WWhats New from OPAL?

Results at $\sqrt{s}$ = 161 GeV

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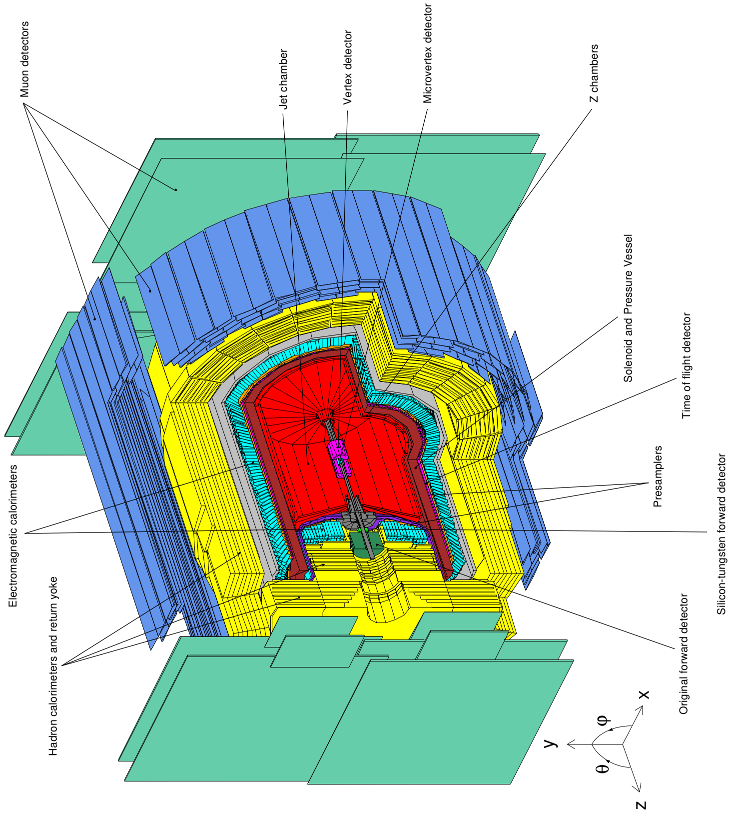
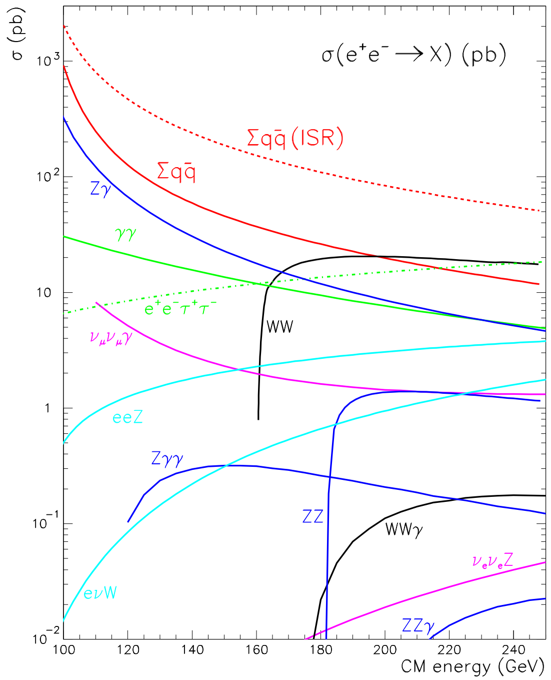
OUTLINE

- Aspects of fermion pair production
- QCD: α_s, Event shapes and all that
- Neutral Current 4-fermion production
- $\mathrm{W^+W^-}$ at threshold (TGC and M_W)
- SM Higgs: (Bjorken on the Shell)
- Synopsis of LEP's High Energy Operation

The OPAL Detector



A Brave New World

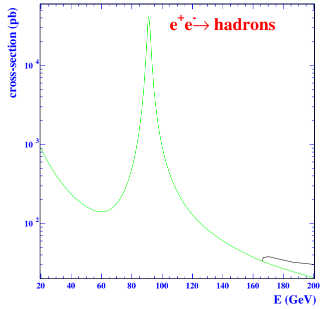


- Life on the Z^0 was a lot simpler:
  - Much larger cross section for events of interest
  - Non-Z^0 processes highly suppressed
- Emergence of Charged and Neutral Current 4-fermion final states $\Longrightarrow$ much more complicated

Fermion Pair Production above the Z^0

- Cross sections are now *highly* suppressed

$$\sigma(\sqrt{s} = 2m_{\mathrm{W}}) \sim 10^{-3}\sigma(\sqrt{s} = m_{\mathrm{Z}})$$



$\sigma \propto 1/s$

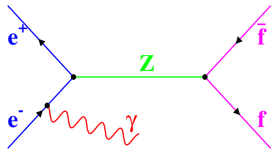
No ISR corrections

- Effective CM energy s' variable due to large ISR effects

Rising edge of Z^0 is no longer a natural cutoff

$\Longrightarrow$ 2 main classes of events:

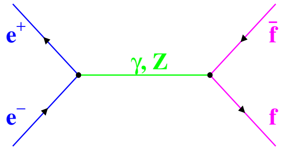
"Radiative return"



$\sqrt{s'} \simeq m_{\mathrm{Z}}$

"Old Physics"

Non-radiative

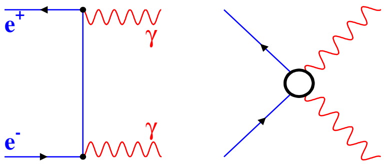


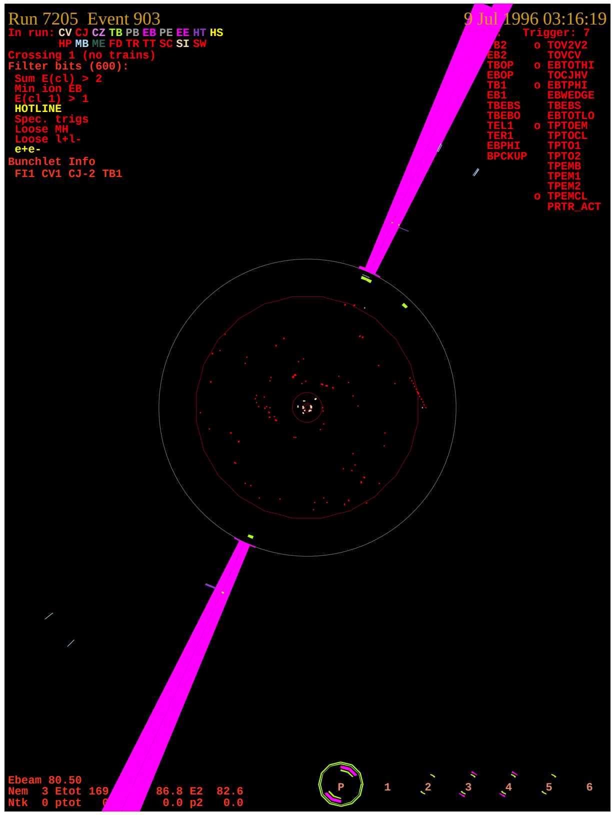
$\sqrt{s'} \simeq \sqrt{s}$

"New Physics"

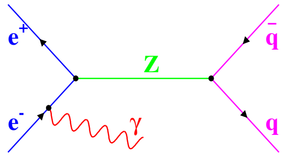
- Cross sections dominated by "radiative return" to the Z^0

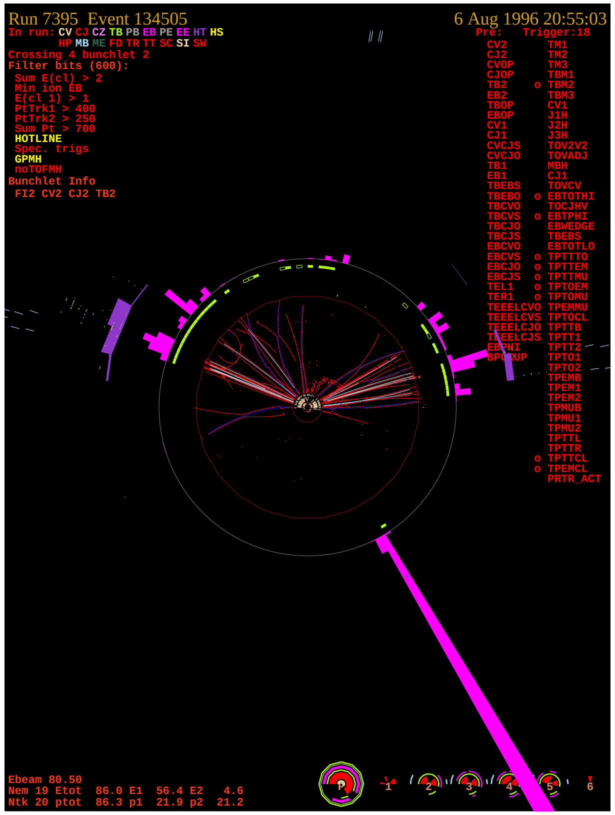
First Gauge Boson Pair at LEP2





Radiative Return Event





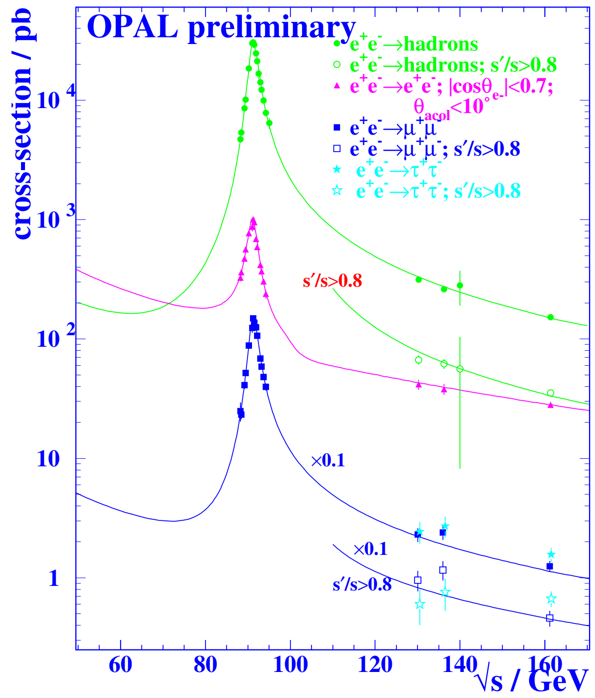
Fermion Pair Production

- Measure
  - Inclusive σ $(s'/s > 0.01)$
  - Non-radiative σ $(s'/s > 0.8)$
- Effective CM energy, s', from observed ISR γ and kinematic fit which allows for 0–2 missing γ
- Select hadrons $\mathrm{q\bar{q}}(\gamma)$, charged leptons $\ell^+\ell^-(\gamma)$, photons $\nu\bar{\nu}(\gamma)$
- Results based on $10.0\ \mathrm{pb}^{-1}$ integrated luminosity

