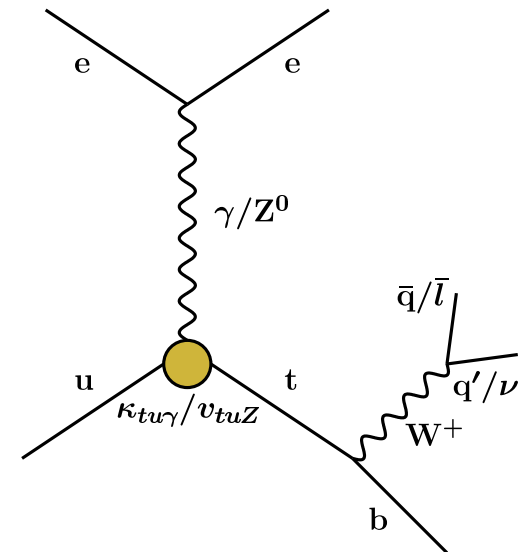
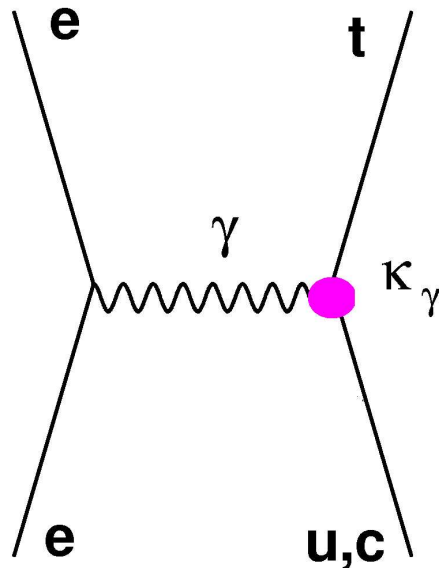


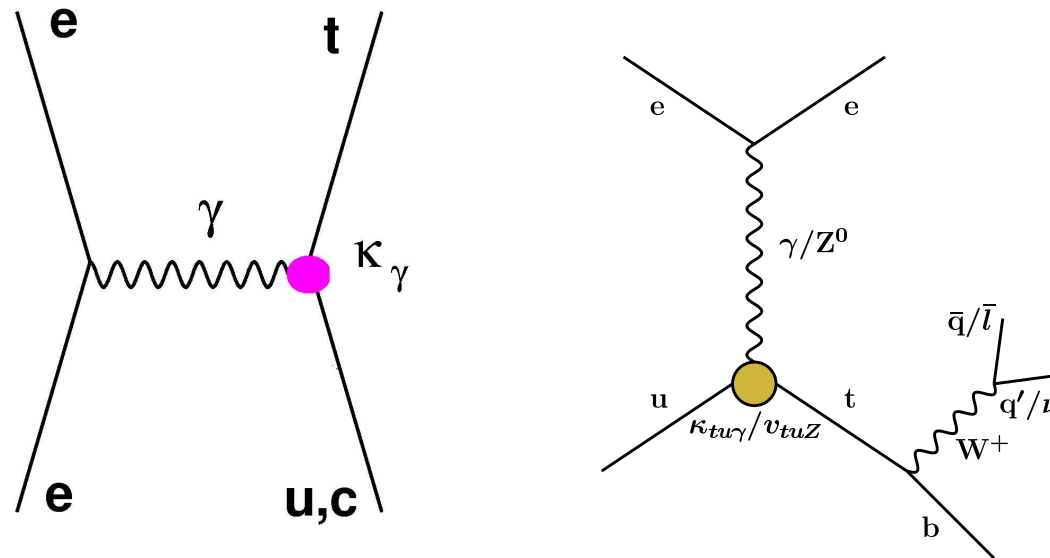
Single Top Production via Flavour Changing Neutral Currents.

James Ferrando - University Of Oxford
EPS03 - Aachen - 18/7/2003.

- *STP.*
- *FCNC.*
- *HERA Searches.*
- *LEP Searches.*
- *Exclusion Limits.*
- *Outlook.*



What is Single Top Production?

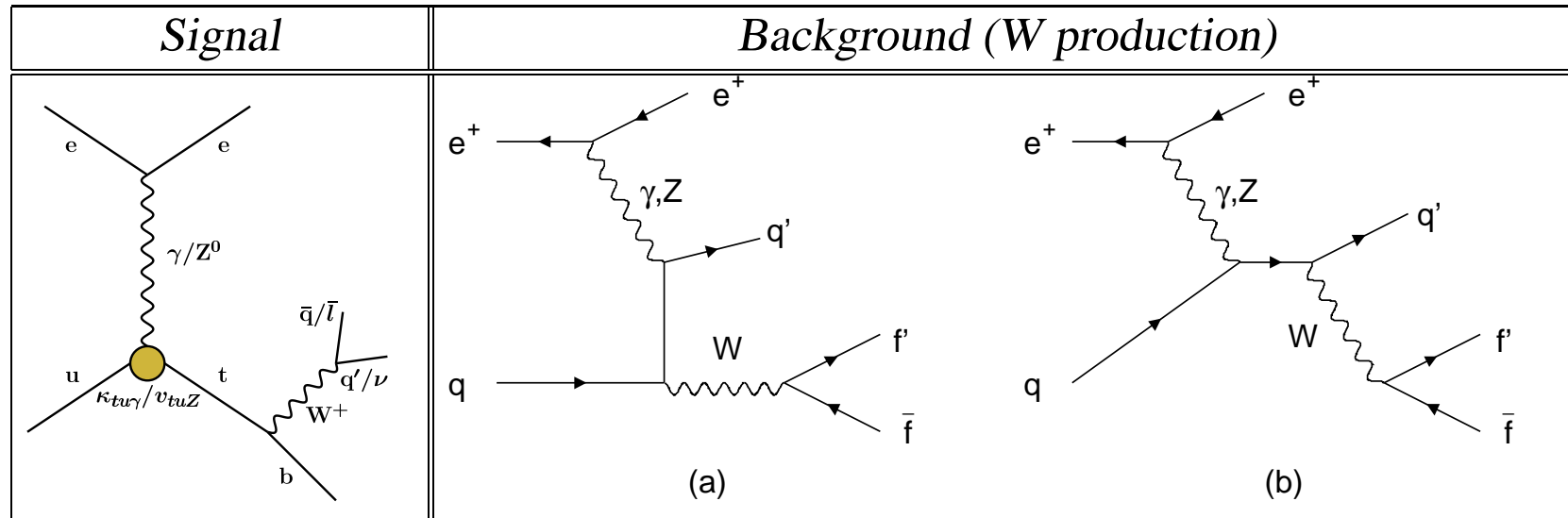


- *Single Top Production (STP) via FCNC as a Standard Model Process:*
 - Not a tree level SM process.
 - Small σ (GIM mechanism): ($\sigma < 1 \text{ fb HERA}, \sigma \approx 10^{-9} \text{ fb LEP}$)
- *Single Top Production via Anomalous FCNC:*
 - $\Delta\mathcal{L}_{\text{eff}} = e e_t \bar{t} \frac{i\sigma_{\mu\nu}q^\nu}{\Lambda} \kappa_{tq\gamma} q A^\mu + \frac{g}{2\cos\theta_W} \bar{t} \gamma_\mu \nu_{tqZ} q Z^\mu + \text{h.c.}$
 - Events at LEP or HERA attributed to STP **must** be from anomalous couplings.
 - Would **unambiguously** signal new physics.

