Results from the OPAL Experiment

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On behalf of the OPAL Collaboration

A Detector Status, Data Sets

B Recent LEP1 Highlights (many! but just pick one)

- V_{cb} update

C LEP2 Results

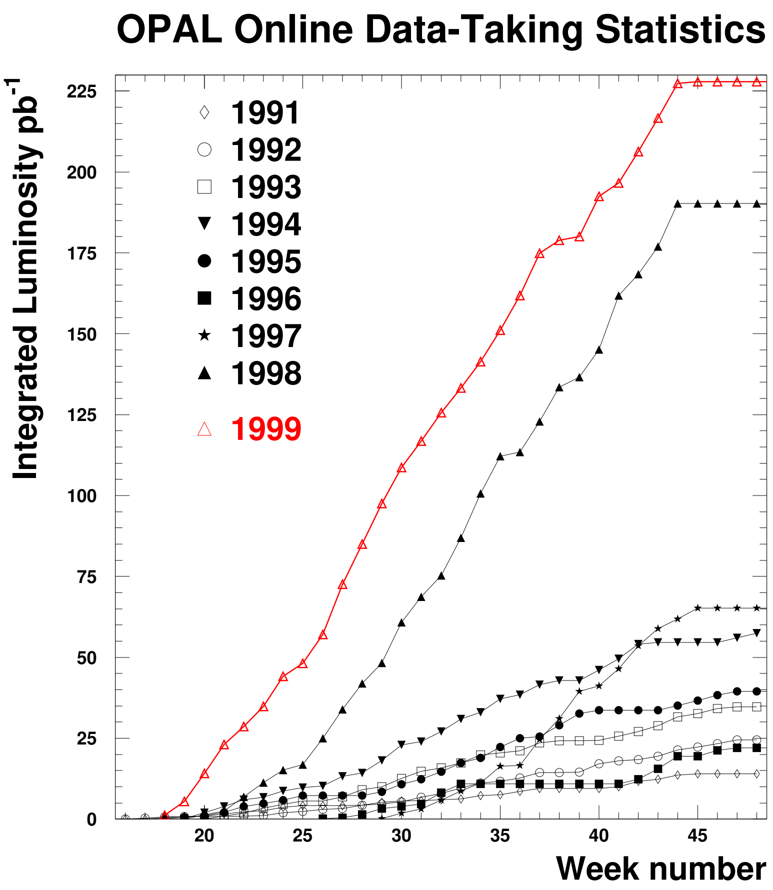
- $\mathrm{e}^{+}\mathrm{e}^{-} \longrightarrow \mathrm{Z}^{0}(\gamma) \longrightarrow \mathrm{f\bar{f}}(\gamma)$ ($\mathrm{f} = \mathrm{q}, \mathrm{e}, \mu, \tau, \nu$)
- $\mathrm{e}^{+}\mathrm{e}^{-} \longrightarrow \mathrm{Z}^{0}\mathrm{Z}^{0}$ (σ_{ZZ}, anomalous couplings)
- $\mathrm{e}^{+}\mathrm{e}^{-} \longrightarrow \mathrm{W}^{+}\mathrm{W}^{-}$, $\mathrm{We}\nu$ (TGC's, M_{W})
- $M_{\mathrm{e}^{+}\mathrm{e}^{-}}$ peaks in $\mathrm{e}^{+}\mathrm{e}^{-} \longrightarrow \mathrm{q\bar{q}e}^{+}\mathrm{e}^{-}$?
- $\ell^{+}\ell^{-} + \not{E}_{T}$ ($\tilde{\ell}^{+}\tilde{\ell}^{-}$, $\mathrm{H}^{+}\mathrm{H}^{-}$, $\tilde{\chi}^{+}\tilde{\chi}^{-}$, ...)
- Compositeness (ℓ^{*}, ν^{*})
- Higgs searches, $\mathrm{e}^{+}\mathrm{e}^{-} \longrightarrow \mathrm{hZ}^{0}$, hA

D Summary

Detector Status

- Successful Y2K test of all online DAQ systems in November
- Opened detector for repair of hadron calorimeter pole tips
- Central detectors filled with flammable gas by the end of this week
- Commissioning subdetector DAQ systems this week
- Will start taking cosmic ray data around March 20th

Data Sets



$\sqrt{s}$ (GeV)	$\mathcal{L}_{\rm tot}$ $({\rm pb}^{-1})$
≈91	175
130-136	10
161	10
172	10
183	57
189	187
192–202	224
161–202	488

V_{cb} from $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}$ update

- Extract V_{cb} from $\bar{B}^0 \to D^{*+}\ell^-\bar{\nu}$ using:

$$\frac{1}{\tau_{B^0}}\frac{dBr}{d\omega} = \mathcal{K}(\omega)\mathcal{F}^2(\omega)|V_{cb}|^2 \qquad \omega = \frac{m^2_{D^{*+}} + m^2_{B^0} - q^2}{2m_{B^0}m_{D^{*+}}}$$

- HQET $\Rightarrow \mathcal{F}(1) = 0.913 \pm 0.042$

Two techniques

Exclusive

$\bar{B}^0 \longrightarrow D^{*+}\, l^-\, \bar{\nu}$

$\quad D^{*+} \longrightarrow D^0\, \pi^+$

$\quad\quad D^0 \longrightarrow K^-\, \pi^+$

$\quad\quad D^0 \longrightarrow K^-\, \pi^+\pi^0$

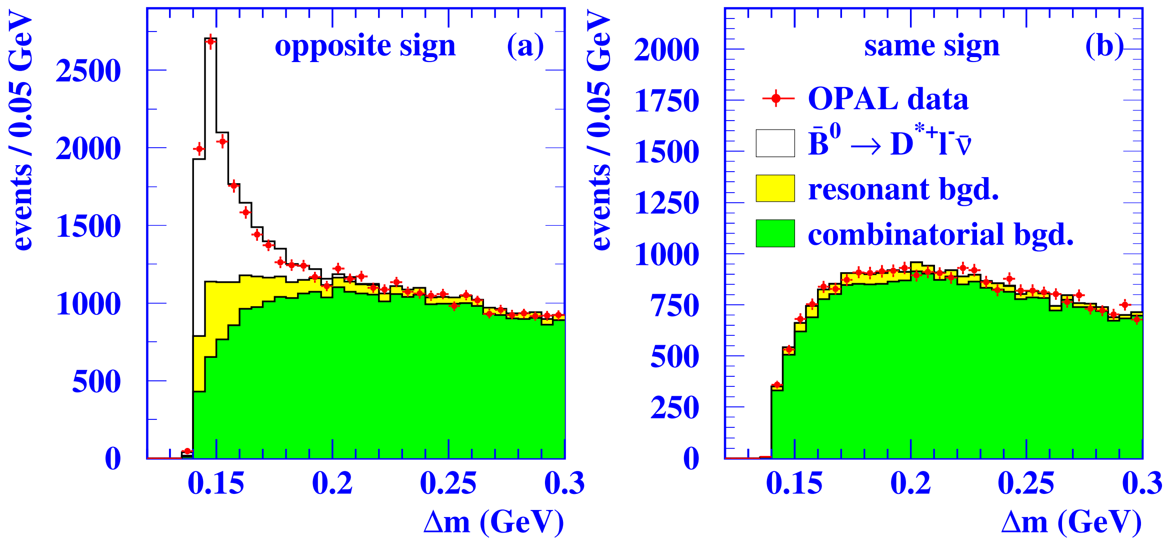
Inclusive

$\bar{B}^0 \longrightarrow D^{*+}\, l^-\, \bar{\nu}$

$\quad D^{*+} \longrightarrow D^0\, \pi^+$

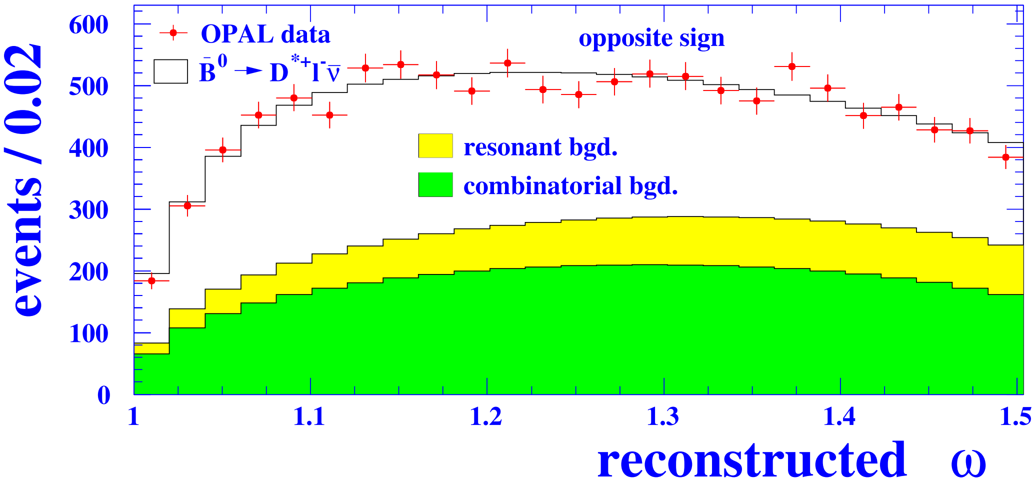
Previous OPAL result: exclusive only. Now inclusive too:

Define $\Delta m = \sqrt{E^2_{D^*} - |p_{D^*}|^2} - m_{D^0}$



Extracting V_{cb}

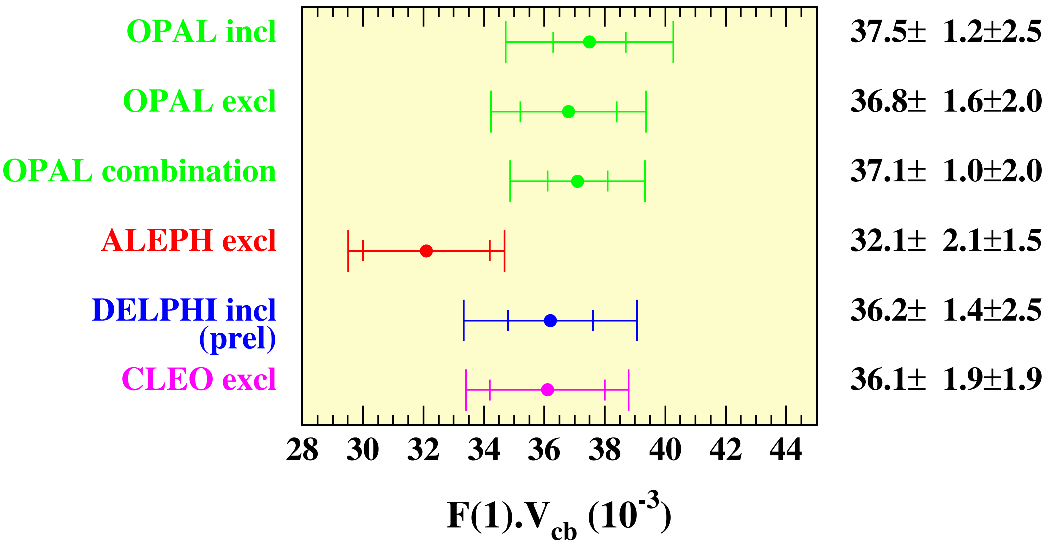
Need Br as $\omega \to 1$



Many "upgrades" improved both inclusive an exclusive results:

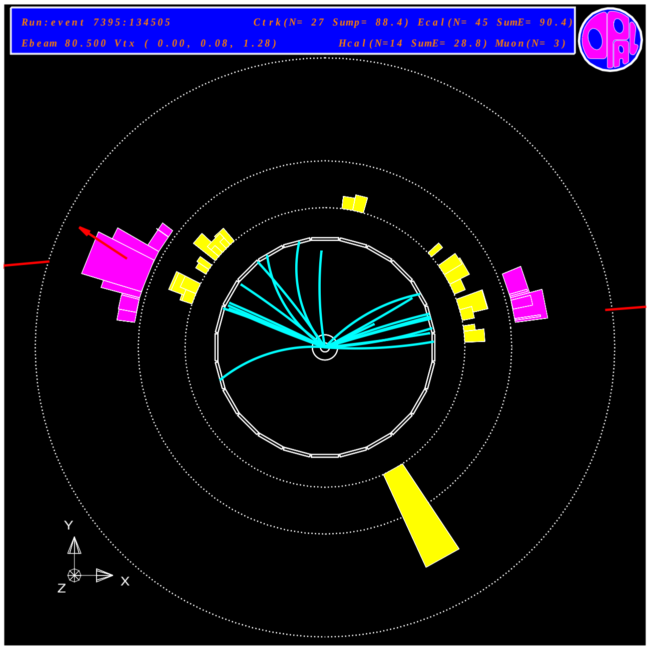
- One parameter (ρ^2) for $\mathcal{F}(\omega)$
- Many updated inputs (branching ratios, *etc.*)
- Improved calculation for D^{**} background

$$\mathcal{F}(1)|V_{\mathrm{cb}}| = (37.1 \pm 1.0 \pm 2.0) \times 10^{-3}$$
$$|V_{\mathrm{cb}}| = (40.7 \pm 1.1 \pm 2.2 \pm 1.6) \times 10^{-3}$$

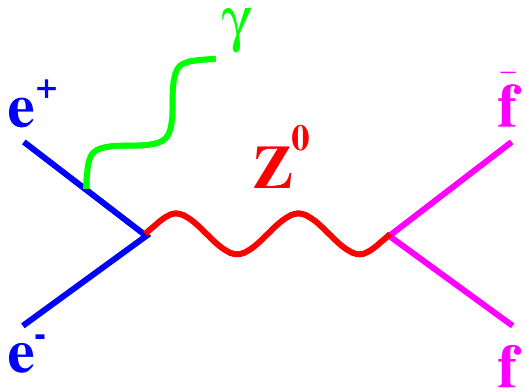


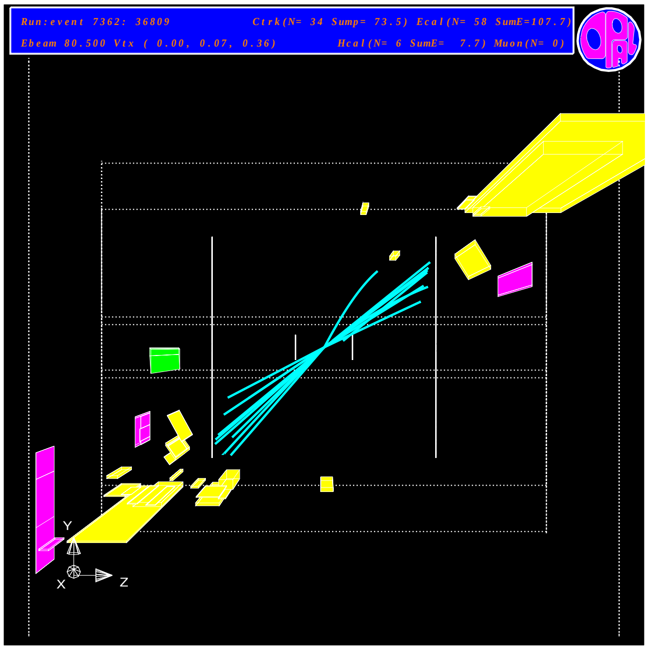
$\mathrm{e^+e^-} \longrightarrow \mathrm{Z^0}(\gamma) \longrightarrow \mathrm{f\bar{f}}(\gamma)$

- Select $\mathrm{e^+e^-} \to \mathrm{q\bar{q}}(\gamma)$, $\mathrm{e^+e^-} \to \ell^+\ell^-(\gamma)$
- Determine effective CM energy, s', from observed γ and a kinematic fit allowing ≤ 2 missing γ
- Consider two event classes:

