What's New at OPAL...

Douglas A. Glenzinski
Enrico Fermi Institute,
University of Chicago

On behalf of the OPAL Collaboration

LEP2 Physics Jamboree
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Recent OPAL Publications

During the LEP2 era:

- $\langle \mathrm{N}_{\mathrm{papers}}(\mathrm{OPAL}) \rangle \approx 40/\mathrm{year}$
- $\mathrm{N}\left(\frac{\mathrm{LEP1}}{\mathrm{LEP2}}\right) = \frac{1}{1}$

$\Rightarrow$ After a decade, OPAL still an exciting place to be!

$\Rightarrow$ LEP1.0 data continues to provide new and interesting results

$\Rightarrow$ Sidetrack to some LEP1 Highlights

$\Rightarrow$ For "LEP2 Jamboree", concentrate on LEP2 results

Recent LEP1 Highlights

$\tau^- \to e^- \overline{\nu_e} \nu_\tau$

- Full LEP1 statistics yields 186k τ-decays
- $\mathrm{BR}\,(\tau^- \to e^- \overline{\nu_e} \nu_\tau) = 17.81 \pm 0.09 \pm 0.06\%$
- most precise measurement

B^0 and B^+ lifetimes

- Full LEP1-SI statistics yields 10k reconstructed secondary vertices
- $\tau_{B^+} = 1.643 \pm 0.037 \pm 0.025$ ps
  $\tau_{B^0} = 1.523 \pm 0.057 \pm 0.053$ ps
- most precise τ_{B^+} meausurement
- test for CPT violation:
  $\frac{\tau(b)-\tau(\bar{b})}{\tau_{\mathrm{avg}}} = -0.001 \pm 0.012 \pm 0.008$

Recent LEP1 Highlights

b-hadron semileptonic BR

- Full LEP1-SI statistics yields 300k identified b-hemispheres
- $\mathrm{BR}(\mathrm{b} \to \ell \mathrm{X}) = 10.80 \pm 0.08^{+0.31}_{-0.25}\%$
  $\mathrm{BR}(\mathrm{b} \to \mathrm{c} \to \ell \mathrm{X}) = 8.29 \pm 0.18^{+0.27}_{-0.30}\%$
- most precise $\mathrm{BR}(\mathrm{b} \to \mathrm{c} \to \ell \mathrm{X})$ measurement
- method affords reduced sensitivity to modelling

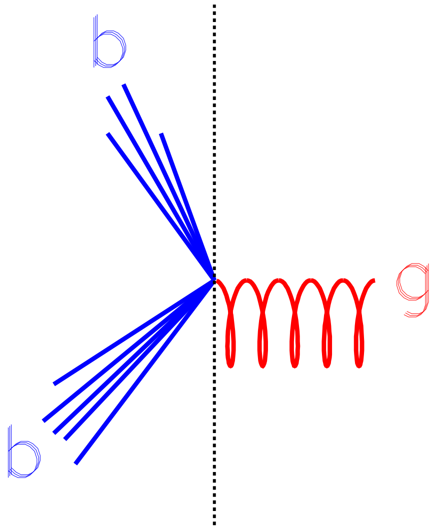
Flavour Independence of α_{s}

- employs $\mathcal{O}(\alpha_{\mathrm{s}}^2)$ calculations including $\mathrm{m}_{\mathrm{b,c}}$
- $\alpha_{\mathrm{s}}^{\mathrm{c}}/\alpha_{\mathrm{s}}^{\mathrm{uds}} = 0.997 \pm 0.038 \pm 0.032$
  $\alpha_{\mathrm{s}}^{\mathrm{b}}/\alpha_{\mathrm{s}}^{\mathrm{uds}} = 0.993 \pm 0.008 \pm 0.013$
- most precise $\alpha_{\mathrm{s}}^{\mathrm{c}}/\alpha_{\mathrm{s}}^{\mathrm{uds}}$ measurement

Recent LEP1 Highlights

Comparisons of quark and gluon jets

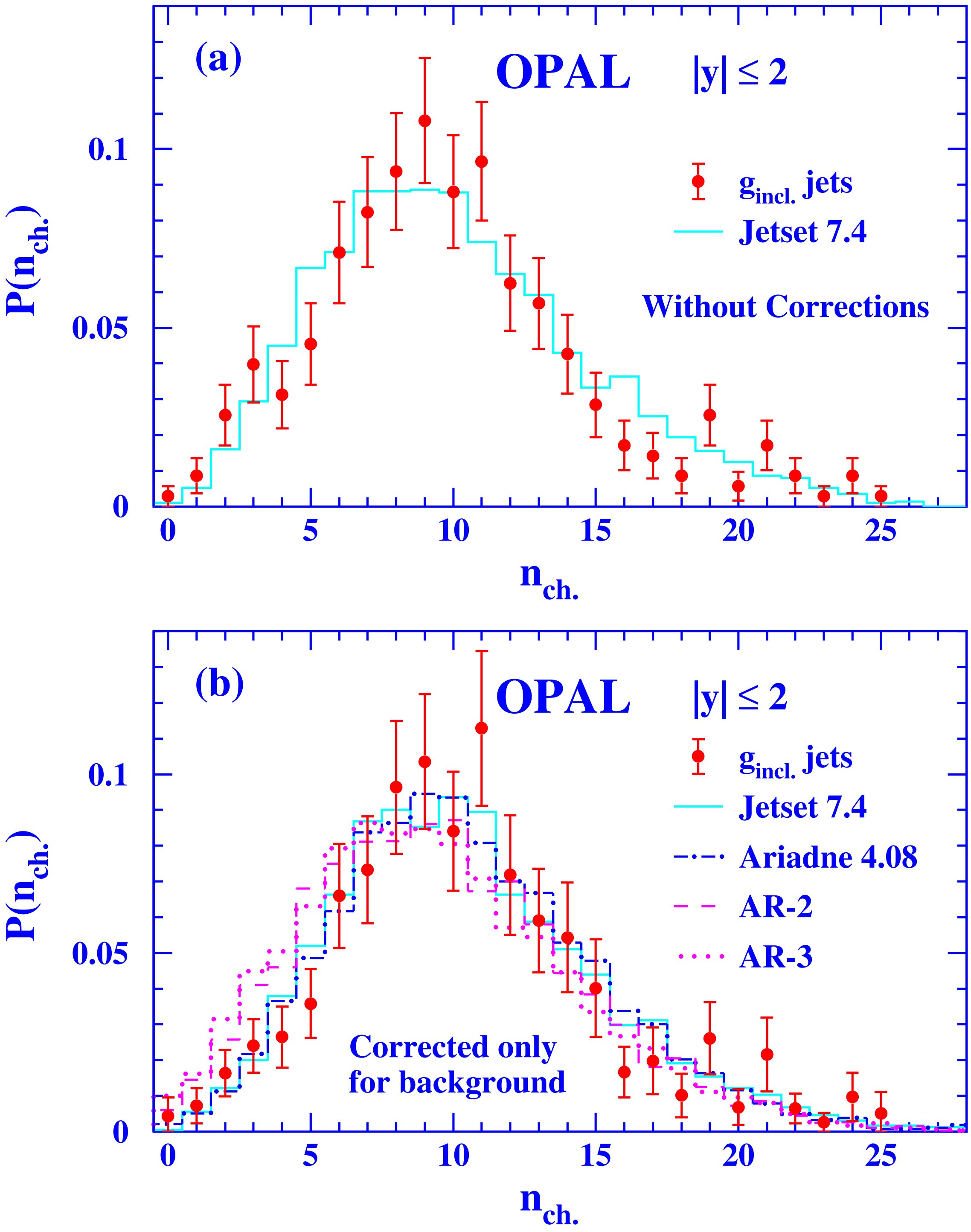
- Full LEP1 statistics
- define "gluon jet" ≈ gluon from a colour singlet point source (facilitates comparisons with QCD)



- compare properties with hemispheres of uds-jets
- measure soft particle mulitplicity
  $\frac{\text{gluon}}{\text{uds}} = 2.29 \pm 0.09 \pm 0.15 \quad \left(\frac{C_A}{C_F} = 2.25\right)$
- offers constraints of CR models (impacts M_W!)
- AR3 and AR2 disfavoured in data

Recent LEP1 Highlights

N_{trk} Distribution in gluon jets



- AR3 and AR2 disfavoured in data

LEP2 Highlights

Outline

- Detector Status/Data Sets
- 2-Fermions Production
- QCD
- W^+W^-
- Higgs Searches
- SUSY Searches
- Conclusions

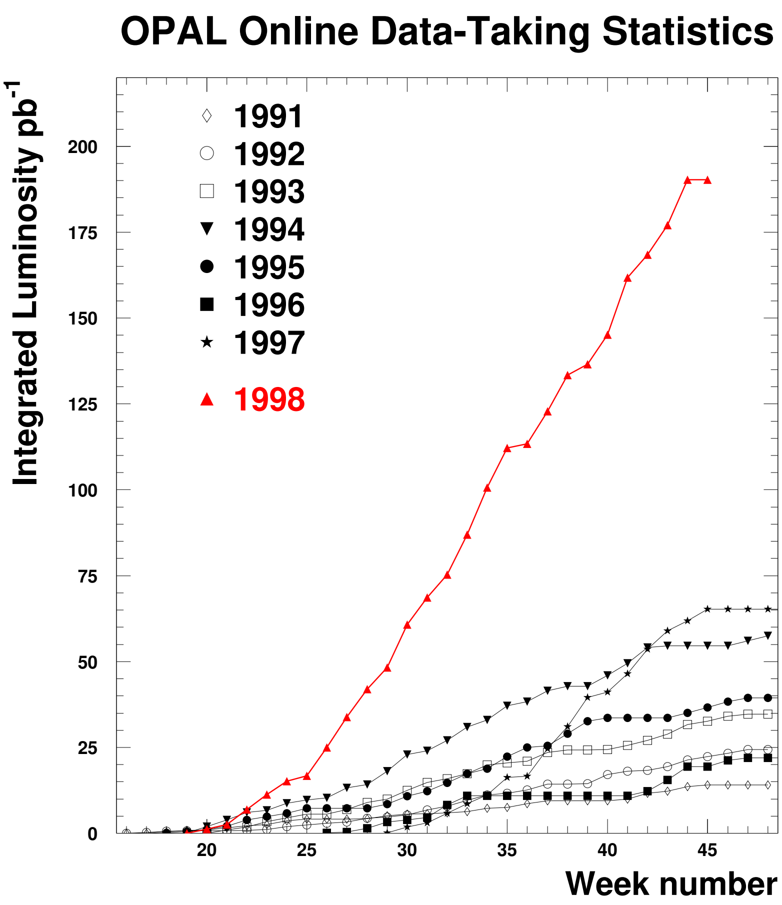
(most are latest available 189 GeV results)

Thank You OPAL for providing so much material!
Apologies as I can't do justice to all topics.

Detector Status

- Nothing new to report since November LEPC
- No major upgrades over 1998-1999 Shutdown
- Expect smooth turn-on

LEP2 Data Sets

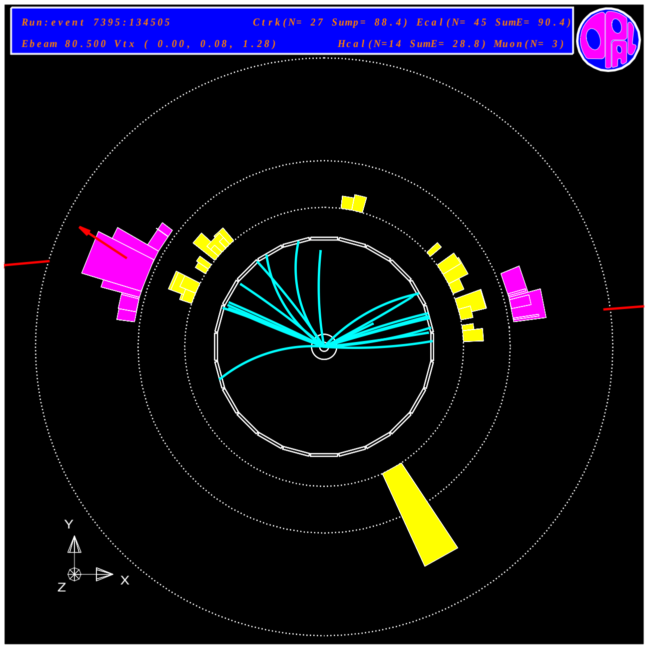


$\sqrt{s}$ (GeV)	$\mathcal{L}_{tot}$ (pb^{-1})
161	10
172	10
183	57
189	187

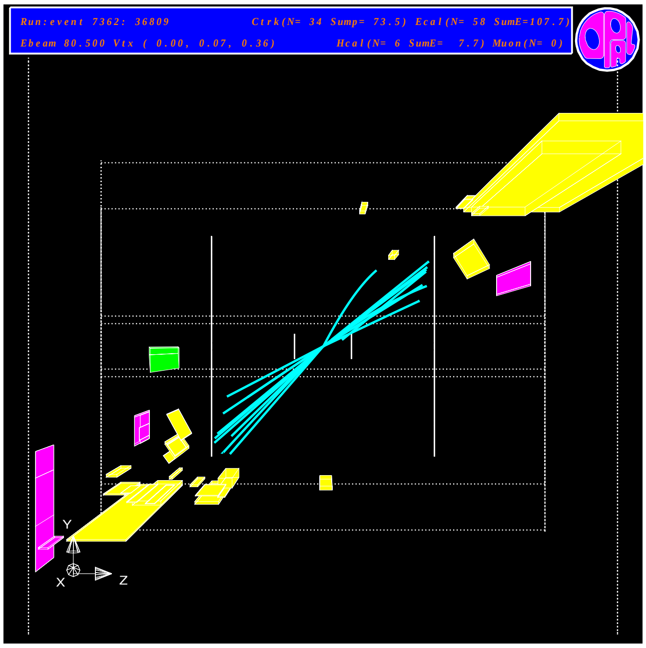
(all data sets reprocessed with final calibration constants)

2-Fermion Physics at 189 GeV

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



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



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

2-Fermion Physics at 189 GeV

- Measure and compare to SM:
  $\sigma(\mathrm{e^+e^-} \rightarrow \mathrm{f\bar{f}})$, $\mathrm{A^f_{FB}}$, $\mathrm{R_b}$, etc.

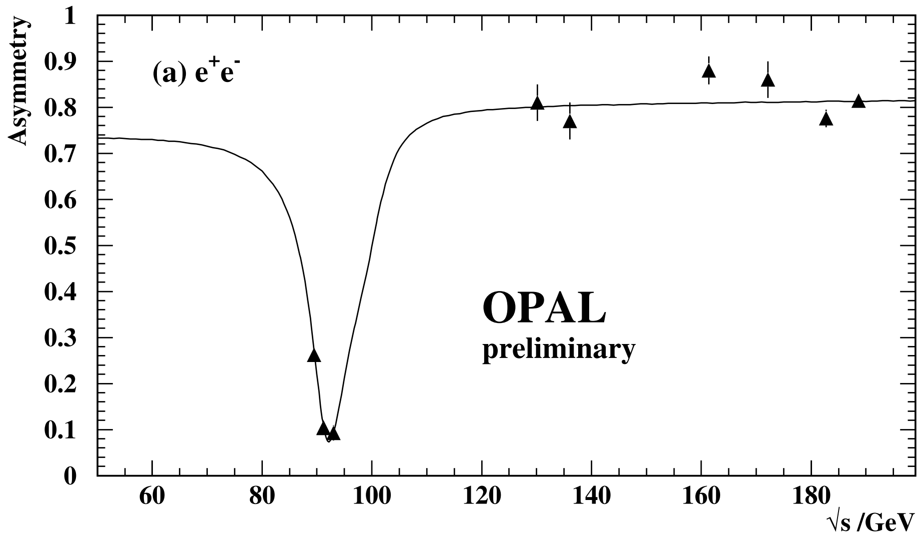
- Can be modified by physics contributions outside SM (ie. contact interactions, $\mathrm{Z'}$, gravitons...)