FCNC Search at the Tevatron

- CDF searched for $t \rightarrow q\gamma$ and $t \rightarrow qZ$ with $\mathcal{L} = 110 \text{ pb}^{-1}$.
- From SM expect 10^{-10} branching fraction.
- use $t\bar{t}$ events, one $t \rightarrow bW$.
- $tq\gamma$
 - Look for γj combination with $140 < M < 210 \text{ GeV}$ + $t \rightarrow bW$ topologies.
 - no b tagged jet in γj combination.
 - main background $W + \gamma + 2$ or more jet events, Estimated using $W + \gamma$ event rate.
 - Branching fraction limit: $3.2\% \rightarrow k_\gamma^2 < 0.176$
- tqZ
 - One t quark goes to 3 jets other $t \rightarrow Zq \rightarrow l^+l^-q$
 - Require opposite charge leptons $75 < M_{ll} < 105$
 - Branching fraction limit: $33\% \rightarrow k_Z^2 < 0.533$

Searches at HERA - I



- *Signature of Single Top Production:*

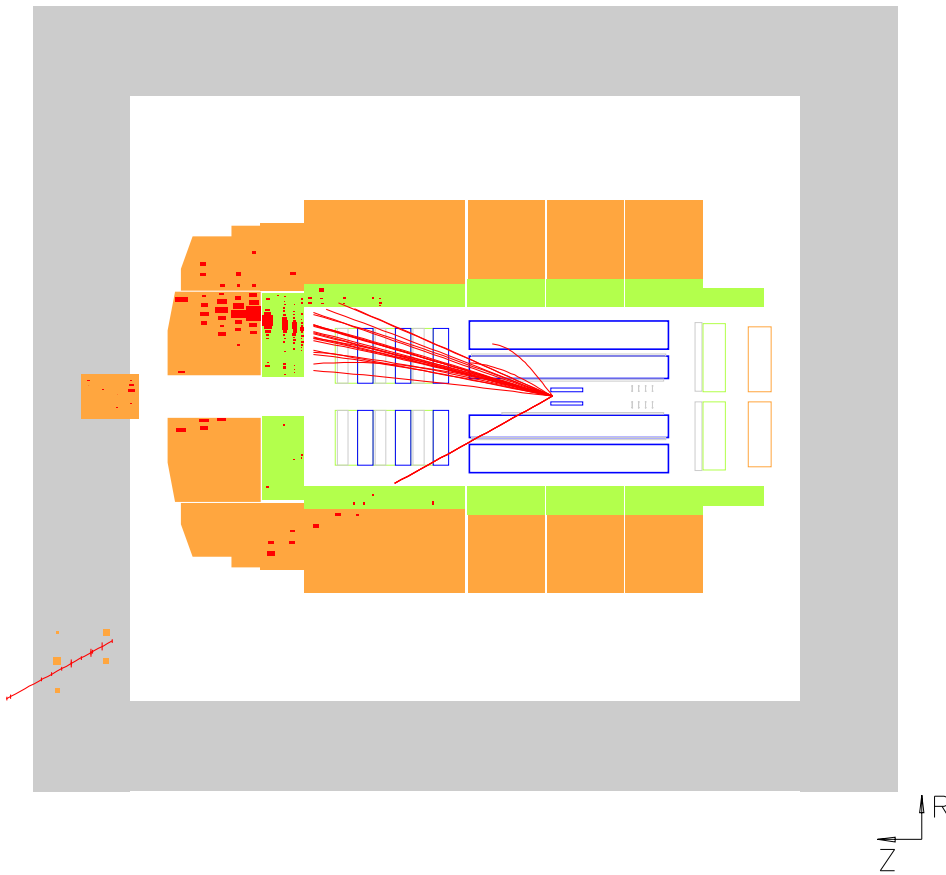
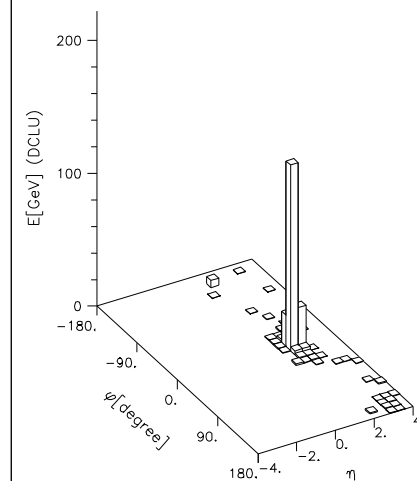
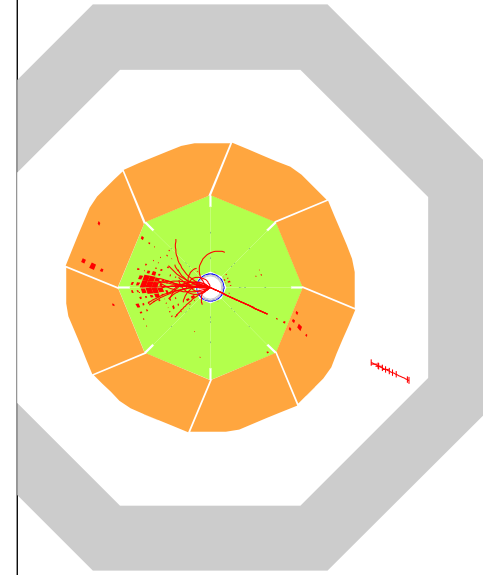
- **Isolated high p_T lepton in events with large missing transverse momentum)**
- Or 3 jets with $M_{jj} \approx M_W$, $M_{3j} \approx M_{\text{top}}$

- *In leptonic channels main backgrounds are 2γ processes (μ), NC DIS and Single W Production.*
- *In hadronic channel, main background is QCD.*
- *Searches have been performed in both hadronic and leptonic channels, $\mathcal{L} \approx 120 \text{ pb}^{-1}$.*

