_T$: scalar sum of tranverse momenta

Quantify possible deviations (deficit or excess)

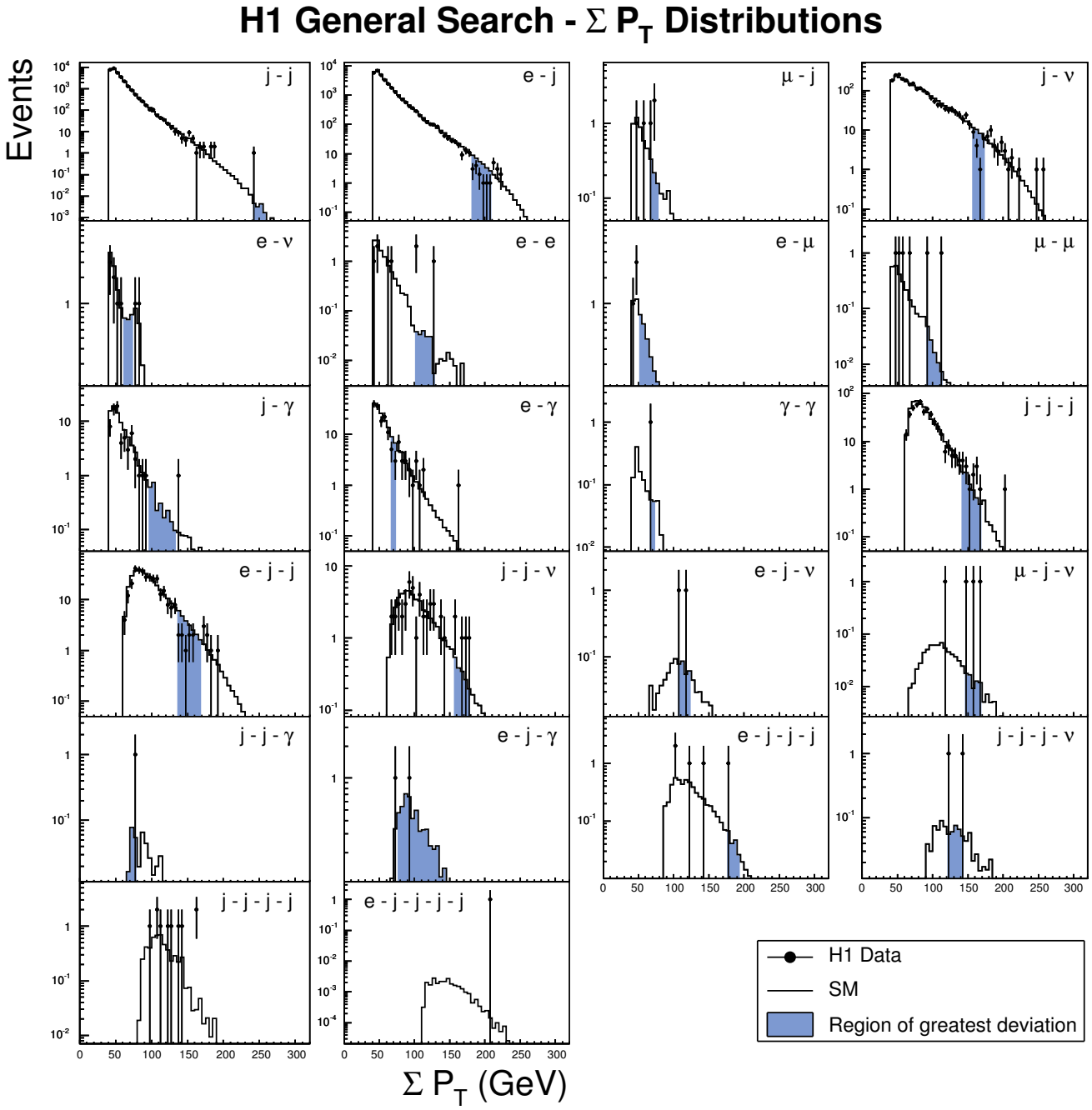
- new algorithm to find region of largest deviation in distribution:

$$p_{\rm region} = G_{\rm syst}({\rm BG}) \otimes P_{\rm Poisson}(N_{obs} \geq N_{SM}, N_{obs} < N_{SM})$$

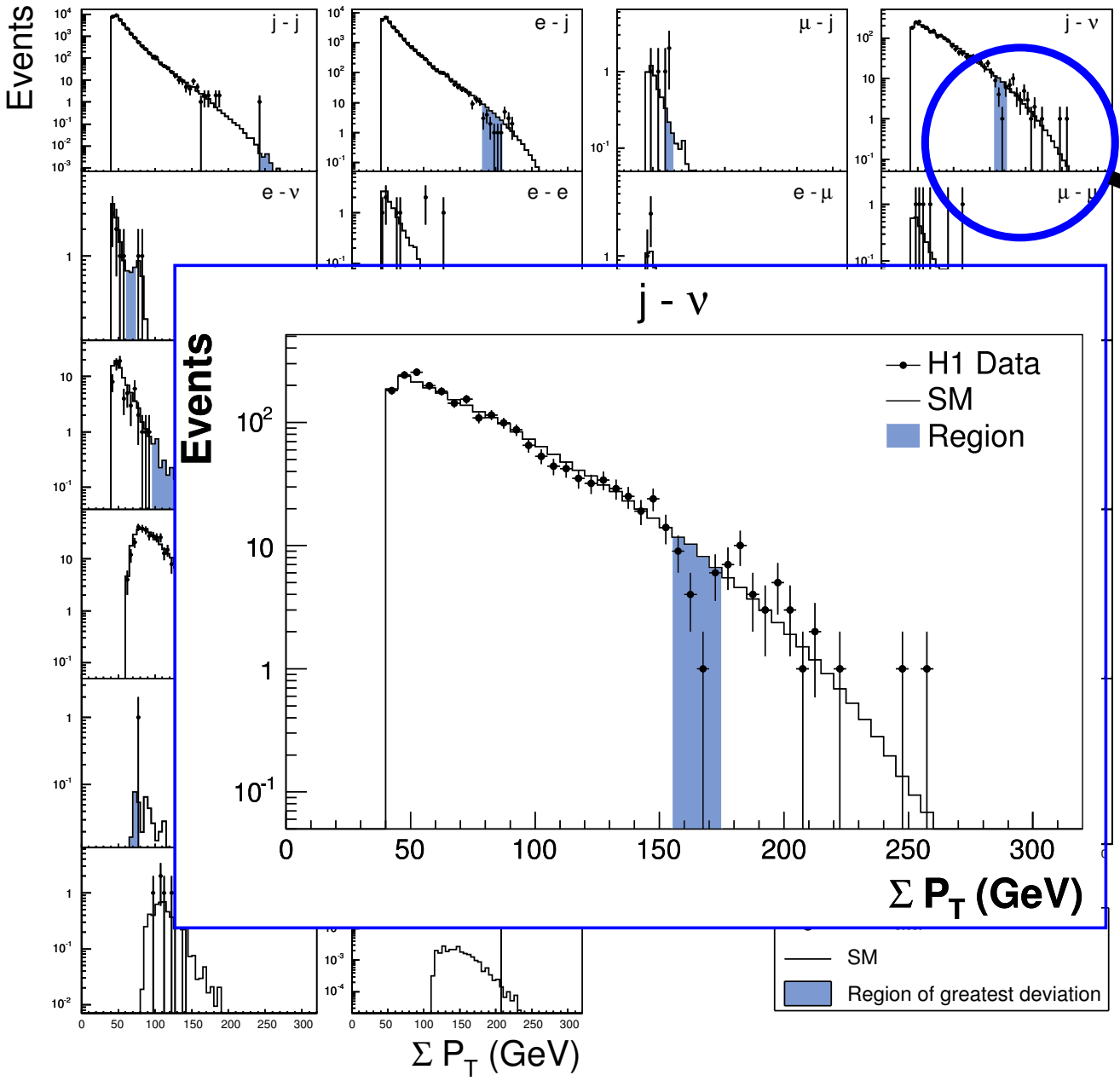
N_{SM} = number of **expected** events in region

N_{obs} = number of **observed** events in region

- significant deviation: $p_{\rm region} \ll 1$


H1 General Search - Σ P_T Distributions
Events
j - j
e - j
μ - j
j - ν
e - ν
e - e
e - μ
μ - μ
j - γ
e - γ
γ - γ
j - j - j
e - j - j
j - j - ν
e - j - ν
μ - j - ν
j - j - γ
e - j - γ
e - j - j - j
j - j - j - ν
j - j - j - j
e - j - j - j - j
H1 Data
SM
Region of greatest deviation
Σ P_T (GeV)