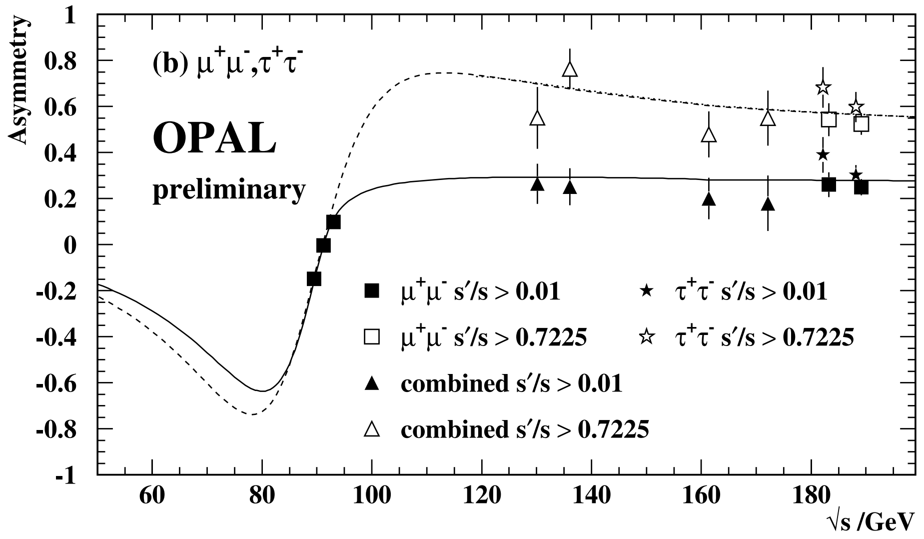
2 fermions	σ (pb)	σ^{SM} (pb)
$\mathrm{q\bar{q}}\ (s'/s > 0.01)$	$98.9 \pm 0.8 \pm 2.0$	98.4
$\mathrm{q\bar{q}}\ (s'/s > 0.7225)$	$22.1 \pm 0.4 \pm 0.5$	22.3
$\mathrm{e^+e^-}(\lvert\cos\theta\rvert < 0.7)$	$20.0 \pm 0.3 \pm 0.3$	20.4
$\mathrm{e^+e^-}(\lvert\cos\theta\rvert < 0.9)$	$110.4 \pm 0.8 \pm 1.5$	111.9
$\mathrm{e^+e^-}(\lvert\cos\theta\rvert < 0.96)$	$304.9 \pm 1.3 \pm 3.4$	311.5
$\mu^+\mu^-(s'/s > 0.01)$	$7.96 \pm 0.24 \pm 0.17$	7.72
$\mu^+\mu^-(s'/s > 0.7225)$	$3.13 \pm 0.14 \pm 0.08$	3.21
$\tau^+\tau^-(s'/s > 0.01)$	$8.65 \pm 0.32 \pm 0.37$	7.71
$\tau^+\tau^-(s'/s > 0.7225)$	$3.53 \pm 0.17 \pm 0.12$	3.21

(for $\mathrm{e^+e^-}$: $\theta_{\mathrm{acol}} < 10°$ and $\theta_{\mathrm{acol}} < 170°$)

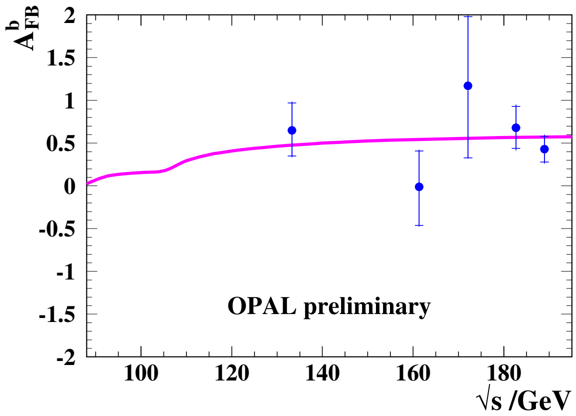
$\Rightarrow$ Data consistent with SM

Lepton Asymmetries:

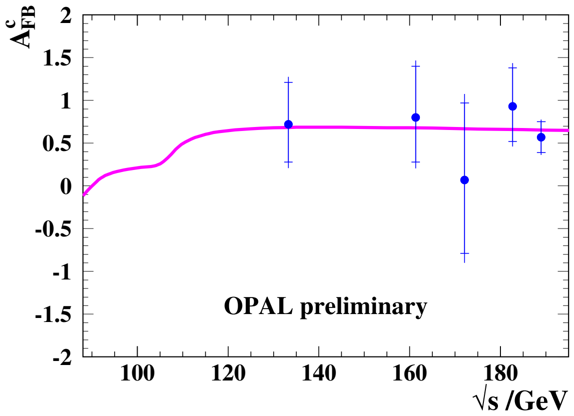




A^b_{FB}:



A^c_{FB}:

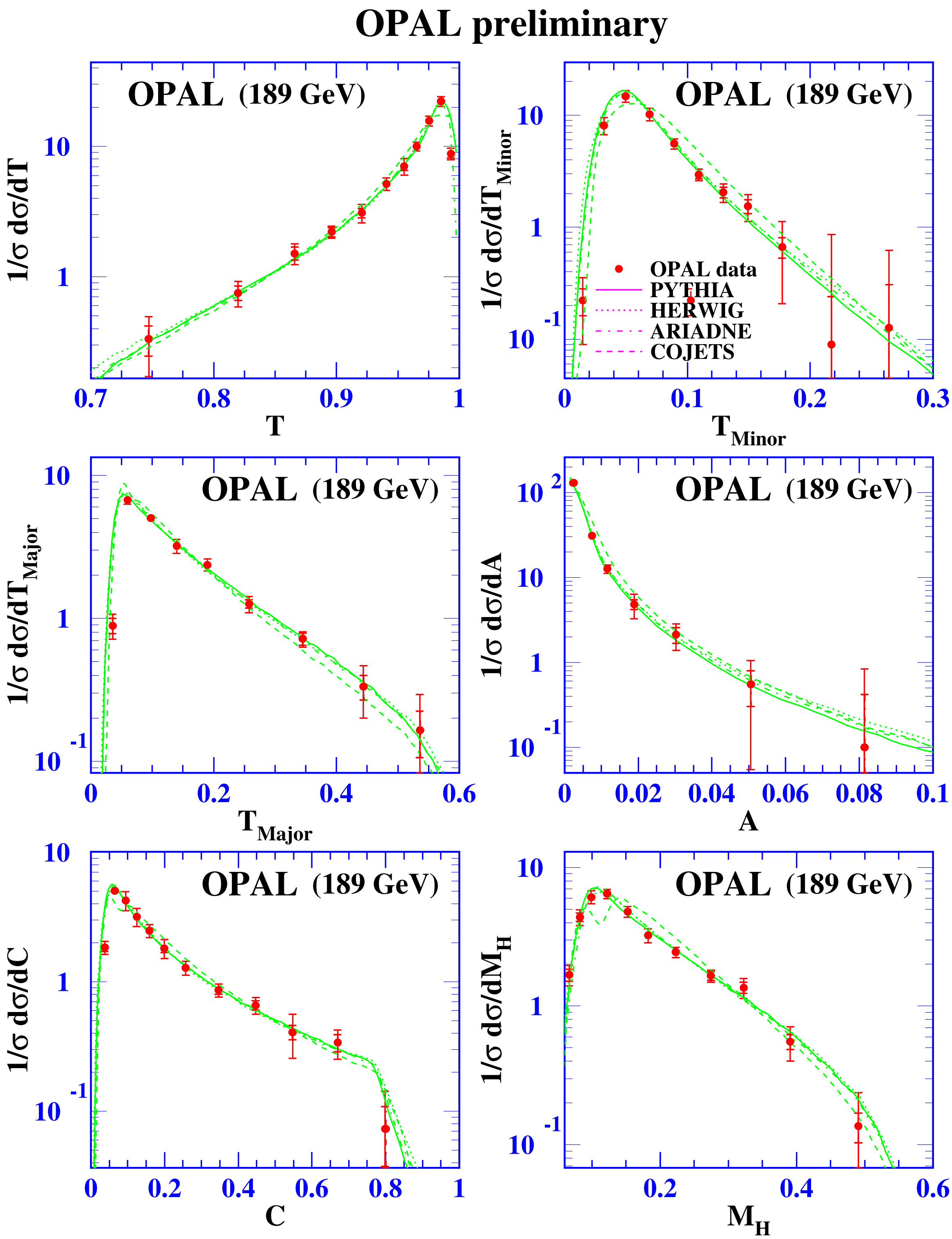


QCD Physics at 189

- New energy scale at which to test QCD
- Verify effects from running of α_s via QCD observables
  - Event Shapes, Jet Rates, etc.
- Only non-radiative events are interesting
  - Require $\sqrt{s} - \sqrt{s'} < 10$ GeV
- Select 4603 events at $\sqrt{s} = 172 + 183 + 189$ GeV
- Expect $\sim 10\%$ 4-fermion background (mostly ZZ and $\mathrm{W^+W^-}$)

$\Rightarrow$ Data consistent with SM

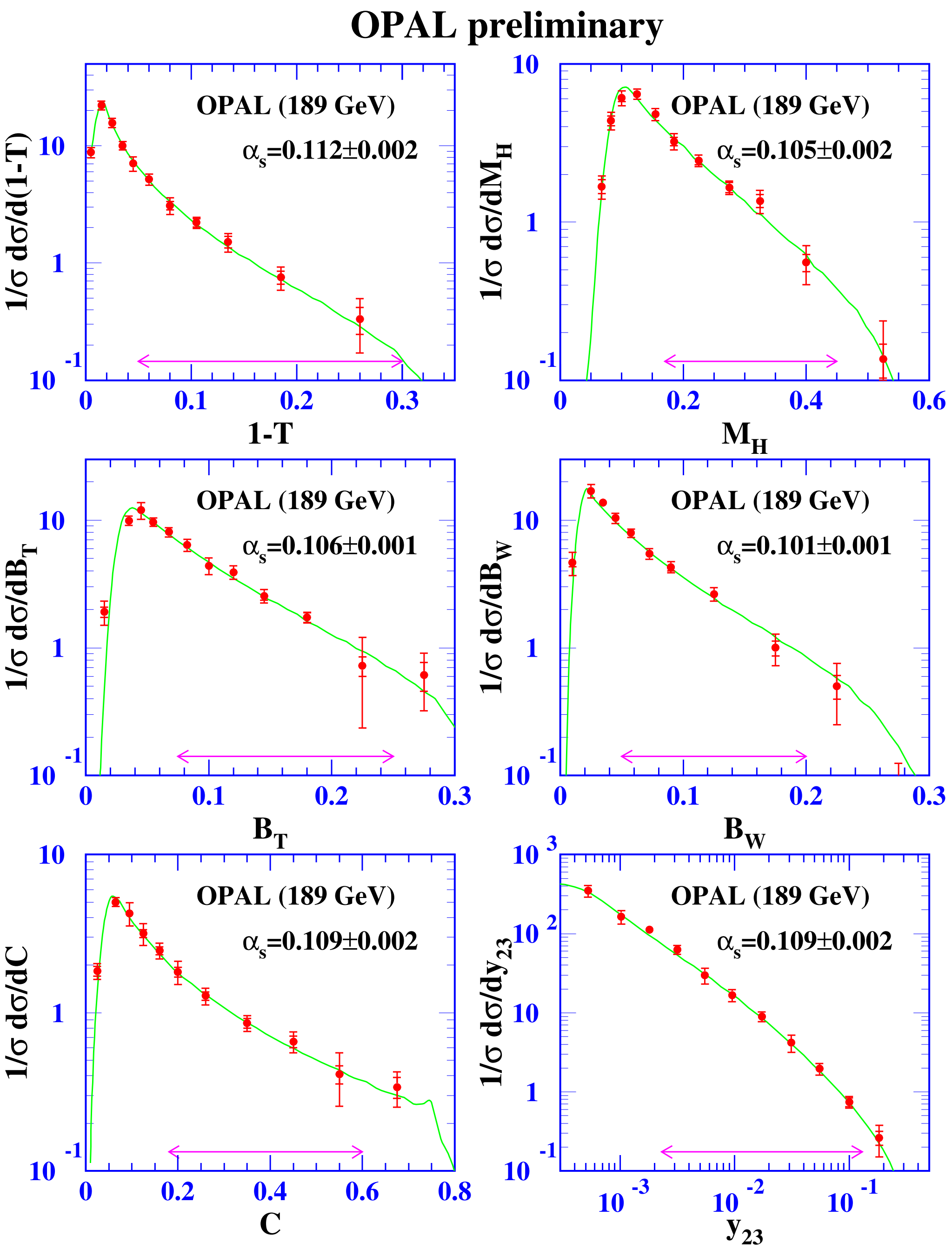
QCD Event Shapes



⇒ event shapes well described by MC generators at $\mathrm{E} \approx 2\mathrm{M}_{Z^0}$

Determination of α_s

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



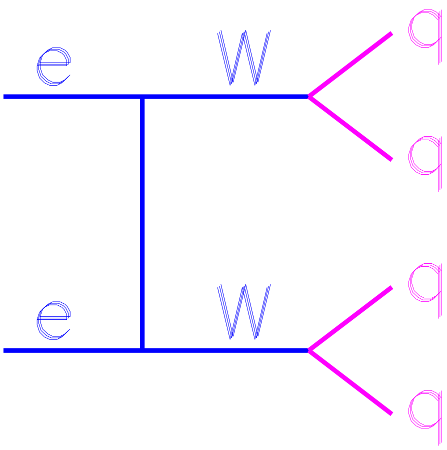
$$\alpha_s(189\mathrm{GeV}) = 0.107 \pm 0.005$$

$$\alpha_s(189 \rightarrow \mathrm{M_{Z^0}}) = 0.117 \pm 0.005$$

$\mathrm{W^+W^-}$ at 189 GeV

- Lots of $\mathrm{W^\pm}$s (≈ 8000 @ LEP2)
- Precision $\sigma(\mathrm{W^+W^-})$, BR, $\mathrm{M_W}$
- Tighter TGC constraints