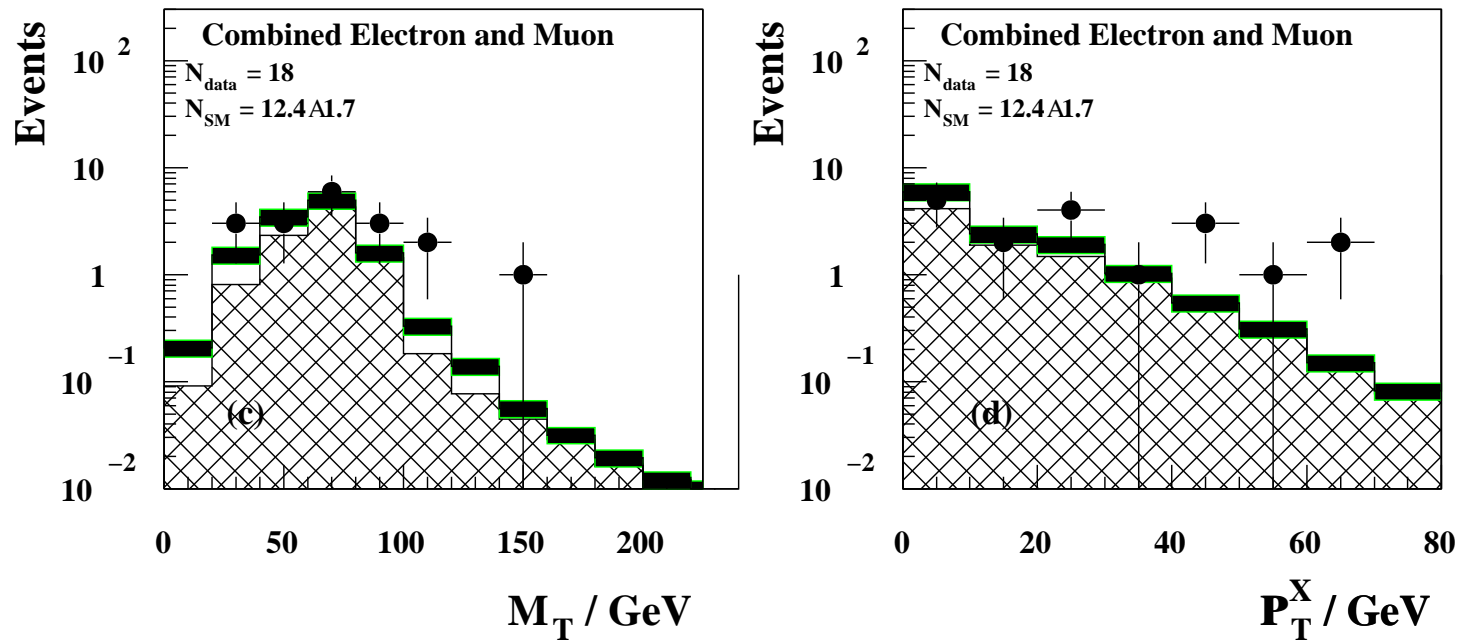
$$e^+p \rightarrow \mu^+ X$$

Event MUON-2

$$P_T^\mu = 28 \text{ GeV}, P_T^X = 67 \text{ GeV}, P_T^{\text{miss}} = 43 \text{ GeV}$$

**H1**

Searches at HERA - II: H1 Isolated Leptons



- 18 Events seen, 12.4 ± 1.7 expected from SM.
- Main excess is at high hadronic p_T - from a Heavy particle decay?.

	<i>e</i> Channel Obs./Exp.	μ channel Obs./Exp.
$P_T^{\text{had}} > 25 \text{ GeV}$	4/1.49 \pm 0.18	6/1.44 \pm 0.18
$P_T^{\text{had}} > 40 \text{ GeV}$	3/0.54 \pm 0.11	3/0.55 \pm 0.12

Searches at HERA - III: H1 Single Top

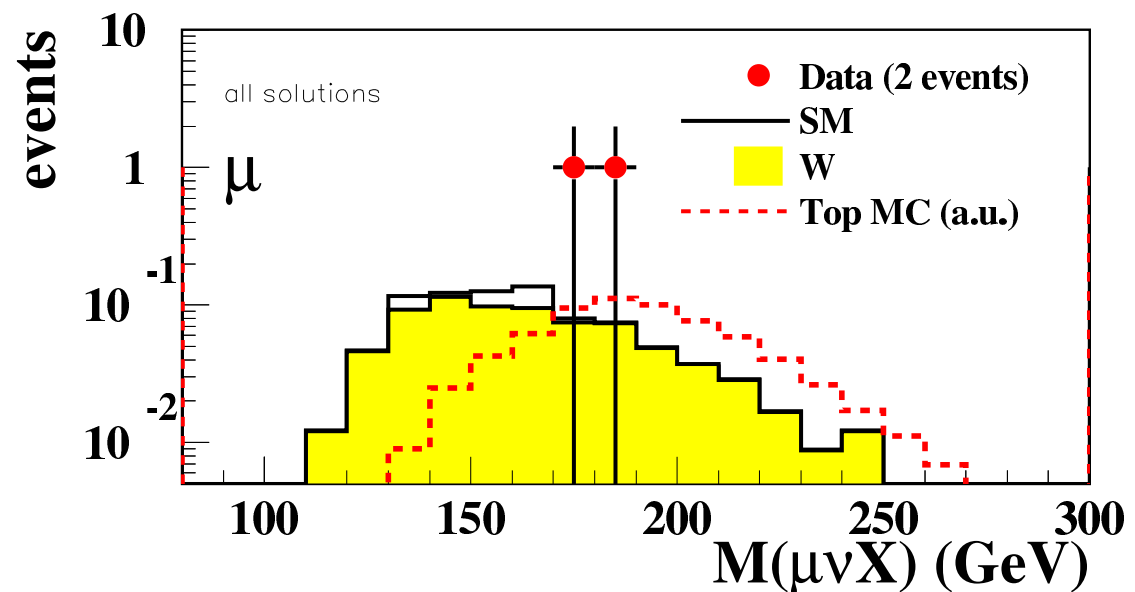
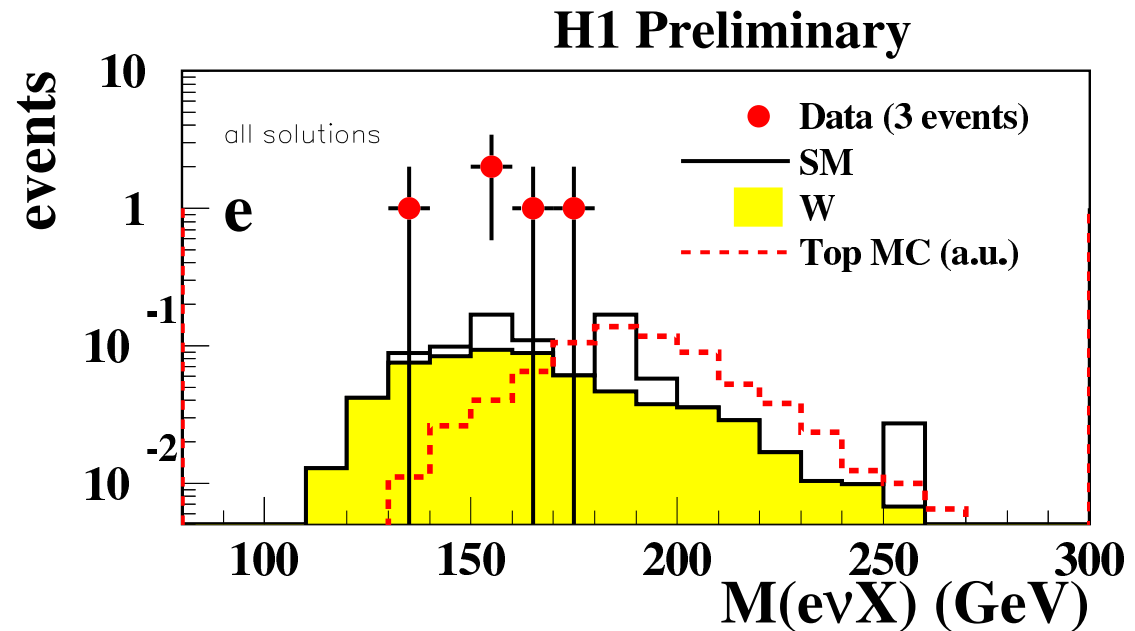
Top mass is reconstructed from invariant mass of $l\nu j$ combinations.