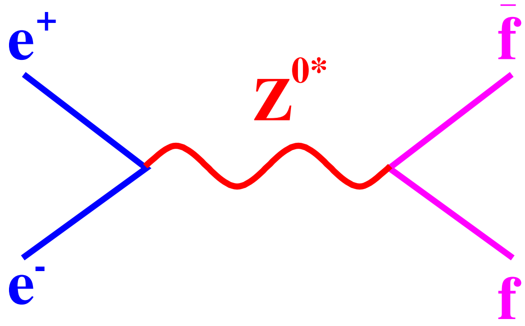


$$\sqrt{s'} < \sqrt{s}$$

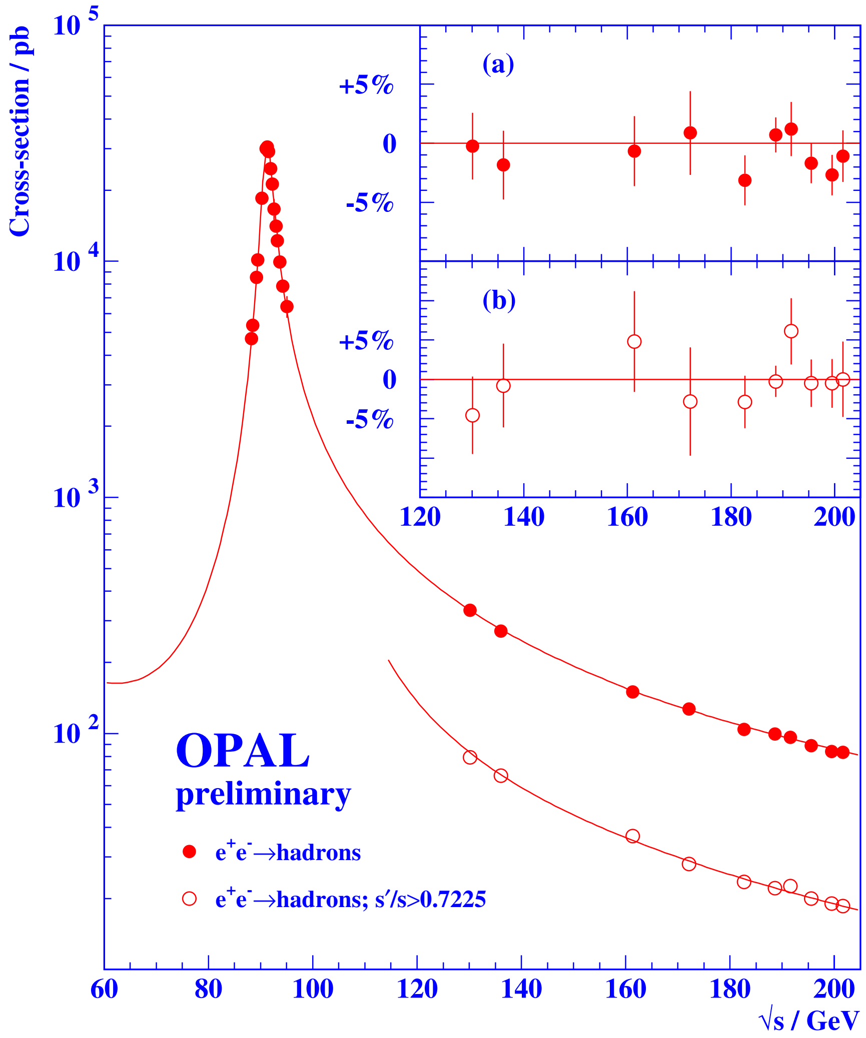


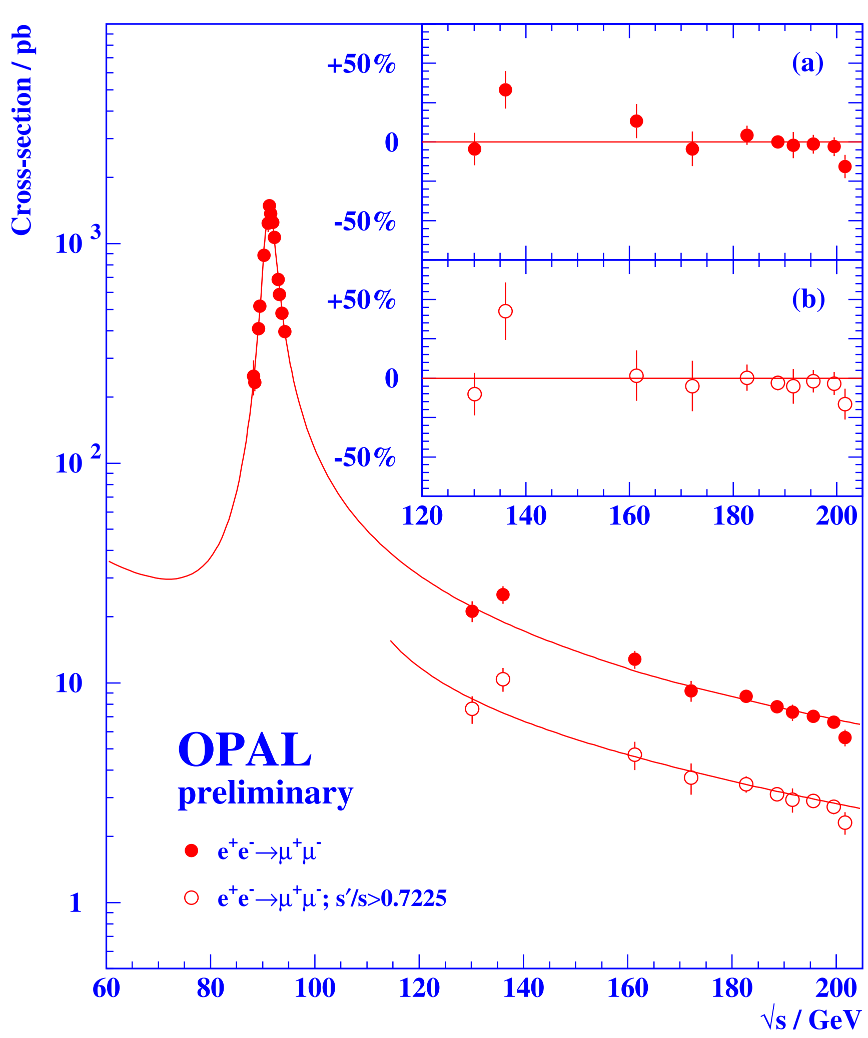


$$\sqrt{s'} \approx \sqrt{s}$$

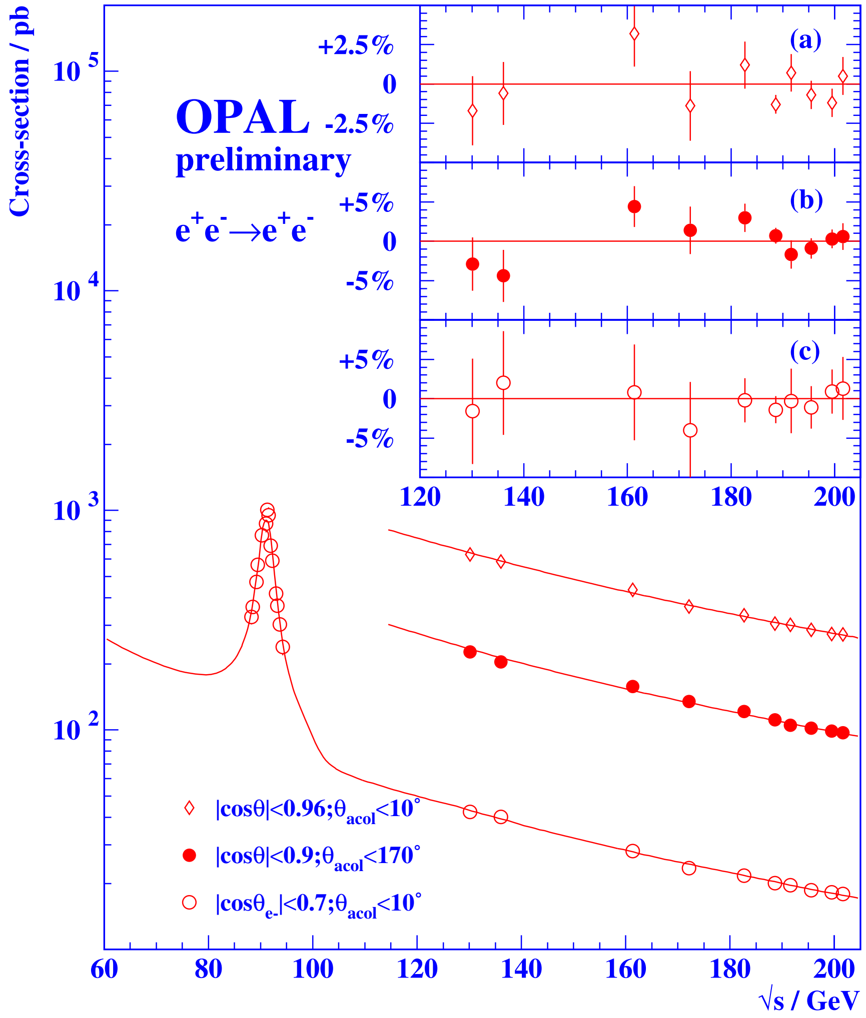


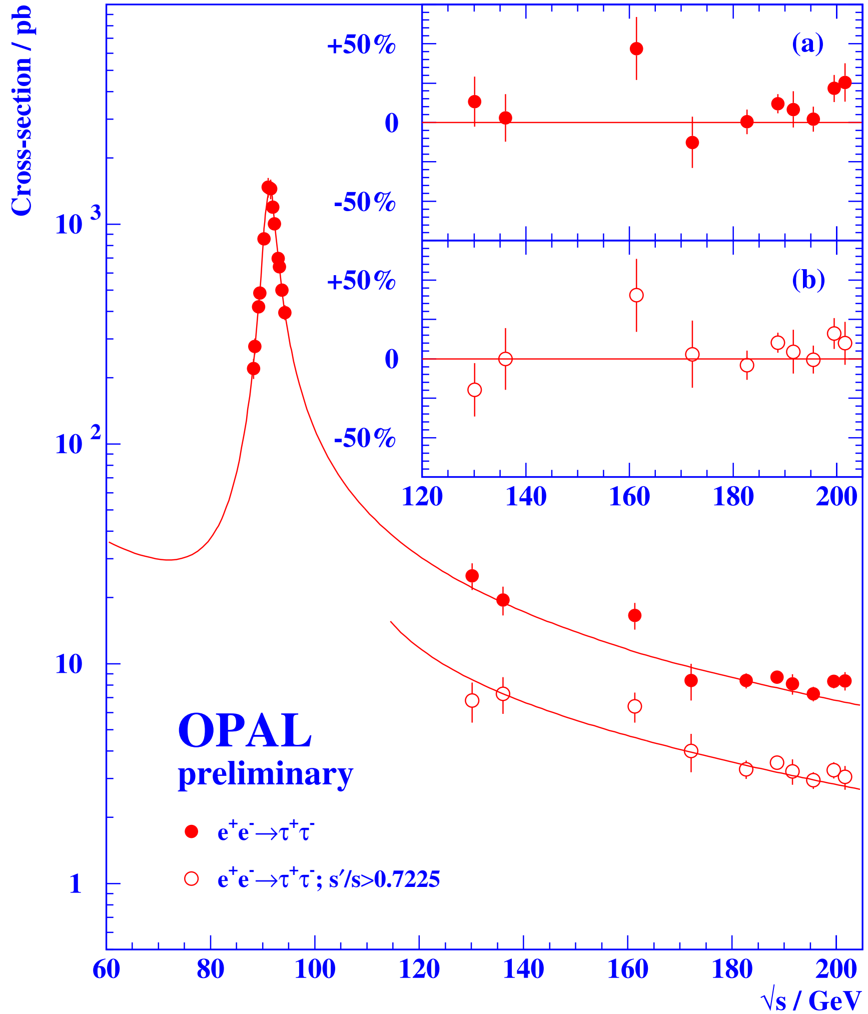
$q\bar{q}(\gamma)$ $\mu^+\mu^-(\gamma)$





$e^+e^-(\gamma)$ $\tau^+\tau^-(\gamma)$

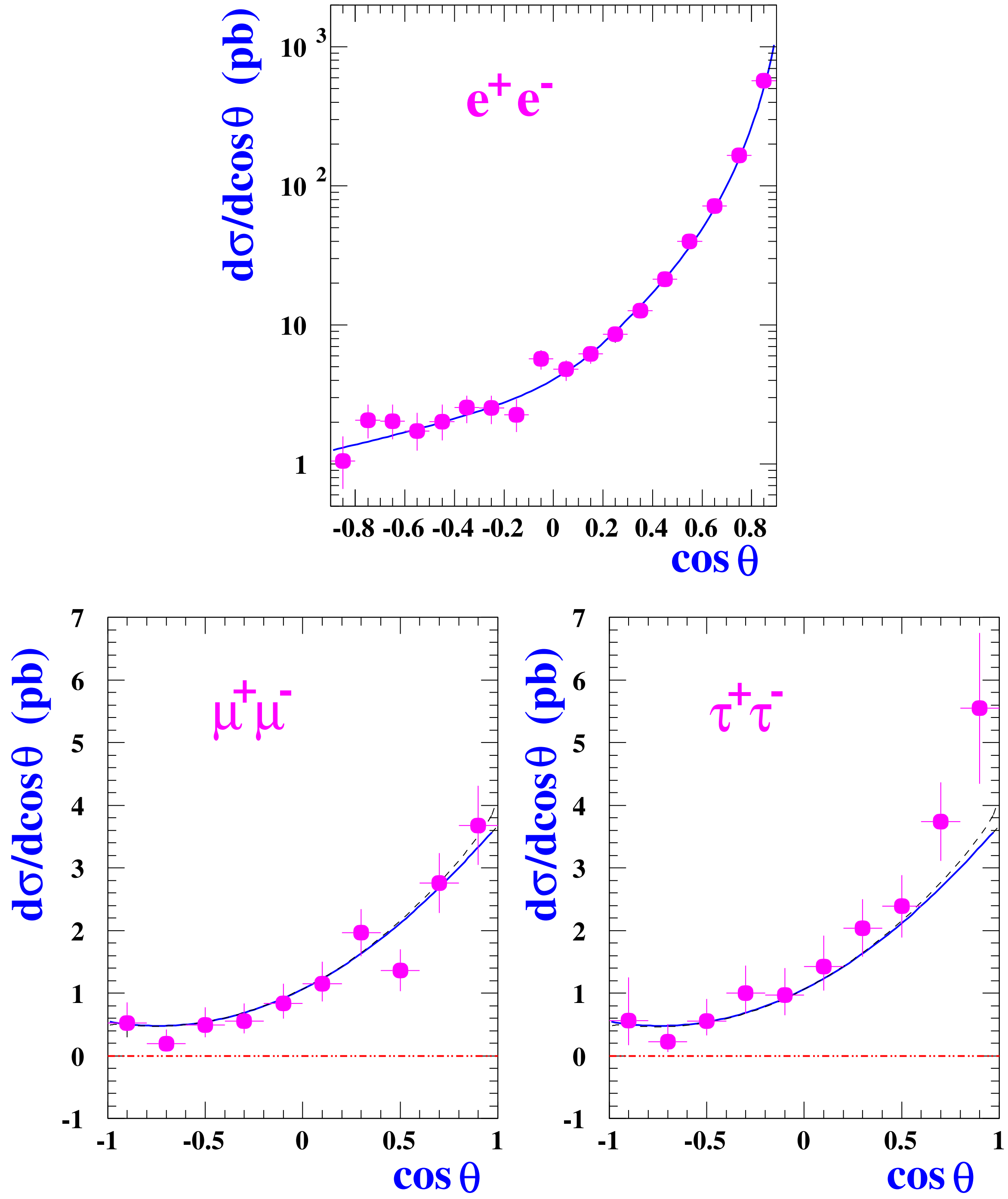




$\ell^+\ell^-(\gamma)$: $\cos\theta_-$

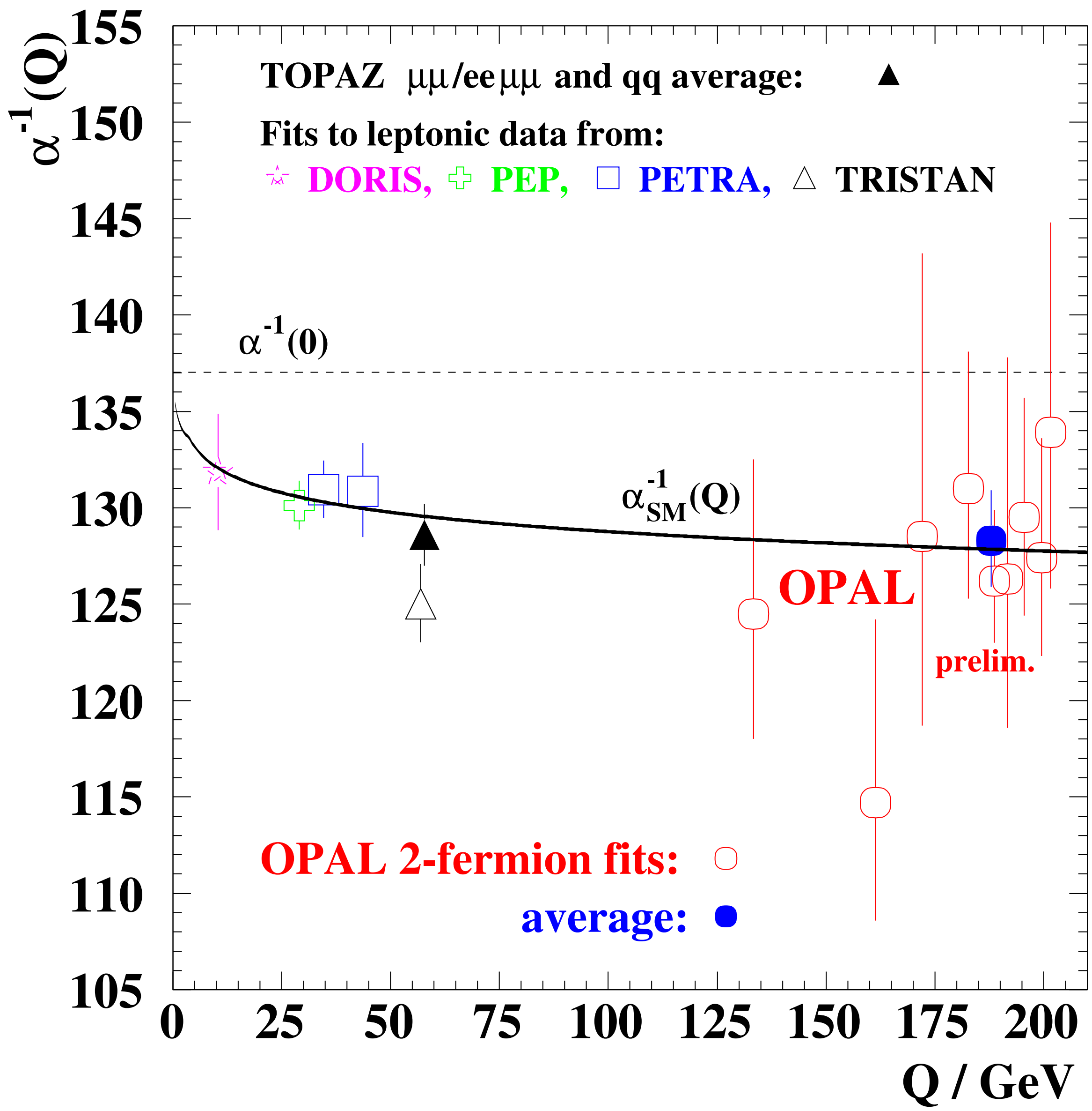
- $\sqrt{s} = 200$ GeV
- e^+e^-: $\theta_{\mathrm{acol}} < 10°$, $\mu^+\mu^-$, $\tau^+\tau^-$: $s'/s > 0.7225$

OPAL 200 GeV preliminary



Running of α_{EM}

- Use cross-sections and asymmetries
- Use ZFITTER fit for α_{EM} at each $\sqrt{s}$
- Also fit using all high energy data