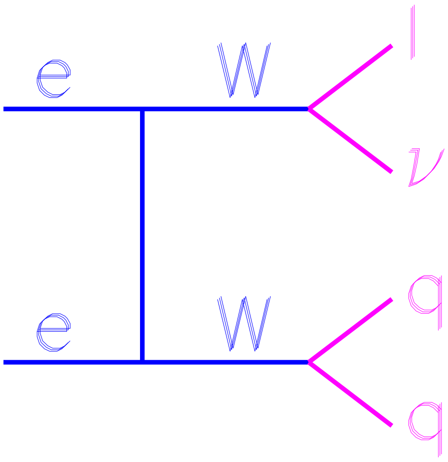
Selections



$\mathrm{BR} \approx 46\%$

$\varepsilon = \mathbf{86\%}$

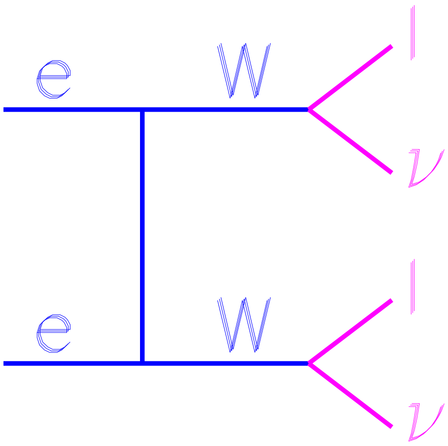
$\mathbf{P} = \mathbf{79\%}$



$\mathrm{BR} \approx 45\%$

$\varepsilon = \mathbf{87\%}$

$\mathbf{P} = \mathbf{90\%}$

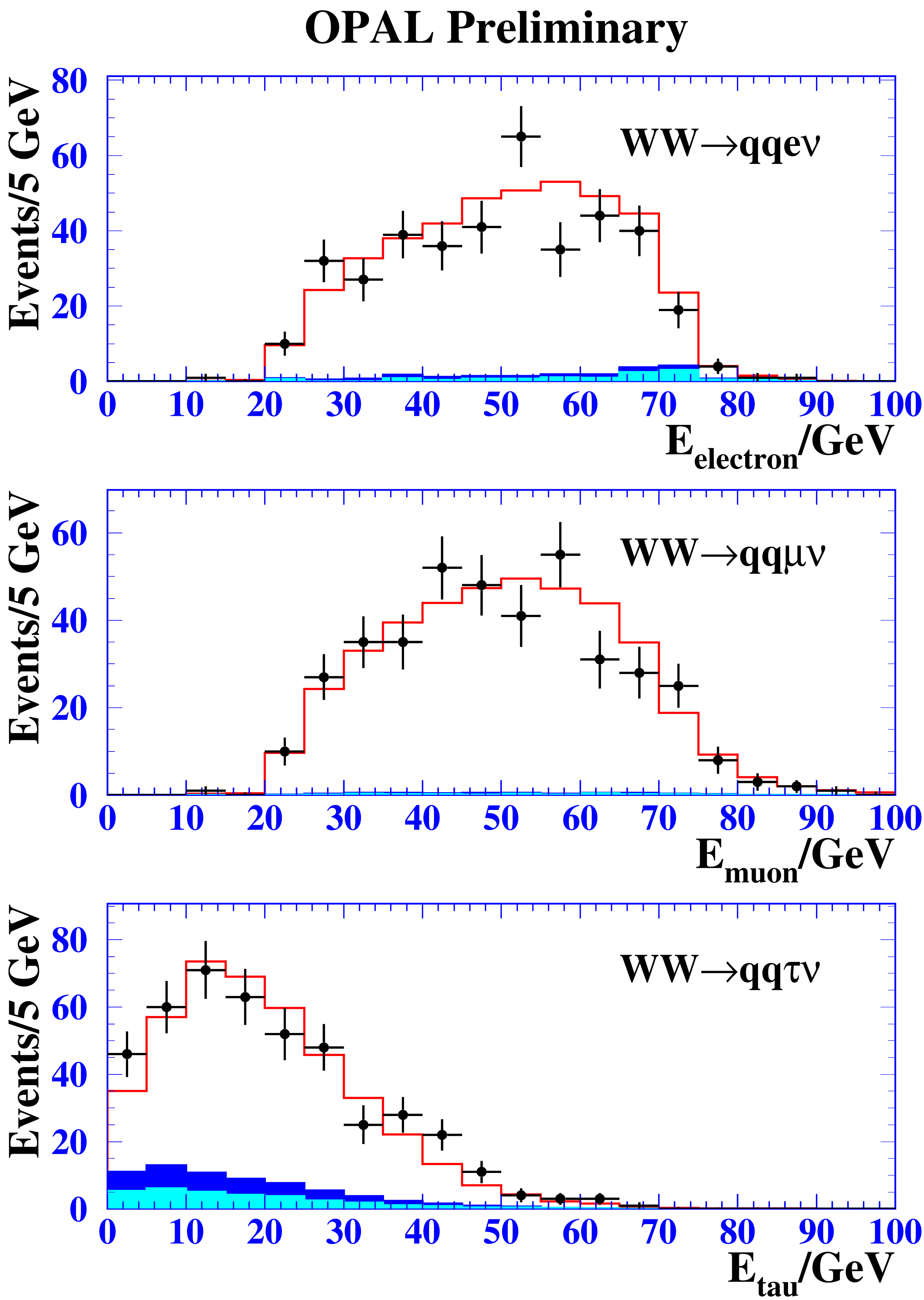


$\mathrm{BR} \approx 10\%$

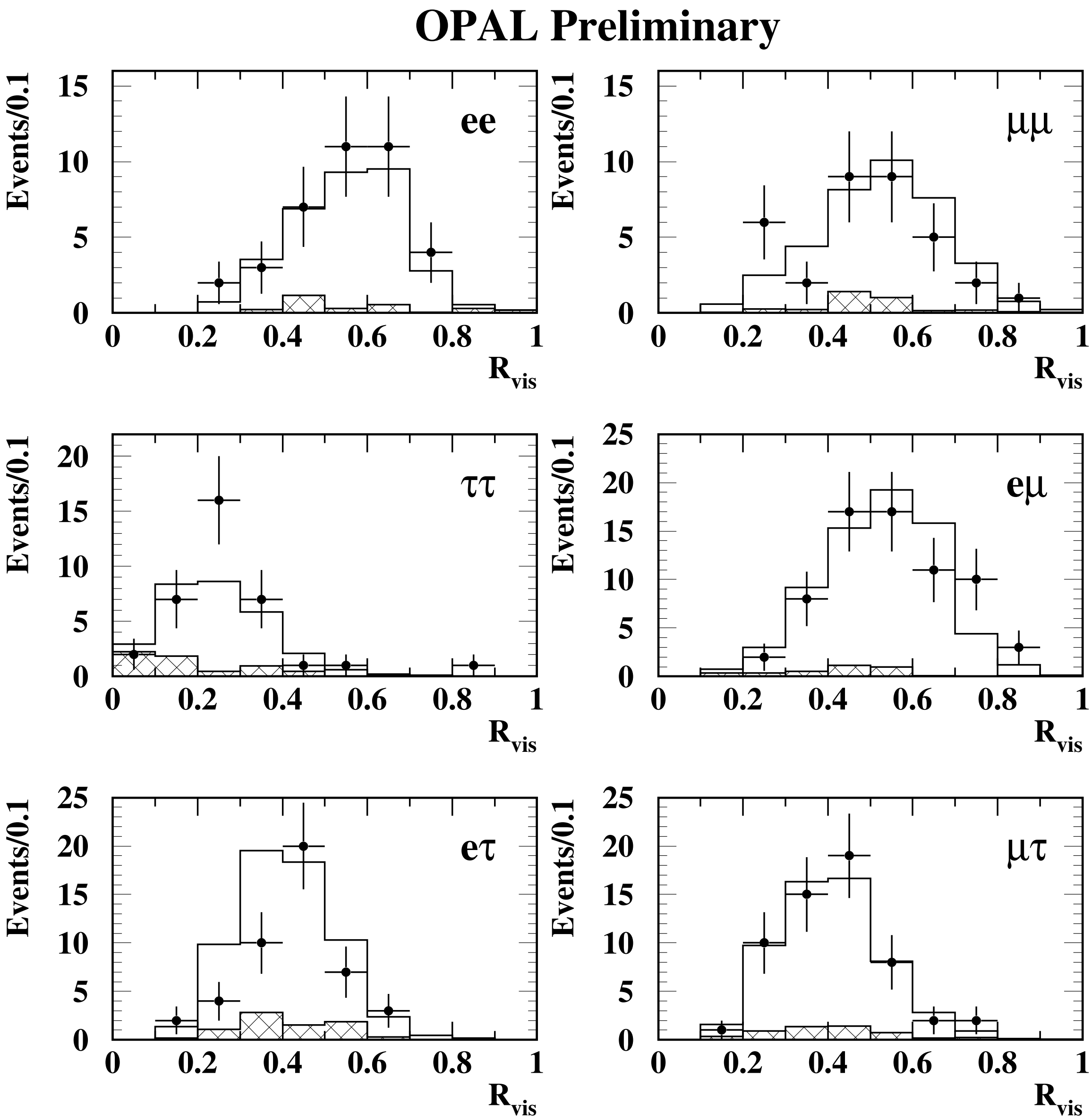
$\varepsilon = \mathbf{82\%}$

$\mathbf{P} = \mathbf{90\%}$

$W^+W^- \rightarrow q\bar{q}\ell\bar{\nu}$ Candidates



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

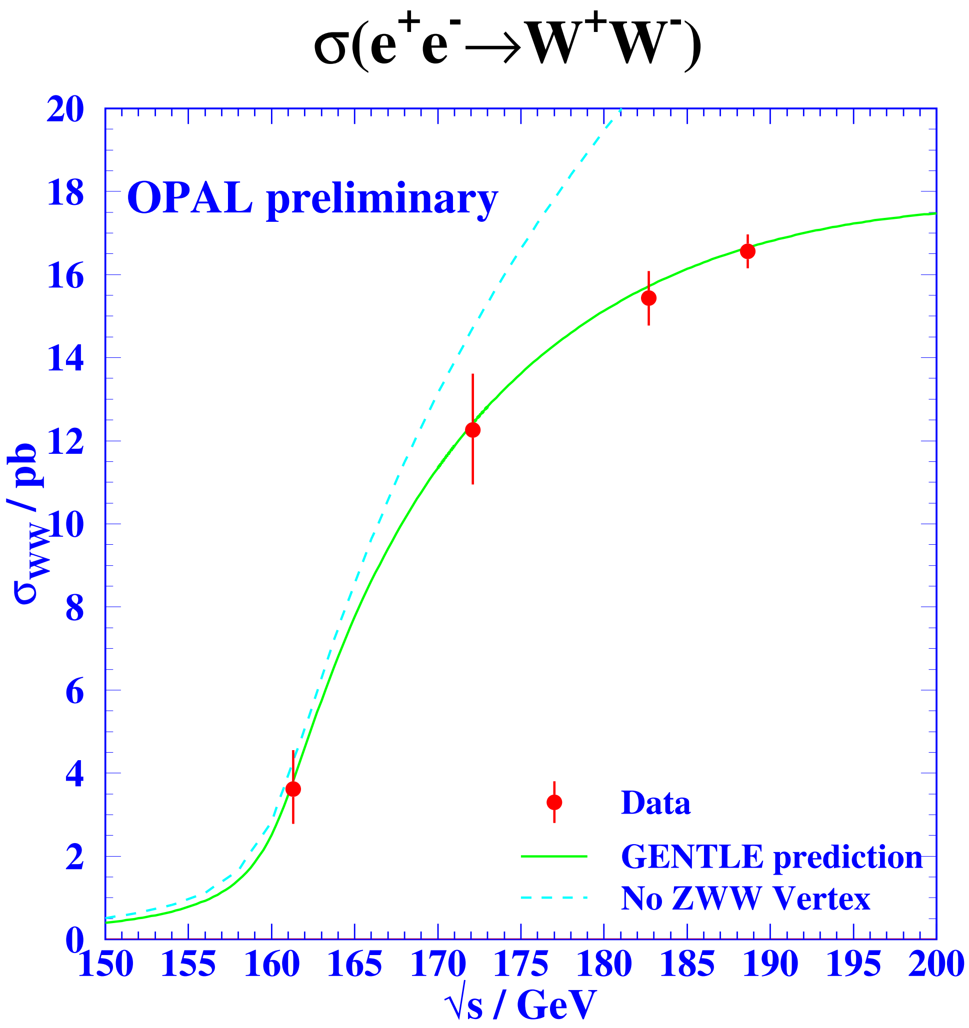


$$R_{vis} = E_{vis}/\sqrt{s}$$

⇒ Data Quality very good

Cross-Section

final state	N_{exp}	N_{obs}
$W^+W^- \to \ell^- \overline{\nu}_\ell \ell'^+ \nu_{\ell'}$	290.0 ± 8.9	278
$W^+W^- \to q\overline{q}\ell\overline{\nu}$	1287.2 ± 29.5	1252
$W^+W^- \to q\overline{q}q\overline{q}$	1511.1 ± 34.9	1546
Combined	3088.3 ± 62.0	3076



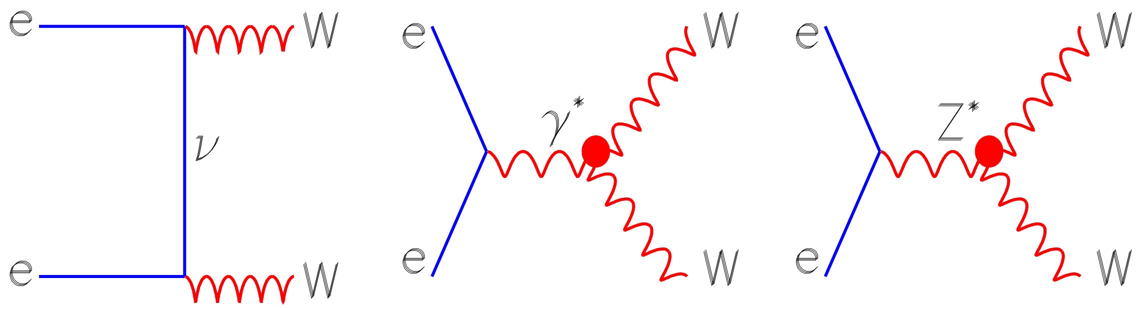
assuming SM branching fractions:

$$\sigma_{WW}(189) = 16.55 \pm 0.35(\mathrm{sta}) \pm 0.20(\mathrm{sys})\ \text{pb}$$

assuming lepton universality:

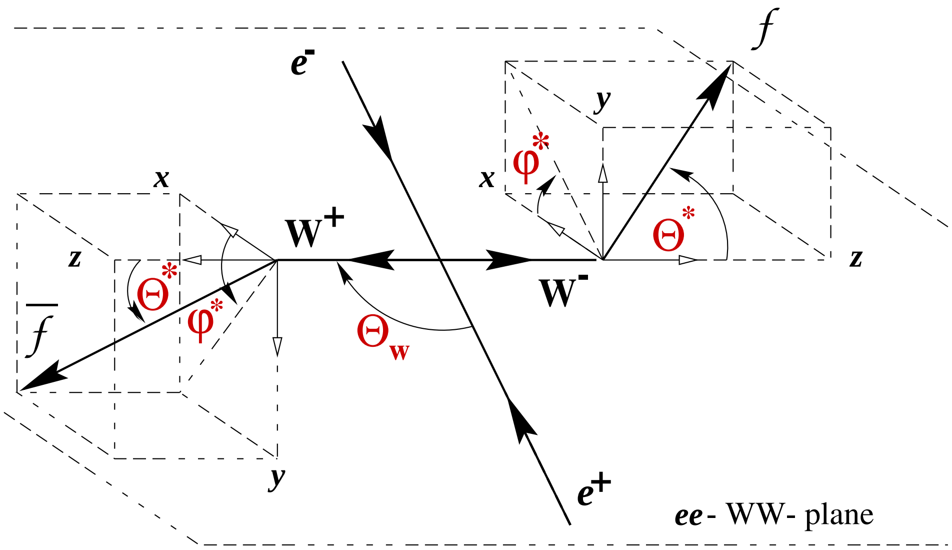
$$\mathrm{BR}(W \to q\overline{q}) = 68.5 \pm 0.7(\mathrm{sta}) \pm 0.4(\mathrm{sys})\%$$

Anomolous Triple Gauge Couplings (TGC)



- TGCs effect $\frac{d\sigma}{d\Omega}$

$$\Omega \;=\; \left(\cos\theta_{\mathrm{W}}, \cos\theta^*_{\mathrm{f}}, \phi^*_{\mathrm{f}}, \cos\theta^*_{\bar{\mathrm{f}}}, \phi^*_{\bar{\mathrm{f}}}\right)$$