- **Final Selection**

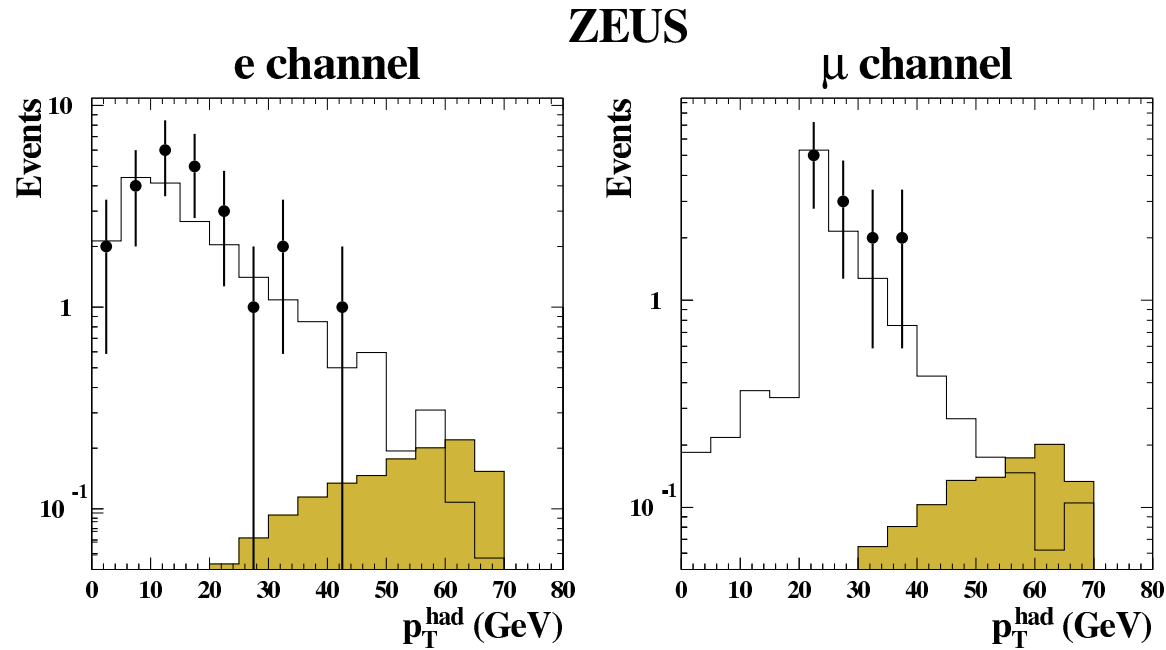
- Isolated l^+ .
- $p_T^X > 25(35)$ GeV.
- $M_T^{l\nu} > 10$ GeV

- **Results**

- 3 e, 2 μ events compatible with STP.
- expect 1.77 ± 0.46 from W production.



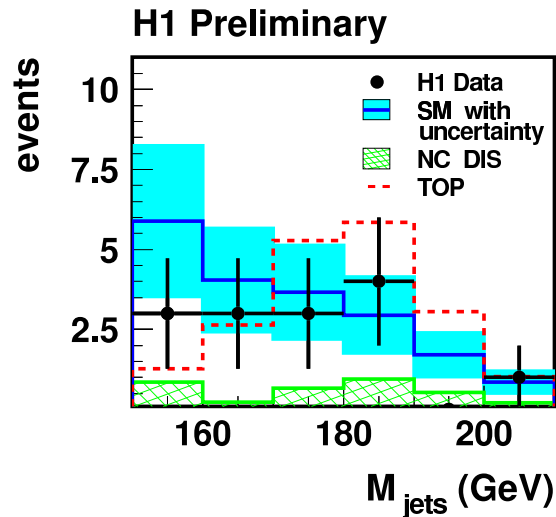
Searches at HERA - IV: ZEUS Isolated Leptons + Single Top



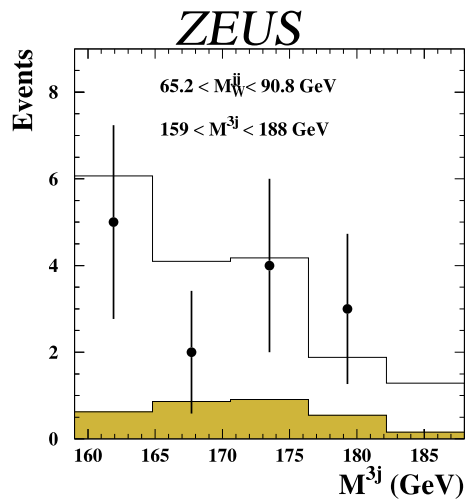
- *Kinematic distributions compatible with SM ,no excess over SM observed*

	<i>e Channel</i> <i>Obs./Exp.</i>	<i>μ Channel</i> <i>Obs./Exp.</i>
<i>preselection</i>	24/20.6 ^{+1.7} _{-4.6}	12/11.9 ^{+0.6} _{-0.7}
$p_T^{\text{had}} > 25 \text{ GeV}$	2/2.90 ^{+0.59} _{-0.32}	5/2.75 ^{+0.21} _{-0.21}
$p_T^{\text{had}} > 40 \text{ GeV}$	0/0.94 ^{+0.11} _{-0.10}	0/0.95 ^{+0.14} _{-0.10}

