First Measurements of W Pair Production at OPAL

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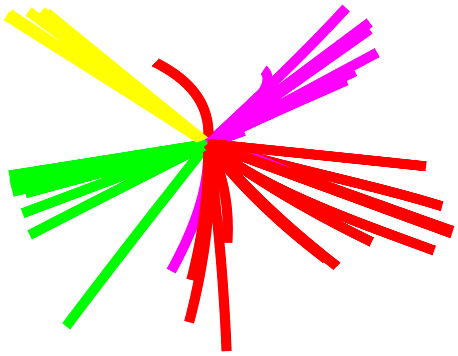
CERN

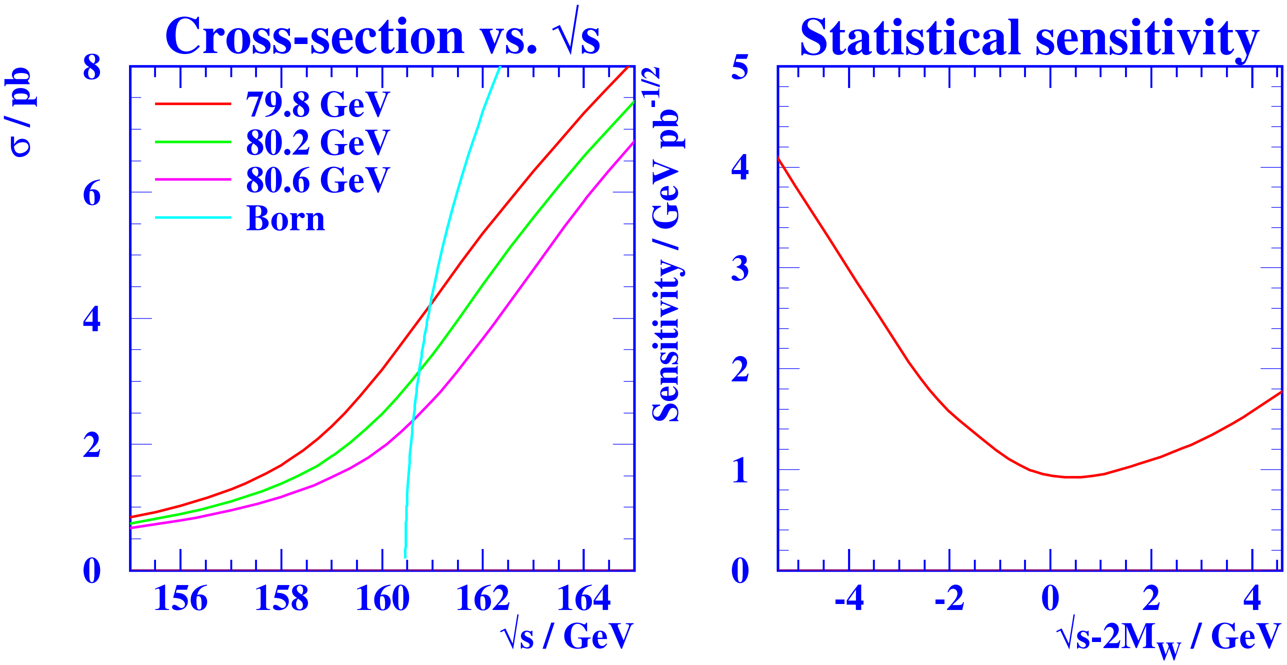


OUTLINE

- Introduction
- Event selection
- Cross-section and W mass measurements
- Triple gauge boson couplings
- Summary

Introduction

- $\sigma(e^+e^- \to W^+W^-)$ increases rapidly close to threshold
- Sharp turn-on at $\sqrt{s} \simeq 2M_W$ distorted by ISR, Γ_W, EW corrections
- Cross-section at a given $\sqrt{s}$ depends on M_W

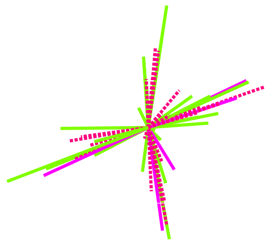


- Statistical sensitivity K best at $\simeq 2M_W + 0.5$ GeV ($\Delta M_W = K/\sqrt{\epsilon\mathcal{L}}$)

LEP2 run at threshold

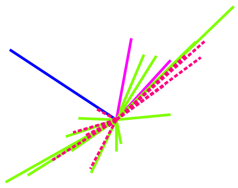
- First LEP2 run $8^{\rm th}$ July – $16^{\rm th}$ August 1996
- OPAL experiment collected $\sim$10 pb^{-1} at $\sqrt{s}$= 161.3 GeV
  (Hoped for ≥ 25 pb^{-1})
- Study all $\mathrm{W^+W^-}$ decay channels:

$\mathrm{q\overline{q}q\overline{q}}$



46%

$\mathrm{q\overline{q}}\ell\overline{\nu}_\ell$
$(\ell = \mathrm{e}, \mu, \tau)$



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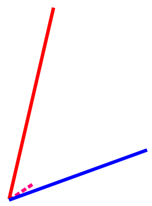
$\ell^-\overline{\nu}_\ell\ell'^+\nu_{\ell'}$
$(\ell, \ell' = \mathrm{e}, \mu, \tau)$



11%

- Main background from $\mathrm{e^+e^-} \rightarrow \mathrm{Z^0}/\gamma \rightarrow \mathrm{f\overline{f}}(\gamma)$
  Cross-section ~ 60 times higher than signal

Event selection

$\mathrm{W^+W^-\to q\overline{q}q\overline{q}}$

4 hadronic jets, high multiplicity, large visible energy

- 4 jets with ≥ 1 track each, $y_{34} > 0.01$
- Kinematic fit with $E, \vec{p}$ conservation, $M_{\mathrm{W}_1} = M_{\mathrm{W}_2}$
  $M_{\mathrm{fit}} > 72$ GeV, $P_{\mathrm{fit}}(\chi^2) > 1\%$
- $E_\gamma / E_\gamma^{\mathrm{ISR}} < 0.71$

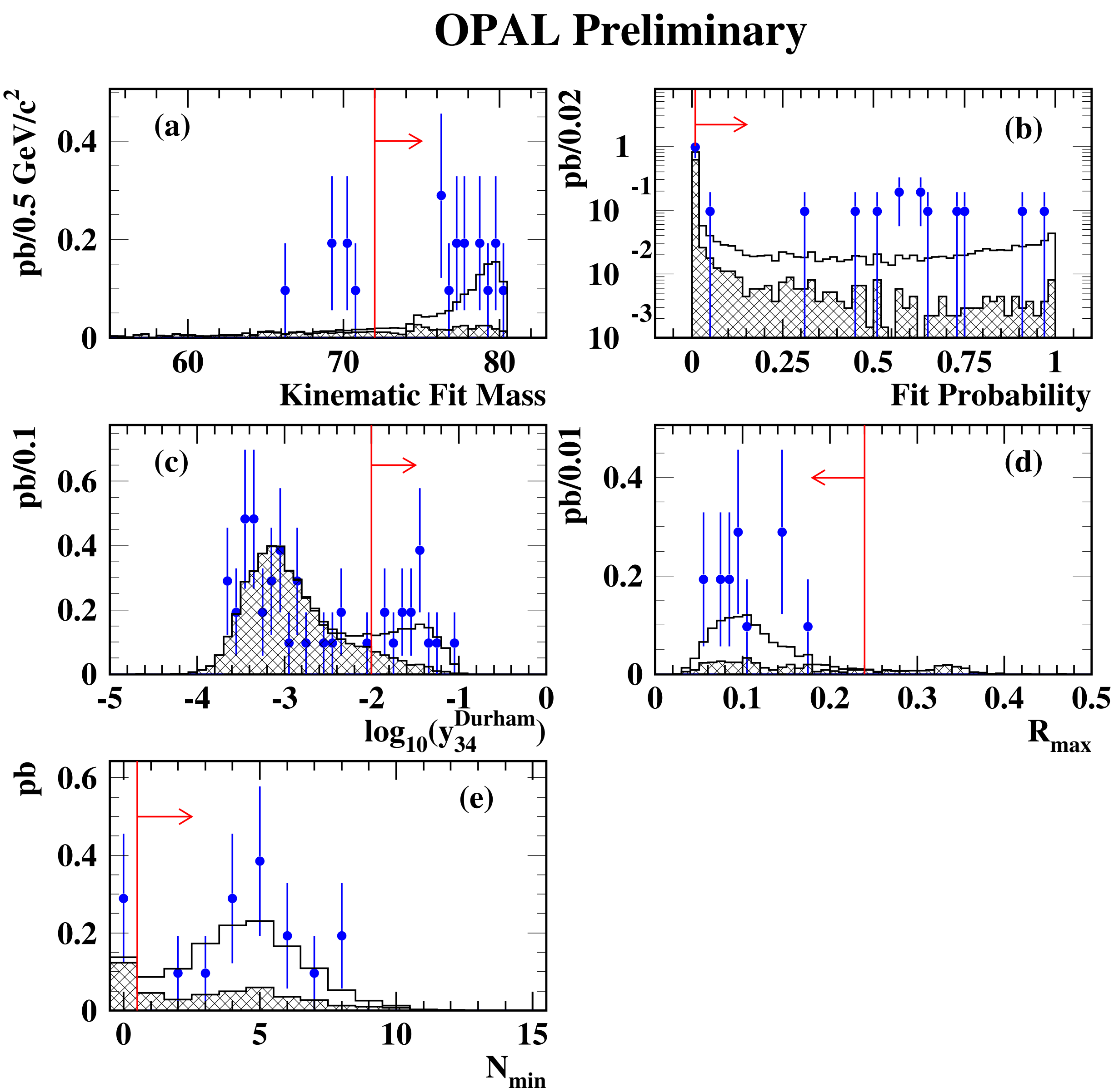
$\mathrm{W^+W^-\to q\overline{q}e\overline{\nu}_e, q\overline{q}\mu\overline{\nu}_\mu}$