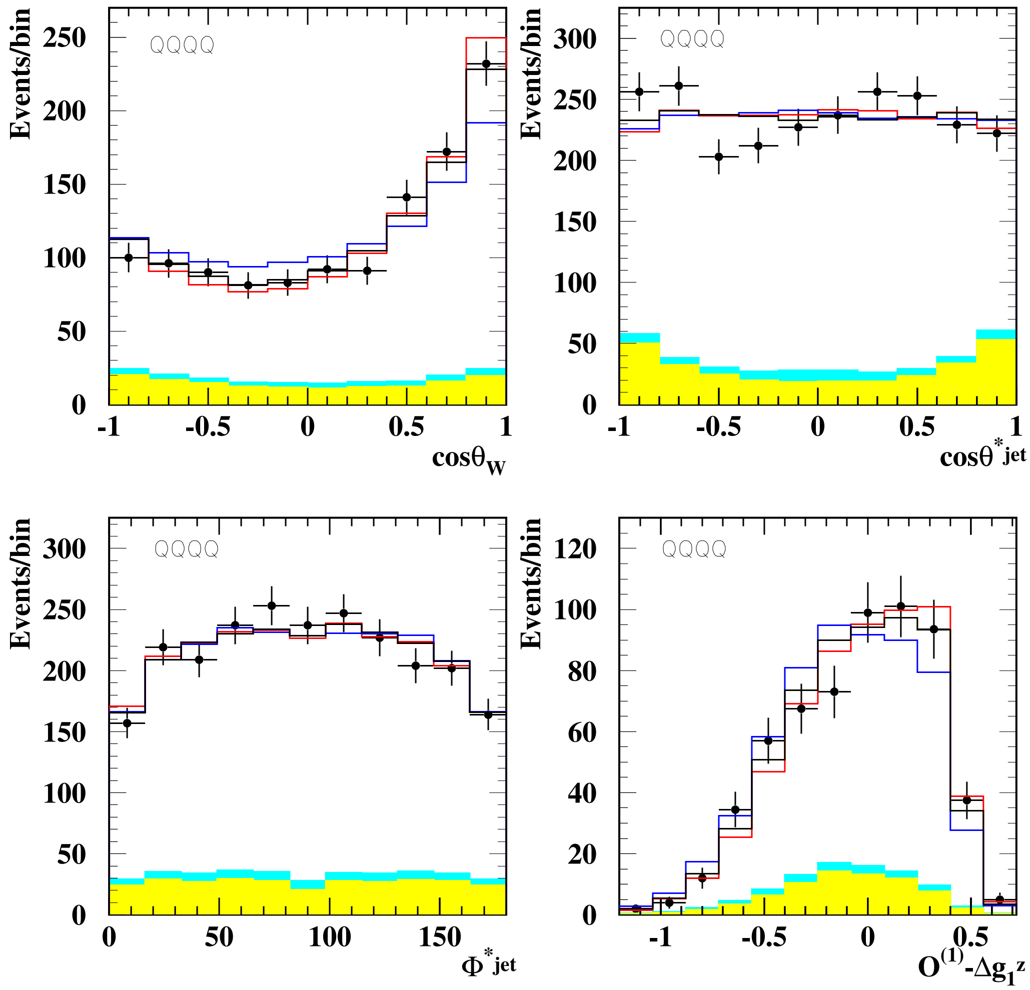
- $\sigma(\mathrm{W^+W^-}) \sim (\mathrm{TGC})^2$

  $\Rightarrow$ use measured $\sigma(\mathrm{W^+W^-})$ as further contraint

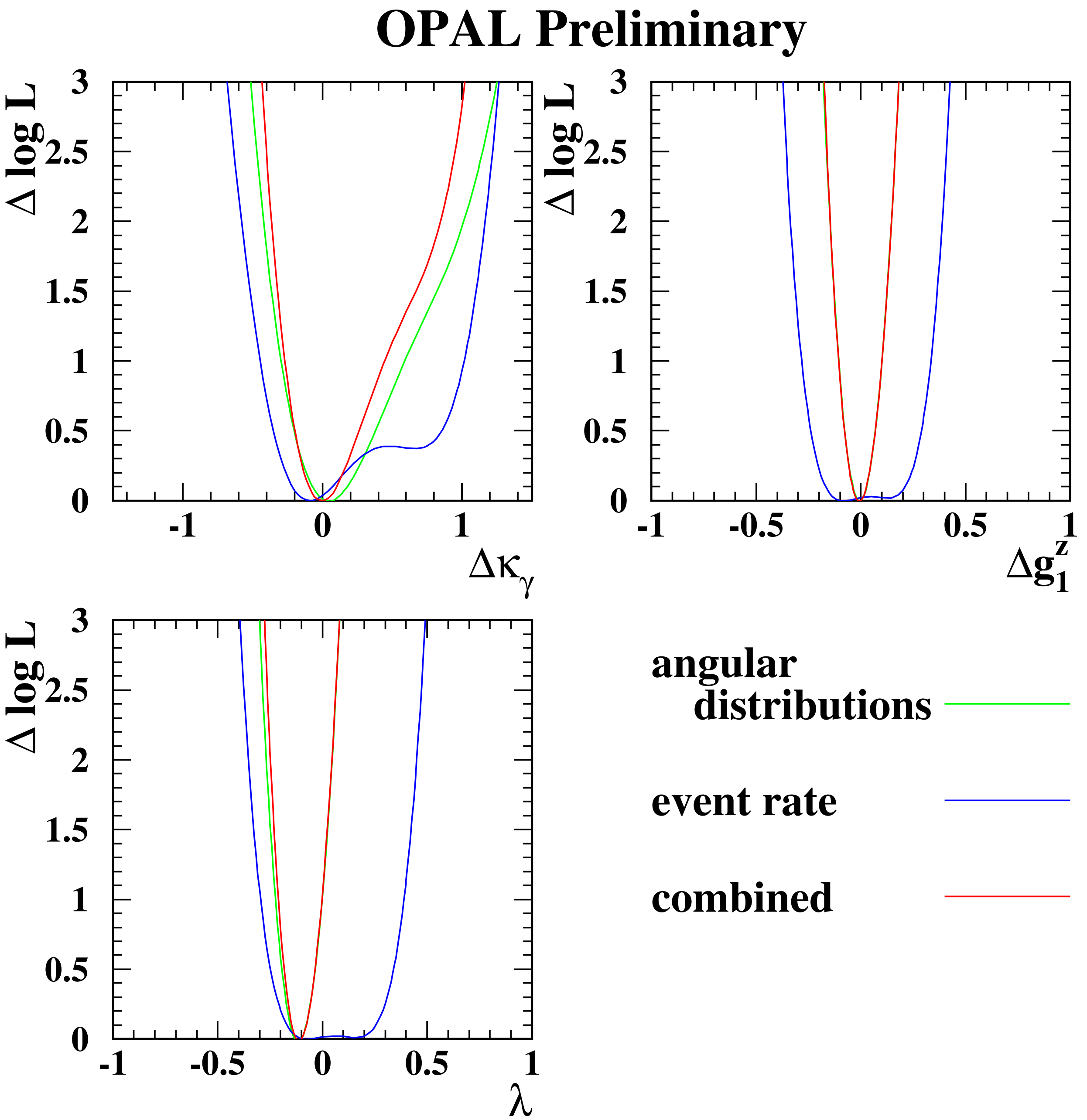
- To extract TGC from $\frac{d\sigma}{d\Omega}$:
  - max. lhood over Ω-space OR
    (used for $\mathrm{W^+W^-} \to \ell^-\overline{\nu}_\ell \ell'^+ \nu_{\ell'}$)
  - Optimal Observable (OO)
    (used for $\mathrm{W^+W^-} \to \mathrm{q\overline{q}}\ell\overline{\nu}$ and $\mathrm{q\overline{q}q\overline{q}}$)

$$\frac{d\sigma}{d\Omega} \sim \left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{SM}} + f_1(\Omega)\cdot(\mathrm{TGC}) + f_2(\Omega)\cdot(\mathrm{TGC})^2$$

$\Rightarrow$ simplifies, retains all information



TGC Limits @ 95% CL



$$-0.36 < \Delta\kappa_\gamma < 0.83$$

$$-0.14 < \Delta g_1^z < 0.14$$

$$-0.25 < \lambda < 0.04$$

($\Delta\kappa_\gamma = \Delta g_1^z = \lambda = 0$ in SM)

Colour-Reconnection (CR) in W^+W^-

- from 183 GeV publication
- Important for M_W(qqqq) !

CR Basics

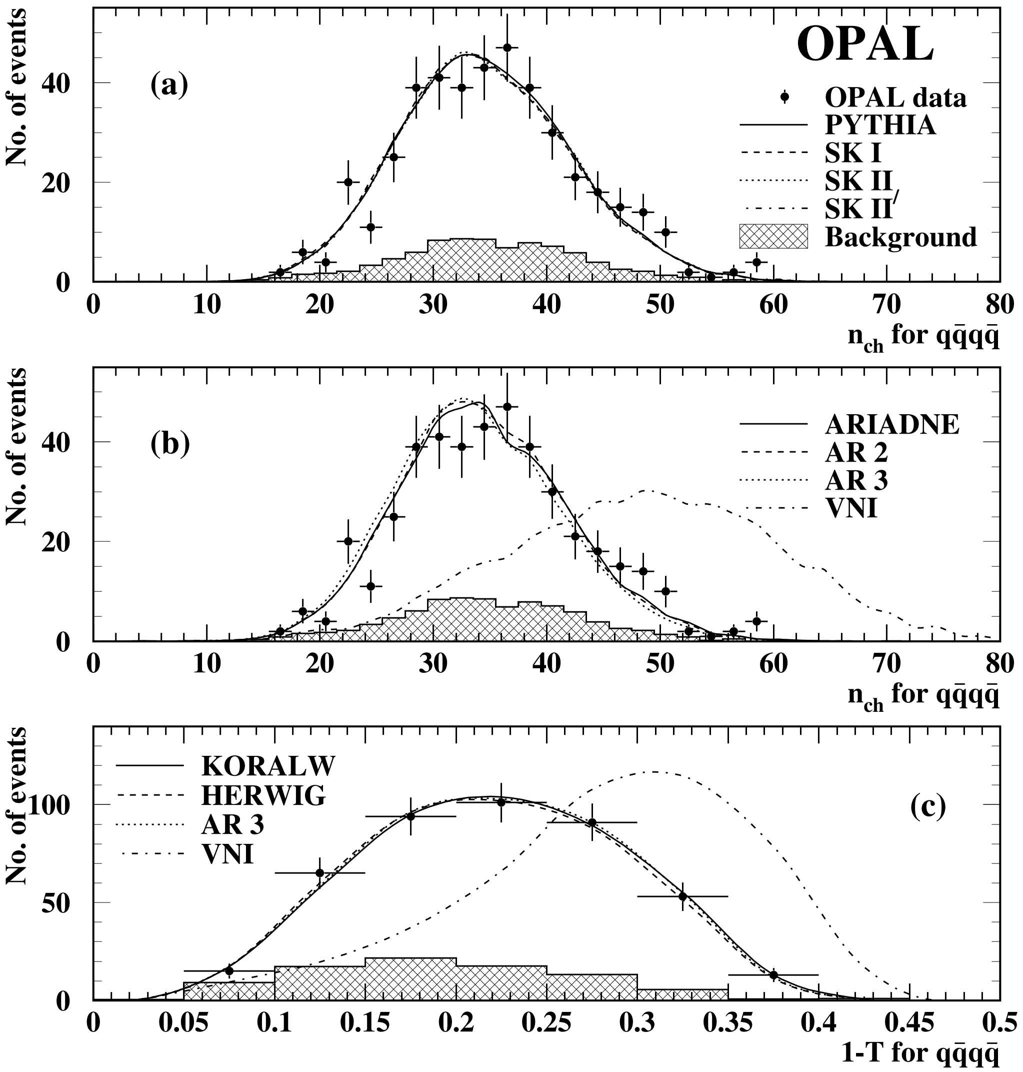
$$1/\Gamma_W \approx \; 0.1\,\mathrm{fm} \;\ll\; 1/\lambda_{QCD} \approx \; 1\,\mathrm{fm}$$

- Can two $W \rightarrow q\overline{q}$ decays “talk” to each other?
- Standard MCs assume independent hadronization
- Introduction of CR effects into MCs alters $m_{rec}^{inv} \Rightarrow M_W^{meas}$
- Magnetude and direction model dependent!

CR effects other observables too:

eg. n_{ch}^{4q}, dn/dx_p, $dn/d\,|y|$,...

$\Rightarrow$ use these to constrain available models

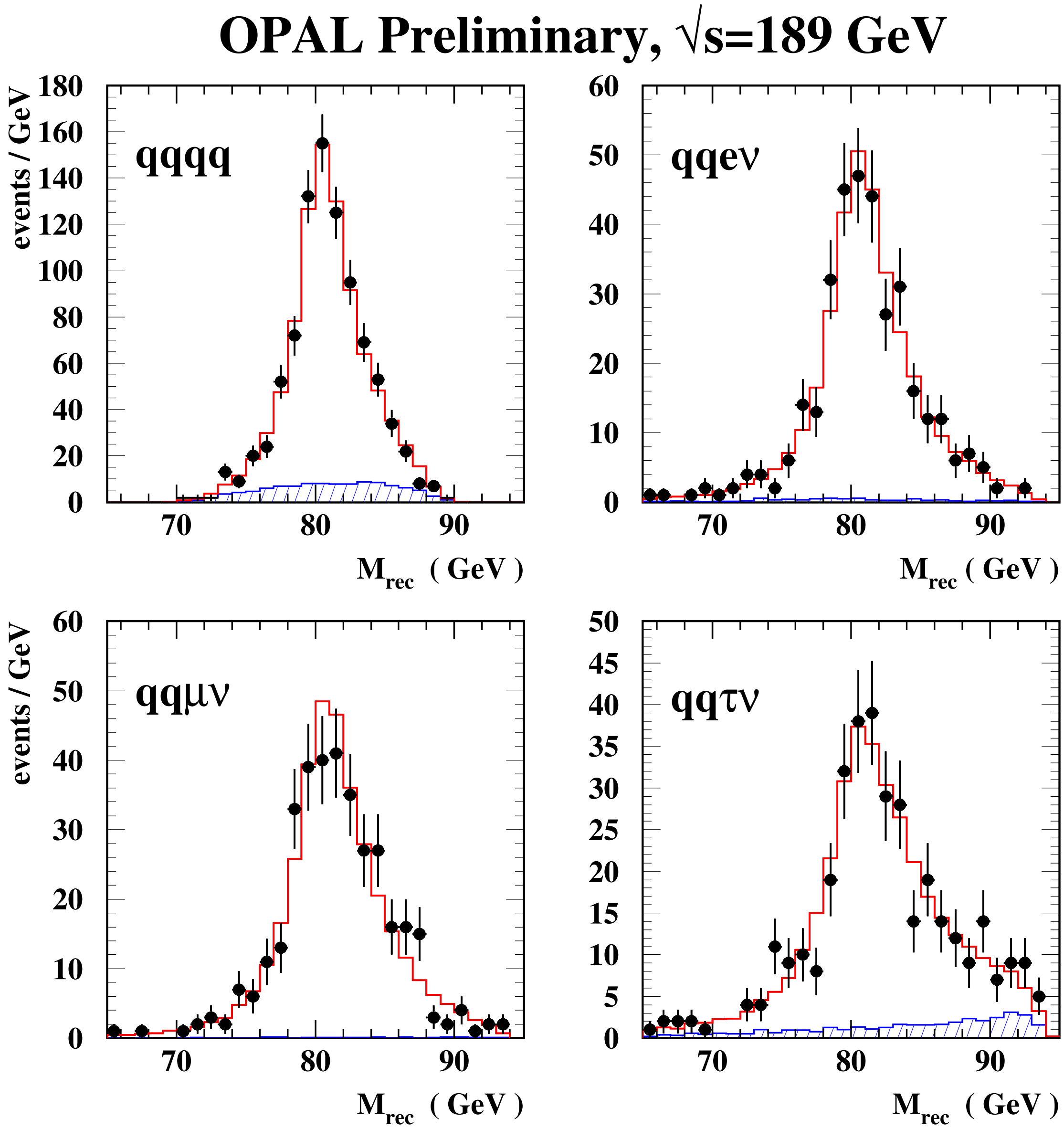


$\Rightarrow$ only surviving models used to estimate

M_W systematic:

$$\mathcal{O}(10^2)\ \mathrm{MeV} \longrightarrow \mathcal{O}(10^1)\ \mathrm{MeV}$$