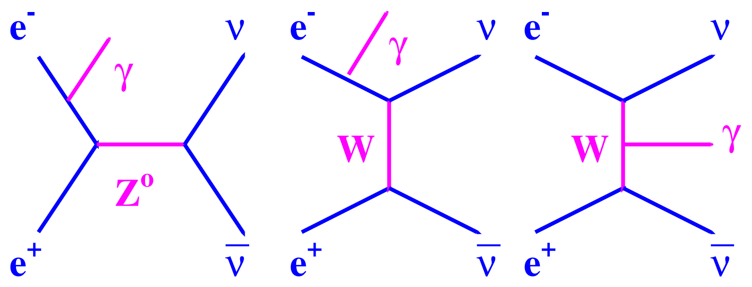


Running high energy result:

$$\alpha_{\mathrm{EM}}(M_{\mathrm{Z}}) = 129.2^{+2.3}_{-2.1}$$ (SM: 128.9)

$e^+e^- \longrightarrow \nu\bar{\nu}\gamma$ Selection

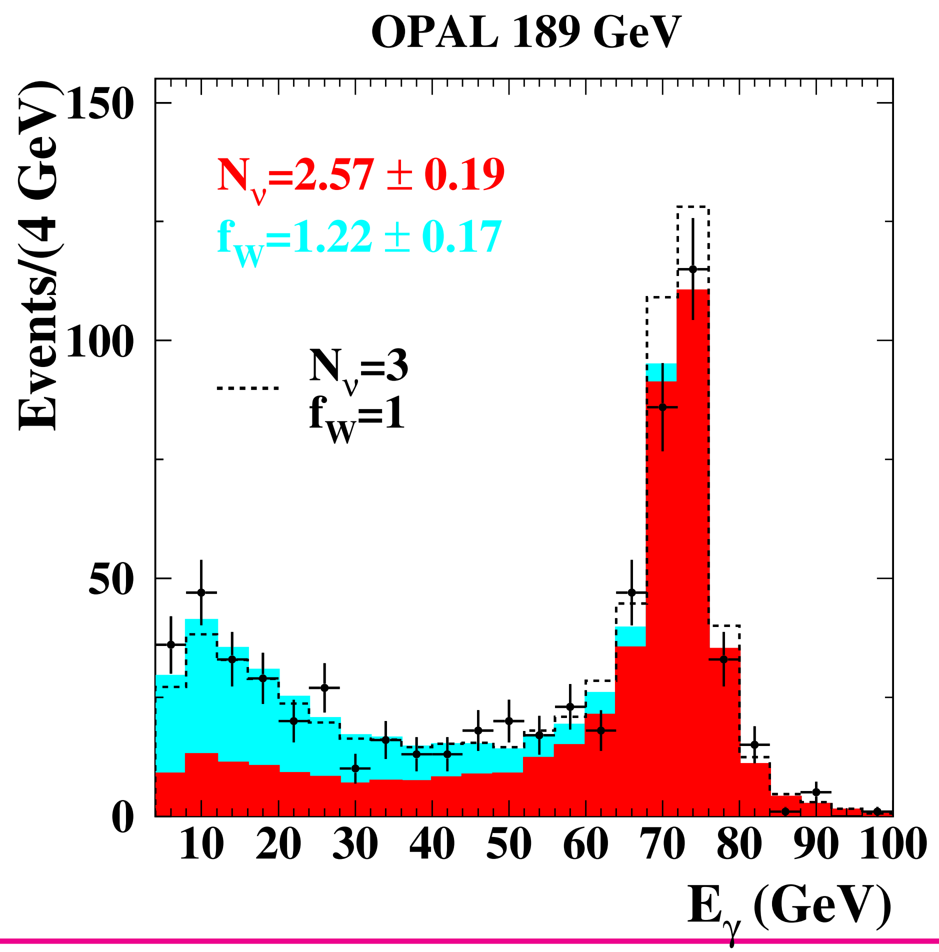
- 3 SM diagrams:



Define $f_W \;=\;$ t-channel $+$ Interference
$\equiv$ 1 in the Standard Model

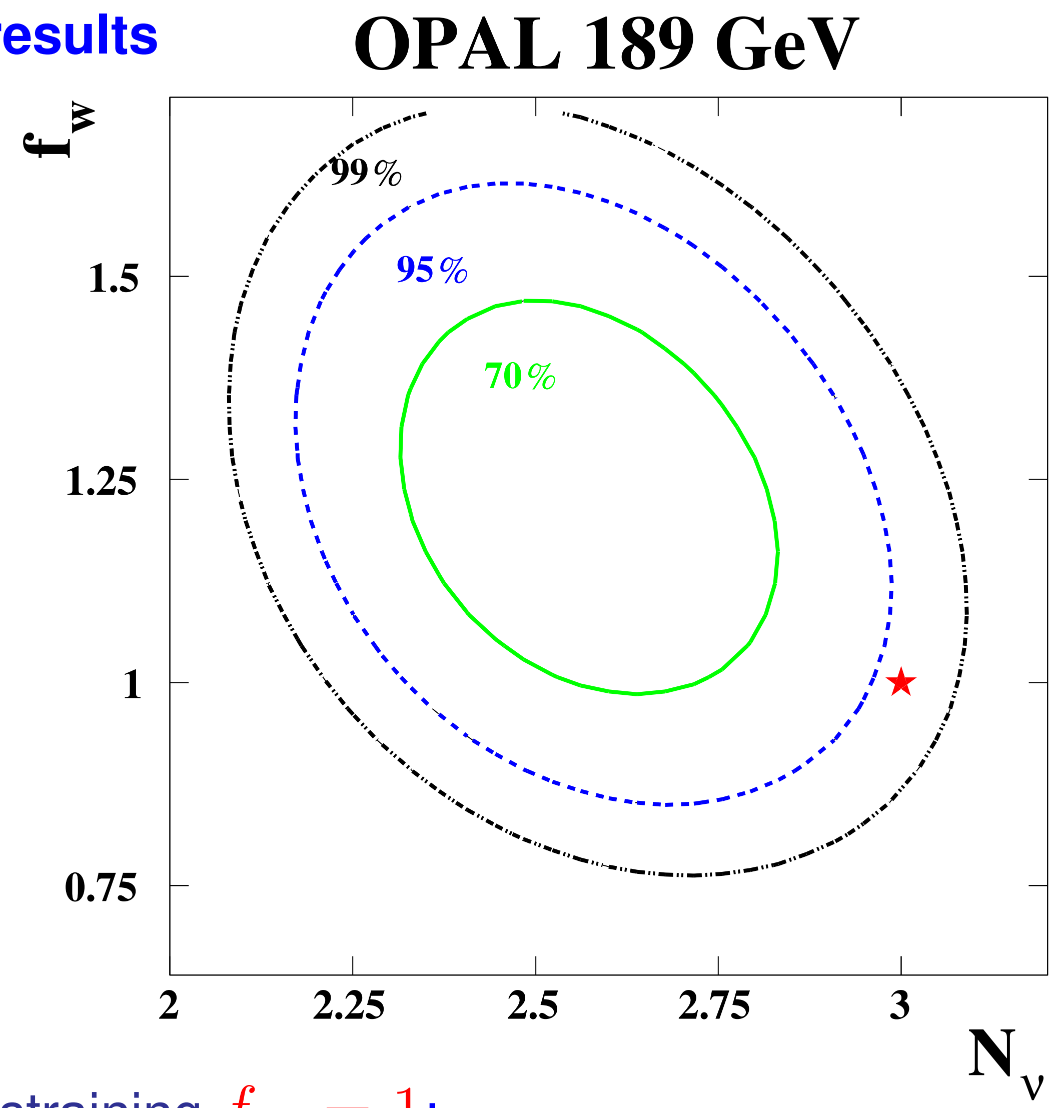
Fit for f_W and N_ν

$\sqrt{s}$ (GeV)	Data	SM Total
189	643	683.6±14.9
192	91	102.6±5.1
196	248	241.9±12.0
200	238	225.6±11.2
202	70	74.8±3.7
192-202	647	644.9±32.0



$e^+e^- \rightarrow \nu\bar{\nu}\gamma$: f_W, N_ν

Fit results



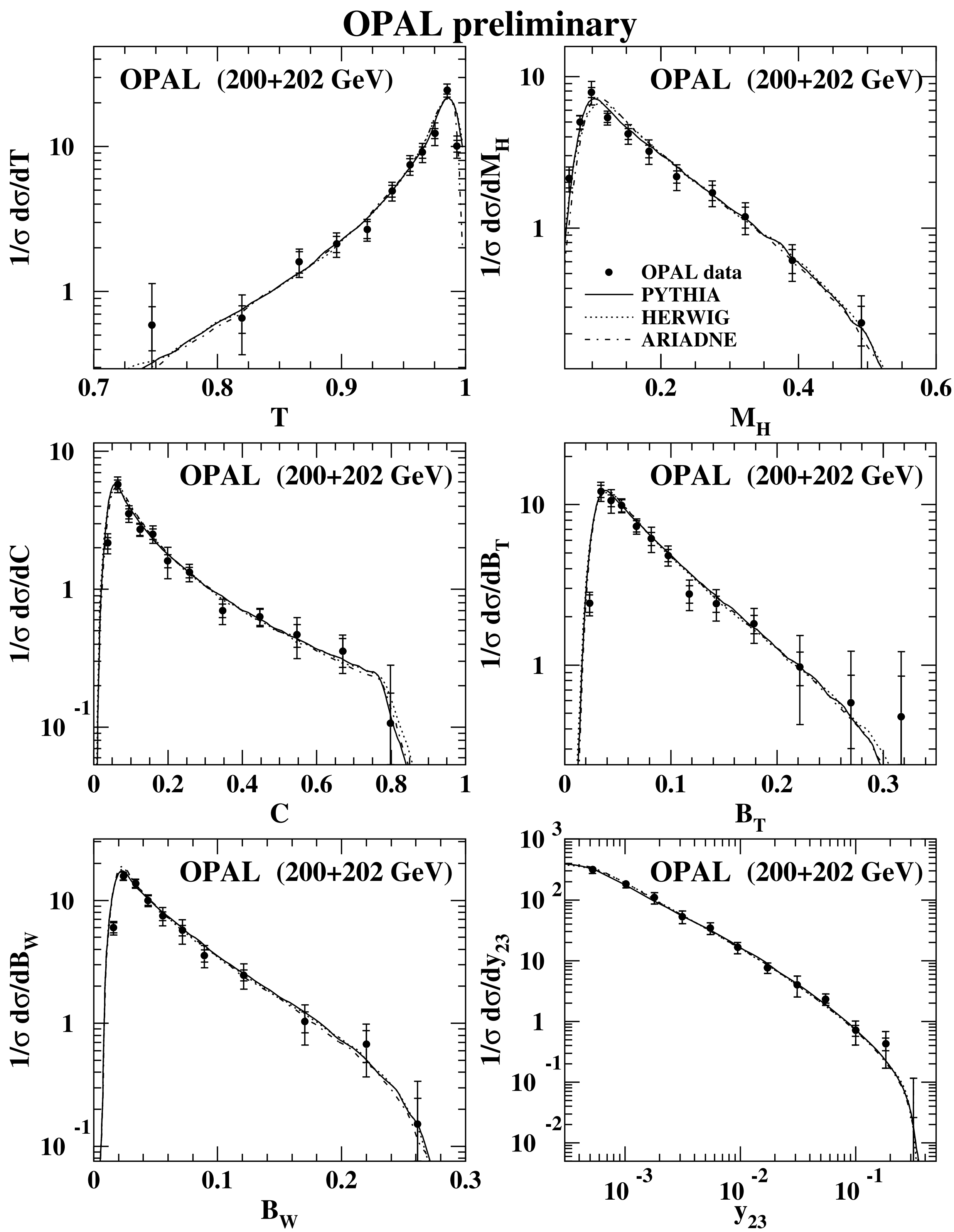
Constraining $f_W = 1$:

$$N_\nu = 2.67 \pm 0.13(\text{sta}) \pm 0.11(\text{sys})$$

Constraining $N_\nu = 3$:

$$f_W = 1.07 \pm 0.12(\text{sta}) \pm 0.12(\text{sys})$$

QCD Event Shapes

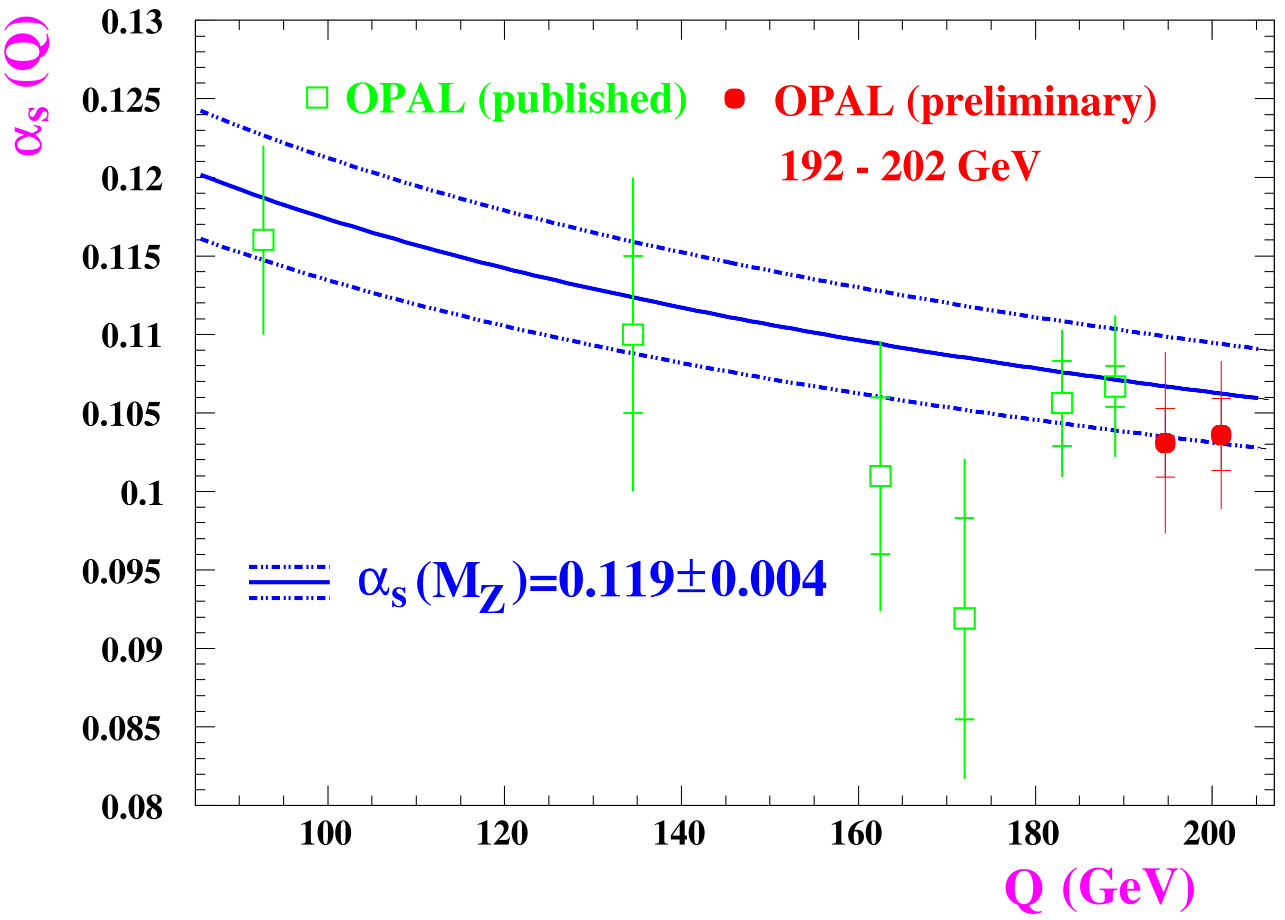


⇒ Event shapes well described by MC generators

Fit for α_s

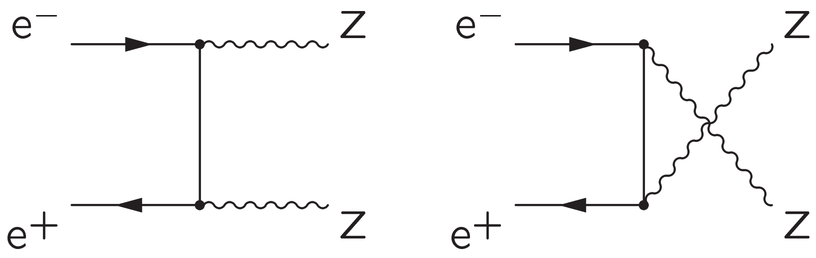
- Fit to $\mathcal{O}(\alpha_s^2)+$ NLLA QCD predictions for event shape variables corrected to parton level

$$\alpha_s(195\ \mathrm{GeV}) = 0.103 \pm 0.002(\mathrm{stat}) \pm 0.005(\mathrm{syst})$$
$$\alpha_s(201\ \mathrm{GeV}) = 0.104 \pm 0.002(\mathrm{stat}) \pm 0.004(\mathrm{syst})$$

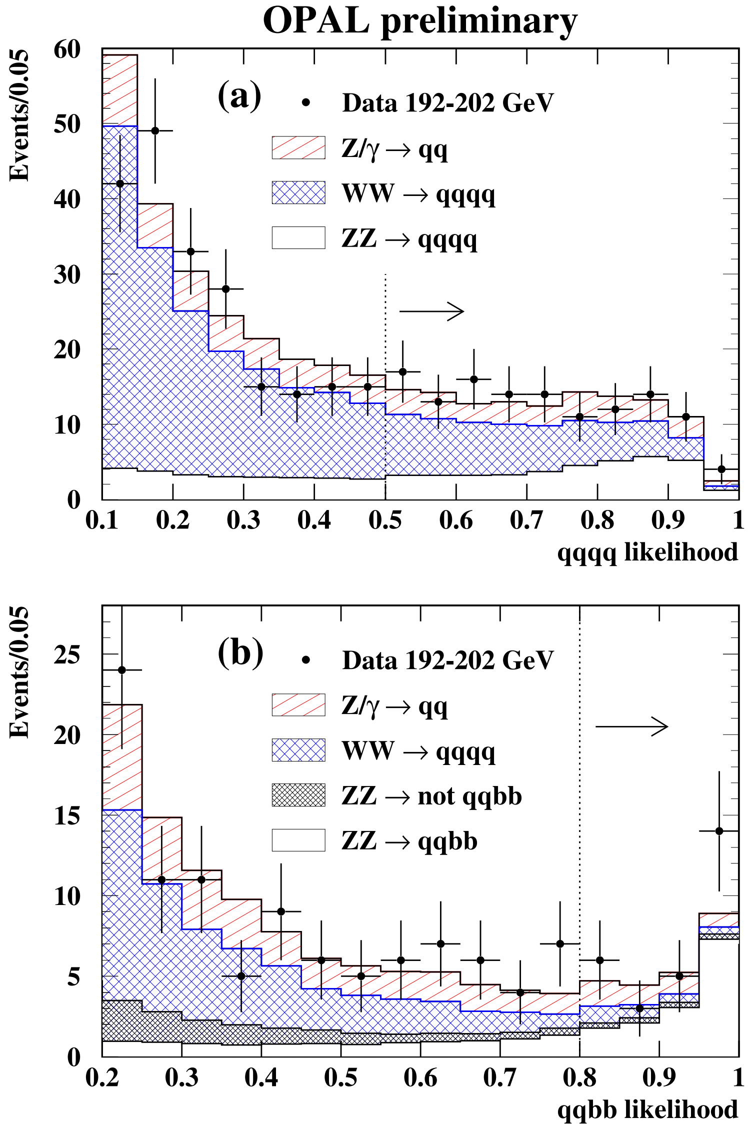


$e^+e^- \longrightarrow Z^0Z^0$ Selection

NC02 diagrams:



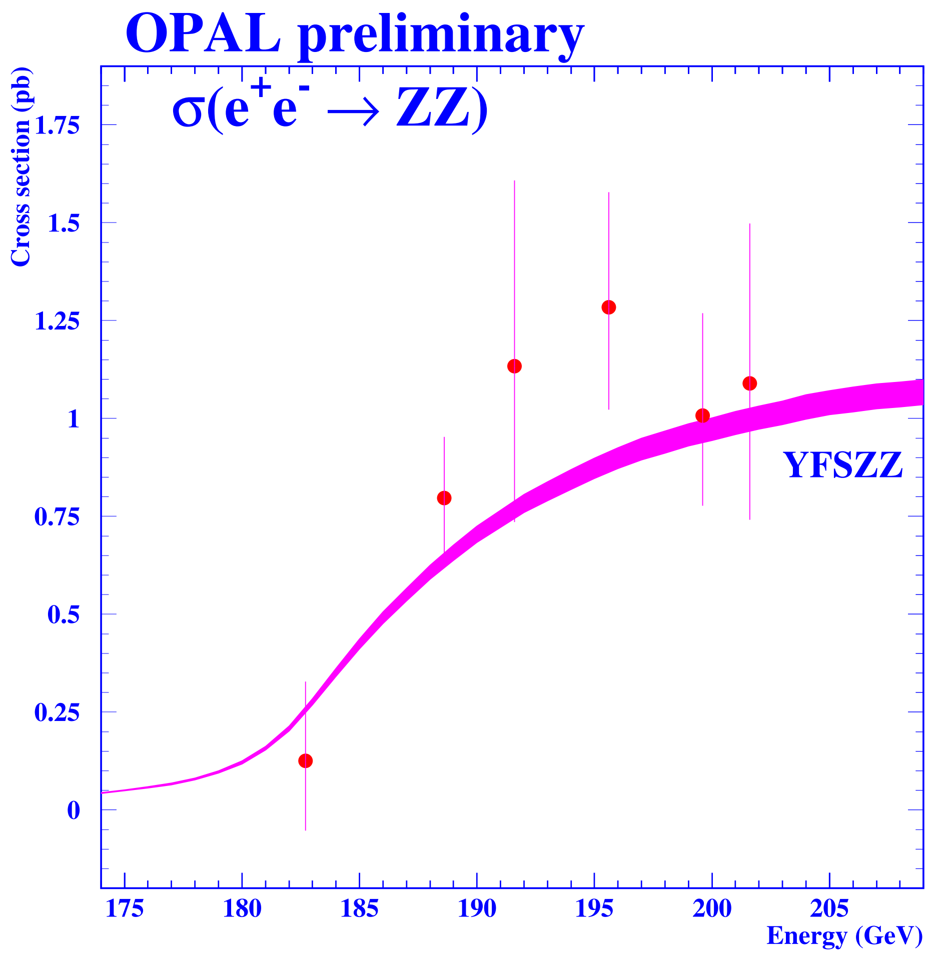
- Every mode except $\nu\bar{\nu}\nu\bar{\nu}$ & $\tau^+\tau^-\nu\bar{\nu}$
- 15 different channels
- b-tag increases purity



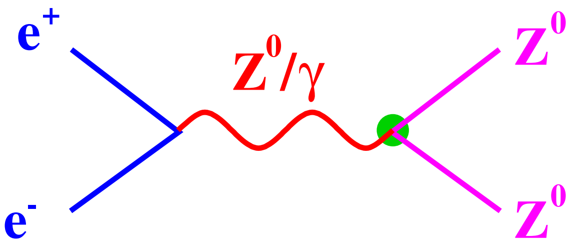
Z^0Z^0 Cross Section

Observed events for $\sqrt{s} = $ 192–202 GeV:

final state	Observed Data	Expected Total SM	Expected Z^0Z^0
$\ell^+\ell^-\nu\bar{\nu}$ & $\ell^+\ell^-\ell^+\ell^-$	4	5.3±0.3	3.3±0.2
$q\bar{q}\ell^+\ell^-$	25	17.4±0.4	15.0±0.3
$q\bar{q}\nu\bar{\nu}$	32	31.1±1.4	17.5±1.1
$q\bar{q}b\bar{b}$	28	23.3±1.1	15.5±0.5
$q\bar{q}q\bar{q}$	112	108.2±8.3	27.9±1.5



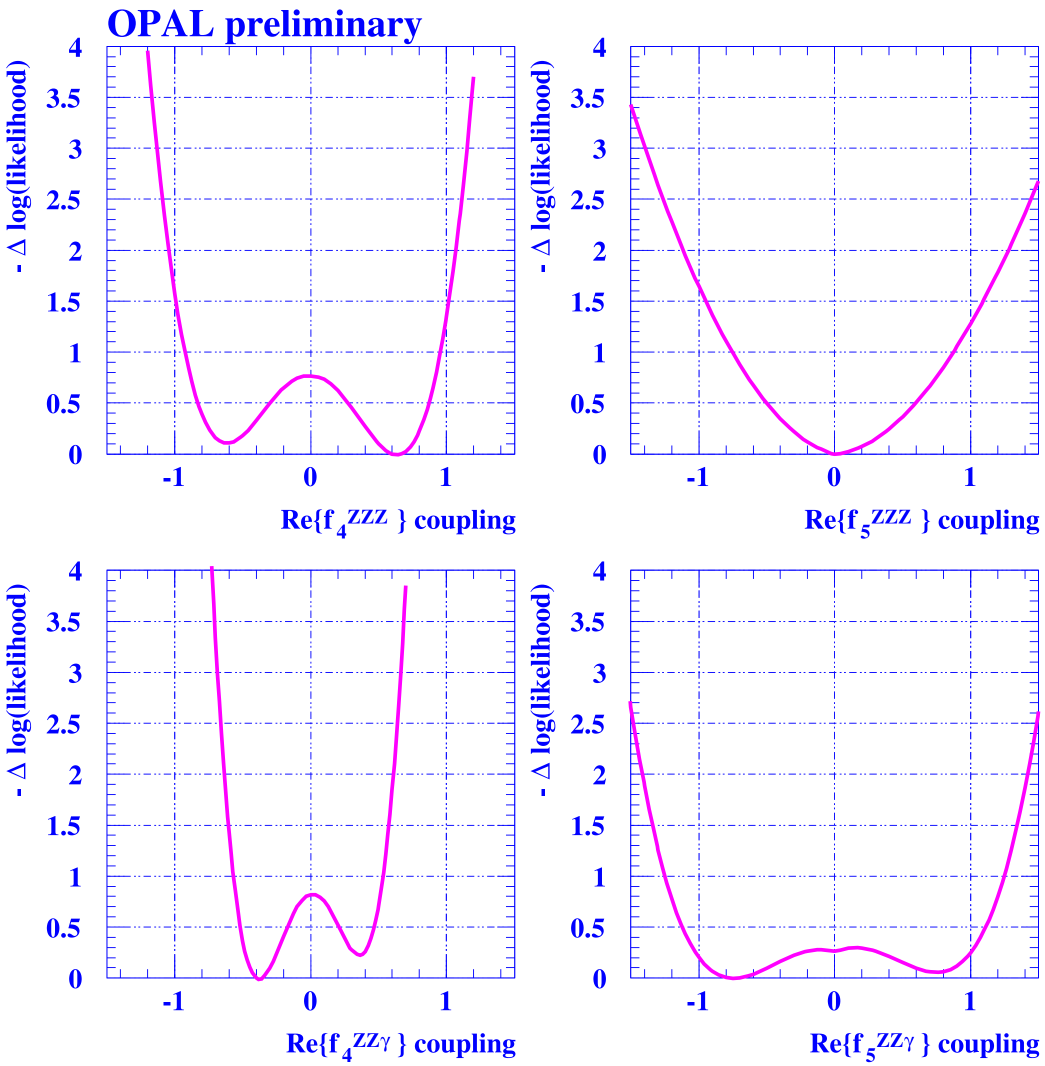
Z^0Z^0 Anomalous Couplings



95% Confidence Level Limits

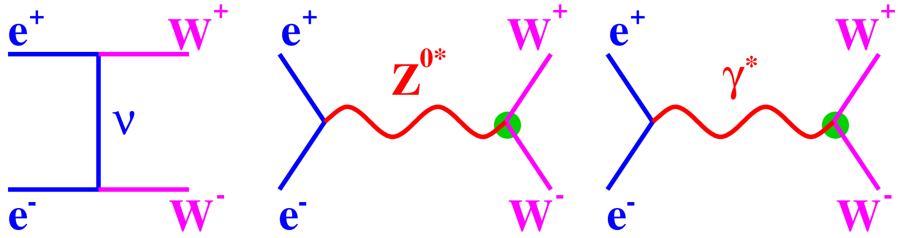
$\sqrt{s} = 183 - 202$ GeV

Coupling	Lower	Upper
$Re\{f_4^{ZZZ}\}$	-1.0	1.1
$Re\{f_5^{ZZZ}\}$	-1.1	1.2
$Re\{f_4^{ZZ\gamma}\}$	-0.6	0.6
$Re\{f_5^{ZZ\gamma}\}$	-1.4	1.4

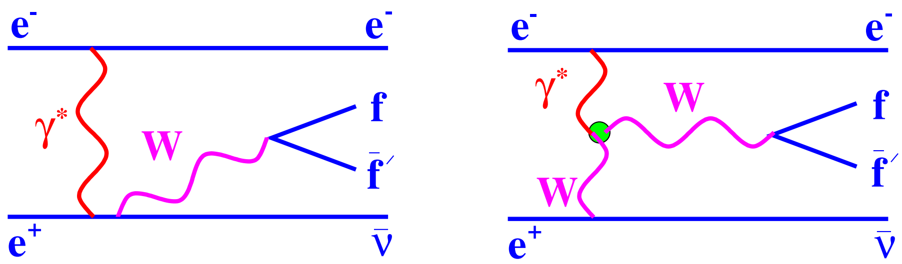


$\mathrm{We}\nu$: TGC's

Previous OPAL results on TGC's from $\mathrm{e}^+\mathrm{e}^- \rightarrow \mathrm{W}^+\mathrm{W}^-$:

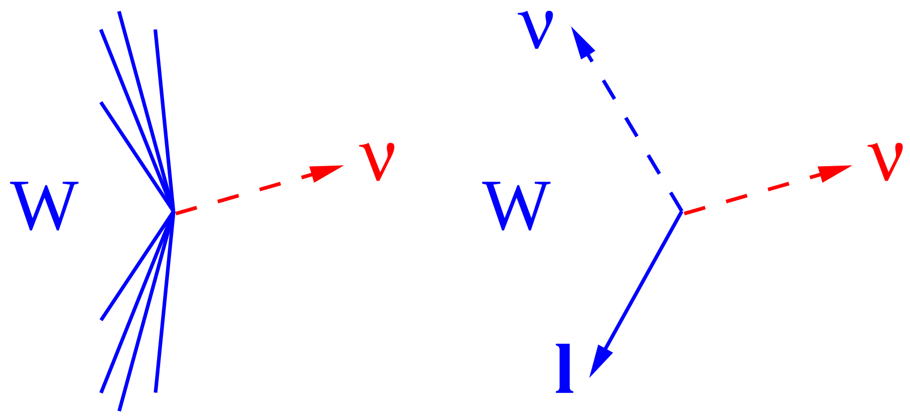


Can improve κ_γ measurement with $\mathrm{e}^+\mathrm{e}^- \rightarrow \mathrm{We}\nu$:

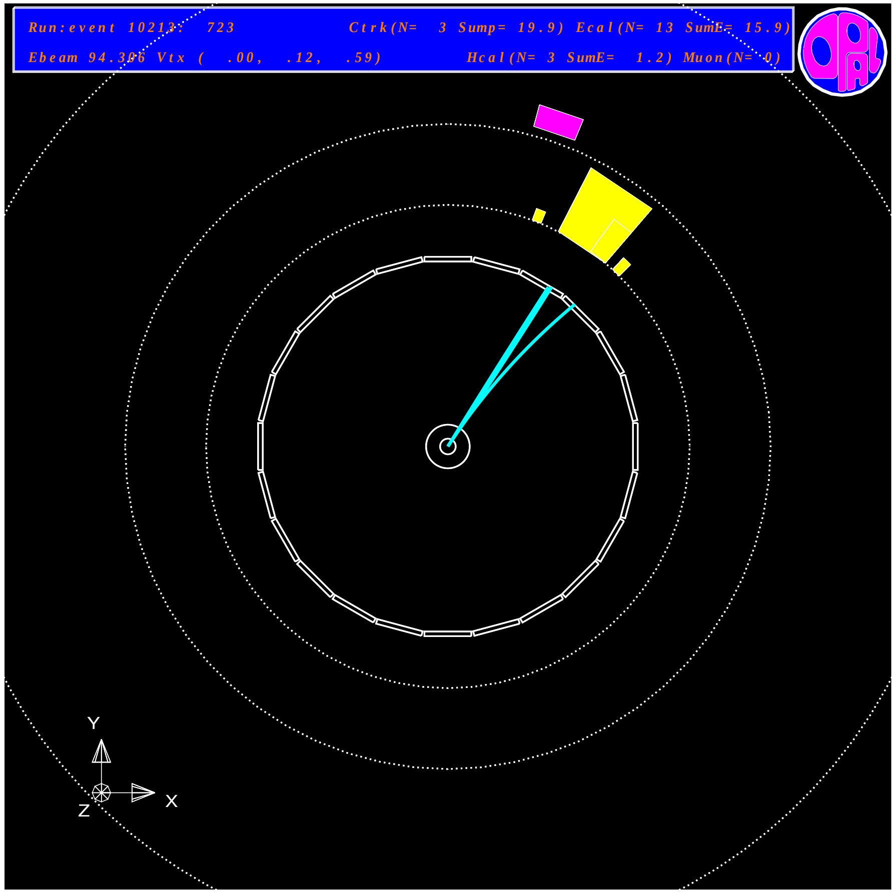


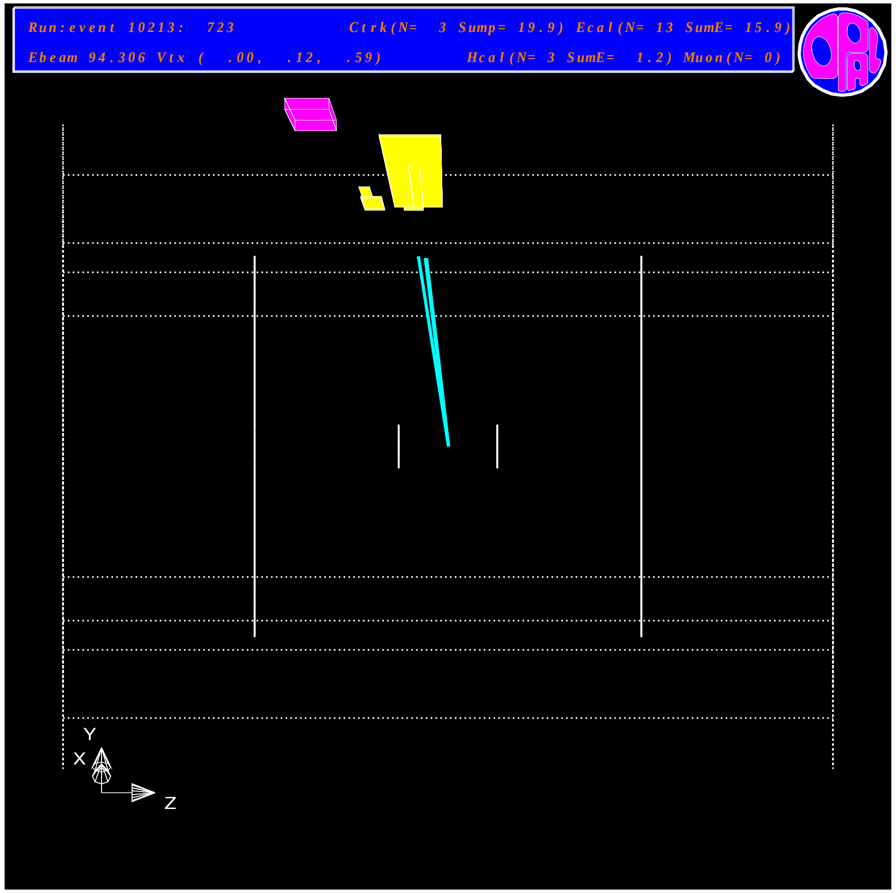
- Electron missing along beam axis
- Event topology is $\mathrm{W}^{\pm} + \not{E}_{\mathrm{T}}$
- Note: 4-fermion backgrounds also depend on TGC's