2 hadronic jets, energetic lepton, missing momentum

- Isolated, high momentum e or μ
- 3-jet like: $y_{23} > 0.005$
- $E_\gamma / E_\gamma^{\mathrm{ISR}} < 0.75$
- $R_{\mathrm{mis}} = |\vec{p}_{\mathrm{mis}}|/\sqrt{s} > 0.07$, $|\cos\theta_{\mathrm{mis}}| < 0.95$
- $R_{\mathrm{vis}} = E_{\mathrm{vis}}/\sqrt{s} \lesssim 1$
- $\sum p_T \gtrsim 12$ GeV

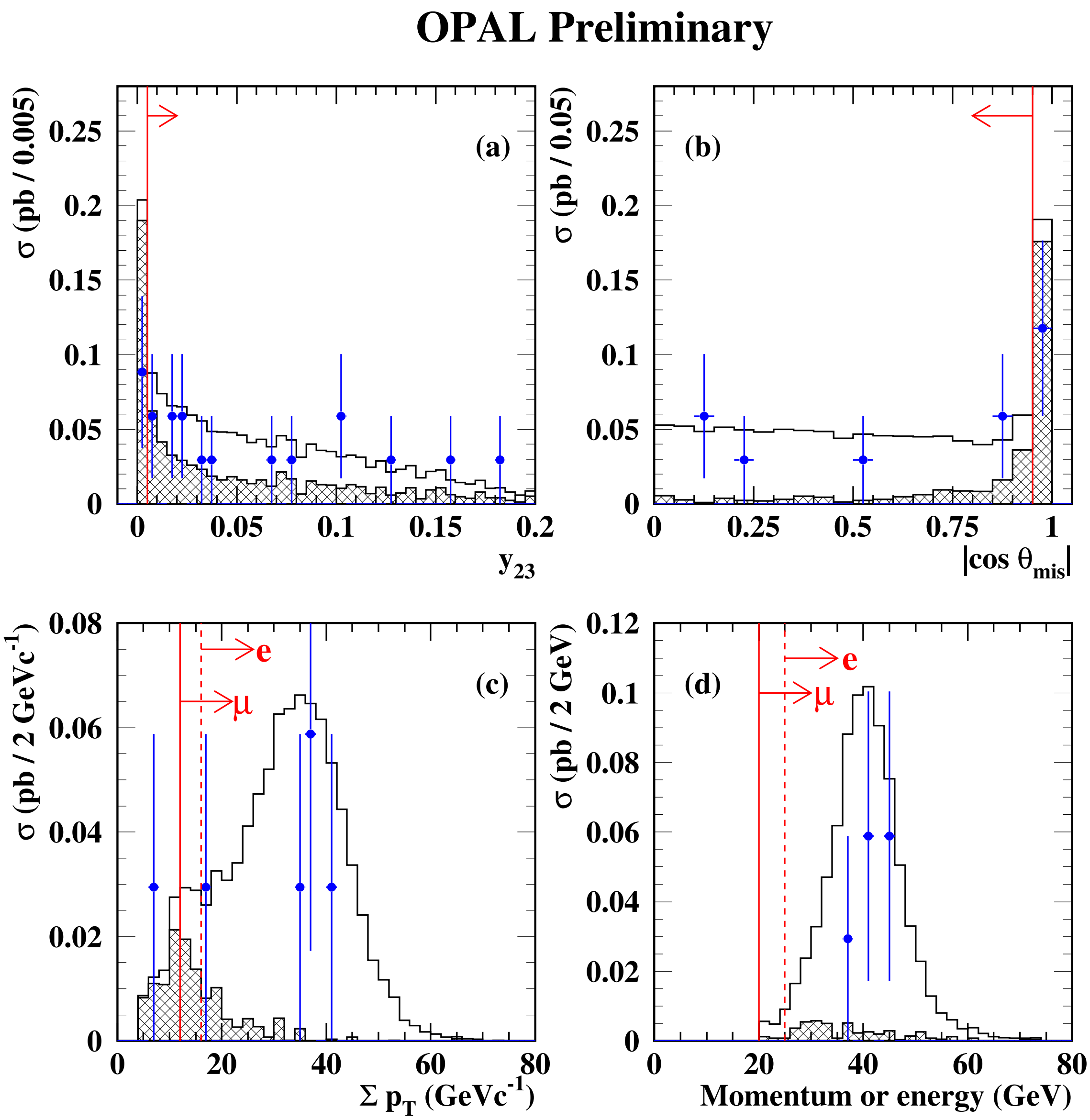
Differ for e, μ

$W^+W^- \to q\bar{q}q\bar{q}$ event selection