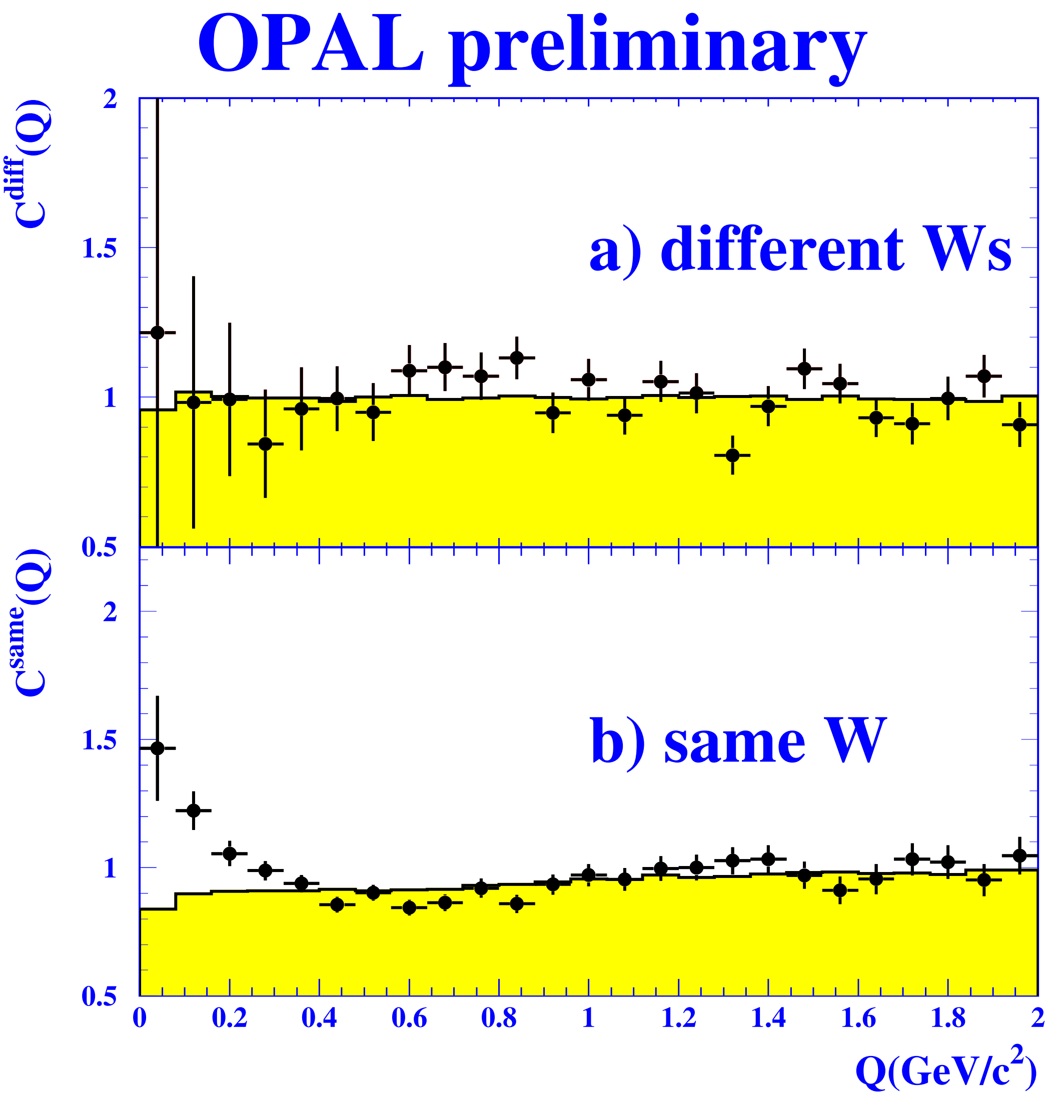
$\mathrm{M_W}$ at 189 GeV



Combining with previous LEP2 data:

$$\mathrm{M_W} = 80.357 \pm 0.067(\mathrm{sta}) \pm 0.044(\mathrm{sys})$$
$$\pm 0.020(\mathrm{cr/bec}) \pm 0.016(\mathrm{E_{bm}})$$
$$\left|\Delta \mathrm{M_W^{4q-2q}}\right| = 0.012 \pm 0.134(\mathrm{sta}) \pm 0.080(\mathrm{sys})$$

B-E Correlations in W^+W^- @ 189 GeV

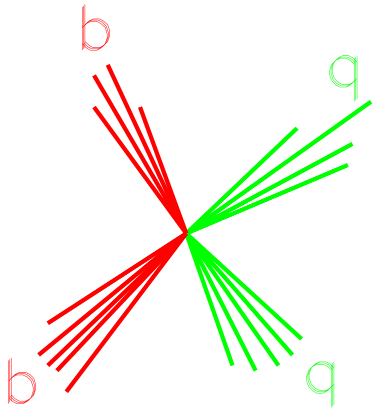


- $C_{\mathrm{same}} \equiv$ BEC between bosons originating from same $W \to q\overline{q}$ decay
- $C_{\mathrm{diff}} \equiv$ BEC between bosons originating from different $W \to q\overline{q}$ decays
- points are OPAL data at 189 GeV
- histograms are MC expectations in the *absence* of BEC

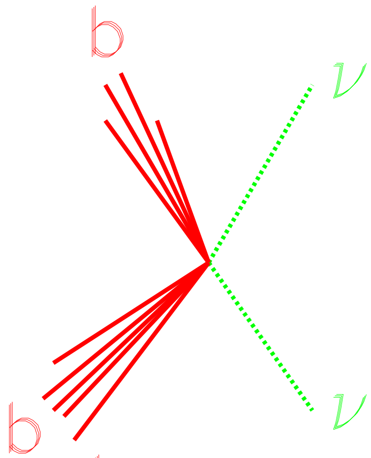
Higgs Searches at 189 GeV

- 1 required by SM: H^0
- SUSY extensions: h^0, H^0, A^0, $\mathrm{H}^\pm$
- Look for them all!

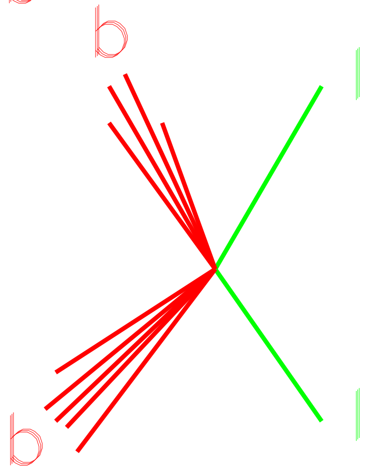
SM $\mathrm{e}^+\mathrm{e}^- \to \mathrm{H}^0\mathrm{Z}^0$ final states



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



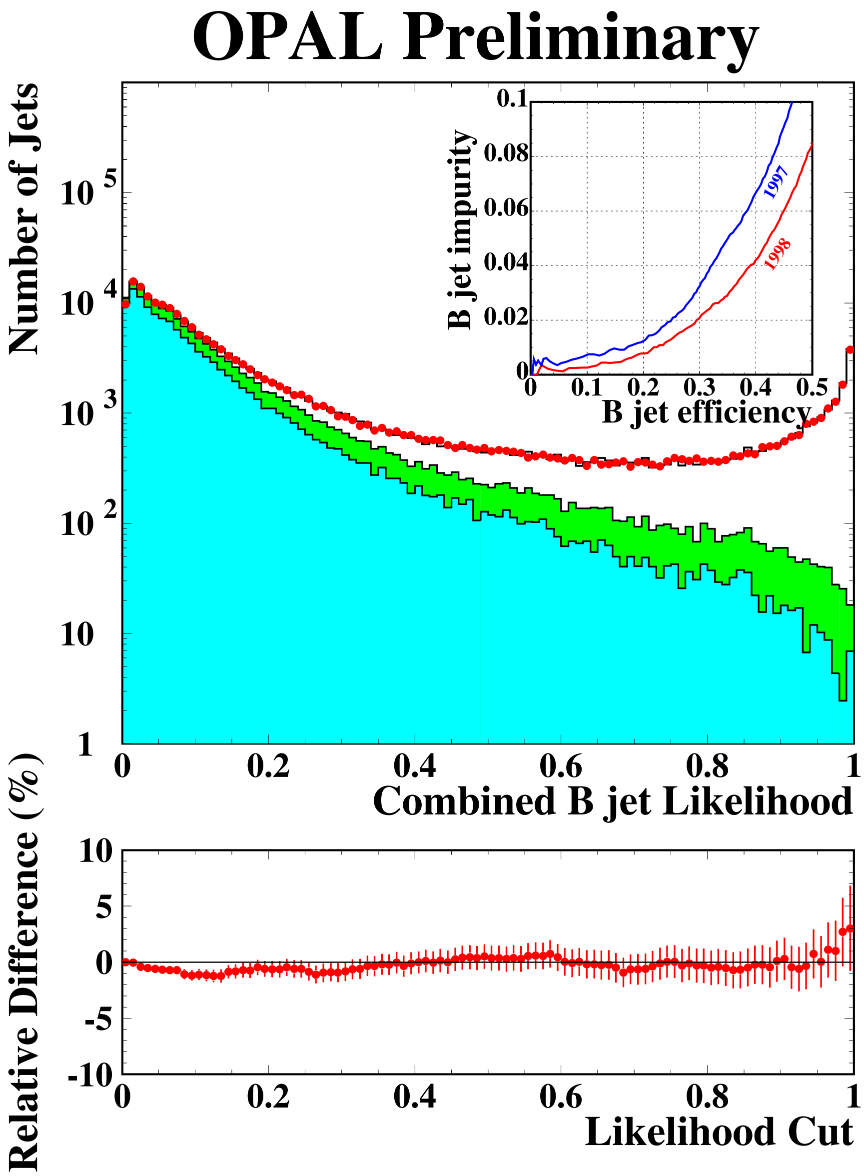
$$\mathrm{H}^0\mathrm{Z}^0 \to \mathrm{b}\bar{\mathrm{b}}\nu\bar{\nu}$$
$$\varepsilon \approx \mathbf{35}\%$$



$$\mathrm{H}^0\mathrm{Z}^0 \to \mathrm{b}\bar{\mathrm{b}}\ell^+\ell^-$$
$$\varepsilon \approx \mathbf{35-65}\%$$

B-tagging

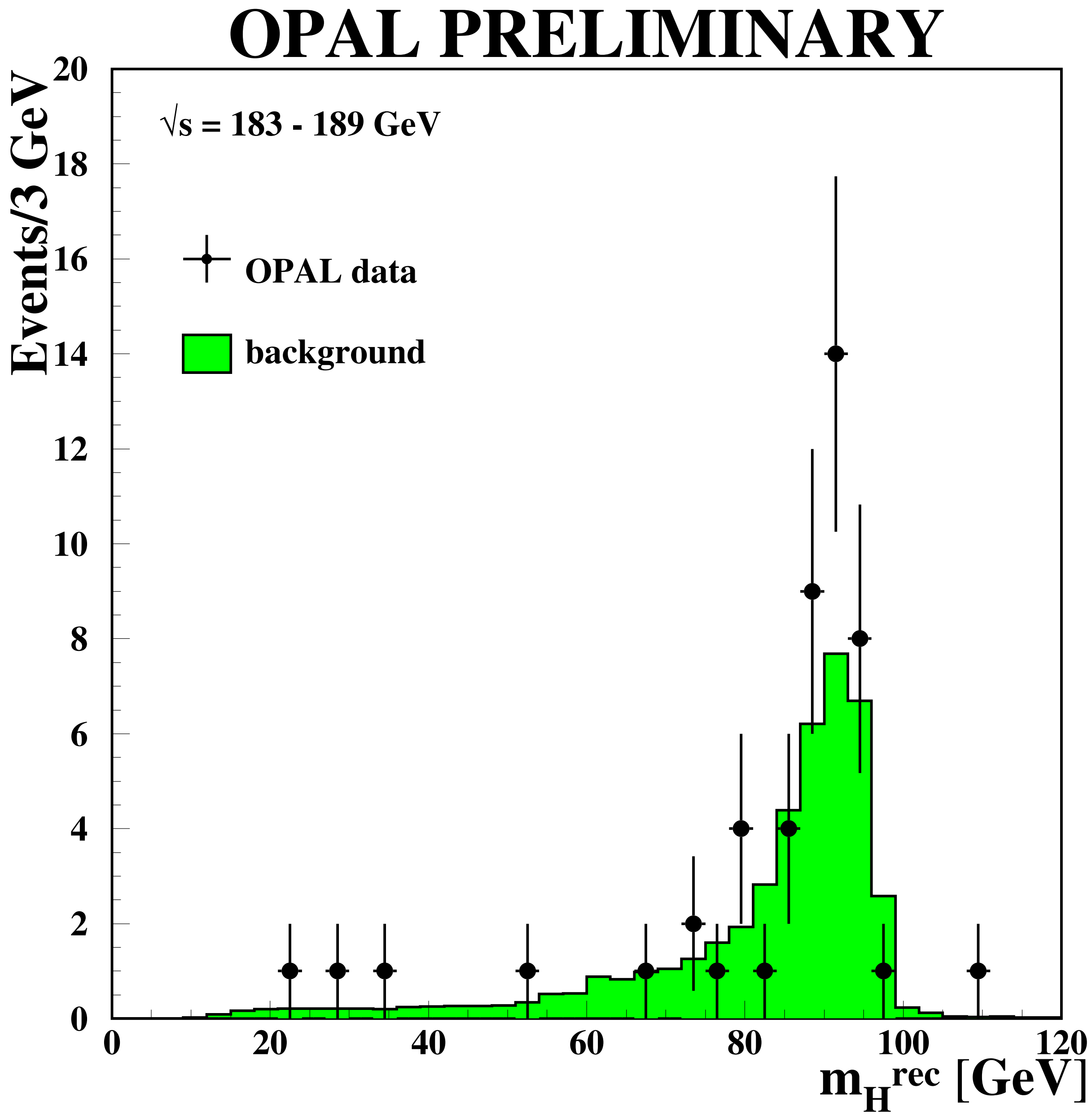
- test performance and modelling using $\sqrt{s} = \mathrm{M_{Z^0}}$, $\mathrm{e^+e^-} \rightarrow \mathrm{Z^0}\gamma$, and $\mathrm{W^+W^-} \rightarrow \mathrm{q\bar{q}}\ell\overline{\nu}$ events