Searches at HERA - V: Hadronic Channel



After all top cuts

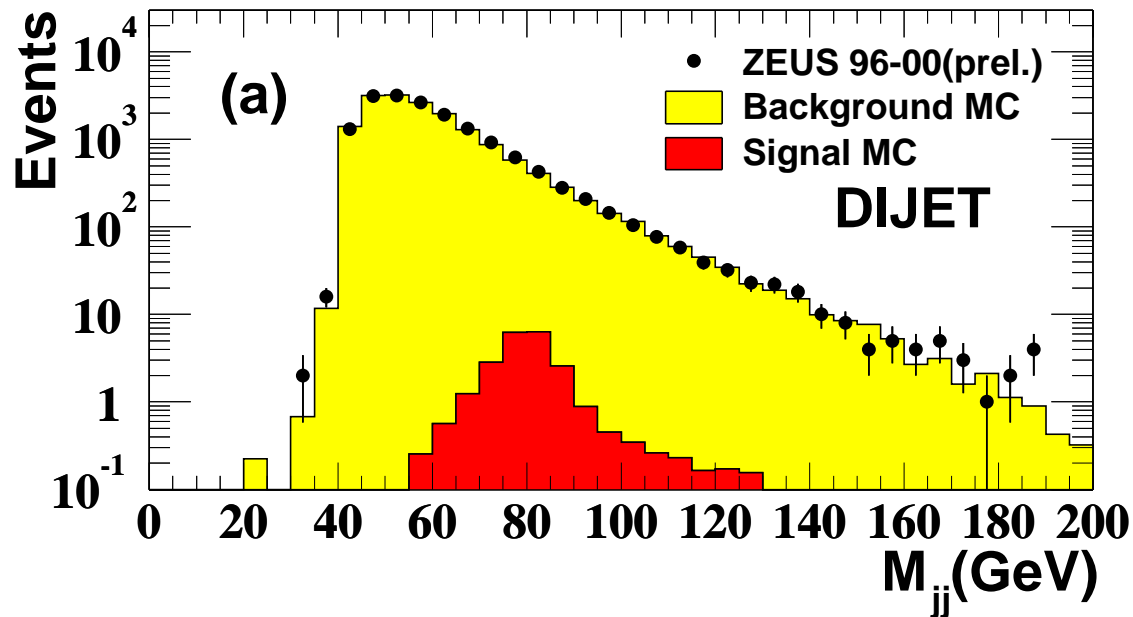
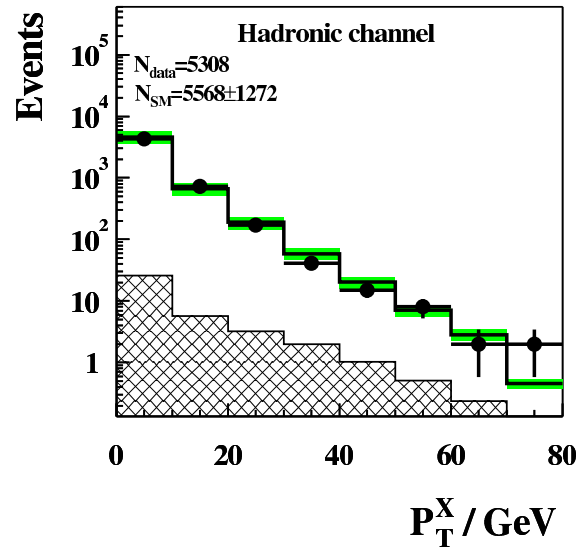
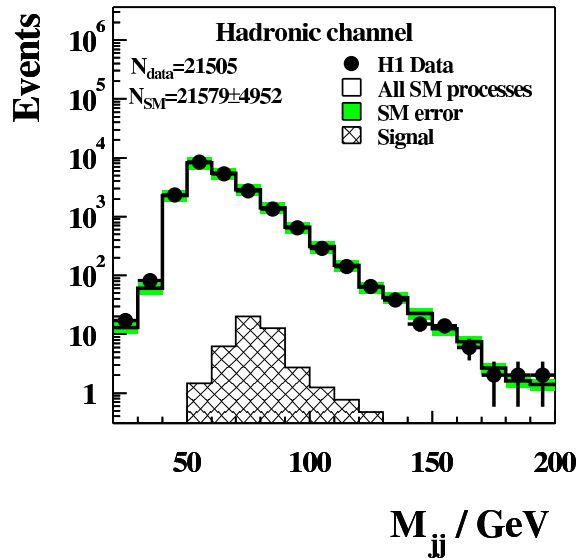


- Search for $eu \rightarrow et \rightarrow ebW \rightarrow ebqq$.
- look for $M_{jj} \approx M_W$, make $3j$ Mass spectrum.
- After final cuts:

	<i>H1(94-00)</i>
<i>Data</i>	14
<i>SM</i>	19.6 ± 7.8
	<i>ZEUS(95-00)</i>
<i>Data</i>	14
<i>SM</i>	$17.6^{+1.8}_{-1.2}$

- No excess in either experiment.

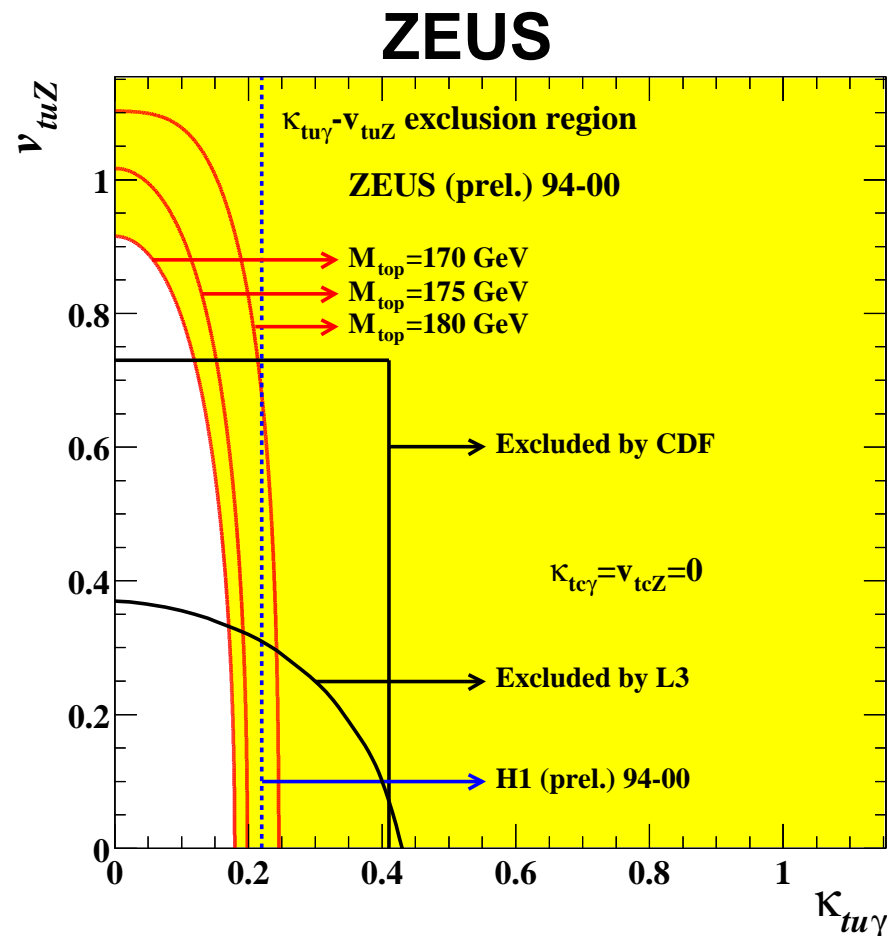
Searches at HERA - VI: $W \rightarrow$ Jets