- Each quantity shown after all other cuts

$W^+W^- \to q\bar{q}e\bar{\nu}_e, q\bar{q}\mu\bar{\nu}_\mu$ event selection



- Cuts are applied successively
- Data points have arbitrary normalisation

$\boxed{\mathrm{W^+W^-} \rightarrow \mathrm{q\overline{q}}\tau\overline{\nu}_\tau}$

3 jets (1 from τ), missing momentum

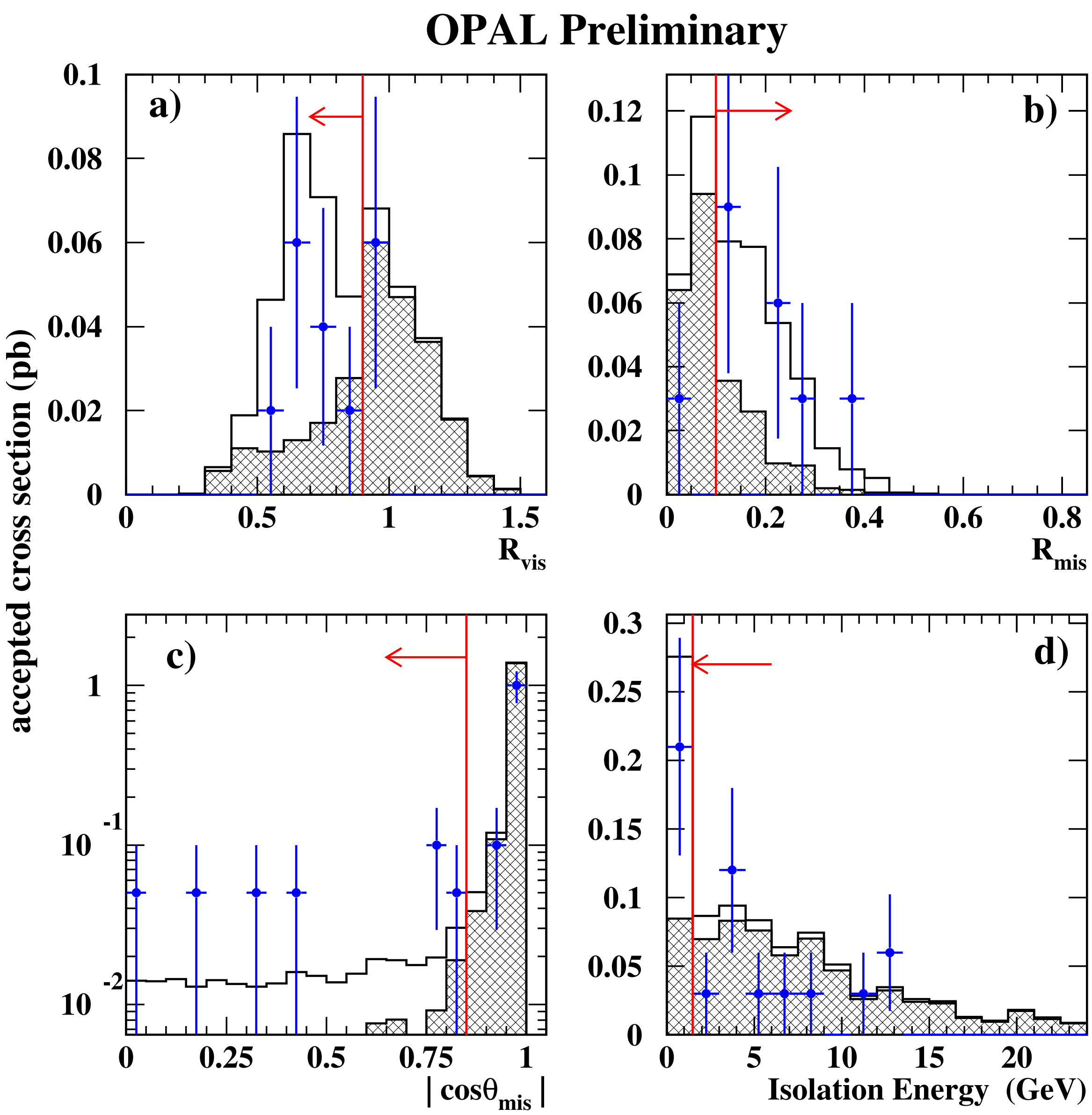
- $\mathrm{q},\overline{\mathrm{q}}$ are most back-to-back
- τ jet isolated, 1 or 3 tracks in 10° cone.
- Other cuts as for e, μ Some tighter