H1 General Search - Σ P_T Distributions

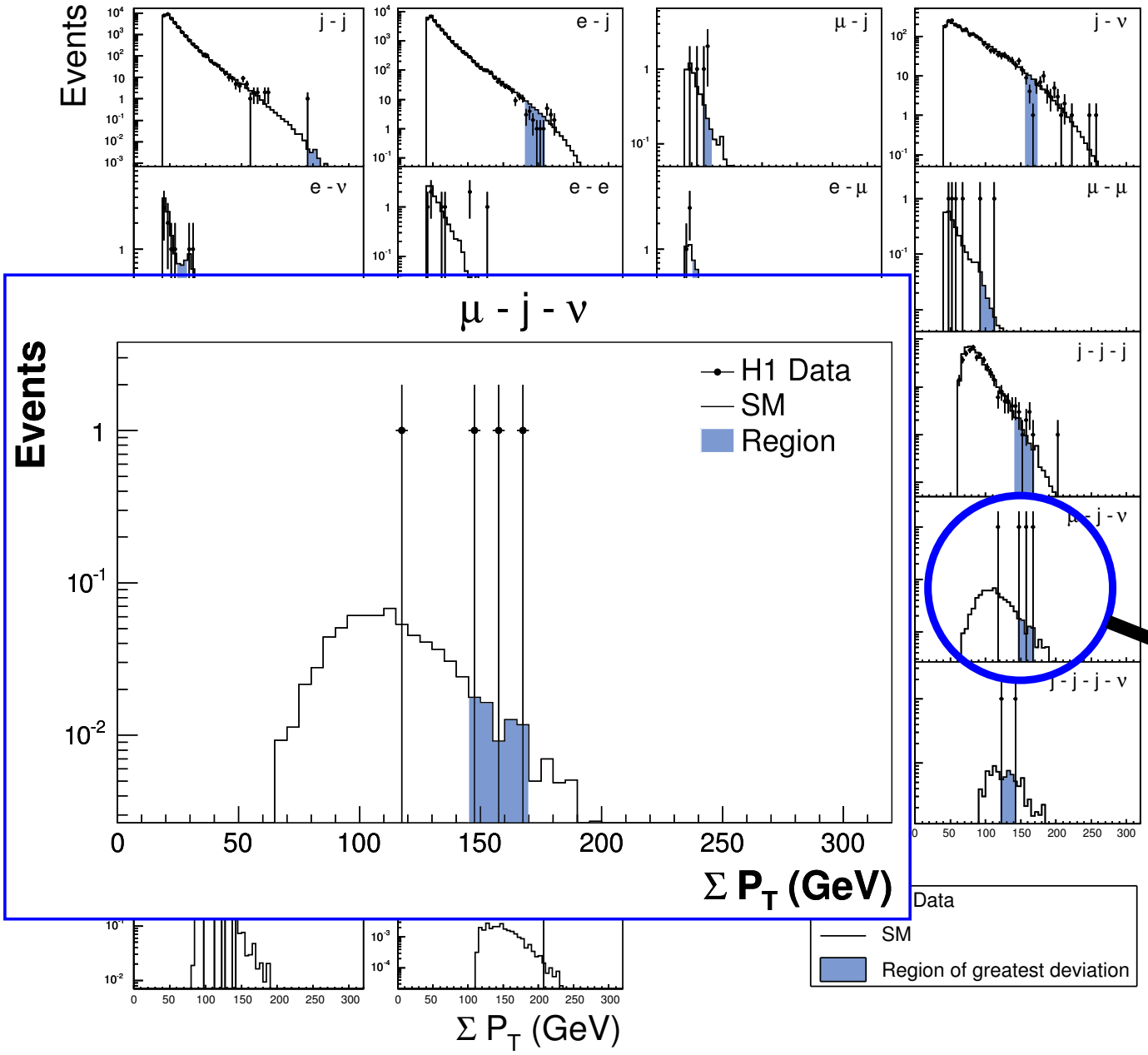


Region of largest deviation:

$\rightarrow$ deficit: 20/36.7$\pm$6.2

$\Rightarrow$ $p_{\mathrm{region}} = 0.023$

H1 General Search - Σ P_T Distributions



Region of bf largest deviation:

$\rightarrow$ excess: 3/0.068$\pm$0.029

$\Rightarrow p_{\mathrm{region}} = 7.5 \cdot 10^{-5}$

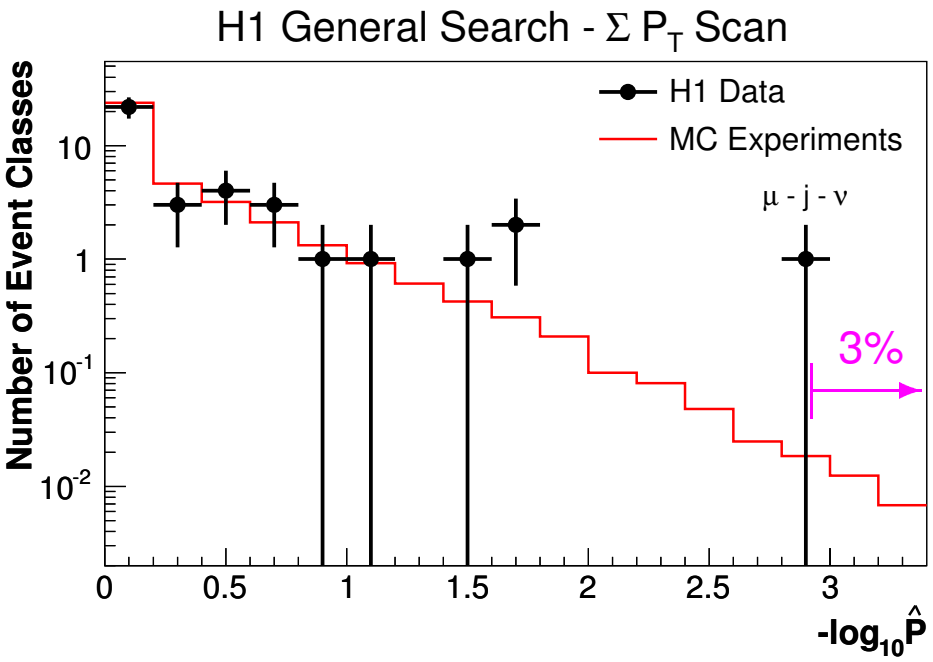
Event Class Probability

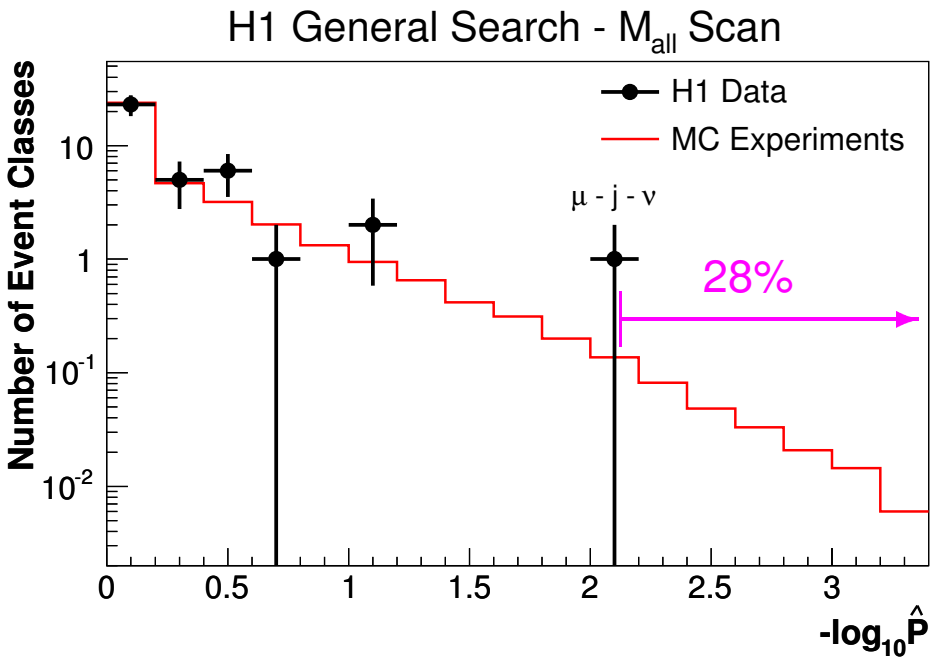
- What is the probability $\hat{P}$ to observe such a deviation $p < p_{\mathrm{region}}$ per class?
- $\hat{P}$ derived from MC experiments