Hadronic Channel | Leptonic Channel



$We\nu$: W $\longrightarrow \tau\nu$ Candidate

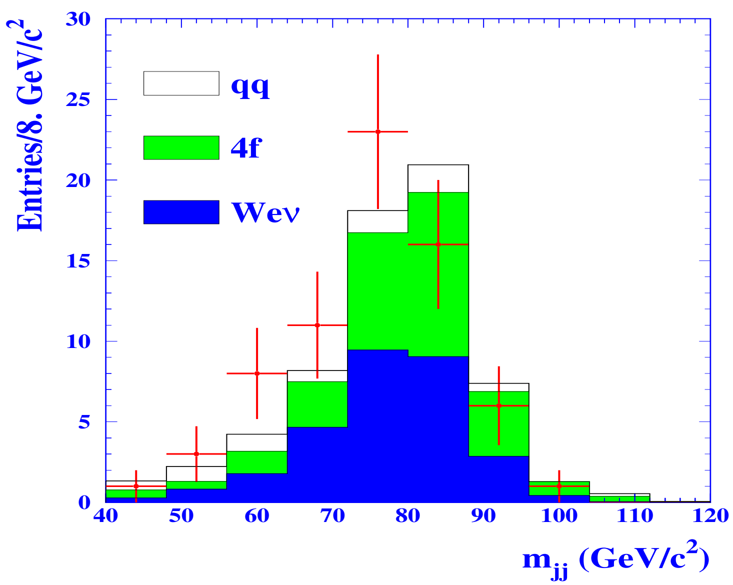




$\mathrm{We}\nu$: Selections at 189 GeV

Hadronic Channel

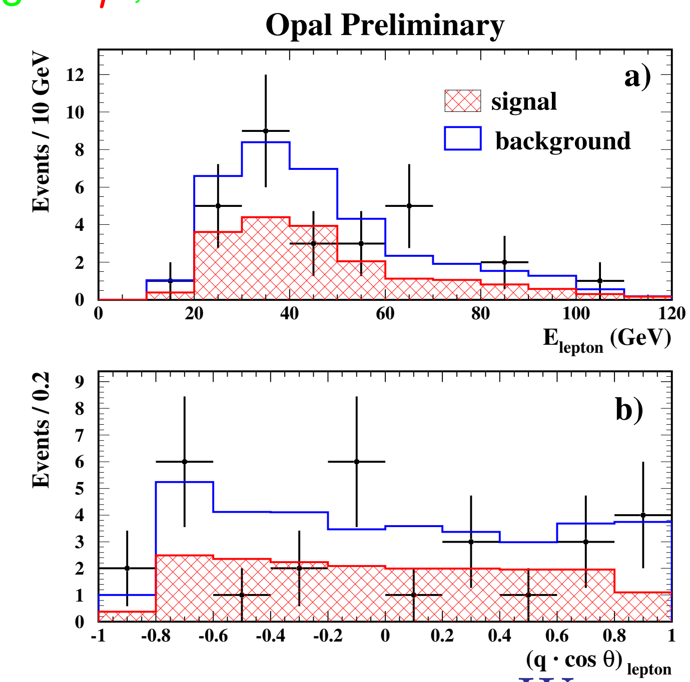
- Select di-jets with $\not\!\!E_T$



Data	Standard Model	$\mathrm{We}\nu$
69	64.3±1.3	29.4±0.5

Leptonic Channel

- Select single eμ, or $\tau \rightarrow \mathrm{h}$



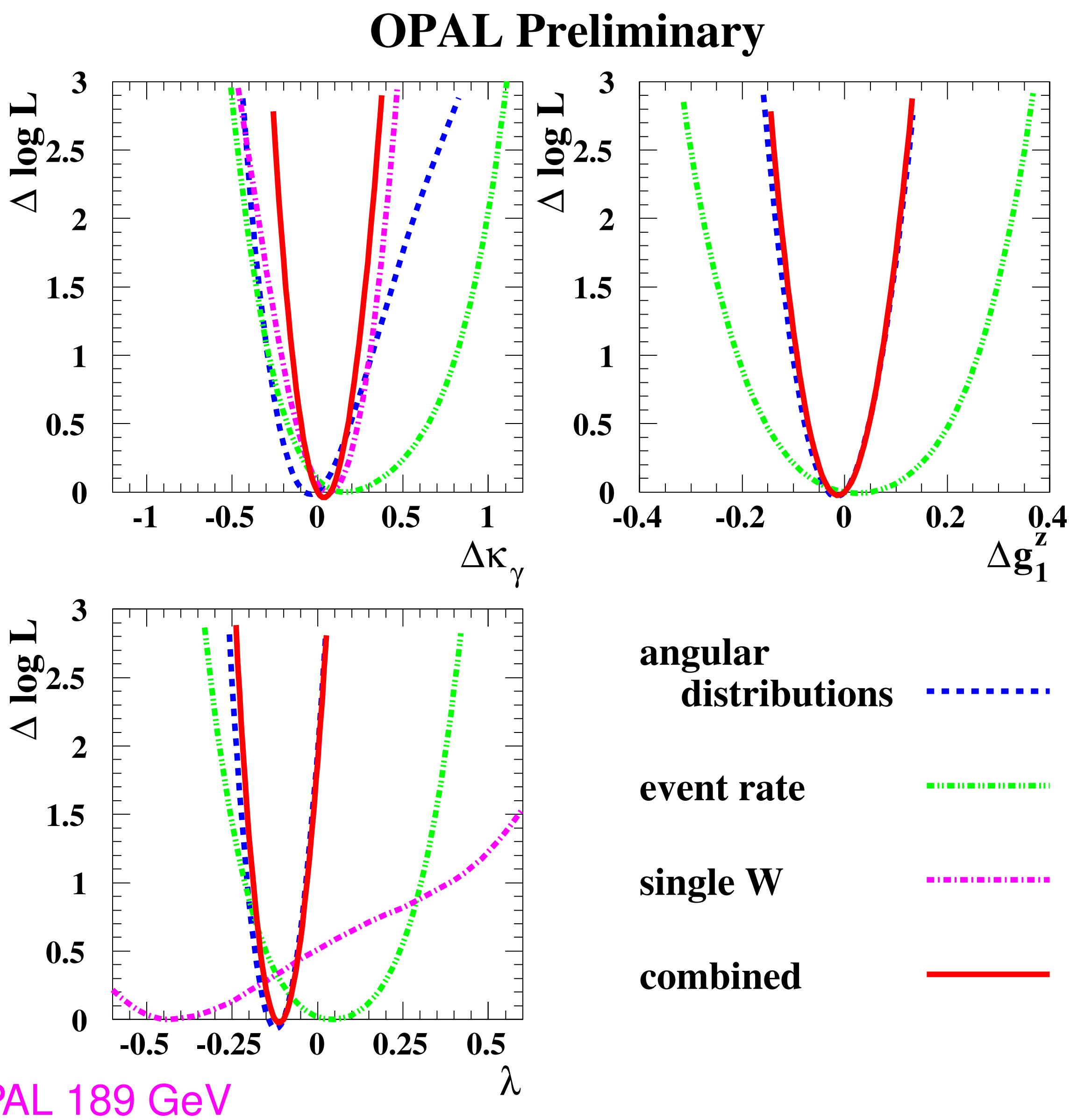
Data	Standard Model	$\mathrm{We}\nu$
29	35.2±0.9	16.5±0.3

$$\sigma_{\mathrm{We}\nu} = (0.67^{+0.16}_{-0.14} \pm 0.06)\ \text{pb} \quad \text{at } \sqrt{s} = 189\ \text{GeV}$$

(grc4f: $\sigma_{\mathrm{We}\nu} = 0.68$ pb)

$e^+e^- \longrightarrow W^+W^-, We\nu$: TGC's

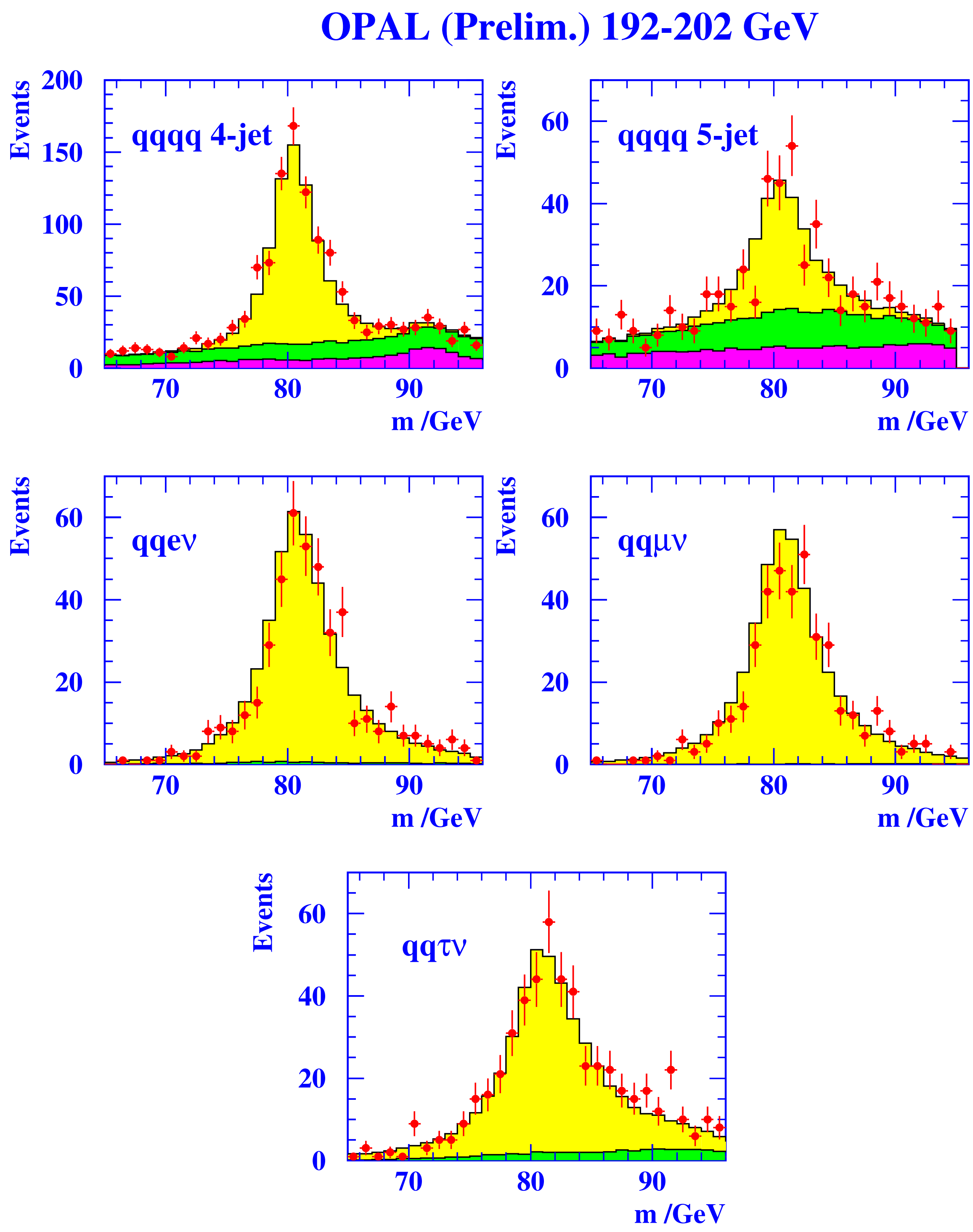
- Combine W^+W^- and $We\nu$ Likelihoods
- Vary one, two, or three couplings



OPAL 189 GeV

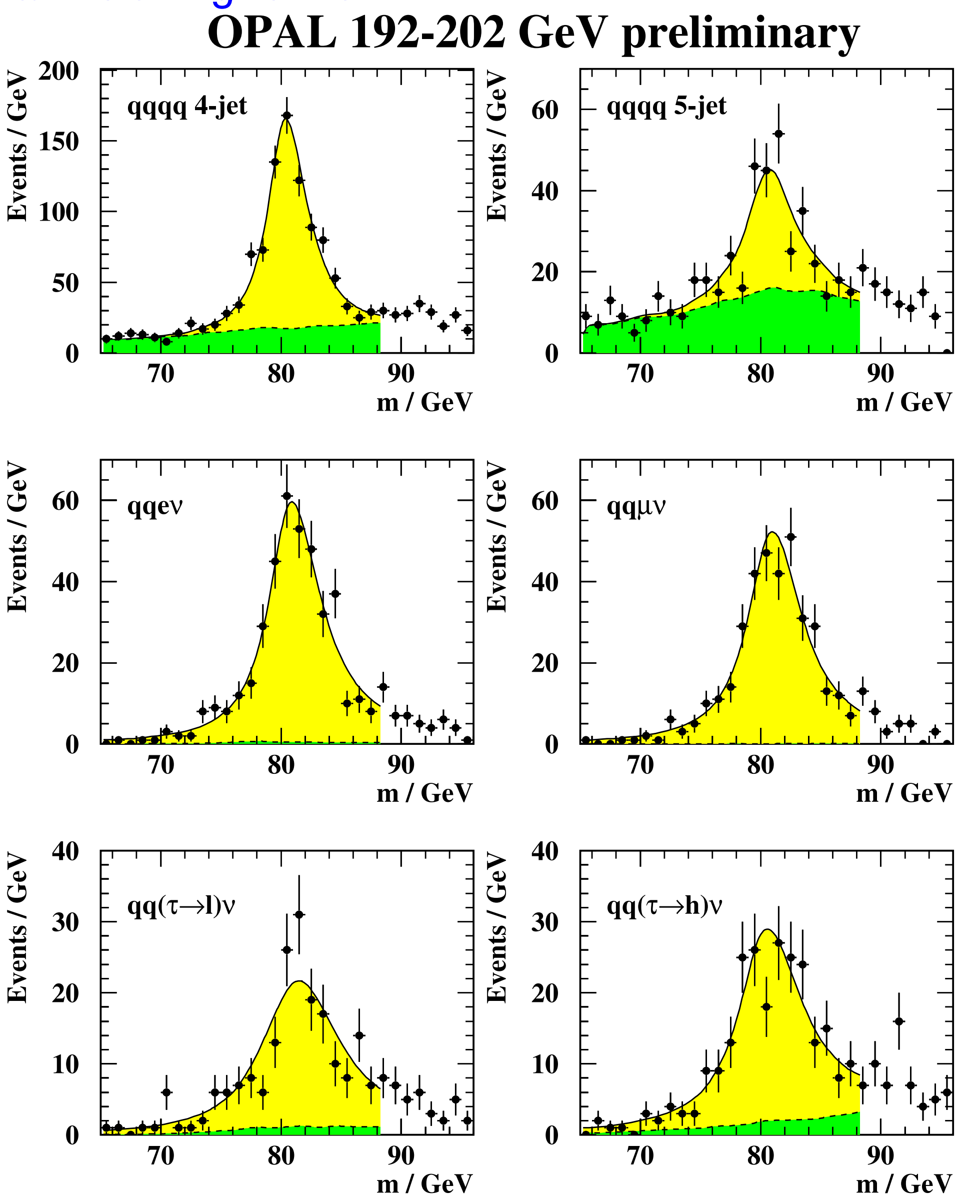
κ_γ	g_1^Z	λ_γ
Combined Results, 1-D		
$1.04^{+0.14}_{-0.13}$	$0.987^{+0.059}_{-0.057}$	$-0.112^{+0.056}_{-0.054}$
Combined Results, 3-D		
$1.09^{+0.15}_{-0.13}$	$1.044^{+0.067}_{-0.068}$	$-0.154^{+0.074}_{-0.072}$

$e^+e^- \longrightarrow W^+W^-: M_W$



$e^+e^- \longrightarrow W^+W^-$: M_W

Using a Breit-Wigner fit:



Combining with previous LEP2 data:

$$M_W = 80.446 \pm 0.051(\mathrm{sta}) \pm 0.028(\mathrm{sys})$$
$$\pm 0.022(\mathrm{FSI}) \pm 0.017(\mathrm{LEP})$$
$$\Delta M_W^{4q-qq\ell\nu} = -0.103 \pm 0.098(\mathrm{sta}) \pm 0.053(\mathrm{sys})$$

$e^+e^- \longrightarrow q\bar{q}e^+e^-$

- Recall DELPHI presentation to LEPC 9/11/99
  - 4-fermion $q\bar{q}e^+e^-$ selection
  - Require $M_{q\bar{q}} \sim M_Z$
  - Mass peak at $M_{ee} \sim$ 53 GeV