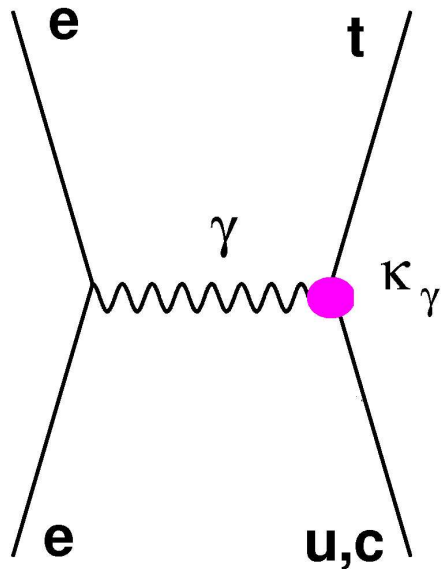
- *Leptonic excess from anomalous W production? ($\sigma_{SM} = 1\text{pb}$)*
- *Check in hadronic channel.*
- *Select Events with 2+ High E_T jets.*
- *Reconstruct invariant mass spectrum.*
- *No excess over SM seen.*
- *Limit (ZEUS):*
 $\sigma < 8.3 \text{ pb}$, *does not eliminate possibility of anomalous W production.*

Searches at HERA - VII: Summary

- Searches for Single Top Production performed by H1 , ZEUS.
- In Leptonic channel H1 sees an excess of isolated lepton events compatible with STP:
 - H1 : 5 seen , expect 1.8.
 - ZEUS: 0 seen, expect 1.0.
- No excess in hadronic channel.
- ZEUS sets strongest limit on photon coupling (0.2).
- ZEUS latest results add sensitivity to v_{tuZ}
- No sensitivity at HERA to tcZ/γ couplings.
- Waiting for HERA II:
 - 10x more luminosity.
 - Improved detectors.



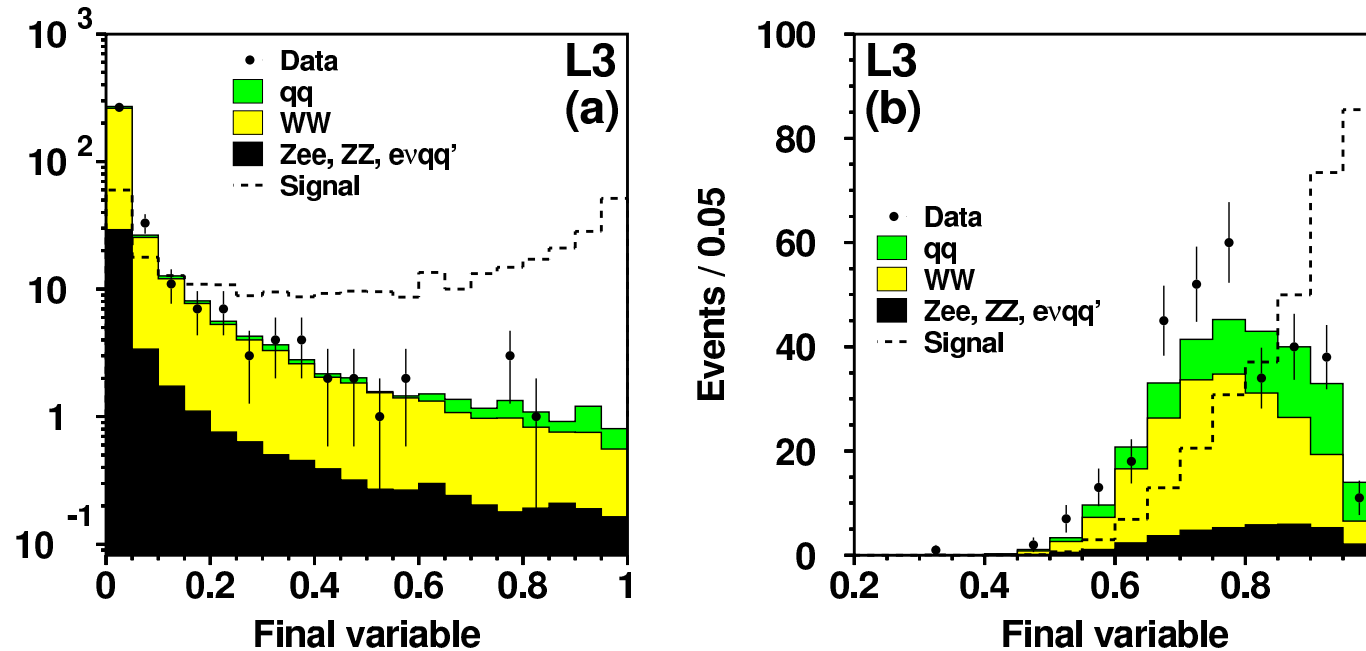
Searches at LEP - I



- Searches for $e^+e^- \rightarrow tq \rightarrow Wbq$
- LEP has sensitivity to $q = u, c$, assume equal.
- Good sensitivity to k_Z .
- $\mathcal{L} \approx 600 \text{ pb}^{-1}$.
- Small difference between m_t and $\sqrt{s} \rightarrow$ clear kinematic signature.
- t is produced almost at rest.

- $E_W \approx (m_t^2 + m_W^2 - m_b^2)/(2m_t) \rightarrow E_b \approx (m_t^2 - m_W^2 + m_b^2)/(2m_t)$.
- One jet from t must be b tagged.
- Signal is diluted as \sqrt{s} increases.
- Variety of sophisticated techniques used.
- Change in Lagrangian means limits for HERA in LEP convention: $k_\gamma^{LEP} = \sqrt{2}k_\gamma^{ZEUS}$
and $k_Z^{LEP} = \sqrt{2}v_Z^{ZEUS}$