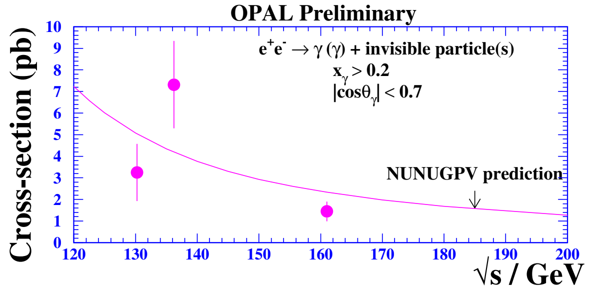
2 fermions	σ (pb)	σ^{SM} (pb)
Hadrons $(s'/s > 0.01)$	152±4±2	149
Hadrons $(s'/s > 0.8)$	35.3±2.0±0.7	33.2
$\mathrm{e^+e^-}$ $(\lvert\cos\theta_{e^-}\rvert < 0.7)$	28.1±1.7±0.2	28.1
$\mathrm{e^+e^-}$ $(\lvert\cos\theta\rvert < 0.96)$	435±7±6	424
$\mu^+\mu^-(s'/s > 0.01)$	12.5±1.2±0.5	11.3
$\mu^+\mu^-(s'/s > 0.8)$	4.6±0.7±0.2	4.5
$\tau^+\tau^-(s'/s > 0.01)$	15.7±2.0±0.7	11.3
$\tau^+\tau^-(s'/s > 0.8)$	6.7±1.0±0.3	4.5
$\nu\bar{\nu}(\gamma)$ $(\lvert\cos\theta_\gamma\rvert < 0.7)$	1.4±0.5	2.3

- Electrons have $\theta_{\mathrm{acol}} < 10^\circ$
- "Neutrinos" have $x_\gamma > 0.2$ and $\lvert\cos\theta_\gamma\rvert < 0.7$
- Data consistent with Standard Model

$\sqrt{s}$ Dependence of σ

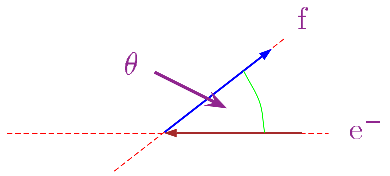


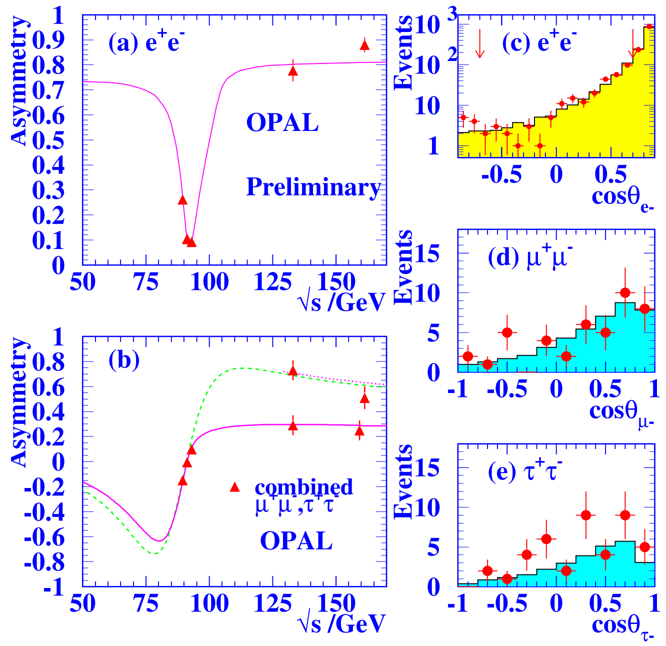
Agree with SM predictions, ZFITTER, ALIBABA



$\sqrt{s}$ Dependence of Asymmetries

- Define $\mathrm{A_{FB}} = \dfrac{\mathrm{N^+ - N^-}}{\mathrm{N^+ + N^-}}$ where $\mathrm{N^+}$ is the number of forward scattered fermions, $q_\mathrm{f} \cos\theta_\mathrm{f} > 0$



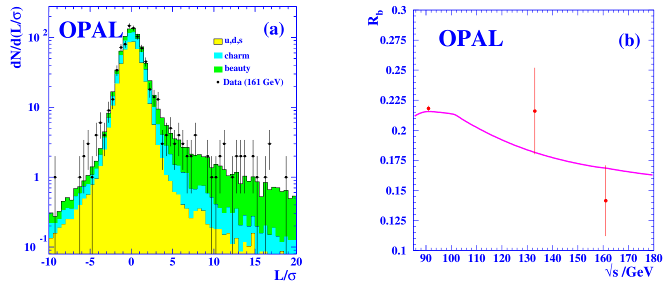


$\sqrt{s}$ Dependence of R_b

- Event Selection:
  - Non-radiative event, $s'/s > 0.8$
  - At least 7 well measured charged tracks
  - $|\cos\theta_T| < 0.9$
  - Require 3-prong vertex with $L/\sigma_L > 3$
- Folded tag technique: use vertices with $L/\sigma_L < -3$ to estimate light quark background $(\mathrm{u, d, s})$
- Rely on MC to estimate $\mathrm{b, c}$ efficiencies

$$N_t - \overline{N}_t = 2N_{had}\ [(\epsilon_\mathrm{b} - \overline{\epsilon}_\mathrm{b})R_\mathrm{b} + (\epsilon_\mathrm{c} - \overline{\epsilon}_\mathrm{c})R_\mathrm{c} + (\epsilon_\mathrm{uds} - \overline{\epsilon}_\mathrm{uds})(1 - R_\mathrm{b} - R_\mathrm{c})]$$

- 326 non-radiative events: 76 forward, 24 backward tags



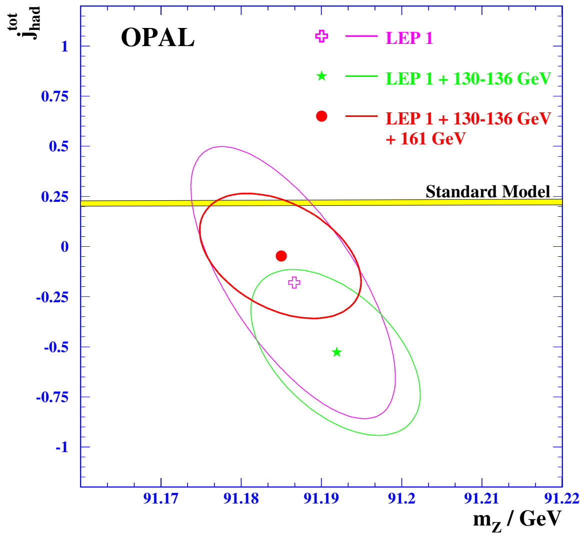
$$\boxed{R_\mathrm{b}(\sqrt{s} = 161\ \mathrm{GeV}) = 0.141 \pm 0.028 \pm 0.012}$$

Precision Electroweak Physics

Tree-level hadronic cross section consists of 3 terms:

$$\sigma_{q\bar{q}}(\sqrt{s}) = \frac{A_\gamma}{s} + \frac{A_{\gamma Z}(s - m_Z^2) + A_Z s}{(s - m_Z^2)^2 + s^2 {\Gamma_Z}^2 / m_Z^2}$$

- Standard lineshape fits fix relative sizes of A_γ, $A_{\gamma Z}$, A_Z
- Model independent "S-matrix" approach $A_{\gamma Z} \Longrightarrow \mathrm{j}_{\mathrm{had}}^{\mathrm{tot}}$ which is allowed to float.
- m_Z and $\mathrm{j}_{\mathrm{had}}^{\mathrm{tot}}$ are highly correlated $\Longrightarrow$ larger m_Z error
- LEP$1.5 + 2$ data reduces $\mathrm{j}_{\mathrm{had}}^{\mathrm{tot}}$ error from 0.68 to 0.31 and correlation with m_Z from -0.70 to -0.41

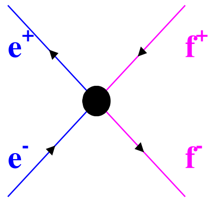


...Precision Electroweak Physics

OPAL data set	$\mathrm{j}_{\mathrm{had}}^{\mathrm{tot}}$	m_Z (GeV)
LEP1 (1989-92)	-0.18 ± 0.68	91.187 ± 0.013
LEP1+1.5	-0.53 ± 0.41	91.192 ± 0.011
LEP1+1.5 + 2	-0.05 ± 0.31	91.185 ± 0.010

- Standard Model value fixes $\mathrm{j}_{\mathrm{had}}^{\mathrm{tot}} = 0.216$ for $m_H = 300$ GeV, $m_t = 180$ GeV
- New LEP2 data reduces $\mathrm{j}_{\mathrm{had}}^{\mathrm{tot}}$-$m_Z$ correlation from -0.70 to -0.41
- Observed improvement much greater than effect of 1993-95 LEP 1 data
- Fits to m_Z assume a s-dependent Z^0 width

Four Fermion Contact Interactions



- Sensitive to new physics at mass scale Λ described by an effective $\mathcal{L}$agrangian:

$$\mathcal{L} = \frac{g^2}{\Lambda^2} \sum_{i,j=L,R} \eta_{ij}[\bar{e}_i\gamma^\mu e_i][\bar{f}_j\gamma_\mu f_j]$$