$q\bar{q}e^+e^-$ selection, full OPAL 183-202 GeV Data Set

$0)$ ≥ 7 tracks including two electron candidates

$1)$ Force 2-jets $+$ 2-e's, 4-C fit

$2)$ $E/p >$ 0.7 for both e's

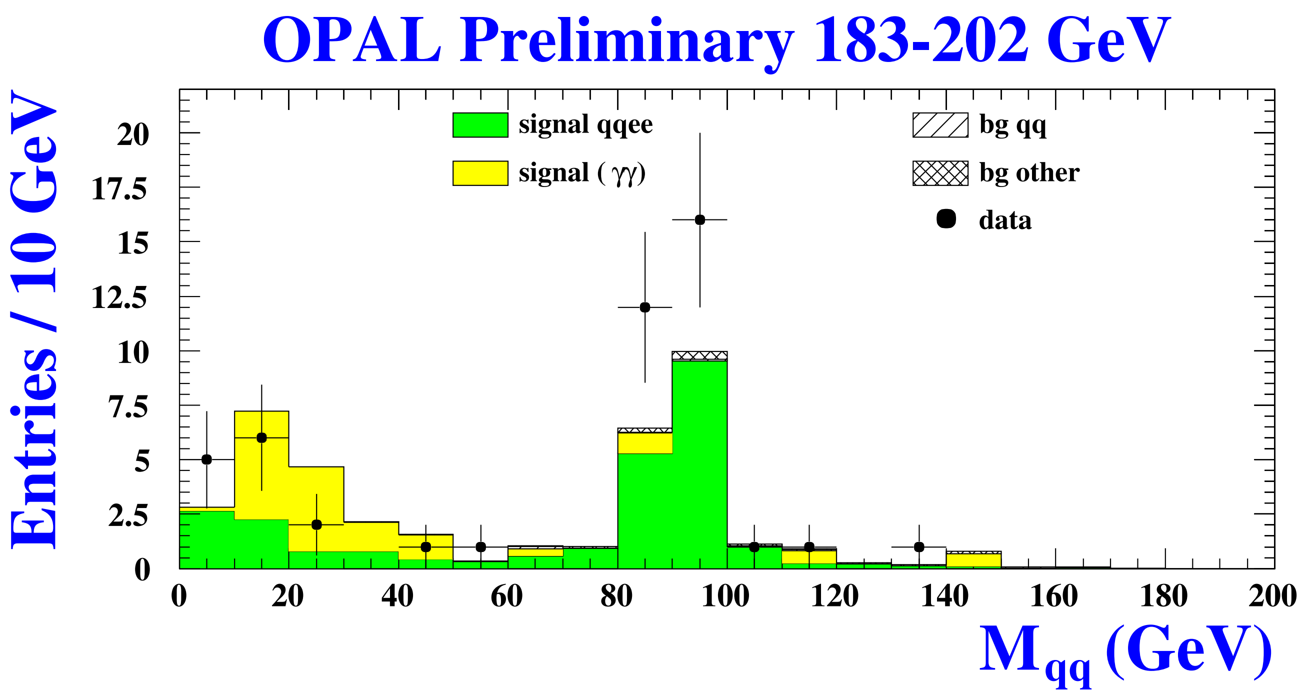
$3)$ $p_1^e + p_2^e >$ 30 GeV

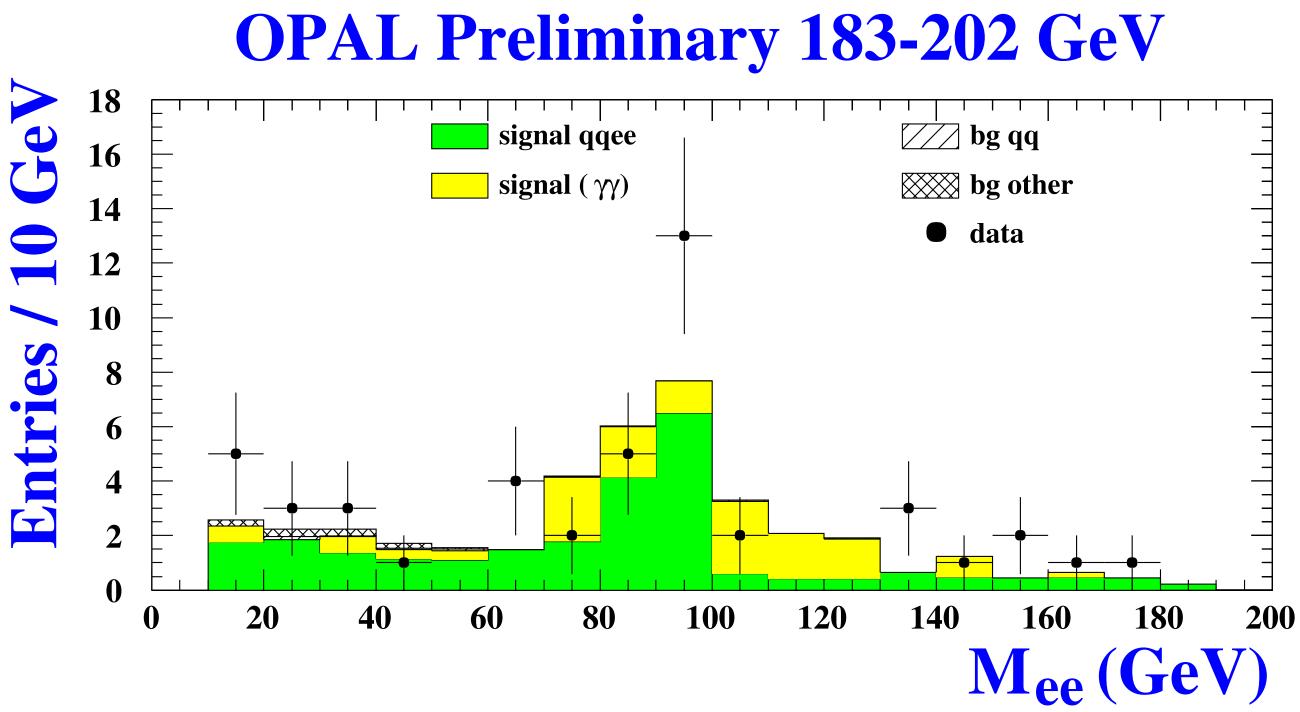
$4)$ $M_{ee} >$ 10 GeV

Cut	Data	S.M. Total	S.M. $q\bar{q}e^+e^-$
0	1087	1168.0±7.5	164.1±5.3
1	220	235.2±3.3	52.6±2.7
2	109	111.4±2.8	48.0±2.5
3	78	72.5±2.5	44.4±2.3
4	46	40.2±2.3	38.8±2.3

$\Rightarrow$ Look at these events

$e^+e^- \longrightarrow q\bar{q}e^+e^-$: Mass plots

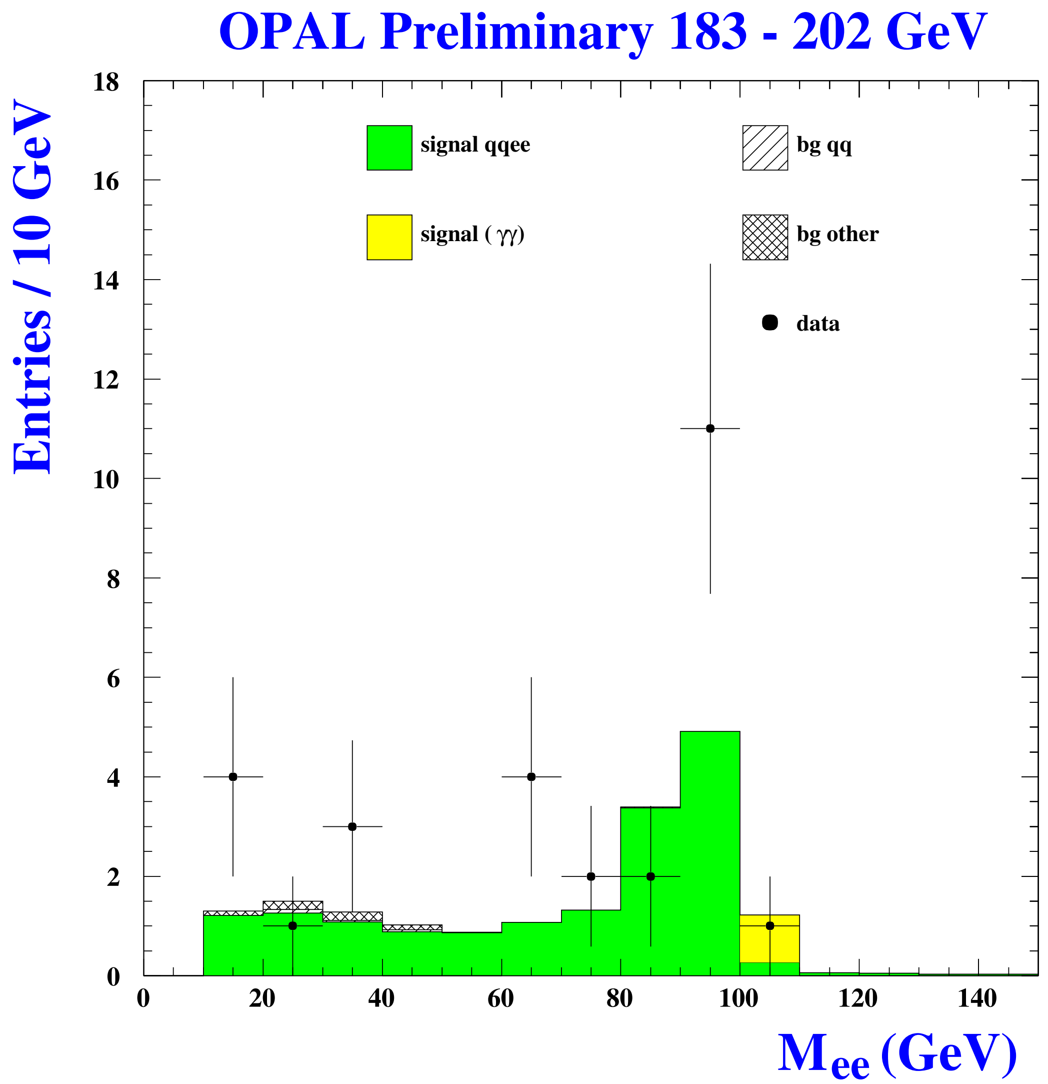




$\Rightarrow$ **Small excess in Z^0Z^0 region**

$e^+e^- \longrightarrow q\bar{q}e^+e^-$: M_{ee}

Cut	Data	S.M. Total
80 GeV $< M_{qq} <$ 102 GeV	28	17.3$\pm$0.8

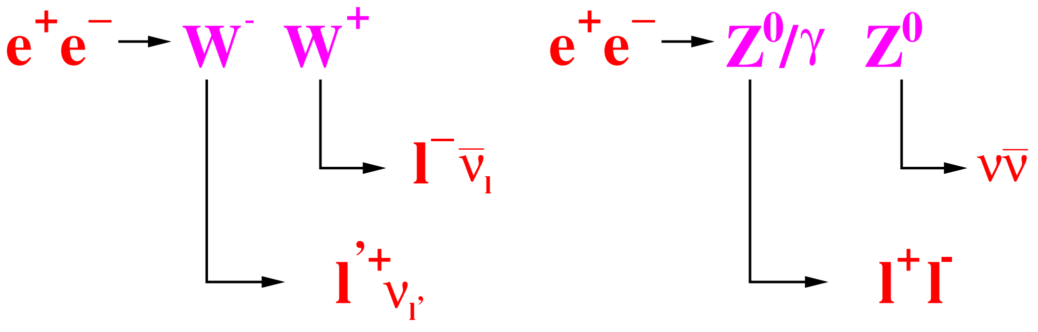


- $q\bar{q}e^+e^-$ efficiency (59$\pm$4)% for 50 GeV $< M_{ee} <$ 60 GeV
- $M_{e^+e^-}$ resolution is 1.7 GeV

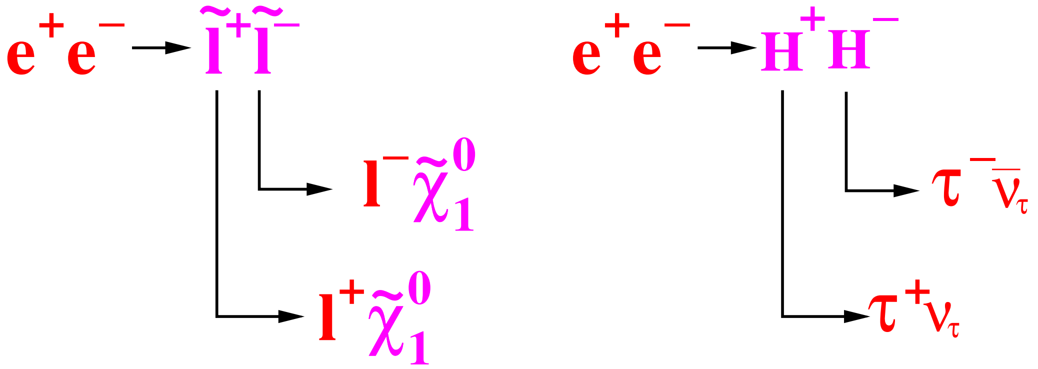
Cut	Data	S.M. Total
50 GeV $< M_{ee} <$ 60 GeV	0	0.80$\pm$0.12

$\ell^+\ell'^- + \not{E}_T$

- In Standard Model: many 4-fermion contributions. *eg:*



- Beyond Standard Model: $\tilde{\ell}^+\tilde{\ell}^-$, $\tilde{\chi}^+\tilde{\chi}^-$, $\mathrm{H}^+\mathrm{H}^-$, $\ell^{*\pm}\ell^{\mp}$, ...



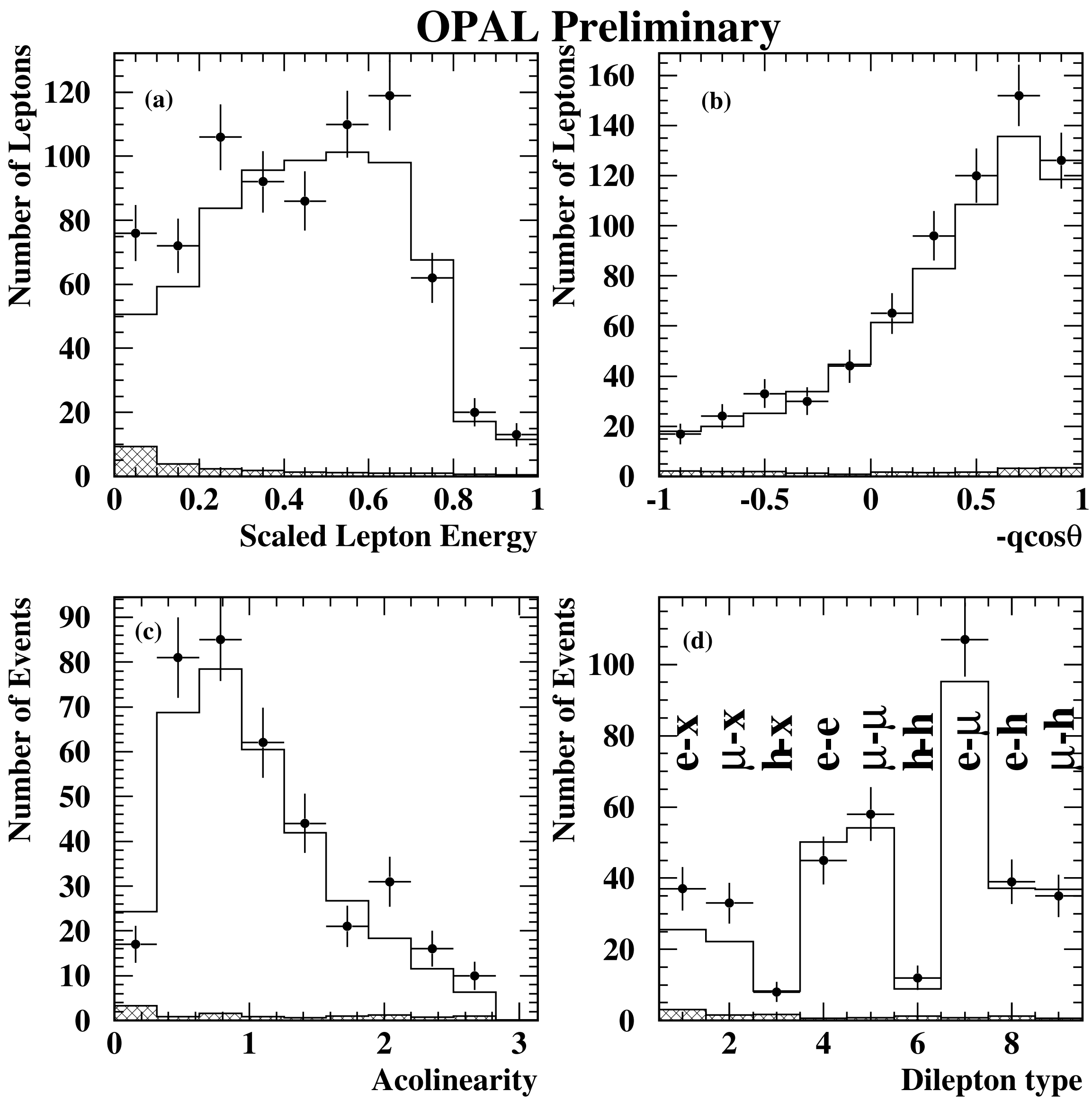
General Selection Results

$\sqrt{s}$ (GeV)	Data	SM Total
183	78	81.4±0.8
189	301	303.3±1.9
192	55	48.8±0.6
196	152	130.5±1.1
200	124	126.0±0.8
202	50	38.0±0.2
192-202	381	343.3±1.7

$\Rightarrow 2.0\,\sigma$ (stat. only) overall excess in 1999 data

$\ell^+\ell'^- + \not{E}_T$: Data *vs.* SM

$\sqrt{s} = 192$–202 GeV



Using Kolmogorov tests:

All shapes consistent with the predominantly $\mathrm{W^+W^-}$ background

Excited Leptons

$e^+e^- \to l^{+*}\ l^-$

$\quad \llcorner \to l^+\gamma, \nu W, lZ$

$e^+e^- \to \nu^*\ \nu$

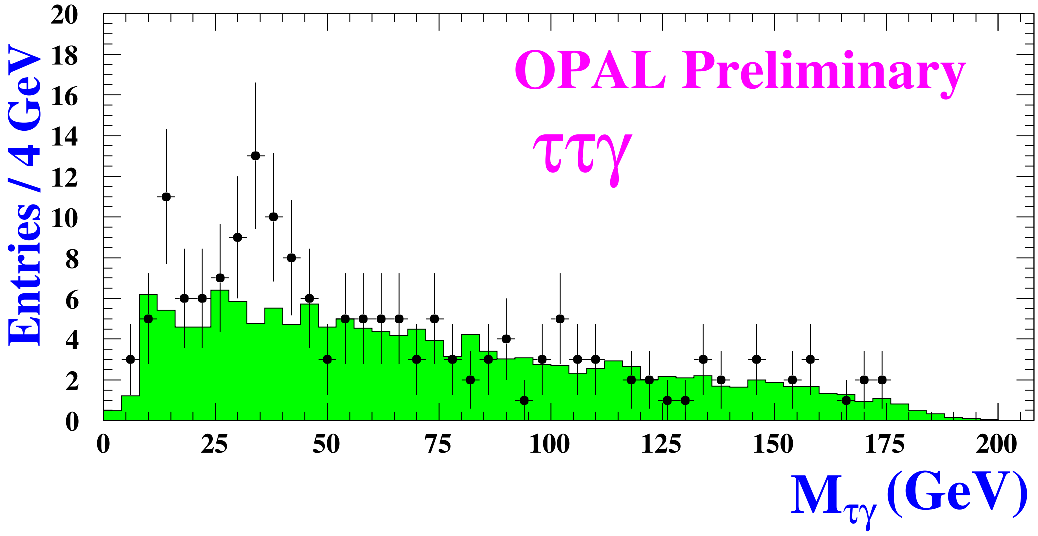
$\quad \llcorner \to \nu\gamma,\ lW, \nu Z$