$\Rightarrow$ for this class: $\hat{P} = 0.001$

Event Class Probabilities (HERA I)

Event Class Probabilities $\hat{P}$ derived for all event classes:





$\Rightarrow$ largest deviation from the SM found in the $\mu j \nu$ class

$\hookrightarrow$ "isolated lepton events" + missing p_T

- excess previously reported by H1 (*Phys.Lett.***B** 561 (2003))

Events with Isolated Leptons + Missing p_T

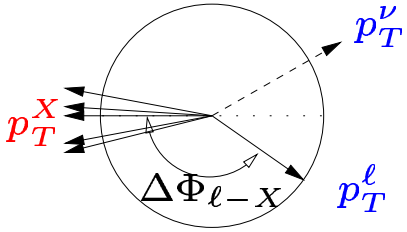
(H1 *Phys.Lett.***B** 561 (2003); ZEUS *Phys.Lett.***B** 559 (2003))

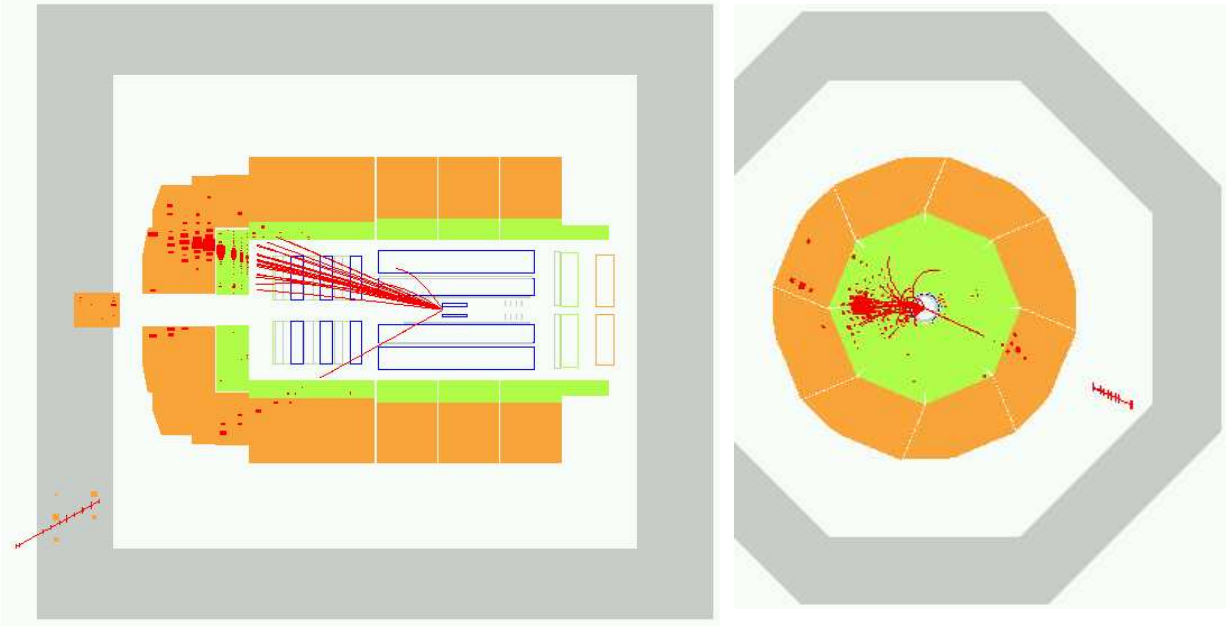
HERA I analyses final

- Main SM production process:

$$eq \to eXW \hookrightarrow \ell\nu$$

p_T^X peaks at low values





isolated e and μ selections

H1 main cuts:

$p_T^\ell > 10$ GeV

$p_T^{\rm calo} > 12$, $p_T^{\rm miss} > 12$ GeV

$D_{\ell,\rm jet} > 1$, $D_{\ell,\rm track} > 0.5$

$\Delta\Phi_{e(\mu)-X} < 160^\circ (170^\circ)$

ZEUS main cuts:

$p_T^\ell > 5$ GeV

$p_T^{\rm calo} > 20$

$D_{\ell,\rm jet} > 1$, $D_{\ell,\rm track} > 0.5$

$\Delta\Phi_{e-X} < 172^\circ$

- Possible other explanations:

anomalous top prod., RPV SUSY: e.g. $ep \to \tilde{t} \to \tilde{b}W$ → HERA SUSY (talk C.Nguyen)

New Isolated Tau Analyses (ZEUS+H1)

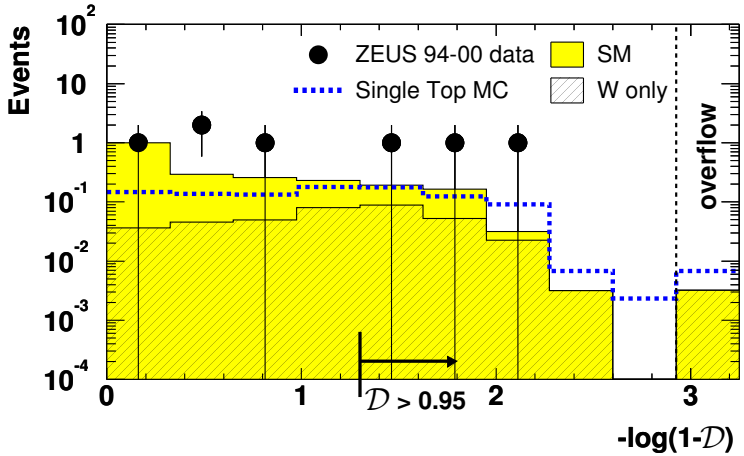
(ZEUS *Phys.Lett.***B** 583 (2004); H1 ICHEP04 Conf. Paper 12-188)

Topology:

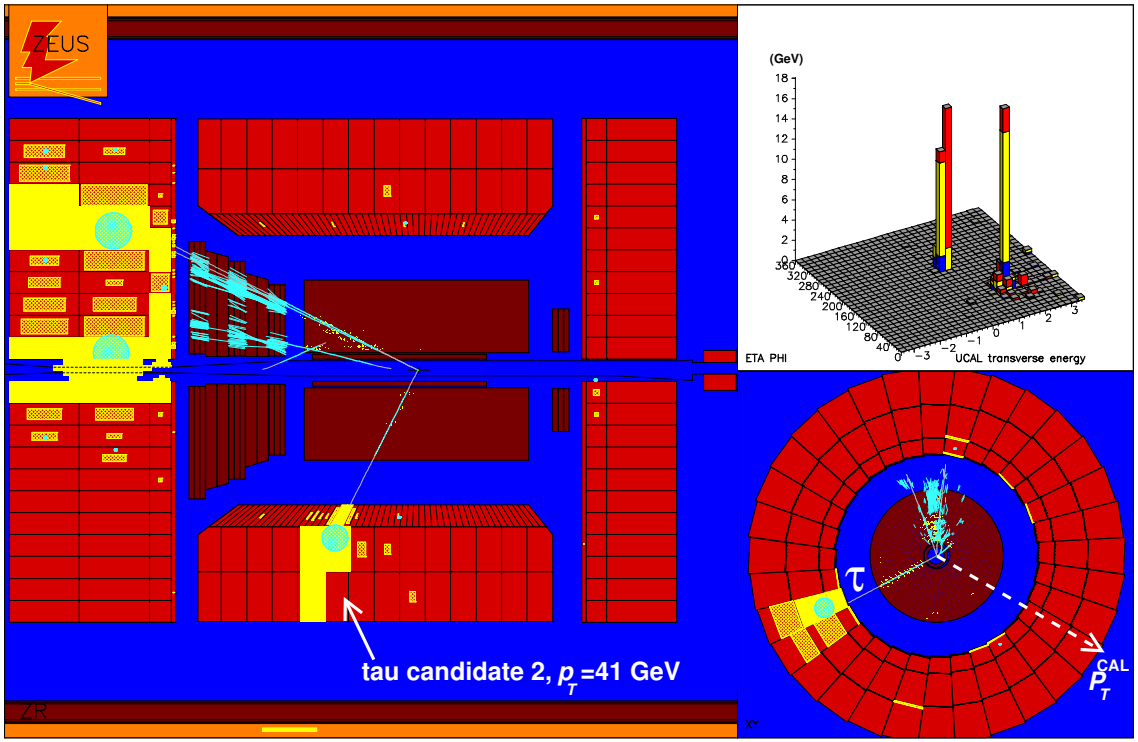
- tau + jet + missing p_T ($p_T^{\rm calo} > 20$ GeV)
- Main background CC-DIS