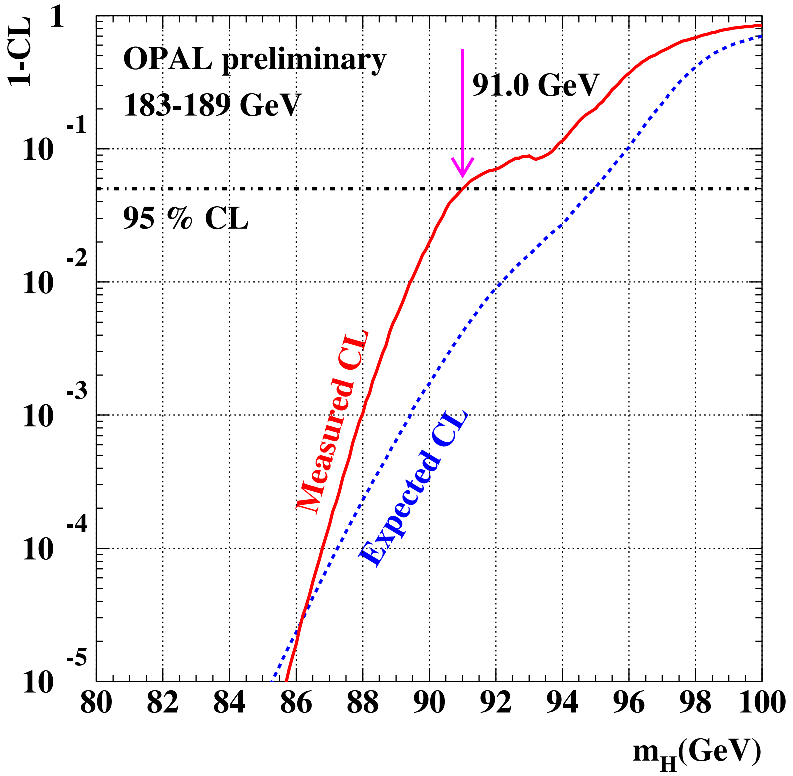
- $\frac{DT}{MC}(\varepsilon_{\mathrm{b}})$ good to $\pm 3\%$
- $\frac{DT}{MC}(\varepsilon_{\mathrm{not-b}})$ good to $\pm 5\%$

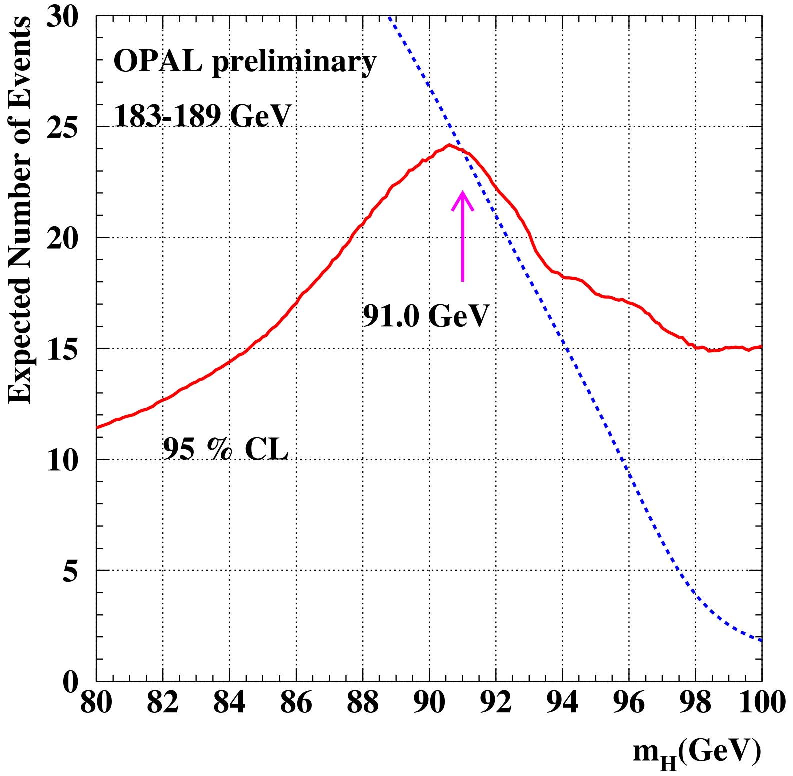
SM Higgs Results at 189 GeV

final state	N_{bkg}	N_{obs}
$b\bar{b}q\bar{q}$	19.9	24
$q\bar{q}\nu\bar{\nu}$	6.9	10
$q\bar{q}\tau\bar{\tau}$	4.0	3
$q\bar{q}\ell\bar{\ell}$	4.7	4
Combined	35.5	41



SM Higgs Limit

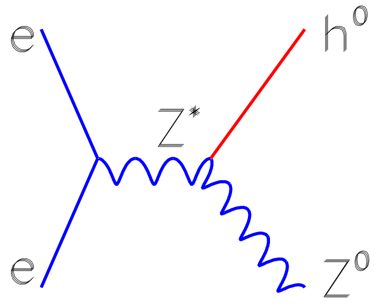




$M^{SM}_{H^0} > 91.0$ GeV @ 95% CL

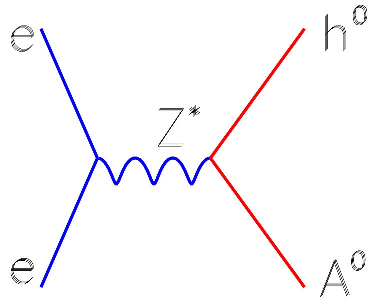
(expected limit > 95 GeV)

SUSY Higgs Searches at 189 GeV



$\sigma(\mathrm{h^0Z^0}) \sim \sin(\beta-\alpha)\cdot\sigma^{\mathrm{HZ}}_{\mathrm{SM}}$

final states $=$ SM $\mathrm{H^0Z^0}$



$\sigma(\mathrm{h^0A^0}) \sim \cos(\beta-\alpha)\cdot\sigma^{\nu\bar{\nu}}_{\mathrm{SM}}$

final states $\neq$ SM $\mathrm{H^0Z^0}$

For $\mathrm{h^0Z^0}$: recycle SM $\mathrm{H^0Z^0}$ analyses

- $\mathrm{N_{bkg}} = 35.5$
- $\mathrm{N_{obs}} = 41$

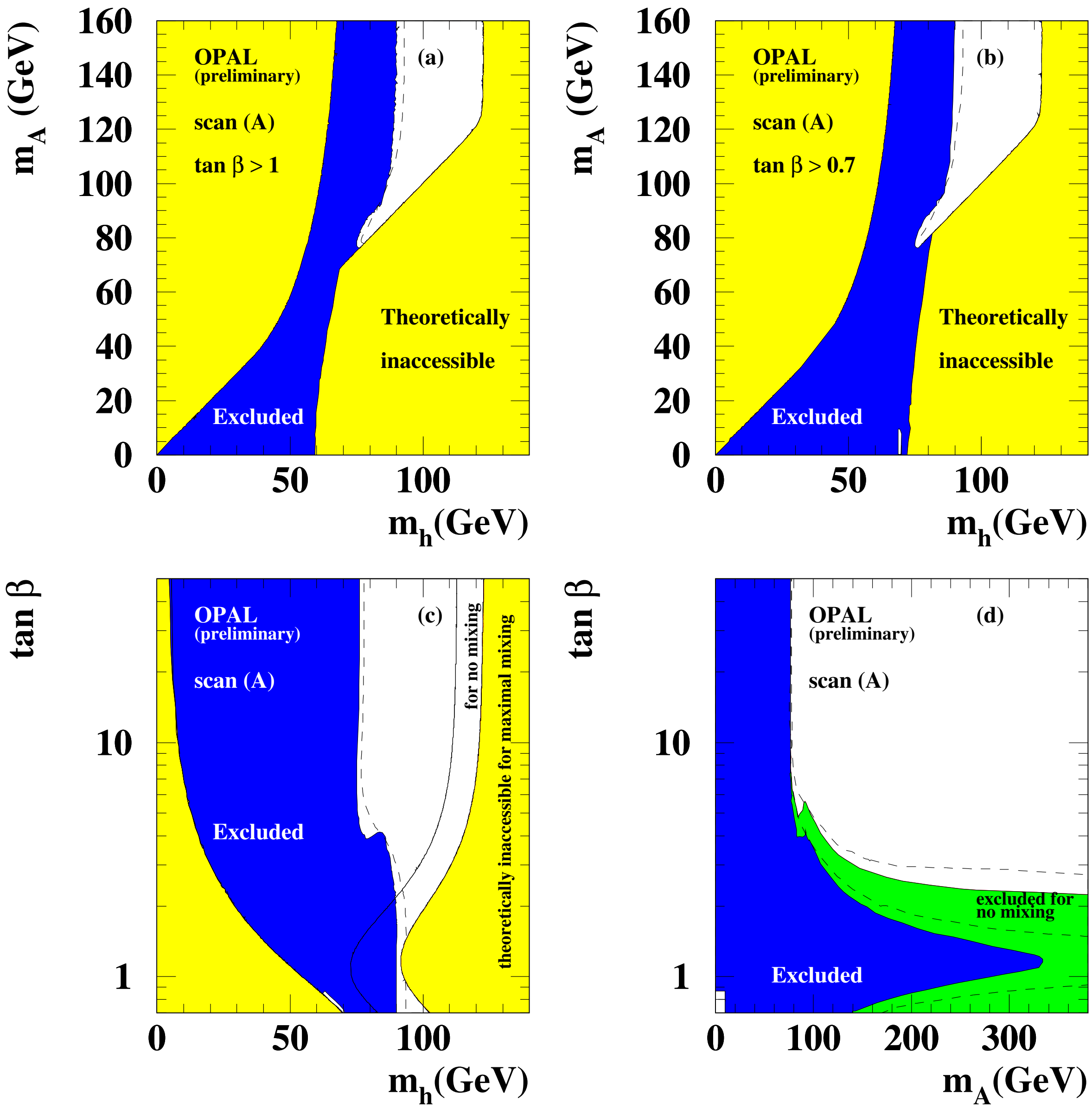
For $\mathrm{h^0A^0}$: employ dedicated analyses

- $\mathrm{N_{bkg}} = 21.6$
- $\mathrm{N_{obs}} = 20$

$\Rightarrow$ Data consistent with SM background

Limits for SUSY Higgs

Limits from “Benchmark” scan over CMSSM



@ 95% CL

$\mathrm{m_h} > 74.8$ GeV

$\mathrm{m_A} > 76.5$ GeV

$\tan\beta > 1$

$m_0 = M_2 = 1$ TeV

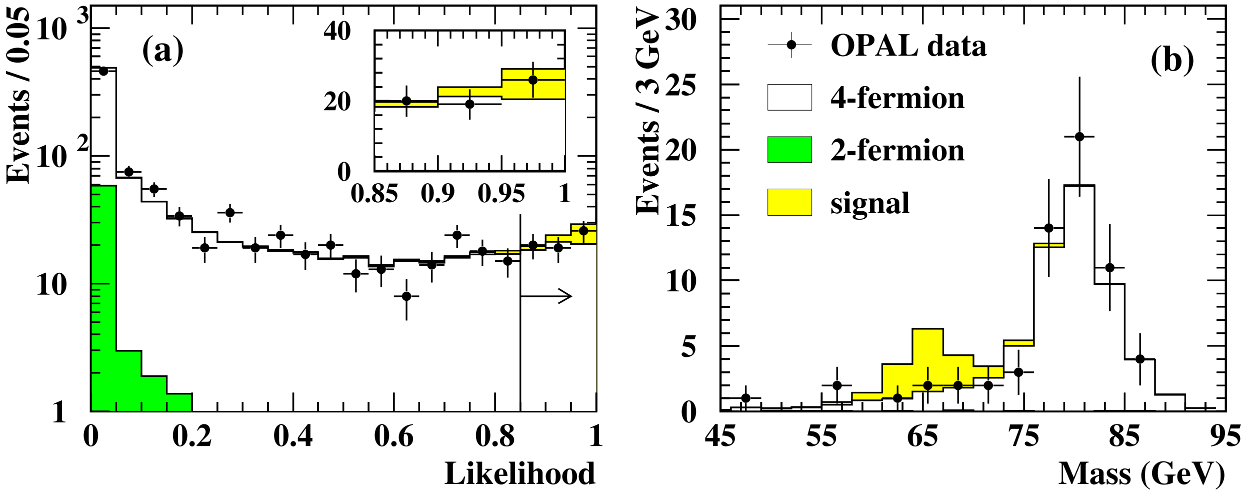
any mixing

Charged Higgs Search at 189 GeV

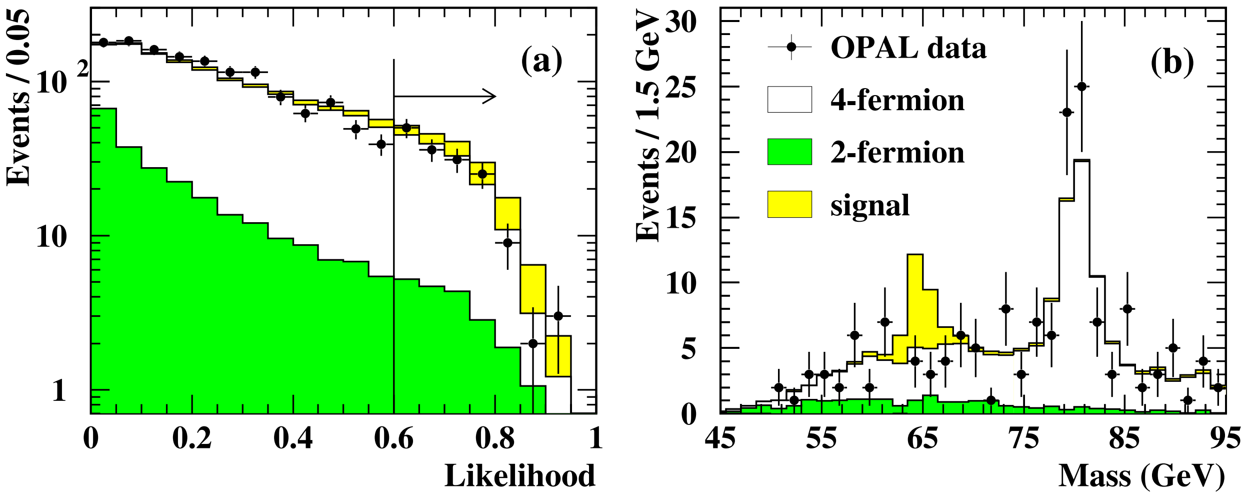
$e^+e^- \rightarrow H^+H^-$ final states: $cscs$, $cs\tau\nu$, $\tau\nu\tau\nu$