$\Rightarrow$ Search for ℓ (or ν) $+ \gamma, \mathrm{W}, \mathrm{Z}^0$

Pair Production 192–202 GeV:

Channel	N_{DATA}	N_{SM}
e^+e^- WW	4	4.9±0.5
$\mu^+\mu^-$ WW	11	9.9±1.1
$\tau^+\tau^-$ WW	66	54±14
$e^+e^-\gamma\gamma$	7	10.4±2.6
$\mu^+\mu^-\gamma\gamma$	4	3.9±0.3
$\tau^+\tau^-\gamma\gamma$	0	3.2±0.3

Single Production 192–202 GeV: bump hunting



$\ell^*,\ \nu^*$: New combinations

$$e^+e^- \to l^{+*}\ \ l^- \qquad\qquad e^+e^- \to \nu^*\ \nu$$

$$l^{+*} \to l^+\gamma,\ \nu W,\ lZ \qquad\qquad \nu^* \to \nu\gamma,\ \ lW,\ \nu Z$$

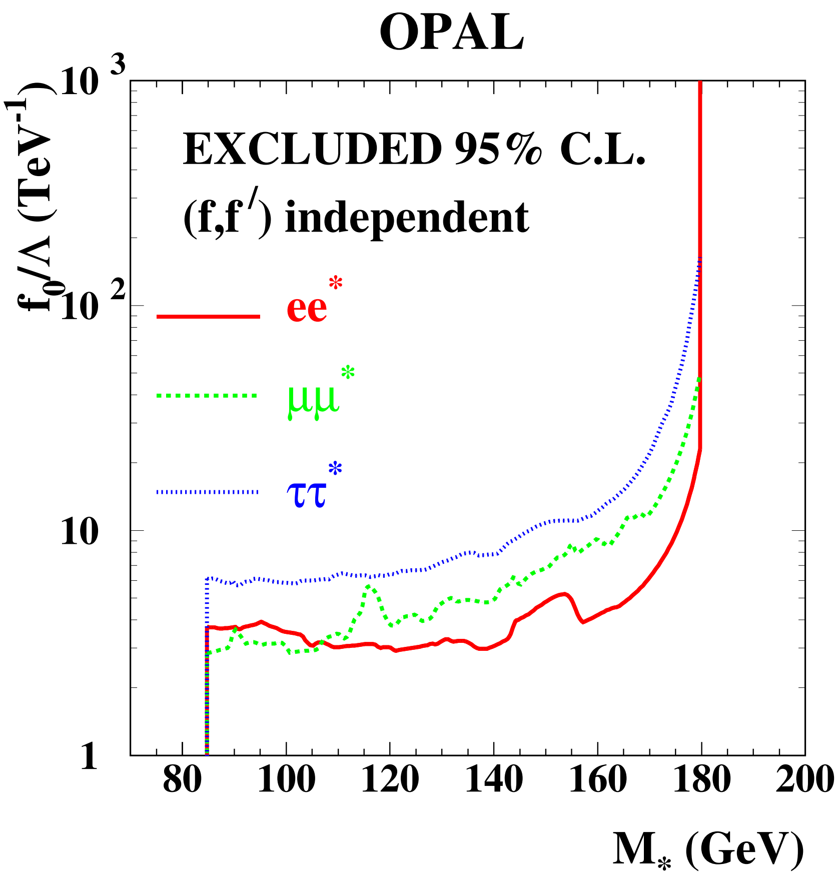
Work in general formalism:

$$\mathcal{L}_{\ell\ell^*} = \frac{1}{2\Lambda}\bar{\ell}^*\sigma^{\mu\nu}\left[g\,f\,\frac{\boldsymbol{\tau}}{2}\mathbf{W}_{\mu\nu} + g'\,f'\,\frac{Y}{2}B_{\mu\nu}\right]\ell_{\mathrm{L}} + \mathrm{h.c.}$$

Old: Picked examples $f = \pm f'$

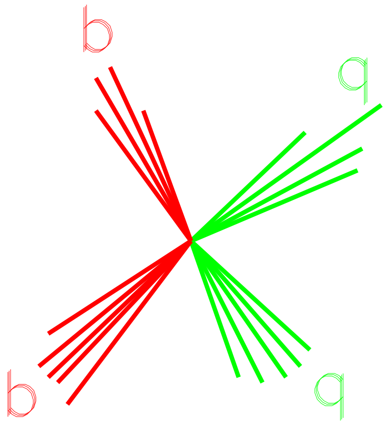
New: $\quad f_0 = \sqrt{\frac{1}{2}(f^2 + f'^2)} \qquad \tan\phi_f = f/f'$

Scan ϕ_f (cross-sections, BR's) $\Rightarrow$

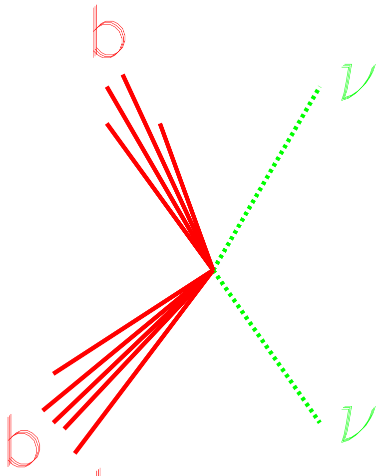


Higgs Searches at 192–202 GeV

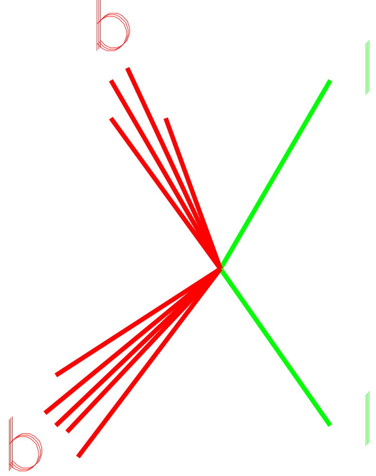
- 1 required by SM: H^0
- Extensions: h^0, H^0, A^0, $\mathrm{H}^\pm$



$$\mathrm{H}^0\mathrm{Z}^0 \to \mathrm{b}\bar{\mathrm{b}}\mathrm{q}\bar{\mathrm{q}}$$
$$\varepsilon \approx 45\%$$



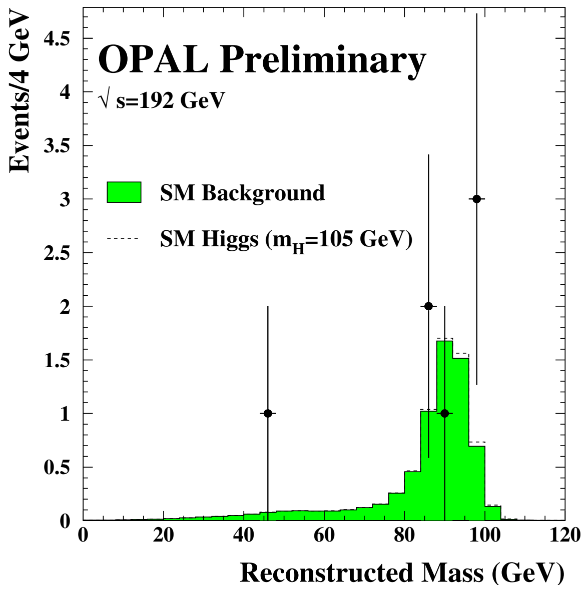
$$\mathrm{H}^0\mathrm{Z}^0 \to \mathrm{b}\bar{\mathrm{b}}\nu\bar{\nu}$$
$$\varepsilon \approx 40\%$$

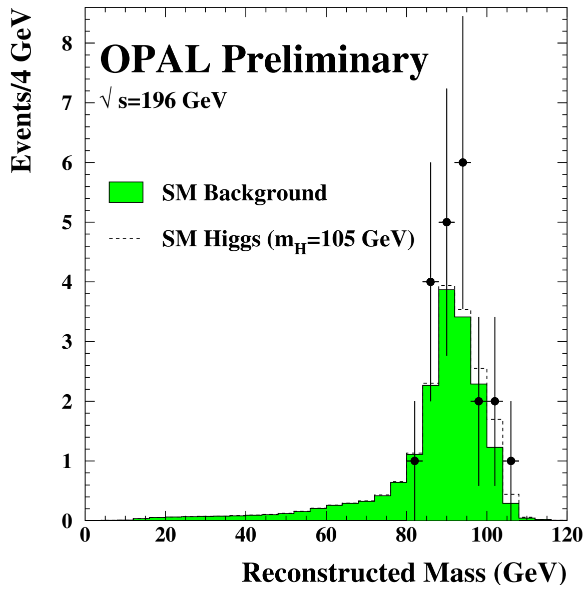


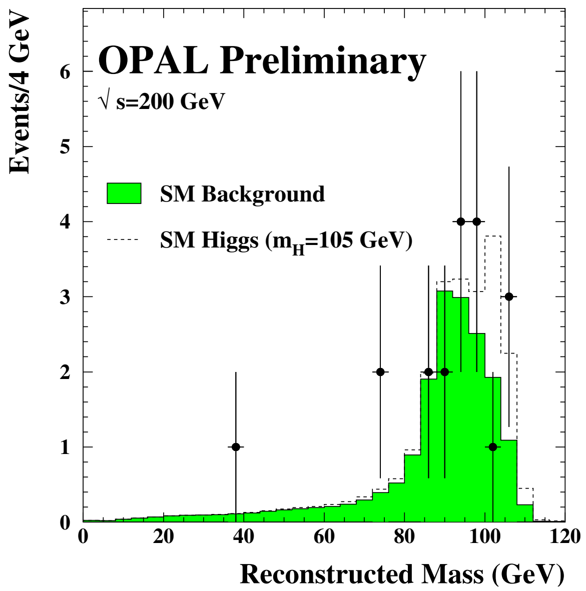
$$\mathrm{H}^0\mathrm{Z}^0 \to \mathrm{b}\bar{\mathrm{b}}\ell^+\ell^-$$
$$\varepsilon \approx 35 - 75\%$$

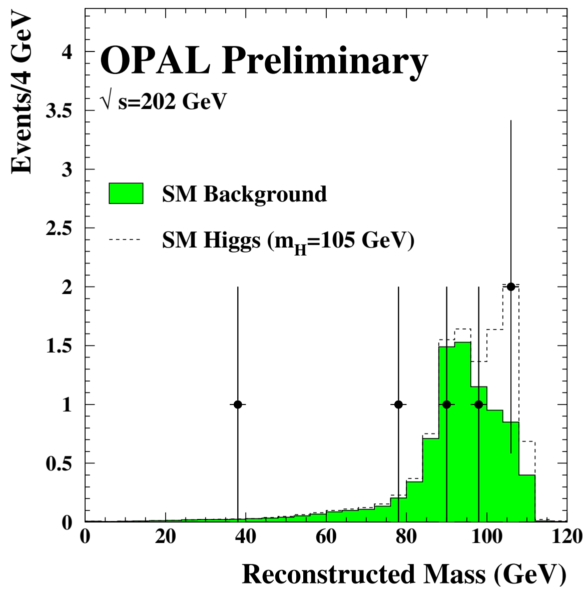
SM Higgs Results for 192–202 GeV

Channel	N_{DATA}	N_{BG}
$H^0Z^0 \rightarrow b\bar{b}q\bar{q}$	33	27.7±3.6
$H^0Z^0 \rightarrow b\bar{b}\nu\nu$	6	9.3±1.1
$H^0Z^0 \rightarrow b\bar{b}\tau^+\tau^-$	4	6.4±1.1
$H^0Z^0 \rightarrow b\bar{b}\ell^+\ell^-$	10	8.1±0.9
Total	53	51.5±6.4