ZEUS Selection:

- Multivariate analysis for tau-id



$\Rightarrow$ three events selected (0.4 expected)



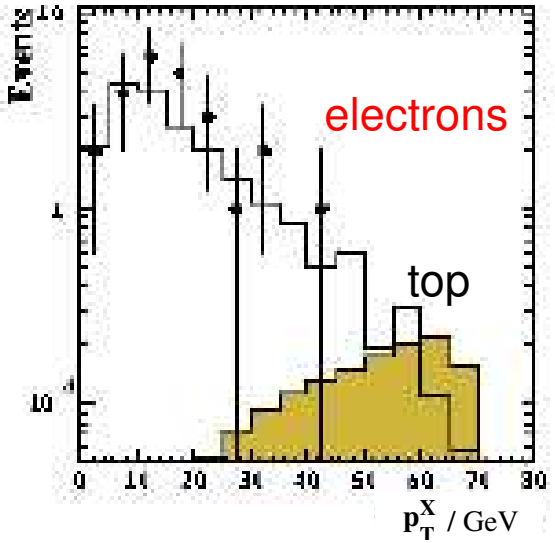
H1 Selection: $\rightarrow \tau\tau$ **pairs (talk E.Sauvan)**

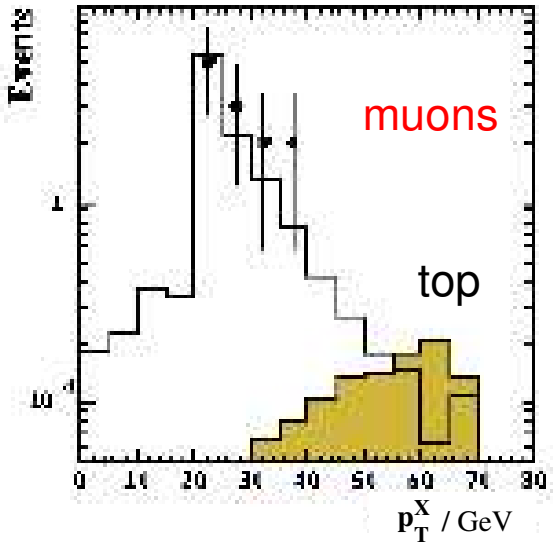
- cut based tau identification
- pencil-like jet: $R_{\rm jet} < 0.12$

$\Rightarrow$ five events observed (5.8 expected)

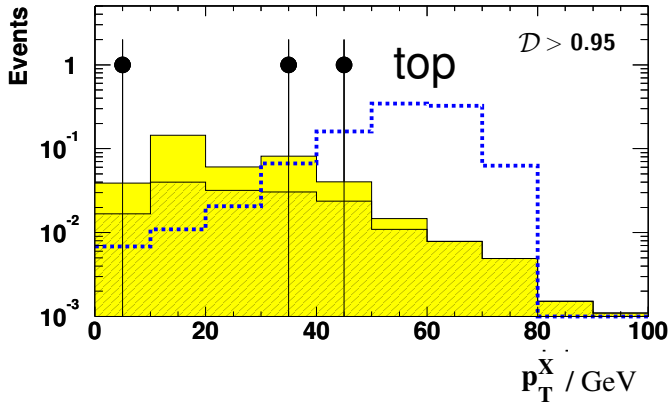
Isolated Leptons HERA I

ZEUS

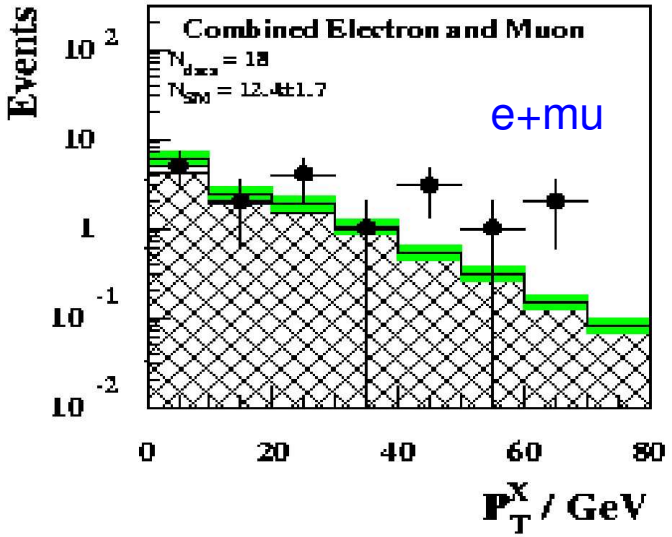




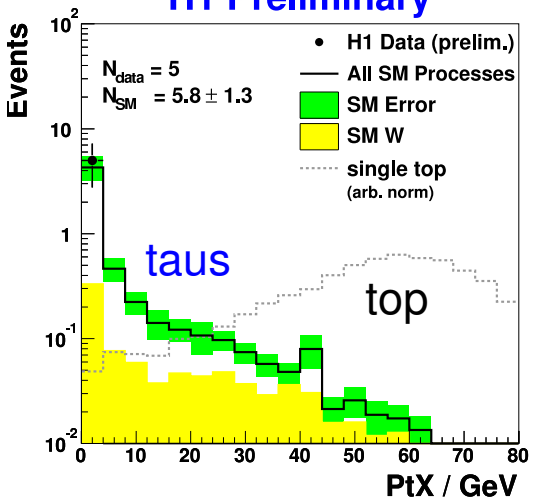
taus



H1



H1 Preliminary



p_T^X sensitive to heavy particle decays (new physics) $\rightarrow$ e.g. anomalous top production

Isolated Lepton Results (HERA I)

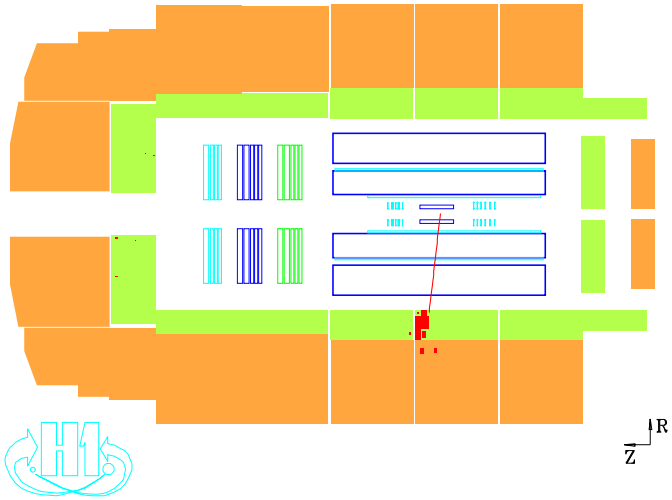
H1 1994-2000 $\mathcal{L}(e^{\pm}p) = 118$ pb^{-1}	Electron obs./exp.	Muon obs./exp.	Tau$^{\mathrm{prel.}}$ obs./exp.	W contrib. $e\mu$ (τ)
Full sample	11 / 11.5 $\pm$1.5	8 / 2.94 $\pm$0.51	5 / 5.81 $\pm$1.36	$\approx$ 75(15)%
$P_T^X > 25$ GeV	5 / 1.76 $\pm$0.29	6 / 1.68 $\pm$0.30	0 / 0.53 $\pm$0.10	$\approx$ 85(50)%
$P_T^X > 40$ GeV	3 / 0.66 $\pm$0.13	3 / 0.64 $\pm$0.14	0 / 0.22 $\pm$0.05	$\approx$ 90(55)%
ZEUS 1994-2000 $\mathcal{L}(e^{\pm}p) = 130$ pb^{-1}	Electron obs./exp.	Muon obs./exp.	Tau obs./exp.	W contrib. $e\mu$ (τ)
Full sample	24 / 20.6 $\pm$3.2	12 / 11.9 $\pm$0.6	3 / 0.4 $\pm$0.12	$\approx$ 17(48)%
$P_T^X > 25$ GeV	2 / 2.9 $\pm$0.46	5 / 2.75 $\pm$0.21	2 / 0.2 $\pm$0.05	$\approx$ 50(50)%
$P_T^X > 40$ GeV	0 / 0.94 $\pm$0.11	0 / 0.95 $\pm$0.12	1 / 0.07 $\pm$0.02	$\approx$ 60(70)%