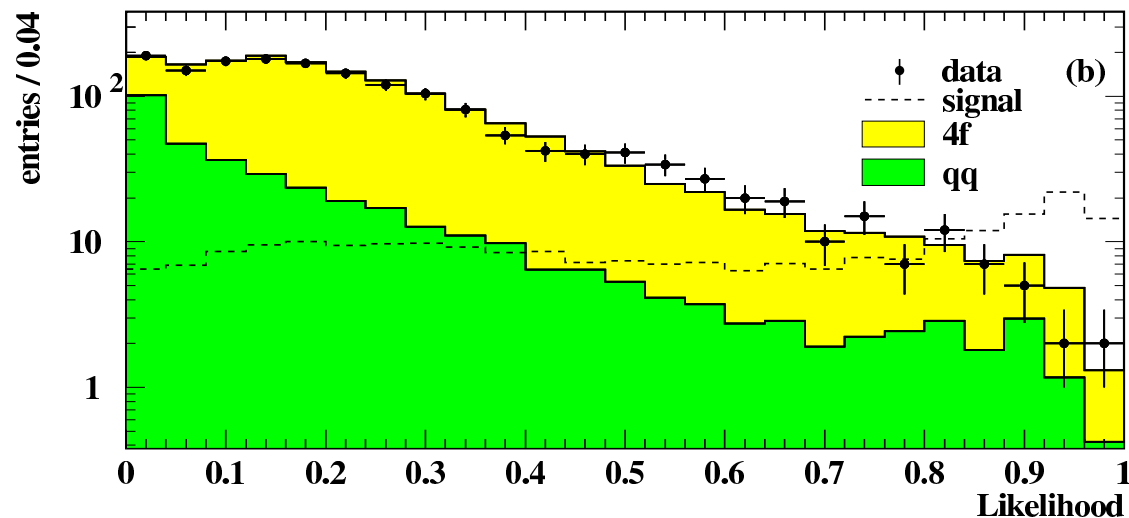
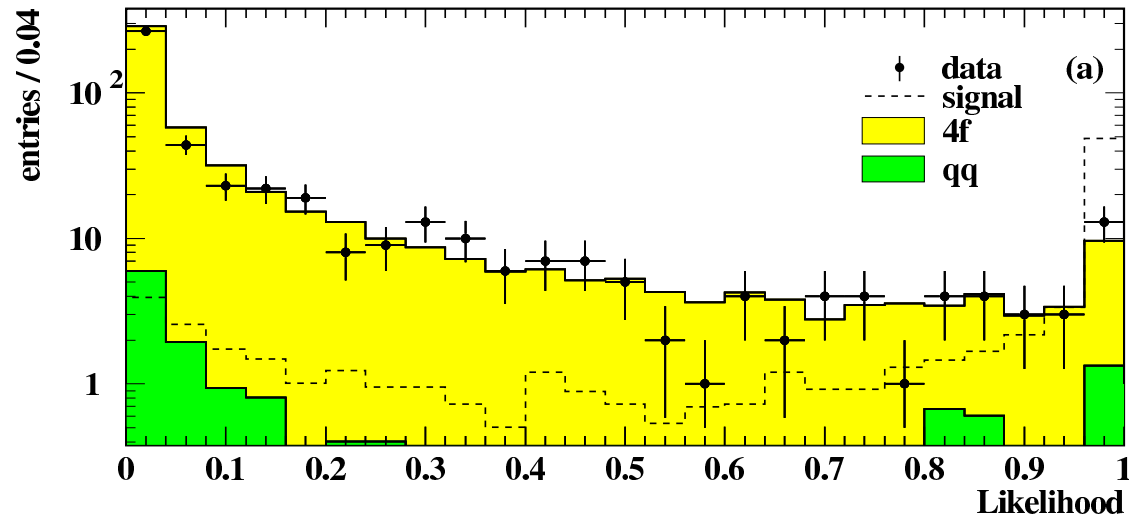
Searches at LEP - II L3



- A neural network technique is used.
- variables include:
 - b -tag.
 - $E_l, \vec{p}_{\text{miss}}, M_{jj}, M_{l\nu}$ (leptonic)
 - jet characteristics, event shapes (hadronic).
- Limits set in k_γ, k_Z plane.

Searches at LEP - III OPAL

OPAL



- Separation with conventional likelihood function.

- $$\mathcal{L} = \frac{\mathcal{P}_{\text{signal}}}{\mathcal{P}_{\text{signal}} + \mathcal{P}_{\text{background}}}$$

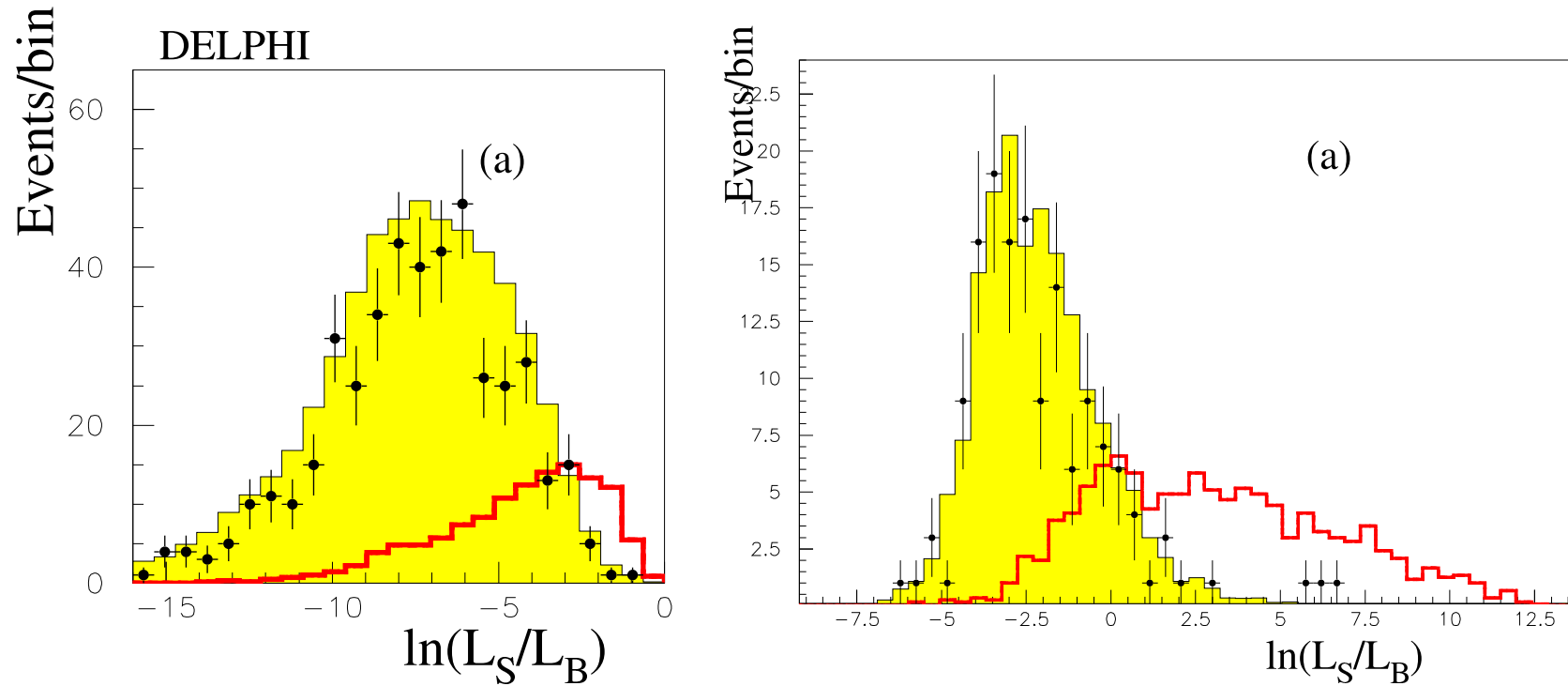
- variables :

- kinematic fits, b tag, $E_{c(u)}$.

- Thrust(hadronic), $M_{l\nu}$ after kinematic fit (leptonic).

- Limits consistent with previous ALEPH result.