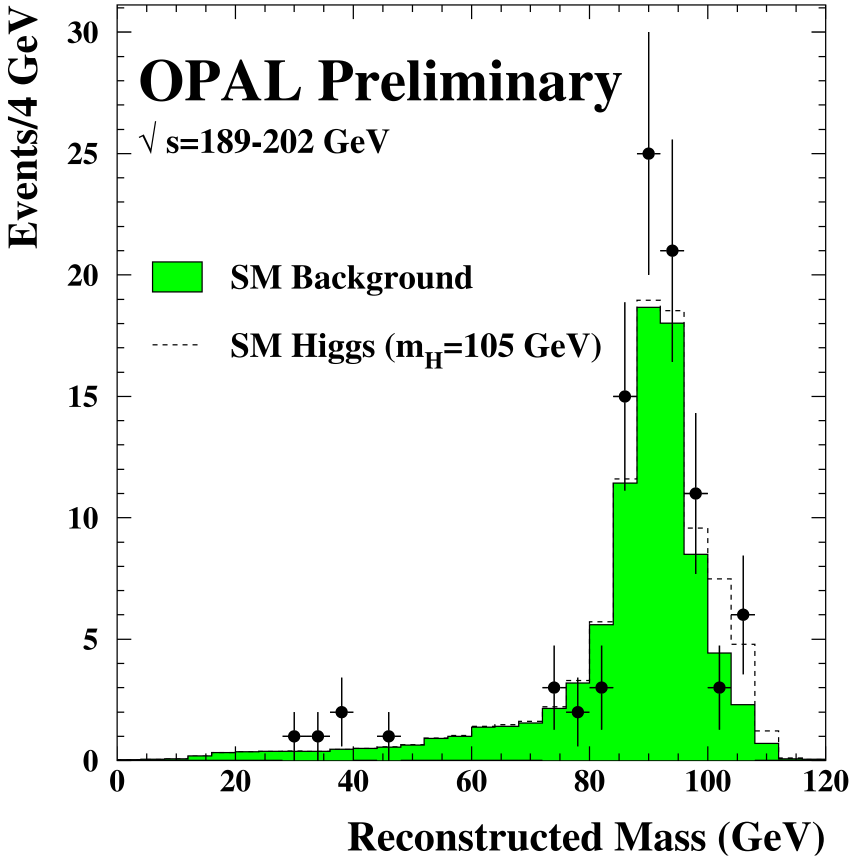


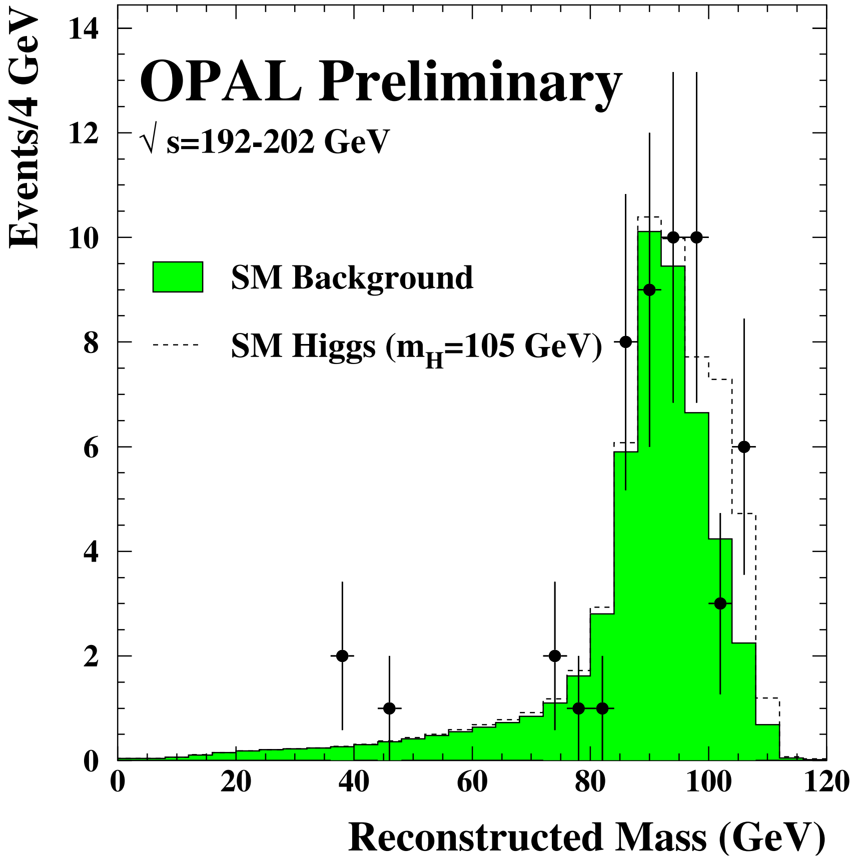






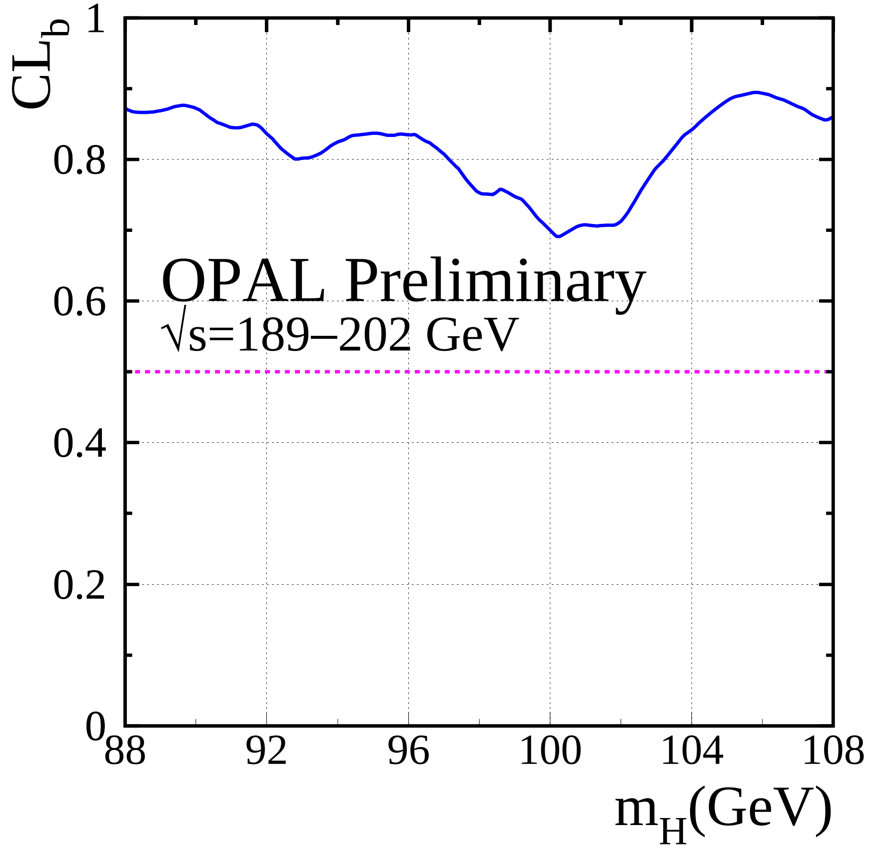
SM Higgs: Mass Plots, 189–202 GeV



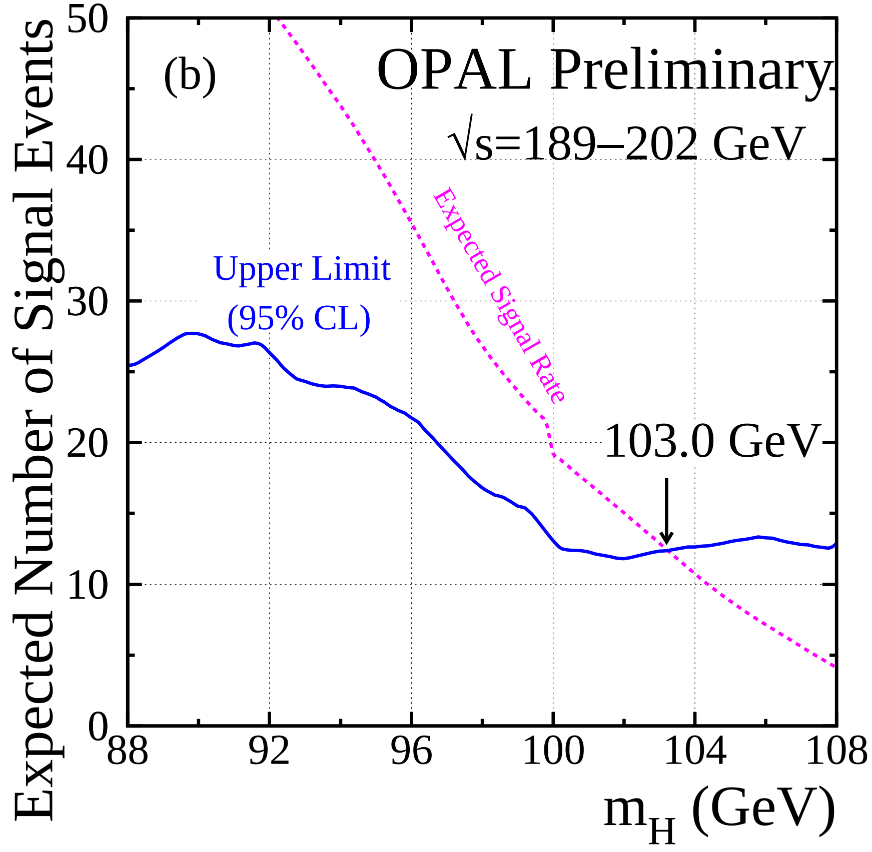


SM Higgs

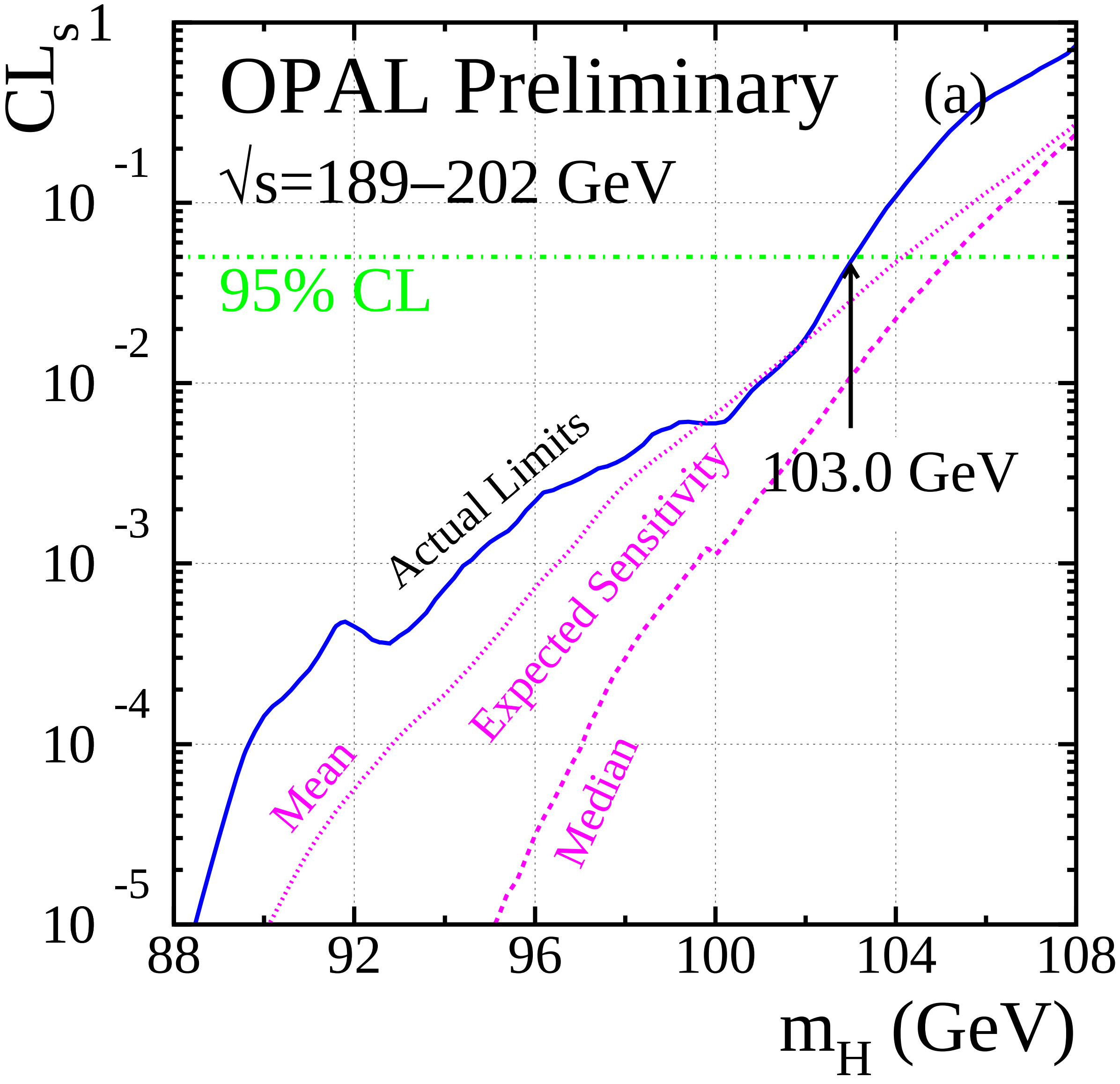
Bkg C.L.



N95



SM Higgs: Mass Limits



$M_{H^0} >$ 103.0 GeV 95% C.L.

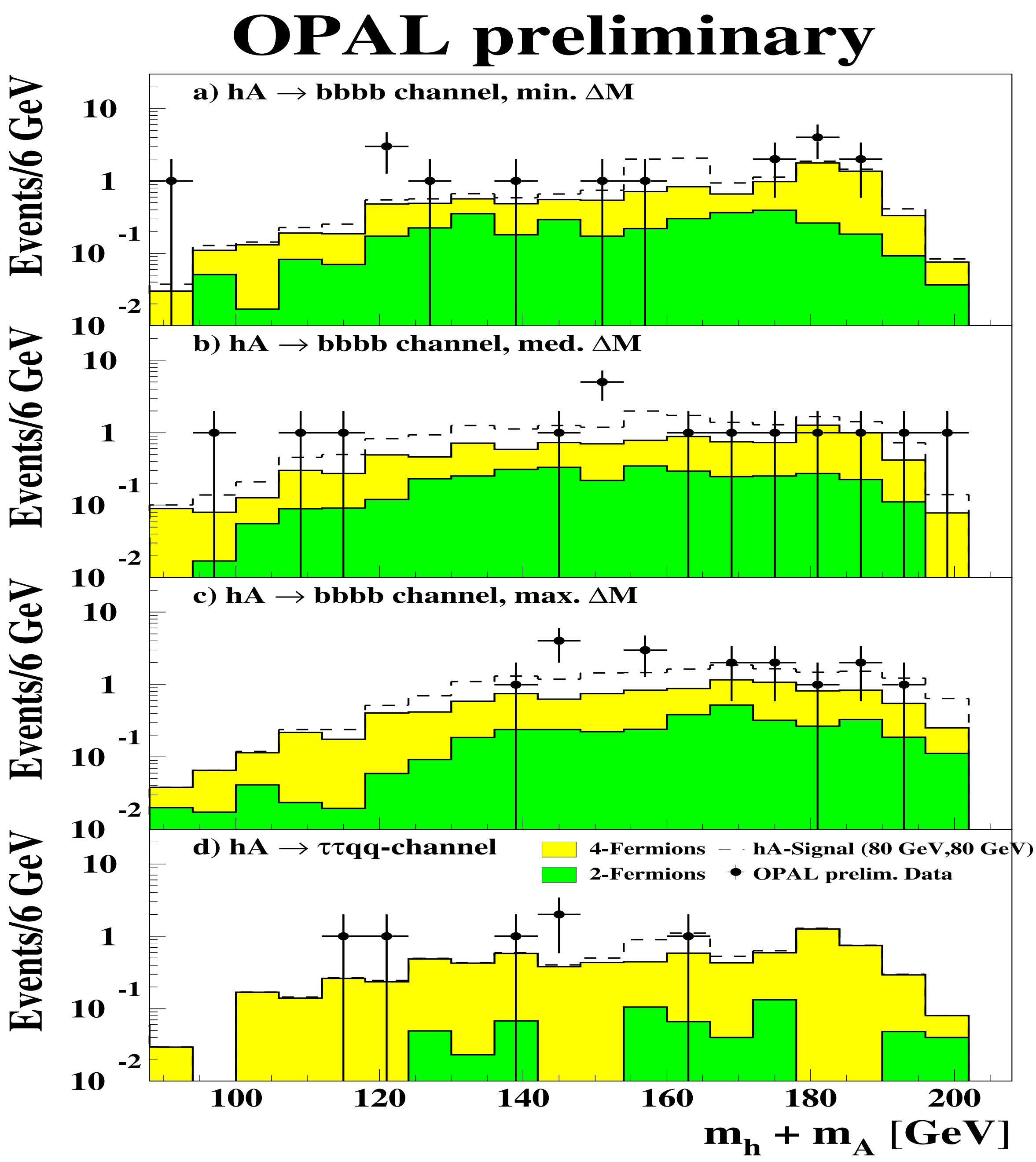
(mean bkg only limit is 104.1 GeV)

(median bkg only limit is 105.2 GeV)

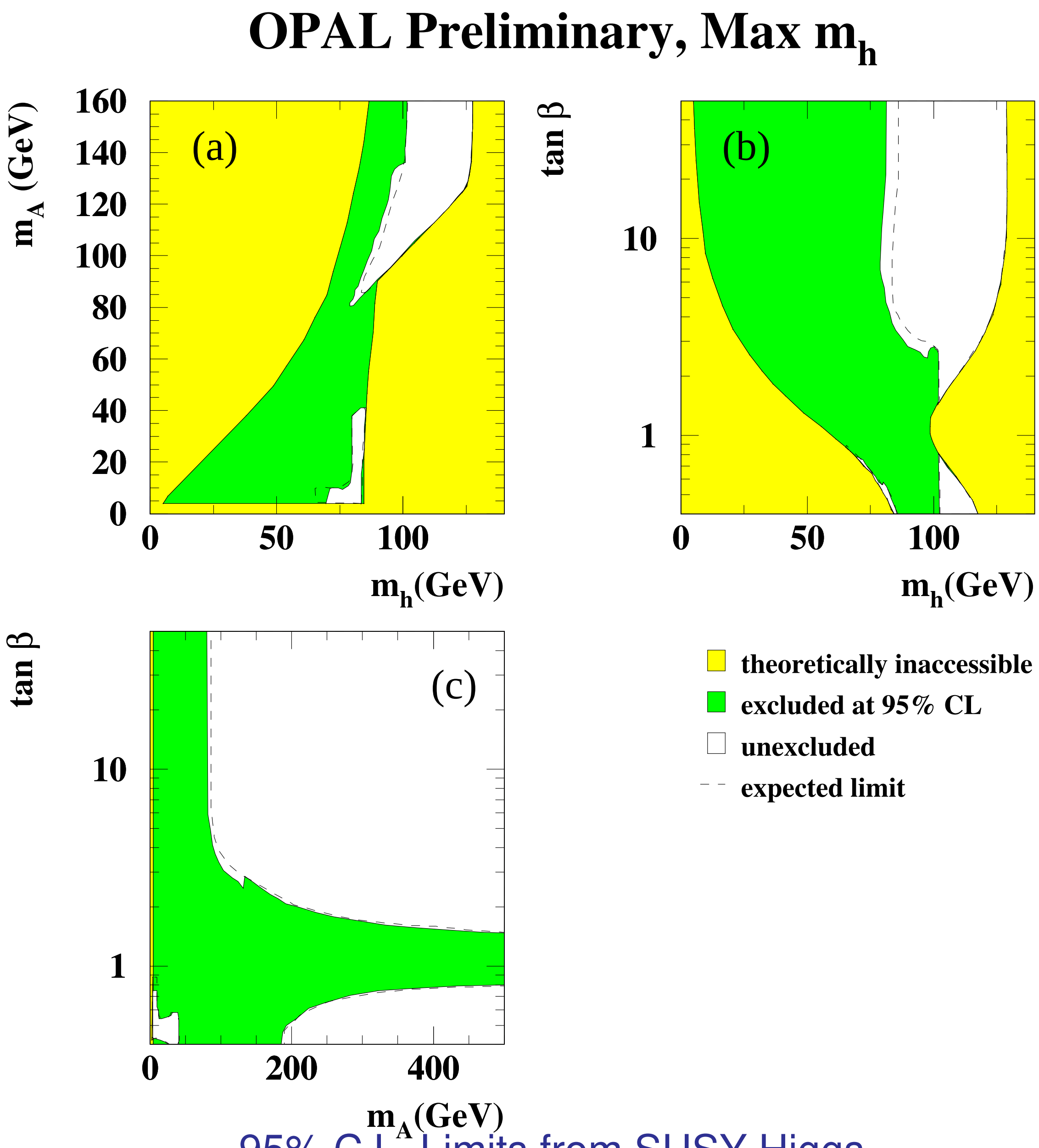
$e^+e^- \longrightarrow A^0h^0$

192–202 GeV

Channel	N_{DATA}	N_{BG}
$A^0h^0 \rightarrow b\bar{b}b\bar{b}$	16	10.5±1.2
$A^0h^0 \rightarrow \tau^+\tau^-b\bar{b}$	6	7.7±1.9



SUSY Higgs Limits



95% C.L. Limits from SUSY Higgs

Scenario	m_{h} $\tan\beta > 1$	m_{A} $\tan\beta > 1$	$\tan\beta$
No Mixing	79.0 (83.9)	80.1 (85.3)	0.9–3.1
Max m_{h}	79.2 (83.7)	80.2 (85.4)	0.8–1.5
Large μ	78.2 (83.5)	80.5 (86.0)	0.4–4.8

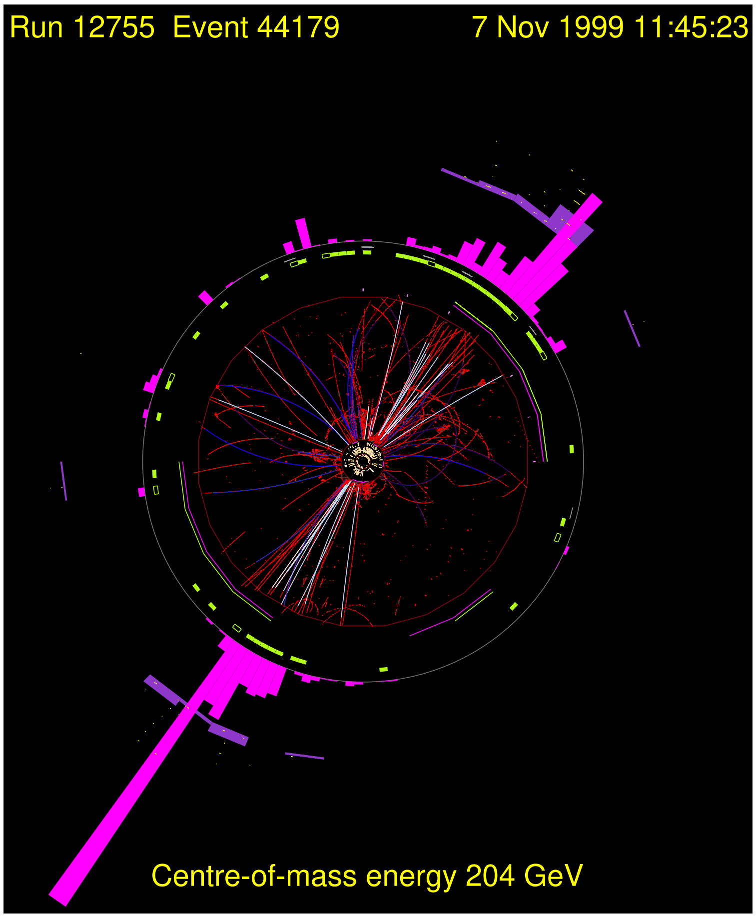
Summary

- LEP1 activity ongoing
- LEP2 precision measurements improving with increasing statistics and detailed systematic studies
- The higgs is not *quite* there yet
- There are excesses under study

7 November 1999

$\sqrt{s} = 204$ GeV

(Taken after mini-ramp)



... and we look forward to more data and higher energies in

Y2K