- 6 different models LL, RR, VV, AA, LR, RL where $\eta_{ij} = \pm 1 \Longrightarrow$ full $\pm$ive interference with SM
- Analgous to Fermi's original description of the weak interaction as VV with $\Lambda \sim m_{\mathrm{W}}$
- Select non-radiative $\mathrm{f\bar{f}}$ events with $s'/s > 0.8$
- Fit angular distributions for postive and negative interference with SM amplitudes

$$\frac{d\sigma}{d\cos\theta} = \mathrm{SM}^\circ(s,t) + C_2^0(s,t)\frac{1}{\Lambda^2} + C_4^0(s,t)\frac{1}{\Lambda^4}$$

Four Fermion Contact Interactions

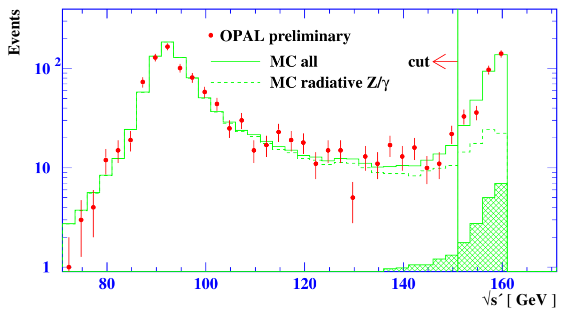
- Results include data at $\sqrt{s} = 136$ GeV and 161 GeV
- By convention $g^2/4\pi = 1$

Channel	Model	λ	Λ^-	Λ^+
$e^+e^- \to e^+e^-$	VV	5.3	4.4	5.3
	AA	3.8	2.2	4.0
	LL	2.6	2.2	2.4
	RR	2.6	2.2	2.4
	LR	3.2	2.9	2.5
$e^+e^- \to \ell^+\ell^-$	VV	6.2	6.6	4.9
	AA	5.2	5.0	4.4
	LL	3.5	3.8	2.7
	RR	3.3	3.6	2.6
	LR	3.2	3.2	2.7
$e^+e^- \to q\bar{q}$	VV	4.1	3.3	2.9
	AA	3.9	2.8	3.5
	LL	3.2	2.1	2.5
	RR	2.8	2.3	2.1
	LR	2.9	2.2	2.1
	RL	2.9	2.6	2.1
Combined	VV	6.3	6.5	5.1
	AA	5.7	5.3	5.0
	LL	4.0	4.0	3.4
	RR	3.3	3.5	2.8
	LR	3.0	3.1	2.8
	RL	3.2	3.5	2.6

- λ (sensitivity), Λ^-, Λ^+ in TeV
- Improvements up to $\mathcal{O}(1\,\mathrm{TeV})$ over LEP-1 for some channels

Properties of Hadronic Events

- New energy scale at which to test QCD
- Verify effects from running of α_s via QCD observables
  - Event Shapes
  - Jet Rates
  - Inclusive particle distributions
- Only non-radiative events are interesting
- Use tighter selection than for $\sigma_{\mathrm{q\bar{q}}}$
  require $\sqrt{s} - \sqrt{s'} < 10$ GeV
- Select 307 events at $\sqrt{s} = 161$ GeV
- Expect $\sim 6\%$ 4-fermion background (NC and $\mathrm{W^+W^-}$)



QCD: Event Shapes

Thrust T:

$$T = \max_{\vec{n}} \left(\frac{\sum_i |p_i \cdot \vec{n}|}{\sum_i |p_i|} \right) \tag{1}$$

where $\vec{n}_T$ defines the Thrust axis

Thrust major T_{maj}: Maximize eqn, 1 with $\vec{n}$ perpendicular to $\vec{n}_T \Longrightarrow \vec{n}_{T_{\mathrm{maj}}}$

Thrust minor T_{min}: Maximize eqn. 1 with $\vec{n}$ perpendicular to $\vec{n}_T$ and $\vec{n}_{T_{\mathrm{maj}}} \Longrightarrow \vec{n}_{T_{\mathrm{min}}}$

Oblateness O: Defined as $O = T_{\mathrm{maj}} - T_{\mathrm{min}}$

Sphericity S and Aplanarity A: Based on the eigenvalues Q_j of momentum tensor:

$$S^{\alpha\beta} = \frac{\sum_i p_i^\alpha p_i^\beta}{\sum_i p_i^2}, \quad Q_1 < Q_2 < Q_3$$

$$S = \frac{3}{2}(Q_1 + Q_2) \quad \text{and} \quad A = \frac{3}{2} Q_1$$

C-parameter C: Based on eigenvalues, λ_j, of the linearised $S^{\alpha\beta}$

$$\Theta^{\alpha\beta} = \frac{\sum_i (p_i^\alpha p_i^\beta)/|p_i|}{\sum_i |p_i|}$$

$$C = 3(\lambda_1\lambda_2 + \lambda_2\lambda_3 + \lambda_3\lambda_1)$$

...QCD: Event Shapes

Heavy Jet Mass M_H: Define hemispheres H_k via plane perpendicular to $\vec{n}_T$

$$M_H = \frac{\max(M_{H_k})}{\sqrt{s}}$$

Jet Broadening B_T and B_W: For each hemisphere k,

$$B_k = \left(\frac{\sum_{i \in H_k} |p_i \times \vec{n}_T|}{2 \sum_i |p_i|} \right)$$

the two observables are

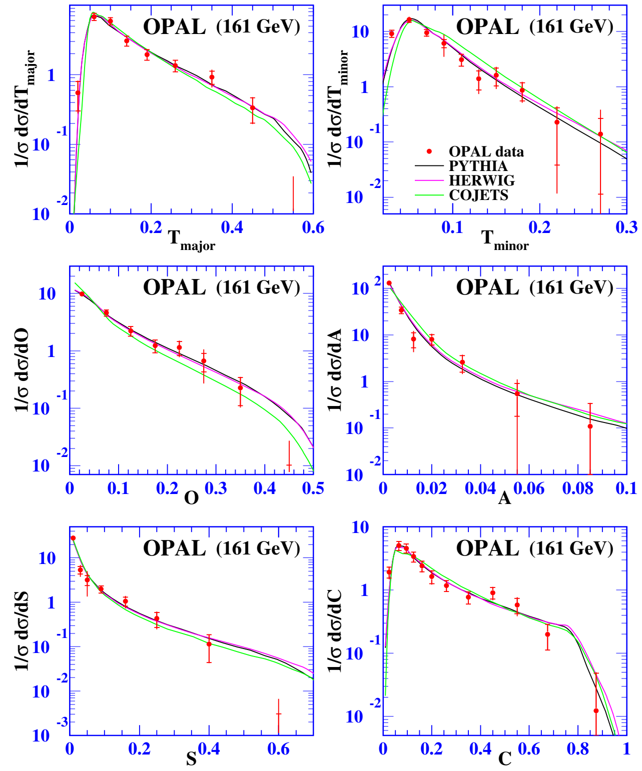
$$B_T = B_1 + B_2 \quad \text{and} \quad B_W = \max(B_1, B_2)$$

where B_T is the total and B_W is the wide jet broadening.

Corrections to Distributions

- Subtract Monte Carlo expection for 4-fermion processes from observed distributions
- Perform bin-by-bin correction to hadron level, accounting for ISR, detector response by using ratio of fully simulated to generated events

...QCD: Event Shapes



- Compare three types of fragmentation scheme
  - String: PYTHIA
  - Cluster: HERWIG
  - Independent: COJETS

Jet Finding

- Recombination Type Schemes:

  Combine "particles" with smallest scaled invariant masses

$$y_{ij} = \left(\frac{M_{ij}}{E_{\rm vis}}\right)^2$$

  until no pairing has $y_{ij} > y_{\rm cut}$

  – JADE E0 Scheme:
  $M_{ij}^2 = 2E_iE_j(1 - \cos\theta_{ij})$

  – Durham D Scheme:
  $M_{ij}^2 \equiv 2\min(E_i^2, E_j^2) \cdot (1 - \cos\theta_{ij})$

- Cone Algorithm:

  – Jet defined as a set of particles within a cone of $1/2$ angle R defined by $\sum \vec{p_i}$ with total energy $> \varepsilon$

  – Vary R for $\varepsilon = 7$ GeV

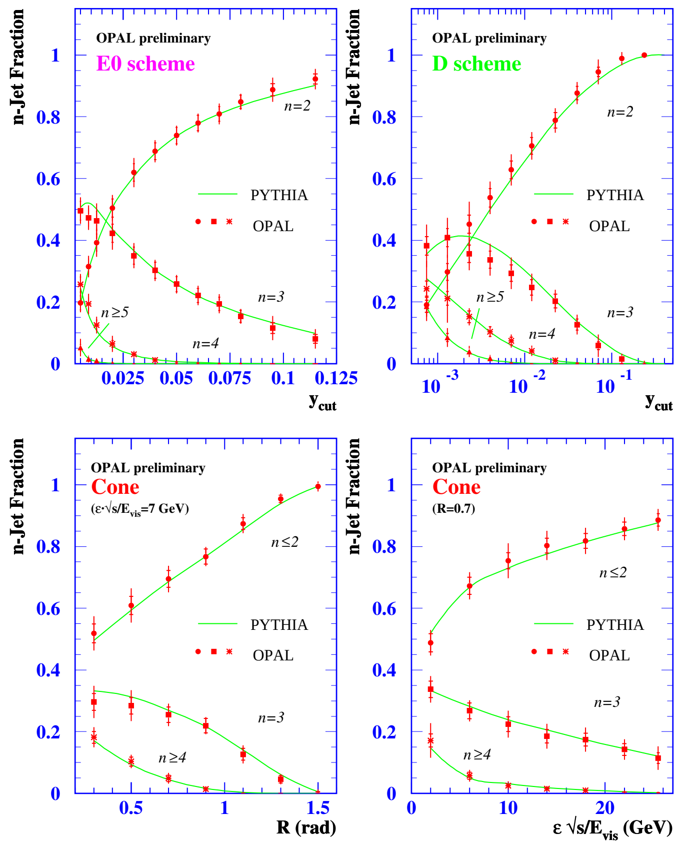
  – Vary ε for $R = 0.7$ radians

- Measure:

  – $R_2 \equiv$ the two-jet rate

  – $D_2 \equiv \dfrac{dR_2}{dy_{\rm cut}}$

Jet Rates



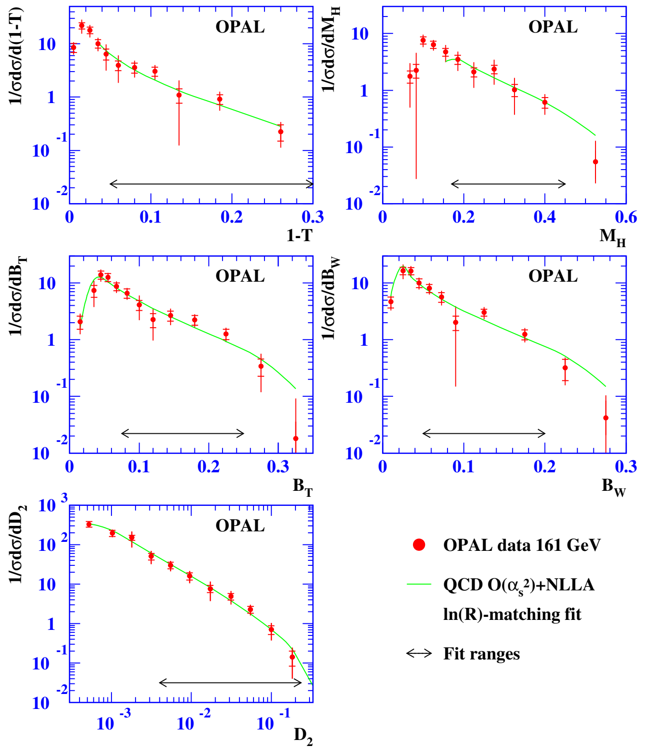
- Measured for JADE E0, Durham and cone schemes

- All jet fractions described by QCD MC (bins correlated)

Measurement of α_s

- Fit to $\mathcal{O}(\alpha_s^2)$ + NLLA QCD predictions of 5 event shape variables corrected to hadron level

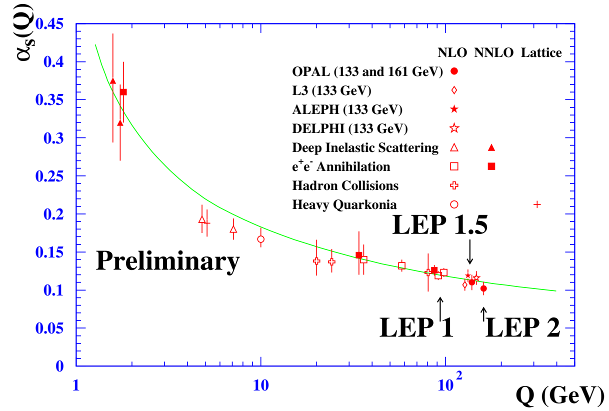
Preliminary



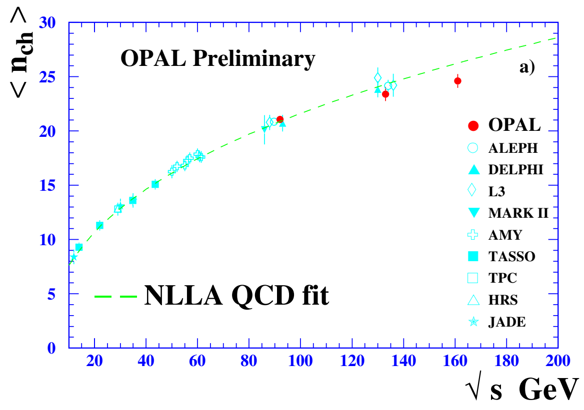
$$\alpha_s(161\mathrm{GeV}) = 0.102 \pm 0.005(\mathrm{stat.}) \pm 0.007(\mathrm{syst.})$$

Energy Evolution

α_s

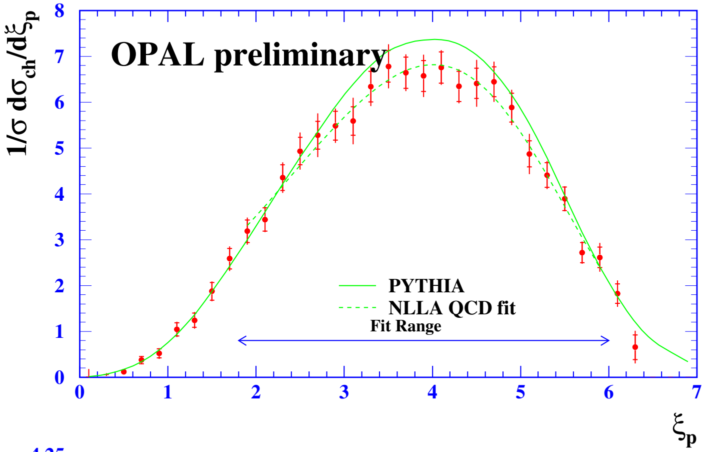


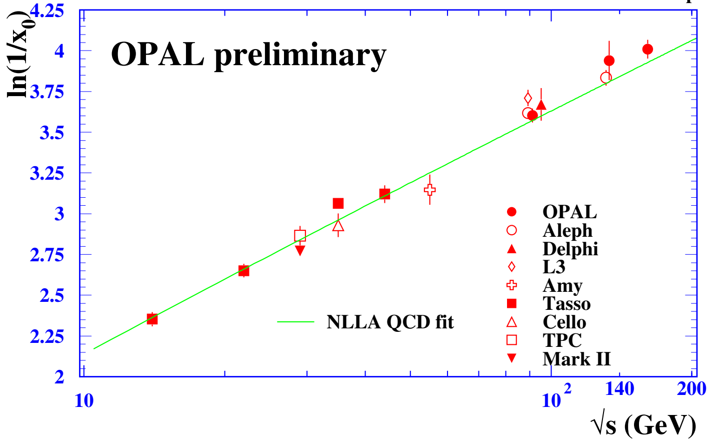
N_{ch}



$$< N_{ch} >= 24.6 \pm 0.4(\mathrm{stat.}) \pm 0.5(\mathrm{syst.})$$
$$R_2 = 1.058 \pm 0.008 \pm 0.007$$

Fragmentation Function



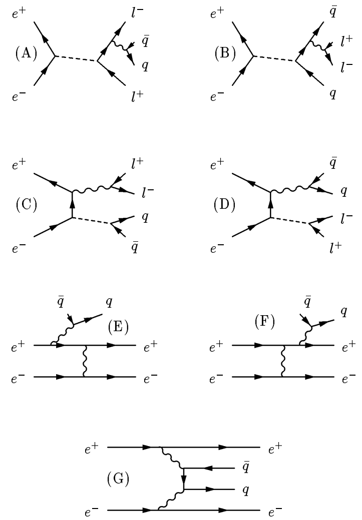


Evolution of peak position predicted by NLLA QCD

$$\xi_0 = 4.01 \pm 0.04(\mathrm{stat.}) \pm 0.04(\mathrm{syst.})$$

Neutral Current 4-Fermion Processes

Schematic Feynman diagrams for $\mathrm{e^+e^-} \rightarrow \ell^+\ell^-\mathrm{q\overline{q}}$



- (A,B) Annihilation: “important” at $\sqrt{s} = m_\mathrm{Z}$
- (C,D) Conversion: dominates for on-shell Z^0
- (E,F) Bremsstrahlung:
- (G) Multiperipheral:

Neutral Current 4-Fermion Processes

OPAL reported an 'Excess' of $\ell^+\ell^-\mathrm{q\bar{q}}$ at LEP1.5

Phys.Lett.**B376** (1996) 376

- High multiplicity channel: $\ell^+\ell^-\mathrm{q\bar{q}}$

  6 charged tracks, ≥ 2 jets, $E_{\mathrm{vis}} > 0.35\sqrt{s}$

  Extend analysis to include $\tau^+\tau^-\mathrm{q\bar{q}}$ channel

  – 2-charged leptons

    $p_\ell > 5$ GeV, $\sum p_\ell > 15$ GeV, $p_{max} < 30$ GeV (τ)

    Transverse mass $M_T > 1(4)$ GeV for $\mathrm{e}(\tau)$

    Electrons: $E/p > 0.8, \mathrm{P(dE/dx)} > 1\%$

    Muons: $E/p < 0.2$, 3 hits in HCAL or muon chambers

    Taus: Accept 1-prong hadronic decays

  – Isolation criteria:

    Require at least 1 ℓ with $\alpha > 30°(45°)$

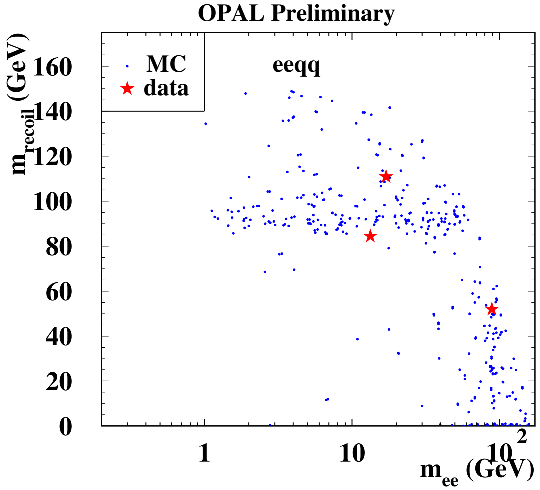
    1 ℓ with $\alpha > 10°(30°)$

Channel	Expected signal	bgnd.	total	Obs.
$\mathrm{e^+e^-q\bar{q}}$	0.71	0.12	0.83	3
$\mu^+\mu^-\mathrm{q\bar{q}}$	0.78	0.13	0.91	0
$\tau^+\tau^-\mathrm{q\bar{q}}$	0.03	0.06	0.09	0
Total	1.5	0.3	1.83	3

- Accounting for systematics expect 1.8 ± 0.3 events:

  1.5 ± 0.3 signal, 0.3 ± 0.1 background

Neutral Current 4-Fermions Processes

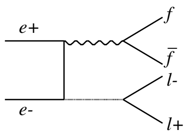


- For $\mathrm{e^+e^-q\bar{q}}$ and $\mu^+\mu^-\mathrm{q\bar{q}}$ channels:

$$m^2_{\mathrm{recoil}} = (1 - 2E_{\ell\ell}/\sqrt{s})\, s + m^2_{\ell\ell}$$

Conversion dominates $\ell^+\ell^-\mathrm{q\bar{q}}$

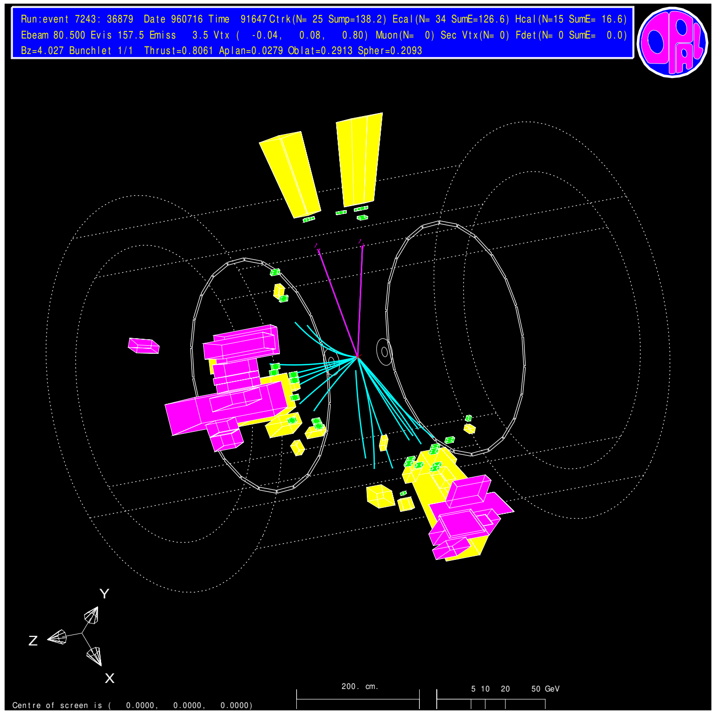
Recoil mass $\sim M_{Z^0}$



- 2 events consistent with $m_{\mathrm{q\bar{q}}} = m_{\mathrm{Z}}$

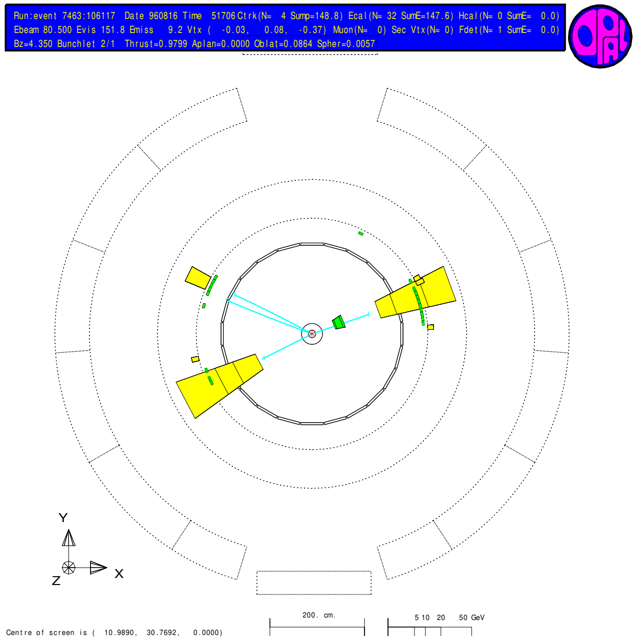
- 1 events consistent with $m_{ee} = m_{\mathrm{Z}}$

$\mathrm{e^+e^-q\overline{q}}$ Candidate



- $m(\mathrm{e^+e^-}) = 13.0 \pm 0.6$ GeV
- $m(\mathrm{q\overline{q}}) = 84.6 \pm 2.4$ GeV

$\ell^+\ell^-\ell'^+\ell'^-$ Candidate



- $m(\max) = 136 \pm 10$ GeV
- $m(\min) = 0.69 \pm 0.03$ GeV

Low Multiplicity 4-Fermion Study

- Low multiplicity channels: $\ell^+\ell^-\ell'^+\ell'^-$

	LEP1.5	161 GeV	sum
Expected	$1.6^{+0.2}_{-0.1}$	2.5 ± 0.3	4.1 ± 0.3
Observed	2	4	6
Probability	47.9%	25.5%	23.2%

High Multiplicity 4-Fermion Study

Channel	LEP1.5	161 GeV	sum
$e^+e^-q\bar{q}$ exp.	0.7 ± 0.1	0.8 ± 0.1	1.6 ± 0.3
observed	1	3	4
$\mu^+\mu^-q\bar{q}$ exp.	0.6 ± 0.1	0.9 ± 0.2	1.5 ± 0.2
observed	5	0	5
$\ell^+\ell^-q\bar{q}$ exp.	1.3 ± 0.2	1.7 ± 0.3	3.1 ± 0.5
observed	6	3	9
Probability	0.3%	25.5%	0.6%

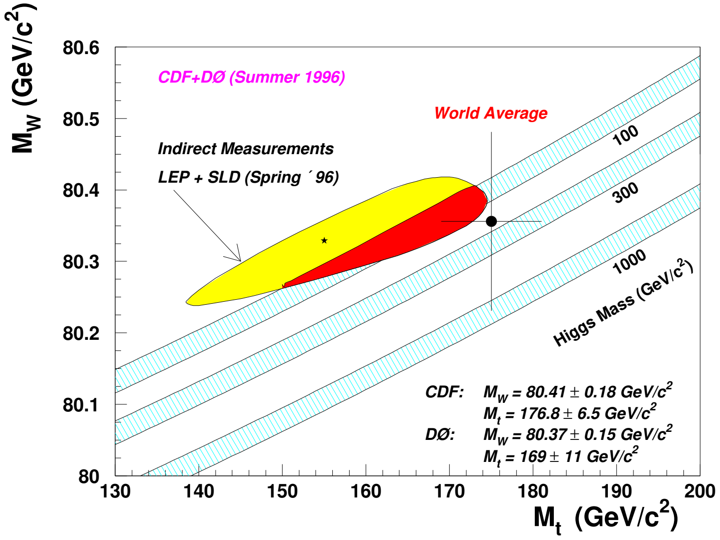
- Doubled total expected number of events
- No increase in significance of LEP1.5 'excess'

WWhat's the Attraction?

- Precise direct knowledge of m_{W} is the missing ingredient in the EW merry-go-round of radiative corrections

$$G_\mu = \frac{\alpha\pi}{\sqrt{2} m_{\mathrm{W}}^2 (1 - m_{\mathrm{W}}^2/m_{\mathrm{Z}}^2)} \frac{1}{(1 - \Delta r)}$$

- Given a precise enough m_{W} and m_{t} . . .

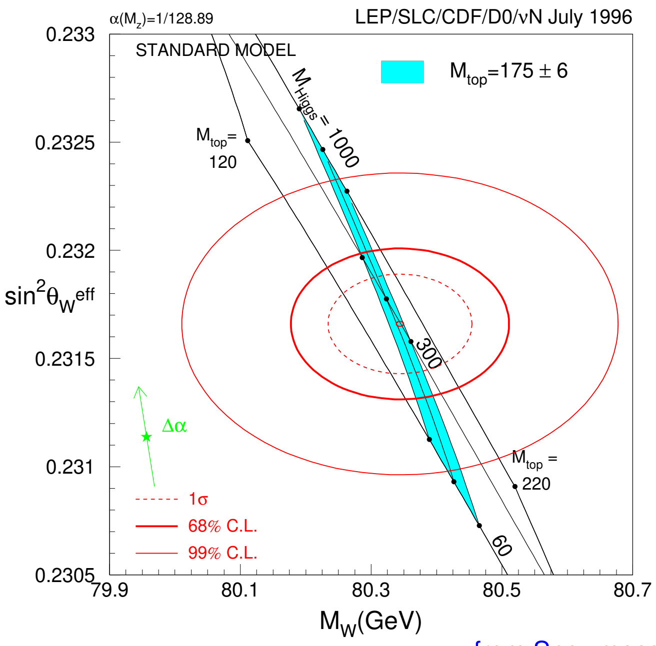


from Snowmass 96

- . . . useful constraints on the Higgs mass begin to emerge

WWhere is that Higgs?

- Combining all available Electroweak information . . .

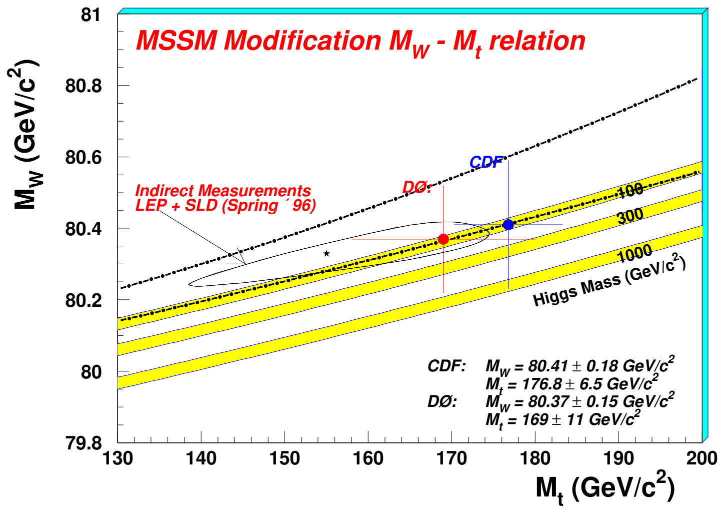


from Snowmass 96

$$\ldots m_{\mathrm{H}} = 149^{+148}_{-82}\ \ \mathrm{GeV}$$
$$m_{\mathrm{H}} < 550\ \ \mathrm{GeV},\ 95\%\ \mathrm{C.L}$$

WWhat about SUSY?