$\boxed{\mathrm{W^+W^-} \rightarrow \ell^-\overline{\nu}_\ell \ell'^+\nu_{\ell'}}$

2 acoplanar “jets”, low multiplicity, missing momentum

- 2 charged, ≤ 1 neutral cone jets
- Veto against forward muons, jets of same charge, ISR photons
- Jets well-contained, acollinear, acoplanar
- Kinematic cuts on $\sum p_T$, $E_{\mathrm{jet}}\ldots$specific to final state (ee, $\mu\mu$, $\tau\tau$, $\mathrm{e}\mu$, $\mathrm{e}\tau$, $\mu\tau$)
- 3-jet selection allows $\ell^-\overline{\nu}_\ell \ell'^+\nu_{\ell'}(\gamma)$

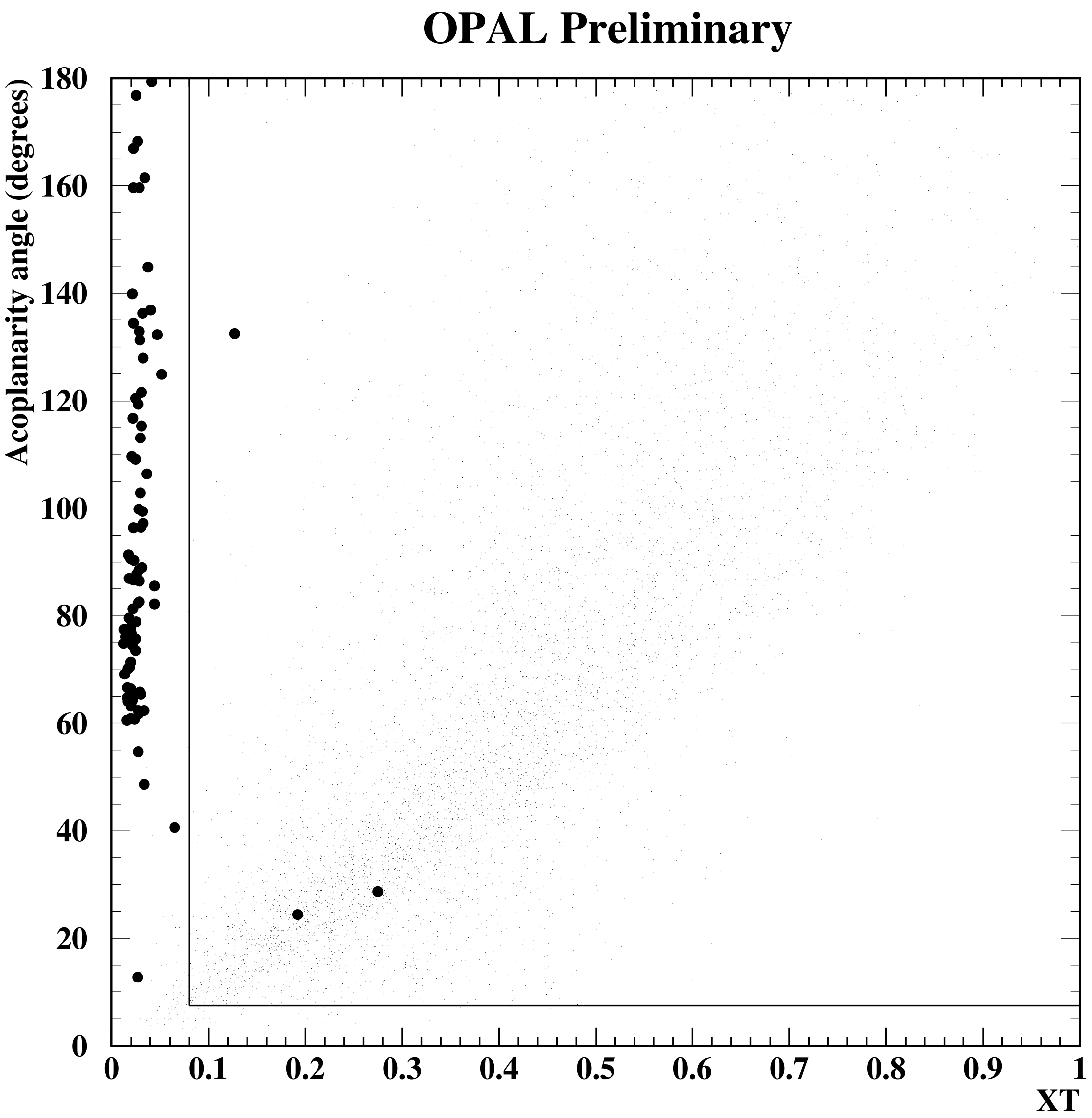
$W^+W^- \to q\bar{q}\tau\bar{\nu}_\tau$ event selection