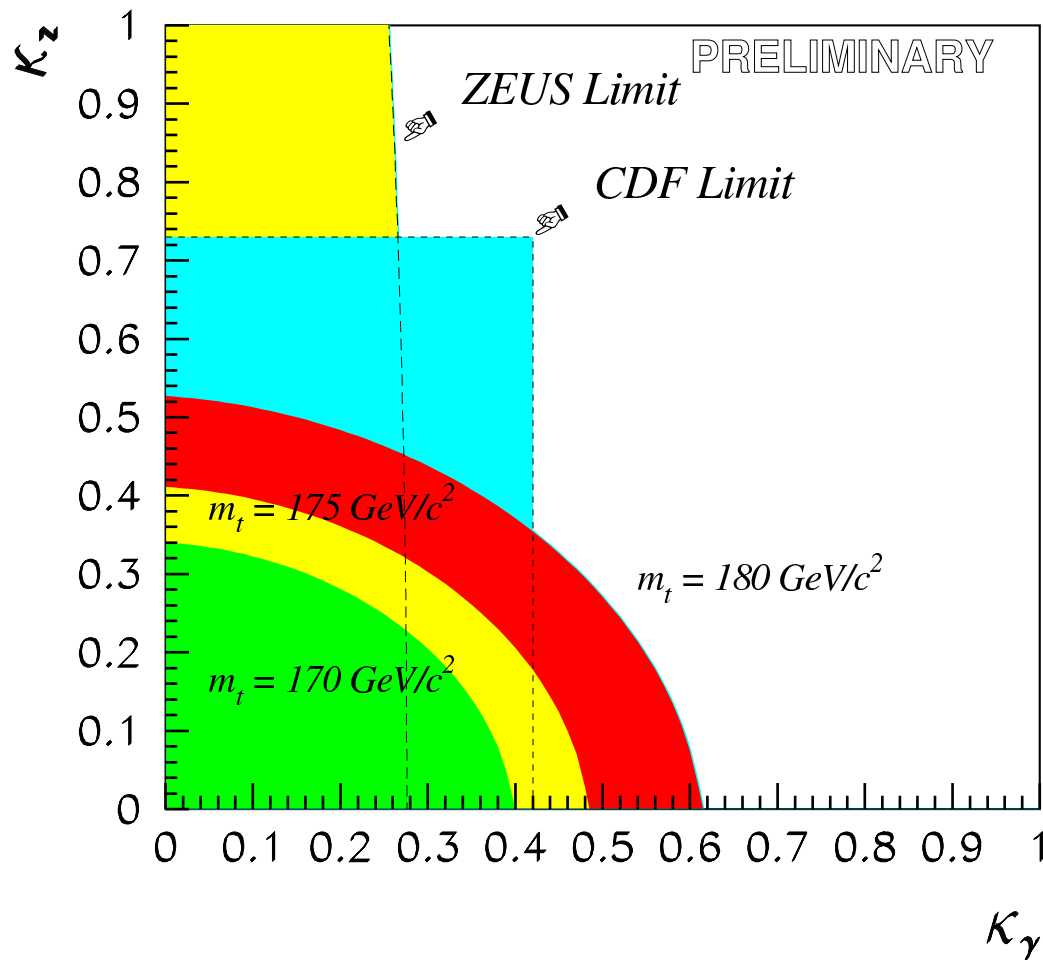
Searches at LEP - IV DELPHI



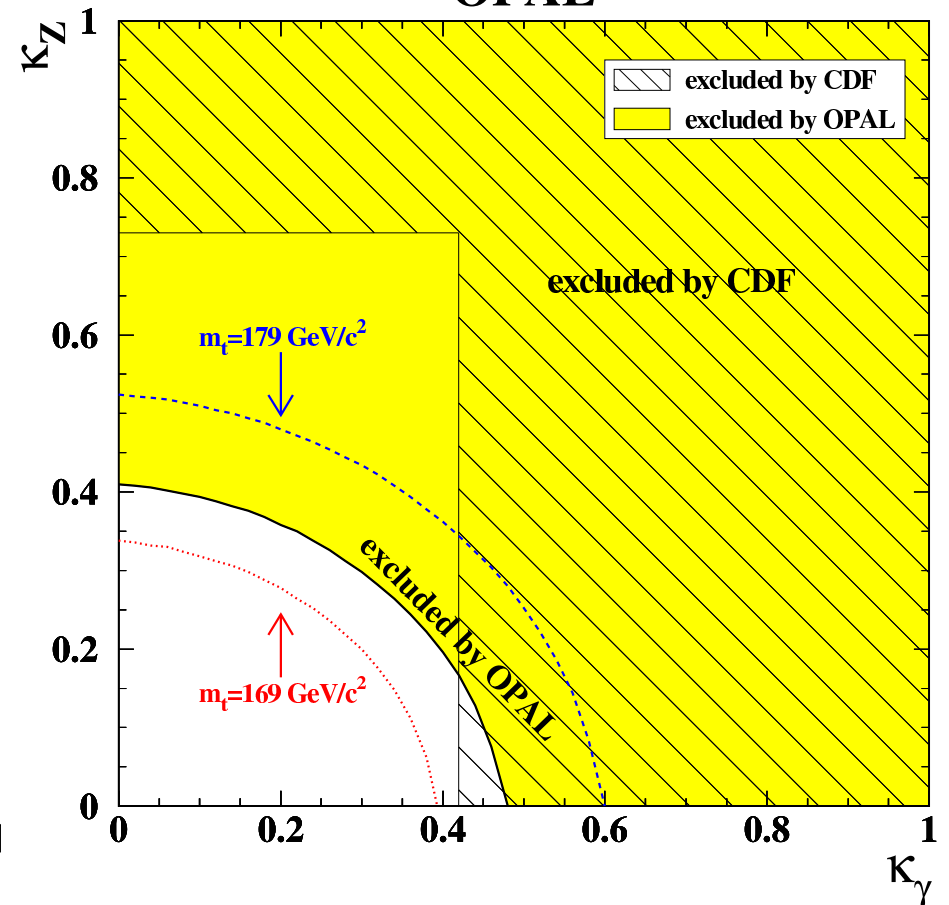
- Separation with $\ln(L_S/L_B)$
- $L_S = \prod_i \mathcal{P}_i^{\text{signal}}$, $L_B = \prod_i \mathcal{P}_i^{\text{background}}$
- Similar variables to OPAL, likelihood function used.
- No evidence for STP seen.

Searches at LEP V: Exclusion Limits

DELPHI 189–208 GeV



OPAL



Searches at LEP - V: Summary

- *Searches have performed with LEP data in hadronic and leptonic channels.*
- *Unlike HERA LEP has sensitivity to $tc\gamma/Z$*
- *No evidence for FCNC observed*
- *Good agreement between all 4 LEP experiments.*

Overall Summary and Outlook

- Searches at Tevatron (Run 1), HERA I, and LEP.
- No evidence seen at LEP for STP via FCNC.
- events compatible with STP via FCNC seen at H1, unconfirmed by ZEUS.
- HERA and LEP set strongest limits on FCNC.
- HERA II and Tevatron Run 2 will lower limits further.
- HERA II data needed to clarify isolated lepton excess seen by H1.