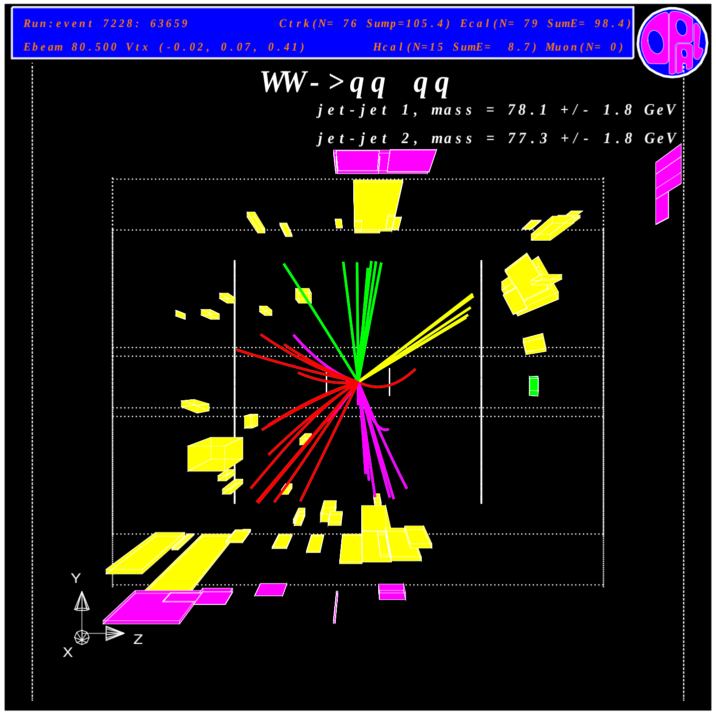
- WWho cares, but seriously . . .
- Given the MSSM with $\tilde{\mathrm{n}}$o particles discovered at LEP2 . . .



from Snowmass 96

- . . . MSSM constraints for $\sigma(m_{\mathrm{W}}) \sim 30$ MeV
- The trick is getting there

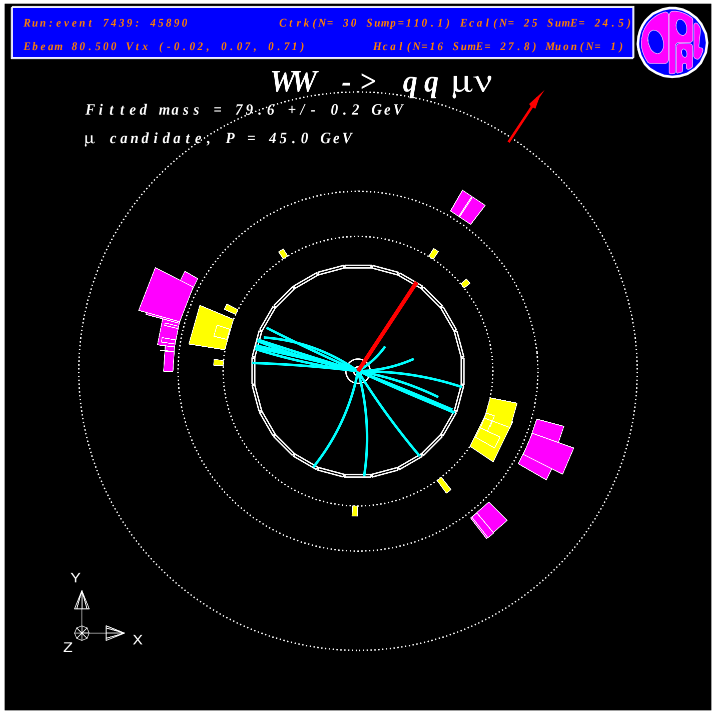
$\mathrm{W^+W^-} \rightarrow \mathrm{q\bar{q}q\bar{q}}$ Event Selection



4 hadronic jets, high multiplicity, large visible energy

- 4-jet like: $y_{34} > 0.01$, no hard ISR γ
- Kinematic fit with $E, \vec{p}$ conservation, $M_{\mathrm{W}_1} = M_{\mathrm{W}_2}$
  very loose cuts on $P_{\mathrm{fit}}(\chi^2)$, M_{fit}

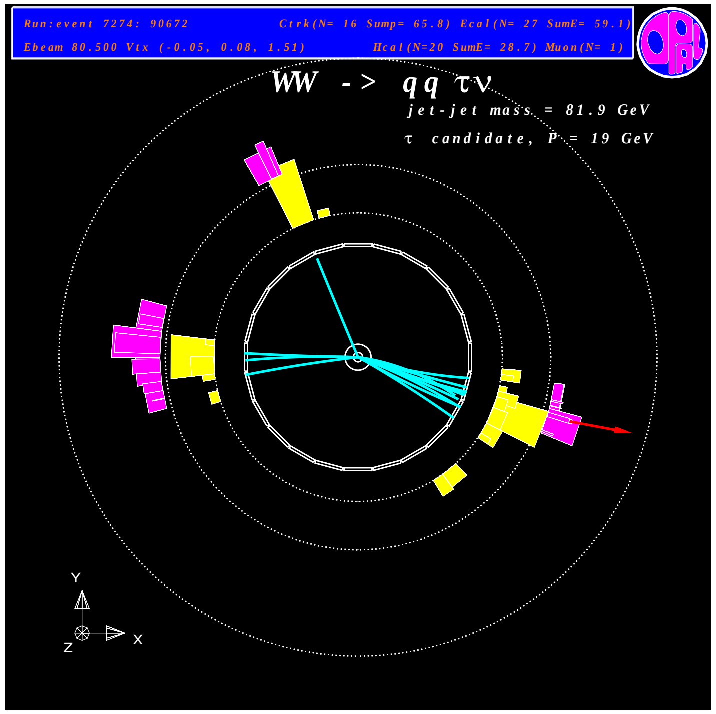
$\mathrm{W^+W^-} \rightarrow \mathrm{q\bar{q}}\ell\bar{\nu}_\ell$ Event Selection



2 hadronic jets, energetic $\ell^\pm$, missing momentum

- Isolated, high momentum e or μ
- 3-jet like: $y_{23} > 0.005$, no hard ISR γ
- significant missing P, $\sum p_T$, not forward

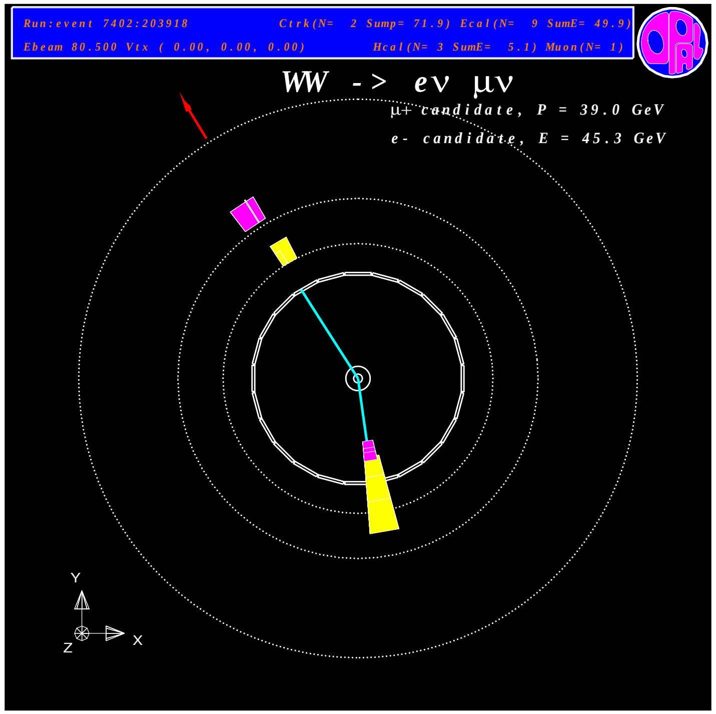
$W^+W^-\to q\bar{q}\tau\bar{\nu}_\tau$ Event Selection



3 jets (1 from τ), missing momentum

- most back-to-back jets $\Rightarrow$ q,$\bar{q}$
- τ jet isolated, 1 or 3 tracks in 10° cone.
- Other cuts similar to e, μ

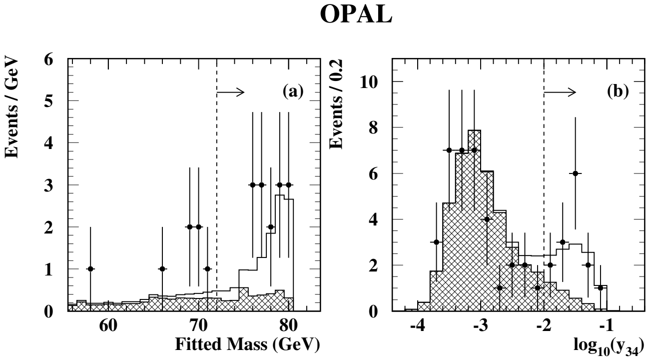
$W^+W^-\to \ell^-\bar{\nu}_\ell\ell'^+\nu_{\ell'}$ Event Selection



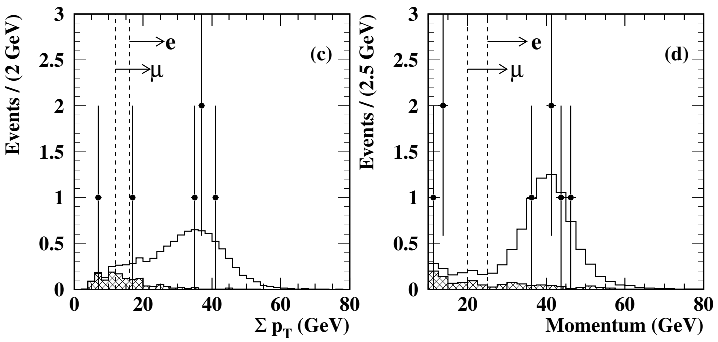
2 acoplanar "jets", low multiplicity, missing momentum