- Each quantity shown after all other cuts
- Data points have arbitrary normalisation

$W^+W^- \to \ell^-\overline{\nu}_\ell \ell'^+\nu_{\ell'}$ event selection

Acoplanarity vs. $\sum p_T / E_{\mathrm{beam}}$:



- Select one $\mu^-\mu^+$ and one $e^-\mu^+$ overall

Results

Channel	Efficiency (%)	Expected signal events	Expected bgnd. events	Observed events
$\mathrm{q\bar{q}q\bar{q}}$	56.7 ± 1.4	9.79 ± 0.24	3.47 ± 0.77	14
$\mathrm{q\bar{q}e}\overline{\nu}_\mathrm{e}$	70.3 ± 2.1	4.01 ± 0.12	0.37 ± 0.16	3
$\mathrm{q\bar{q}}\mu\overline{\nu}_\mu$	74.3 ± 2.5	4.31 ± 0.13	0.15 ± 0.07	2
$\mathrm{q\bar{q}}\tau\overline{\nu}_\tau$	39.8 ± 1.8	2.20 ± 0.10	1.11 ± 0.75	7
$\ell\overline{\nu}_\ell\bar{\ell}\nu_\ell$	66.3 ± 1.8	2.66 ± 0.07	$0.20^{+0.12}_{-0.04}$	2
Combined	60.7 ± 0.9	23.0 ± 2.6	5.3 ± 1.1	28

Systematic uncertainties in expected signal

W mass	80.33 ± 0.15 GeV*	8.5%
Beam energy	80.65 ± 0.10 GeV	6.0%
MC model		2.6%
Selection efficiency		1.5%
Luminosity	10.17 ± 0.27 pb^{-1}	2.7%
Total		11.2%