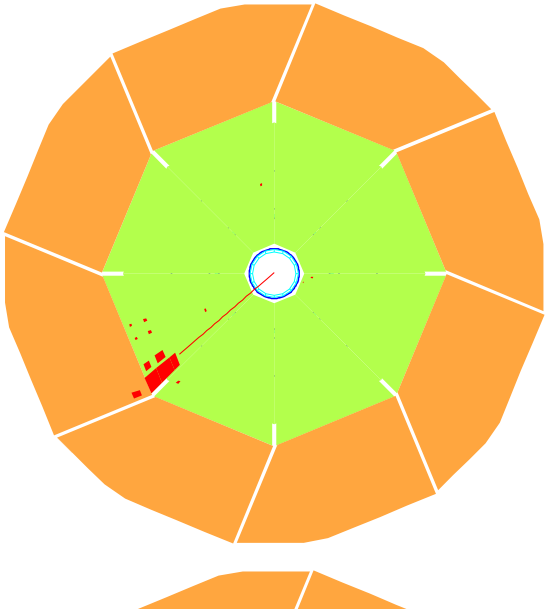
SM expectation is NLO: P.O.Diener et al.

observed excesses in H1 + ZEUS do not match channels

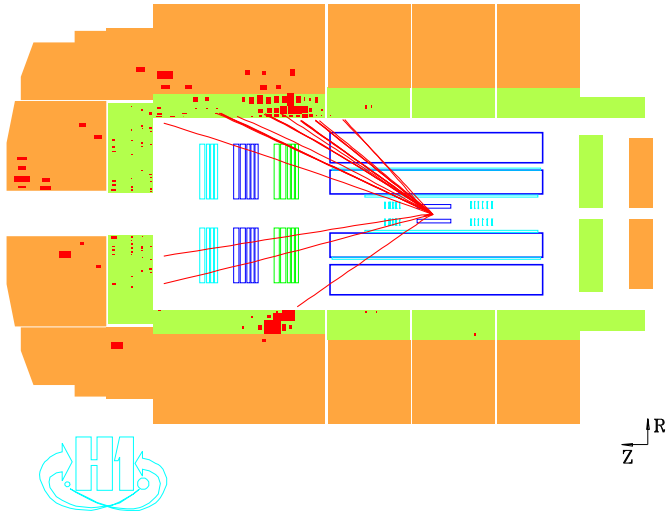
New Isolated Lepton Candidates (HERA II)

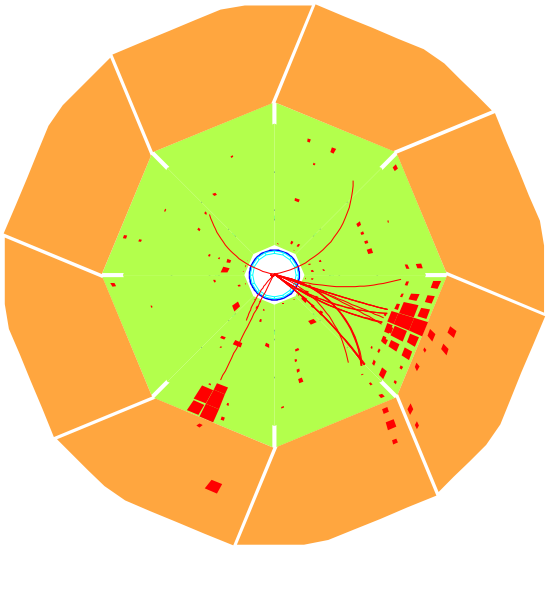
(H1 Coll. ICHEP04 Conf. Paper 12-765)





elastic W candidate

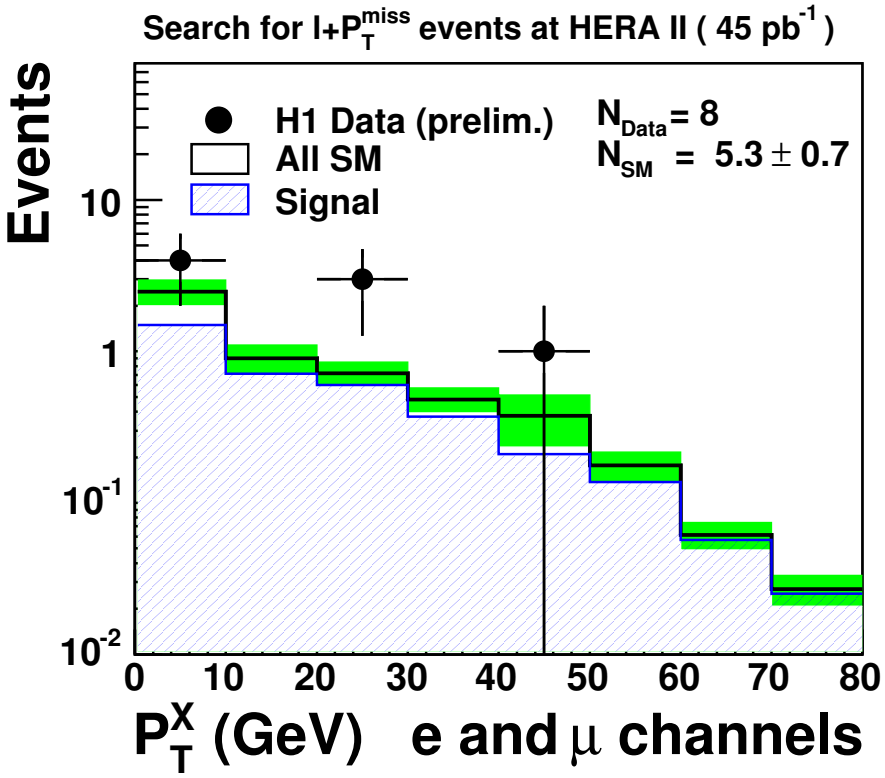




Isolated Leptons at HERA II

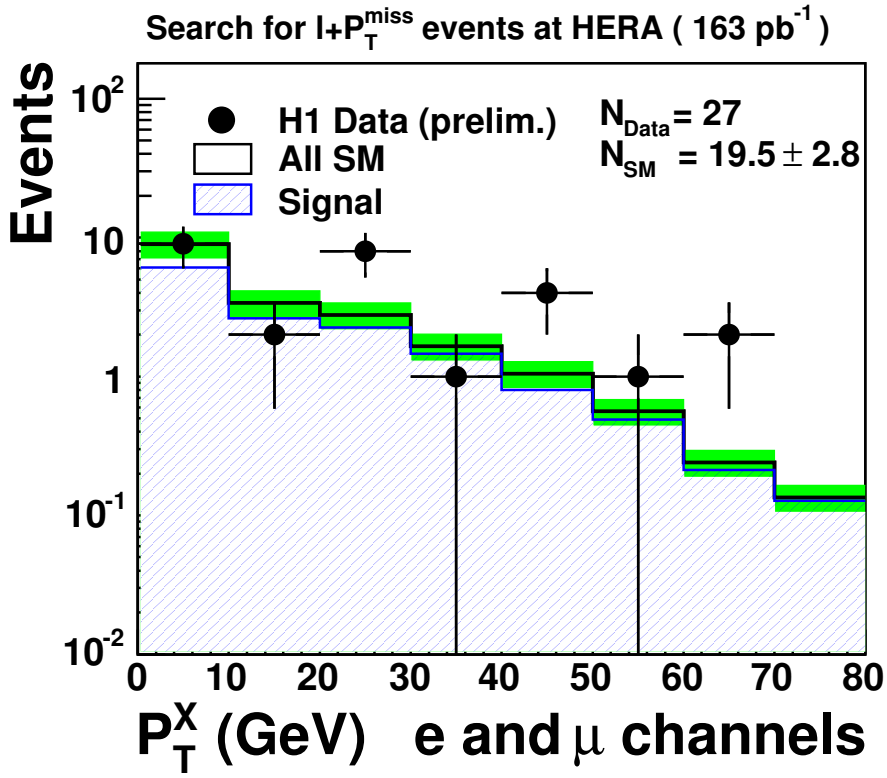
(H1 Collaboration)

HERA II **new data!**



slight excess at high p_T^X in new H1 data

HERA I+II **combined**



clear excess at high p_T^X in combined data

Isolated Leptons: Comparison HERA I+II

H1 Collaboration:

H1 1994-2000 (HERA I) $\mathcal{L}(e^{\pm}p) = 118$ pb^{-1}	Electron obs./exp.	Muon obs./exp.	Combined obs./exp.
Full sample	11 / 11.5 $\pm$1.5	8 / 2.94 $\pm$0.51	19 / 14.4 $\pm$2.01
$P_T^X > 25$ GeV	5 / 1.76 $\pm$0.29	6 / 1.68 $\pm$0.30	11 / 3.44 $\pm$0.59
H1 2003-2004 (HERA II) $\mathcal{L}(e^{+}p) = 43$ pb^{-1}	Electron obs./exp.	Muon obs./exp.	Combined obs./exp.
Full sample	7 / 4.08$\pm$ 0.58	1 / 1.2$\pm$ 0.16	8 / 5.28$\pm$ 0.68
$P_T^X > 25$ GeV	3 / 0.74$\pm$ 0.16	0 / 0.76$\pm$ 0.11	3 / 1.5$\pm$ 0.24

$\Rightarrow$ New data: excess in electron channel, no new candidates in muon channel

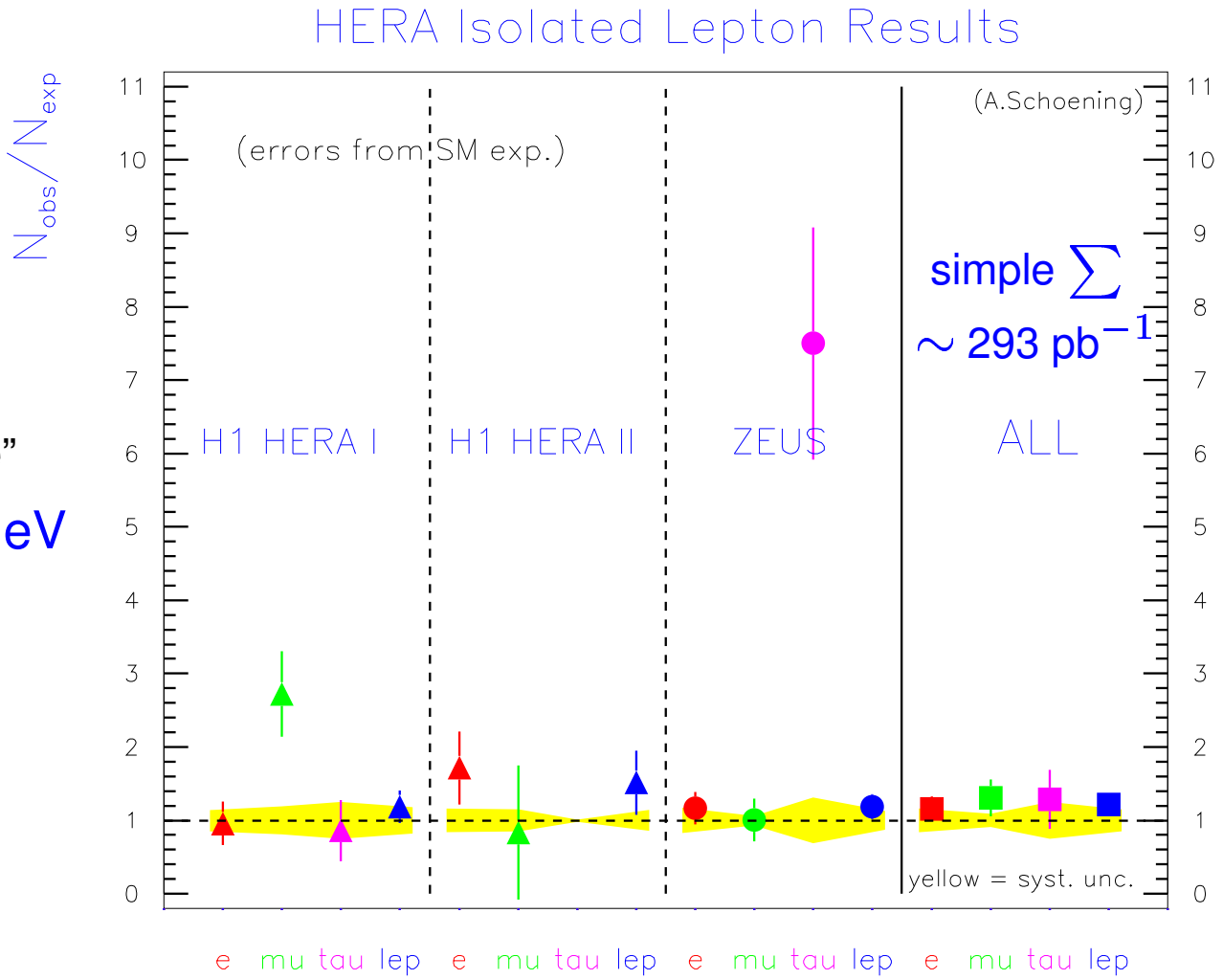
Isolated Leptons: HERA II Updated Comparison

H1 1994-2004 $\mathcal{L}(e^{\pm}p) = 163$ pb^{-1}	Electron obs./exp.	Muon obs./exp.	Tau obs./exp.	W contrib. $e\mu$ (τ)
Full sample	18 / 15.4 $\pm$2.1	9 / 4.1 $\pm$0.7	5 / 5.81 $\pm$ 1.36	$\approx$ 75(15)%
$P_T^X > 25$ GeV	8 / 2.6 $\pm$0.5	6 / 2.5 $\pm$0.5	0 / 0.53 $\pm$ 0.10	$\approx$ 85(50)%

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

note different purities!

Isolated Lepton Summary Plot



"Full Sample"

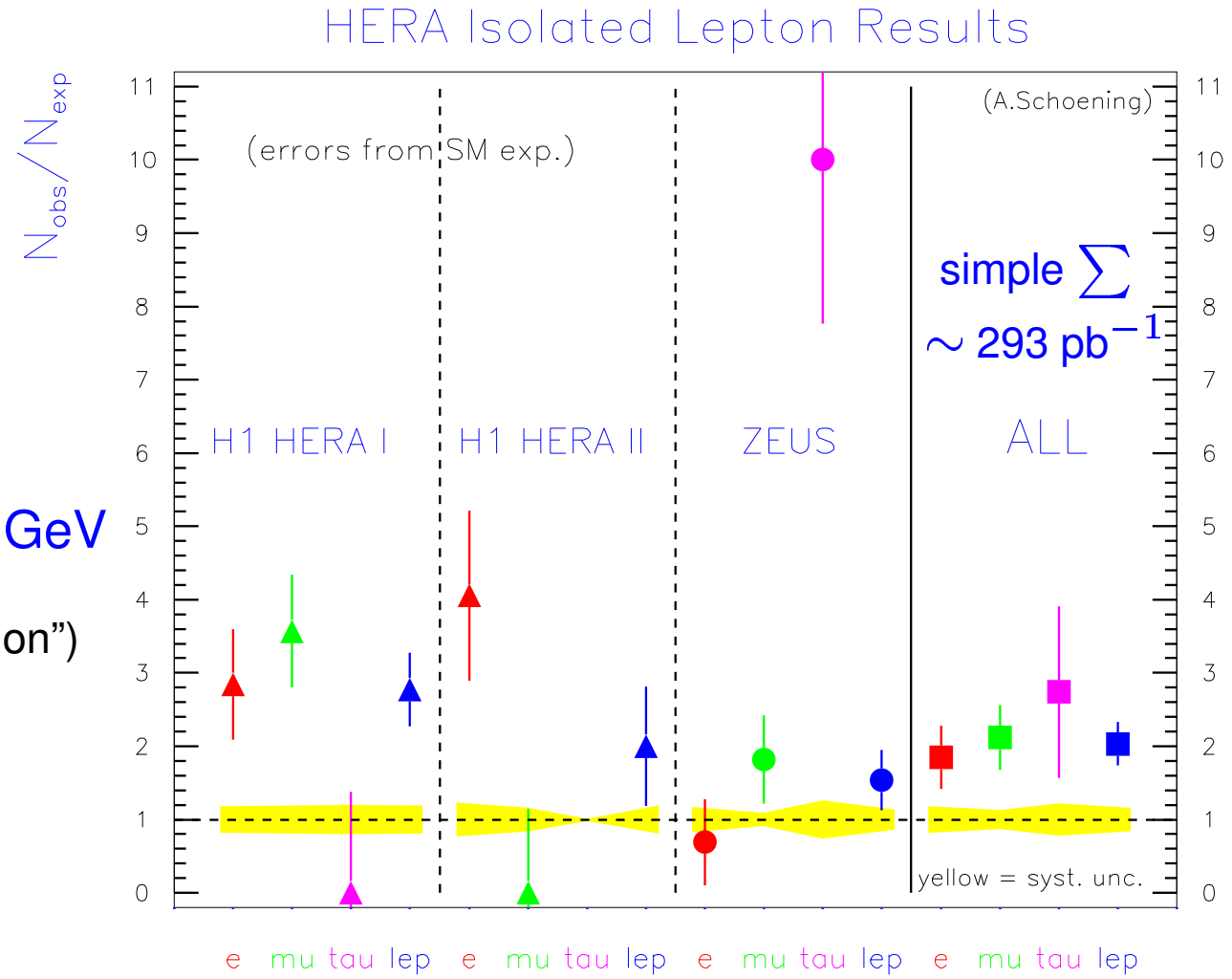
$p_T^X \geq 0$ GeV

SM:

$\rightarrow \chi^2 = 26.8/8$ dof

- $W \rightarrow q\bar{q}$ consistent with the SM (H1 *Phys.Lett.***B** 561 (2003); ZEUS EPS2003 Conf. note 499)

Isolated Lepton Summary Plot



$p_T^X > 25$ GeV

("BSM region")

SM:

$\rightarrow \chi^2 = 42.2/8$ dof

Best Fit:

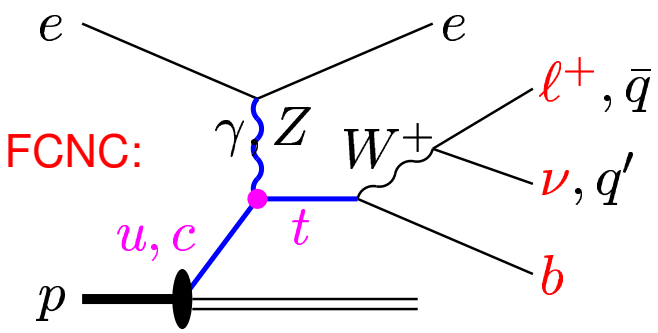
$N_{\rm fit}/N_{\rm exp} = 2$

$\rightarrow \chi^2 = 30.6/8$ dof

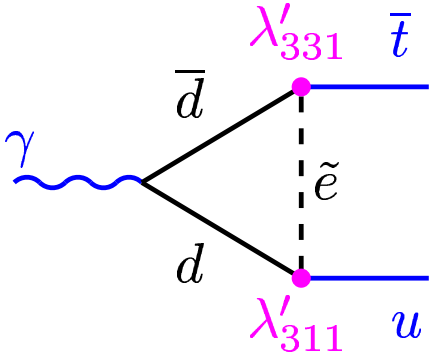
Single Top Production (H1+ZEUS)

(H1 *Eur.Phys.J.C33* (2004), ZEUS *Phys.Lett.***B** 559 (2003))

- Production of single top quarks at HERA via anomalous magnetic coupling κ_γ
  - Search for: $eq \to eXt^+$



sensitive to new physics: e.g. SUSY



$\to$ isolated lepton topology (excess at high p_T^X !) / high E_T 3-jet events

- Effective Lagrangian:

$$\mathcal{L}_{\text{eff}} = \sum_{U=u,c} i\frac{ee_U}{\Lambda}\bar{t}\,\sigma_{\mu\nu}q^\nu\,\kappa_{\gamma,U}UA^\mu \quad + \quad \frac{g}{2\cos\Theta_W}\bar{t}\,\gamma_\mu v_{Z,U}UZ^\mu \quad + \quad \ldots$$

  - $\kappa_{\gamma,U}$ is the anomalous magnetic coupling
  - $v_{Z,U}$ is the anomalous Z boson vector coupling

T.Han and J.L.Hewett PR D60 (1999)

Theoretical Model	BR$(t \to cV)$
Standard Model	$10^{-13} - 10^{-12}$
Two Higgs Doublet Models	$10^{-9} - 10^{-8}$
Supersymmetry	$10^{-9} - 10^{-8}$
Multi Higgs Doublet Models	$10^{-6} - 10^{-5}$
Singlet Quarks	10^{-2}
Dynamical EWSB	10^{-2}

Top Quark Selections (HERA I)

H1 Selection

Analysis Methods

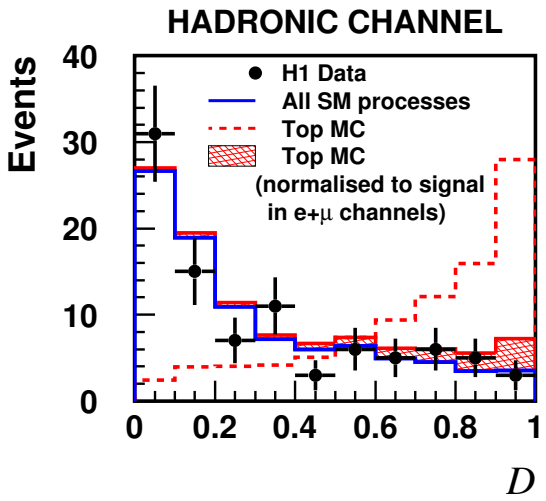
- cut based / multivariate

Variables:

- e, μ decay: p_T^{b}, $M_{\ell\nu b}$, $\cos\Theta_W^{\ell}$

  $\rightarrow$ 5 events / 1.31$\pm$0.22 expected

- hadronic decay: p_T^{b}, M_{jets}, $\cos\Theta_W^{\bar{q}}$



hadr. channel consistent with SM exp.

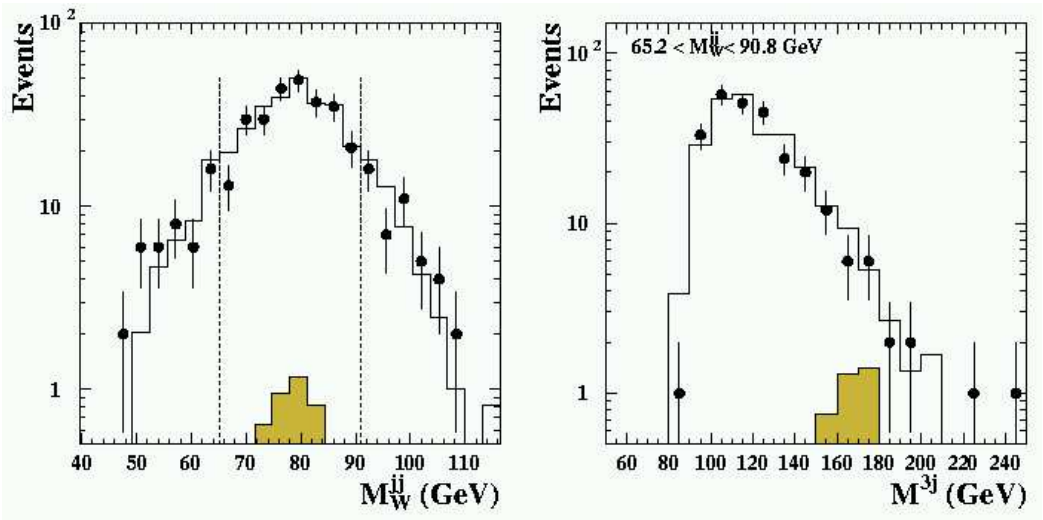
ZEUS Selection

e, μ decay

- isolated leptons $p_T^X > 40$ GeV

hadronic decay

- $p_T^{\mathrm{jet}(1,2,3)} > 40, 25, 24$
- W-, t mass cuts



$14/17.6^{+2.5}_{-1.5}$ consistent with SM expextation

Limits on Anomalous Top Couplings

Top Cross Section Limits

($\sqrt{s} = 318$ GeV, CL 95%):