Employ multi-variate Lhood Analyses sensitive to each of these

semi-leptonic final state

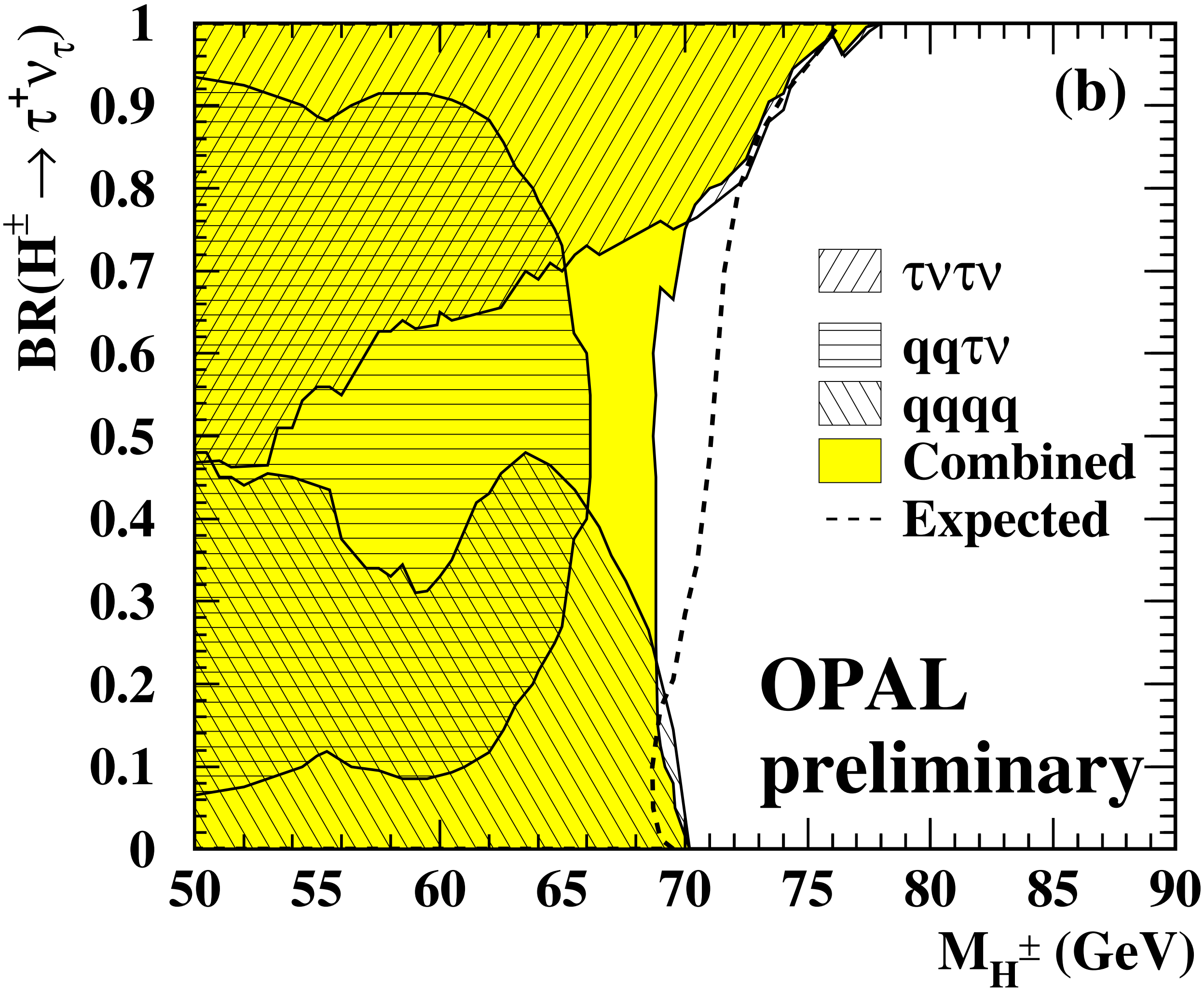


hadronic final state



$\Rightarrow$ Data consistent with SM Background

Charged Higgs Limits



$$M_{H^\pm} \;>\; 68.7 \text{ GeV @ } 95\% \text{ CL}$$

for any $\mathrm{BR}(\mathrm{H}^+ \to \tau\nu)$

SUSY Searches at 189 GeV

- MANY TOPOLOGIES!

- only discuss those new since Nov

  - $\tilde{\chi}_1^{\pm}$, $\tilde{\chi}^0$
  - $\tilde{\mathrm{t}}$, $\tilde{\mathrm{b}}$
  - $\gamma\gamma$ $\not{E}$ (ie. ν^*,$\tilde{\mathrm{G}}$,...)

- Many OPAL SUSY Searches ought be available as publications soon

$\tilde{\chi}_1^{\pm}$, $\tilde{\chi}^0$ Searches at 189 GeV

- "Standard" CMSSM guides the analysis
- $\tilde{\chi}_1^0 \equiv \mathrm{LSP}$
- R-Parity is conserved

$\Rightarrow$ $\tilde{\chi}^{\pm}$ and $\tilde{\chi}^0$ are pair produced

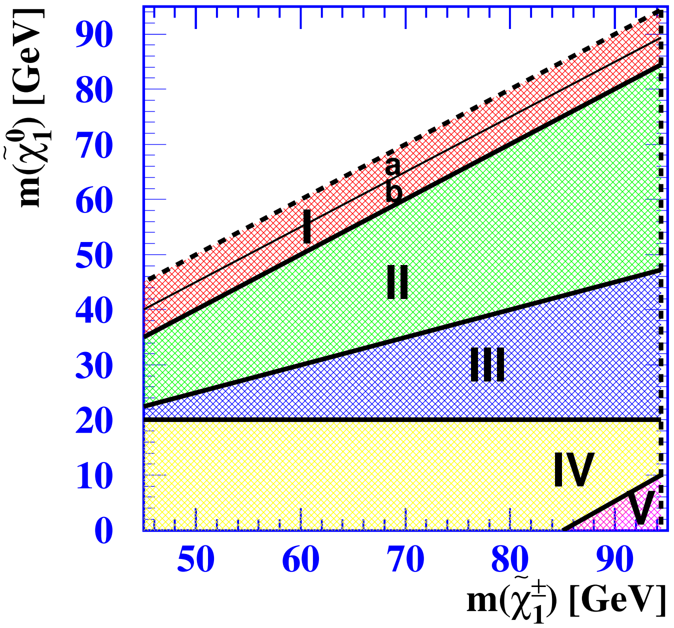
$\Rightarrow$ $\tilde{\chi}_1^0$ goes undetected ($\not{E}$)

$\Rightarrow$ $\mathrm{BR}(\tilde{\chi}^{\pm} \to \mathrm{W}^* \tilde{\chi}_1^0)$ and $\mathrm{BR}(\tilde{\chi}_2^0 \to \mathrm{Z}^* \tilde{\chi}_1^0)$ large over most of parameter space

- Final State Topologies:
  - $\tilde{\chi}_1^+ \tilde{\chi}_1^- \to \mathrm{W}^* \mathrm{W}^* + \tilde{\chi}_1^0 \tilde{\chi}_1^0$
  - $\tilde{\chi}_2^0 \tilde{\chi}_1^0 \to \mathrm{Z}^* + \tilde{\chi}_1^0 \tilde{\chi}_1^0$

$\Rightarrow$ Visible kinematics depend on

$$\Delta\mathrm{M} = \mathrm{M}_{\tilde{\chi}} - \mathrm{M}_{\tilde{\chi}_1^0}$$



Analysis optimized by final state topology and in regions of ΔM.

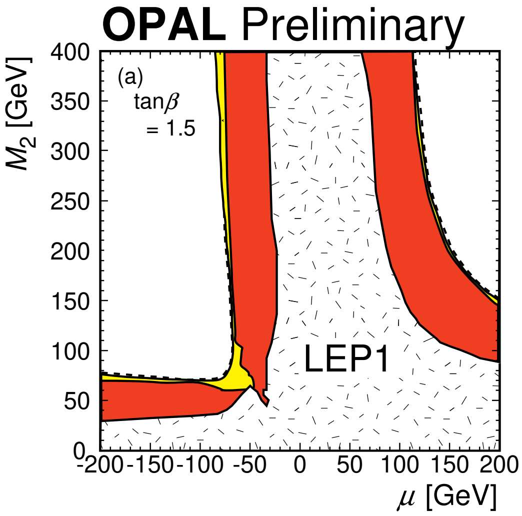
$\tilde{\chi}^\pm$, $\tilde{\chi}^0$ search results:

final state		I	II	III	IV	V
Jets	N_{obs}	2	3	22	29	34
	N_{bkg}	1.5	2.0	17.8	27.0	29.3
Jets+	N_{obs}	2	1	4	7	27
Leptons	N_{bkg}	4.4	2.0	4.6	6.5	23.5
Leptons	N_{obs}	20	23	77	112	–
	N_{bkg}	13.3	20.0	72.8	116.4	–

$\Rightarrow$ Data consistent with SM background

Exclusions at 95% CL

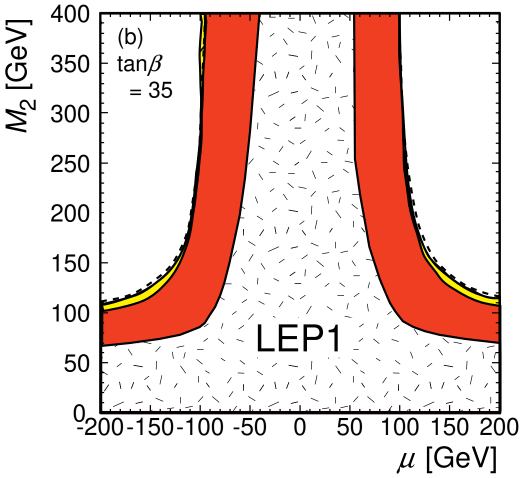
(for $m_0 \geq 500$ GeV and $\Delta M_{\pm(0)} \geq 5\ (10)$ GeV)



$M_{\tilde{\chi}_1^\pm} > 93.6$ GeV

$M_{\tilde{\chi}_2^0} > 67.8$ GeV

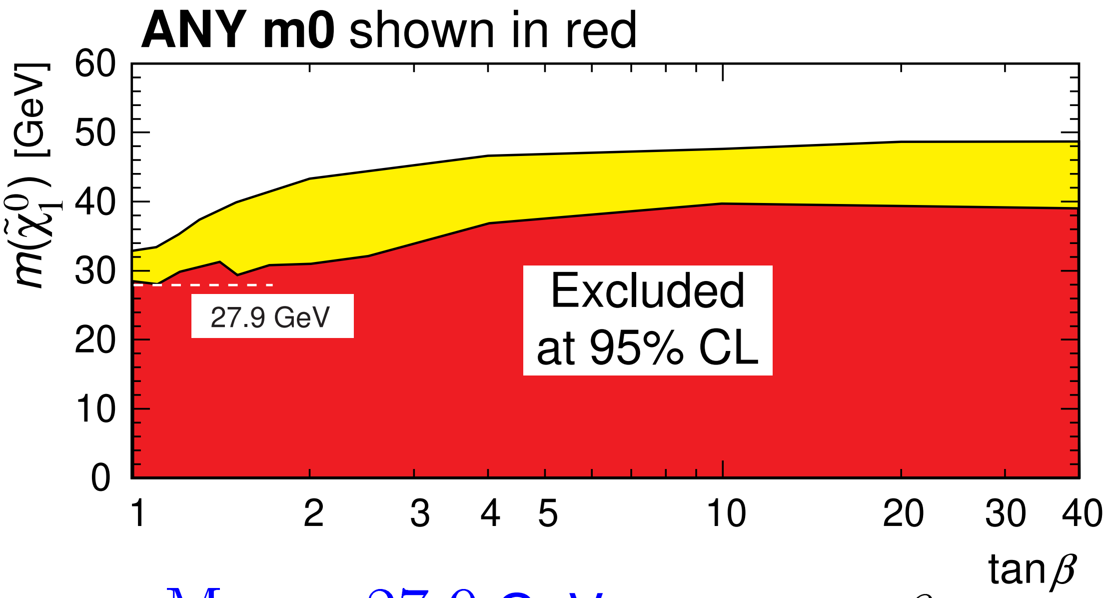
$(\tan\beta = 1.5)$



$M_{\tilde{\chi}_1^\pm} > 94.1$ GeV

$M_{\tilde{\chi}_2^0} > 94.3$ GeV

$(\tan\beta = 35)$



$M_{\tilde{\chi}_1^0} > 27.9$ GeV (any m_0, $\tan\beta$)

$\tilde{\mathrm{t}}$ and $\tilde{\mathrm{b}}$ at 189 GeV

- First publication from 189 GeV
- due to large $\mathrm{M_{top}}$, $\tilde{\mathrm{t}}_1$ may be light
- mass eigenstates are mixed L and R

$$\tilde{\mathrm{t}}_1 = \tilde{\mathrm{t}}_{\mathrm{L}} \cos\theta_{\tilde{\mathrm{t}}} + \tilde{\mathrm{t}}_{\mathrm{R}} \sin\theta_{\tilde{\mathrm{t}}}$$

- at large $\tan\beta$, $\tilde{\mathrm{b}}_1$ also light

final state topologies

- $\tilde{\mathrm{t}} \to \mathrm{c}\tilde{\chi}^0_1$

  $\Rightarrow \mathrm{e^+e^-} \to \tilde{\mathrm{t}}_1\tilde{\mathrm{t}}_1$ yields: $\mathrm{cc} + \not{E}$

- $\tilde{\mathrm{t}} \to \mathrm{b}\ell\tilde{\nu}$

  $\Rightarrow \mathrm{e^+e^-} \to \tilde{\mathrm{t}}_1\tilde{\mathrm{t}}_1$ yields: $\mathrm{bb}\ell\ell + \not{E}$

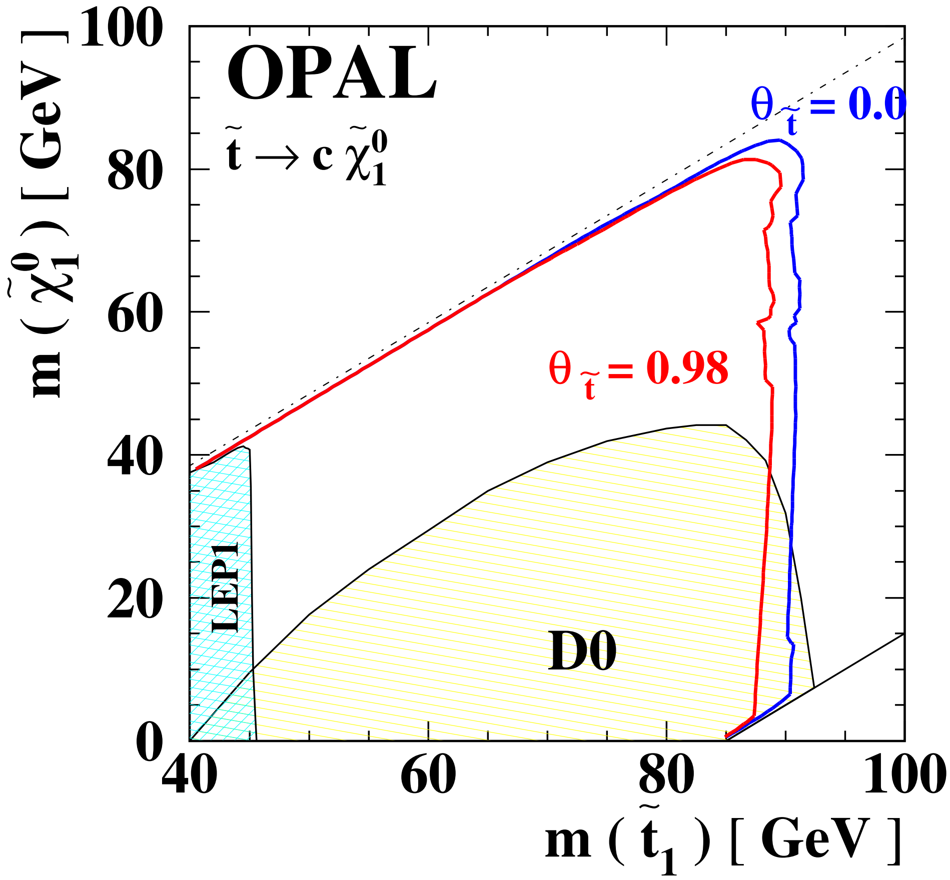
- $\tilde{\mathrm{b}} \to \mathrm{b}\tilde{\chi}^0_1$

  $\Rightarrow \mathrm{e^+e^-} \to \tilde{\mathrm{b}}_1\tilde{\mathrm{b}}_1$ yields: $\mathrm{bb} + \not{E}$