* Prior to summer conferences

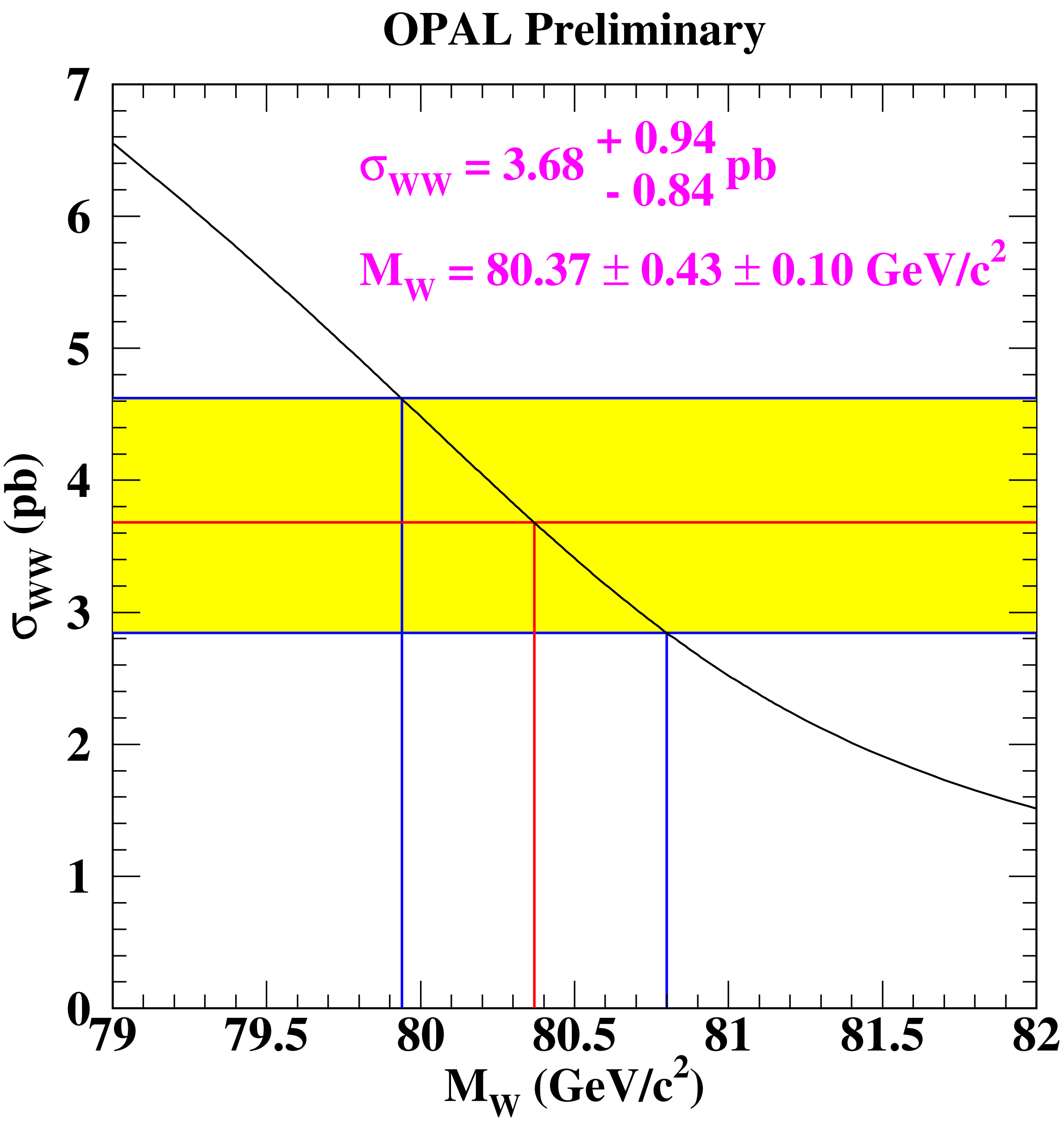
Cross-section and mass measurements

- $e^+e^- \rightarrow W^+W^-$ cross-section at $\sqrt{s}$=161.3 GeV

$$\sigma_{WW} = 3.68^{+0.94}_{-0.84} \text{ pb}$$

- Corresponds to CC03 diagrams
- GENTLE program $\longrightarrow$ M_W from cross-section
- Assume no significant variation of acceptance with M_W

W mass

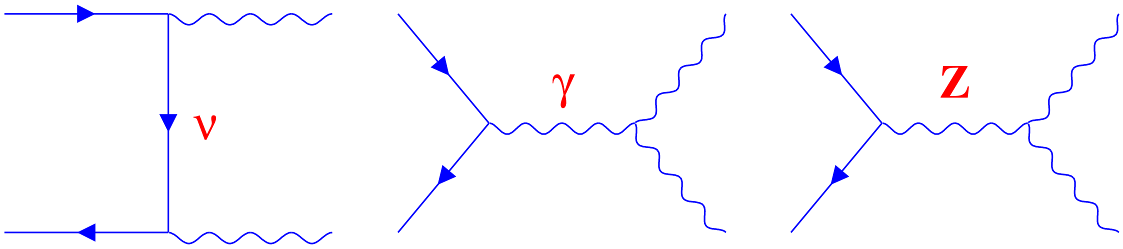


- 1^{st} uncertainty dominated by statistics
- 2^{nd} uncertainty from LEP beam energy

Triple Gauge Boson Couplings

- Couplings affect total cross-section and angular distributions

- $\mathrm{e^+e^-} \longrightarrow \mathrm{W^+W^-}$ diagrams:



	$\mathrm{WW}\gamma$ vertex	WWZ vertex
	2 coupling constants	7 coupling constants
	$x_\gamma\,,\, y_\gamma$	$\delta_\mathrm{Z}\,,\, x_\mathrm{Z}\,,\, y_\mathrm{Z}$ etc.

- Coupling constants zero in SM, non-zero if anomalous

- Highest sensitivity in $\alpha_{W\phi}$ model:

$$\alpha_{W\phi} = x_\gamma = \delta_z \sin\theta_w \cos\theta_w \qquad \text{varies}$$
$$x_z = -x_\gamma \sin\theta_w / \cos\theta_w$$

all other constants zero

[In general $x_\gamma \equiv \Delta\kappa_\gamma$]

TGC from total event yield

- Cross-section measurement uses efficiency estimate,

  efficiency depends on x_γ

  $\Longrightarrow$ compare number of events

- Expected number of events derived from MC samples:

  - $\alpha_{W\phi}$ model
  - $x_\gamma = 0, \pm 1, \pm 2$
  - full detector simulation