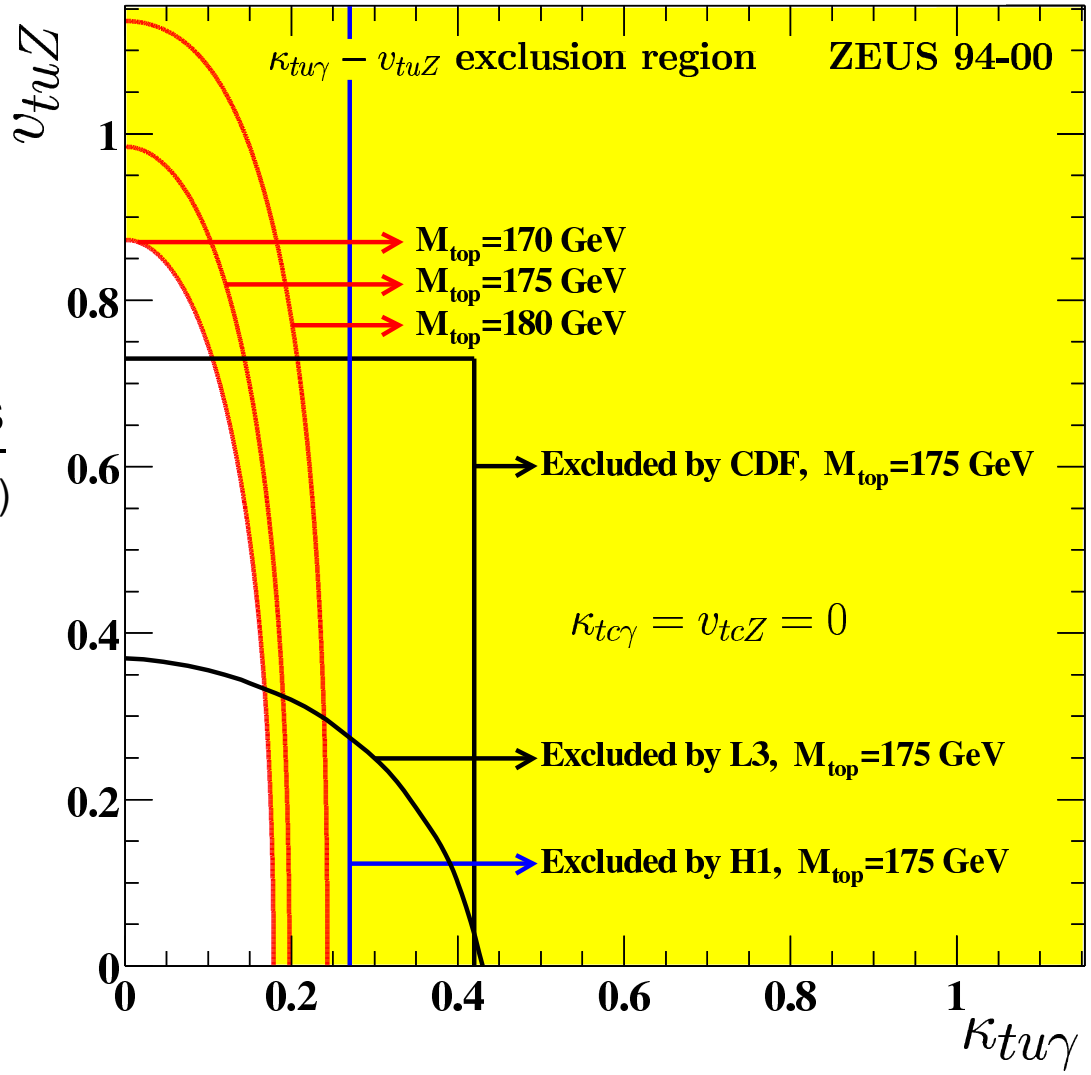
- H1: $\sigma(ep \to etX) < 0.55$ pb
- ZEUS: $\sigma(ep \to etX) < 0.225$ pb

Conversion to anomalous couplings

(NLO: Belyaev and Kidonakis, $m_t = 175$ GeV)

- H1: $\kappa_{tu\gamma} < 0.27$
- ZEUS: $\kappa_{tu\gamma} < 0.174$

$\Rightarrow$ results compatible with LEP and Tevatron limits



Limits on Anomalous Top Couplings

Top Cross Section Limits

($\sqrt{s} = 318$ GeV, CL 95%):

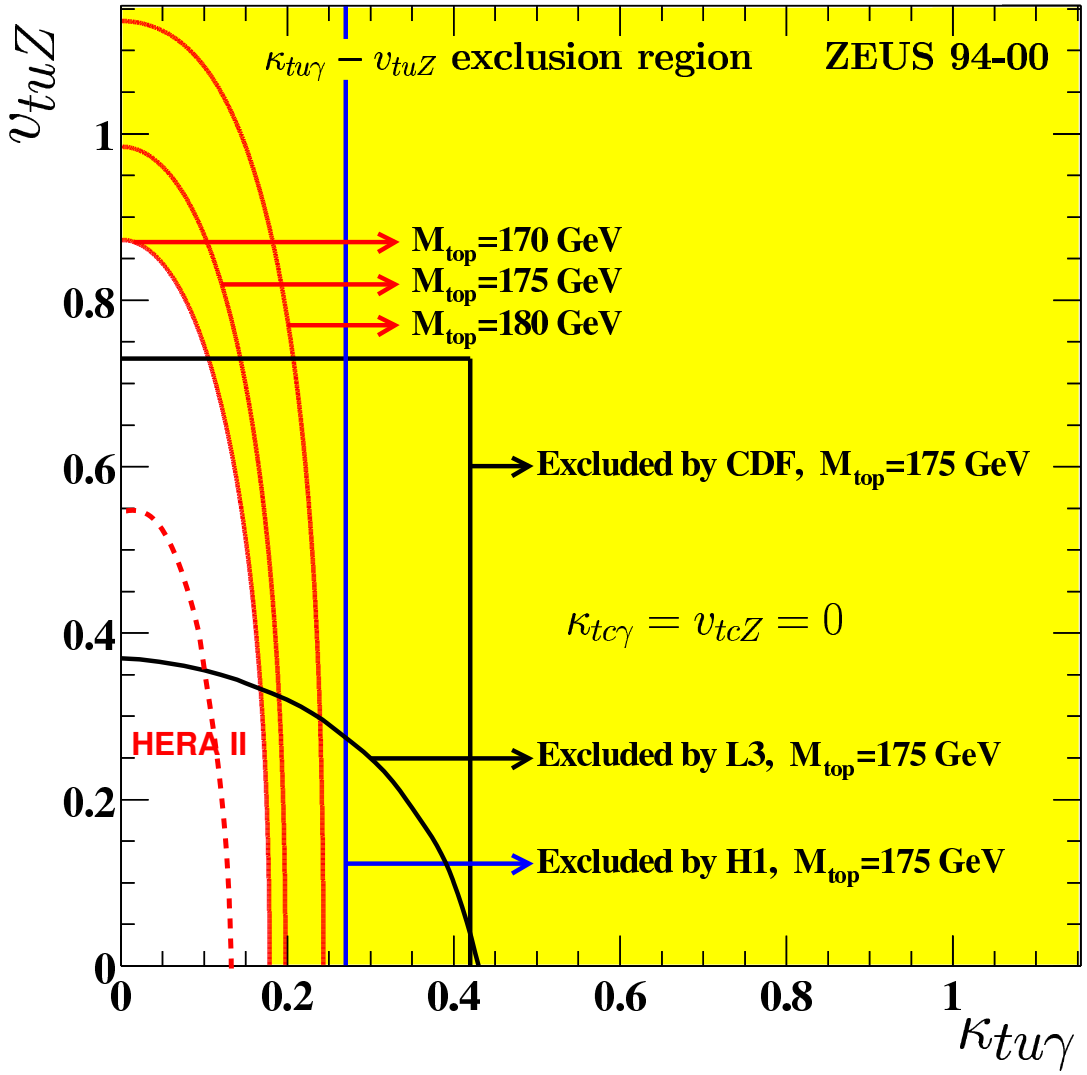
- H1: $\sigma(ep \to etX) < 0.55$ pb
- ZEUS: $\sigma(ep \to etX) < 0.225$ pb

Conversion to anomalous couplings

(NLO: P.O.Diener et al., $m_t = 175$ GeV)

- H1: $\kappa_{tu\gamma} < 0.27$
- ZEUS: $\kappa_{tu\gamma} < 0.174$

$\Rightarrow$ results compatible with LEP and Tevatron limits



Summary

- H1 model independent General Search:

  overall agreement with standard model - outstanding event classes $ejp_T\nu$ + $\mu jp_T\nu$

- Excesses of isolated lepton events seen in $ejp_T\nu$ + $\mu jp_T\nu$ by H1, in $\tau jp_T\nu$ by ZEUS and in also recent data $ejp_T\nu$ (H1).

- upper limits on anomalous production of top quarks set

$\Rightarrow$ more luminosity required to resolve "Isolated Lepton Puzzle"

$\rightarrow$ OUTLOOK

- change to e^-p collisions after this summer shutdown (only $\mathcal{O}(20)$ pb^{-1} from 98/99)

  $\Rightarrow$ interesting potential for more "New Physics from HERA"