$\Rightarrow$ 2 jets$+\not{E}$ and 2 jets$+2\ell+\not{E}$ events

$\Rightarrow \mathrm{N_{obs}} = 7$, $\mathrm{N_{bkg}} = 10.9 \pm 1.4$

$\tilde{\mathrm{t}}$ and $\tilde{\mathrm{b}}$ Limits @ 95% CL



for $\Delta \mathrm{M}_{\tilde{\mathrm{t}}} > 10$ GeV

$\mathrm{m}_{\tilde{\mathrm{t}}_1} > 90.3$ GeV for $\theta_{\tilde{\mathrm{t}}} = 0$

$\mathrm{m}_{\tilde{\mathrm{t}}_1} > 87.2$ GeV for any $\theta_{\tilde{\mathrm{t}}}$

for $\Delta \mathrm{M}_{\tilde{\mathrm{b}}} > 7$ GeV

$\mathrm{m}_{\tilde{\mathrm{b}}_1} > 88.6$ GeV for $\theta_{\tilde{\mathrm{b}}} = 0$

$\mathrm{m}_{\tilde{\mathrm{b}}_1} > 65.8$ GeV for any $\theta_{\tilde{\mathrm{b}}}$

(exceeds previous limits by 10 GeV)

$e^+e^- \to \gamma(\gamma)\,\not{E}$

- topological search sensitive to:
  - SM: $e^+e^- \to \gamma Z^* \to \nu\bar{\nu}\gamma$
  - SUSY: $e^+e^- \to \tilde{\chi}^0_1\tilde{\chi}^0_2 \to \tilde{\chi}^0_1\tilde{\chi}^0_1\gamma$
  - SUSY: $e^+e^- \to \tilde{\chi}^0_1\tilde{\chi}^0_1 \to \tilde{G}\tilde{G}\gamma\gamma$
  - ???: $e^+e^- \to X^0X^0 \to Y^0Y^0\gamma\gamma$

final state topologies

- Single: $1\gamma + \not{E}$

$$N_{obs} = 562$$

$$N_{exp} = 615.9 \pm 2.5$$

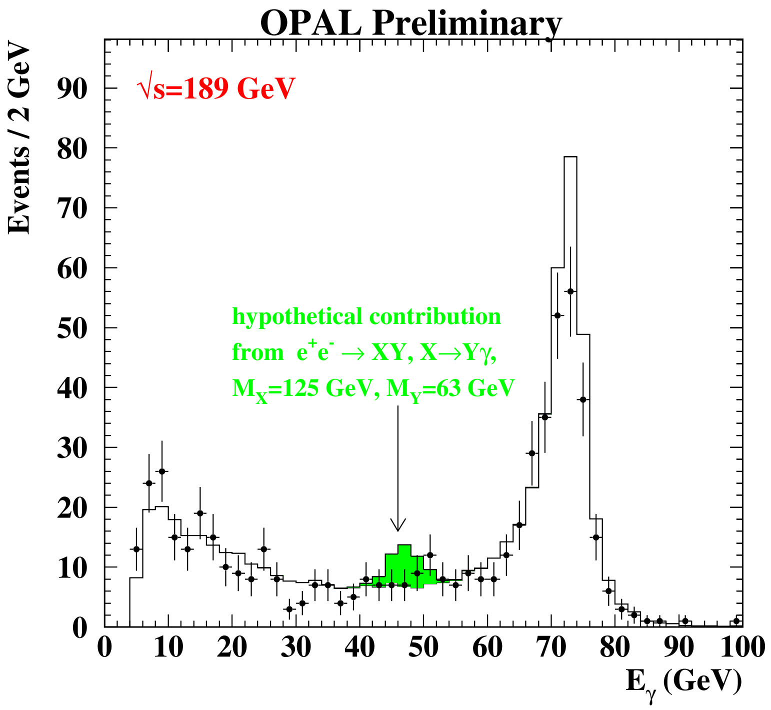
- Double: $\gamma\gamma + \not{E}$

$$N_{obs} = 24$$

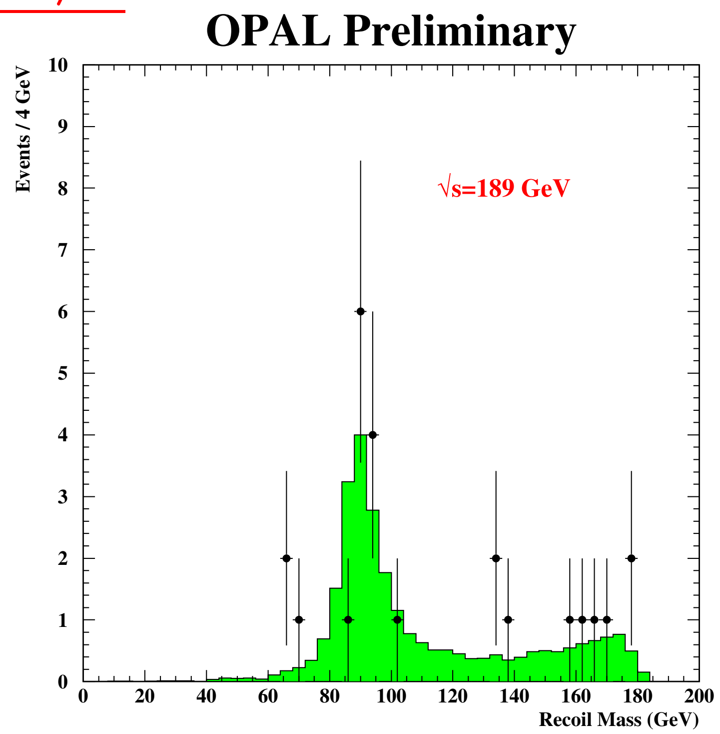
$$N_{exp} = 26.7 \pm 0.3$$

$\Rightarrow$ Data consistent with SM

from $\gamma + \not{E}$:



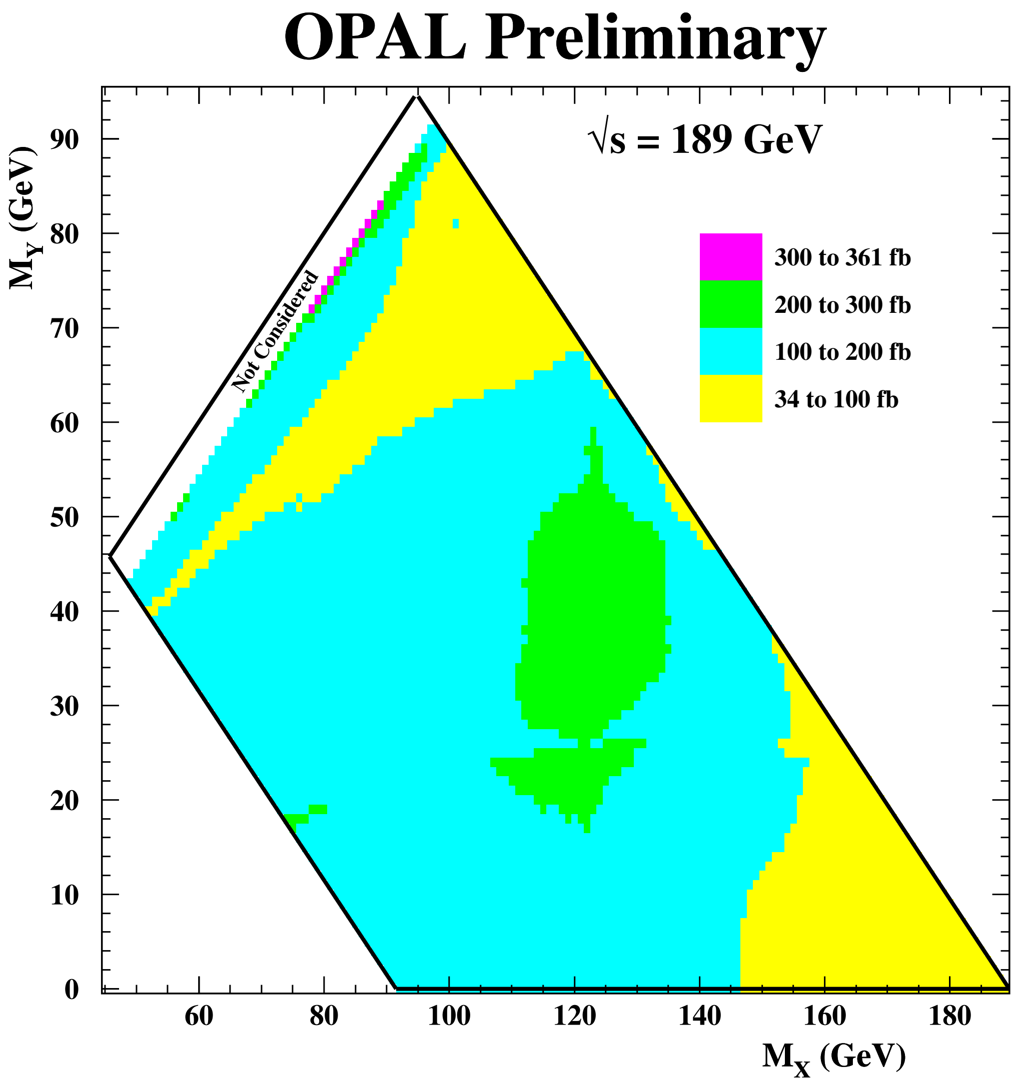
from $\gamma\gamma + \not{E}$:



$$\sigma(\nu\bar{\nu}\gamma) = 4.23 \pm 0.25(\text{total}) \text{ pb}$$

$$\sigma_{\rm SM} = 4.66 \pm 0.03 \text{ pb}$$

Limits from $\gamma(\gamma)\ \not{E}$ @ 95% CL



- upper limits on $\sigma(\mathrm{e^+e^-} \to \mathrm{XY}) \cdot \mathrm{BR}(\mathrm{X} \to \mathrm{Y}\gamma)$
- for $\mathrm{M_X} - \mathrm{M_Y} \ > \ 5$ GeV
- assuming isotropic production and decay

Search for "Extra Dimensions"

- Recent theoretical attention
  - N.Arkani-Hamed, et. al., PLB429 (1998) 263.
  - I.Antoniadis, et. al., PLB436 (1998) 257.
  - G.F.Guidice, et. al., CERN-TH/98-354.
  - J.L.Hewett, SLAC-PUB-8001.
  - E.A.Mirabelli, et. al. SLAC-PUB-8002.
  - T.G.Rizzo, et. al. SLAC-PUB-8036.
  - postulate quantum-gravity scale in $D = n + 4$ dimensions solves hierarchy problem: $\mathrm{M_D} \approx 1$ TeV
  - poses a range of theoretically interesting questions/problems...
  - MOST IMPORTANTLY:(for the purposes of this talk) yields testable consequences
- effects differential distributions

$$\frac{d\sigma}{dz} = \left(\frac{d\sigma}{dz}\right)_{\mathrm{SM}} + A(z)\left(\frac{\lambda}{\mathrm{M_D^4}}\right) + B(z)\left(\frac{\lambda}{\mathrm{M_D^4}}\right)^2$$

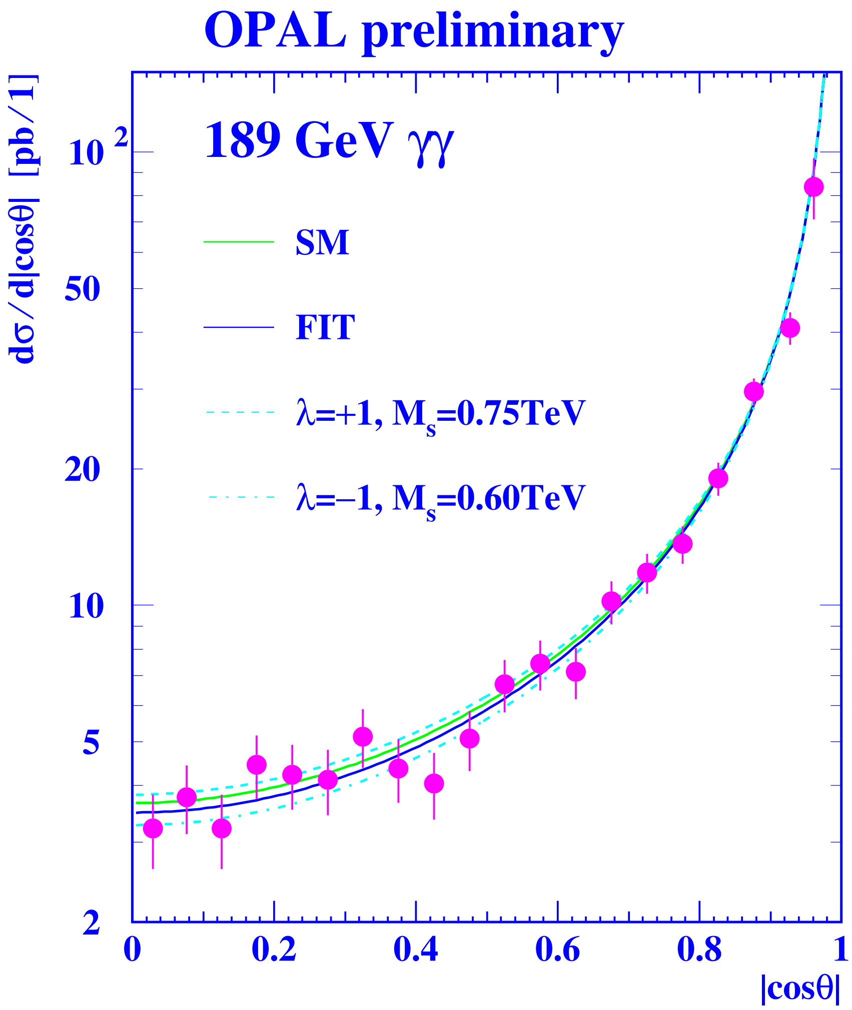
$\Rightarrow$ Use $\frac{d\sigma}{dz}(\mathrm{e^+e^-} \to \mathrm{f\bar{f}},\ \gamma\gamma)$ data

Basics of "Extra-Dimensional" Phenomenology

(as understood by an experimentalist!)

- postulate quantum-gravity scale in $D = n + 4$ dimensions solves hierarchy problem:
  $\mathrm{M_D} \approx 1$ TeV
  - SO gravitational interactions become strong at weak scale
  - BUT SM fields cannot propagate into the bulk... (precision EWK constraints tell us so) forced to lie on a 3-d "brane" of the $(n + 4)$-d space
  - THUS graviton interactions largely constrained to the n-dimensional "bulk" (ie. gravity appears weak in 4-d since we only observe its projection from $(n + 4)$ space)
  - $\mathrm{M_D}$ can be identified with string scale $\mathrm{M_s}$
  - MOST IMPORTANTLY: yields testable consequences

Limits on $\mathrm{M_s}$ at 95% CL



from $\gamma\gamma$:

$\mathrm{M_s} > 0.75$ TeV for $\lambda = +1$

$\mathrm{M_s} > 0.60$ TeV for $\lambda = -1$

from $\mu^+\mu^-, \tau^+\tau^-$:

$\mathrm{M_s} > 0.65$ TeV for $\lambda = +1$

$\mathrm{M_s} > 0.64$ TeV for $\lambda = -1$

Conclusions

- LEP1 data still providing new and interesting results
- LEP2 data leaves
  - SM looking good
  - Searches still looking
- looking forward to *collecting* $10^2\ \mathrm{pb}^{-1}$ at $\sqrt{s} = 200$ GeV

Perhaps next time the talk will be...

Wh^{0}A^{0}t's New at OPAL...