- Kinematic cuts on $\sum p_T$, $E_{\rm jet}\ldots$ specific to final state (ee, $\mu\mu$, $\tau\tau$, $e\mu$, $e\tau$, $\mu\tau$)
- 2 charged, ≤ 1 neutral cone jets, allows $\ell^-\bar{\nu}_\ell\ell'^+\nu_{\ell'}(\gamma)$
- veto forward $\mu^\pm$, net charge, ISR γ

W^+W^- Event Selection

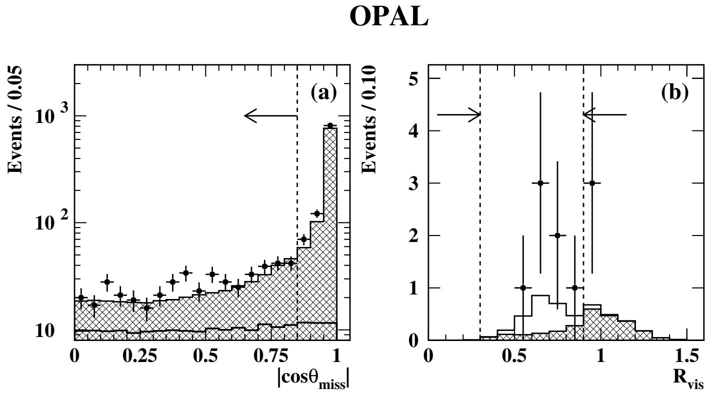


- $W^+W^- \to q\overline{q}q\overline{q}$: Kinematic Fit Mass and $\log y_{34}$

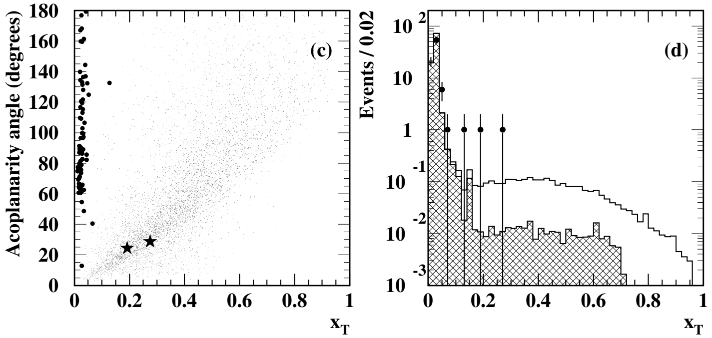


- $W^+W^- \to q\overline{q}\ell\overline{\nu}_\ell$: $\sum p_T$ and lepton momentum

W^+W^- Event Selection



- $W^+W^- \to q\overline{q}\tau\overline{\nu}_\tau$: $|\cos\theta_{\rm miss}|$ and $R_{\rm vis}$



- $W^+W^- \to \ell^-\overline{\nu}_\ell\ell'^+\nu_{\ell'}$: $x_T \equiv$ scaled $\sum p_T$ and acoplanarity angle ϕ_{acop}

W^+W^- Selection Summary

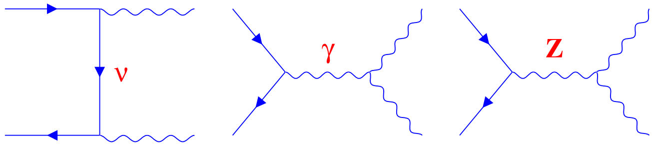
Selection efficiency good for all W^+W^- decay modes

Channel	ε (%)	Expected signal	bgnd.	total	Obs.
$q\overline{q}q\overline{q}$	57	9.6	3.4	13.0 ± 1.1	14
$q\overline{q}e\overline{\nu}_e$	71	3.9	0.2	4.1 ± 0.5	3
$q\overline{q}\mu\overline{\nu}_\mu$	77	4.2	0.2	4.5 ± 0.5	2
$q\overline{q}\tau\overline{\nu}_\tau$	42	2.3	1.0	3.2 ± 0.4	7
$\ell\overline{\nu}_\ell\overline{\ell}\nu_\ell$	65	2.6	0.2	2.8 ± 0.3	2
Total	61	22.6	5.0	27.6 ± 2.5	28

- Uncertainty in expected signal due to
  - ΔM_W 150 MeV
  - $\Delta E_{\rm beam}$ 100 MeV
  - $\Longrightarrow \sim 10\%$ systematic error
- Accepted by Phys.Lett.**B**, Nov. 29, 1996

Triple Gauge Boson Couplings

- Couplings affect total cross-section and angular distributions
- $e^+e^- \to W^+W^-$ diagrams:



$WW\gamma$ vertex	WWZ vertex
2 coupling constants	7 coupling constants
x_γ, y_γ	δ_Z, x_Z, y_Z etc.

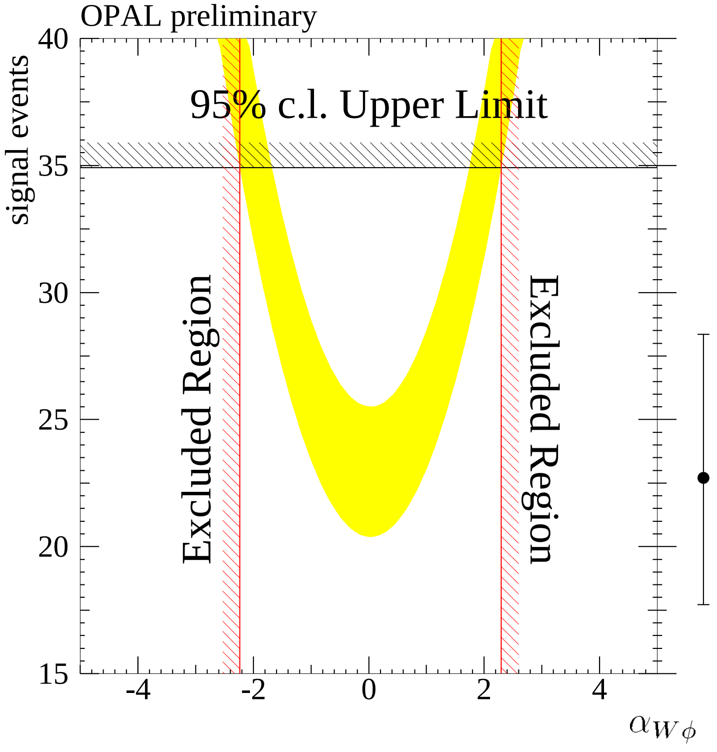
- Anomalous couplings zero in SM
- Highest sensitivity in $W\phi$ model: free parameter $\alpha_{W\phi}$
- Efficiency depends on $\alpha_{W\phi}$

  $\Longrightarrow$ compare number of events
- Expected number of events derived from MC samples:
  - $W\phi$ model
  - $\alpha_{W\phi} = 0, \pm 1, \pm 2$
  - full detector simulation
- Include systematics in prediction

TGC from total event yield

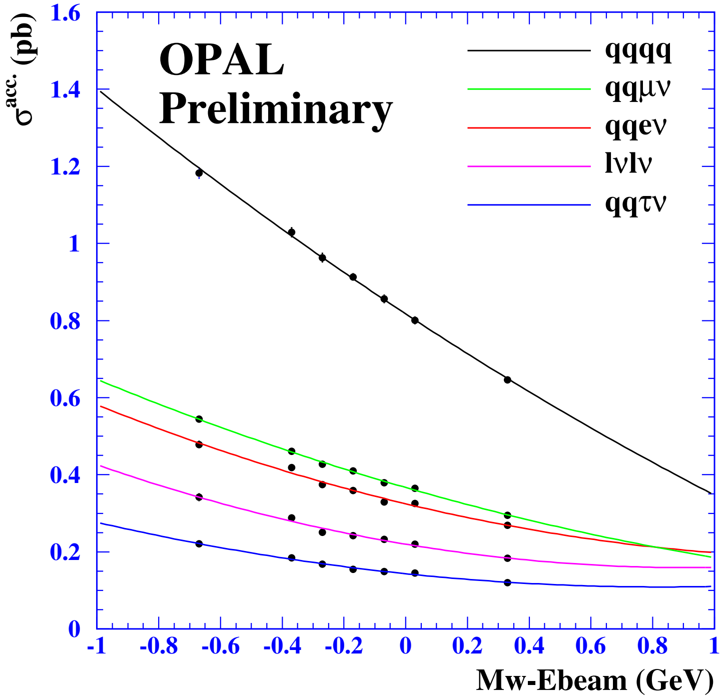
- Observe 28 W^+W^- candidates, + expected background
  $\Rightarrow$ N(signal) $<$ 34.9 @ 95% c.l.
- Compare with expectation, including systematics.

$\boxed{-2.2 < \alpha_{W\phi} < 2.3}$ @ 95% c.l.