- Include systematics in prediction,

  - M_{W}
  - beam energy
  - MC models
  - efficiency
  - luminosity

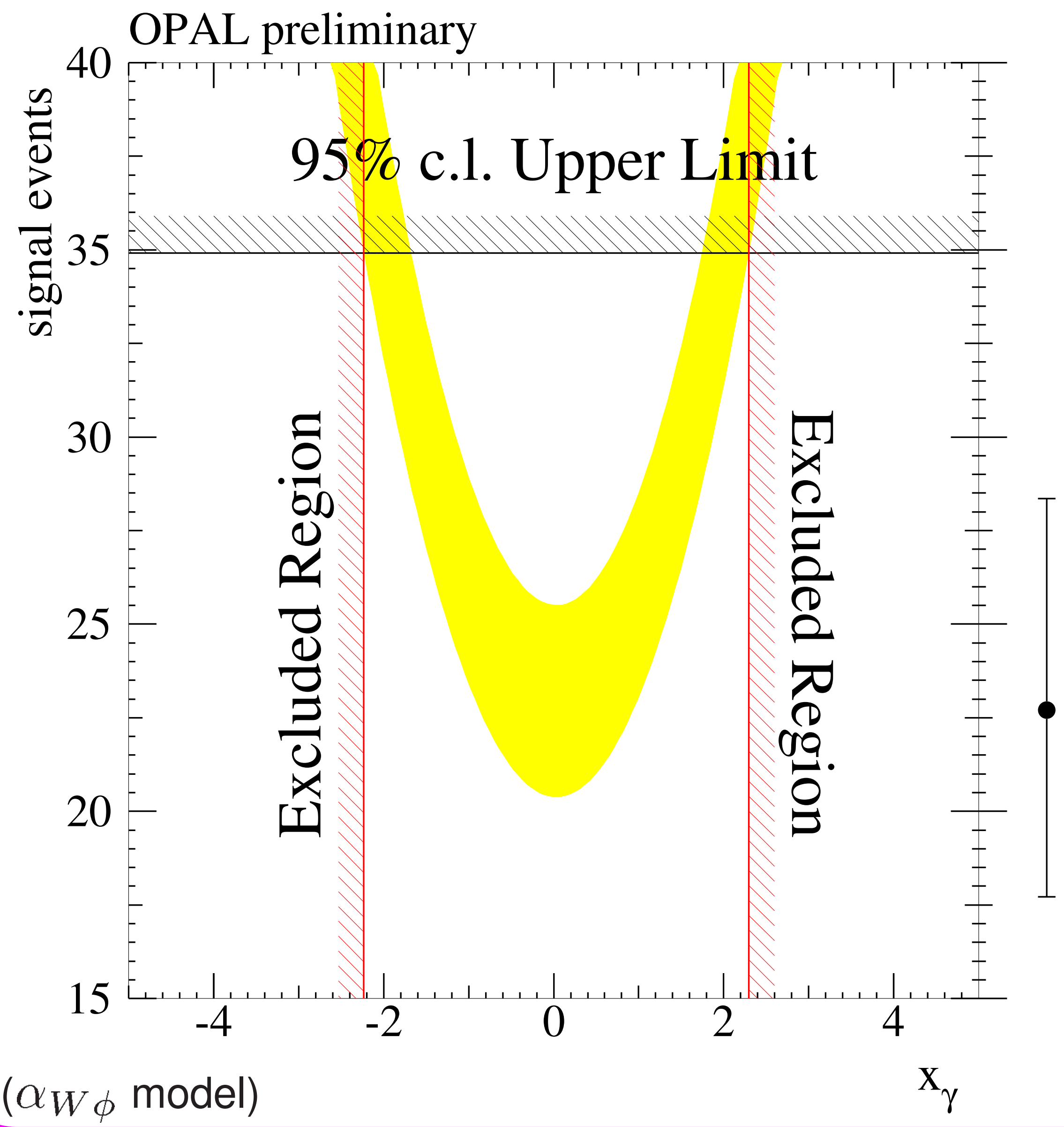
TGC from total event yield

- Observe 28 W^+W^- candidates, expect 5.3$\pm$1.1 background

  $\Rightarrow$ N(signal) $<$ 34.9 @ 95% c.l.

- Compare with expectation, including systematics.

$$\boxed{-2.2 < x_\gamma < 2.3}$$ @ 95% c.l.



($\alpha_{W\phi}$ model)

Summary

- $\sim 10\ \mathrm{pb}^{-1}$ data at $\sqrt{s} = 161.3$ GeV
  $\Rightarrow$ first observations of $\mathrm{e^+e^-\to W^+W^-}$

- Observe 28 events, expect $\left\{ \begin{array}{l} 23.0\pm2.6\ \mathrm{W^+W^-} \\ 5.3\pm1.1\ \text{background} \end{array} \right.$

- Preliminary measurements:

$$\sigma_{\mathrm{WW}} = 3.68^{+0.94}_{-0.84}\ \text{pb}$$
$$M_{\mathrm{W}} = 80.37 \pm 0.43 \pm 0.10\ \text{(LEP) GeV}$$
$$-2.2 < x_\gamma < 2.3 \qquad \text{@ 95\% c.l.}$$

  in agreement with Standard Model

- Combination of 4 LEP experiments will give

$$\Delta M_{\mathrm{W}} \simeq 240\ \text{MeV} \qquad \text{from 161 GeV data}$$
$$\Delta M_{\mathrm{W}} \simeq 35\text{-}45\ \text{MeV} \qquad \text{from LEP2}$$

- Many other measurements will be possible !