W Mass Measurement

- Interference $W^+W^- \leftrightarrow$ other 4-fermion states
- Predict M_W dependence of σ^{acc}, ε, background, using grc4f + detector simulation



- Max. $\mathcal{L}$ fit, channel by channel, incl. correlations
- Systematics by repeated MC trials

$$\boxed{M_W = 80.40^{+0.44}_{-0.41}(\text{stat.})\ ^{+0.09}_{-0.10}(\text{syst.})\ \pm 0.10\ (\text{LEP})}$$

W^+W^- Cross-section Measurement

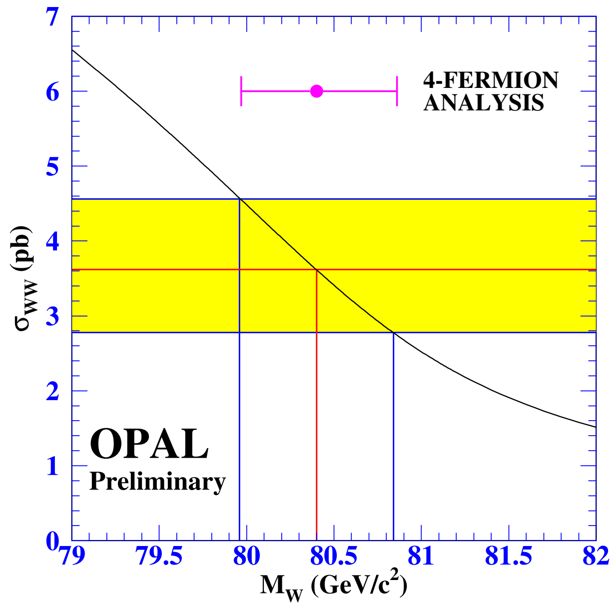
Direct measurement of W^+W^- production cross-section

- Max. $\mathcal{L}$ fit, channel by channel, incl. correlations

Assumptions:

- Subtract non-W^+W^- processes
- Absorb interference into background

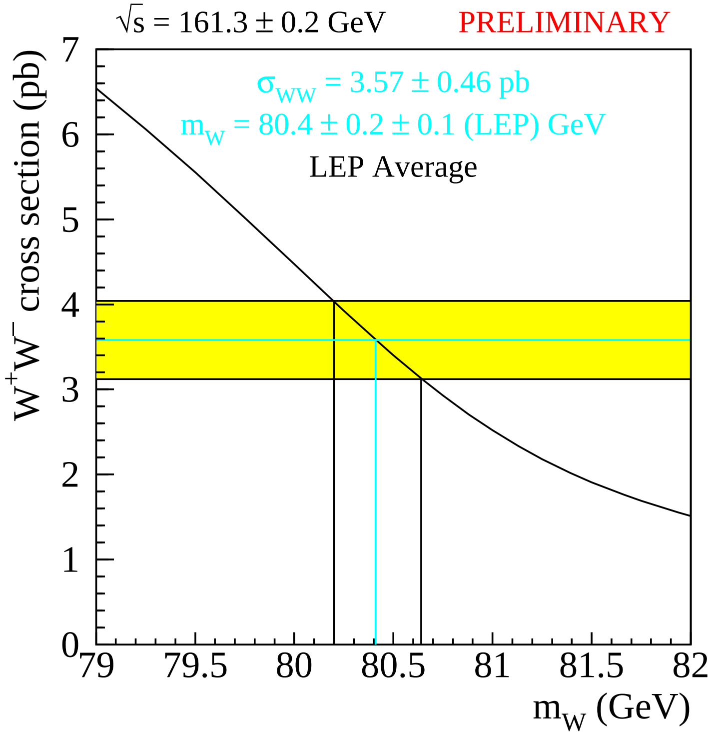
$\boxed{\sigma_{WW} = 3.62^{+0.93}_{-0.82}(\mathrm{stat.}) \pm 0.16(\mathrm{syst.})\ \mathrm{pb}}$ CC03



σ_{WW} + GENTLE $\Rightarrow$ consistent M_W.

LEP Combined W Mass Measurement

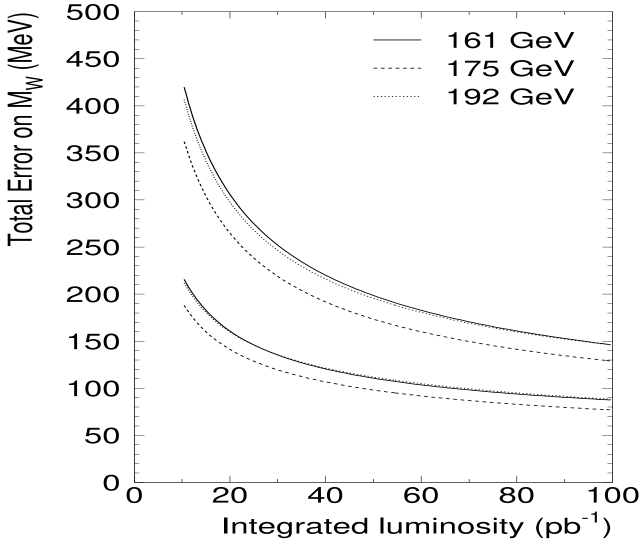
Obtain M_W by averaging σ_{WW} from all LEP experiments



LEPC 8 Oct 96
LEP EW Working Group

$\Delta M_{\rm W}$: Future Extrapolation

- $\sqrt{s} = 161$ GeV: Cross-section at threshold
  - $\sim$ $\pm$ 80 MeV from background uncertainties
  - $\sim$ $\pm$ 20 MeV (currently 100 MeV!) from $E_{\rm beam}$
- $\sqrt{s} > 170$ GeV:
  - $\sim$ $\pm$ 20 MeV from ISR, Fragmentation, etc
  - $\sim$ $\pm$ 10 MeV from Mass fit (bigger at higher energy)
  - $\sim$ $\pm$ 20 MeV from $E_{\rm beam}$
  - $\sim$ $\pm$ 100 MeV from "colour-reconnection" (qqqq only)

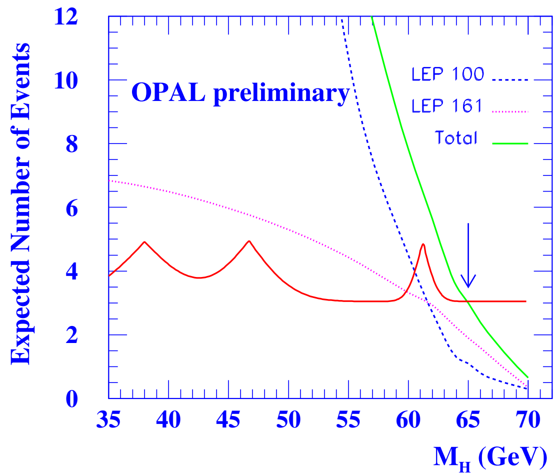


Standard Model Higgs Search

- Sensitive to all relevant decay channels

Channel	Rate	Eff.	$\sigma \cdot \varepsilon$	N_{bg}	N_{obs}
4-jets	0.60	23%	0.14	0.8	1
2-jets + $\not{E}$	0.18	46%	0.08	0.9	1
2-jets $+\ell^+\ell^-$	0.07	66%	0.05	0.1	0
2-jets $+\tau^+\tau^-$	0.09	20%	0.02	0.2	0

- Efficiencies correspond to case $m_{\rm H} = 65.0$ GeV
- Total expected background 2.0 ± 0.1 events
- 2 Candidates Observed: $m_{\rm H} = 46.6 \pm 3.1$ GeV
  $m_{\rm H} = 39.3 \pm 4.9$ GeV

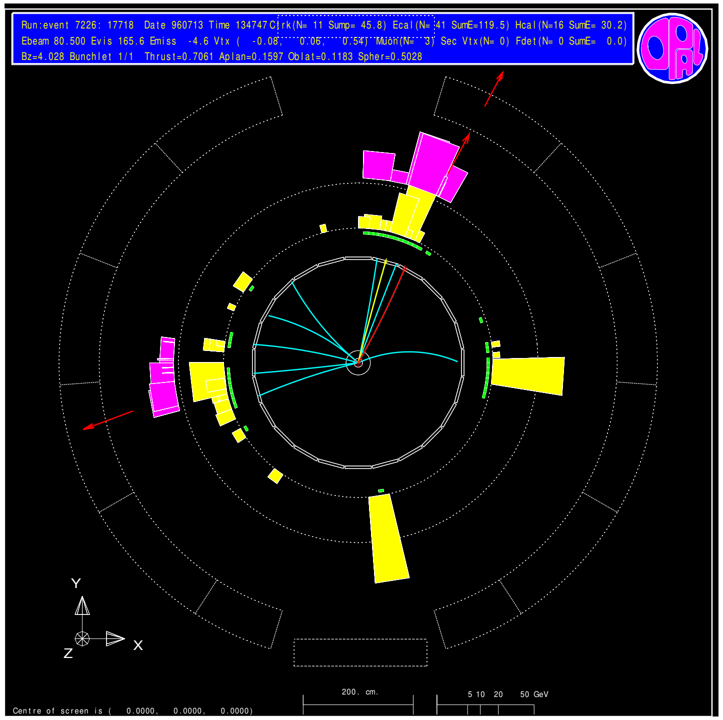


$\boxed{m_{\rm H} > 65.0 \text{ GeV}}$ @ 95% C.L.

Synopsis of LEP2

- June 14: First Beam . . . June 19: Bottles out
- July 5: Change from $108°/60°$ to $90°/60°$ Optics
- July 9: First $\mathrm{W}^+\mathrm{W}^-$ pair
- July 9 $\longrightarrow$ August 16
  Physics at 161 GeV, $12.1\ \mathrm{pb}^{-1}$ delivered
  6 mA current limit (RF); $\mathcal{L}_{\mathrm{peak}} = 3 \times 10^{31}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- August 17 $\longrightarrow$ October 10
  RF Upgrade to 2.0 GV
- October 15 $\longrightarrow$ November 3
  Physics at 172 GeV, $\sim 8.5\ \mathrm{pb}^{-1}$ delivered
  4.2 mA ; $\mathcal{L}_{\mathrm{peak}} = 3.4 \times 10^{31}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- November 4-6: Commision $108°/90°$ Optics
- November 7 $\longrightarrow$ November 19
  Countinue at 172 GeV, $\sim 2.2\ \mathrm{pb}^{-1}$ delivered
  4.2 mA; $\mathcal{L}_{\mathrm{peak}} = 2.2 \times 10^{31}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
  However problems running at 91 GeV
- Conclusions:
  - Super-conducting RF Status: very good
  - Still no satisfactory high energy machine lattice

A Candidate for Something?



Conclusions

OPAL has been busy, 8 papers submitted with results on

- Measured 2-fermion cross-sections and asymmetries
- Measured QCD event shapes,

$$\alpha_s(161\mathrm{GeV}) = 0.102 \pm 0.005 \pm 0.007 \text{ (prel.)}$$

- Observed $\mathrm{W^+W^-}$ production:

$$\sigma_{\mathrm{WW}} = 3.62^{+0.93}_{-0.82} \pm 0.16 \text{ pb}$$
$$M_{\mathrm{W}} = 80.40^{+0.44}_{-0.41}\,^{+0.09}_{-0.10} \pm 0.10 \text{ (LEP) GeV}$$

$$-2.2 < \alpha_{W\phi} < 2.3 \quad @\ 95\% \text{ c.l.}$$

- Studied other 4-fermion processes, no excess observed
- Improved mass limits on SM Higgs Boson

BUT

- Still WWondering where all the new physics is